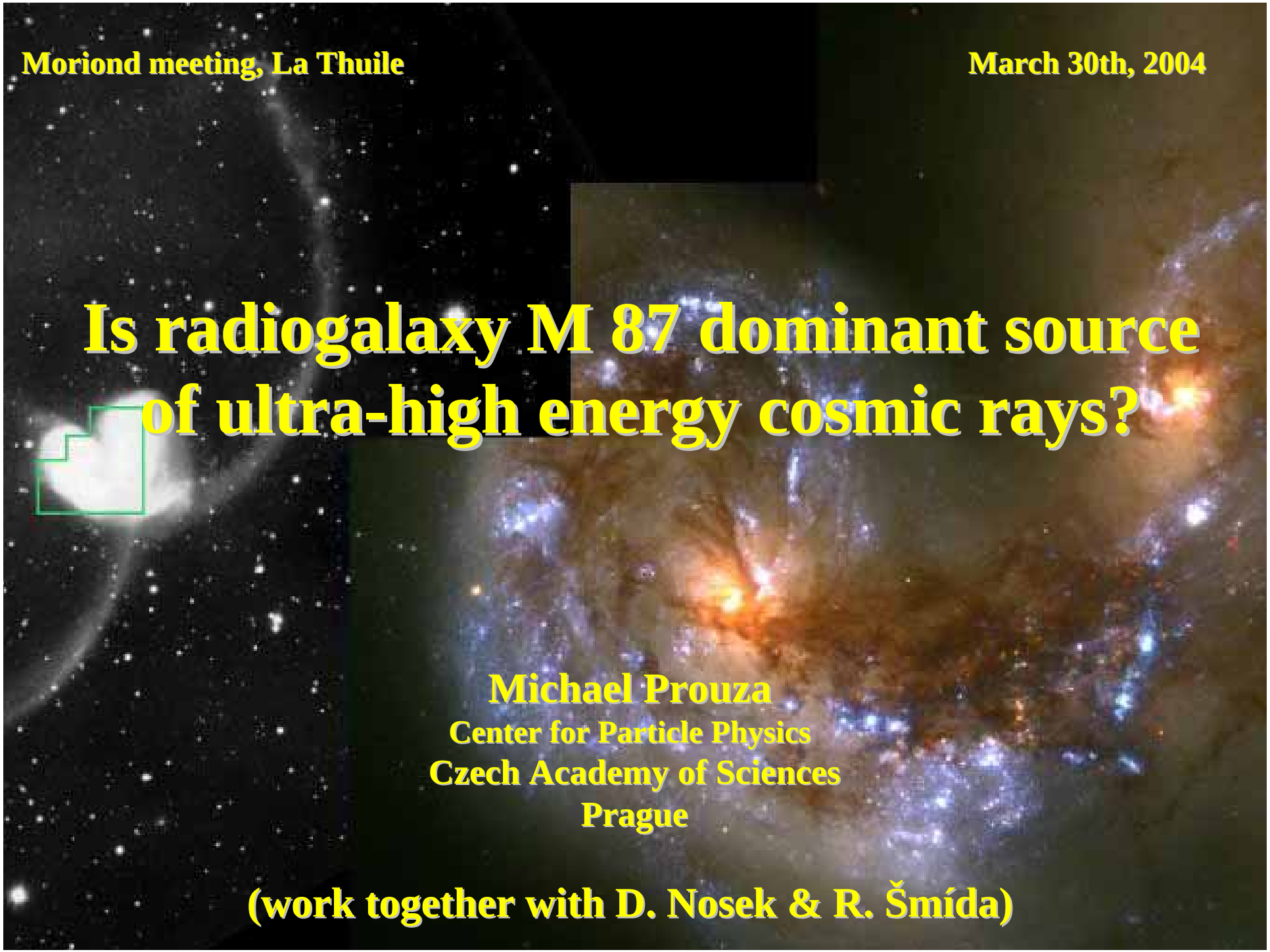


Moriond meeting, La Thuile

March 30th, 2004

# Is radiogalaxy M 87 dominant source of ultra-high energy cosmic rays?

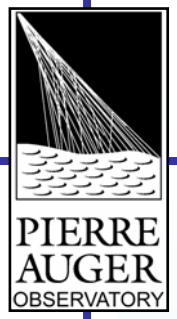

**Michael Prouza**

Center for Particle Physics

Czech Academy of Sciences

Prague


**(work together with D. Nosek & R. Šmída)**




***"Astrophysics in 21st century will concentrate mainly on two fundamental problems. The first problem is with something, what we would like to see, but we don't see. This something is dark matter. And the second problem is with something, what we don't want to see, but what we unfortunately observe. In this second case I mean the ultra-high energy cosmic rays..."***

David Schramm, 1994
*(not exact citation)*

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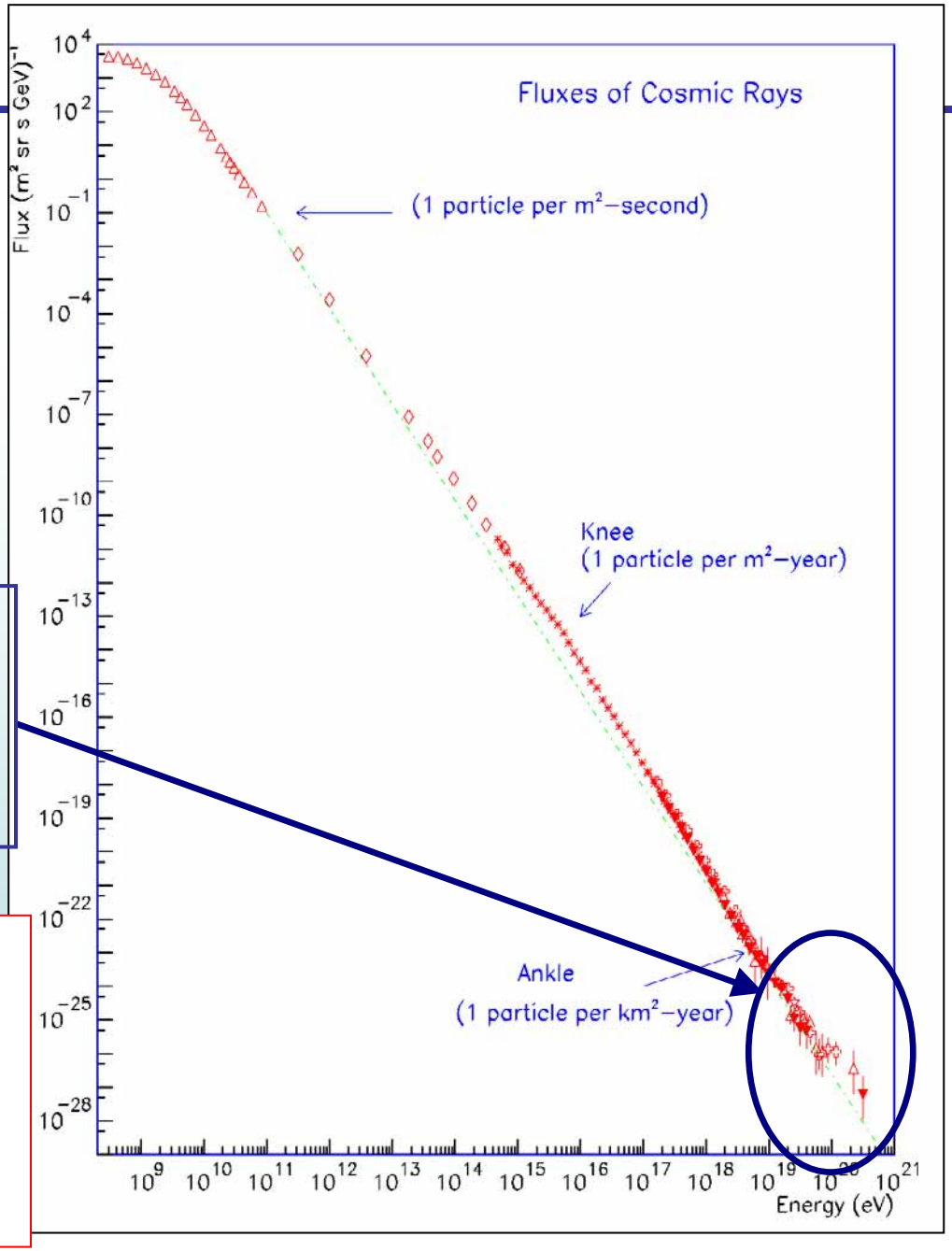
# What are ultra-high energy cosmic rays (UHECRs)?

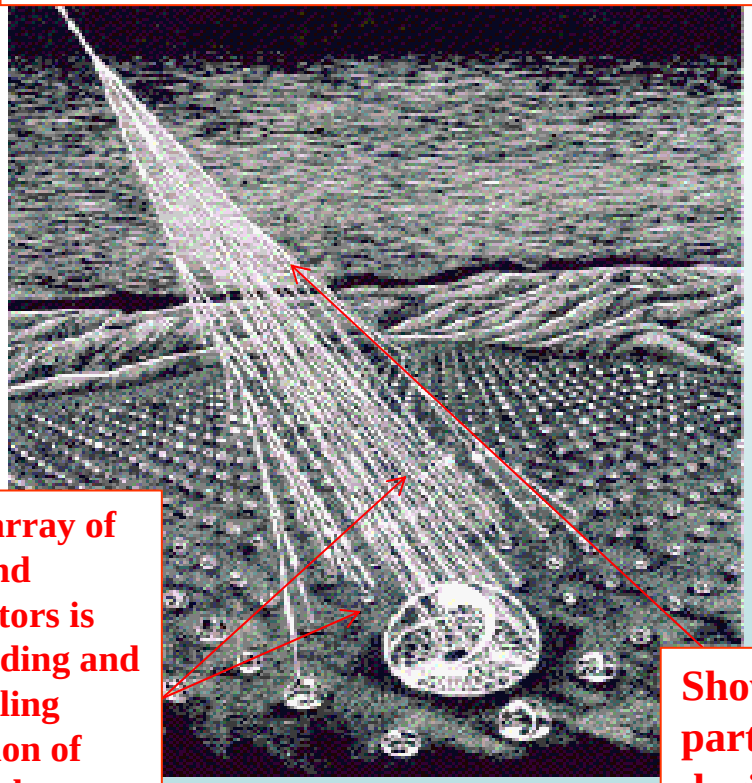
**UHECRs are particles with energy above "ankle", that is above $10^{19}$ eV, or more specifically above $4 \times 10^{19}$ eV.**

**The most energetic event:**
**Detector Fly's Eye, Utah, USA, October 15th 1991**
**$3.10^{20}$ eV ≈ 50 J**
**(as tennis ball moving with speed 80 km/h)**



# How we detect UHECRs?

Primary particle coming from space (proton or light nucleus) is hitting the atmosphere of the Earth



The array of ground detectors is recording and sampling fraction of secondary particles.

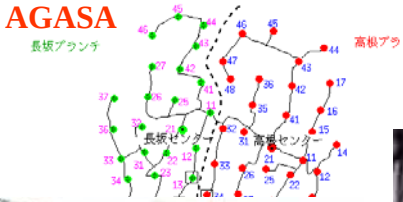
Shower of secondary particlesoriginates during collissions with molecules in the atmosphere

- The number of secondary particles is proportional to energy of primary particle
- Relative time of detection of individual secondary particles carries information about incident direction of primary particle
- Types of detectors: ground arrays and fluorescence telescopes

# Detectors of cosmic rays with ultra-high energies

**7 different detectors were in operation during 40 years of measurements and achieved detection of approximately 200 particles with energies over $4.10^{19}$ eV and only 20 particles with energies over $10^{20}$ eV.**


- Volcano Ranch, USA (1959 – 1963)
- SUGAR, Australia (1968 – 1979)
- Haverah Park, UK (1968 – 1987)
- Jakutsk, Russia (1970 – today)
- Fly's Eye, USA (1981 – 1992)
- AGASA, Japan (1990 – 2004)
- HiRes, USA (1998 – today)





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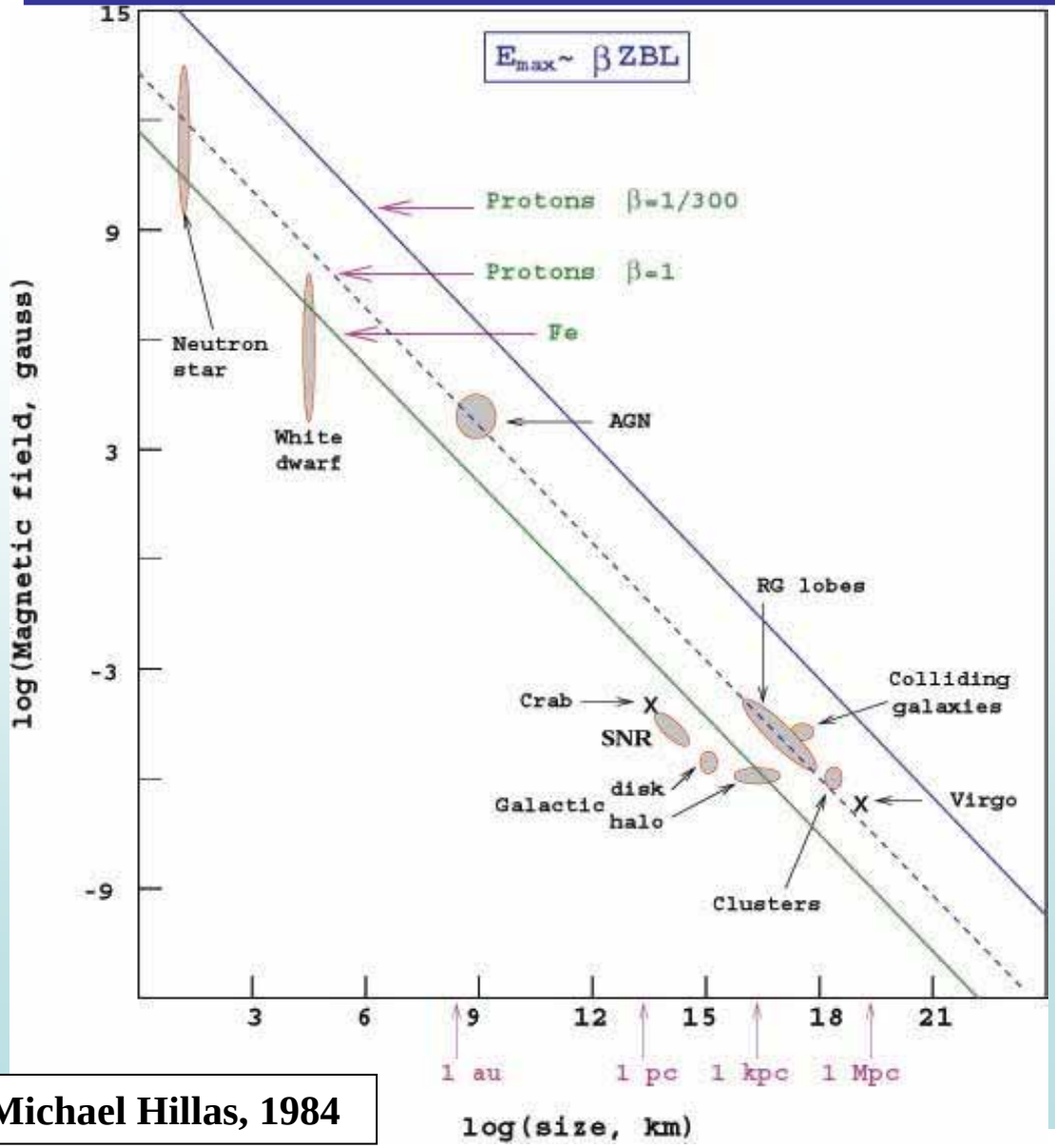
# Sites of origin of UHECRs




**Michael Hillas, 1984**

- **Fermi acceleration in magnetic fields.**
- **We need extremely strong magnetic fields OR extremely large magnetic fields to accelerate particles above $10^{20}$ eV.**
- **Young neutron stars - populated in the Galactic plane - unlikely (observed anisotropy?).**
- **Other sources - quite distant.**

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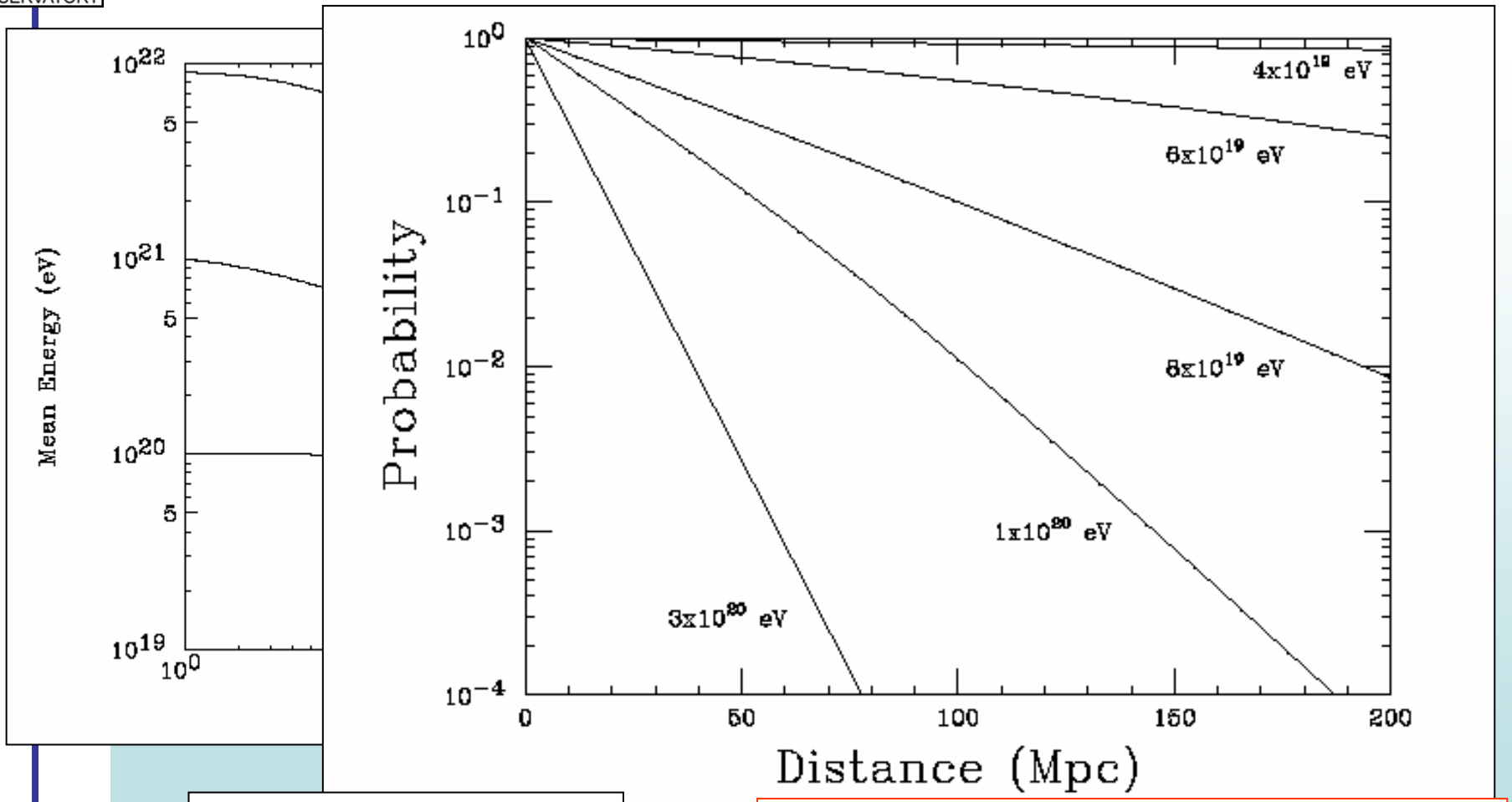
# GZK cutoff




**Paul Sommers, 2003**

**Sources of particles with E > $10^{20}$ eV have to be within "GZK-sphere" (100 Mpc)**

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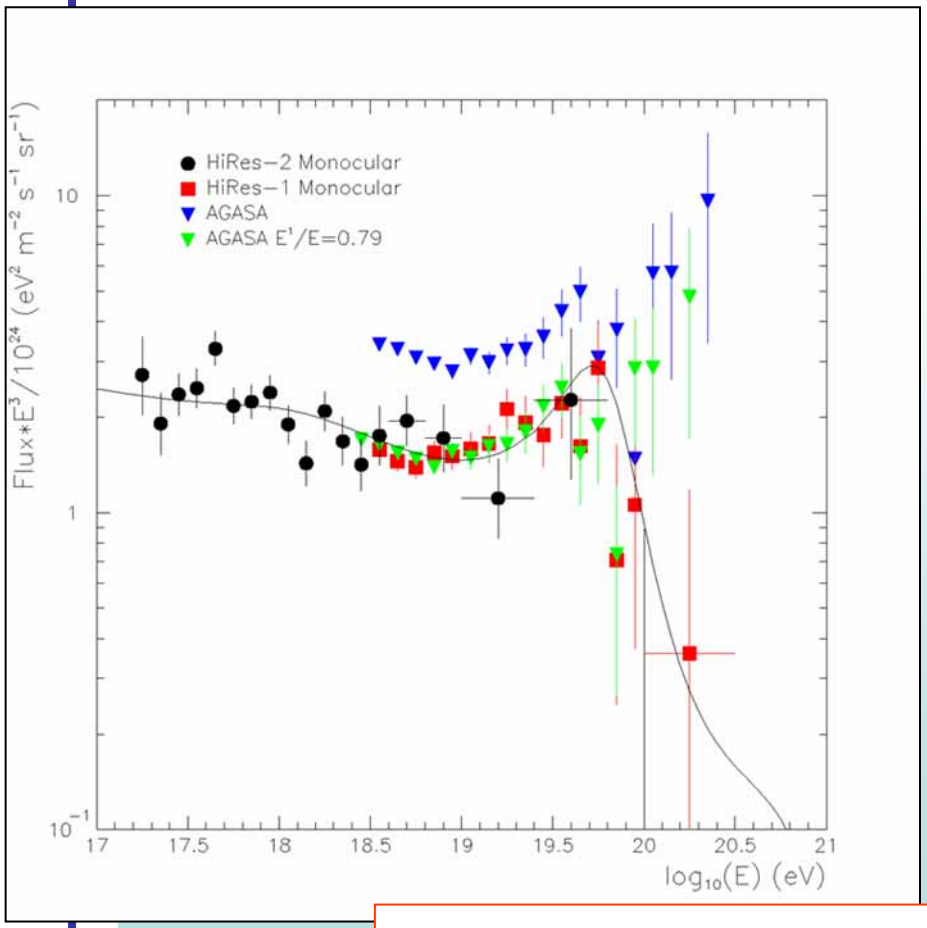
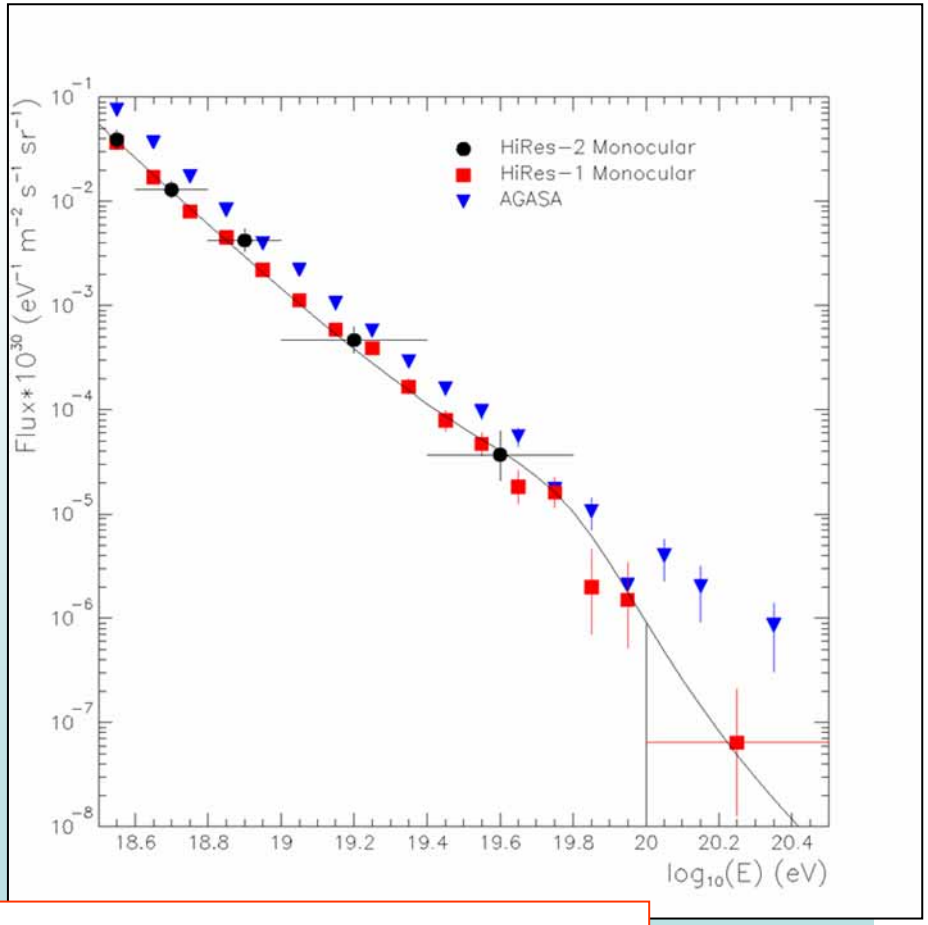
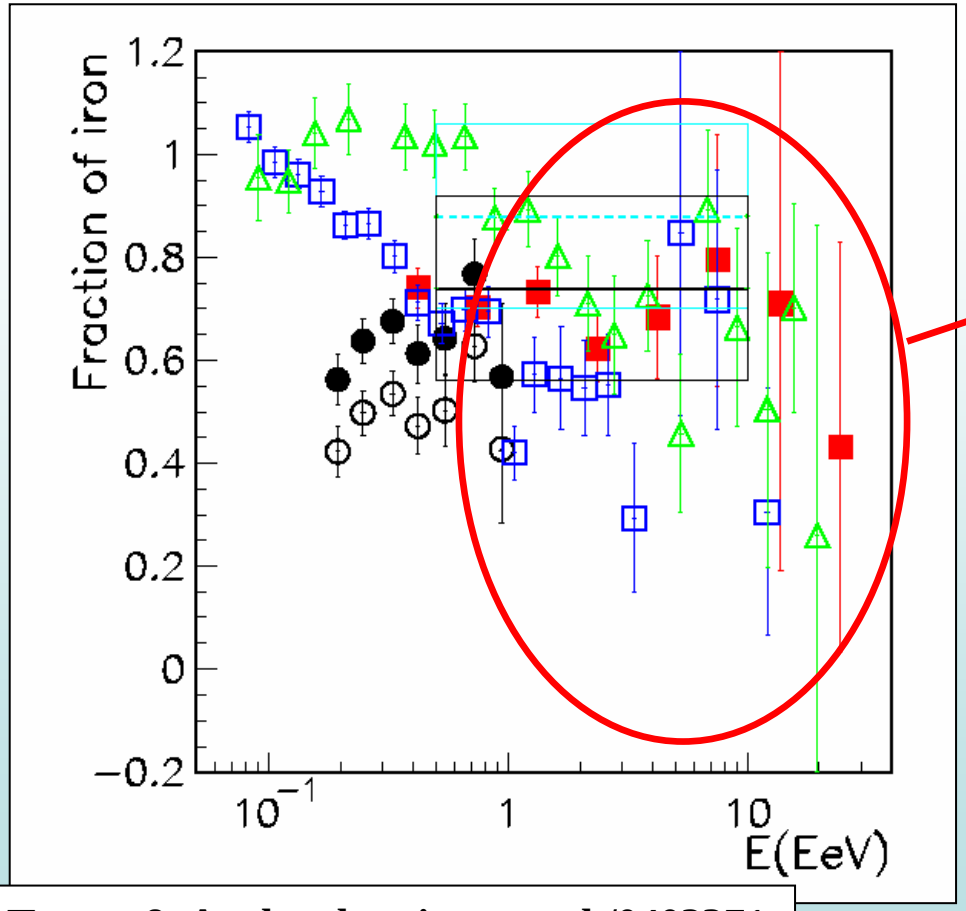
# HiRes vs. AGASA – the most important contradiction




**Is there really GZK-cutoff? Where are the sources?**

# Chemical composition of UHECR

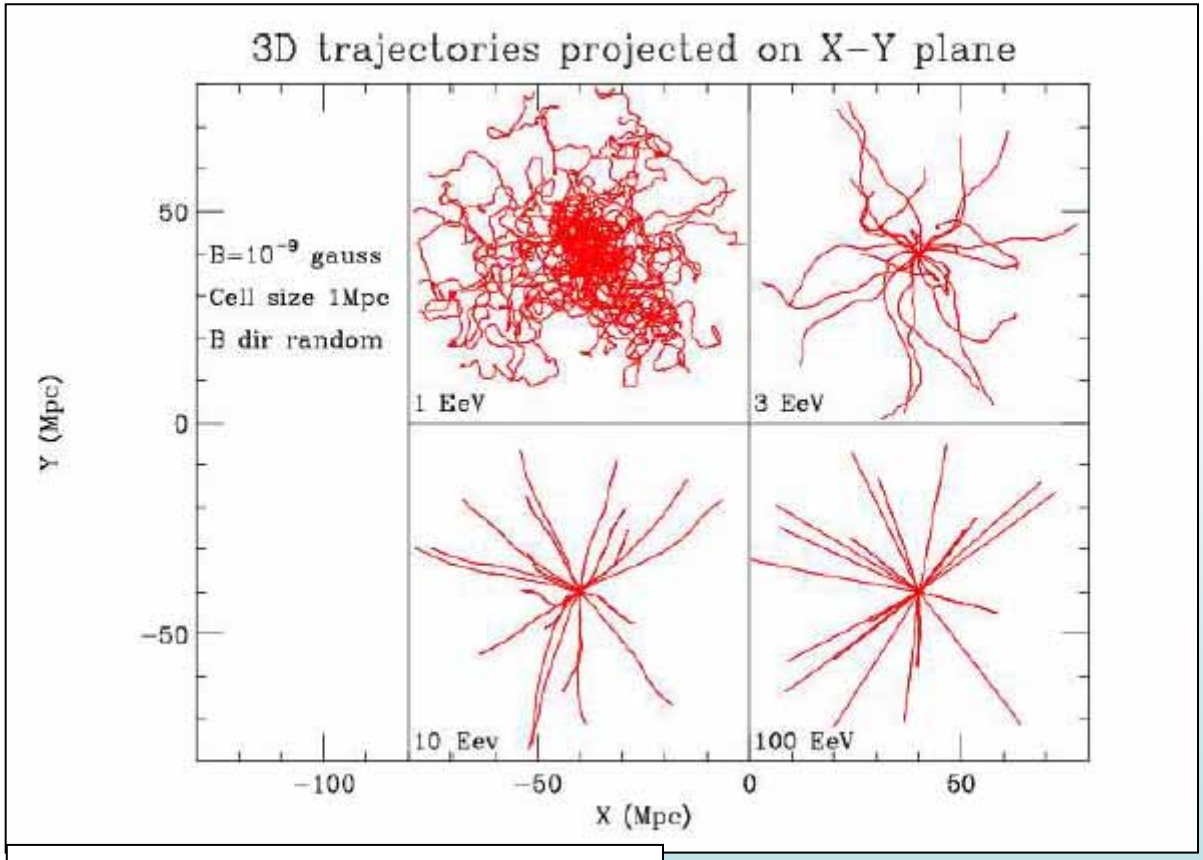



Torres & Anchordoqui, astro-ph/0402371

**Protons or iron nuclei?**

**We (once again) don‘t know.**

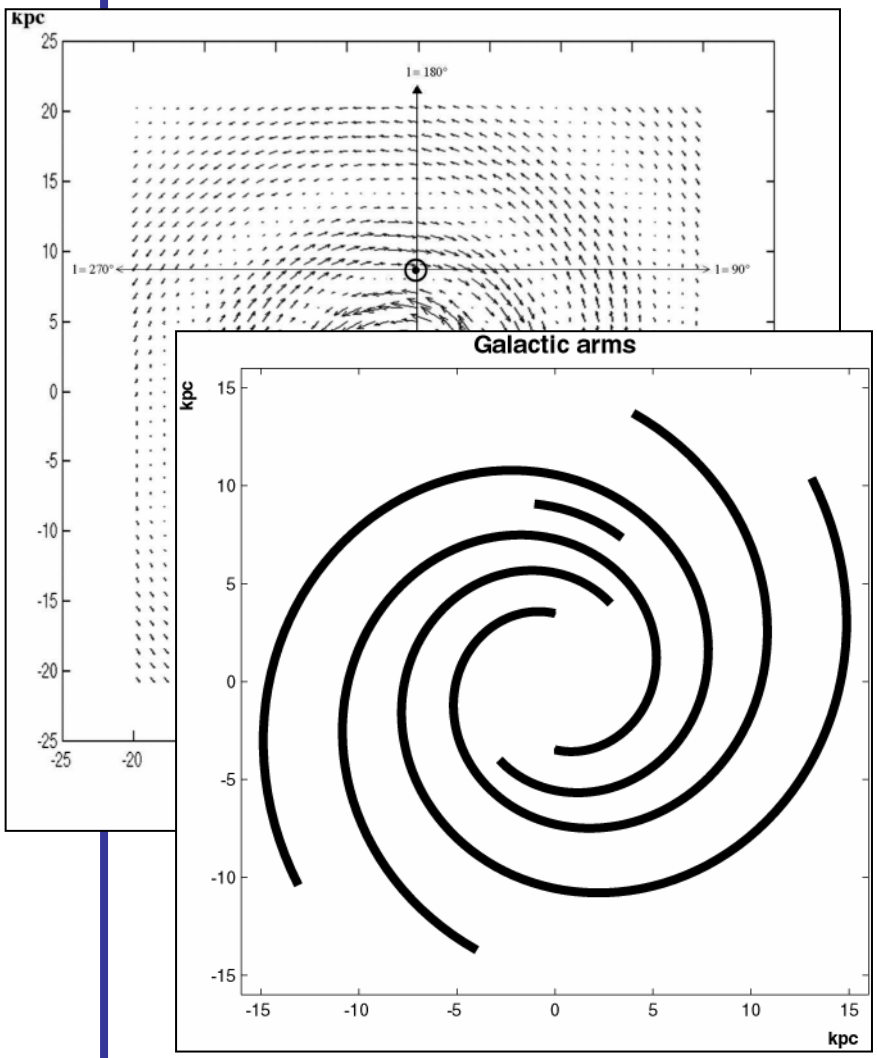
# Influence of magnetic fields




James Cronin, astro-ph/0402487

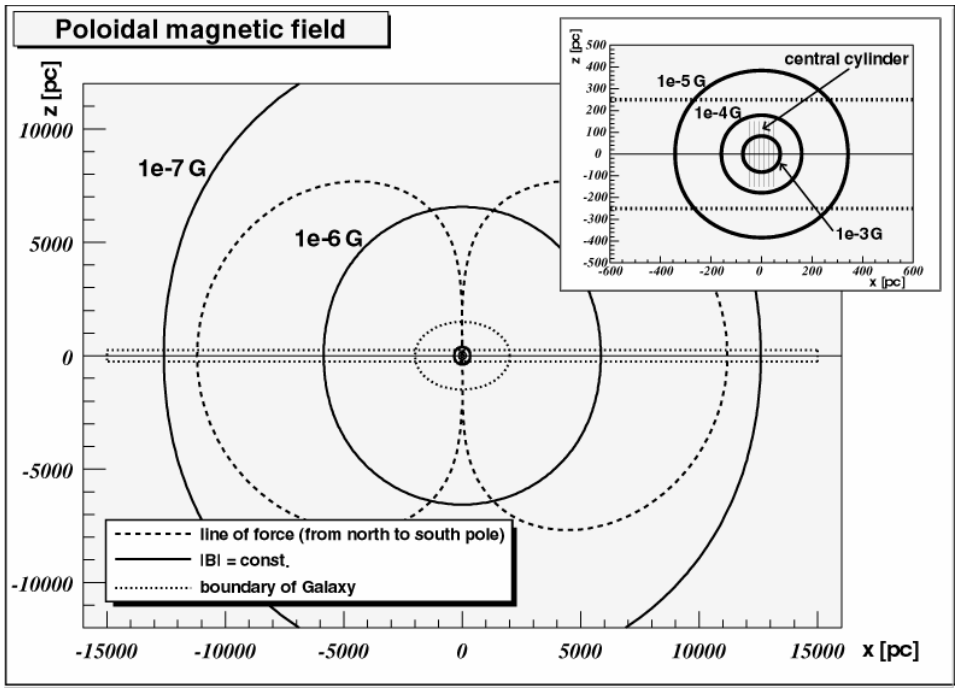
- Above $10^{19}$ eV - not curved trajectories ? - "Cosmic ray astronomy" ?
- Not so sure…
- Extragalactic magnetic fields could be very important, especially if UHECRs are mainly iron nuclei.
- And what about Galactic magnetic field?

# Galactic Magnetic Field




**What do we know?**

- **linear polarization, …, Faraday rotation measurements → field strength ~ μG**
- **global structure surely spiral**
- **turbulent component has up to 3x higher intensity**
- **poloidal and toroidal component exist**



# “Antiparticle tracing” method

- **characteristic size of a cell with given orientation of magnetic field ~ 50 pc**
- **particular Earth position (8.5 kpc from GC, inside of Local Galactic Arm)**
- **unfortunately, we are unable to simulate directly incoming isotropical flux and detect the particles on the position of the Earth (computational reasons → $10^9$ magnetic field cells within Galactic volume)**

**Antiparticle tracing:**

- **opposite charge**
- **we assume motion of charged particle only in magnetic field (electric field is not present)**
- **Lorentz equation solution:** $\boldsymbol{a} = \frac{q}{m}(\boldsymbol{v} \times \boldsymbol{B})$
- **4th order Runge-Kutta method**

Michael Prouza, Prague

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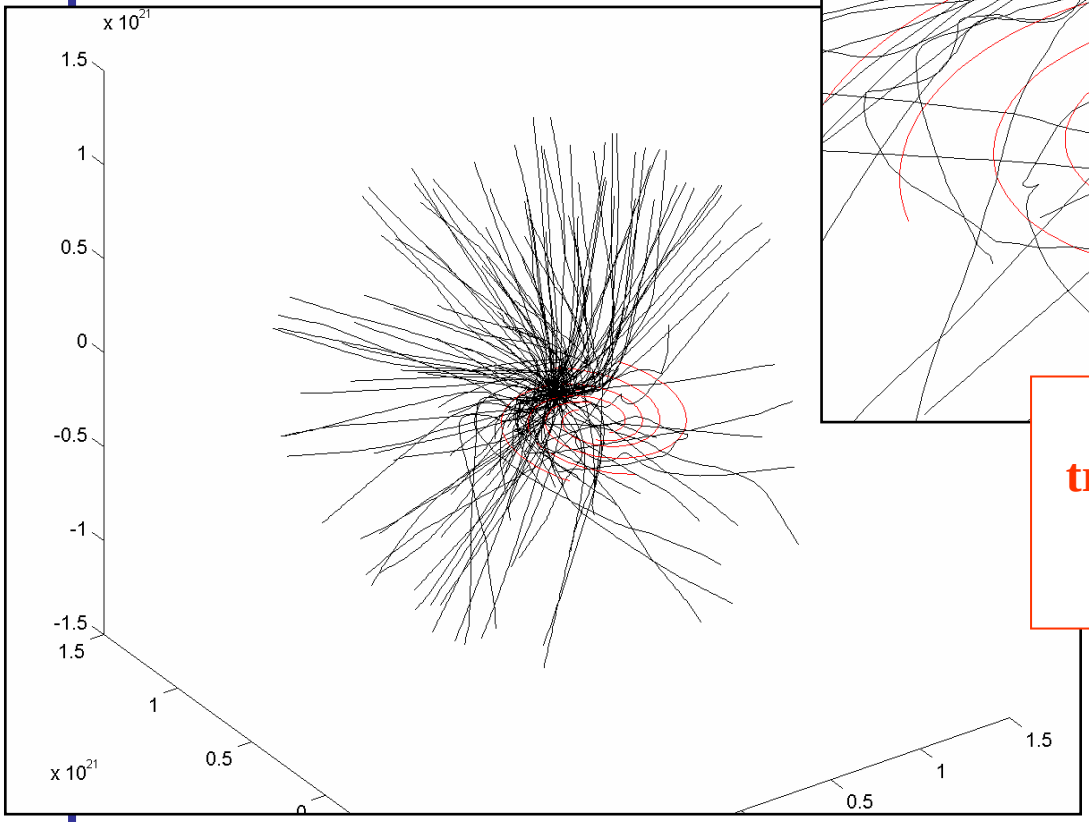
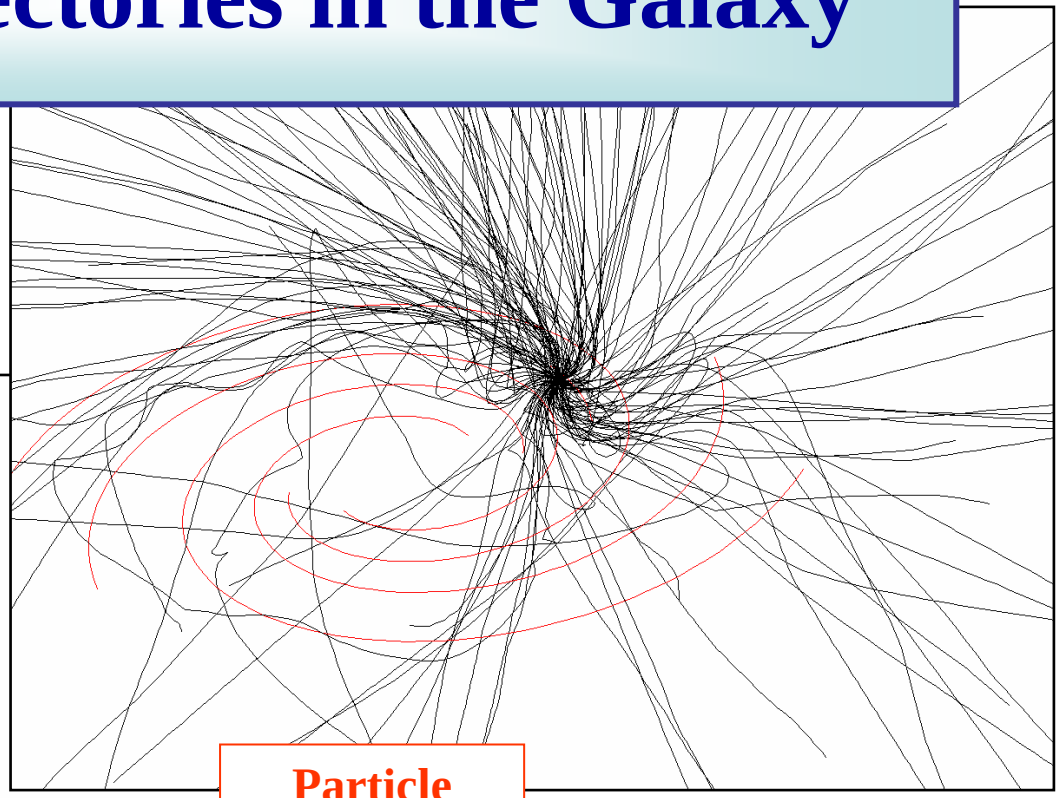
# Particle trajectories in the Galaxy

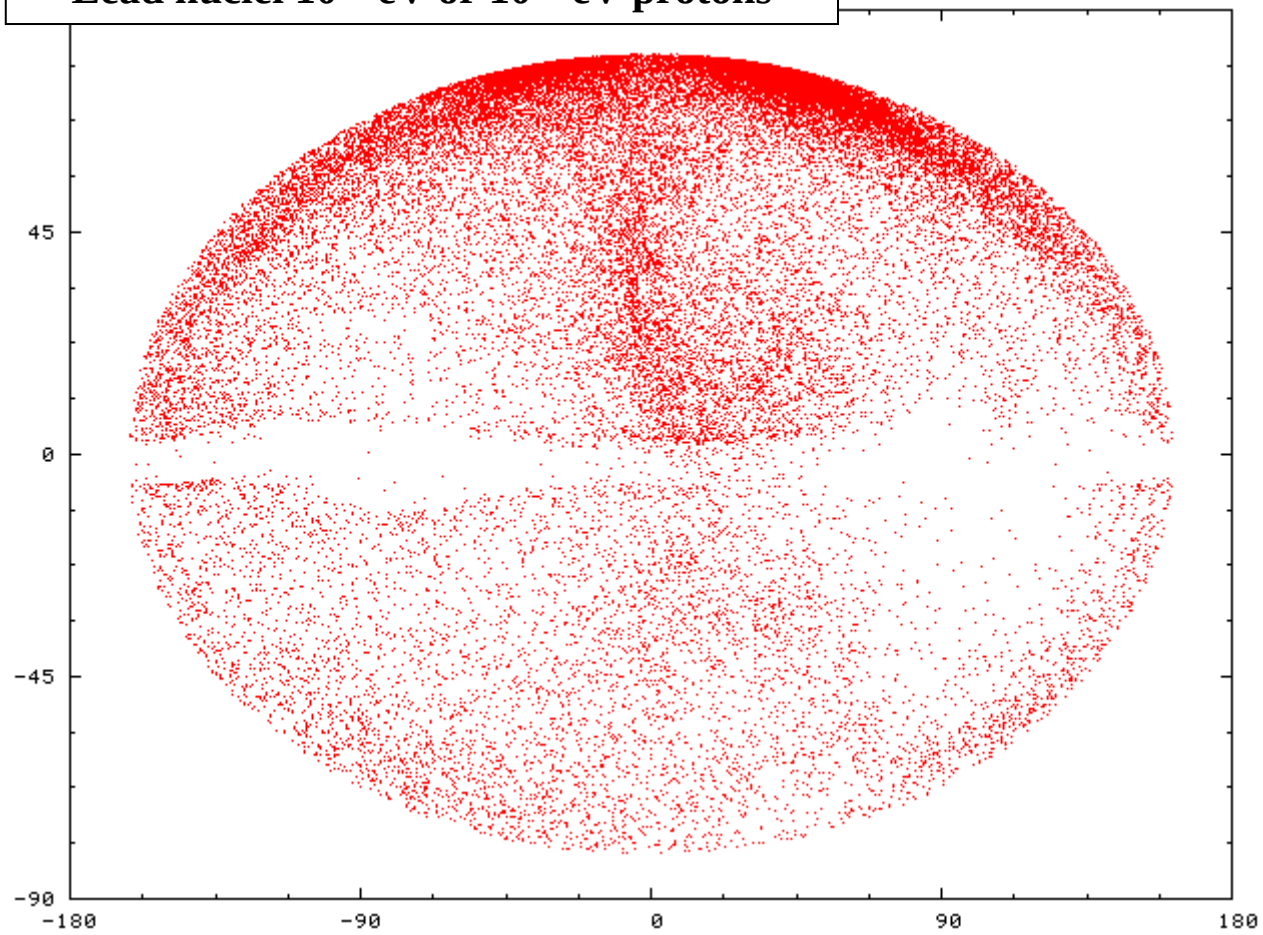


**Particle trajectories in the Galaxy**

# Results of simulations: Many-particle studies

**Lead nuclei $10^{20}$ eV or $10^{18}$ eV protons**




**For protons:**

- **only slight directional changes**
- **different „clustering“**

**For heavier nuclei (iron):**

- **great directional changes**
- **origin of pseudo-regular structures**
- **on some places overdensities, on other ones are particles swept away**

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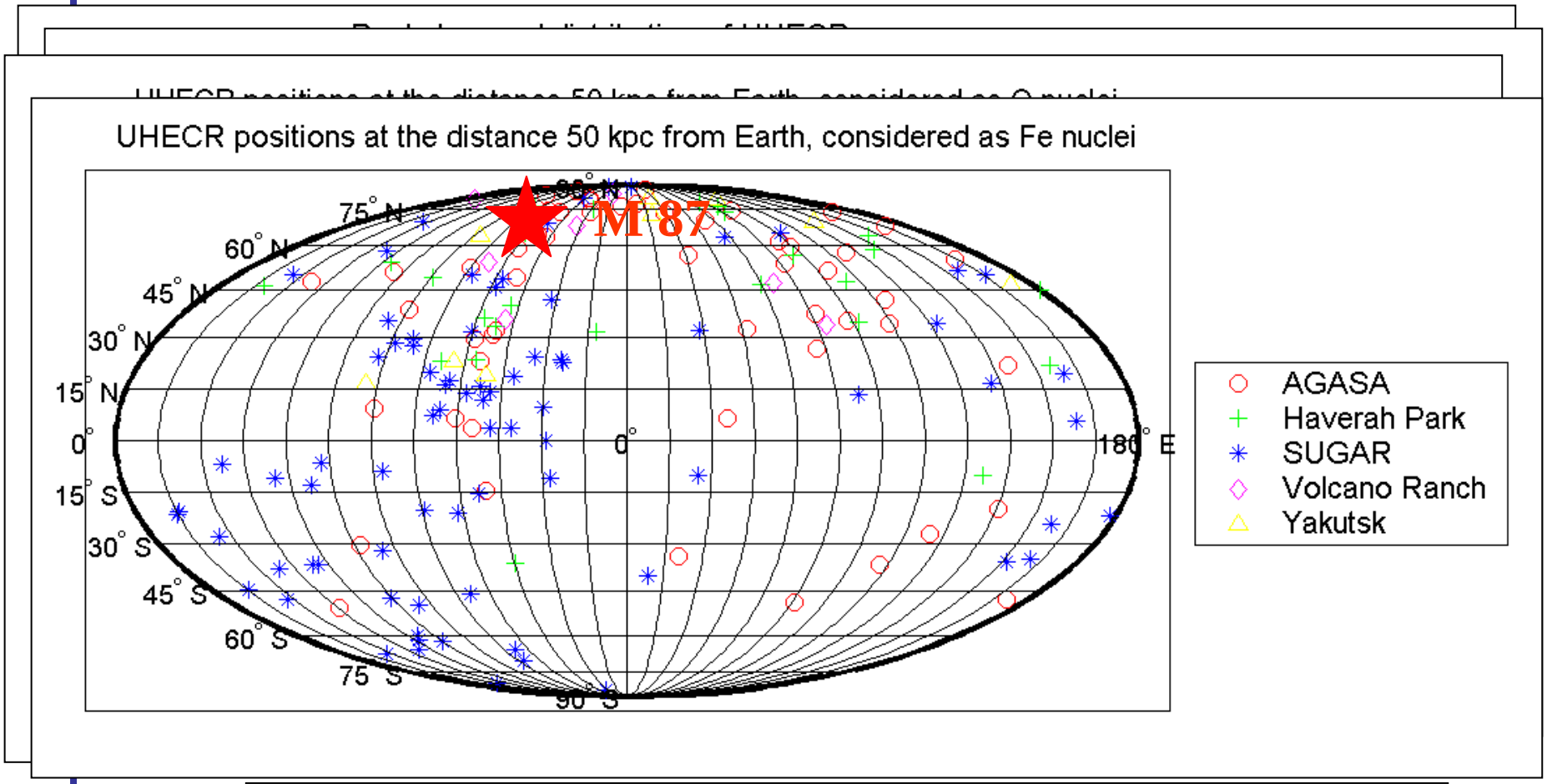
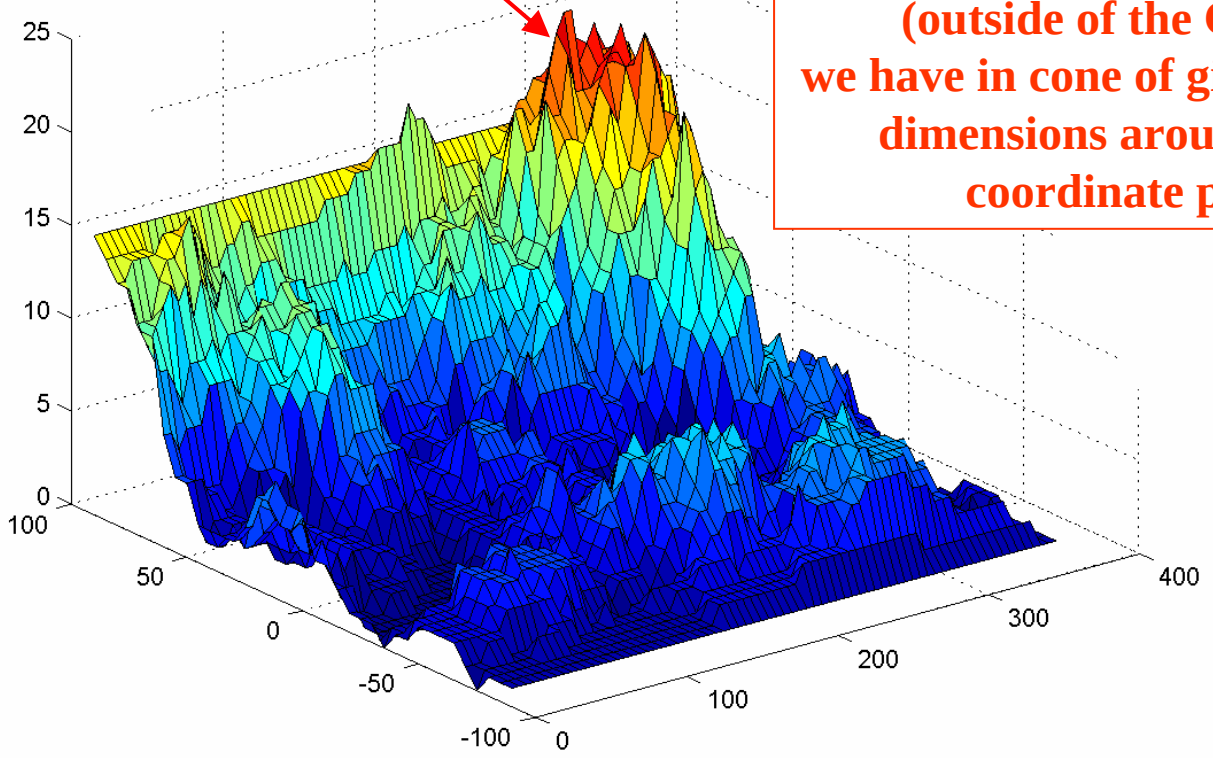
# Simulation results: Real available data > $4 \times 10^{19}$ eV




- great influence of poloidal field! (only two-point calibration)
- however → see position of radiogalaxy M 87

# Statistical analysis – counts in cones

**Really one dominant “source”?**

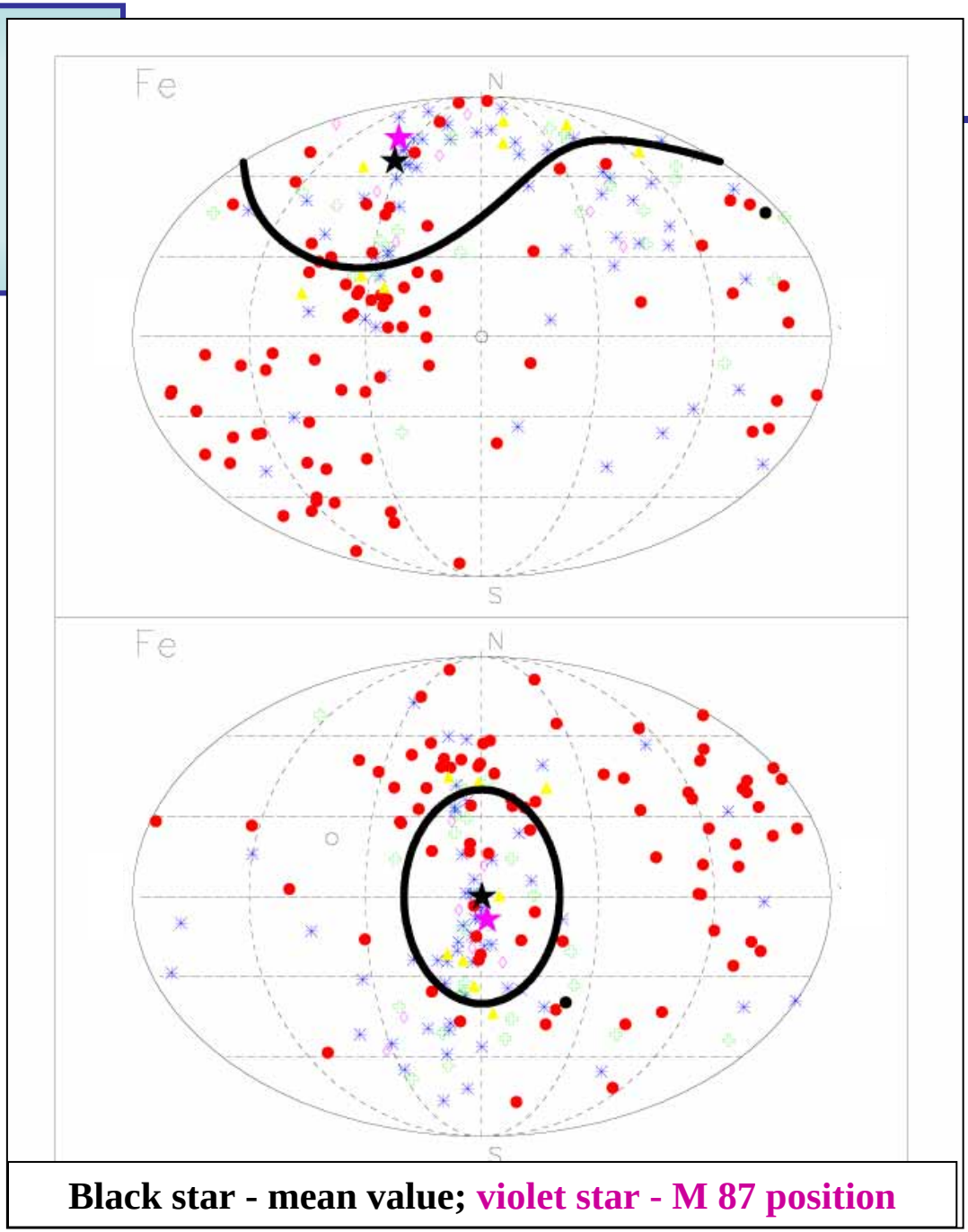



**First naive approach:**
**Just count how many particles (outside of the Galaxy) we have in cone of given angular dimensions around given coordinate point**

# Statistical analysis

**Statistical analysis - search for potential single source; computation of mean value on the sphere and of its variance**

**Position of the mean value: [283°; 67°] Variance: 41.6°**




**Black star - mean value; violet star - M 87 position**

# Conclusions

**We don't claim that M 87 is dominant source of UHECR, however:**

- **Although we observe isotropical distribution of UHECRs on the Earth, the incoming flux into Galaxy *could* be anisotropical**
- **If UHECRs are not protons, but heavier nuclei, the influence of magnetic fields (both Galactic and extragalactic) is really significant**
- **Anisotropy studies in lower energy ranges ($10^{18}$ - $10^{19}$ eV) will be very helpful (AGASA suggest anisotropy near GC)**
- **Big need for more data...**