Research Technology Digitization

DZA – German Centre for Astrophysics

Towards the German Center for Astrophyasics in Lusatia

DPG Spring Meeting

Gießen

Tuesday, 12. March 2024

Joint initiative of German astronomy and astroparticle physics

- Germany makes outstanding contributions to astronomical research (Nobel Prize)
- European Southern Observatory (ESO) and European Space Agency (ESA) state treaties allow German astrophysics to play leading roles.
- For future large international astrophysics projects the situation is different.
- The Square Kilometre Array (SKA) radio observatory planned jointly by various nations, the Einstein Telescope, the Vera Rubin Observatory, and the European Solar Telescope all require new national structures that are not existing in Germany today.
- SKA is calling for regional data centres. The Einstein Telescope is looking for partners in Europe to set up large test and development centres for gravitational wave interferometers.
- The possibilities for German industry to participate in such tenders require institutional commitment.

DZA Team and Network

AIP

RDS

KAT. Komitee für Astro.Teilchen.Physik

VdR

HZDR
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Uniwersytet Wrocławski

SKAO

ET EINSTEIN TELESCOPE

SILICON SAXONY
THE HIGH-TECH NETWORK

futureSAX
Ideen. Transfer. Innovation.

LRT
SACHSEN/THÜRINGEN

OHB DIGITAL

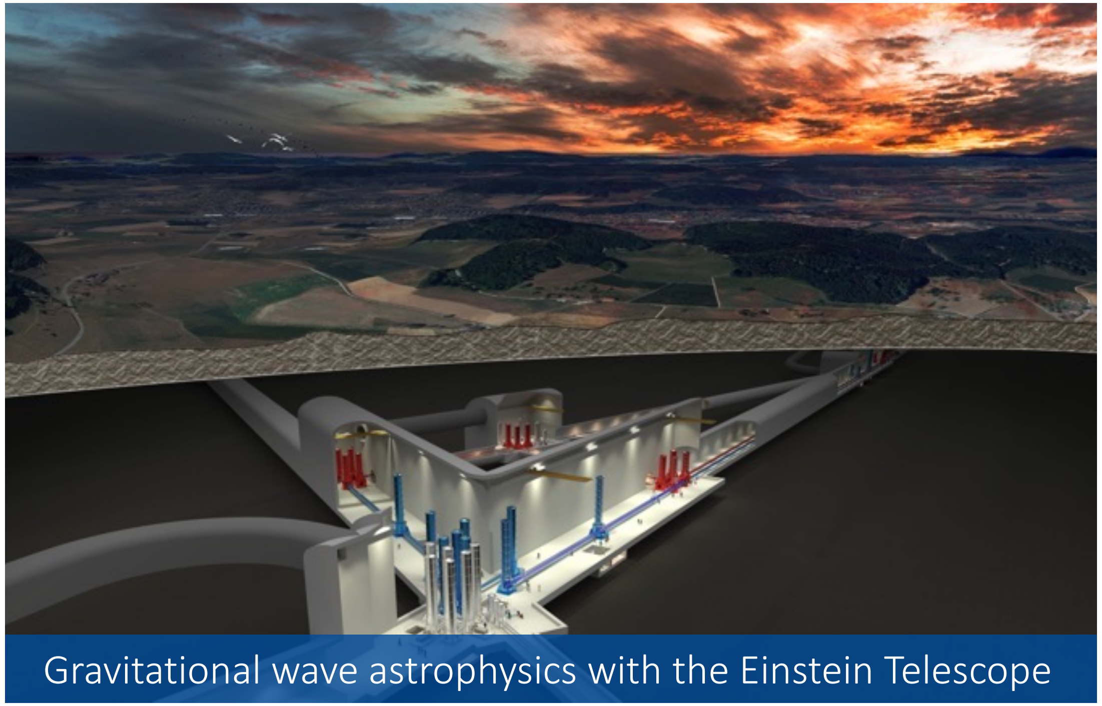
Stadt Görlitz

DOMOWINA

DZA

A national lighthouse with international visibility

Radioastronomy with SKA



Gravitational wave astrophysics with the Einstein Telescope

Future telescopes are global in nature and need large international cooperation.

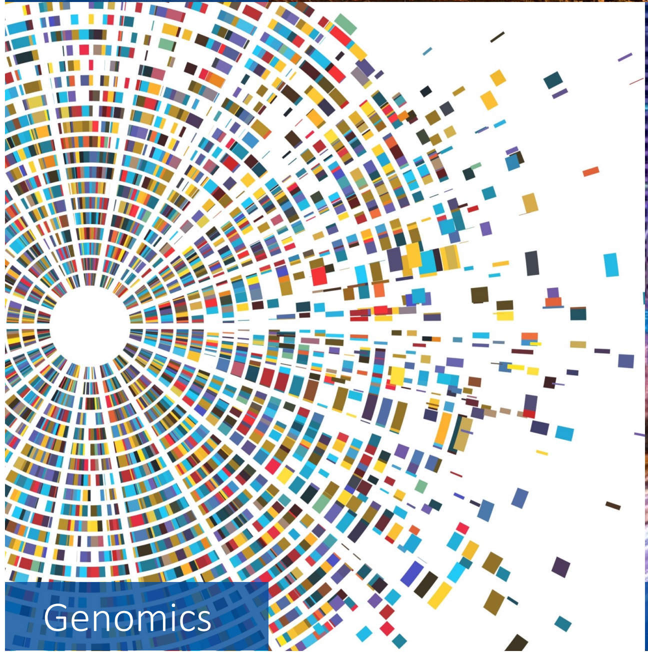
The German astrophysics community is well positioned but it needs a national center to participate institutionally in these endeavors, to drive scientific, technological, and digitization development.

Focus on Innovation Potential

- Synergies in science but also in technology: radio and gravitational wave astronomy
- Both fields have exciting new developments and instruments that provide huge opportunities, especially in opening innovation potential and collaboration with industry.
- Especially radio astronomy will produce (among) the largest rate and volume of data in any kind of science, pre-empting future requirements across society and science, feeding into a seemingly endless stream of data to research.

Our research mission has large societal impact!


SKAO


Genomics


Smart City

DZA

DZA concept : 3 pillars

Astronomy

Square Kilometre Array Observatory (SKAO)

Einstein Telescope (Low Seismic Lab)

Instruments

Developments for future astronomical experiments

Strong participation of Saxon industry

Data Intensive Computing

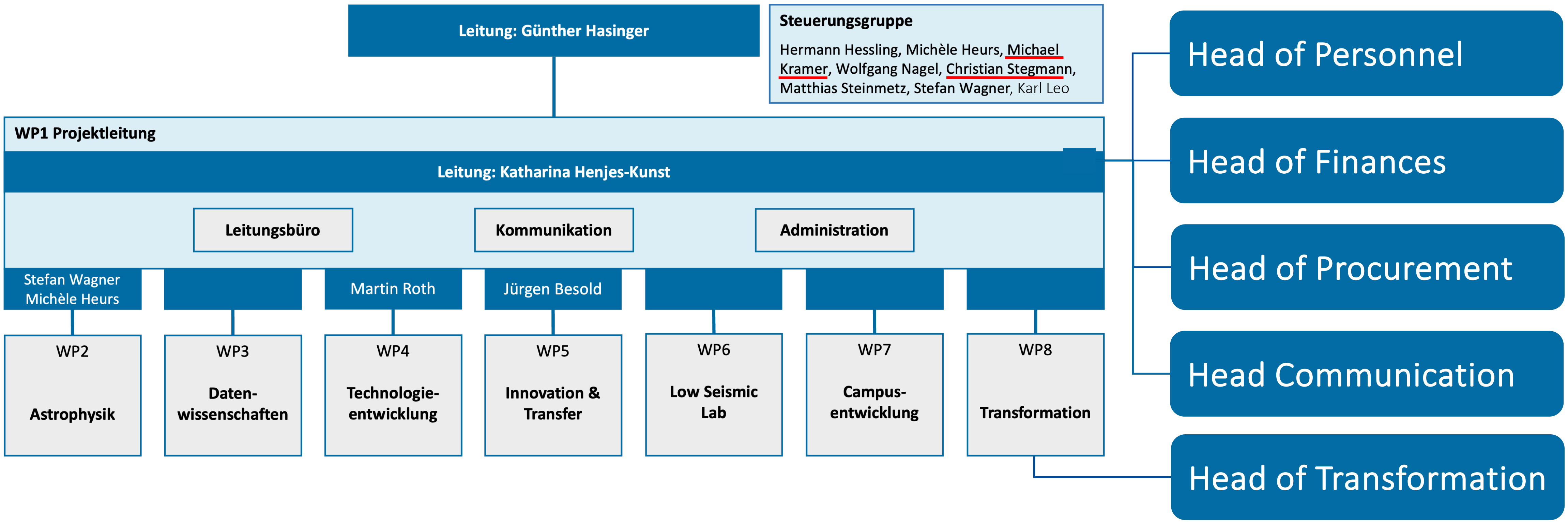
Processing huge amounts of astrophysics data from all over the world

Innovative AI based and Smart Green Computing

Interlocking of pillars → unique synergies

DZA Project Structure until legal Foundation

We have filled

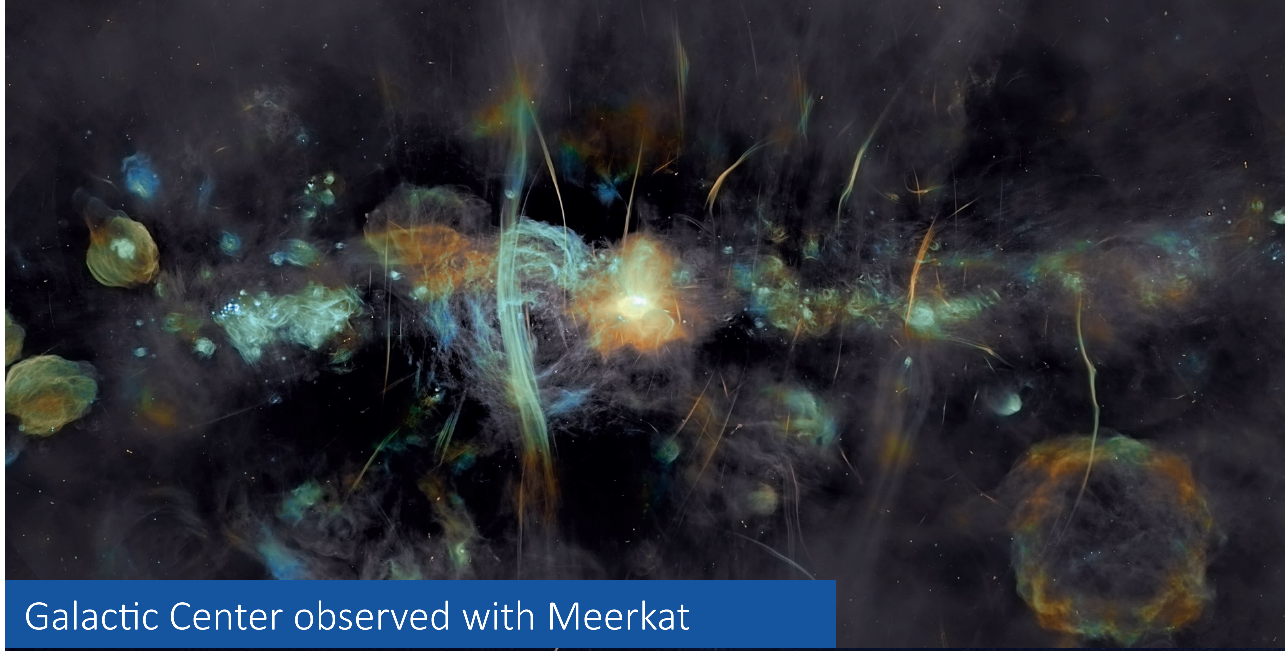


https://www.deutscheszentrumastrophysik.de/de/news/aktuelle-stellenausschreibungen-des-dza

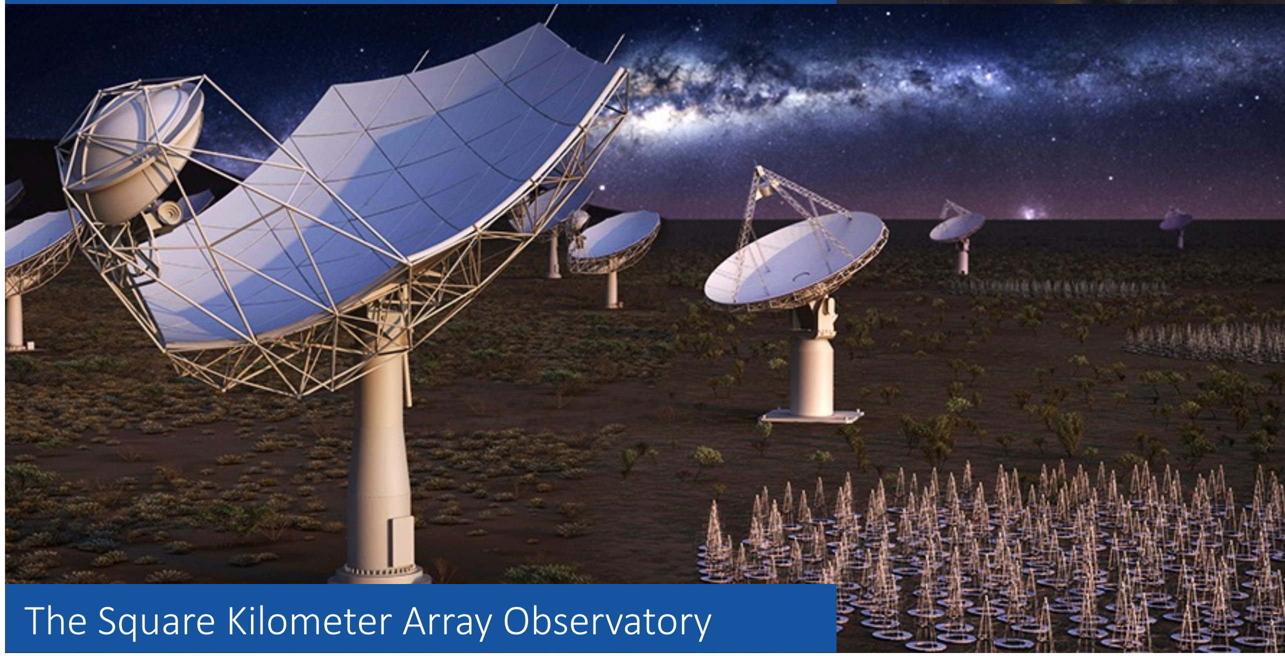
Radio astronomy – a hugely expanding field

Digitization and advances in computing create opportunities and in turn drive innovation – what happened with WiFi is about to happen again on the data side

- Large number of new upcoming word-class facilities:
  - The Square Kilometre Array Observatory (SKAO)
  - MeerKAT and **MeerKAT+**
  - LOFAR 2.0, DSA2000, ngEHT, ngVLA
- Instrumentation and ability to detect and process signals gives the edge: strategy for DZA!
- DZA will build on German researchers & institutions in leading positions and can start immediately.
- SKAO as fundamental pillar of modern astrophysics – **German community 3rd-largest contributor to science case**
- Institutional commitment underlines the need for DZA



Galactic Center observed with Meerkat



The Square Kilometer Array Observatory

First MeerKAT Plus Antenna – Prototype for SKA

Festive inauguration ceremony of the first MPG antenna in the Karoo region in South Africa on February 21. 2024

Under the presence of SARAO, MPIfR, DZA and OHB.

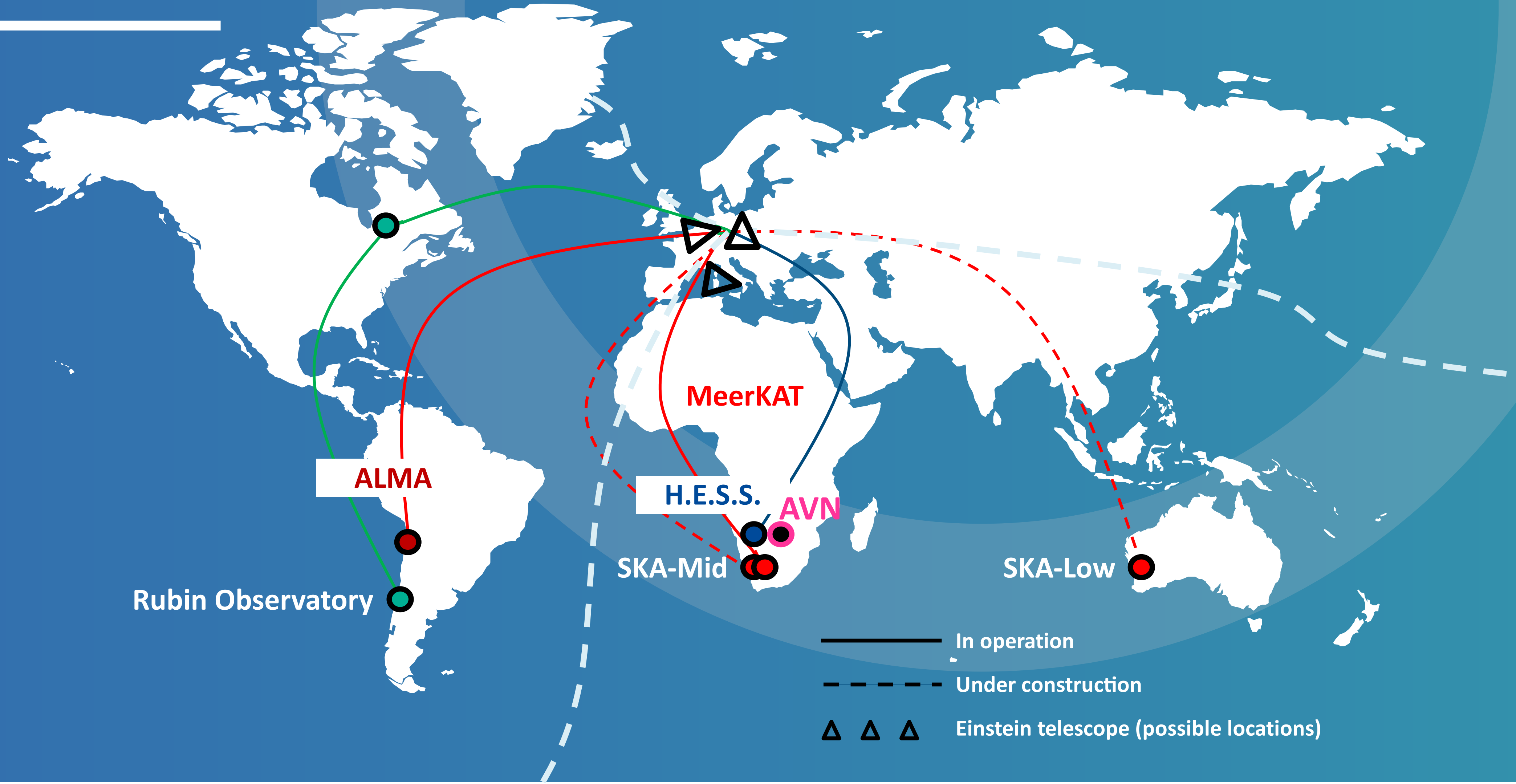
This is the first working antenna of the SKA Mid design!

DZA will receive two antennas of the same kind.

Signature of MoU between DZA and Botswana University BIUST

For the first leg of an African VLBI Network (AVN) in Botswana, on February 27, 2024

Astrophysics Data from all over the world



Long-term IT challenges ...

STRATEGIES FOR COPING WITH DATA IRREVERSIBILITY

Dynamic Filtering (TUD, SpiNNaker, FZJ)

- Extract information from huge data streams in real-time
- Make sensors smart (machine learning, novel processors)

Dynamic Archiving and Analytics (DZA, TUD, HZDR)

- Feedback from archives to sensors in (quasi-) real-time

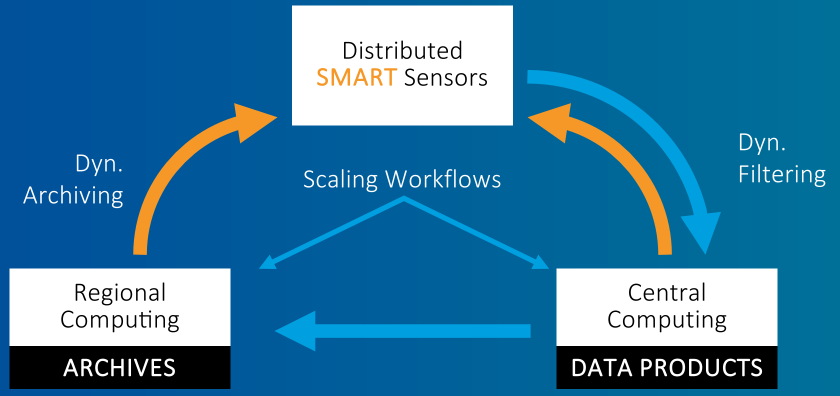
Scaling

- Online: massive parallelization of analysis workflows
- Offline: novel computing architectures (⇒ Huge Data Objects)

Reproducibility

- Reconstruction how decisions were taken
- Simulations (essential for validation and understanding)

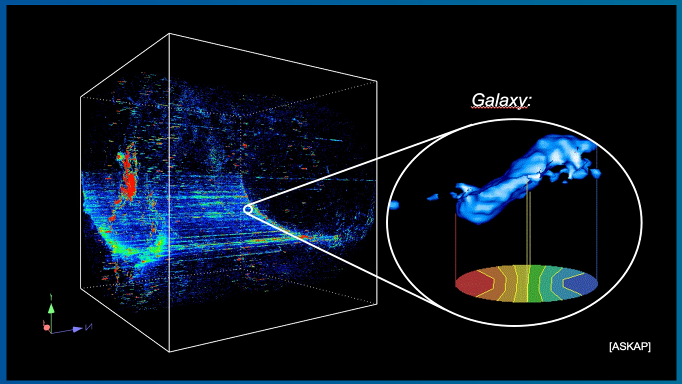
... DRIVEN BY ASTRONOMY



HUGE DATA OBJECTS

SKA: up to ~ 1 Petabyte / 3D cube

Genomics/biomedicine: complex long time series



DZA

Innovative AI and
Smart Green Computing

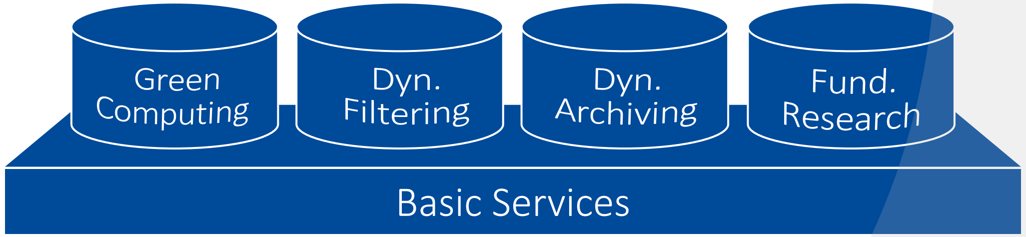
Innovative AI based Methods

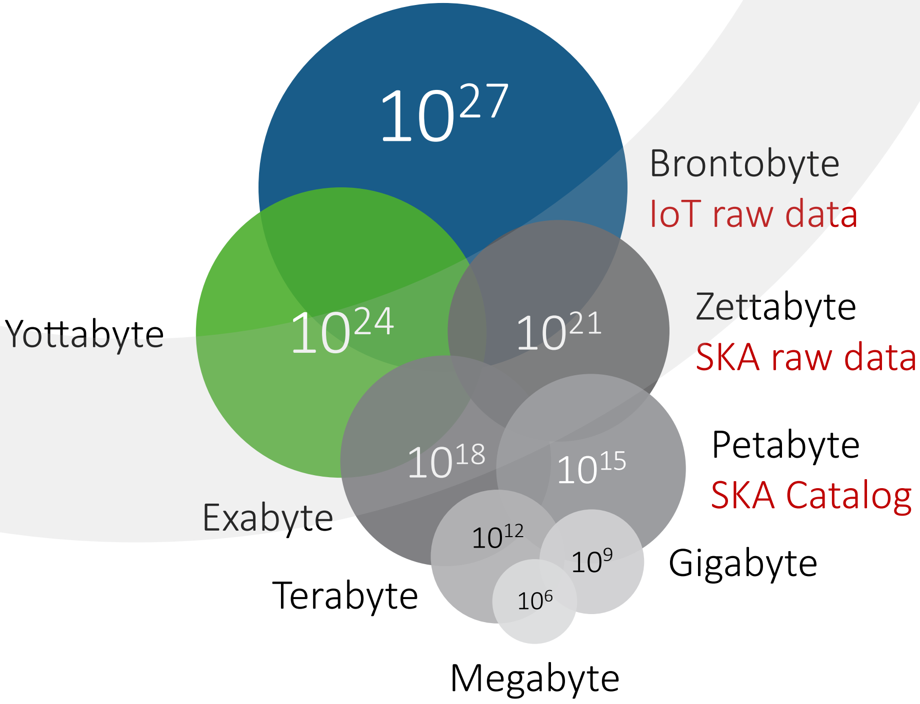
- Improved detection methods (knowledge graphs, ML)
- Filtering and archiving fundamental issues
- Data and Computational Science will drive success

Smart Green Computing

- Warm Water cooling
- Energy-efficient hardware
- In 2030, ~ 20 % of worldwide electricity consumption due to IT [Nature, 2018]
- Reducing Data Irreversibility (online + offline)

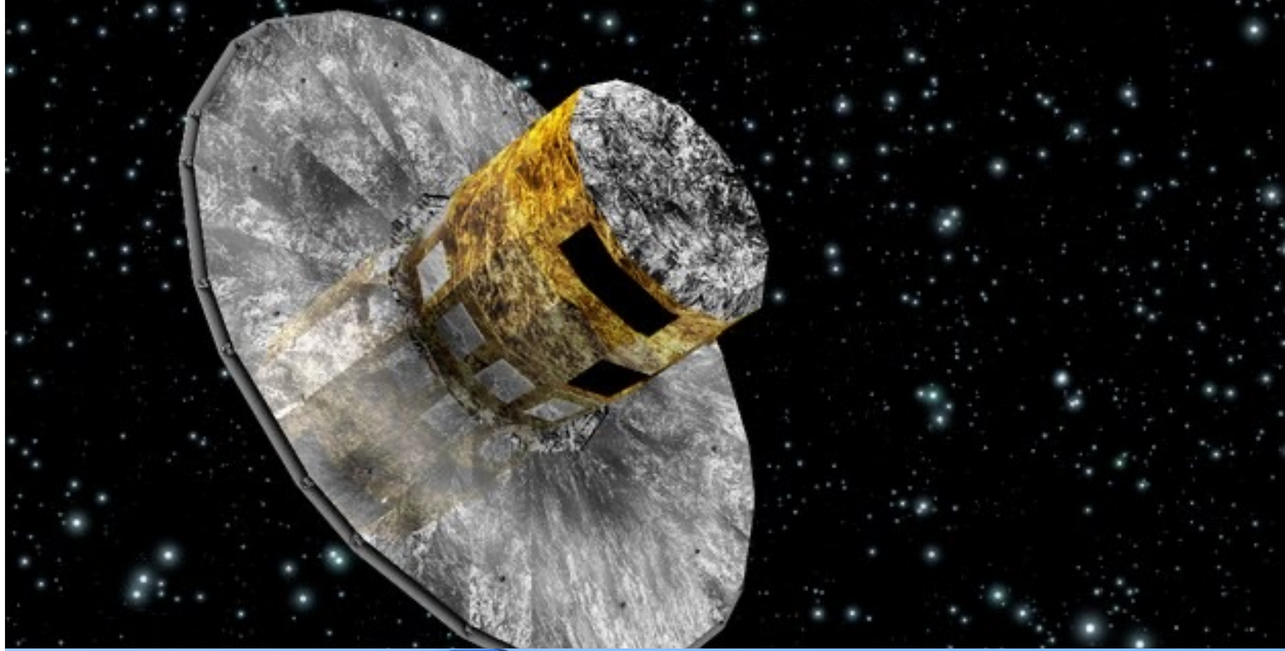
  ➔ Contributions to limit the energy hunger of IT

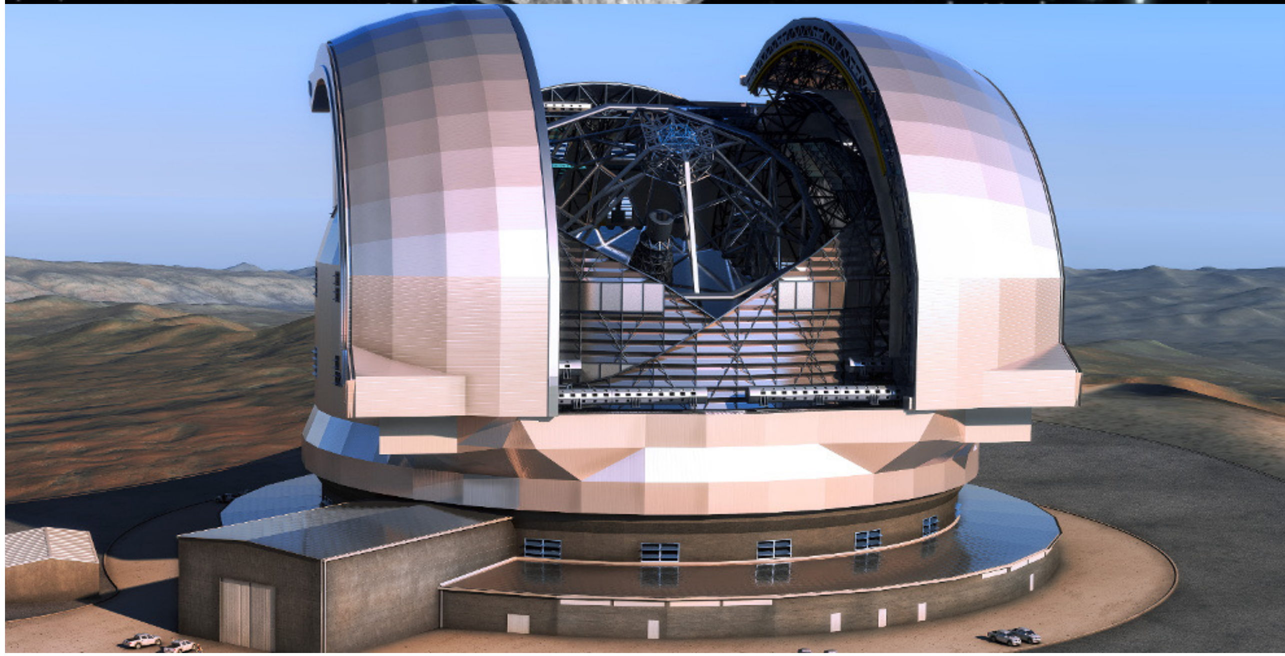




Electromagnetic sensor/optics technology

- detector technology through 2050 & wide field-of-view optics
- science-grade CMOS with low read noise (possible applications in fast microlensing surveys)
- curved detectors
- integrated optics (astrophotonics)
- optics for next-generation interferometry, laser frequency combs
- NIR array detectors (e.g. for GAIA-NIR)

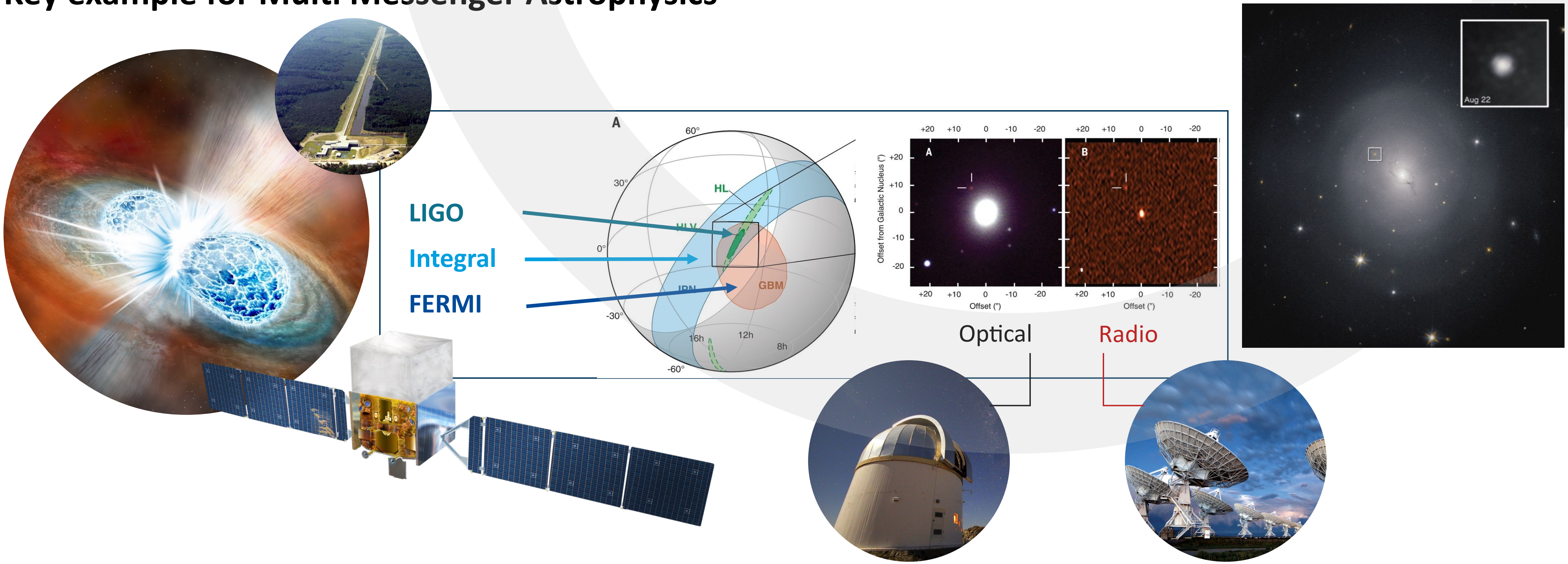




Astrophysics with all senses

The universe and the world today can only be understood, if we combine vastly different information – using both fast real-time and archival data.

Key example for Multi Messenger Astrophysics



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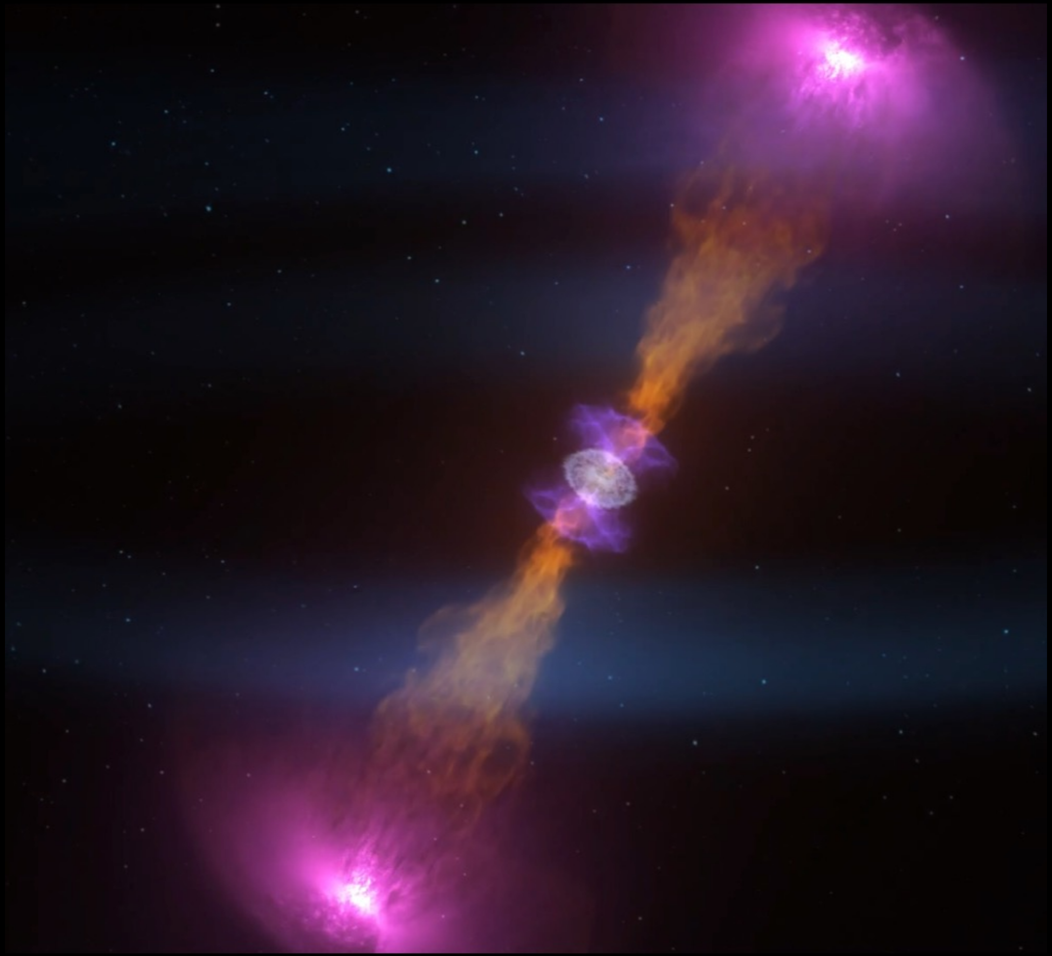
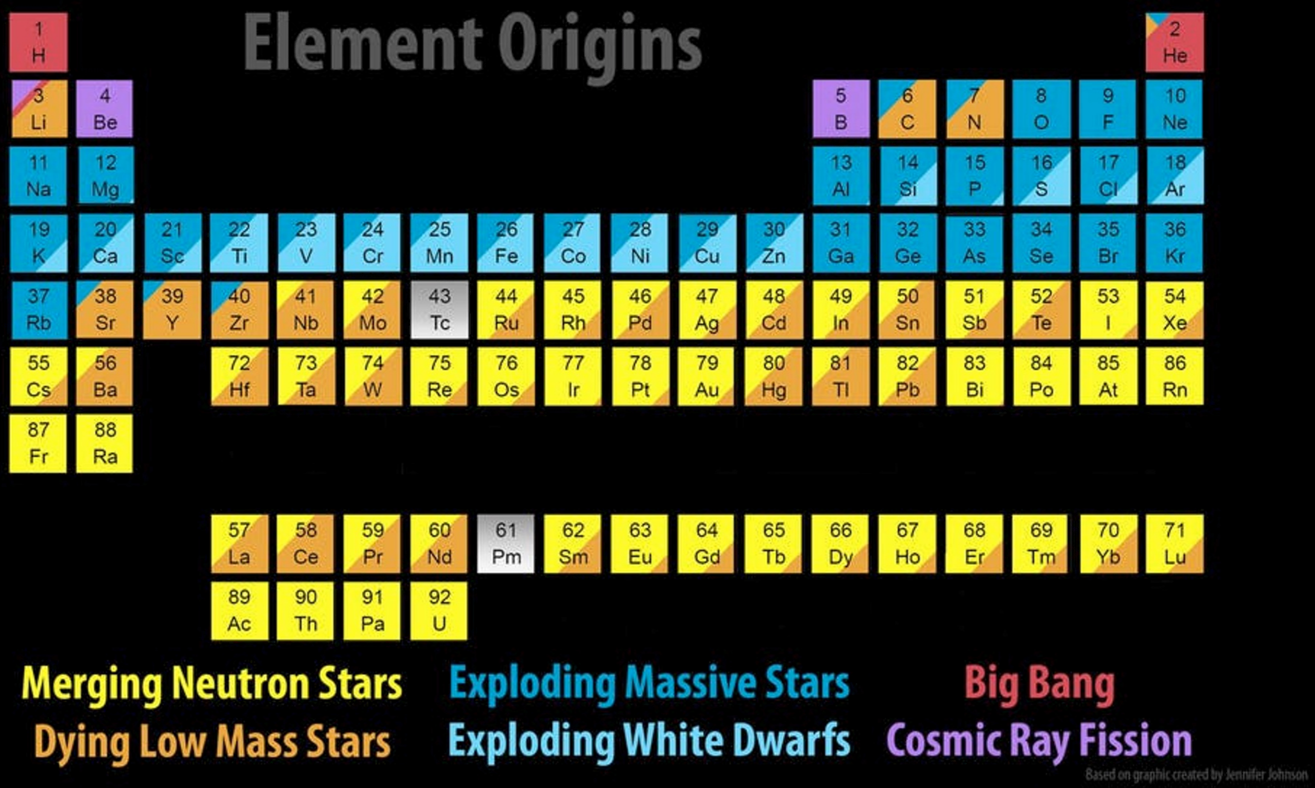
Fundamental new physical knowledge





We are not only made of star dust, we are also neutron star dust!

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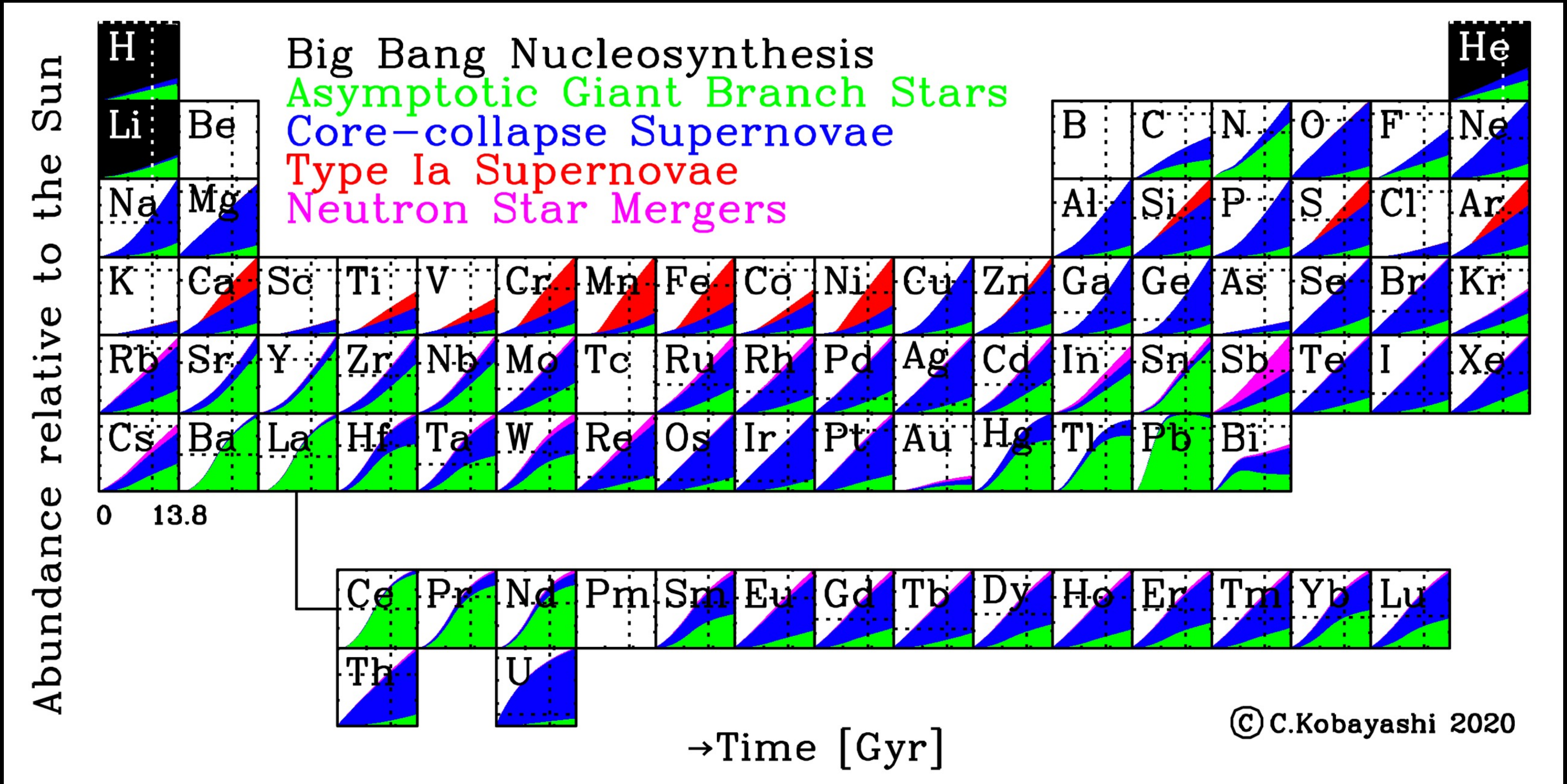
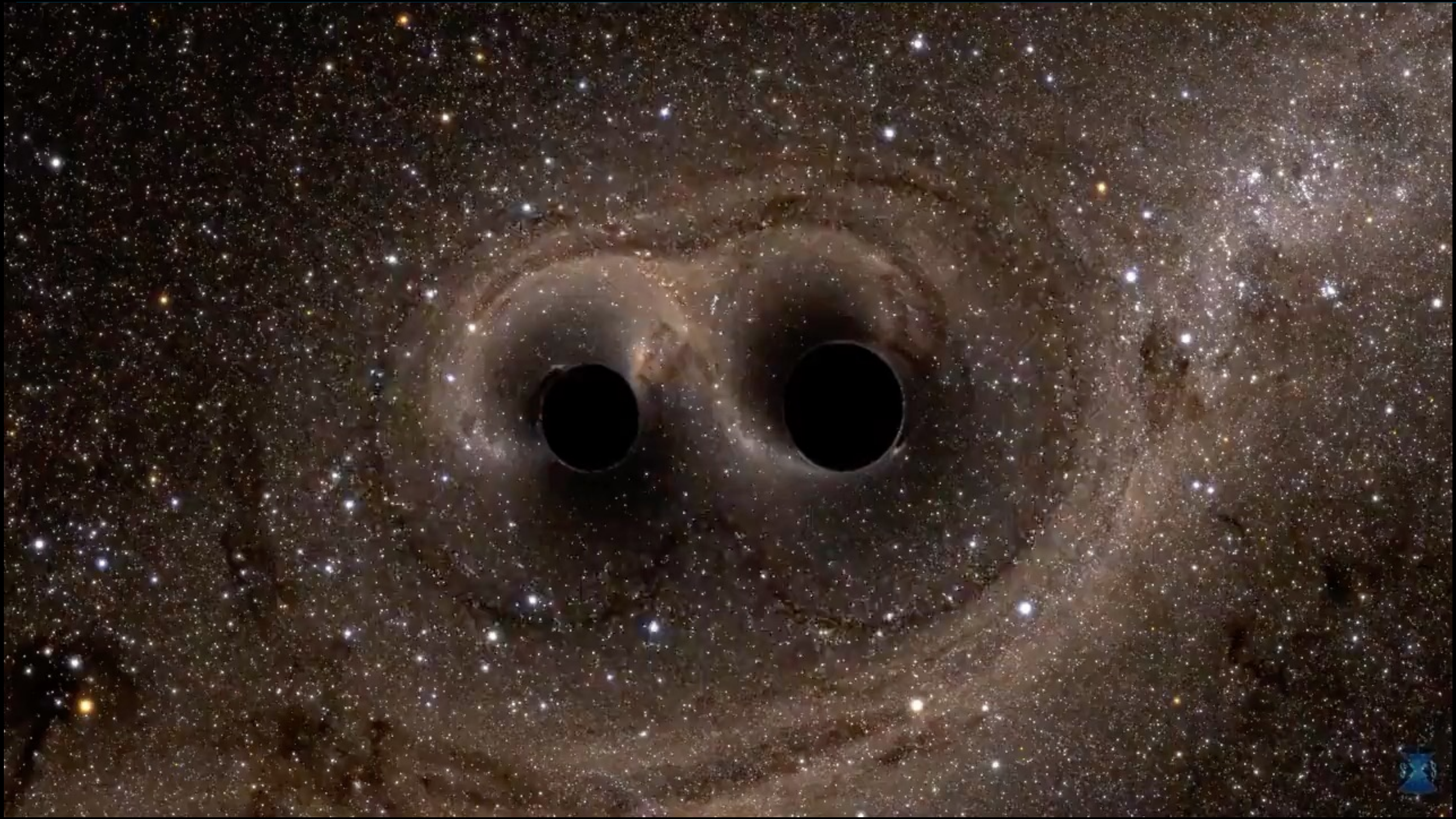
However, things are not as simple as they seemed …



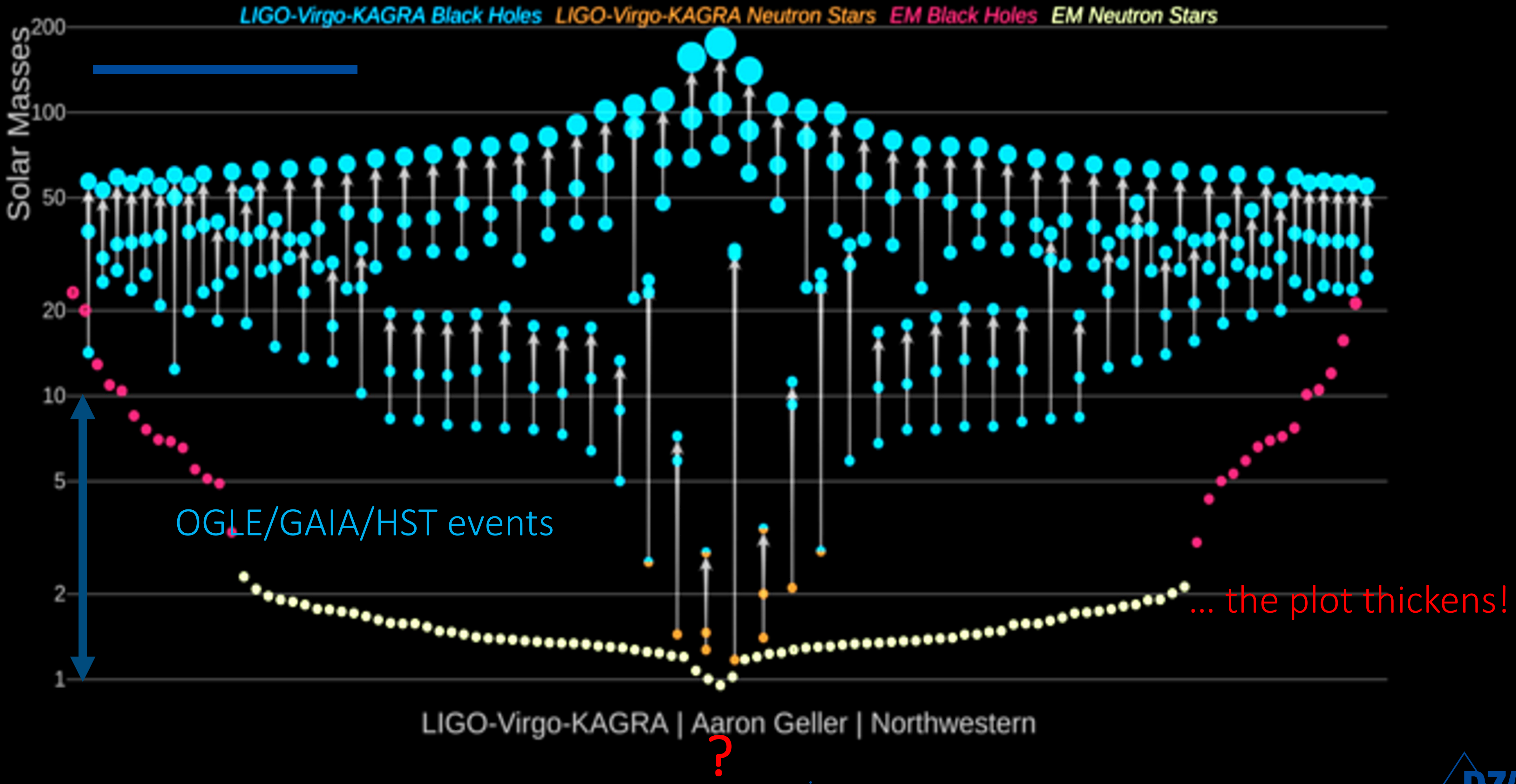
Kobayashi, C., Karakas, A. I., Lugaro, M. (2020). "The Origin of Elements from Carbon to Uranium", *The Astrophysical Journal* 900, 179

Simulation of the merger between two Black Holes



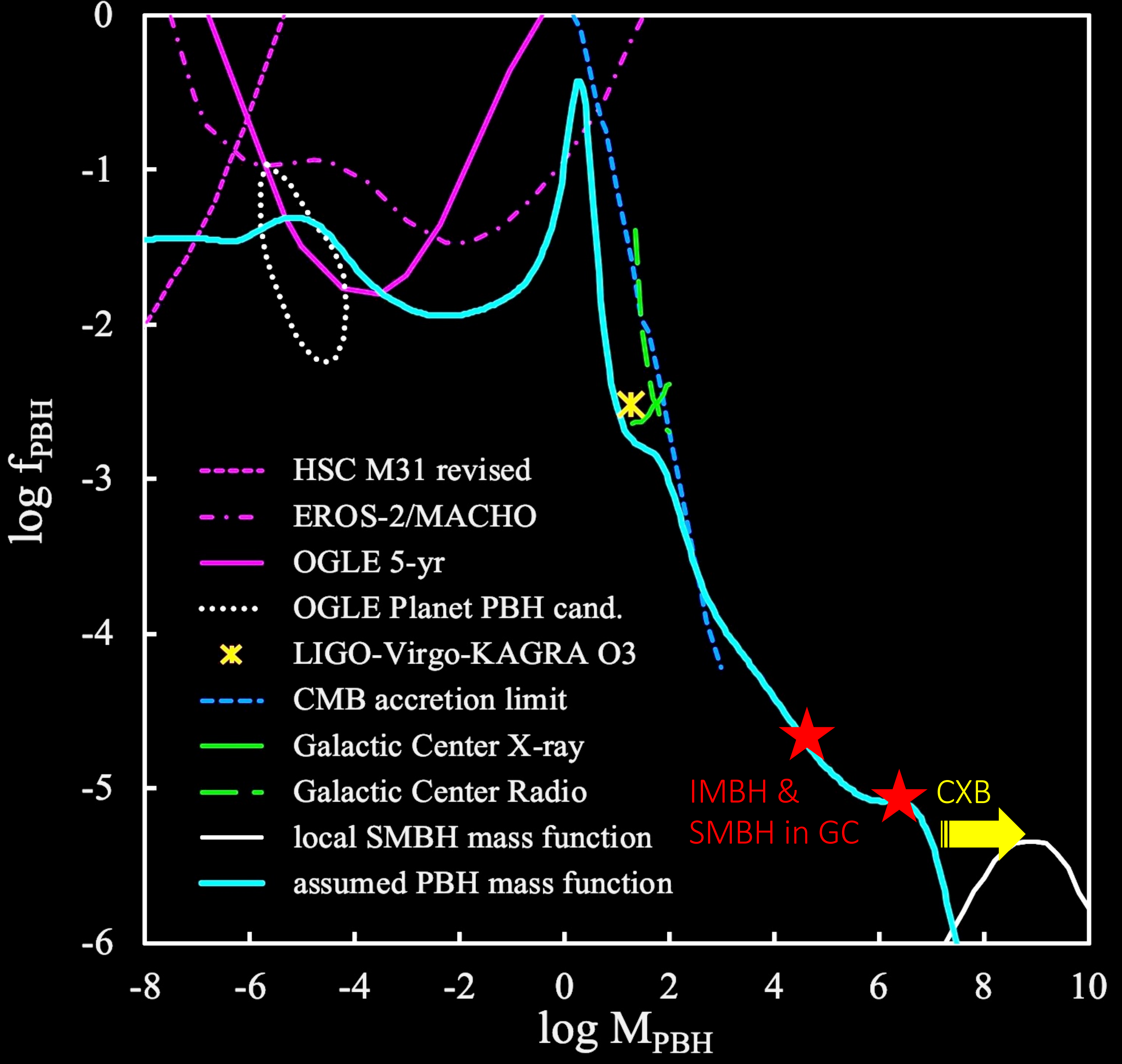
LIGO/Virgo/
Kagra/GEO O4
observations since
May 2023!

Masses in the Stellar Graveyard



Multi-Messenger Quest for the first Black Holes

Primordial Black Holes may be a solution to the Early Quasar and Dark Matter Problems



Bernard Carr, Juan García-Bellido et al. are working on Primordial Black Holes created through the thermal history of early Universe phase transitions, in particular the electroweak transition, the QCD phase and the electron-positron annihilation.

WE use a version of their PBH mass spectrum with rolling index of the primordial power spectrum to estimate the PBH contribution to the extragalactic backgrounds and early star formation.

Hasinger 2020 JCAP

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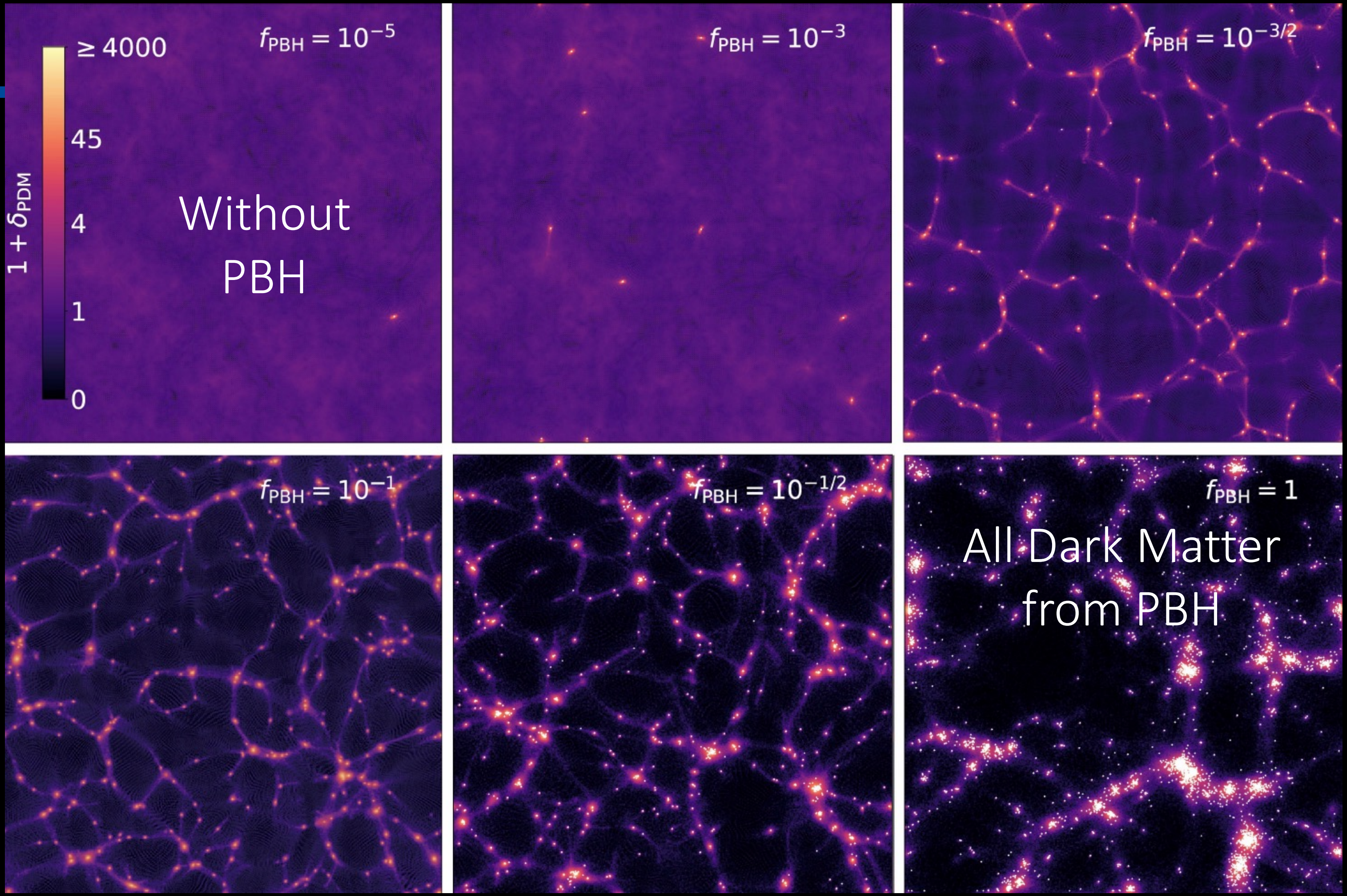
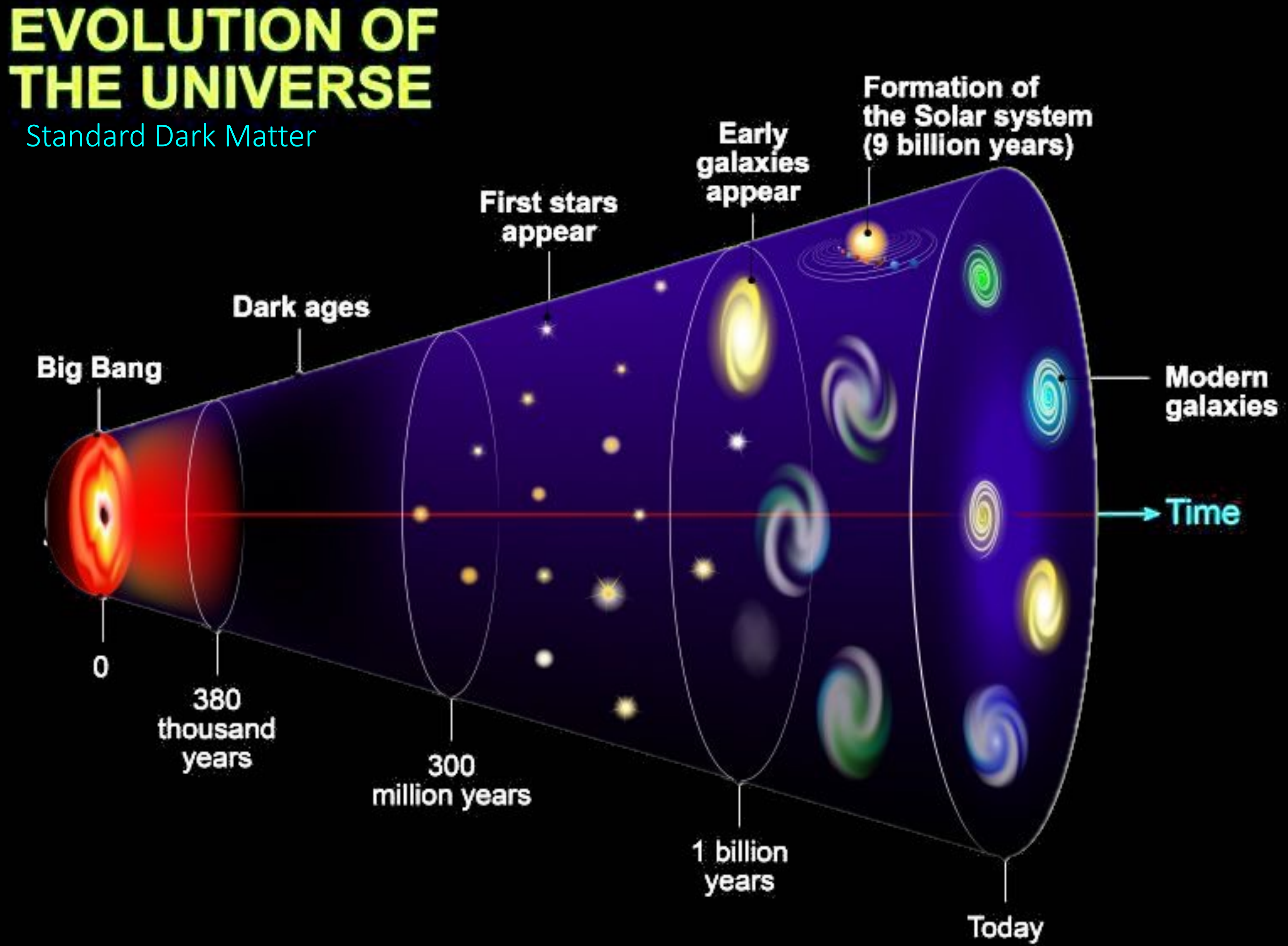
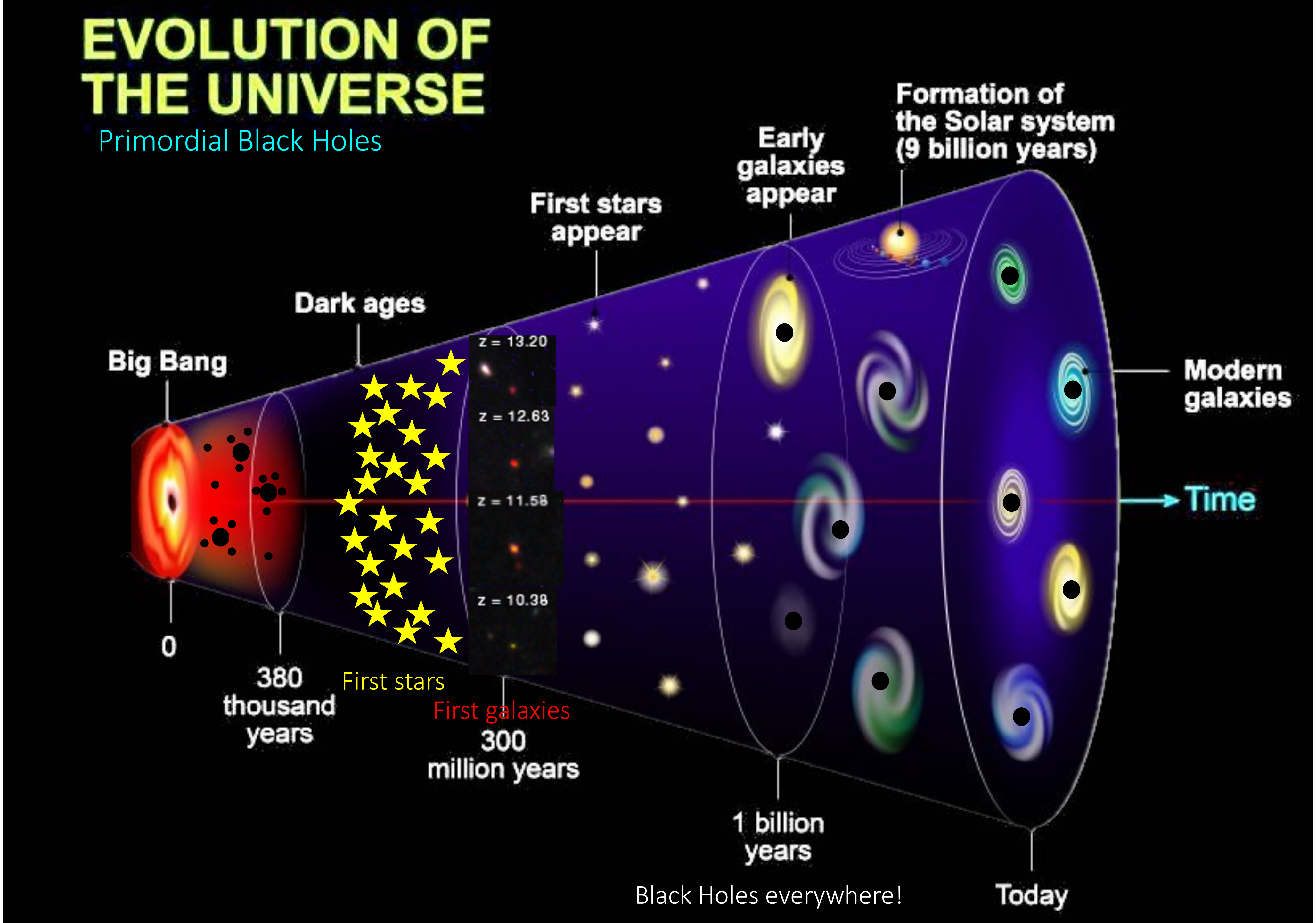
Growth of Large-Scale Structure at z=10

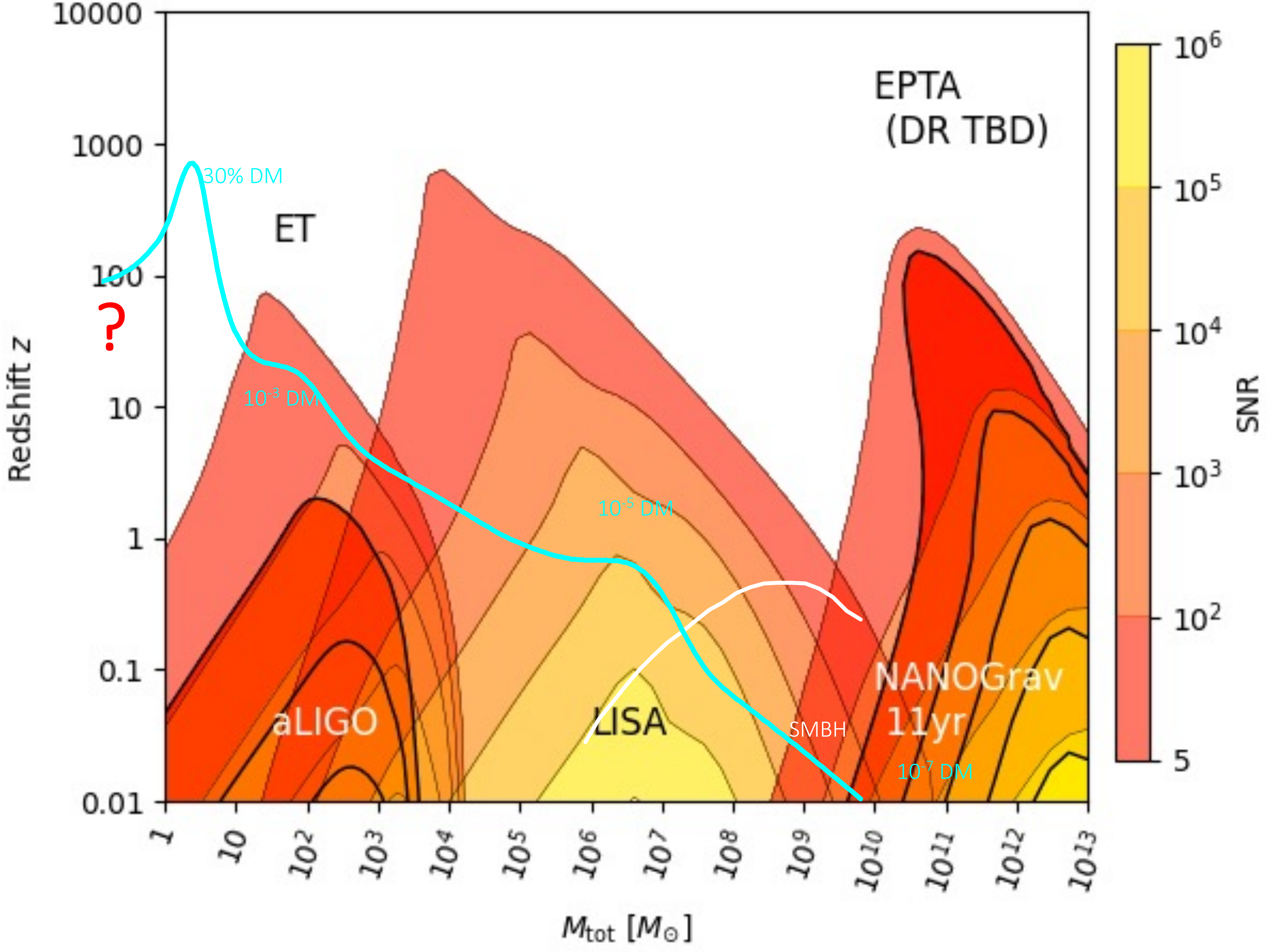


D. Inman and Y. Ali-Haïmoud, Early structure formation in primordial black hole cosmologies, Phys. Rev. D 100, 083528 (2019), arXiv:1907.08129


EVOLUTION OF
THE UNIVERSE
Standard Dark Matter
Big Bang
Dark ages
First stars appear
Early galaxies appear
Formation of the Solar system (9 billion years)
Modern galaxies
Time
0
380 thousand years
300 million years
1 billion years
Today



EVOLUTION OF THE UNIVERSE
Primordial Black Holes
Big Bang
Dark ages
First stars appear
Early galaxies appear
Formation of the Solar system (9 billion years)
Modern galaxies
Time
z = 13.20
z = 12.63
z = 11.58
z = 10.38
0
380 thousand years
First stars
First galaxies
300 million years
1 billion years
Black Holes everywhere!
Today



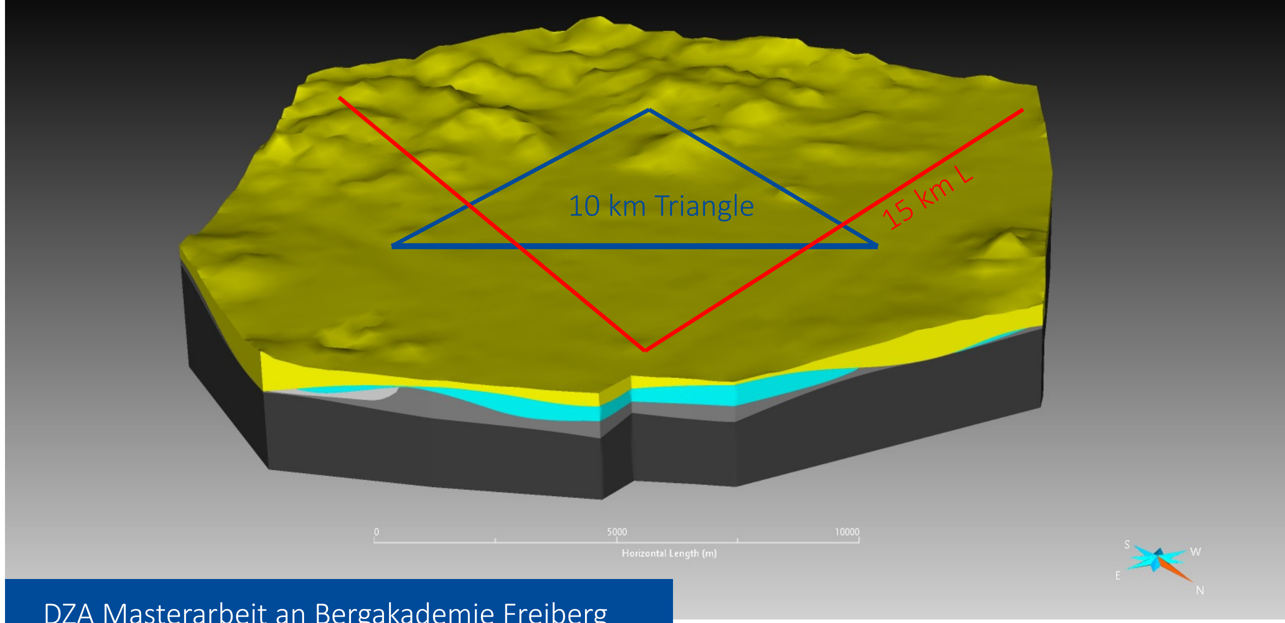
Sensitivity to BH-BH Mergers

So far, all of these "fingerprints" are tantalizing, but only circumstantial evidence.

However, future Gravitational Wave observations can uniquely discriminate between astrophysical and primordial black holes!

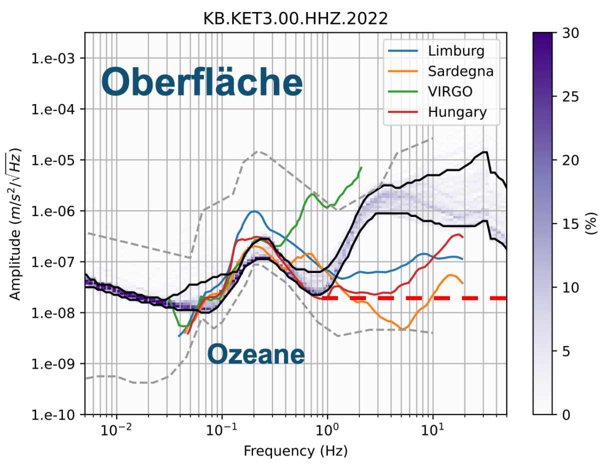
Granite to a depth of 250m

A unique, monolithic and smooth block of granite with a diameter of around 20 km and a homogeneous seismic damping and isolation layer

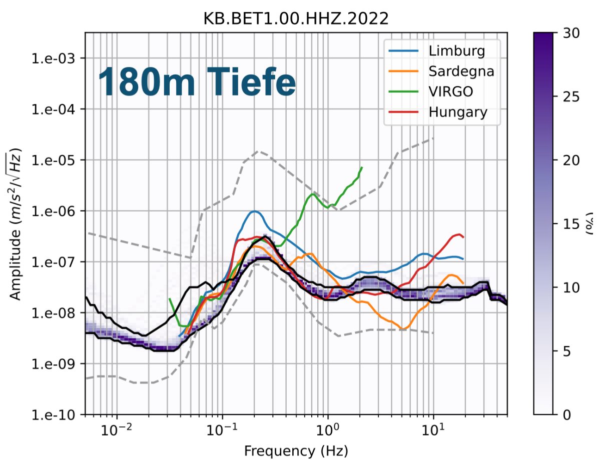


DZA Masterarbeit an Bergakademie Freiberg

Bohrkerne



Oberflächenmessung



In 180m Tiefe

Boreholes in Cunnewitz

The Low Seismic Lab

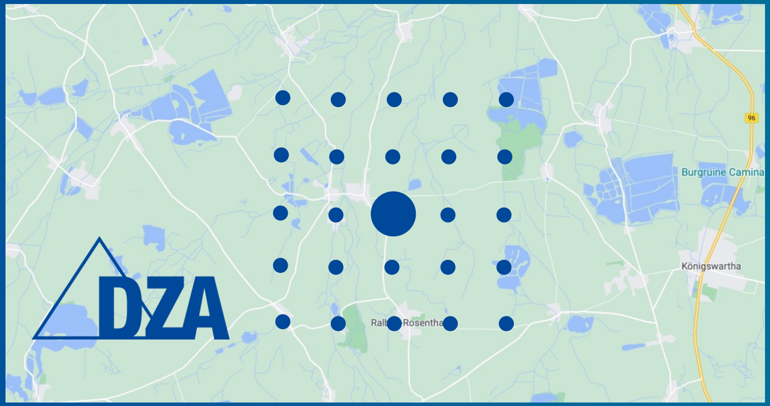
Innovation platform of approx. (40 x 30 x 30) m^3
size *at 200 m depth in Lusatia granite*

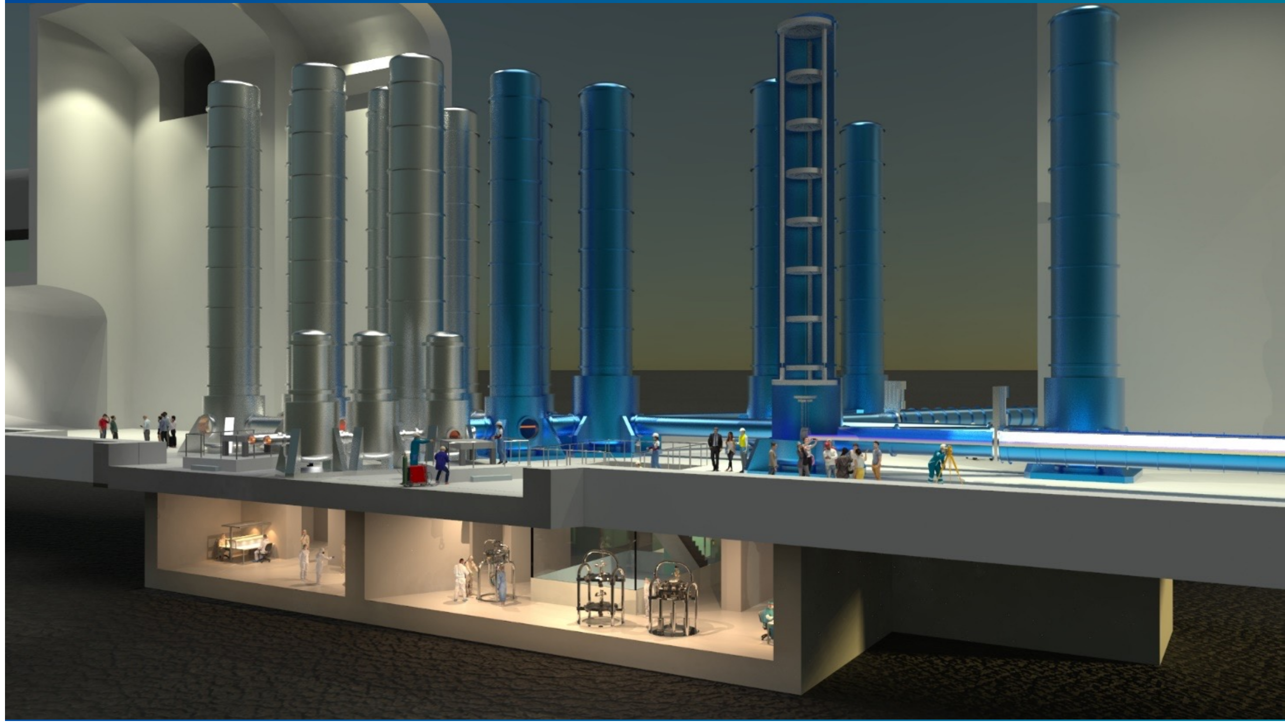
with square-kilometer *3D seismometer sensor array*

➔ *Metrological validation* of advanced full-scale seismic isolation concepts

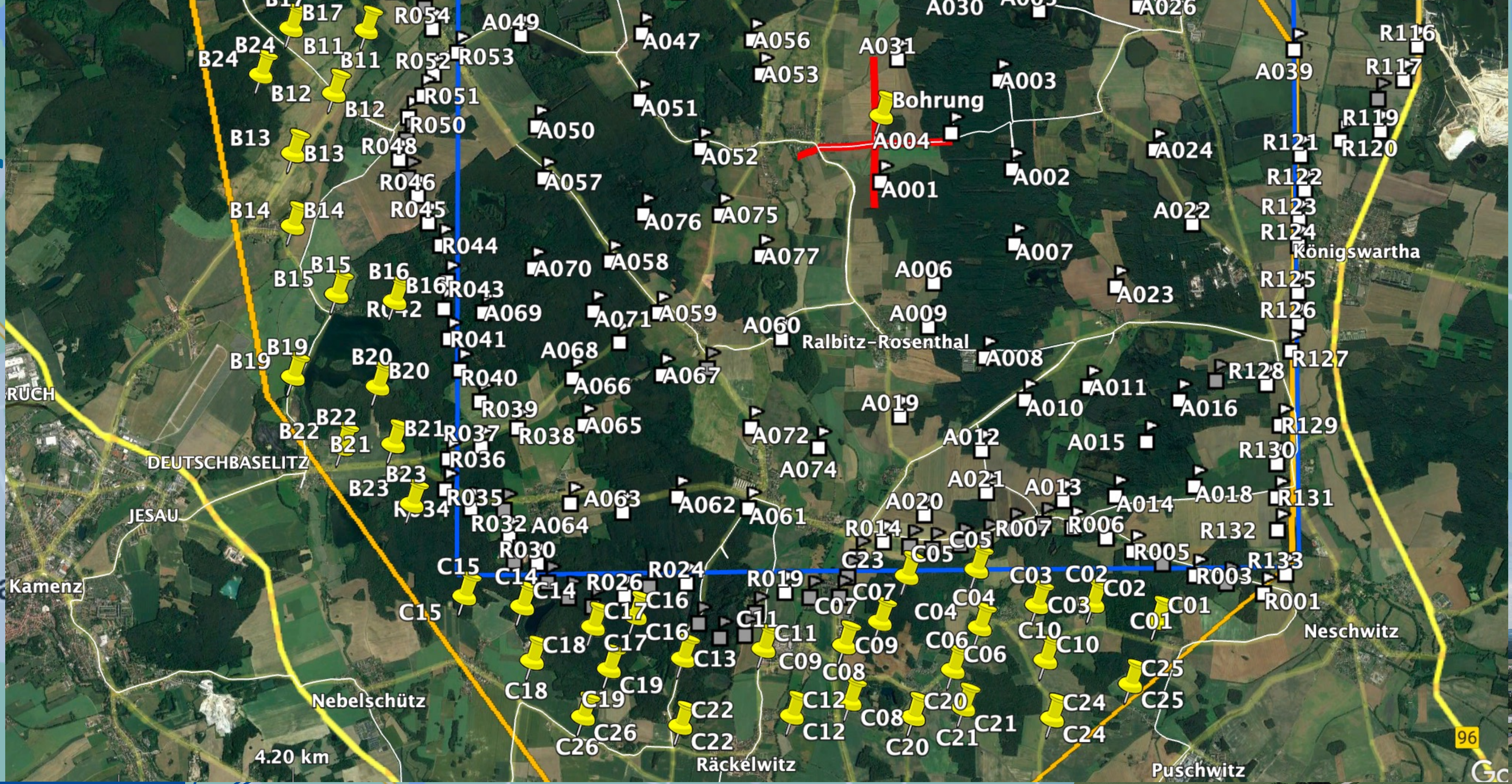
THE LOCATION FOR FUTURE "DEEP TECH":

- Technology development for gravitational wave astronomy
- Adaptive seismic noise cancellation
- Sub-nanometer microscopy and photolithography
- Quantum computing experiments
- Accelerator-based astrophysics





Messunge
Schatz der



Surface Seismometers

Test Drills in Cunnewitz

Key pilot projects and academic appointments (2023-2025)

Projects

- Purchasing 2 additional Meerkat+ antennas as in-kind contribution towards Meerkat+ and later SKAO and development of the African VLBI leg. Telescope control station in Görlitz with OHB.
- Data sciences at TU Dresden, focusing on large (<1 PB) data objects and real-time algorithms for noise suppression and data compression.
- Cryogenic silicon mirrors and high reflectvity coatings for the Einstein Telescope.
- Development of fast NIR array detectors, possibly from organic materials and characterization of CMOS detectors for astronomy

Academic Appointments at TU Dresden and creation of a technical astrophysics master program

- Three astrophysics professorships (radio astronomy, cosmology, astro technology)
- One informatics and data science professorship
- One data intensive microelectronics/semsoric professorship

- Possibly one additional astrophysics professor jointly appointed with Univ. Wroclav (and Prag?)

Summary

- National lighthouse with international appeal and societal impact.
- Unique combination of research and development in digitization, sensor technology and materials research.
- Jobs with a long-term future in many areas.
- Magnet for business and institutions, support for start-ups and spin-offs, transfer.
- Education from day care through vocational training to university.
- Prospects for young people in the region, securing the need for skilled workers. We attract people and prevent brain drain.
- Our strength: leading competence from research and development through planning to the implementation of major projects and operation.
- We do not have to build national and international networks. We will bring them with us.

DZA