the transition between galactic and extragalactic cosmic rays

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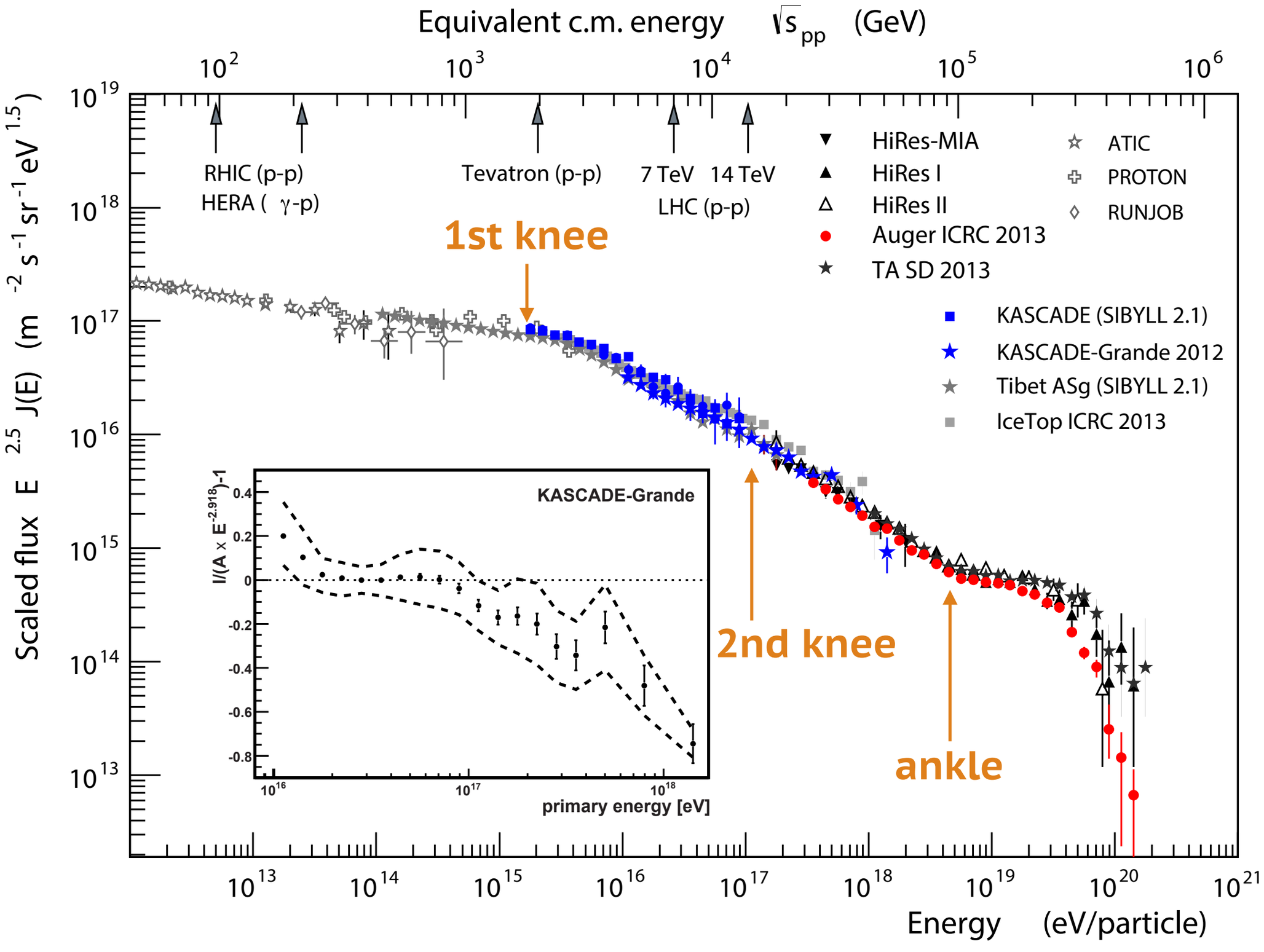
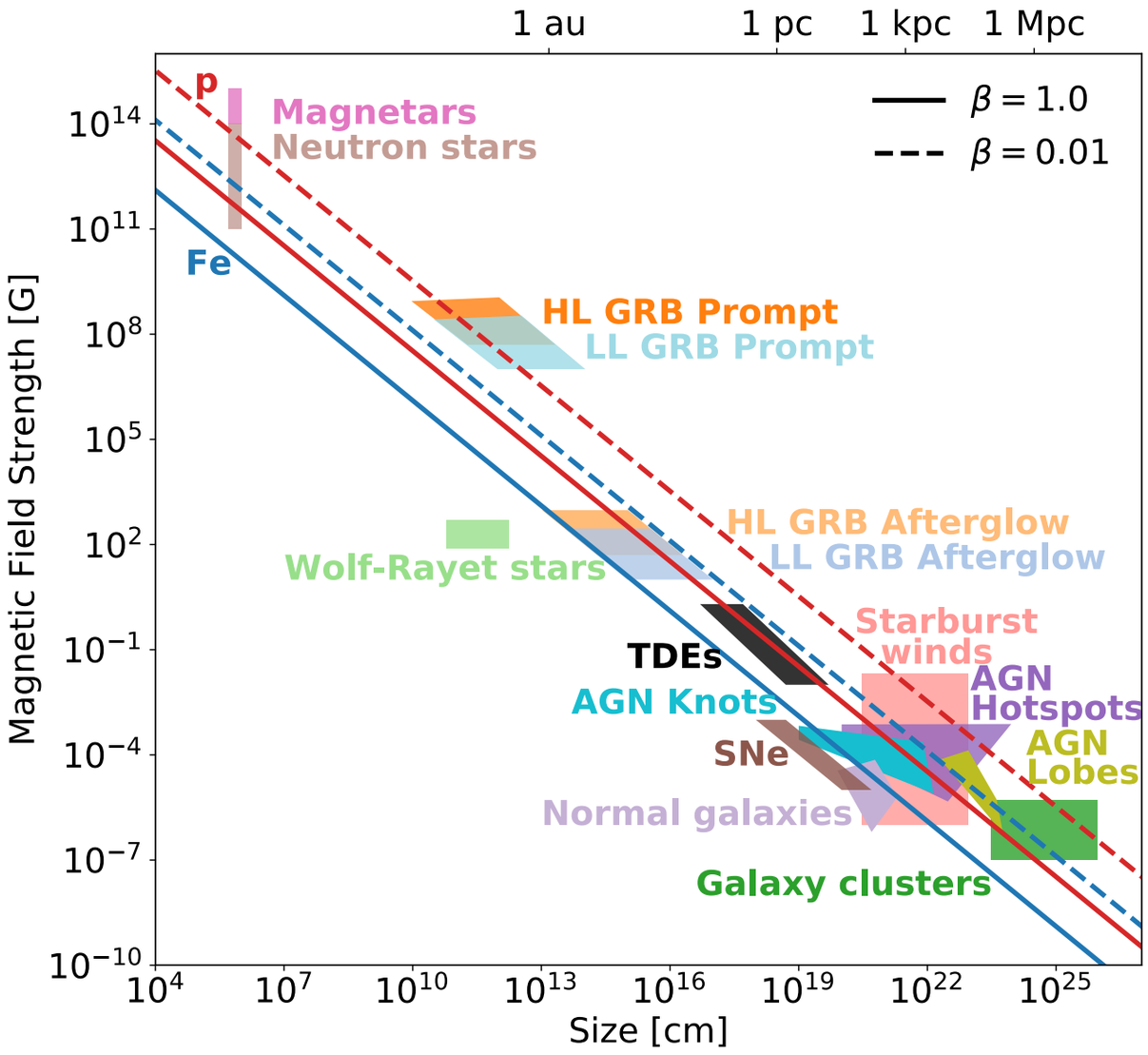
Karlsruhe

anatomy of the cosmic-ray spectrum



the Hillas condition



- the maximal attainable energy is given by :

$$E_{max} = Z\beta_{sh}EBR \sim 3Z\left(\frac{\beta_{sh}}{0.1}\right)\left(\frac{B}{\mu\text{G}}\right)\left(\frac{R}{10\text{ kpc}}\right)\text{ PeV}$$

- if $E > E_{max}$, the magnetic field can longer confine the CRs

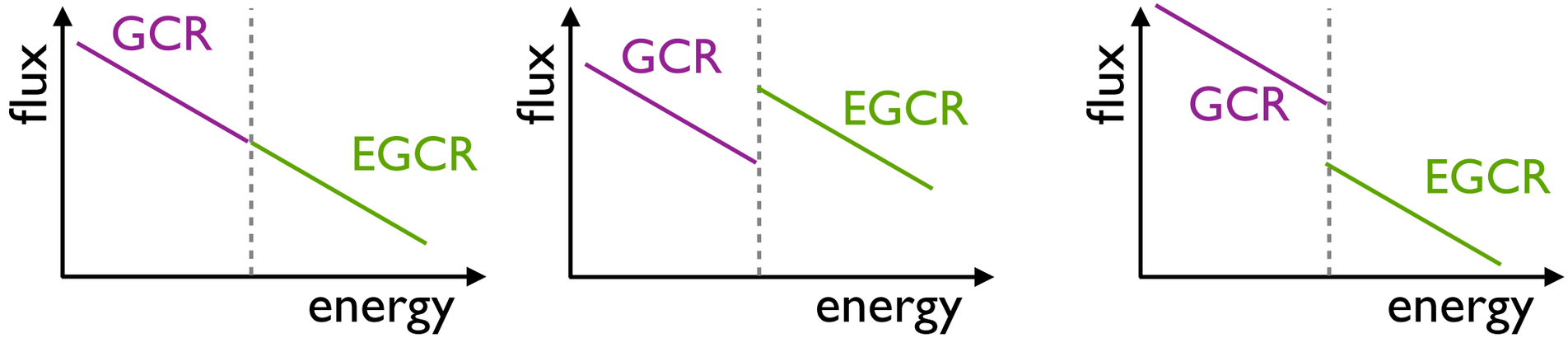
- if we adopt typical numbers for the galaxy, Emax~3 PeV for protons and 80 PeV for iron

~1st knee

~2nd knee

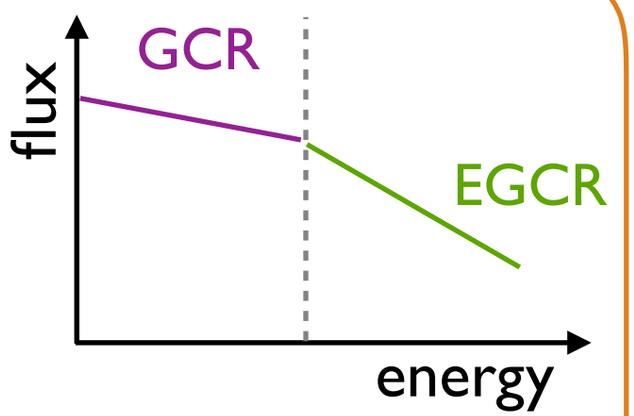
where is the GCR-EGCR transition?

same spectral indices



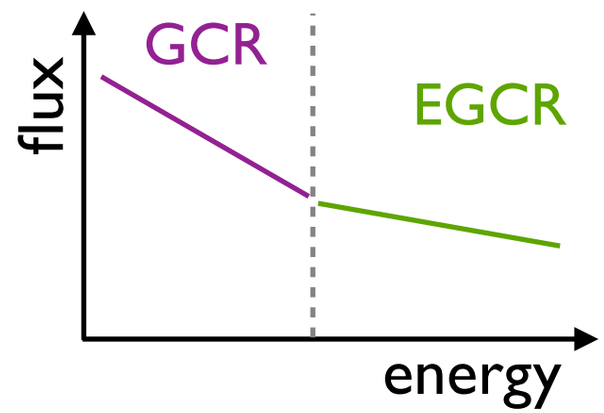
- second and third cases excluded by observations
- first case possible, but unlikely

spectral hardening



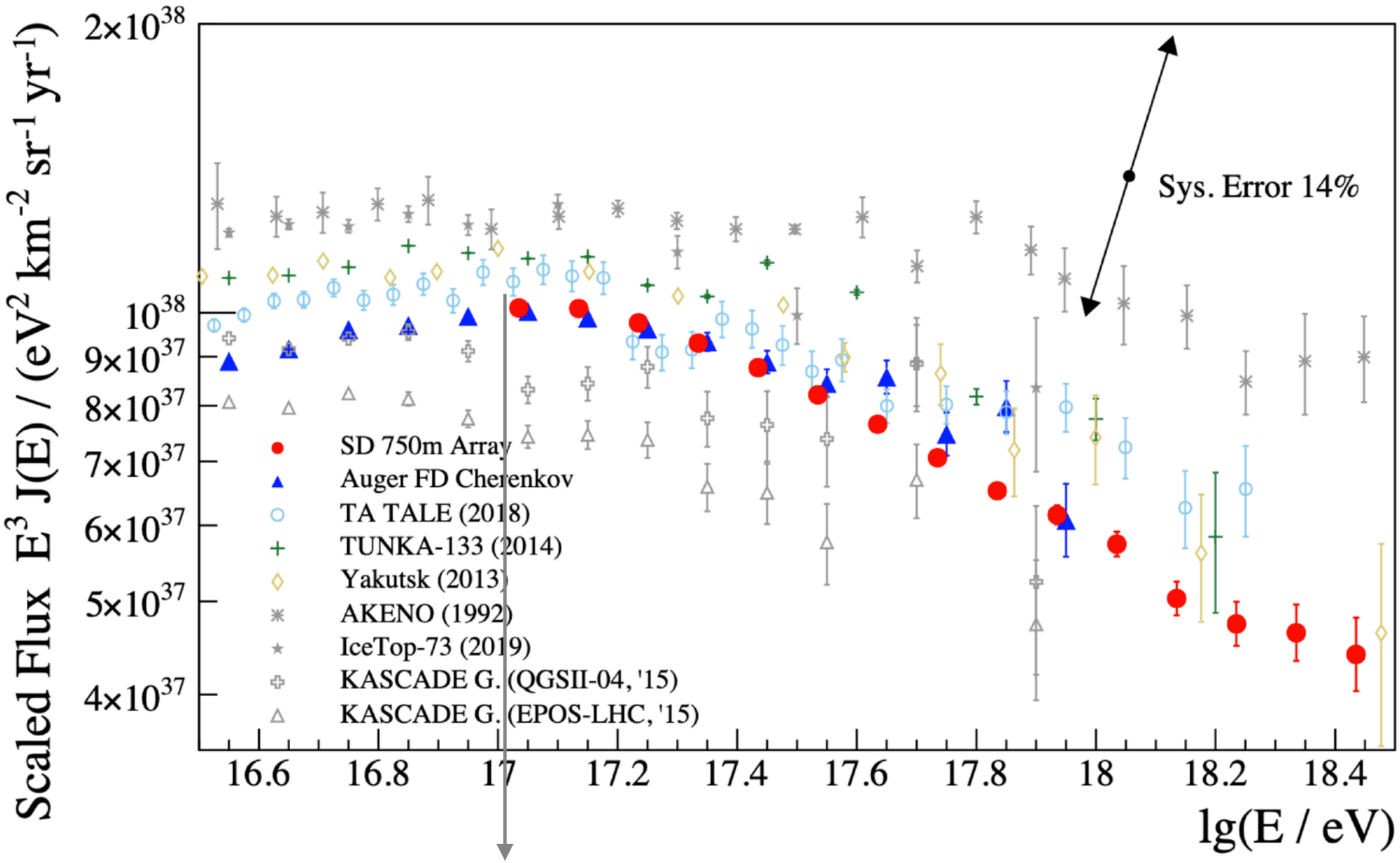
- unless the spectra match *exactly* at the transition, this is unlikely

spectral softening



- no problems, in principle

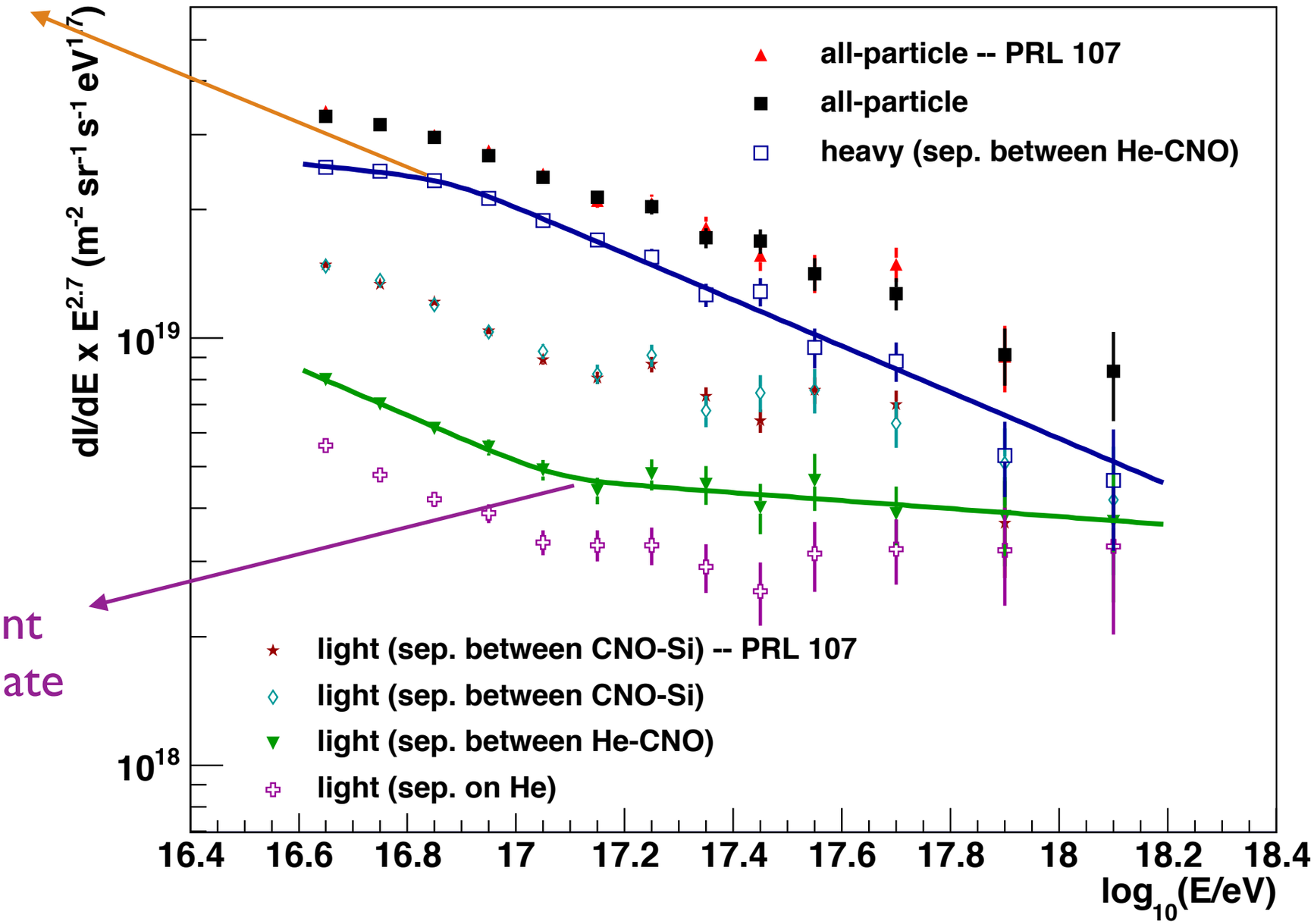
the spectrum around the transition region



need to separate the components

composition-dependent spectrum

suppression of the heavy component

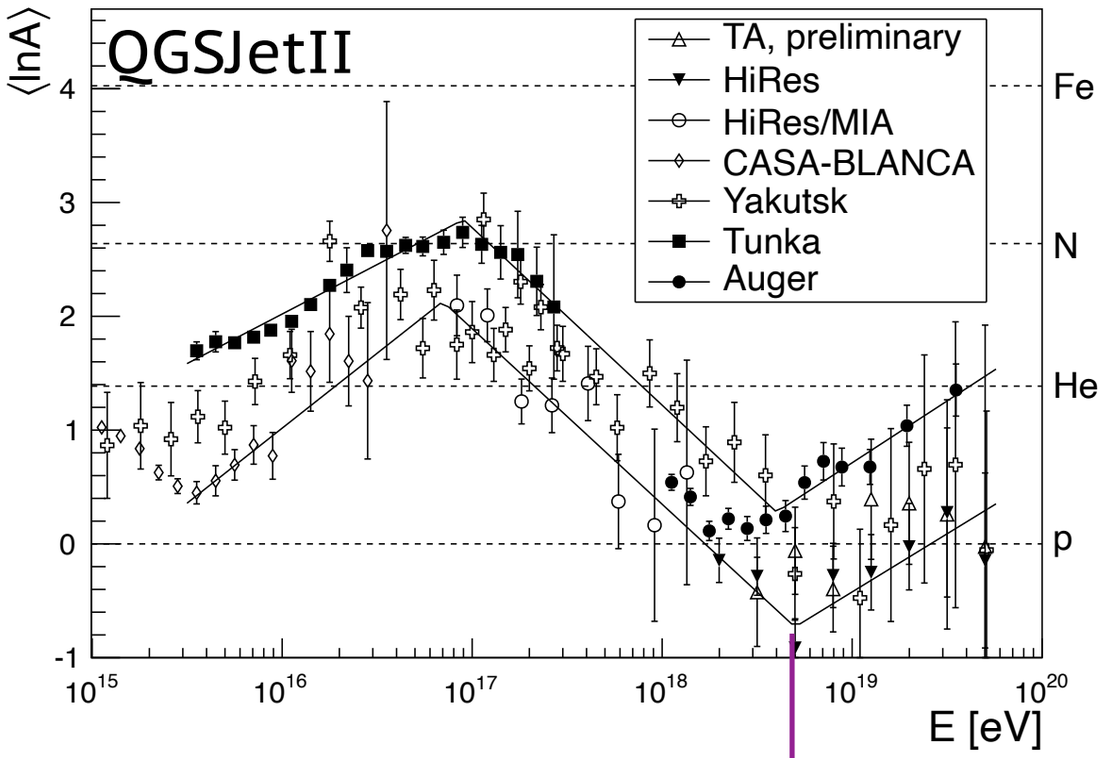


light component starts to dominate

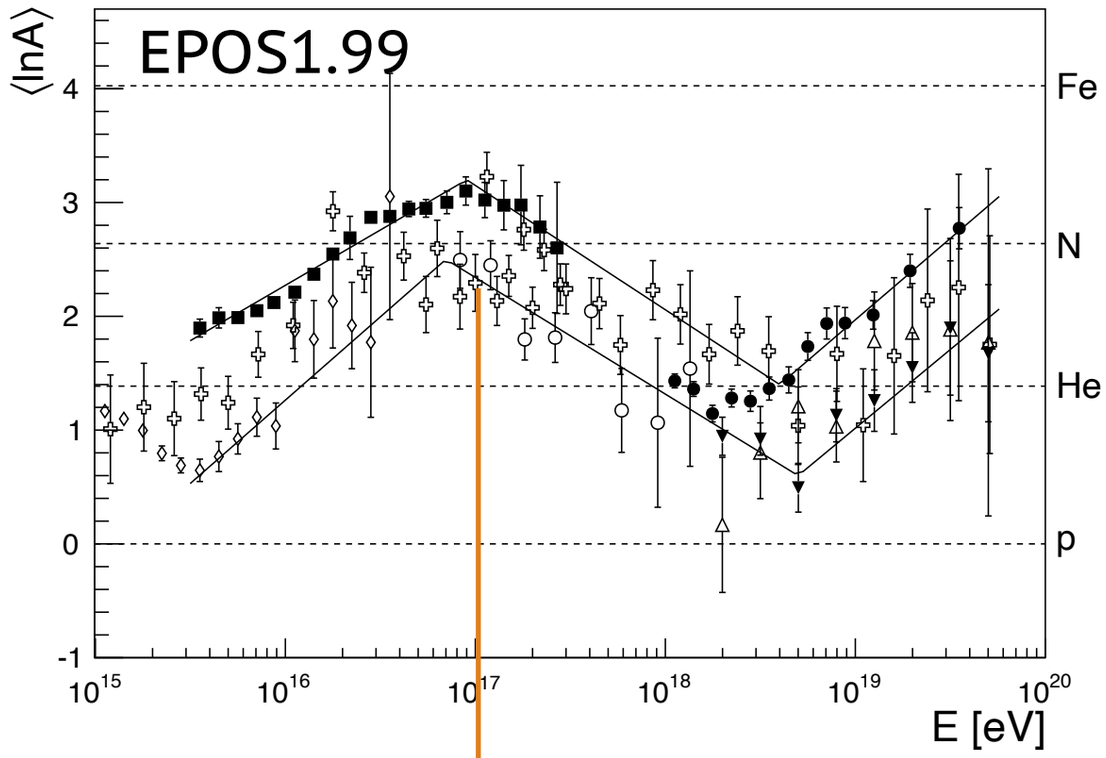
KASCADE-Grande Collaboration. Phys. Rev. D 87 (2013) 081101(R)

composition around the transition

Kampert & Unger. Astropart Phys. 35 (2012) 660.

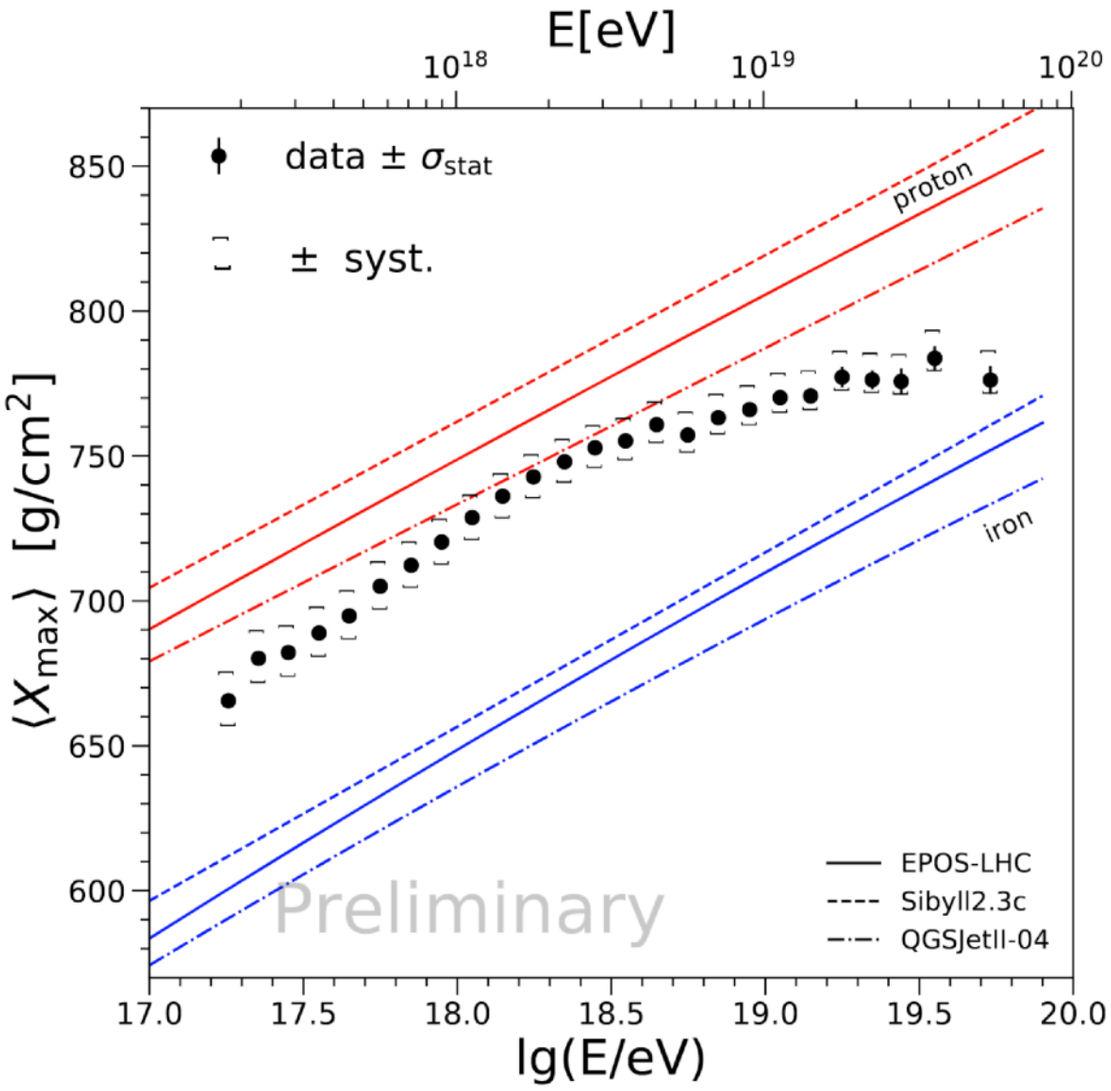


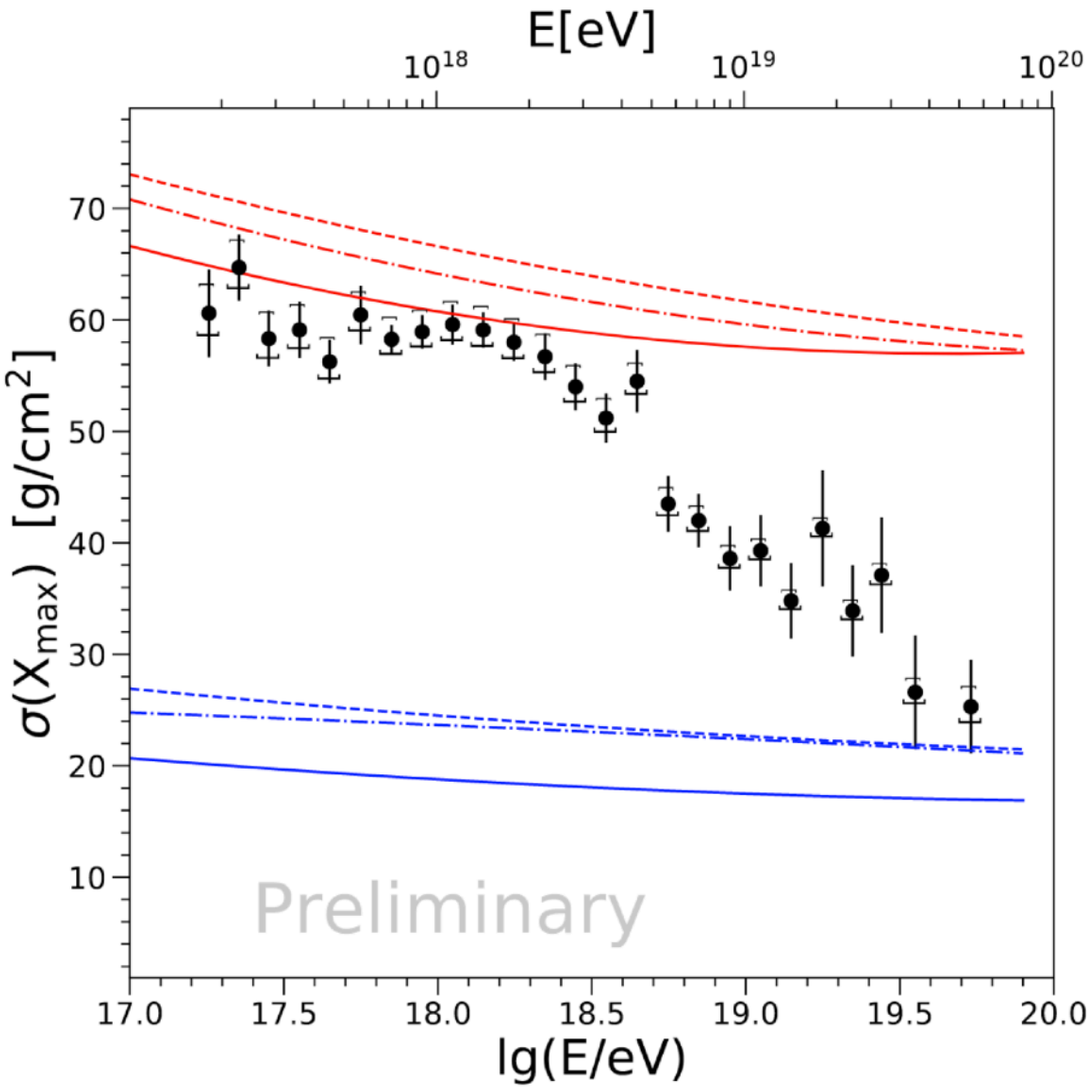
light (but mixed) composition around the ankle



heavy composition around the 2nd knee

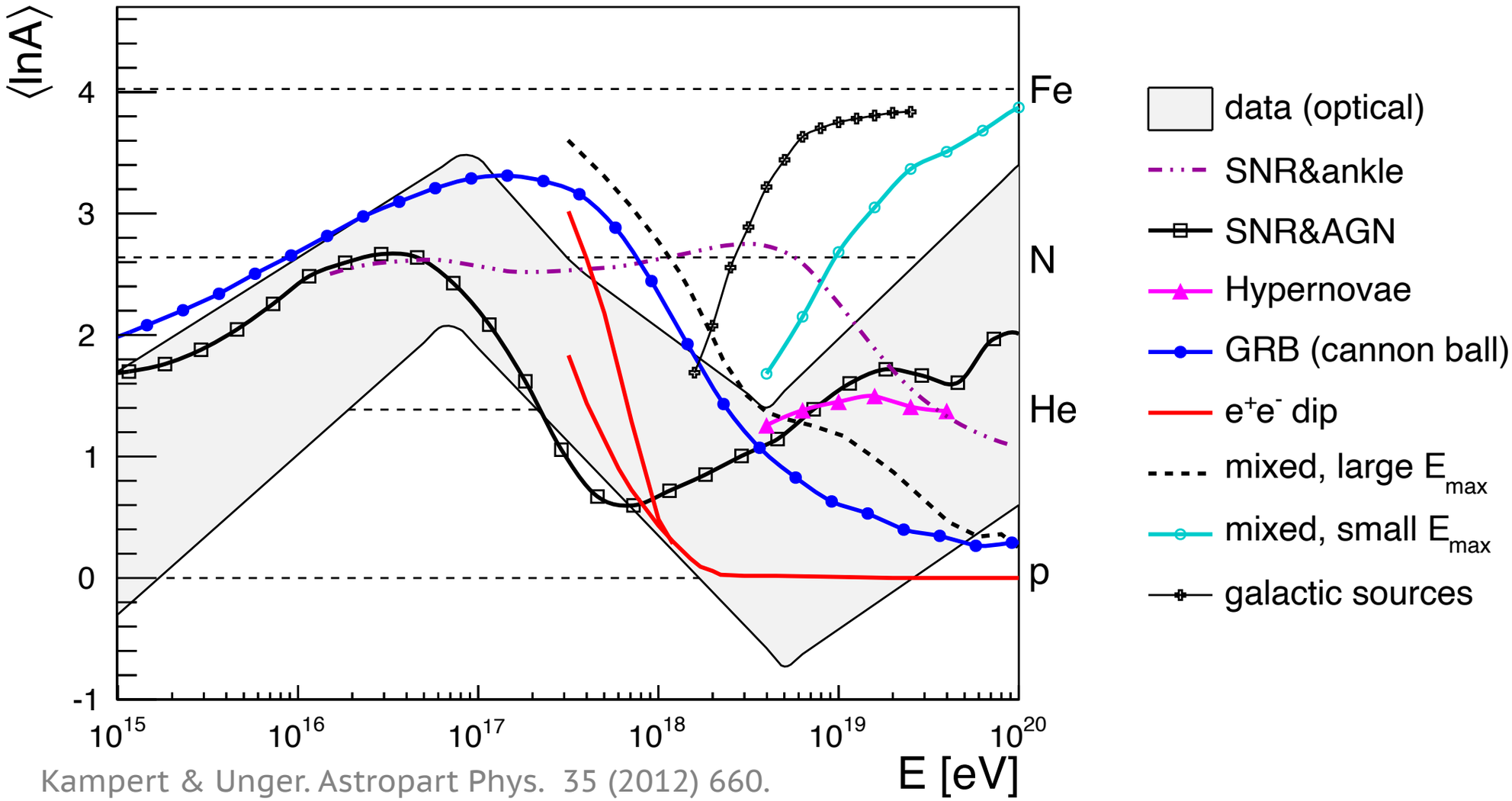
composition around the transition





Yushkov for the Pierre Auger Collaboration. PoS (ICRC2019)

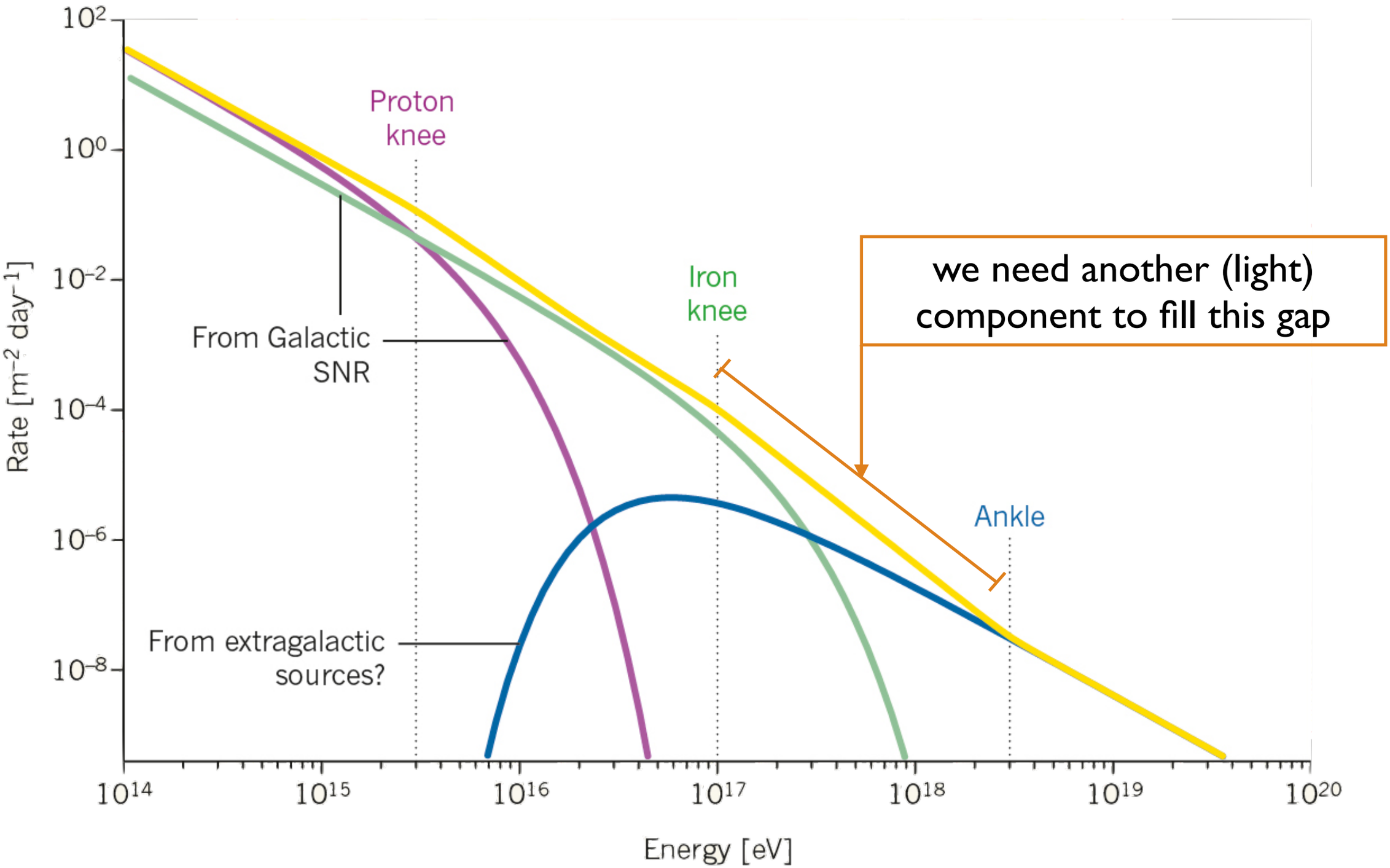
phenomenological models for the composition



Kampert & Unger. Astropart Phys. 35 (2012) 660.

- these can easily change if more effects are taken into account (magnetic fields, source distributions, etc)

the transition: three components?

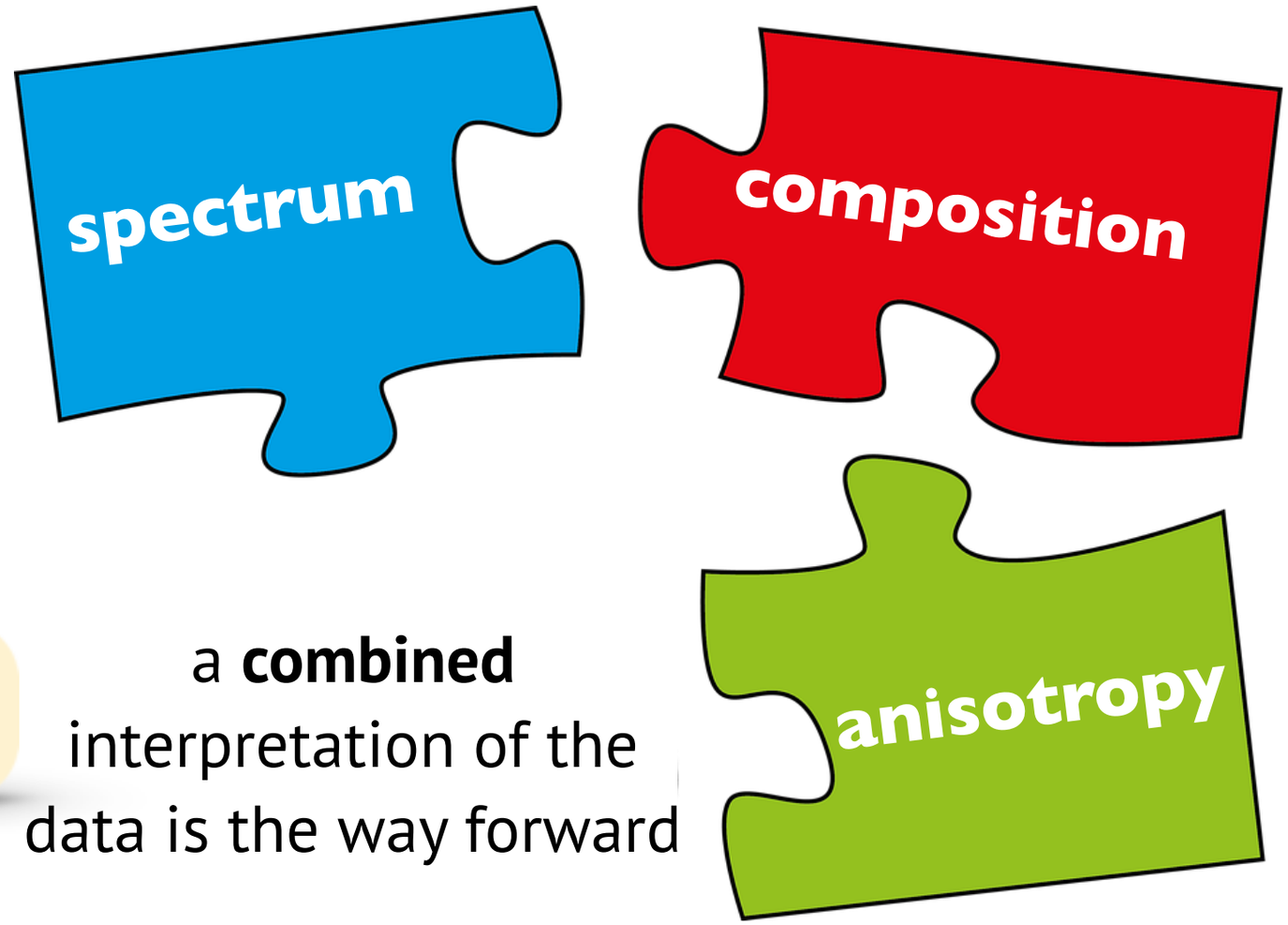


Alves Batista et al. Front. Astron. Space. Sci. D 6 (2019) 23.

the "natural" explanation of the transition

- 1st knee: end of galactic proton spectrum
- 2nd knee: end of galactic iron spectrum
- ankle: onset of the extragalactic component

What happens between the second knee and the ankle?



a **combined** interpretation of the data is the way forward

galactic EeVatron(s)

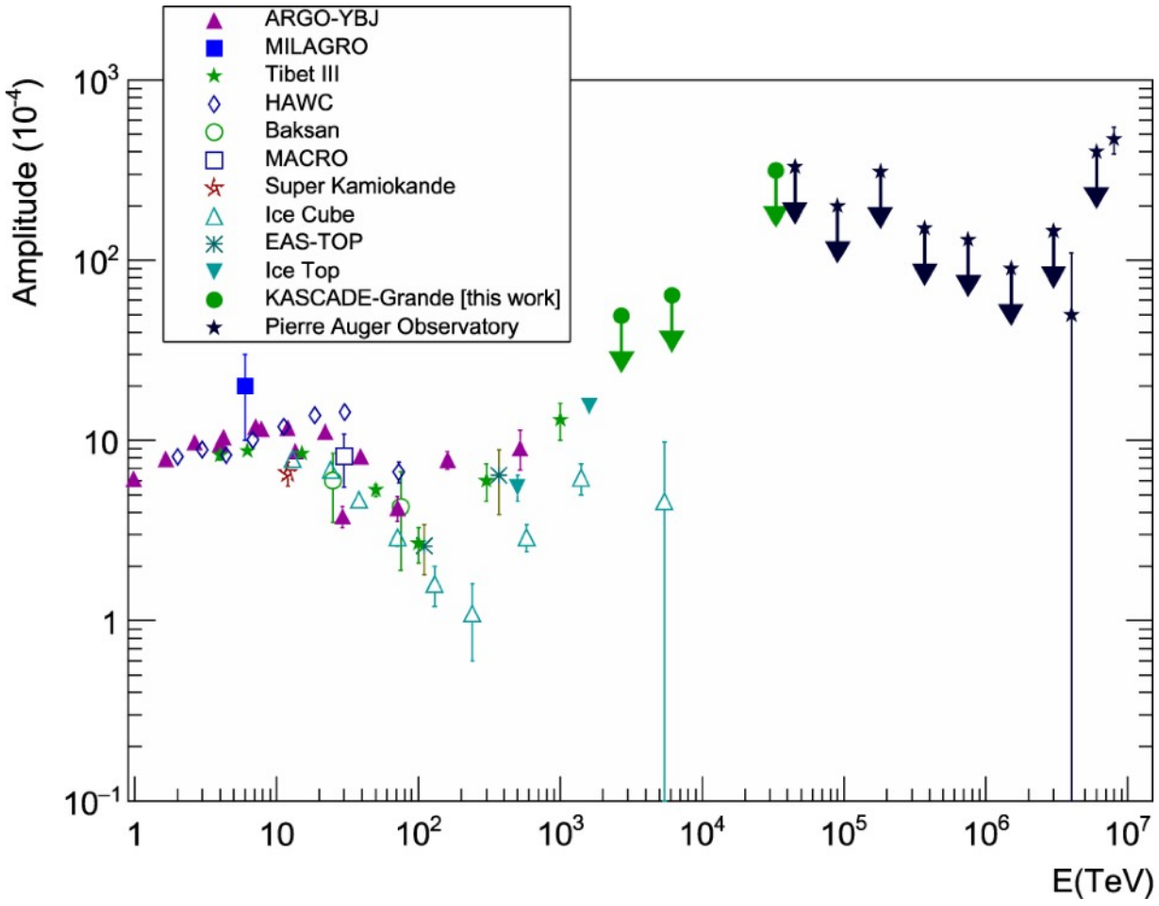
- theoretically difficult to get ~EeV energies from galactic sources
- may lead to strong anisotropies

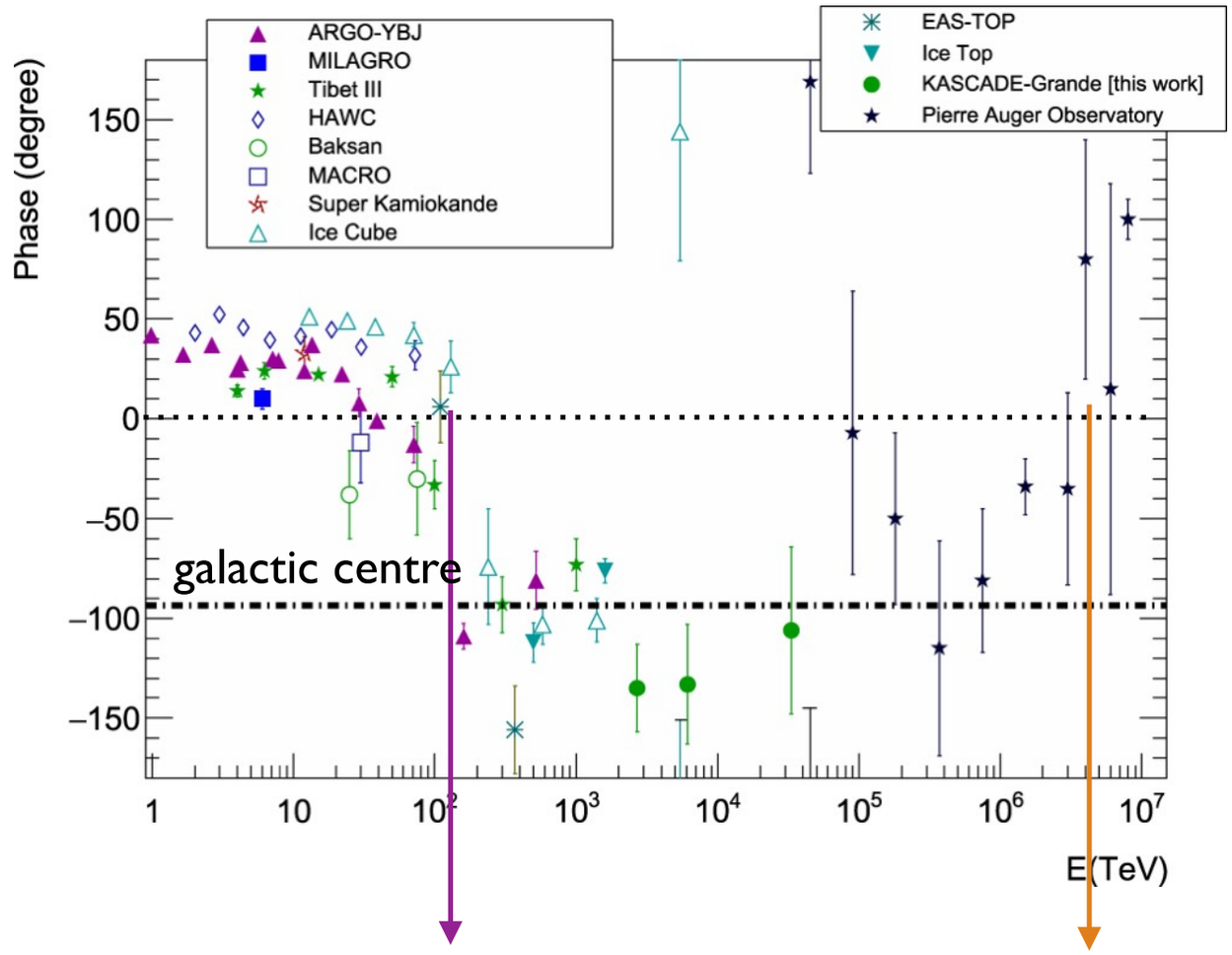
nearby extragalactic source(s)

- they need to accelerate light CRs → what would happen with the heavy component?

anisotropies around the transition

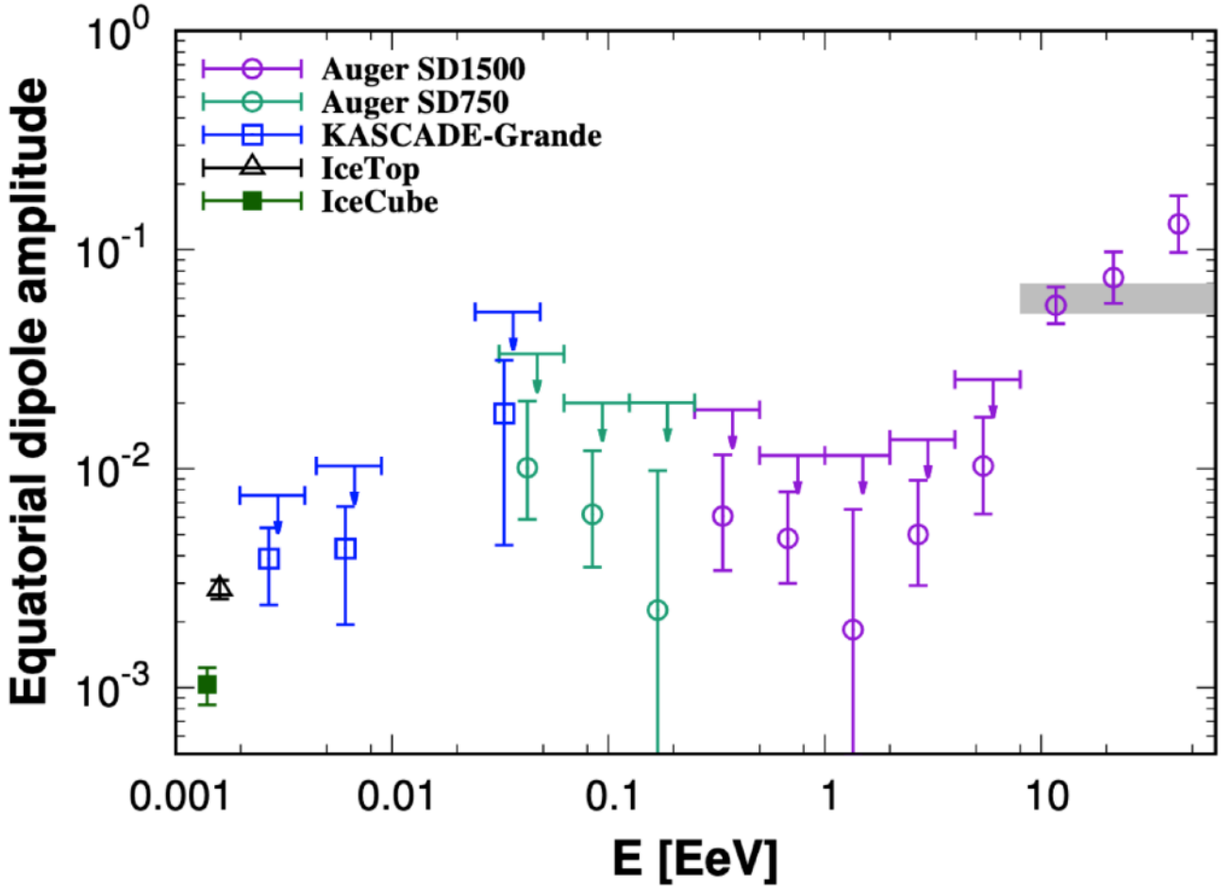
KASCADE-Grande. Astrophys. J. 870 (2019) 91.

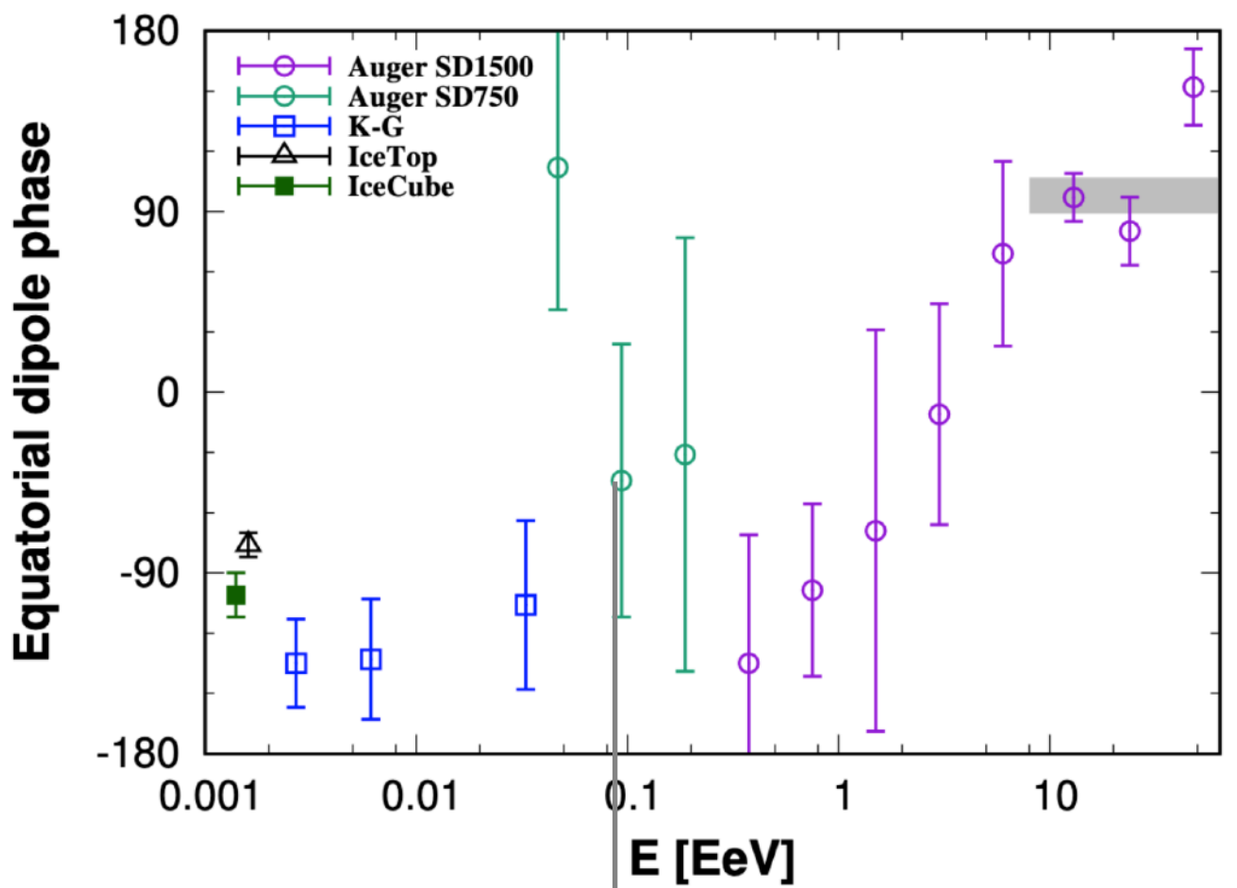




anisotropies around the transition

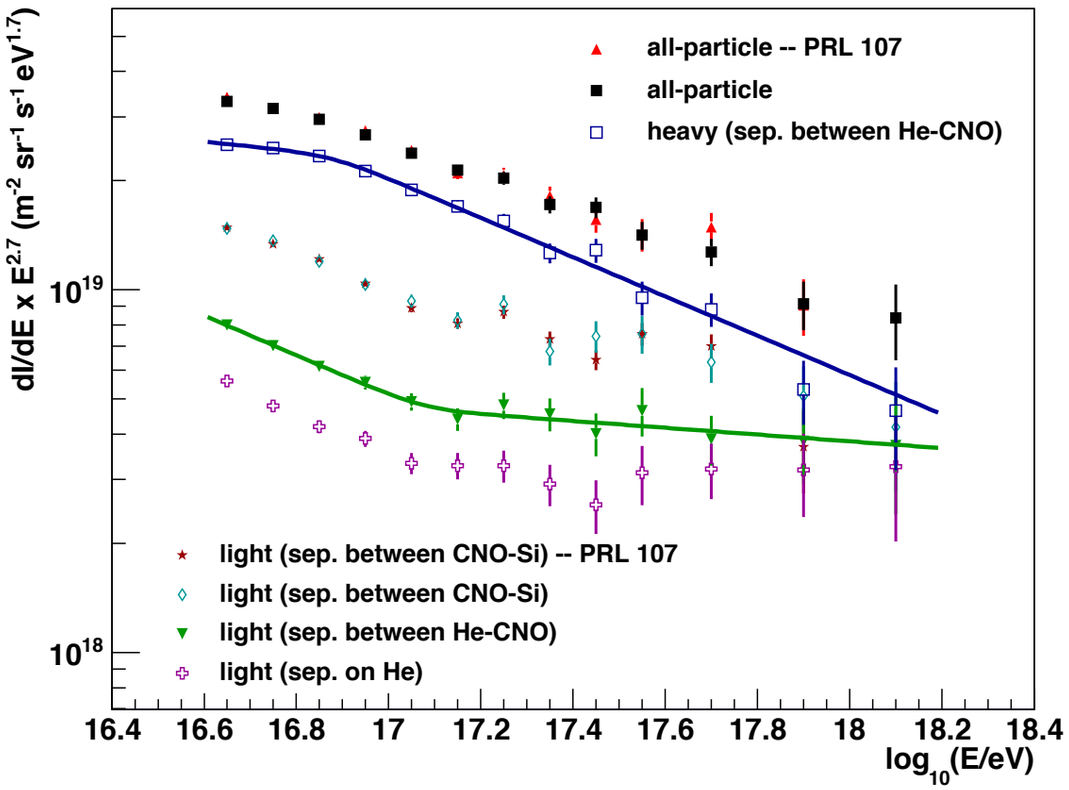
Roulet for the Pierre Auger Collaboration. PoS (ICRC2019) 408.





need more statistics!

at a glance



- need better X_{max} resolution to differentiate elemental groups (spectrum and composition)
- need more statistics around 10^{16} - 10^{18} eV (anisotropy)

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