Effects of Galactic Magnetic Field on the UHECR Anisotropy Studies

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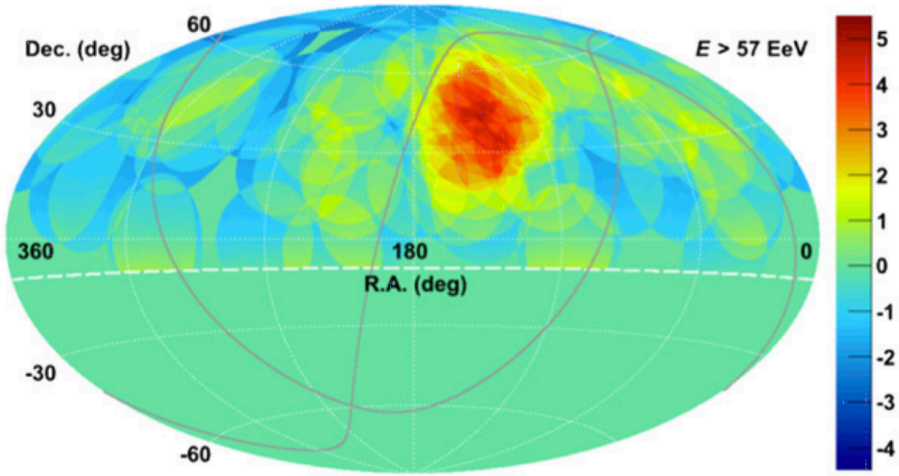
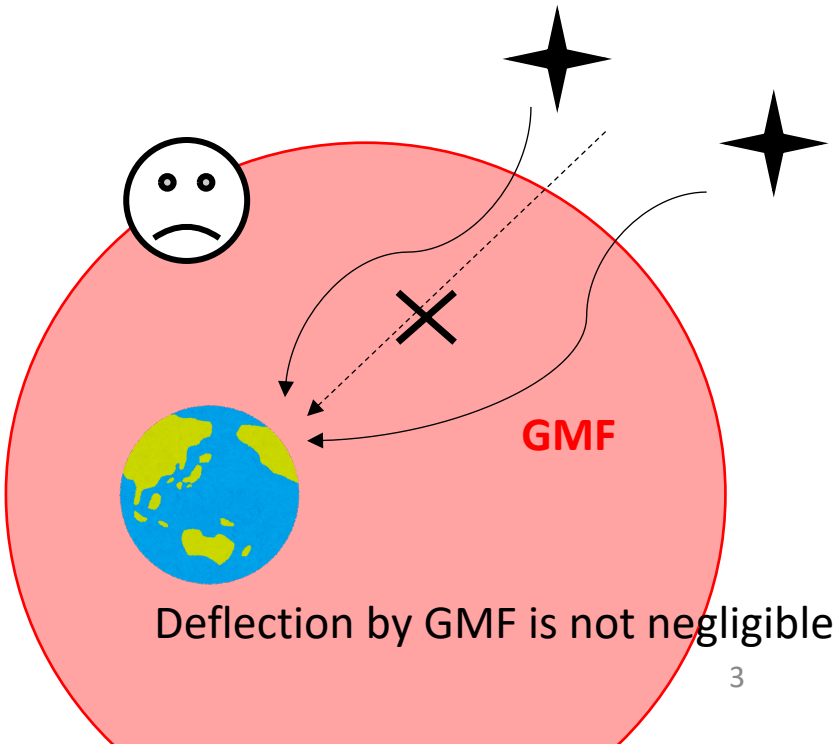
Kiyomizu-dera, 2020/12/09, 7:08 a.m.

UHECR Anisotropy

- **<u>Search for origin of UHECR anisotropy</u>**
  - **TA Hotspot**, Dipole etc…
- Possible Candidates
  - SBGs, AGNs…
  - Parameter estimation (later)
    - ->~10% of anisotropy comes from SBGs? (Auger2018, 1st day's talk)
- Deflection by Magnetic Field
  - Galactic magnetic field (GMF)
    - ~10deg at 60 EeV (Jansson&Farrar 2012)
  - Extragalactic magnetic field (EGMF)

TA HotSpot (TA 2014)





Constraints on Anisotropy

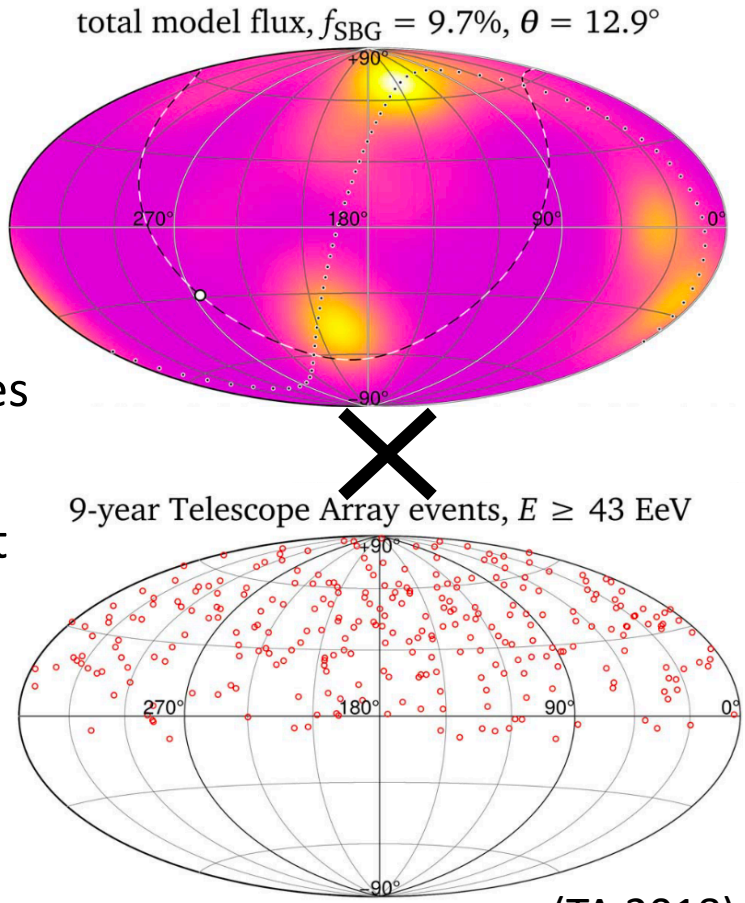
- 2 Parameters to constrain source candidates (Auger 2018)
  - **anisotropic fraction(f_sig)**
    - the fraction of all events due to the sources
  - **separation angular scale(Θ)**
    - RMS angular separation between an event and its source (smearing angle)
- Estimation Process:
  - CR Flux model from the source(SBGs)+isotropic flux
    - with parameter (f_sig, Θ)

$$F(\hat{\mathbf{n}}; f_{\rm sig}, \Theta) = \frac{\omega(\hat{\mathbf{n}})}{\mathcal{C}} \left[(1 - f_{\rm sig}) + f_{\rm sig} \sum_{i=1}^{N_{\rm cat}} \mathcal{F}_{\gamma,i}\, w(z_i)\, \mathfrak{F}(\hat{\mathbf{n}}, \hat{\mathbf{s}}_i; \Theta) \right] \times \text{exposure}$$

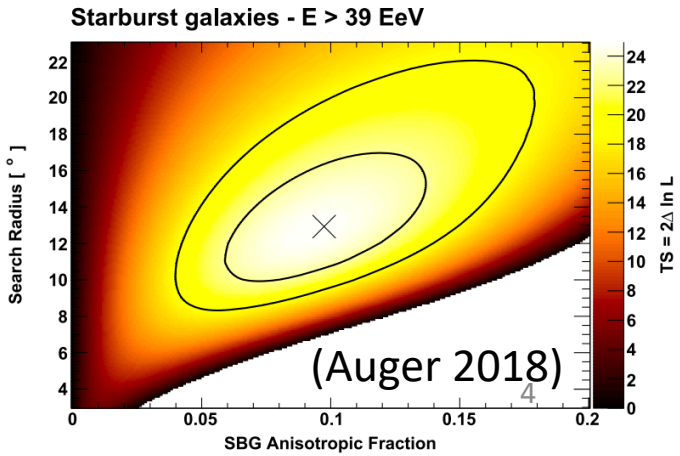
  - UHECR events (TA/Auger/Mock events)
  - Maximizing likelihood:

$$\mathscr{L}(f_{\rm sig}, \Theta; \hat{\mathbf{n}}_j) = \prod_{j=1}^{N} F(\hat{\mathbf{n}}_j; f_{\rm sig}, \Theta)\,,$$

  - Estimate (f_ani, Θ), changing 2 parameters



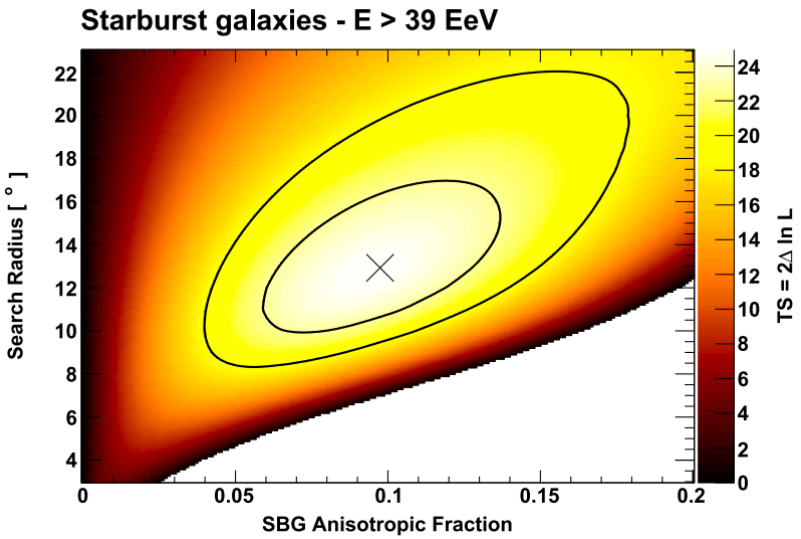
(TA 2018)



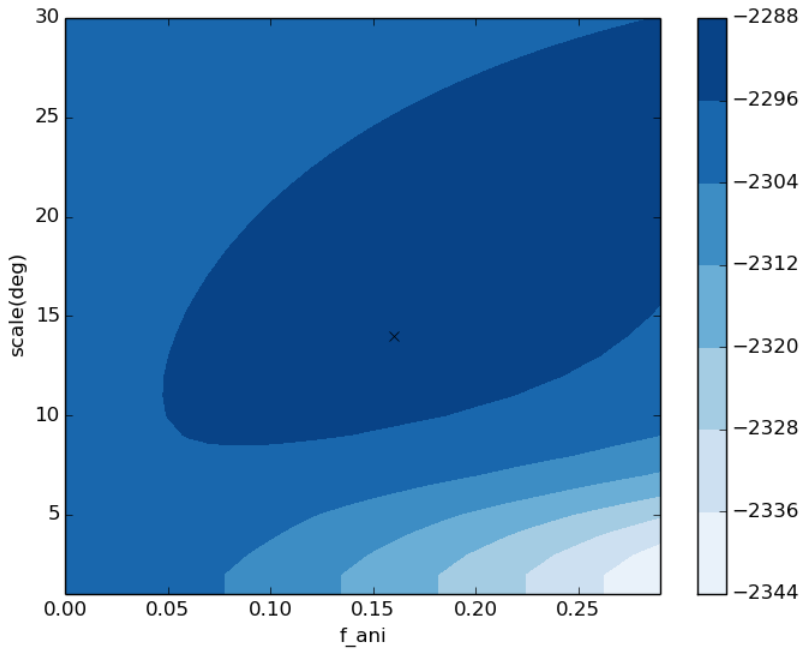
(Auger 2018)

1st Step: Training of my calculation

- Sources: 23 nearby SBGs (Auger 2018)
- UHECR events (published data of Auger 2015)
  - without GMF
  - (f_sig, Θ)=(16%,14deg)



(Auger 2018)

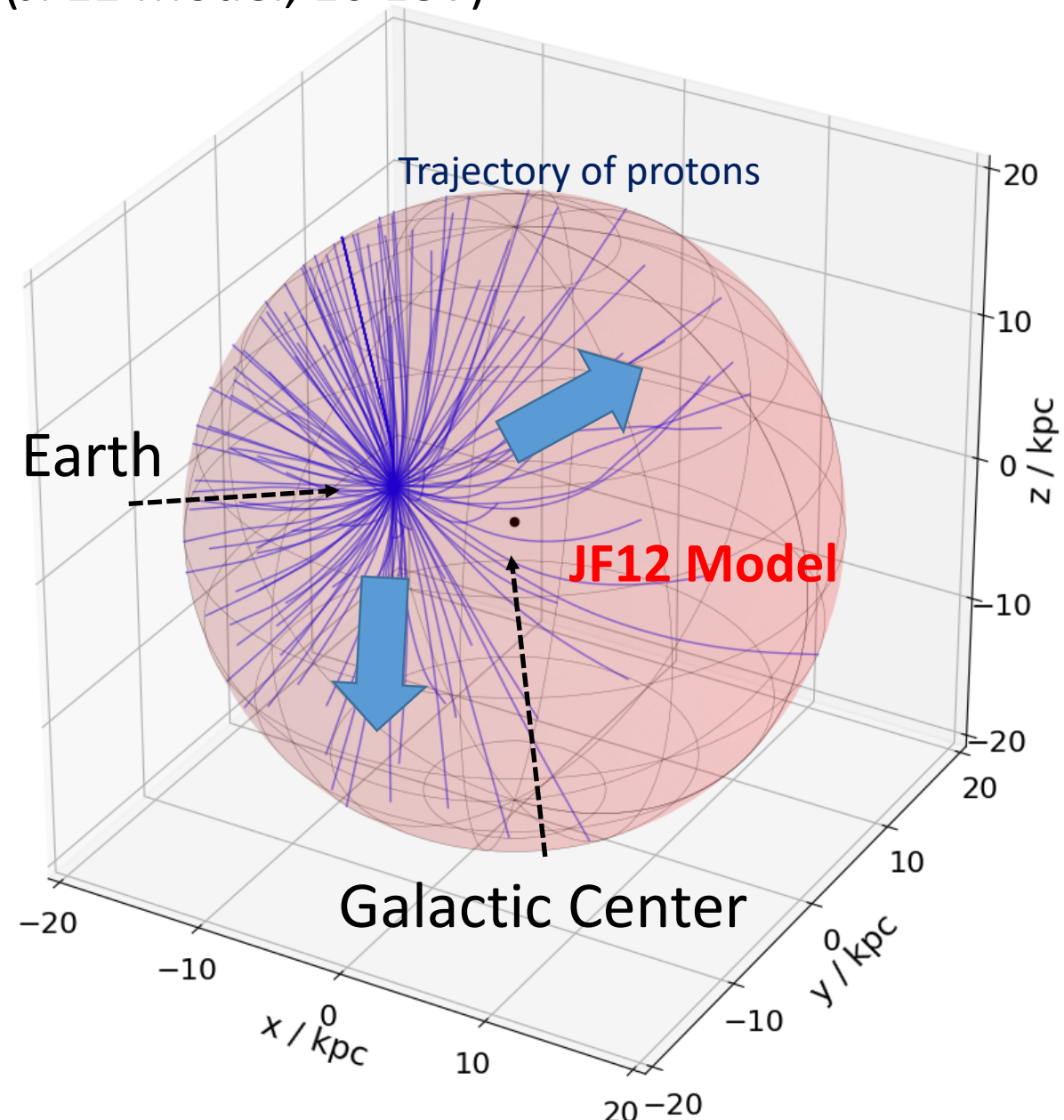


This Study

Looks fine! -> with GMF (next step)

Backtracking in GMF (with CRPropa)

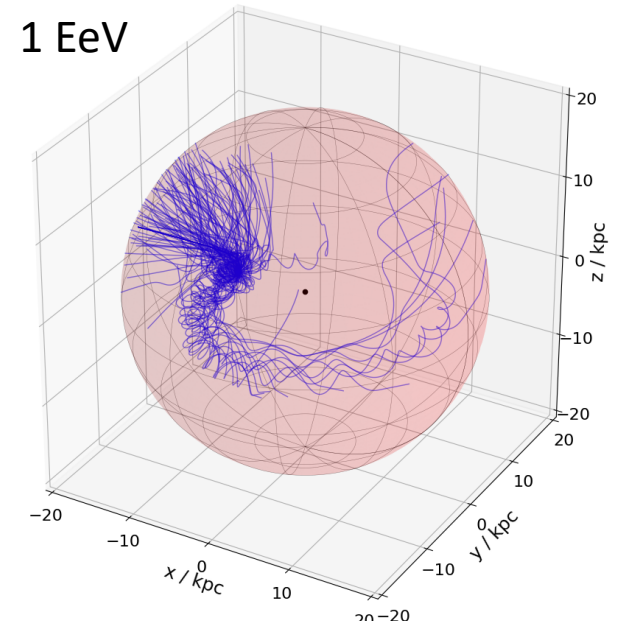
(JF12 Model, 10 EeV)



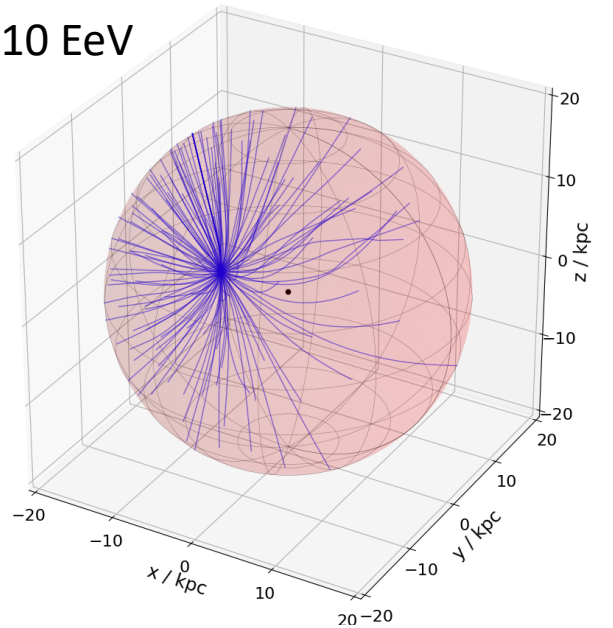
- **Backtracking:** inverse calculation using anti-particle from the earth
  - **particle: anti-proton**
  - back to 20 kpc from the galactic center
- Tool: CRPropa 3
  - software for UHECR propagation
  - propagation with GMF
- GMF : JF12 Model (Jansson&Farrar+12)

JF12 Backtracking (Proton)

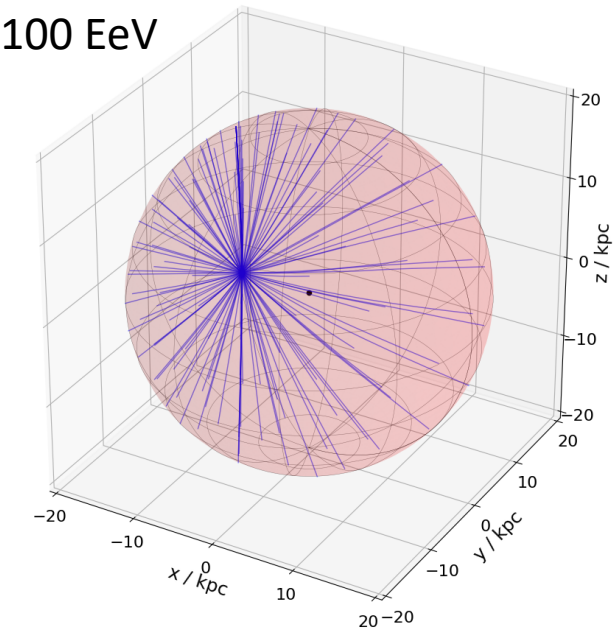
1 EeV



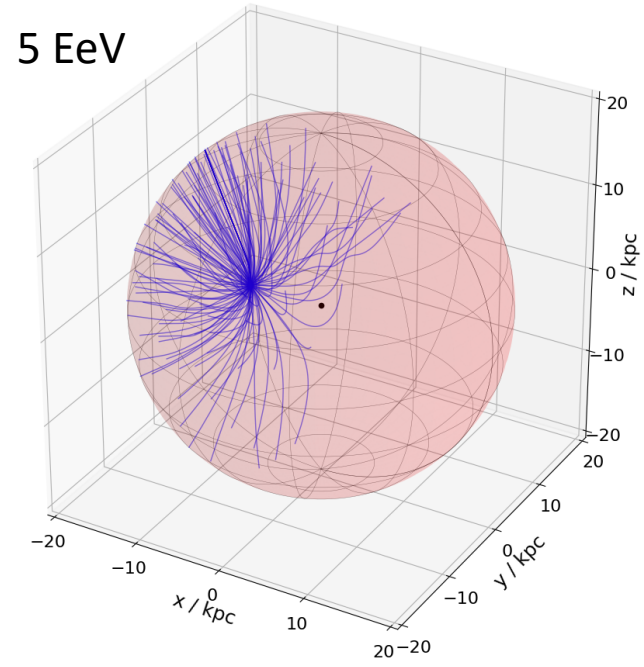
10 EeV



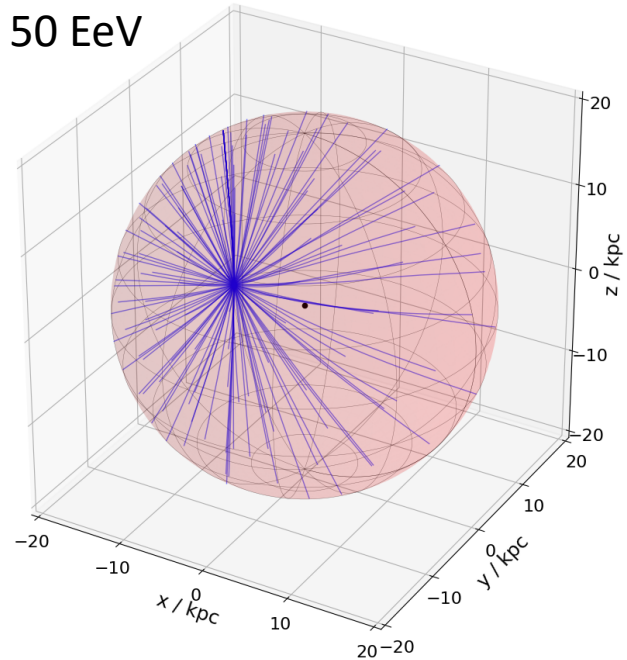
100 EeV



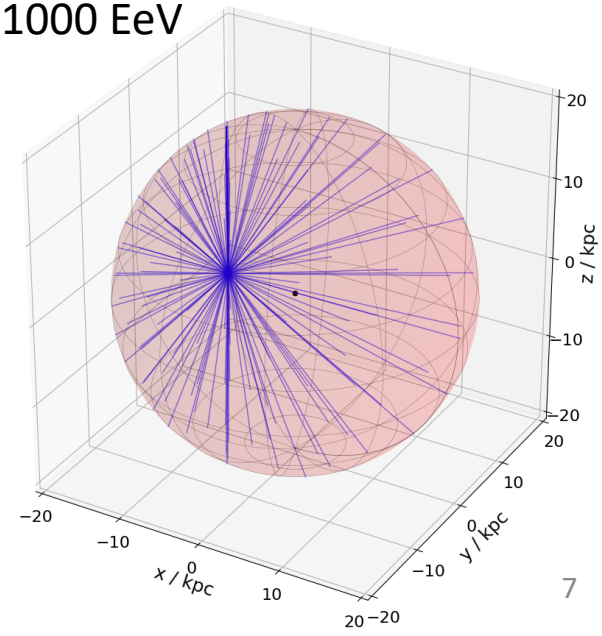
5 EeV



50 EeV



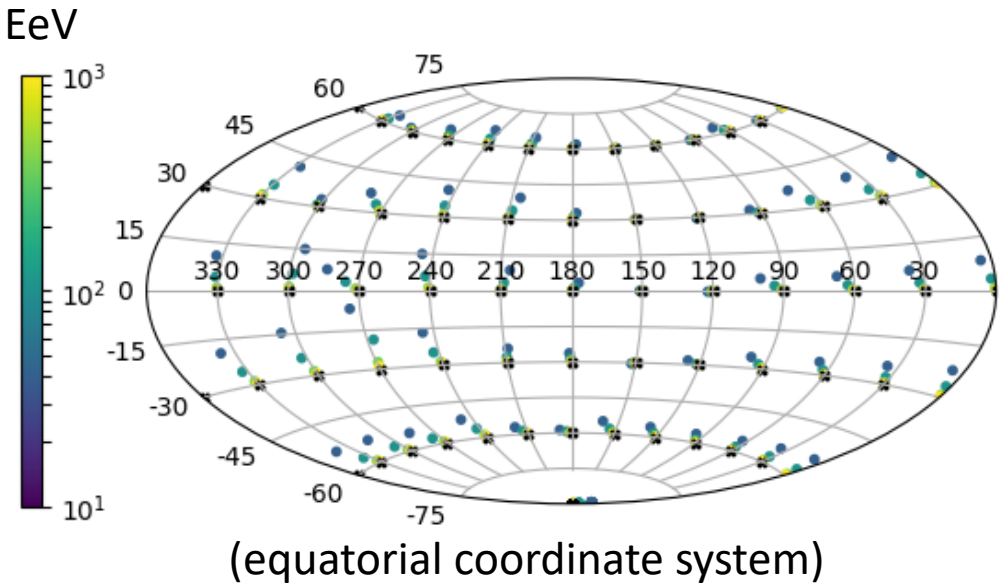
1000 EeV



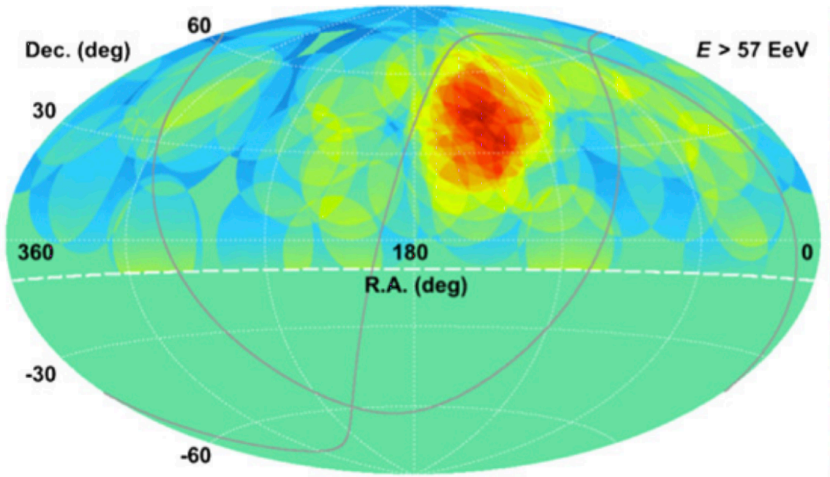
Deflection of Protons by JF12 model

x: observed arrival direction on the earth

●: original direction at 20 kpc from the galactic center (40, 100, 400, 1000 EeV)



(equatorial coordinate system)



- Symmetric deflection with Galactic plane
- Small deflection angle around TA Hotspot
- ~10 deg deflection at maximum (in case of proton)

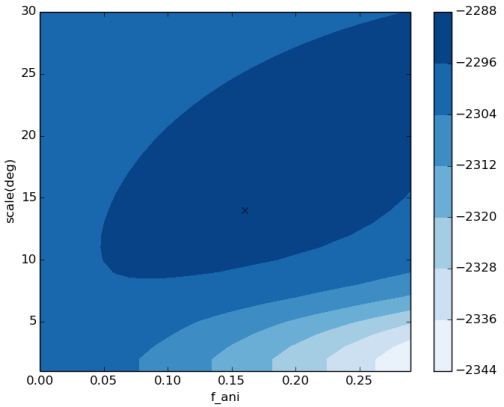
2nd Step: Parameters Estimation with backtracked events

- UHECR sample from Auger 2015
  - without GMF(upper)
    - (f_sig, Θ)=(16%,14deg)
  - with GMF(bottom)
    - with backtracked events (pure proton assumption)
    - (f_sig, Θ)=(14%,14deg)

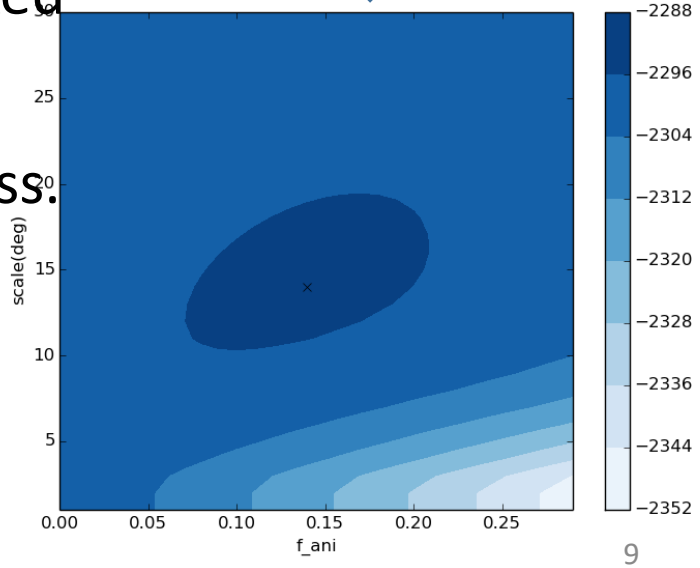
- **Parameters do not change significantly with pure proton assumption.**

- Deflection would be larger considering a mixed mass composition.
- Event-by-event backtracking is not feasible because we do not know event-by-event mass.

- -> Remaking CR flux pattern with
  - GMF model
  - Mixed mass composition
  - Energy spectrum

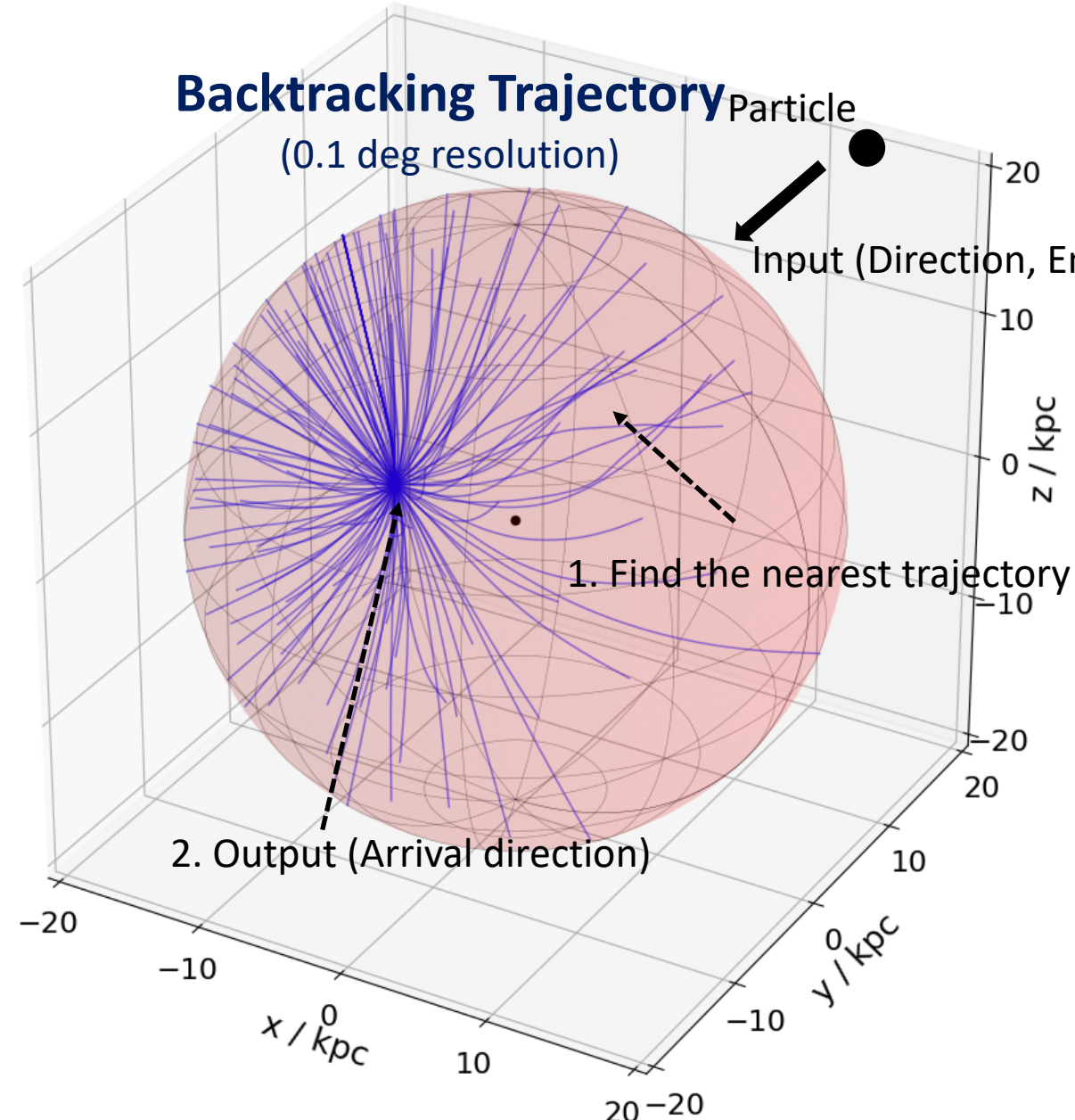


without GMF



with GMF

GMF Forward Tracking Function

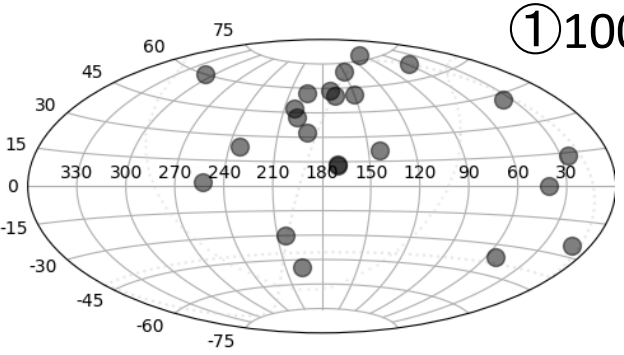


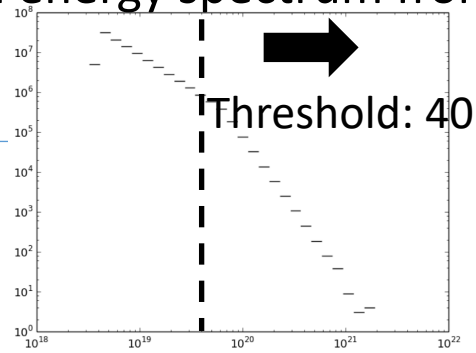
- Input:
  - Direction (outside the galaxy)
  - Rigidity (E/Z) of the particle
  - Output: Arrival direction (on the earth)

- Procedure
  1. Find the nearest trajectory in the backtracking trajectory
  2. Output the arrival direction on the earth

CR Flux Patterns through GMF

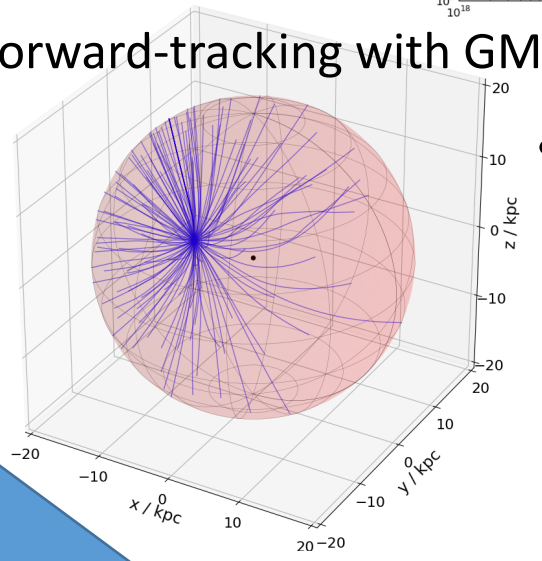
①1000 proton with energy spectrum from each source





Energy Spectrum: Broken Power Law(index=-2.69, -4.63(broken at E=10^19.81eV))

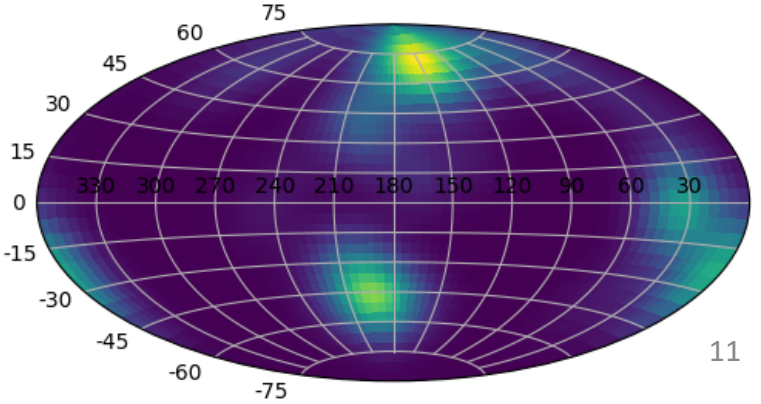
②Forward-tracking with GMF



- Use a GMF tracking-function from backtracking-trajectory

③Flux pattern (with GMF)

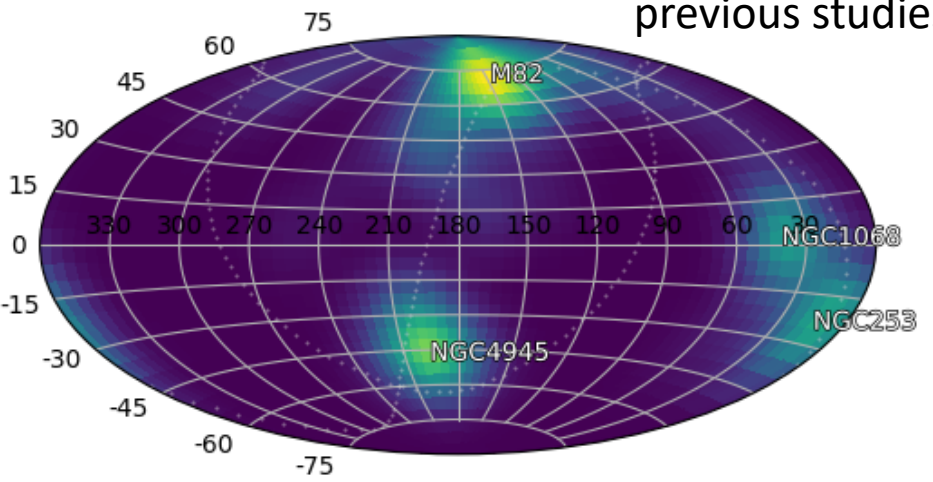
- add smearing + isotropic component



Effects of GMF on the CR Flux Pattern

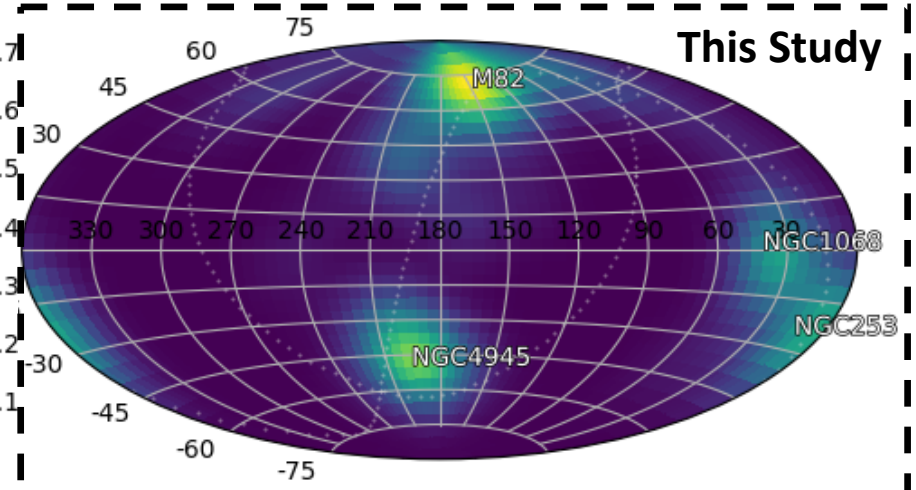
Flux pattern without GMF **(flux0)**

previous studies



Flux pattern with GMF **(flux1)**

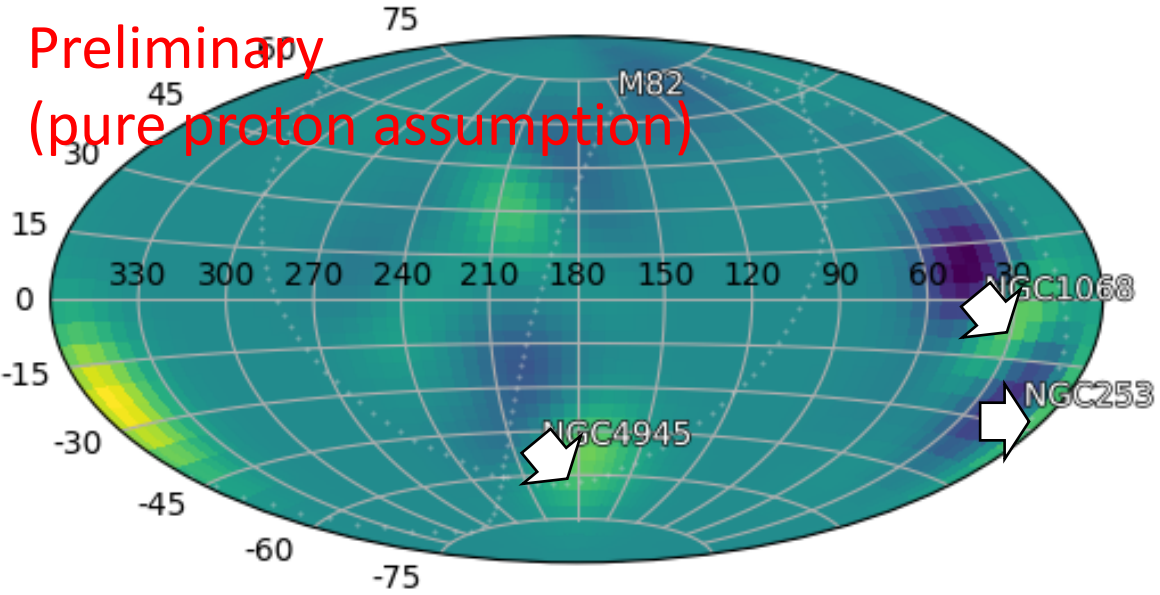
This Study

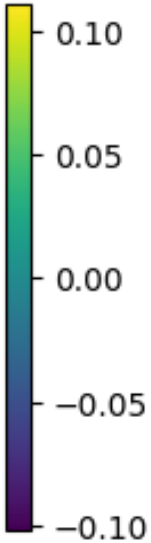


Threshold energy: 40EeV

Difference of Flux Patterns between with/without GMF **(flux1-flux0)**

Preliminary
(pure proton assumption)





- ~15% fluctuation of flux at maximum (compared with maximum of flux0)
- <7 deg deflection of the peak of the flux
- <14 deg deflection in case of He

Summary

- Source Candidates of UHECR Anisotropy
  - SBGs are good candidates of UHECR anisotropy (Auger 2018)
- 2 Parameter Estimation (Auger 2018)
  - anisotropic fraction f_sig
  - separation angular scale Θ
- Effect of GMF is studied based on the Auger 2015 published events
  - Events are backtracked using CRPropa3 with JF12 GMF model
  - Only small difference (-2% in f_sig) is found
  - Small GMF effect on this analysis (with pure proton assumption)
  - -> Mixed mass composition in the next step
- Convoluting GMF, Mass composition and Energy spectrum into CR flux pattern instead of backtracking
  - Forward-tracking function is constructed
  - With pure proton assumption, maximum 15% effect on flux and 7deg displacement of source (SBG) position are observed.
  - -> Next step: mixed mass composition