

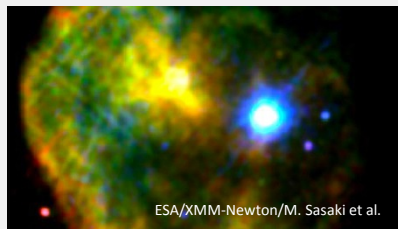
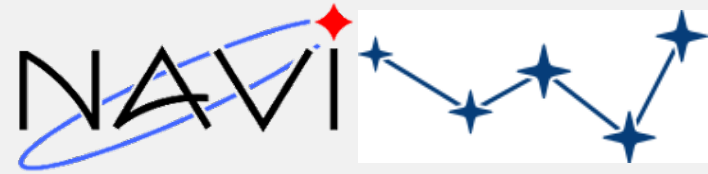


# Nuclear de-excitation lines as potential tracers of cosmic ray acceleration

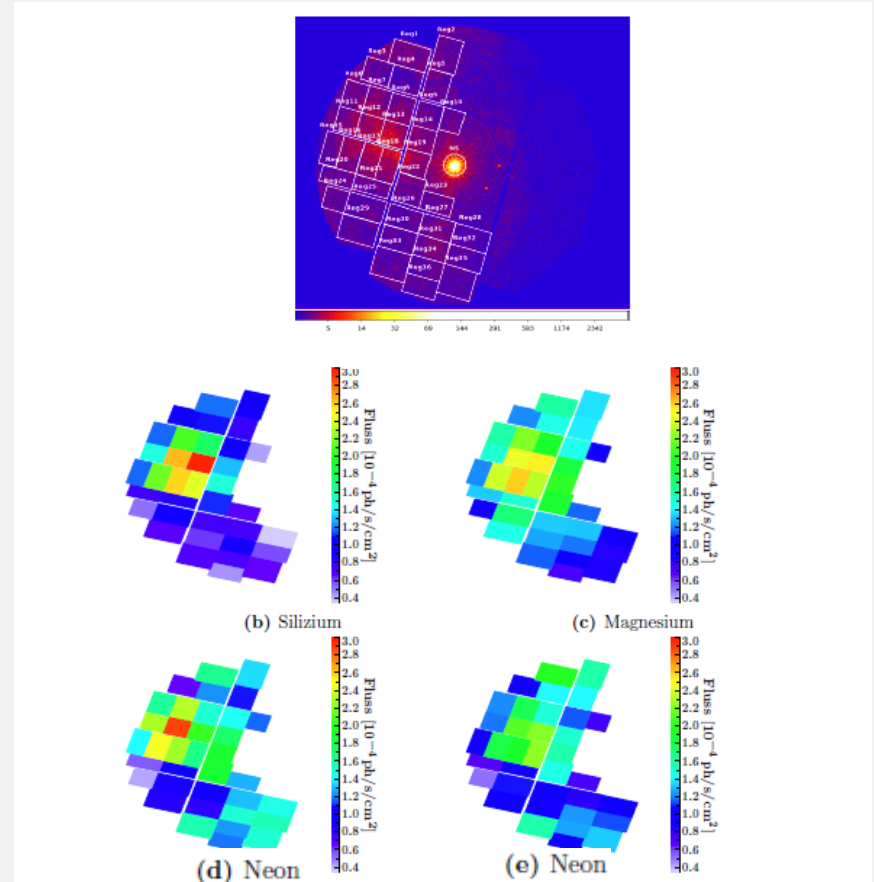
Dominik Elsässer  
Karl Mannheim  
Alexander Summa



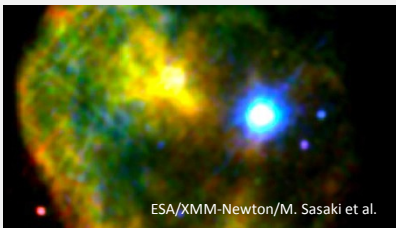




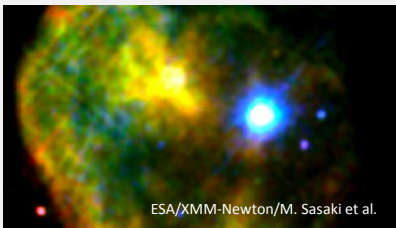
Core collapse supernovae  
as sites of element  
Synthesis and enrichment  
of the ISM



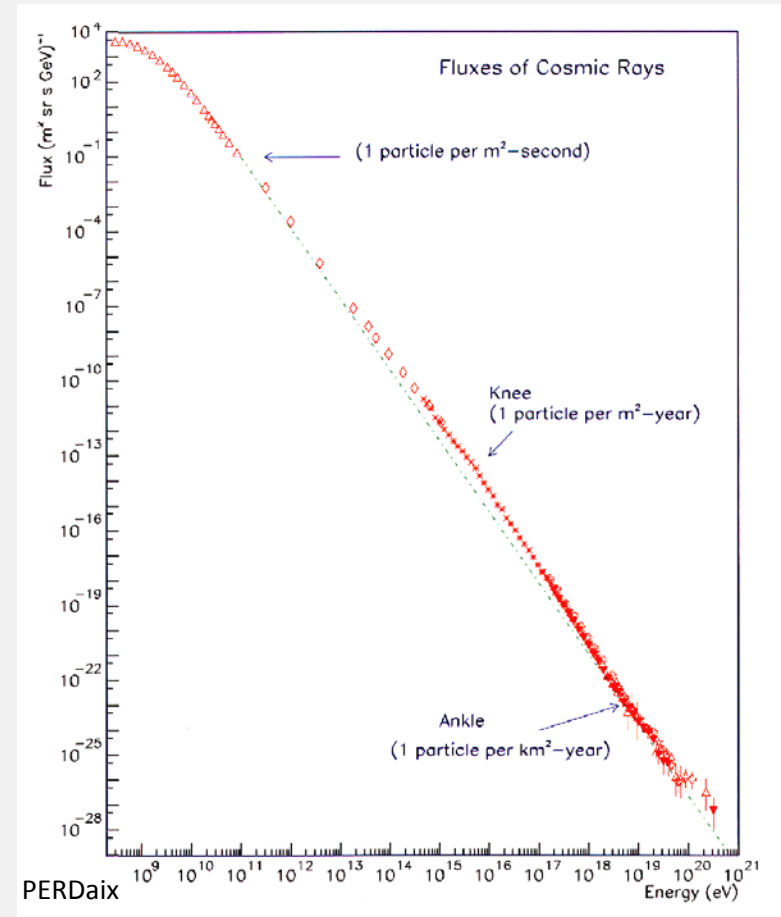
Sonja Boyer, PhD-Thesis (2015)



Supernova remnants  
as potential sites of (Galactic)  
cosmic ray acceleration

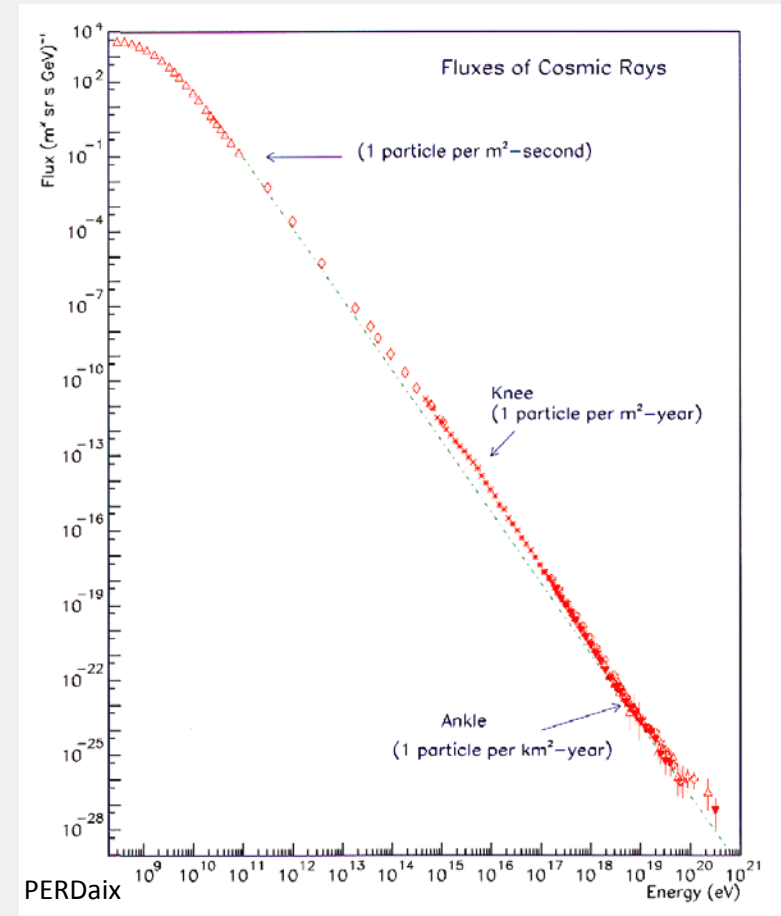


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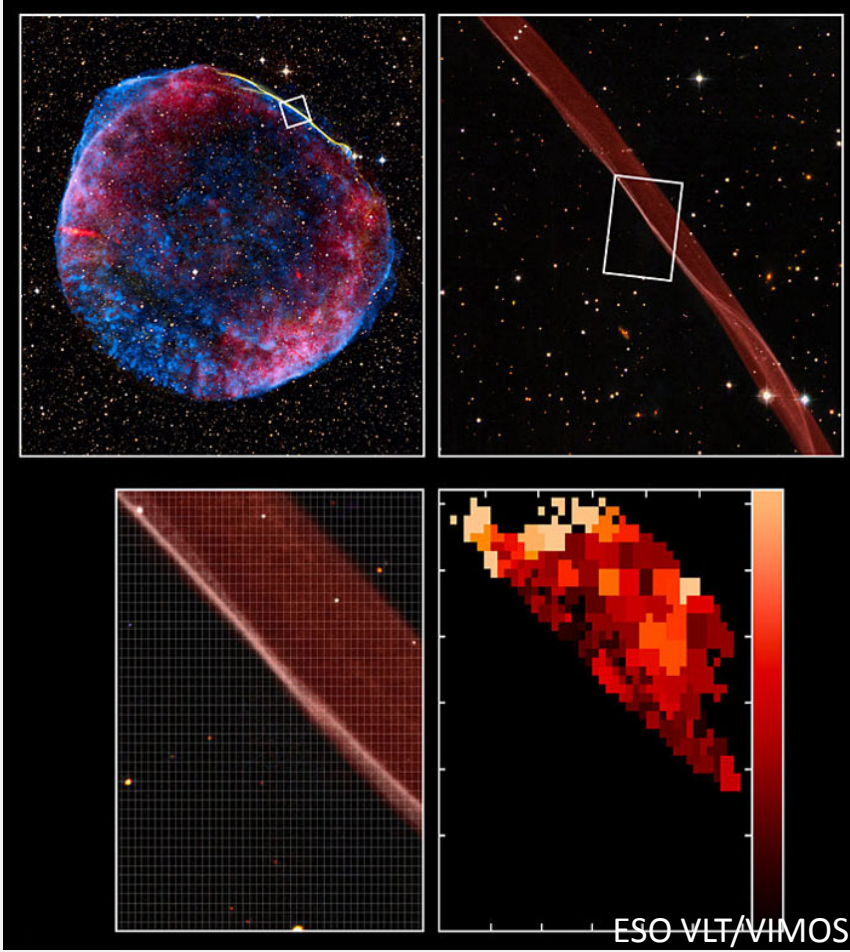




- Galactic component: energy range GeVs to (many) PeVs
- Measured energy density of Galactic component:  $\sim 10^{-12}$  erg/cm<sup>3</sup>
- 2-3 Supernovae per century and CR lifetimes of millions of years implicate SNRs as potentially (the) major contributors to the Galactic CR energy density
- Observational tests?

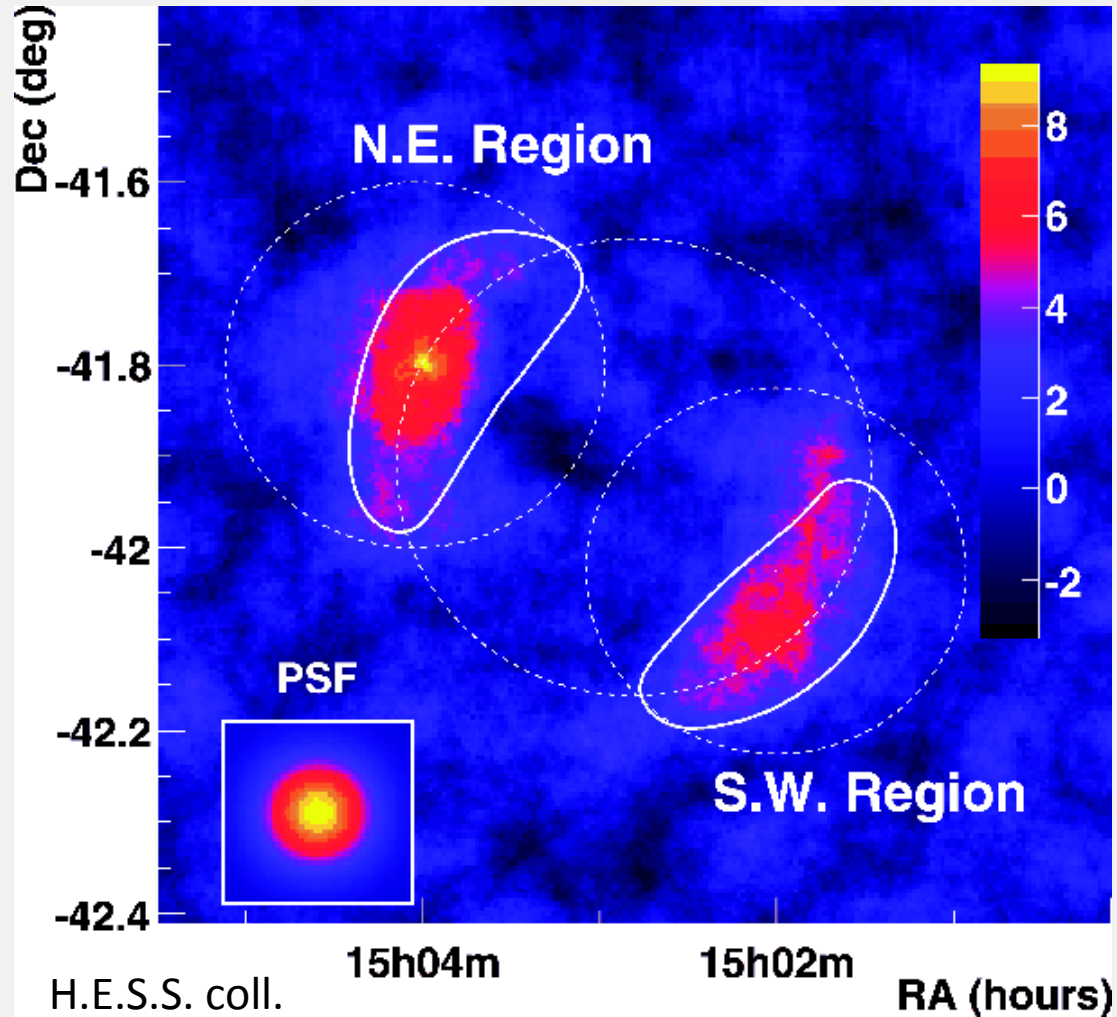


# Fast moving particles as CR seeds?



SN1006, optical

# Direct tracers of CRs: VHE gamma-rays? Tantalizing first hints:



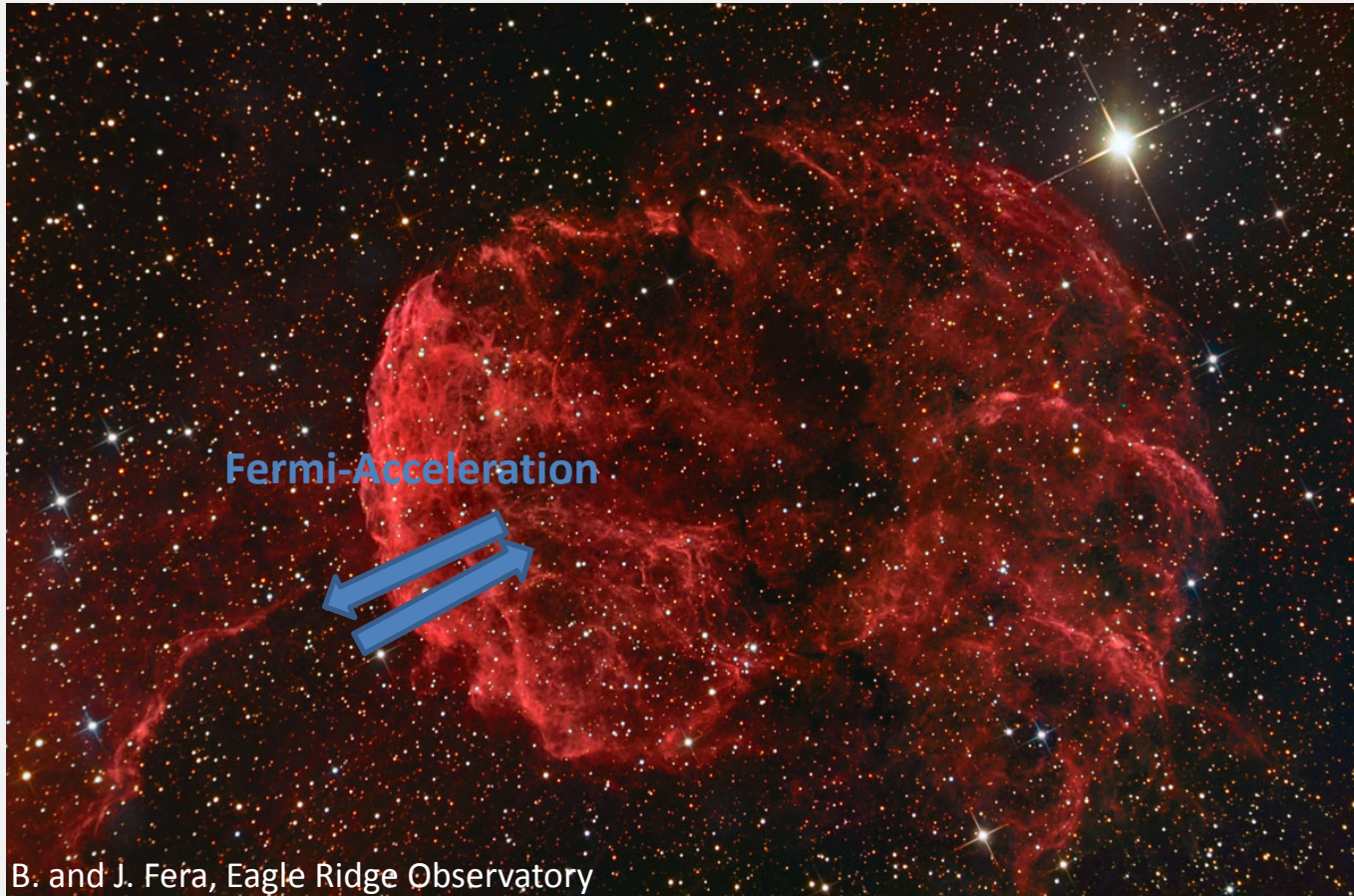


# Some mechanisms for VHE gamma-ray production

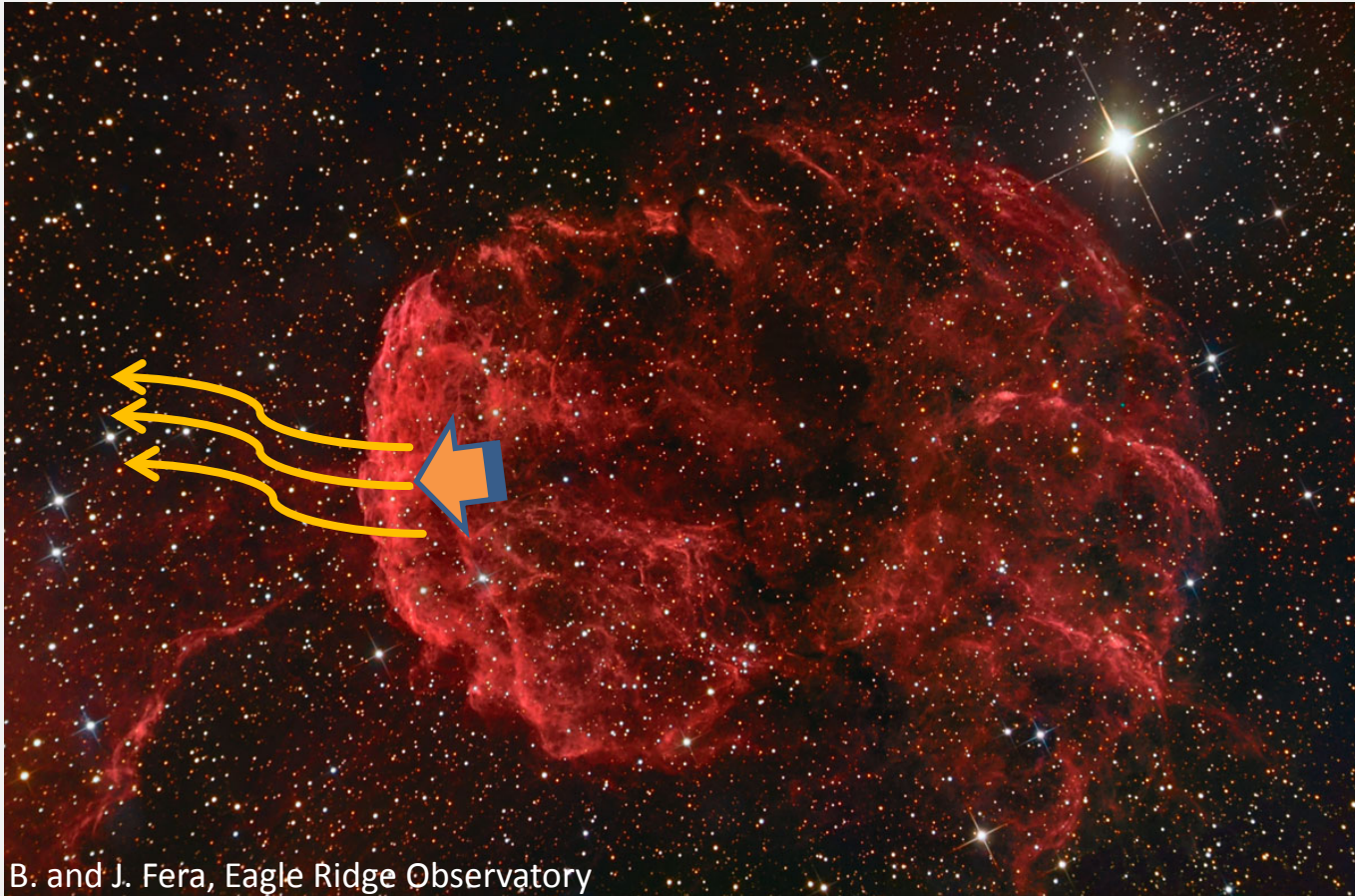


B. and J. Fera, Eagle Ridge Observatory

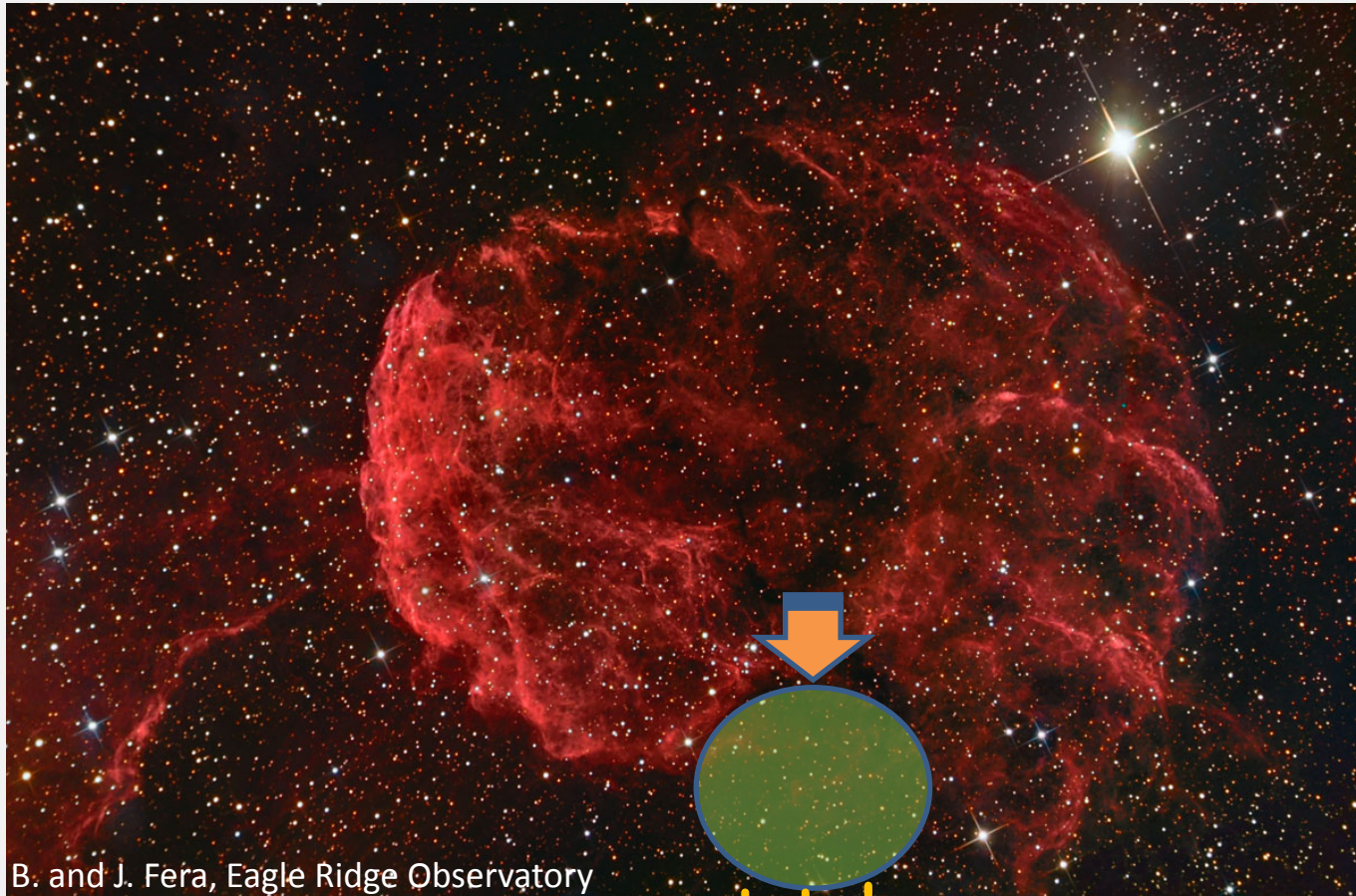
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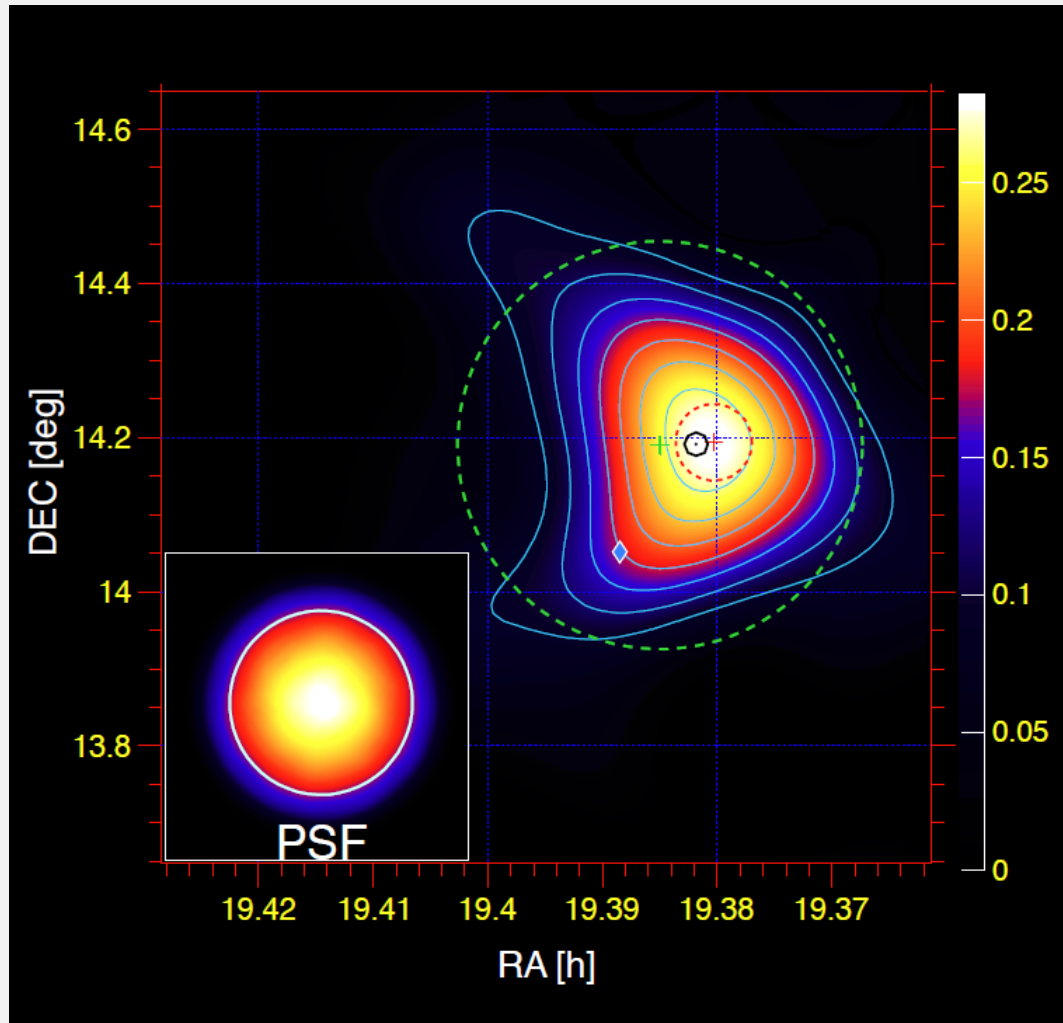
# Some mechanisms for VHE gamma-ray production



B. and J. Fera, Eagle Ridge Observatory

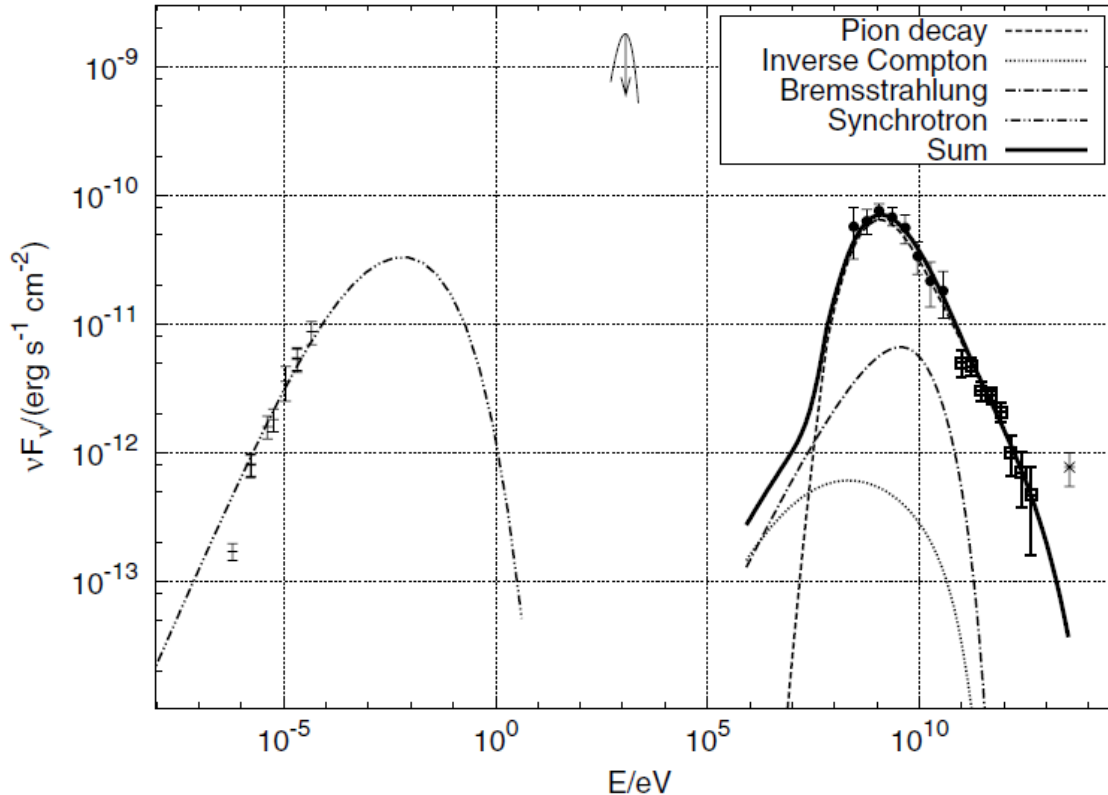
- This is in principle well testable by gamma-ray observations!

# MAGIC observations of W51



MAGIC Coll., A&A 541, A13

# MAGIC observations of W51



- Satisfactory modelling of SED possible in a heavily hadron-dominated scenario: protons interacting with molecular cloud
- However, very simplistic Ansatz regarding e.g. homogeneity
- Leptonic scenarios (IC-upscattering of CMB photons) can not be strictly ruled out this way

MAGIC Coll., A&A 541, A13

# Unequivocal fingerprints of hadrons?

- Neutrinos



# Unequivocal fingerprints of hadrons?

- Neutrinos
- Nuclear de-excitation lines

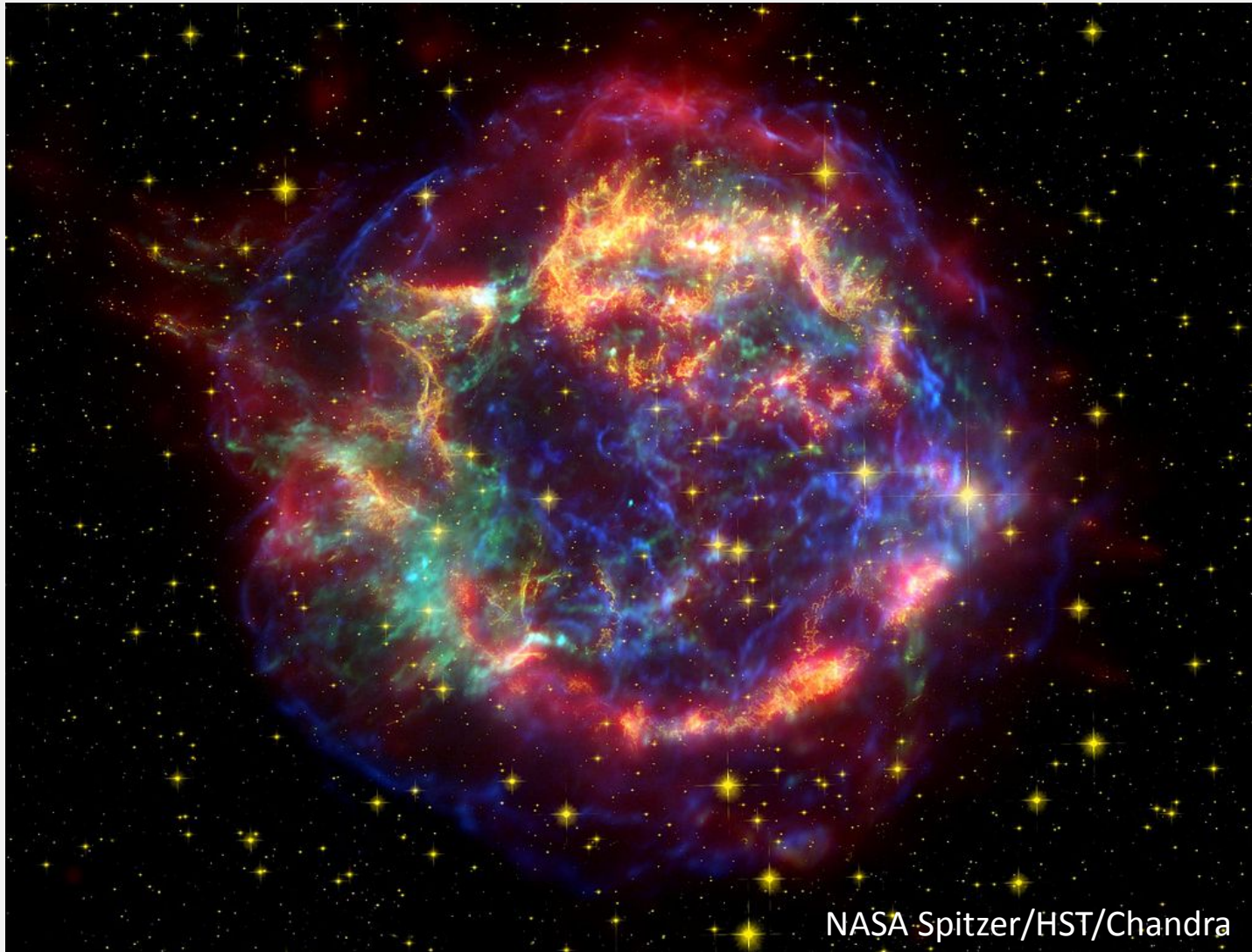
# Unequivocal fingerprints of hadrons?

- Neutrinos
- Nuclear de-excitation lines
- Inelastic scattering of energetic particles on heavier nuclei / spallation reactions
  - > excited nuclei
  - > de-excitation processes
  - > gamma-ray lines in 1 to 20MeV range

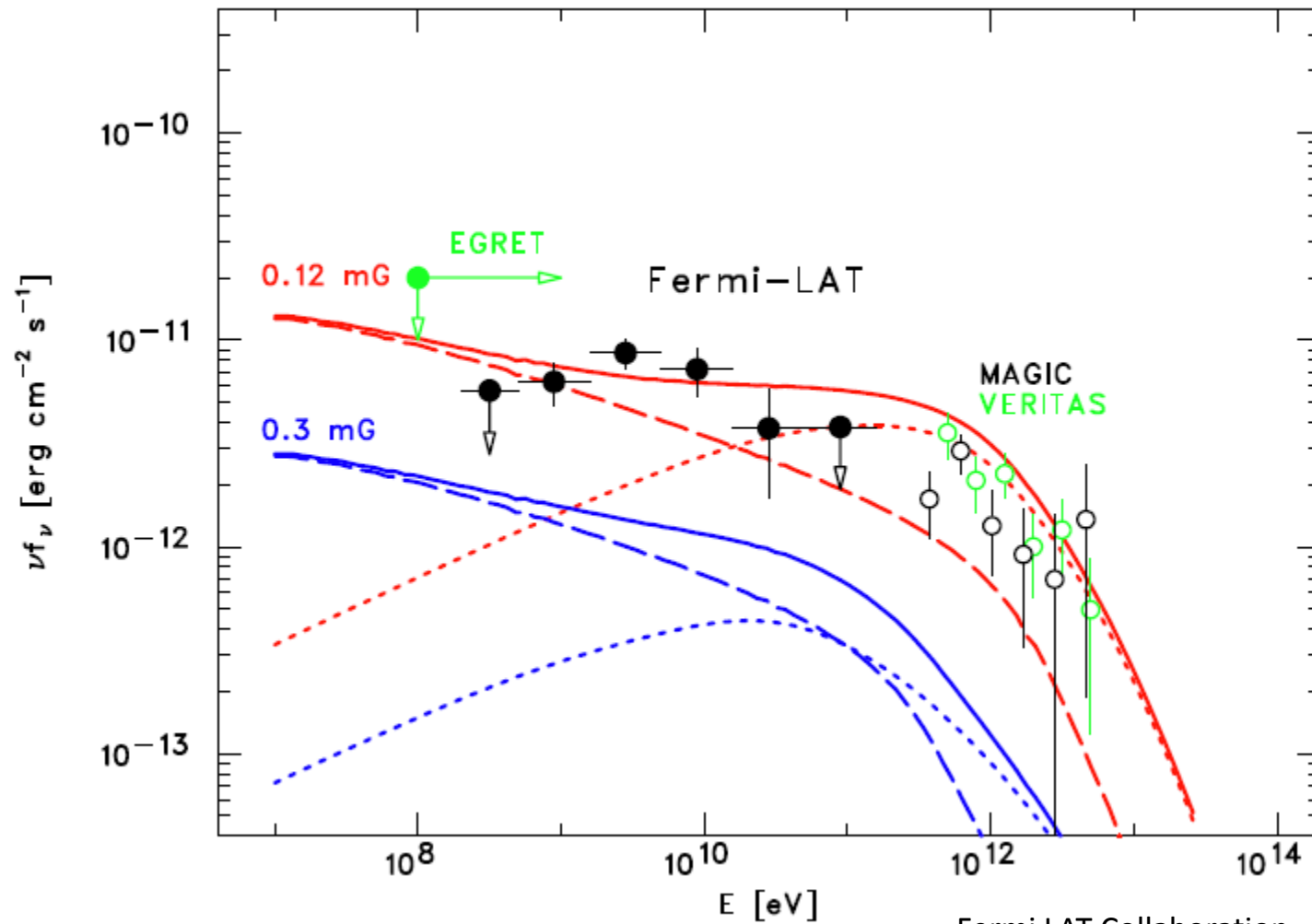
- Study CRs with energies  $<100\text{MeV}$  (at higher energies, flux from pion desintegration after p-p and p- $\alpha$  will overwhelm lines)
- Extrapolate CR spectrum from hadronic modelling of gamma-ray emission down to  $\sim 10\text{MeV}$  and see if detectable lines arise as hard prediction

# Caveats

- MeV range at this point in time not covered by highly sensitive mission  
-> bright and nearby targets may be most promising
- Elemental abundances of target regions must be known to good precision



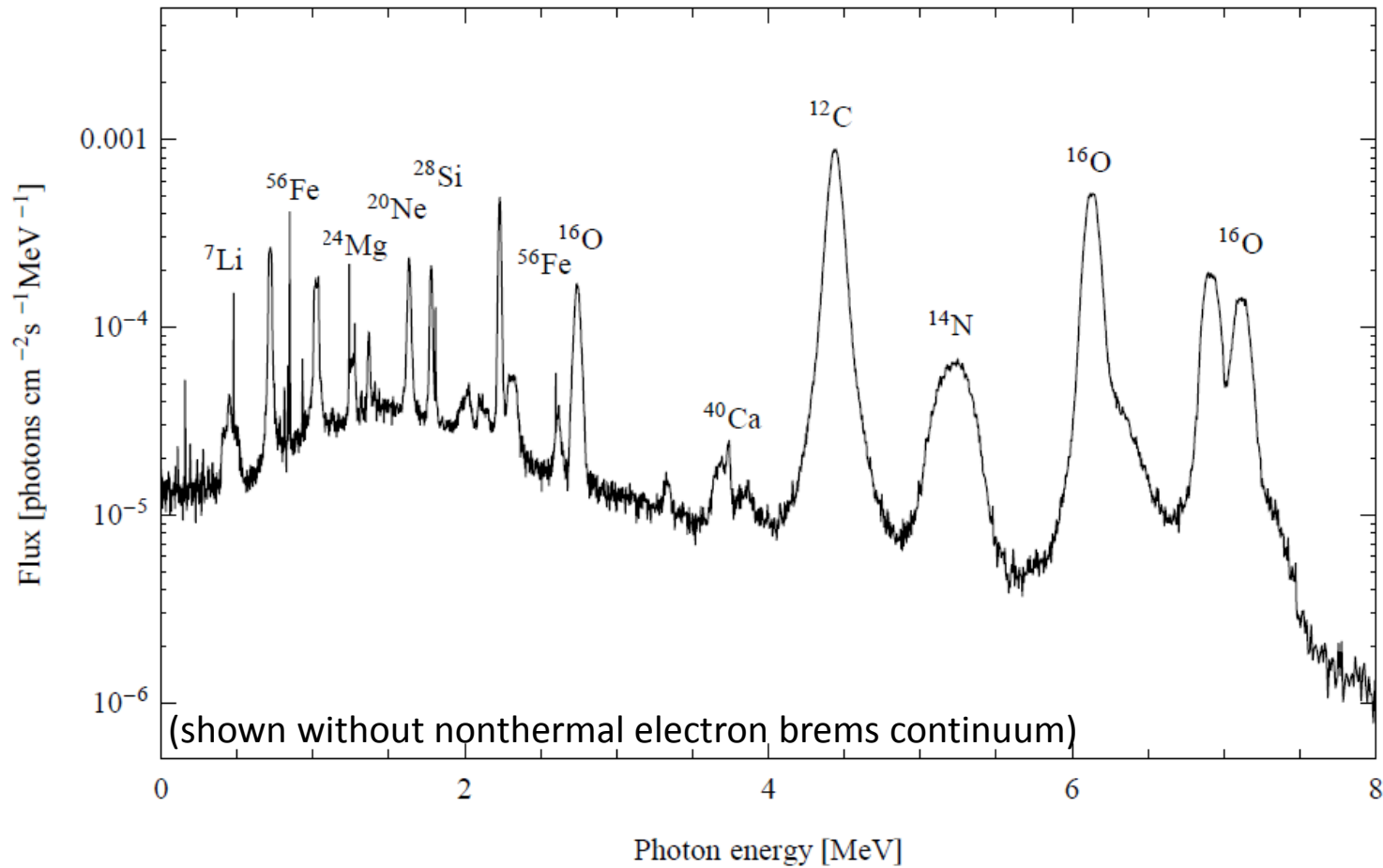
NASA Spitzer/HST/Chandra



Fermi LAT Collaboration, *ApJ* **710** L92

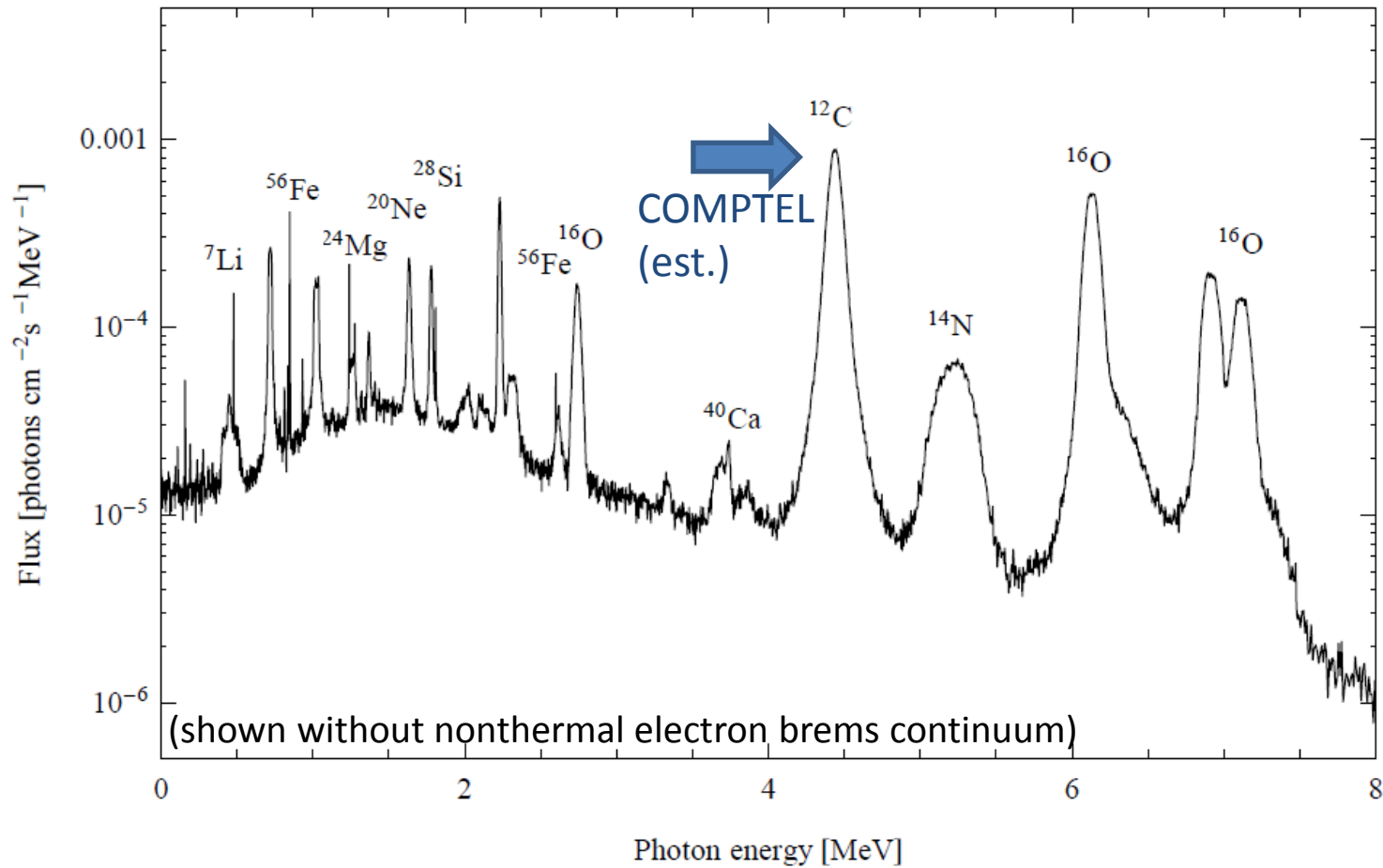
ratio	mean	rms
H/Si	$< 2.29 \times 10^{-5}$	-
He/Si	$< 4.93 \times 10^{-3}$	-
C/Si	1.76	0.88
O/Si	1.69	1.37
Ne/Si	0.24	0.37
Mg/Si	0.16	0.15
S/Si	1.25	0.24
Ar/Si	1.38	0.48
Ca/Si	1.46	0.68
FeL/Si	0.19	0.65
FeK/Si	0.60	0.51
Ni/Si	1.67	5.52

- Elemental abundances from Willingale et al. (2002), Docenko & Sunyaev (2010) [X-ray] and Chevalier & Kirshner (1979) [H & He, optical]
- MonteCarlo code from Ramaty, Kozlovsk & Lingenfelter (ApJS, 40, 487)
- Calculate de-excitation line spectrum

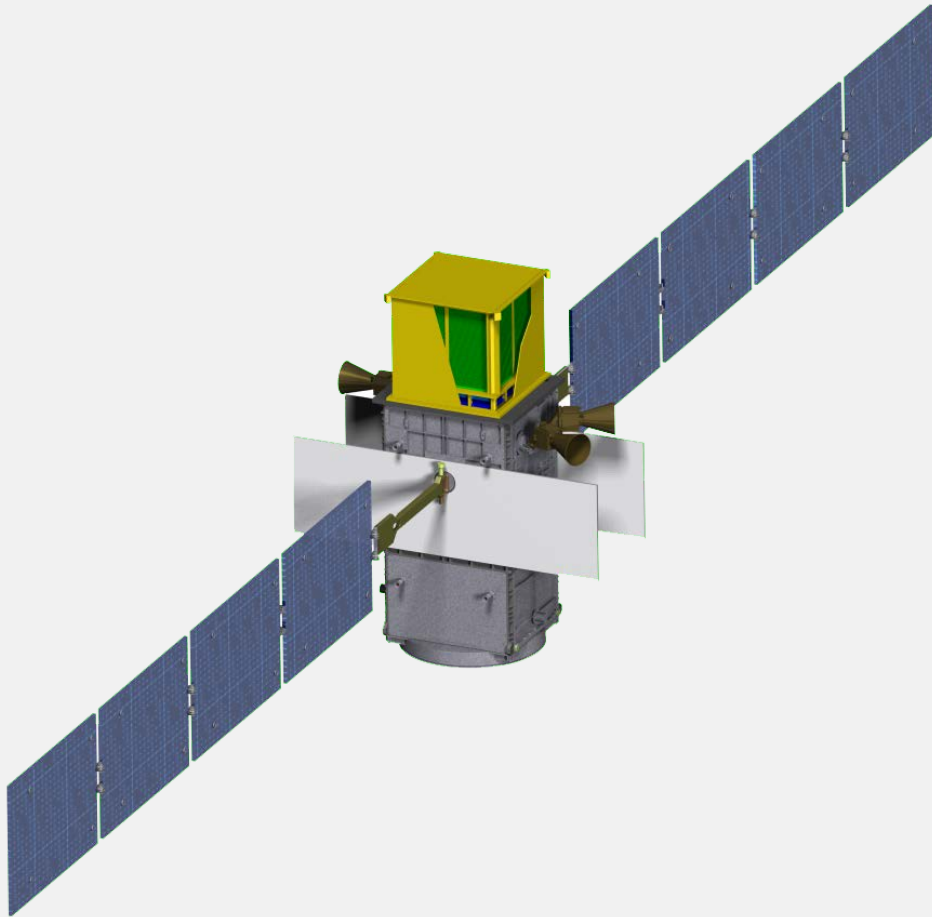


Summa, Elsässer & Mannheim, A&A 533, A13



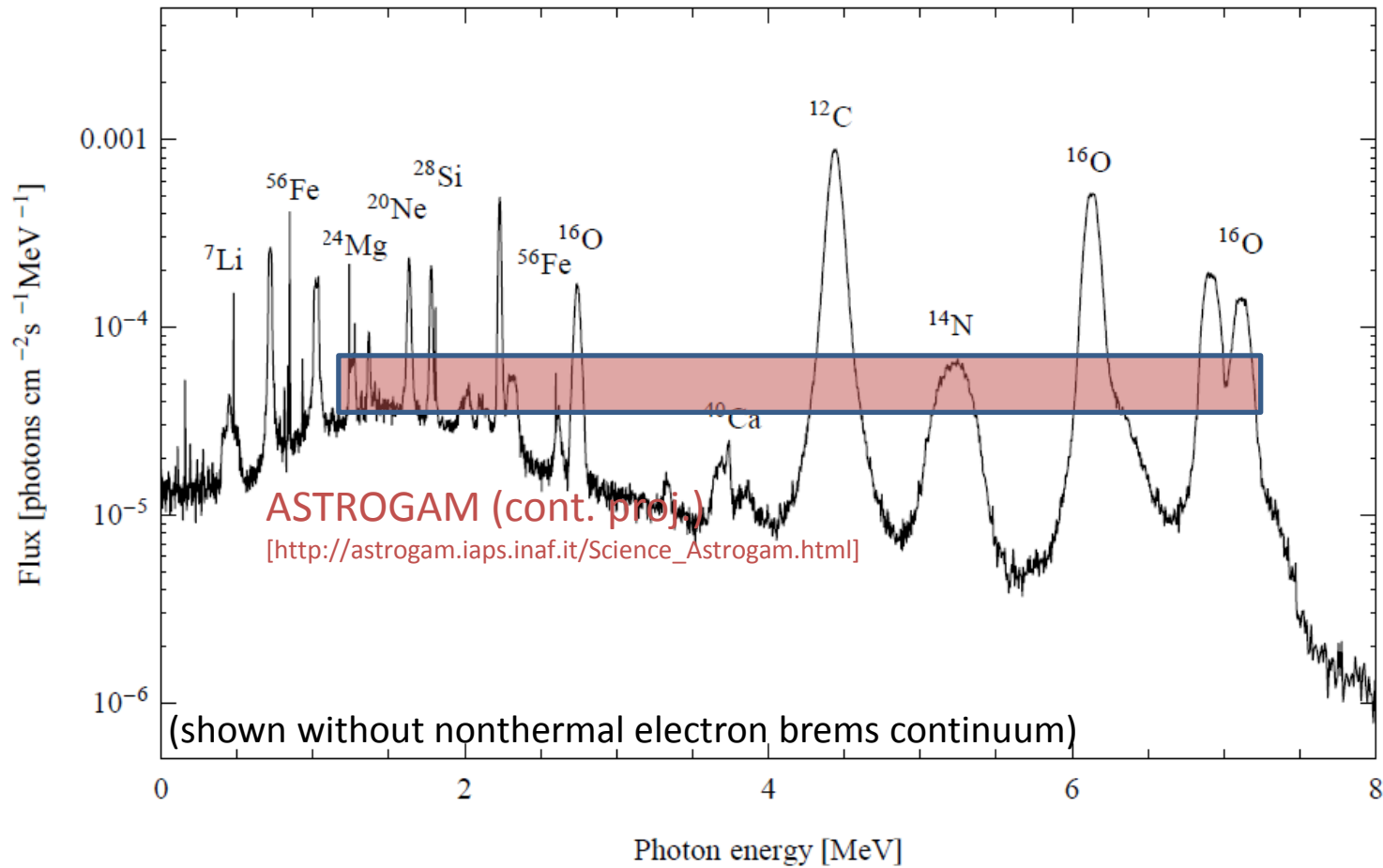


# ASTROGAM



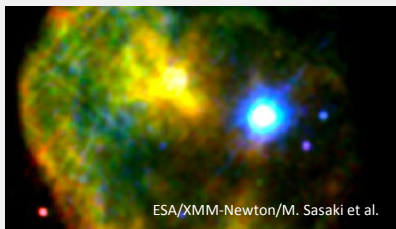
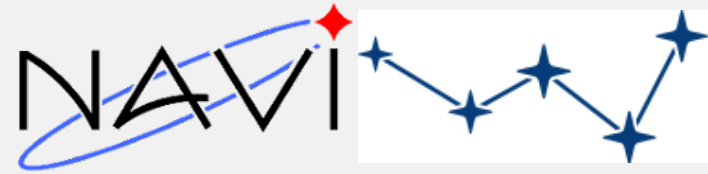
- Proposed mission for the ESA M4 slot (launch ~2025)
- Silicon detectors for both Compton- and pair-event detection
- Energy range 300 keV - 3 GeV
- Factor 10-30 improvement over COMPTEL

<http://astrogam.iaps.inaf.it/index.html>

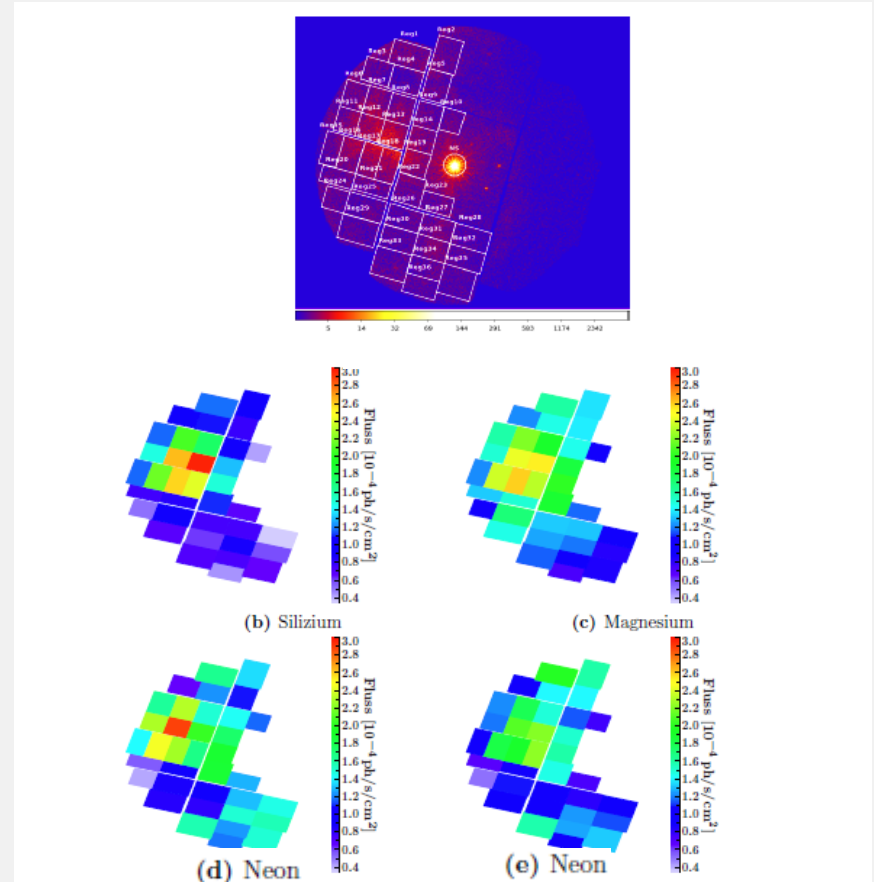


# Conclusions & Outlook

- To produce unambiguous evidence (or limits to!) CR acceleration in SNRs, complimentary channels will be needed even in the CTA era
- This may e.g. be neutrino detections or detection of de-excitation lines (or upper limits, respectively)
- At least for nearby objects, de-excitation lines should well be detectable with future MeV instruments
- **Refined measurements of abundances of great value!**



Core collapse supernovae  
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- Refined measurements of abundances of great value!
- Effect of spallation product yield on cosmic abundances of e.g. Li, Be, B?