Propagating UHECRs in the universe with CRPropa

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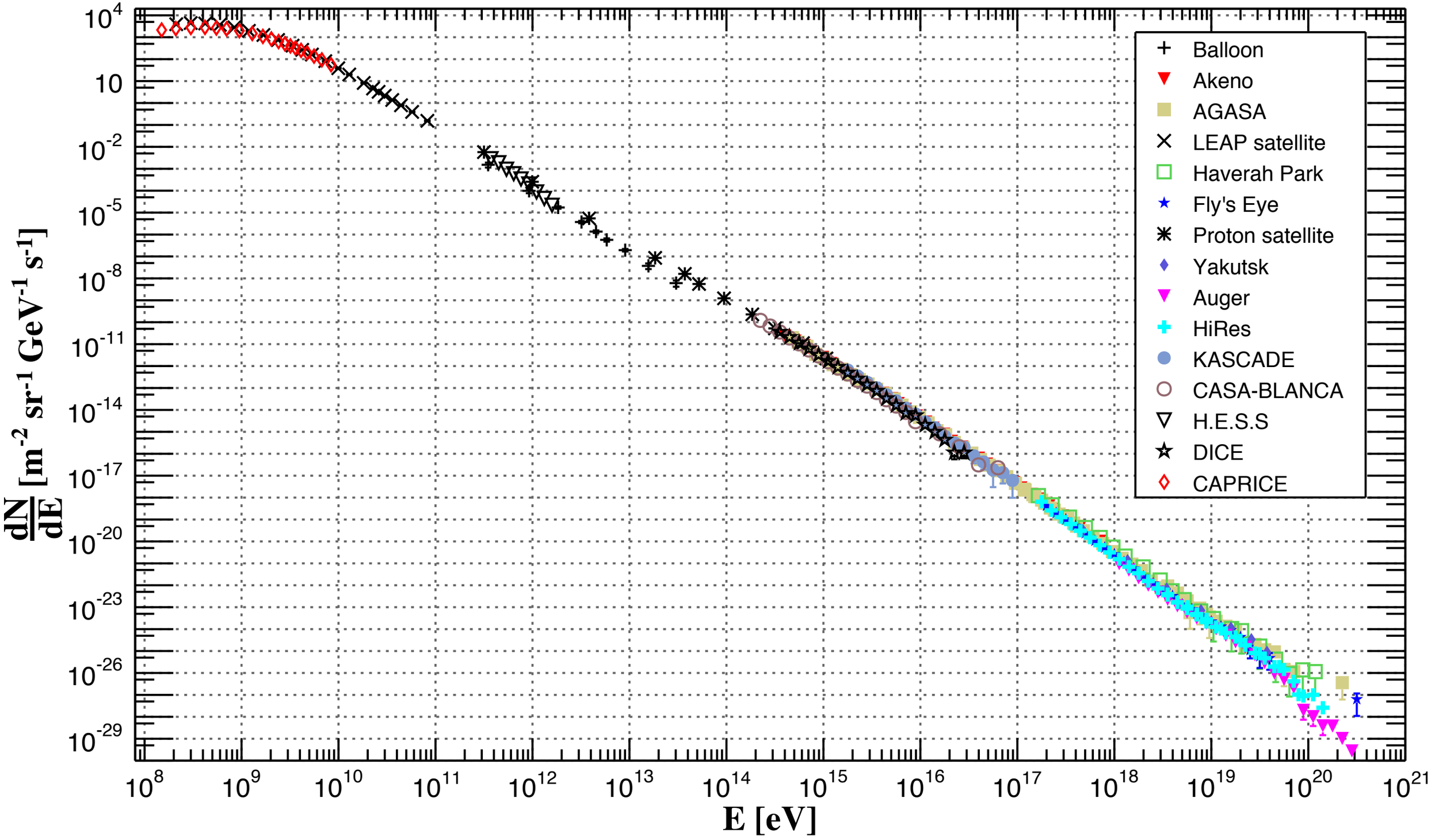
DESY Theory Workshop
25.09.2013

the cosmic ray spectrum



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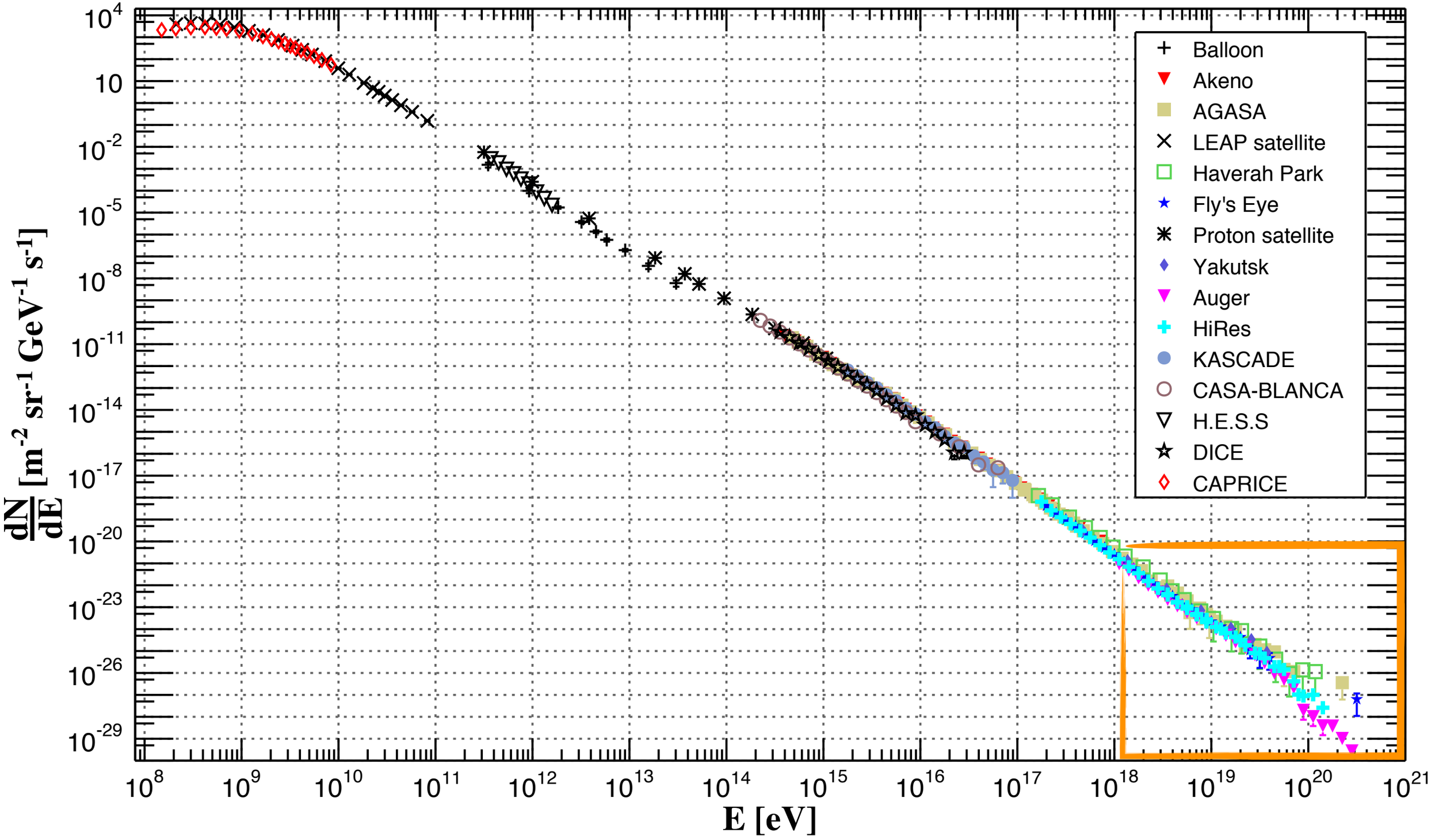
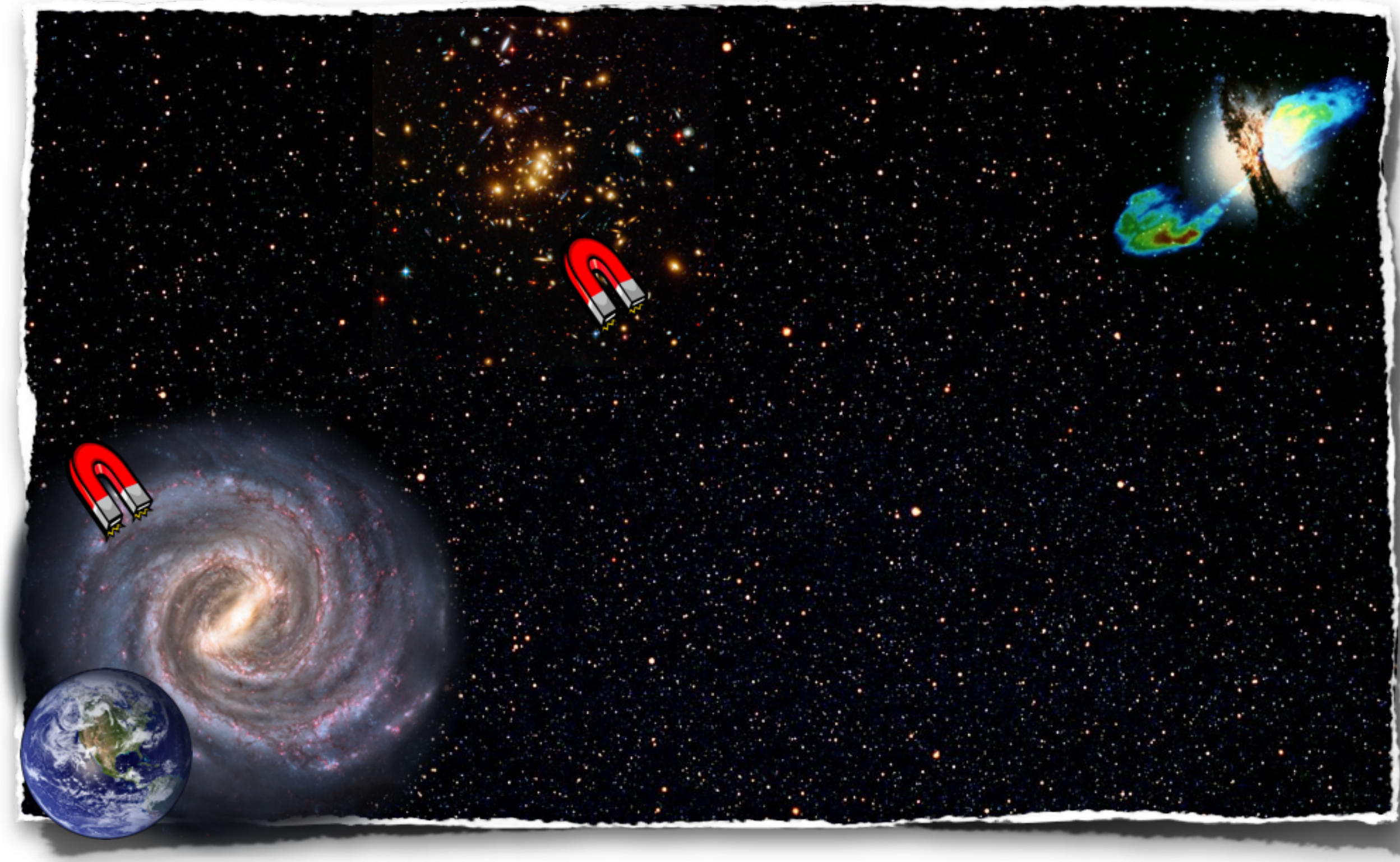


open questions

- ✦ where do they come from?
- ✦ what is their chemical composition?
- ✦ what are the acceleration processes?
- ✦ is there a maximum energy that they can reach?
- ✦ can we see hint of new physics through their interaction?

general picture



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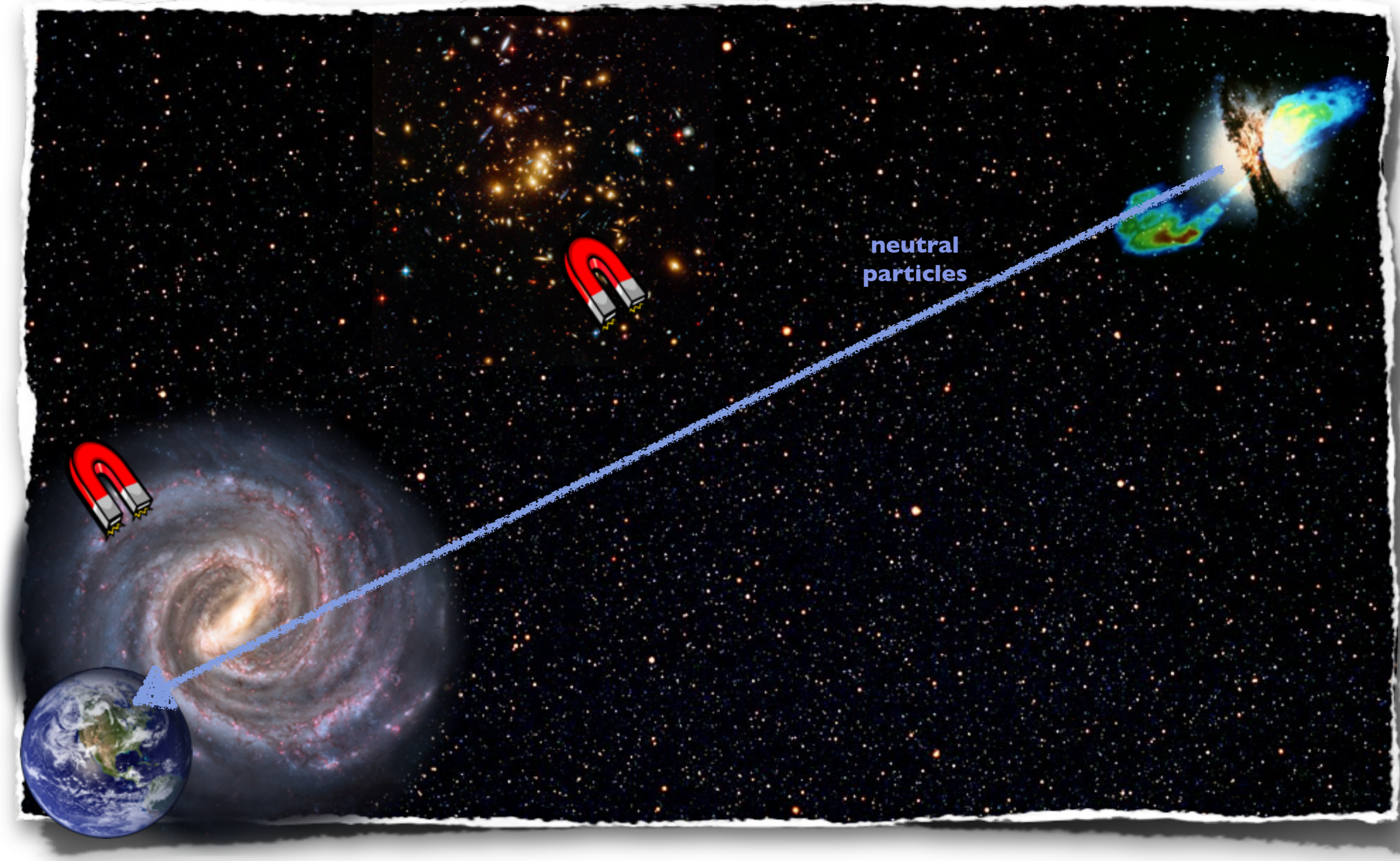

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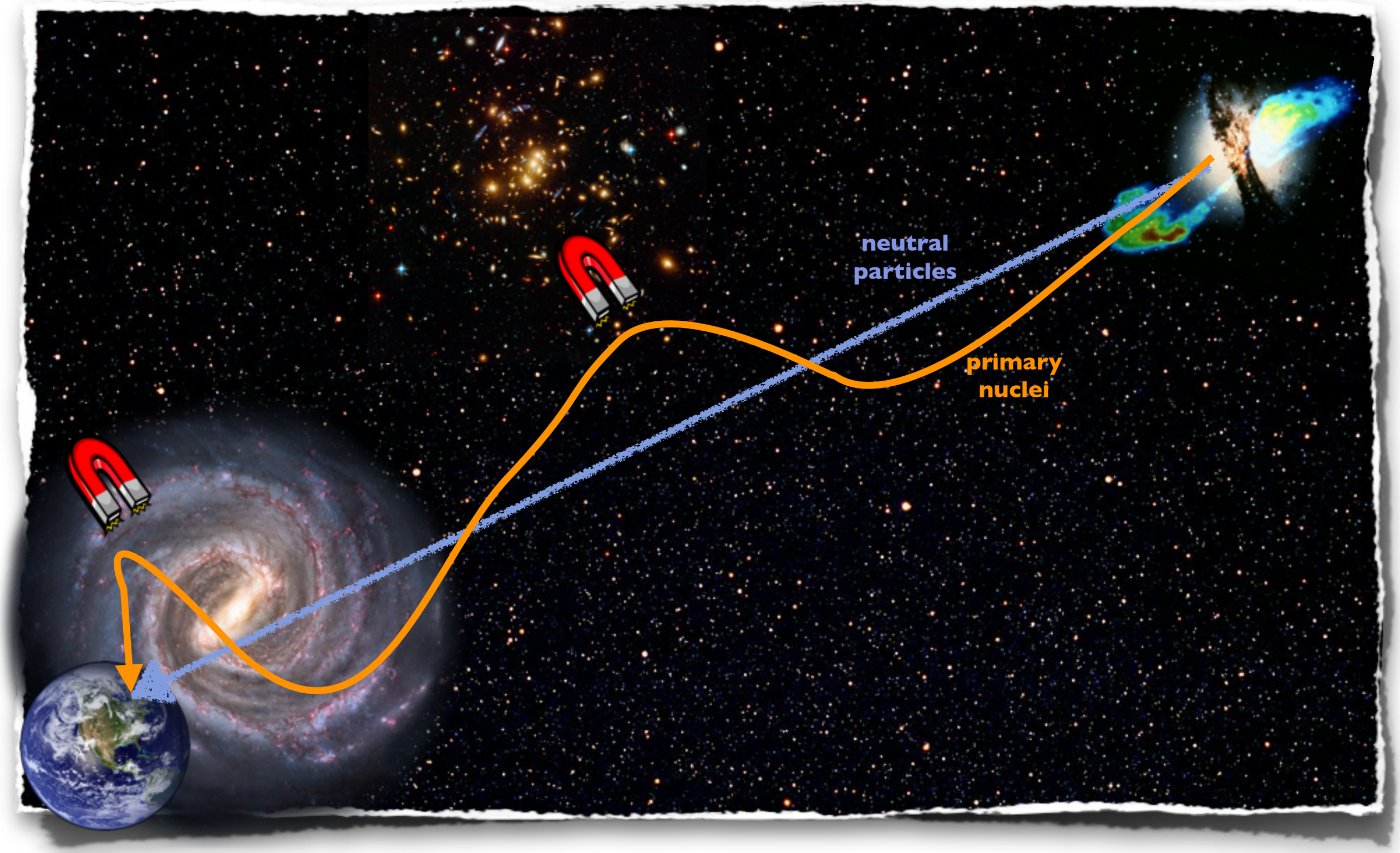

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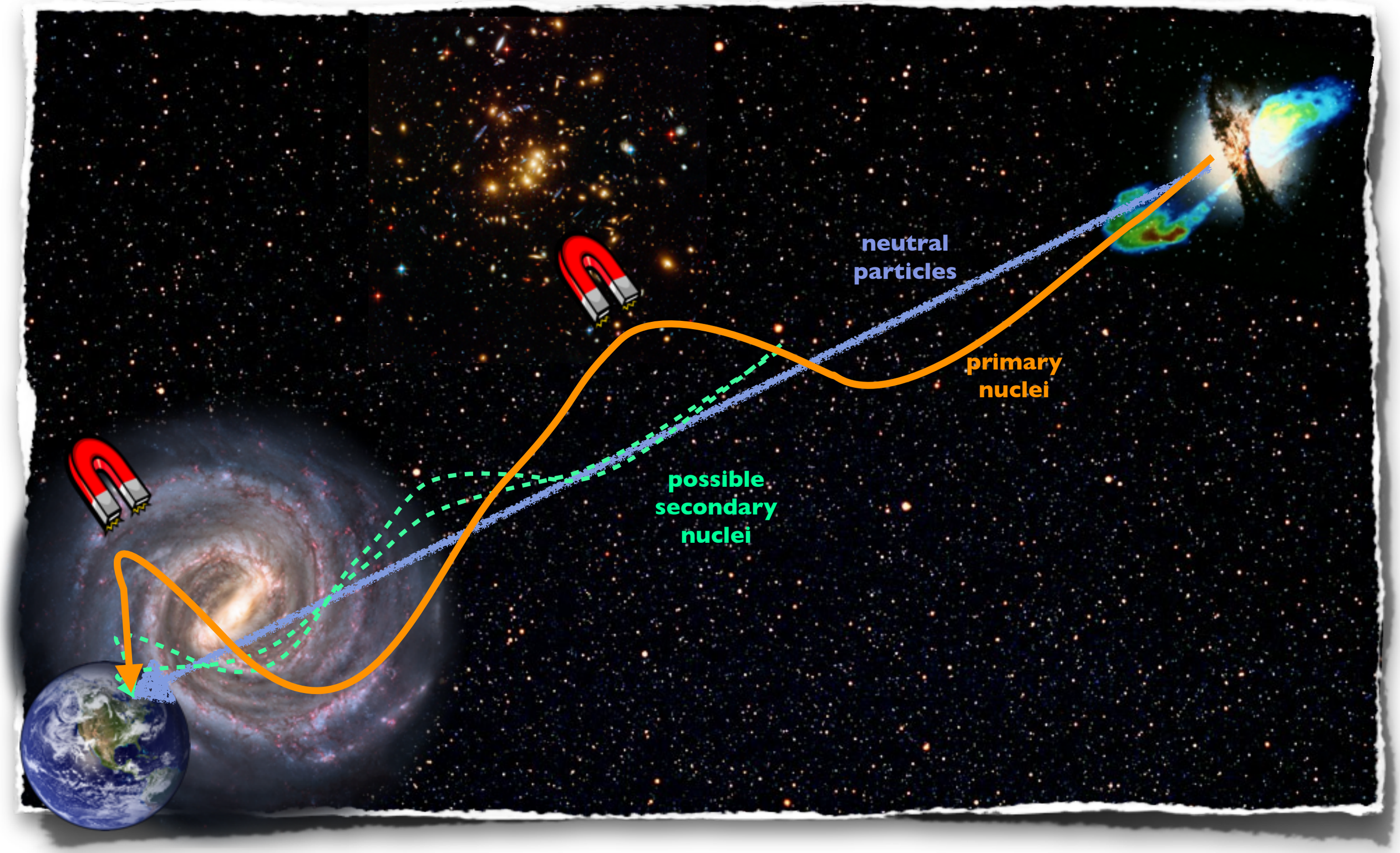

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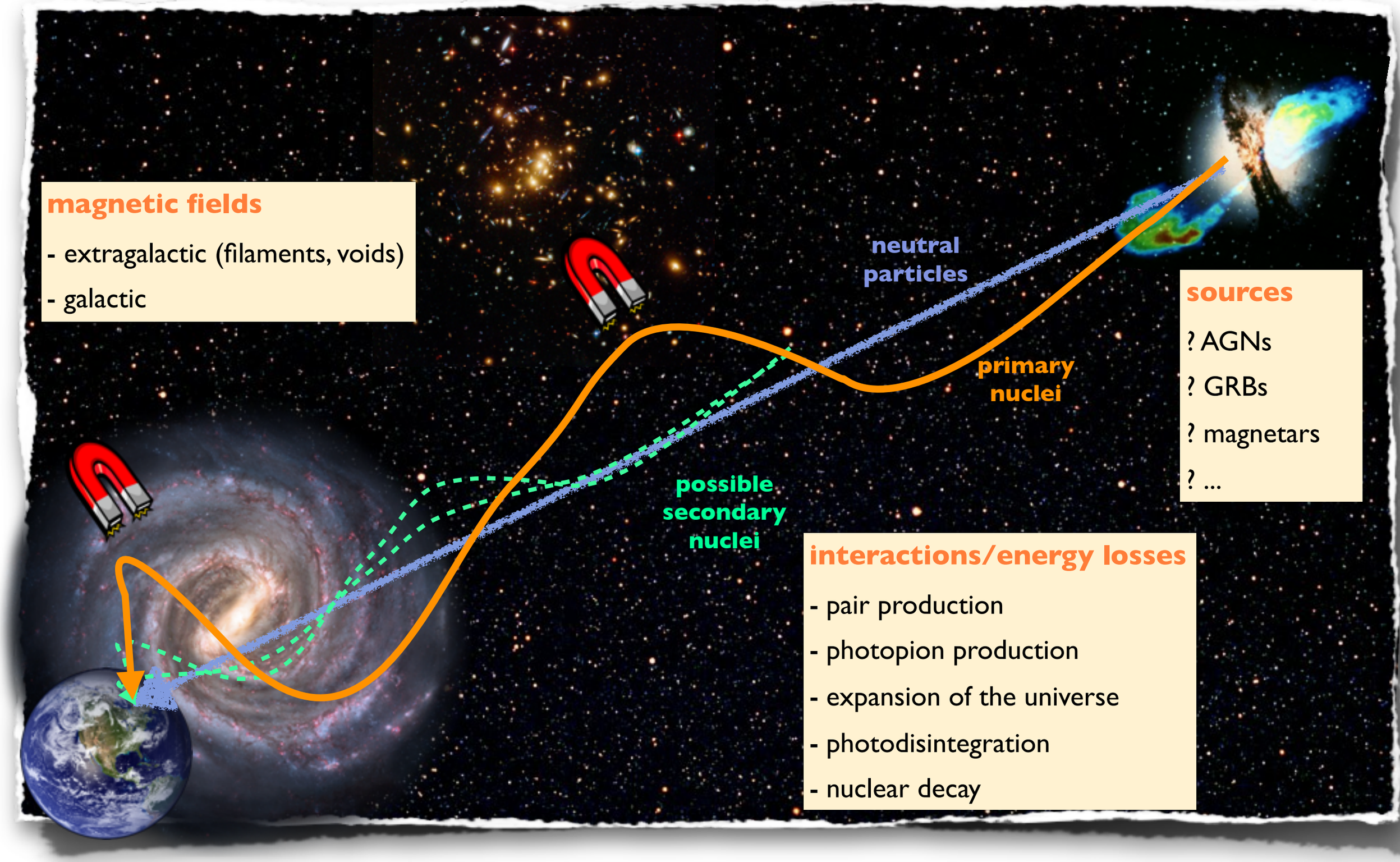


energy loss and interaction processes

photopion production

$$p + \gamma \rightarrow \Delta^+ \rightarrow \begin{cases} p + \pi^0 \\ n + \pi^+ \end{cases}$$

- mean free path for nuclei written as a function of the mfp for protons and neutrons

expansion of the universe

$$\frac{dt}{dz} = \frac{1}{H_0} \frac{1}{1+z} \frac{1}{\sqrt{\Omega_m (1+z)^3 + \Omega_\Lambda}}$$

$$E = \frac{E_0}{1+z}$$

pair production

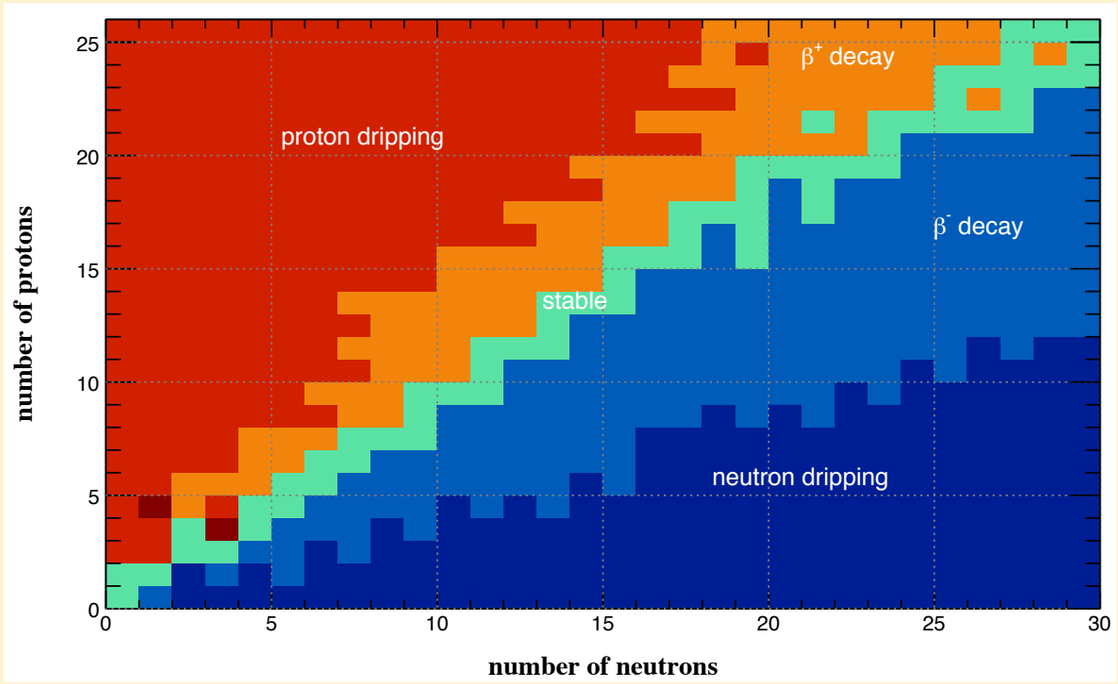
$$-\frac{dE_{A,Z}}{dt} = 3\alpha\sigma_T h^{-3} Z^2 m_e c^2 k_B T f(\Gamma)$$

photodisintegration

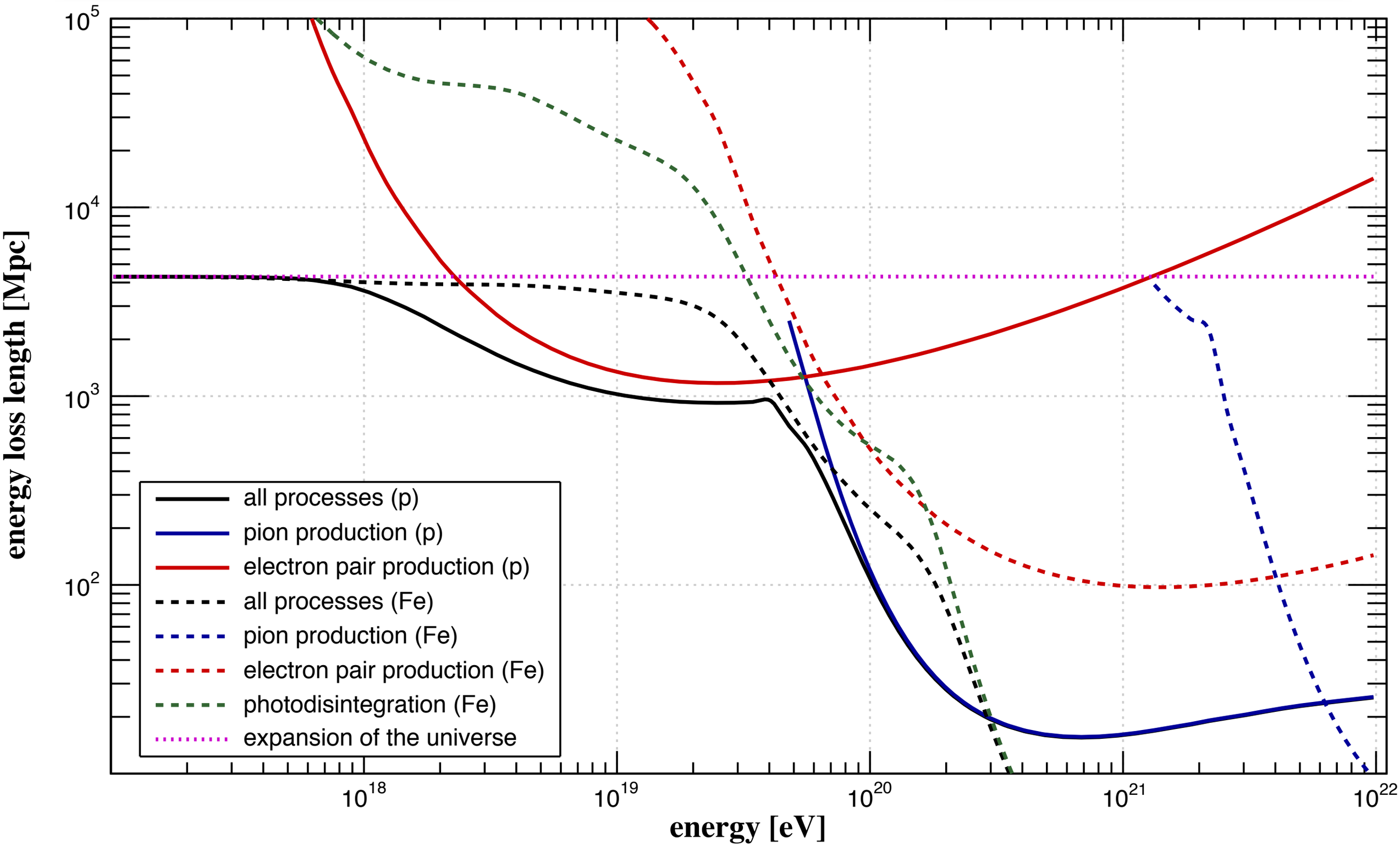
- tabulated cross sections

$$\frac{1}{\lambda(\Gamma)} = \int_{E_{min}}^{E_{max}} n(\epsilon, z) \bar{\sigma}(\epsilon'_{max} = 2\Gamma\epsilon) d\epsilon$$

nuclear decay

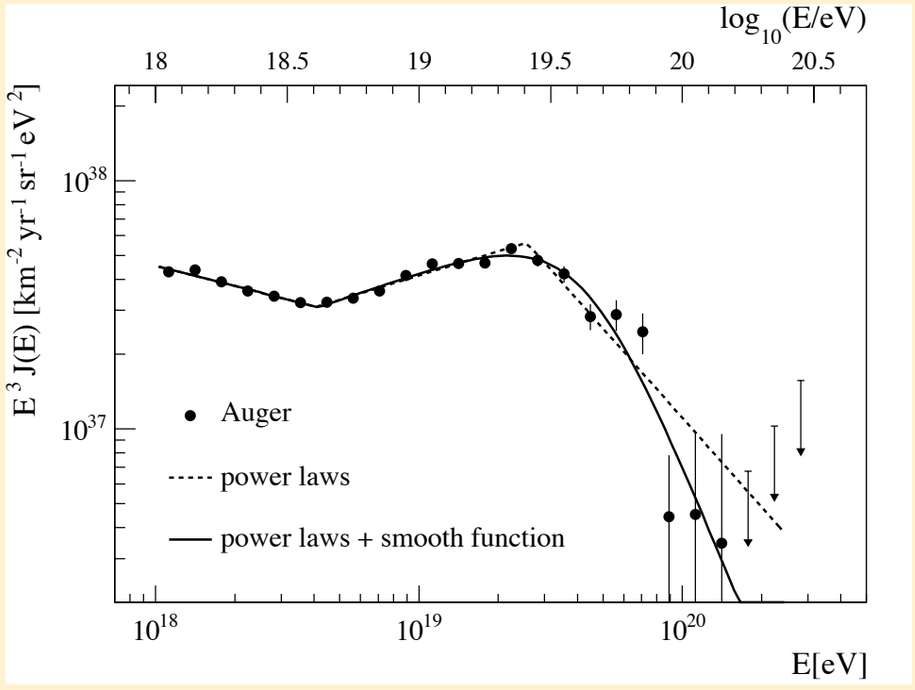


energy loss processes



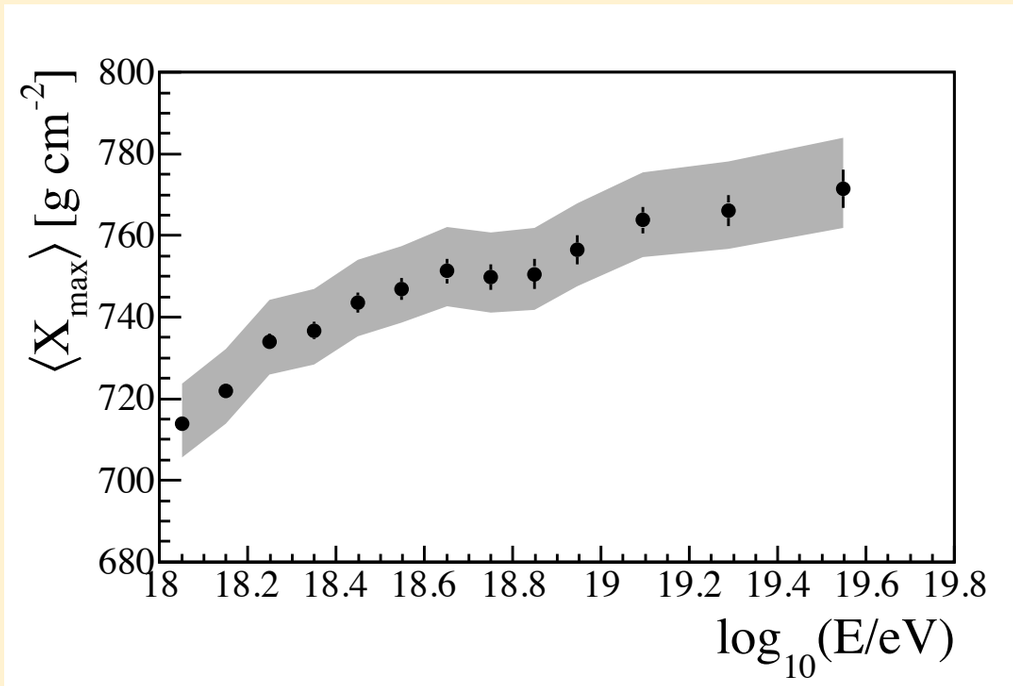
motivation

spectrum



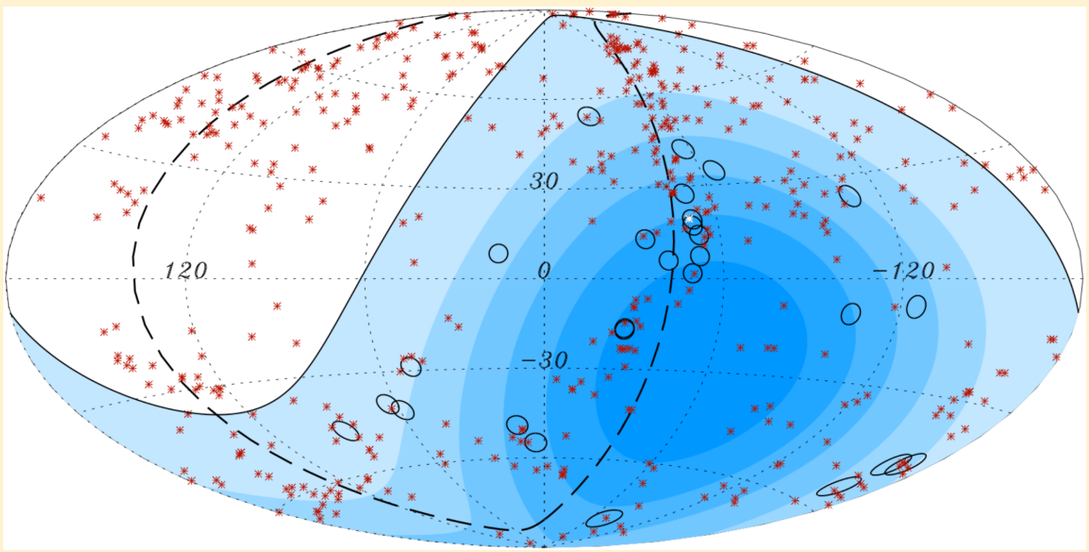
Pierre Auger Collaboration. ICRC 2011.

composition



Pierre Auger Collaboration. JCAP 02 (2013) 026.

anisotropy



Pierre Auger Collaboration. Science 318 (2007) 938.

- ✦ explain these three observables
- ✦ magnetic fields and source distribution may affect spectrum and composition, and certainly affect anisotropy
- ✦ 3D simulations are needed
- ✦ large parameter space => fast simulations

CRPropa

CRPropa 2.0

- ✦ available in: crpropa.desy.de
- ✦ "official" release
- ✦ paper: Kampert et al. Astropart. Phys. 42 (2013) 41

CRPropa 3.0

- ✦ available in: crpropa.desy.de/CRPropa3
- ✦ development version
- ✦ new features: modular structure, parallelization, cosmology in 3D, galactic lensing

33RD INTERNATIONAL COSMIC RAY CONFERENCE, RIO DE JANEIRO 2013
THE ASTROPARTICLE PHYSICS CONFERENCE

arXiv:1307.2643

ICRC 2013

CRPropa 3.0 – a Public Framework for Propagating UHE Cosmic Rays through Galactic and Extragalactic Space

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how does it work

source

magnetic field

magnetic field

turbulent
uniform
large scale structure
- uniform grids
- SPH

source

spectrum
composition
distribution
evolution

particle

observer

interactions

secondaries

cosmology

interactions/ energy losses

pair production
pion production
photodisintegration
nuclear decay
expansion of the universe

backgrounds

microwave background (CMB)
infrared background (CIB)
radio background (CRB)

galactic lensing

how does it work

source

source

spectrum
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distribution
evolution

[only 1D]

[only 3D]

magnetic field

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turbulent
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microwave background (CMB)
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radio background (CRB)

secondaries

cosmology

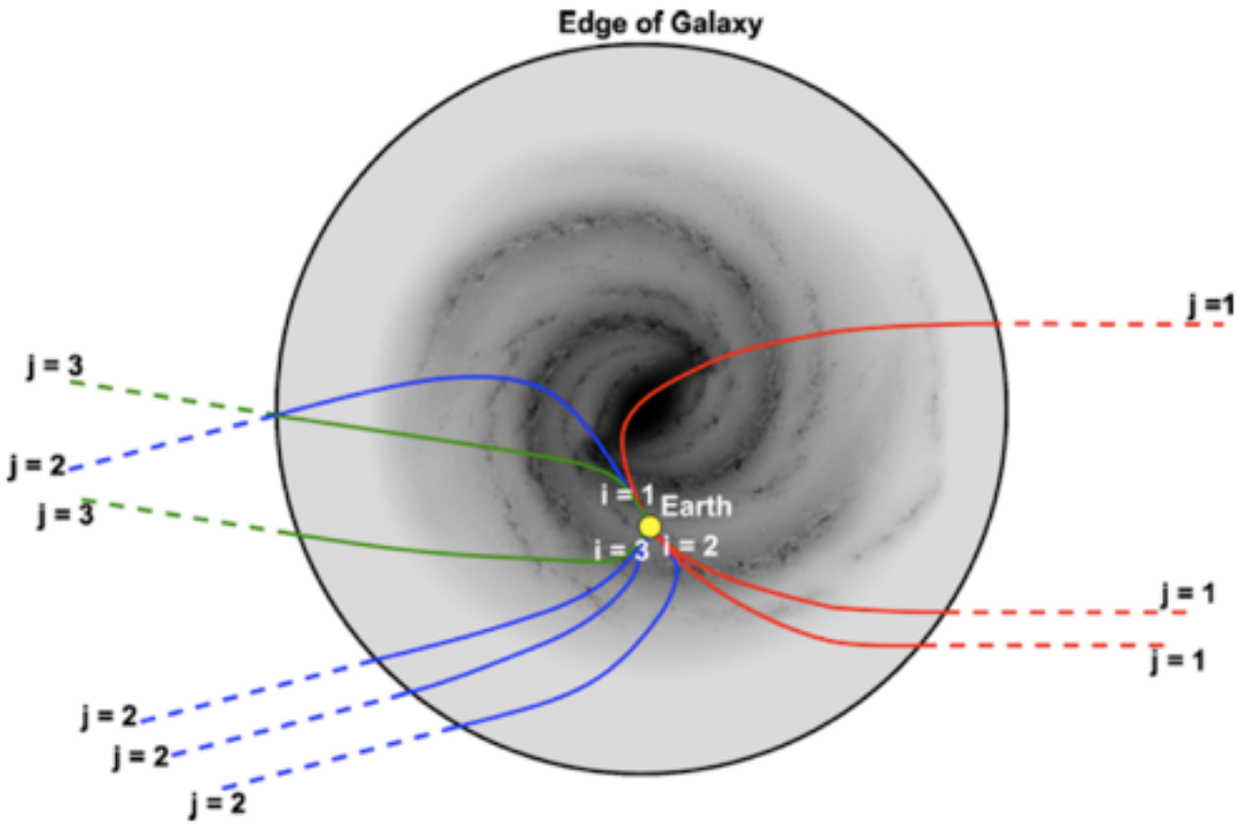
[a posteriori correction made for 3D]

galactic lensing

[only 3D]

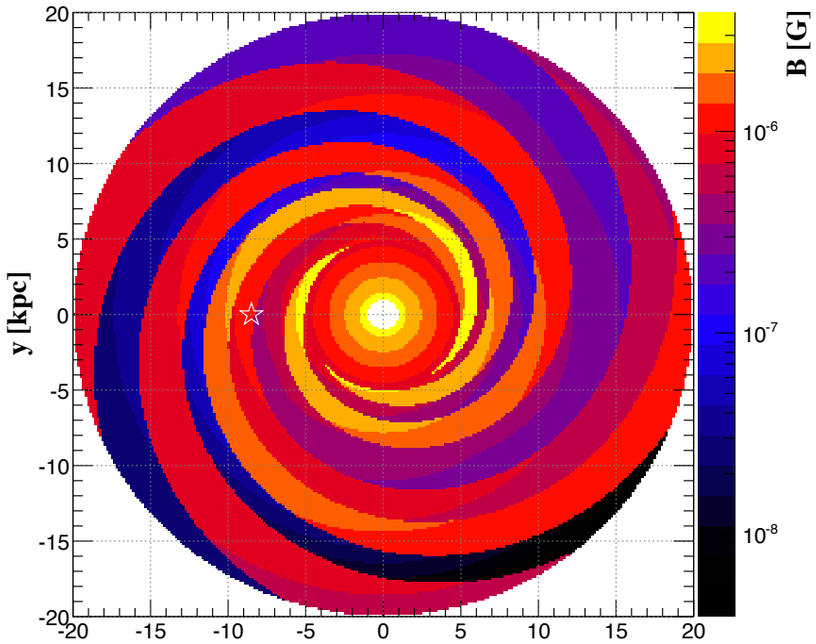
lensing technique: galactic magnetic field

- ✦ assumes no energy losses
- ✦ each "lens" corresponds to a different energy bin
- ✦ backtrack protons to the galactic border
- ✦ nuclei will have deflection of Z times the deflection for protons

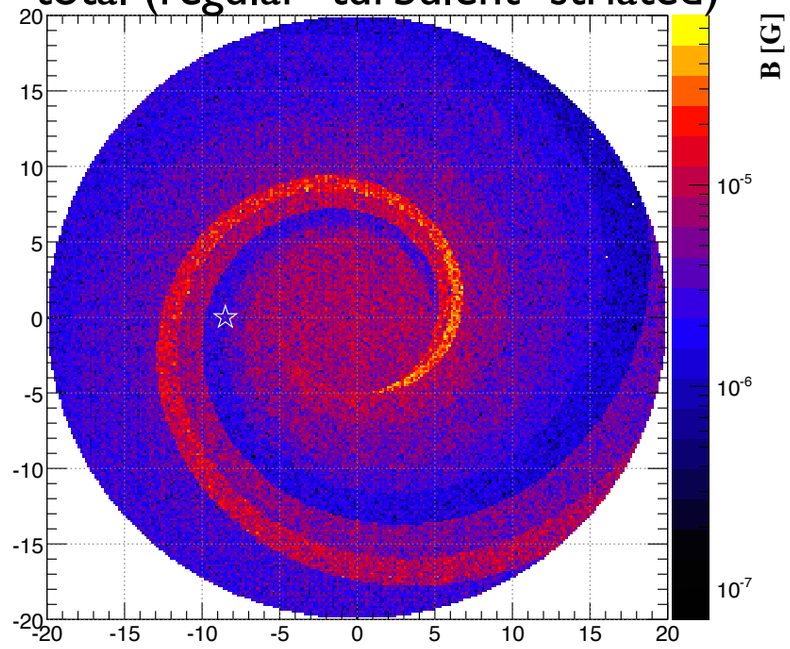


Jansson & Farrar, ApJ 761 (2012) L11

regular

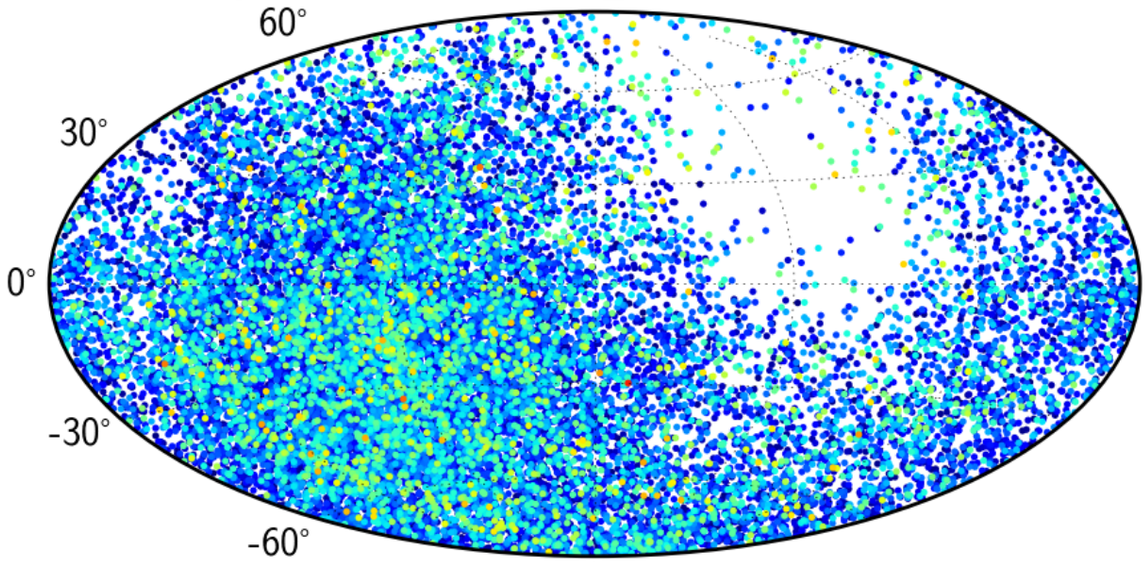


total (regular+turbulent+striated)

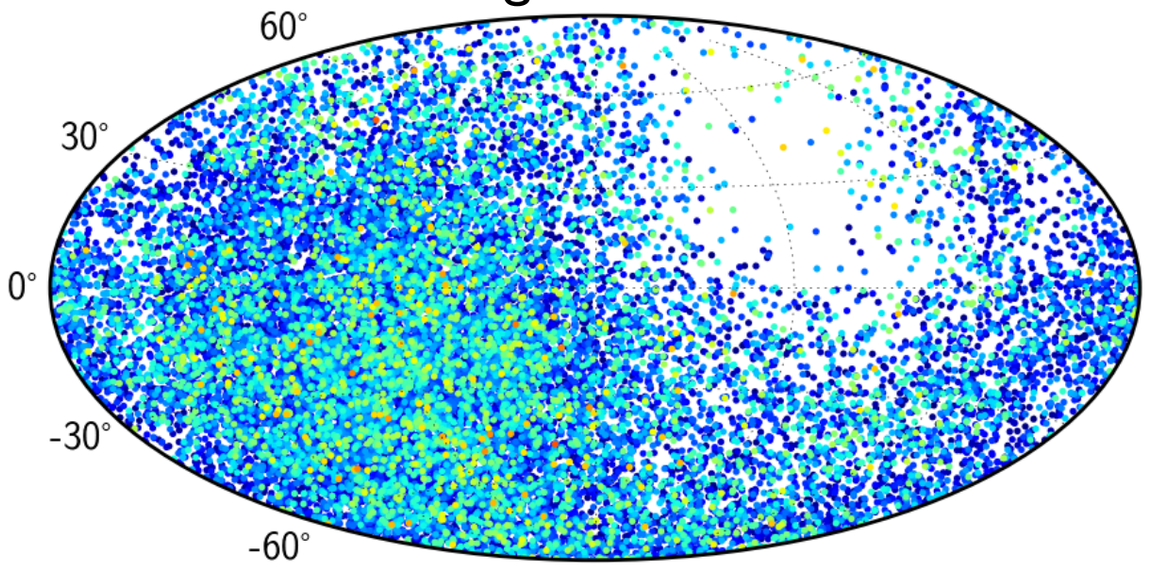


example: galactic lensing

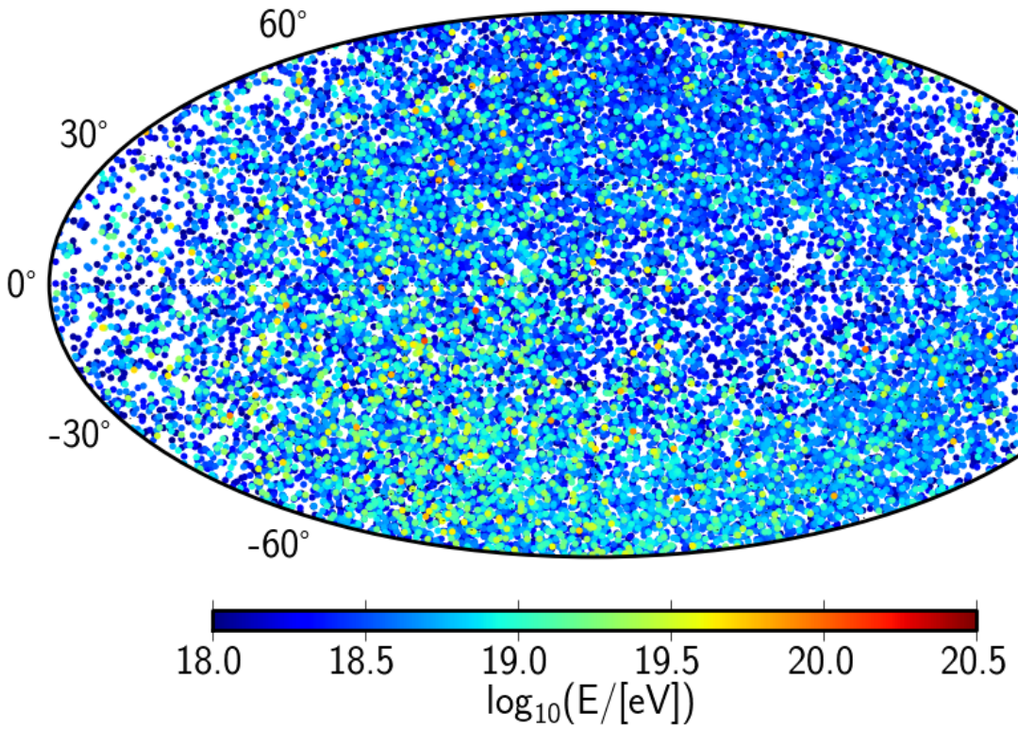
protons at the galactic border



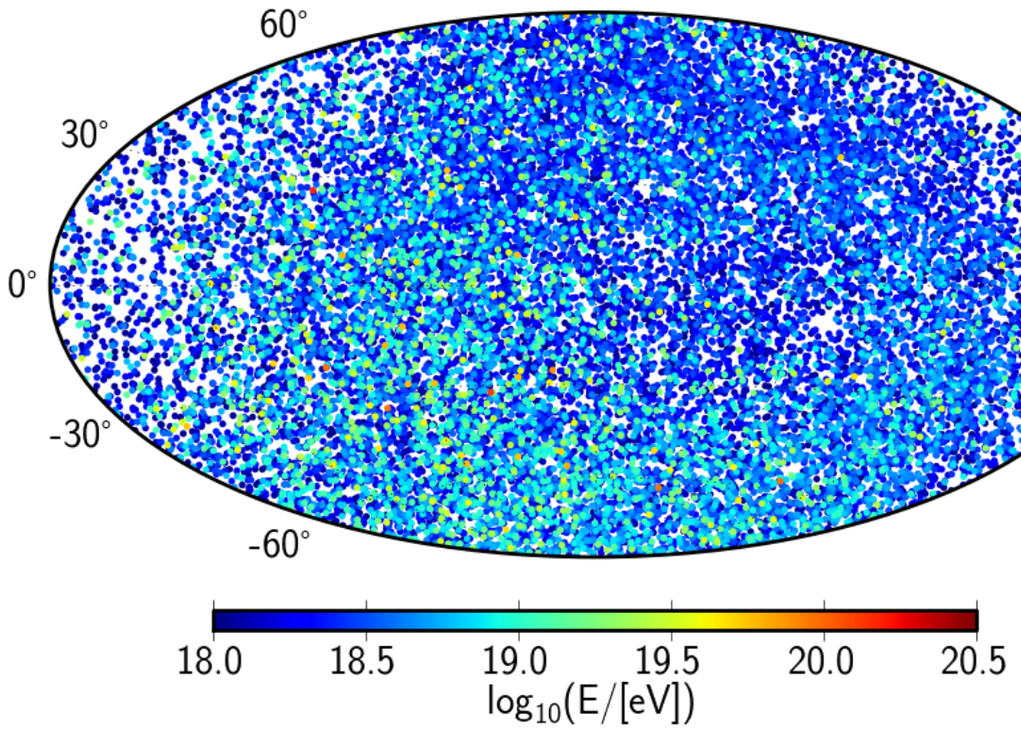
iron at the galactic border



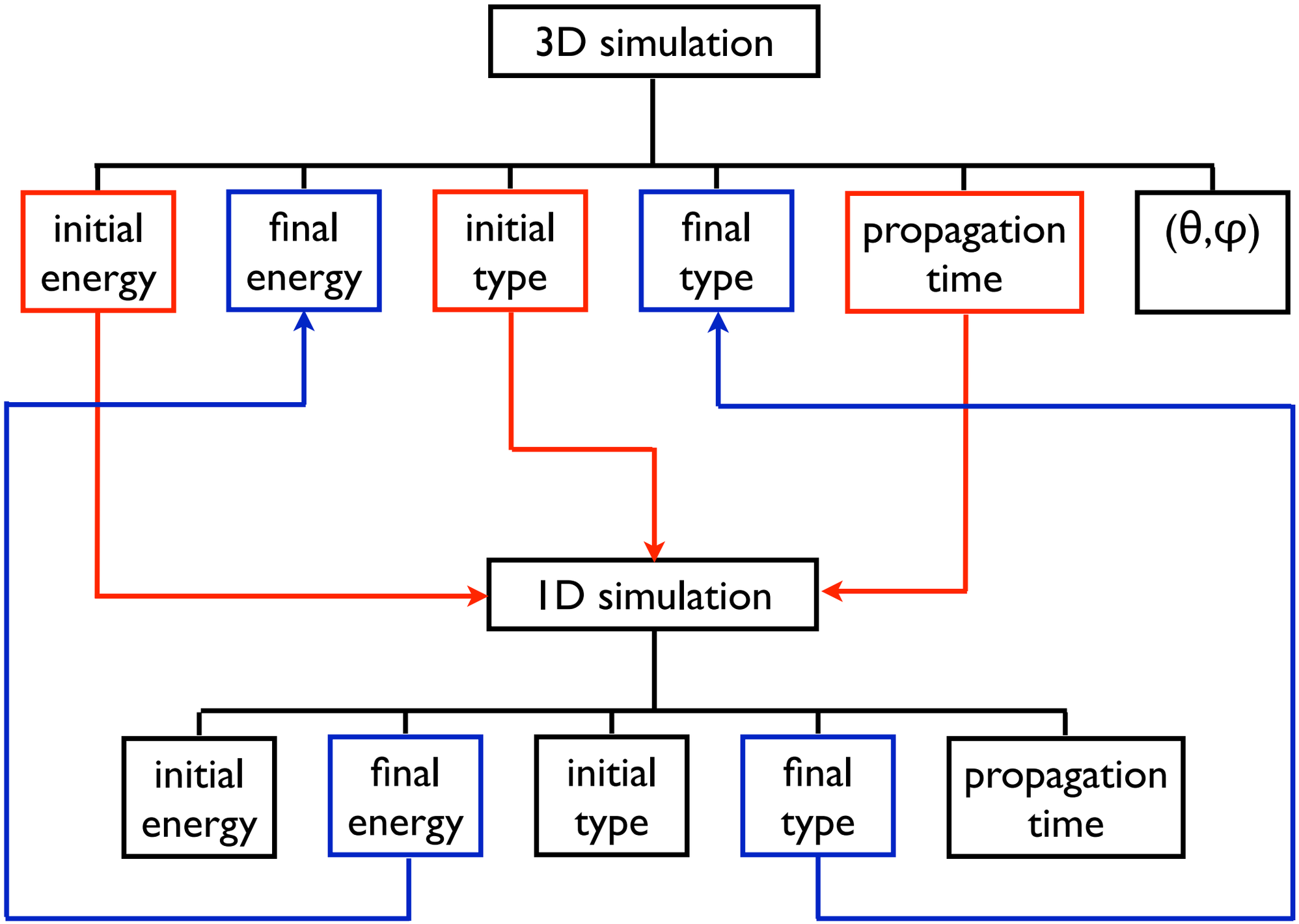
protons at Earth



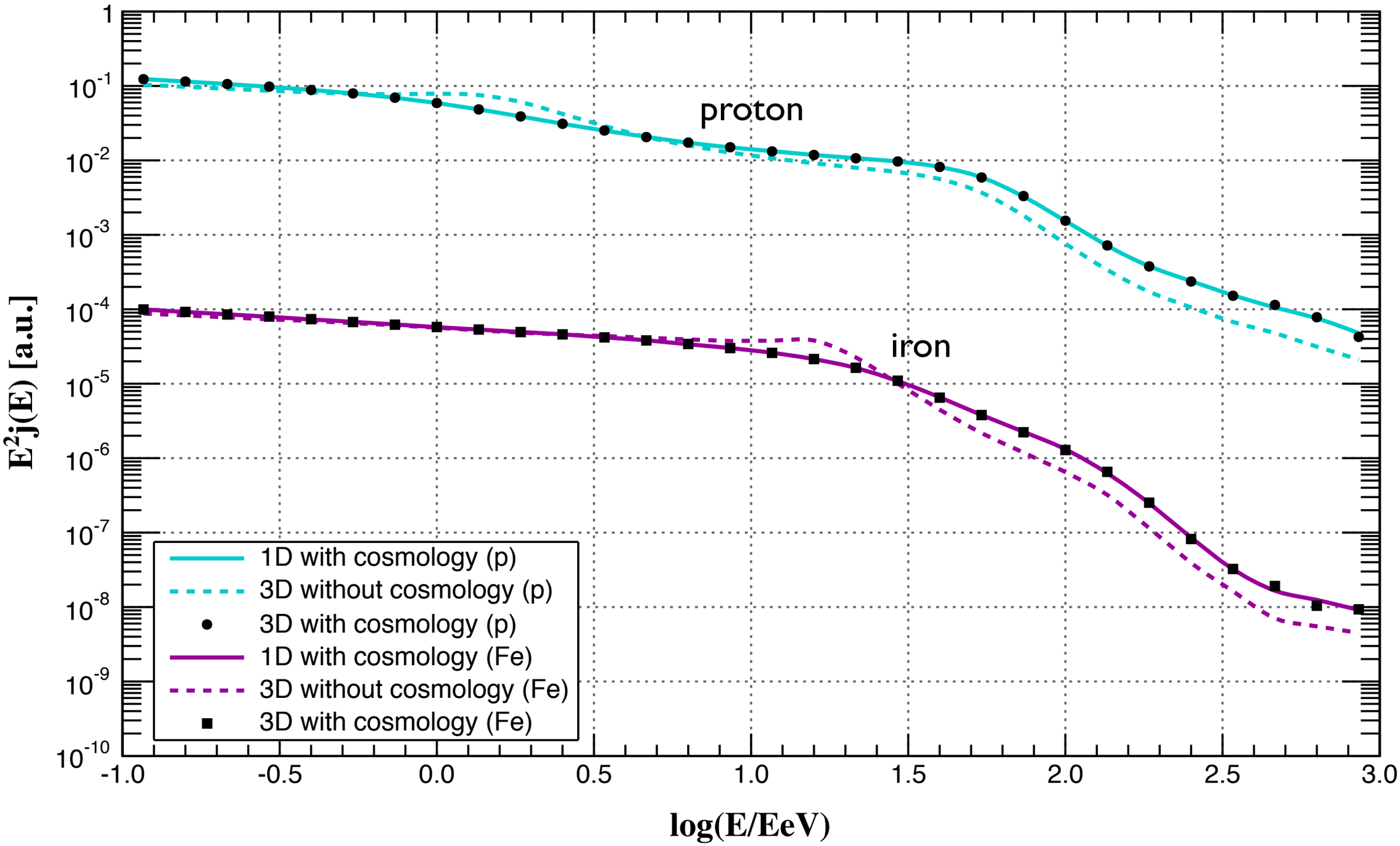
iron at Earth



correcting for cosmology in 3D simulations



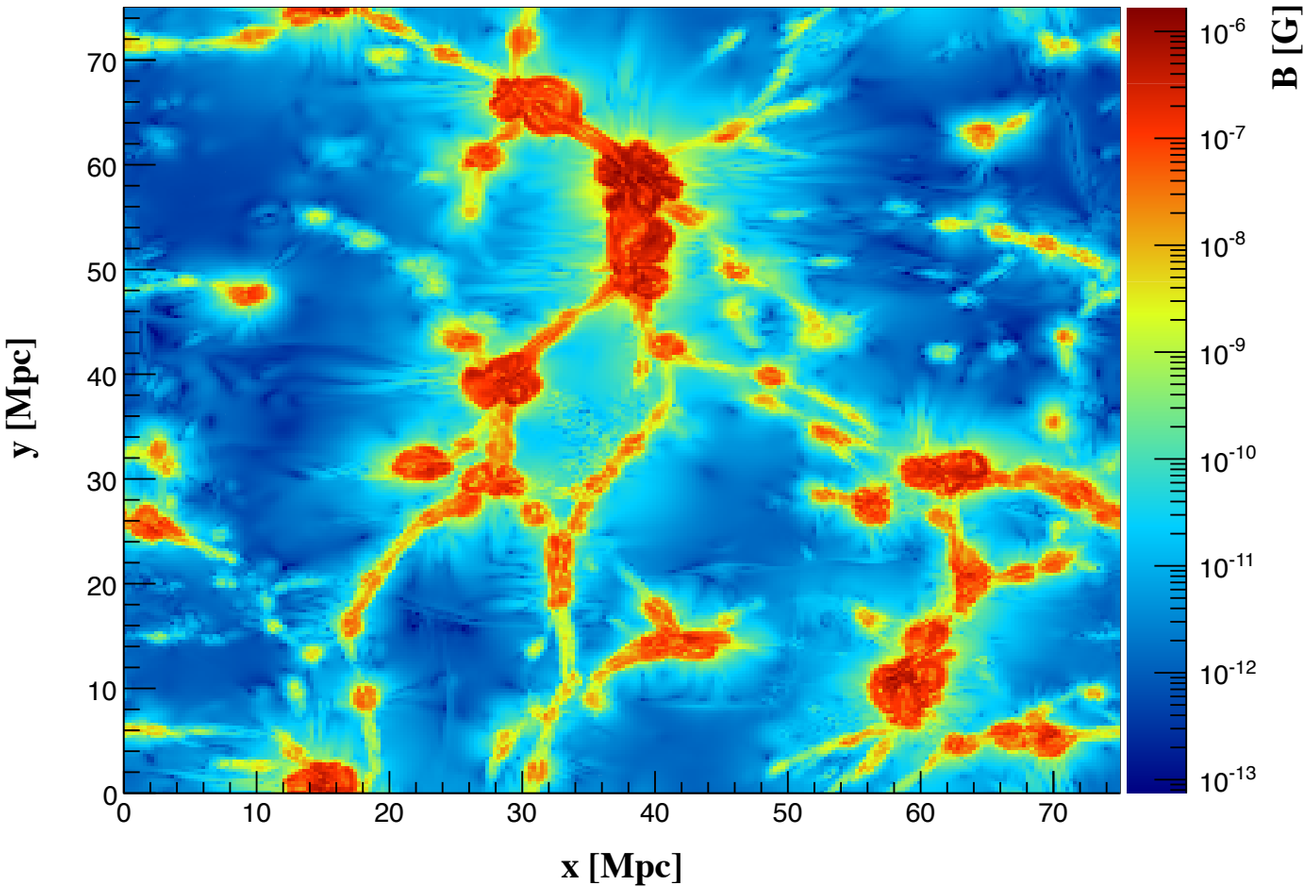
testing the cosmology correction



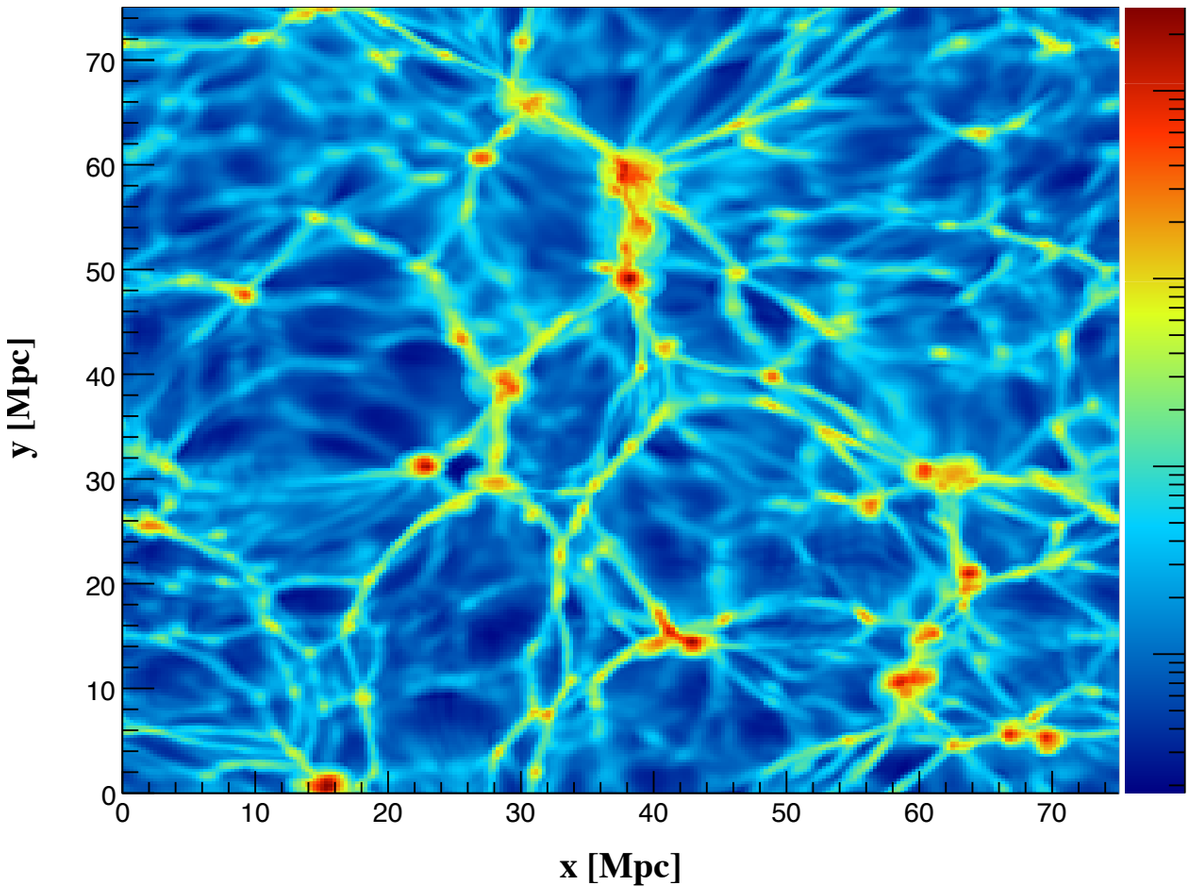
- uniform source distribution
- sources up to 4000 Mpc
- injection spectrum source = -2.2
- maximum propagation length = 4000 Mpc

application: simulation setup

magnetic field



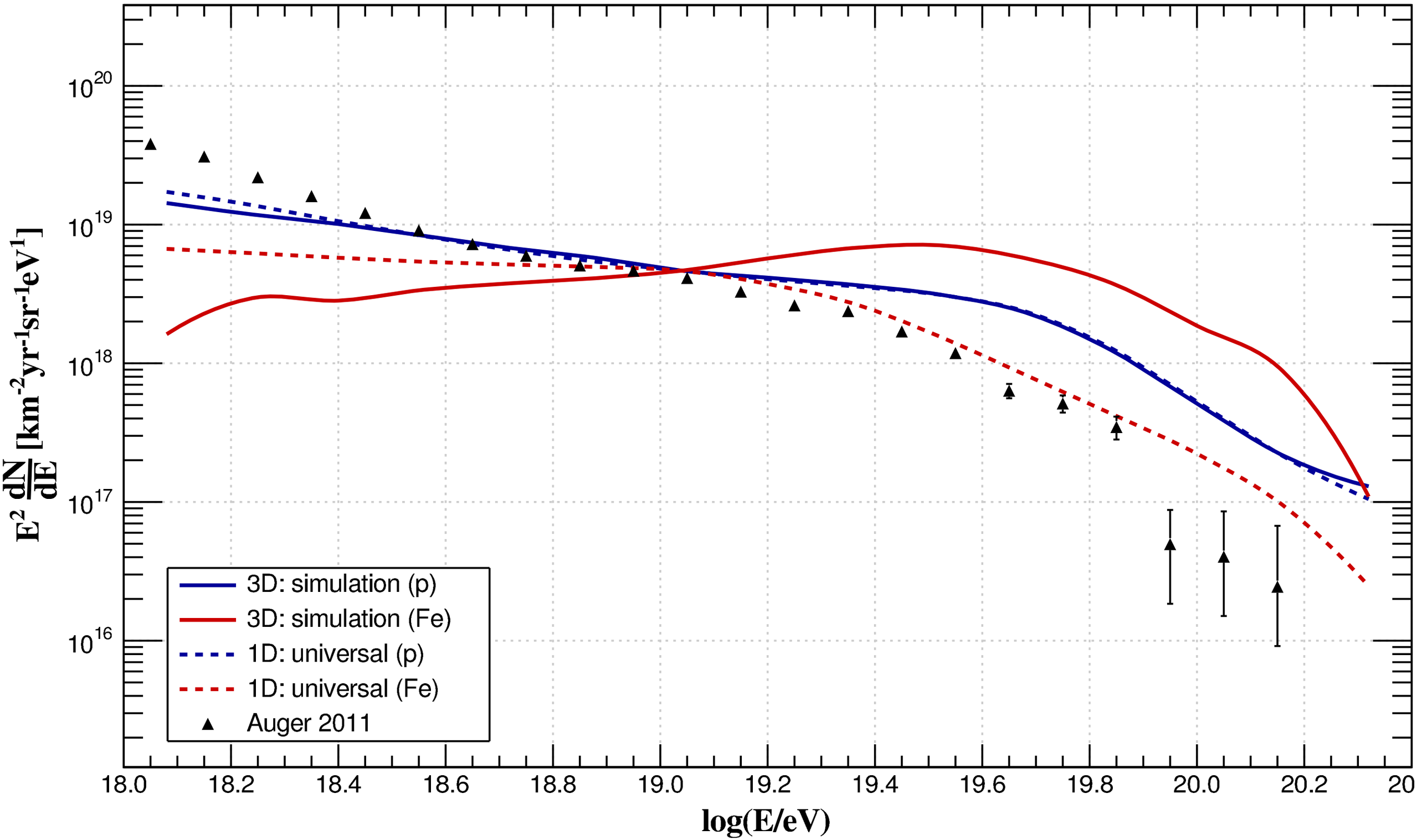
baryon density



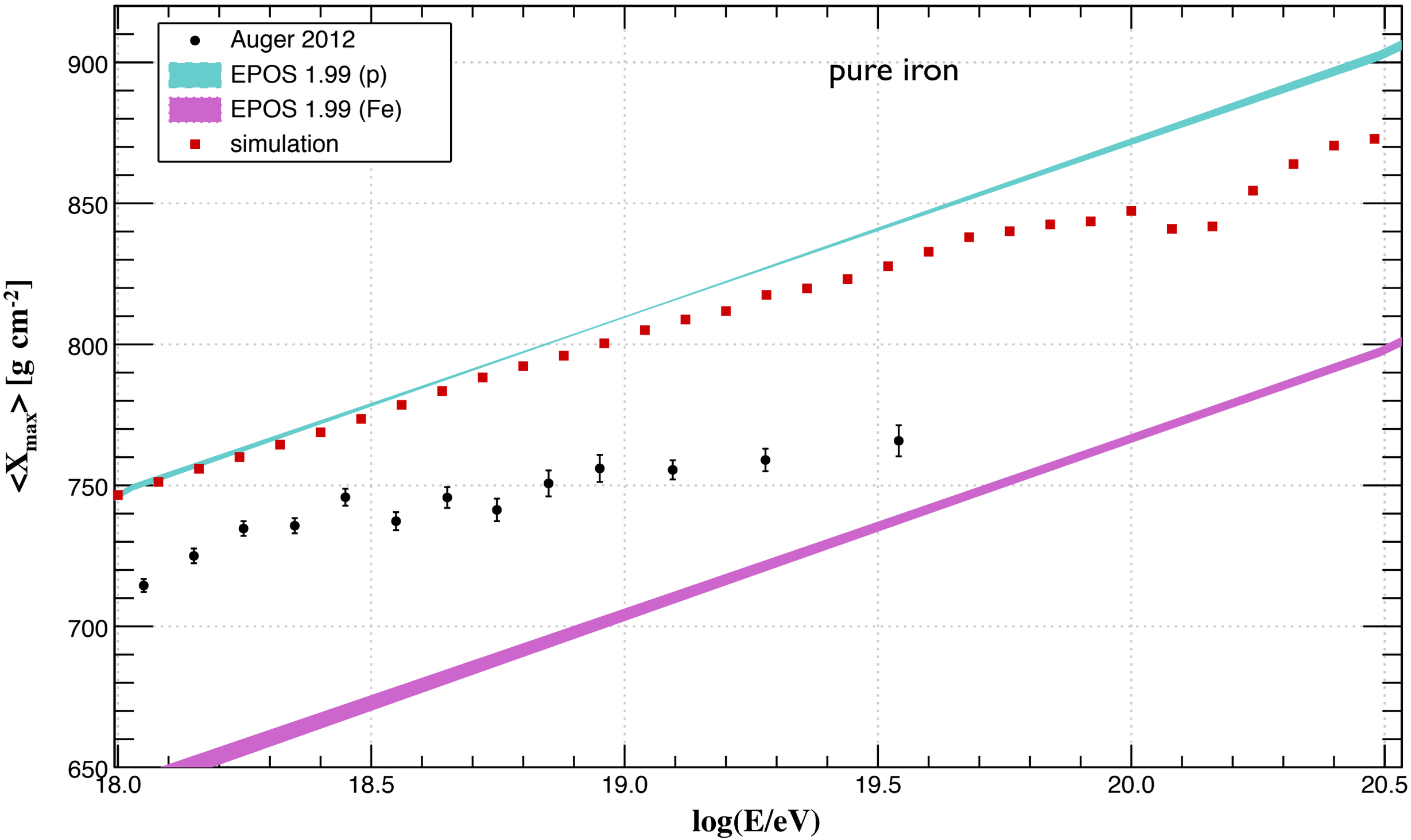
- ✦ MHD simulation from F. Miniatti
- ✦ maximum rigidity = 1000 EeV
- ✦ maximum source distance = 2 Gpc
- ✦ sources following LSS baryon density
- ✦ magnetic field from the grid

- ✦ composition: proton and iron (two cases)
- ✦ minimum energy = 1 EeV
- ✦ uniform grid

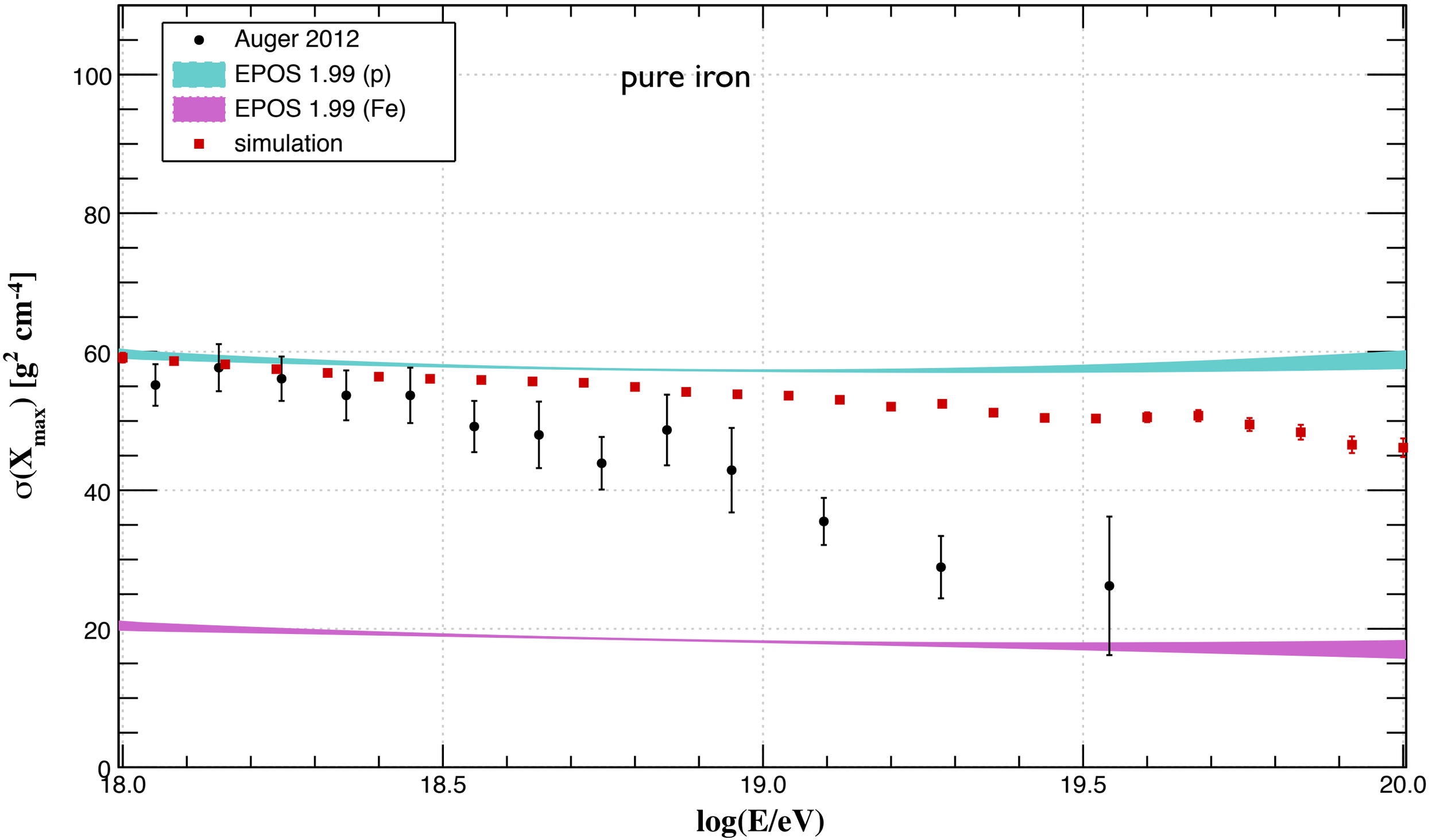
application: spectrum



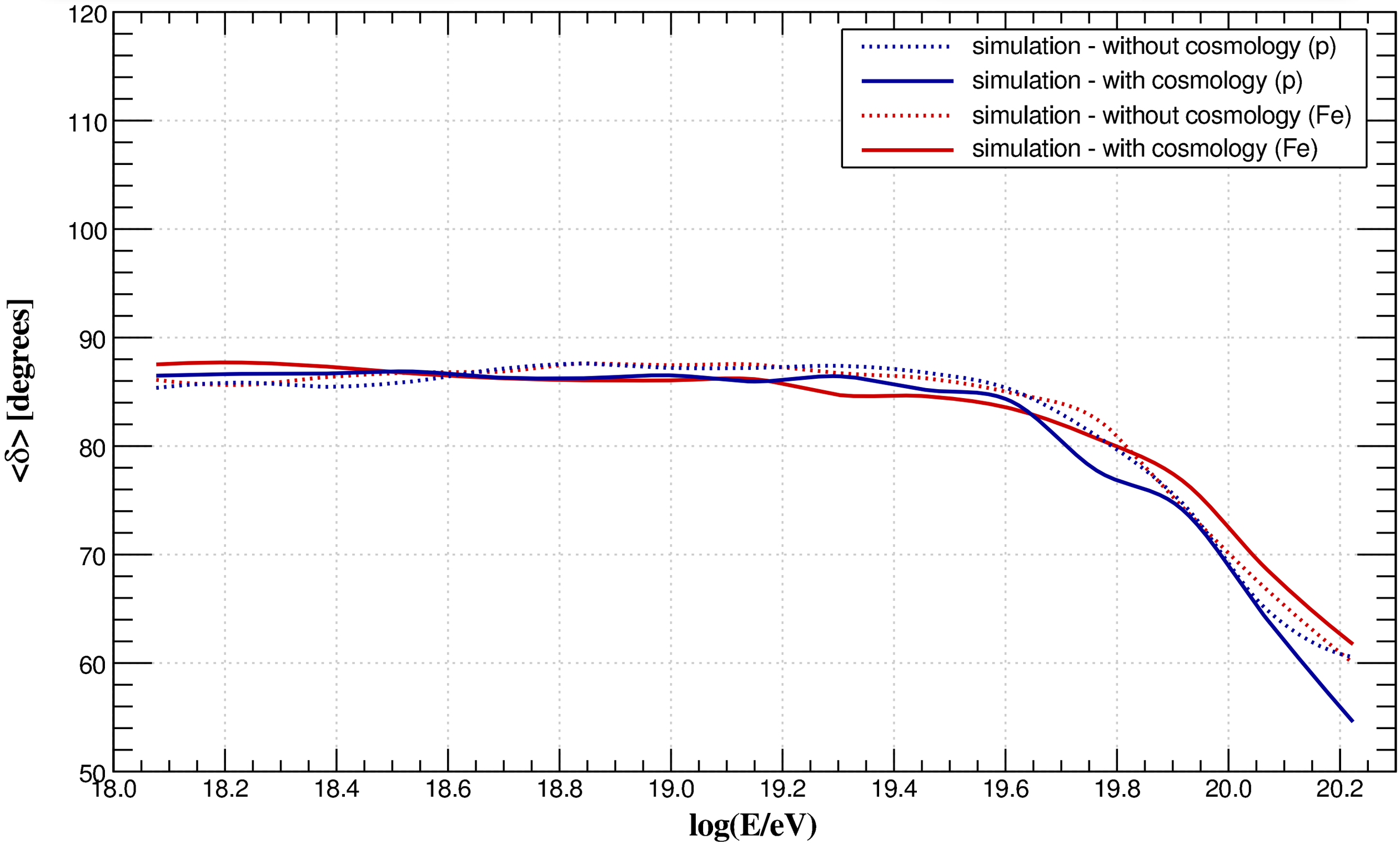
application: composition



application: composition



application: anisotropy



summary

- ✦ CRPropa framework: allows the simulation of propagation of UHE particle
- ✦ publicly available
- ✦ version 3.0 under development
- ✦ new features of version 3.0: cosmology in 3D, magnetic lensing
- ✦ parallelization allows for fast simulations => span a wide range of parameters
- ✦ comparison of simulations with observations
- ✦ possibility of multimessenger studies

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Thank you!