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FÜR KERNPHYSIK

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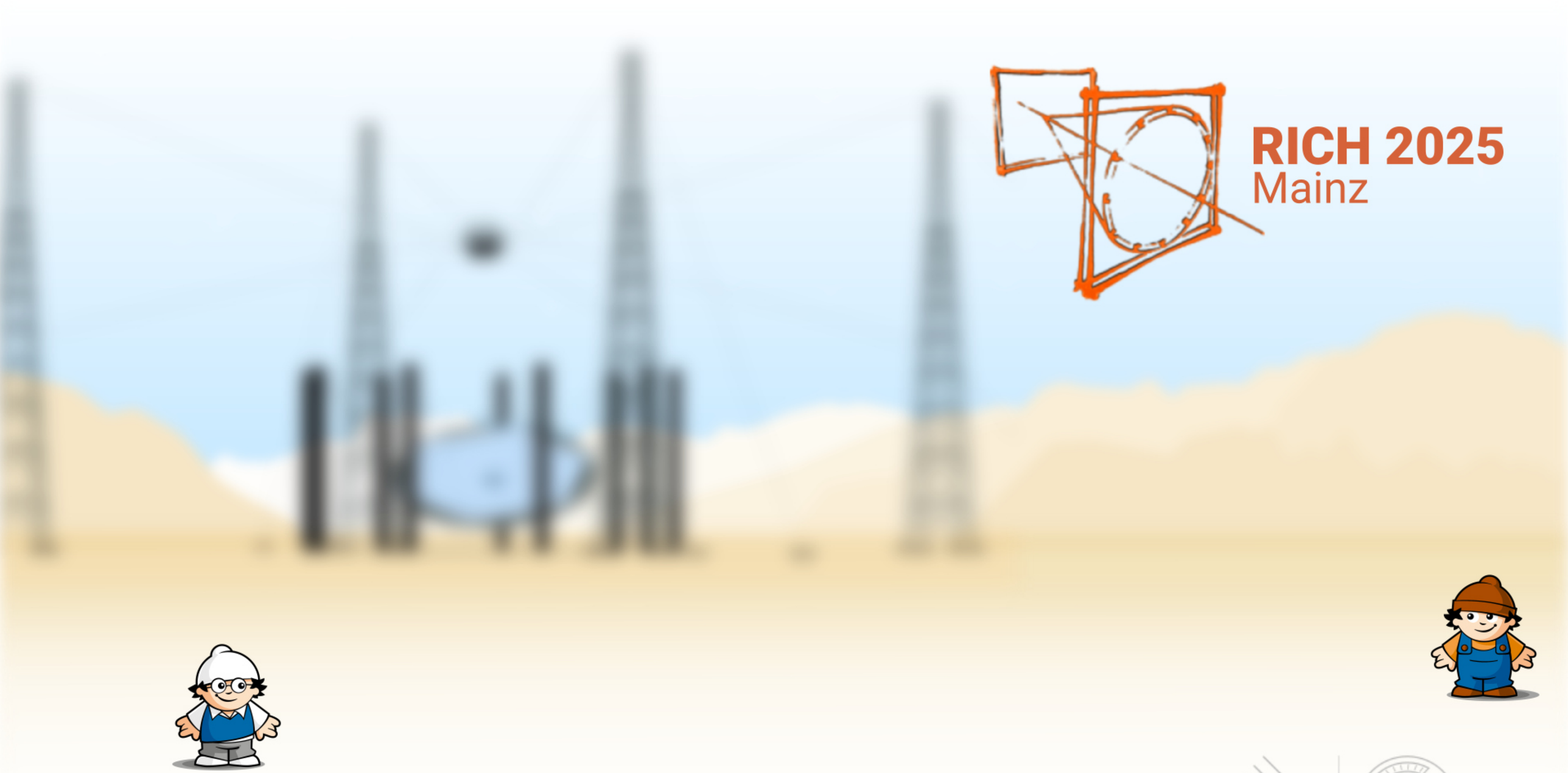

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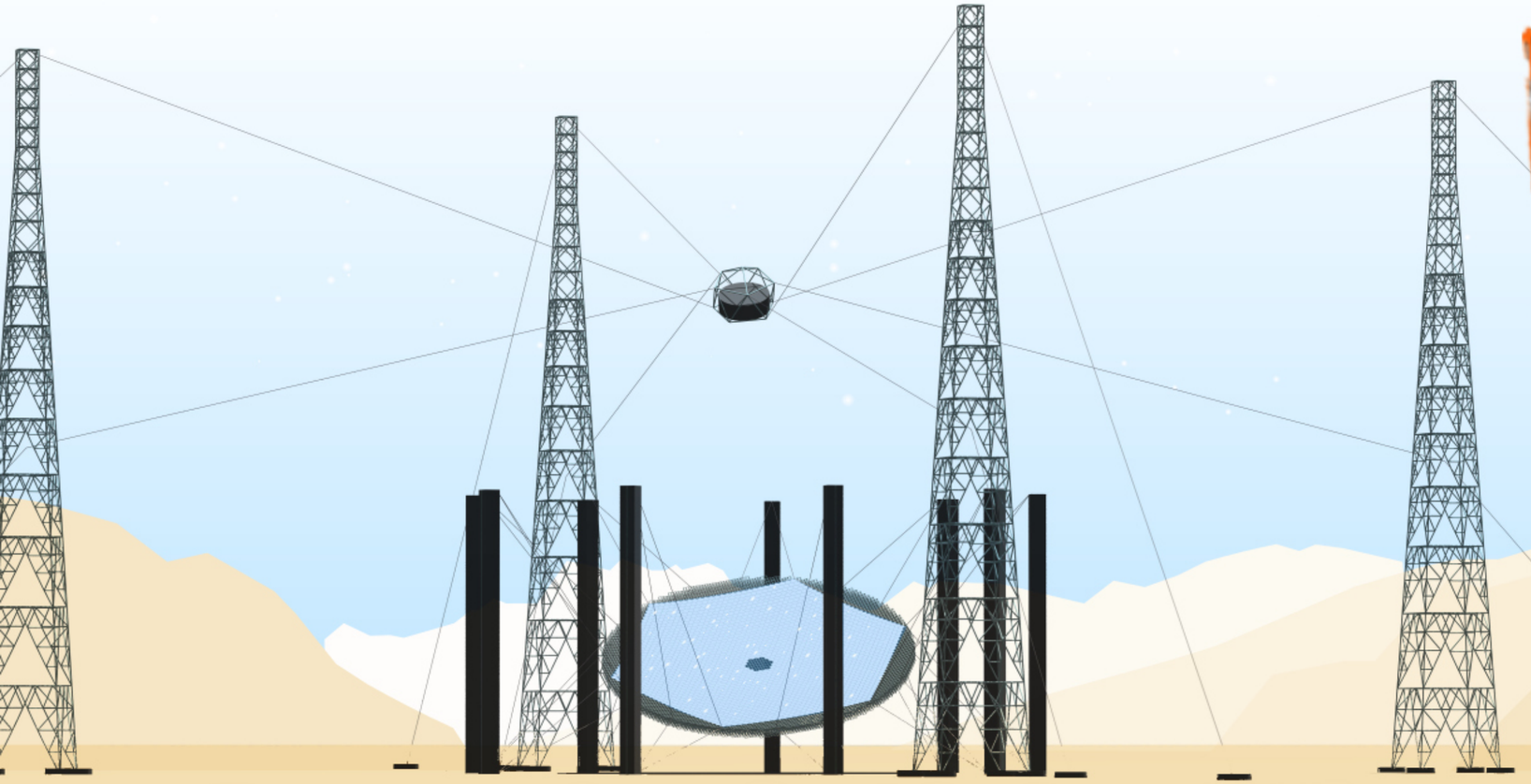

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Overcoming the Limits of Cherenkov Telescopes

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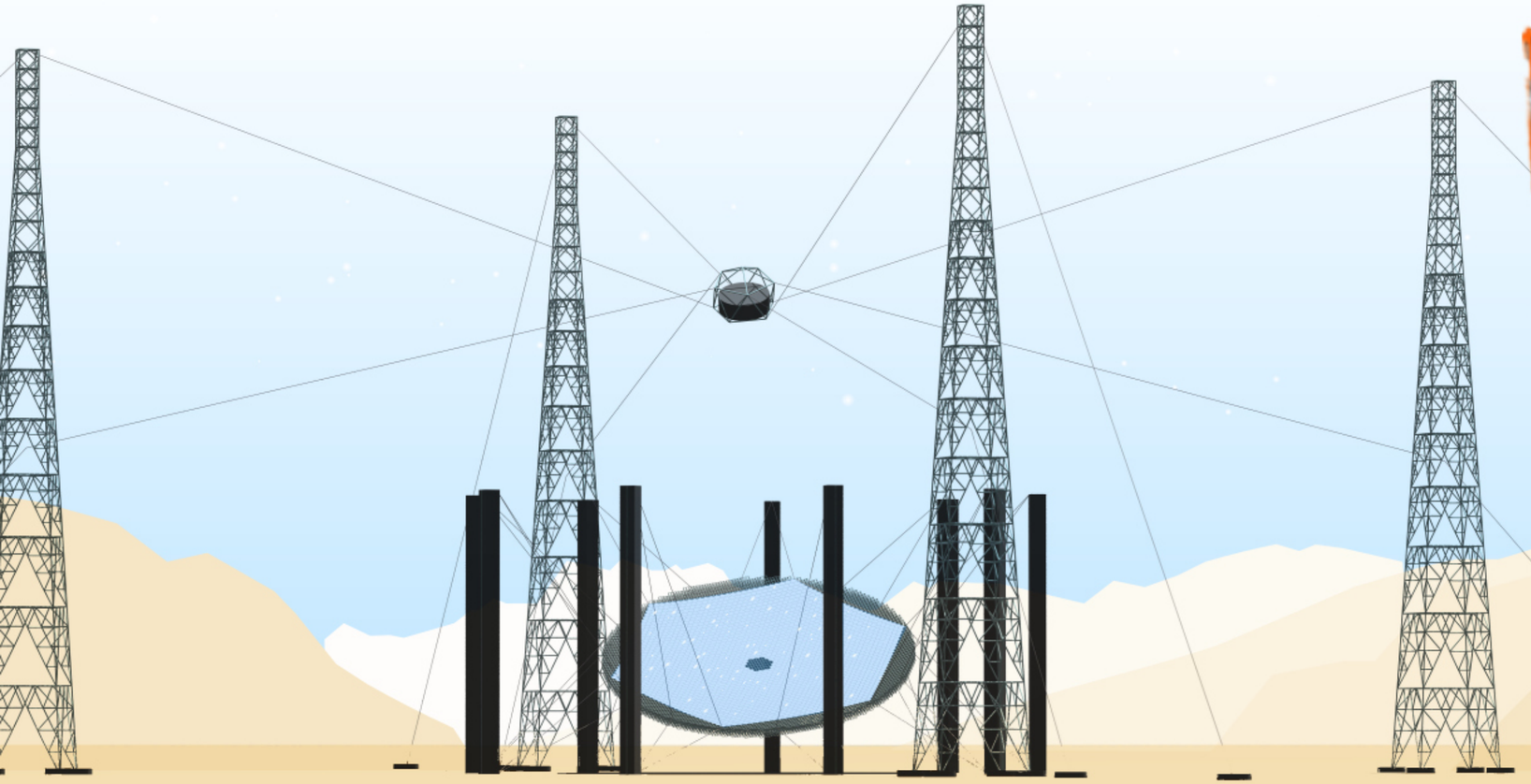

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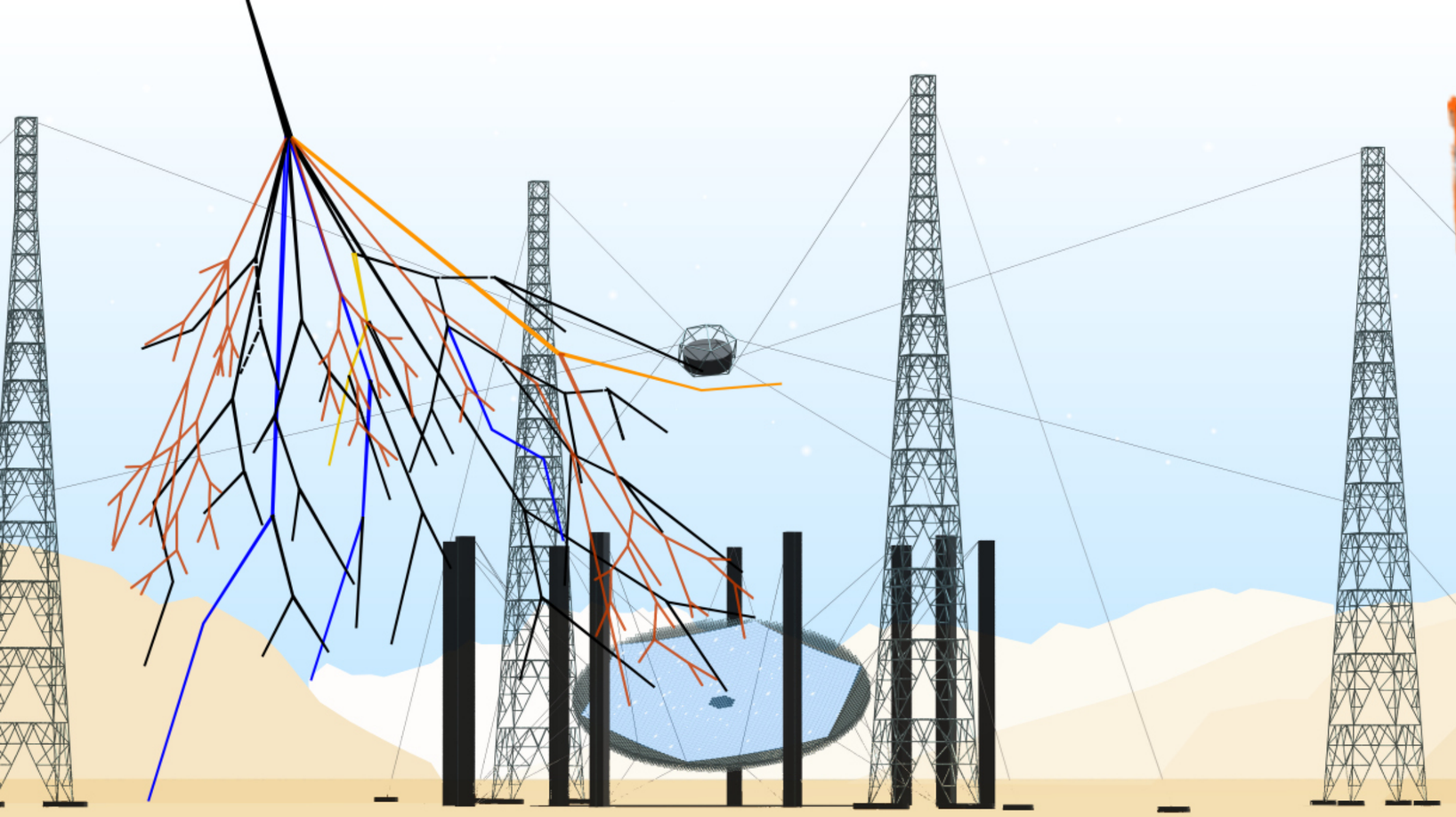

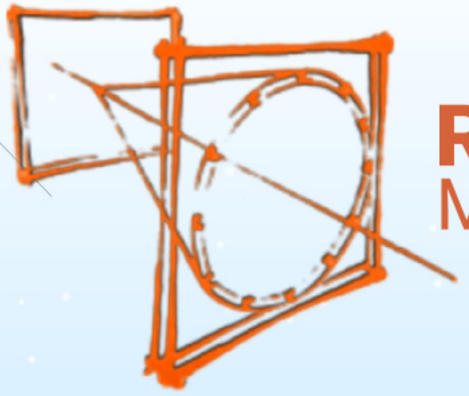

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Overcoming the Limits of Cherenkov Telescopes

Cherenkov Plenoscope

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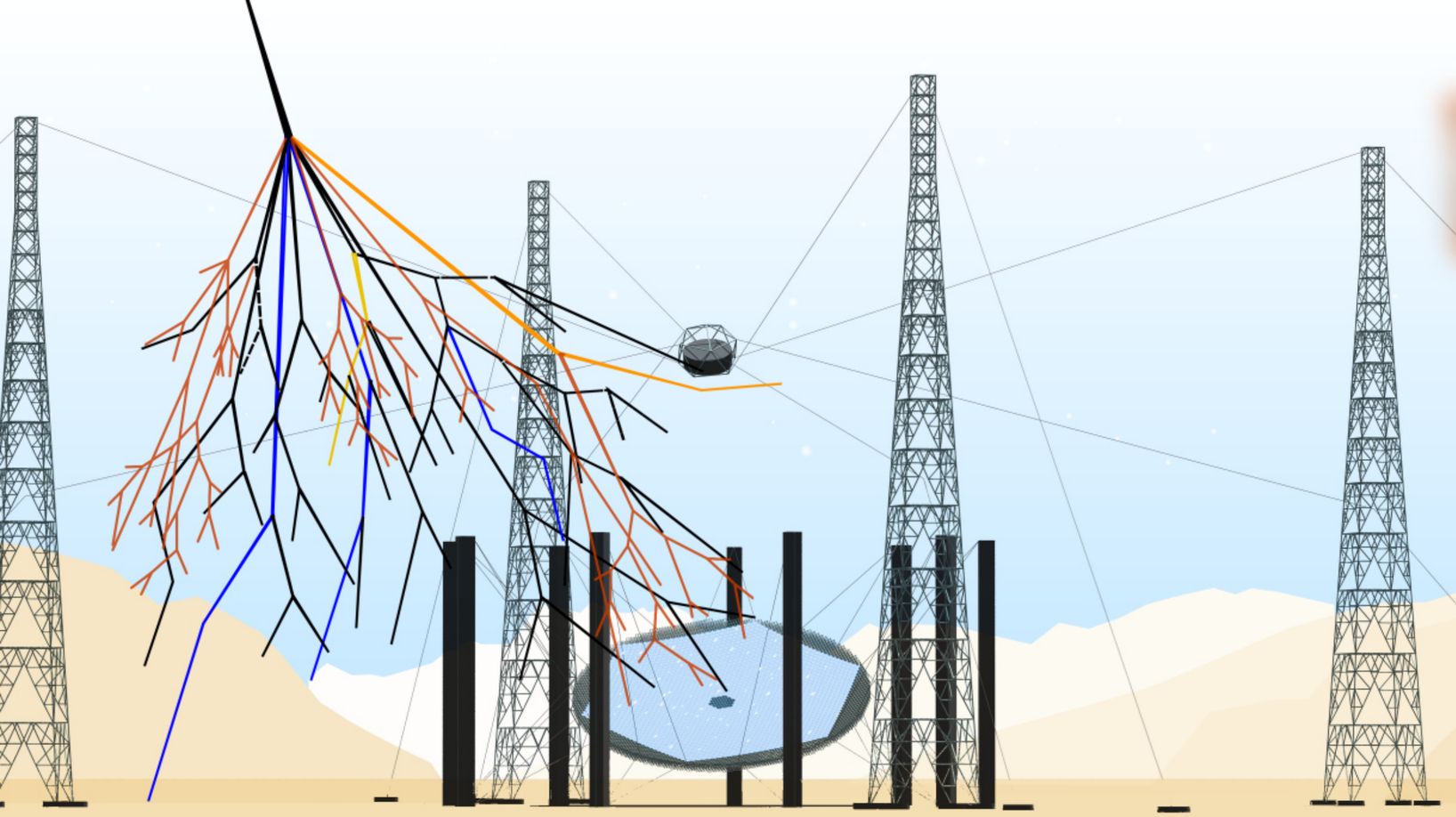

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Overcoming the Limits of Cherenkov Telescopes

Cherenkov Plenoscope

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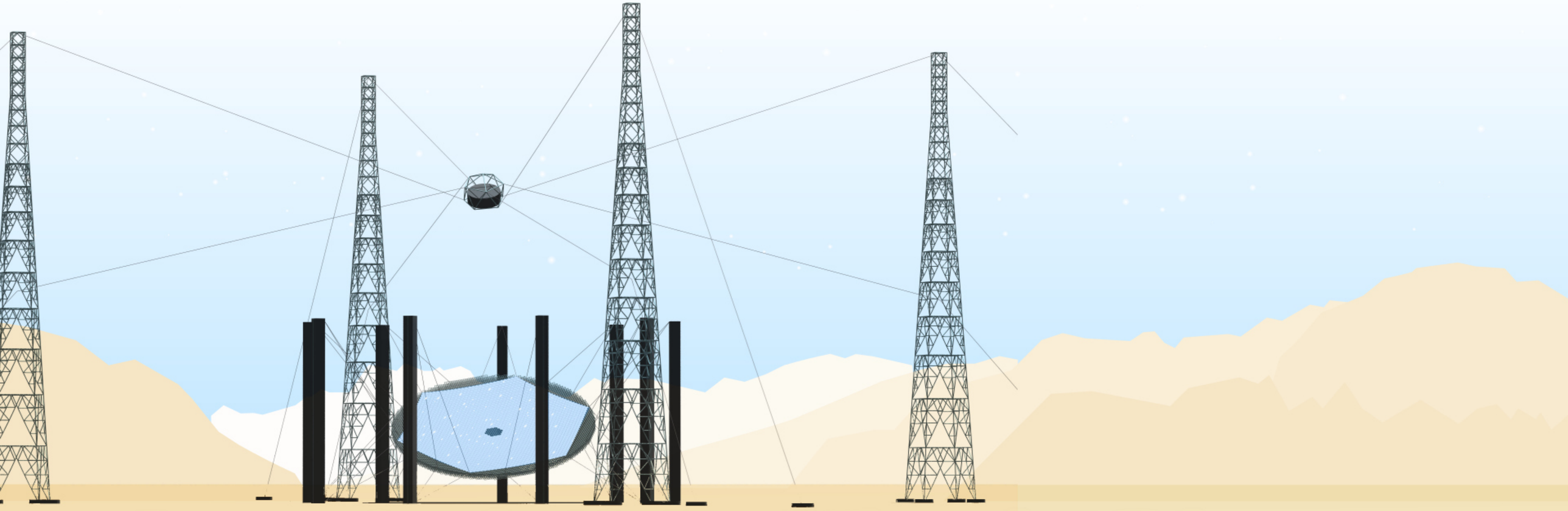
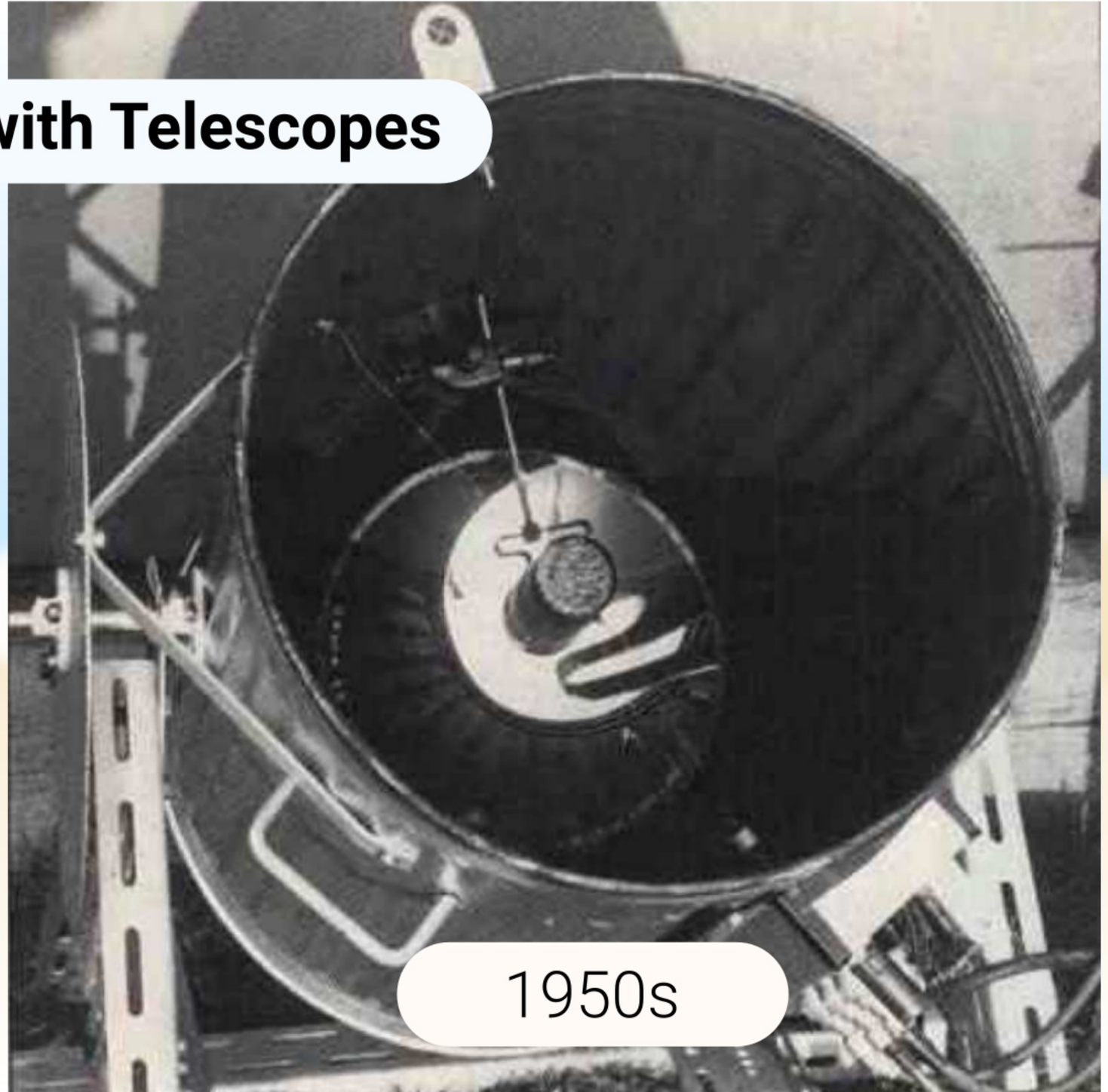


Overcoming the Limits of Cherenkov Telescopes

Cherenkov Plenoscope

Imaging with Telescopes

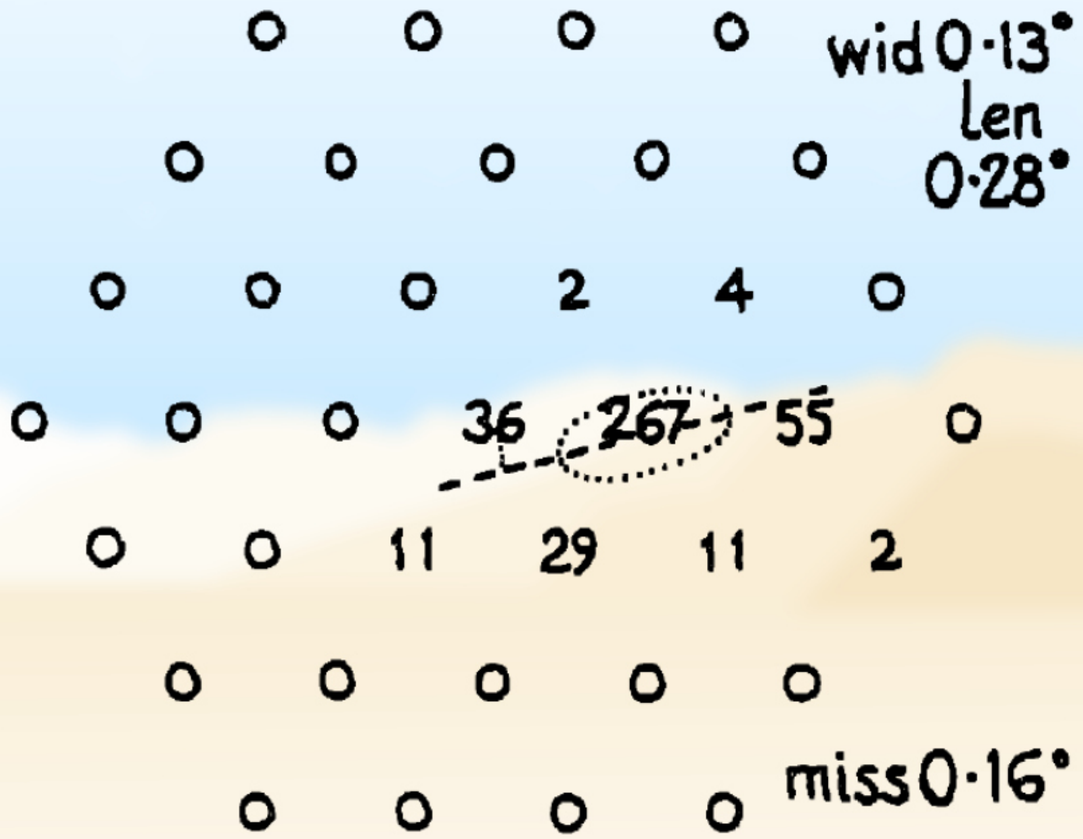
Imaging with Telescopes



1950s

Galbraith, W., Jelley, J.V. 1953
Light Pulses from the Night Sky
associated with Cosmic Rays.
Nature 171: 349-350.

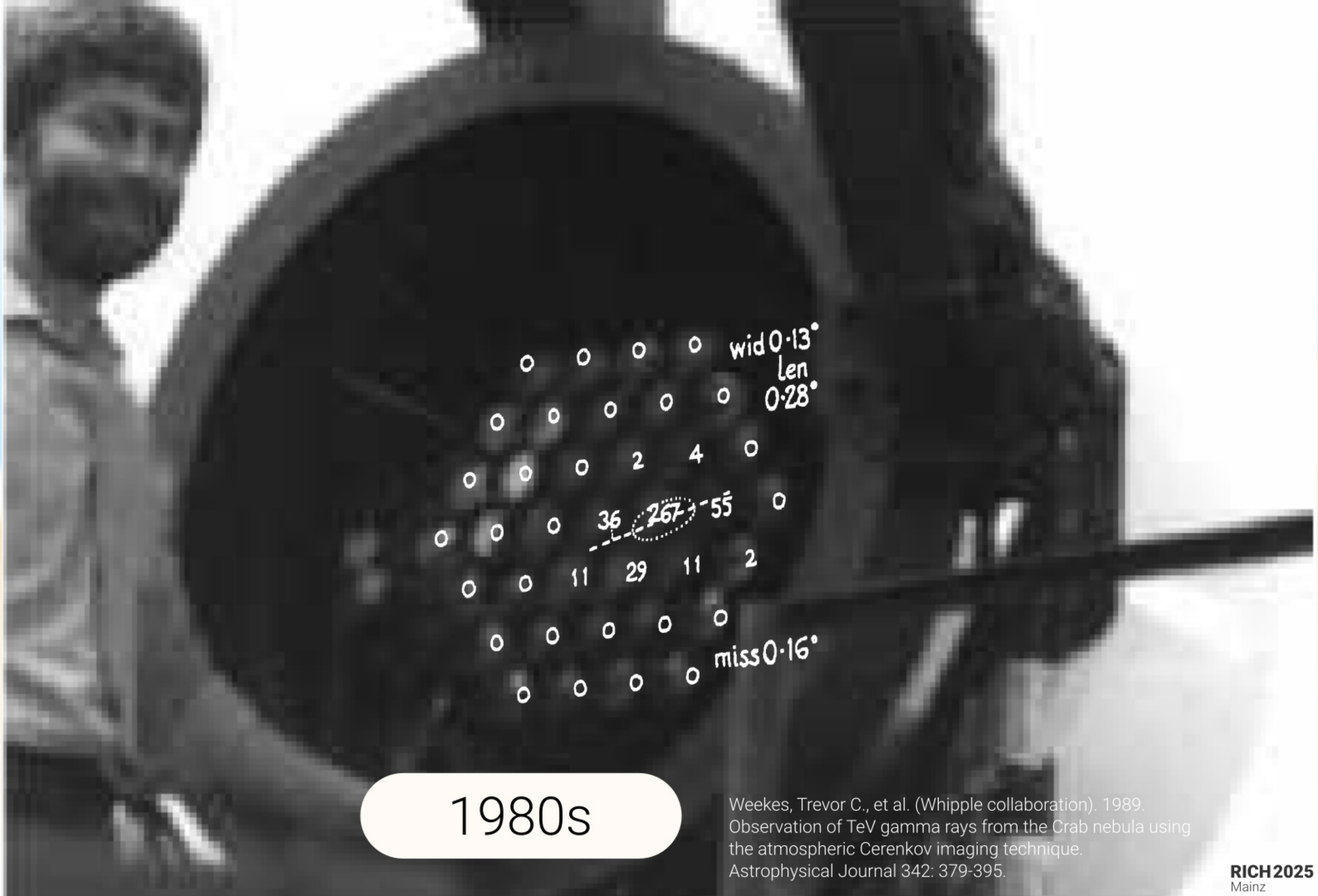
Imaging with Telescopes



1980s

Michael A. Hillas, 1985
Cerenkov light images of EAS produced by primary gamma,
ICRC 1985, Vol.3

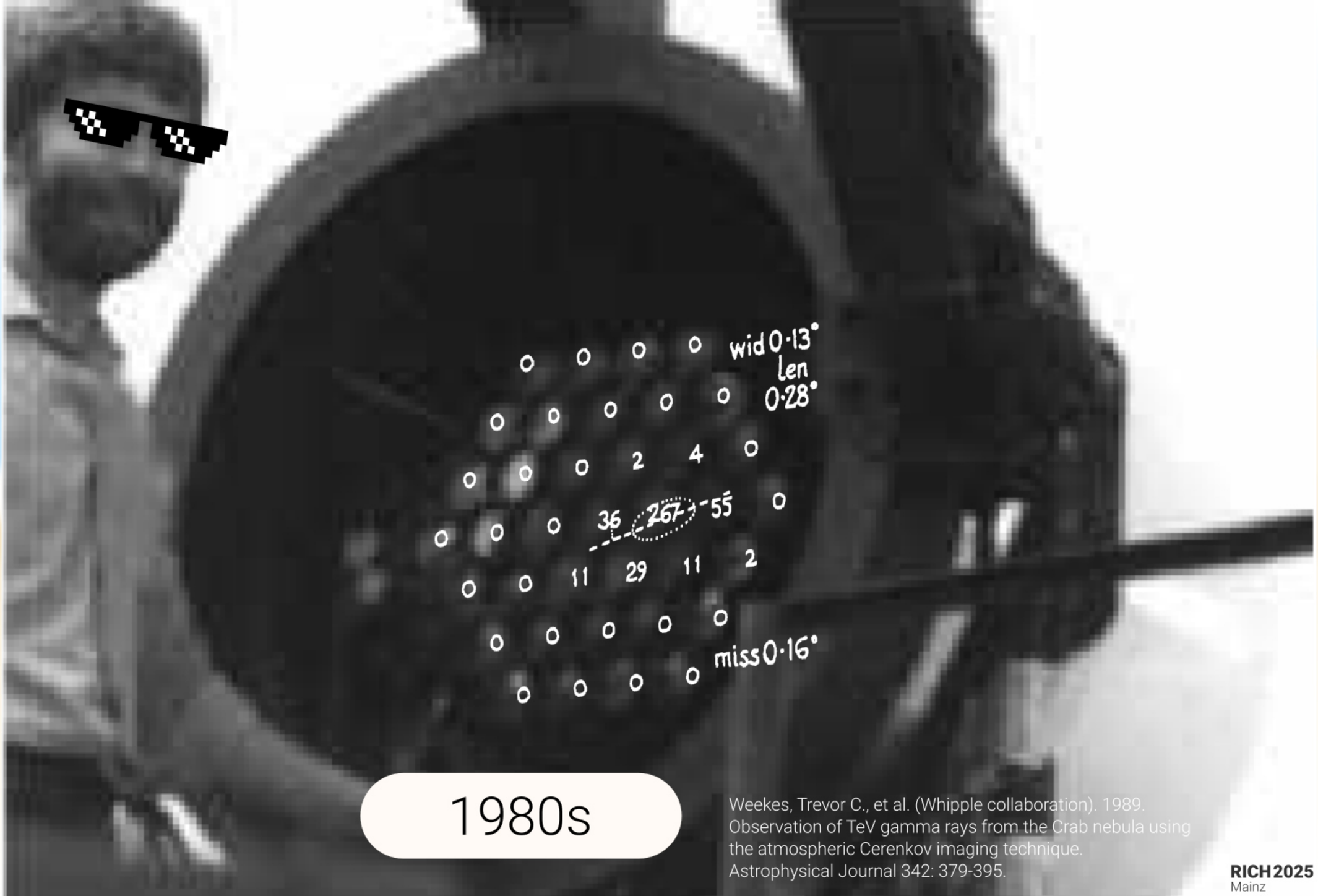
Imagine



1980s

Weekes, Trevor C., et al. (Whipple collaboration). 1989. Observation of TeV gamma rays from the Crab nebula using the atmospheric Cerenkov imaging technique. Astrophysical Journal 342: 379-395.

Imagine



1980s

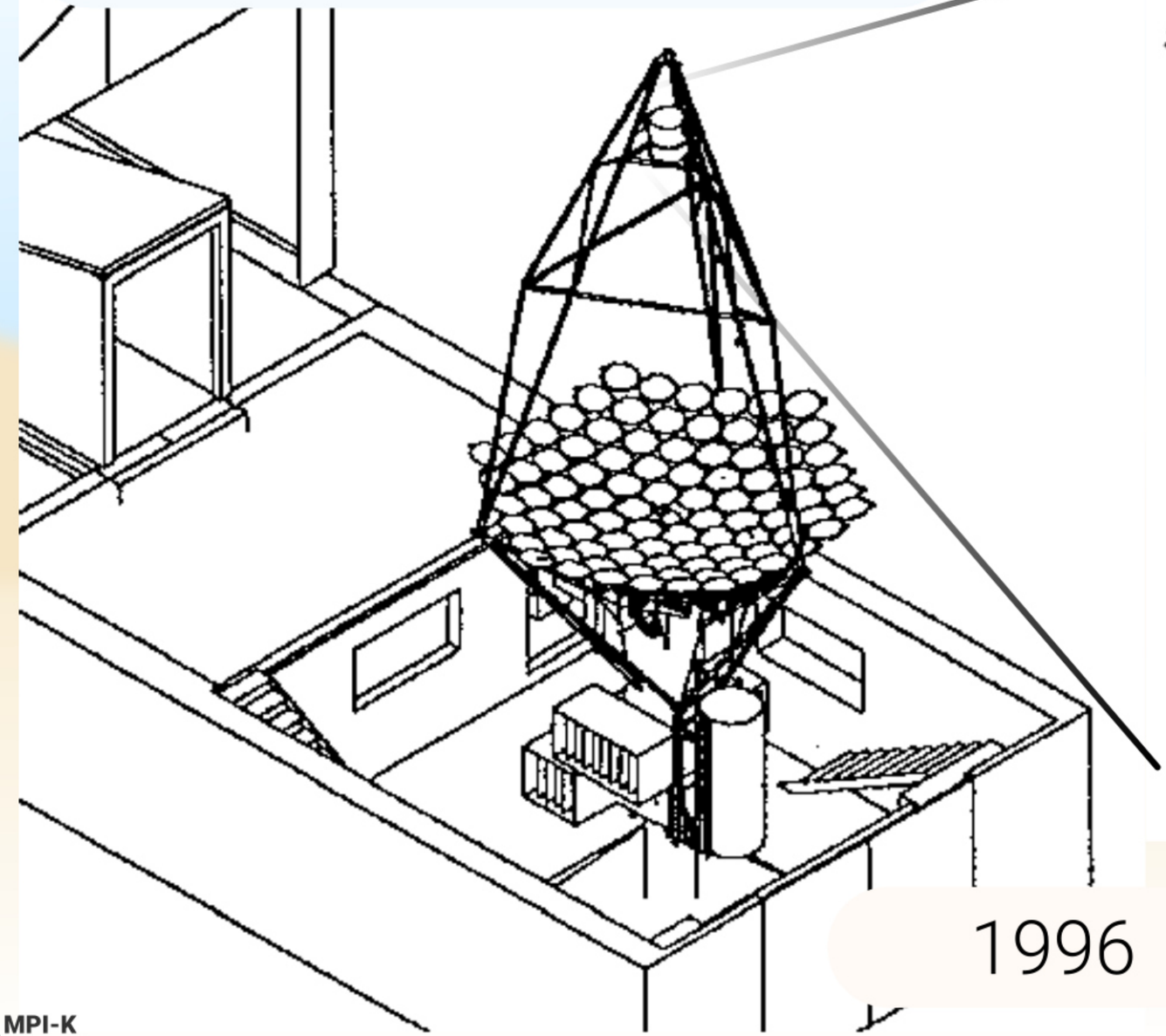
Weekes, Trevor C., et al. (Whipple collaboration). 1989. Observation of TeV gamma rays from the Crab nebula using the atmospheric Cerenkov imaging technique. Astrophysical Journal 342: 379-395.

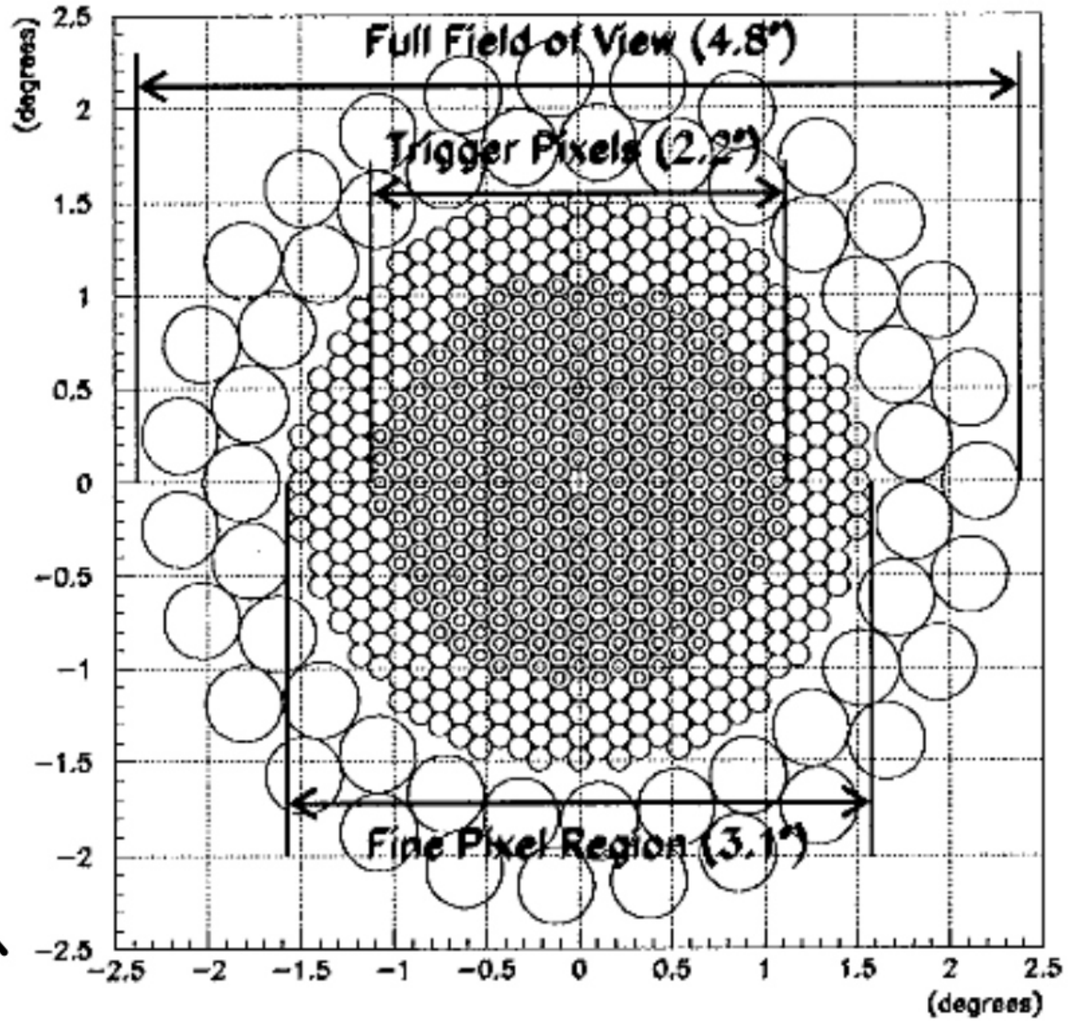
Imaging with Telescopes

1992

Towards a major atmospheric Cherenkov detector for TeV astroparticle physics

Imaging with Telescopes

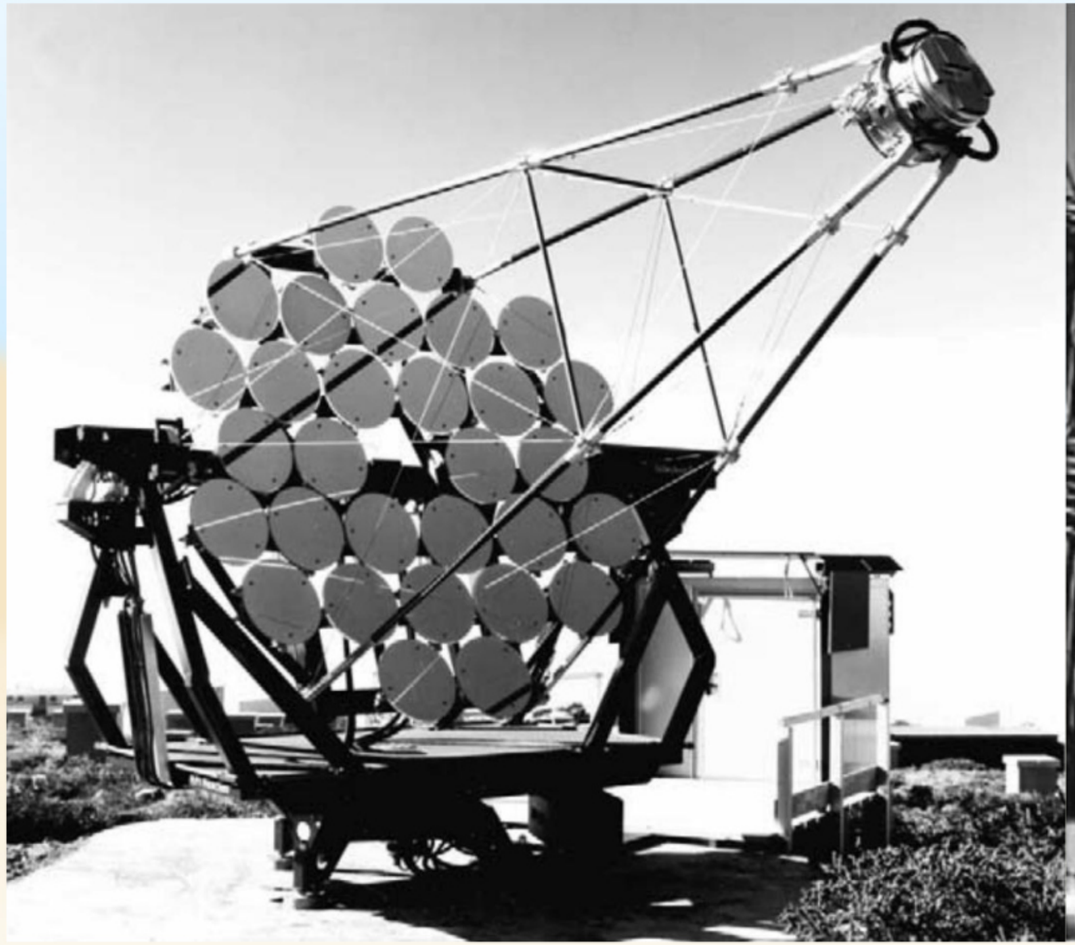




1996

Barrau A., Bazer-Bachi R., Beyer E. et al., 1998
The CAT imaging telescope for very-high-energy gamma-ray astronomy
Nuclear Instruments and Methods Vol.416 II p.278-292

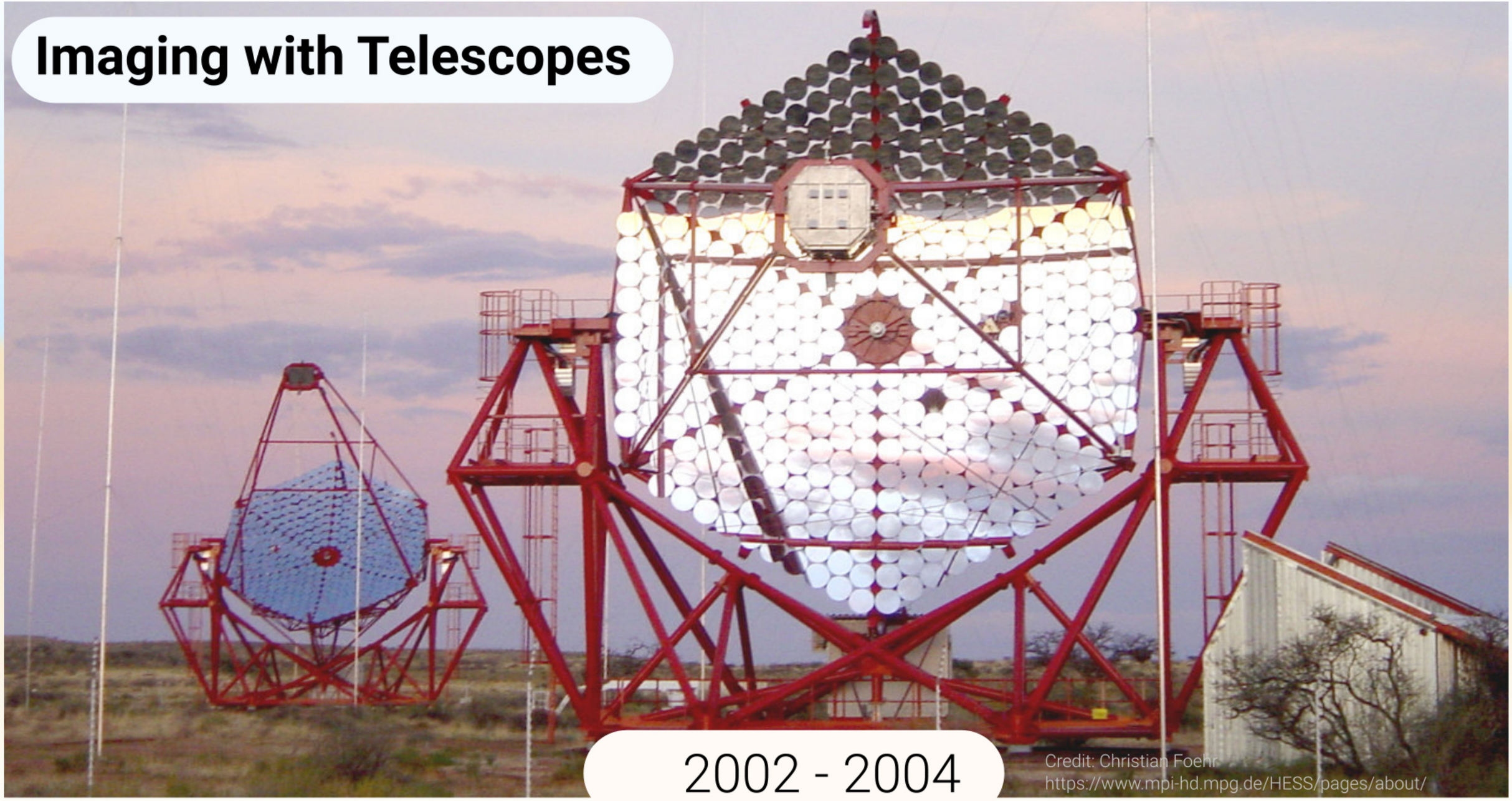
Imaging with Telescopes



1997

Puehlhofer, G. and Bolz, O. and Goetting, N., 2003
The technical performance of the HEGRA system of imaging air Cherenkov telescopes
Astroparticle Physics, Vol.20 III, p267-291

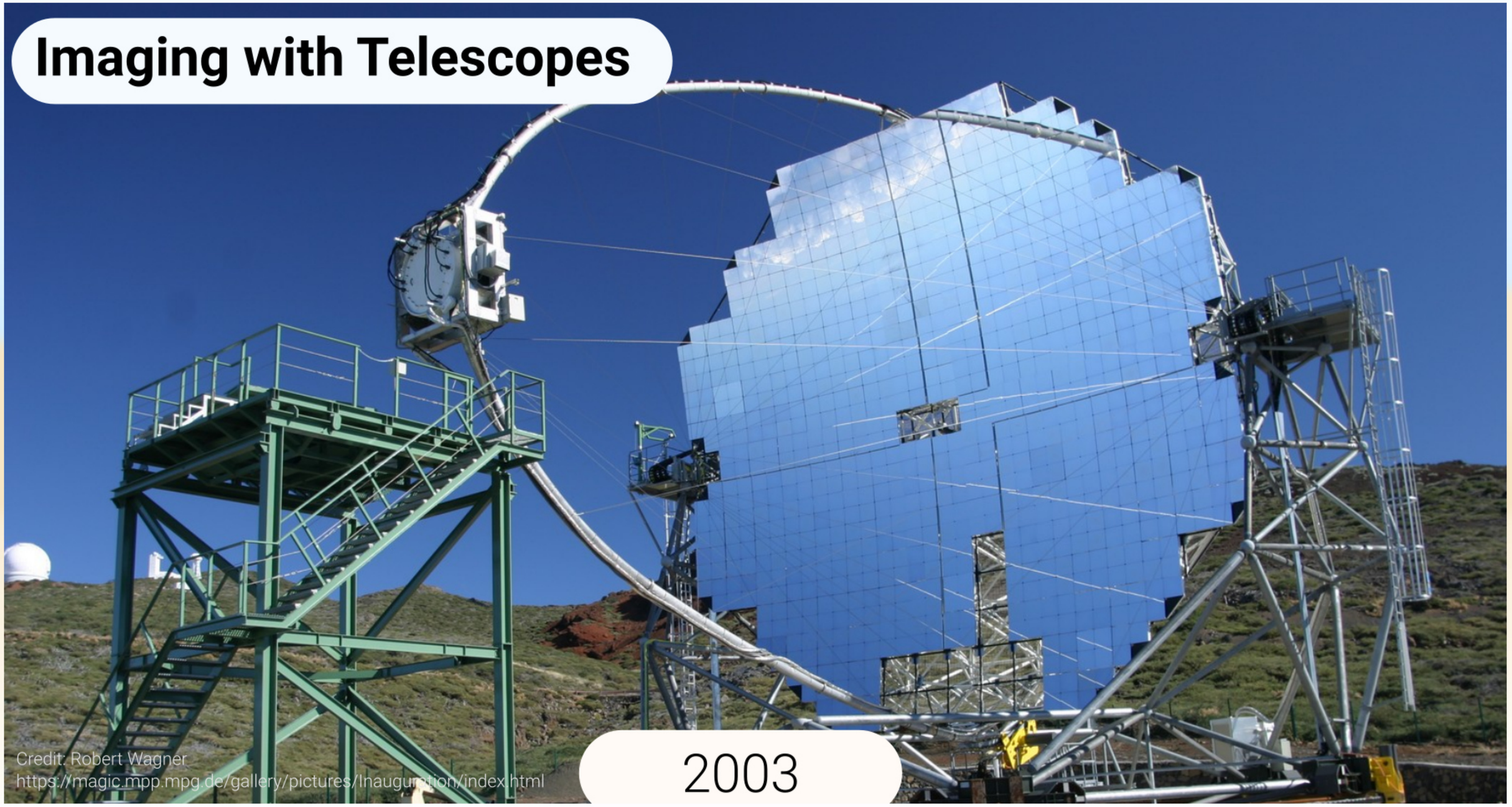
Imaging with Telescopes



2002 - 2004

Credit: Christian Foehr
https://www.mpi-hd.mpg.de/HESS/pages/about/

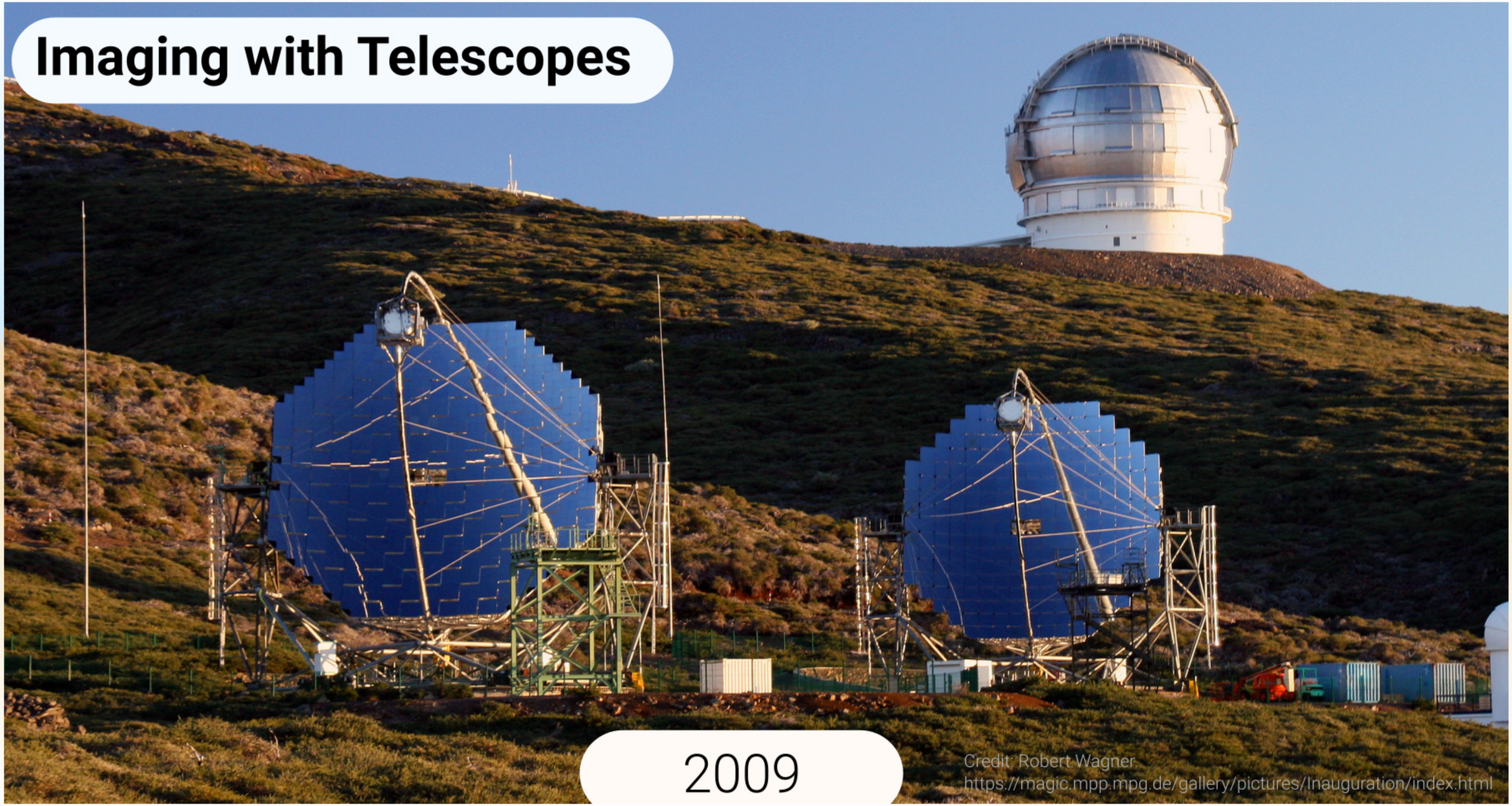
Imaging with Telescopes



Credit: Robert Wagner
https://magic.mpp.mpg.de/gallery/pictures/Inauguration/index.html

2003

Imaging with Telescopes

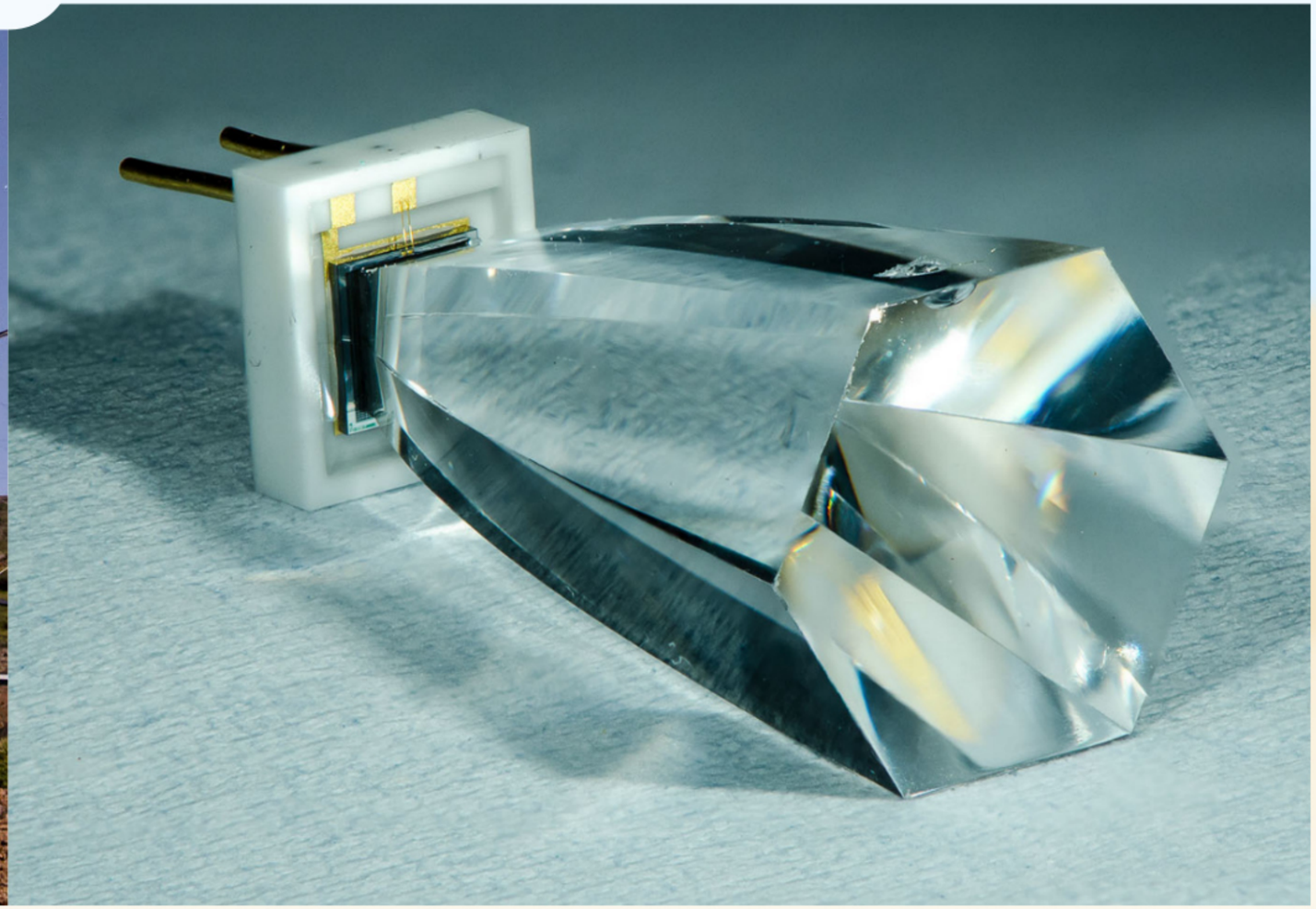


2009

Credit: Robert Wagner
https://magic.mpp.mpg.de/gallery/pictures/Inauguration/index.html

Imaging with Telescopes

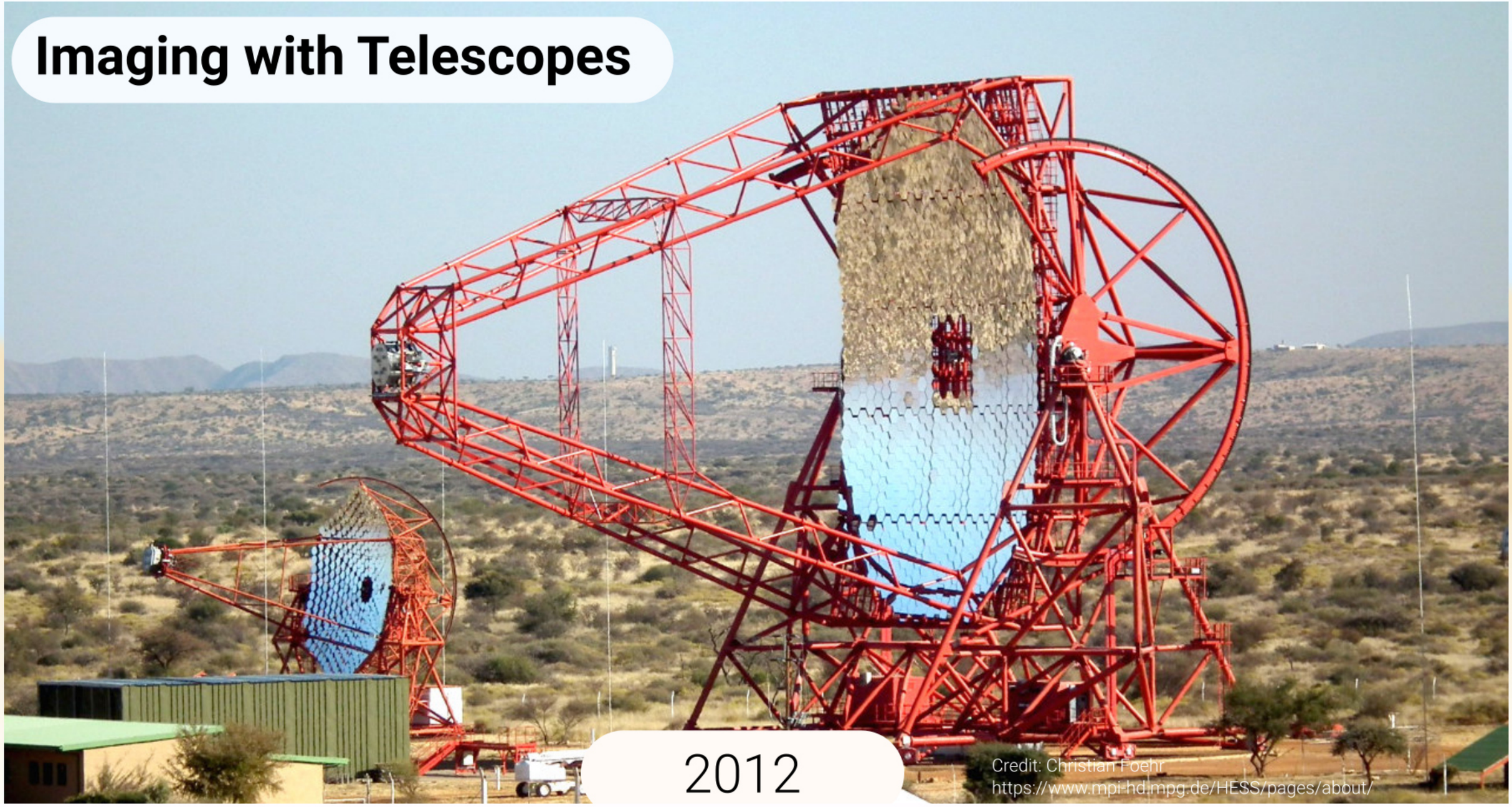
Credit: Jens B. Buss



Credit: Thomas Kraehenbuehl

2011

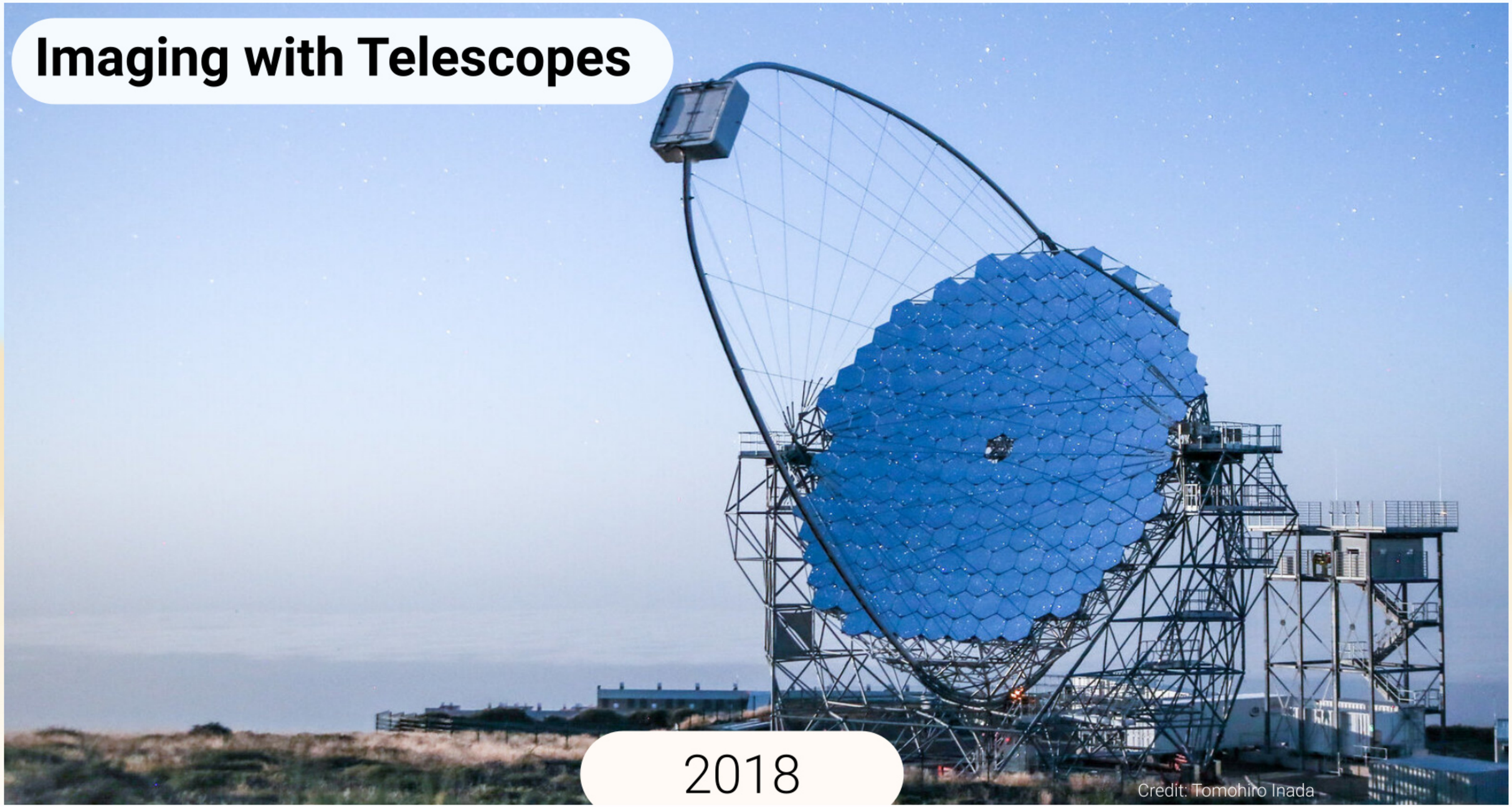
Imaging with Telescopes



2012

Credit: Christian Foehr
https://www.mpi-hd.mpg.de/HESS/pages/about/

Imaging with Telescopes



2018

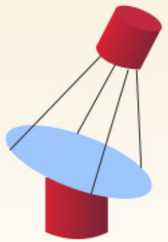
Credit: Tomohiro Inada

Imaging with Telescopes

future

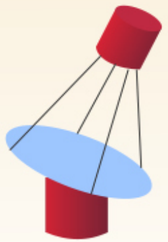
Credit: Tomohiro Inada

Limits of Telescopes



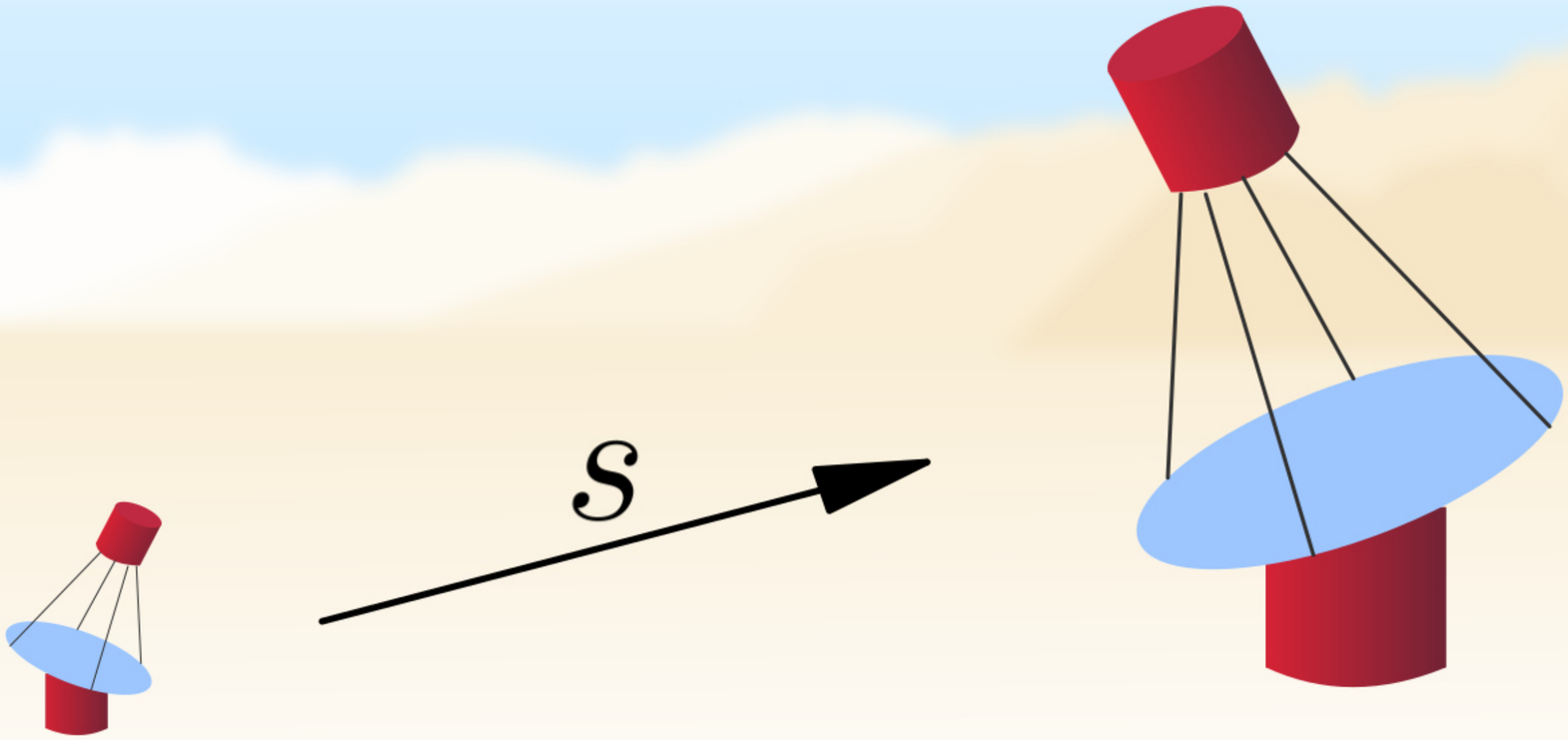
Limits of Telescopes

square-cube-law



Limits of Telescopes

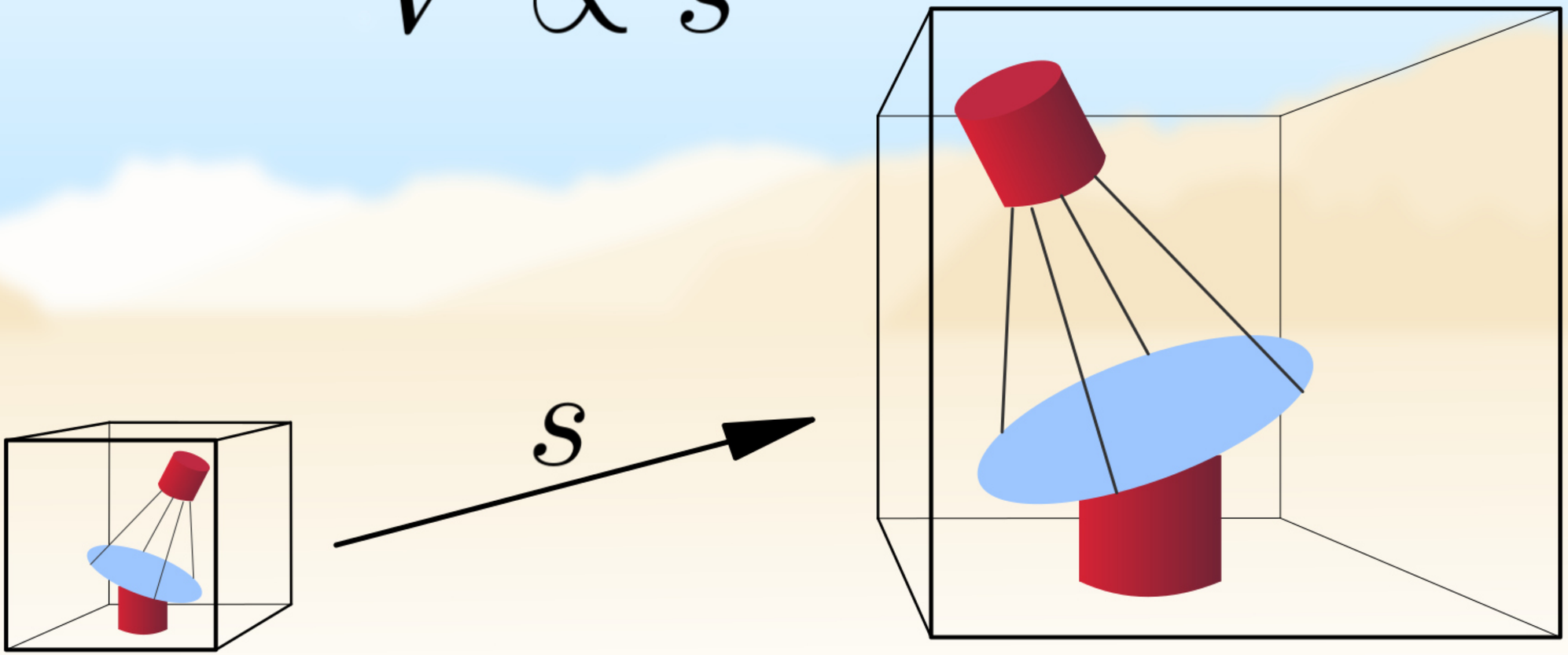
square-cube-law



Limits of Telescopes

square-cube-law

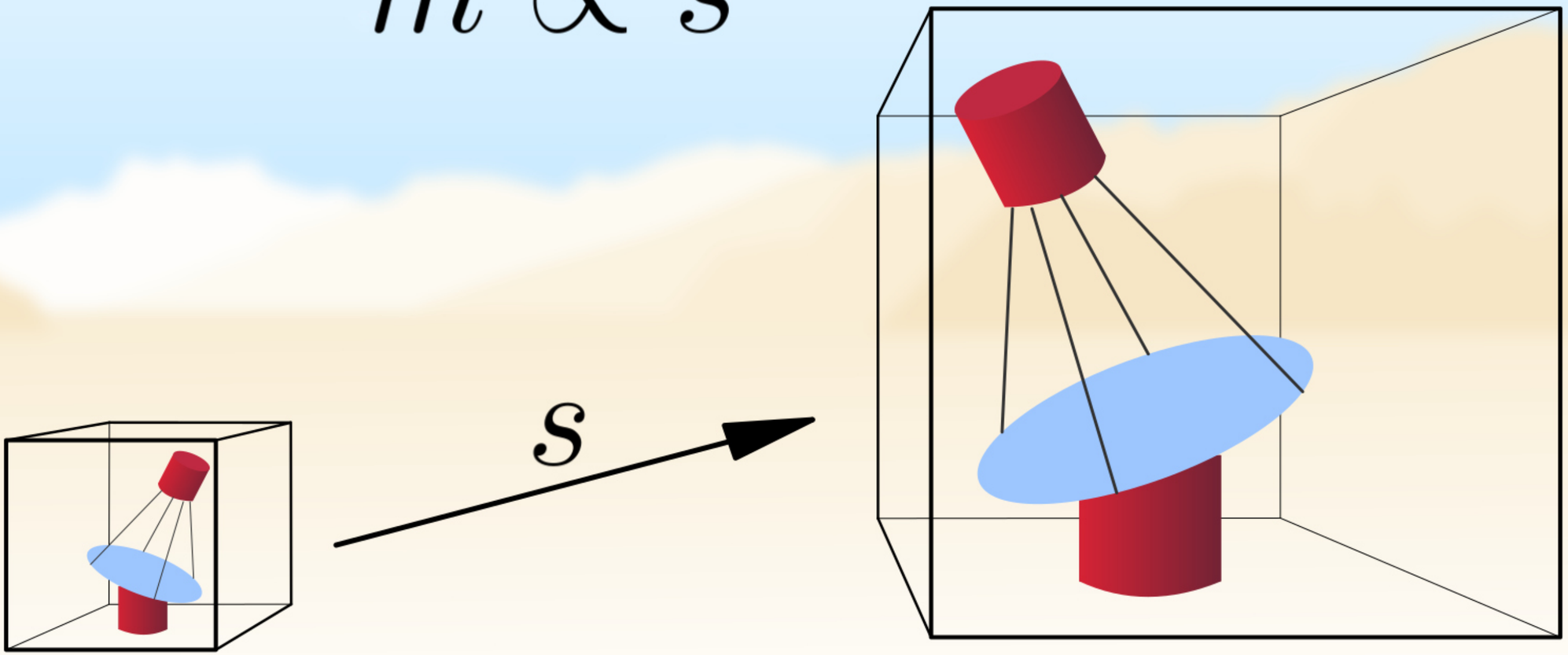
$$V \propto s^3$$



Limits of Telescopes

square-cube-law

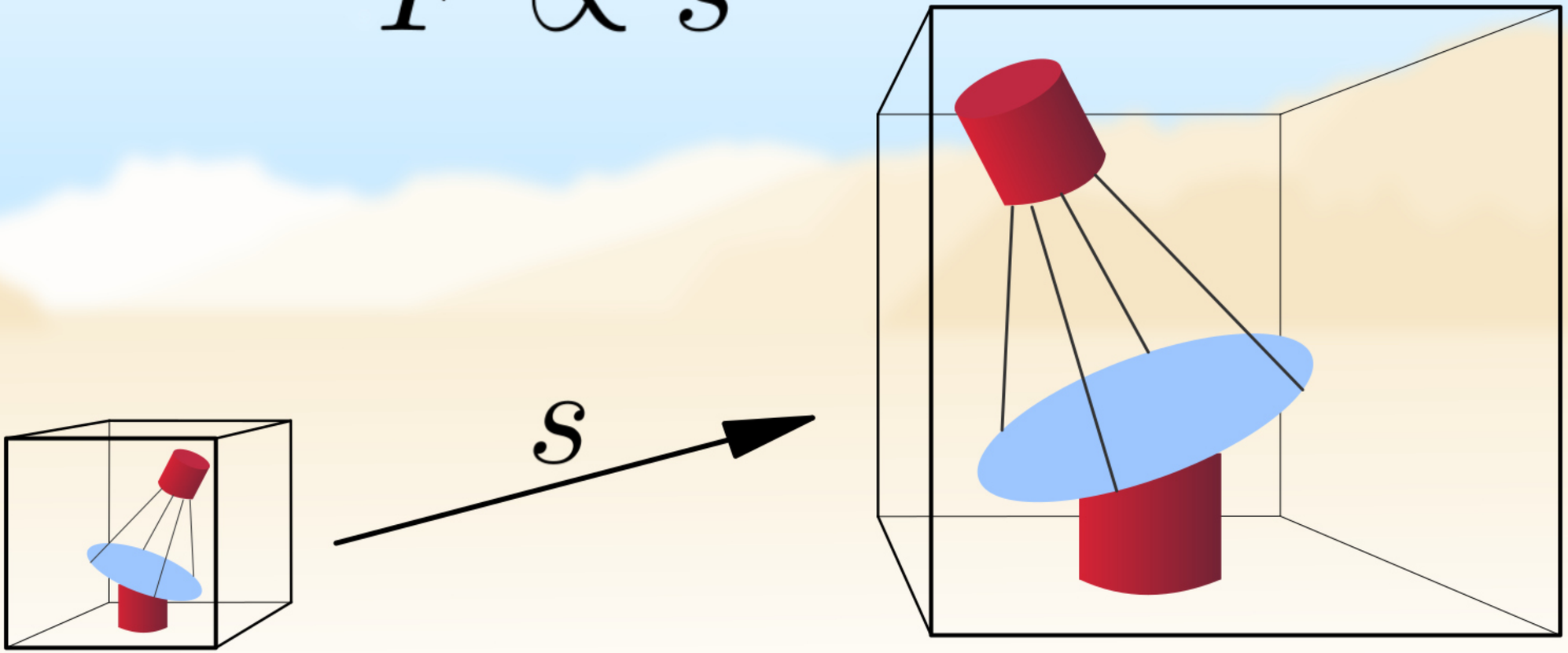
$$m \propto s^3$$



Limits of Telescopes

square-cube-law

$$F \propto s^3$$

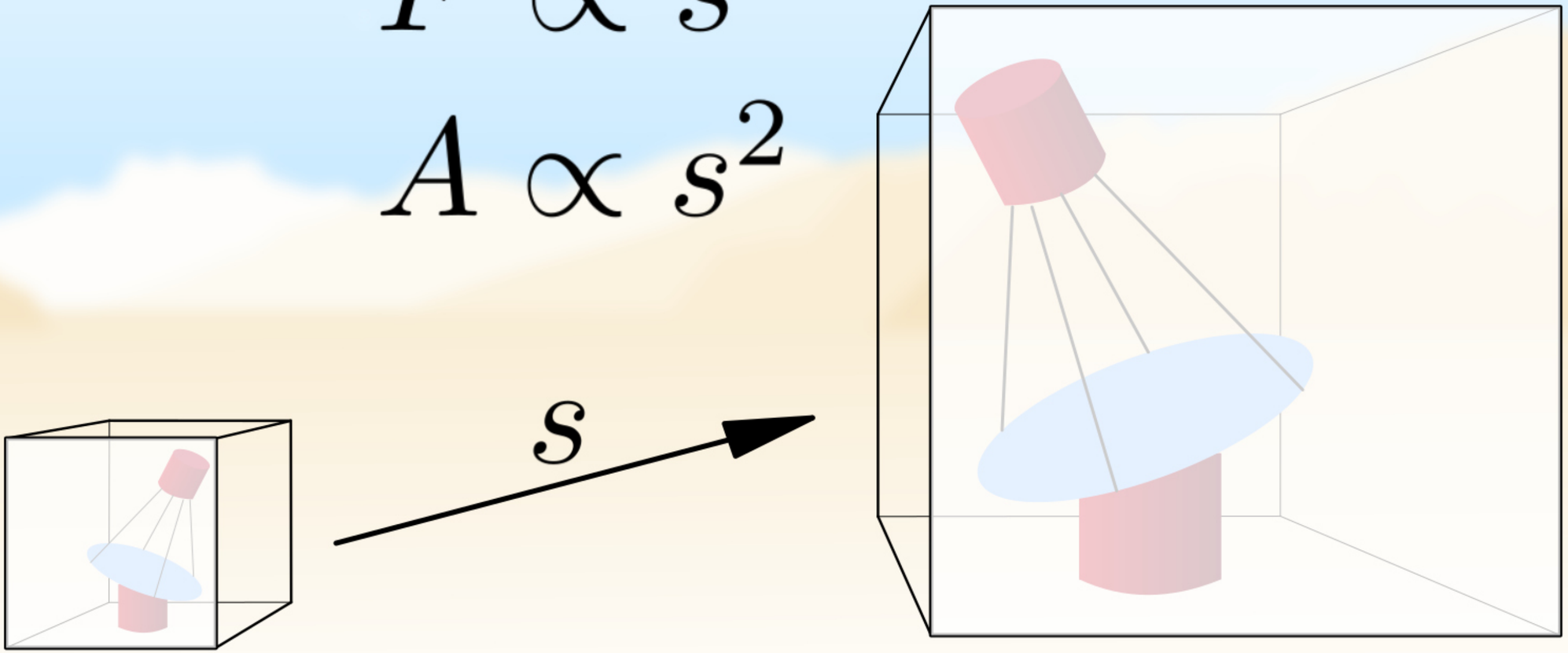


Limits of Telescopes

square-cube-law

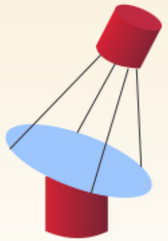
$$F \propto s^3$$

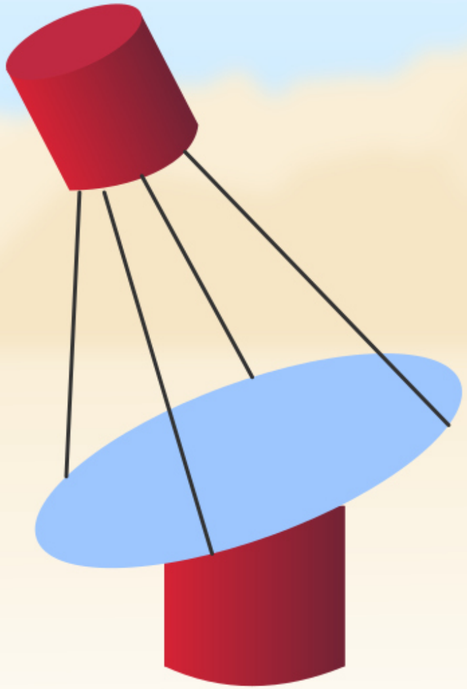
$$A \propto s^2$$



Limits of Telescopes

depth-of-field

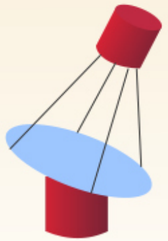


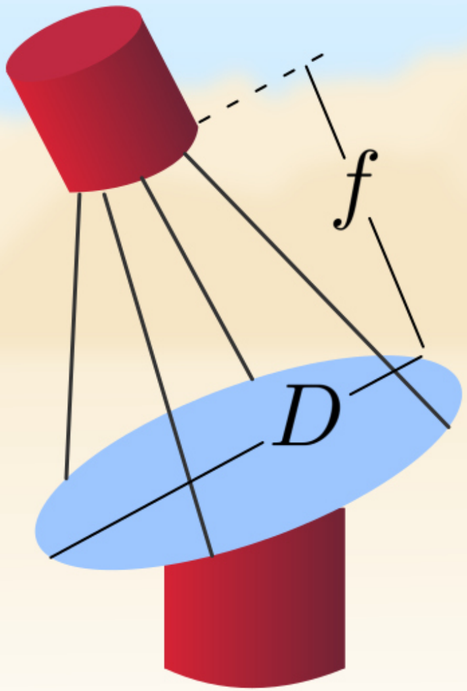


Limits of Telescopes

depth-of-field

larger (D, f)



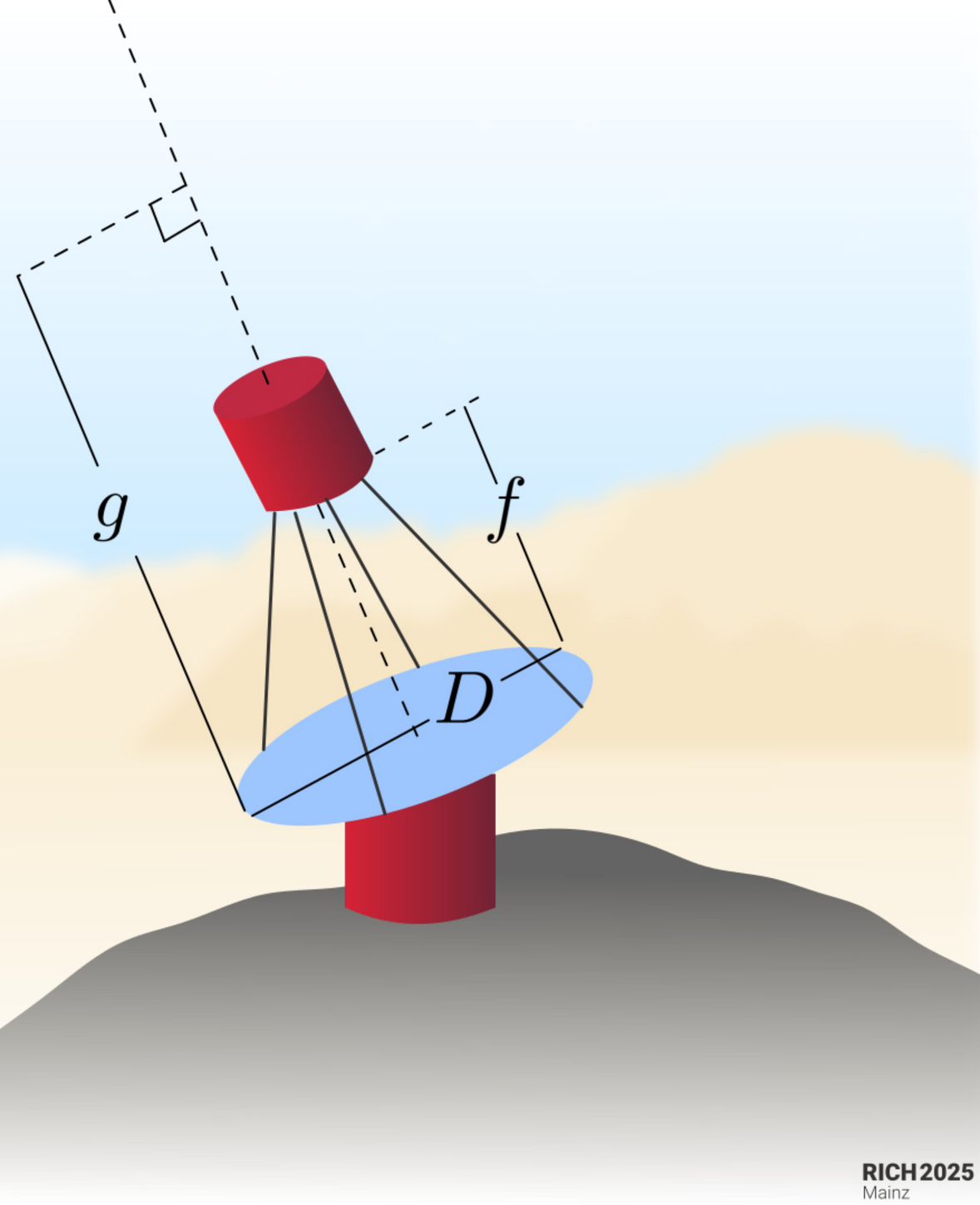


Limits of Telescopes

depth-of-field

larger (D, f)

on mountains, closer to shower (g)



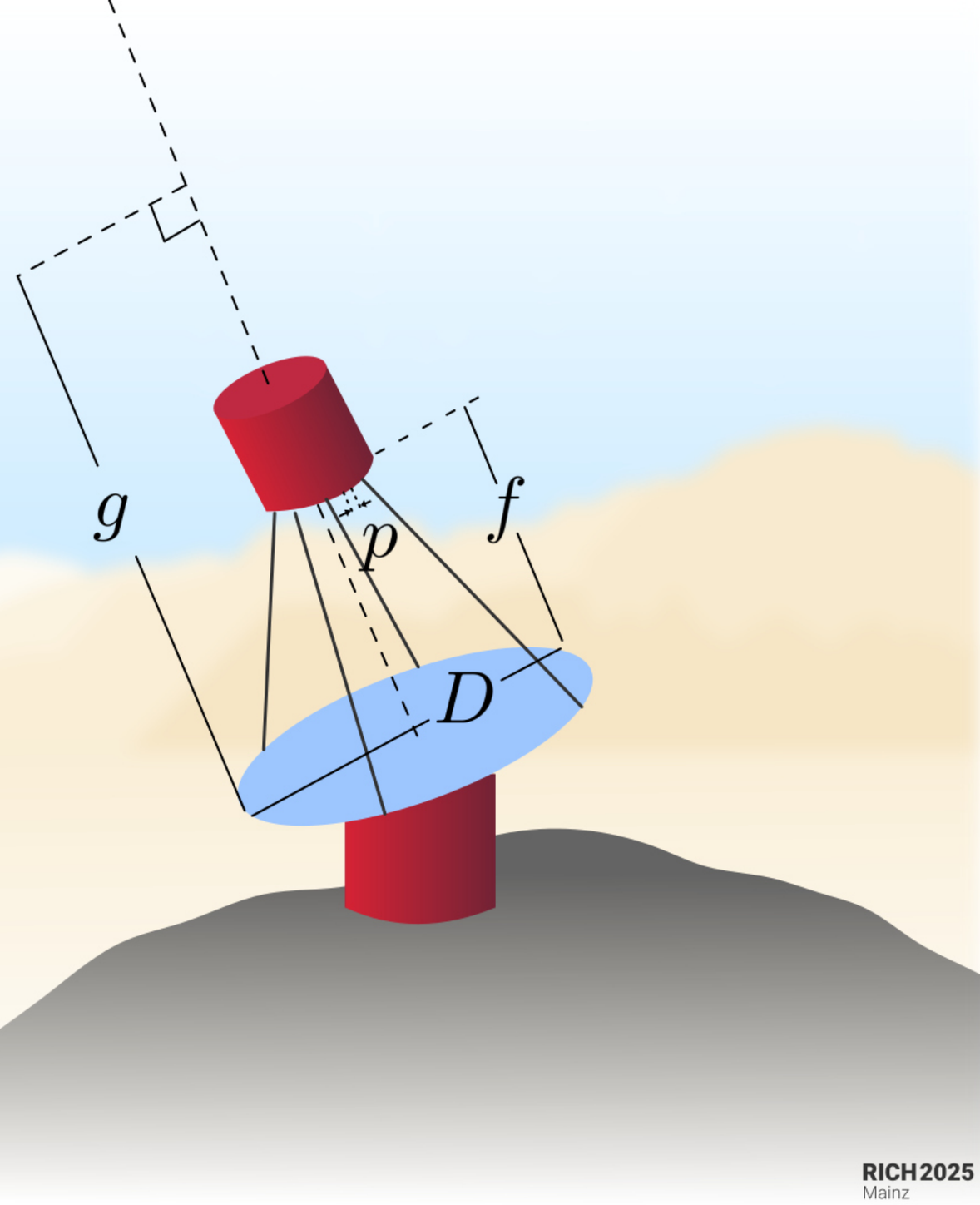
Limits of Telescopes

depth-of-field

larger (D, f)

on mountains, closer to shower (g)

finer pixelation (p)



Limits of Telescopes

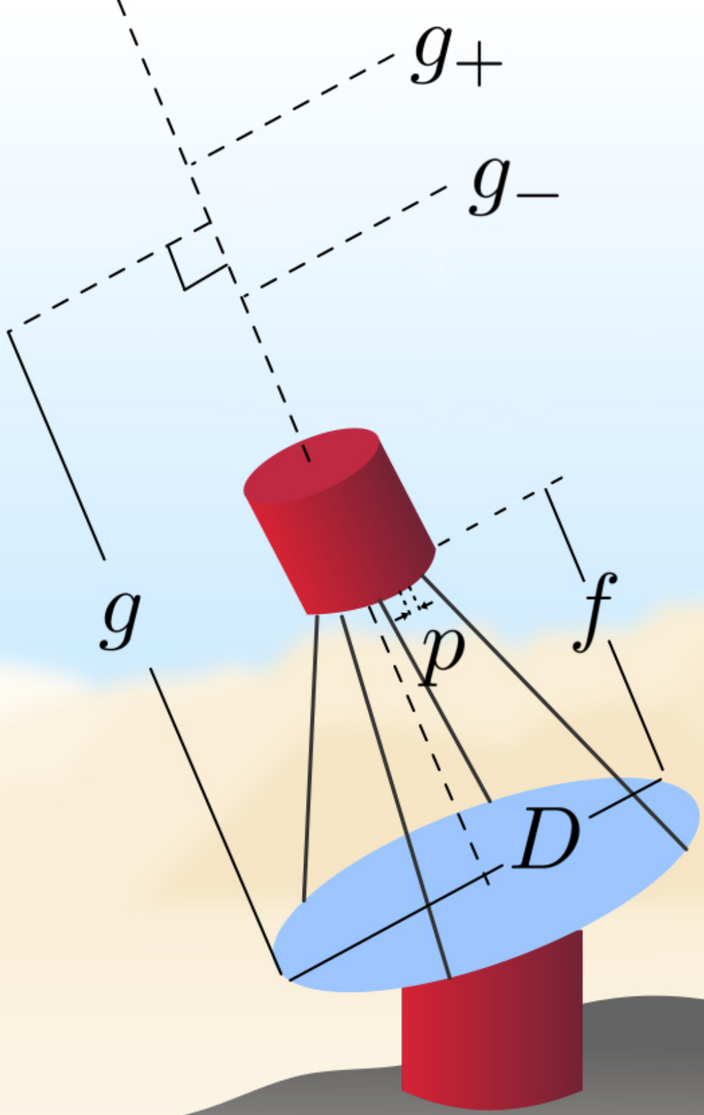
depth-of-field

larger (D, f)

on mountains, closer to shower (g)

finer pixelation (p)

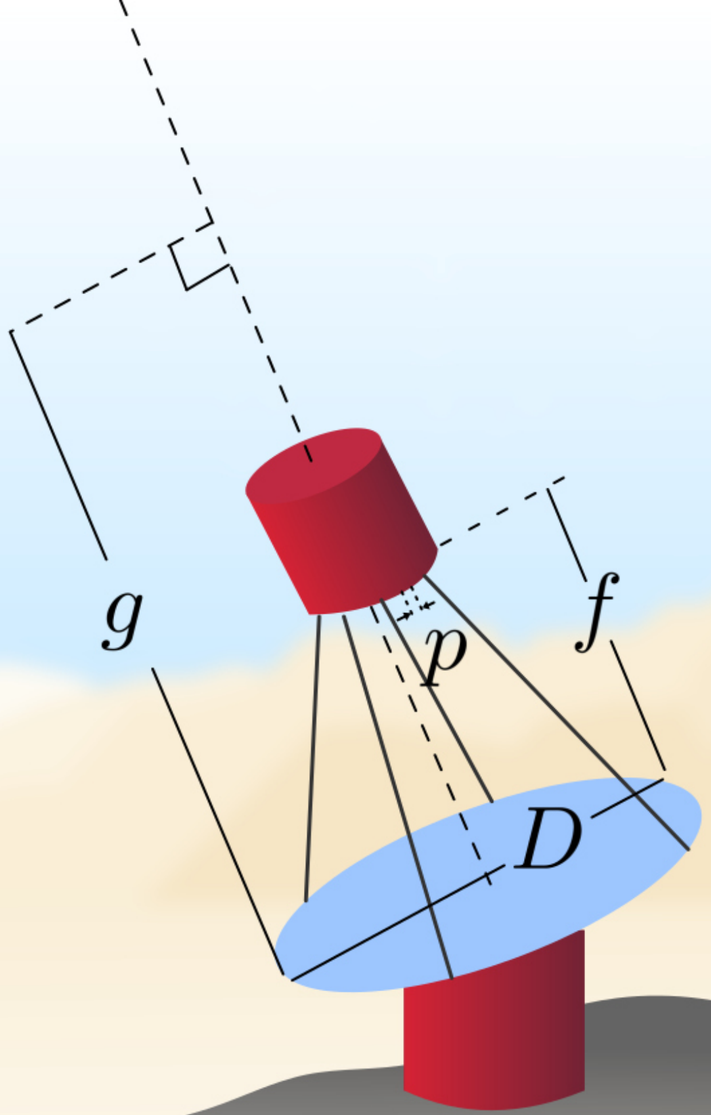
$$g_{\pm} = g(1 \pm pg/(2fD))$$



K. Bernloehr et al. 2013
Monte Carlo design studies for the Cherenkov Telescope Array
Astroparticle Physics, vol.43 p.171-188

Limits of Telescopes

depth-of-field



$$g_{\pm} = g(1 \pm pg/(2fD))$$

K. Bernloehr et al. 2013
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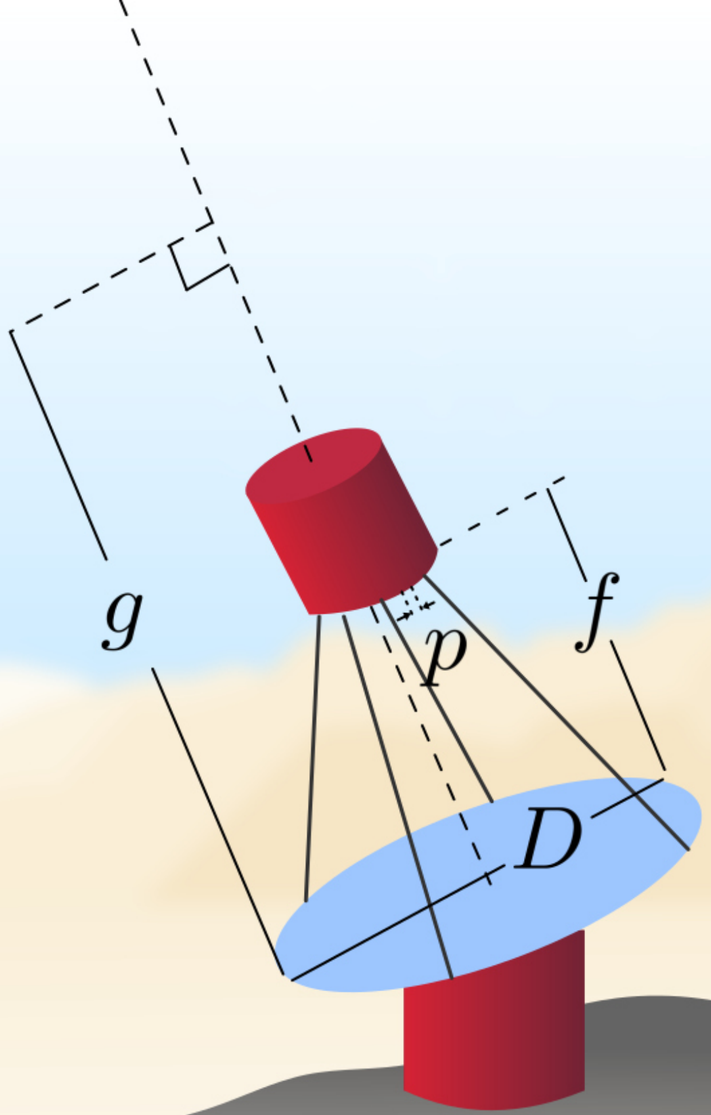
Astroparticle Physics, vol.43 p.171-188

Limits of Telescopes

depth-of-field

$$D = 71\,\mathrm{m}$$

$$g_{\pm} = g(1 \pm pg/(2fD))$$



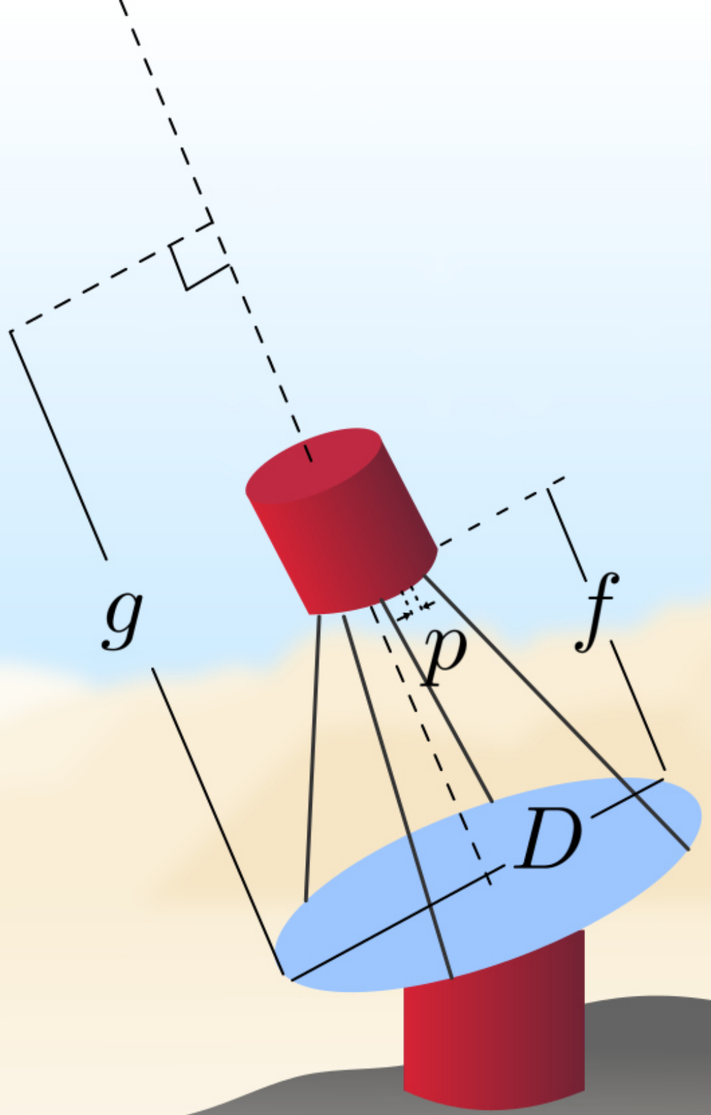
Limits of Telescopes

depth-of-field

$$D = 71\,\mathrm{m}$$

$$f/D = 1.5$$

$$g_{\pm} = g(1 \pm pg/(2fD))$$



Limits of Telescopes

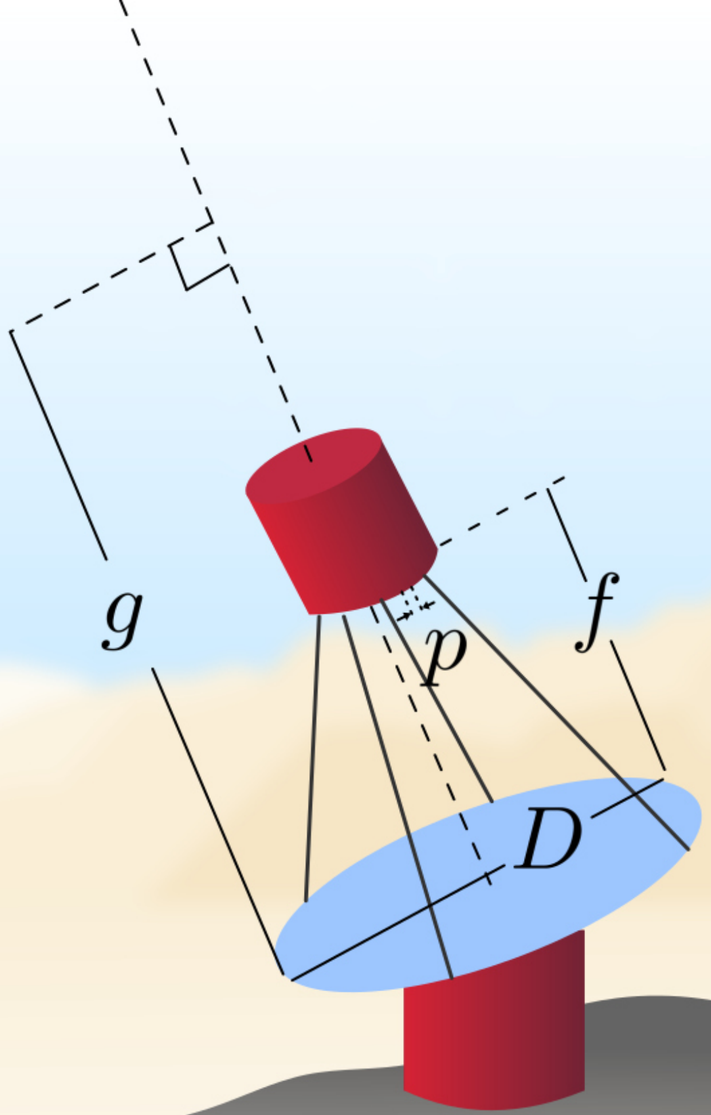
depth-of-field

$$D = 71\,\mathrm{m}$$

$$f/D = 1.5$$

$$p = 124\,\mathrm{mm}\ (0.067°)$$

$$g_\pm = g(1 \pm pg/(2fD))$$



Limits of Telescopes

depth-of-field

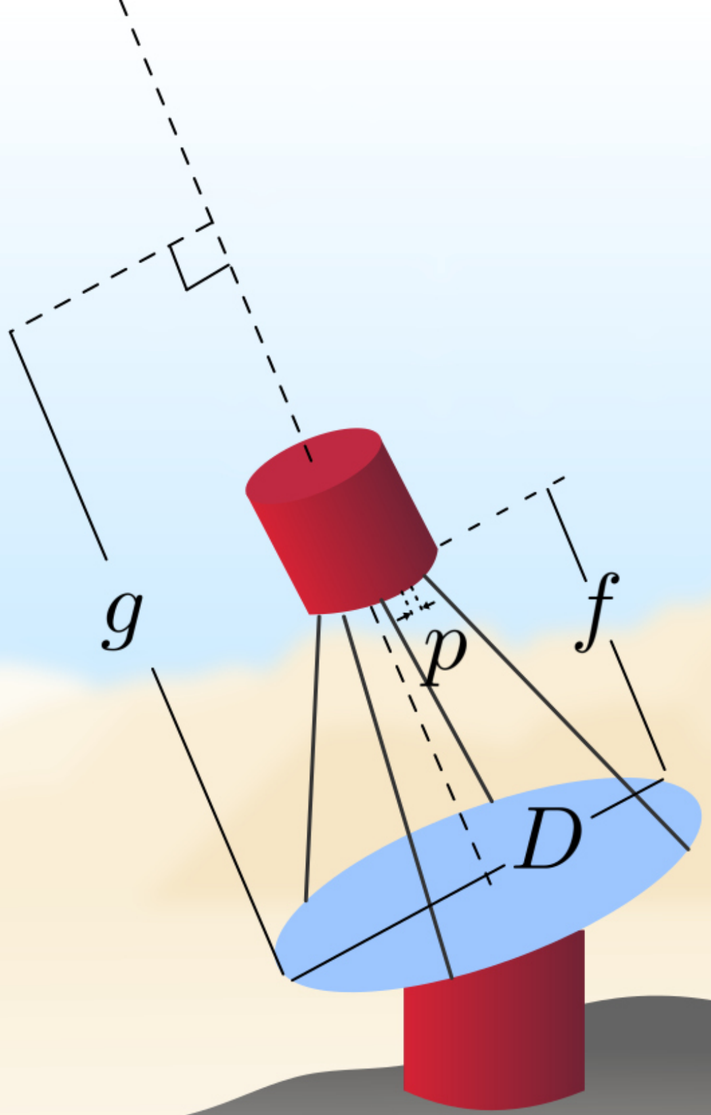
$$D = 71\,\mathrm{m}$$

$$f/D = 1.5$$

$$p = 124\,\mathrm{mm}\ (0.067°)$$

$$g = 10\,\mathrm{km}$$

$$g_\pm = g(1 \pm pg/(2fD))$$



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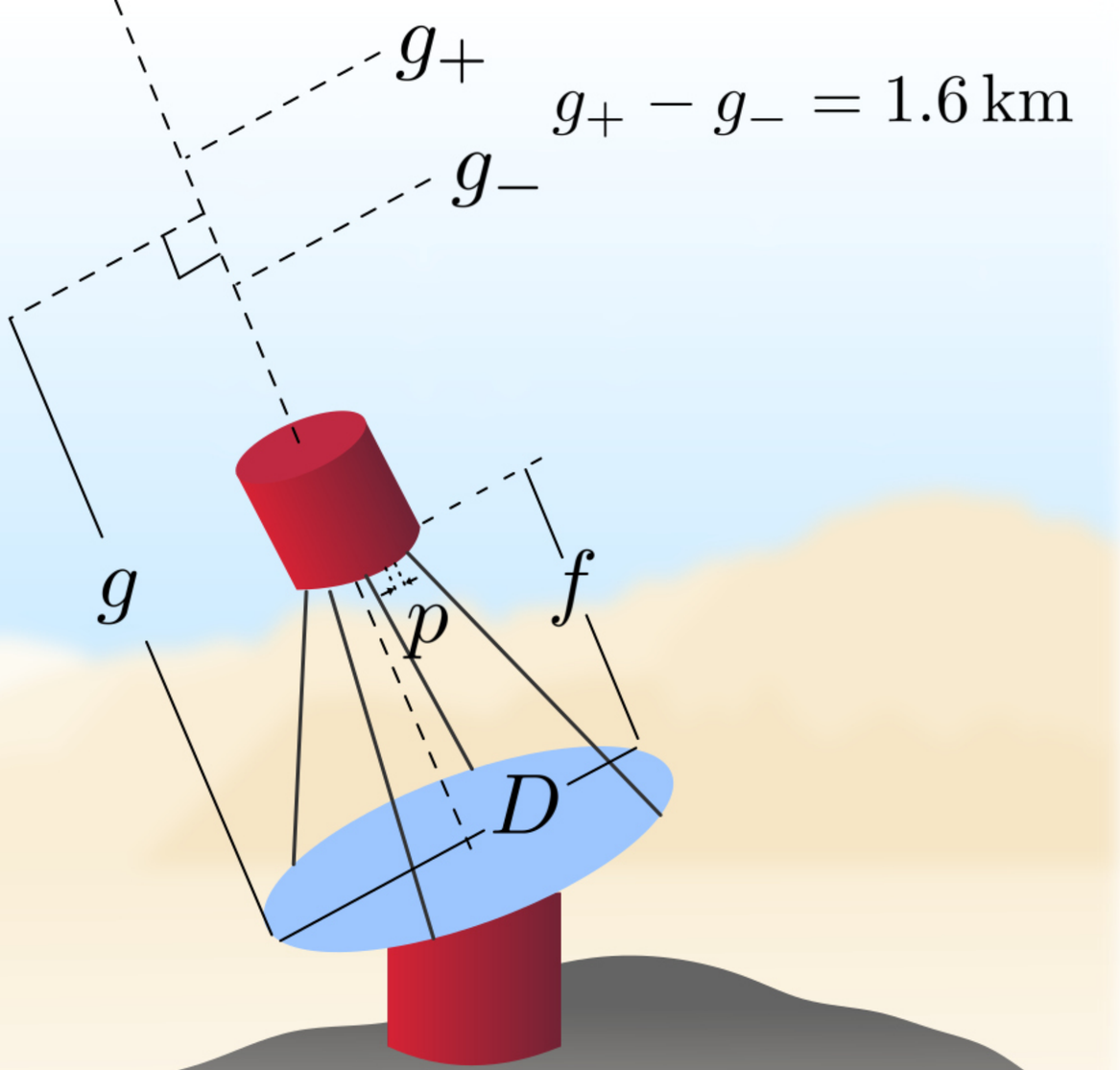

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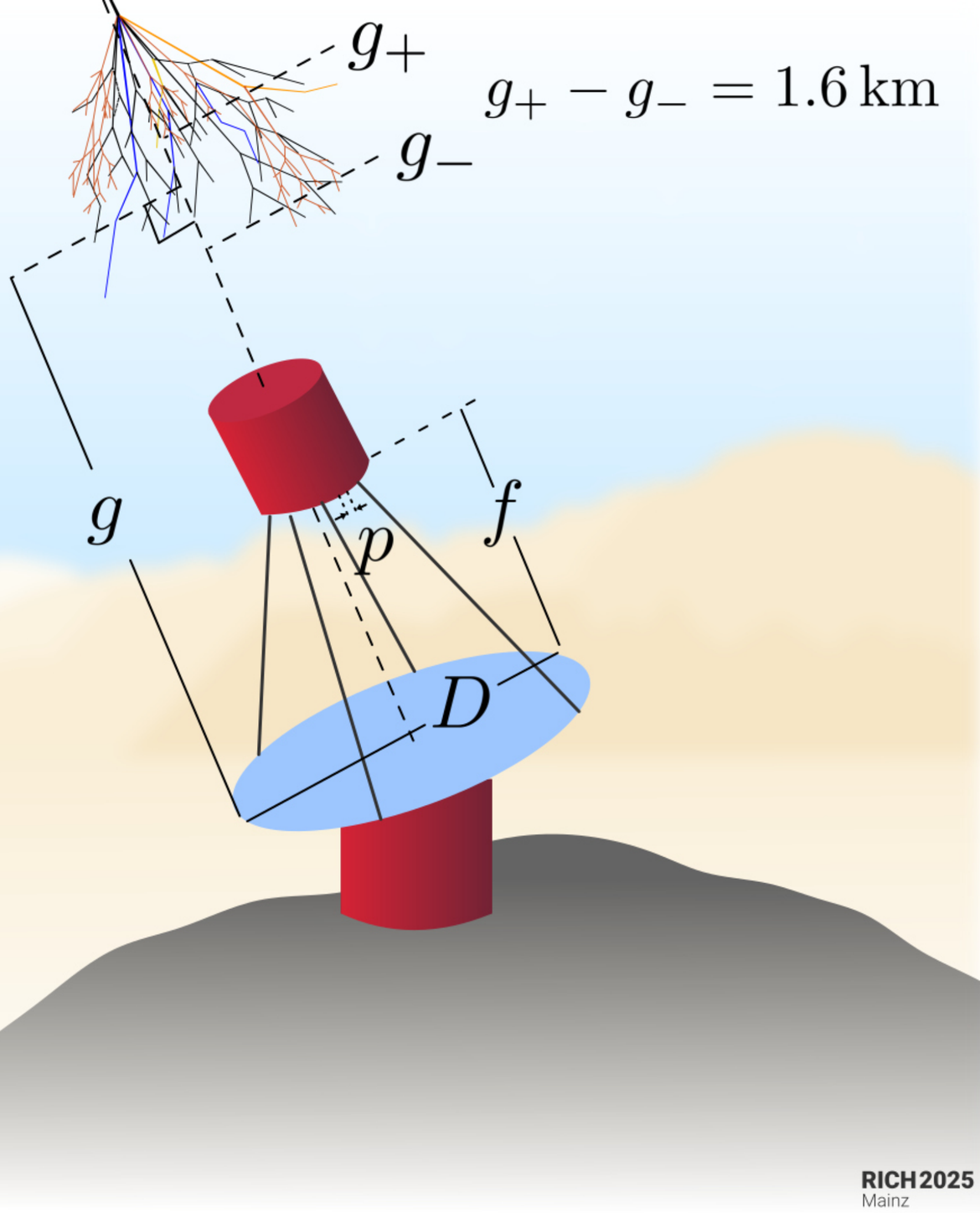


Motivation

Motivation

depth-of-field

aberrations

Motivation

deformations and misalignments

depth-of-field

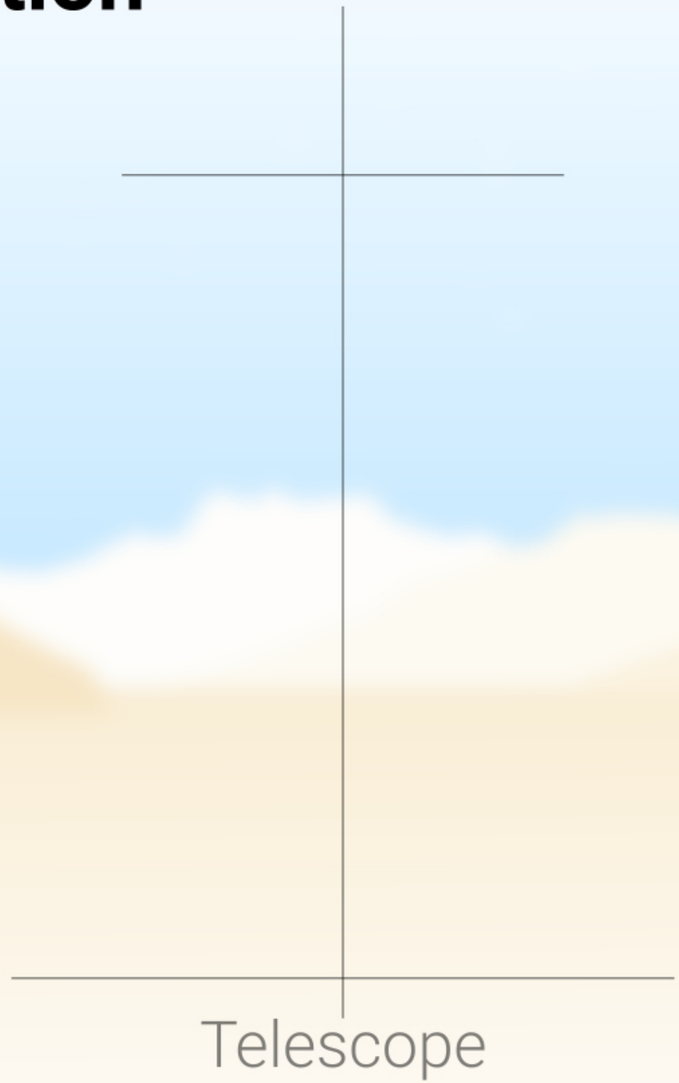
aberrations

Motivation

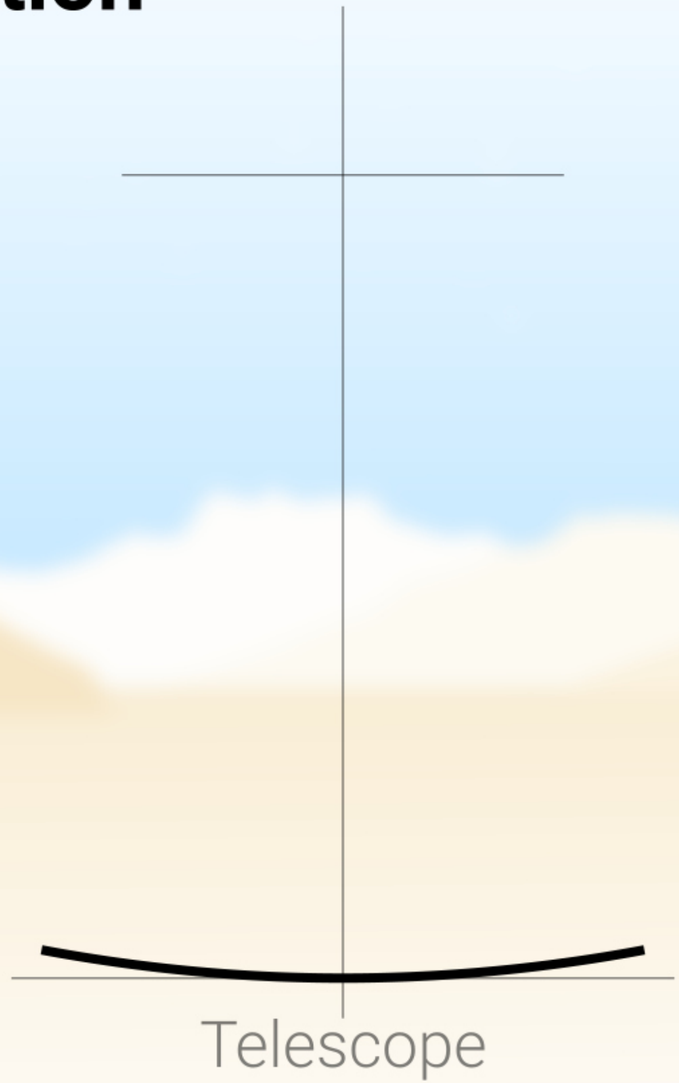
deformations and misalignments

depth-of-field

Motivation



Motivation



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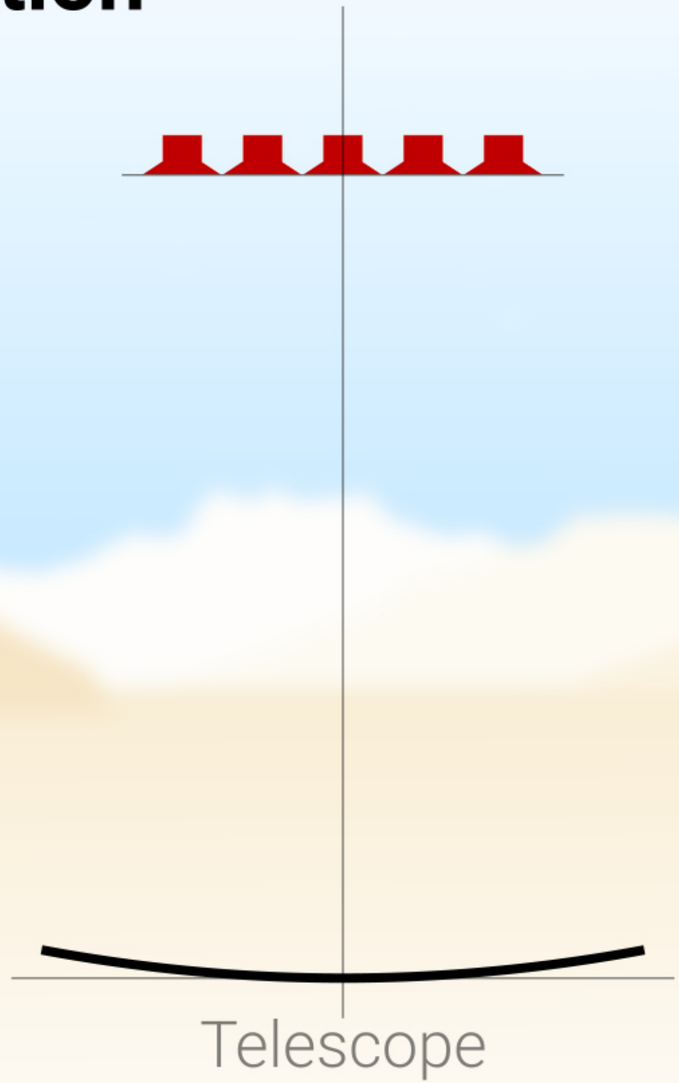
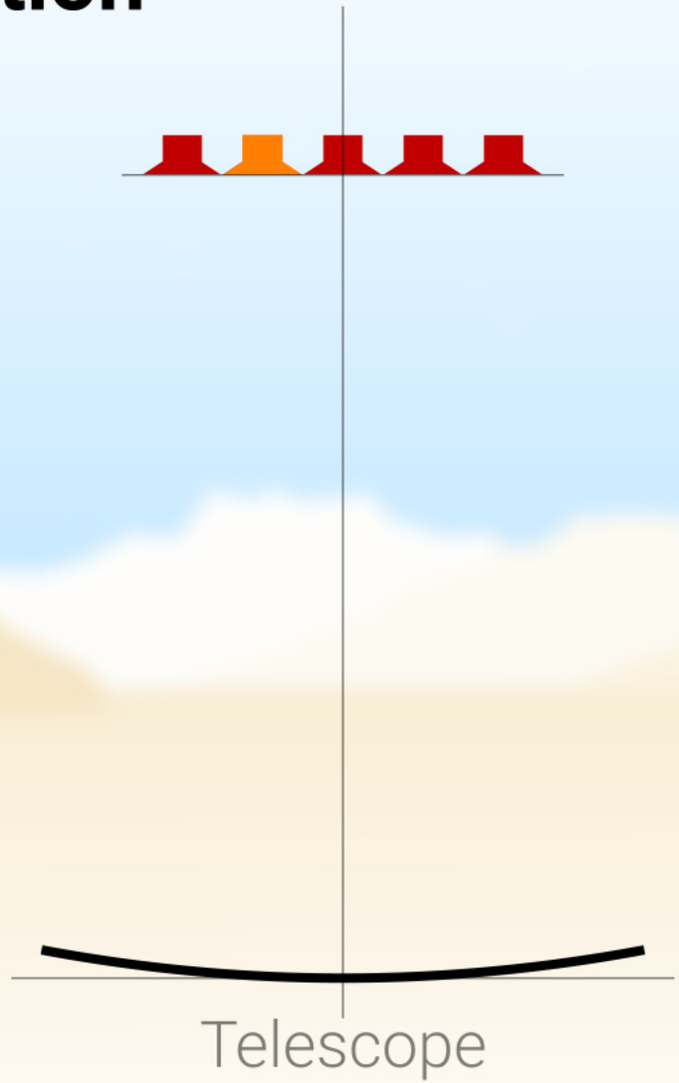
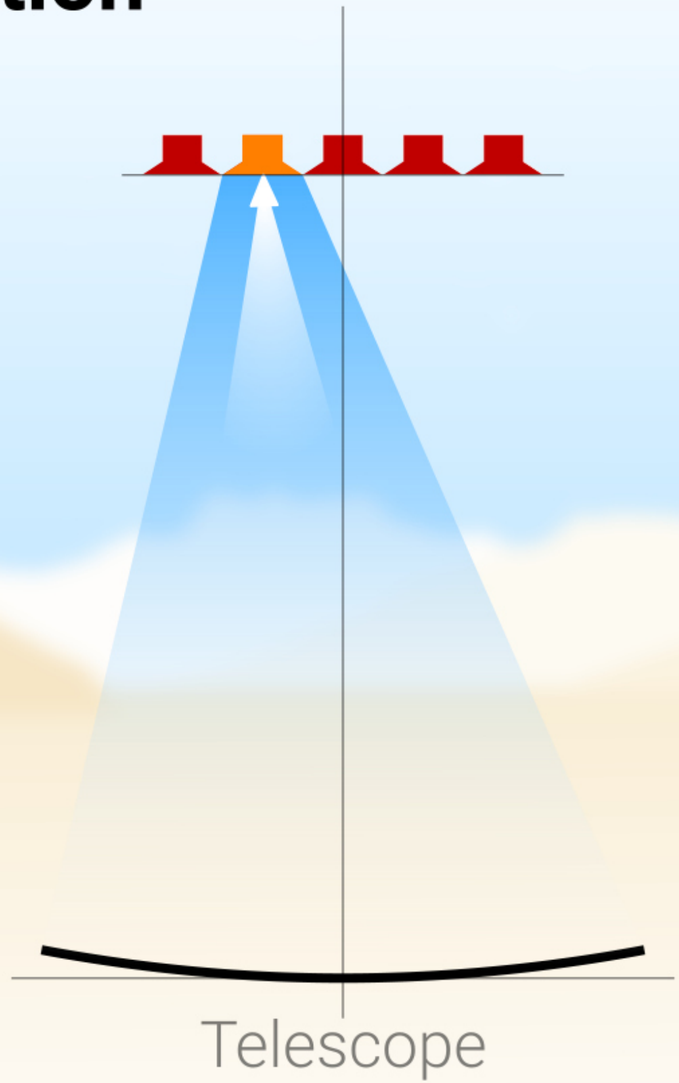


Motivation



Motivation



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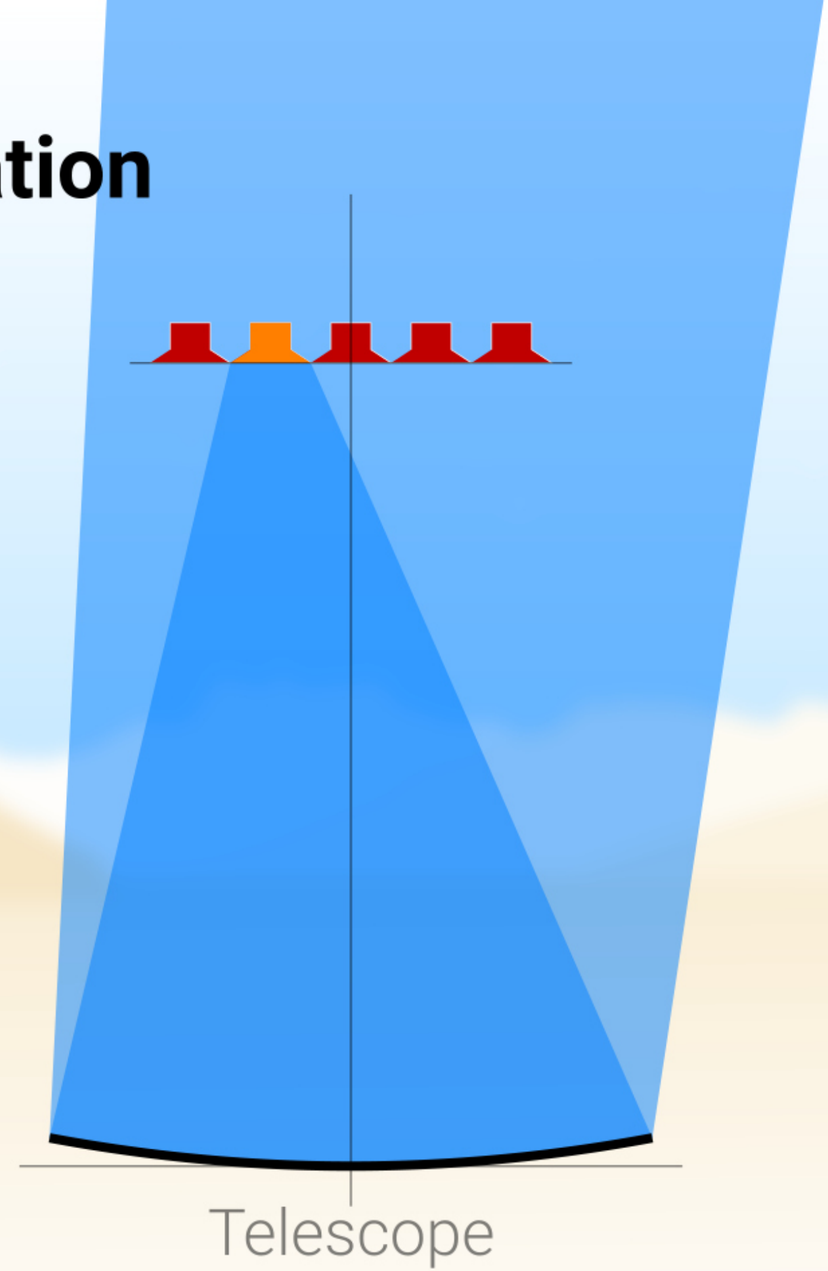

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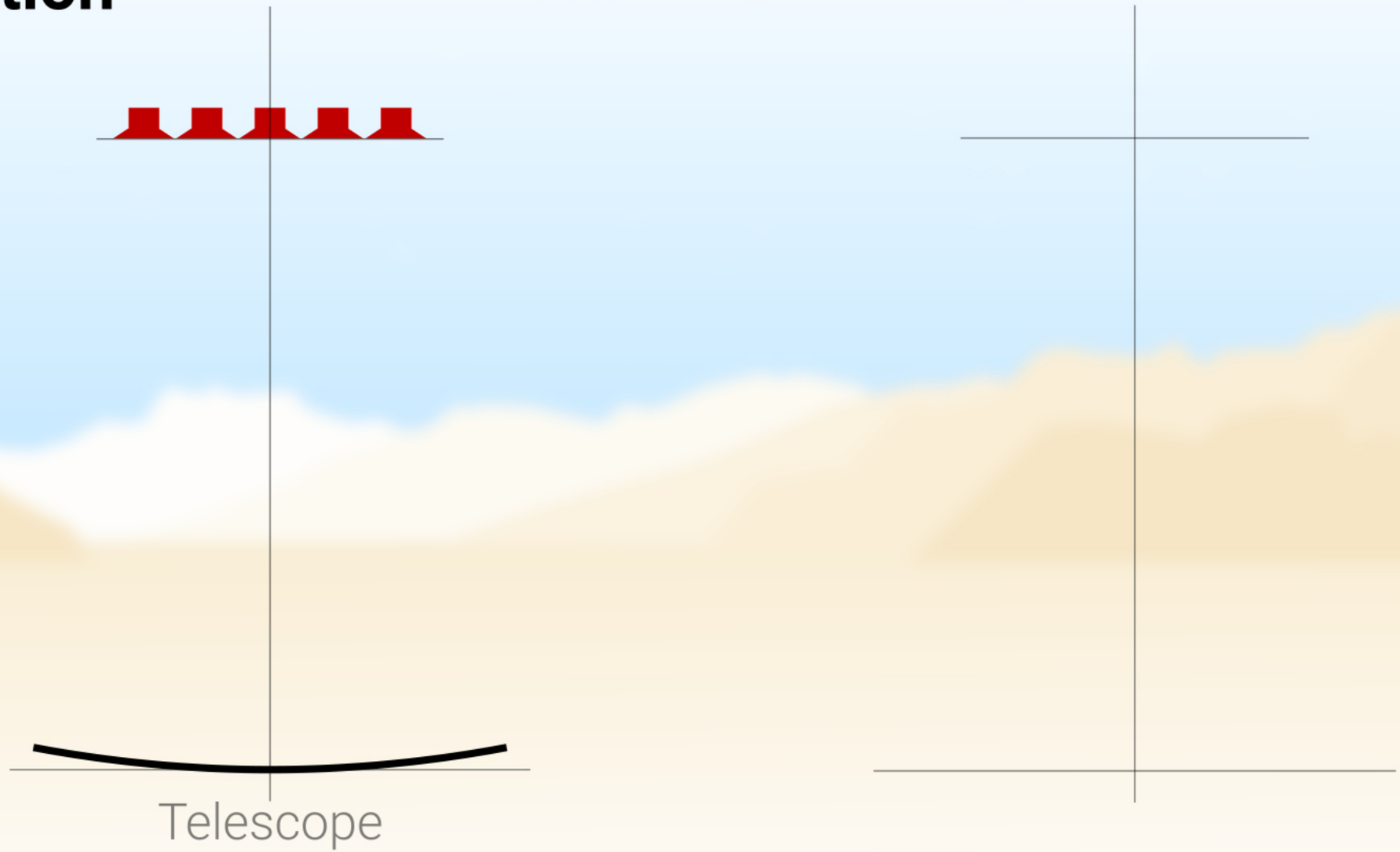

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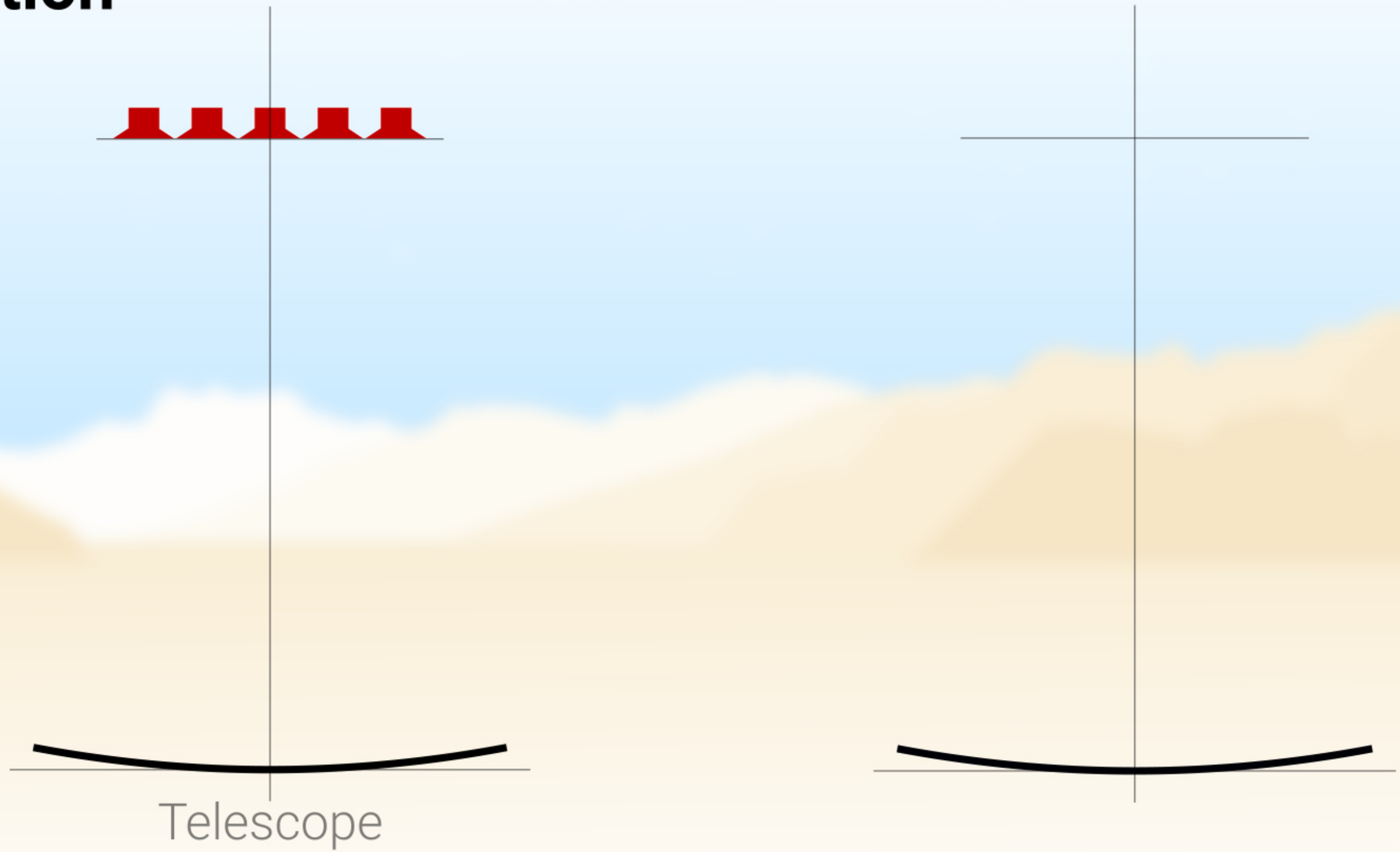

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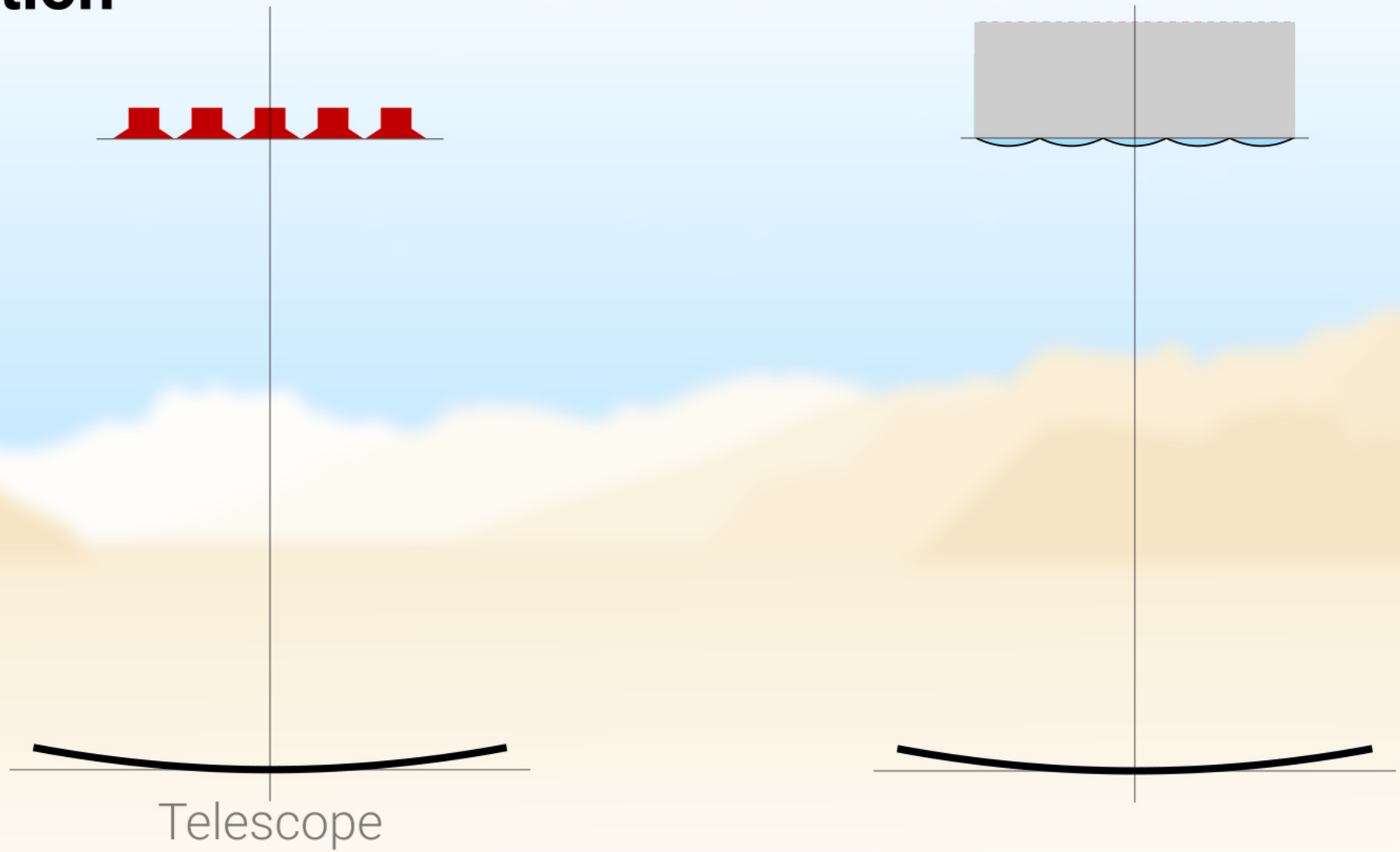

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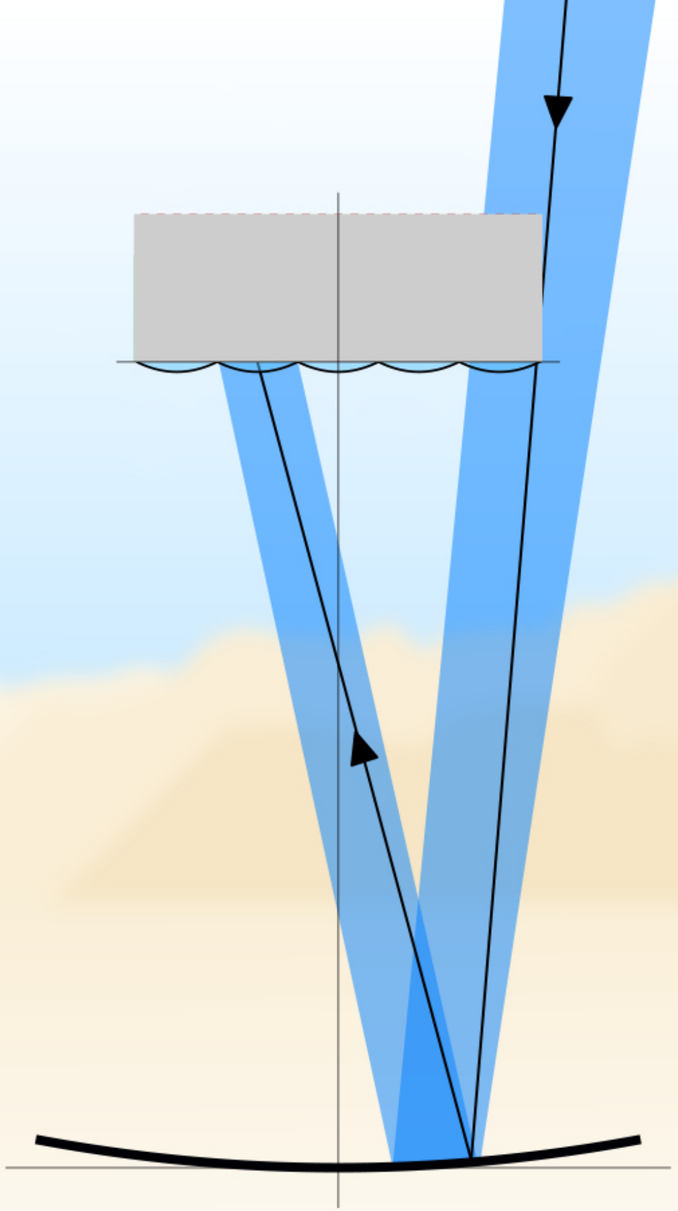

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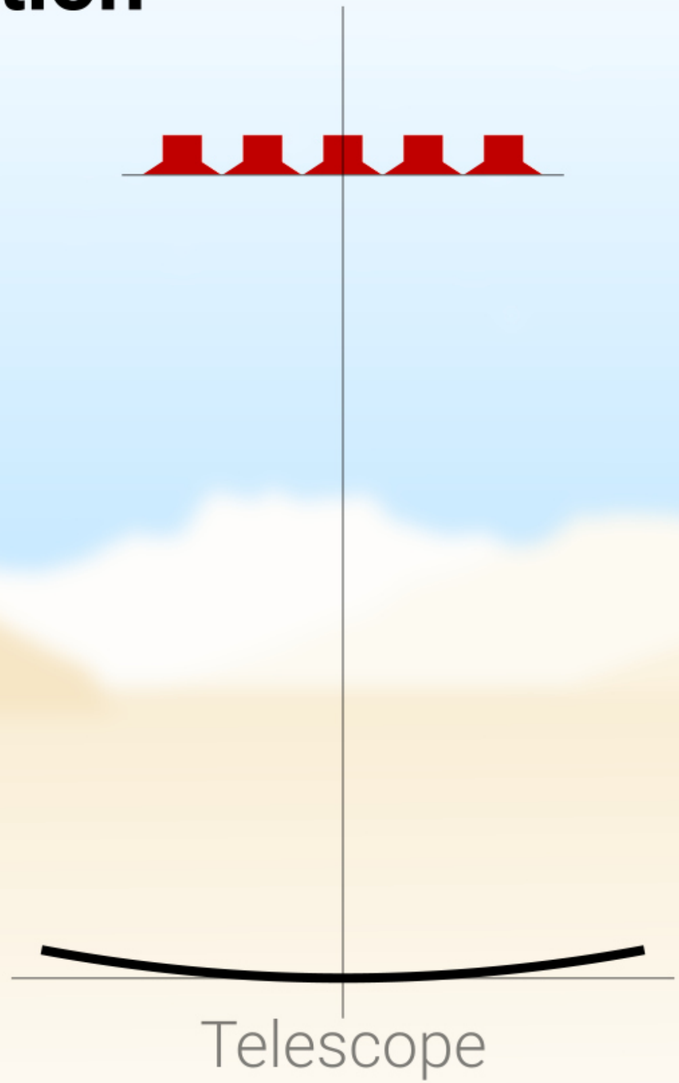

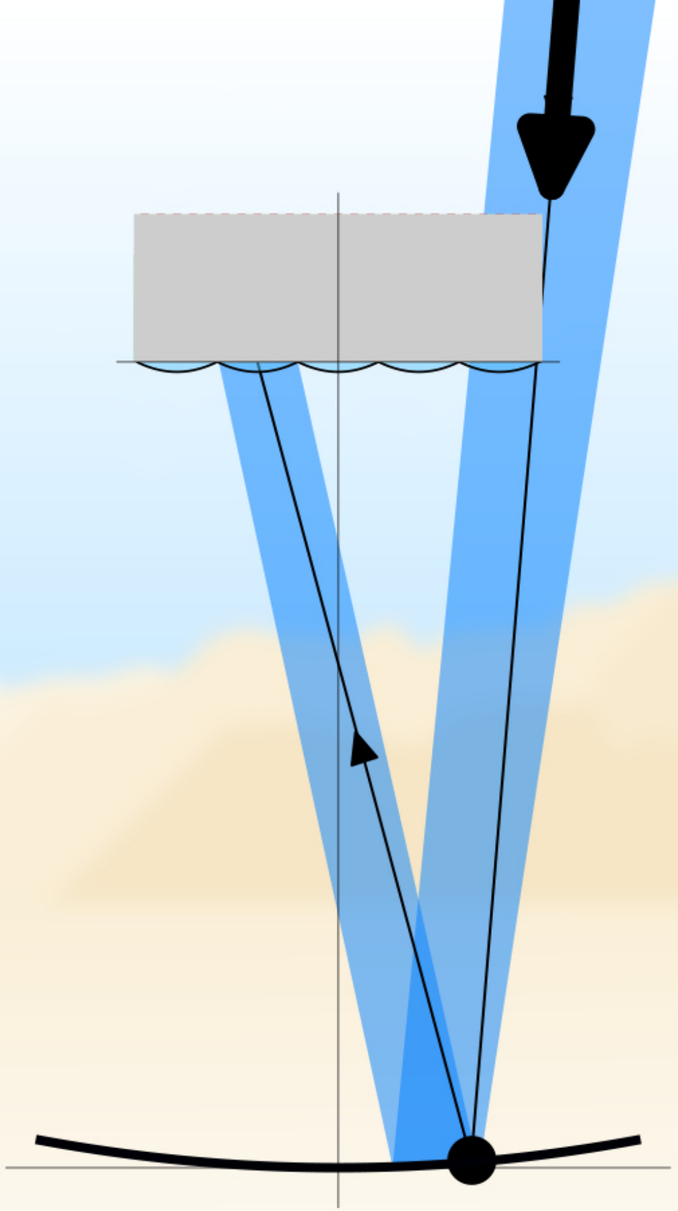

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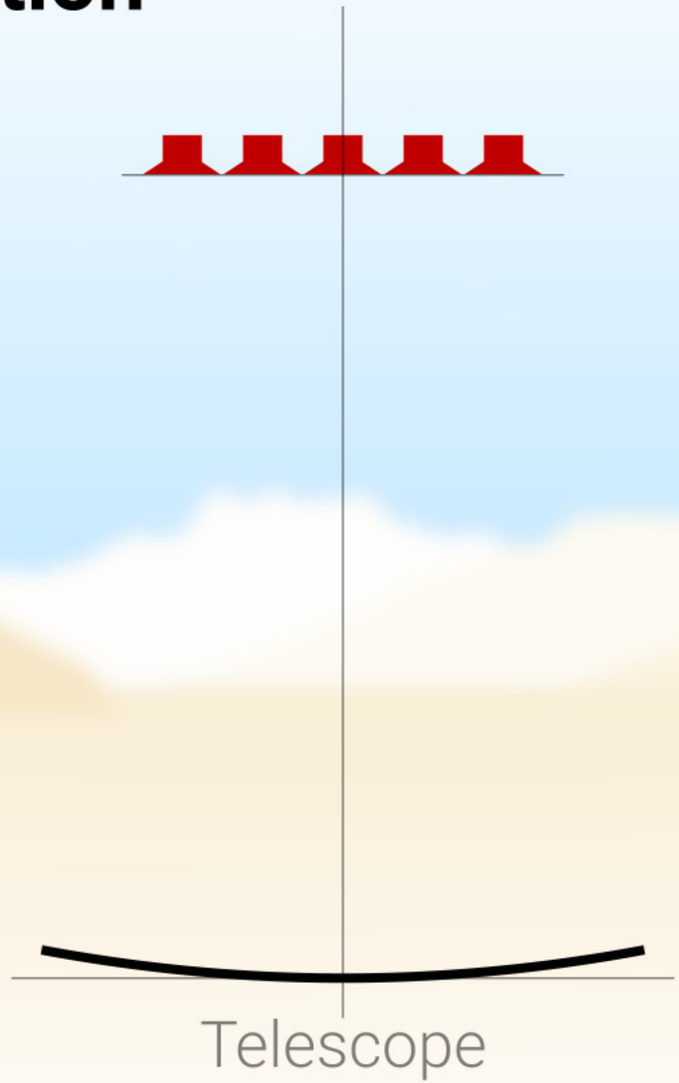

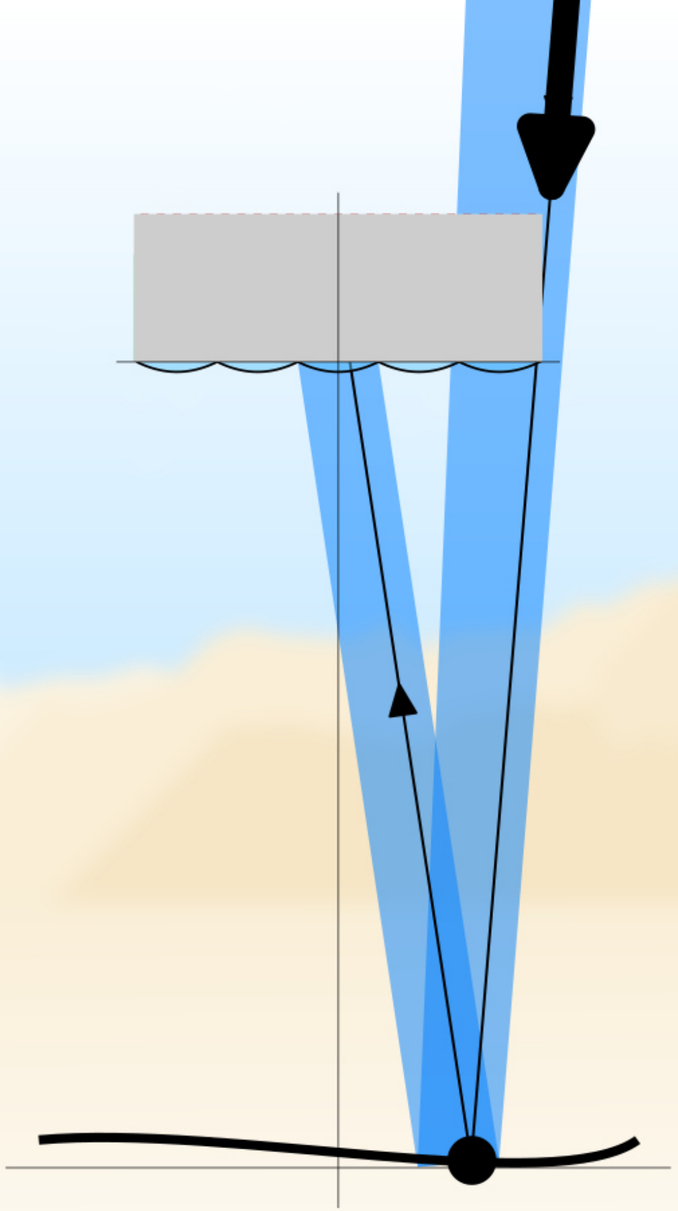

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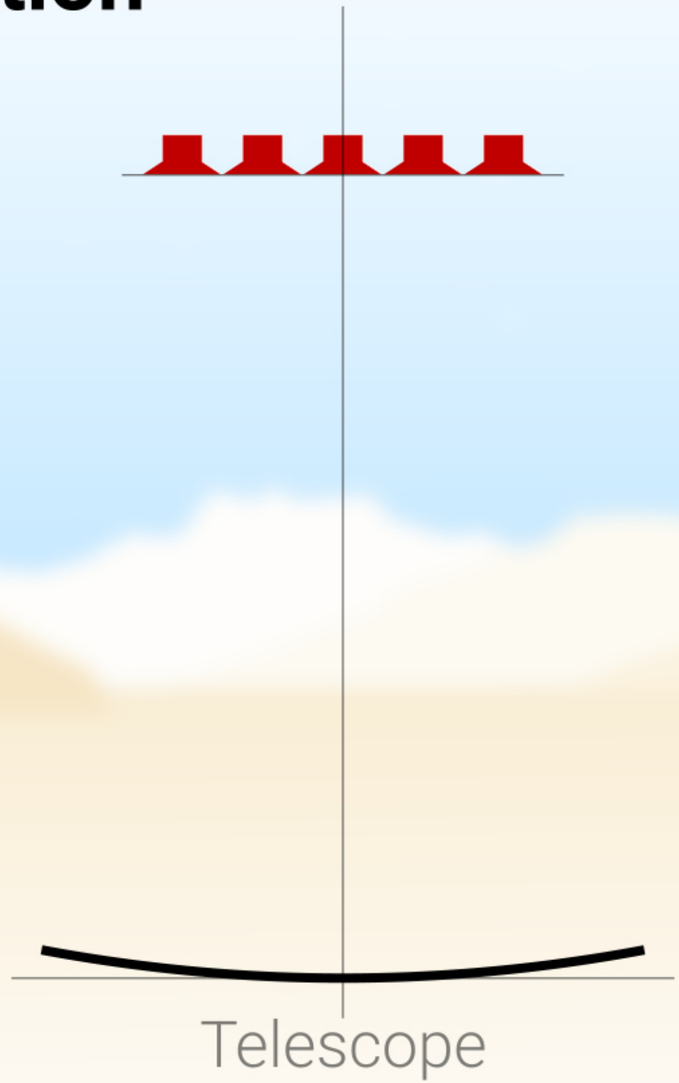

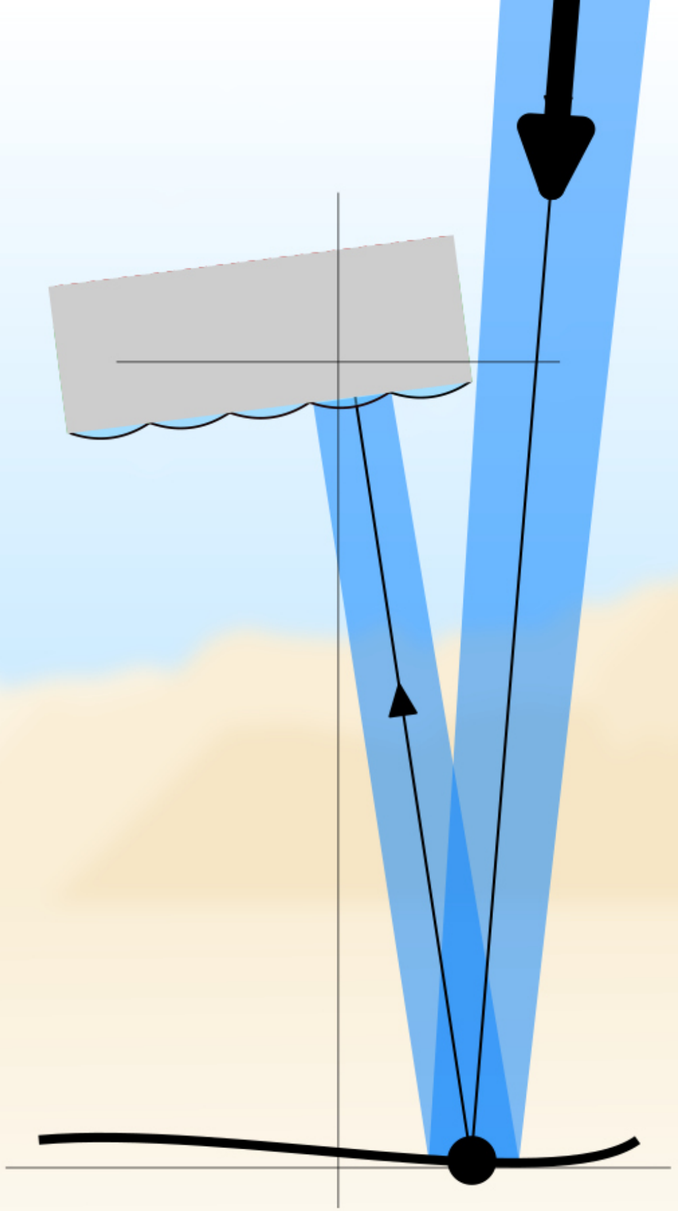

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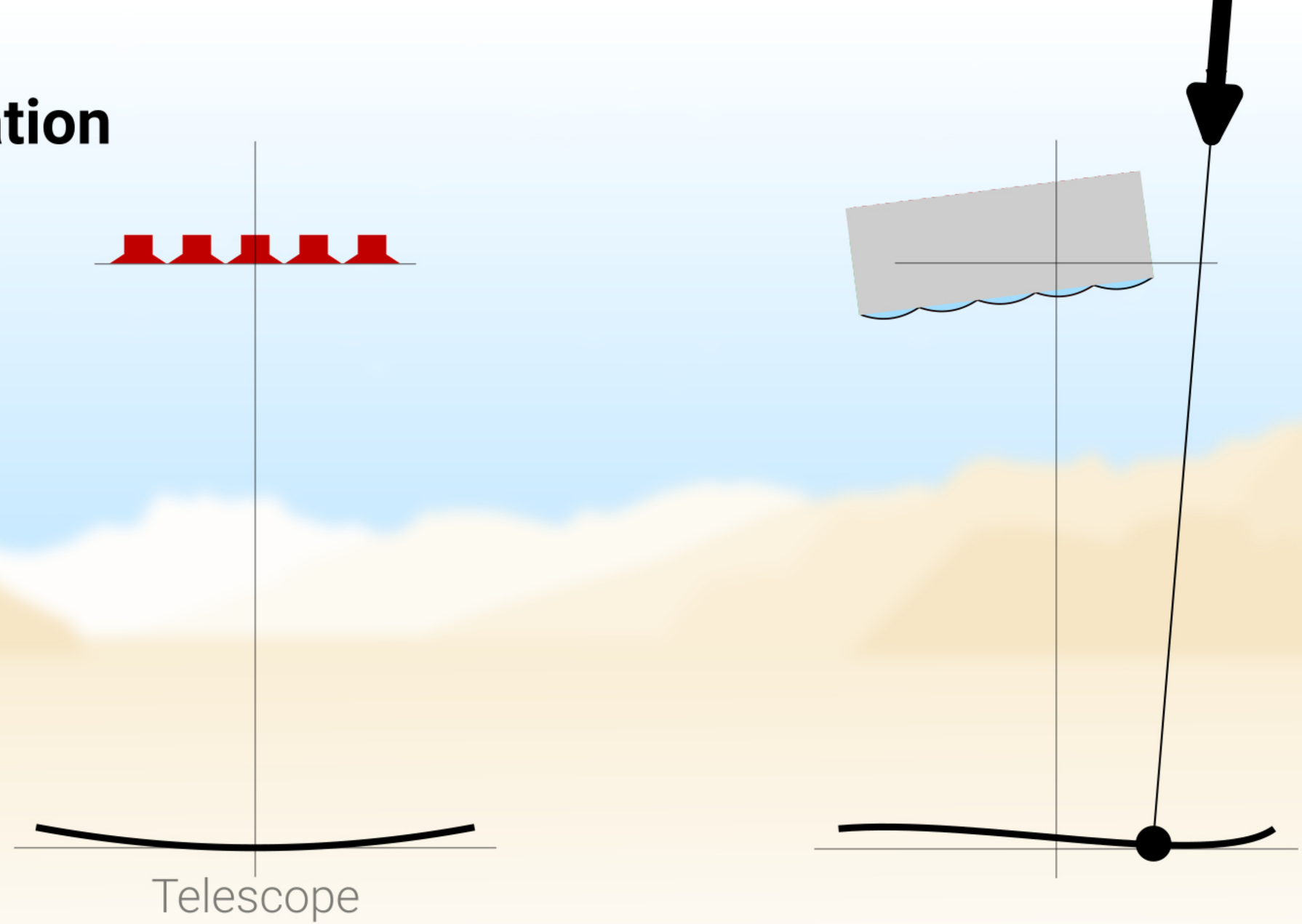

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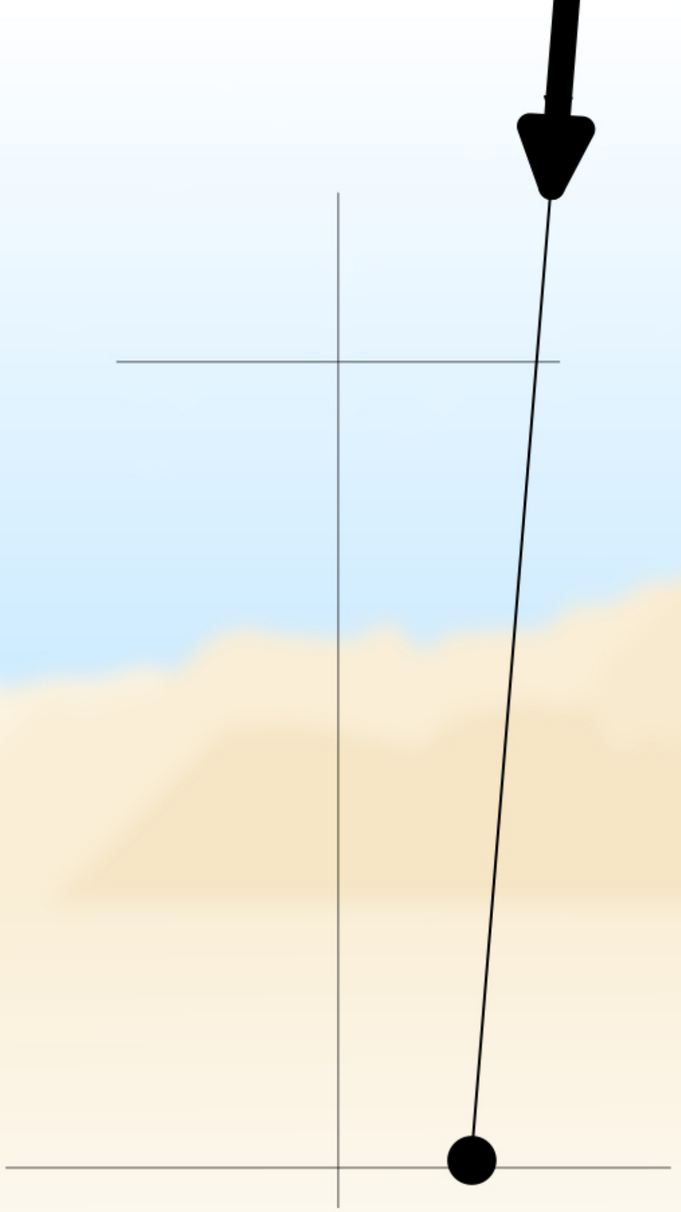

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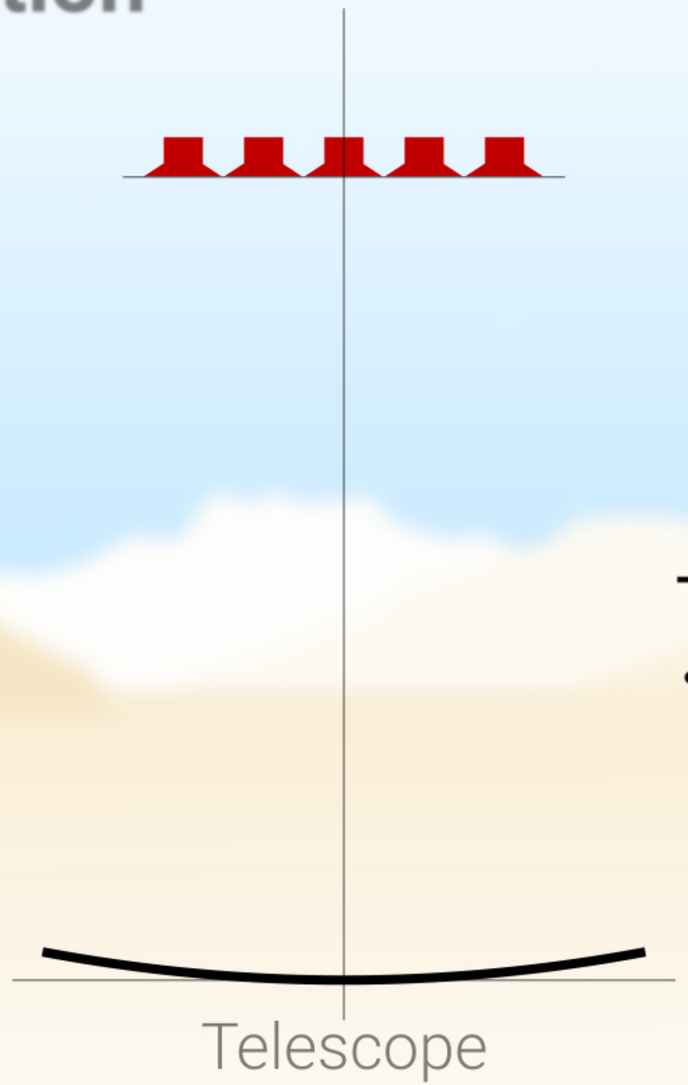
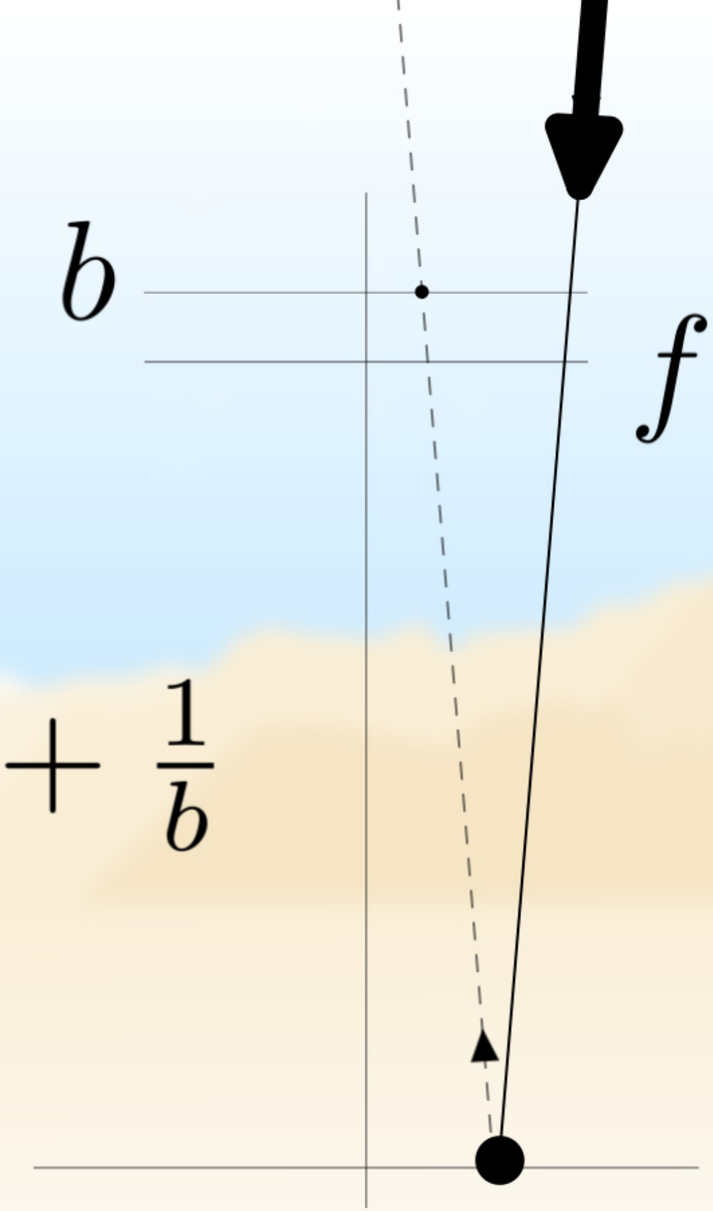
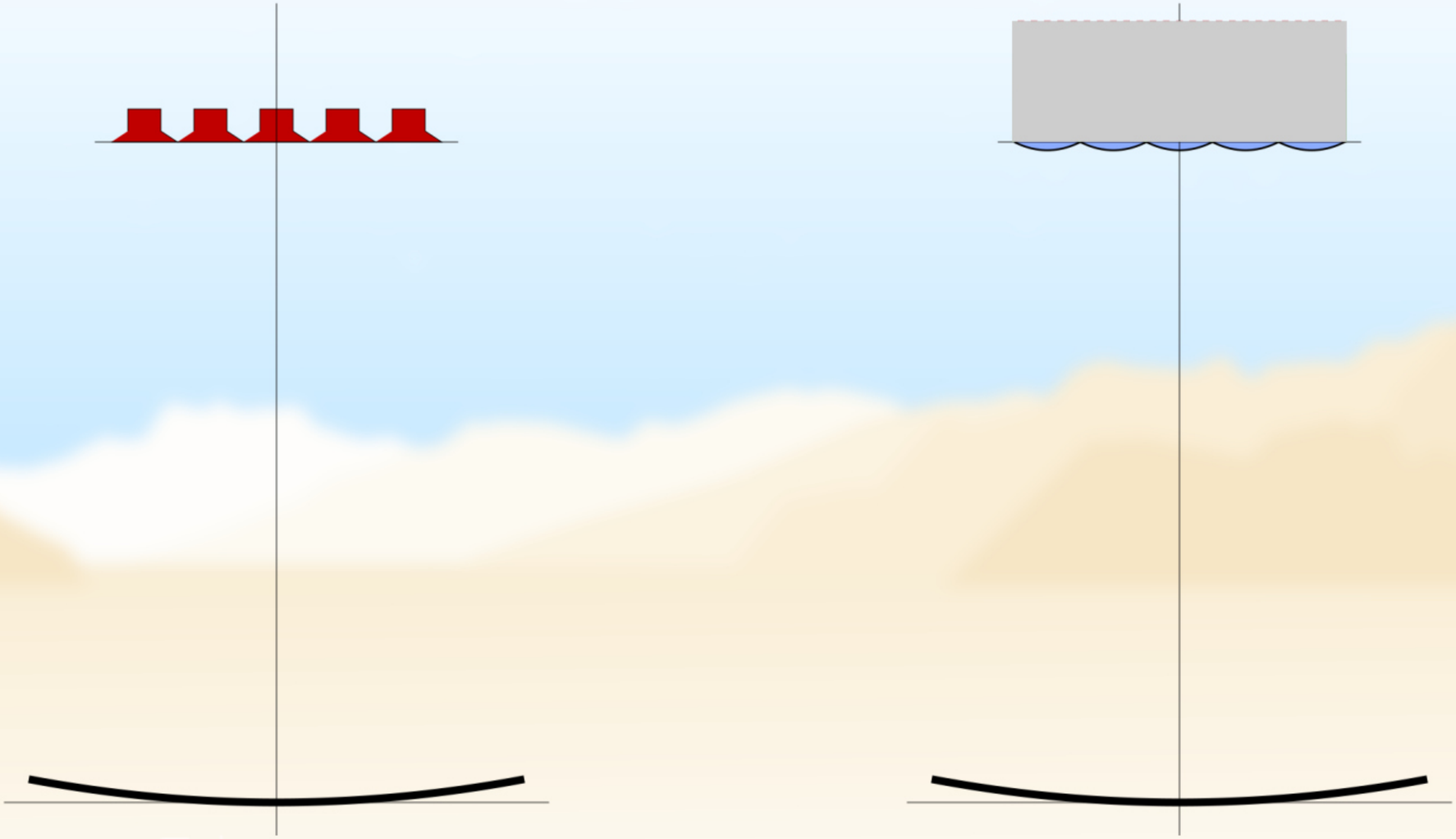


$$\frac{1}{f} = \frac{1}{g} + \frac{1}{b}$$

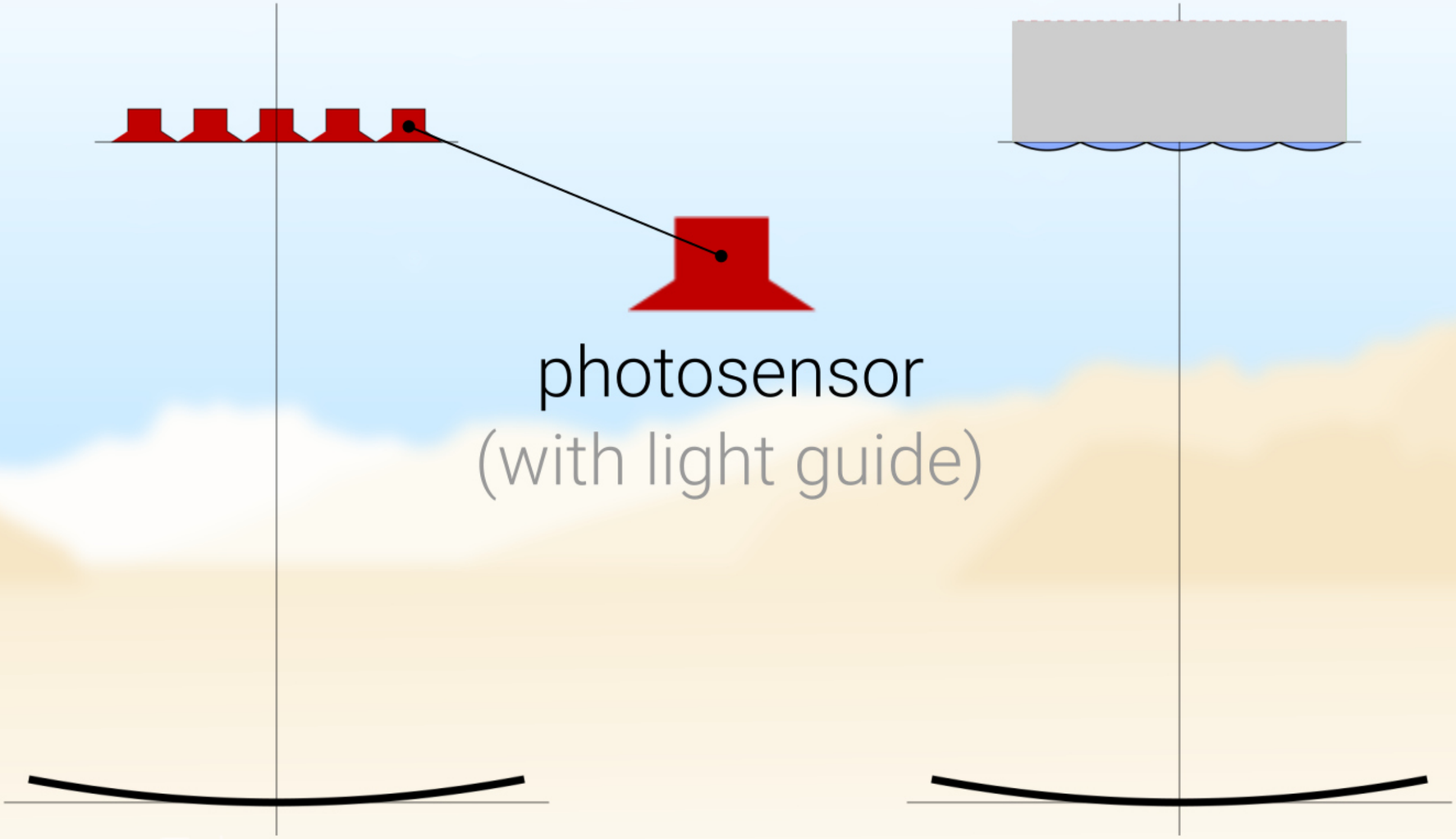


Optics

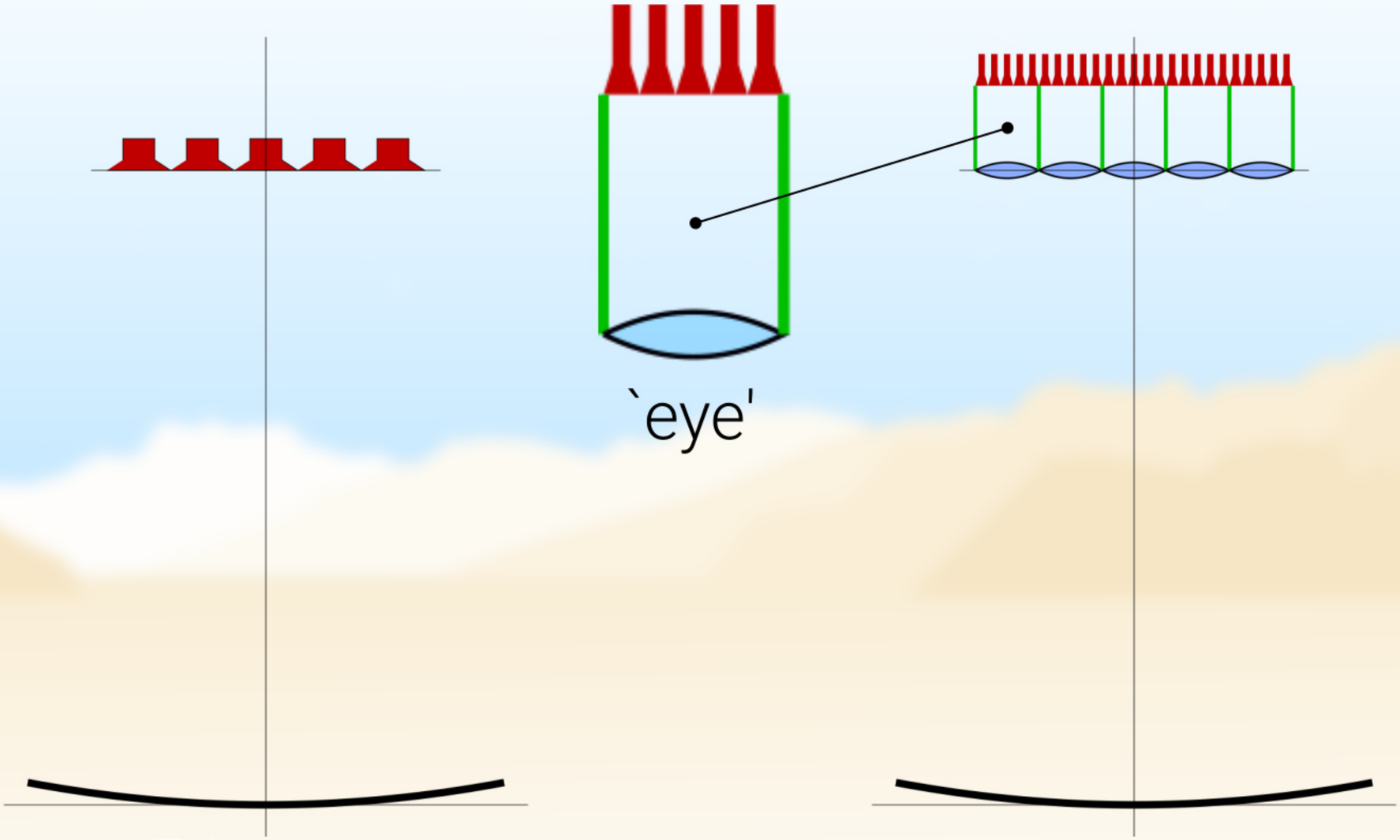


Telescope

Optics

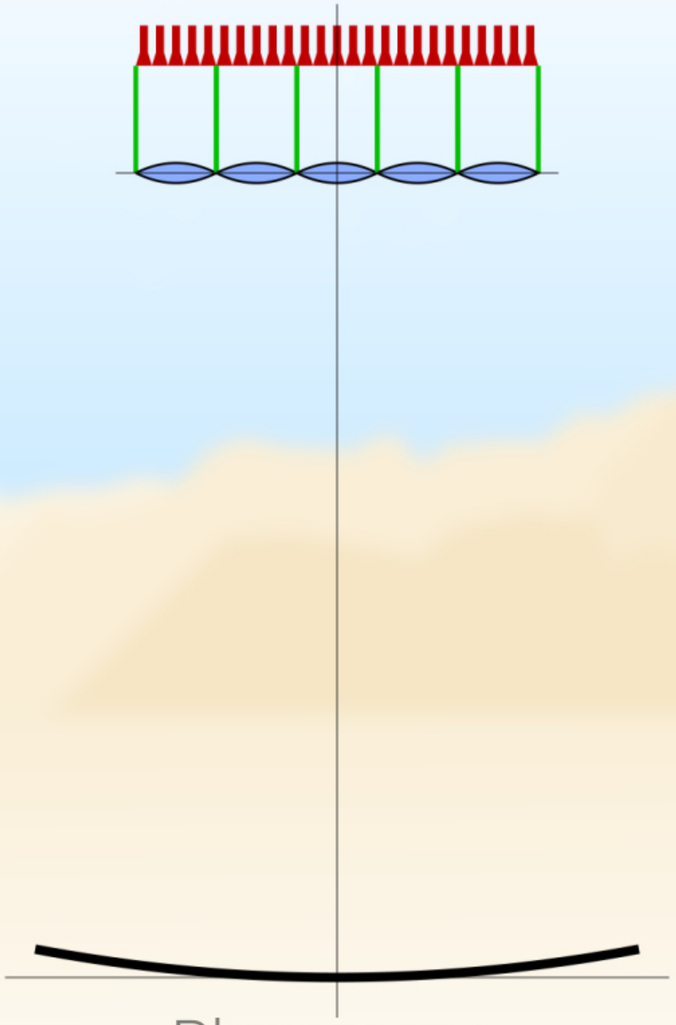


Optics



Optics

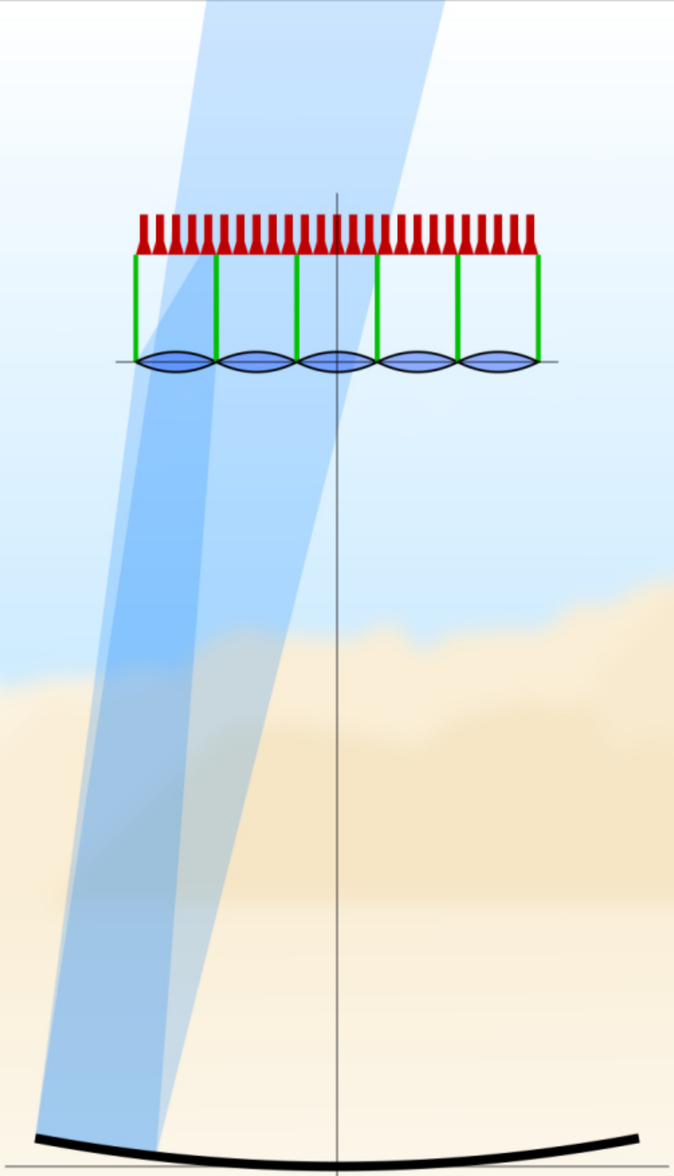
Telescope



Plenoscope

Optics

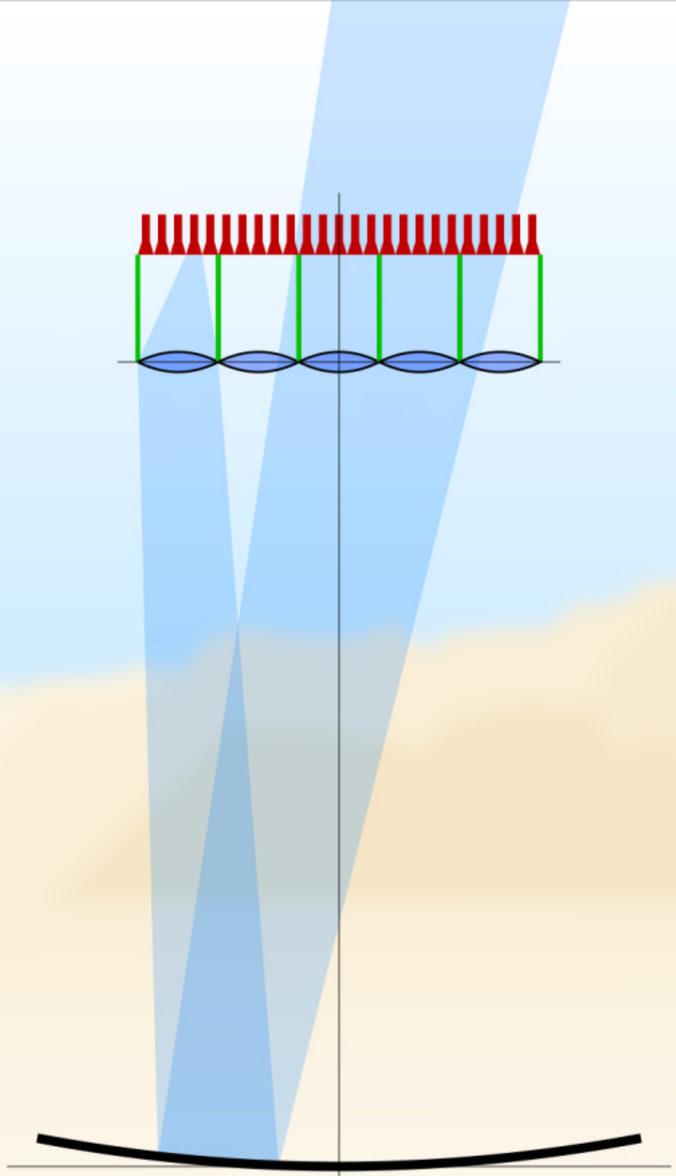
Telescope



Plenoscope

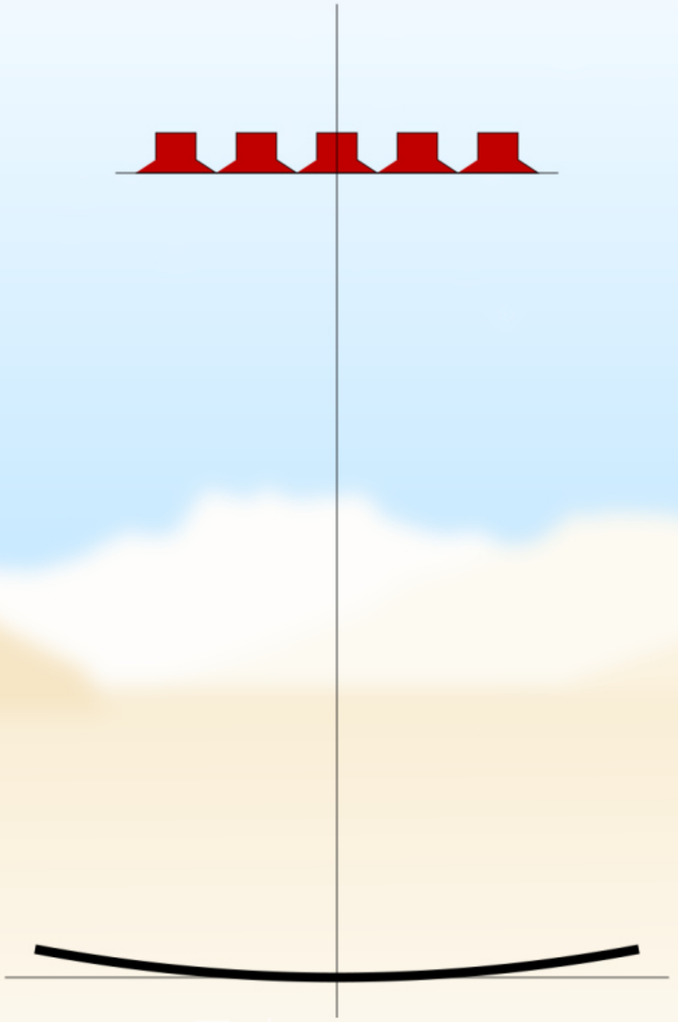
Optics

Telescope

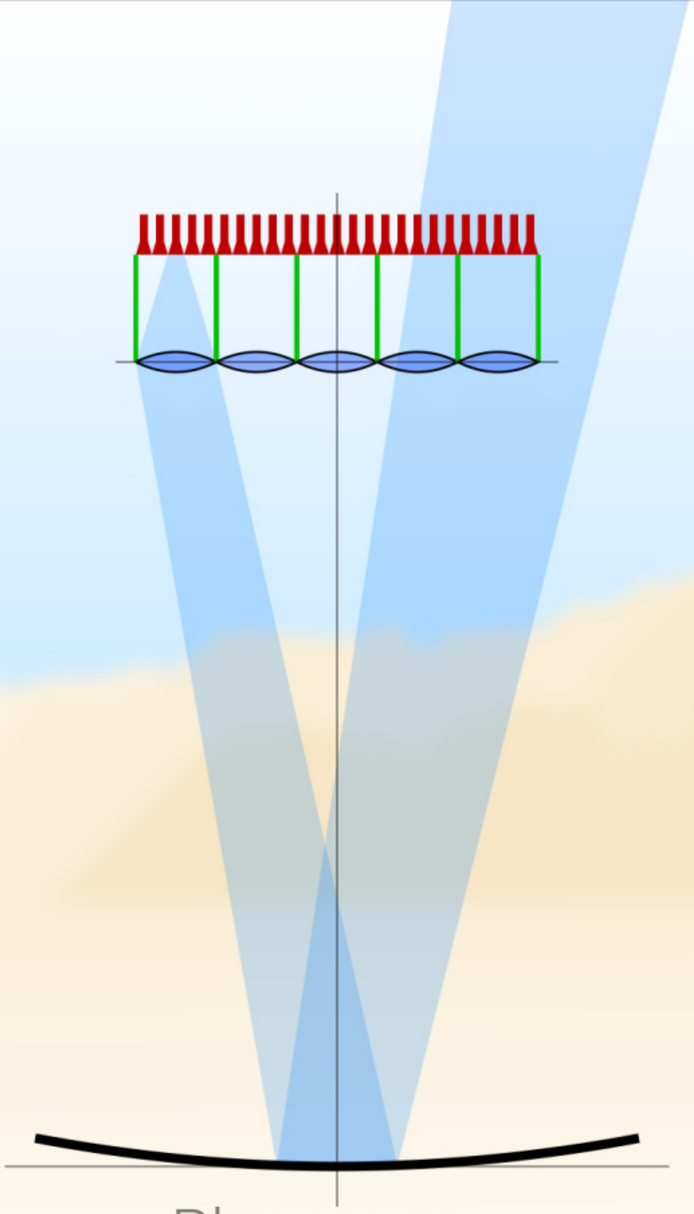


Plenoscope

Optics



Telescope



Plenoscope

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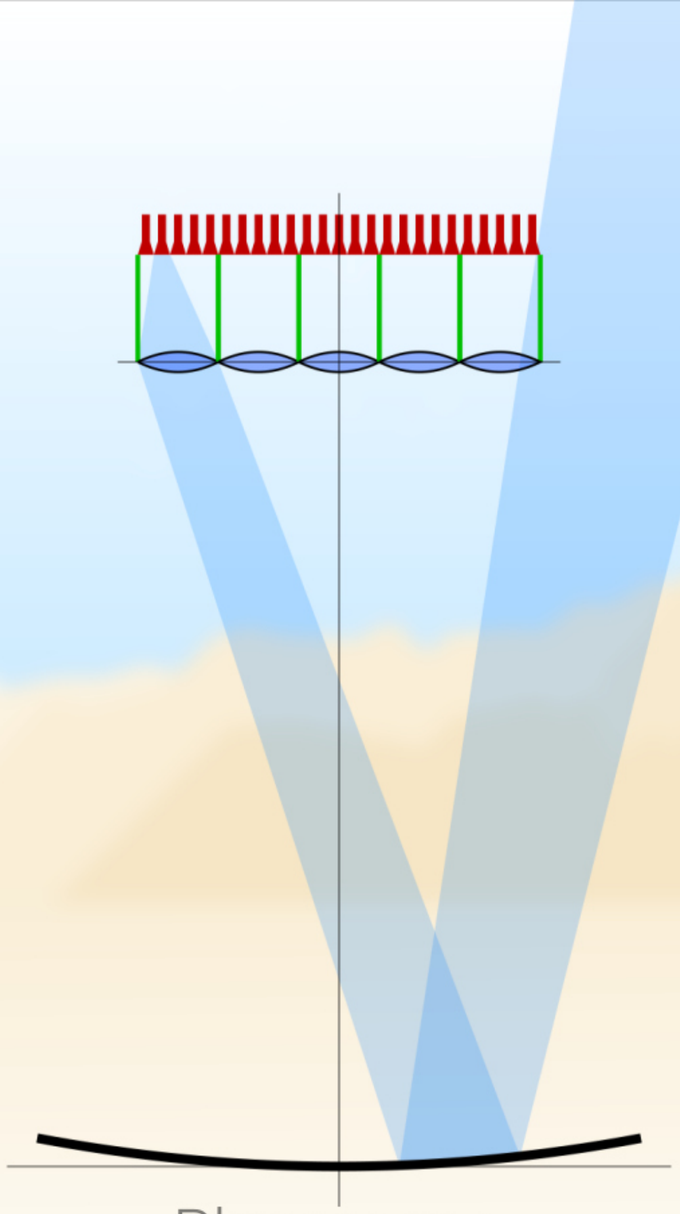
Telescope



Plenoscope

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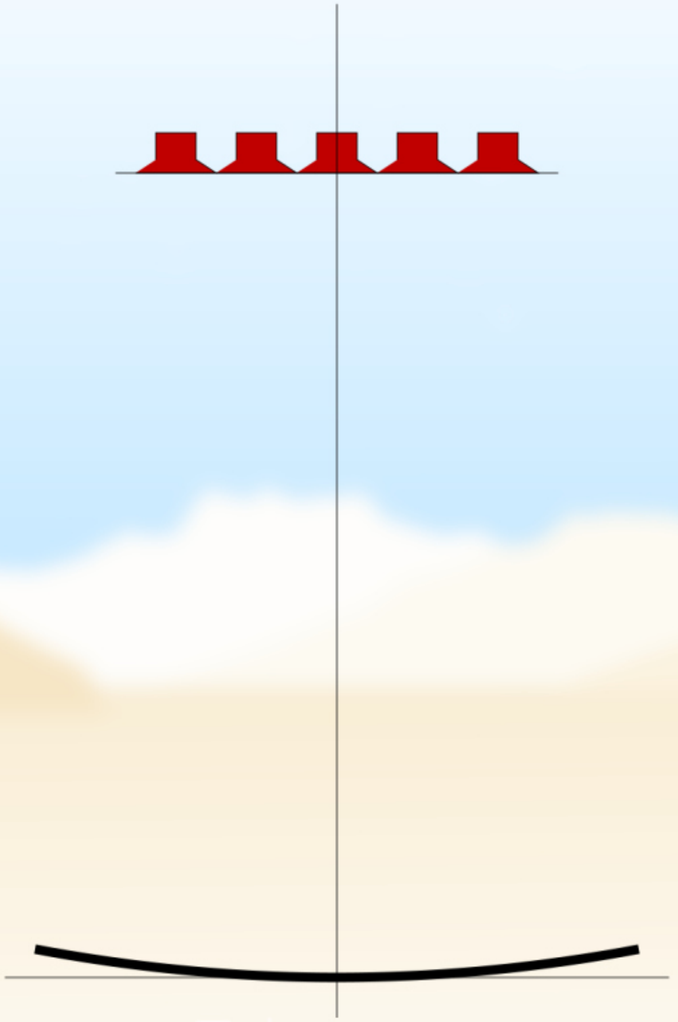
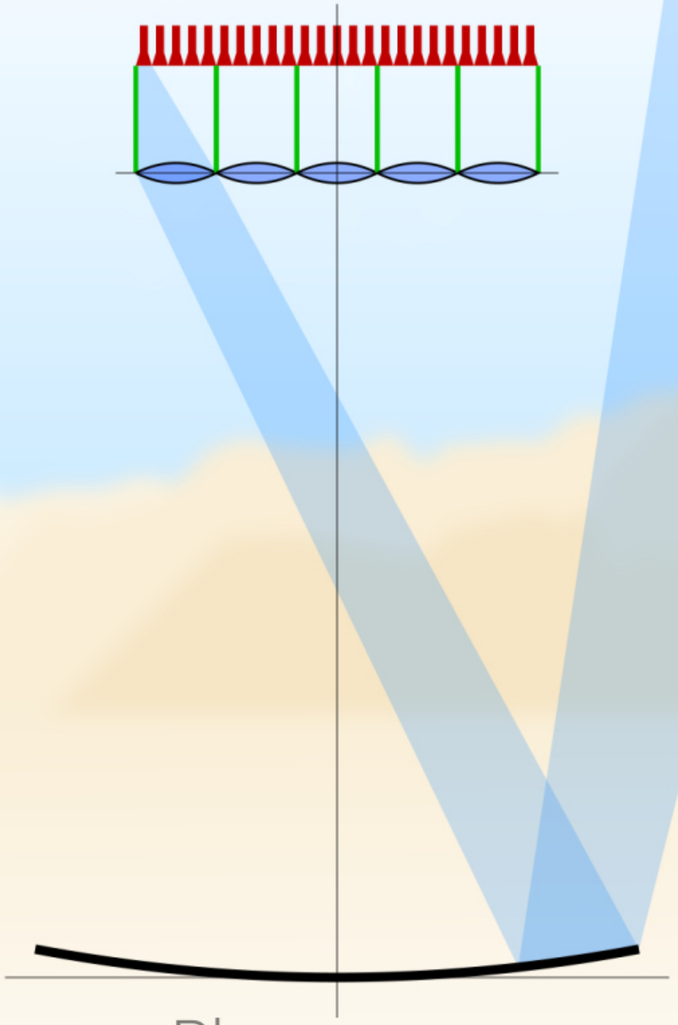


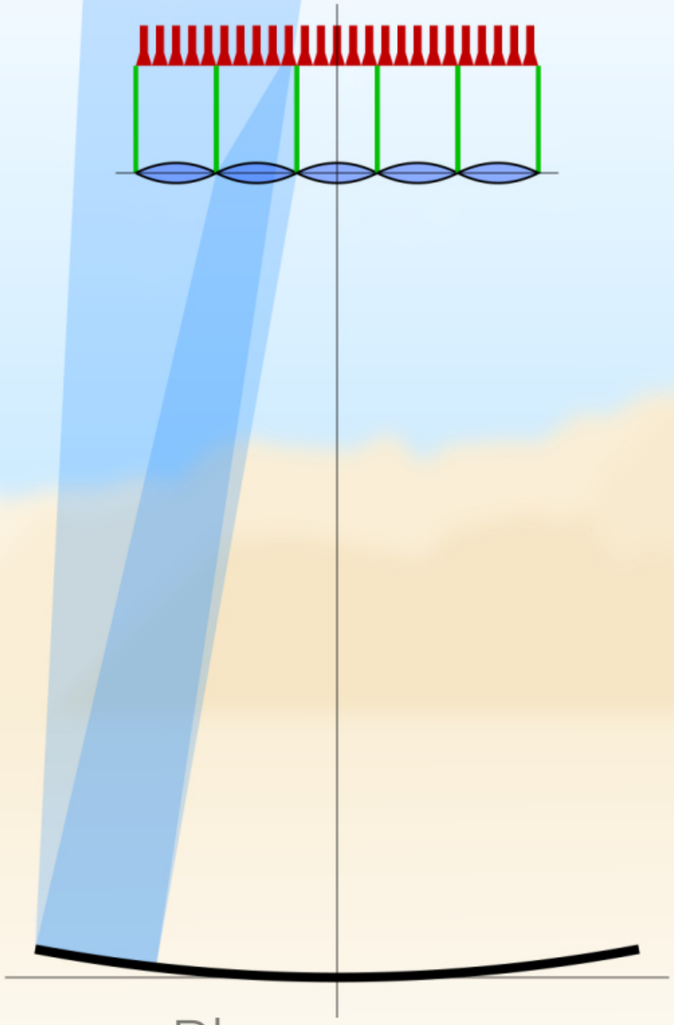
Telescope



Plenoscope

Optics

Telescope



Plenoscope

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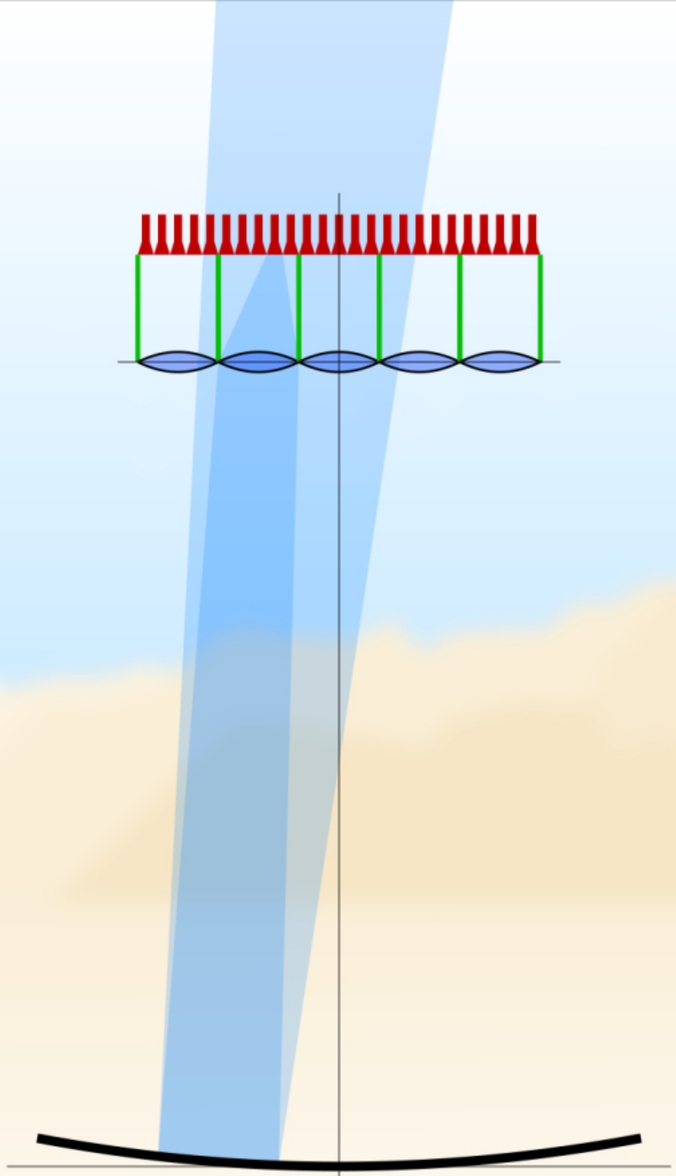
Telescope



Plenoscope

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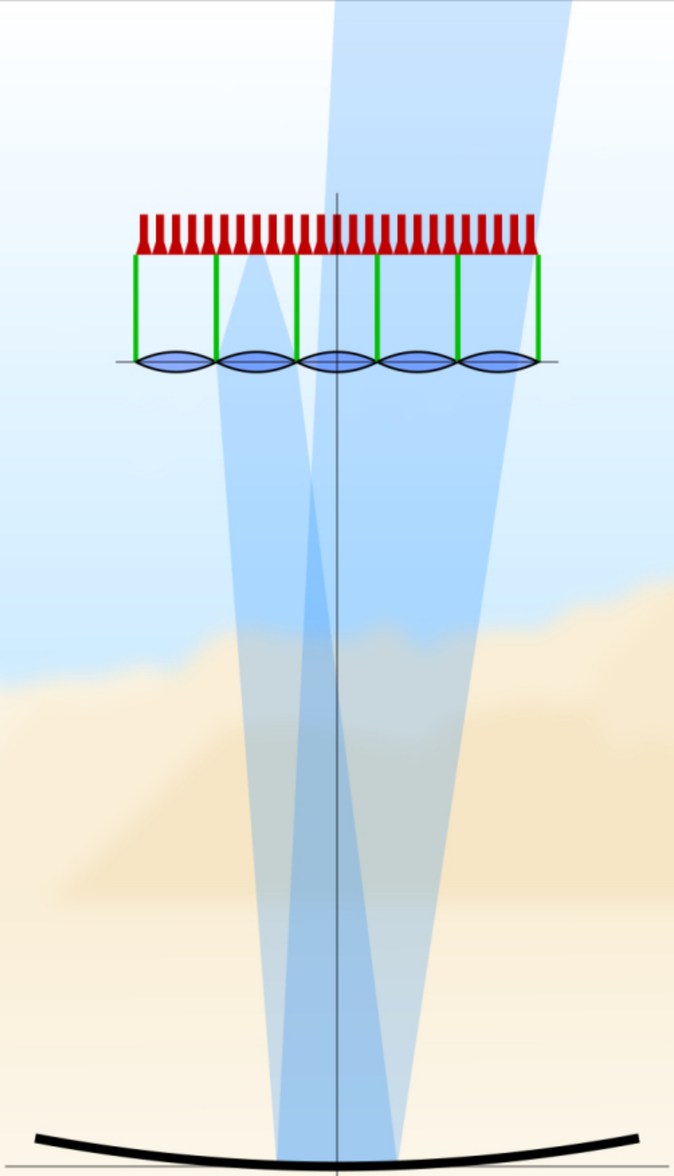
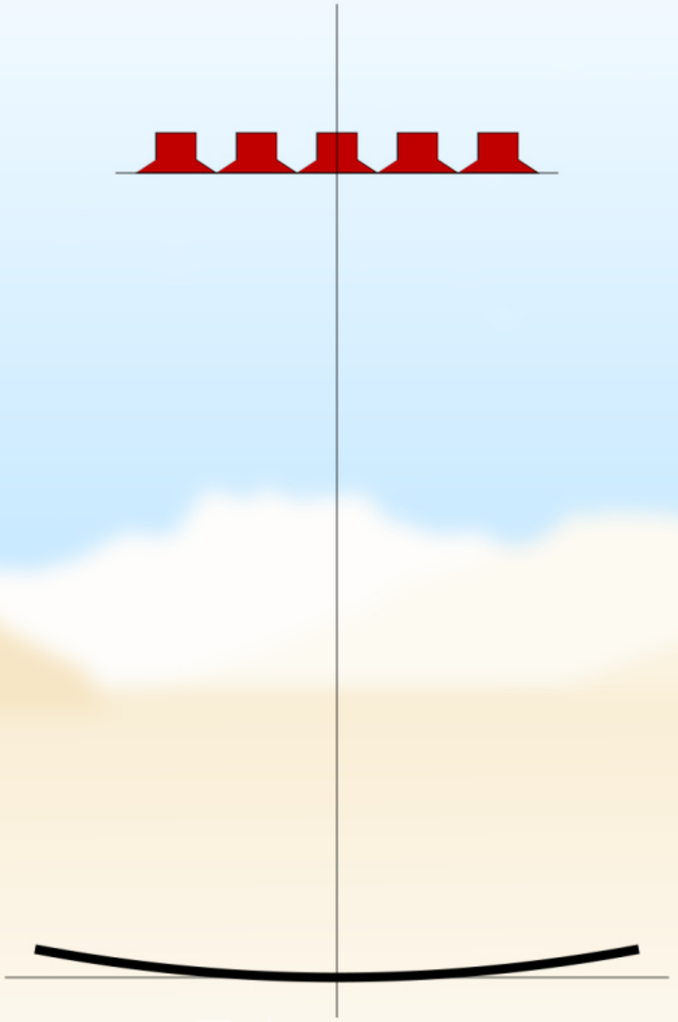
Telescope



Plenoscope

Optics



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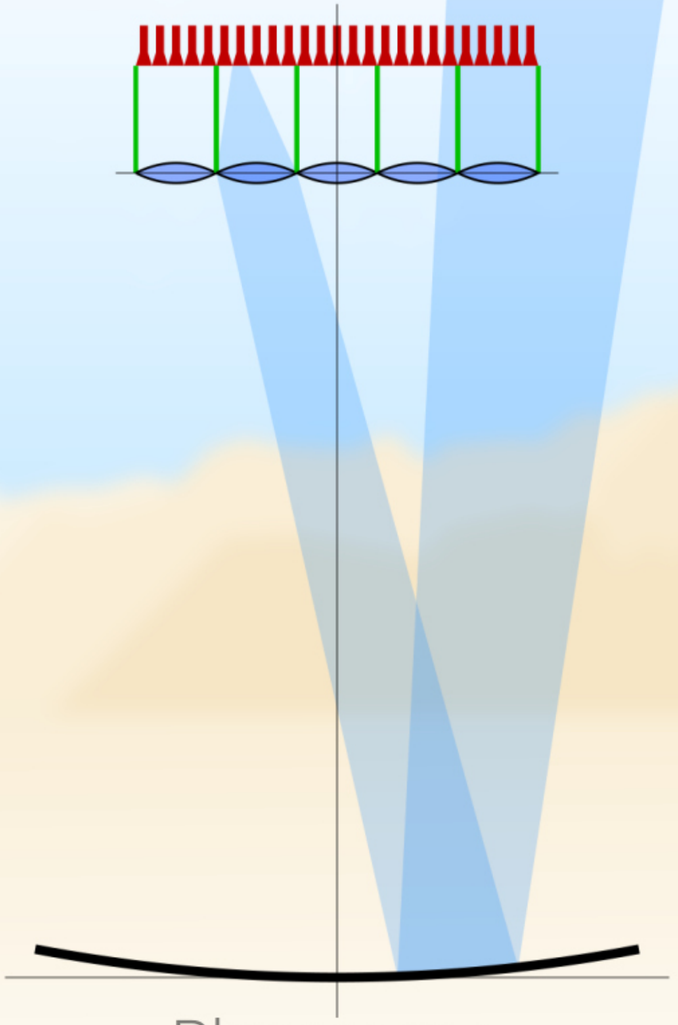

Plenoscope

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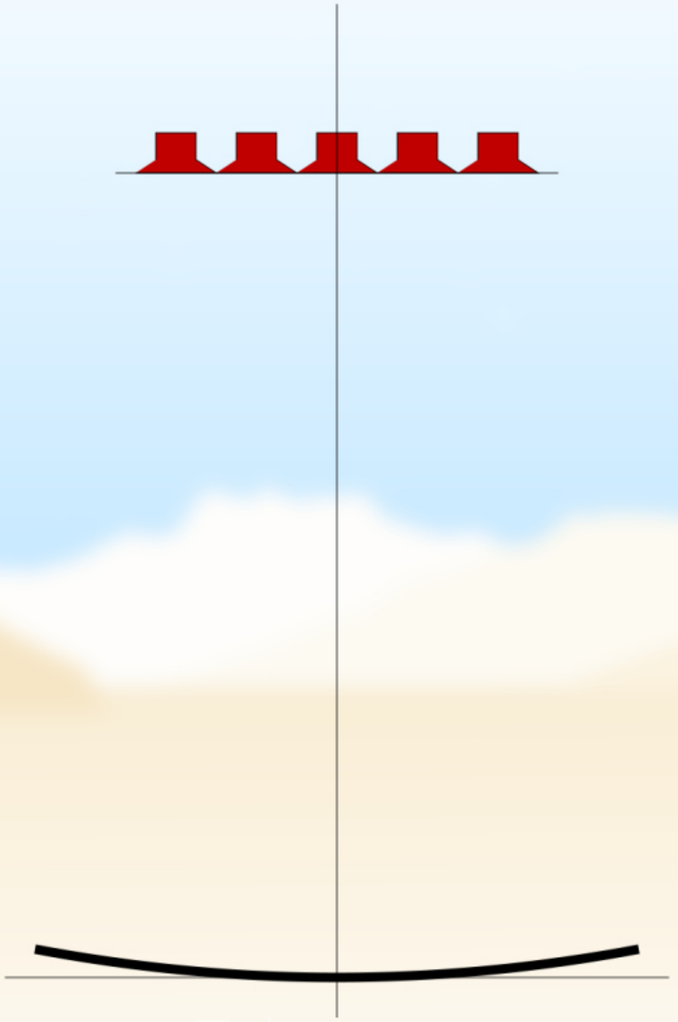

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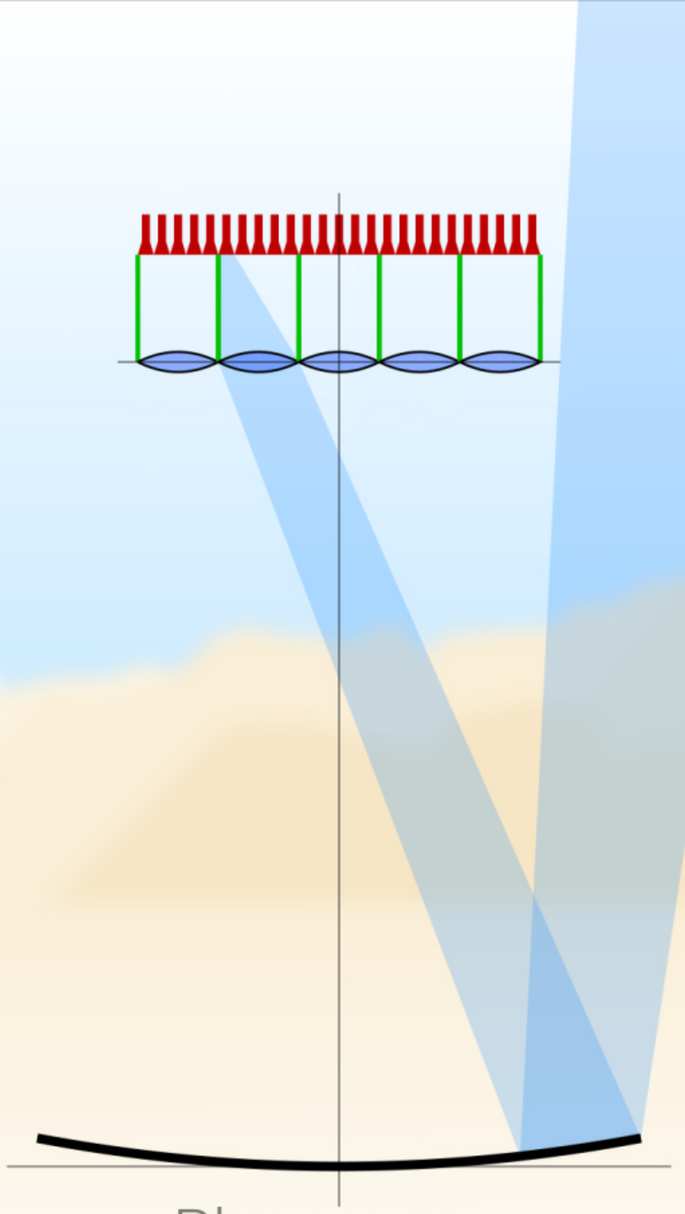

Plenoscope

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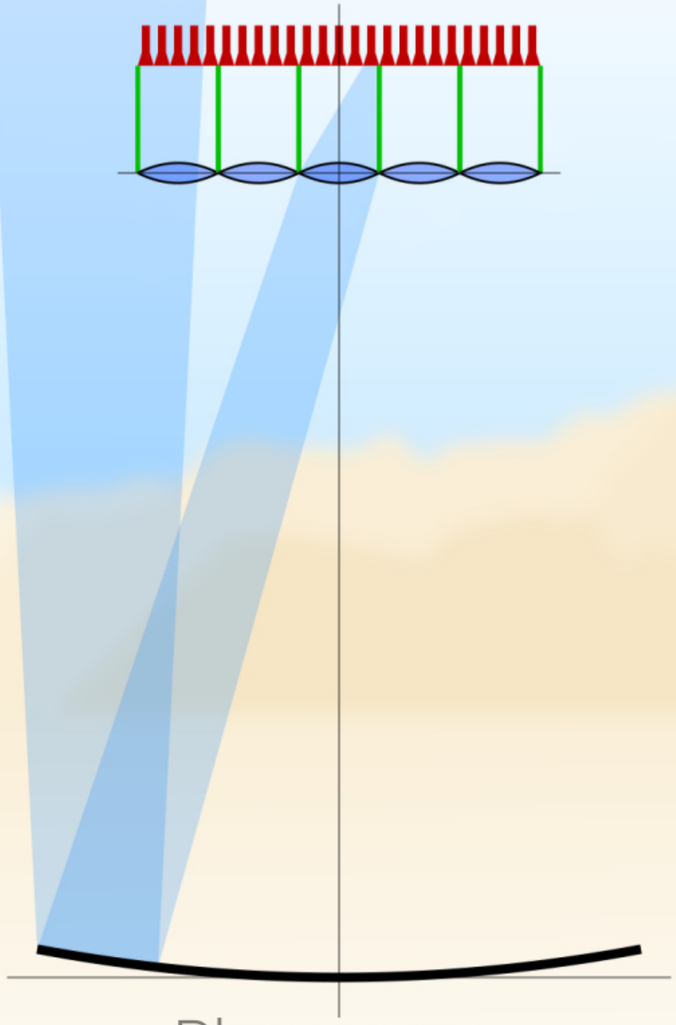

Plenoscope

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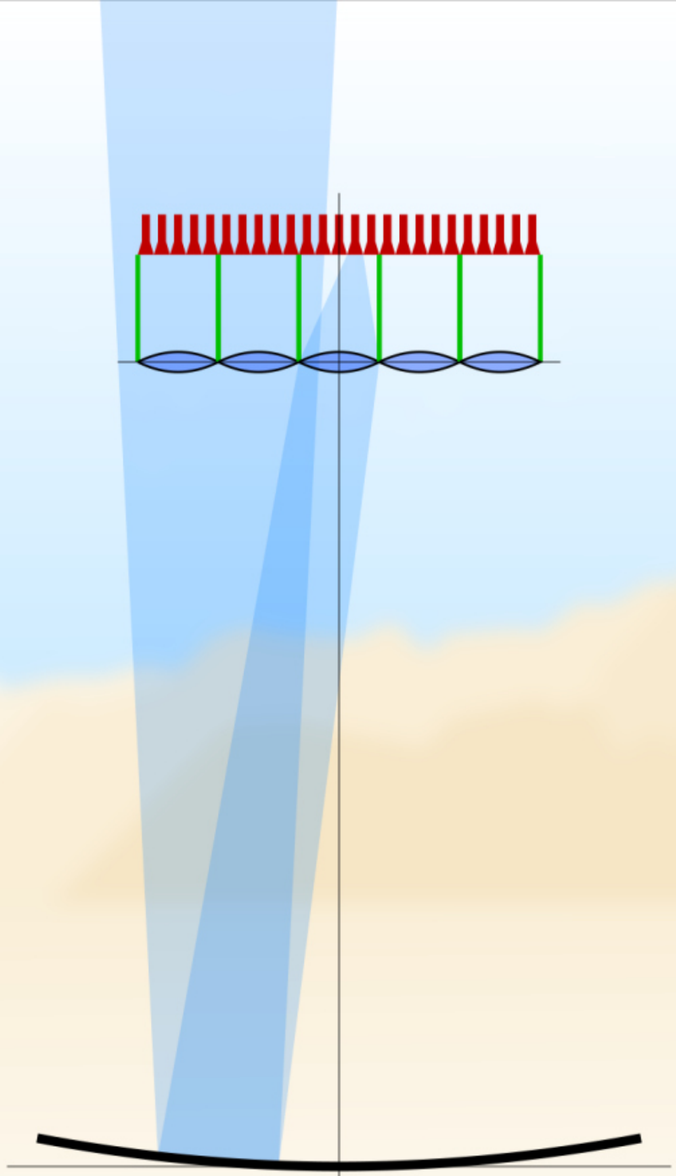

Plenoscope

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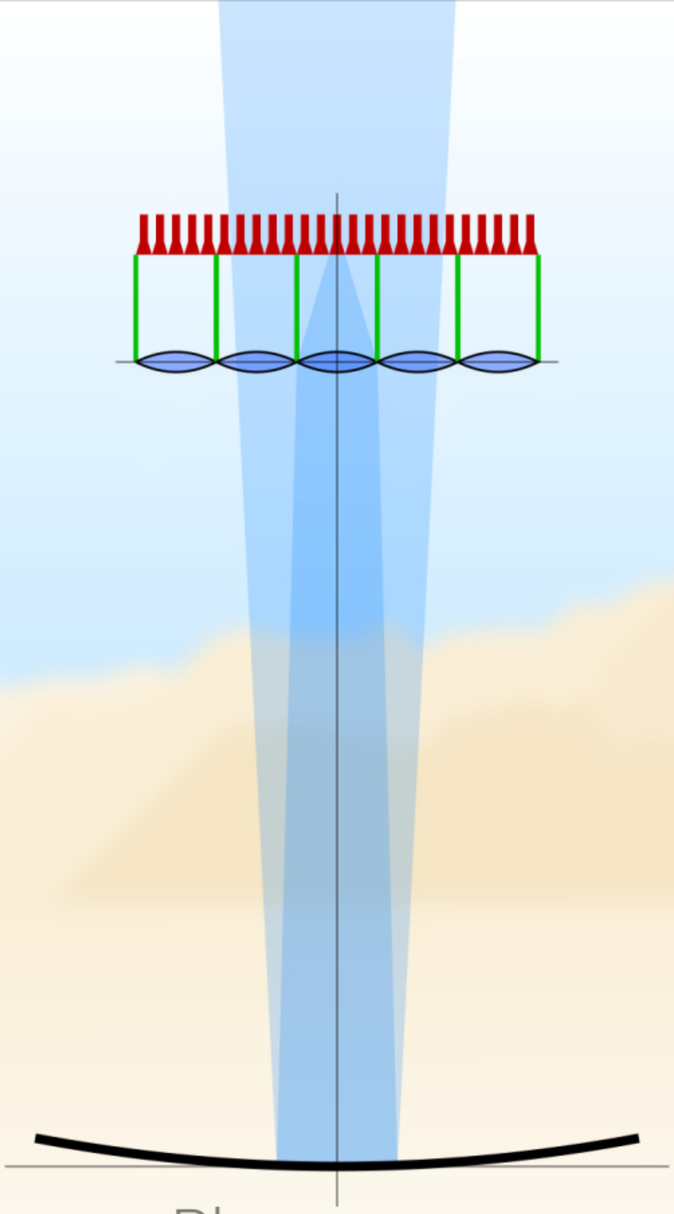

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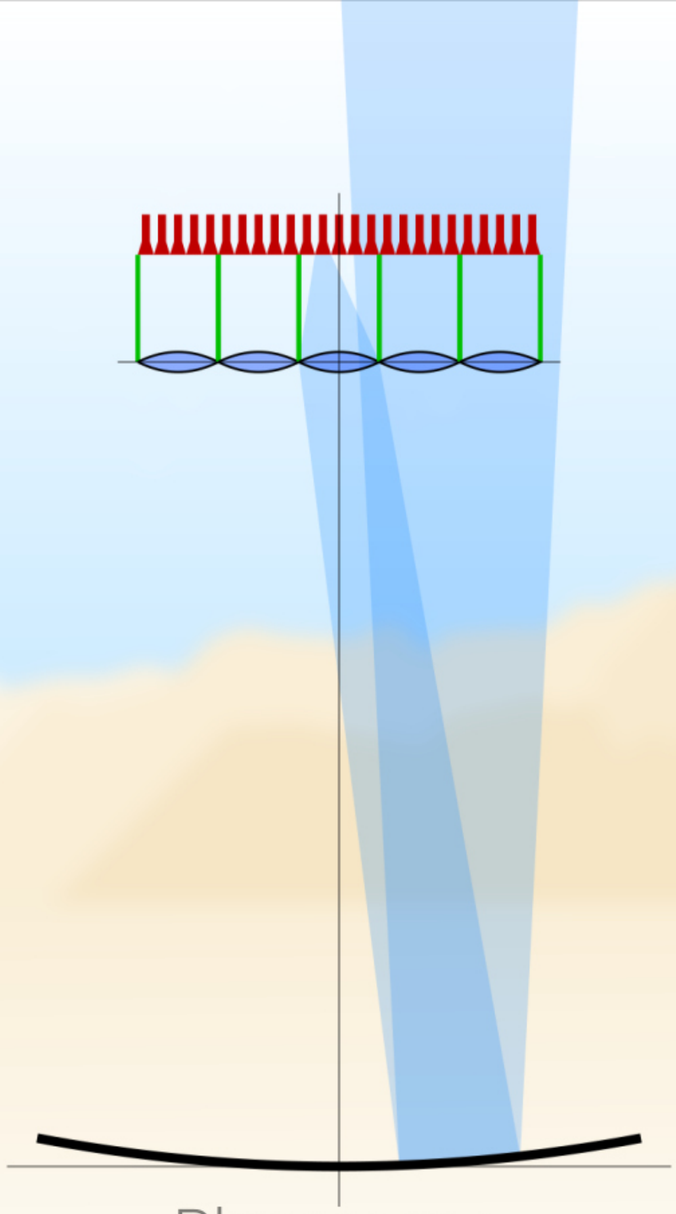

Plenoscope

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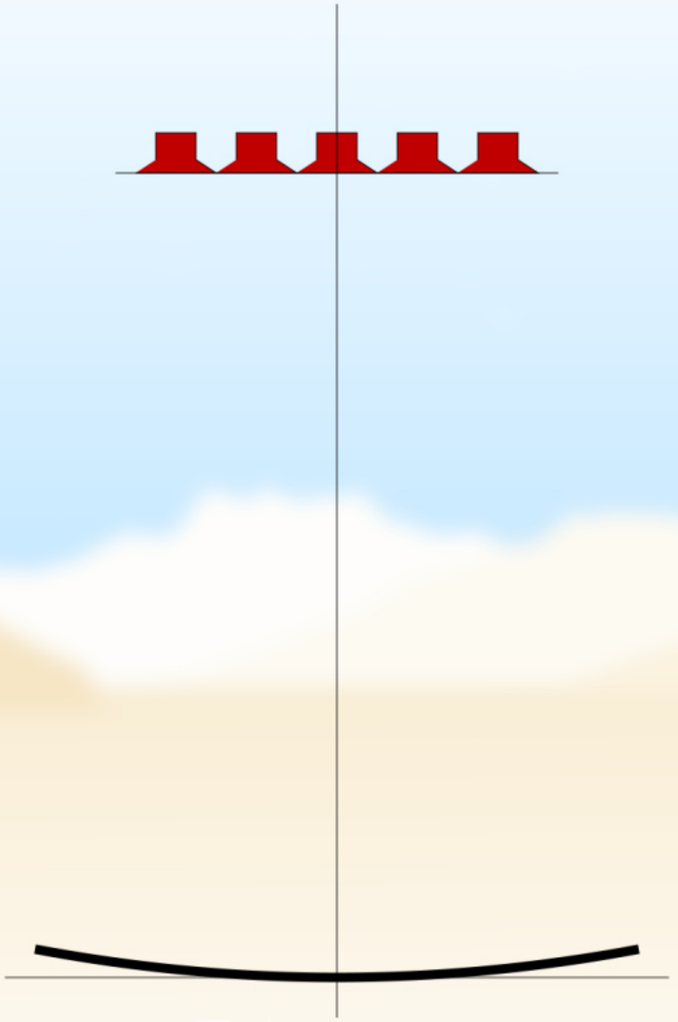

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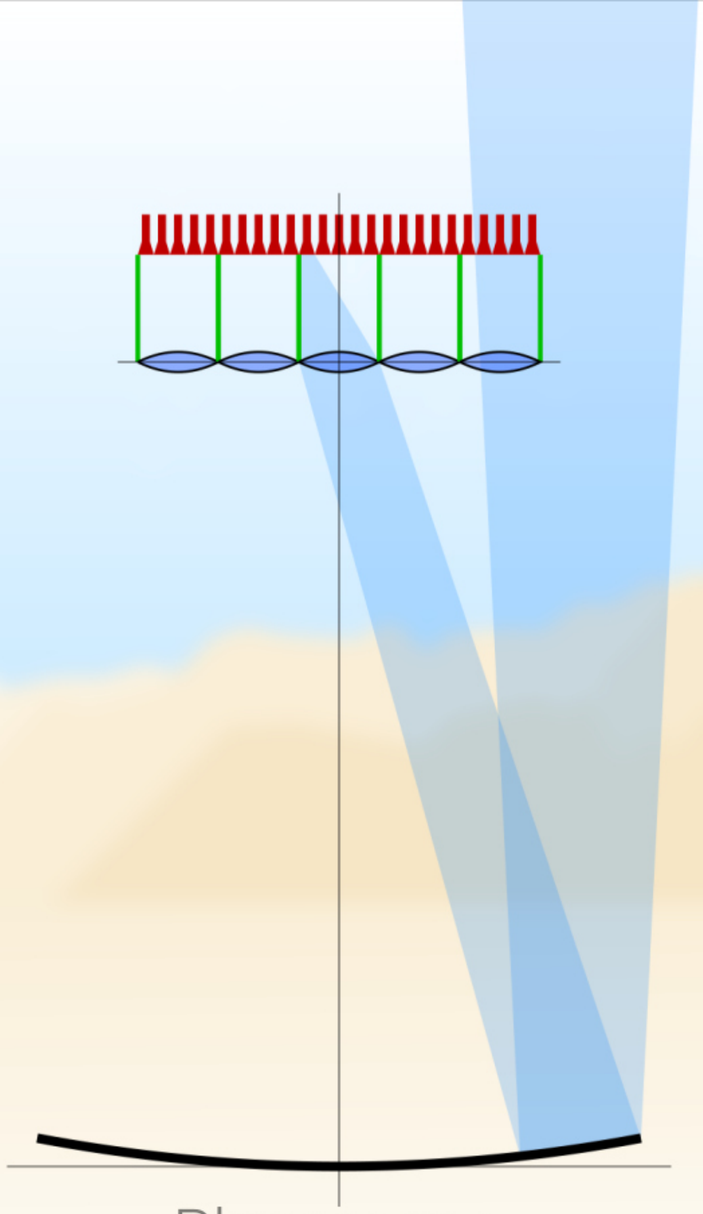

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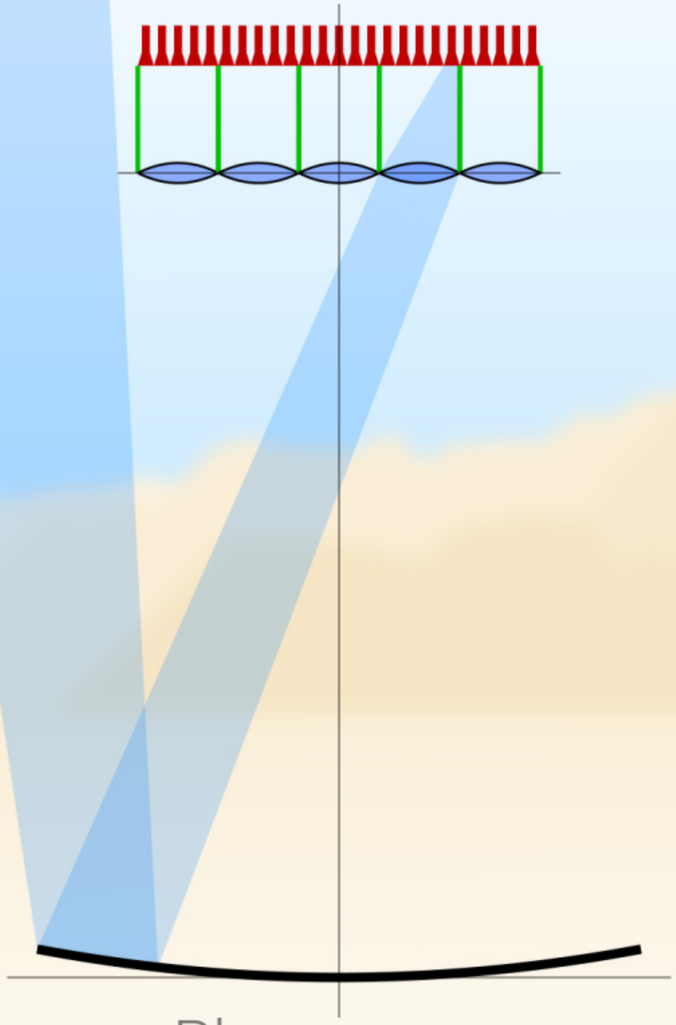

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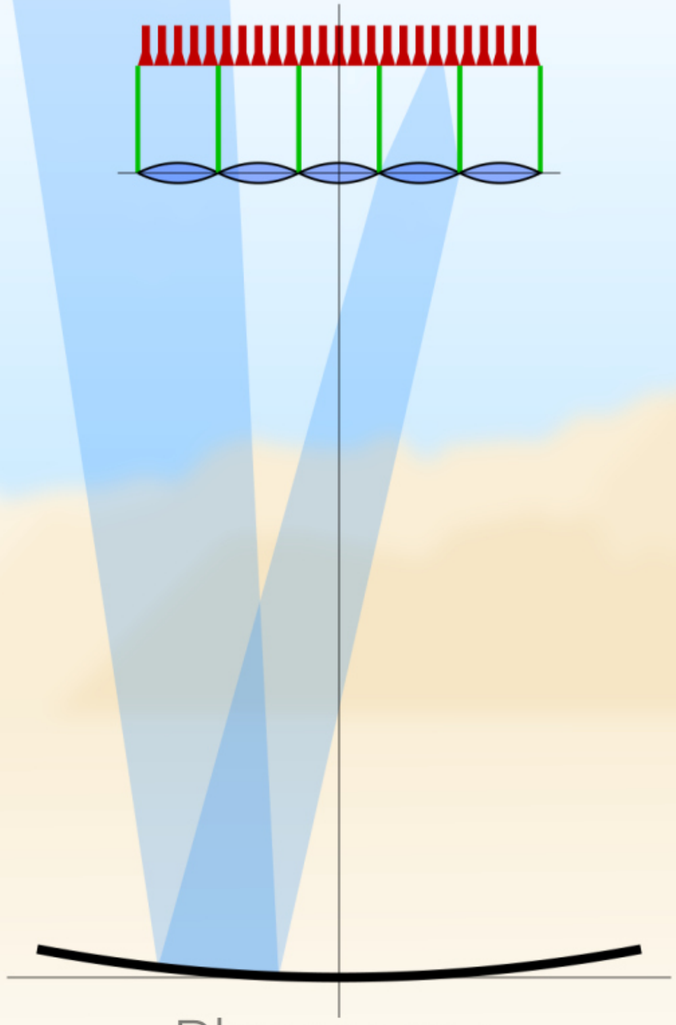

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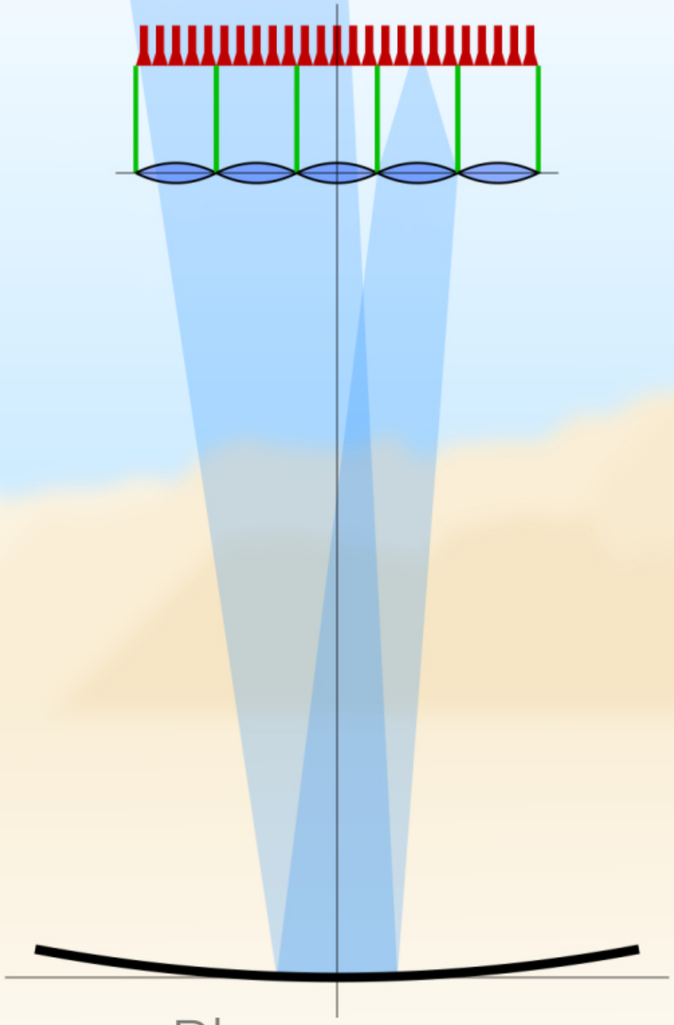

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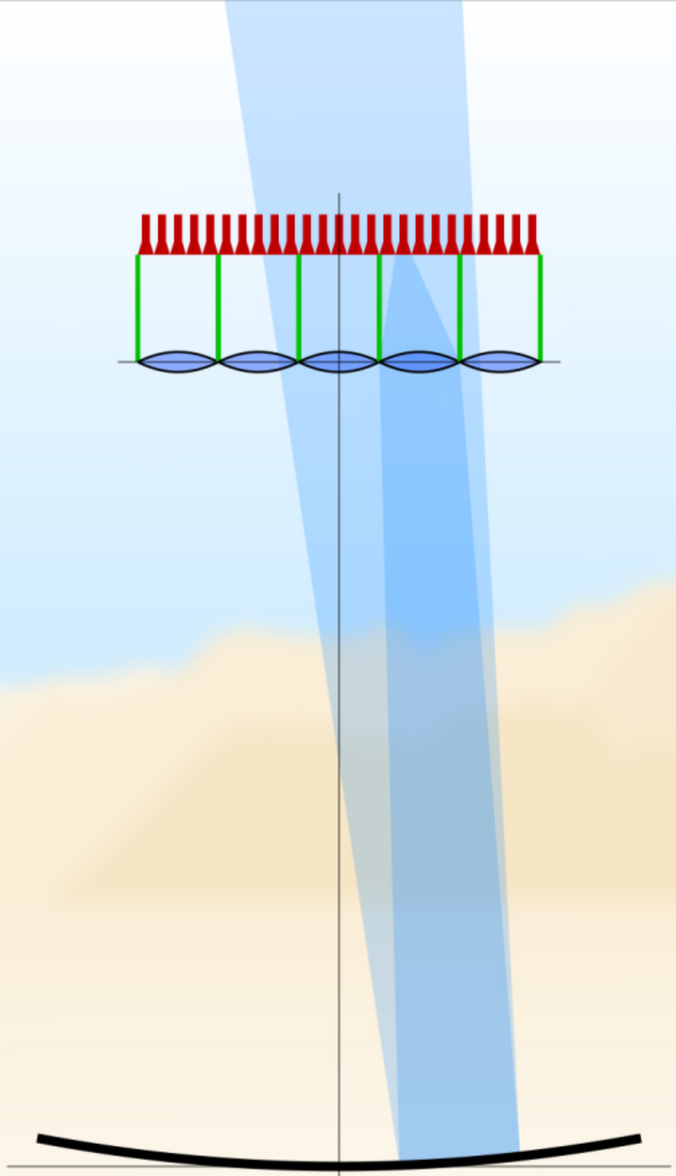

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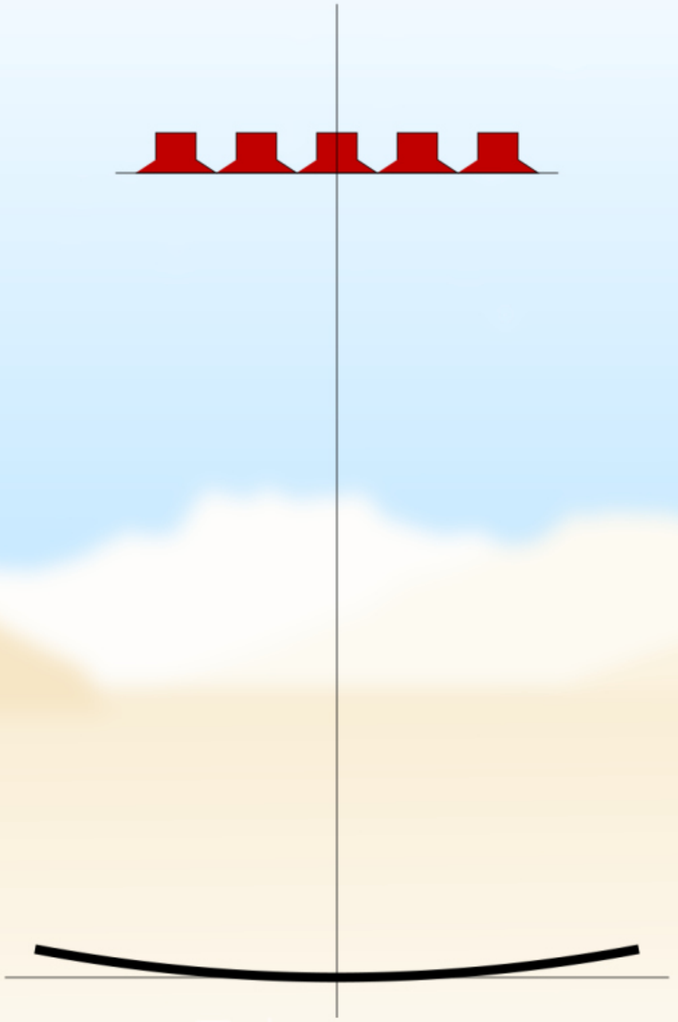

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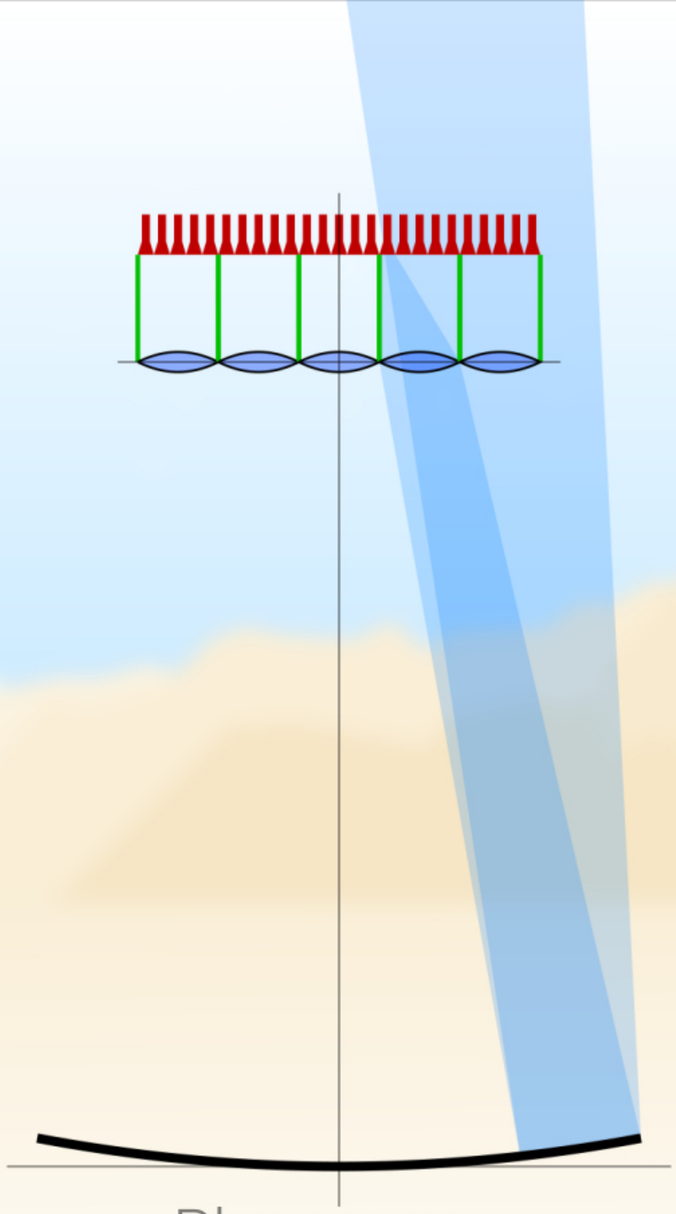

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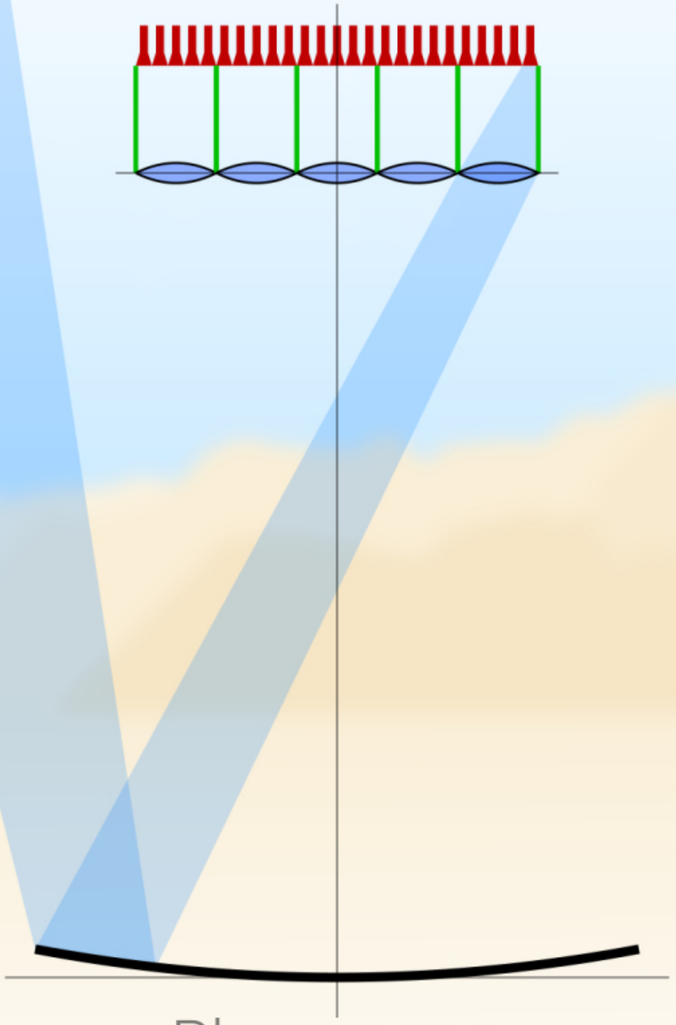

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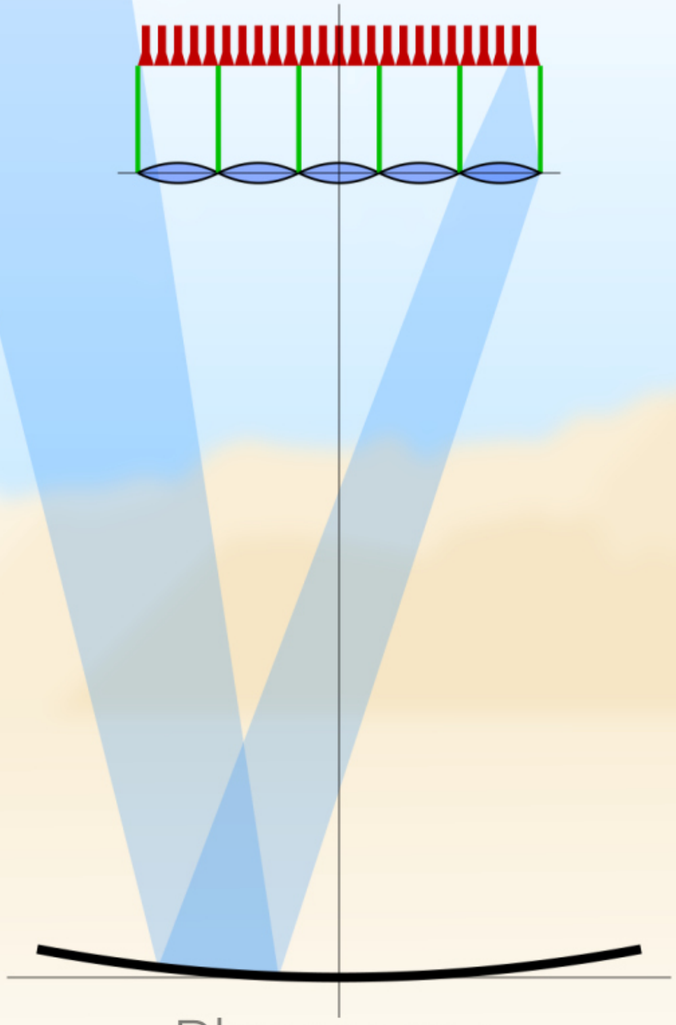

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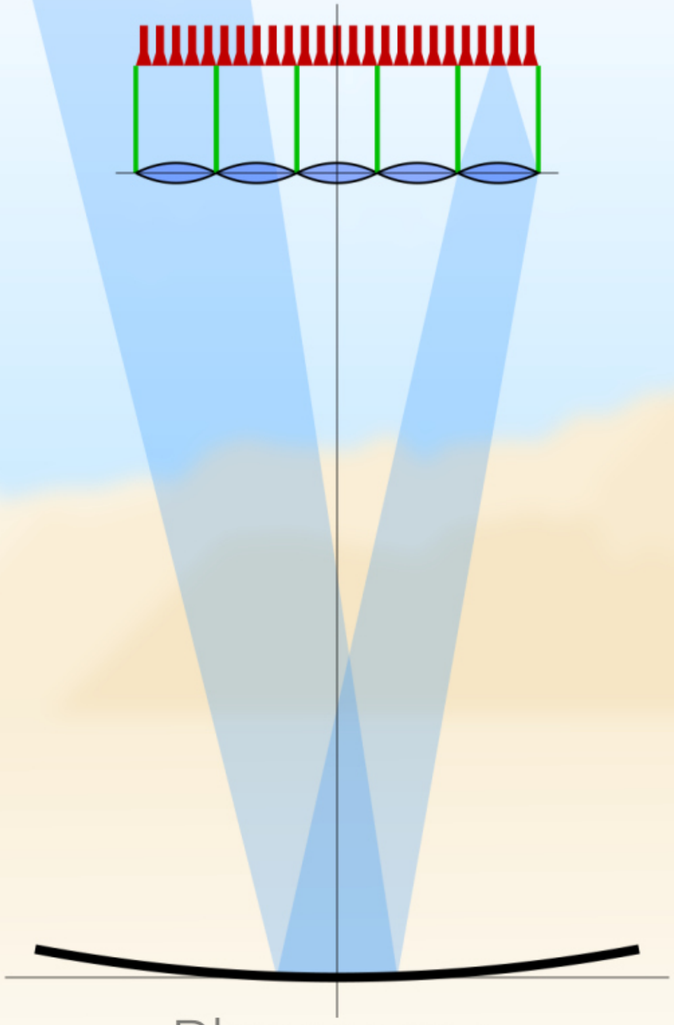

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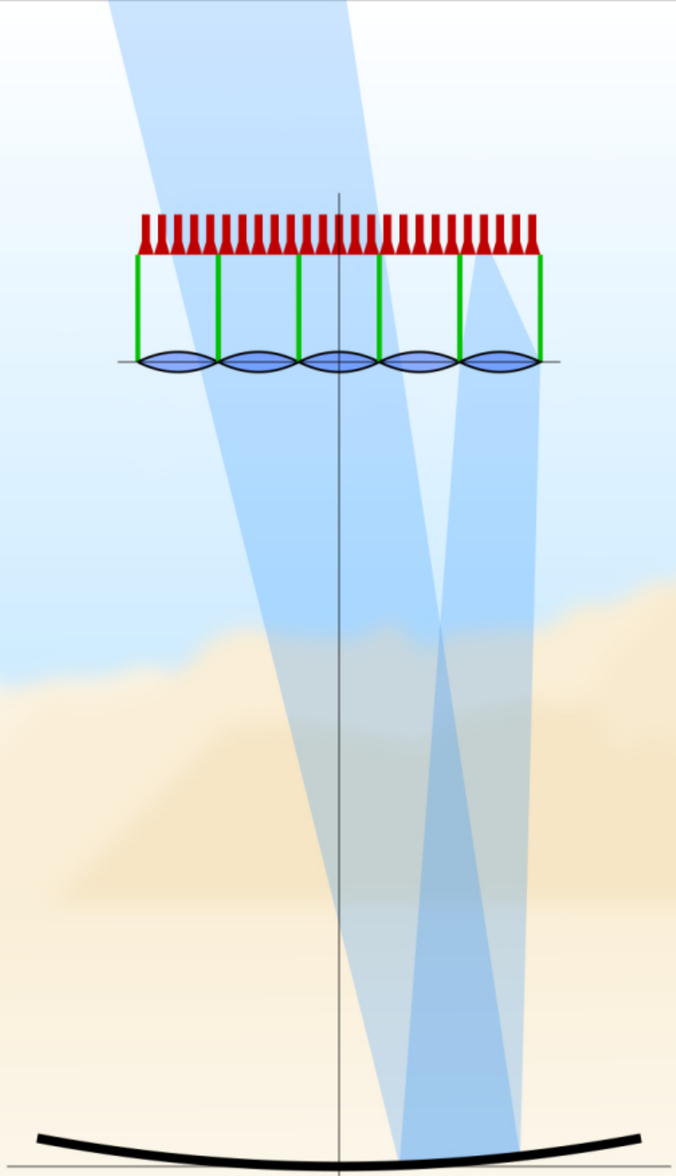
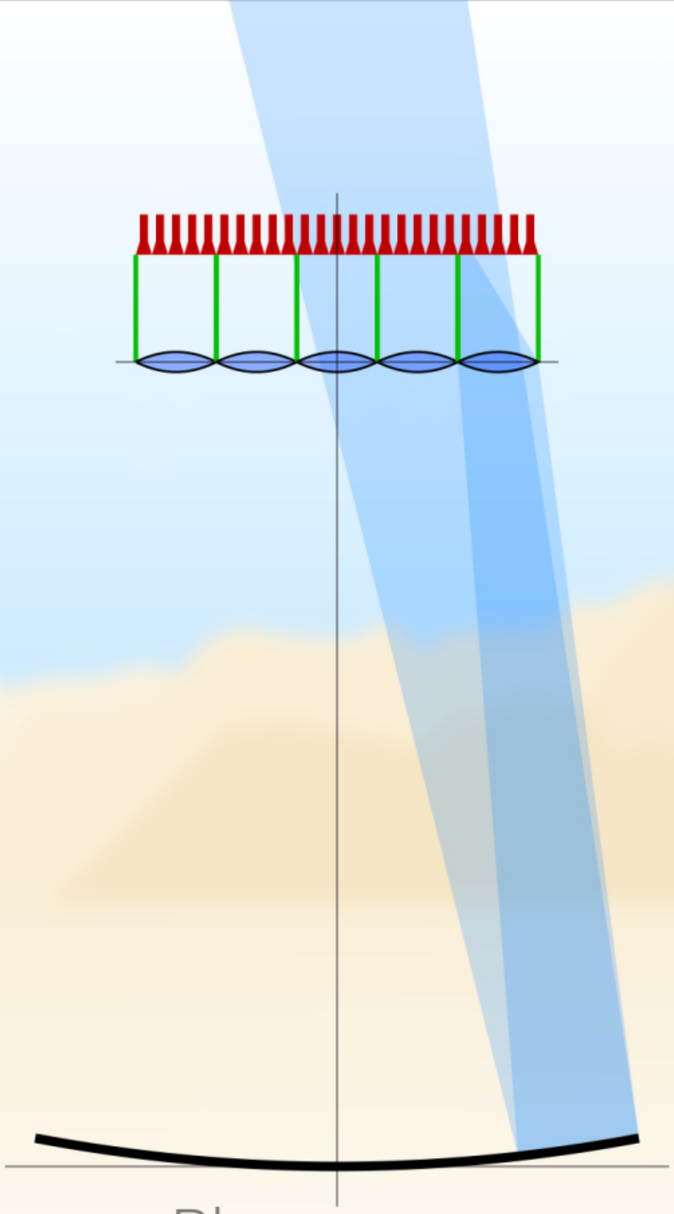


Plenoscope

Optics

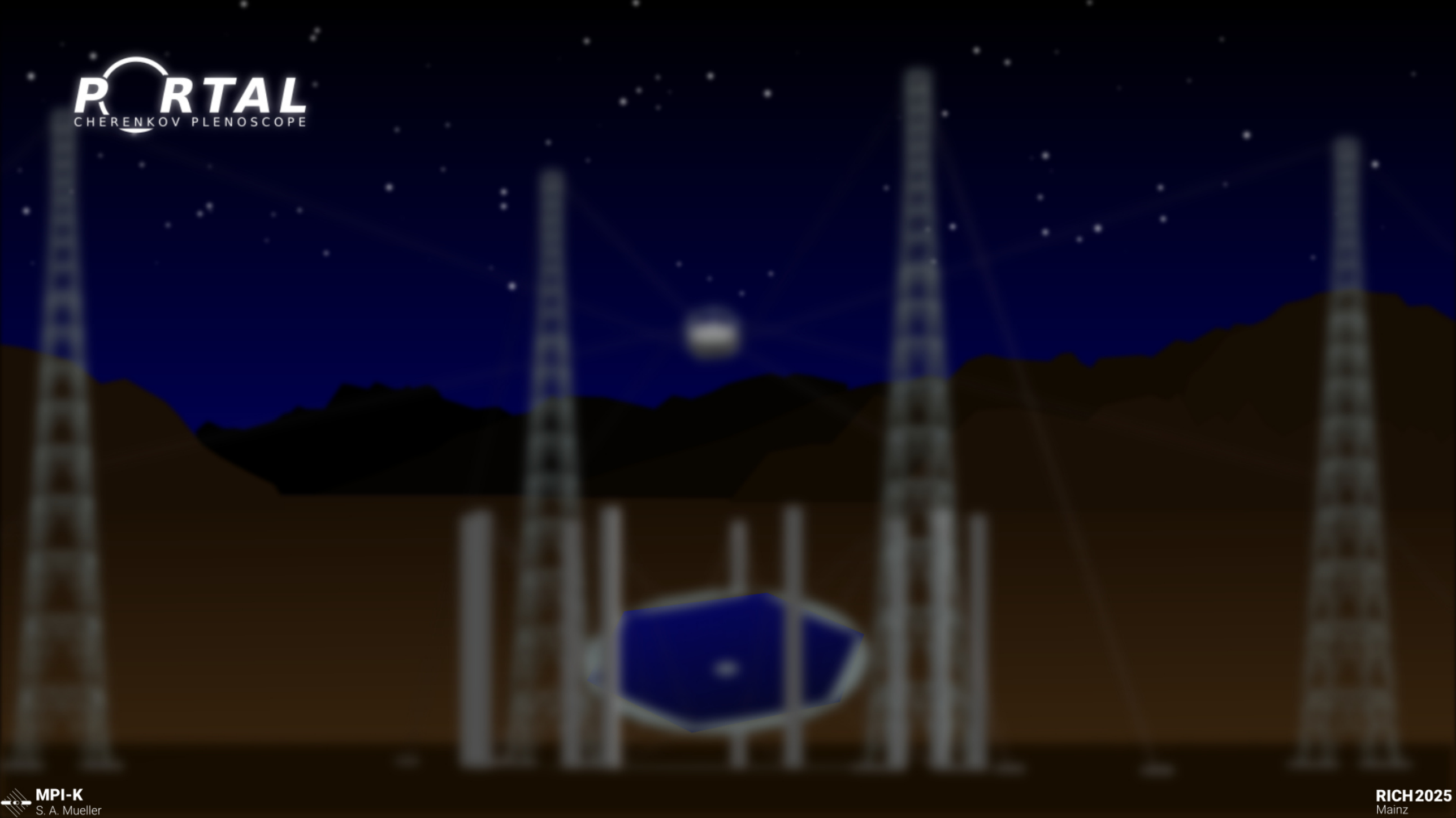
Telescope

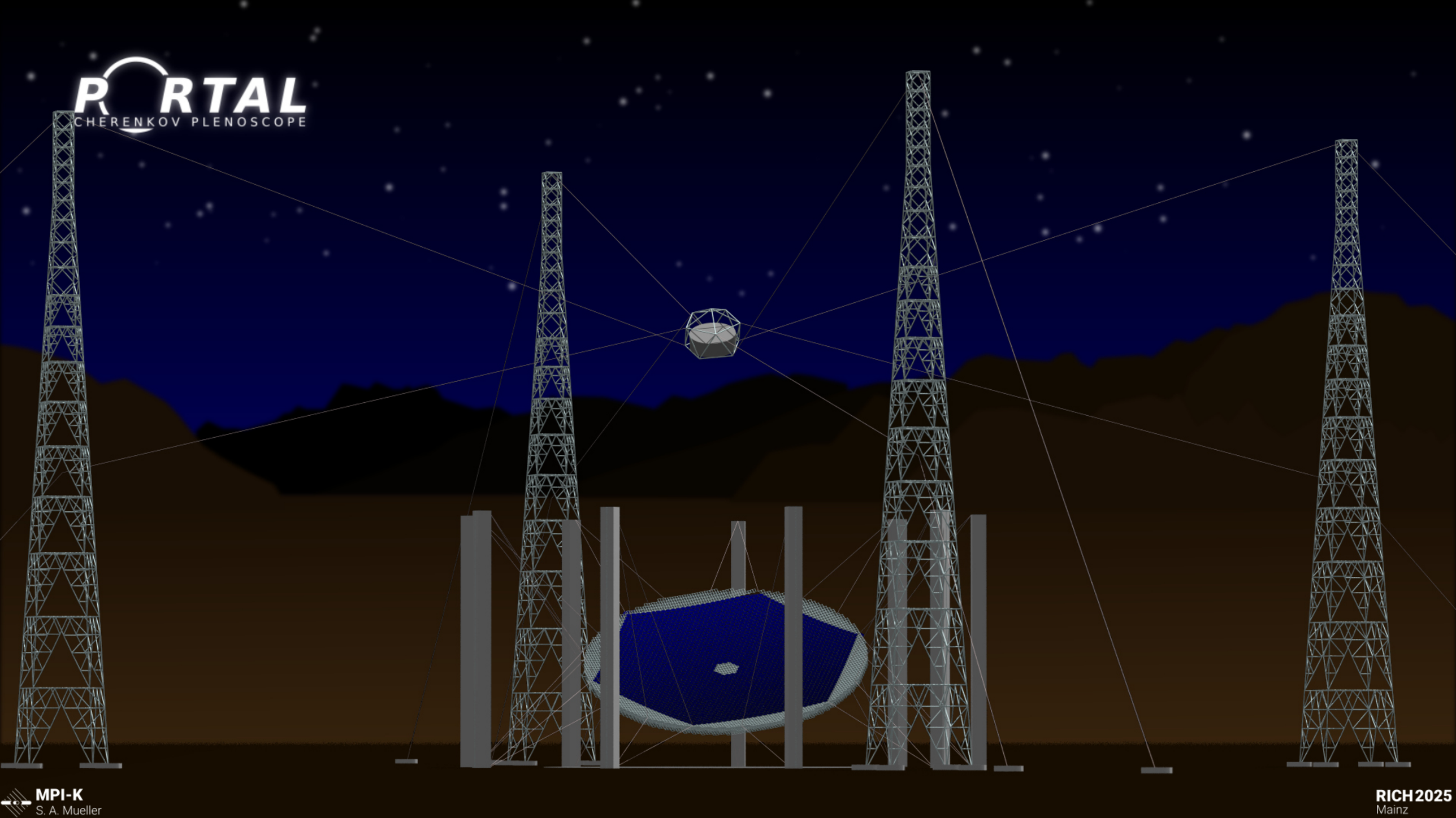


Plenoscope

PORTAL

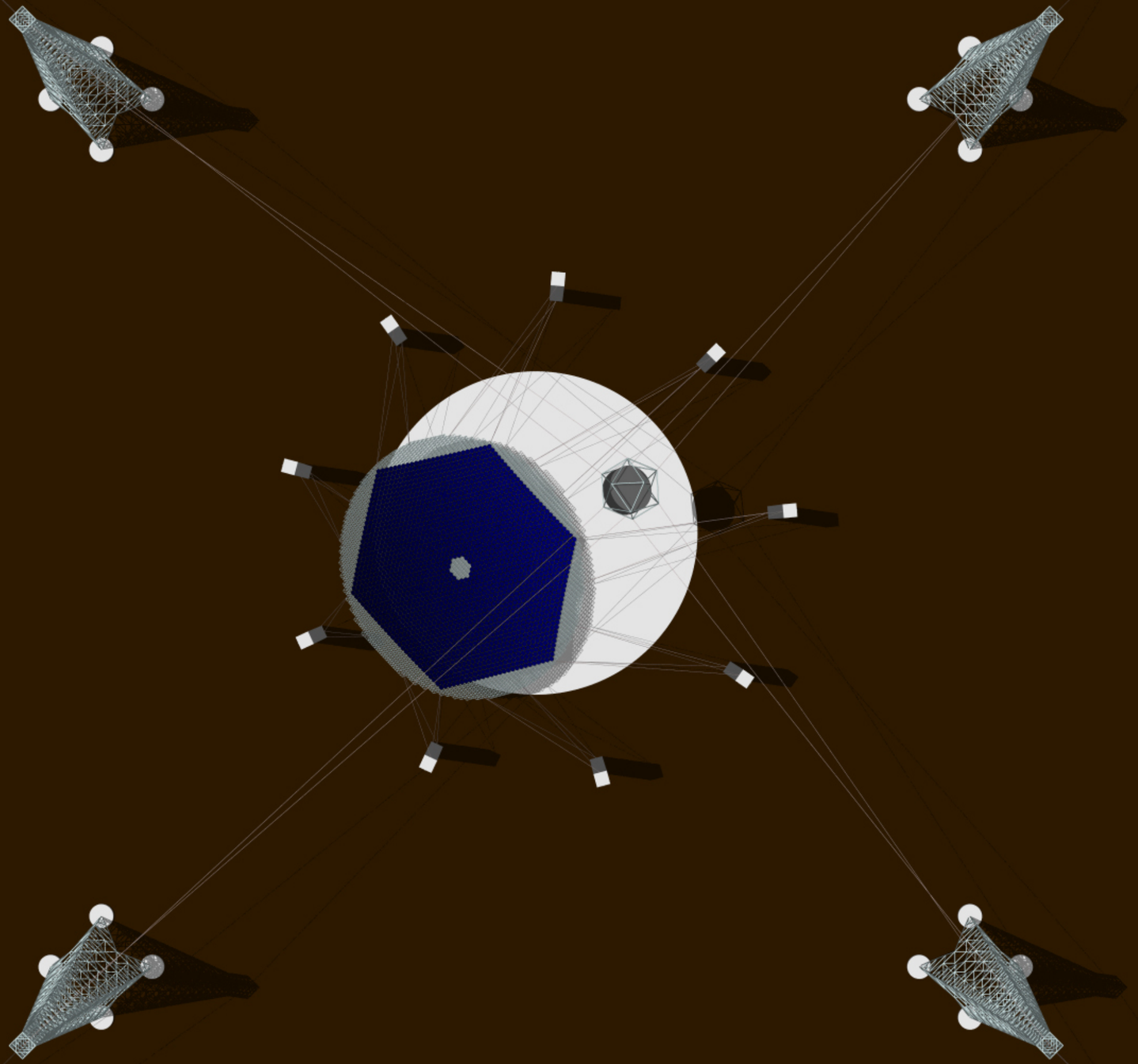
PORTAL
CHERENKOV PLENOSCOPE


PORTAL
CHERENKOV PLENOSCOPE


PORTAL
CHERENKOV PLENOSCOPE

PORTAL

CHERENKOV PLENOSCOPE



MPI-K
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PORTAL
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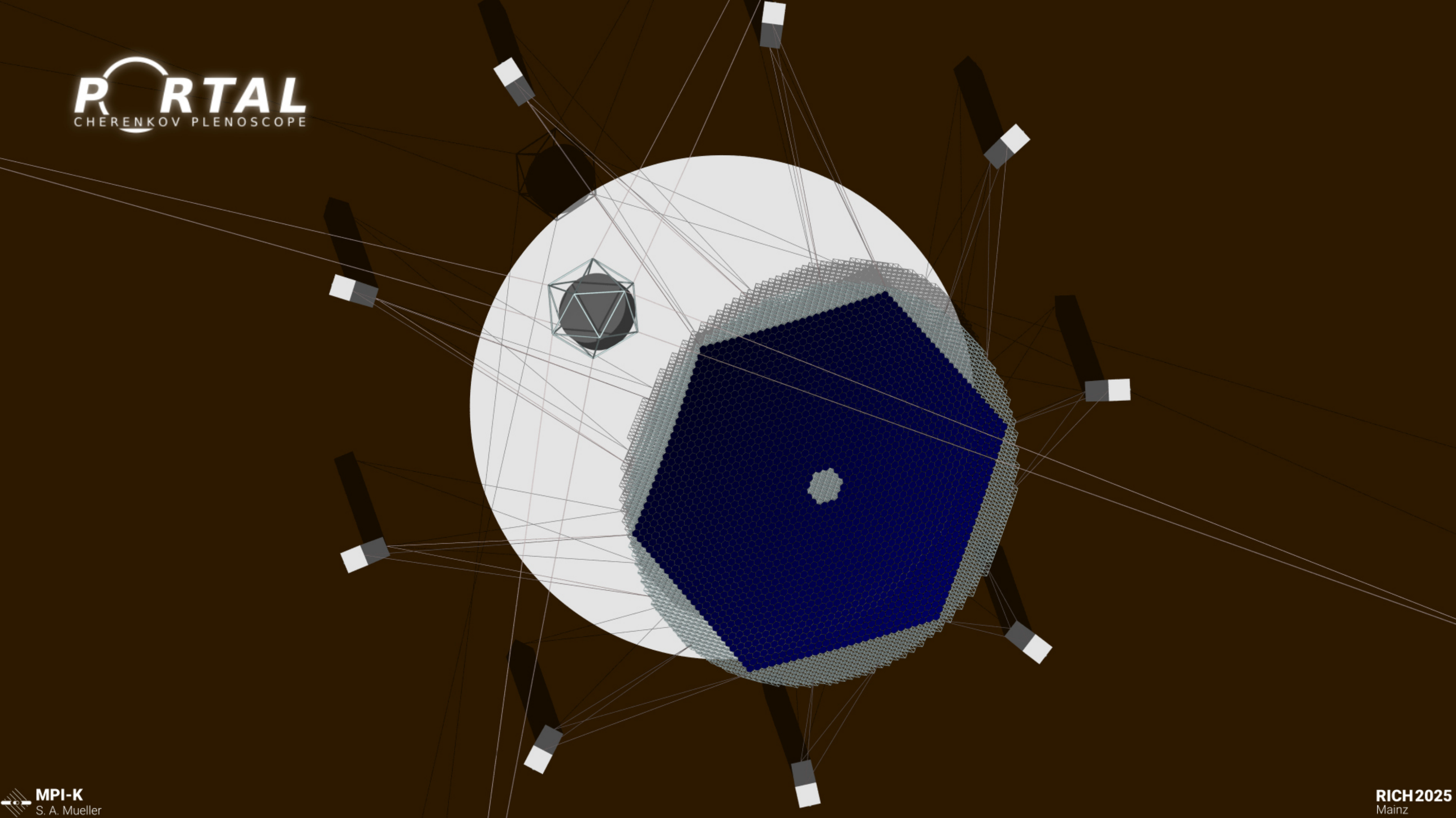
Philipp Miermeister et al. 2016
(Fraunhofer IPA, MPI bio. Cybernetics, Korea University)
The CableRobot Simulator: Large Scale Motion Platform Based on Cable Robot Technology
International Conference on Intelligent Robots and Systems
Daejeon, Korea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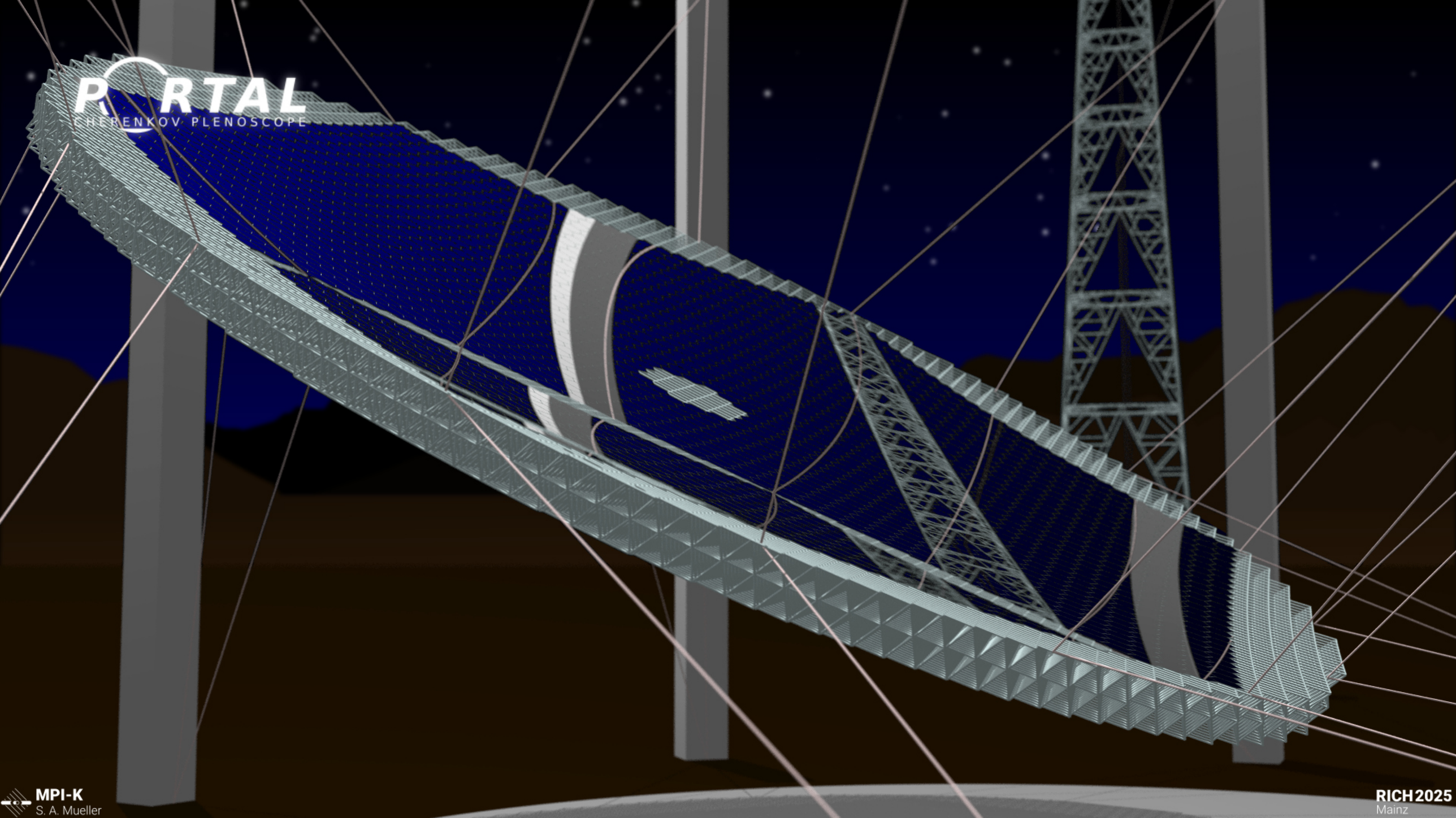
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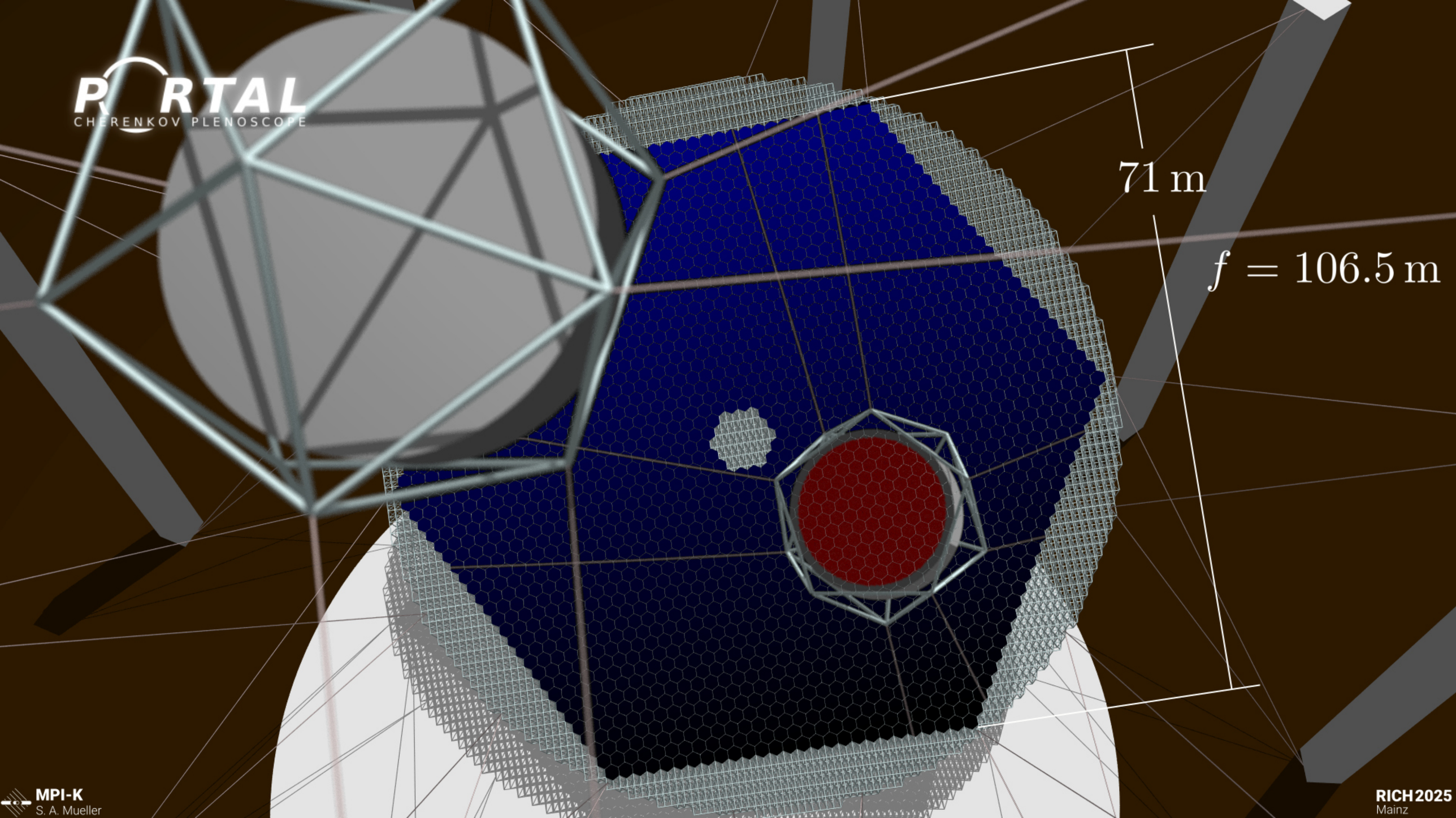
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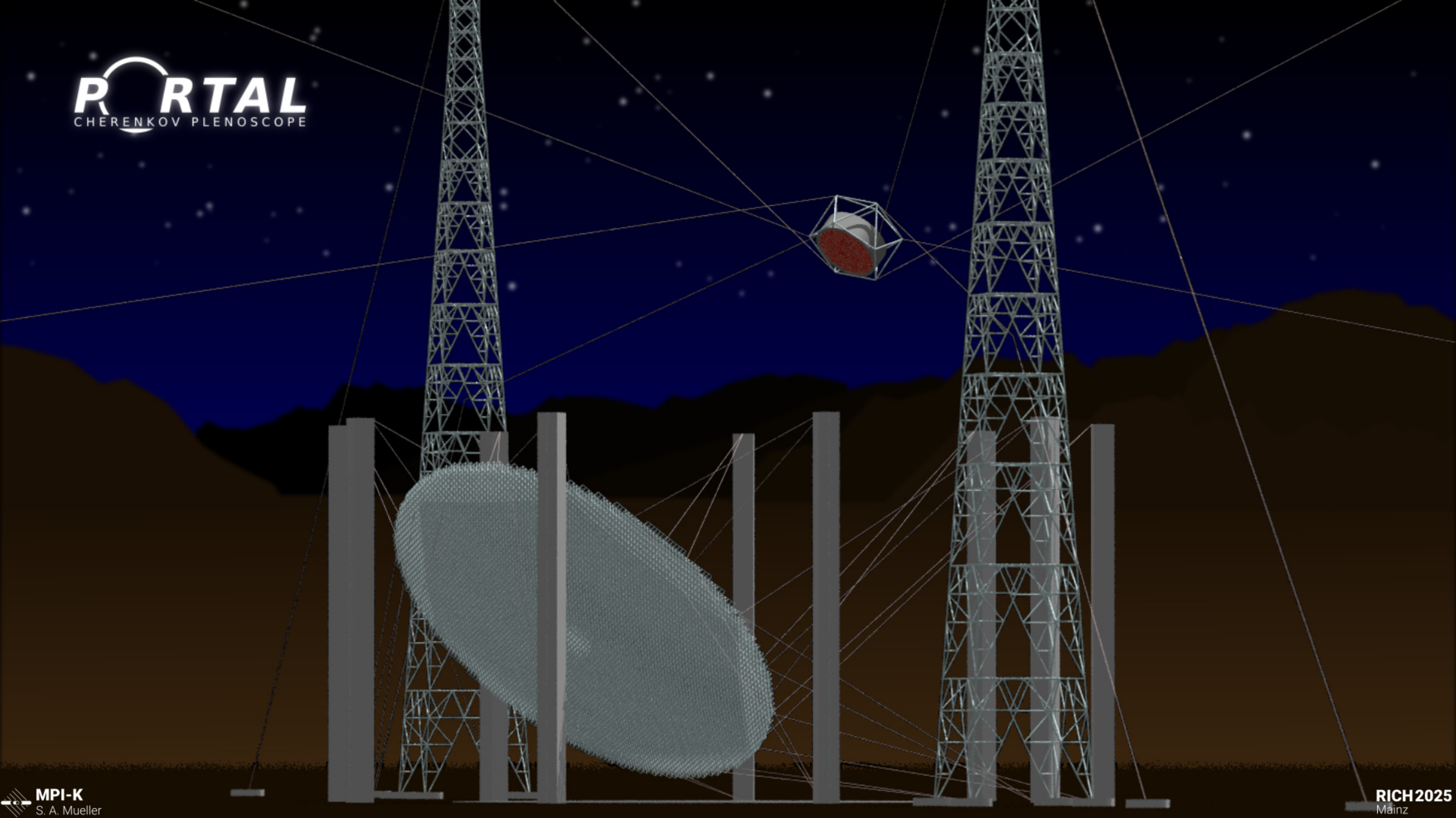
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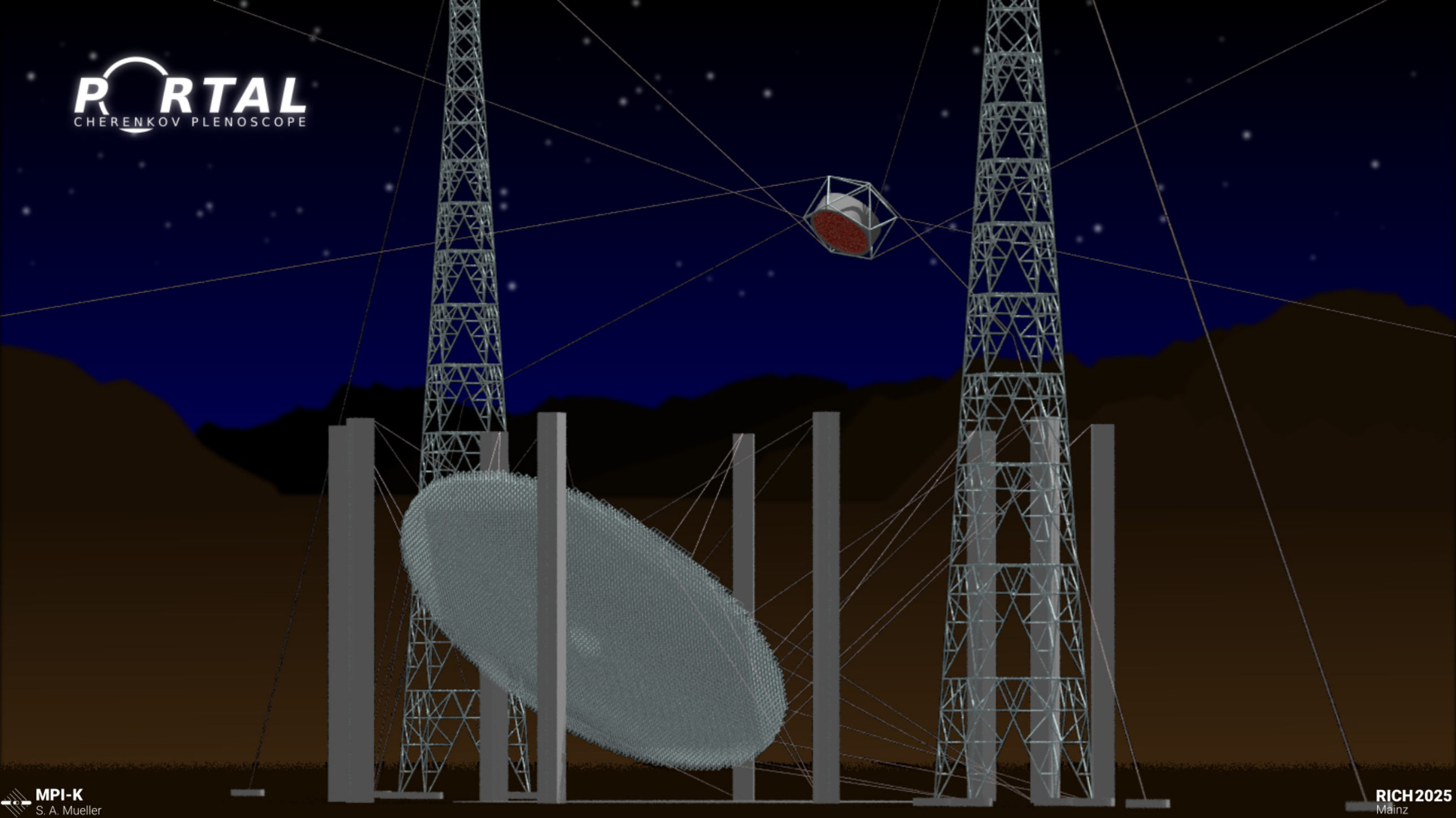
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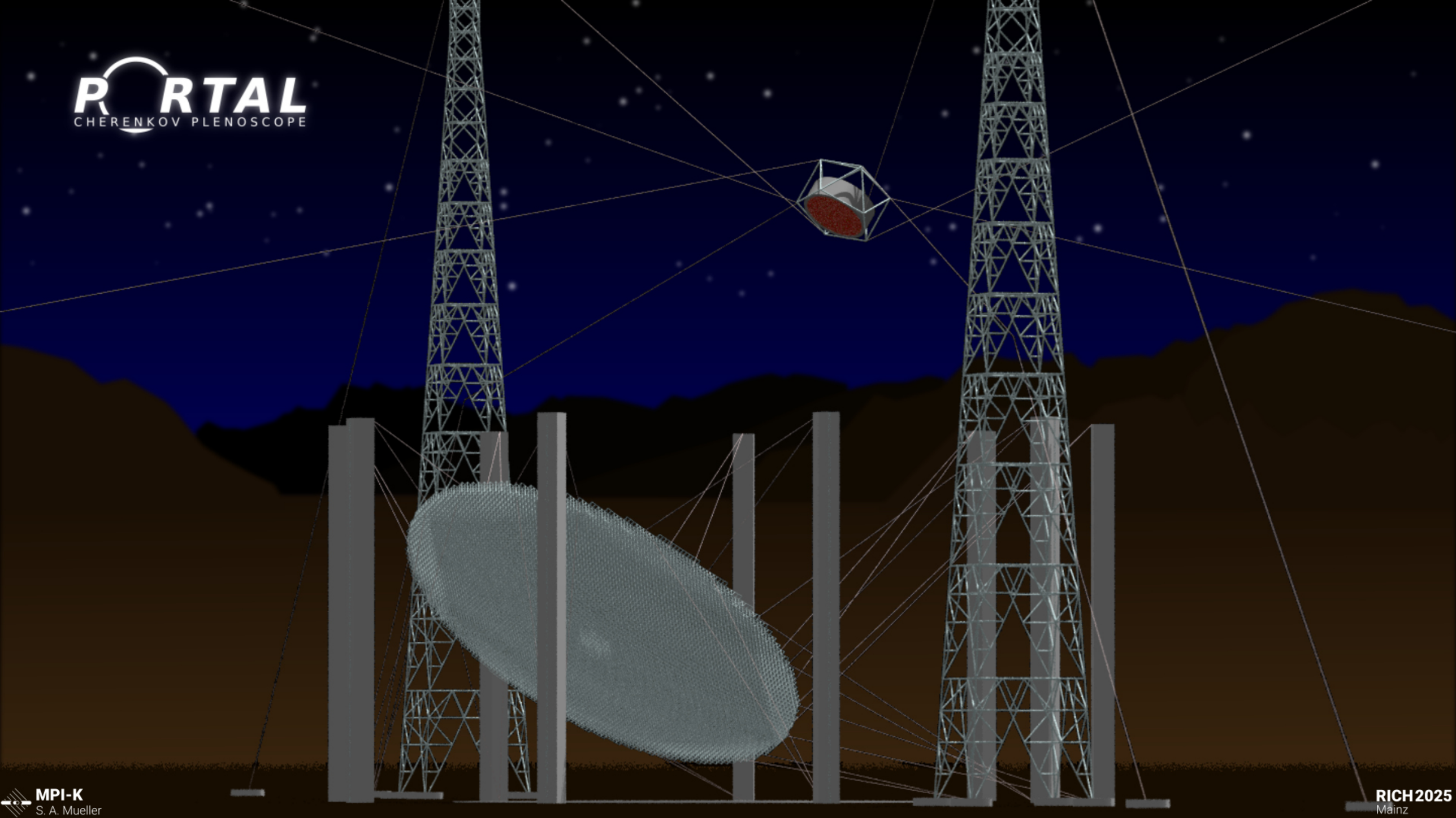
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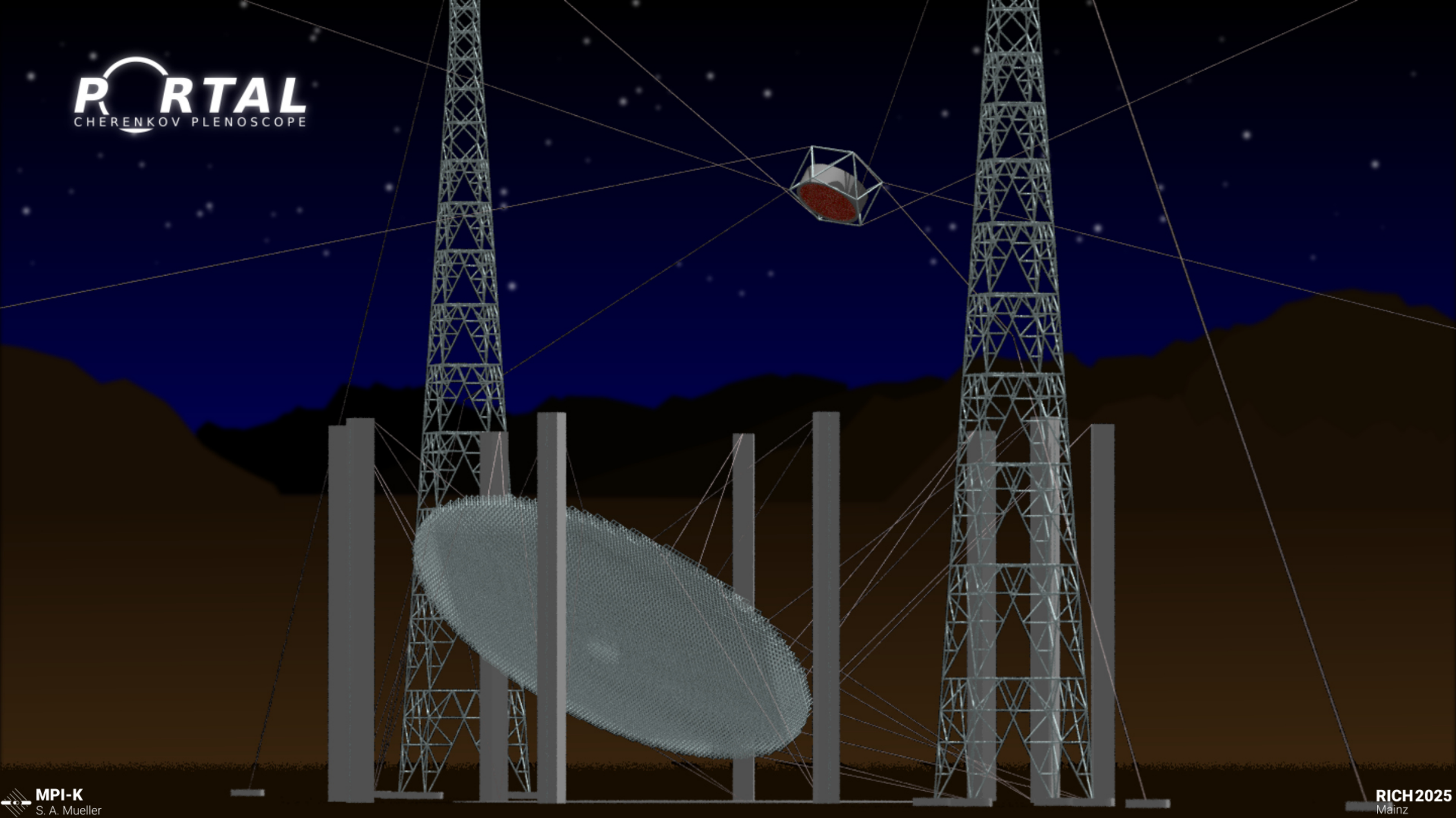
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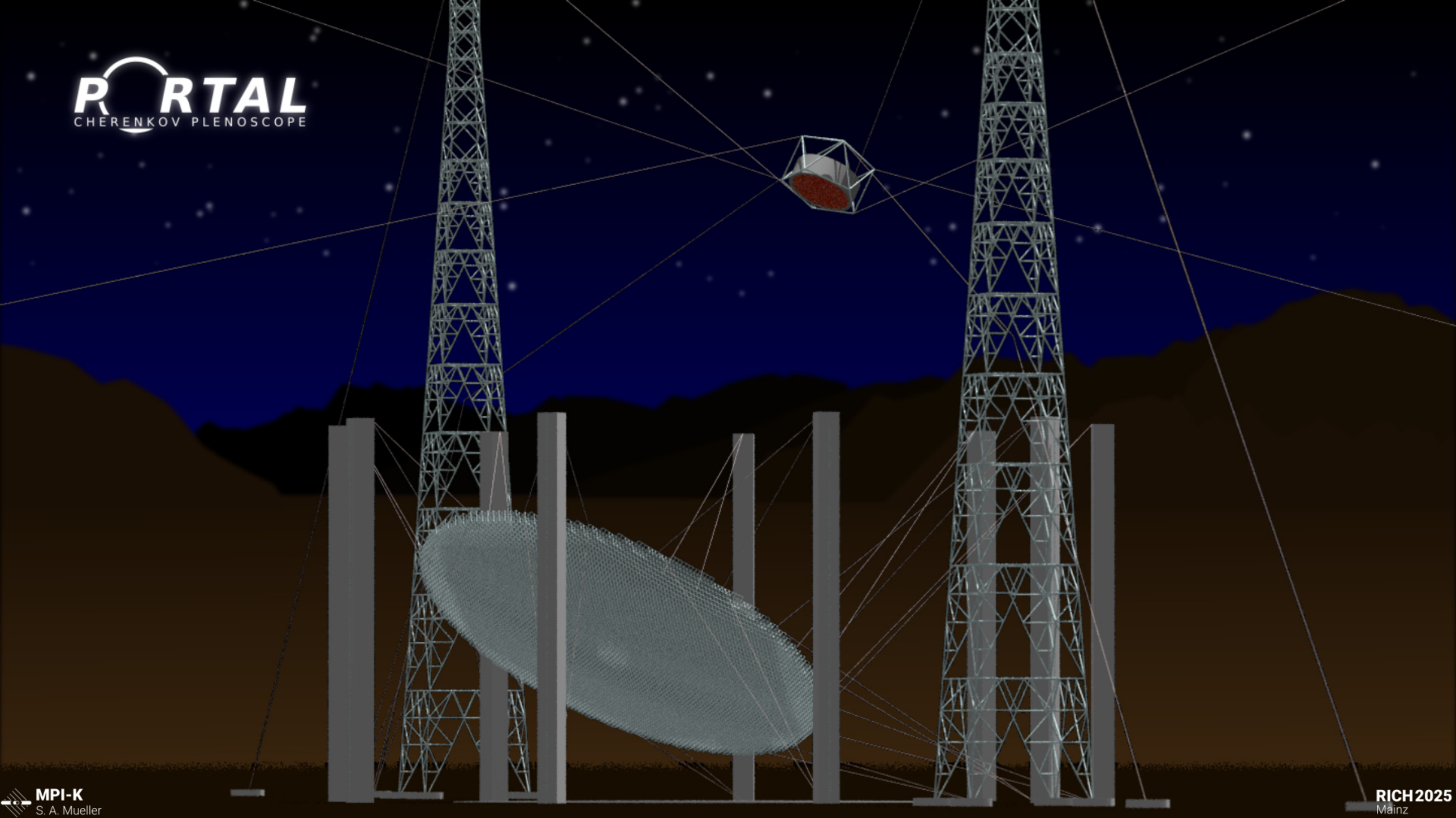
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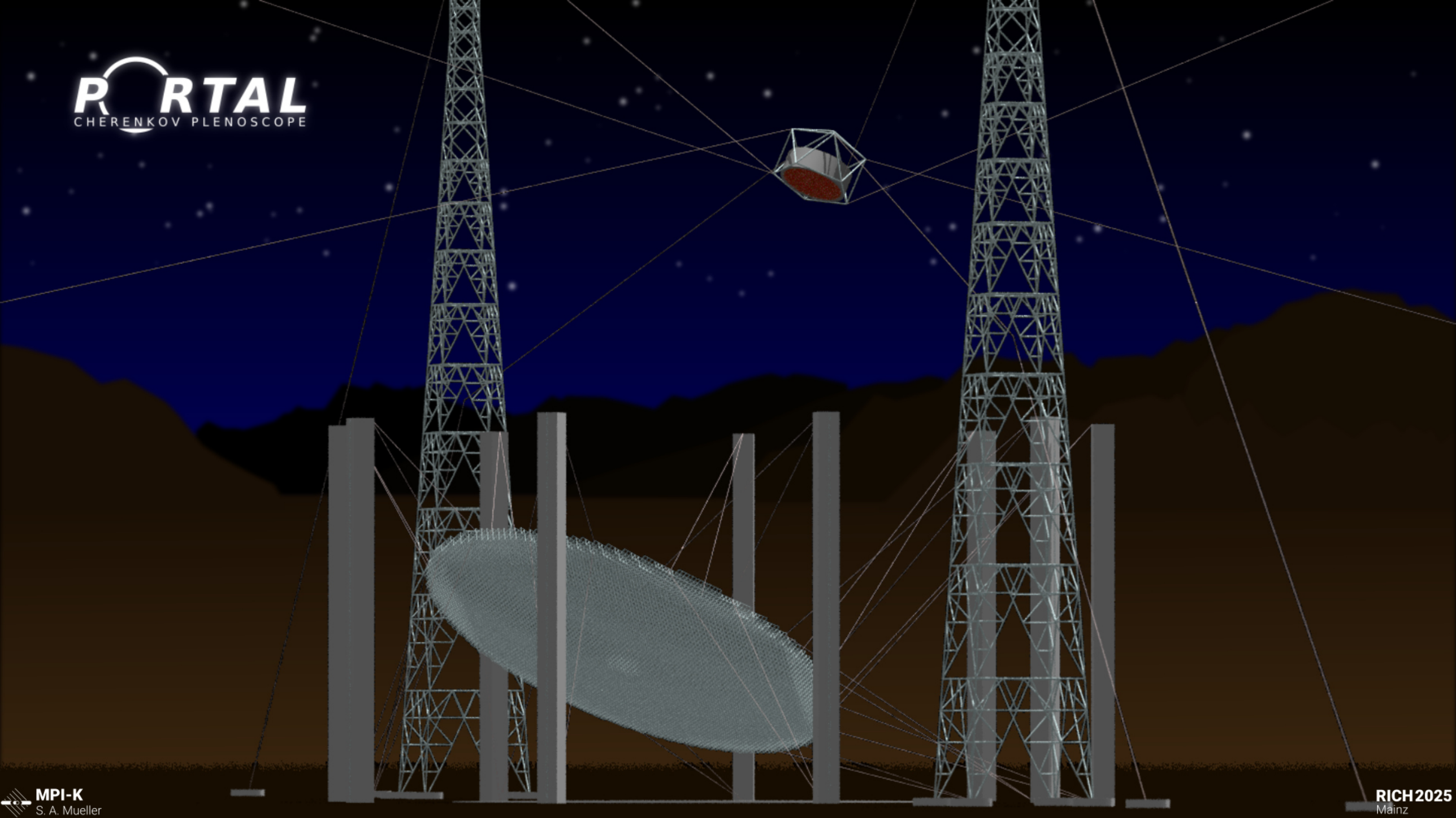
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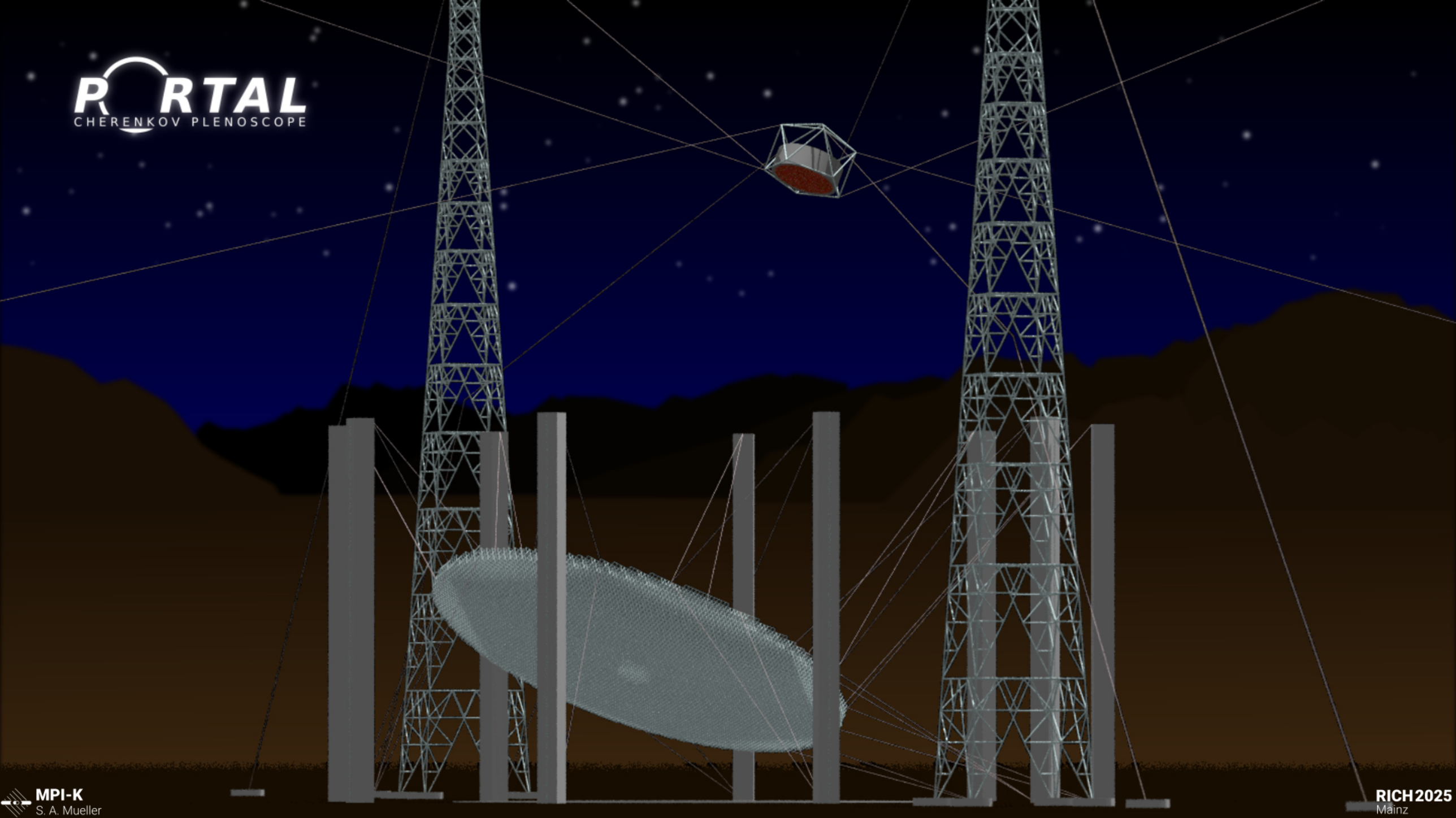
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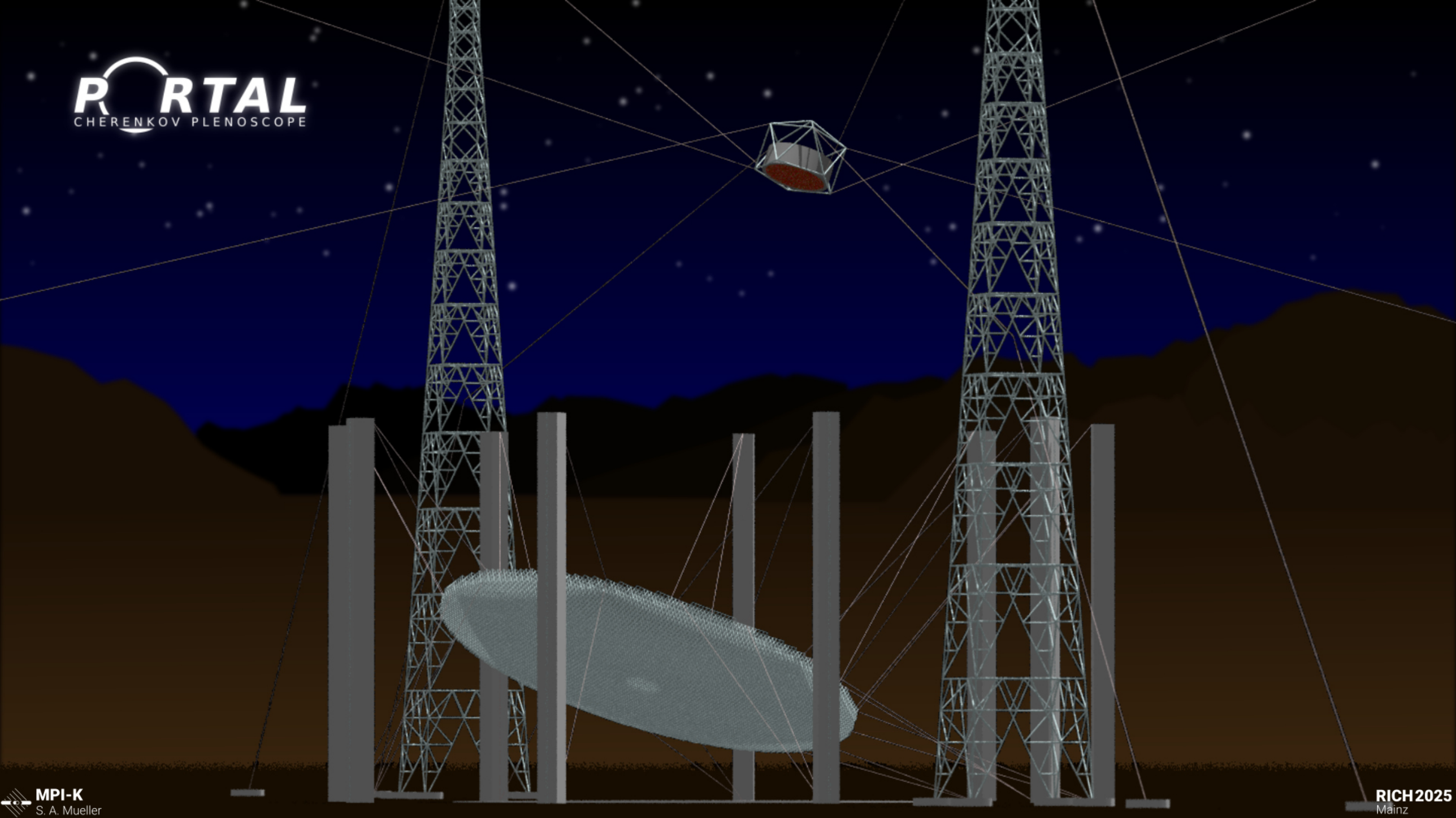
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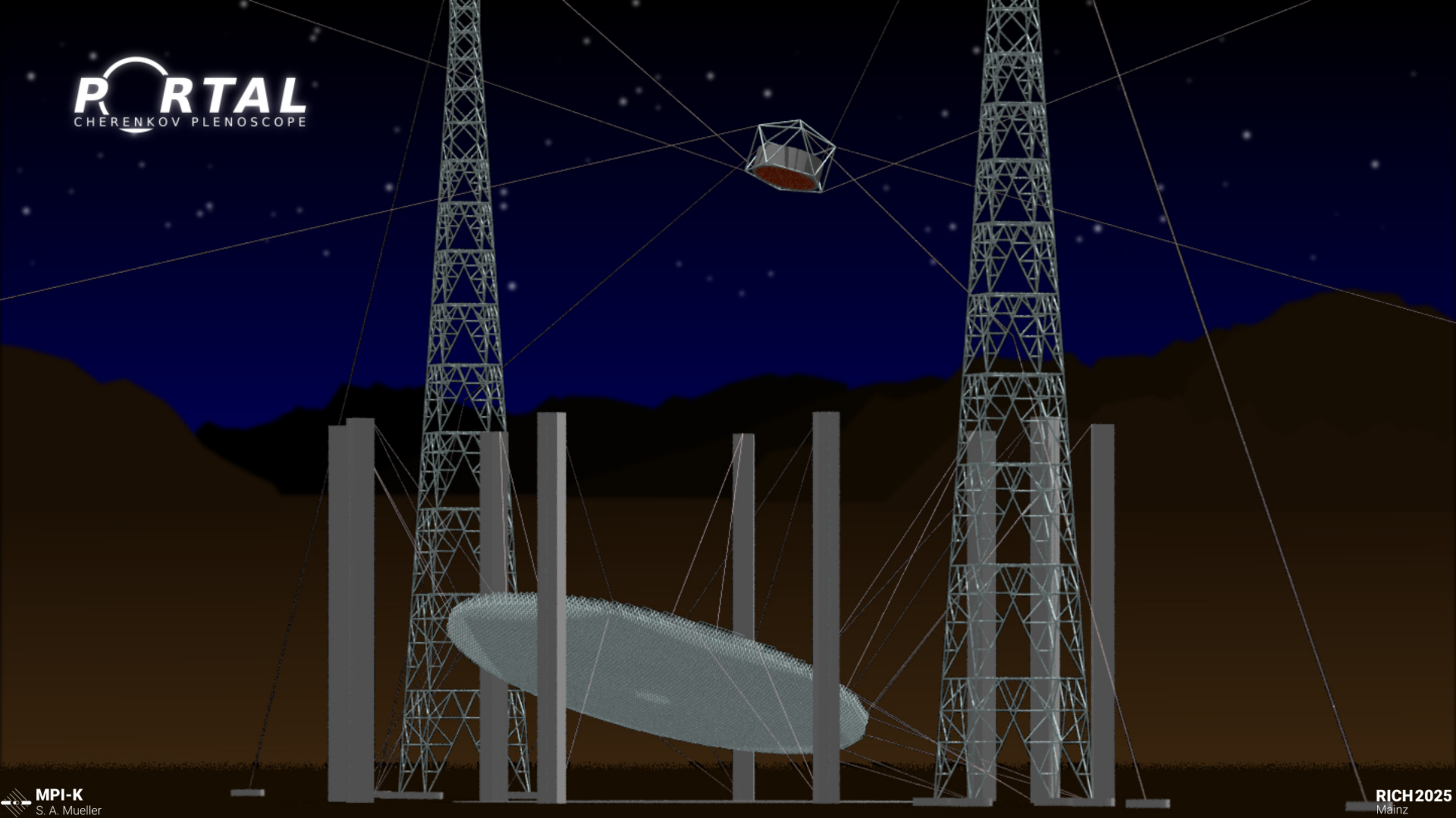
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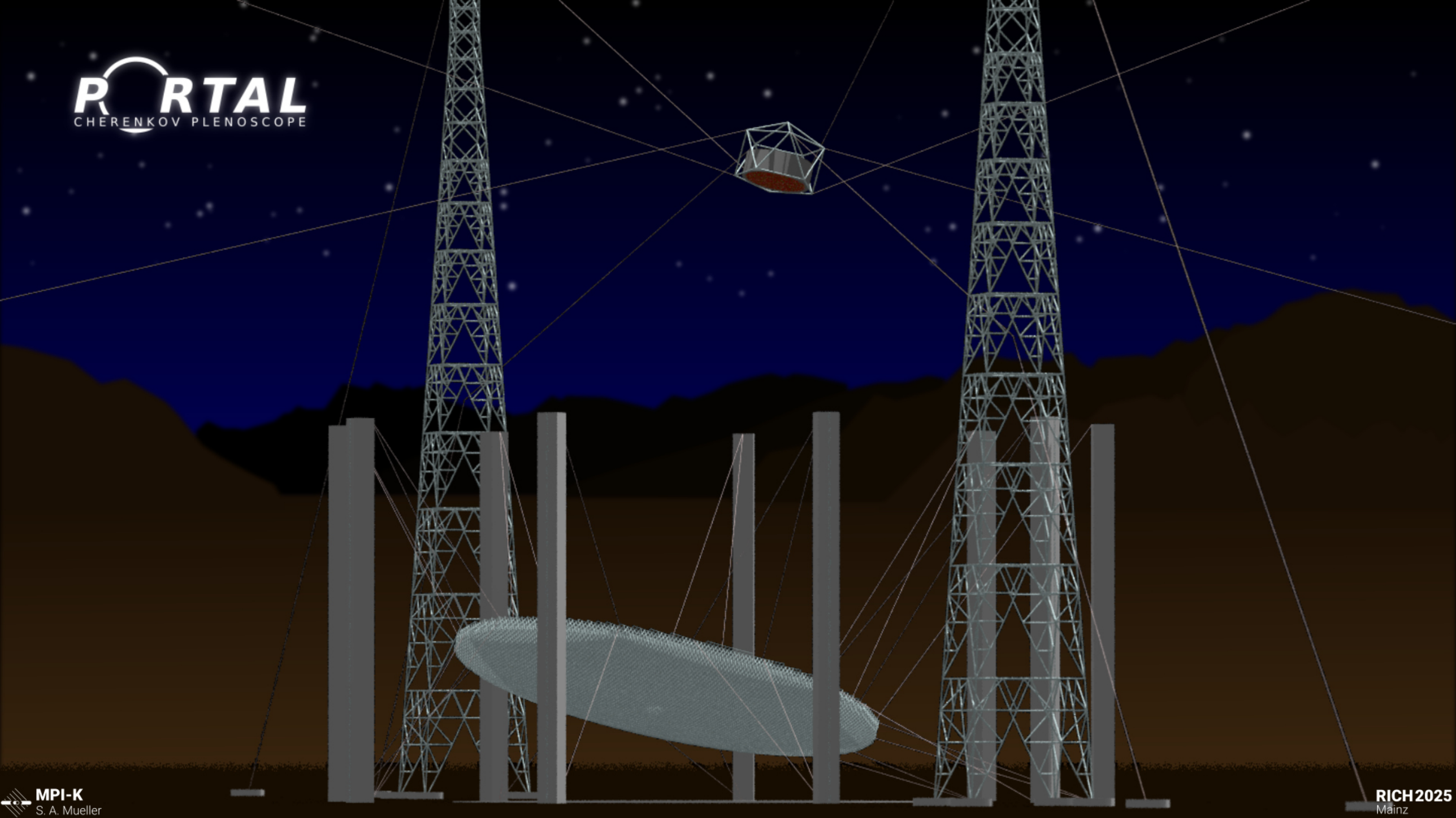
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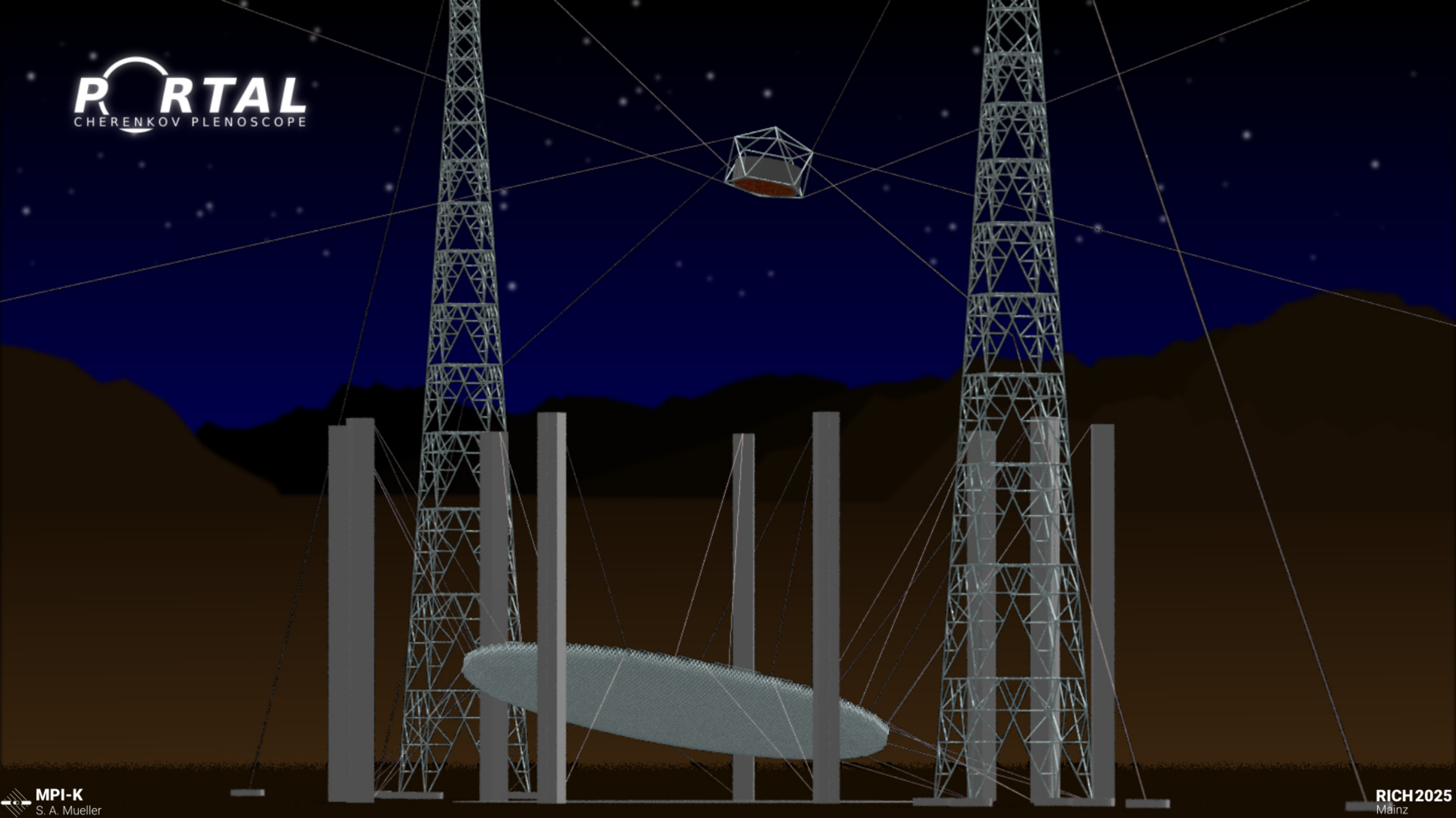
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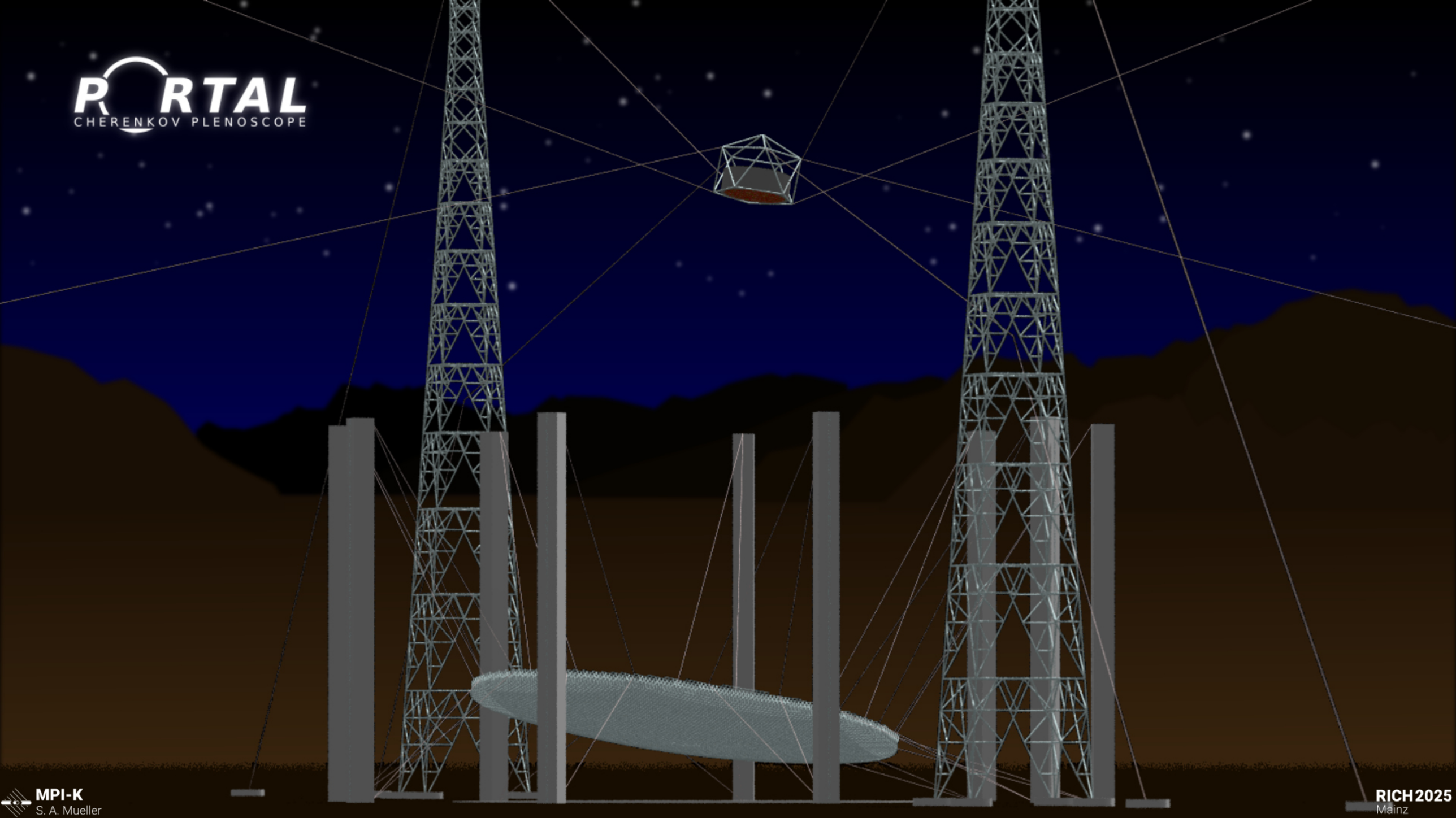
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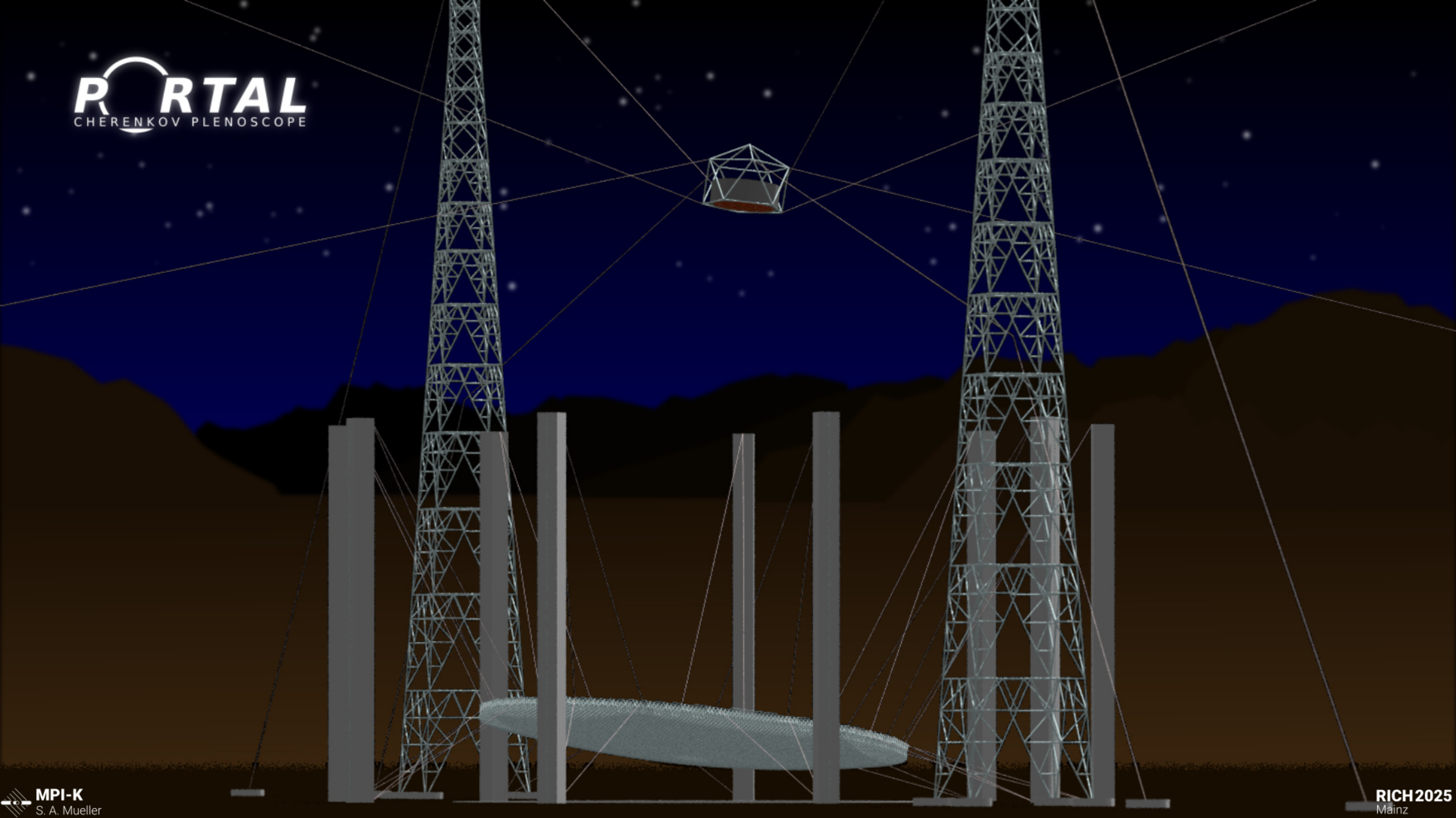
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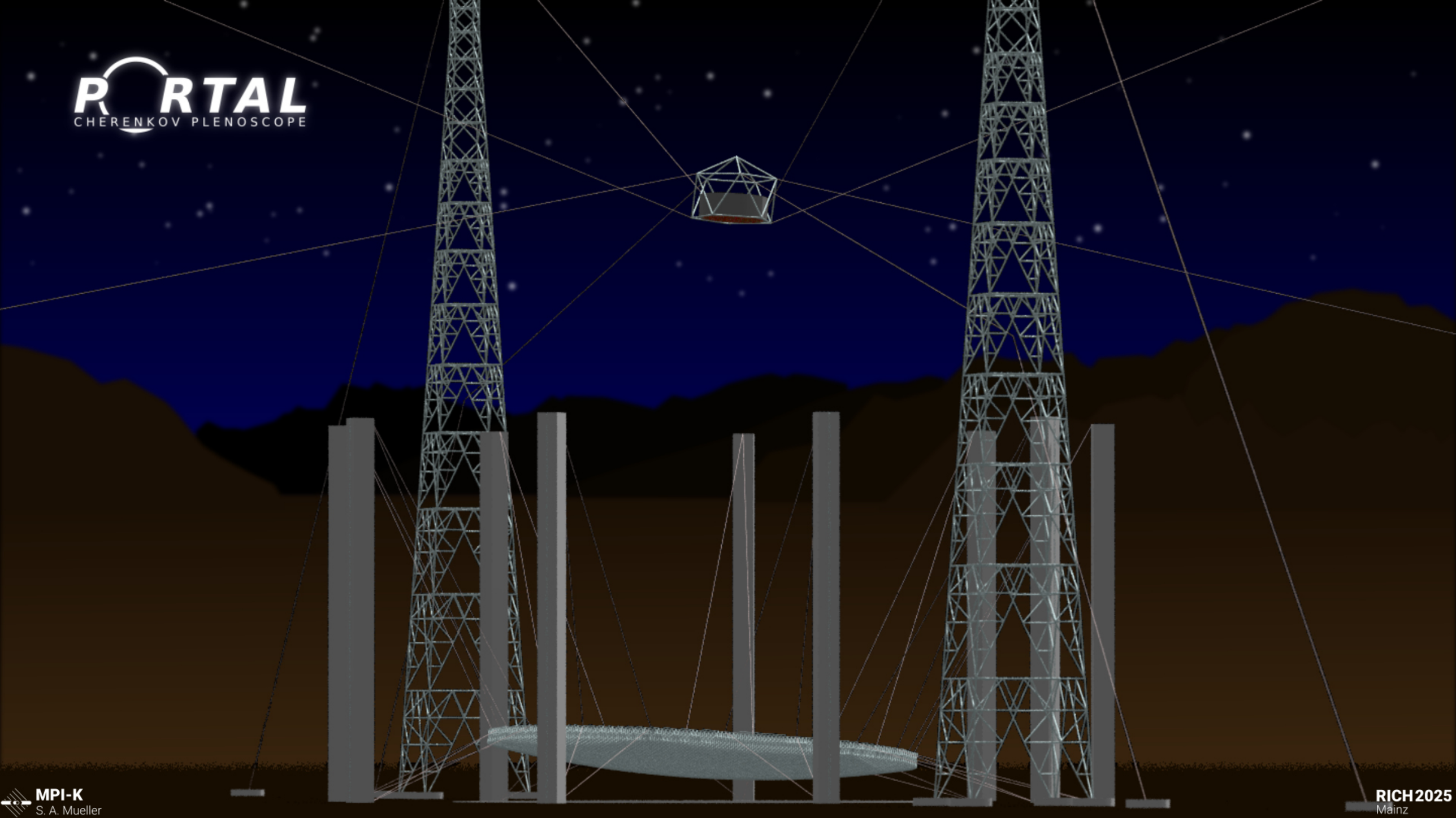
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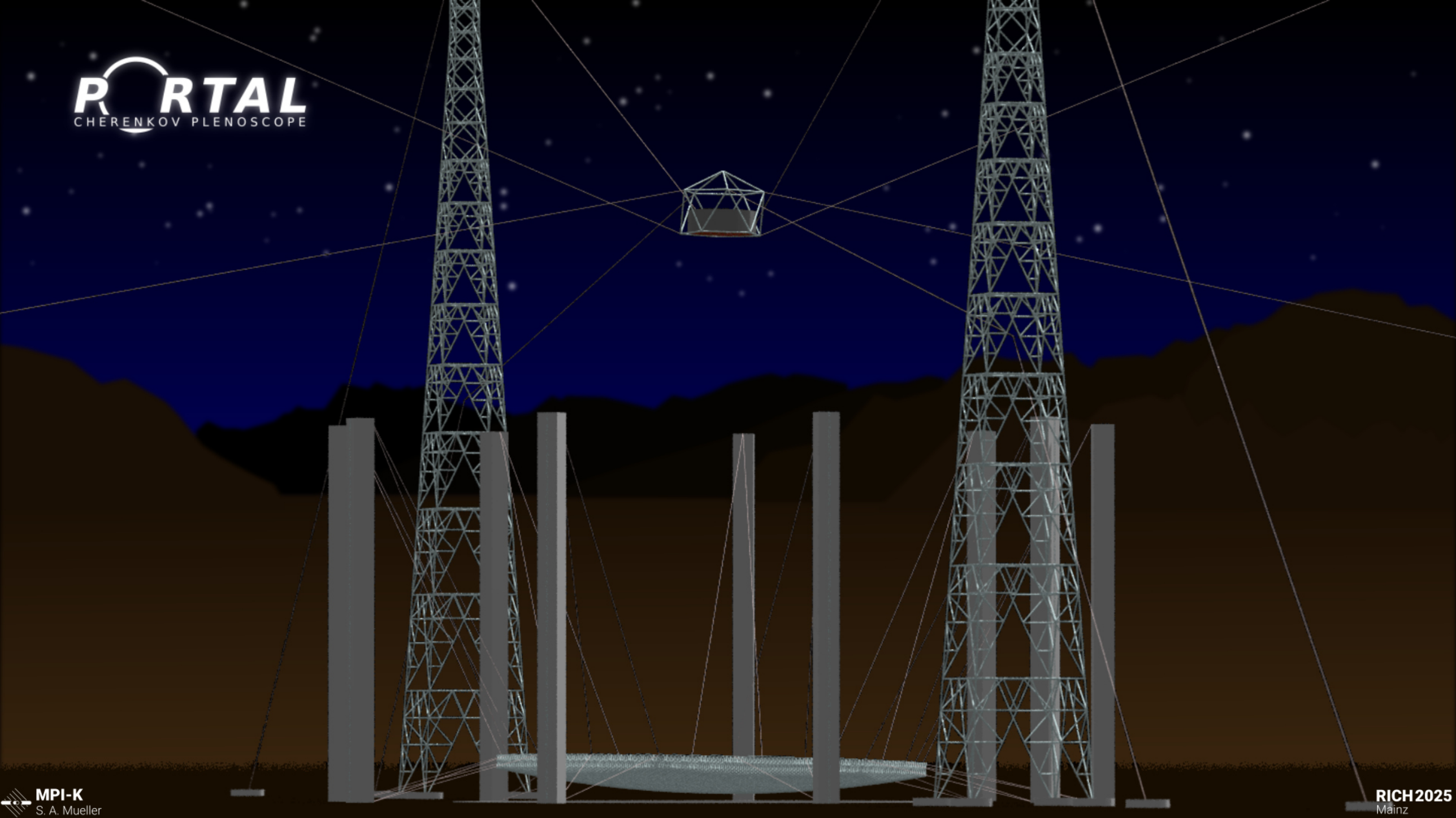
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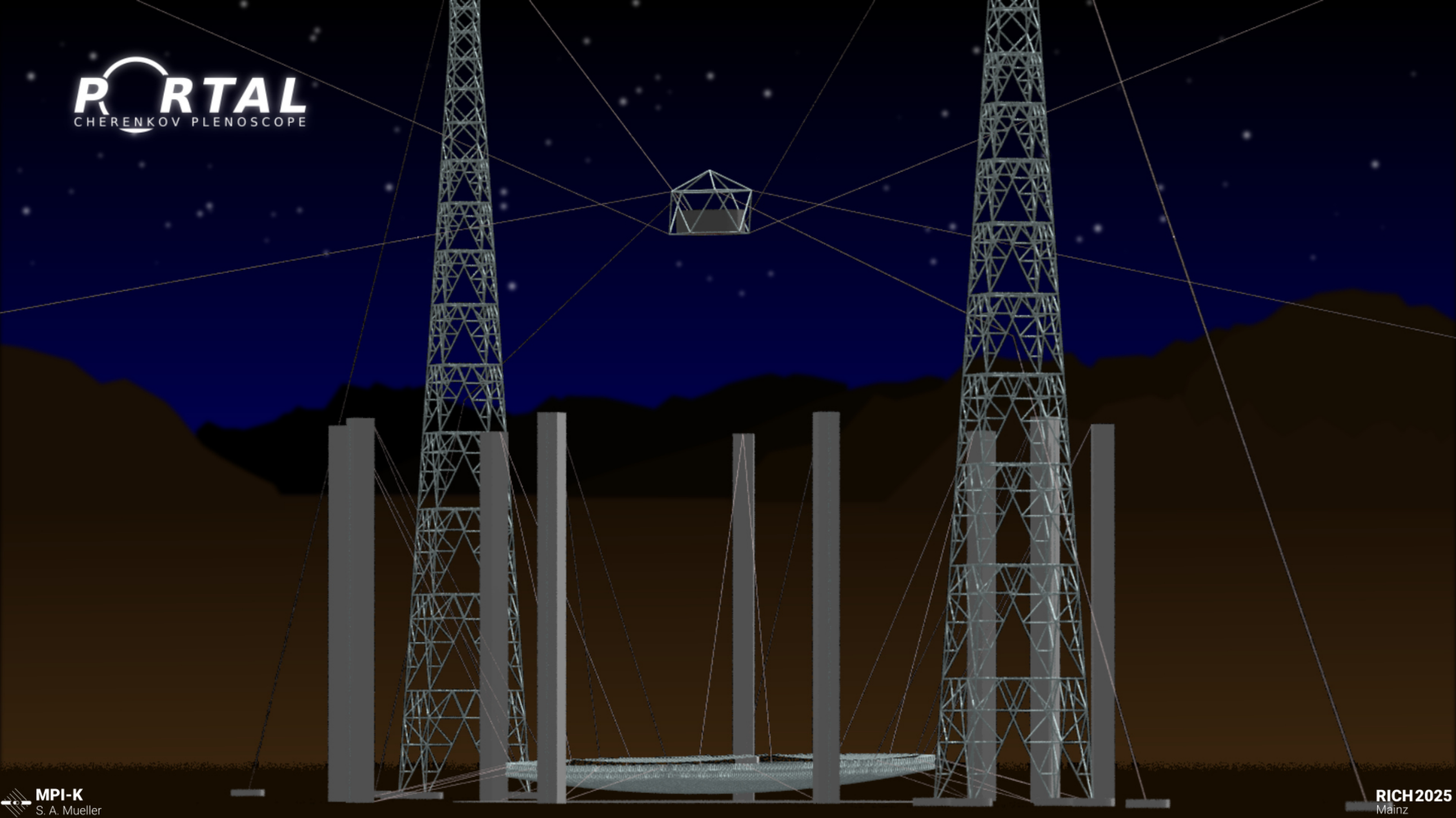
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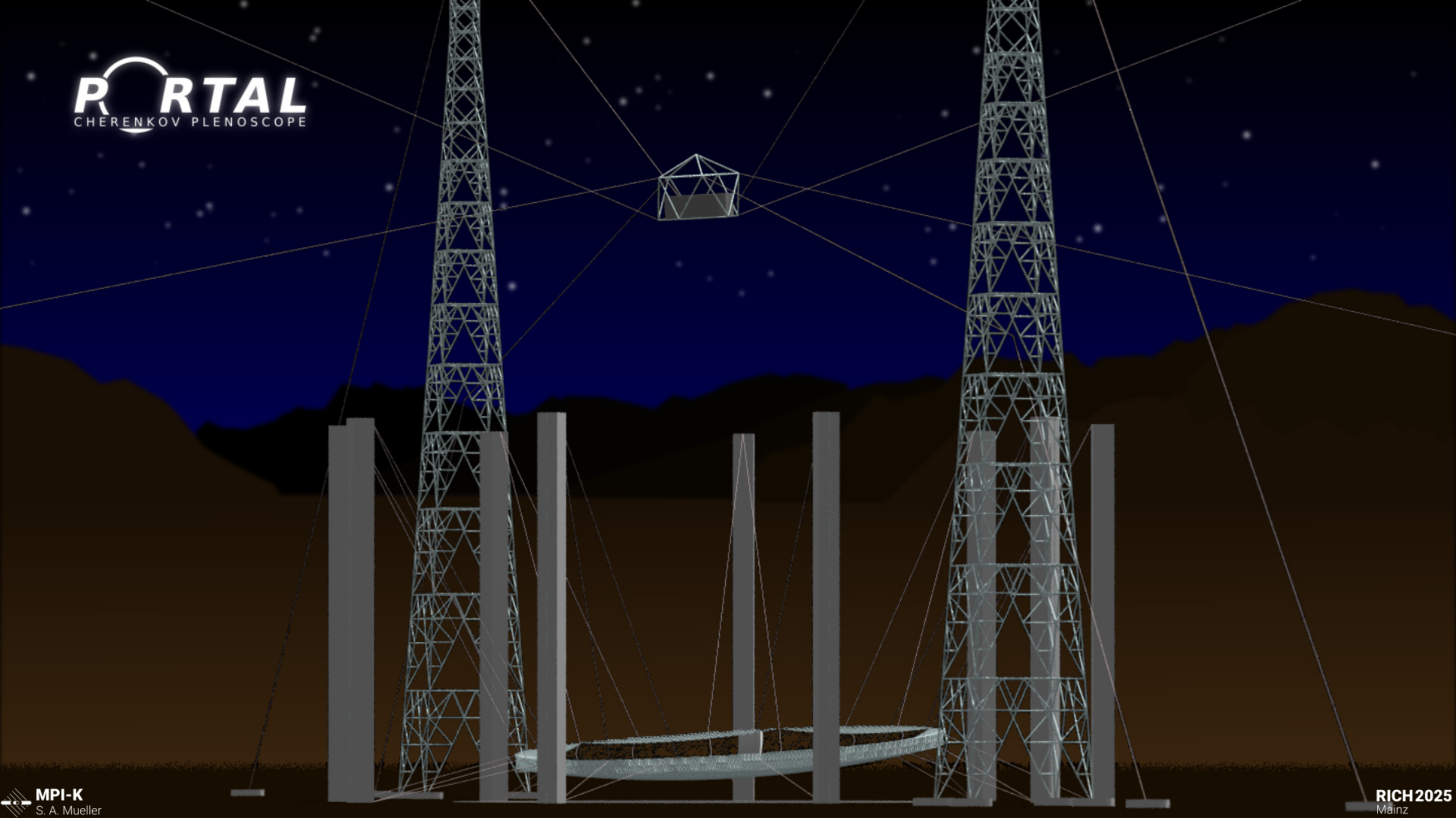
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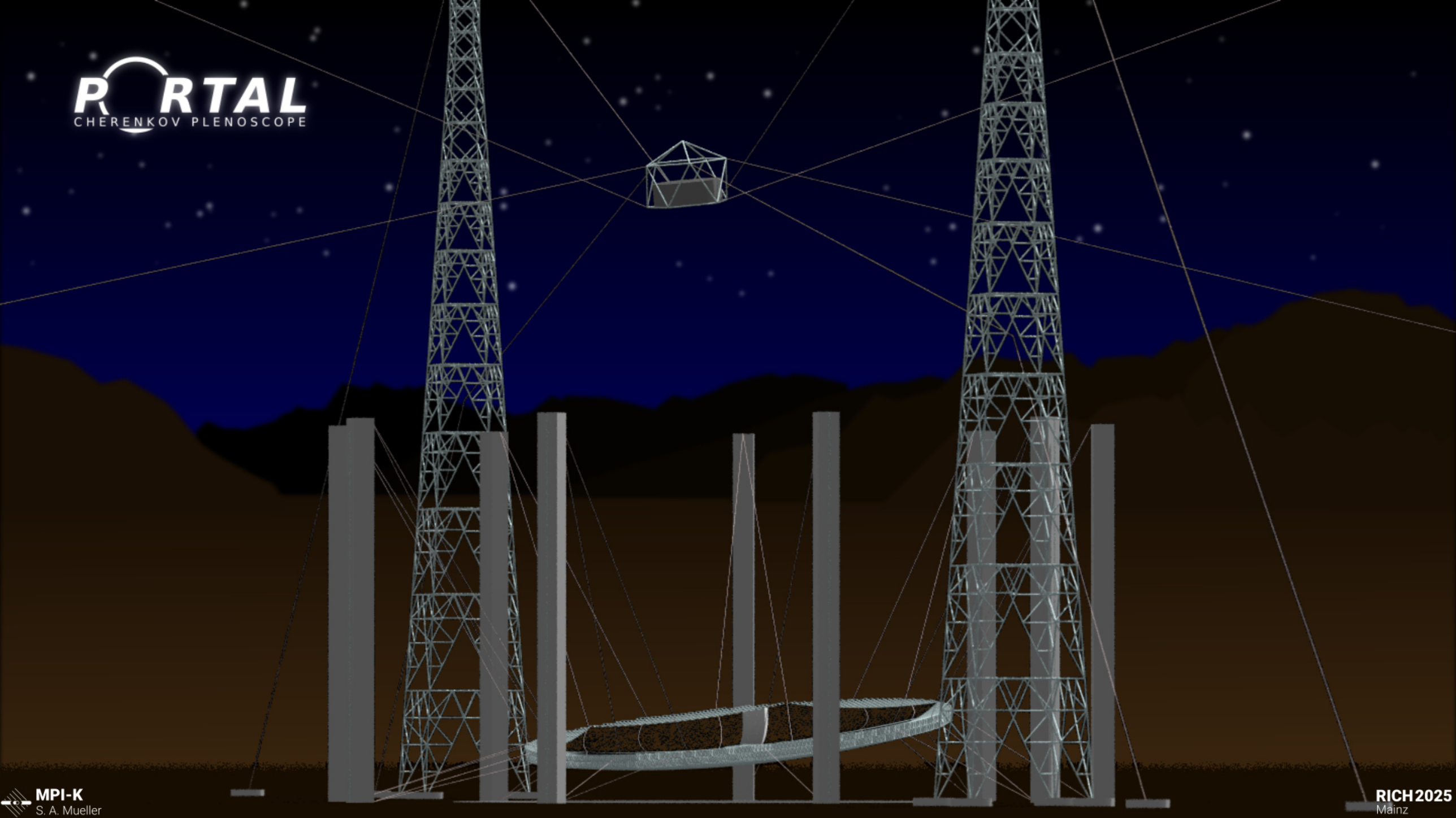
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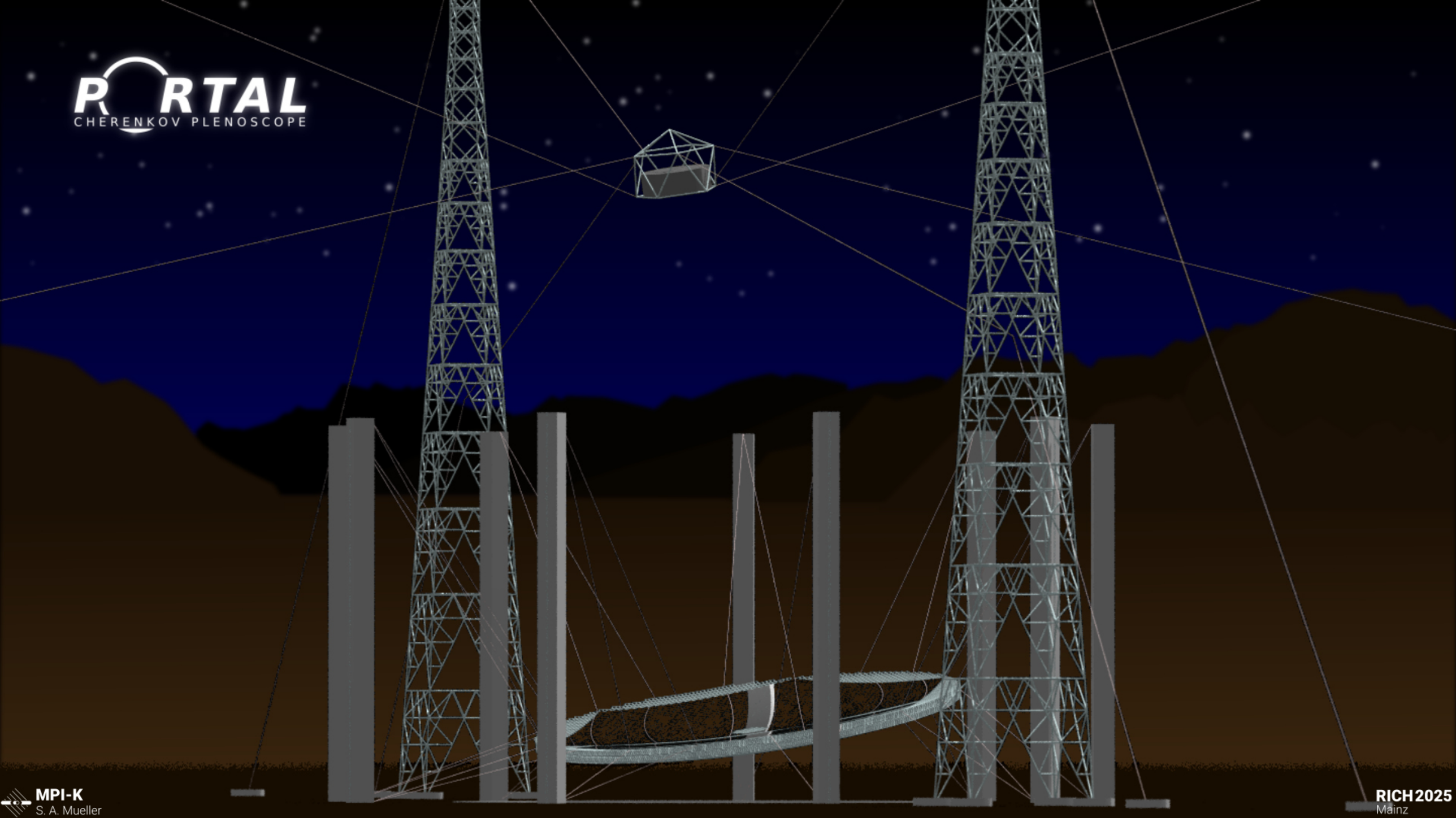
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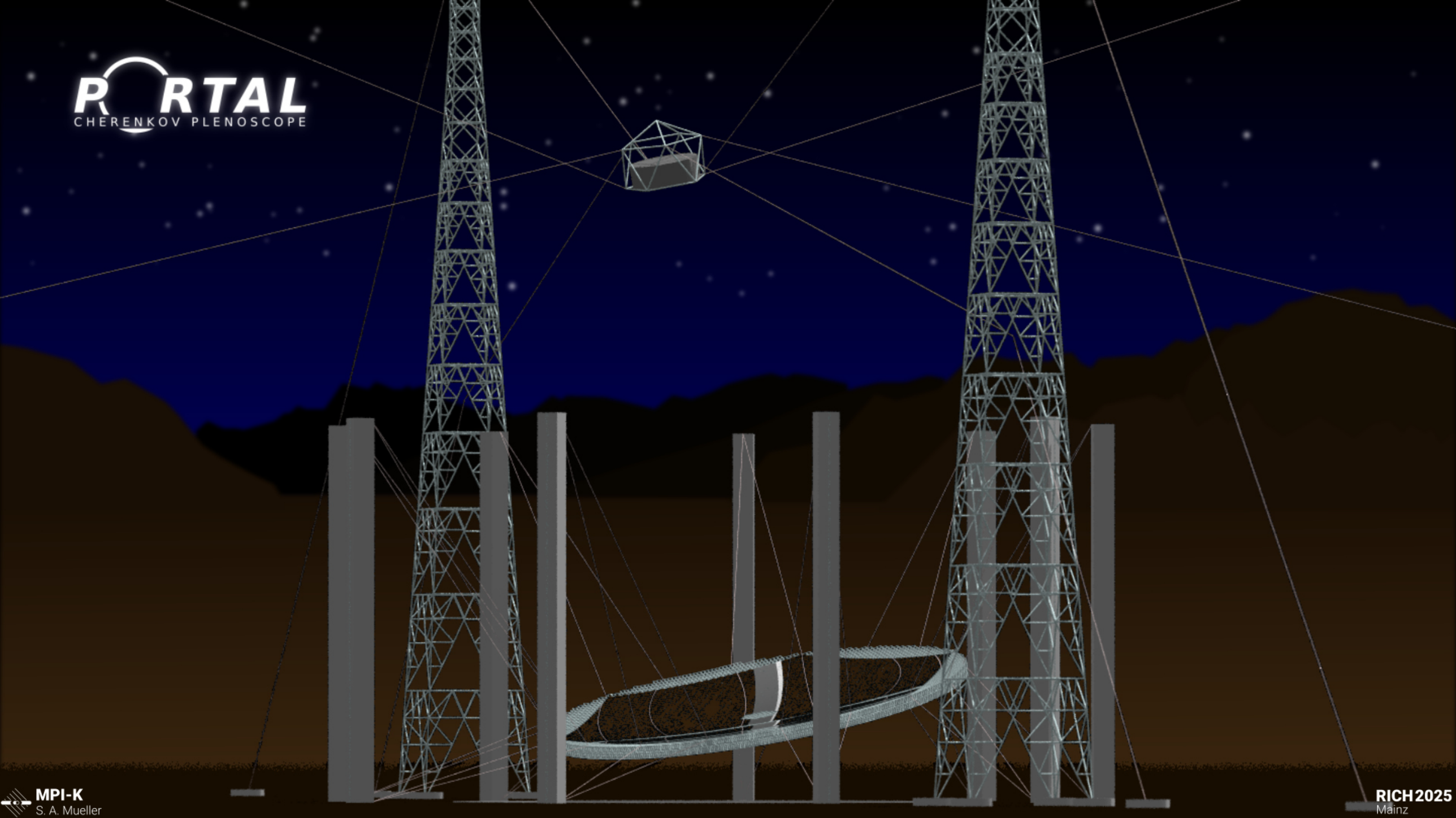
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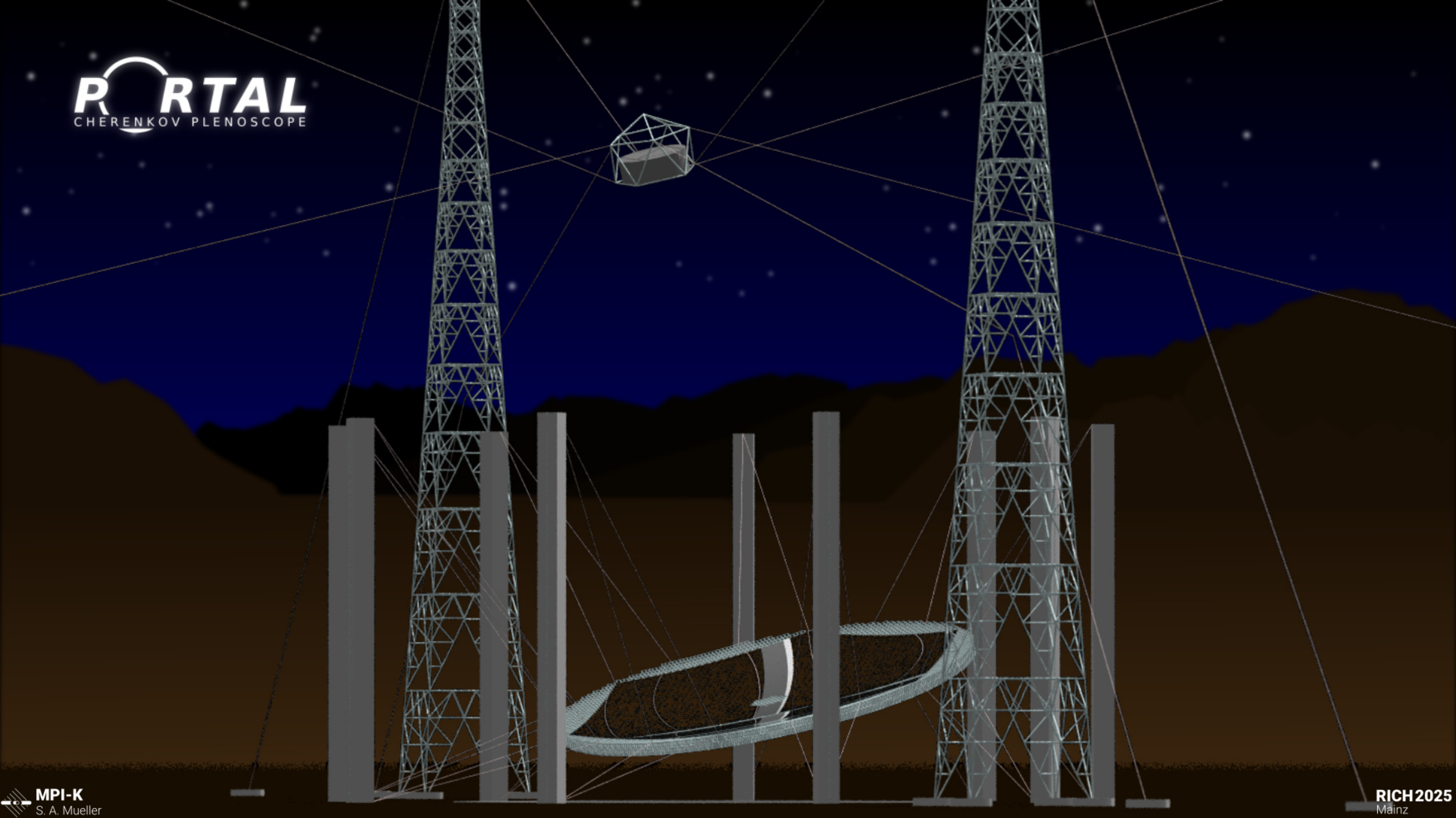
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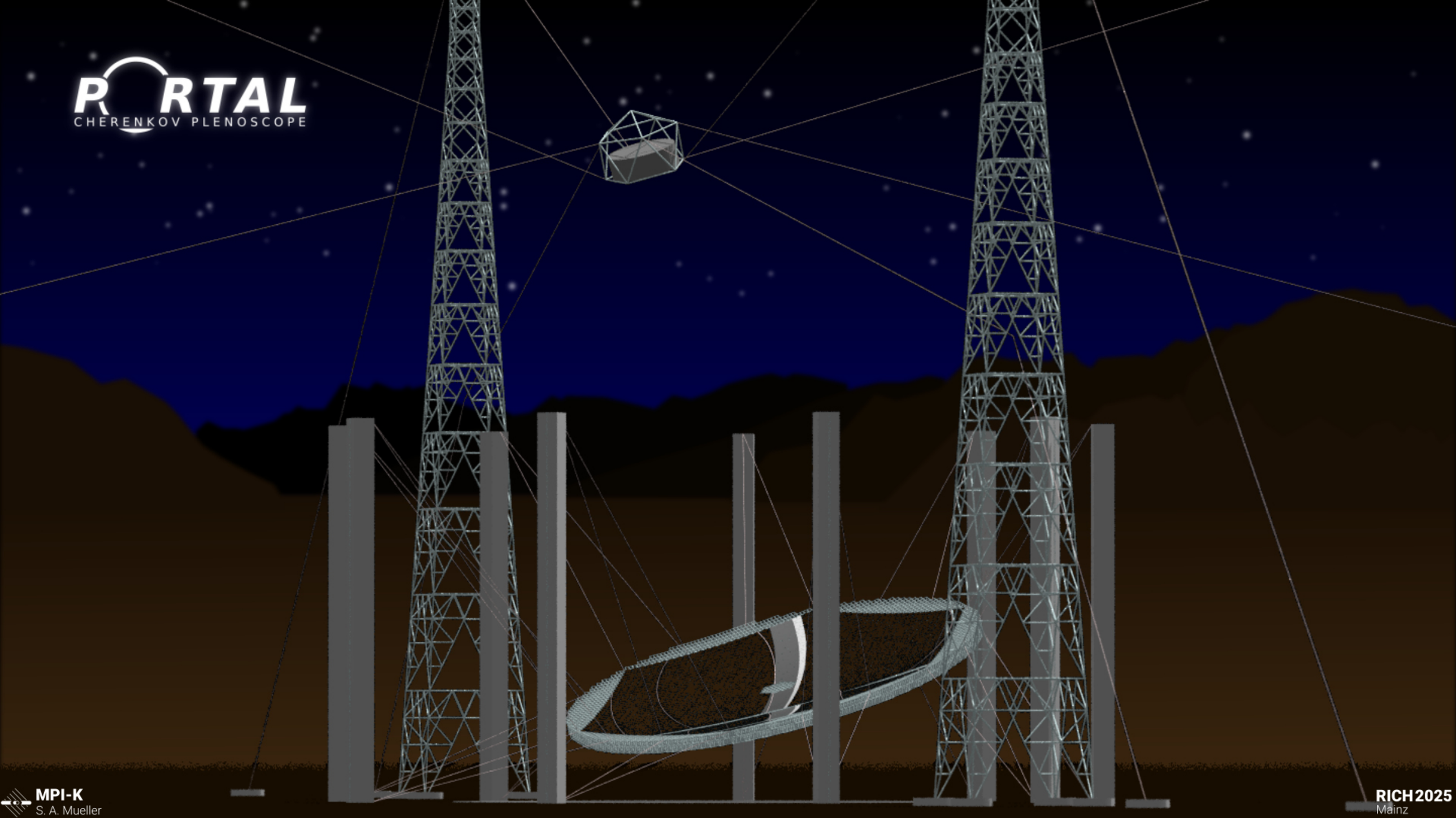
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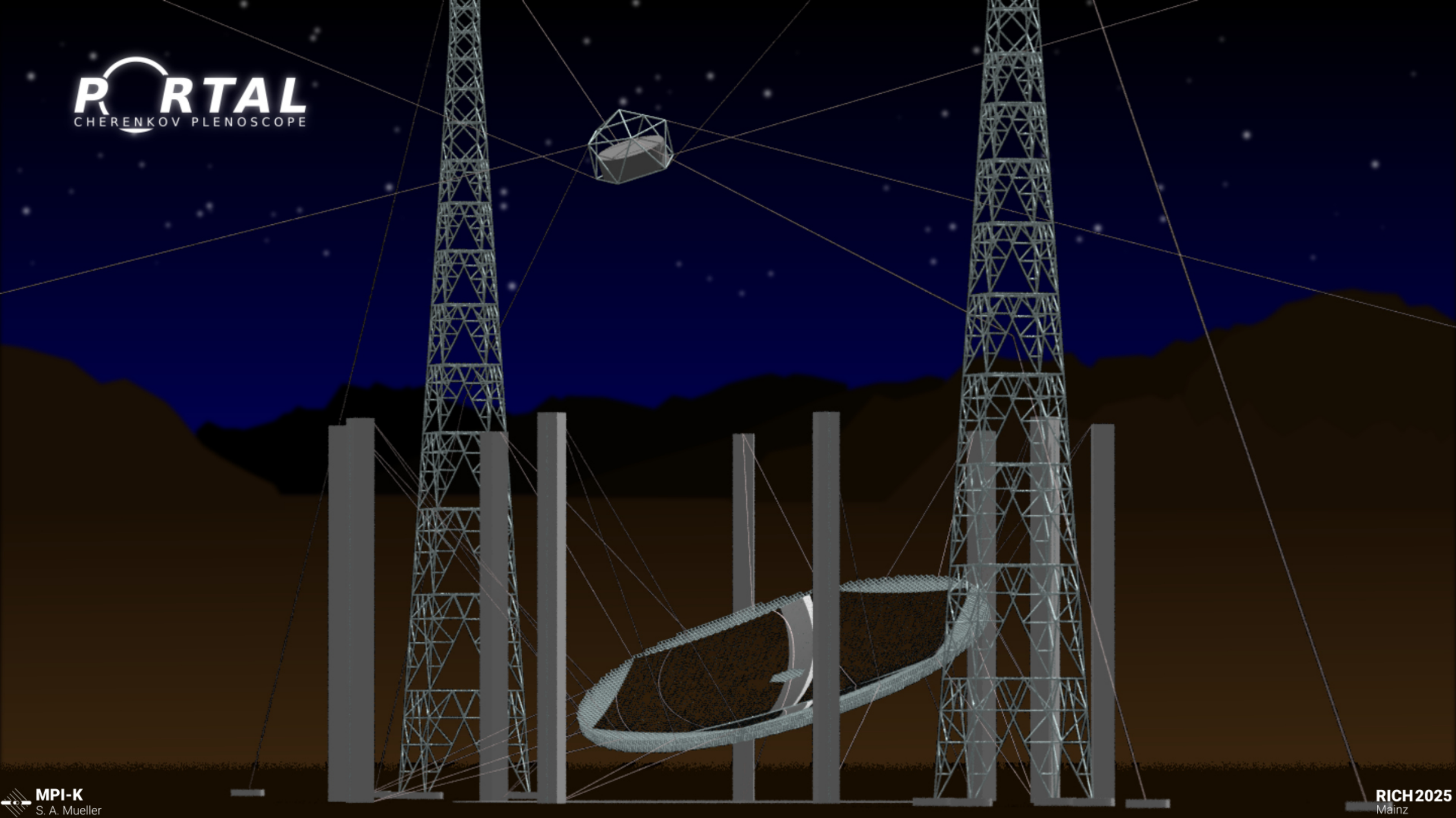
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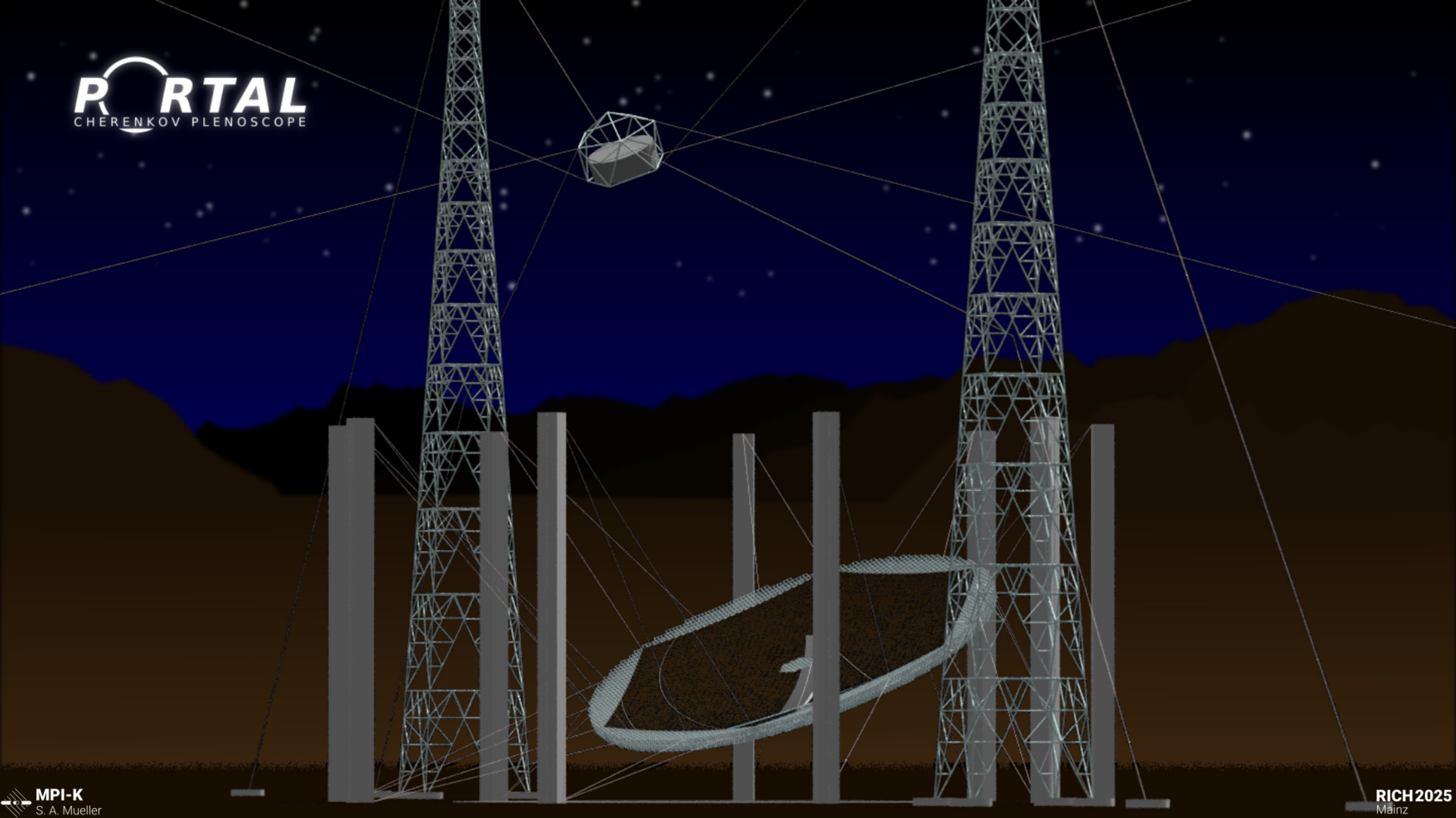
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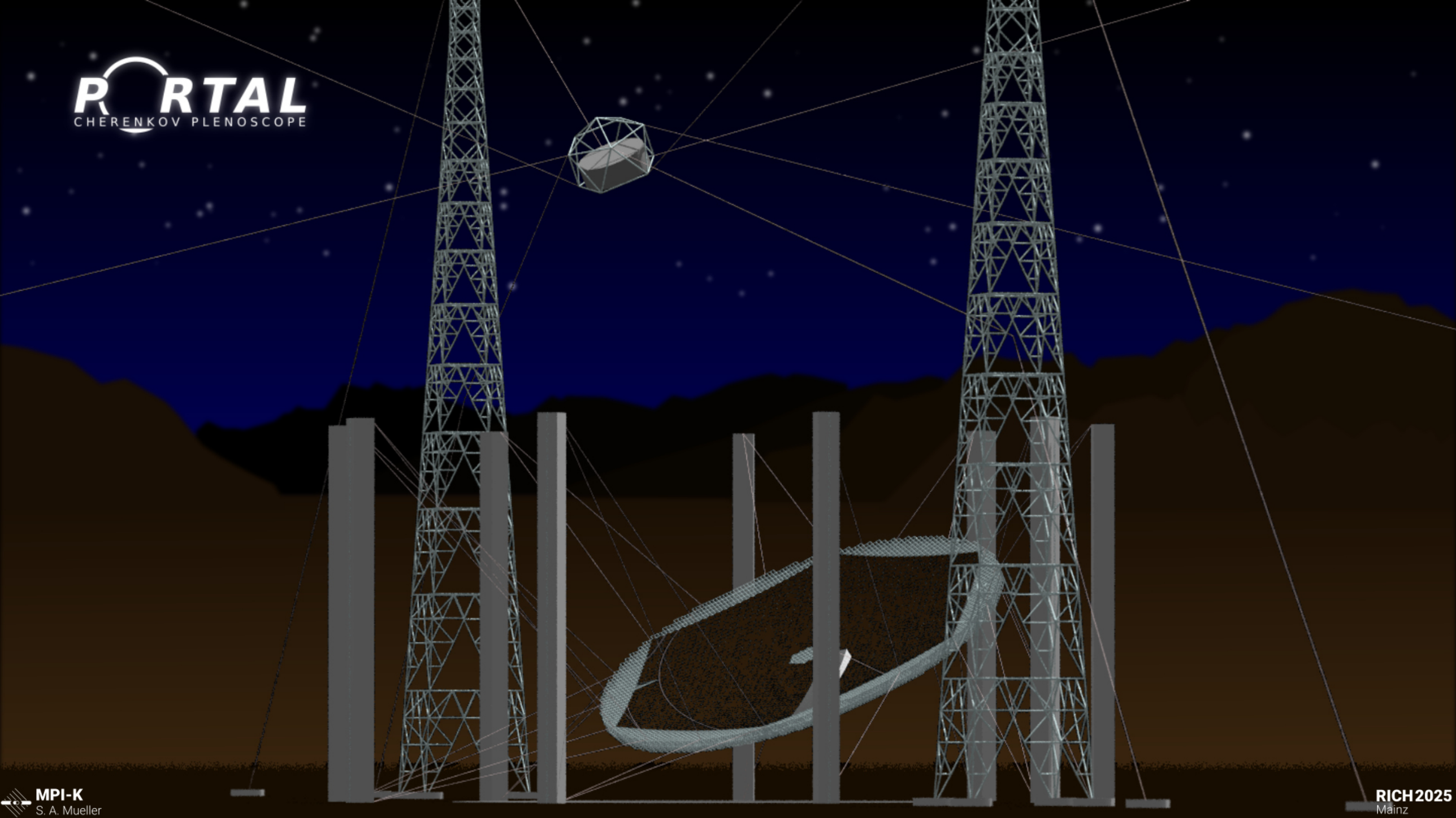
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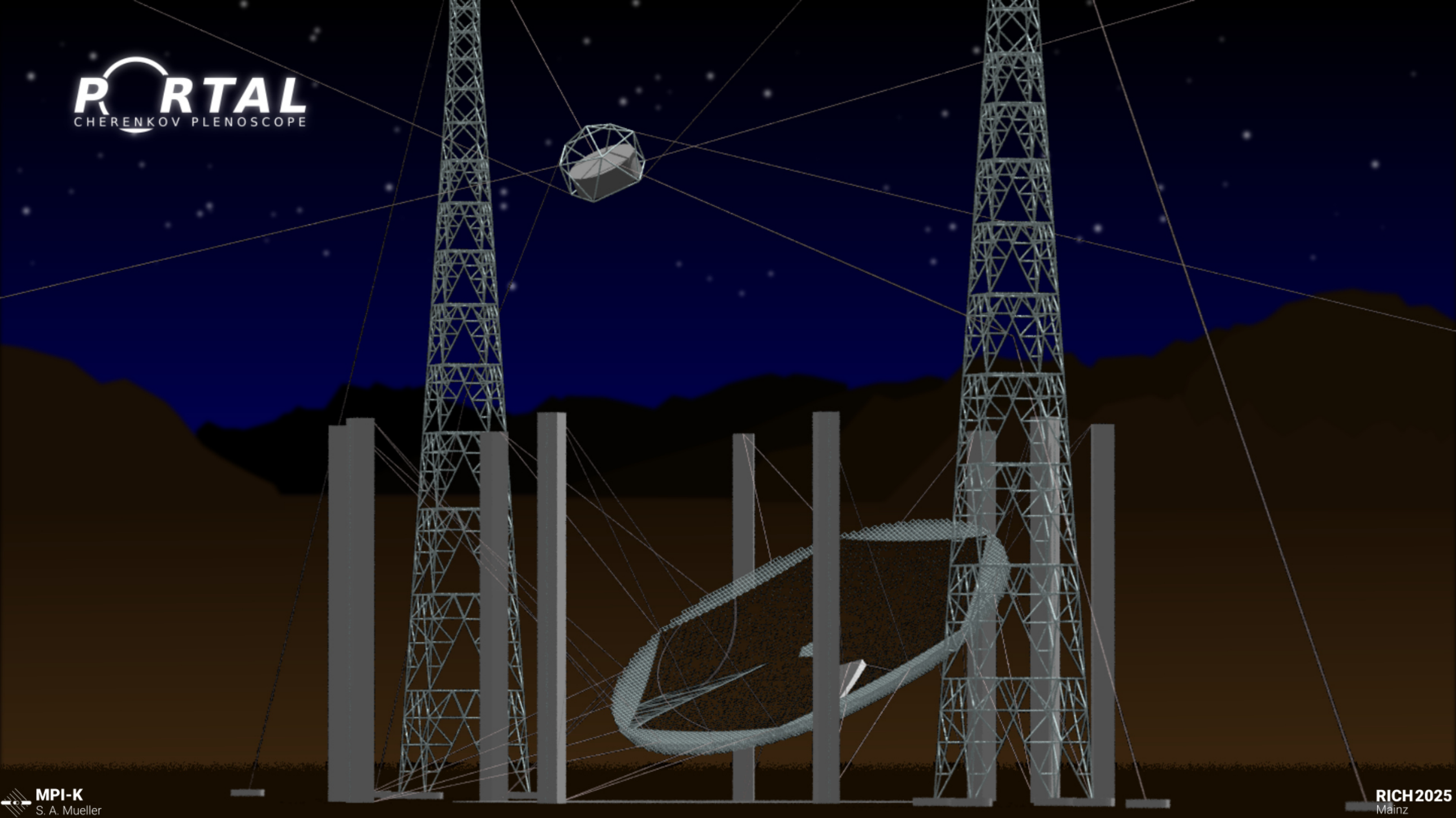
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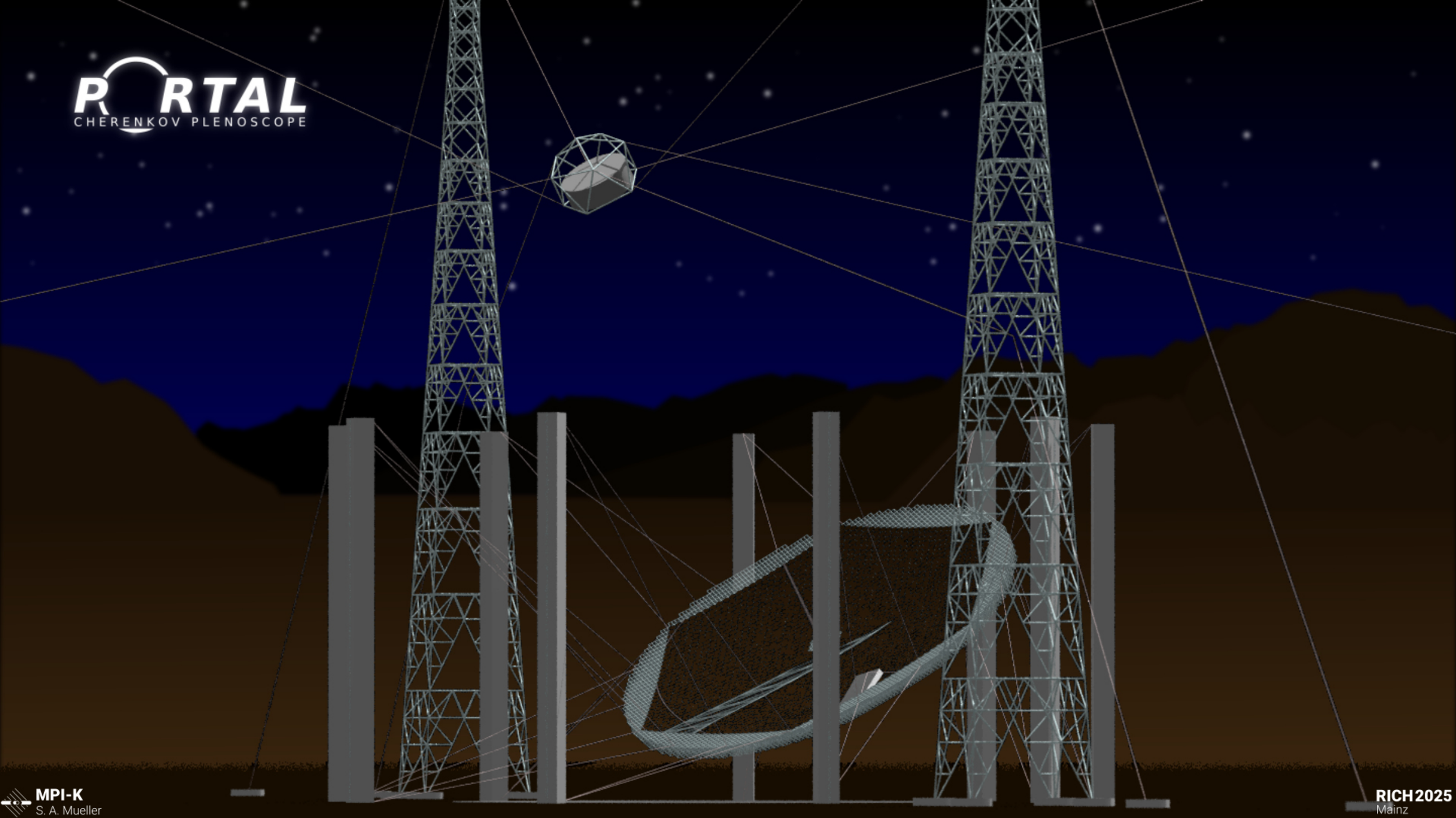
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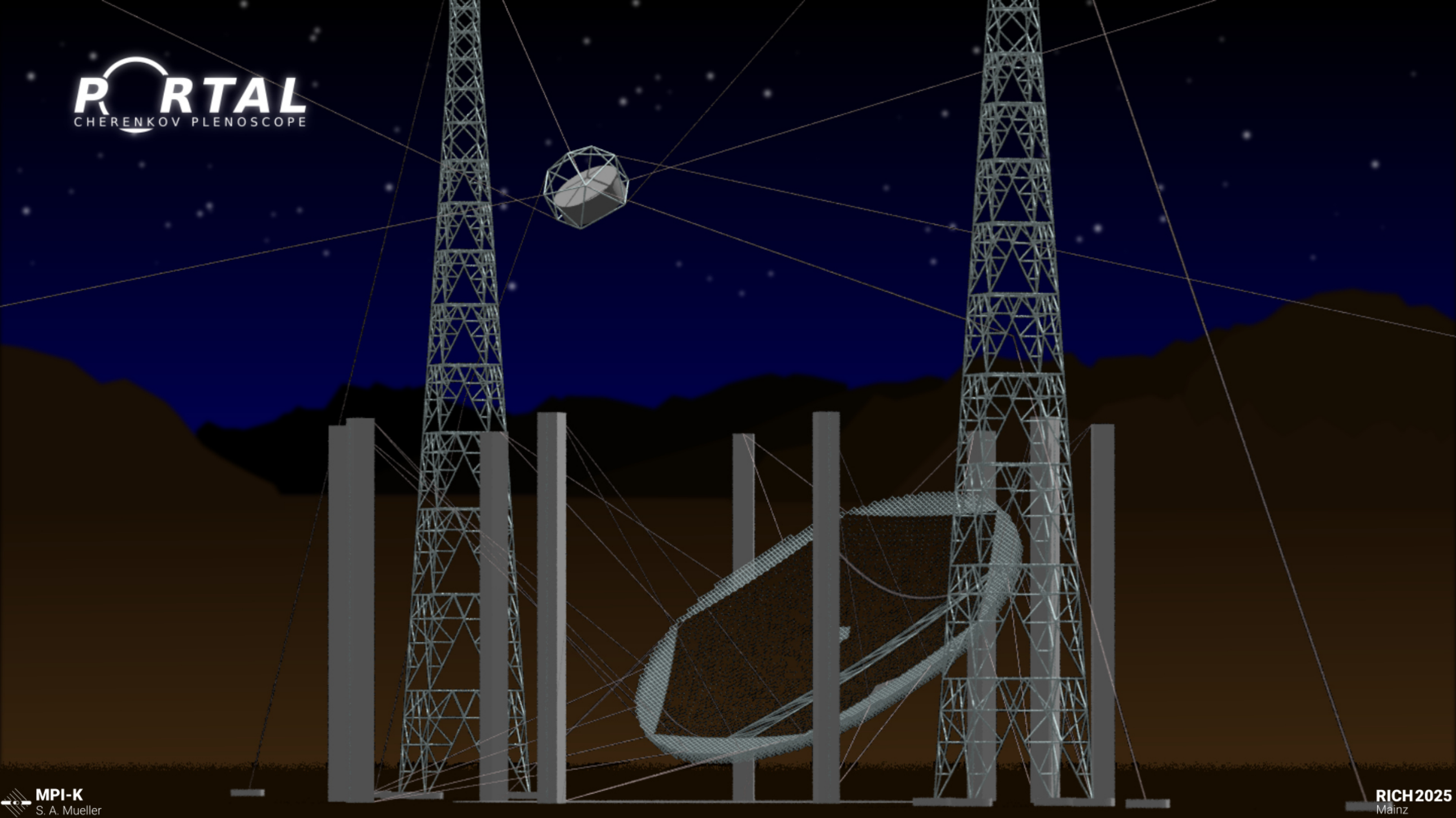
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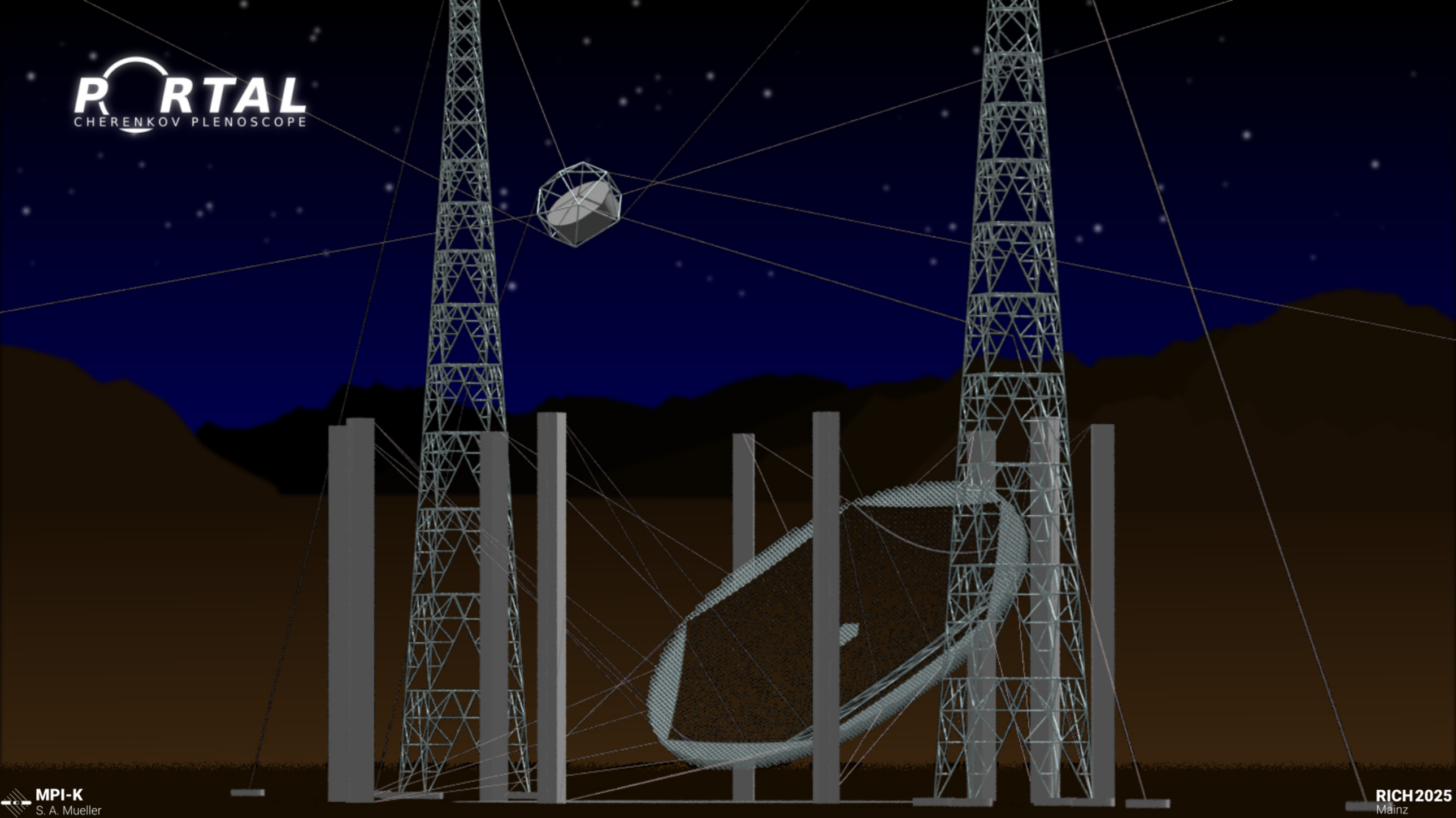
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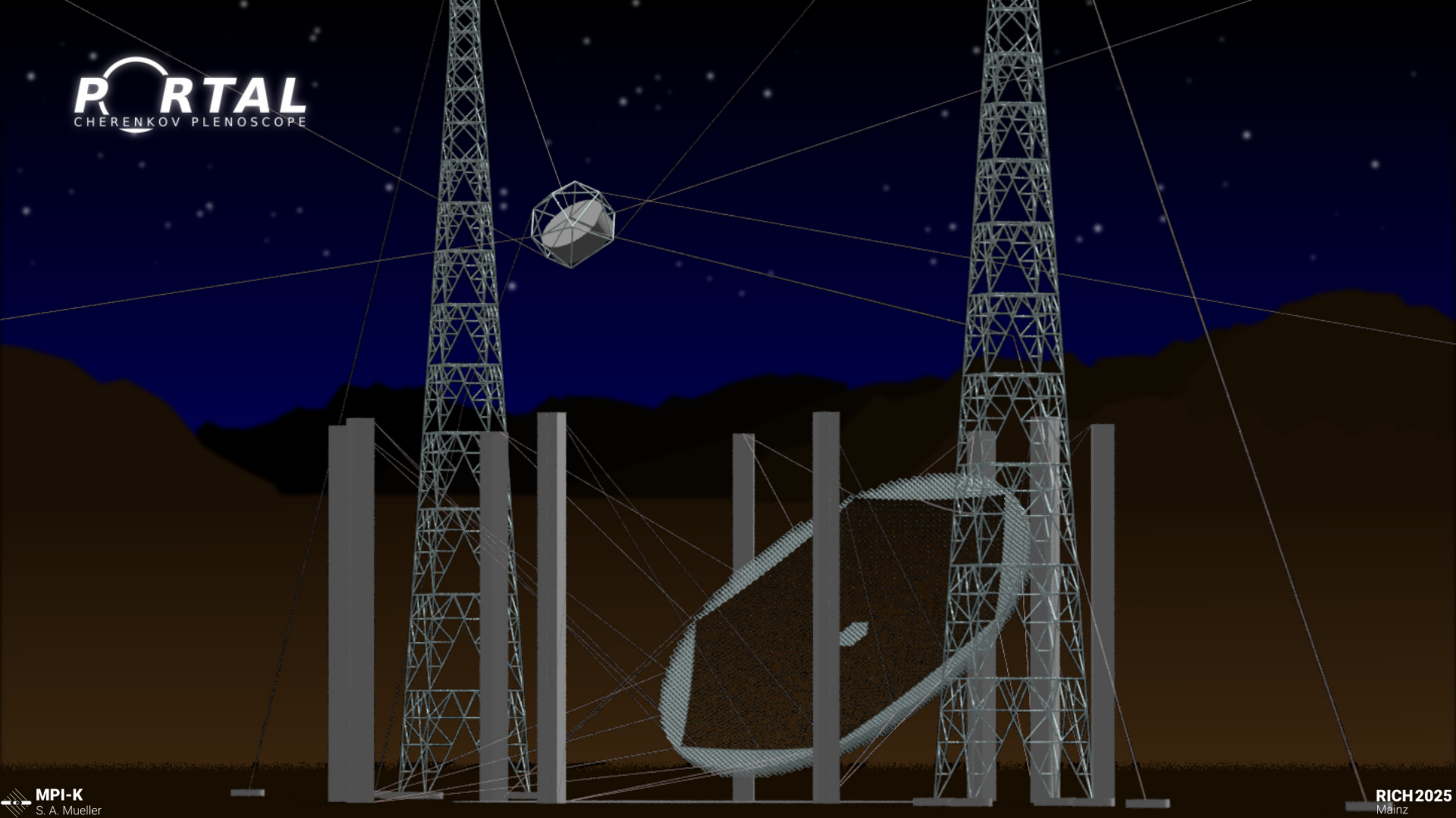
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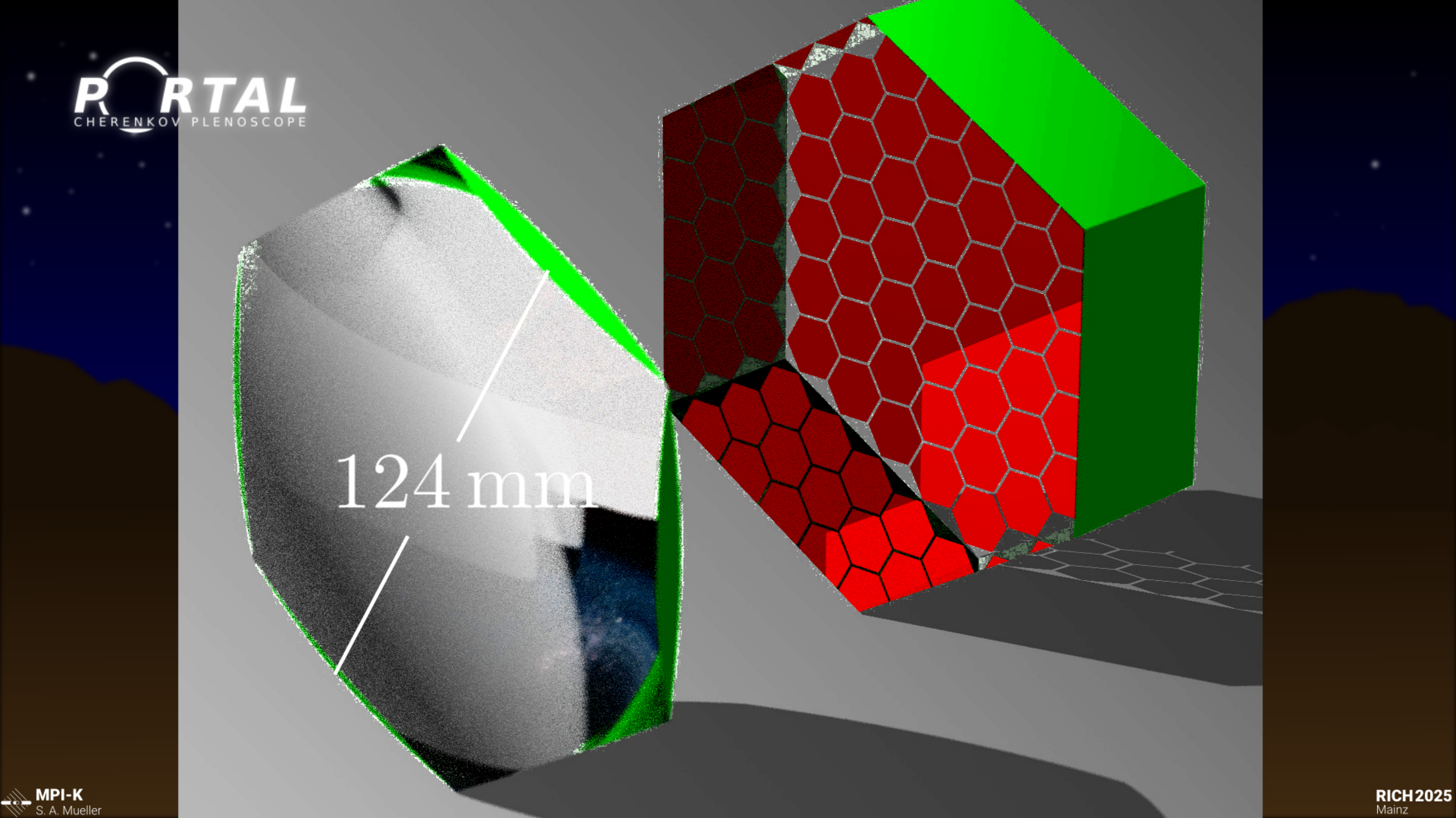

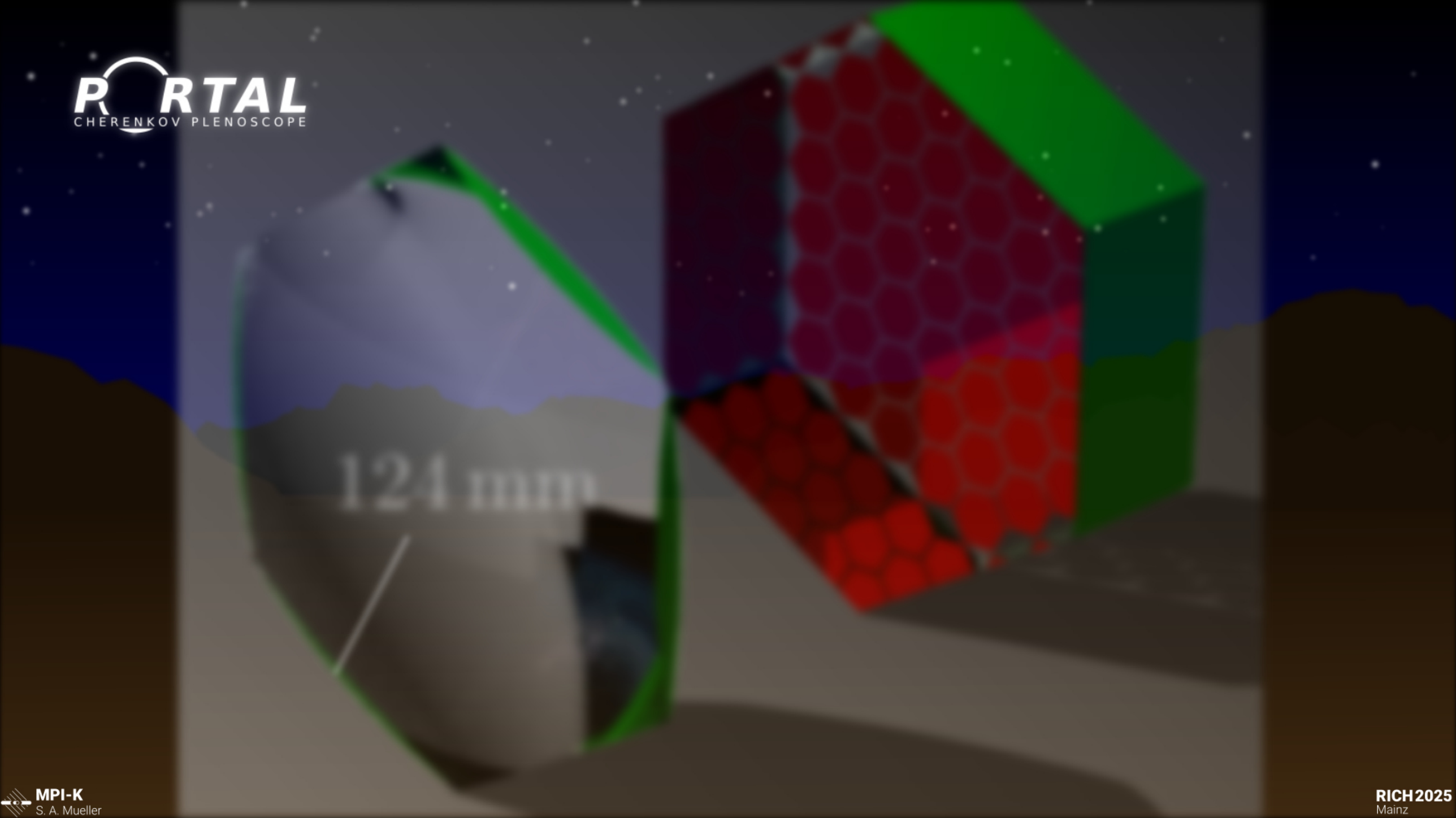
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PORTAL
CHERENKOV PLENOSCOPE

PORTAL

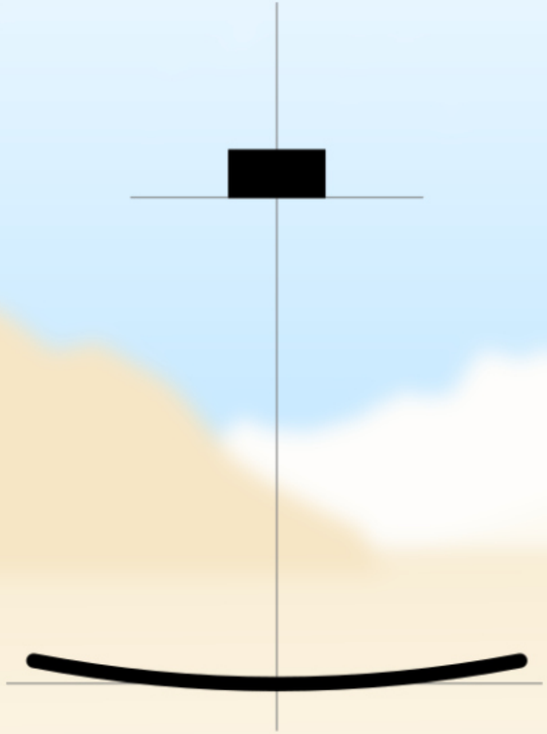
Optics

Optics

cameras

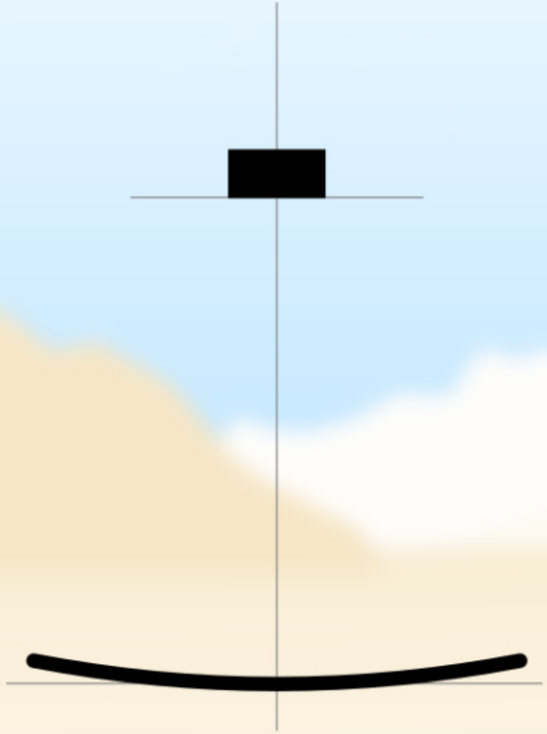
Optics

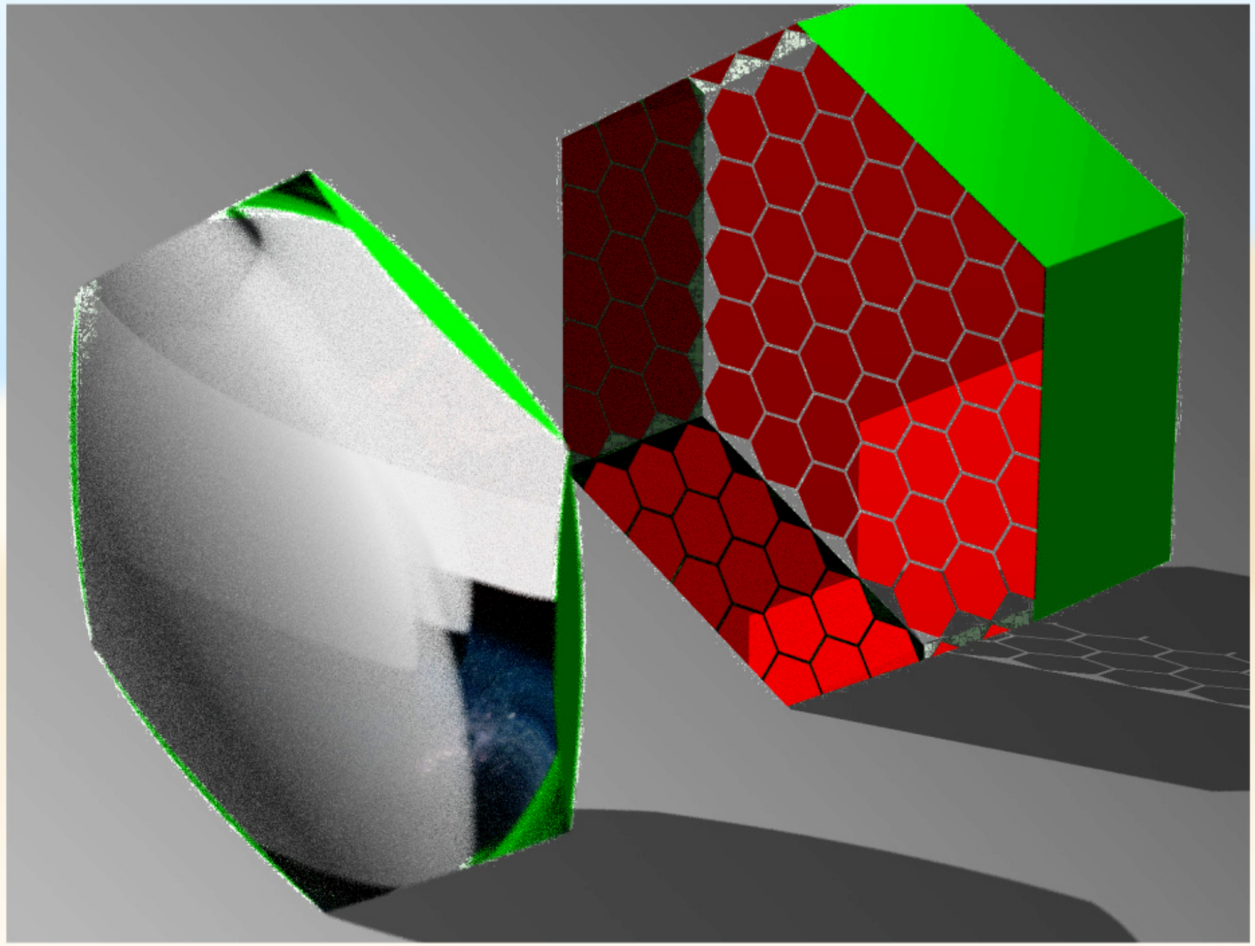
cameras



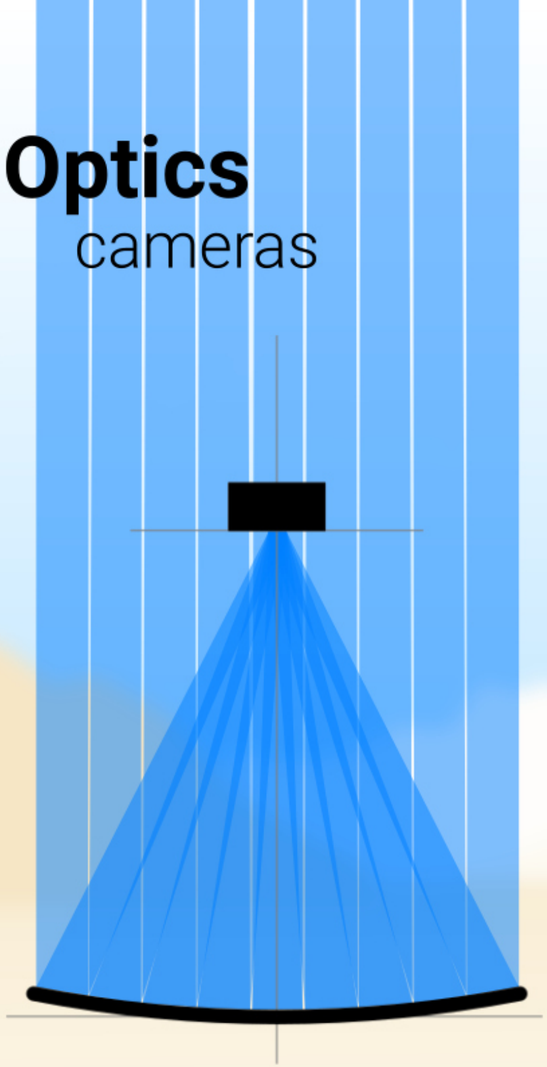
Optics

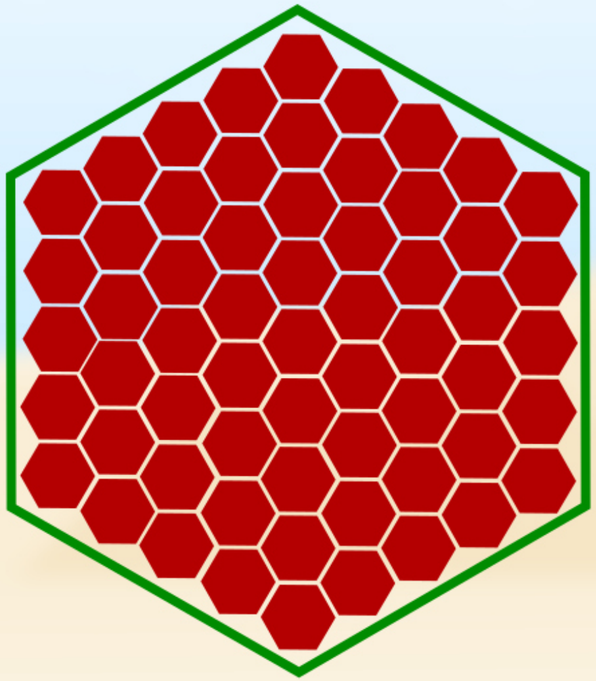
cameras





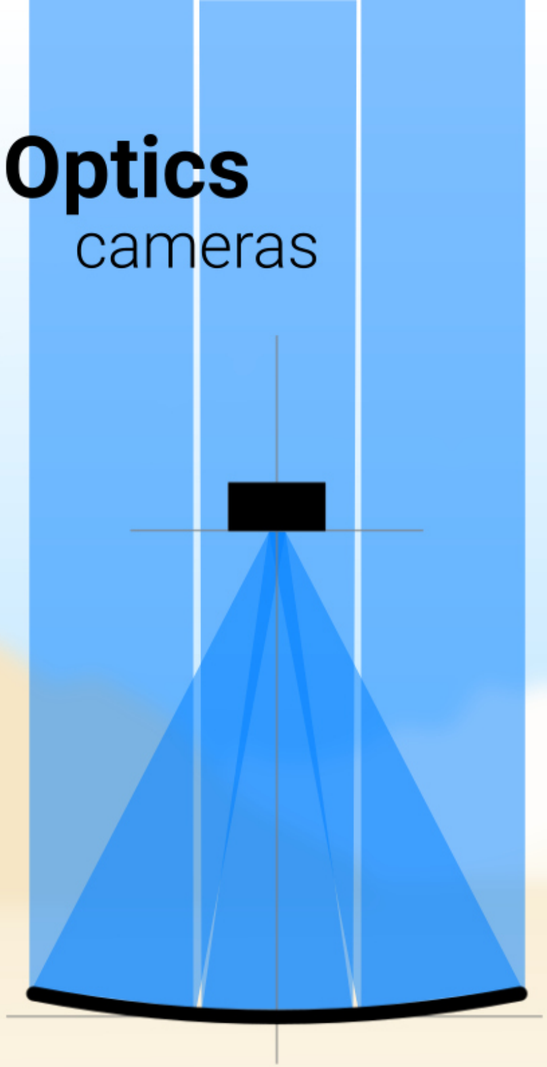
Optics
cameras

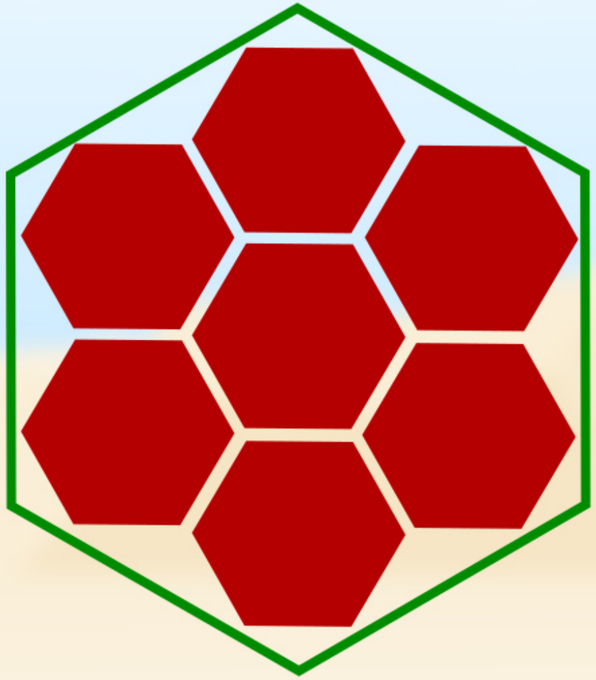




61 impact positions / mirror
(plenoscope)

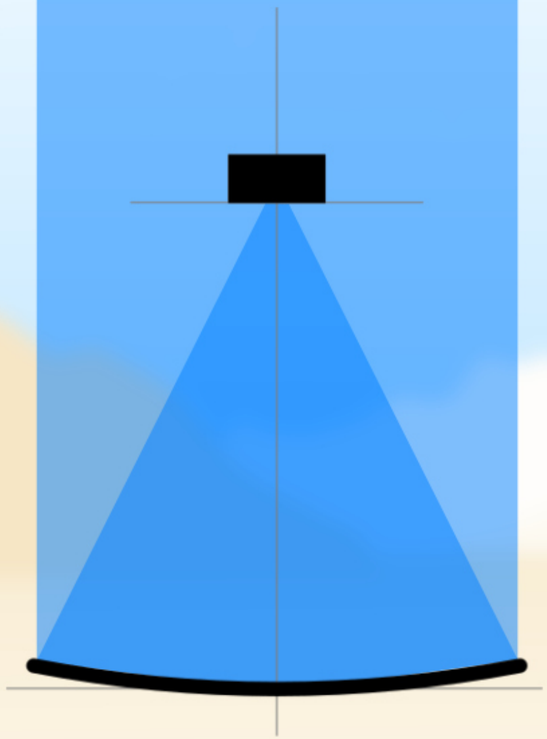
Optics
cameras

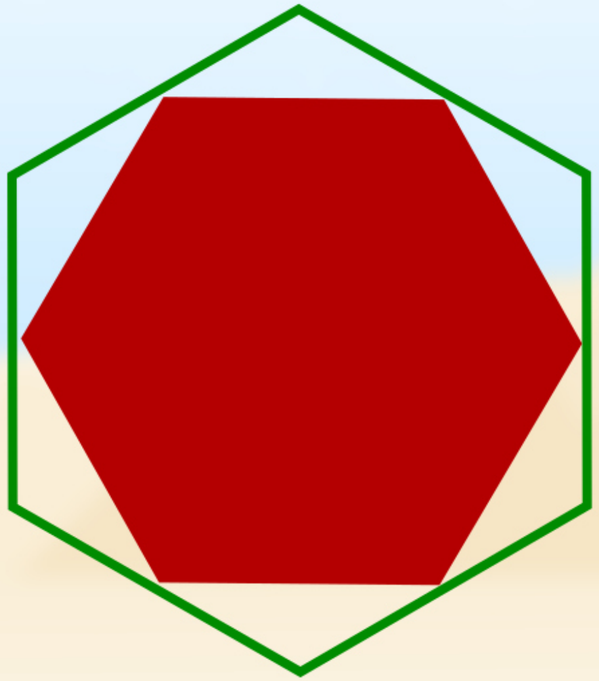




7 impact positions / mirror
(plenoscope)

Optics
cameras

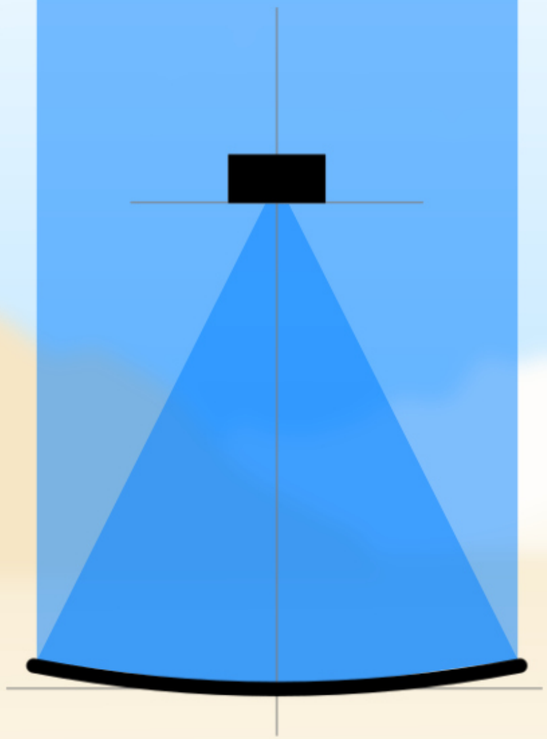


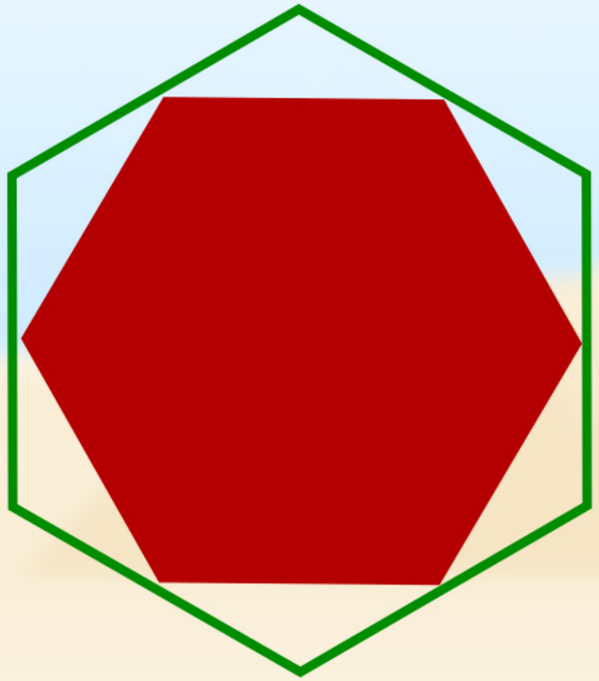


1 impact position / mirror
(telescope)

Optics

cameras

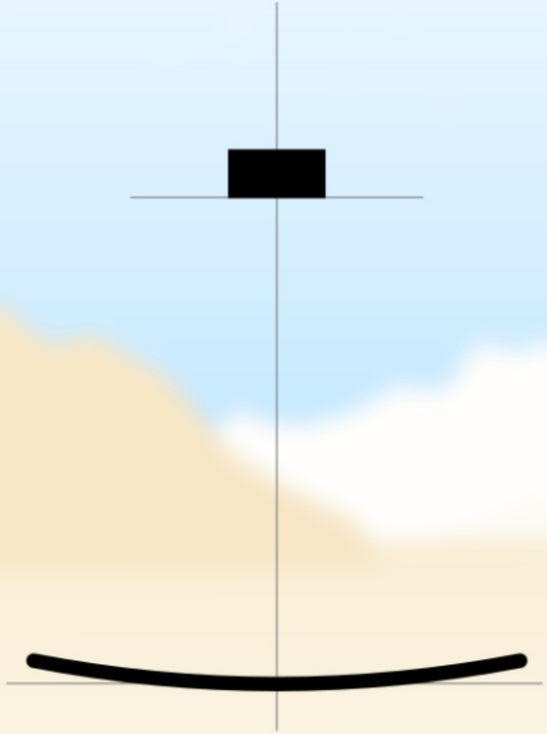




1 impact position / mirror
(telescope)

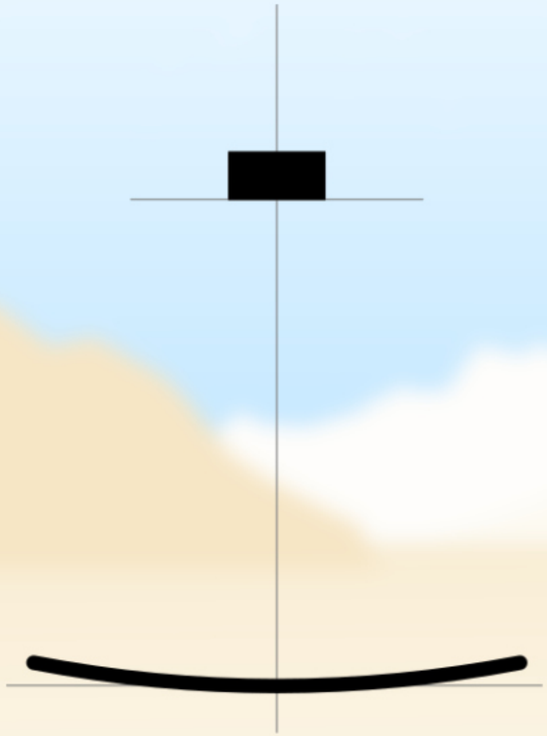
Optics

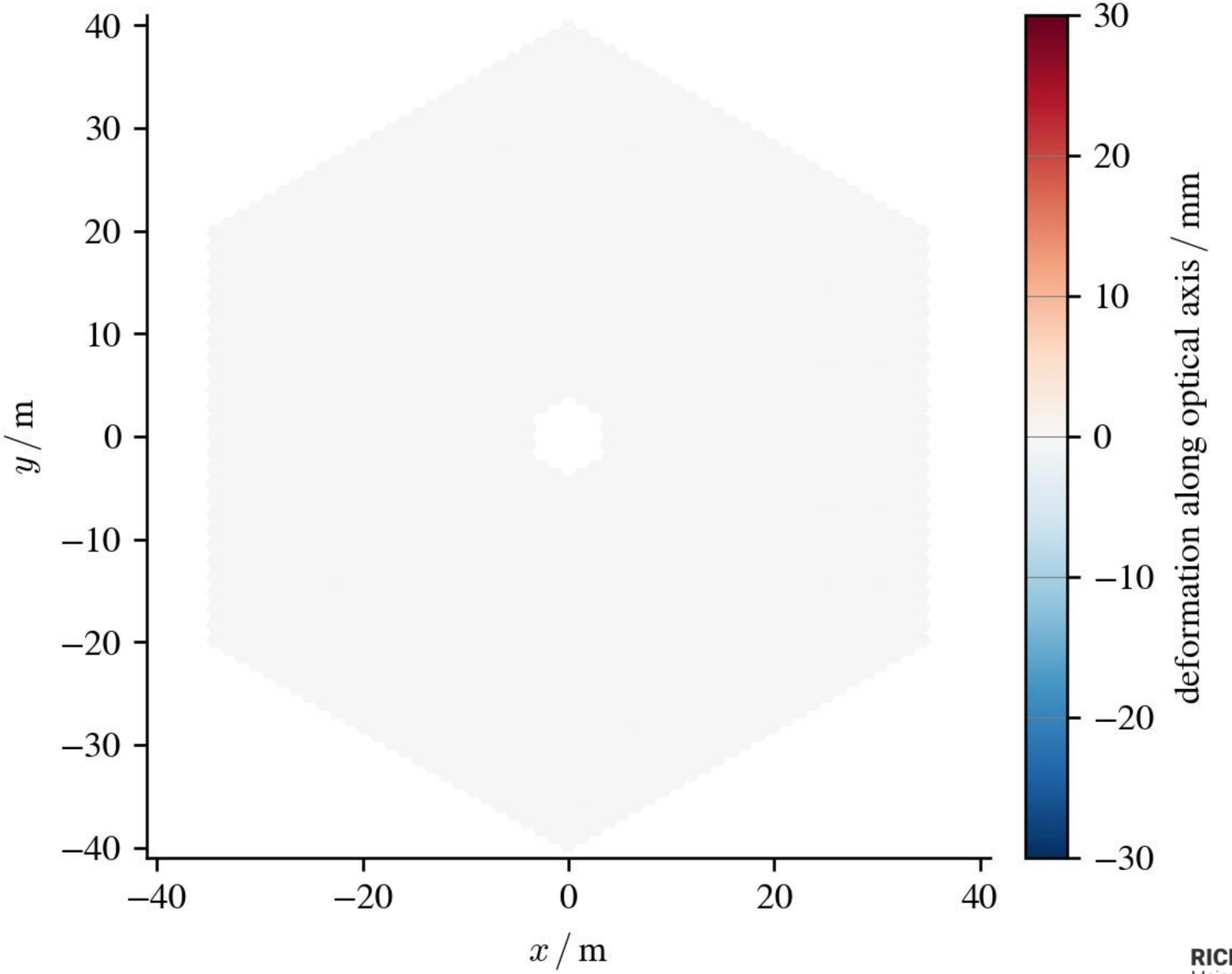
mirror deformations



Optics

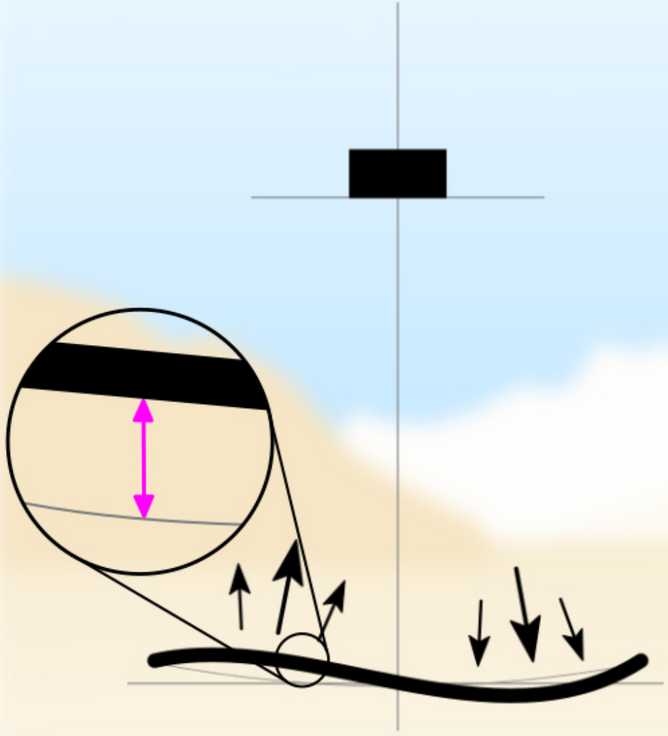
mirror deformations

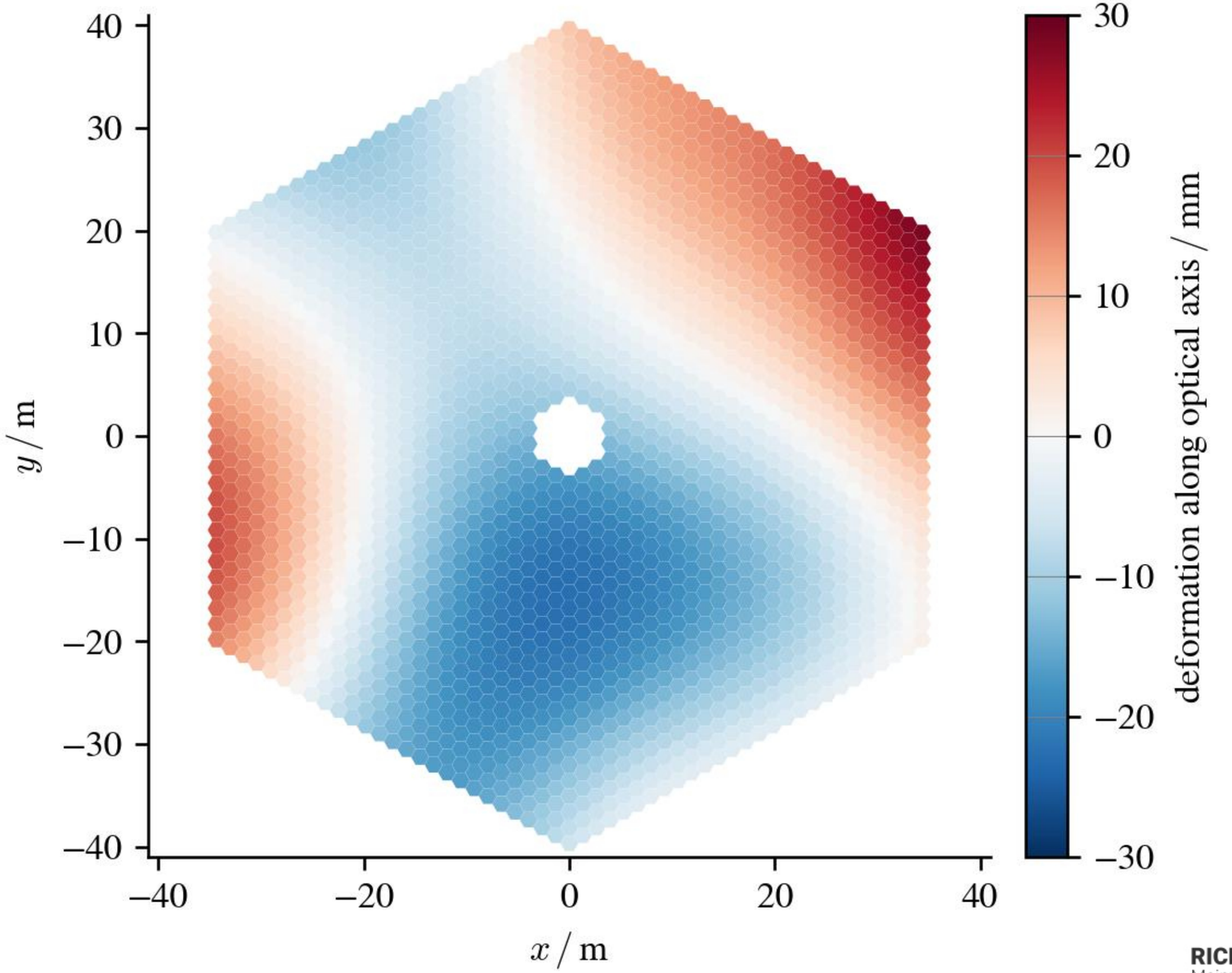




Optics

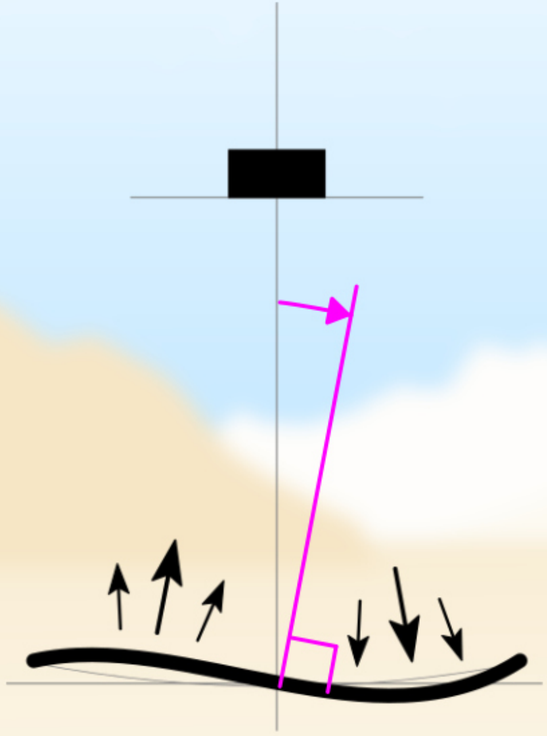
mirror deformations

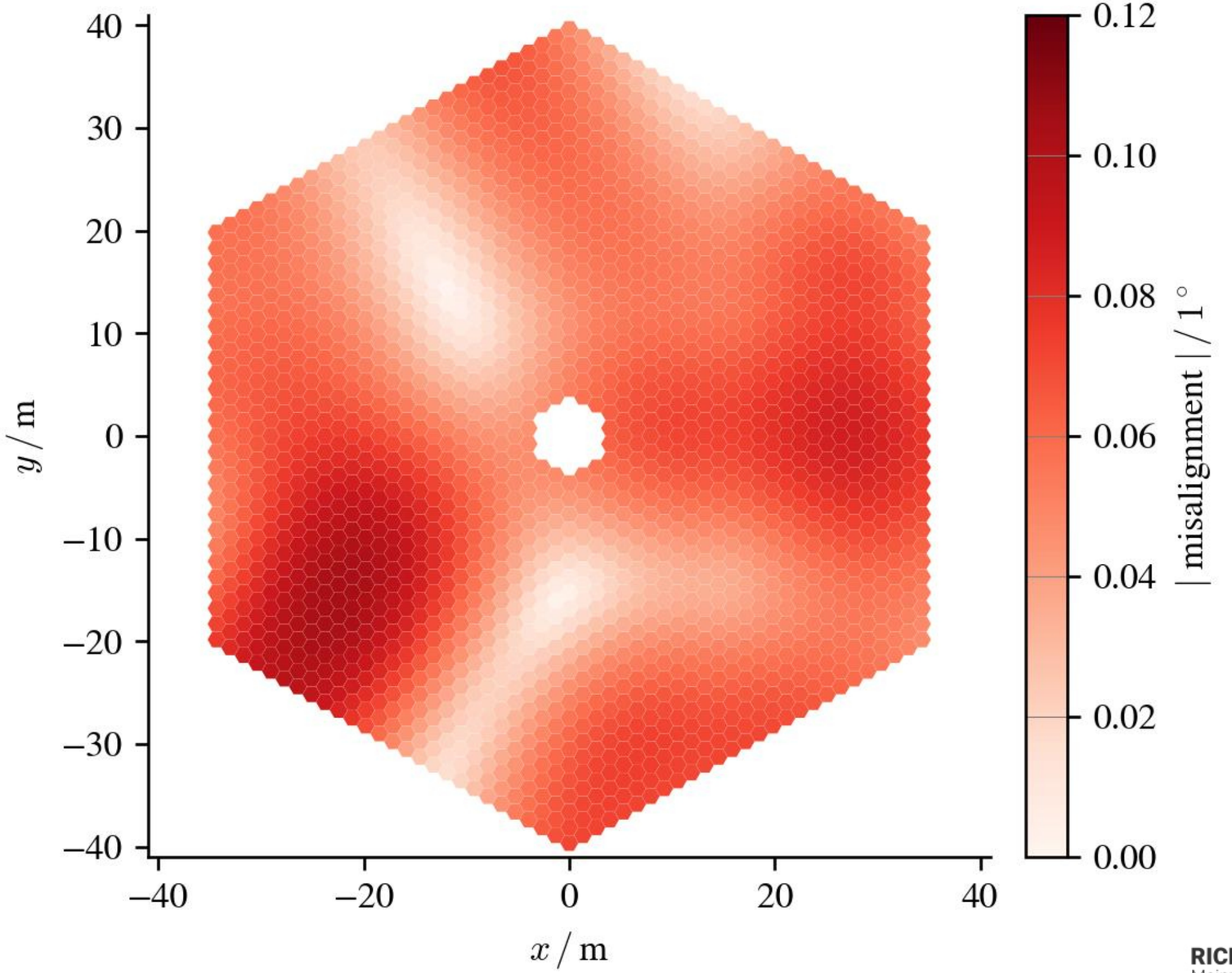




Optics

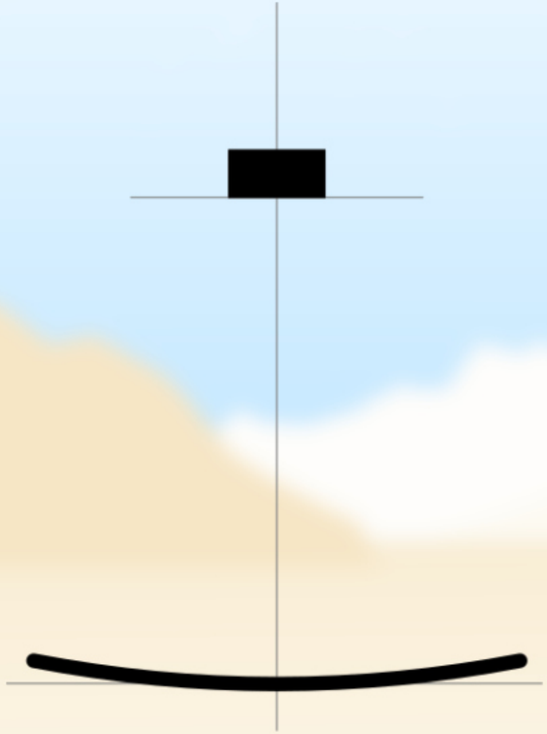
mirror deformations





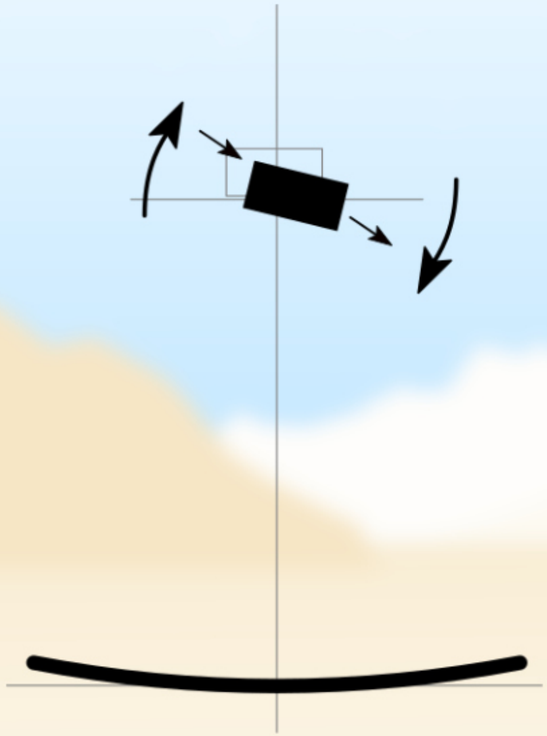
Optics

camera misalignment



Optics

camera misalignment

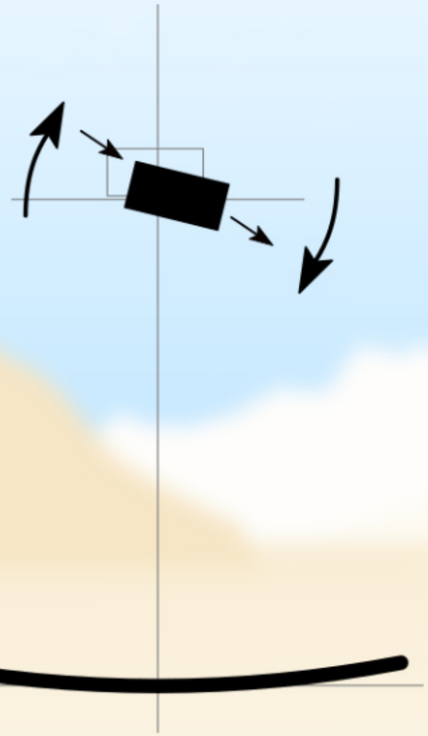


$$
\begin{aligned}
\text{Tait-Bryan-}xyz &= (1.0,\ 3.0,\ 5.0)^\circ \\
\text{translation-}xyz &= (-100,\ 200,\ -532.5)\,\text{mm} \\
&= (-0.1,\ 0.2,\ -0.5)\%f
\end{aligned}
$$

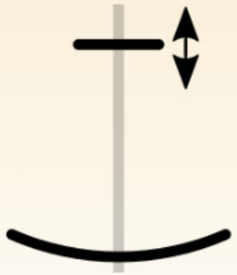
P1 P7 P61

Optics

camera misalignment



$$\begin{aligned} \text{Tait-Bryan-}xyz &= (1.0,\, 3.0,\, 5.0)^\circ \\ \text{translation-}xyz &= (-100,\, 200,\, -532.5)\,\text{mm} \\ &= (-0.1,\, 0.2,\, -0.5)\%f \end{aligned}$$

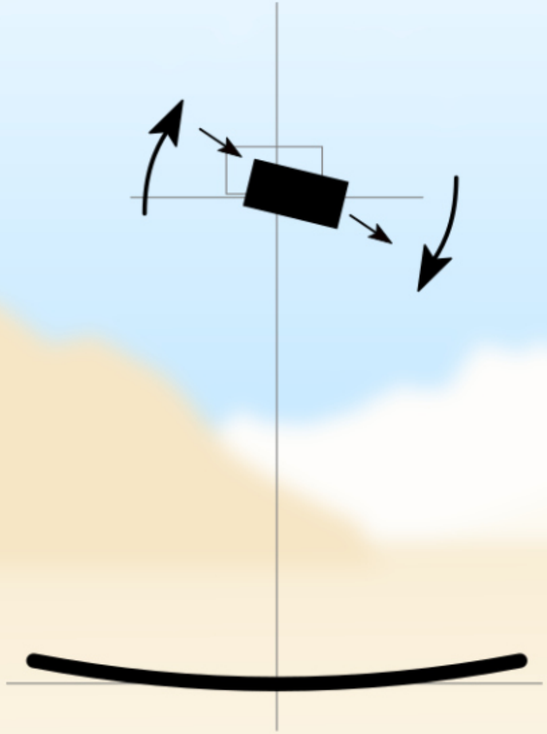


$$g = 10.0\,\text{km} \rightarrow g \approx 18.6\,\text{km}$$

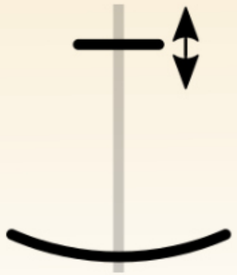
P1 P7 P61

Optics

camera misalignment



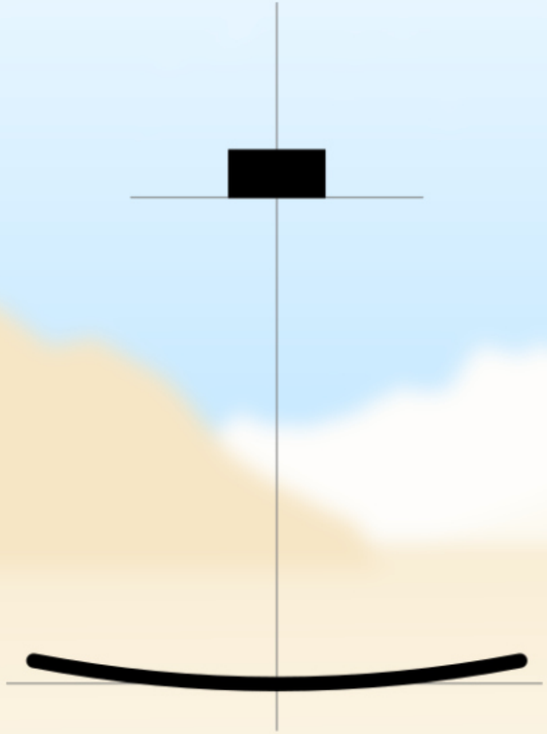
$$\begin{aligned} \text{Tait-Bryan-}xyz &= (1.0,\, 3.0,\, 5.0)^\circ \\ \text{translation-}xyz &= (-100,\, 200,\, -532.5)\,\text{mm} \\ &= (-0.1,\, 0.2,\, -0.5)\%f \end{aligned}$$



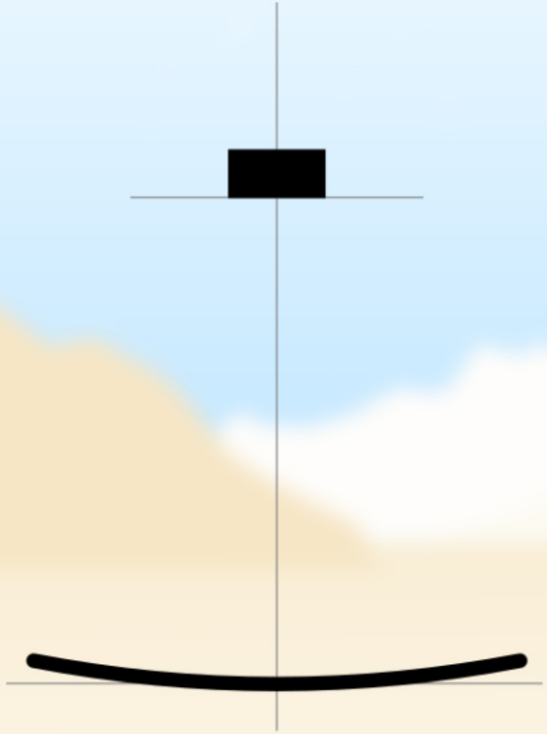
$$g = 10.0\,\text{km} \rightarrow g \approx 18.6\,\text{km}$$

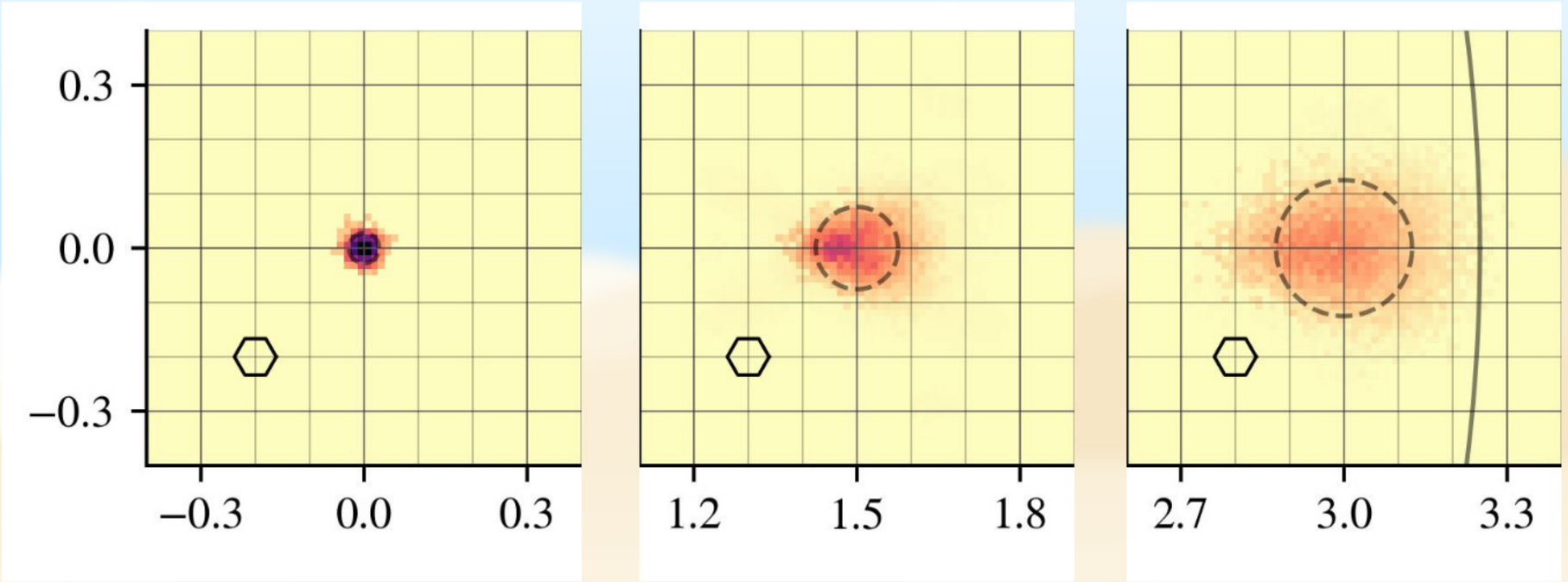
Optics

performance

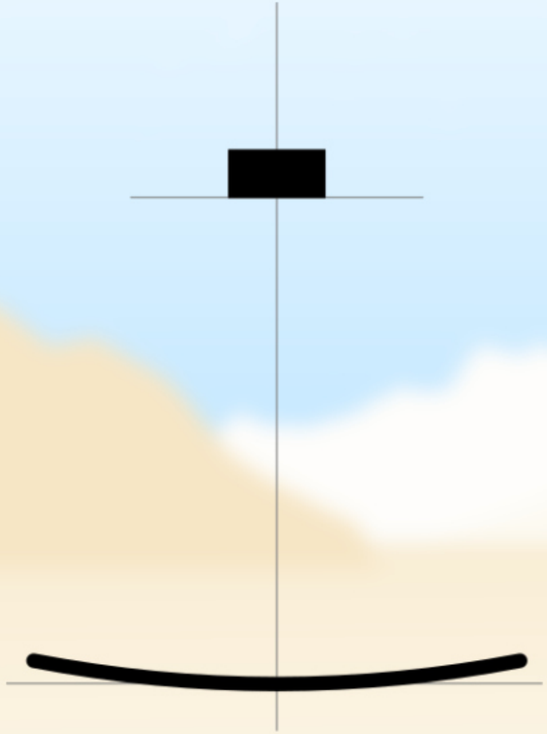


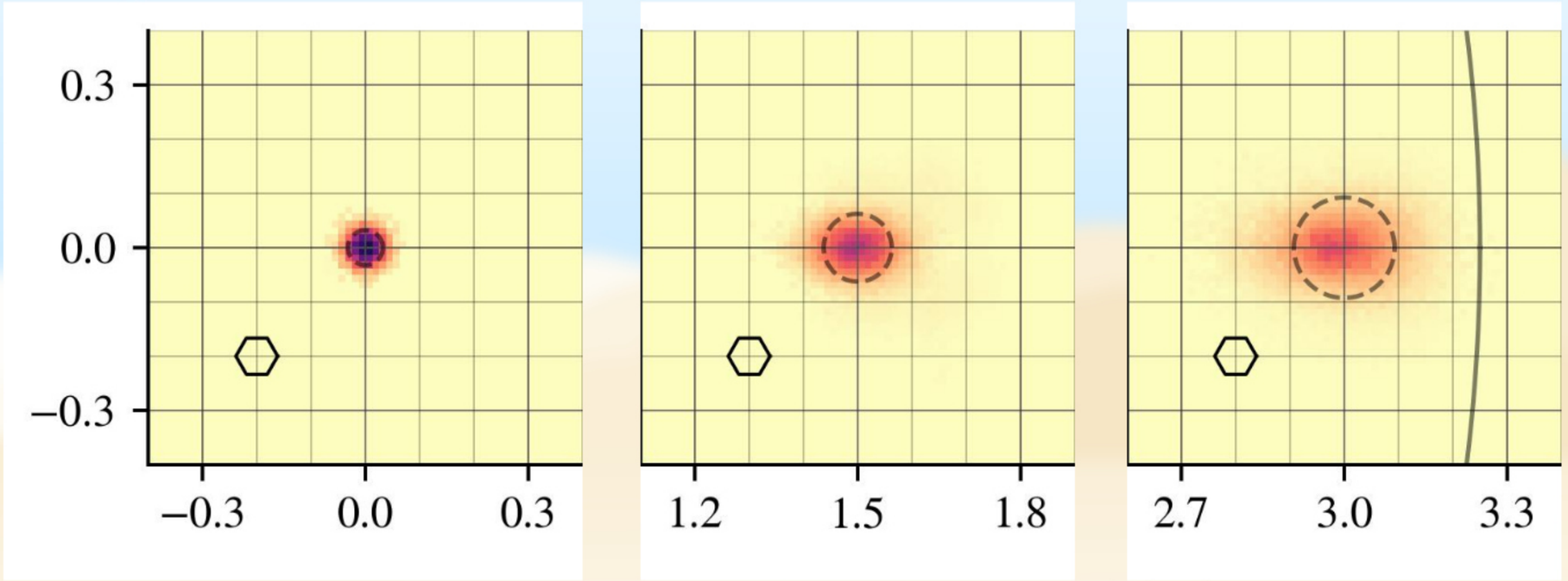
Optics
performance



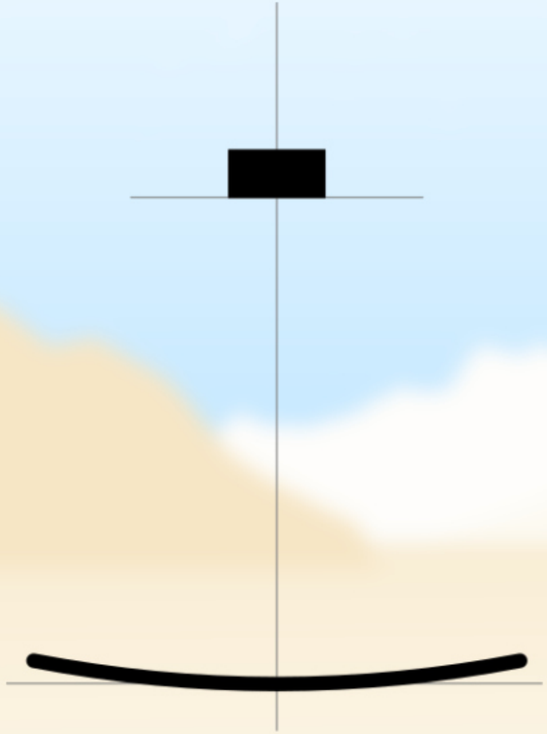


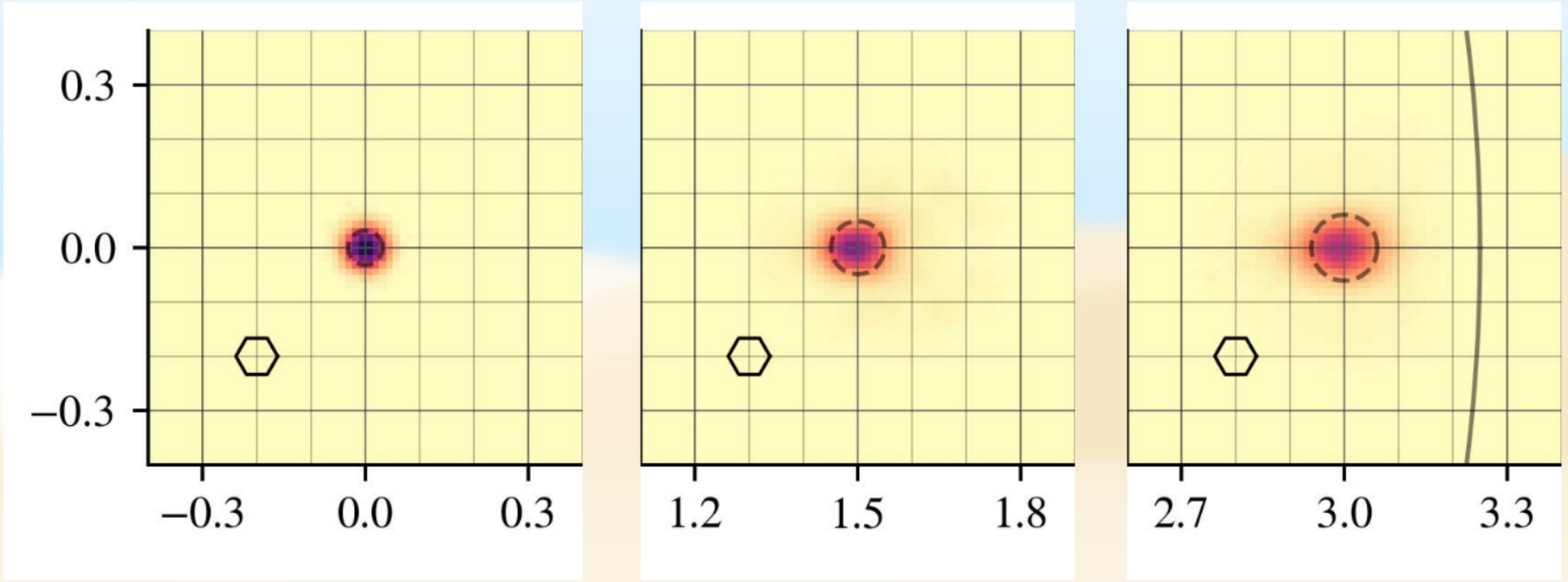
Optics
performance



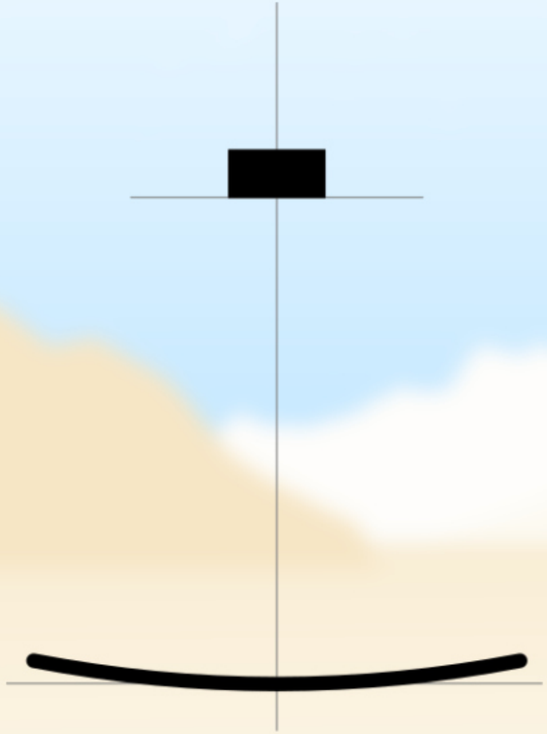


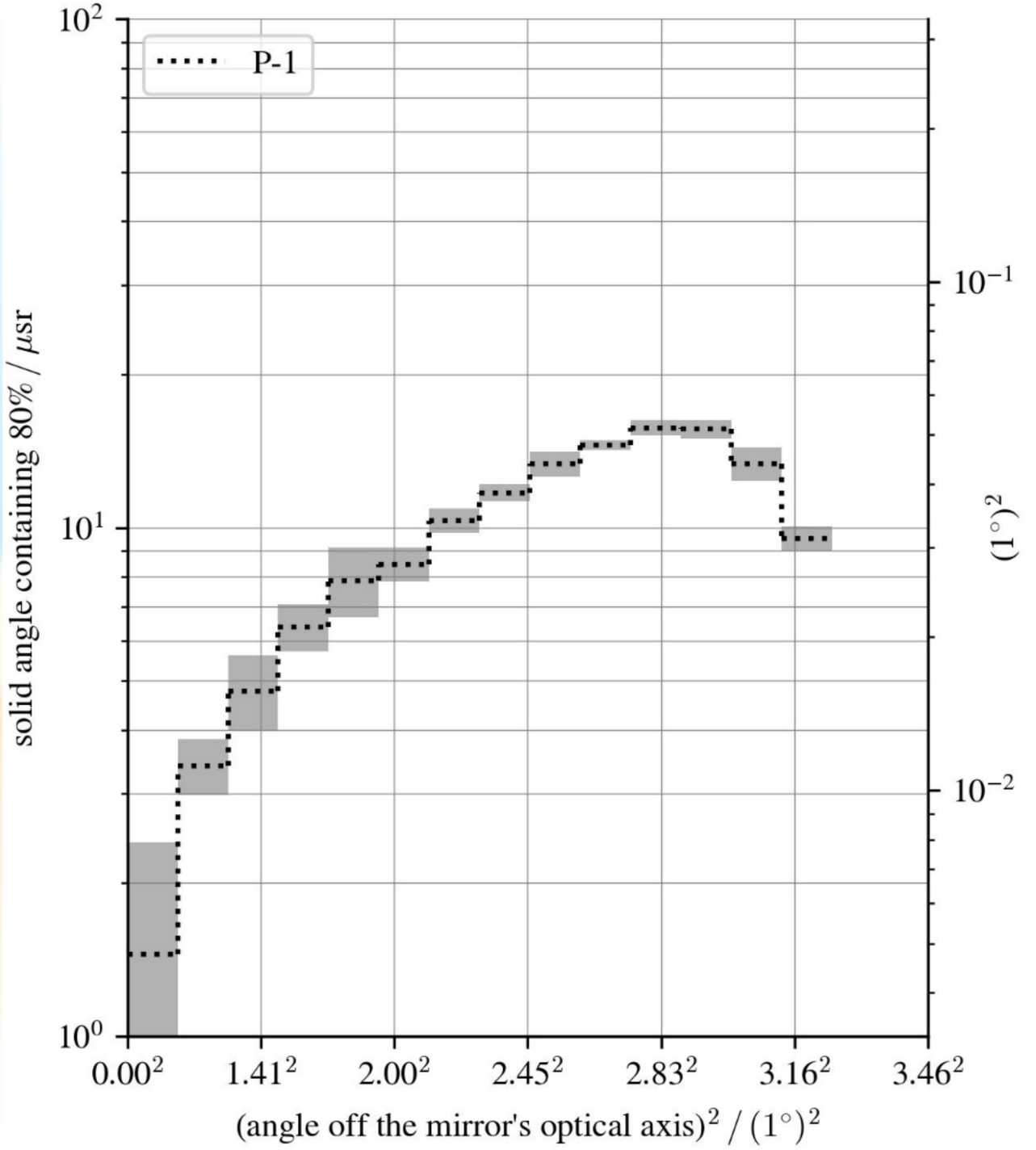
Optics
performance



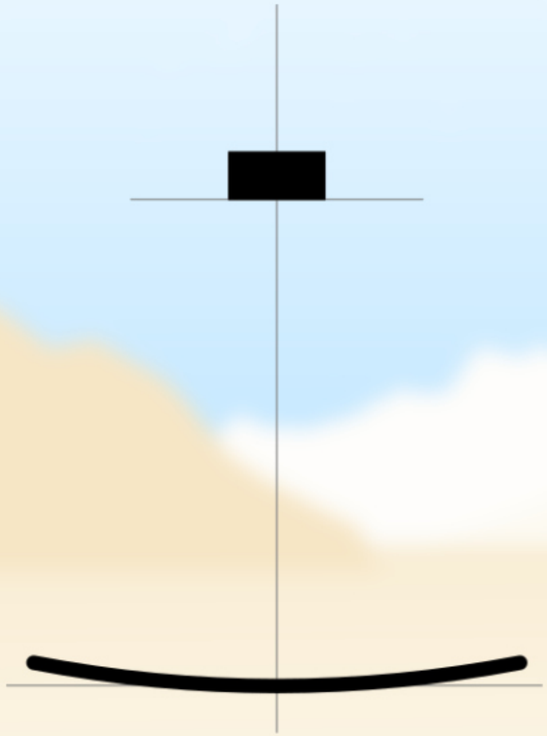


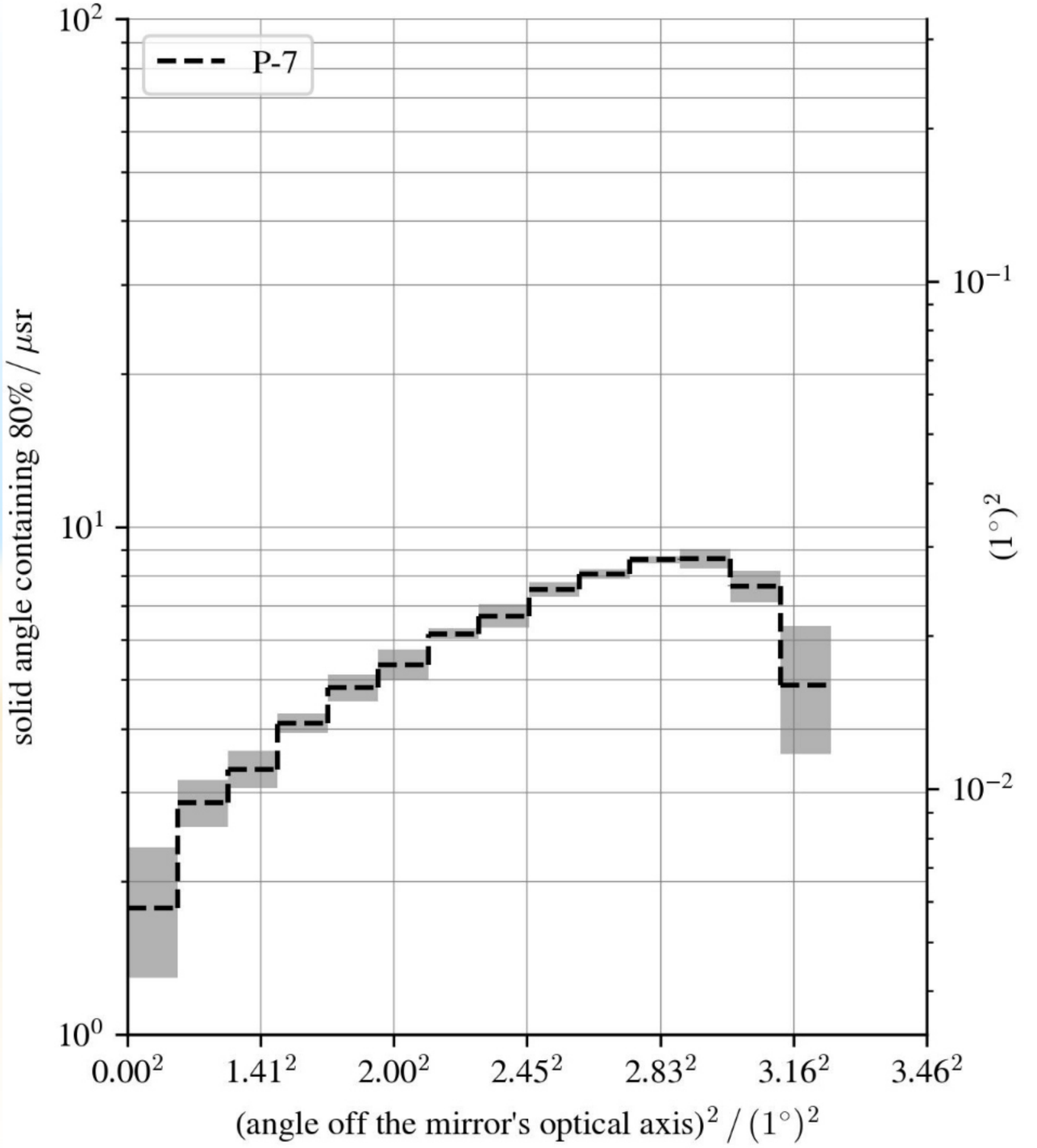
Optics
performance



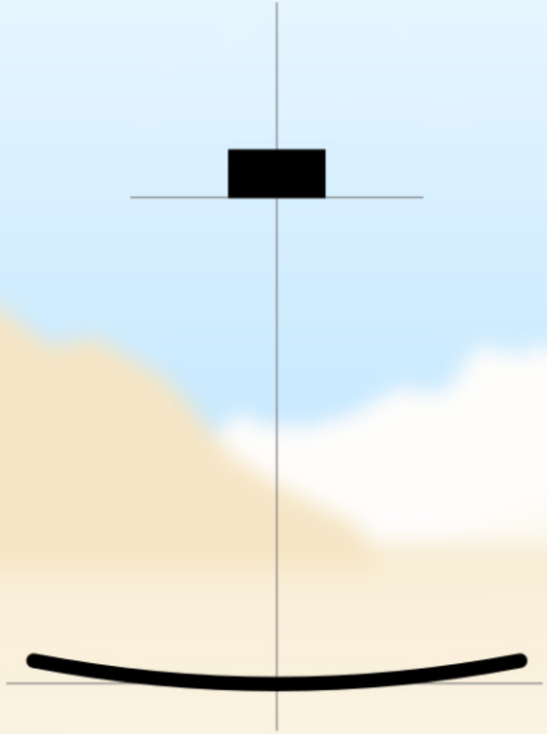


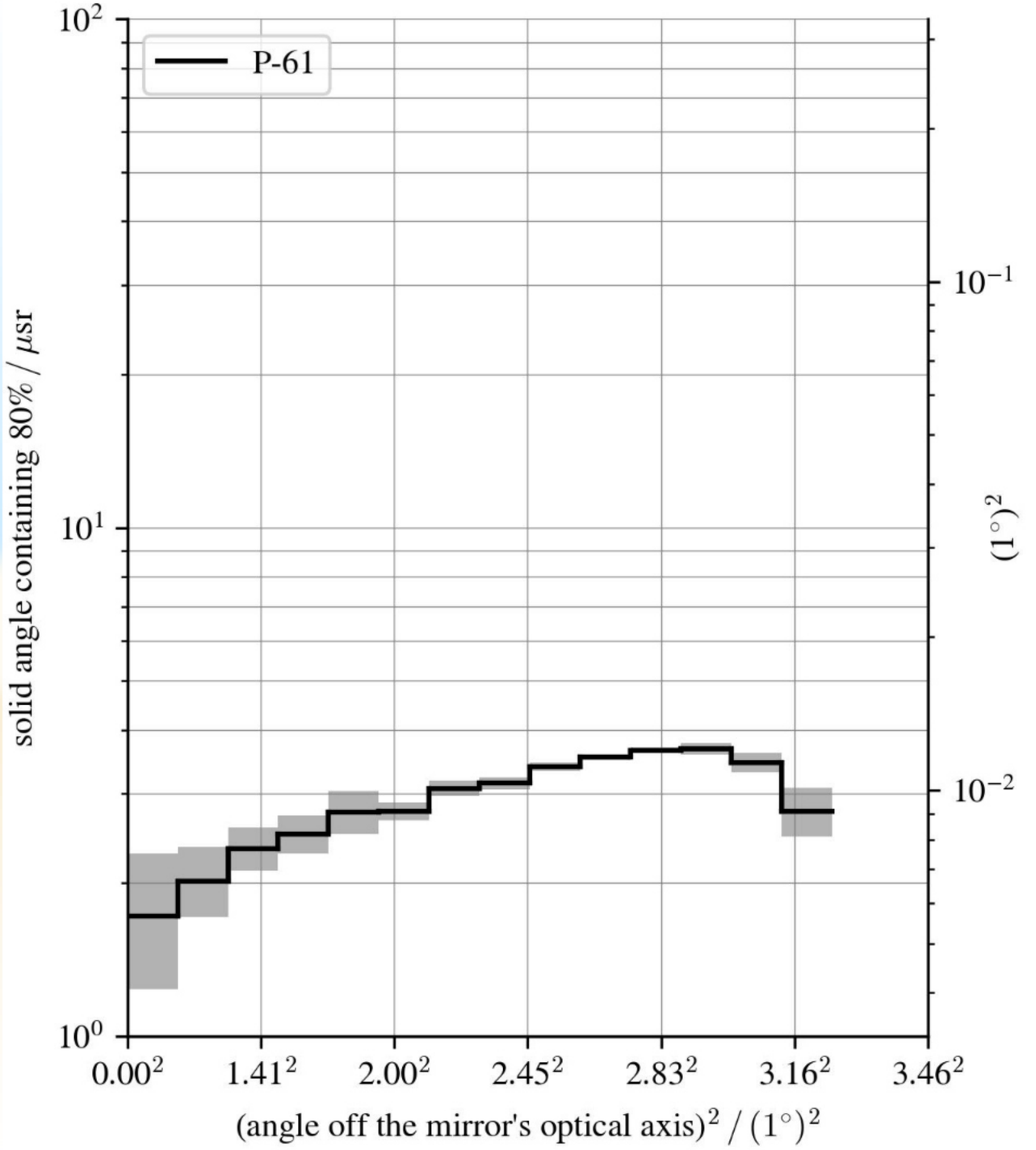
Optics
performance





Optics
performance





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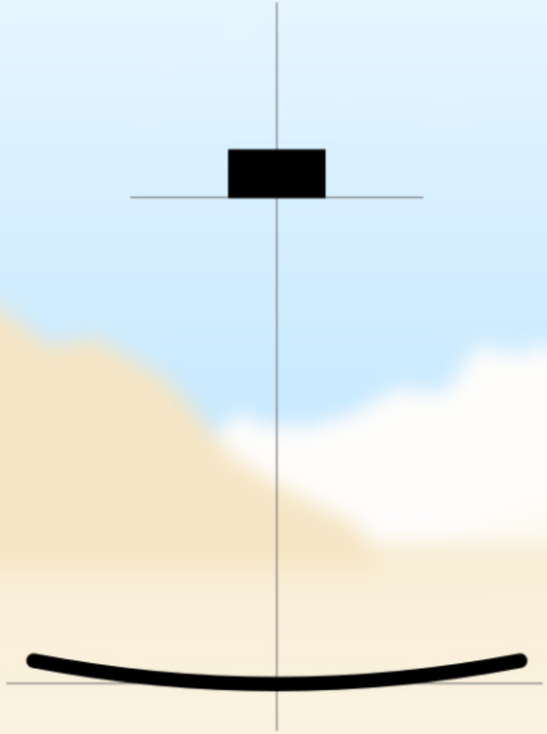

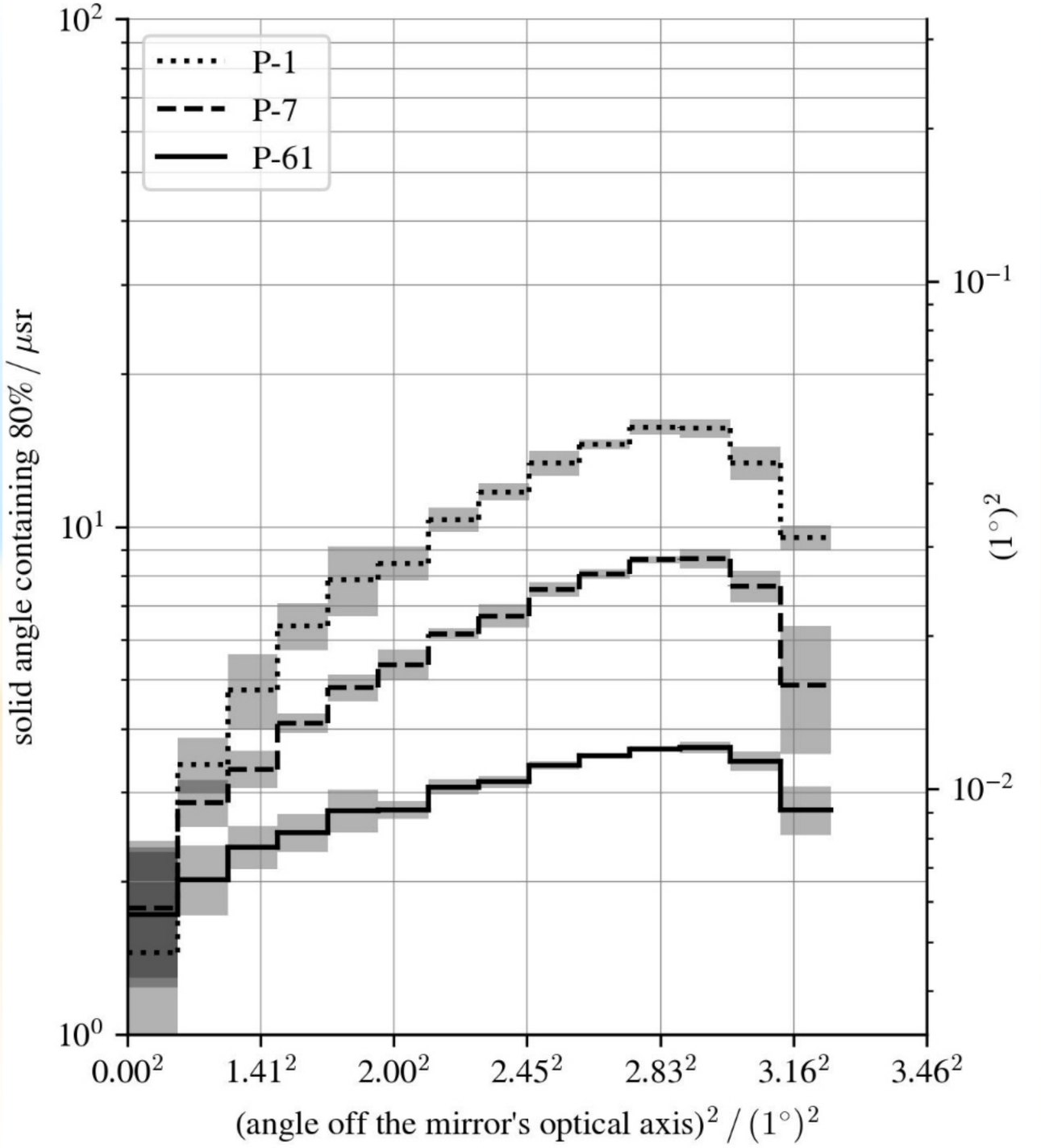

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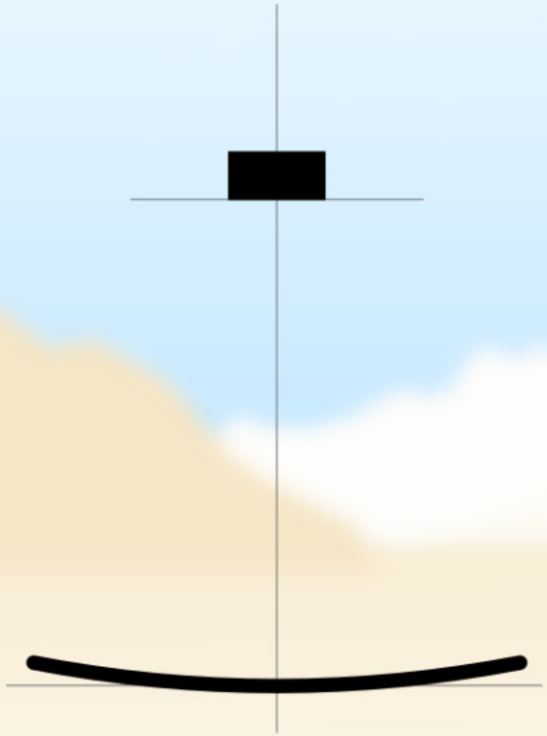

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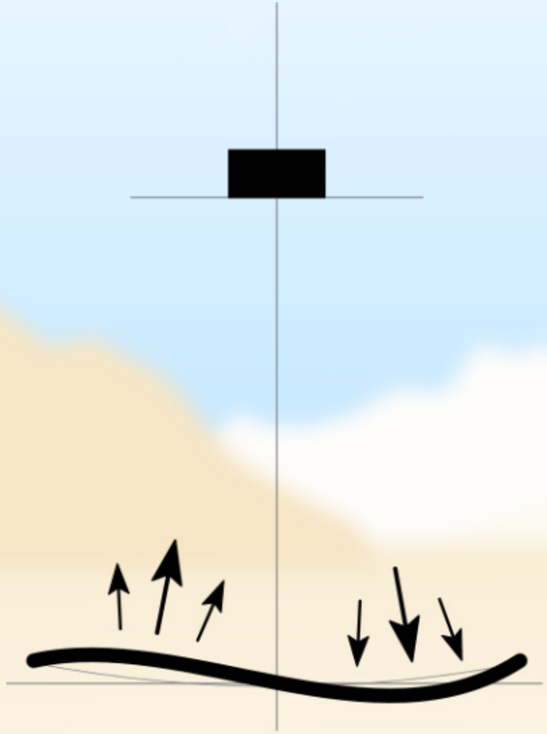

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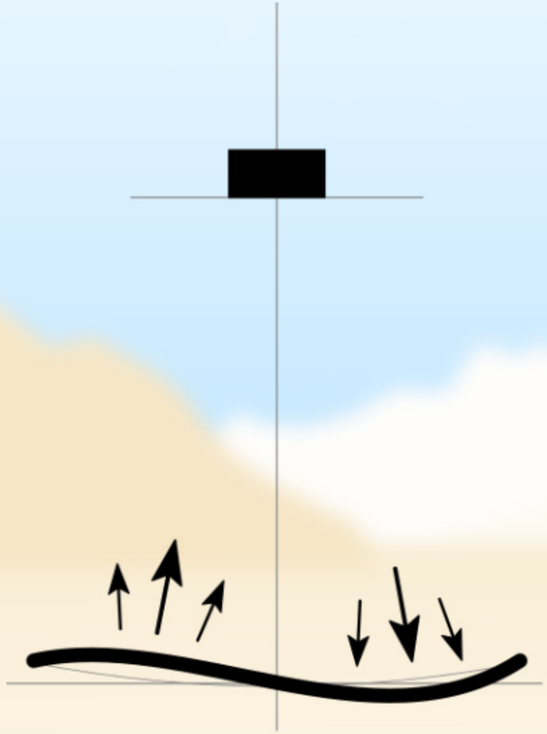

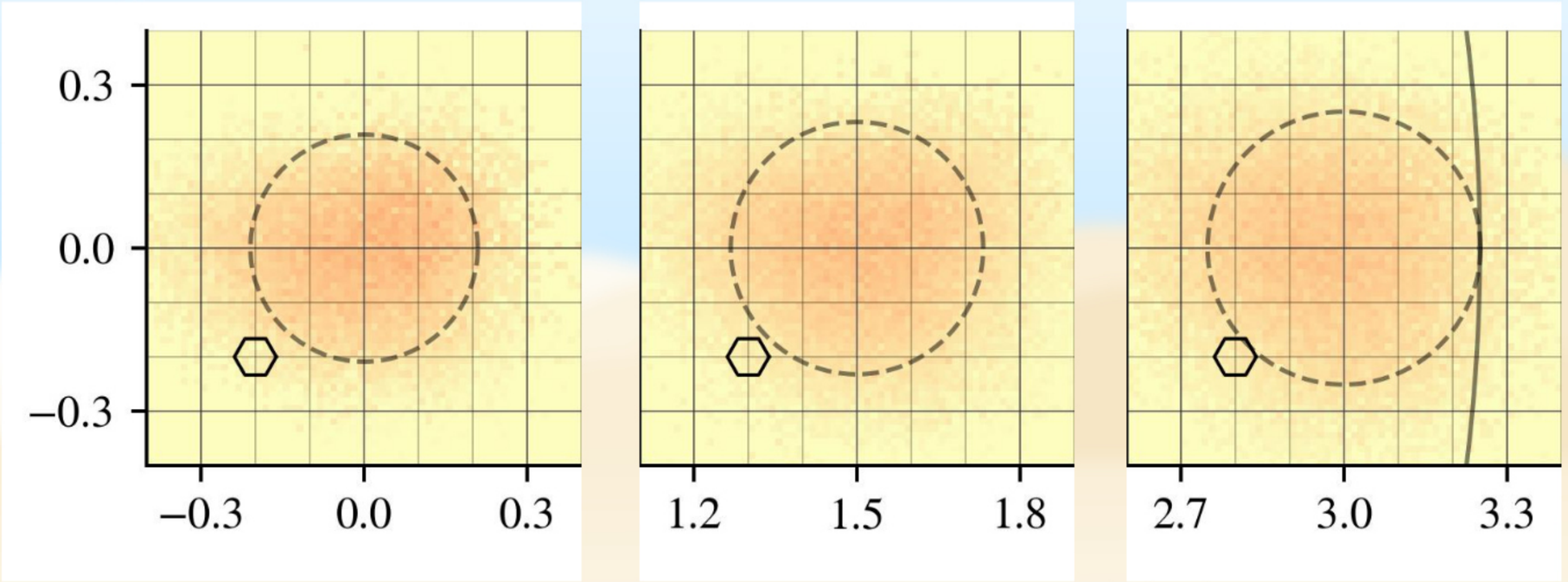

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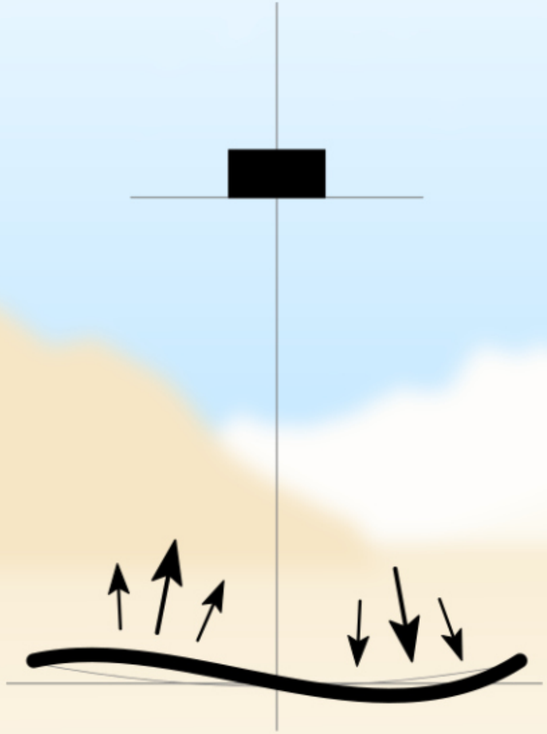

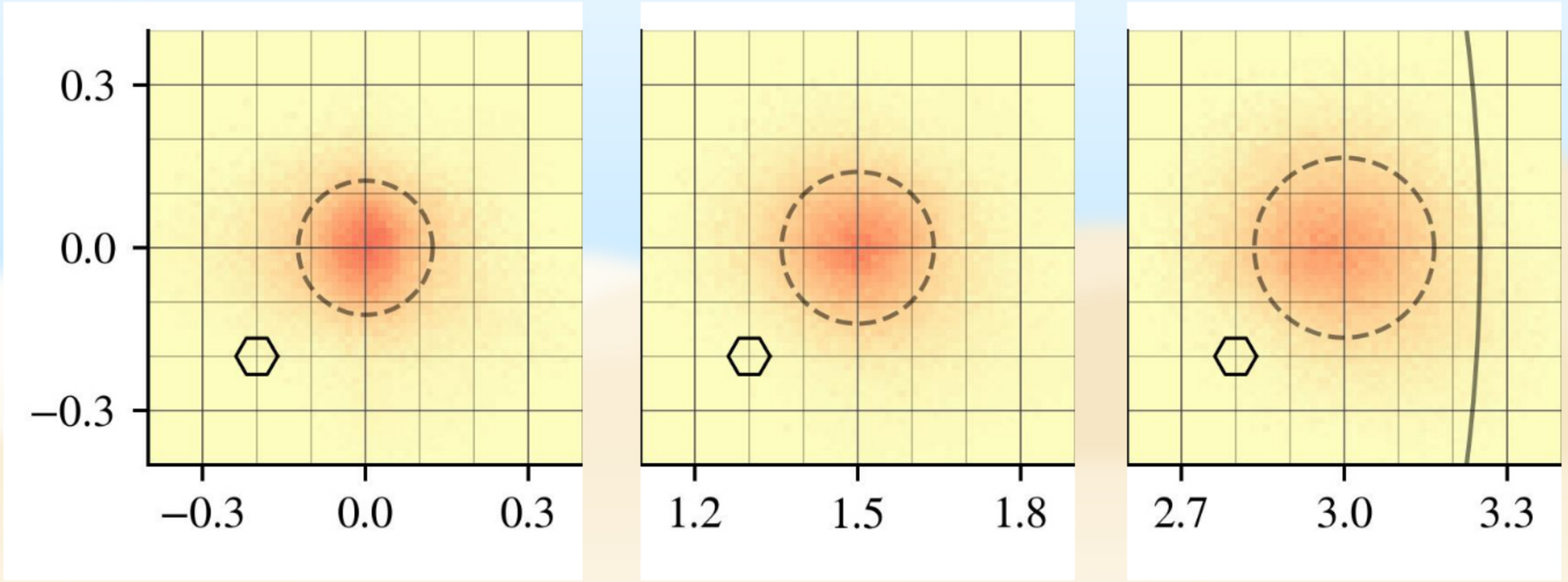

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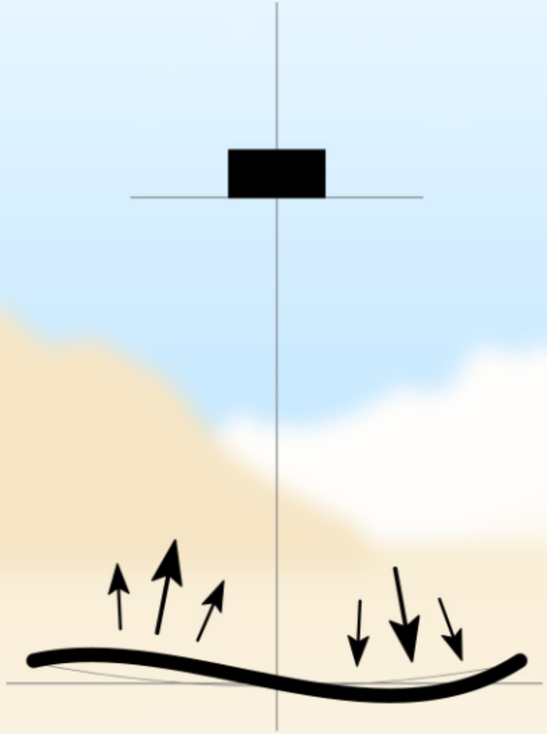

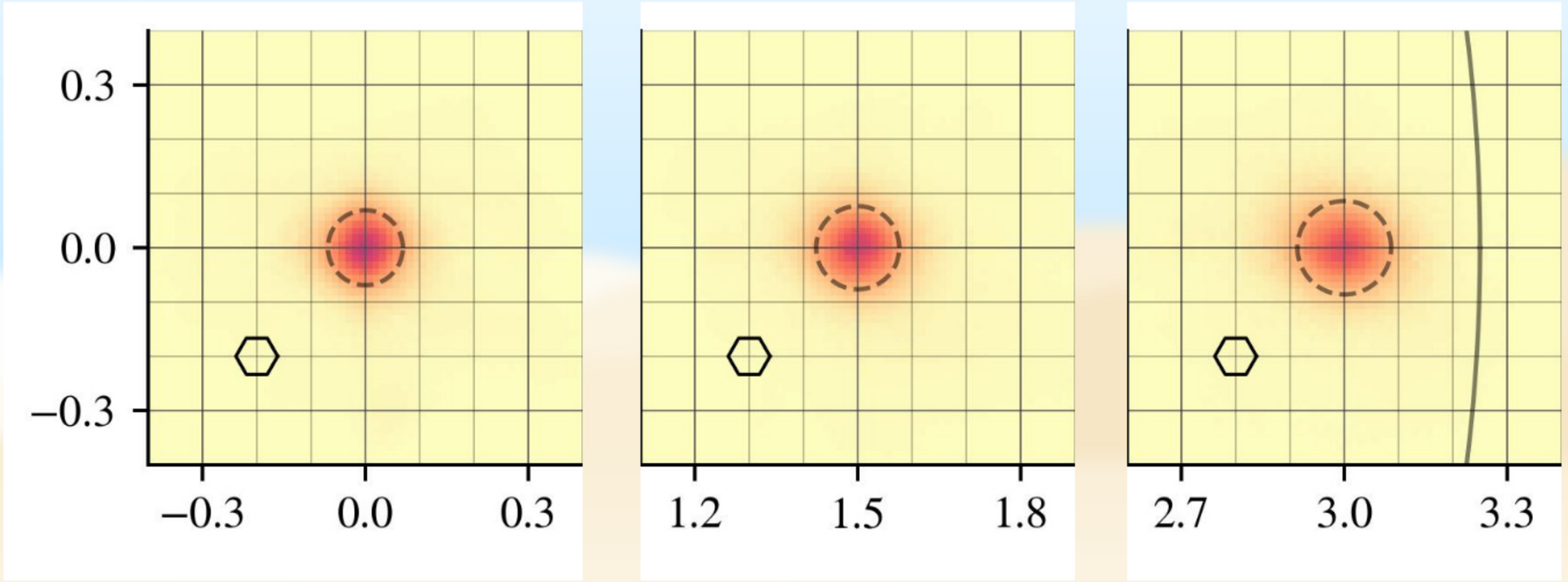

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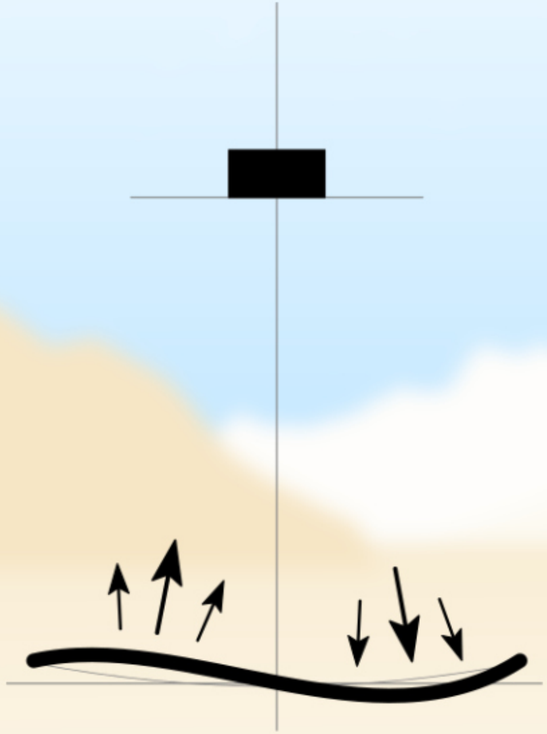

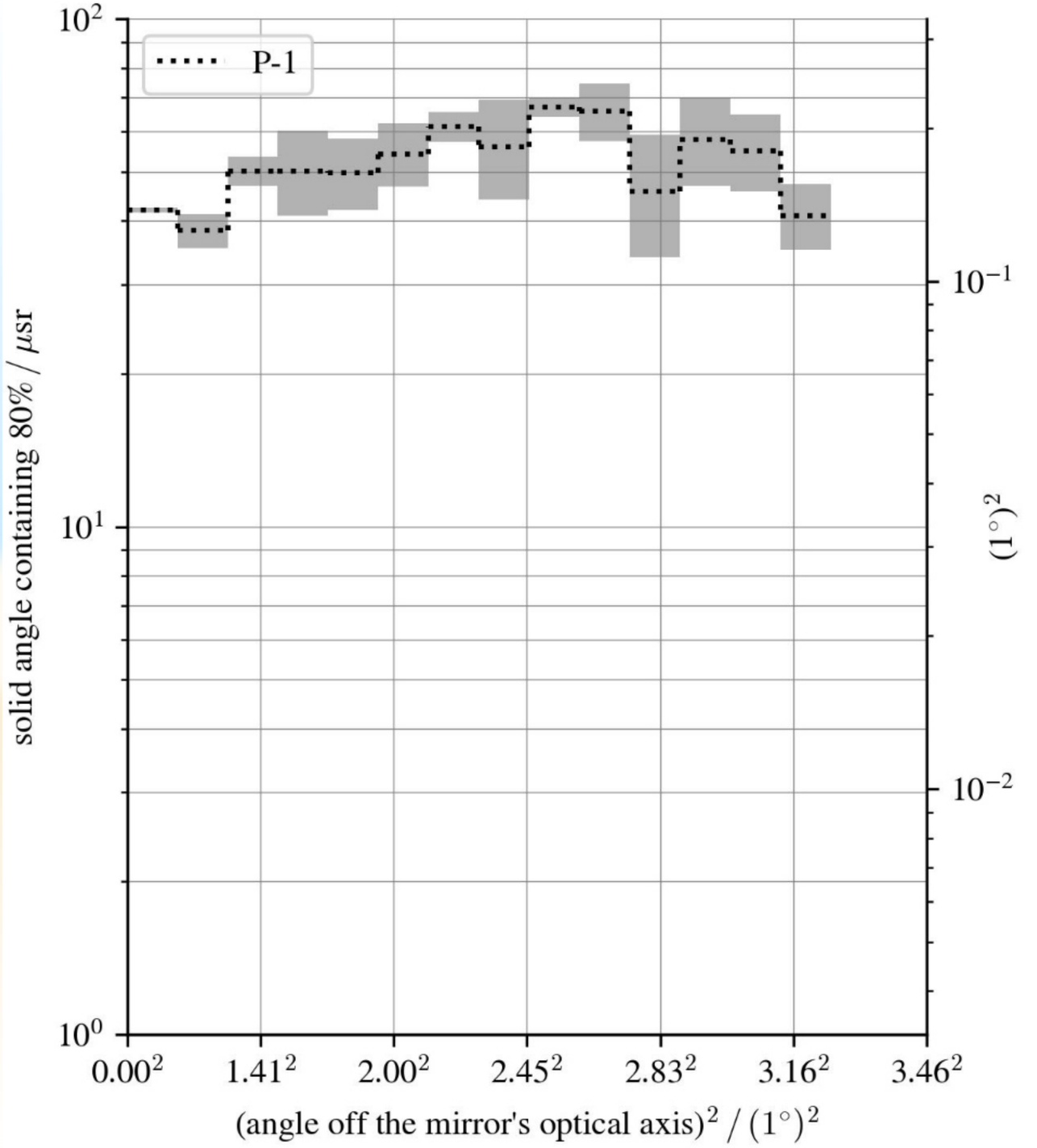

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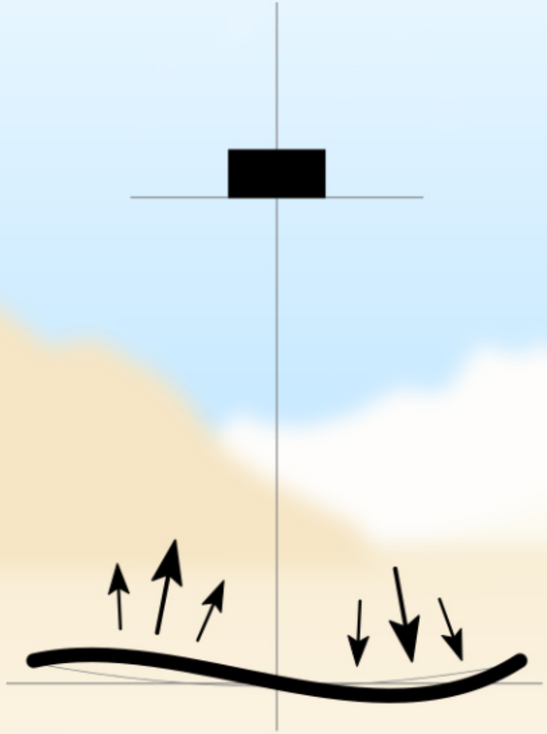

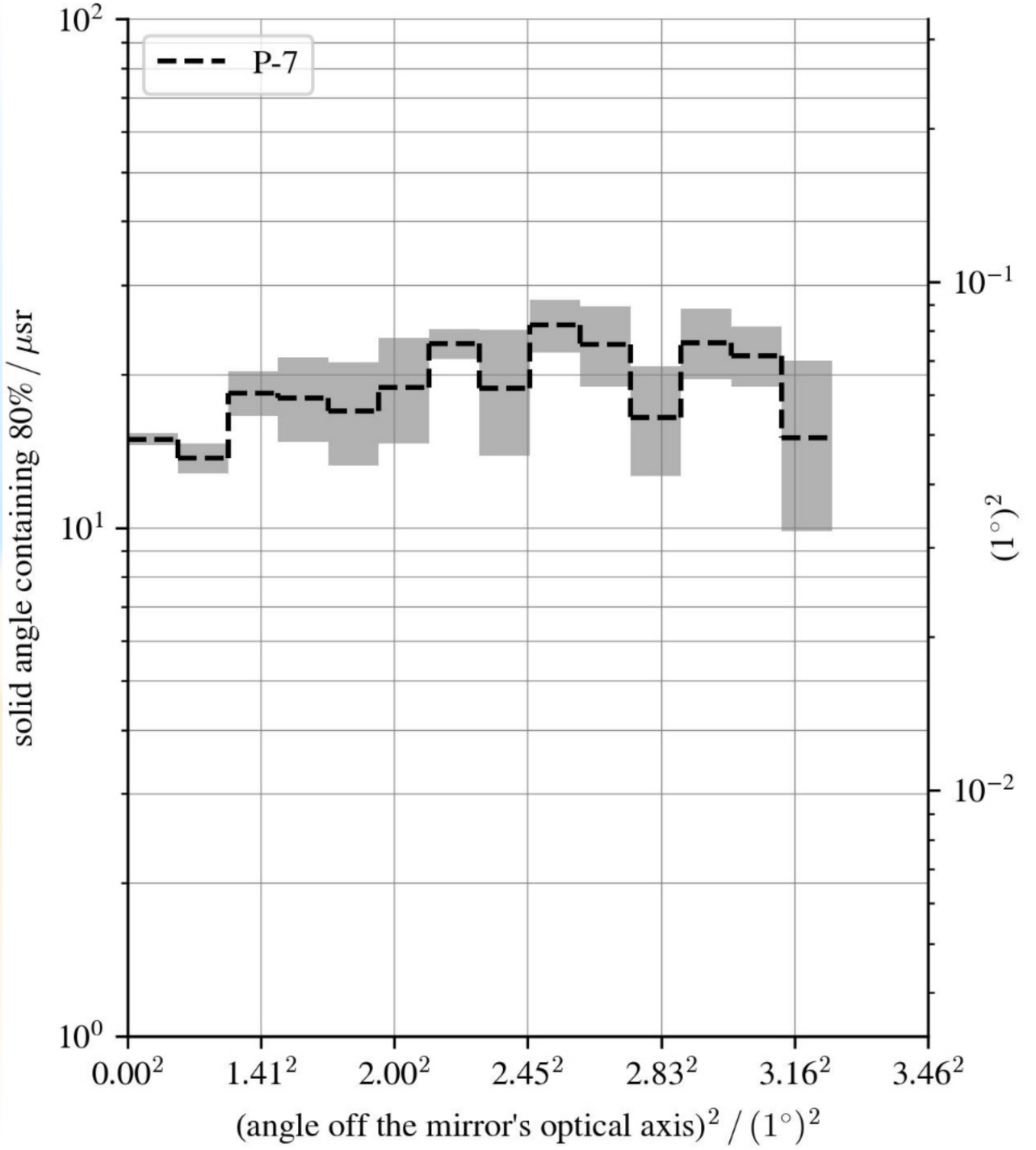

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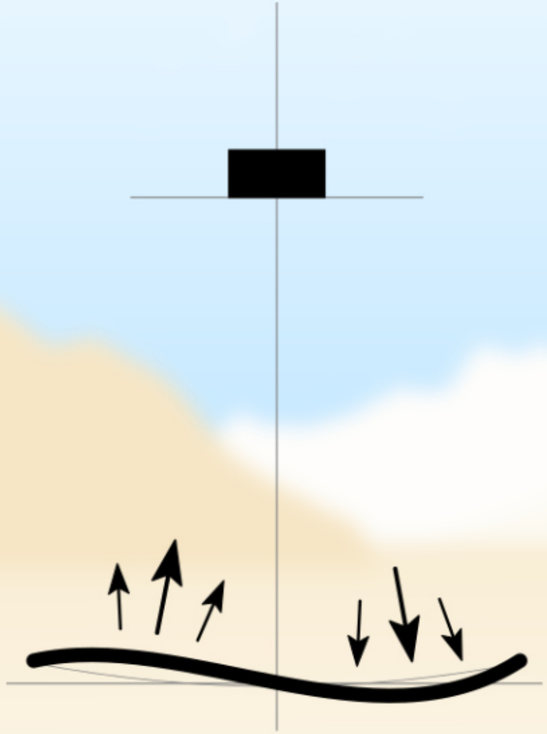
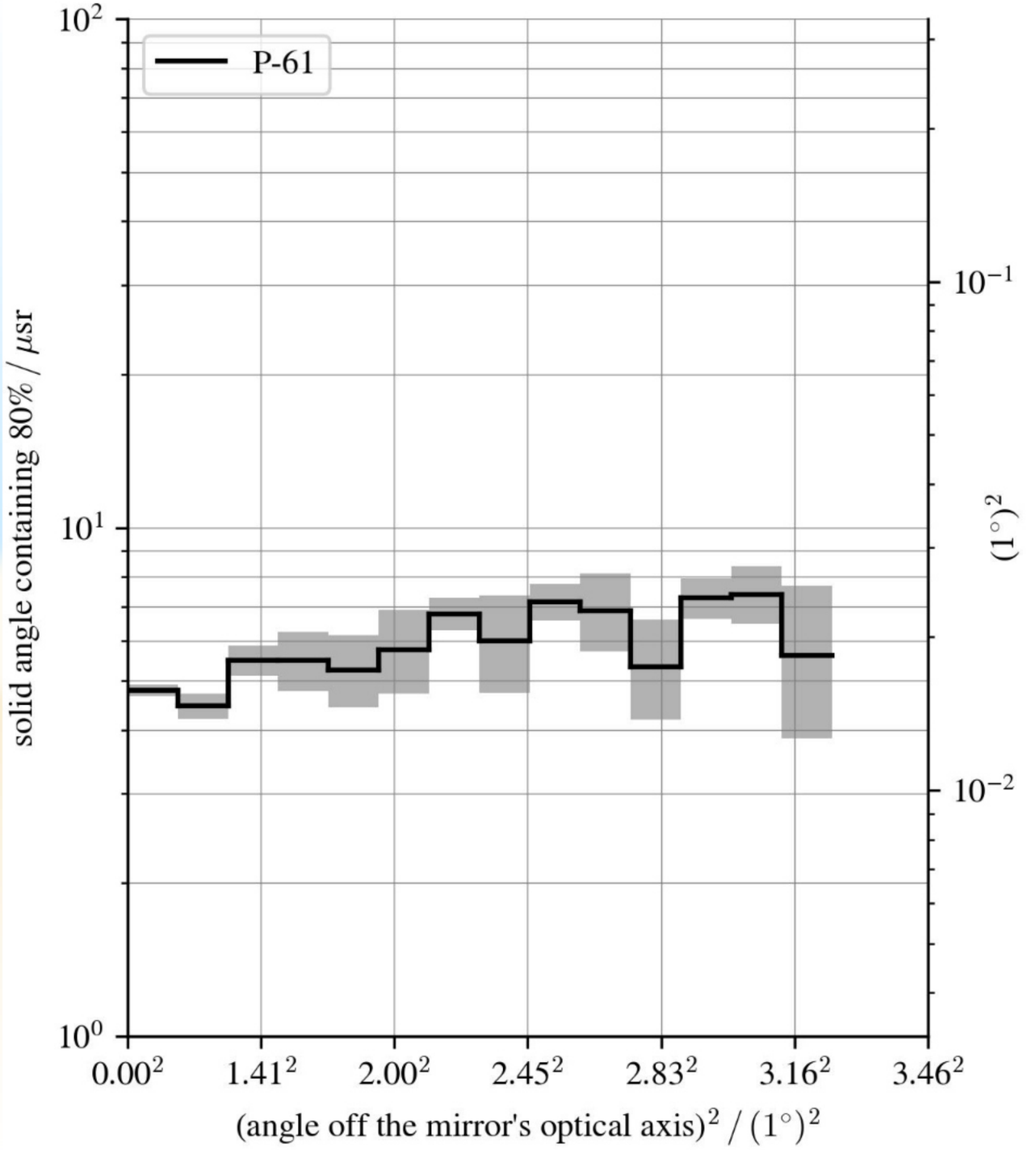
performance





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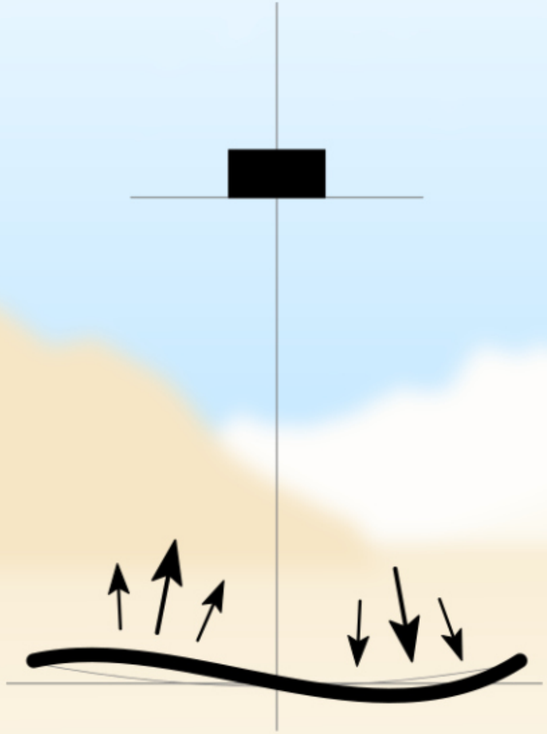

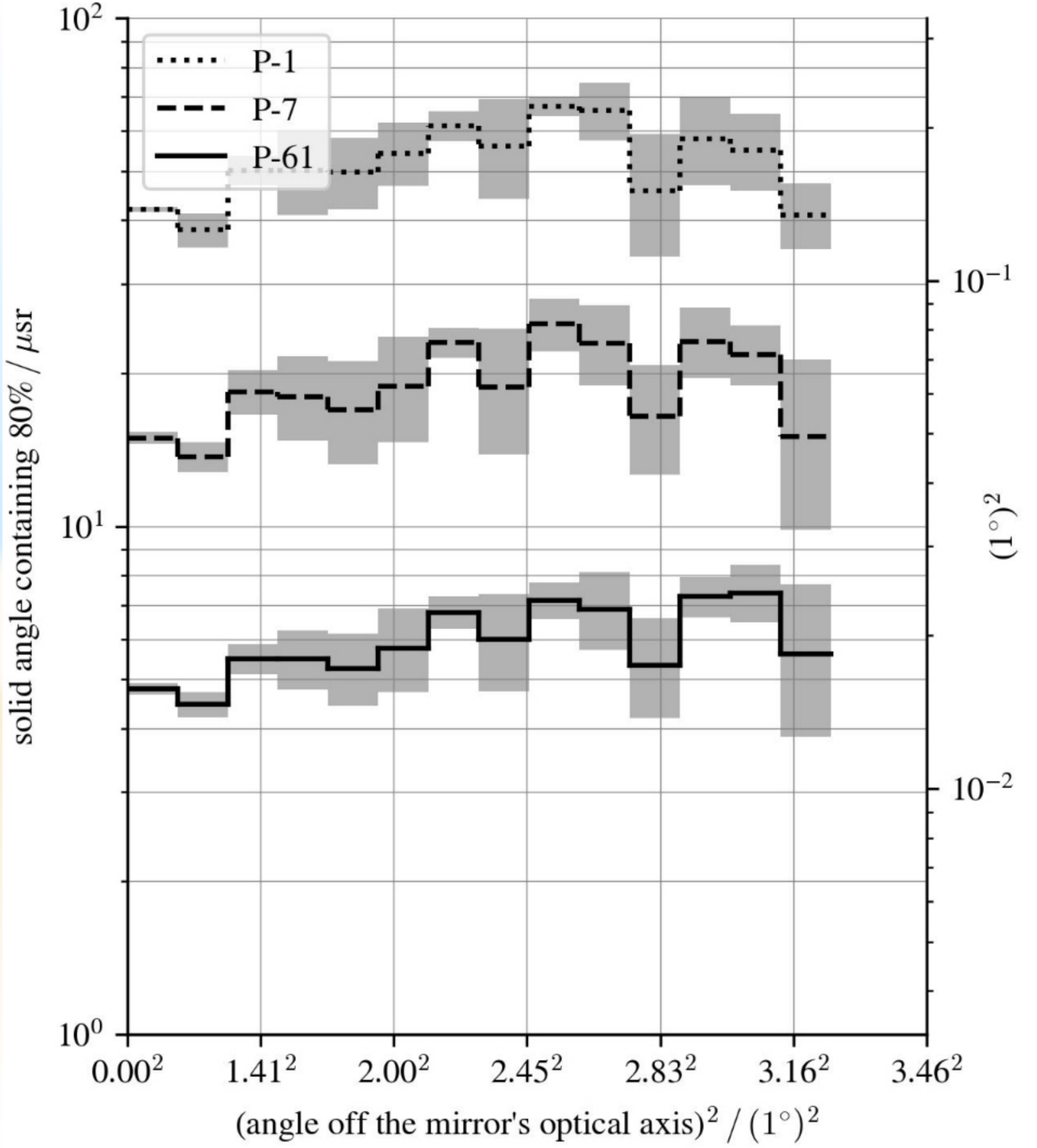

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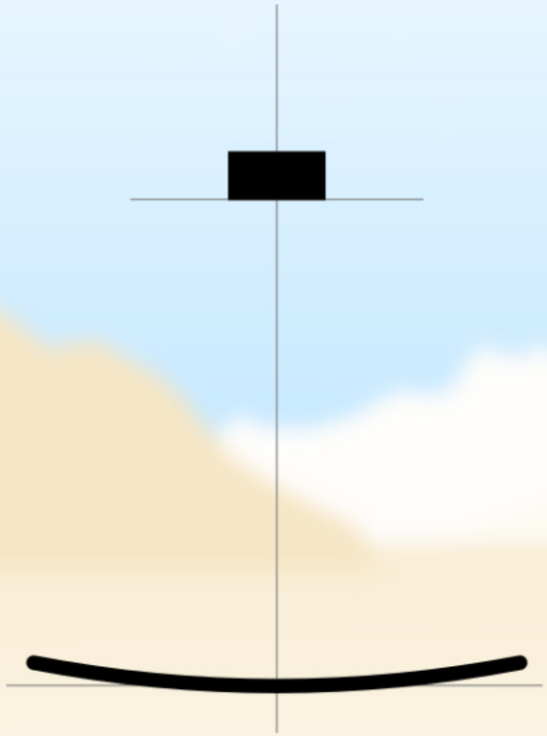

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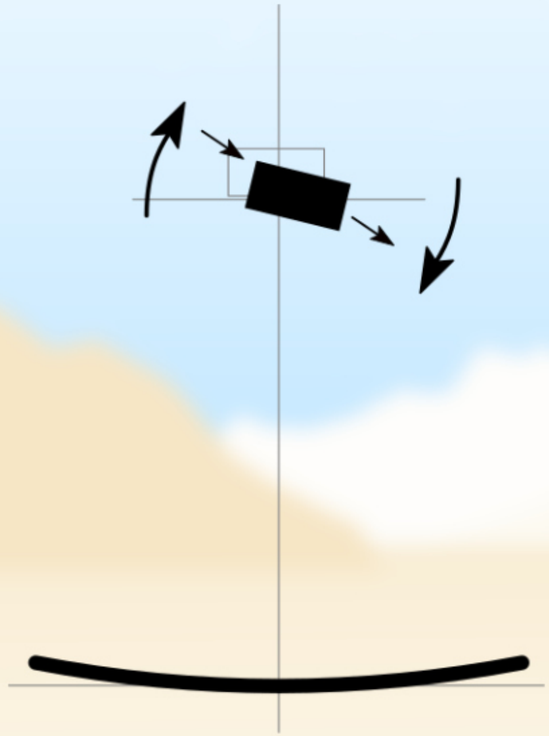

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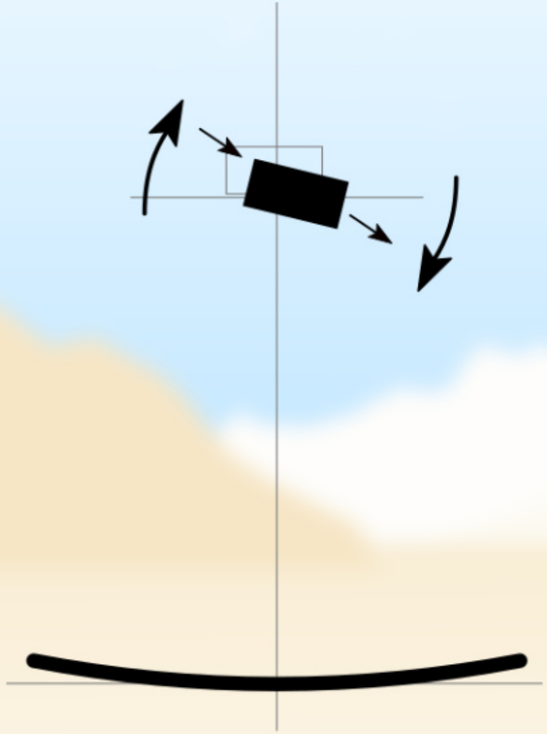

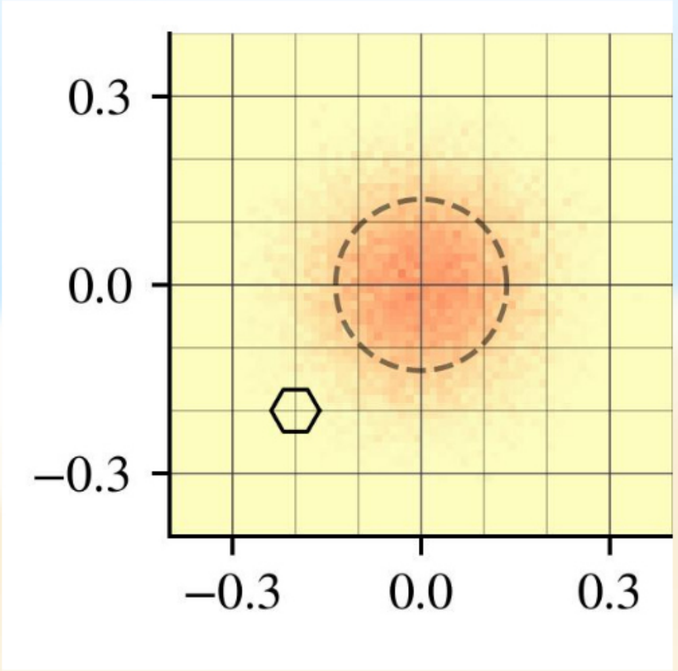

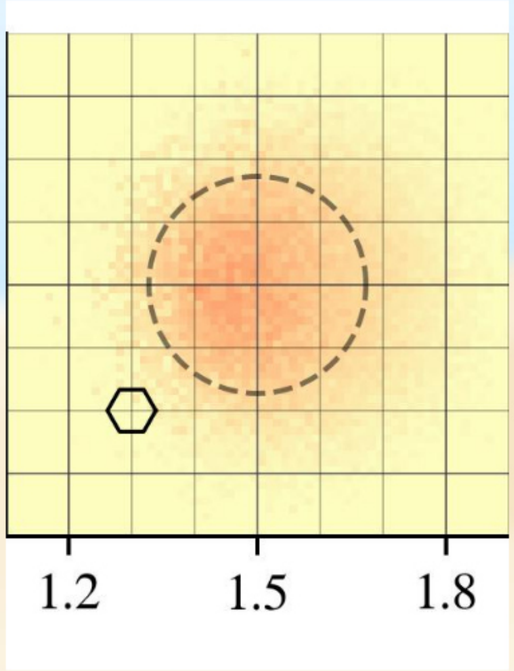

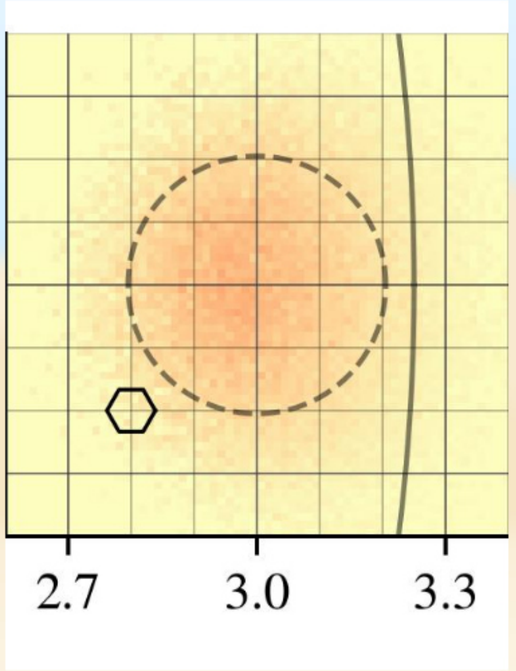

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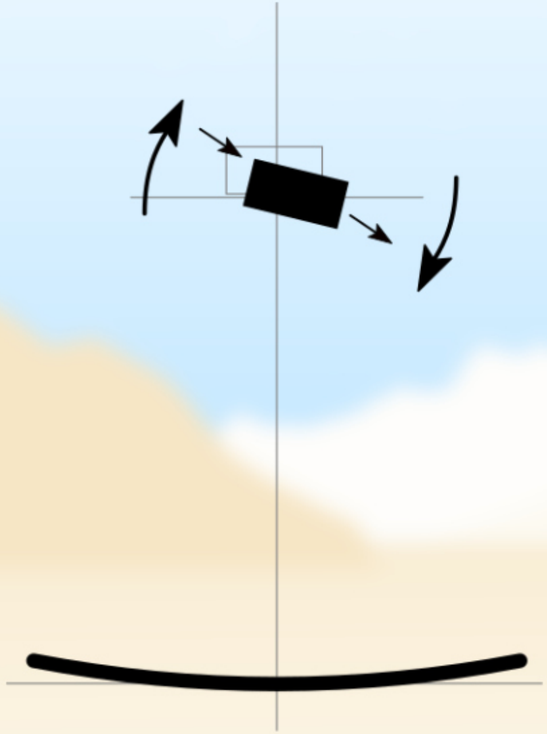
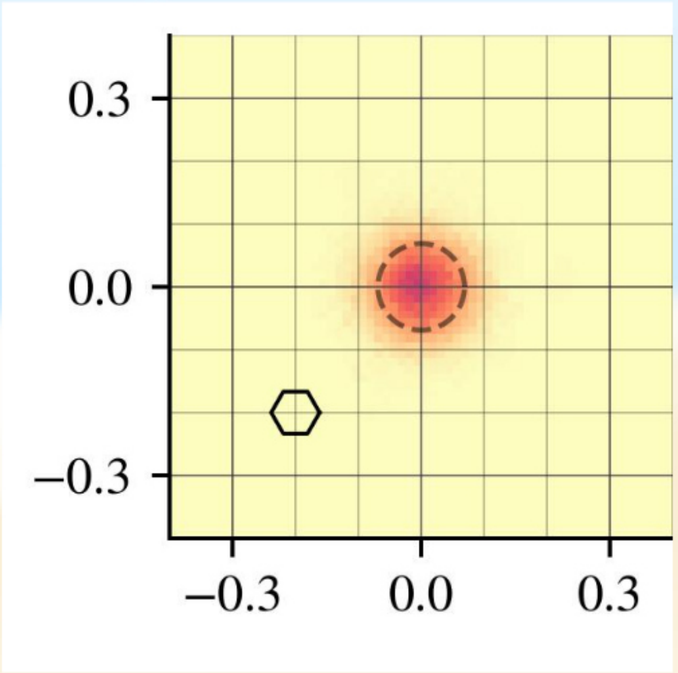
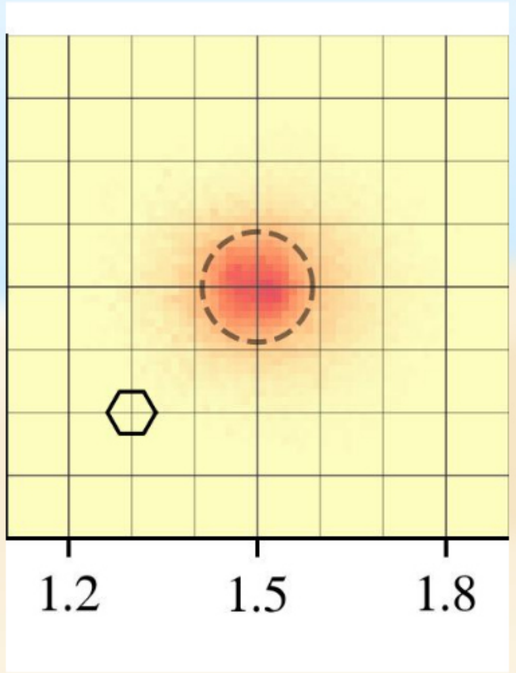
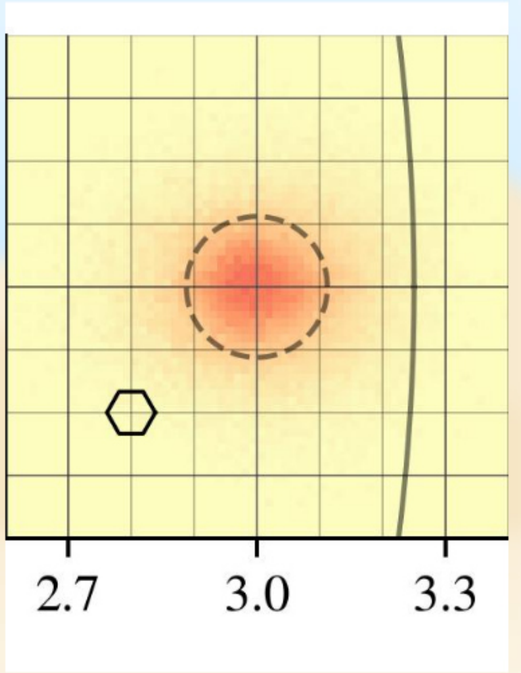
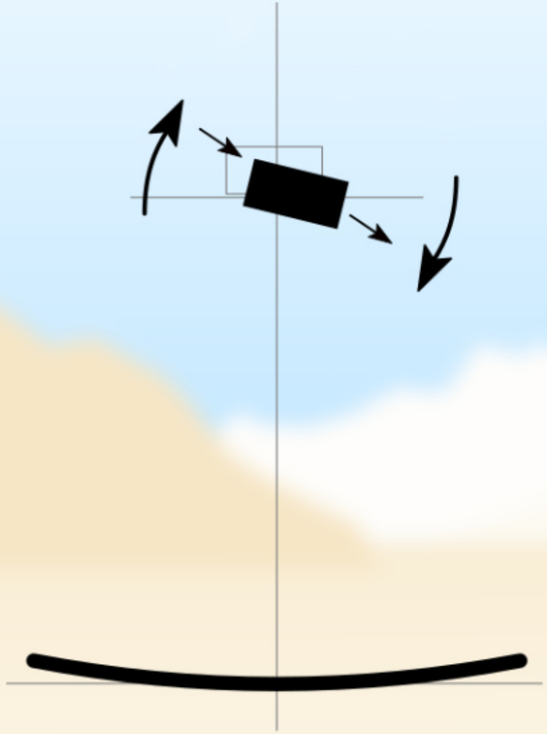


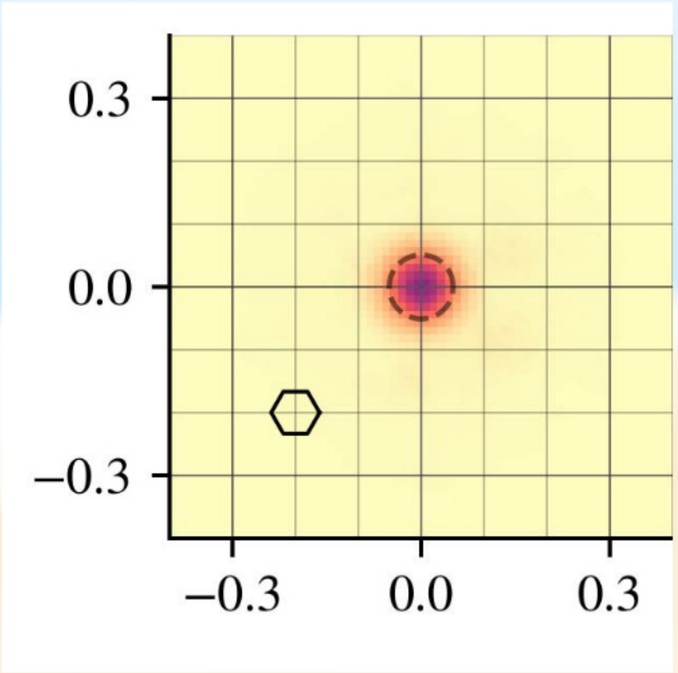


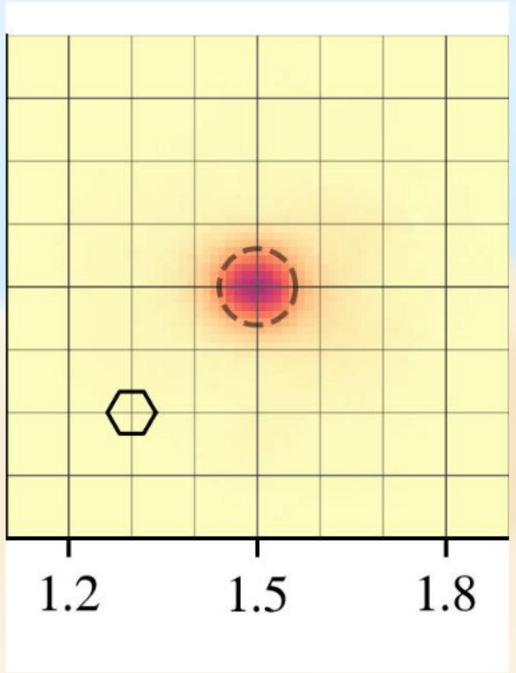


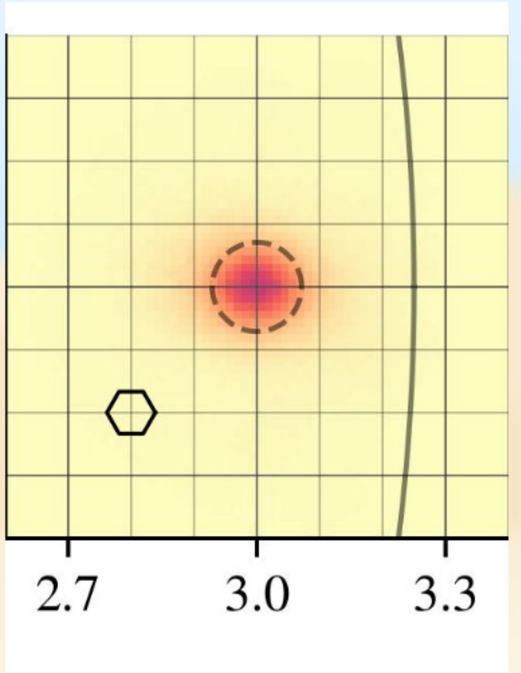


Optics
performance

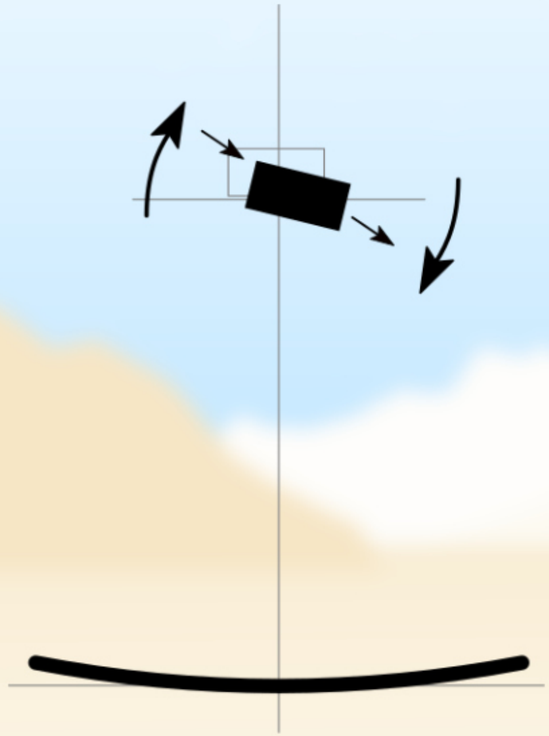


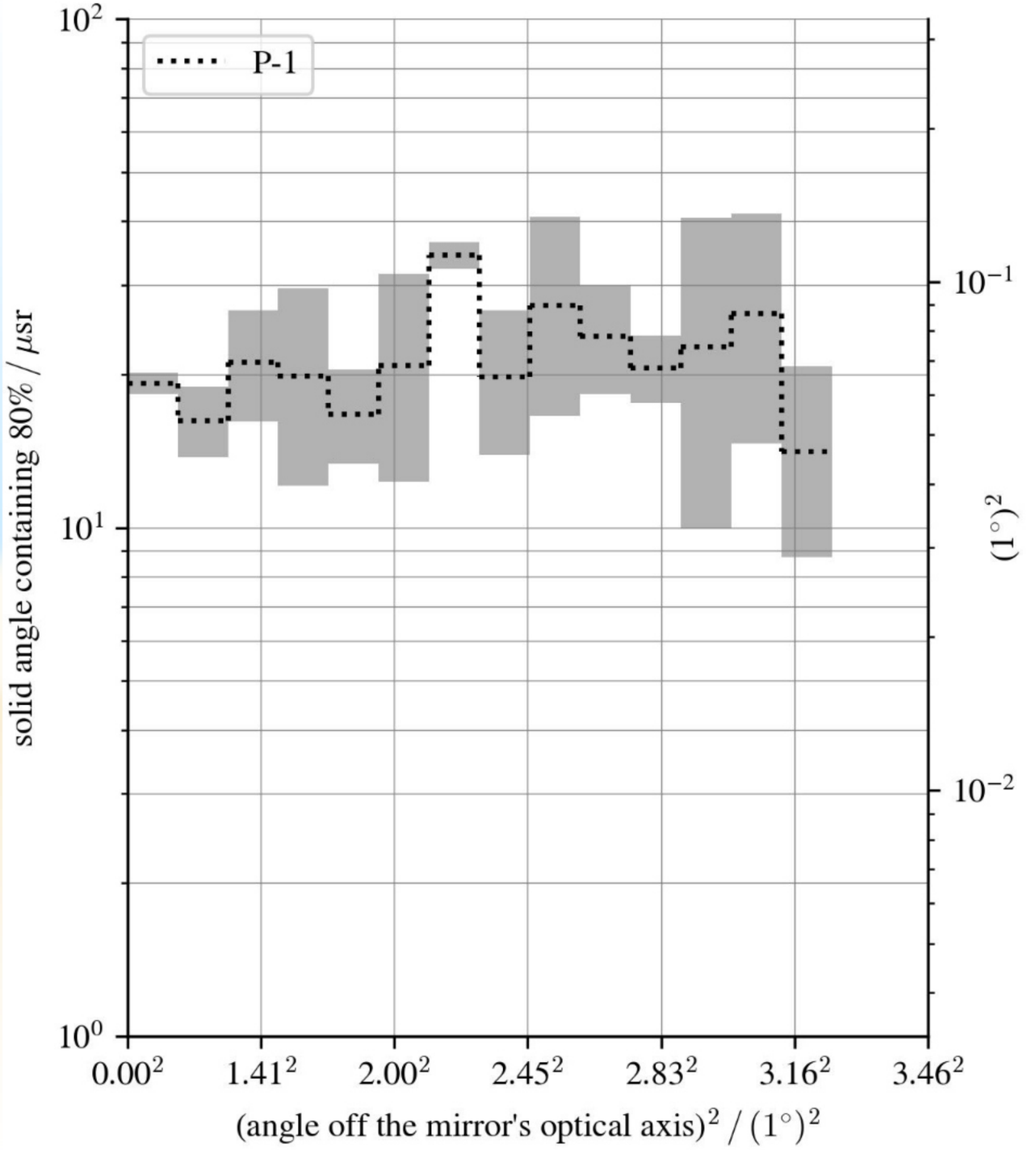




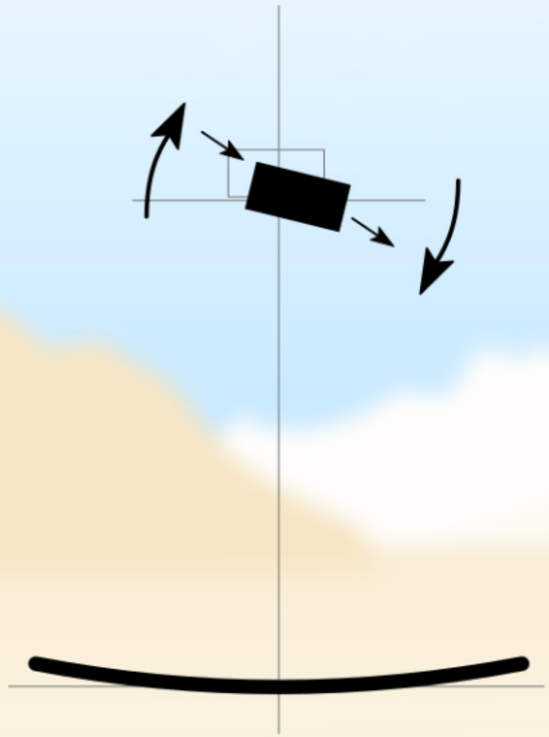


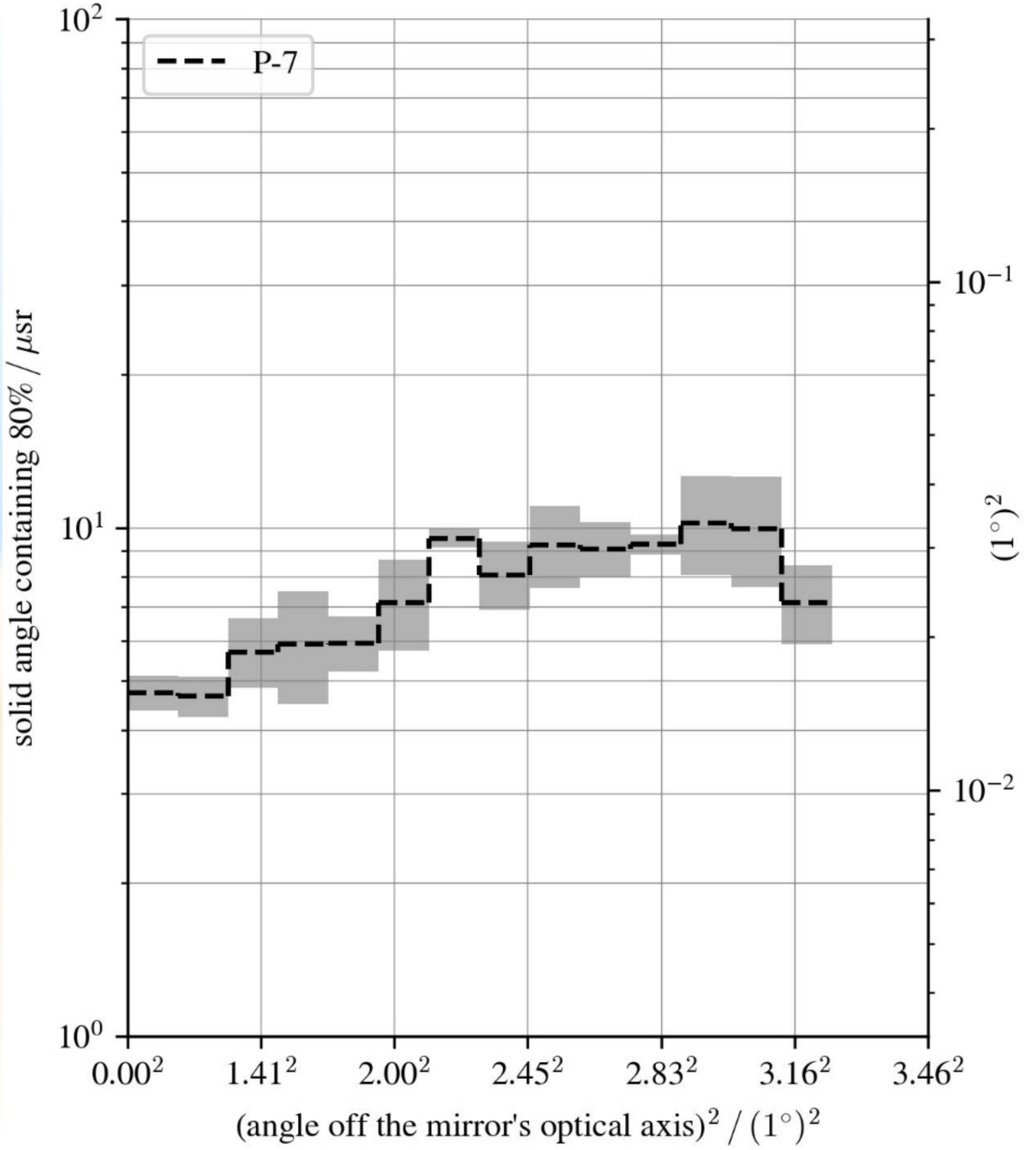
Optics
performance



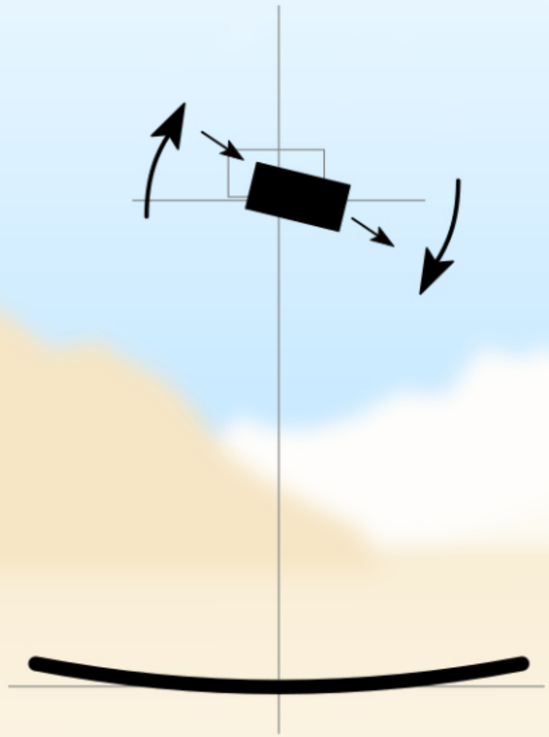


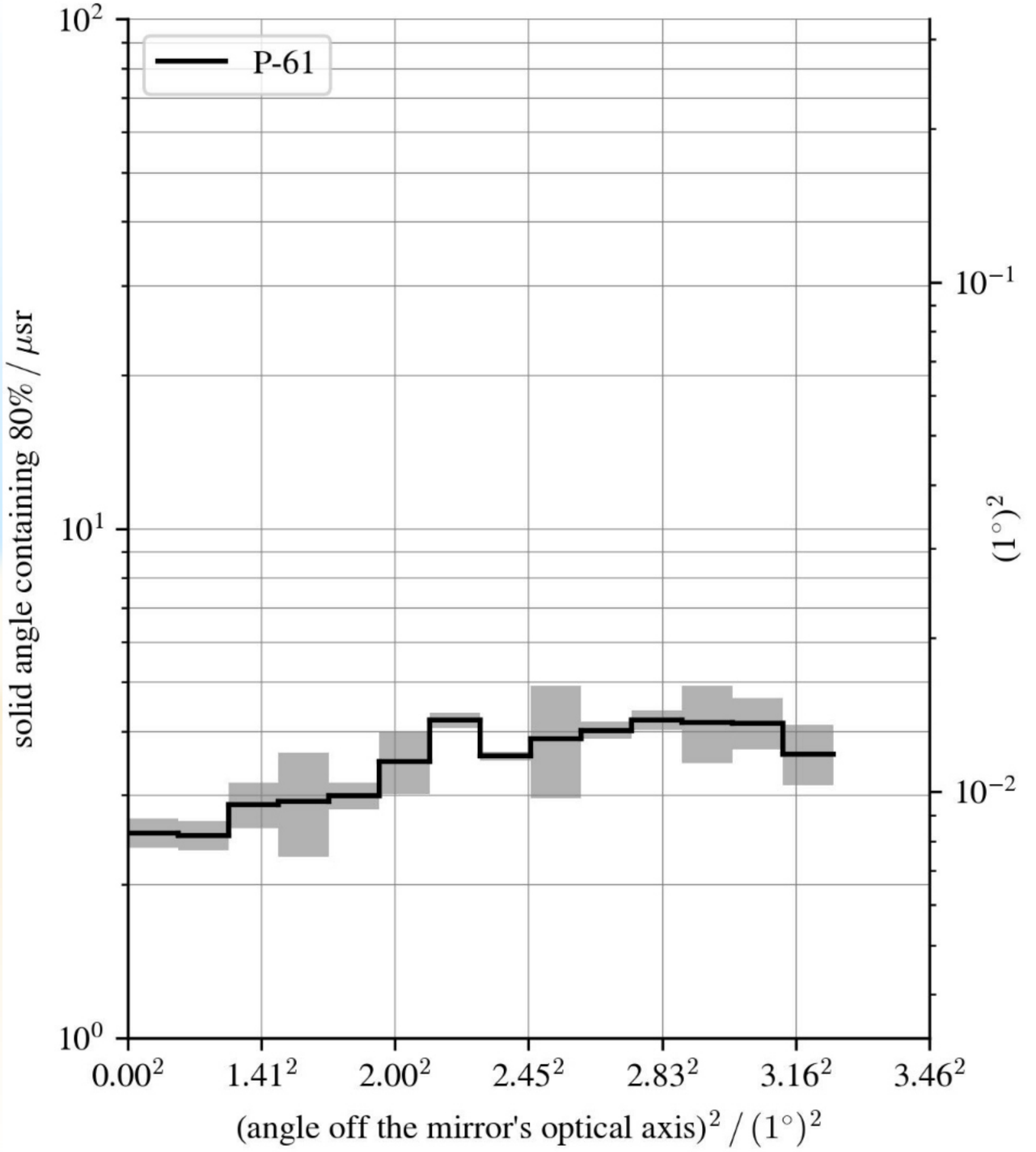
Optics
performance





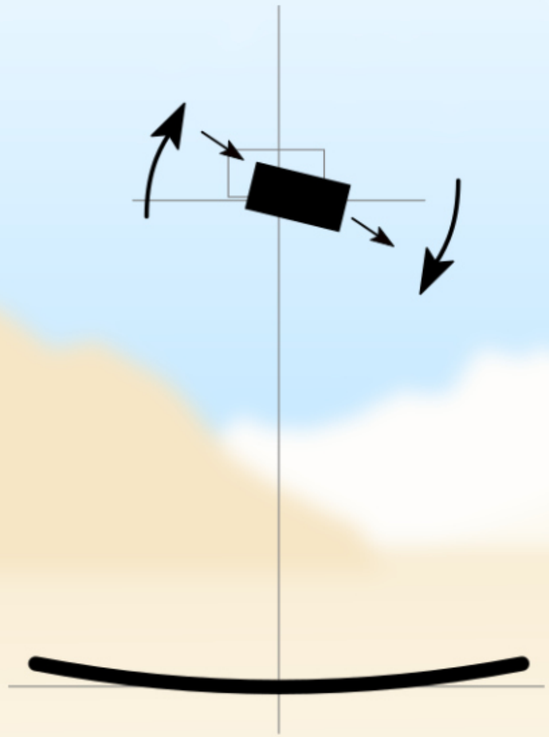
Optics
performance

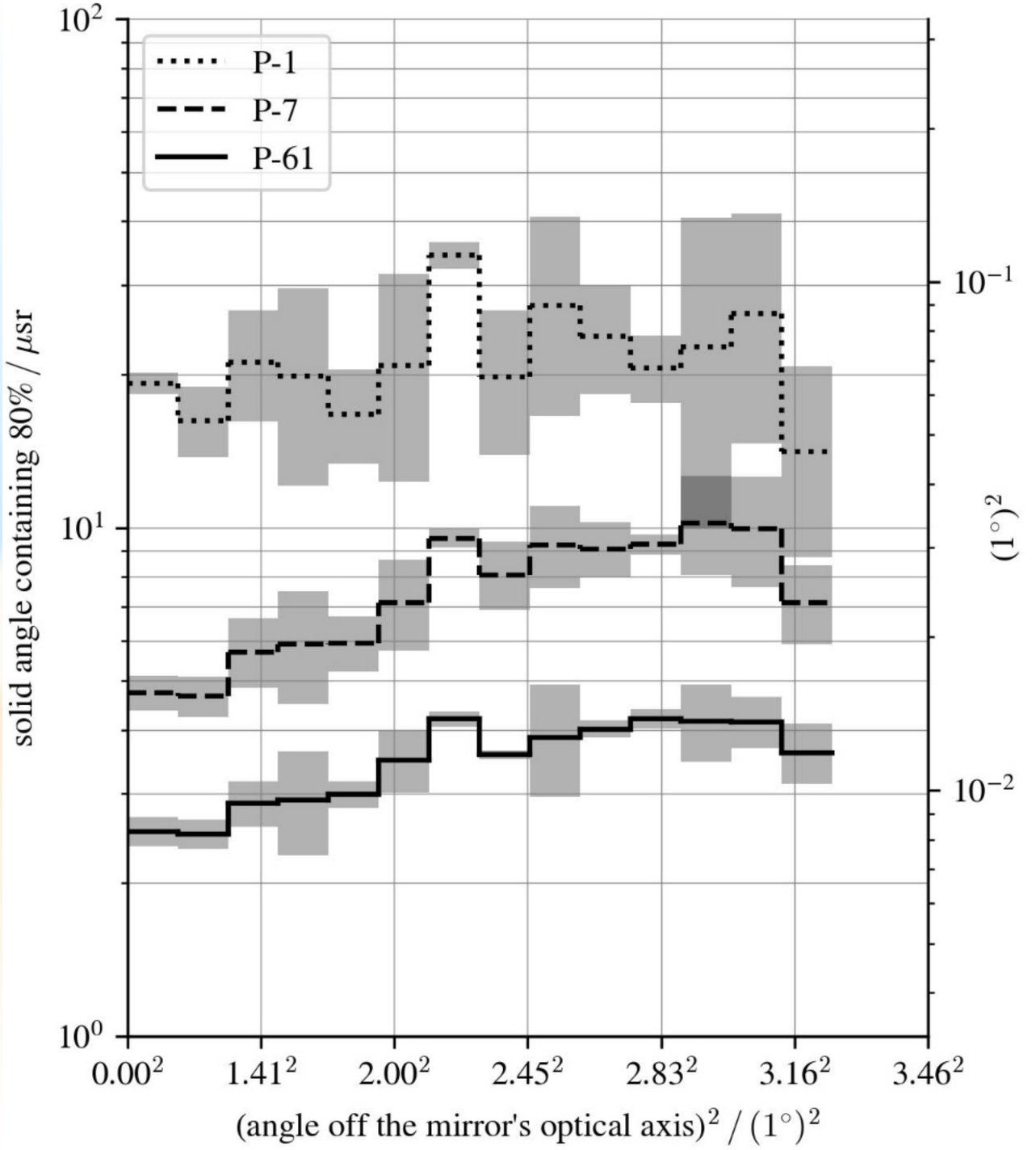




Optics

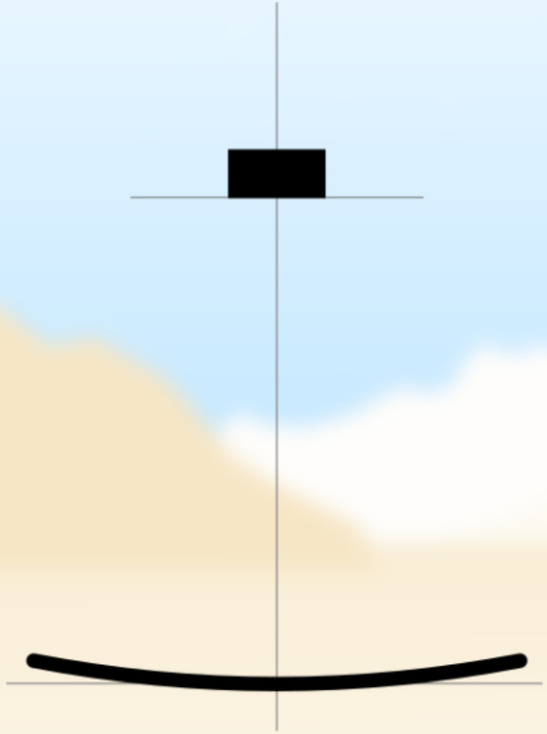
performance





Optics

refocussing to any depth



Optics

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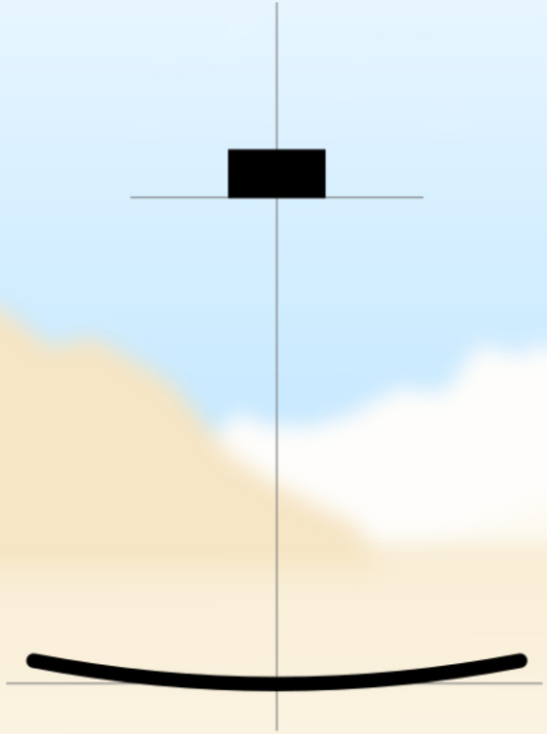
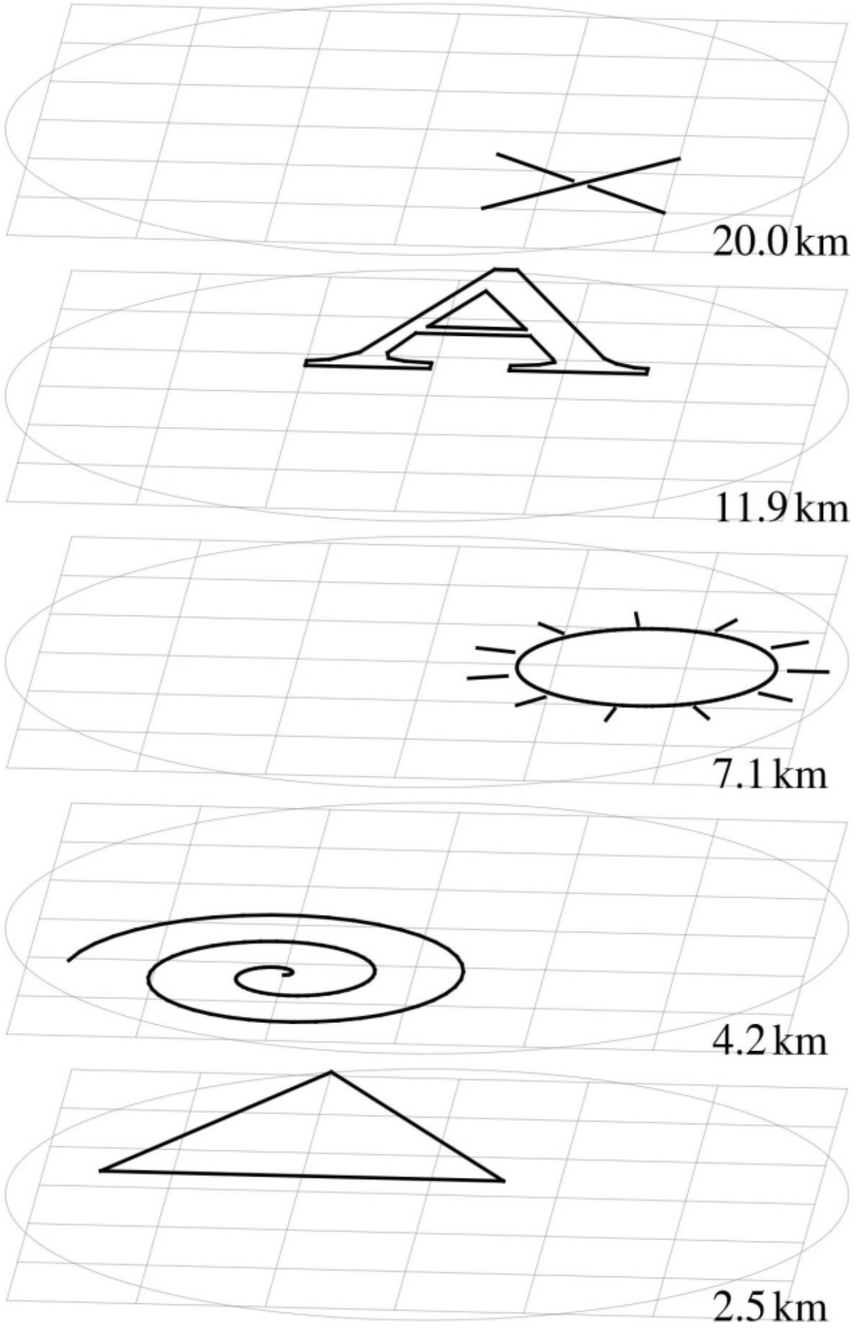
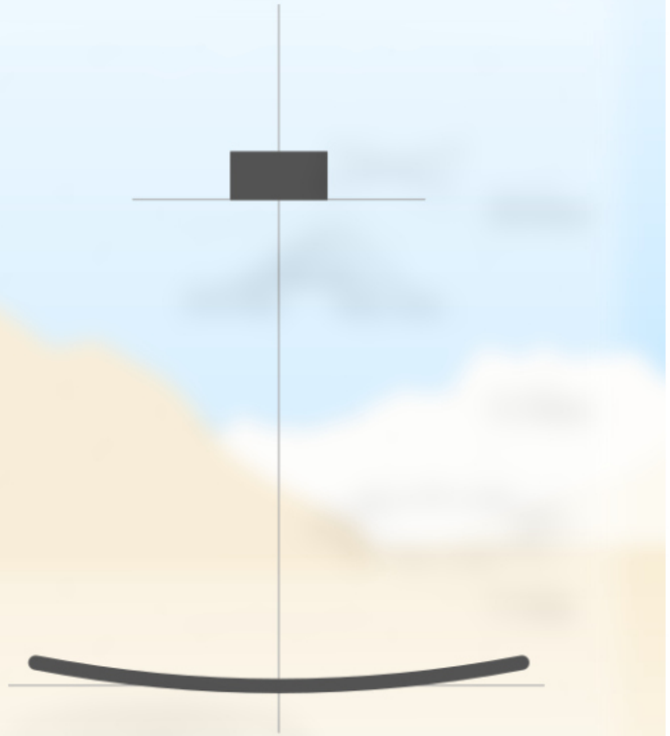


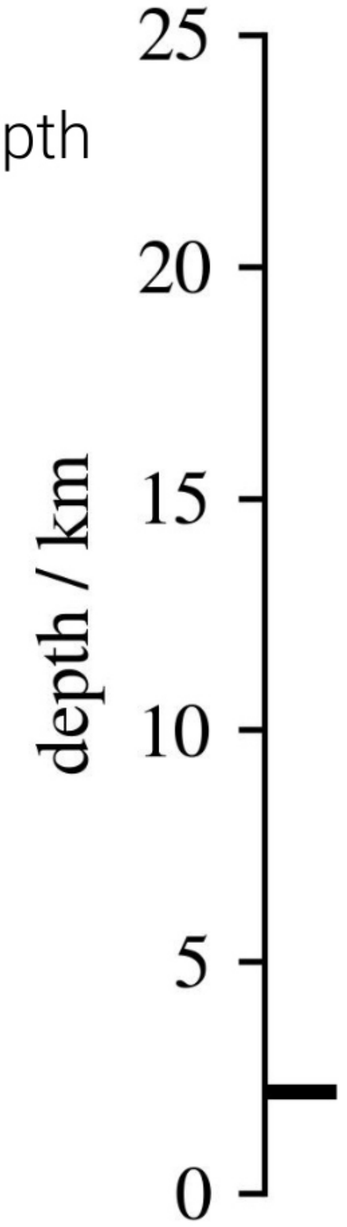


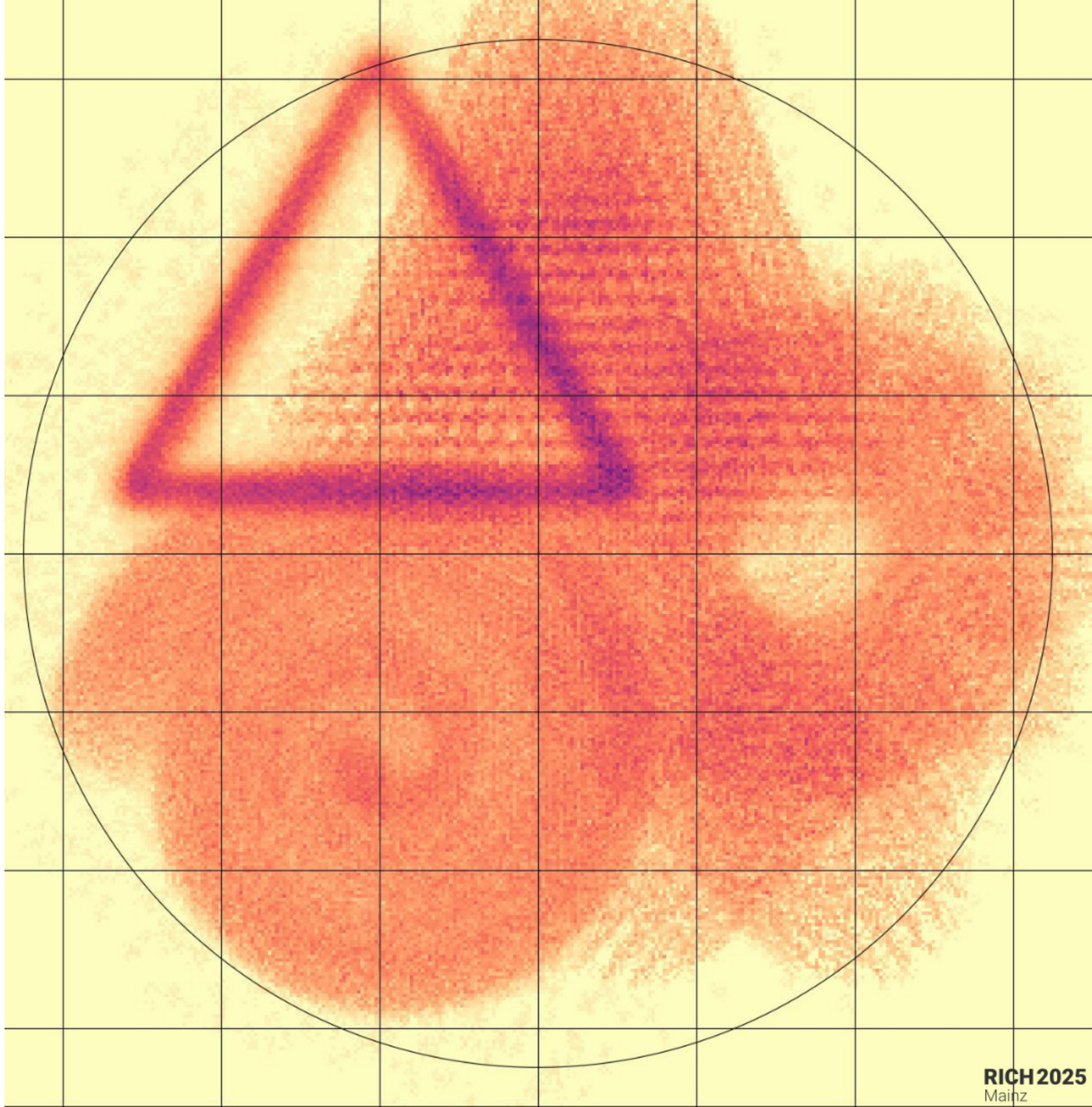
phantom in atmosphere

Optics

refocussing to any depth

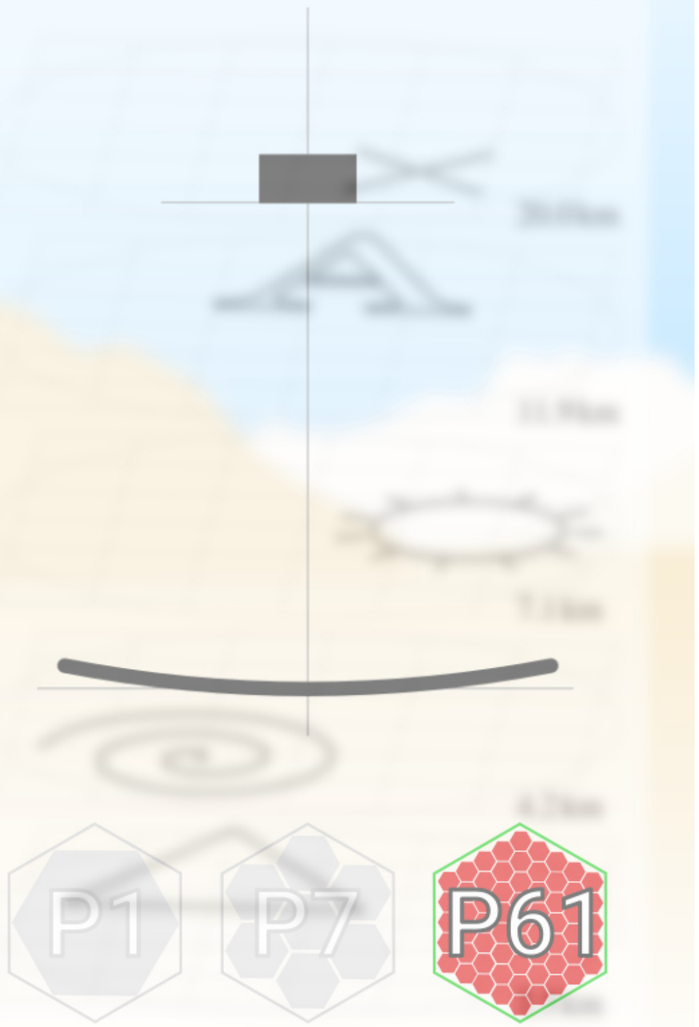


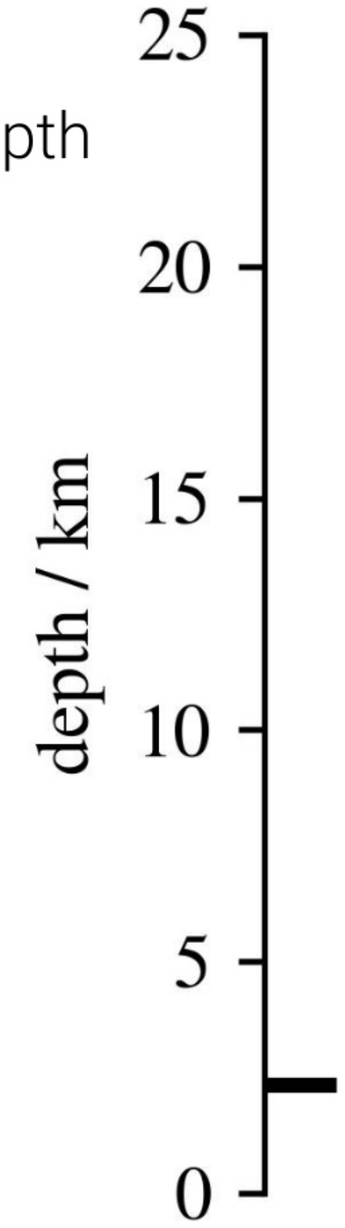


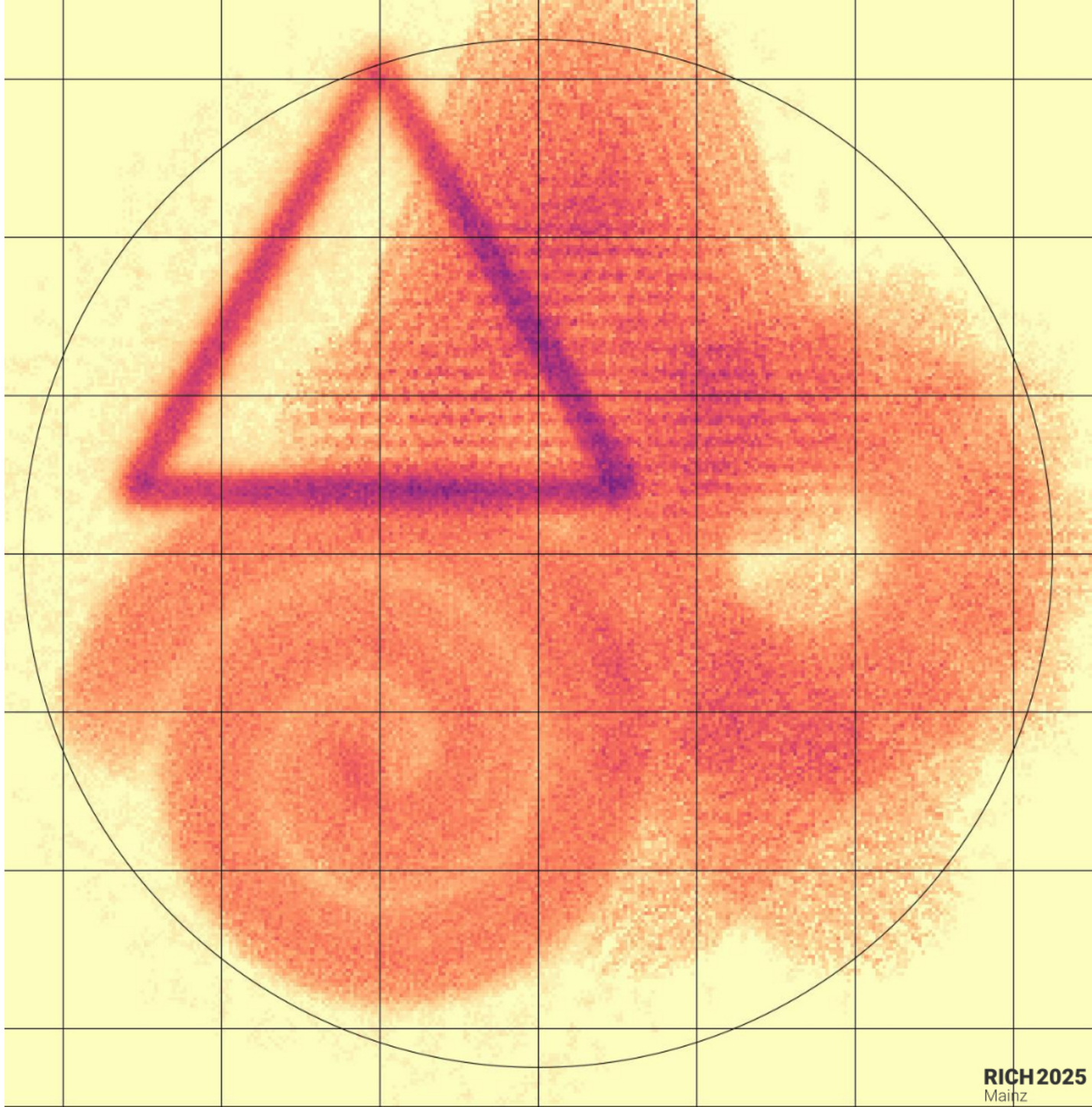


Optics

refocussing to any depth

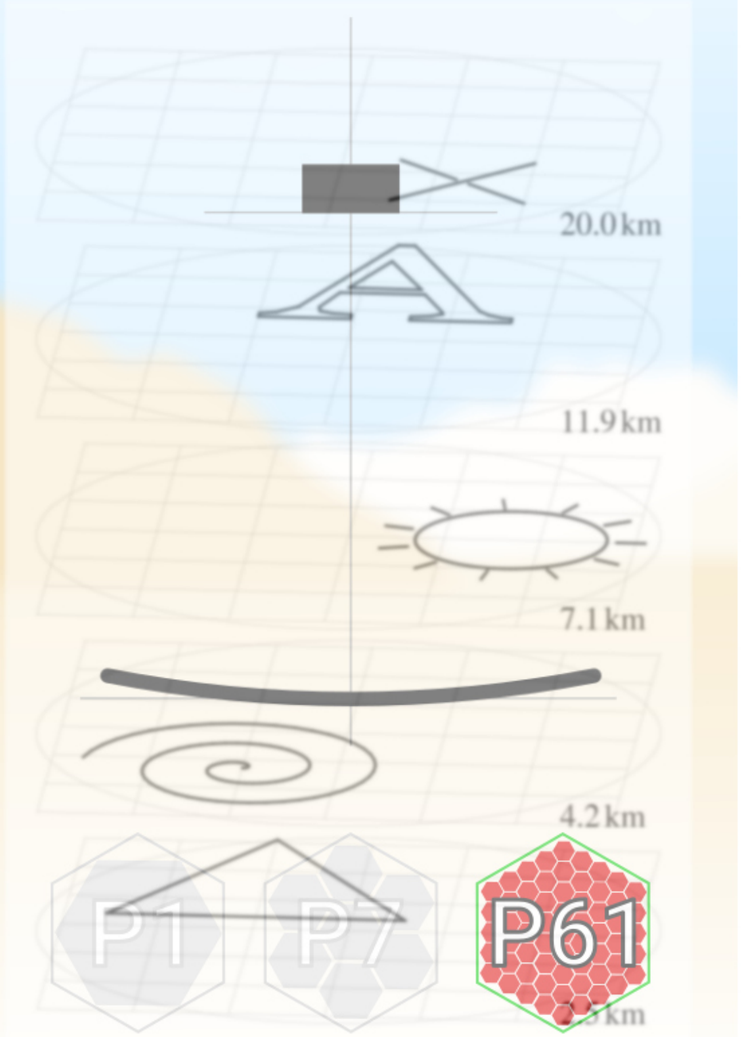


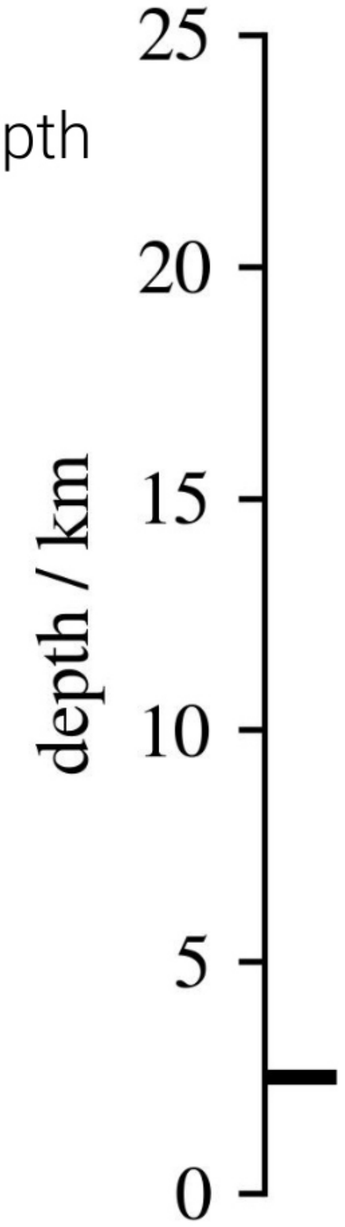


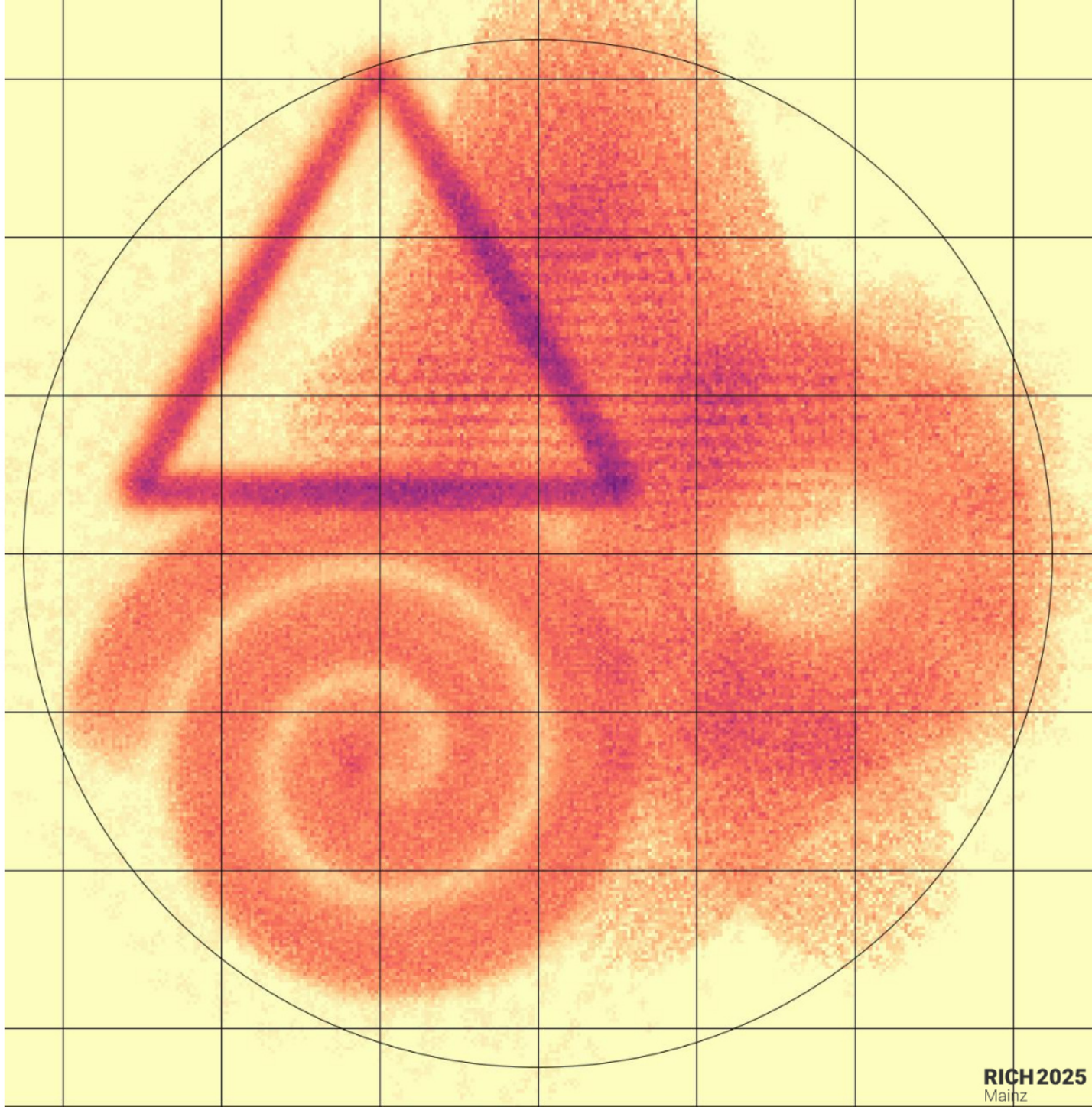


Optics

refocussing to any depth

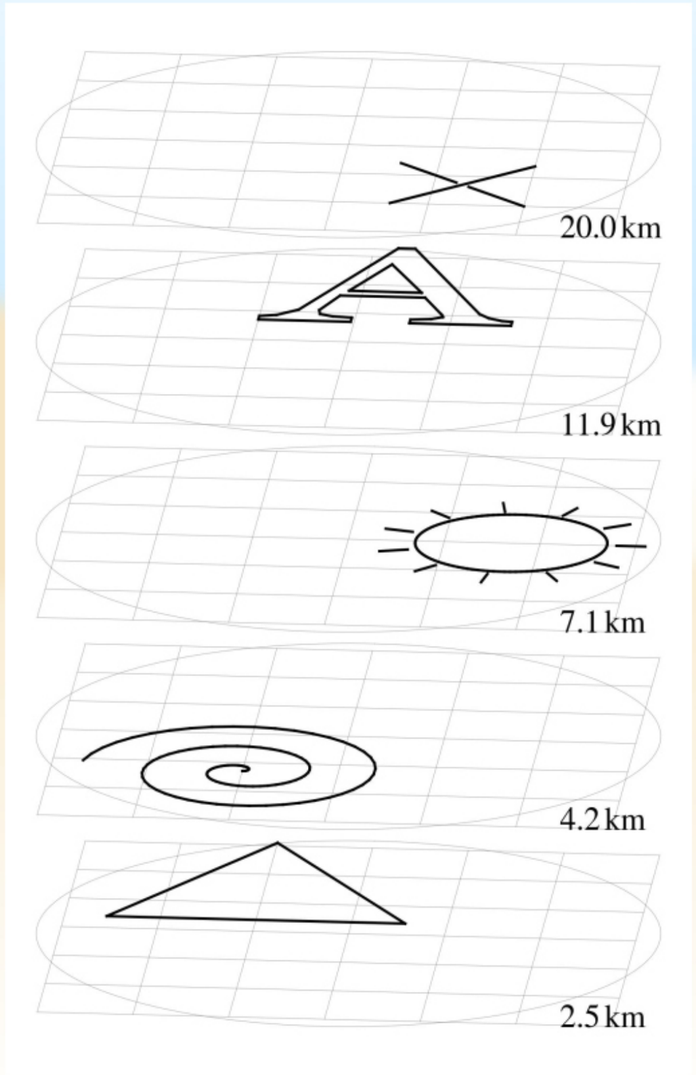


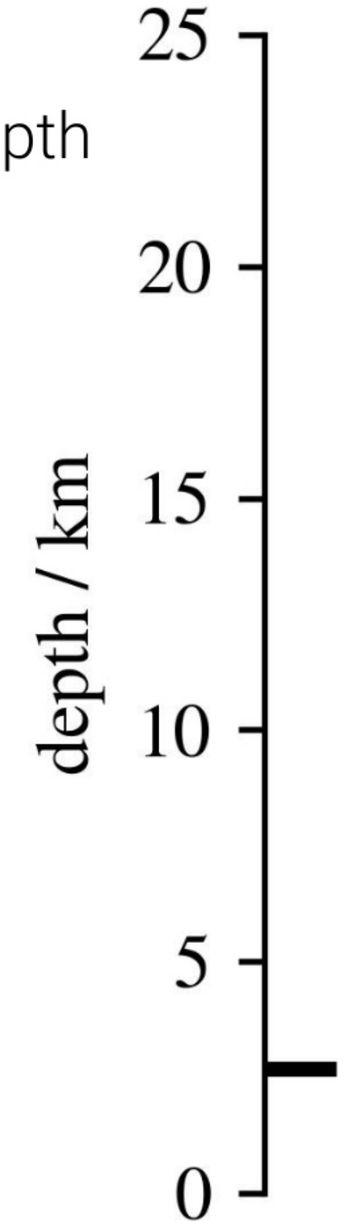


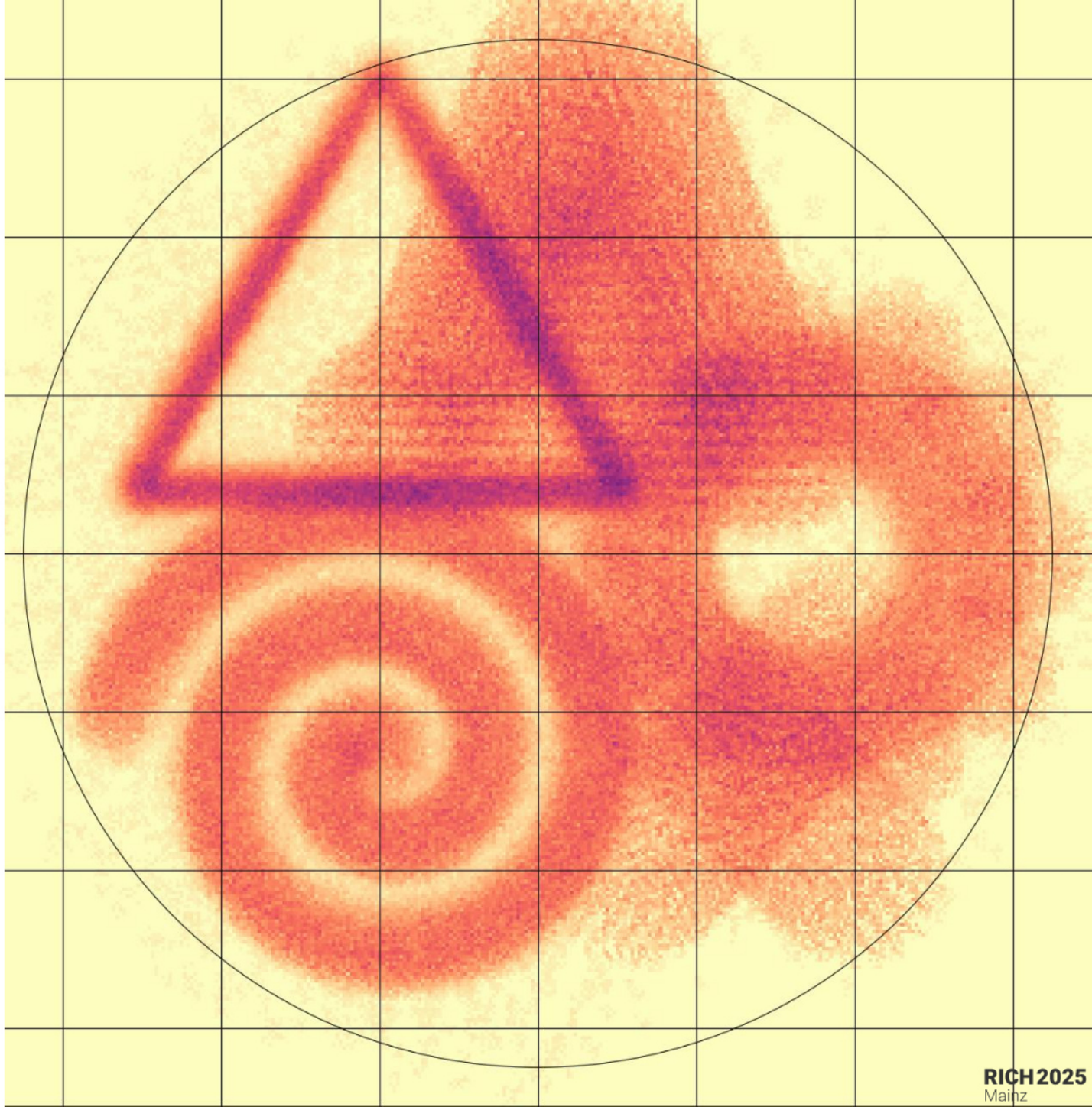


Optics

refocussing to any depth

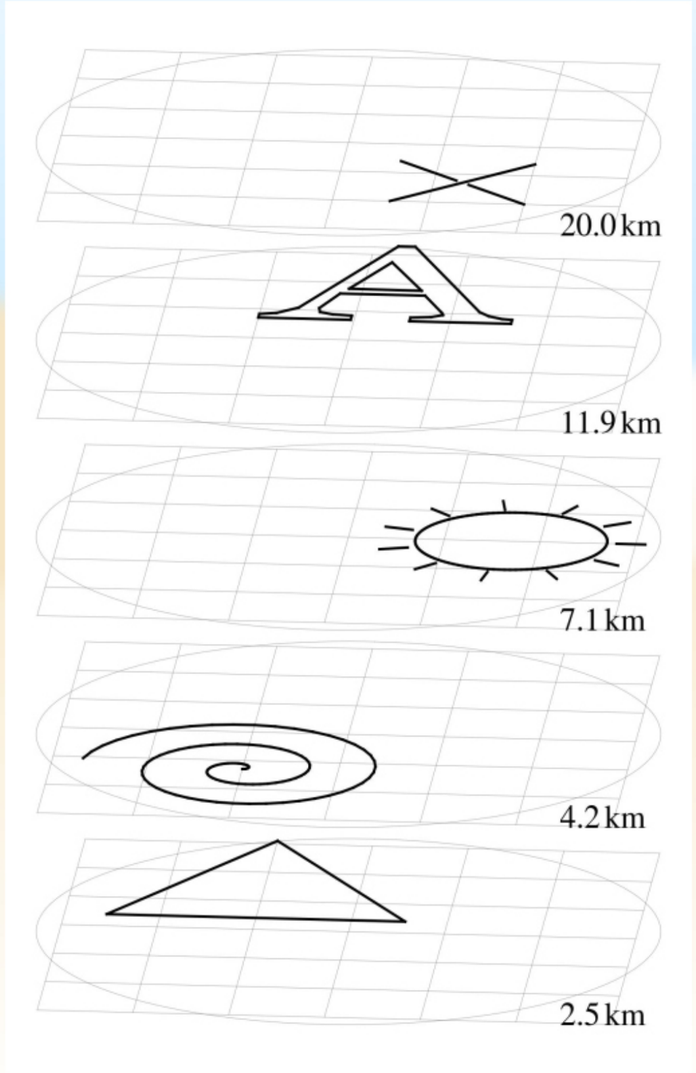


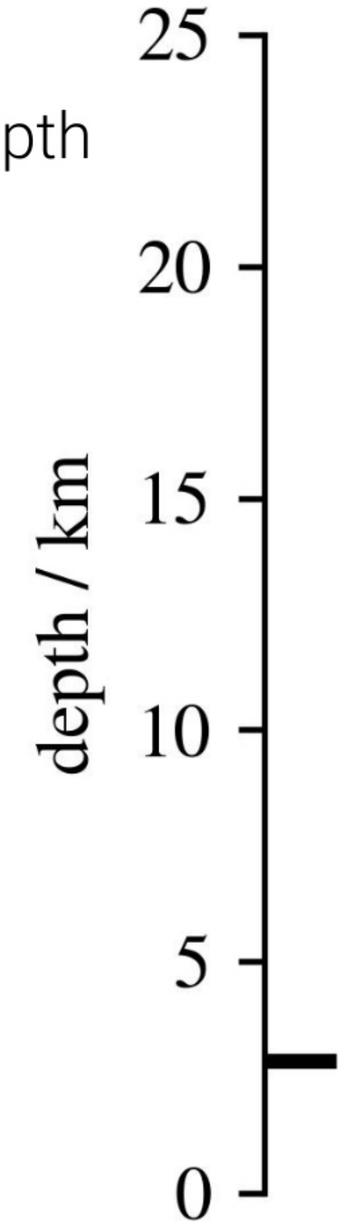


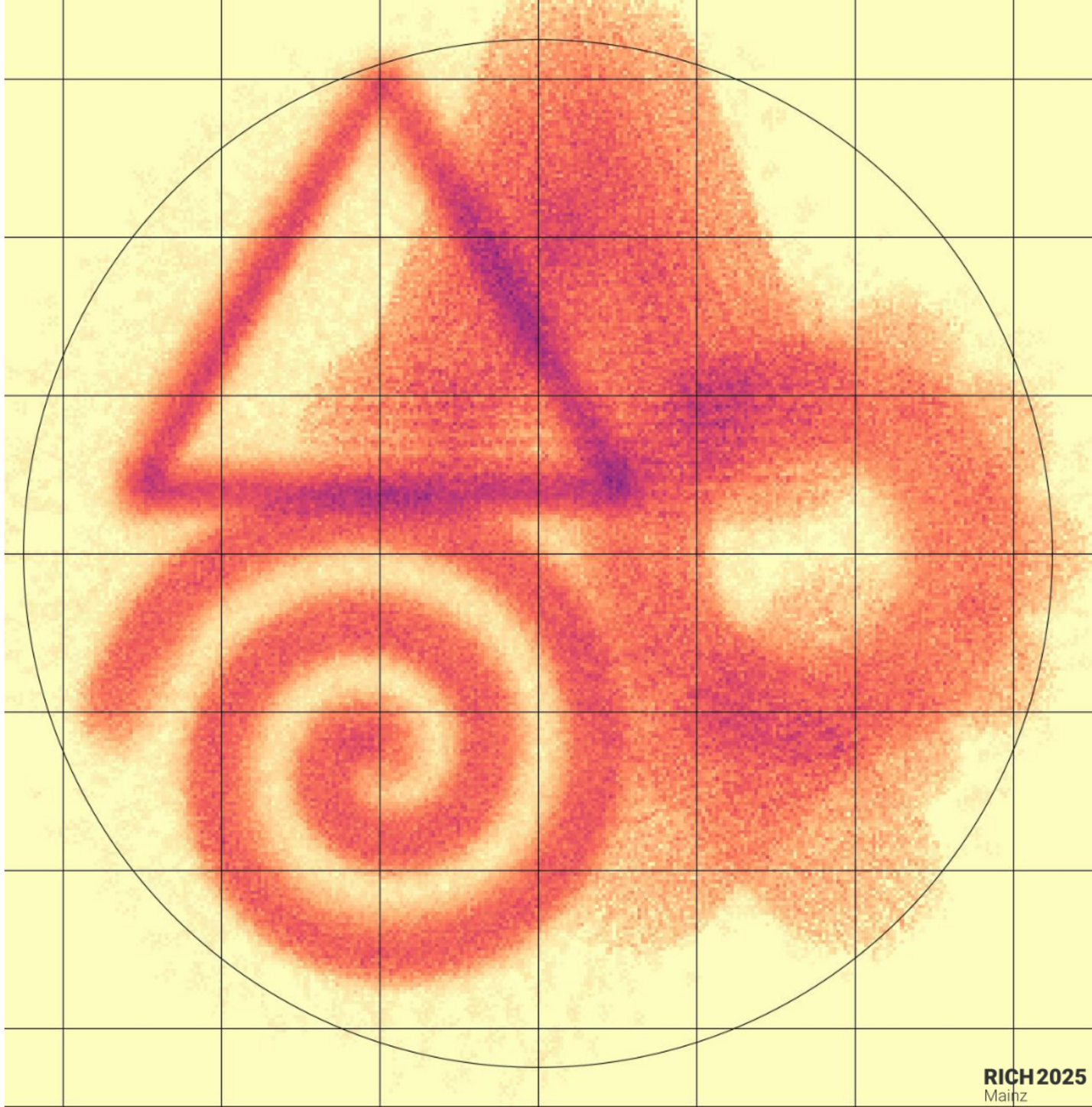


Optics

refocussing to any depth

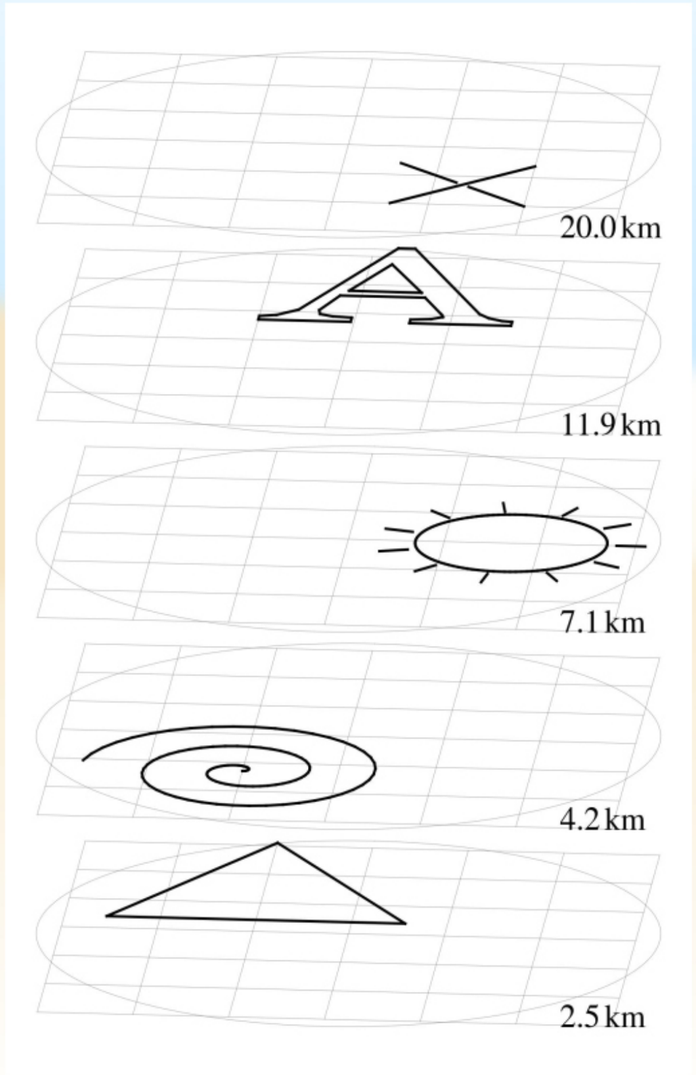


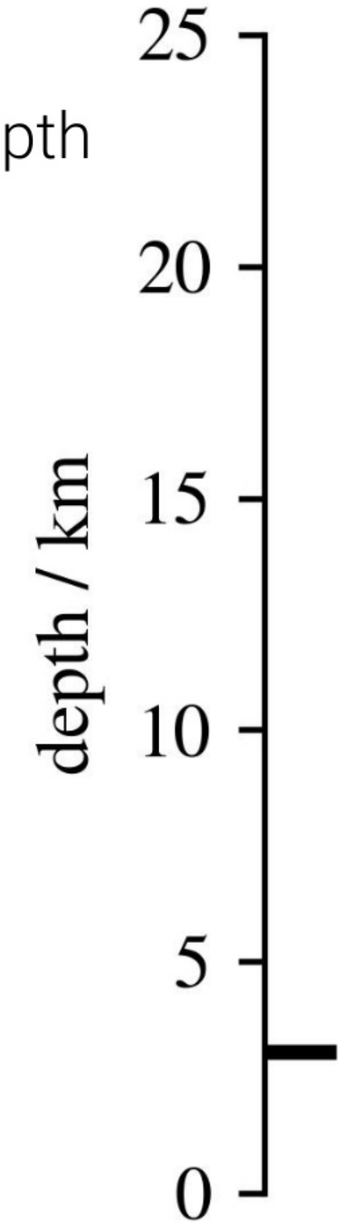


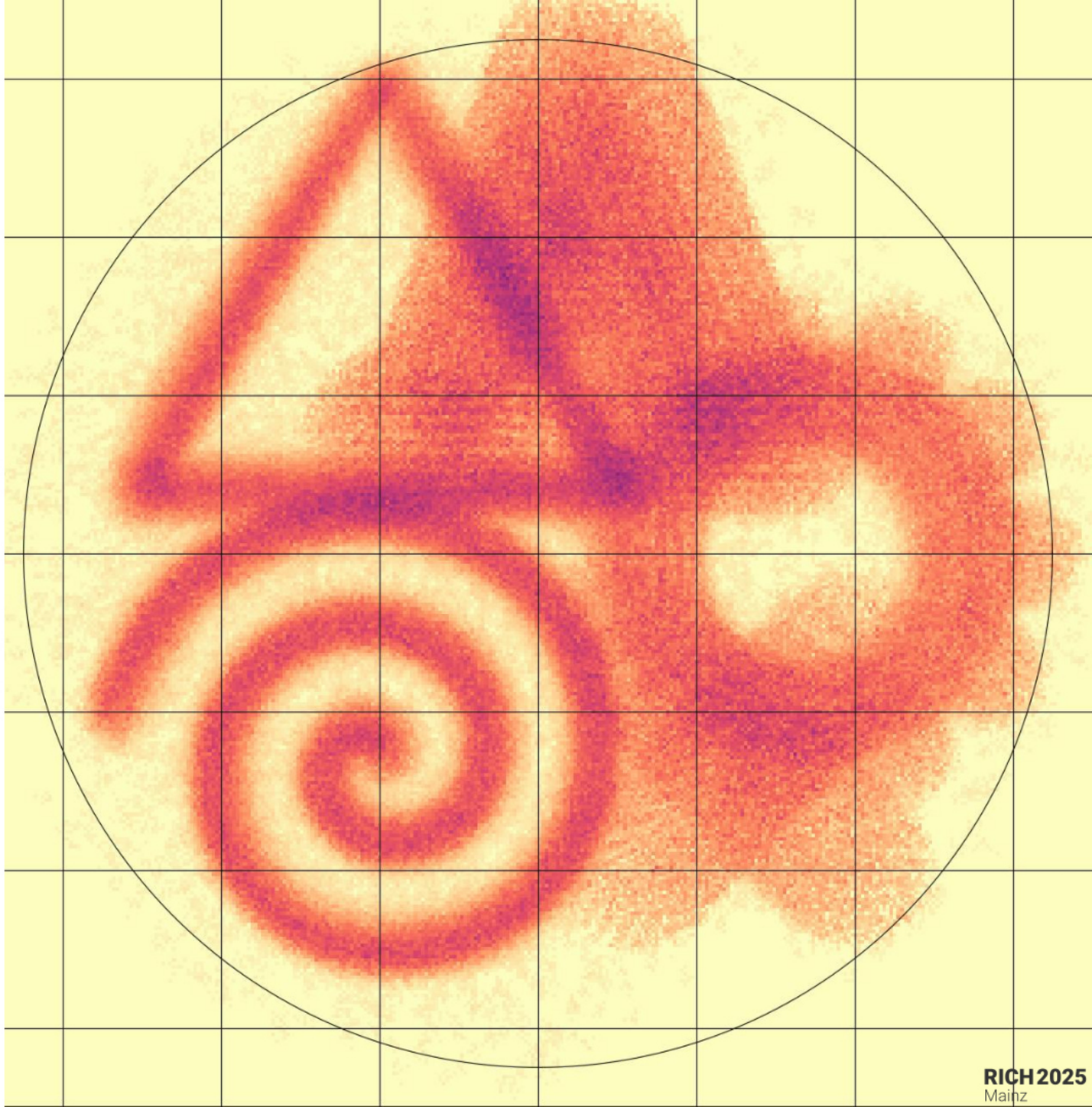


Optics

refocussing to any depth







Optics

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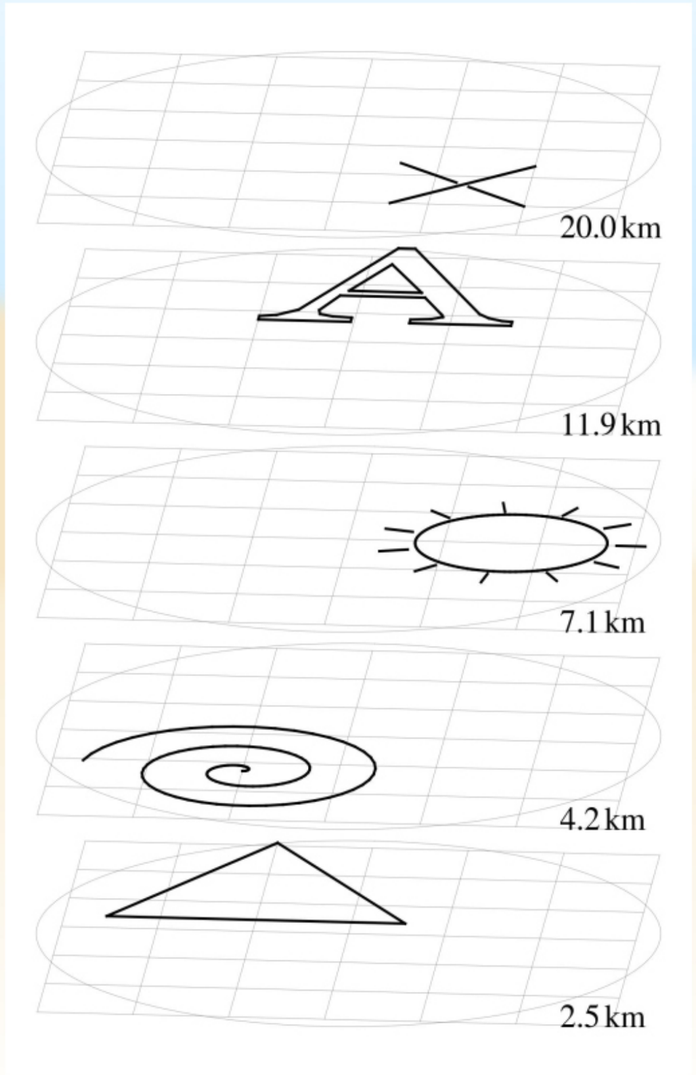

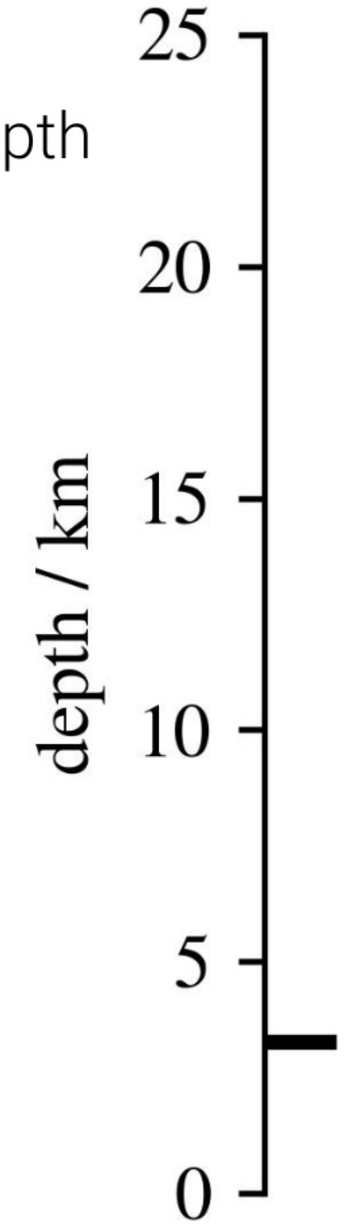

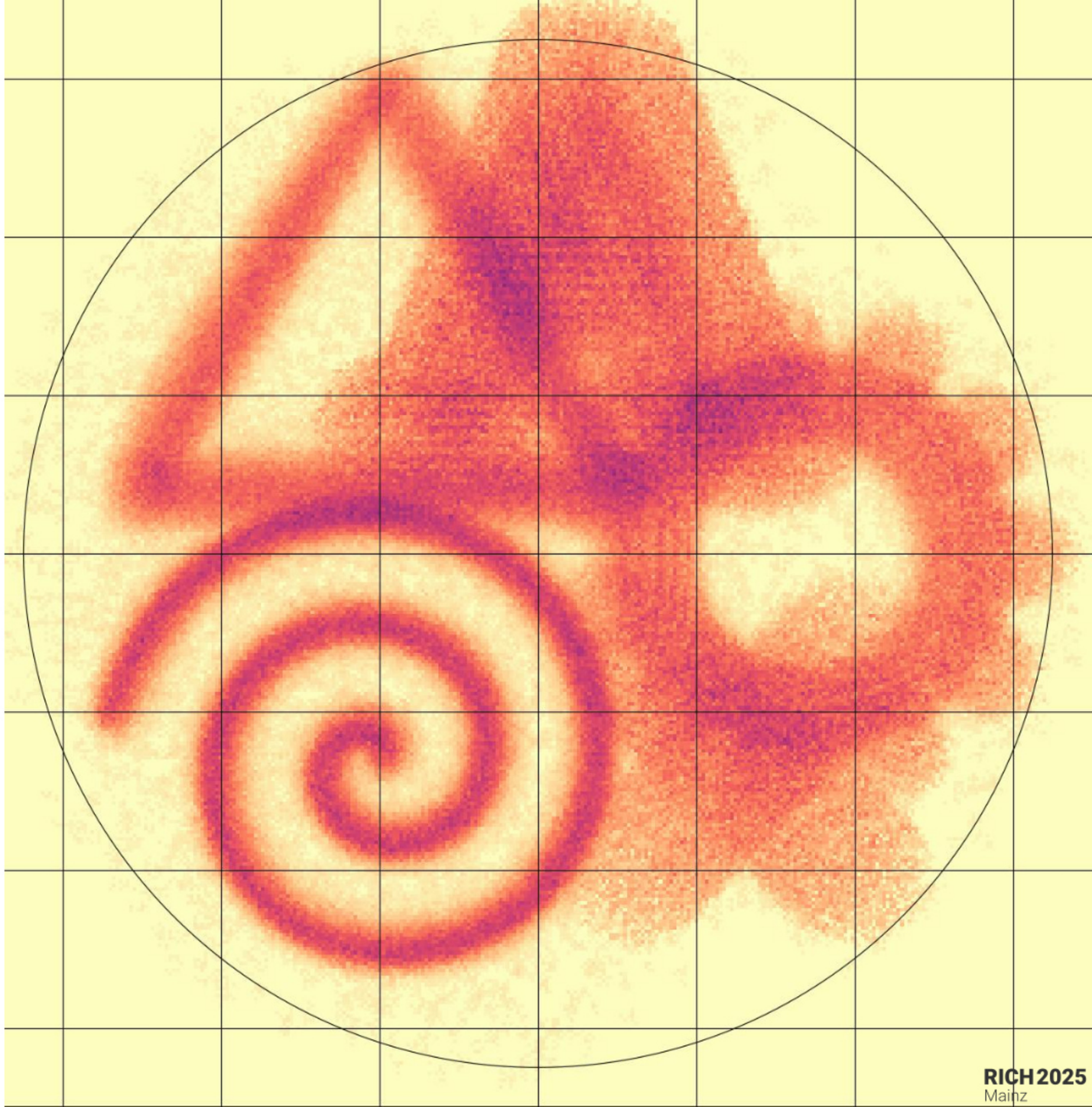

Optics

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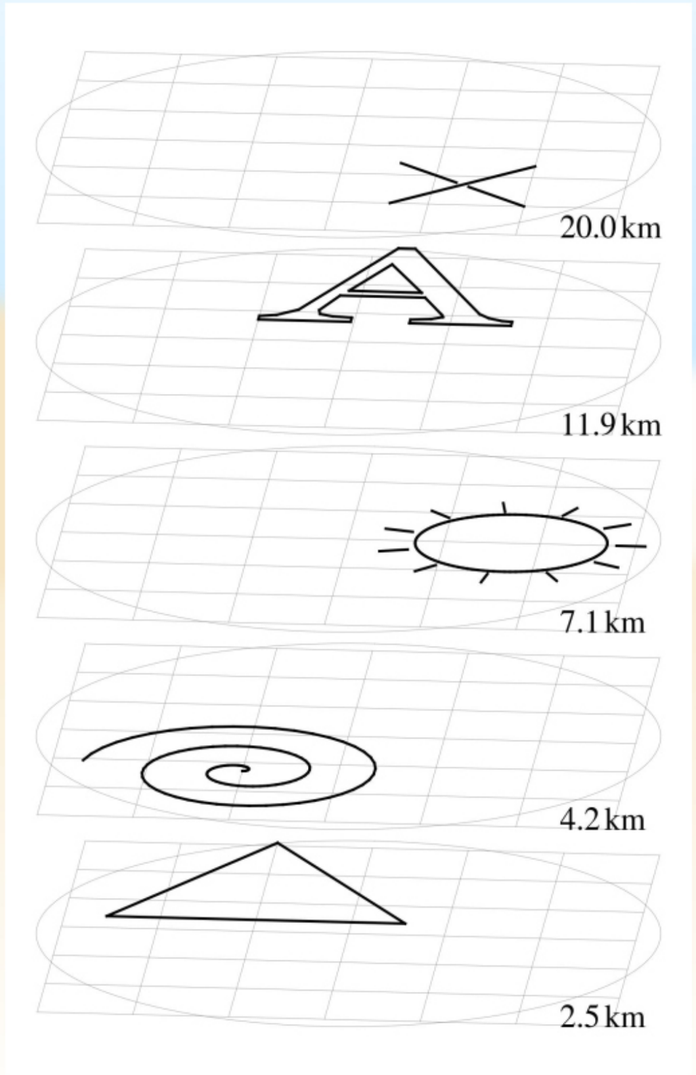

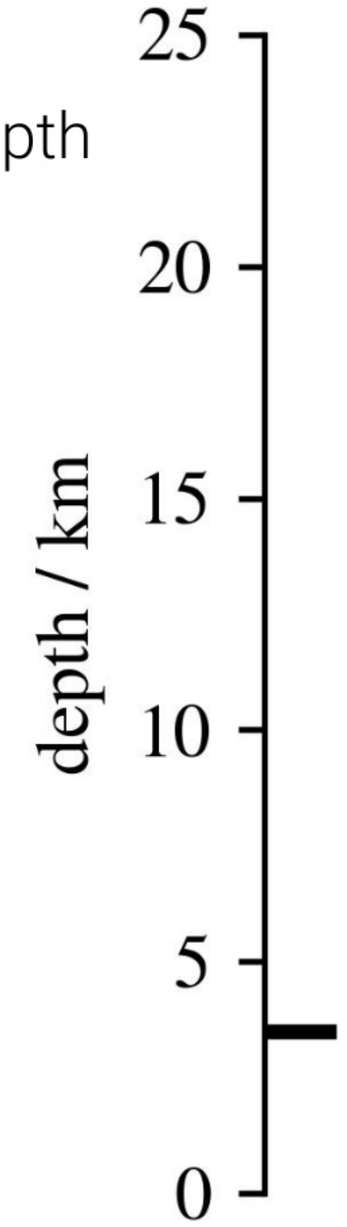

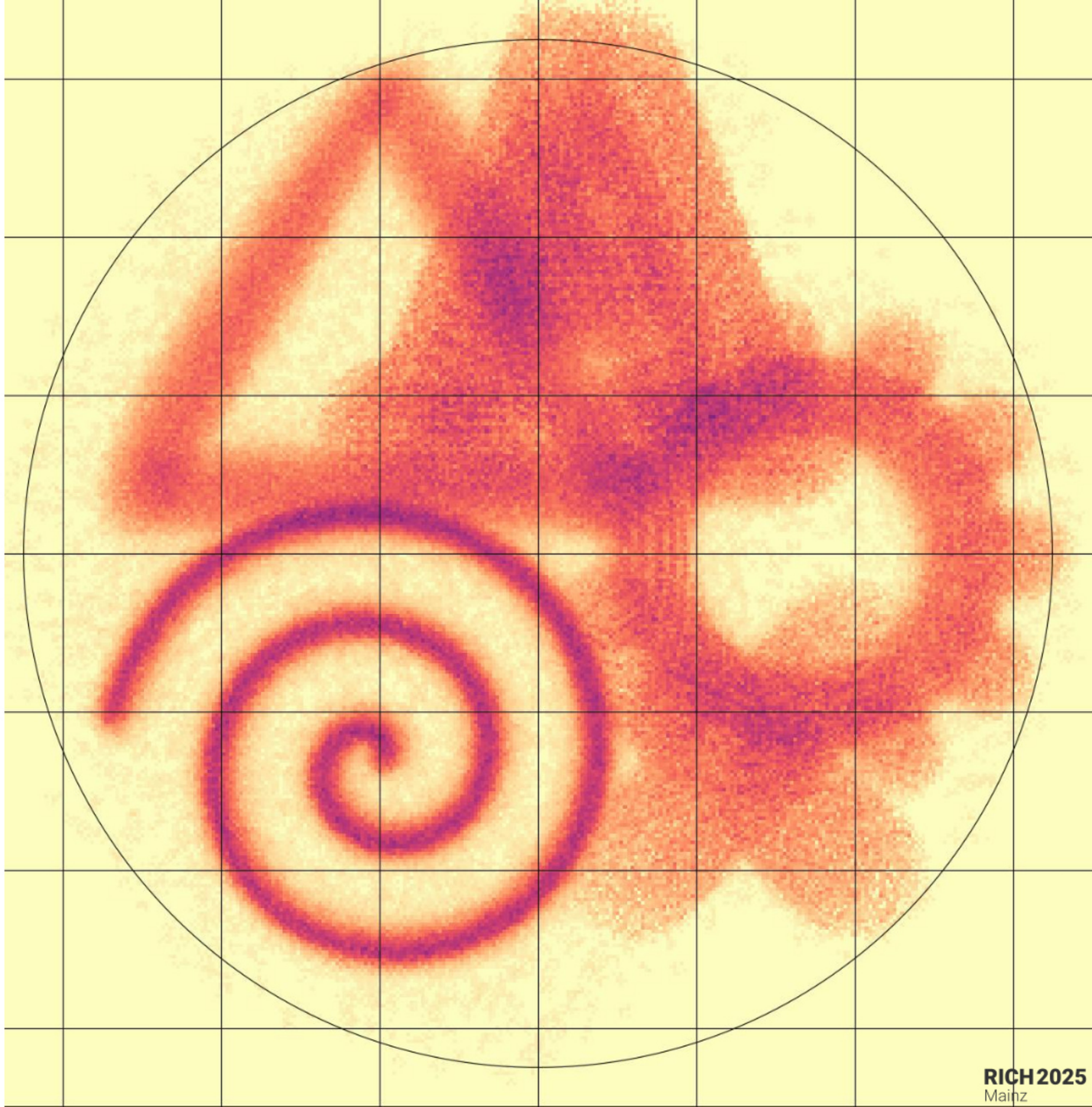

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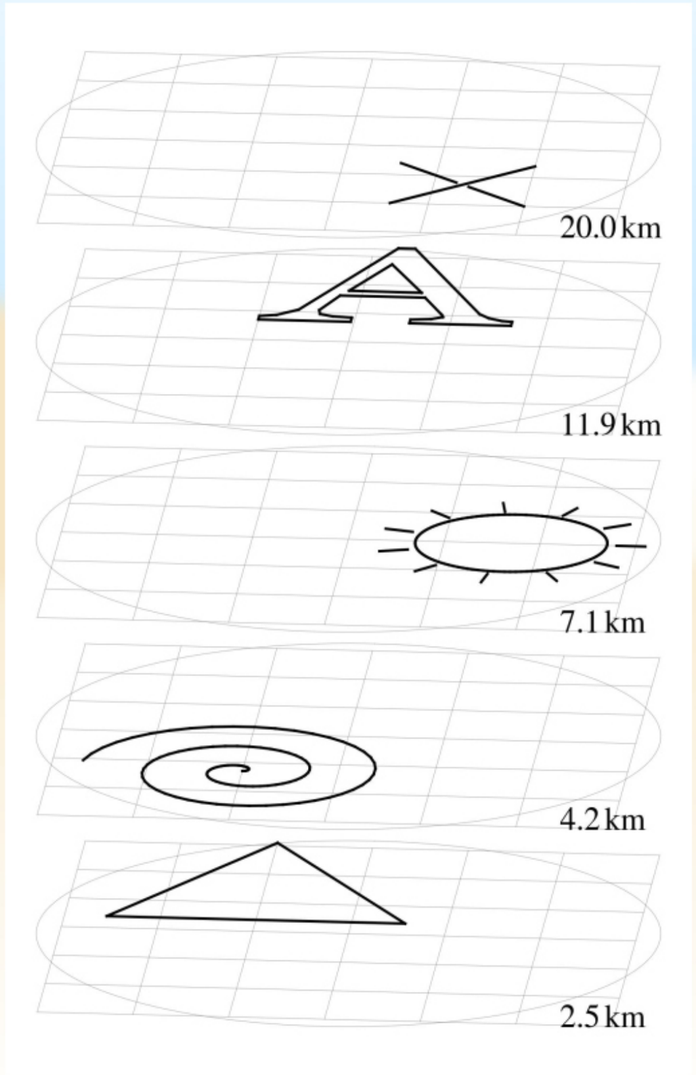

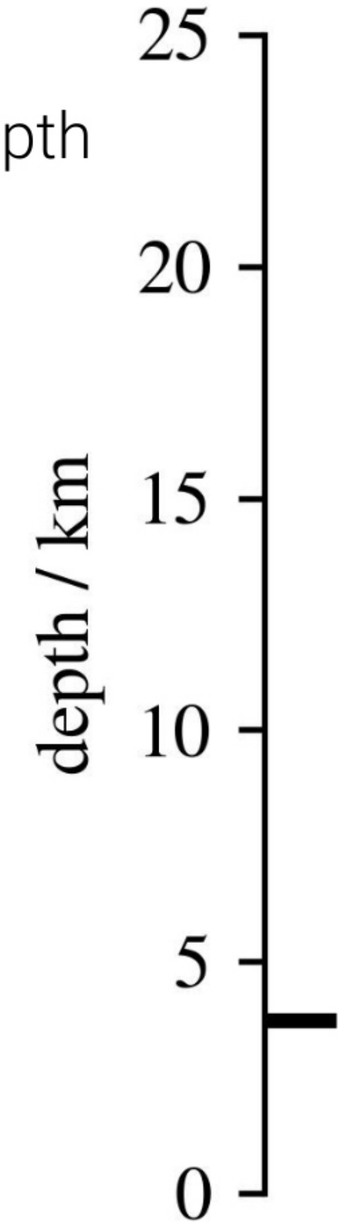

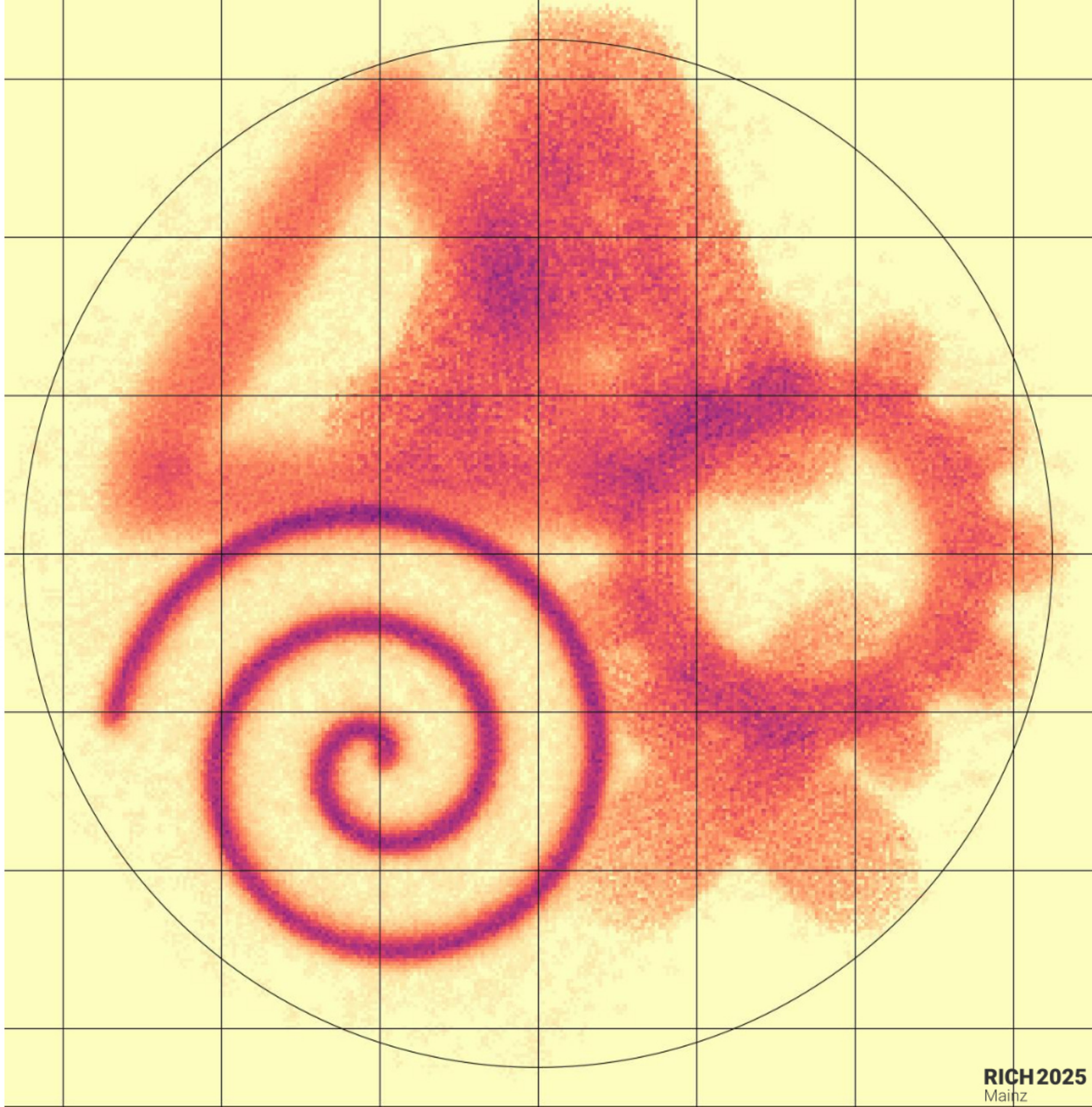

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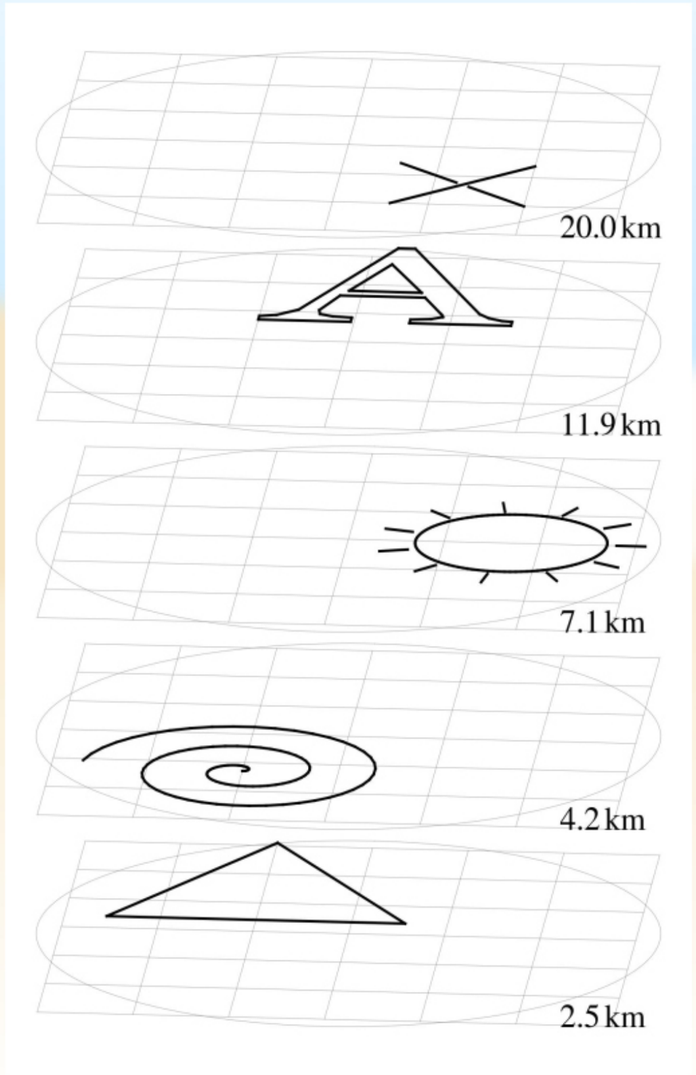

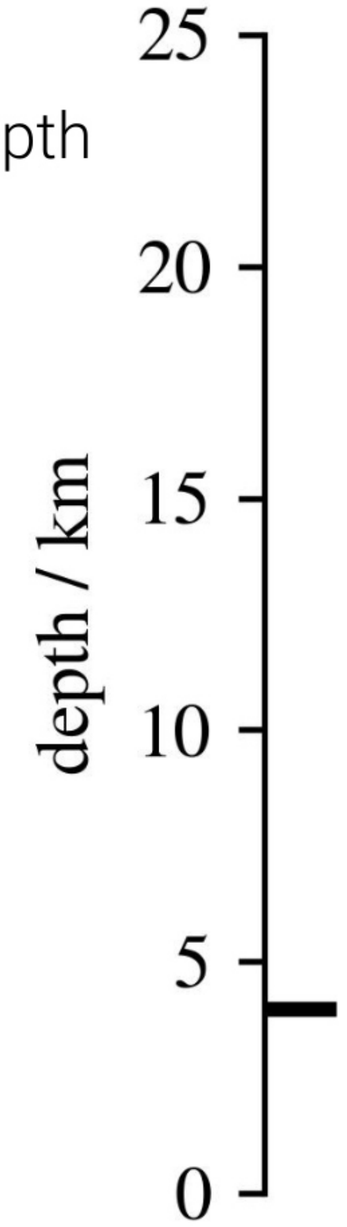

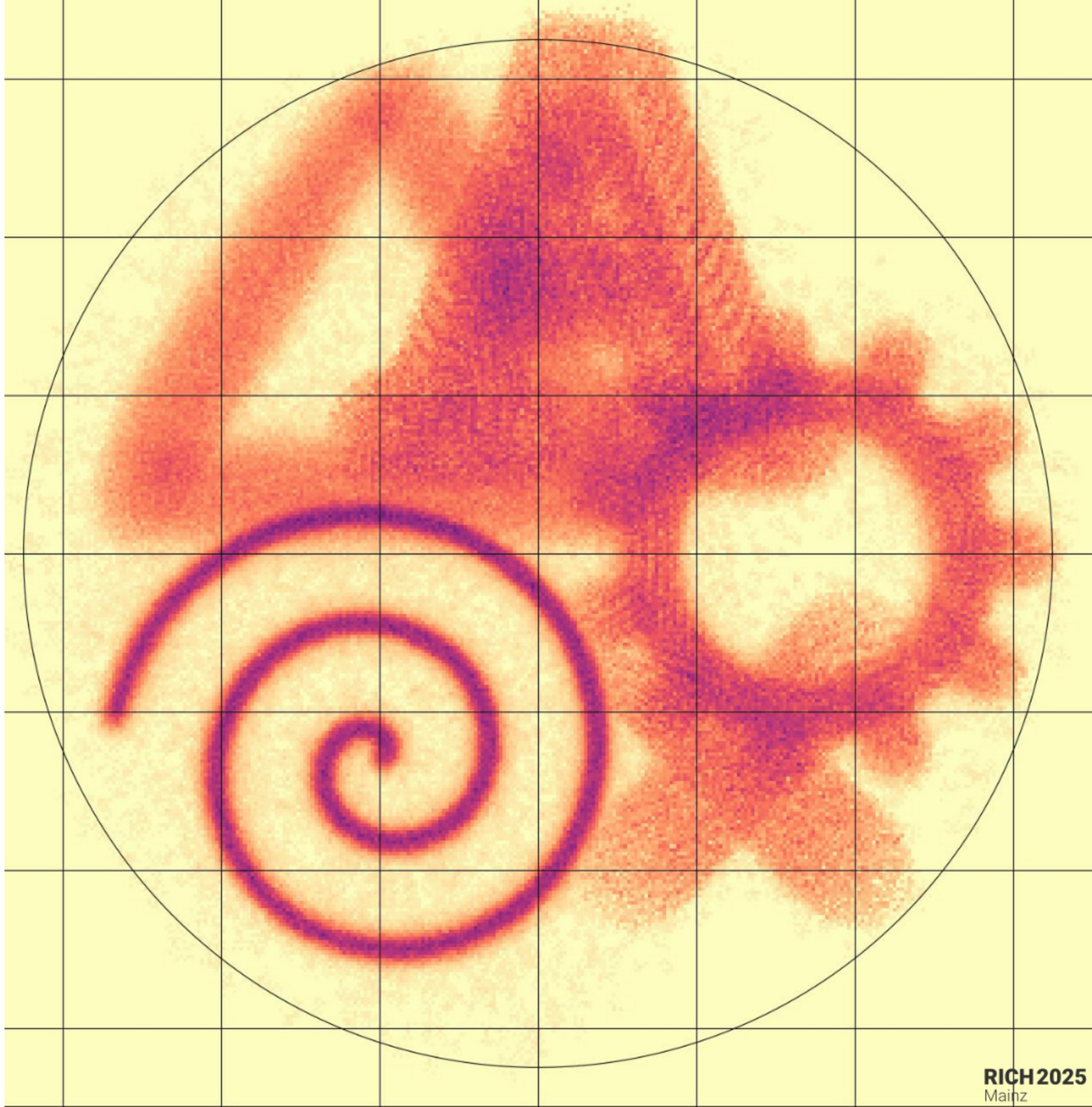

Optics

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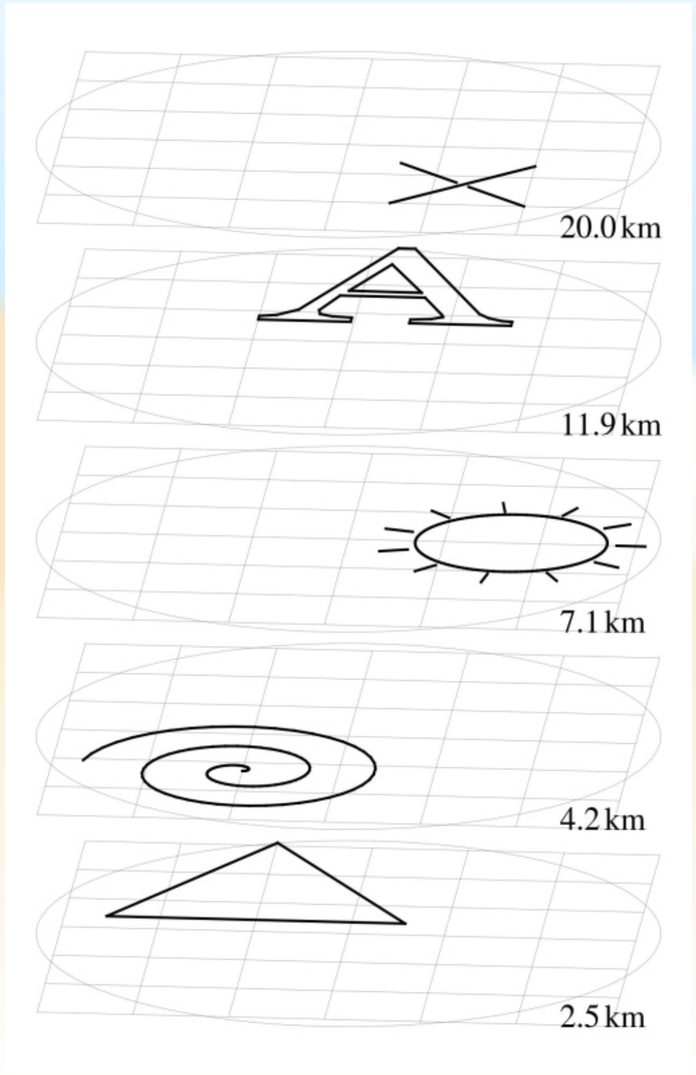

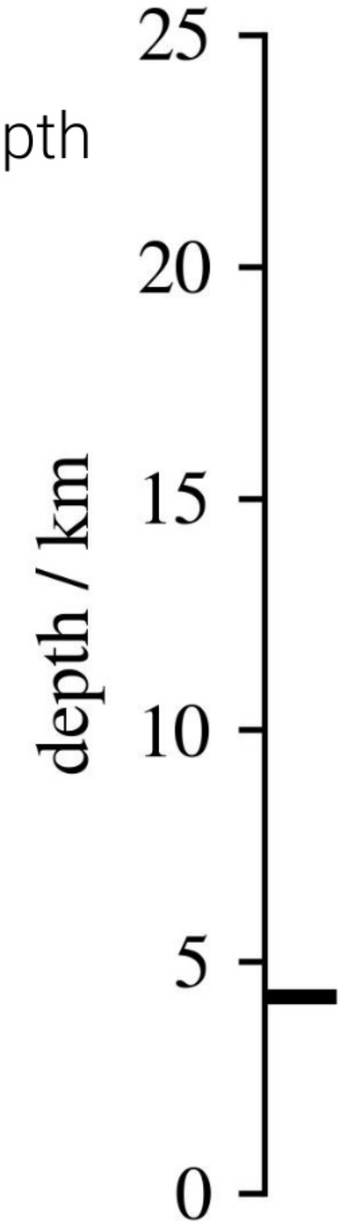

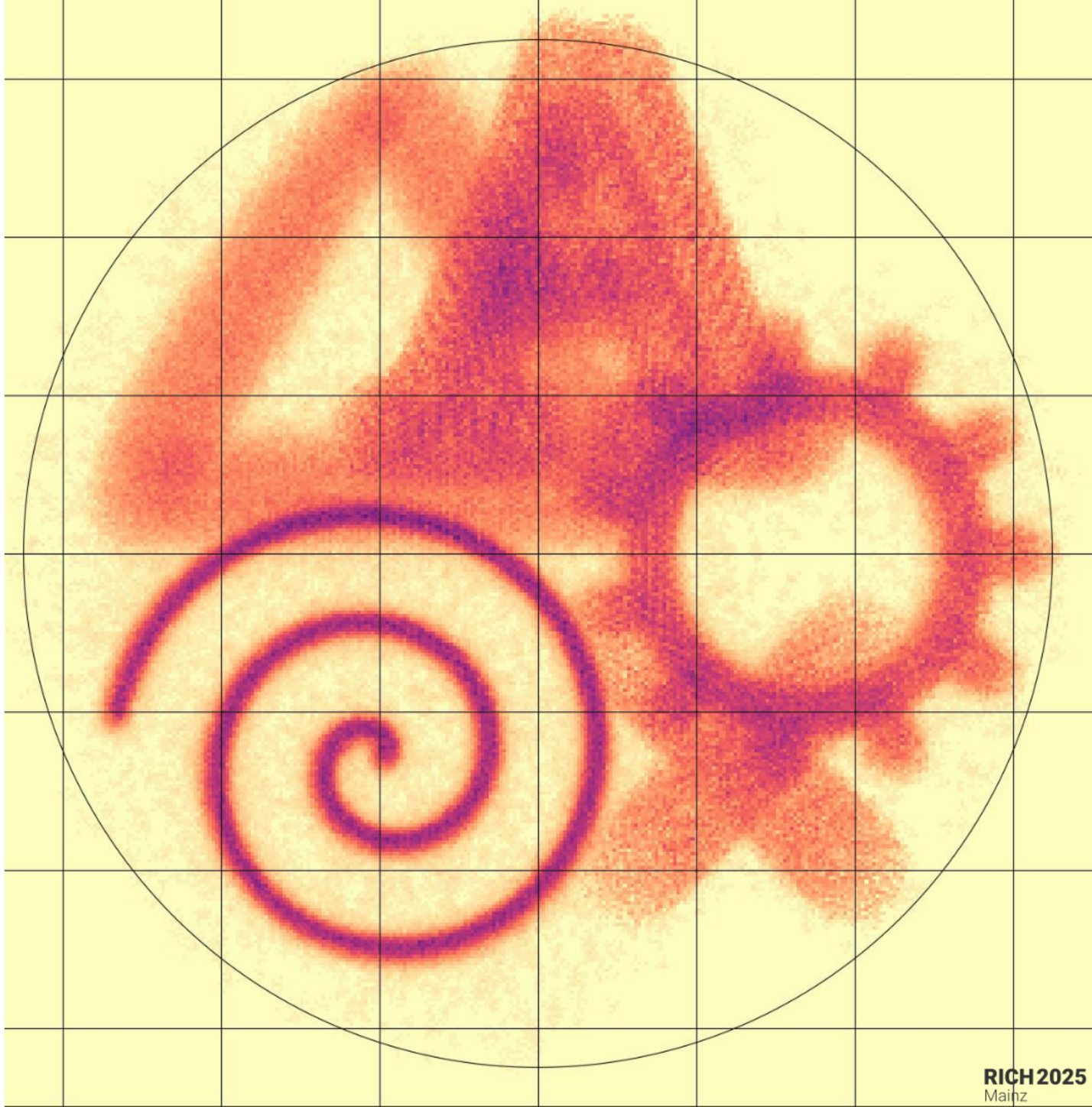

Optics

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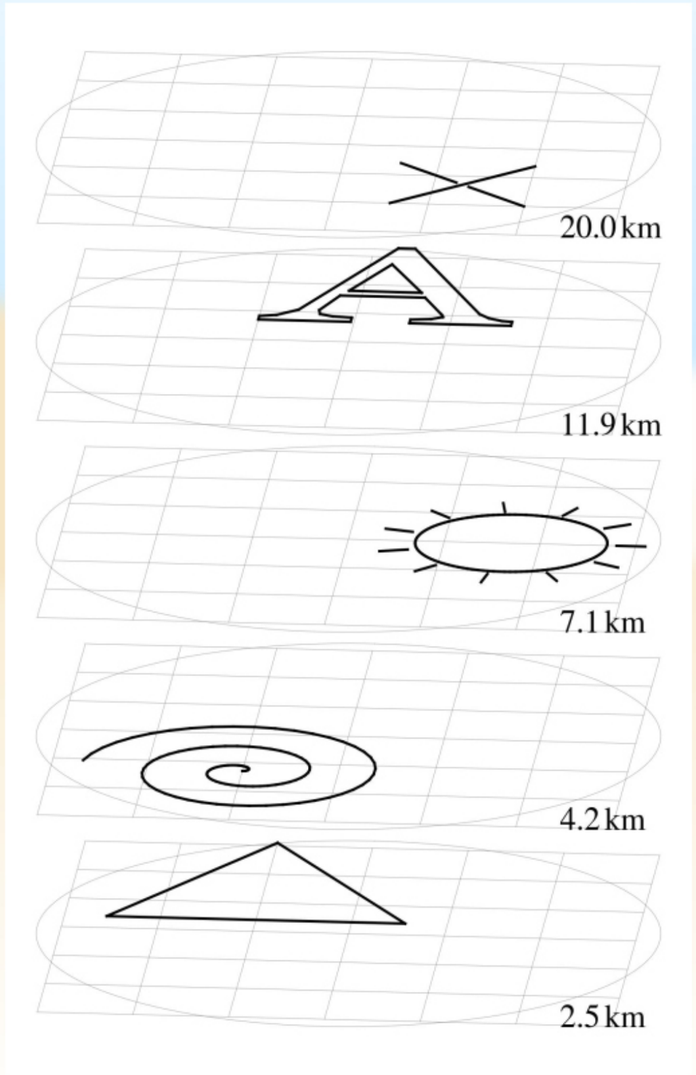
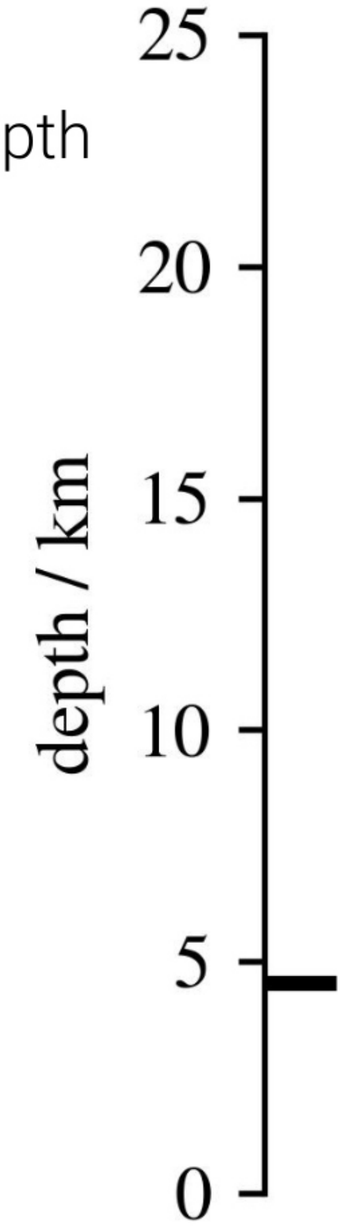
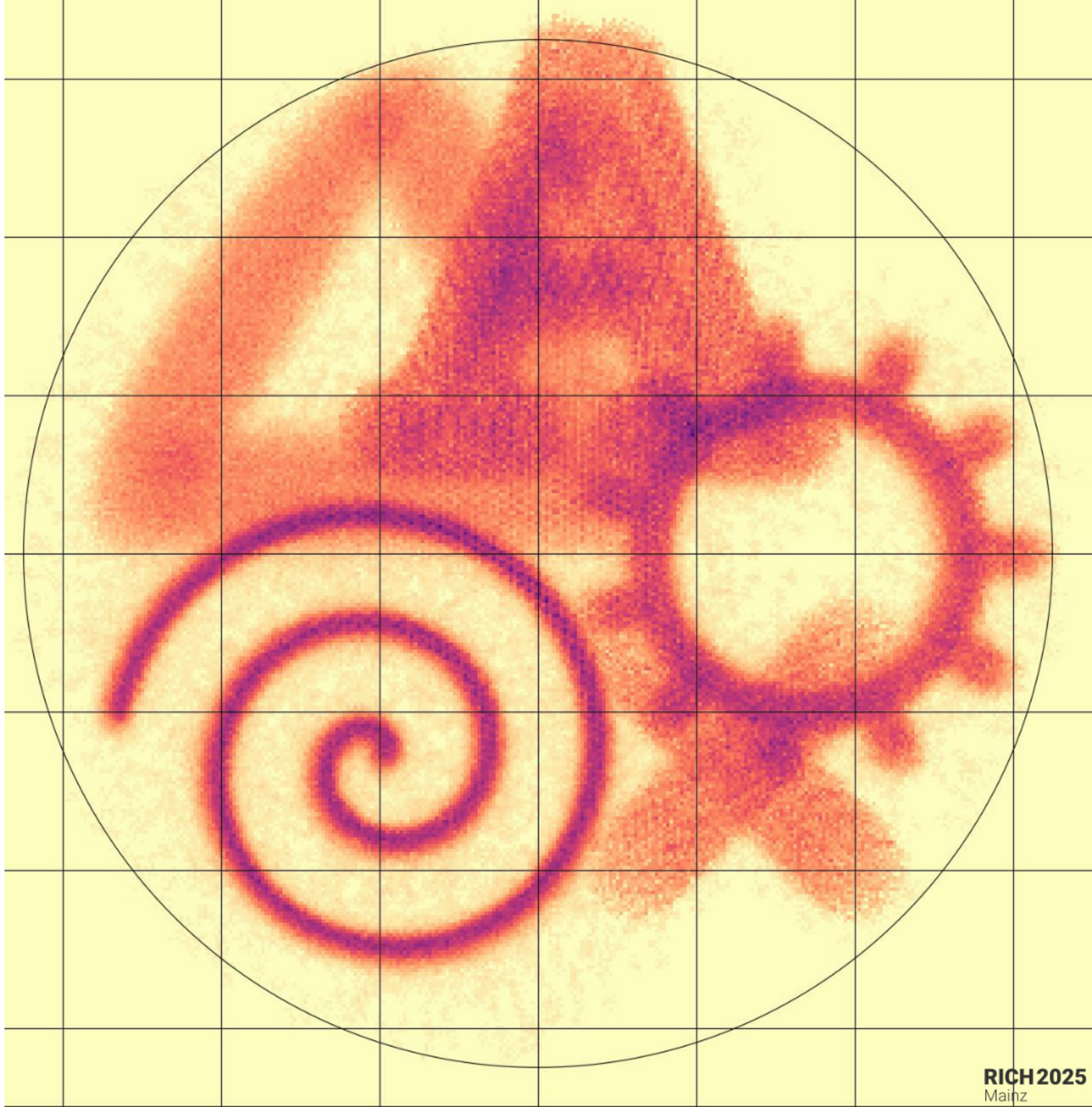
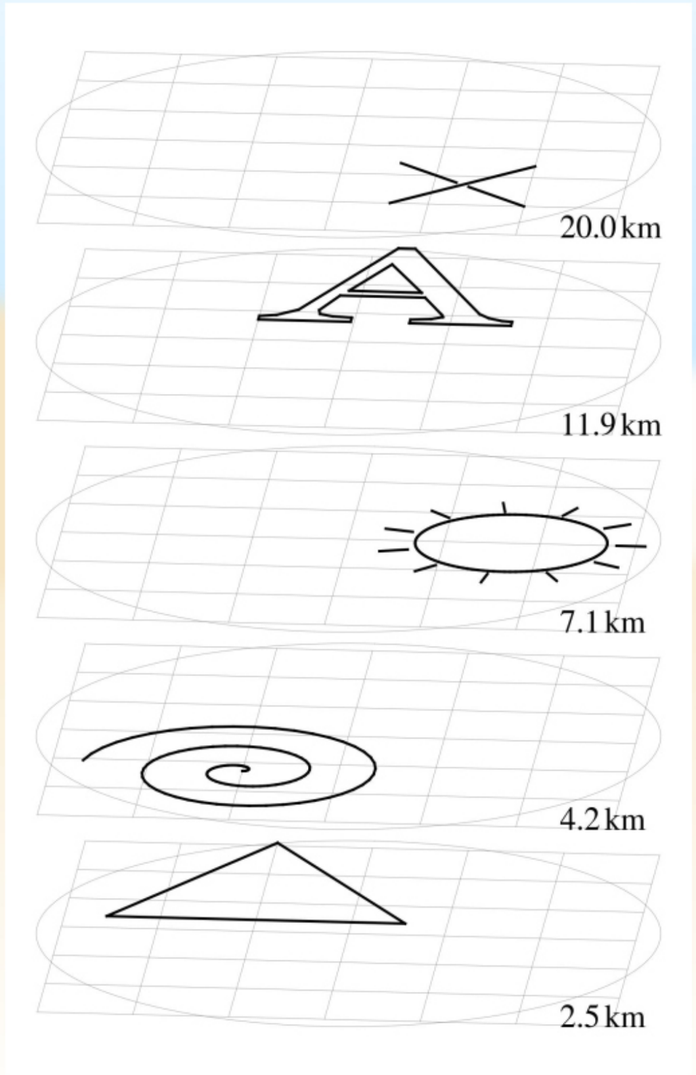


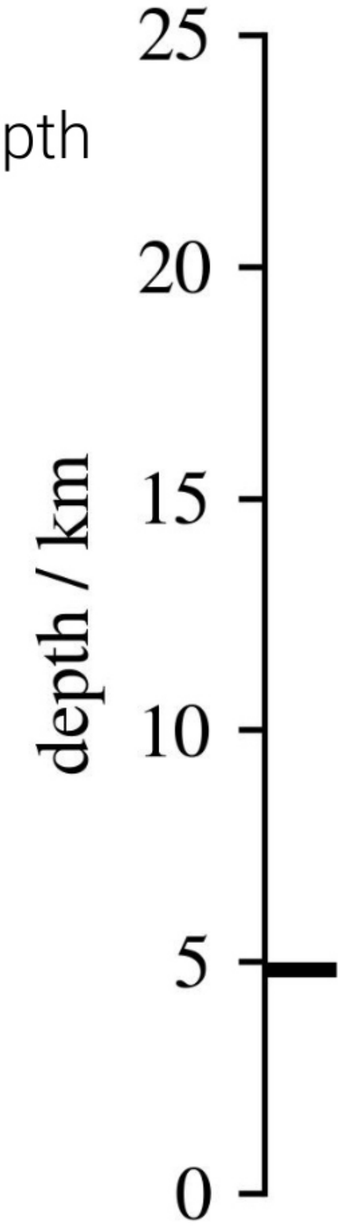


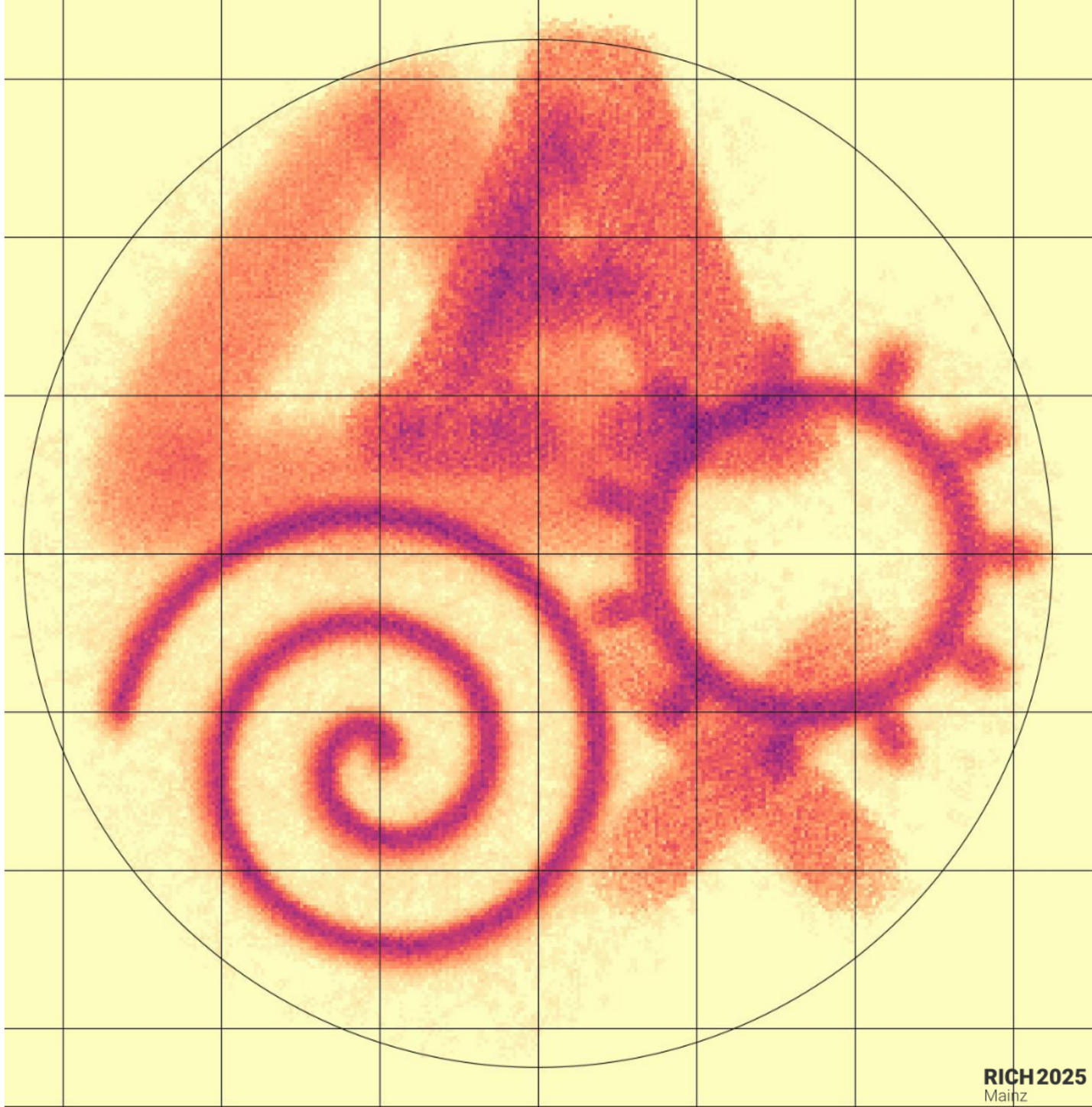


Optics

refocussing to any depth







Optics

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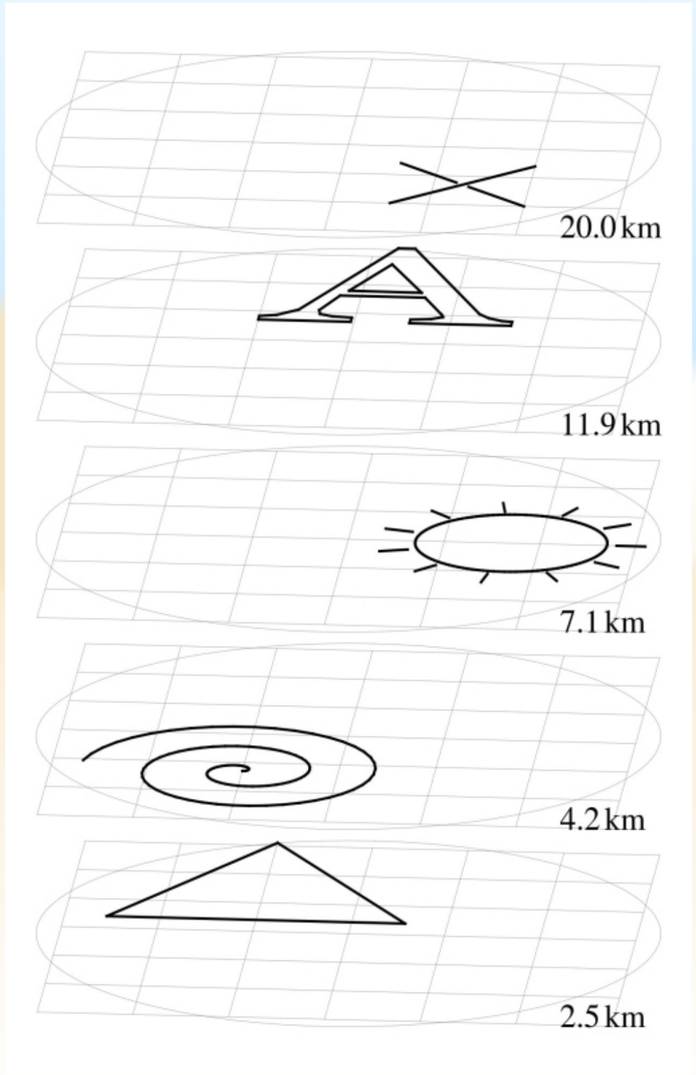

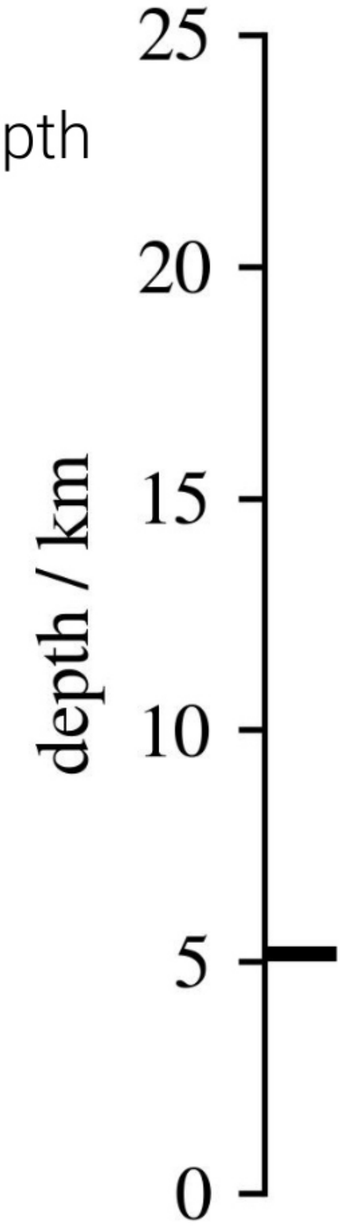

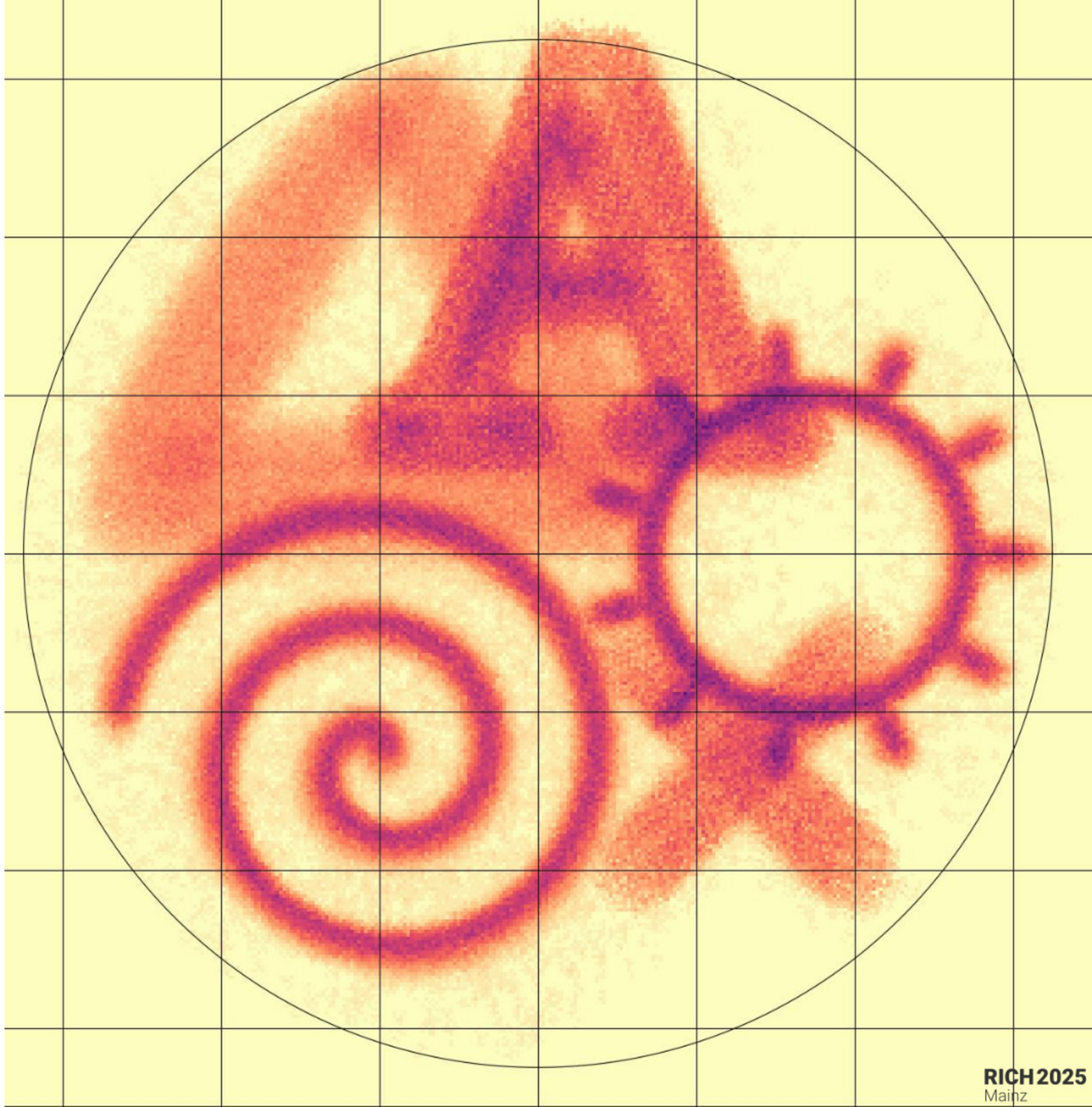

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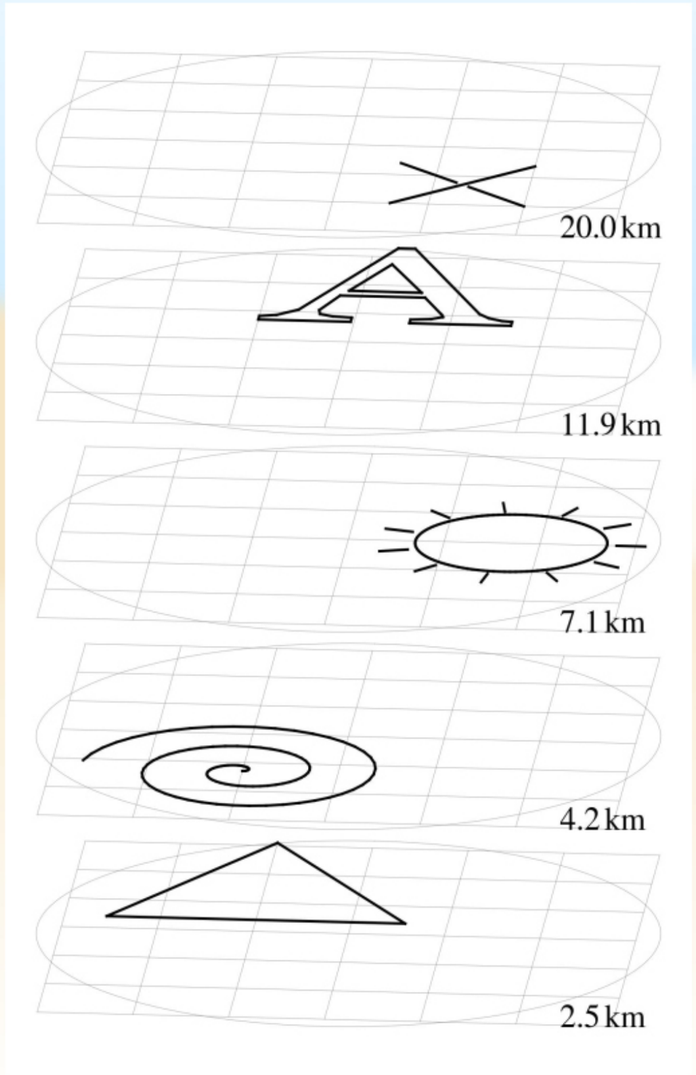
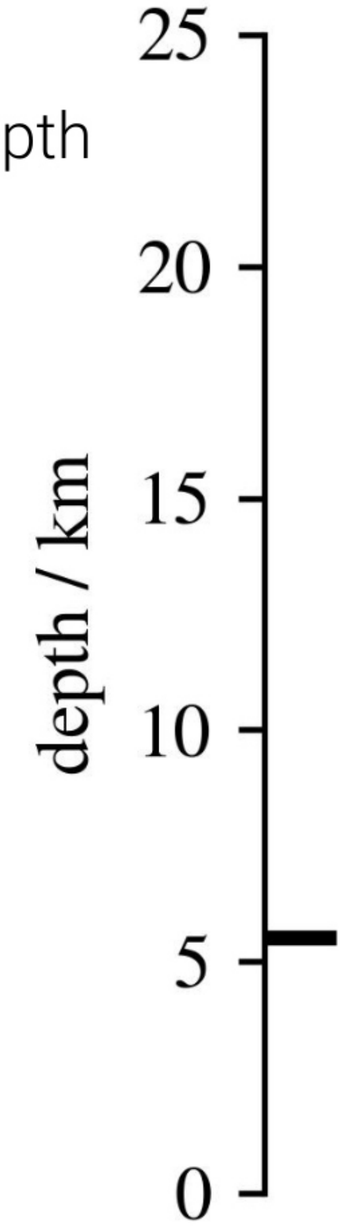
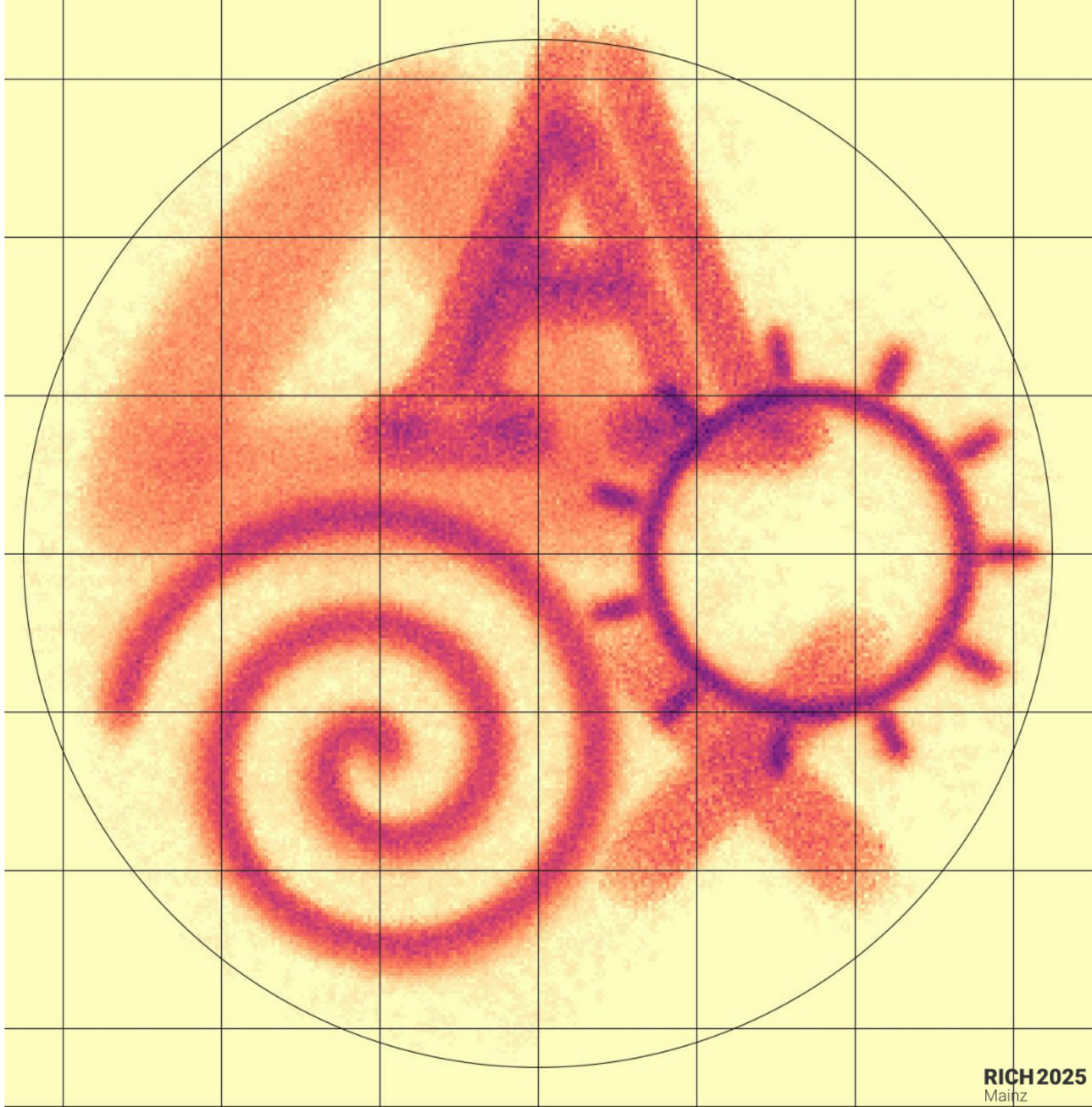
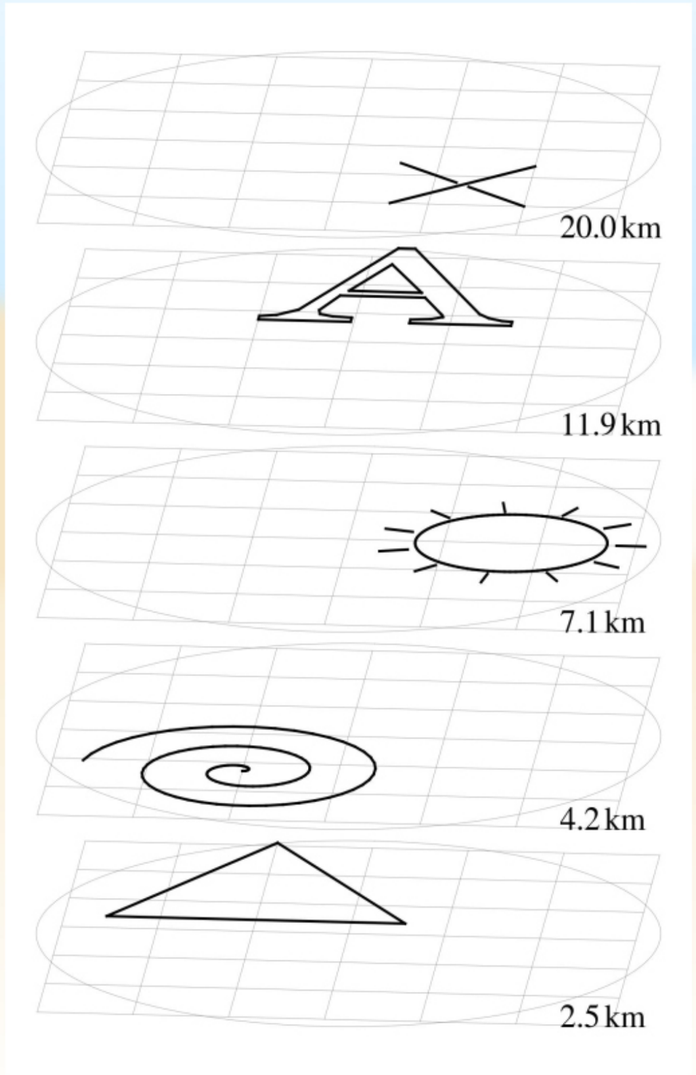


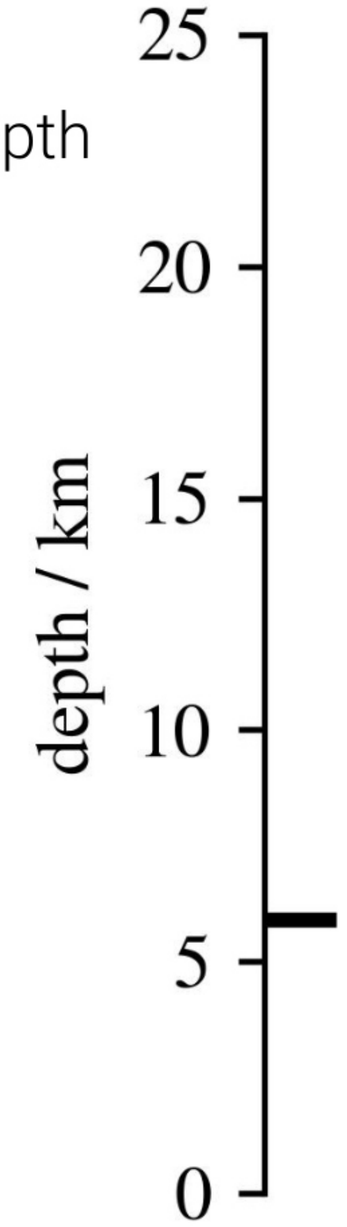


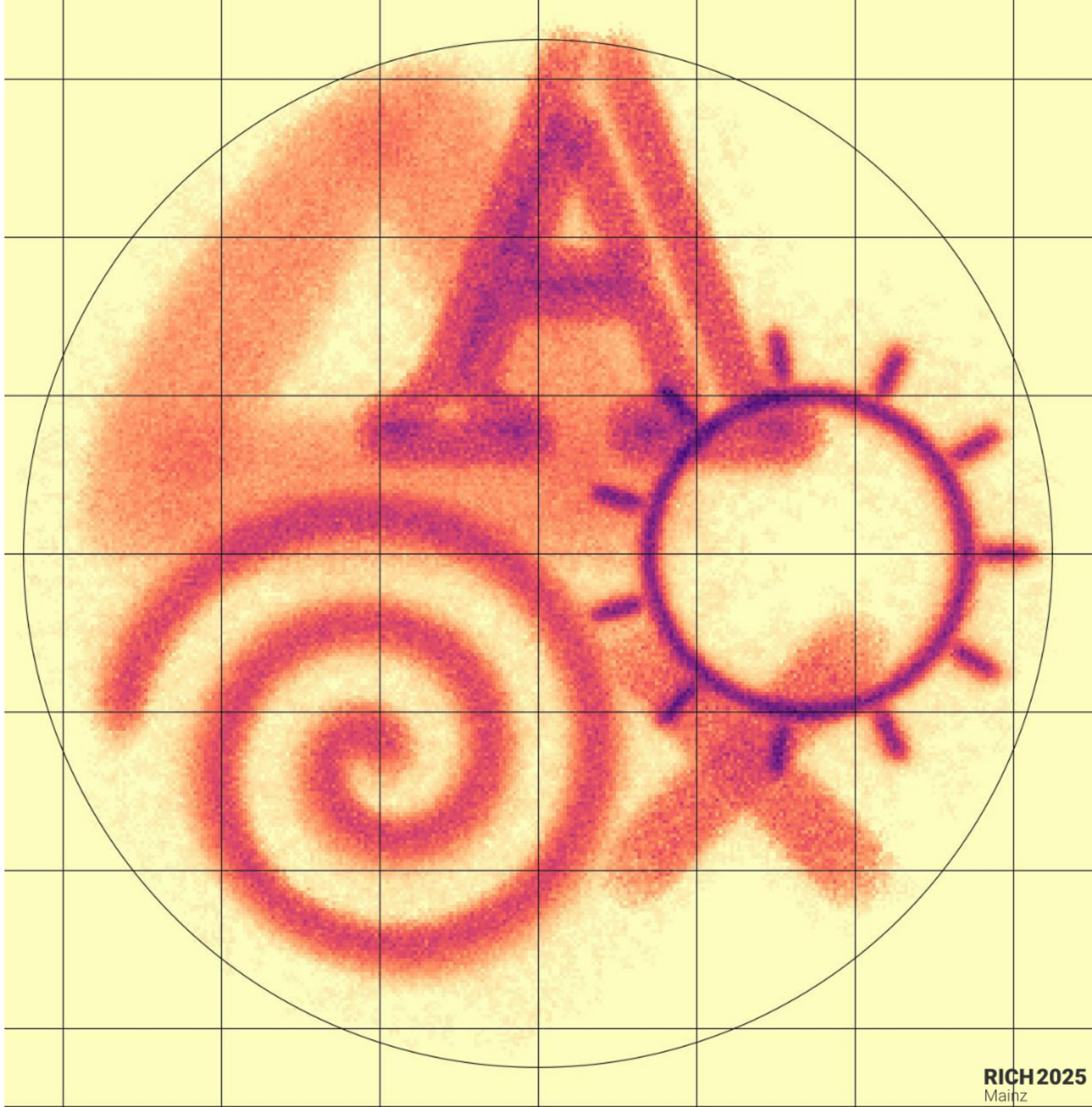


Optics

refocussing to any depth

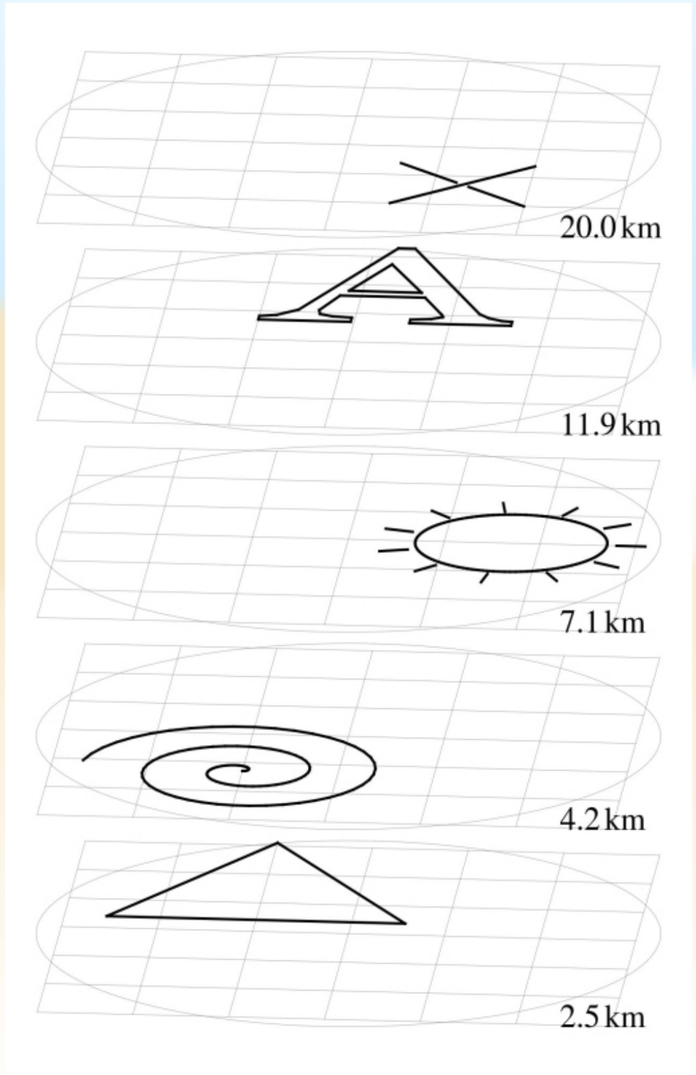


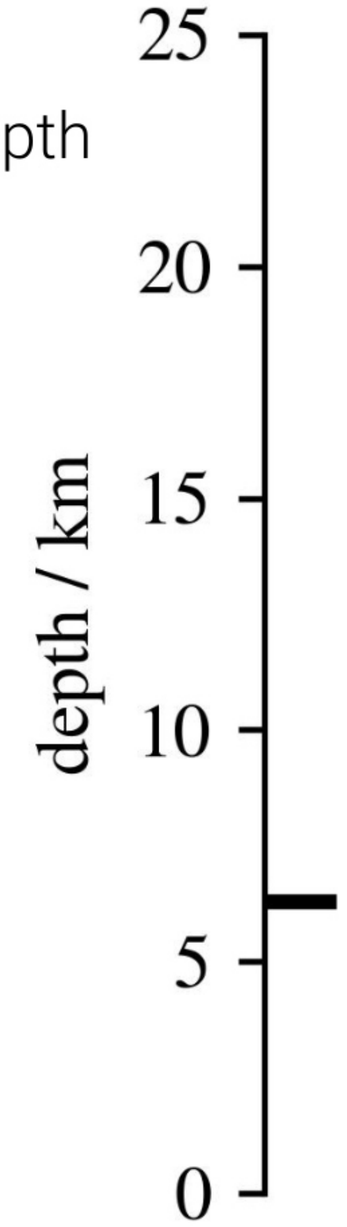


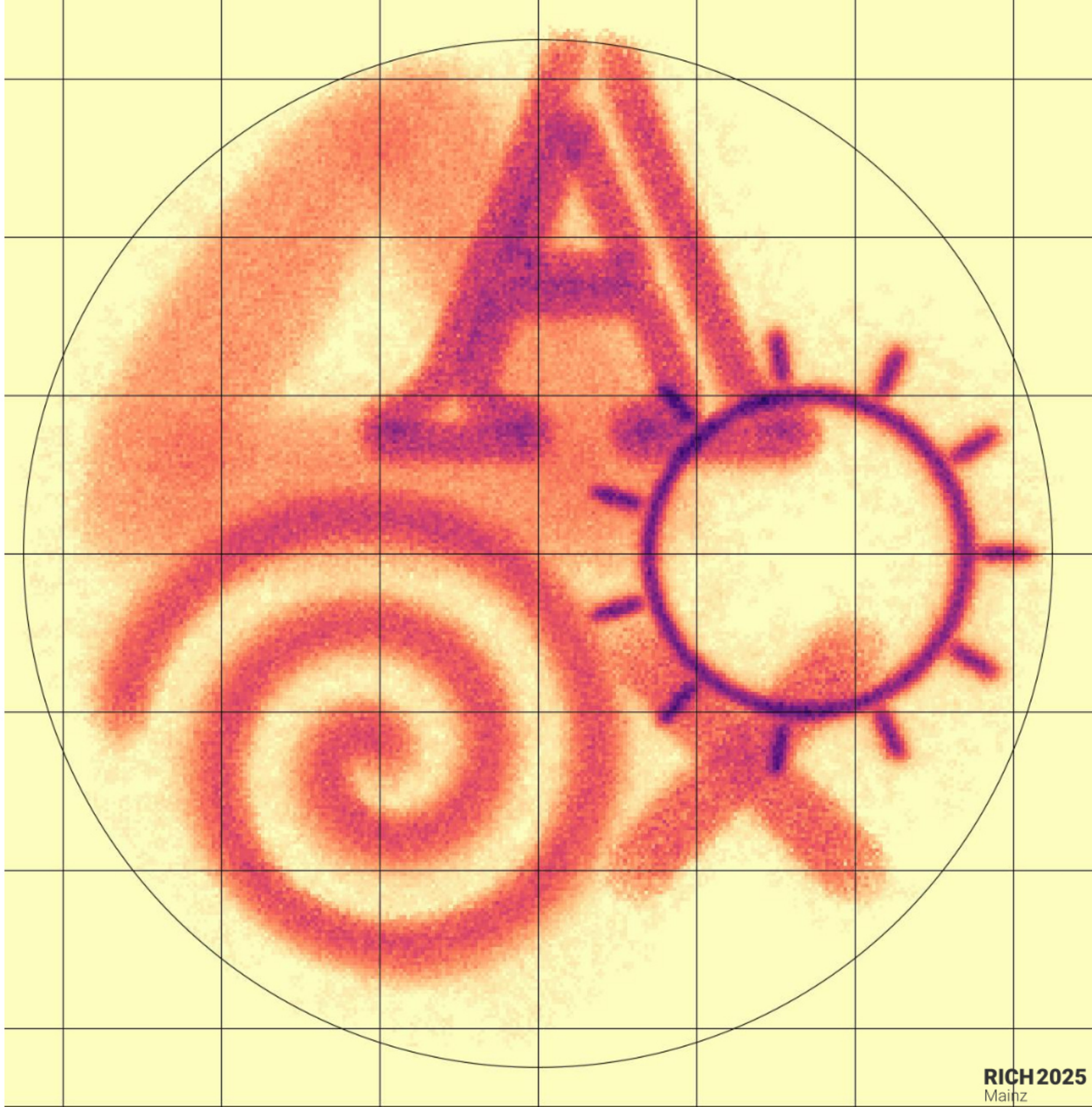


Optics

refocussing to any depth







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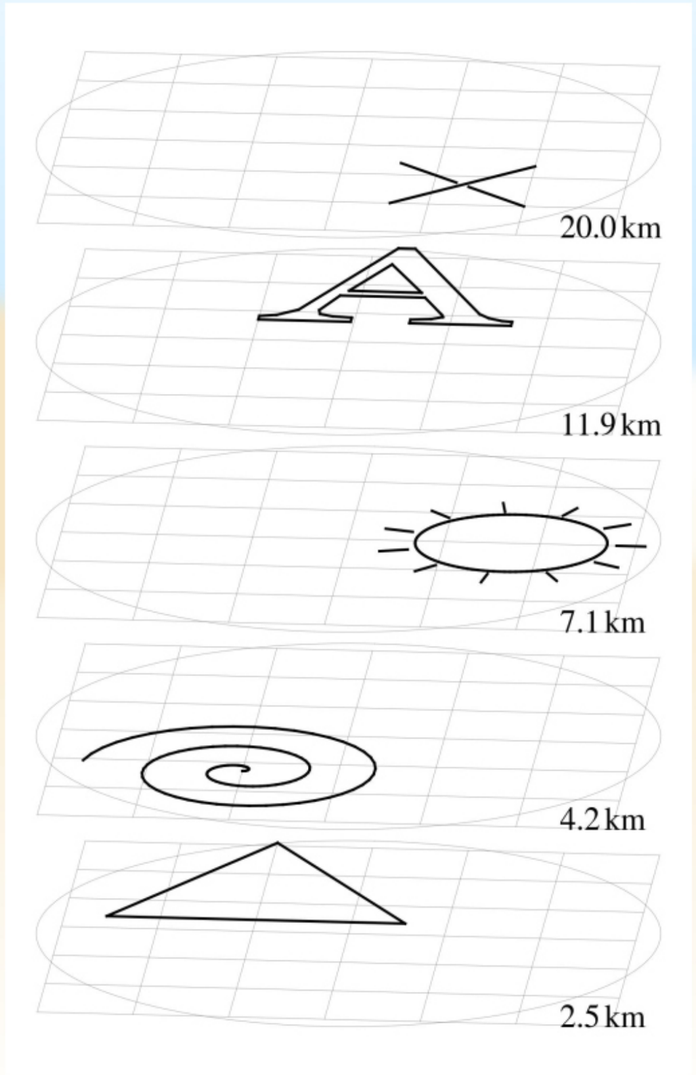

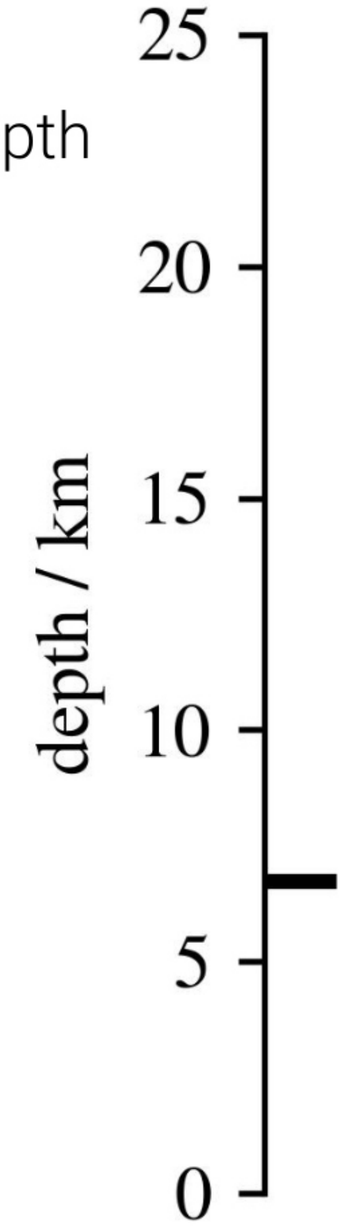

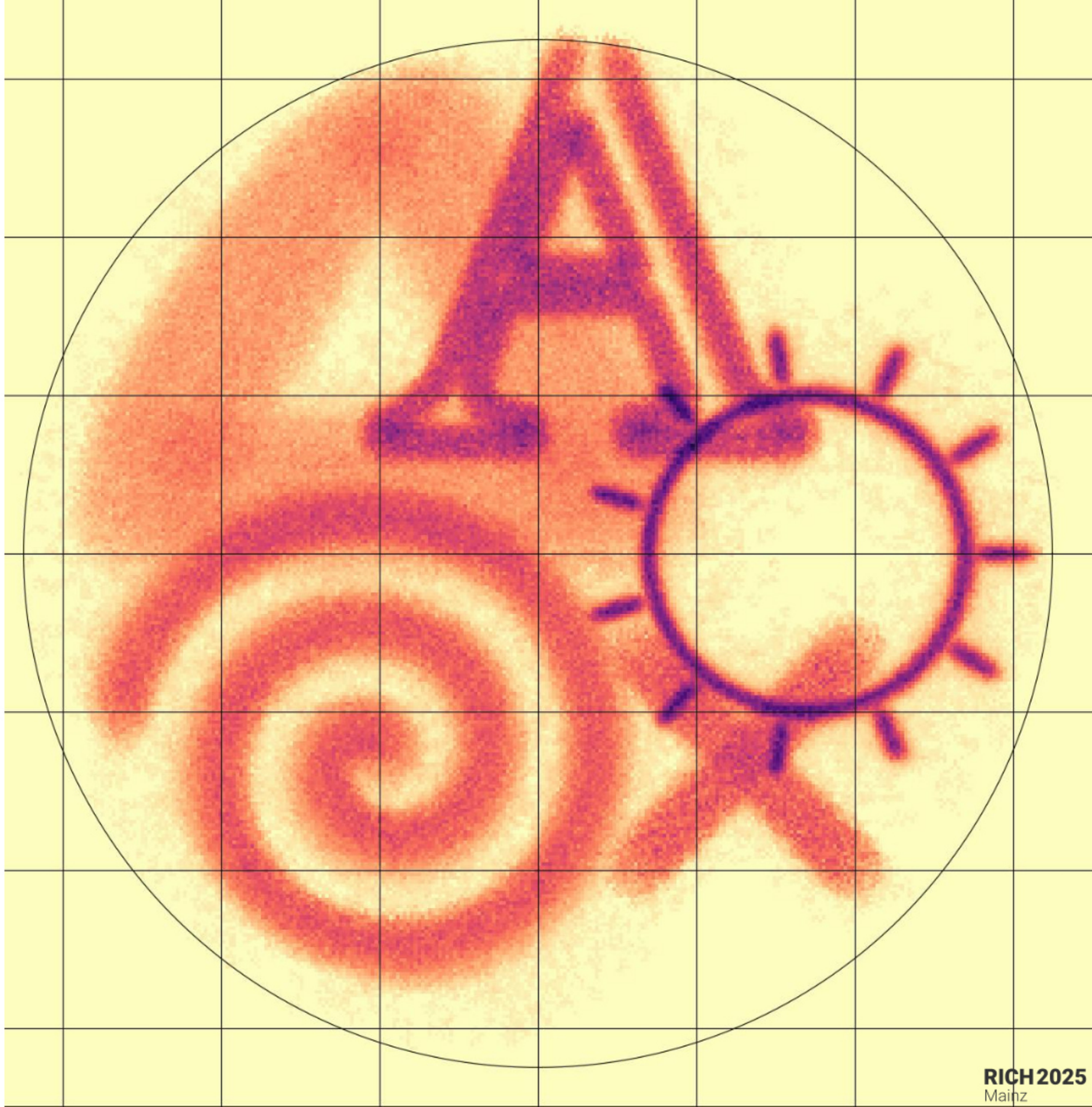

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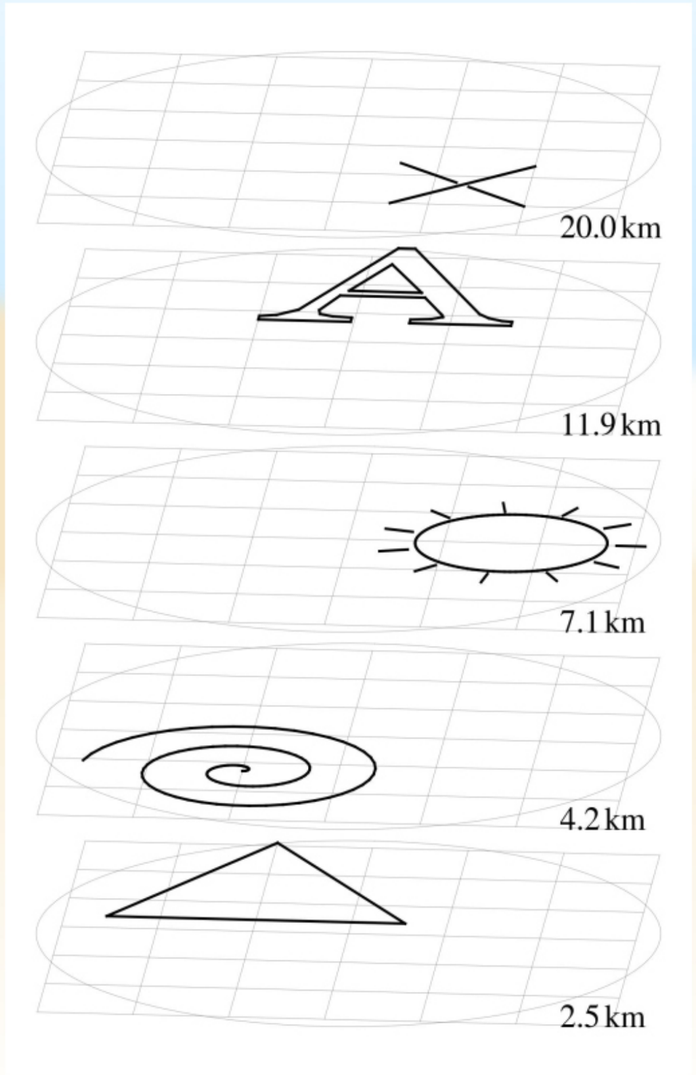

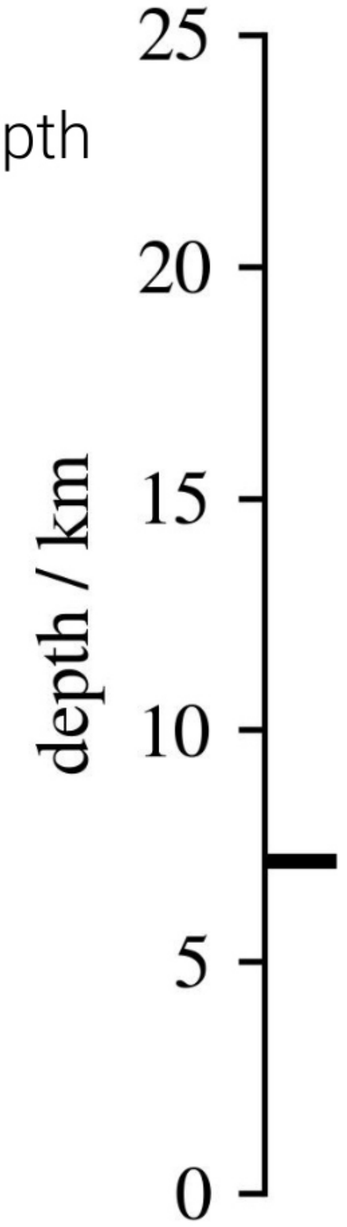

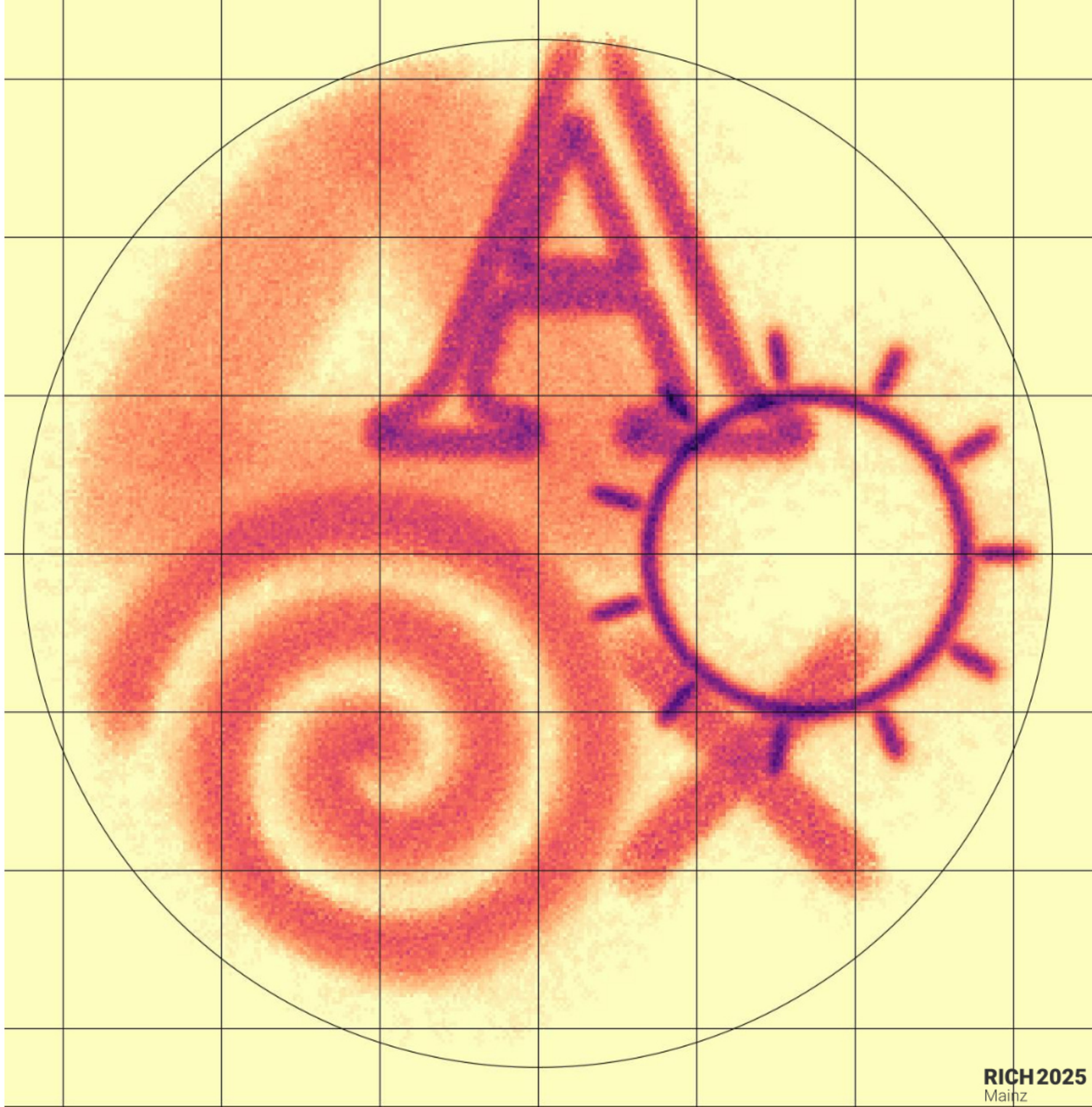

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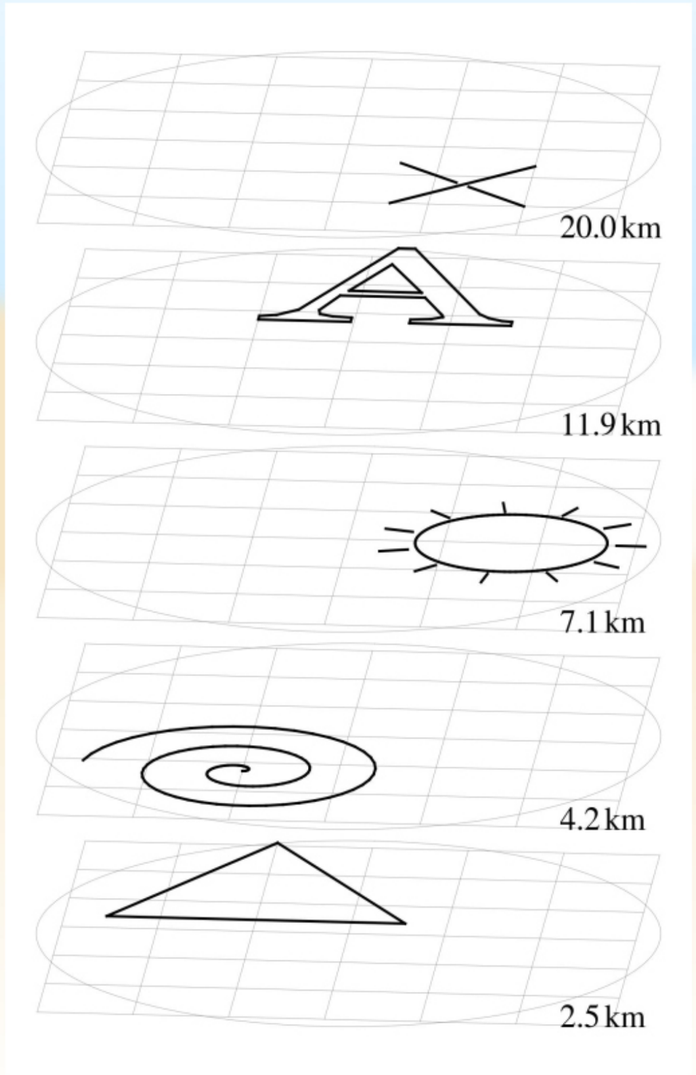

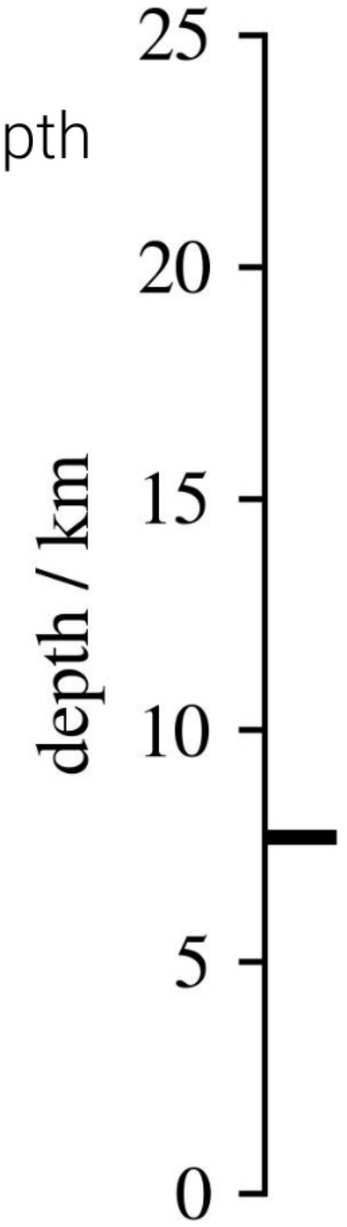

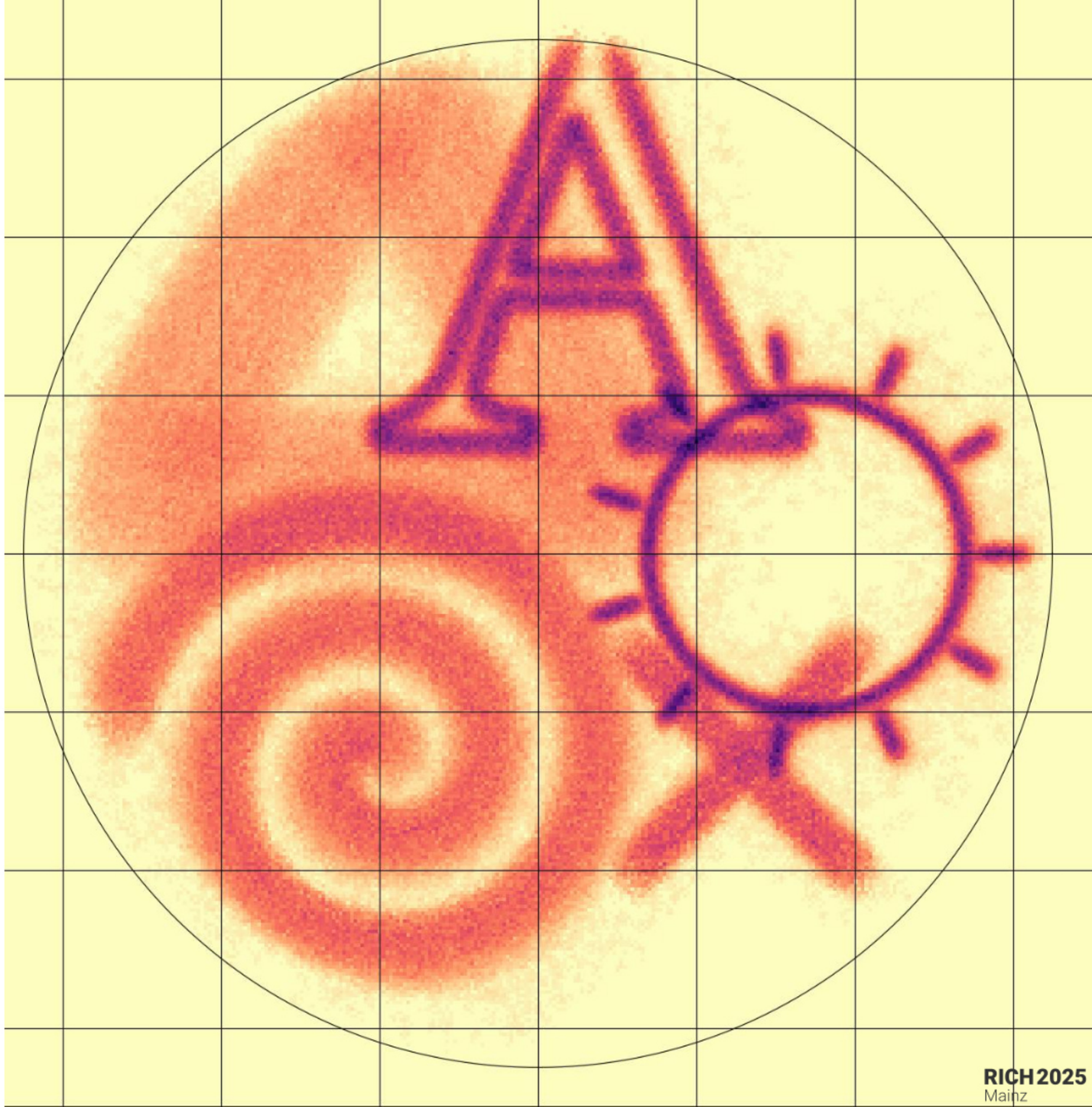

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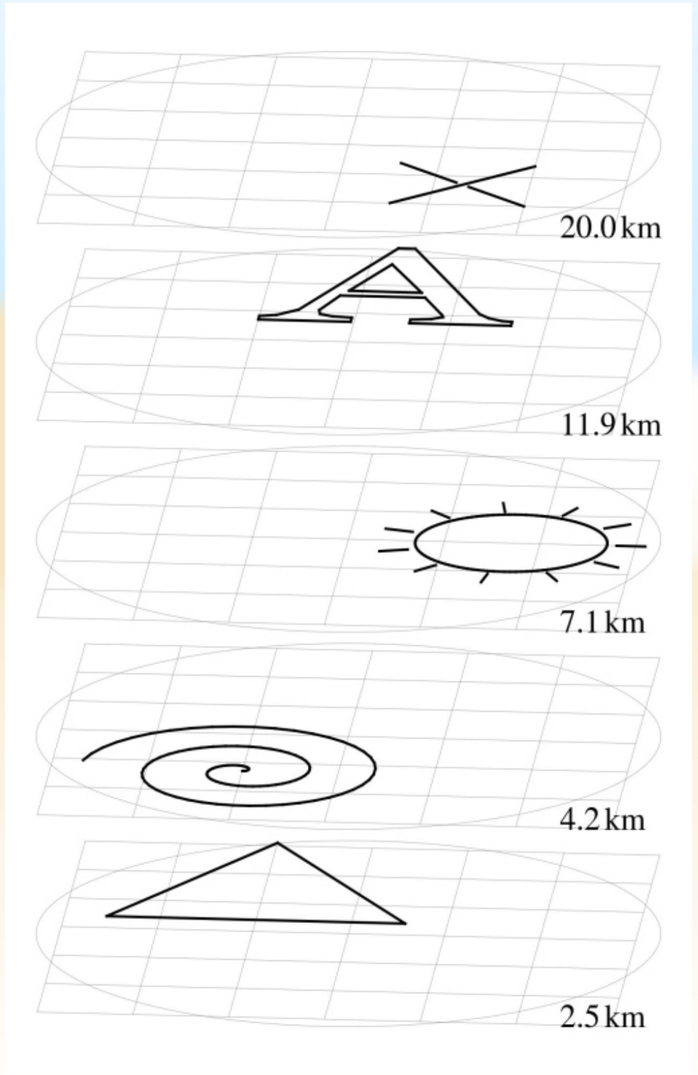

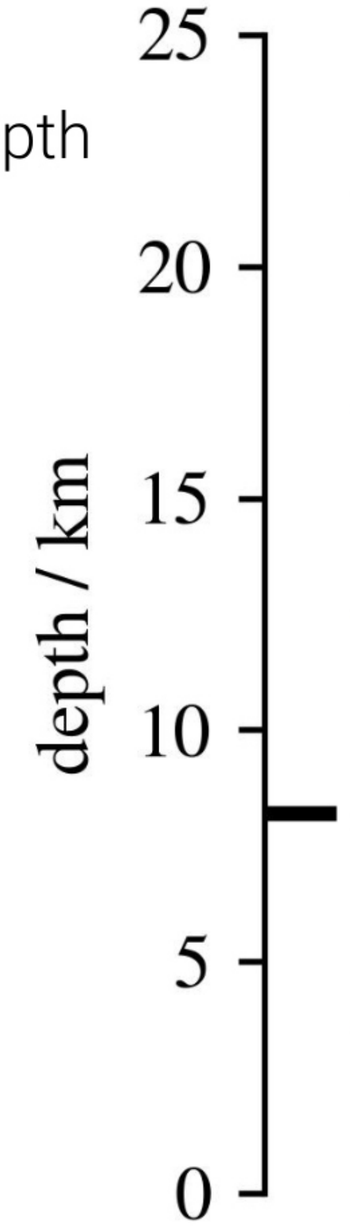

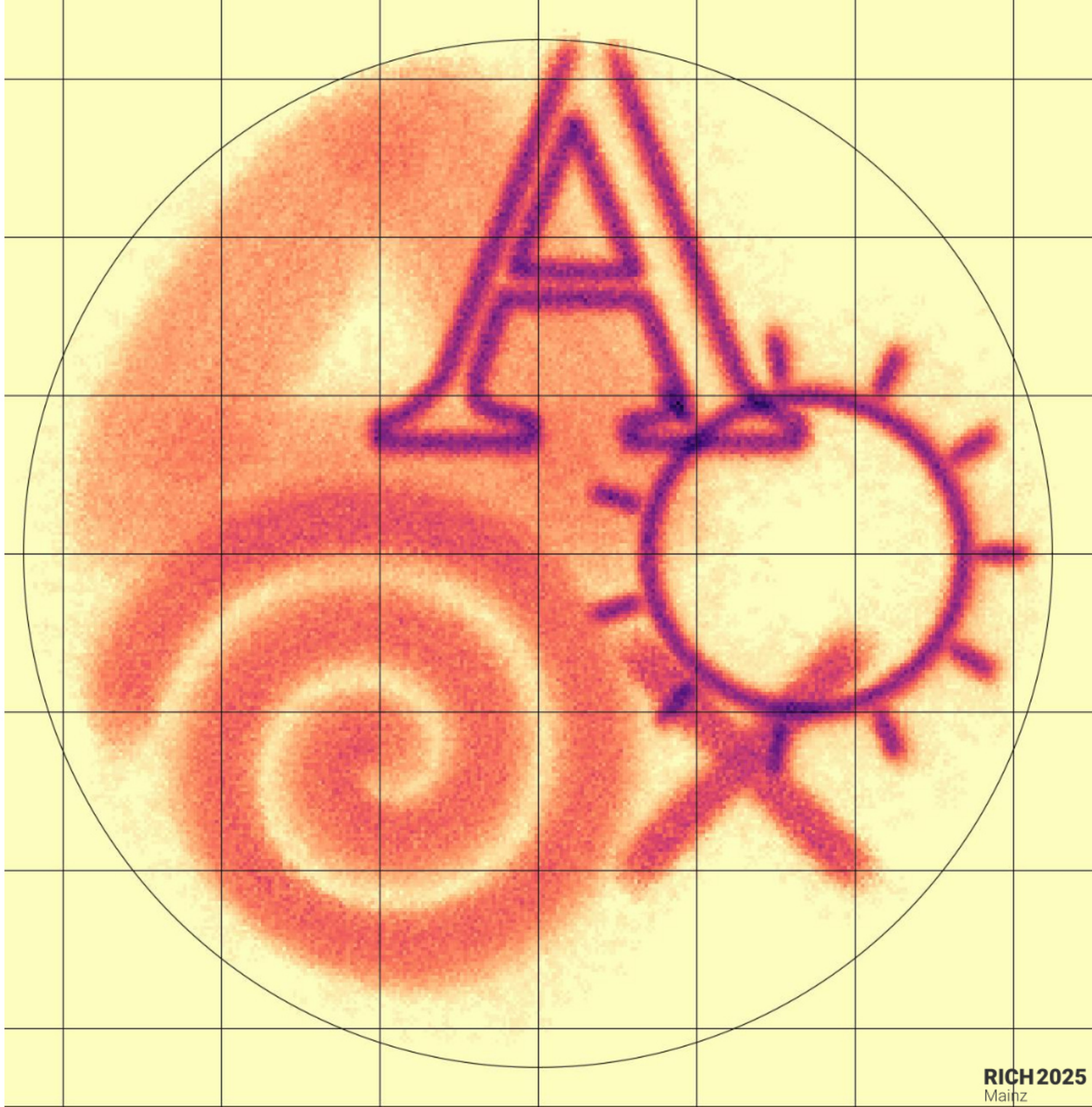

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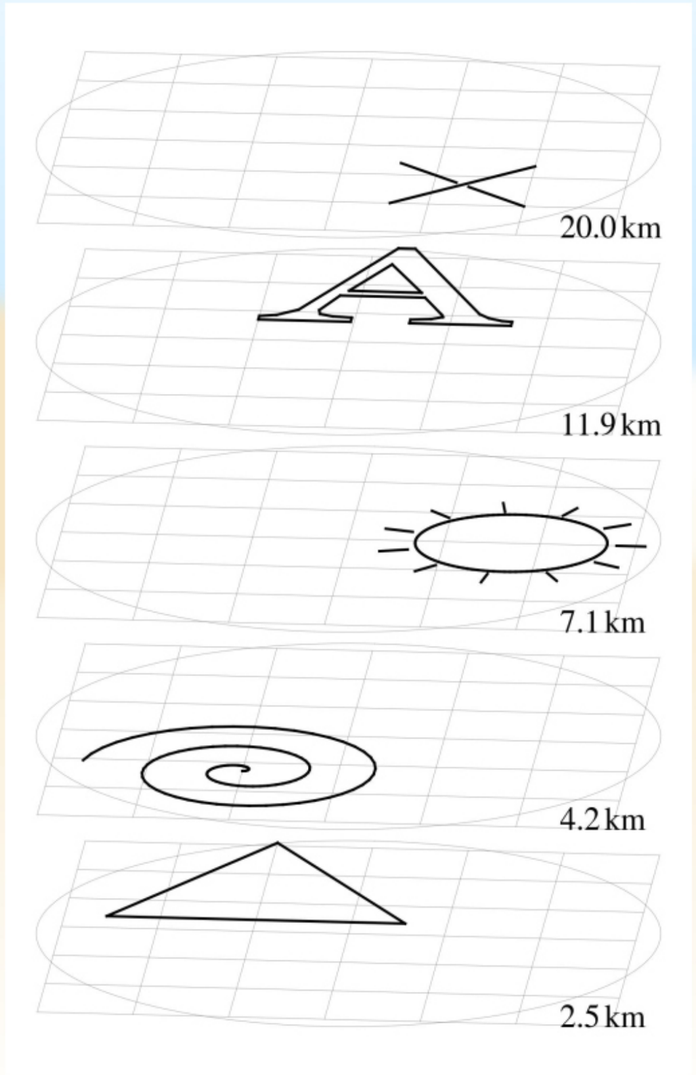

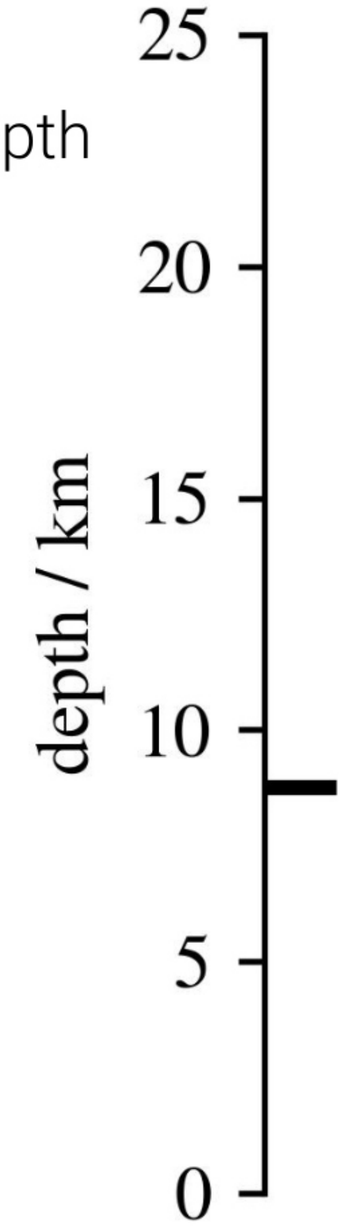

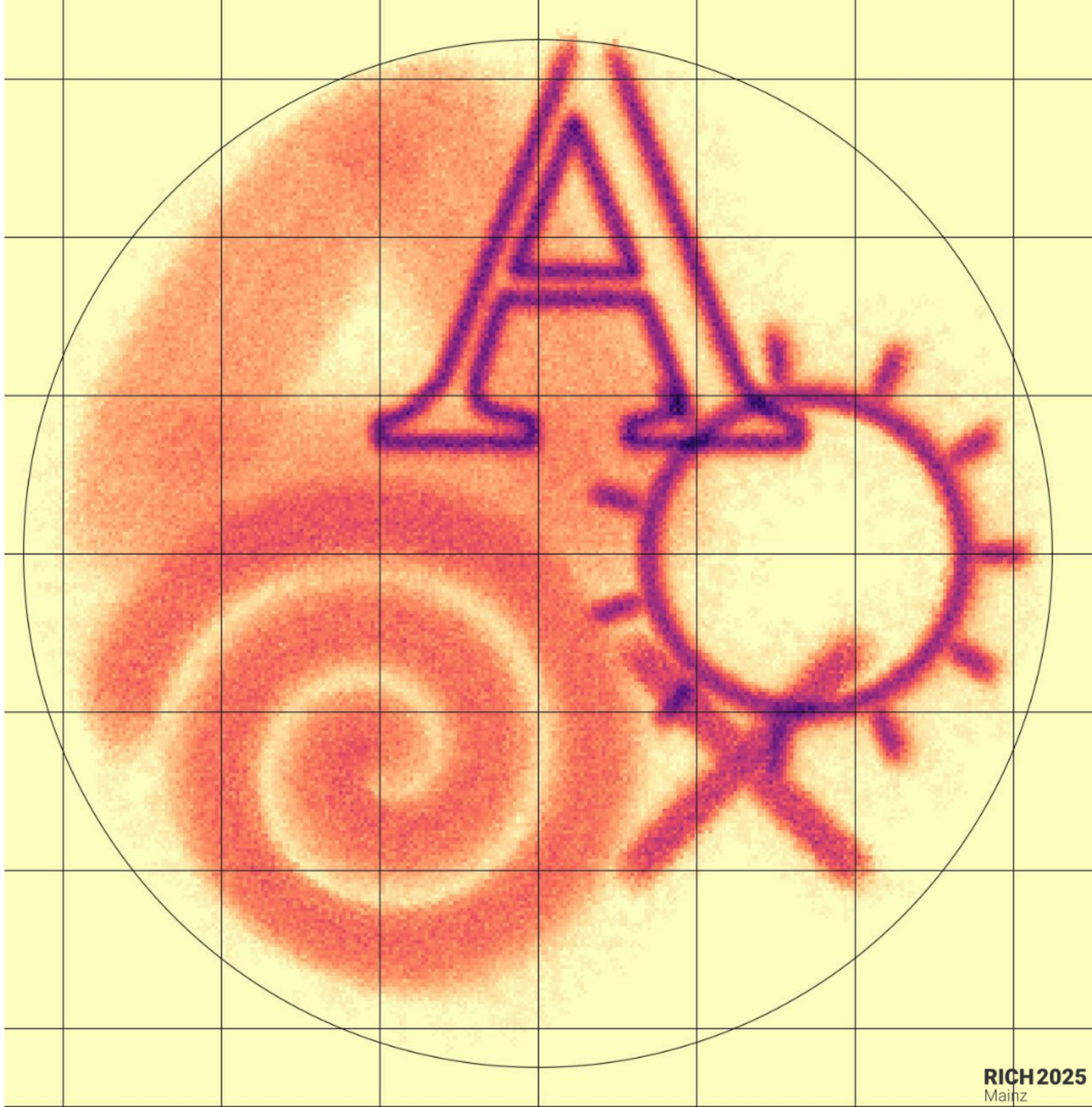

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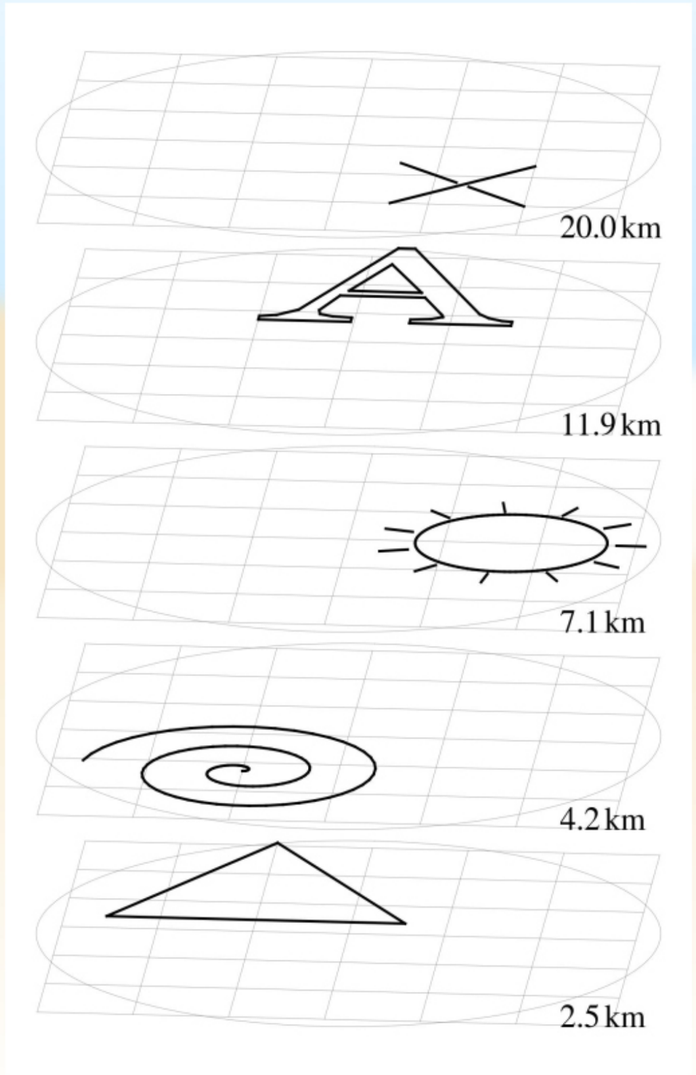

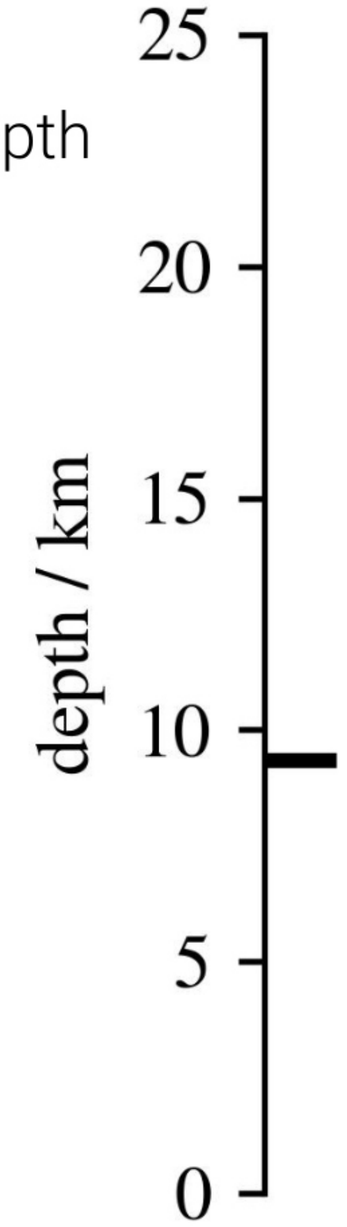

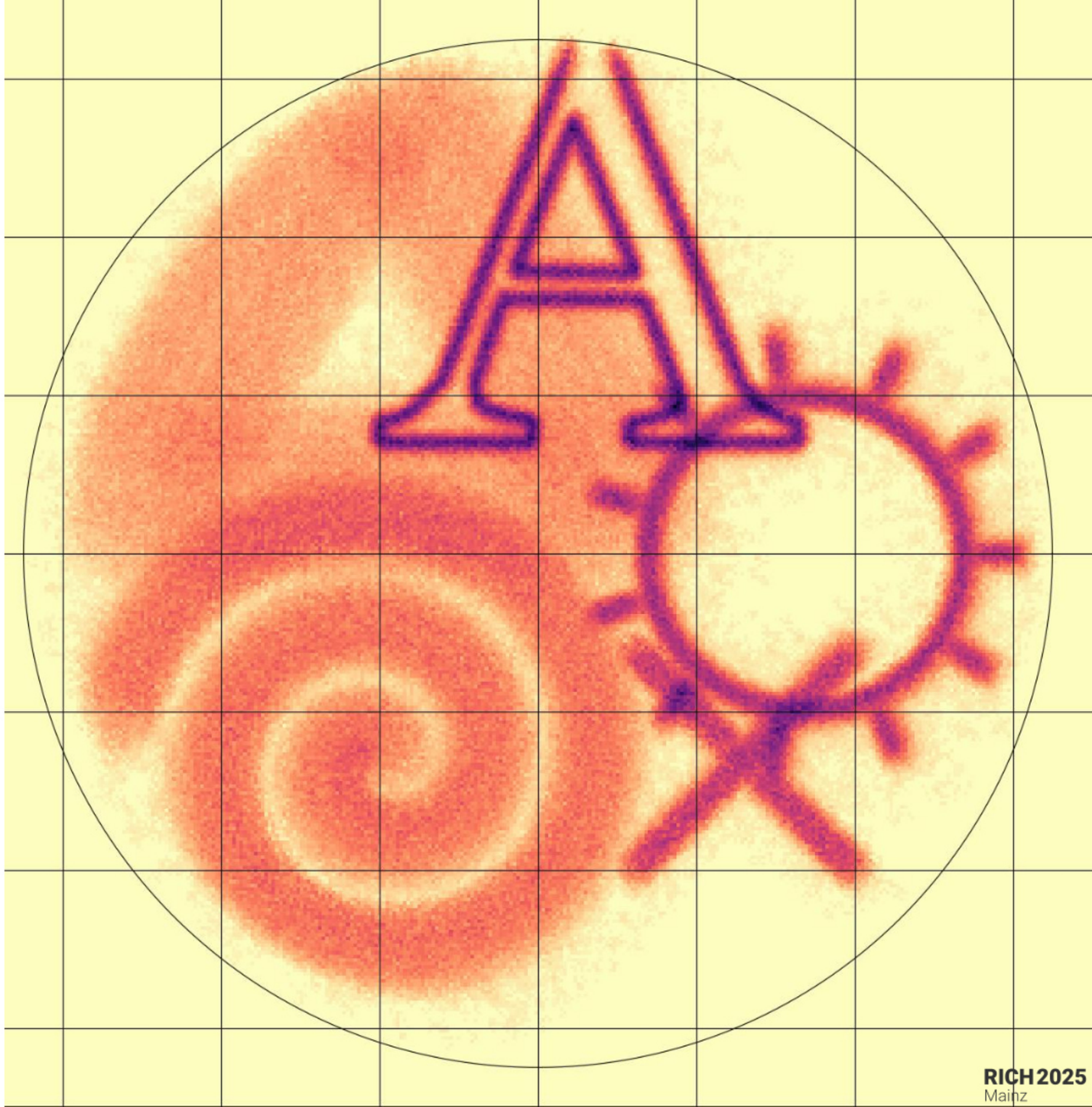

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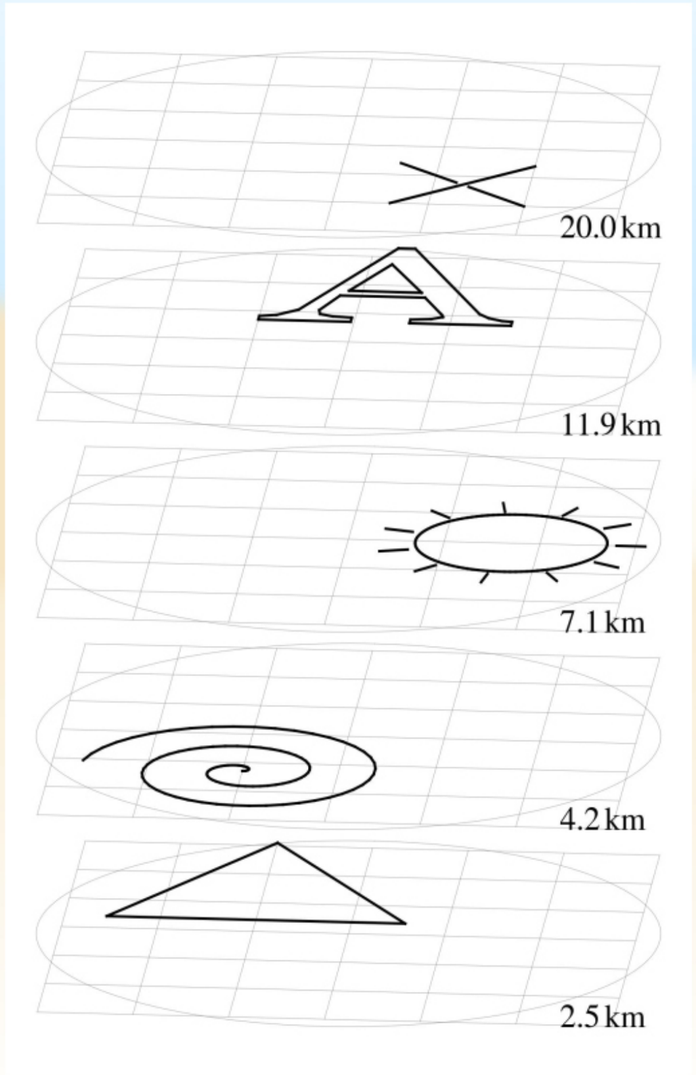

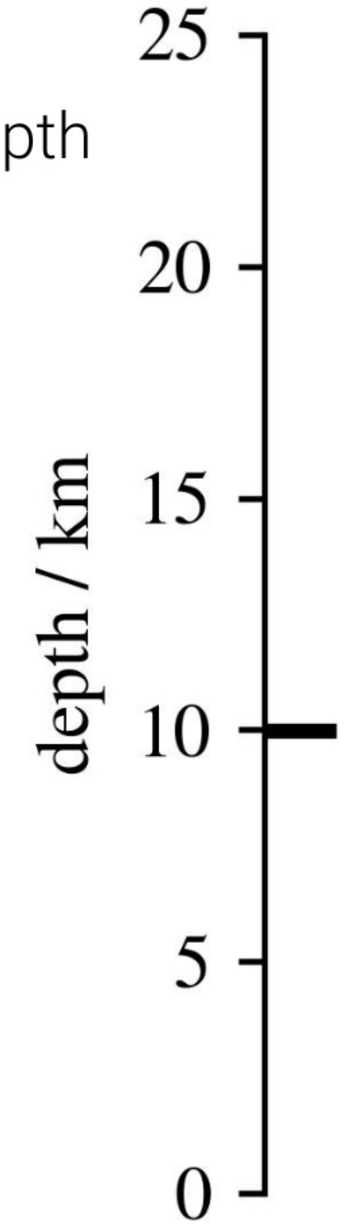

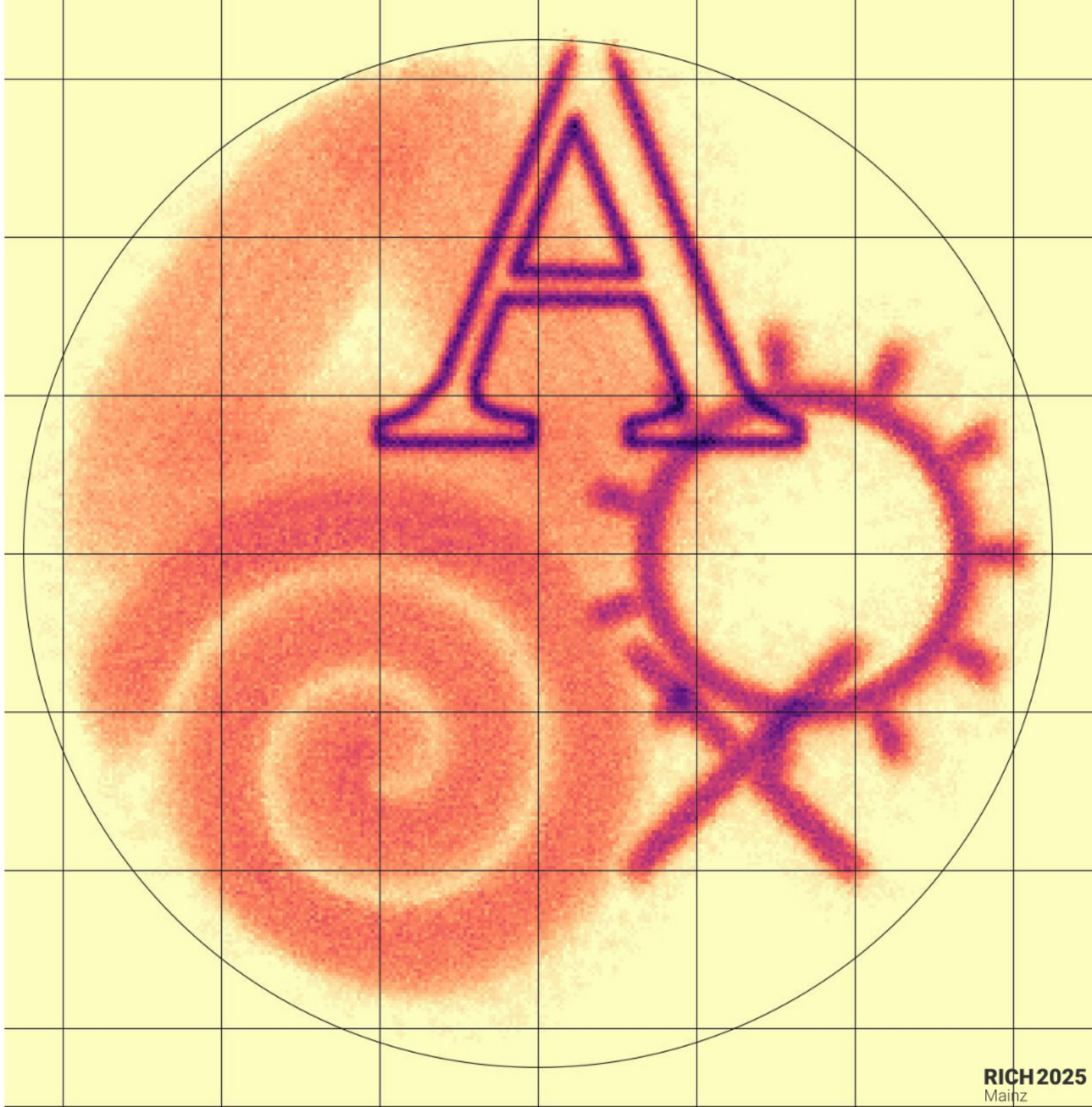

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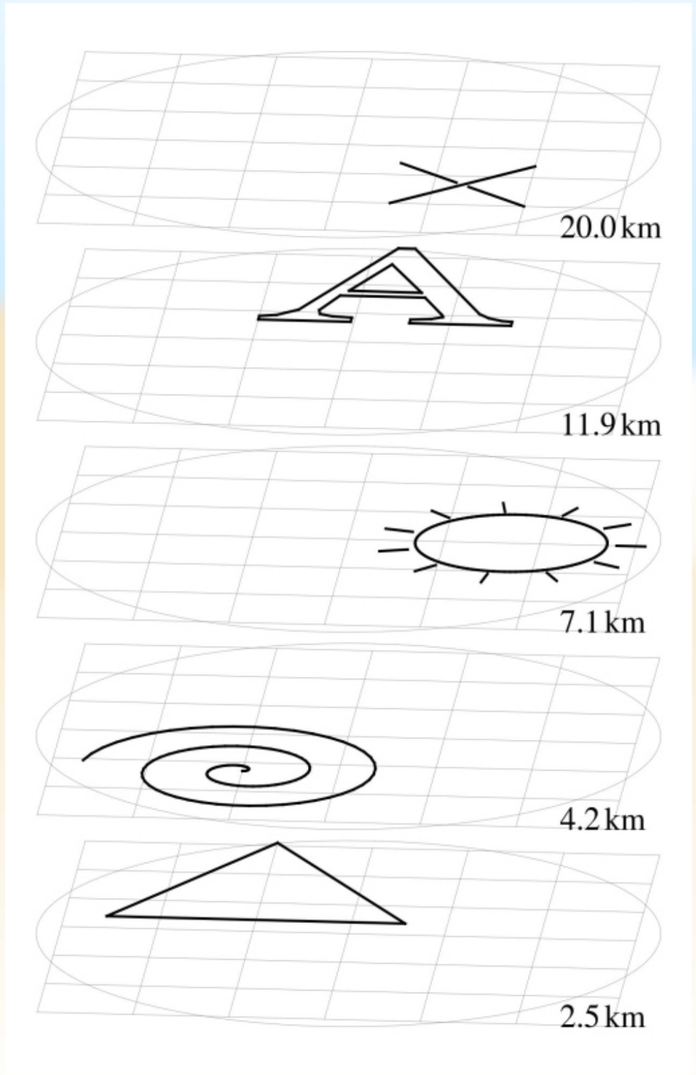

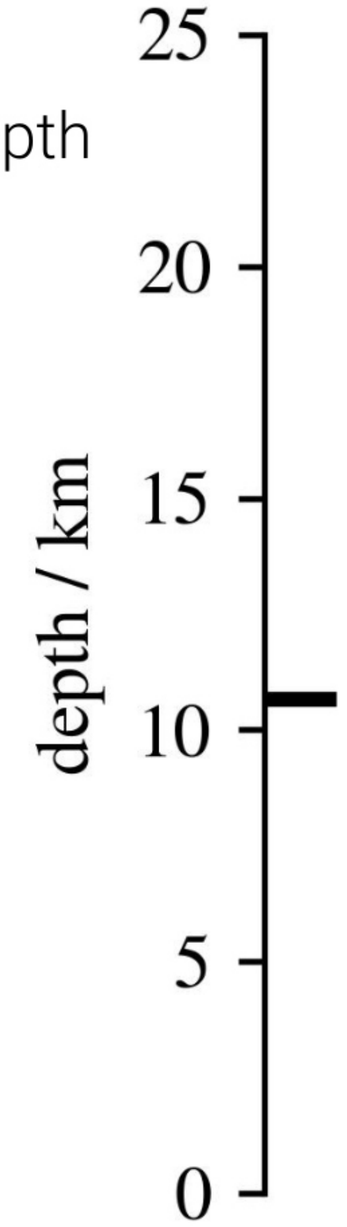

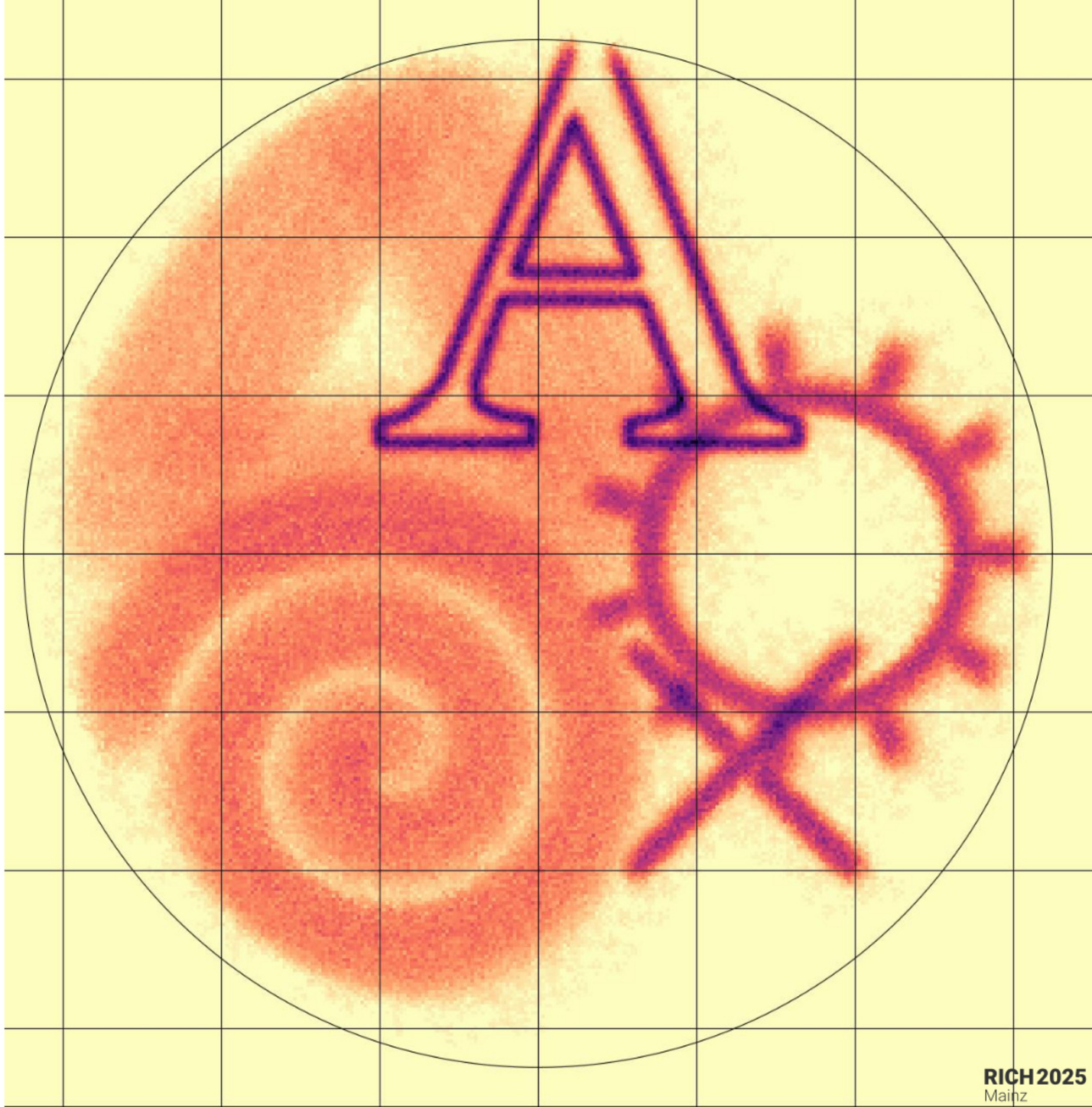

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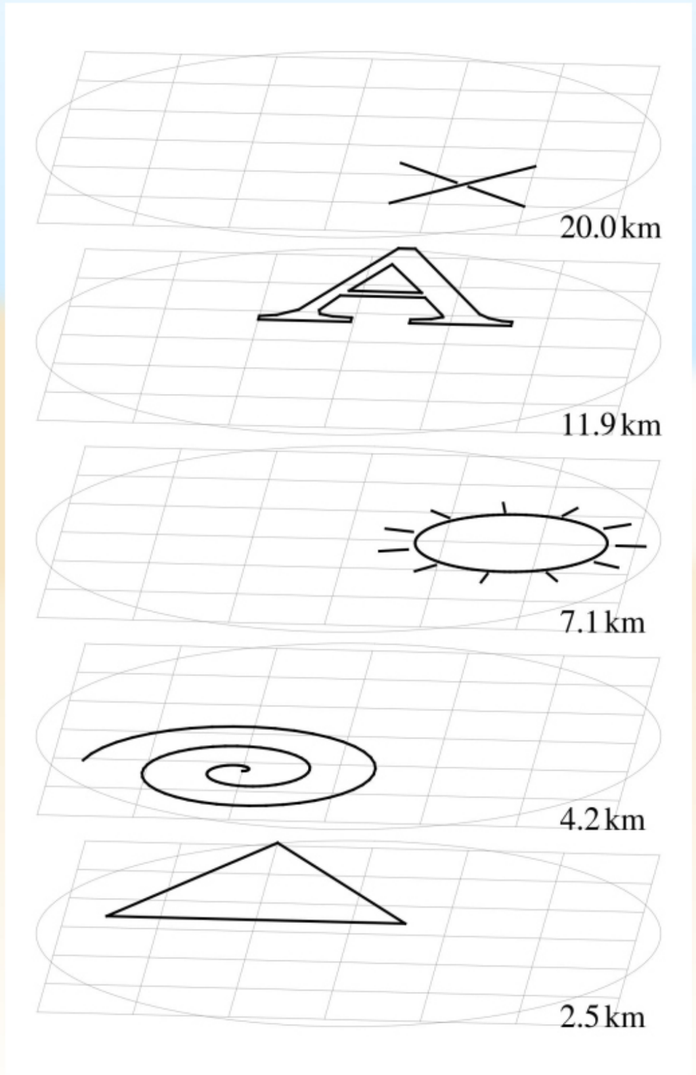

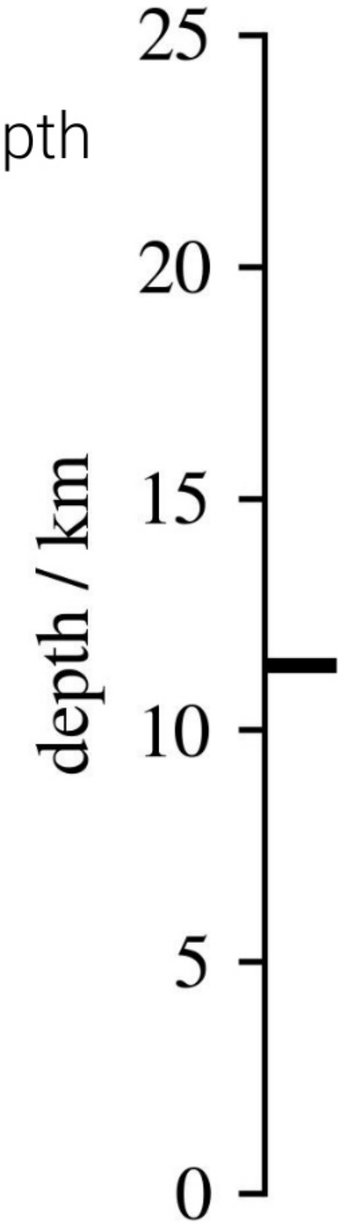

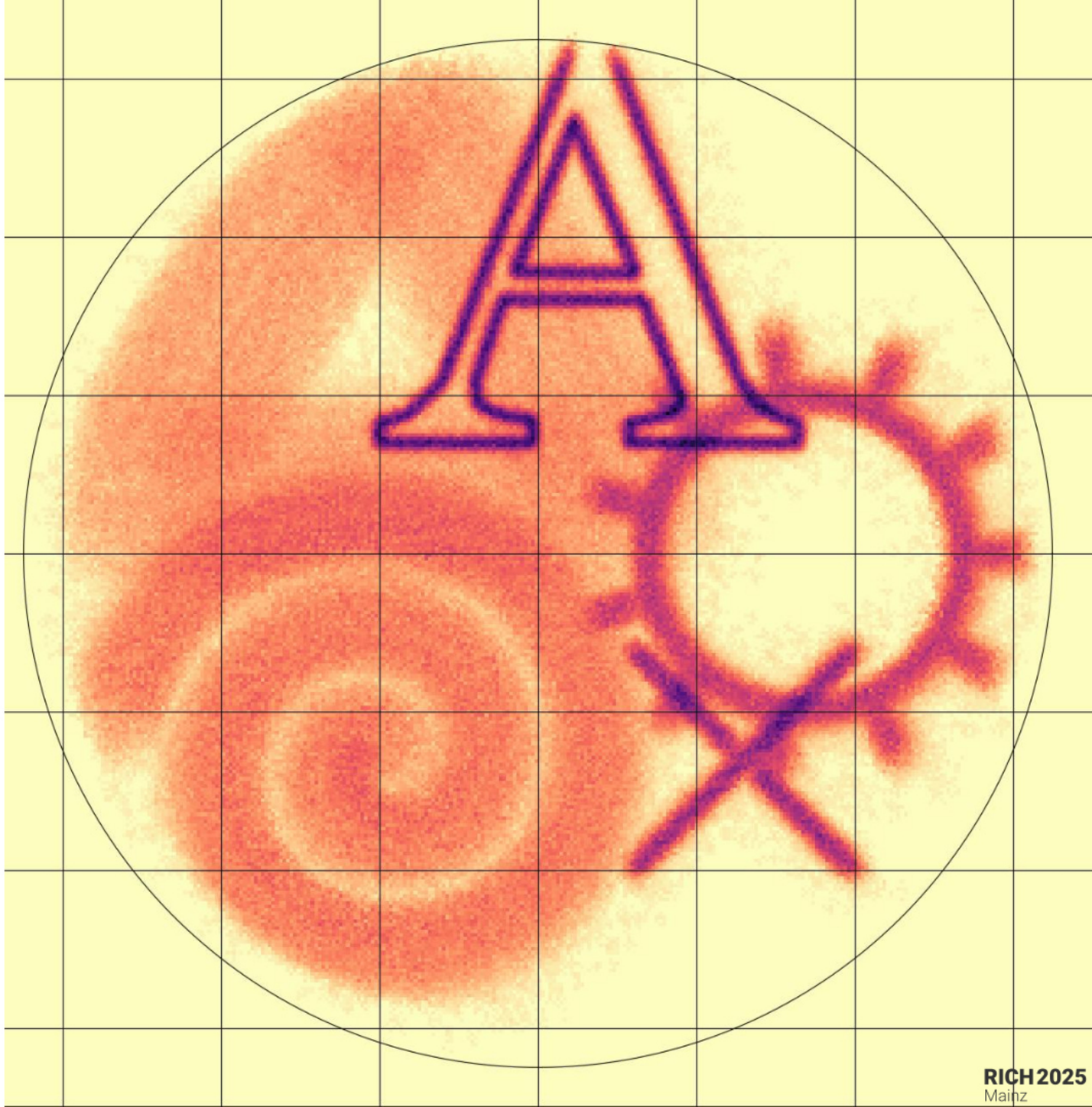

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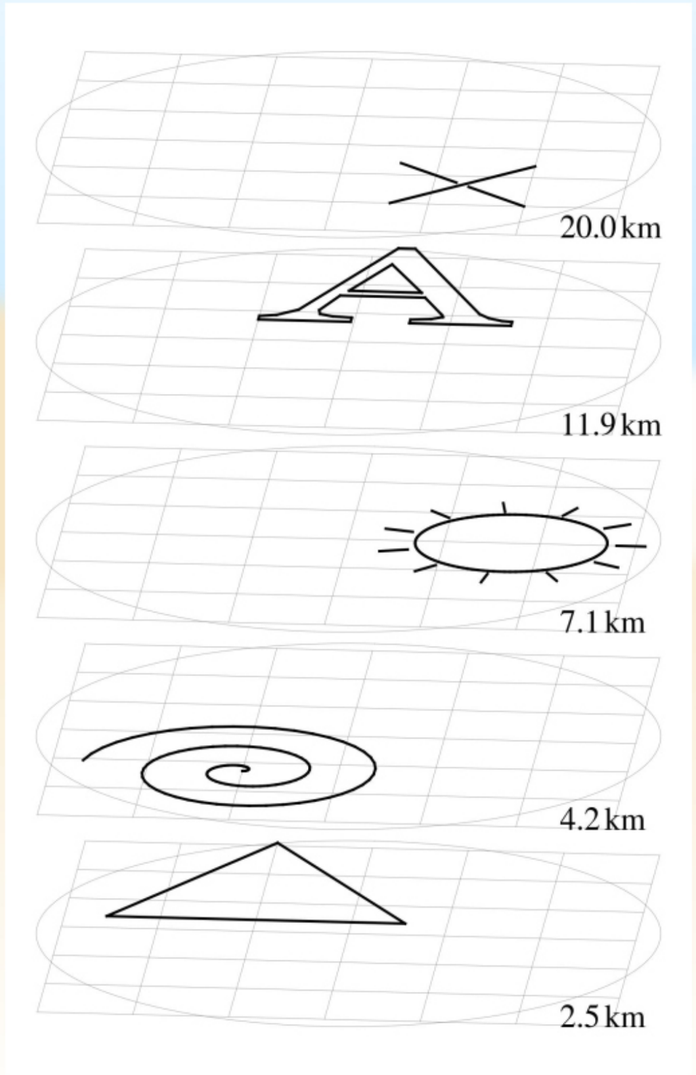

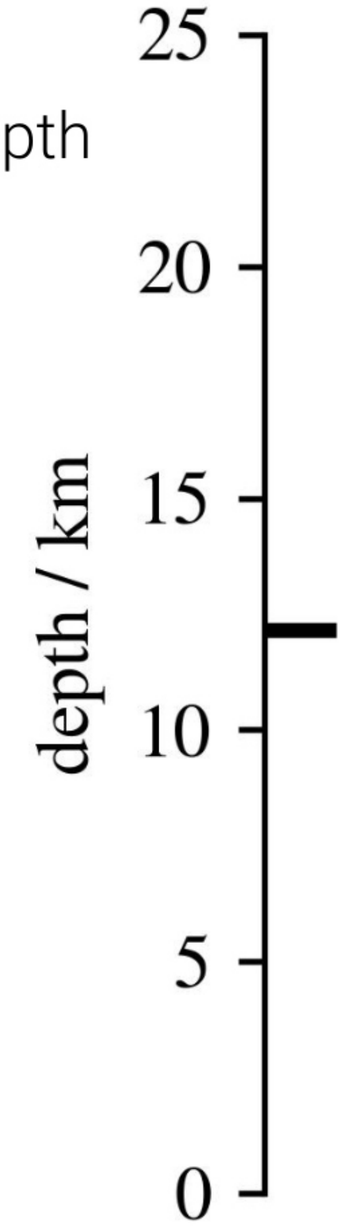

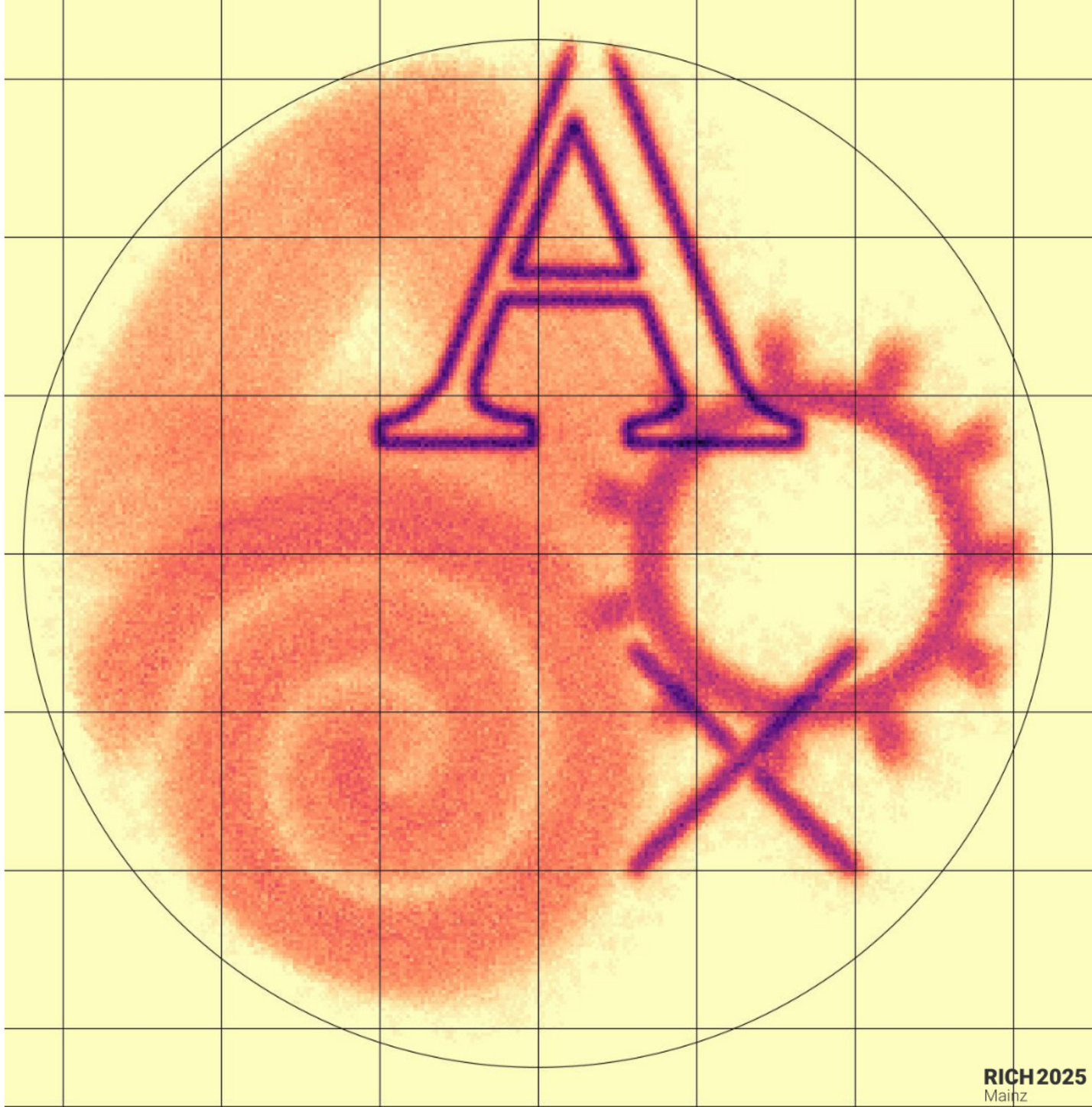

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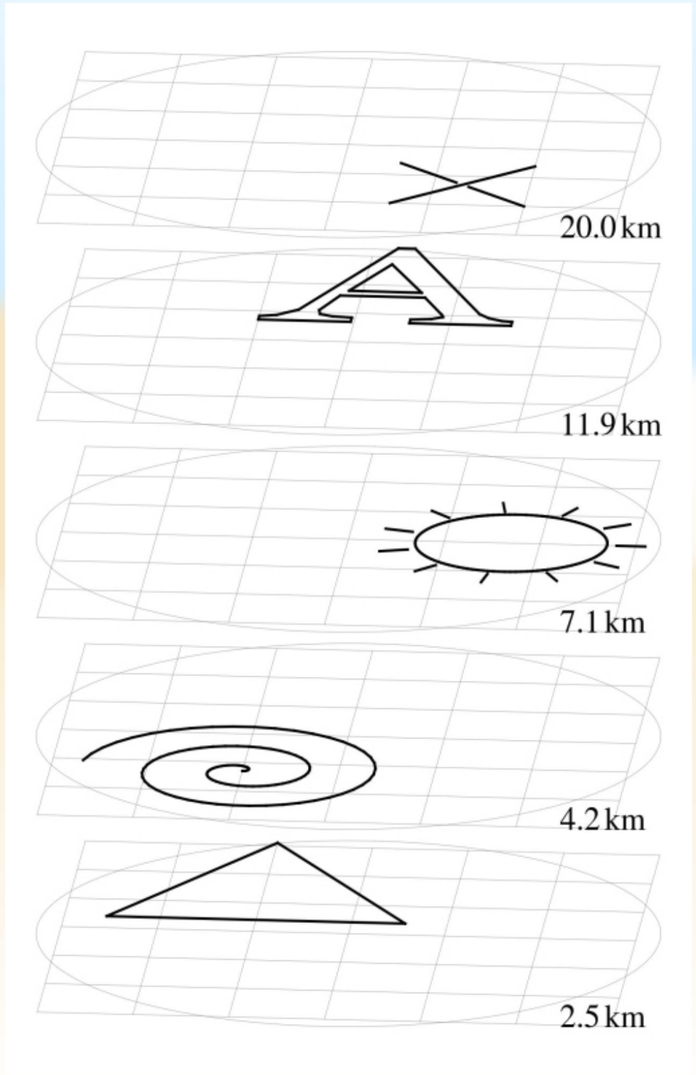

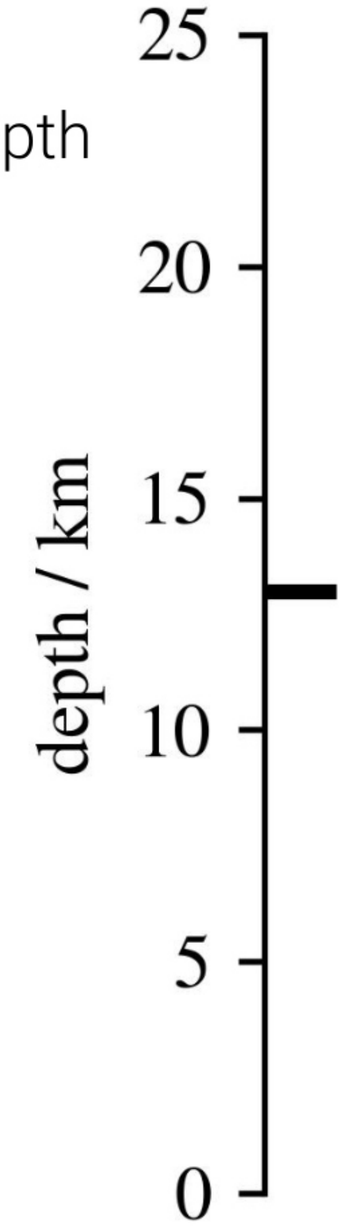

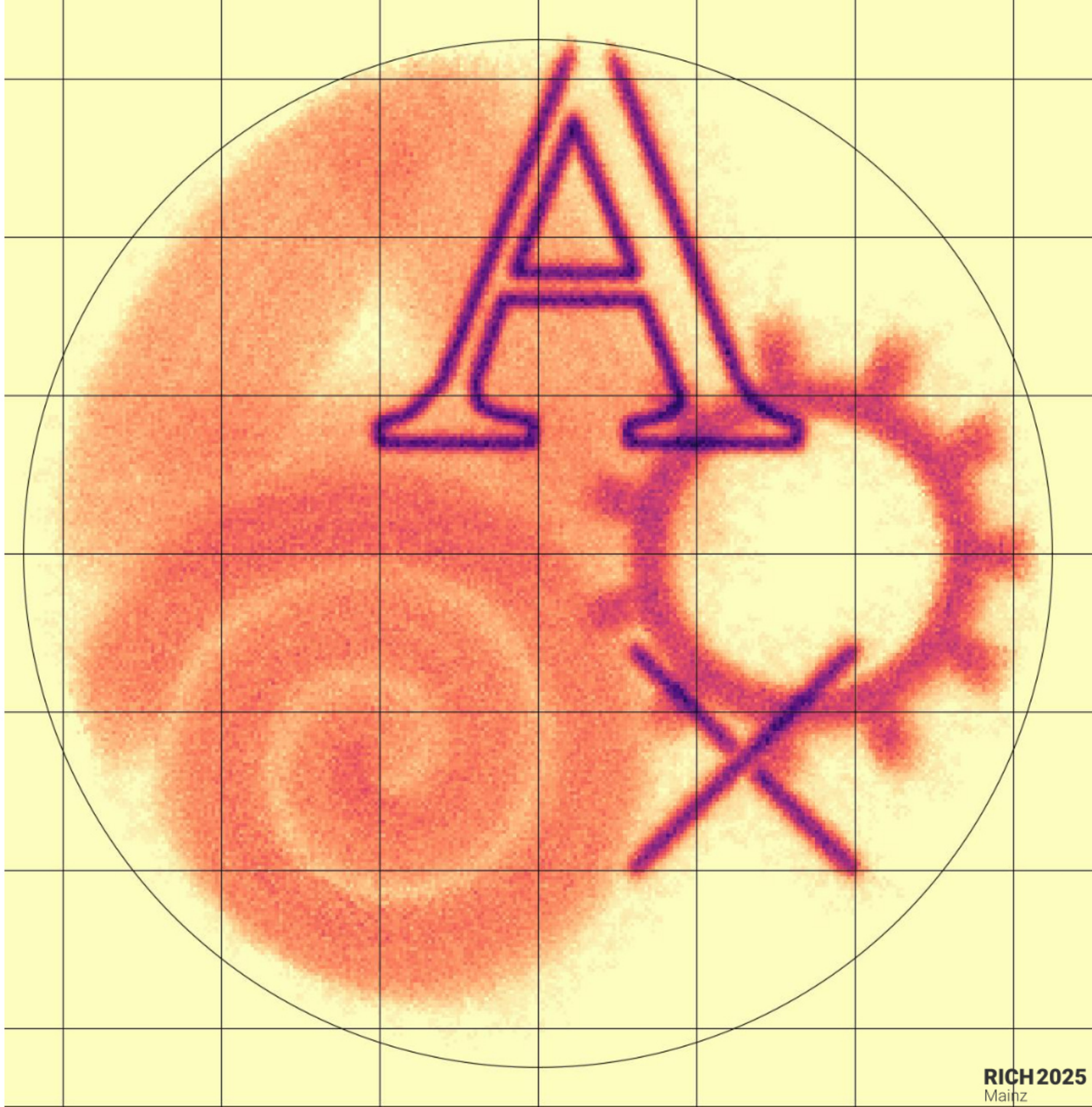

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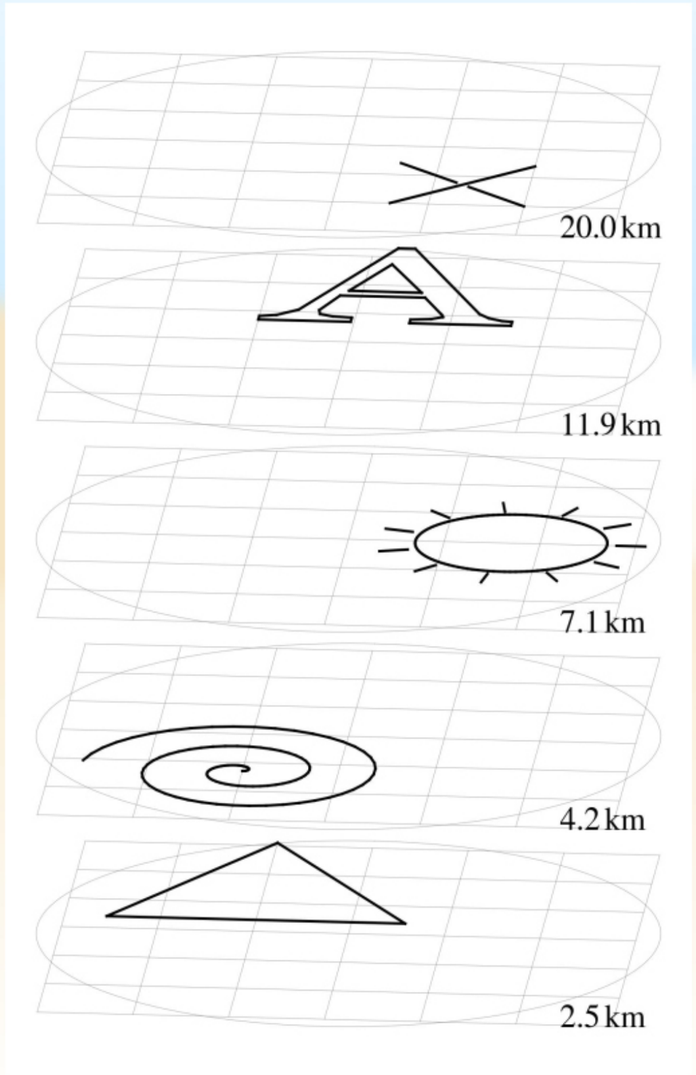

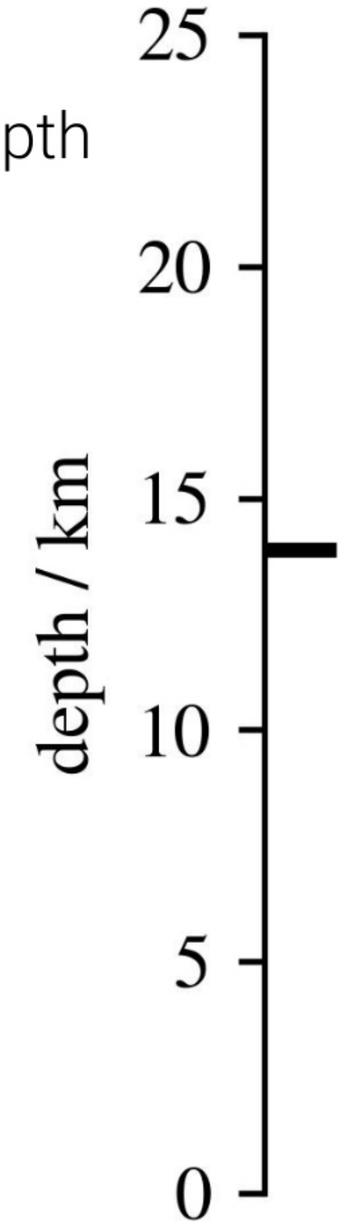

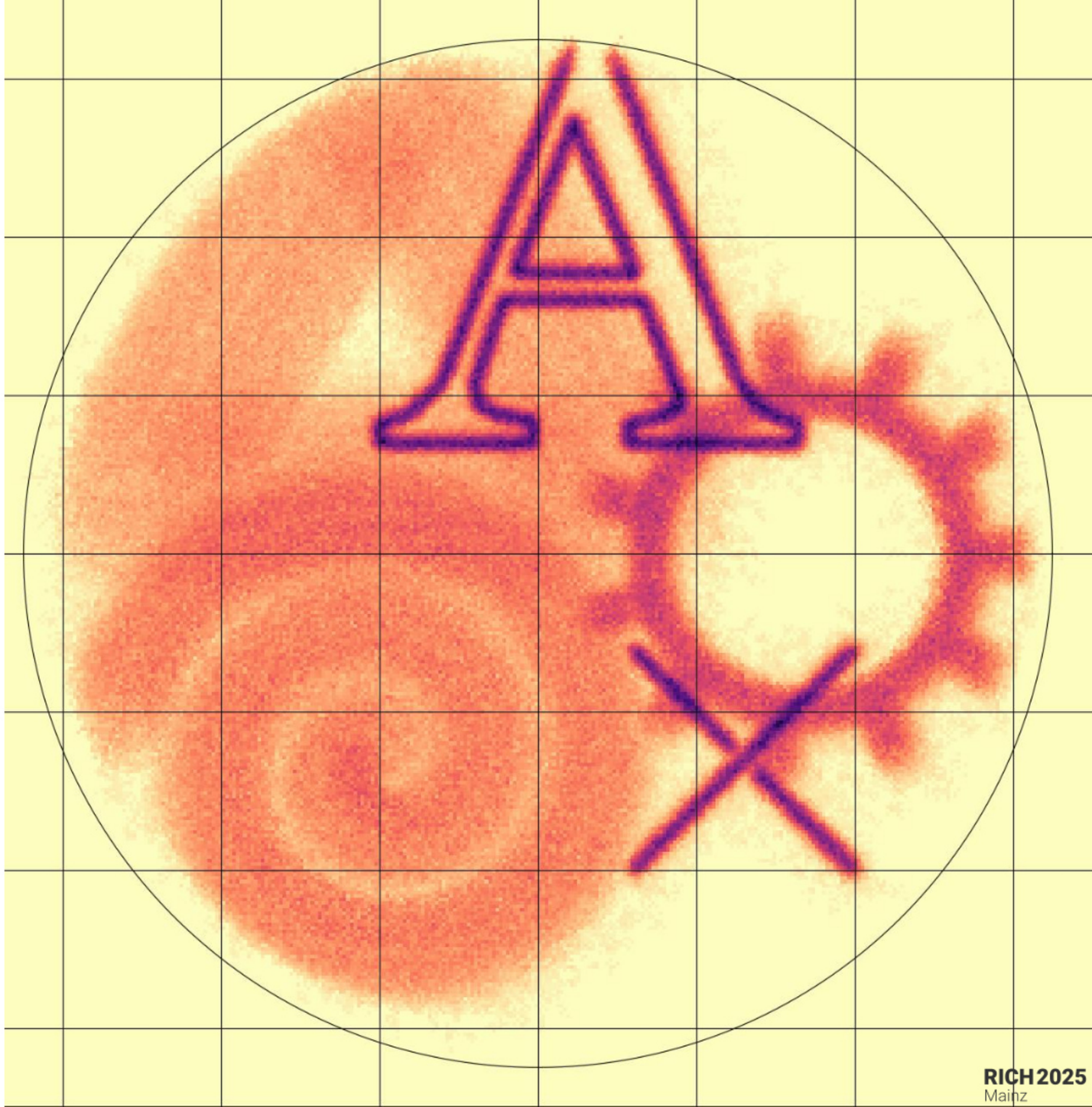

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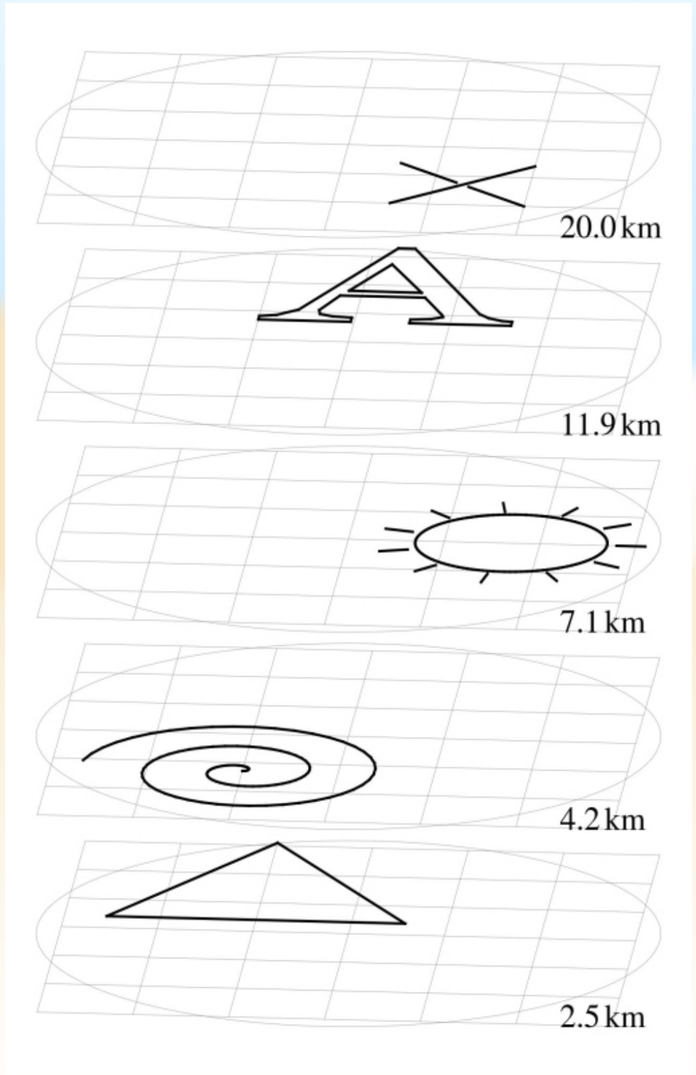

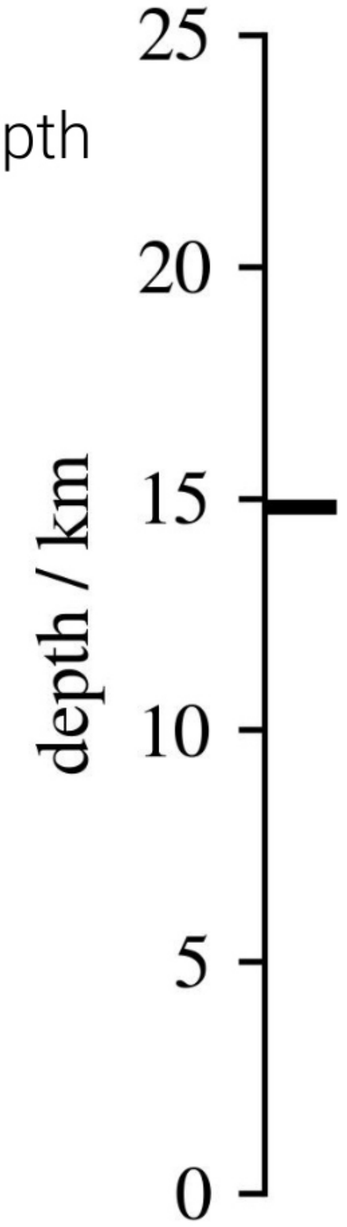

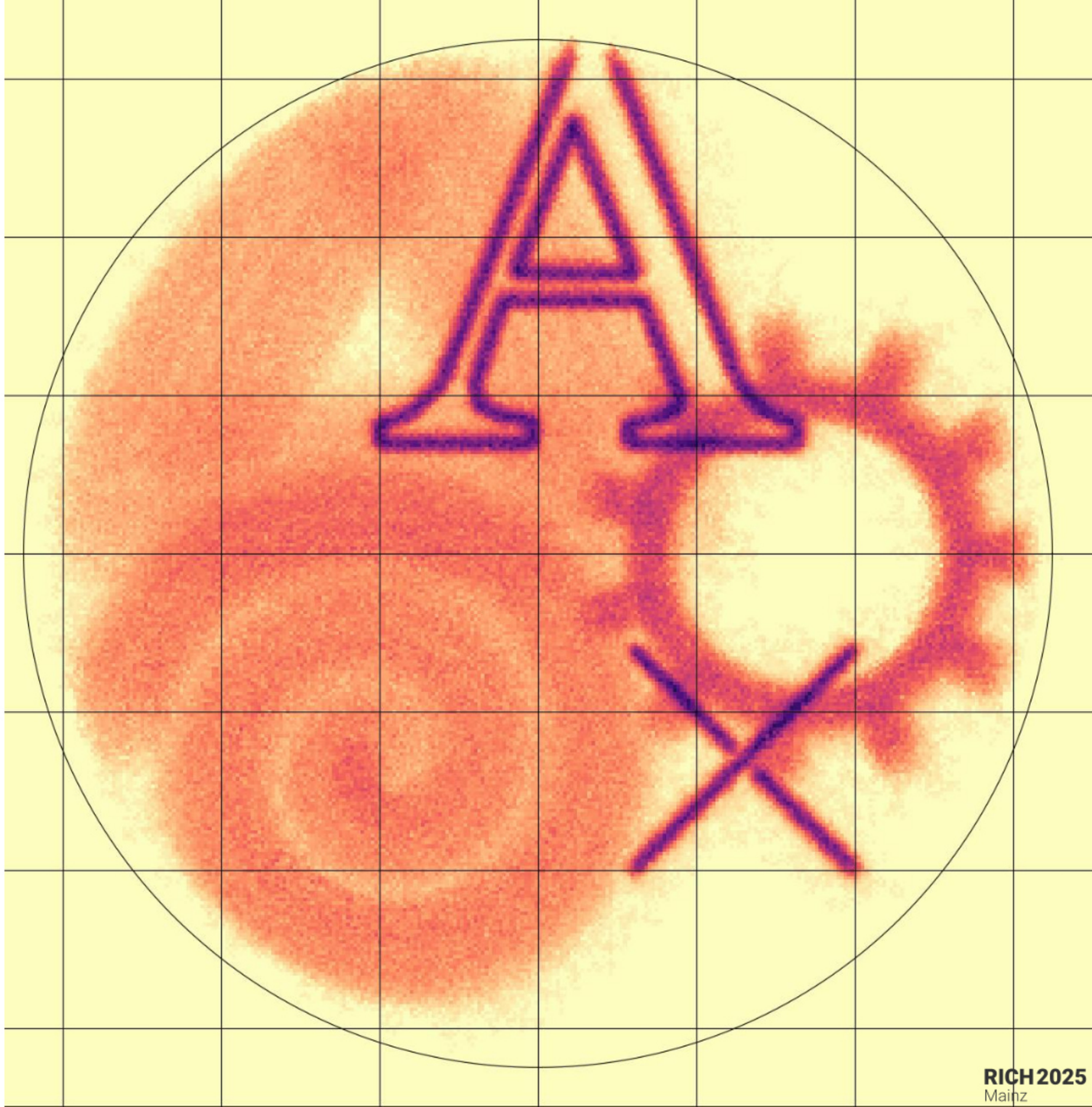

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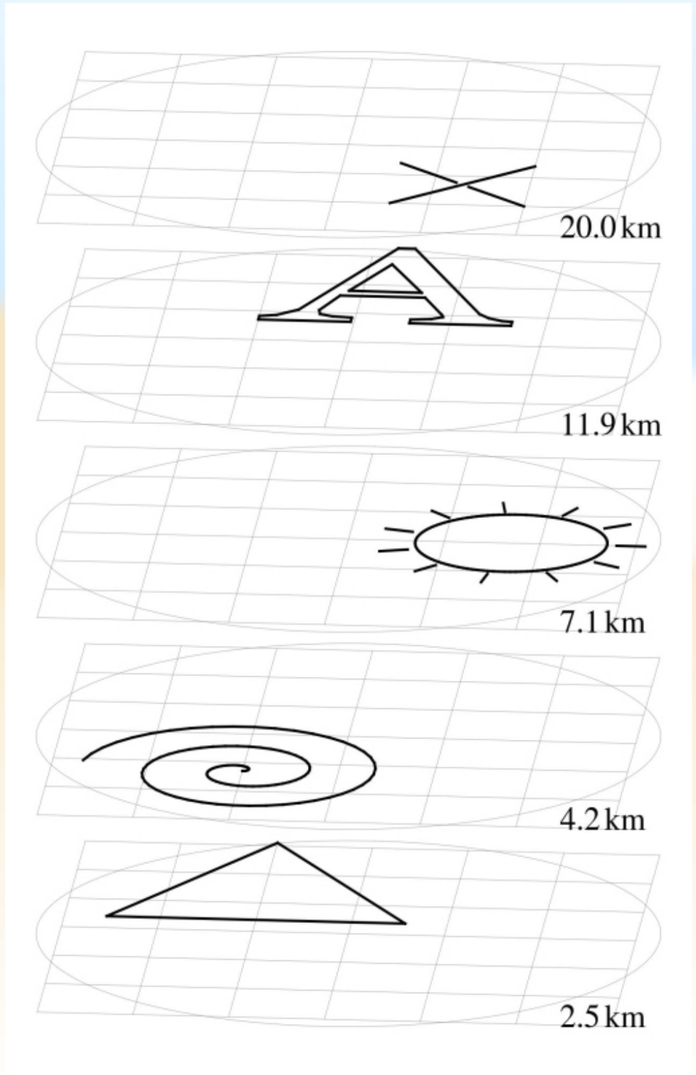

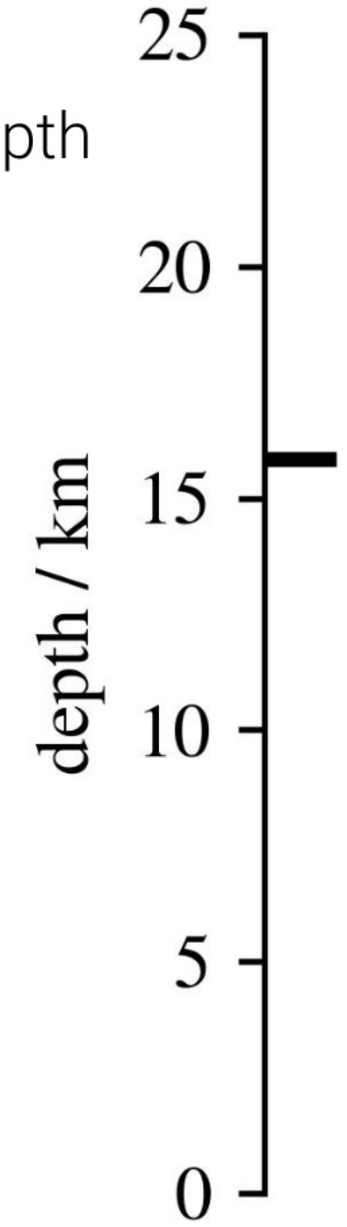

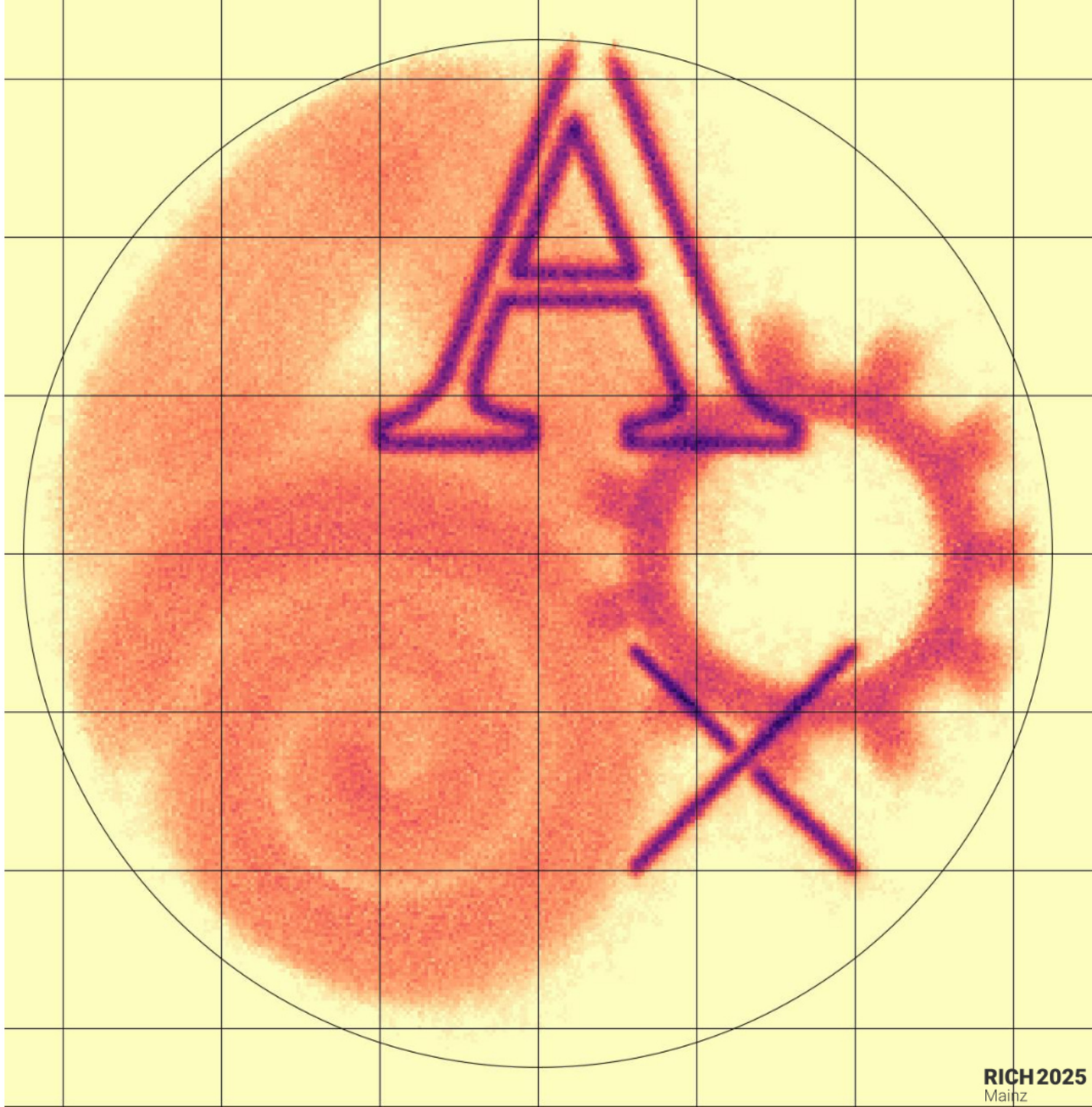

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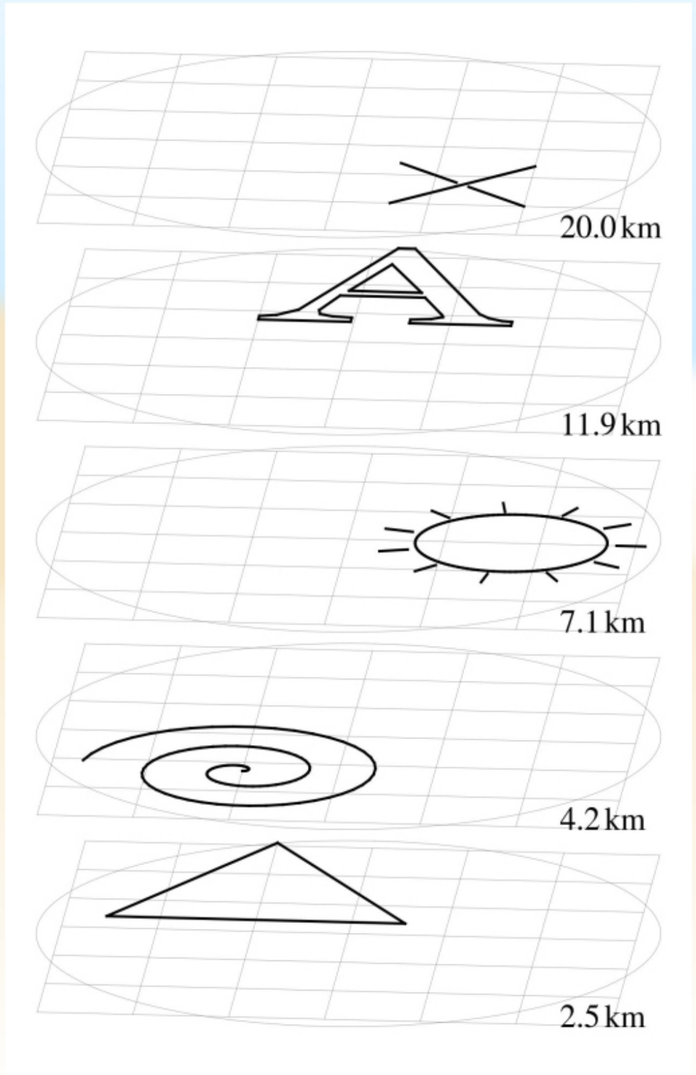

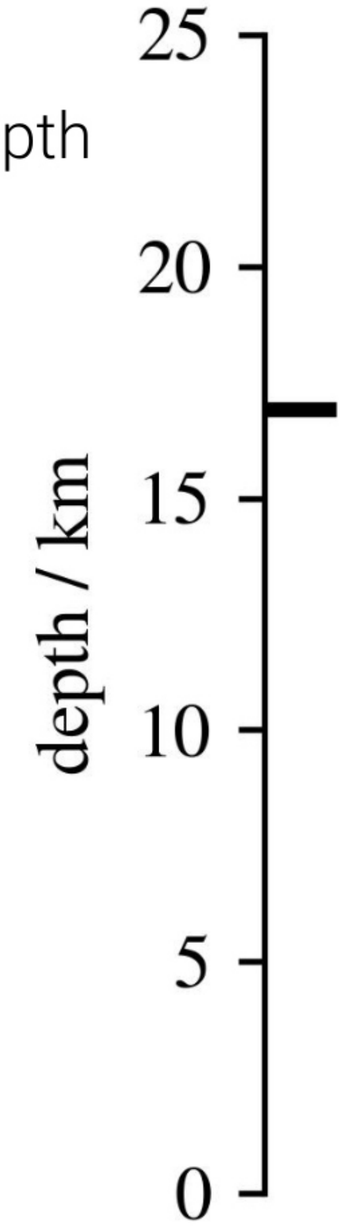

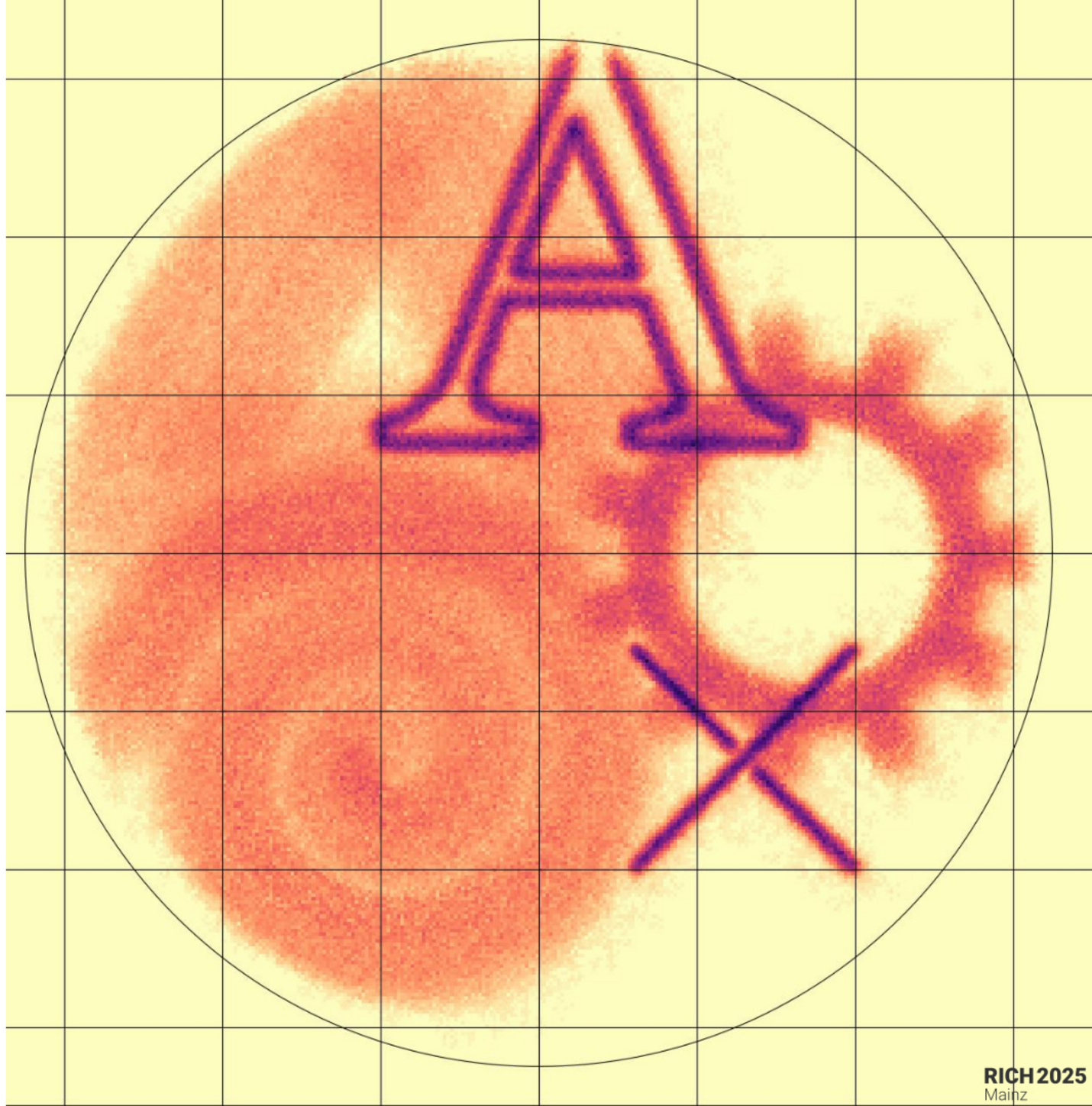

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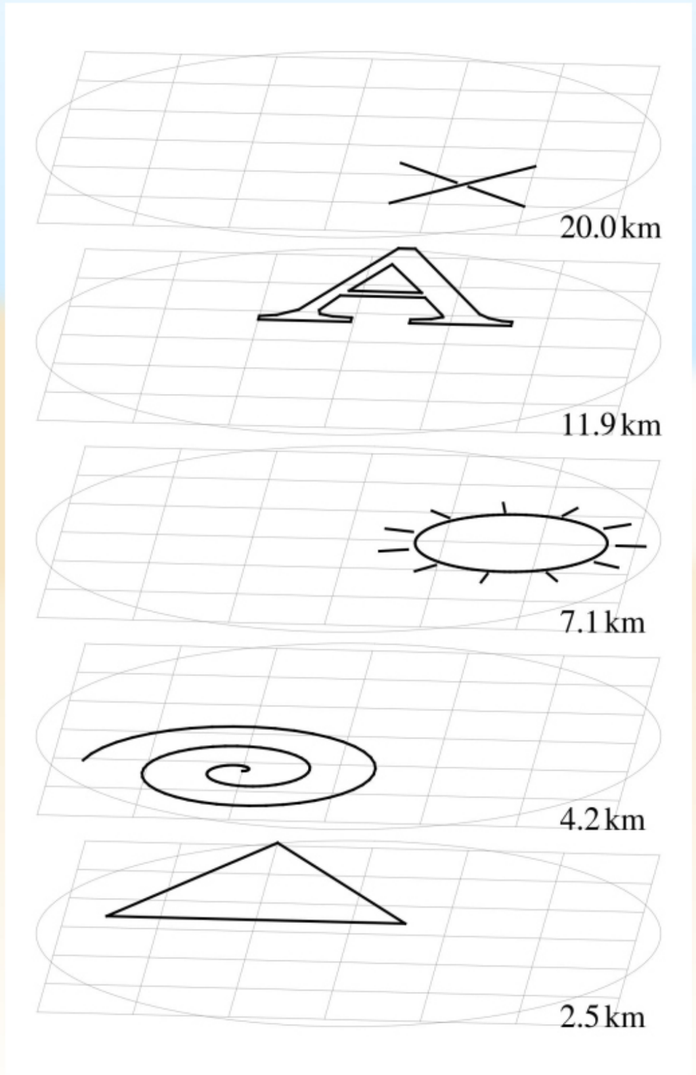

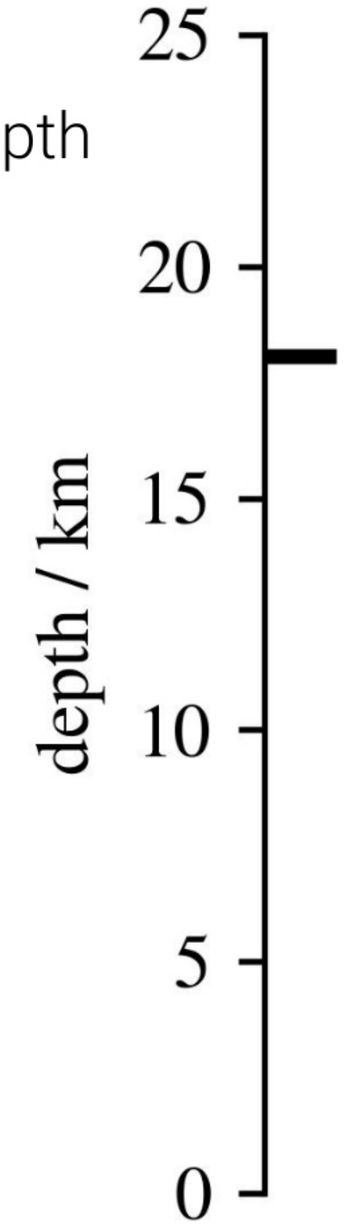

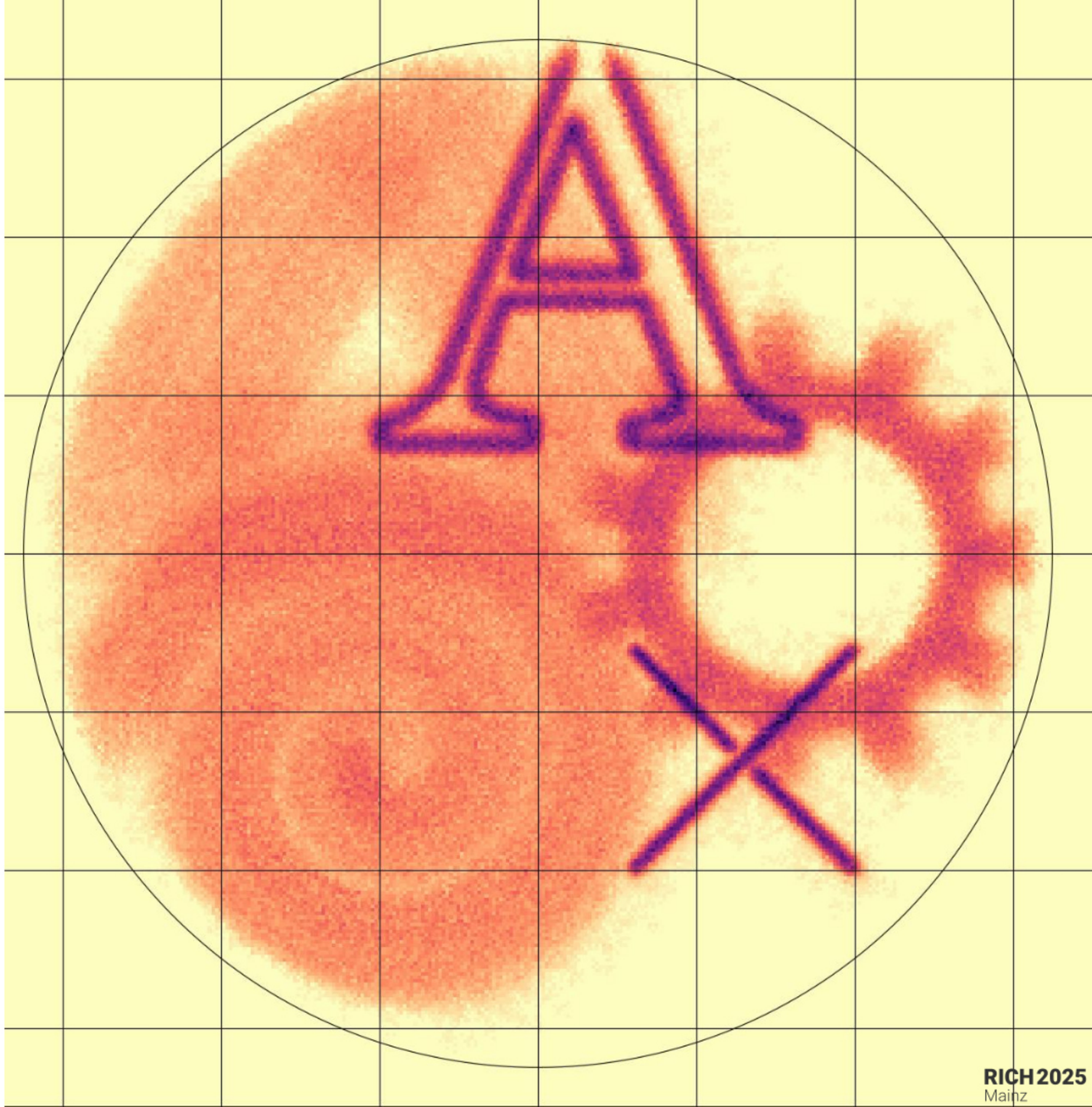

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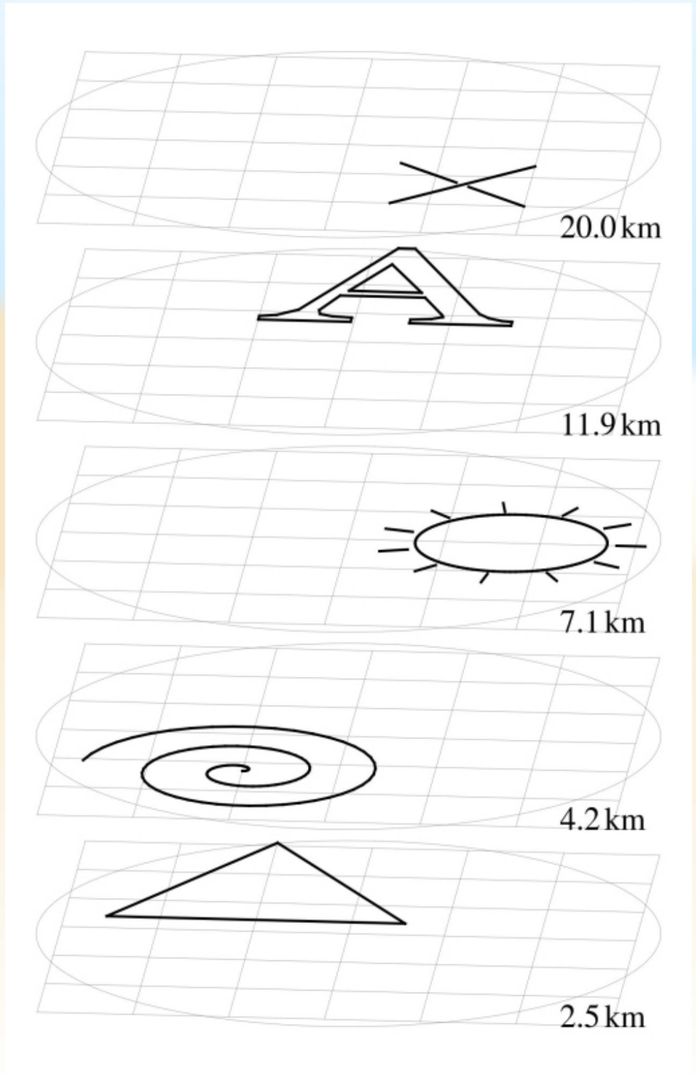

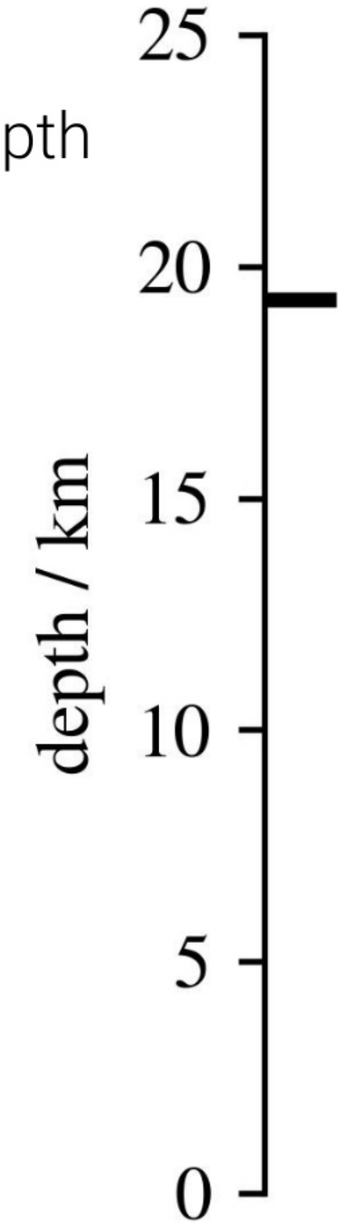

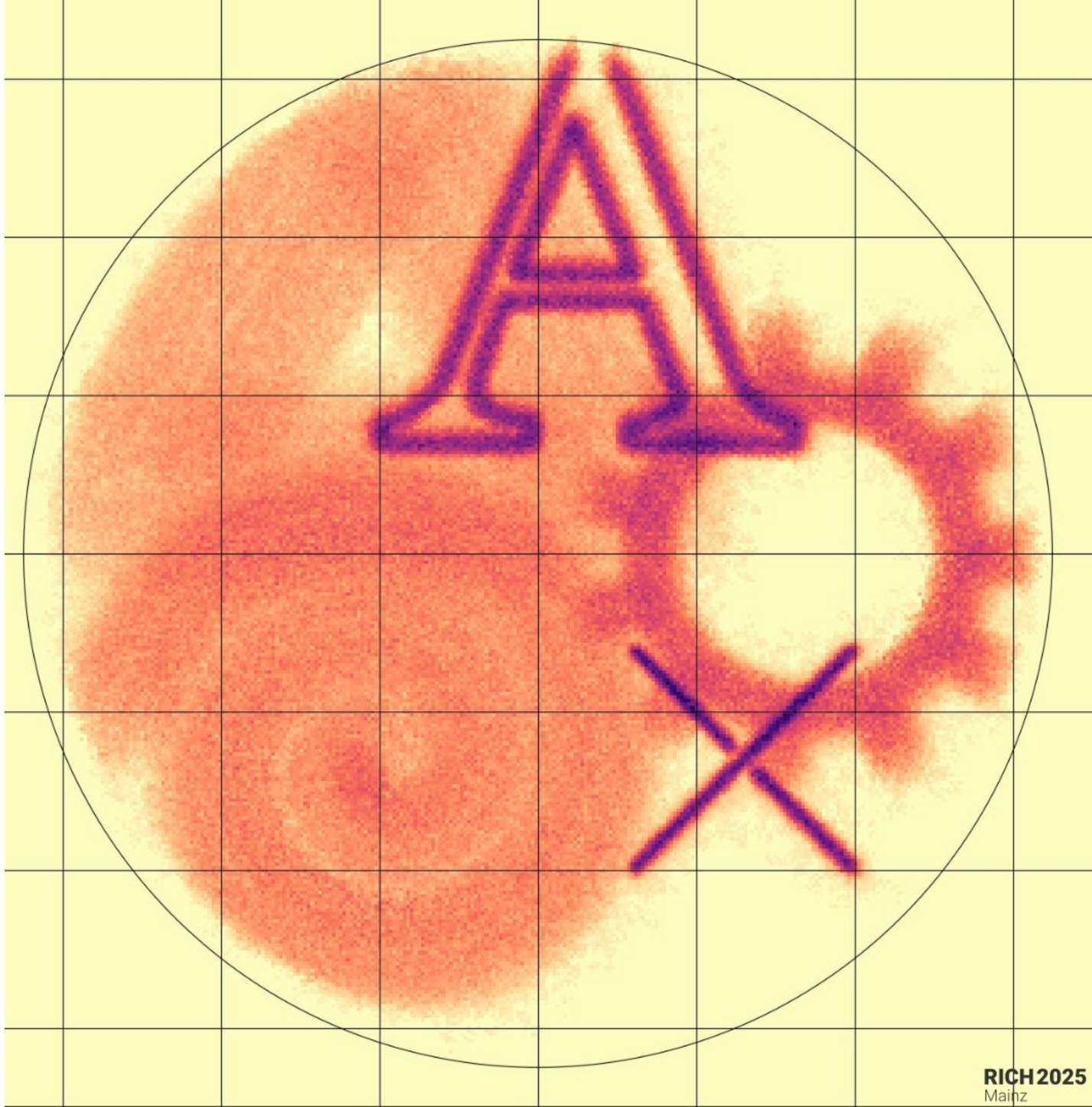

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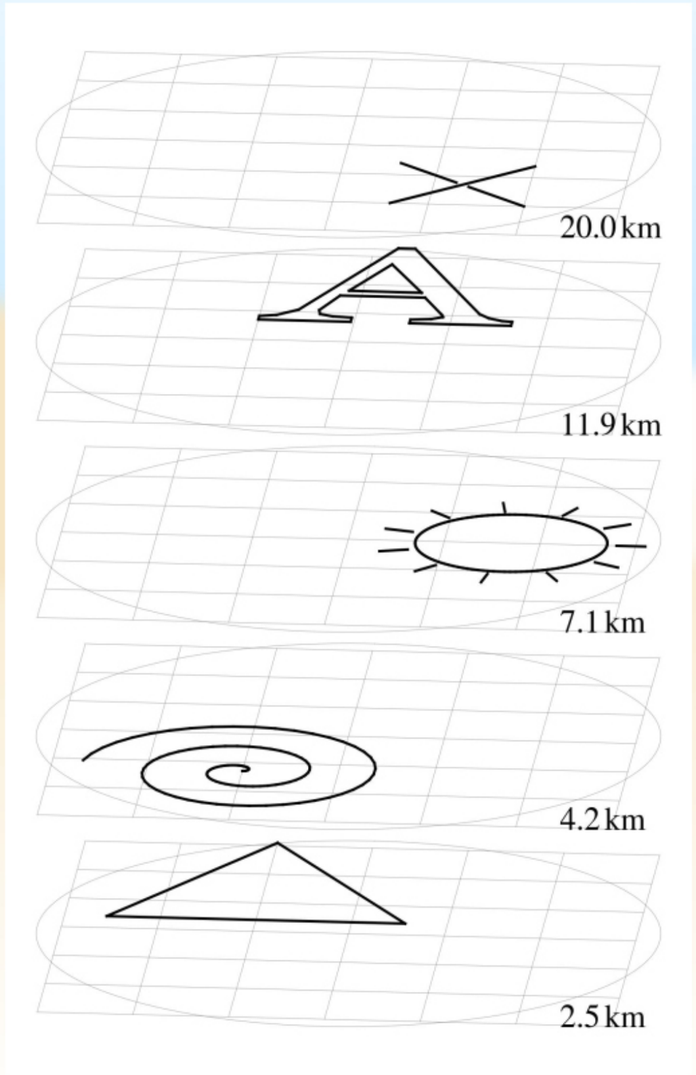
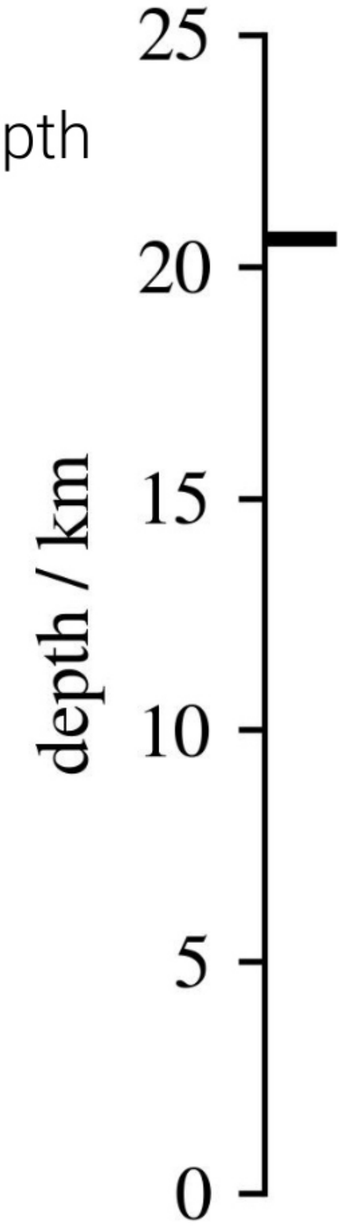
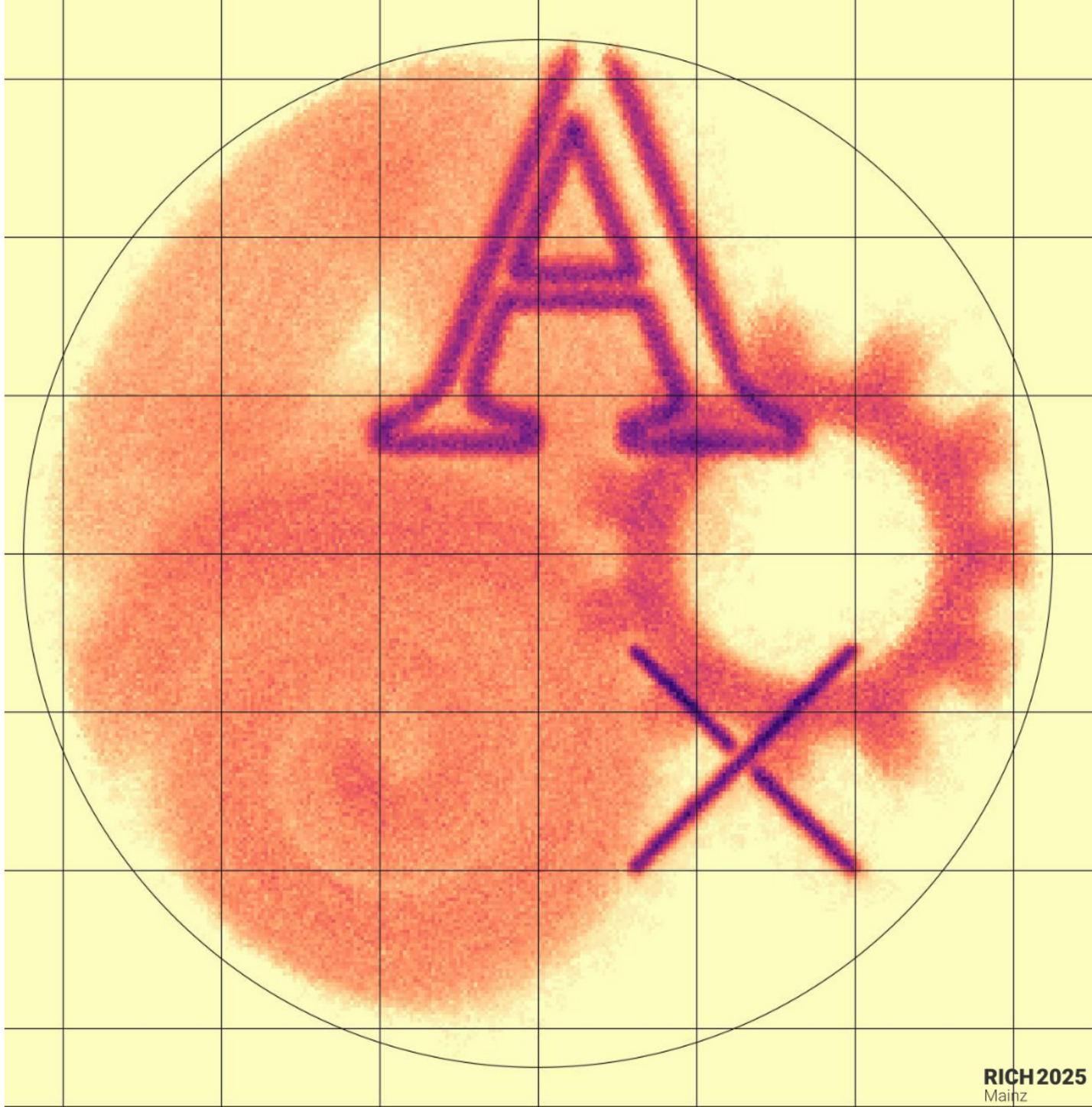
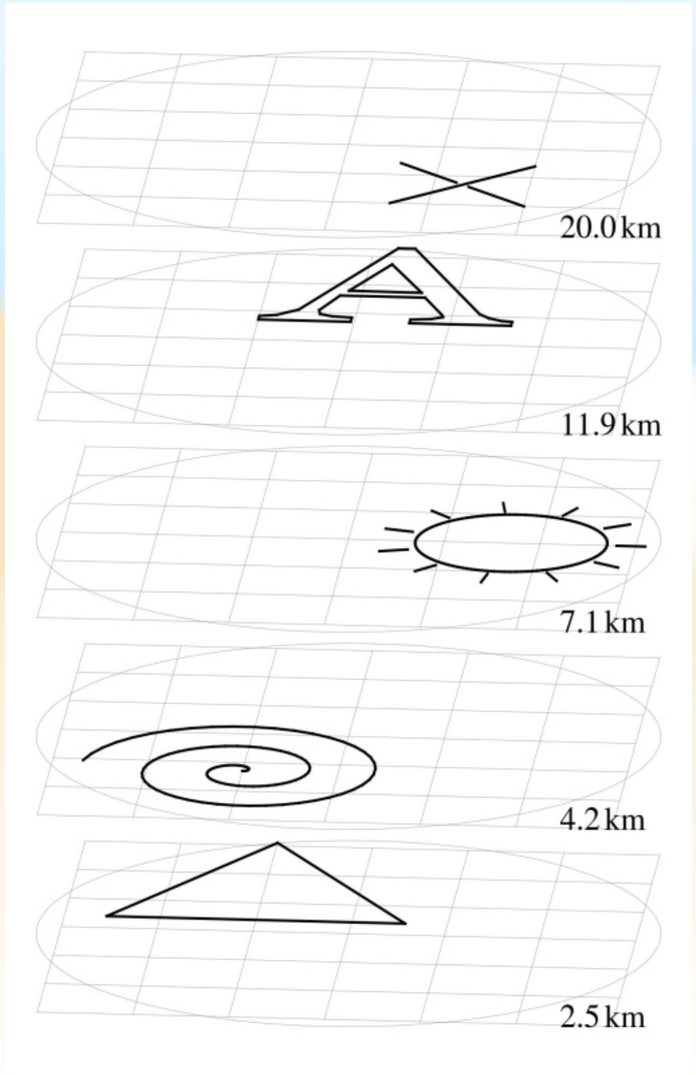


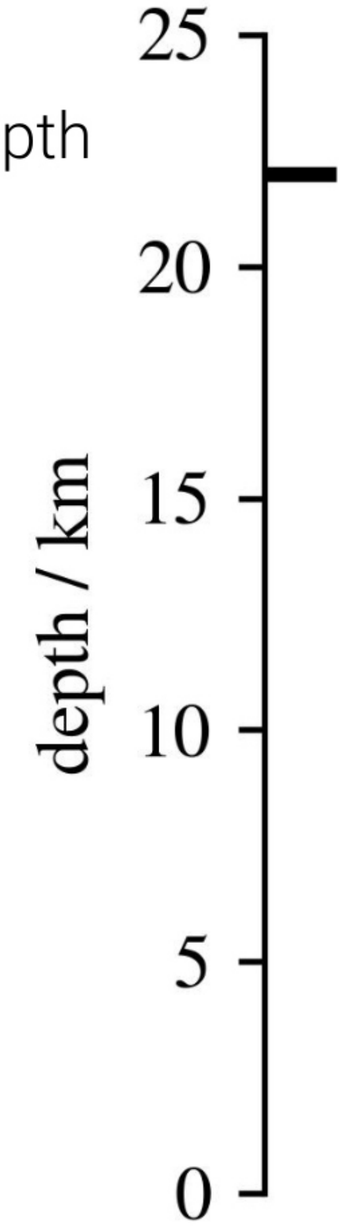


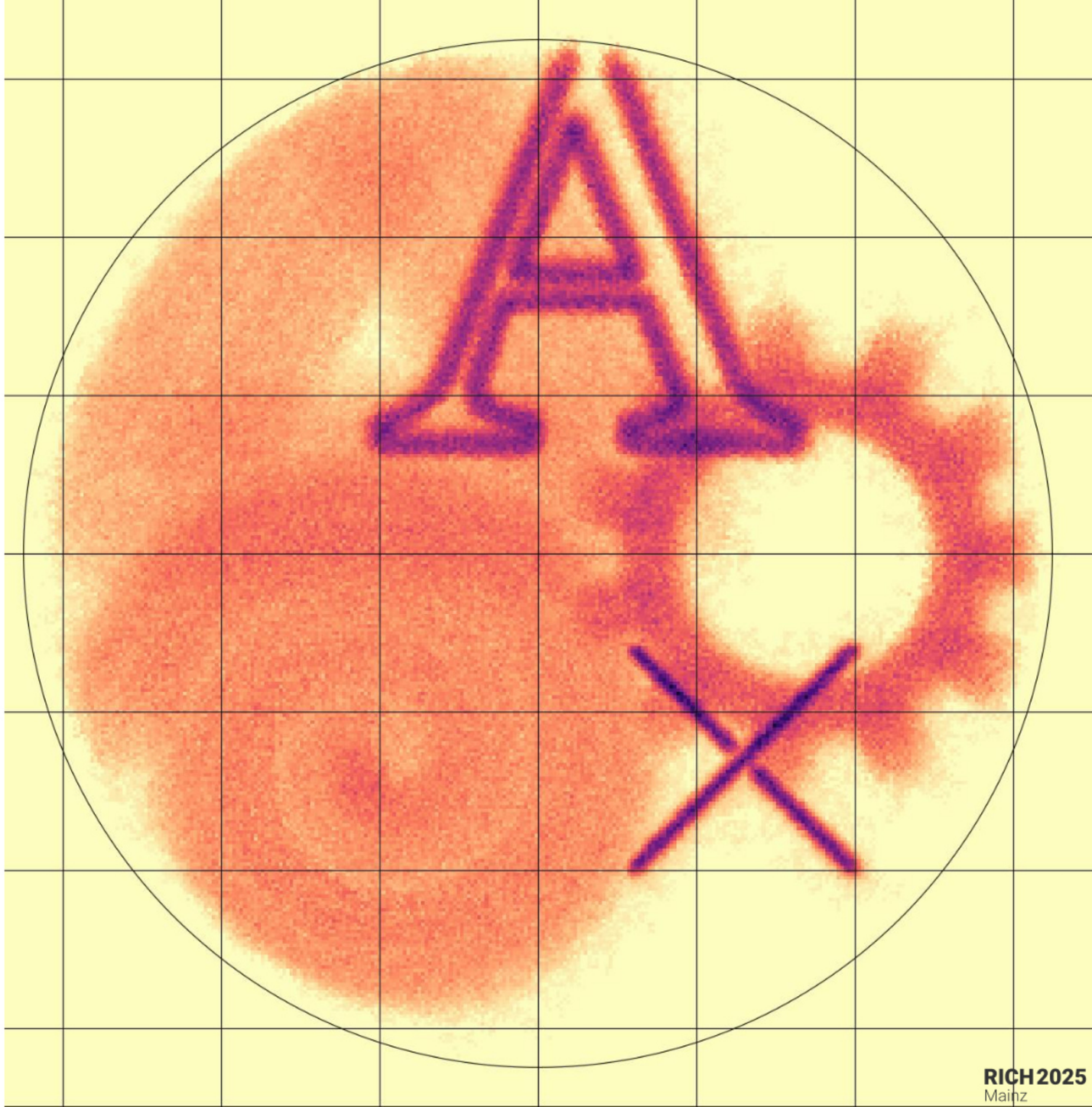


Optics

refocussing to any depth

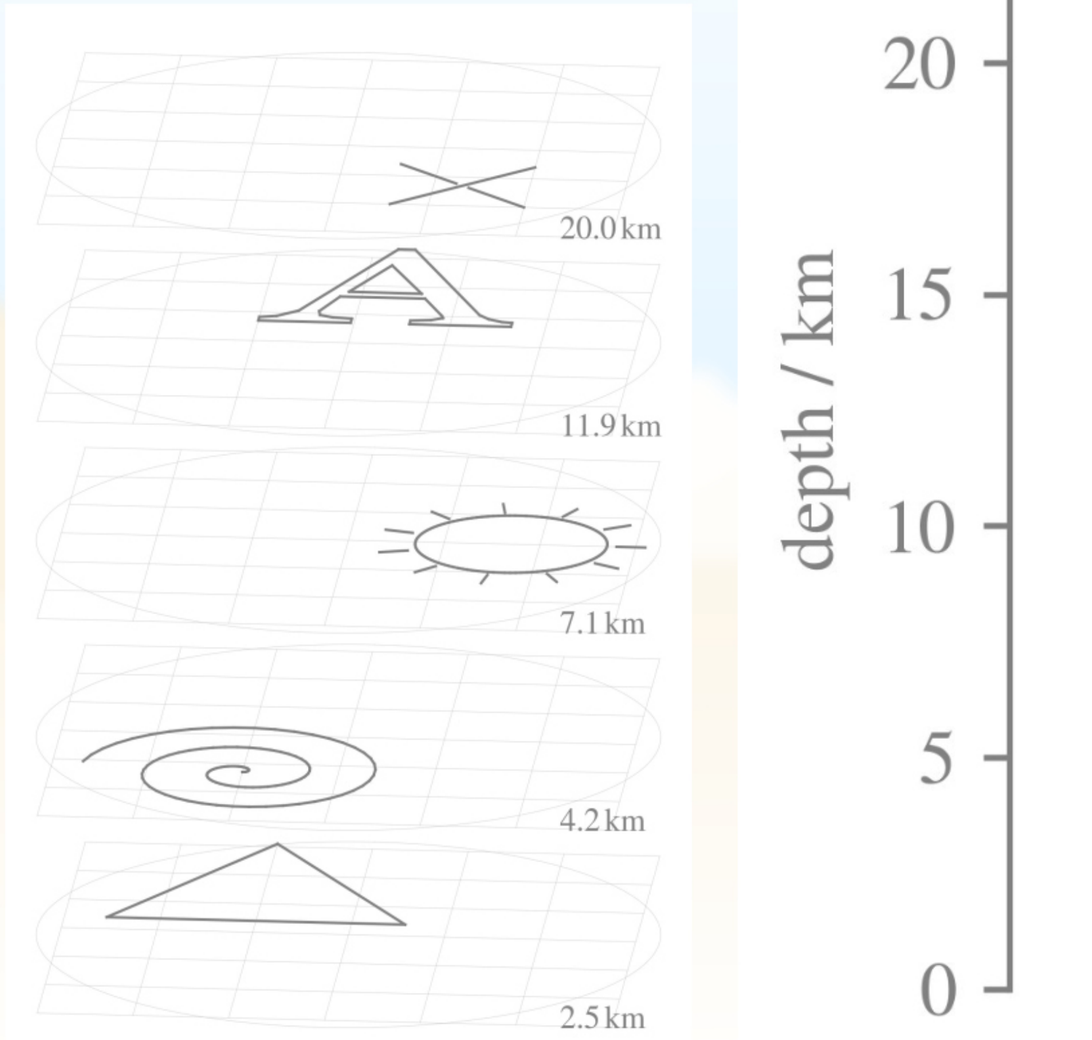


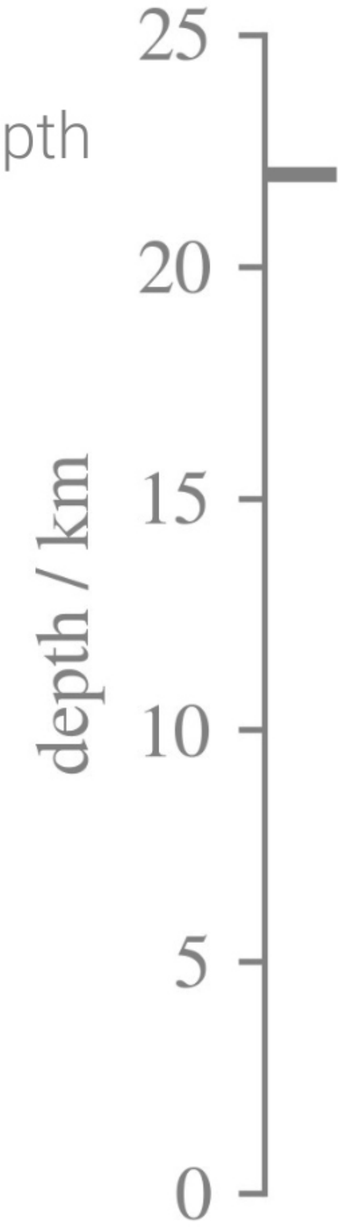


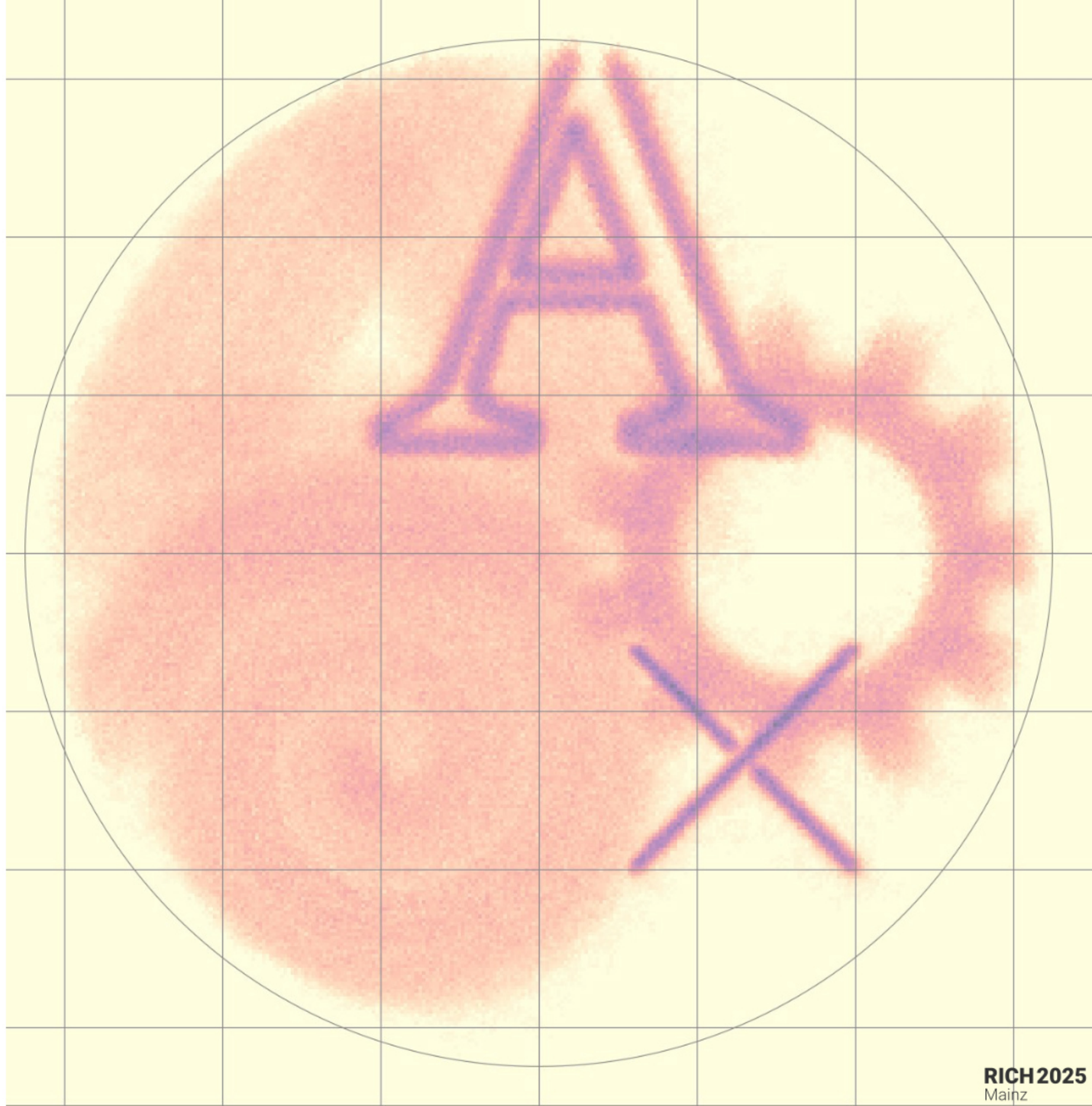


Optics

refocussing to any depth





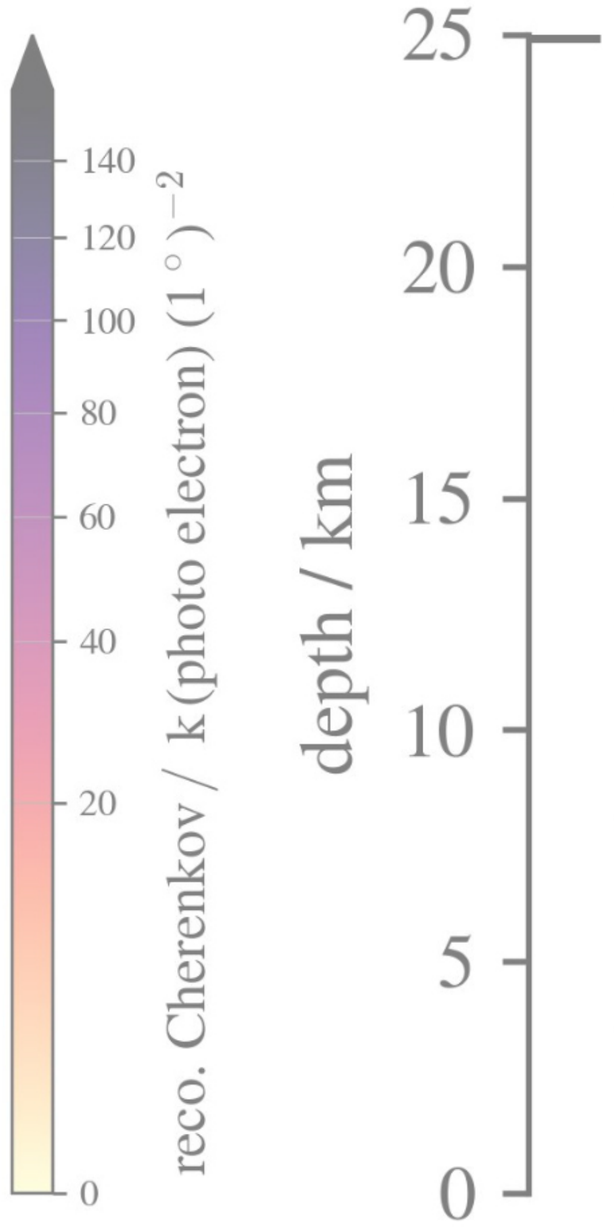


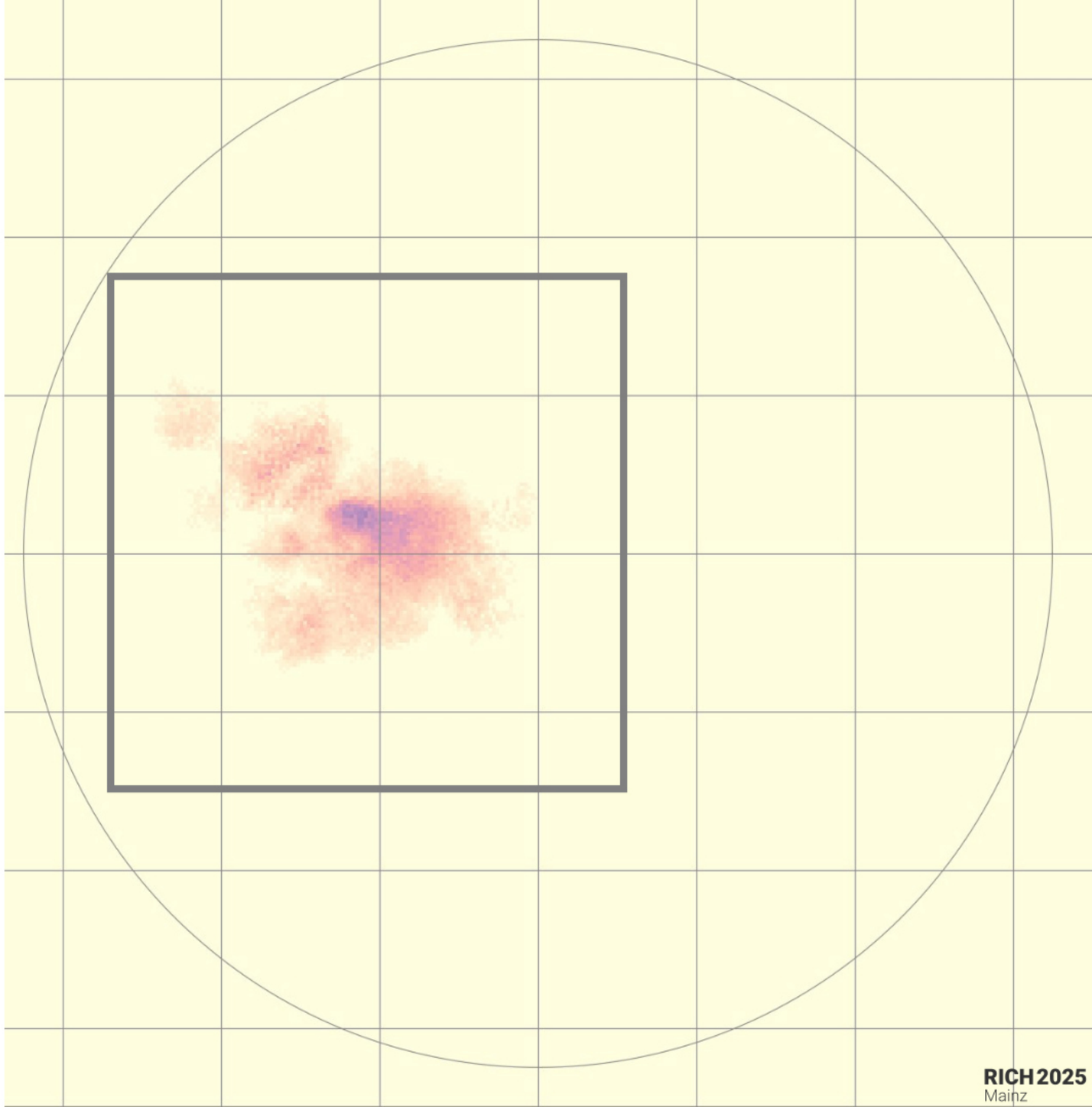
Airshower

Helium

882GeV

13,473p.e.





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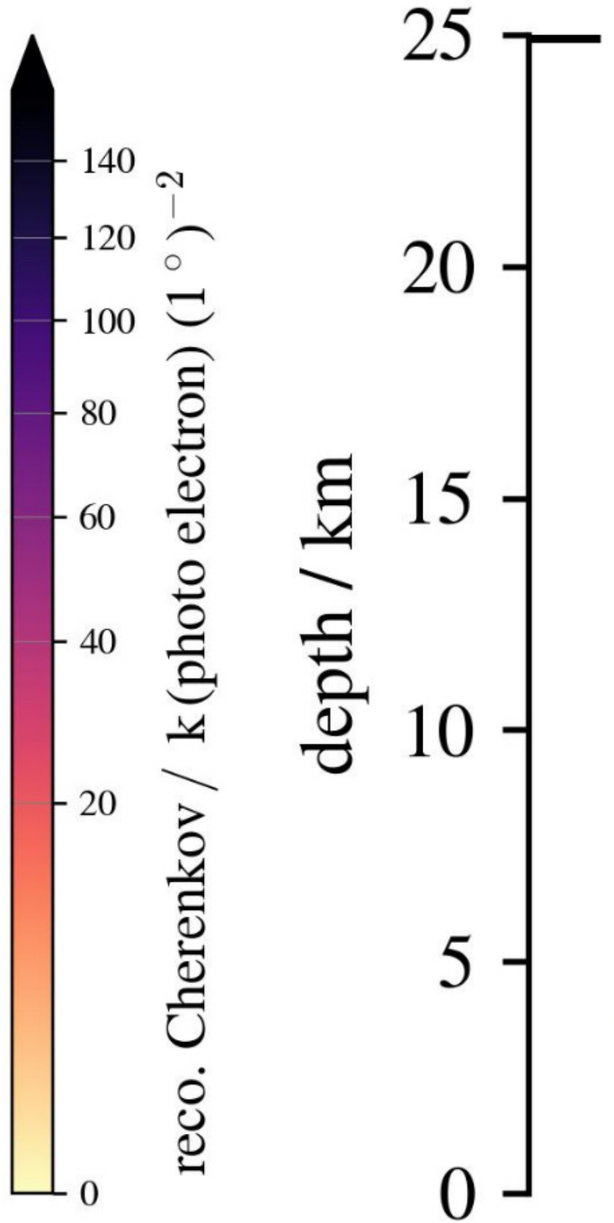

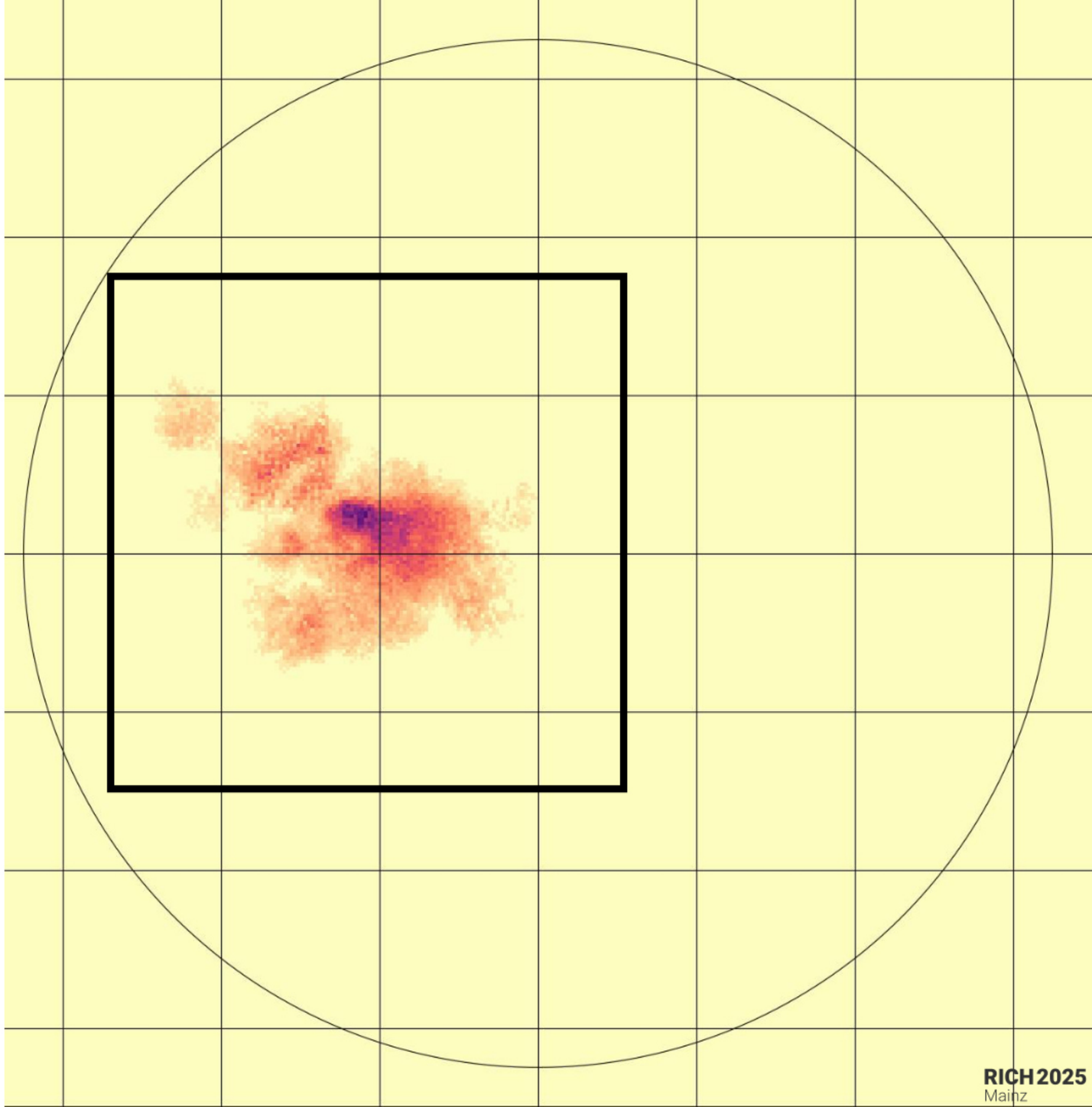

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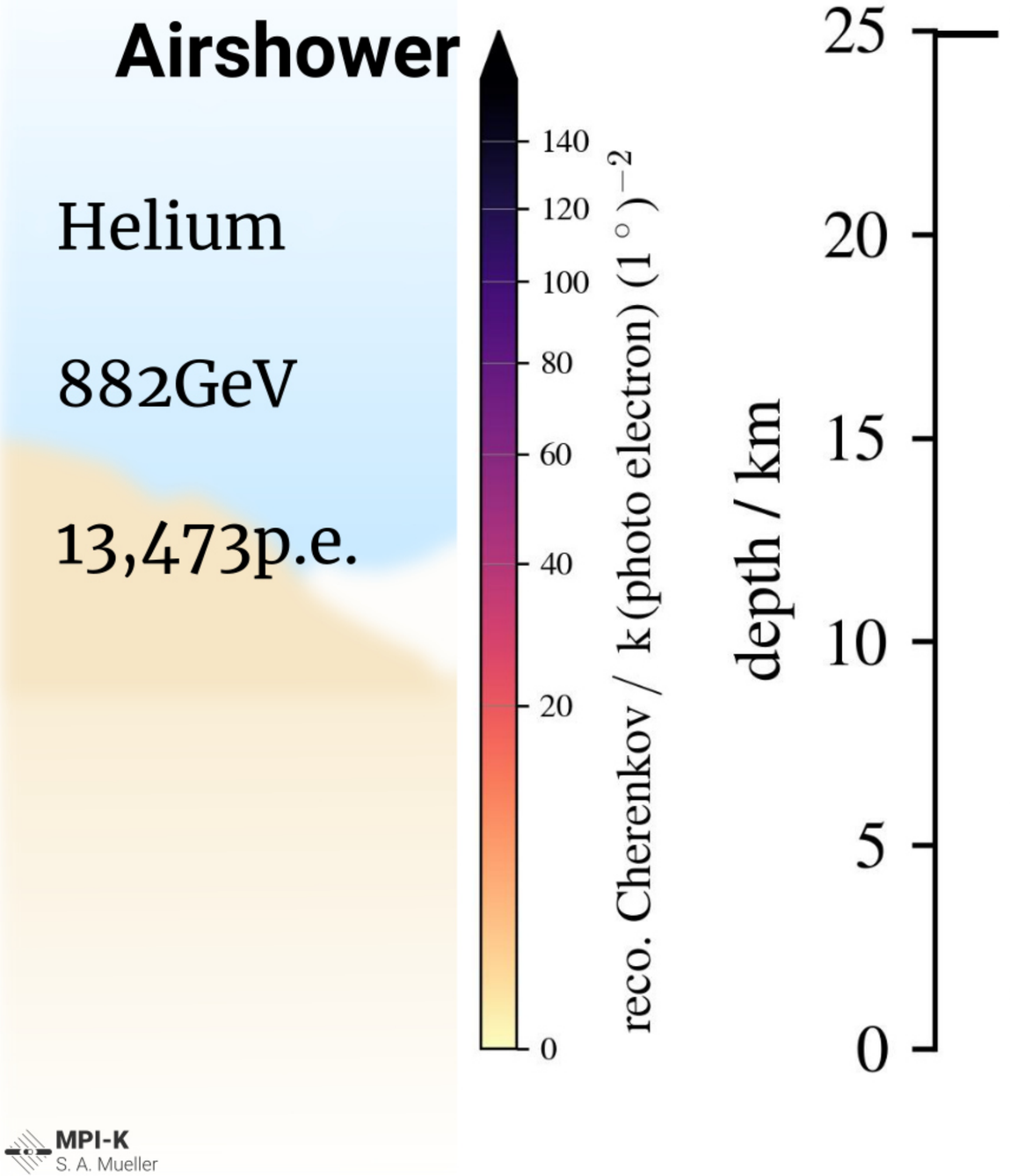

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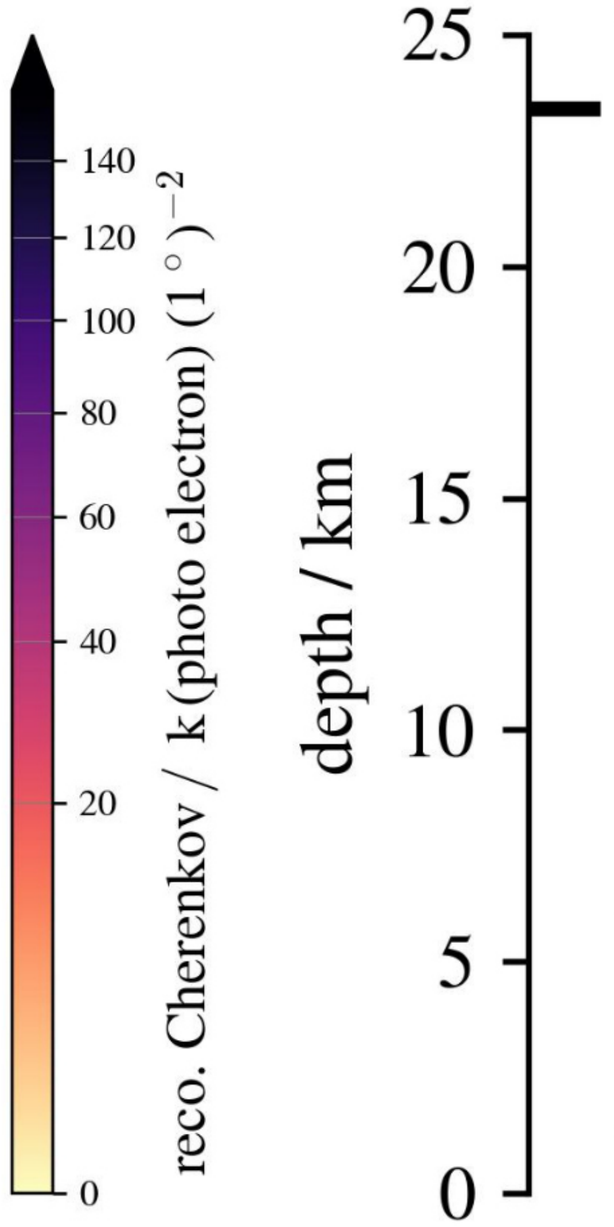

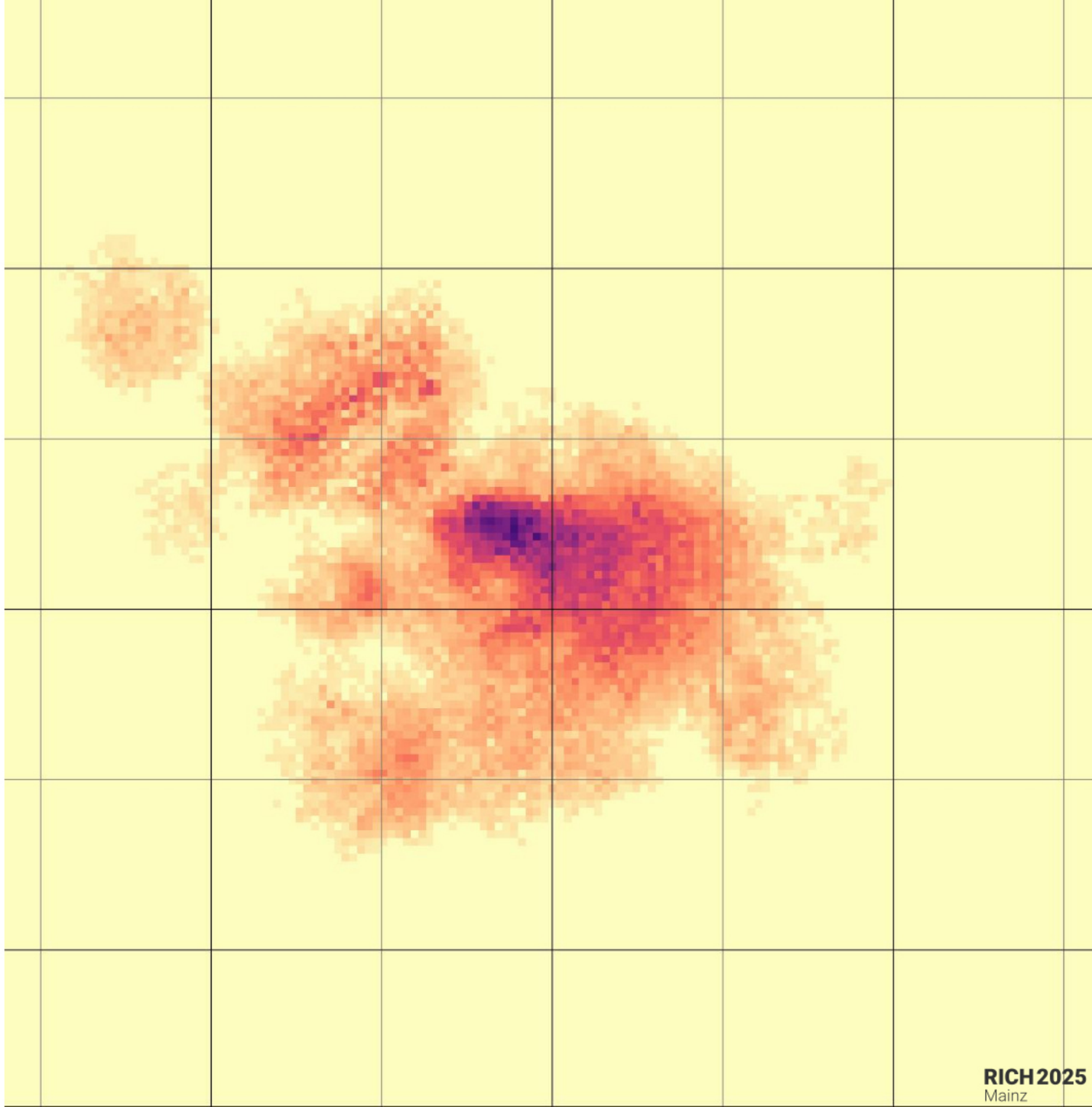

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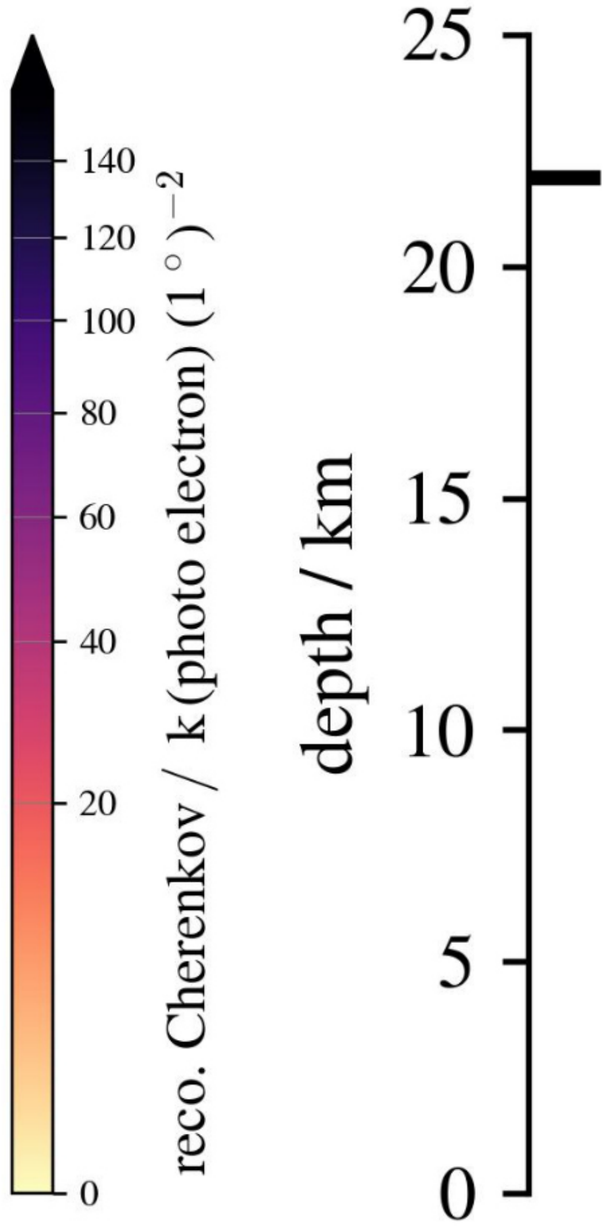

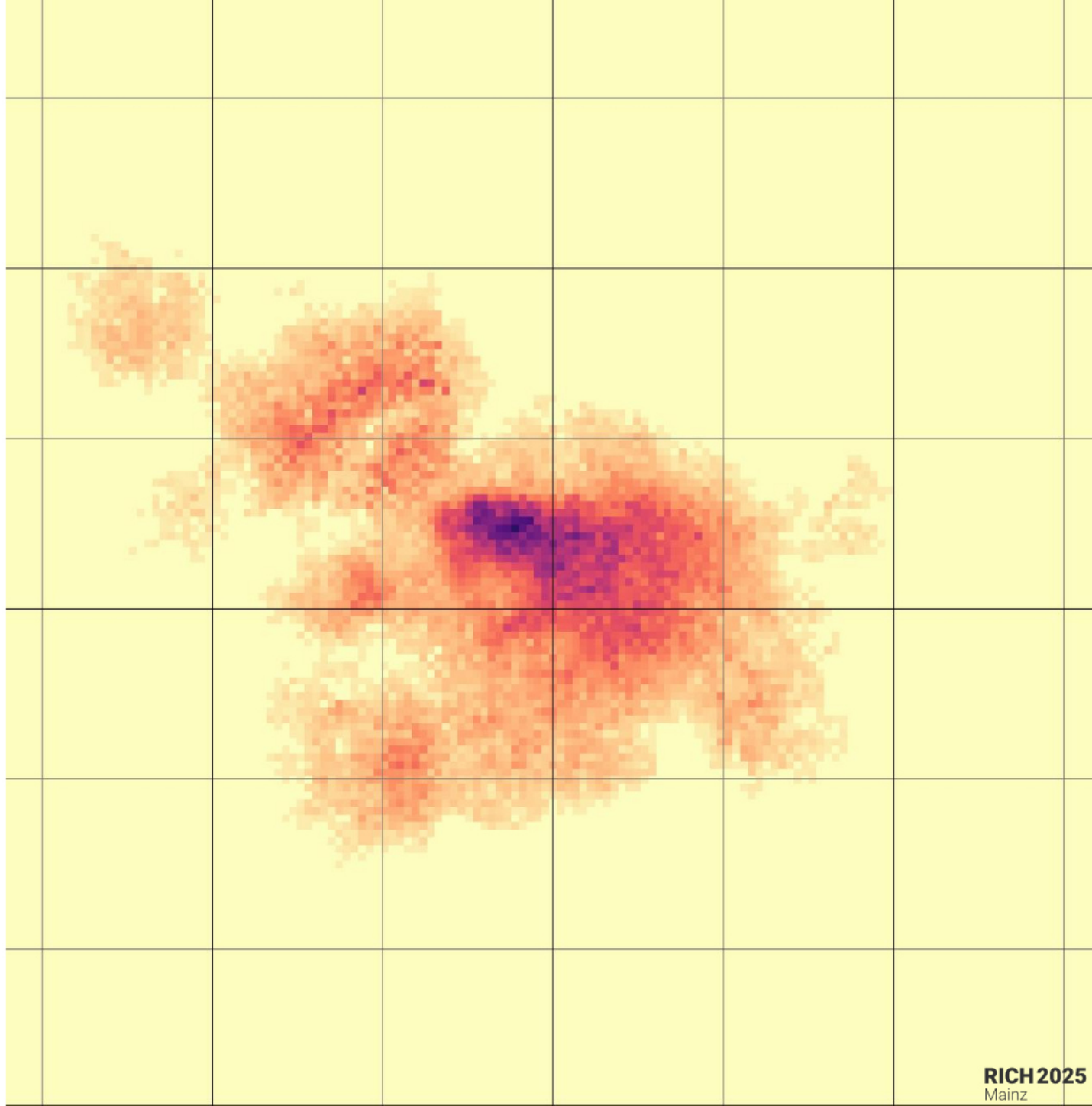

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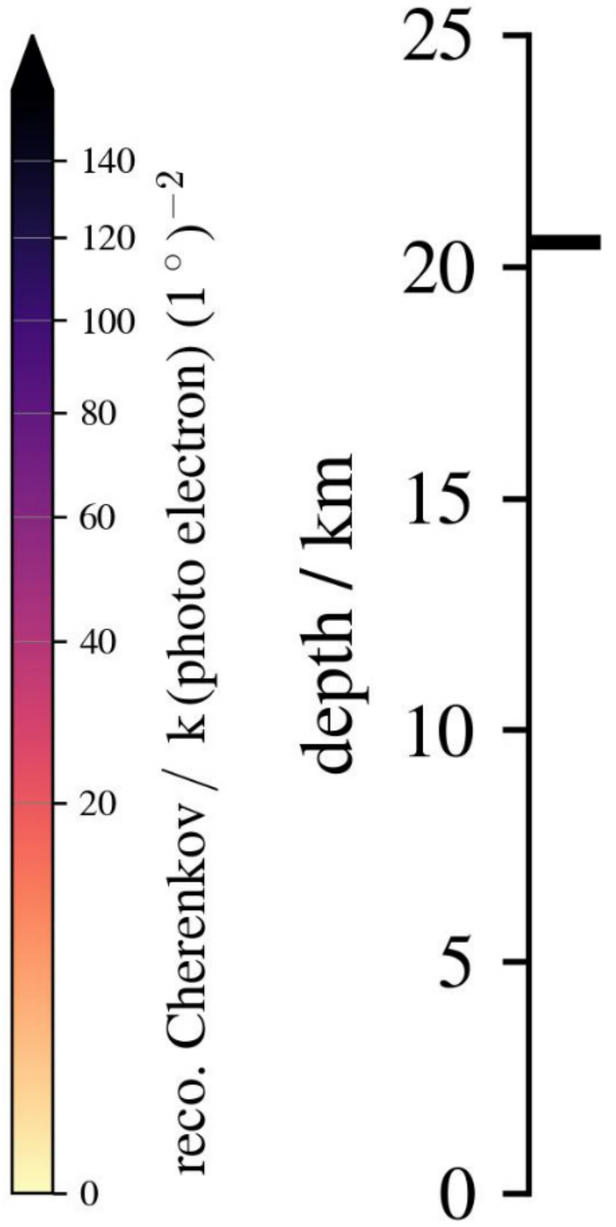

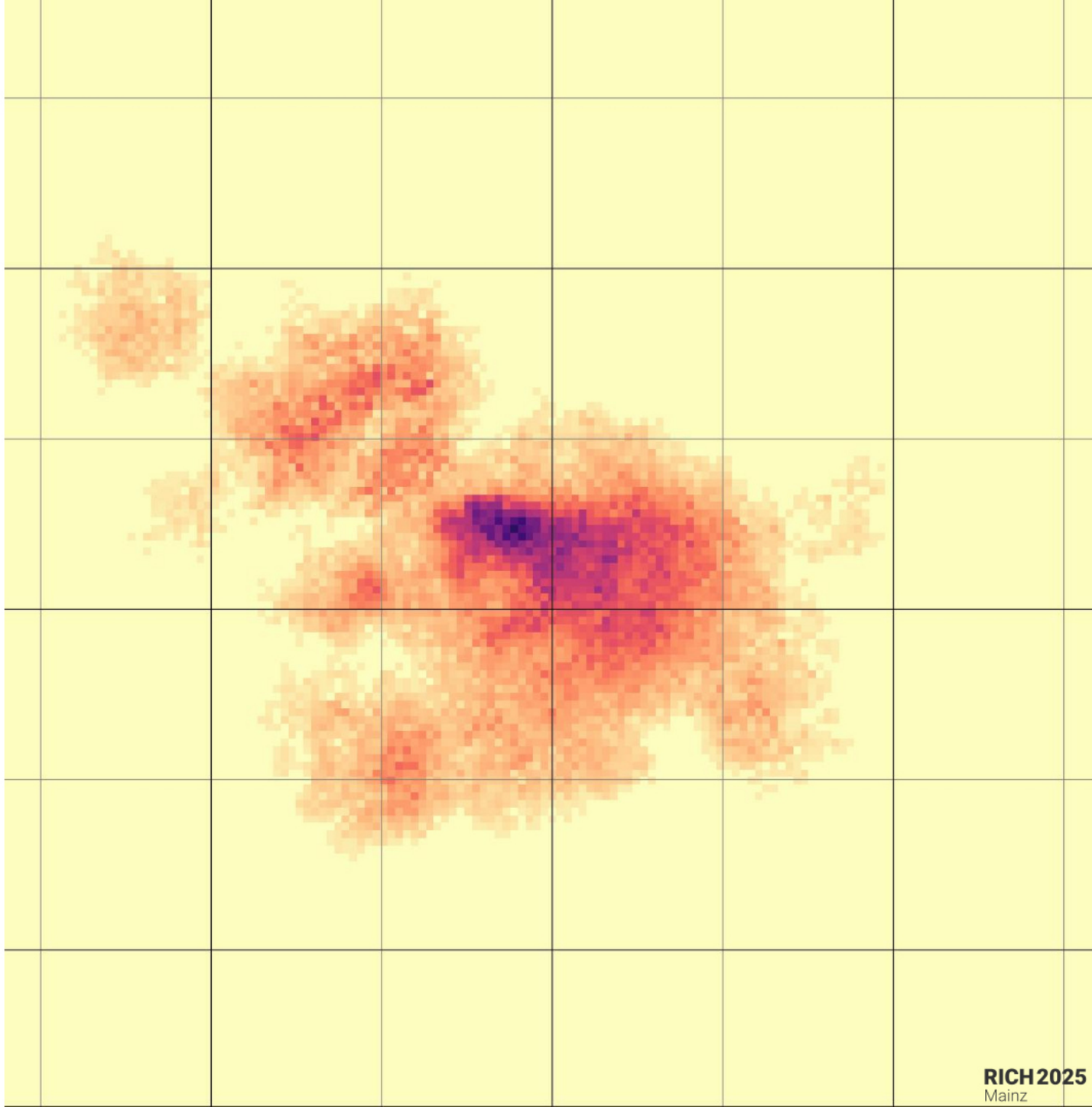

Airshower

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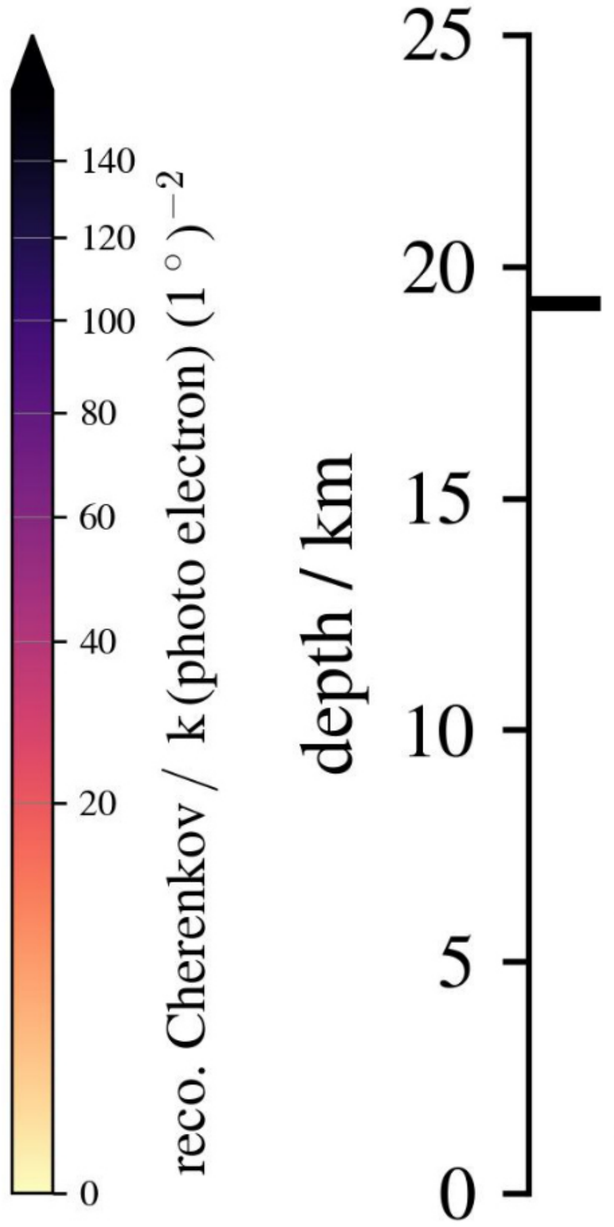

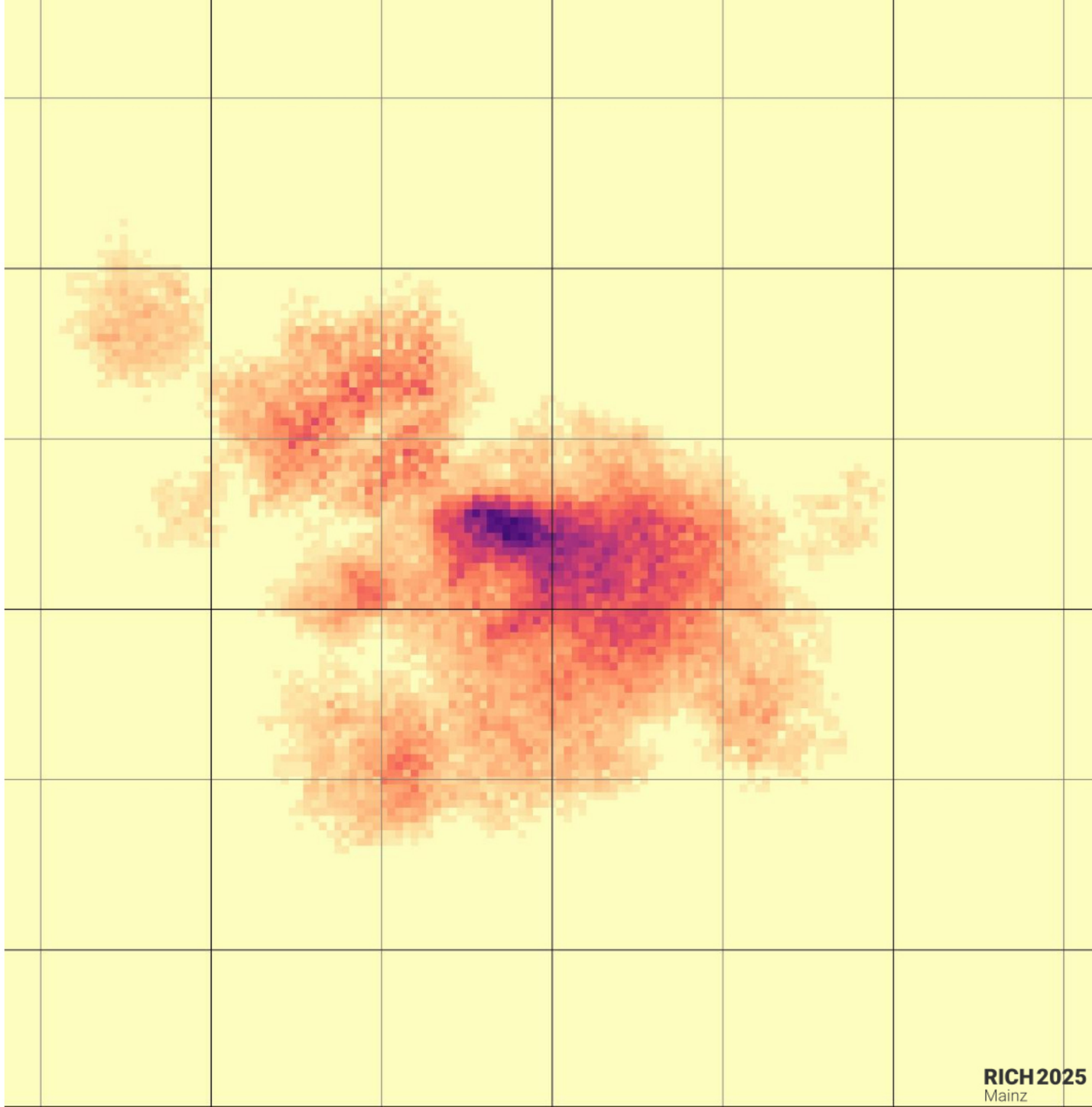

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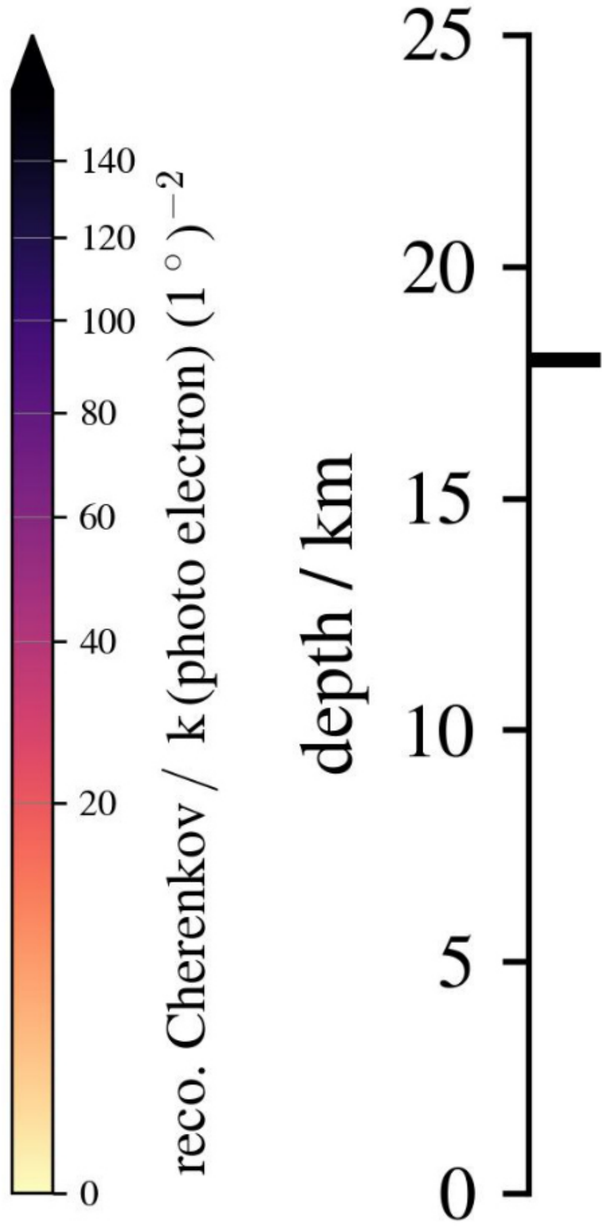

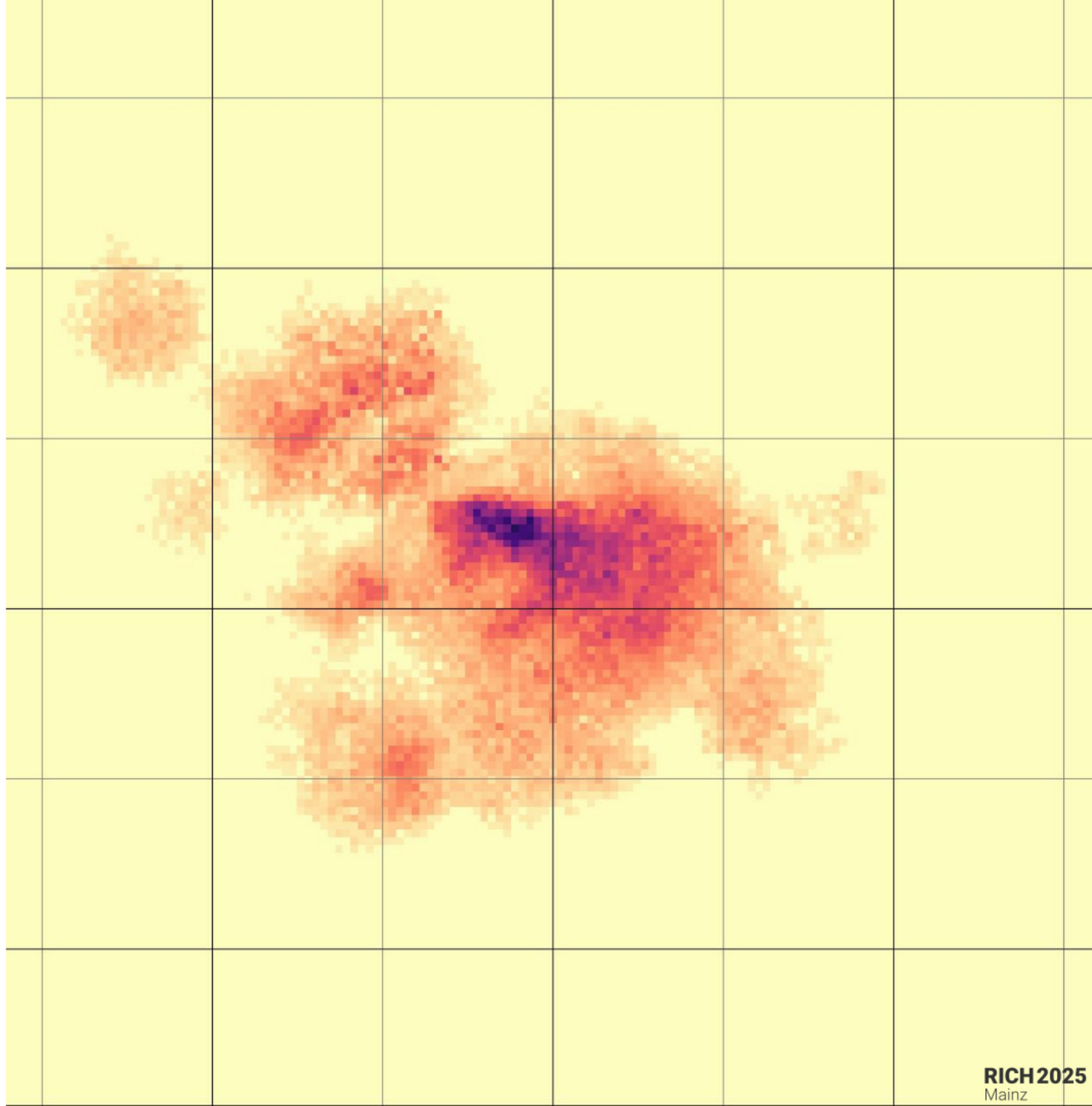

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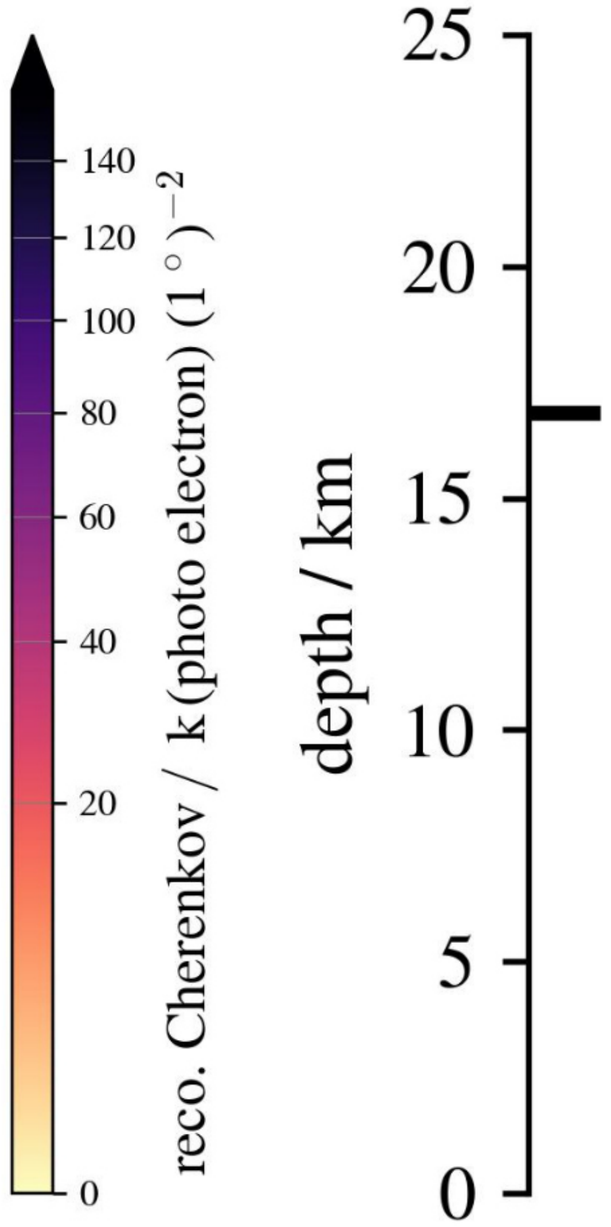

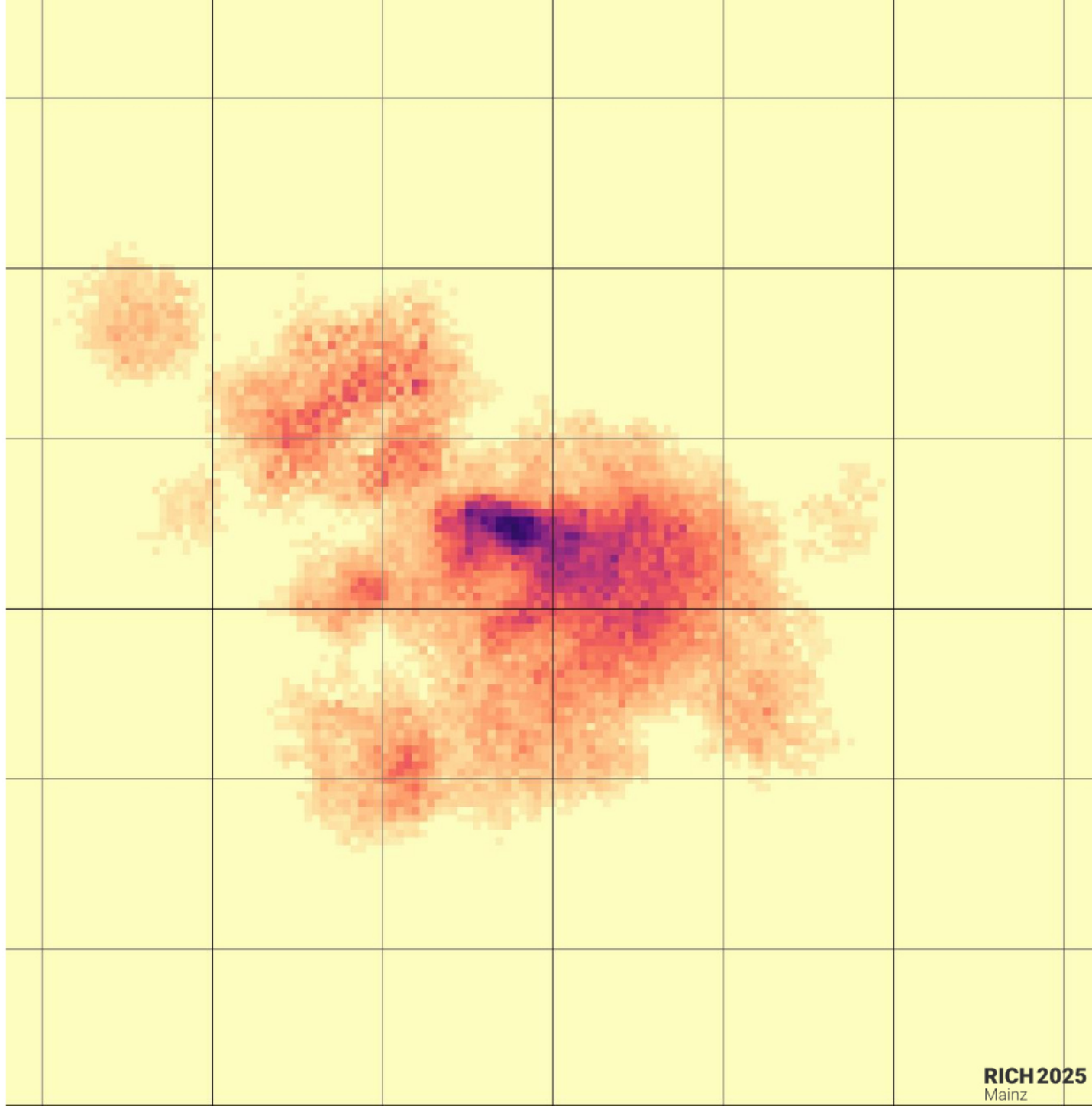

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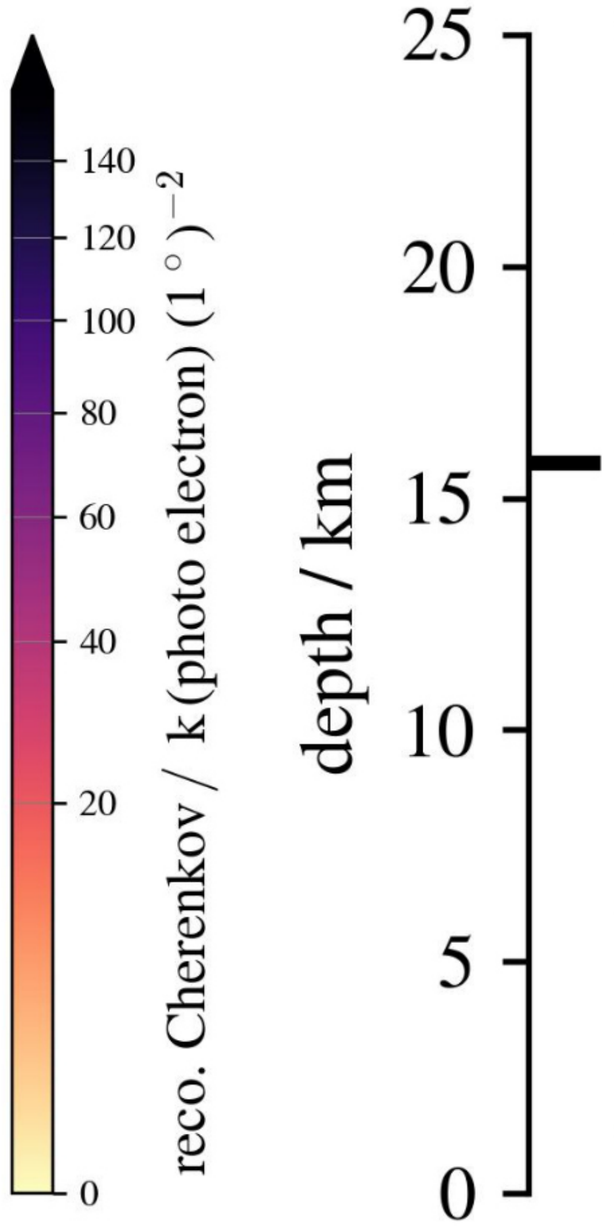

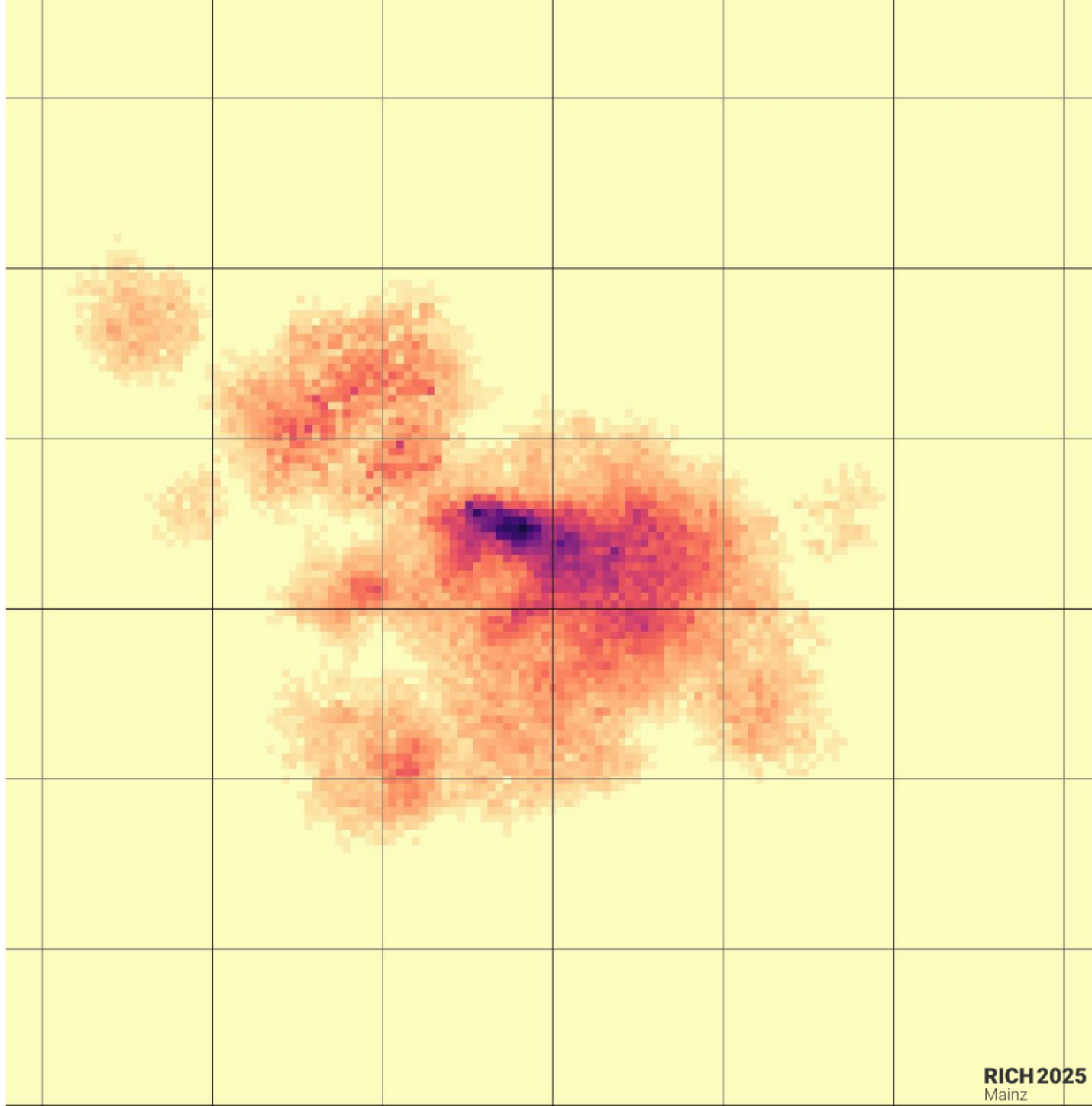

Airshower

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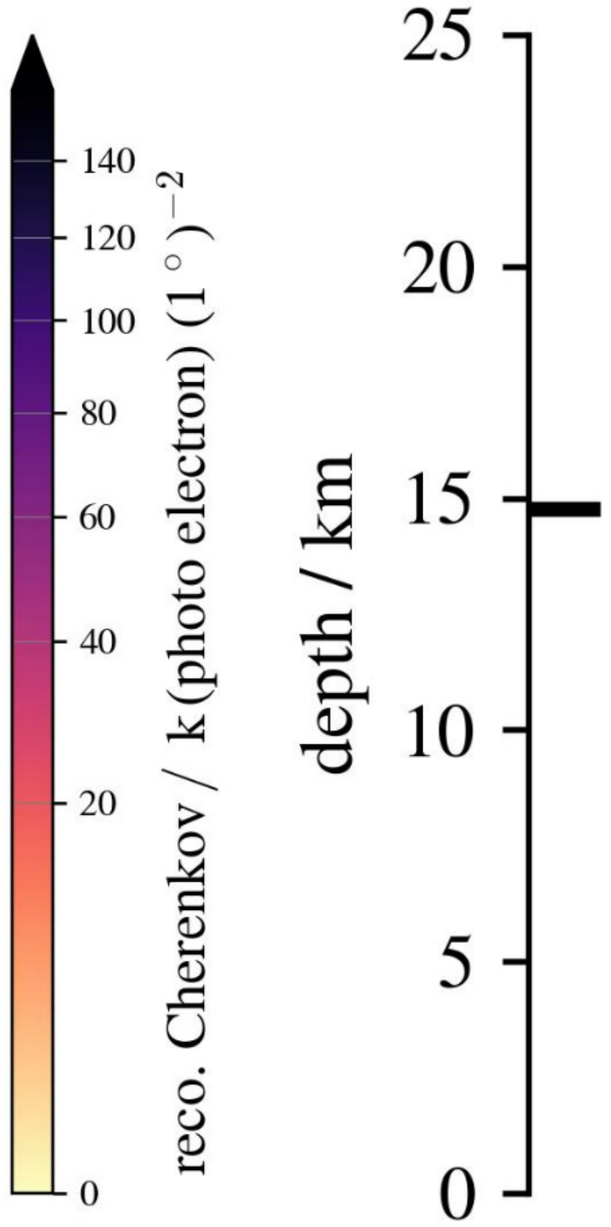

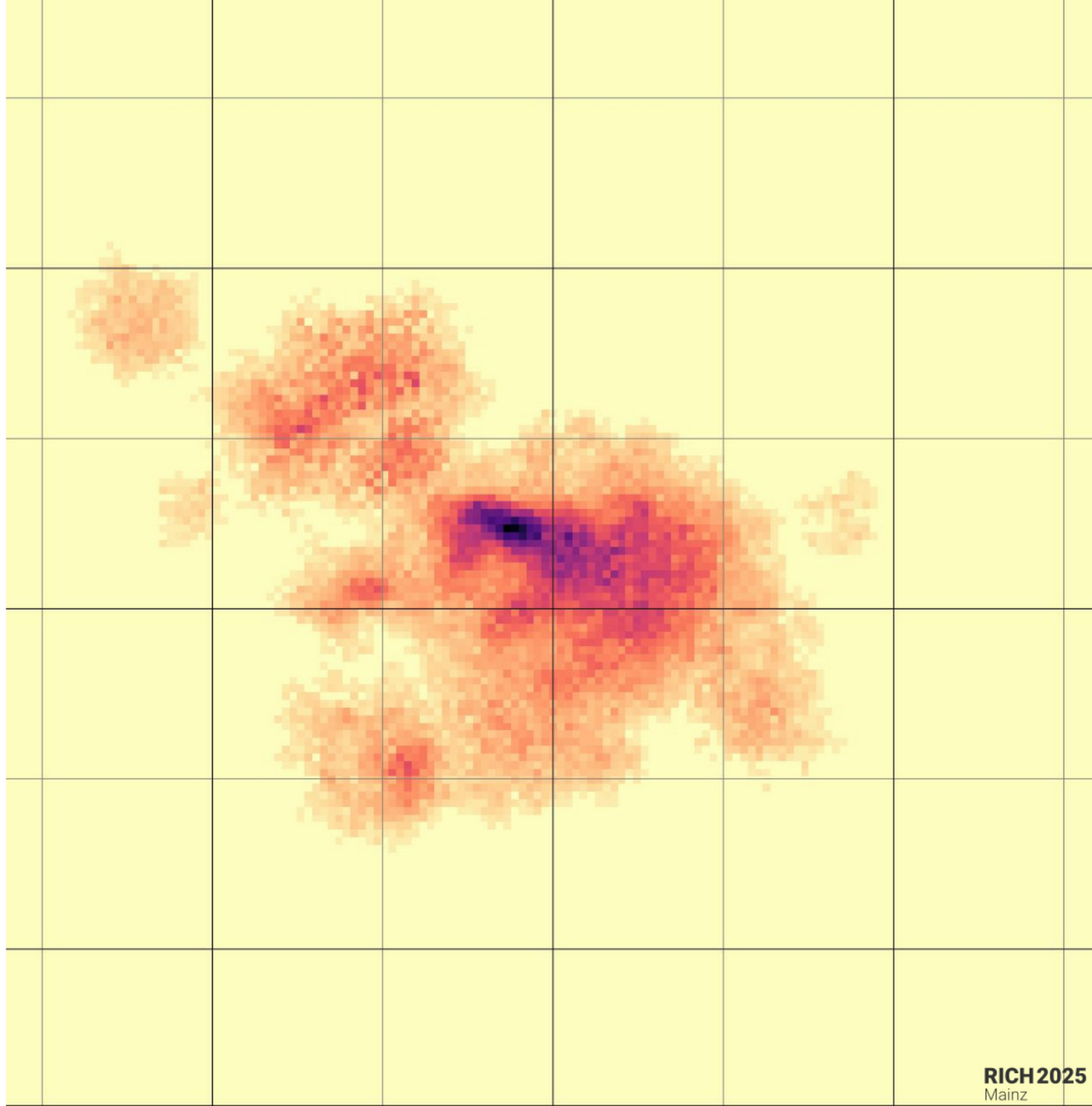

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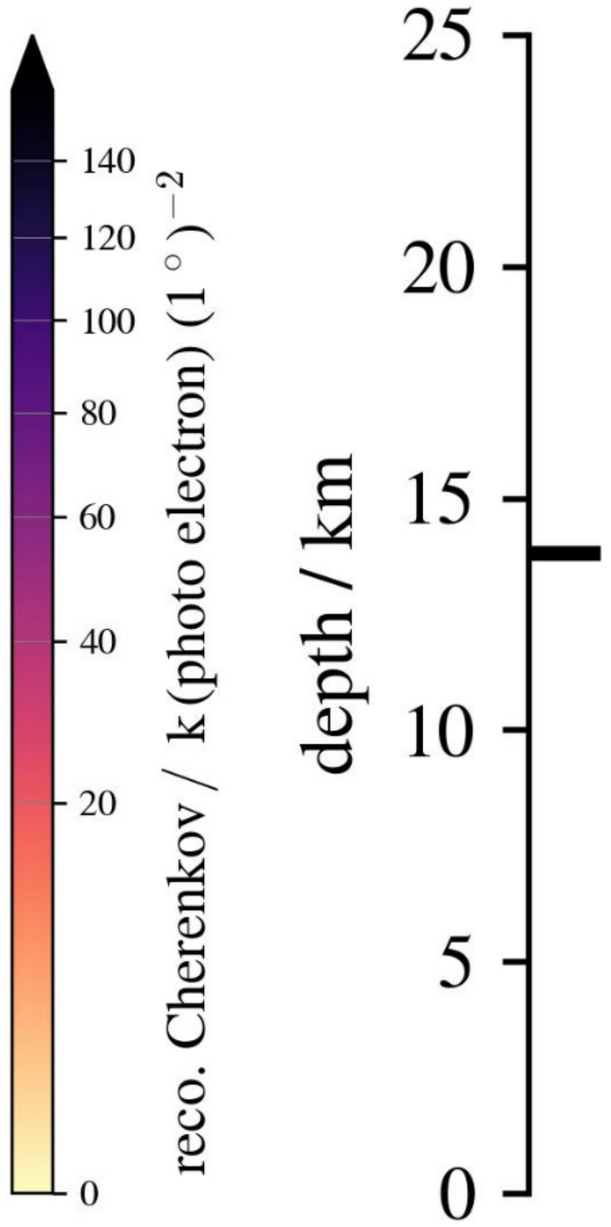

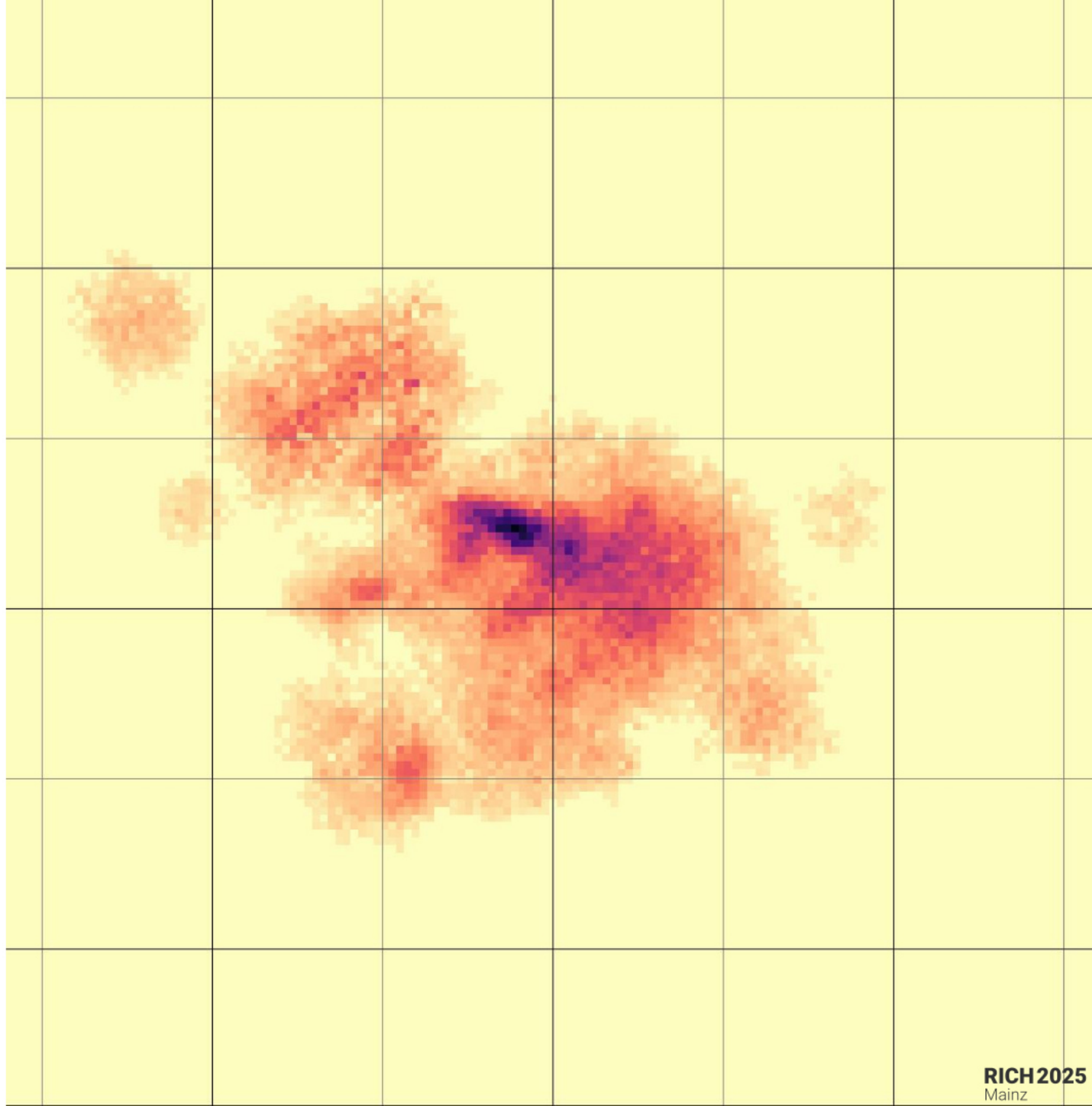

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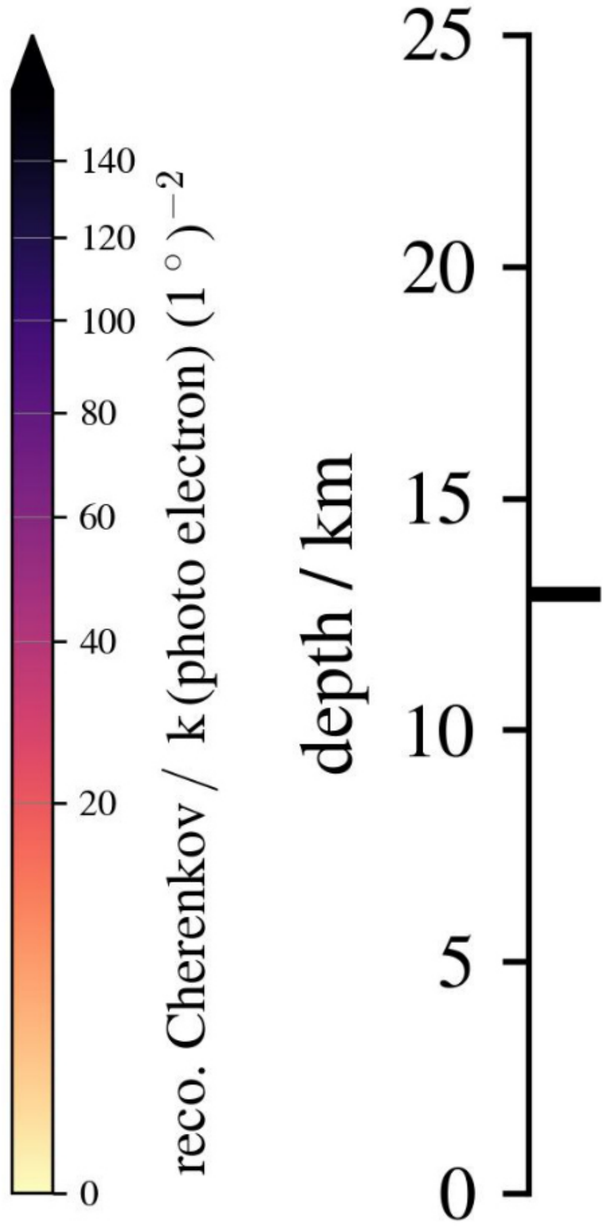

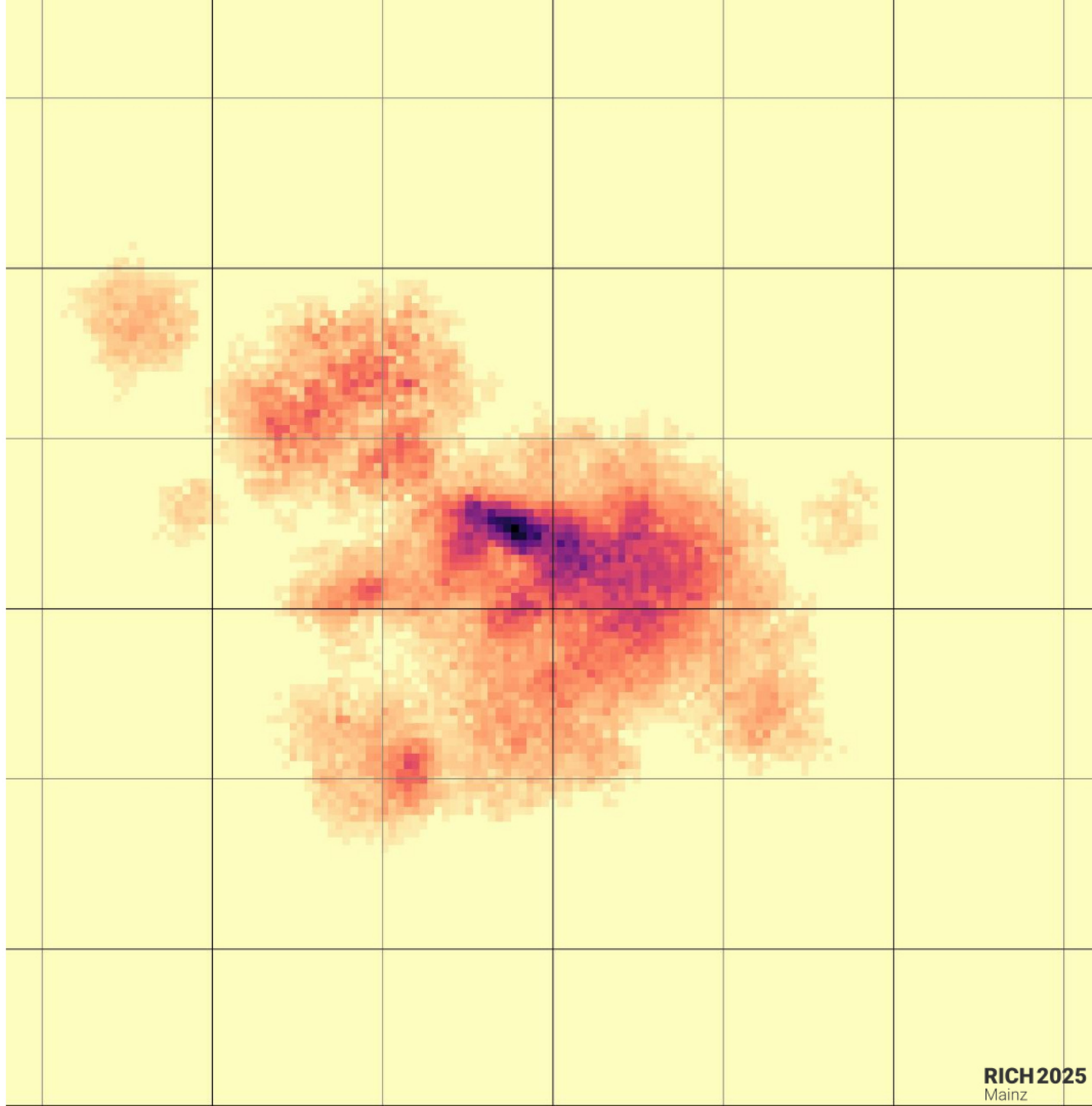

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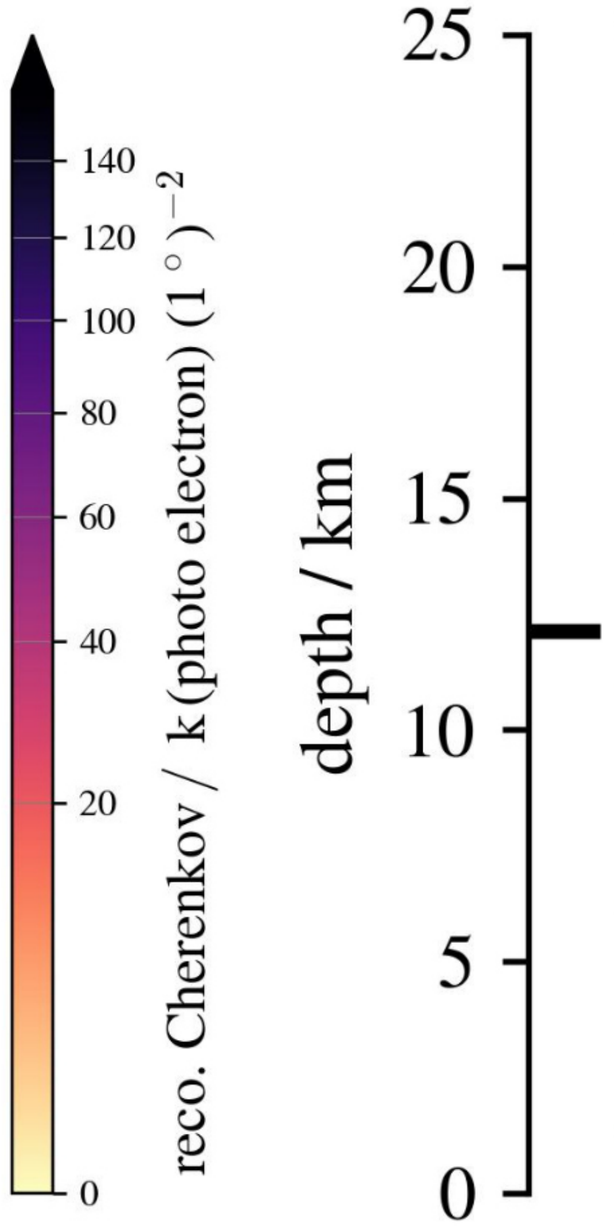

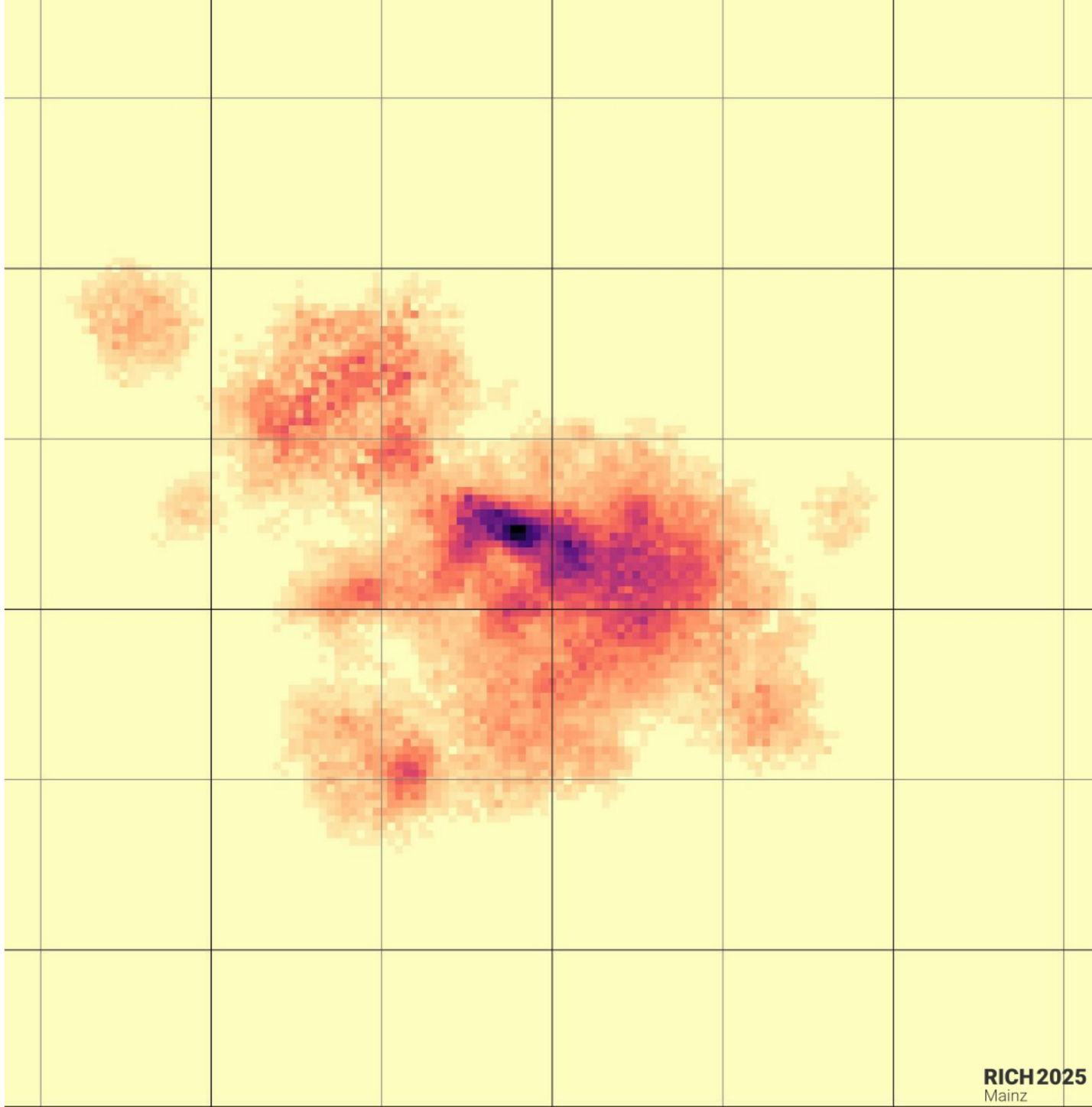

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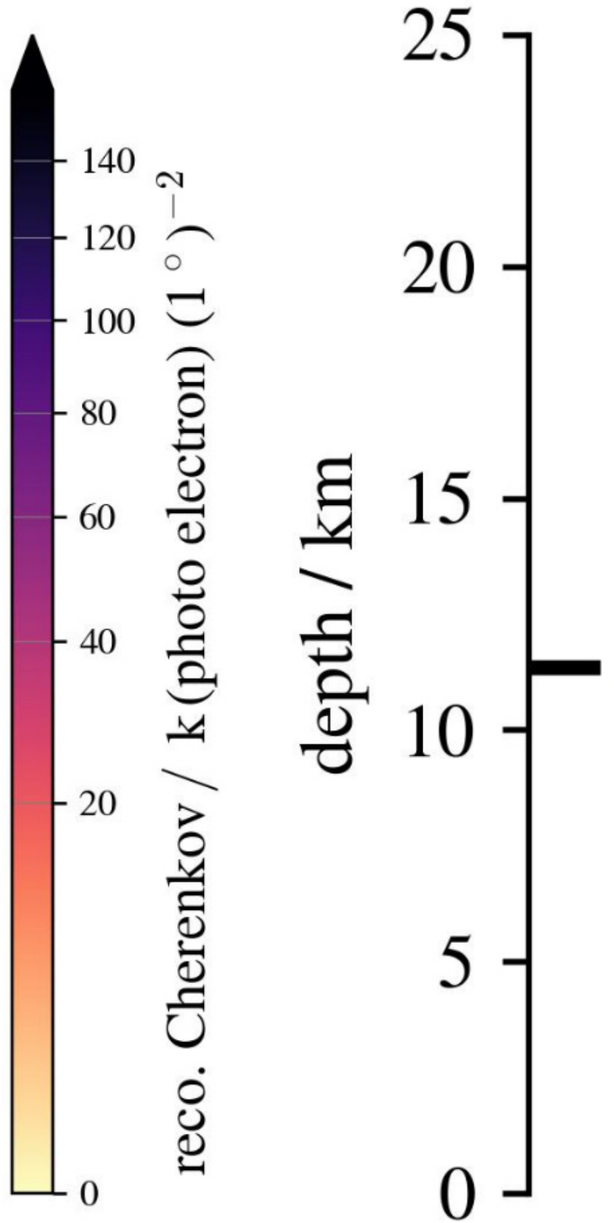

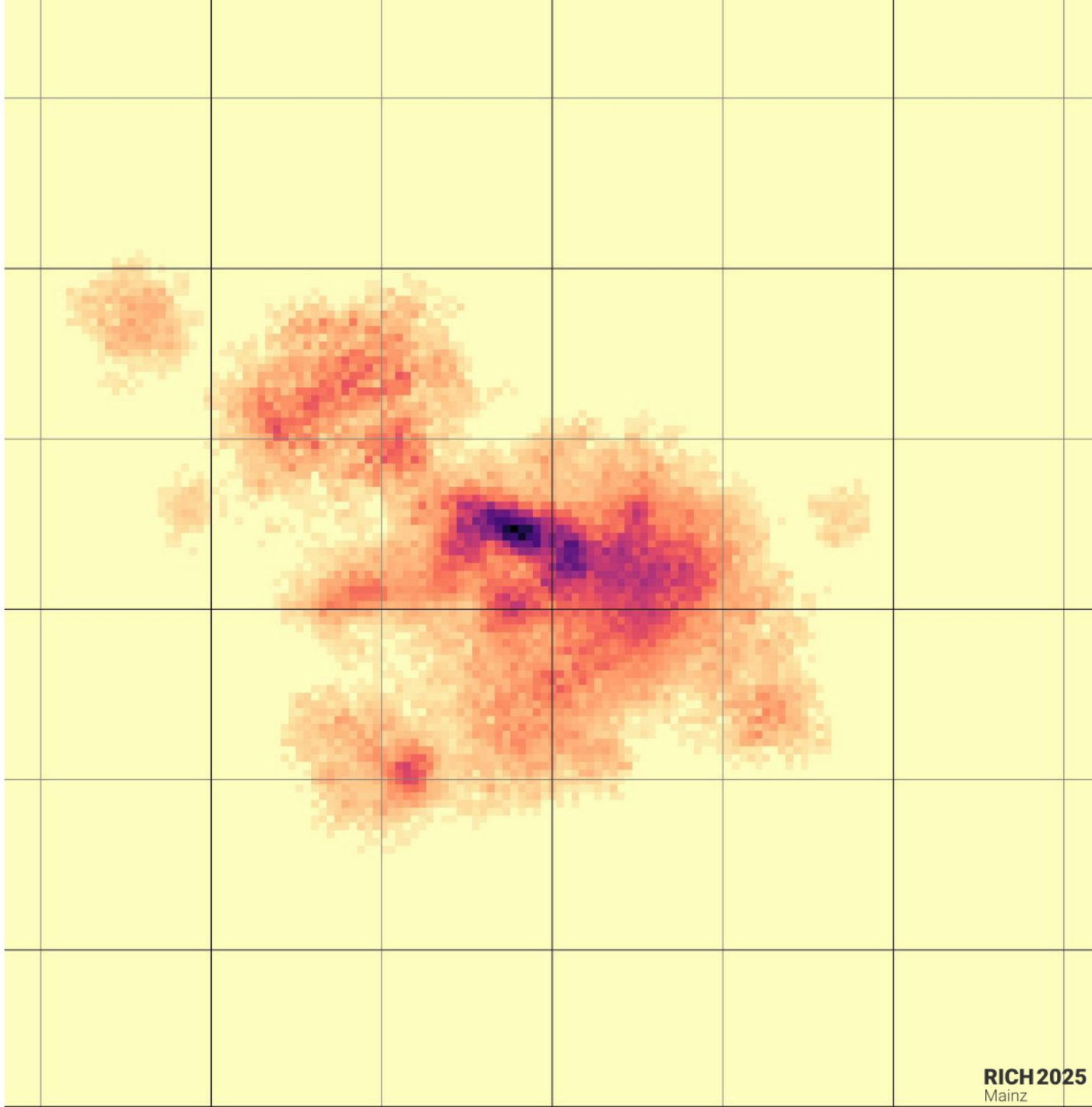

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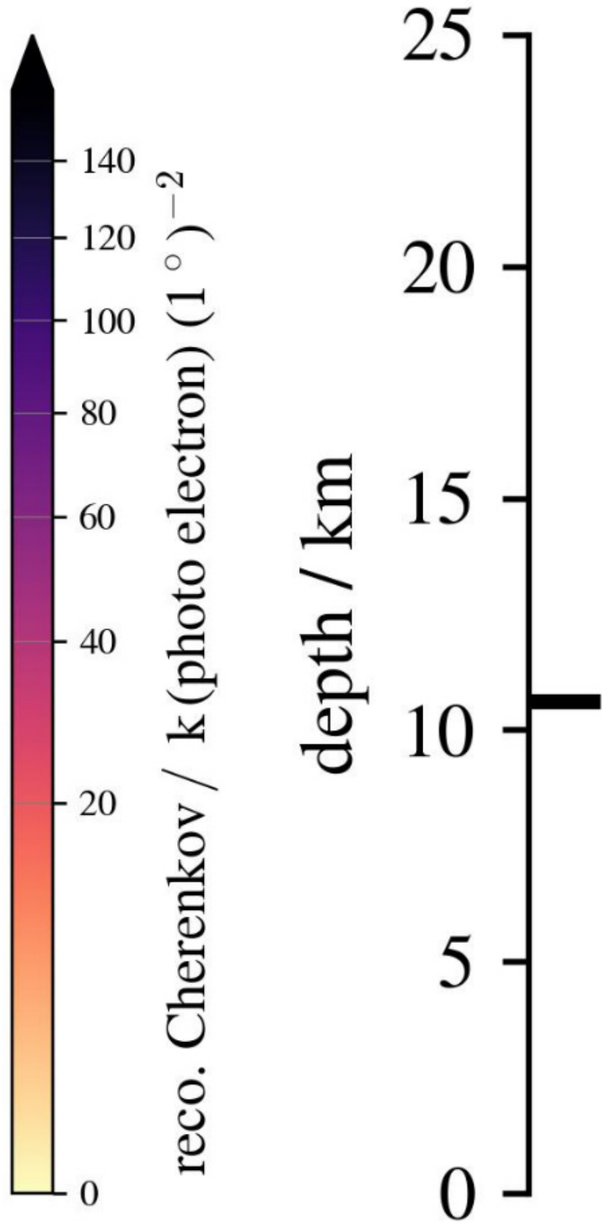

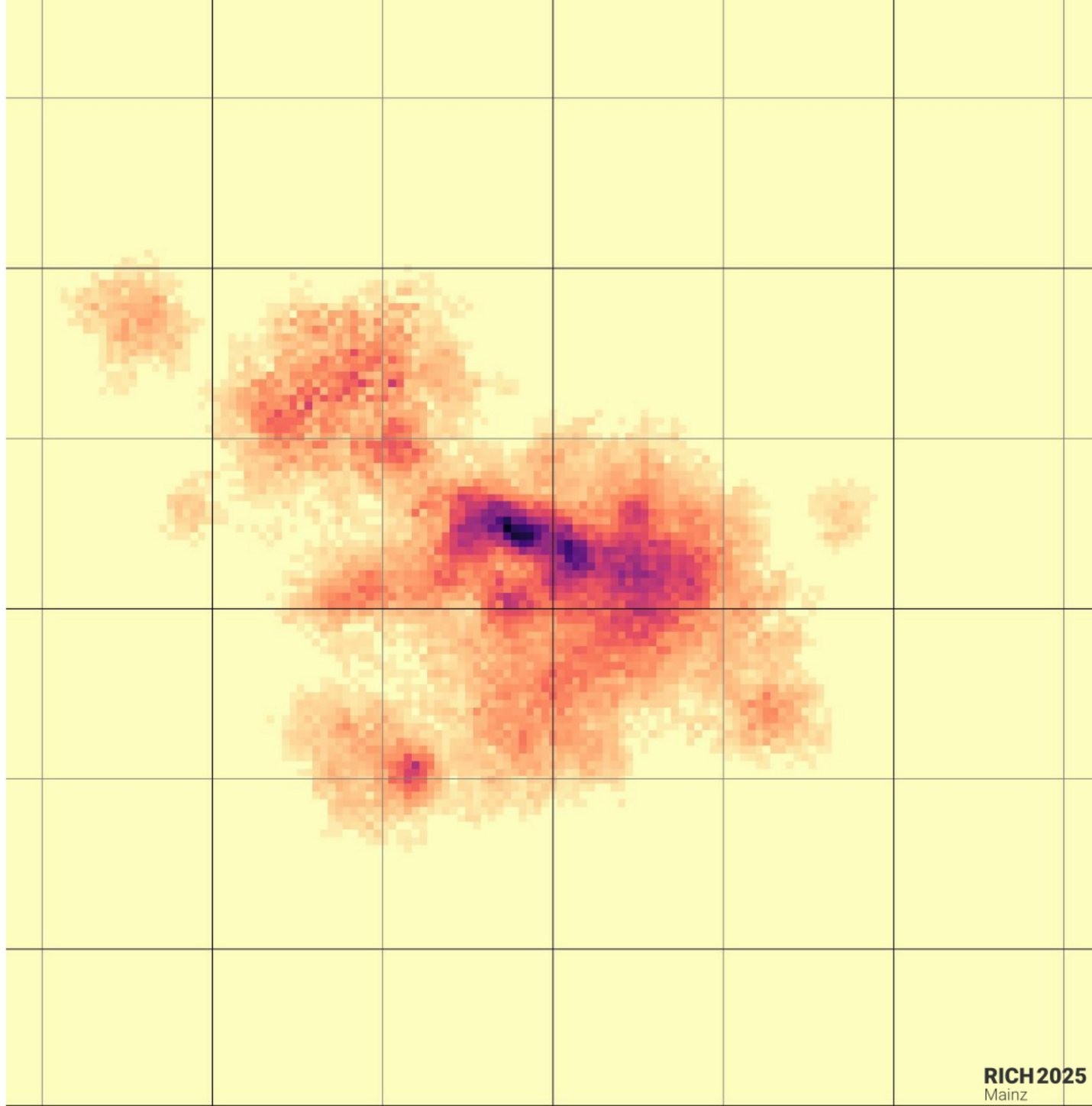

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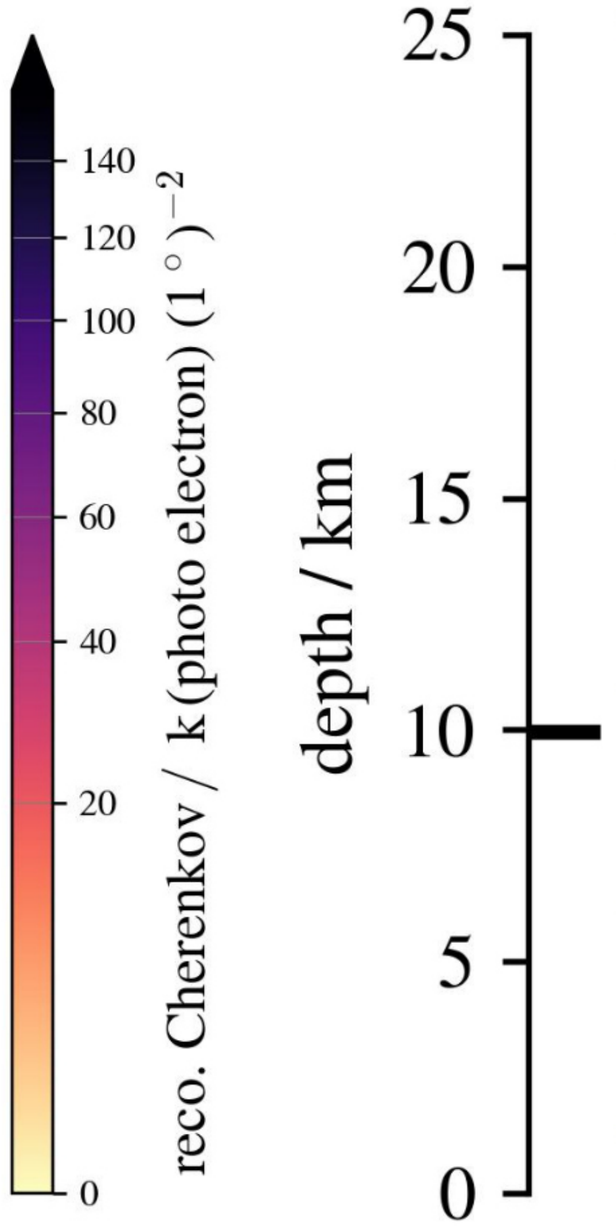

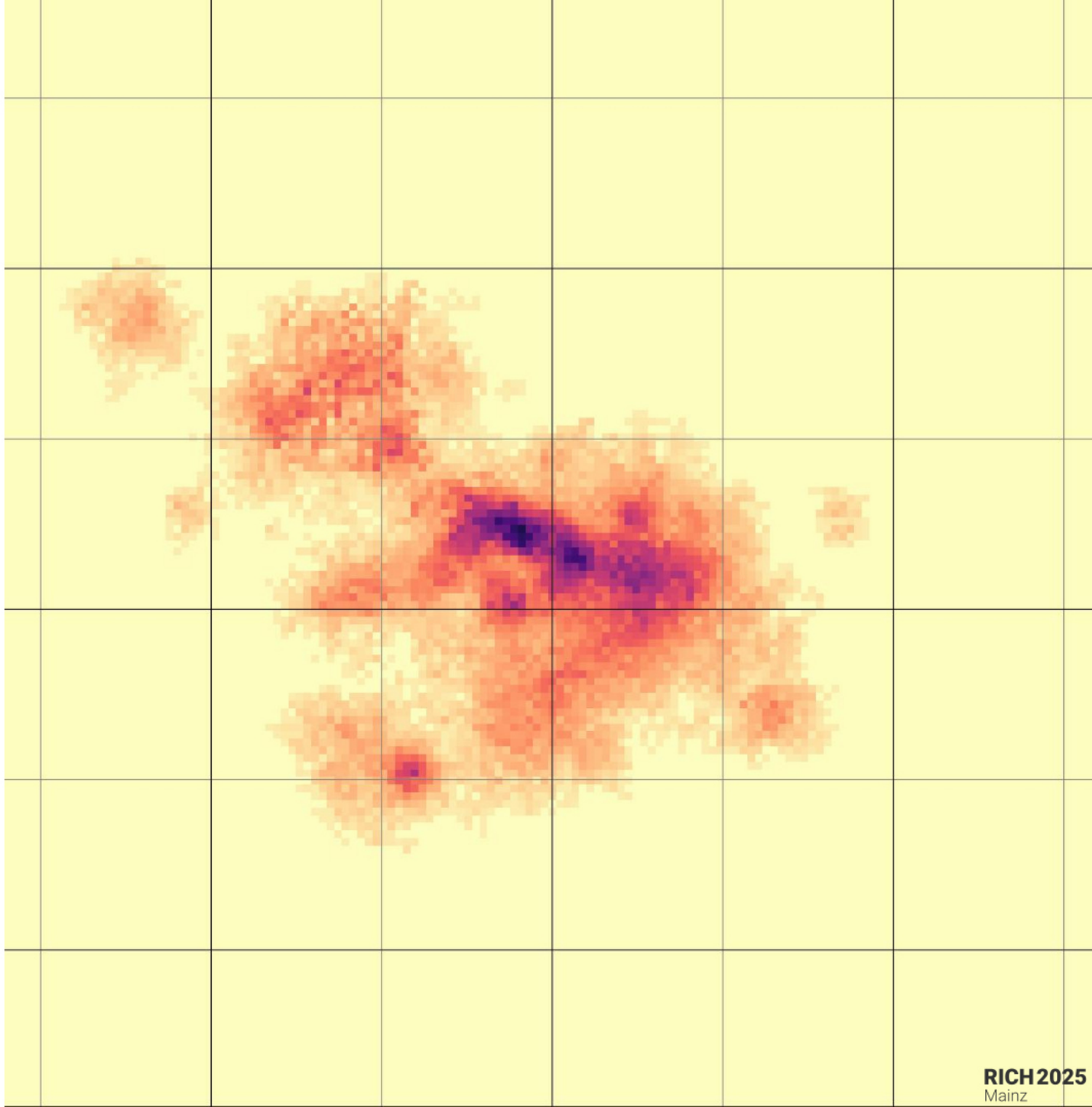

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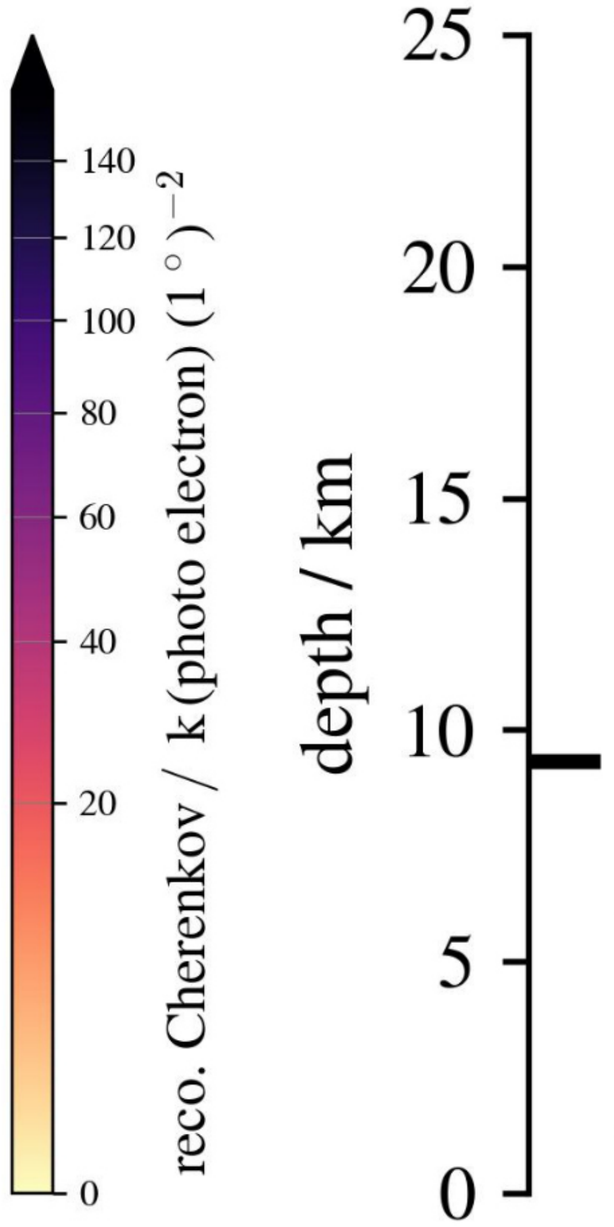

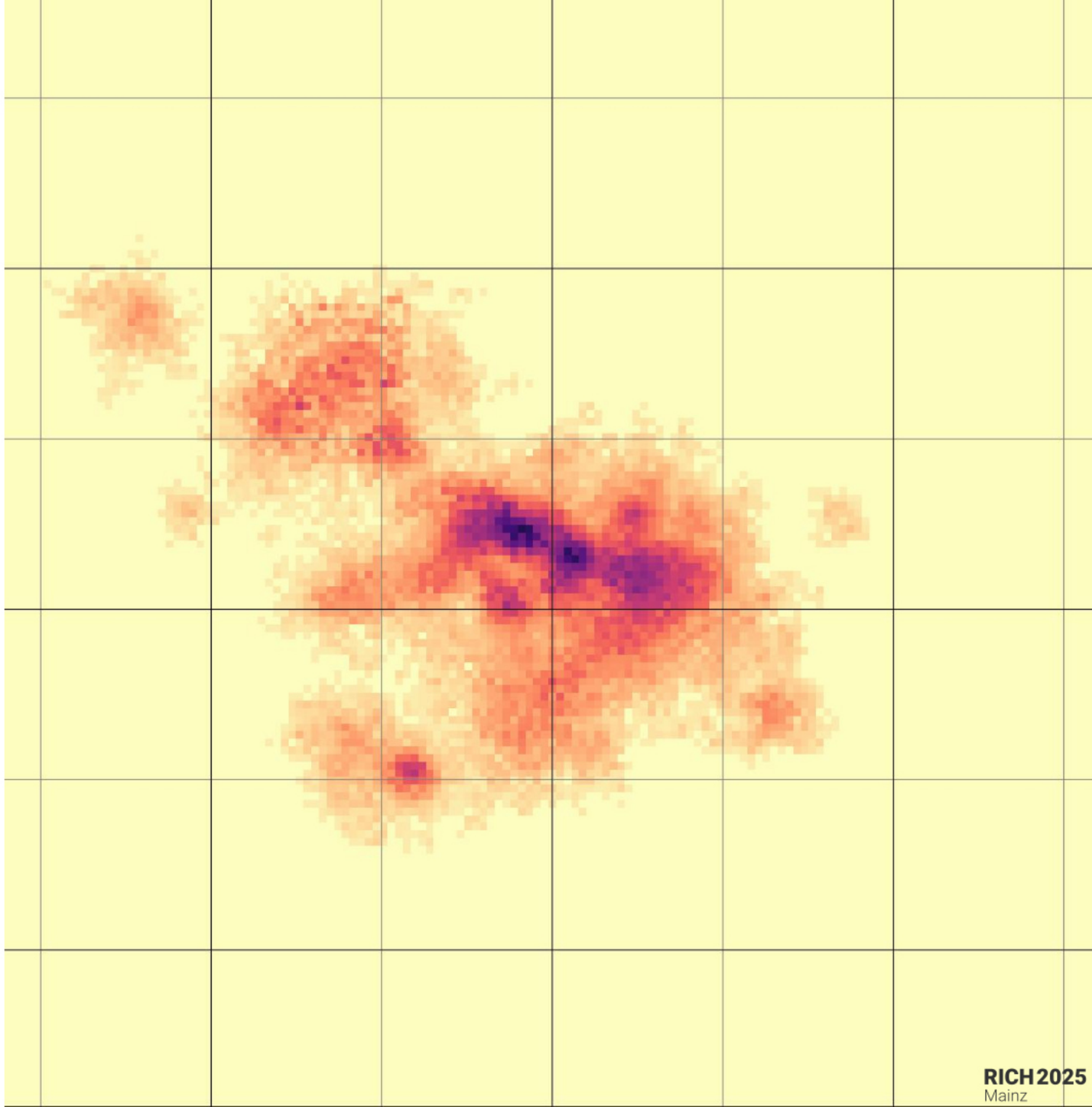

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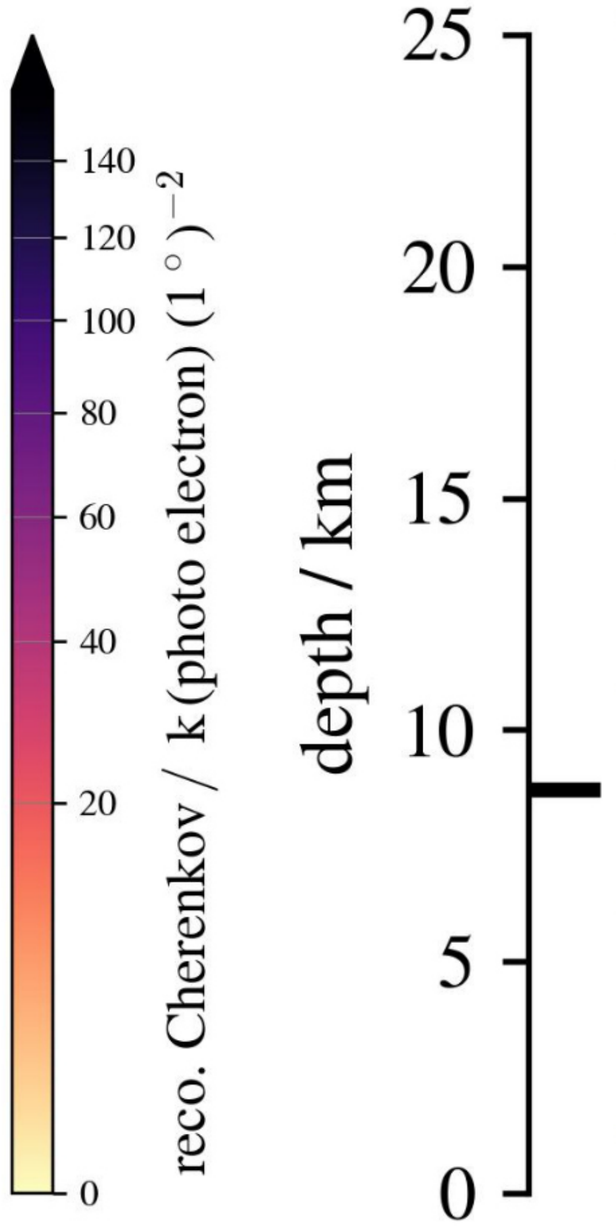

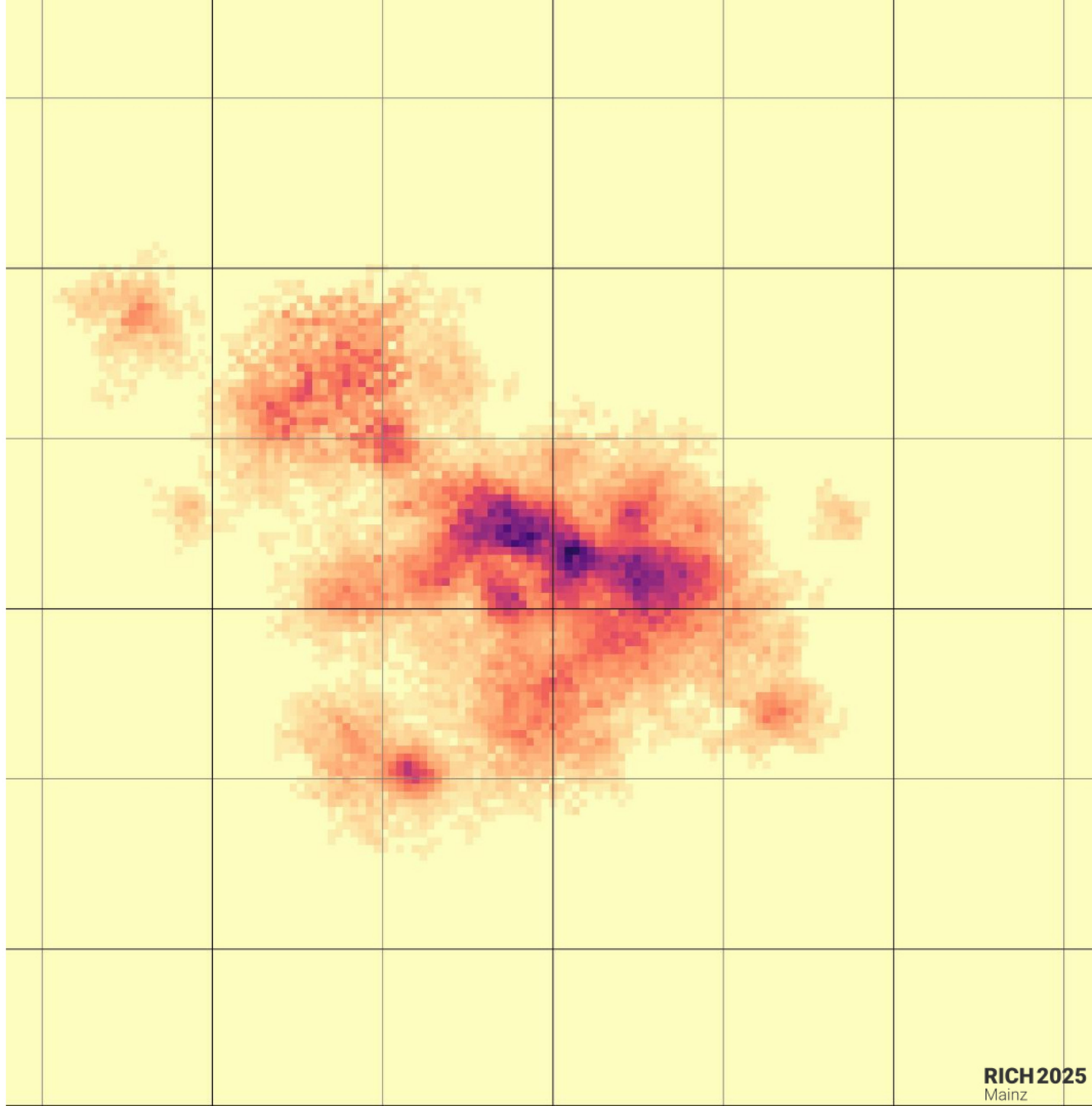

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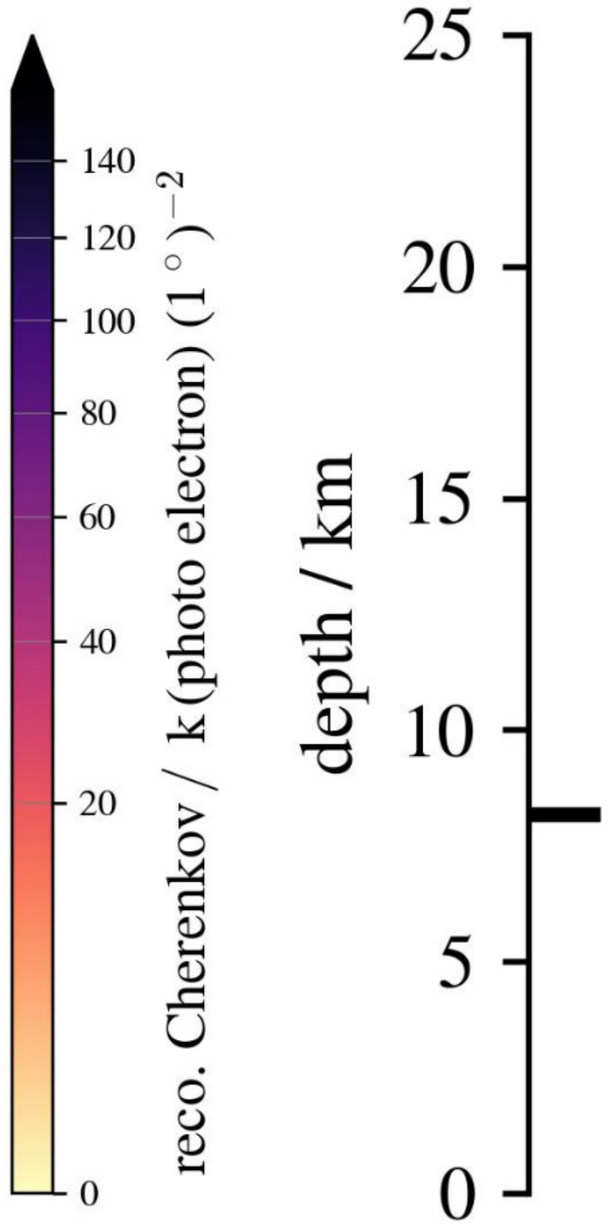

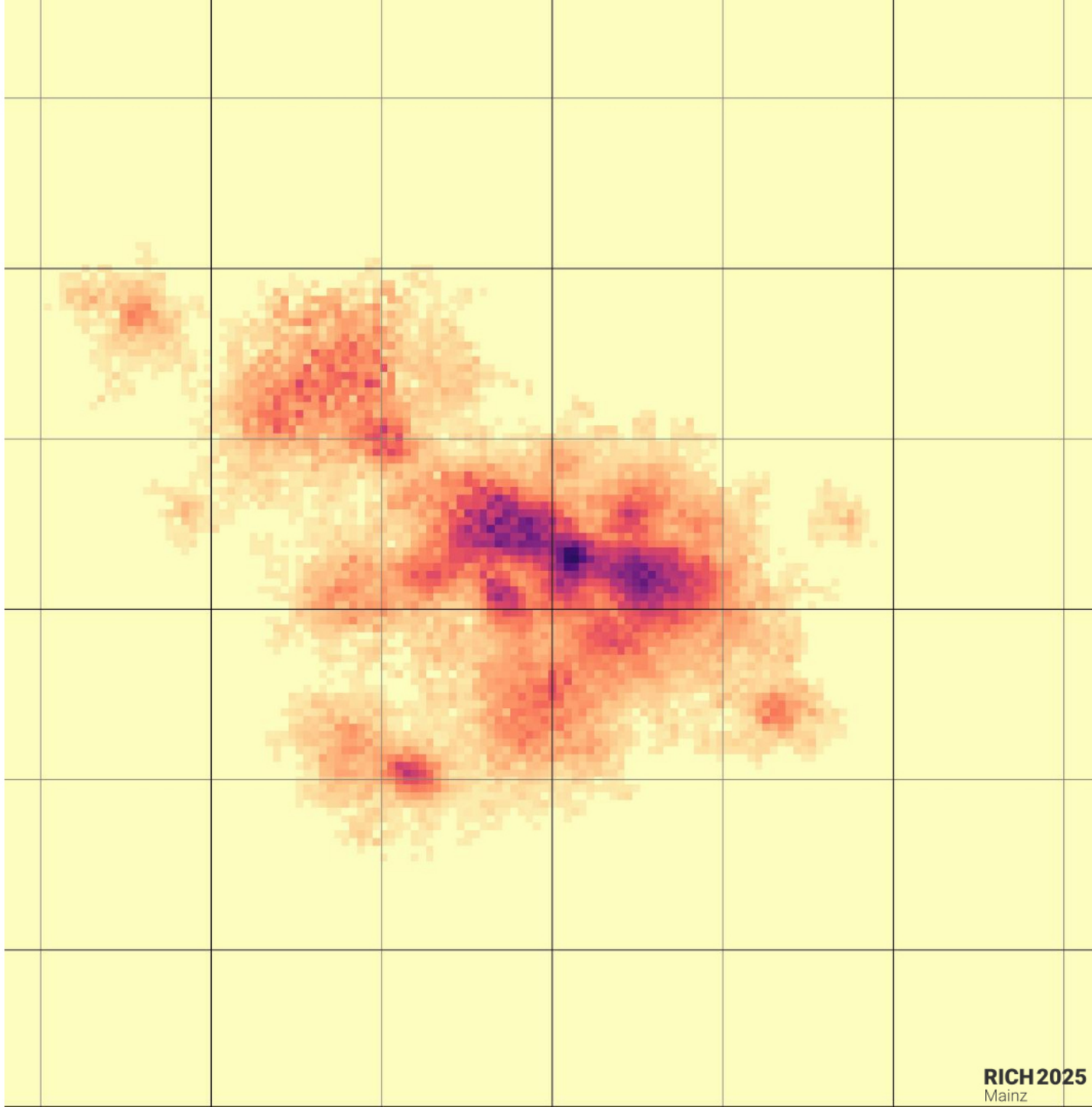

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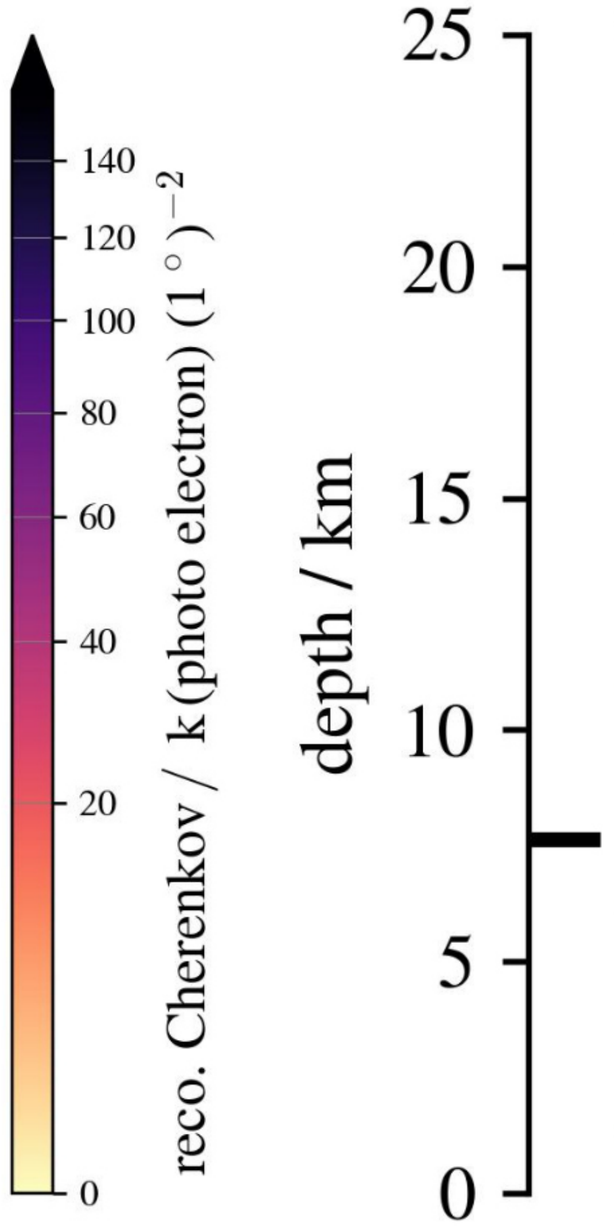

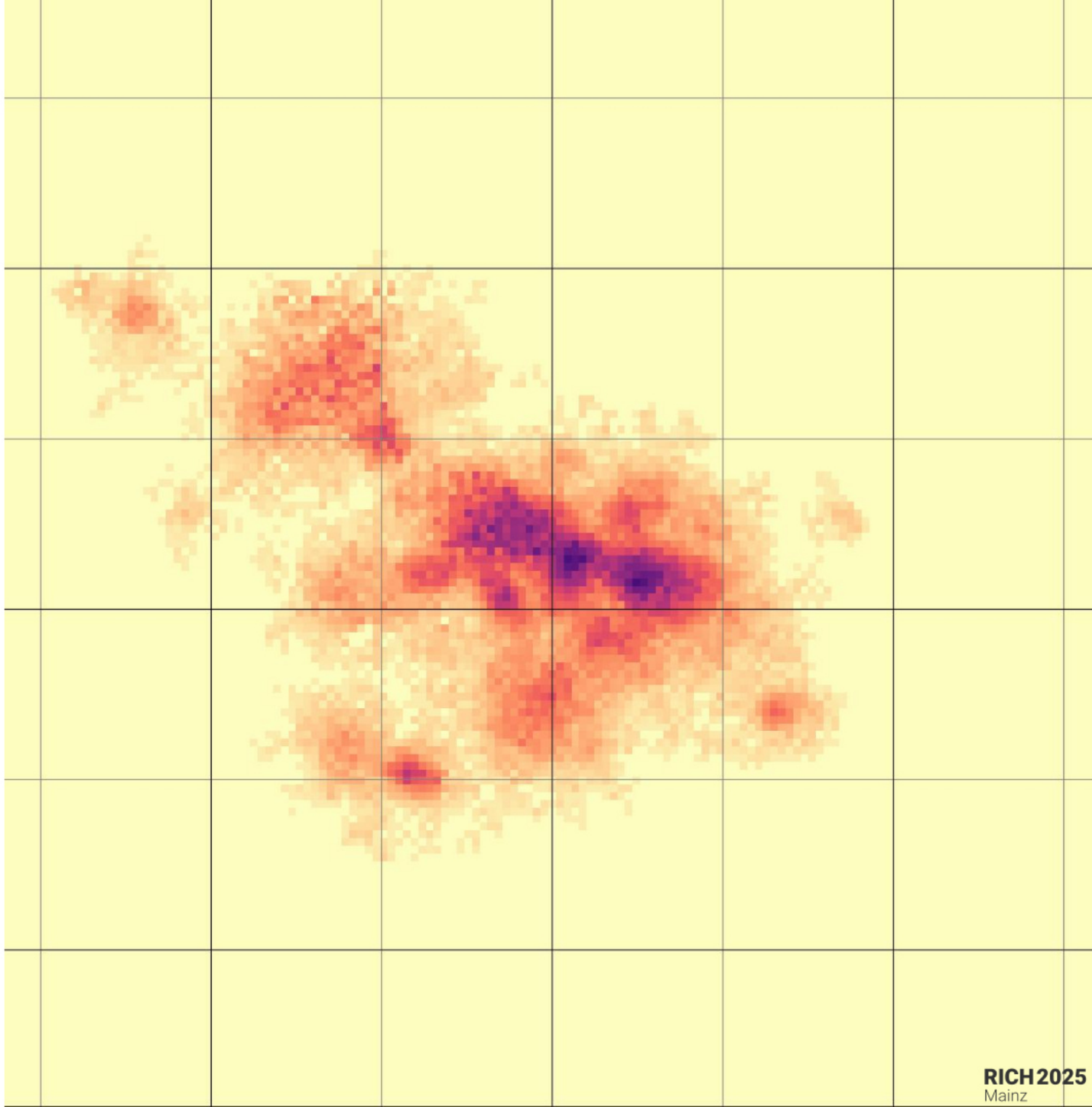

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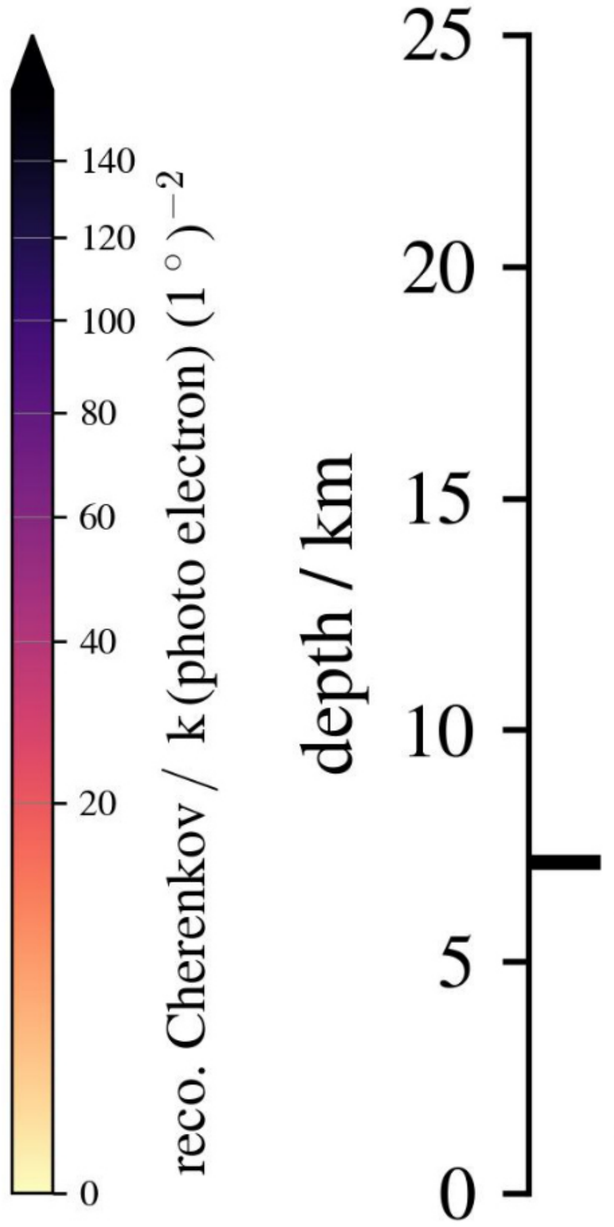

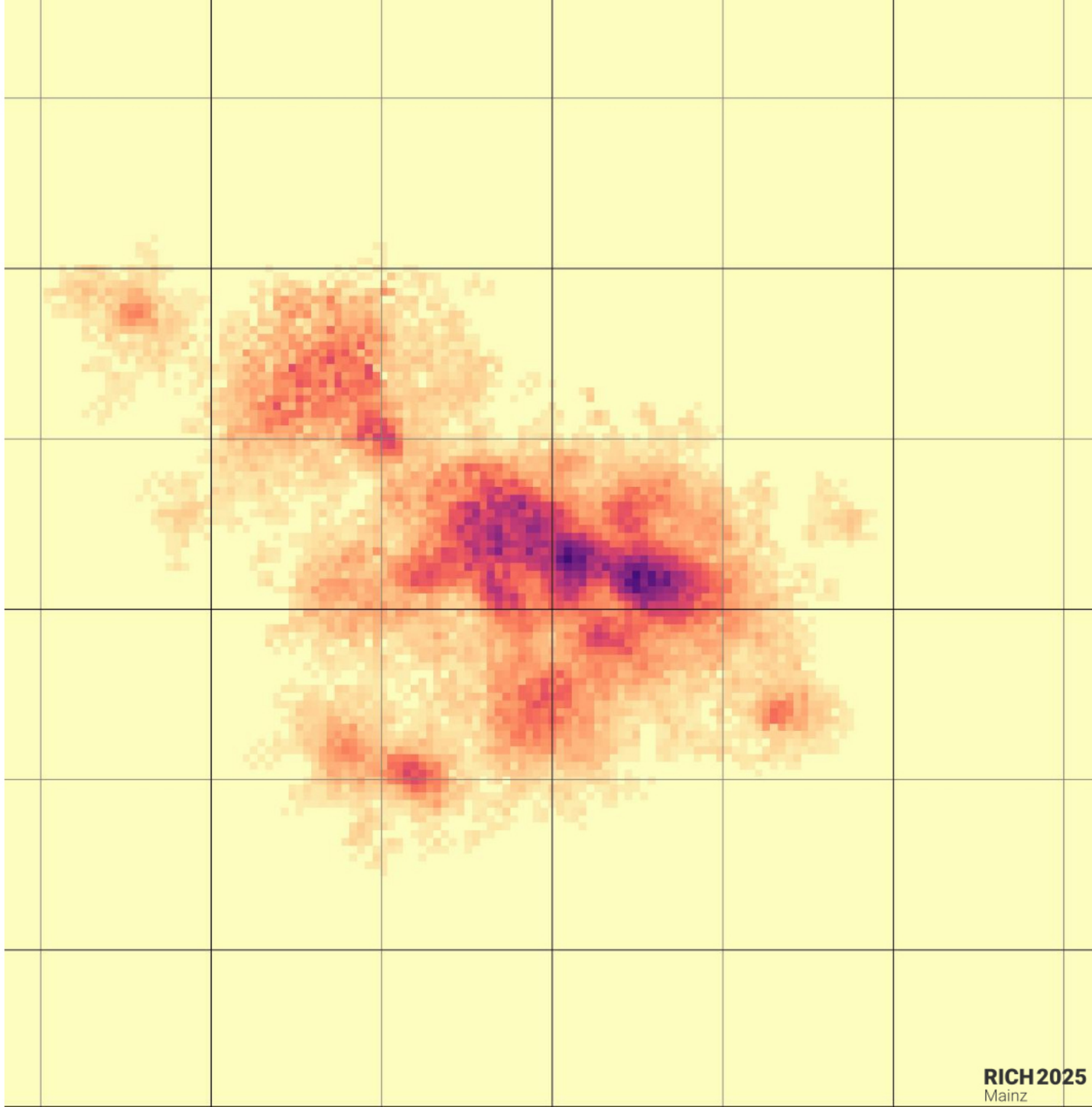

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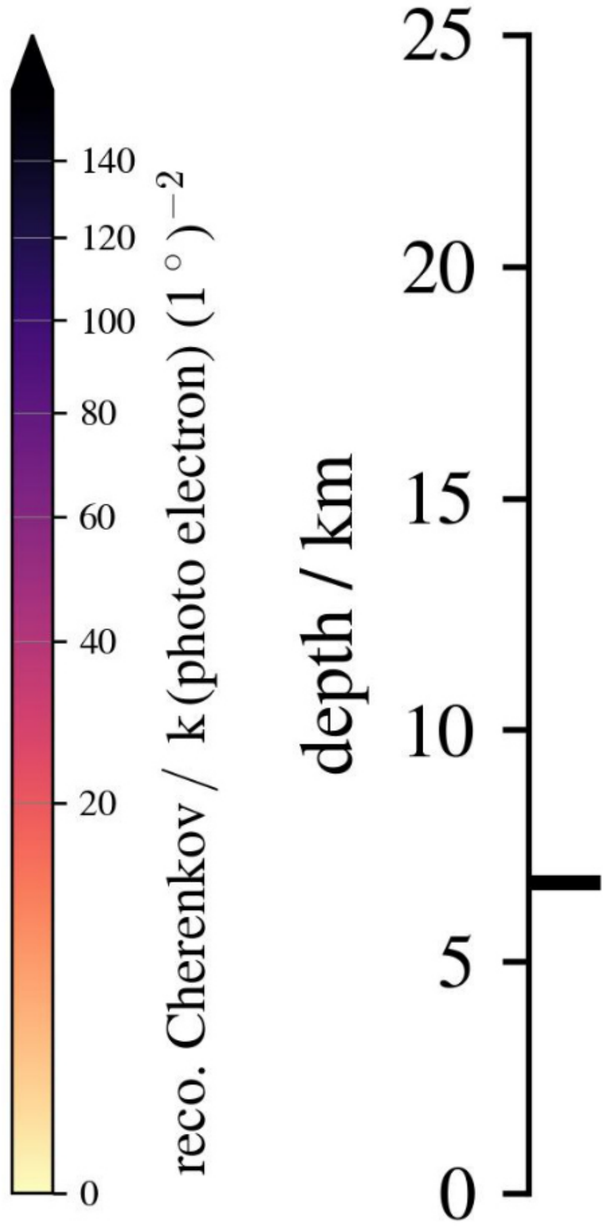

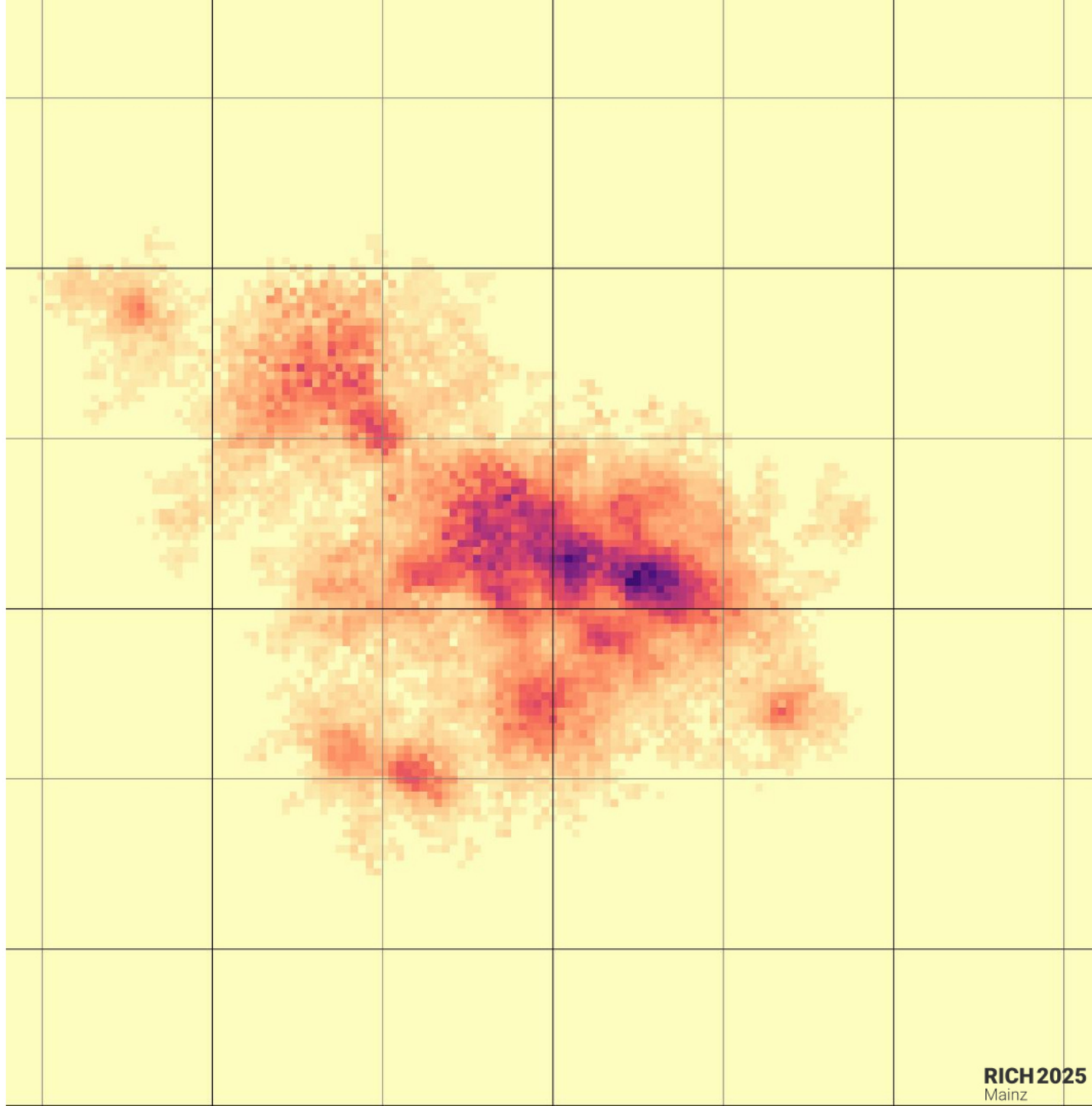

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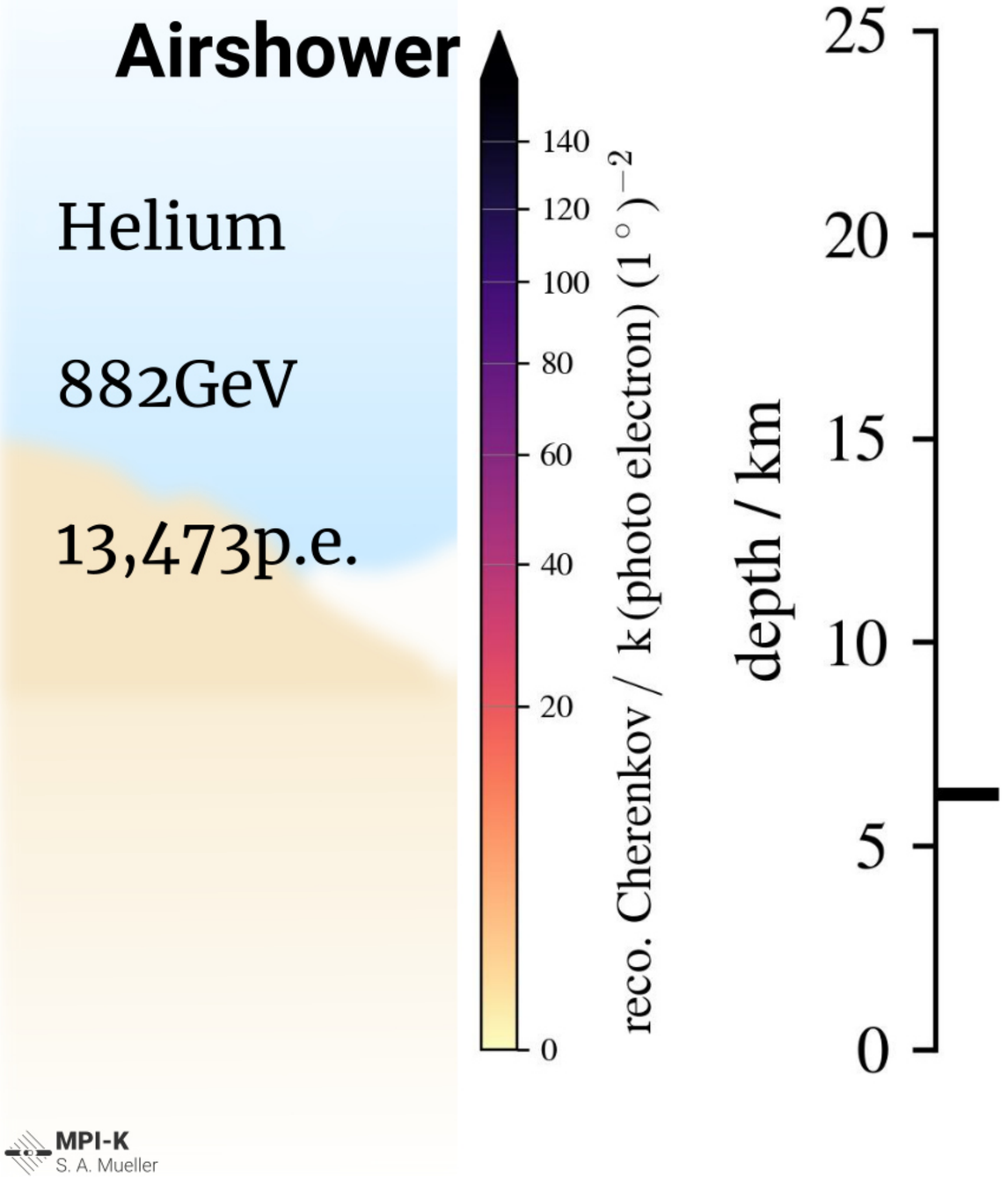

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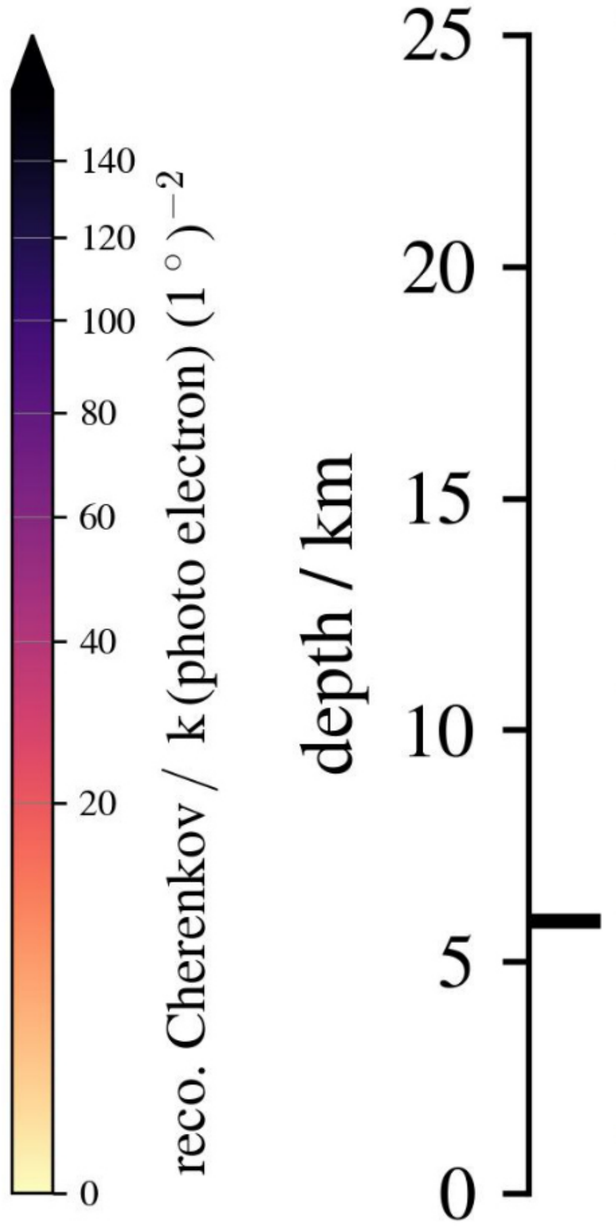

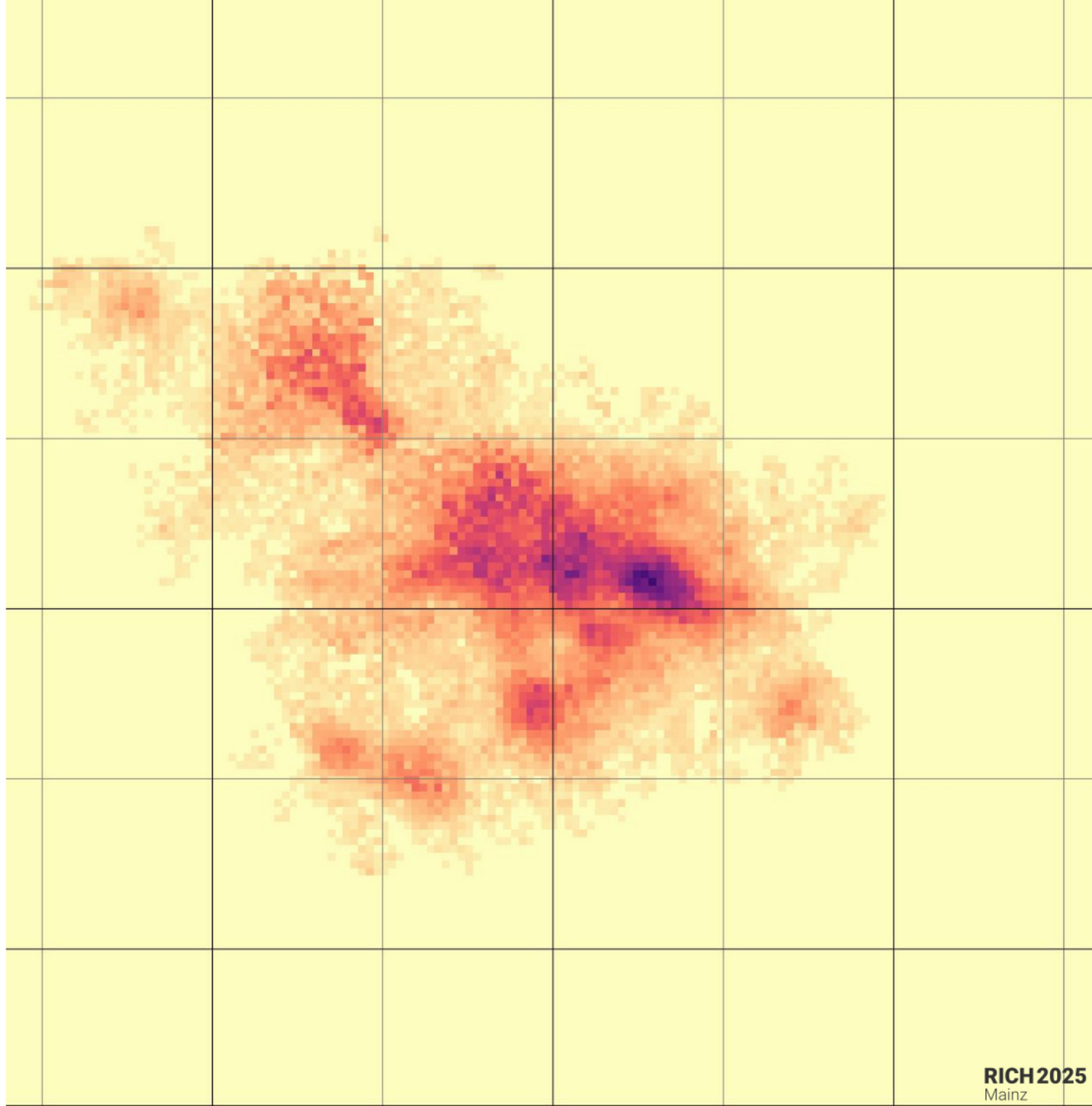

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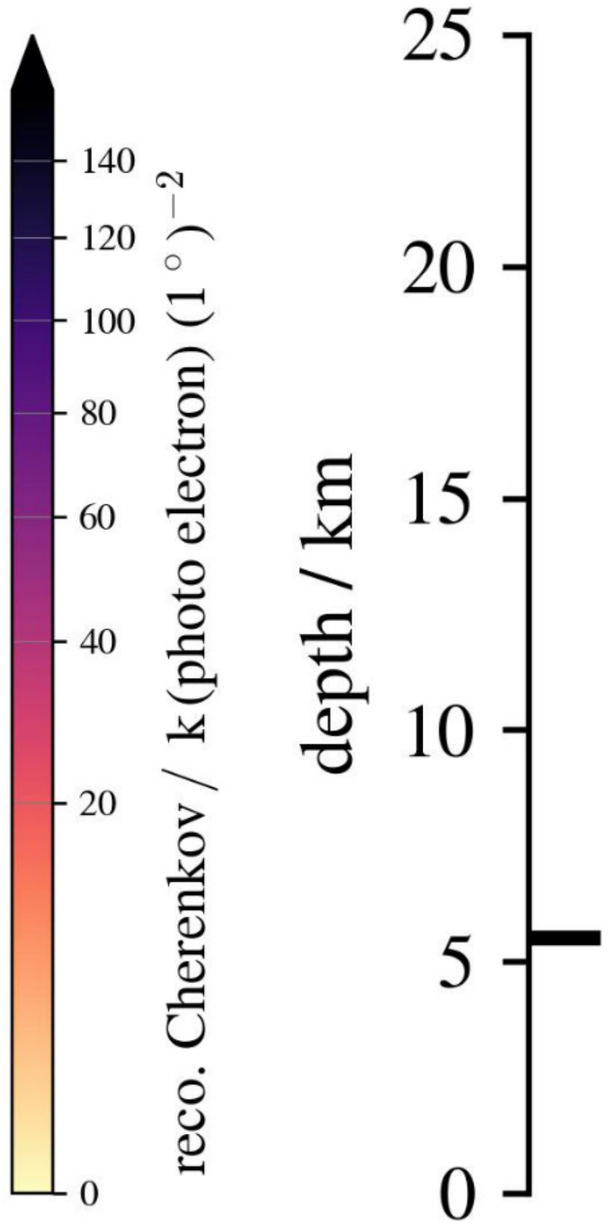
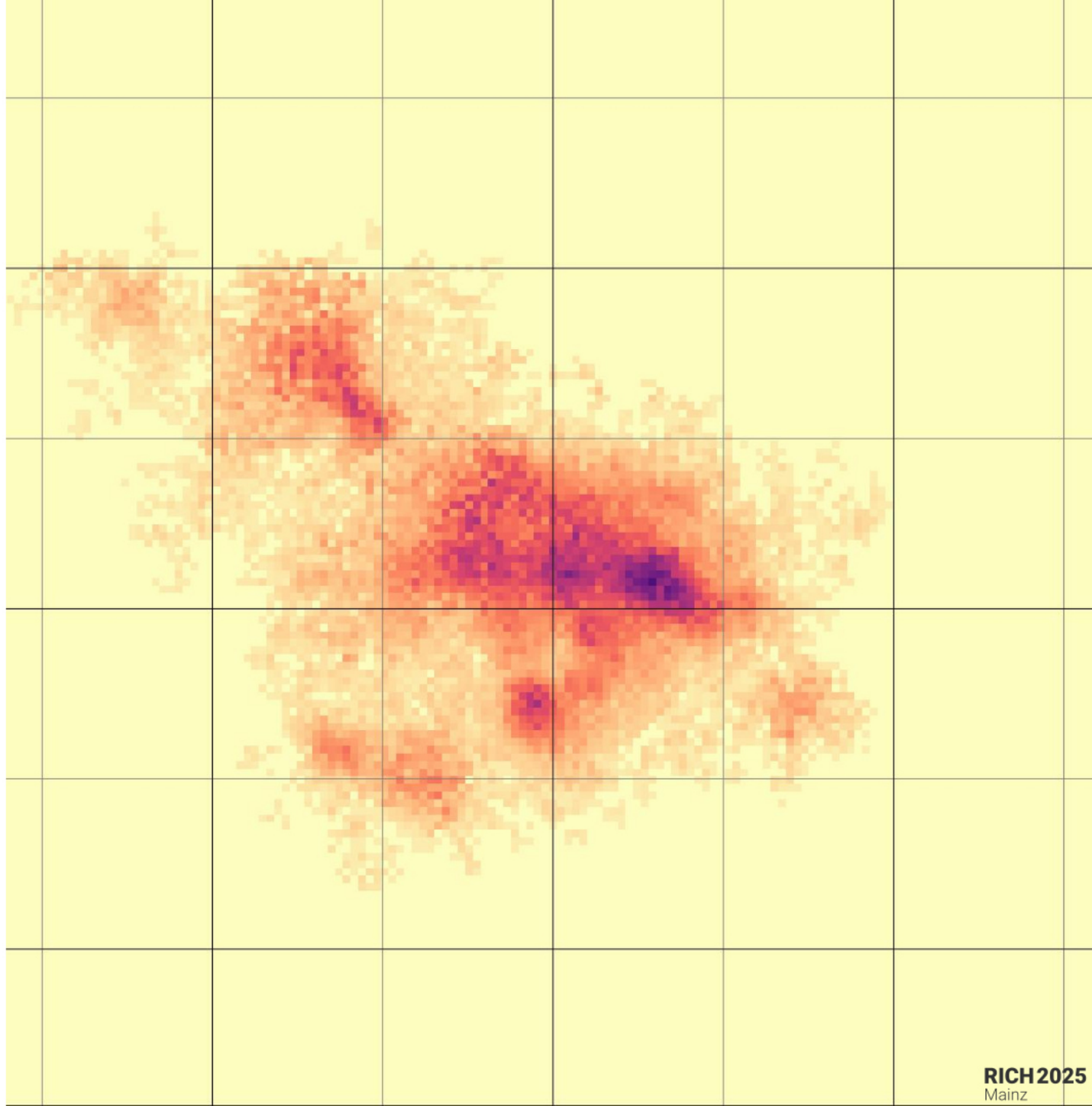
13,473p.e.



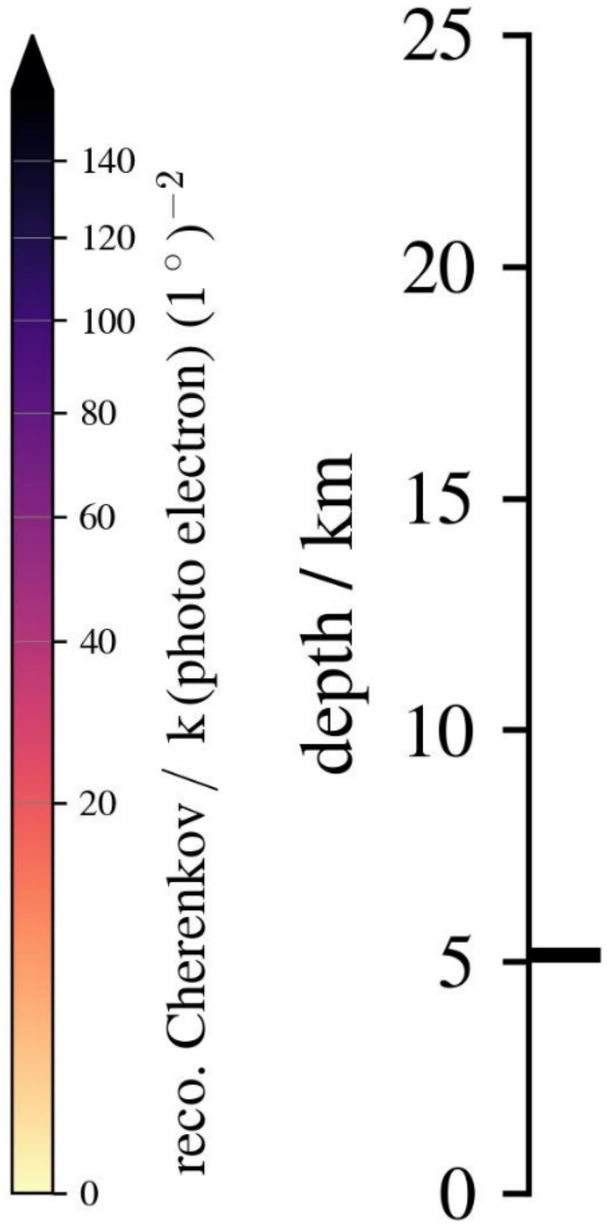


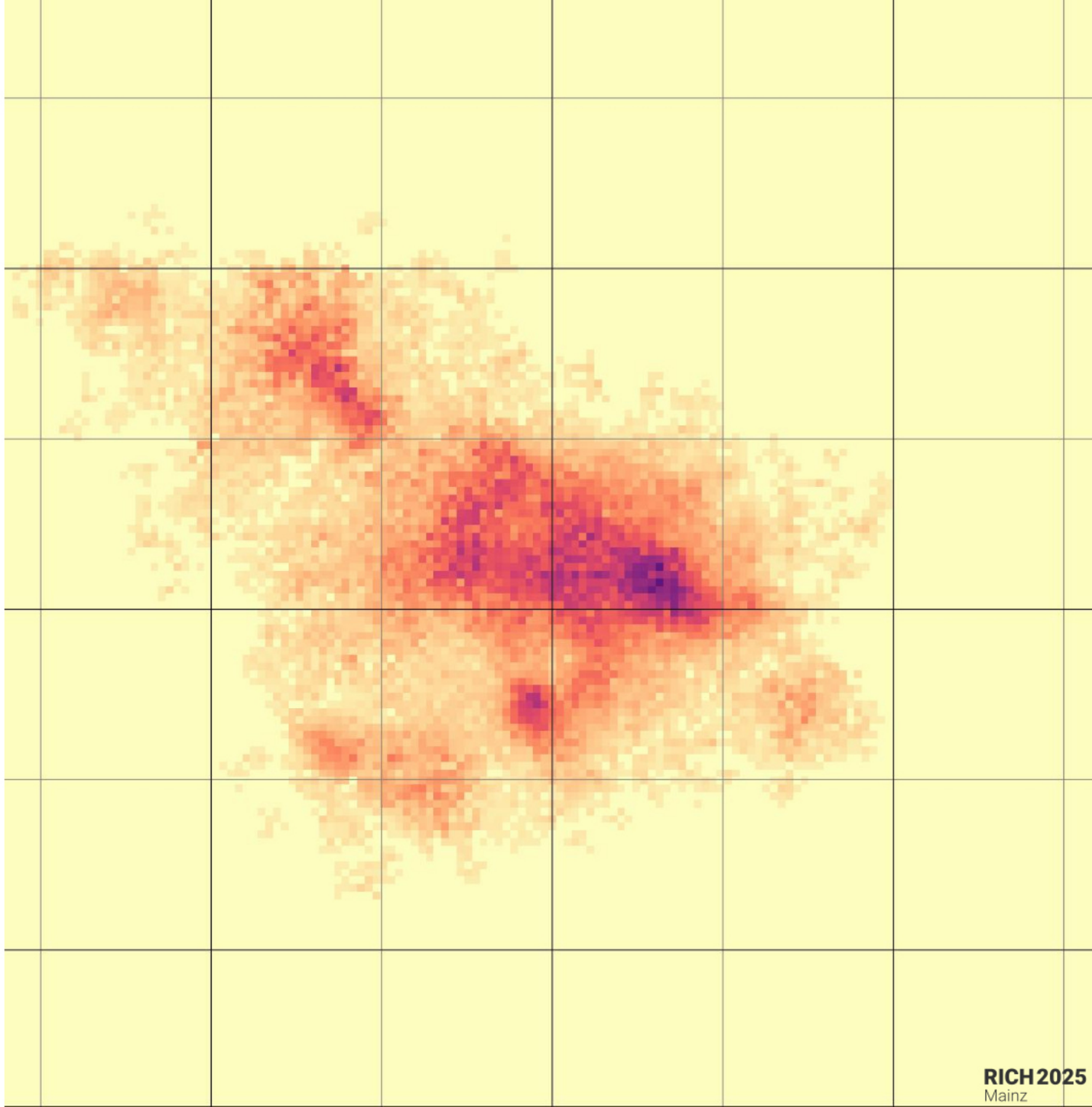
Airshower

Helium

882GeV

13,473p.e.



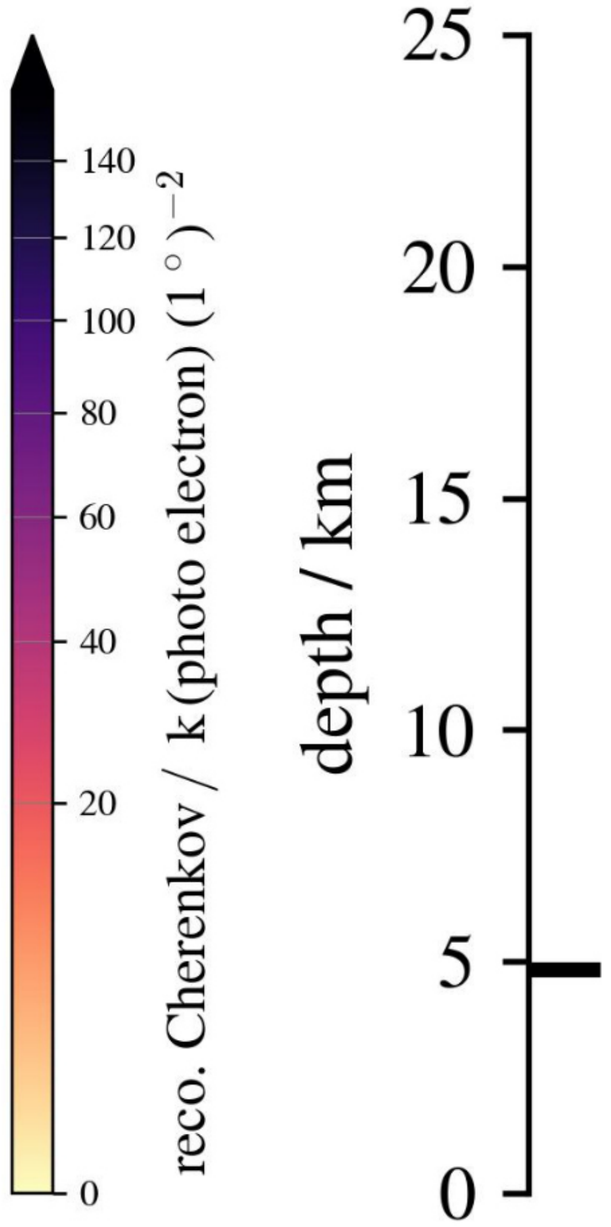


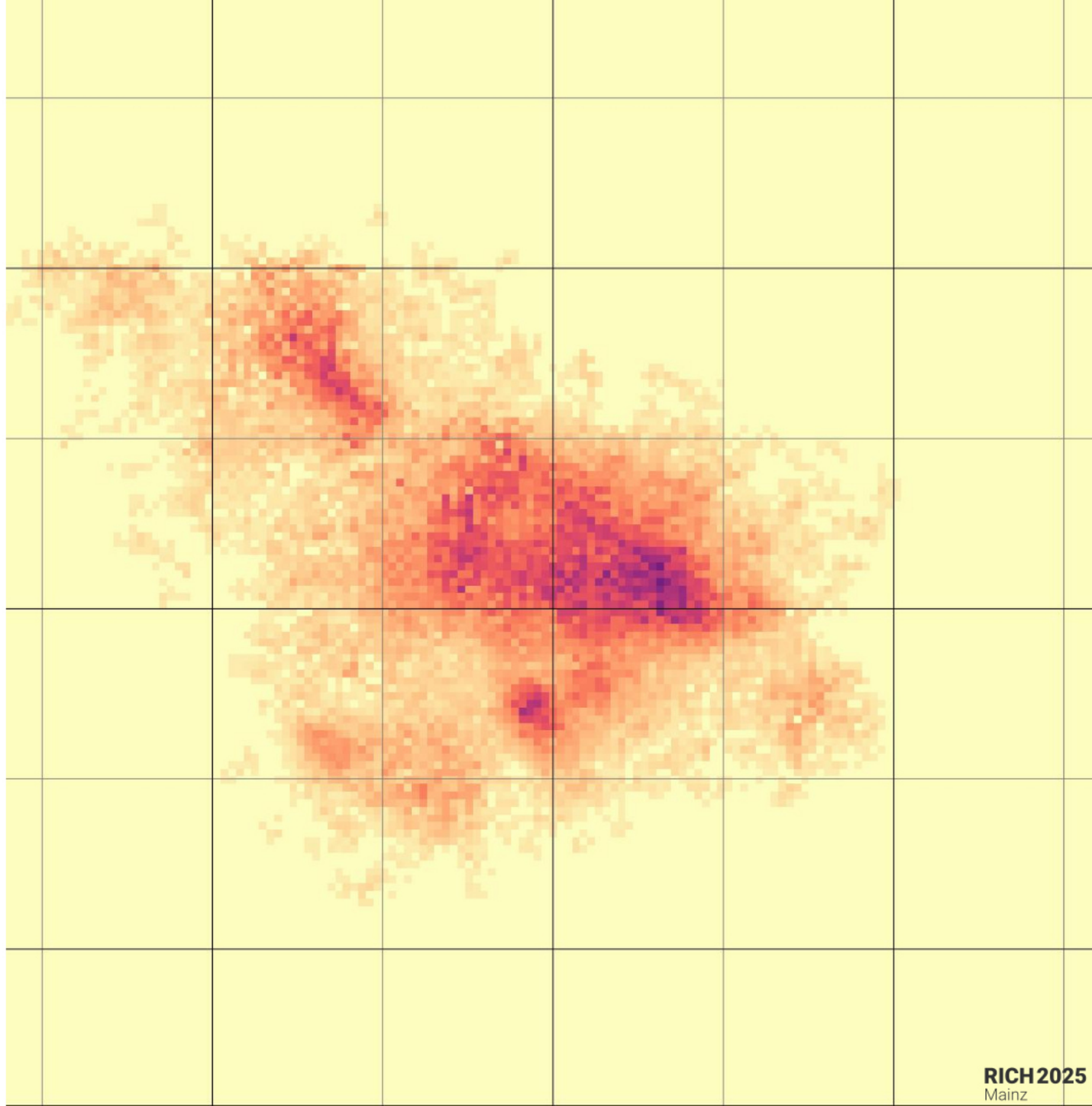
Airshower

Helium

882GeV

13,473p.e.



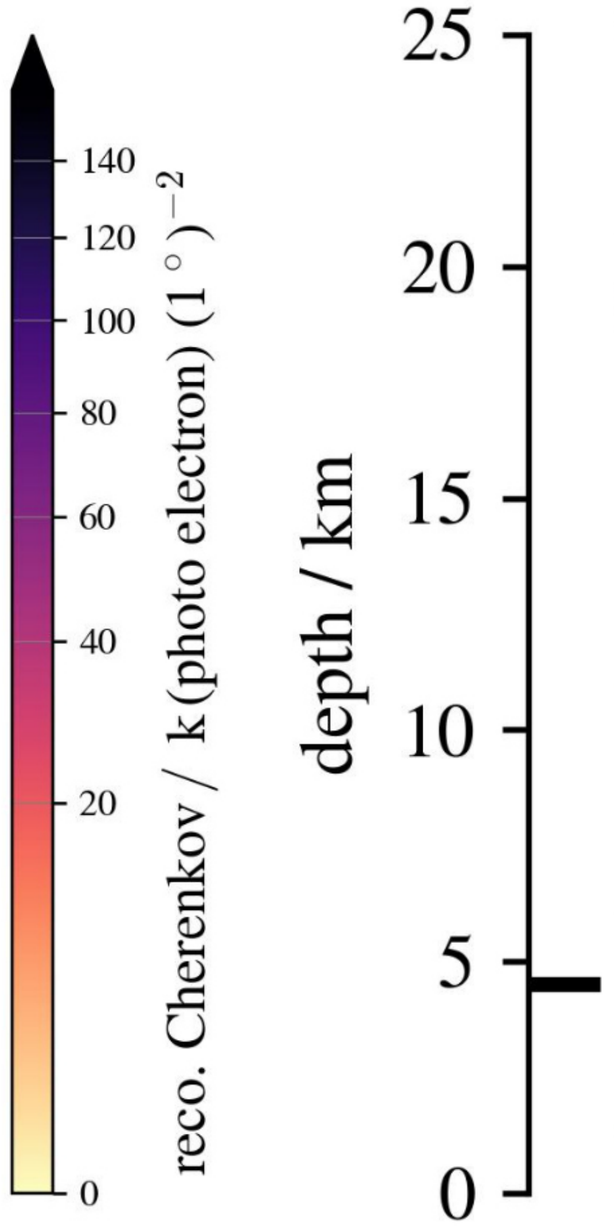


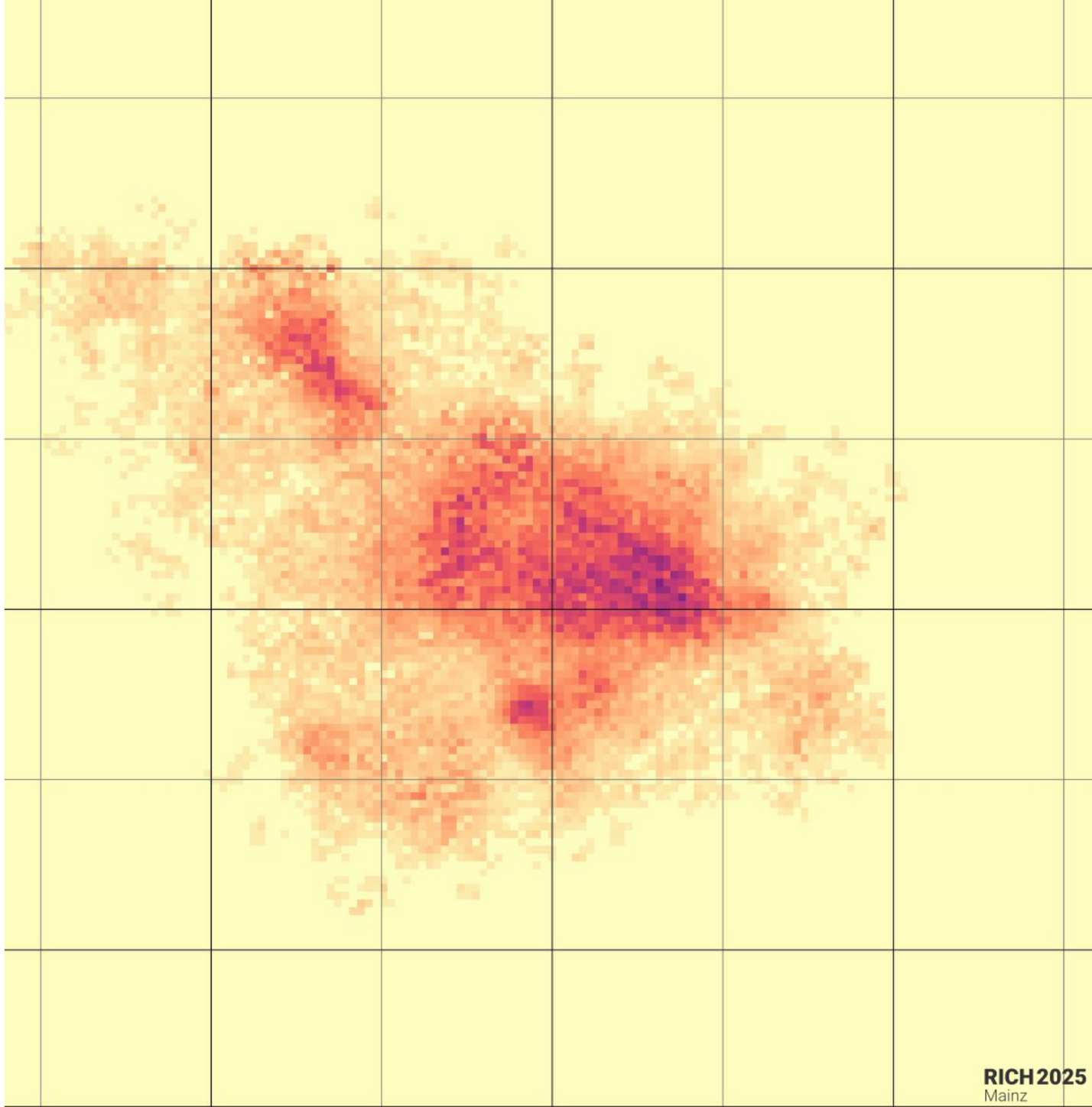
Airshower

Helium

882GeV

13,473p.e.





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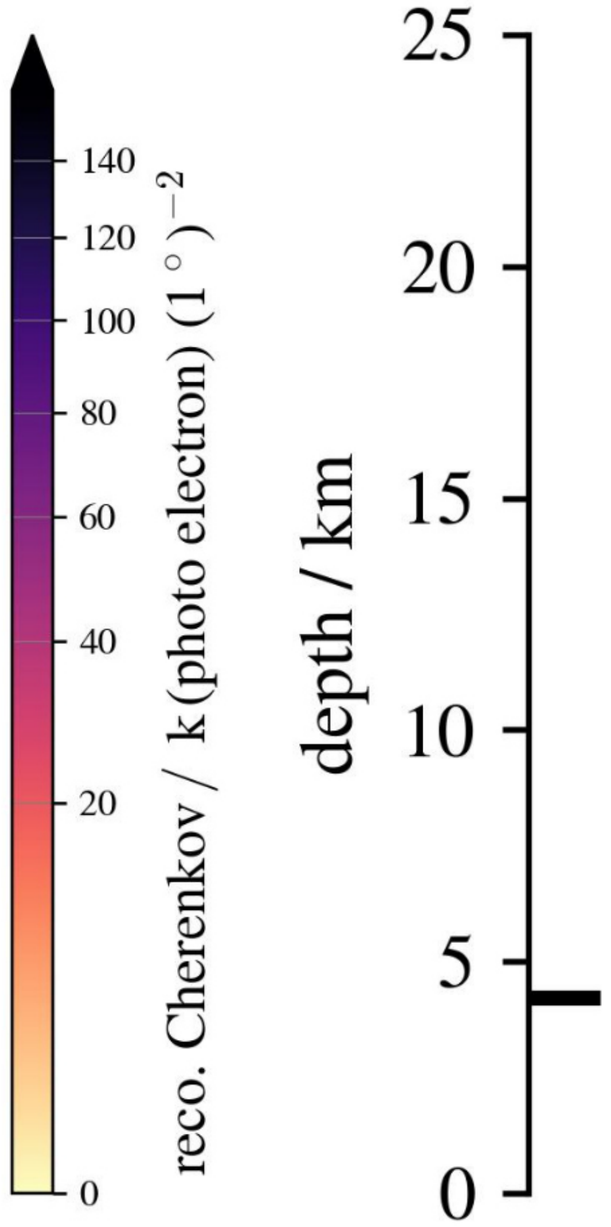
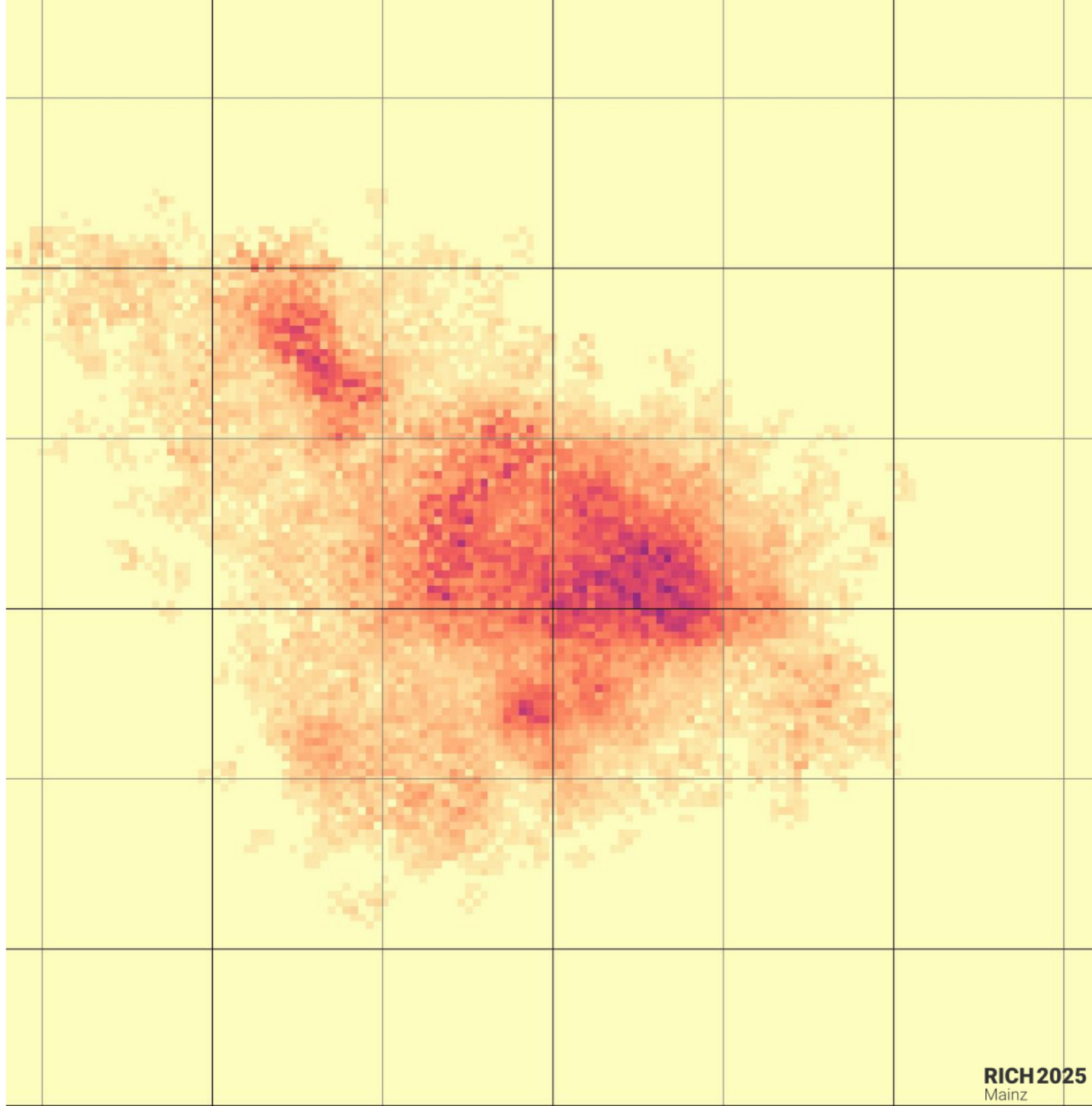
13,473p.e.





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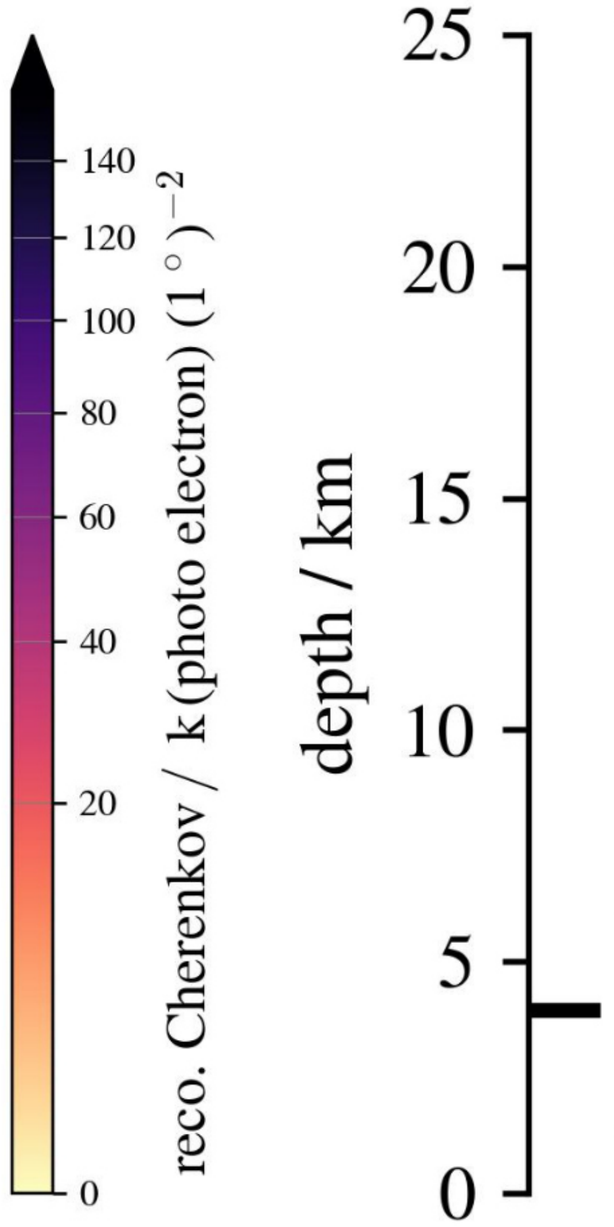
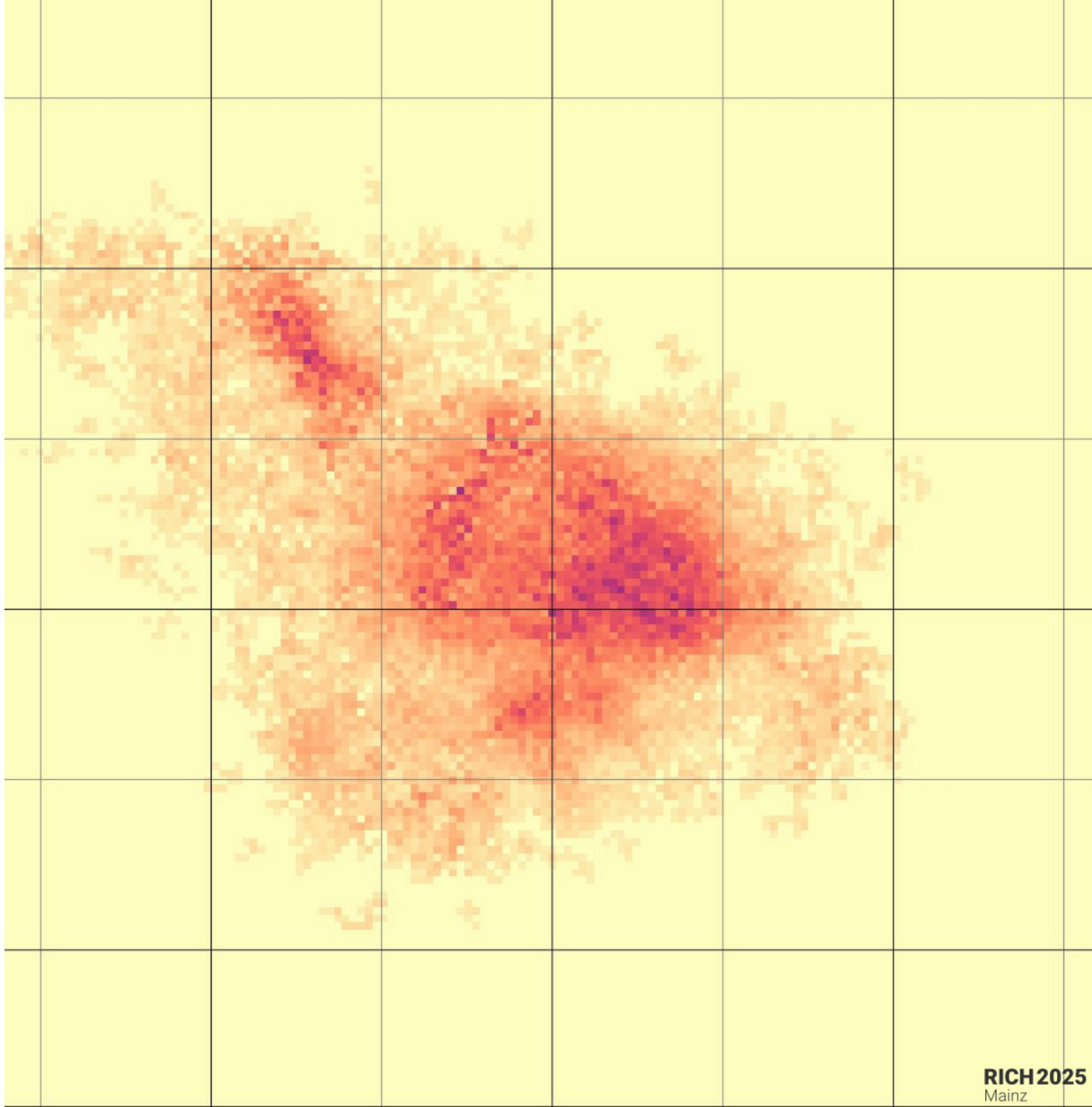


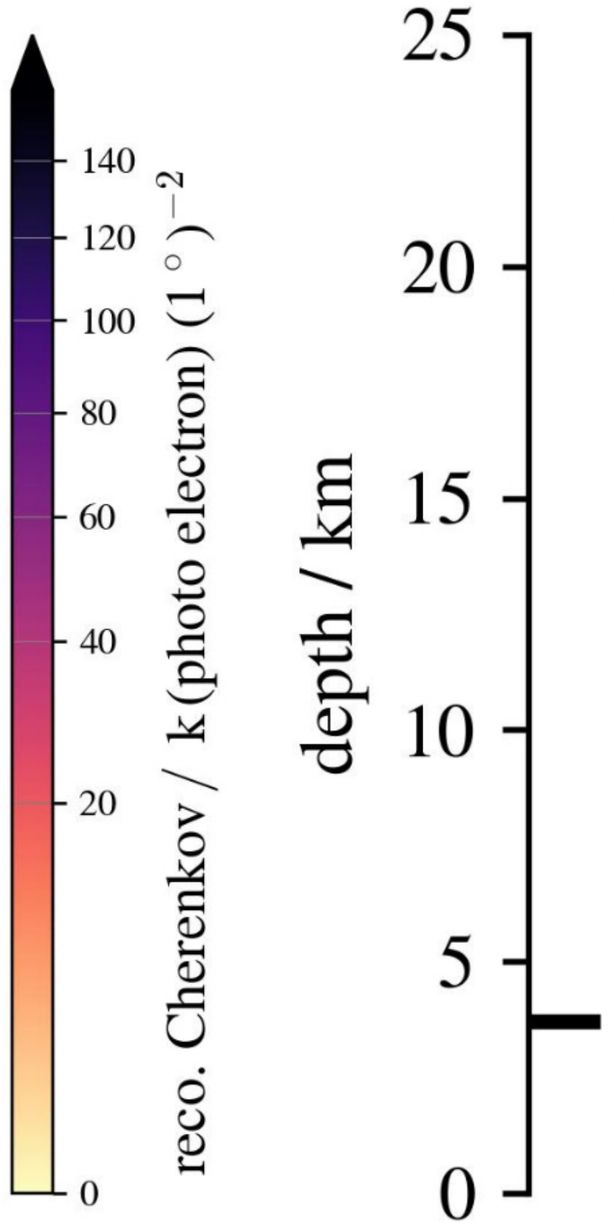


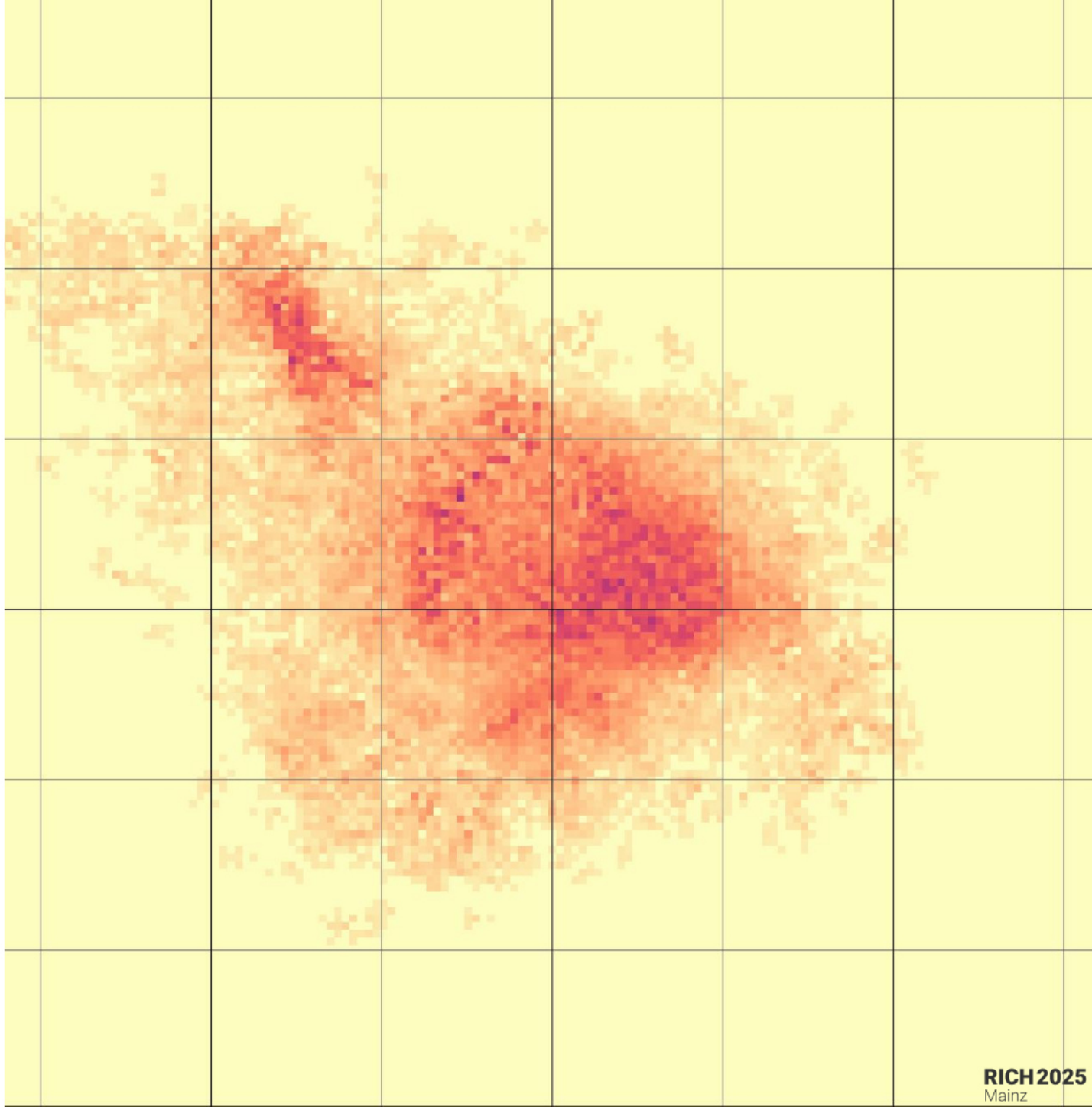
Airshower

Helium

882GeV

13,473p.e.





Airshower

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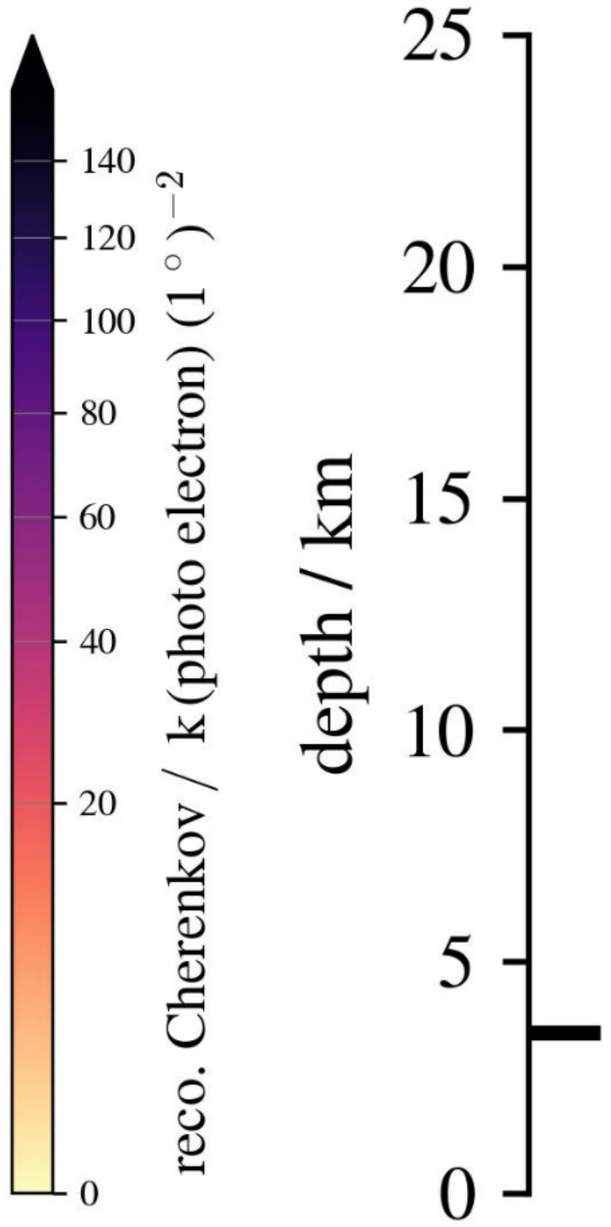
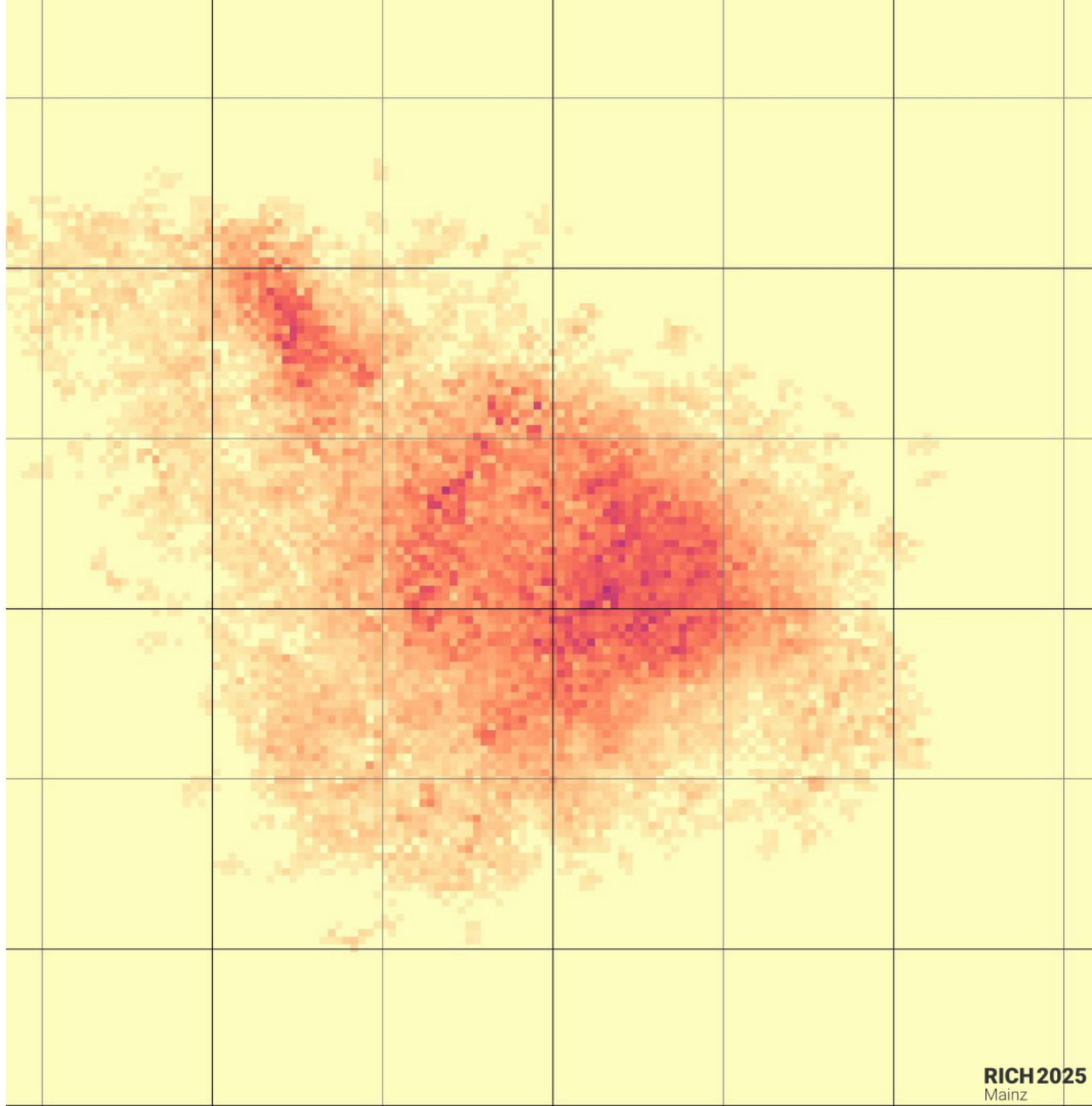
882GeV

13,473p.e.





Airshower

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882GeV

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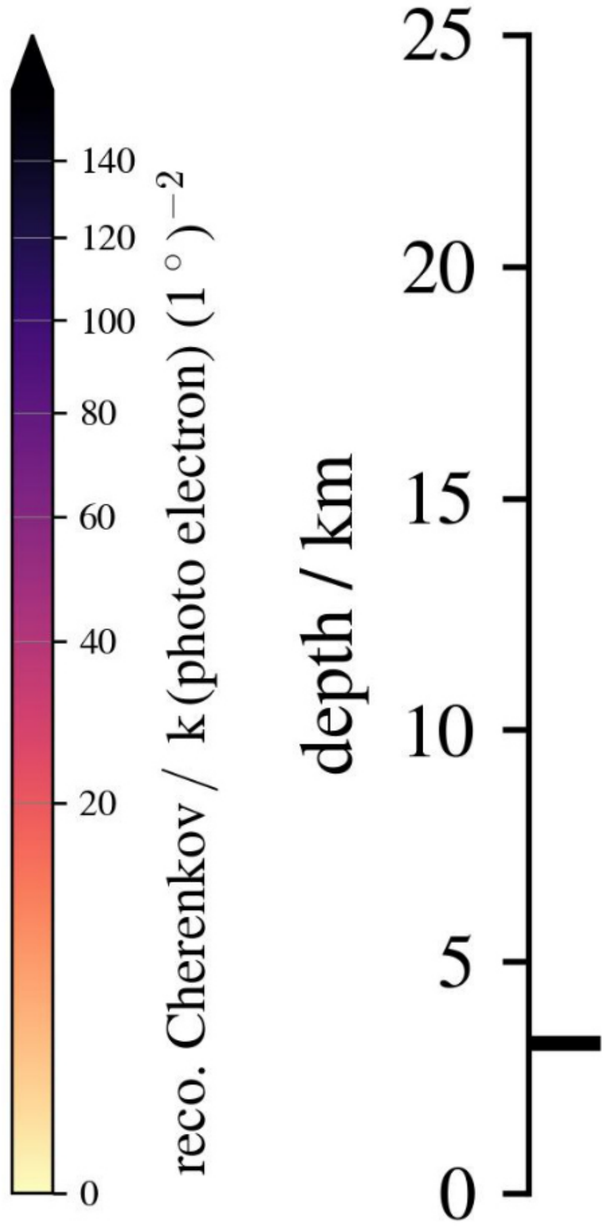

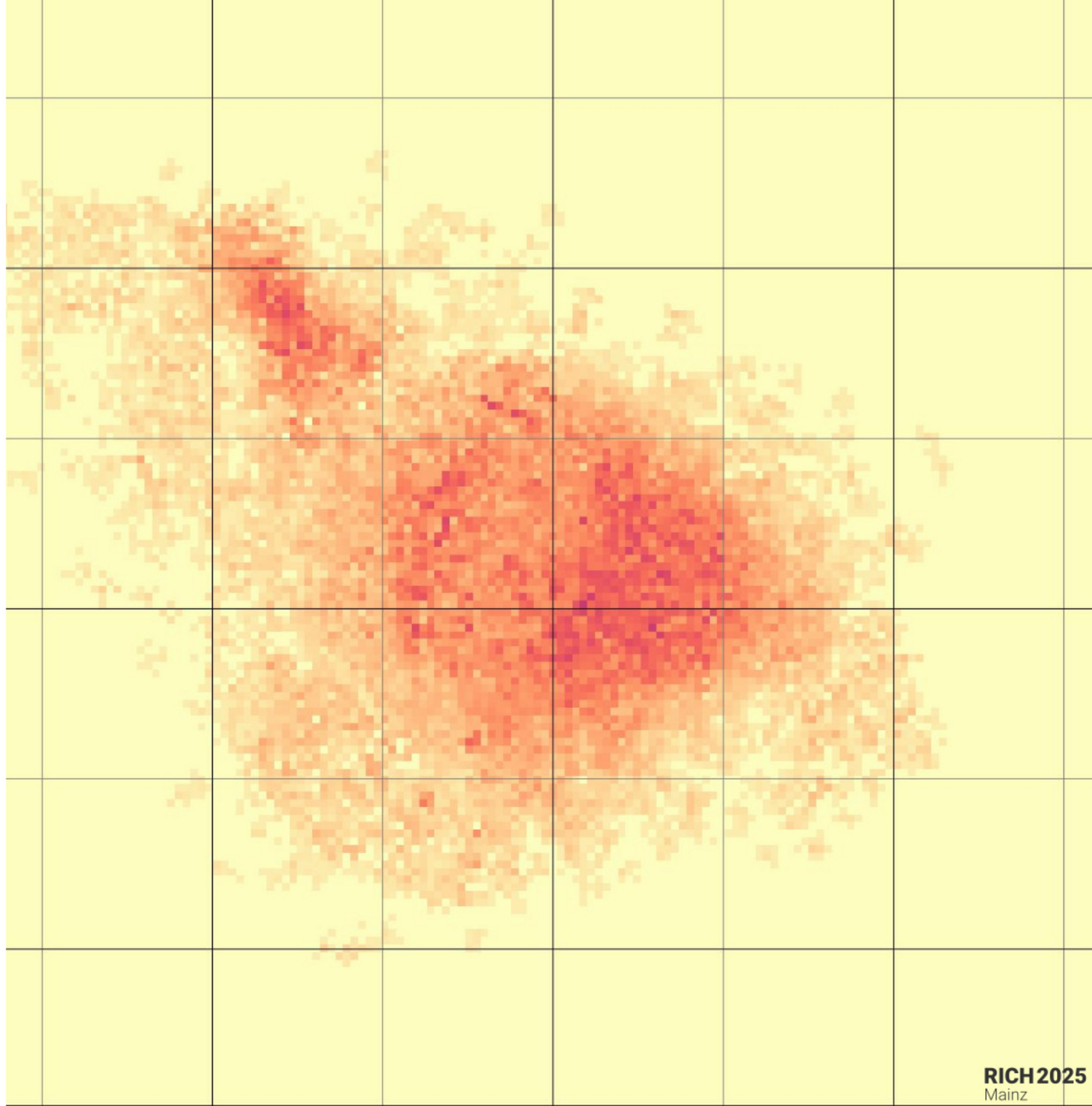

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882GeV

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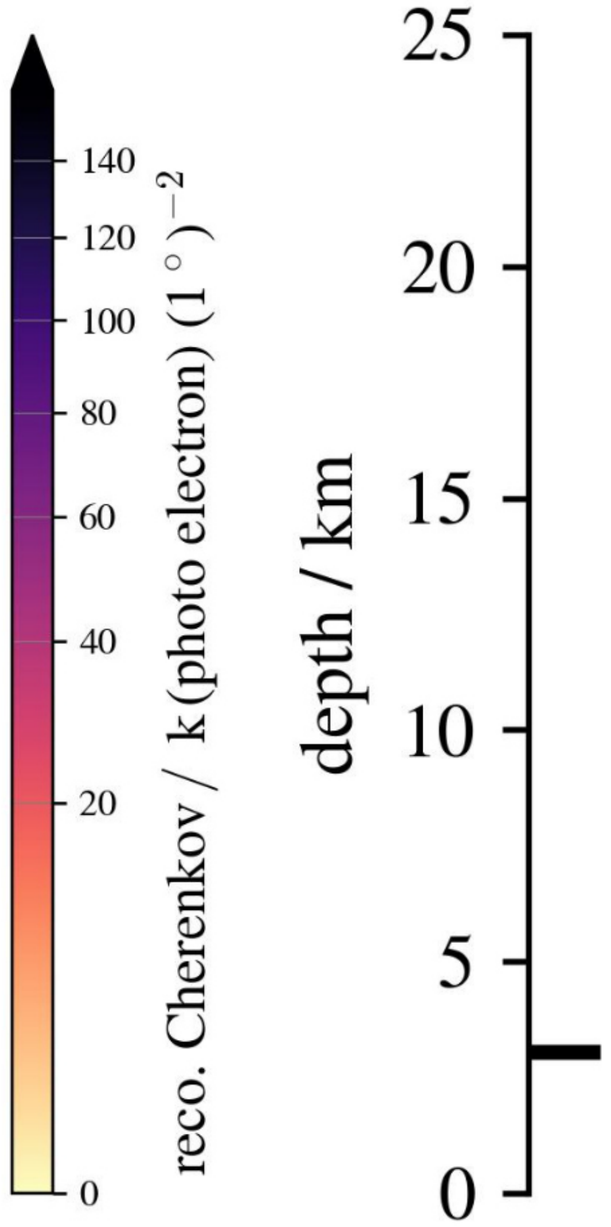

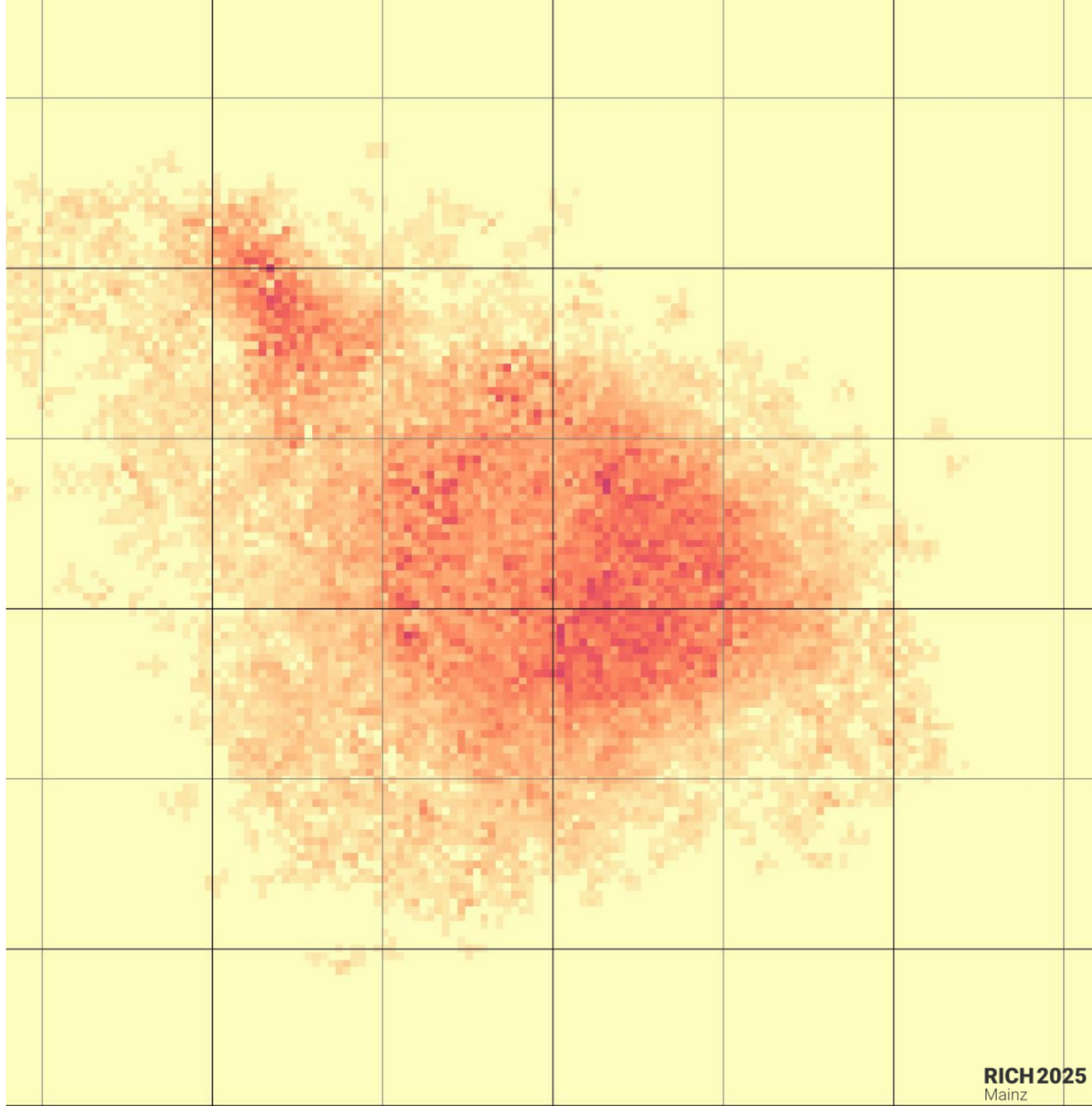

Airshower

Helium

882GeV

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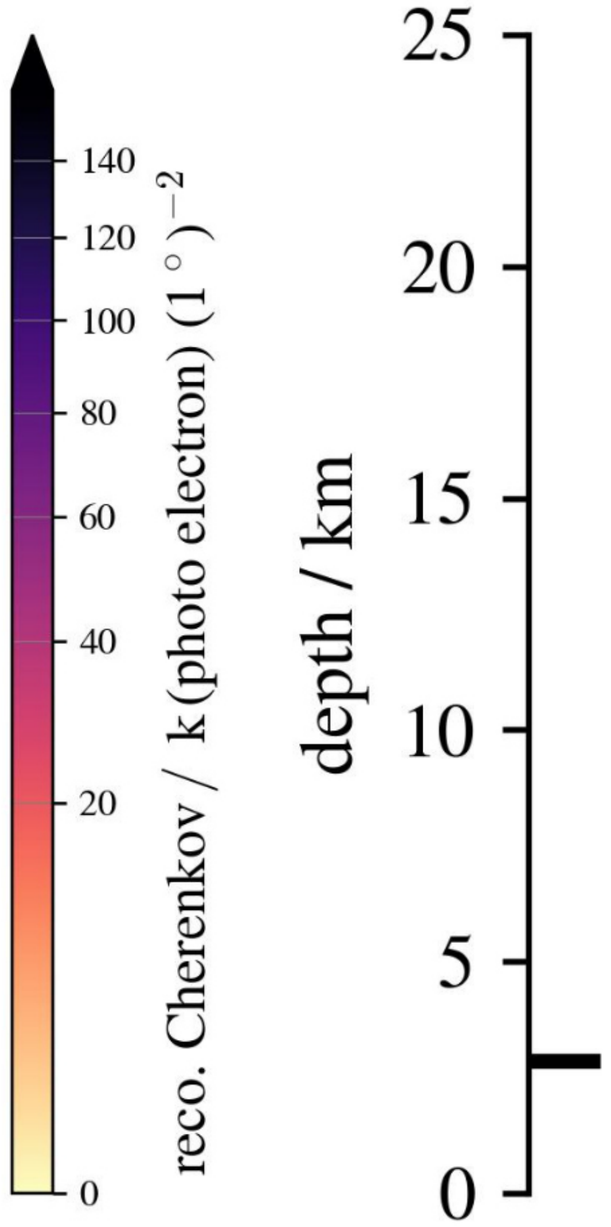
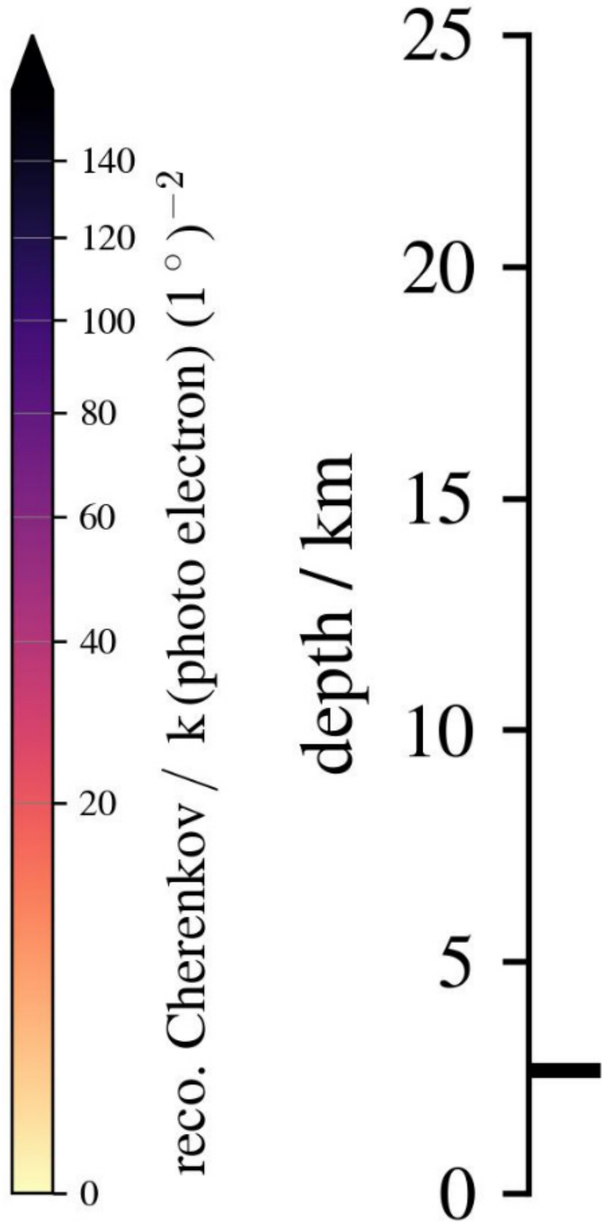


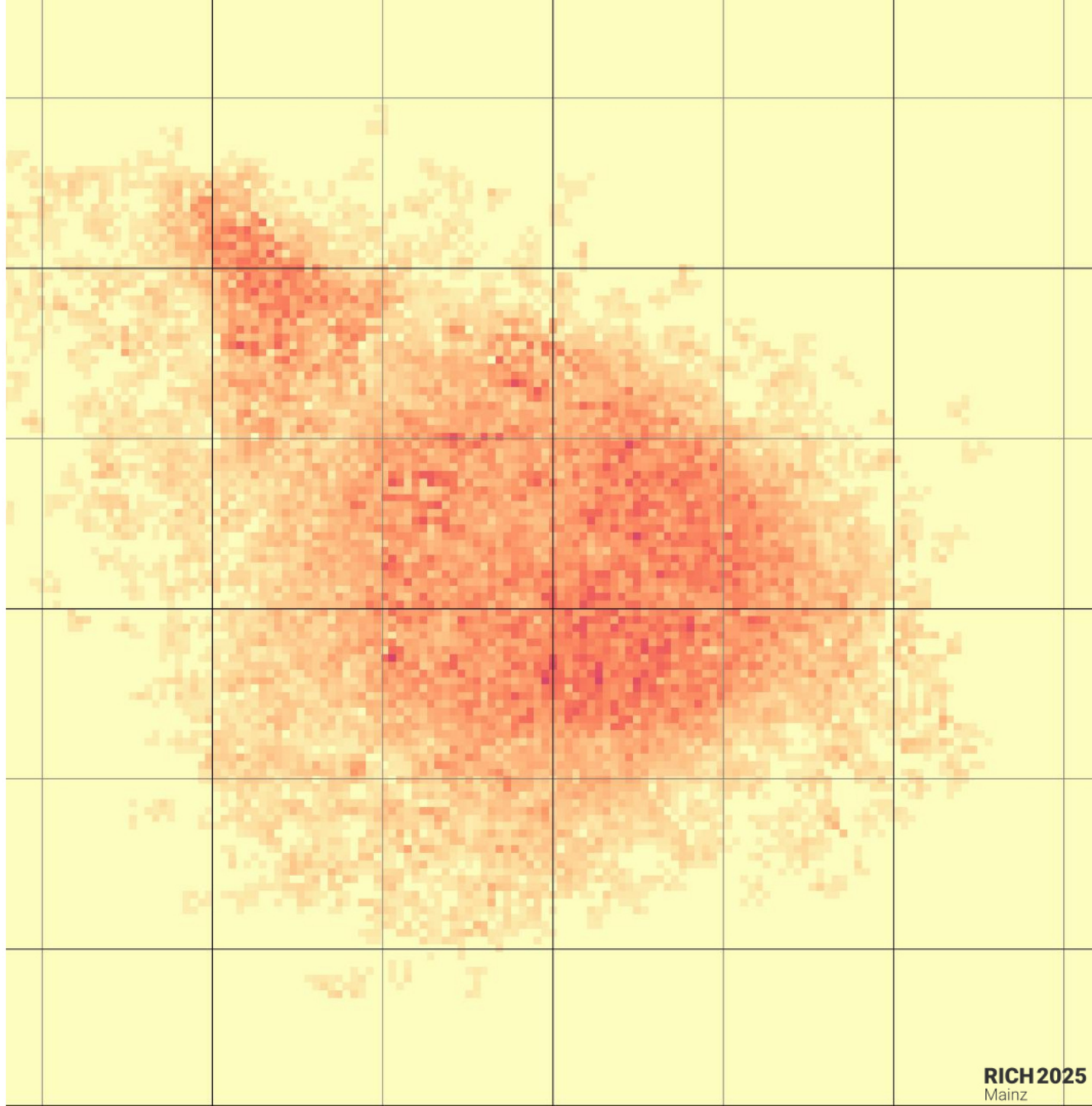
Airshower

Helium

882GeV

13,473p.e.





Airshower

Helium

882GeV

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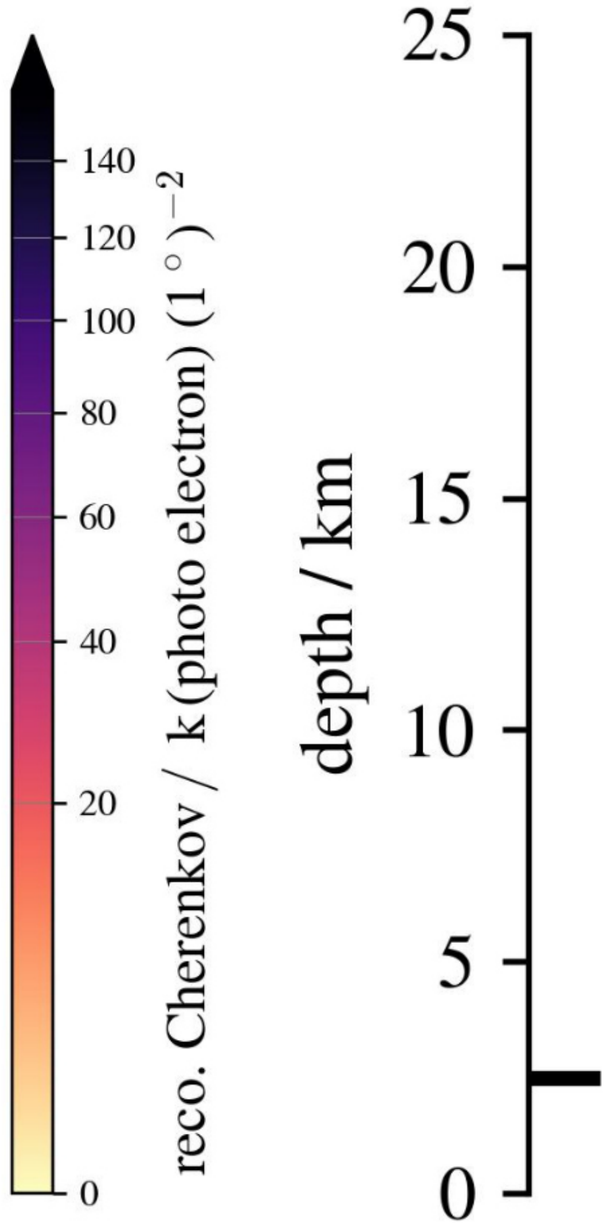

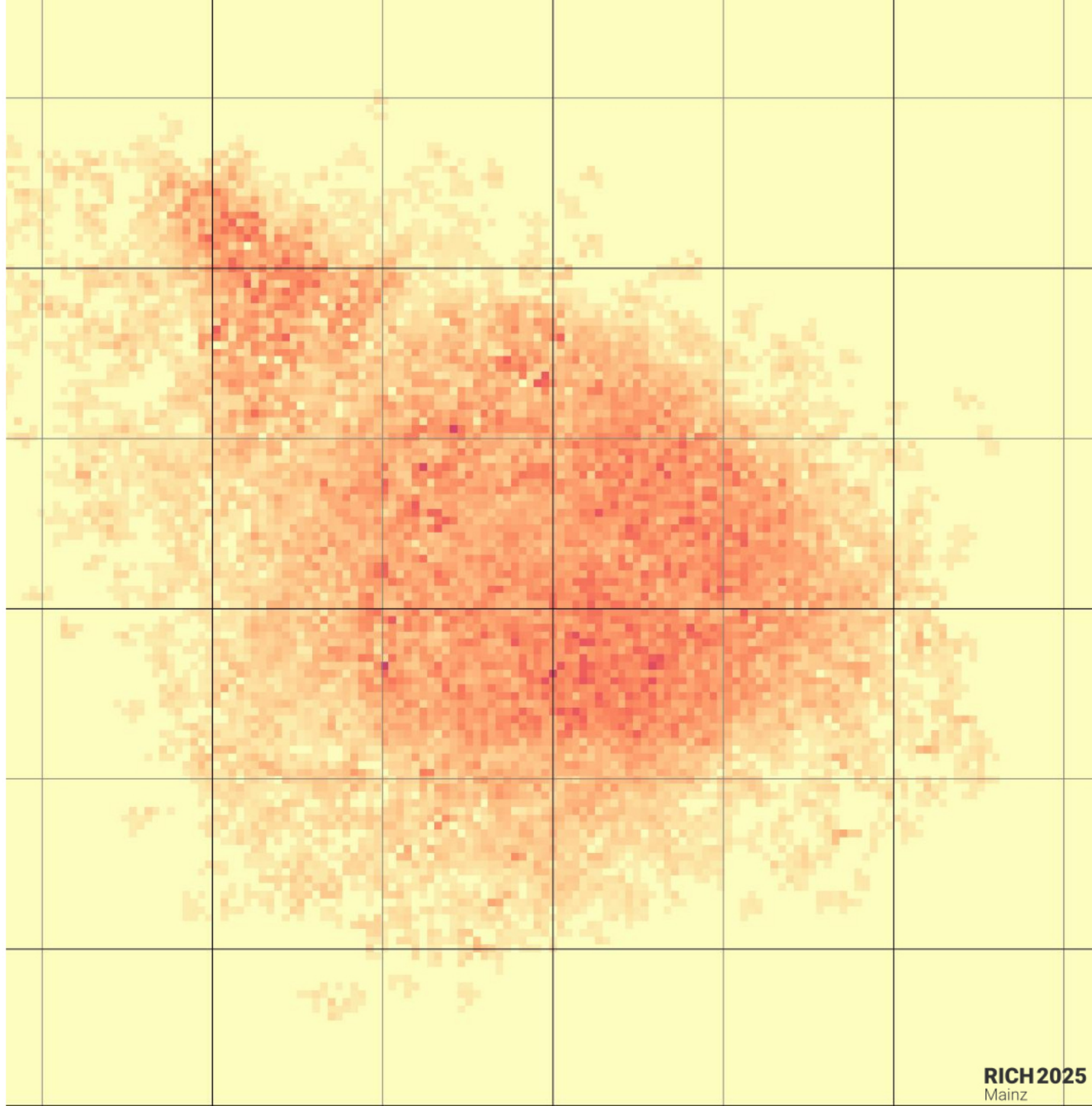

Airshower

Helium

882GeV

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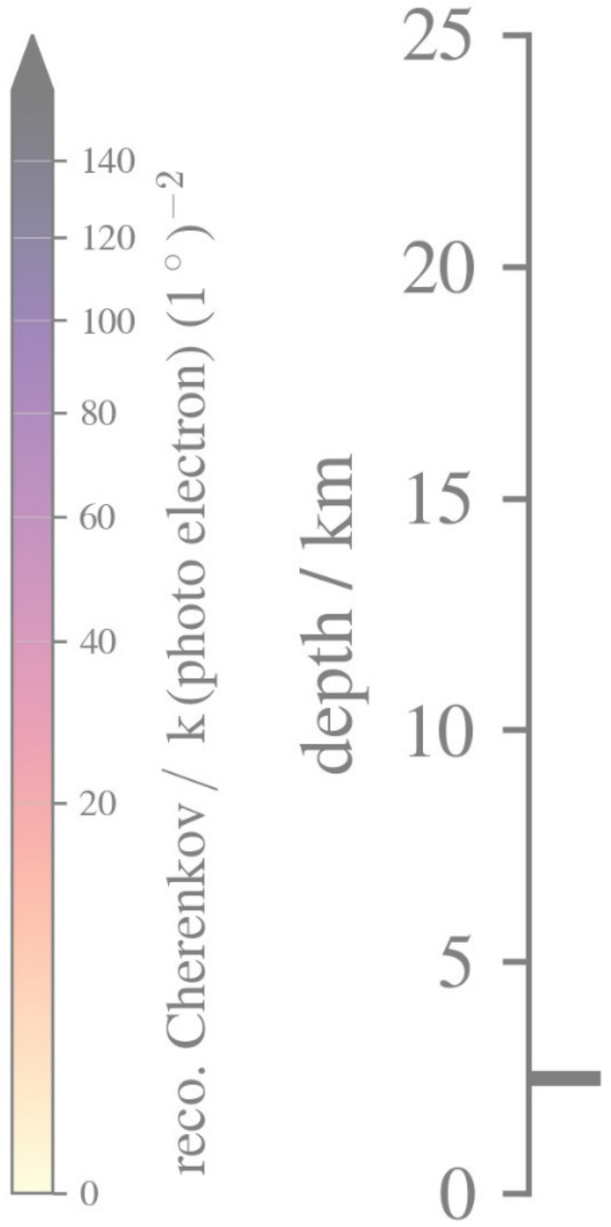


Airshower

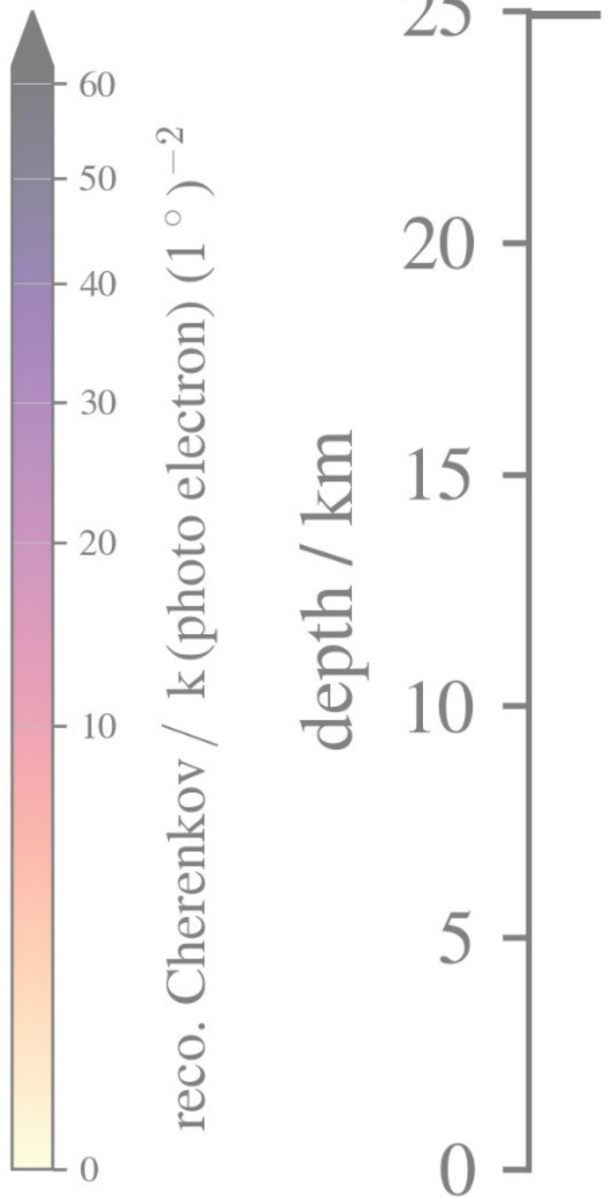
Proton

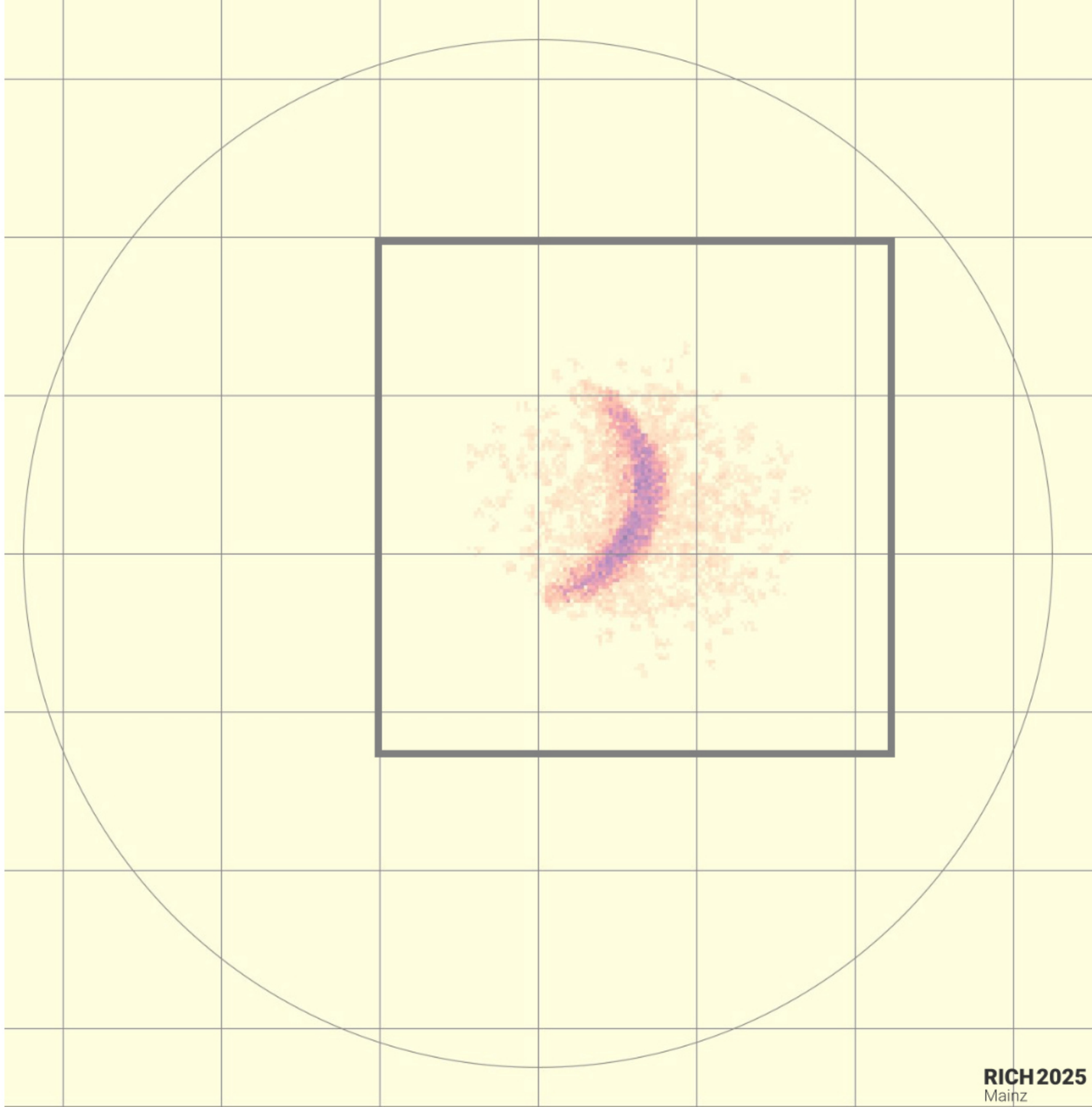
44GeV

4,814p.e.

Muon ring?

core > 1km





Airshower

Proton

44GeV

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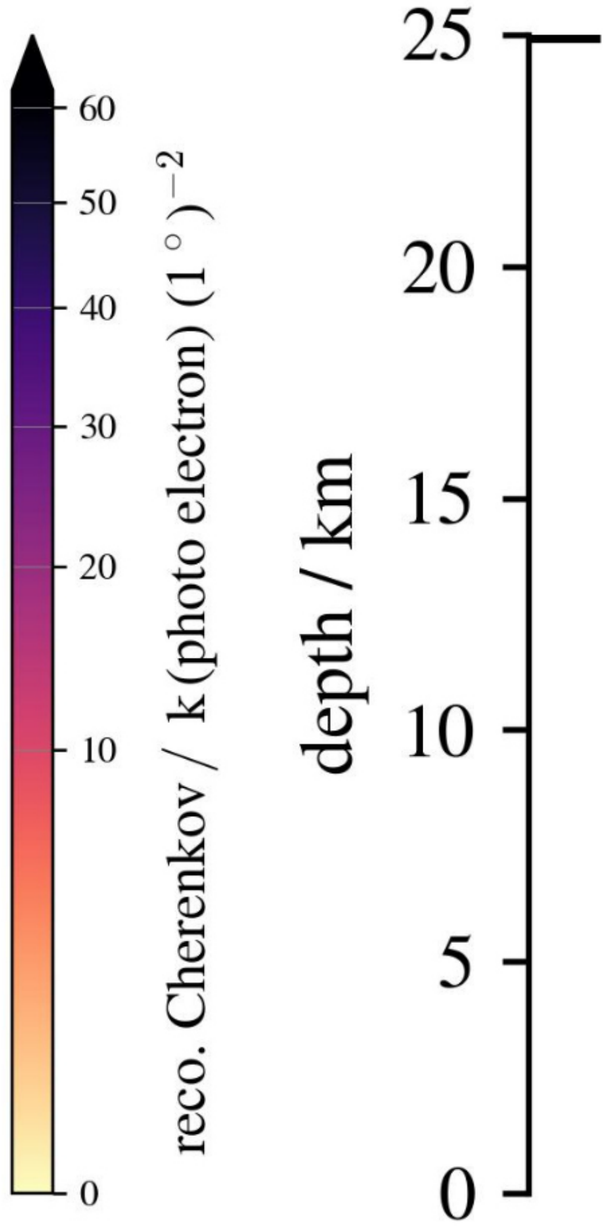
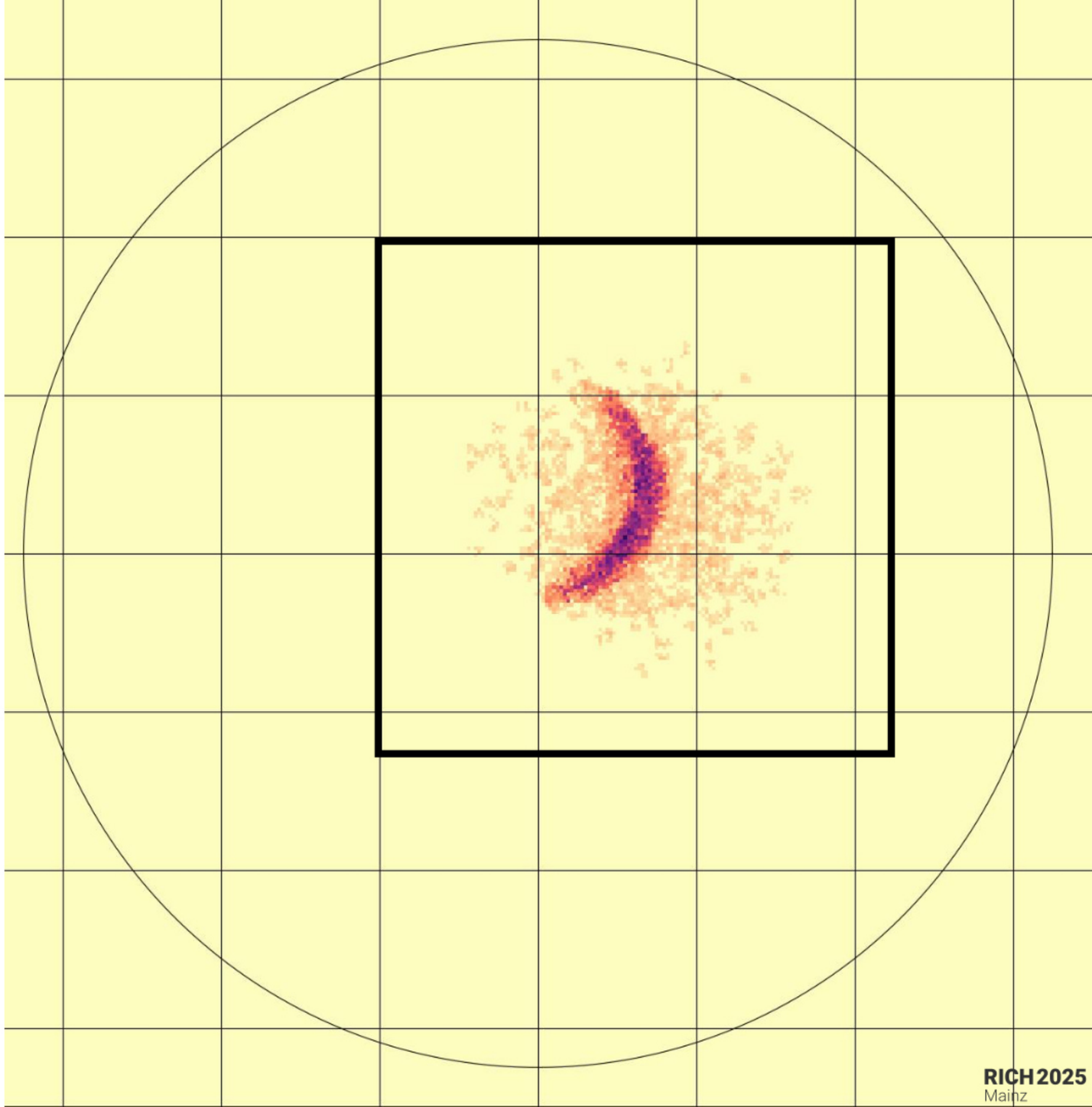
Muon ring?

core > 1km





Airshower

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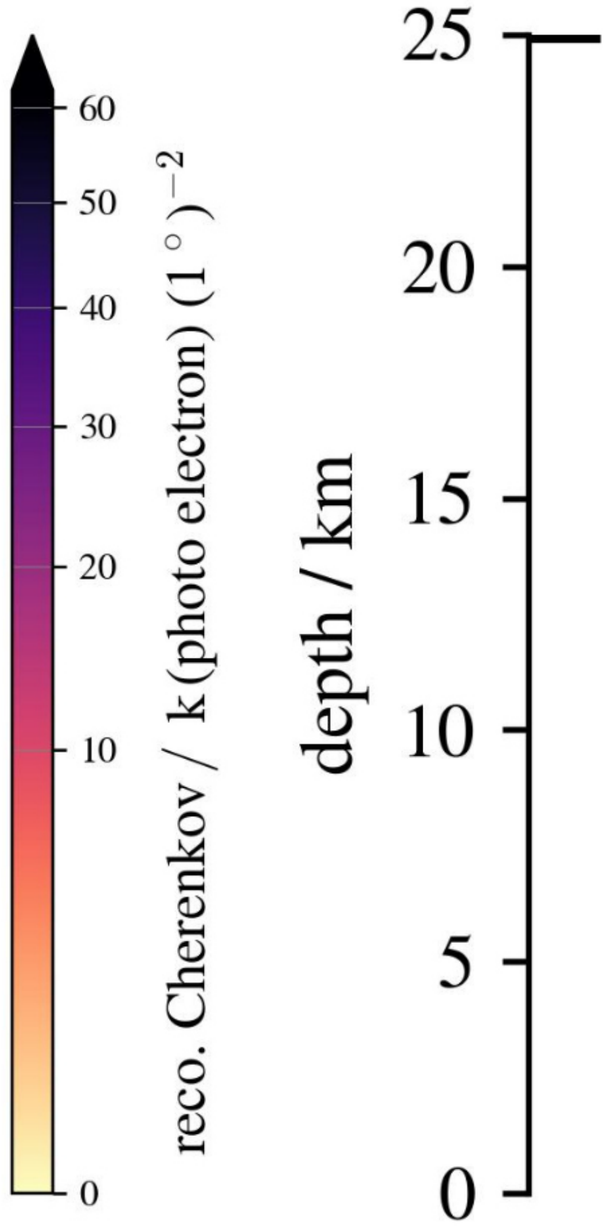
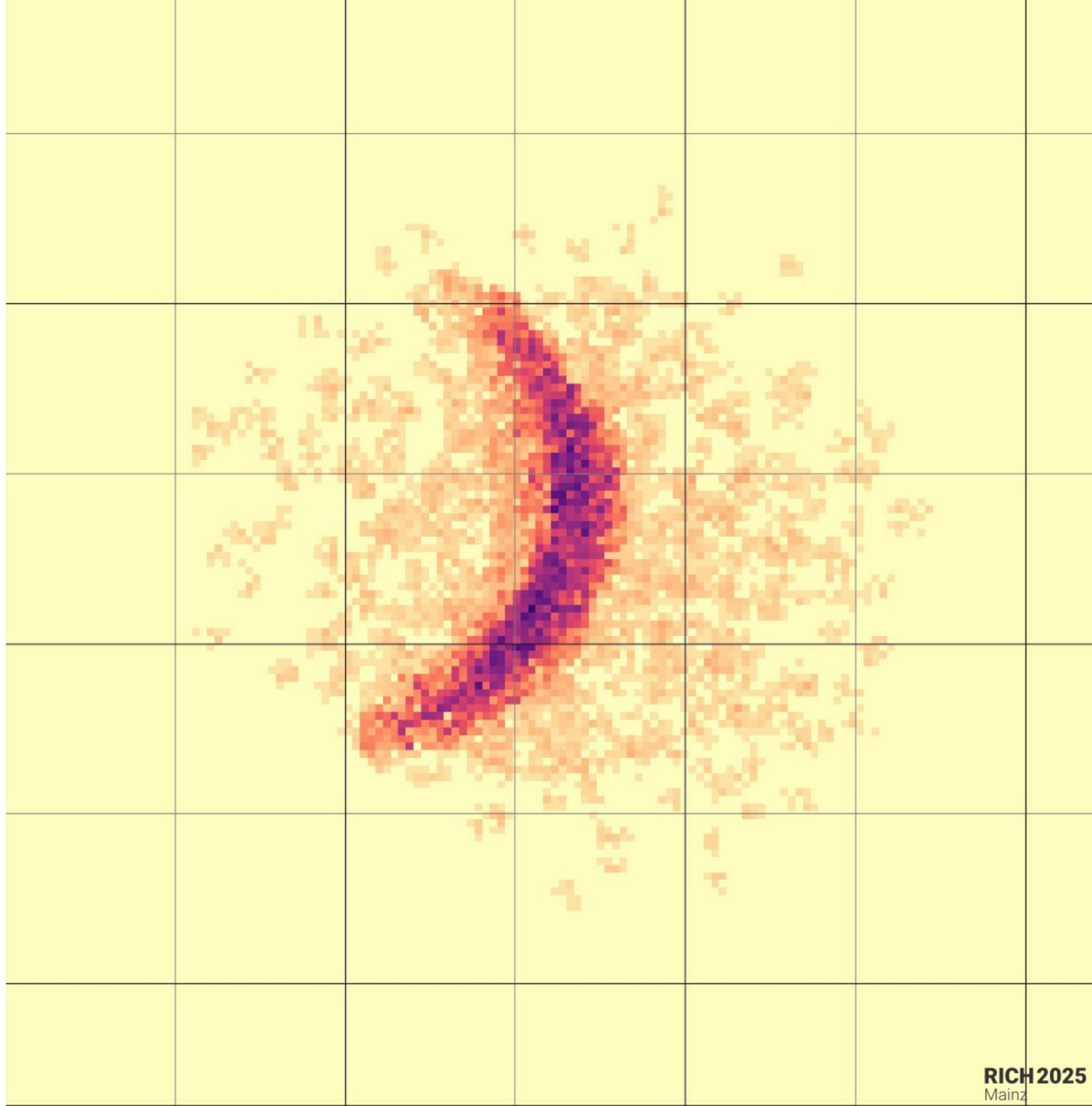
Muon ring?

core > 1km





Airshower

Proton

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Muon ring?

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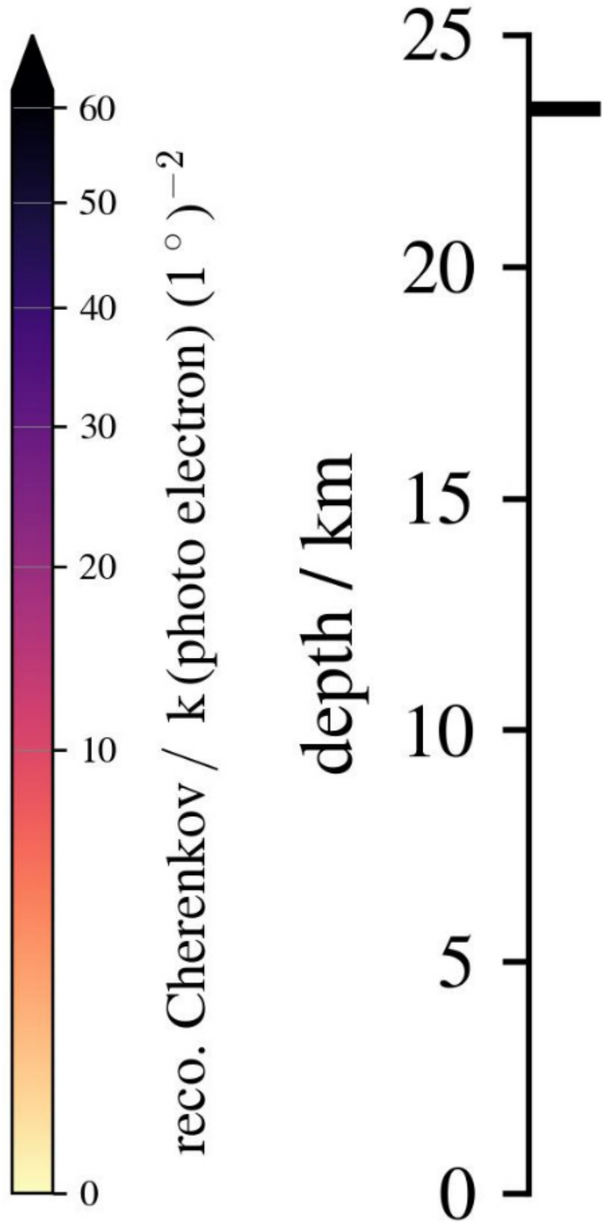

Airshower

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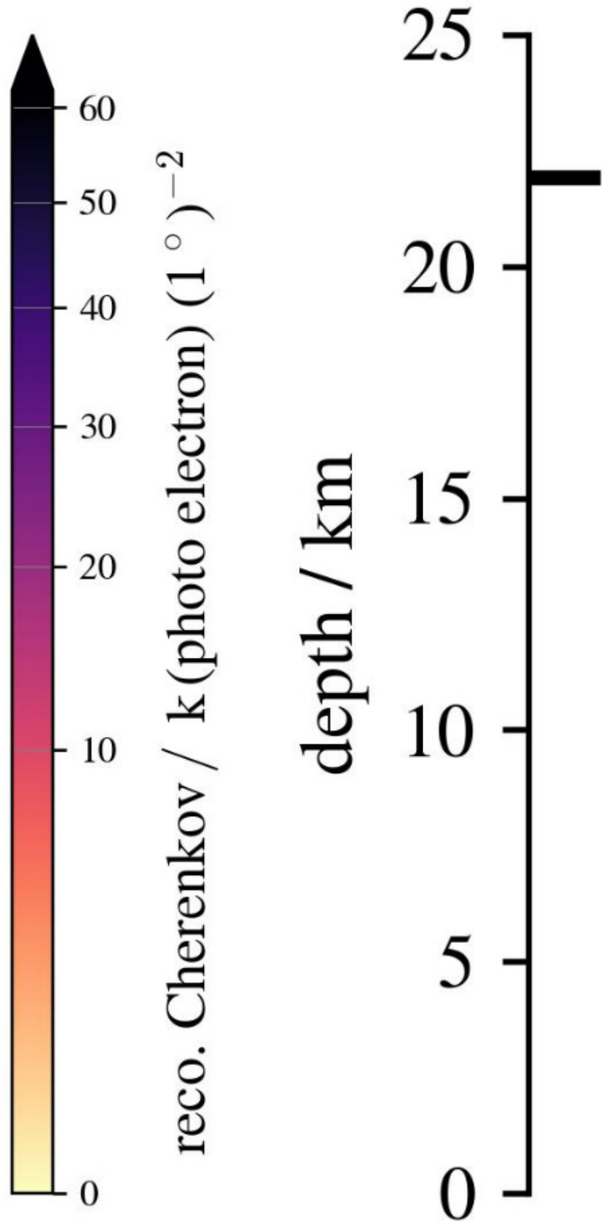

Airshower

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Muon ring?

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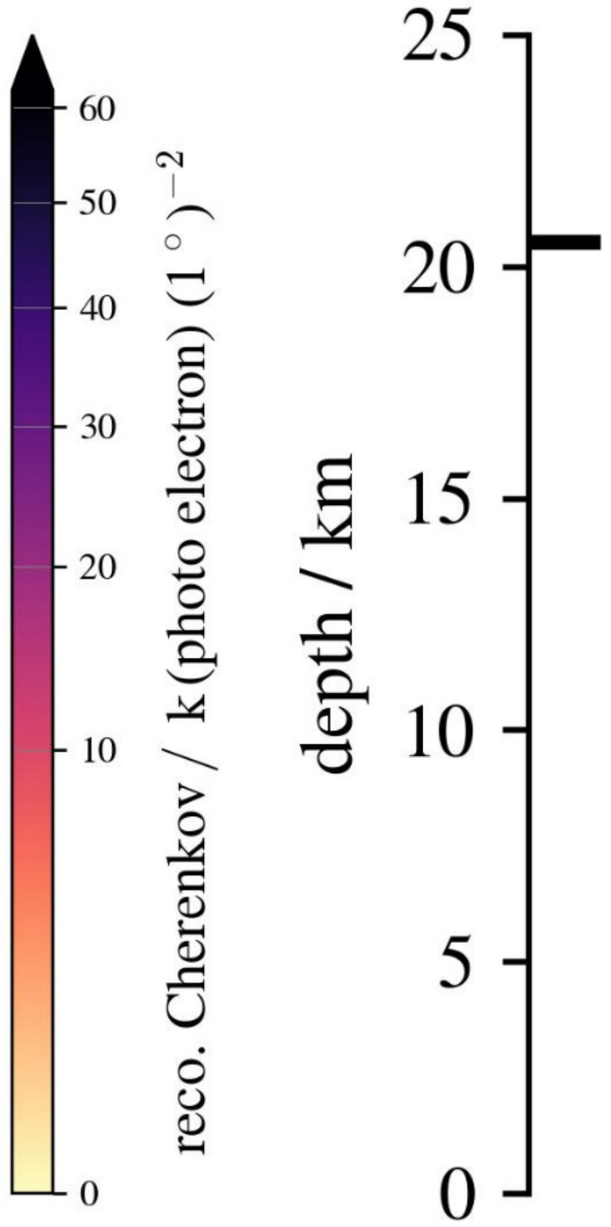

Airshower

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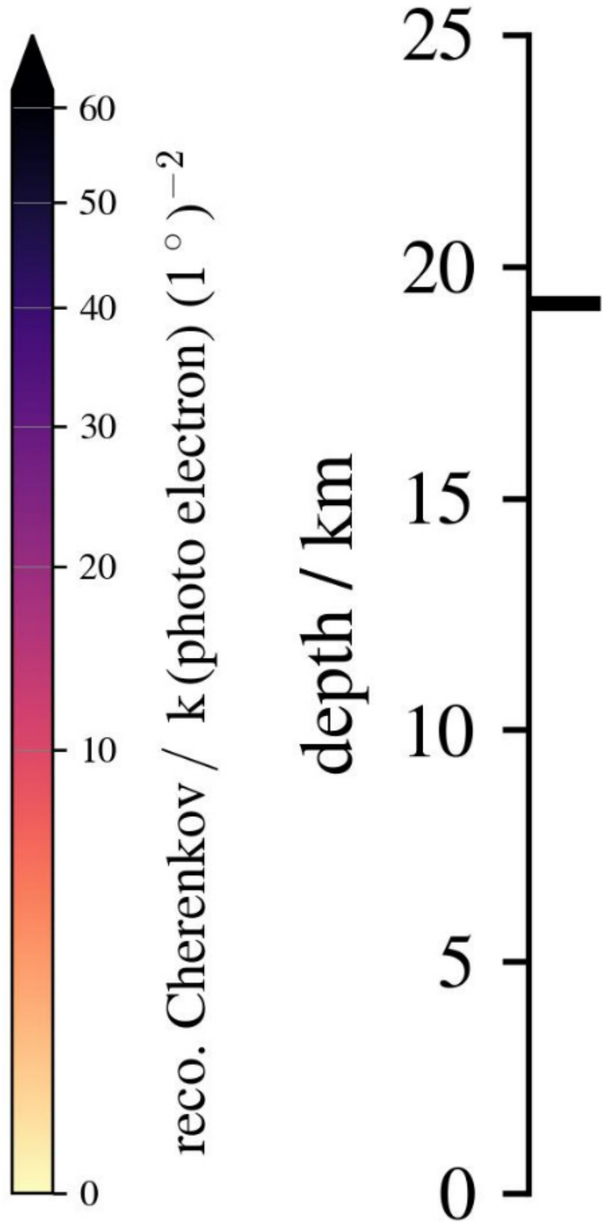

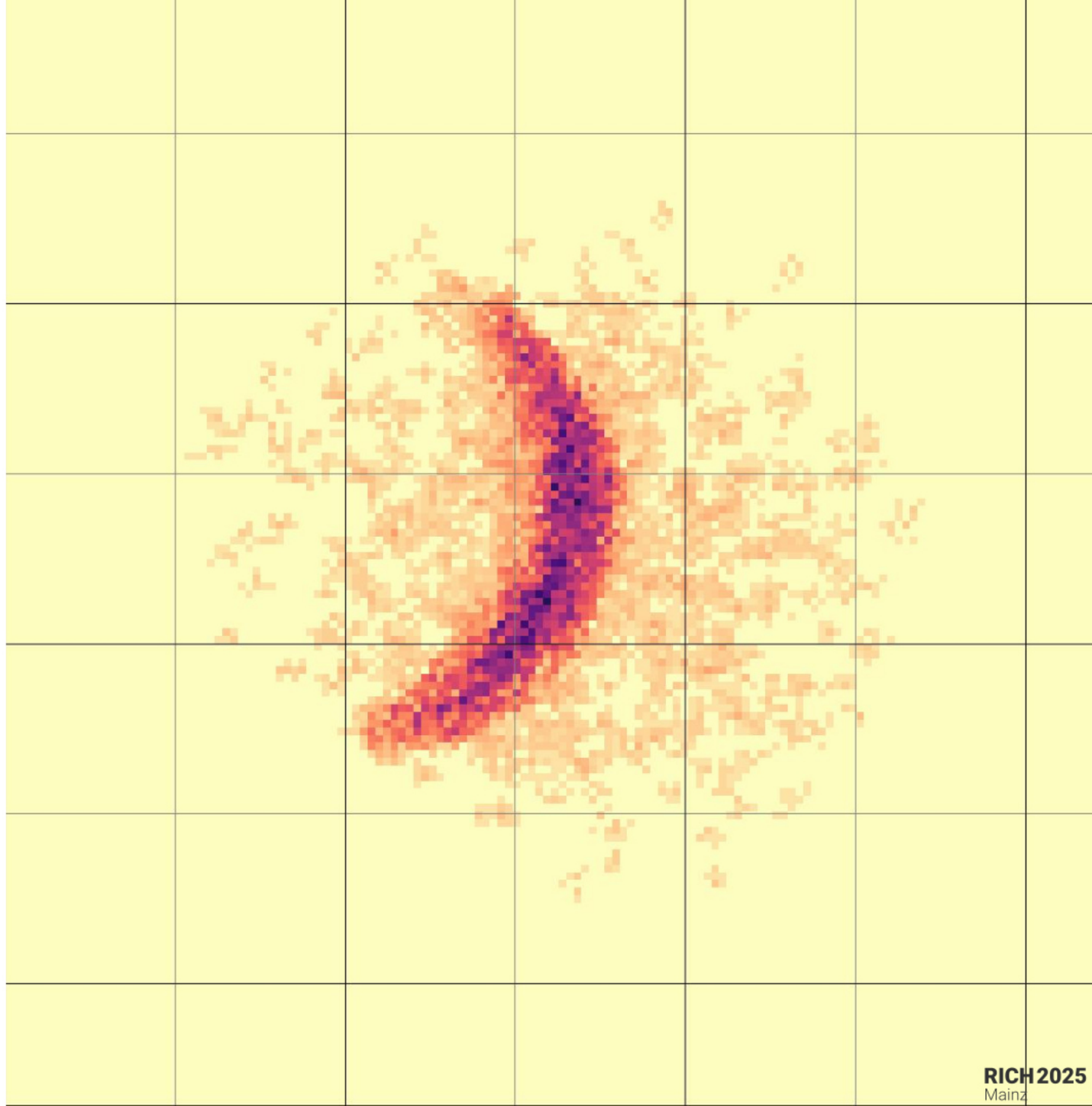

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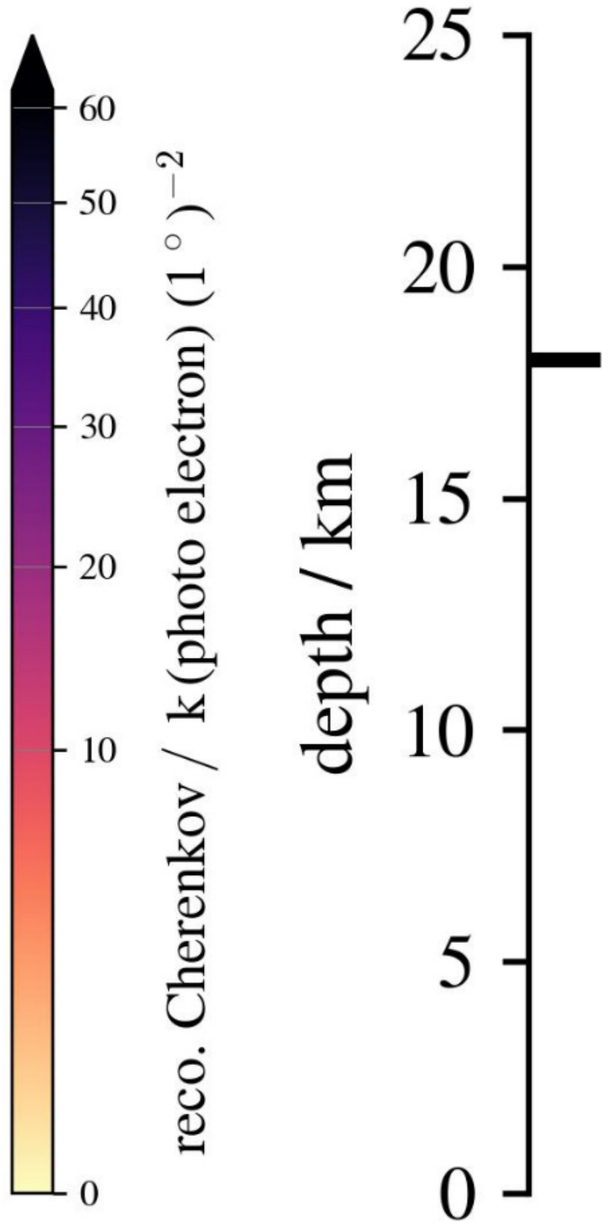

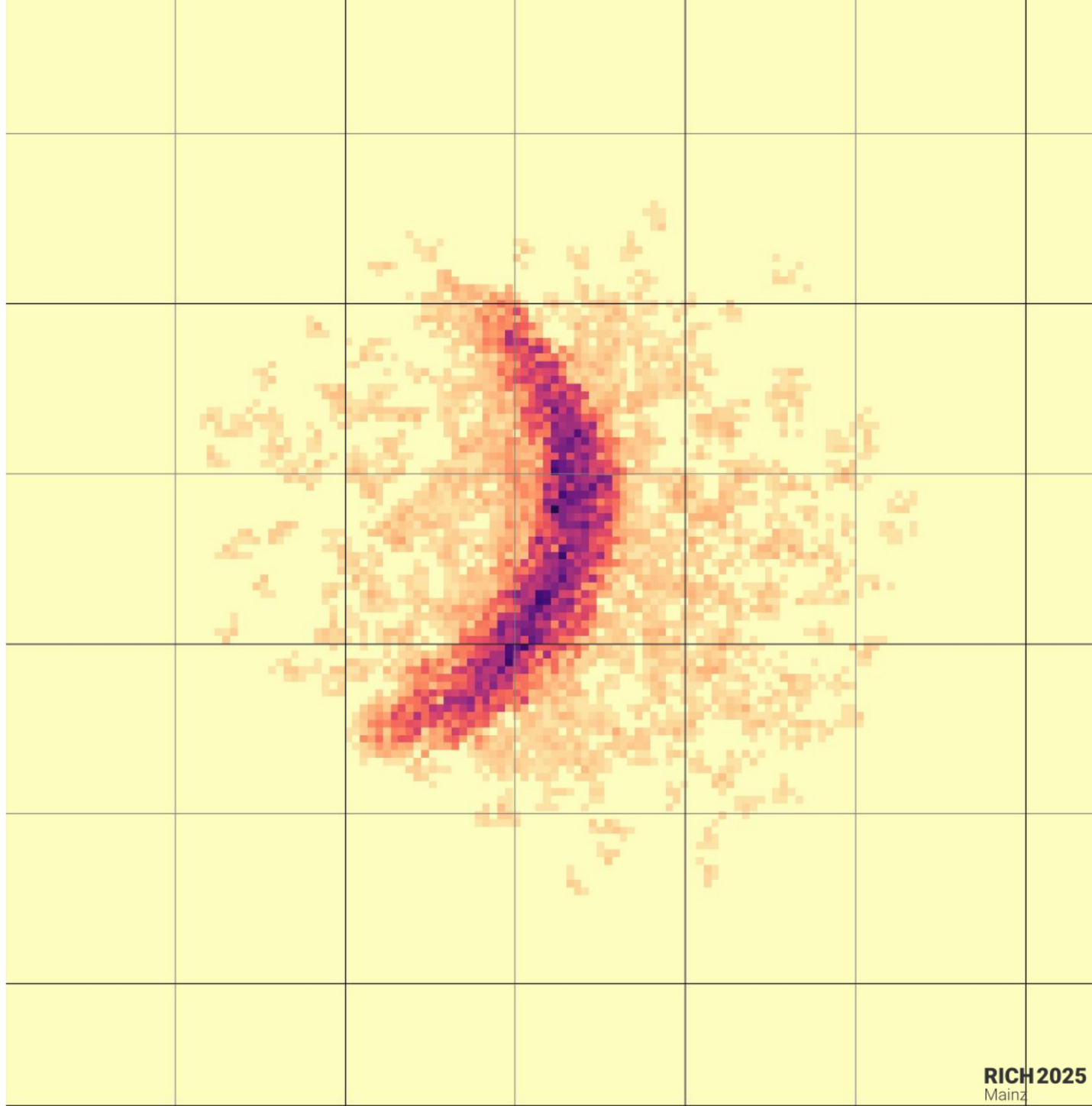

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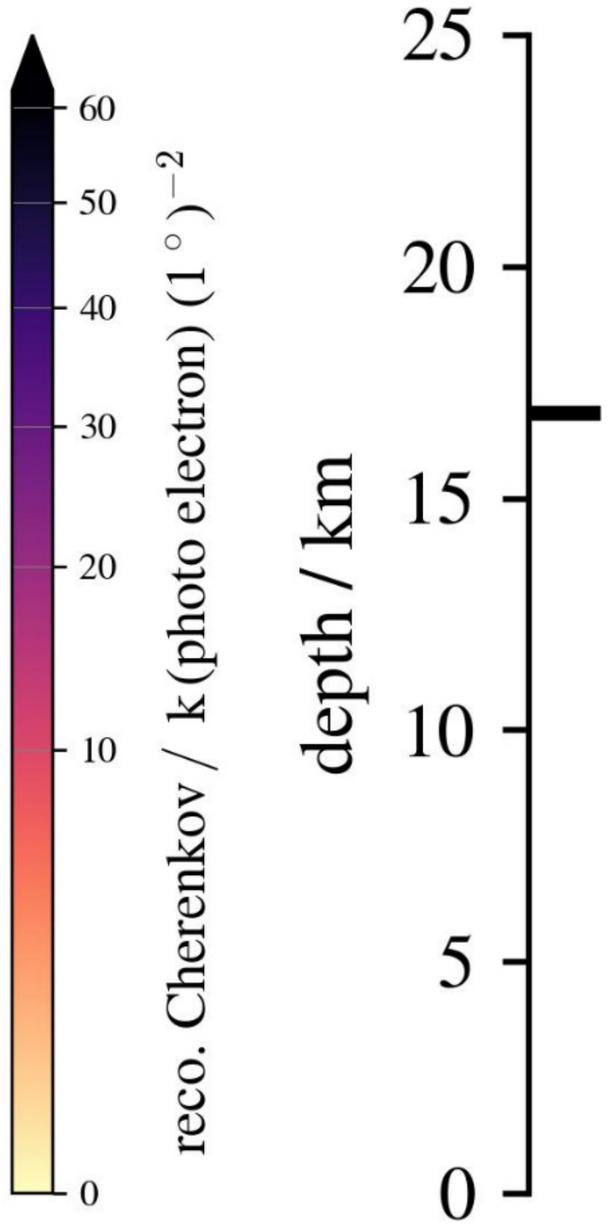

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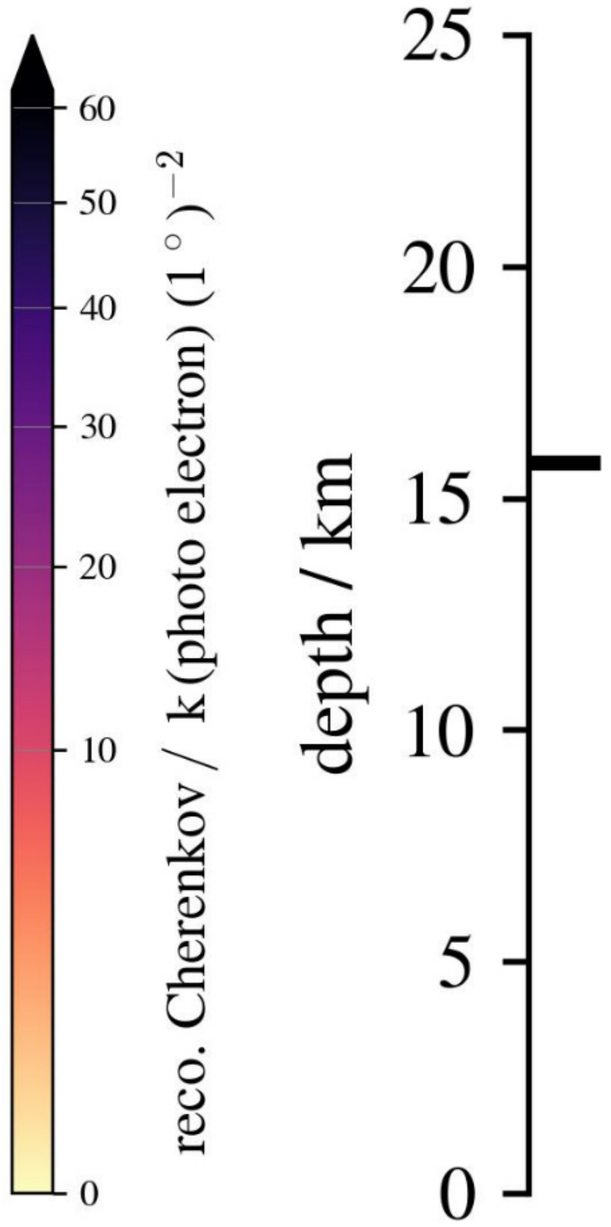

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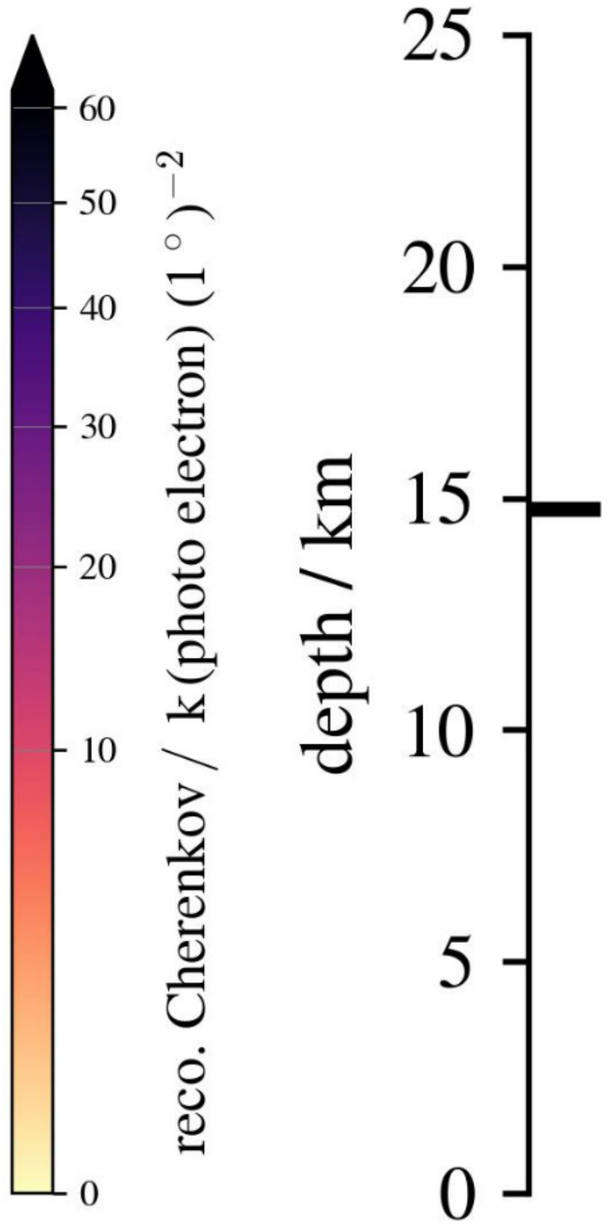

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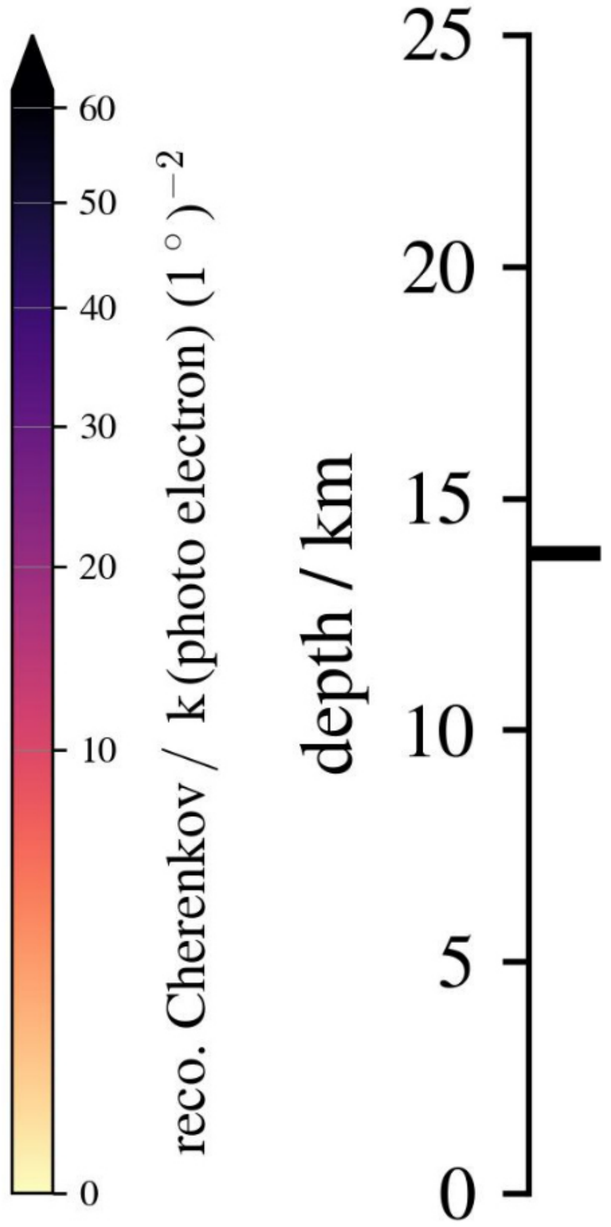

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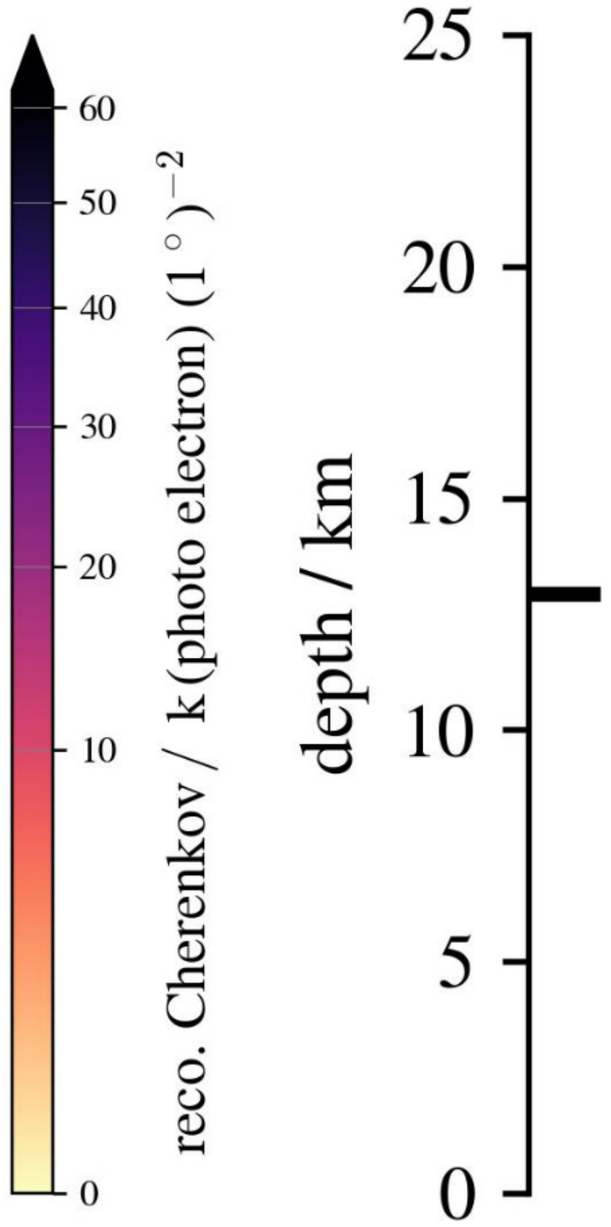

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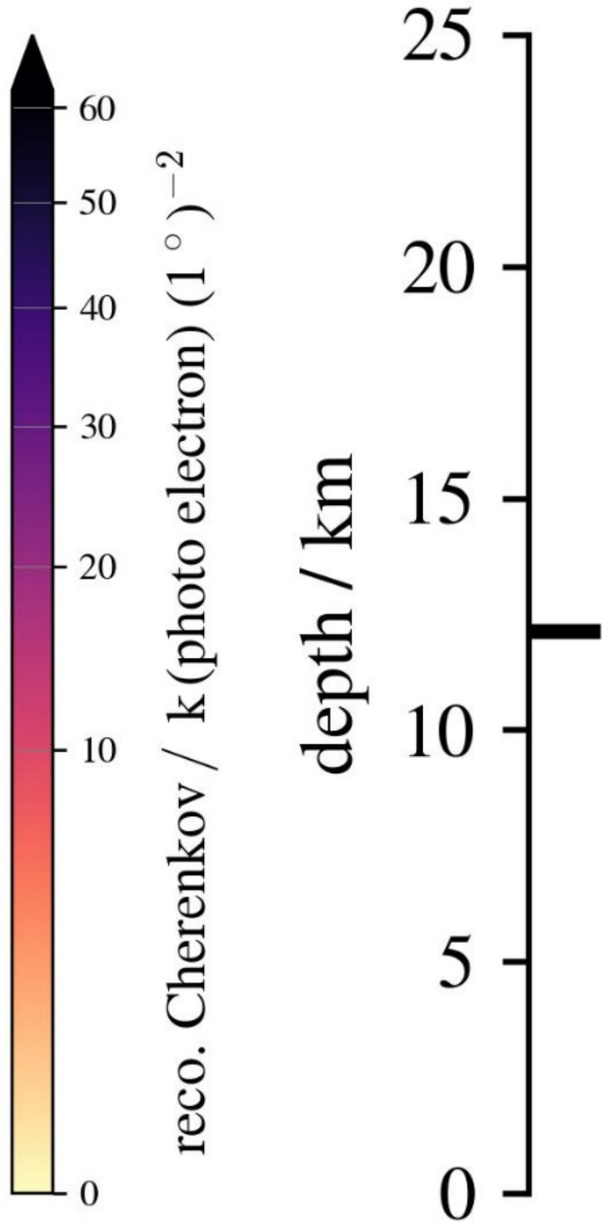

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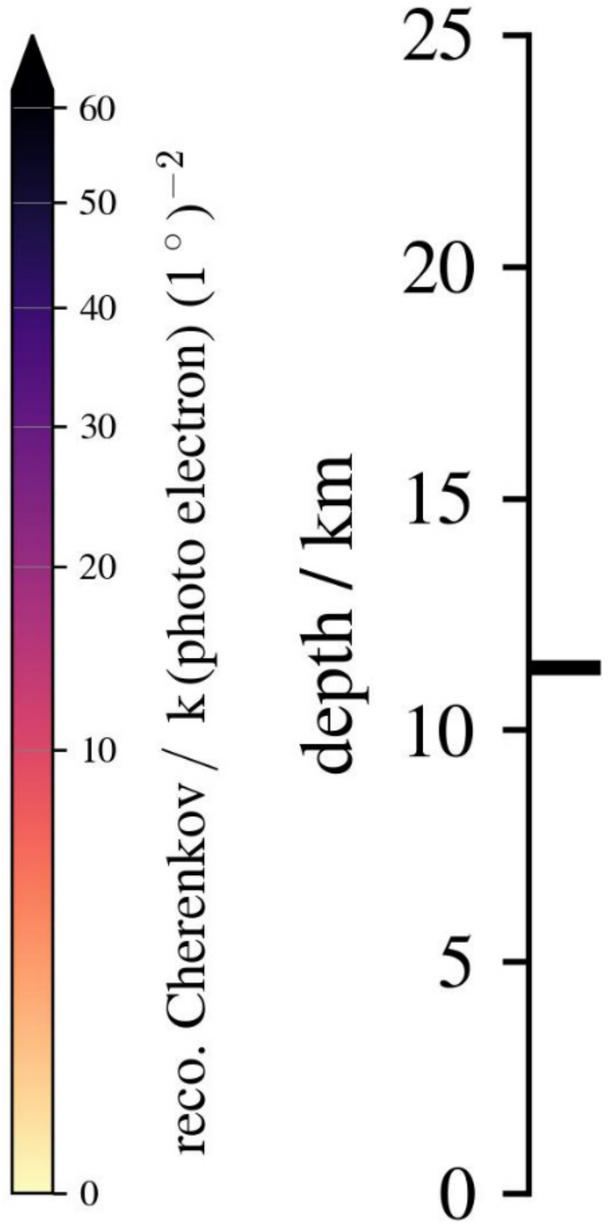

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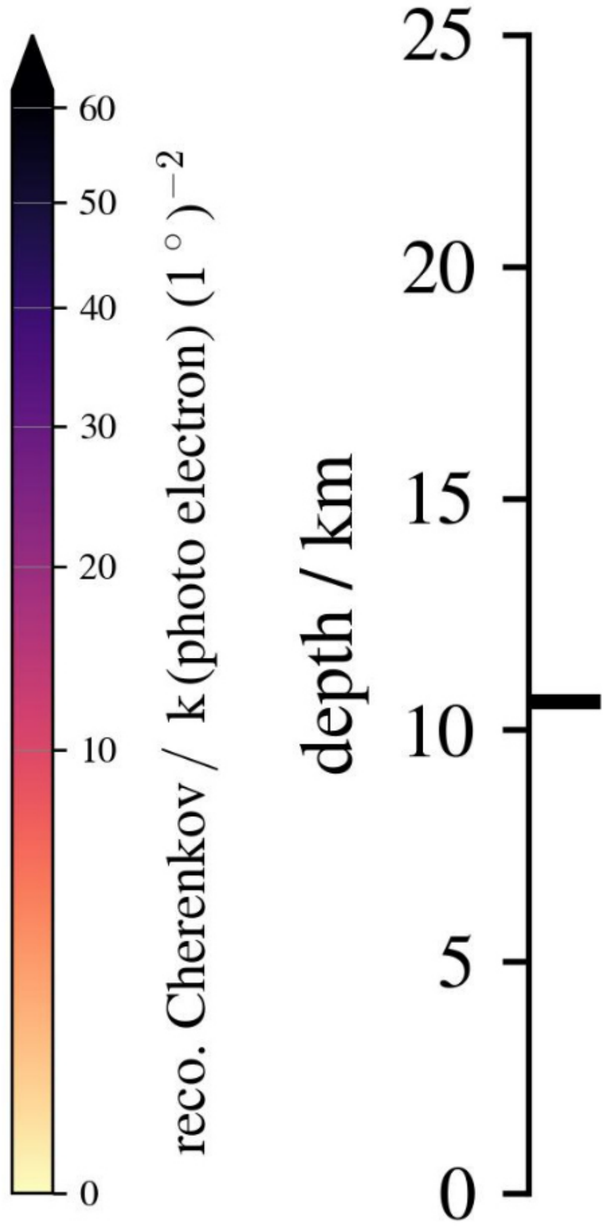

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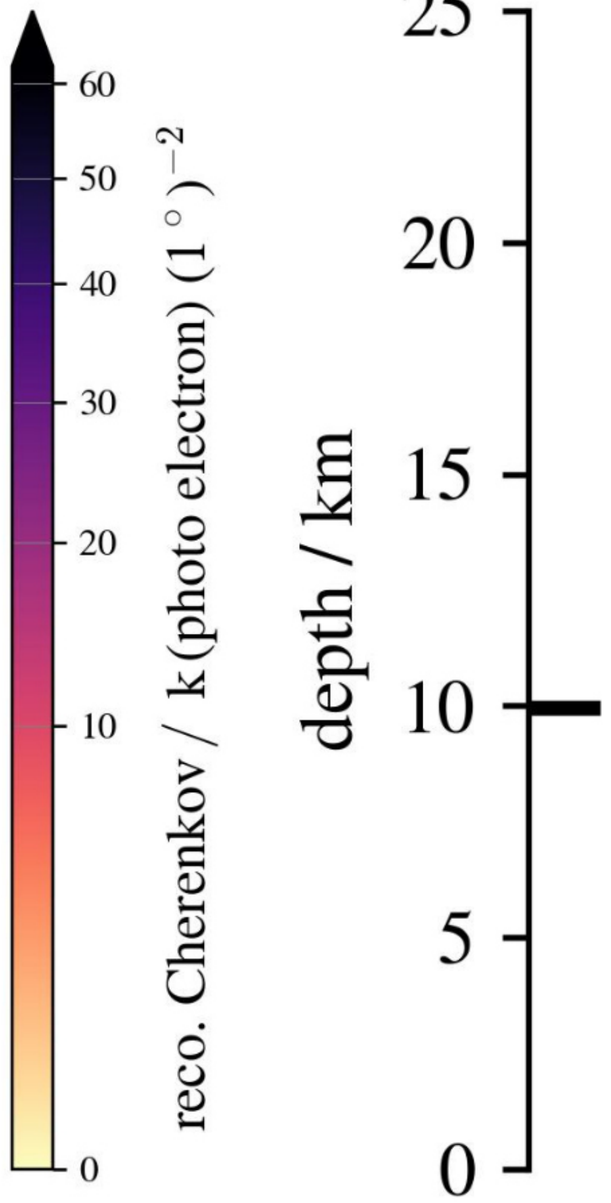

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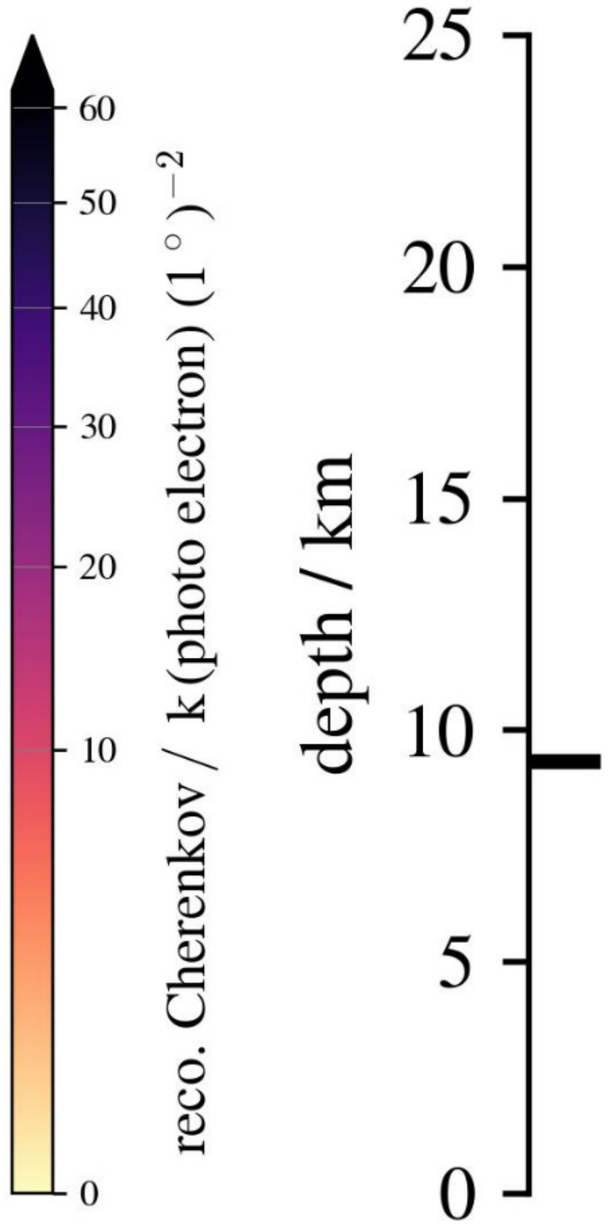

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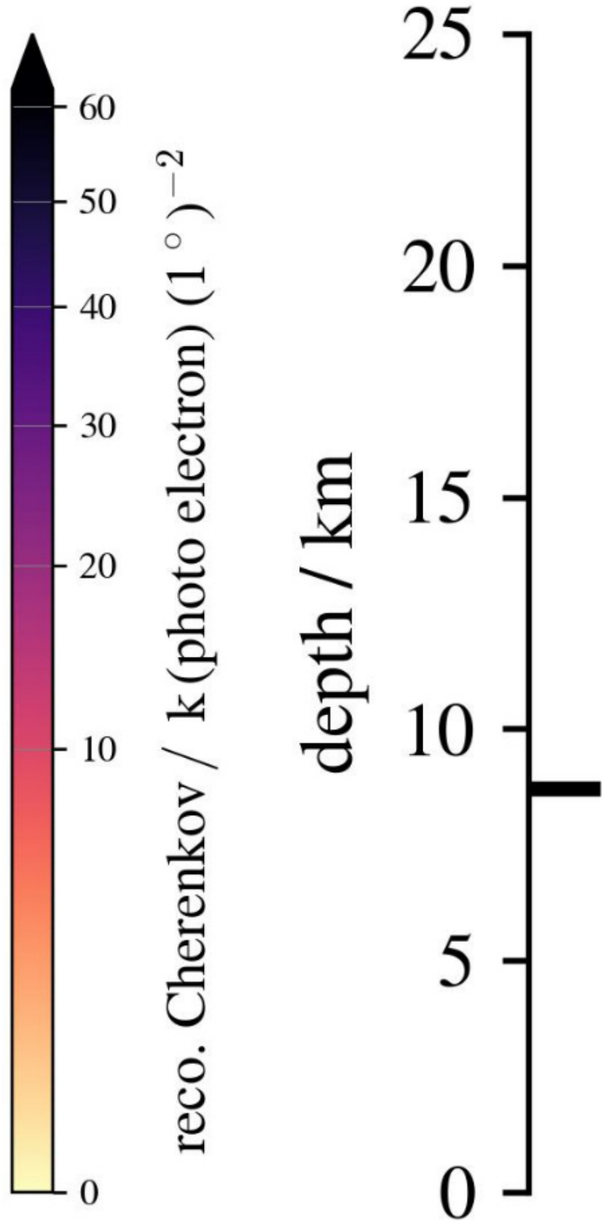

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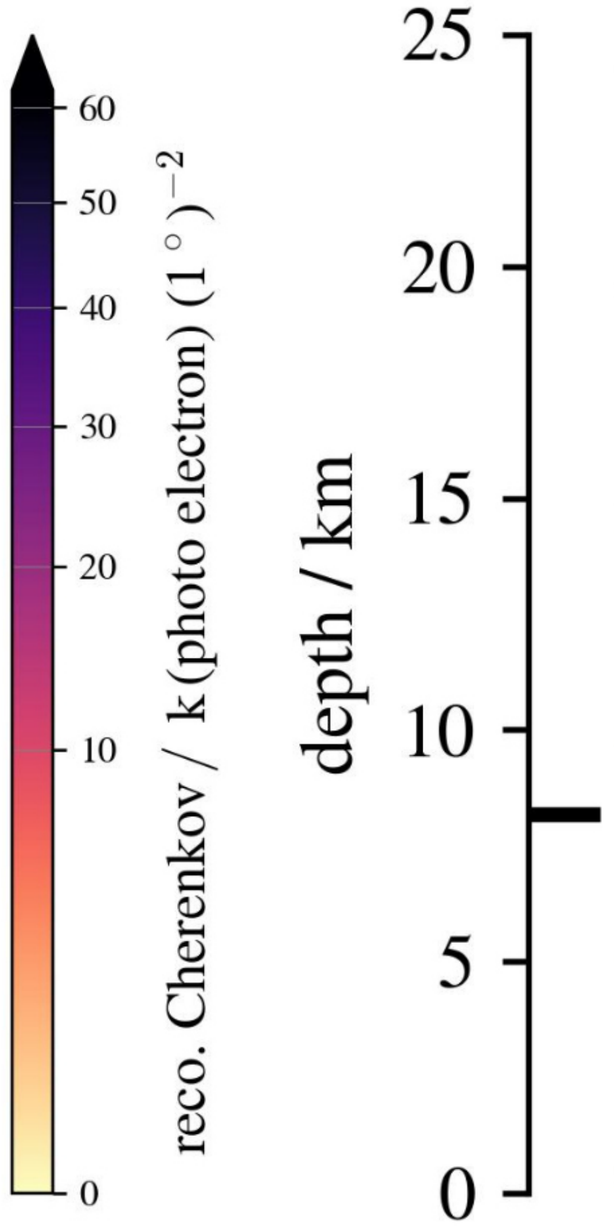

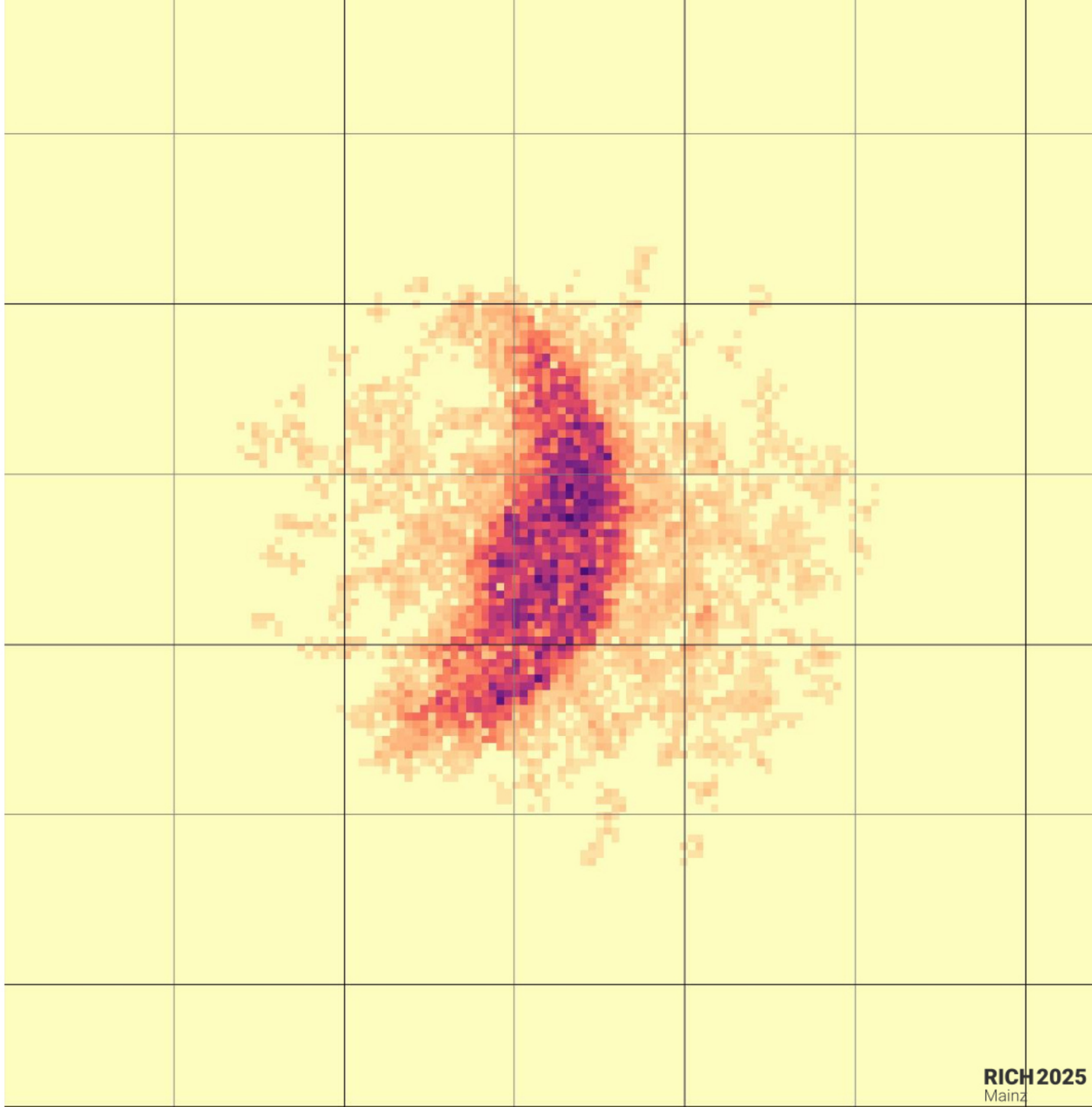

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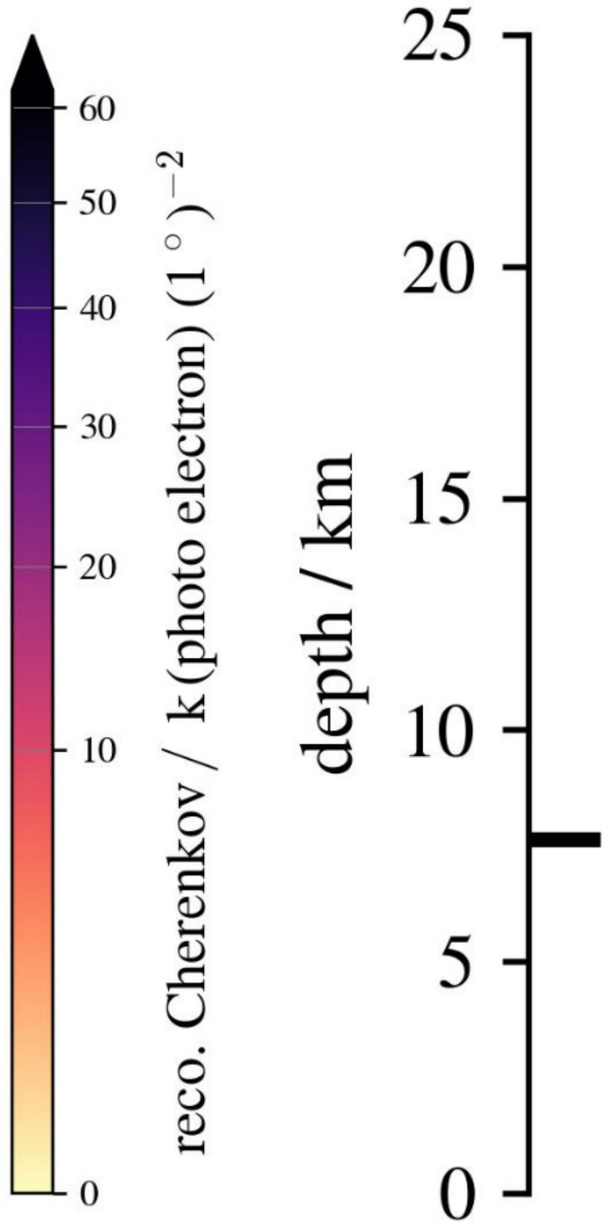
Muon ring?

core > 1km



Airshower

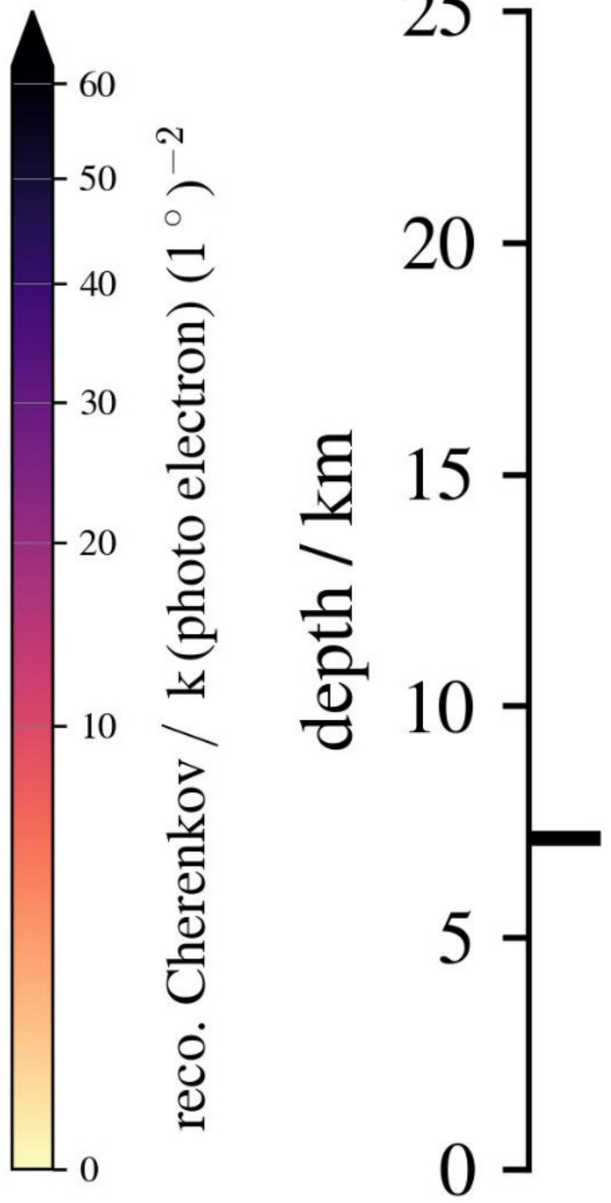
Proton

44GeV

4,814p.e.

Muon ring?

core > 1km



Airshower

Proton

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Muon ring?

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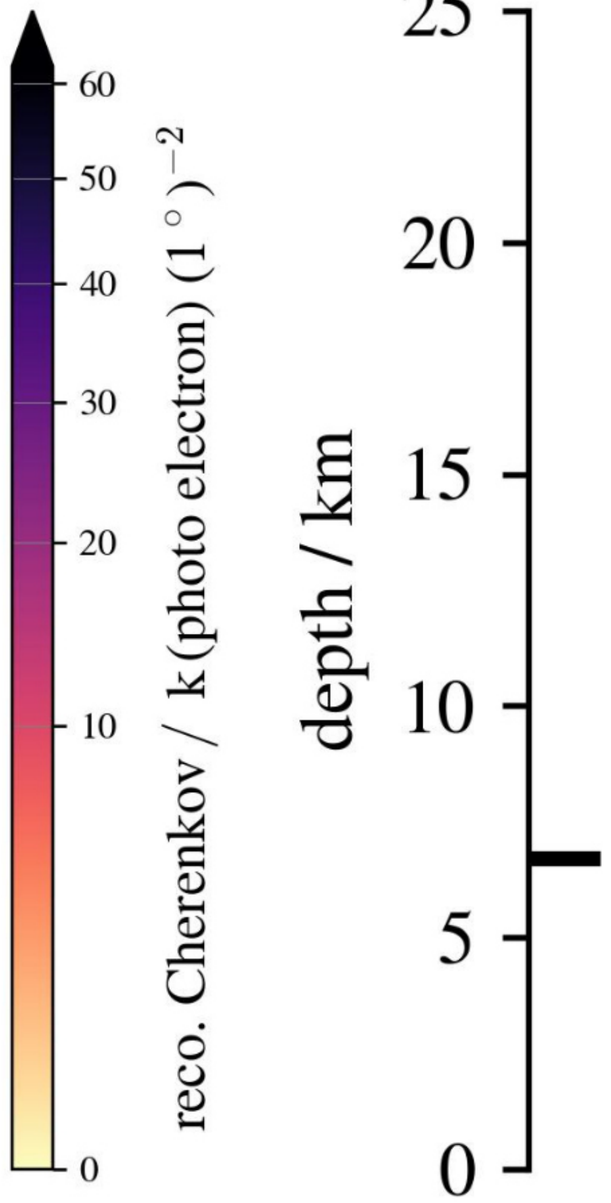

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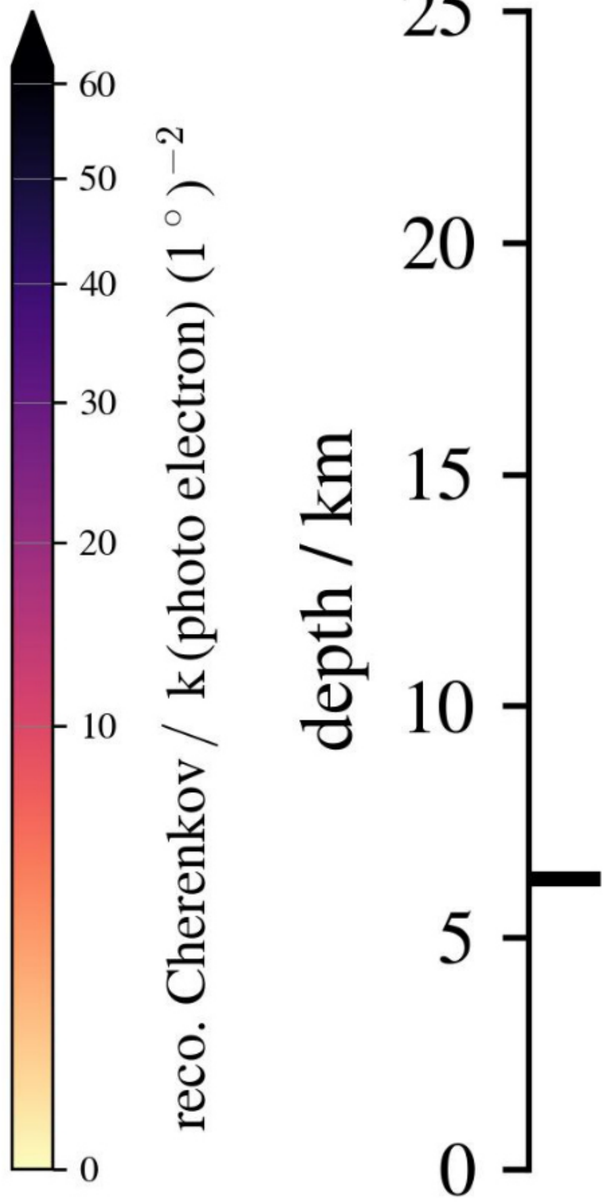

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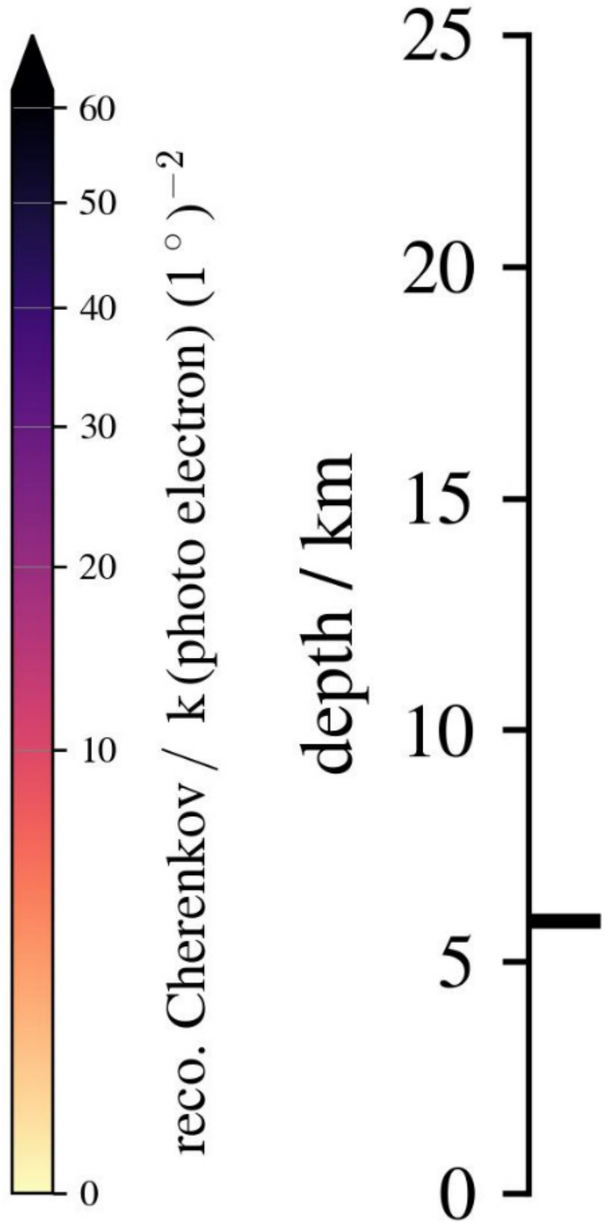

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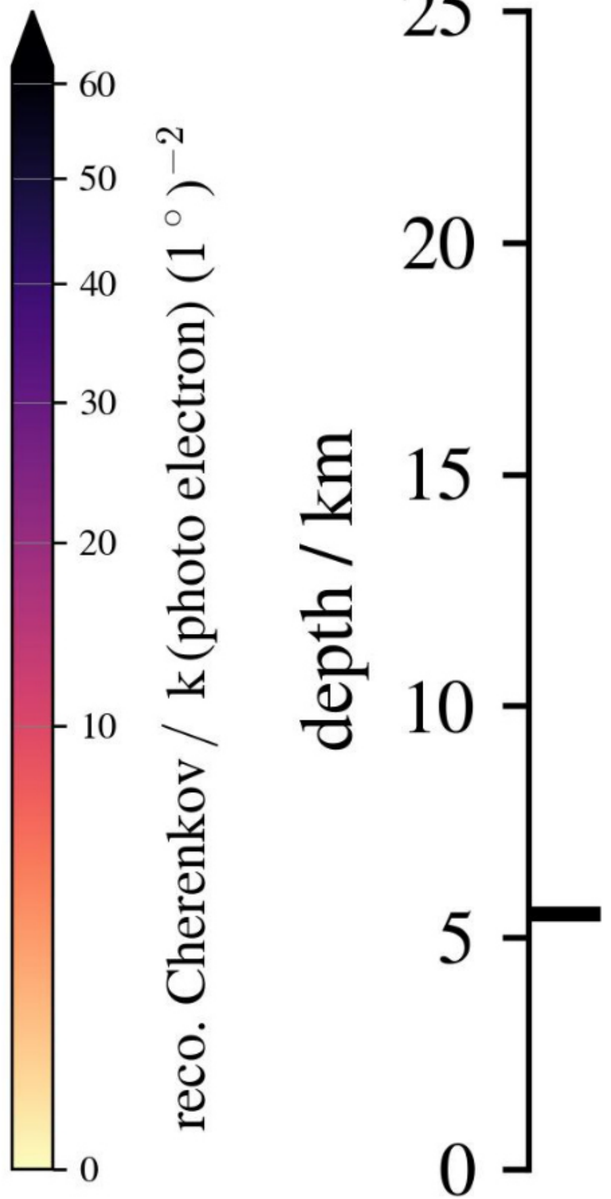

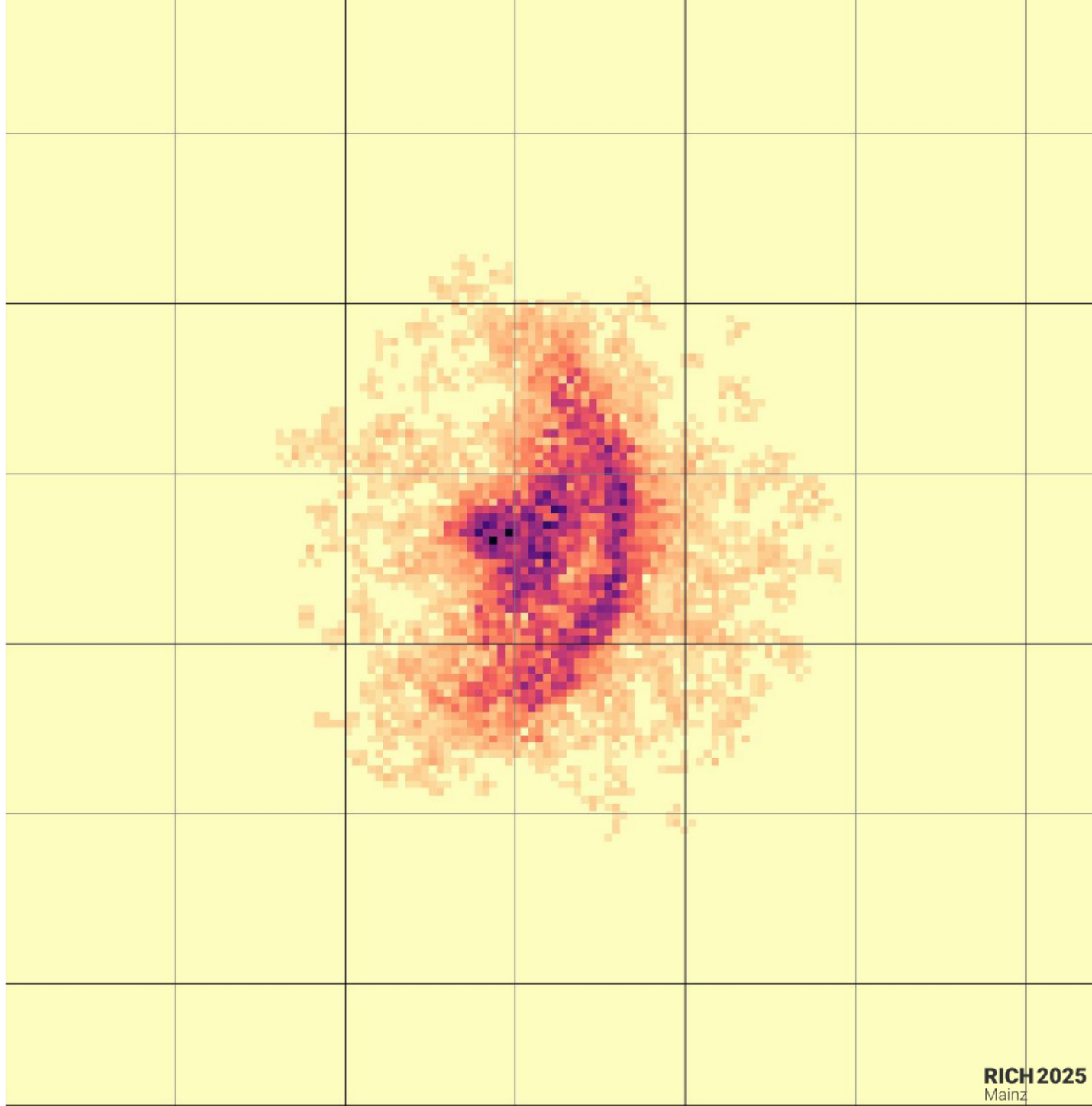

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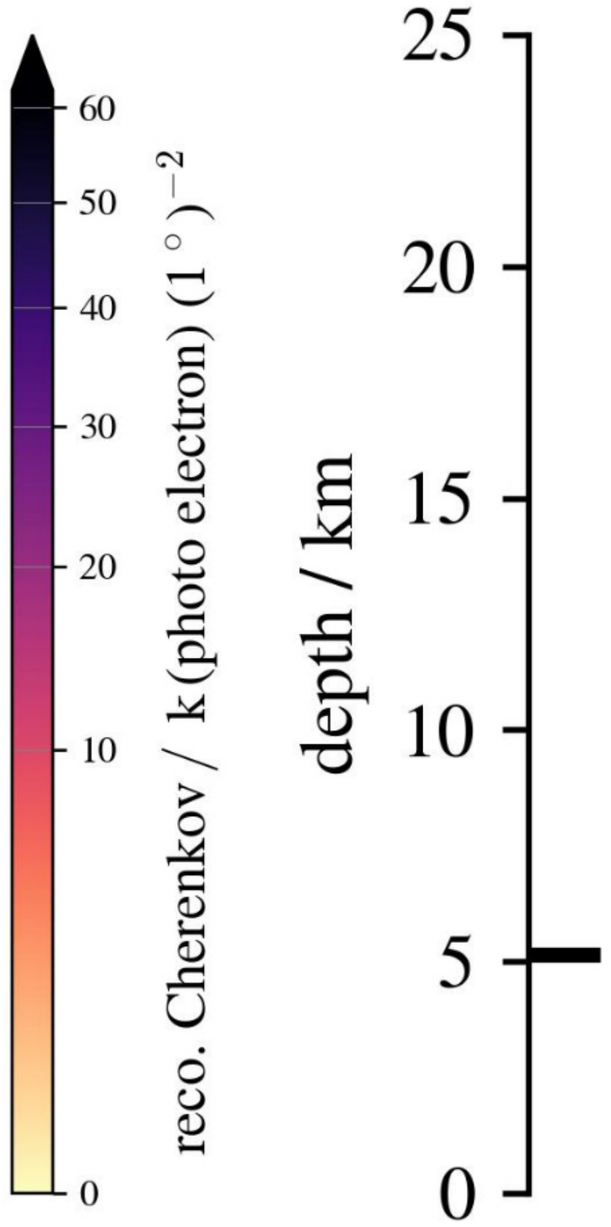

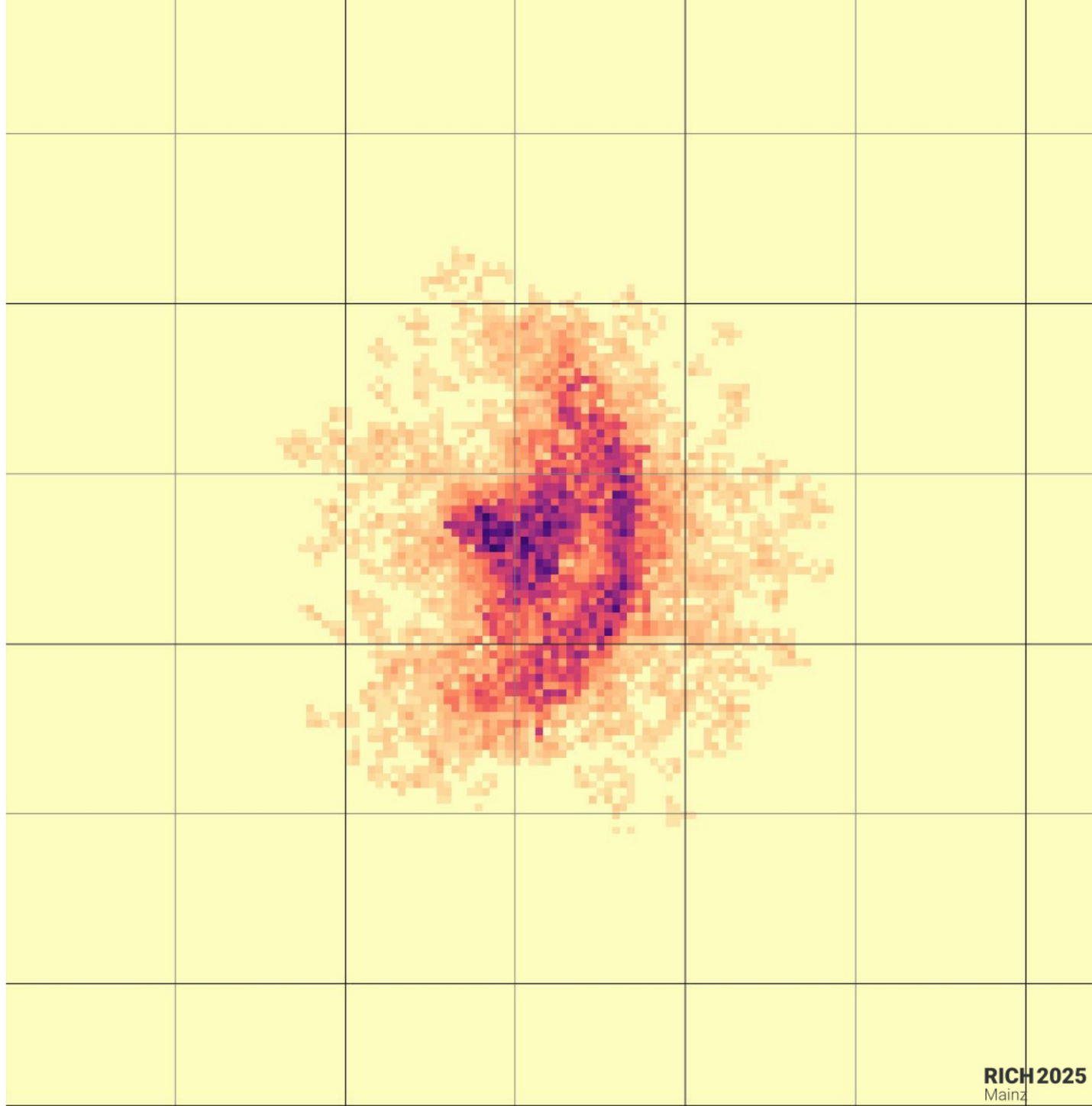

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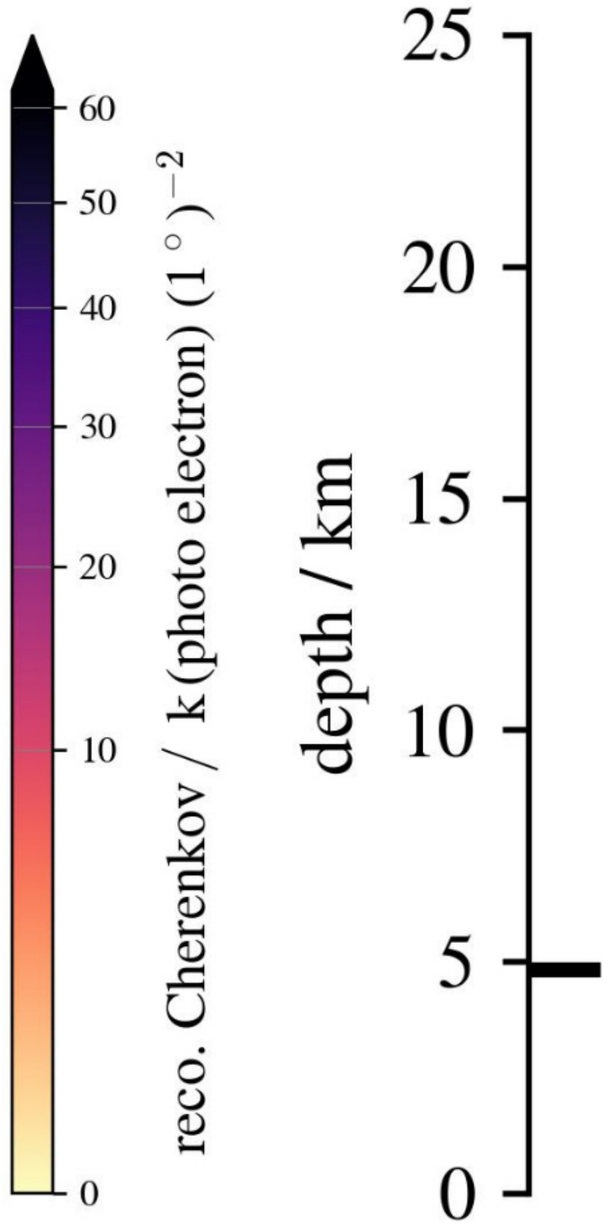

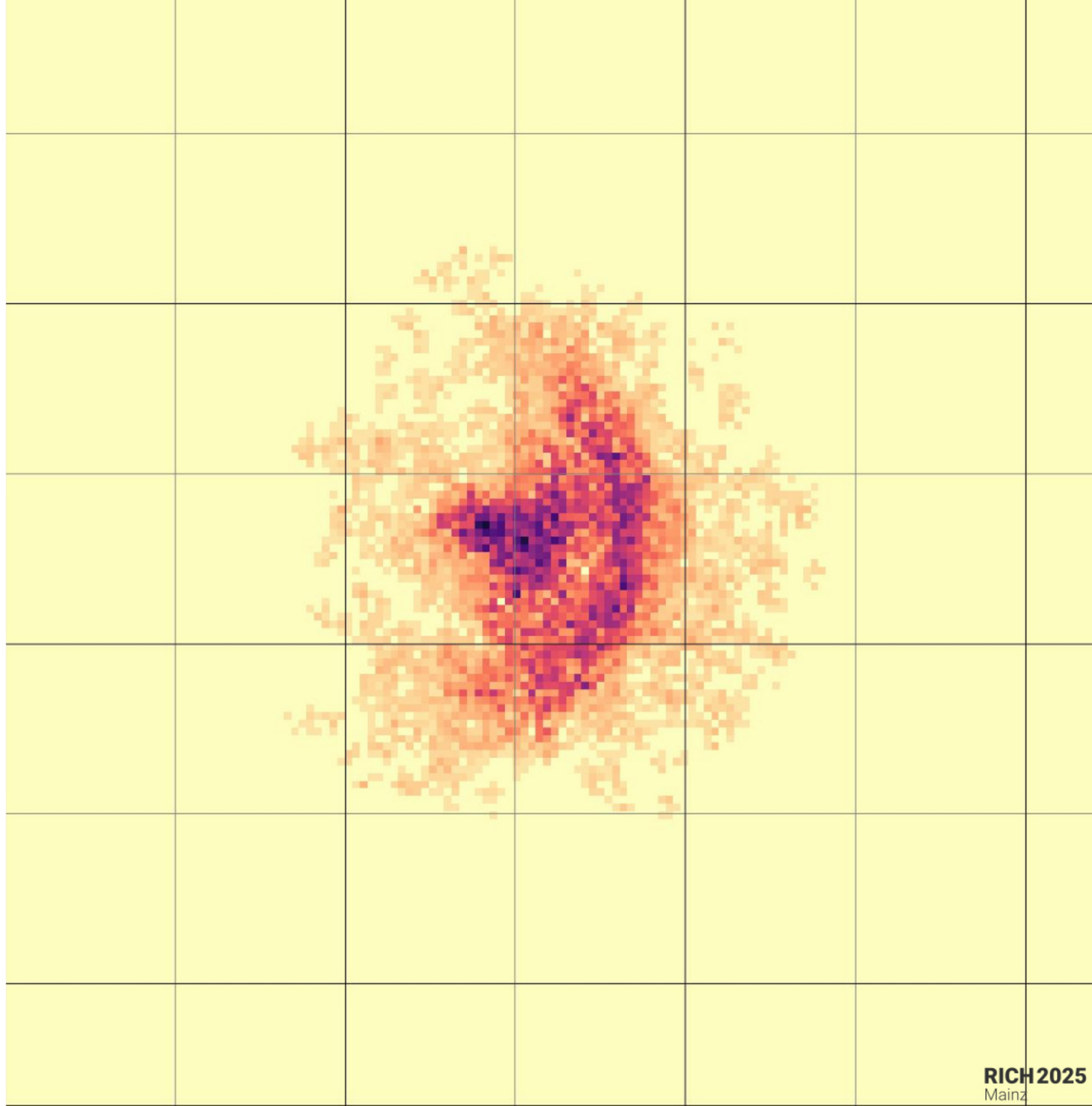

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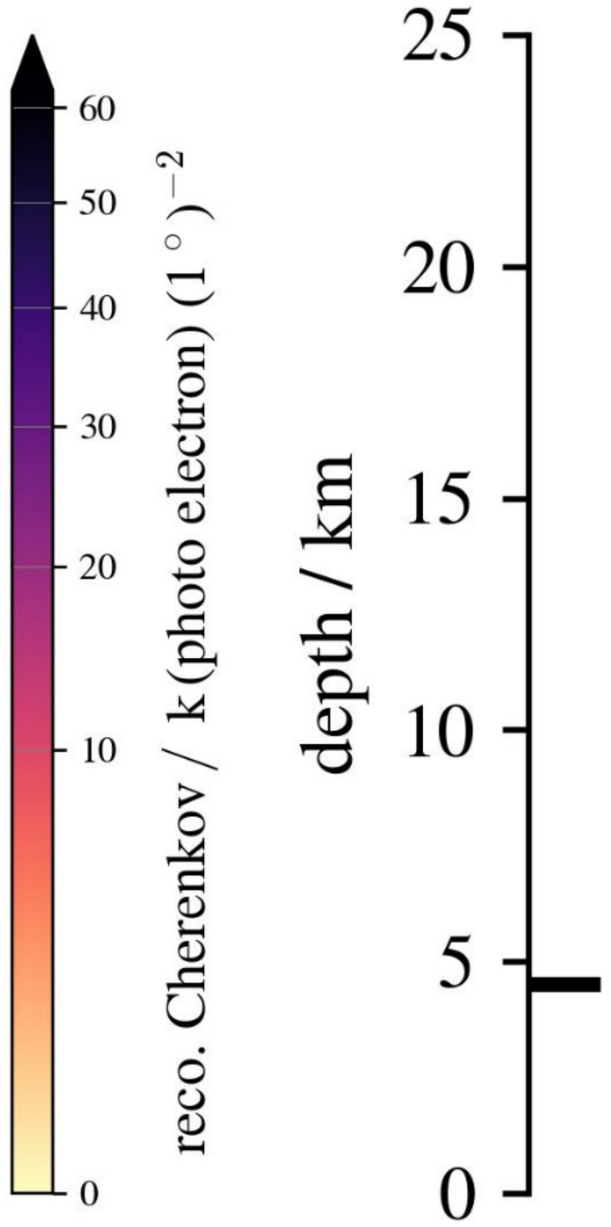

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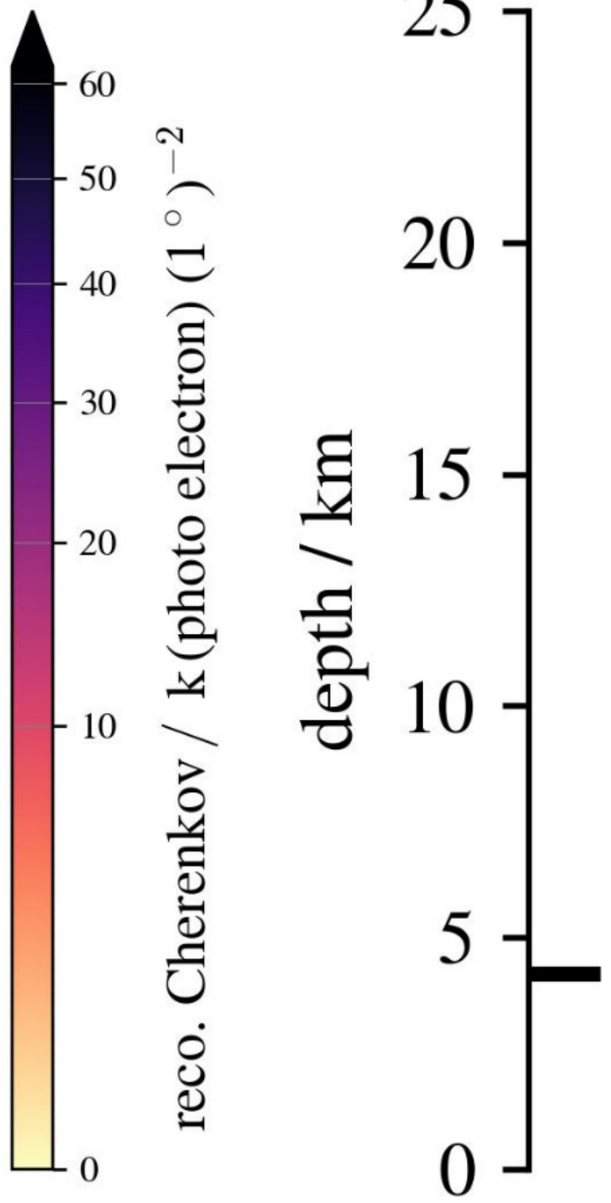

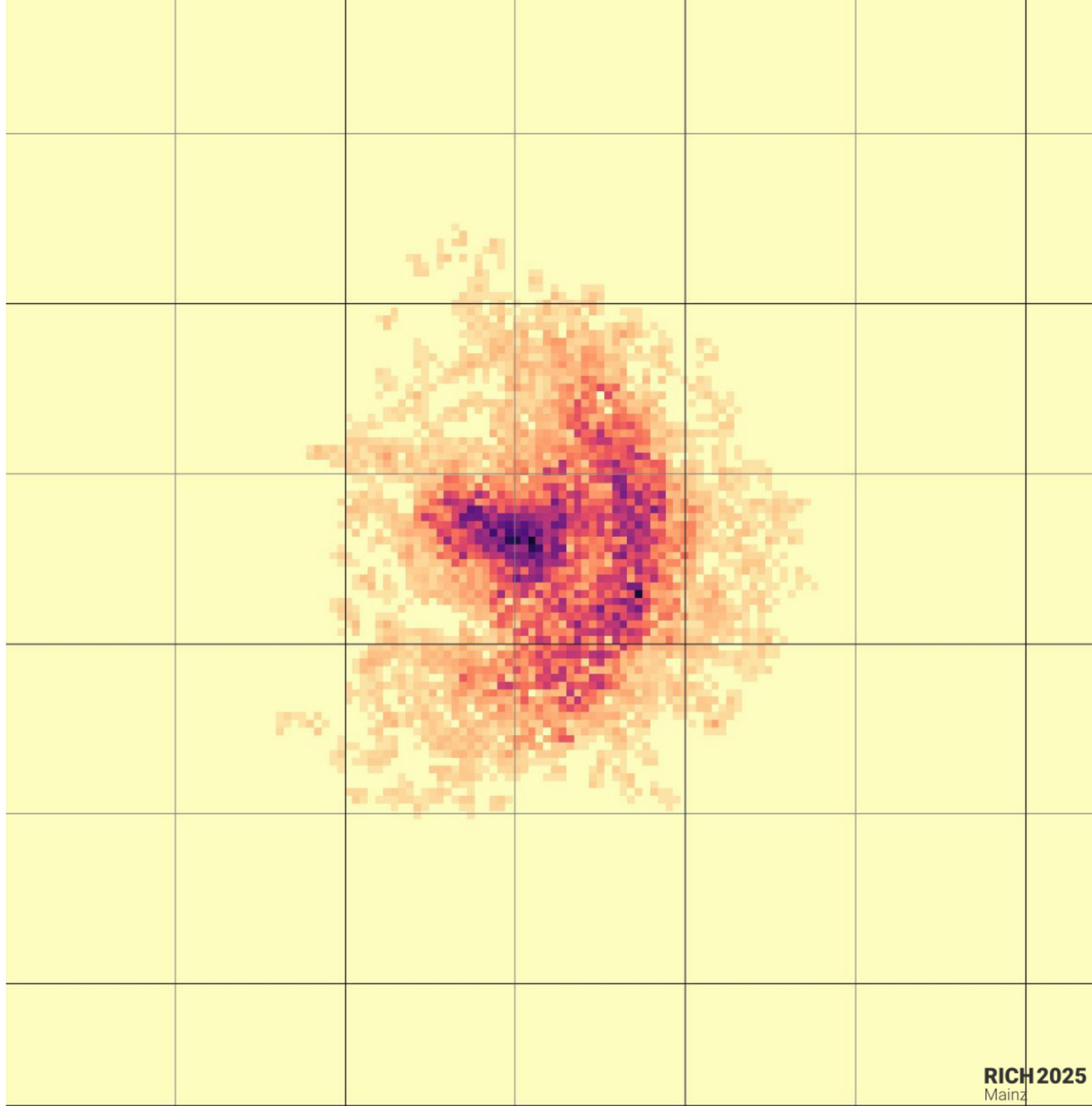

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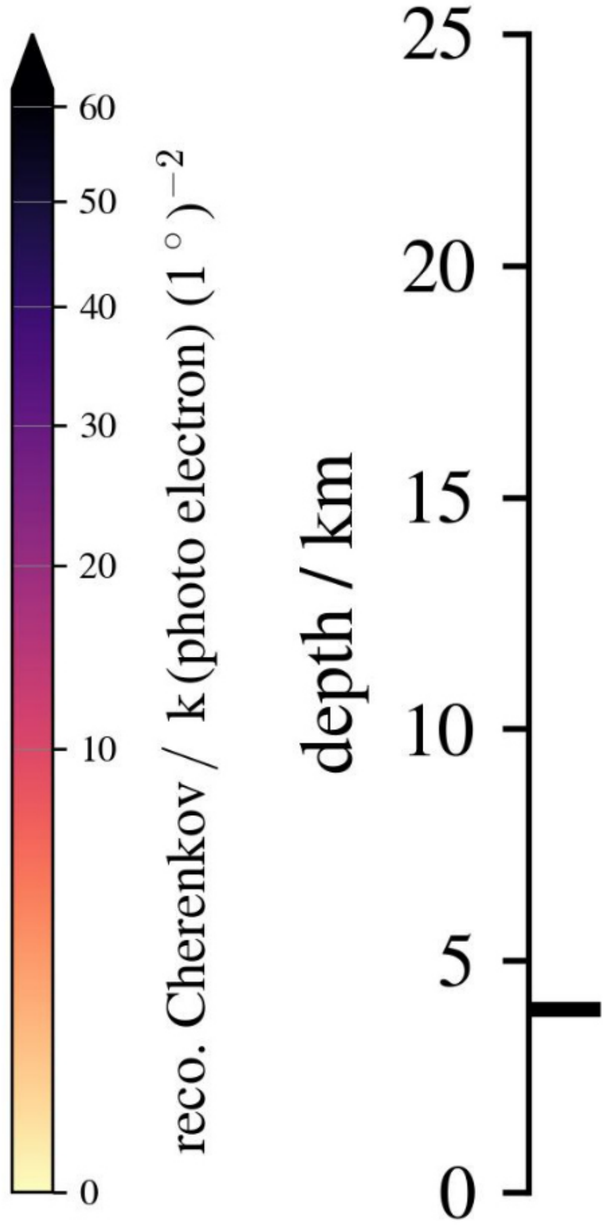

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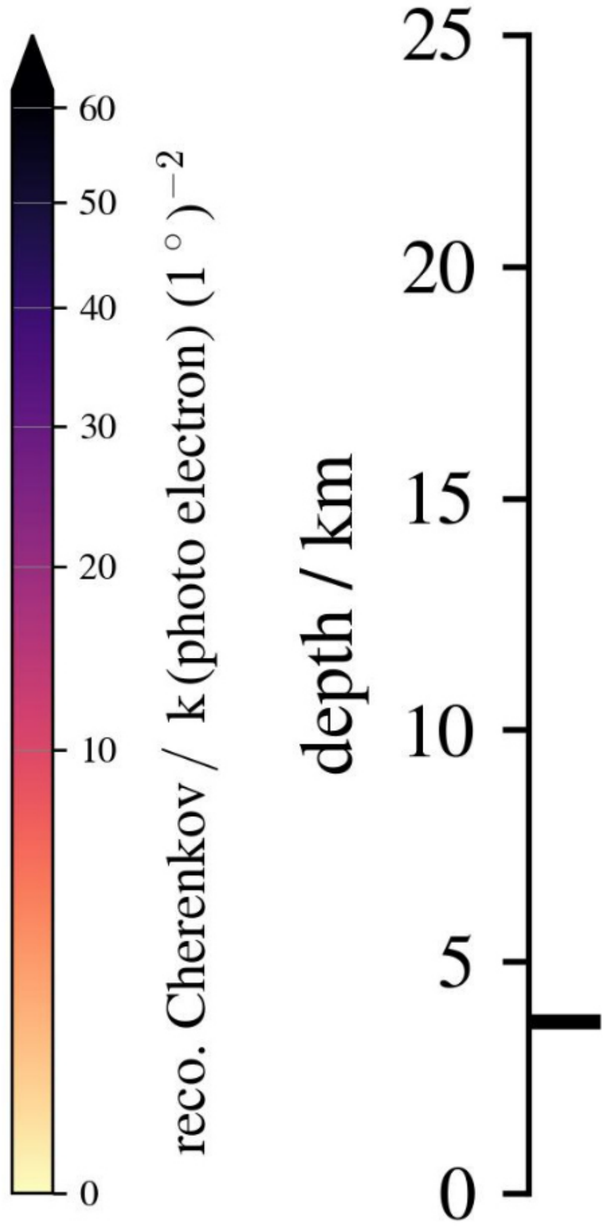

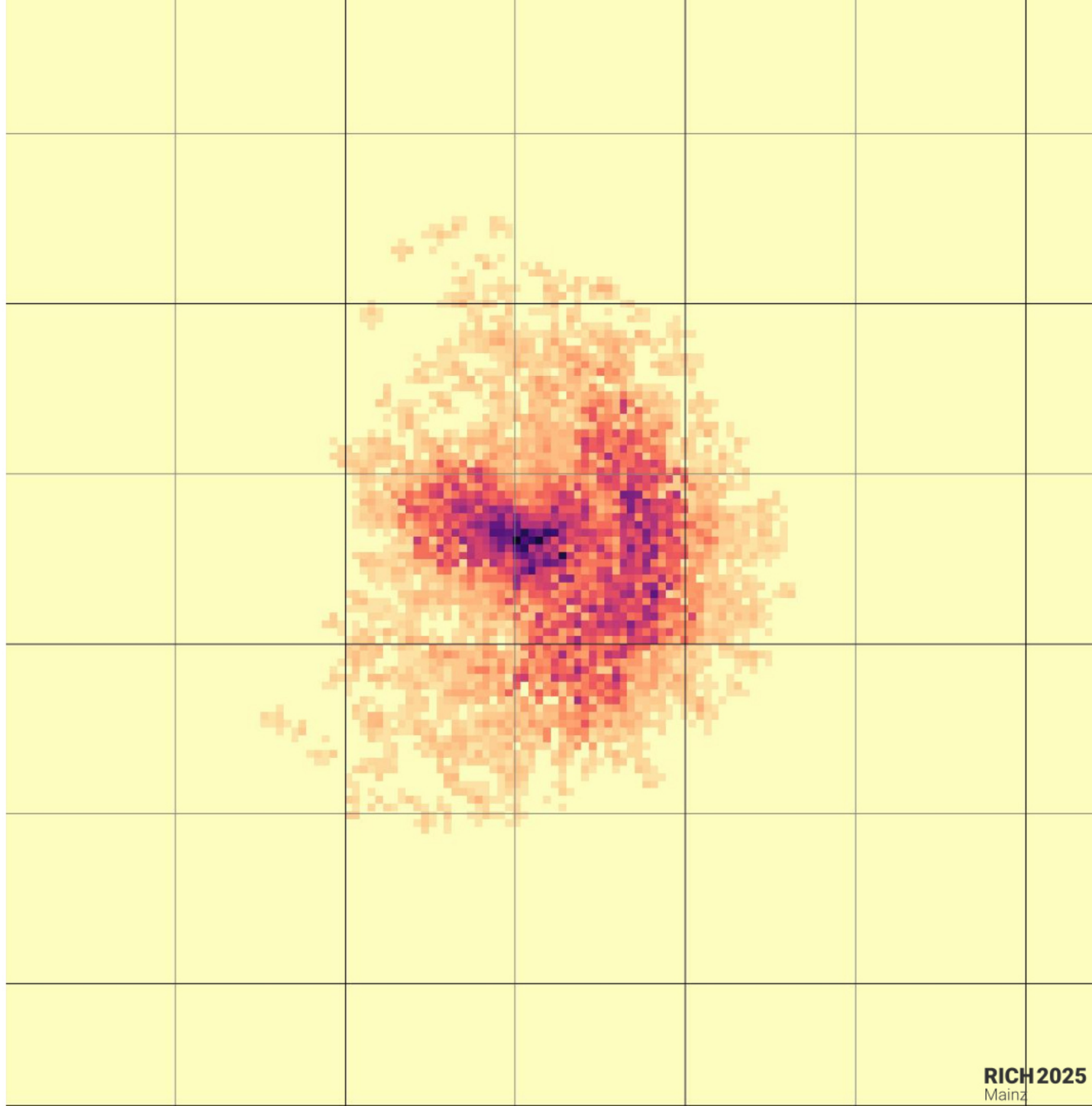

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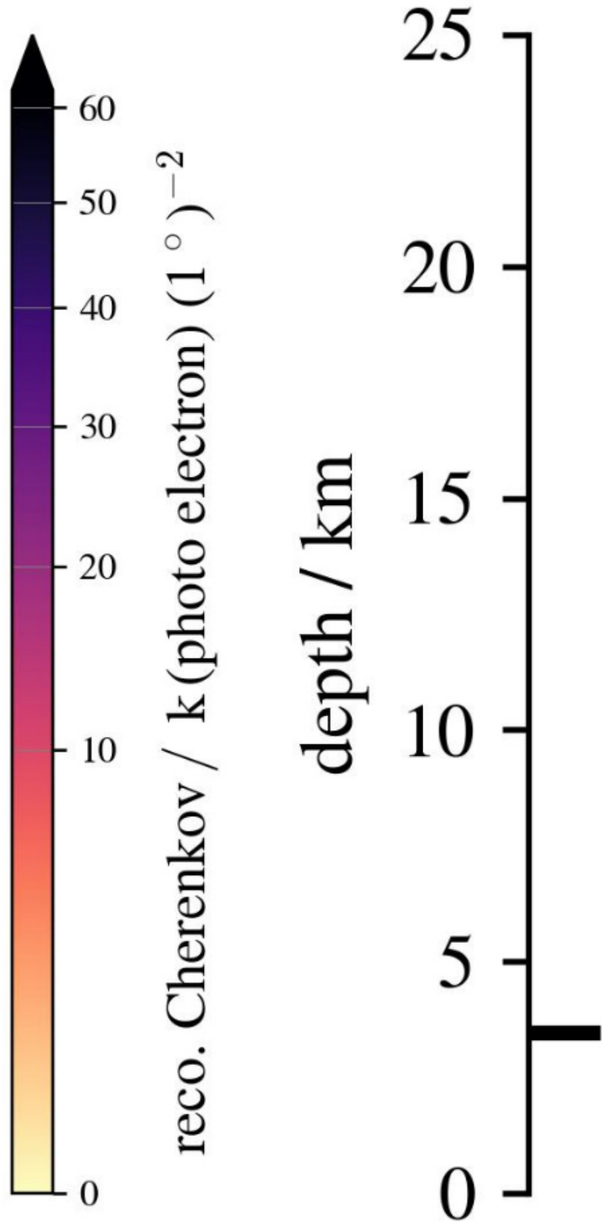

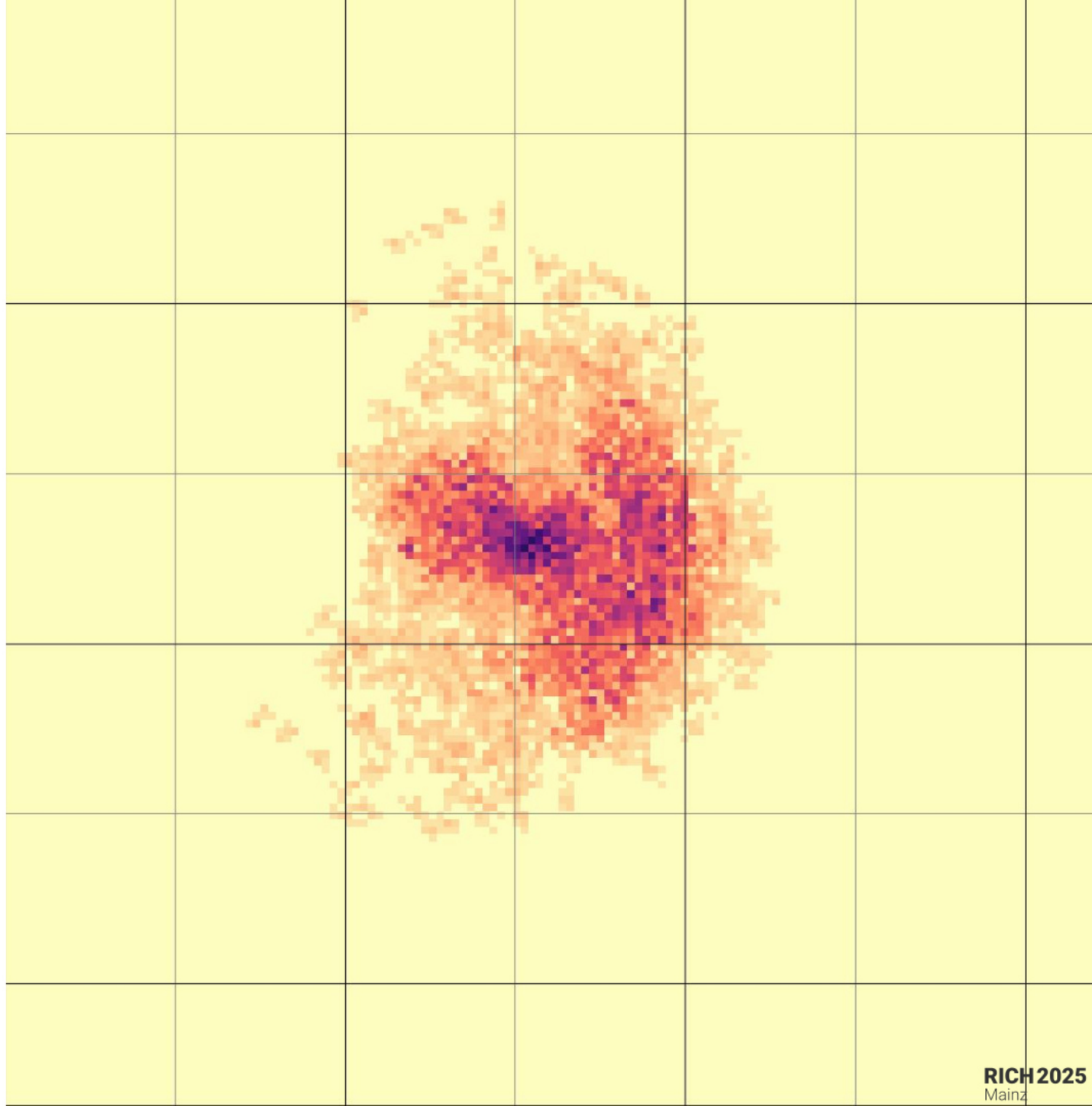

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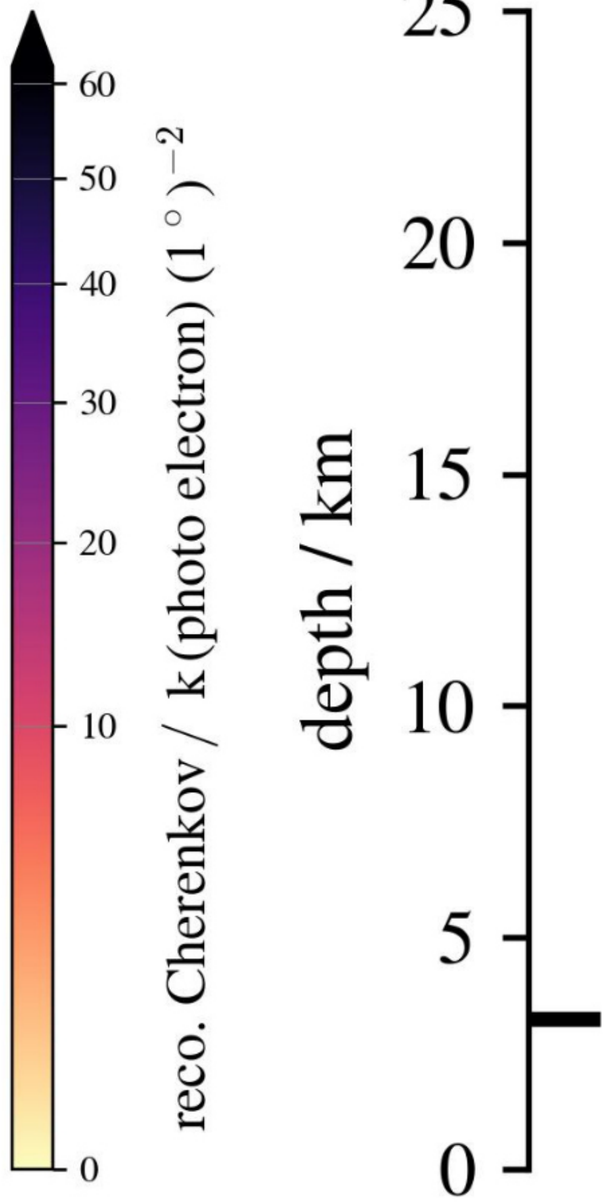

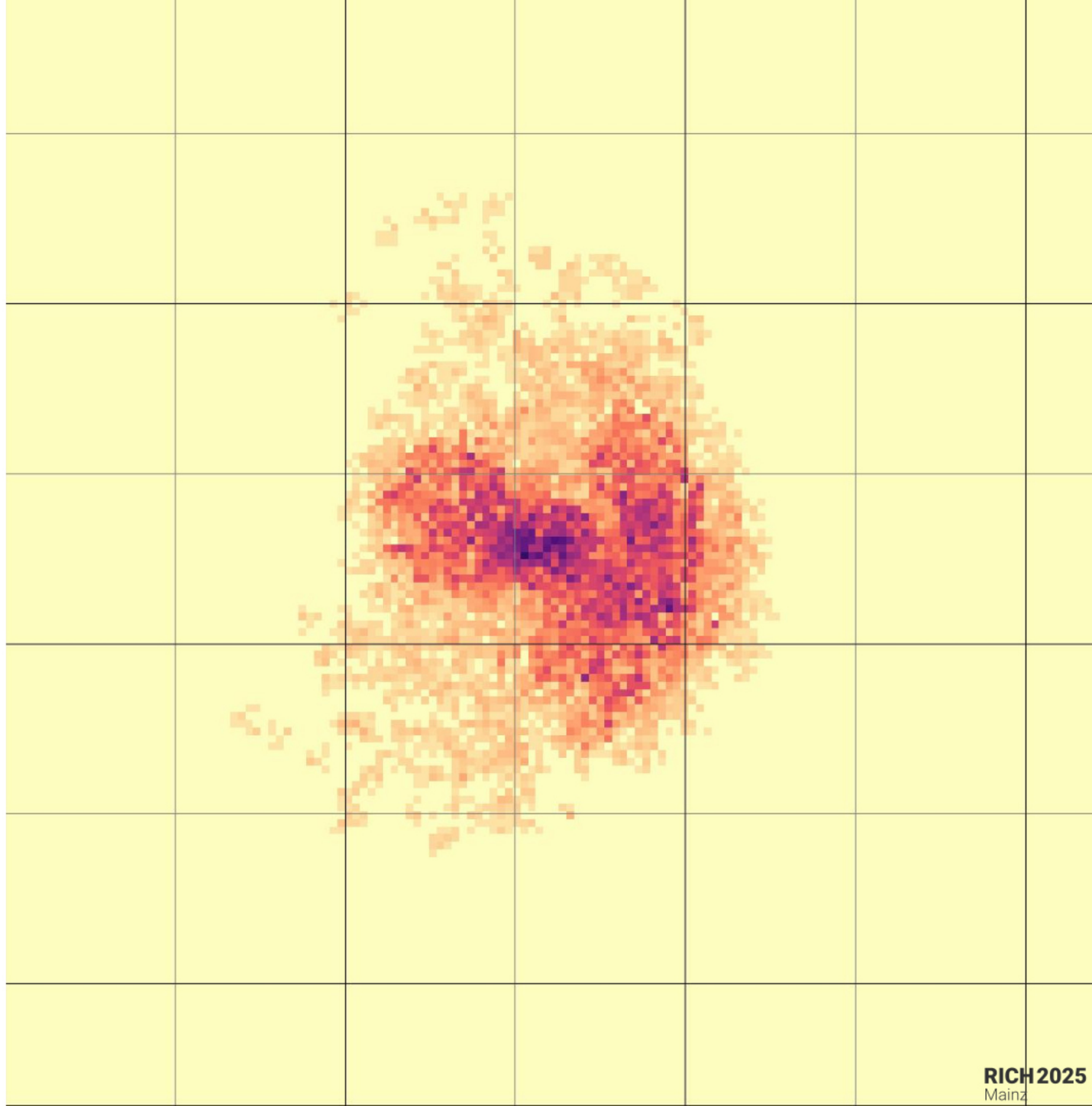

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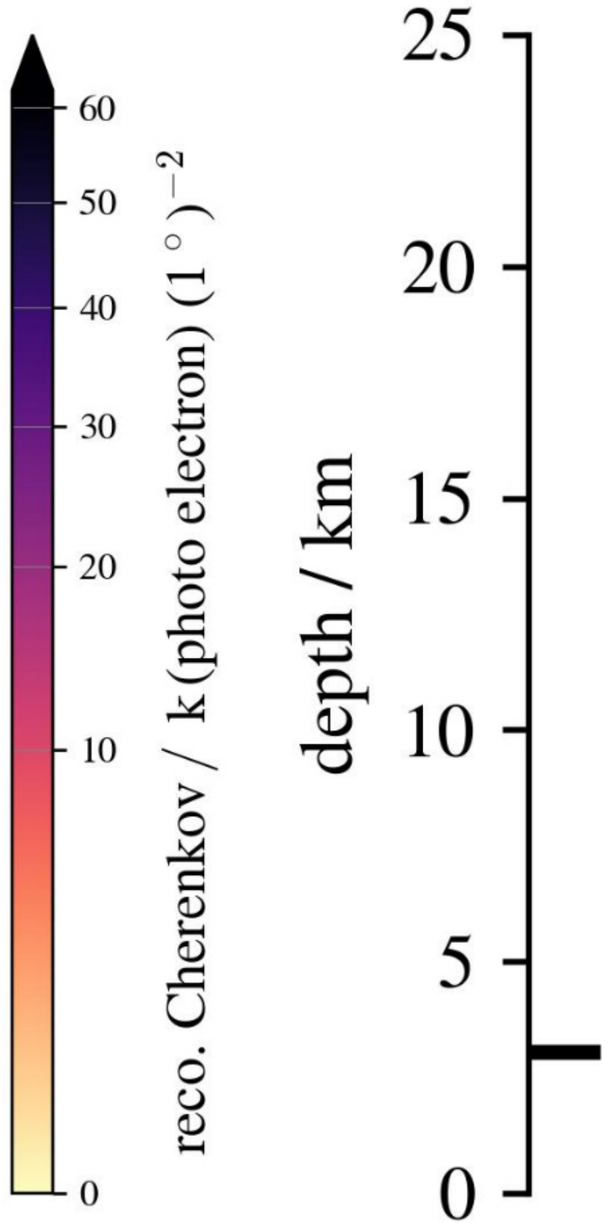

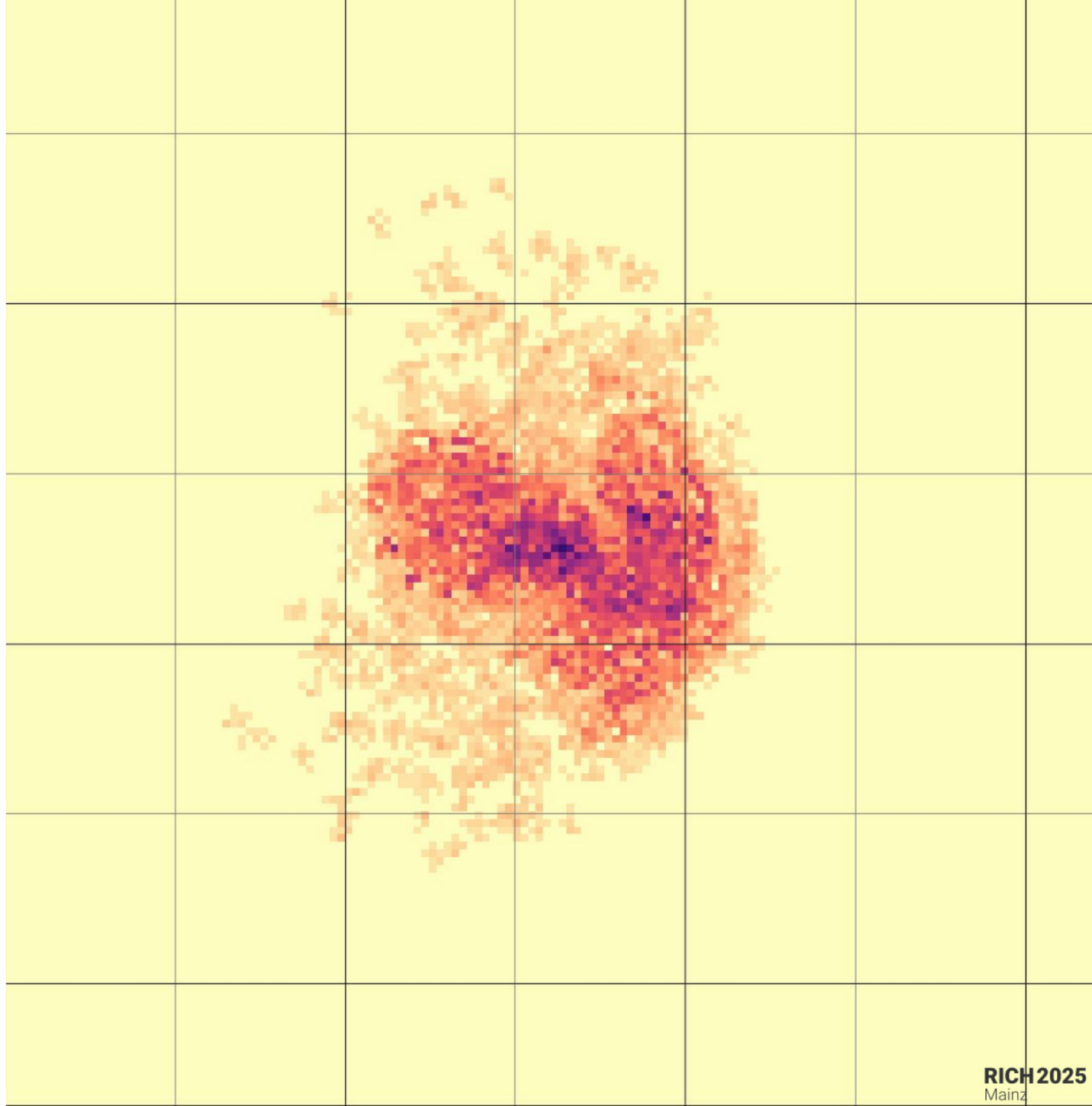

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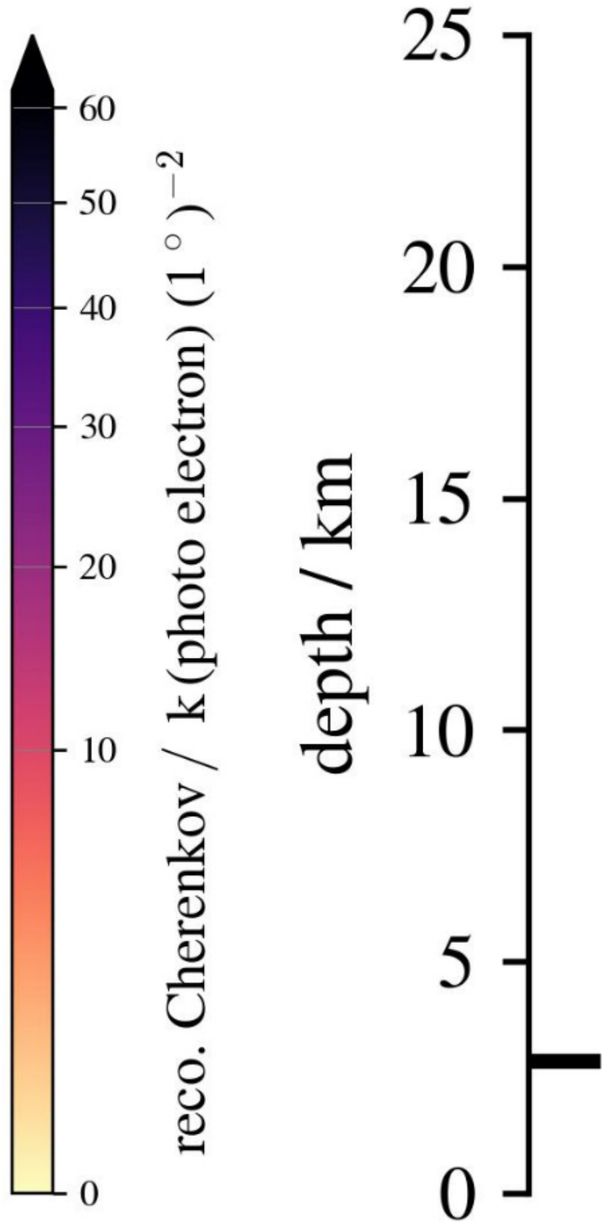

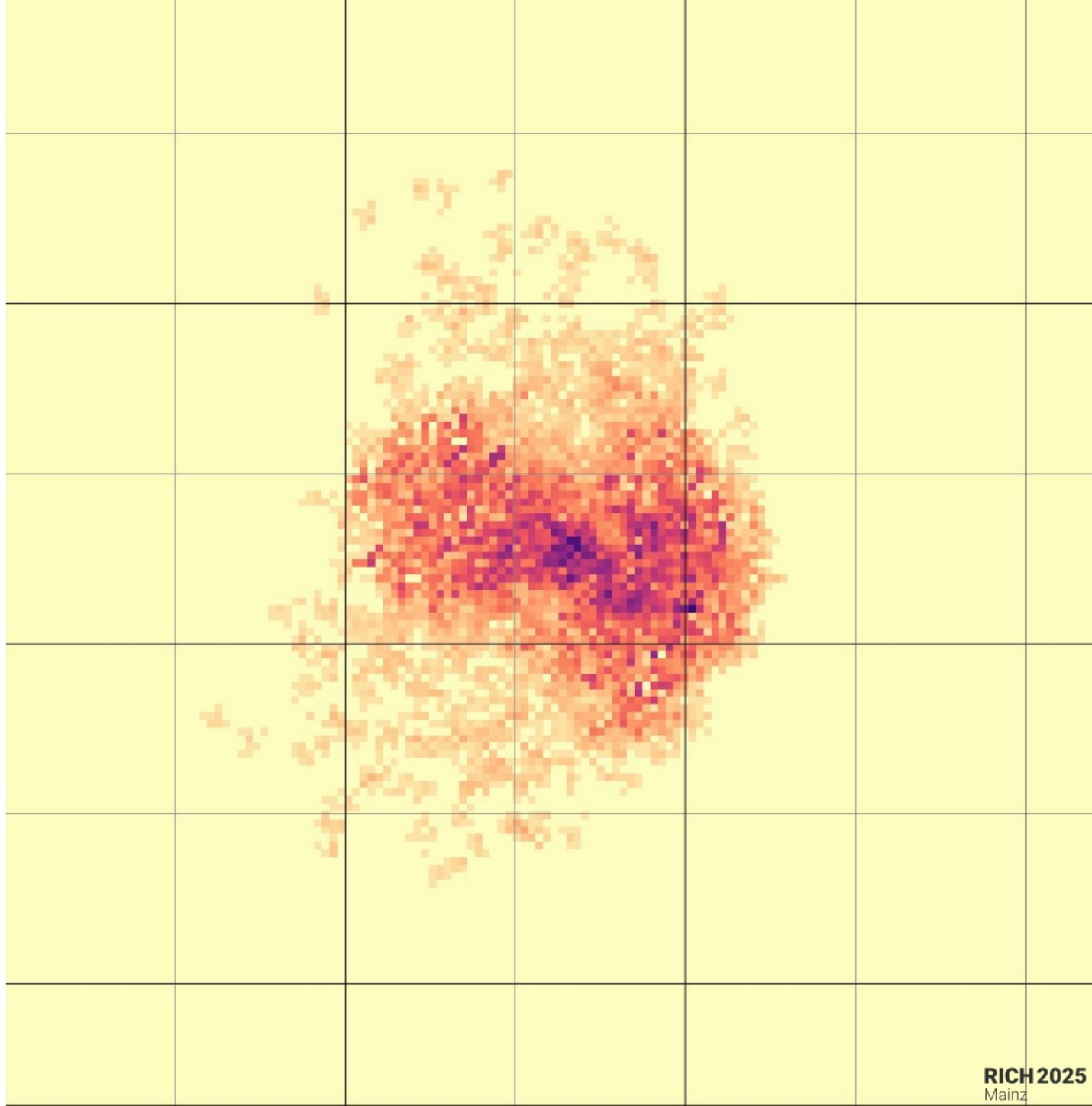

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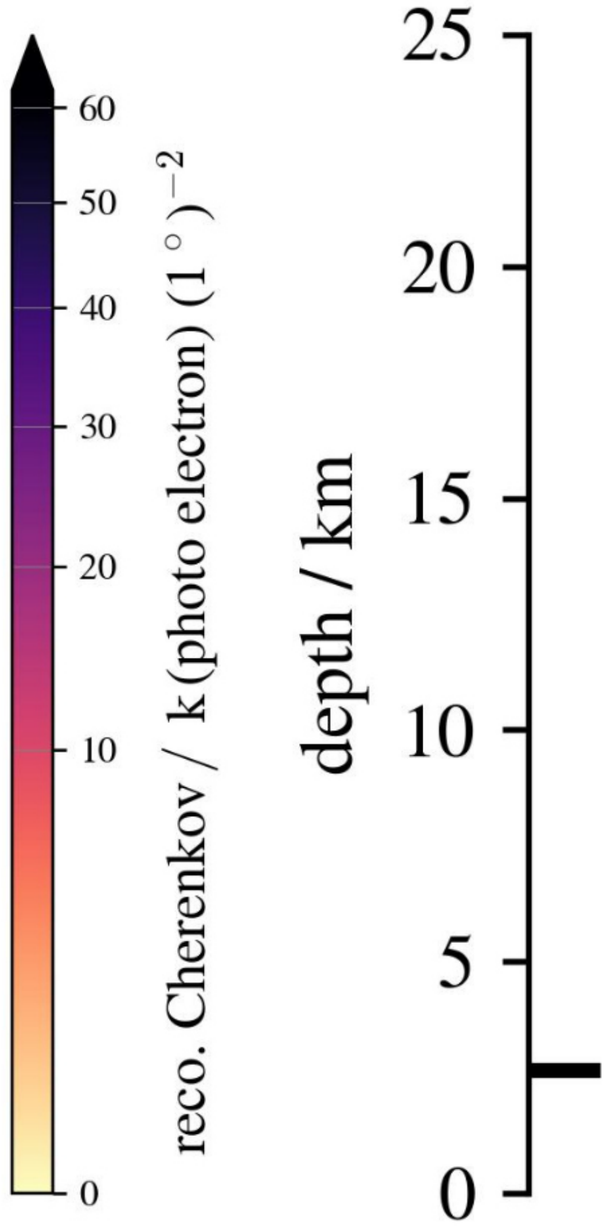

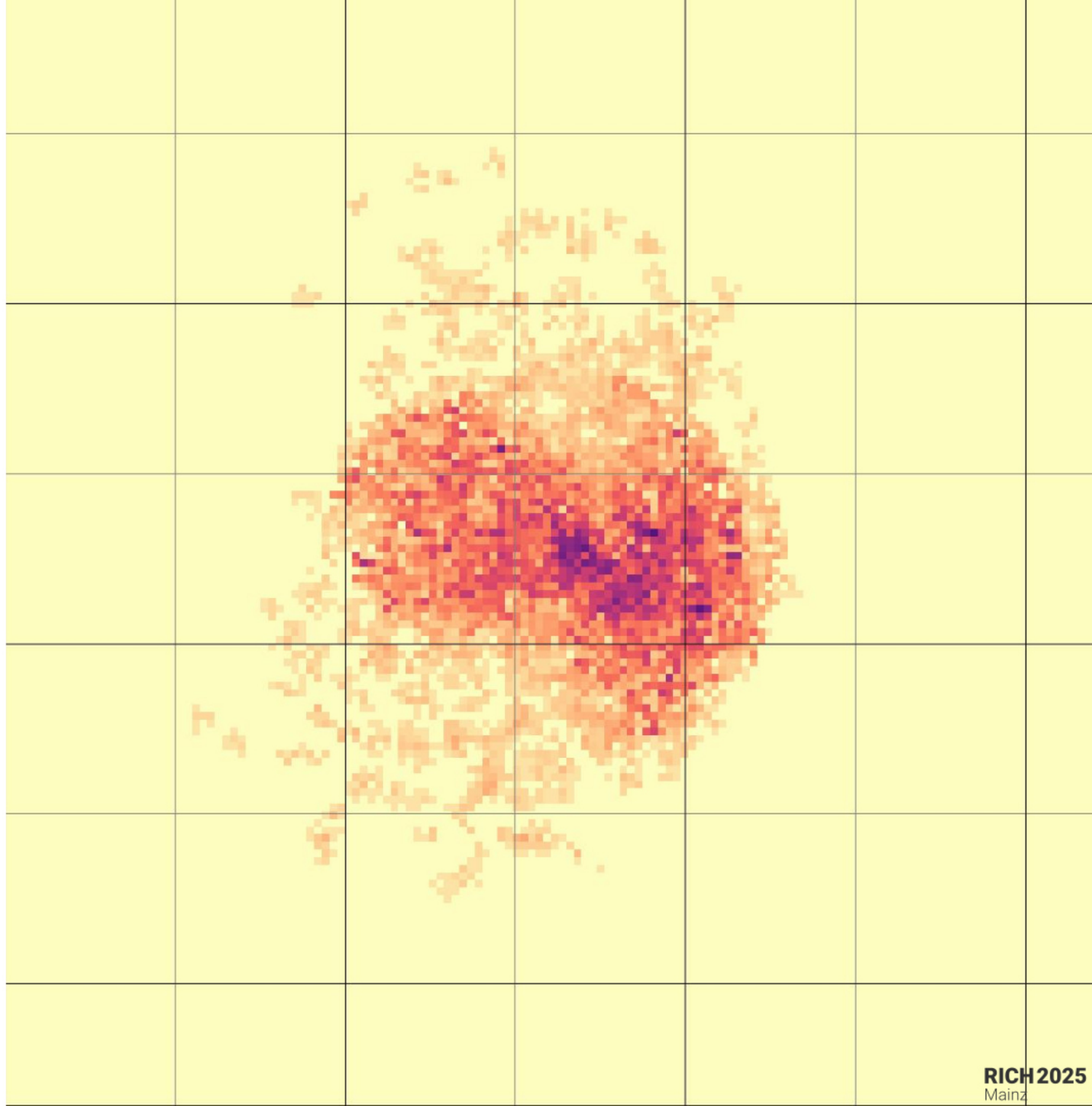

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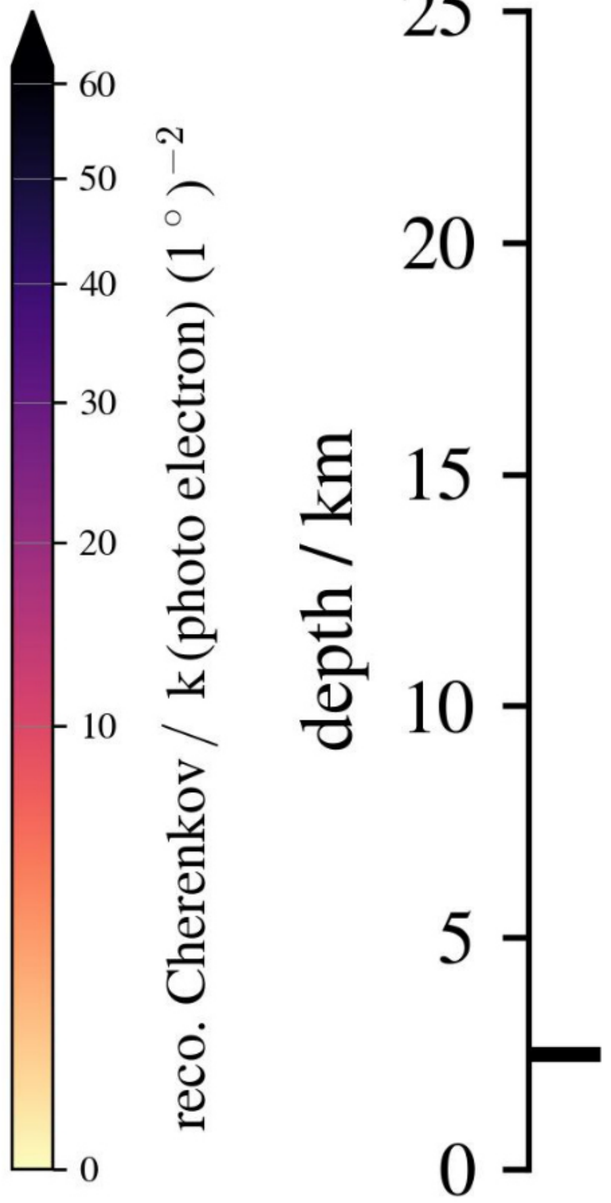

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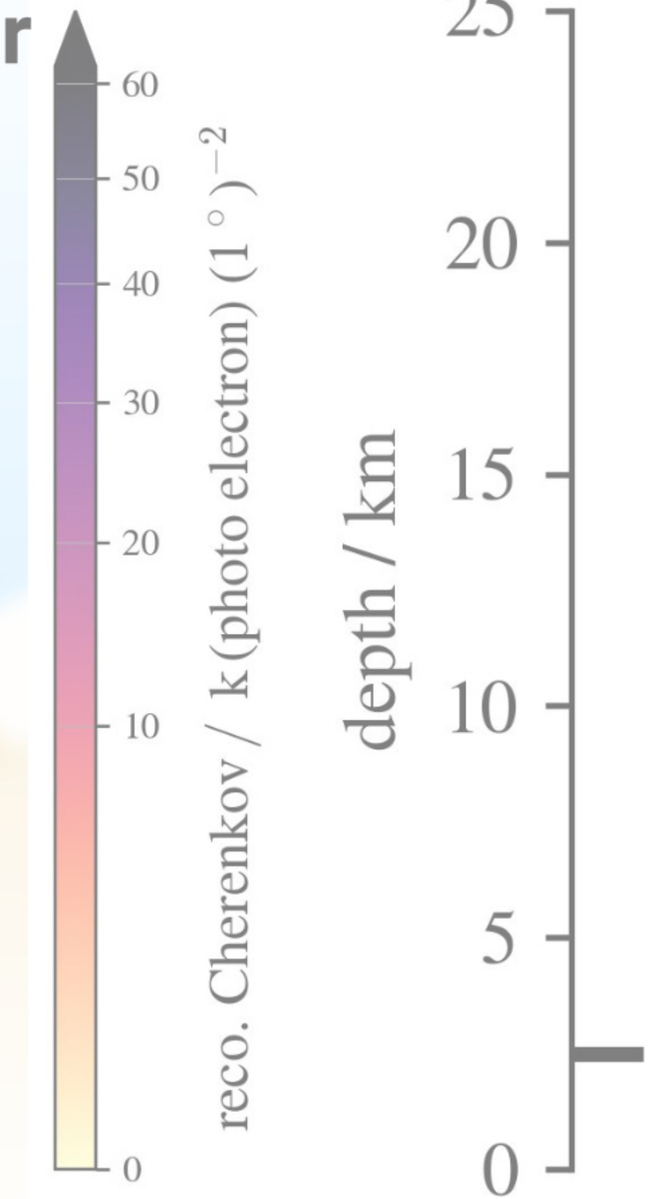
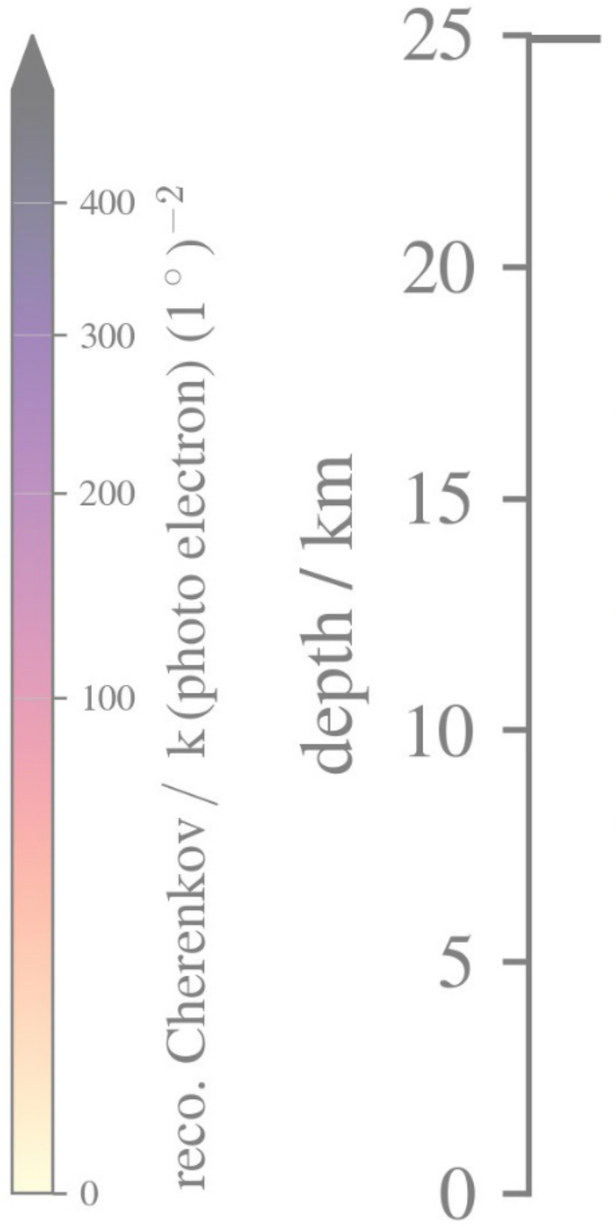


Airshower

Gamma

529GeV

36,518p.e.

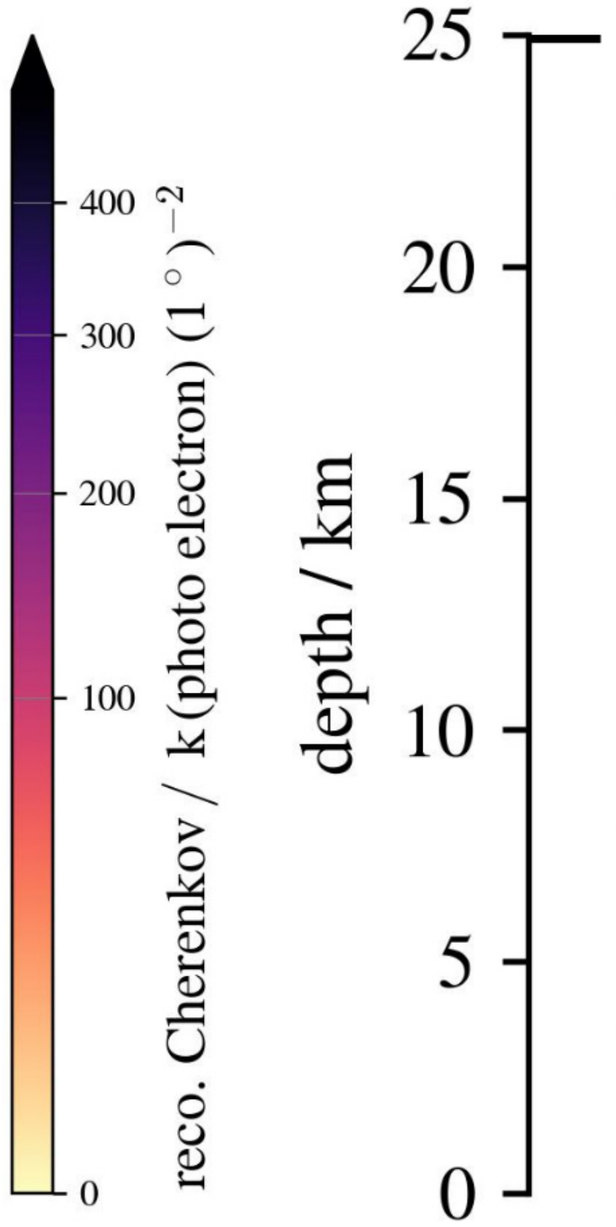


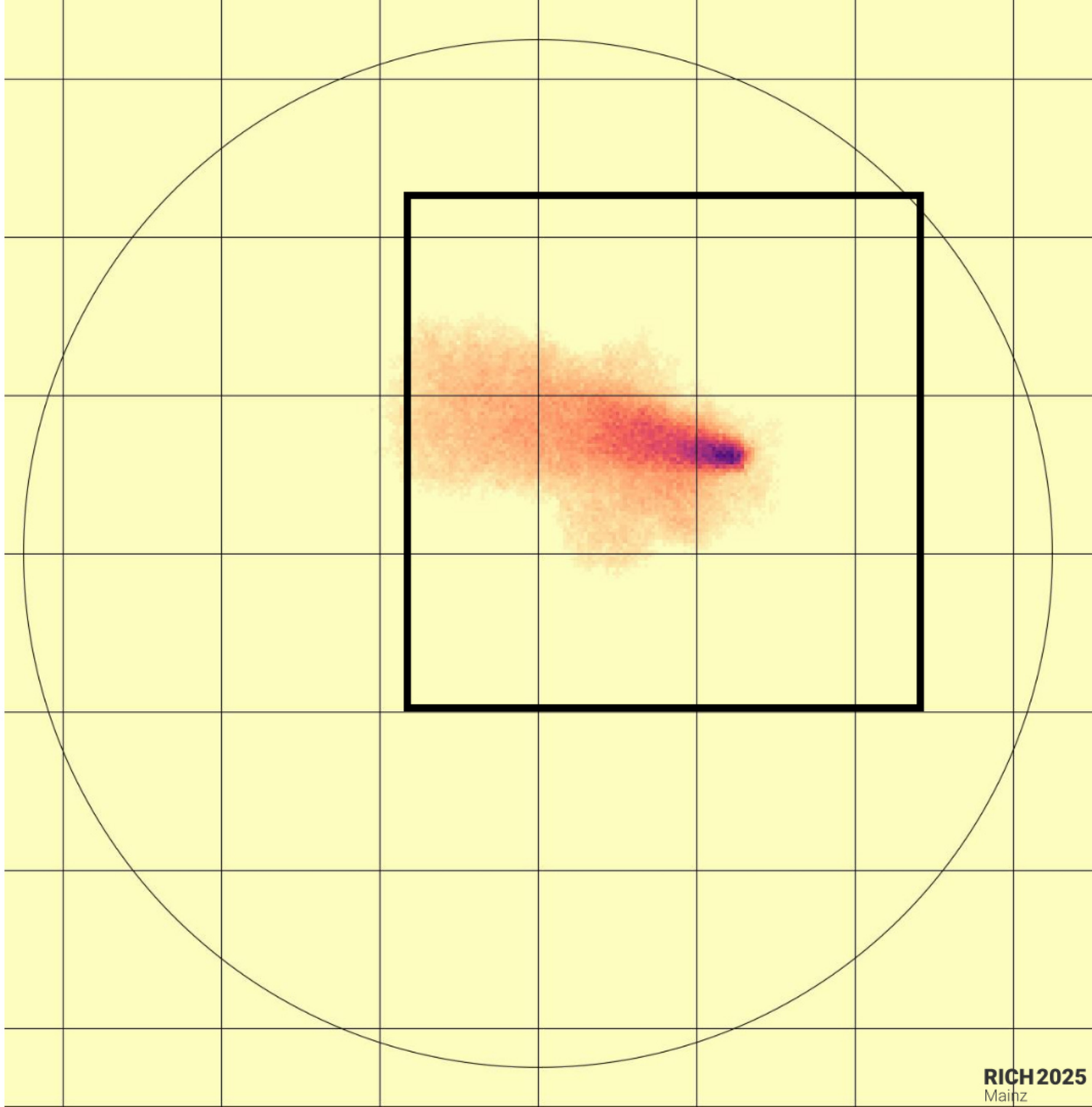
Airshower

Gamma

529GeV

36,518p.e.



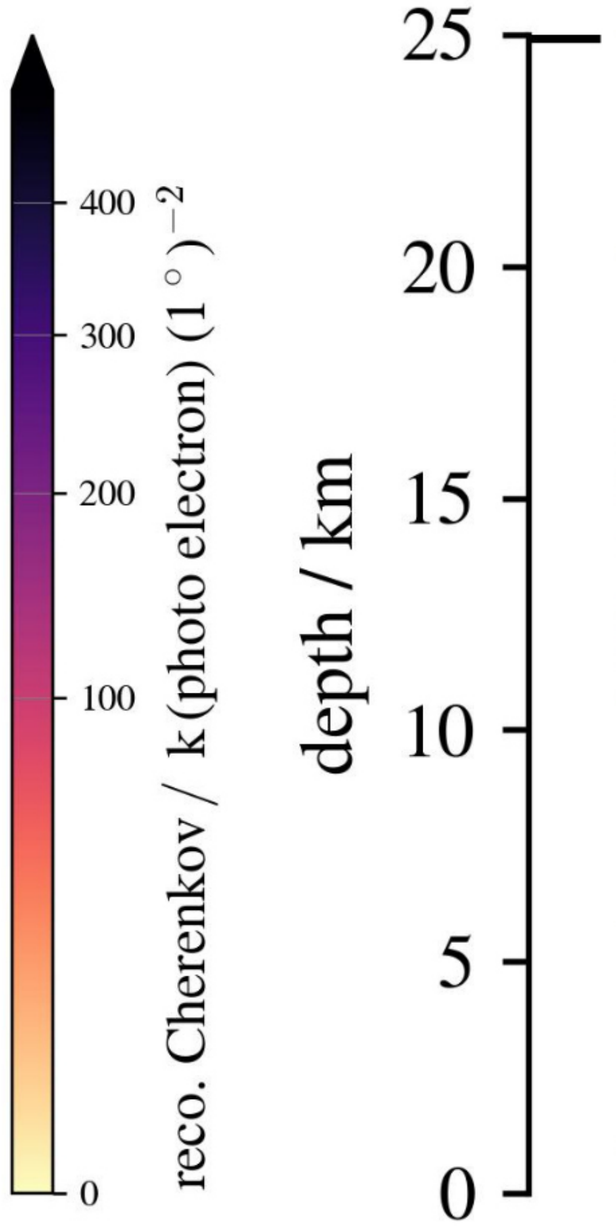


Airshower

Gamma

529GeV

36,518p.e.



Airshower

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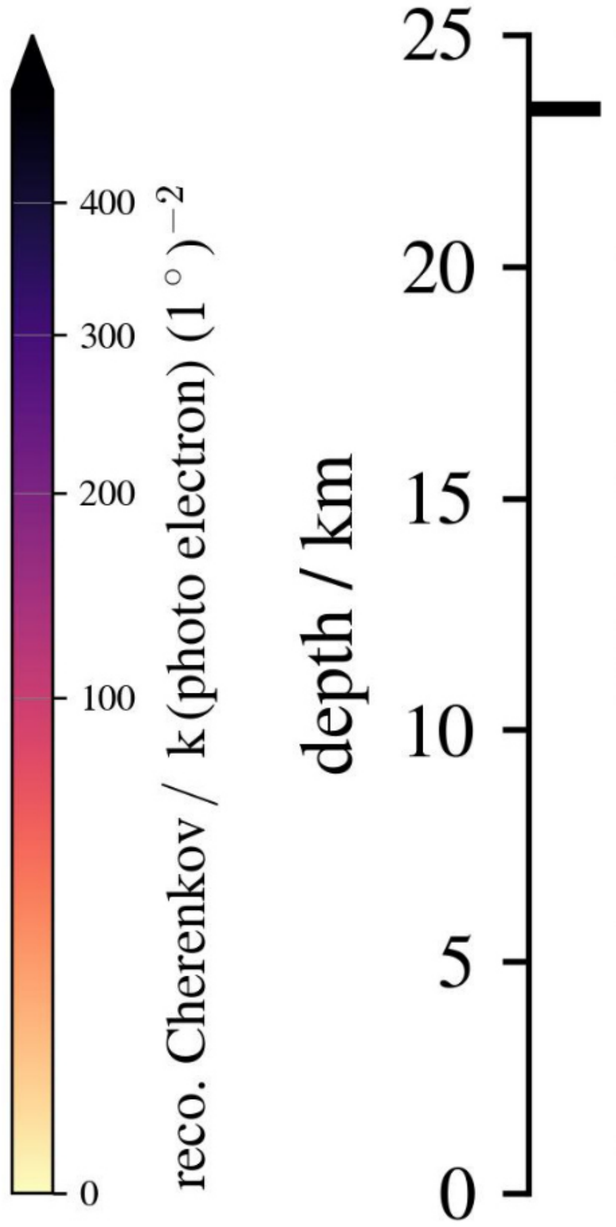

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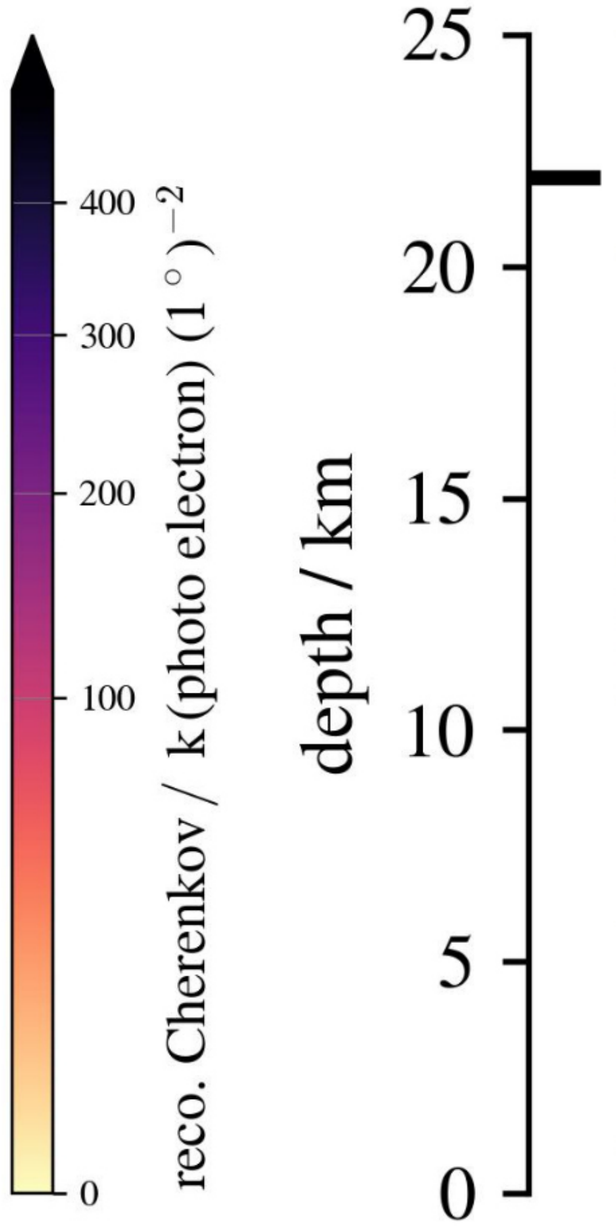

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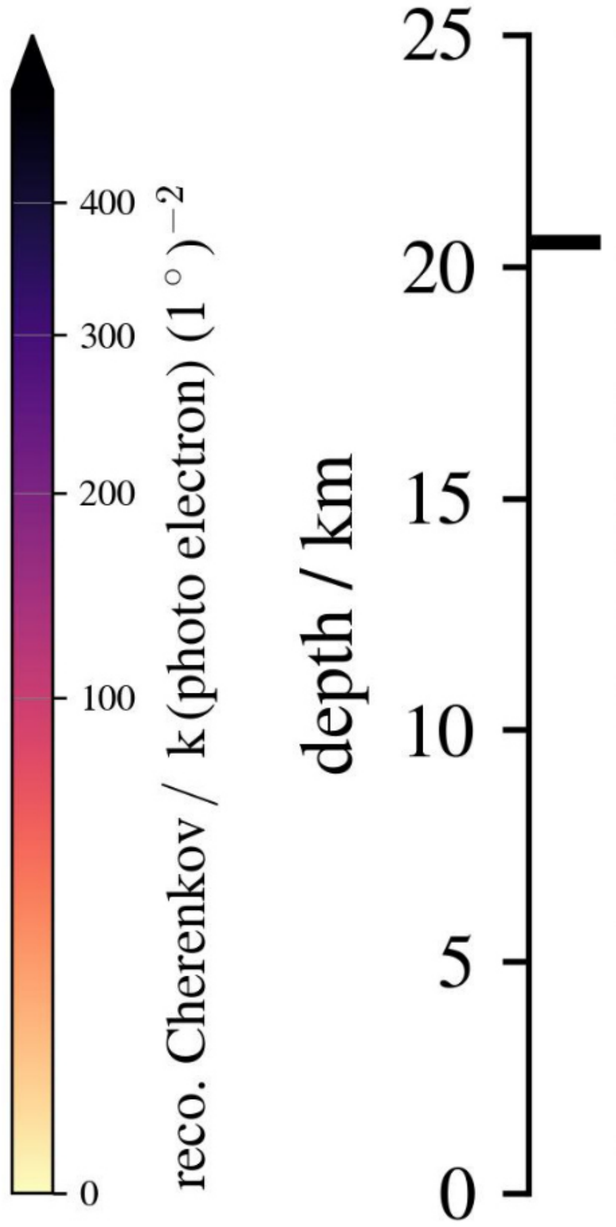

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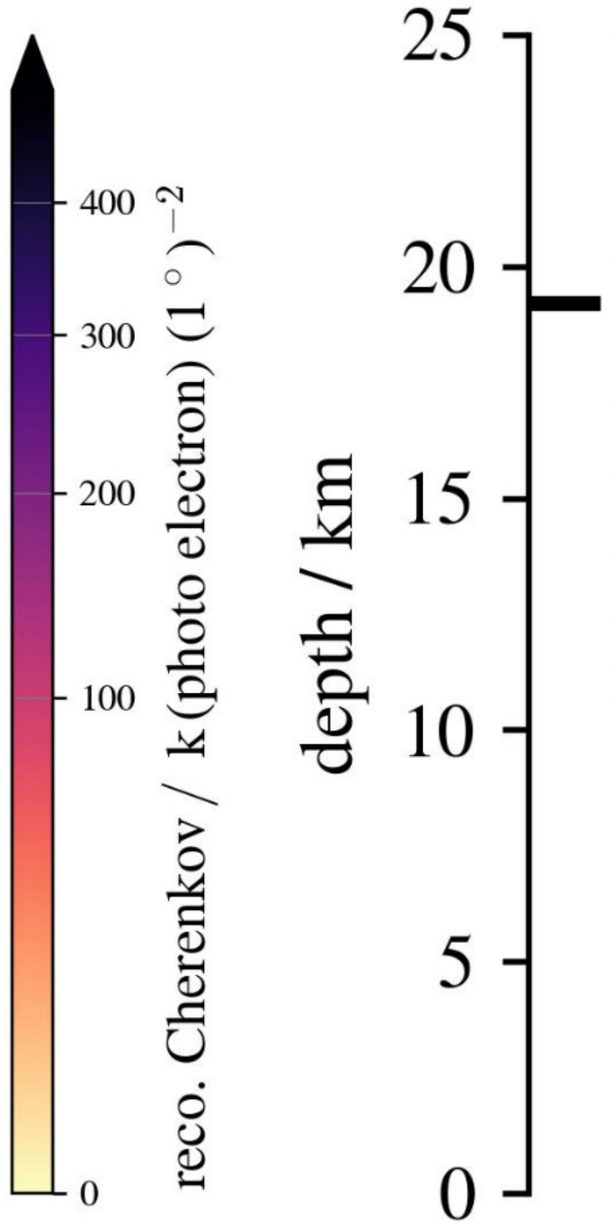

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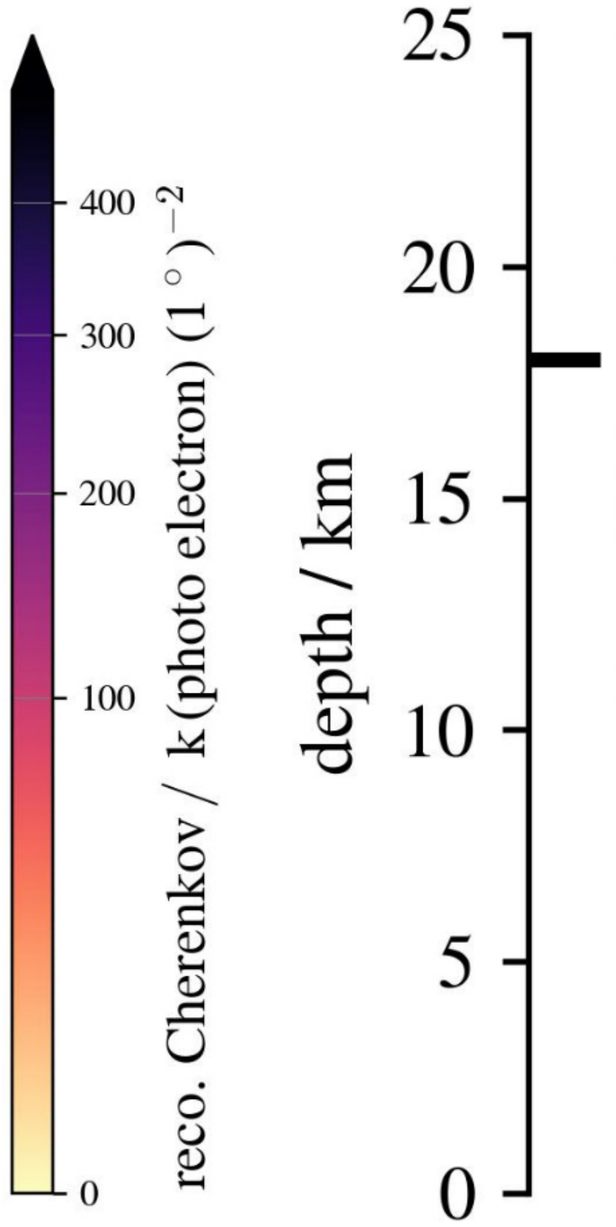

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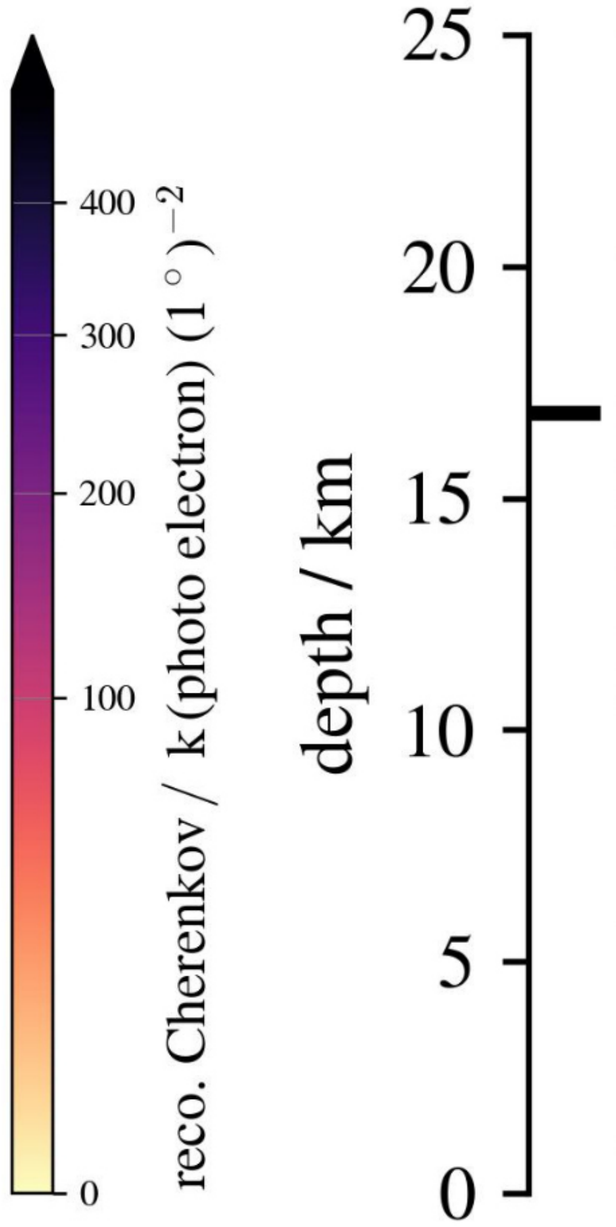

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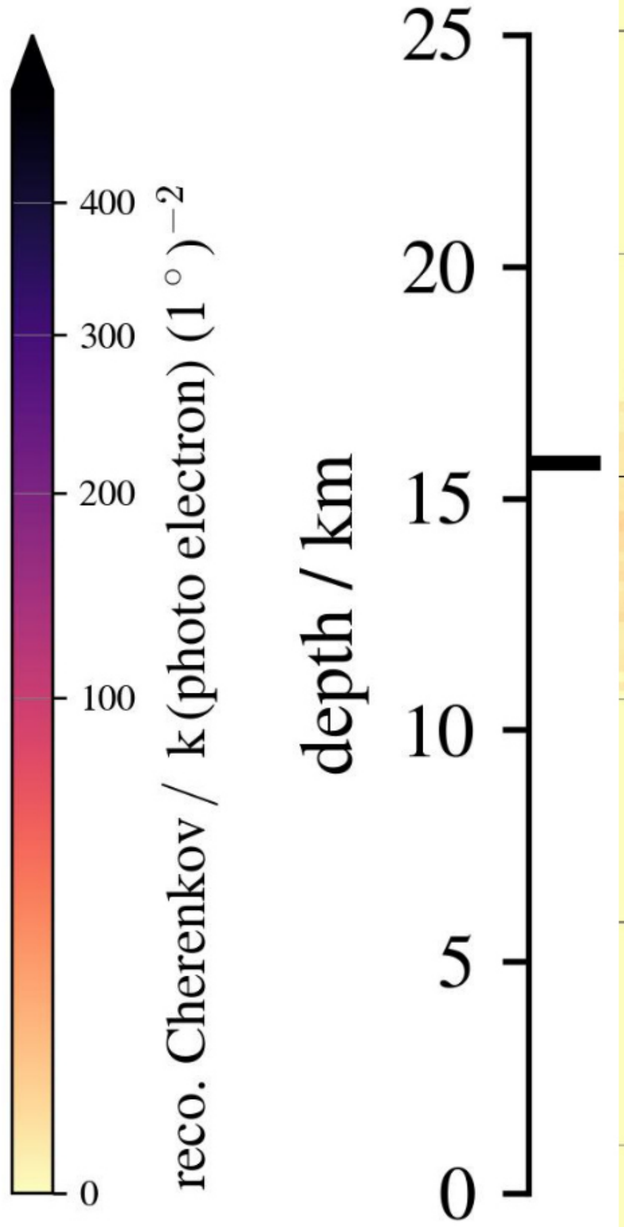

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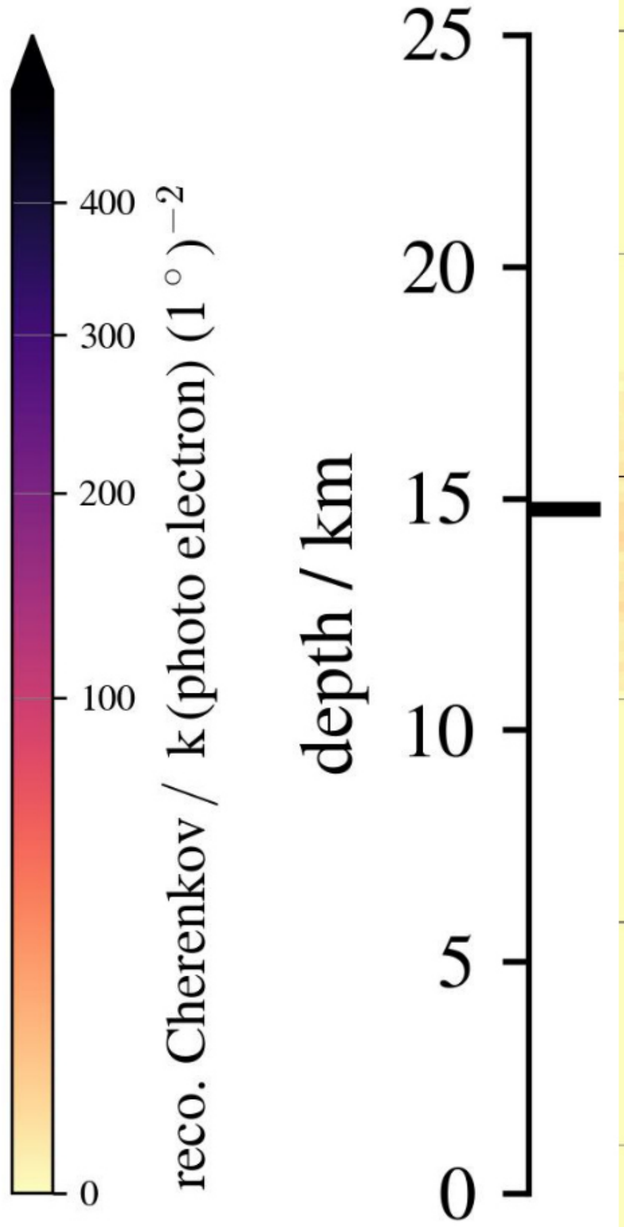

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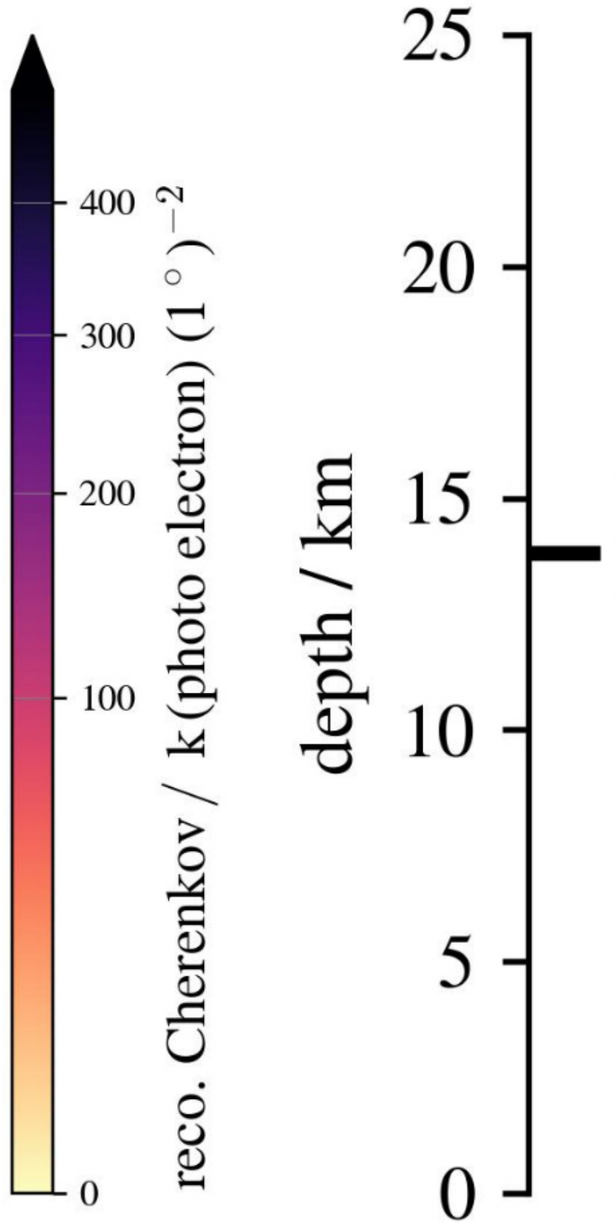

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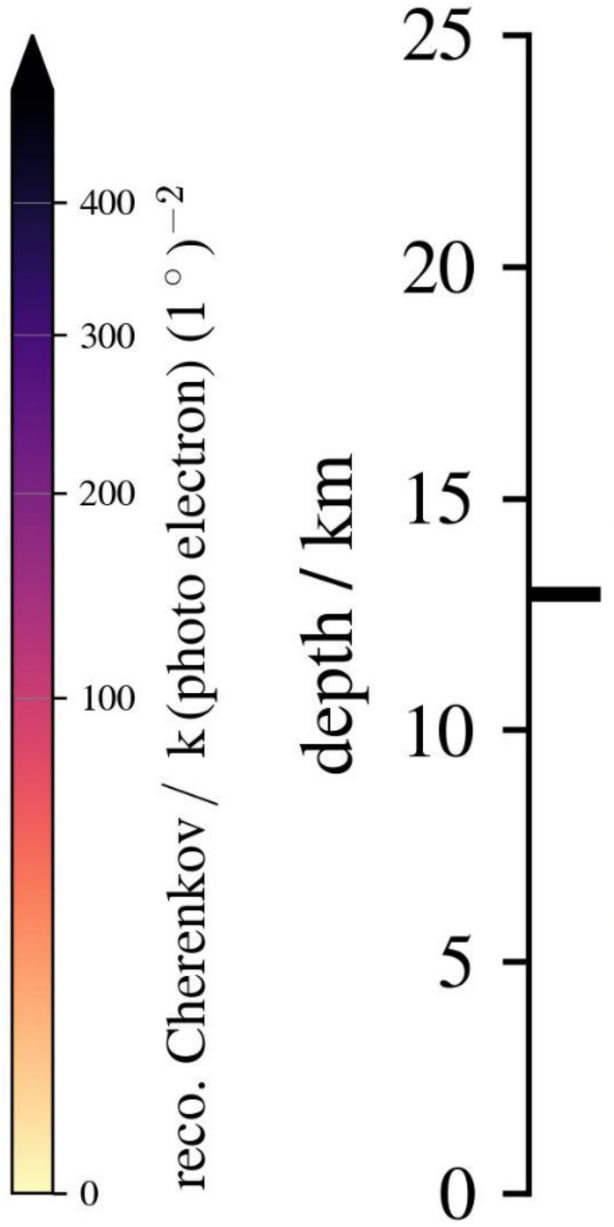

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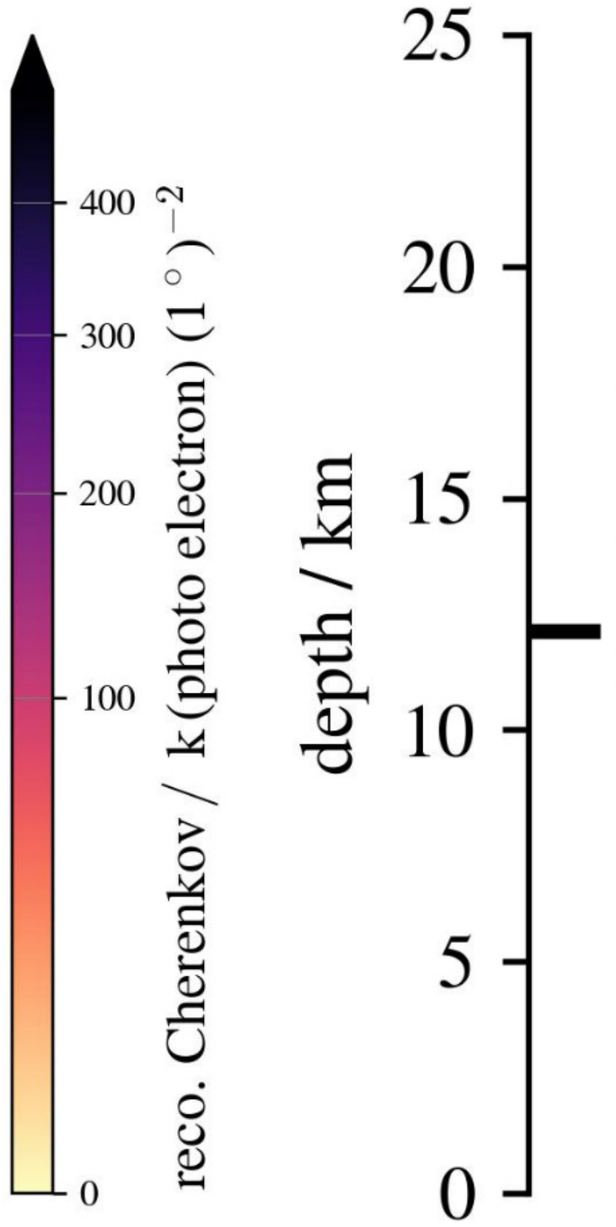

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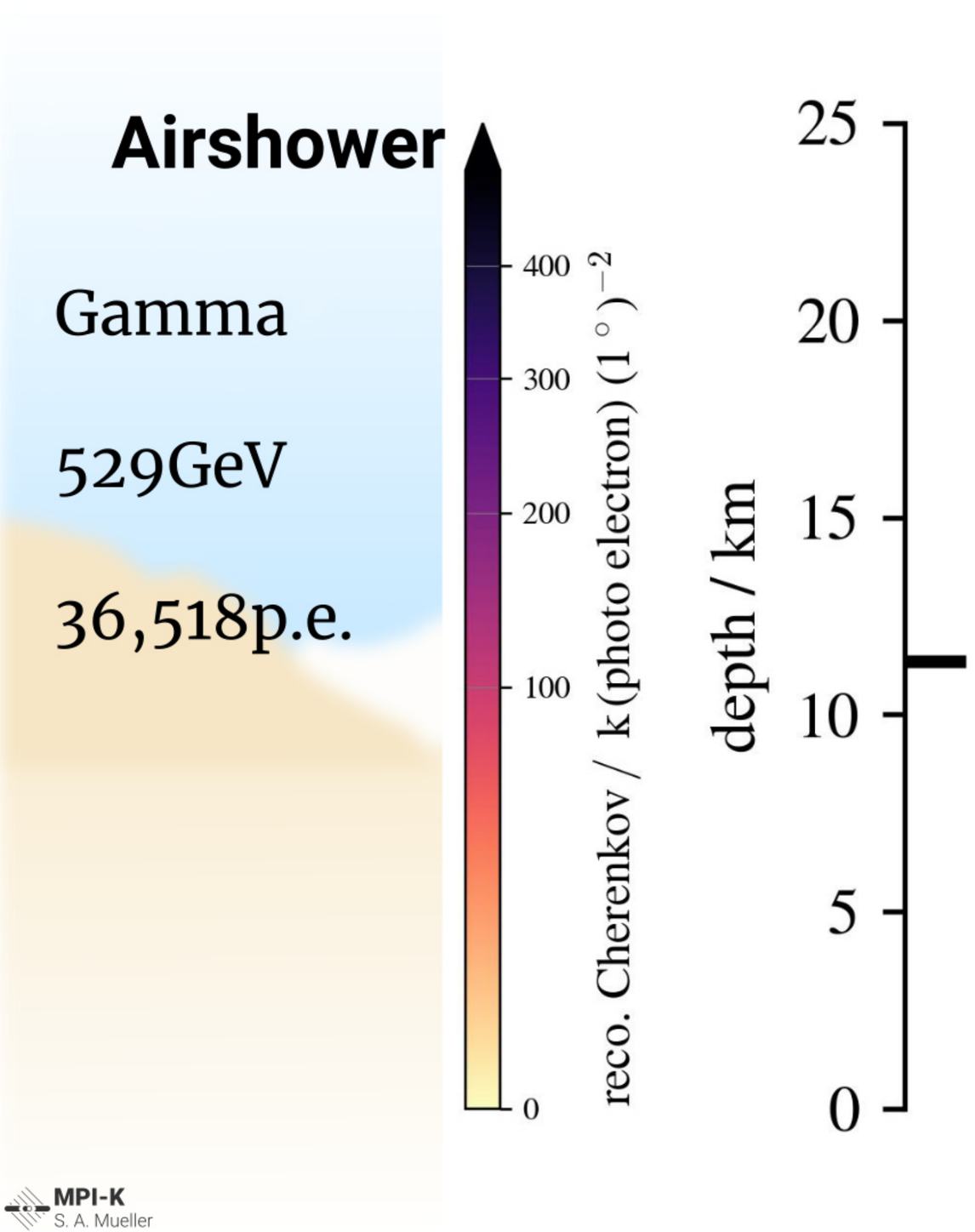

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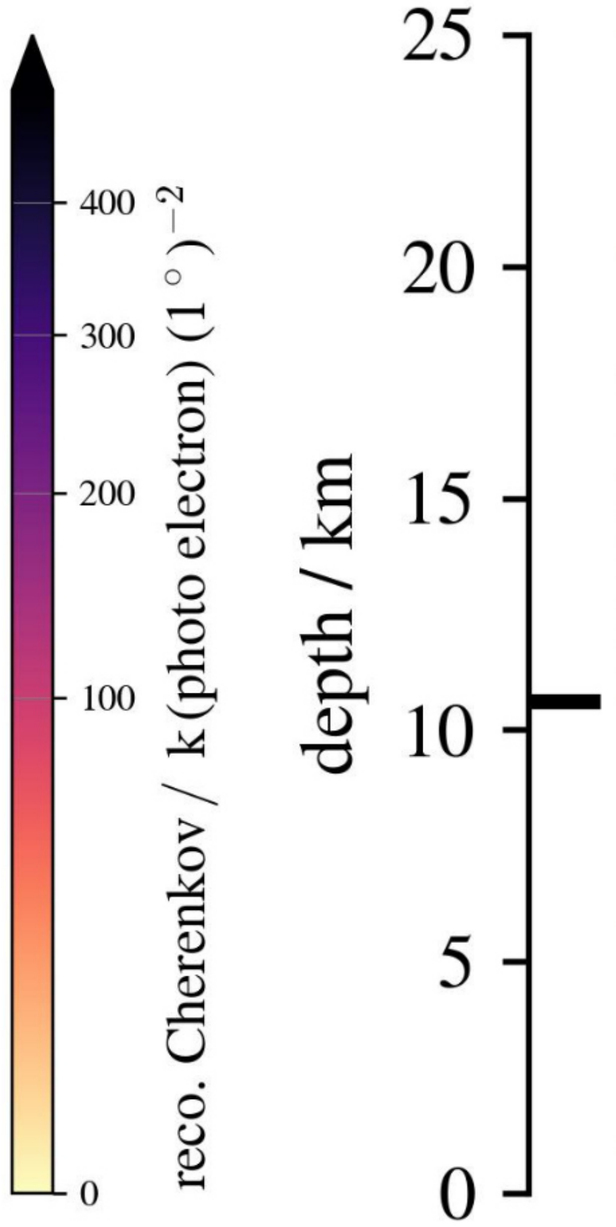

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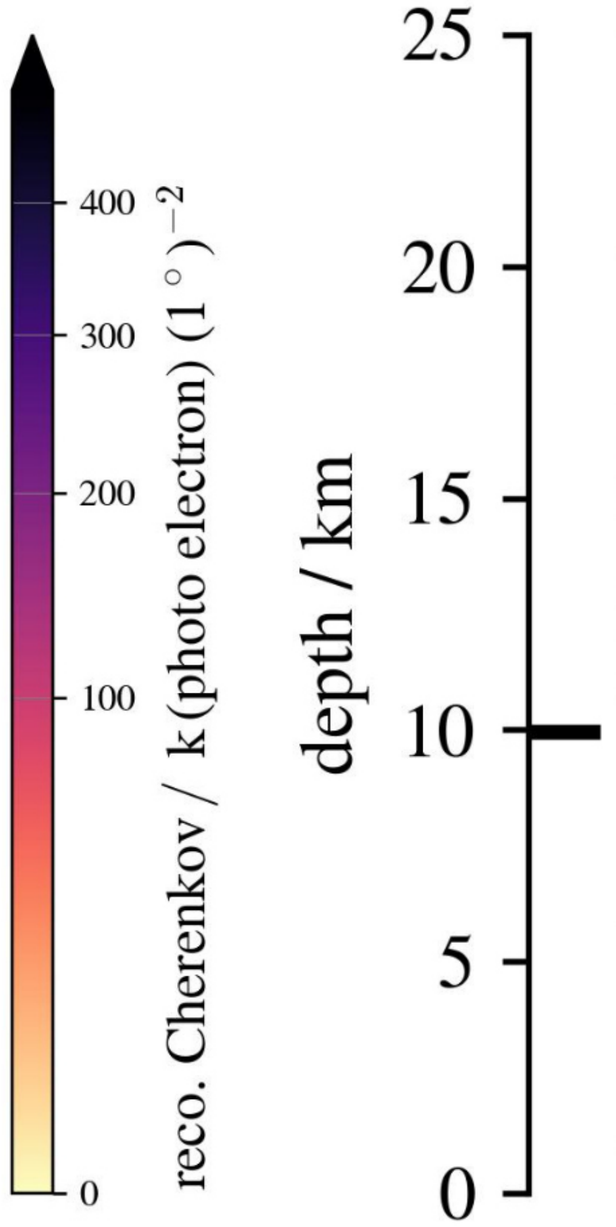

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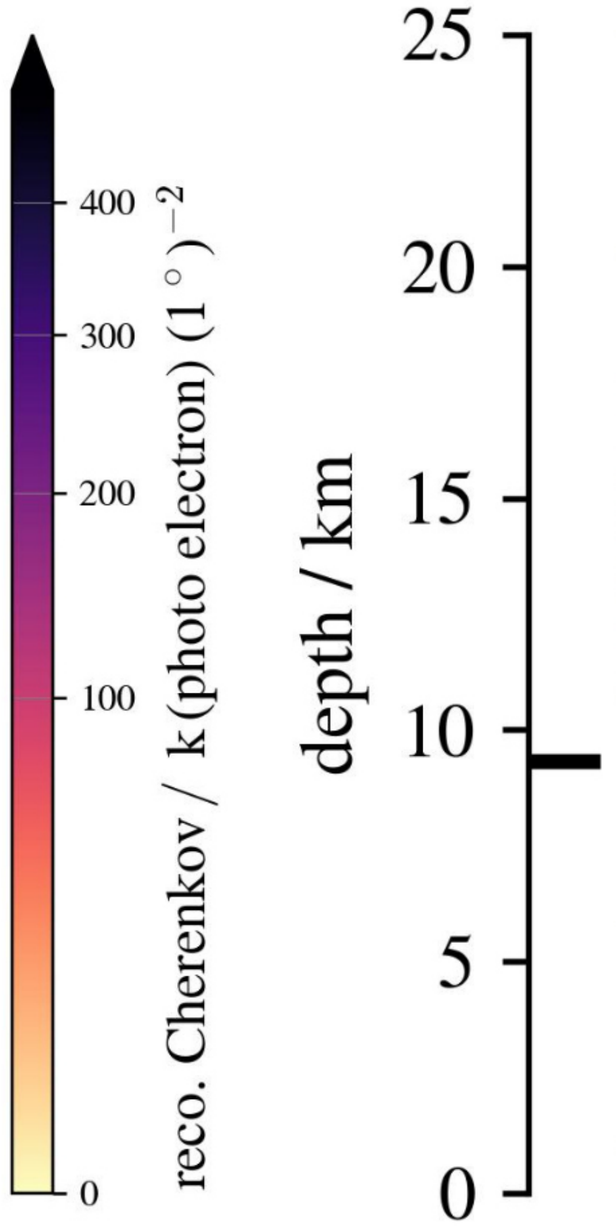

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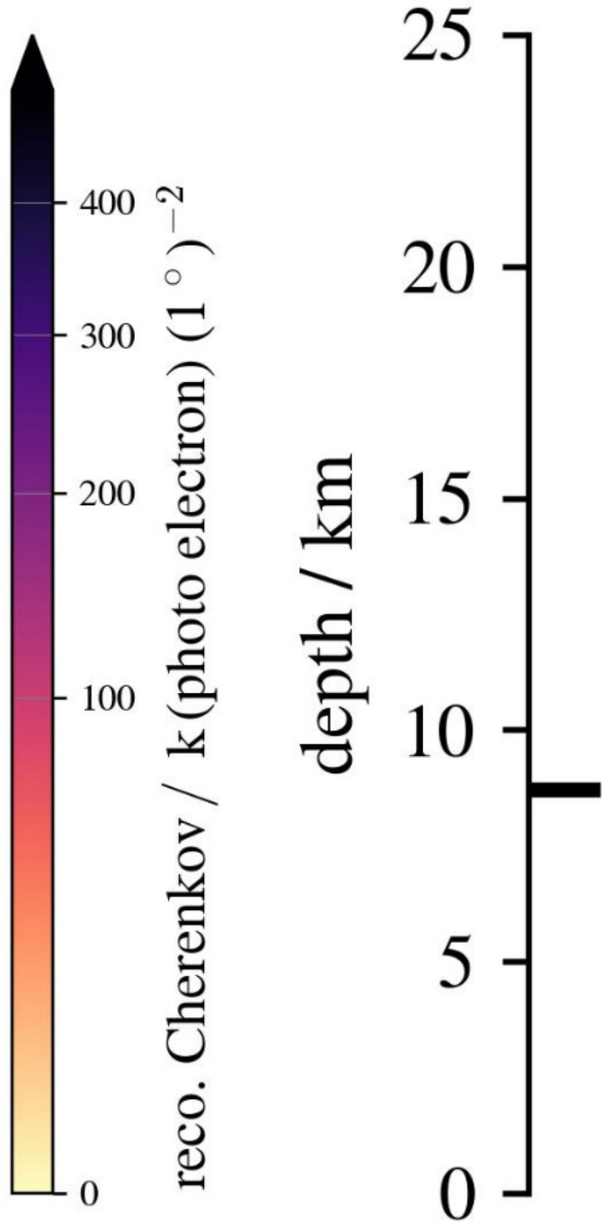

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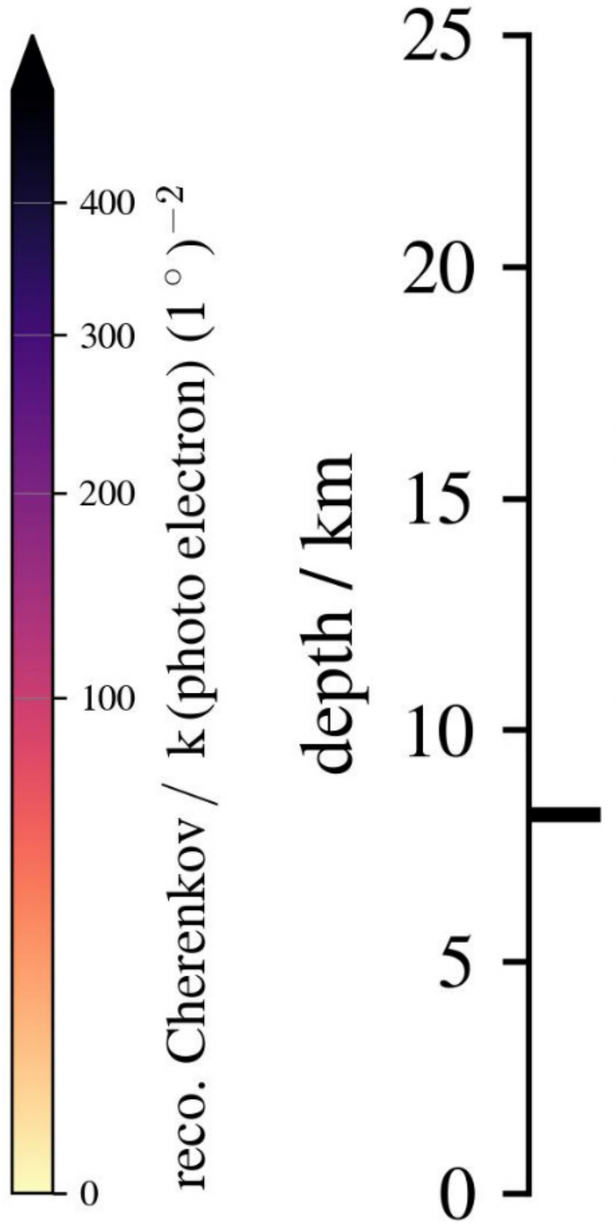

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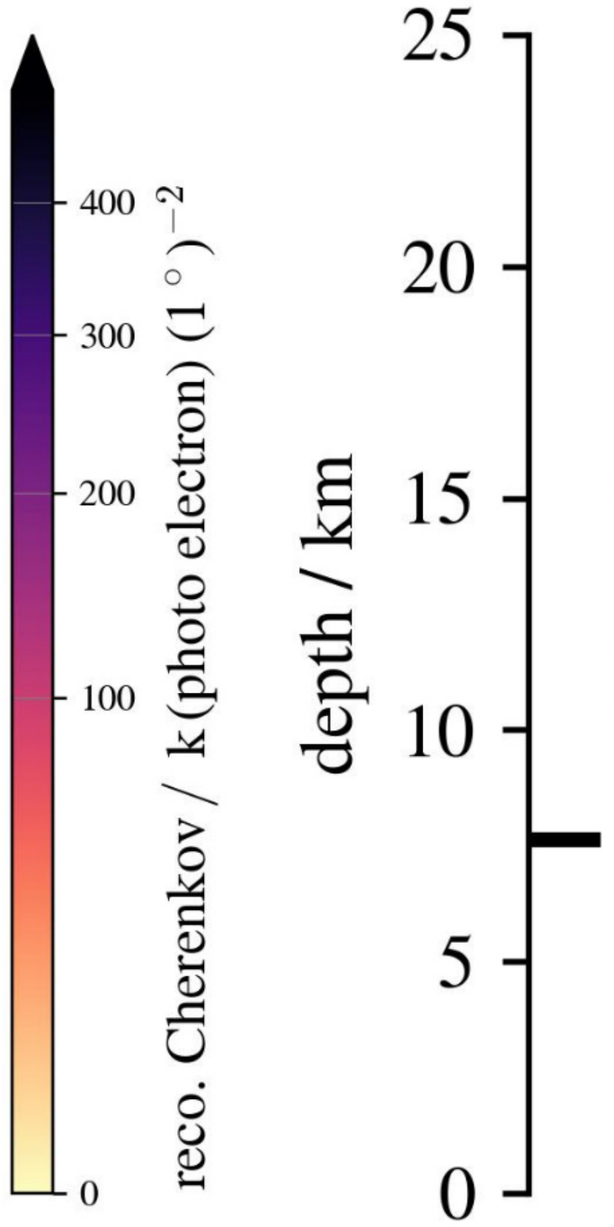
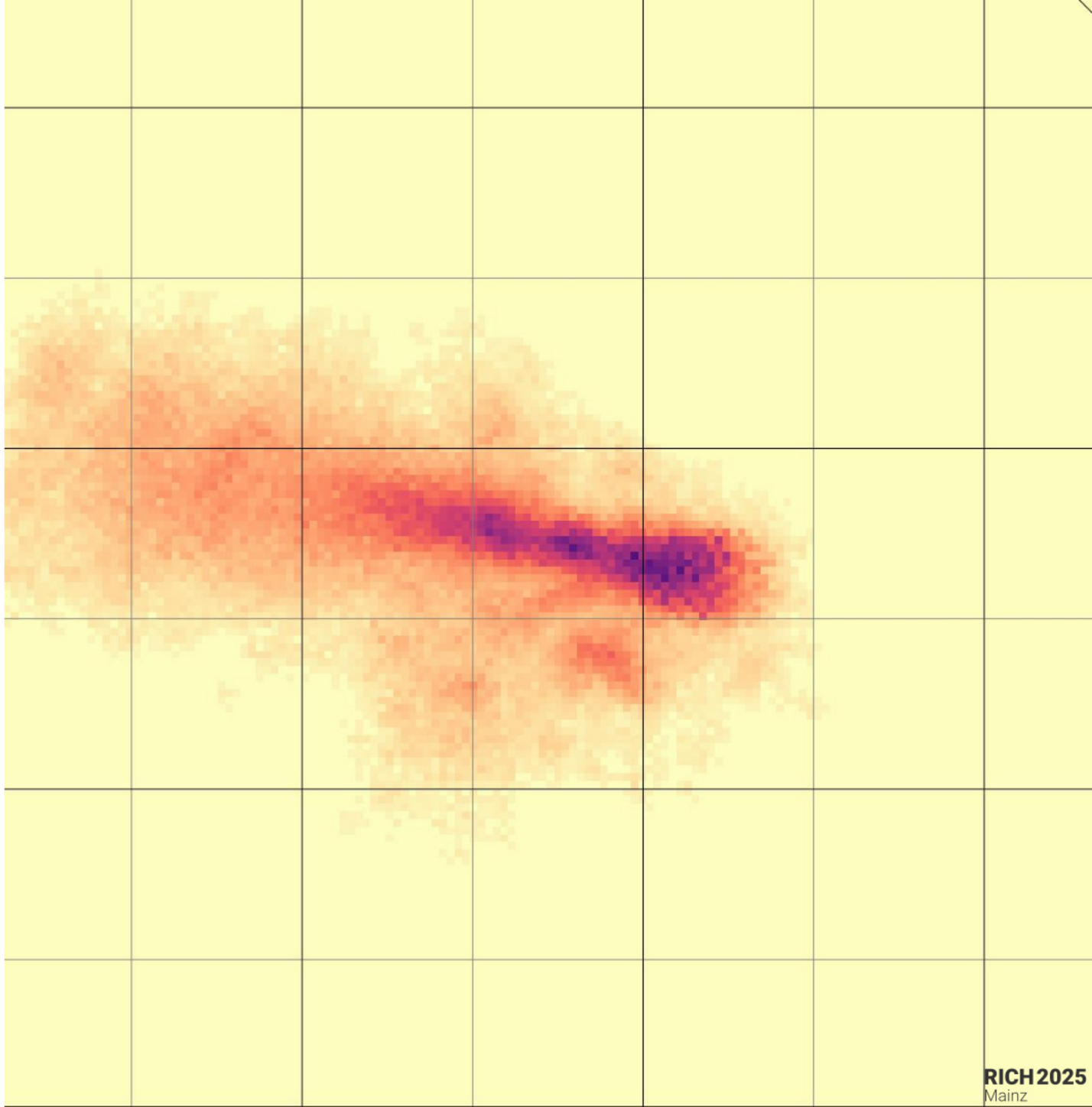
36,518p.e.



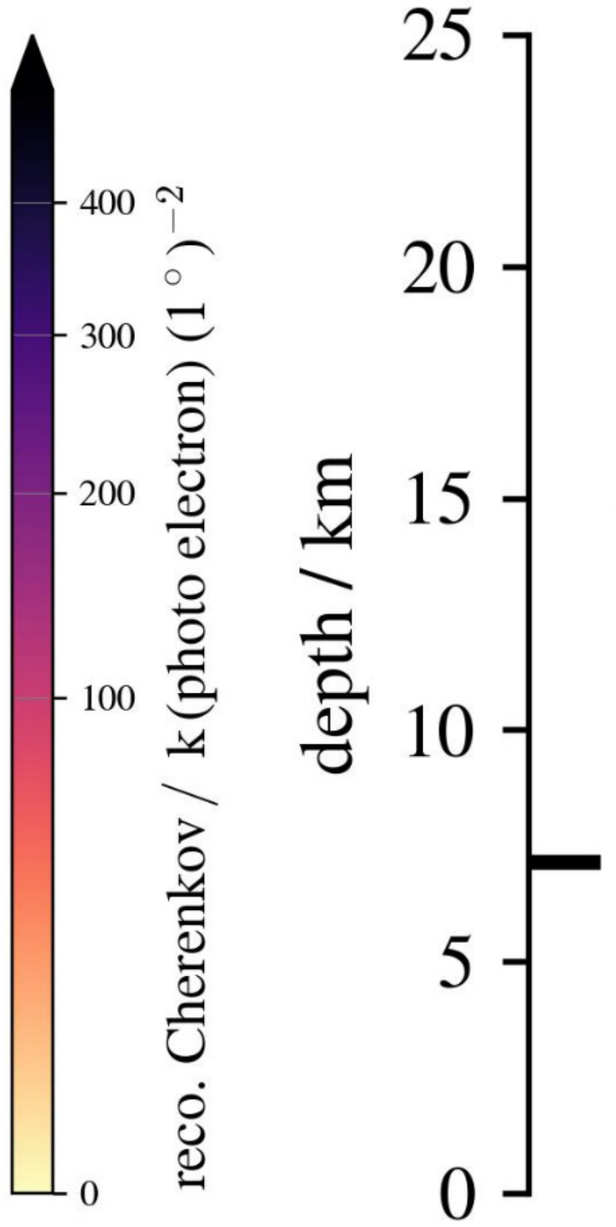


Airshower

Gamma

529GeV

36,518p.e.

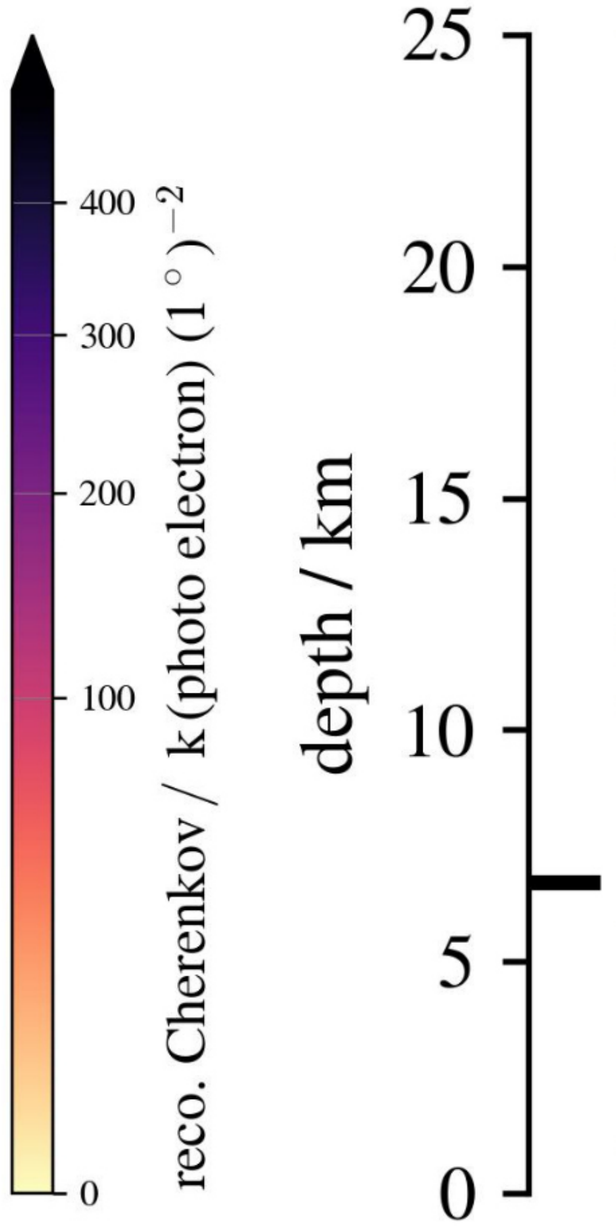


Airshower

Gamma

529GeV

36,518p.e.

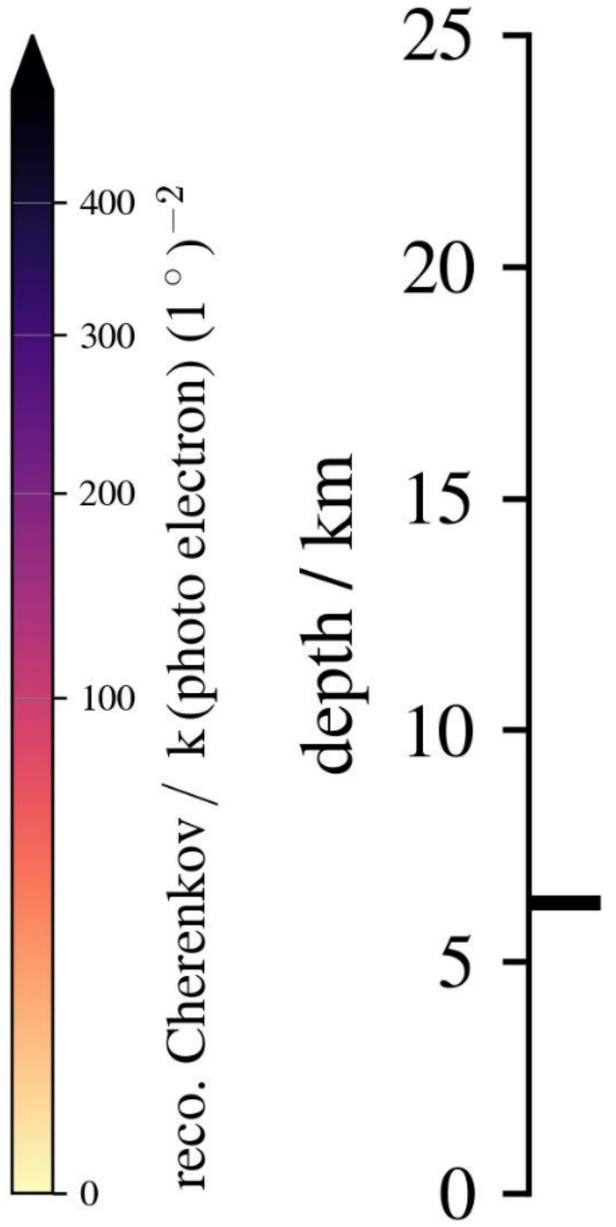


Airshower

Gamma

529GeV

36,518p.e.

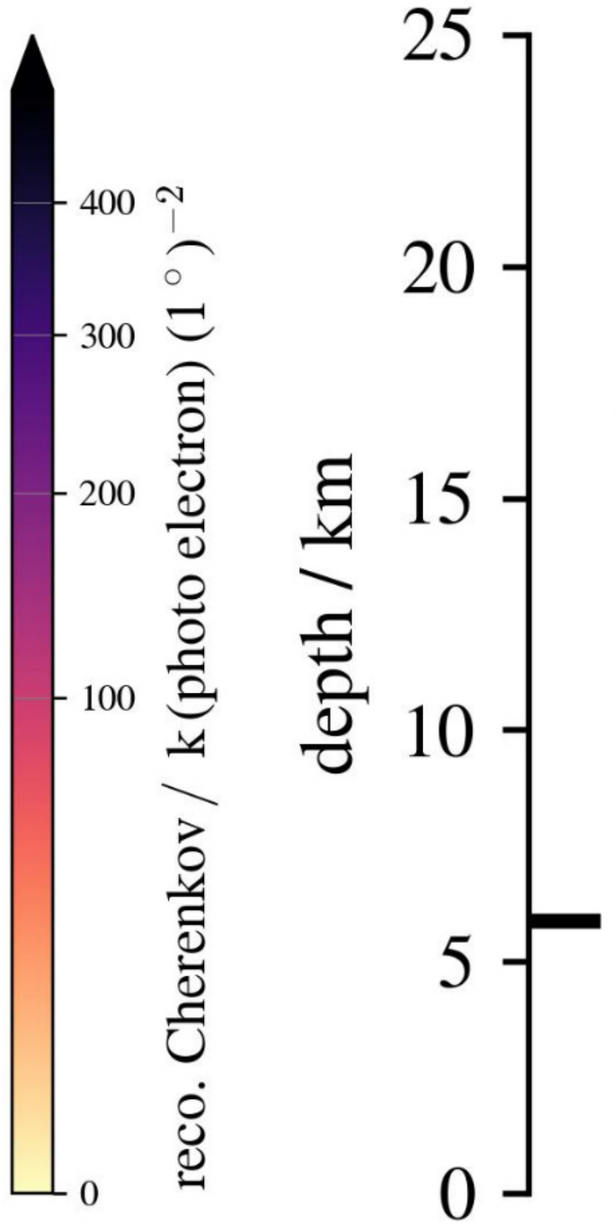


Airshower

Gamma

529GeV

36,518p.e.

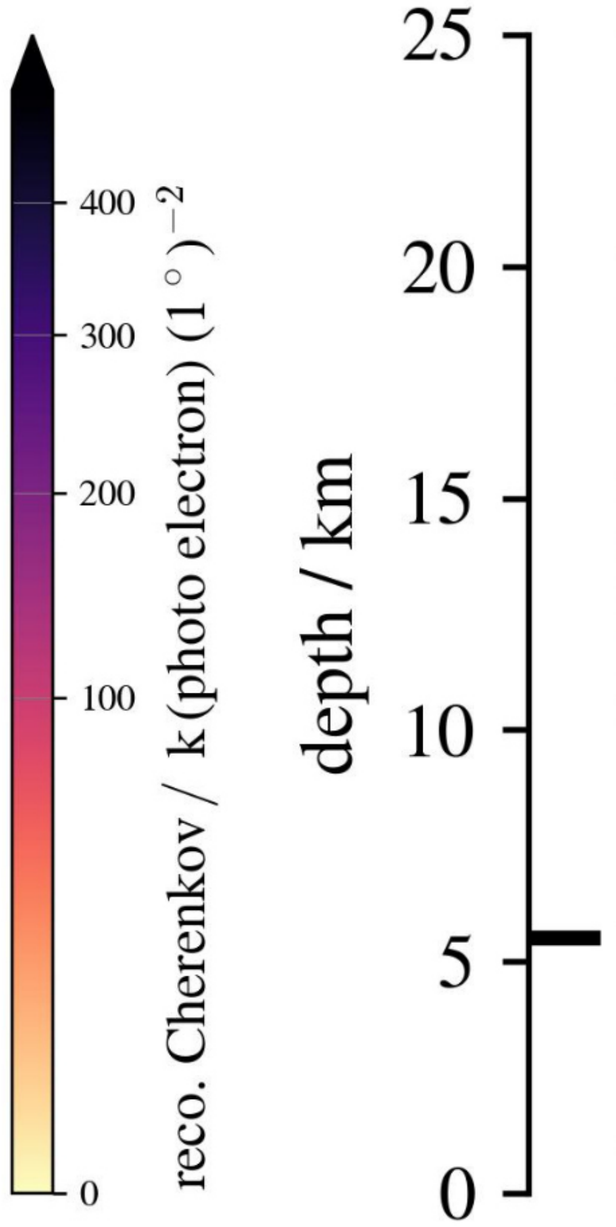


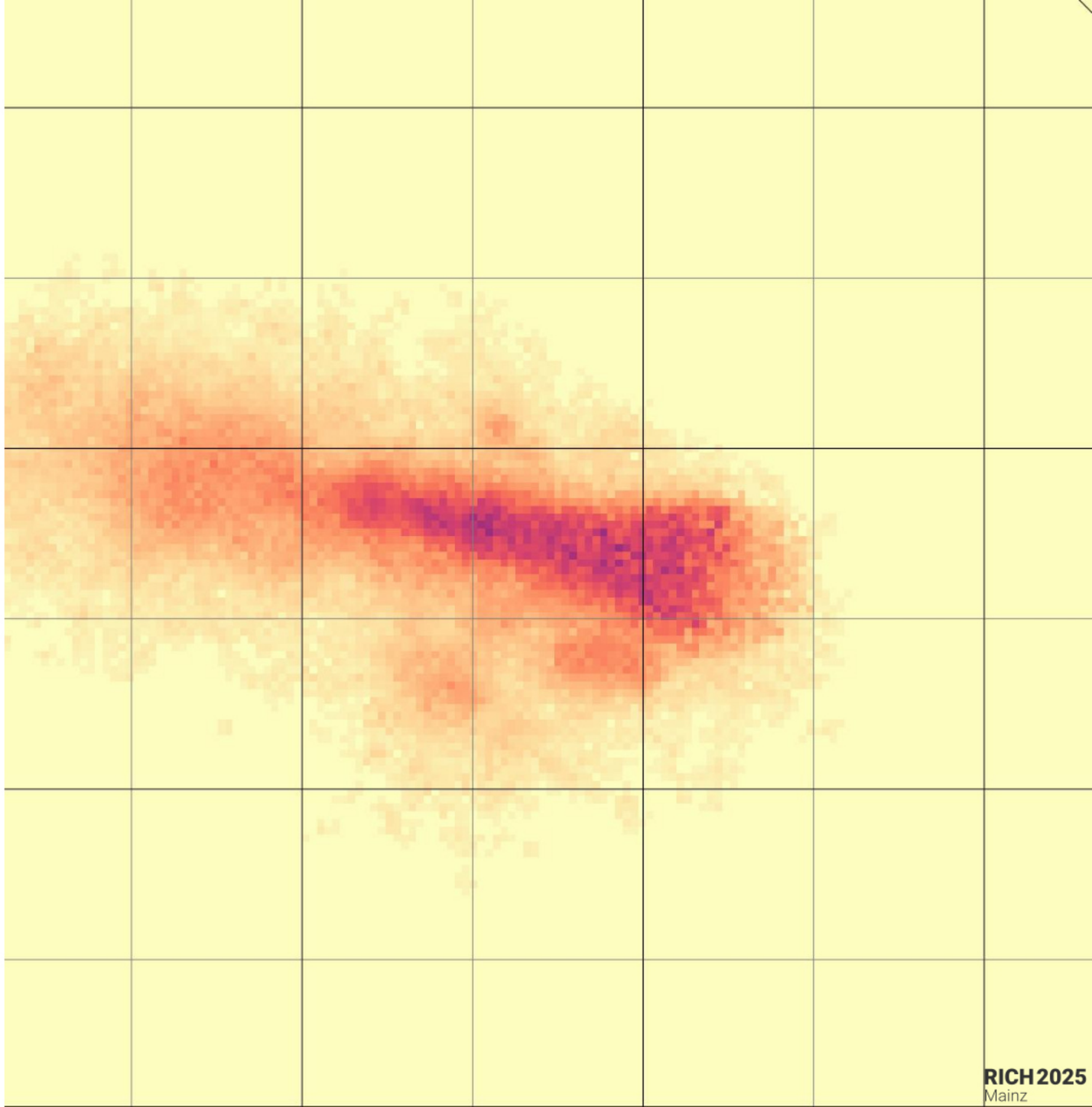
Airshower

Gamma

529GeV

36,518p.e.



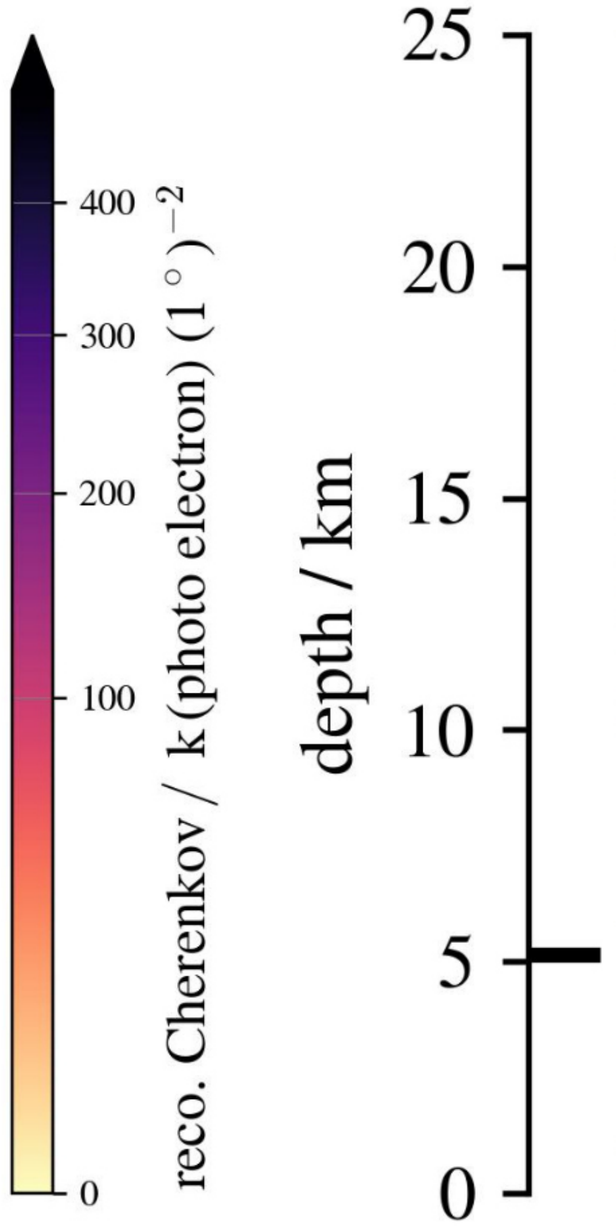


Airshower

Gamma

529GeV

36,518p.e.

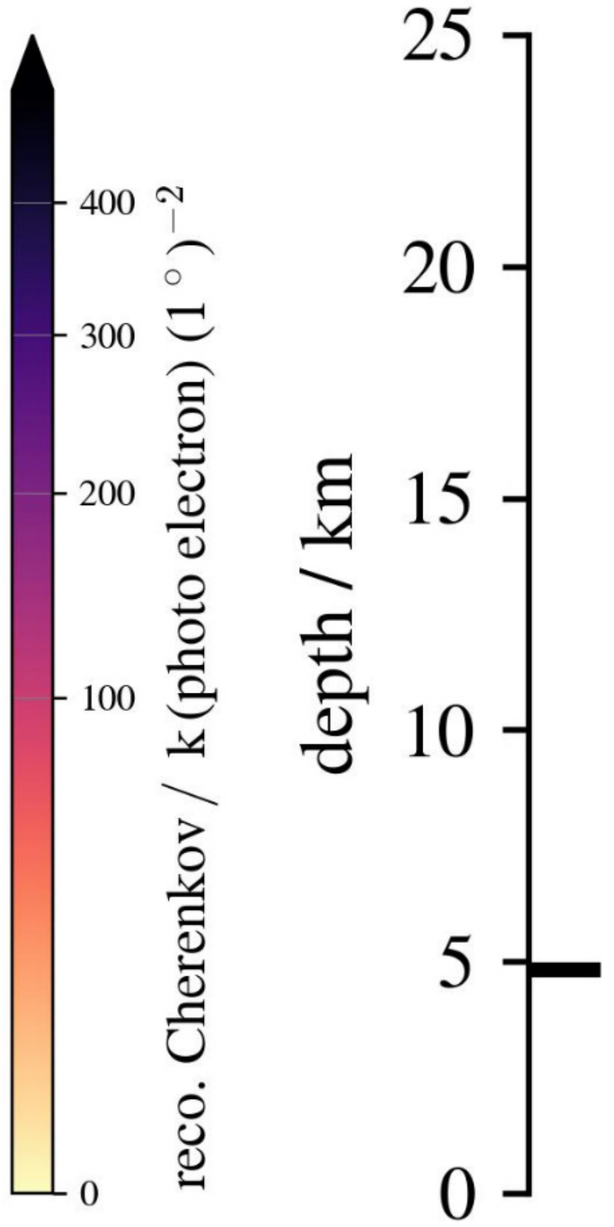


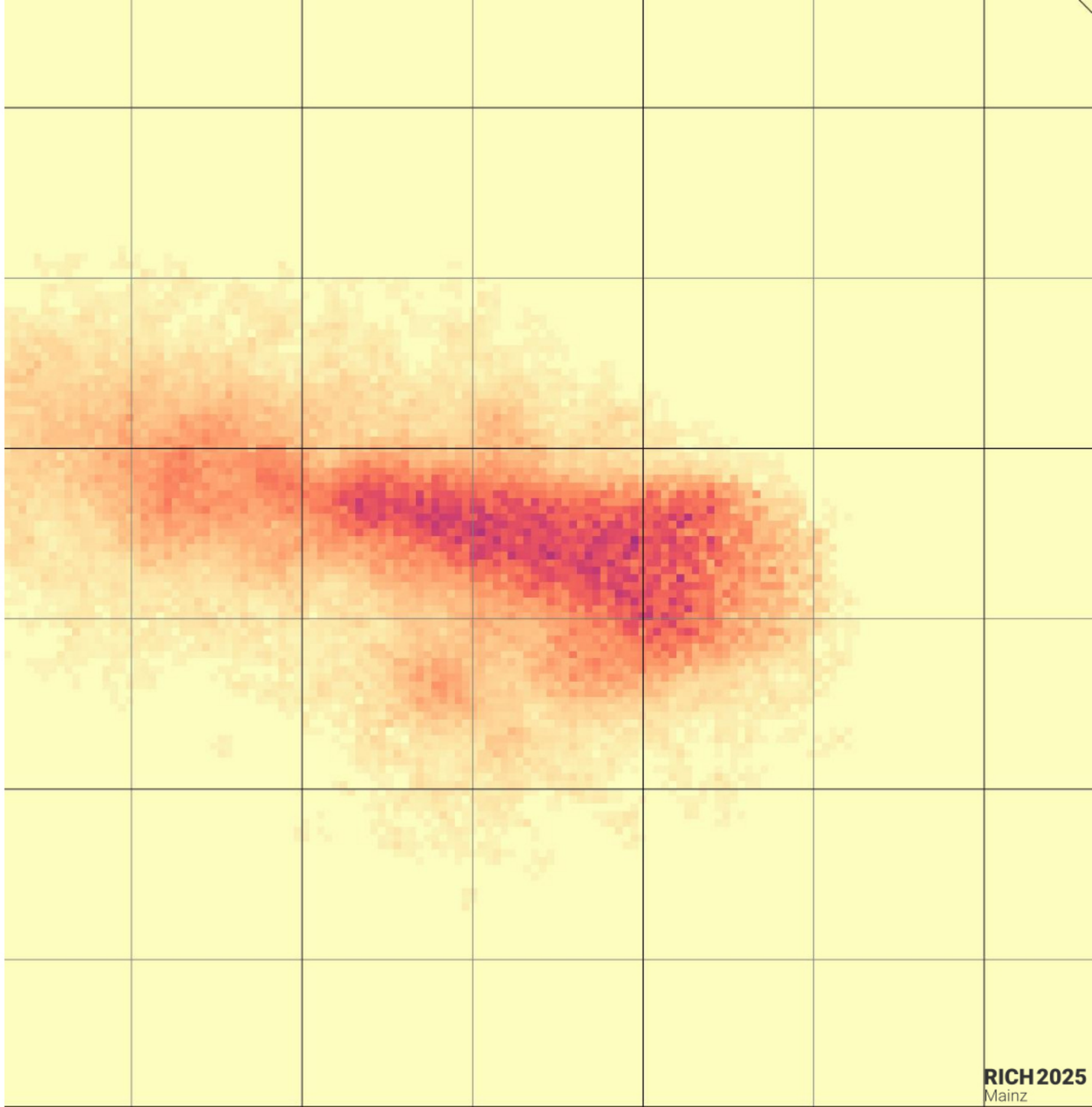
Airshower

Gamma

529GeV

36,518p.e.



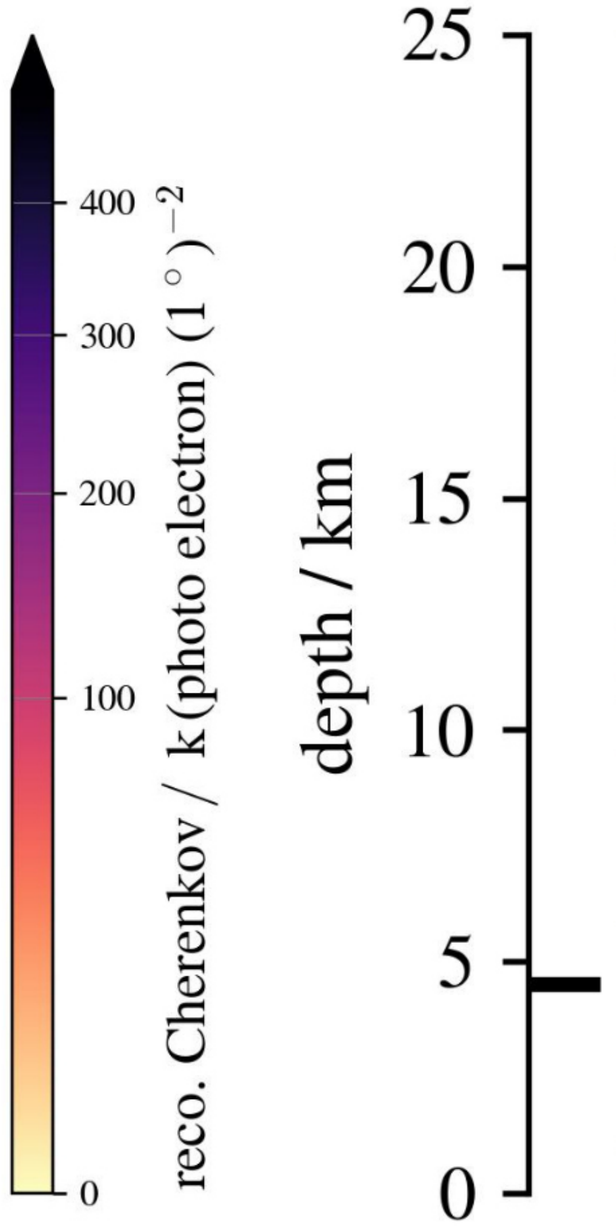


Airshower

Gamma

529GeV

36,518p.e.

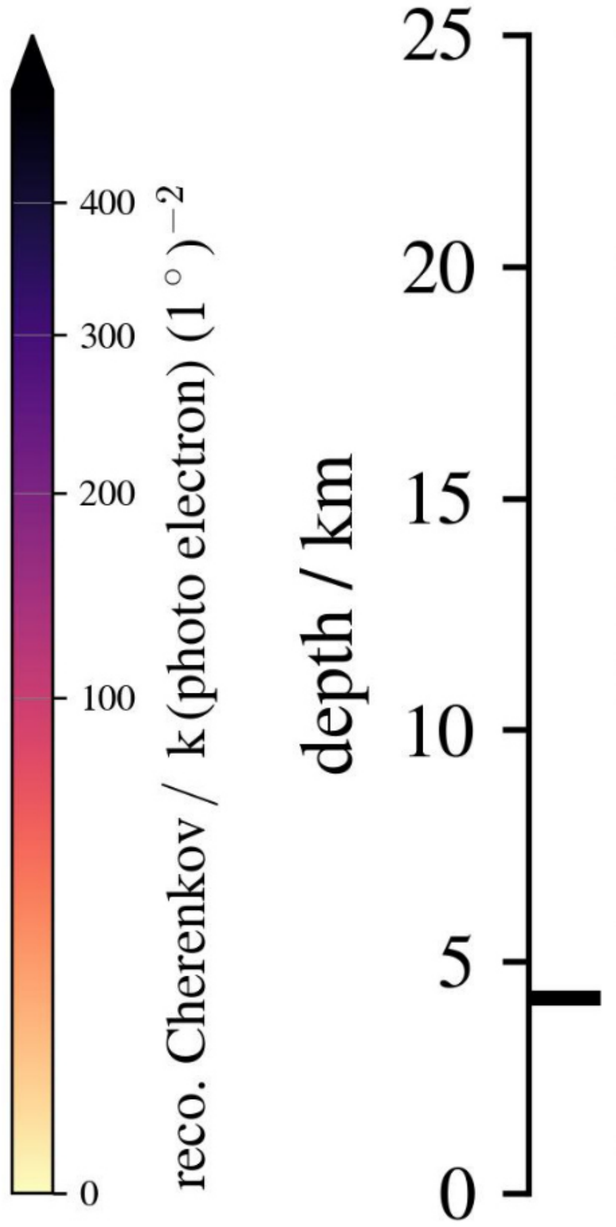


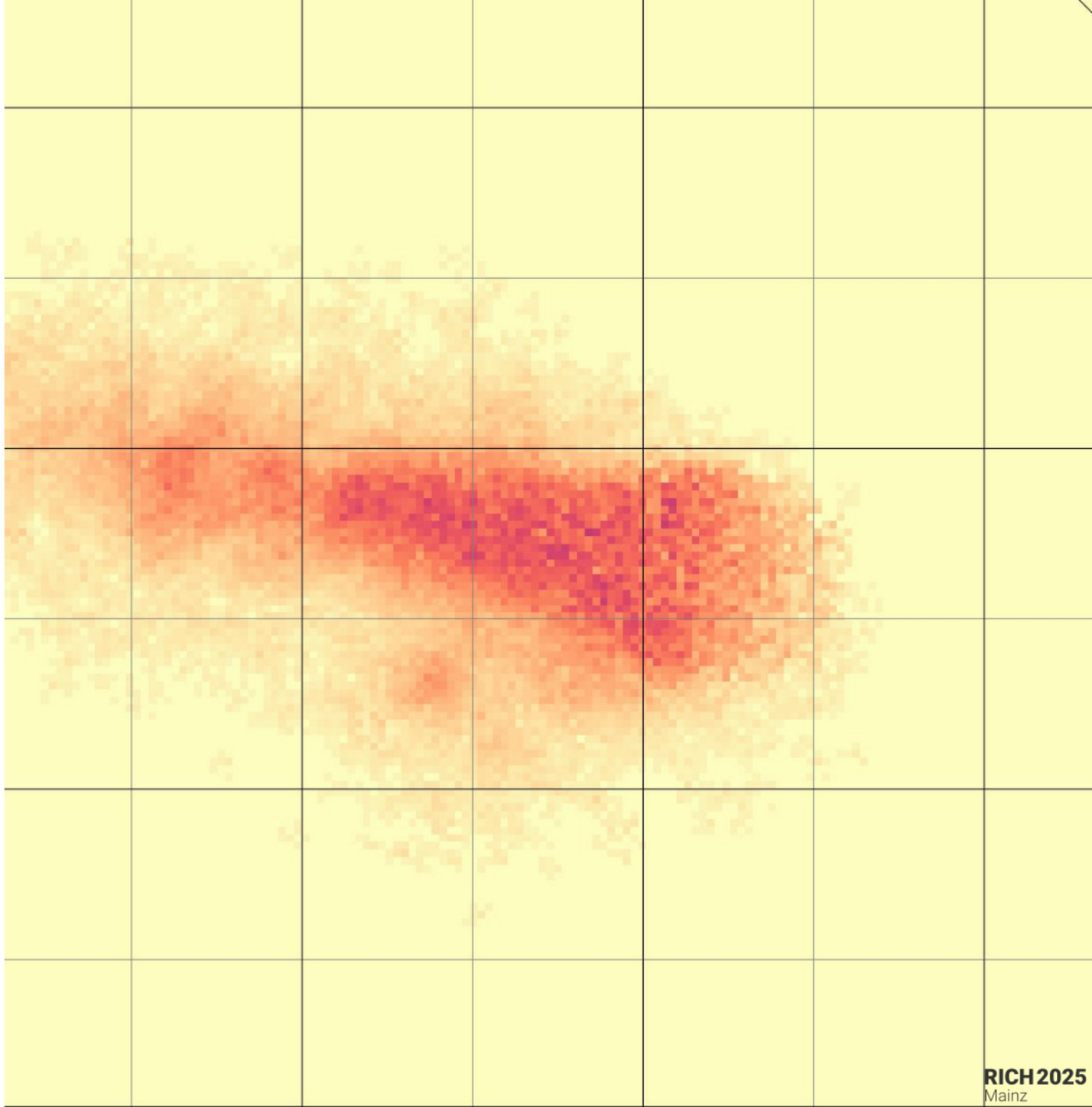
Airshower

Gamma

529GeV

36,518p.e.



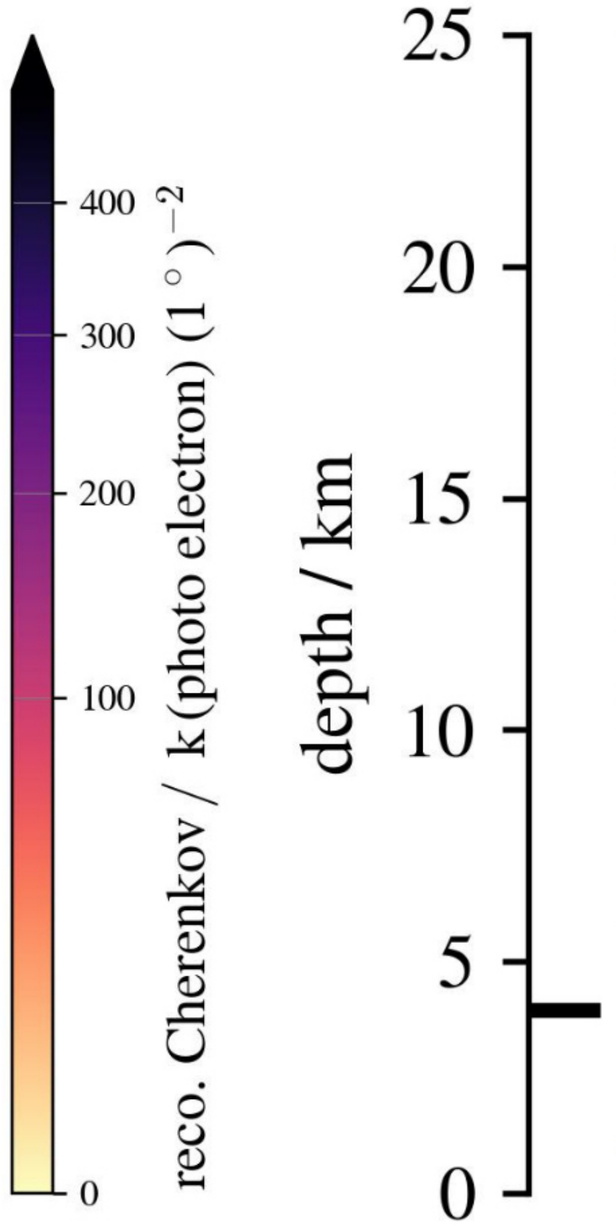


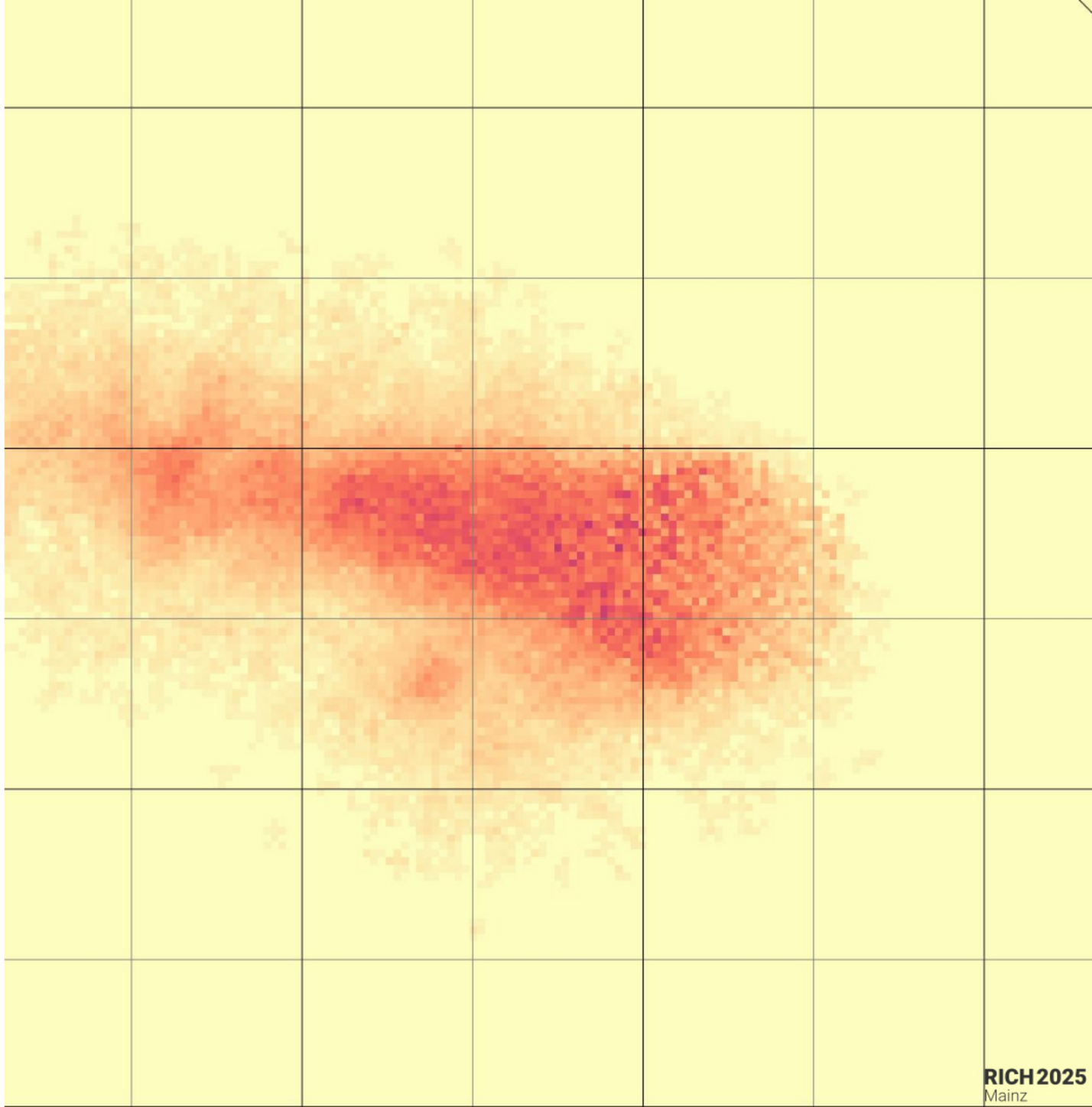
Airshower

Gamma

529GeV

36,518p.e.



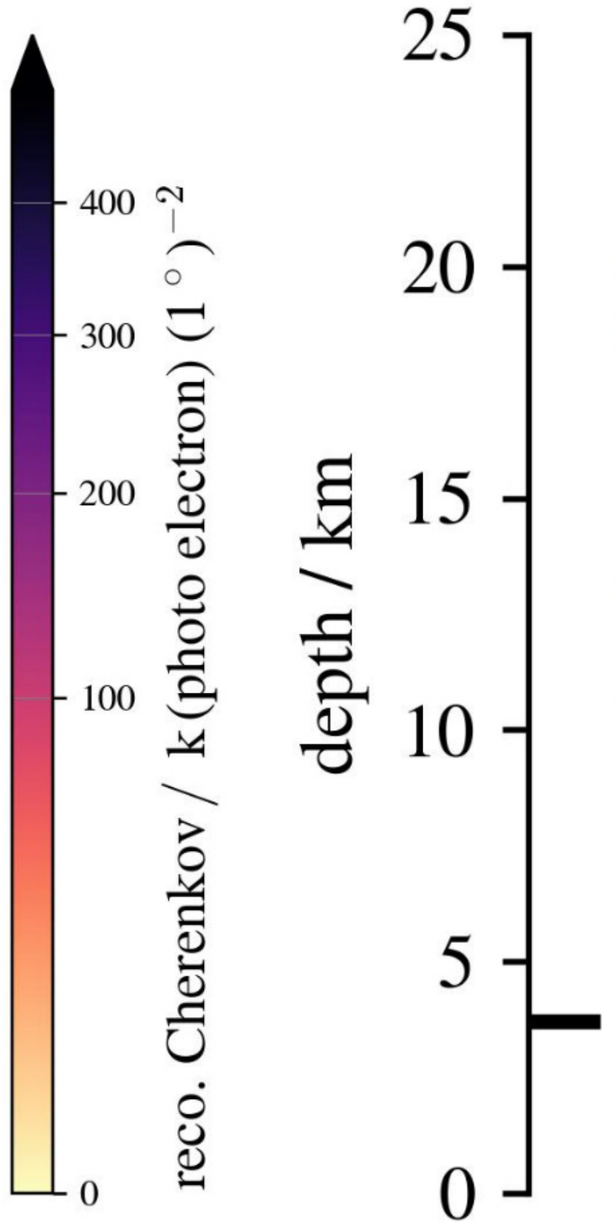


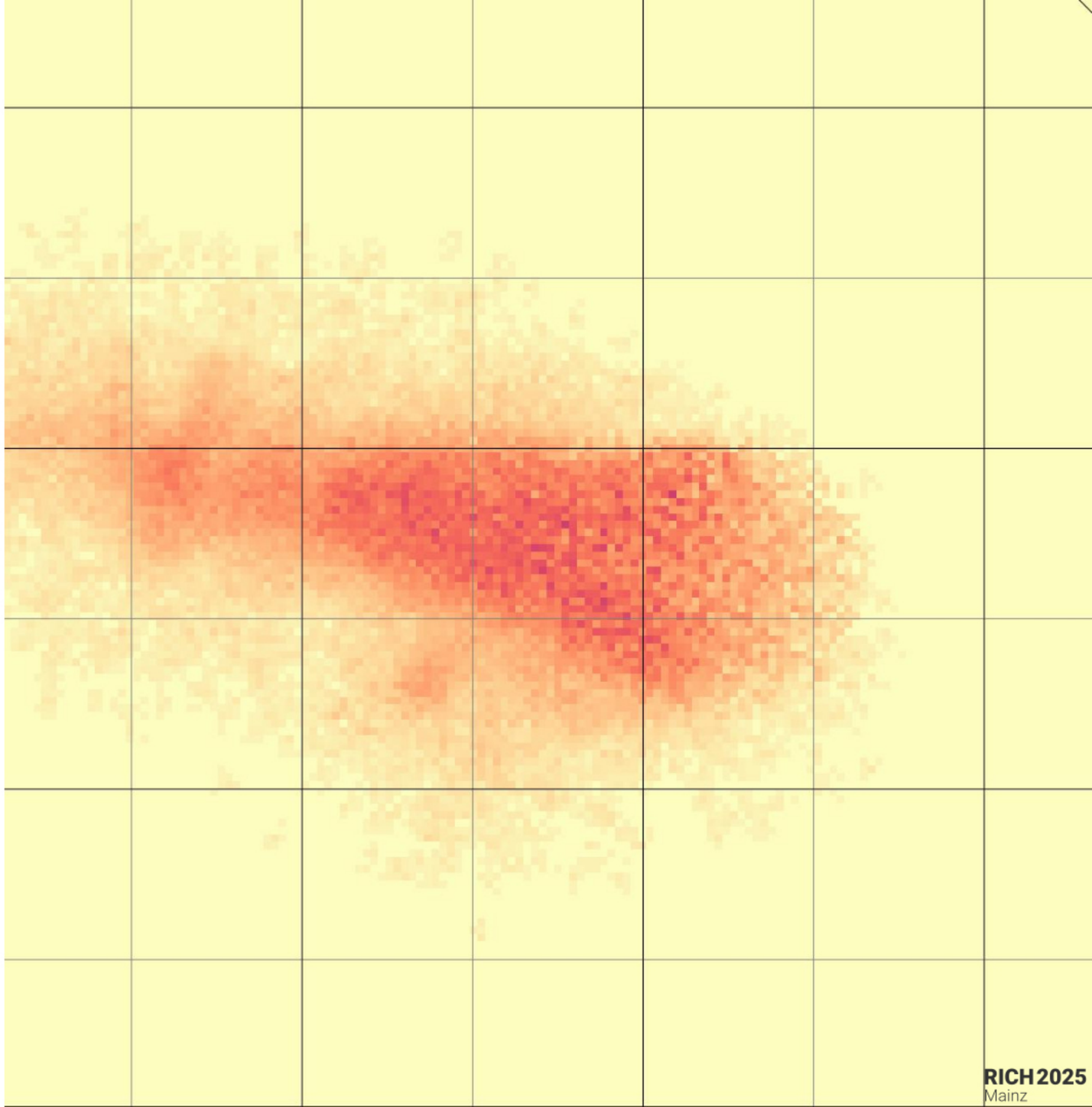
Airshower

Gamma

529GeV

36,518p.e.



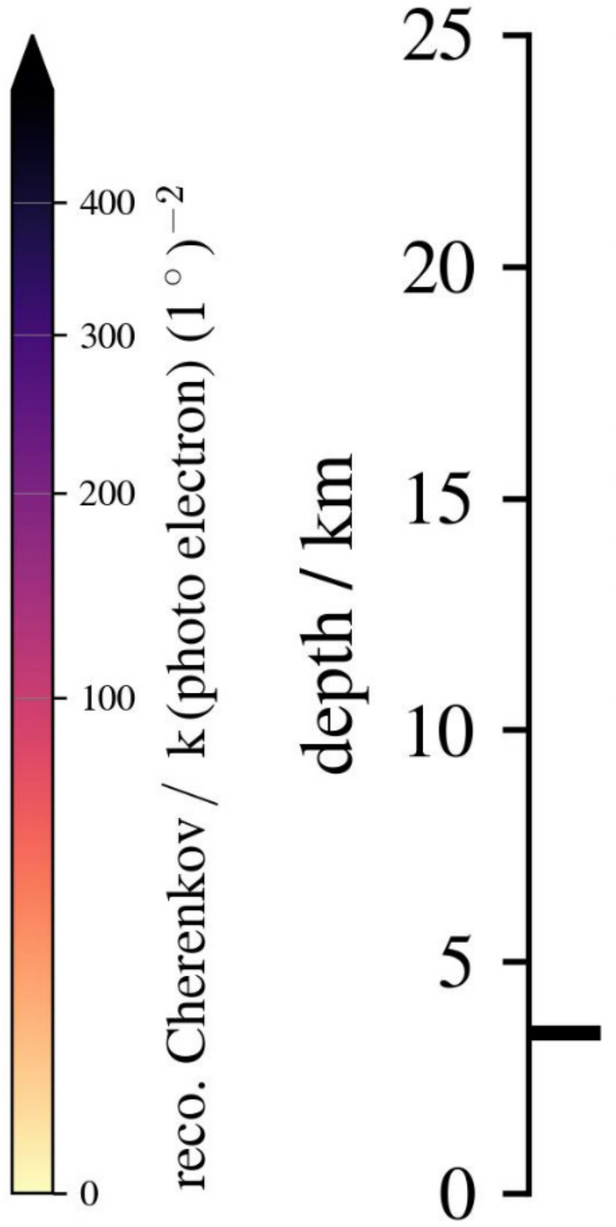


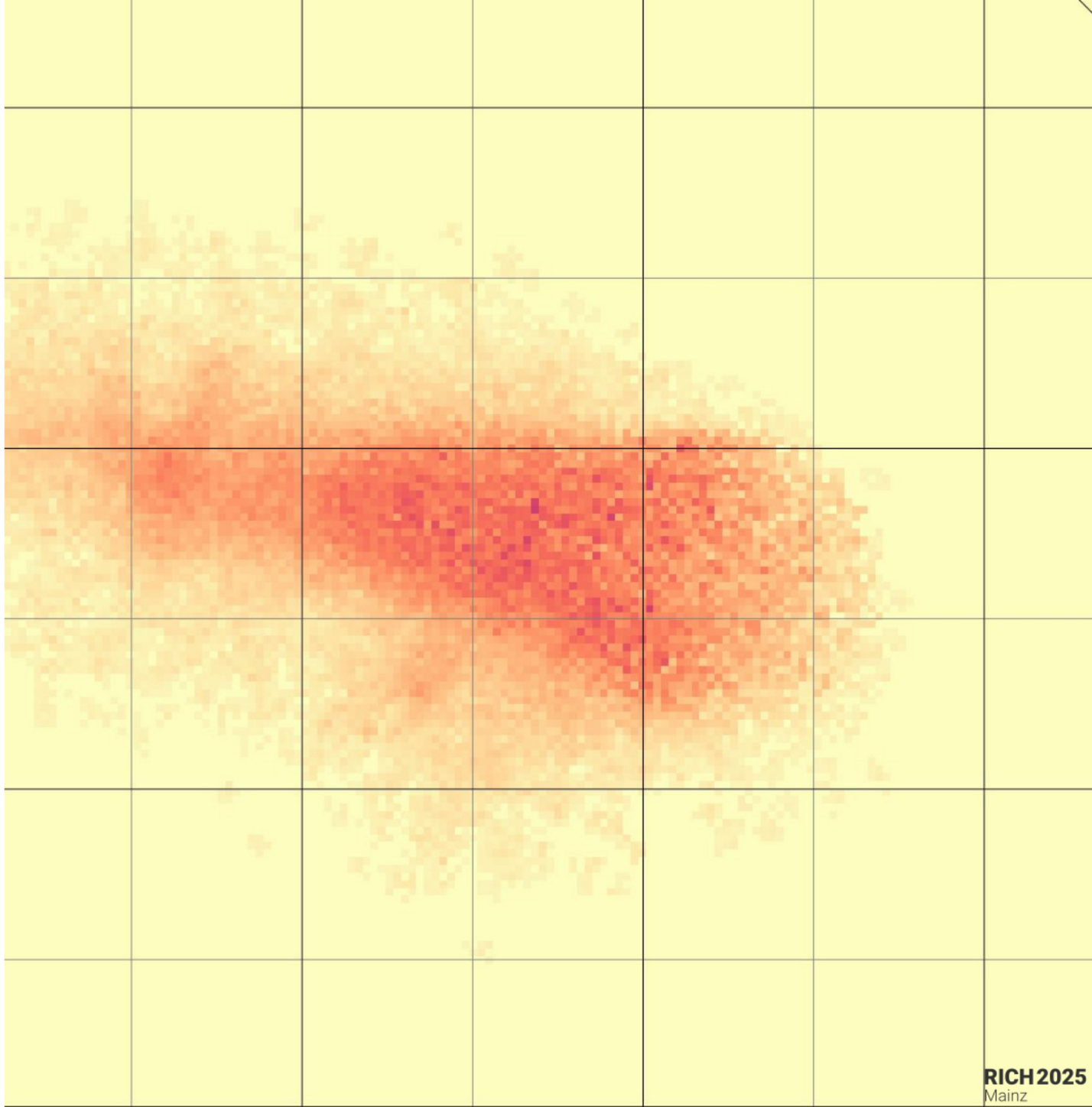
Airshower

Gamma

529GeV

36,518p.e.



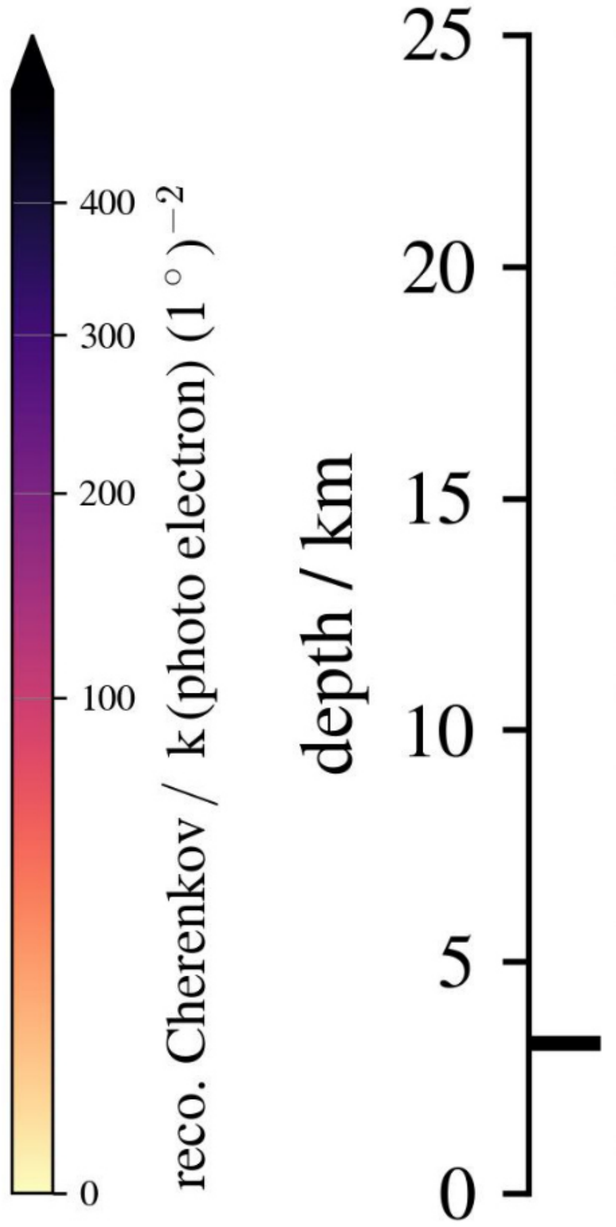


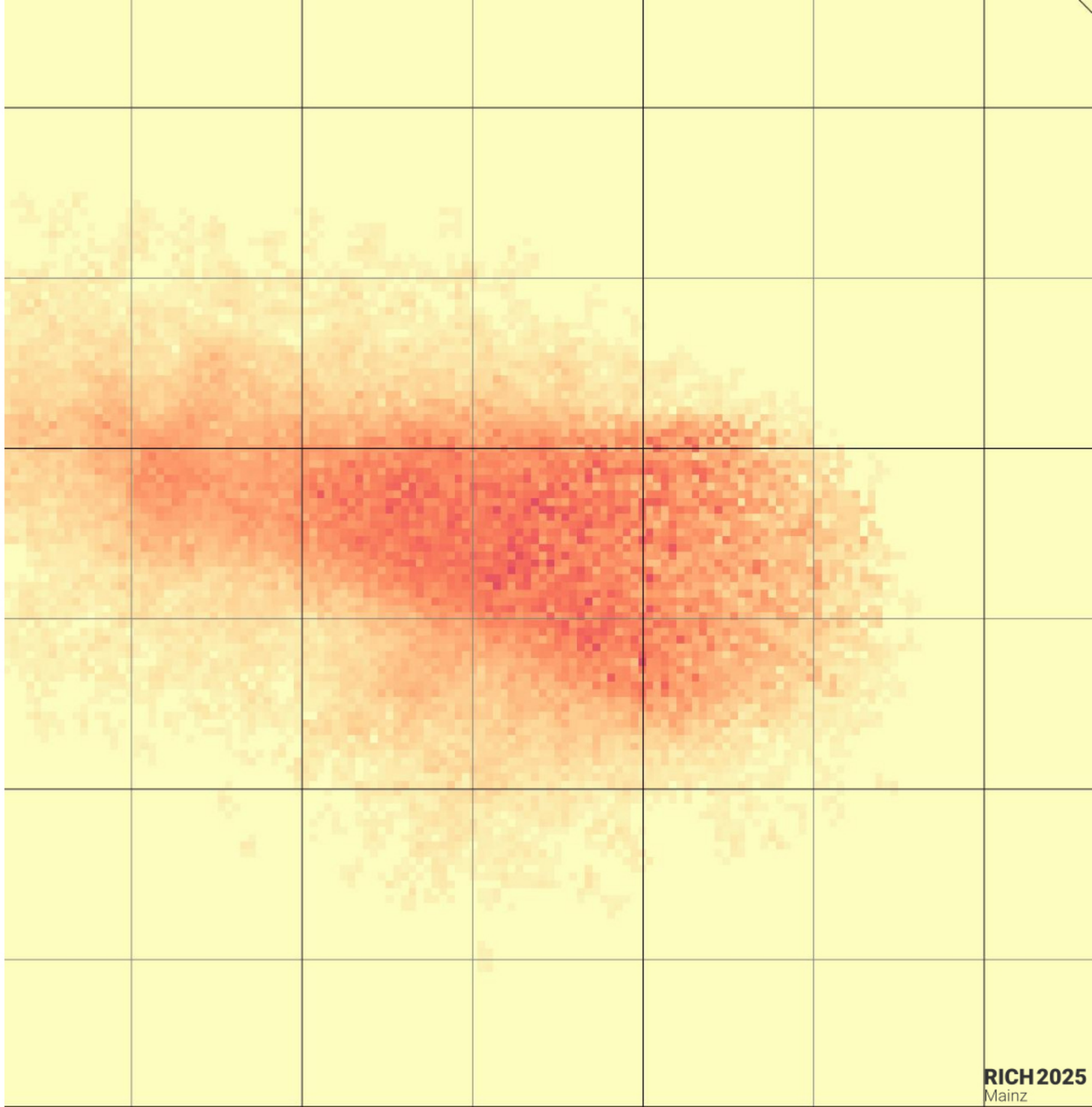
Airshower

Gamma

529GeV

36,518p.e.



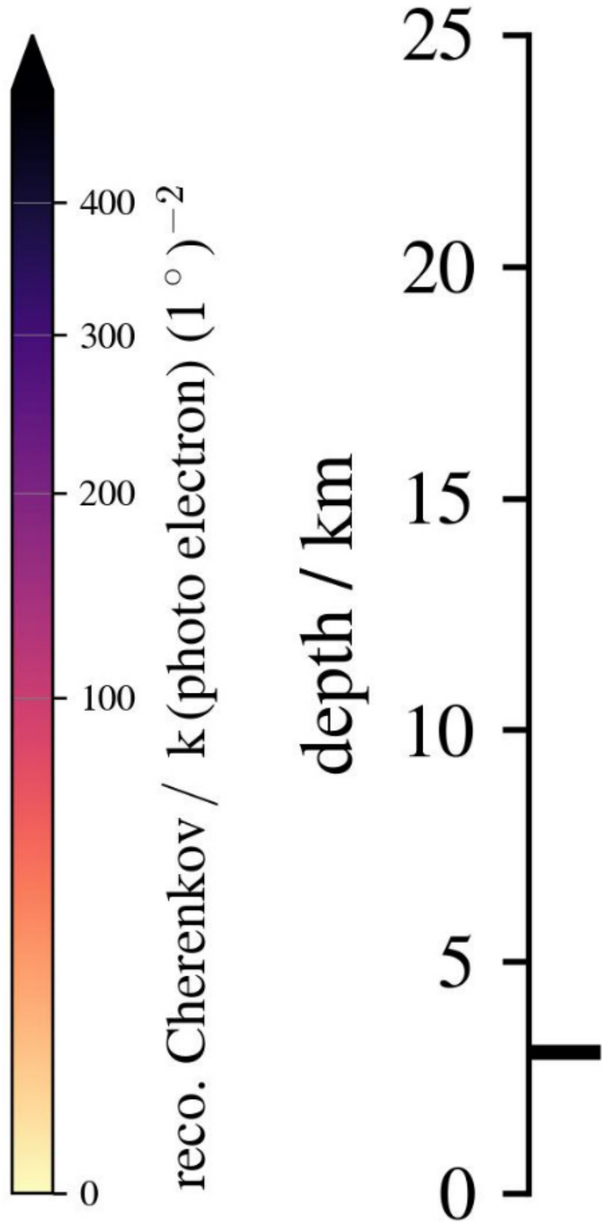


Airshower

Gamma

529GeV

36,518p.e.

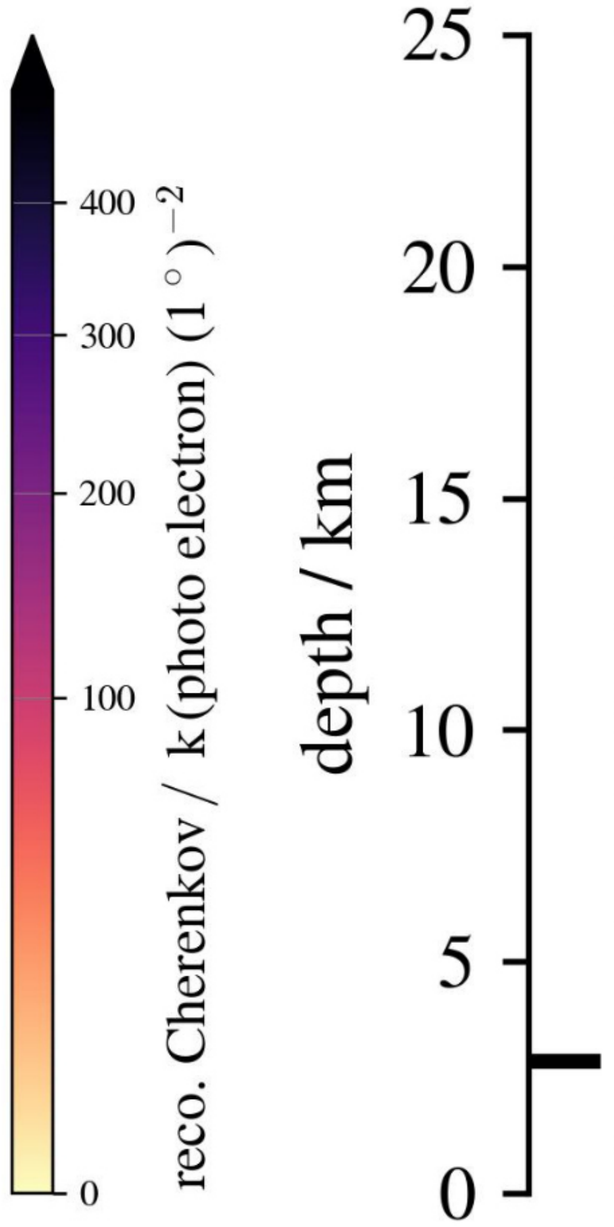


Airshower

Gamma

529GeV

36,518p.e.

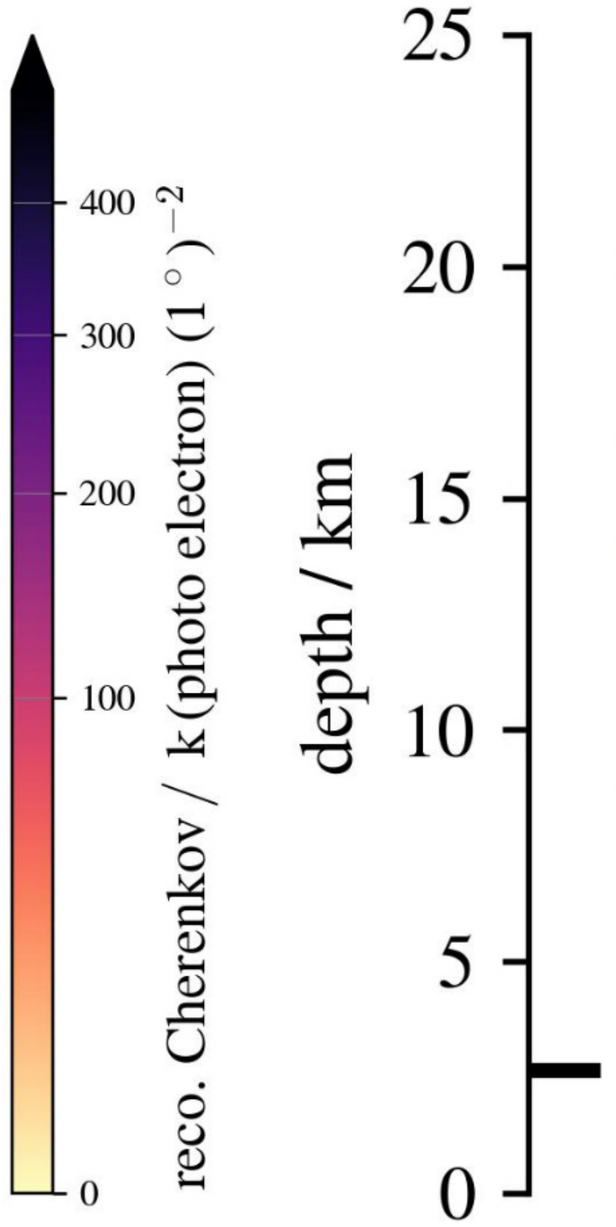


Airshower

Gamma

529GeV

36,518p.e.

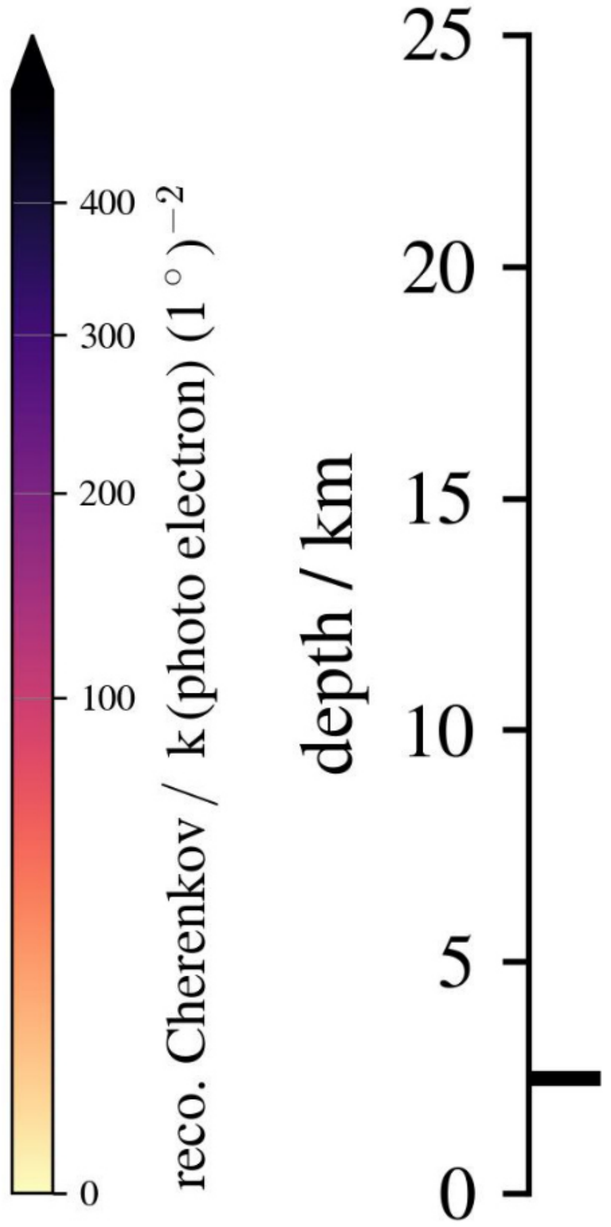


Airshower

Gamma

529GeV

36,518p.e.

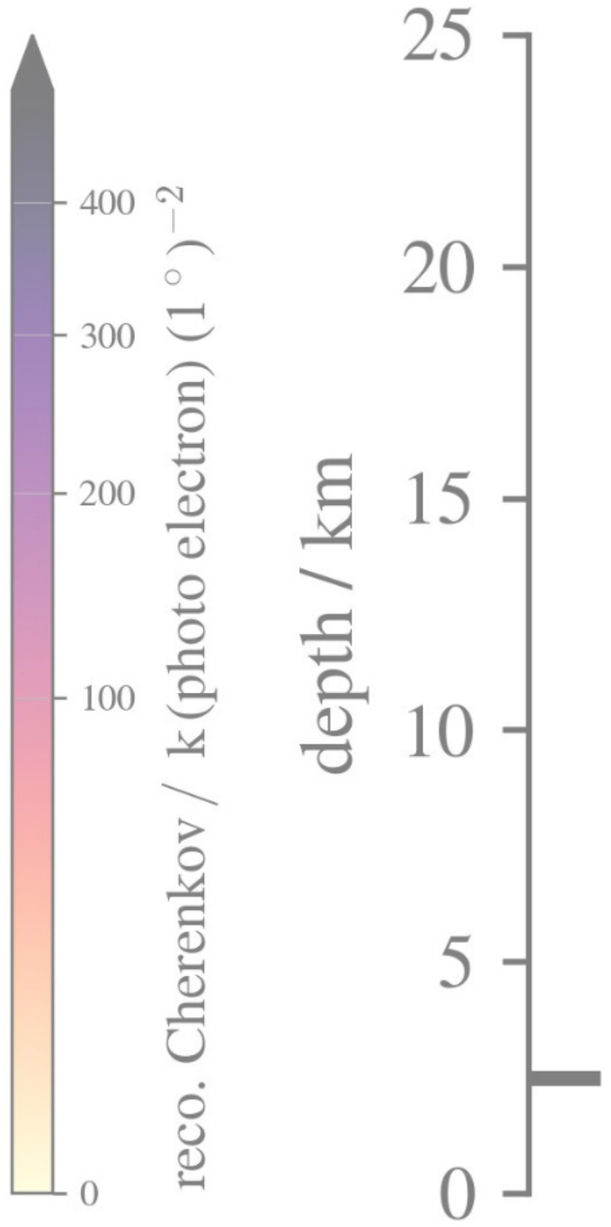


Airshower

Gamma

529GeV

36,518p.e.

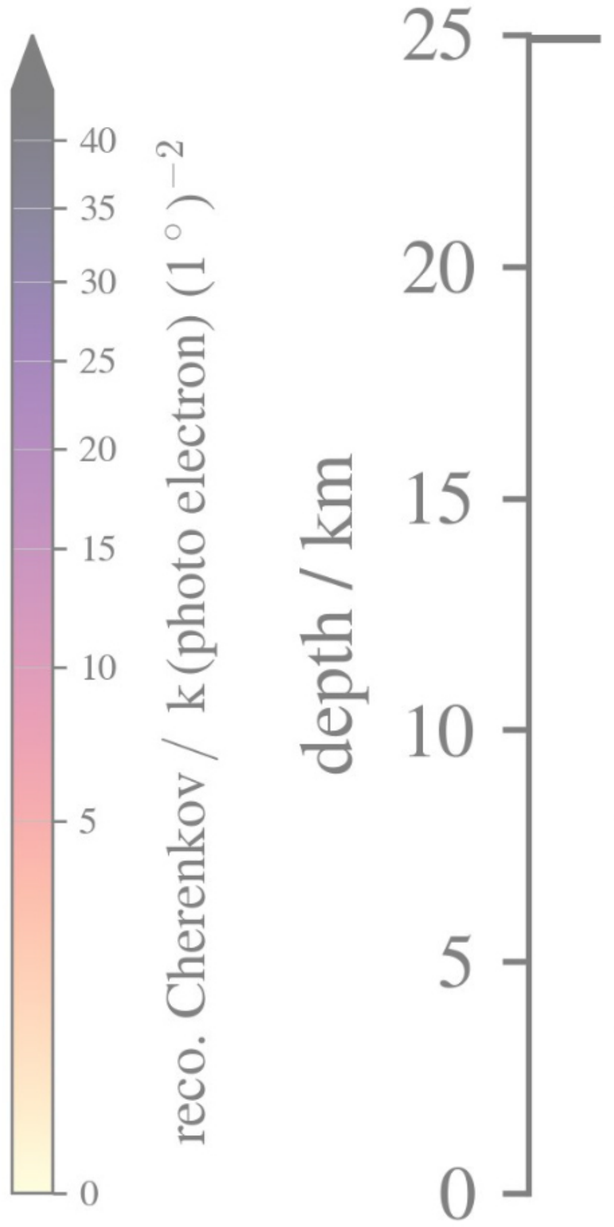


Airshower

Gamma

3.2GeV

708p.e.

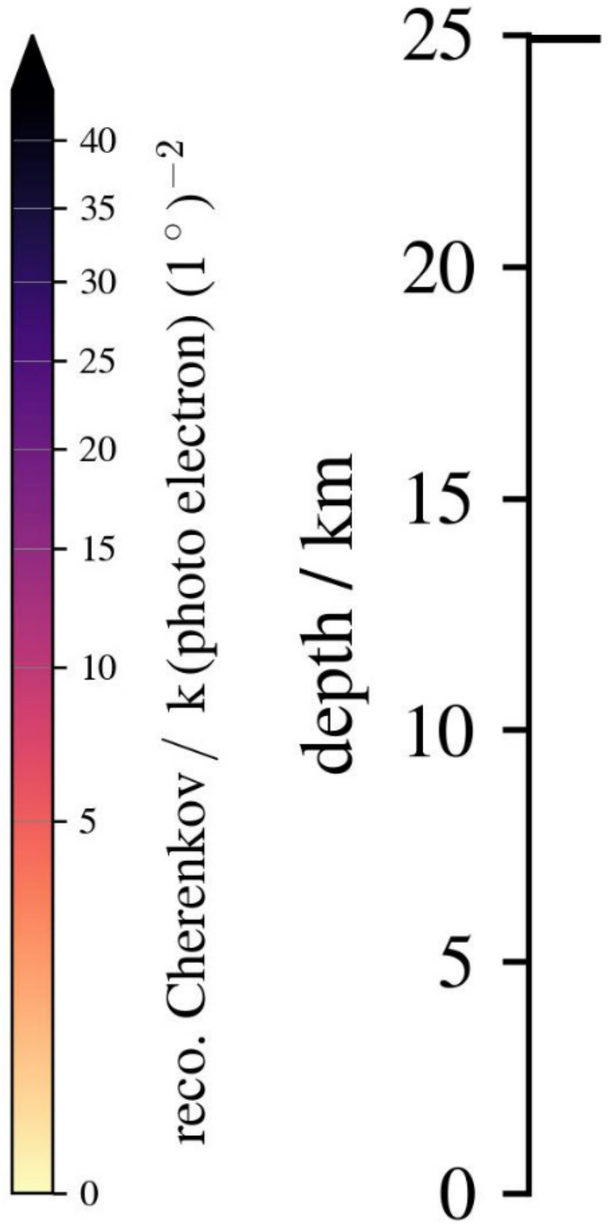


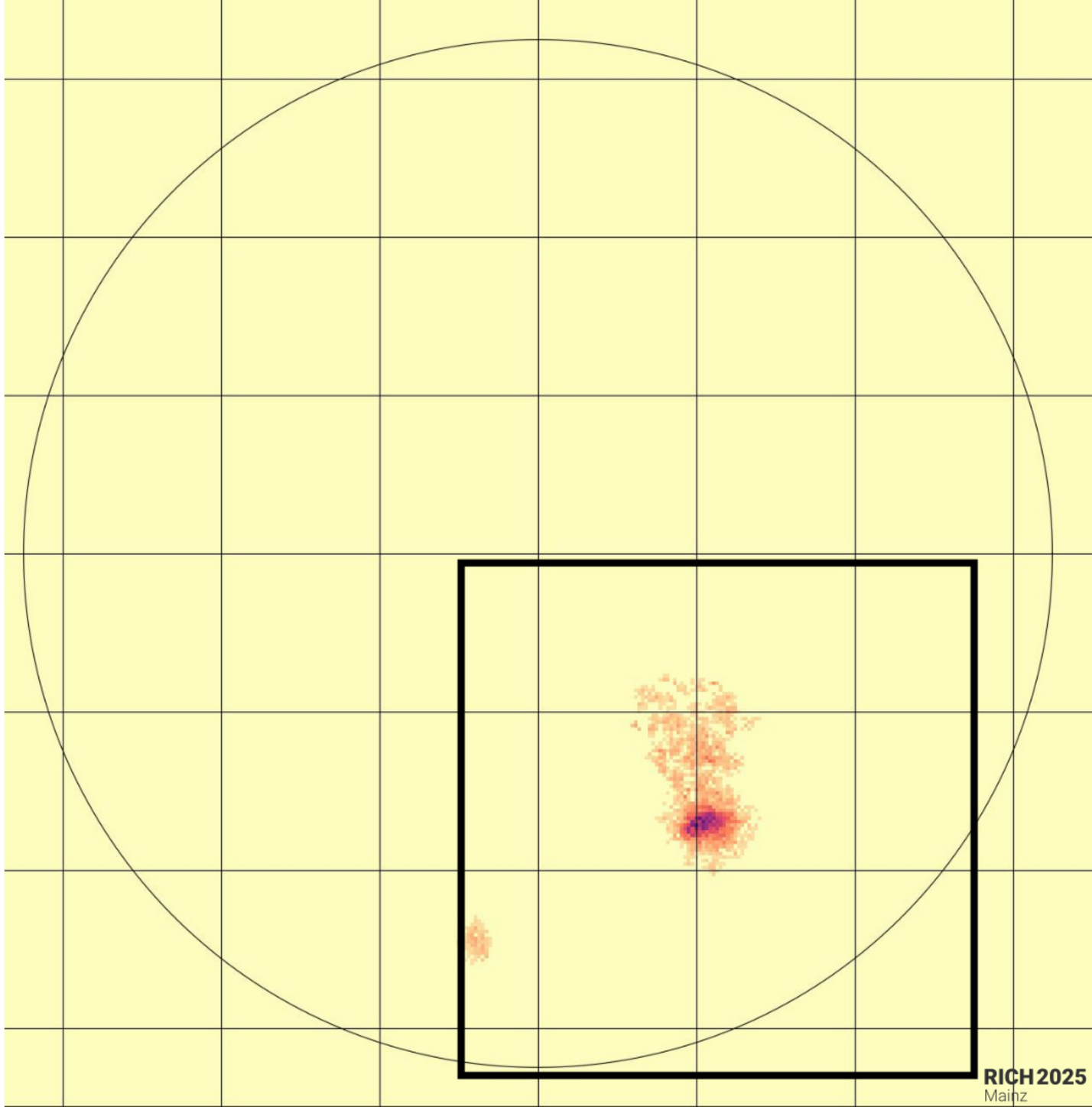
Airshower

Gamma

3.2GeV

708p.e.



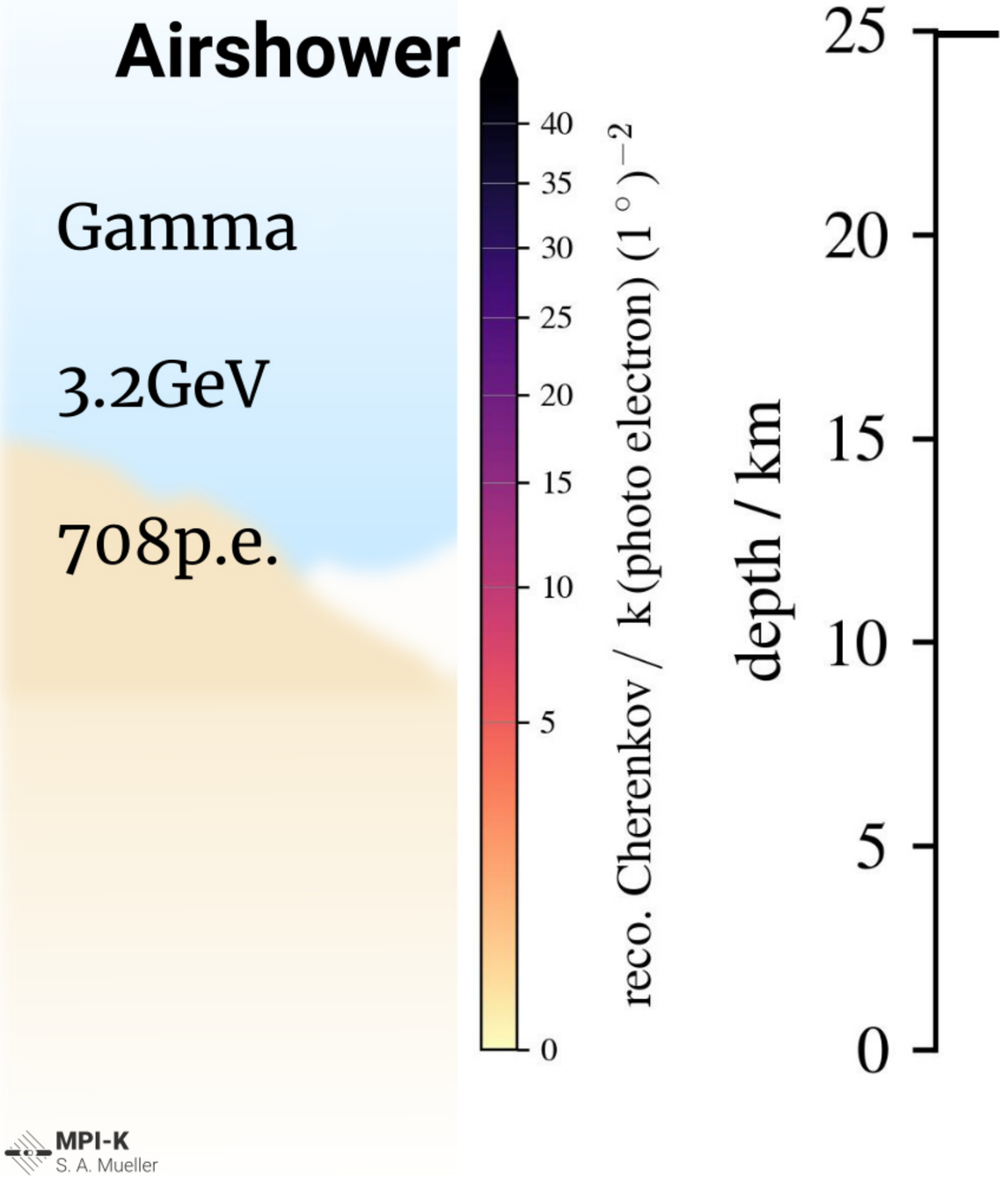


Airshower

Gamma

3.2GeV

708p.e.

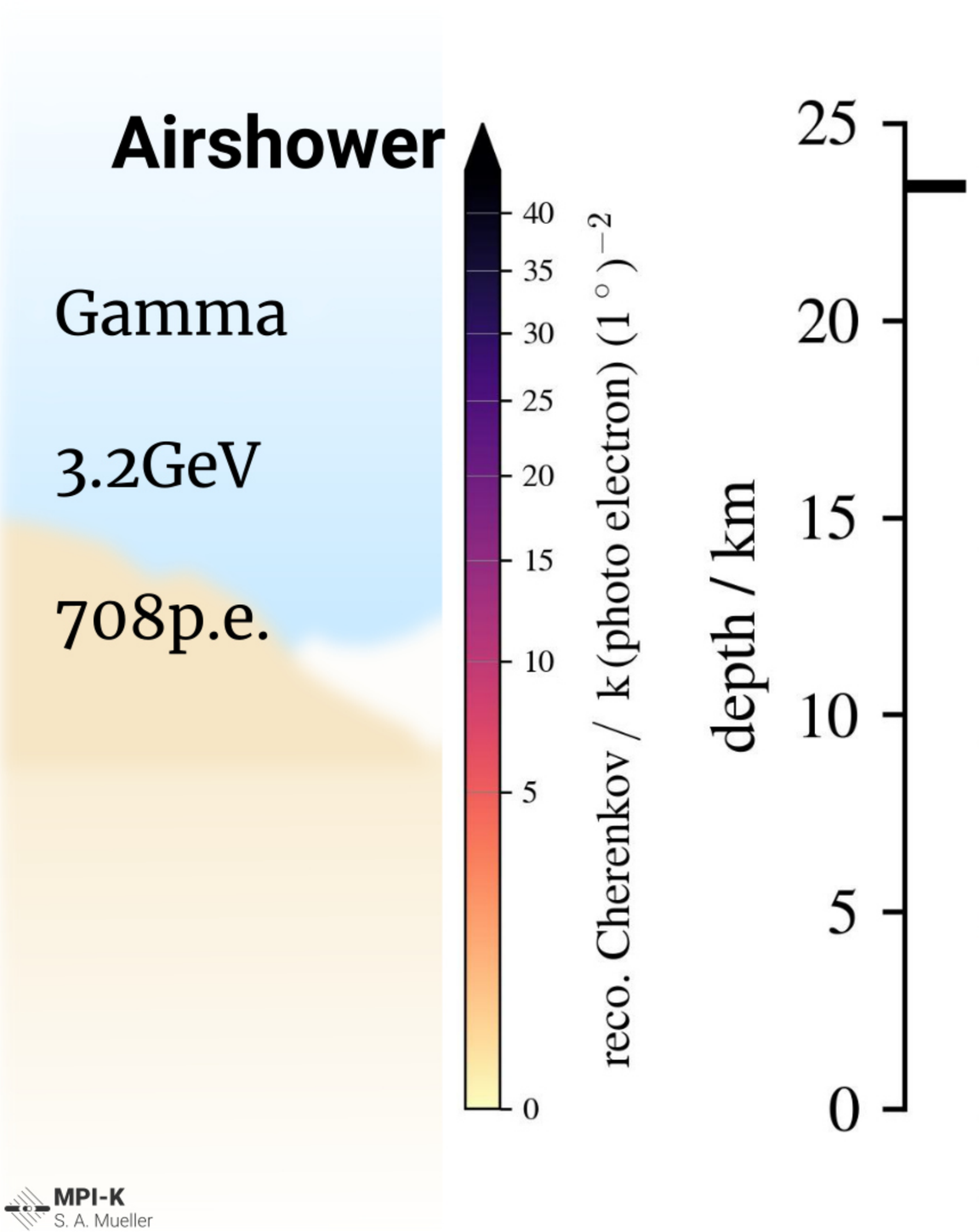


Airshower

Gamma

3.2GeV

708p.e.

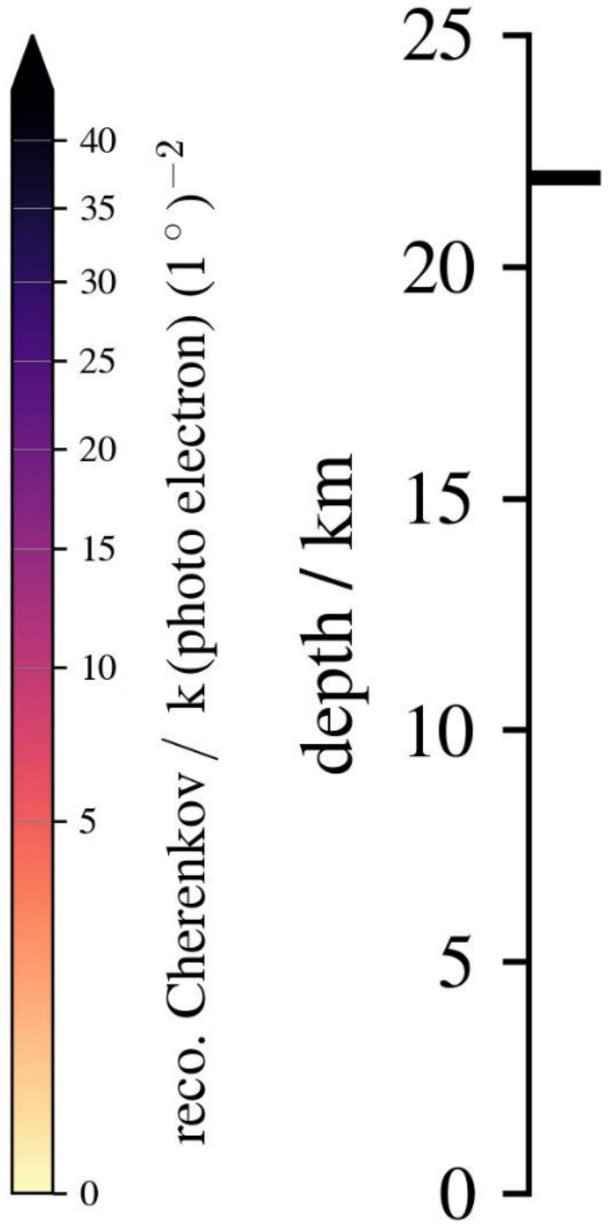


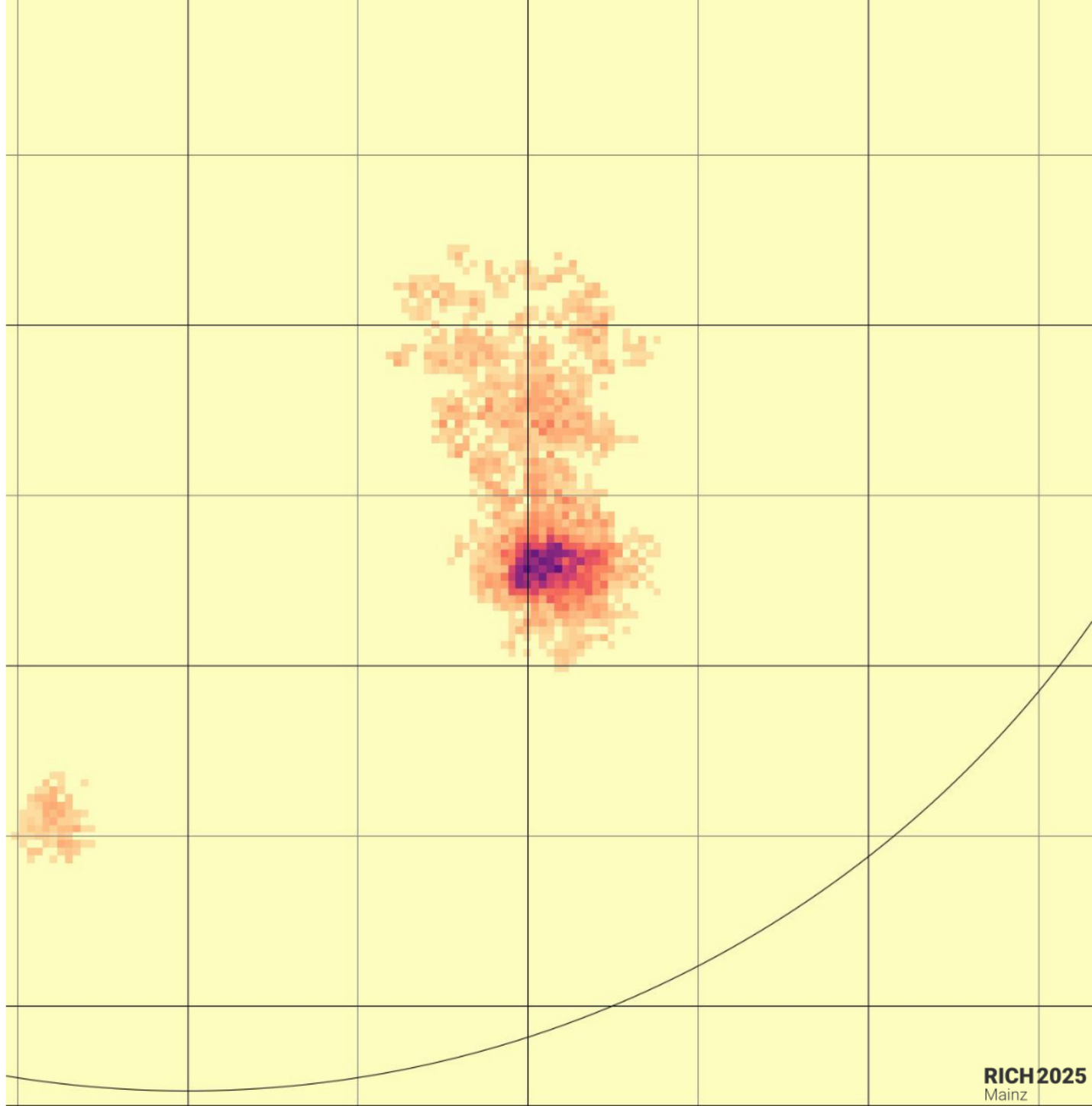
Airshower

Gamma

3.2GeV

708p.e.



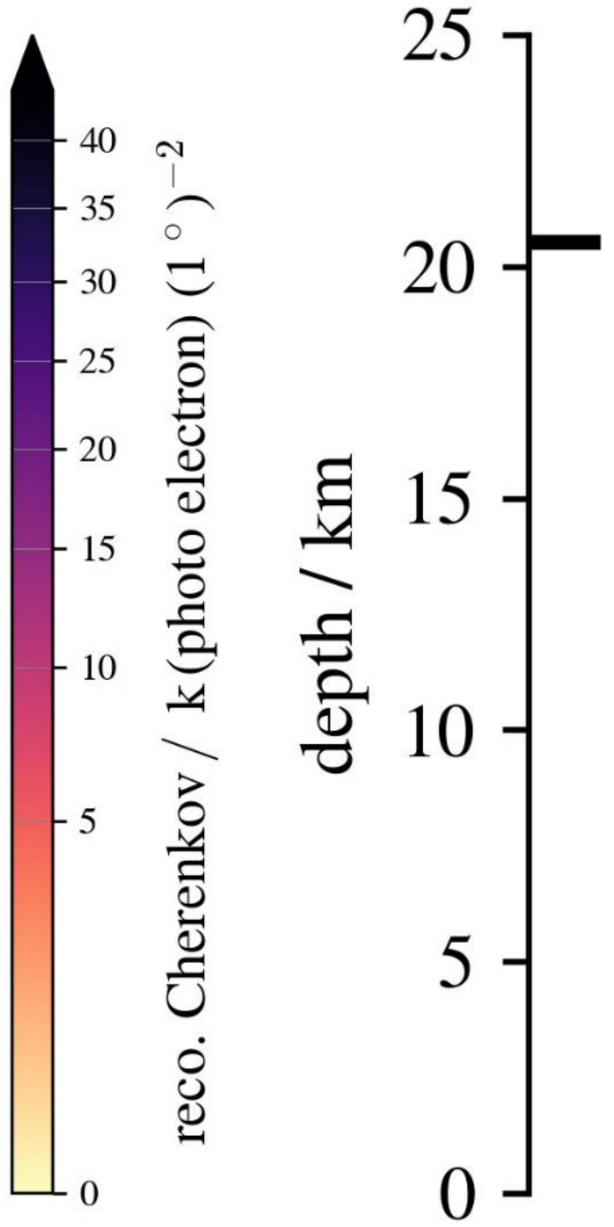


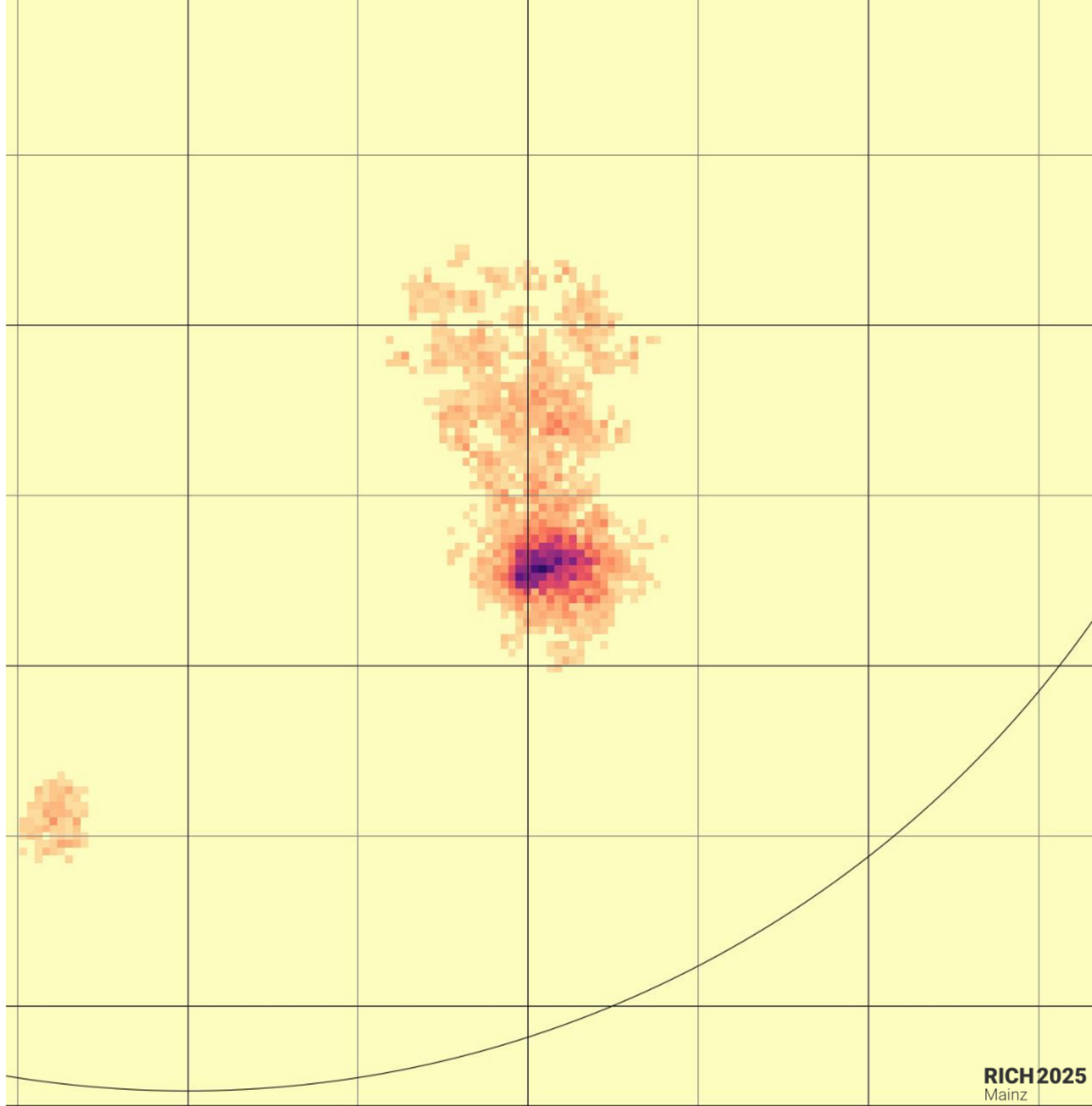
Airshower

Gamma

3.2GeV

708p.e.



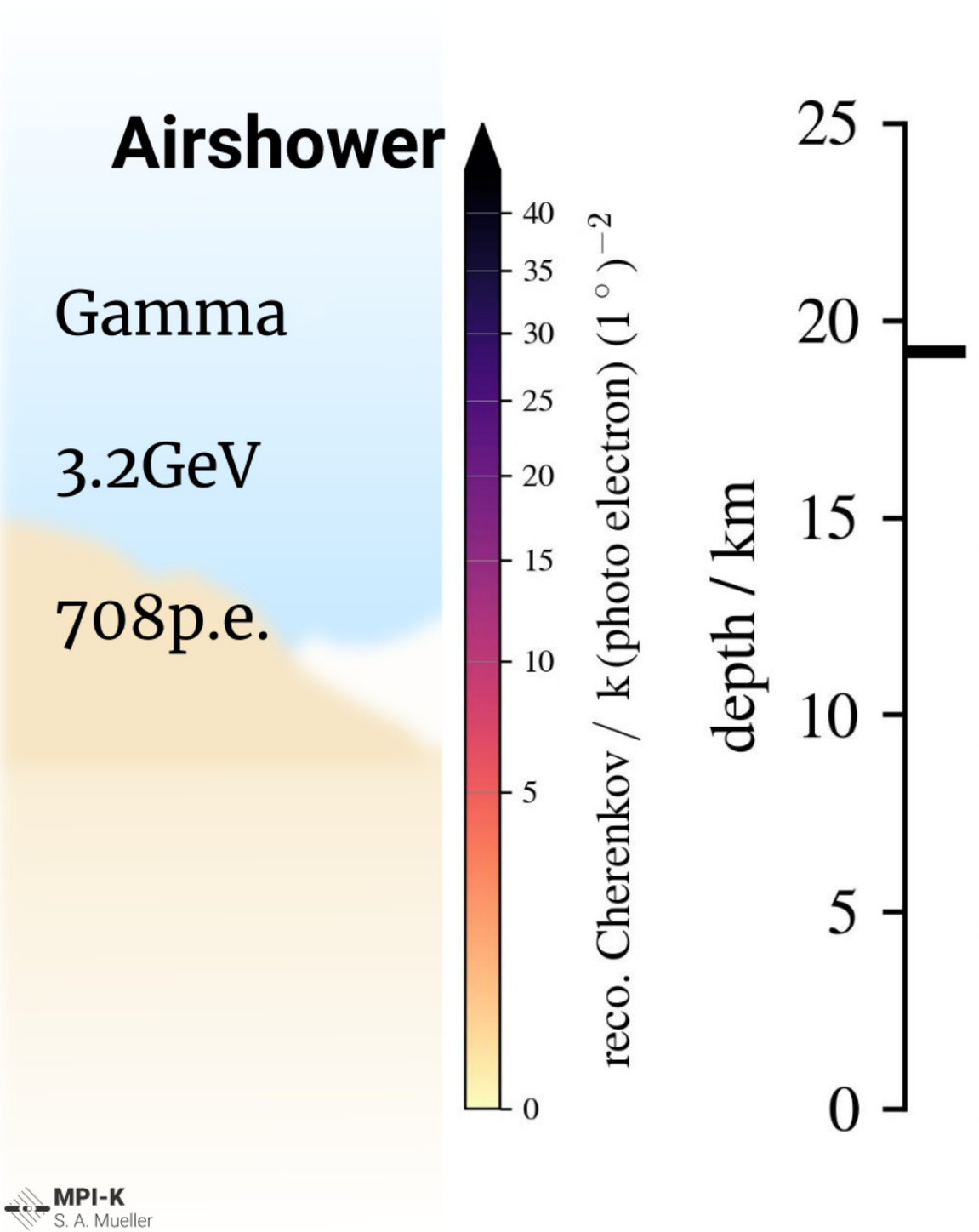


Airshower

Gamma

3.2GeV

708p.e.

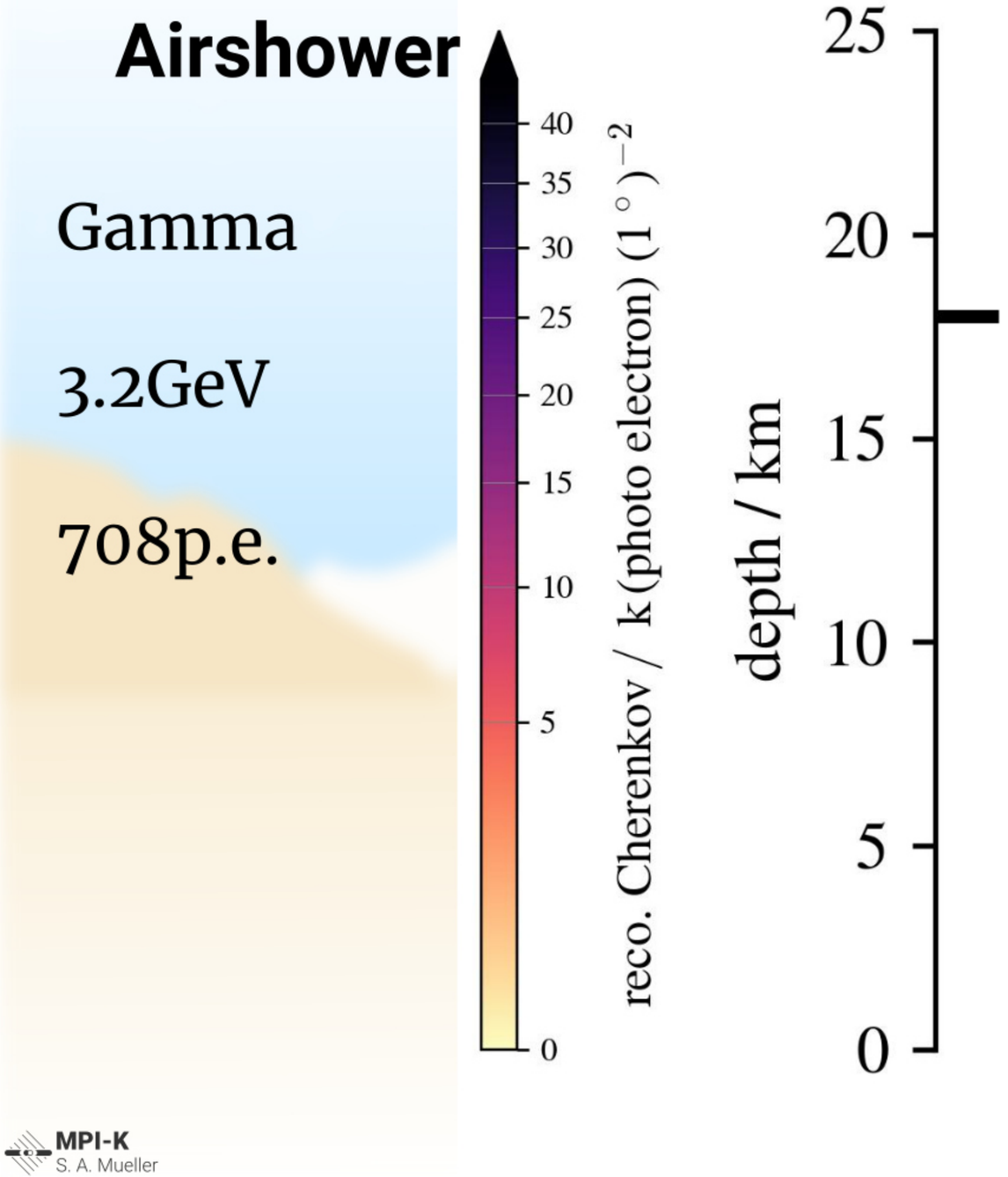


Airshower

Gamma

3.2GeV

708p.e.

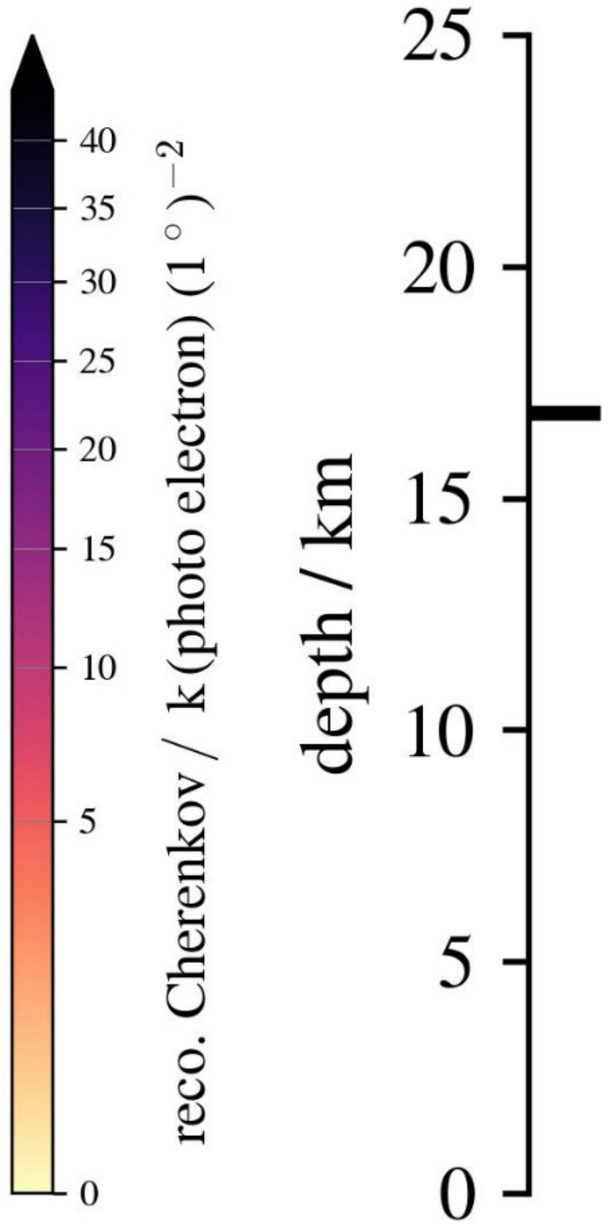


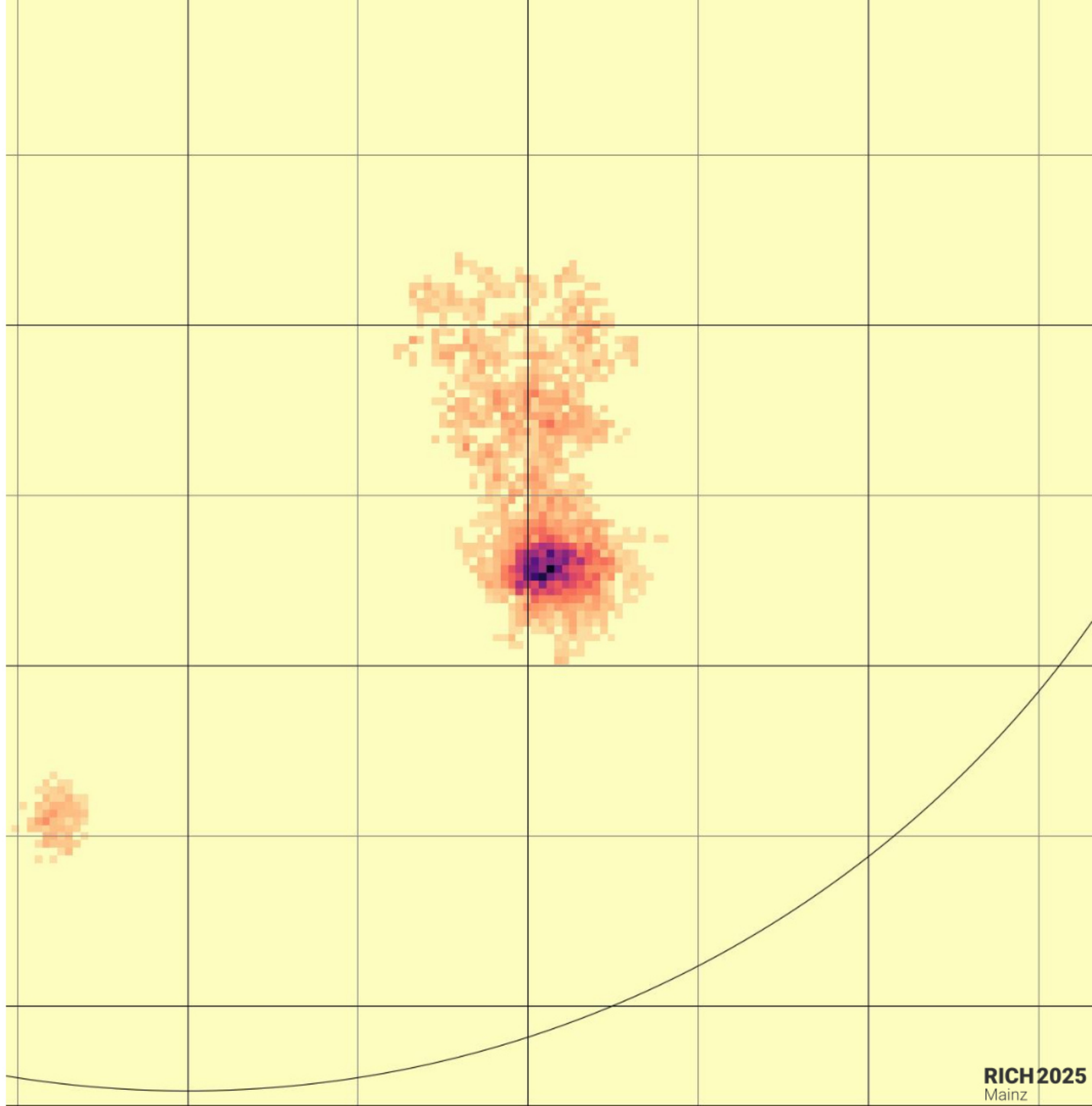
Airshower

Gamma

3.2GeV

708p.e.



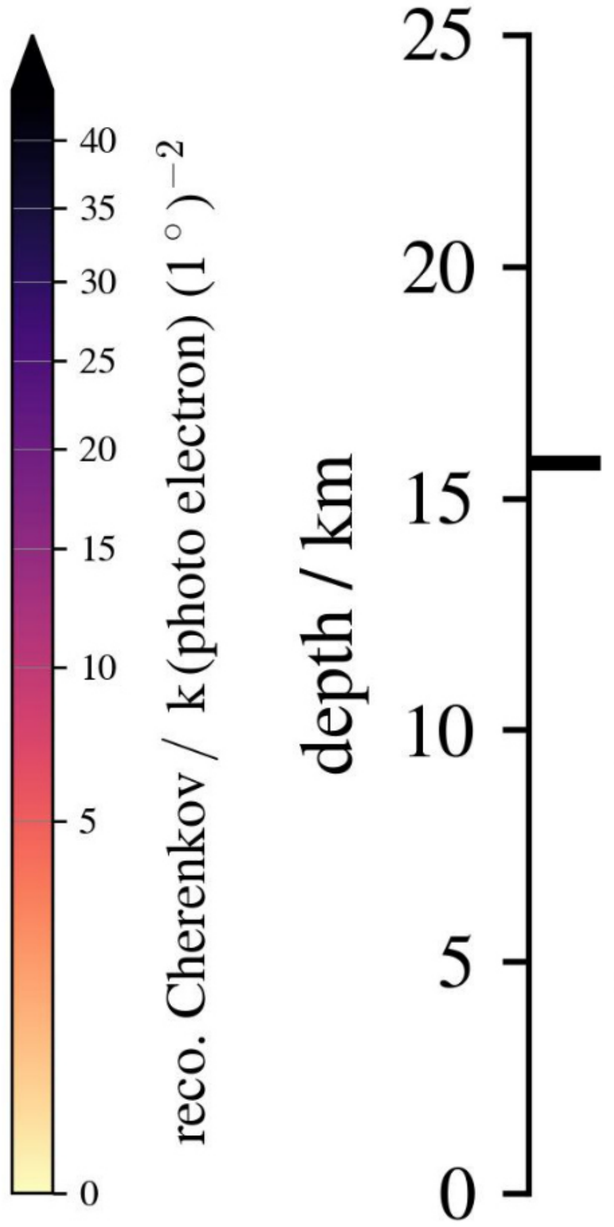


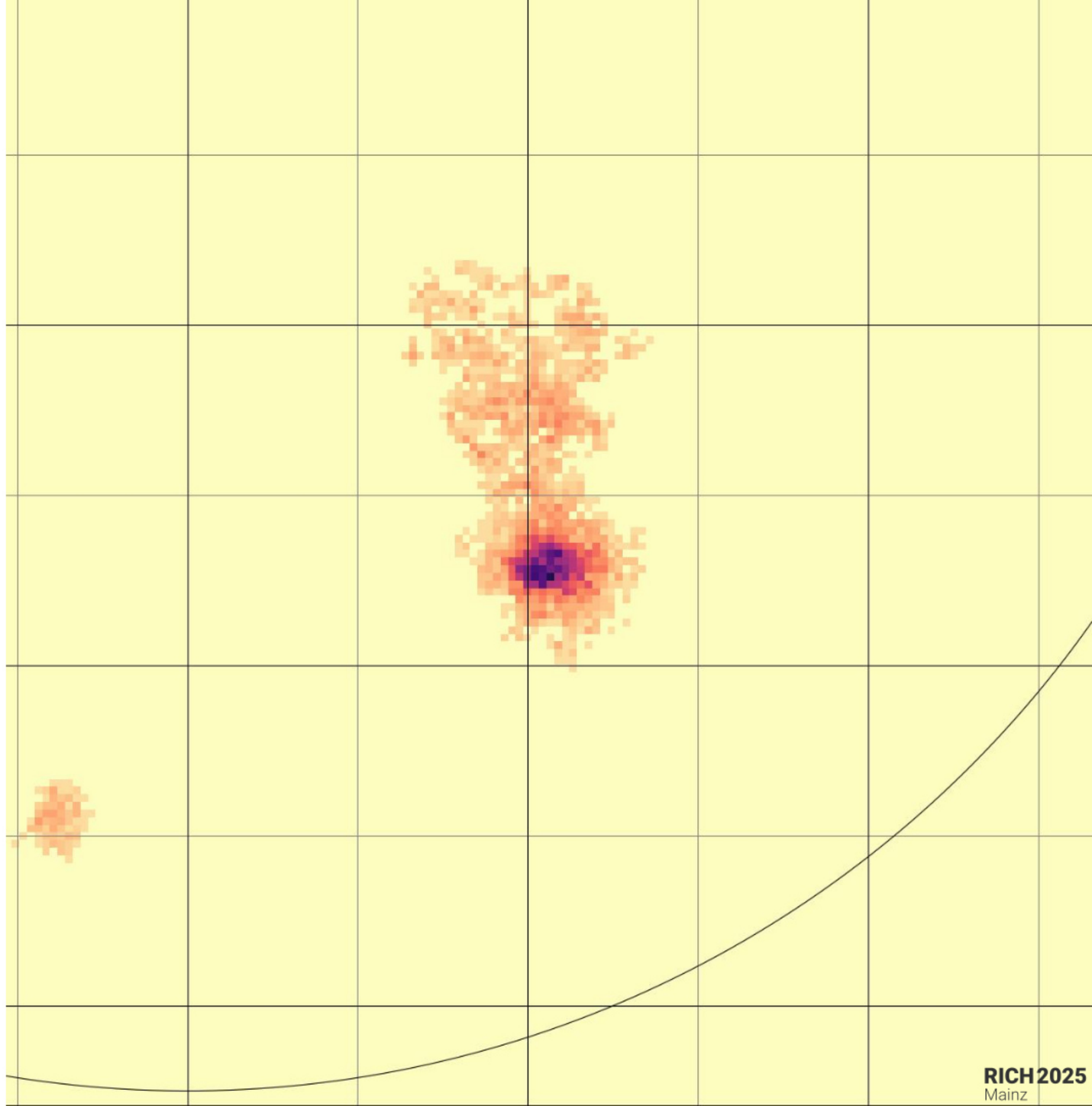
Airshower

Gamma

3.2GeV

708p.e.



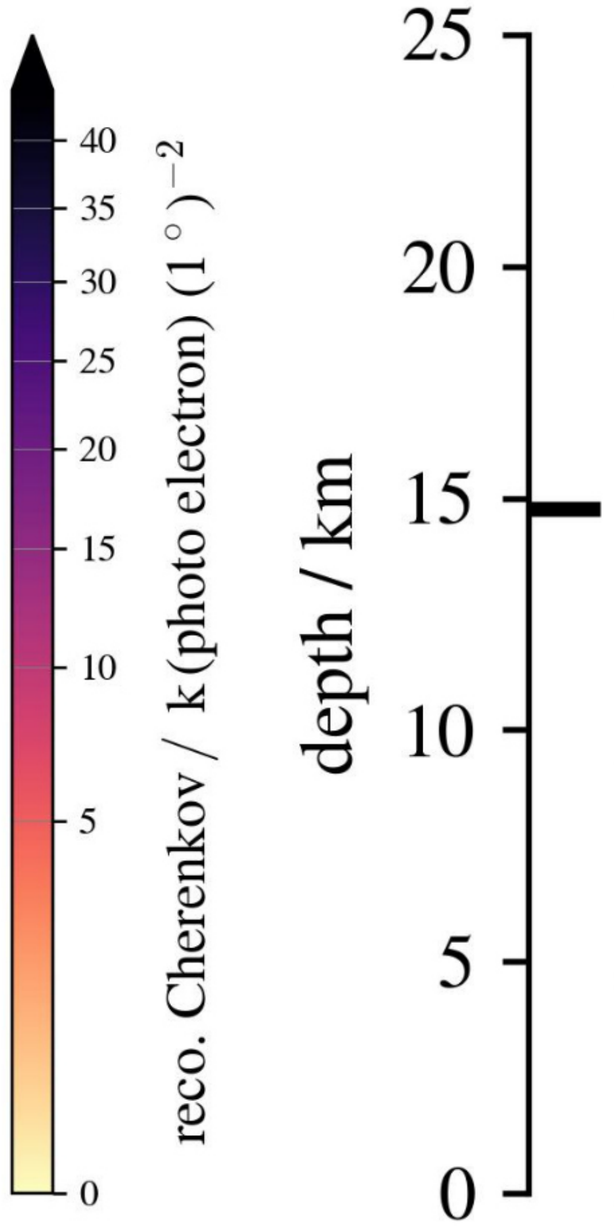


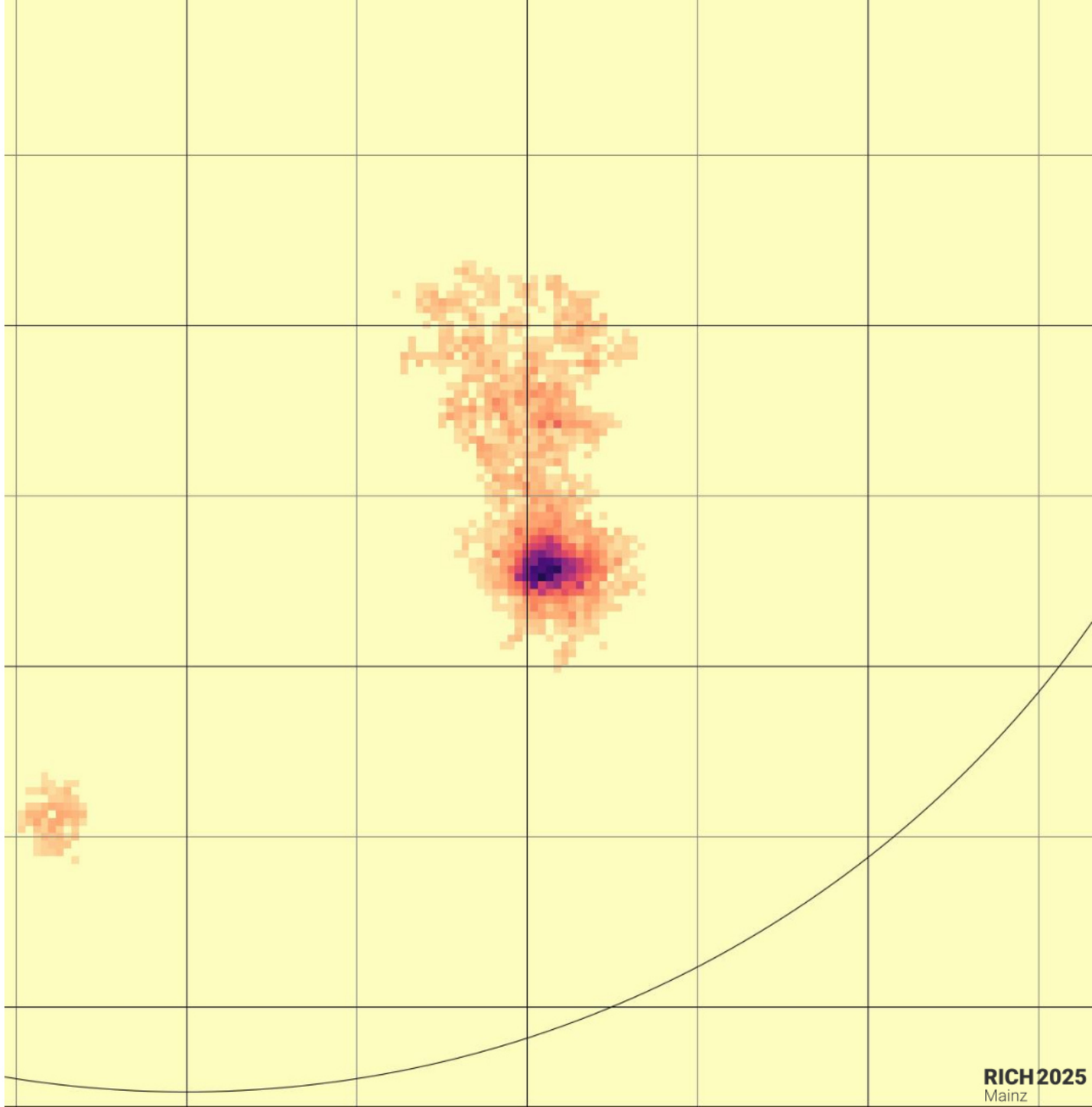
Airshower

Gamma

3.2GeV

708p.e.



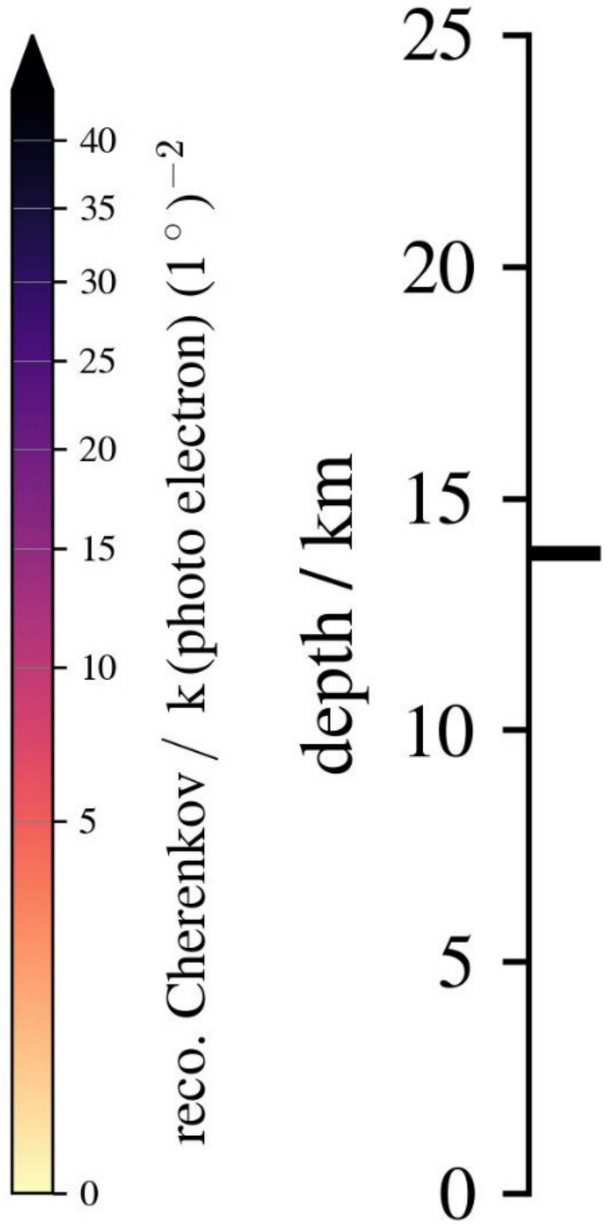


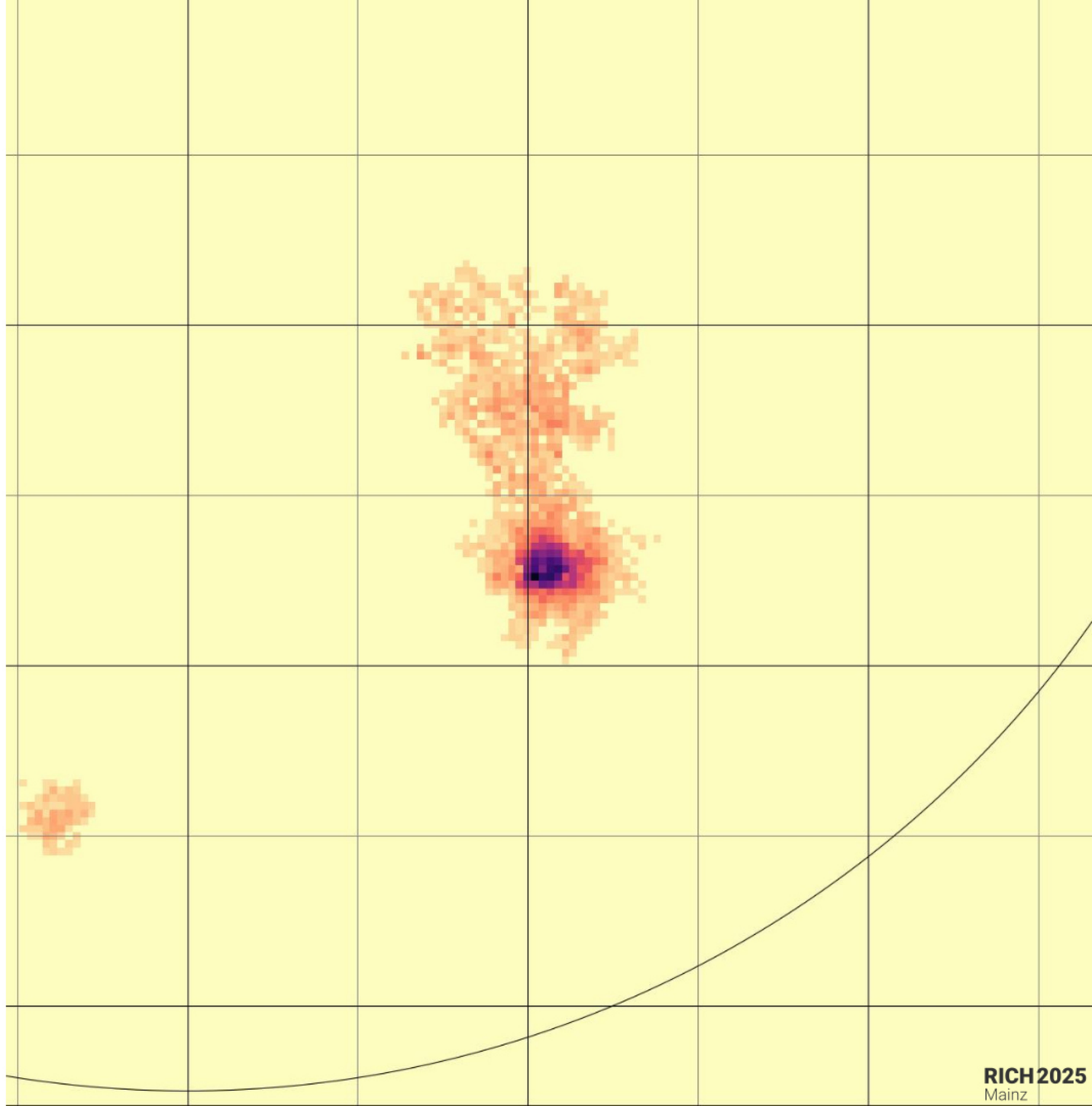
Airshower

Gamma

3.2GeV

708p.e.



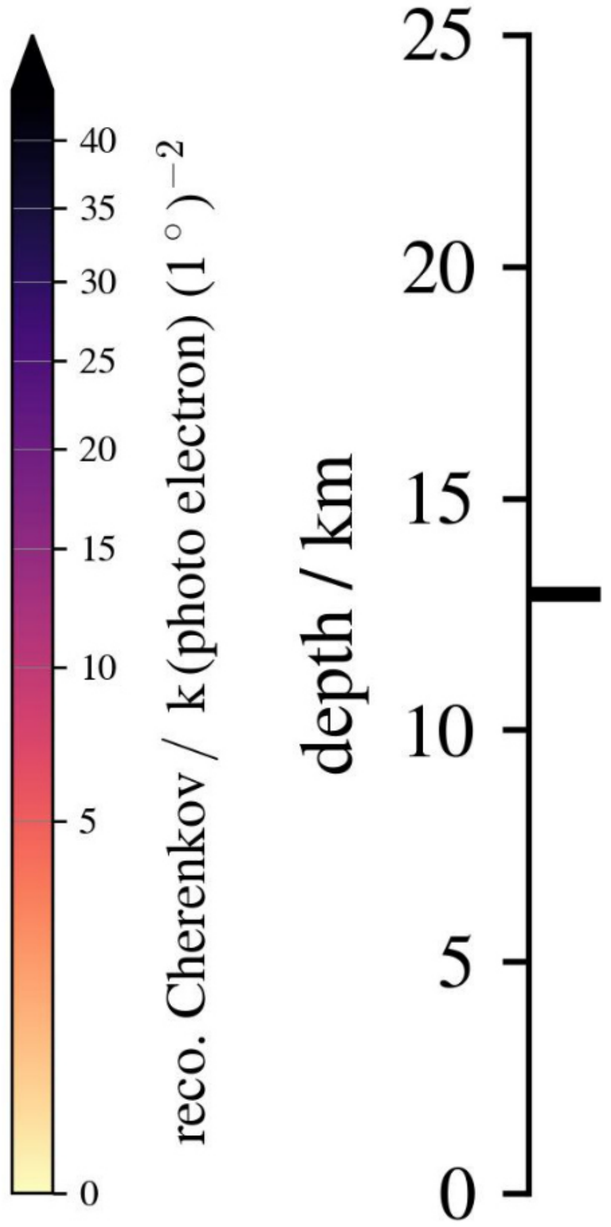


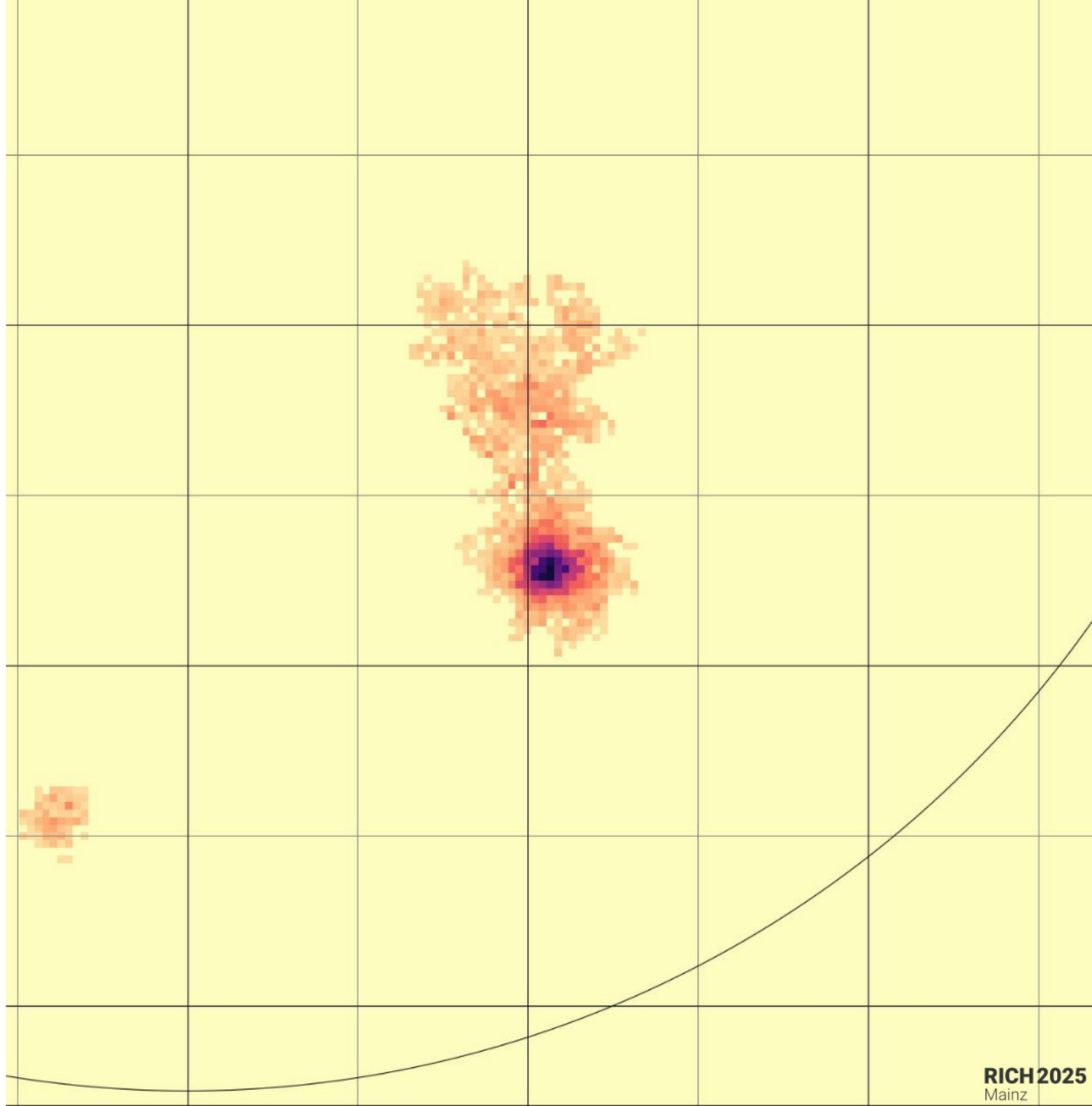
Airshower

Gamma

3.2GeV

708p.e.



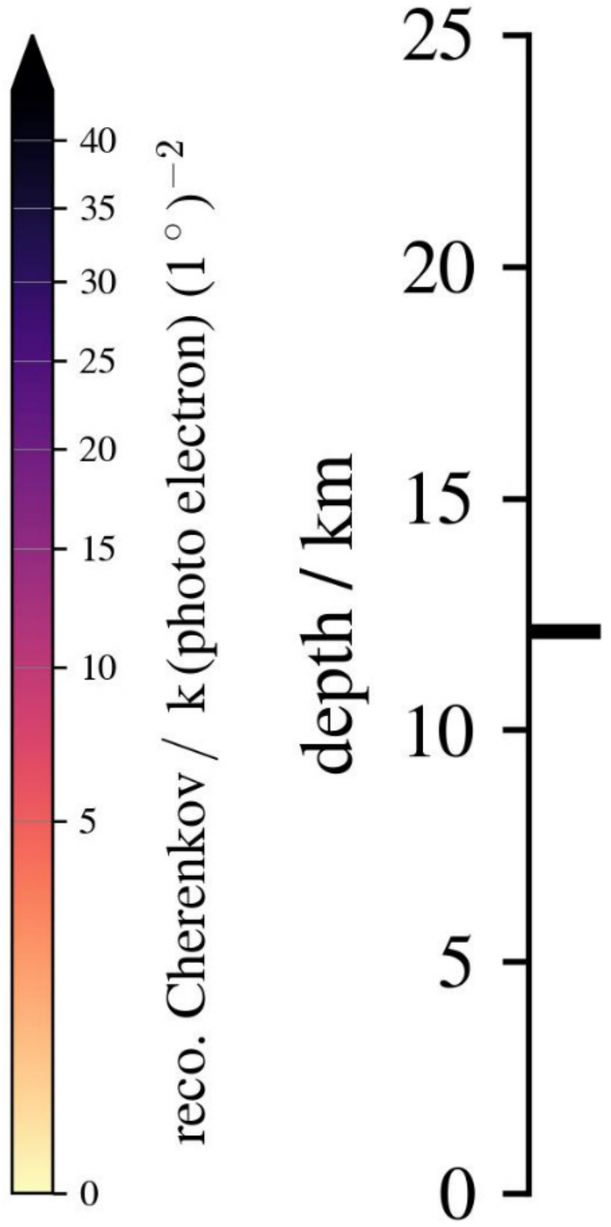


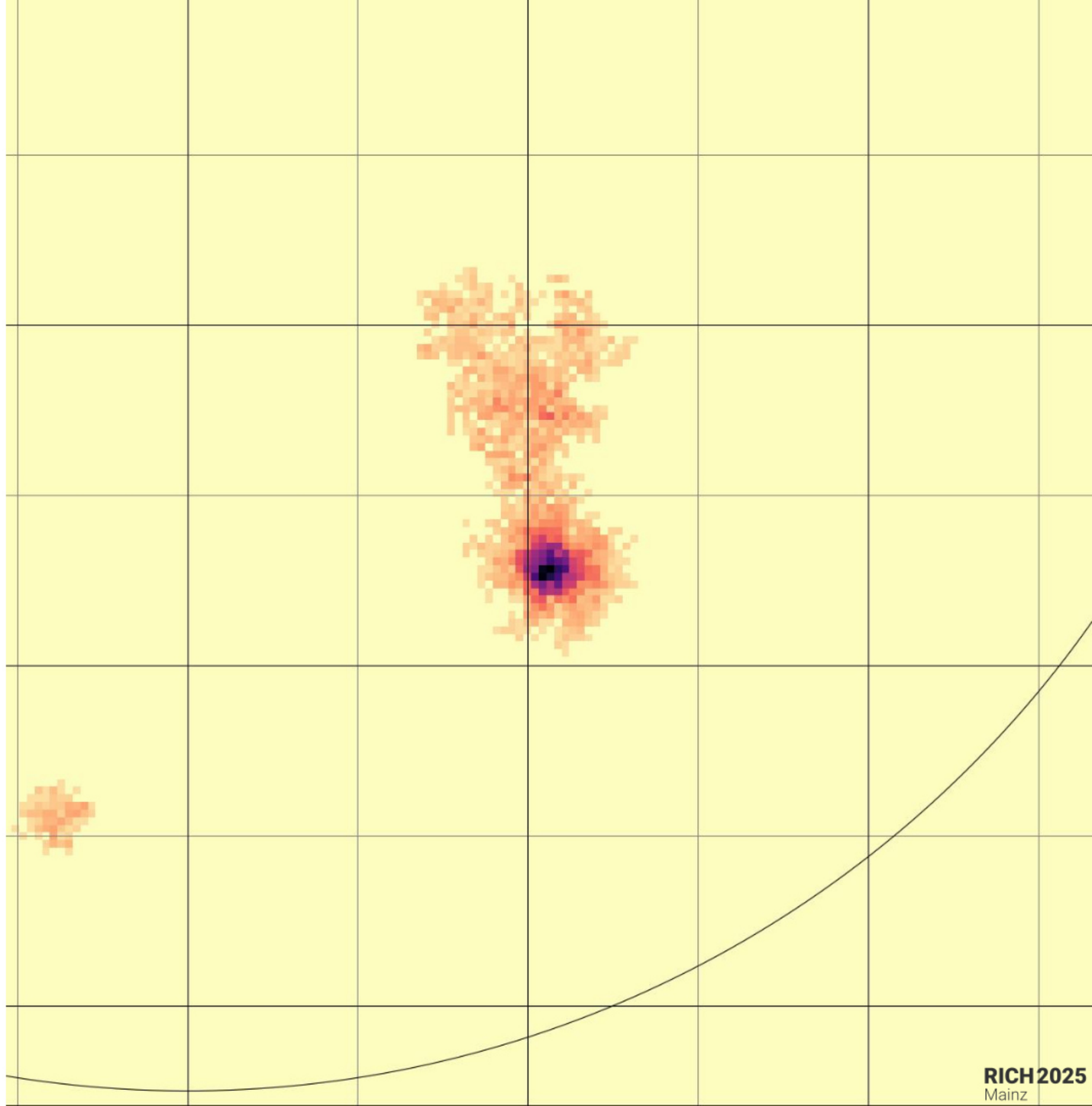
Airshower

Gamma

3.2GeV

708p.e.



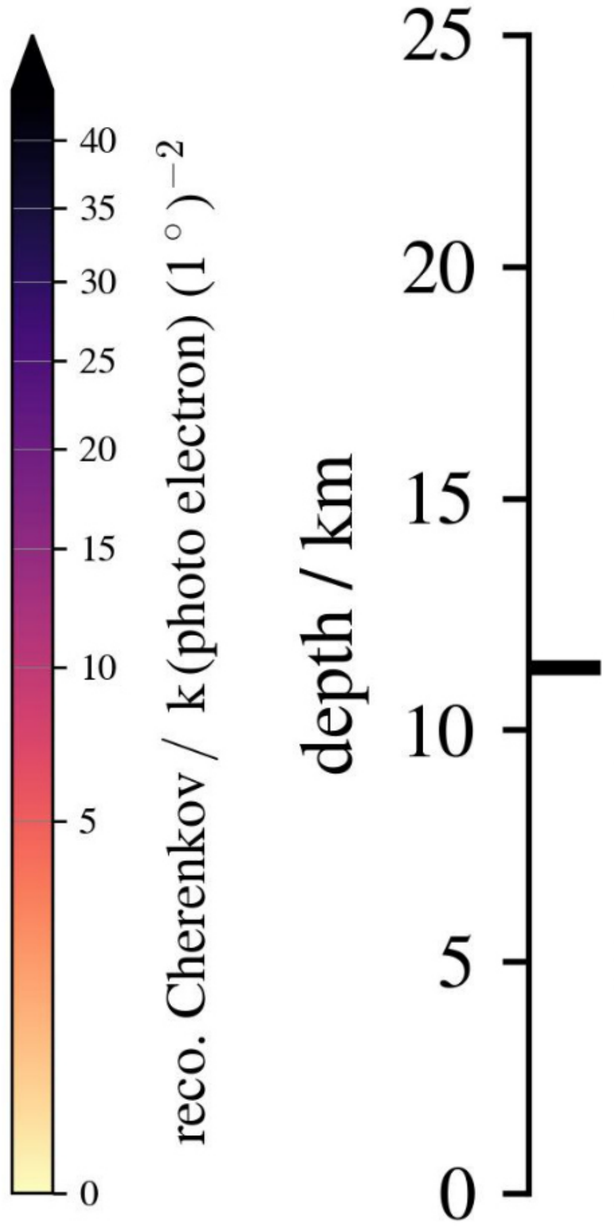


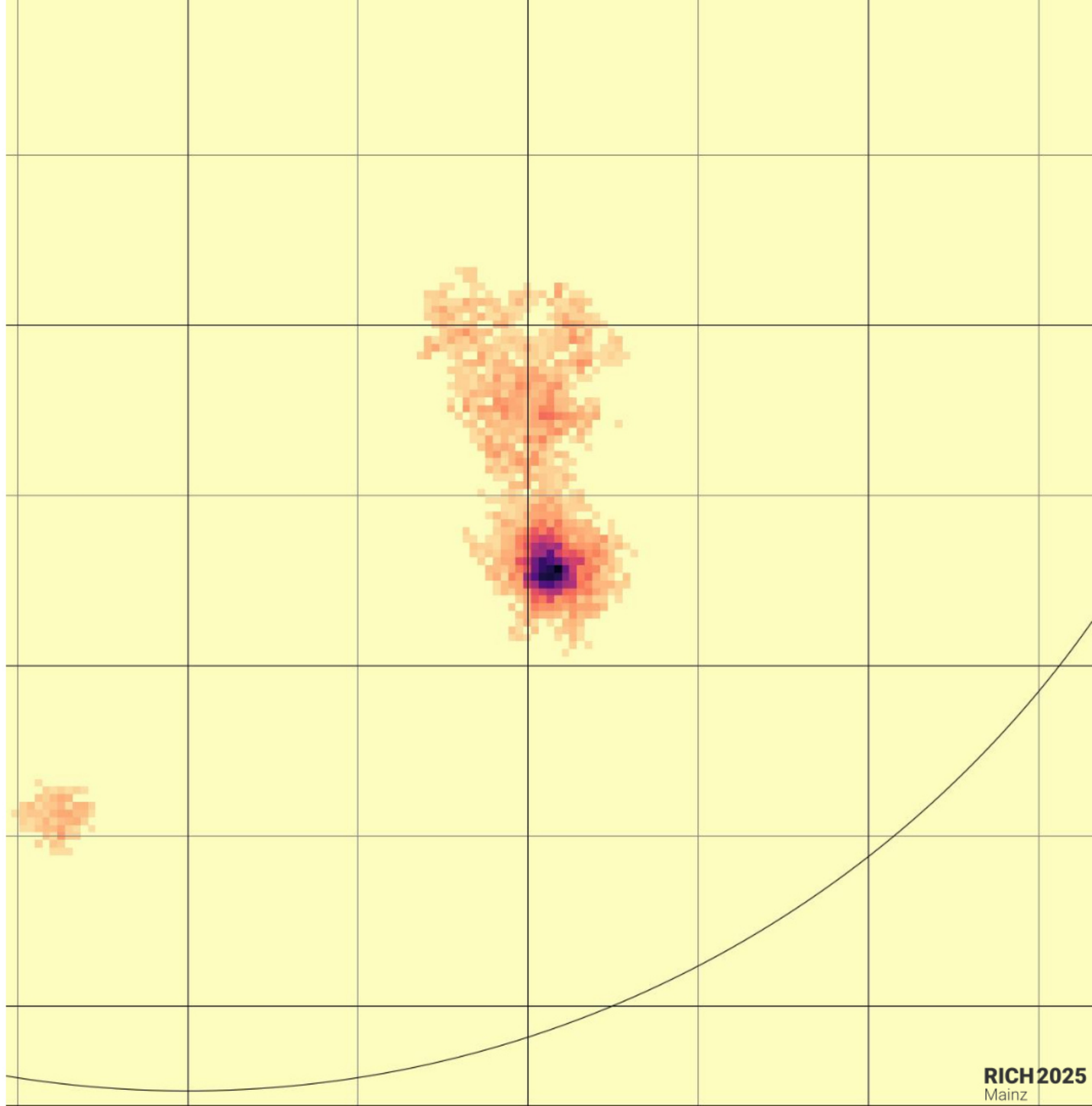
Airshower

Gamma

3.2GeV

708p.e.



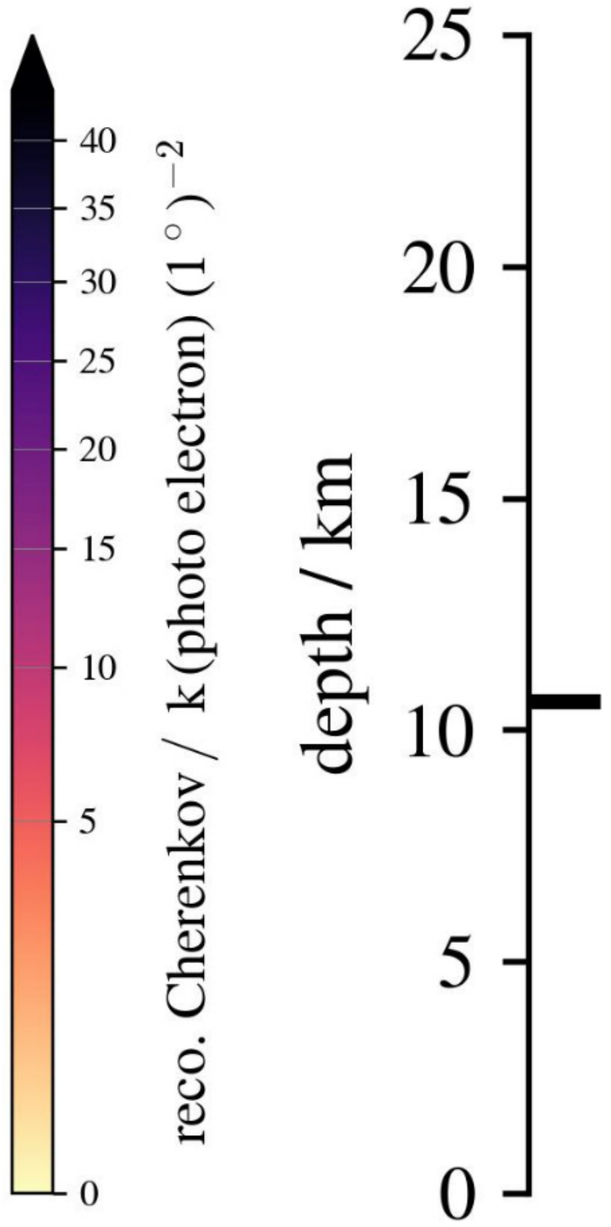


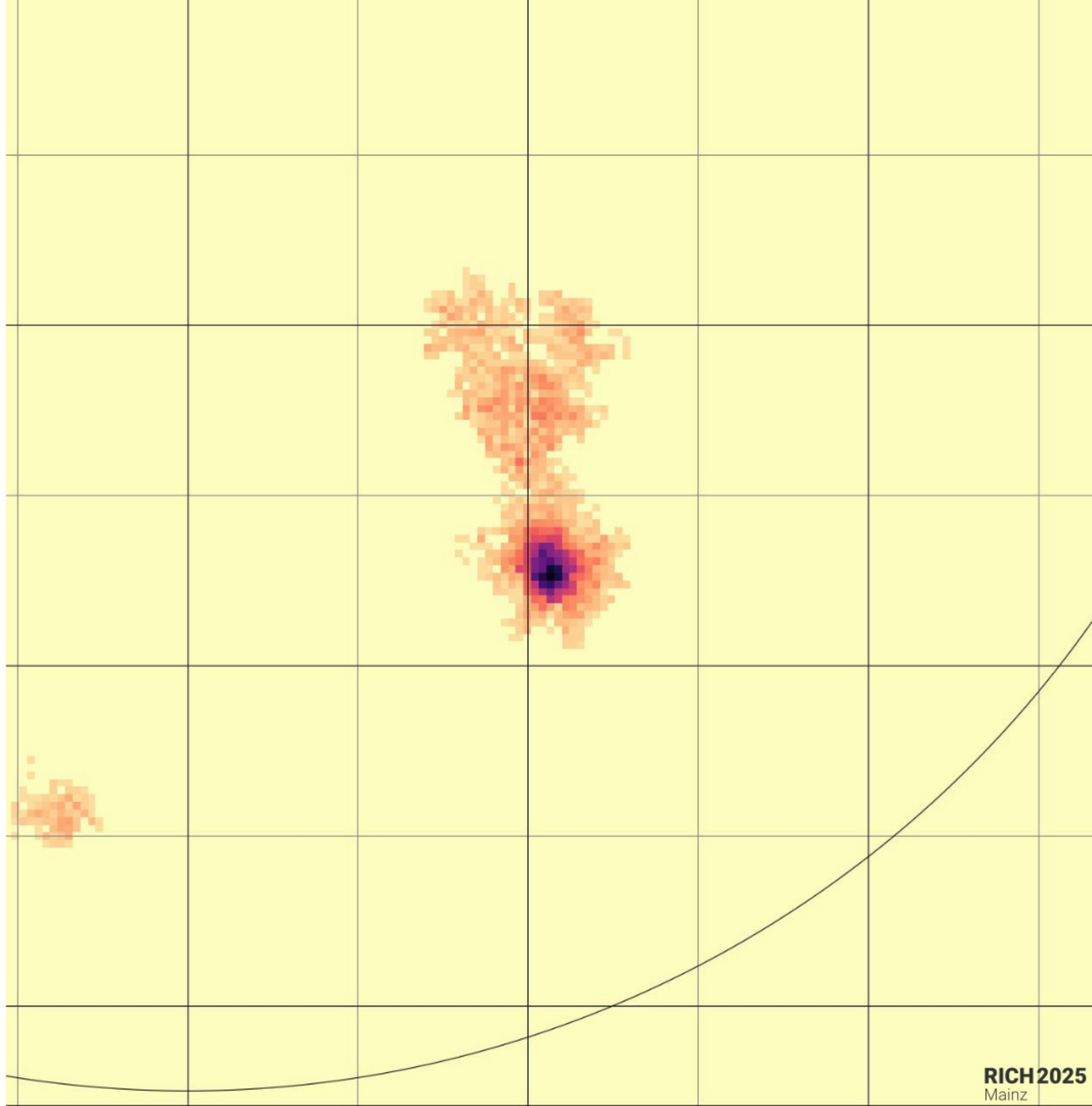
Airshower

Gamma

3.2GeV

708p.e.



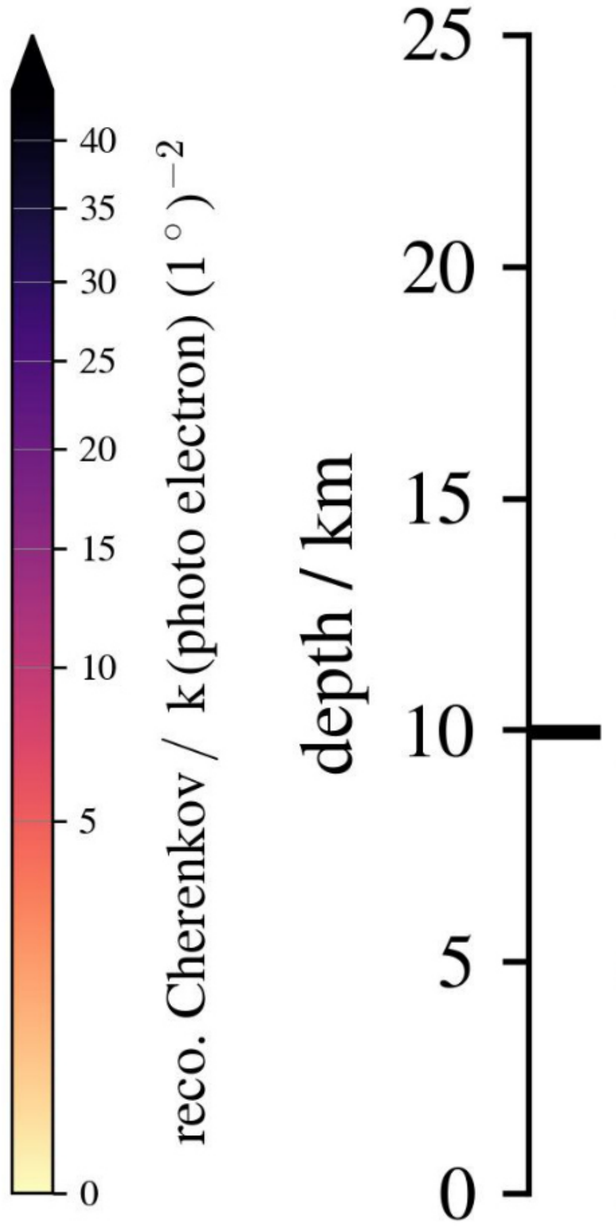


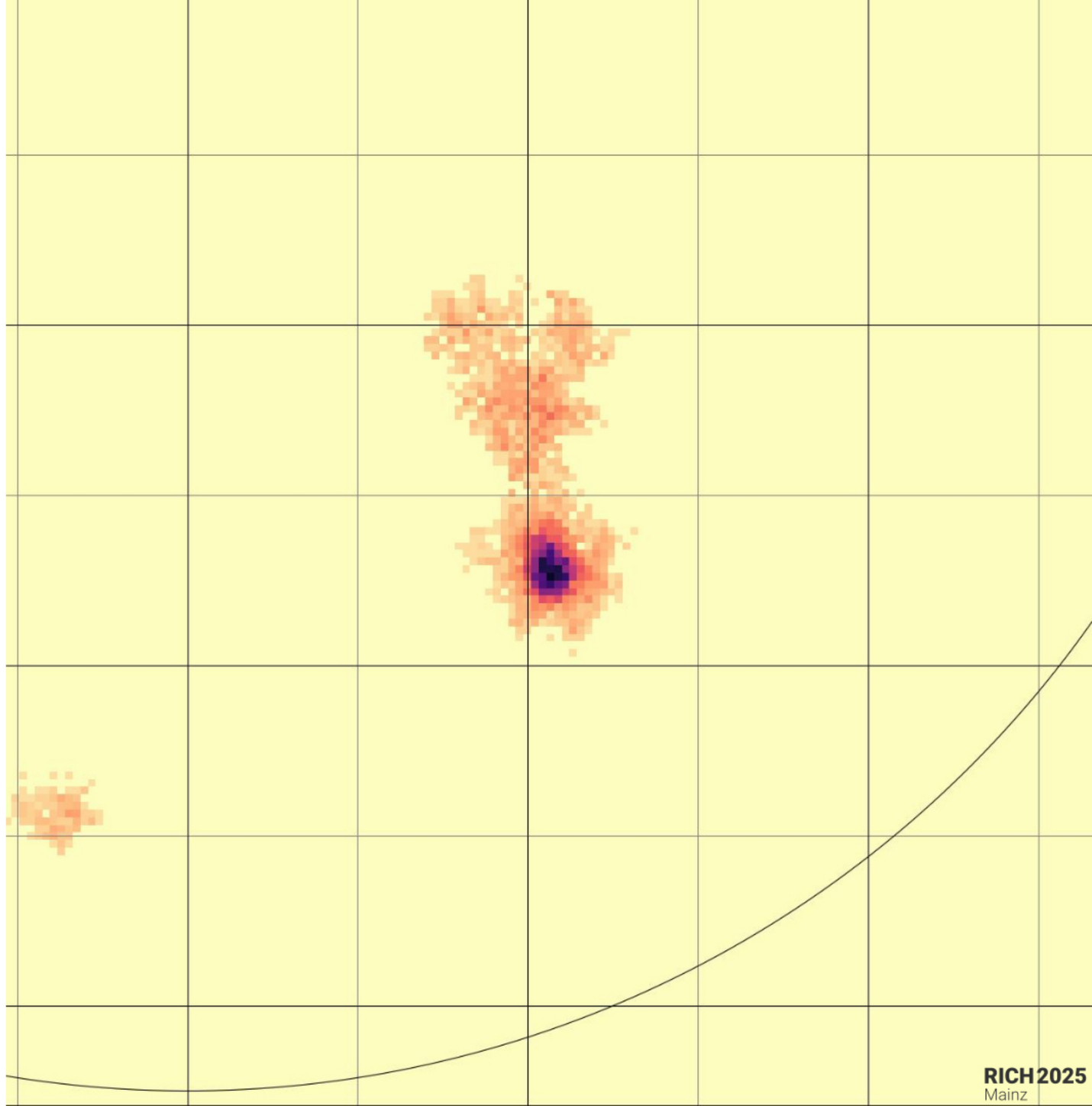
Airshower

Gamma

3.2GeV

708p.e.



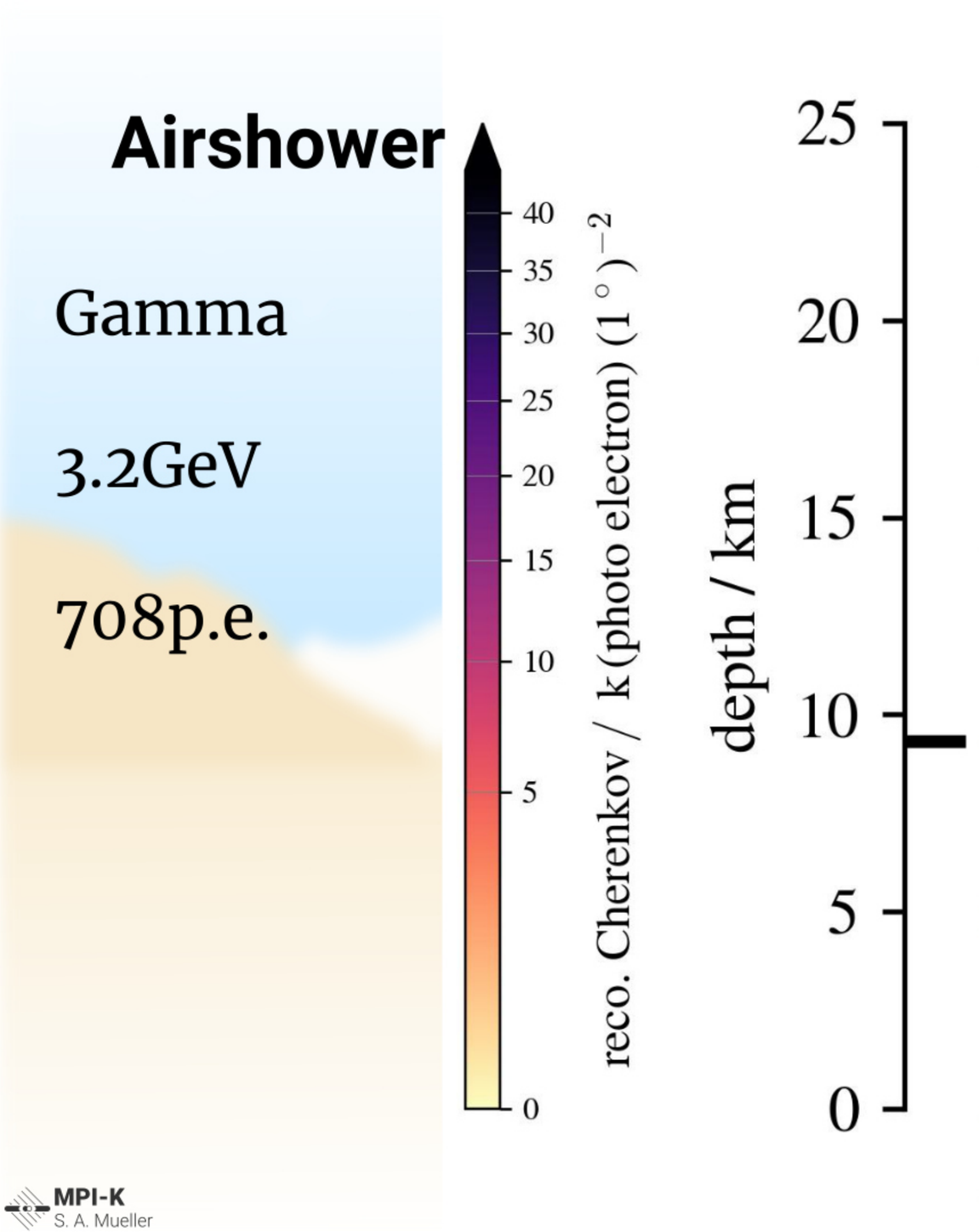


Airshower

Gamma

3.2GeV

708p.e.



Airshower

Gamma

3.2GeV

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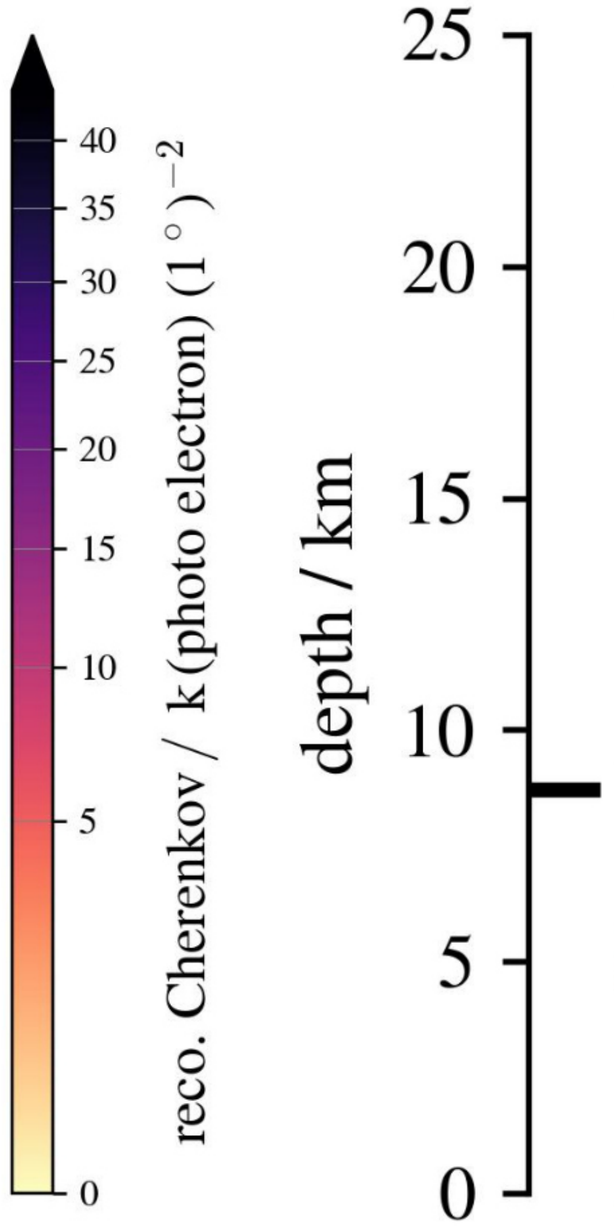
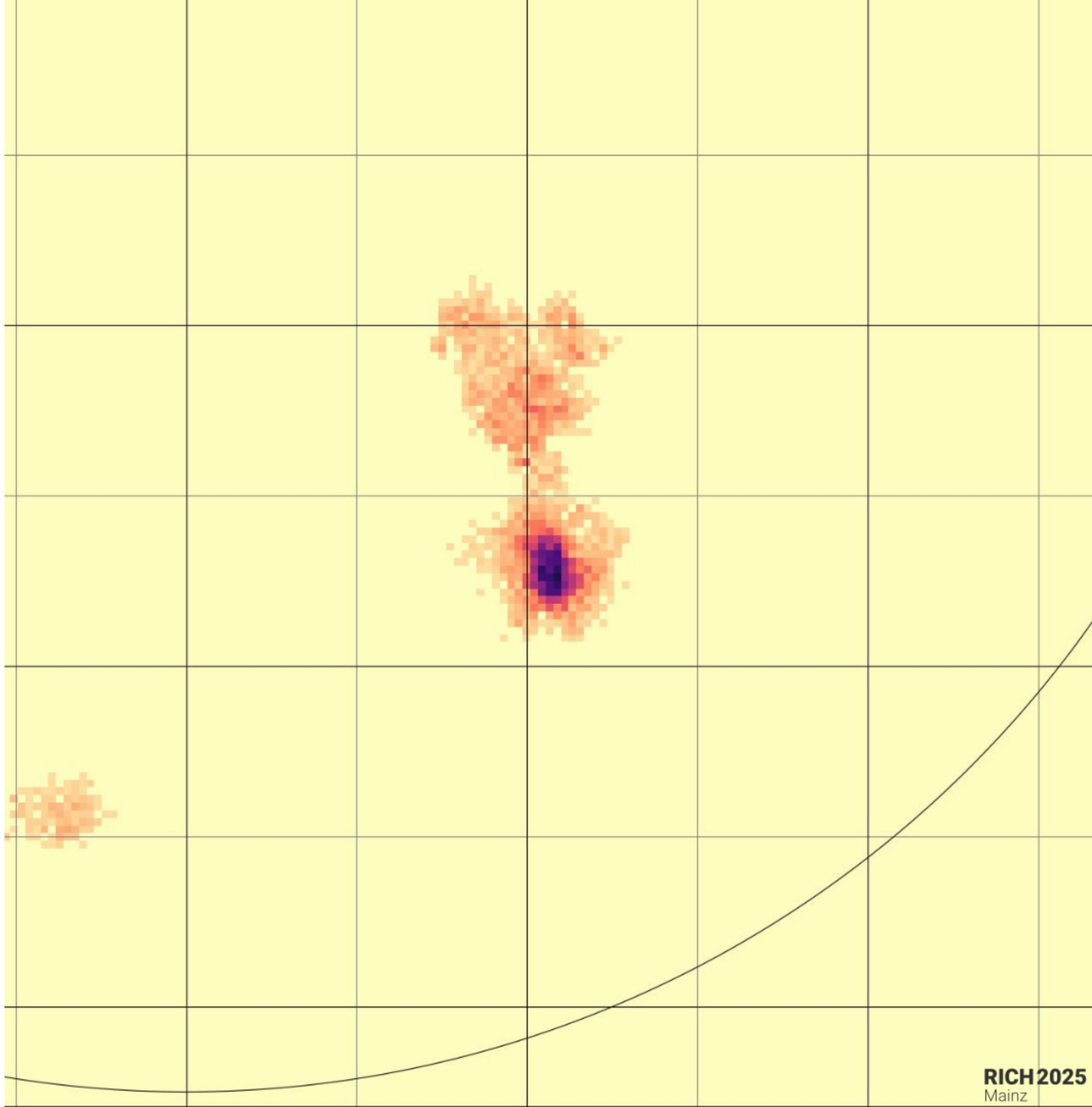


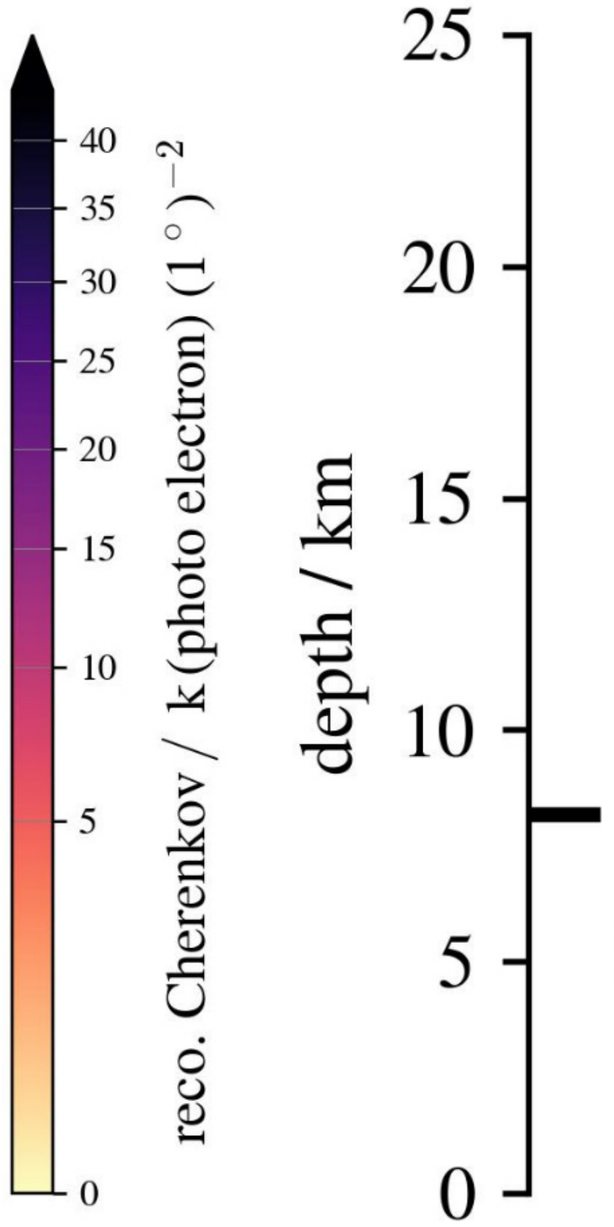


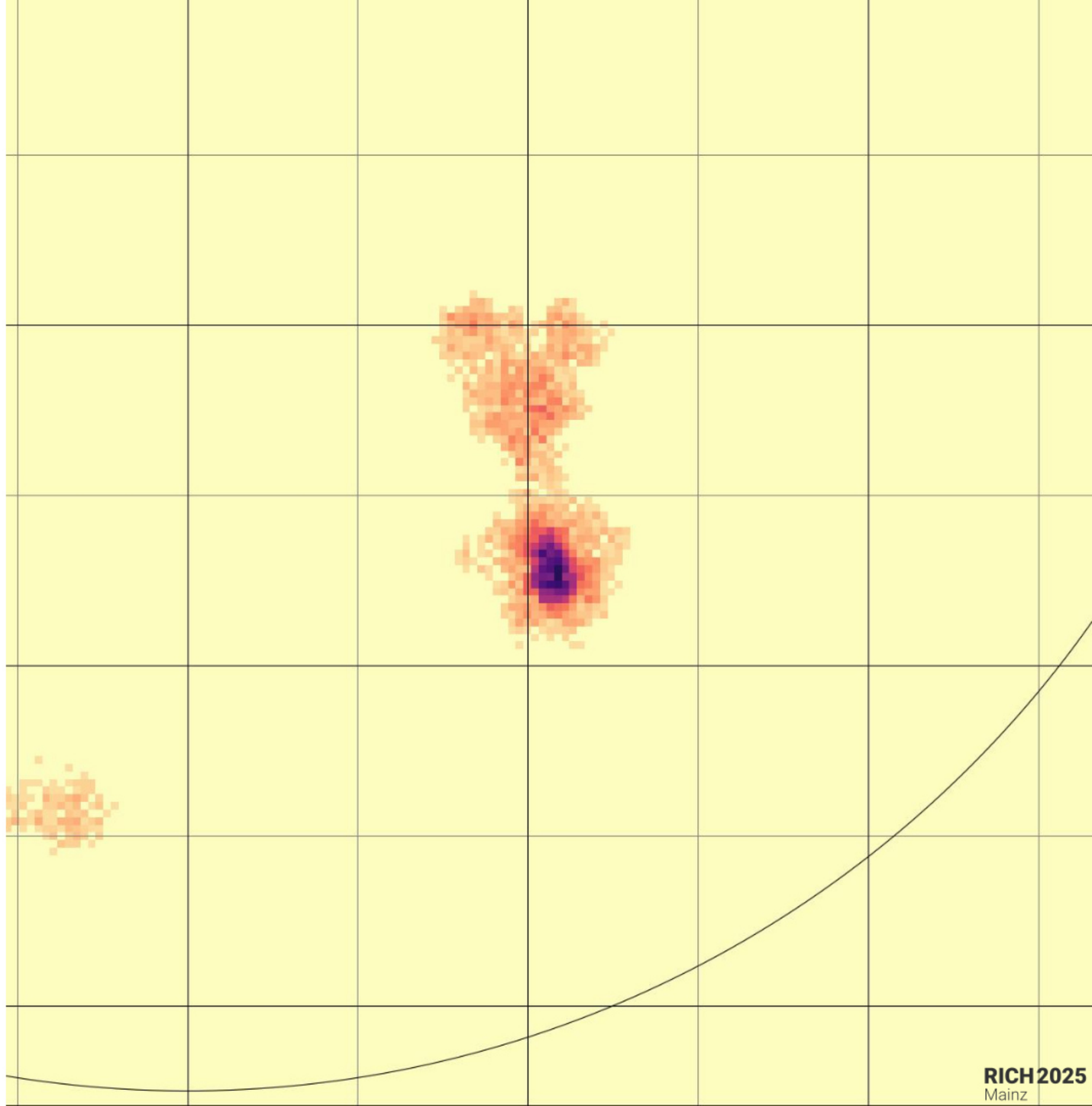
Airshower

Gamma

3.2GeV

708p.e.





Airshower

Gamma

3.2GeV

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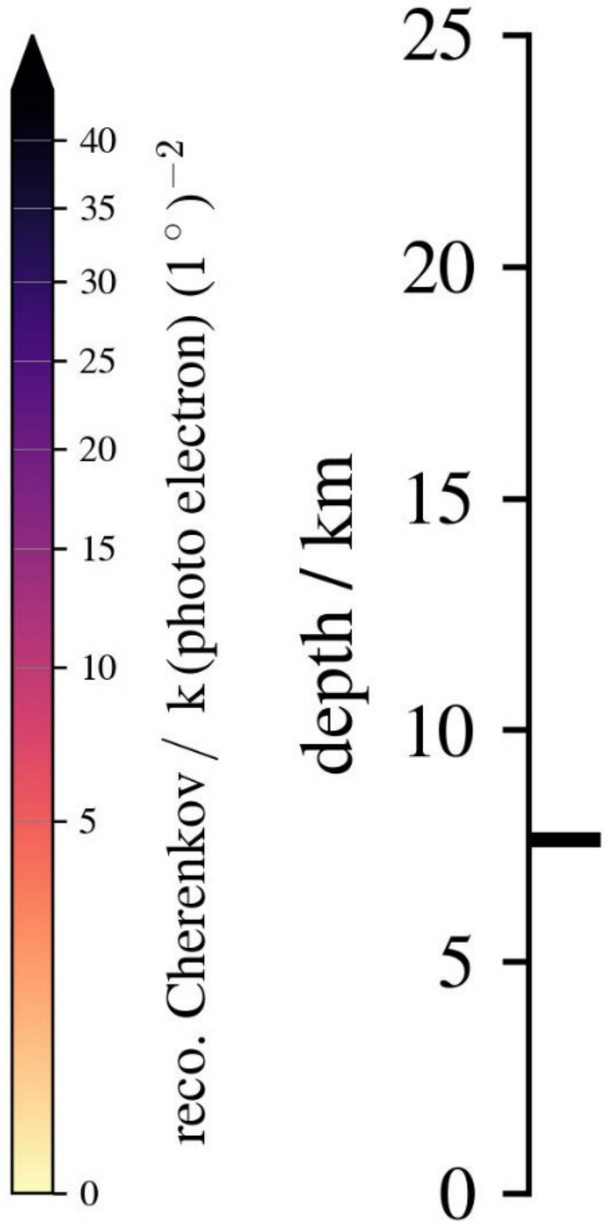

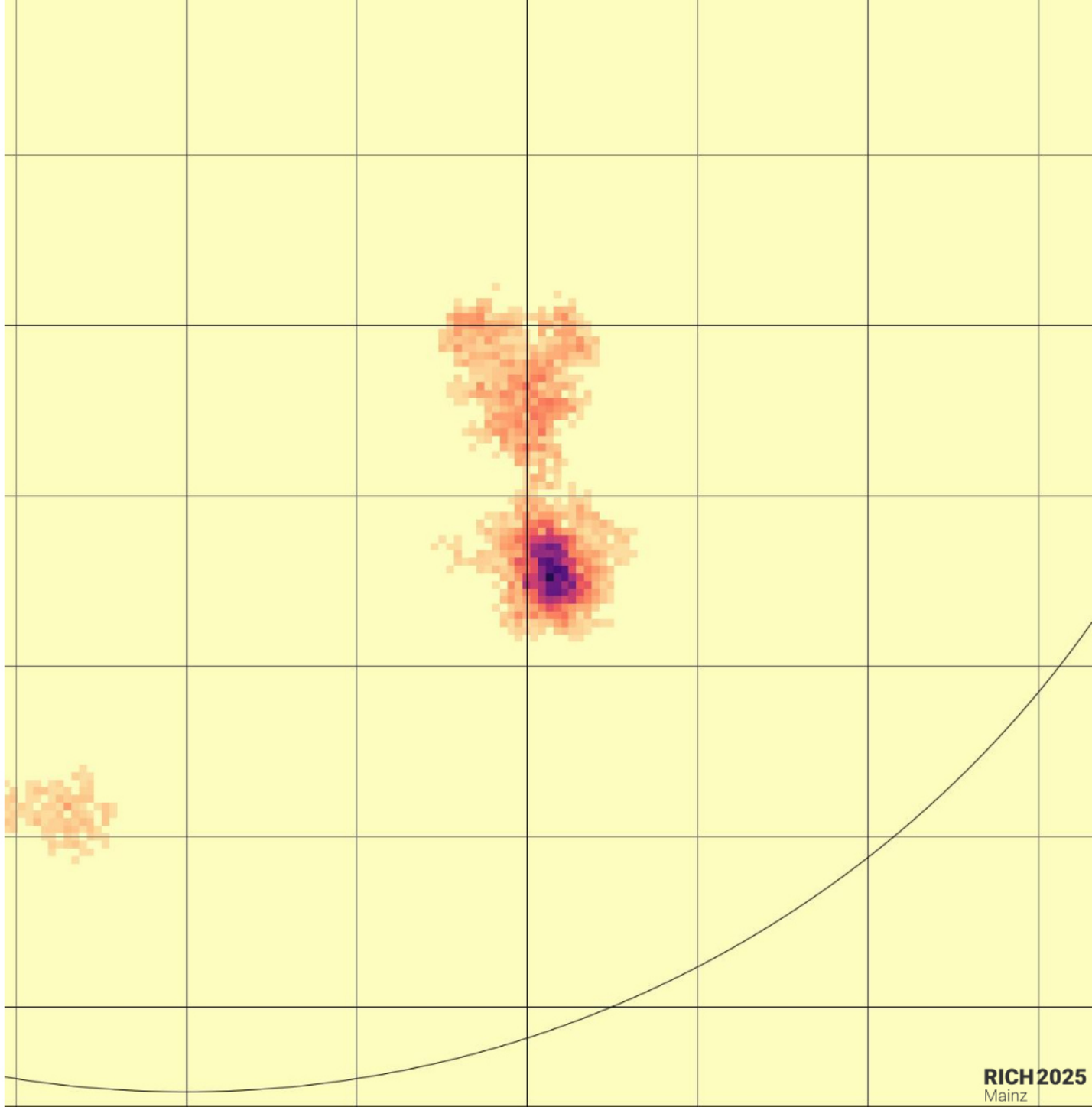

Airshower

Gamma

3.2GeV

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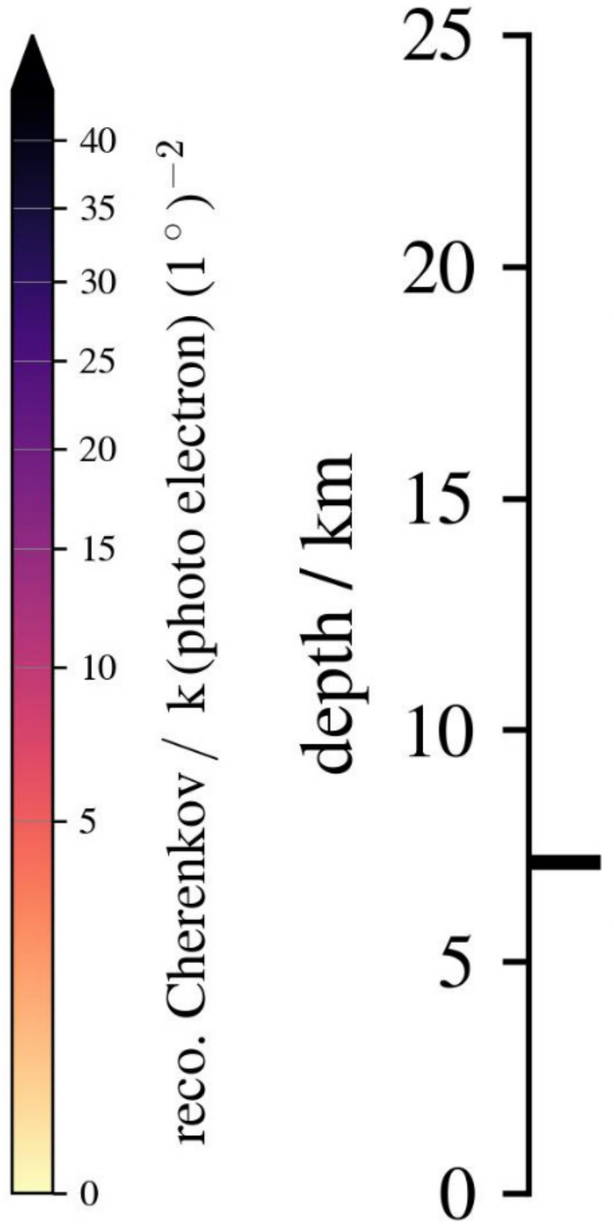

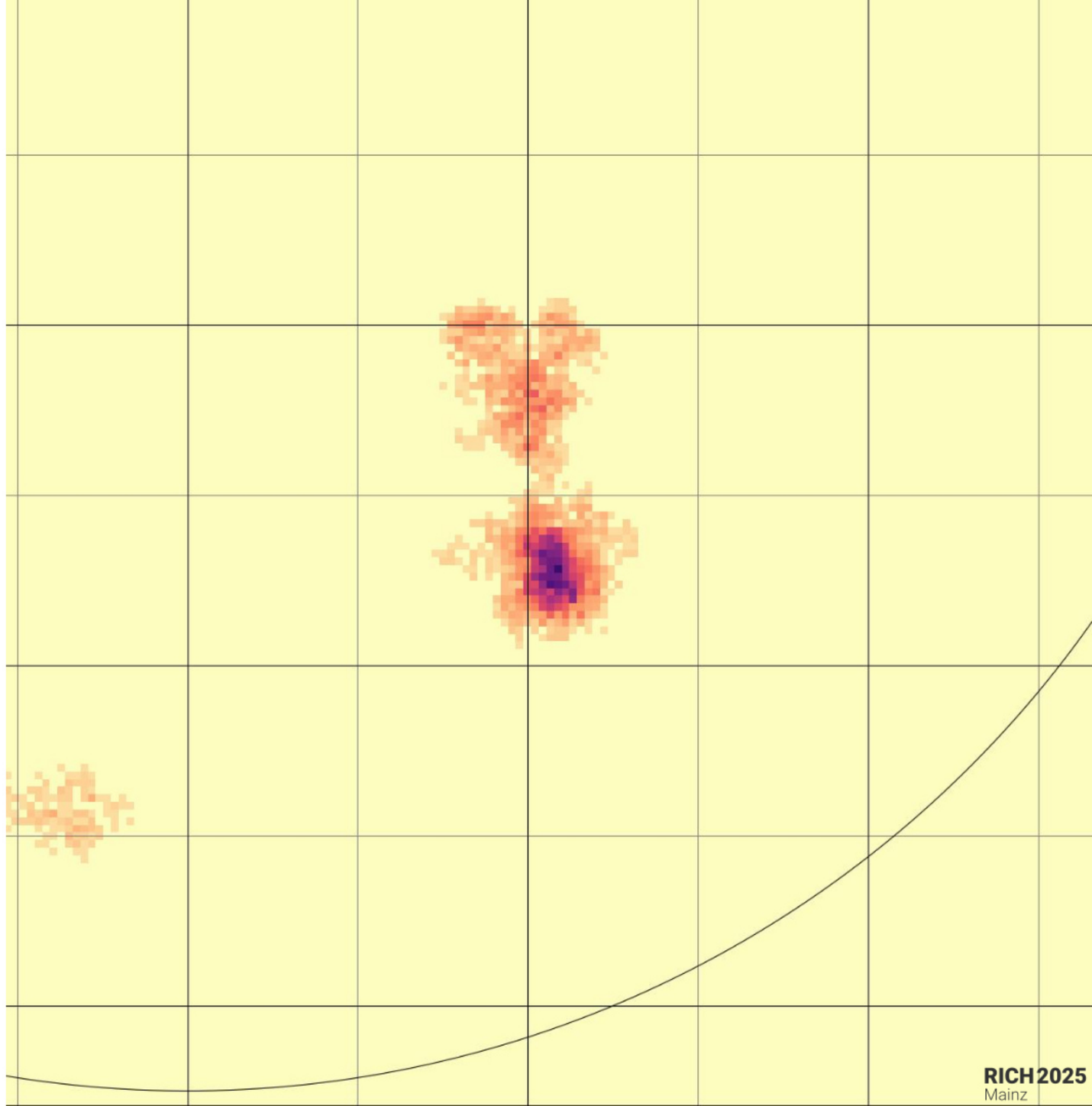

Airshower

Gamma

3.2GeV

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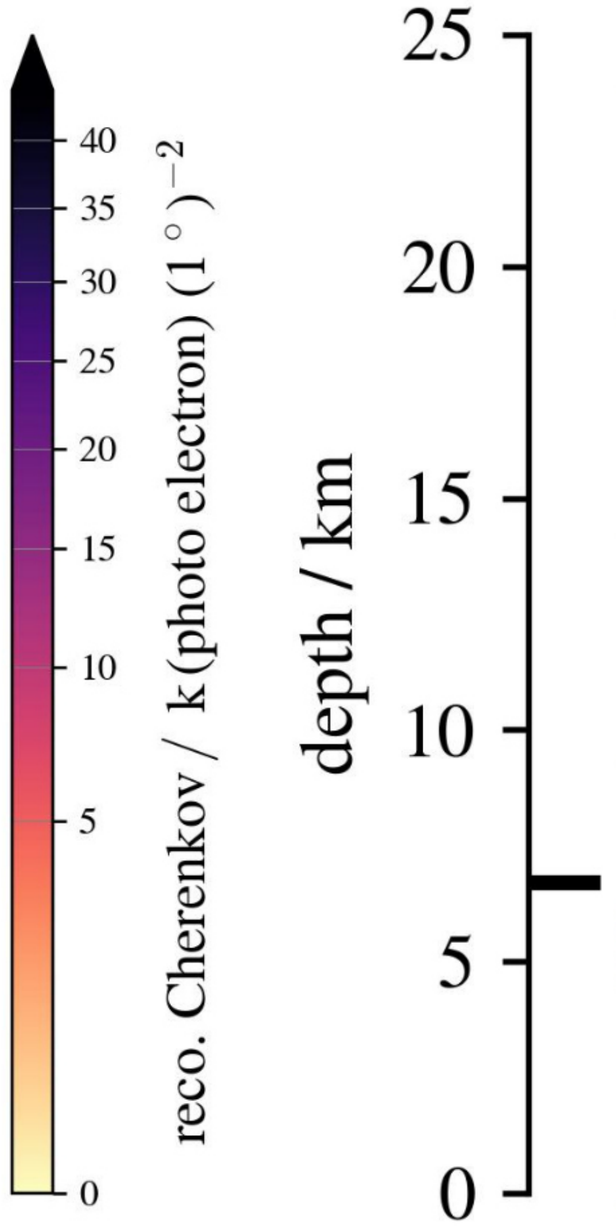

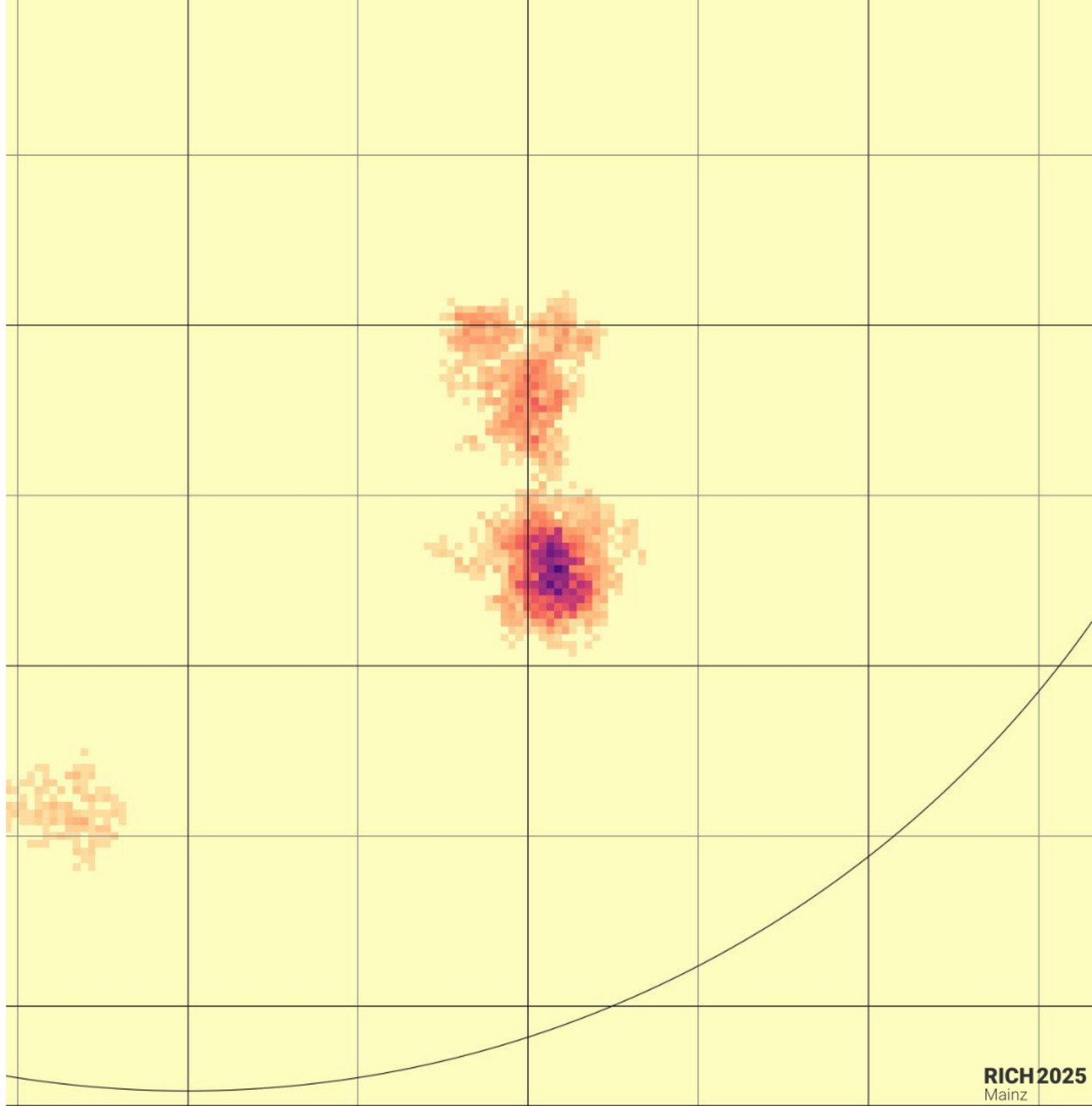

Airshower

Gamma

3.2GeV

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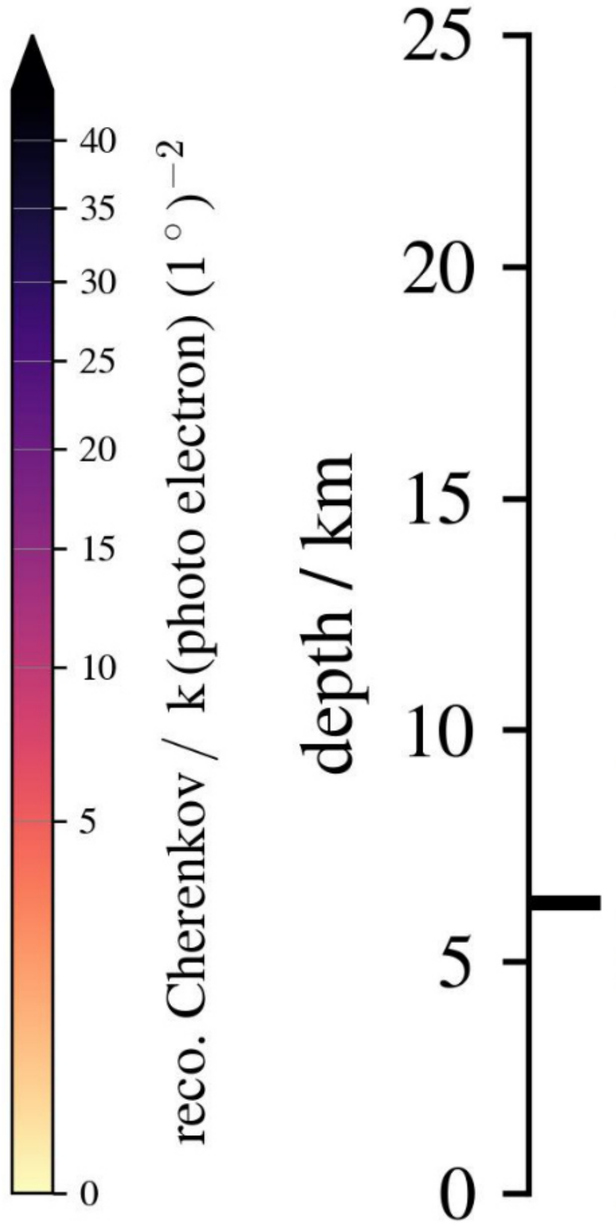

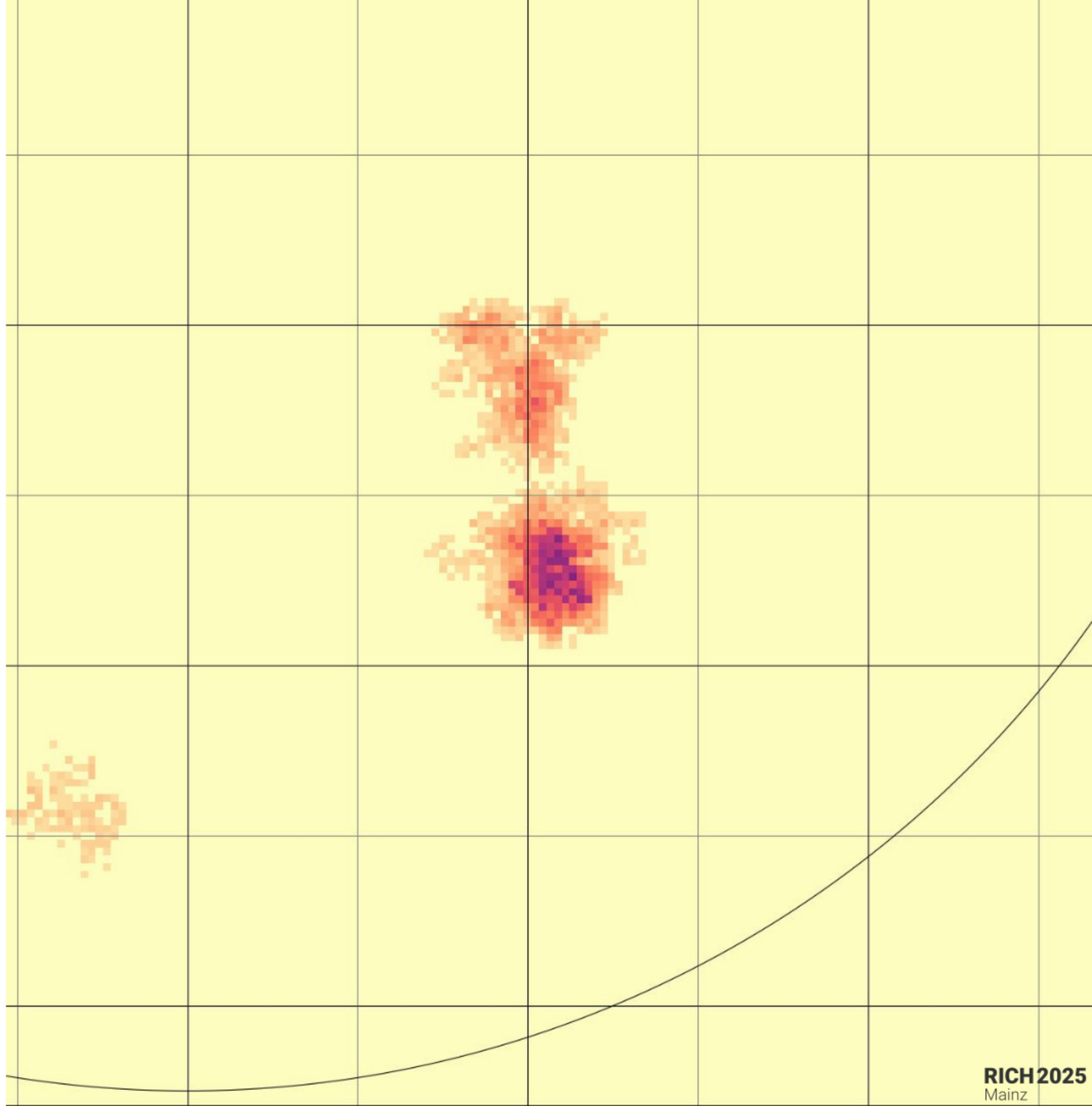

Airshower

Gamma

3.2GeV

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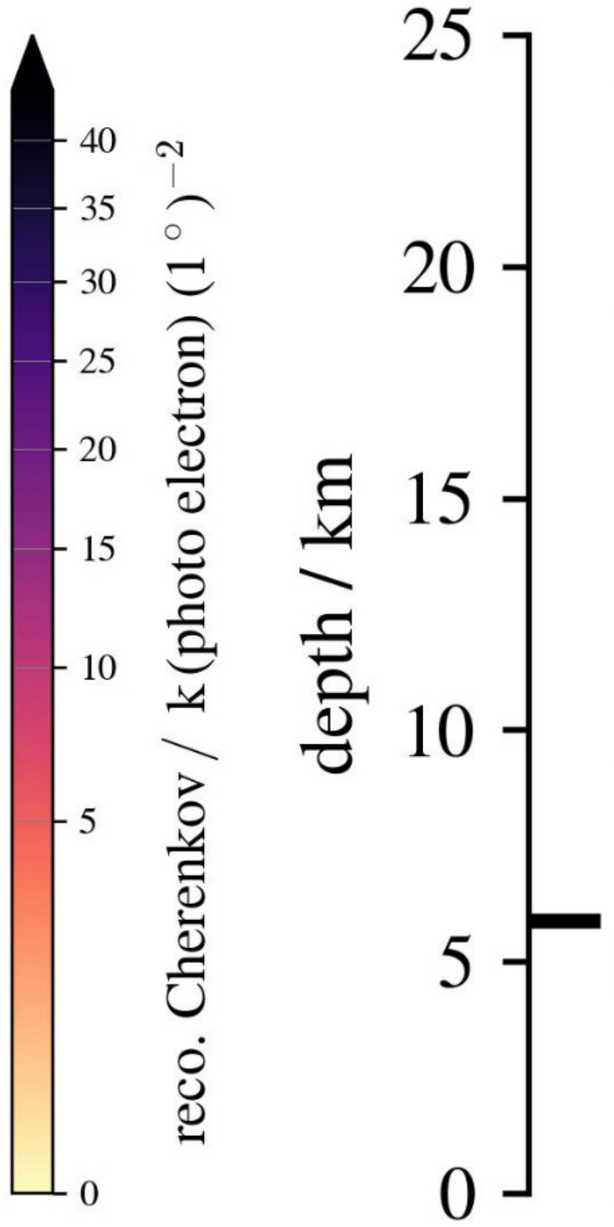

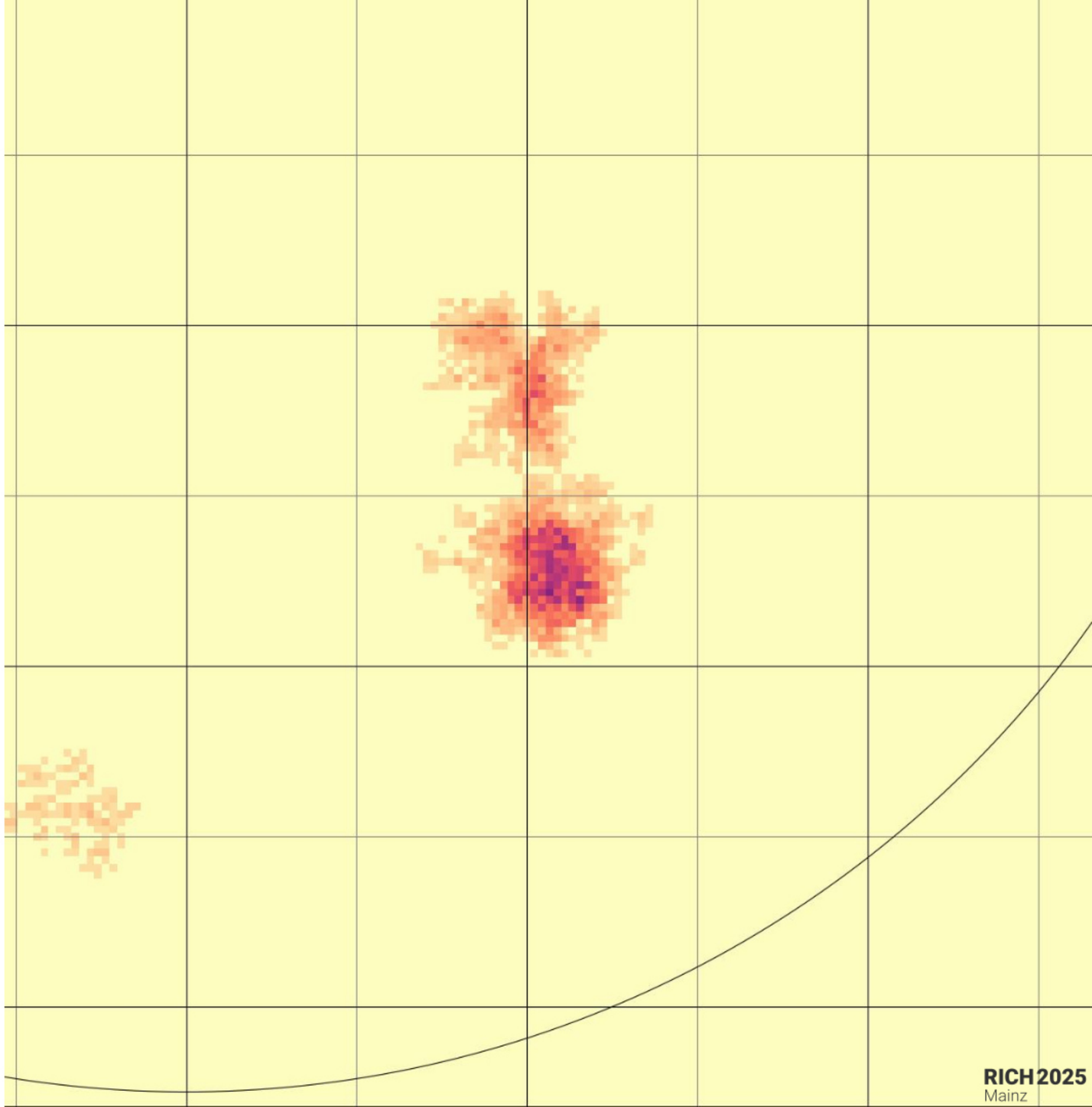

Airshower

Gamma

3.2GeV

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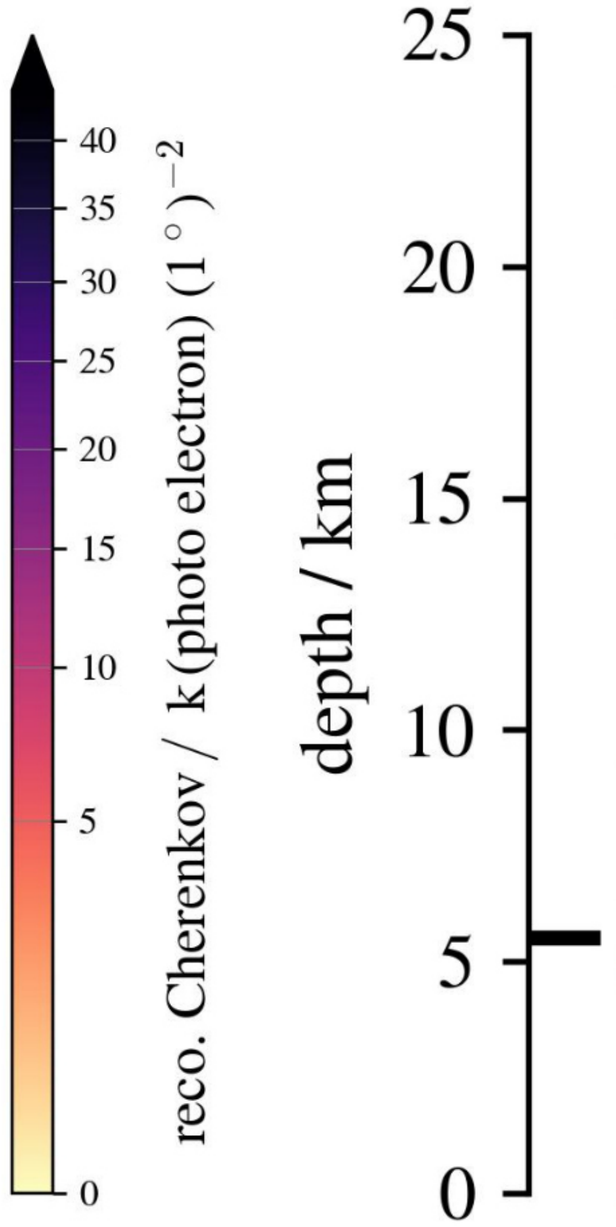

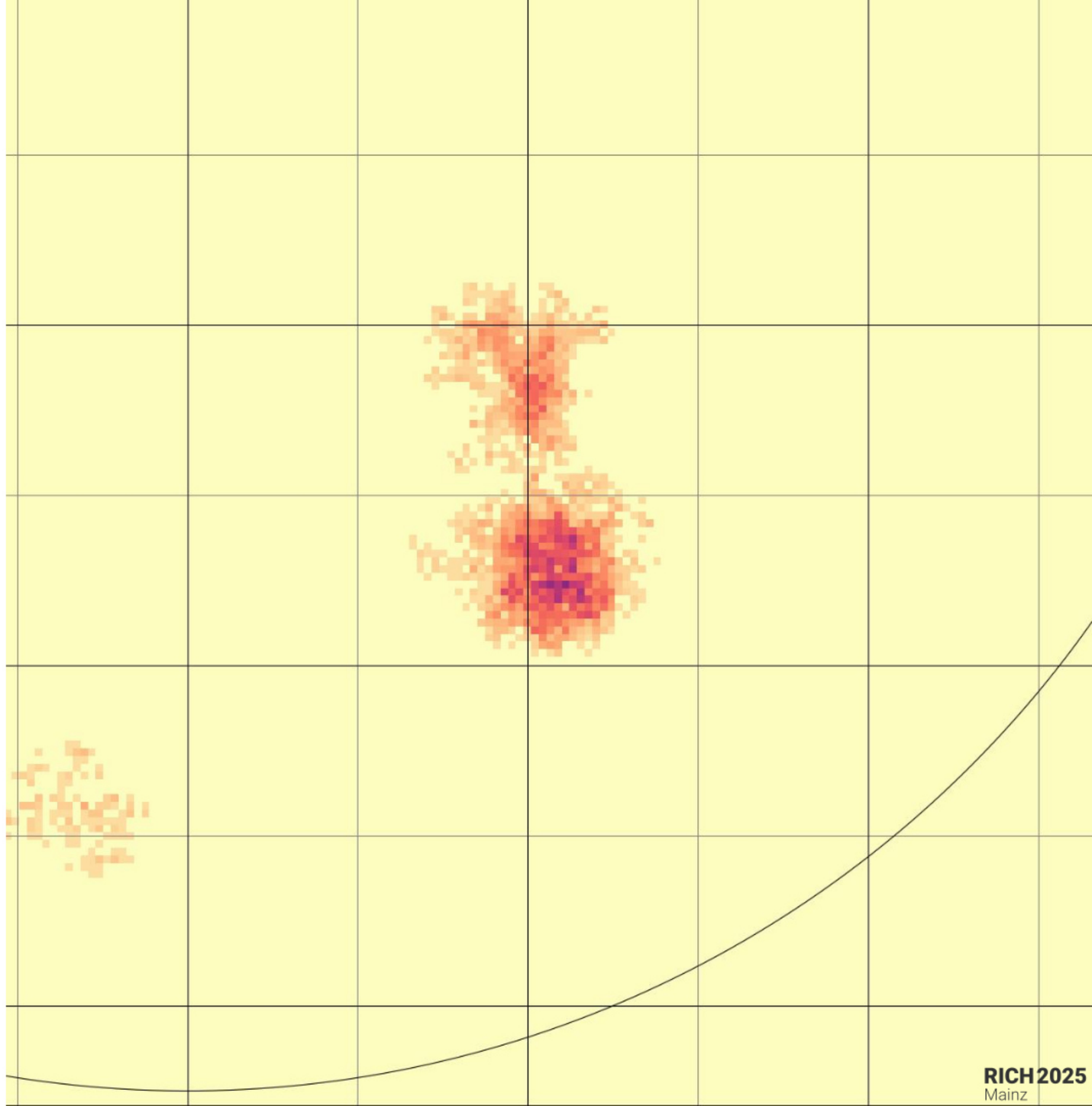

Airshower

Gamma

3.2GeV

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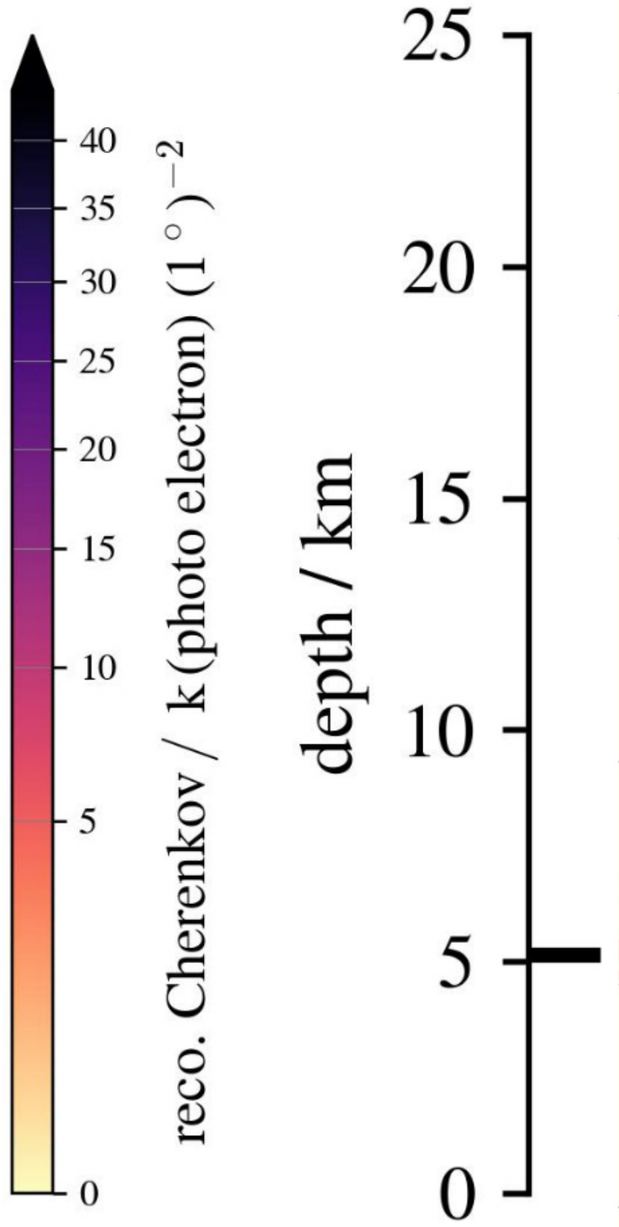
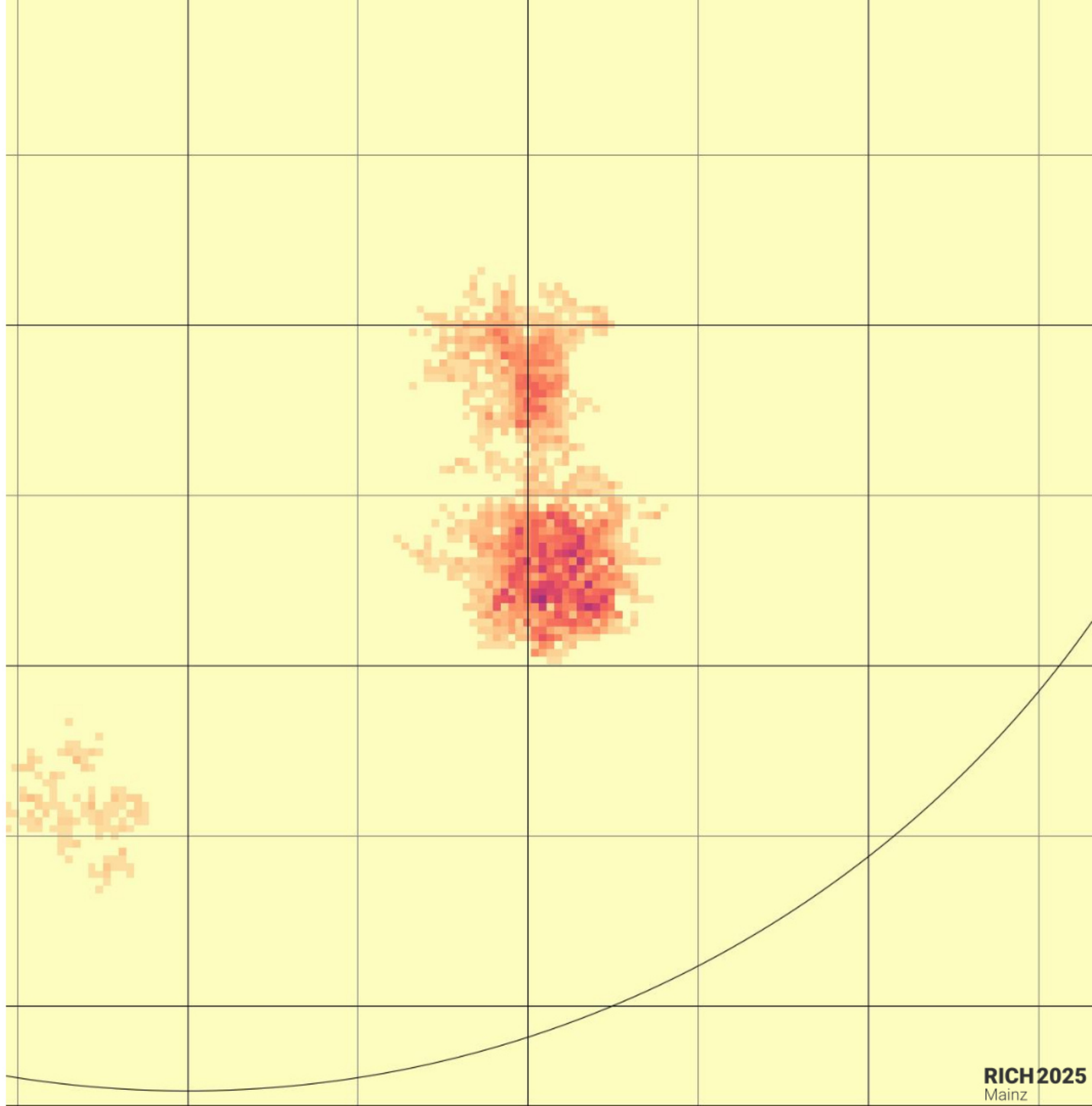


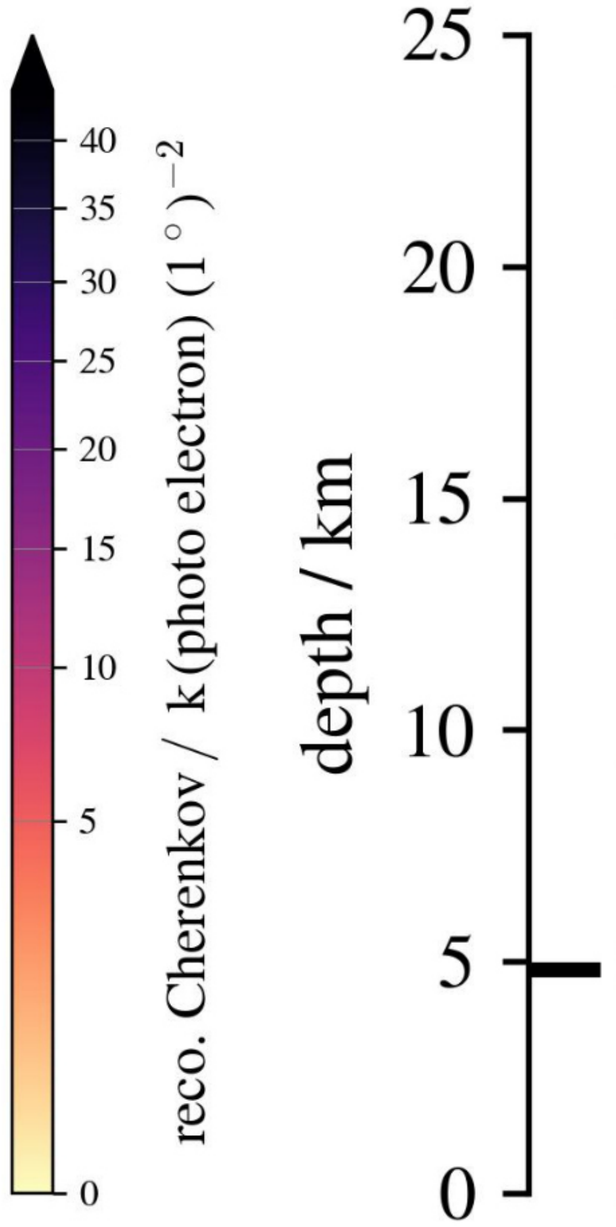


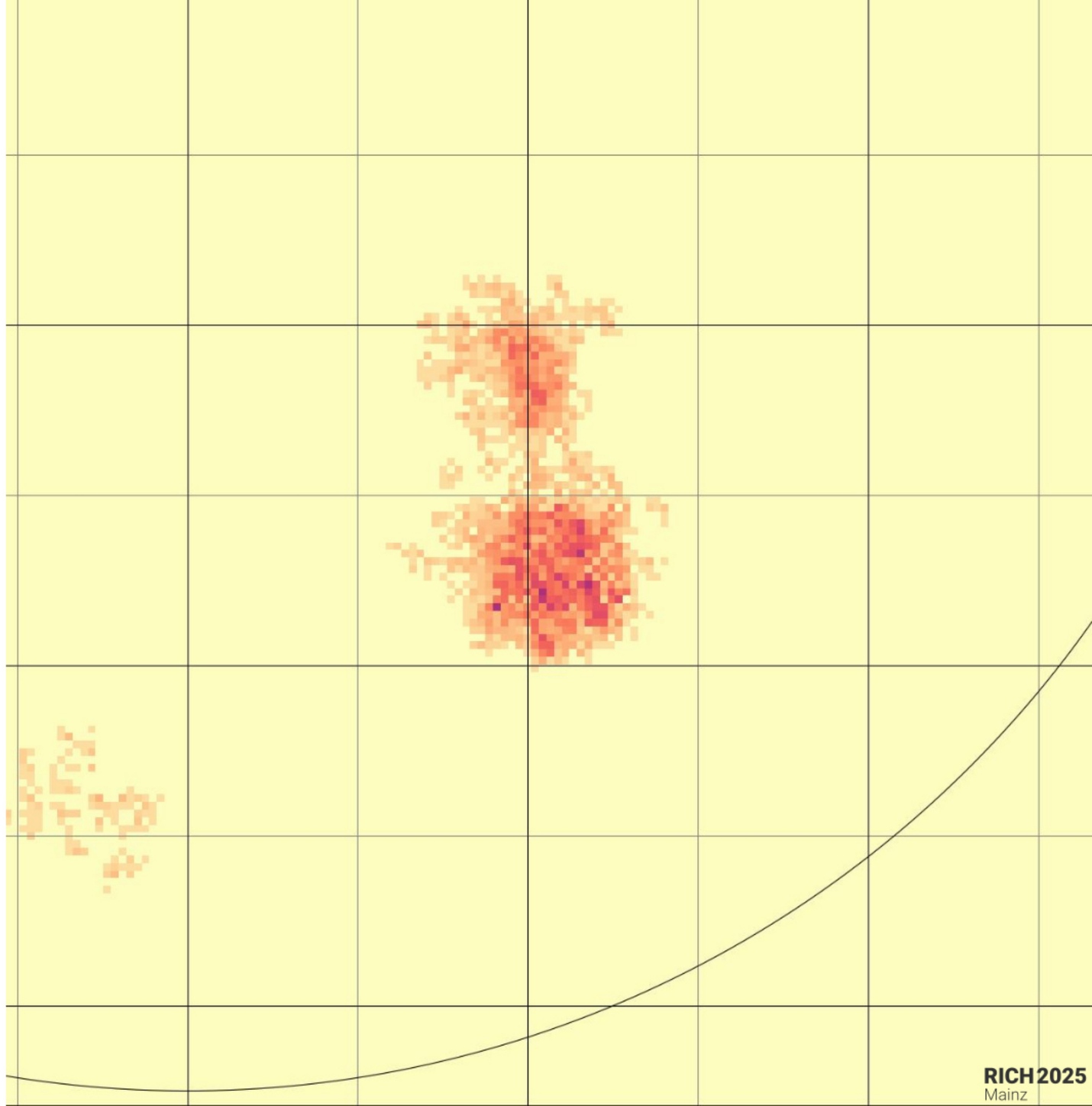
Airshower

Gamma

3.2GeV

708p.e.





Airshower

Gamma

3.2GeV

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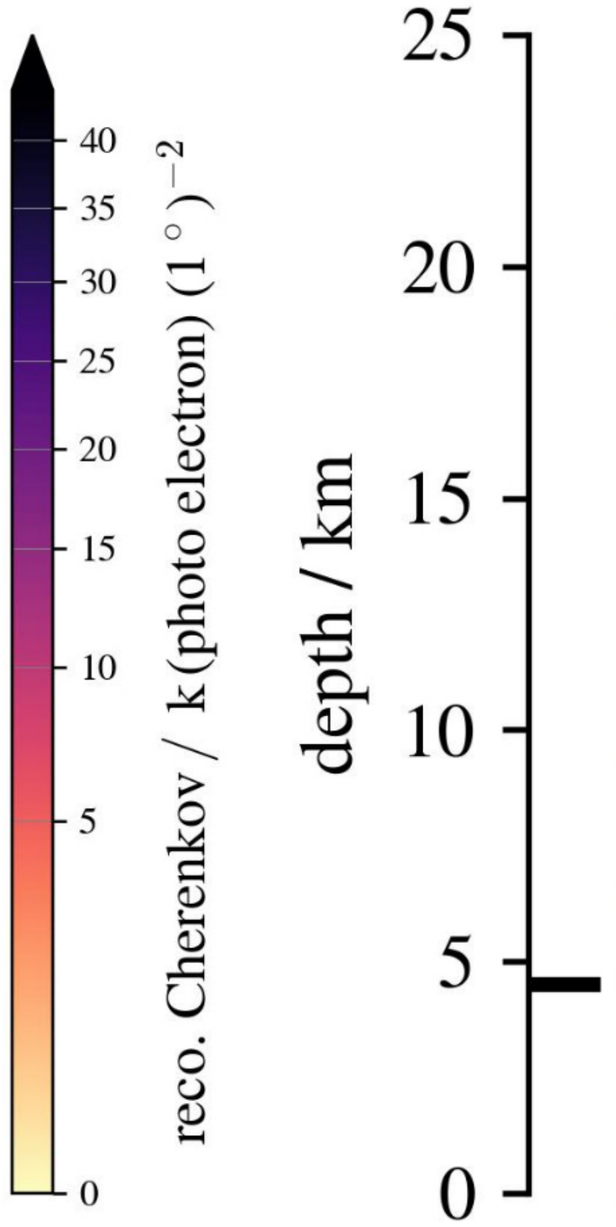

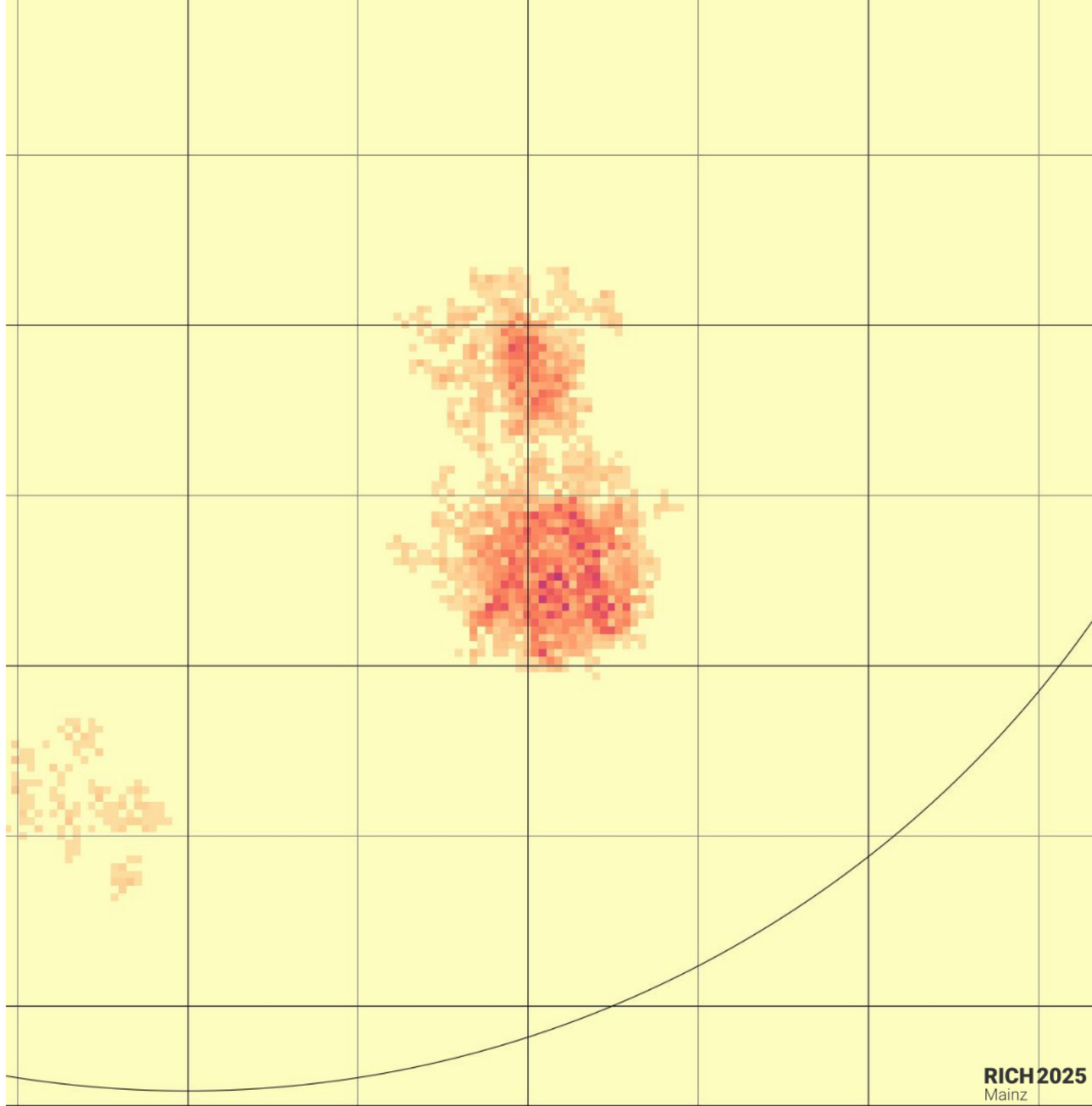

Airshower

Gamma

3.2GeV

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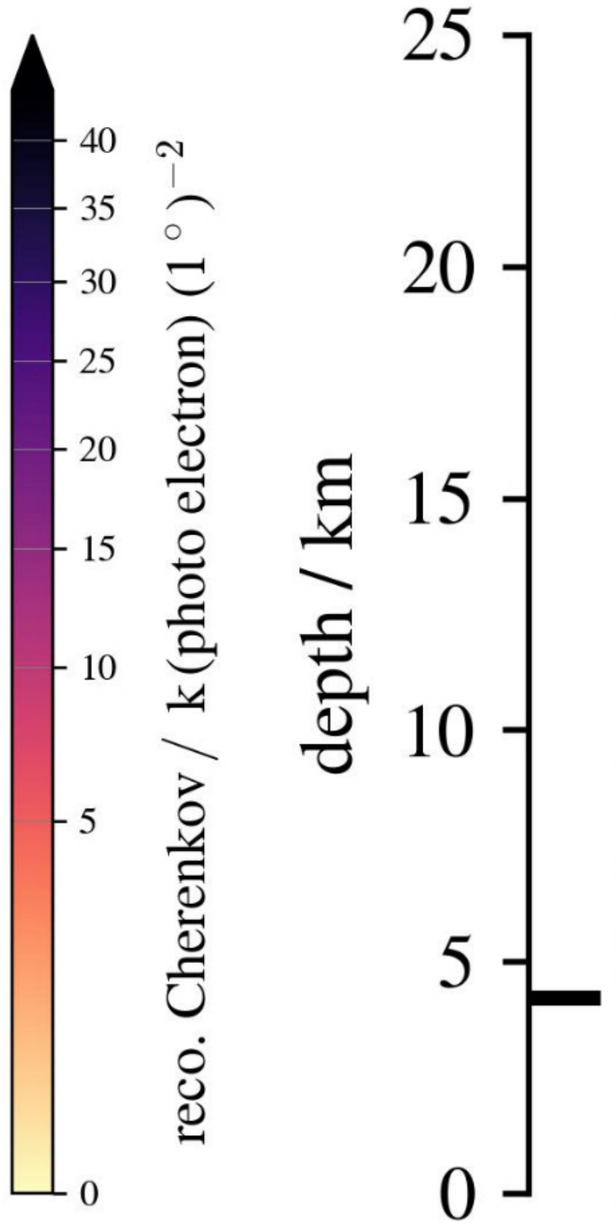

Airshower

Gamma

3.2GeV

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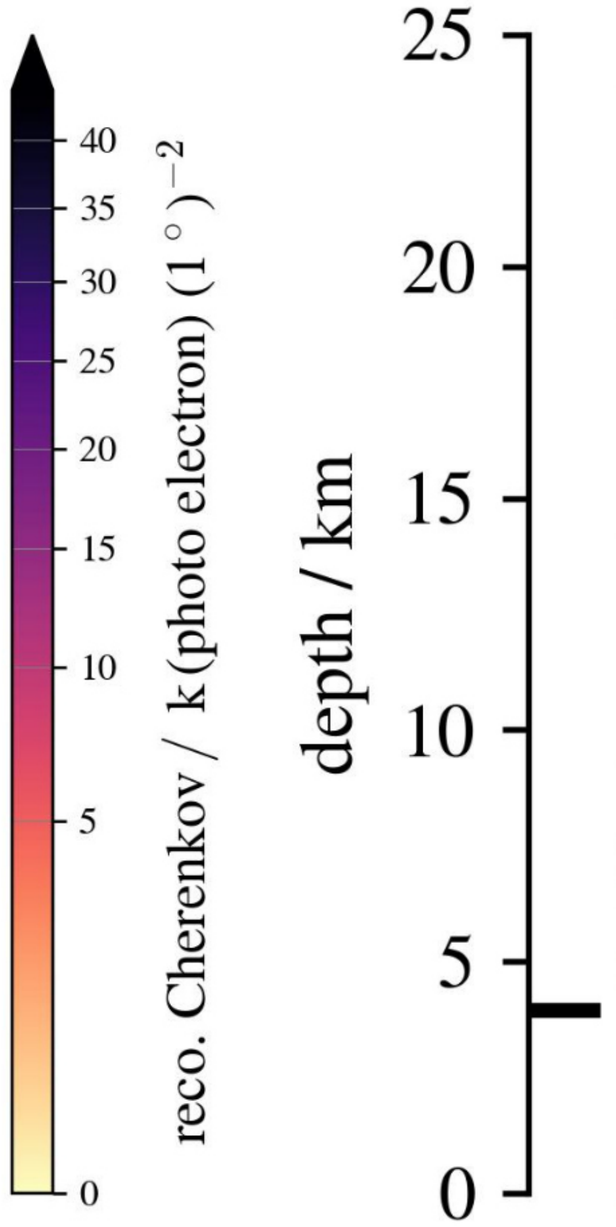

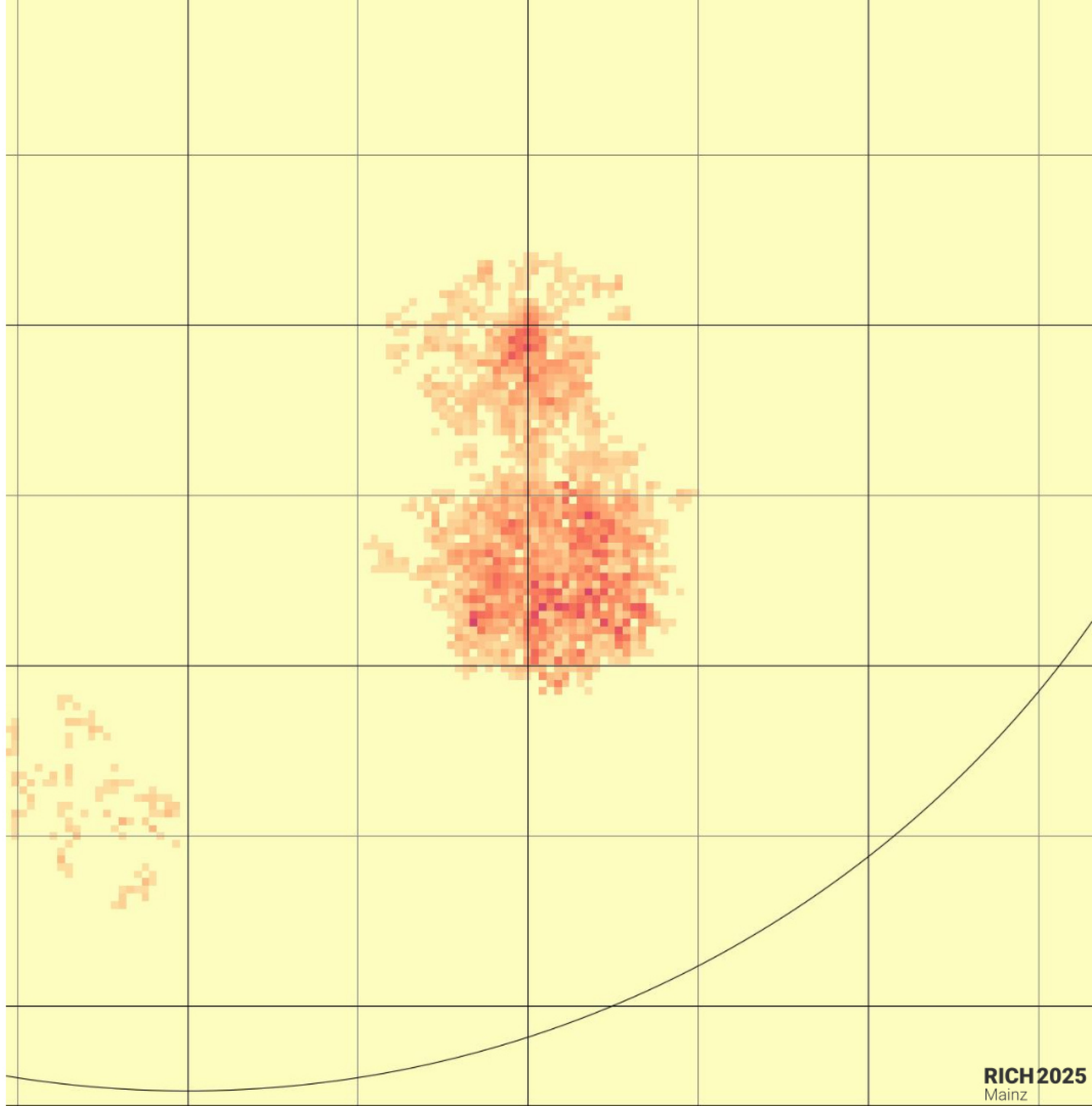

Airshower

Gamma

3.2GeV

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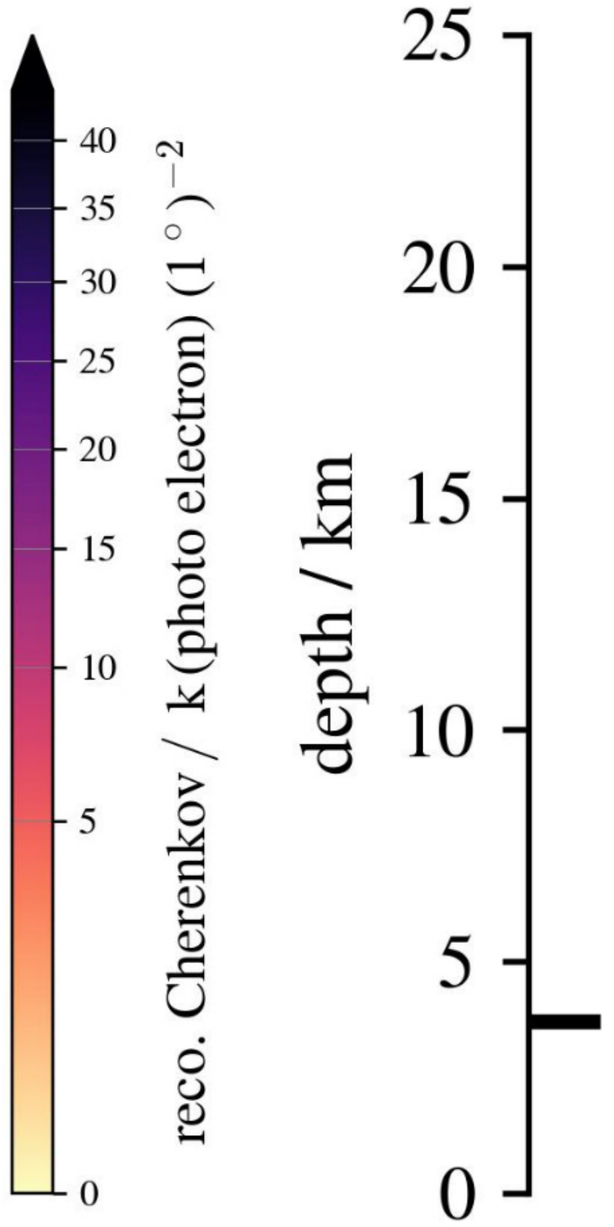

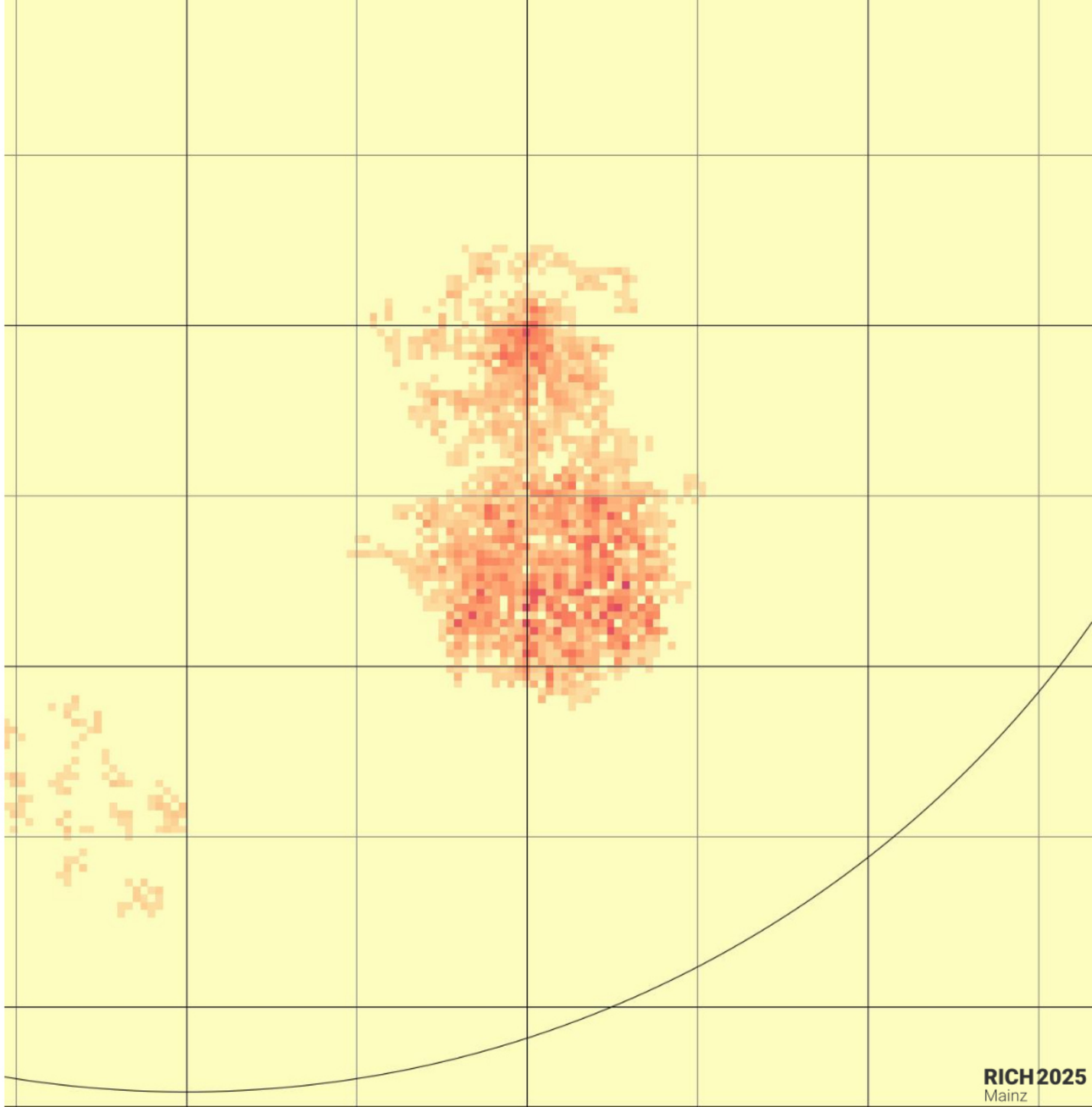

Airshower

Gamma

3.2GeV

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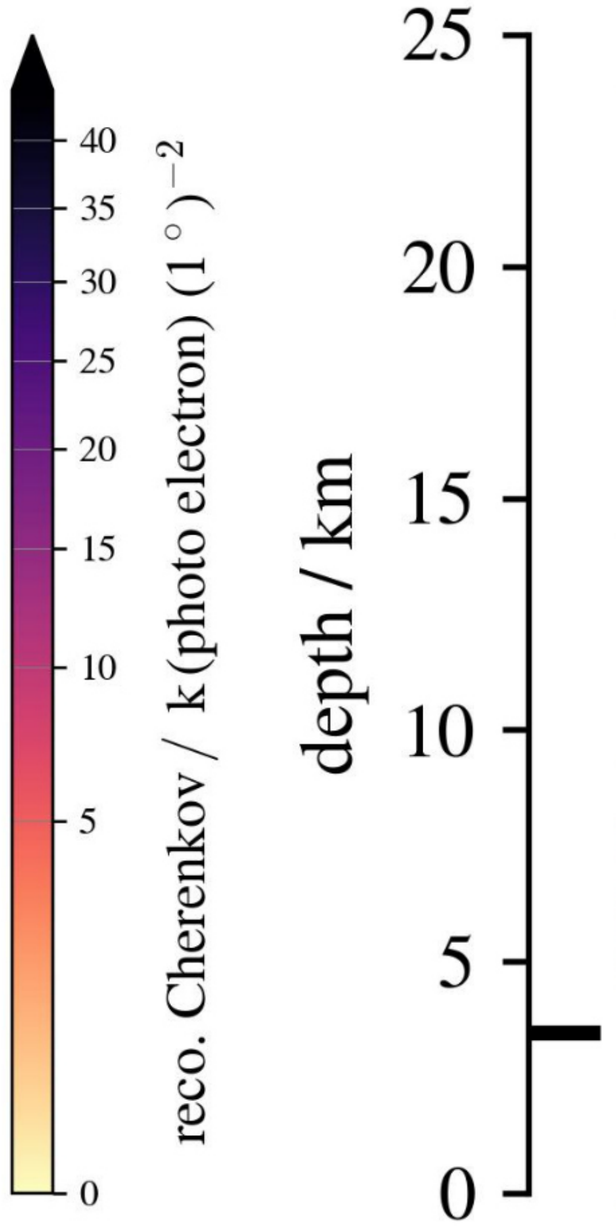

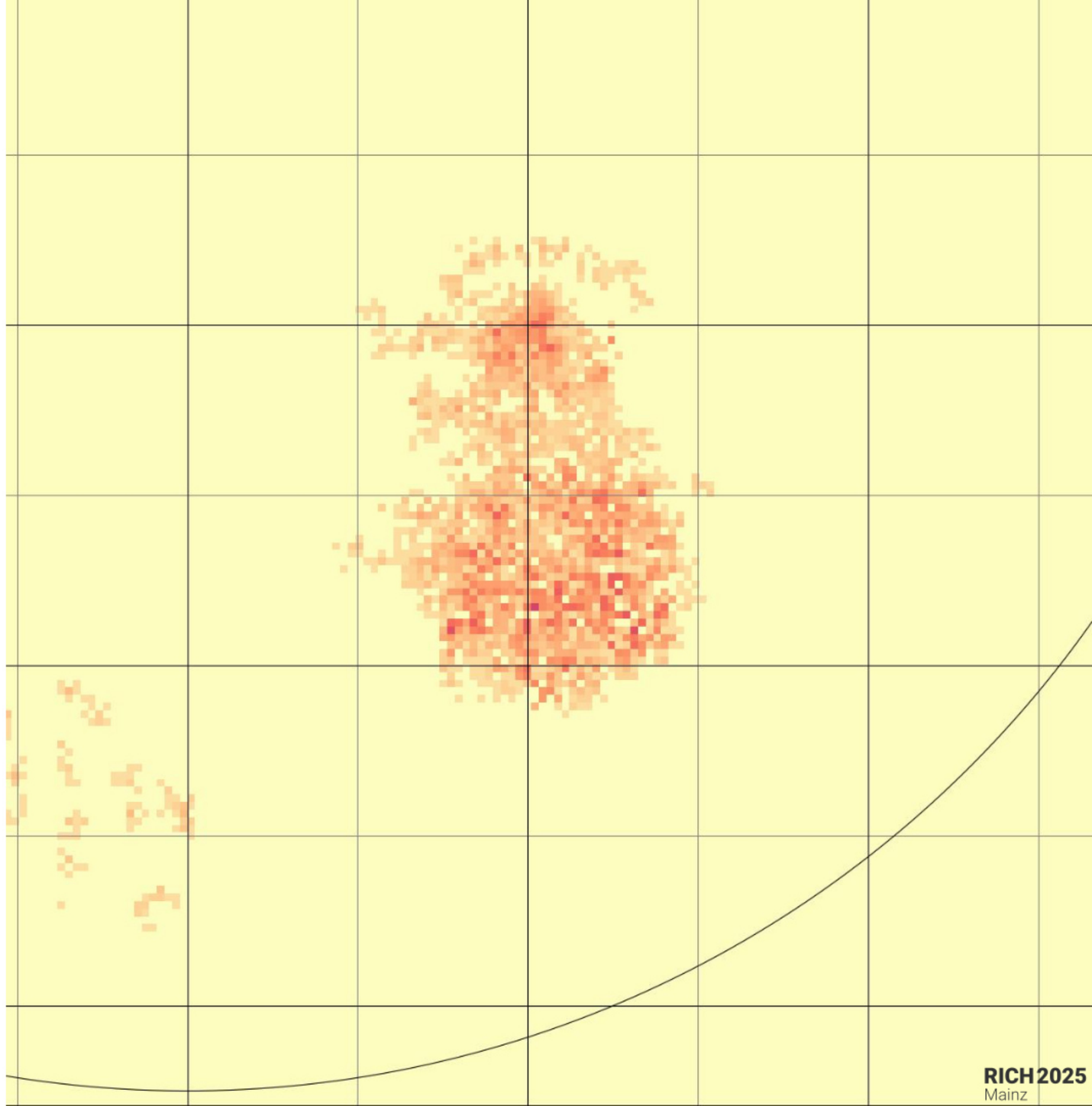

Airshower

Gamma

3.2GeV

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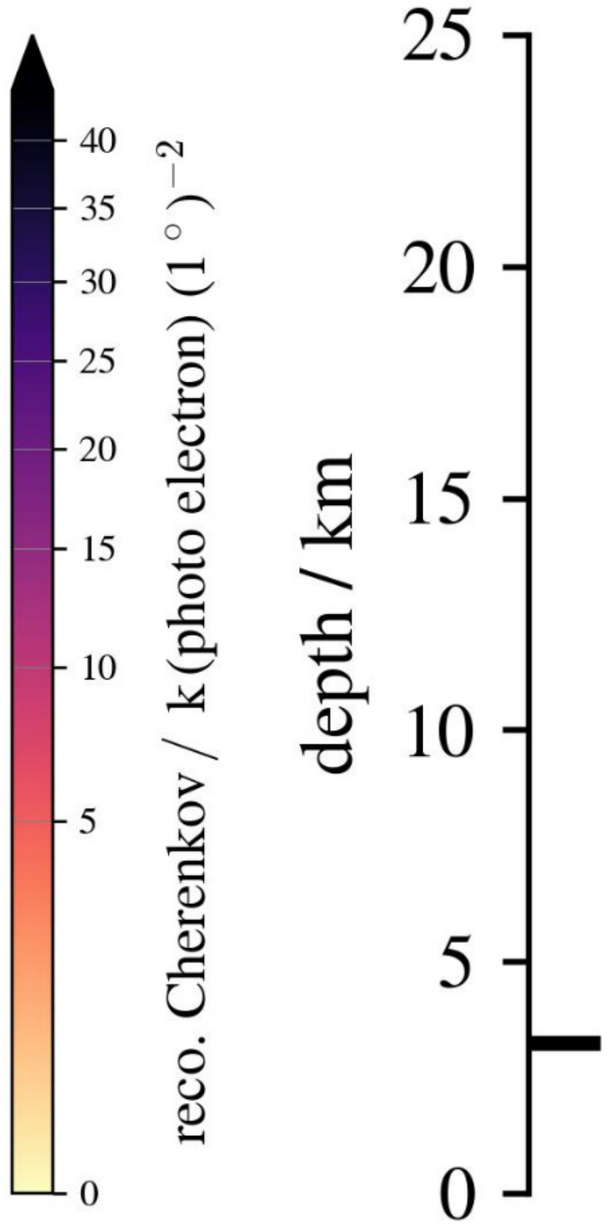

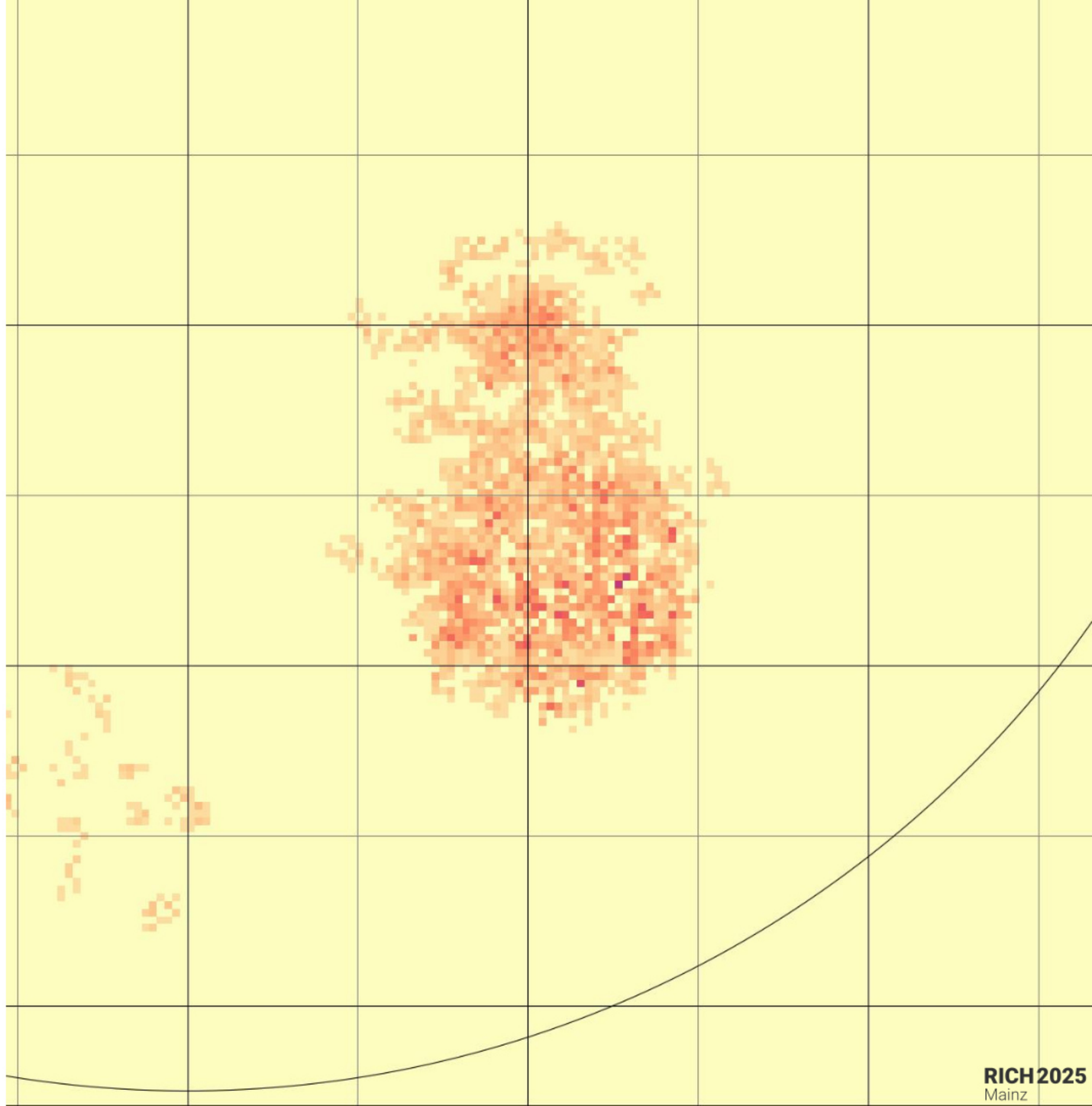

Airshower

Gamma

3.2GeV

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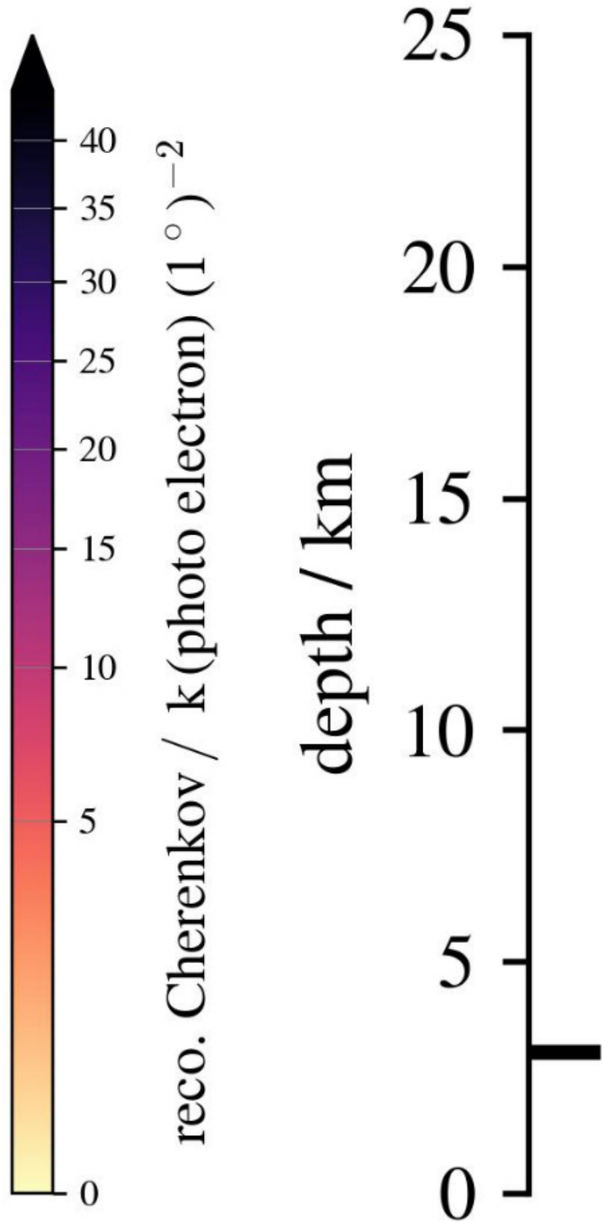

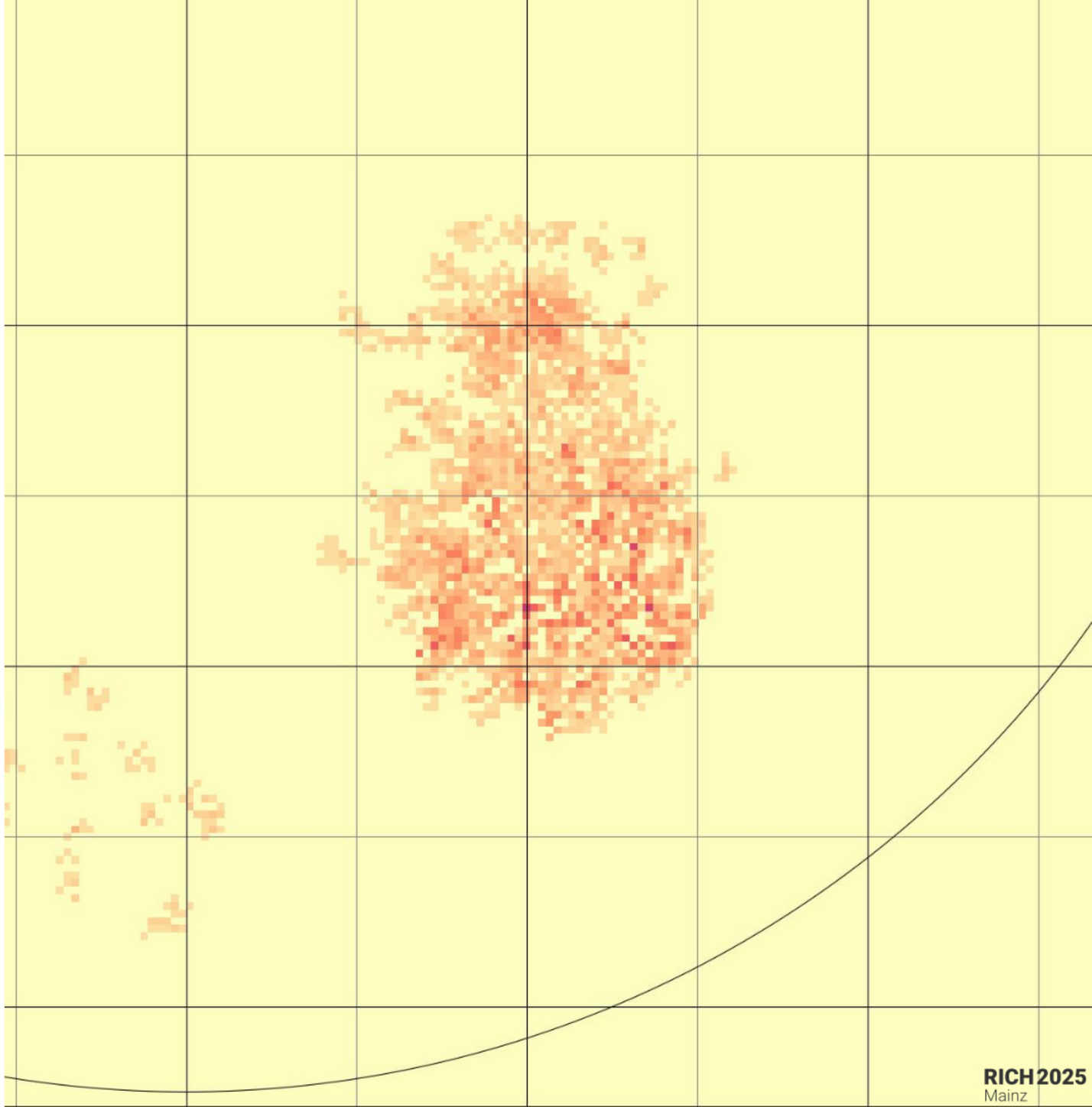

Airshower

Gamma

3.2GeV

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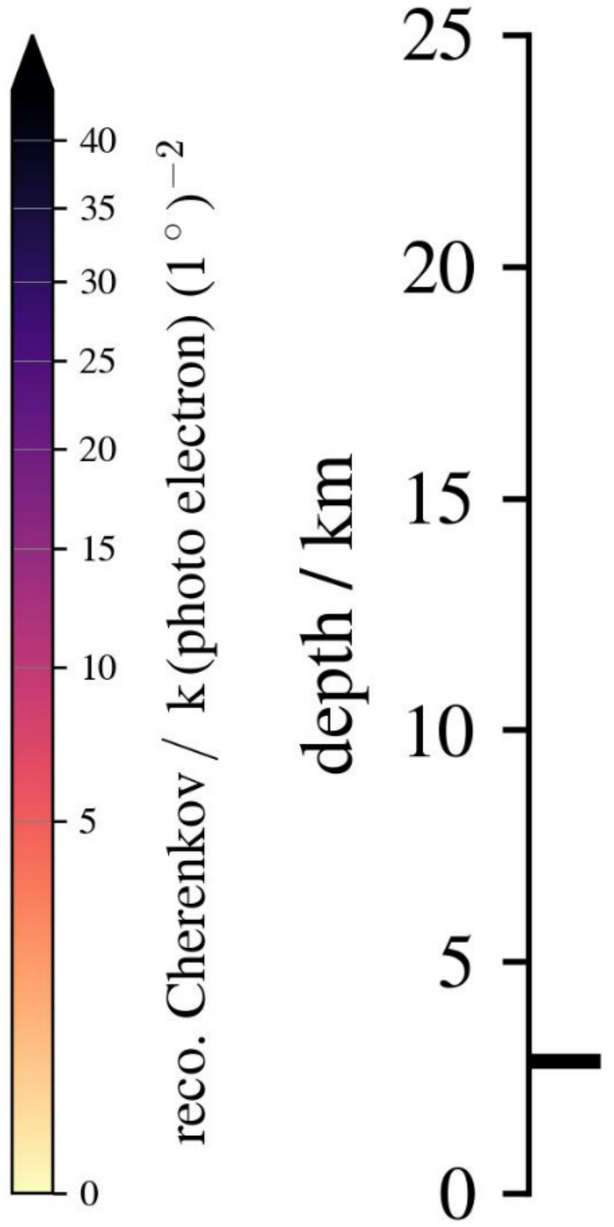
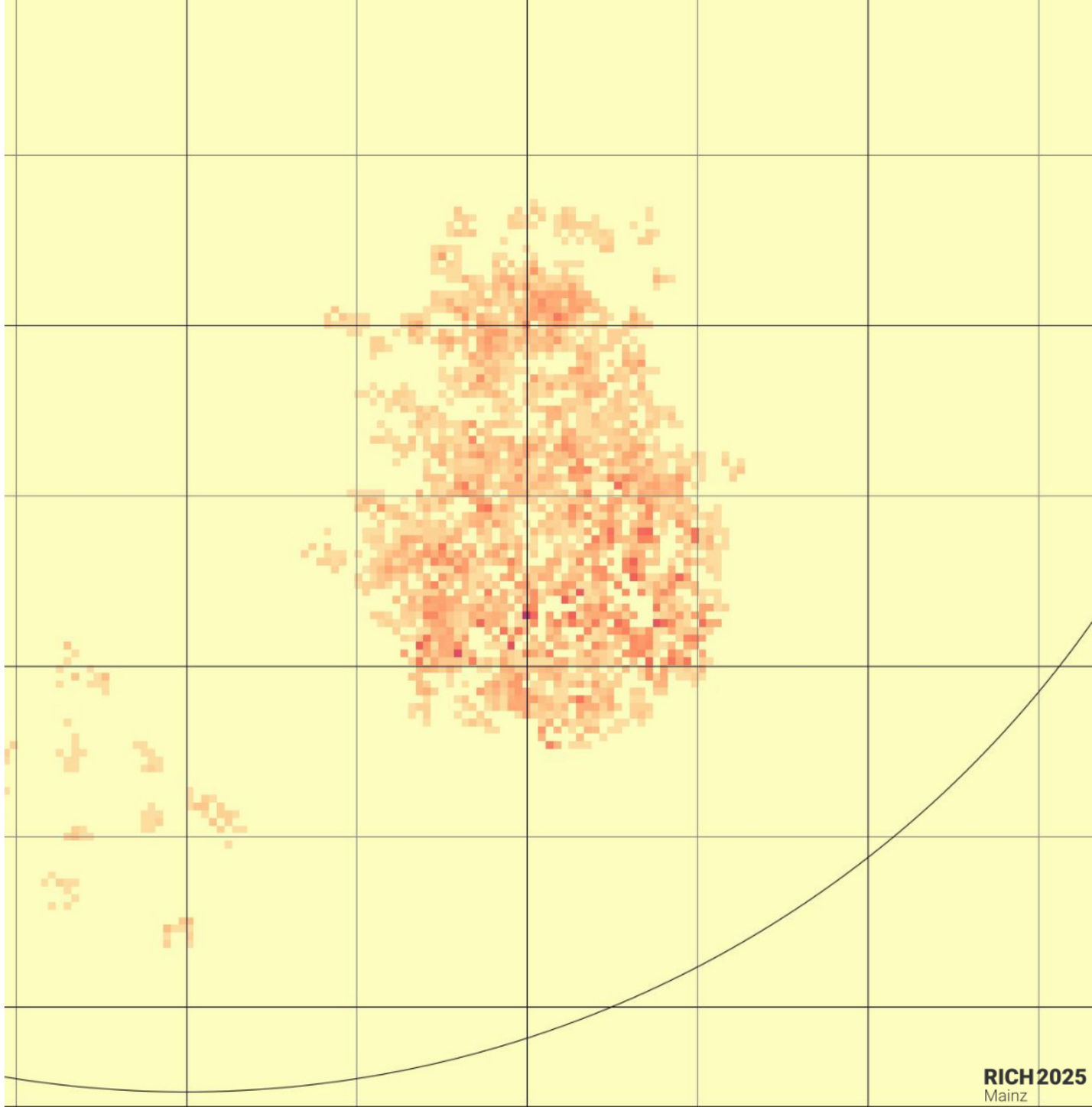


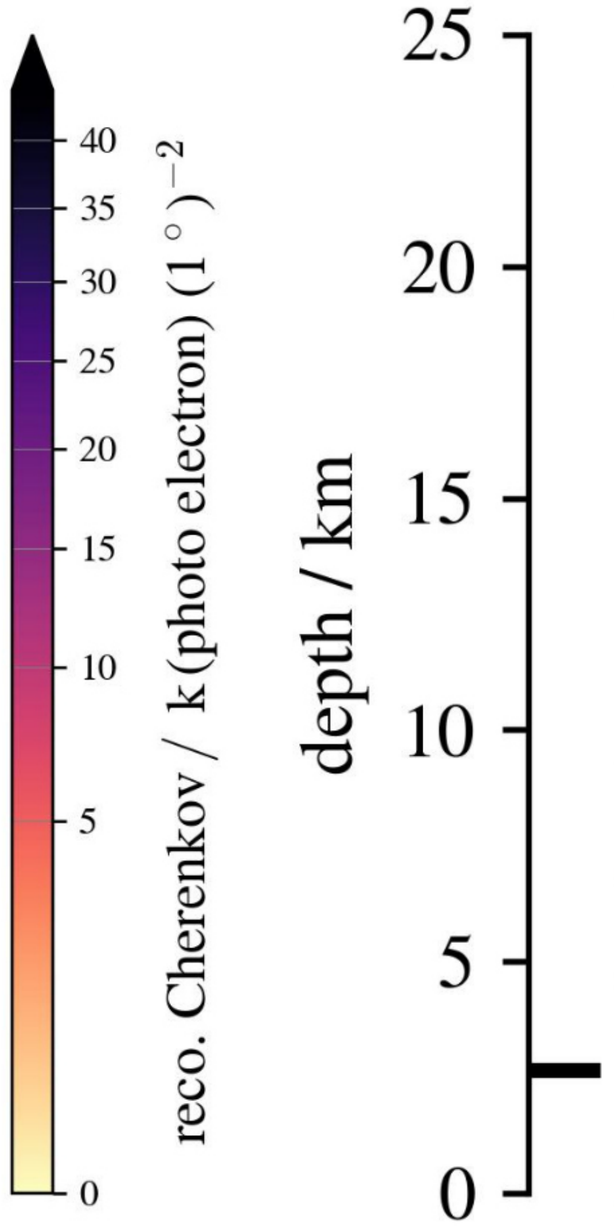


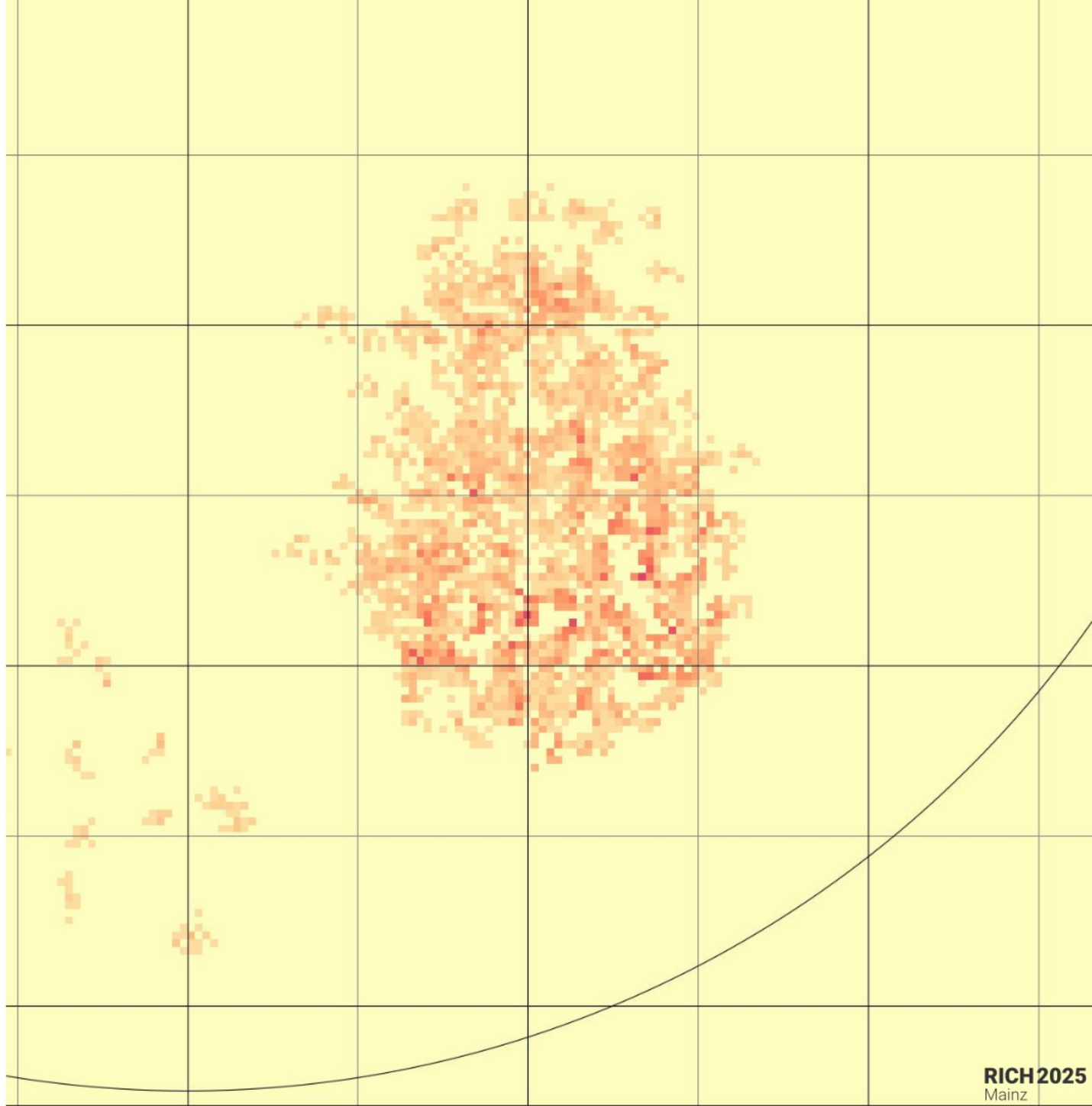
Airshower

Gamma

3.2GeV

708p.e.





Airshower

Gamma

3.2GeV

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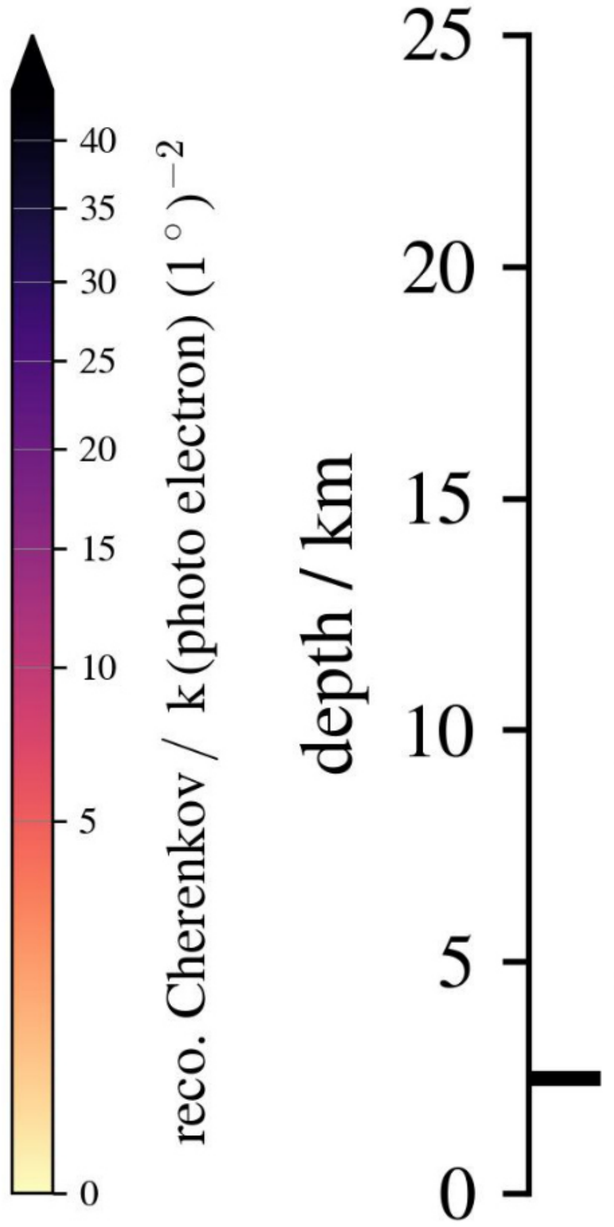

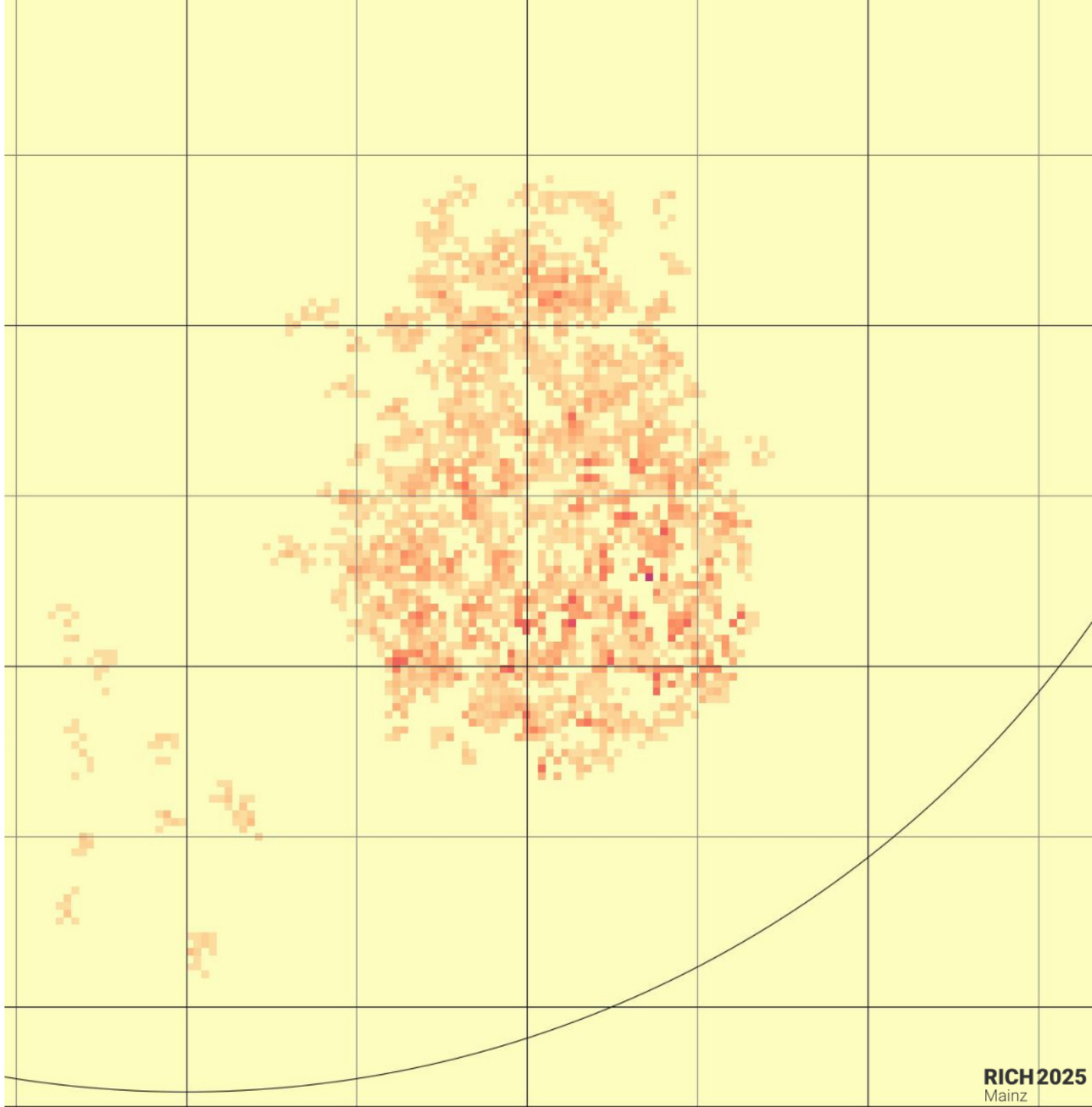

Airshower

Gamma

3.2GeV

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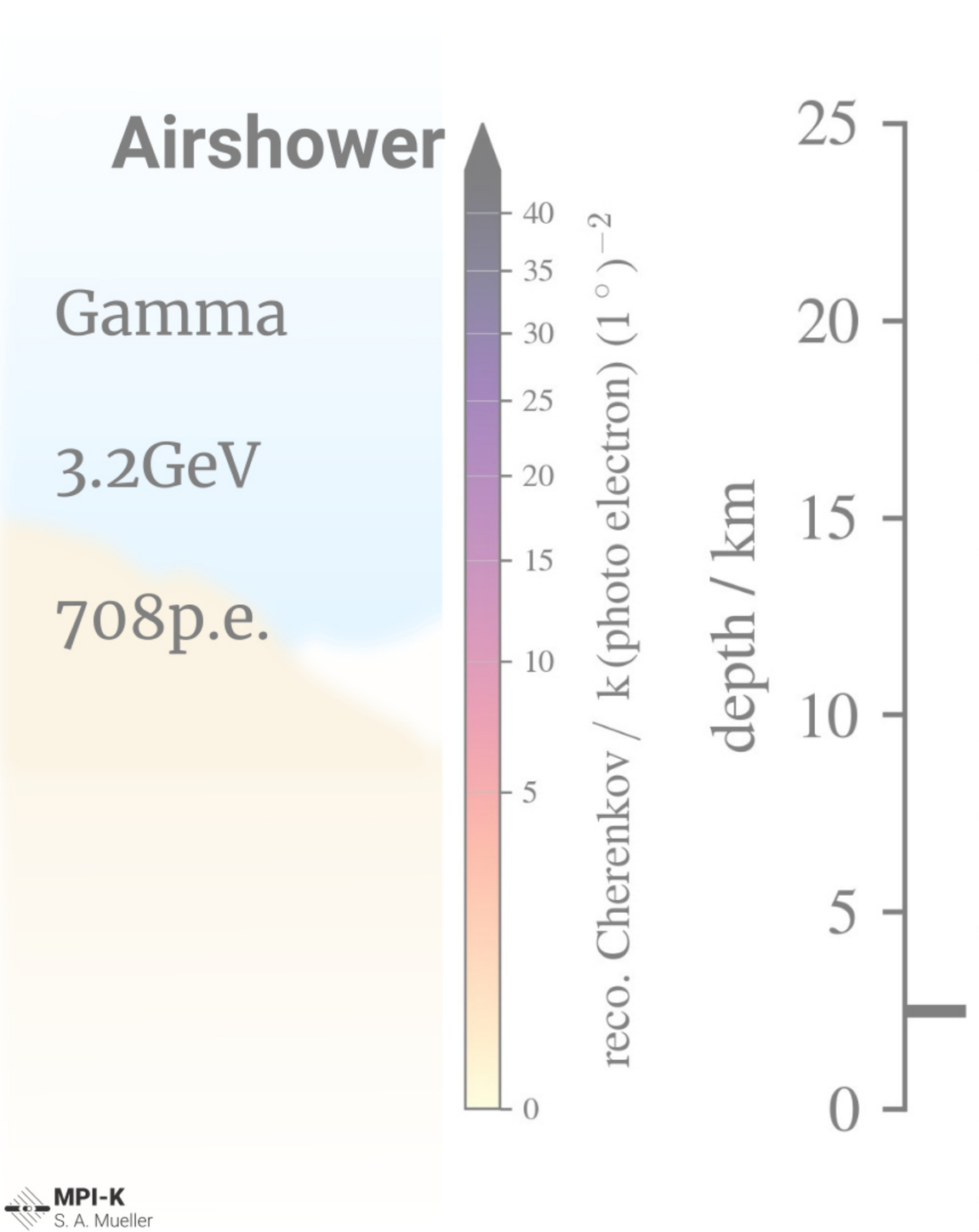
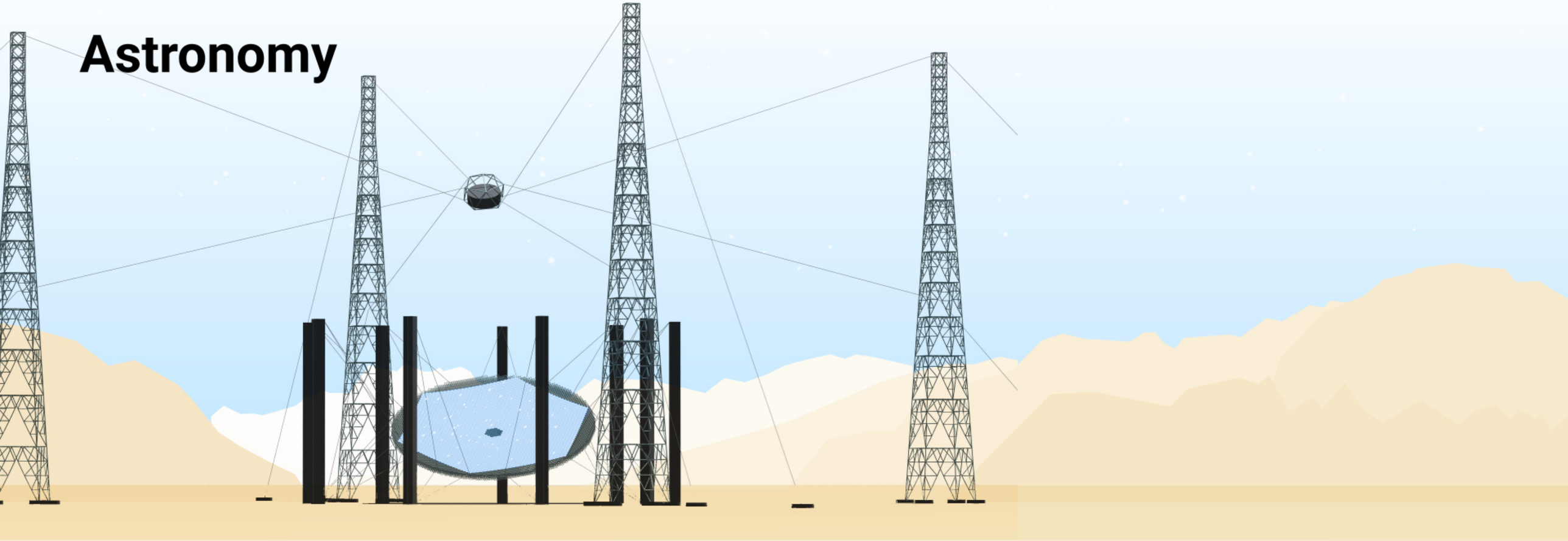


Astronomy

Astronomy



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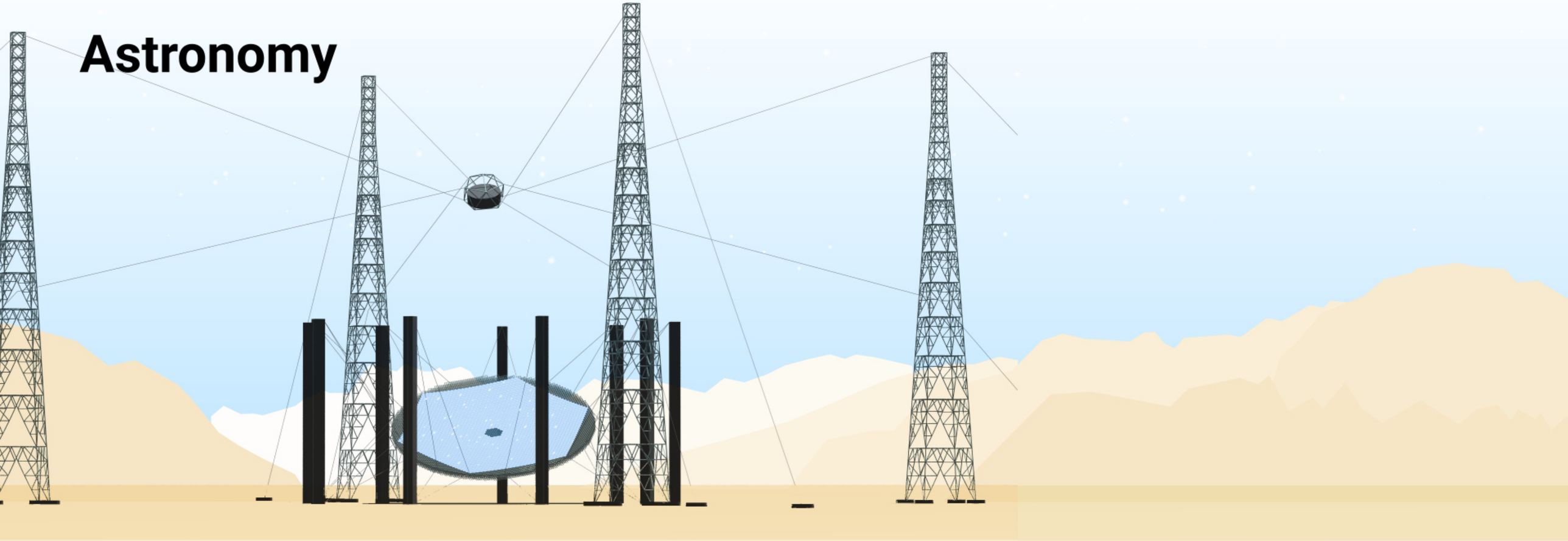
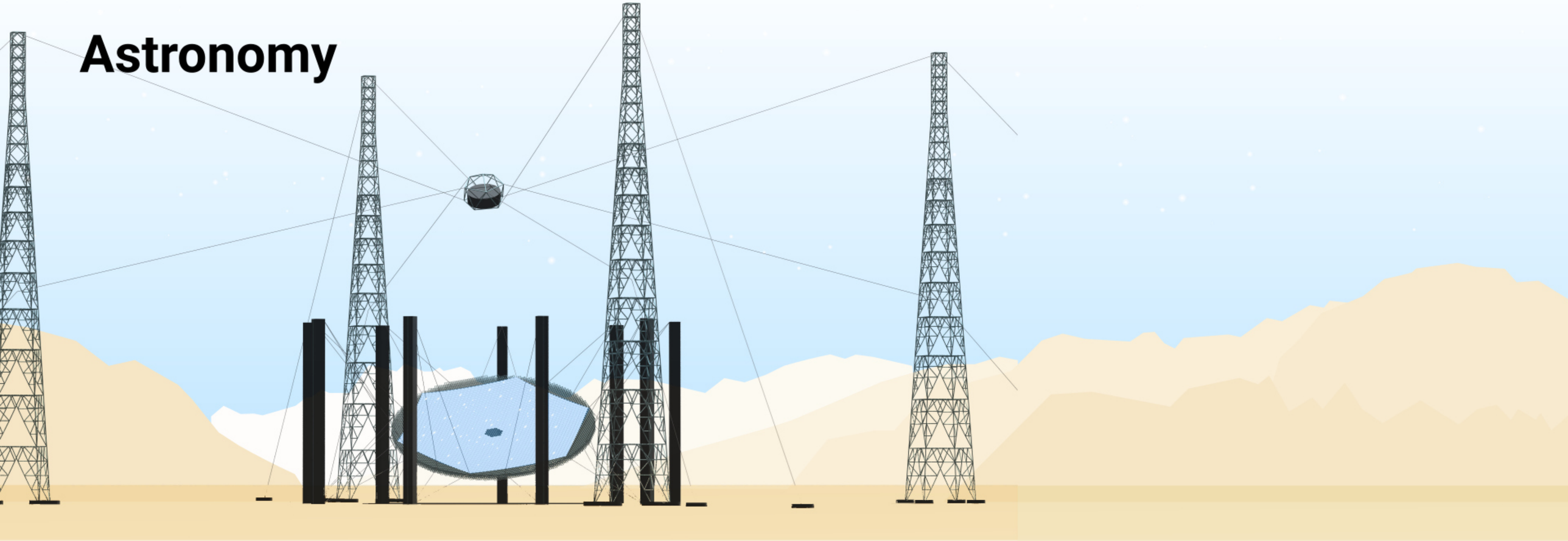


Preliminary. Not peer reviewed. Production run 2025-03-21, analysis run 2025-09-10.
See: https://github.com/cherenkov-plenoscope/starter_kit

Astronomy



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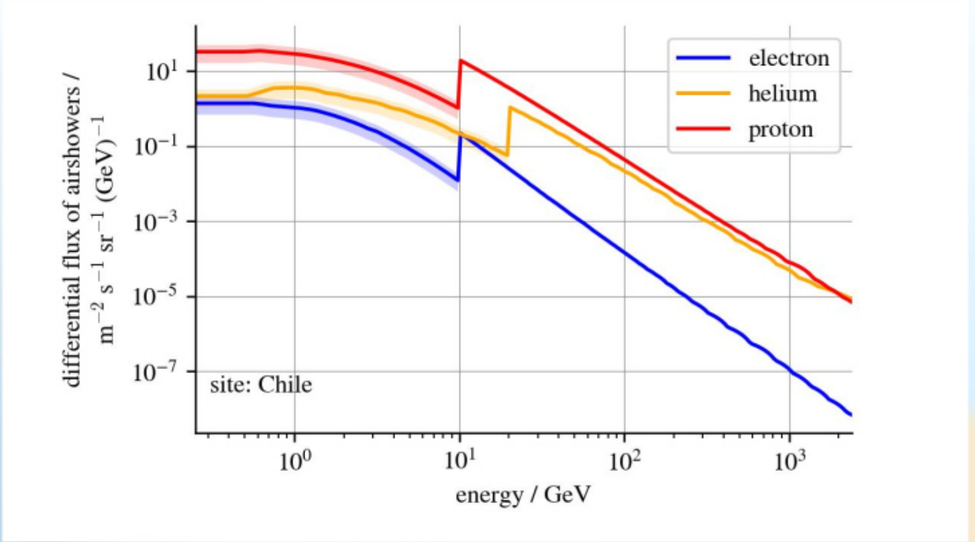

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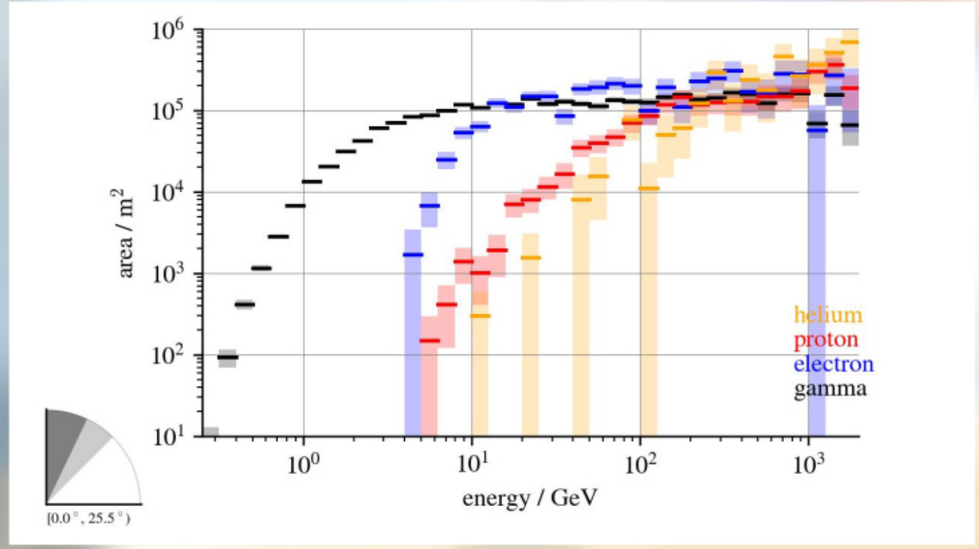

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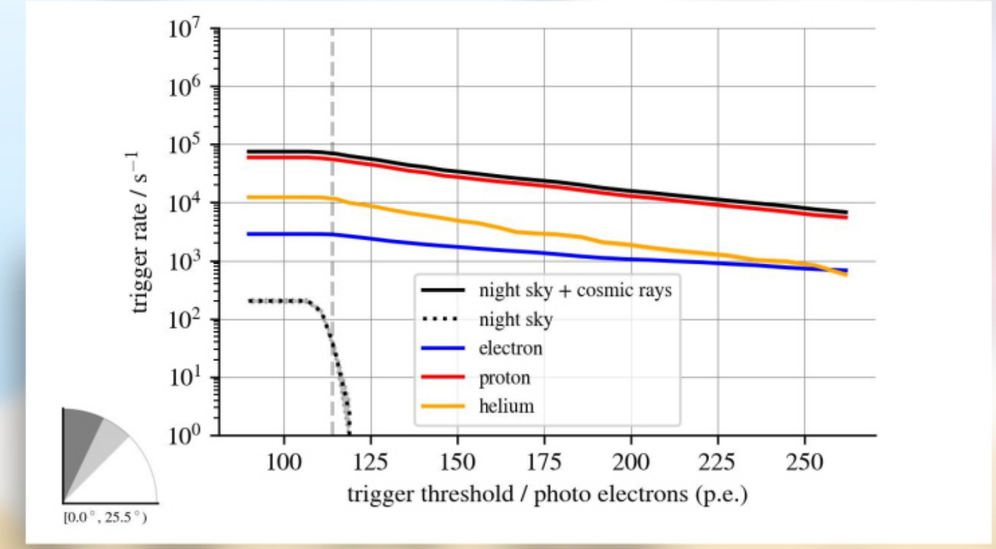

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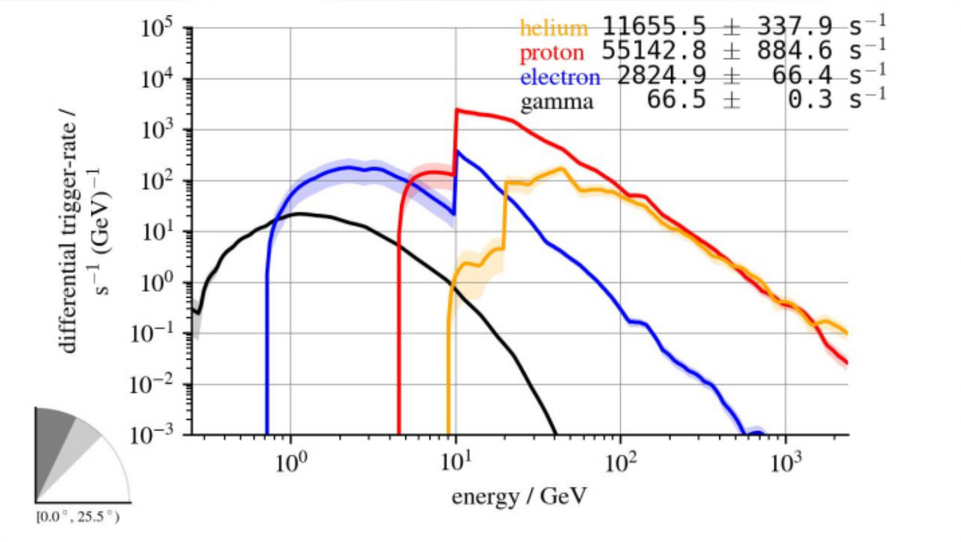

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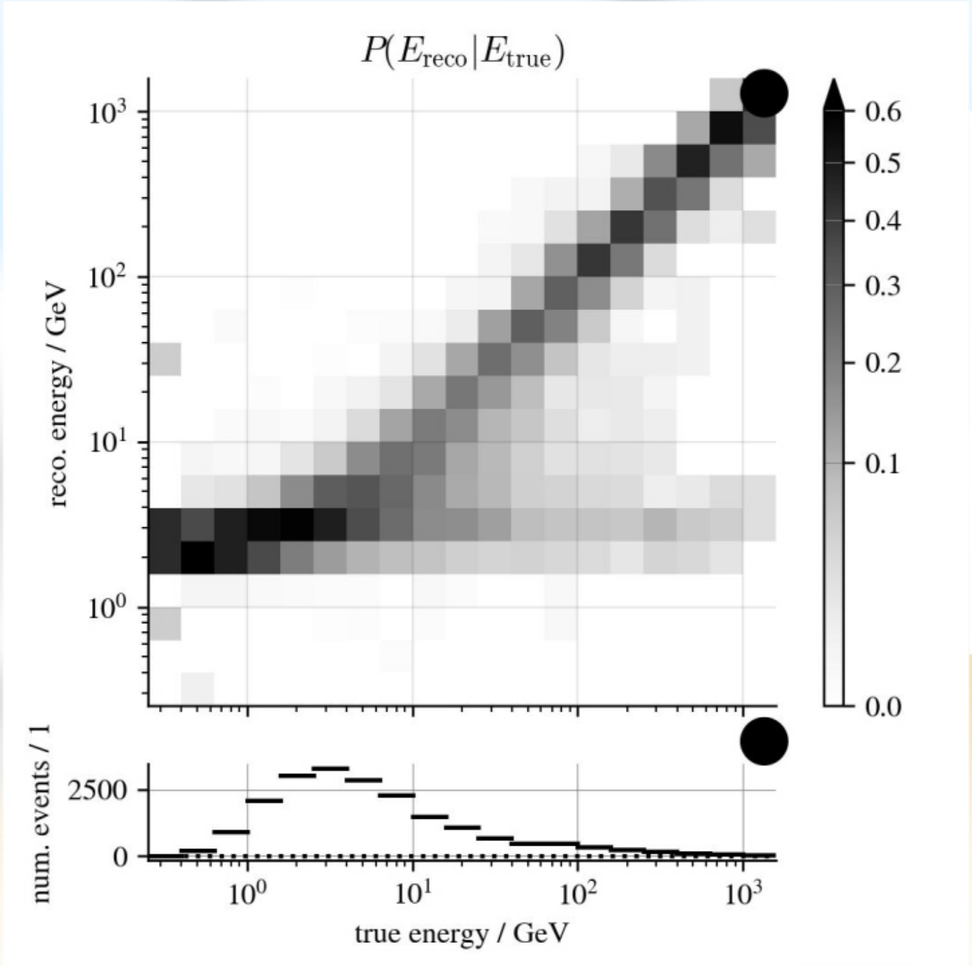

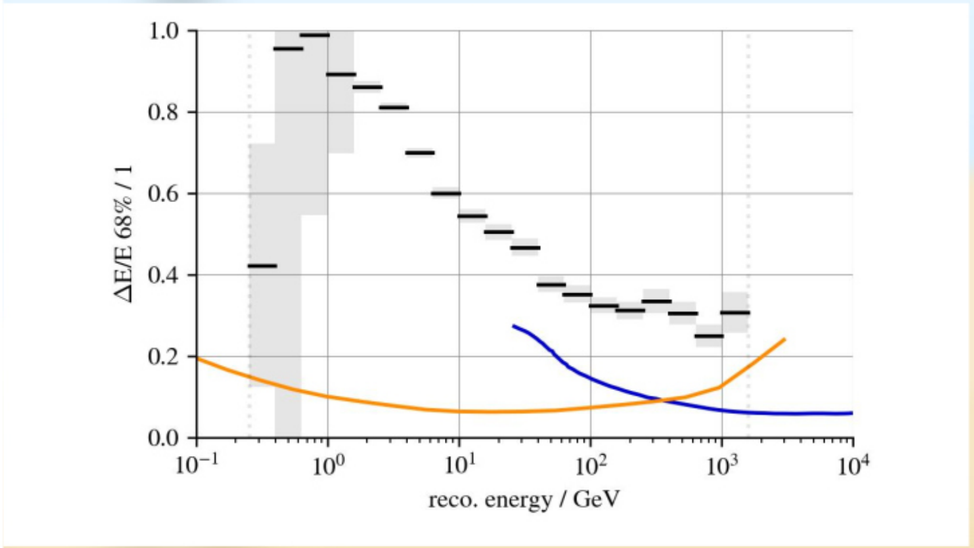

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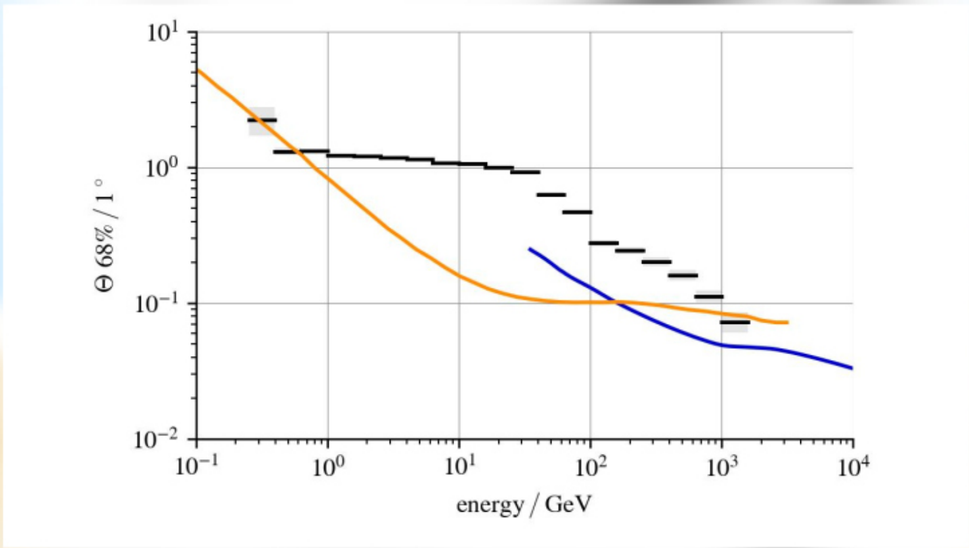
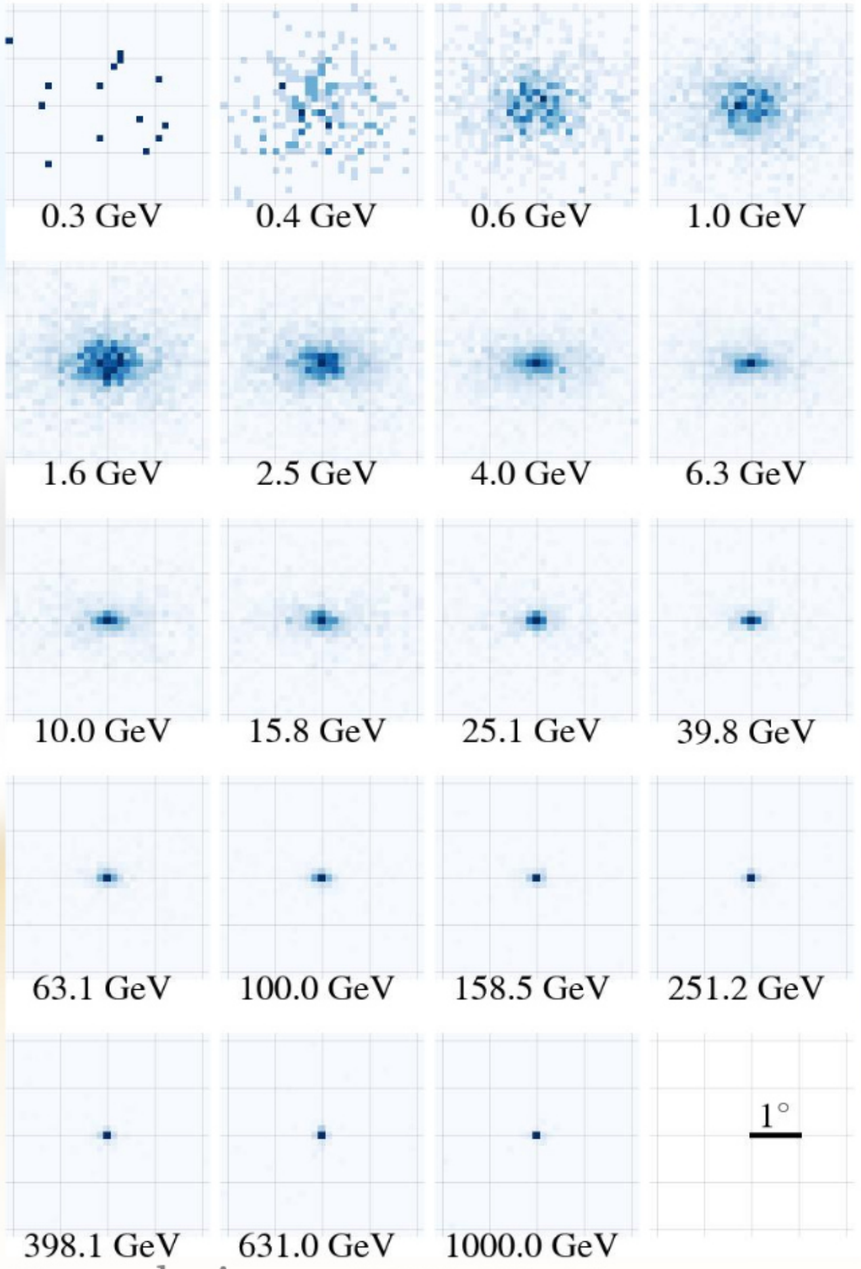
Astronomy





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See: https://github.com/cherenkov-plenoscope/starter_kit

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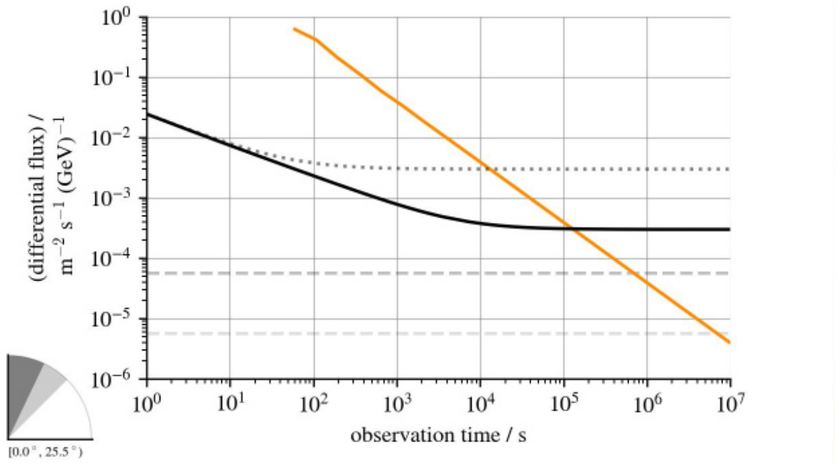

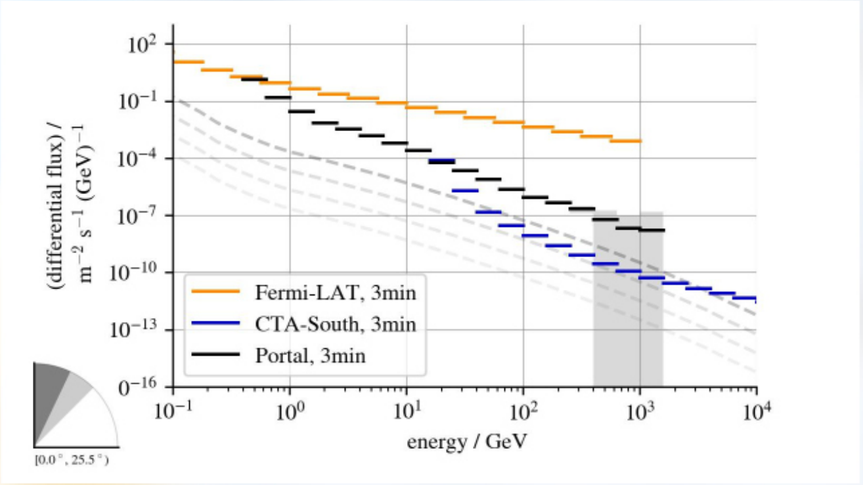

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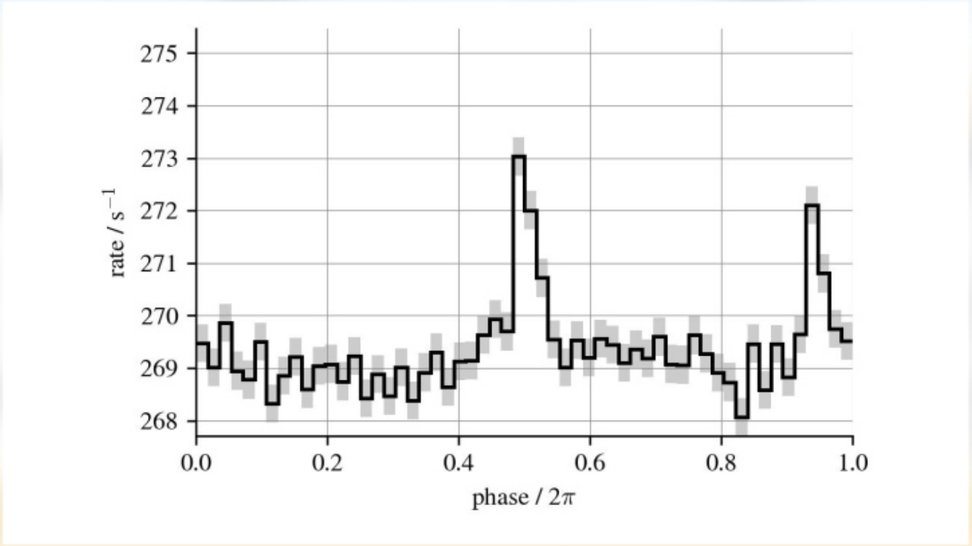

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Astronomy

Astronomy

History of pleneptics

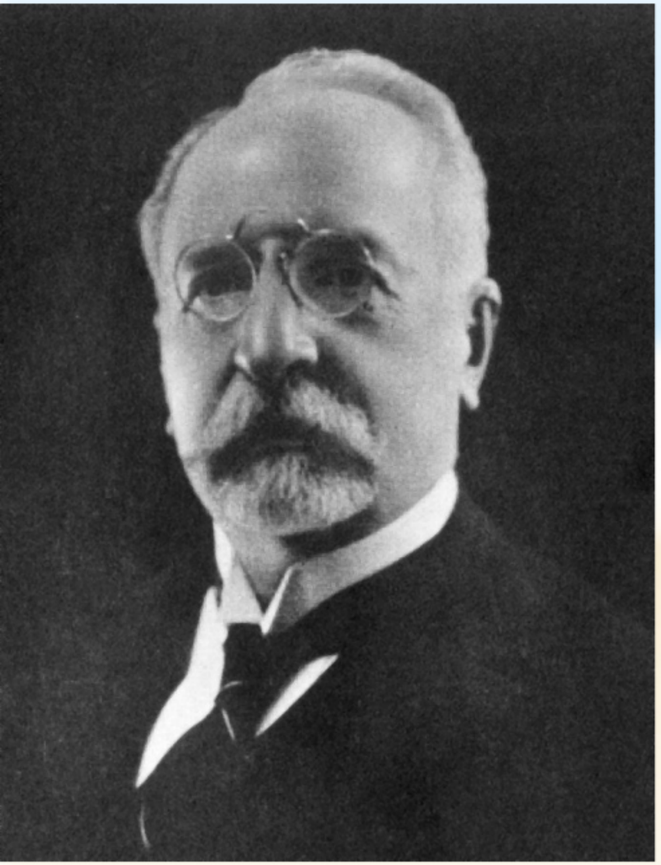
History of plenoptics

(light fields, wavefronts, integral images, lenticular optics)

History of plenoptics

1904

Hartmann's `Filter' or `Mask'



Zeitschrift für Instrumentenkunde.

Redaktionskuratorium:

Geh. Reg.-Rat Prof. Dr. **H. Landolt**, Vorsitzender, Prof. Dr. **A. Westphal**, geschäftsführendes Mitglied,
Prof. Dr. **E. Abbe**, Dr. **H. Krüss.**

Redaktion: Prof. Dr. **St. Lindeck** in Charlottenburg-Berlin.

XXIV. Jahrgang. **Januar 1904.** Erstes Heft.

Objektivuntersuchungen.

Von

J. Hartmann in Potsdam.

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History of plenoptics

1904

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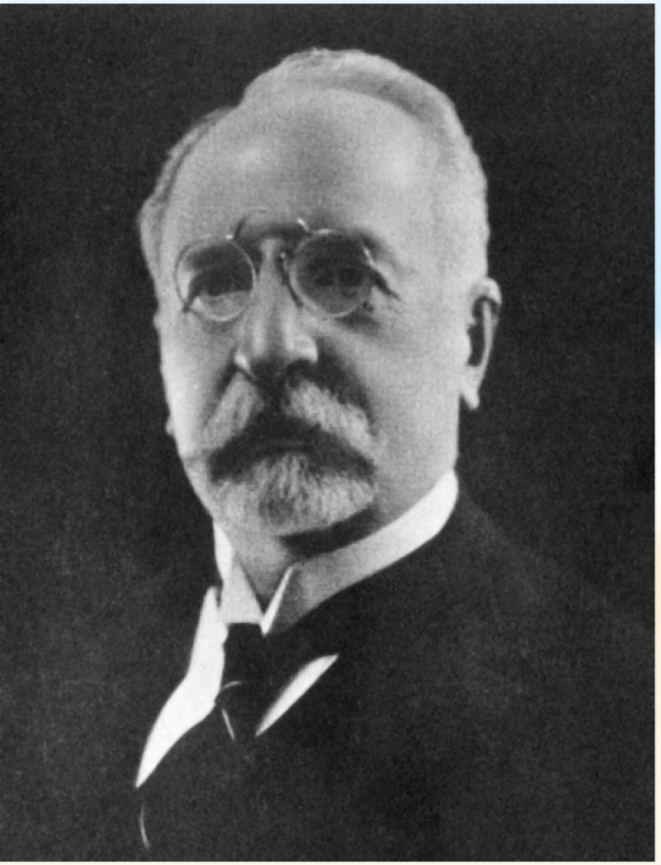

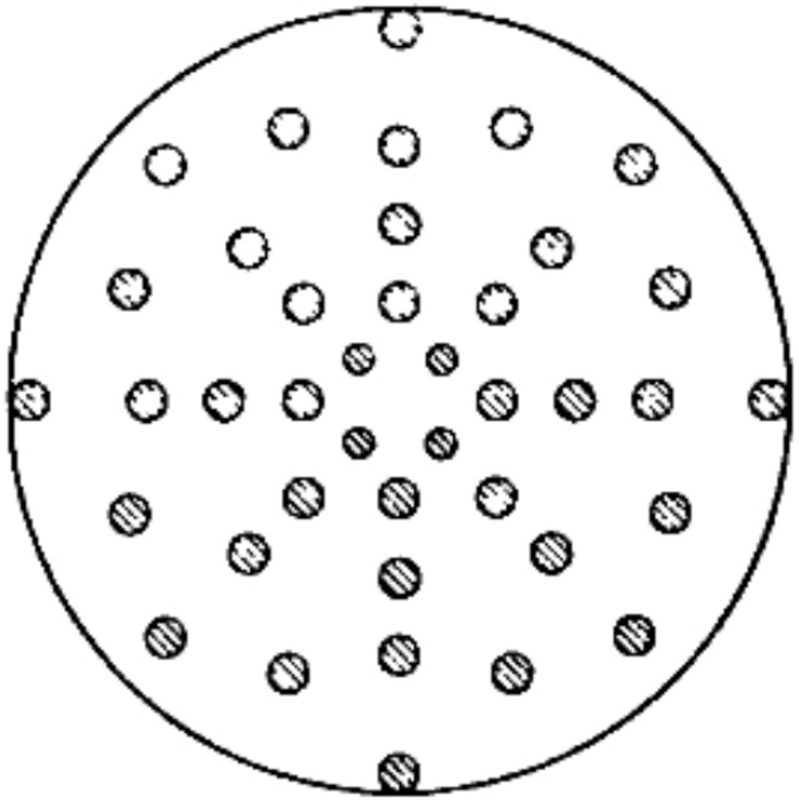

Fig. 2.

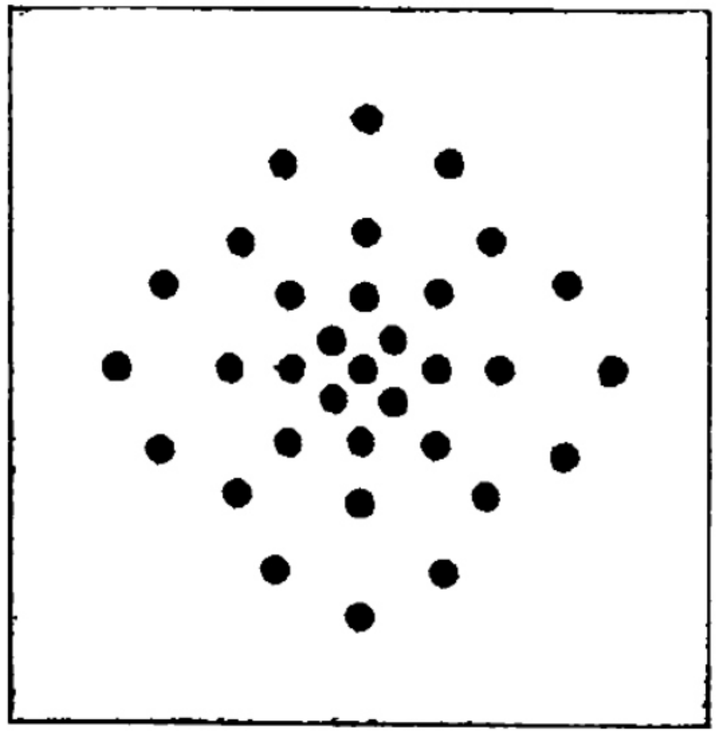

Fig. 4.

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History of plenoptics

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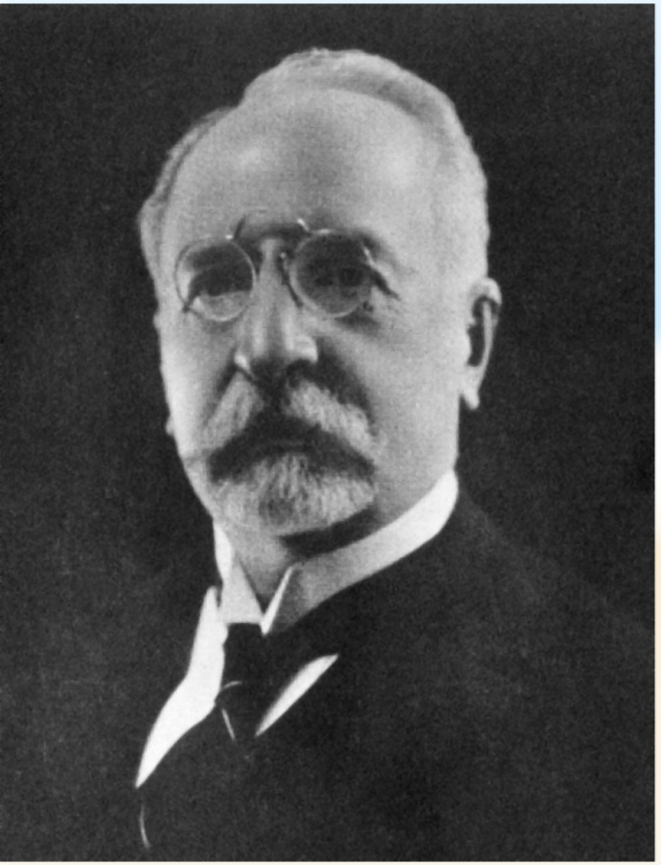

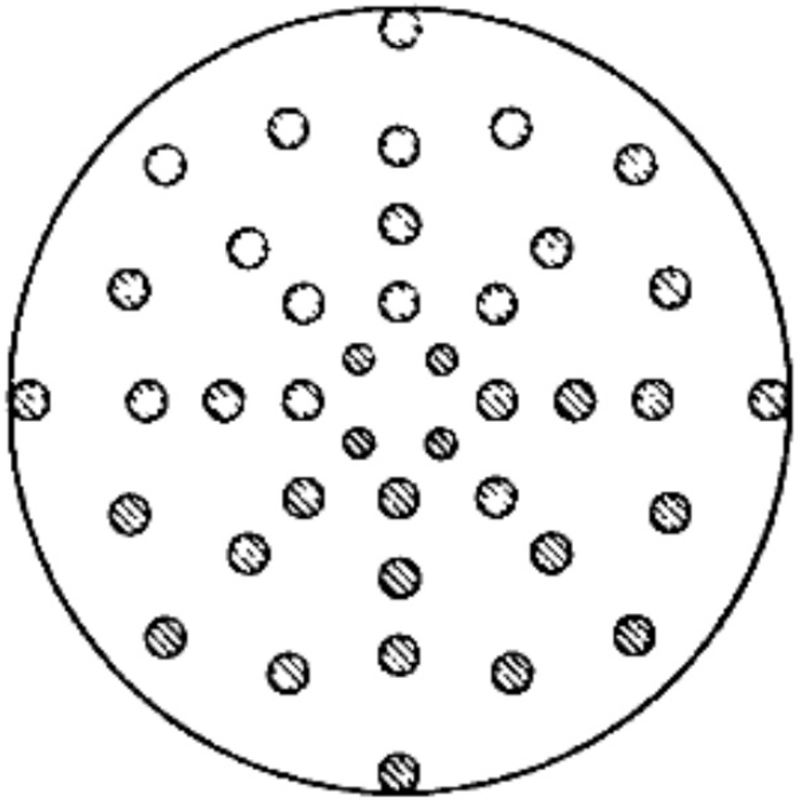

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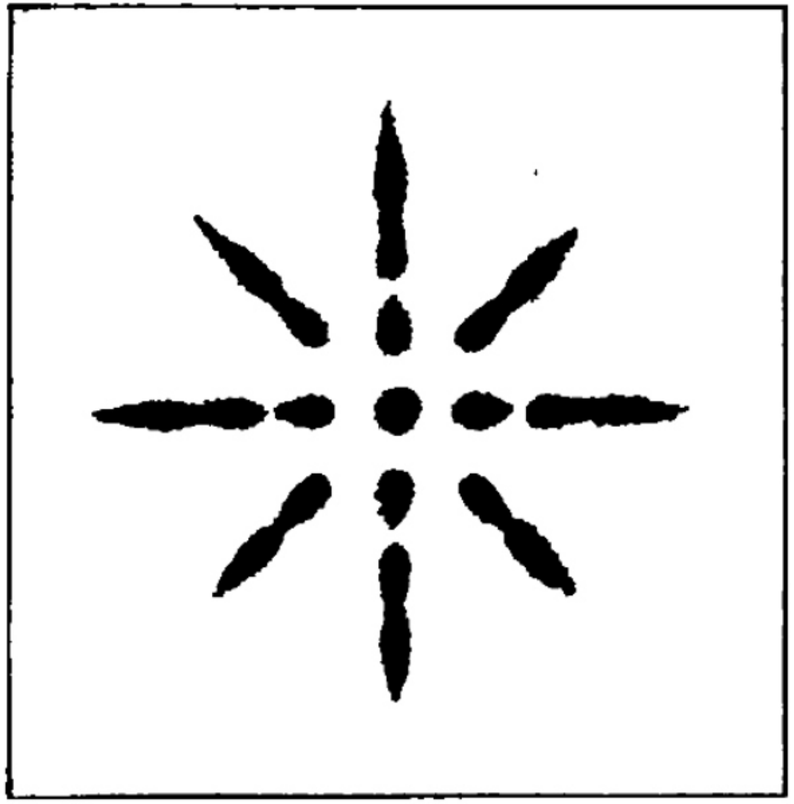


Fig. 3.

J. Hartmann, Objektivuntersuchungen, Zeitschrift fuer Instrumentenkunde, Vol. 1, 1904

History of plenoptics 1908

Lippmann's display

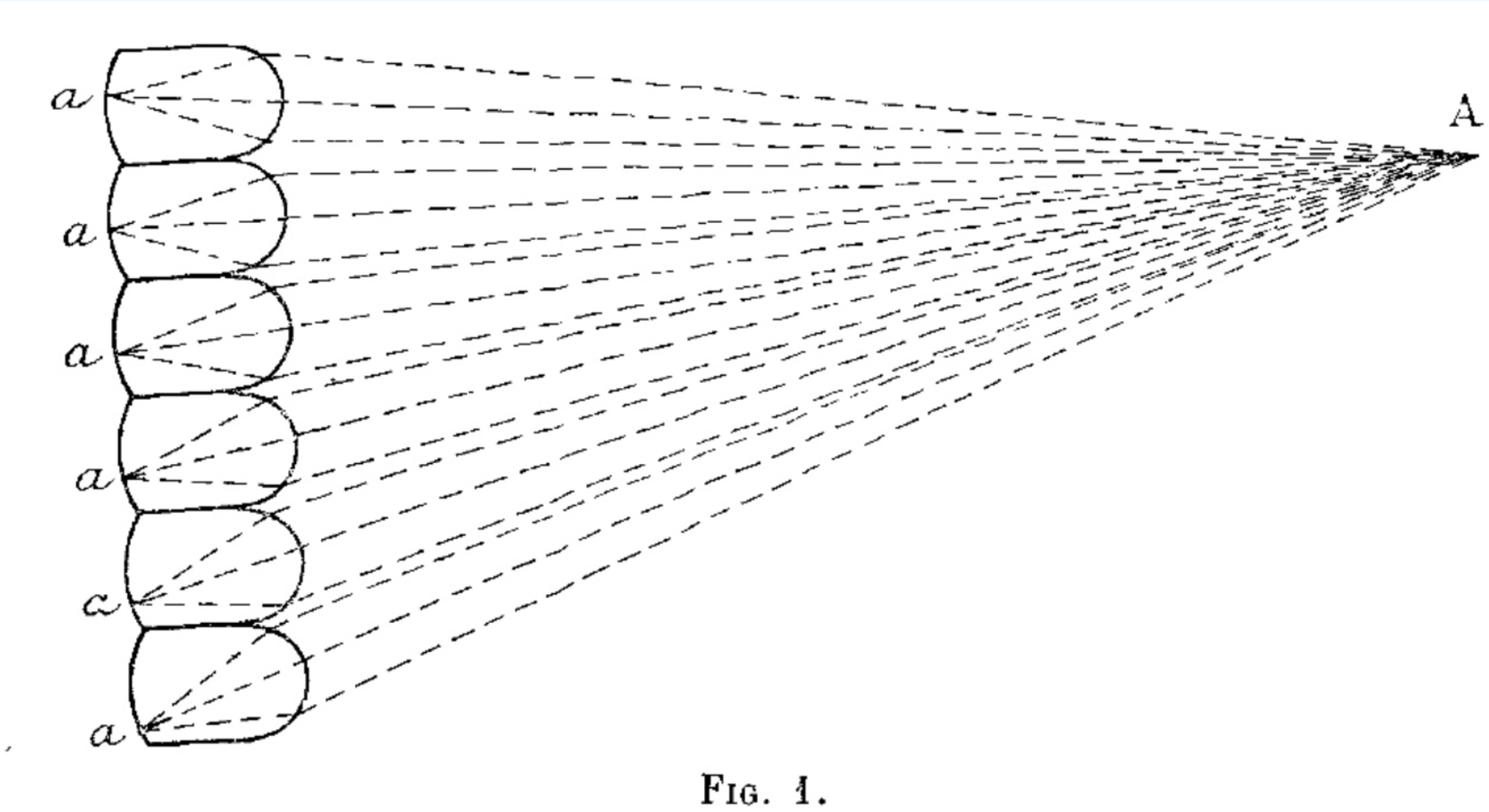


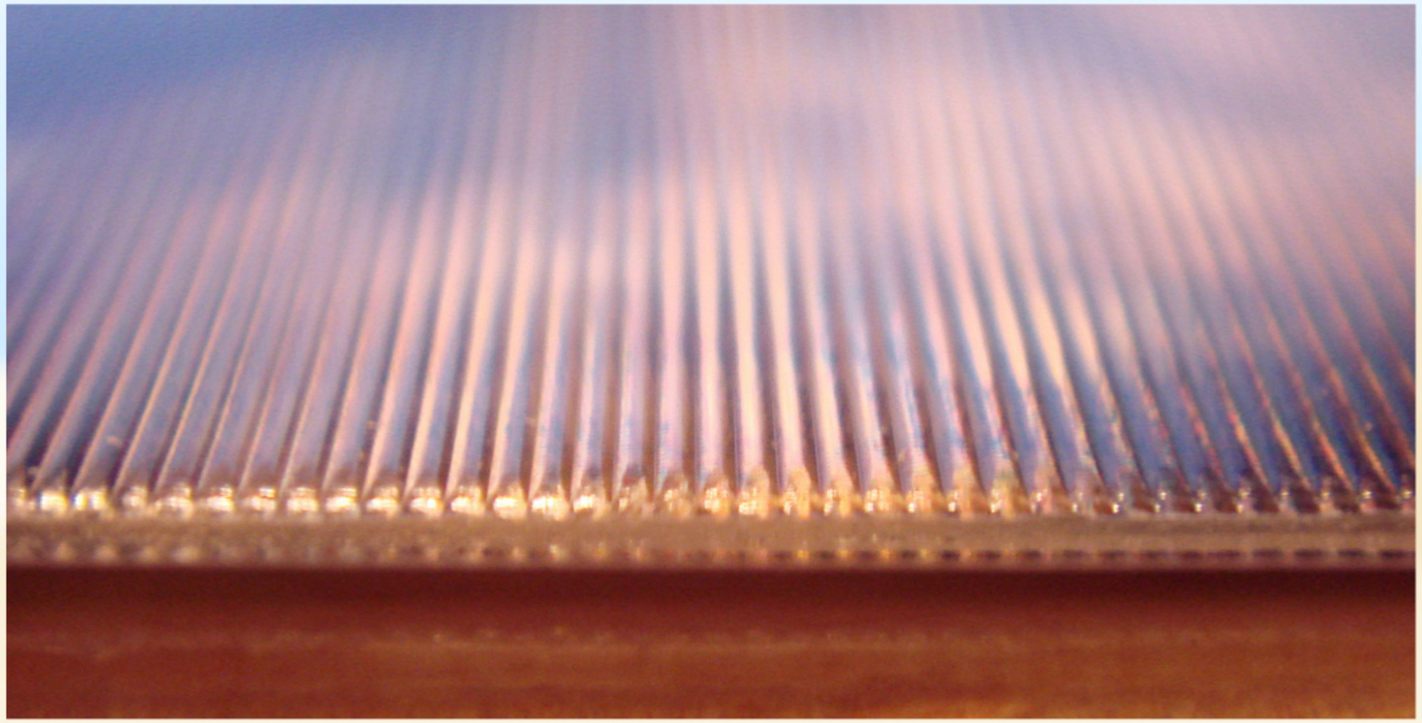
FIG. 1.

G. Lippmann, Epreuves reversibles donnant la sensation du relief, J. Phys. Theor. Appl. 7 821-825, 1908

History of plenoptics

Lippmann's display in (1D)
(lenticular display)

1940s until today



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History of plenoptics

Lippmann's display in (1D)
(lenticular display)

1940s until today

since 1980s

https://petapixel.com/2023/02/15/photographer-makes-real-life-gifs-via-lenticular-printing/

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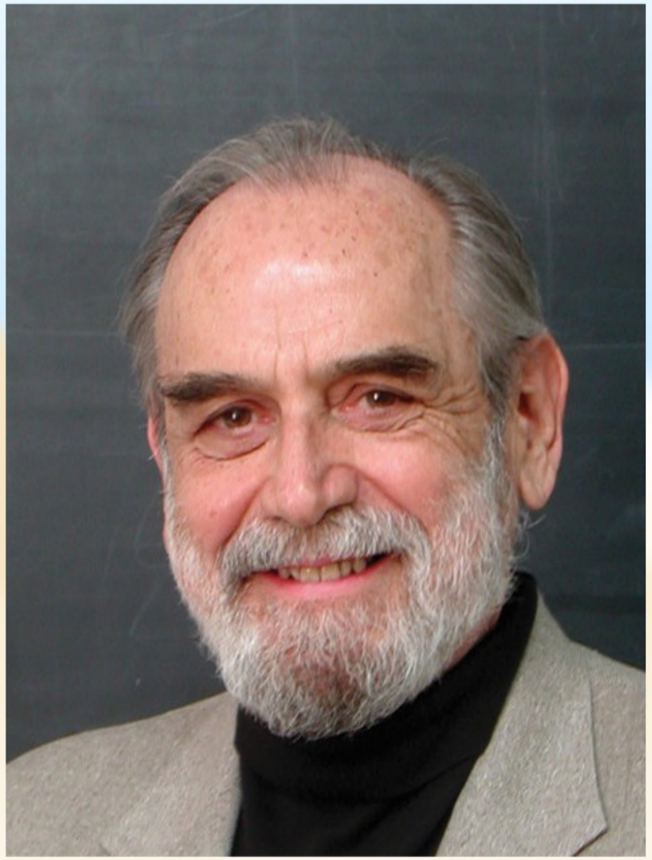
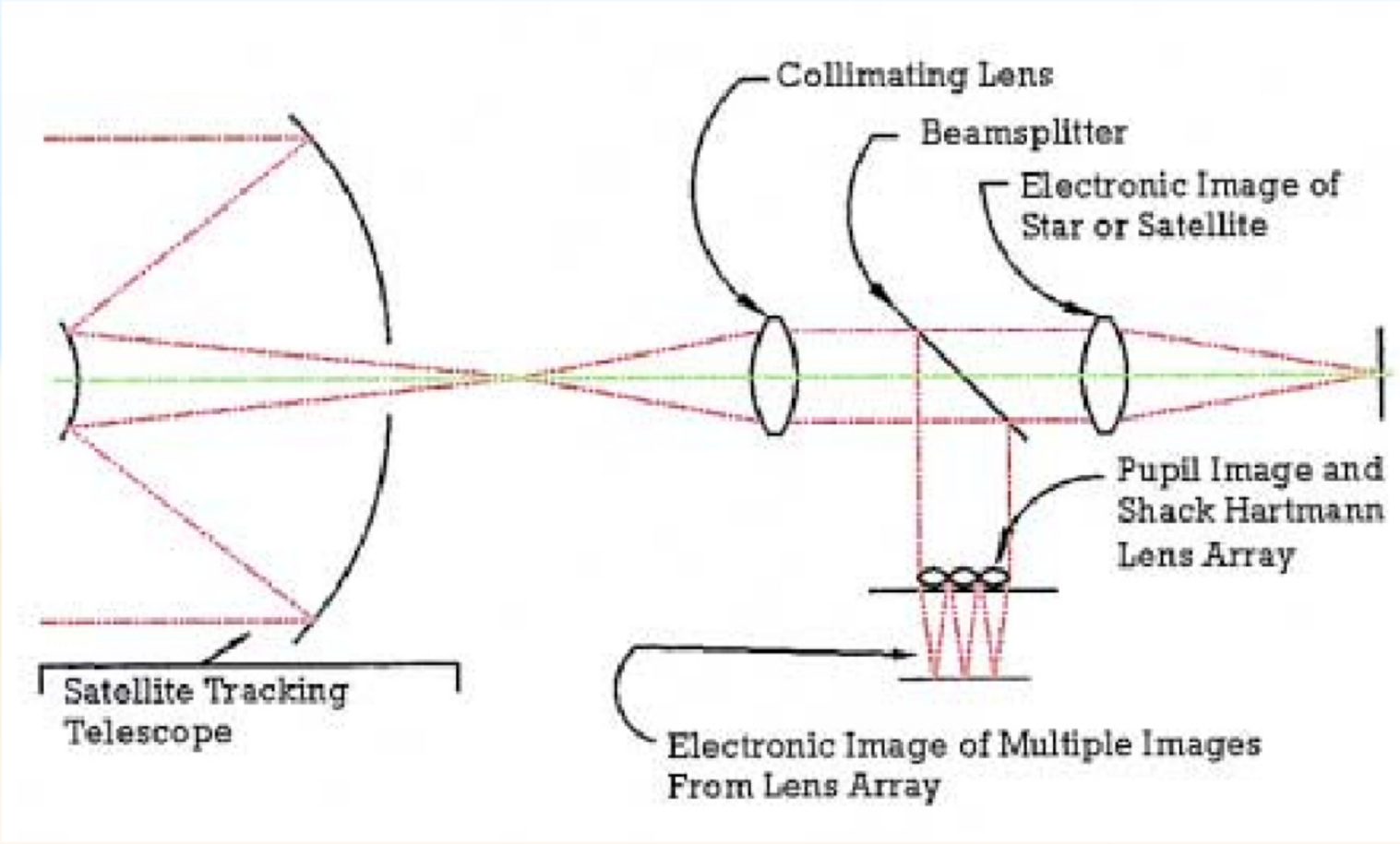
History of plenoptics

Shack's and Platt's lens array

1960 - 1970





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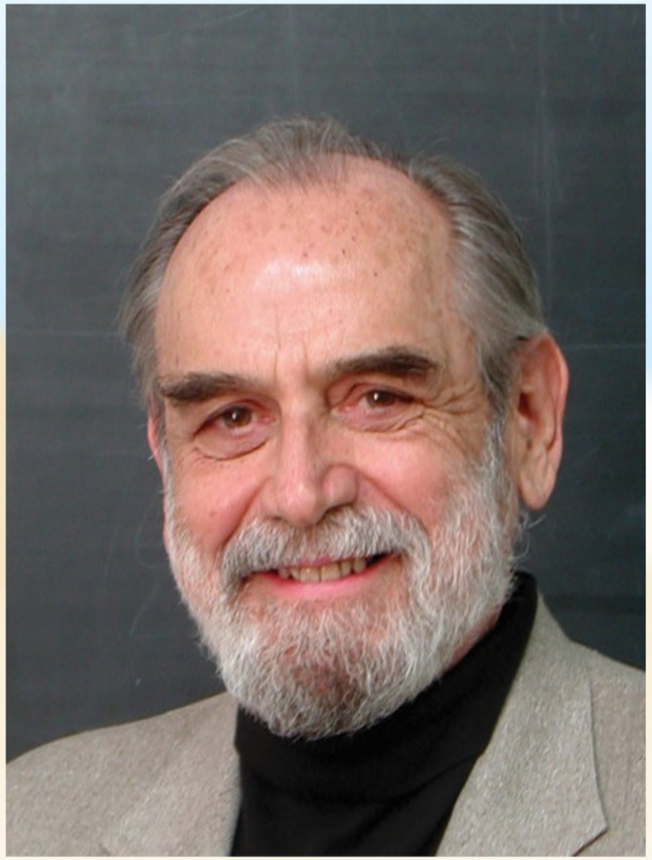

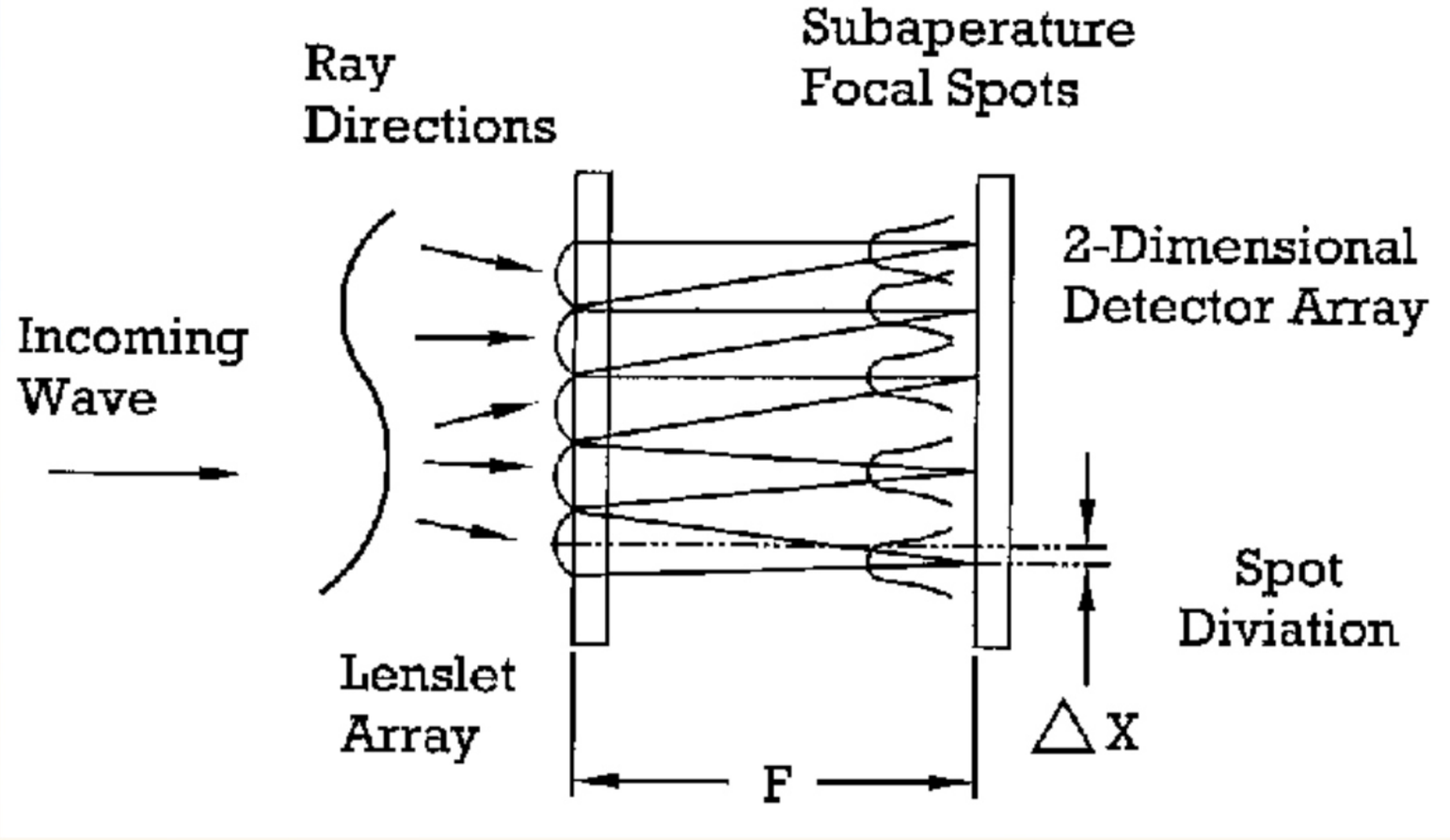

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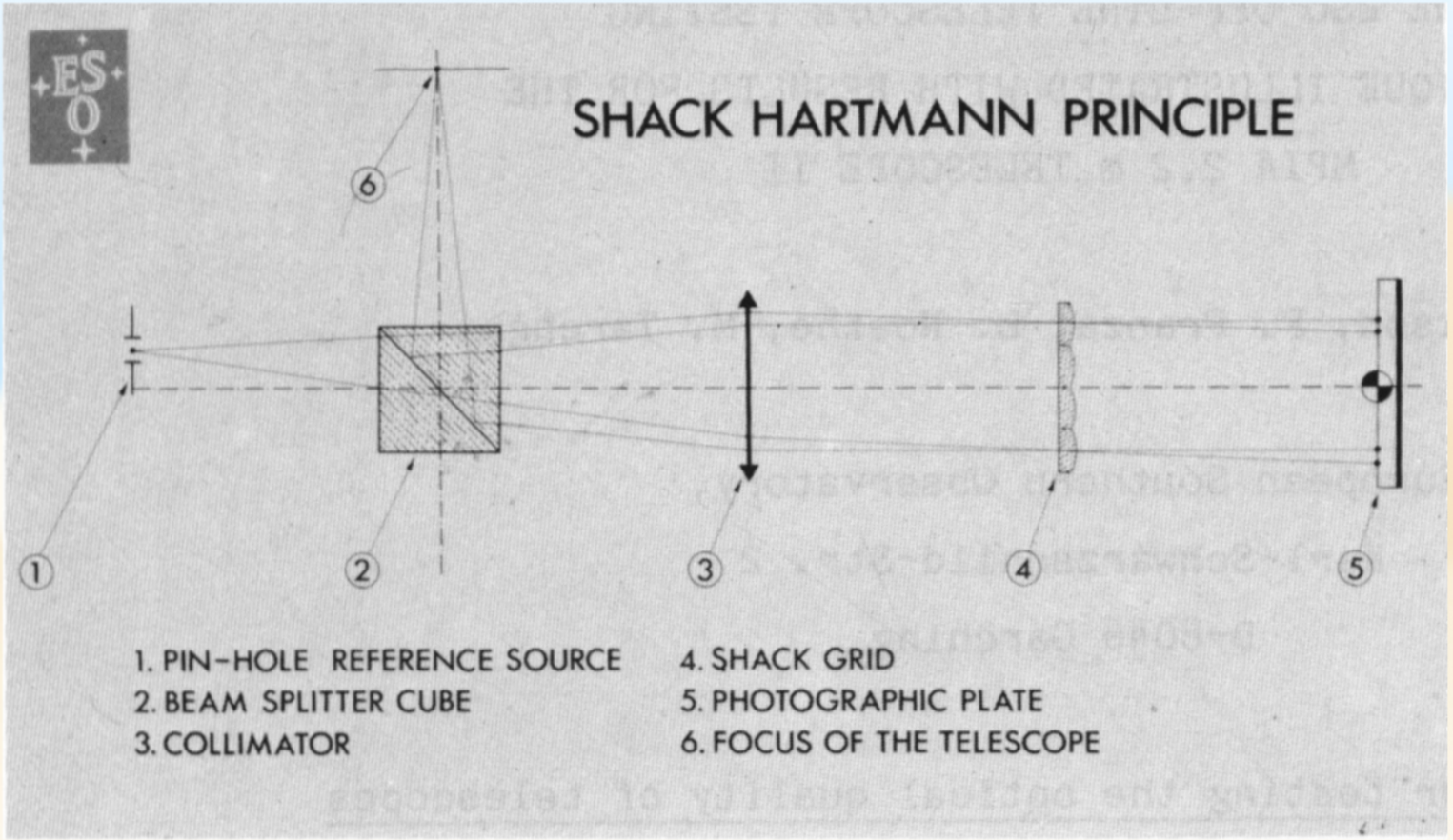
History of plenoptics

1984

Wilson's testing technique



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History of plenoptics

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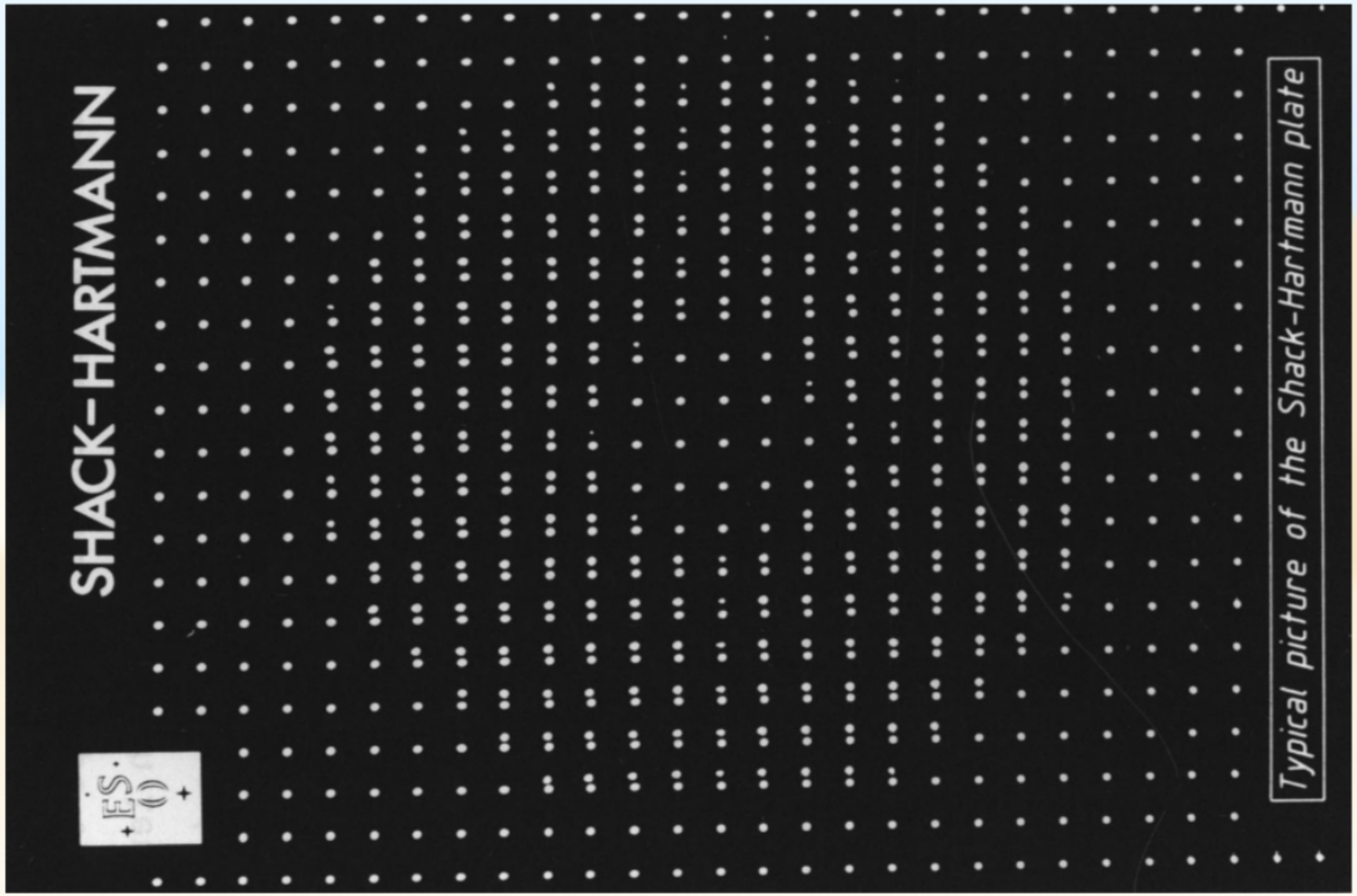

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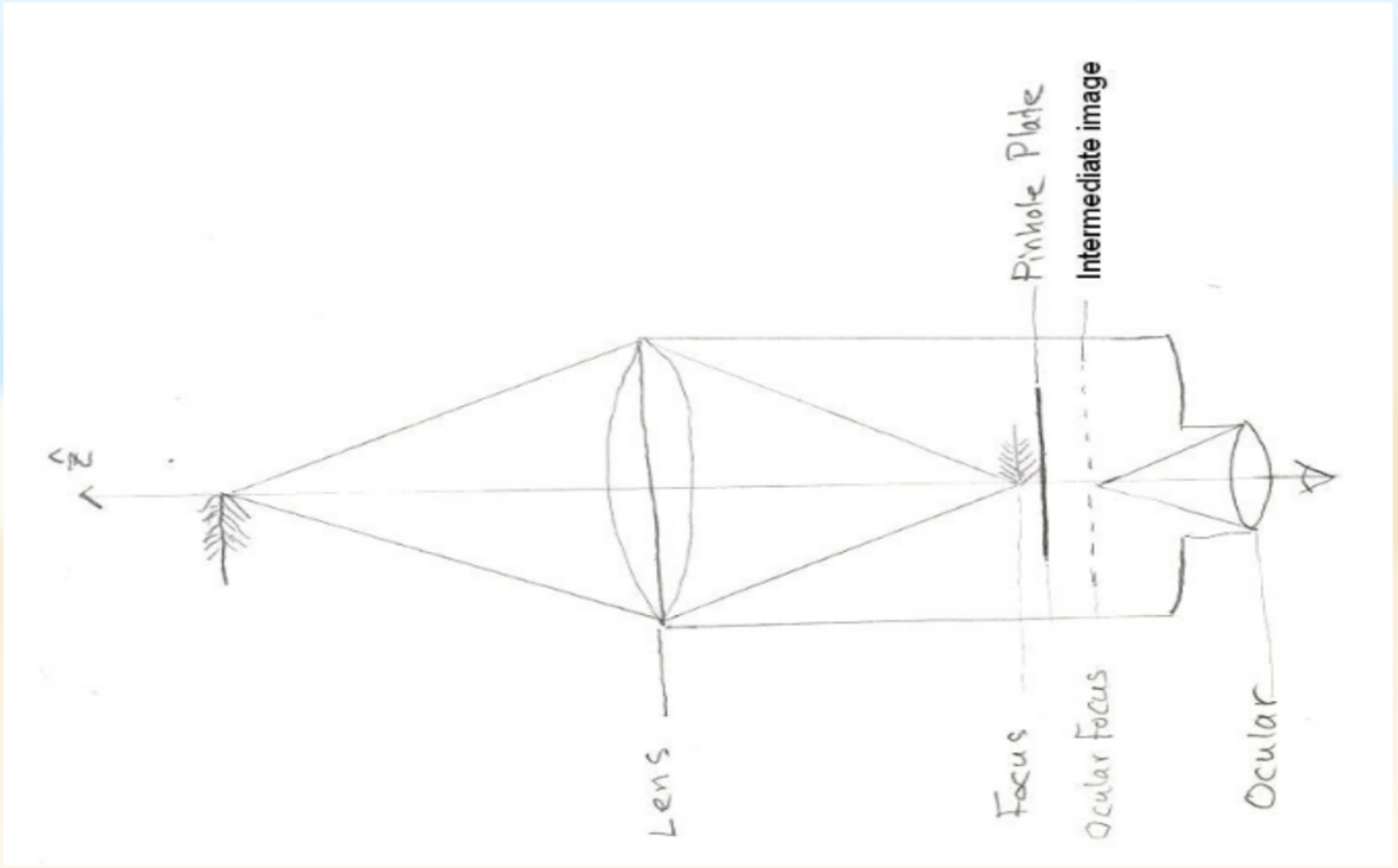
History of plenoptics 2002

Bergholm's hand-held plenoscope



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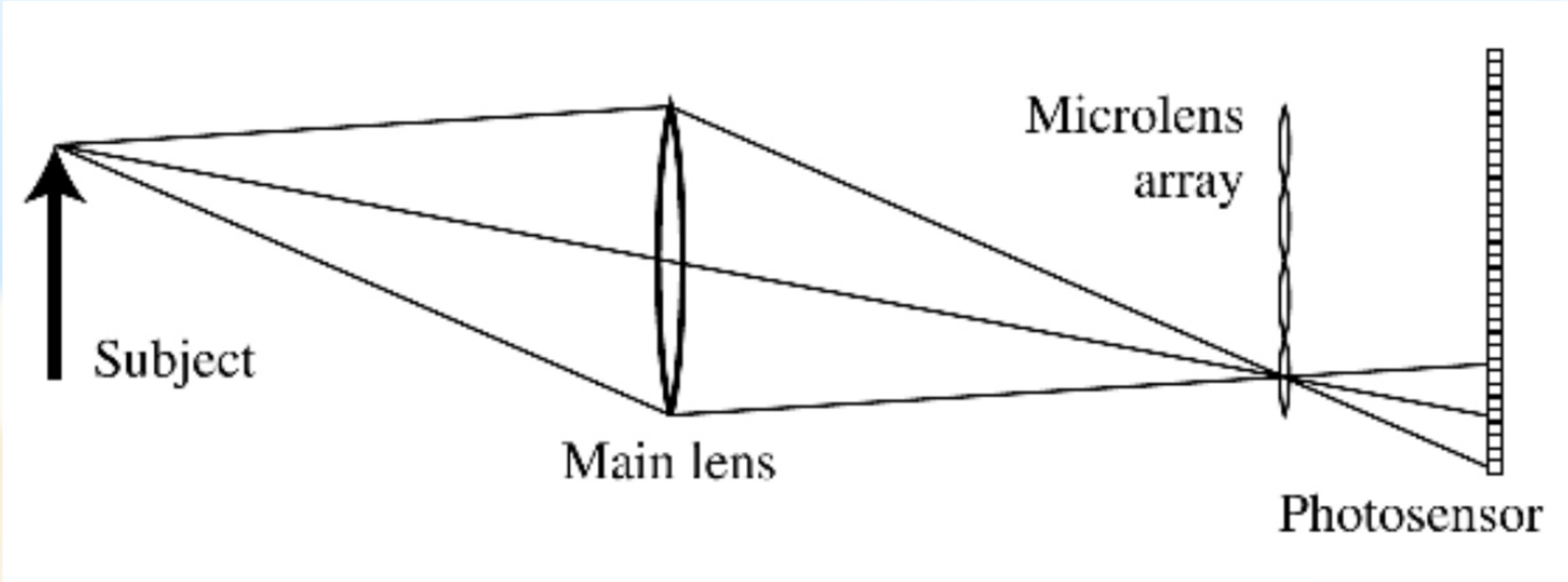
History of plenoptics 2005

Ng et al. hand-held plenoptic camera



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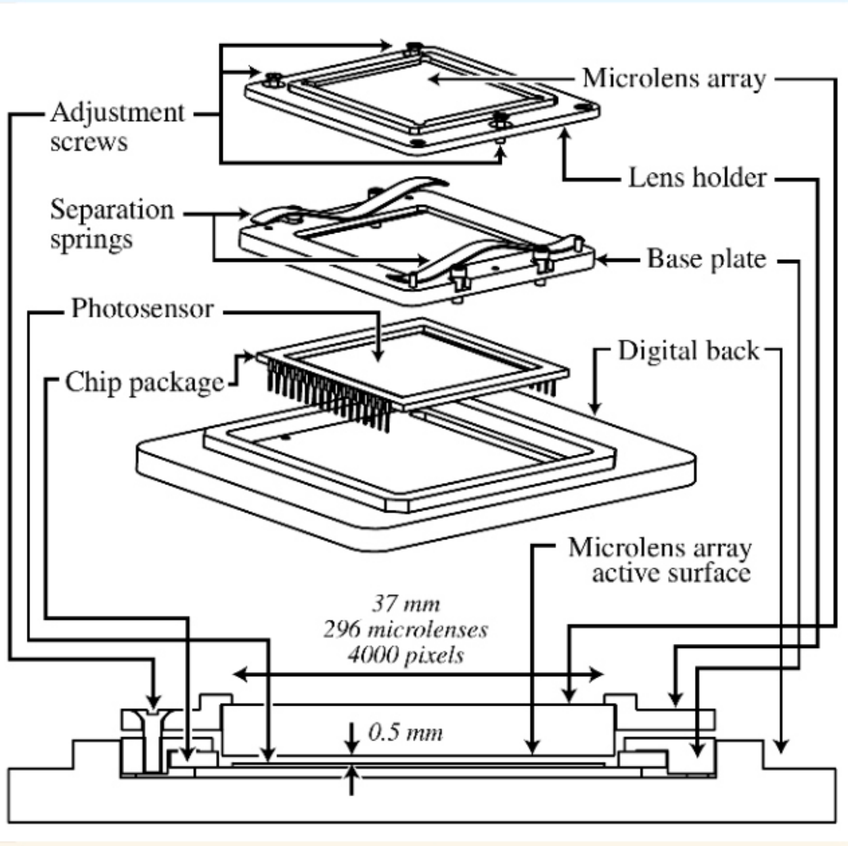

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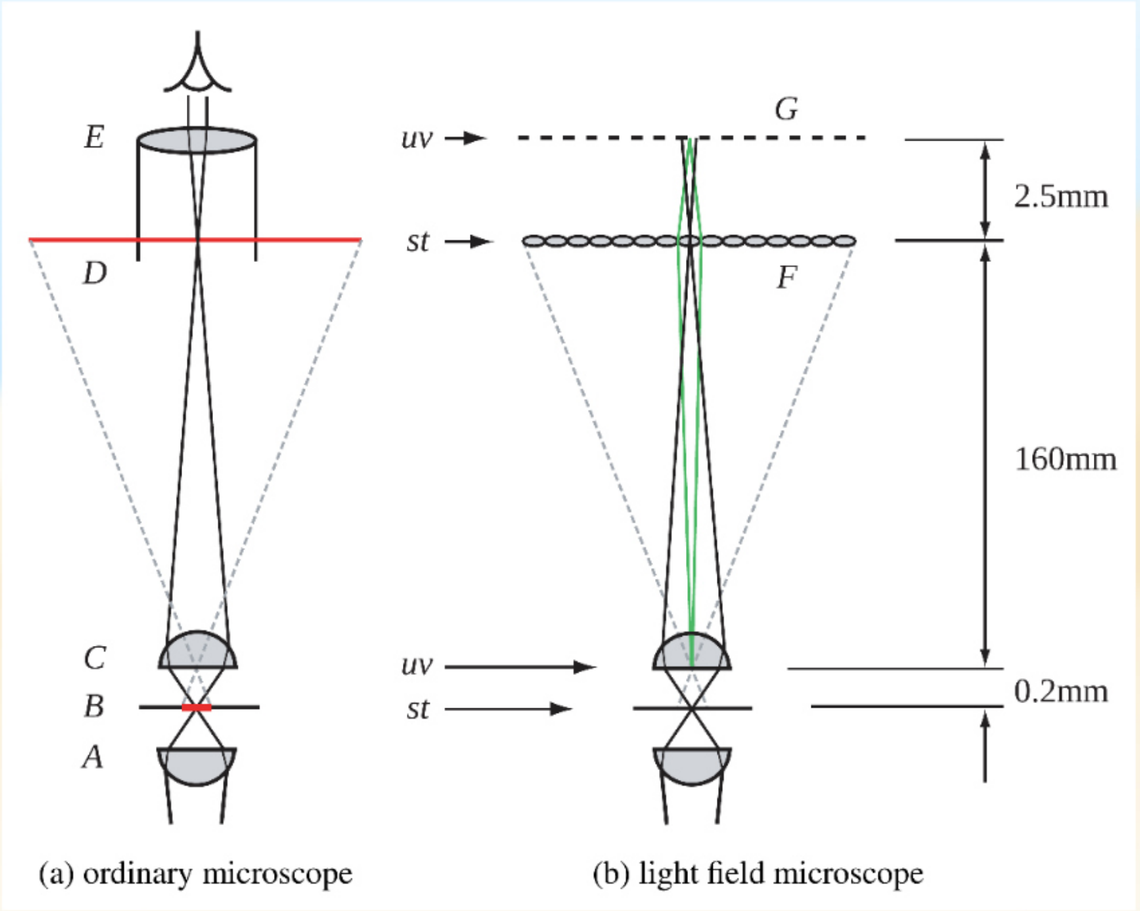

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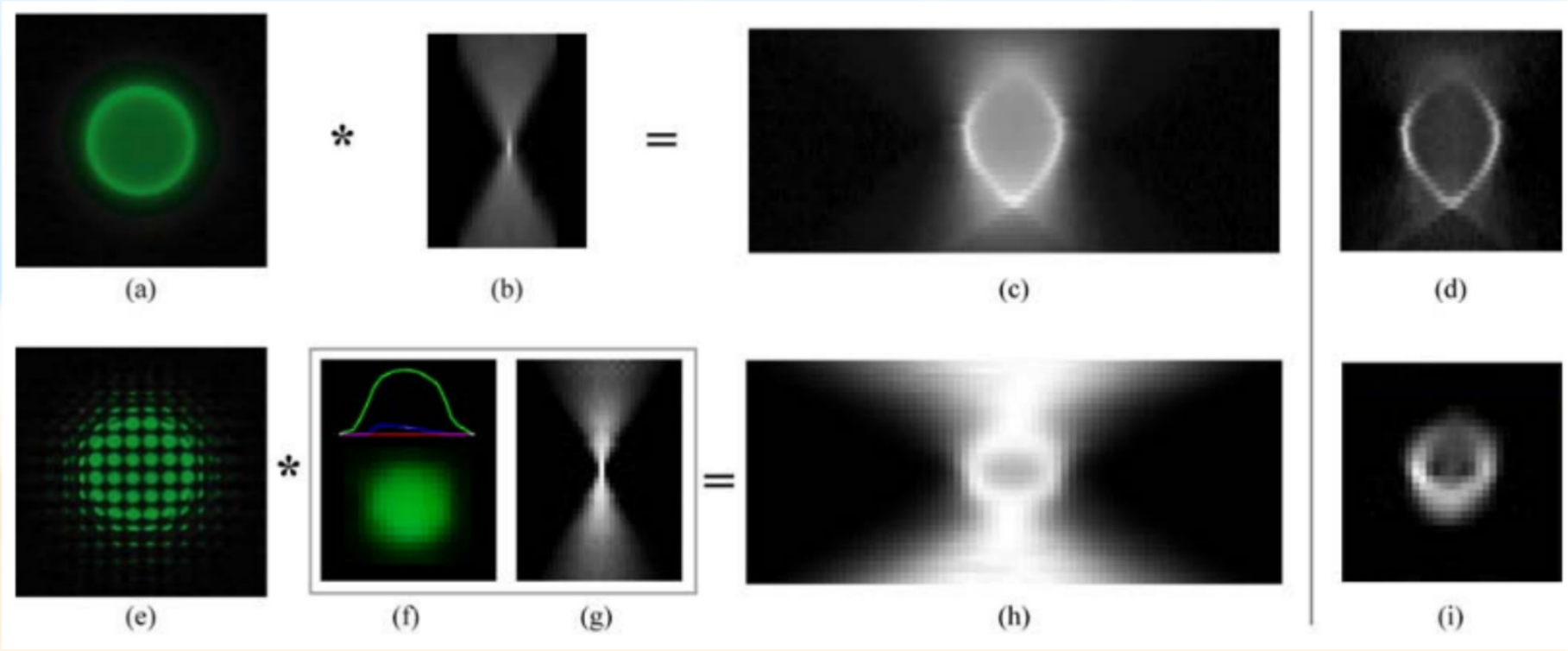

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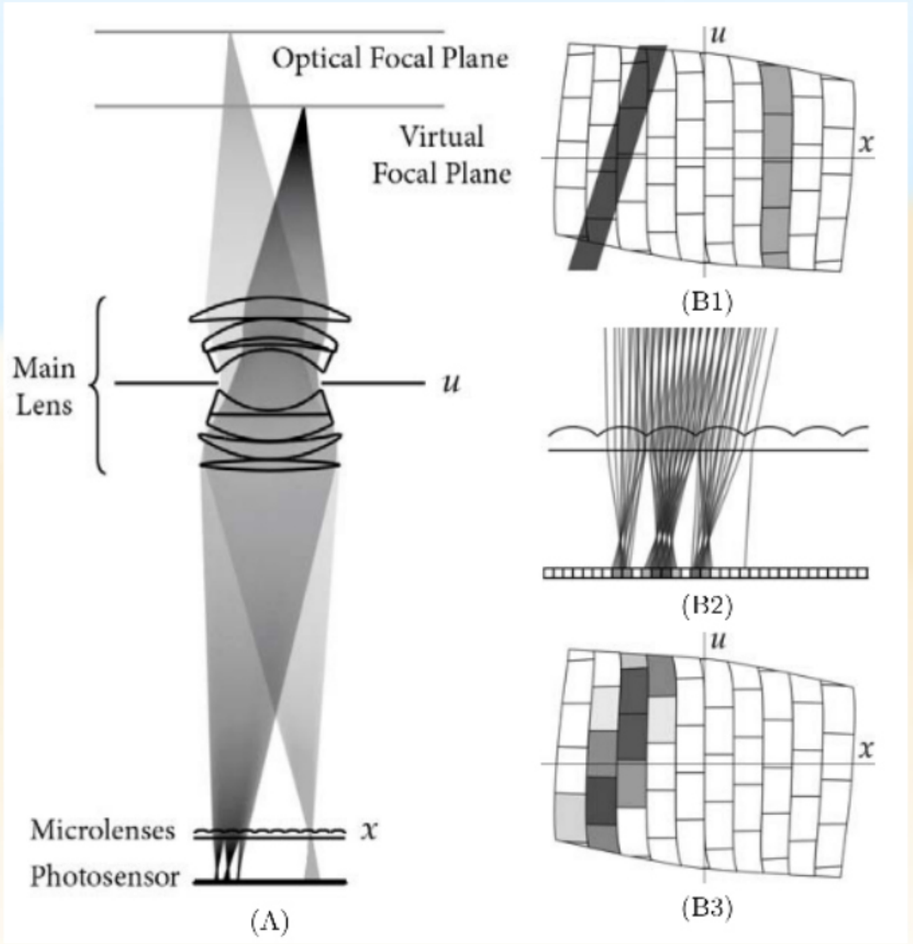

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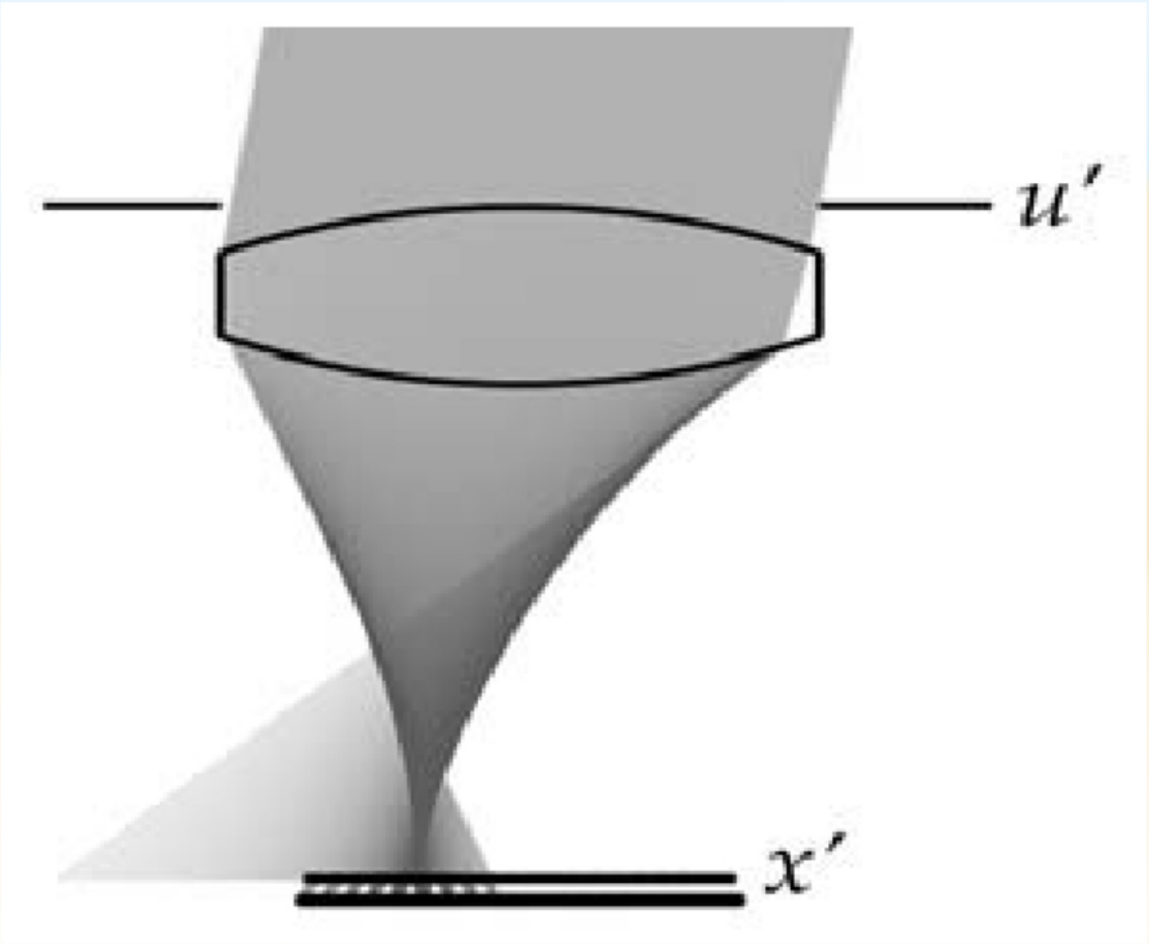

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History of plenoptics

2006

R. Ng starts up Lytro

History of plenoptics

R. Ng starts up Lytro

2006

History of plenoptics

2011

Lippmann's display (1D)

TOSHIBA

Toshiba 55LZ2 TV, Internationale Funkaustellung (IFA), Berlin, 2011
Pictures taken from: www.computerbase.de

History of plenoptics

Lippmann's display (1D)

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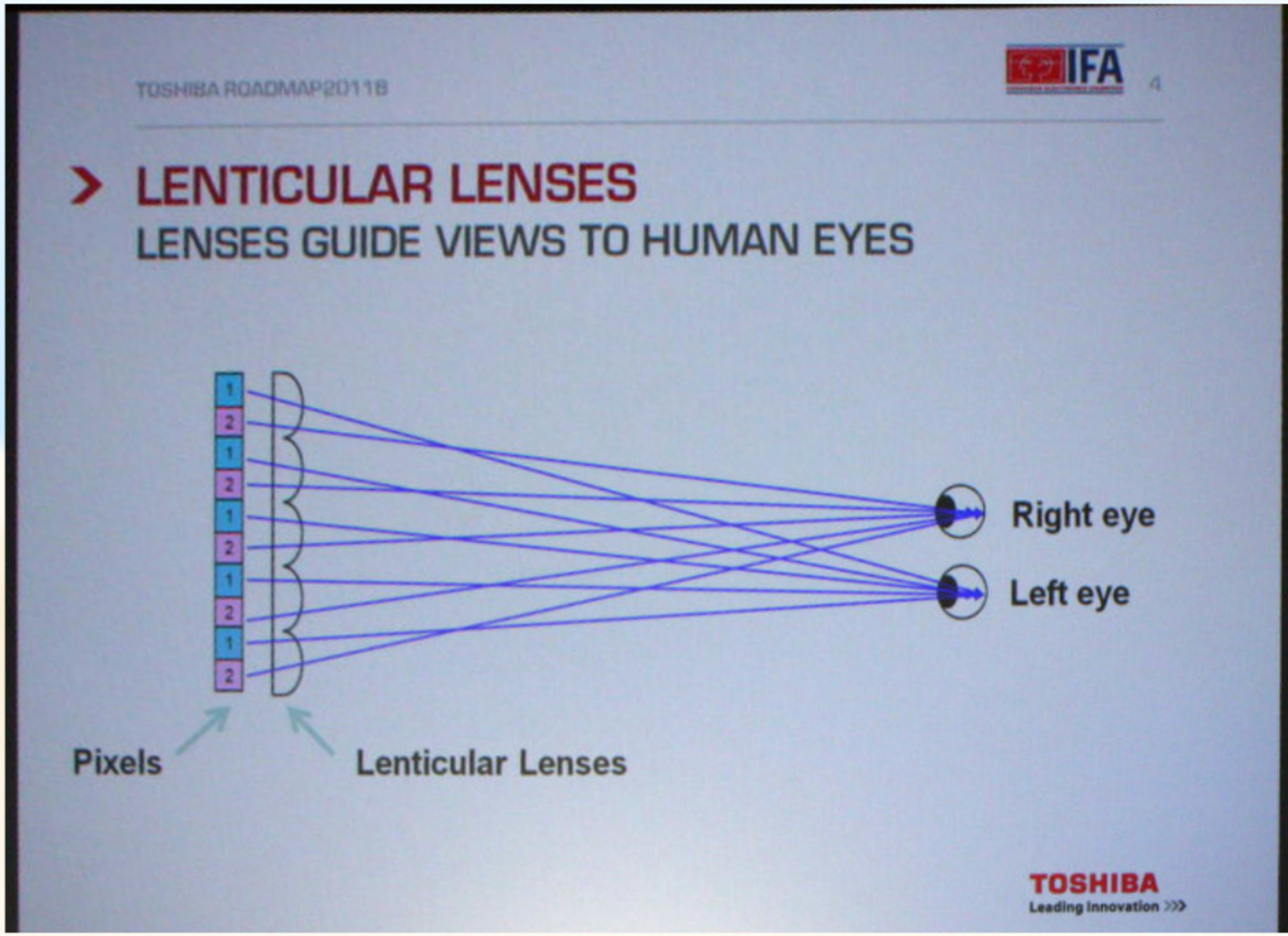

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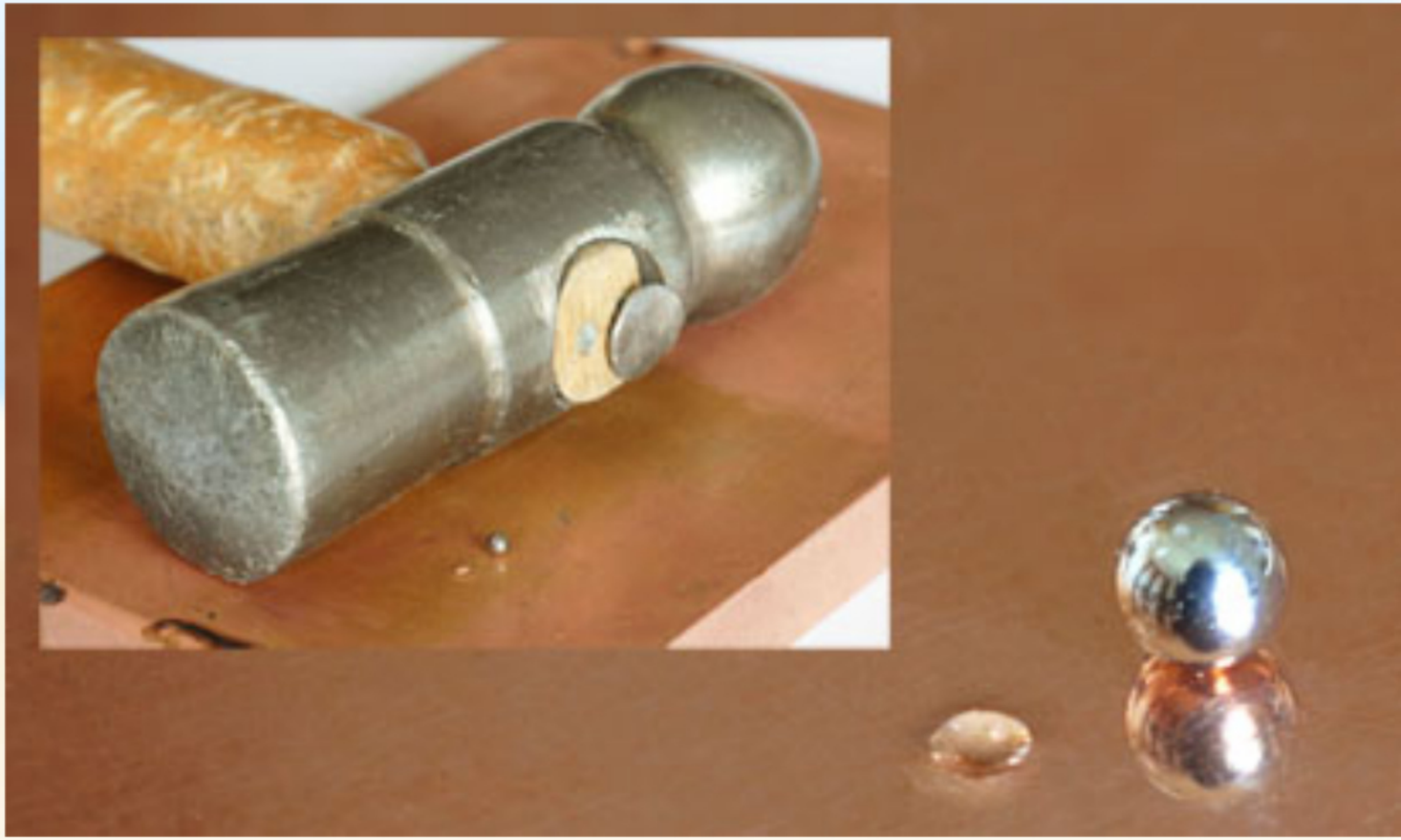

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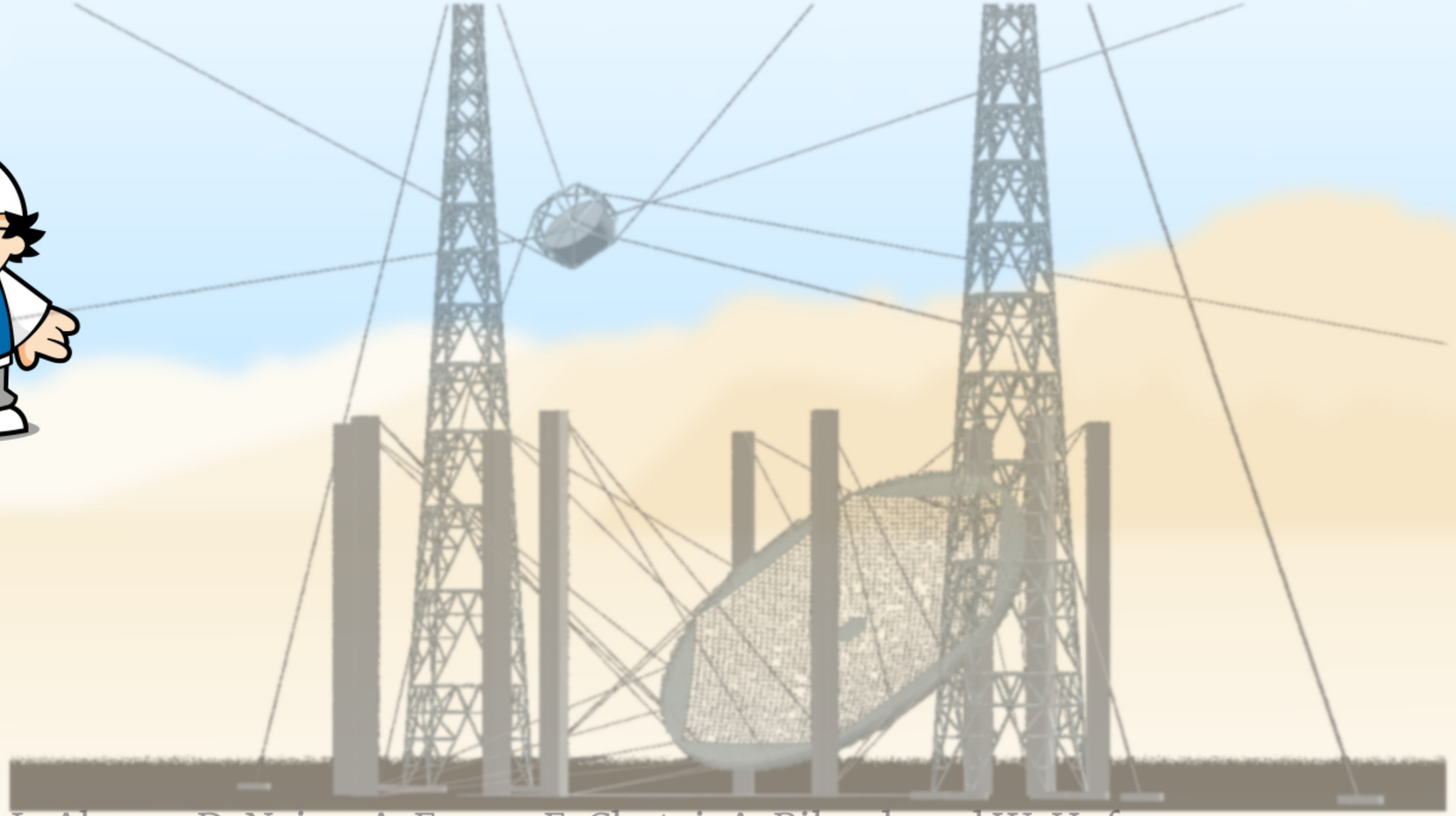
History of plenoptics 2018 - 2024

S. A. Mueller et al.: Cherenkov Plenoscope for Gamma-Ray Astronomy



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History of plenoptics 2018 - 2024

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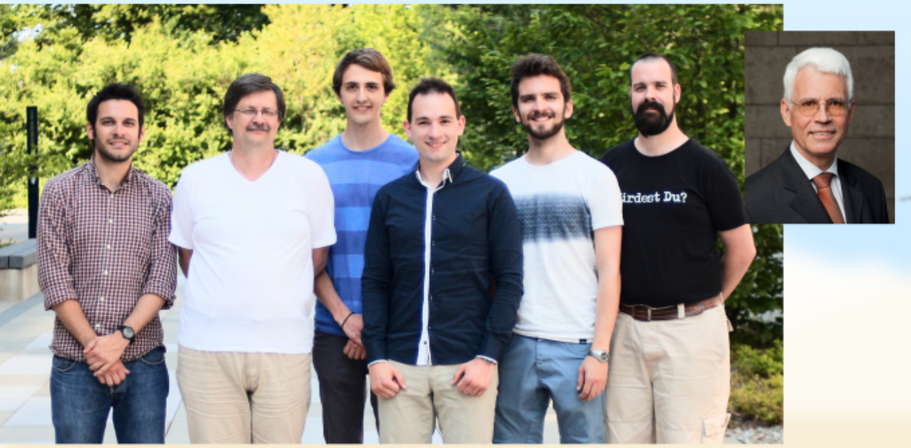

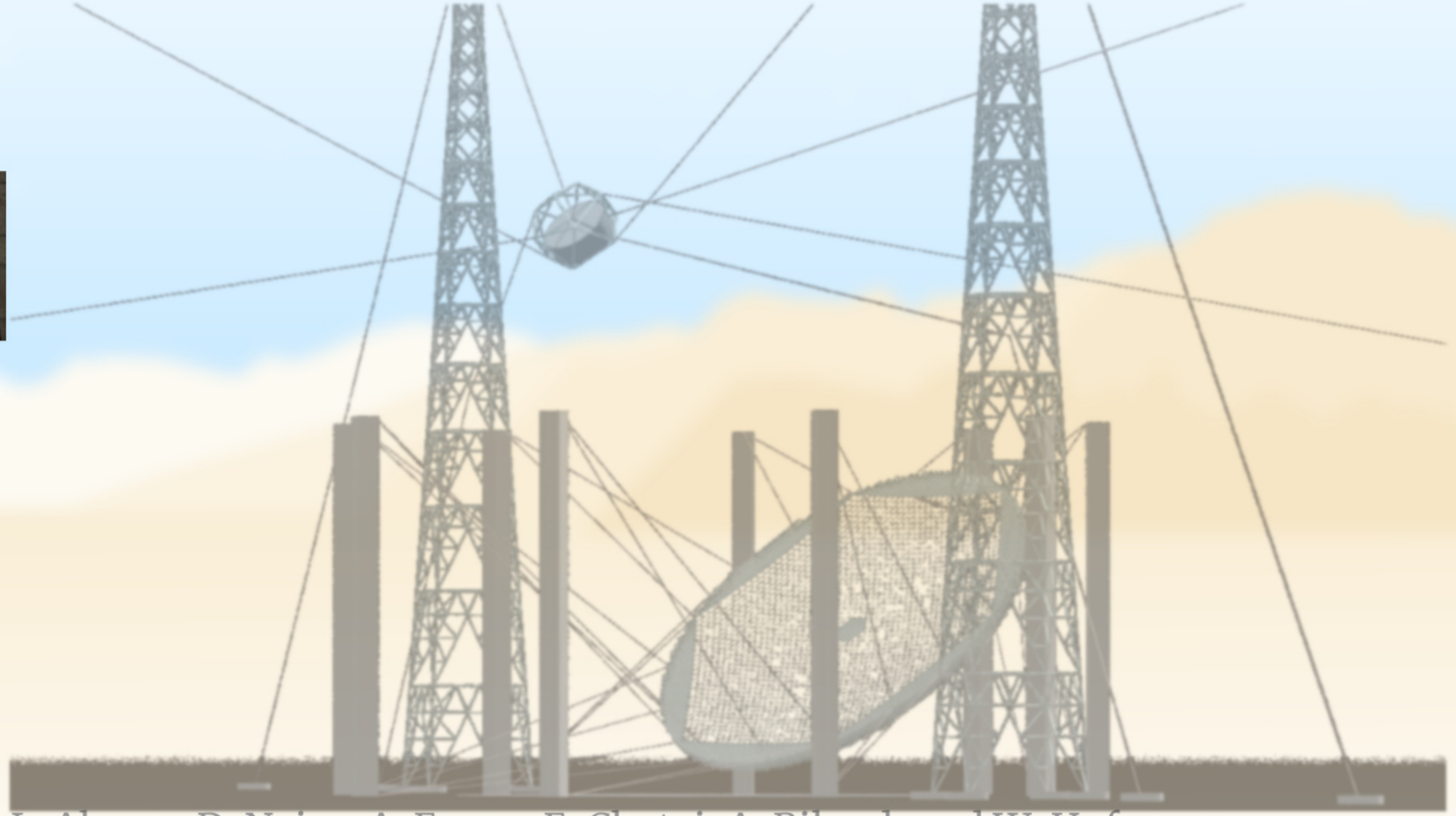

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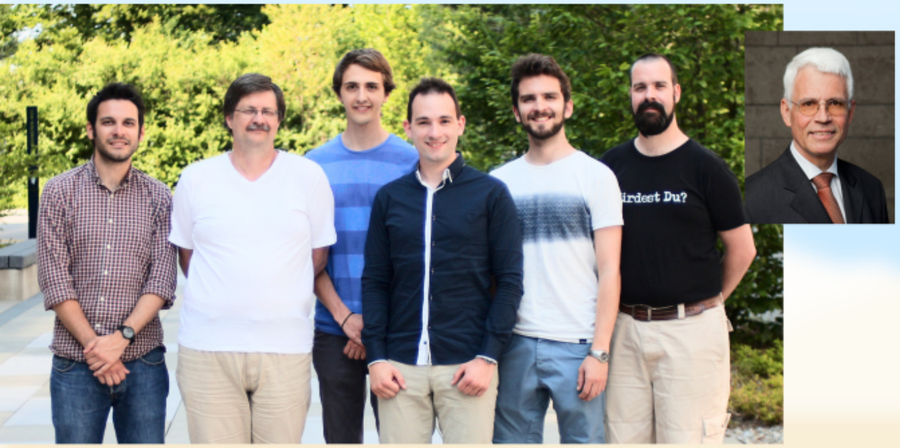

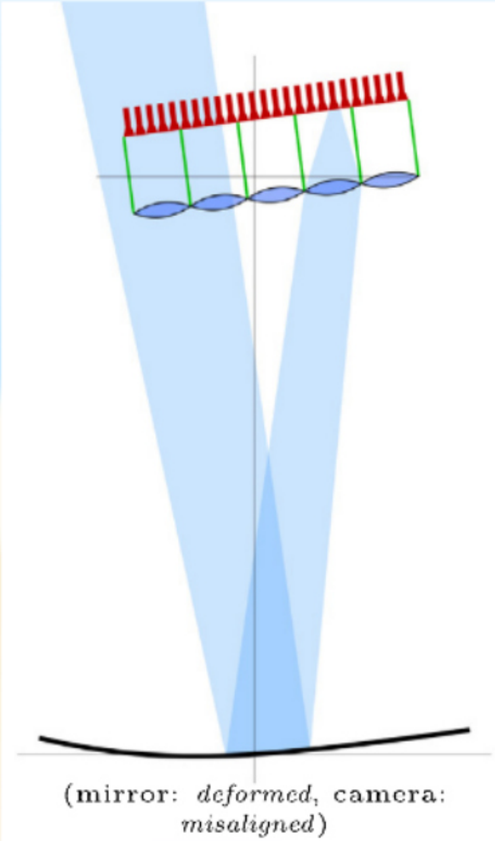

(mirror: *deformed*, camera: *misaligned*)

$$I_g = U(g) \cdot \mathcal{R}_h$$

with the imaging matrix

$$U(g) = \begin{bmatrix} u_{1,1}(g) & u_{1,2}(g) & \cdots & u_{1,K}(g) \\ u_{2,1}(g) & u_{2,2}(g) & \cdots & u_{2K}(g) \\ \vdots & \vdots & \ddots & \vdots \\ u_{N,1}(g) & u_{N,2}(g) & \cdots & u_{N,K}(g) \end{bmatrix}$$

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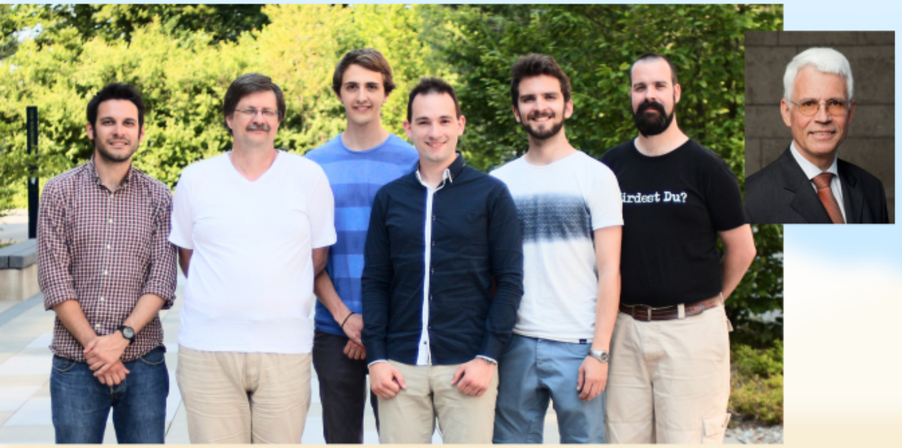
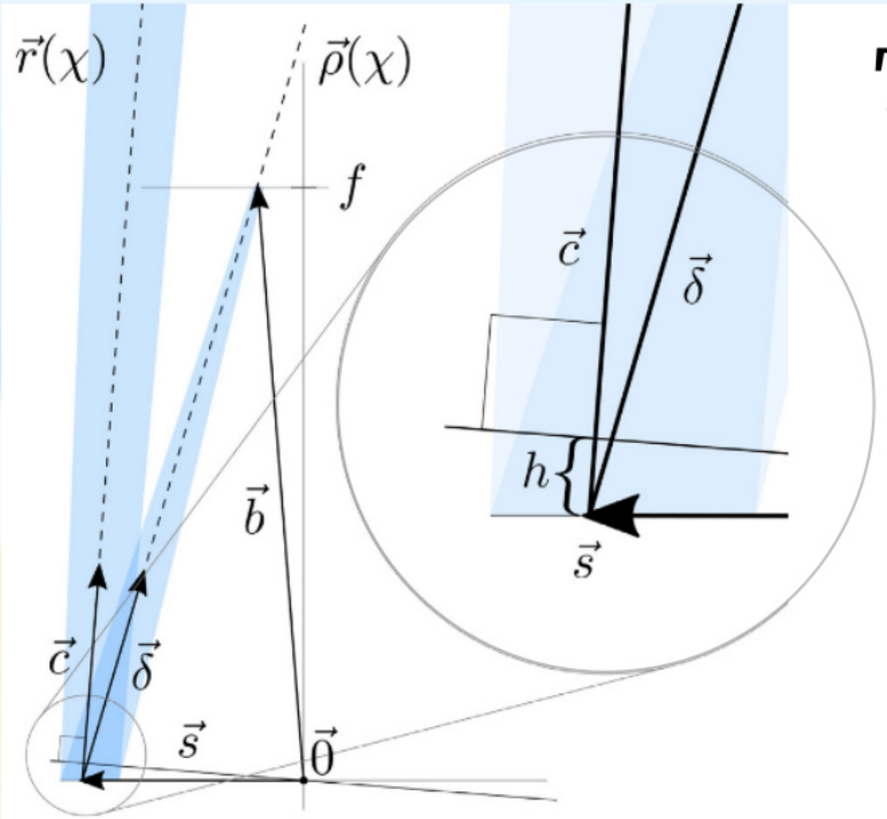


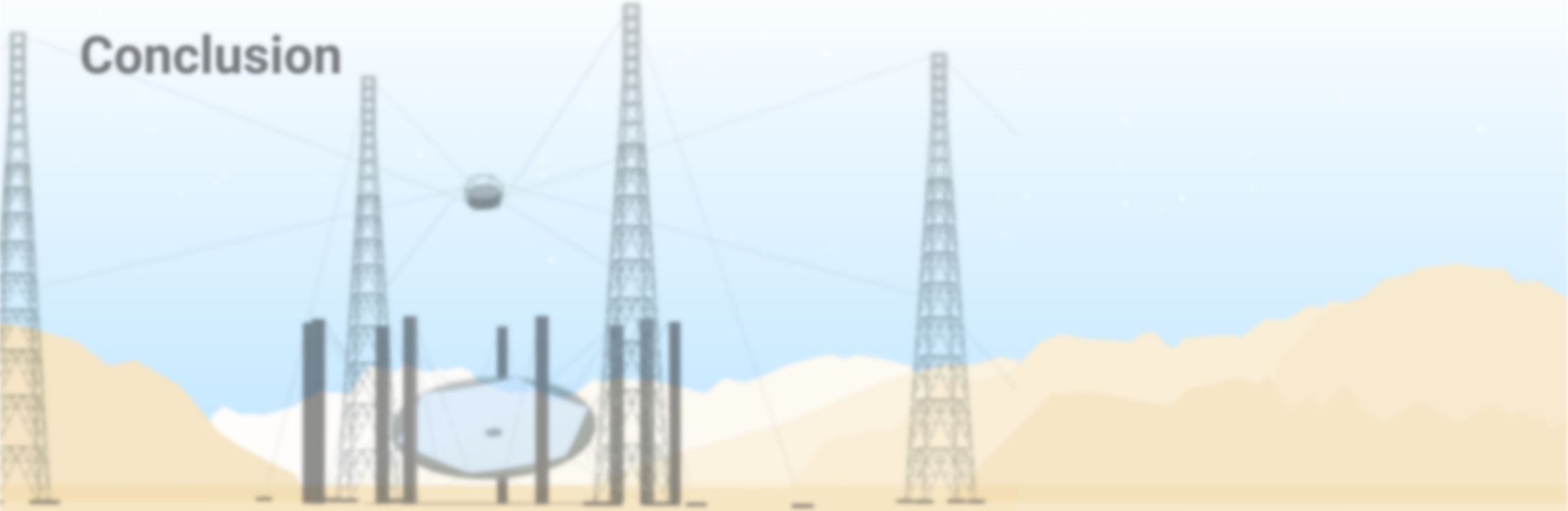


Timing in images

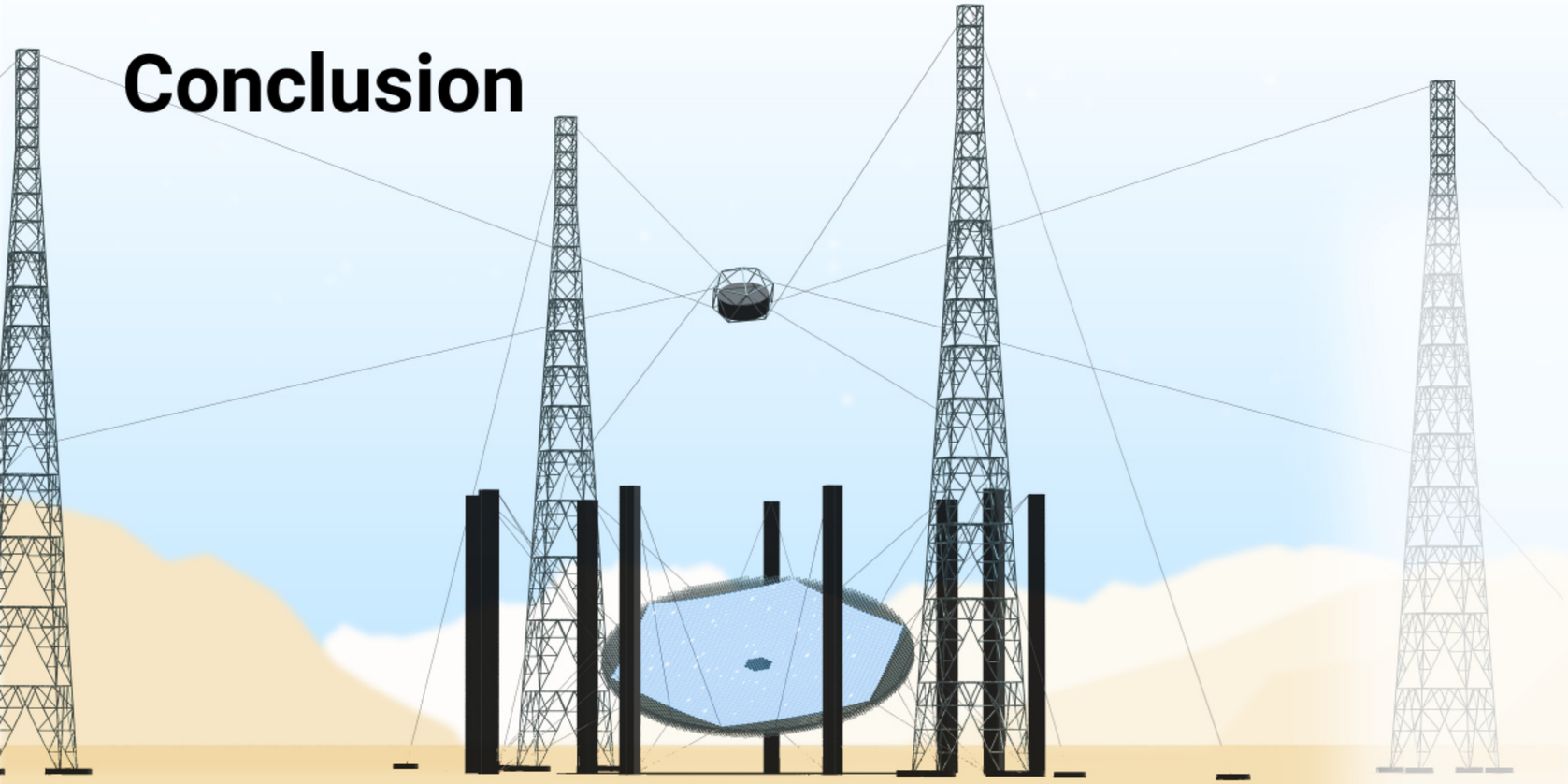
Correcting aberrations in the time domain.

S. A. Mueller, S. Daglas, A. A. Engels, M. L. Ahnen, D. Neise, A. Egger, E. Chatzi, A. Biland, and W. Hofmann, Exploring one giga electronvolt cosmic gamma rays with a Cherenkov plenoscope capable of recording atmospheric light fields, Part 1: Optics, Astroparticle Physics, Vol.158, 2024

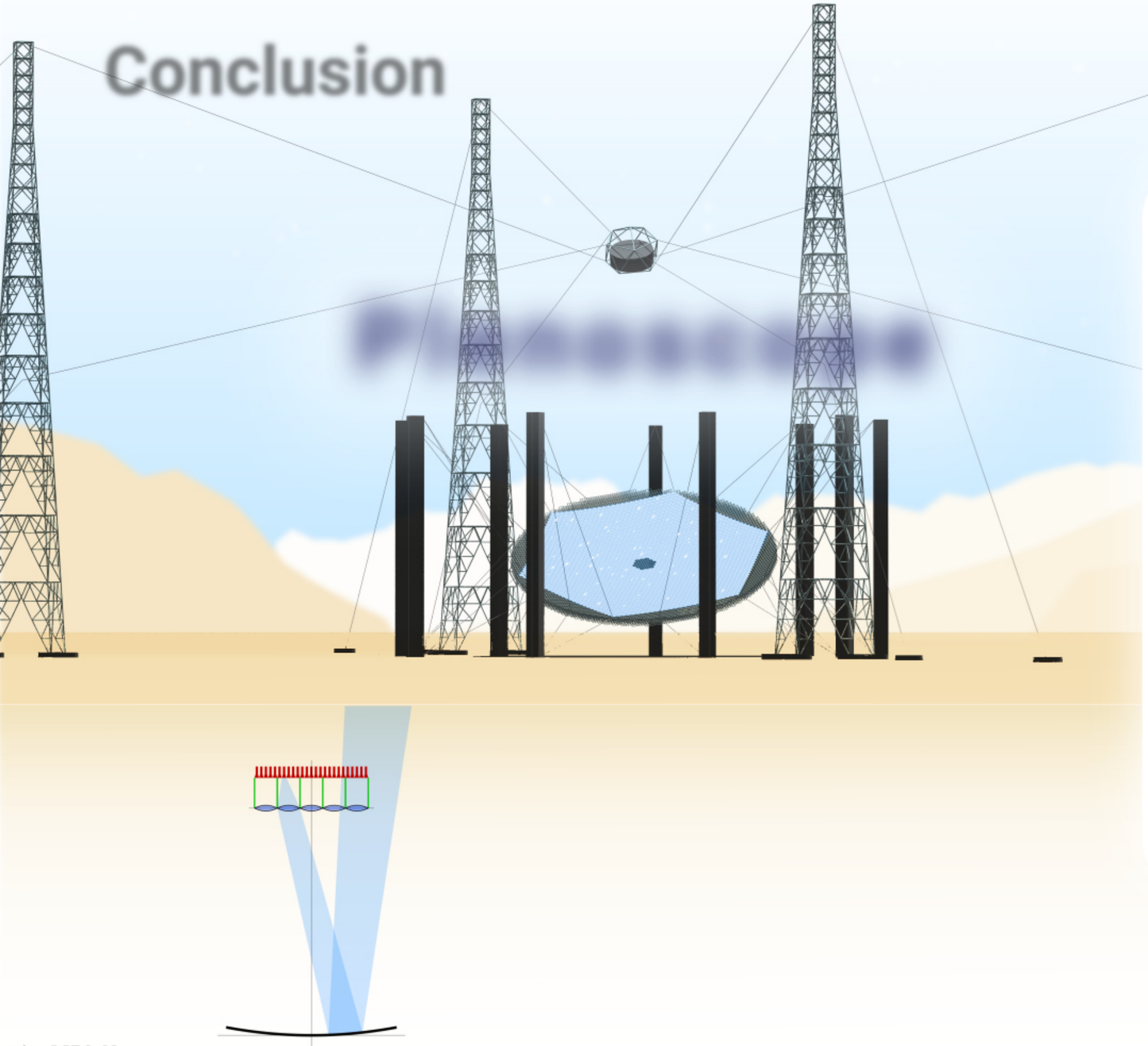
Conclusion



Conclusion



Conclusion



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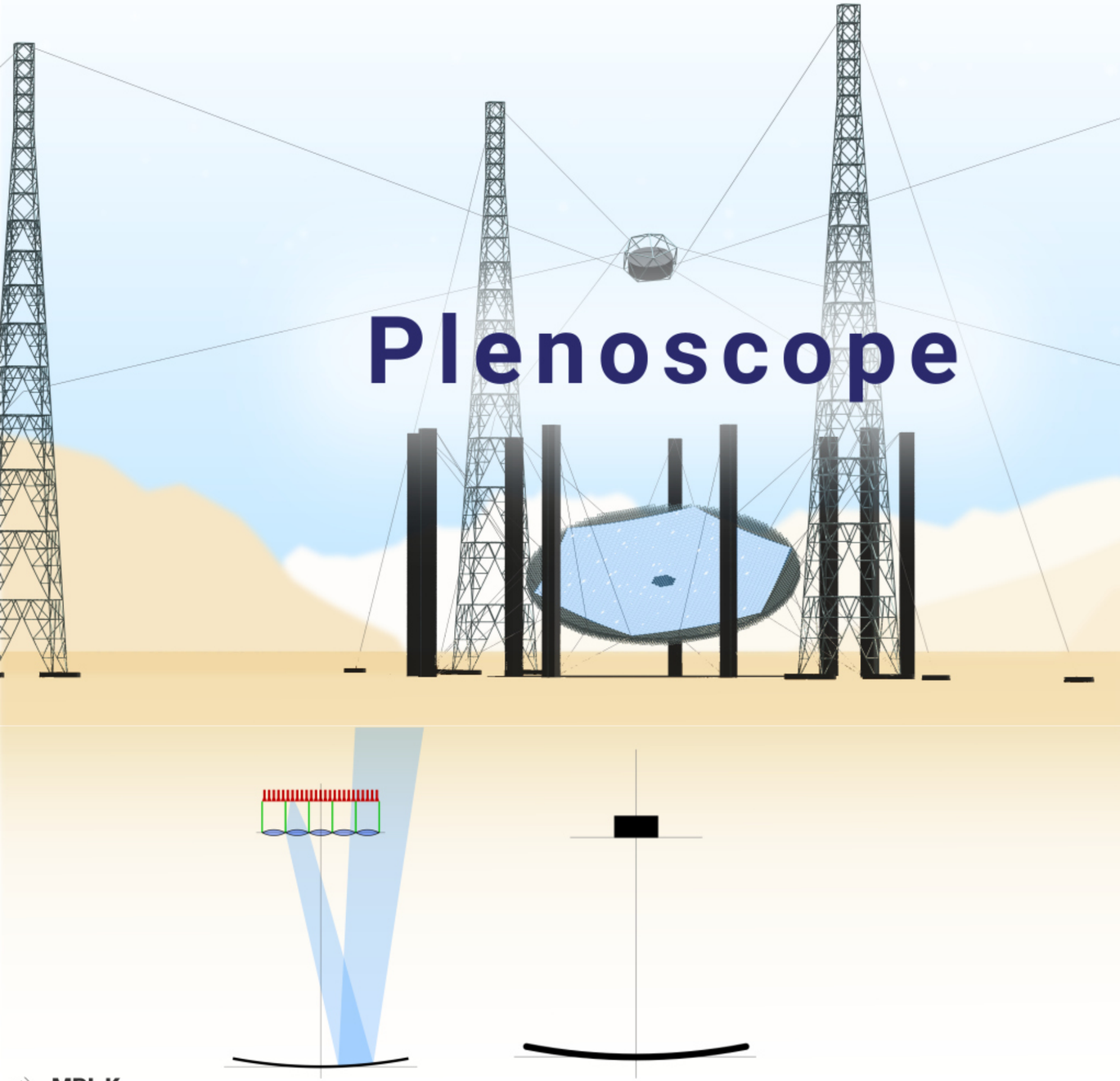
Plenoscope



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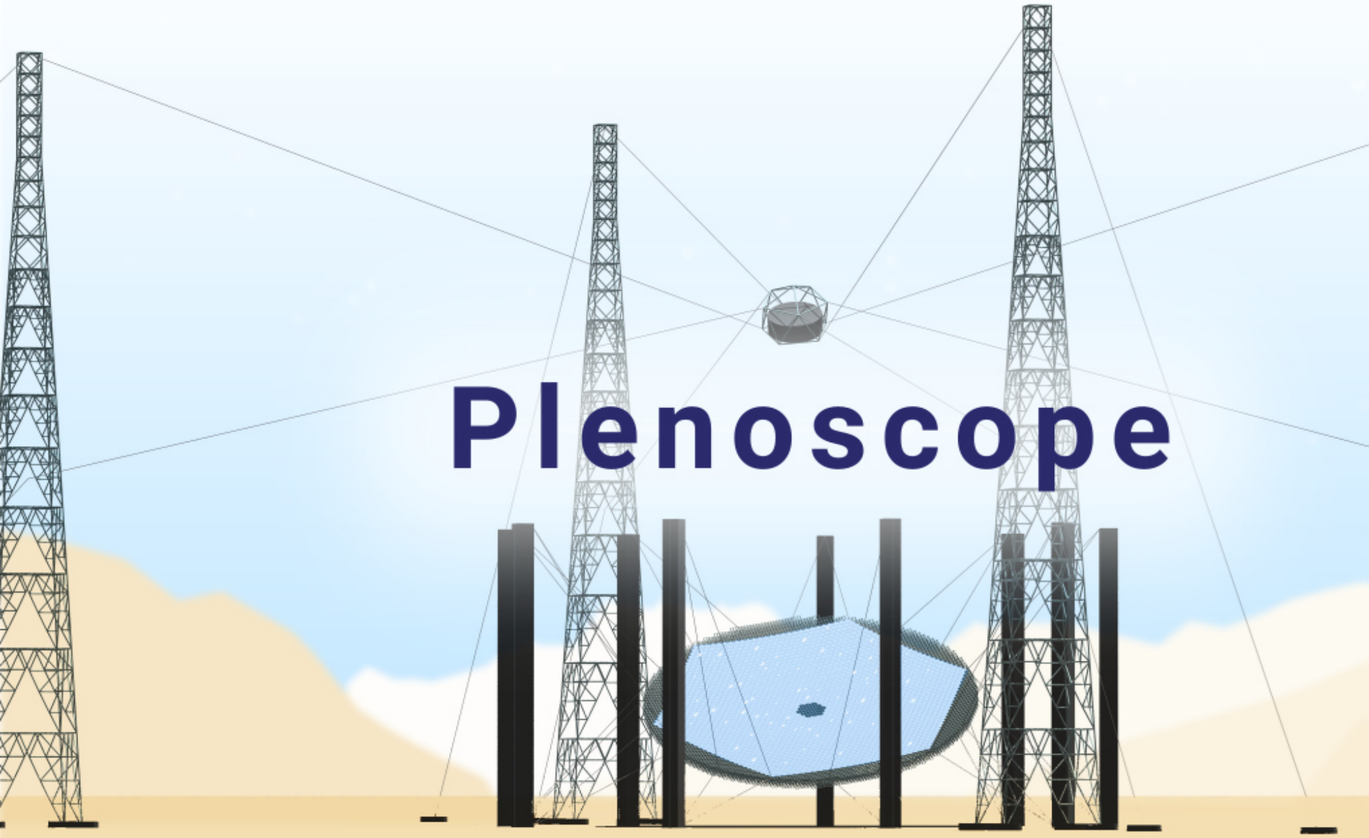

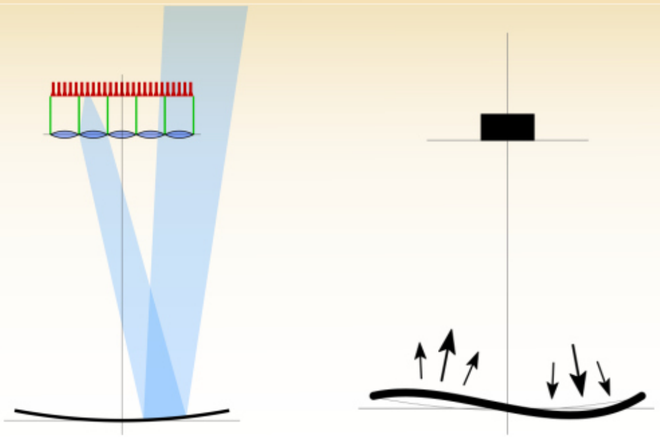

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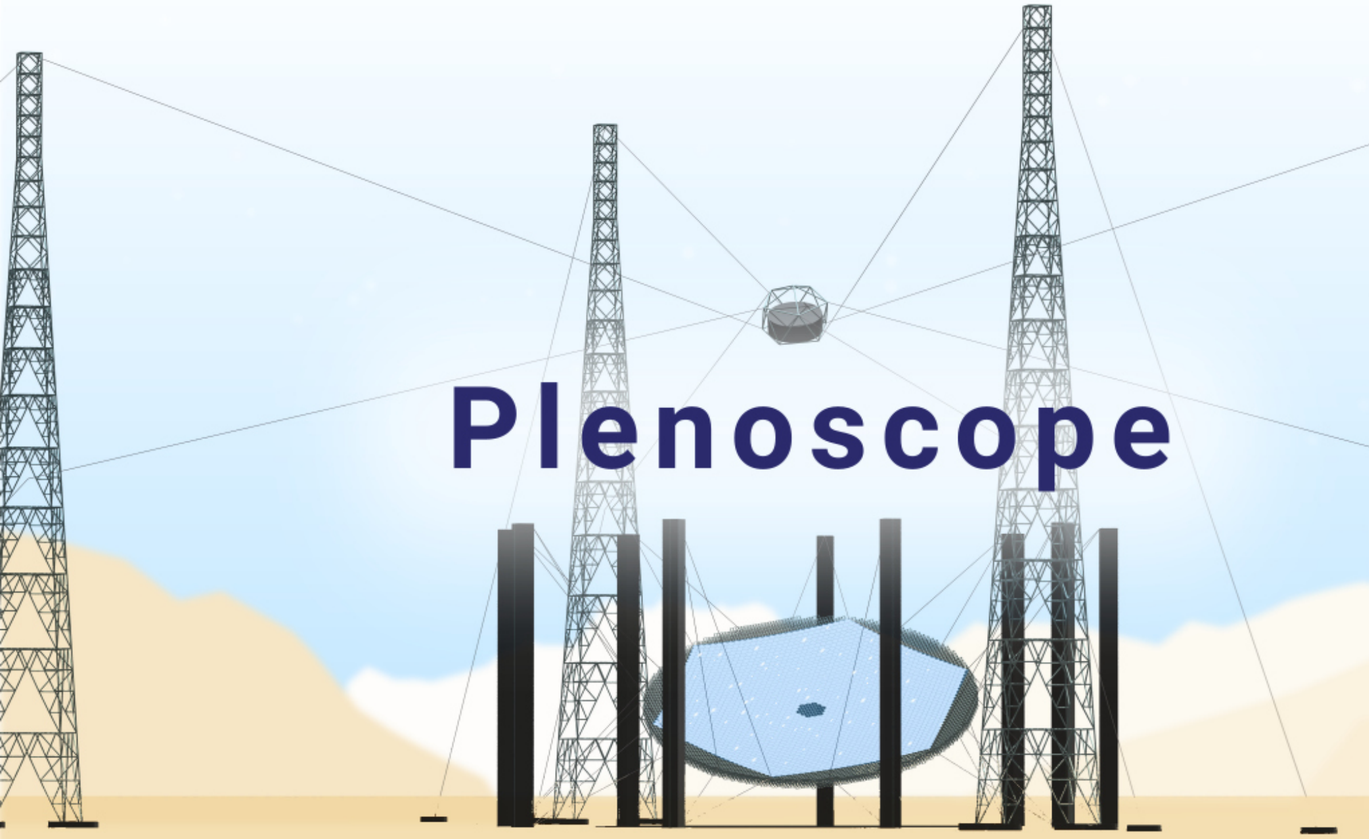

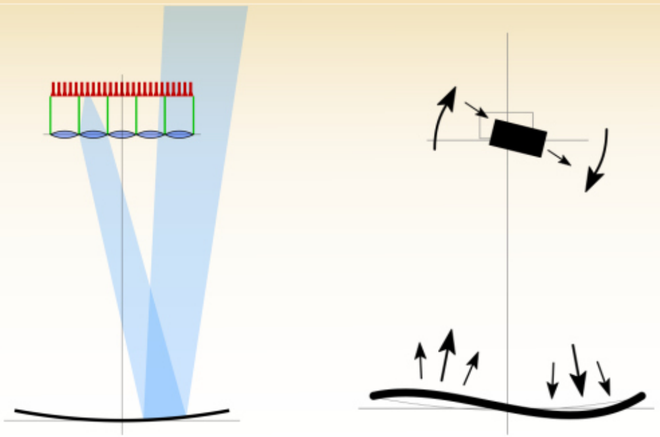

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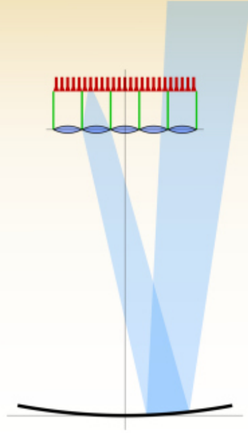

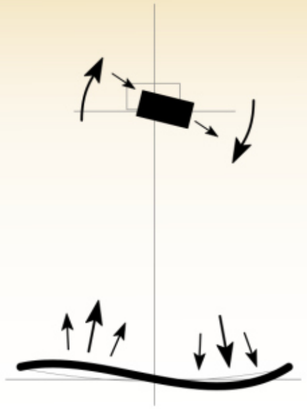

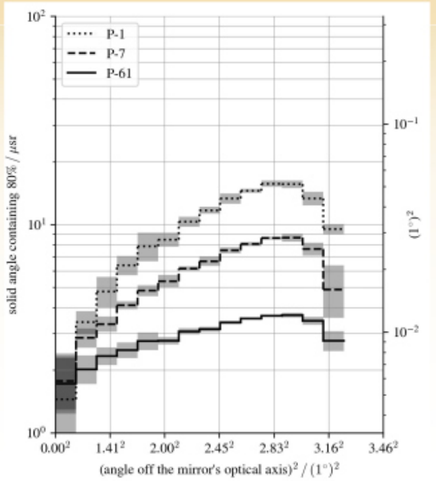

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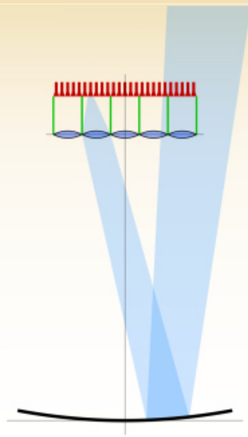
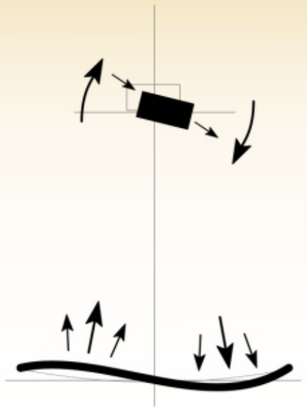
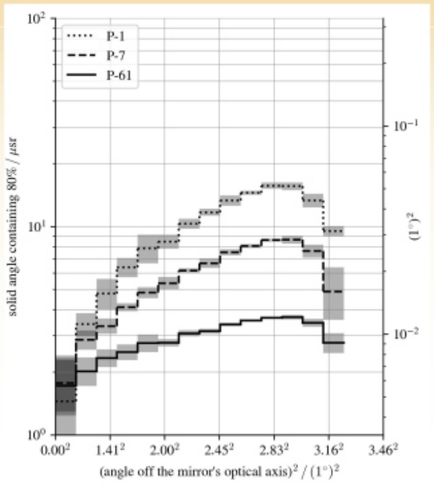
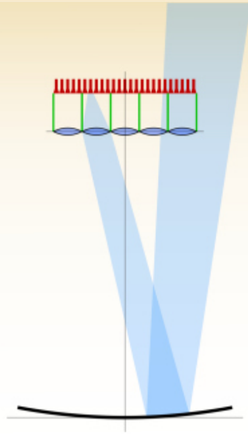
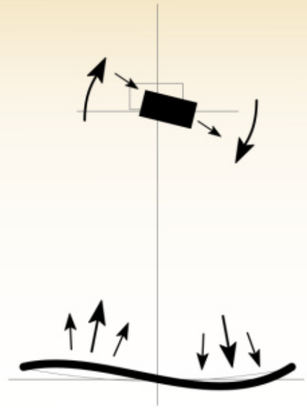


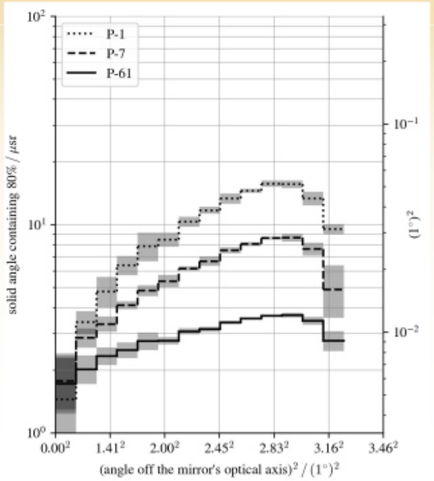



P-1
P-7
P-61
solid angle containing 80% / μsr
(angle off the mirror's optical axis)² / (1°)²
(1°)²

Plenoscope







Cherenkov plenoscope

observing cosmic gamma rays at one giga electron Volt in large collecting areas

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work in progress

work in progress

Science

Cosmic gamma rays are a special probe to investigate sudden cosmic events in the universe. Unlike thermal emission, which ranges from radio to X-rays, cosmic gamma rays are often a direct probe of bursts or other short lived cosmic catastrophes. Today, the timing of cosmic gamma rays is a vivid part of astronomy. Cherenkov telescopes observe the rare gamma rays with energies of several hundred giga electron Volt in large collecting areas exceeding the size of soccer or football fields. Particle detectors on satellites observe the much more abundand gamma rays with energies of about one giga electron Volt in small collecting areas with the size of about a car's windshield. But for better timing, we want to collect the abundand gamma rays with low energies in large collecting areas in order to have large statistics in short amounts of time. This is the goal of the atmospheric Cherenkov plenoscope.

github.com/cherenkov-plenoscope