Effects of the Galactic Magnetic Field on Observed Properties of Ultra-High Energy Cosmic Rays

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Outline

- Why do we study the Galactic Magnetic Fields (GMF)?
- What is known about the GMF?
- GMF models and cosmic ray composition
- Effects of the GMF on Ultra-High Energy Cosmic Rays (UHECR)
- UHECR anisotropy
- UHECR energy spectrum
- What do we learn?

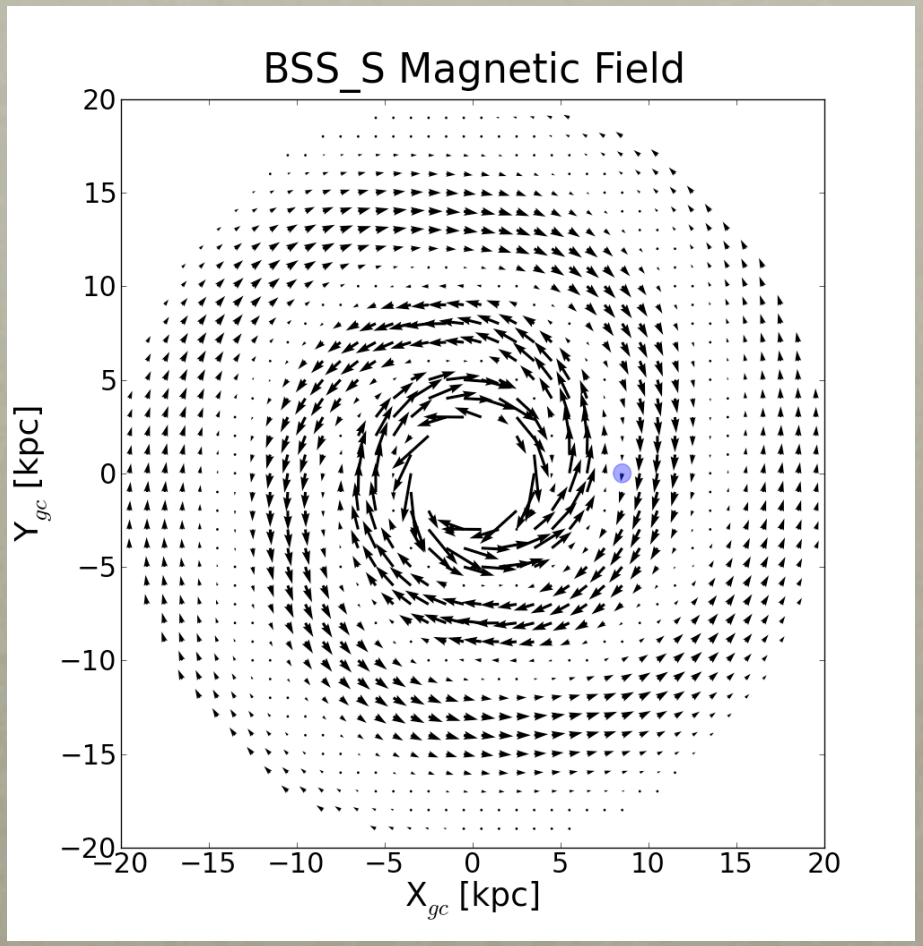
Why do we study the GMF?

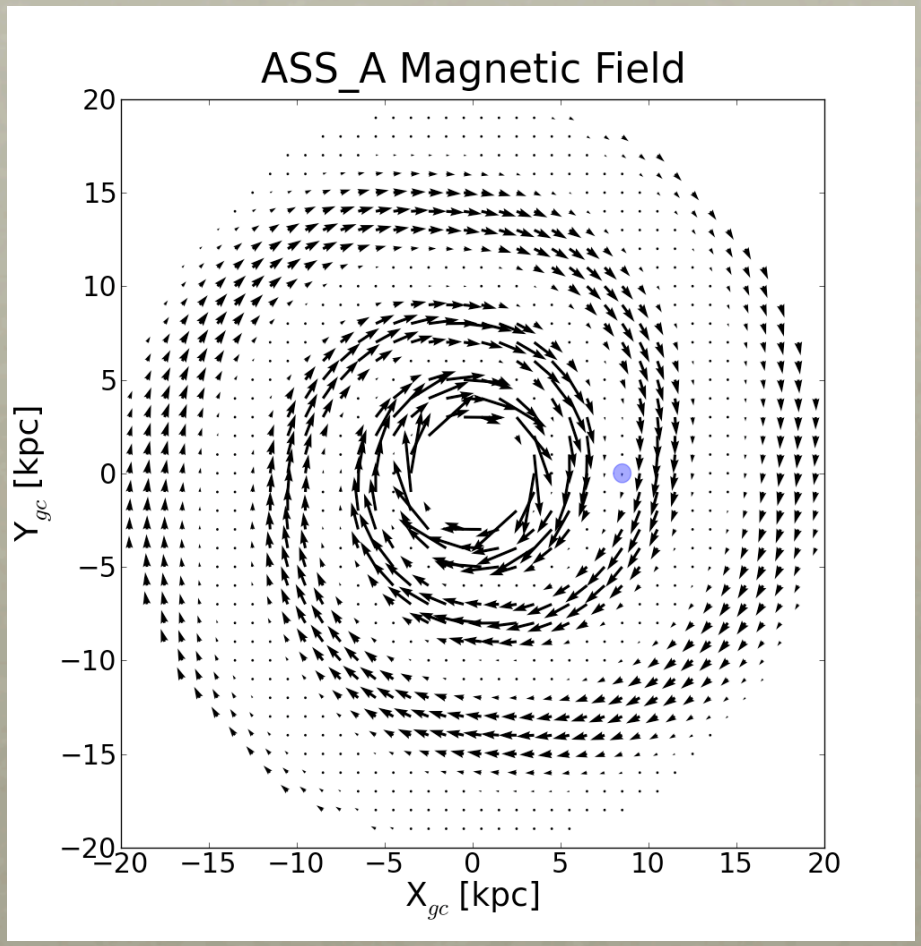
- Charged particles deflected in magnetic fields
- To identify the UHECR sources, we need to correct the effects of the magnetic fields
- There are the Galactic and Extragalactic Magnetic Fields (EGMF) that might affect the UHECR
- EGMF is three orders of magnitude smaller than the GMF
- UHECR deflections due to the EGMF are probably negligible compared to those due to the GMF (for "nearby" sources)

What is known about the GMF?

Well known locally: 1-10 μ G, geometry
Poorly known: Large scale, Disk and Halo, Field Reversals

Bisymmetric quadrupole ← Symmetric Spiral → Axisymmetric dipole



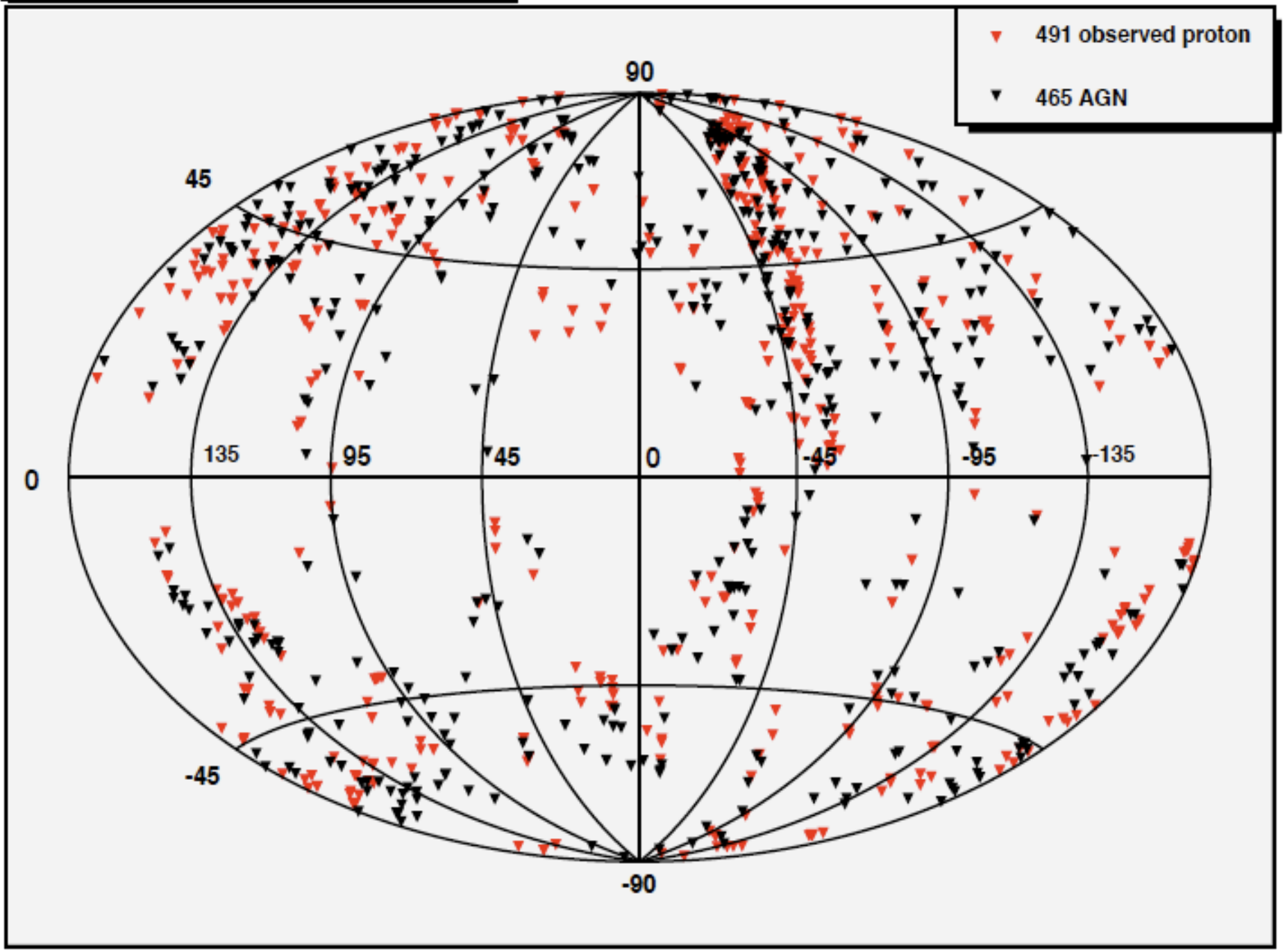


GMF models and cosmic ray compositions

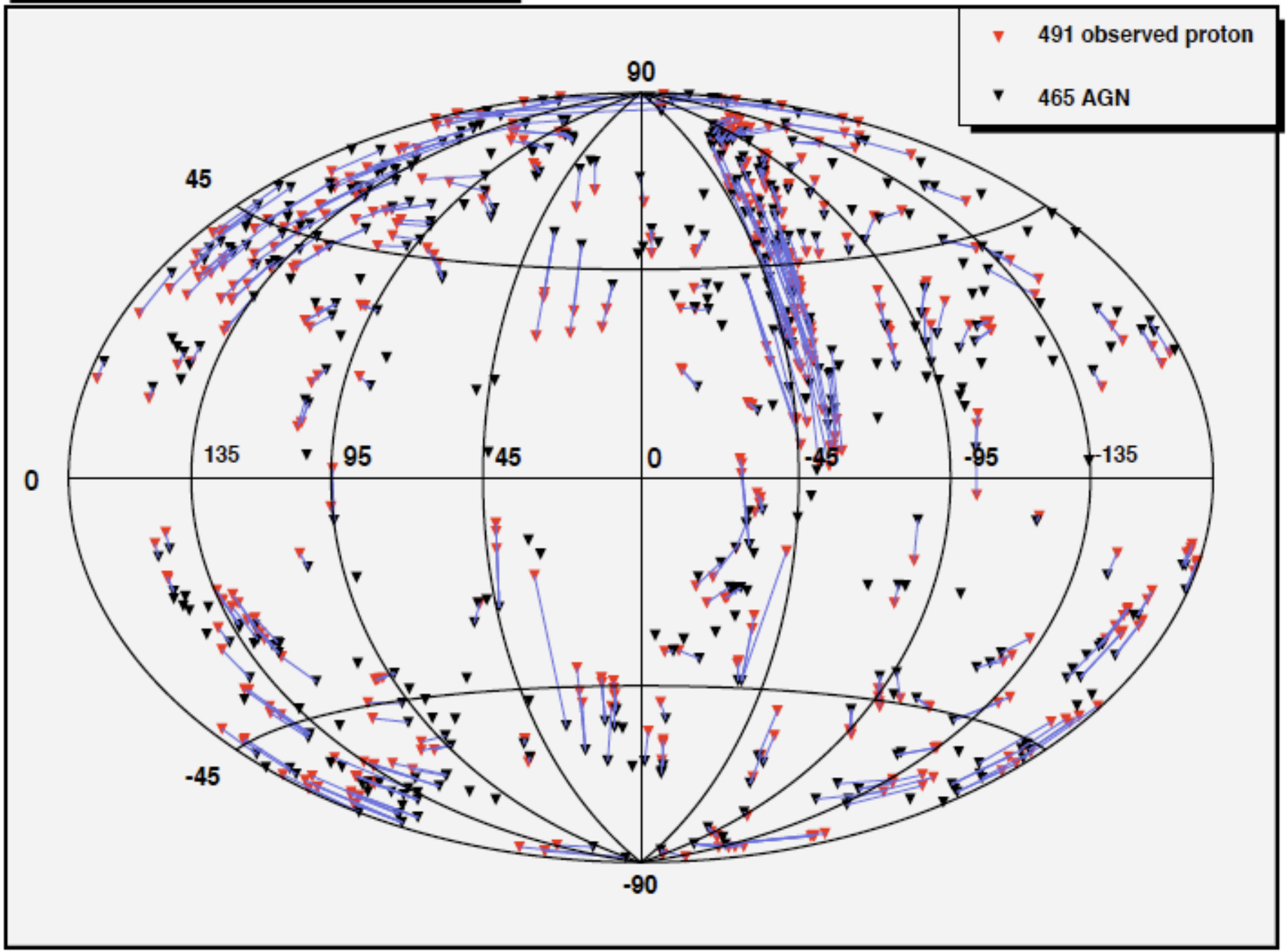
- GMF models used: BSS_A, BSS_S, ASS_A, ASS_S, ARING (Stanev model)
- Particles are Protons and Iron nuclei
- 10,000 particles from each of the AGN ($Z \leq 0.018$) in the VCV catalog
- 55 < Energy <150 EeV
- At the source: $dN/dE = E^{-\gamma}$, $\gamma = 2$
- Forward-track the particles through GMF using *CRT code

*Sutherland et al, 2010

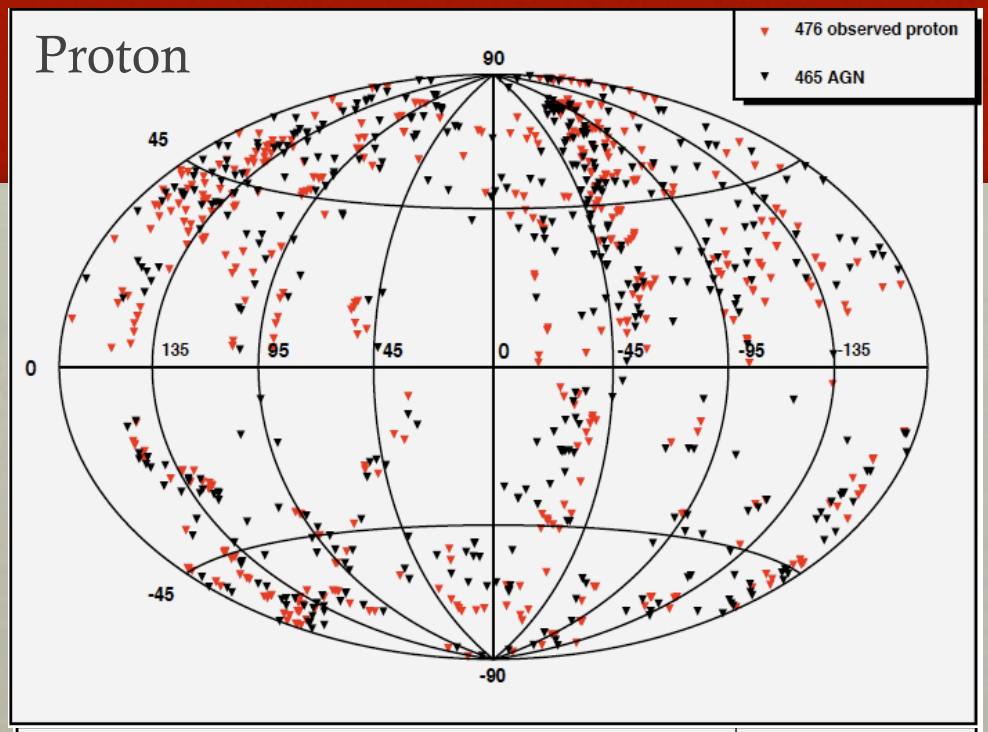
BSS_A GMF Model

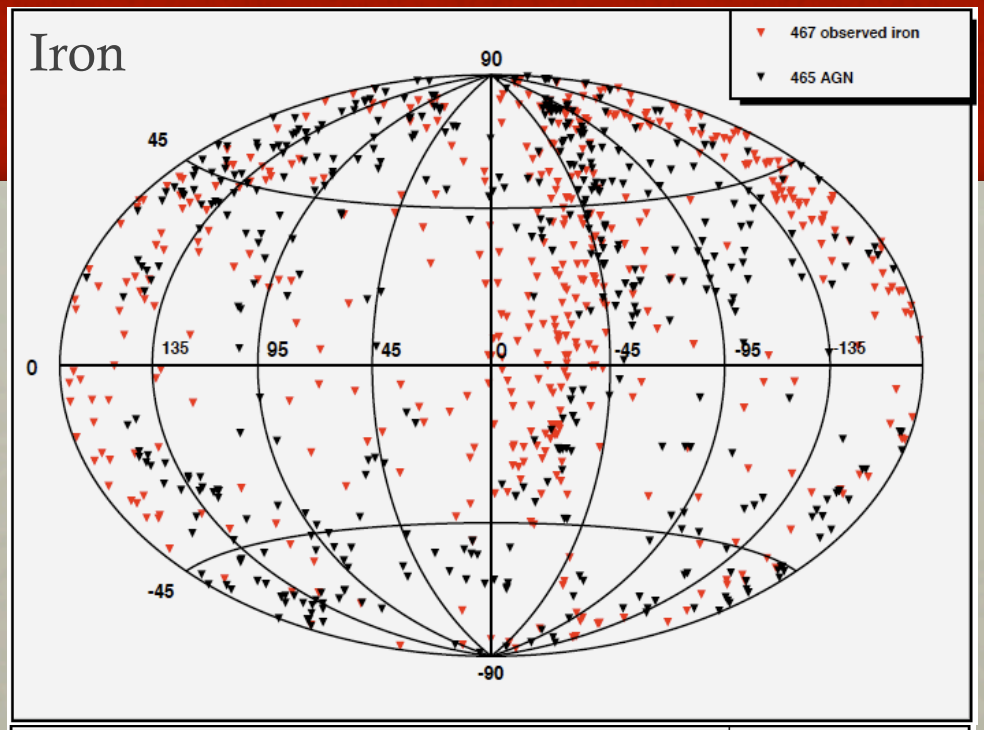


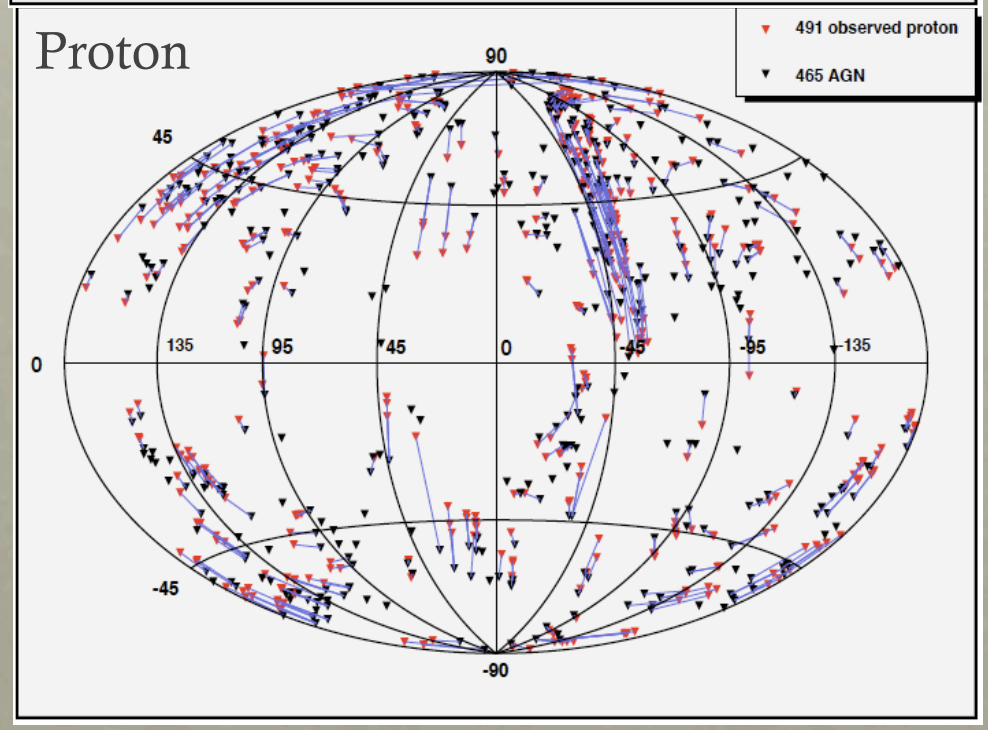
BSS_A GMF Model

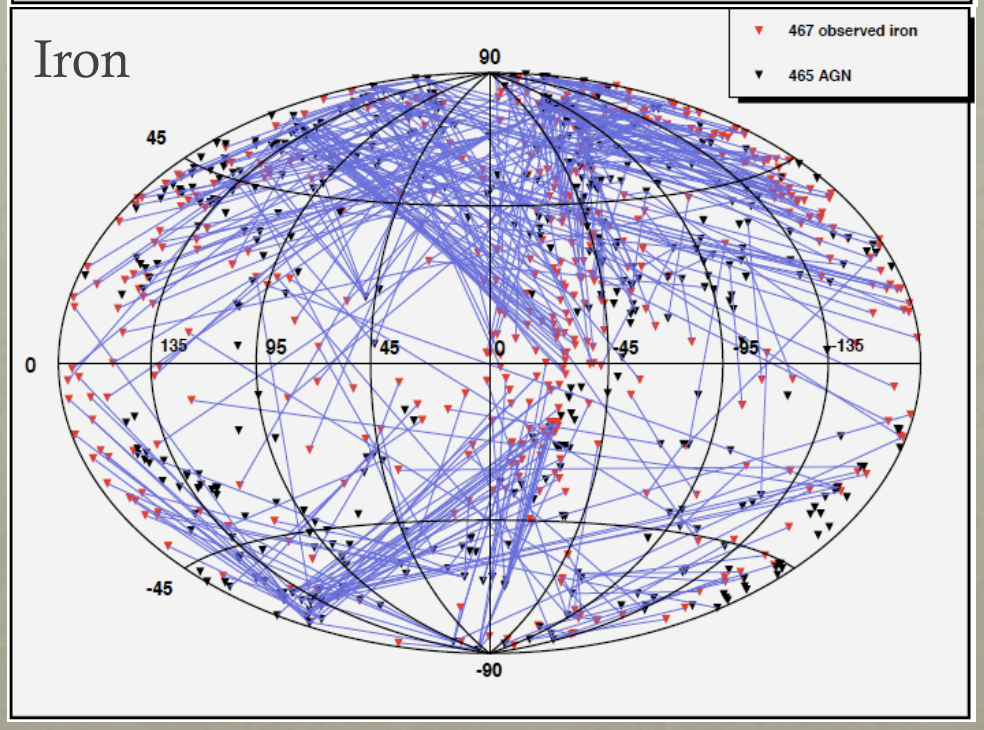


BSS_A GMF Model









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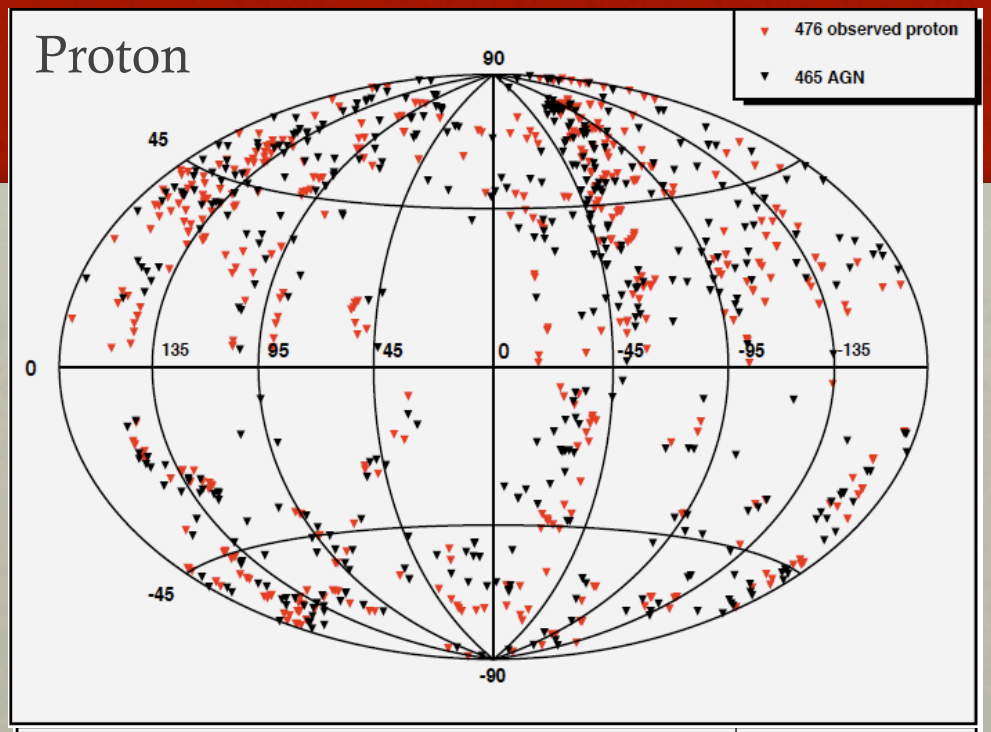
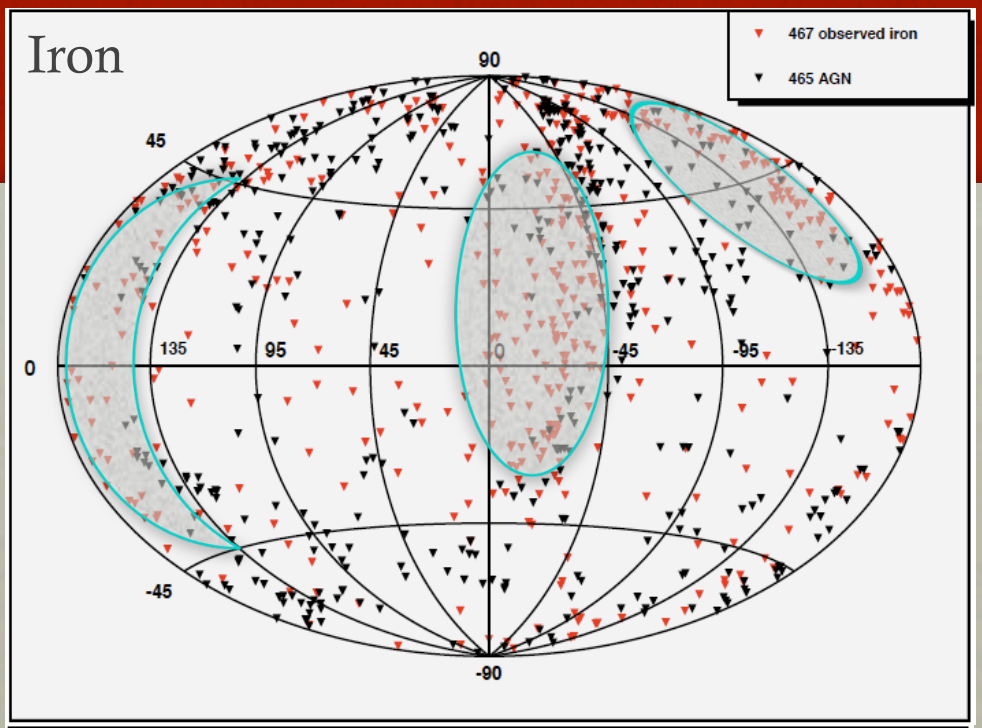
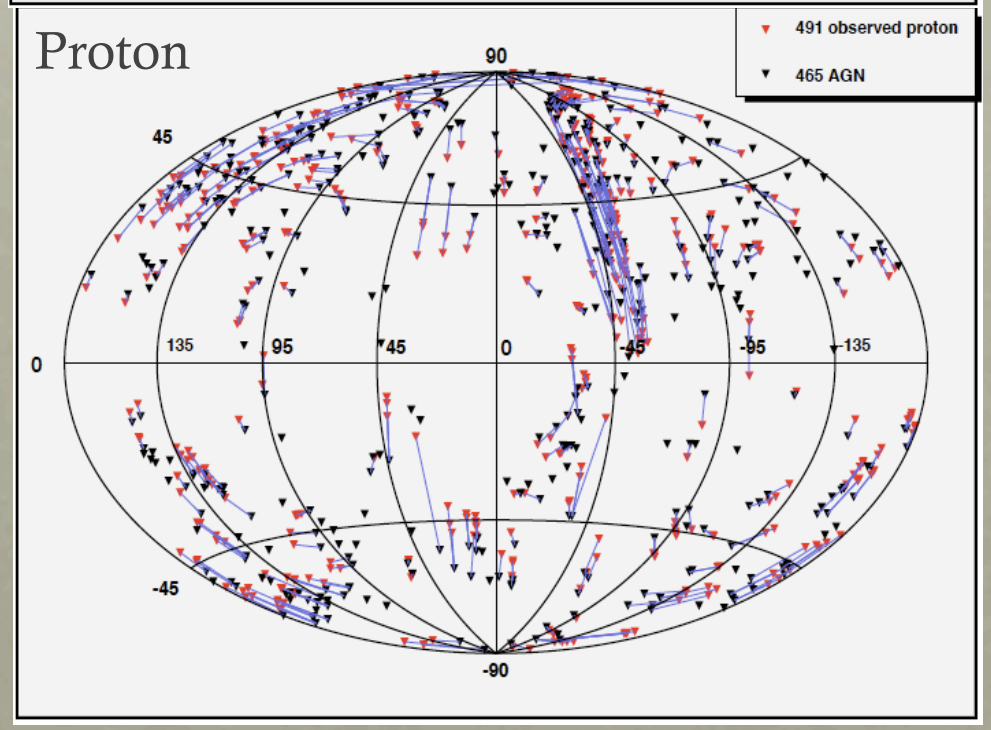
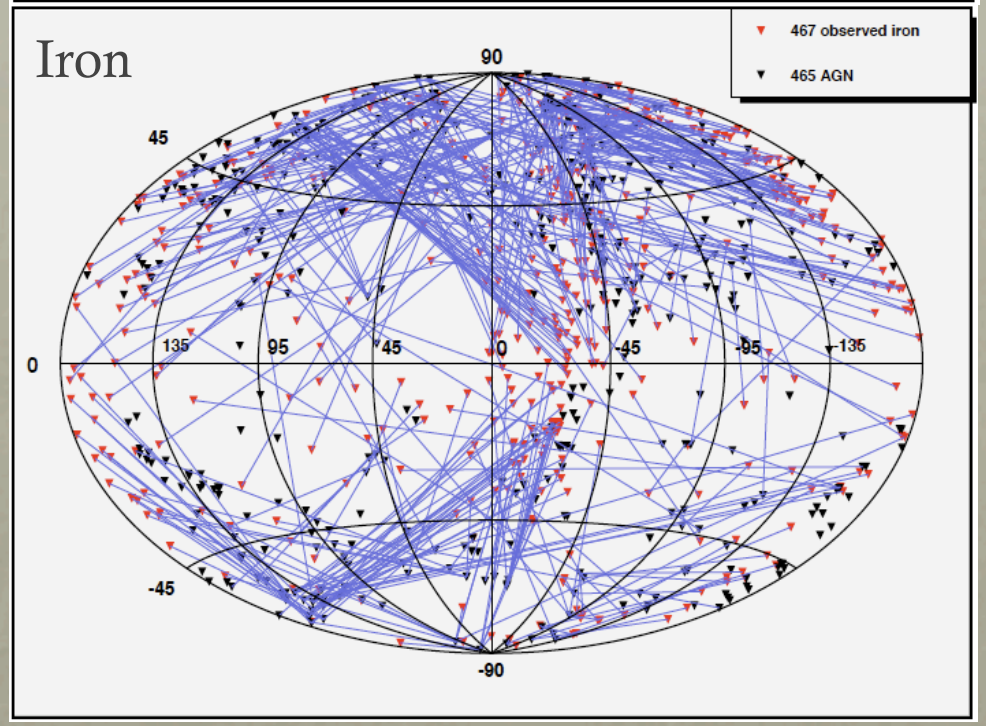
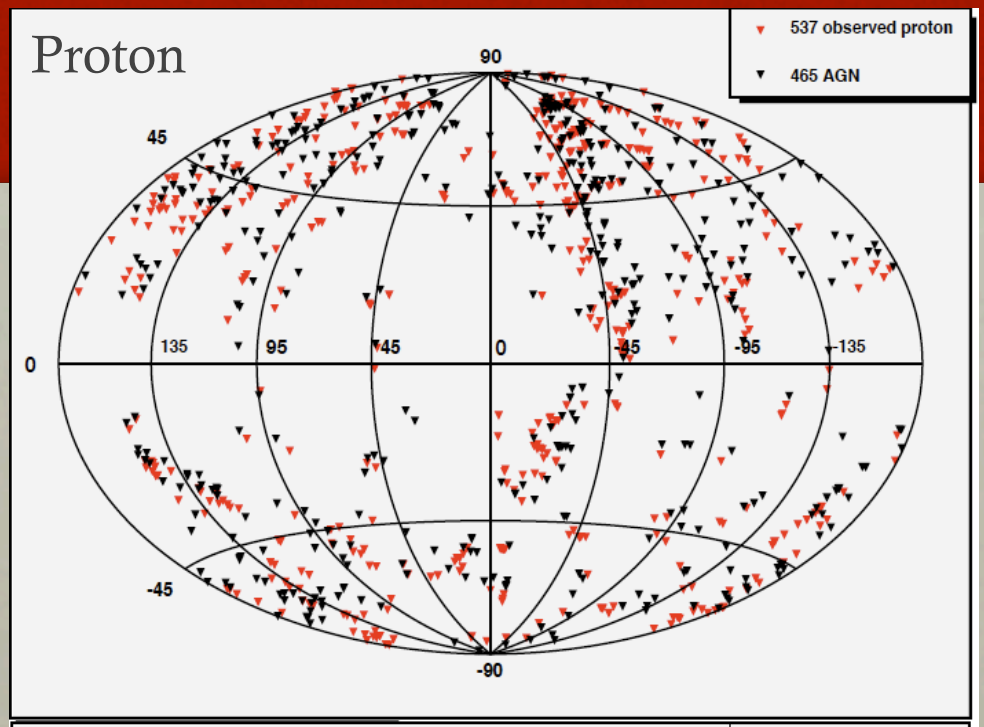


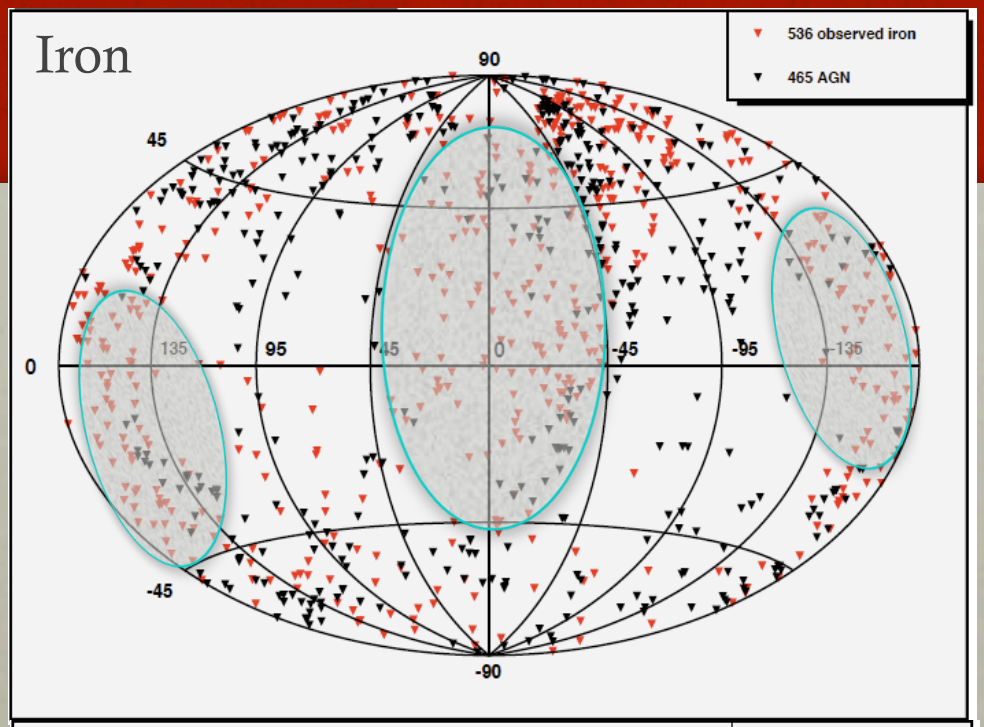


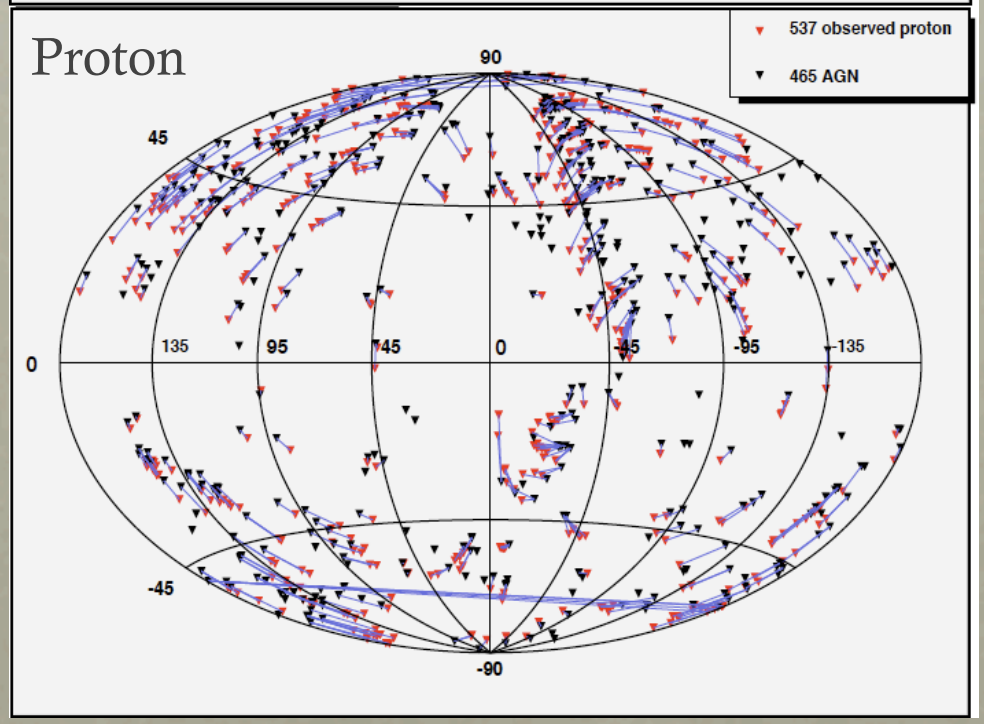


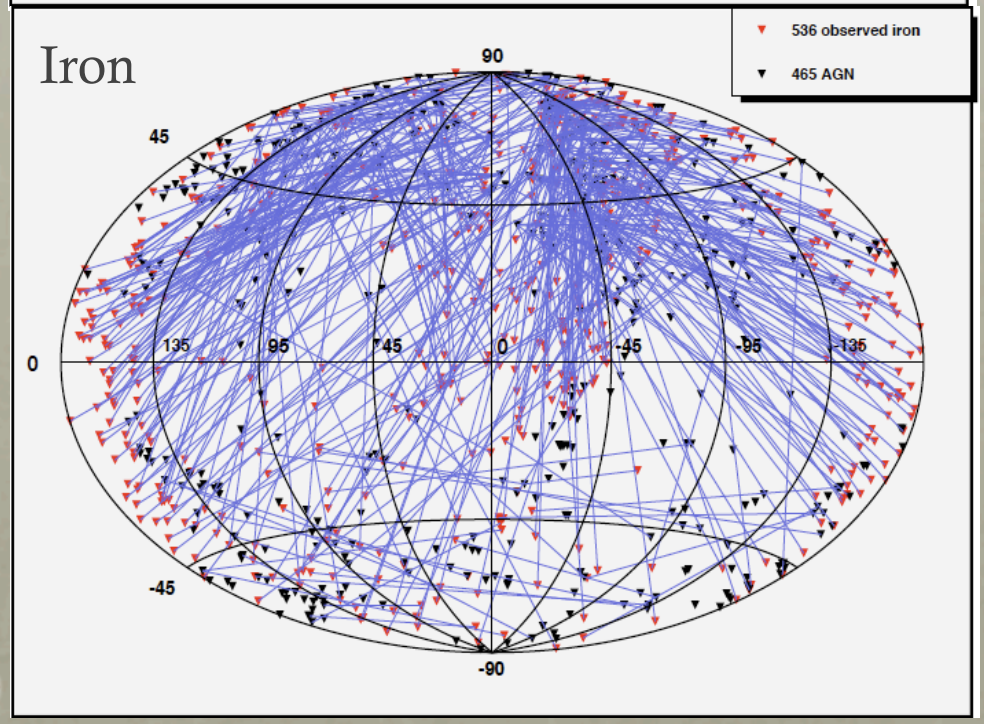


BSS_S GMF Model

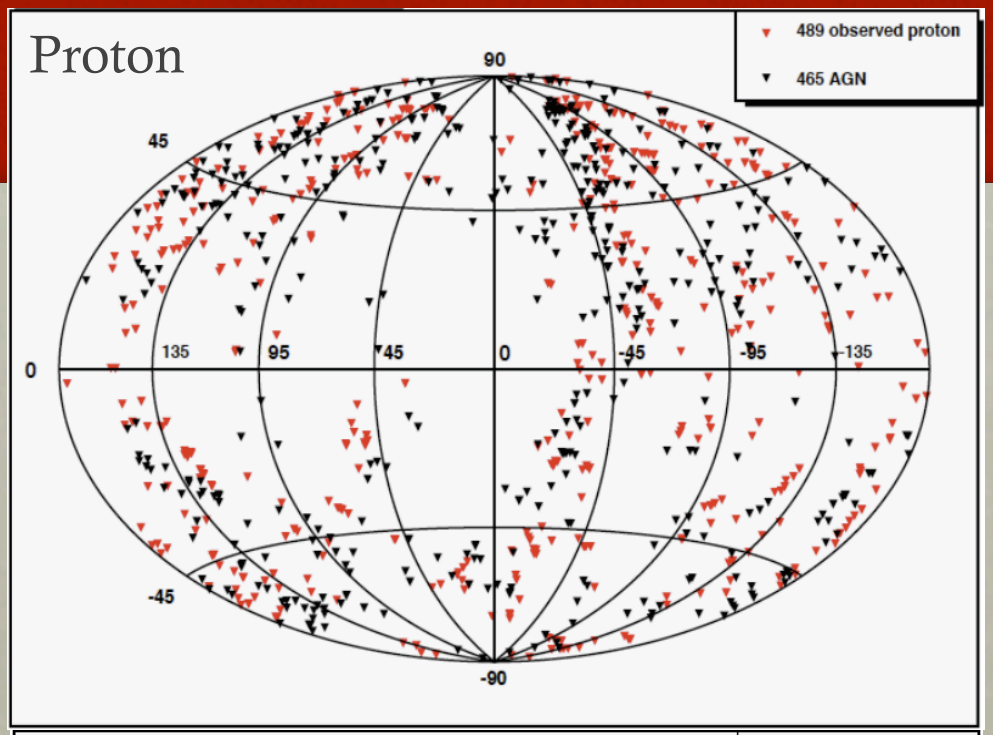


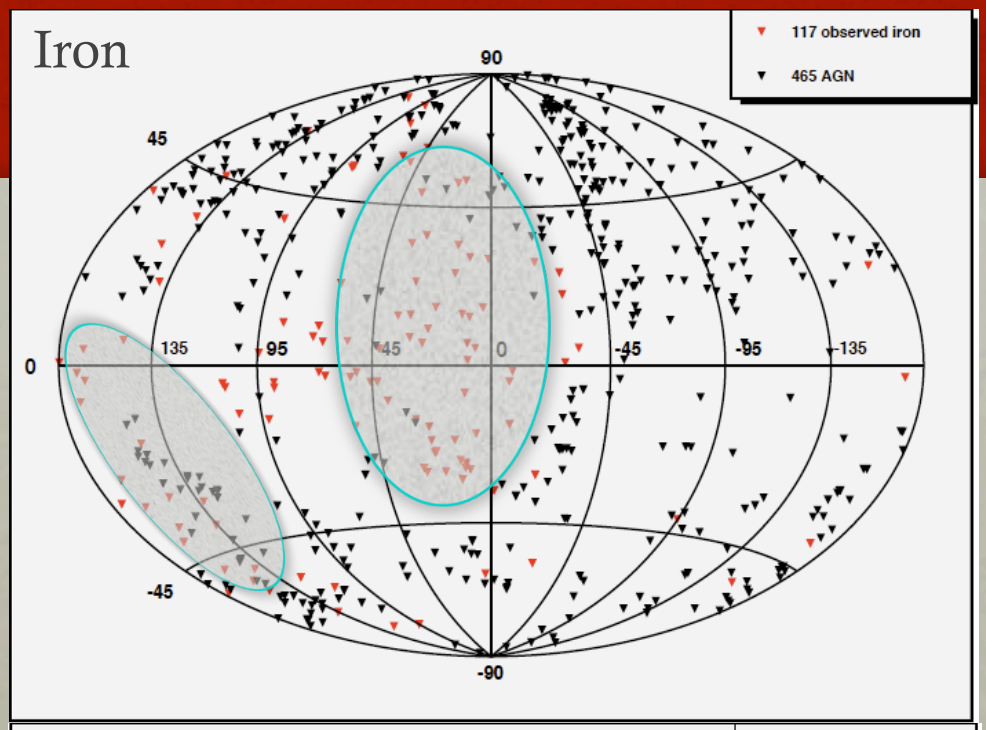


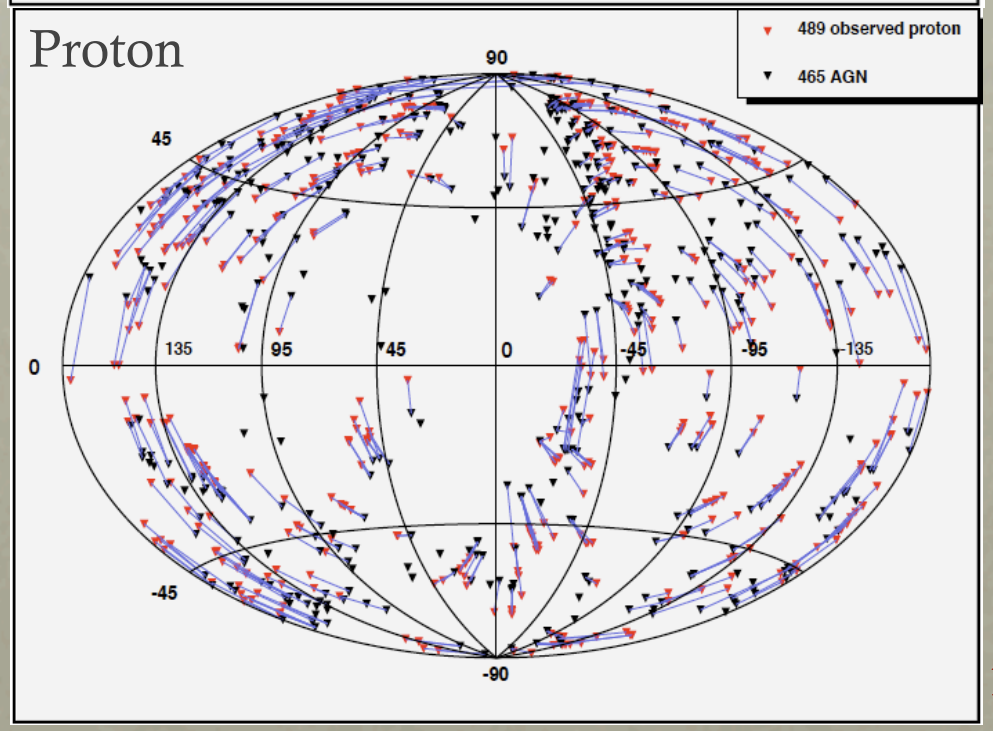


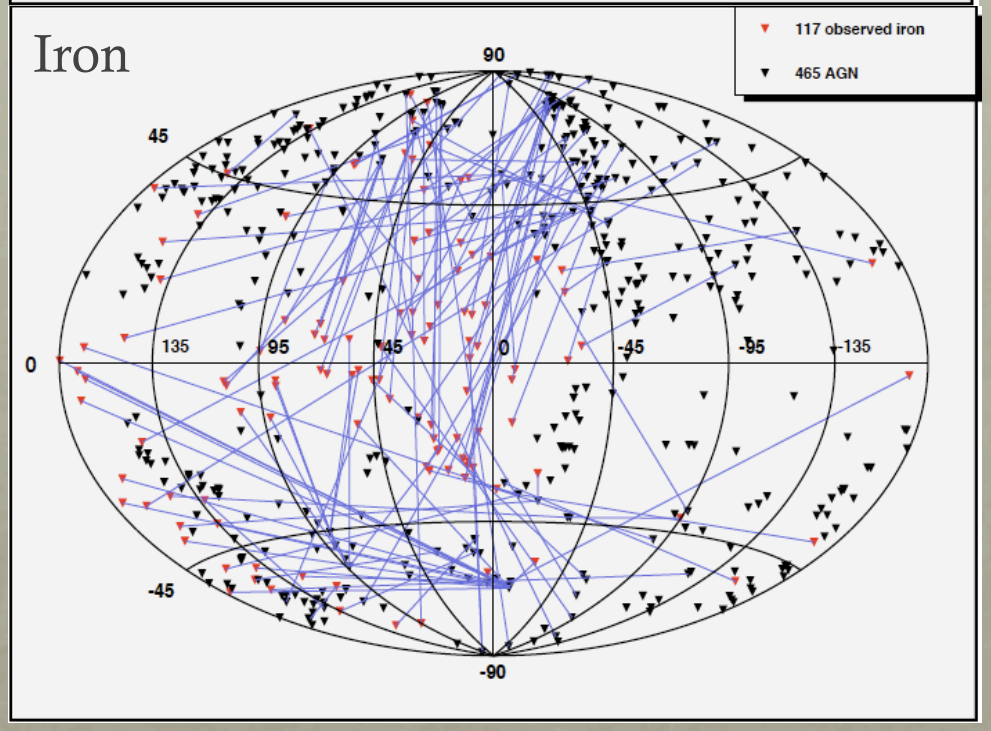


ASS_A GMF Model

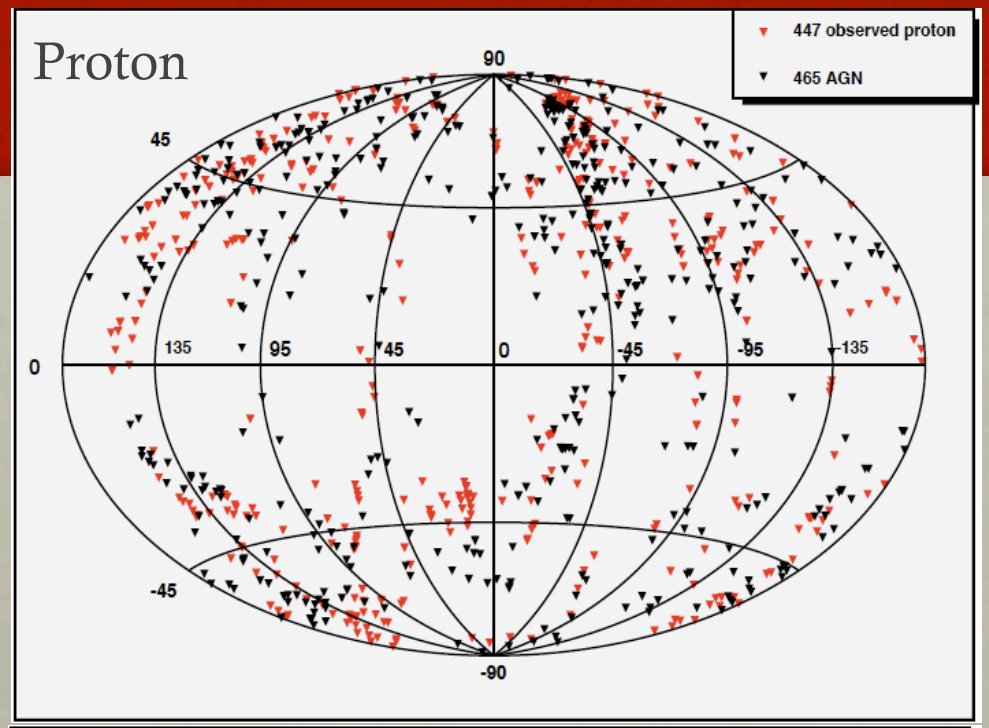


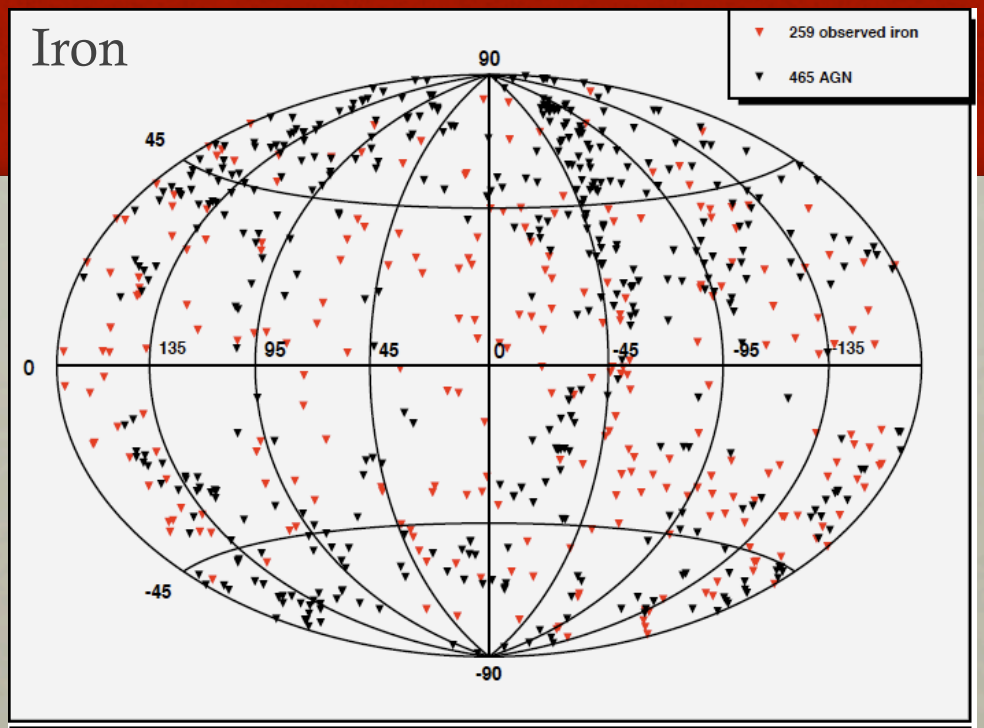


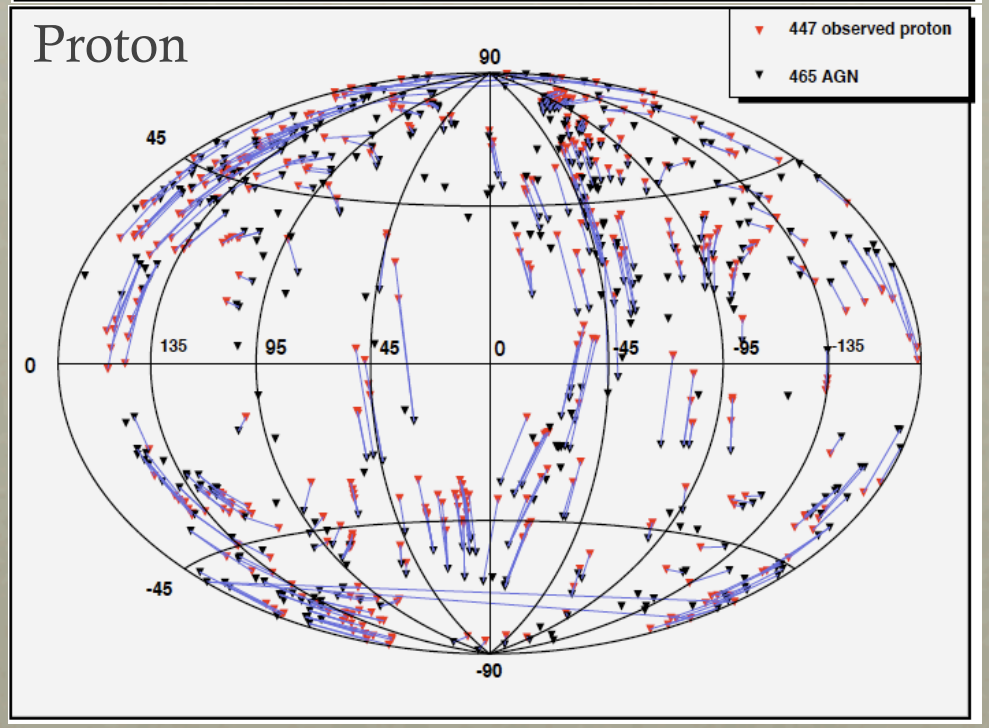


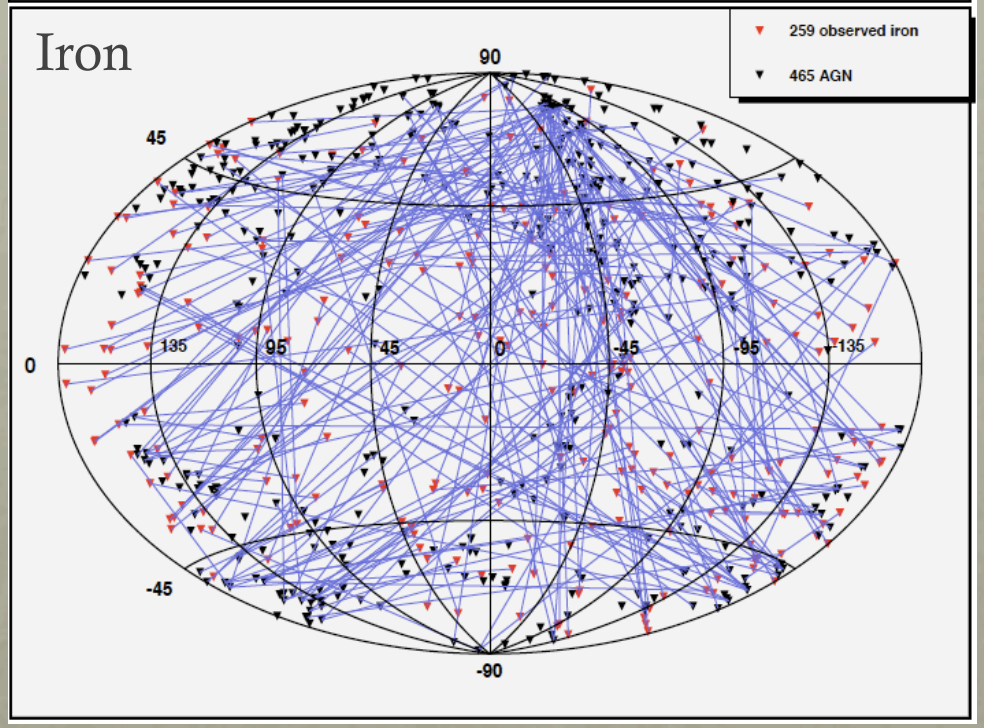


ASS_S GMF Model

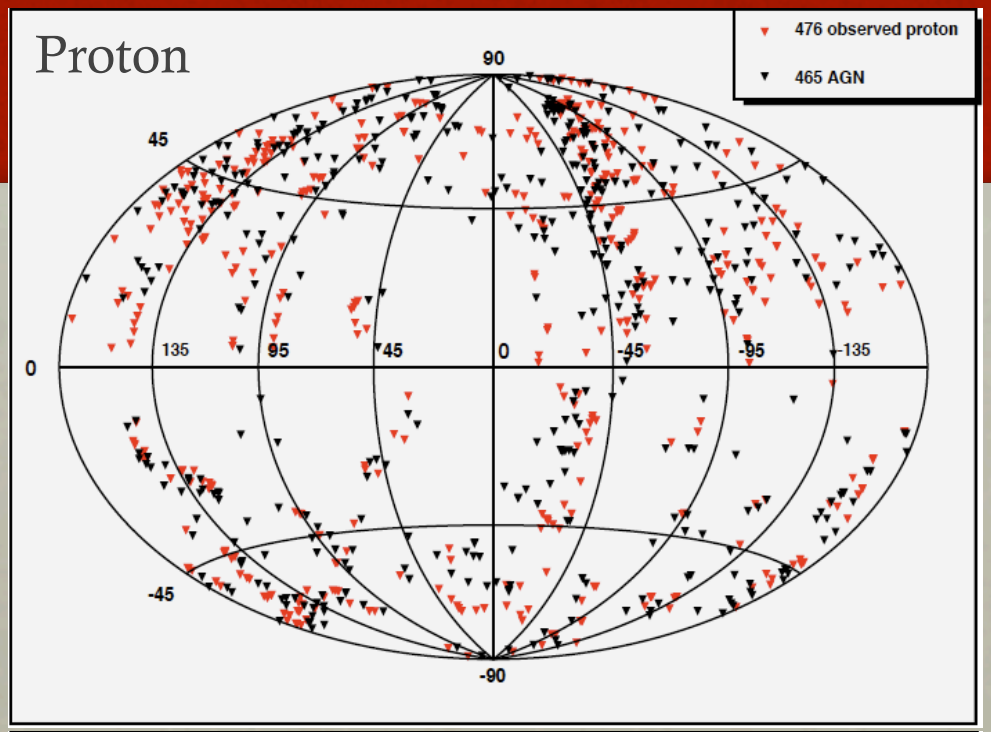


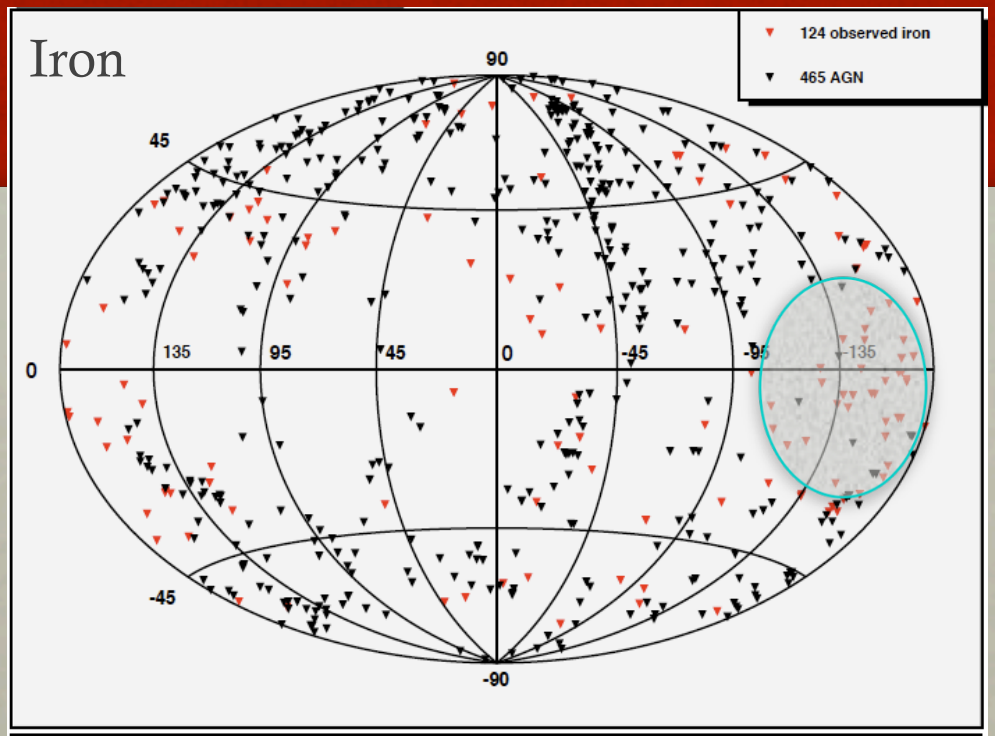


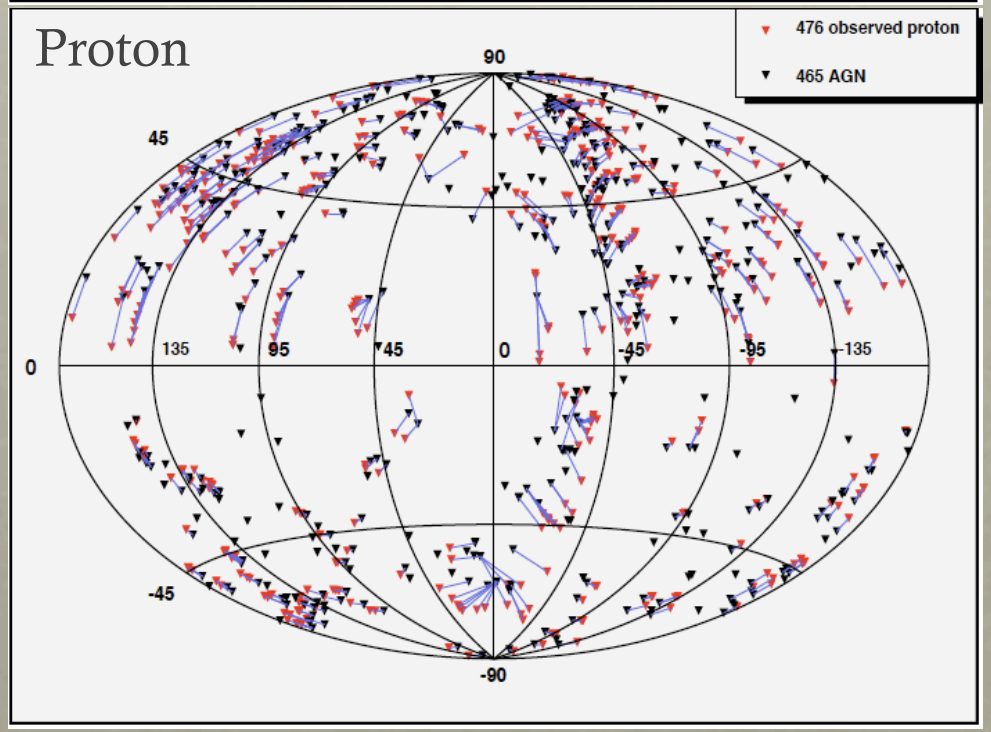


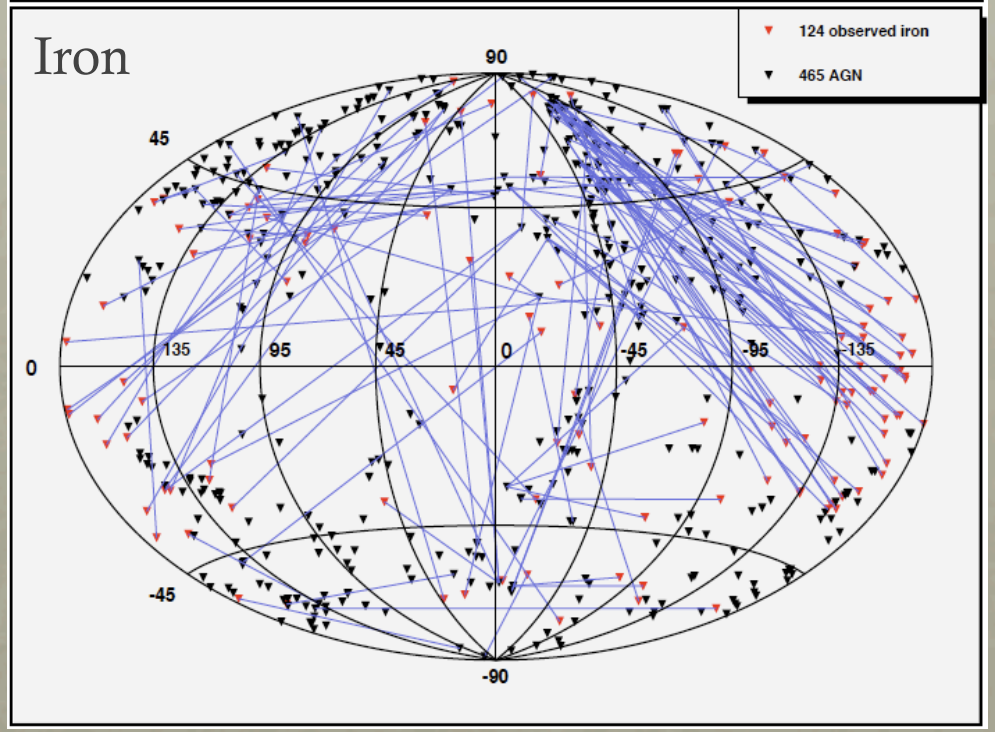


ARING GMF Model







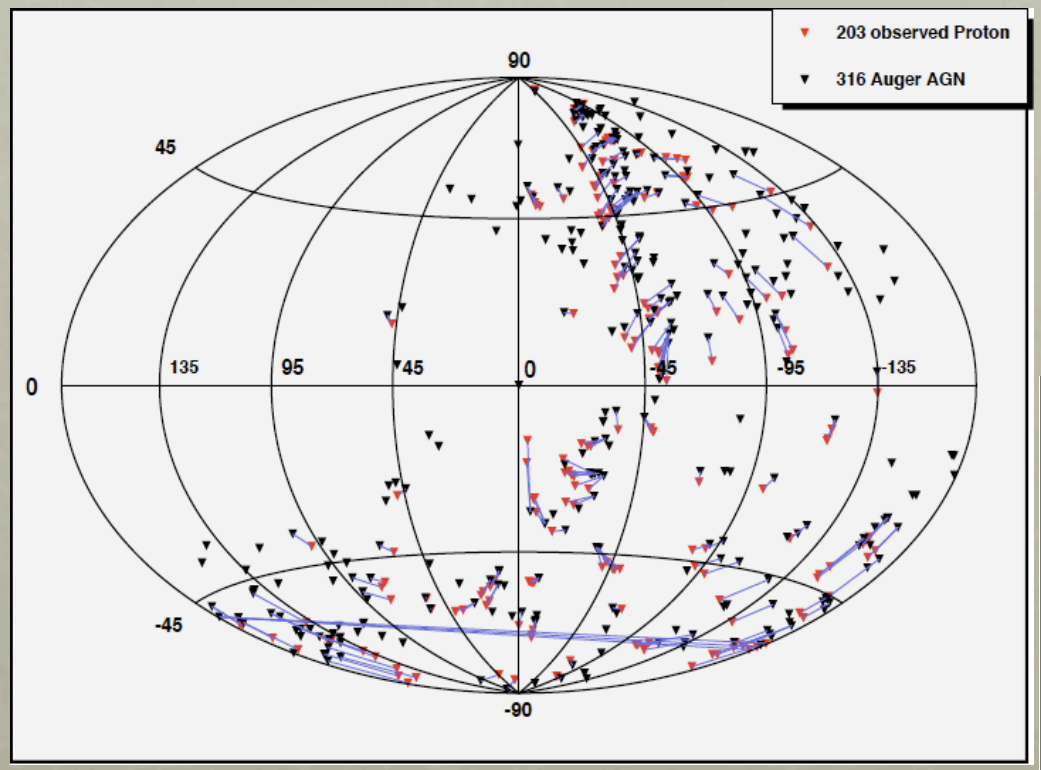


Results for Whole Sky

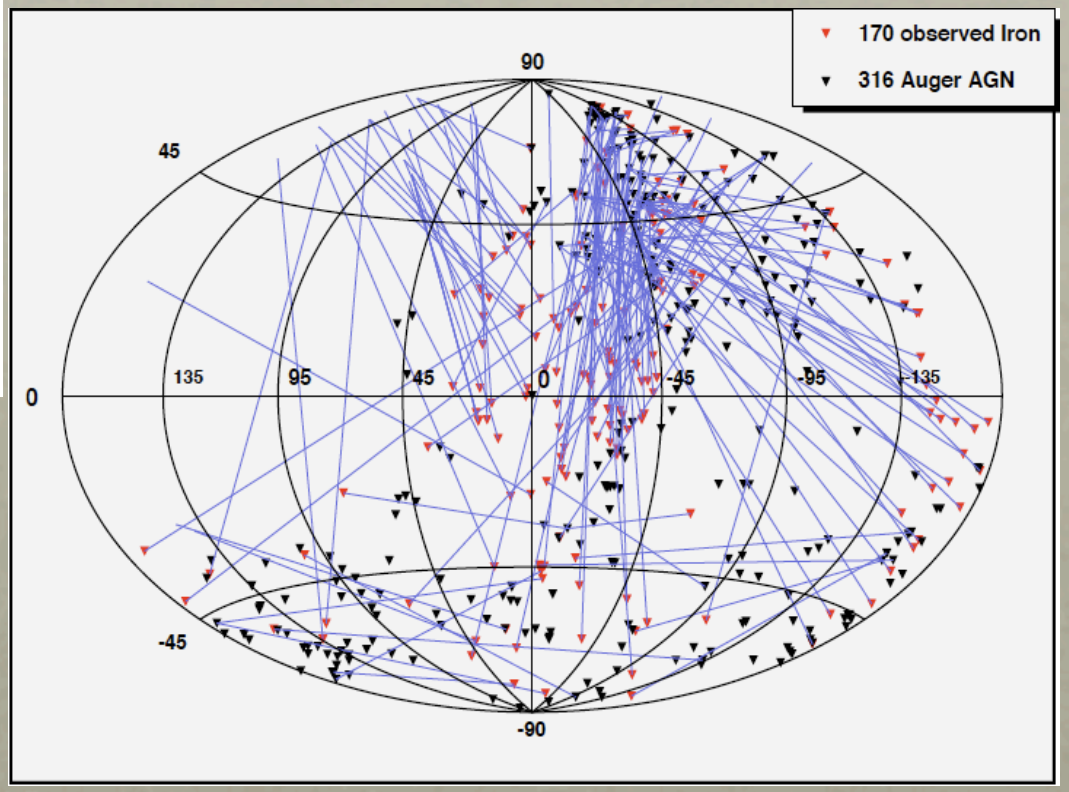
23 % for isotropic sky

GMF Models & particles	N1: observed	deflection angle avg	observed angle [AGN-evt] avg	N2: angle<3.1°	N2/N1 (%)
BSS_S Proton	536	6.6°	3.3°	282	53 ± 4
BSS_S Iron	537	64.4°	6.2°	160	30 ± 3
BSS_A Proton	491	7.6°	3.4°	260	53 ± 4
BSS_A Iron	467	49.5°	5.8°	151	32 ± 3
ASS_S Proton	447	9.9°	4.5°	198	44 ± 4
ASS_S Iron	259	85.6°	7.0°	57	22 ± 3
ASS_A Proton	489	9°	4.6°	175	36 ± 3
ASS_A Iron	117	75.3°	10.2°	19	16 ± 4
ASS+RING Proton	476	5.8°	3.5°	255	54 ± 4
ASS+RING Iron	124	84.4°	6.9°	31	25 ± 5

Southern Sky: BSS_S GMF Model



(using Auger Exposure)



Proton

Iron

Results for Southern Exposure

23 % for isotropic sky

GMF Models & particles	N3: observed	deflection angle avg	observed angle [AGN-evt] avg	N4: angle<3.1°	N4/N3 (%)
BSS_S Proton	203	6.6°	3.4°	103	51 ± 6
BSS_S Iron	171	70.1°	7.3°	50	29 ± 5
BSS_A Proton	181	8.7°	3.6°	93	51 ± 6
BSS_A Iron	171	51.5°	6.2°	55	32 ± 5
ASS_S Proton	156	11.1°	4.9°	63	40 ± 6
ASS_S Iron	113	85.8°	6.7°	22	19 ± 4
ASS_A Proton	175	8.8°	4.7°	57	33 ± 5
ASS_A Iron	38	69.8°	12°	4	10 ± 5
ASS+RING Proton	163	6.2°	3.6°	85	52 ± 7
ASS+RING Iron	42	85.4°	6.3°	9	22 ± 8

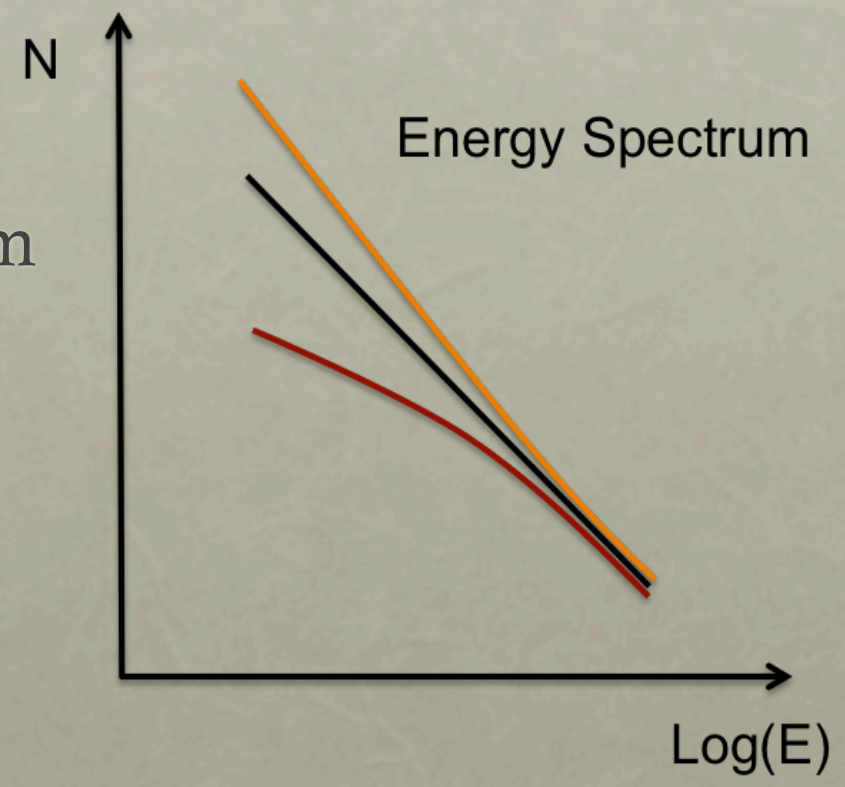
Results for Southern Sky compare to the Whole Sky

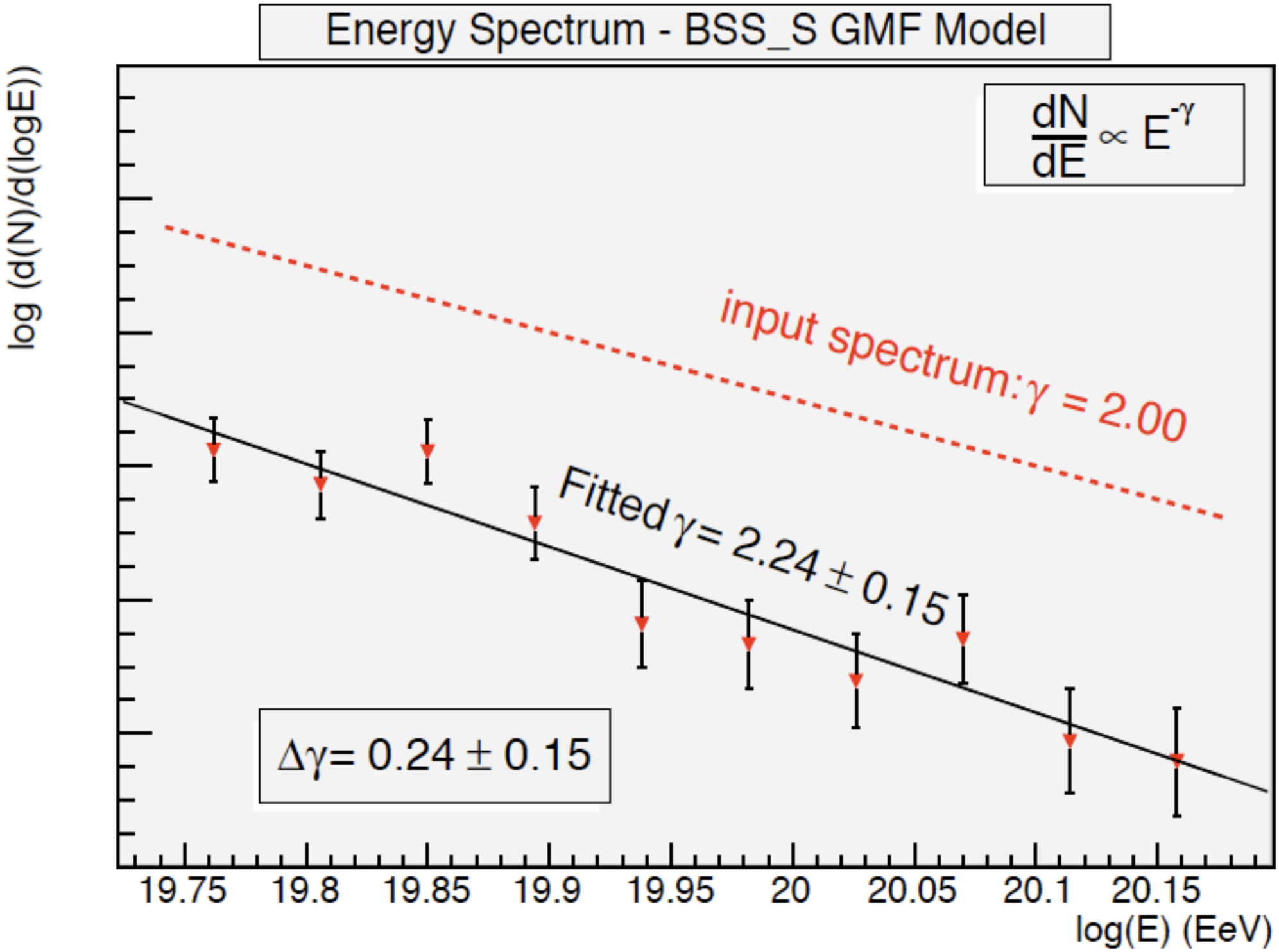
23 % for isotropic sky

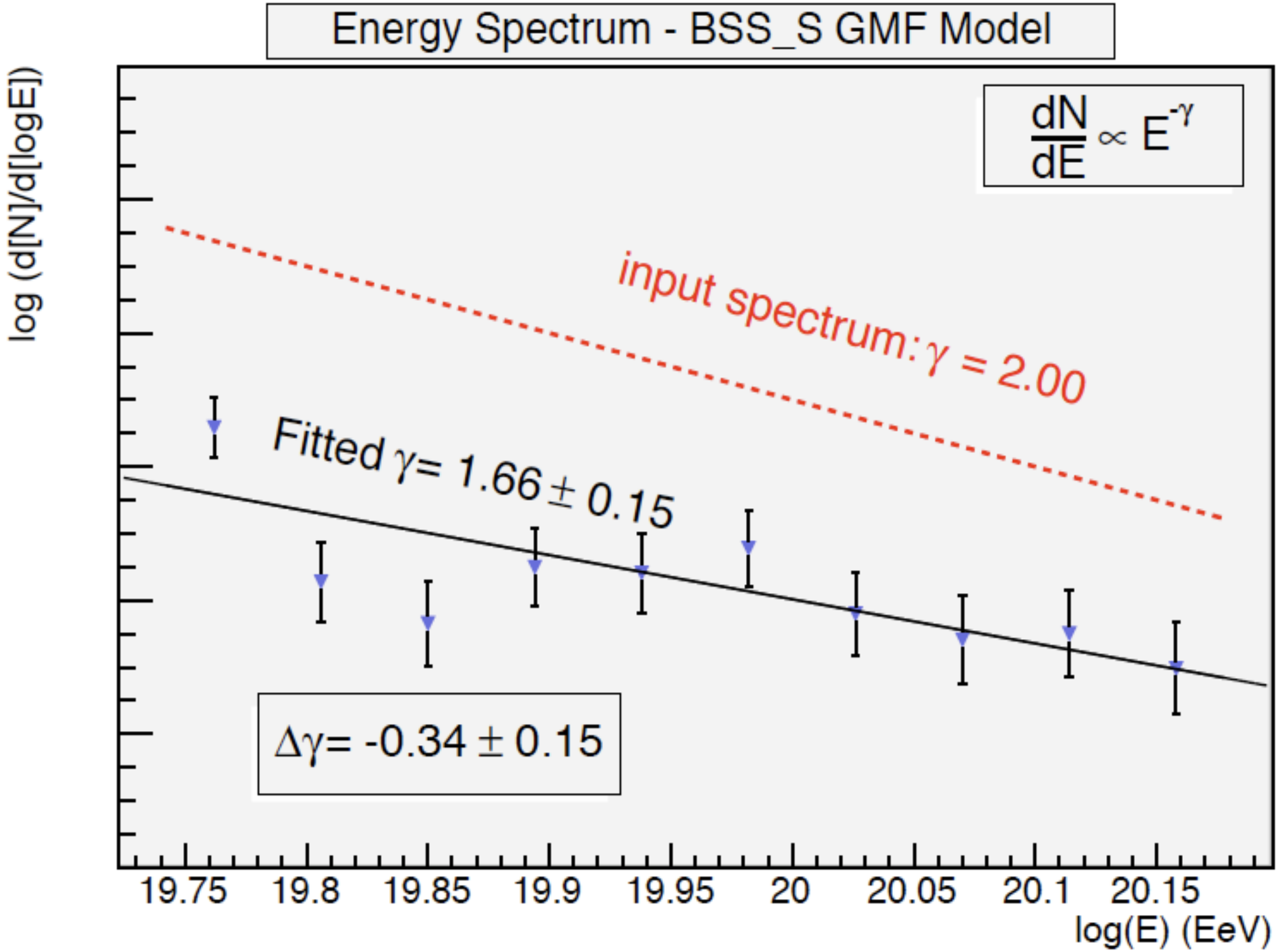
GMF Models & particles	N4/N3 (%)	N2/N1 (%)
BSS_S Proton	51 ± 6	53 ± 4
BSS_S Iron	29 ± 5	30 ± 3
BSS_A Proton	51 ± 6	53 ± 4
BSS_A Iron	32 ± 5	32 ± 3
ASS_S Proton	40 ± 6	44 ± 4
ASS_S Iron	19 ± 4	22 ± 3
ASS_A Proton	33 ± 5	36 ± 3
ASS_A Iron	10 ± 5	16 ± 4
ASS+RING Proton	52 ± 7	54 ± 4
ASS+RING Iron	22 ± 8	25 ± 5

Observed Energy Spectrum

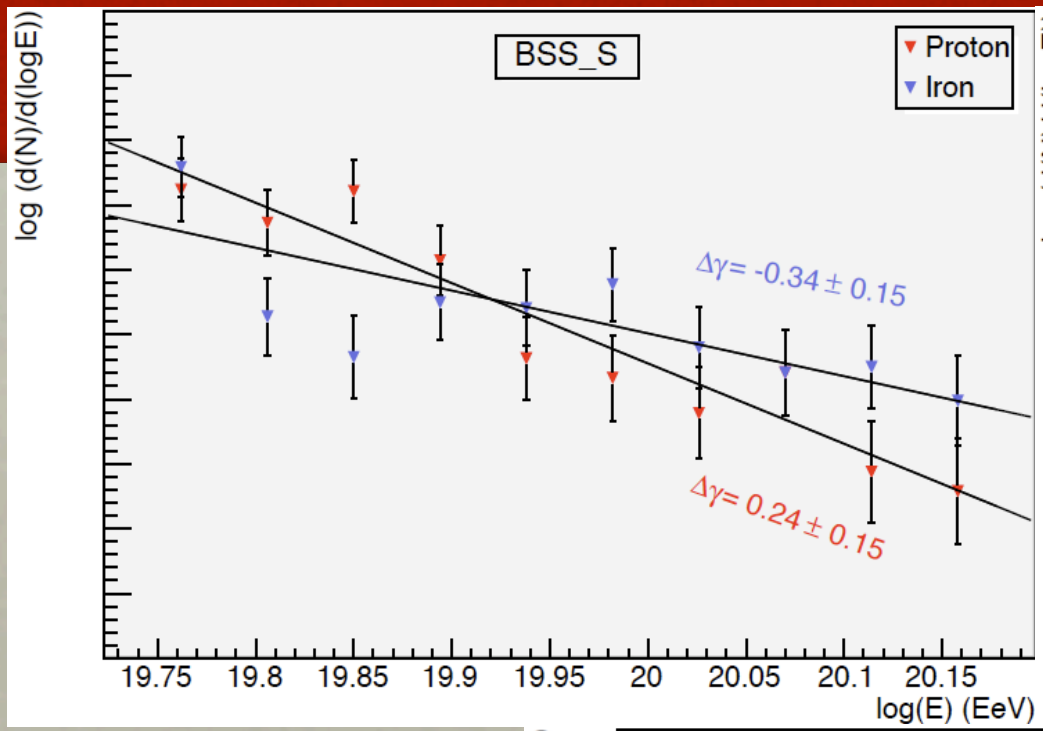
- Galactic magnetic field can influence the observed energy spectrum
- Does the GMF deflect lower energy events more?
- Does the observed energy spectrum change at lower energies?

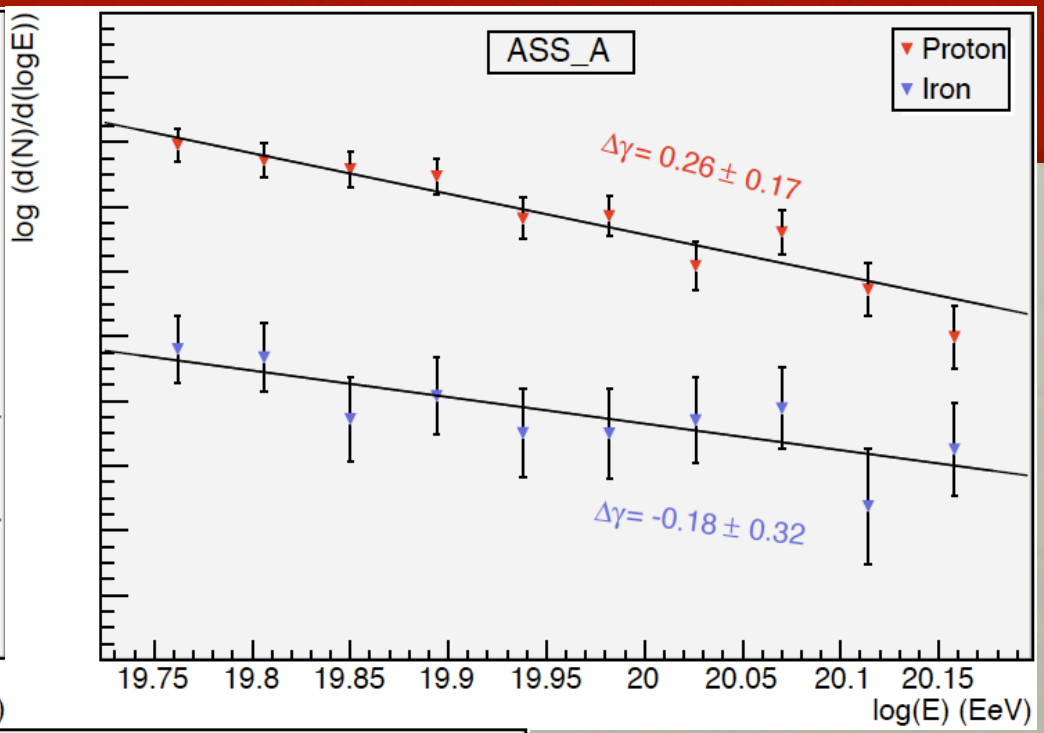


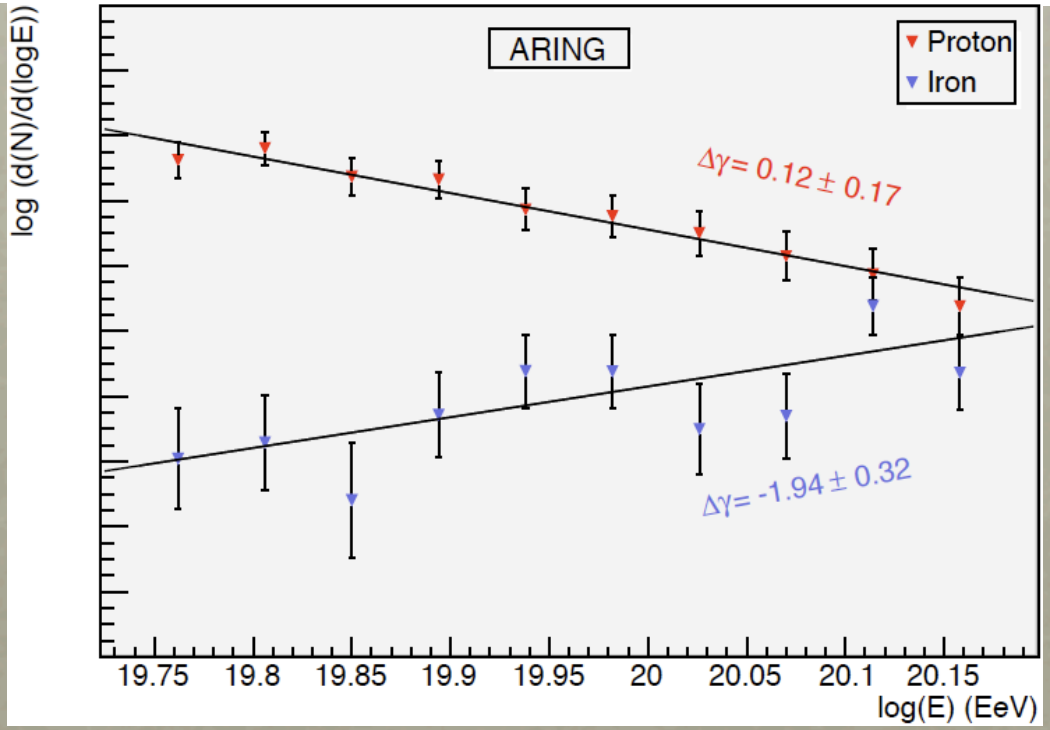

Energy Spectrum - BSS_S GMF Model
$\frac{dN}{dE} \propto E^{-\gamma}$
input spectrum: $\gamma = 2.00$
Fitted $\gamma = 2.24 \pm 0.15$
$\Delta\gamma = 0.24 \pm 0.15$
log (d(N)/d(logE))
19.75
19.8
19.85
19.9
19.95
20
20.05
20.1
20.15
log(E) (EeV)


Energy Spectrum - BSS_S GMF Model
$\frac{dN}{dE} \propto E^{-\gamma}$
input spectrum: $\gamma = 2.00$
Fitted $\gamma = 1.66 \pm 0.15$
$\Delta\gamma = -0.34 \pm 0.15$
log (d[N]/d[logE])
19.75
19.8
19.85
19.9
19.95
20
20.05
20.1
20.15
log(E) (EeV)

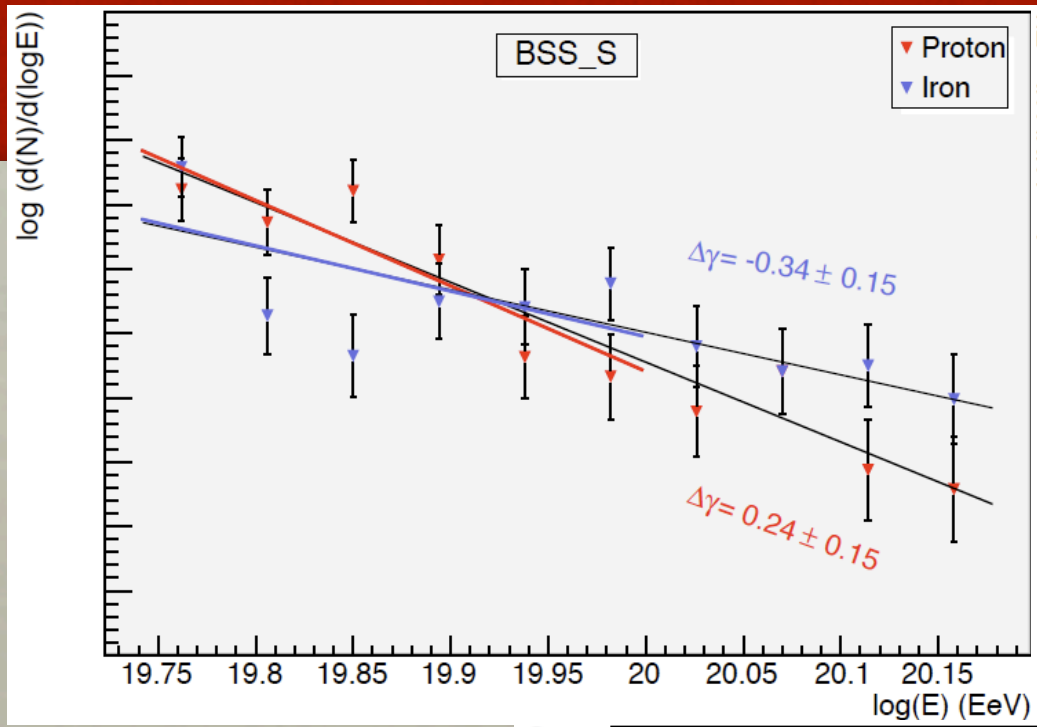
Observed Energy Spectrum

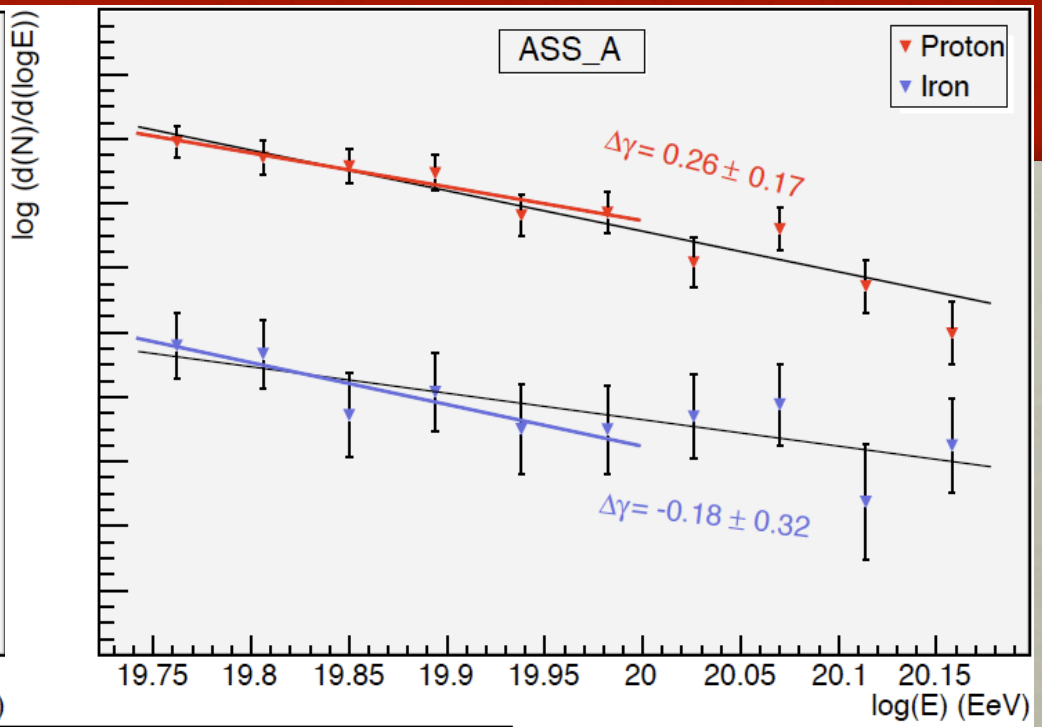


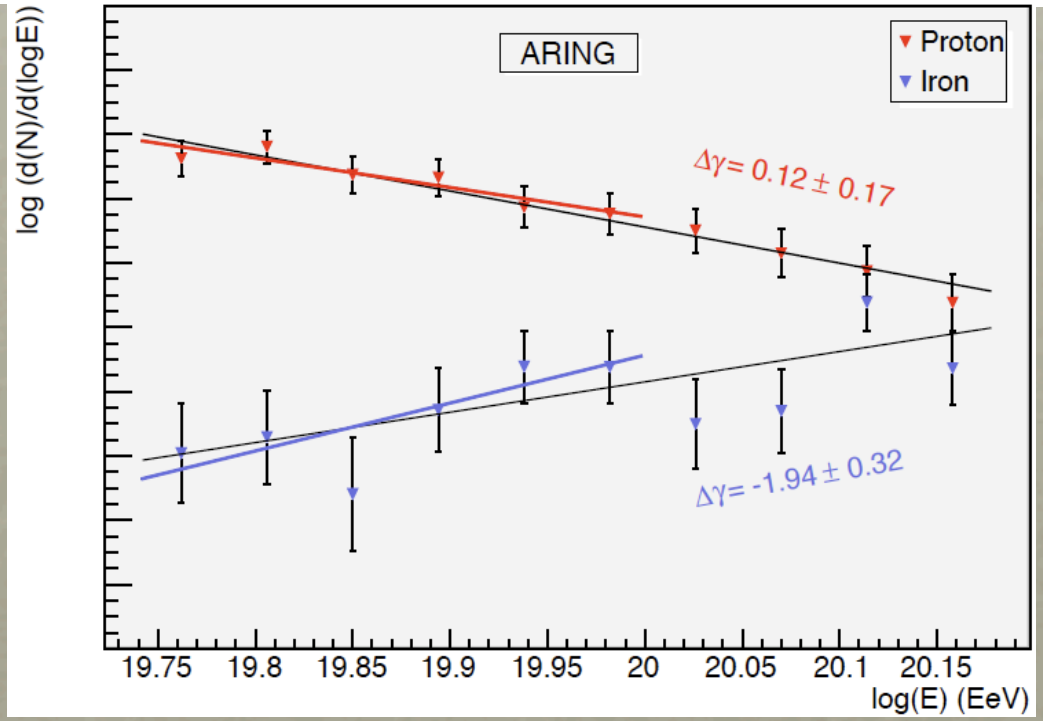




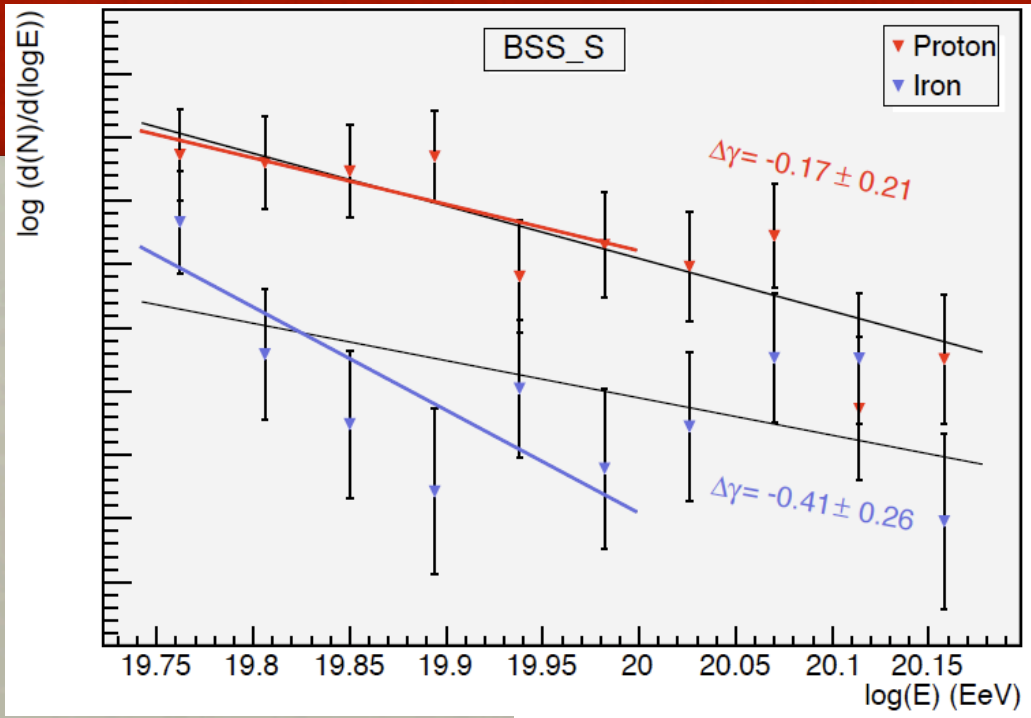
Observed Energy Spectrum, Lower Energies

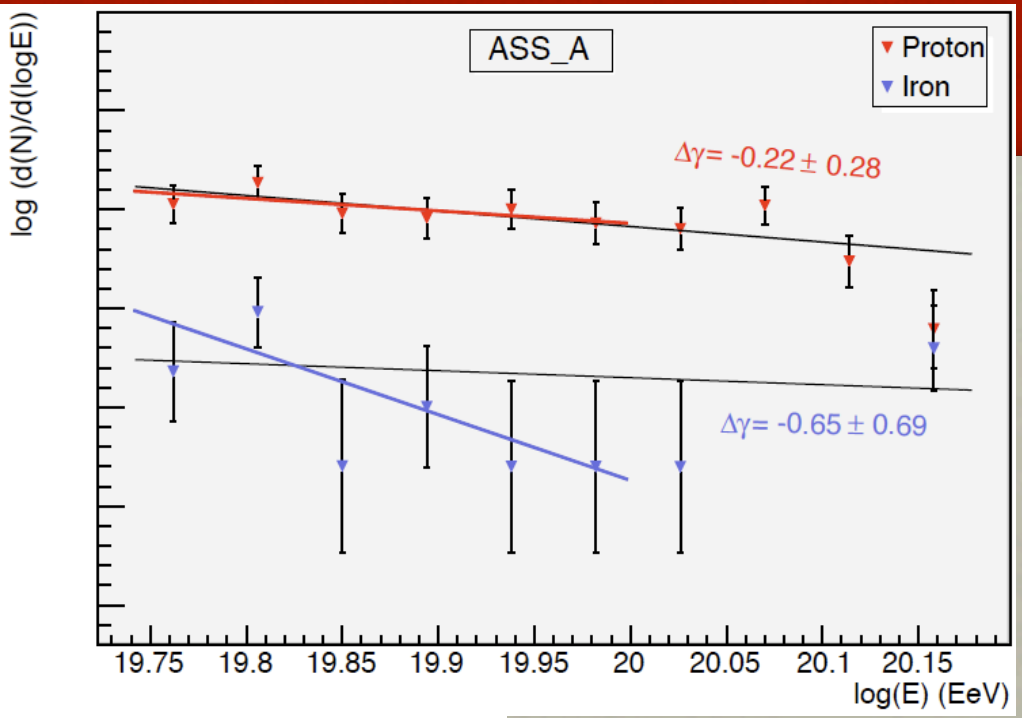


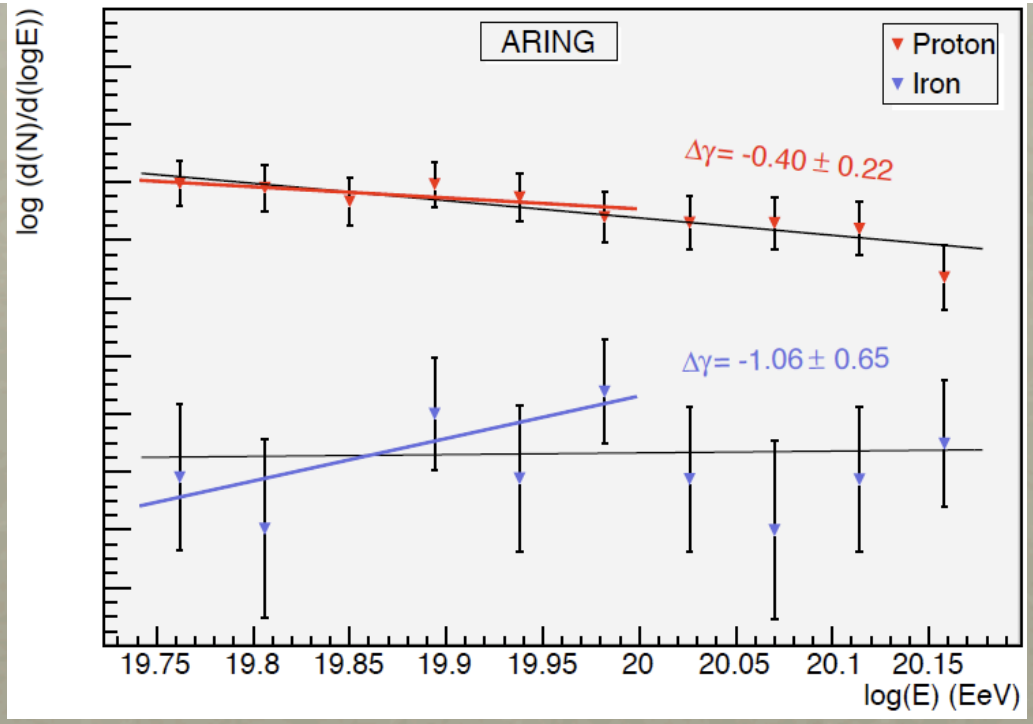




Observed Energy Spectrum, Correlated Events







These plots are for Events with separation angle < 3.1° of an AGN in VCV catalog (Correlated Events)

What do we learn?

- The results are GMF model-dependent.
- For protons the ratio of events correlating is between 33-54% (isotropy= 23%)
- For iron nuclei the ratio is between 10-32%
- Observed energy spectrum does slightly change depending on the model
- Observed energy spectrum does not change significantly at lower energies