Patterns of the geomagnetic fields in the arrival directions of the highest energy cosmic rays

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Plan

- Global anisotropy in the arrival directions of the HECR
- Combined analysis
- Critical angle and critical energy
- Conclusion: conjectures and their tests (the next talk by *Grigory I. Rubtsov*)

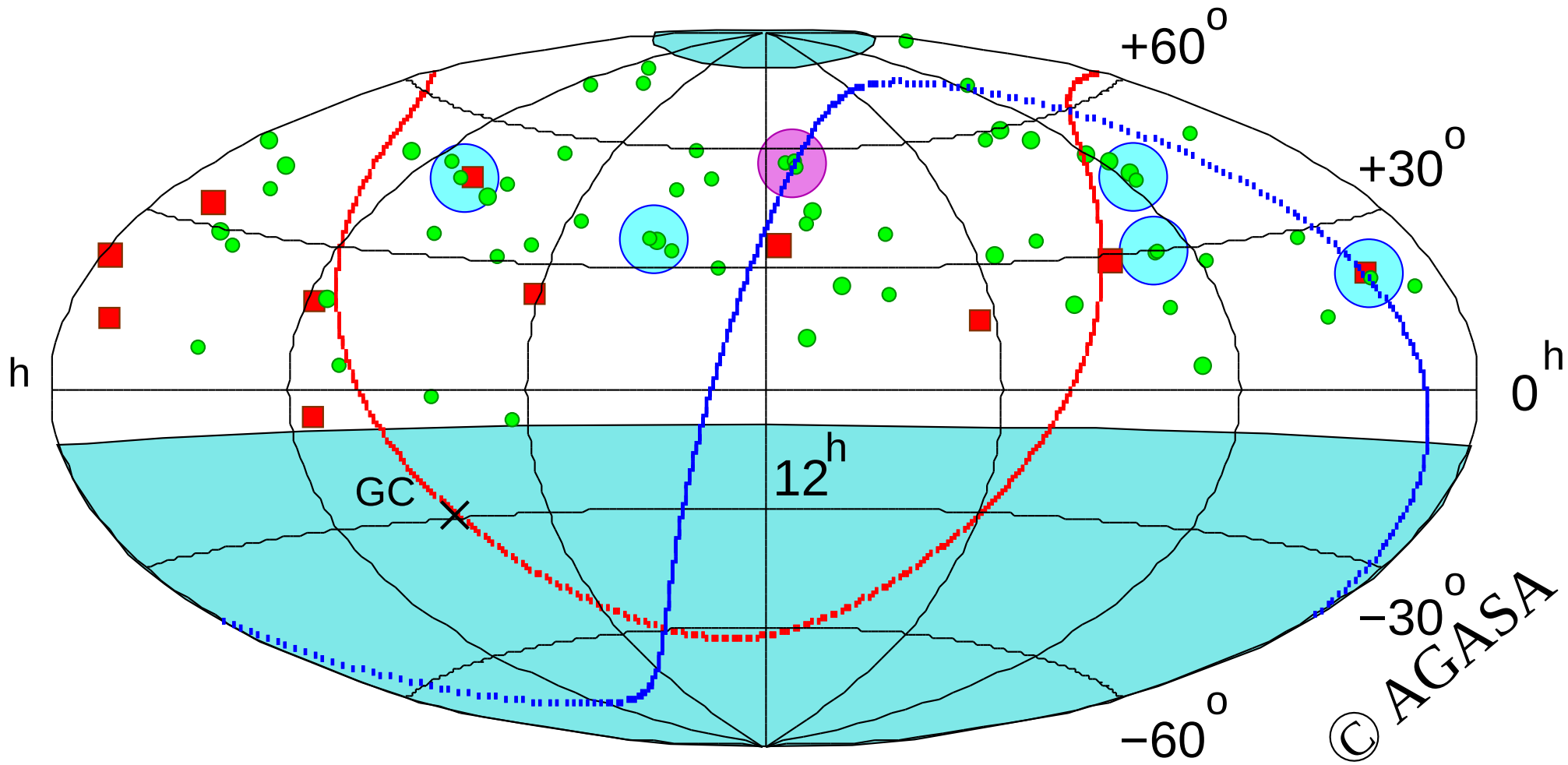
The main motivation

Red boxes — $E > 10^{20}$ eV

Green circles — $4 \cdot 10^{19}$ eV $< E < 10^{20}$ eV

No events from Celectial North!

isotropically distributed!

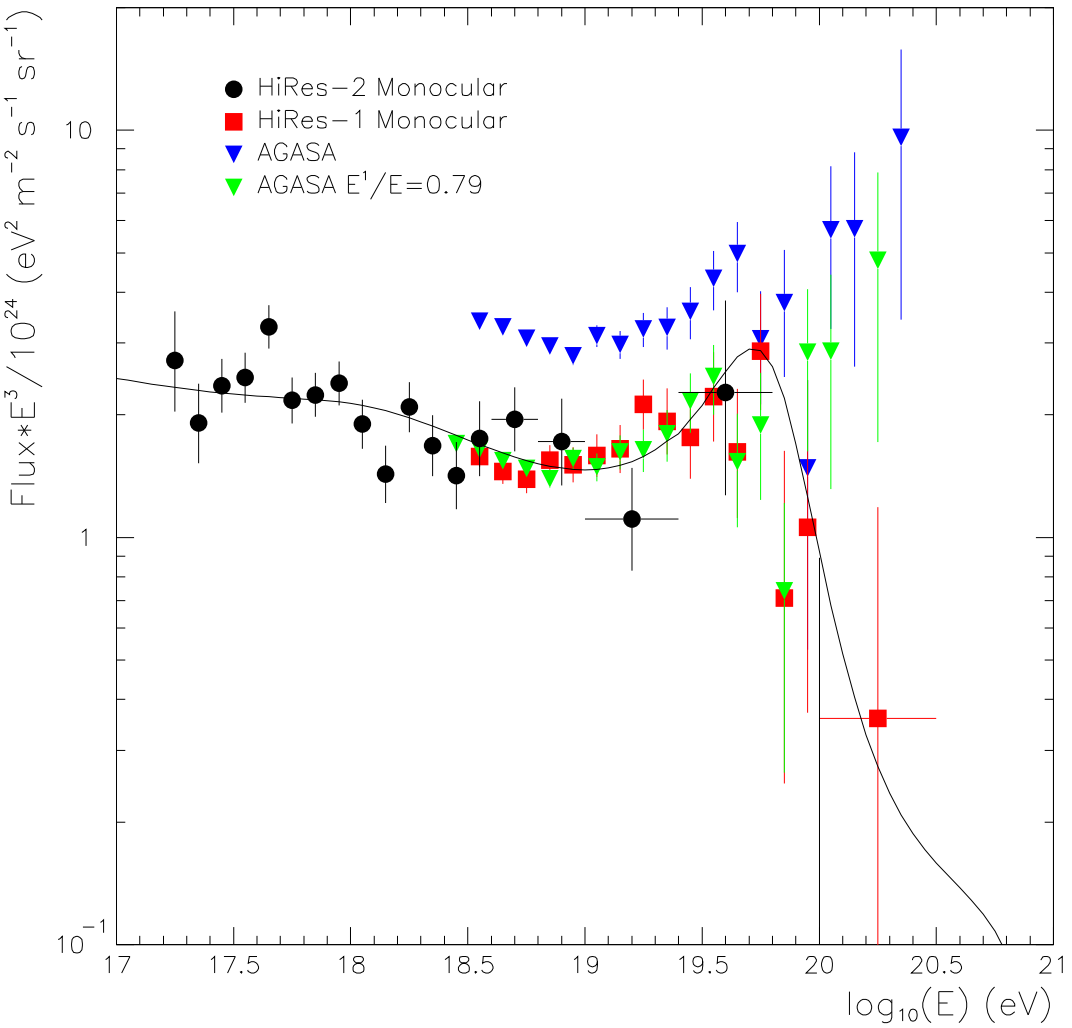


Arrival directions of the highest energy events

Northern hemisphere, $E > 10^{20}$ eV, $z < 45°(60°)$

Experiment	$E/(10^{20}\ \mathrm{eV})$	RA (°)	DEC (°)
Volcano Ranch	1.39	306.7	46.8
AGASA	1.01	124.25	16.8
AGASA	2.13	18.75	21.1
AGASA	1.34	281.25	48.3
AGASA	1.44	241.5	23.
AGASA	1.05	298.5	18.7
AGASA	1.50	294.5	-5.8
AGASA	1.20	349.	12.3
AGASA	1.04	345.75	33.9
AGASA	1.22	84.	29.
AGASA	1.21	176.	36.3
AGASA	2.46	358.5	22.3
Fly's Eye	3.2	85.2	48.
HiRes (Mono)	2.06	128.	20.
HiRes (Stereo)	2.	146.	23.
HiRes (Stereo)	2.	228.	2.

Combined analysis is allowed, since the shapes coincide...



Difference in overall normalization is due to systematic errors in energy determination...

Rescaling procedure

$$E \to E' = \eta E \,, \qquad \eta = (J_{\rm ref}/J)^{1/2}$$

where cosmic ray flux $J \equiv dN/dE$ and we assumed $J \propto E^{-3}$

($E^{-2} \ldots E^{-4}$ — the same results)

HiRes is a reference detector

(change of the reference detector $\longleftrightarrow$ change of the critical energy, $E_{\rm crit} \sim 10^{20}$ eV)

η provides with $J \approx J_{\rm ref}$ @ 10^{19} eV (within 1σ)

Northern hemisphere

Experiment	flux J (10^{-33} m^{-2} s^{-1} sr^{-1} eV^{-1})	η	total exposure A (10^{16} m^2 s sr)
Volcano Ranch	3 ± 1	0.95	0.2
Haverah Park	2.2	0.90	0.9
Yakutsk	4.3 ± 0.6	0.70	1.8
Fly's Eye	2.5 ± 0.3	0.89	2.6
AGASA, $>10^{20}$ eV		0.85	5.3
AGASA, $<10^{20}$ eV	2.7 ± 0.2	0.85	4.0
HiRes I mono	1.6 ± 0.2	1.00	6.5
HiRes II mono	1.6 ± 0.3	1.00	0.7
HiRes stereo	2.2 ± 0.2	0.95	4.6

Joint experiment has the exposure function of

$$dA = \sum_i dA_i$$

normalized to the total number of observed events

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Set II

Northern hemisphere,

$$4 \cdot 10^{19}\ \mathrm{eV} < E < 10^{20}\ \mathrm{eV},\ z < 45^{\circ}$$

Volcano Ranch, AGASA, Yakutsk

Illustration of the anisotropy

1. The observed part of the sky is divided into five (six, seven...) bands in DEC with equal areas, and dA is integrated over these bands.
2. These exposures is compared then to the # of observed events, band per band.

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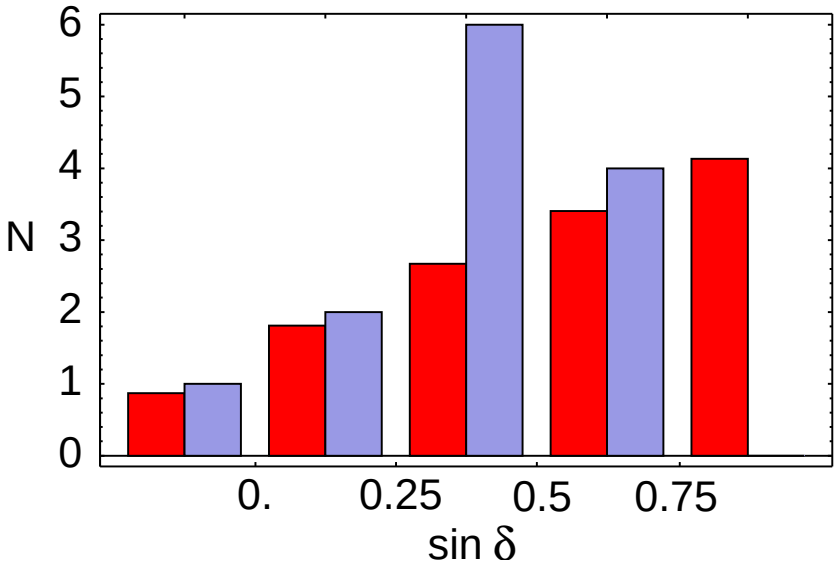
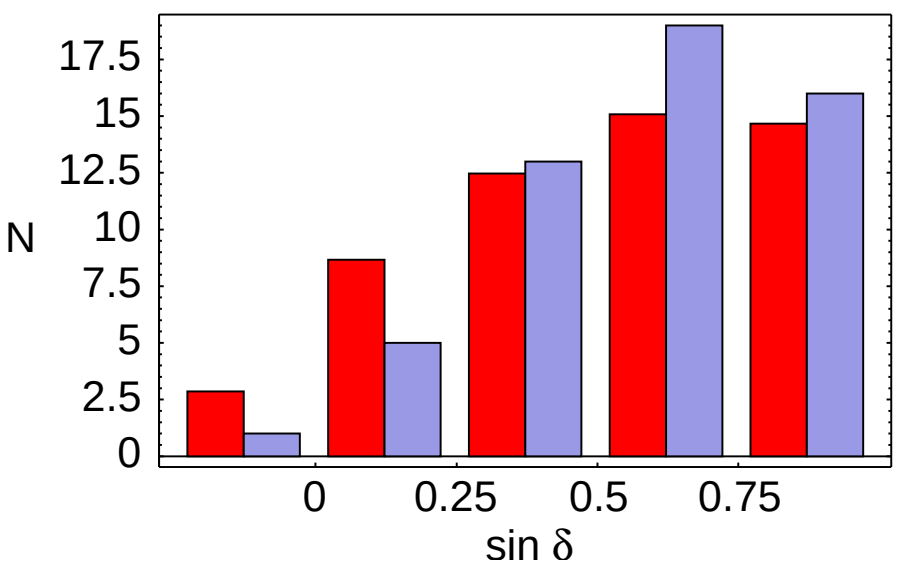


Set I $(E' > 10^{20}$ eV)



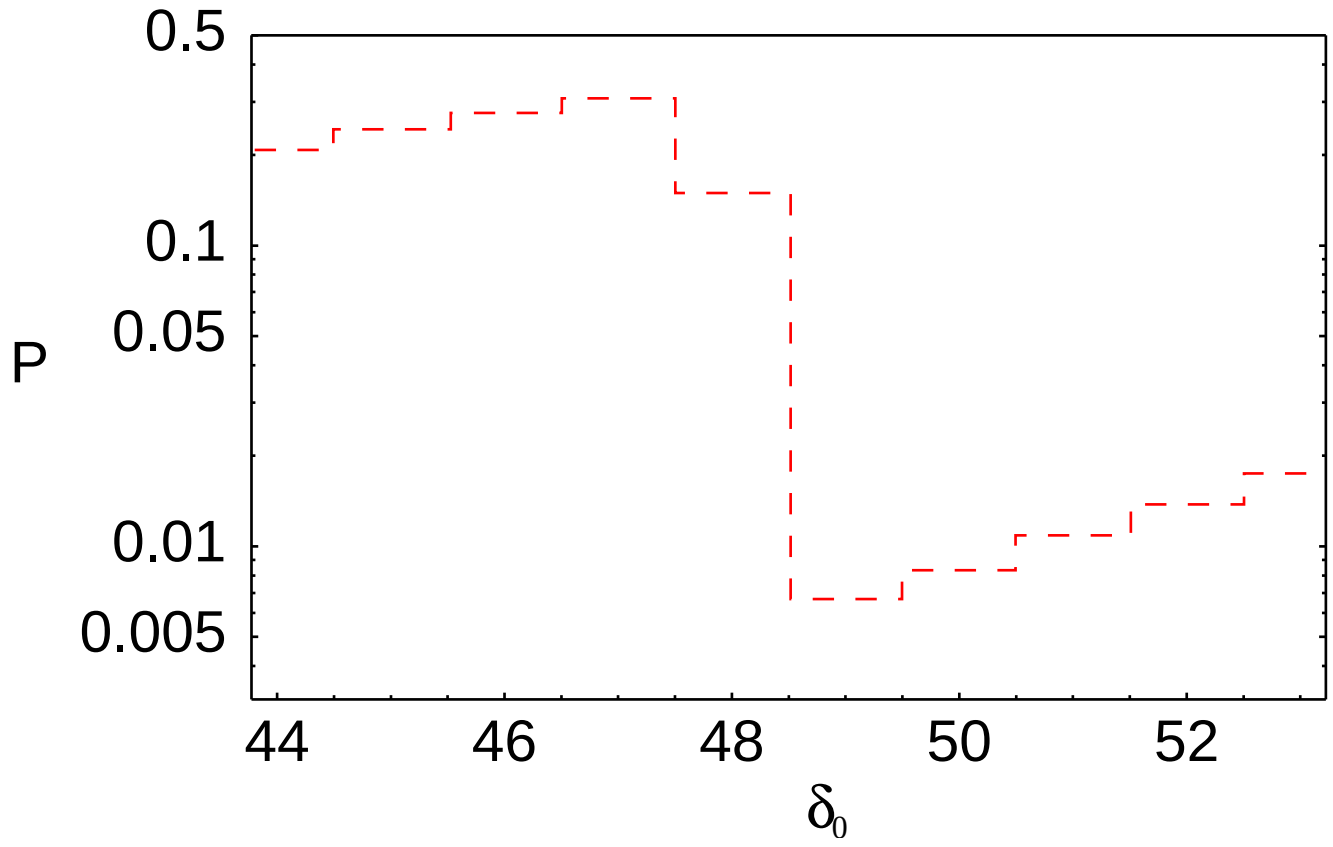
Set II $(4 \cdot 10^{19}$ eV$< E' < 10^{20}$ eV)

Expected and observed distributions of declinations of the cosmic rays.

Monte Carlo simulation # 1

Set I $(E' > 10^{20}$ eV)

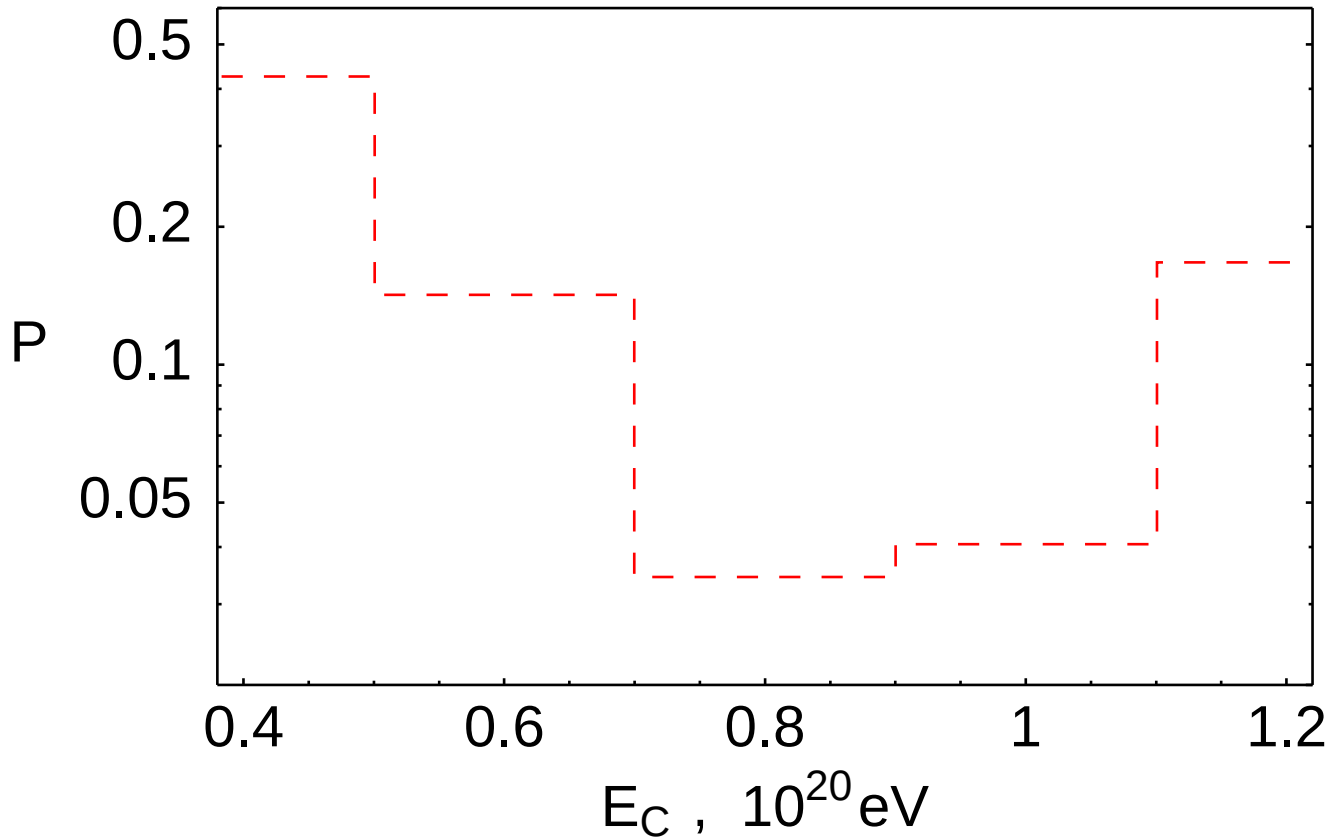
Probability P to observe the actual # of events in the Northern bin $(\delta > \delta_0)$ as a result of a statistical fluctuation, versus δ_0



Monte Carlo simulation # 2

Set II $(E' > 4 \cdot 10^{19}\ \mathrm{eV} > E_{crit})$

Probability P to observe the actual # of events in the Northern bin $(\delta > \delta_0)$
as a result of a statistical fluctuation, versus the critical energy E_{crit}



Conclusion

- Low energies — protons from AGN (BL Lacs), high energies — superGZK particles. . . ?
- Anisotropy — global structure in the Universe
- Anisotropy — magnetic field — photons (X-particles or axions as primaries. . . ?)