

Итоги рабочего совещания по физике
космических лучей сверхвысоких энергий
(КЛСЭ),
(ИЯИ РАН, Москва, 14-16 апреля 2005 г.)

III МАРКОВСКИЕ ЧТЕНИЯ,

Москва, ИЯИ РАН, 13 Мая 2005 г.

Дмитрий Горбунов

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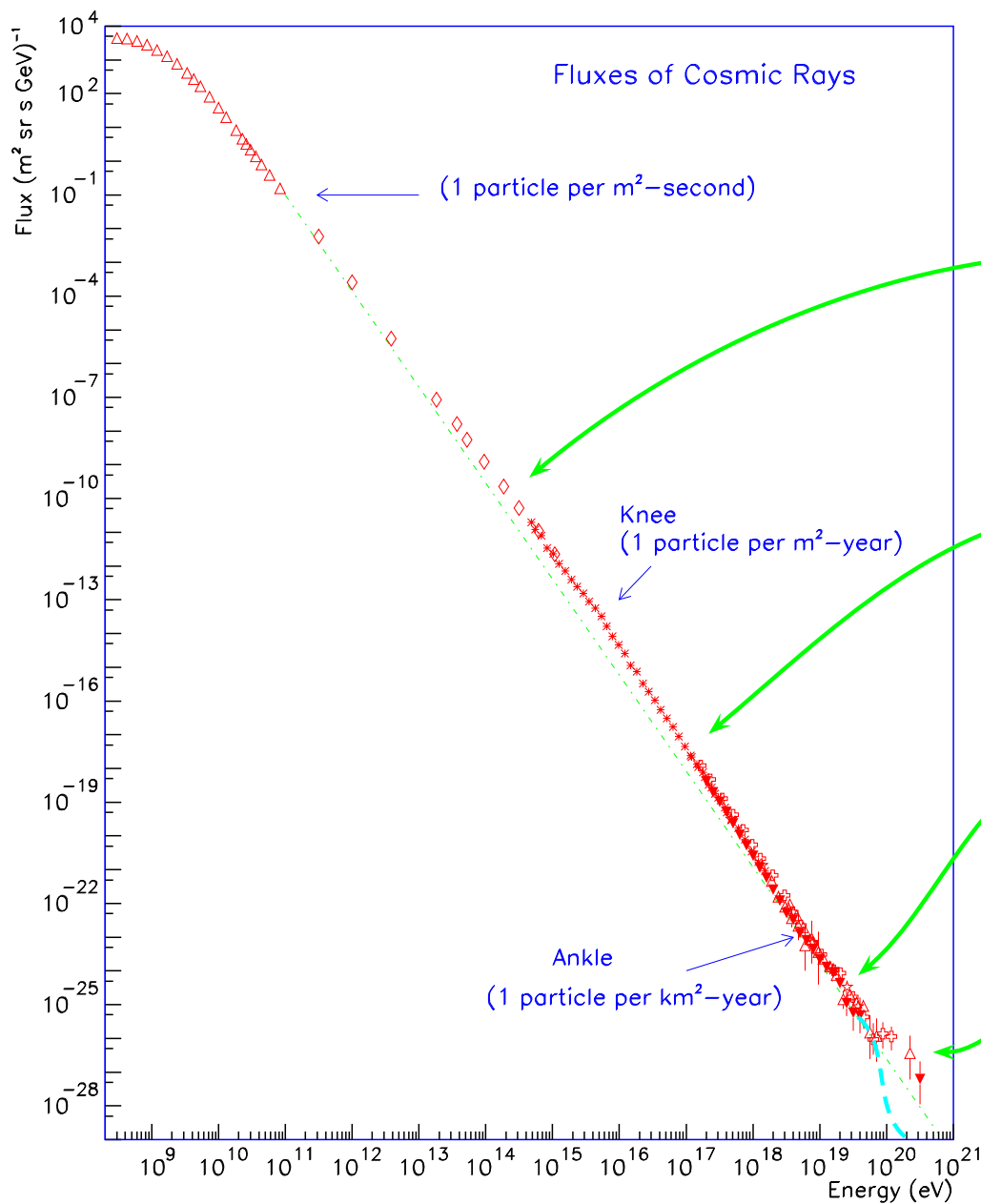
Институт ядерных исследований РАН, Москва



План

- **Спектр космических лучей**
- **Широкие атмосферные ливни**
- **Неожиданные результаты AGASA**
- **Невозможность объяснения в рамках СМ**
- **Результаты других экспериментов**
- **Поиски астрофизических источников**

Поток заряженных космических лучей



$$\frac{dN}{dE} \propto E^{-2.65}$$

$$\frac{dN}{dE} \propto E^{-3.05}$$

Knee2:

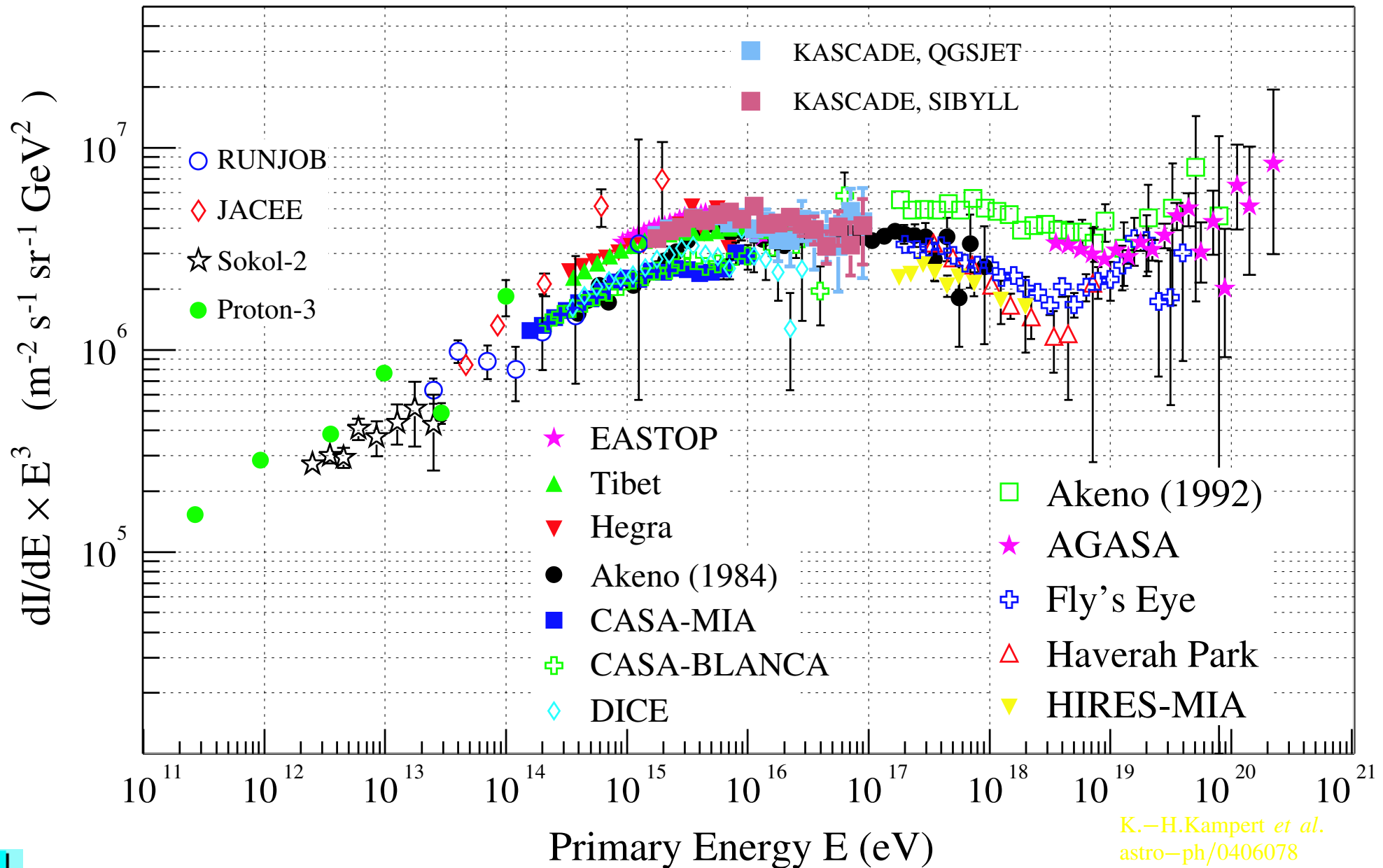
$$\frac{dN}{dE} \propto E^{-3.20}$$

$$\frac{dN}{dE} \propto E^{-2.7}$$

$$\frac{dN}{dE} \propto E^{-2.7}$$

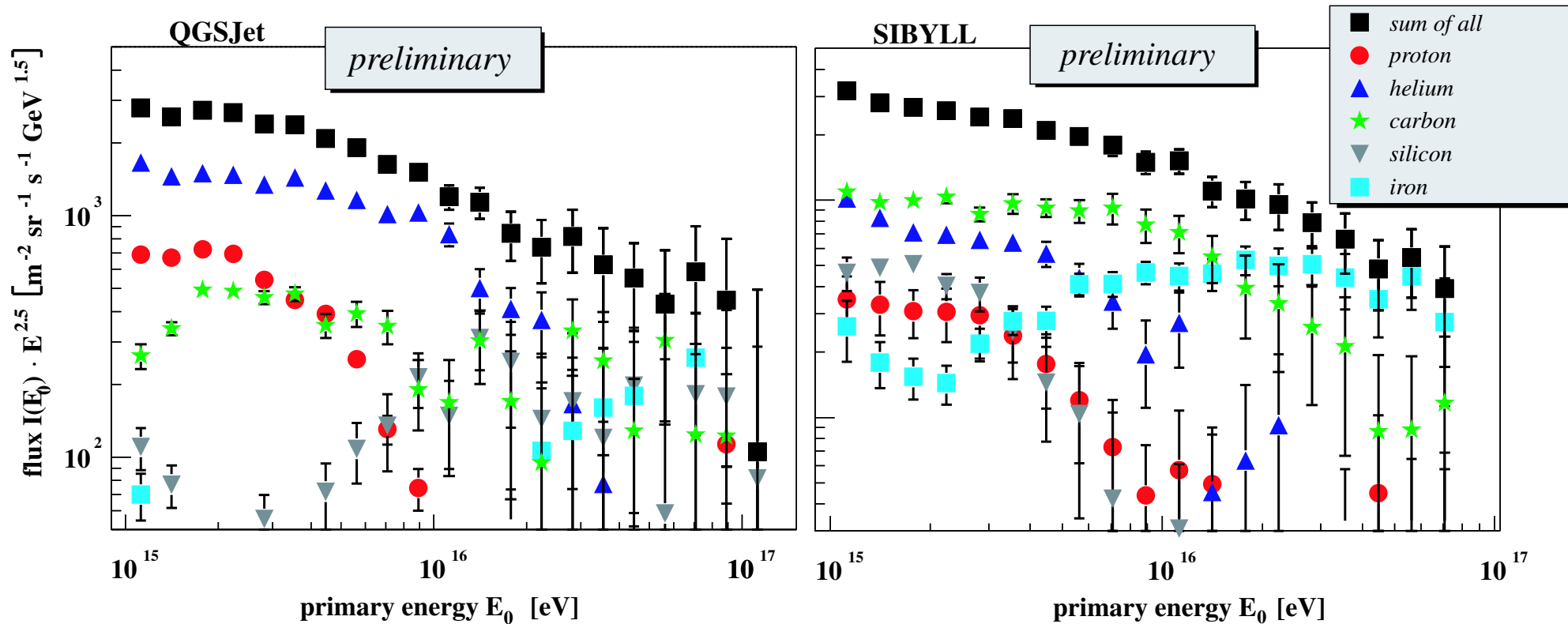
ГЗК-обрезание (1966)

Причины особенностей спектра



K.—H.Kampert *et al.*
astro-ph/0406078

Причины особенностей спектра: состав КЛ



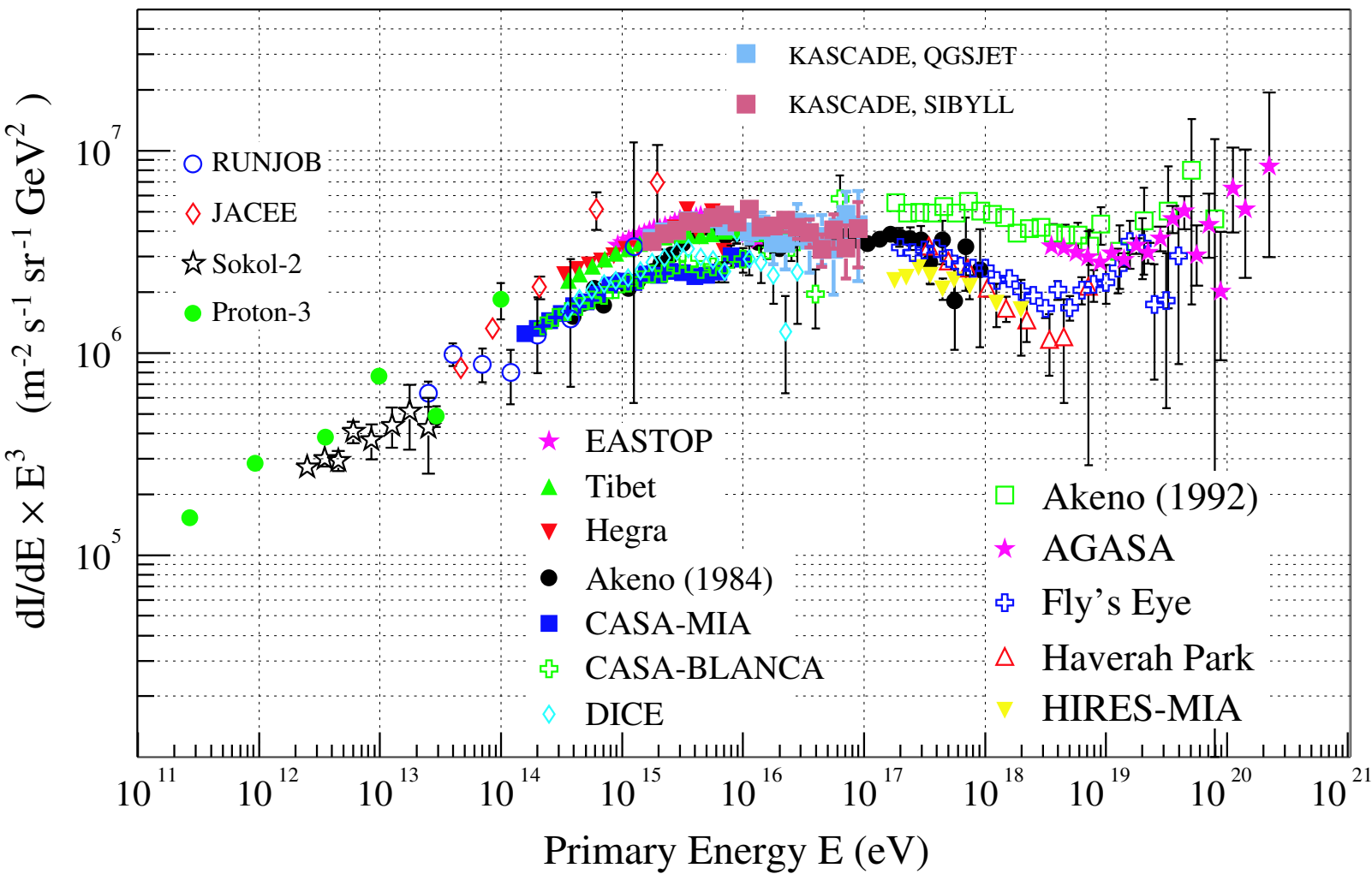
K.-H.Kampert *et al.*
astro-ph/0406078

$$\frac{Z}{M_A} :$$

определяет и ускорение и распространение,
нет заметных энергетических потерь



Причины особенностей спектра: ГМП

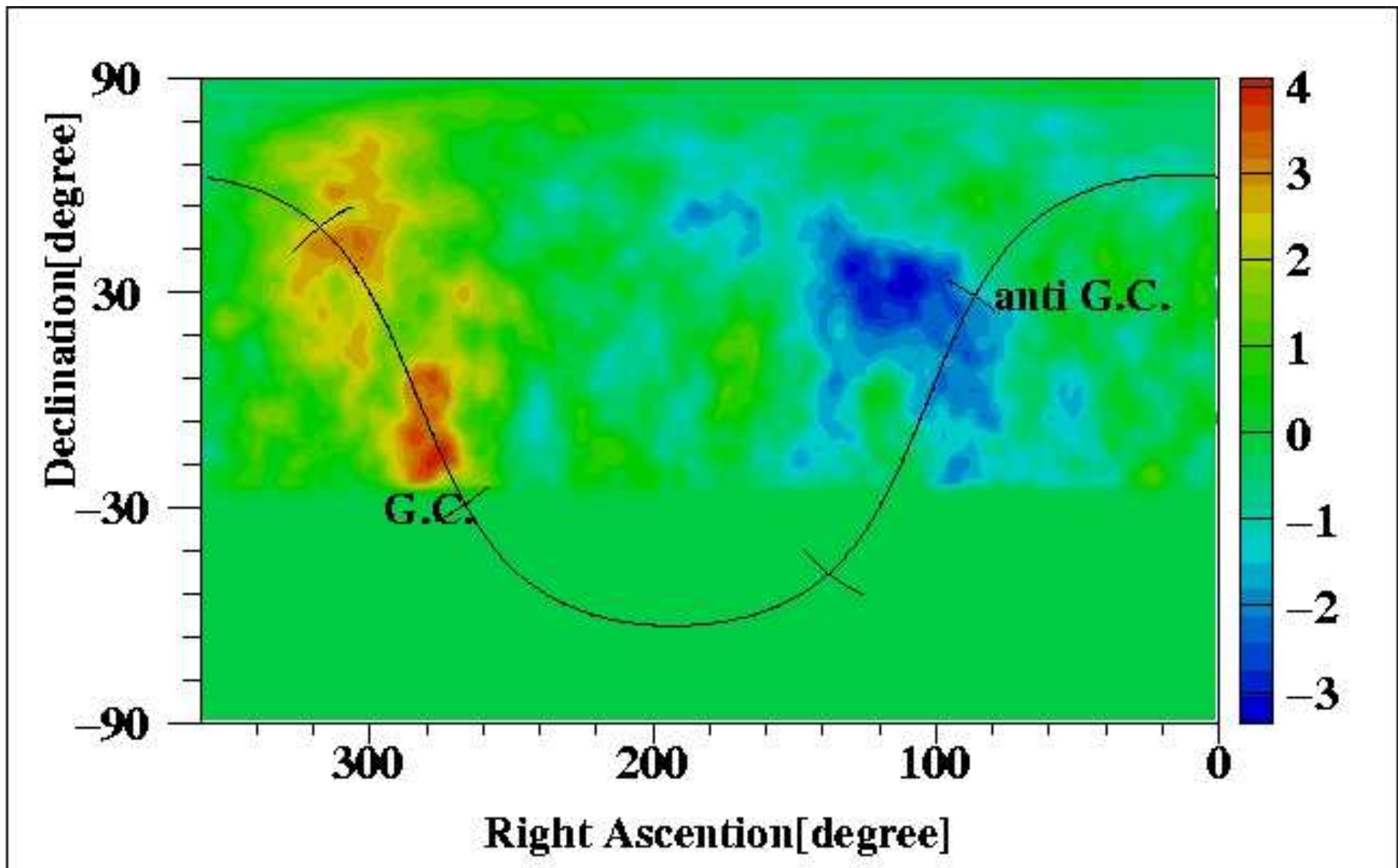


K.—H.Kampert *et al.*
astro-ph/0406078

конфайнмент в галактике

$$\frac{E}{4 \cdot 10^{18} \text{ eV}} \lesssim Z \frac{B}{\mu\text{G}} \frac{R_L}{10 \text{ kpc}}$$

Галактическая анизотропия

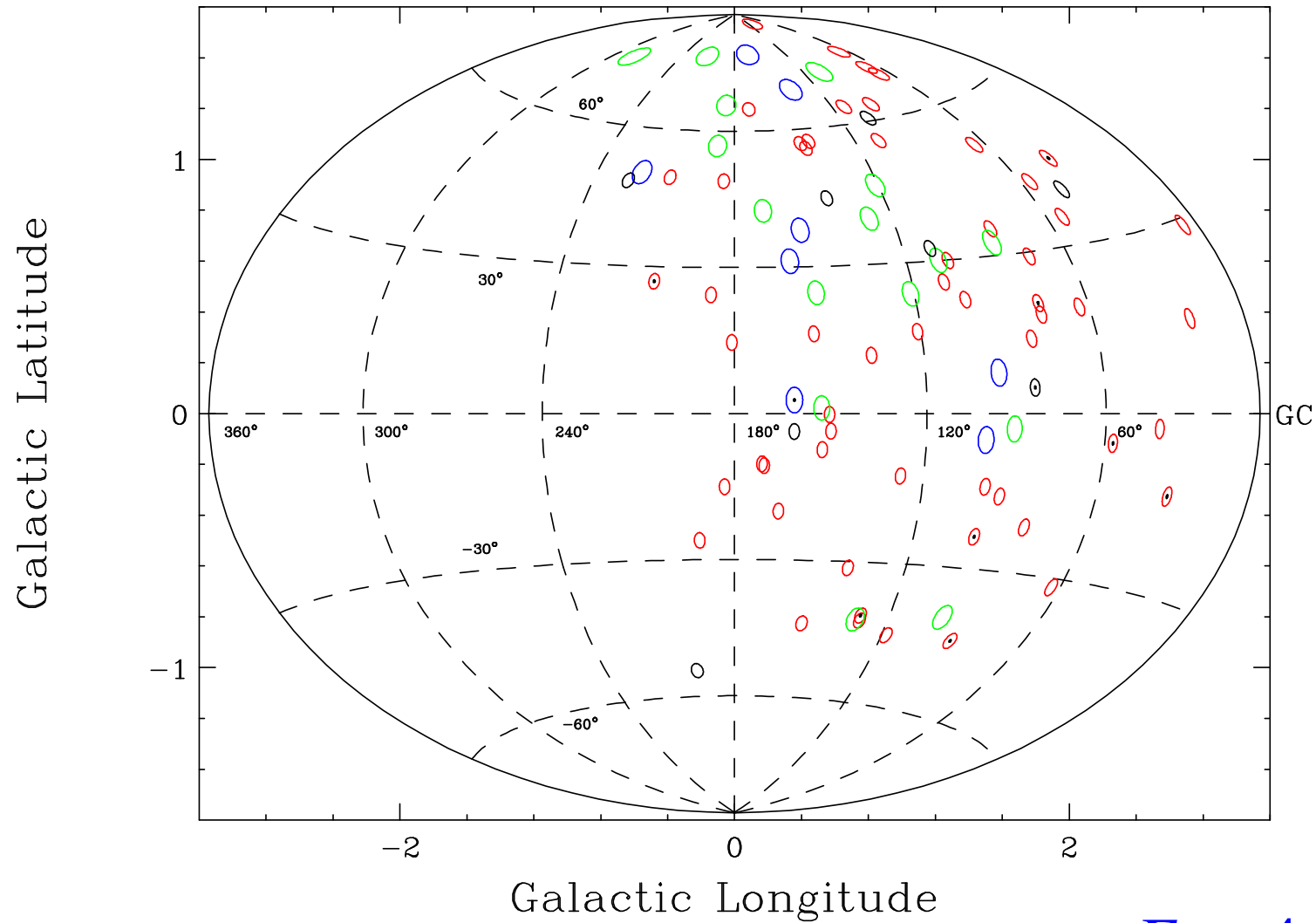


Akeno+AGASA (11 лет): 4% диполь @ $E \sim 10^{18}$ eV

N.Hayashida *et al.*
astro-ph/9807045

Внегалактическая изотропия

89 events, $E > 4 \times 10^{19}$ eV AGASA(red),Haverah(green),Yakutsk(blue),Volcano(black)



J.Cronin
astro-ph/0402487

$E > 4 \cdot 10^{19}$ eV



Выводы для КЛ

Энергии

$$E \sim 10^{14-15}$$

$$4 \cdot 10^{17} \lesssim E \lesssim 4 \cdot 10^{18}$$

$$4 \cdot 10^{18} \lesssim E \lesssim 5 \cdot 10^{19}$$

$$E > 5 \cdot 10^{19}$$

Источники

ударные

волны в SN

галактические

внегалактические

внегалактические (?)

Элементарный состав

p, He, ...

..., Fe, ...

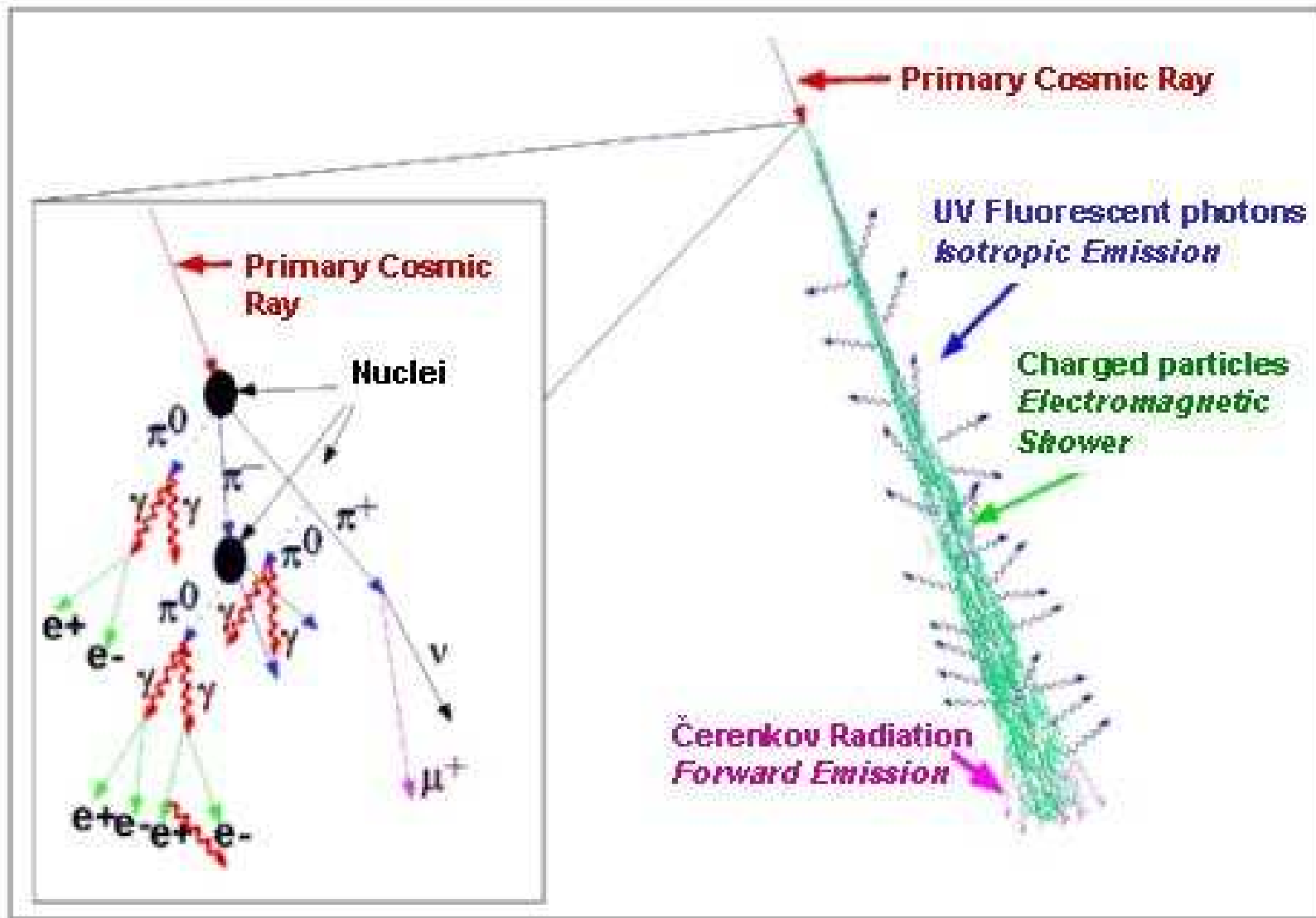
p, He(?)

Fe ($\lesssim 40\%$), γ ($\lesssim 30\%$)

p(?), ..., Fe(?), γ ($\lesssim 50\%$)



Широкие атмосферные ливни



Наблюдаемые & Эксперименты

Экспозиция в
 $10^{16} \text{ cm}^2 \text{ s sr}$

СЦИНТИЛЛЯЦИОННЫЕ

Volcano Ranch	0.2
Haverah Park	0.9
Yakutsk	1.8
AGASA	5.3

флуоресцентные

Fly's Eye	2.6
HiRes I,II Mono	7.2
HiRes Stereo	4.6

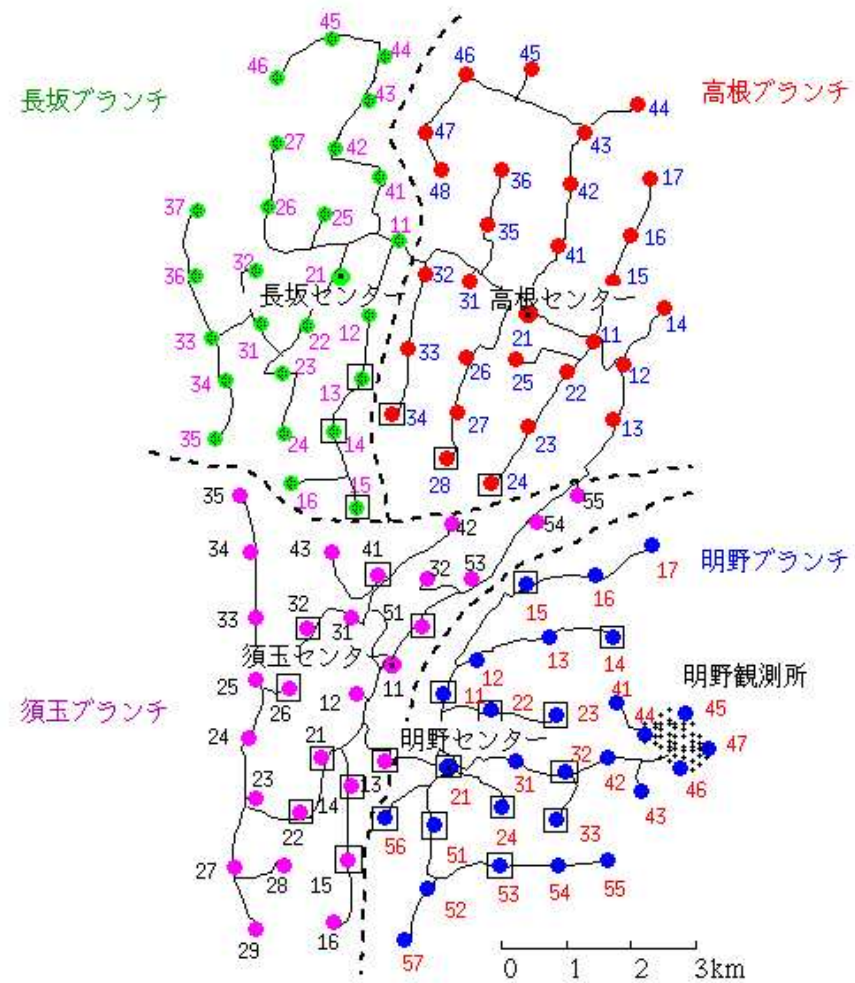
гибридный:

Pierre Auger (2005)

7* HiRes' апертура



Сцинтилляторные установки: AGASA

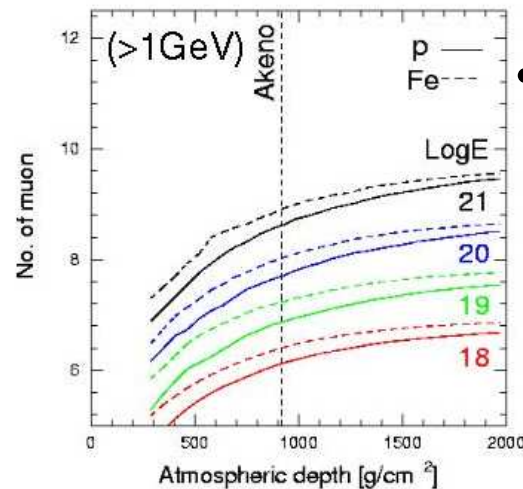
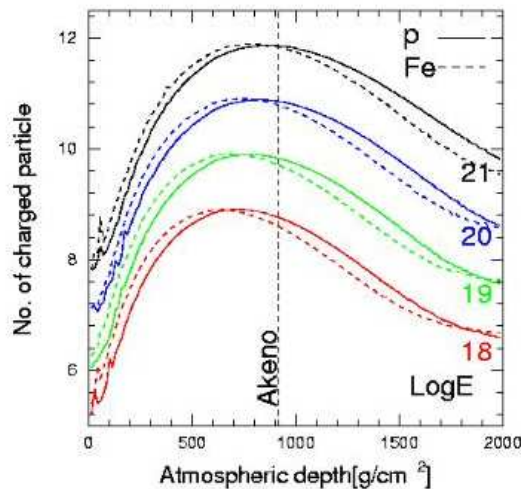
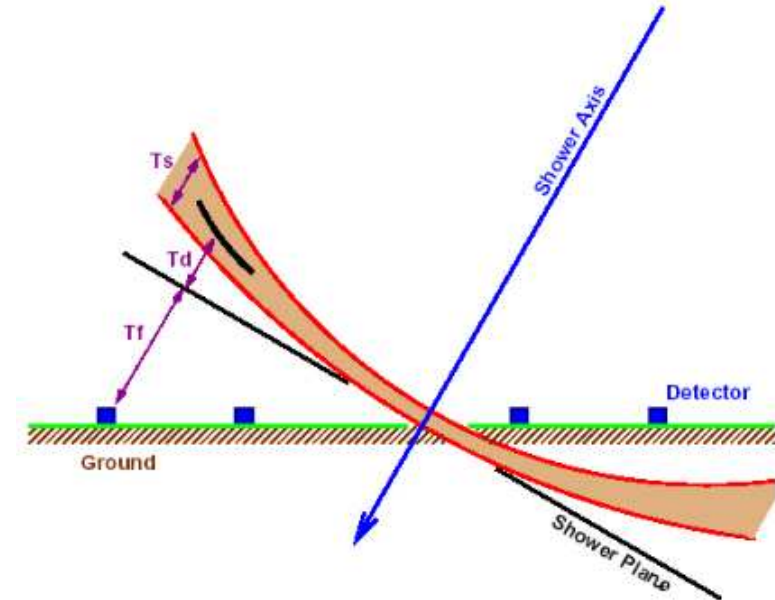
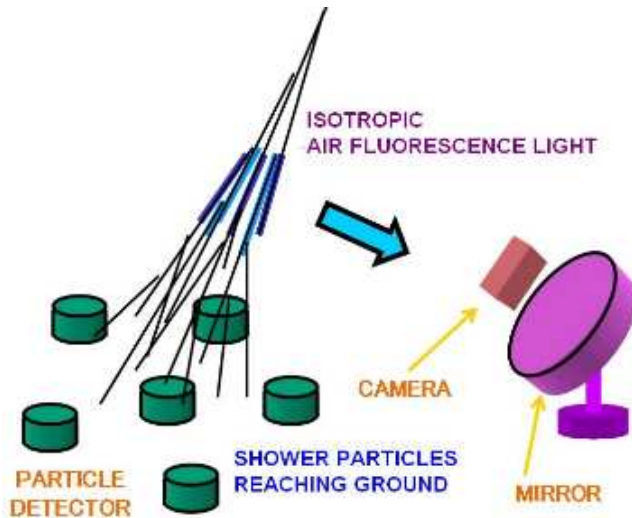


Обсерватория Акепо:

~ 100 km²

111 пластиковых сцинтилляторов & 27 мюонных детекторов

Observation techniques



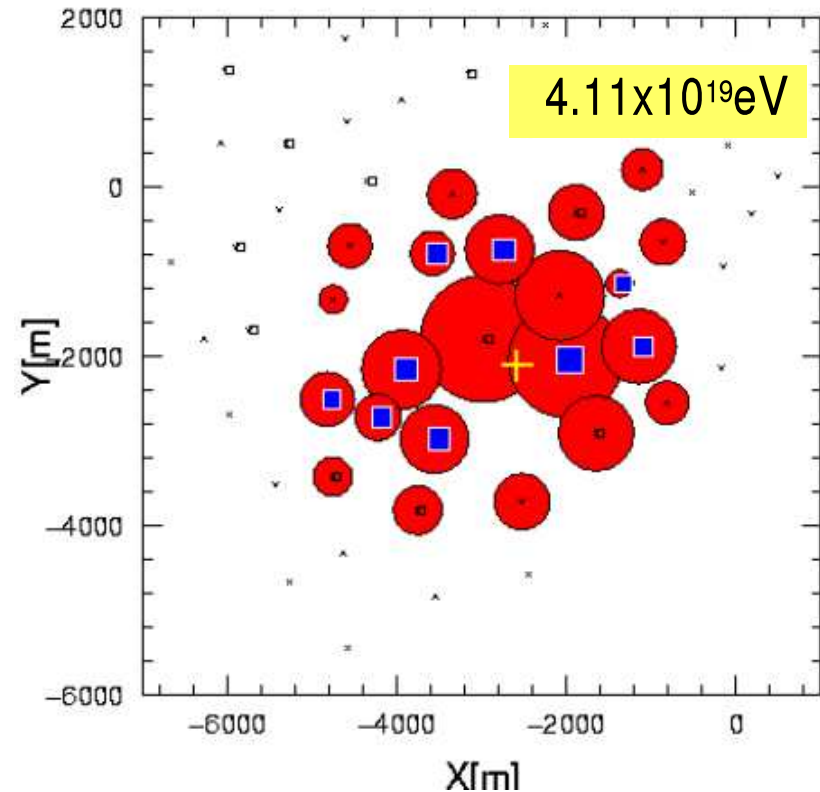
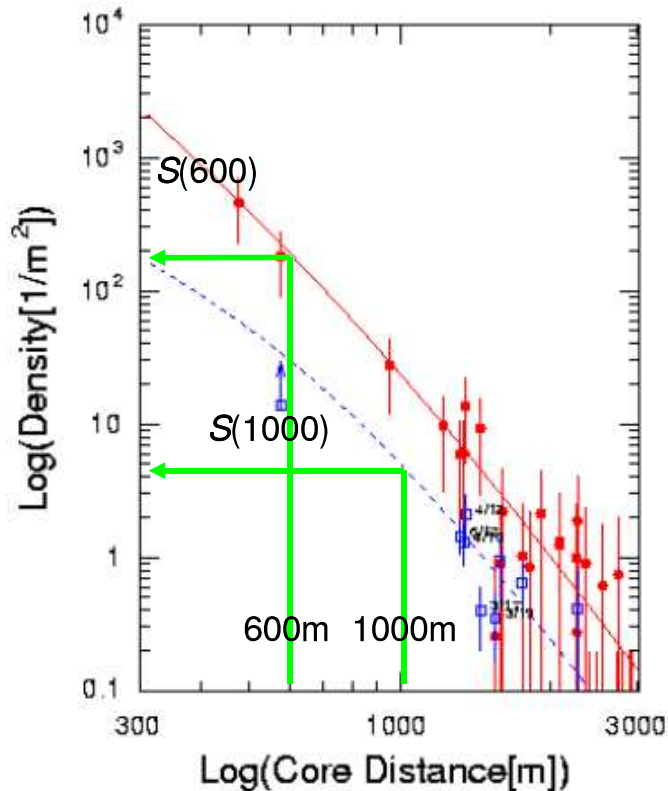
AIRES Sim. (QGSJET model)

• Observable

- EM Energy
 - Carrying 90% energy
- Muons 1ry particle ID
 - Reflecting hadronic interactions

K.Shinozaki *et al.*
QUARKS'04

Event sample & observables



- Energy estimator (charged particle density @600m): $S(600)$
 - $S(600)$ attenuation modified by empirical function
- Primary mass estimator (muon density@1000m): $S(1000)$

K.Shinozaki *et al.*
QUARKS'04

Формулы для оценки энергии

Энергия vs $S(600)$ для вертикальных ливней:

результаты MC с COSMOS+QCDJET

Dai *et al.*
1988

$$E_0[eV] = 2.03 \cdot 10^{17} S_0(600), \quad S(600) = S_0(600)$$

Для наклонных ливней:

Эмпирическое соотношение:

$$S(600) = S_0(600) \cdot \exp \left(-\frac{X_0}{\Lambda_1 (\sec \theta - 1)} - \frac{X_0}{\Lambda_2 (\sec \theta - 1)^2} \right)$$

X_0 — глубина атмосферы (920 g/cm² @ Akeno)

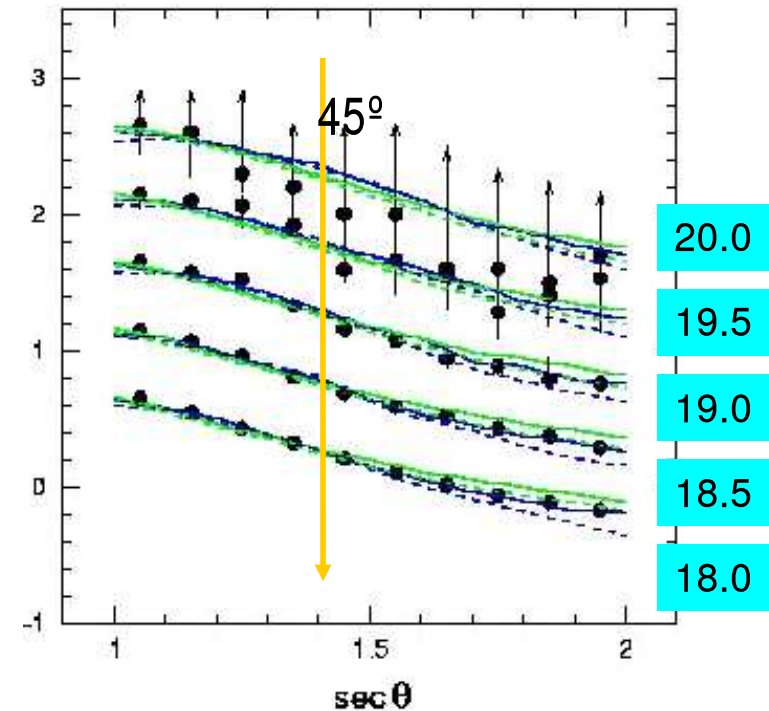
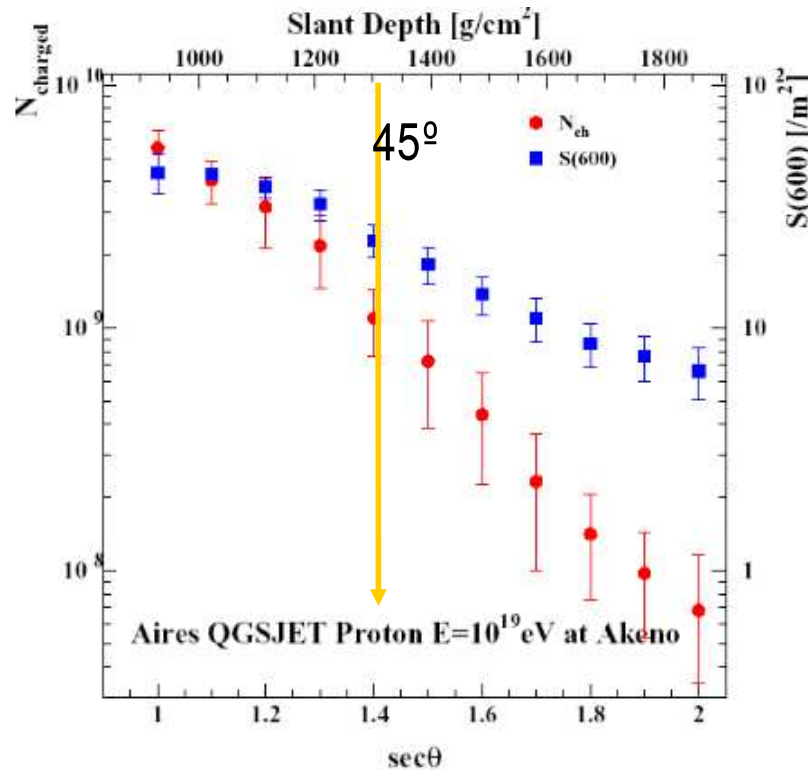
$$\Lambda_1 = 500 \text{ g/cm}^2$$

$$\Lambda_2 = 594 \text{ g/cm}^2$$



S(600) attenuation curve

AIRES code + QGSJET / SIBYLL model for p / Fe



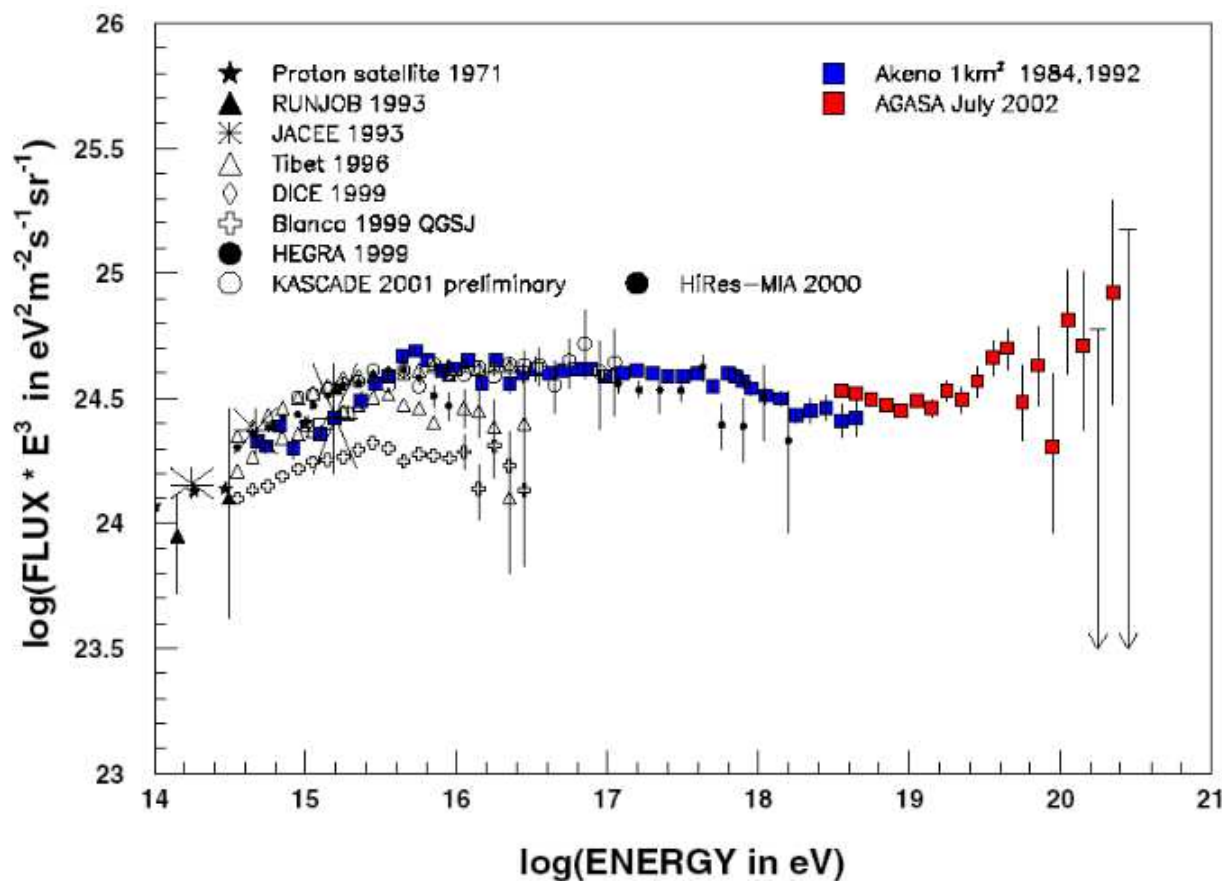
- **S(600) attenuating rather slowly**
 - Correction factor less than 2 up to 45° zenith angle
- **S(600) attenuation curve consistent between data & MC**
 - Depending less on 1ry particles or interaction models

K.Shinozaki *et al.*
QUARKS'04

Систематические ошибки ($z < 45^\circ$)

Определение энергии: $\Delta E/E < 18\% @ E > 10^{19}$ eV

Направления прихода: $\Delta\delta < 1.8^\circ @ E > 4 \cdot 10^{19}$ eV



Систематика: мелкомасштабные флуктуации

Energy estimation fluctuations, shower 1

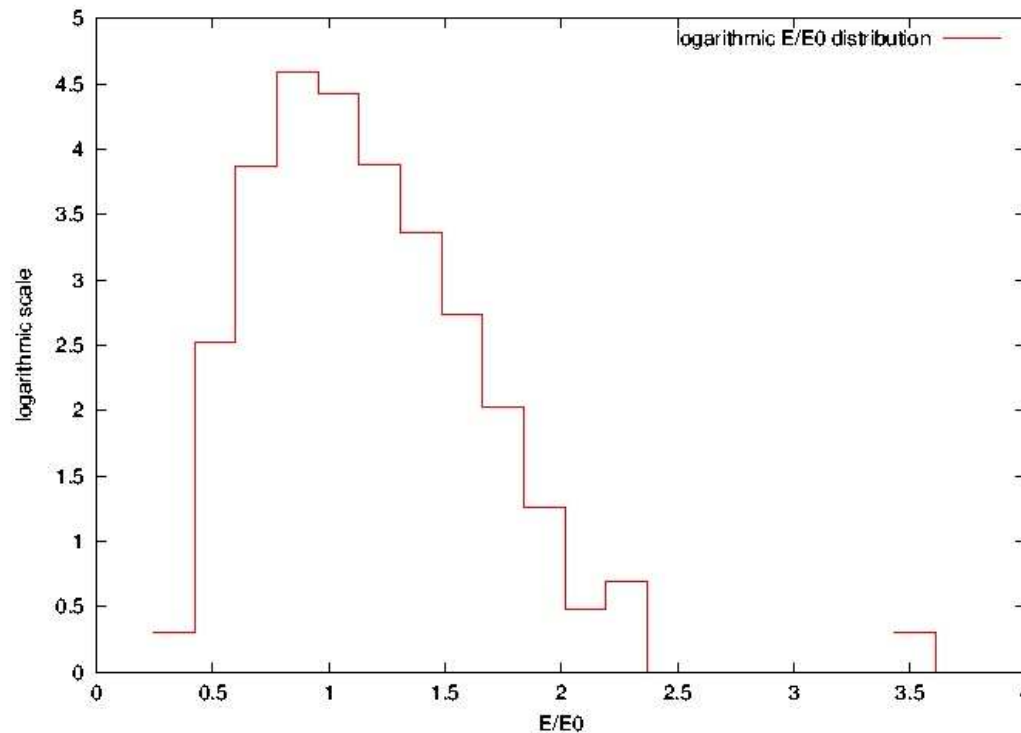
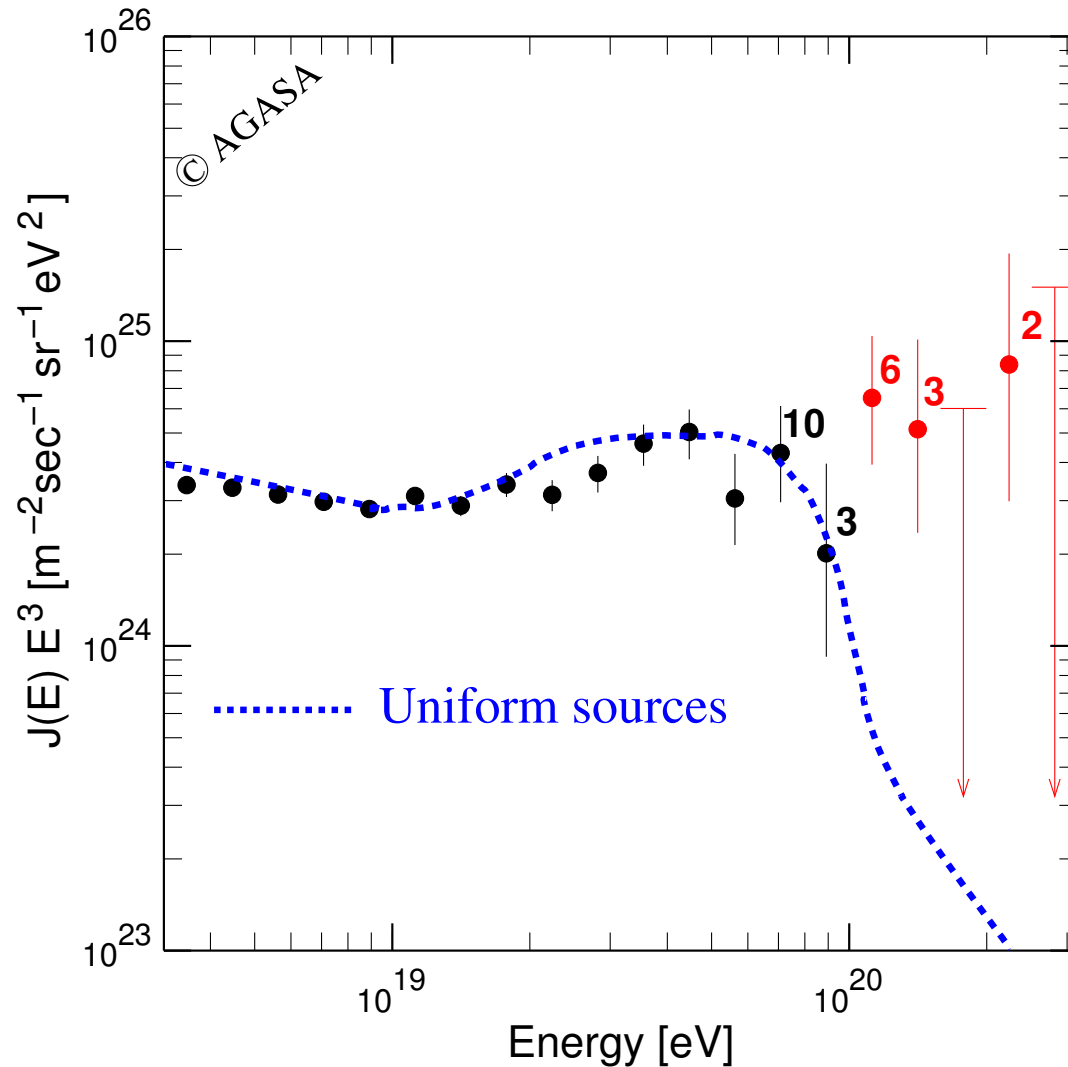


Fig. 2: E/E_0 distribution ($E_0 = 10^{18} \text{ eV}$, 83525 energy estimation acts)

AGASA: энергетический спектр ($z < 45^\circ$)



fit:

$$dN/dE = F_0 \cdot E^{-\gamma}$$

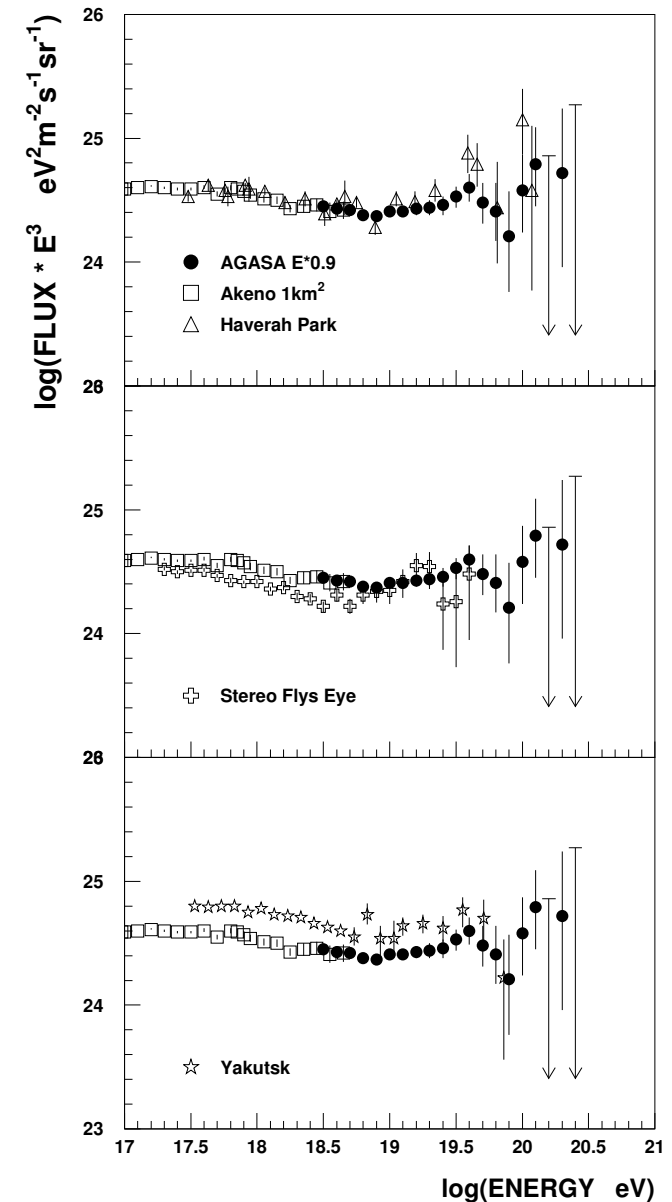
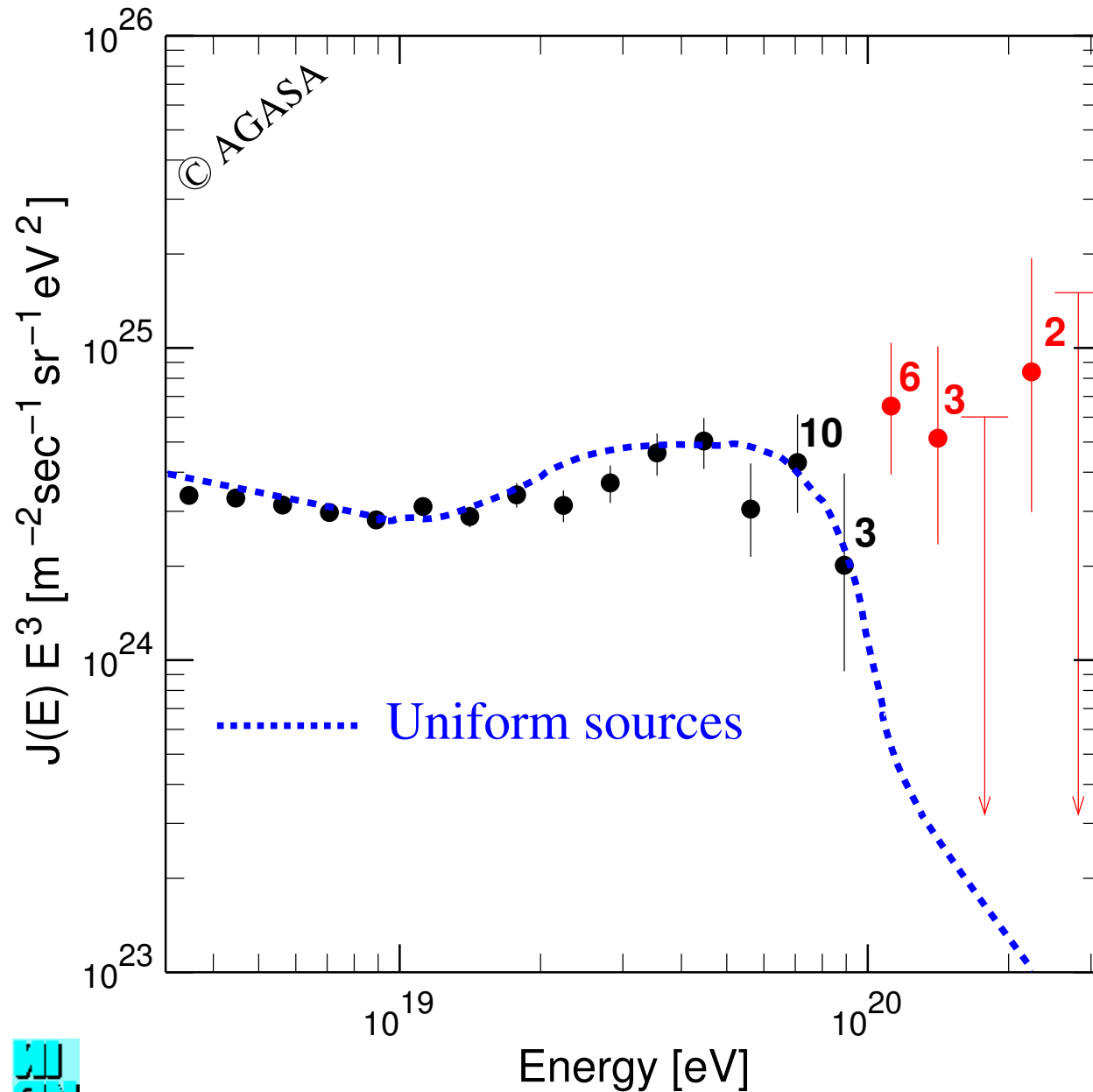
F_0, γ — low E

1.9 событий
ожидалось

11 событий
зарегистрировано

4.4 σ
отличие

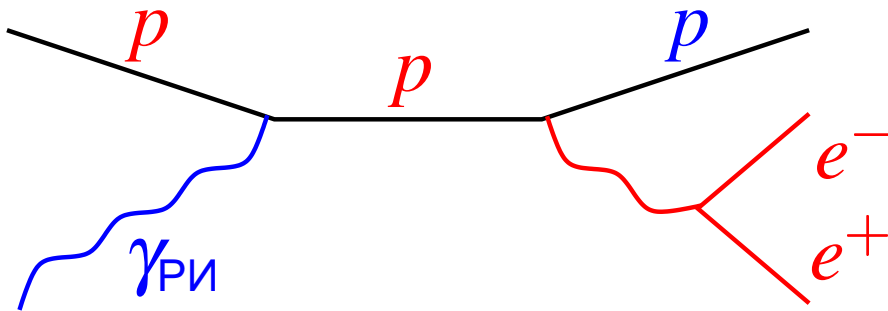
Другие эксперименты с малой экспозицией



ГЗК-обрезание для протонов

неподавляемый фон: фотоны РИ

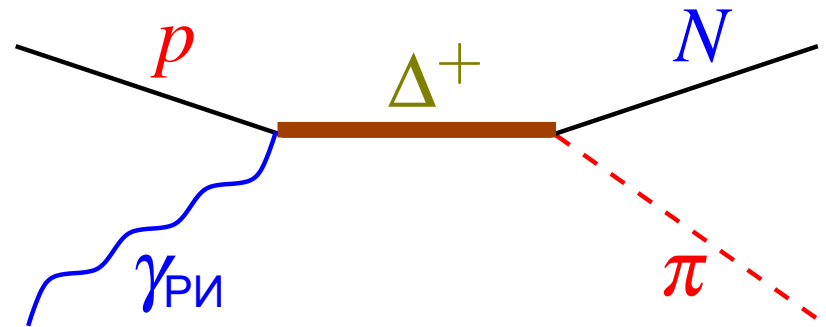
$$E_p \lesssim 5 \cdot 10^{19} \text{ eV}$$



$$L_{p\gamma_{\text{РИ}} \rightarrow p e^+ e^-}^{m.f.p.} \sim 1 \text{ Мpc}$$

$$\Delta E_p / E_p \sim 10^{-3}$$

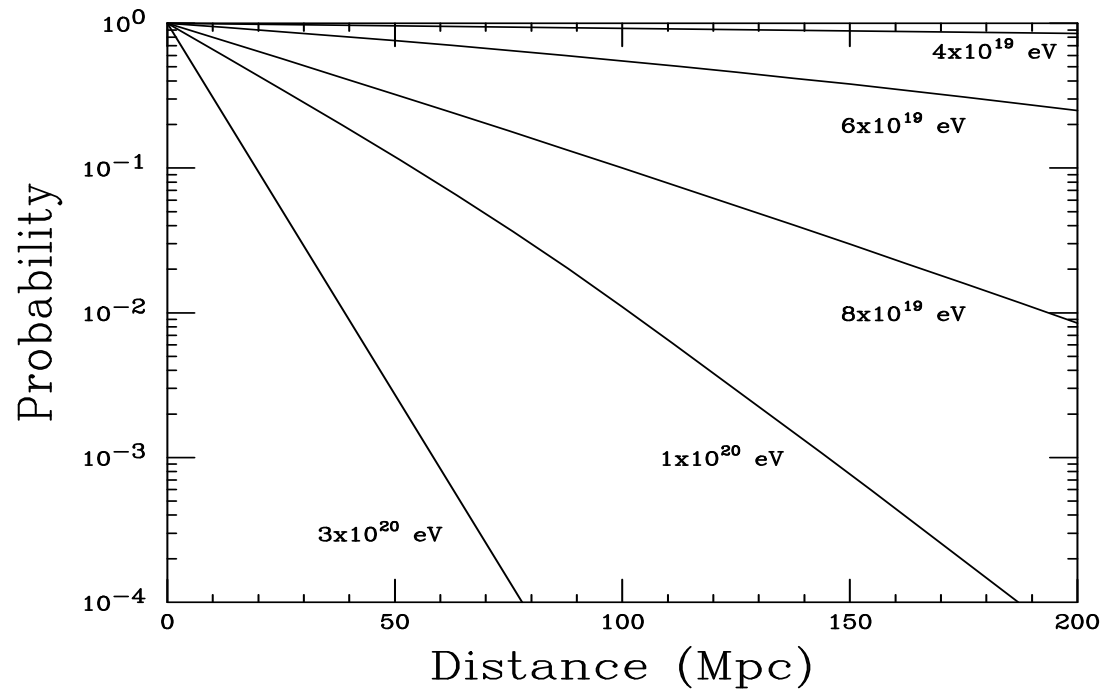
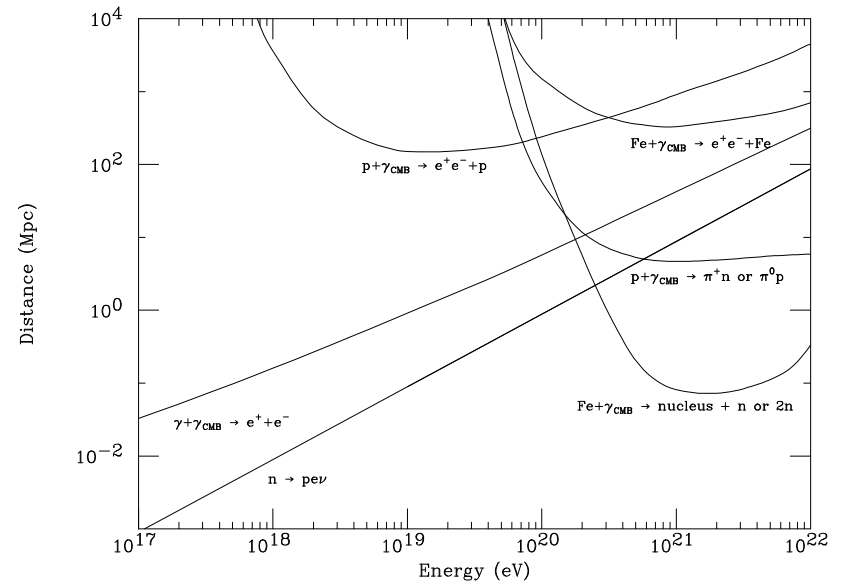
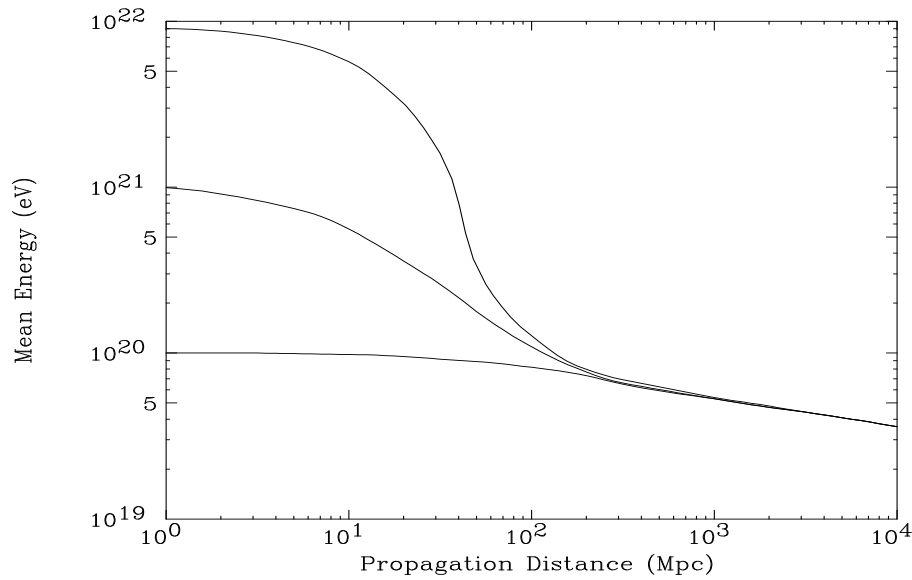
$$E_p \gtrsim 5 \cdot 10^{19} \text{ eV}$$



$$L_{p\gamma_{\text{РИ}} \rightarrow N \pi}^{m.f.p.} \sim 5 \text{ Мpc}$$

$$\Delta E_p / E_p \sim 20\%$$

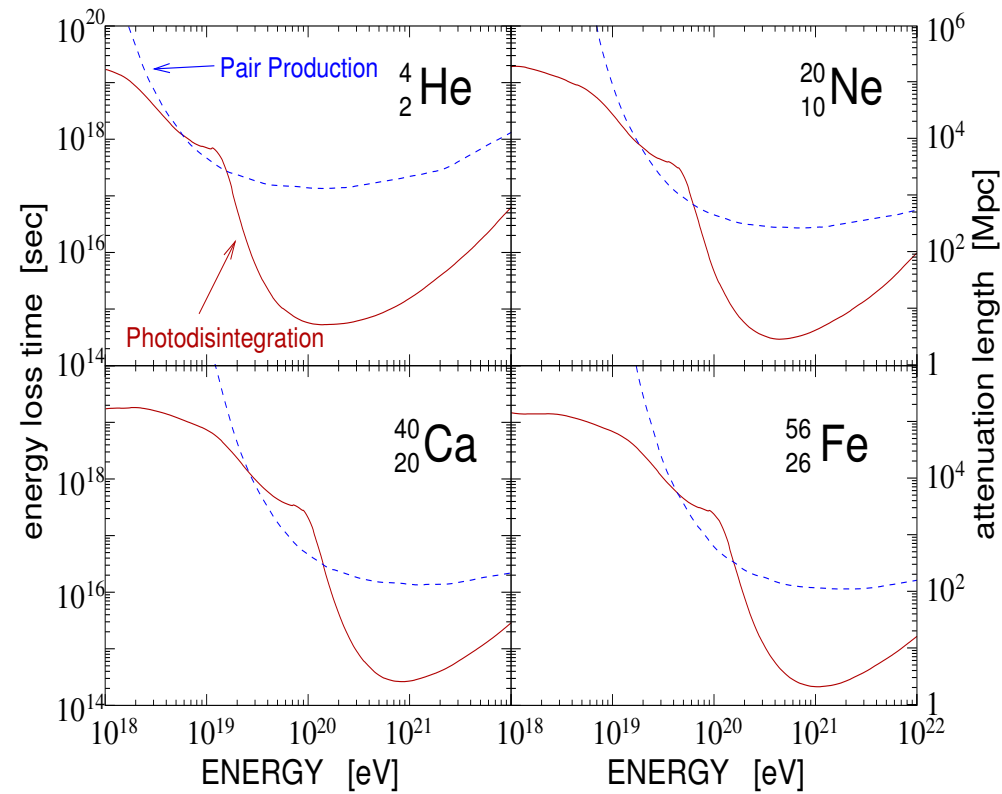
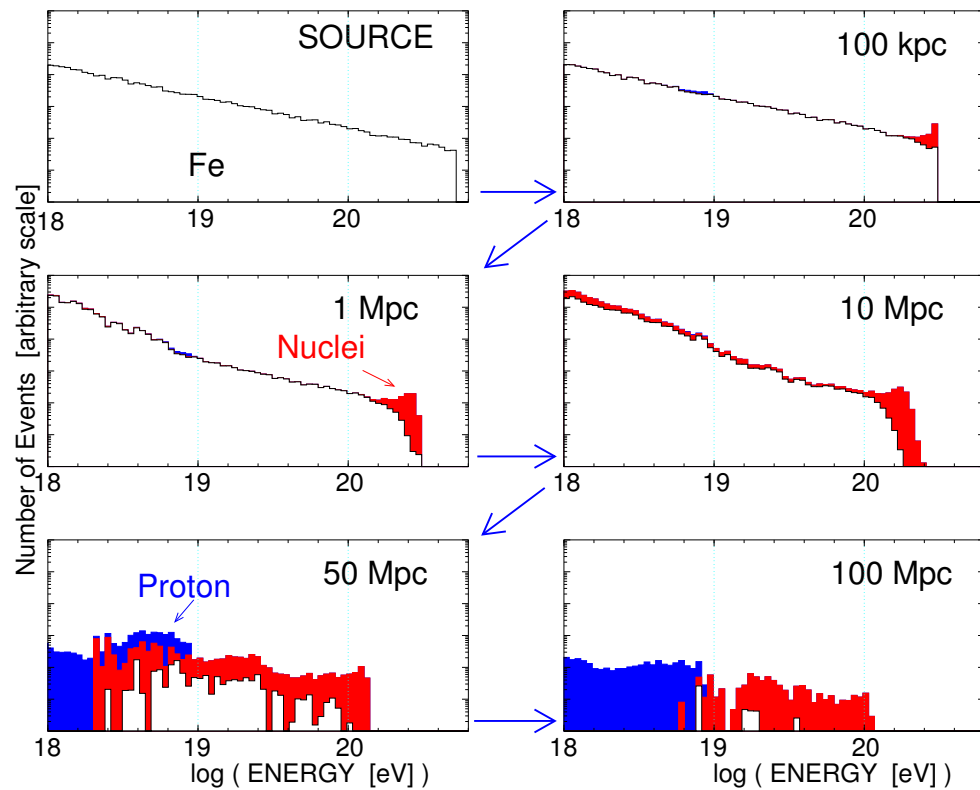
Потери энергии на РИ: протоны



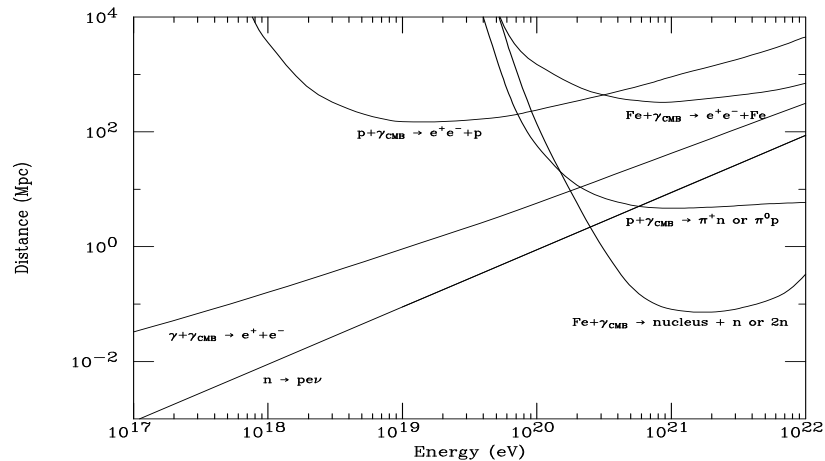
J.Cronin
astro-ph/0402487

равномерно распределённые
источники с $dN_p/dE \propto E^{-2.5}$

Потери энергии на РИ: ядра



T.Yamamoto *et al.*
astro-ph/0312275



J.Cronin
astro-ph/0402487

“Естественное решение” в рамках СМ: ν

Источник: распадающиеся СЭ $\pi^\pm$

- внутри астрофизических ускорителей: $p_{UHE} + p(\gamma) \rightarrow \pi \dots \pi$,
 $\pi^\pm \rightarrow \nu$
- по всей Вселенной: $p_{UHE} + \gamma_{CMB} \rightarrow n_{UHE} + \pi^+$, $\pi^\pm \rightarrow \nu$

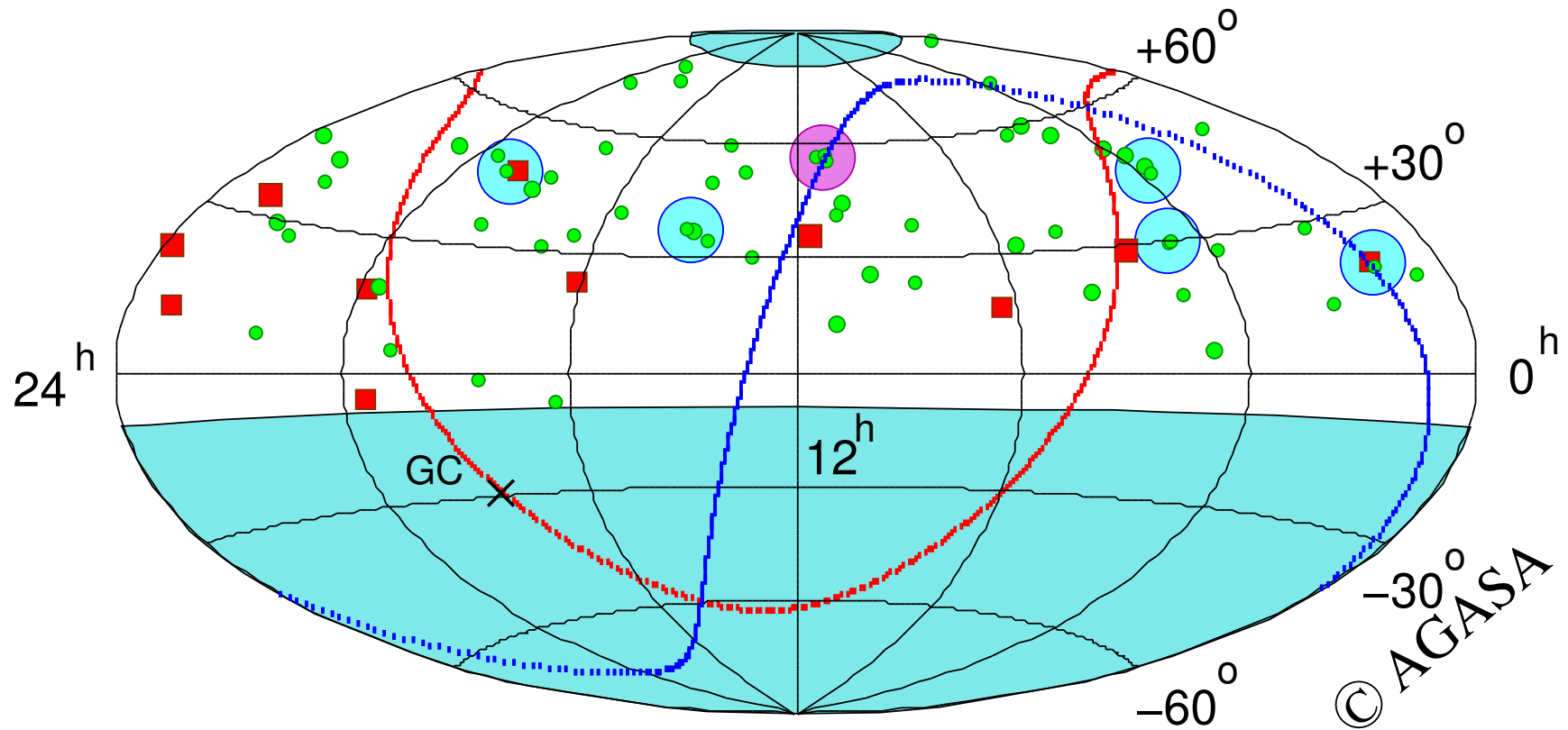
Потери на РИ: Нет!

ШАЛ: Да, но ... горизонтальные !!! — никаких указаний...

Все ШАЛы выше порога ГЗК начали развитие в высоких слоях атмосферы

Они определённо вызваны не СЭ ν

AGASA: мультиплеты



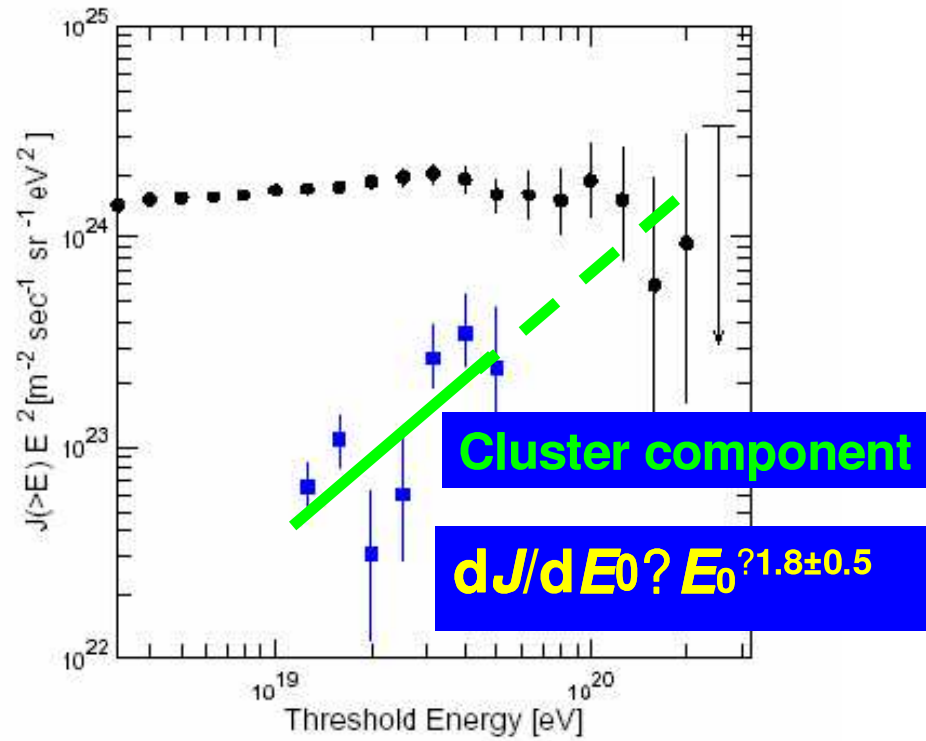
P.Tinyakov, I.Tkachev
astro-ph/0102101

AGASA: $E > 4 \cdot 10^{19}$ eV @ 2.5° : 5 дублетов & 1 триплет, $P_{autcr} < 10^{-3}$

Yakutsk: $E > 2.4 \cdot 10^{19}$ eV @ 4° : 5 дублетов & 1 триплет, $P_{autcr} \sim 10^{-3}$

Новые мультиплеты в (AGASA+Yakutsk+HP+VR) $P \sim 10^{-3}$ Y.Uchihori et al.
astro-ph/9908193

Integral EHECR spectrum (Ordinary EHECR vs. cluster comp.)



- **Harder spectrum of cluster component**
 - Scattering lower energy EHECRs
 - Watching spectrum at nearby sources?
- **Extrapolation meeting highest energy cosmic ray flux @ $\sim 10^{20}$ eV**

K.Shinozaki *et al.*
QUARKS'04

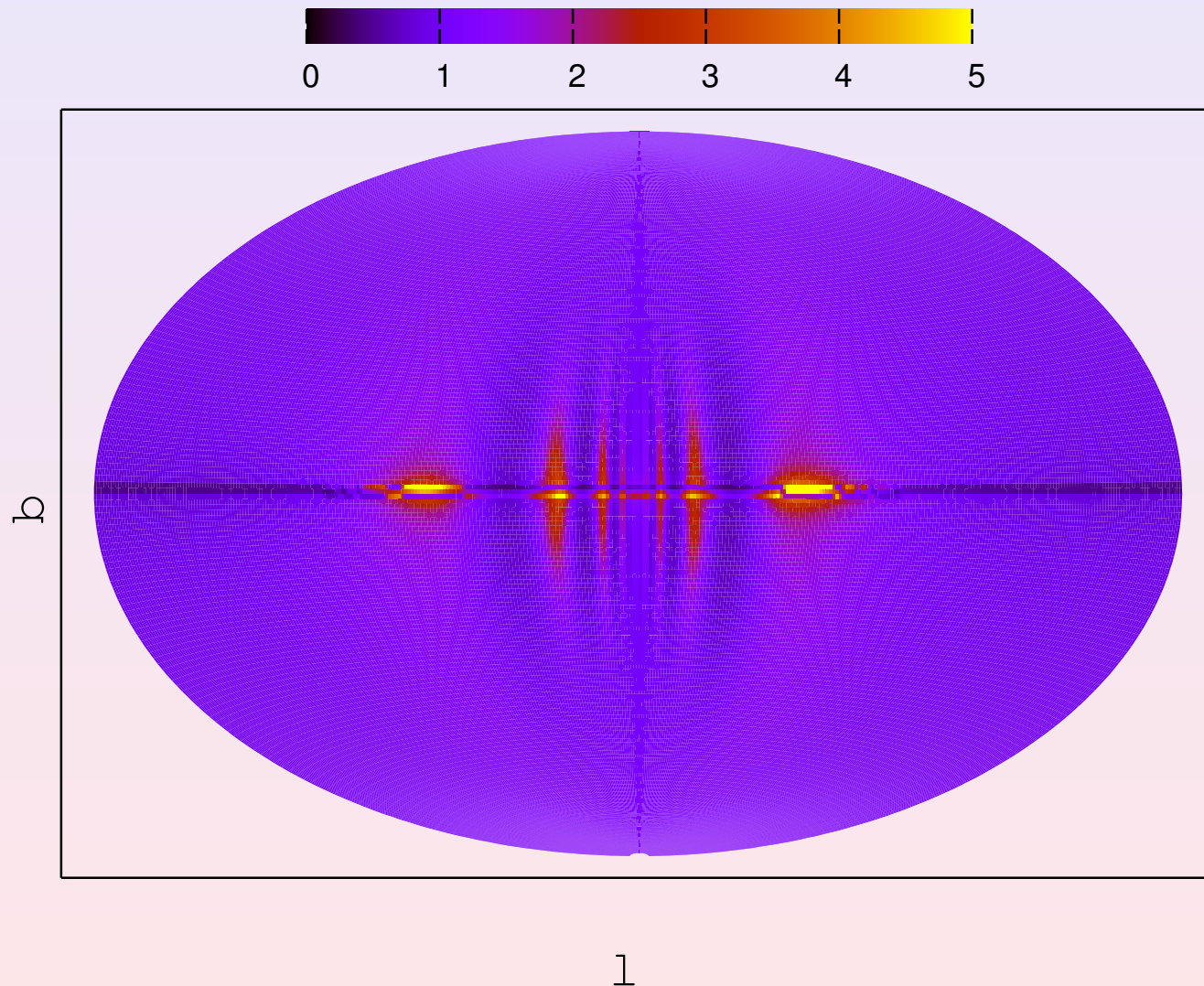
Указание?

- Яркие далёкие источники, $\sim \#100$
- Магнитное линзирование # близких источников

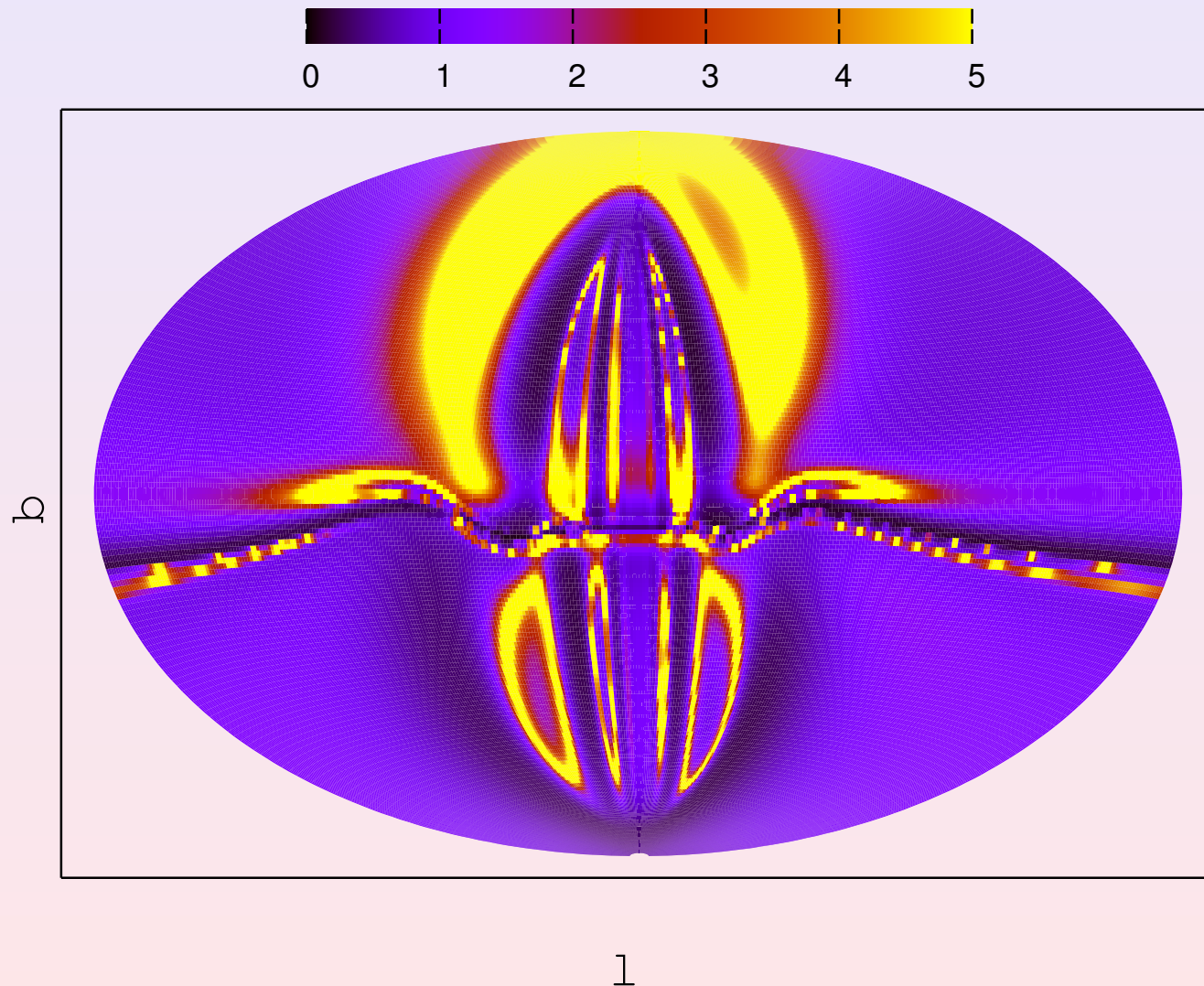
S.Dubovsky, P.Tinyakov, I.Tkachev
astro-ph/0001317



(De-) Magnification for $eE/Q = 4 \times 10^{19}$ eV: TT model



(De-) Magnification for $E/Q = 2 \times 10^{19}$ eV: HMR model



Указание?

- Яркие далёкие источники, $\sim \#100$
- Магнитное линзирование **# близких источников**

S.Dubovsky, P.Tinyakov, I.Tkachev
astro-ph/0001317

Little GZK-problem : не видно близких ($L \lesssim 50$ Мpc)
астрофизических источников способных ускорять до 10^{20} eV



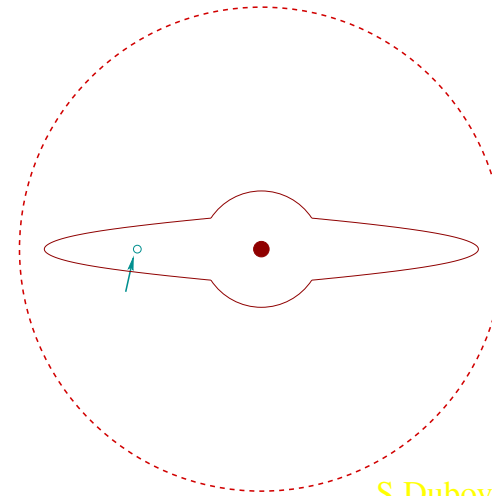
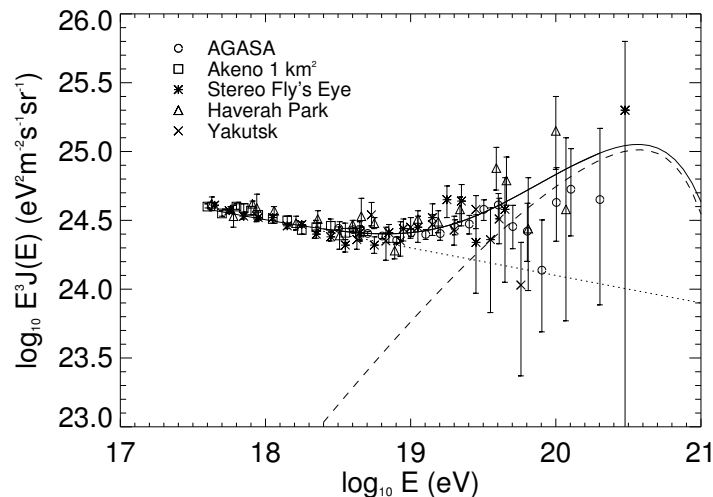
Указание?

- Яркие далёкие источники, $\sim \#100$
- Магнитное линзирование # близких источников
- Образующие сгустки нестабильные тяжёлые реликтовые частицы (Тёмная материя в Галактике)

S.Dubovsky, P.Tinyakov, I.Tkachev
astro-ph/0001317

V.Rubakov, V.Kuzmin
astro-ph/9709187

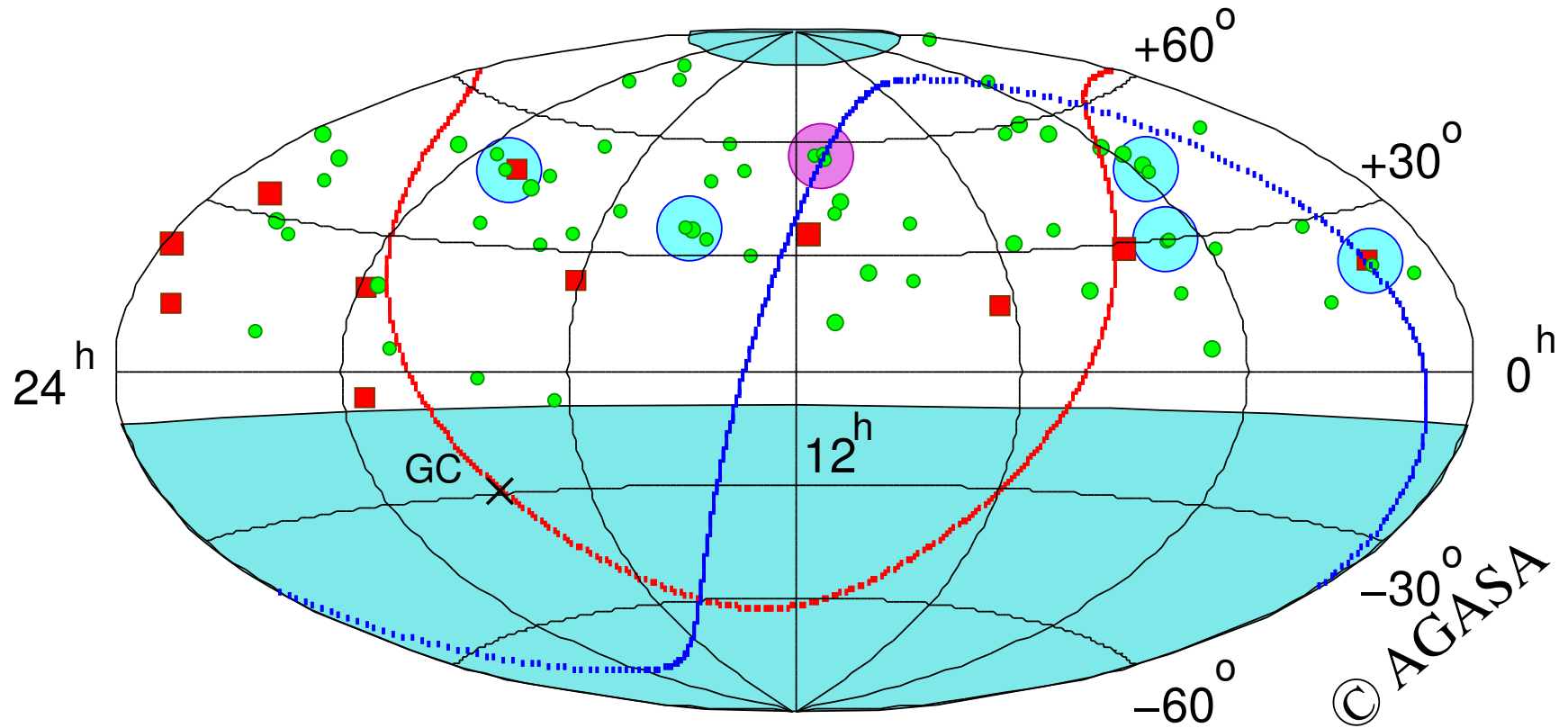
V.Berezinsky, M.Kachelriess, A.Vilenkin
astro-ph/9708217



S.Dubovsky, P.Tinyakov
hep-ph/9802382

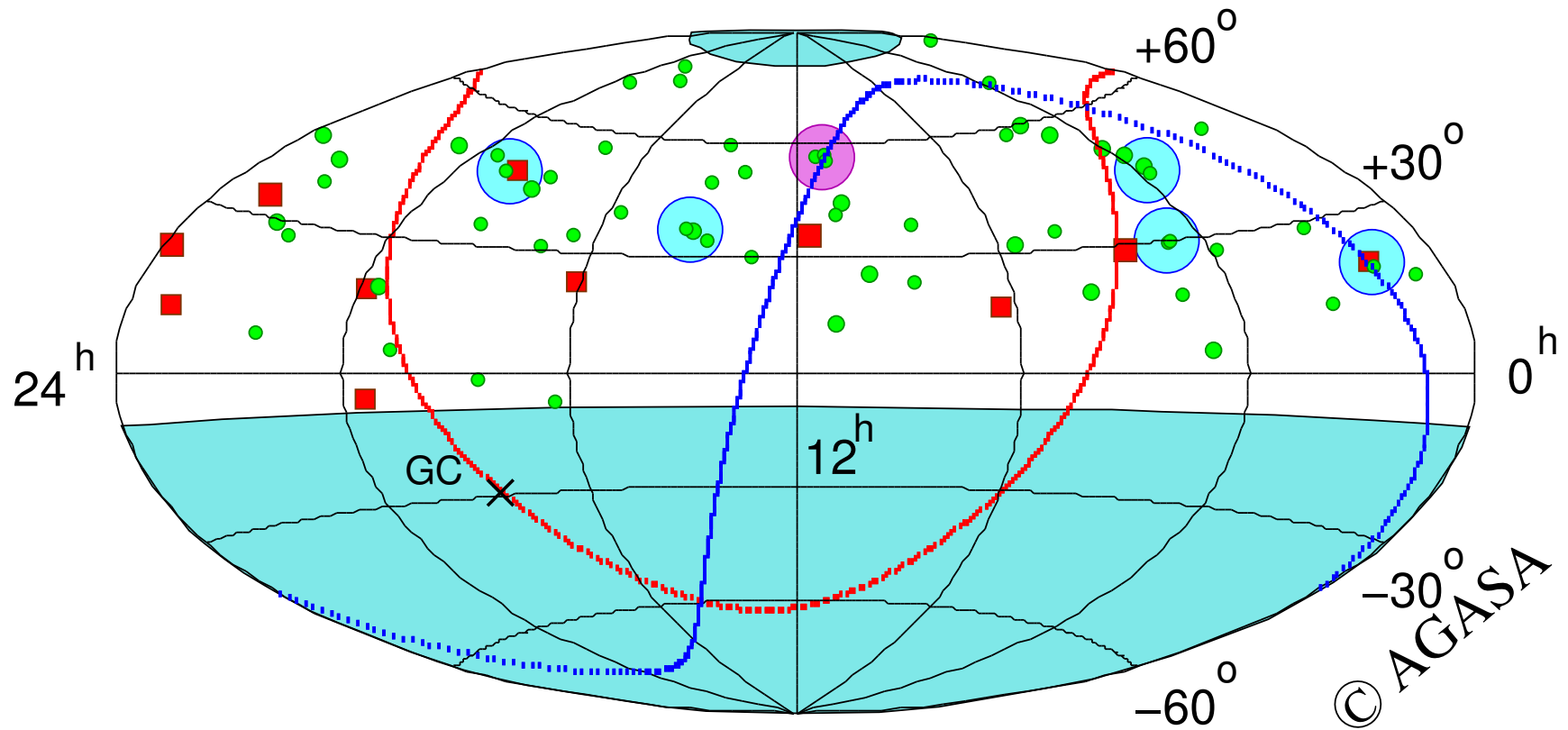
Little GZK-problem : не видно близких ($L \lesssim 50$ Мpc)
астрофизических источников способных ускорять до 10^{20} eV

Нет глобальной анизотропии



© AGASA

Глобальная анизотропия @ $E \gtrsim 10^{20}$ eV ?



Результаты **всех других экспериментов** **подтверждают** эту **анизотропию**, $P \sim 10^{-2}$

D.G., S.Troitsky
astro-ph/0306145

Все КЛСЭ с $E > 10^{20}$ eV (всего около 15 событий) пришли из области $\theta < 45^\circ$

Фотоны СВЭ: спектр AGASA

Reconstructed AGASA spectrum

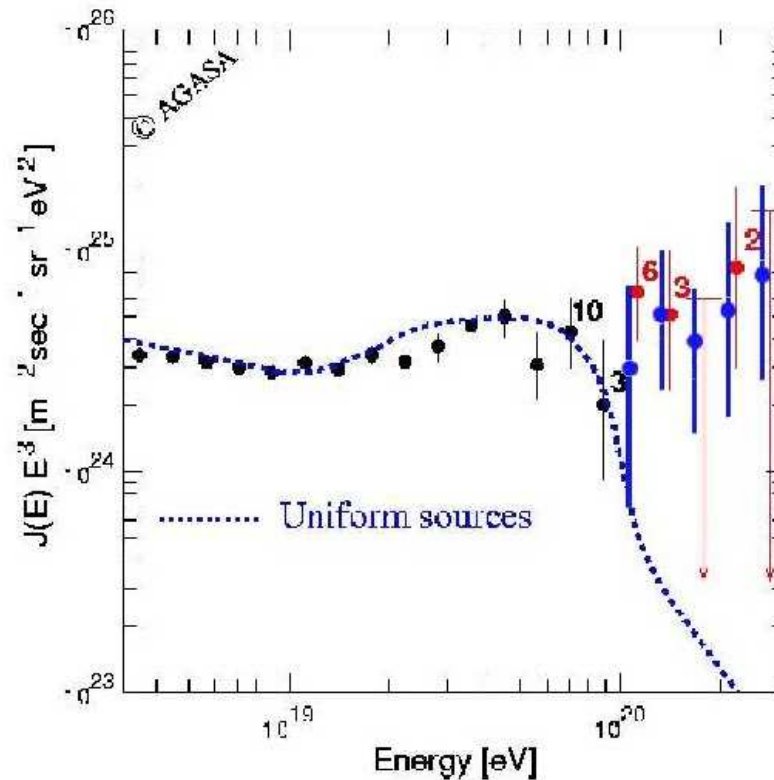


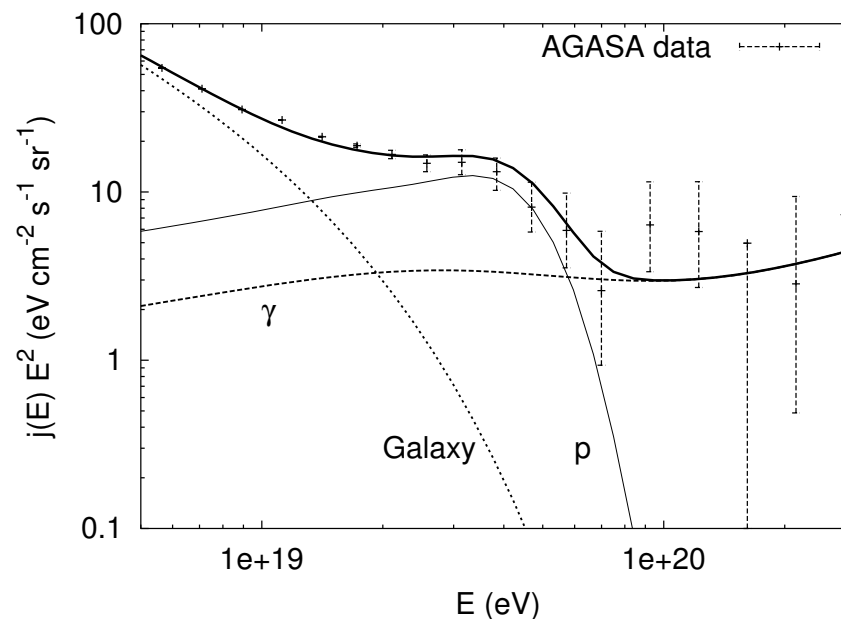
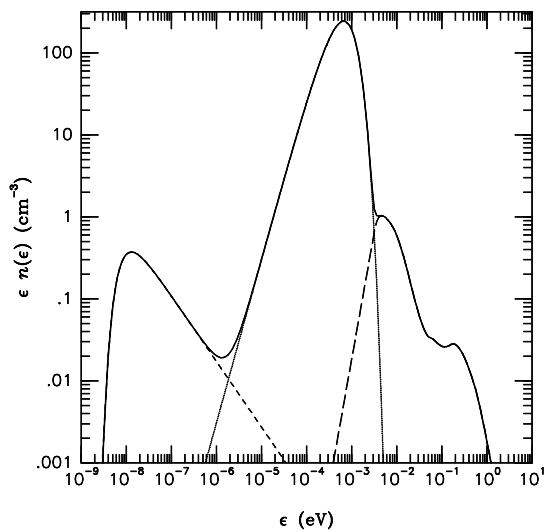
Fig. 5: AGASA spectrum in the assumption of photonic primaries

Указание на фотоны СЭ?

- реликтовые тяжёлые X -частицы
- закрытая модель Z -вспышки

Указание на фотоны СЭ?

- реликтовые тяжёлые X -частицы
- закрытая модель Z -вспышки
- астрофизические ускорители: чистый фотонный источник?



S.Lee
astro-ph/9604098

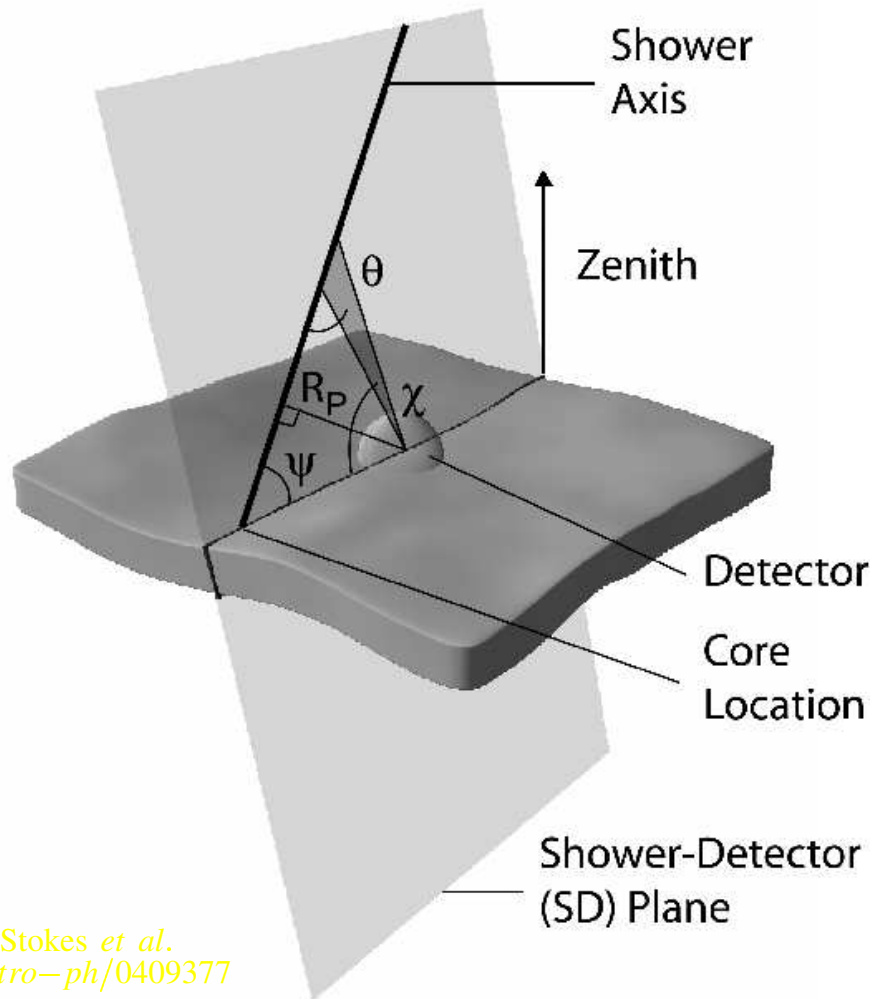
$$z_{min} = 0.03, N_{\gamma}/N_p = 3, dN_{p,\gamma}/dE \propto E^{-1.5}, E_{max} = 10^{23} \text{ eV}$$

O.Kalashev *et al.*
astro-ph/0107130

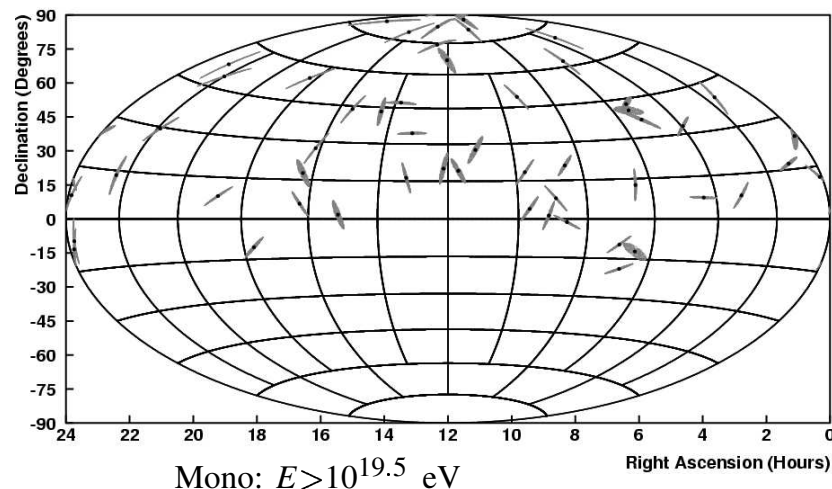
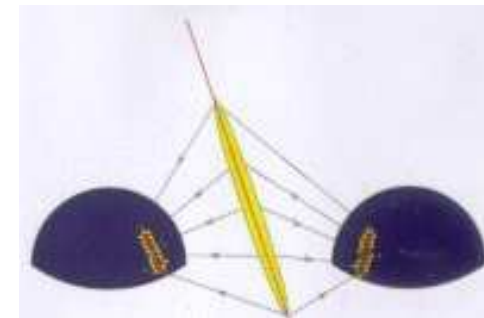
$$z_{min} = 0.03, N_{\gamma}/N_p = 45, dN_{p,\gamma}/dE \propto E^{-1.75}, E_{max} = 10^{22} \text{ eV}$$

Нереалистичный спектр: степенной закон с α и E_{max}

Флюорисцентные детекторы: HiRes



B.Stokes *et al.*
astro-ph/0409377

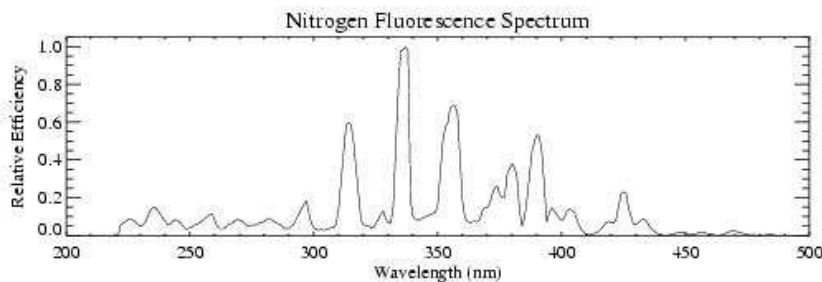


направления Mono: $\Delta\delta_{SD} \sim 1^\circ$, $\Delta\psi \sim 5.5^\circ$

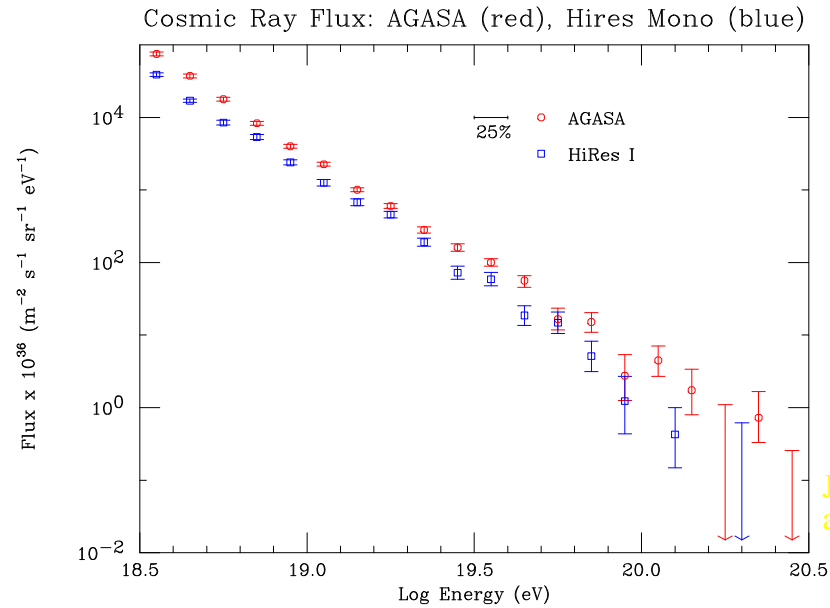
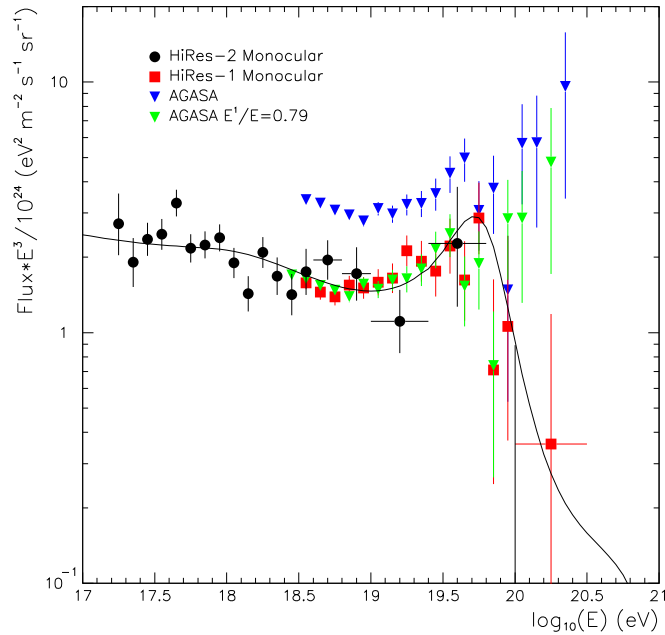
прихода Stereo: $\Delta\delta \approx 0.6^\circ$

ошибка Mono: $\Delta E/E < 25\%$ @ $E > 10^{18.5}$ eV

в энергии Stereo: $\Delta E/E < 15\%$ @ $E > 10^{18}$ eV

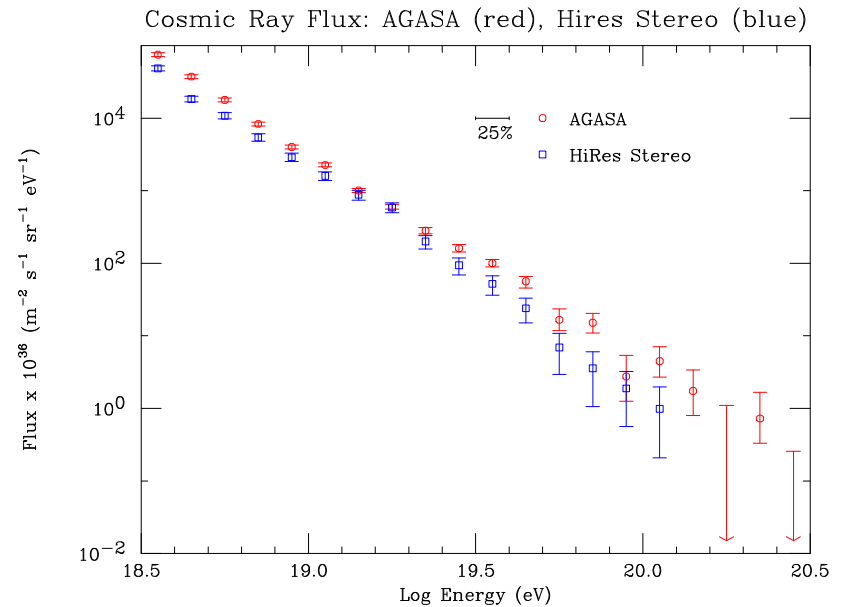
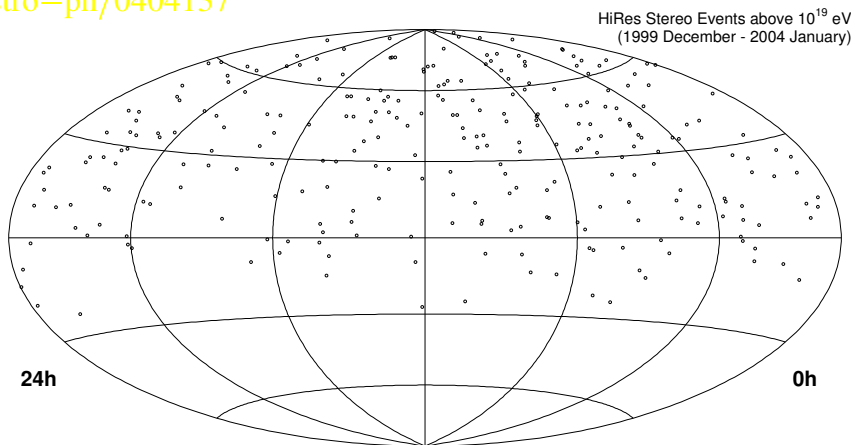


HiRes: результаты



J.Cronin
astro-ph/0402487

R.Abbasi *et al.*
astro-ph/0404137

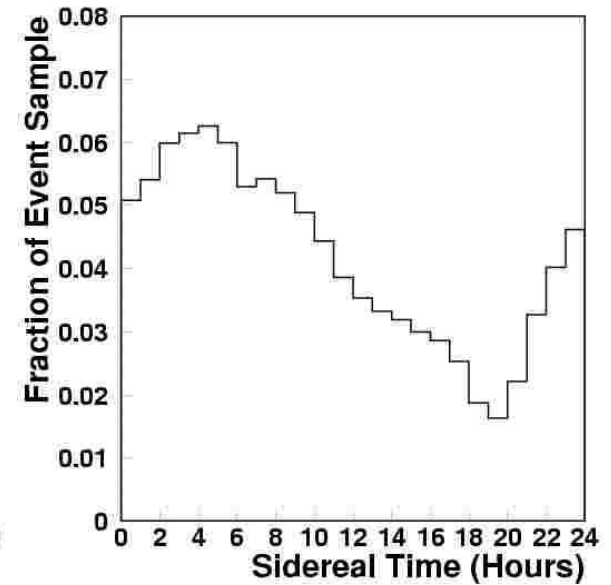
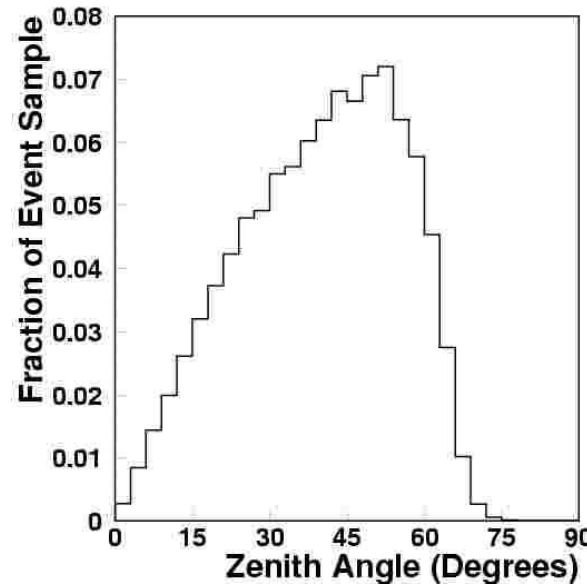
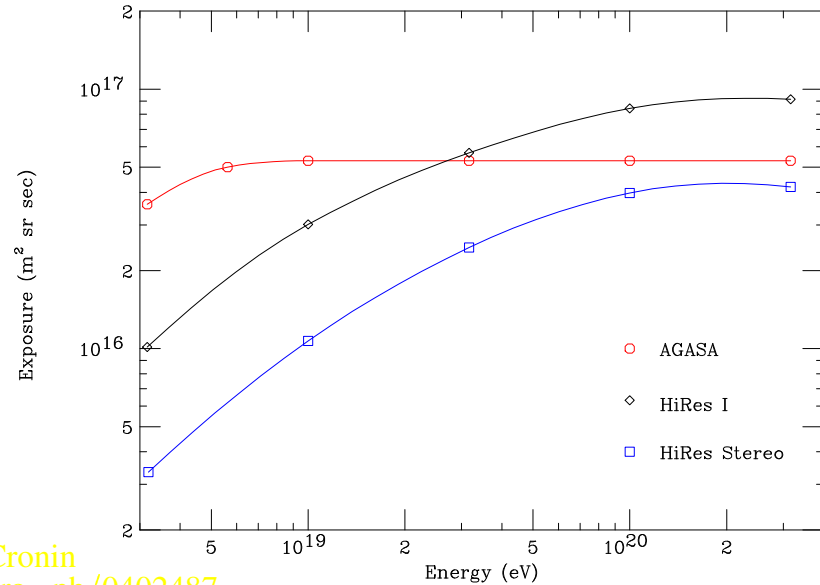


Дмитрий Горбунов

Загадки космических лучей сверхвысоких энергий – p. 35/61

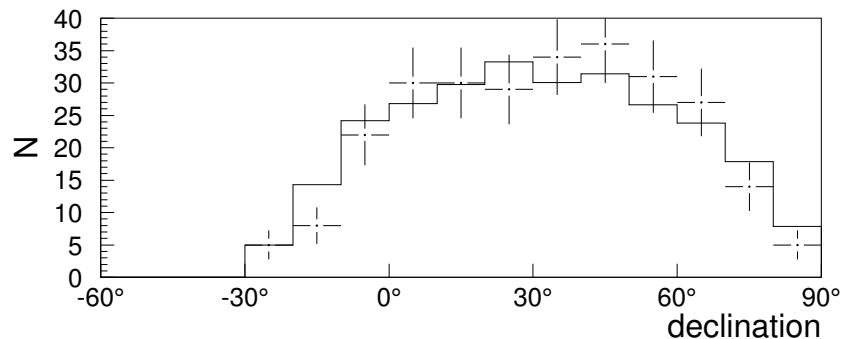
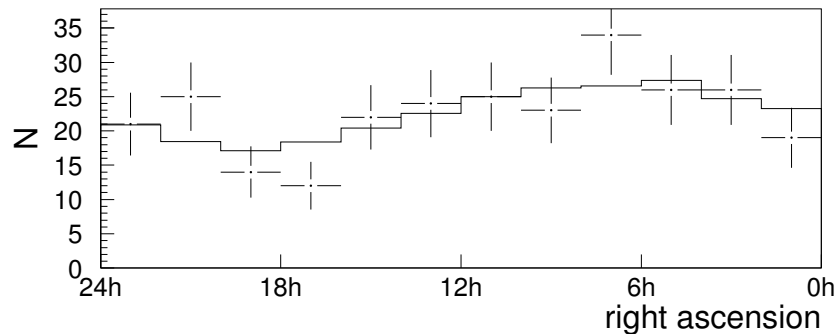


HiRes против AGASA



Chronin
astro-ph/0402487

B.Stokes, C.Jui, J.Matthews
astro-ph/0307491



экспозиция HiRes'a:

безоблачные безлунные ночи

R.Abbasi *et al.*
astro-ph/0404137

Дмитрий Горбунов

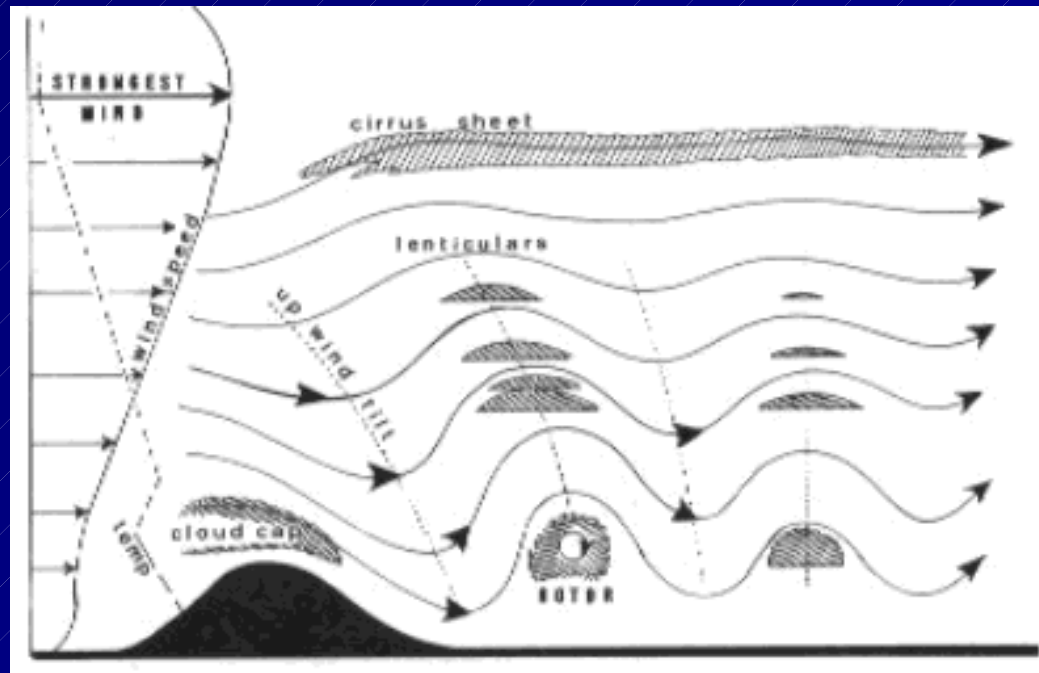
Загадки космических лучей сверхвысоких энергий – p. 36/61



Особенности атмосферы

UHECR detectors and gravity waves

- HiRes, AUGER South, TA are all located on high plateaus leeward (down-wind) of a major mountain range.
 - AUGER south is located downwind of the Andes: a high and narrow range exposed to unobstructed ocean winds on its western slopes
- Obstructed air motion generates (a) downslope winds (Foehn, El Zonda) and (b) “gravity” waves leeward of the mountain (analogous to deep ocean waves) called **“mountain waves”** or **“lee-waves”**.

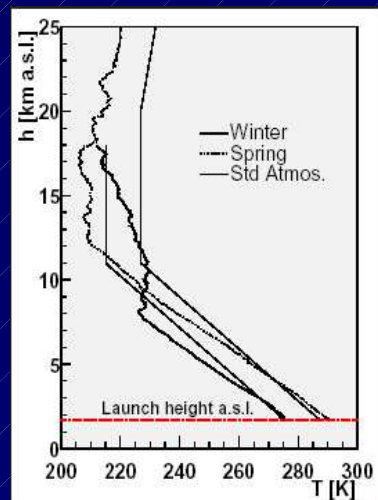


K. Belov INR Moscow April 2005

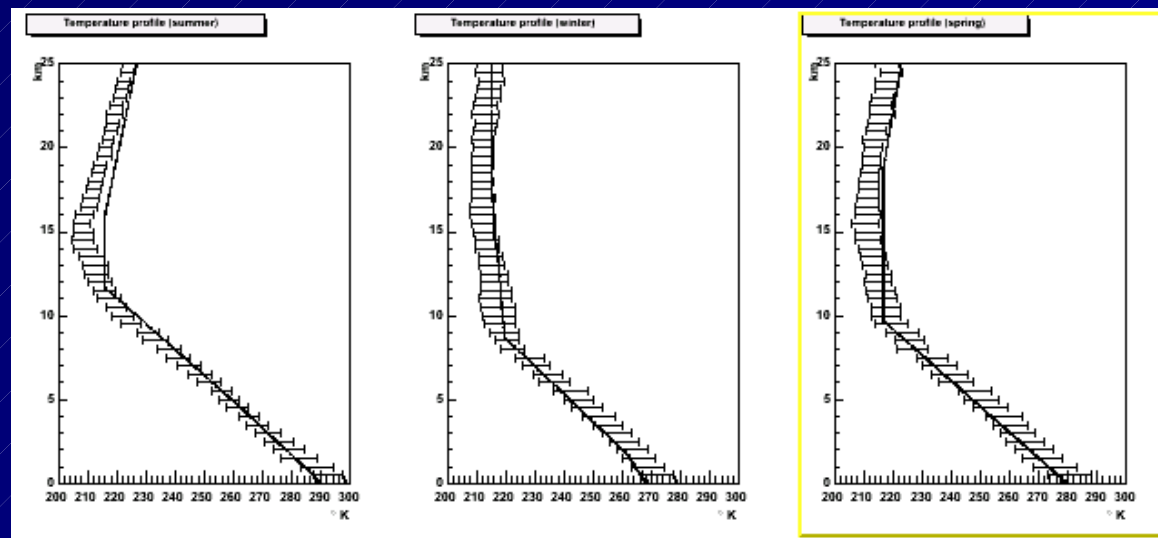
Особенности атмосферы

Temperature Profile

Auger



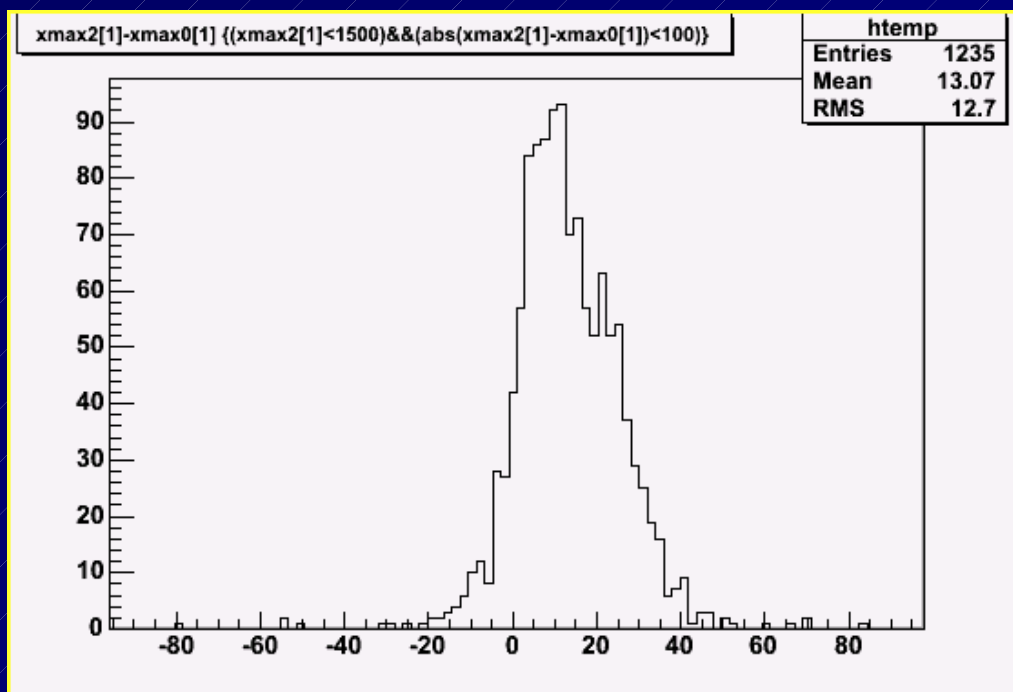
Hires



K. Belov INR Moscow April 2005

HiRes: Особенности атмосферы

$X_{\max}$ correction



Each event reconstructed
With radiosonde data and
Compared with reconstruction
Using HiRes model.

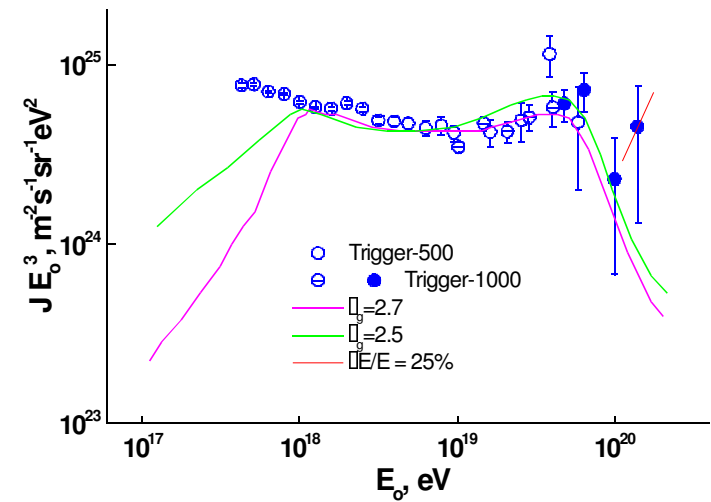
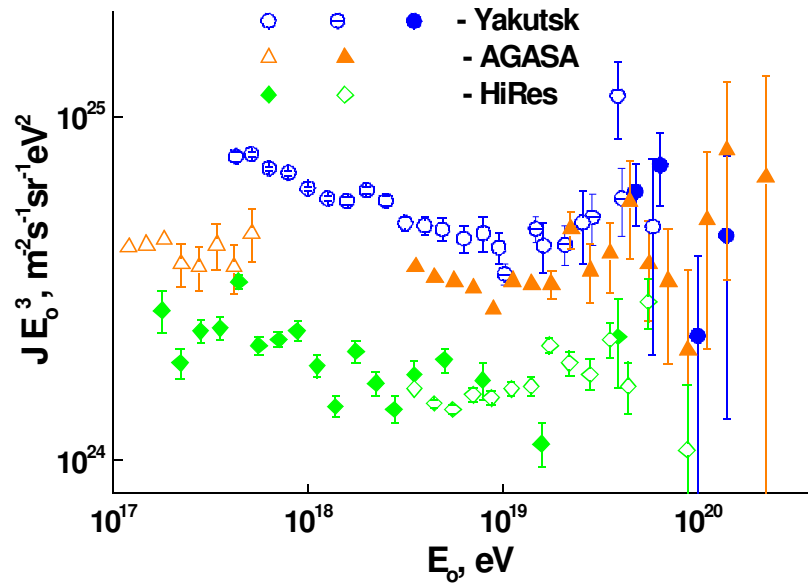
$X_{\max 2}$ – radiosonde
 $X_{\max 0}$ – HiRes model

HiRes underestimates $X_{\max}$
By 13 g/cm².

K. Belov INR Moscow April 2005

Yakutsk: в поддержку AGASA

Differential Energy Spectrum at $E_0 > 10^{17}$ eV



Comparison of the Yakutsk array Spectrum with accounts from AGN
Berezinsky V.S., Gazizov A.Z., Grigorieva S.I. // preprint 2002, hep-ph/0204357

The Spectrum obtained on the Yakutsk array will agree with the assumption, that the particles with $E_0 > 10^{19}$ eV are mainly formed in extragalactic sources

M.I. Pravdin

CONCLUSION

In terms of test functions:

- The basic formula used for energy estimation at the Yakutsk array have been confirmed at energies of 10^{18} eV.
- At energies $\sim 10^{20}$ eV simulations display larger energies than this formula shows supporting the Greizen-Zatsepin-Kuzmin enigma.
- Lateral distribution function of signal used at the Yakutsk array have been confirmed by simulations.
- Estimate of energy of the giant air shower detected at the Yakutsk array is not less than $3 \cdot 10^{20}$ eV.
 $\chi^2=57$ for 25 d.o.f.

L.G. Dedenko

Yakutsk против AGASA

Harmonic analysis. Interval about 10^{17} eV

The inhomogeneity of the sky survey is essential to the Yakutsk EAS array. Its account considerably decreases amplitudes of anisotropy vectors

Taking account distorting factor, the statistical significant anisotropy of the first and second harmonics is not observed:
By sidereal time

amplitude of the first harmonic is smaller than 0.6% with the probability 0.95 and for second harmonic it is 0.65%;

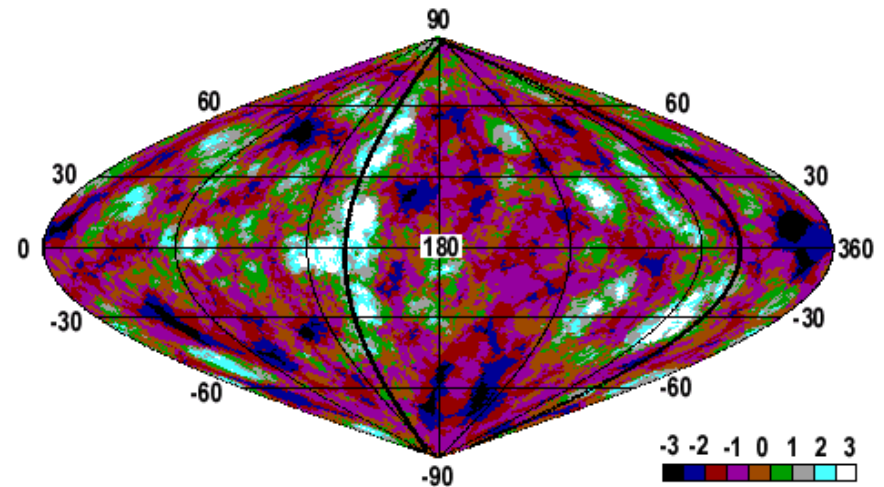
In the analysis samples of previous work (1997) the amplitude of the first harmonic with respect to the RA with regard to the perturbing factors is **$(0.45 \pm 0.55)\%$** . (Instead of 1.35)

Harmonic analysis. Interval about 10^{18} eV

At $18.0 < \text{Log}(E_0) < 18.5$, Events: 27301, **$r_1 = (0.7 \pm 0.9)\%$**

At 10^{18} eV the statistically significant anisotropy is not observed.

Our results do not confirm given AGASA. The Yakutsk array cannot observe the center of the Galaxy.



Map of distribution on arrival directions of cosmic rays with $E_0 > 8 \cdot 10^{18}$ eV in galactic coordinates on Yakutsk data and SUGAR. Intensity - in terms of a standard deviation of a difference of observable number and expected average for an isotropic flux. A bold line - a plane of the Supergalaxy

Events with $E_0 > 10^{19}$ eV

Harmonic analysis RA: $19.0 < \text{Log}(E_0) < 19.5$, events 312,

$r_1 = (26.4 \pm 8.0)$, $\alpha_1 = (2.3 \pm 1.2)^\circ$, $P = 0.004$

M.I. Pravdin

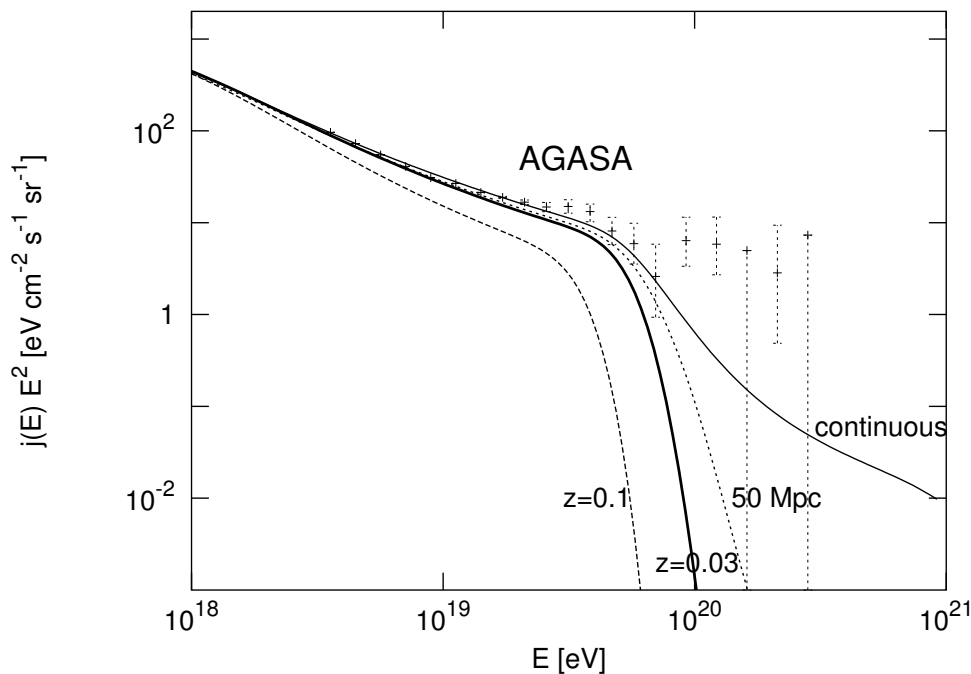
This result specifies existence anisotropic components of cosmic rays in the given interval of energy

Видит ли HiRes ГЗК-обрезание?



Видит ли HiRes ГЗК-обрезание?

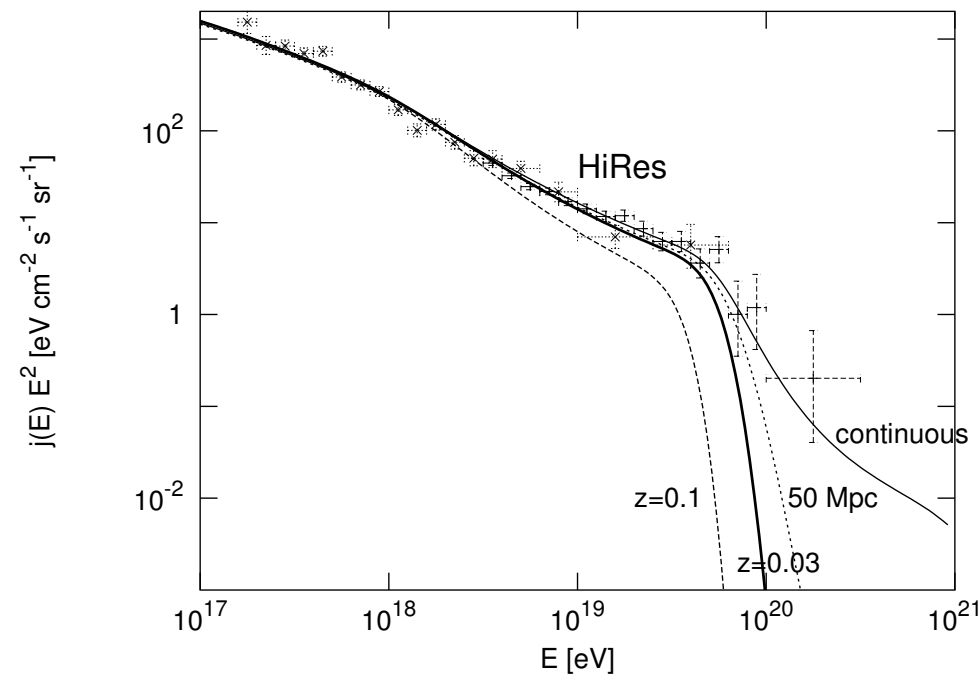
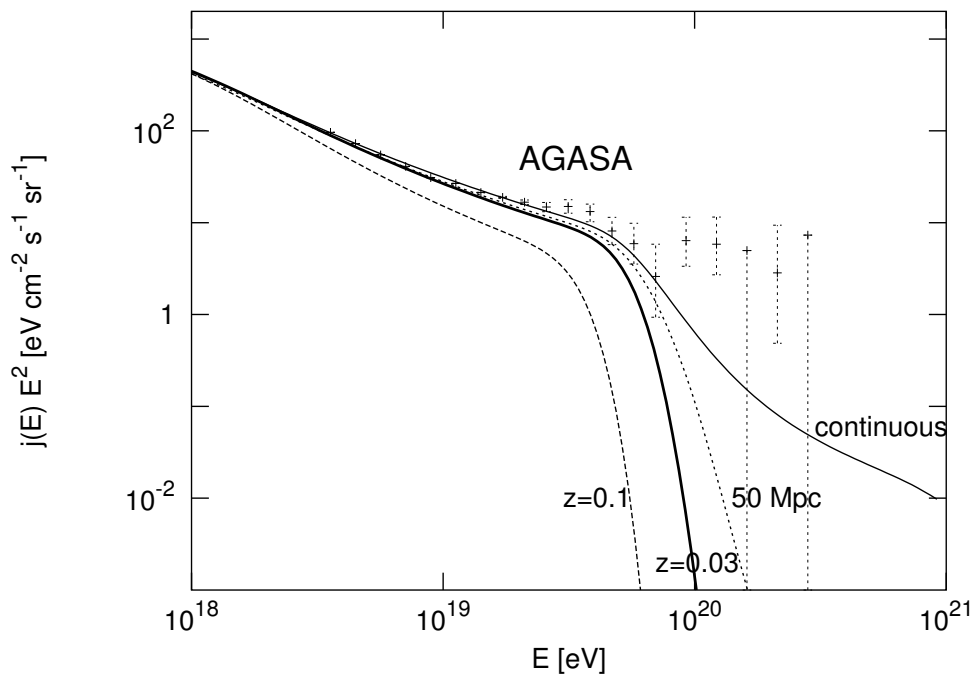
Little GZK-problem : не видно близких ($L \lesssim 50$ Мпс) астрофизических источников способных ускорить до 10^{20} eV



M.Kachelries, D.Semikoz, M.Tortola
astro-ph/0402487

Видит ли HiRes ГЗК-обрезание?

Little GZK-problem : не видно близких ($L \lesssim 50$ Мпс)
астрофизических источников способных ускорить до 10^{20} eV



M.Kachelries, D.Semikoz, M.Tortola
astro-ph/0402487

Нет!

Выводы

- ASASA не видит ГЗК-обрезания спектра КЛСЭ!!!
- Отсутствие видимых близких астрофизических ускорителей приводит к заключению, что результаты HiRes'a также противоречат ГЗК-обрезанию!!!
- Для объяснения результатов AGASA & HiRes недостаточно физики в рамках СМ

Феноменологически приемлемые решения

● Нестабильные тяжёлые реликтовые частицы

- галактическая анизотропия
- КЛСЭ — фотоны

D.Gorbunov, G.Raffelt, D.Semikoz
hep-ph/0103175

● Лёгкие нейтральные частицы: аксионы и лёгкие адроны

- слабое рождение в источнике или
- ШАЛ специального вида

D.Chung, G.Farrar, E.Kolb
astro-ph/0402487
M.Kachelries, D.Semikoz, M.Tortola
astro-ph/0402487

● Нарушение Лоренц-инвариантности

S.Coleman, S.Glashow
hep-ph/9812418

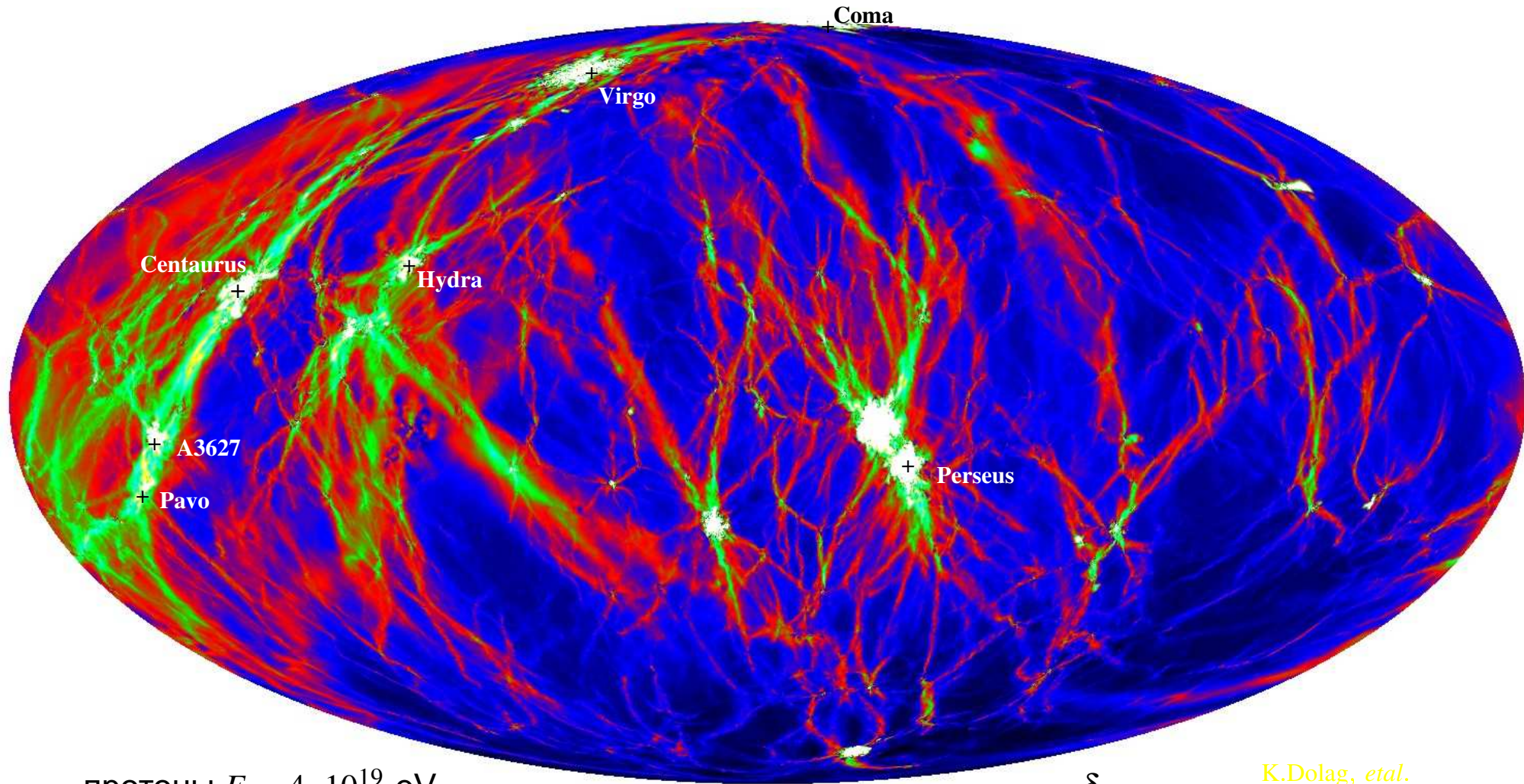


Поиски источников: астрономия СВЭ



Отклонение в межгалактических $\vec{B}$ (I)

$$\delta(E, L) \simeq 0.6^\circ \left(\frac{4 \cdot 10^{19} \text{ eV}}{E} \right) \left(\frac{L}{100 \text{ Mpc}} \right)^{1/2} \left(\frac{L_c}{1 \text{ Mpc}} \right)^{1/2} \left(\frac{B}{10^{-10} \text{ G}} \right)$$



протоны $E = 4 \cdot 10^{19} \text{ eV}$

глубина $L = 107 \text{ Mpc}$

0

1

2

3

4

5

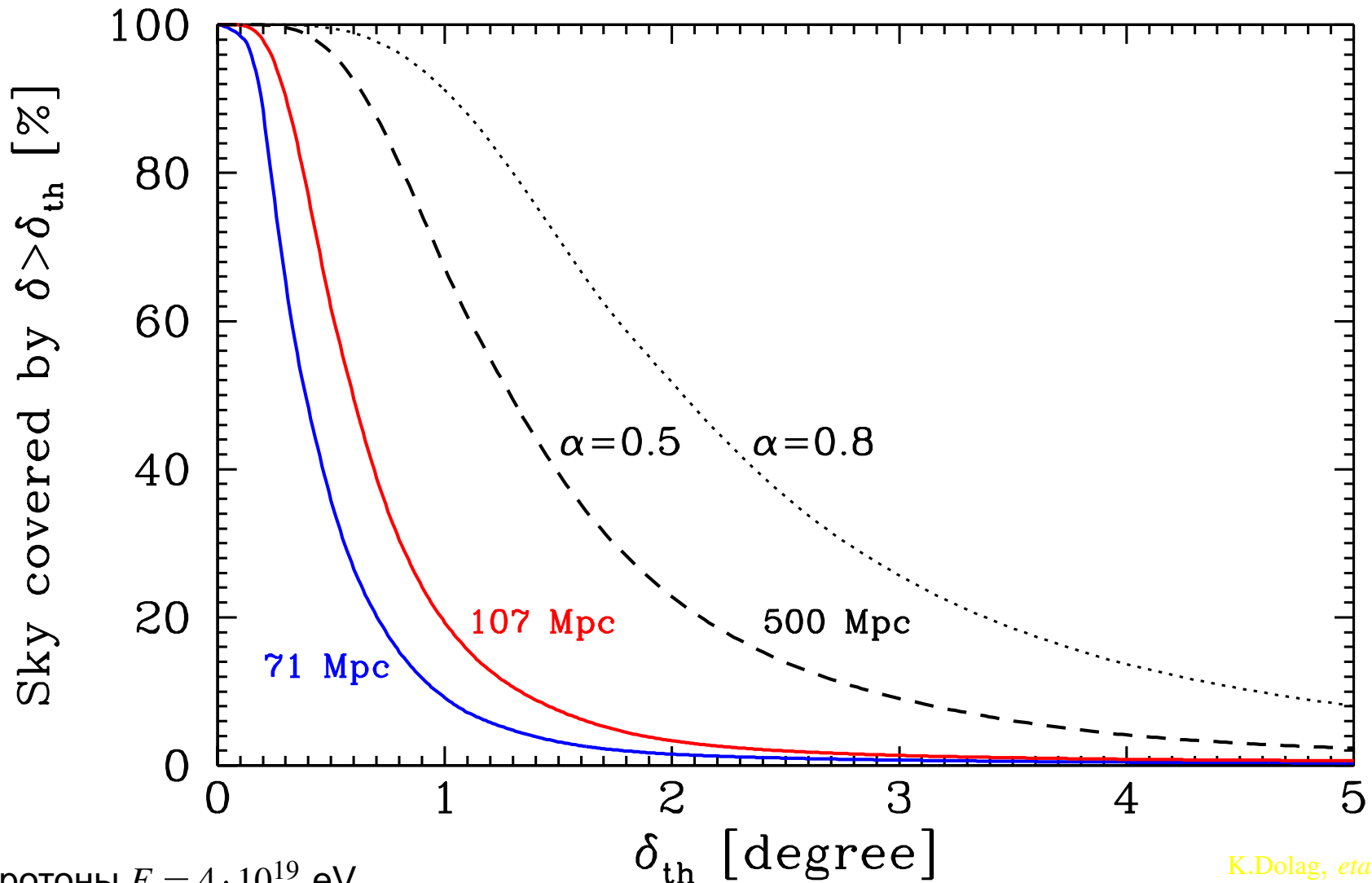
δ

[Degrees]

K.Dolag, *etal.*
astro-ph/0310902

Отклонение в межгалактических $\vec{B}$ (II)

$$\delta(E, L) \simeq 0.6^\circ \left(\frac{4 \cdot 10^{19} \text{ eV}}{E} \right) \left(\frac{B}{10^{-10} \text{ G}} \right) \left(\frac{L}{100 \text{ Mpc}} \right)^{1/2} \left(\frac{L_c}{1 \text{ Mpc}} \right)^{1/2} A(\delta_{th}, L) = A_0 (\delta_{th} (L_0/L)^\alpha), \alpha \rightarrow 0.5$$

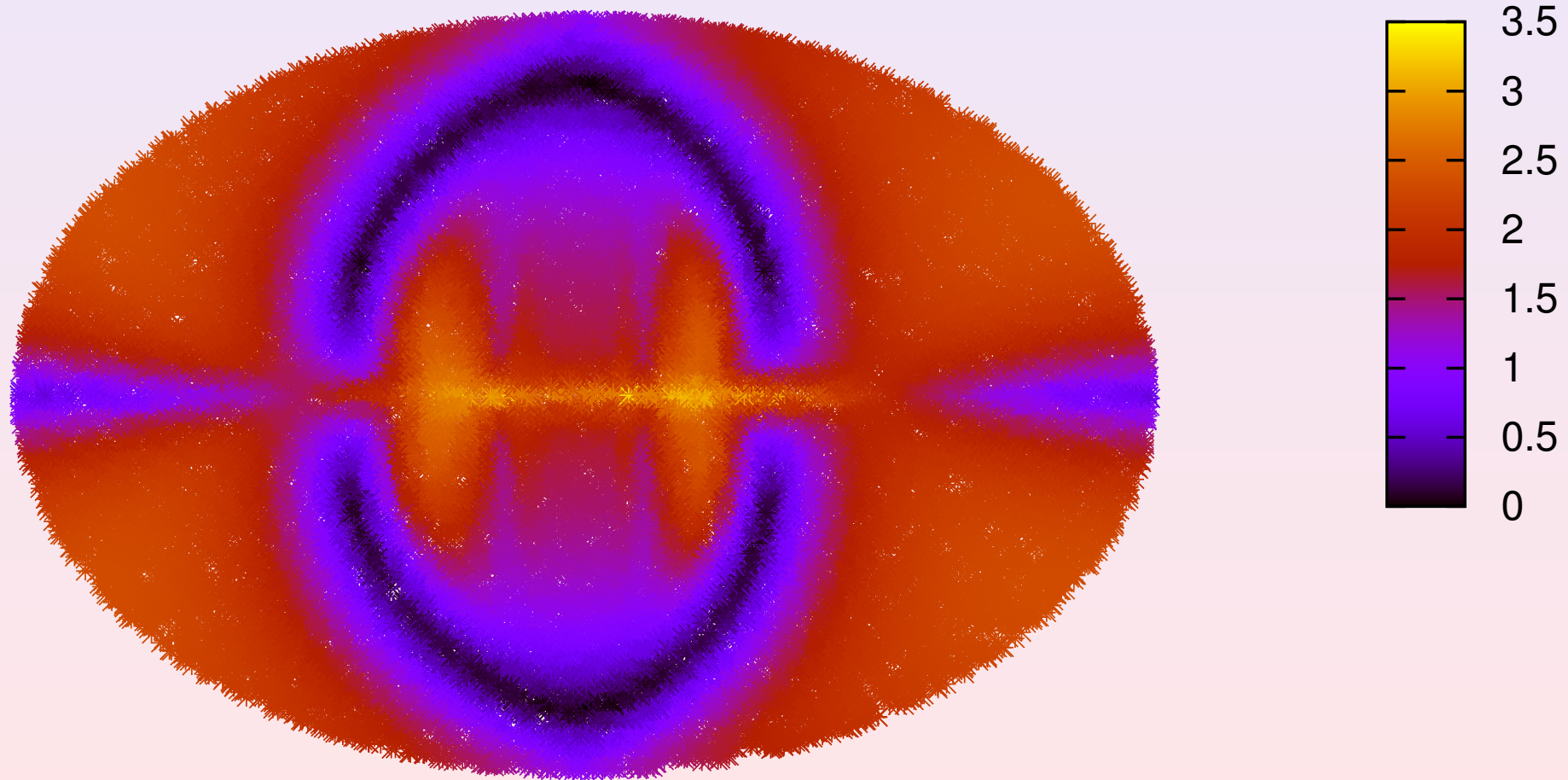


протоны $E = 4 \cdot 10^{19} \text{ eV}$

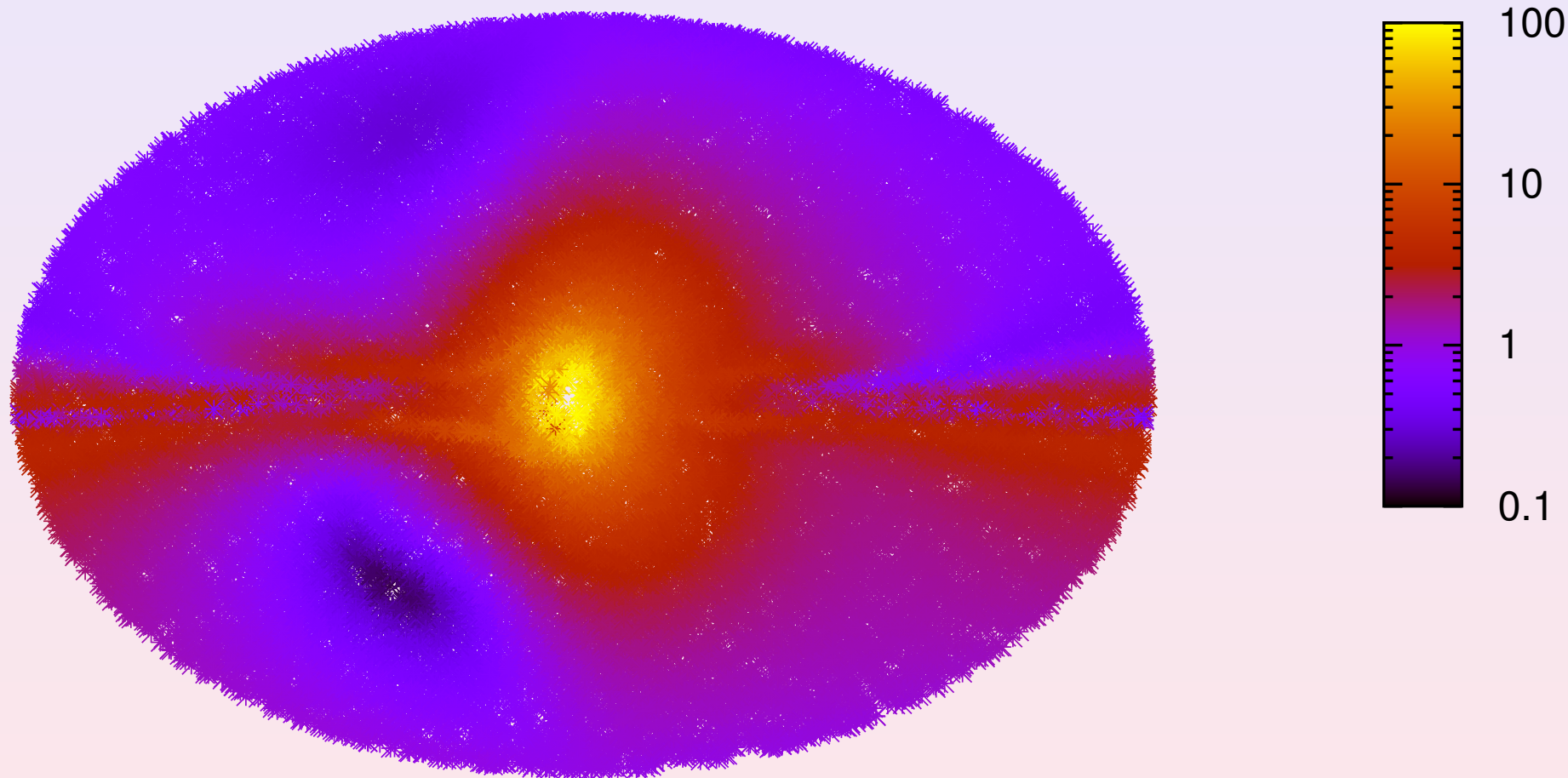
K.Dolag, *etal.*
astro-ph/0310902

Deflections for $eE/Q = 10^{20}$ eV: TT model

deflections $\gtrsim 2.5^\circ$ at 4×10^{19} eV in large fraction of sky

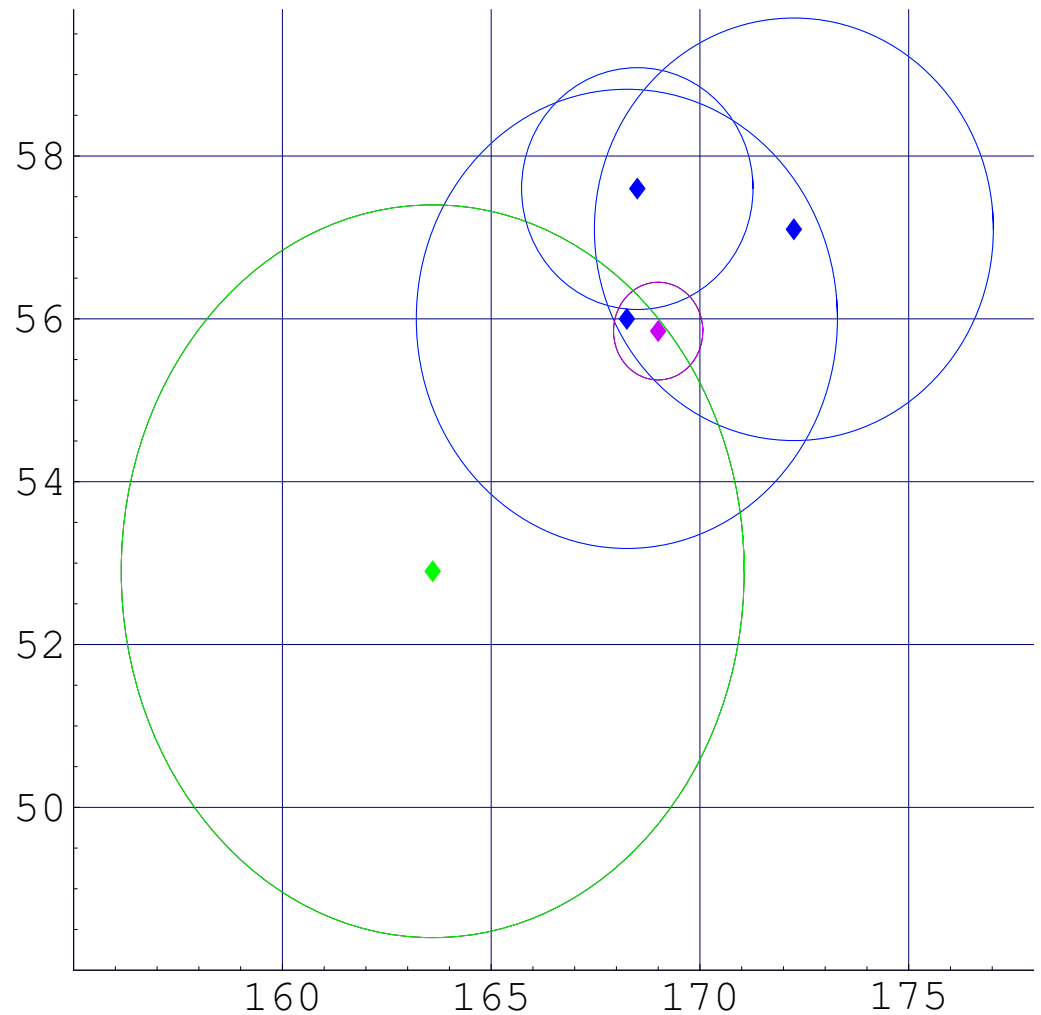


Deflections for $eE/Q = 10^{20}$ eV: PS model



Мультиплет в магнитном поле

YAKUTSK 2005 REANALIZED: FIVEPLET



Мультиплет в магнитном поле

• THESE MODELS DO NOT MAKE THE FIT BETTER.

• BUT SOME MAGNETIC FIELDS DO



AN UNKNOWN COMPONENT
OF GALACTIC OR EXTRAGALACTIC MAGNETIC FIELD
MAY EXIST

S.V. Troitsky



Testing various catalogues of UHECR

candidates:

(AGASA, Yakutsk,

Haverah Park, Volcano Ranch)

- colliding galaxies
- radio galaxies FRI, FRII
- Seyfert galaxies
- HP-blazars
- BL Lacs
- γ -ray sources
- FSRQ
- GeV sources
- TeV sources
- dead quasars
- ...

(E, θ, φ)

were measured
with a

reasonable accuracy

chance probability

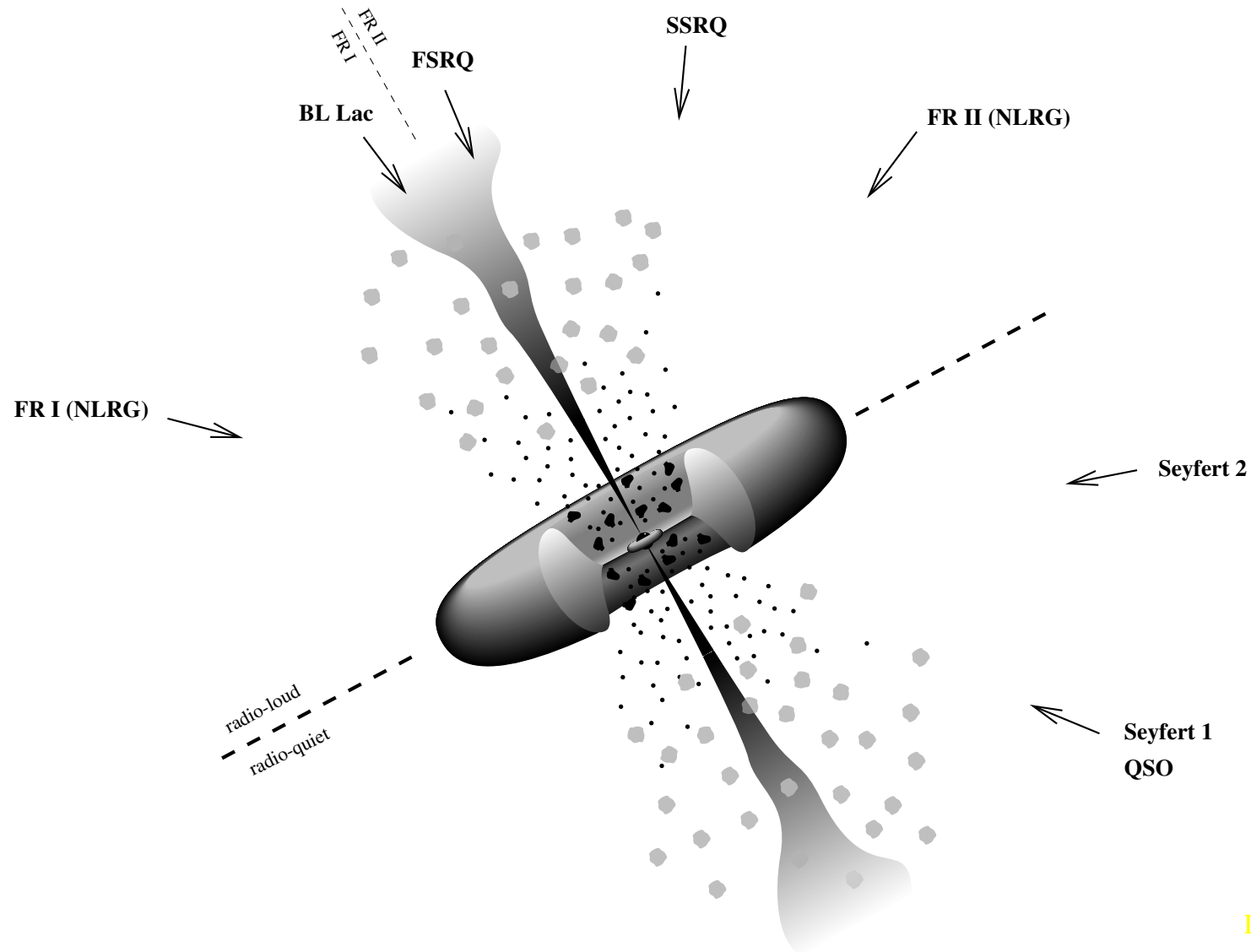
of positional coincidences

candidates $\longleftrightarrow$ UHECR events

D.S.G., S.V. Troitsky, Astropart. Phys. 23, 175 (2005)



HiRes & AGASA: корреляции с лацертидами!



D.Torres, L.Anchoridoqui
astro-ph/0402371

Корреляции с лацертидами

подкласс лацертид

$mag < 18, F_{6cm}^{radio} > 0.17 \text{ Jy}$

γ -ray-loud (EGRET)

$mag < 18$

каталог КЛСЭ

autocor AGASA+Yakutsk

autocor AGASA+Yakutsk

AGASA $E > 4 \cdot 10^{19} \text{ eV}$

$P(\delta_{ang.res.})$

$\lesssim 10^{-4}$

$10^{-4} - 10^{-7}$

$10^{-2} - 10^{-4}$

P. Tinyakov, I. Tkachev, JETP Lett. 74, 445 (2001)

D. G., P. Tinyakov, I. Tkachev, S. Troitsky, Astrophys. J. 577, L93 (2002)

P. Tinyakov, I. Tkachev, Astropart. Phys. 18, 165 (2002)

Среди лацертид
есть ИСТОЧНИКИ КЛСЭ !!!



Корреляции с лацертидами

подкласс лацертид

$mag < 18, F_{6cm}^{radio} > 0.17 \text{ Jy}$

γ -ray-loud (EGRET)

$mag < 18$

каталог КЛСЭ

autocor AGASA+Yakutsk

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D. G., P. Tinyakov, I. Tkachev, S. Troitsky, Astrophys. J. 577, L93 (2002)

P. Tinyakov, I. Tkachev, Astropart. Phys. 18, 165 (2002)

Среди лацертид
есть источники КЛСЭ !!!

Гипотеза подтверждена на независимом наборе КЛСЭ (HiRes)

D.S.G., P.G. Tinyakov, I.I. Tkachev, S.V. Troitsky (astro-ph/0406654, Pis'ma v ZhETF 80
167 (2004))



Предсказания

Experiment	σ_E	R_s	N_E	A_E	b_E	N_{95}
HiRes, original	0.6°	0.85°	271	14.5	3.5	
HiRes,	0.6°	0.85°	300	14.5	3.9	5 - 22
HiRes, $z < 60^\circ$	0.6°	0.85°	300	14.9	5.1	6 - 24
AGASA, $z < 45^\circ$	2.4°	3.39°	1500	15.3	270	277 - 365
Ground PA, $z < 60^\circ$	3.0°	4.24°	1500	8.1	227	223 - 286
Ground PA, $z < 60^\circ$	3.0°	4.24°	8000	8.1	1210	1248 - 1470
Hybrid PA, $z < 60^\circ$	0.45°	0.64°	200	7.3	0.81	0 - 8
Hybrid PA, $z < 60^\circ$	0.45°	0.64°	1500	7.3	6.1	13 - 49
TA, $z < 60^\circ$	0.62°	0.88°	1500	15.5	22.8	40 - 112

D.S.G.



Эксперименты отдалённого(?) будущего

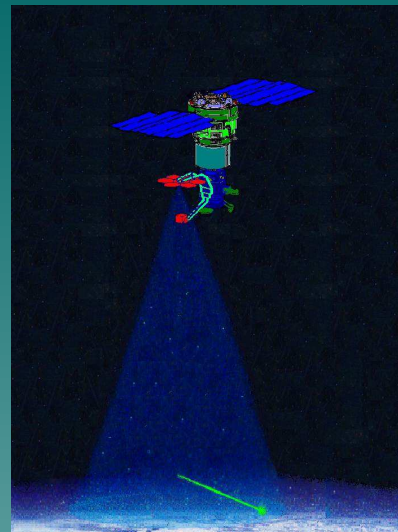
KLYPVE is a narrow FOV detector (“telescope”) with a large area mirror-concentrator. What advantages the telescope has compared to the OWL-EUSO wide FOV detectors?

3. Large mirror makes possible to detect UHECR already measured with the ground-based detectors (calibration of the space detector method).
4. When mirror area is enlarged up to 100 m^2 (energy threshold 3 EeV), the telescope observing the area of 10^4 km^2 will let us measure the anisotropy of CR in the energy range $3\text{-}10 \text{ EeV}$ where the transition from Galactic to extragalactic origin is expected.
5. Low energy threshold will help to look beyond GZK horizon registering “cosmological” neutrinos.
6. Development of the large mirror-concentrator technology is of great interest for space researches. A reliable, large area mirror-concentrator is easier to construct than the complex lens optics.
5. For example, when the mirror area is enlarged to 1000 m^2 , it will be possible to register EAS and other optical flashes almost at the whole atmosphere disc with a telescope in a geostationary orbit.

The TUS Project Scientific Goals.

1. Proofing the new technology of EAS observation by the Space Detector.
2. Experimental study of the Cosmic Ray energy spectrum in the range of energies $>50 \text{ EeV}$ with the geometrical factor not less than $3\,000 \text{ m}^2 \text{ sr}$ per year with the EAS energy threshold of $30\text{-}50 \text{ EeV}$.
3. A search for “exotic” EAS with $X_{\text{max}} > 1200 \text{ g/cm}^2$ (initiated by neutrino) and with $X_{\text{max}} < 300 \text{ g/cm}^2$ (initiated by relativistic dust grains).
4. UHECR anisotropy study.
5. A search for other phenomena of UV atmospheric flashes.
6. Testing the TUS mirror-concentrator design in view of using it for construction of large area mirrors in space (up to 100 m^2).

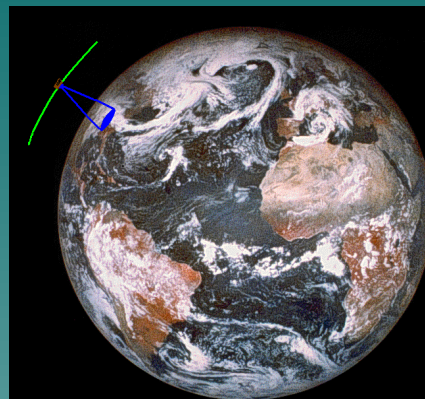
The first mirror telescope is an additional payload at the RESURS DK-1 mission (planned to be next after the Pamela experiment).



The TUS (Tracking Ultraviolet Set Up) detector registers an EAS track from the Space Platform.

The light collector and photo detector are highlighted in red.

“Tatiana” is orbiting the Earth at approximately circular polar orbit with the height of 1000 km .



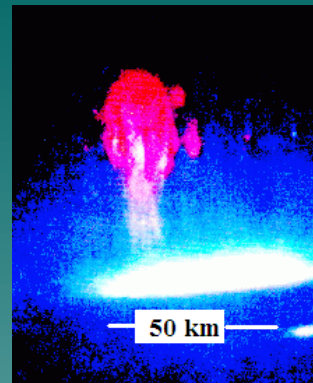
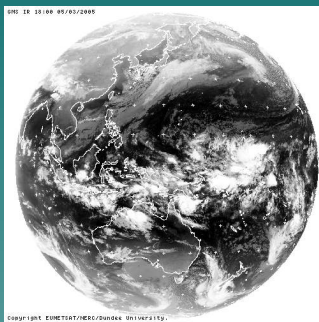
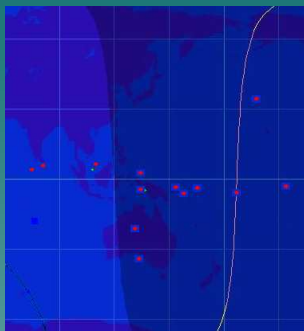
Diameter of the observed atmosphere is 250 km . Several types of UV measurements:

1. Every 4 sec ACD measures the PMT charge collected in integration time 60 msec . (measurements of UV on-route)
2. Digital oscilloscope measures the UV flashes with time sample $16 \mu\text{s}$ (duration $<4 \text{ msec}$).
3. Digital oscilloscope measures the UV flashes with time sample $256 \mu\text{s}$ (duration $<64 \text{ msec}$).

In 2 and 3 only the brightest events are sent to the mission center (problem of poor telemetry).

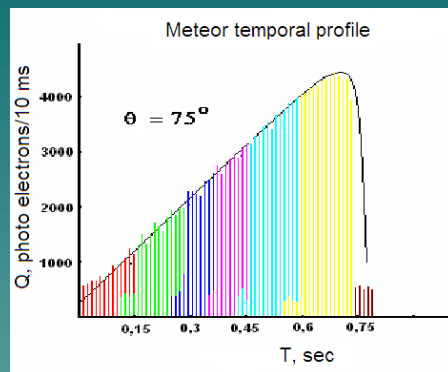
B.A. Khrenov

Geographic coordinates of the short UV flashes correlate around the equator. In the same region the IR measurement (right panel) indicates heavy clouds (may be thunderstorms). Looks like UV detector registers the blue jets (discharges between clouds and mesosphere)

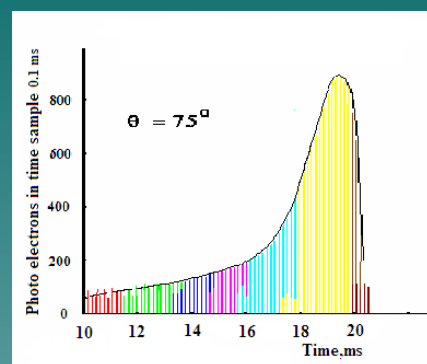


The phenomenon of blue jet is incomparably brighter than the EAS of 100 EeV energy. For registering blue jets the gain in the TUS pixels should be much less than needed for the EAS observations.

The other phenomenon to be detected in the TUS detector are meteors. Entering the atmosphere with the velocity of 30 km/s they ionize the atmosphere and excites the fluorescence. Expected signal in TUS with the “slow” digital oscilloscope is shown below:



Similar but faster signals are expected from the fast dust grains. Dust grains, entering the atmosphere with the velocity of $\sim 10^9$ cm/s, are expected from the 10^4 year old SN's (Khrenov&Tsytovich, 2005).



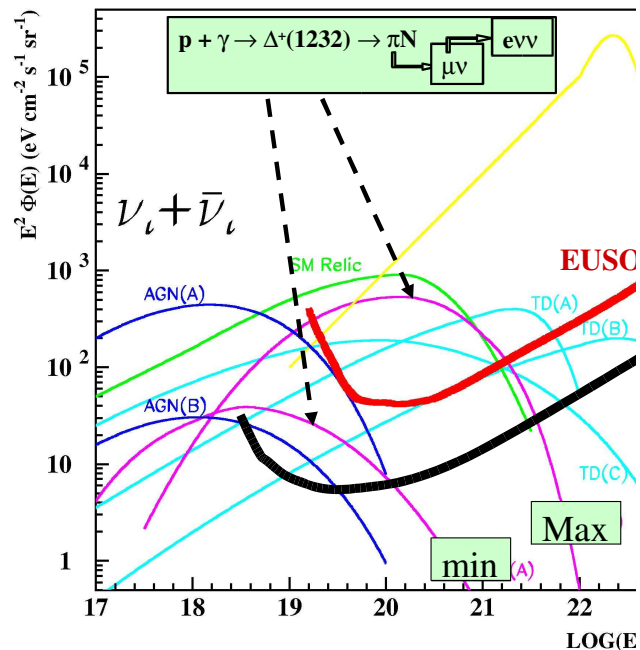
метеоры

Дмитрий Горбунов

B.A. Khrenov

Эксперименты далёкого(?) будущего

EUvO



	EUSO like		Multi-mirror	
H (km)	400		400	
Total FoV (°)	60	→	90	
Radius on ground (km)	235		413	
Area on ground (10 ³ km ²)	173		536	
Pixel on ground (km * km)	0.8 x 0.8		1.6 x 1.6	
Φ pixel on detector (cm)	0.6		2.0	
“ “ with corrector			1.2	
Area/pixel (≈n. of pixels)	270k		238k	
Pupil diameter (m)	2.0	2.0 → 5.0	7.5	10.0
Photo detection efficiency	20%	50%	50%	50%
E threshold (EeV)	50	20	5.5	3.2
Proton events/year,				
GKZ + uniform source distrib.	1200	8000	300k	900k
with E _p > 100 EeV)	100	100	310	310
Neutrino events per year (≈ min)	0.6	1.5	18	30
Neutrino events per year (≈ Max)	12	18	108	138

P. Spillantini

Дмитрий Горбунов

Загадки космических лучей сверхвысоких энергий – p. 59/61

Эксперименты очень далёкого(?) будущего

Imprints of UHECR be in the Lunar Crust

D.S.G.

Advantages:

- enormous exposure: $t \sim \tau_{Moon} \simeq 4 \cdot 10^9$ year

Then per 1 m²:

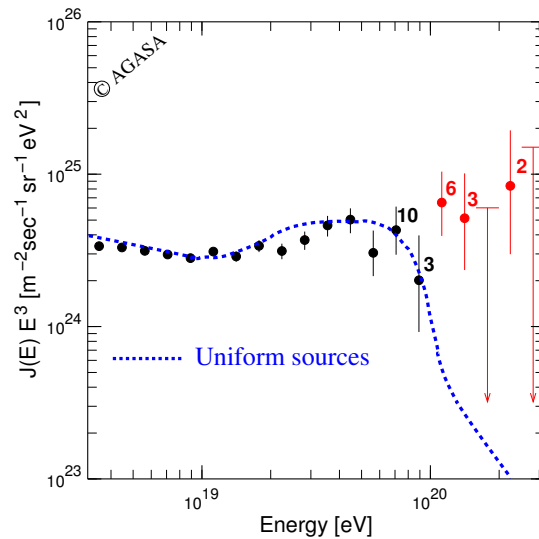
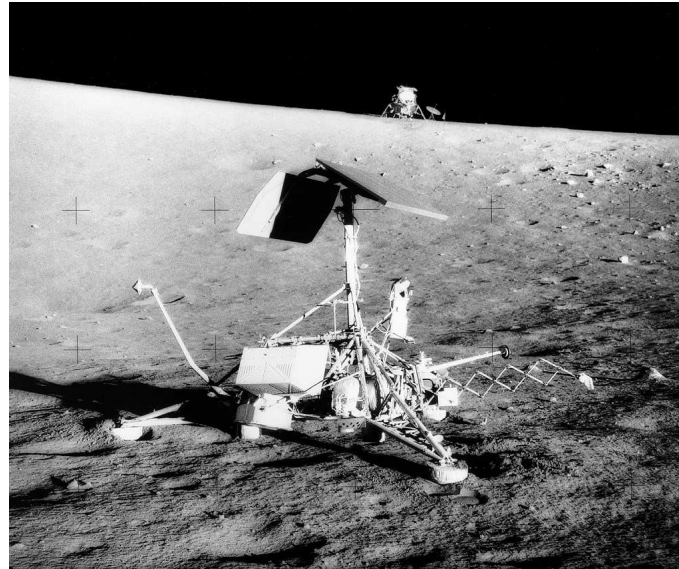
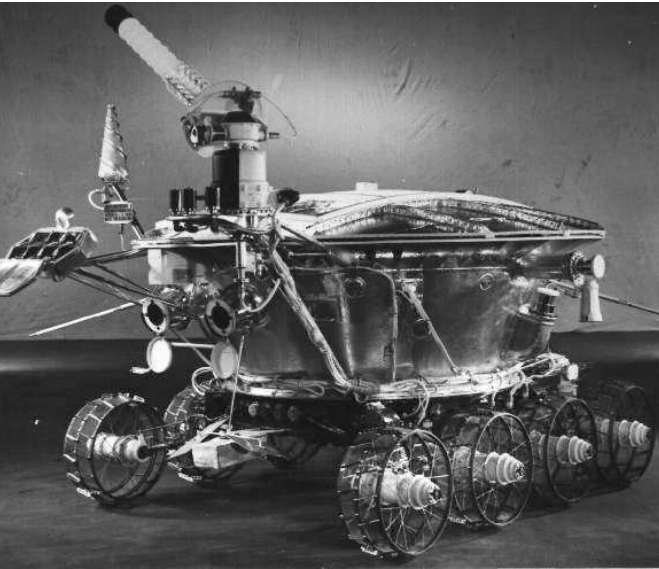
- GZK — false — ~ 100 imprints
- GZK — true — ~ 1 imprint



- search for the ultimate cutoff in UHECR spectrum — the highest energy events for the last 1/4 of the Universe's life



Lunar Robotic Missions



D.S.G.