Anisotropy studies with Galactic magnetic fields in a catalog based search

L. Deval, R. Engel, T.Fitoussi, M.Unger

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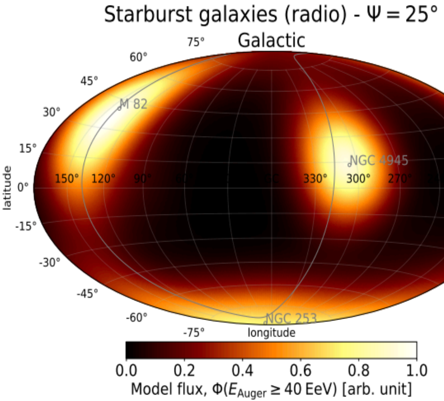
Karlsruher Institut für Technologie

HIRSAP
Helmholtz International Research School for Astroparticle Physics

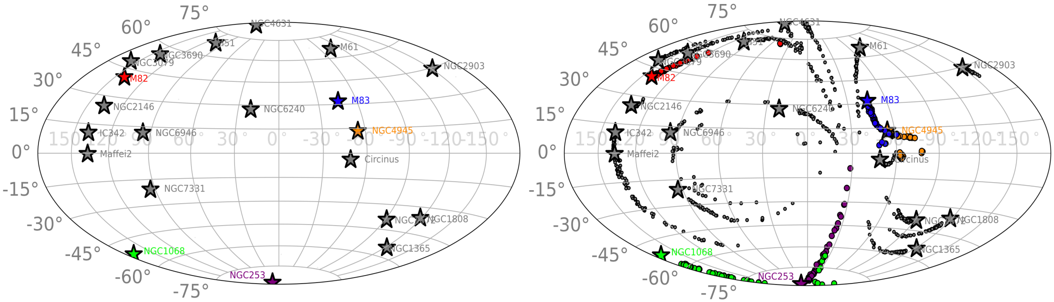
UNSAM

- 4 source catalogs have been considered in the Auger analysis
- Focus of this study: Starburst Galaxies (SBG) (44 sources with distances between 2.7 Mpc and 180 Mpc)
- Main contribution related to 3 sources



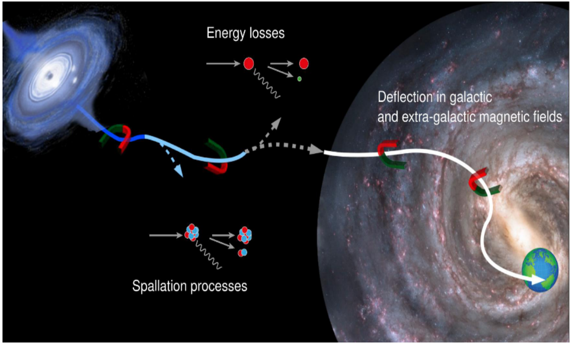
Role of the galactic magnetic field

- No coherent deflections have been considered in the flux model
  $\rightarrow$ What is the meaning of the observed correlation?

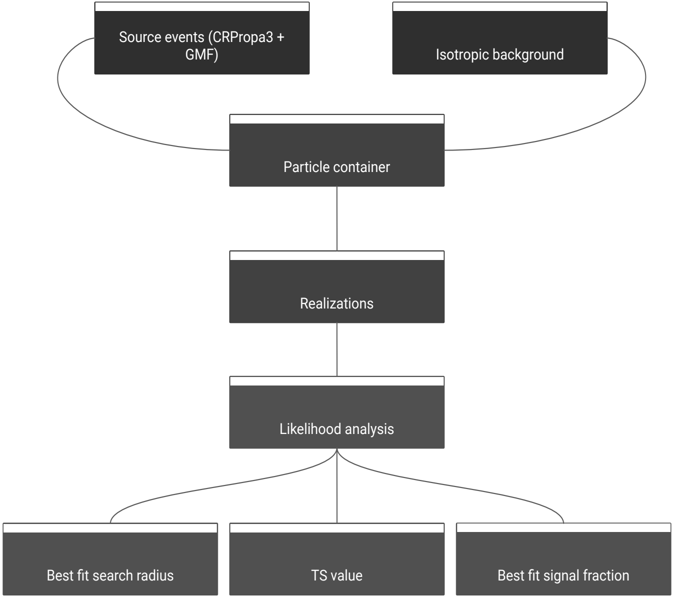


Where were we one year ago?

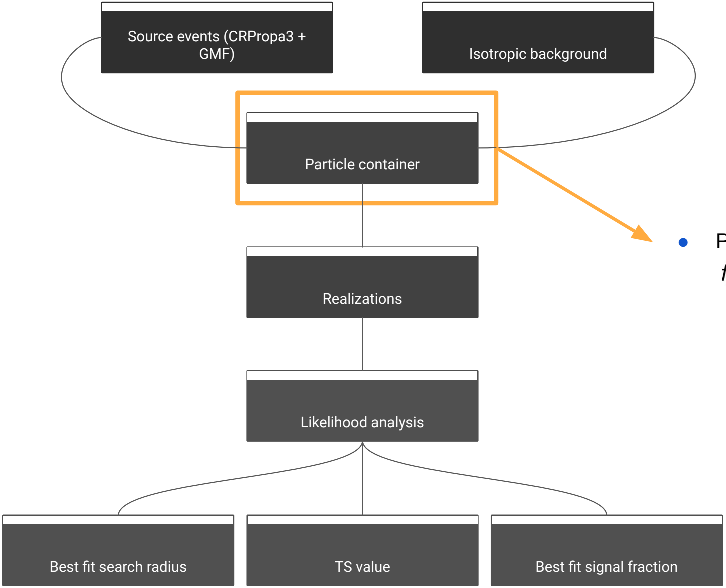
- Analysis based on 2019 ICRC proceeding:
  - SBG catalog with 33 sources
  - TS = 29.5
    (Highest TS reported so far)
  - Events considered: 1309 above 38 EeV
  - GMF model: Jansson&Farrar (2012)
  - Extra Galactic propagation: CRPropa3



Analysis method

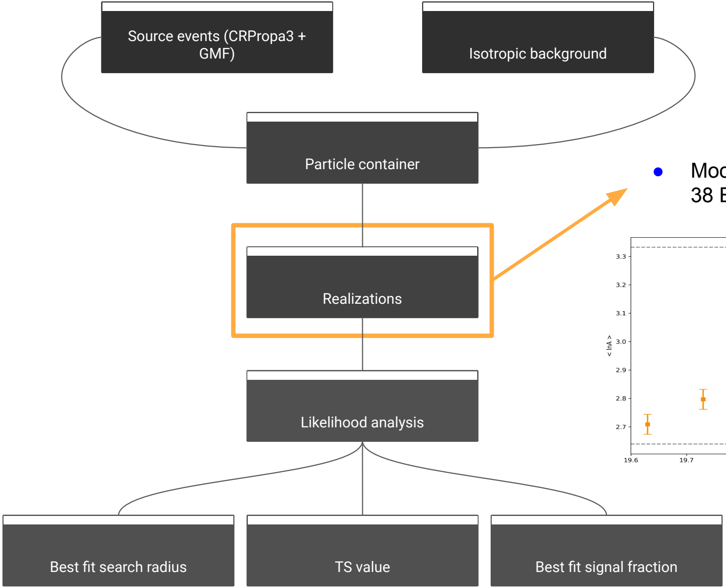


Analysis method

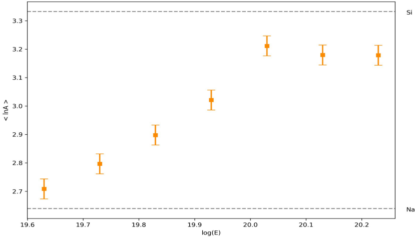


- Particle container:
  $f_{srcs} \cdot N_{tot} + (1 - f_{srcs}) \cdot N_{tot}$

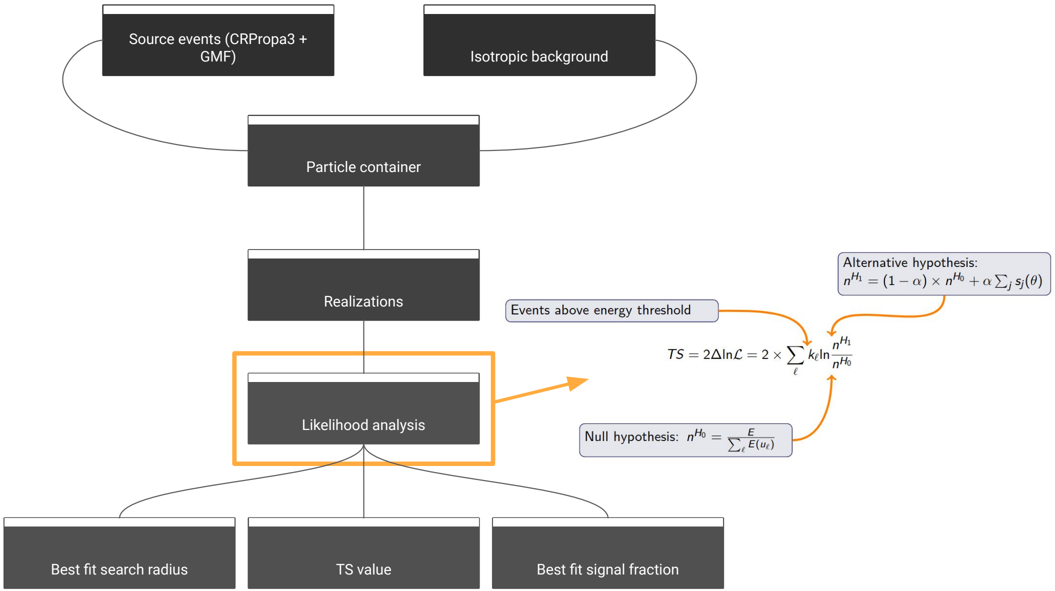
Analysis method



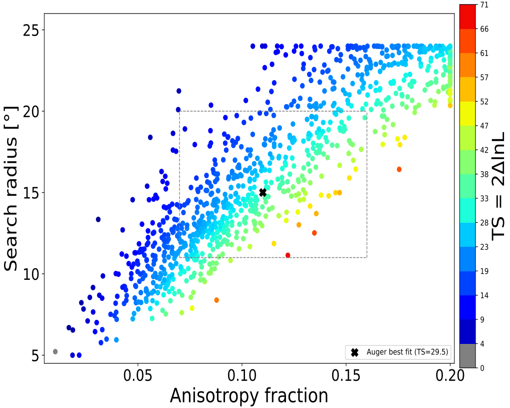
- Mock dataset: 1309 events above 38 EeV

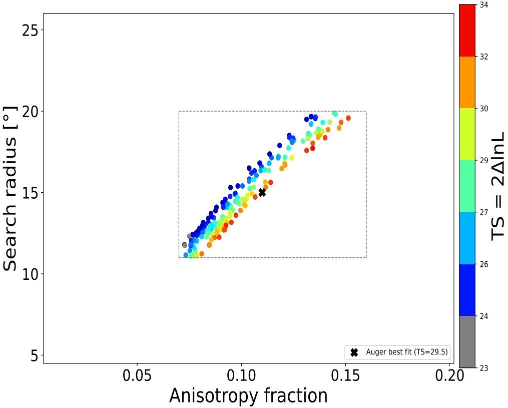


Analysis method



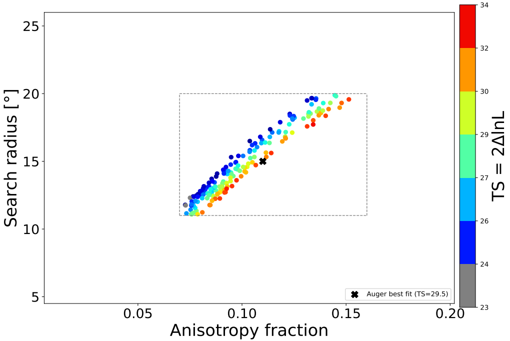
Fit results for mock data sets

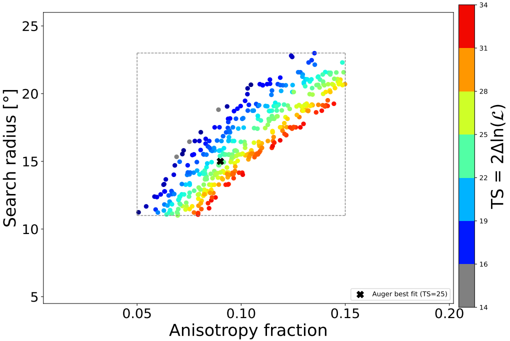




Important changes since last year

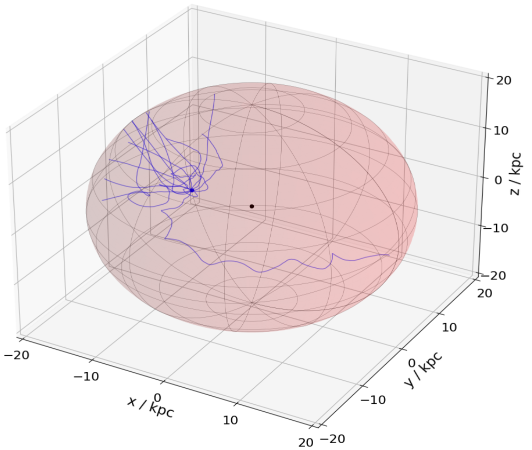
- Simulation framework:
  - Updated catalog (from 33 to 44 sources)
- TS analysis:
  - Updated number of events above 38 EeV
  - Updated best fit parameters values
  - Updated thresholds for TS selection





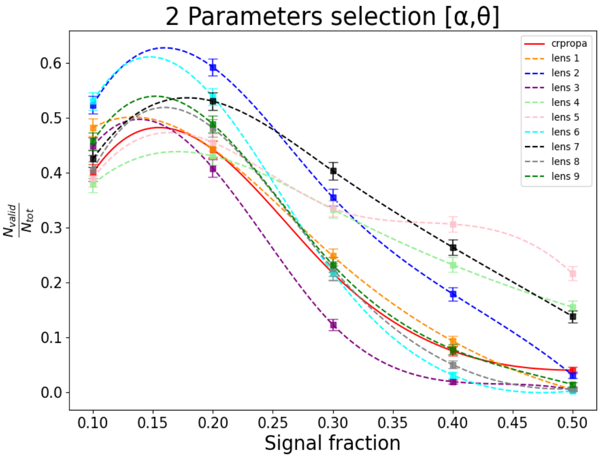
What's new then?!

- What is the impact on the analysis is different configurations of the GMF are considered?
- Lens creation (*):
  - Backtracking of anti-proton (nside=1024)
  - $R_{min} = 18.00$, $R_{max} = 21.00$
  - GMF model: Jansson&Farrar (2012)
  - 9 lenses have been constructed with different configuration of the random field

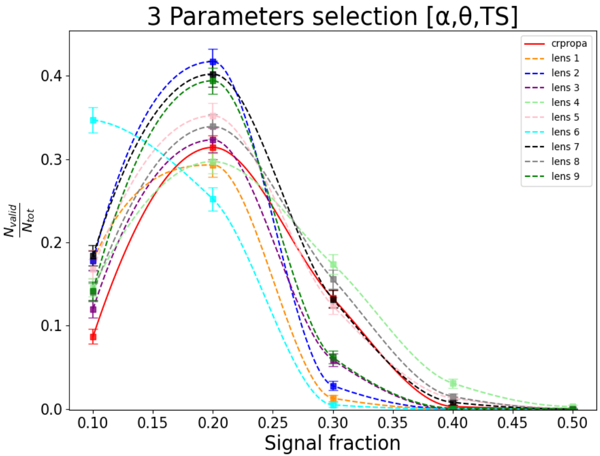


*: CRPropa3

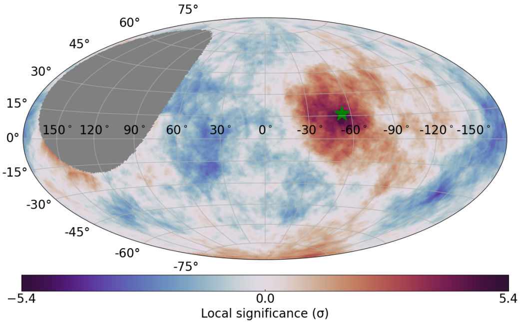
- Selection parameters:
  - $\alpha \in [0.05, 0.15]$
  - $\theta \in [11, 23]$
- Similar behavior for different lenses if 2 parameters are considered
- General max for $f_{src} = 0.15$
- Source contribution is increased ($f_{src} > \alpha^{Auger}$)



- Selection parameters:
  - $\alpha \in$ [0.05,0.15]
  - $\theta \in$ [11,23]
  - TS $\in$ [14,34]
- Similar behavior for different lenses if 3 parameters are considered
- General max for $f_{src} = 0.2$
- Source contribution is increased ($f_{src} > \alpha^{Auger}$)



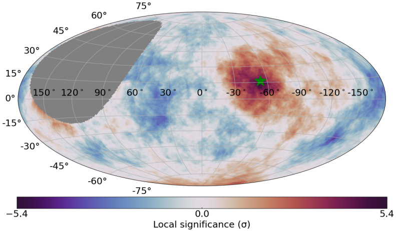
- Recap current LiMa computation:
  - Best signal fraction (α): 0.09
  - Best search radius (θ): 15°
  - LiMa significance:
    - Overdensity in the CenA region
    - Smoothing angle: 24°
    - Energy threshold: 41 EeV
  - Coherent deflections have not been considered
- Strength and angular scale of the first and second "hot spot" in the data?

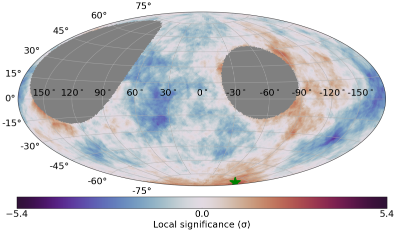


Ref: Arrival Directions of Cosmic Rays above 32 EeV from Phase One of the Pierre Auger Observatory

Closer look: LiMa analysis

- Method:
  - LiMa computation → LiMa_{inside}
  - Exclusion circular region (34°) around Centaurus region
  - LiMa computation after exclusion → $\text{LiMa}_{outside}$
  - Set of points (LiMa_{inside}, $\text{LiMa}_{outside}$) displays the main difference with observed data [a] in term of:
    - value
    - position in the sky

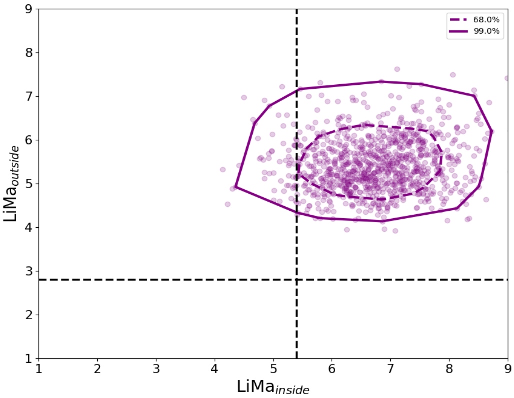




[a] $\text{LiMa}^{obs}_{inside} = 5.4$, $\text{LiMa}^{obs}_{outside} = 2.8$

Closer look: LiMa behavior inside and outside Centaurus region

- Presence of $\text{LiMa}_{outside} > \text{LiMa}^{obs}_{outside}$:
  - NGC253 causes a large overdensity in all 9 GMF realizations
  - NGC253 causes a large overdensity which dominates the sky
- Presence of $\text{LiMa}_{inside} > \text{LiMa}^{obs}_{inside}$:
  - Overshooting due to the deflected events in NGC4945 region coming from M83
- Is an EGMF necessary?

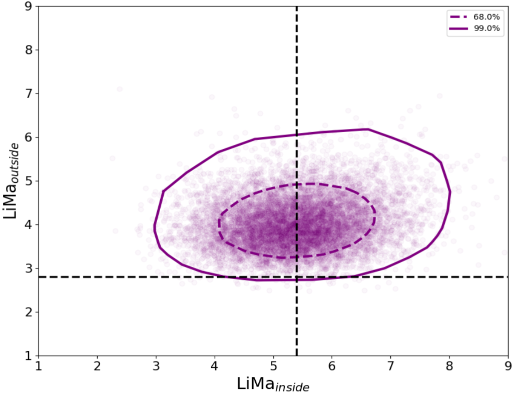


Closer look: LiMa behavior inside and outside Centaurus region with EGMF

- EGMF applied by considering a Fisher distribution where [a]:

$$\theta_{sm} = \theta^* \sqrt{\frac{D_{source}}{D^*}} \frac{R^*}{R_{event}}$$

- Effect of the extra smearing:
  - Broadening the region of interest → LiMa_{inside} and $\text{LiMa}_{outside}$ reduced
  - It is possible to recover scenarios compatible with both values (only 22 of 10.000 realizations in the lower-right quadrant)



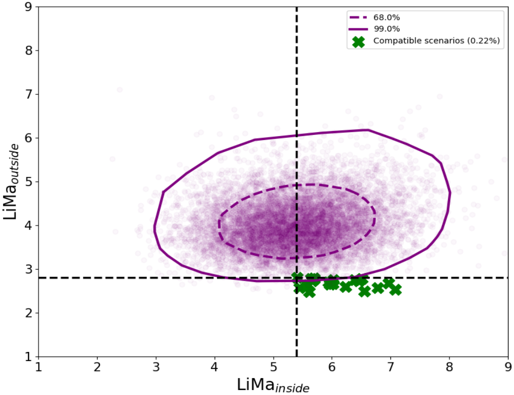
[a] D^*=3.72 Mpc, R^*=40/7 EV and $\theta^* = 5°$

Closer look: LiMa behavior inside and outside Centaurus region with EGMF

- EGMF applied by considering a Fisher distribution where [a]:

$$\theta_{sm} = \theta^* \sqrt{\frac{D_{source}}{D^*}} \frac{R^*}{R_{event}}$$

- Effect of the extra smearing:
  - Broadening of the region of interest → $\text{LiMa}_{outside}$ and $\text{LiMa}_{outside}$ reduced
  - It is possible to recover scenarios compatible with both values (only 22 of 10.000 realizations in the lower-right quadrant)
  - Overall behavior for all GMF configurations?



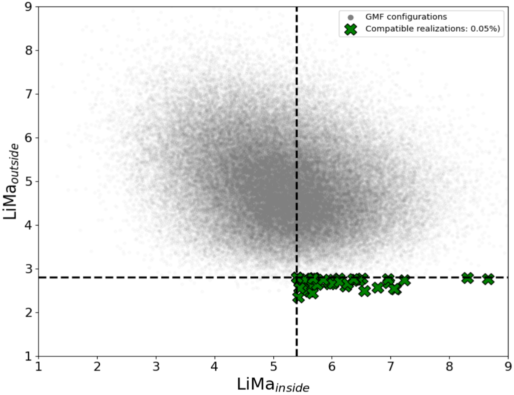
[a] D^*=3.72 Mpc, R^*=40/7 EV and $\theta^* = 5°$

Closer look: LiMa behavior inside and outside Centaurus region with EGMF

- EGMF applied by considering a Fisher distribution where [a]:

$$\theta_{sm} = \theta^* \sqrt{\frac{D_{source}}{D^*}} \, \frac{R^*}{R_{event}}$$

- Effect of the extra smearing:
  - Broadening of the region of interest $\rightarrow$ $LiMa_{outside}$ and $LiMa_{outside}$ reduced
  - It is possible to recover scenarios compatible with both values (only 45 of 90.000 realizations in the lower-right quadrant)



[a] D^*=3.72 Mpc, R^*=40/7 EV and $\theta^* = 5°$

- Introduction of a rigidity dependence in the TS:
  - Fisher distribution with a smearing angle which keeps track of the rigidity of the particle ($R = E_{\text{event}}/Z_{\text{event}}$)
  - Smearing angle:

$$\theta_{\text{smearing}} = \theta^* \sqrt{\frac{D_{\text{source}}}{D^*}} \frac{R^*}{R_{\text{event}}} \tag{1}$$

  - Every simulated event is smeared with and angle which follows equation 1
  - n^{H_1} is computed throughout the simulated events and not analytically

- TS is computed with the Auger events and still test the validity of the alternative hypothesis versus isotropy (exposure)

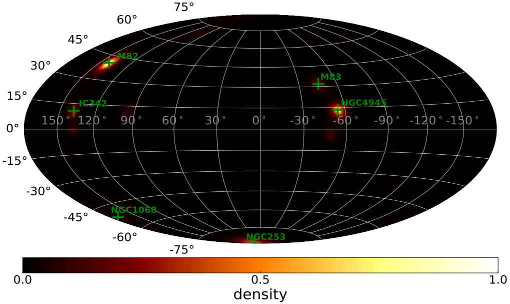
Changes in the TS

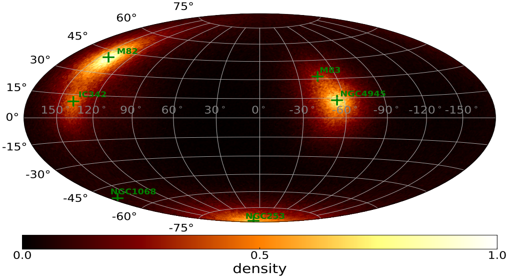
$$n_{H_1}(u) = (1-\alpha) \times n_{H_0}(u) + \alpha \times \frac{E(u) \sum_j \phi_j N(u, u_j, \theta)}{\sum_l \sum_j \phi_j E(u_l) N(u_l, u_j, \theta)}$$

Null hypothesis

Current 2D Gaussian (Fisher distribution)

$$\sum_j \phi_j N(u, u_j, \theta_{\text{smearing}})$$





Final conclusions

- Catalog based analysis (ApJ 2022): no coherent deflections included
- This study: simulated realizations (CRPropa3+JF12)
- Realizations return compatible parameters in terms of anisotropy fraction, search radius and test statistic
- Galactic variance:
  - Minor differences in the behavior of the analysis when different configurations of the GMF are considered
  - Considering a 3 parameters selection brings a minor shift in the best scenario
- LiMa analysis:
  - NGC253 overdensity present also if different configurations of the random field are considered
  - Introduction of EGMF smearing reduces the overdensity contribution to the sky map
  - Low probability of compatibility with both values also when different GMF configurations are considered