NTNU

UHECR 2012

Deflection of UHE Heavy Nuclei in the Galactic Magnetic Field

Gwenael Giacinti (NTNU, Trondheim, Norway)

M. Kachelriess ***(NTNU, Trondheim)***

D. V. Semikoz ***(APC, Paris)***

G. Sigl ***(U. Hamburg)***

JCAP 1008, 036 [arXiv:1006.5416]

Astropart. Phys. 35, 192 [arXiv:1104.1141]

Motivations

- Explore the consequences for UHECR deflections in the (Galactic) magnetic fields, ***in case of*** a shift towards a heavier composition at the highest energies.
- Results important to understand future **experimental sky maps**.

-> 1) Several **important** and not (so) trivial **effects** would appear in case of heavy primaries;

-> 2) Differences between deflections of p/nuclei may give additional information on the composition.

Goals

- Propagate **iron** nuclei with **E > 60 EeV** in the Galactic magnetic field:

  I - Sources images

  II - Magnetic lensing effects

A few words about the Galactic magnetic field

Galactic Magnetic Field

-> Regular component :

-> Turbulent component :

Galactic Magnetic Field

- Regular Galactic magnetic field geometry still poorly known. Test the model-dependence :

-> Regular component : Take several recent models :

- Prouza and Smida (PS) *Astron. Astrophys.* ***410*** *(2003) 1*
- Sun et al. (Sun 08) *Astron. Astrophys.* ***477****, 573 (2008)*
- Sun 08 – MH (modified halo)
Giacinti, Kachelriess, Semikoz, Sigl JCAP 1008,036 (2010)
- Pshirkov et al. ASS and BSS versions *arXiv:1103.0814*
- etc ...

Expected deflections in avg-> In this sense, **'generic'** results

-> Turbulent component :

Galactic Magnetic Field

- Regular Galactic magnetic field geometry + turbulent component still poorly known. Test the model-dependence :

-> Regular component : Take several recent models :

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- etc ...

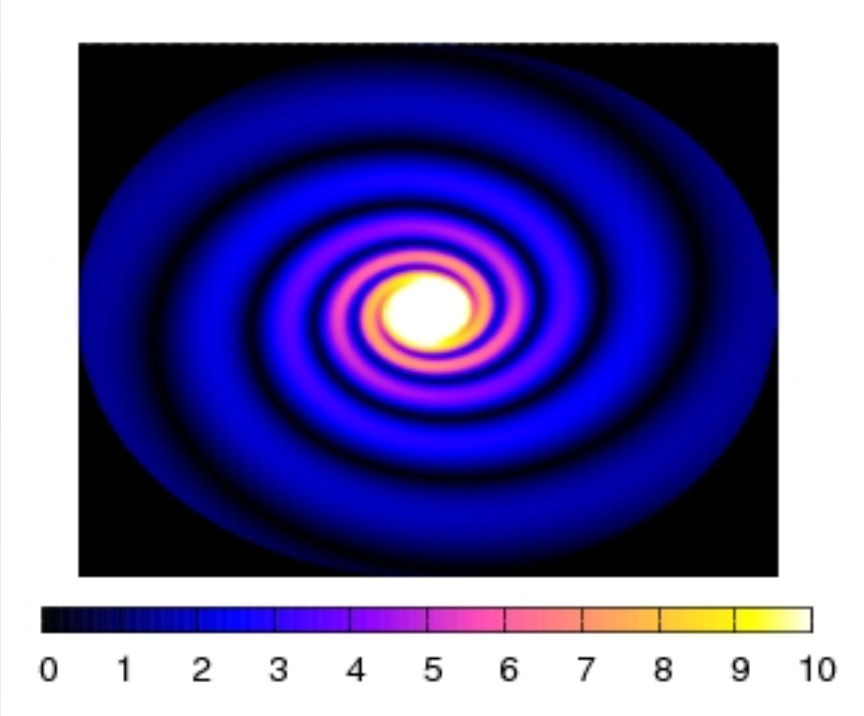
Expected deflections in avg-> In this sense, **'generic'** results

-> Turbulent component :

Generate a 3D turbulent field configuration. **Vary :**

- Strength (at Earth): B_0; - Extension in the halo Z_0.

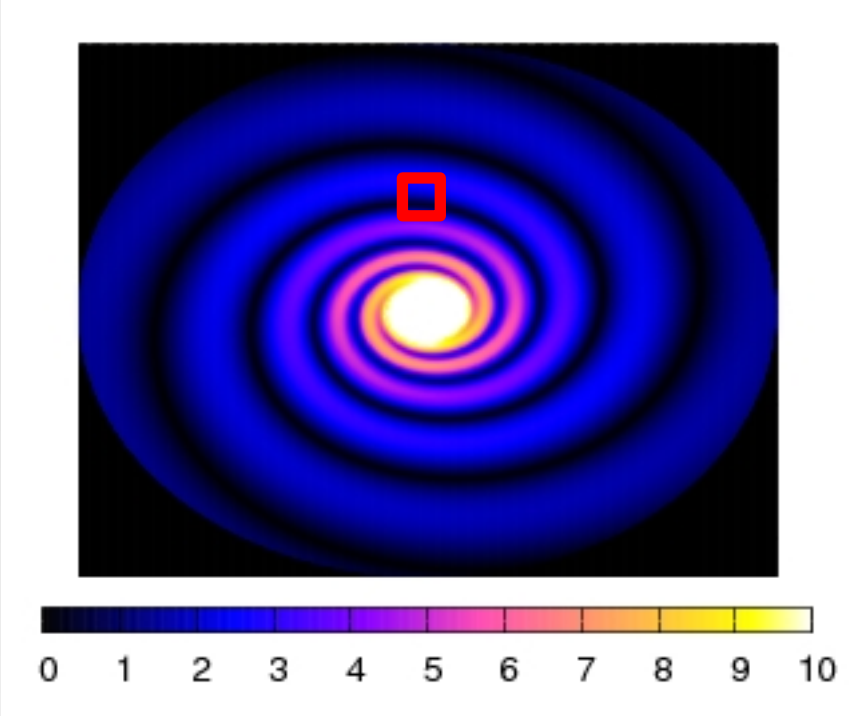
Simulation of the GMF



|**B**| (μG)

Reg. GMF (PS)

Simulation of the GMF



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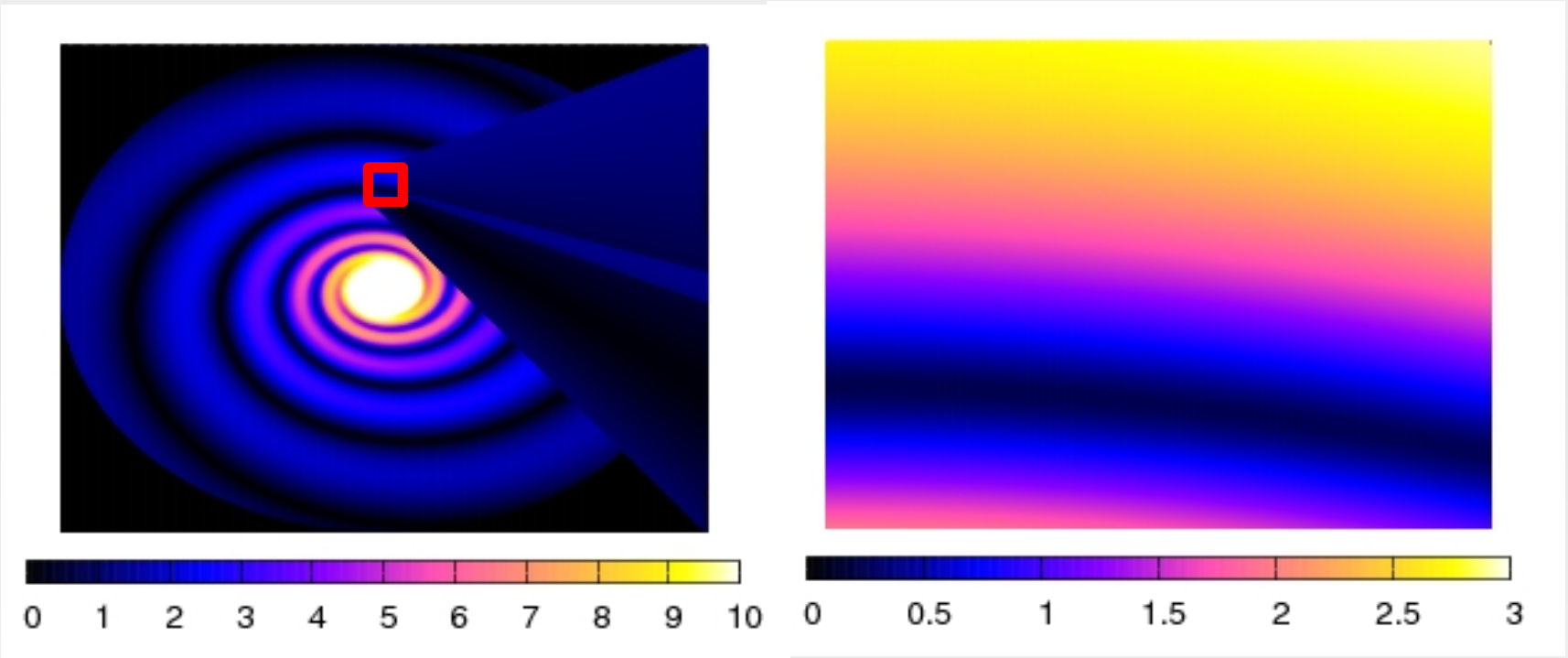

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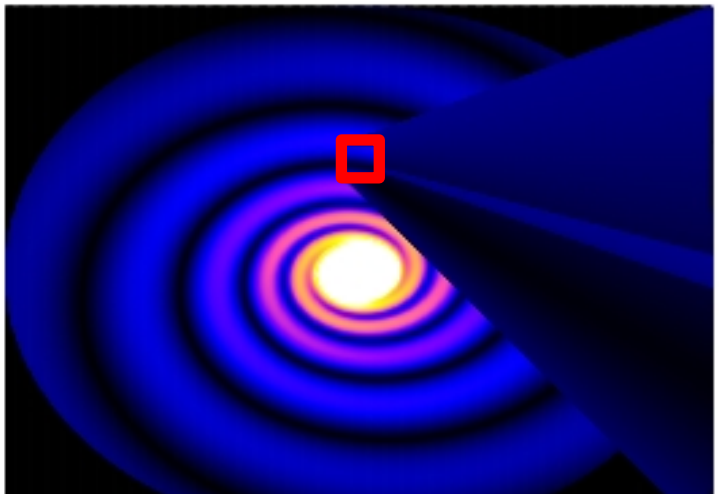
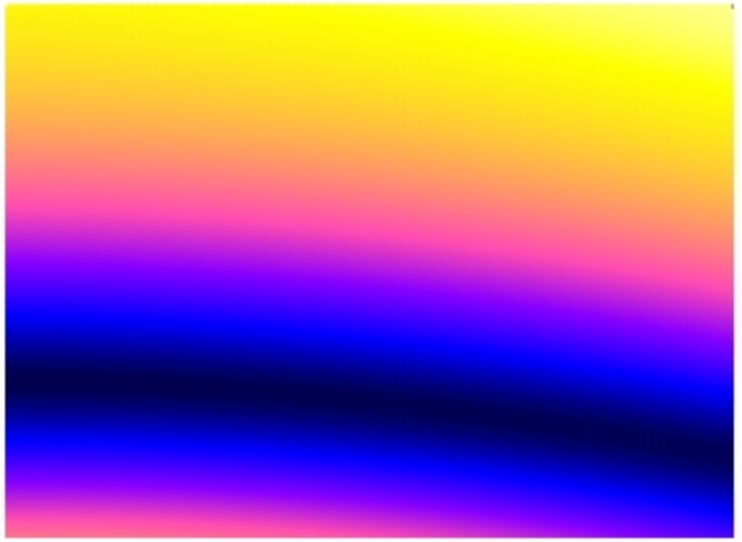
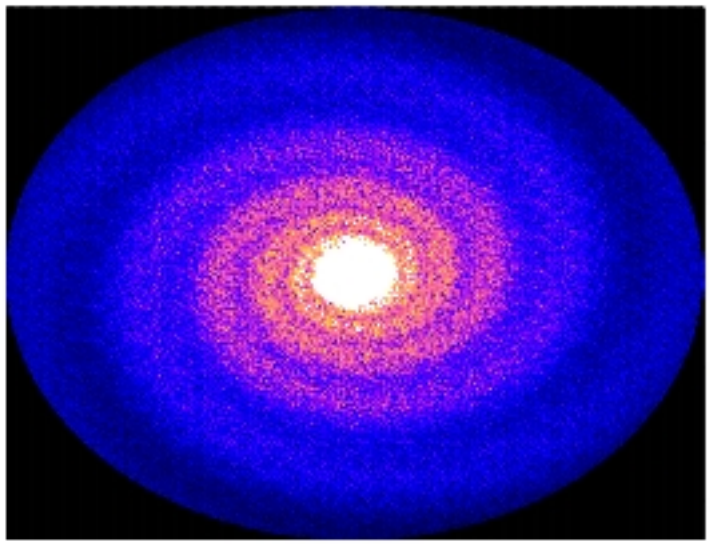




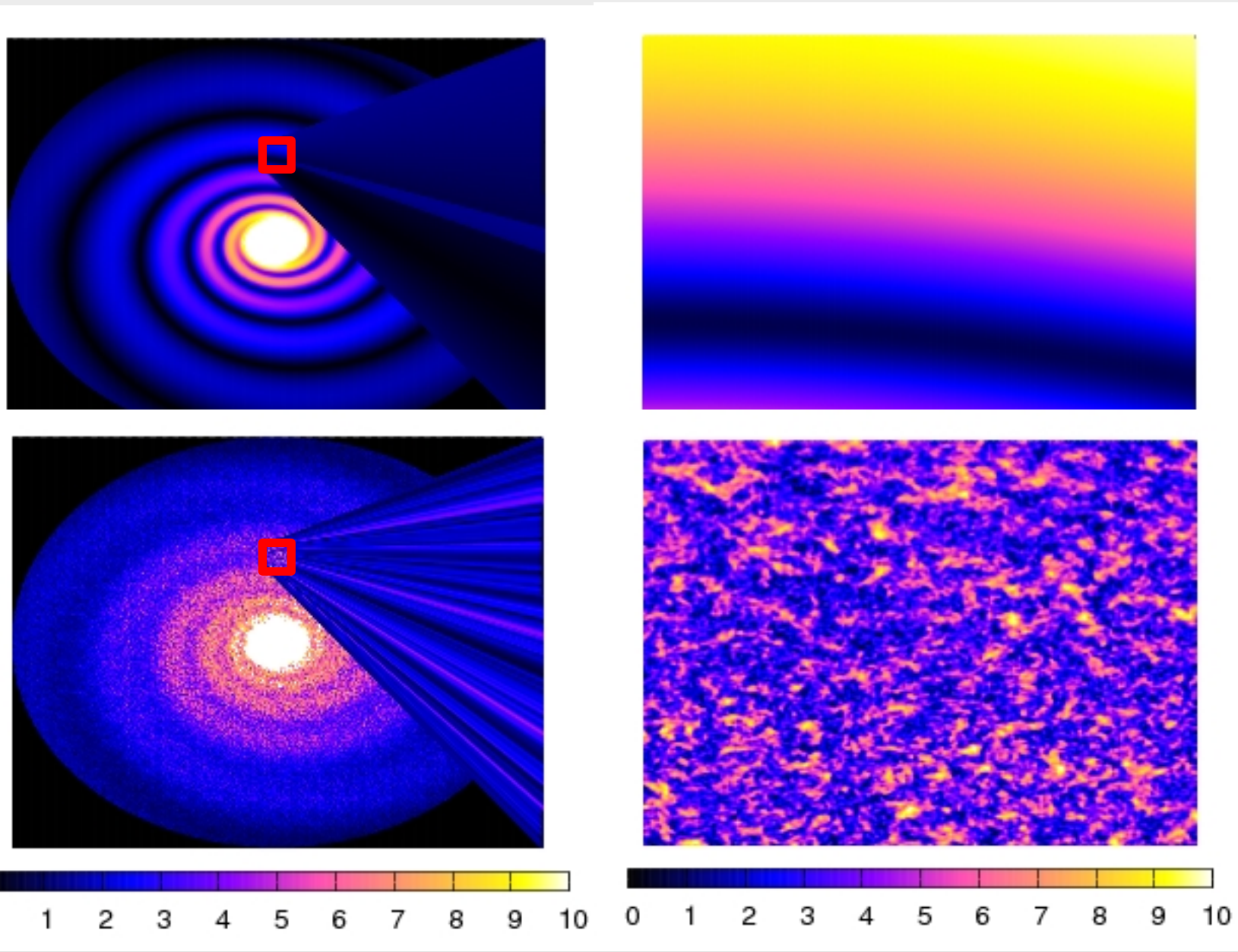
Reg. GMF (PS)



+

Turb. GMF

Simulation of the GMF



Reg. GMF (PS)

+ Turb. GMF

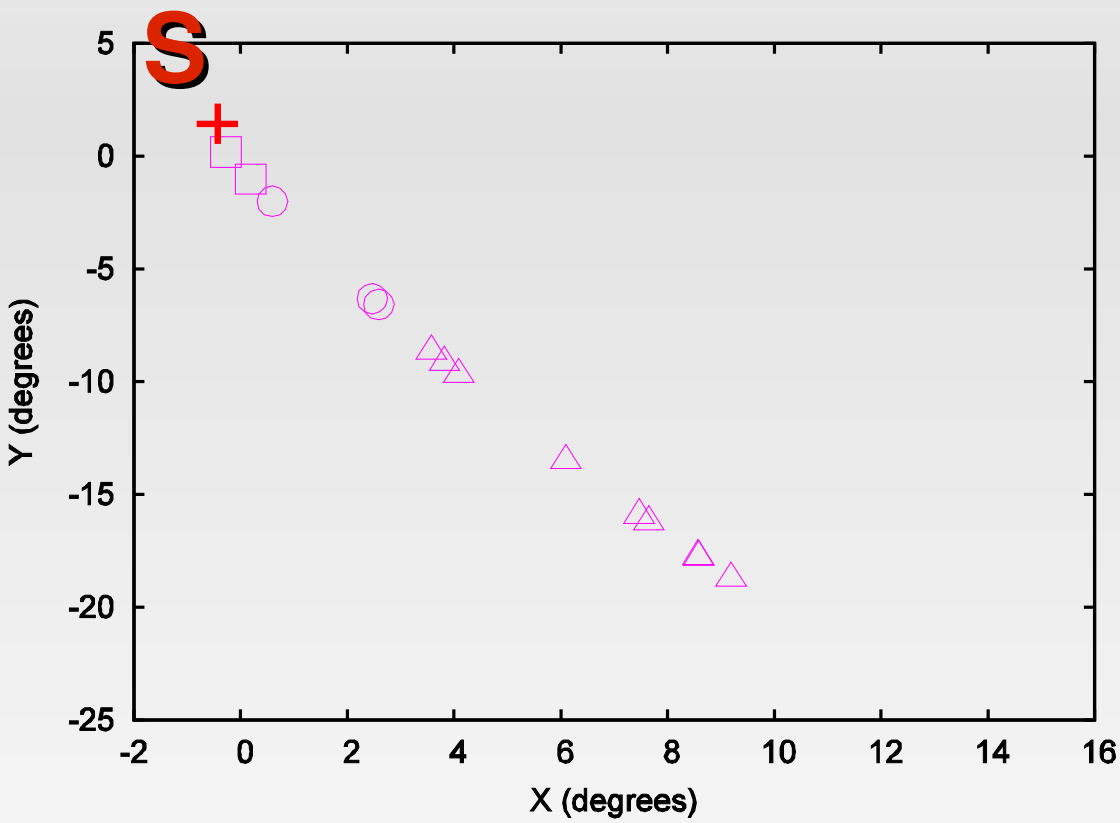
I – Images of UHE heavy nuclei sources

Case of proton sources

– Deflection in the regular Galactic Magnetic Field:

$$\delta_{reg} \approx 8.1^{\circ} \frac{40\,EeV}{E/Z} \left| \int \frac{ds}{3\,kpc} \times \frac{B}{2\mu G} \right| \approx \frac{D}{E}$$

(D. Harari *et al.* astro-ph/0205484)



(Giacinti, Derkx, Semikoz, JCAP1003,022 (2010))

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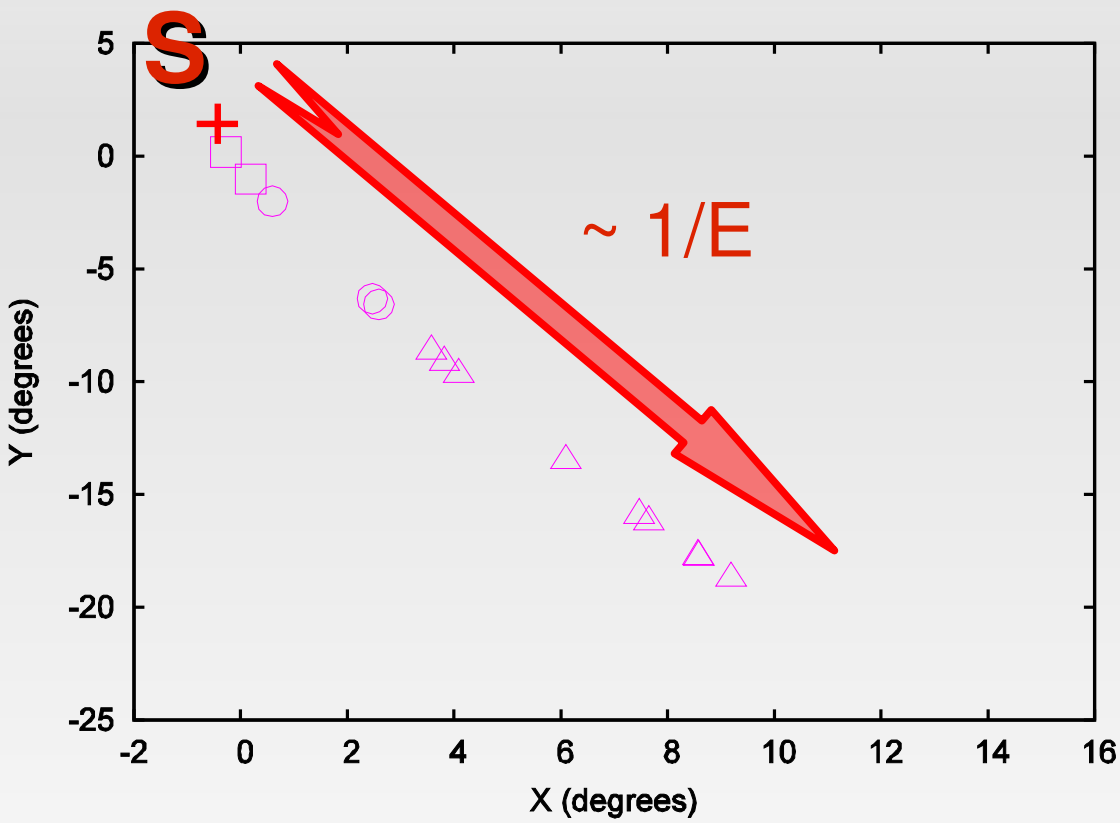

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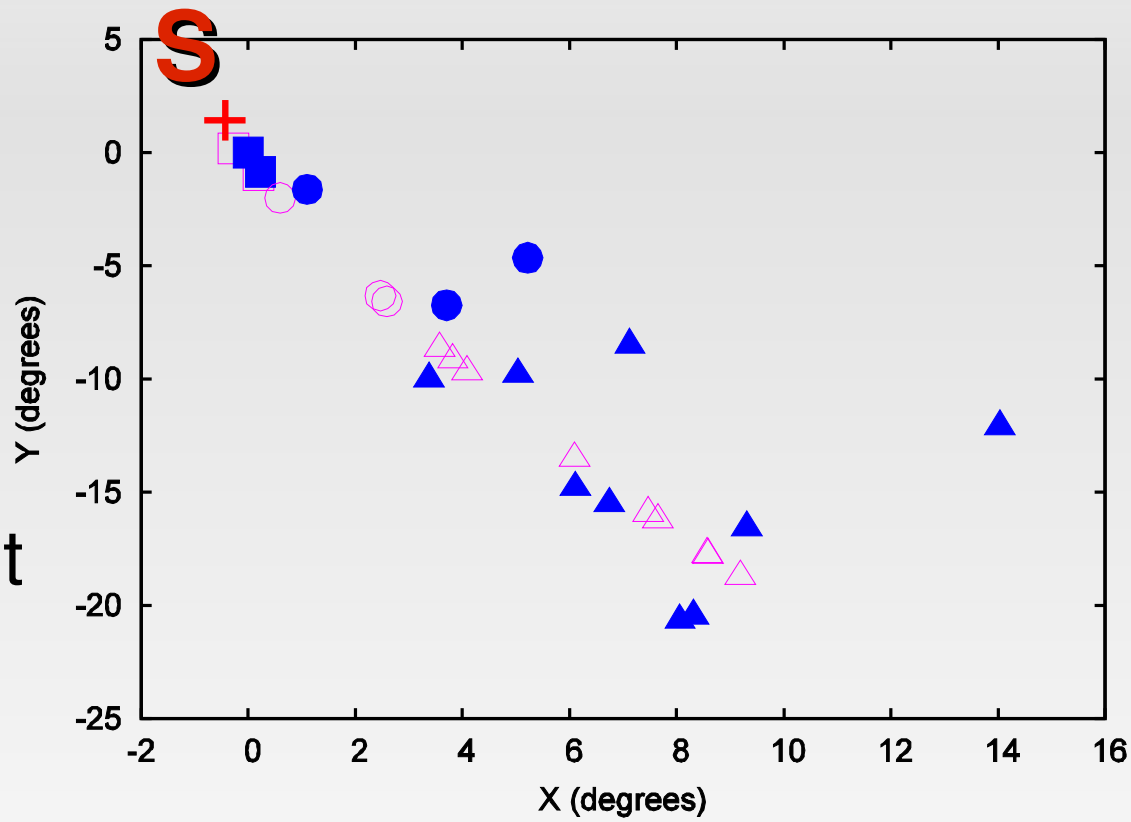
- Deflection in the turbulent Galactic Magnetic Field



(Giacinti, Derkx, Semikoz, JCAP1003,022 (2010))

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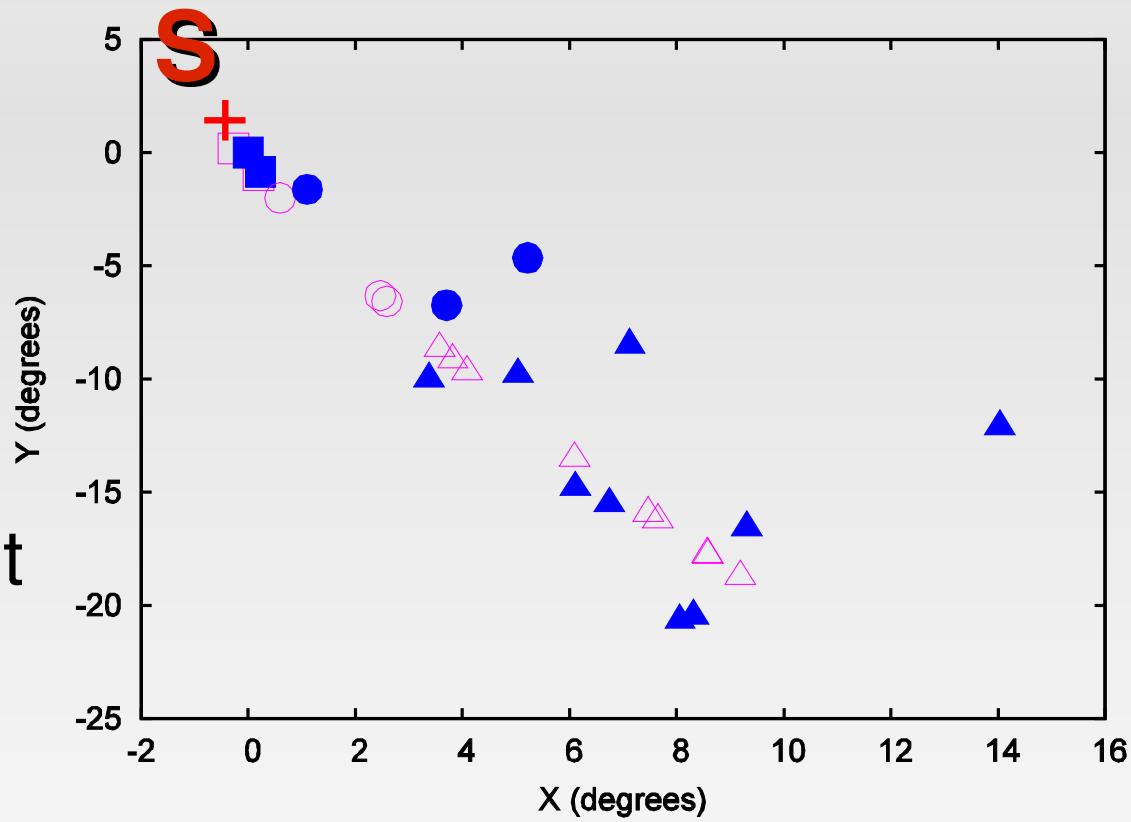
(D. Harari *et al.* astro-ph/0205484)

- Deflection in the turbulent Galactic Magnetic Field
- (Extragalactic fields)



(Giacinti, Derkx, Semikoz, JCAP1003,022 (2010))

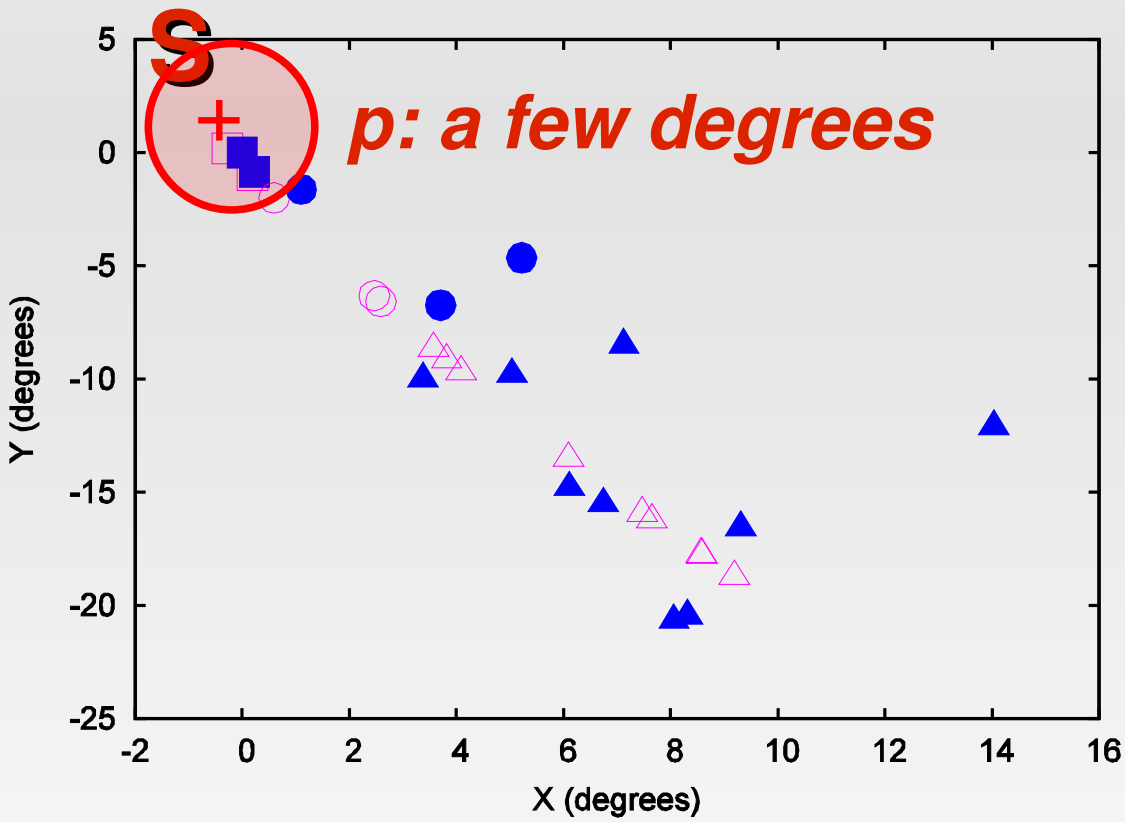
Case of proton sources

– ***Iron with E = 60 EeV*** :

On avg ***~ 50 – 70°***

(from ~ 20 to > 100°, depending on the direction on the sky)

...Proton features x Z ?



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Case of proton sources

– ***Iron with E = 60 EeV*** :

On avg ~ 50 – 70°

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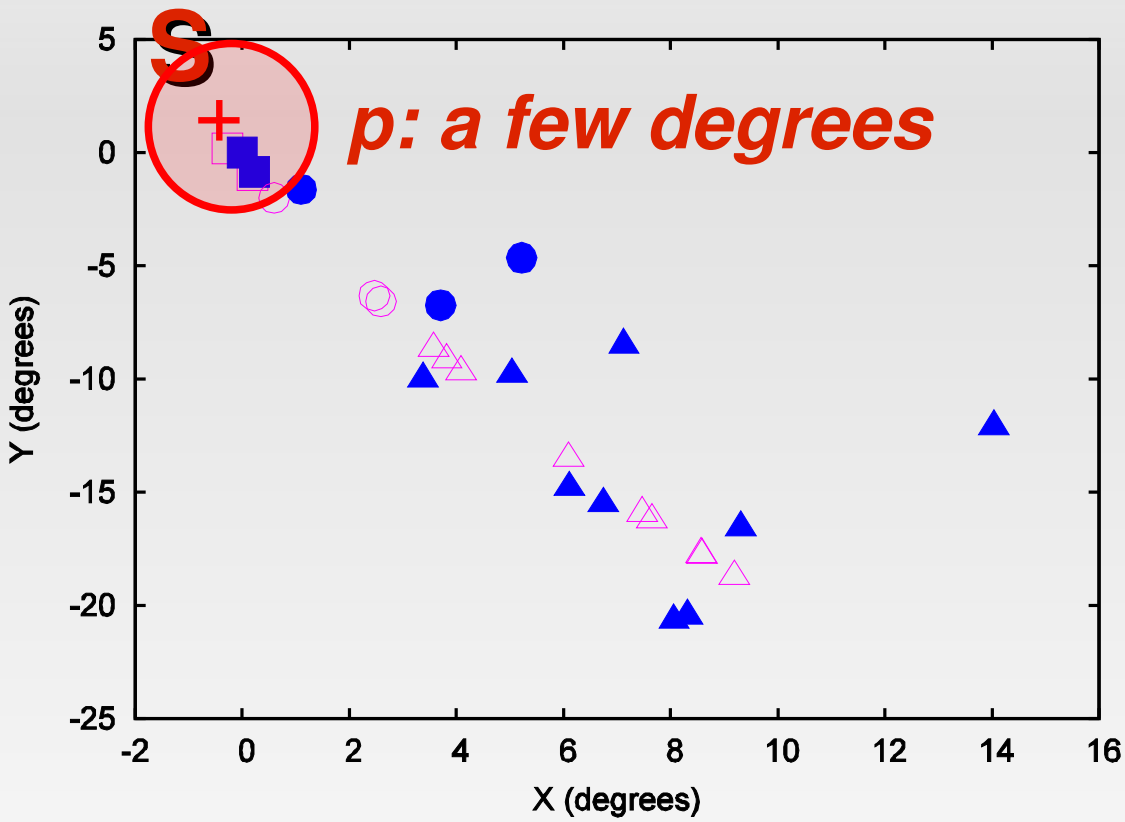
...Proton features x Z ?

In general, No !

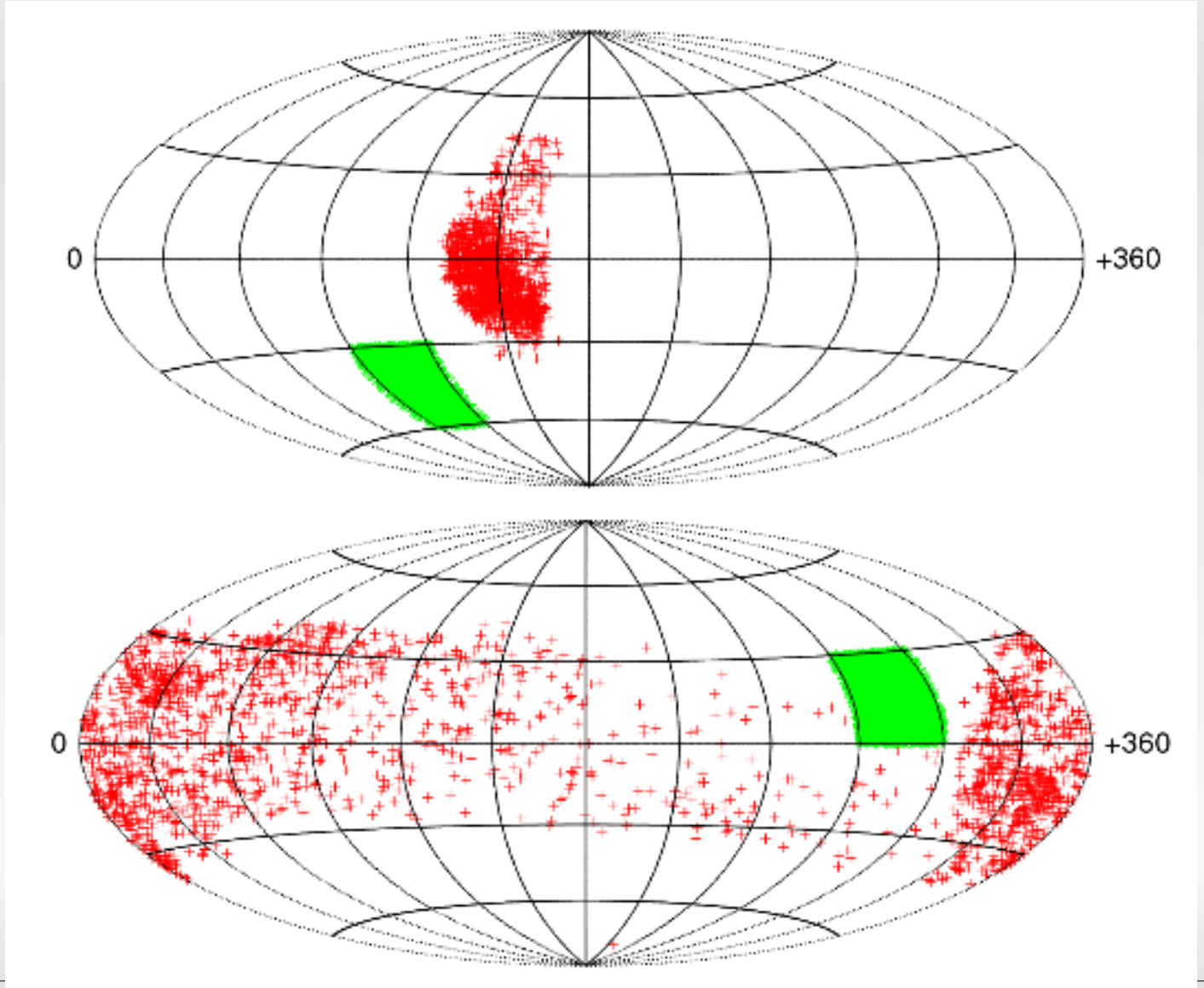


(Giacinti, Derkx, Semikoz, JCAP1003,022 (2010))

Shifts of sky patches

- Backtrace 60 EeV Fe from the Earth to outside the Galaxy

(PS model)



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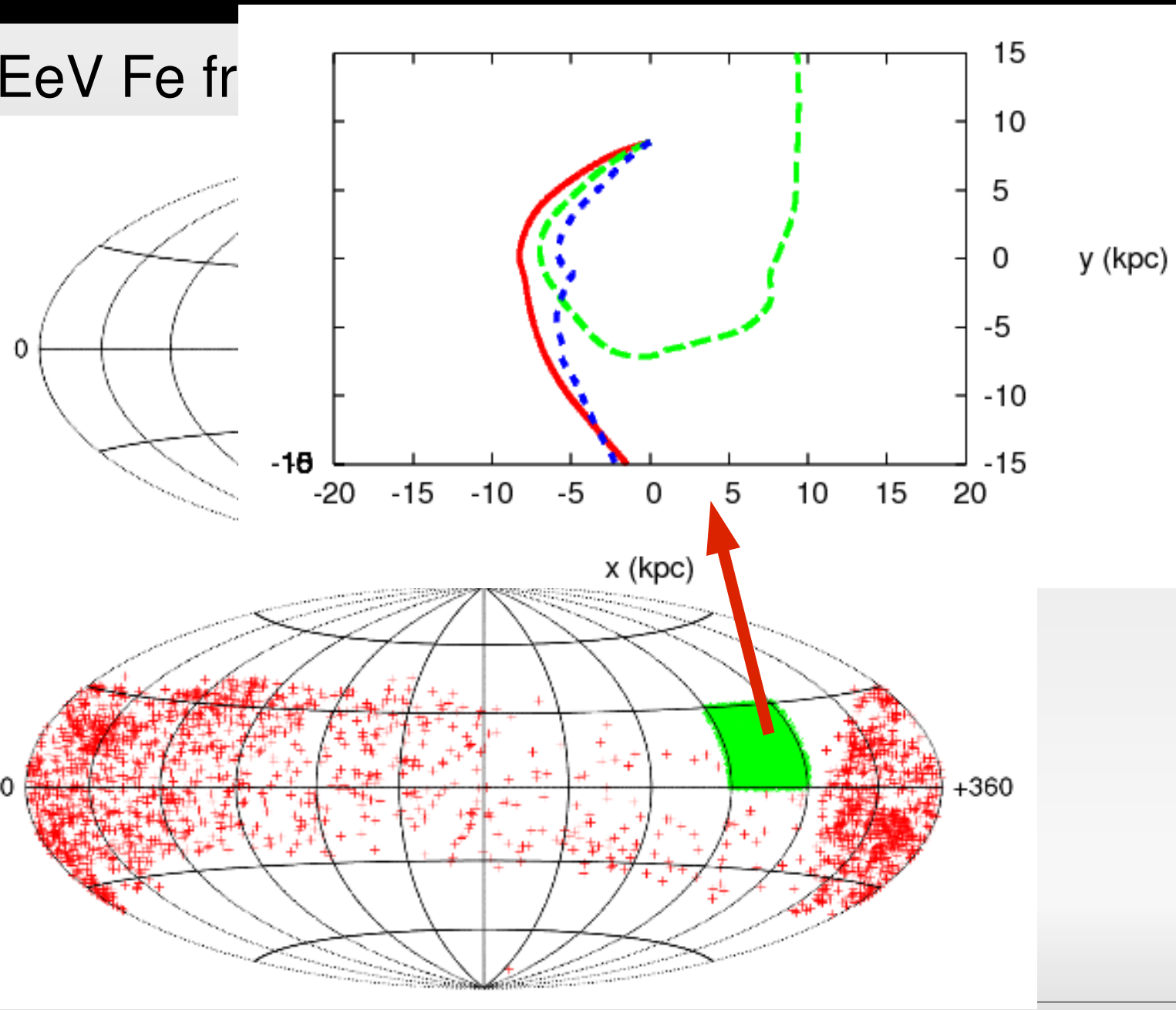

No one-to-one correspondence !

- Backtrace 60 EeV Fe from the Earth to outside the Galaxy

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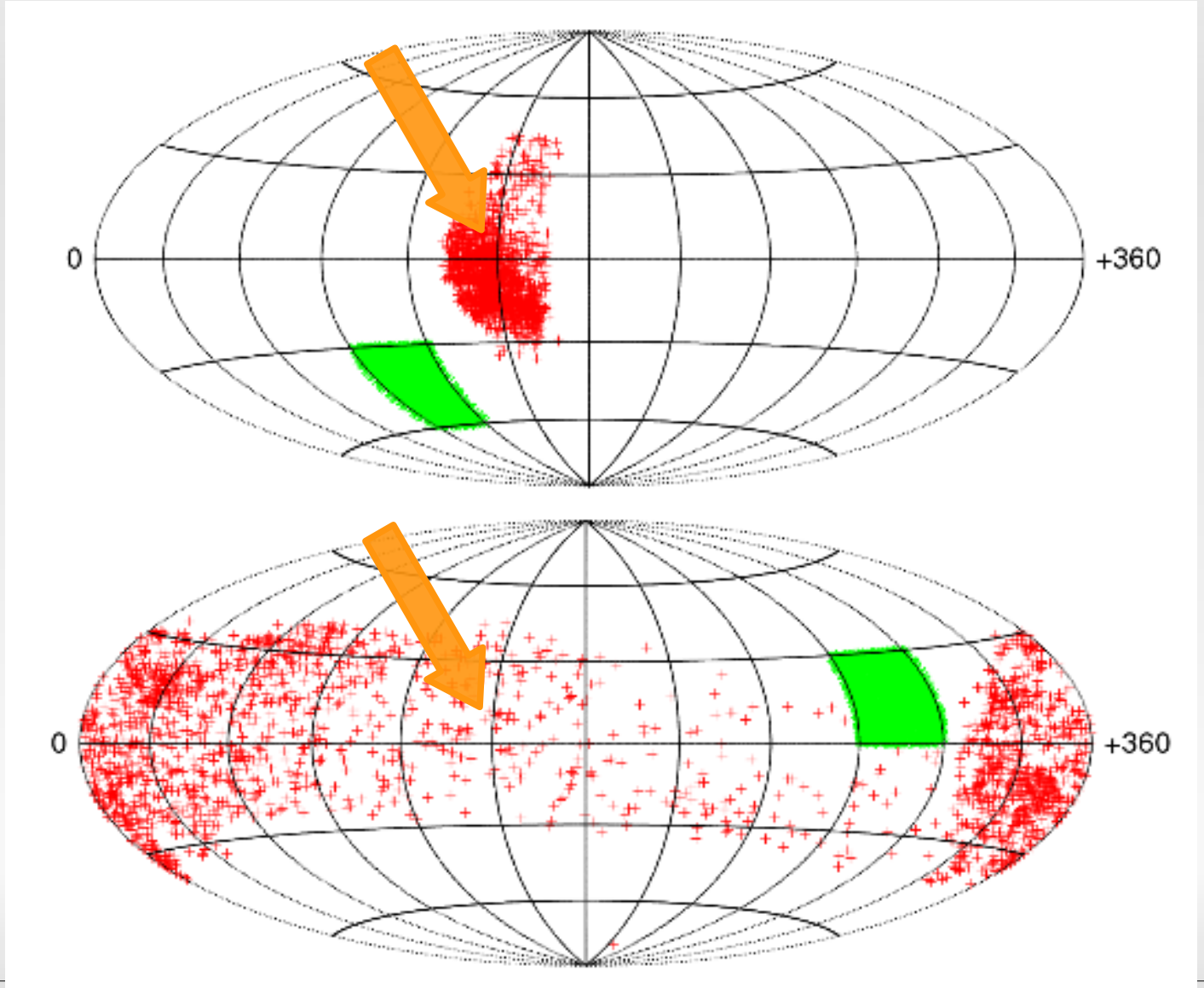
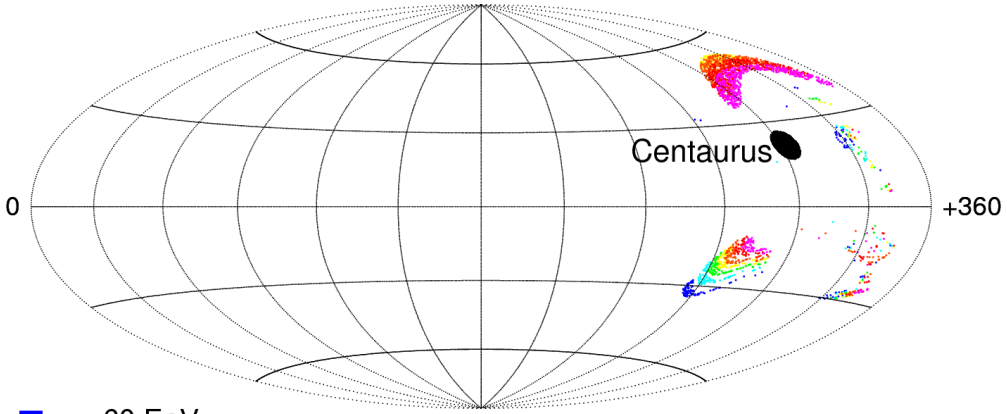
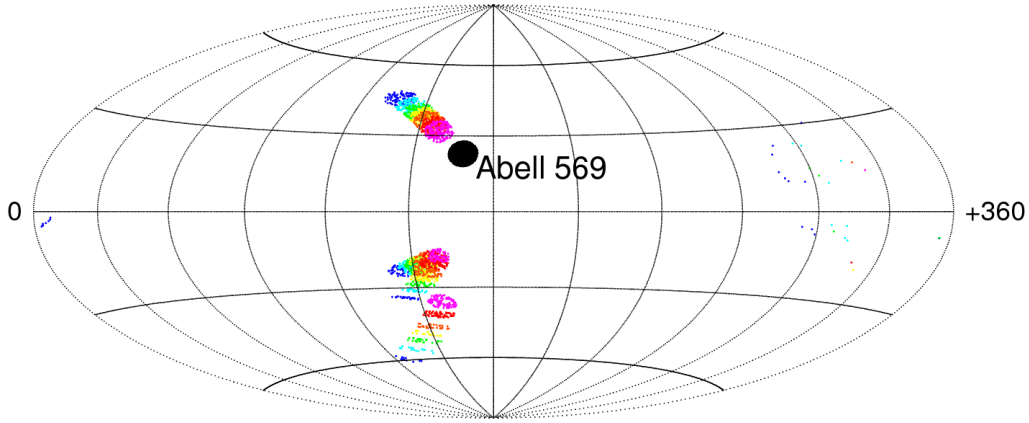


Fe images of nearby galaxy clusters



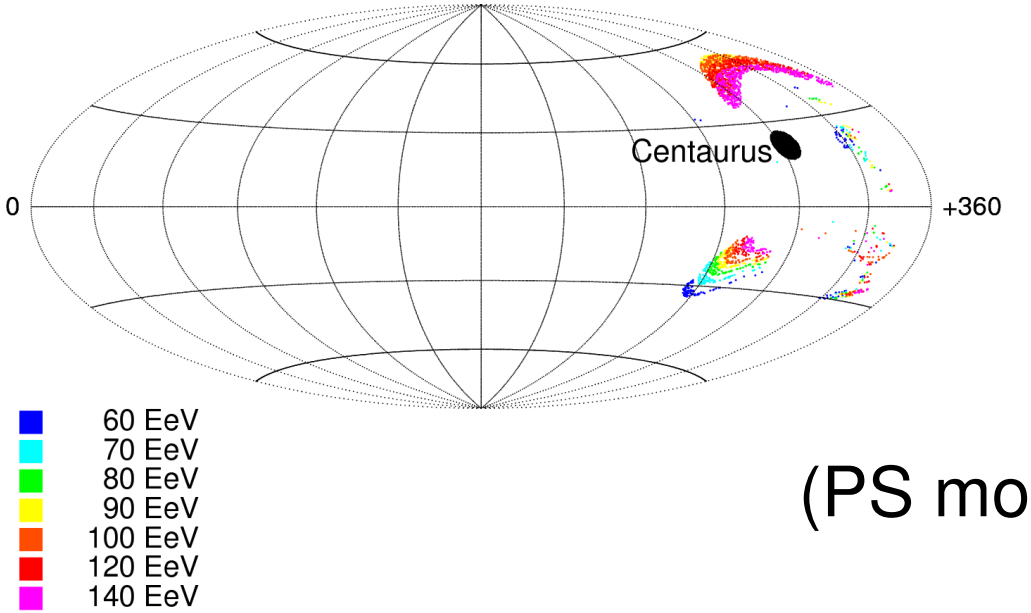


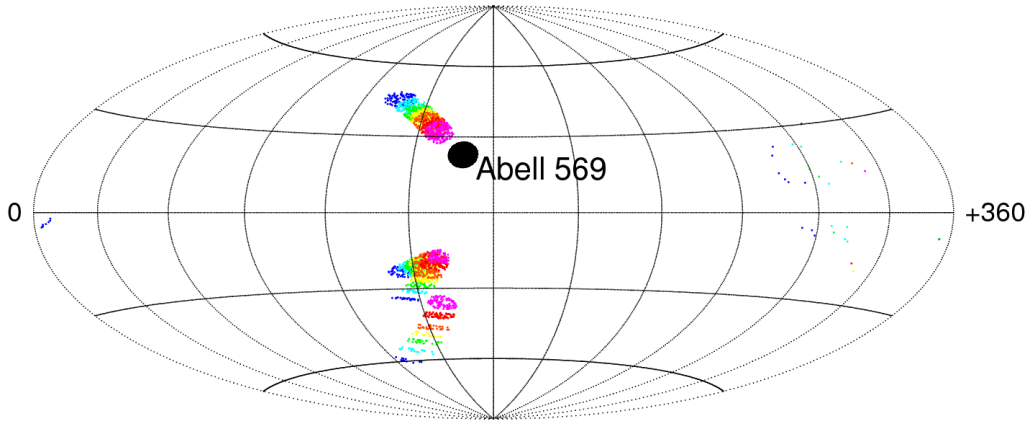
60 EeV
70 EeV
80 EeV
90 EeV
100 EeV
120 EeV
140 EeV

(PS model)

- Small deflections in EGMF -> See clusters as extended sources

Fe images of nearby galaxy clusters

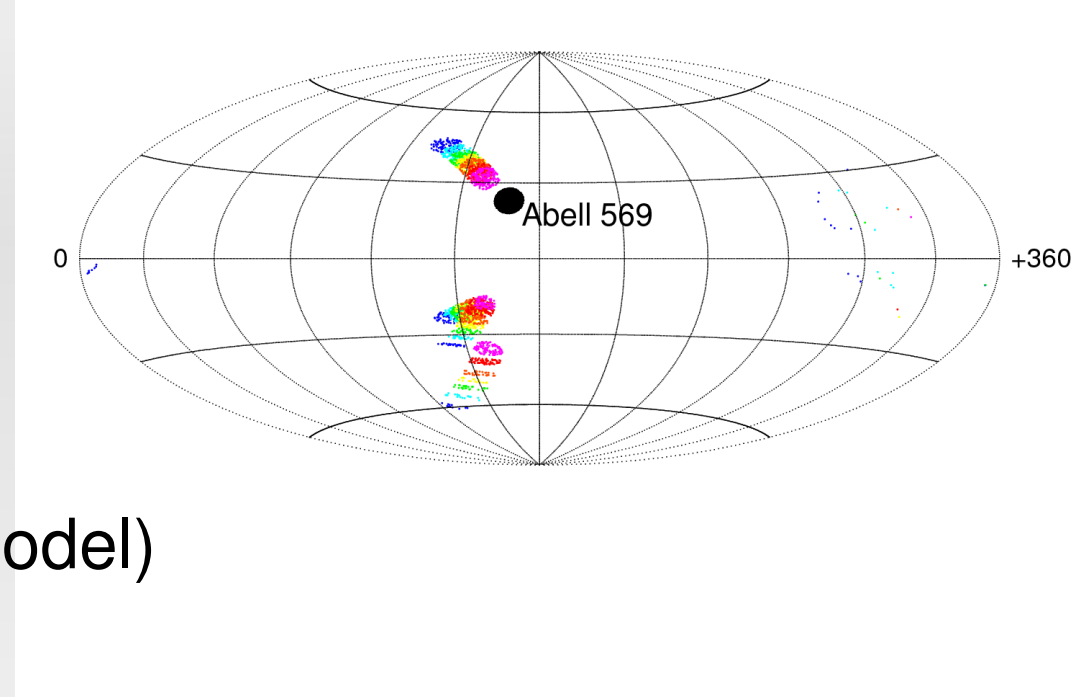




(PS model)

- Multiple distorted images
- Energy ordering often far from 1/E
- Images (dis-) appear above E thresholds / Merge

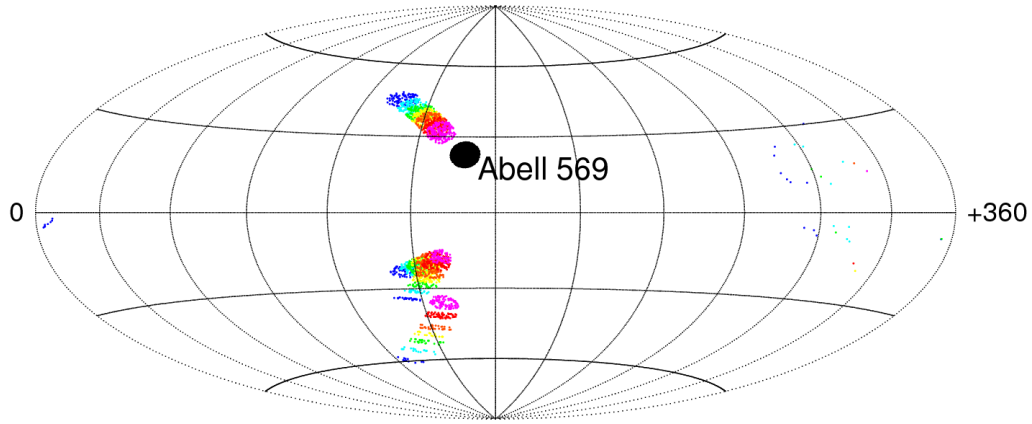
Model-dependence



(PS model)

Model-dependence

- **In most cases**, a better knowledge of the GMF than available is necessary to find UHE heavy nuclei sources **-> Modeling of the GMF; + future data LOFAR, SKA.**



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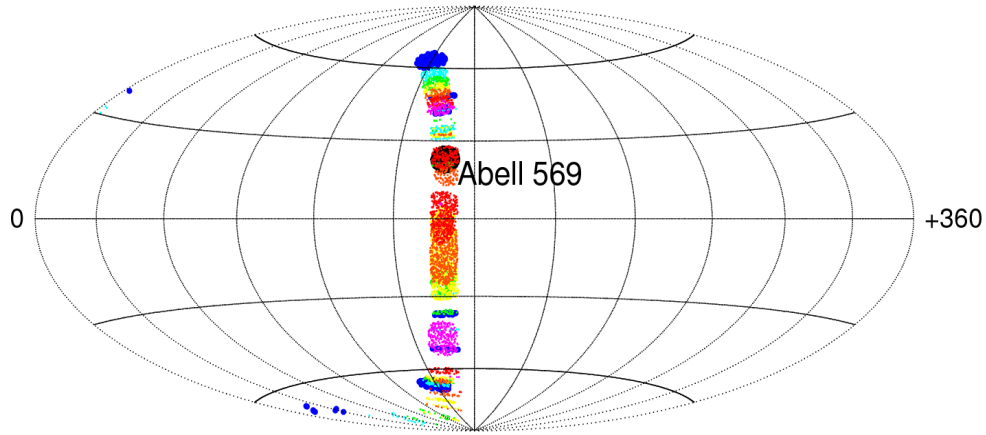

(Pshirkov *et al.* ASS model)

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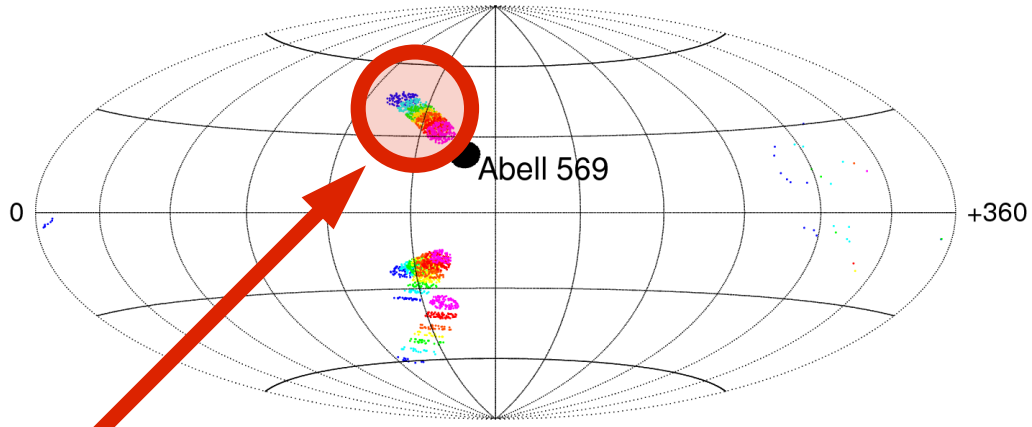
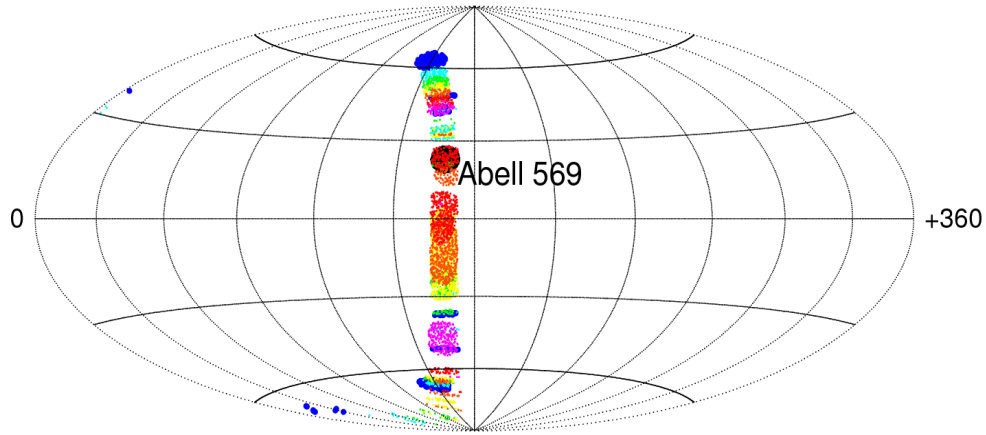


(PS model)

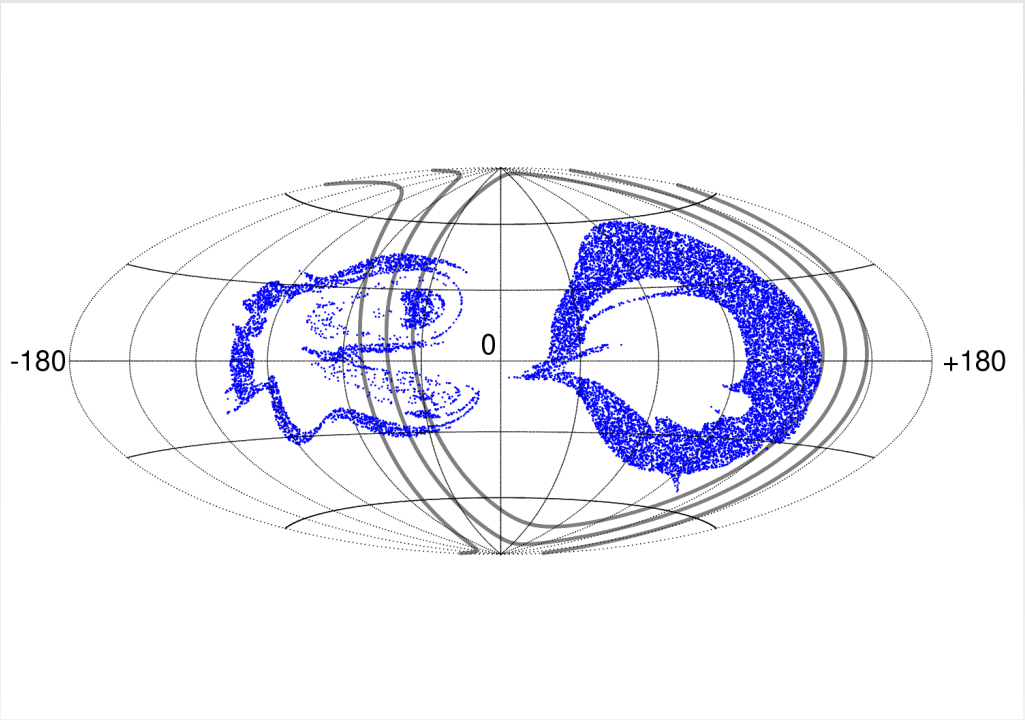
- In a few favorable cases, enlarged proton-like images may exist



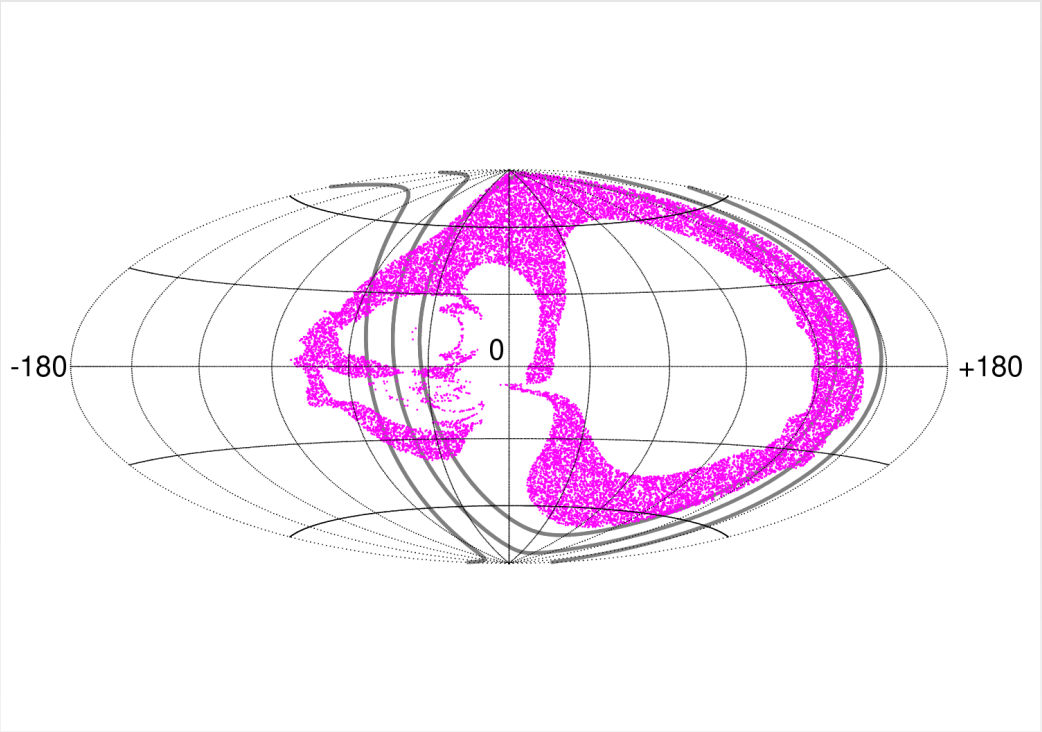
(Pshirkov *et al.* ASS model)

Supergalactic plane image

- (Large deflections in EGMF)



60 EeV Fe



140 EeV Fe

(PS model)

Supergalactic plane image

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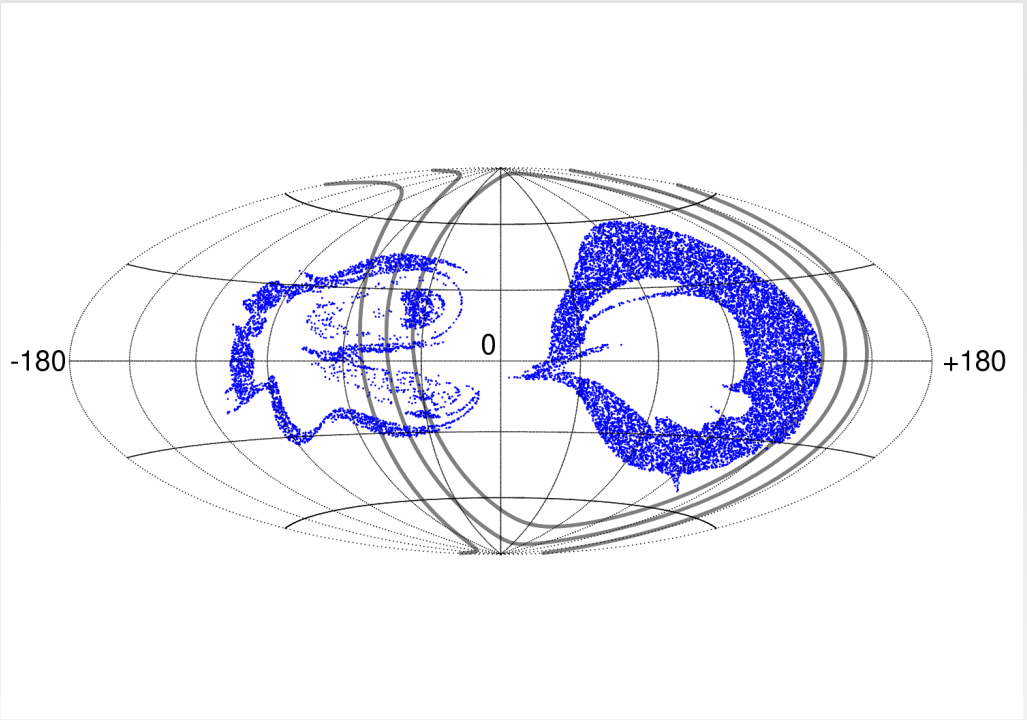

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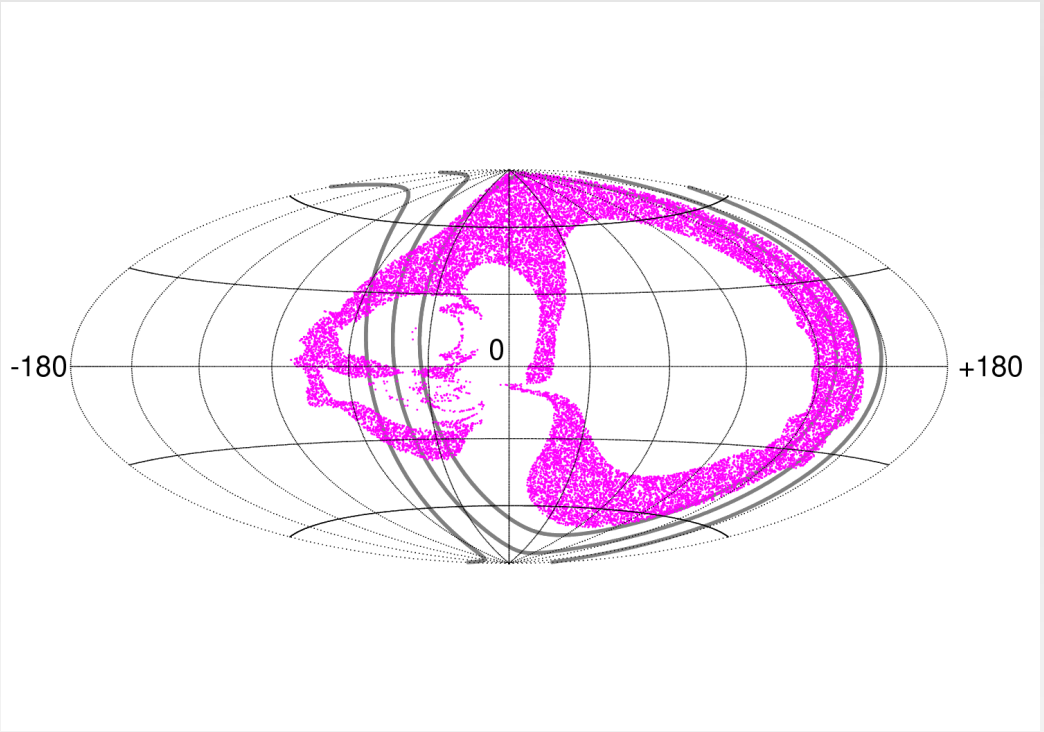
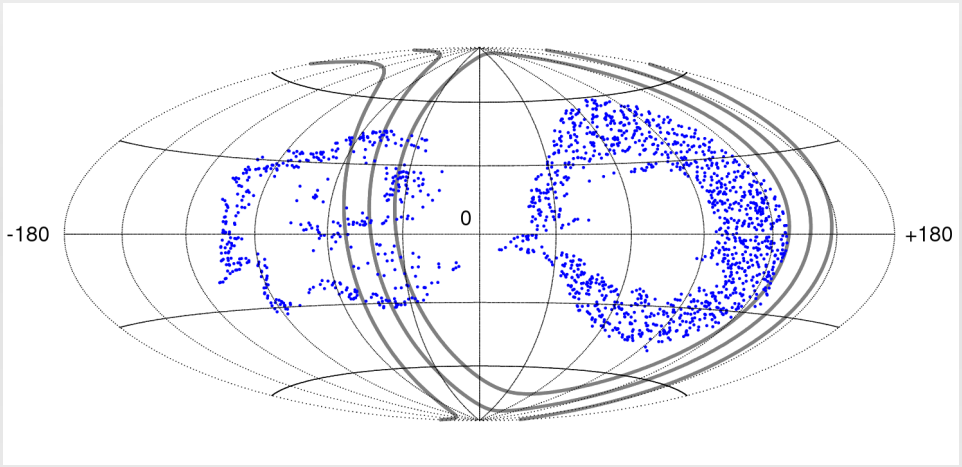


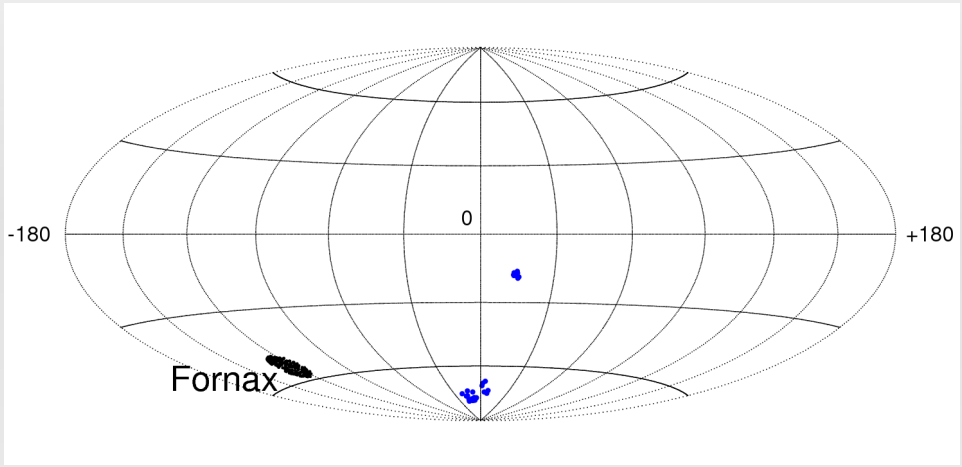
140 EeV Fe

Pure iron and anisotropic !

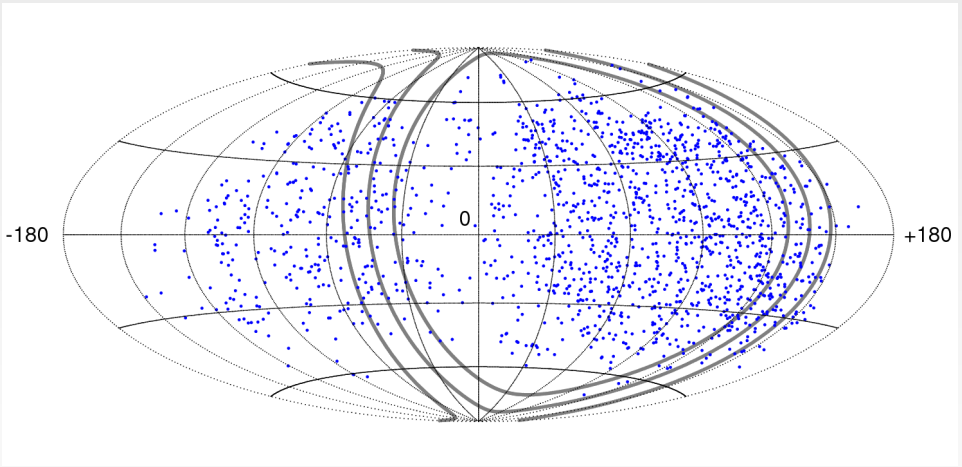
(PS model)

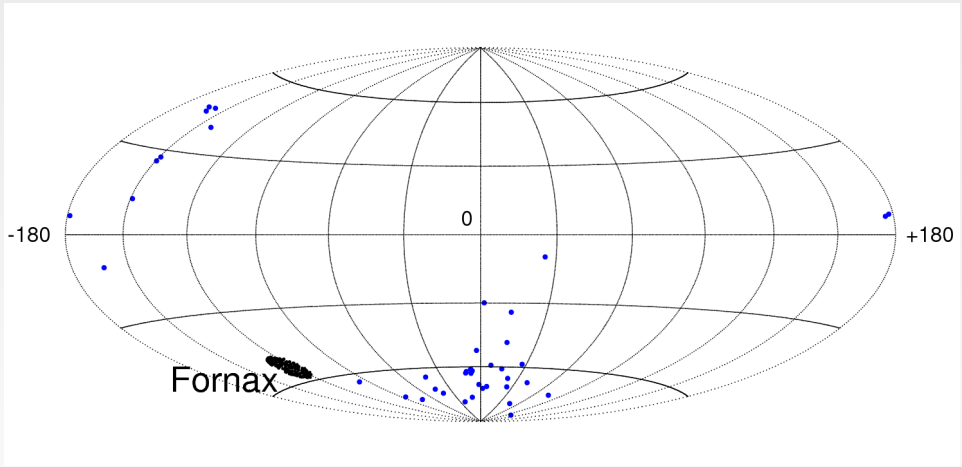
Impact of the turbulent GMF





$B_0 = 0\ \mu G,\ z_0 = 0$ kpc



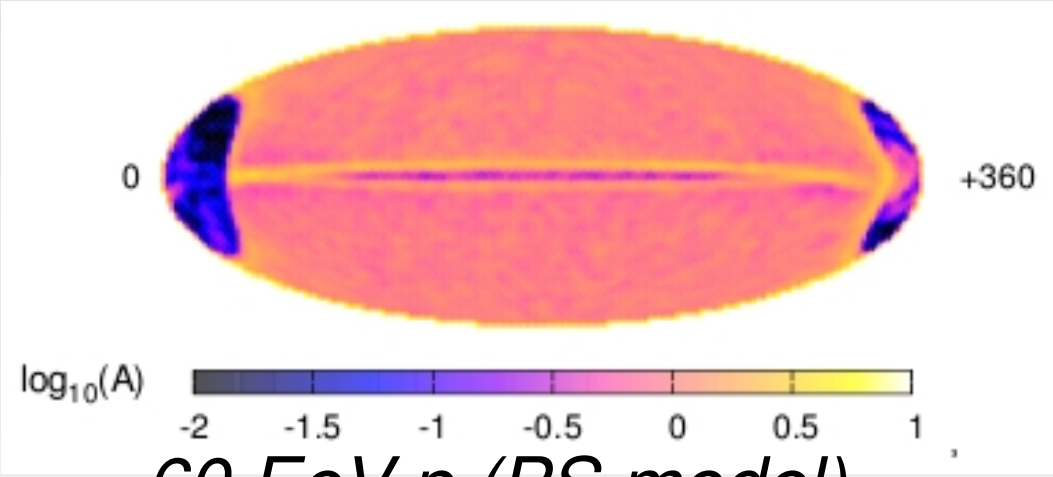


$B_0 = 4\ \mu G,\ z_0 = 3$ kpc

II – (De-)magnification of nuclei source fluxes - Magnetic lensing

(De-)magnification of fluxes

- Due to **magnetic lensing effects** in the GMF, the fluxes of sources is multiplied by a factor **A**. A(<)>1: (de)magnification



60 EeV p (PS model)

- Negligible in most of the sky for UHE p

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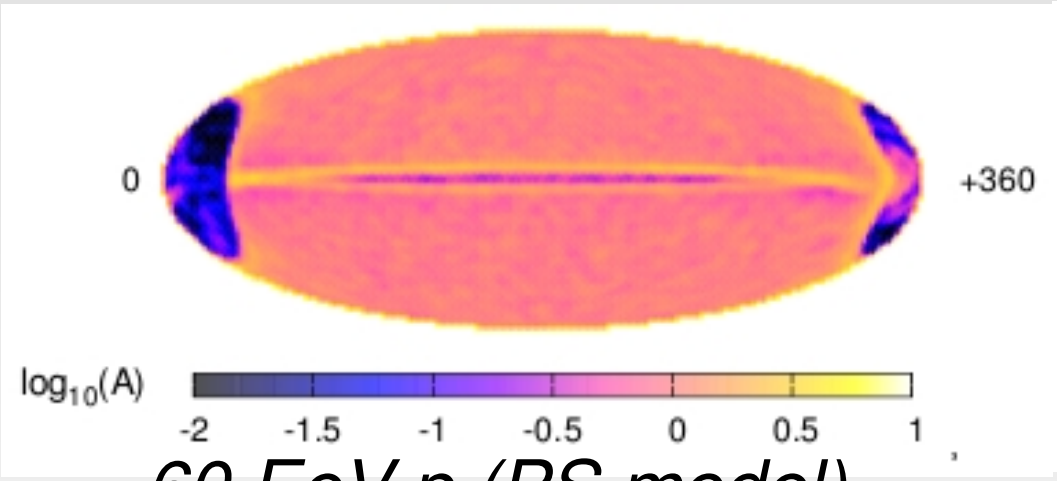
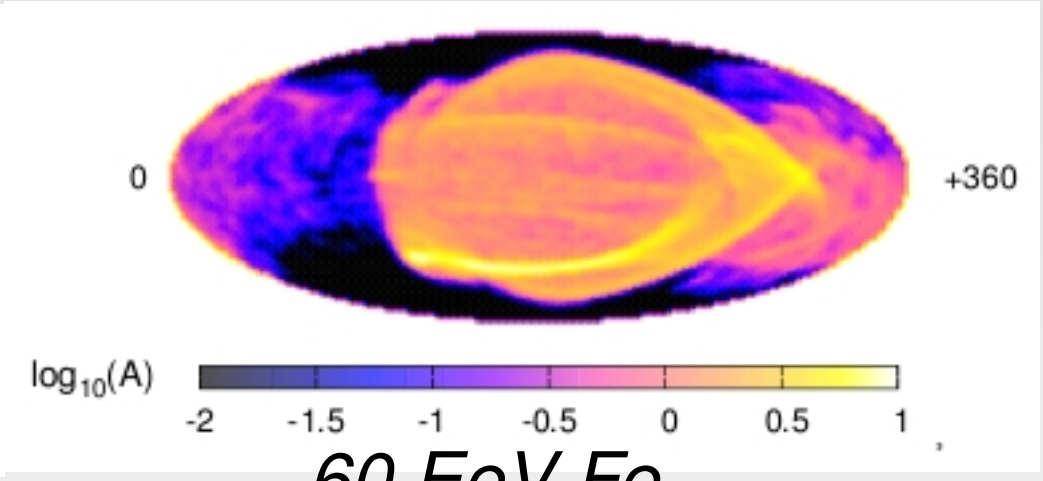
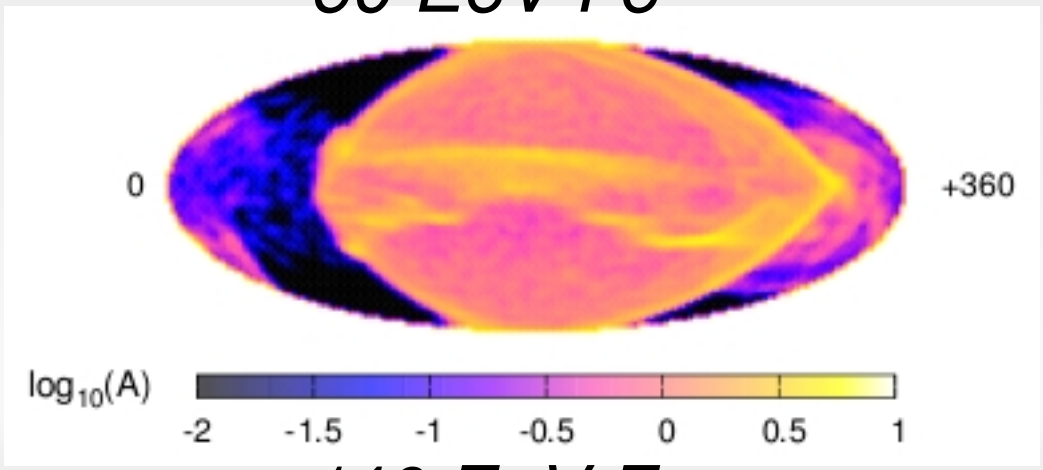


60 EeV p (PS model)



60 EeV Fe

- Negligible in most of the sky for UHE p
- Significant for Fe



140 EeV Fe

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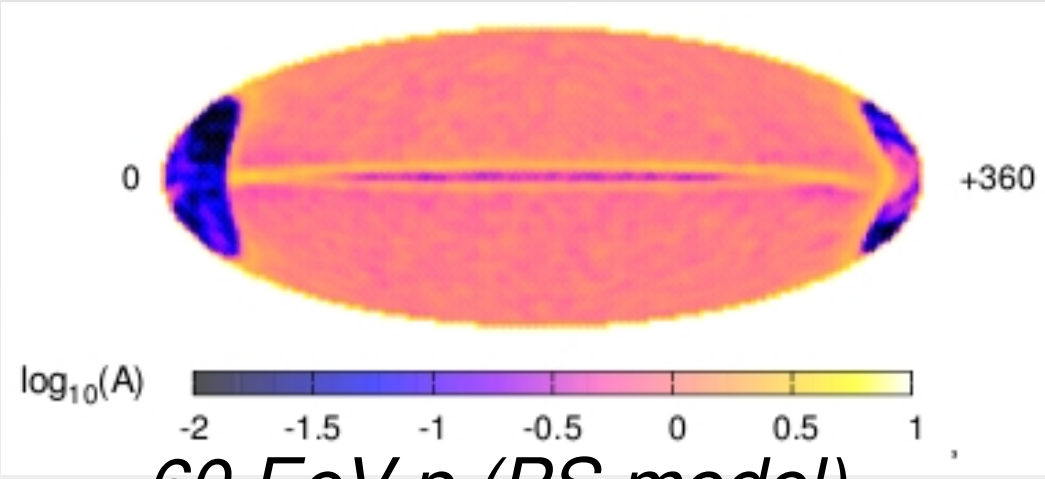
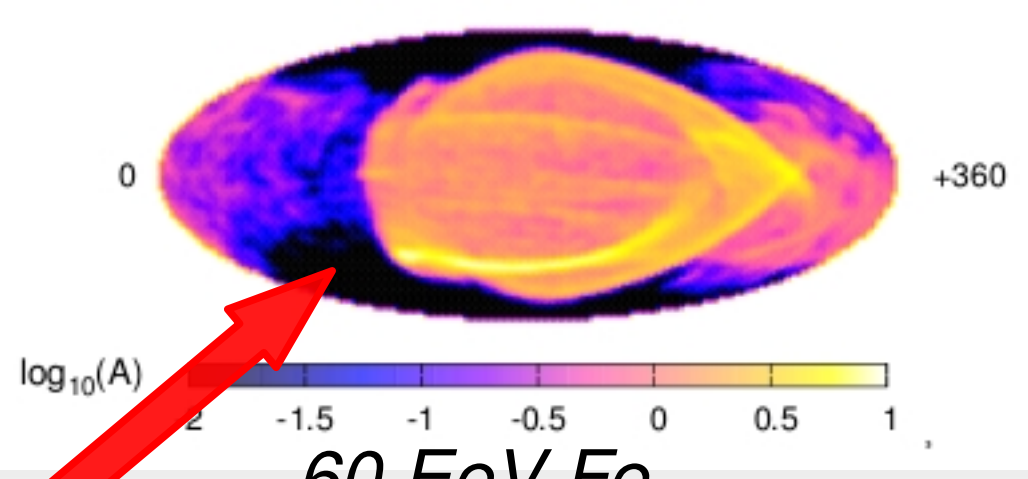
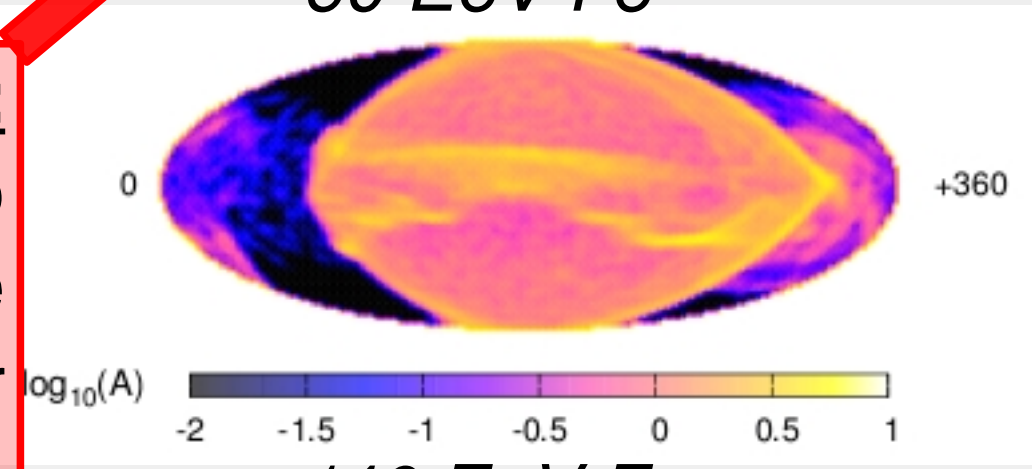


60 EeV p (PS model)



60 EeV Fe

- **« Blind regions » (A<1/100):** 60EeV Fe sources in up to **~20-25% of the sky** would be **undetectable** by present/near future experiments.



140 EeV Fe

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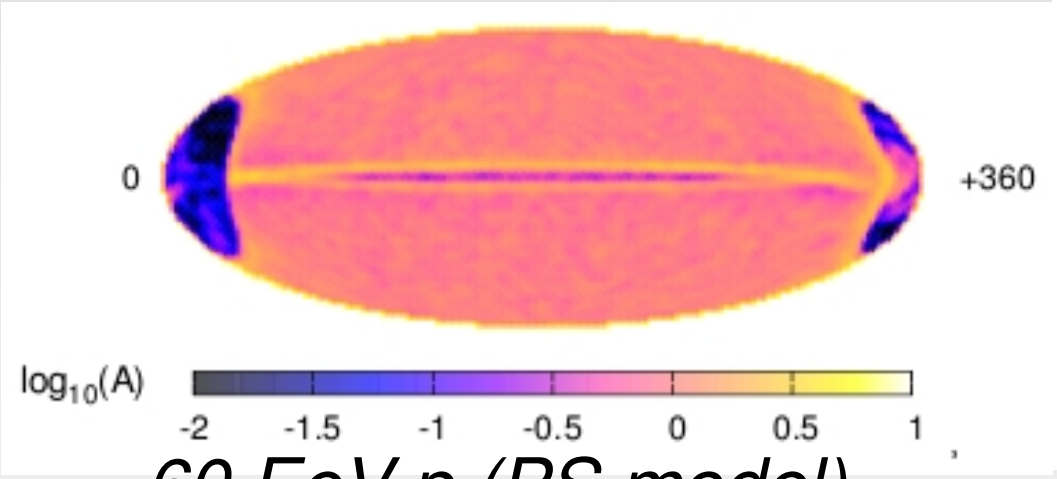
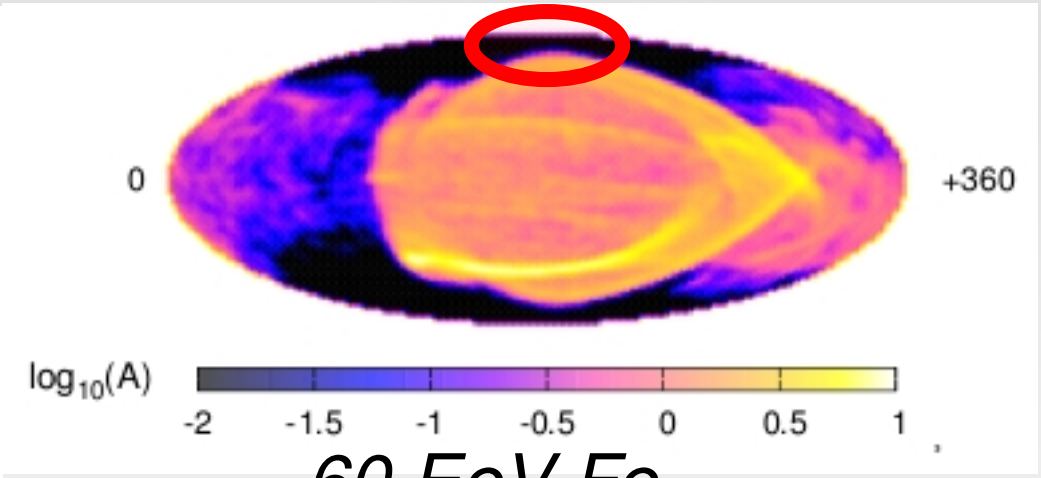


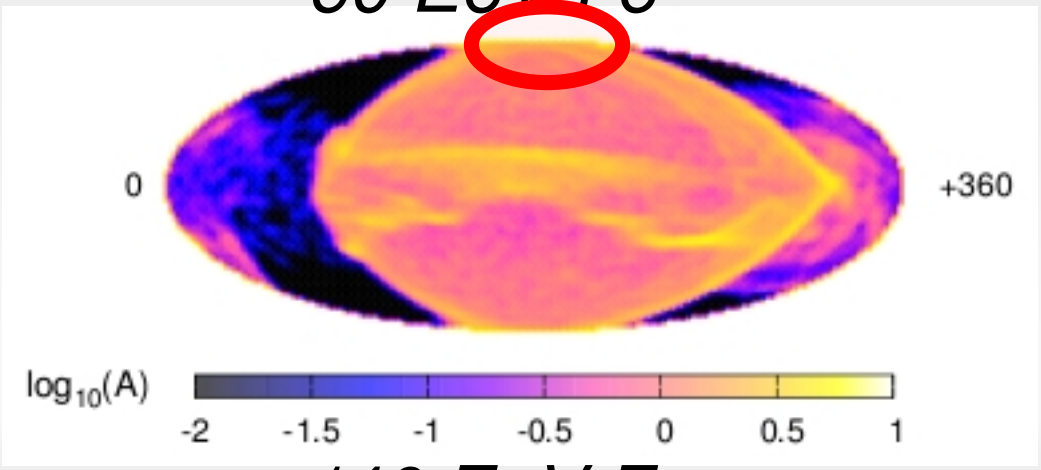
60 EeV p (PS model)



60 EeV Fe

- **Spectra distortion:**

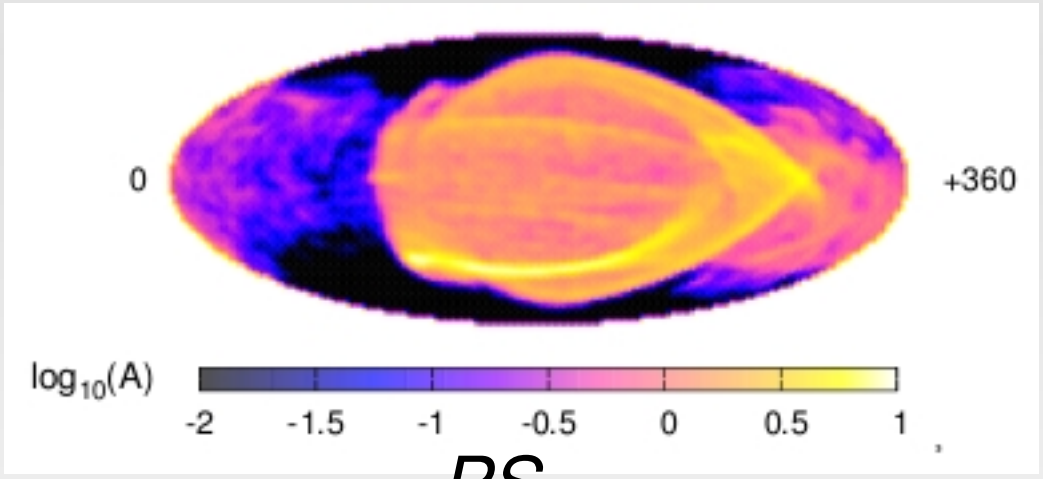
A is a function of E.



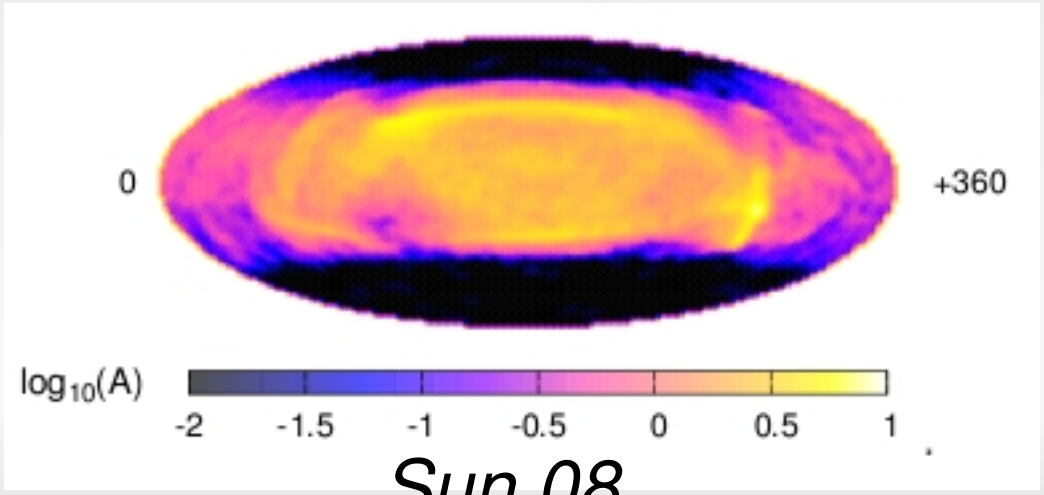
140 EeV Fe

Model-dependence

- Sky maps model-dependent



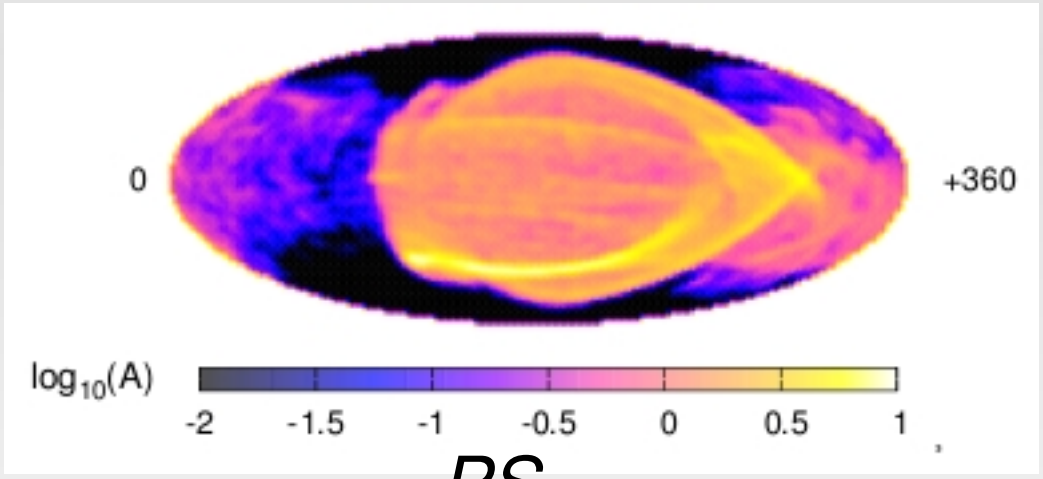
PS



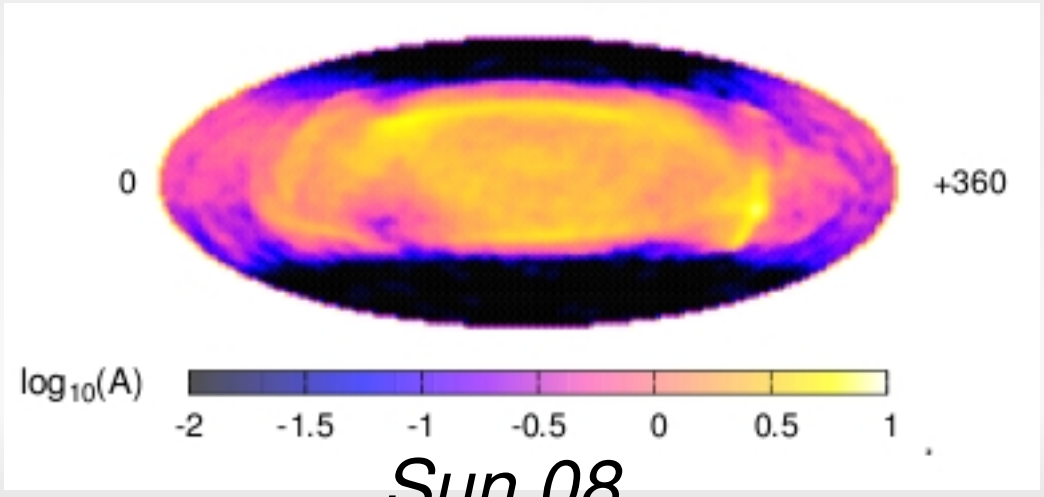
Sun 08

Model-dependence

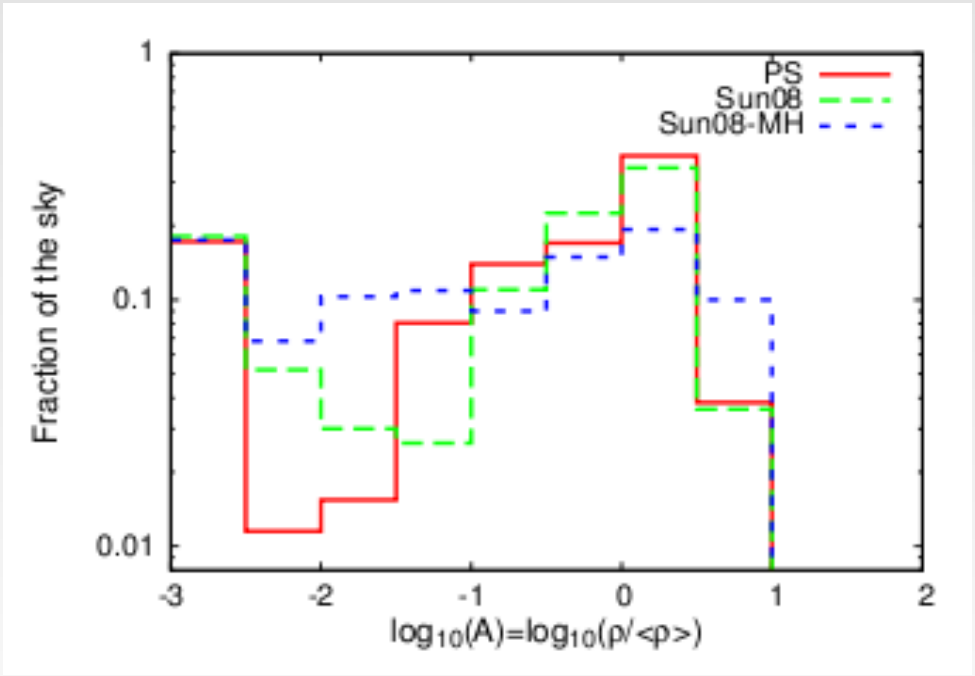
- Sky maps model-dependent
- Fractions of sky with given A less model-dependent



PS

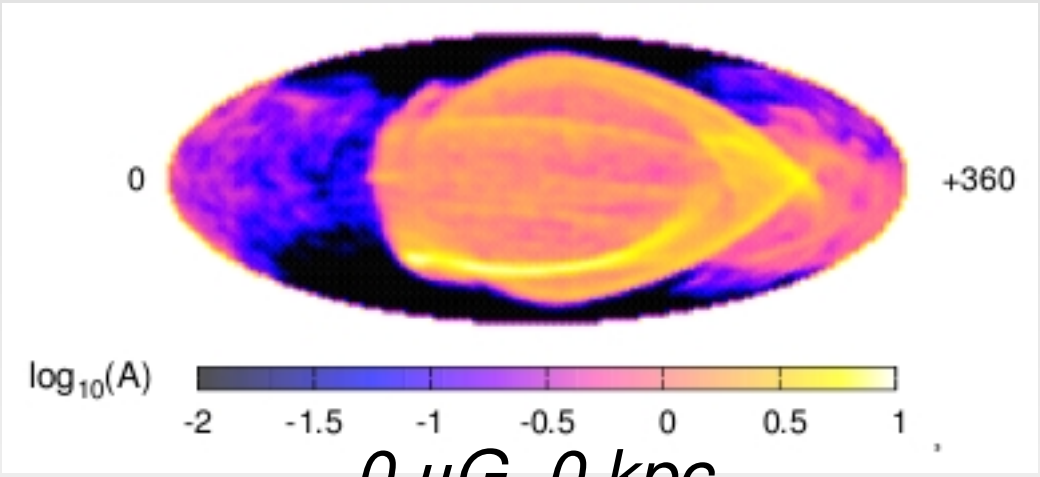


Sun 08

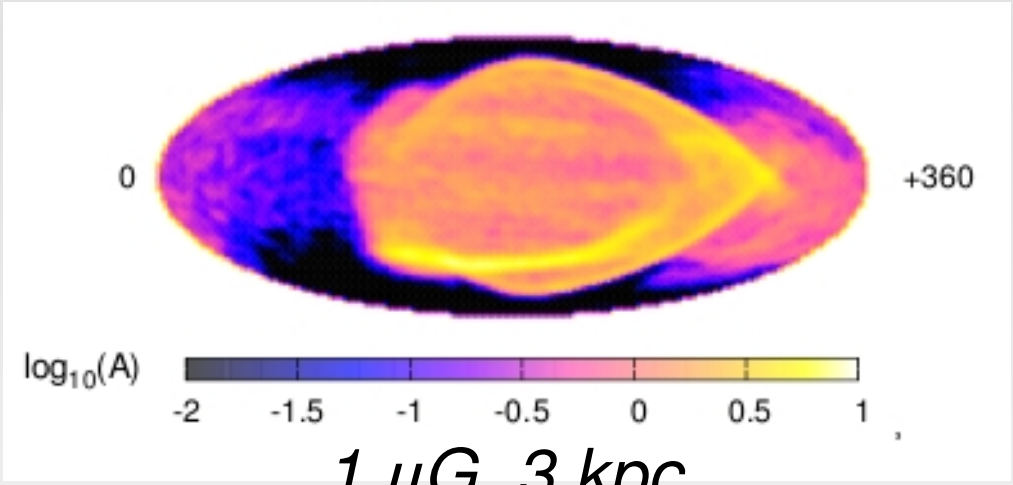


Impact of the turbulent component

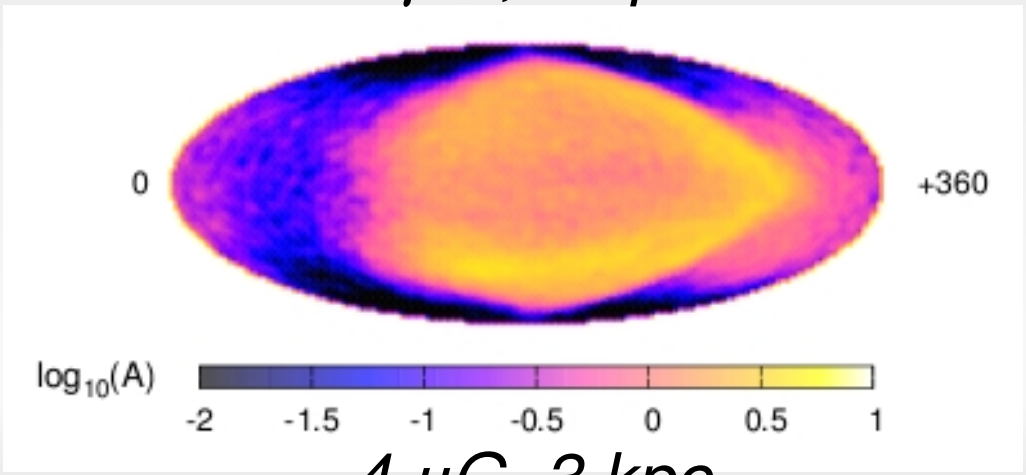
- Increasing turbulent field RMS strength and extension in the halo **reduce regions of extreme (de-) magnification**.



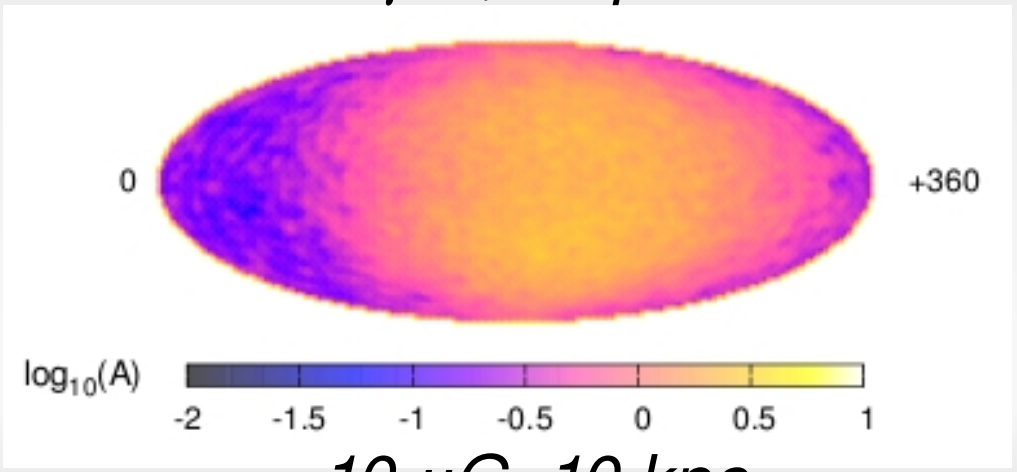
0 μG, 0 kpc



1 μG, 3 kpc



4 μG, 3 kpc



10 μG, 10 kpc

Conclusions

- We have studied the propagation of iron nuclei with E>60EeV in recent GMF models. -> Differences may give additional information on the composition

- Source searches: No one-to-one correspondance between directions on extragalactic sky and sky at Earth. Better knowledge of the GMF often needed.
LOFAR / SKA will improve it.
Maybe 1,... enlarged proton-like image(s)...

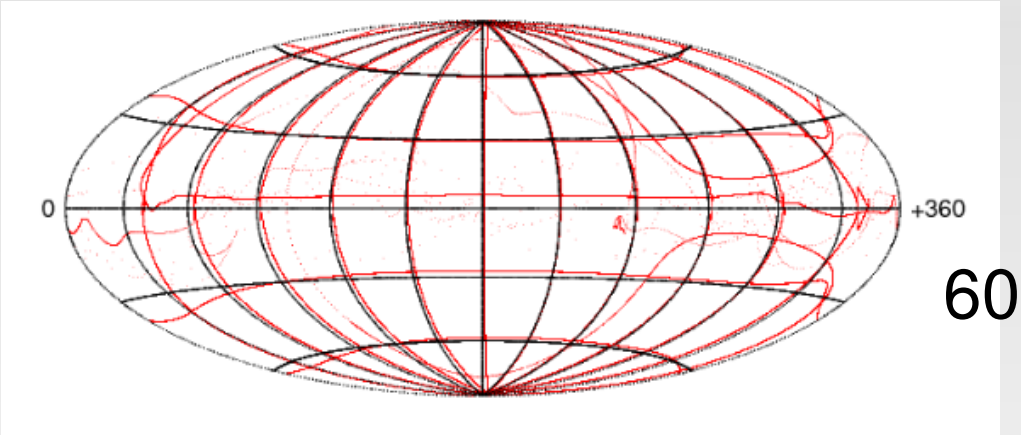
- Magnetic lensing effects substential. Large (de)magnification. Sources located in a non-negligible fraction of the sky would not contribute to the flux detected at Earth. Spectrum distortion.

- Direction 'to go' : *Large statistics above ~ 50 – 60 EeV.*

Backup slides

« Sky sheets » backtraced

- Backtrace « sky sheets » from the Earth to outside the Galaxy, see works of D. Harari *et al.*

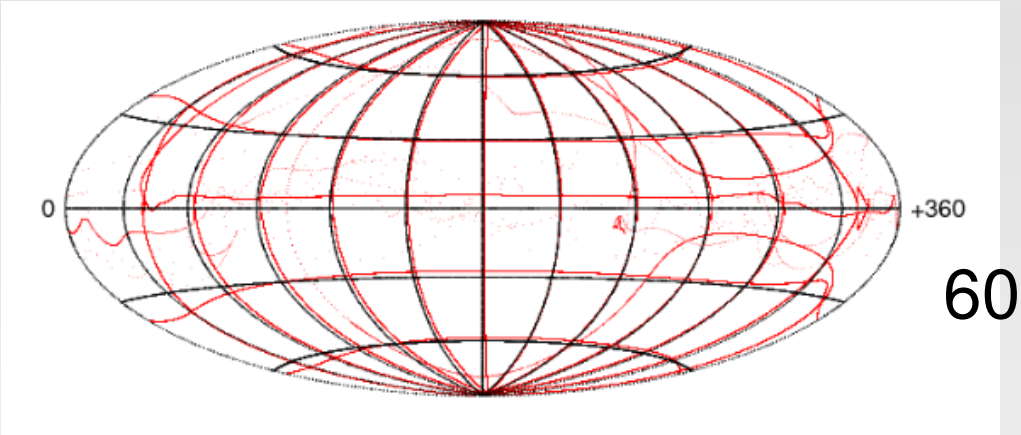


60 EeV p

(PS model)

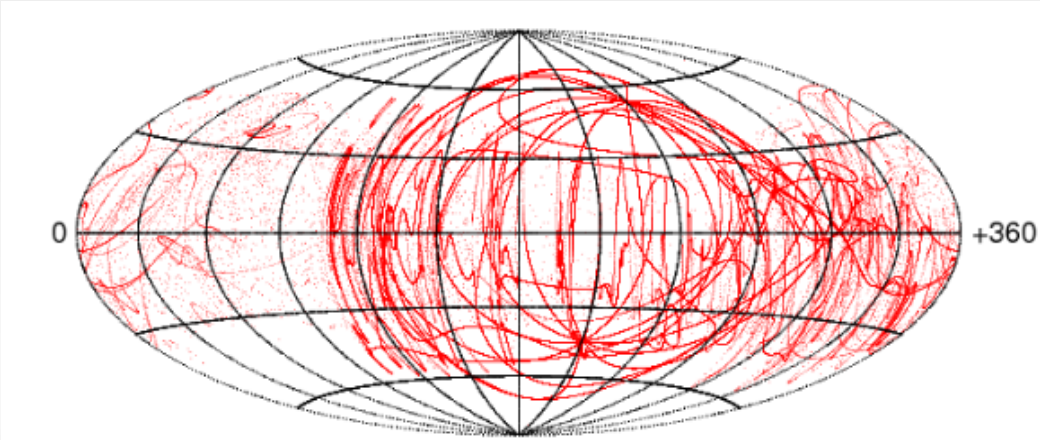
« Sky sheets » backtraced

- Backtrace « sky sheets » from the Earth to outside the Galaxy, see works of D. Harari *et al.*

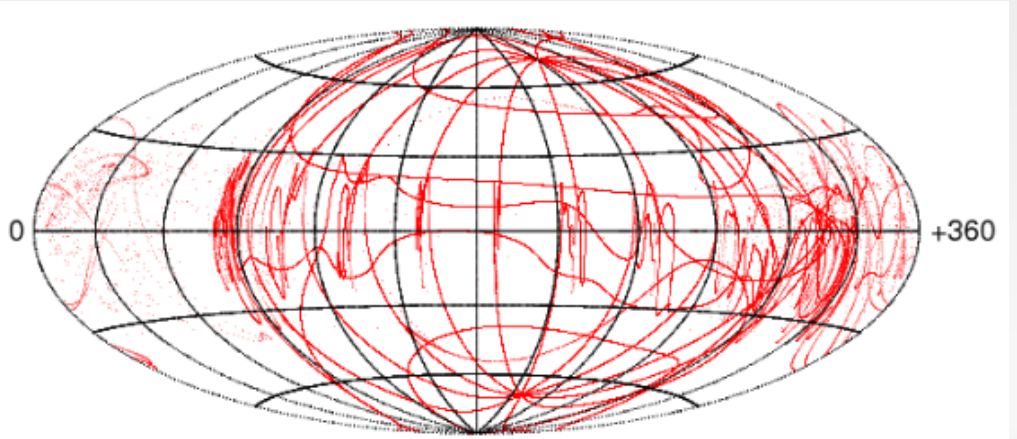


60 EeV p

(PS model)



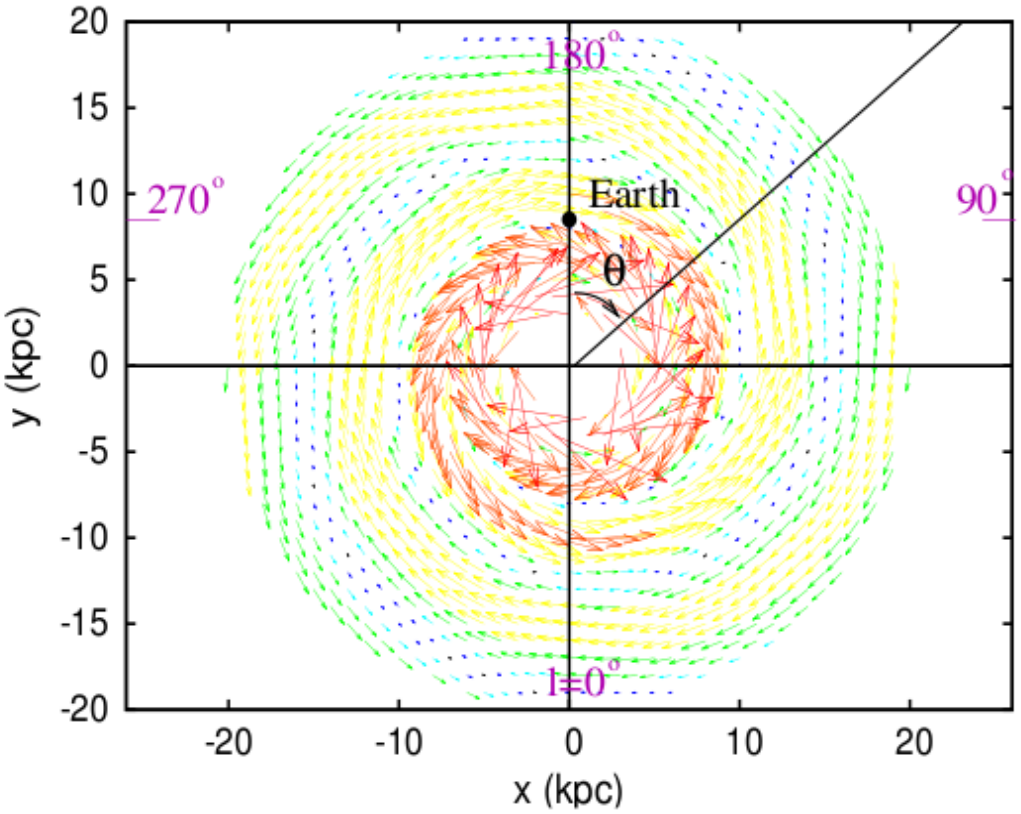
60 EeV Fe



140 EeV Fe

Galactic Magnetic Field

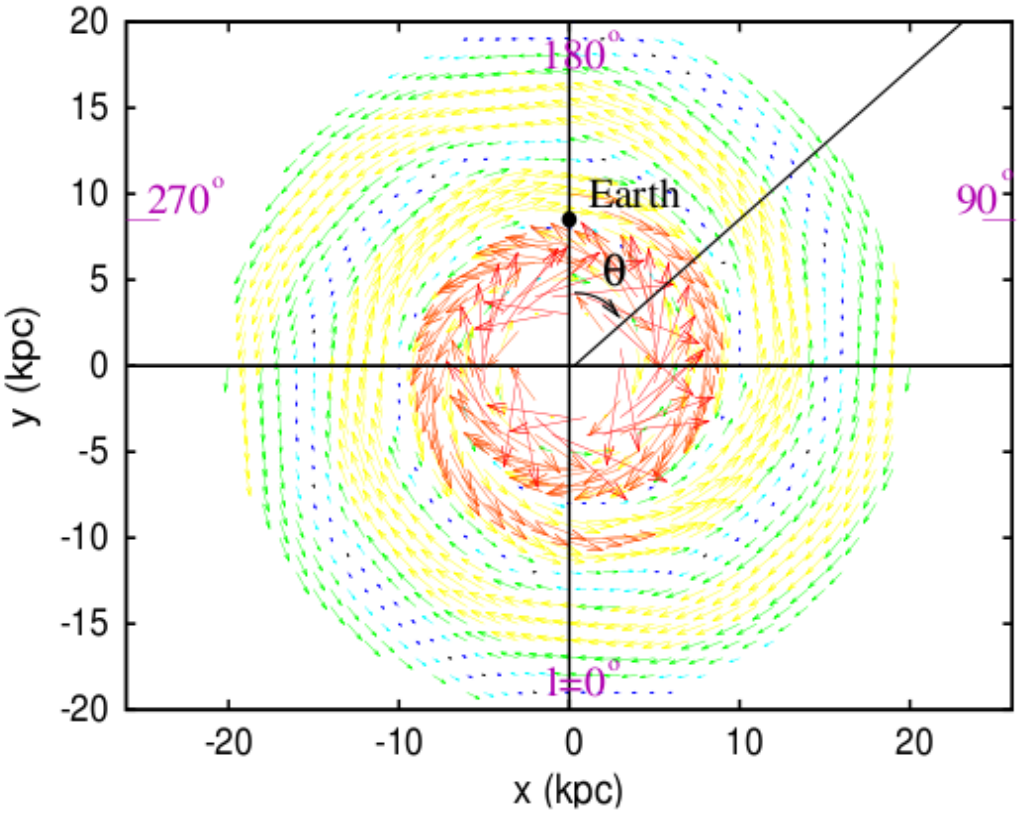
-> Regular component :



Prouza and Smida (PS) **disk** model astro-ph/0510444

Galactic Magnetic Field

-> Regular component :

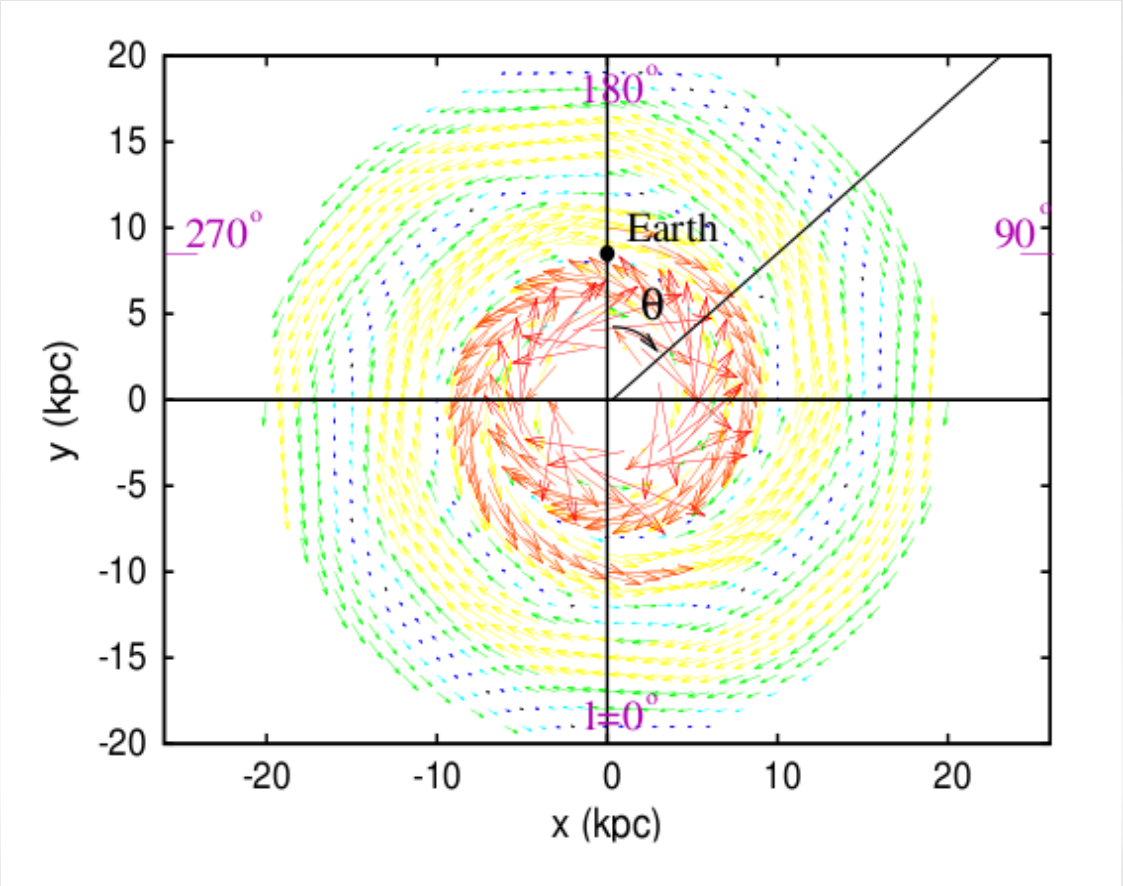


Prouza and Smida (PS) **disk** model astro-ph/0510444

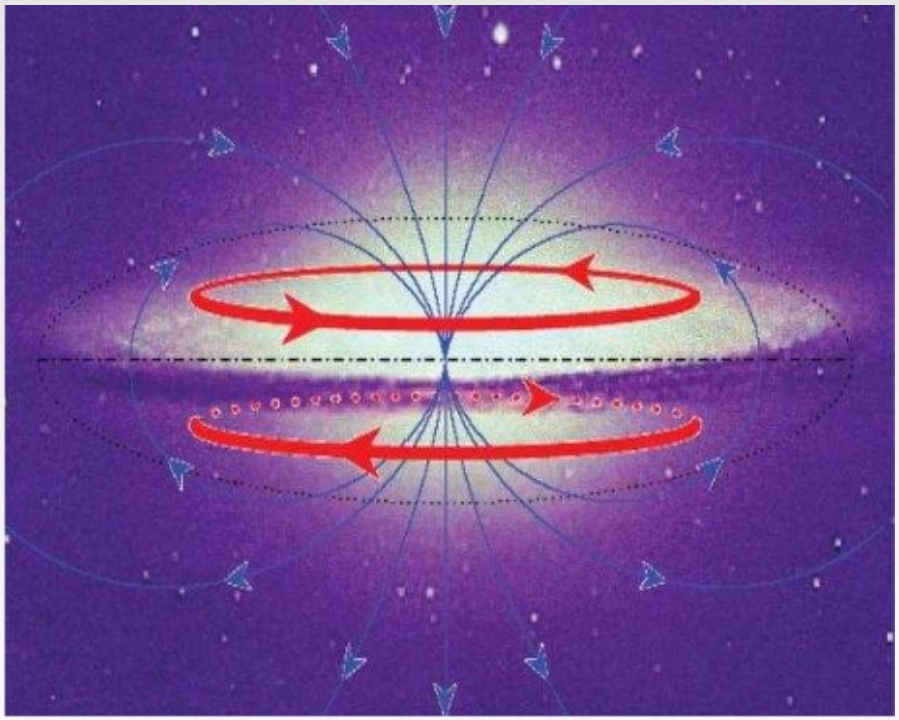
... and several other proposed geometries: RING, ASS, ...

Galactic Magnetic Field

-> Regular component :



In the halo...

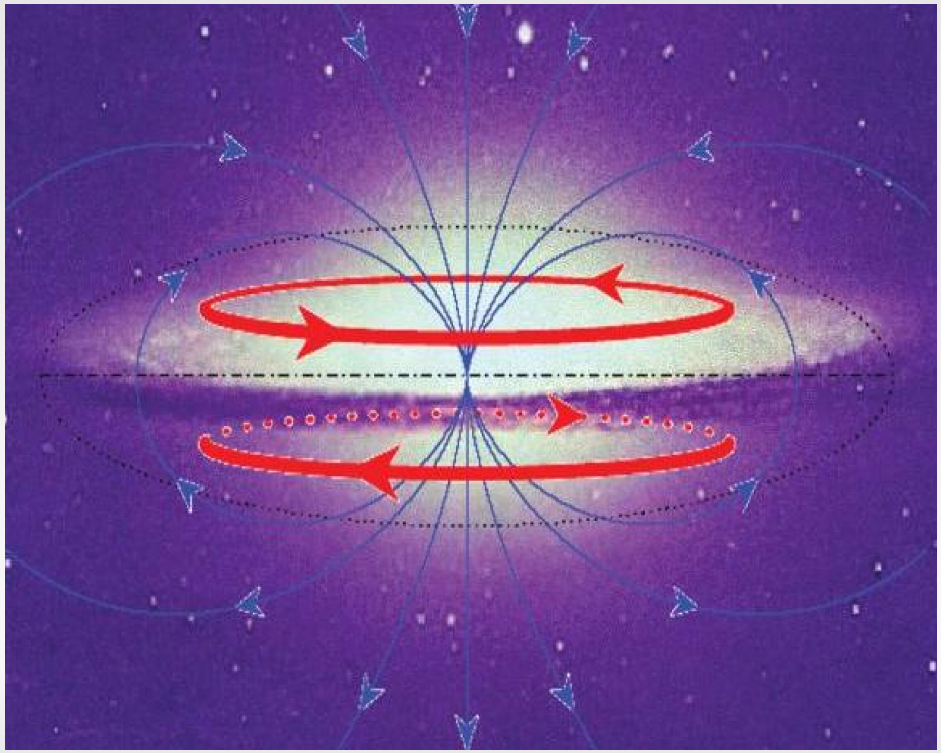


J.L. Han arXiv:0901.0040

UHE nuclei in the GMF

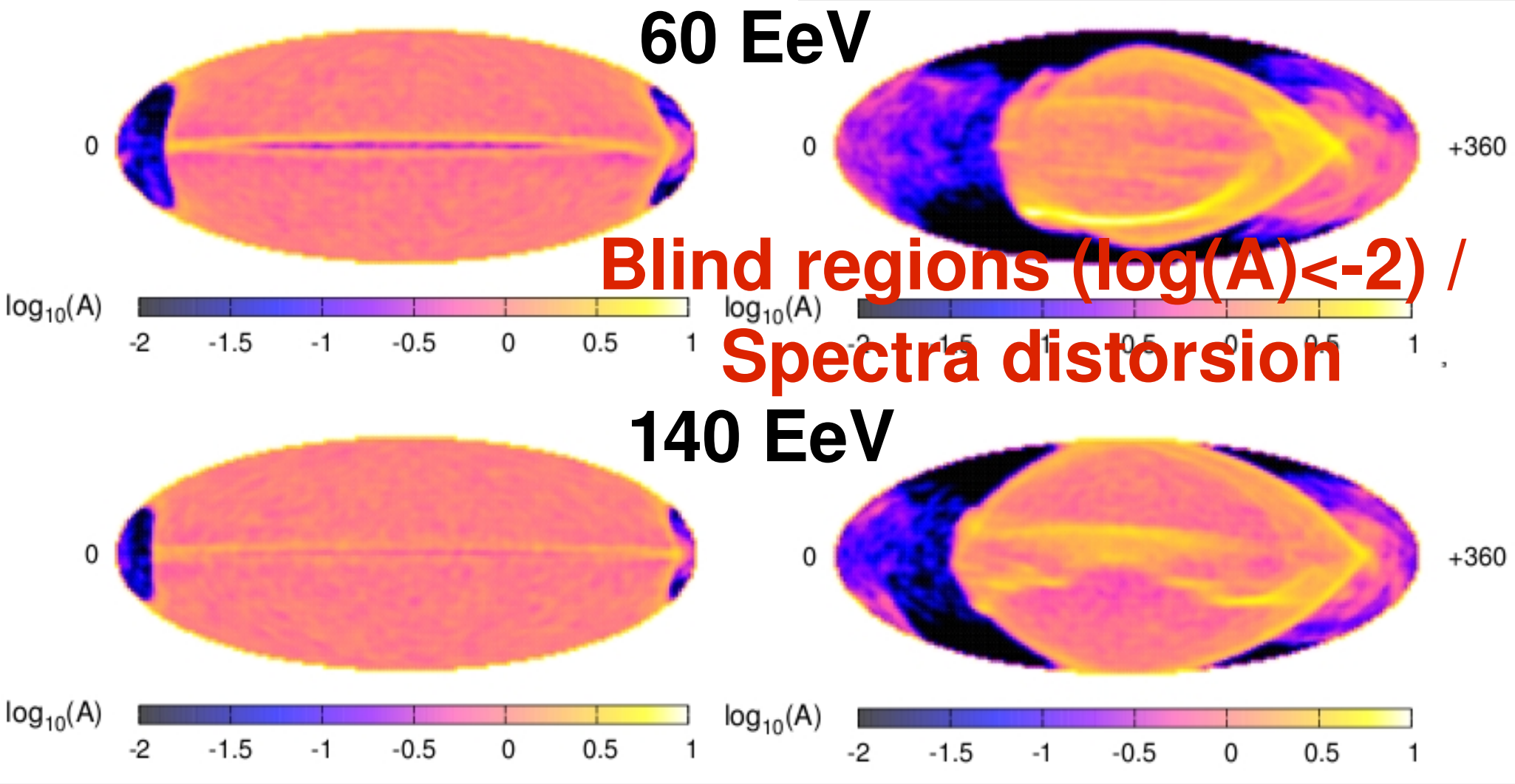
- Galactic magnetic field still poorly known. Test the model-dependence :

-> Regular component :

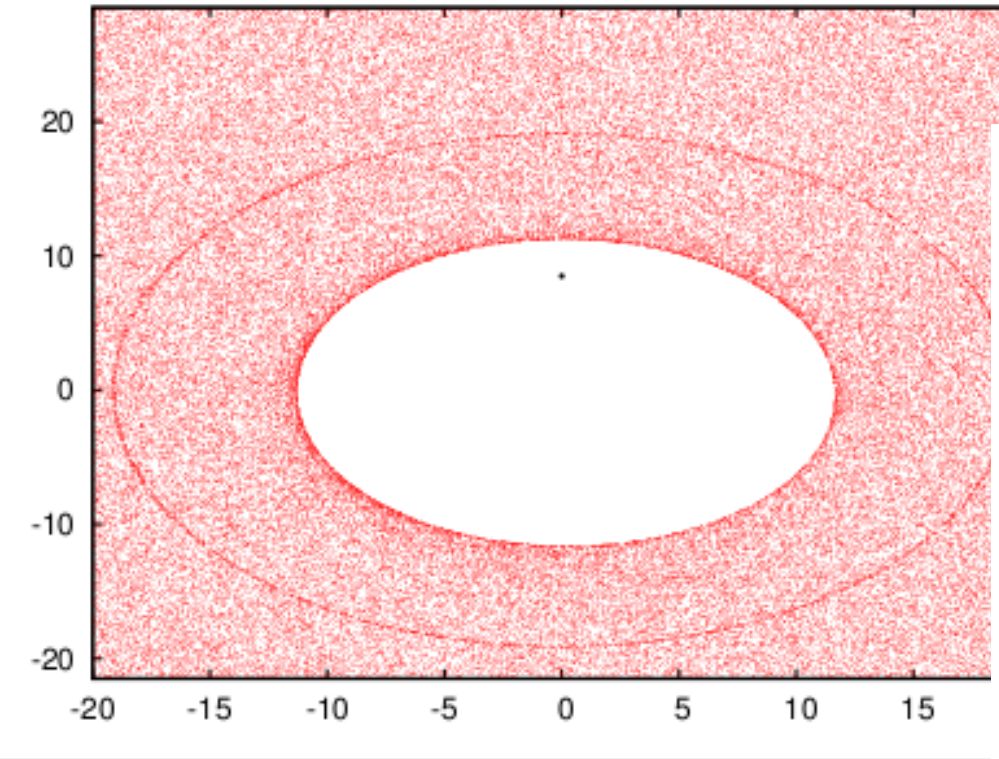


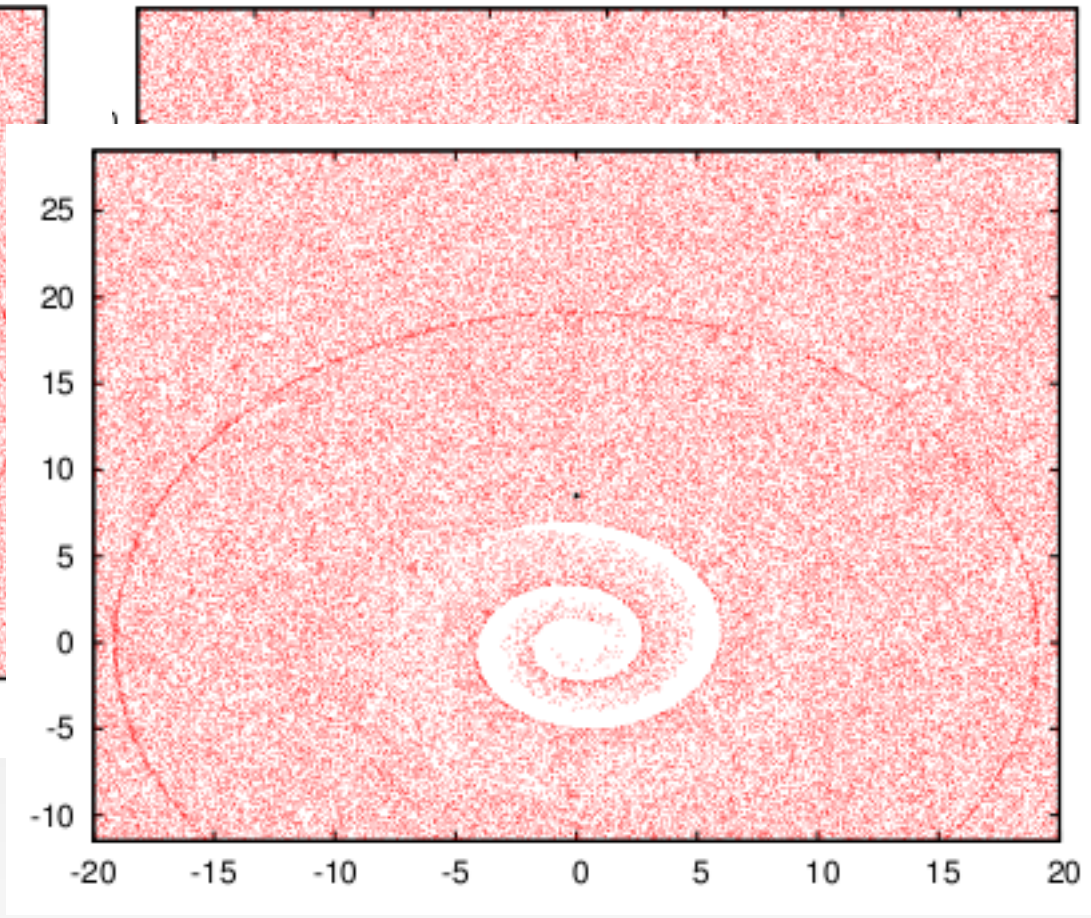
J.L. Han
arXiv:0901.0040

2) (De-) magnification of source fluxes; Blind regions :



2) (De-) magnification of source fluxes; Blind regions :





60 EeV

PS model without dipole

2) (De-) magnification of source fluxes; Blind regions : « Model-dependence »

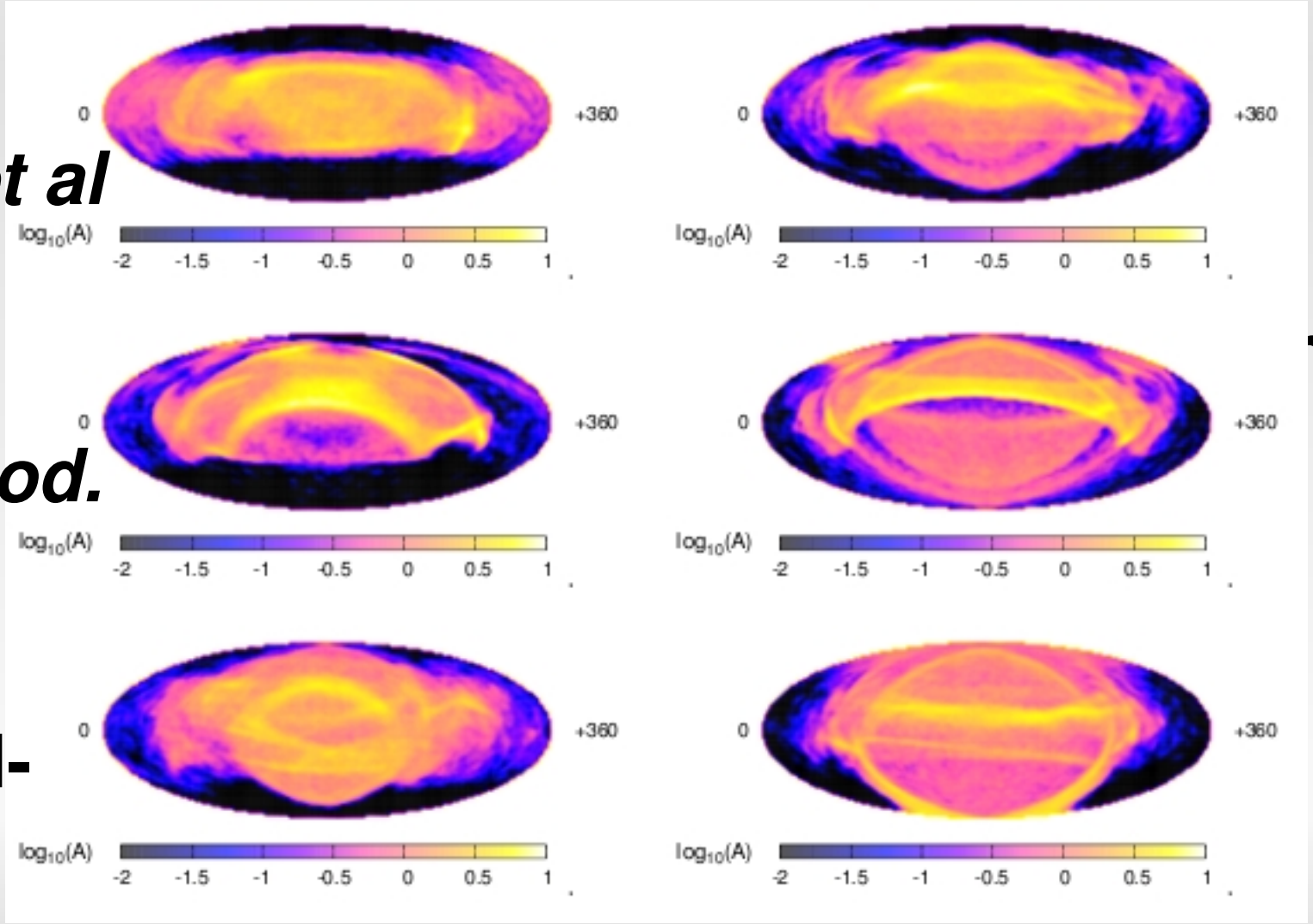
60 EeV 140 EeV

Sun *et al*

Sun *mod.*

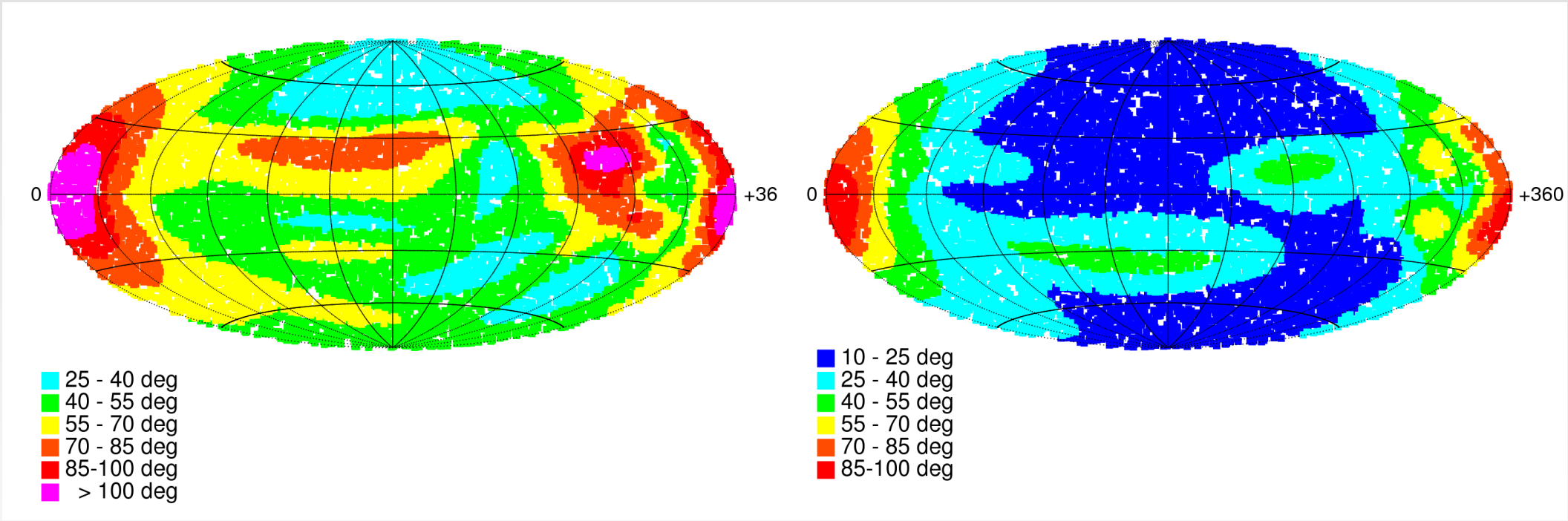
PTKN-ASS

Iron nuclei



Deflection angles for iron nuclei

- Recent GMF models predict ~ 50°- 60° average deflections on the sky for 60 EeV iron nuclei



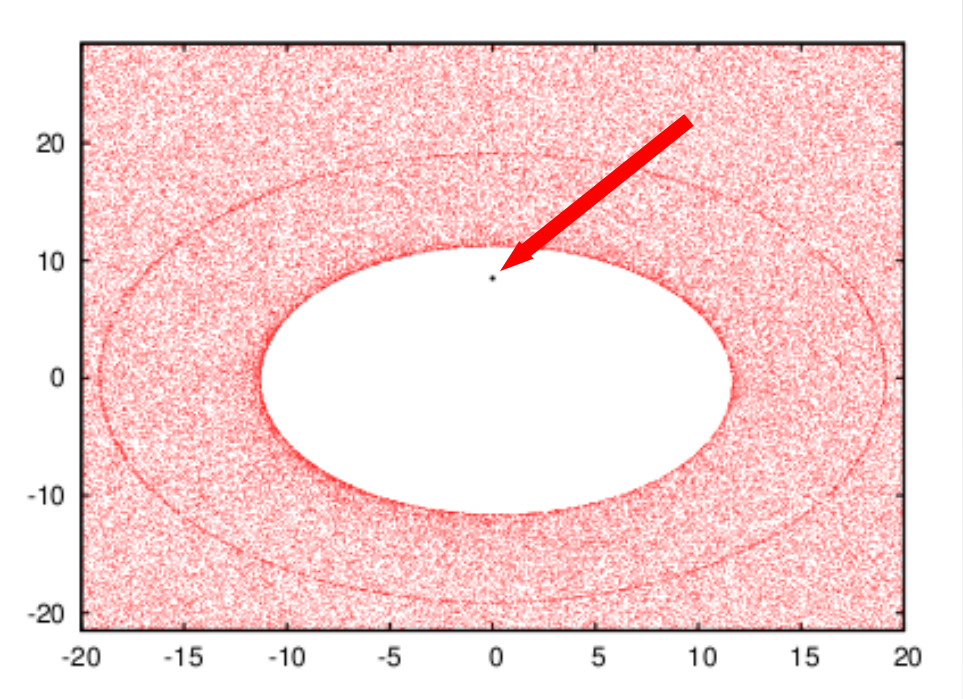
60 EeV

140 EeV

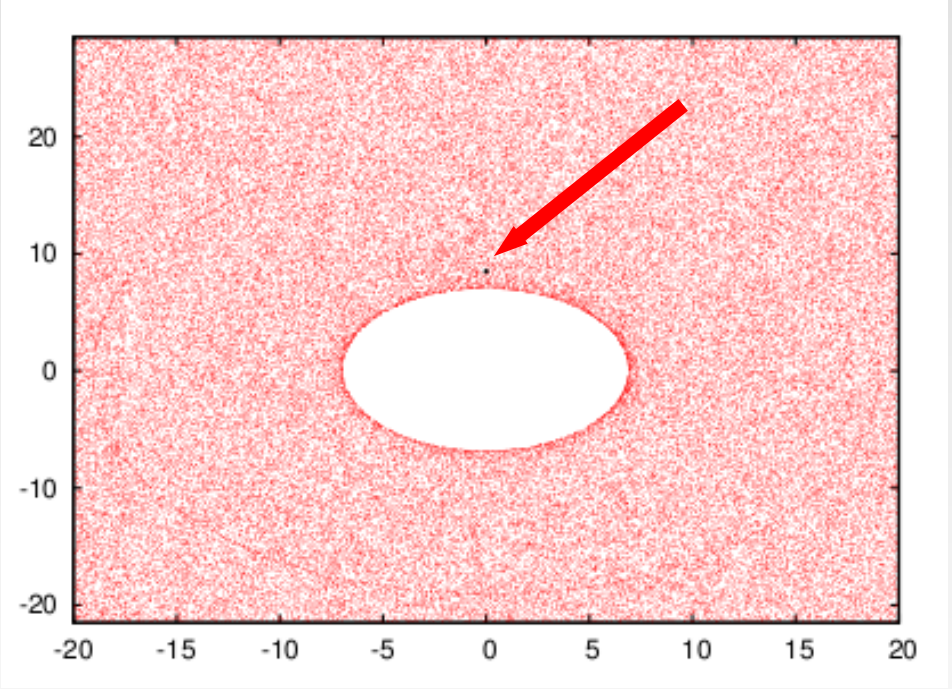
(PS model)

Paths of nuclei in the Galaxy

- Nuclei crossing the Galactic plane from a source at b=90° (PS model – **NOT** a generic example)



60 EeV



140 EeV

UHE nuclei in the GMF

- Galactic magnetic field still poorly known. Test the model-dependence :

-> Regular component : Take several recent models :

- Prouza and Smida (PS) *Astron. Astrophys.* ***410*** *(2003) 1*

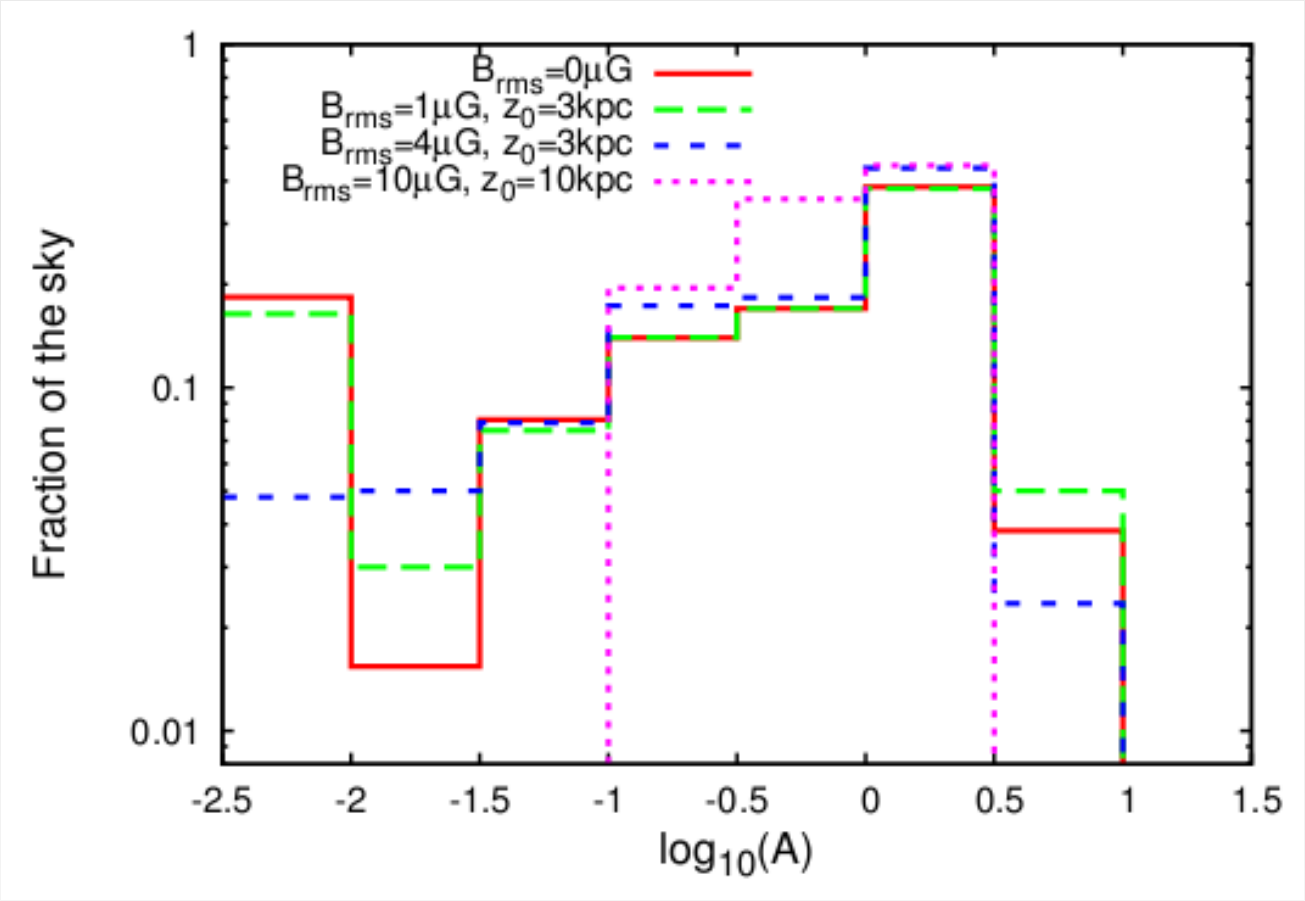
- Sun et al. (Sun 08) *Astron. Astrophys.* ***477****, 573 (2008)*

- Sun 08 – MH (modified halo)

Giacinti, Kachelriess, Semikoz, Sigl JCAP 1008,036 (2010)

- Pshirkov et al. ASS and BSS versions *arXiv:1103.0814*

Impact of the turbulent component



- Similar for all tested recent GMF models