Physics of High-Energy Cosmic Rays

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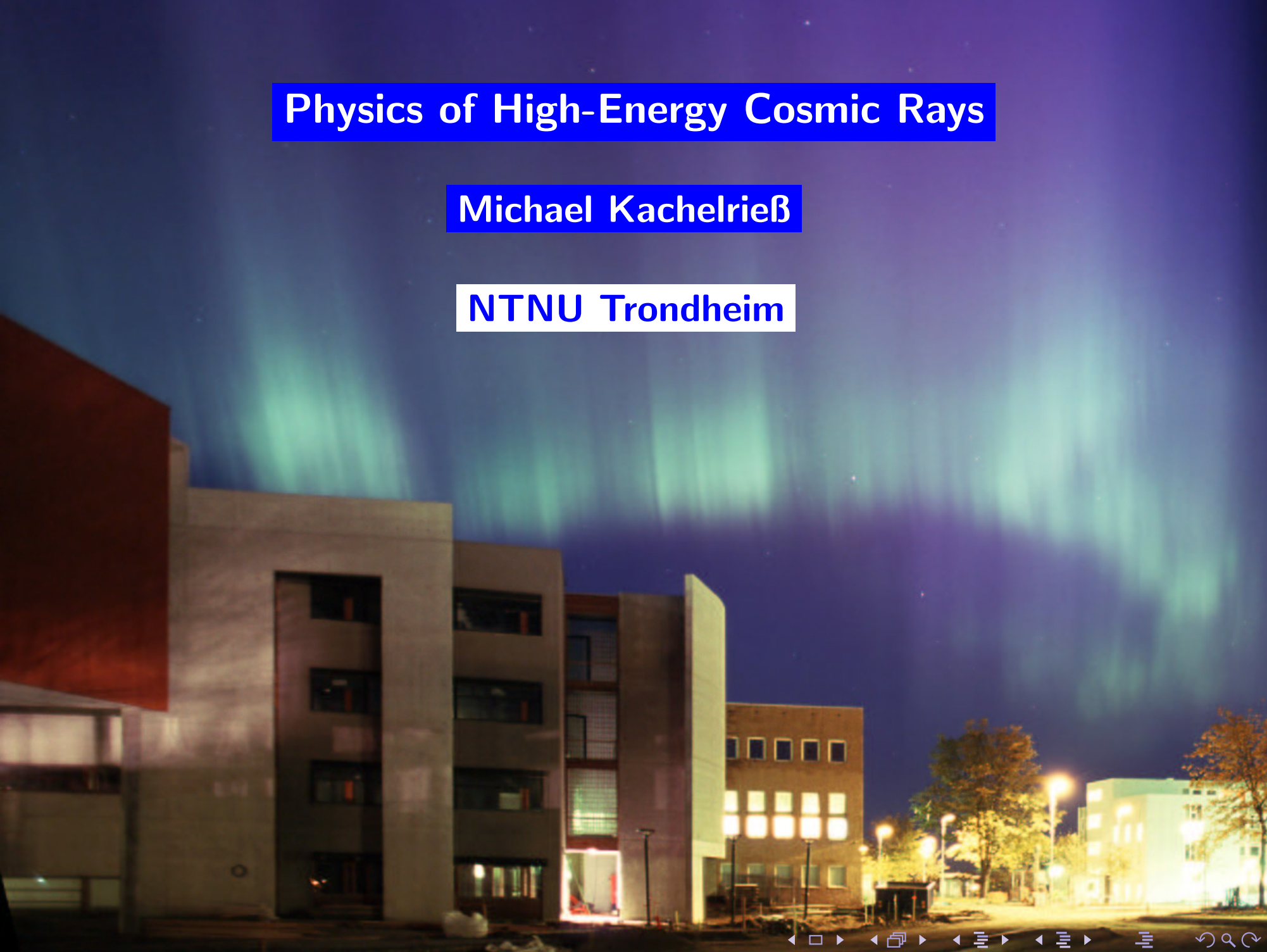
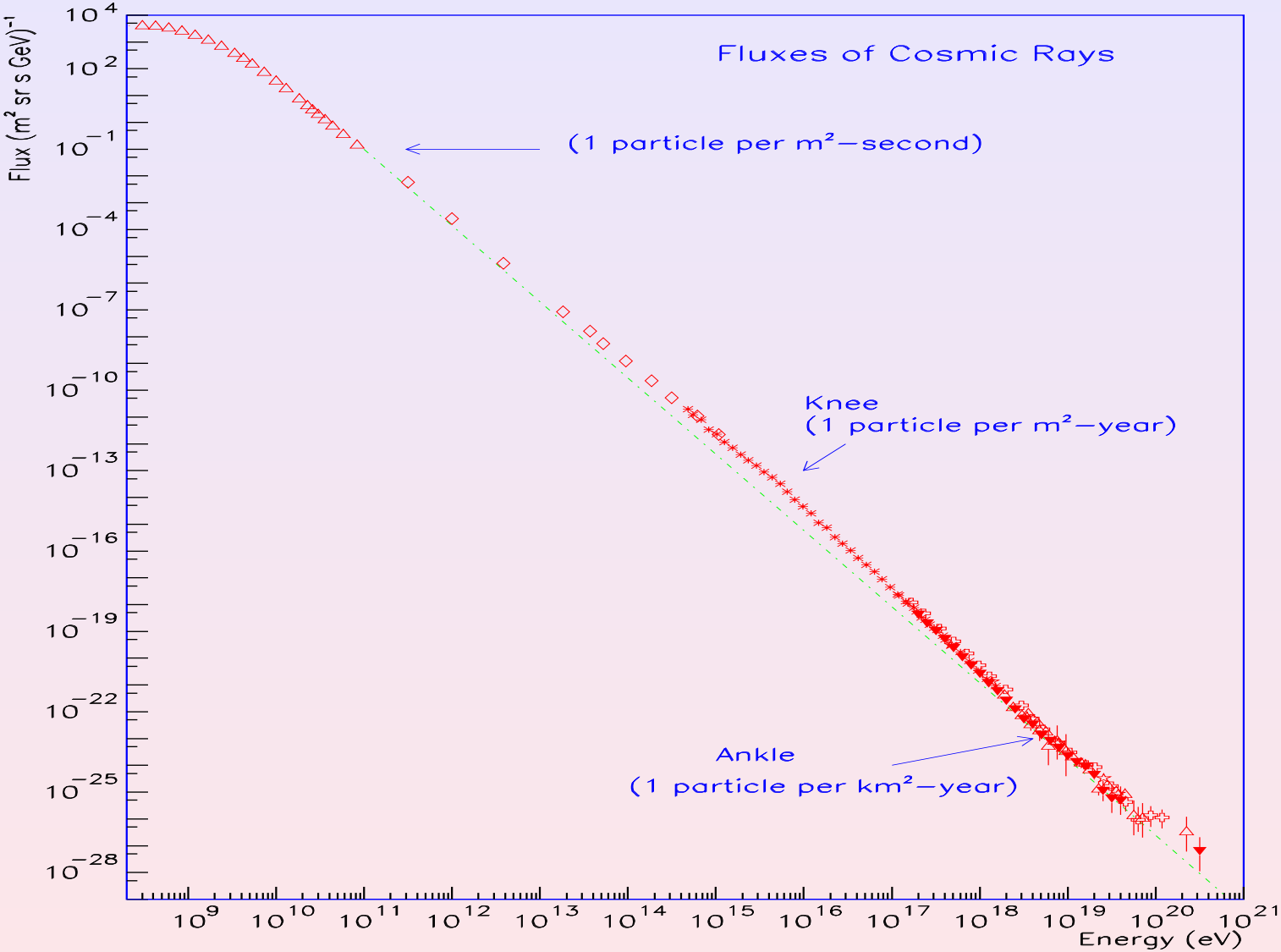
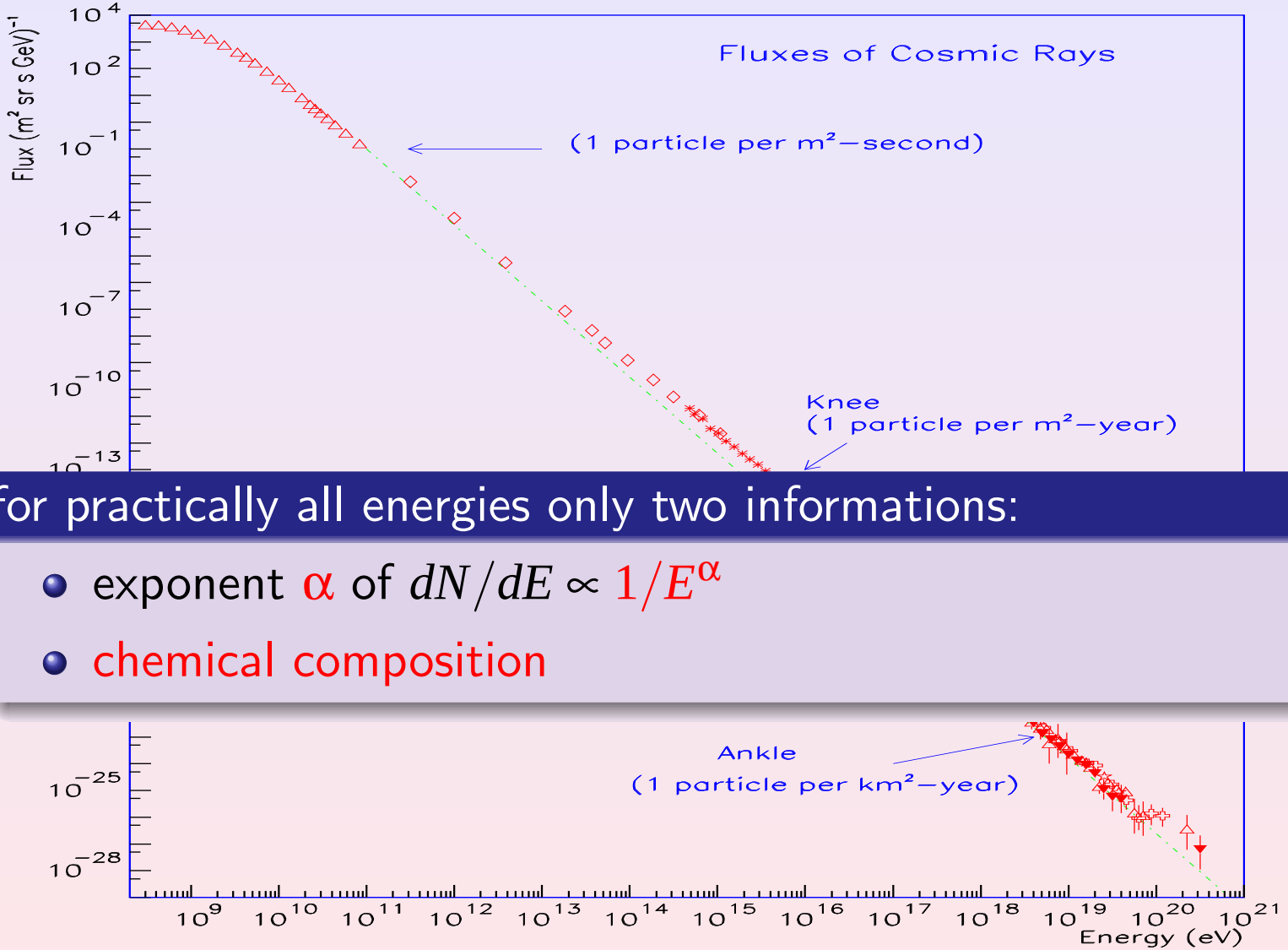


CR spectrum


Fluxes of Cosmic Rays
(1 particle per m²−second)
Knee
(1 particle per m²−year)
Ankle
(1 particle per km²−year)
Flux (m² sr s GeV)⁻¹
Energy (eV)

CR spectrum

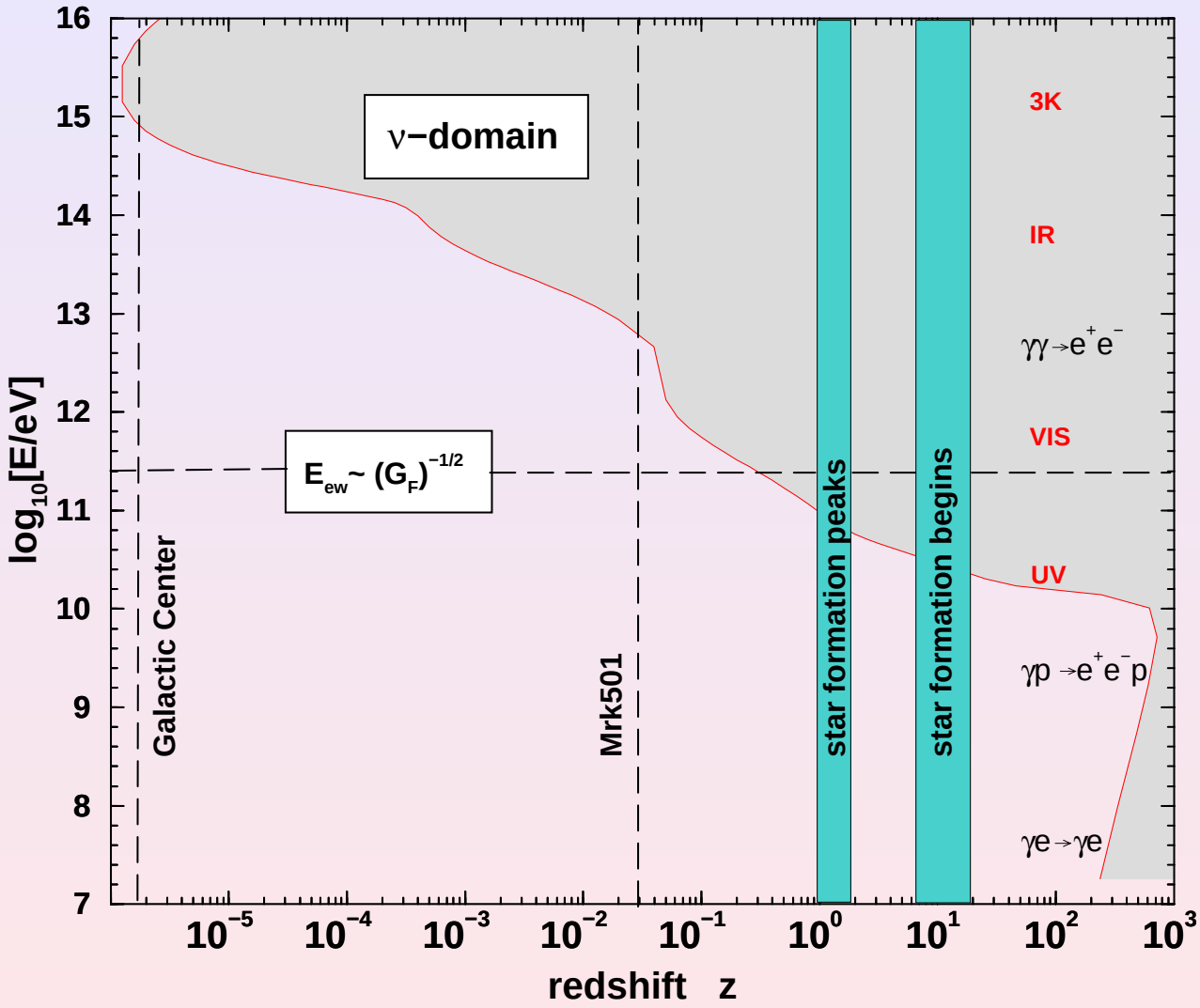


for practically all energies only two informations:

- exponent α of $dN/dE \propto 1/E^{\alpha}$
- chemical composition

Why UHECR astronomy:

- astronomy with HE photons restricted to few Mpc:



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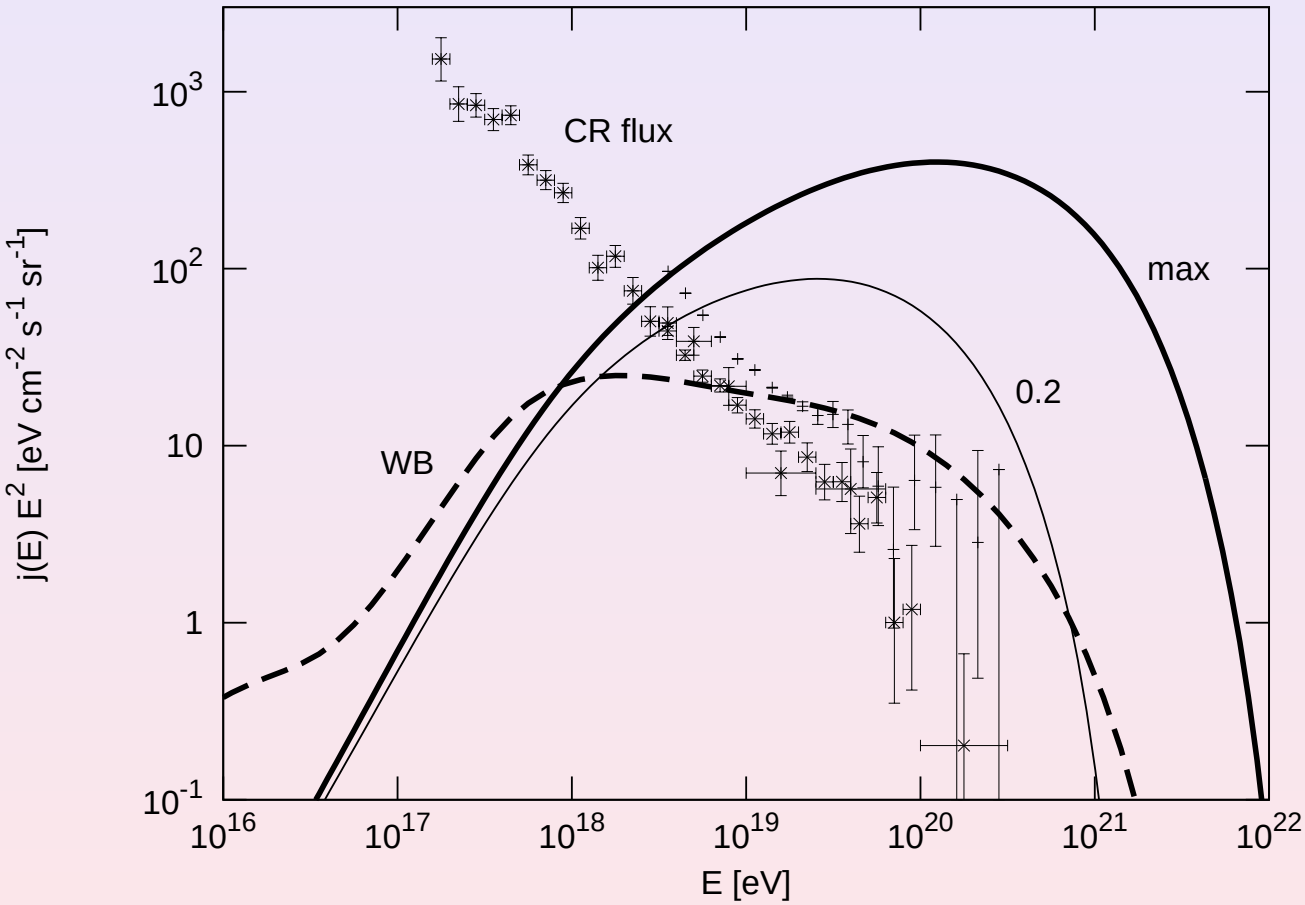
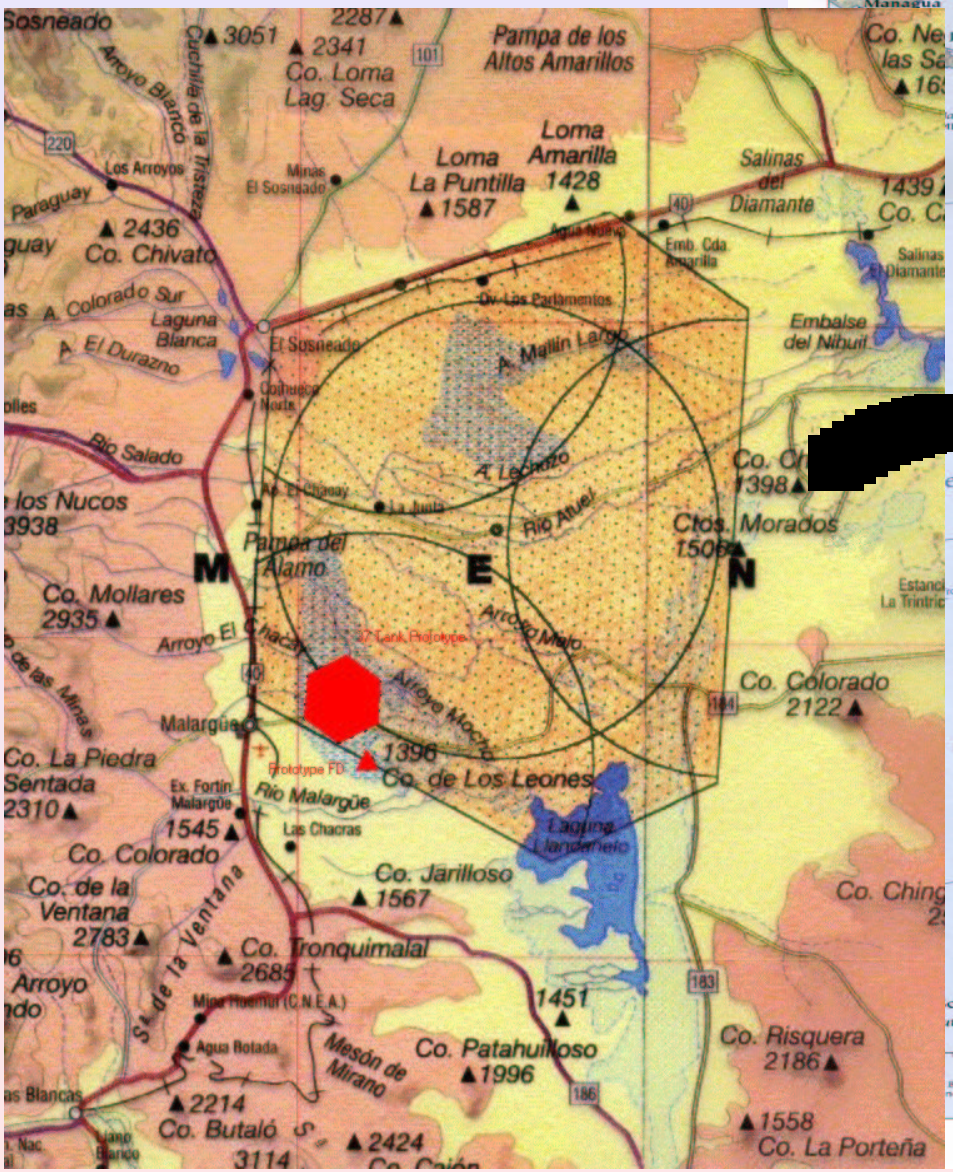
- very small neutrino event numbers: $\lesssim$ few/yr for AUGER



AUGER experiment:



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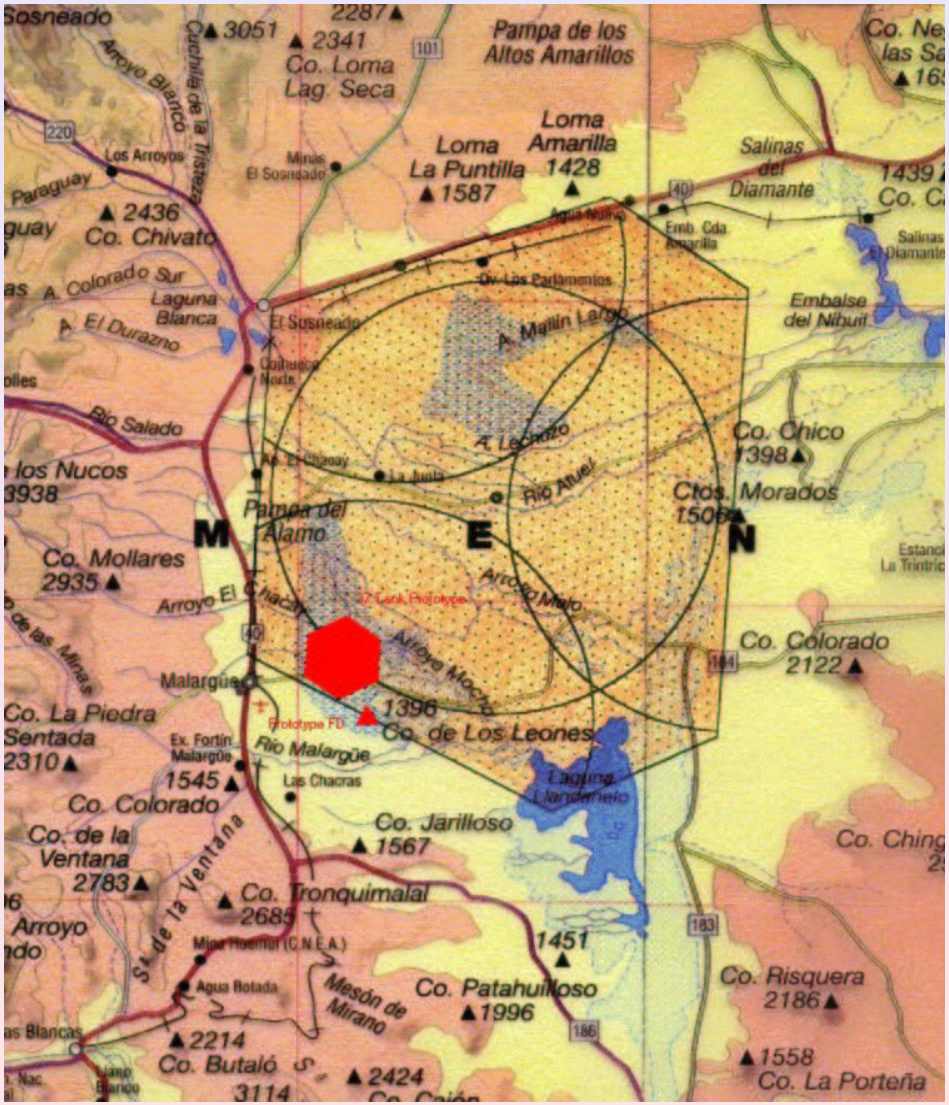

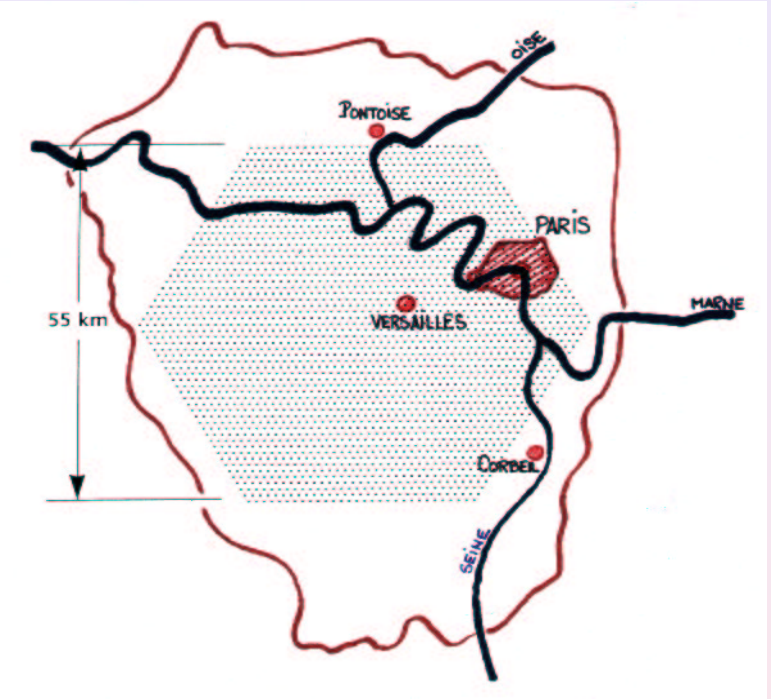

AUGER: Pampa + Detector

Standard picture

- Galactic SNR produce observed CRs up to $E \sim 10^{17}$ eV

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- Fermi shock acceleration explains power-law $1/E^{2.2}$
- modified by energy dependent diffusion
- extragalactic sources only above $E \sim 10^{19}$ eV

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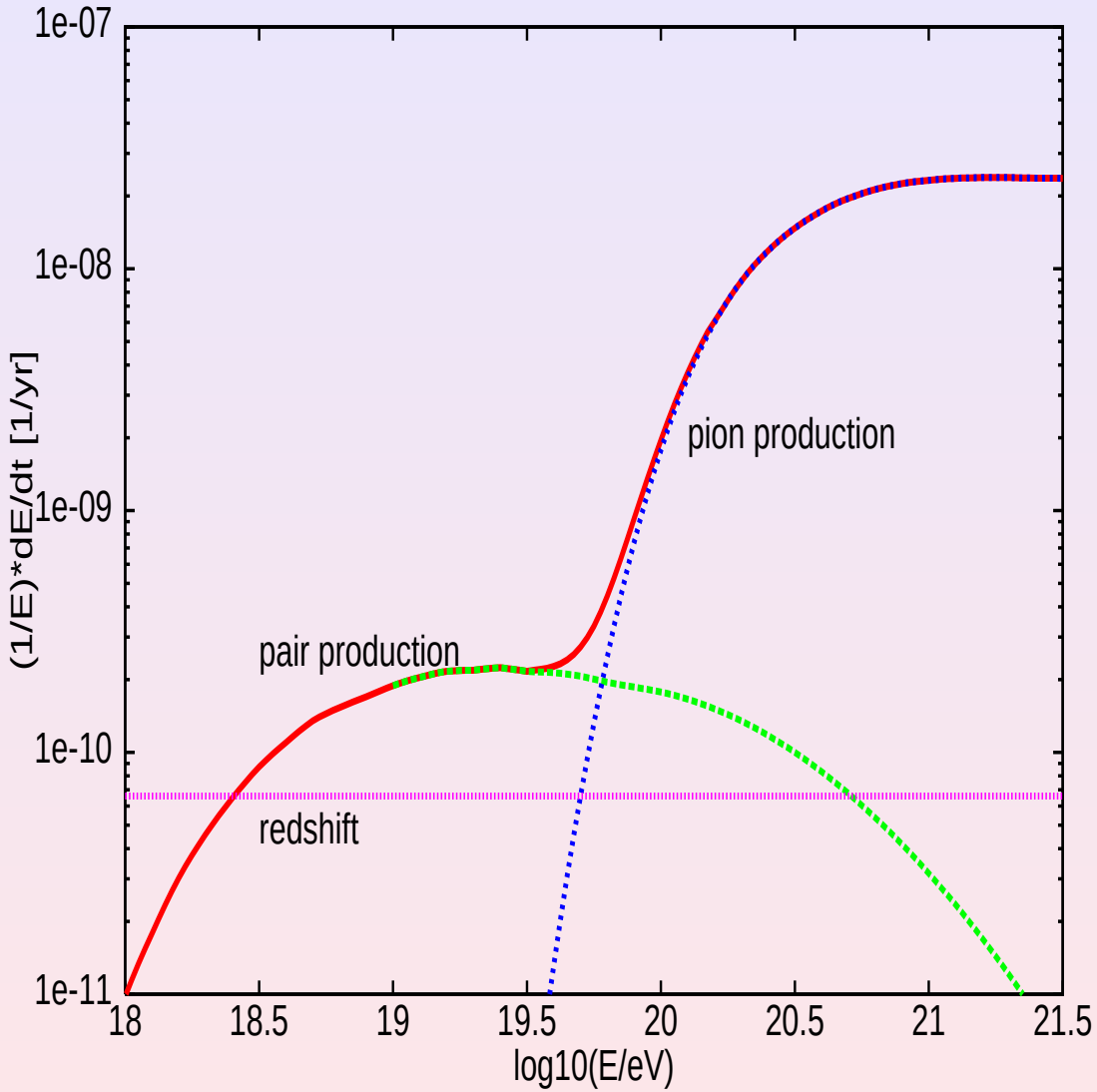
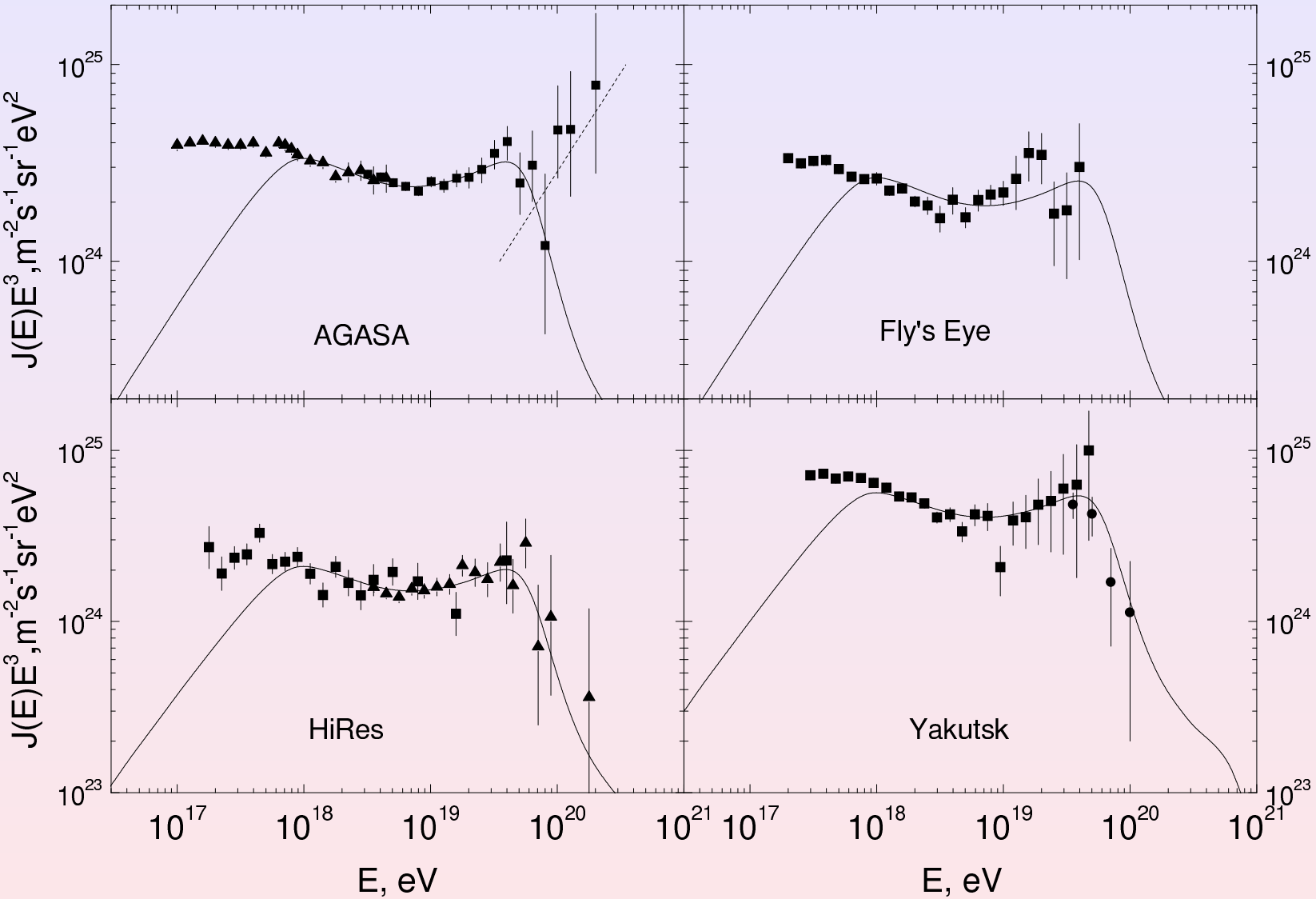
- Is astronomy with UHECRs possible?
  - role of magnetic fields
  - protons vs nuclei as primaries
- Is physics beyond the SM needed to explain UHECR events?
  - energy spectrum consistent with GZK suppression?
    - suppression depends on number of sources, their minimal distances, magnetic fields, ...
  - correlations with sources at cosmological distances?

Energy losses, the dip and the GZK cutoff

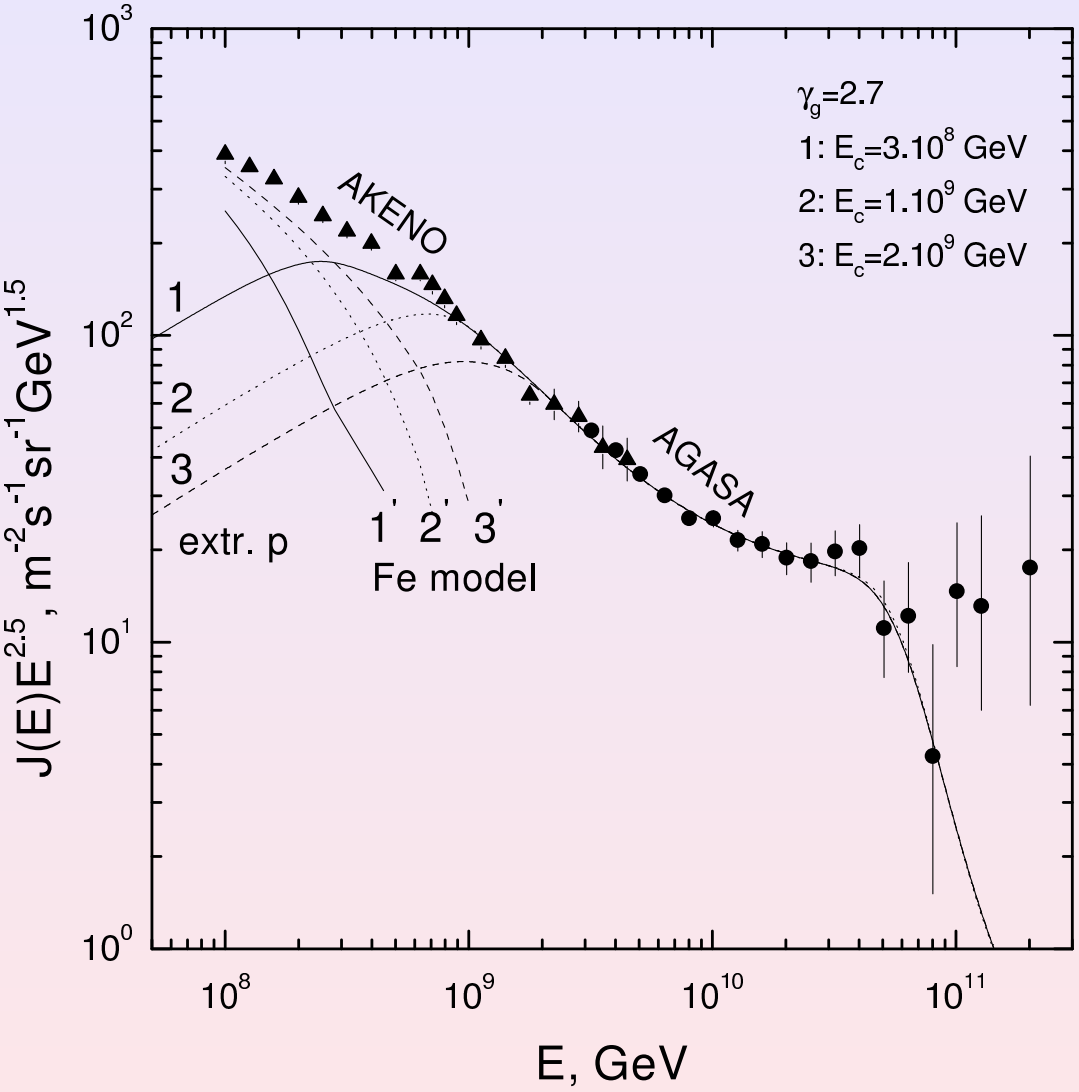


- at $E \sim 4 \times 10^{19}$ eV: $N + \gamma_{3K} \rightarrow \Delta \rightarrow N + \pi$ starts and reduces free mean path to ~ 20 Mpc
- pair production leeds to a dip at $\sim 10^{19}$ eV

Cosmic ray spectrum: the dip at 10^{19} eV [*Berezinsky, Grigorieva, Hnatyk '04*]



Transition to extragalactic protons



[Berezinsky, Grigorieva, Hnatyk '04]

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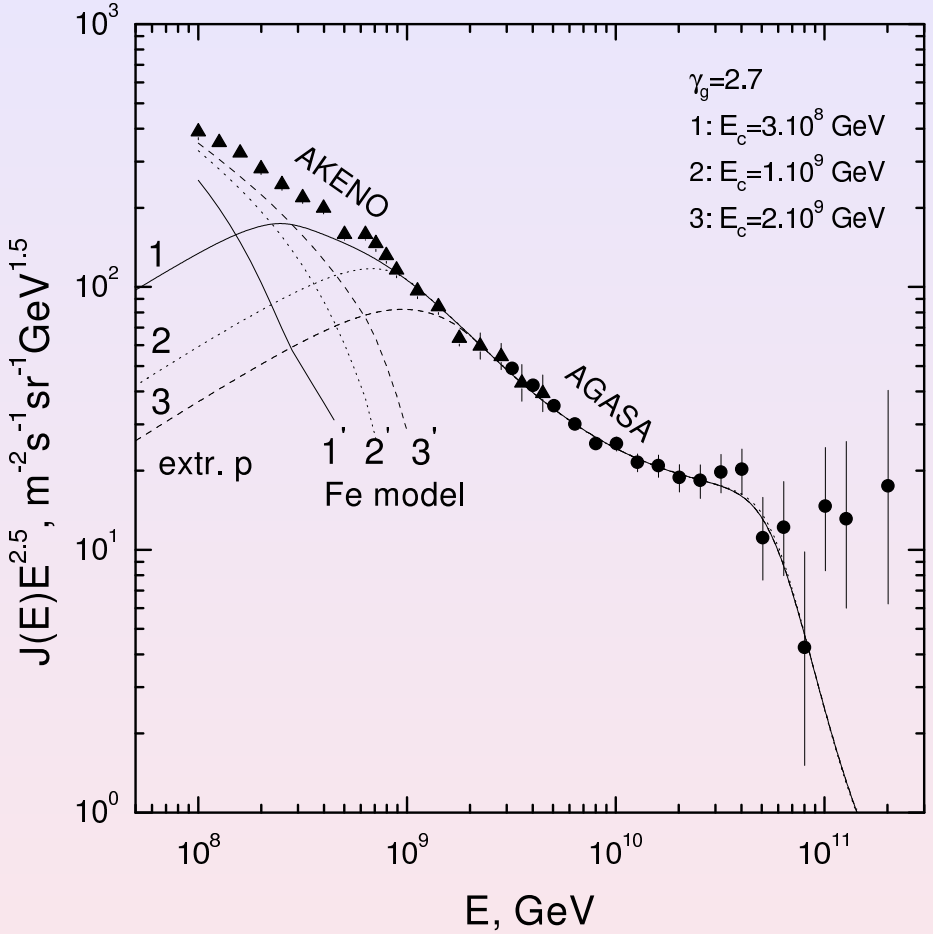
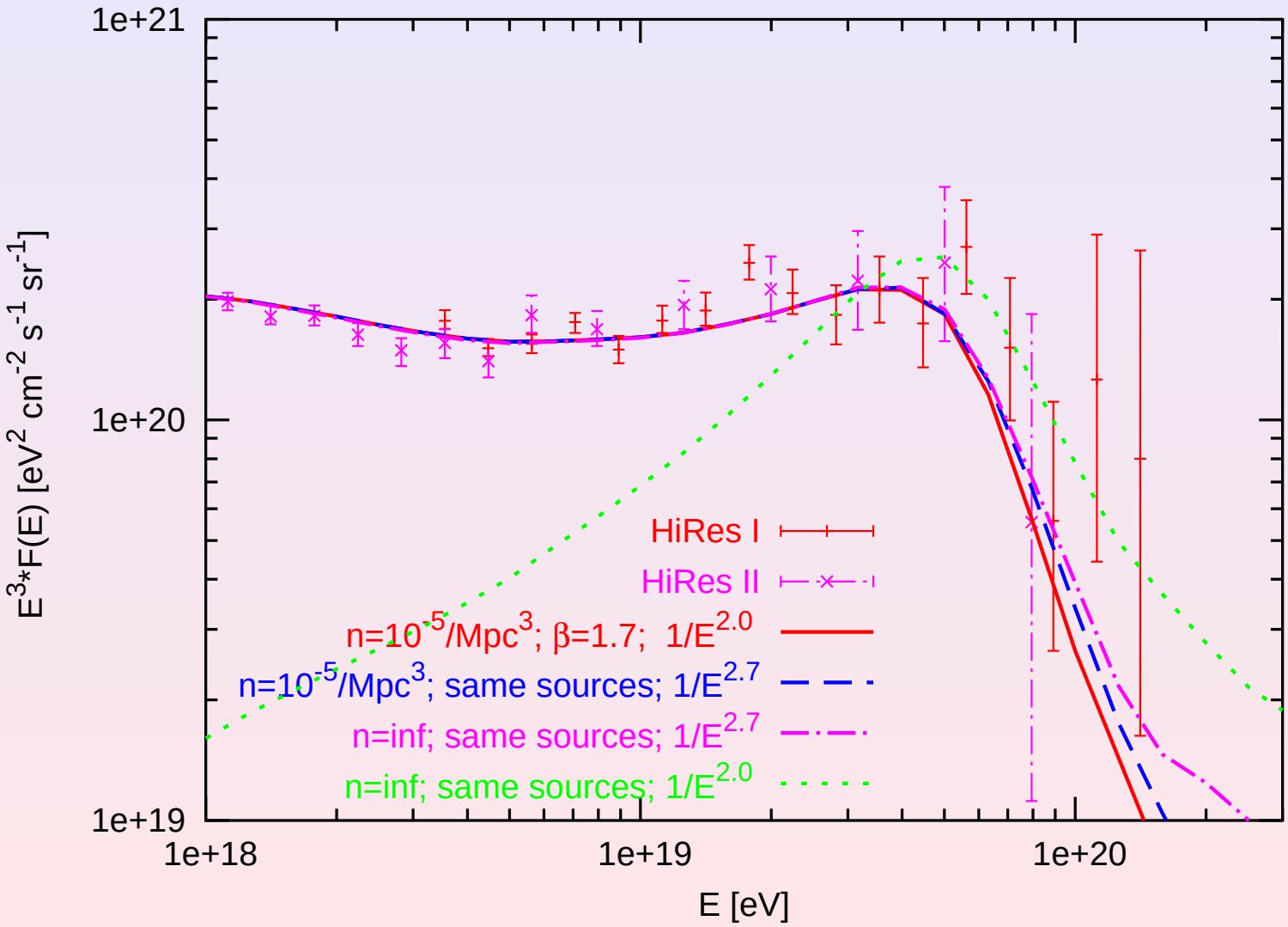


[Berezinsky, Grigorieva, Hnatyk '04]

dip suggests: primaries above 10^{18} eV are extragalactic protons

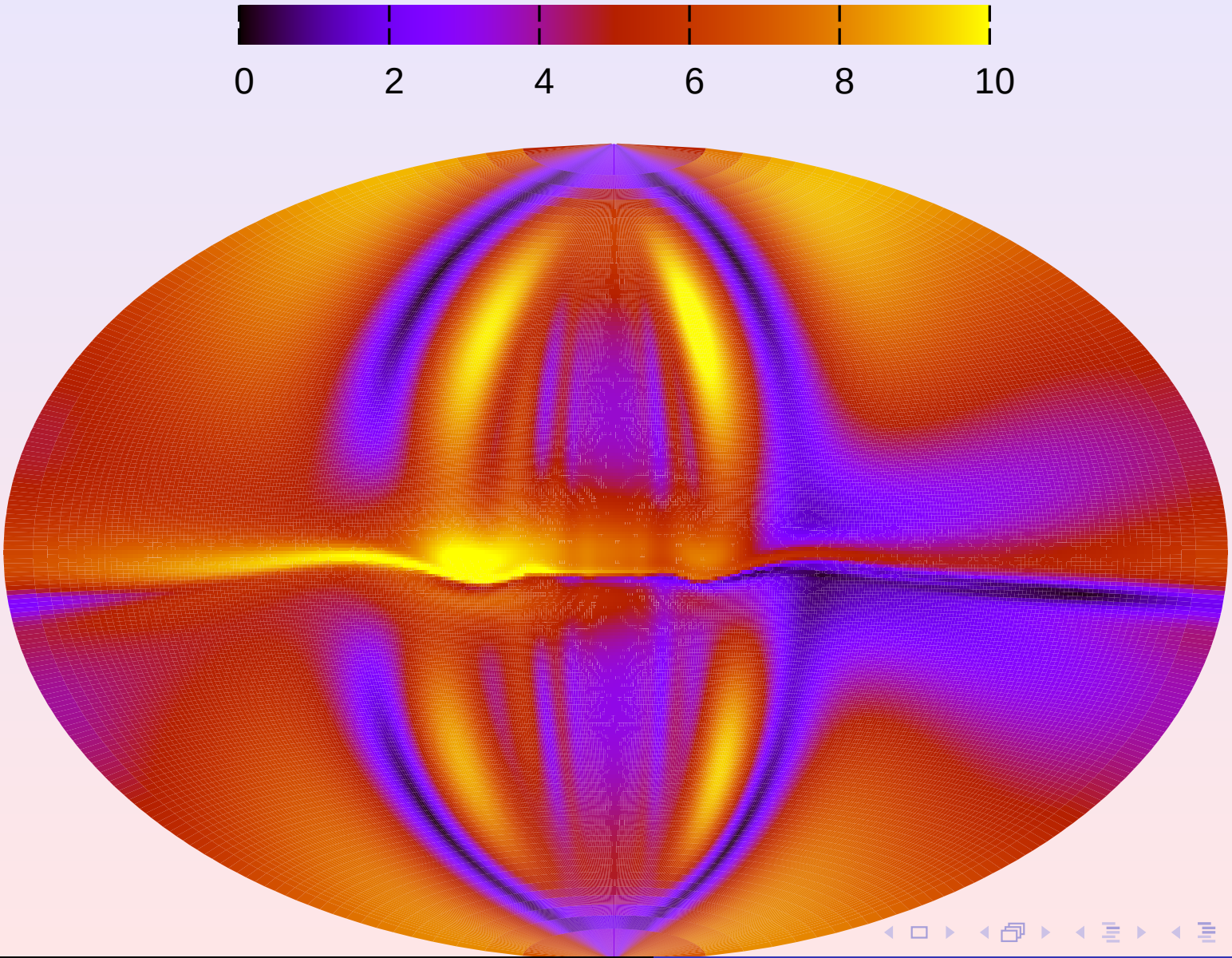
Contradiction between shock acceleration and observed spectrum?



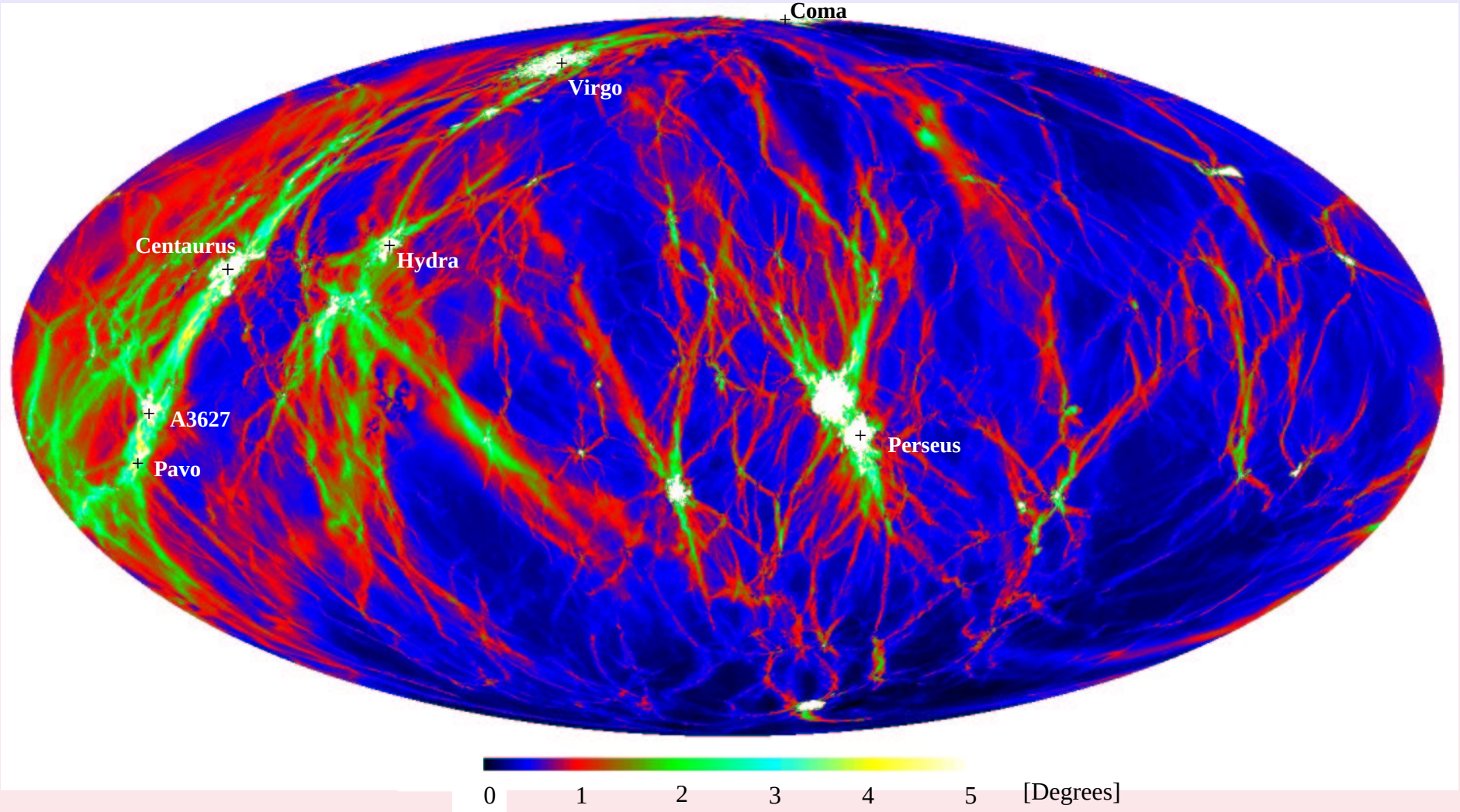
Contradiction between shock acceleration and observed spectrum?

- good fit with just 2 free parameters, compatible with th. models
- strong evidence for extragalactic protons above 10^{18} eV
- is astronomy possible?
  - proton as primary necessary but not sufficient condition
  - still depends on magnetic fields...

Deflections for $eE/Q = 4 \times 10^{19}$eV in the GMF:



Extragalactic magnetic field – simulation DGST:



[*Dolag, Grasso, Springel, Tkachev '03*]

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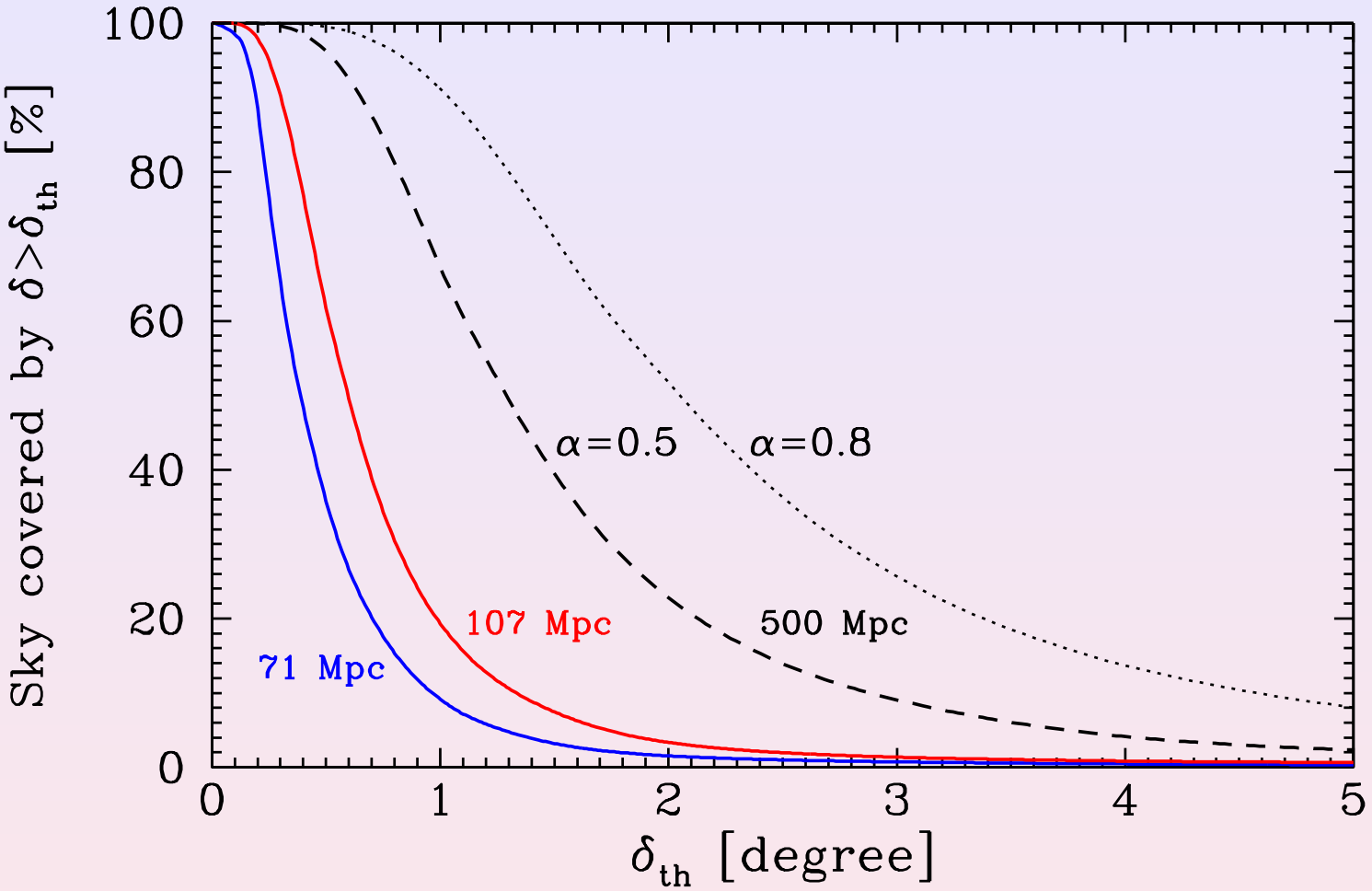
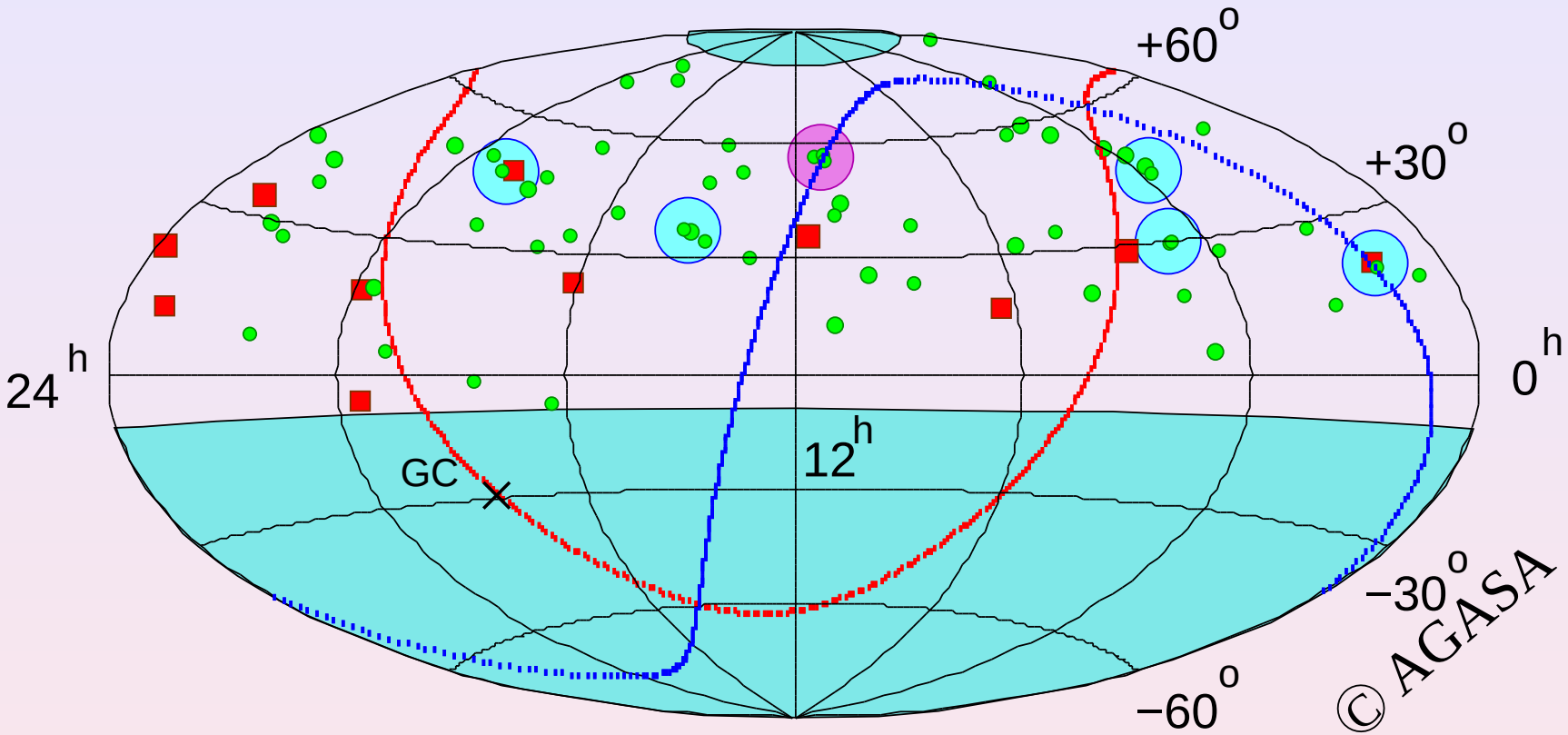


DGST: astronomy with UHE protons possible in large part of sky!

Examples for astronomical studies:

- finding point sources:



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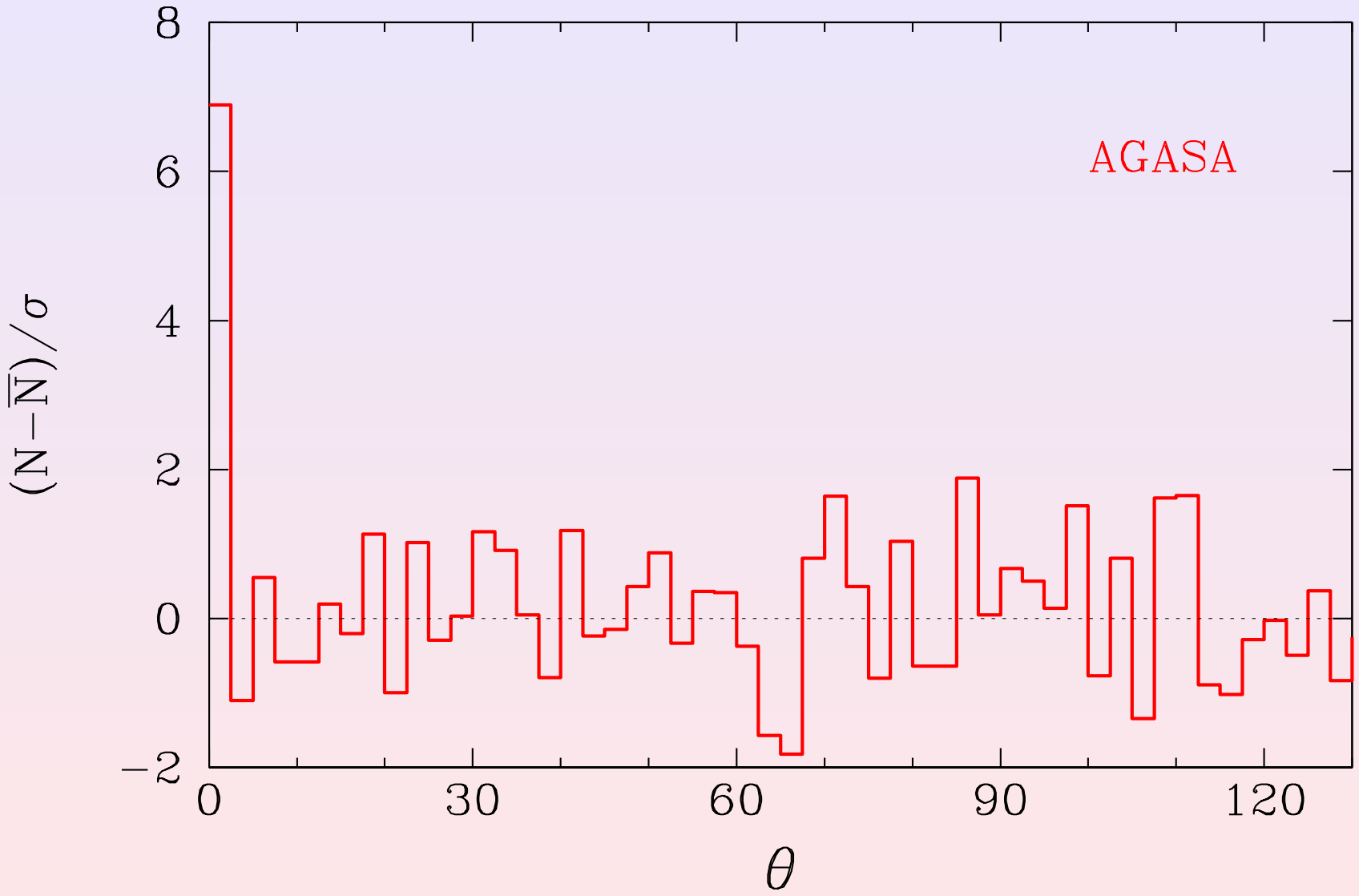

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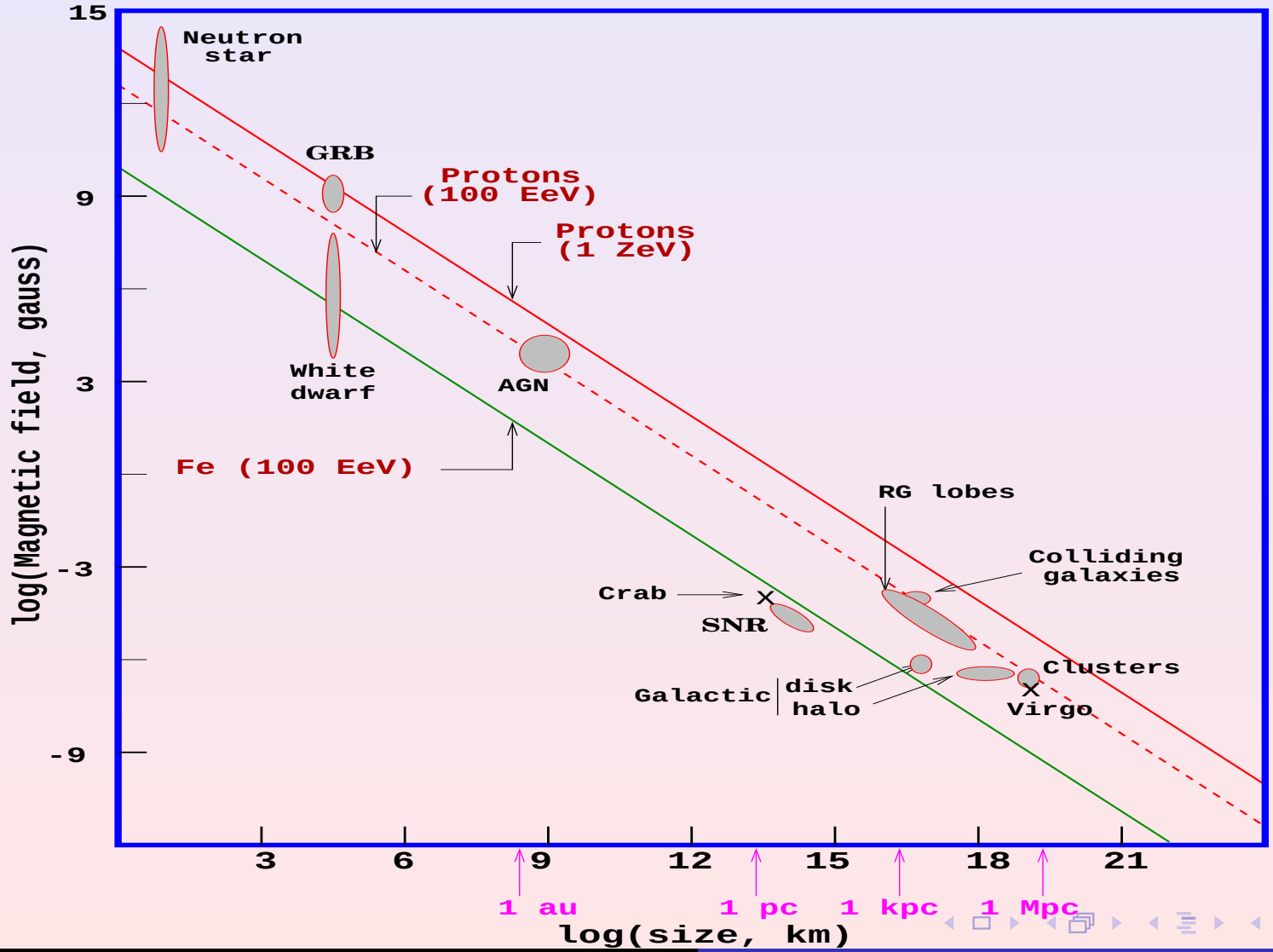

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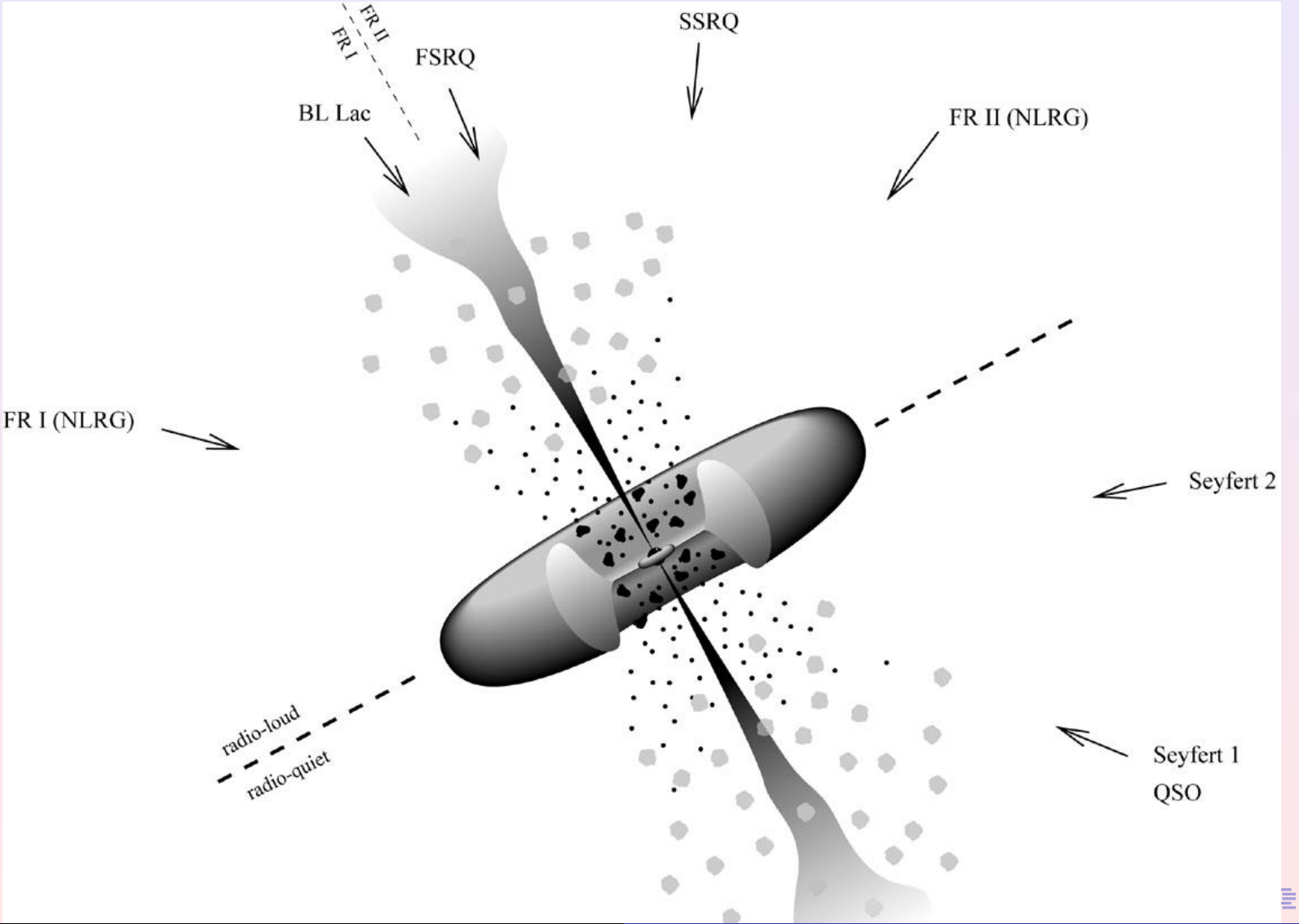

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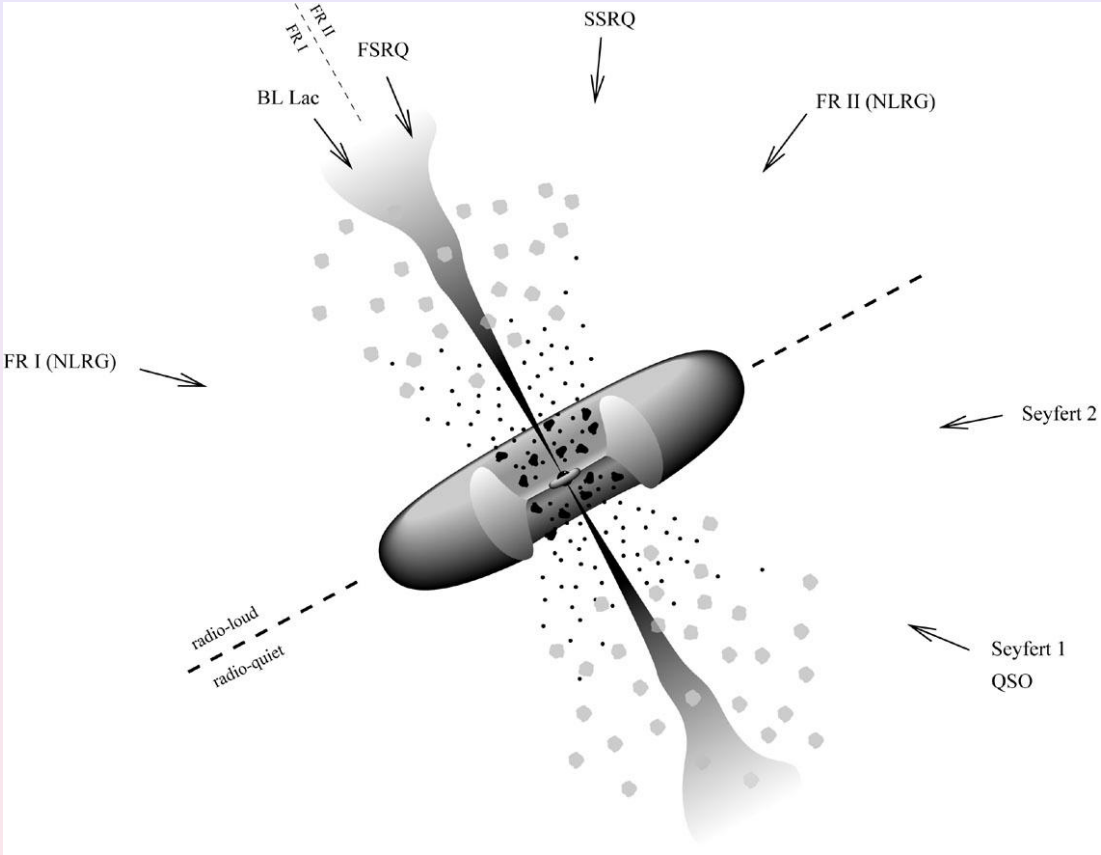

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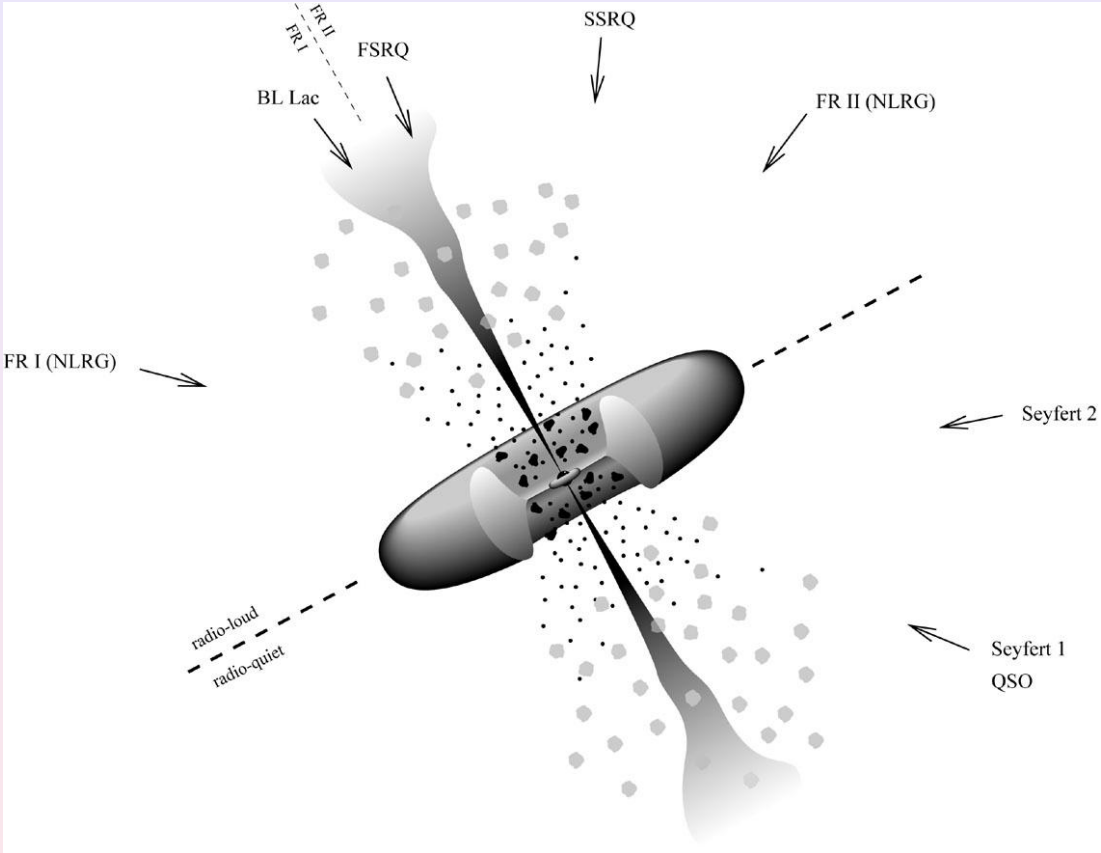

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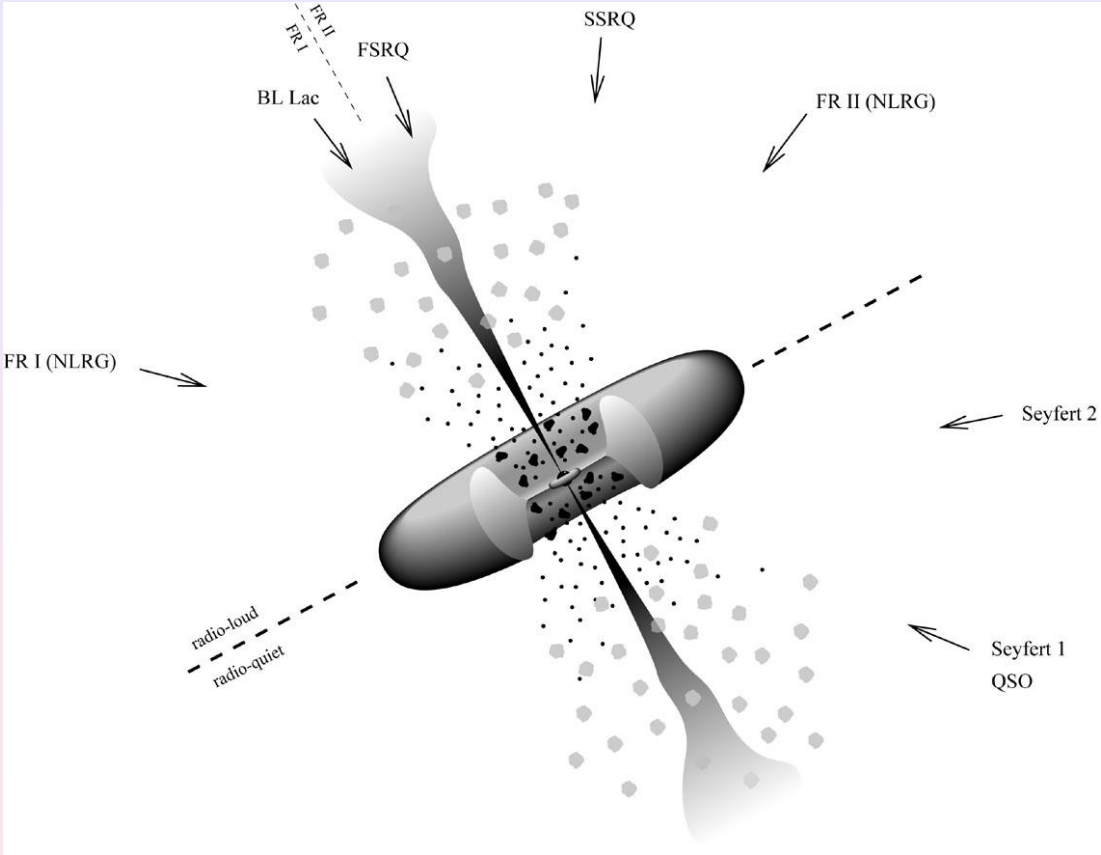

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  - identification of acceleration mechanism
- correlation with large-scale structure of sources

Example: Number density n_s of sources

- As n_s decreases, sources become brighter for fixed flux $\Rightarrow$ probability for clustering increases [*Waxman, Fisher, Piran '96*]

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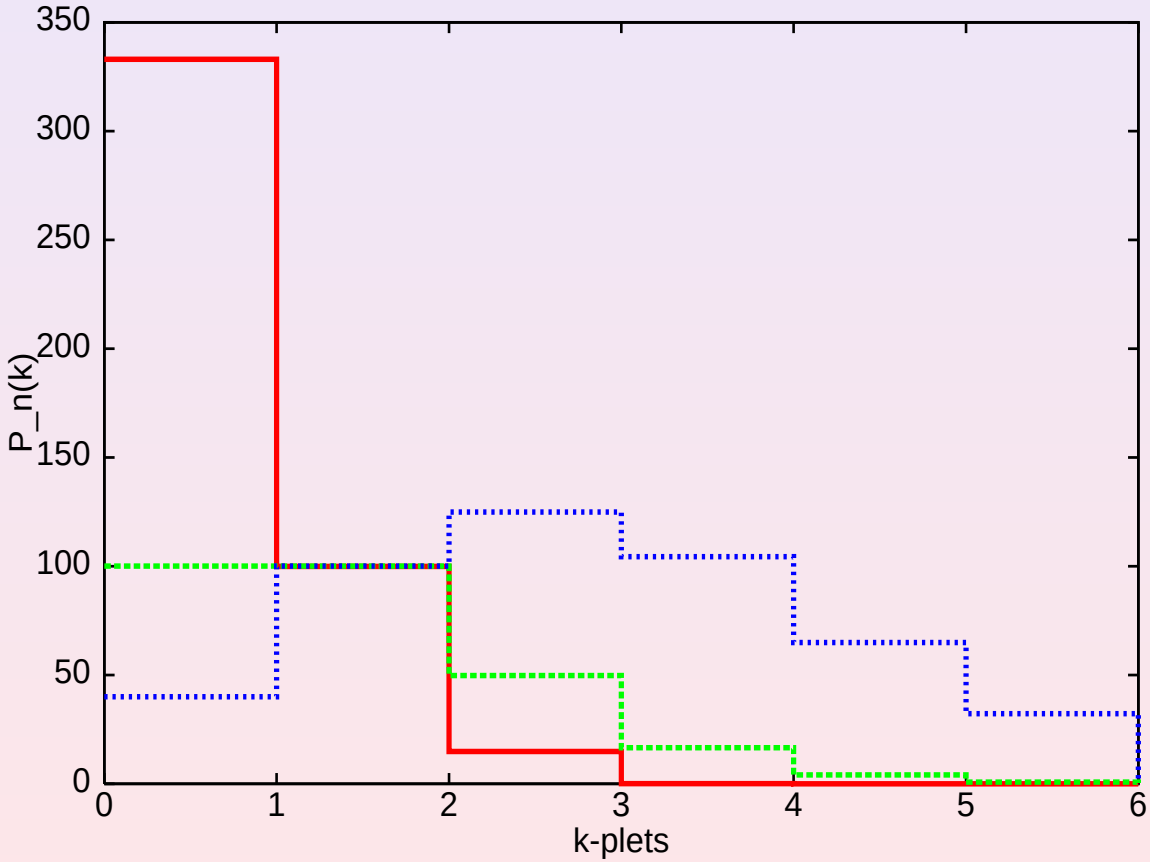

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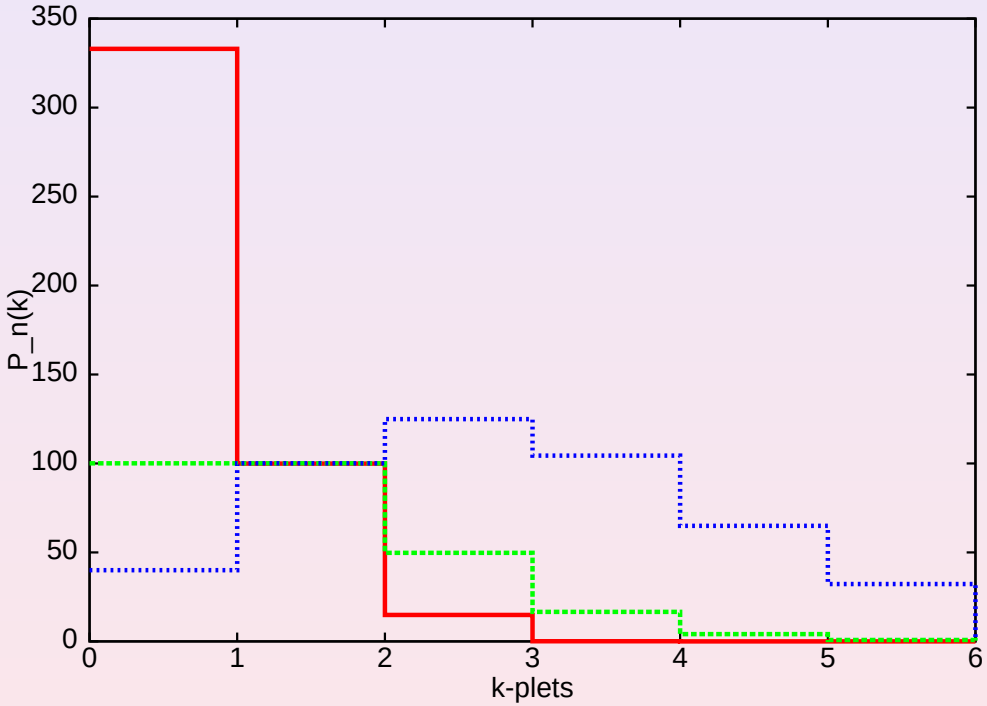
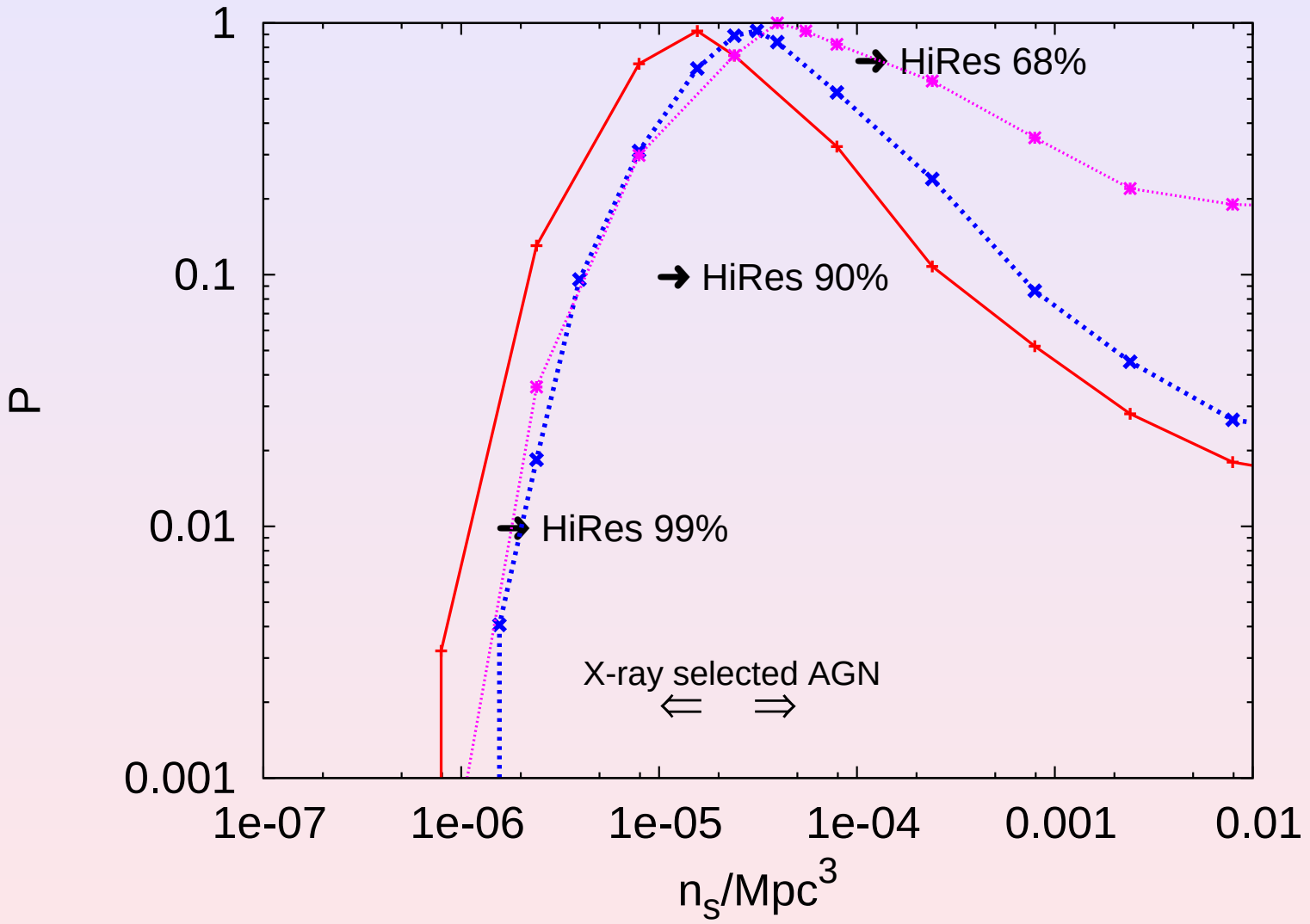
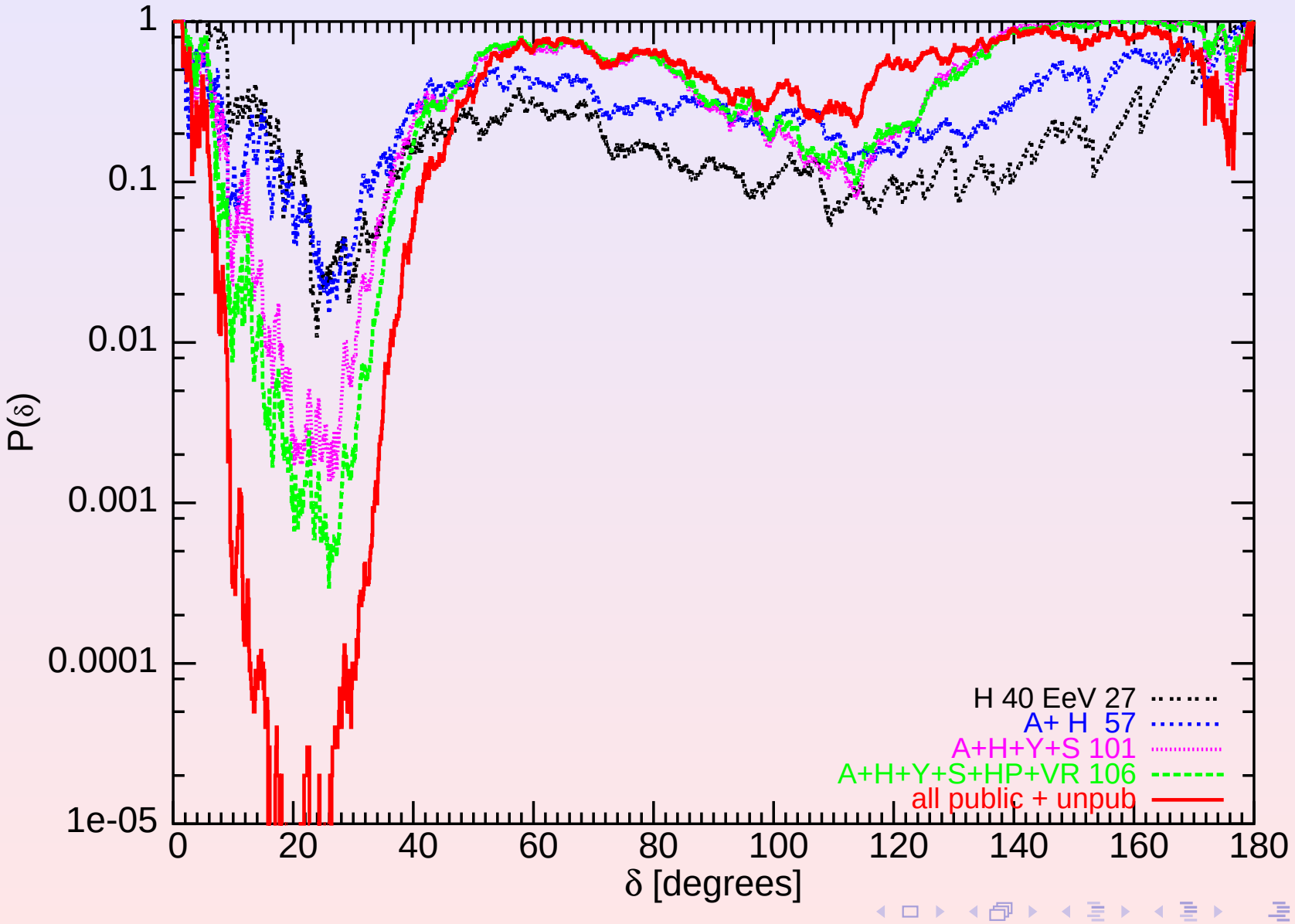


- allows to estimate n_s

Small-scale clusters and density of sources:



Medium-scale anisotropies in UHECRs:



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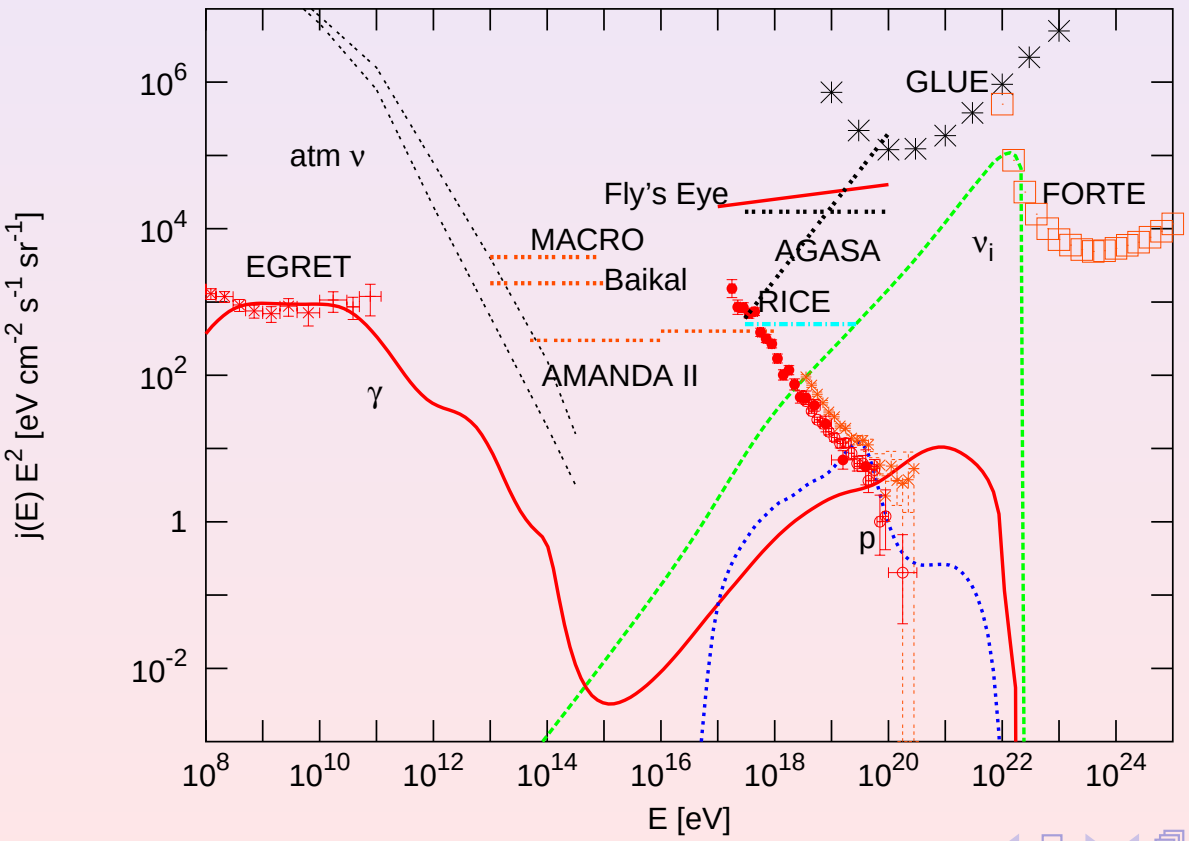
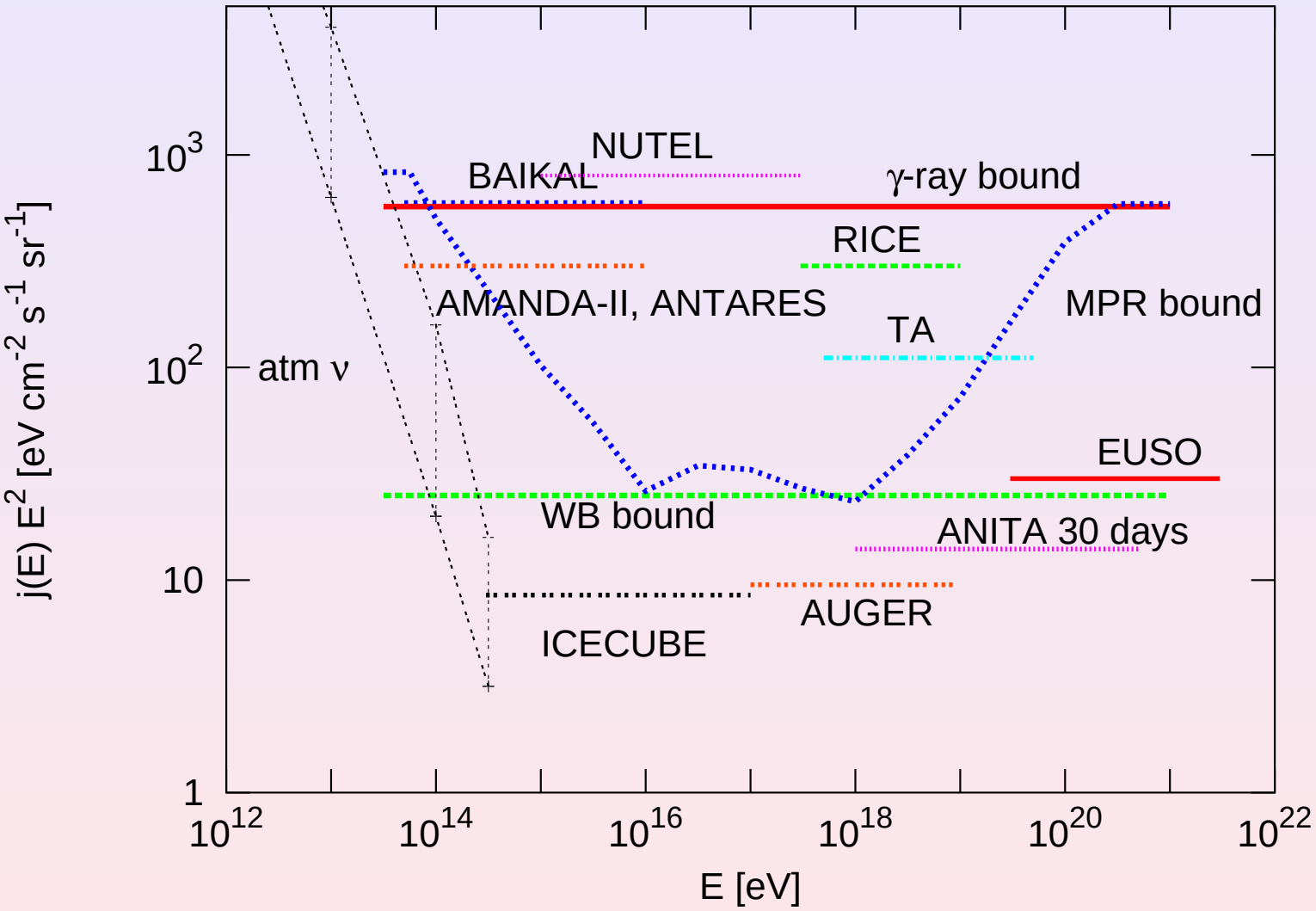
- all three fluxes are related: e.g. CR flux bounds neutrino flux
- all energy in γ and $e^{\pm}$ cascades down to MeV–GeV range, bounded by observations:



[Semikoz, Sigl '03]

Sensitivity of neutrino detectors



Summary I:

- UHECR data will provide soon unique information about
  - structure of galactic magnetic field
  - magnitude of extragalactic magnetic fields

if both are "small", astronomy with UHECRs will be possible

- determination of source density n_s
- determination of source classes
- acceleration mechanism?

if primary type is established, QCD studies with UHECRs will test

- inelastic cross section, elasticity
- QCD color-glas condensate

Summary II

- Z bursts and topological defects can be only subdominant sources of UHECR
- no positive evidence for superheavy dark matter from its two key signatures:
  - photons
  - galactic anisotropy

open questions for AUGER, Anita, . . . :

- clustering due to point sources?
- correlations with BL Lacs?
- existence of GZK suppression?
- photons as primaries?
- detection of UHE neutrinos: opens a new window to the Universe