Ultra-energetic nuclei propagation and the interpretation of the ankle

New views of the Universe

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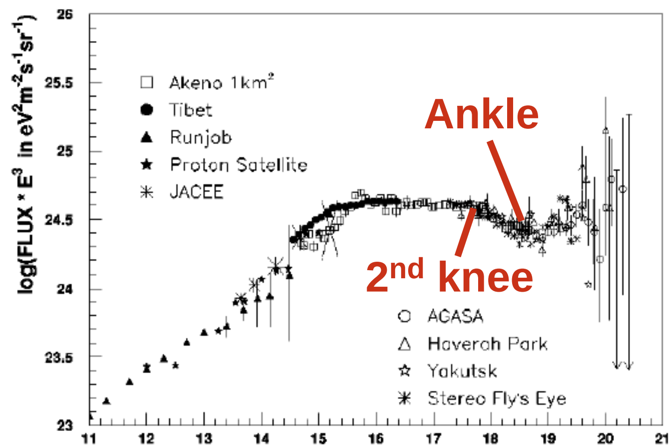
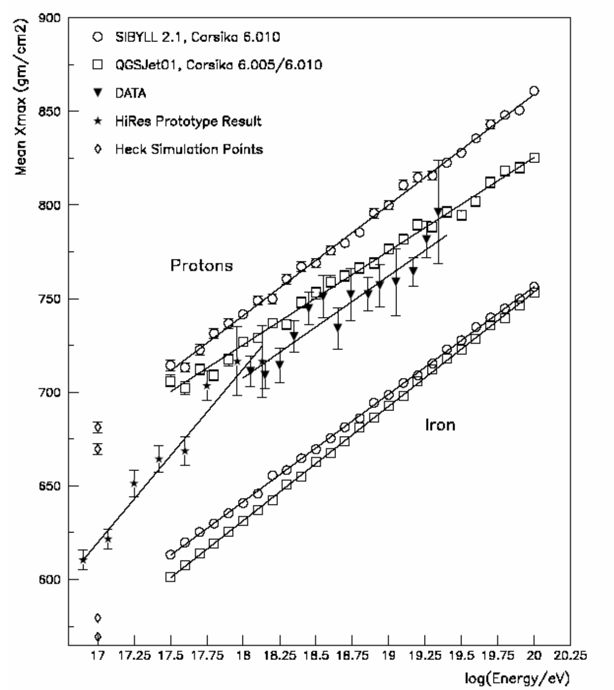
Introduction

- Ankle feature (~5.10^{18} eV) in the spectrum first interpreted as CGR to ECGR transition
- Recent Hires elongation rate claim for a composition change between 10^{17} and 10^{18} eV $\rightarrow$ CGR to ECGR transition below the ankle (second knee transition model SKT)
- In this case the ankle is due to proton pair production dip (Berezinsky et al. 1988, 2002, 2004)
- Most of the propagation studies only include protons as primaries

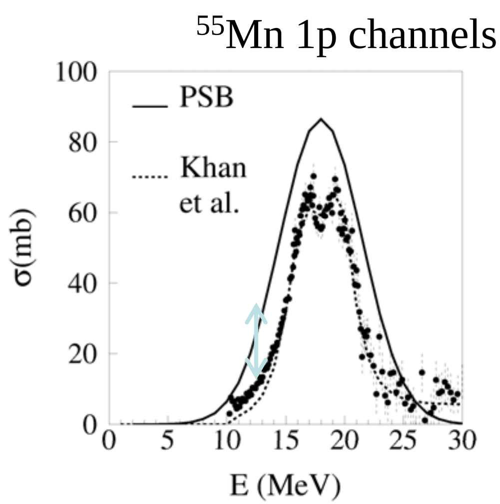


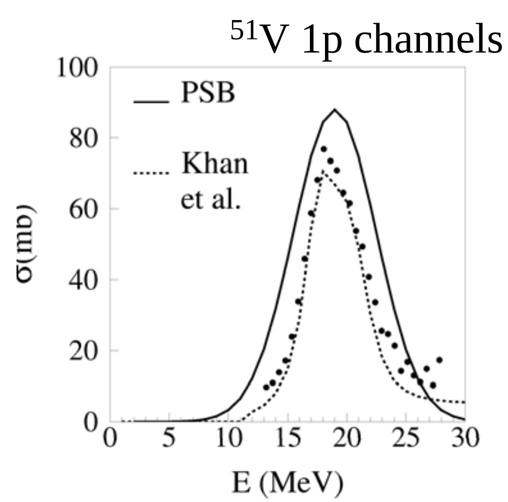


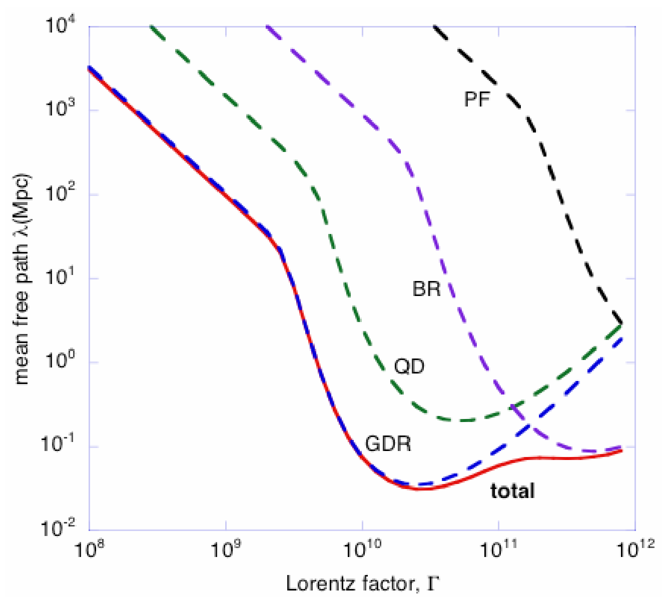
What happens when one also consider heavier nuclei at ultra-high energies?

Nuclei interactions

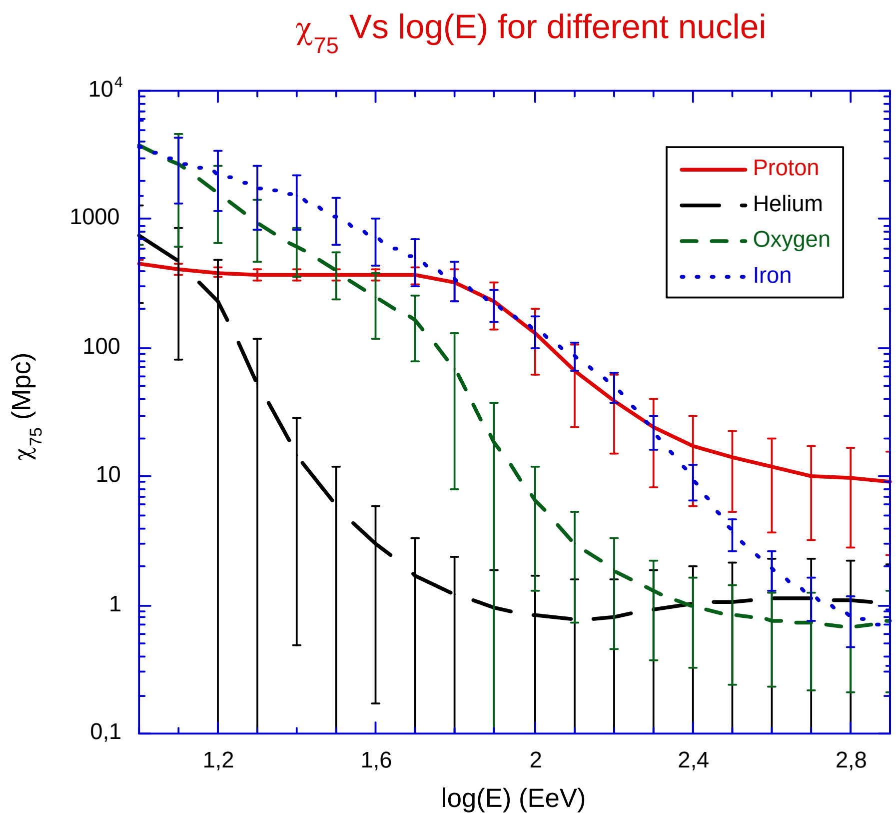
- Giant dipole resonance (GDR) (from Khan et al. 2005) **dominant process (appear at the lowest energy and with largest cross sections)**
- Quasi-deuteron (QD)
- Baryonic resonances (BR)
- Photo-fragmentation (PF)
- pair production from Rachen 1996







Nuclei interactions : attenuation length



- •GDR cut-offs for nuclei at energies increasing with the mass
- •Iron attenuation length comparable to proton's between 100 and 300 EeV
- •Only heavy nuclei can contribute at the highest energies (already obvious after PSB 76)

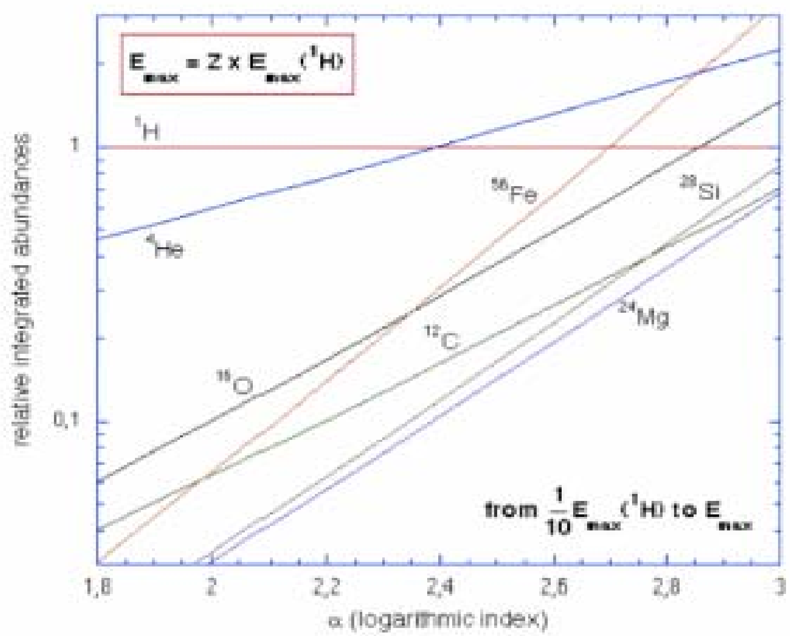
- •Most of the studies after PSB76 dealt with possible presence of heavy or super-heavy nuclei at the highest energies
- •However intermediate and low mass nuclei in the extragalactic composition could have a very important contribution in the ankle region

Generic mixed composition hypothesis

- At the highest energies, the composition is unknown
- We assume a composition similar to low energy ECGR→We use composition derived from Ulysses and HEAO data (Du Vernois and Thayer 1996)

The number of nuclei of species i between E and E+dE is given by :

$$\tilde{\Phi}_i(E) = x_i A_i^{\beta-1} \mathrm{K} E^{-\beta}$$



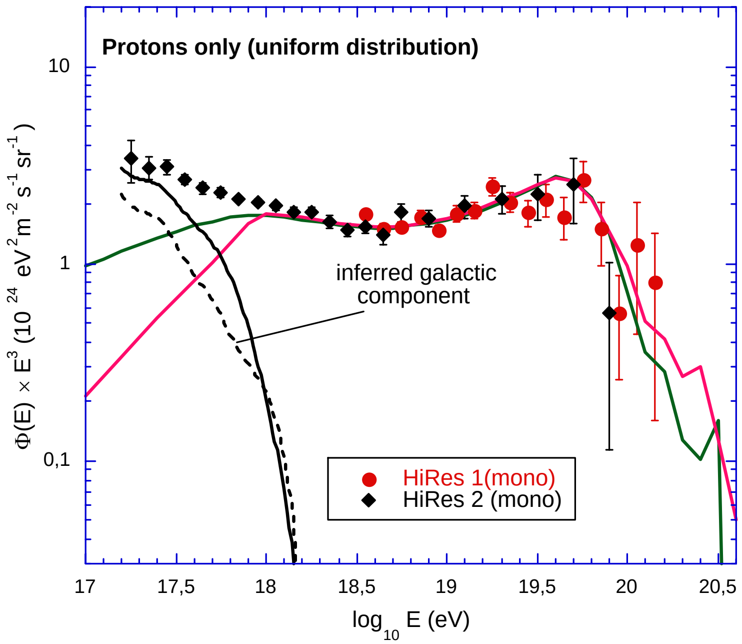
^1H	$9.2*10^4$
^4He	$1.3*10^4$
^{12}C	447.4
^{16}O	526.3
^{24}Mg	108.4
^{28}Si	100
^{56}Fe	97

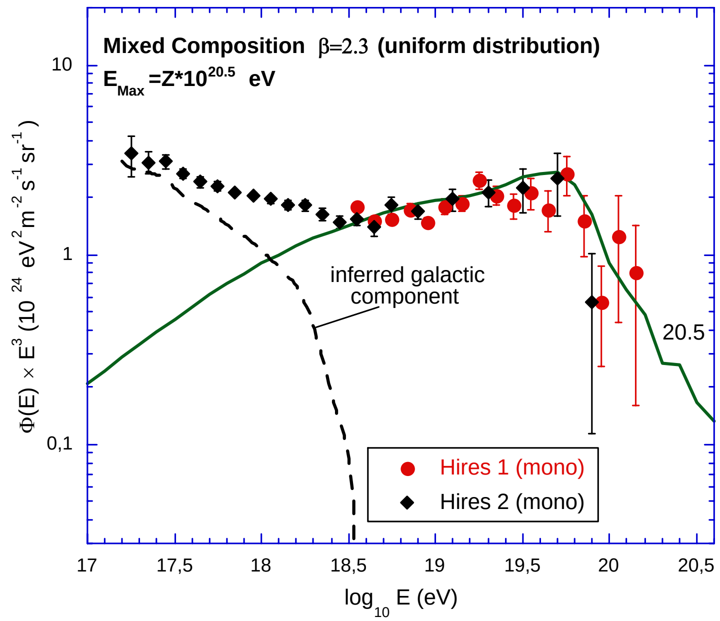
Relative abundances (Si=100) at a given energy per nucleon

We tested different spectral index for a uniform distribution of sources to find the best agreement with data

Propagated spectra

- we assume a uniform distribution of source and a negligible EGMF
- we consider the cases of a mixed and a pure proton EG composition



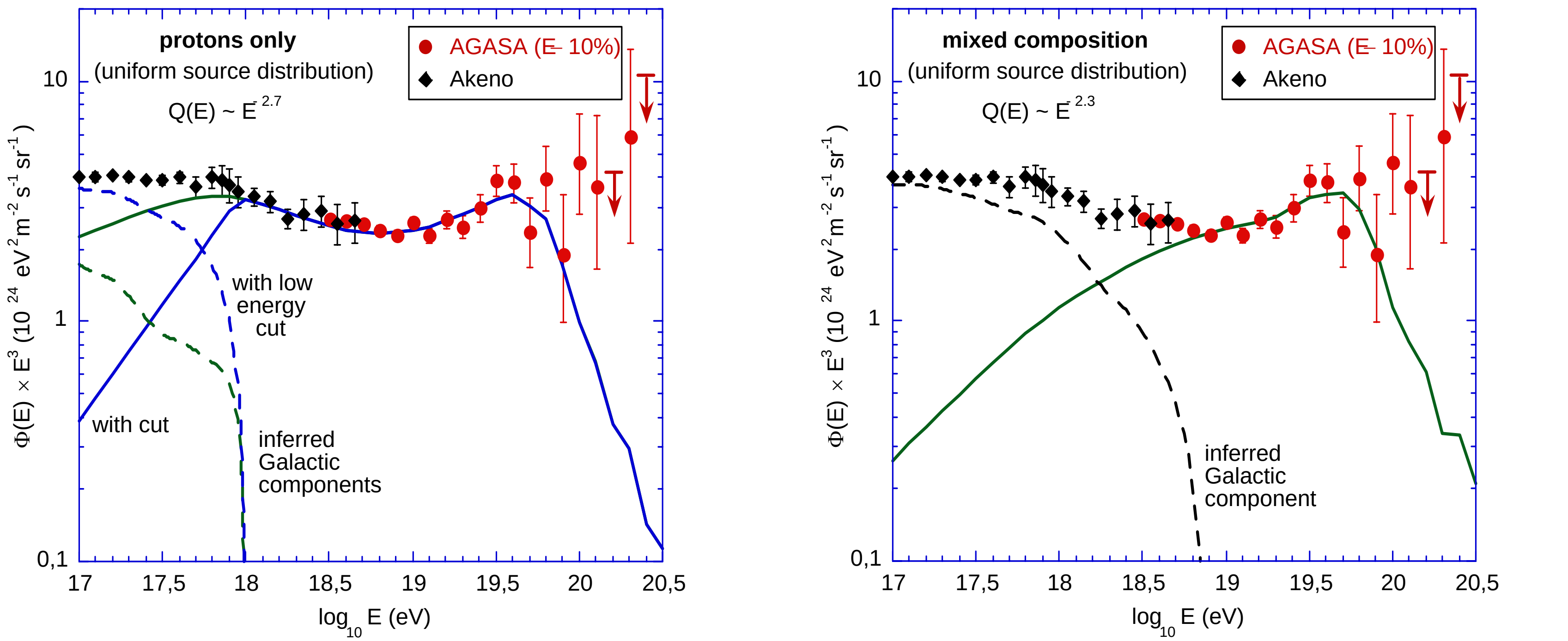


The two composition hypothesis give similar agreement with the data above the ankle

A pure proton composition reproduce the ankle due to the effect of the pair production losses whereas for a mixed composition the ankle is the signature of the end of the GCR to EGCR transition

Best fit spectral index β=2.3 for mixed composition : less problematic extrapolation at low energies

Propagated spectra



Same conclusion with AGASA data although the energy scale of the ankle is different

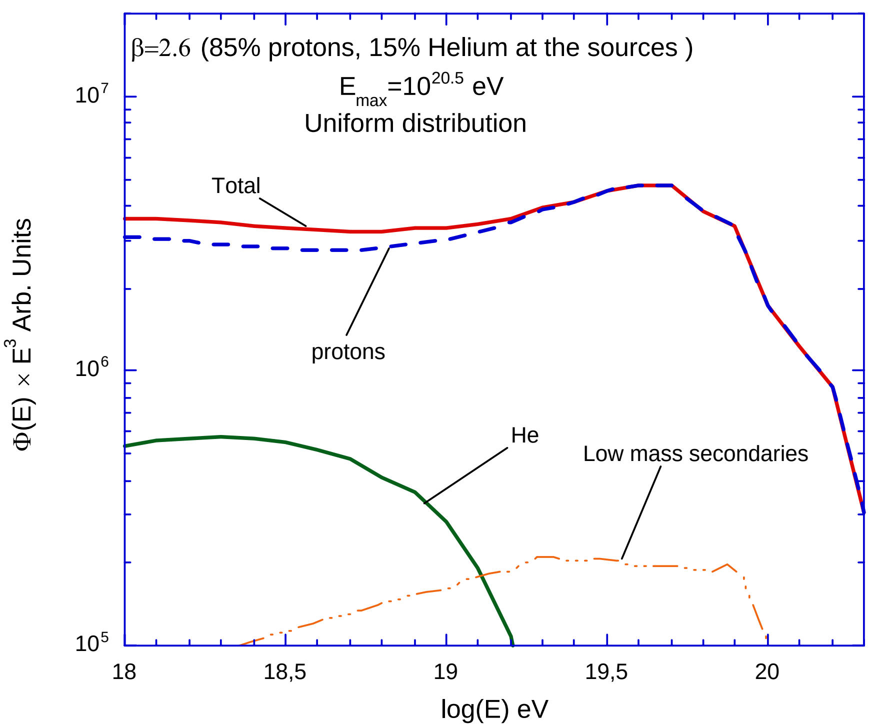
Remark : in both case the second the second knee (uncertain energy scale) is a feature of the galactic component and cannot be reproduced by the sole EG component

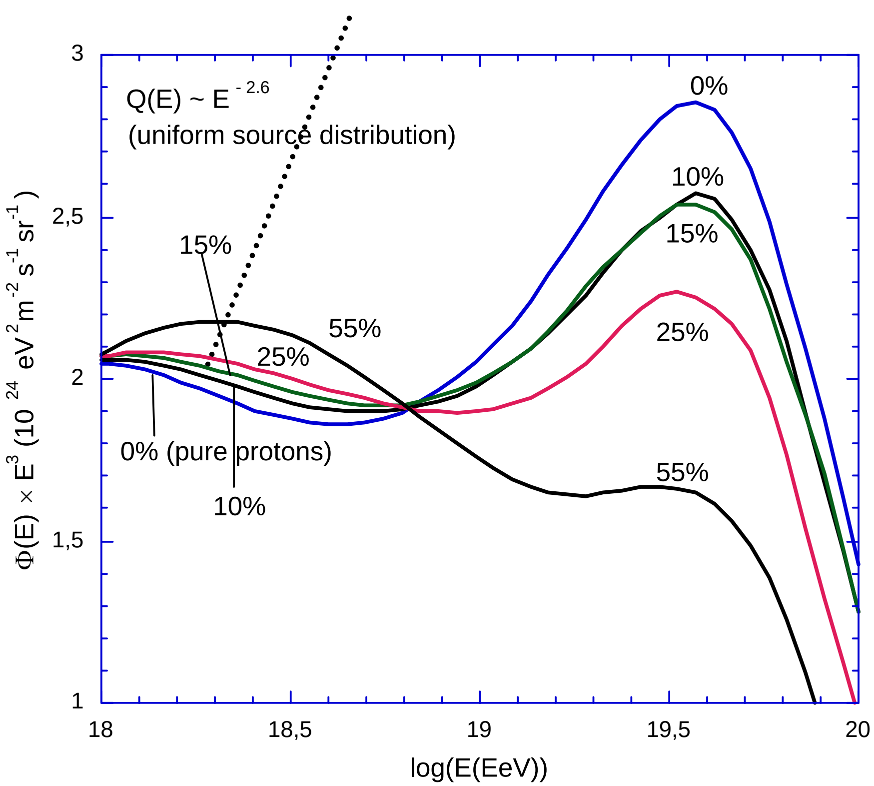
Requirement for a pair production dip as an interpretation of the ankle

Is the proton pair production dip still present if a small fraction of nuclei is emitted at the source?

- with a mixed composition proton + He

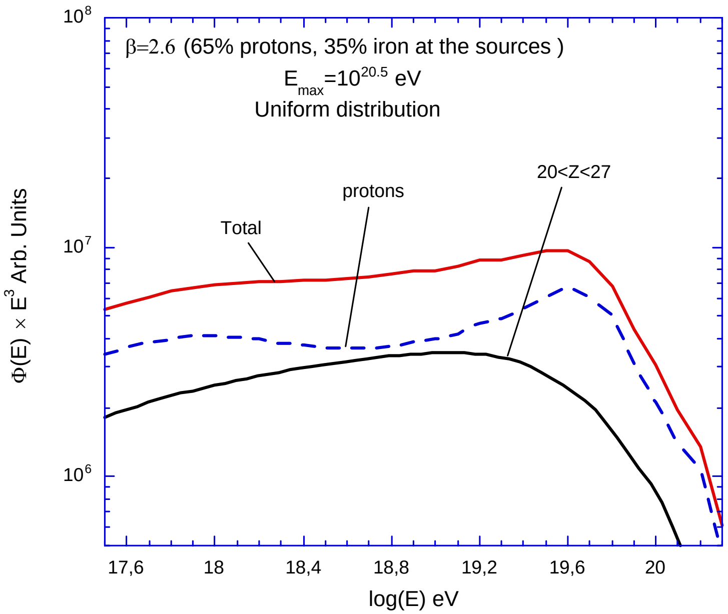
The proton pair production dip is filled by the presence of Helium

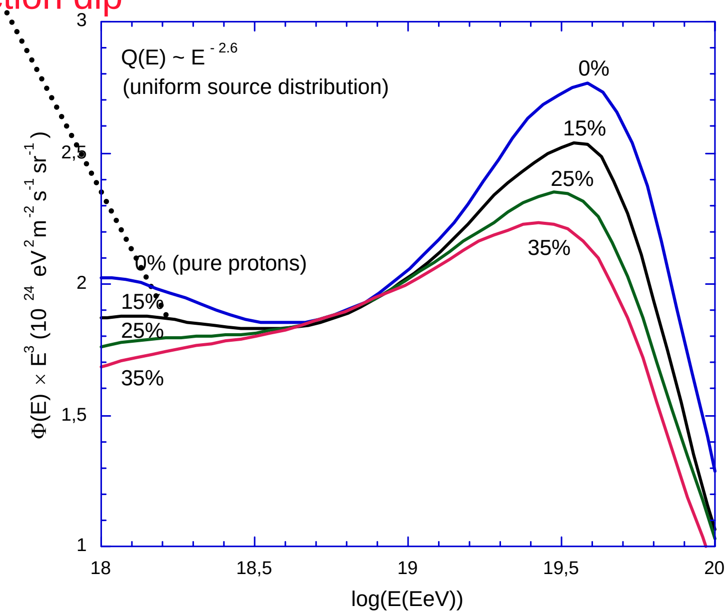




Requirement for a pair production dip as an interpretation of the ankle (2)

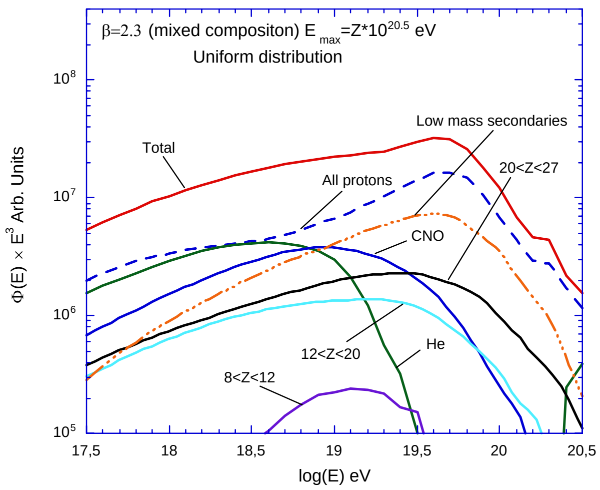
The shape of the ankle cannot be reproduce solely with the proton pair production dip

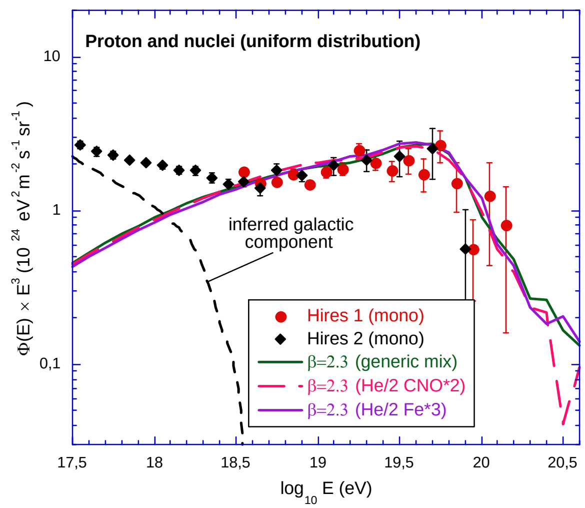


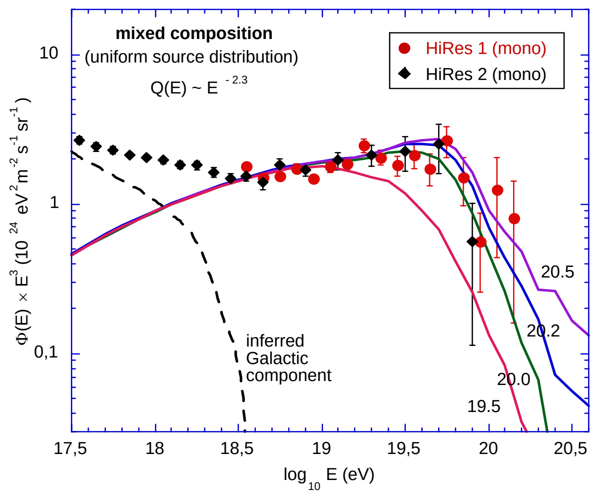


A pair production dip requires an extremely high proton fraction at the sources (>85%)

Requirements for a mixed composition





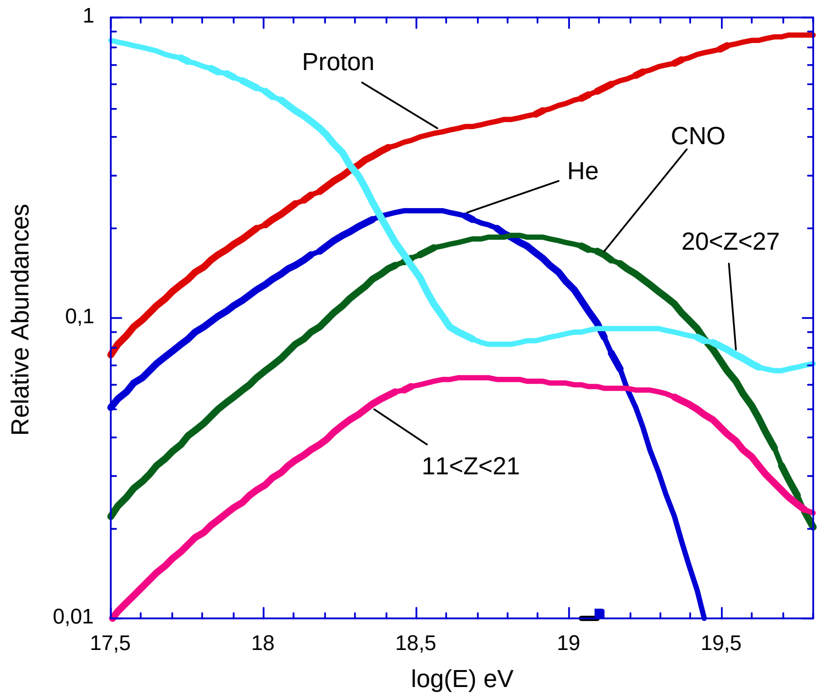


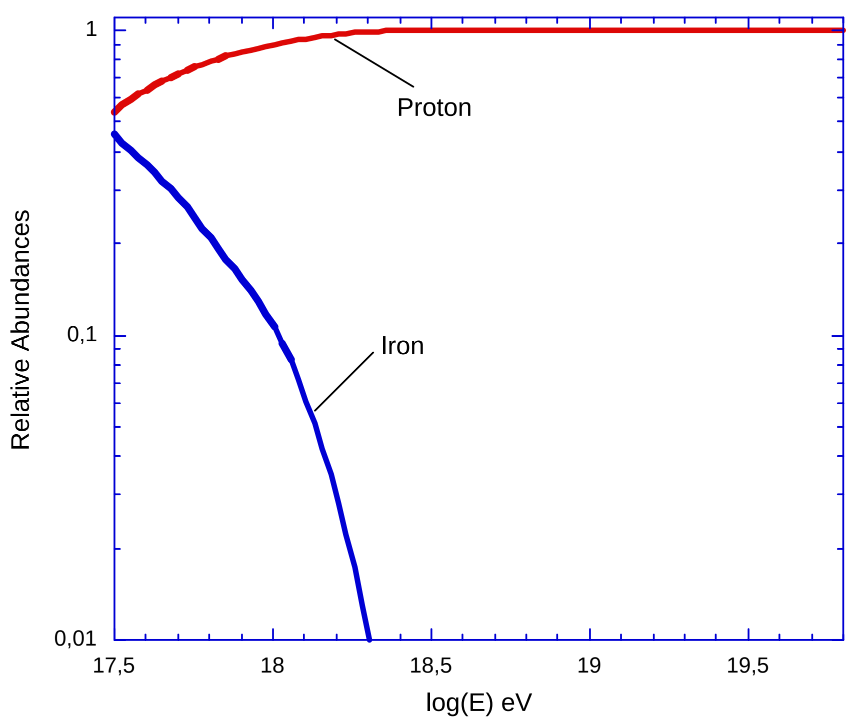
A mixed composition has to be dominated by protons but the exact details of the composition is not critical

Protons have to be accelerated above 10^{20} eV

Relative abundances after propagation

- •Relative abundances of the EG component is trivial to extract with our code
- •We need an assumption on the remaining galactic component if we want to characterize the transition : we assume pure iron above $10^{17.5}$ eV
- •From HiRes data :

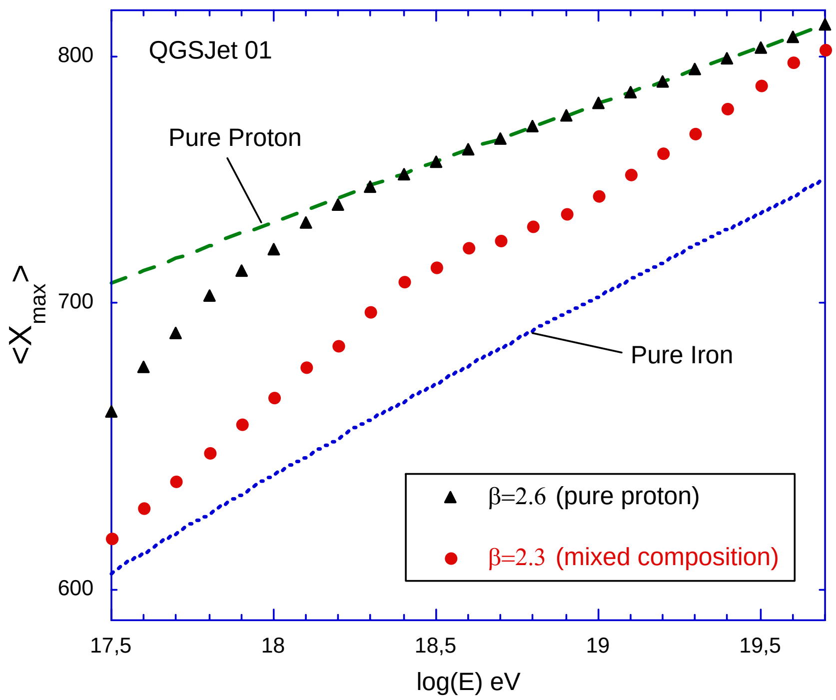




Elongation rates

• knowing relative abundances after propagation, one can predict elongation rates for both composition hypothesis

•We use 25000 Corsika and Aires showers for three hadronic models and different primaries (H, He, CNO, Mg, Si, Fe)

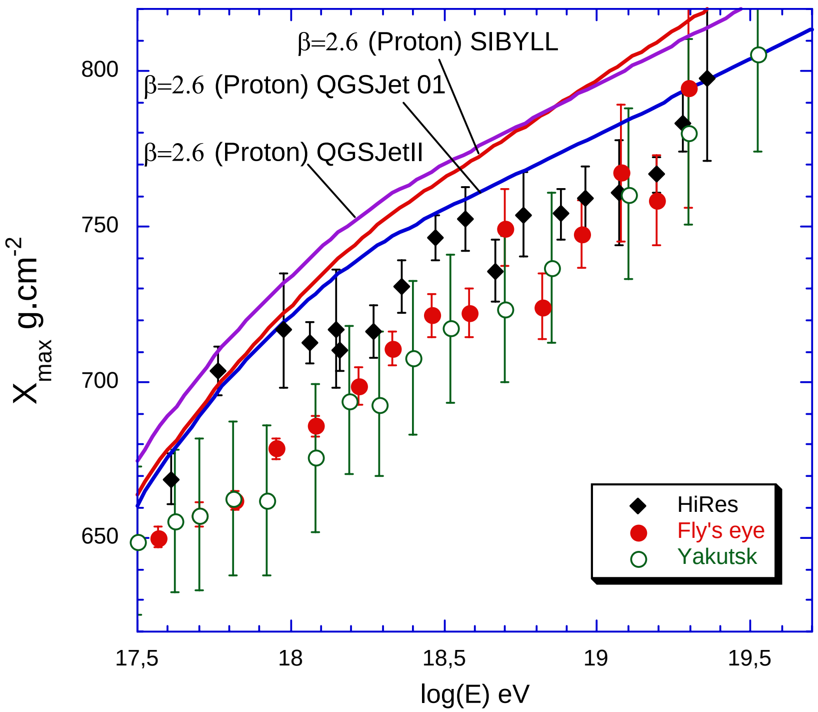


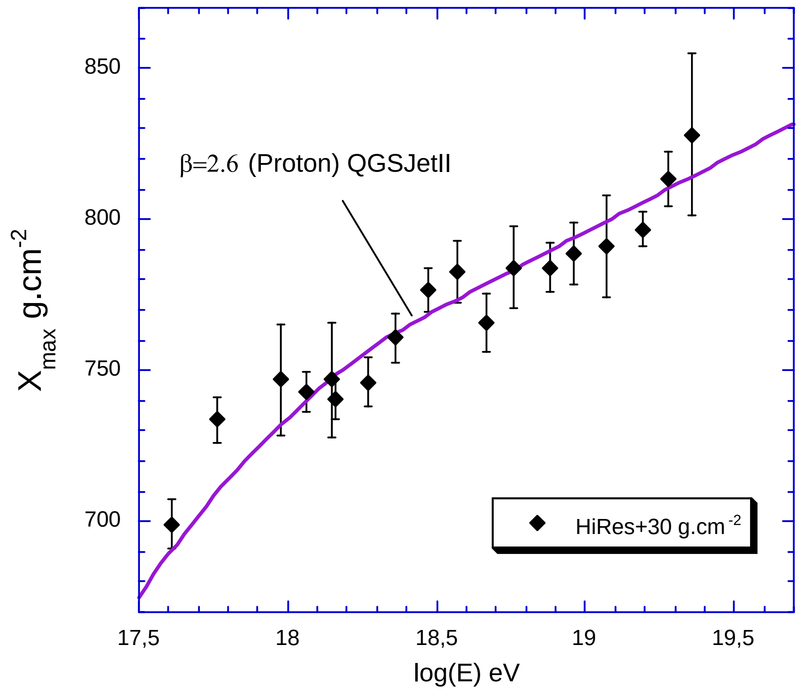
Very different elongation rates predicted for the two hypothesis:

• proton:very sharp transition followed by a pure proton regime

•Mixed composition, more complex “s” shape steep-flat-steep

Comparison with data



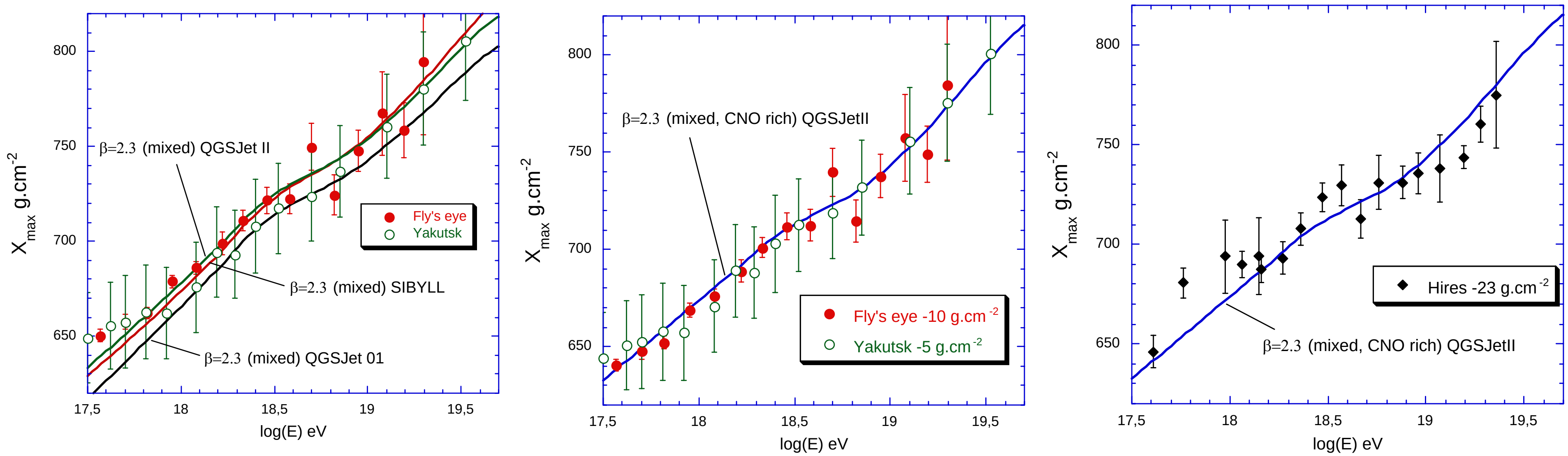


The predicted transition compatible with HiRes below 10^{18} eV

Reasonable agreement if HiRes is rescaled

Yakutsk and Fly's eye : not steep enough at low energy, too steep at high energy (but the uncertainties are large)

Comparison with data



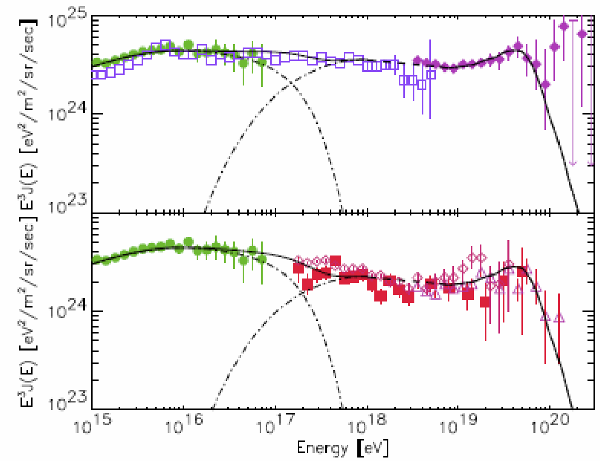
Without any rescaling, very good agreement with Yakutsk and Fly's eye data

Agreement even better providing a small rescaling

HiRes rescaled within its systematics gives also a good agreement with a mixed composition

The three experiments are compatible with the "s" shape of a mixed composition (However a more detailed elongation rate by Auger is needed)

Possible influence of EGMF



- at low energy : possible magnetic horizon effect
  - •For pure proton-> transition even steeper
  - •For mixed composition: more complicated (Z dependant horizon)

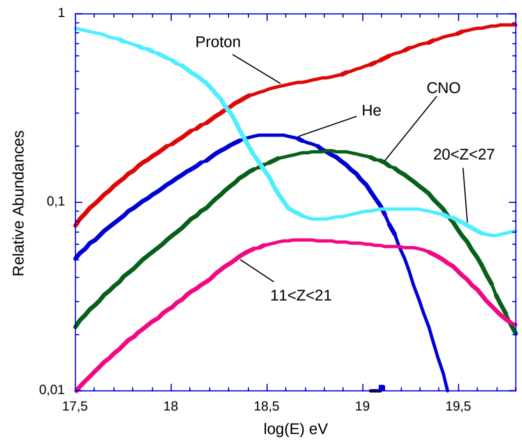
- at high energy :
  - •For pure proton-> very stable
  - •For mixed composition: magnetic field increases the path length -> enhance the effect of photodisintegration

  Possible to imagine that the EGMF is so strong that no UHE EG nuclei can arrive at the earth

  Several orders of magnitude uncertainty on the EGMF->difficult to estimate this effect

  70% of protons above 2.10^{19} eV

  ->certainly large validity domain in term of EGMF



conclusion

•Pure proton and mixed EG compositions fit very well the UHE spectra but with different interpretation of the ankle

•Pair production dip is unstable wrt heavier nuclei pollution->transition scheme very constrained (has to be very sharp)

•Characteristic elongation rate expected in the case of a mixed composition

•Smoothness of the transition induced by a mixed EG composition appears more consistent with most of the experimental data

•Effect of EGMF very difficult to infer (lack of constrains on EGMF)

•Future experiment should provide a complete understanding of the transition : Kascade-Grande and Auger

Comparison with ground array data

• with the relative abundances extracted from the comparison with akeno/AGASA spectrum we extract the expected evolution of <lnA>

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

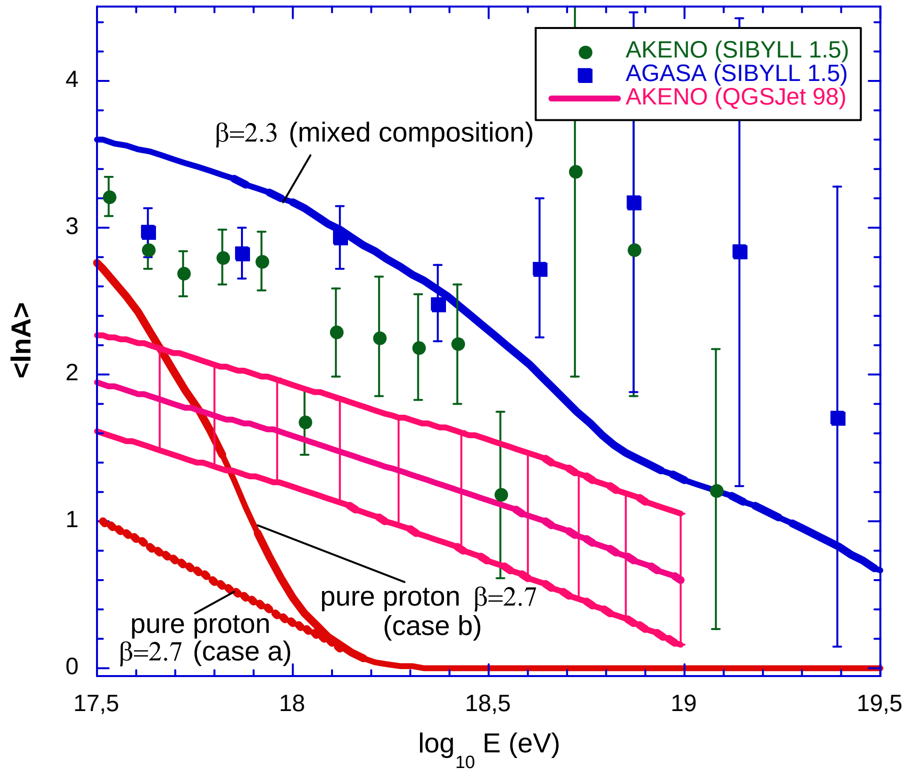
•In the pure proton case the evolution of <lnA> is reduced to the evolution of proton/iron fractions-> comparable to Akeno/AGASA proton/iron fractions

•In the mixed composition case the large presence of intermediate nuclei make difficult to compare with proton/iron fractions

Akeno/AGASA iron fraction

Data points from Dova et al.,2005(gracias Analisa)

<lnA>=ln56*%iron



- Data interpretation very model dependent but both model show a smooth transition in disagreement with a pair production dip

- The current hadronic models would give fraction between the two but certainly closer to Sibyll 1.5

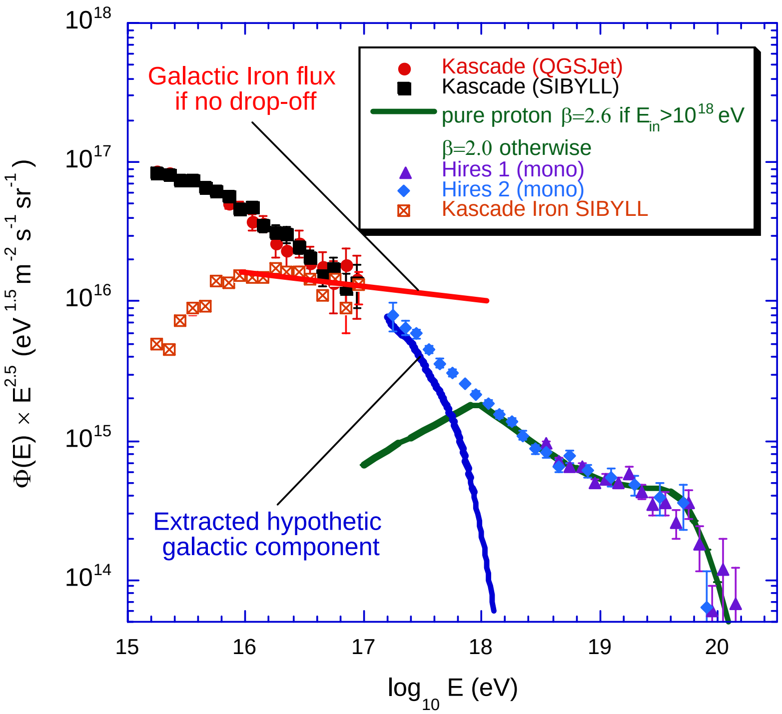
conclusion

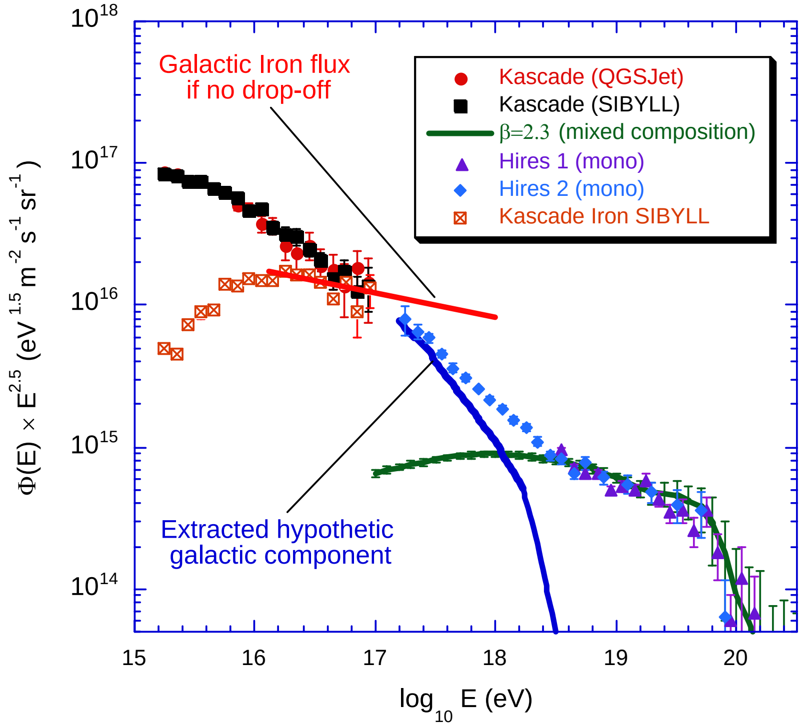
- Using two (outdated) hadronic models the transition seen by Akeno/AGASA appears smooth
- Quite incompatible with the requirements of a pair production dip
- Consistency with a mixed EG composition difficult to establish (at least the smoothness of the transition is not a problem)
- **Auger : for the first time, possible to study the consistency of Elongation rate and SD composition analysis within the same experiment**

Conclusion

- Very different signature for the two composition hypothesis in term of elongation rate
- The three data set are consistent with the typical shape of a mixed composition
- HiRes results are compatible with the very sharp transition required for a pair production dip, poorer agreement with Yakutsk and Fly’s eye
- A more detailed elongation rate from Auger is really needed

Energy scale of the transition

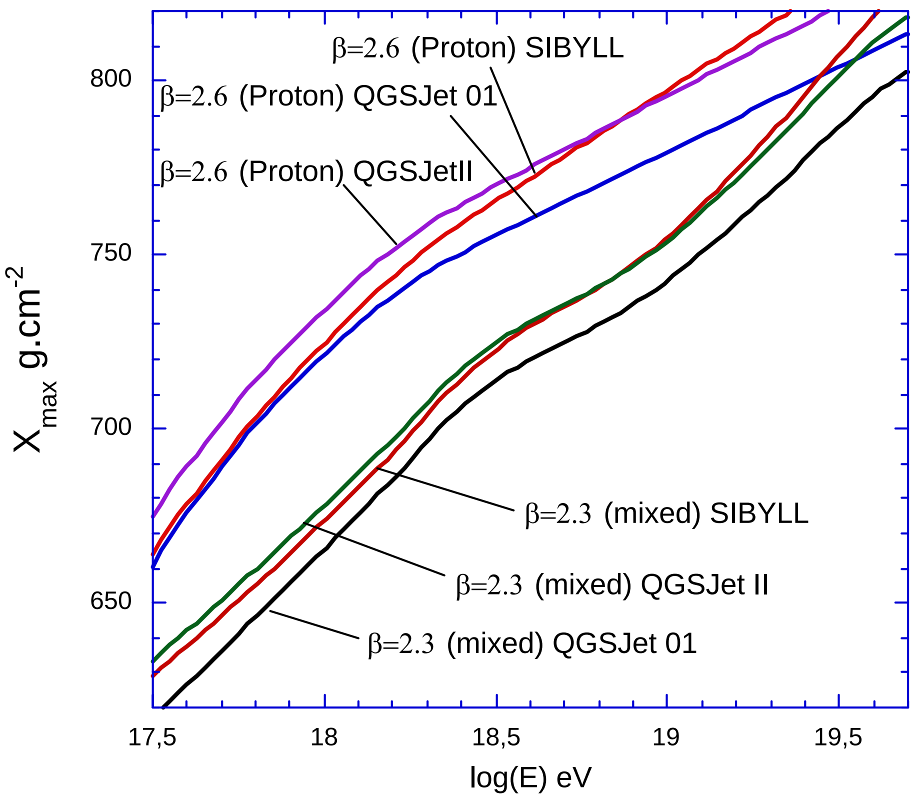




For both composition hypothesis, the energy scale of the transition is different : 10^{18} eV for pure proton and 2-6.10^{18} eV for mixed

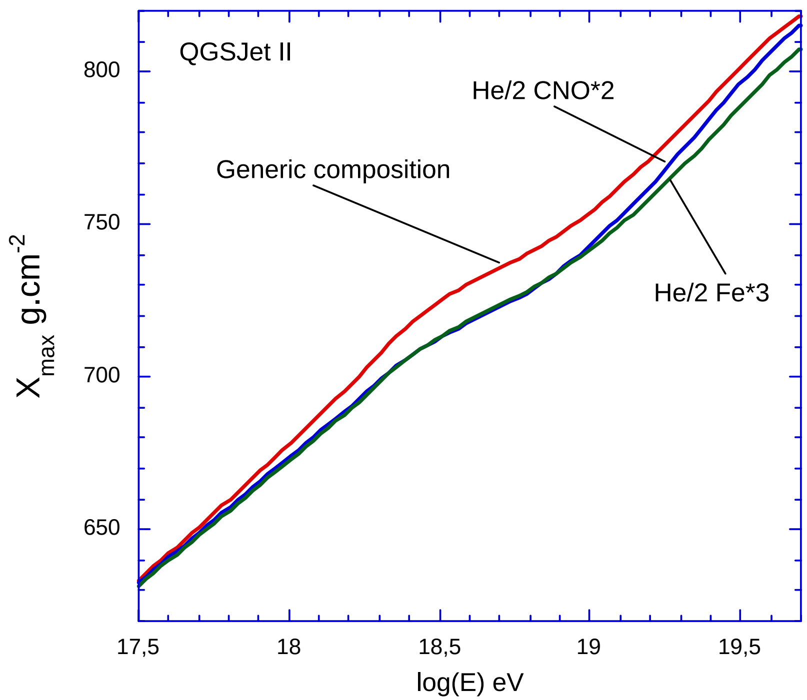
However none of then is in contradiction with a galactic iron drop-off around 10^{17} eV (the final drop-off of the galactic component is just steeper in the pure proton case)

Elongation rates



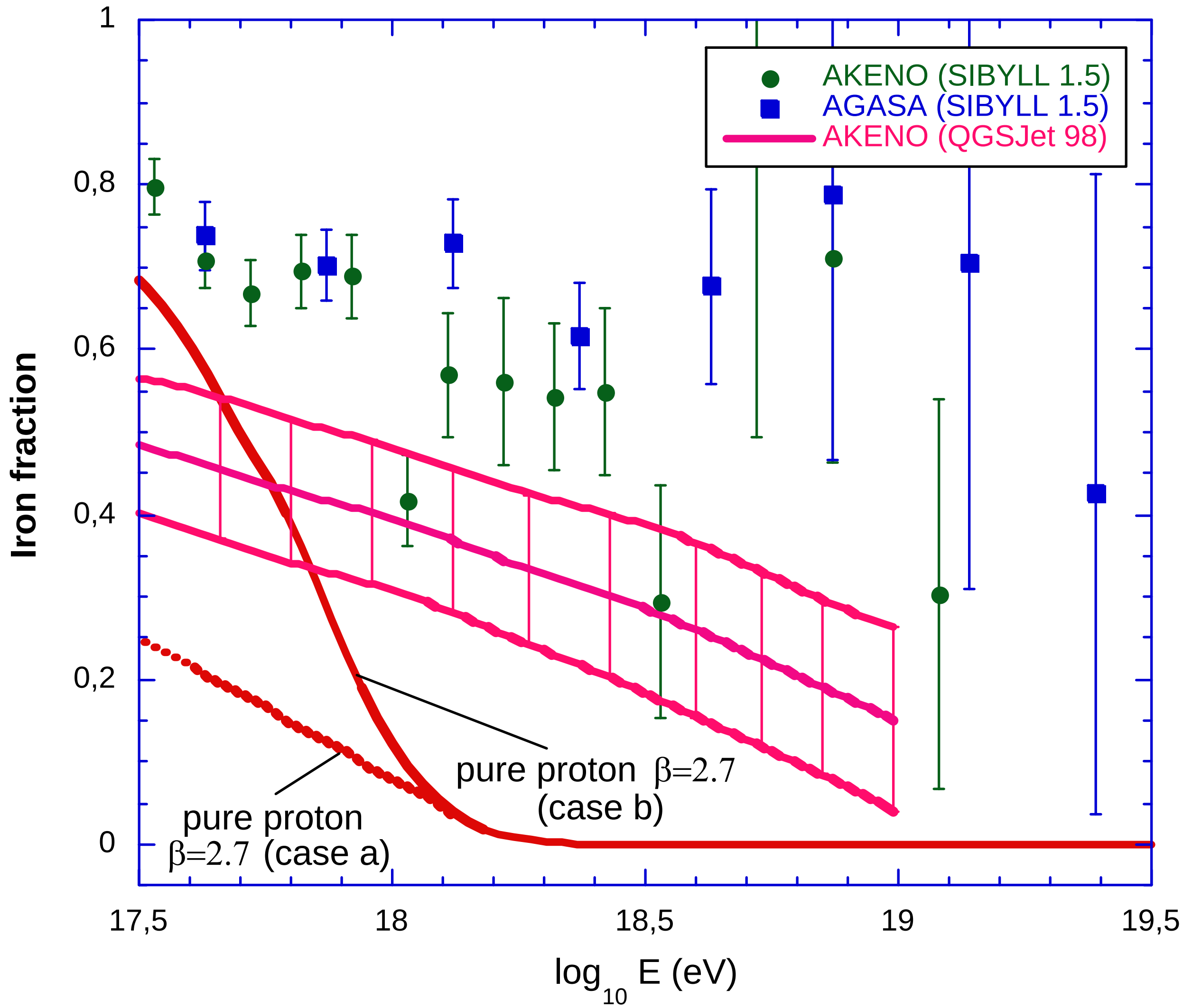
In the transition regions the slope of the elongation rate is pretty independent of the hadronic model but not the absolute scale

Influence of the detail of the composition



The elongation rate is more dependant on the exact detail of the composition than the spectrum

If an “s” shape elongation rate is observed the steepness of each part can give information about the composition of EG component



AKENO (SIBYLL 1.5)
AGASA (SIBYLL 1.5)
AKENO (QGSJet 98)
Iron fraction
1
0,8
0,6
0,4
0,2
0
17,5
18
18,5
19
19,5
log10 E (eV)
pure proton β=2.7
(case b)
pure proton
β=2.7 (case a)