What can we learn about CR acceleration from observations?

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CfFP Workshop on Cosmic Particles, Abingdon, Feb 18-20, 2005

Not as much as we would like, but still quite a lot!
Much recent progress...

Evidence from observations

Spectrum (energy/rigidity)

Composition

Isotropy

Spatial distribution

Signatures of sources

Warning!

Spectrum observed is NOT source spectrum!

Composition is NOT source composition!

Angular distribution does NOT reflect source directions!

Propagation!

(and modulation)

Spectrum

Very well described by power-law from below a GeV to 100TeV per nucleon - index about 2.7 - then the "knee" etc.

Low energy spectrum below 100MeV only poorly constrained.

Propagation has steepened spectrum, true source spectrum in range 2.0-2.3

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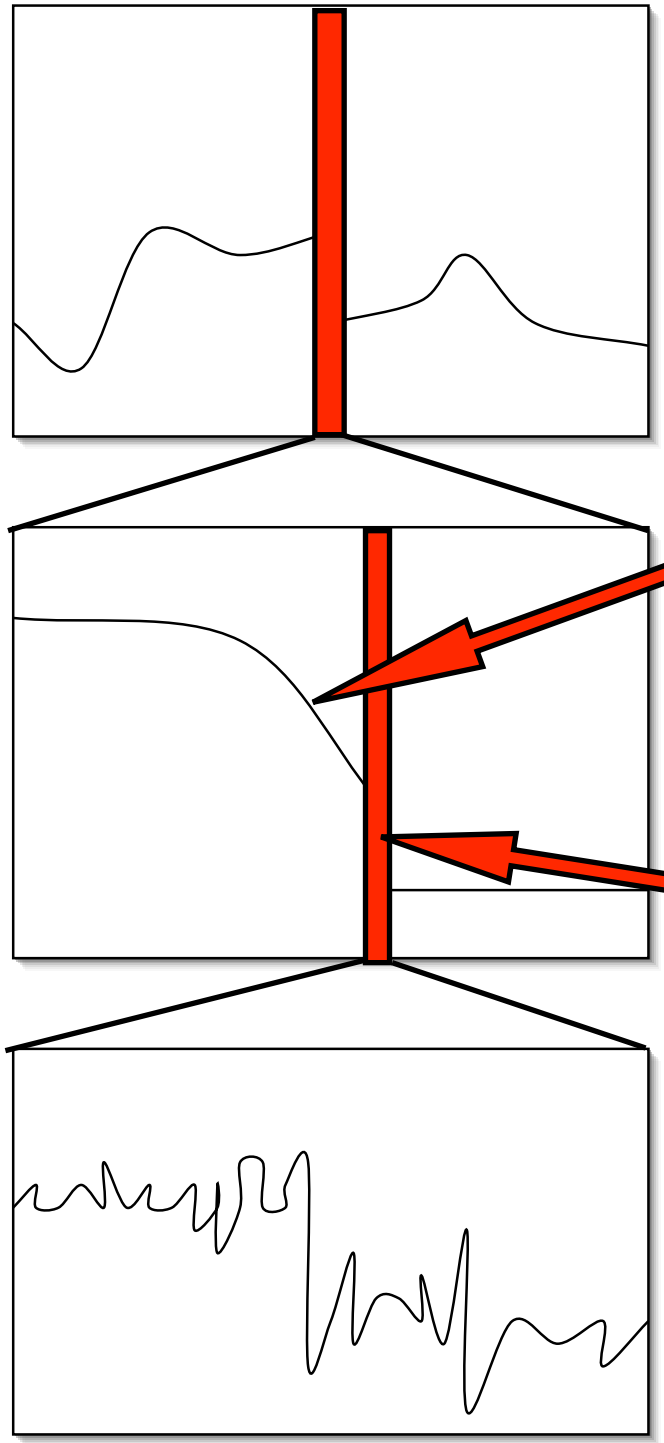
Power-law over five or six decades with no obvious feature => scale independent acceleration process.

Shock acceleration is essentially only theory going (pulsars, reconnection remain possibilities, but no quantitative theory).

Nonlinear shock acceleration is almost certainly important.....



Outer scale
Astrophysics

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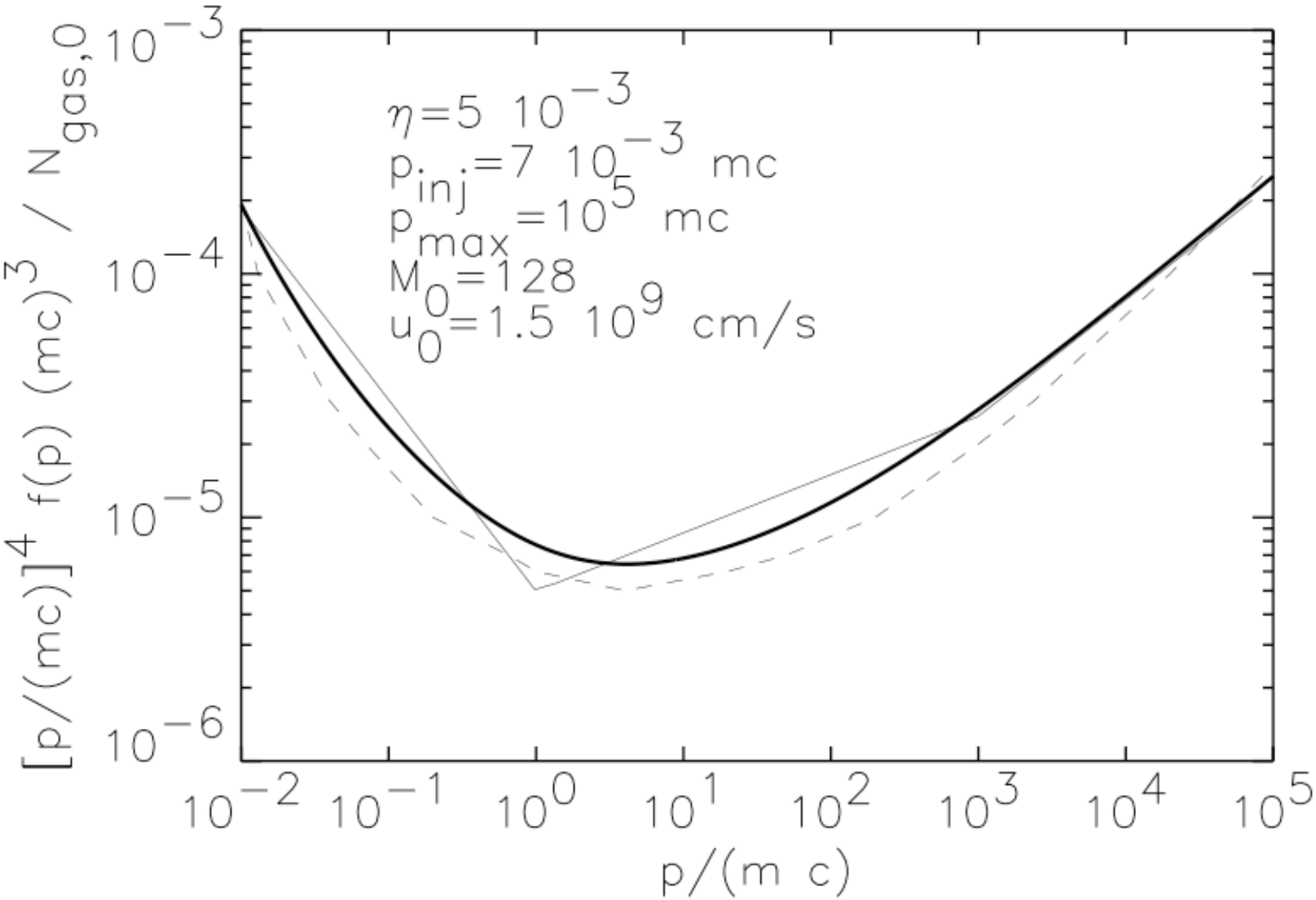
Intermediate scales
Shock acceleration theory

Inner scale
Plasma physics
Injection!



From P. Blasi, 2002

Strong "filtering" needed to throttle back injection from plasma collisionless shock structure to shock acceleration on intermediate scales => easier to inject high rigidity species => expect more heavy ions, very few electrons.

Composition

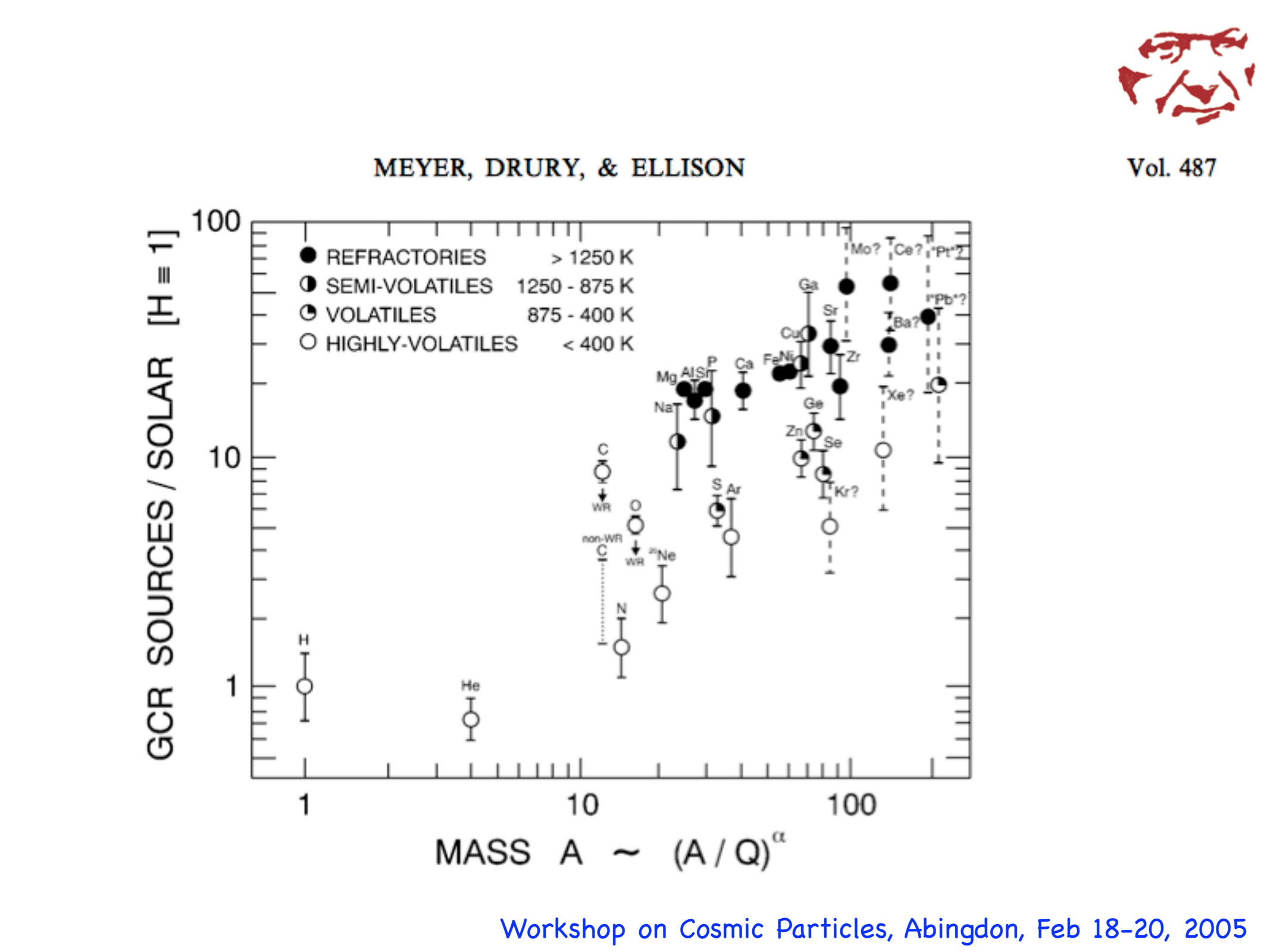
Very well determined at GeV/nucleon energies (even isotopic data in many cases - radioactive ages, K-capture)

Spectra of spallation secondaries =>

Energy dependent propagation

Harder source spectra

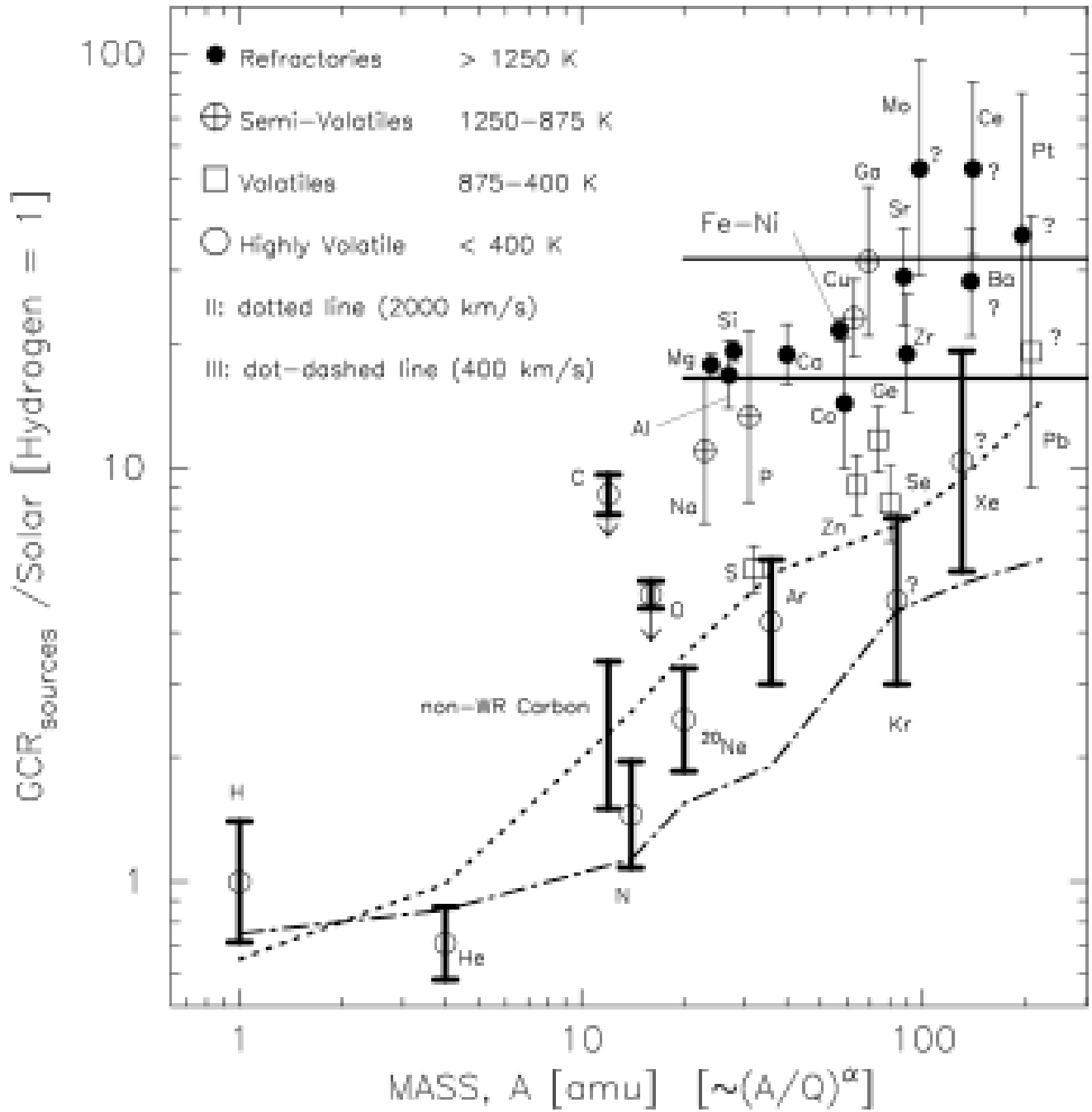
No such constraints at higher energies (but watch this space...).


MEYER, DRURY, & ELLISON
Vol. 487
REFRACTORIES > 1250 K
SEMI-VOLATILES 1250 - 875 K
VOLATILES 875 - 400 K
HIGHLY-VOLATILES < 400 K
GCR SOURCES / SOLAR [H ≡ 1]
MASS A ~ (A / Q)^α
100
10
1
1
10
100
H
He
C
WR
non-WR
C
O
WR
N
Ne
Na
Mg
Al
Si
P
S
Ar
Ca
Fe
Ni
Cu
Ga
Ge
Zn
Se
Kr?
Sr
Zr
Mo?
Ba?
Ce?
Xe?
Pt?
Pb?

Heavy elements are over-abundant, but not obviously any simple A/Q effect.

But in ISM Fe, Ca, Al, Si etc are almost entirely in the form of dust grains....

Small dust grains behave like very heavy ions when charged...



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Isotropy

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CRs below the "knee" are isotropic to about 10^{-4}

=> much scattering by magnetic fields

=> large confinement volume

=> no nearby active sources

=> multiple sources

Spatial distribution

GeV gamma-ray data from EGRET => rather smooth distribution of CRs throughout the Galactic disc. Possibly too smooth and extended (but comes back to propagation models...). Probably related to extreme isotropy...

All indirect evidence, but shock acceleration in SNRs looks like best bet for the GCRs below the "knee".

What about direct evidence?

Radio synchrotron => electron acceleration to GeV energies

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Astron. Astrophys. 287, 959–971 (1994)

The gamma-ray visibility of supernova remnants. A test of cosmic ray origin

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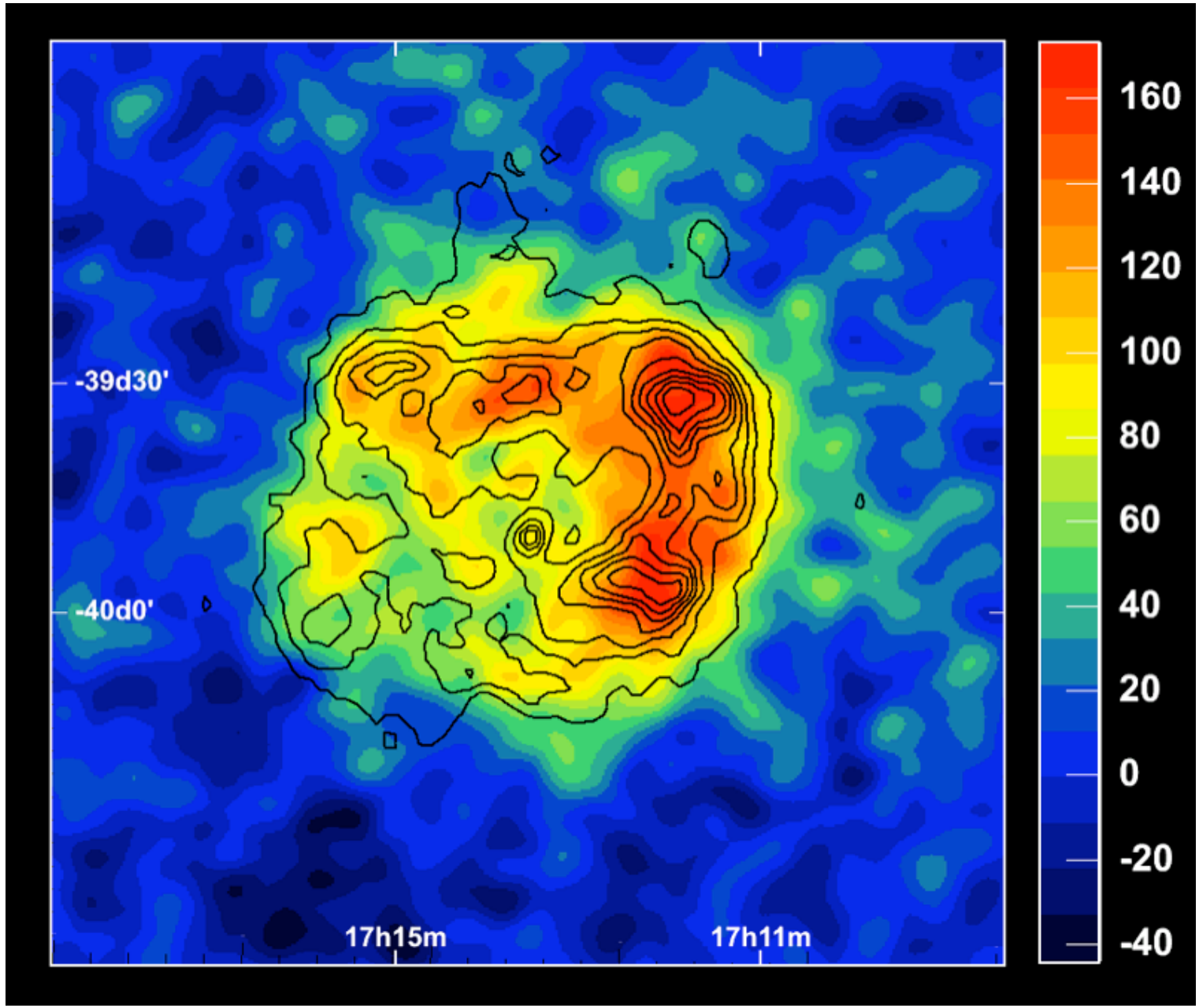

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Spectrum is close to E^{-2} from 1 to 10 TeV.

Very good correlation between X-rays and TeV emission (surprisingly good!).

Unambiguous evidence for acceleration of charged particles to 10^{14} eV.

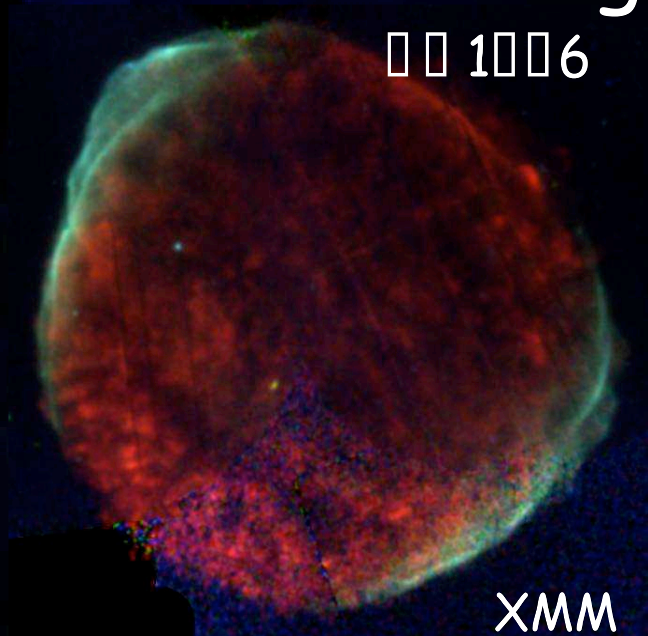
But could be just accelerated electrons..

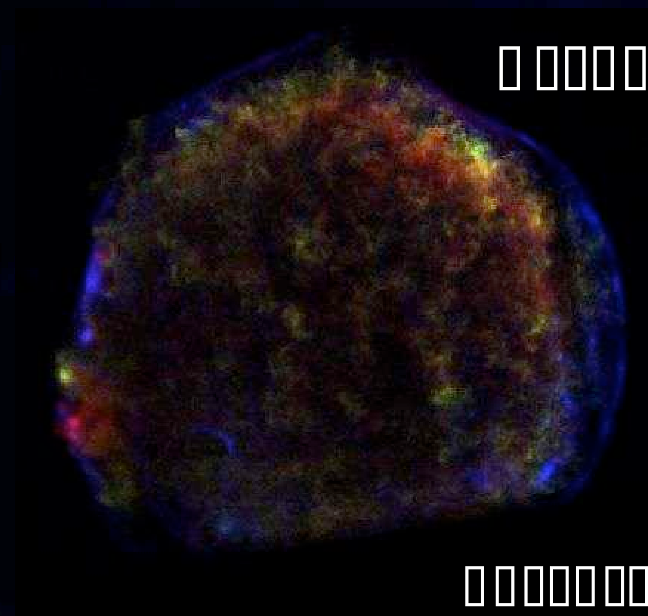
Another cosmic conspiracy - 10^{14}eV electrons IC scattering the CMB make gammas at 10^{13}eV and 10^{14}eV protons also make gammas at the same energy by neutral pion production.

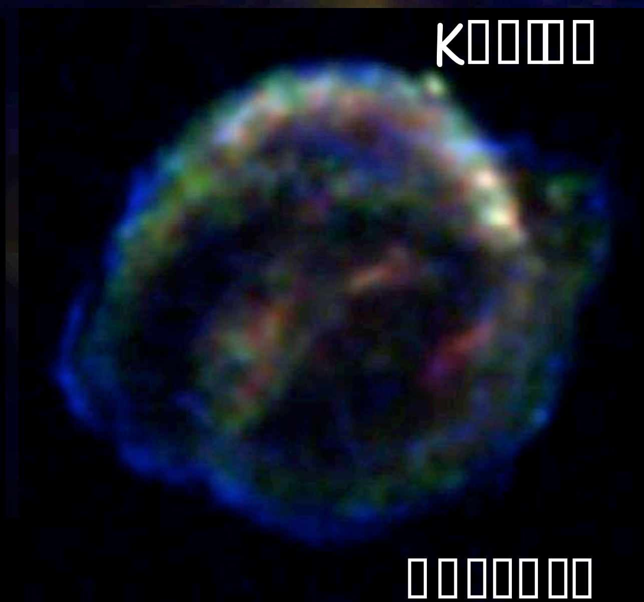
Crucially depends on the magnetic fields.

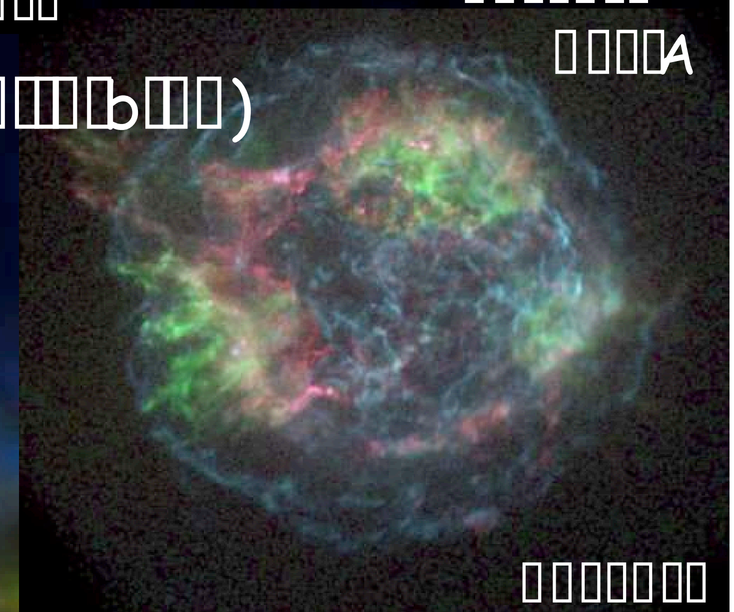
Growing evidence for substantially enhanced fields in young SNRs

Generally favours hadronic models, but jury is still out.


XMM







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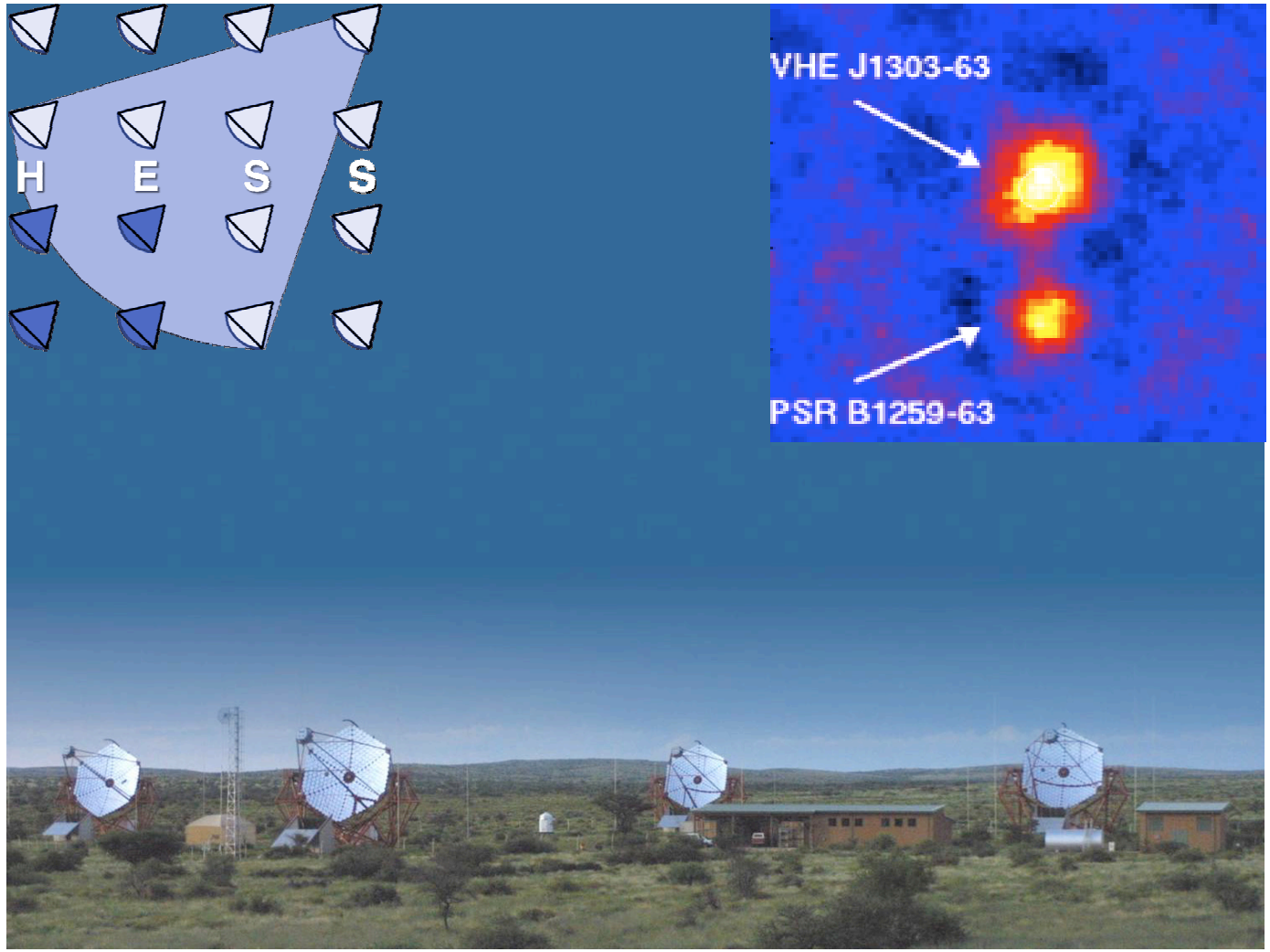
Sharp narrow rims seen in non-thermal X-rays are most easily explained by rapid synchrotron cooling of electrons in strong magnetic field of order 0.1mG

If fields are 30-100 times larger than standard ISM fields, can accelerate protons to 30-100 times higher energies.

Possible evidence for Bell-Lucek process?

Conclusions

Shock acceleration in SNRs with some magnetic field amplification seems to be able to explain almost all observations of CRs below the "knee" - but there are the HESS unidentified sources also!



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Ex Africa semper aliquid novi.

"There are always new things to be found in Africa",
Pliny the elder.