Probing Cosmic Accelerators

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What would we like to learn from CTA? (about cosmic accelerators)

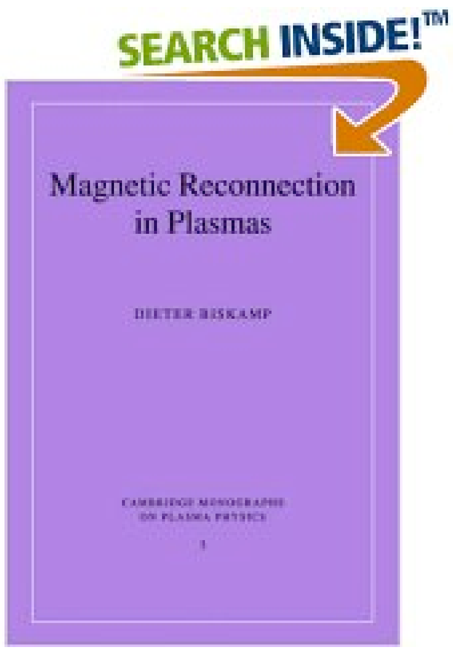
- Is it always shock acceleration?
- Are the cut-offs as expected?
- Do we see non-linear effects?
- Ion/electron ratio, injection rates etc?

Other acceleration mechanisms?

Shock acceleration is the "standard model" but there are other possibilities.....

- Magnetic reconnection.
- Shear acceleration in relativistic flows.
- 2nd order Fermi (turbulence).
- Direct electric fields (eg perhaps in pulsar magnetospheres).

Reconnection



- Observed in Earth's magnetotail
- Thought to drive solar flares
- Seen in laboratory plasmas
- But no good theory and not very efficient

Shear acceleration

- Acceleration from repeated crossings of a shear layer.
- Only likely to be relevant at edges of relativistic jets.
- But always have shocks as well, so difficult to distinguish....

(See Rieger and Duffy, astro-ph/0610187)

Classical Fermi

- Must occur, but usually very slow
- Basically just diffusion in momentum space
- Driven by bulk turbulence
- NB an ensemble of weak shocks produces an almost identical effect....

Direct E fields

- Requires breakdown of the MHD conditions.
- Auroral electrons.
- Pulsar magnetospheres.
- As part of reconnection process.

Cut-offs as expected?

- Magnetic field amplification?
- Produce the “knee”?
- Suppression by wave damping?

Cesarsky Lagage limit

- Maximum energy is given by finite age or size of shock
- Around $10^{14}\,\mathrm{eV}$ for conventional SNR parameters
- Uncomfortably low....
- Key parameter is magnetic field strength

$$t > t_{\mathrm{acc}} \approx 10\frac{\kappa}{U^2}$$

$$R \gg \frac{\kappa}{U}$$

$$\kappa \propto B/E \quad \Rightarrow \quad E_{\max} \approx BUR$$

Difficult to do much with R or U, so have to increase B if we want to get significantly higher energies....

Field amplification by mesoscale instabilities!

Very sharp and narrow nonthermal X-ray rims observed in essentially all young SNRs

→ Suggests strong magnetic fields generated at high Mach number collisionless shocks

→ Strong mesoscale instabilities driven by accelerated particles!

The Instability Zoo

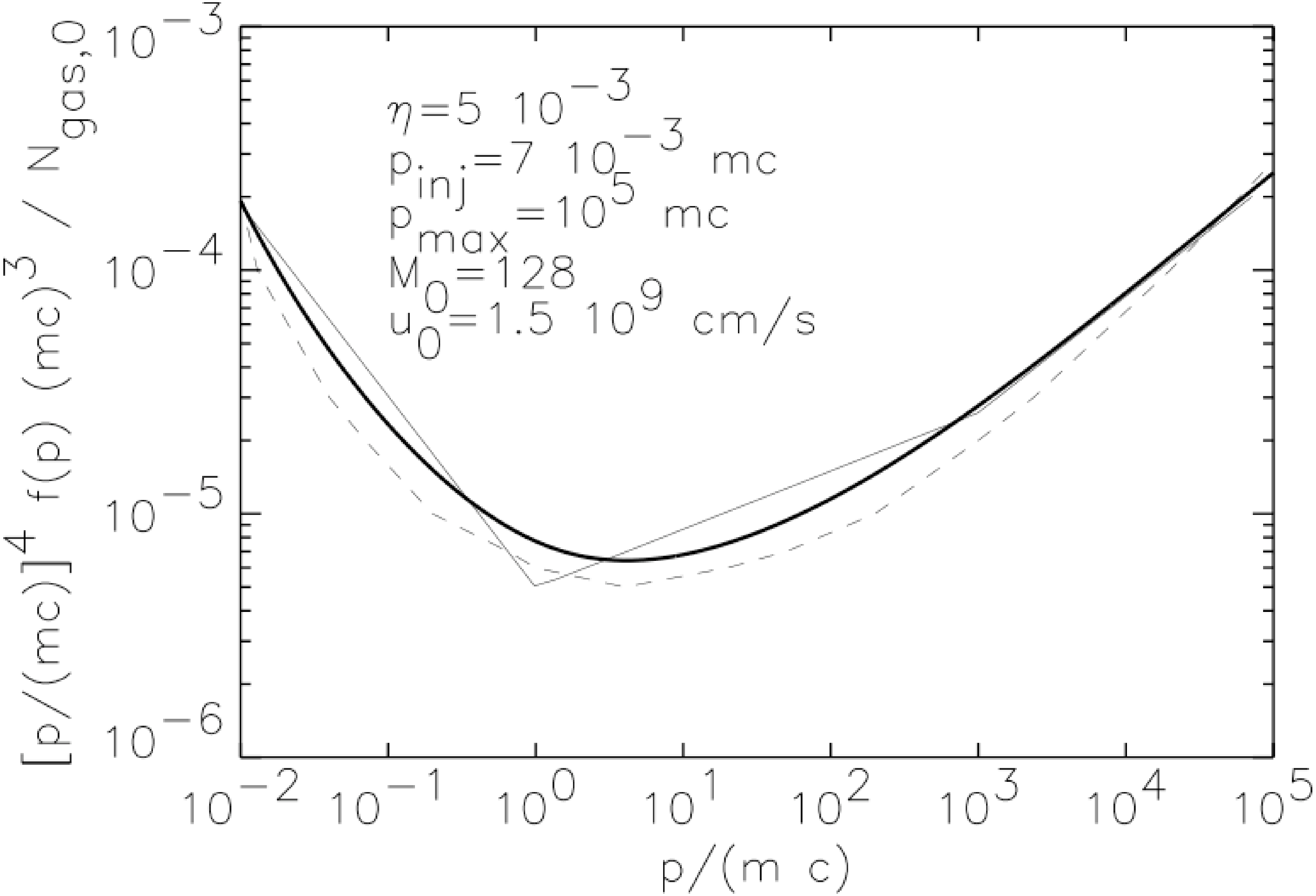
- Acoustic instability (Drury and Falle, 1986)
- Parker instability (1966, 1967)
- McKenzie and Voelk, 1981 - wave heating or "plastic deformation of field".
- Bell and Lucek, 2000, 2001; Bell 2004, 2005
- Generic Weibel-type instabilities

- Strong observational indications of amplified fields in young SNRs
- Allows acceleration of protons to “knee region” (testable with CTA)
- Indirect, but powerful, evidence of efficient shock acceleration!

- Ion-neutral damping can suppress some of the instabilities
- May lead to lower cut-offs in dense regions?
- From point of view of CTA important point is that a number of physical processes can affect the location and shape of upper energy cut-offs.
- Where are the "knee" sources?

Non-linear effects?

- Should be able to see spectral curvature
- Would allow direct estimate of acceleration efficiency
- Important implications for bulk dynamics, shock compression ratios etc....

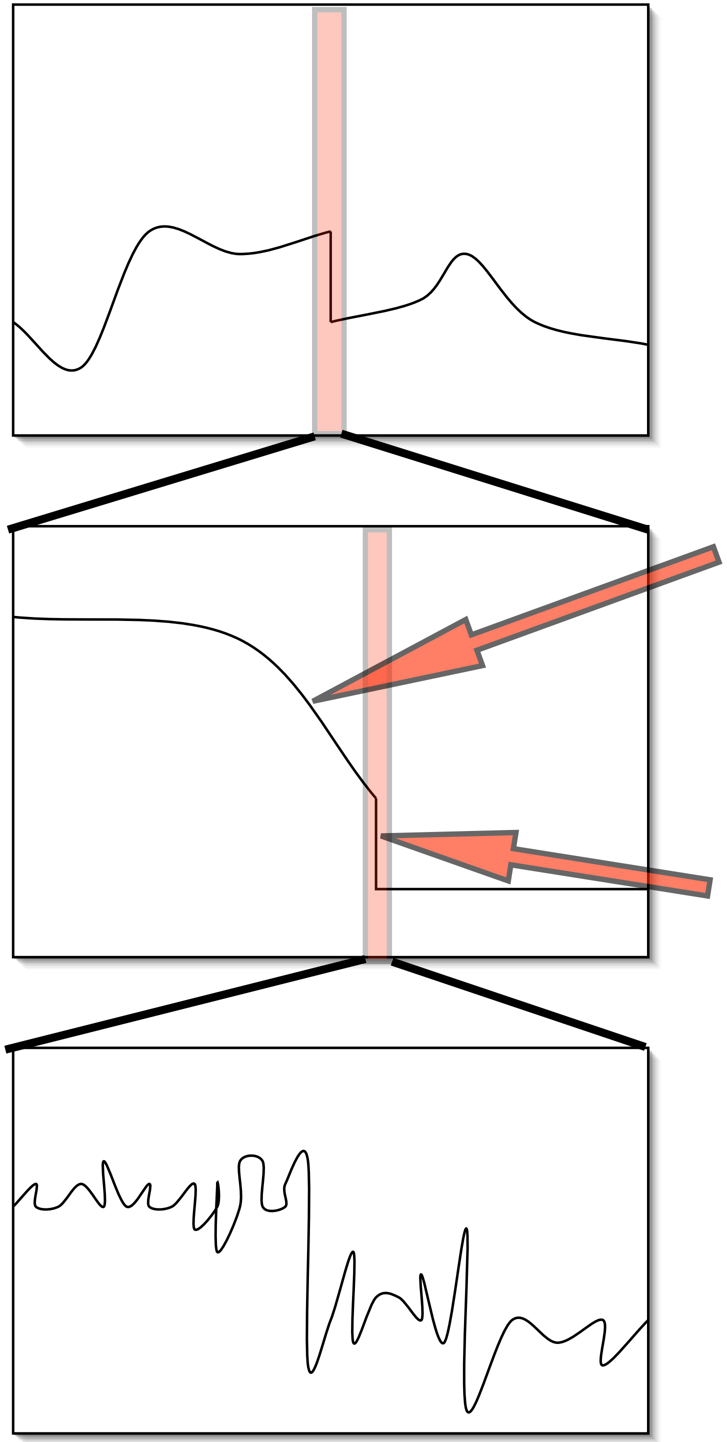


From P. Blasi, 2002

- Reasonably well understood theoretically (but on assumption of quasi-steady shock structure!)
- Still no indisputable observational evidence for non-linear effects.
- Has very important implications for interpretation of X-ray data

Injection

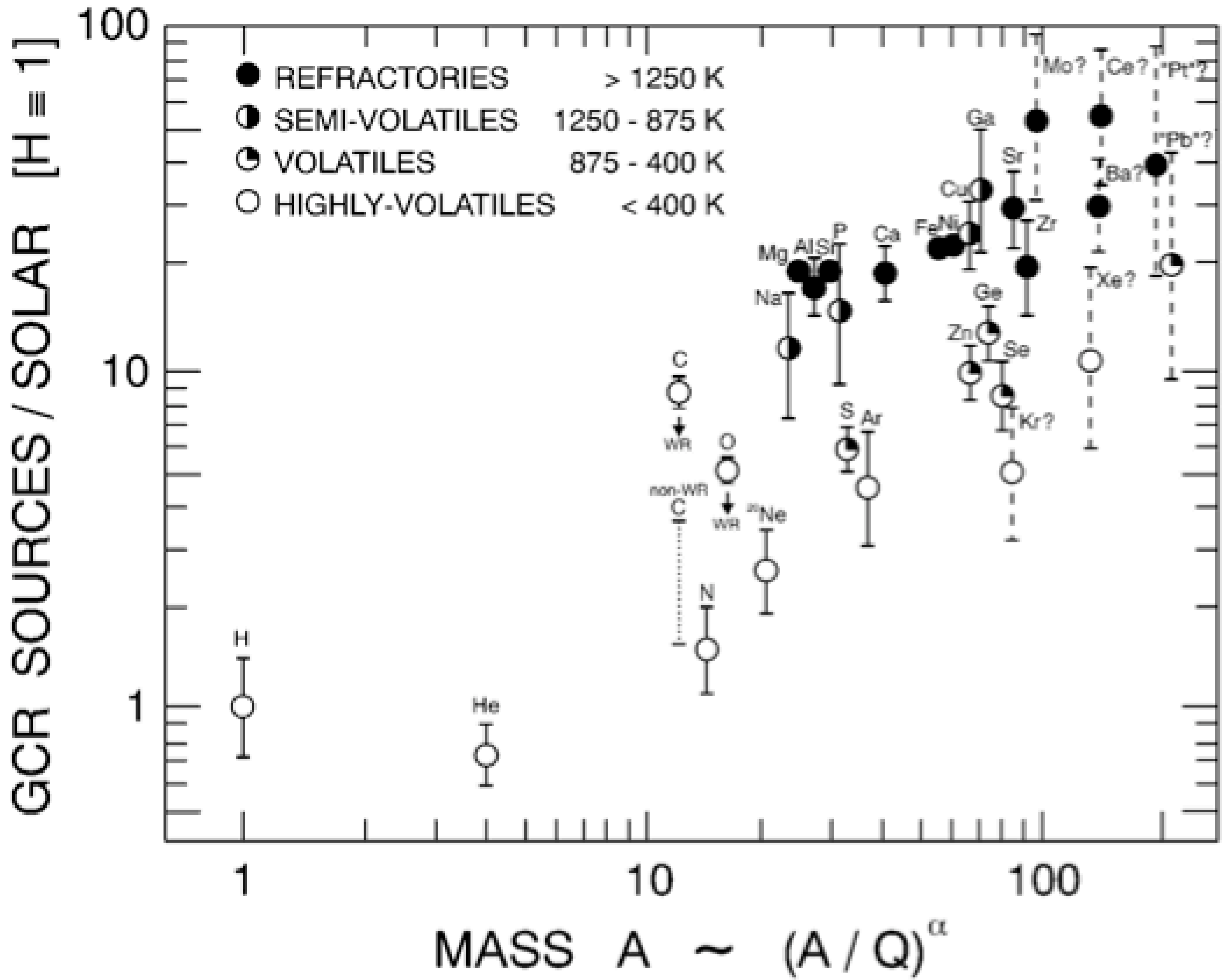
- Chemical composition of the GCRs?
- Electron/proton ratio?
- Possibly pure proton accelerators?

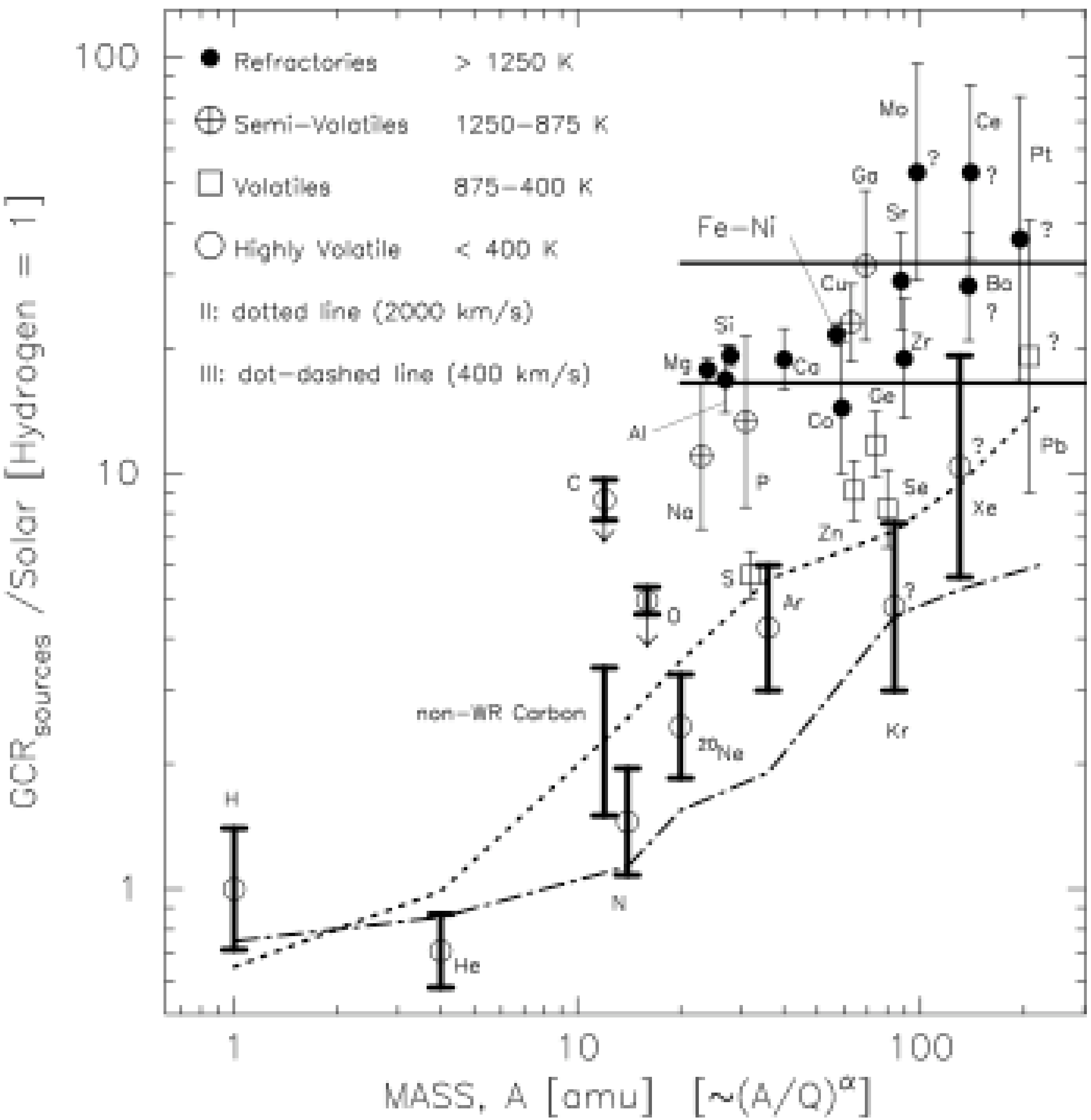


Outer scale
Astrophysics

Intermediate scales
Shock acceleration theory

Inner scale
Plasma physics
Injection!


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
H
He
C
WR
non-WR C
N
O
WR
Ne
Na
Mg
Al
Si
P
S
Ar
Ca
Fe
Ni
Cu
Zn
Ga
Ge
Se
Kr?
Sr
Zr
Mo?
Xe?
Ba?
Ce?
"Pt"?
"Pb"?
1
10
100


Refractories > 1250 K
Semi-Volatiles 1250–875 K
Volatiles 875–400 K
Highly Volatile < 400 K
II: dotted line (2000 km/s)
III: dot-dashed line (400 km/s)
Fe–Ni
non-WR Carbon
GCR$_{sources}$ /Solar [Hydrogen = 1]
MASS, A [amu] [~(A/Q)$^{\alpha}$]

- Injection should favour “heavy” ions
- Electron injection not well understood
- Are there shocks which are almost pure ion accelerators?
- Requires clean separation of IC and π^0 signals....not easy!

Conclusions

- Plenty of open questions about cosmic accelerators.
- Many of these can be addressed with CTA