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Gran Sasso

COMPACT SOURCES of UHECR

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Outline:

- Auto-correlations in AGASA and Yakutsk data
- Search for sources:
  - ⋆ BL Lacertae are probable candidates

Clustering of UHECR:

- 4 directions (clusters) are identified as "significant" in the world data set of cosmic rays with energies $E > 10^{19}$ eV.

  N.N. Efimov, A.A. Mikhailov, Astropart.Phys. **2** (1994) 329

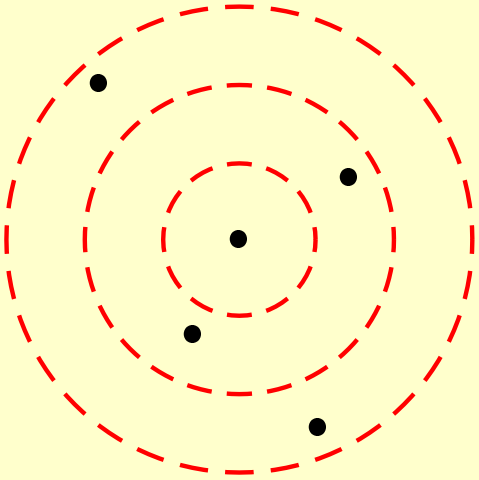
- 47 AGASA events with energies $E > 4 \times 10^{19}$ eV form 1 triplet and 3 doublets within 2.5°; the chance probability $< 1\%$.

  M. Takeda et al., Ap.J. **522** (1999) 225

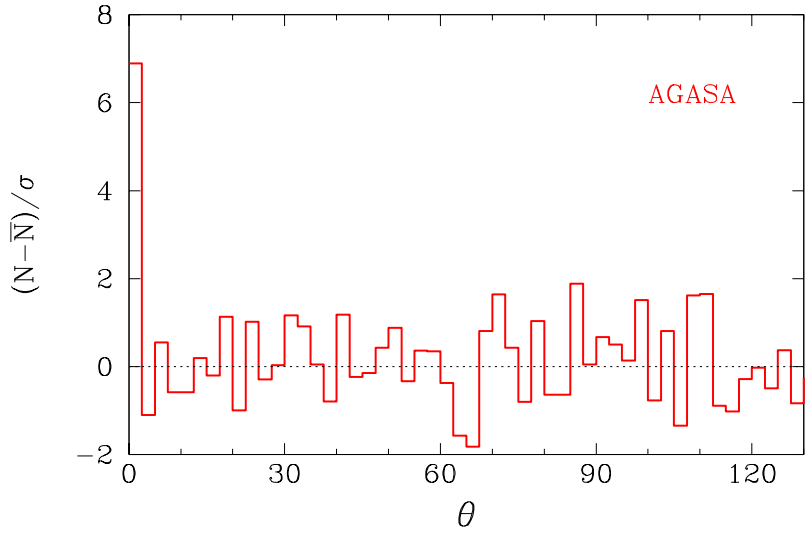
- 2 triplets and 6 doublets at 3° in the world data set of 92 events with energy $E > 4 \times 10^{19}$ eV; the chance probability $\sim 1\%$.

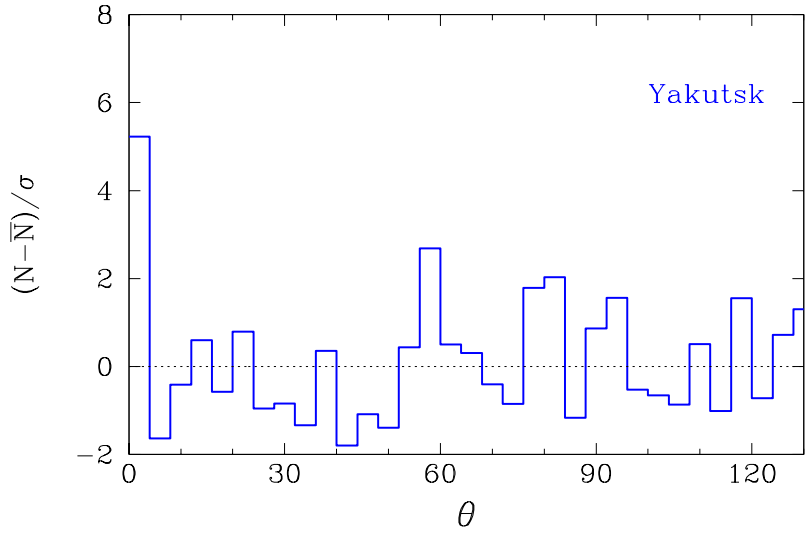
  Y. Uchihori et al., Astropart. Phys **13** (2000) 151

Correlation function:



- Count events N_i in binning of arrival directions for the real data and for a large set of Monte-Carlo simulations.
- **Derive:**
  - ⋆ $\dfrac{N_i - N_i^{\mathrm{MC}}}{\sigma_i}$
  - ⋆ Probability $P(\delta)$ of the excess in the first bin (δ is the bin size)





Auto-correlation functions for

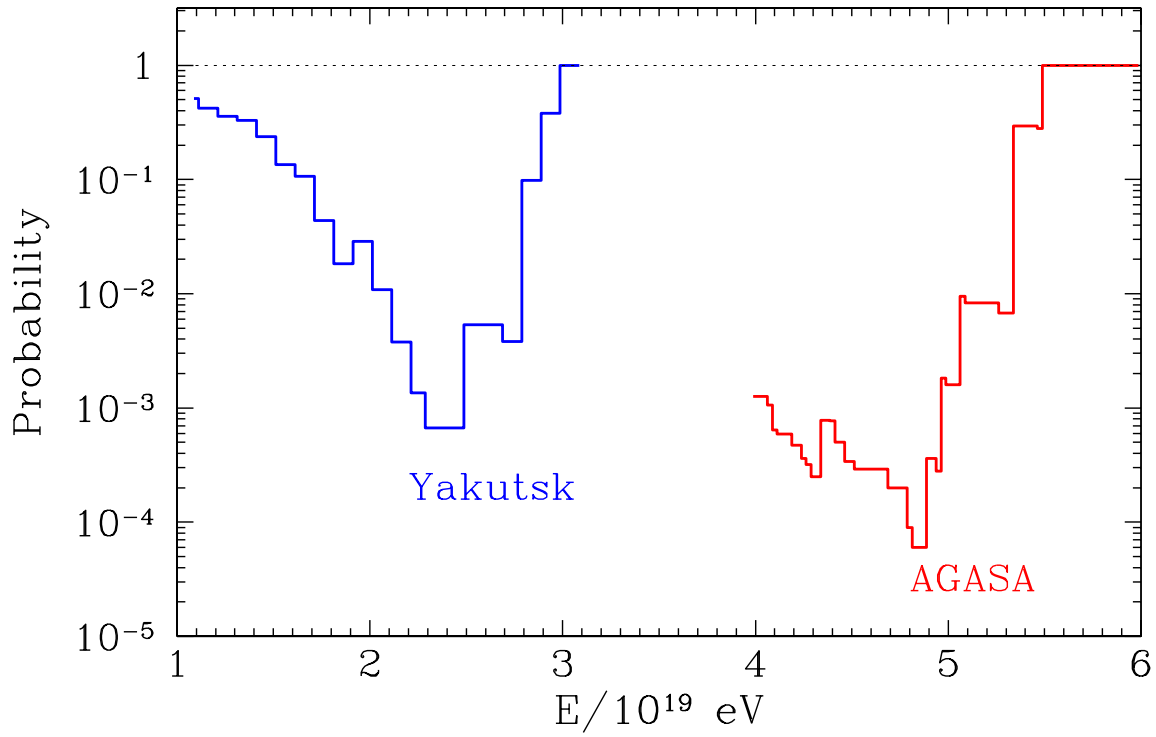
AGASA events with $E > 4.8 \times 10^{19}$ eV and

Yakutsk events with $E > 2.4 \times 10^{19}$ eV.

The energy cut:

It should be chosen so as to maximize the signal.

experiment	$E_{\rm min}$	# of events	P
AGASA	4.8×10^{19} eV	39	3×10^{-4}
Yakutsk	2.4×10^{19} eV	26	2×10^{-3}



$P(\delta)$ as a function of $E_{\rm min}$.

Combined probability is 4×10^{-6}

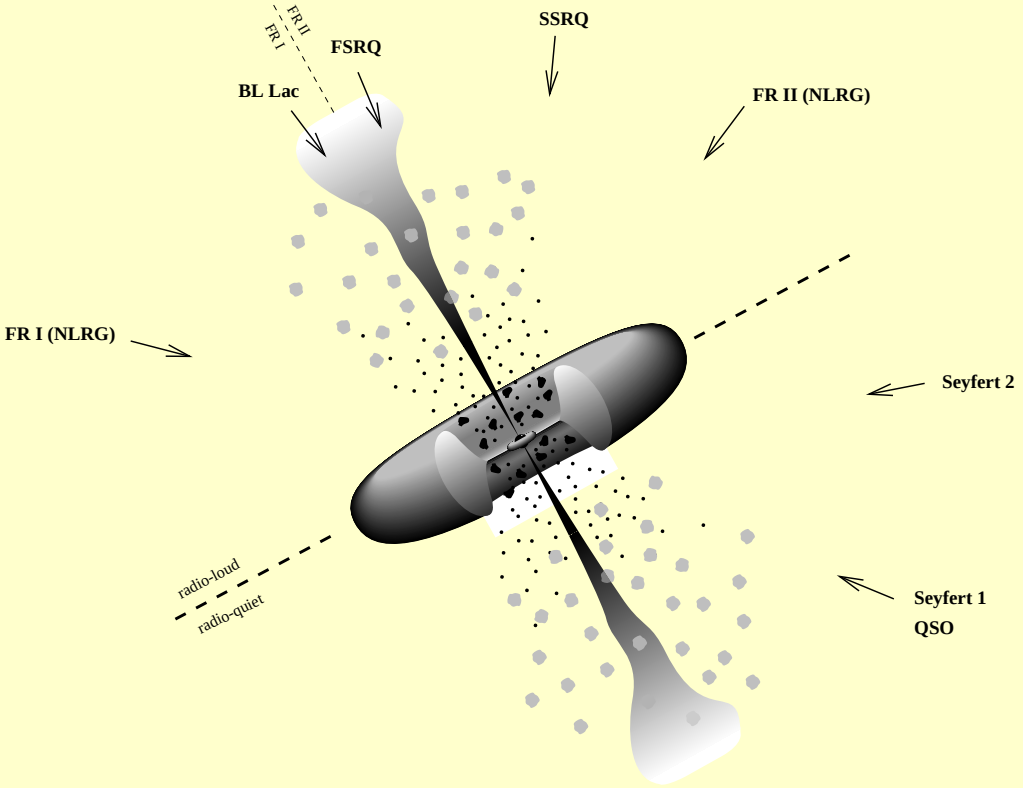
$\Rightarrow$ Little chance that clusters are random.

SEARCH FOR SOURCES

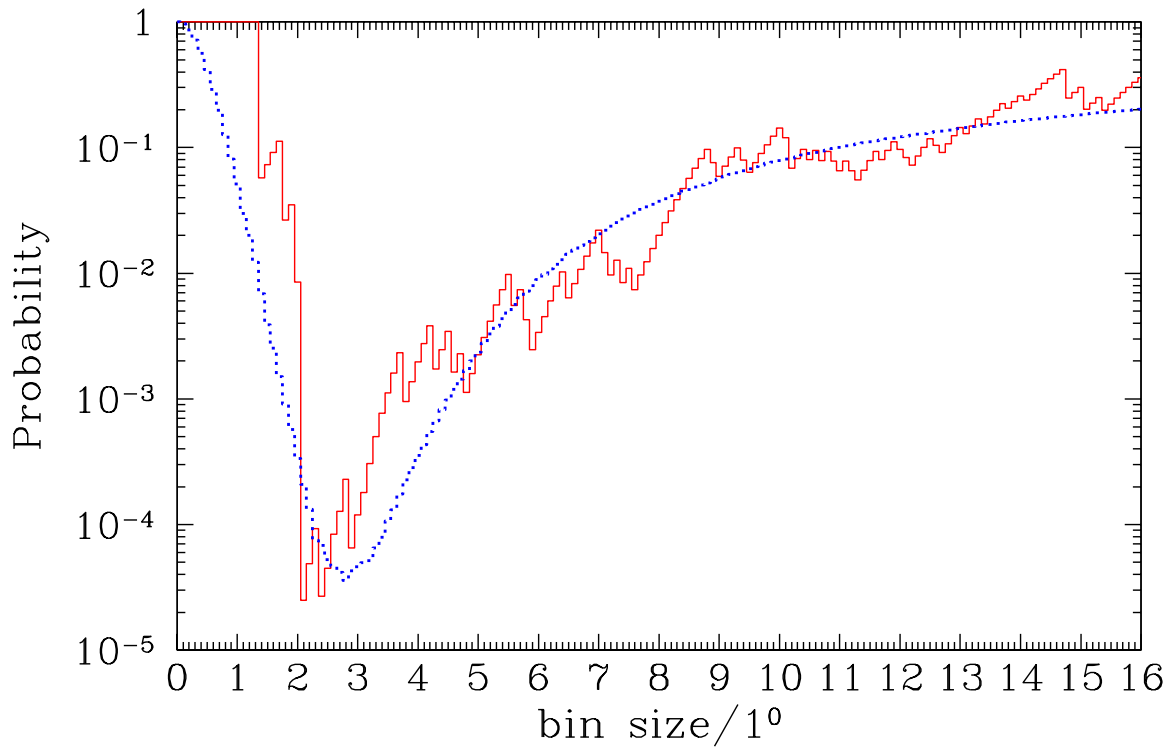
- Best chances to find sources are with the set of events having large auto-correlations.
- From clustering one expects *several hundred* sources *in total* provided they are of similar luminosity

  [Dubovsky, Tinyakov, I.T., PRL 85(2000) 1154]
- Possible correlations with astrophysical objects — galactic and extragalactic — were considered before:
  - ⋆ Takeda et al., ApJ **522** (1999) 225
  - ⋆ Uchihori et al., Astropart.Phys. **13** (2000) 151
  - ⋆ Elbert, Sommers, ApJ **441** (1995) 151
  - ⋆ Farrar, Bierman, PRL **81** (1998) 3579
  - ⋆ Virmani et al., astro-ph/0010235
  - ⋆ Sigl et al., astro-ph/0008363

- AGNs are potential sources of UHECR.



- Should select AGNs with jets directed along the line of sight (blazars).
- BL Lacertae : subclass of blazars with weak emission lines.
- In a world **without** GZK cut-off distance to the source should not be limited
- Most recent catalog contains 306 BL Lacs.



$\mathbf{P}(\delta)$ for combined Yakutsk and AGASA set (65 events) and 22 brightest BL Lacs. Cuts:

$z > 0.1$ or unknown

mag < 18

$F_6 > 0.17$ Jy

Dotted line: simulated signal from 9 sources assuming angular resolution of 1.8^o

Possible caviats:

- Incompleteness of the BL Lac catalog
  NOT IMPORTANT !
- Autocorrelations in UHECR set
  We verified that the result does not change if we use MC sets with the same amount of autocorrelations as real data
- Cuts
  We found penalty which should be assigned for the adjustment of cuts

$$p_{\rm cor} \approx 5 \times p^{0.9}$$

The final answer assuming penalty

$$p_{\rm cor} < 2 \times 10^{-4}$$

CONCLUSIONS:

- Clustering of UHECR favours point sources
- BL Lacs are probable sources of the observed UHECR.
- Correlations at 3° are likely due to neutral particles (otherwise they would be destroyed by the Galactic magnetic field)