A BAYESIAN SOURCE ASSOCIATION ANALYSIS OF UHECRS

K. Watanabe[1], A. Fedynitch[2,3], F. Capel[1,*], H. Sagawa[3]

[1]Max Planck Institute for Physics, Munich, Germany
[2]Institute of Physics, Academica Sinica, Taipei, Taiwan
[3]The Institute for Cosmic Ray Research, University of Tokyo, Kashiwa, Japan
*Presenter, capel@mpp.mpg.de

1. Background

We investigate possible associations between UHECRs and astrophysical sources, building on the statistical analysis developed in Capel & Mortlock (2019) [1].

The advantages of this analysis are:
- UHECR source energies and spectral shape are included as parameters of the fit
- Results and uncertainties can be interpreted in a physical way

2. Key questions

What is the impact of the **Galactic magnetic field** (GMF) and **UHECR composition** on source–UHECR associations?

Are there differences in source–UHECR associations between the **Northern** and **Southern** skies?
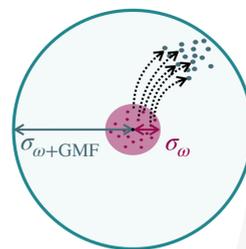
3. Methods

Sources have a power law spectrum, equal luminosities and single UHECR composition.

Extra-Galactic magnetic field (EGMF) **deflections** are modelled analytically (~2° for protons and ~16° for nitrogen).

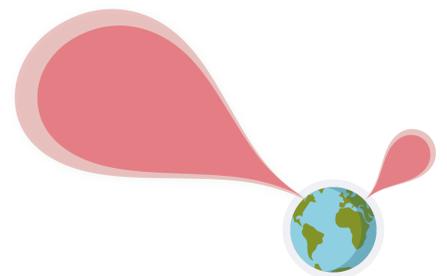$$\theta_{\rm rms} \approx 2.3° \ Z \left(\frac{E}{50\ {\rm EeV}}\right)^{-1} \left(\frac{B}{1\ {\rm nG}}\right) \left(\frac{D}{10\ {\rm Mpc}}\right)^{1/2} \left(\frac{l_c}{1\ {\rm Mpc}}\right)^{1/2}$$

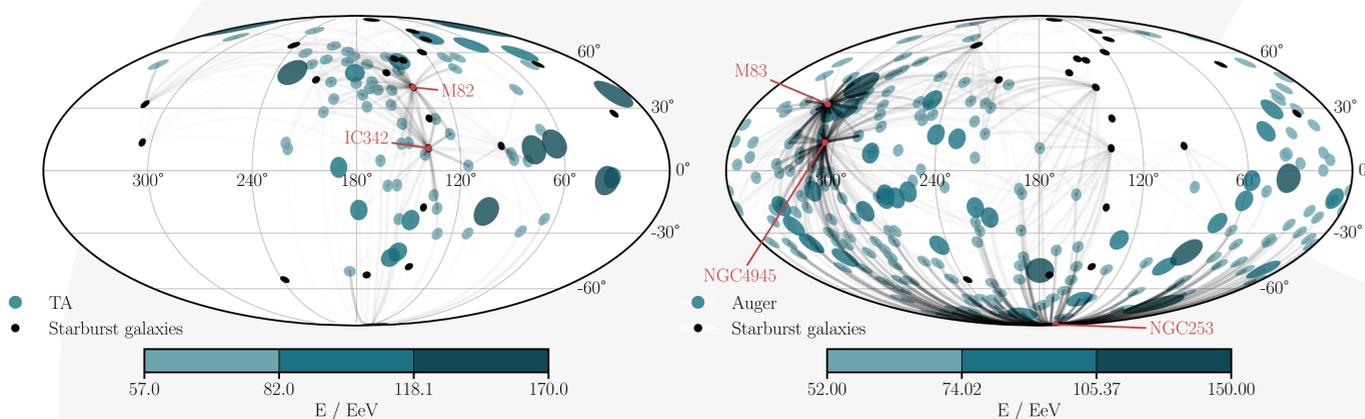The fit is done using a hierarchical Bayesian model implemented in Stan (https://mc-stan.org/).

GMF deflections are approximated by backtracking with CRPropa 3 (JF12 model) [2,3]. We compute possible deflections for each UHECR individually and model them as von Mises-Fisher distributions.

Energy losses are approximated using loss lengths as implemented in CRPropa 3 [2]. Each UHECR has its own "bubble" of possible origins.
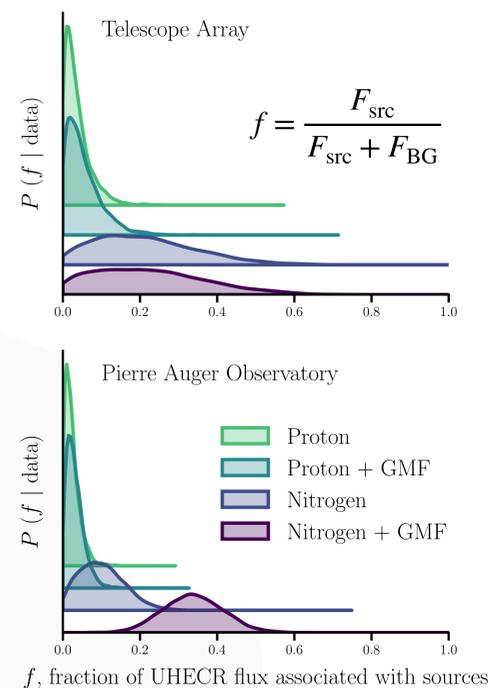
4. Results

We apply our model to publicly available data from the Telescope Array with E > 57 EeV [4] and the Pierre Auger Observatory with E > 52 EeV [5]. We consider the catalogue of starburst galaxies originally proposed in [6].

- TA
- Starburst galaxies

57.0   82.0   118.1   170.0
E / EeV

- Auger
- Starburst galaxies

52.00   74.02   105.37   150.00
E / EeV

For the nitrogen+GMF case, we show the **source–UHECR association probabilities** in Galactic coordinates. Most UHECRs with E > 100 EeV do not have clear source associations.

We also fit the source luminosities, spectral index, the diffuse background flux and the strength of the EGMF.

Summary of the effect of the Galactic magnetic field and composition on the **associated fraction, f,** of UHECRs:

Telescope Array

$$f = \frac{F_{\rm src}}{F_{\rm src} + F_{\rm BG}}$$

Pierre Auger Observatory

- Proton
- Proton + GMF
- Nitrogen
- Nitrogen + GMF

f, fraction of UHECR flux associated with sources

5. Conclusions

Including the Galactic magnetic field and UHECR composition allows for more source–UHECR associations to be found.

Similar results are seen in both the Northern and Southern skies.

References
[1] Capel & Mortlock, 2019, MNRAS, 484(2), 2324.
[2] Alves Batista et al., 2022, JCAP, 09, 035.
[3] Jansson & Farrar, 2012, ApJL, 761, L11.
[4] Abbasi et al., 2014, ApJL, 790, L21.
[5] Aab et al., 2015, ApJ, 804, 15.
[6] Aab et al., 2018, ApJL, 853, L29.

Code on GitHub:

UHECR 2022