Interpretation of cosmic ray anisotropy at highest energies

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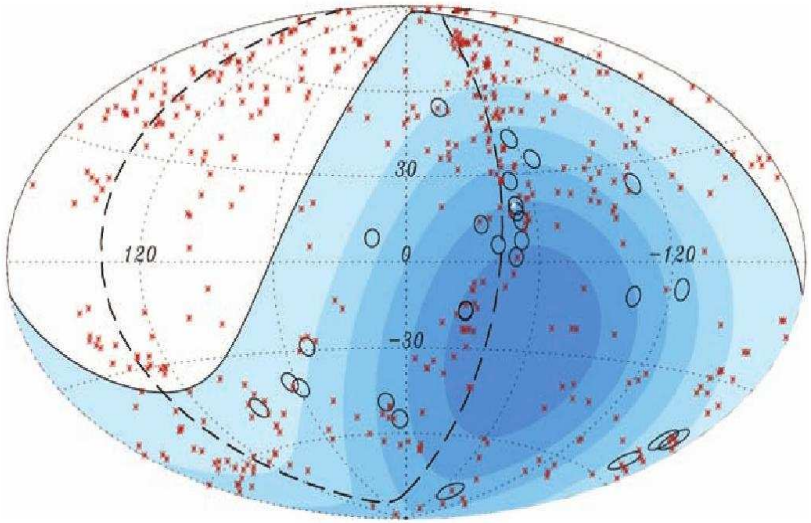
Gorbunov, P.T., Tkachev, Troitsky,
arXiv:0711.4060 [astro-ph]
arXiv:0804.1088 [astro-ph]
H.Koers, P.T. in preparation

OUTLINE

- Introduction
- Correlation analysis and its limitations
- Possible interpretations
- Hypothesis-specific tests
- Conclusions

Introduction: correlation with AGN in PAO data

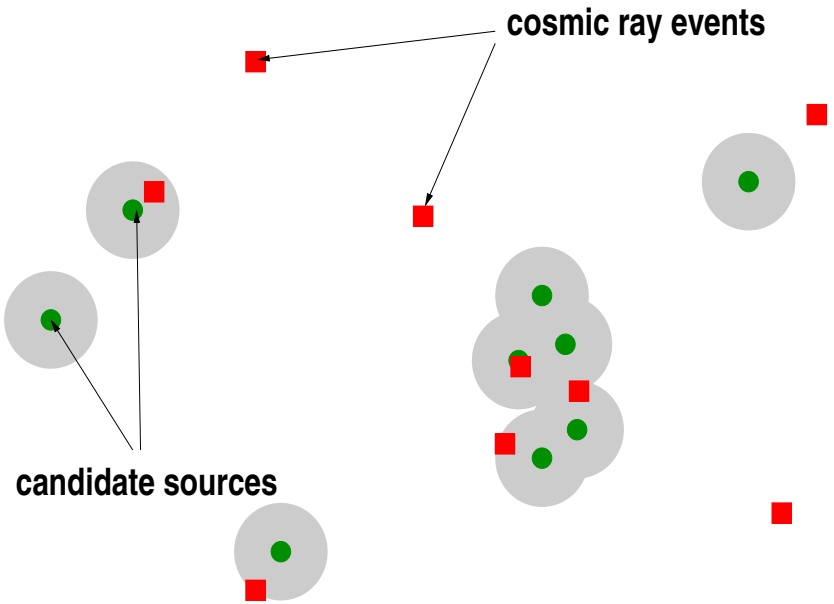
Science 318:938-943,2007 [arXiv:0711.2256]
Astropart.Phys.29:188-204,2008 [arXiv:0712.2843]



- energy cut $E > 5.6 \times 10^{19}$ eV $\Longrightarrow$ 28 events
- angular size $\delta = 3.1^\circ$
- 472 AGN with redshift $z < 0.018$ (distance $D < 75$ Mpc)
- significance of correlation: 1.7×10^{-3} (derived from "control" set)

POSSIBLE INTERPRETATIONS?

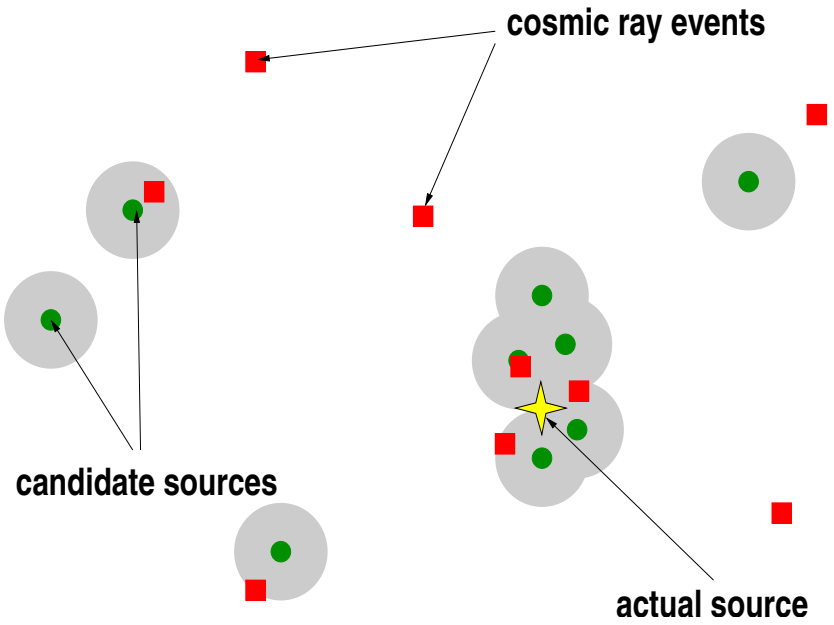
Correlation analysis and its limitations



P.T., I. Tkachev, JETP Lett.74:1-5,2001 [astro-ph/0102101]
JETP Lett.74:445-448,2001 [astro-ph/0102476]
Phys.Rev.D69:128301,2004 [astro-ph/0301336]

Correlation analysis compares data to isotropic distribution. If there is a correlation signal, it means only that the data are not isotropic. It does not tell anything about the actual sources.

Correlation analysis and its limitations



P.T., I. Tkachev, JETP Lett.74:1-5,2001 [astro-ph/0102101]
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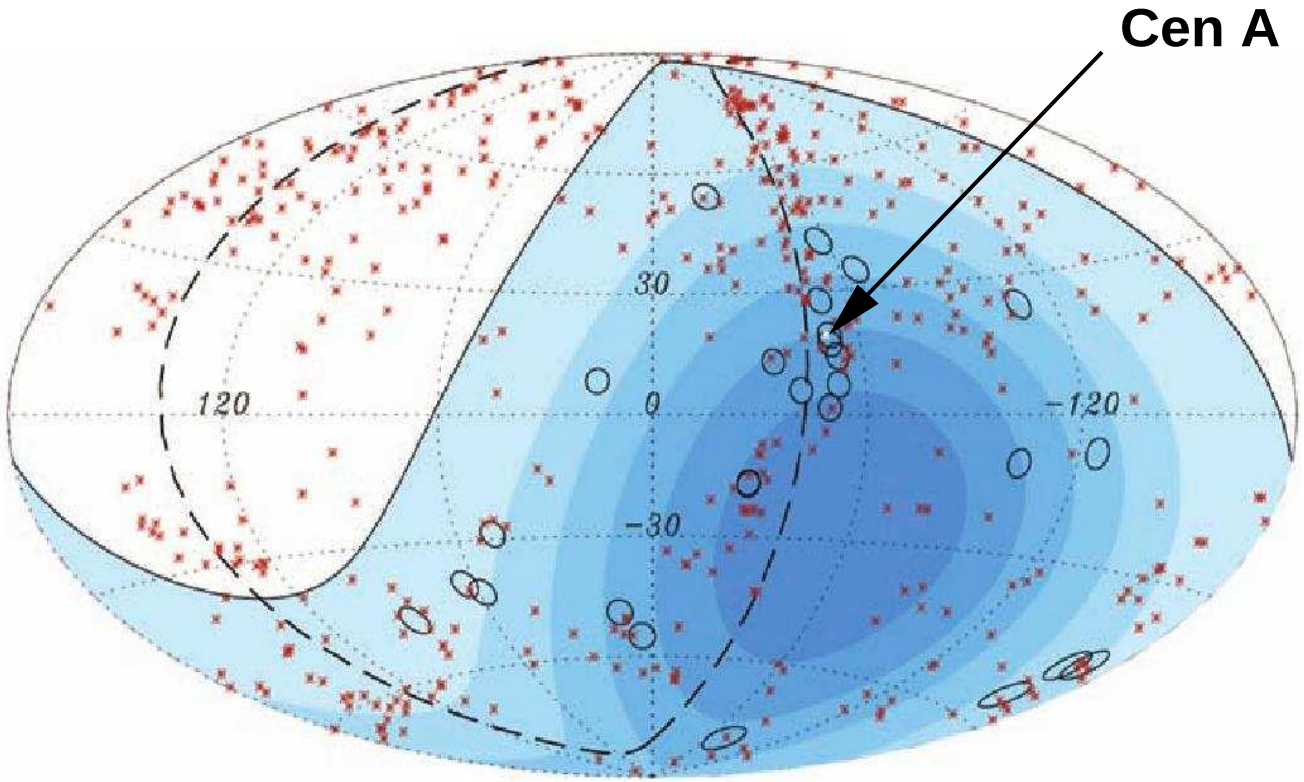
Clustering of sources = DANGER

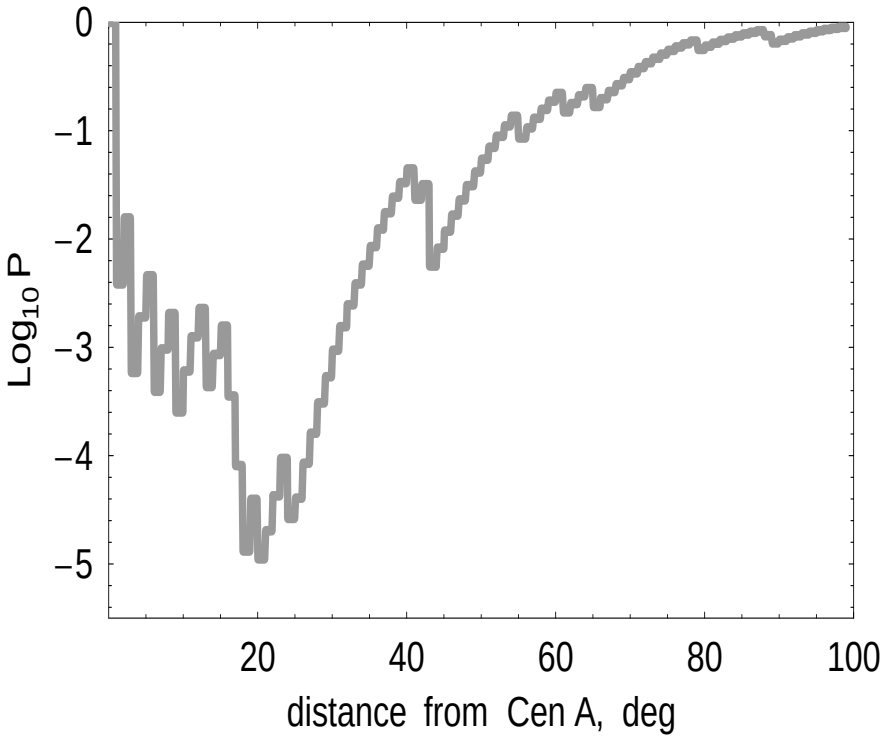
Correlation analysis compares data to isotropic distribution. If there is a correlation signal, it means only that the data are not isotropic. It does not tell anything about the actual sources.

Example: excess around Cen A



P = the probability to obtain by chance, in the uniform distribution, the excess of CR events within given angle from Cen A equal or larger than that found in the data.

Note: this is not a real significance, because no penalties are included



If AGN are indeed sources, the correlation with Cen A will increase with statistics, since Cen A is located in the region with the overdensity of background AGN.

If instead Cen A is actual source of CRs and produces a cloud of events around it (say, deflected by $\lesssim 20^\circ$ by magnetic fields) while other AGN have nothing to do with UHECR, the correlation between AGN and UHECR will also increase with statistics, for the same reason.

Conclusion: correlation analysis alone cannot distinguish these completely different cases.

$\Longrightarrow$ The question of interpretation remains open

POSSIBLE INTERPRETATIONS OF CORRELATION

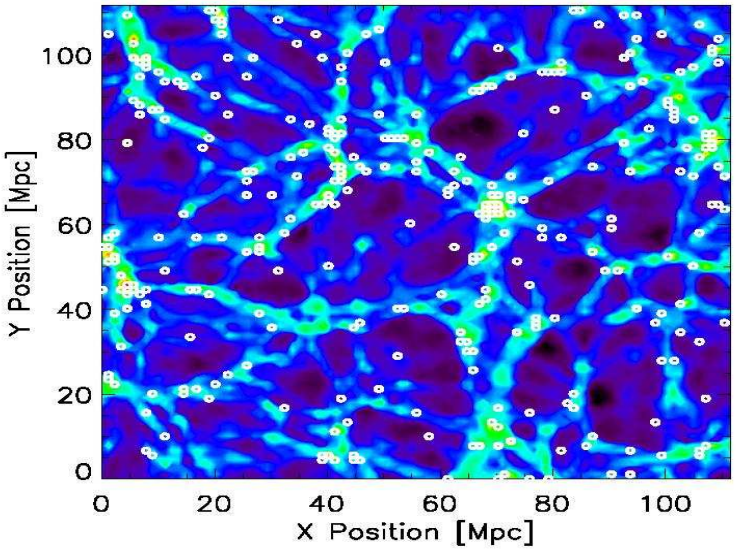
- AGN or any subclass that is distributed in space in a similar way

  Which particular subclass of AGN?

  George et al, arXiv:0805.2053
  Nagar, Matulich arXiv:0806.3220
  Ghisellini et al, arXiv:0806.2393
  Farrar, Greene, Zaw, arXiv:0806.3470

- Re-scattering on local structure of CR produced in remote sources

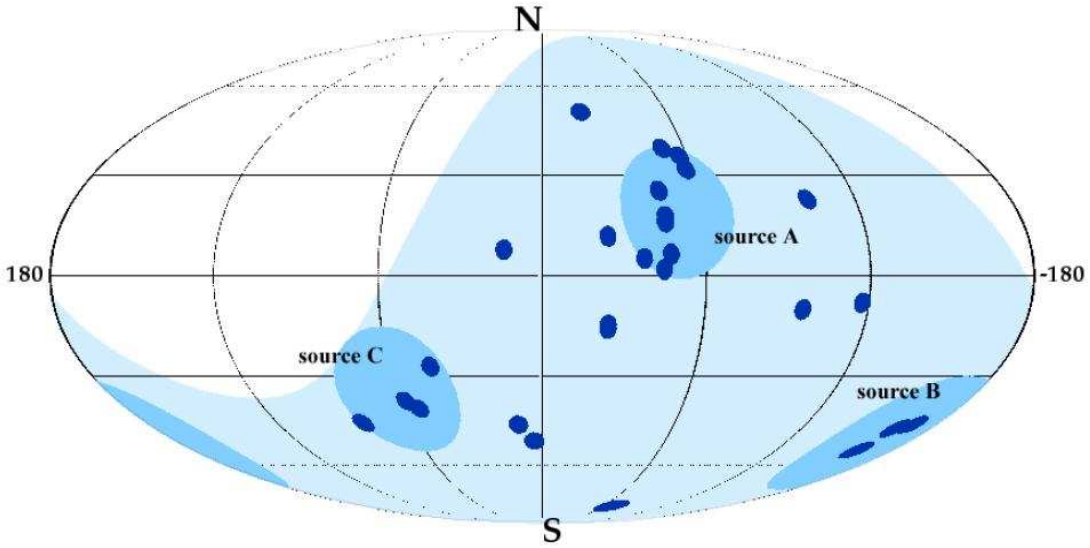
  Kotera, Lemoine arXiv:0801.1450



[From: Kotera, Lemoine, arXiv:0801.1450]

- One or a few sources projected by chance on the local structures

Gorbunov et al, arXiv:0711.4060
Wibig, Wolfendale arXiv:0712.3403



From: Wibig, Wolfendale, arXiv:0712.3403

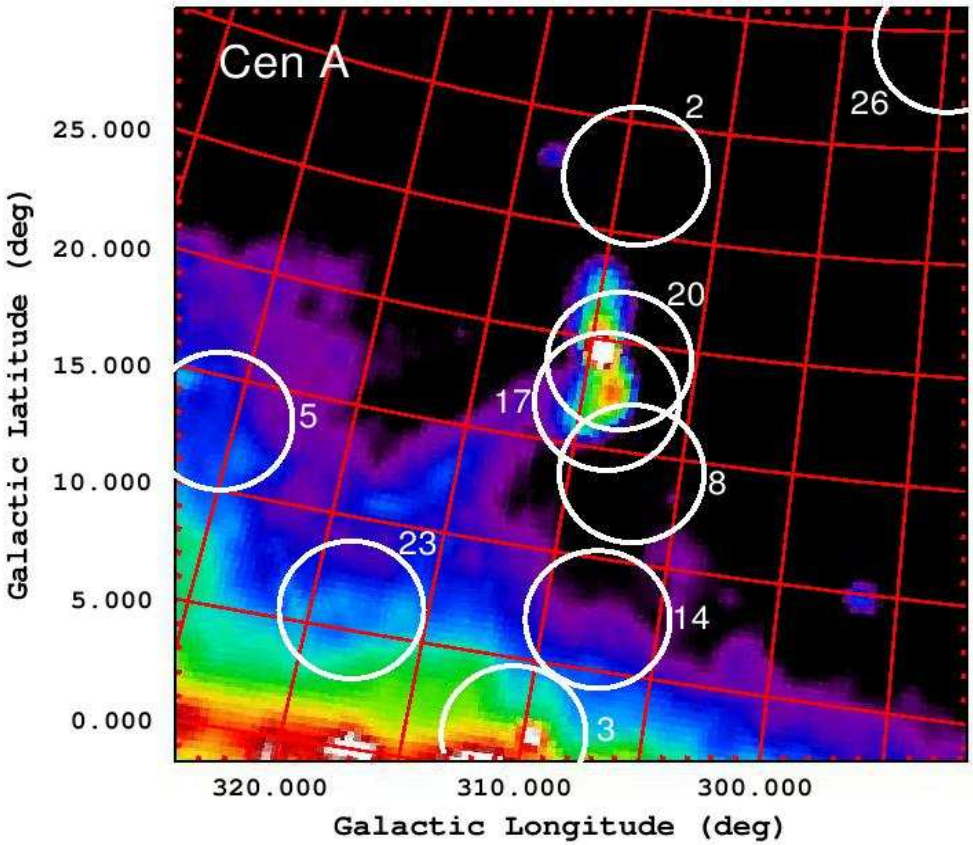
Contrary to AGN case, this explanation requires large ($\sim 20^\circ$) deflections in the magnetic fields

One of the candidates for such a source is Cen A:

Gorbunov et al, arXiv:0711.4060
Fargion, arXiv:0801.0227
Moskalenko et al, arXiv:0805.1260
Hardcastle et al, arXiv:0808.1593

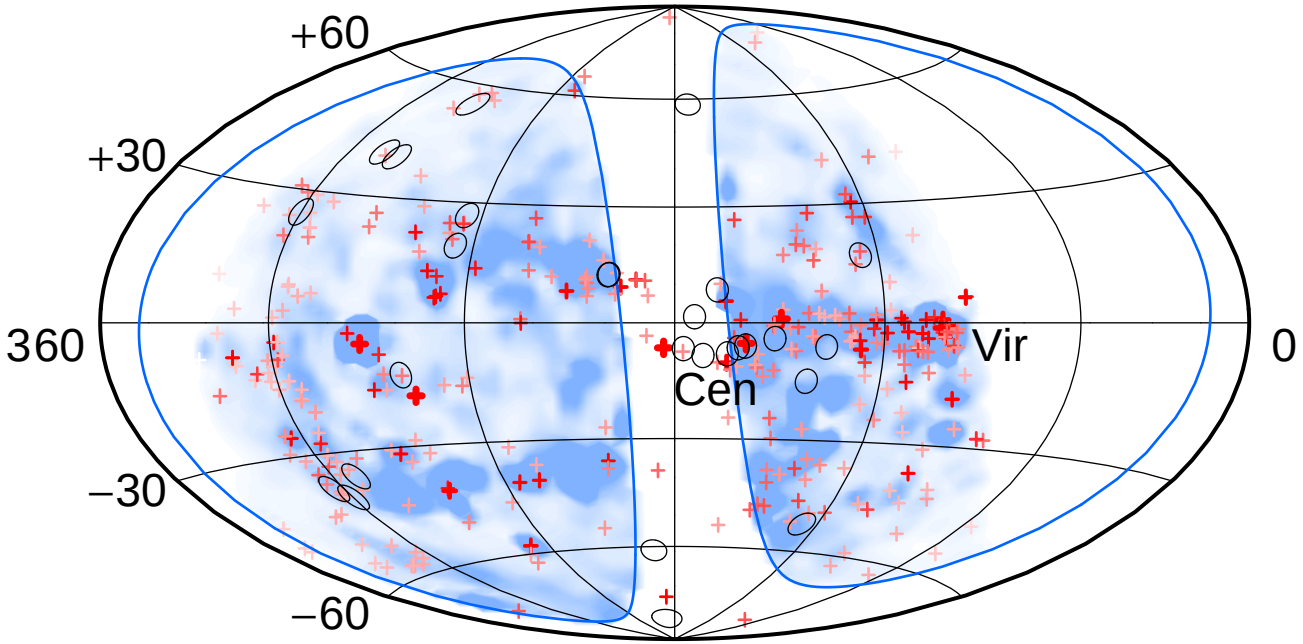
- anomalously close (~ 3.5 Mpc) powerful radio-galaxy
- possesses jets and radio-lobes usually considered as potential acceleration sites
- has been proposed as a potential source of UHECR by many authors
- the study of composition of UHECR by PAO indicates change to heavy or mixed composition $\Longrightarrow$ larger deflections in GMF
- outer lobes of Cen A extend to about 10° roughly in the direction of the supergalactic plane $\Longrightarrow$ a number of events may be associated with Cen A without assuming large deflections

Local map of Cen A region



From: Moskalenko et al, arXiv:0805.1260 [astro-ph]

HYPOTHESIS-SPECIFIC TESTS



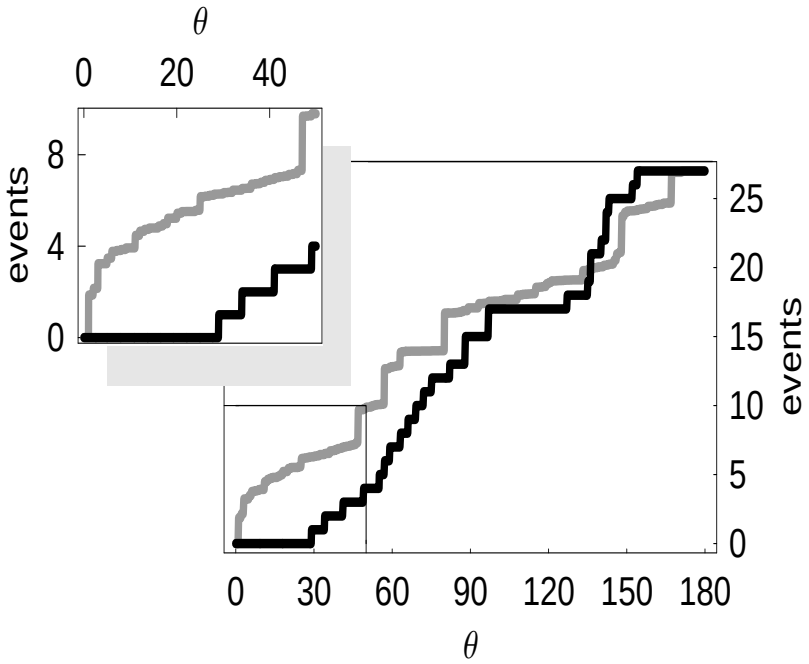
Open circles — CR events; Red crosses — AGN

The color saturation of red crosses shows CR flux expected from a particular AGN, including the effect of the distance and the GZK attenuation.

Quantifying the deficit of events from Virgo region:

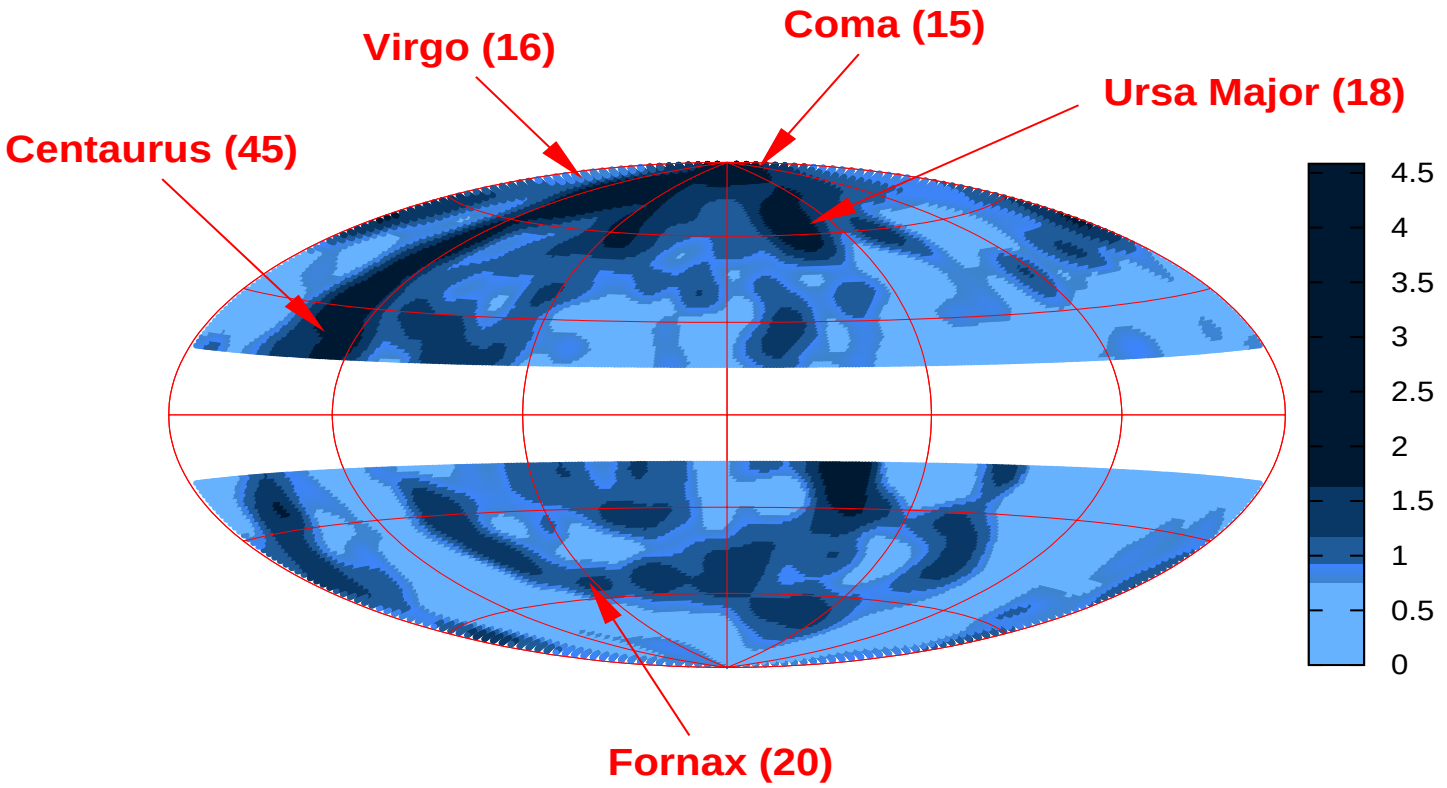
In the circle of 20° from the center of Virgo 6 events are expected while zero are observed ($P \sim 10^{-3}$).

Distributions of observed and expected events in angular distances from Virgo are different ($P = 2 \times 10^{-4}$ according to KS test).



Caveat: no penalty for the choice of central point is included

Expected CR flux if sources trace matter distribution ($E > 60$ EeV)



Each color band contains equal fraction of total flux

These ideas may be used to design a simple statistical test:

H.Koers, P.T., in preparation

- Calculate the distribution of "colors" for the data
- Compare to the expected distribution

Pros: sensitive; binless ($\Longrightarrow$ no ambiguities). Tests the "structure hypothesis", not isotropy.

Cons: blind to certain types of deviations.

CONCLUSIONS

* The question of interpretation remains open. The hypothesis that AGN are sources is simplest, but not necessarily the most probable one.

* Specific test are required to discriminate between existing possibilities.

* More data will come soon. It is important to define the hypotheses and testing procedures *before that* to avoid *a posteriori* tests.