Clustering of UHECRs and their sources

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Outline

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Sommers, Astropart. Phys. 14 (2001) 271.
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Farrar & Biermann, Phys. Rev. Lett. 81, 3579. Hoffman, Phys. Rev. Lett. 83, 2471. Sigl, Torres, Anchordoqui & Romero, Phys. Rev. D63 (2001) 081302.
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1. Introduction: the sky distribution of UHECRs.

2. Correlation with astrophysical objects?

3. Clustering in the AGASA data and angular resolution.

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The distribution of the data of some experiments (AGASA, Yakutsk) at small angles, shows a non-random clustering .

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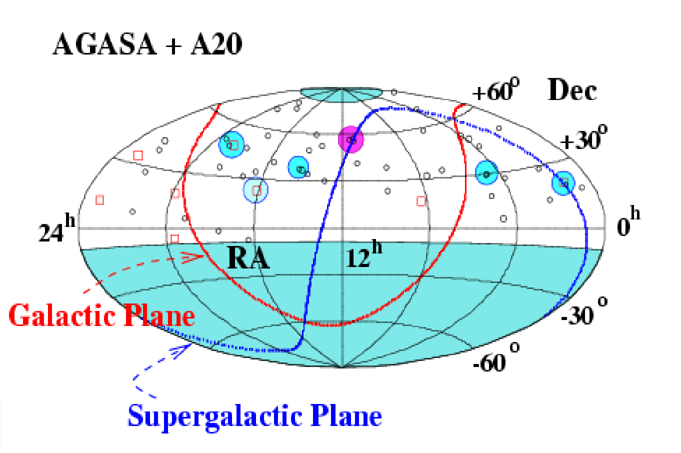
The situation will improve with AUGER, although a northern site for full sky coverage would be necessary. Sommers 01.

Clustering at small scales

The AGASA experiment has detected several doublets and triplets within the angular resolution of the experiment. This clustering is difficult to explain if CRs hit isotropically the Earth's atmosphere ($\mathcal{P} \sim 0.1\%$). Uchiori et. al. 00



Other experiments, e.g. Haverah Park, do not appreciate significant clustering.

Correlation with astrophysical objects?

Several claims for directional correlations between different sources and UHECRs have been pointed out and dismissed after subsequent analysis.

Farrar and Biermann proposed compact radio quasars (QSOs) as sources based on an a priori theoretical reason (a new neutral hadron) and the alignment of the highest energy events with high redshifted quasars ($\mathcal{P} \sim 0.5\%$). Hoffman noted that one event should be dropped because it was used to introduce the hypothesis ($\mathcal{P} \sim 3\%$). An updated event list lowered the statistical significance to $\mathcal{P} \sim 27\%$.

In 01, Tinyakov & Tkachev, make a strong claim for a correlation between UHECRs and BL Lacertae (BL Lacs, a subgroup of the QSOs). After imposing several cuts in the samples analyzed they quote a significance of $6 \cdot 10^{-5}$ after multiplying by a penalty factor that would account for the cuts performed.

Selected UHECRs

"Knowing production sites of UHECRs will help to explain the apparent absence of the Greisen-Zatsepin-Kuzmin (GZK) cutoff. "

"There are observational reasons to believe that UHECRs are produced by compact sources ".
Tinyakov & Tkachev 01.

To test the correlation a subgroup of CRs is selected:

39 AGASA events with $E > 4.8 \cdot 10^{19} eV$.

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

The energy cuts are motivated by an earlier autocorrelation analysis (using similar techniques as here).

Note that the second set is clearly below the GZK cutoff.

Selected BL Lacs

Assuming that the ability to emit UHECRs is correlated with optical and radio emission, cuts are imposed to select the most powerful BL Lacs:

$$z > 0.1 \; or \; unknown; \qquad mag < 18; \qquad F_6 > 0.17 Jy$$

Only 22 BL Lacs out of 306 satisfy this criteria. Two of them coincide with the two triplets of UHECRs, one with a doublet and two lie close to a single event.

The Introduction to the catalogue of BL Lacs used states: *This catalogue should not be used for any statistical analysis as it is not complete in any sense*.

Moreover, half of the BL Lacs have unknown redshift and some magnitudes are said to be inaccurate.

The end probabilities given correspond to a further restricted sample of only 5 BL Lacs.

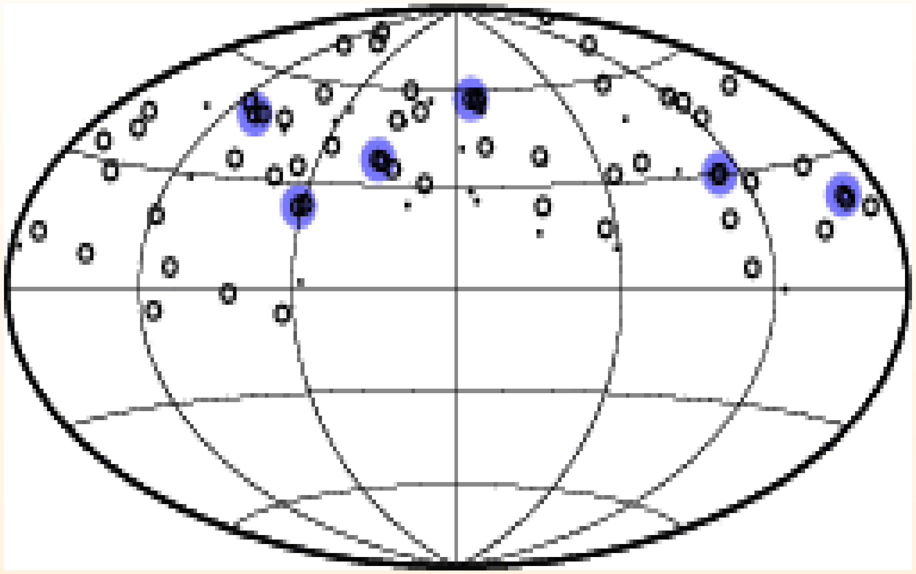
Is the signal robust

A penalty factor, of order a few, is introduced to compensate for the cuts performed. Possible contamination due to autocorrelations in the UHECR data are estimated, in principle, by generating random samples with the same clusters as the experimental data.

To check whether the claimed correlation is robust I will remove the cuts imposed and compare the result to the signal expected when GRBs are considered.

I won't consider the Yakutsk events because they are below the GZK cutoff and the angular resolution is worse ($\sim 4^o$). By doing this, the significance with still all the cuts, drops to 0.15% before multiplying by any penalty factor.

Samples used



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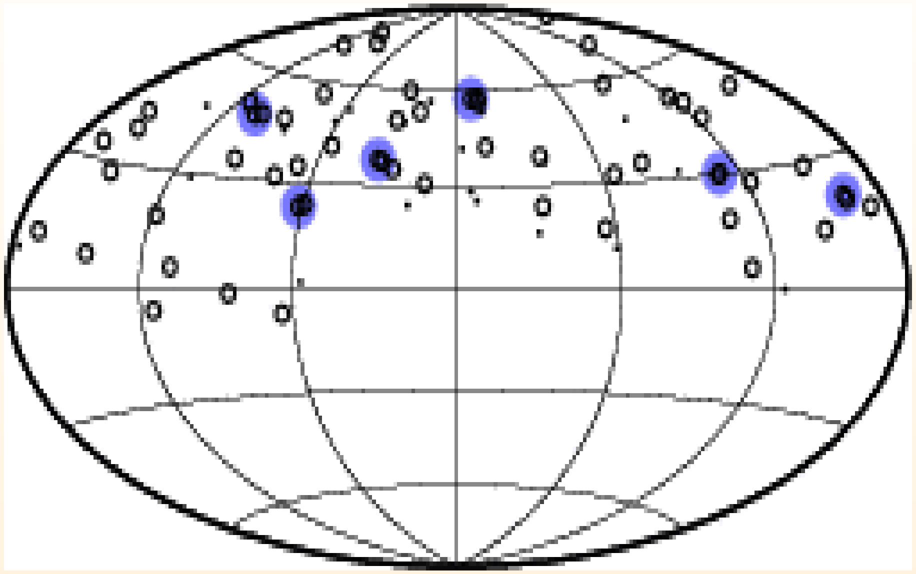

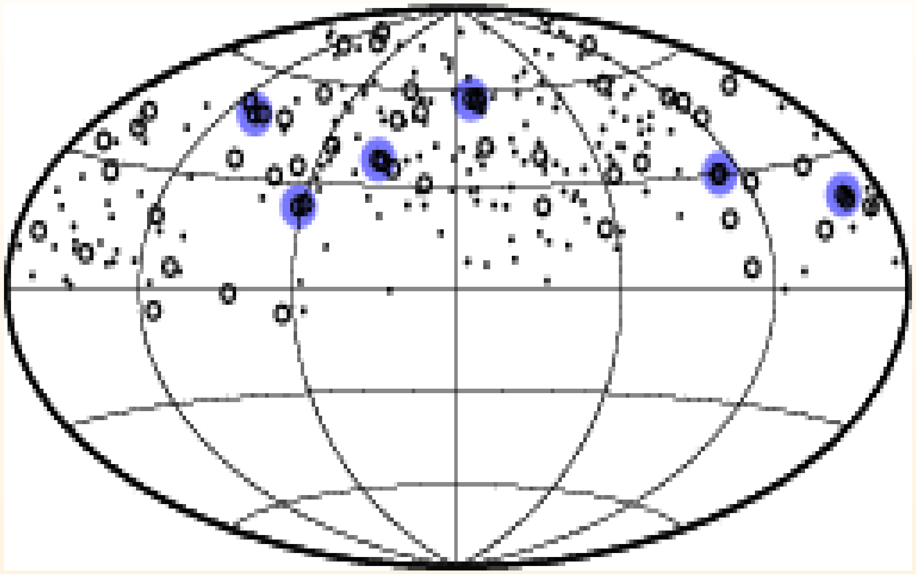

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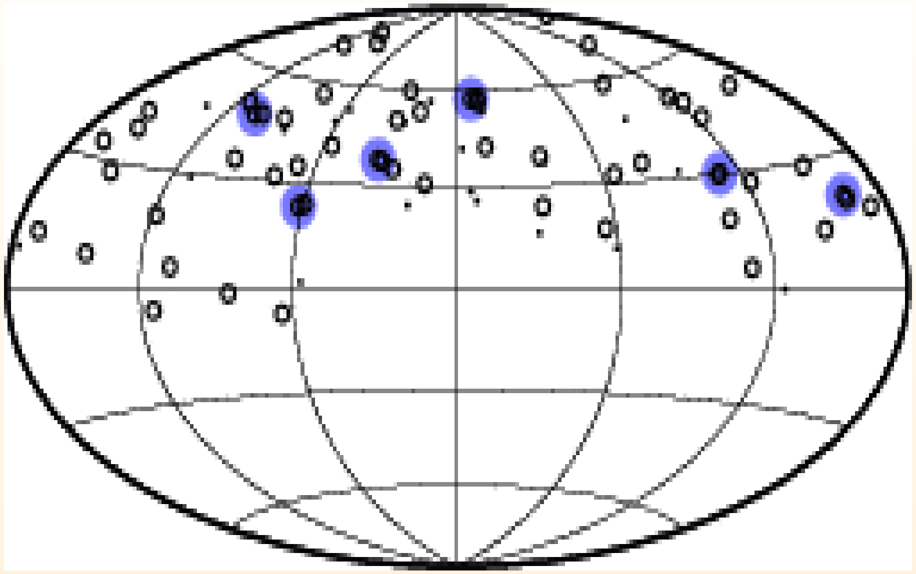
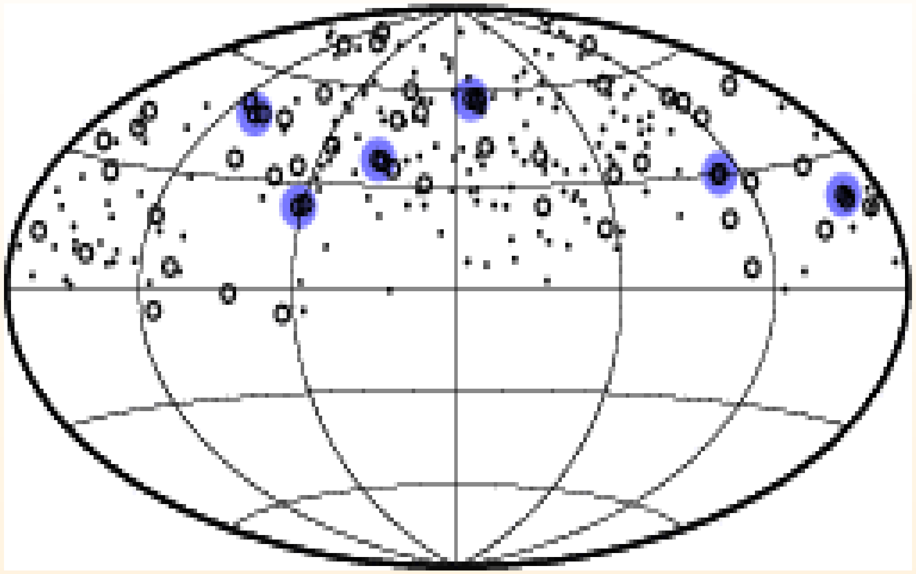
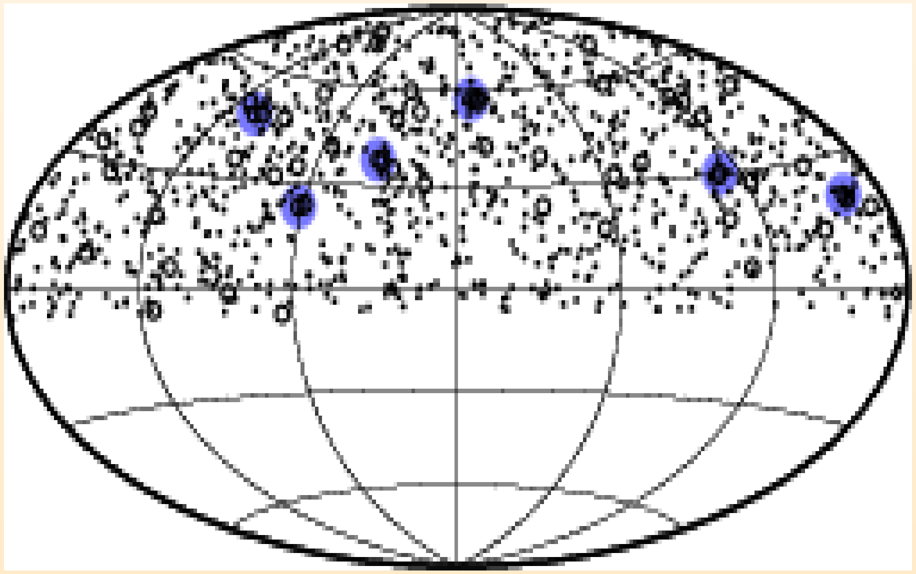
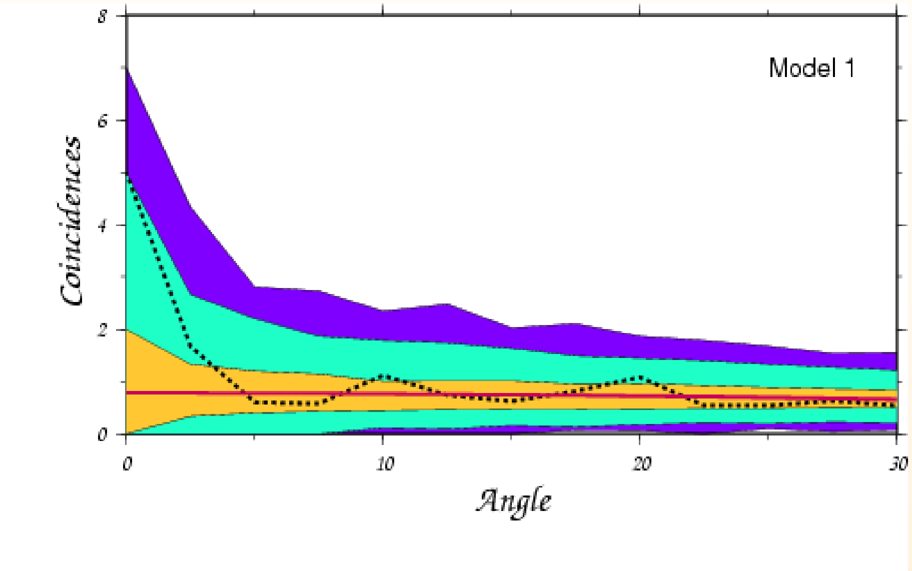






Removing the cuts.



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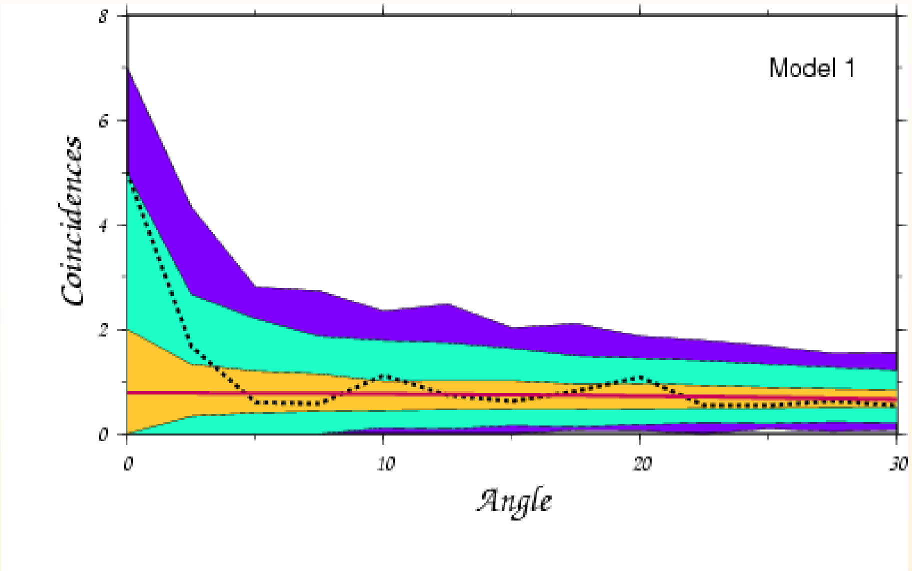

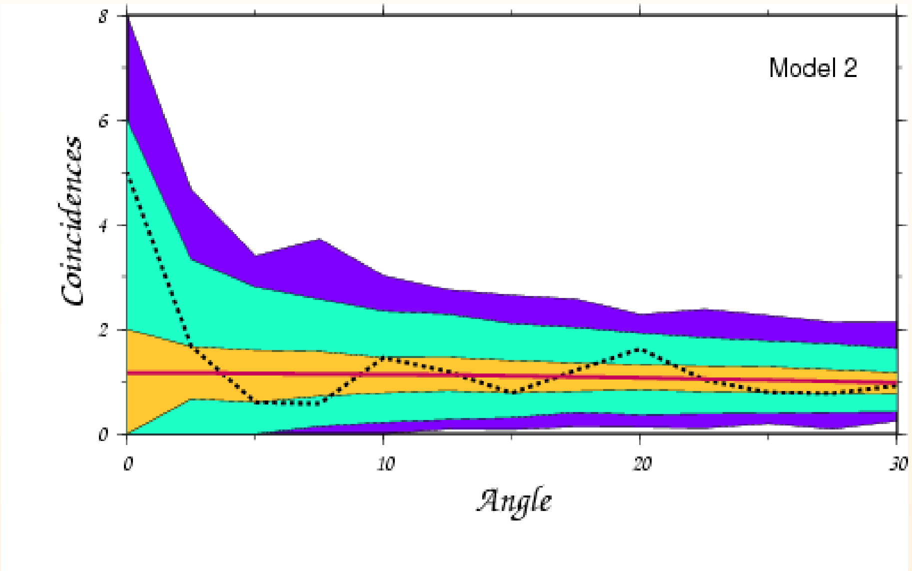

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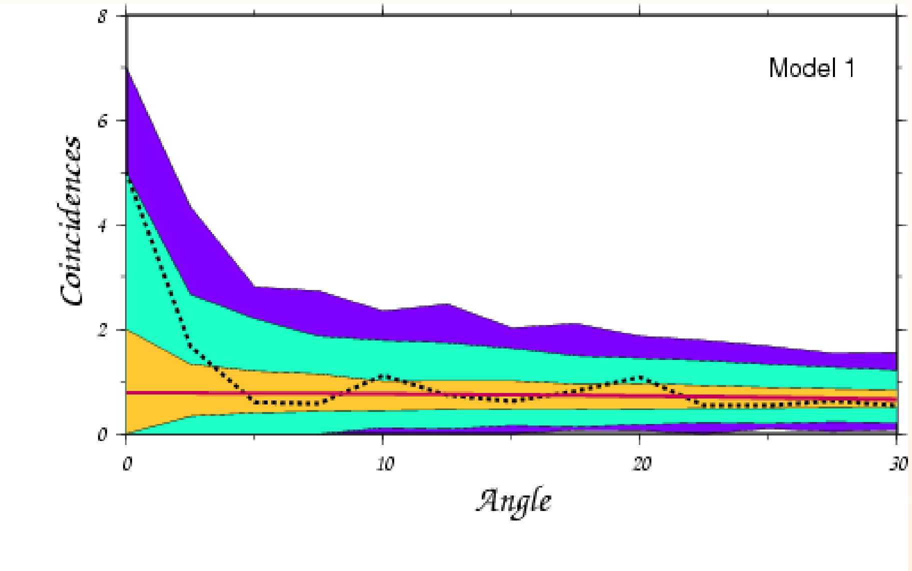

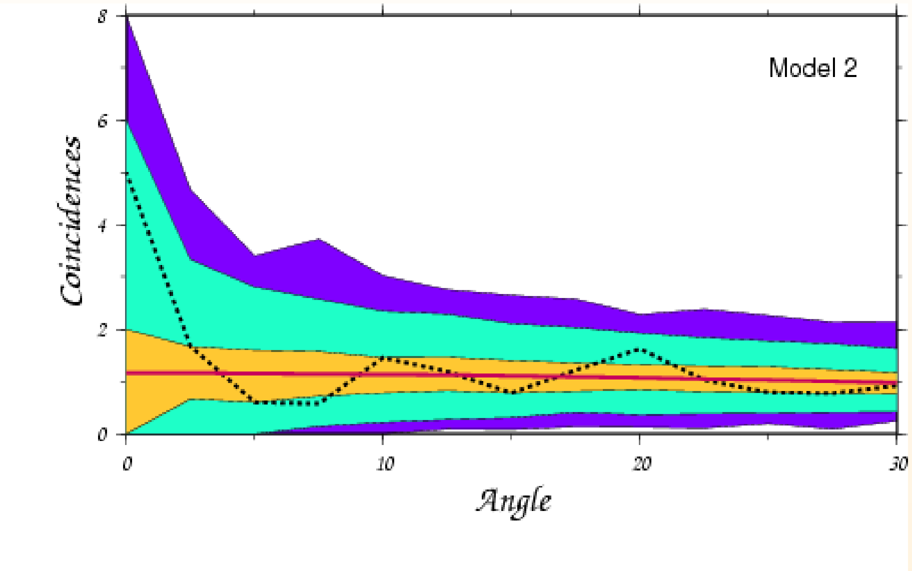

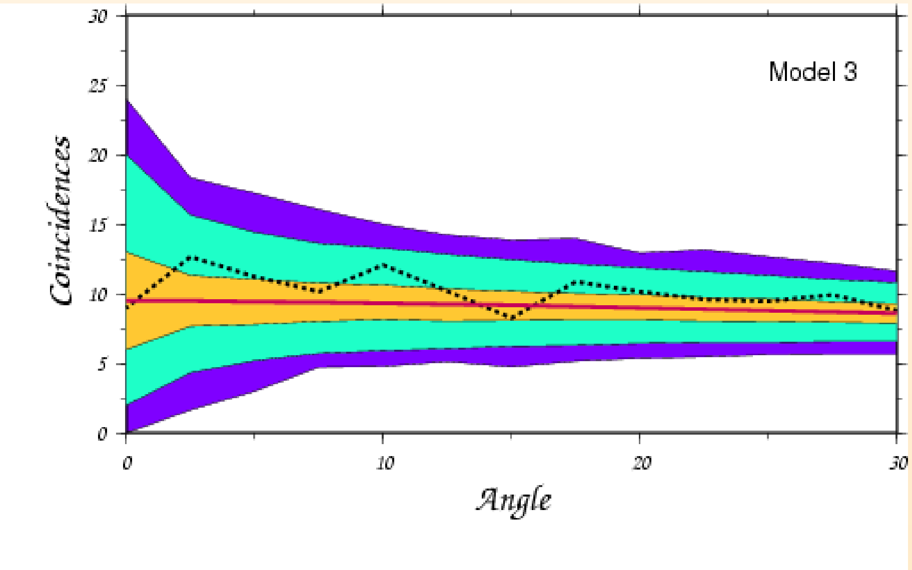

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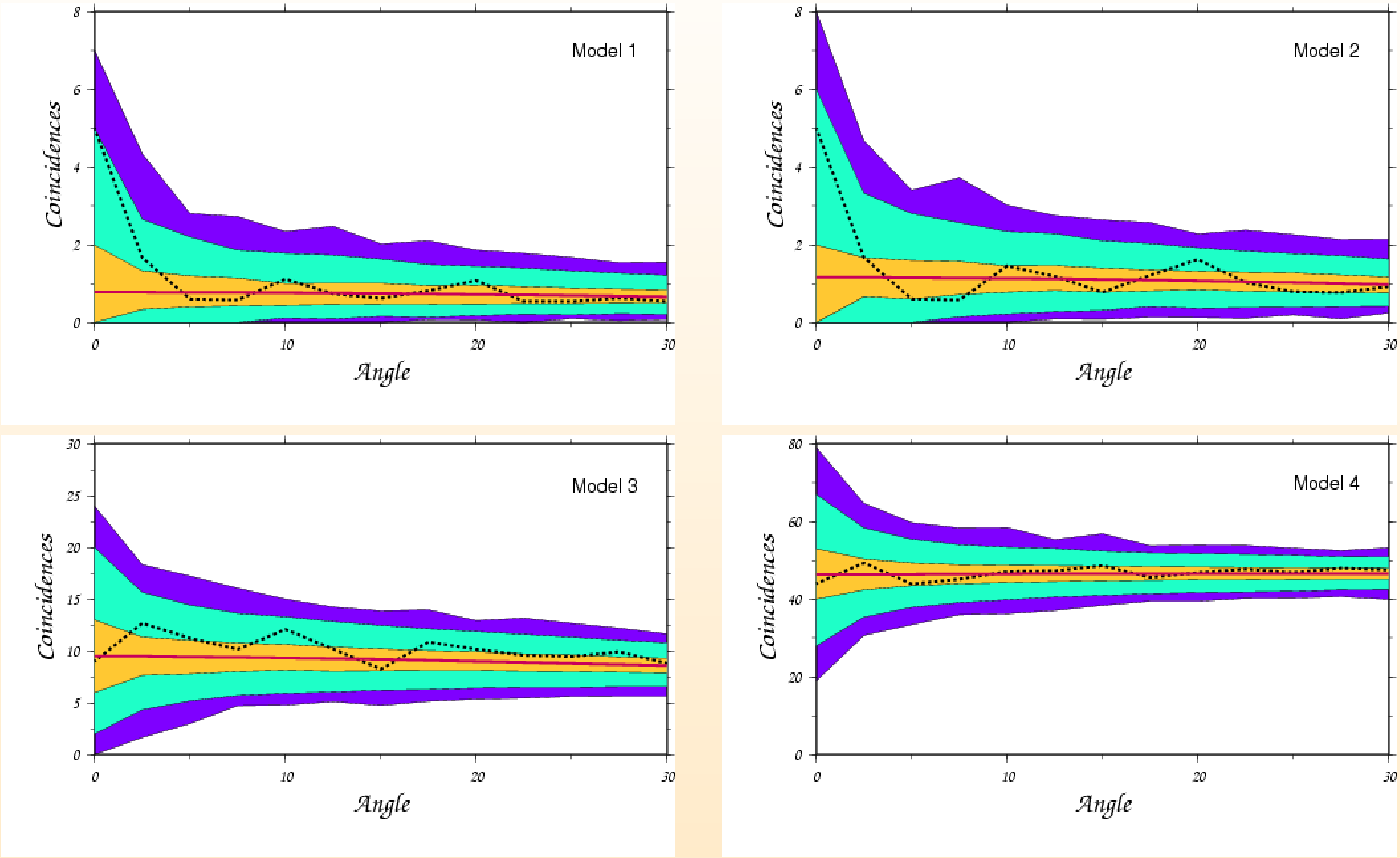
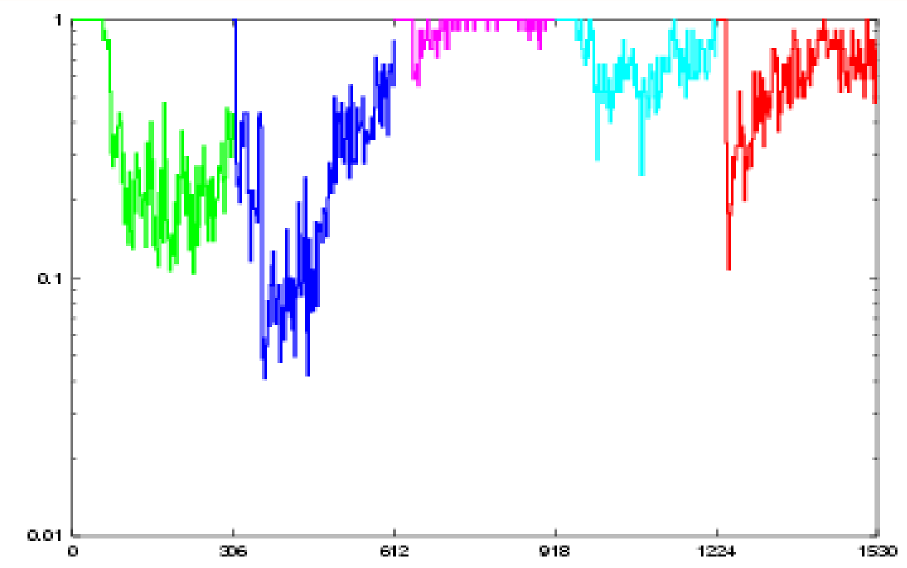
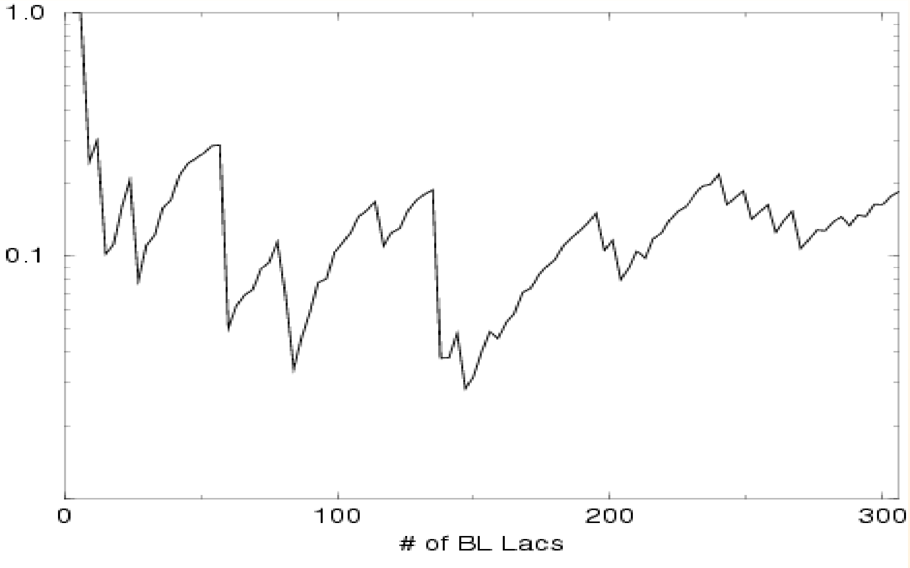


Introducing random cuts in the sources





Using the three columns in the Batse catalogue to impose ~ 100 cuts, one finds a particular sample of 147 GRBs with a probability to have randomly the same number of coincidences with doublets of $6 \cdot 10^{-5}$.

Contamination from autocorrelations

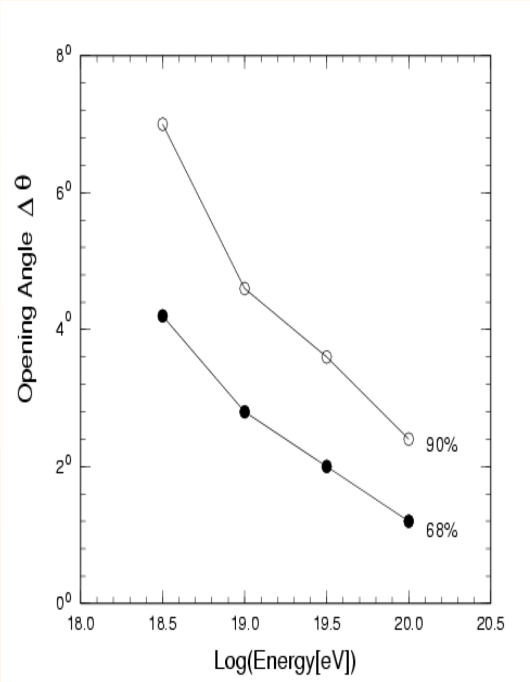
The random samples generated to be compared to the experimentally observed CRs won't have as much clustering. This could artificially enhance the signal.

One way to account for that is substitute each cluster by a single event. Then the significance of the correlation to BL Lacs drops to $\sim 14\%$.

If instead samples with the same number of clusters are generated, the previous signal in the GRBs drops to $\sim 23\%$. But in the BL Lacs case, also drops to $\sim 0.6\%$! Multiplying by a penalty factor of order a few would further decrease the significance of any correlation, even if one believed that the cuts are justified.

Clustering in the AGASA data and angular resolution.

The angle used in this analysis is $2.5^o = \sqrt{2}1.8^o$ (maximises signal to noise ratio). The method doesn't account for energy variation of the angular precision and gives the same weight to two events separated 1.5^o (inside 1σ cone) that to a pair 2.5^o far apart.



If we use as statistical estimator the overlap integral of the angular spread of each event with all the others (where the spread is correctly modelled as a Gaussian with width depending on the energy), the significance of the clustering of the AGASA sample drops by more than a factor of 10, to 1.2% (4% if the factor $\sqrt{2}$ is kept)!

Conclusions

The claimed correlation of UHECRs with BL Lacs is not robust. Removal of the cuts erases the signal.

A recent bold test, using HP and VR data, but keeping all the cuts in the BL Lacs catalogue also didn't find any significant correlation.

The clustering of the AGASA sample might be overestimated because the angular precision is not properly taken into account.