Sensitivity of JEM-EUSO to Ensemble Variations in the Ultra-High Energy Cosmic Ray Flux

M. Ahlers, L. Anchordoqui, A. Olinto, T. Paul, A. Taylor

IceCube Particle Astrophysics Symposium, Madison, May 13, 2013

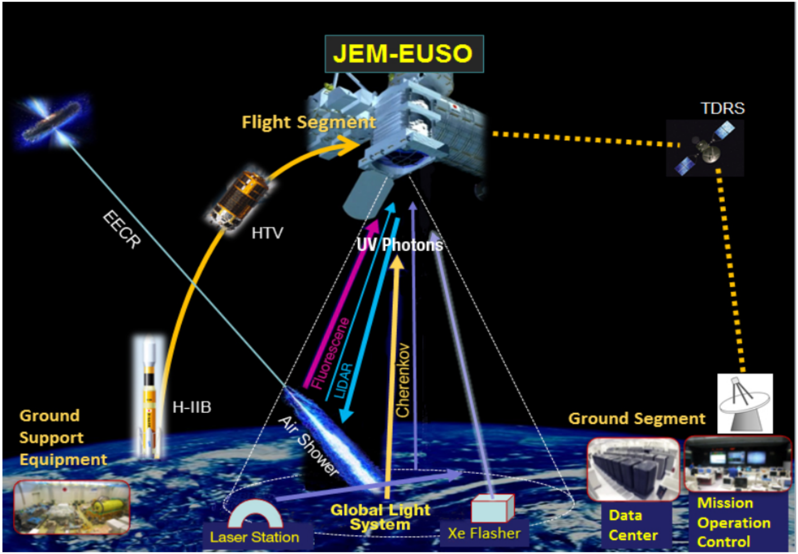
Outline

- What are ensemble variations ?
- Dependence of on source density, proximity, composition, energy, ...
- Some examples compared to current data
- Sensitivity of JEM-EUSO to ensemble variations

M. Ahlers, L. Anchordoqui, and A. Taylor, PRD87 (2013) [arXiv:1209.5427]

M. Ahlers, L. Anchordoqui, A. Olinto, T. Paul, and A. Taylor, in preparation

JEM-EUSO Mission (reminder)



Ensemble Variation : Introduction

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- Next step : quantify possible deviations from the mean prediction. *i.e.* estimate next statistical moment of the distribution. This is the ensemble variation .

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- Will JEM-EUSO be able to discern this variation from statistical fluctuations?

Flux Variation

Defining residual $\delta X \equiv X - \langle X \rangle$, the covariance between relative flux of two particle species A, B populating energy bins i, j :

$$\langle \delta N_{A,i} \delta N_{B,j} \rangle \equiv \langle N_{A,i} N_{B,j} \rangle - \langle N_{A,i} \rangle \langle N_{B,j} \rangle$$

Relative variation of total flux described by two-point density perturbations :

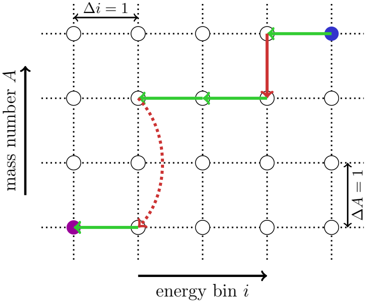
$$\sigma_{\rm loc}^2 = \sum_{A,B} \frac{\langle \delta N_A(E/A) \delta N_B(E/B) \rangle}{\langle N_{\rm tot}(E) \rangle^2}$$

M. Ahlers, L. Anchordoqui and A. Taylor, PRD87 (2013)

Flux Variation

Analytical estimate of ensemble variations including :

- Density of sources
- Source emission parameters
  γ and E_{max}
- Propagation effects
  [M. Ahlers and A. Taylor, PRD82 (2010)]
- Energy losses ☞ migration in energy bin
- Photodisintegration ☞ migration in mass



$\mathcal{H}_0 \sim 10^{-6} - 10^{-5}\ \mathrm{Mpc}^{-3}$ consistent with absence of clustering

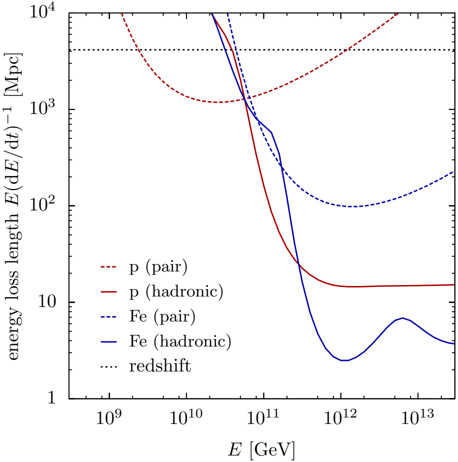
Pierre Auger Collaboration JCAP 2013 (accepted)

E. Waxman, K. B. Fisher, T. Piran ApJ 483 (1997)

T. Kashti and E. Waxman, JCAP 05 (2008)

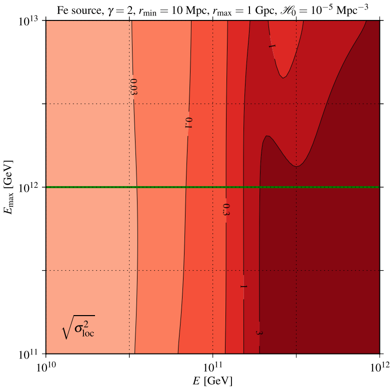
H. Takami, S. Inoue, and T. Yamamoto, Astropart. Phys 35 (2012)

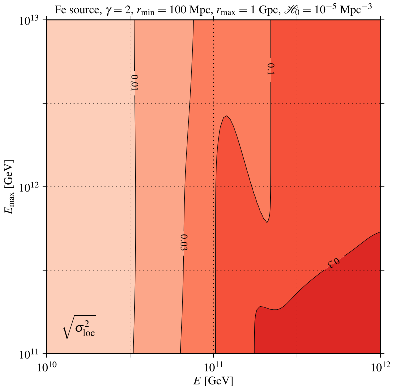
Energy Loss Lengths



- Energy losses carve the average energy spectrum and modulate the ensemble variation

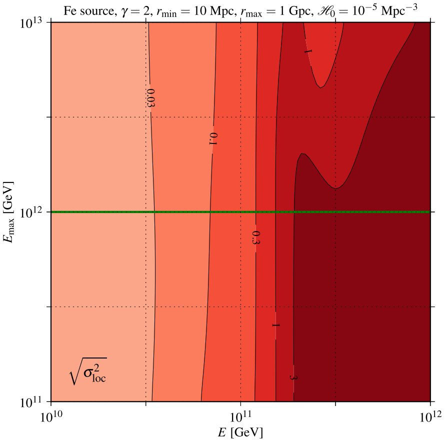
Relative Ensemble Variation (Fe sources)

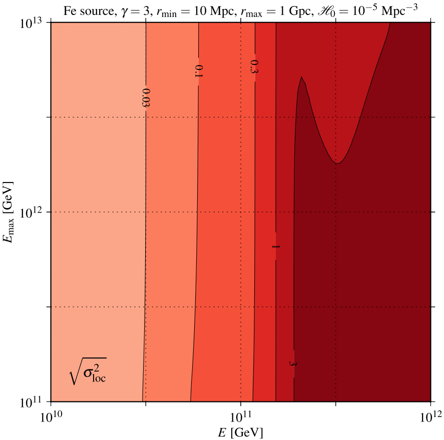




- Different minimal distances ($r_{\rm min}$) to source populations, with the same source density assumption
- $r_{\rm min} = 10$ Mpc : relative ensemble fluctuation increases with E (above the level of 10% at about $10^{10.8}$ GeV)
- $r_{\rm min} = 100$ Mpc : ensemble variations smaller by factor ~ 3

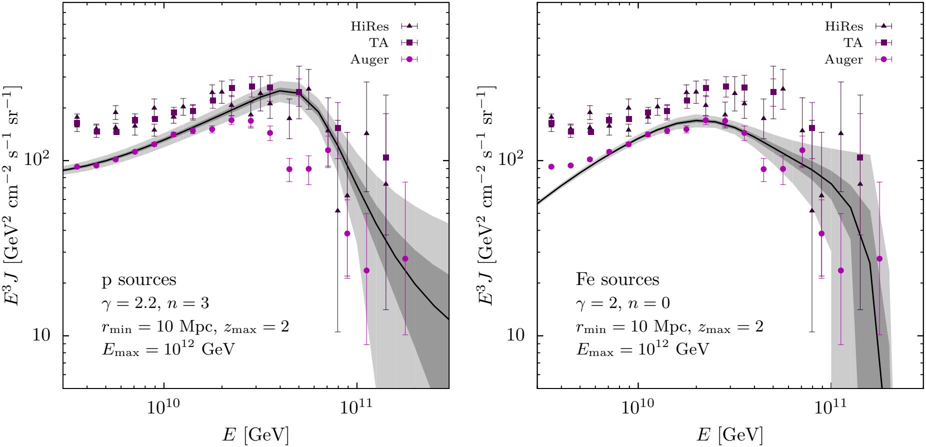
Relative Ensemble Variation (Fe sources)





Results do not strongly depend on the spectral index

$r_{\min} = 10$ Mpc

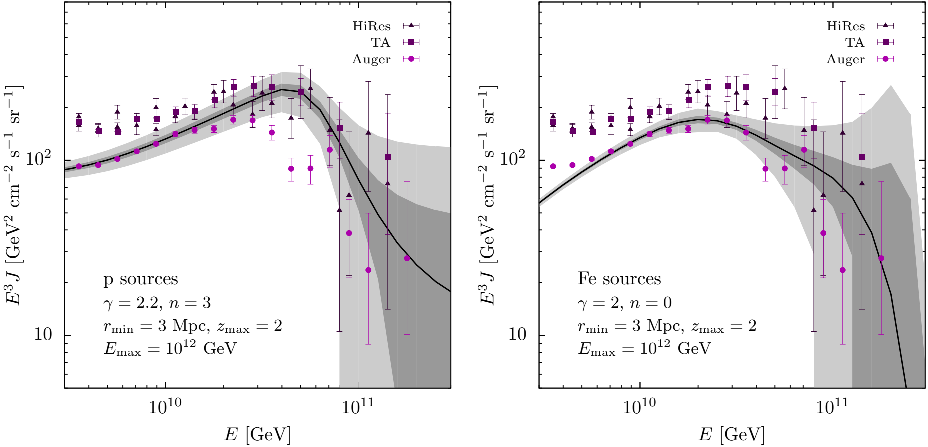


Approximate variation of the flux assuming a local source distribution:

$\mathcal{H}_0 = 10^{-5}$ Mpc^{-3} (dark gray band)

$\mathcal{H}_0 = 10^{-6}$ Mpc^{-3} (light gray band)

$r_{\min} = 3$ Mpc



Approximate variation of the flux assuming a local source distribution:
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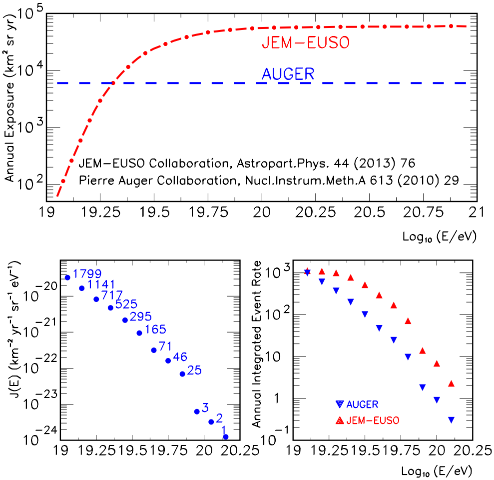
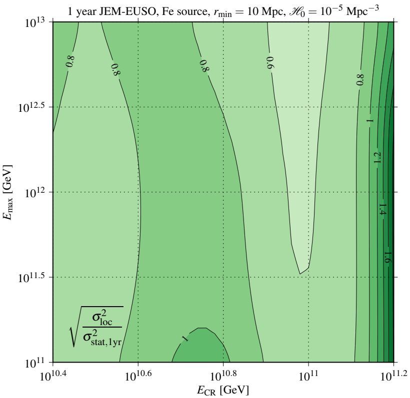
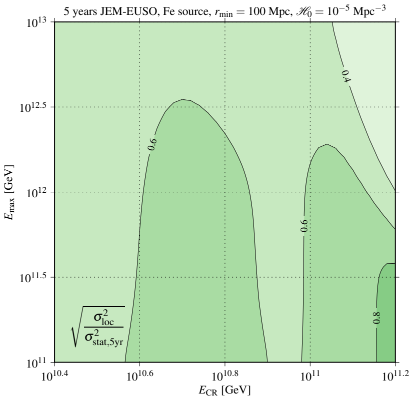
JEM-EUSO Potential : Annual Exposure



Estimate of JEM-EUSO sample size ☞ scale Auger spectrum according to Auger vs. JEM-EUSO aperture.

Ensemble Variations vs. Statistics, JEM-EUSO

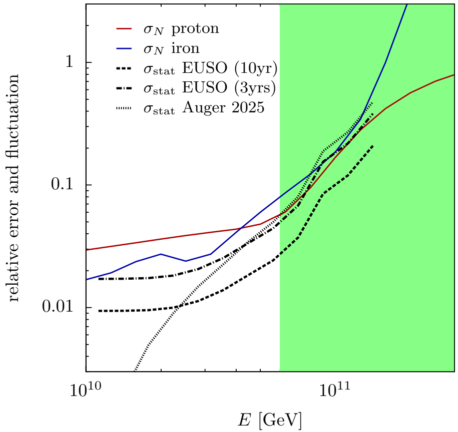


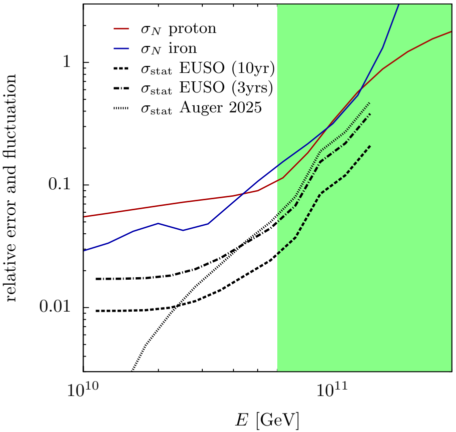


Uncovering hints if $r_{\min} = 10$ Mpc is possible

$r_{\min} = 100$ Mpc probably out of range

Ensemble fluctuation compared to statistical errors





$r_{\rm min} = 10$ Mpc ☞ 3σ

$r_{\rm min} = 3$ Mpc ☞ 5σ

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