Spallation of Cosmic Ray Nuclei

Karl Mannheim, Universität Würzburg

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Radioactive isotopes

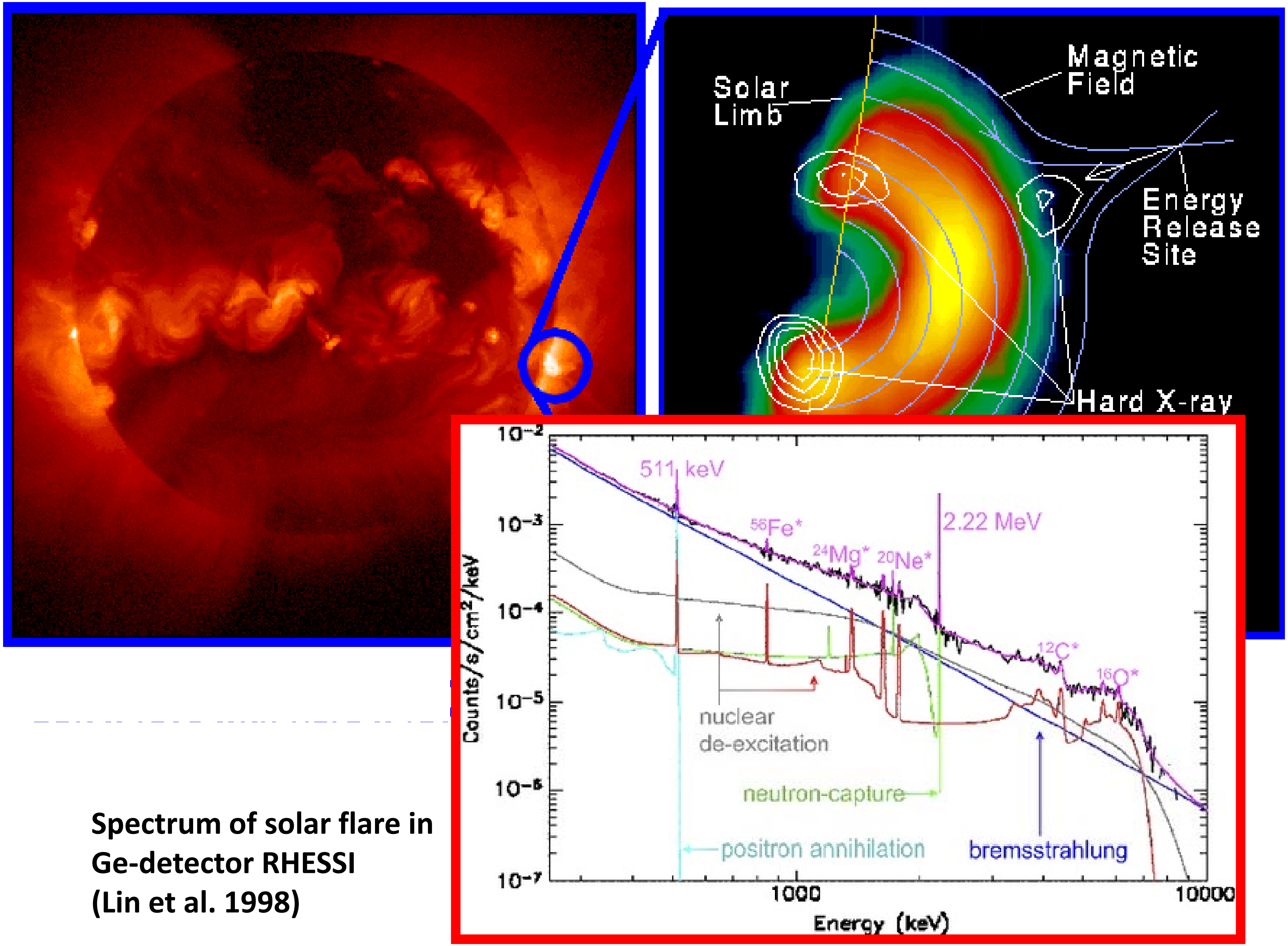
- Explosive nucleosynthesis
- R- process
- S-process
- Other n-driven processes

Positronium

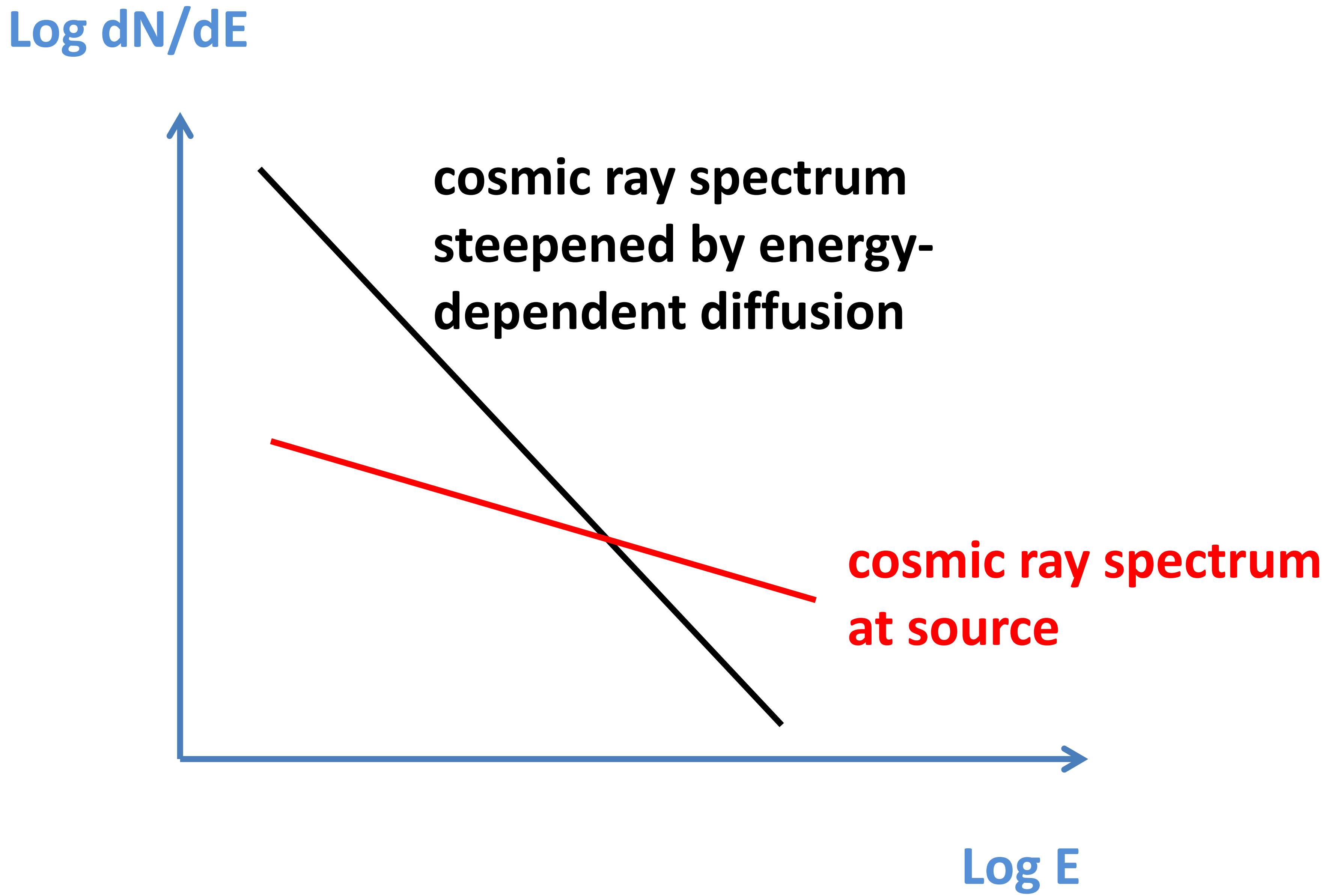
- Anti-matter
- Supercritical magnetospheres
- Light dark matter?
- Bethe-Heitler

Nuclear de-excitation lines

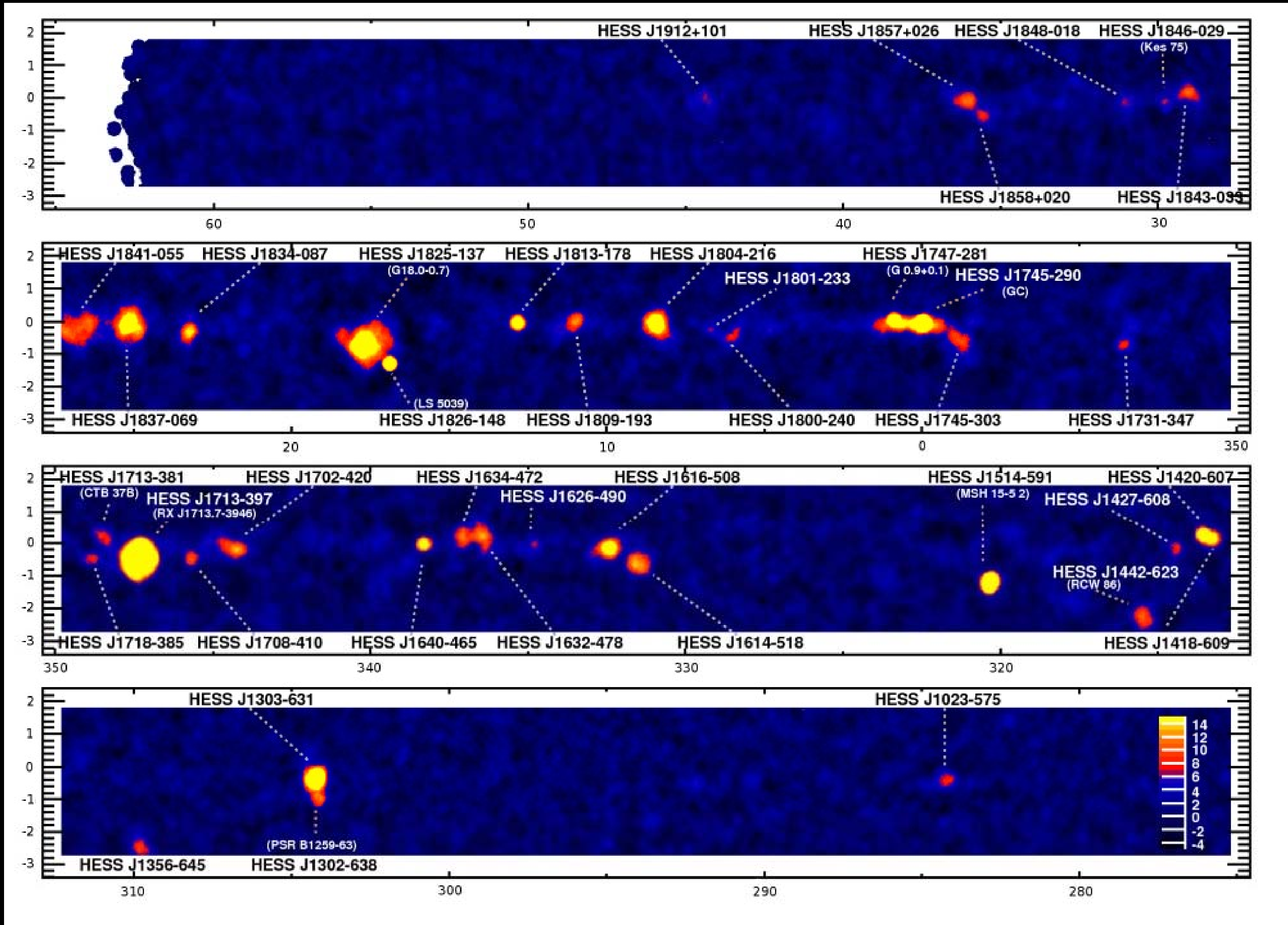
- Non-thermal plasma
- Cosmic ray acceleration
- Spallation yields → Li/Be/B abundances
- CR heating of ISM



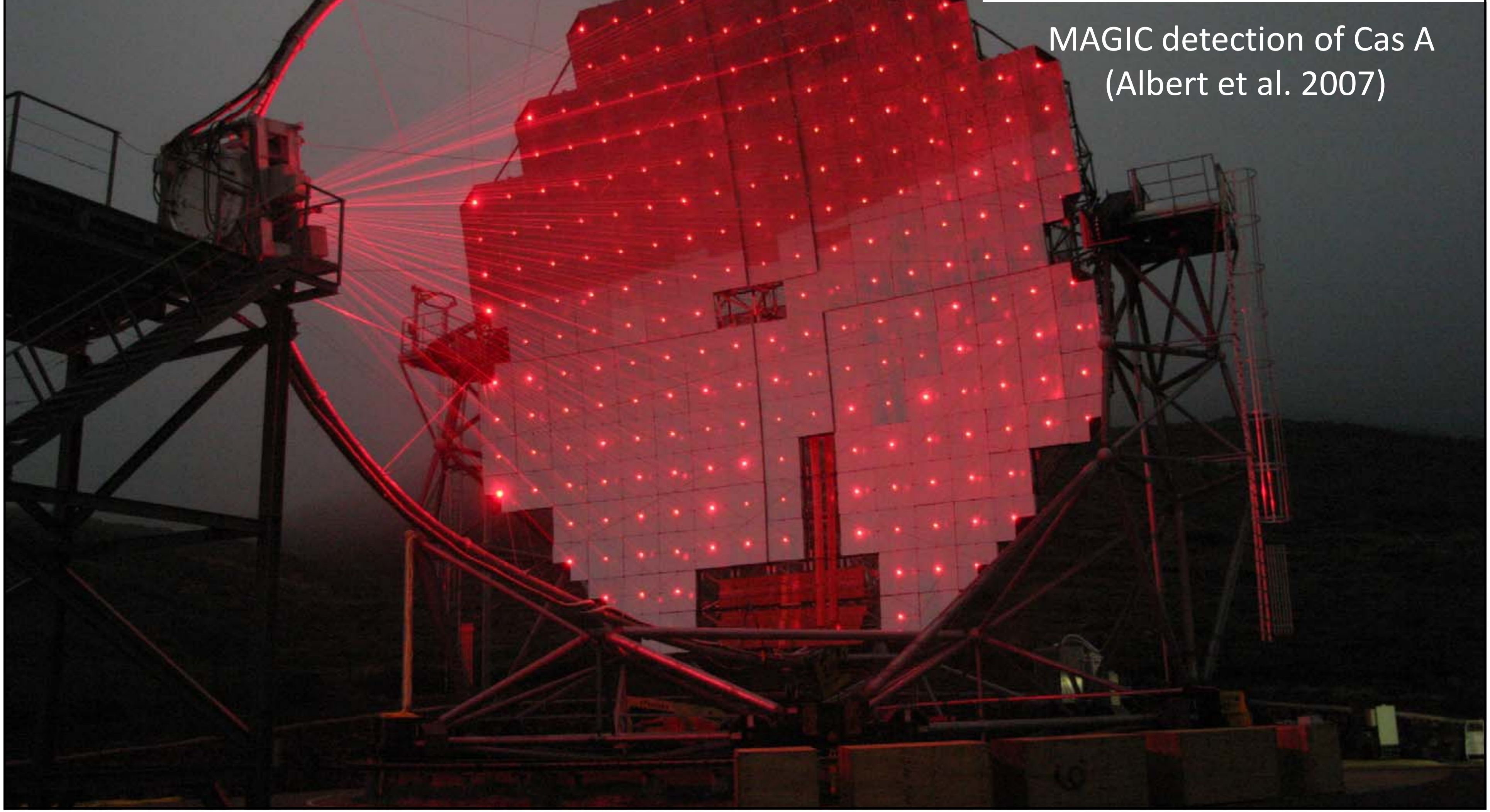
Spectrum of solar flare in Ge-detector RHESSI (Lin et al. 1998)

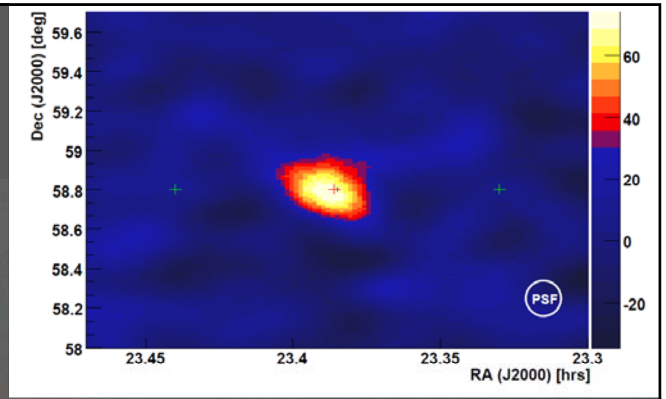

Log dN/dE
cosmic ray spectrum
steepened by energy-
dependent diffusion
cosmic ray spectrum
at source
Log E

Hess galactic plane survey at TeV energies reveals candidate sources of cosmic rays

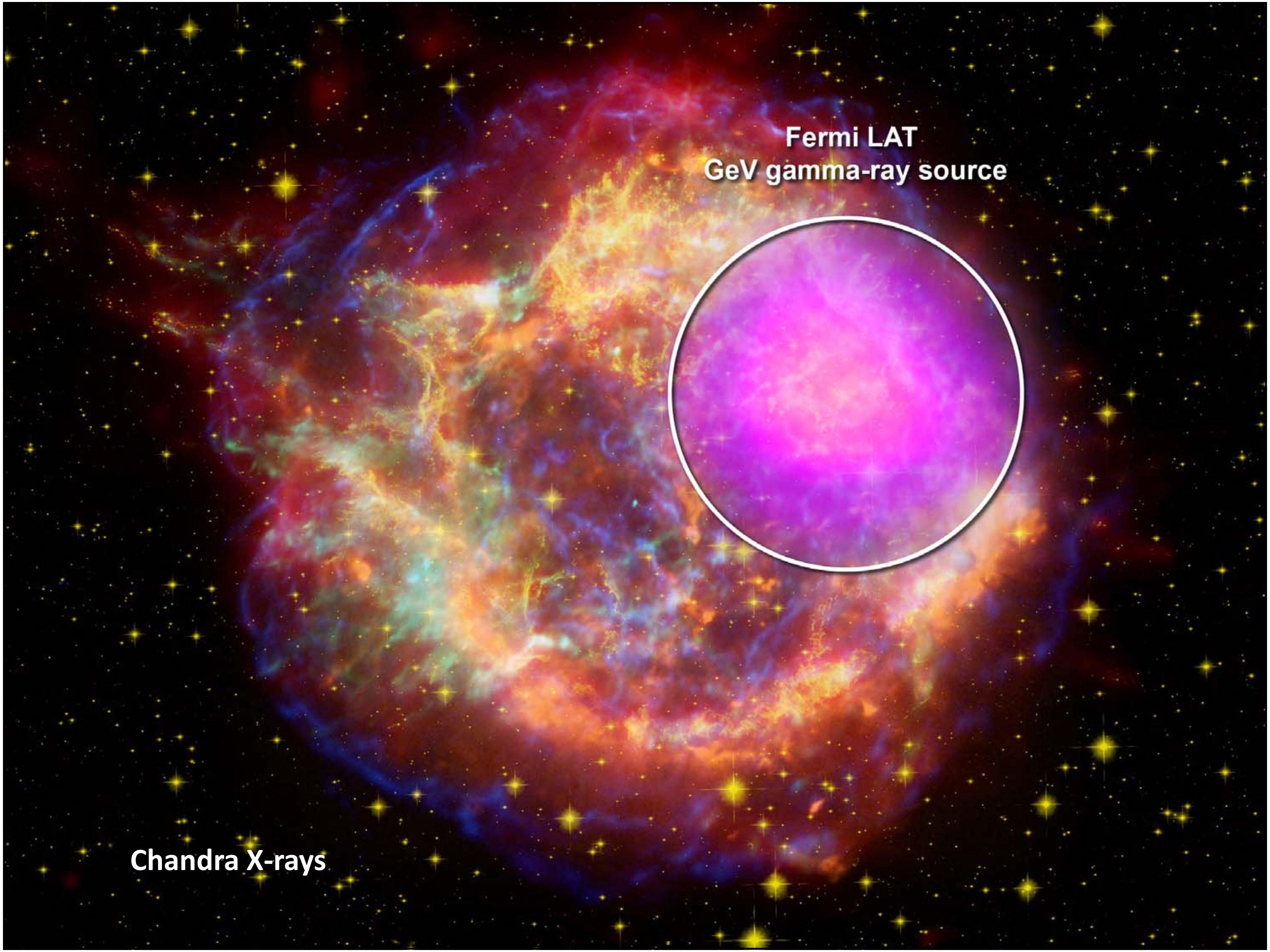


A case study:
The young SNR Cassiopeia A

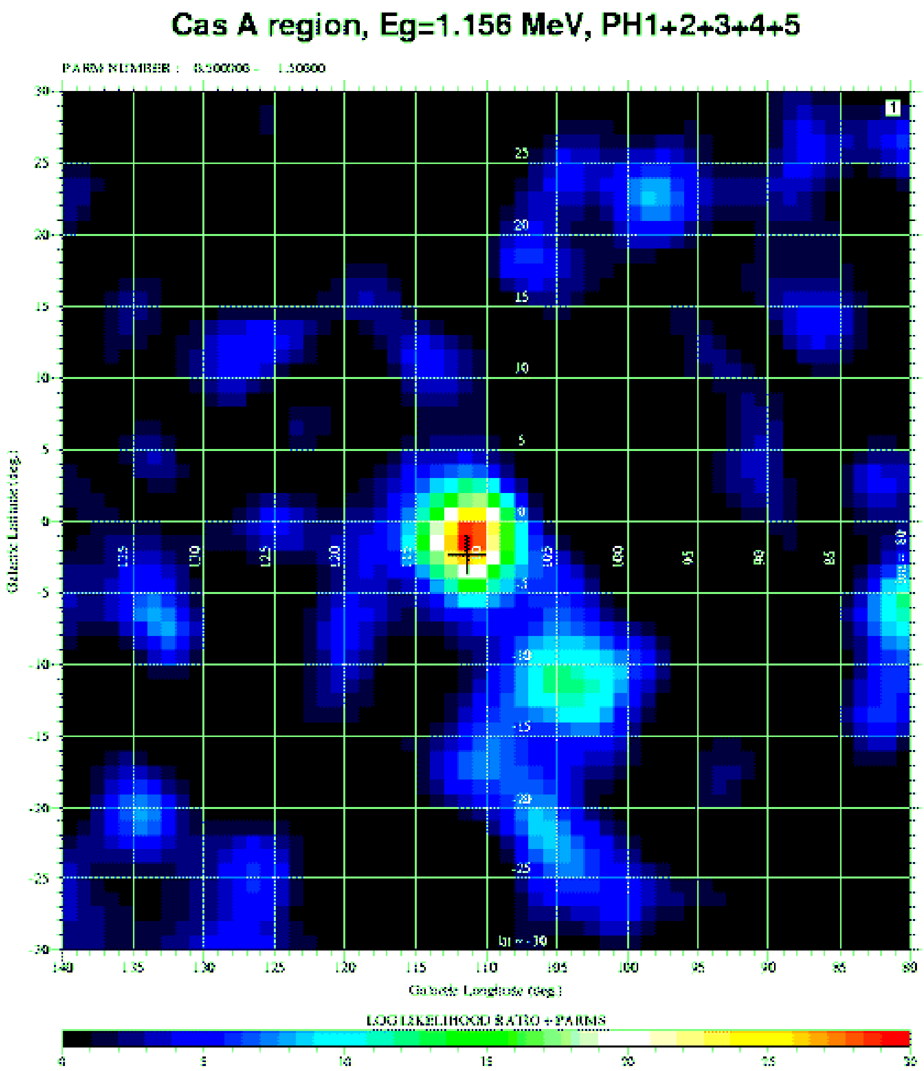




MAGIC detection of Cas A
(Albert et al. 2007)

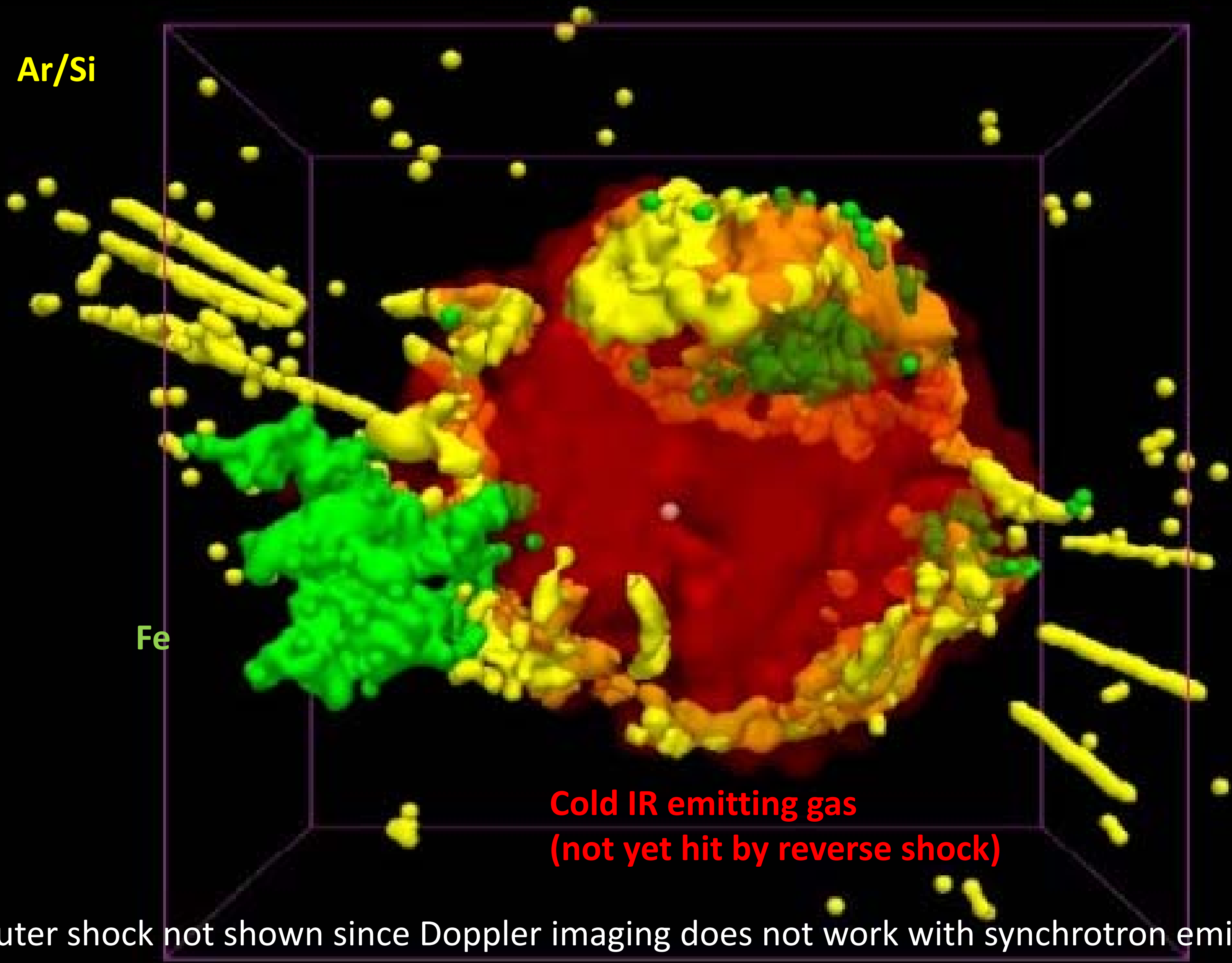

Fermi LAT
GeV gamma-ray source
Chandra X-rays

Ti-44 line discovered with COMPTEL (Iyudin et al. 1994)



- ^{44}Ti nucleosynthesis (by-product of ^{56}Ni)
- Half-life of 86 yrs
- Comptel flux (4.8 ± 0.9)x10^{-5} cm^{-2} sec^{-1}
- ^{44}Ti mass of (1.62 ± 0.31)x10^{-4} M_O
- Mass is highly sensitive to NS models
- High value may be hint of asymmetry
- ^{44}Ti → ^{44}Sc → ^{44}Ca
- X-ray lines at 68 keV and 78 keV
- Confirmed by BeppoSax

3D-model from Doppler imaging (Delaney et al.)



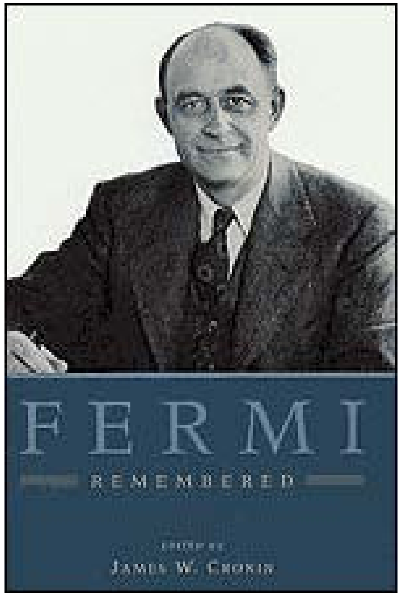
Outer shock not shown since Doppler imaging does not work with synchrotron emission

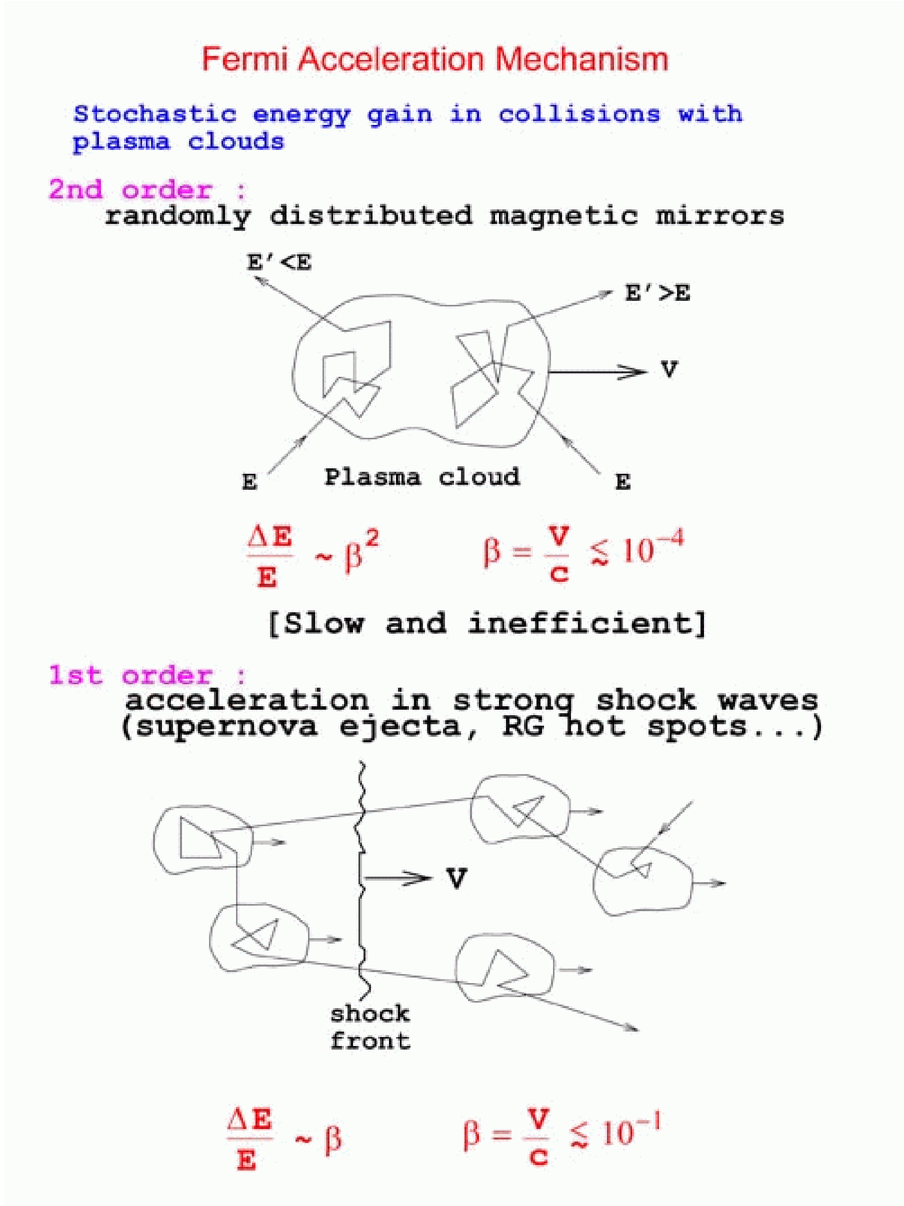
V.L.Ginzburg, S.I.Syrovatskii (1964)

The Origin of Cosmic Rays in shell-type SNRs

Fermi (1949, 1951)

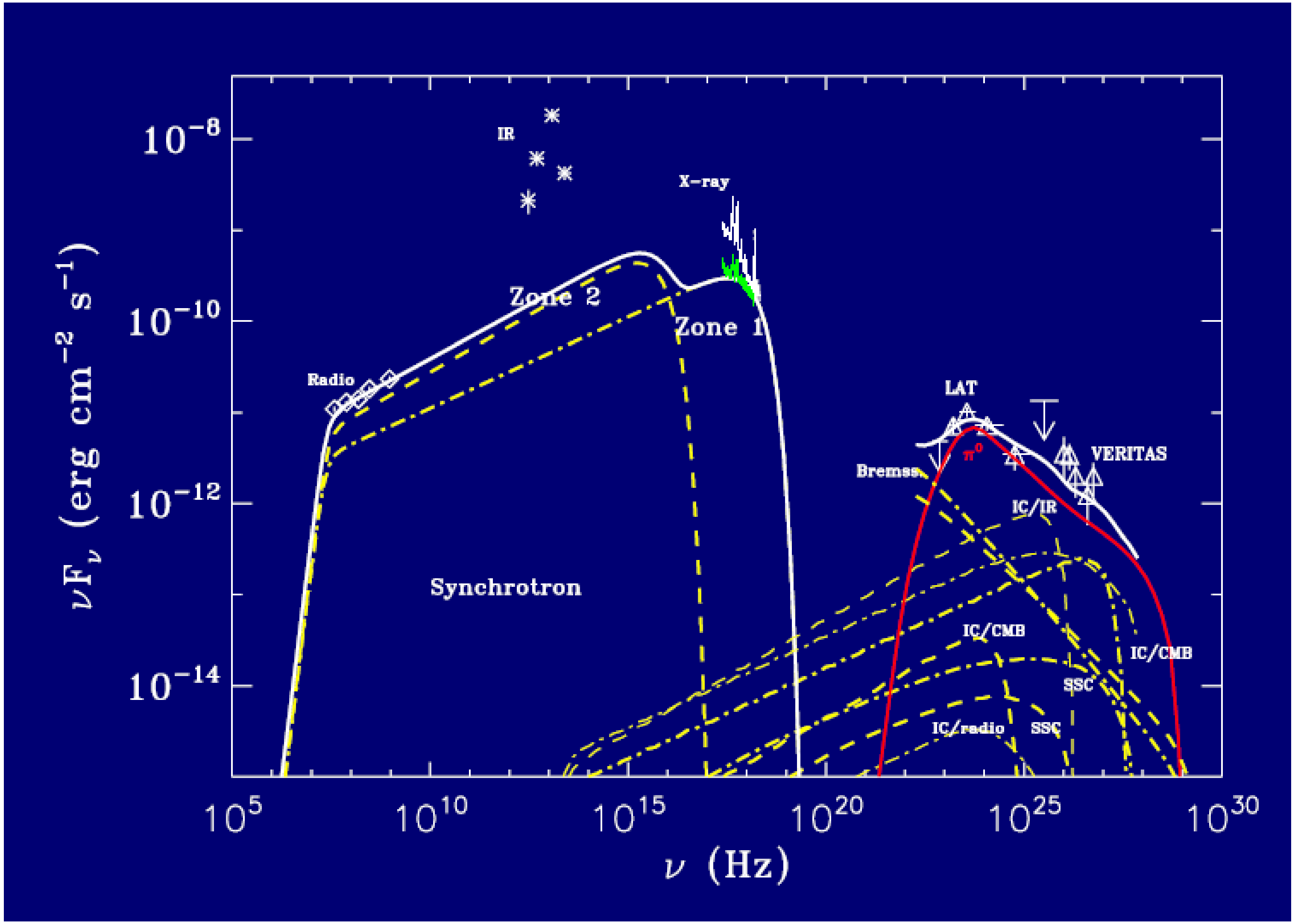
Particle acceleration by magnetic scattering off moving clouds





Cf. Gaisser: Cosmic rays and particle physics

Spectral energy distribution of Cas A: Evidence for pion production from cosmic rays



Araya & Cui 2010

Target abundances from X-ray and optical spectroscopy: Heavy-element enriched Wolf-Rayet wind mixed with supernova ejecta

Table 1. Mean measured abundance mass ratios and rms scatter resp. upper limits according to the results of Willingale et al. (2002), Docenko & Sunyaev (2010) and Chevalier & Kirshner (1979).

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

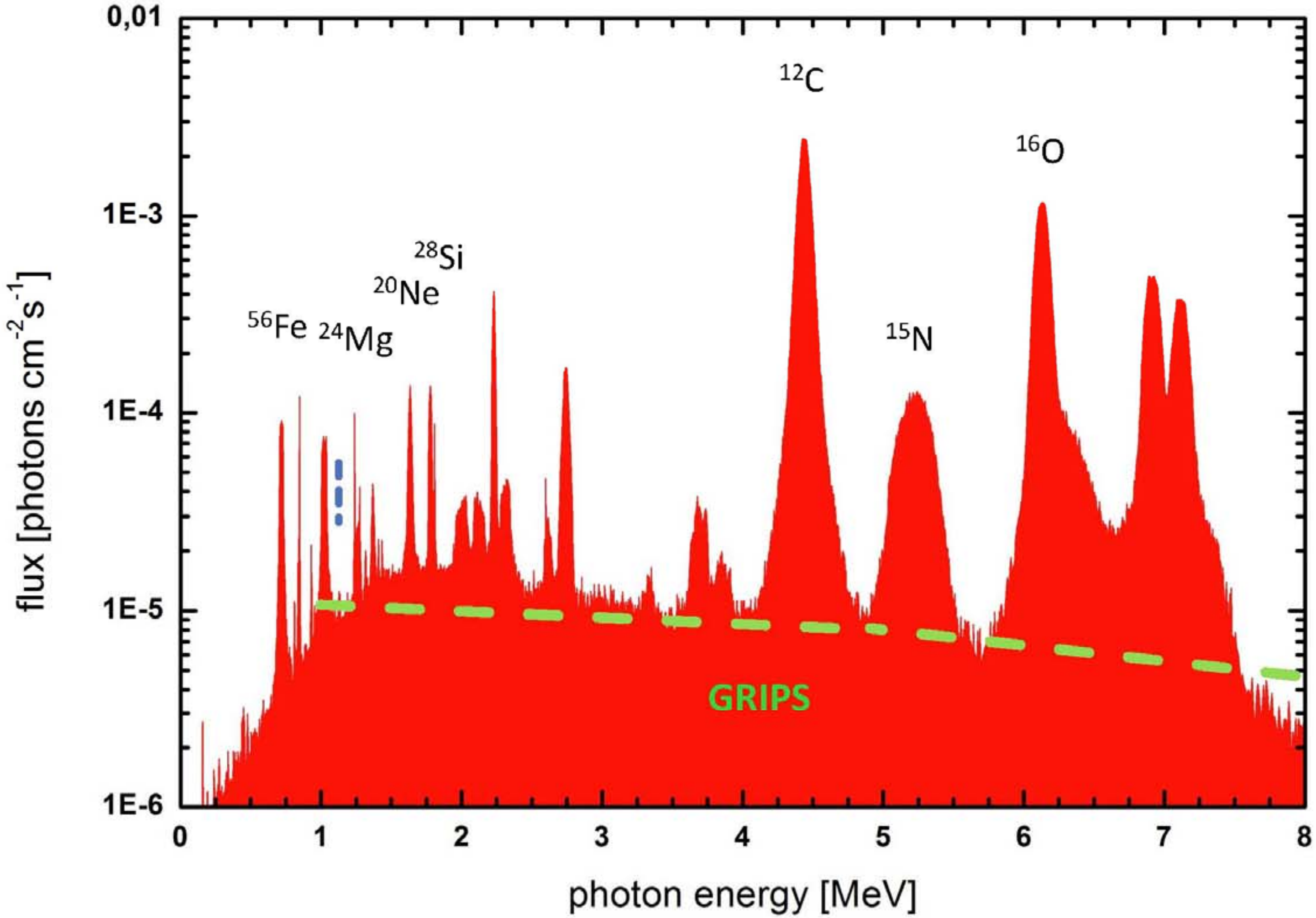
*slope of CR spectrum form HE/VHE observations, similar results obtained using full nonlinear acceleration model (Berezhko, Pühlhofer, and Völk 2003)

Kozlovsky & Ramaty (2002) code

observed CR spectrum*

Target abundances

Prediction of nuclear de-excitation lines based on high-energy spectrum observed from Cas A



Summa et al. (2011)

Nuclear de-excitation lines measurements to answer key questions in cosmic ray physics

- Unambiguous spectroscopic fingerprint of cosmic ray acceleration
- Chemical composition of cosmic rays and SNR ejecta from line profiles (Doppler broadening)
- Important corollaries:
  - Spallation yields and thus enrichment of the light elements Li/Be/B (otherwise believed to be of primordial origin)
  - Cosmic ray heating of molecular clouds and ISM
  - Cosmic ray acceleration efficiency

→Cf. Helmholtz-Alliance for Astroparticle Physics!