Study of the effect of Magnetic Fields on UHE anisotropies

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Previous anisotropy studies in Auger

INDICATION OF ANISOTROPY IN ARRIVAL DIRECTIONS OF ULTRA-HIGH-ENERGY COSMIC RAYS THROUGH COMPARISON TO THE FLUX PATTERN OF EXTRAGALACTIC GAMMA-RAY SOURCES

THE PIERRE AUGER COLLABORATION
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ABSTRACT

A new analysis of the dataset from the Pierre Auger Observatory provides evidence for anisotropy in the arrival directions of ultra-high-energy cosmic rays on an intermediate angular scale, which is indicative of excess arrivals from strong, nearby sources. The data consist of 5514 events above 20 EeV with zenith angles up to 80° recorded before 2017 April 30. Sky models have been created for two distinct populations of extragalactic gamma-ray emitters: active galactic nuclei from the second catalog of hard *Fermi*-LAT sources (2FHL) and starburst galaxies from a sample that was examined with *Fermi*-LAT. Flux-limited samples, which include all types of galaxies from the *Swift*-BAT and 2MASS surveys, have been investigated for comparison. The sky model of cosmic-ray density constructed using each catalog has two free parameters, the fraction of events correlating with astrophysical objects and an angular scale characterizing the clustering of cosmic rays around extragalactic sources. A maximum-likelihood ratio test is used to evaluate the best values of these parameters and to quantify the strength of each model by contrast with isotropy. It is found that the starburst model fits the data better than the hypothesis of isotropy with a statistical significance of 4.0σ, the highest value of the test statistic being for energies above 39 EeV. The three alternative models are favored against isotropy with $2.7-3.2\sigma$ significance. The origin of the indicated deviation from isotropy is examined and prospects for more sensitive future studies are discussed.

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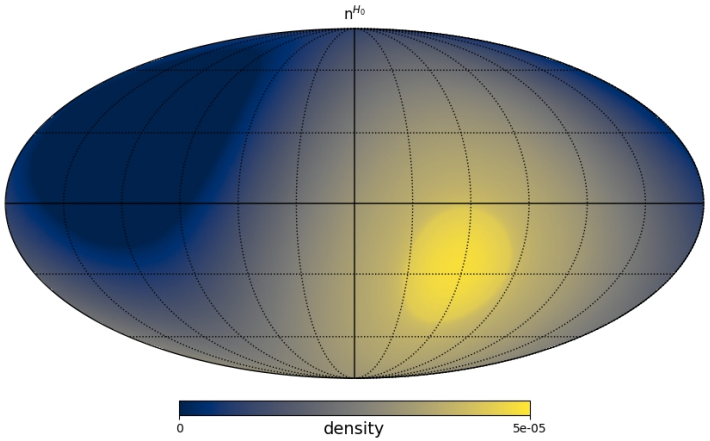
Maximum likelihood ratio test

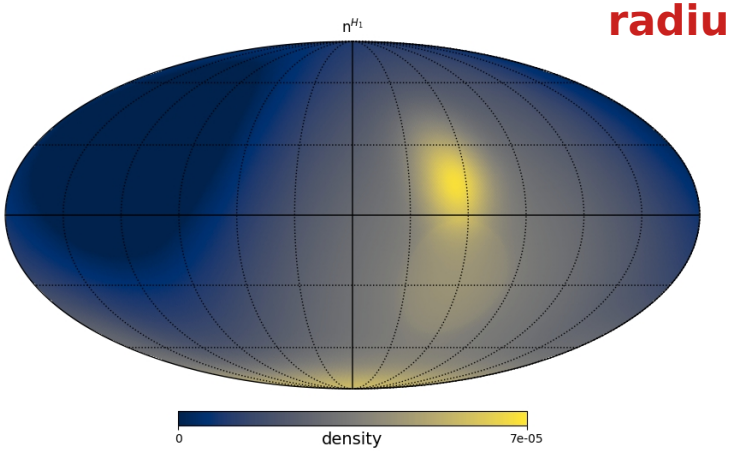
$$n^{H_0}(\mathbf{u}) = \frac{E(\mathbf{u})}{\sum_l E(\mathbf{u}_l)}$$

$$n^{H_1}(\mathbf{u}) = (1-\alpha) \times n^{H_0}(\mathbf{u}) + \alpha \times \frac{E(\mathbf{u}) \sum_j \phi_j \mathcal{N}(\mathbf{u}; \mathbf{u}_j, \theta)}{\sum_l \sum_j \phi_j E(\mathbf{u}_l) \mathcal{N}(\mathbf{u}_l; \mathbf{u}_j, \theta)}$$

Anisotropy fraction

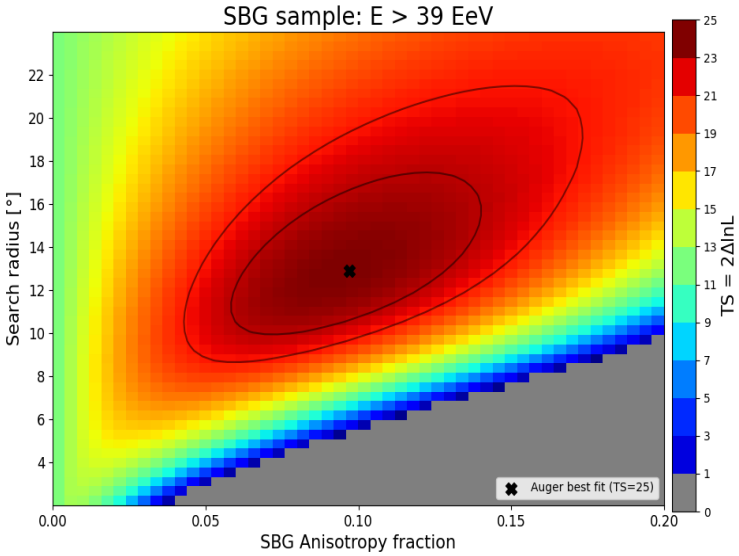
Search radius

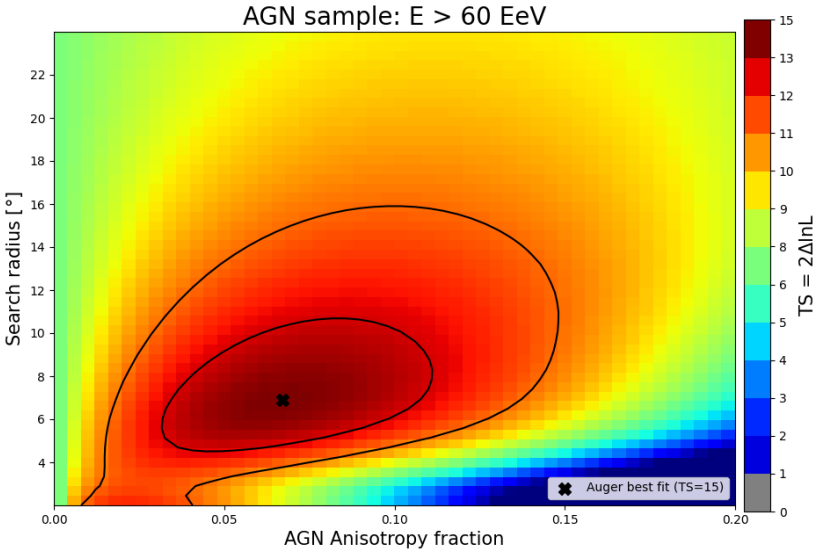




$$TS = \sum_l k_l \ln \frac{n^{H_1}(u_l)}{n^{H_0}(u_l)}$$

Auger results

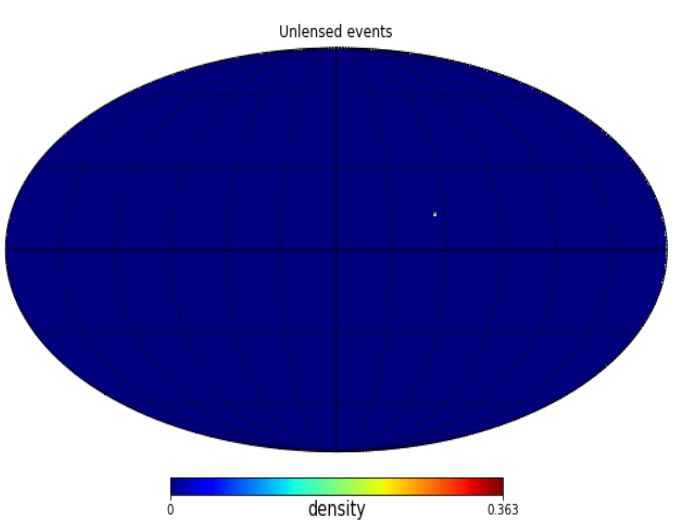




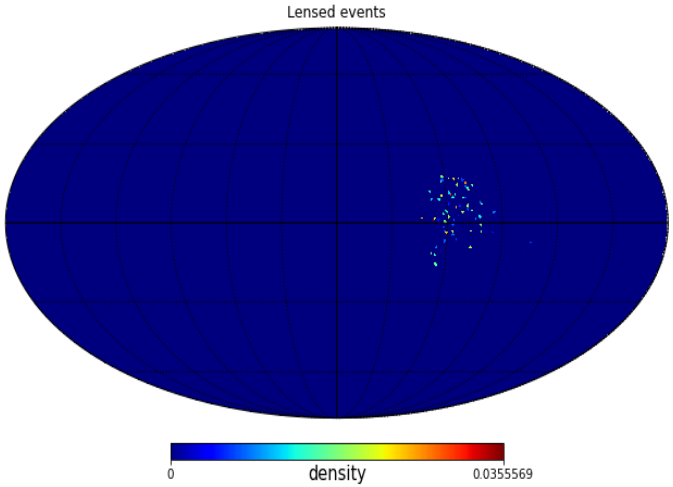
Test hypothesis	Null hypothesis	Threshold energy[a]	TS	Local p-value $\mathcal{P}_{\chi^2}(TS, 2)$	Post-trial p-value	1-sided significance	AGN/other fraction	SBG fraction	Search radius
SBG + ISO	ISO	39 EeV	24.9	3.8×10^{-6}	3.6×10^{-5}	$4.0\,\sigma$	N/A	9.7%	12.9°
γAGN + SBG + ISO	γAGN + ISO	39 EeV	14.7	N/A	1.3×10^{-4}	$3.7\,\sigma$	0.7%	8.7%	12.5°
γAGN + ISO	ISO	60 EeV	15.2	5.1×10^{-4}	3.1×10^{-3}	$2.7\,\sigma$	6.7%	N/A	6.9°
γAGN + SBG + ISO	SBG + ISO	60 EeV	3.0	N/A	0.08	$1.4\,\sigma$	6.8%	0.0%[b]	7.0°

Simulation with CRPRopa

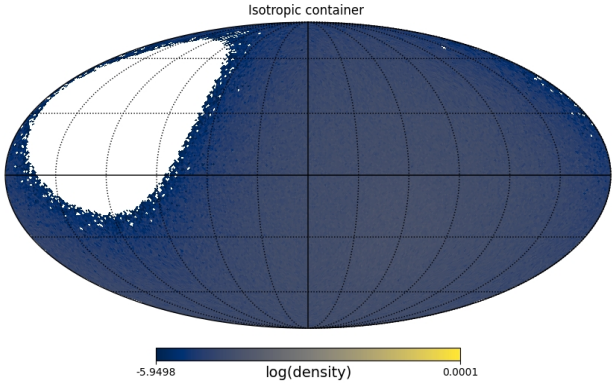
CRPropa

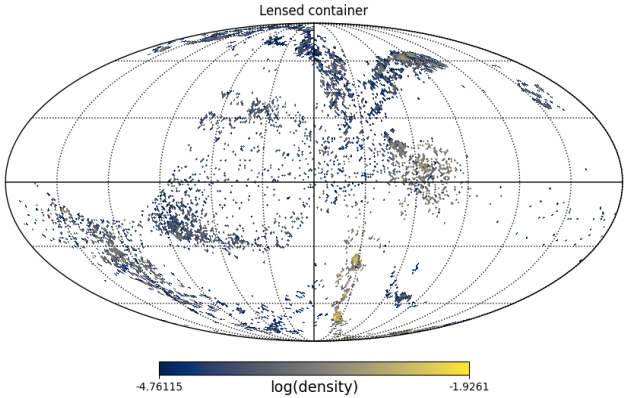


Lensing simulated events with JF12 model



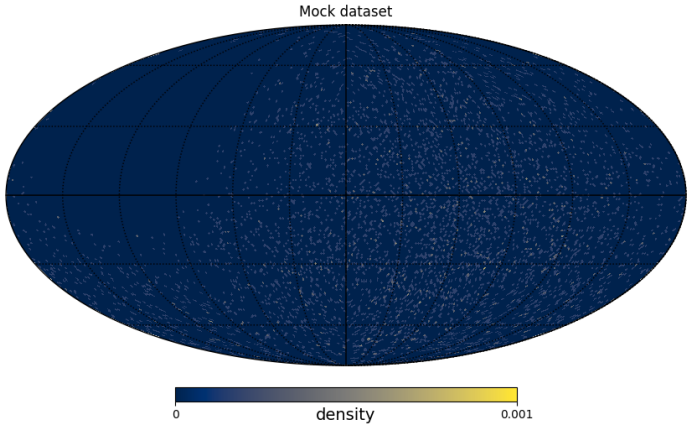
Simulation with N scenario





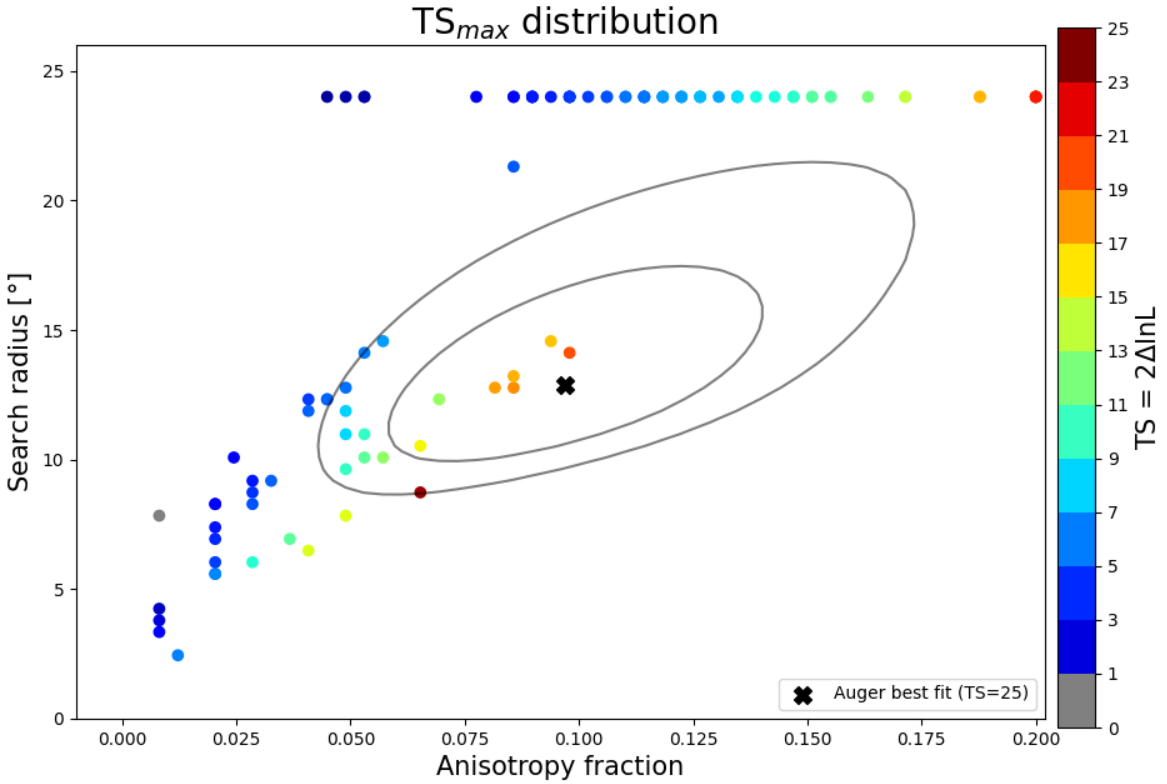
90% background

10% signal

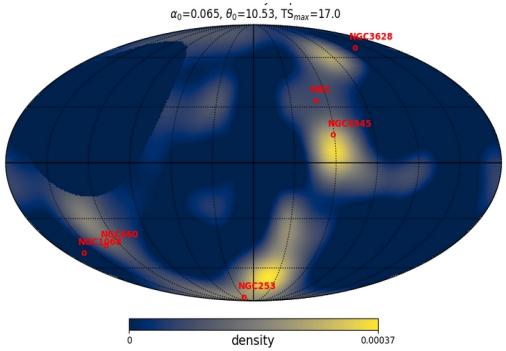


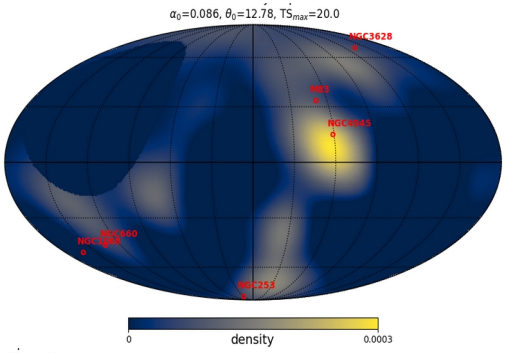
Background analysis

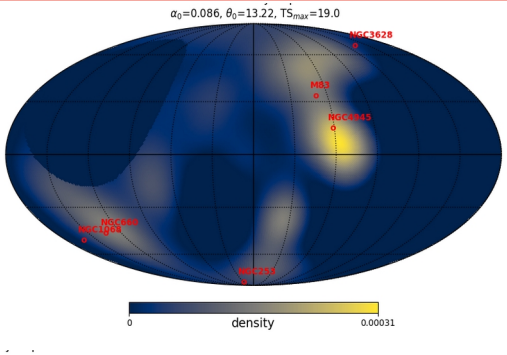
- **Variation of the background fraction between 0.1 and 0.9**
- **With a background fraction = 0.8, 7 scenarios are compatible with Auger parameters**

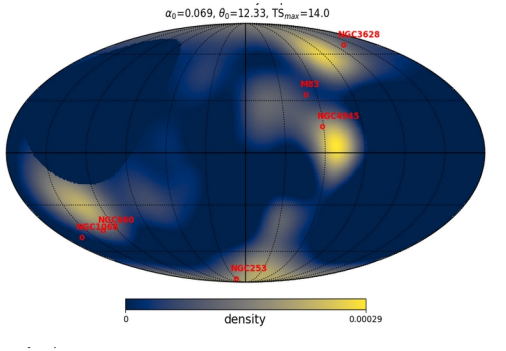


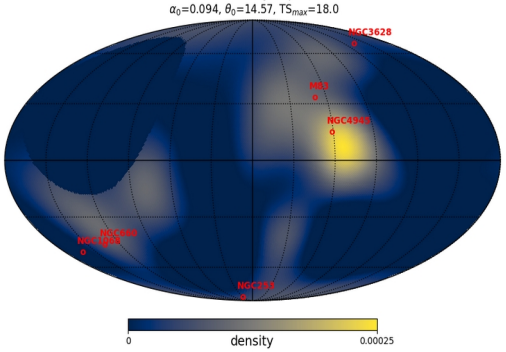
Overdensity maps best scenarios SBG

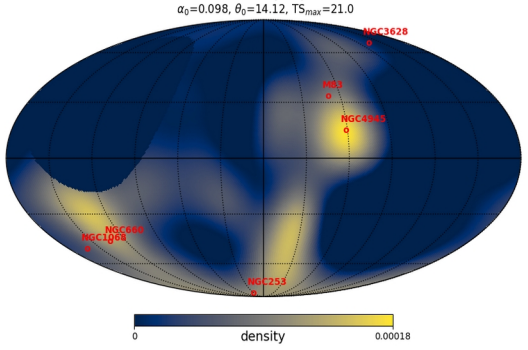


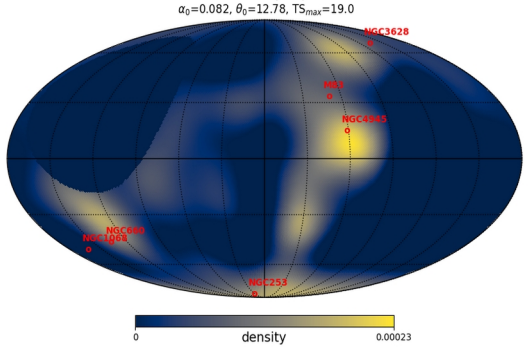


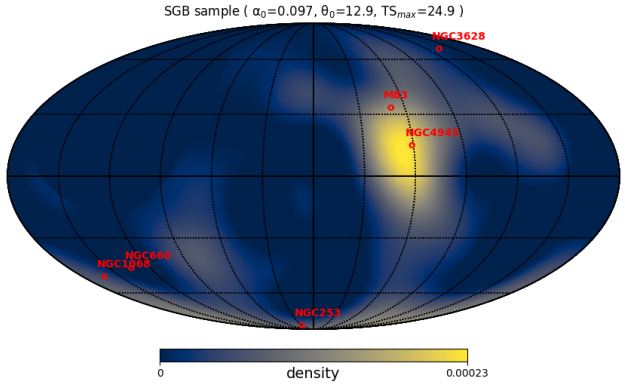






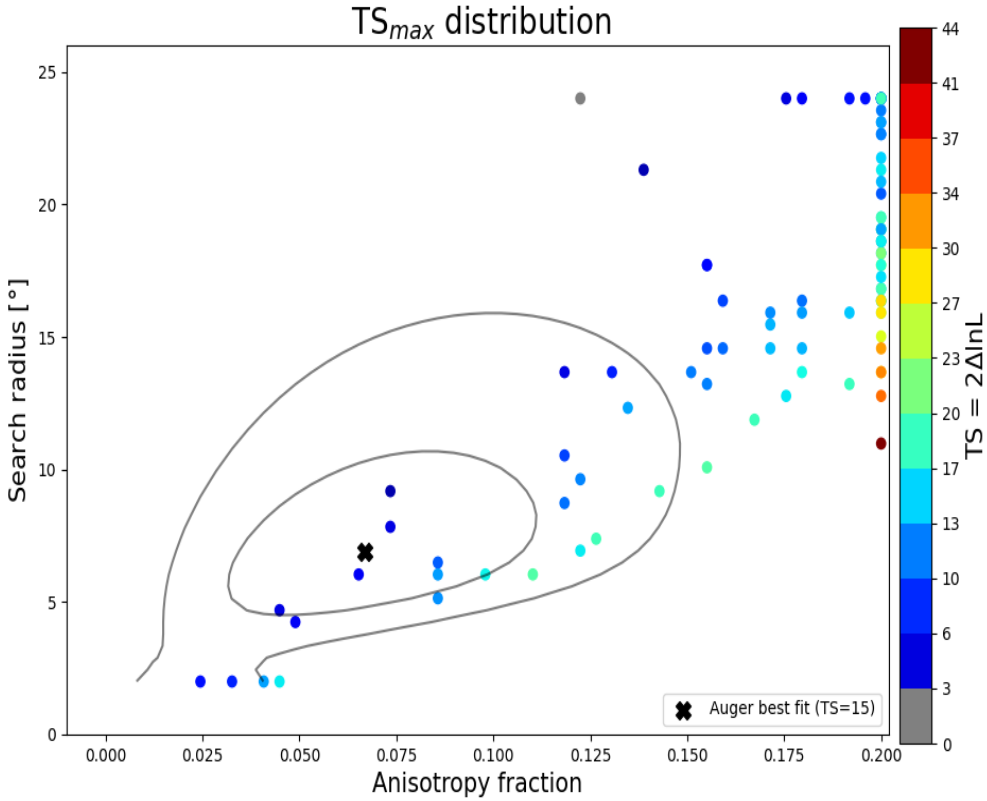




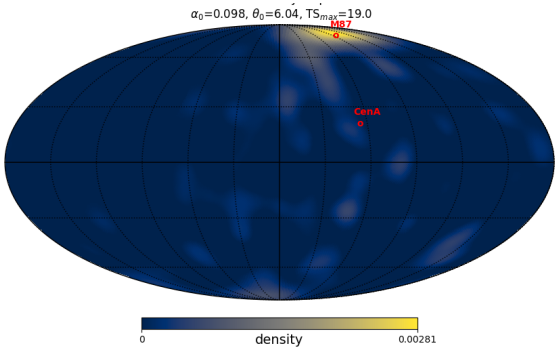


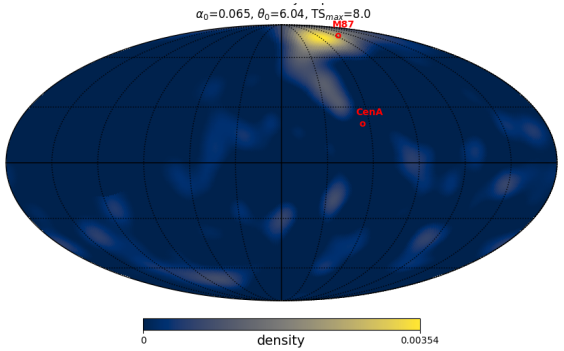
AGN analysis

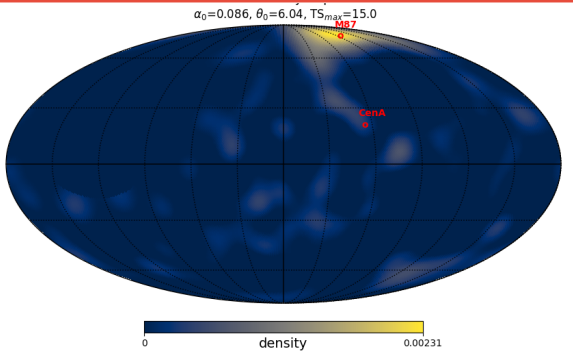
- **Best composition scenario: Silicon**
- **Container: 90% background, 10% signal fraction**
- **6 compatible scenarios**

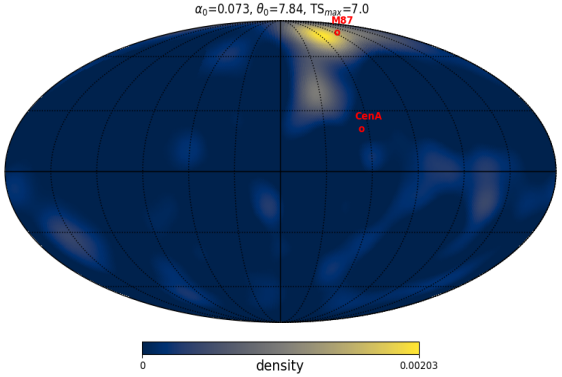


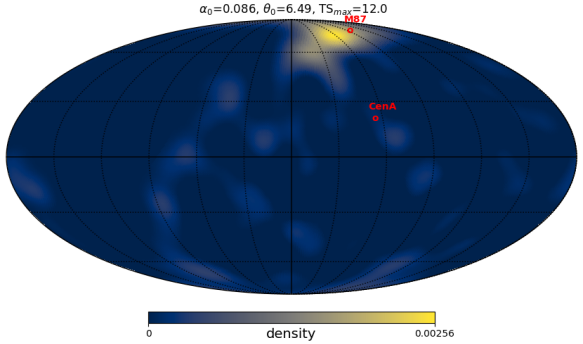
Overdensity maps best scenarios AGN

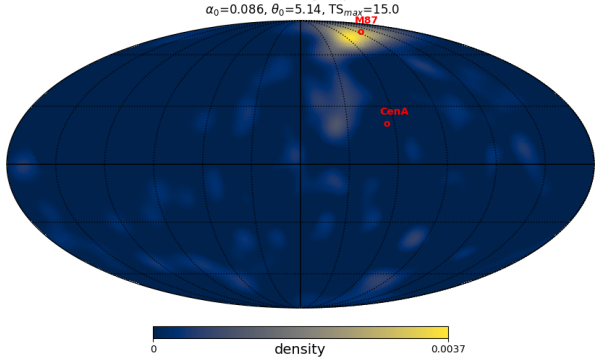


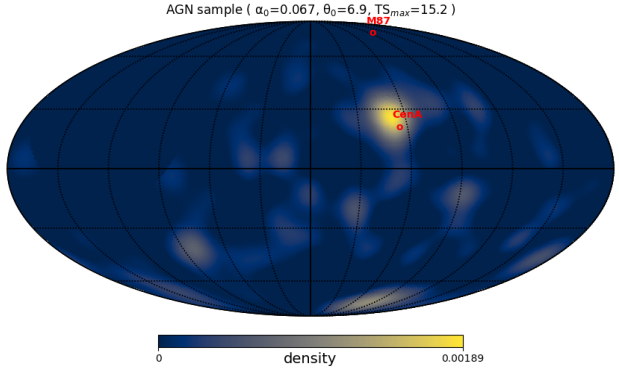




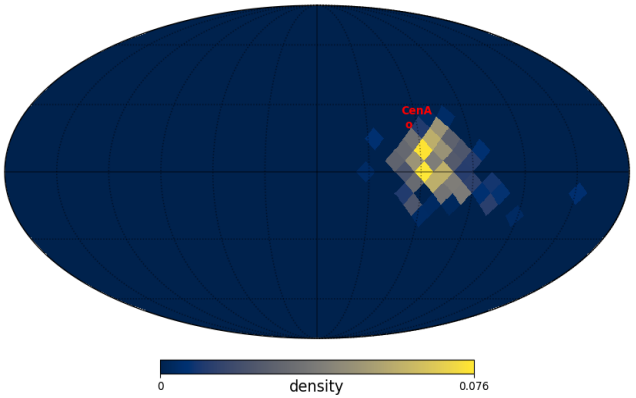


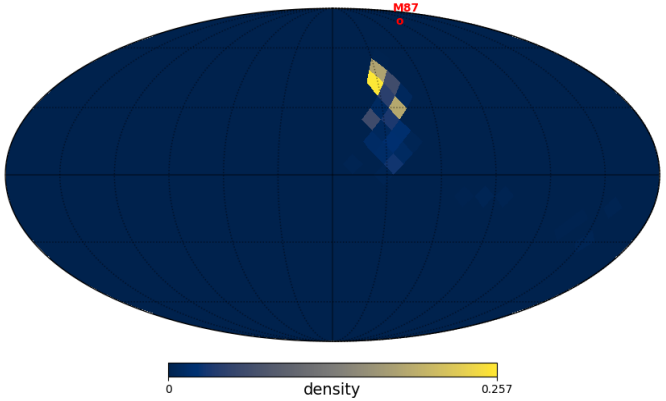


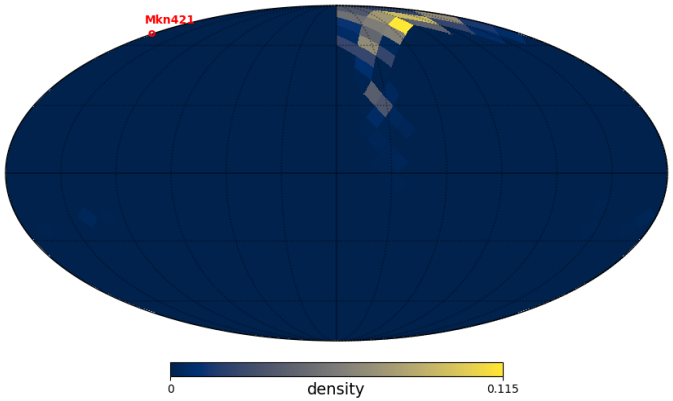


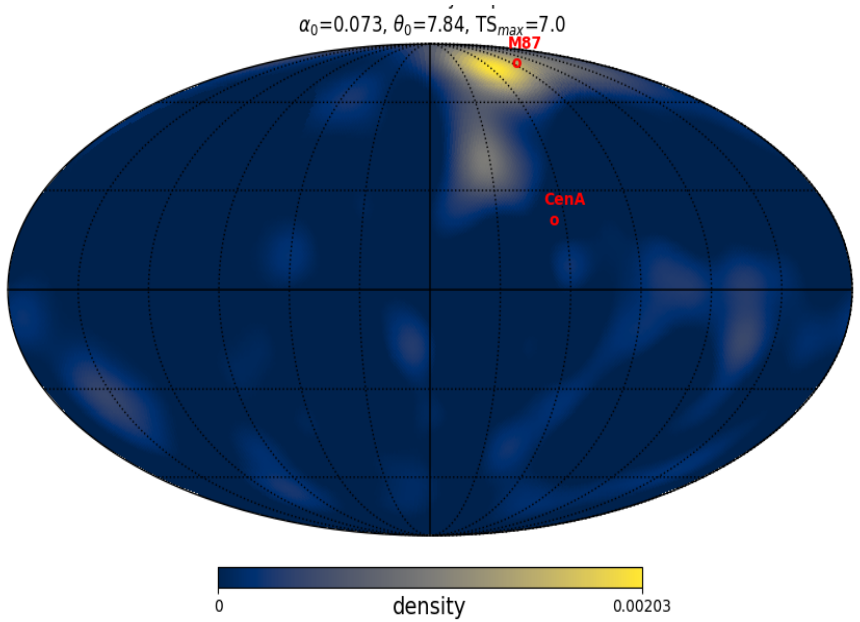


Contribution lensed events in AGN scenario







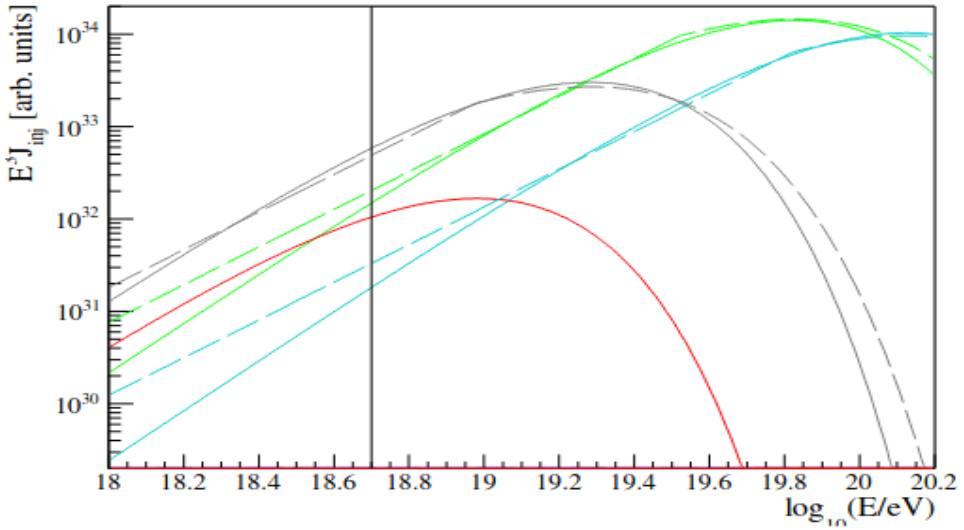


Possible explanations

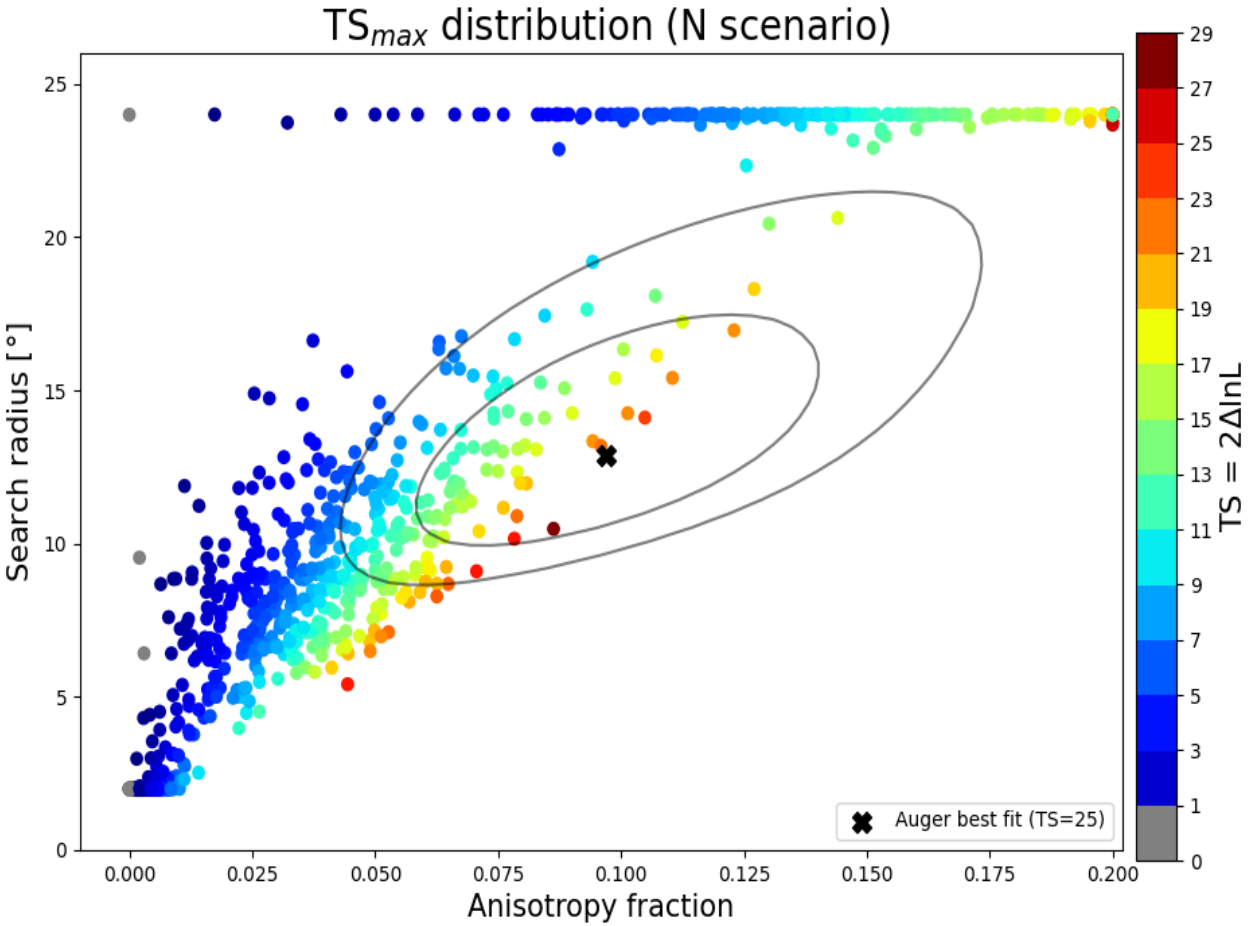
- **High flux weight related to Mkn 421**

γAGNs	l [°]	b [°]	Distance[a] [Mpc]	Flux weight [%]
Cen A Core	309.6	19.4	3.7	0.8
M 87	283.7	74.5	18.5	1
NGC 1275	150.6	-13.3	76	2.2
IC 310	150.2	-13.7	83	1
3C 264	235.8	73	95	0.5
TXS 0149+710	127.9	9	96	0.5
Mkn 421	179.8	65	136	54
PKS 0229-581	280.2	-54.6	140	0.5
Mkn 501	63.6	38.9	148	20.8

- **Single injected element is not a valid assumption for the AGN sample**



Preliminary results: increased statistic



Conclusions

- **Compatible scenarios with Auger results considering single injected elements and impact of the GMF**

- **Signal fraction has to be increased**

- **No contribution of the EGMF necessary to recover Auger results**