Galactic Cosmic Rays

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APC , Paris

Overview:

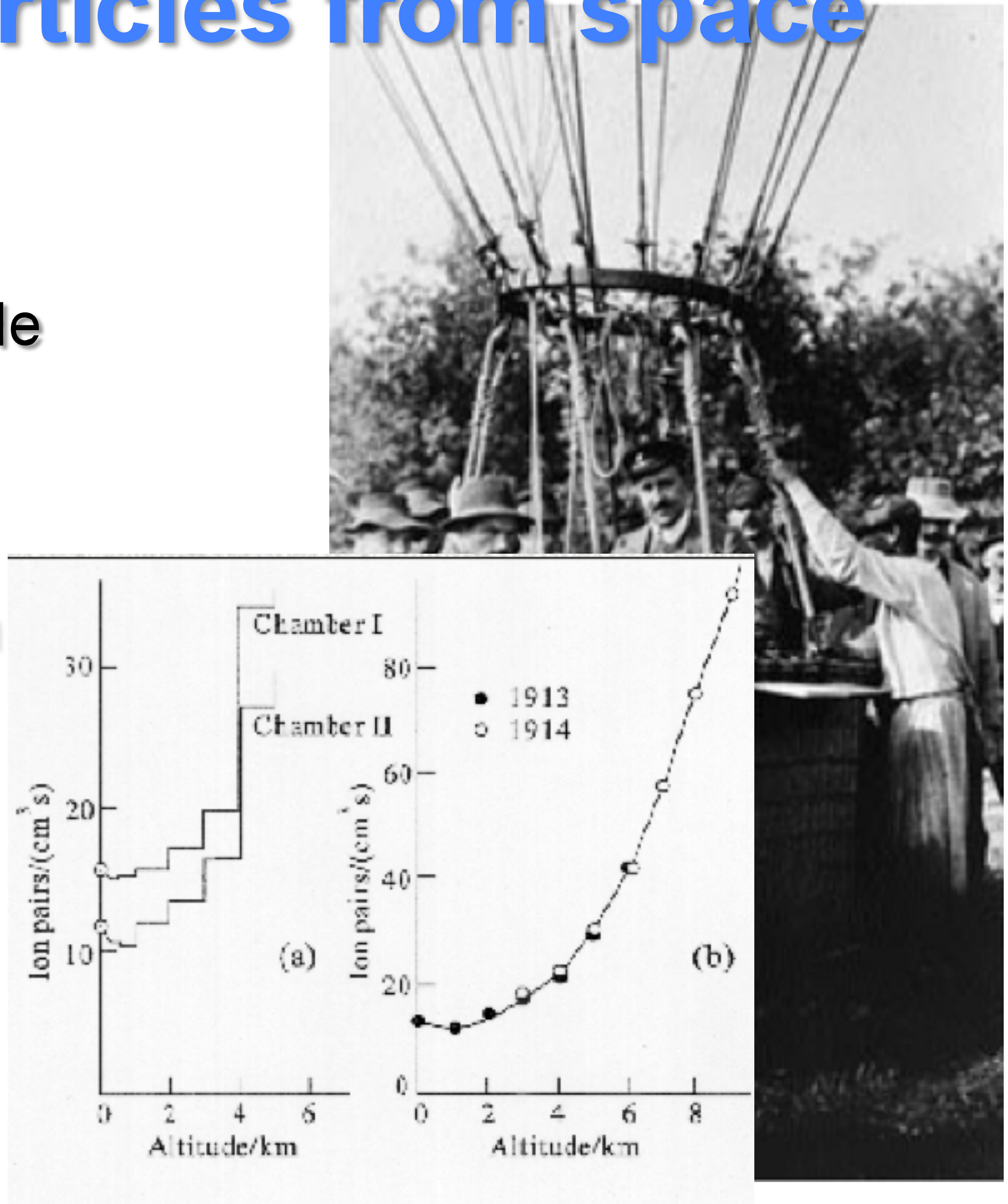
- *Introduction: what we know about cosmic rays?*
- *Galactic to extra-galactic cosmic ray transition*
- *Cosmic ray spectrum at E< TeV*
- *Knee region*
- *Detection of sources of galactic cosmic rays*
- *Summary*

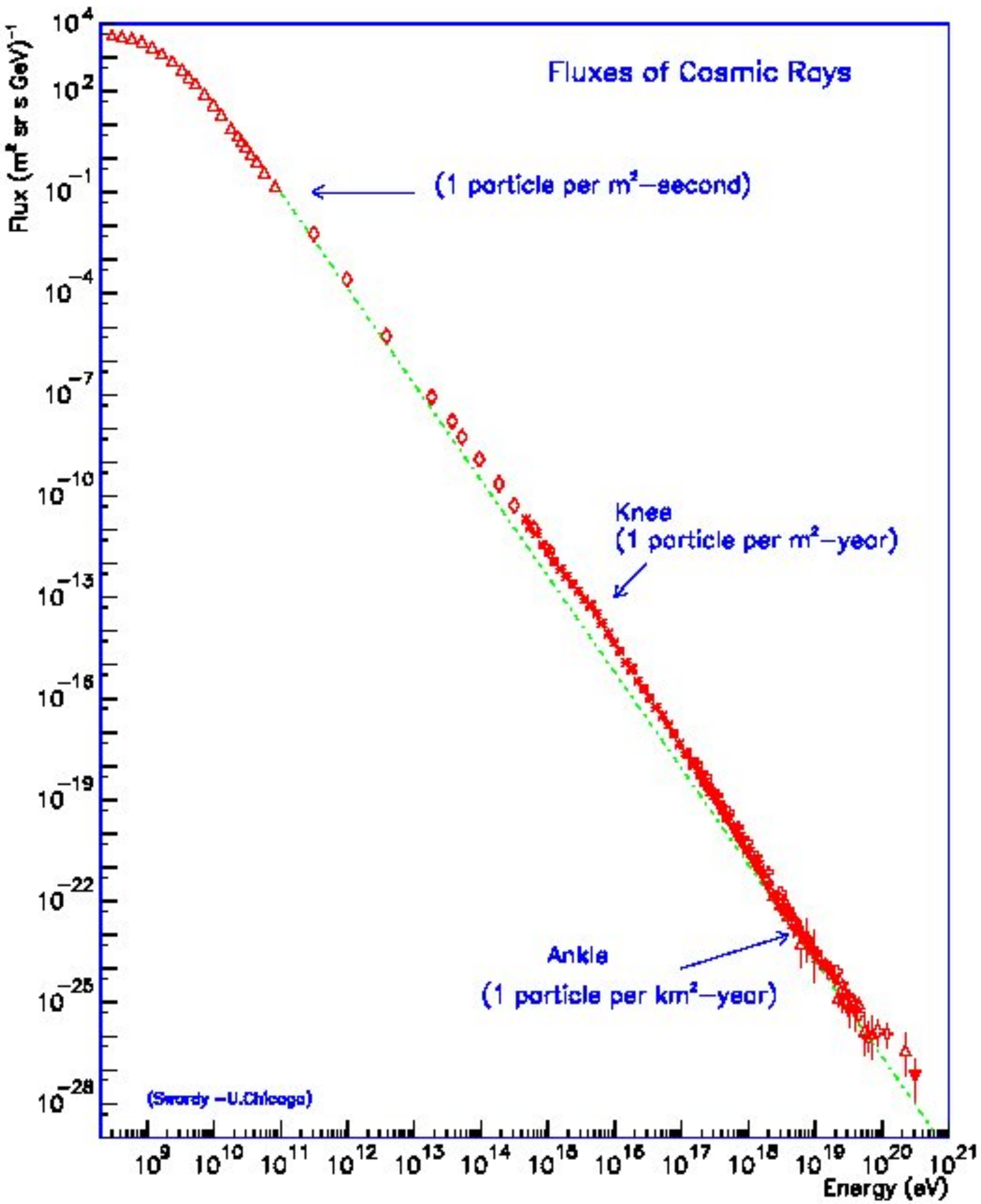
Introduction: what we know about cosmic rays?

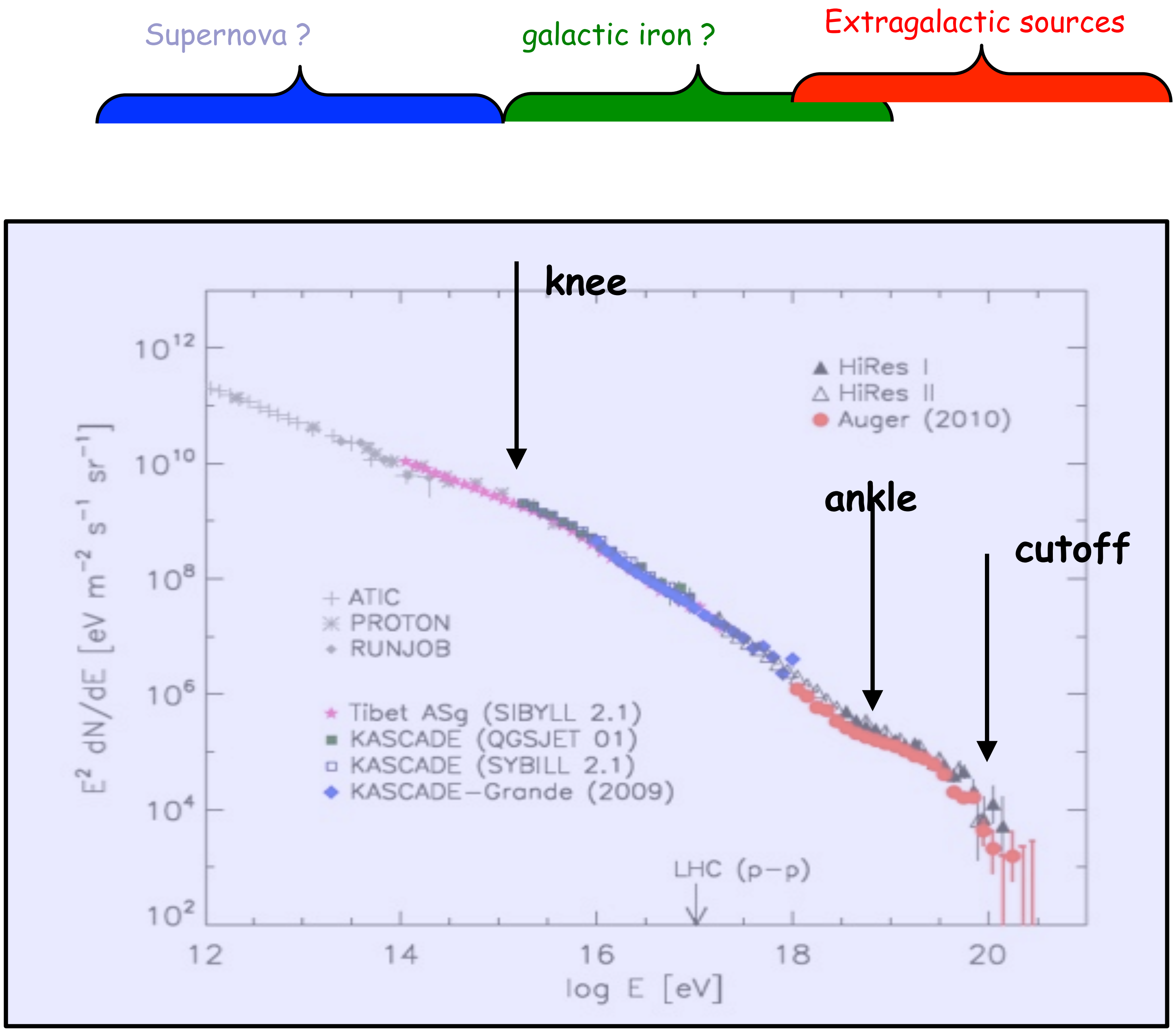
•High-energy particles from space

•Cosmic Rays (CR) are charged high-energy particles coming from outside the atmosphere.

•Discovered 100 yr ago by V.Hess in 1912, via detection of increase of the rate of discharge of an electrometer with increase of the altitude.

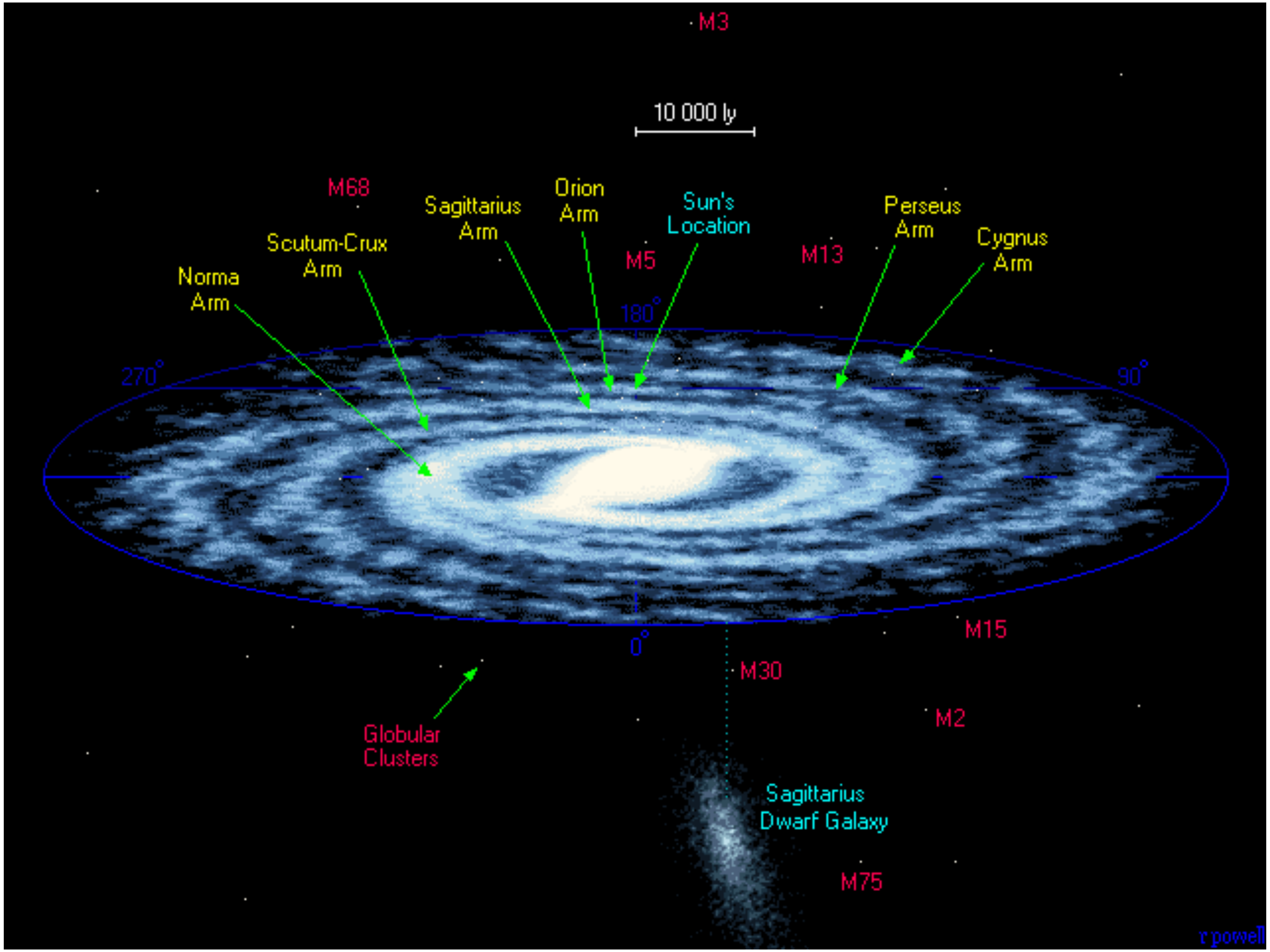



Fluxes of Cosmic Rays
(1 particle per m²–second)
Knee
(1 particle per m²–year)
Ankle
(1 particle per km²–year)
(Swordy – U.Chicago)
Flux (m² sr s GeV)⁻¹
Energy (eV)



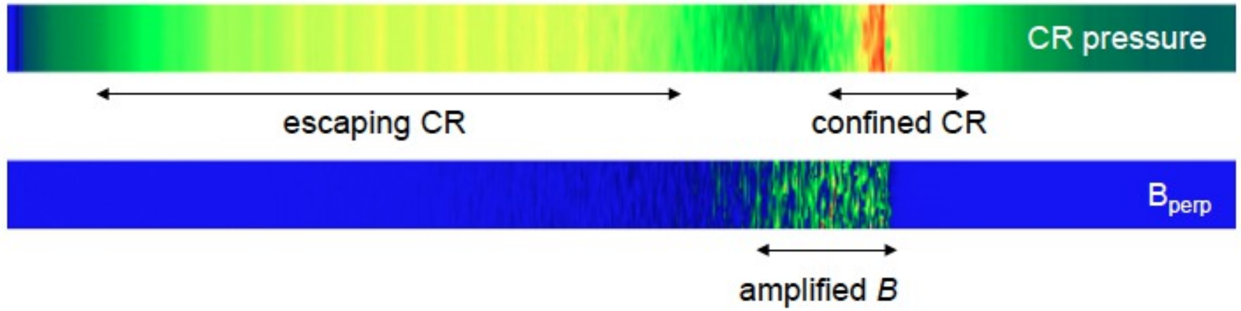
Supernova ?
galactic iron ?
Extragalactic sources
knee
ankle
cutoff
HiRes I
HiRes II
Auger (2010)
ATIC
PROTON
RUNJOB
Tibet ASg (SIBYLL 2.1)
KASCADE (QGSJET 01)
KASCADE (SYBILL 2.1)
KASCADE−Grande (2009)
LHC (p−p)
E^2 dN/dE [eV m^{-2} s^{-1} sr^{-1}]
log E [eV]

MILKY WAY GALAXY



Acceleration

CR confinement by *B*



Condition for CR confinement: $\int \gamma_{max} dt \approx 5 \longrightarrow \int j dt \approx 10 \sqrt{\frac{\rho}{\mu_0}}$

Current carries CR energy: $j = \frac{\eta \rho u_{shock}^3}{\varepsilon}$

Mean energy of escaping CR: $\varepsilon \approx 230\, n_e^{1/2}\, u_7^2\, R_{pc}$ TeV

- n_e: in cm^{-3}
- u_7: in 10,000 km s^{-1}
- R_{pc}: radius in parsec

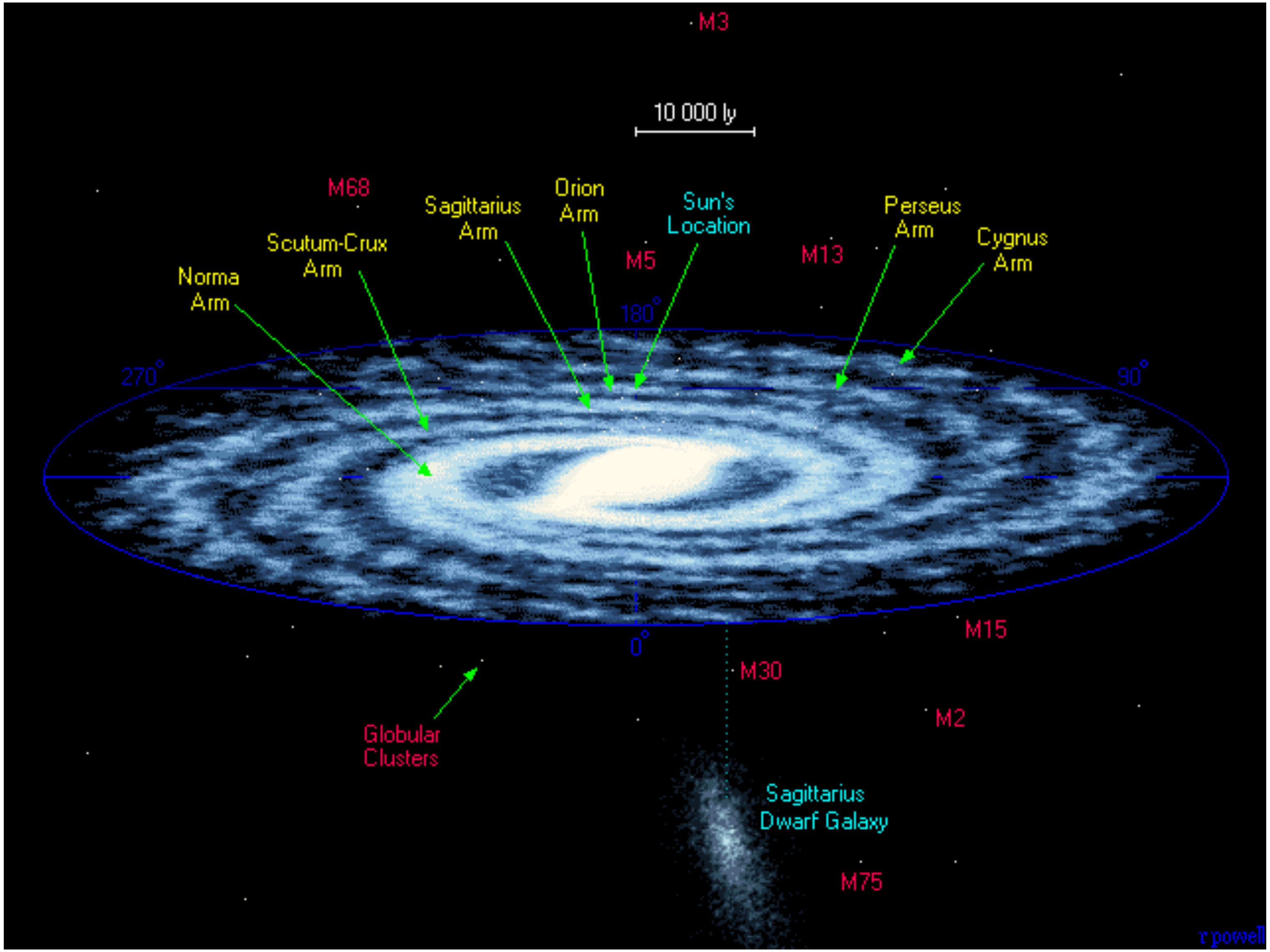
From T.Bell, CR Workshop Paris 2012

Questions for Galaction CR:

- *At E< 1 TeV cosmic rays affected by Sun. Real spectrum of cosmic rays? Total energy accumulated in cosmic rays?*
- *What are the sources of Galactic cosmic rays?*
- *At which energy extragalactic cosmic rays show up?*
- *Mass composition of cosmic rays above 100 TeV?*
- *Problem of acceleration above 100 TeV*

Galactic magnetic field

MILKY WAY GALAXY



Galactic magnetic field

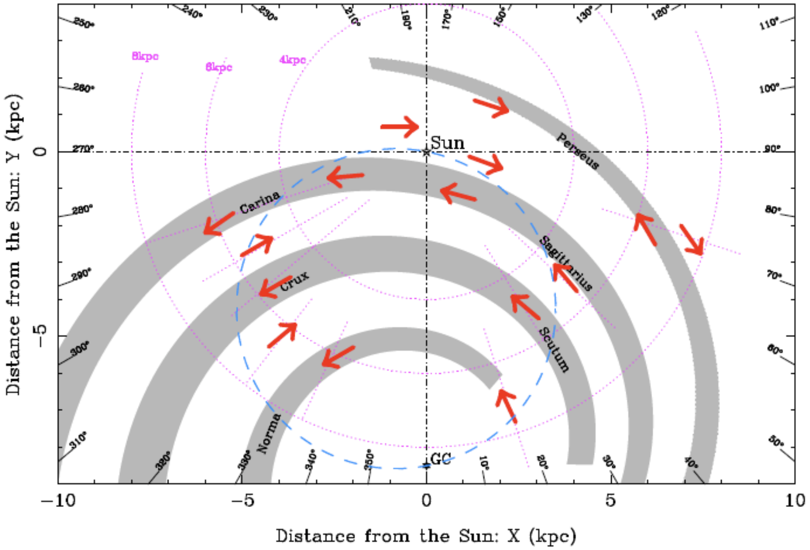
- B = B_disk (regular) + B_disk (turbulent) + B_halo(regular) + B_halo (turbulent)

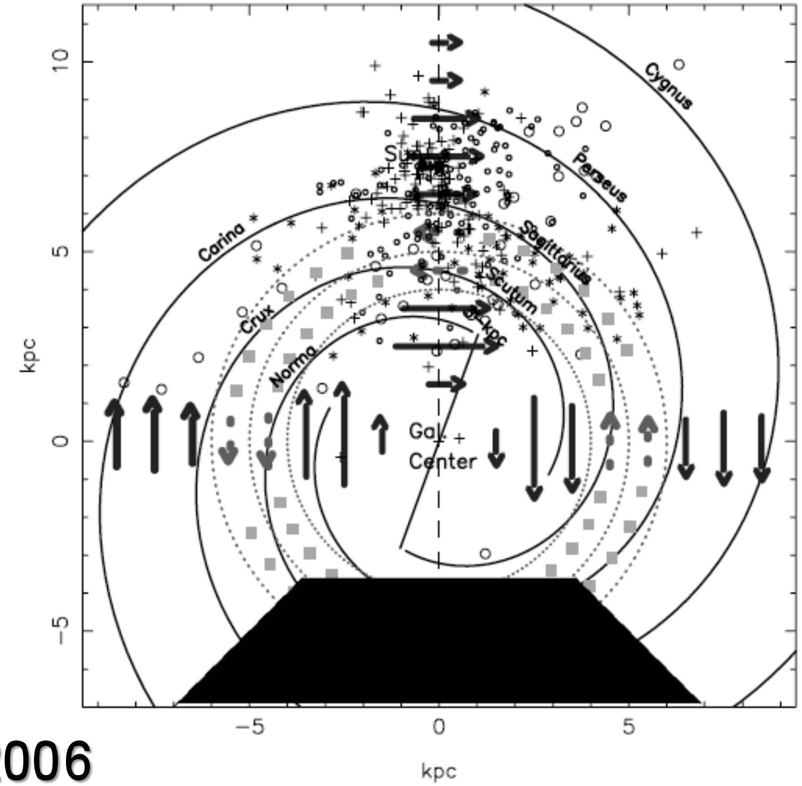
Rotation measure

$$\mathrm{RM} \simeq 0.81 \int_0^L \left(\frac{n_e(l)}{\mathrm{cm}^{-3}}\right) \left(\frac{B_{\|}(l)}{\mu\mathrm{G}}\right) \left(\frac{\mathrm{d}l}{\mathrm{pc}}\right)$$

$$\theta \ = \ \theta_0 + \mathrm{RM}\, \lambda^2$$

Galactic magnetic field: disk

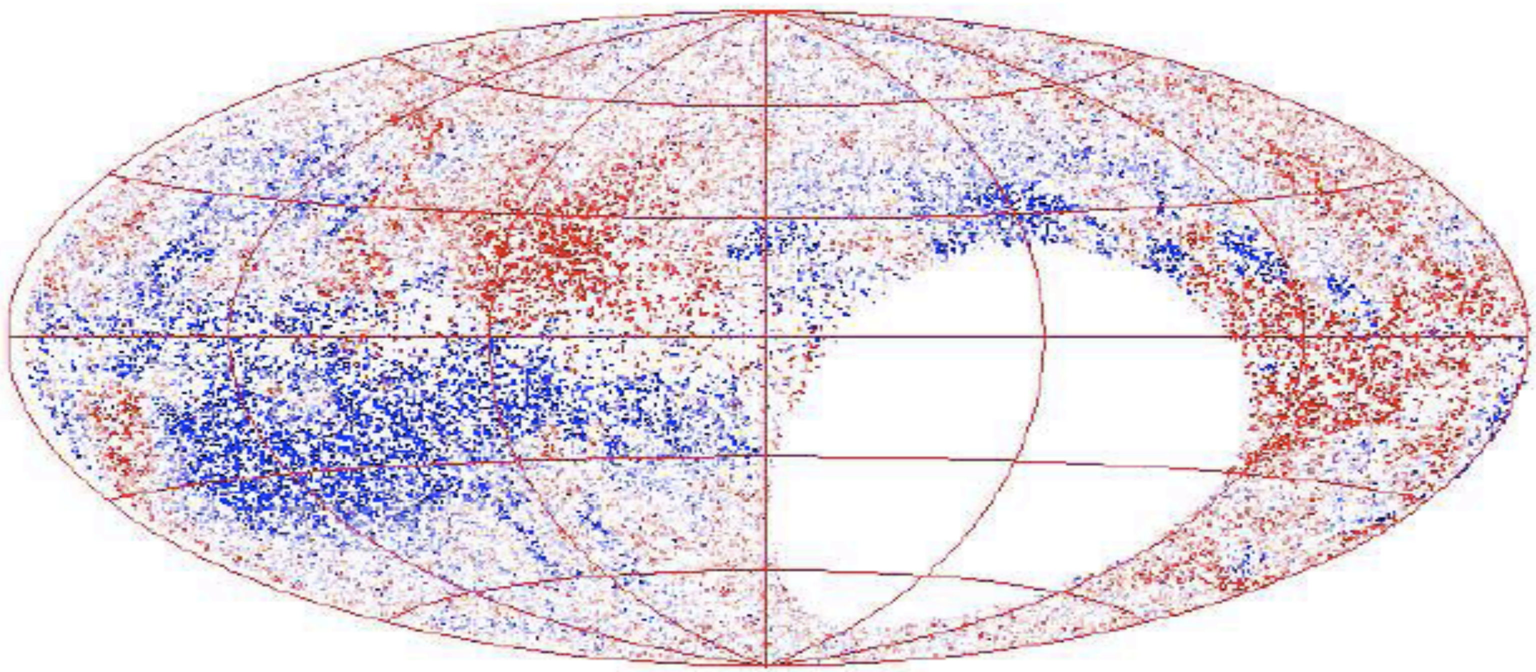




J.L.Han et al, Astrophys.J.642:868-881,2006

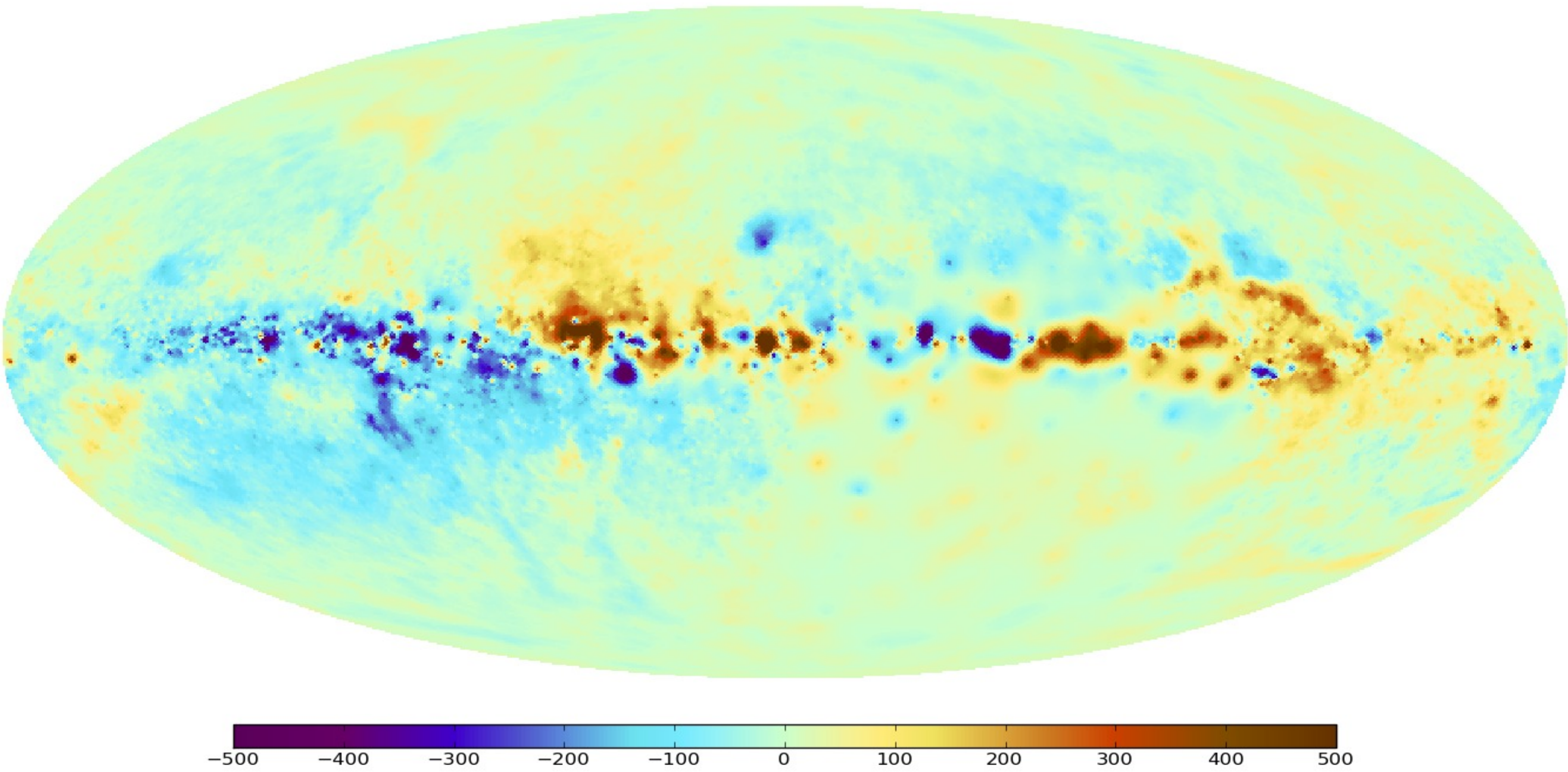
J.Vallee, Astrophys.J. 619:297–305, 2005

Galactic magnetic field measurement: RM

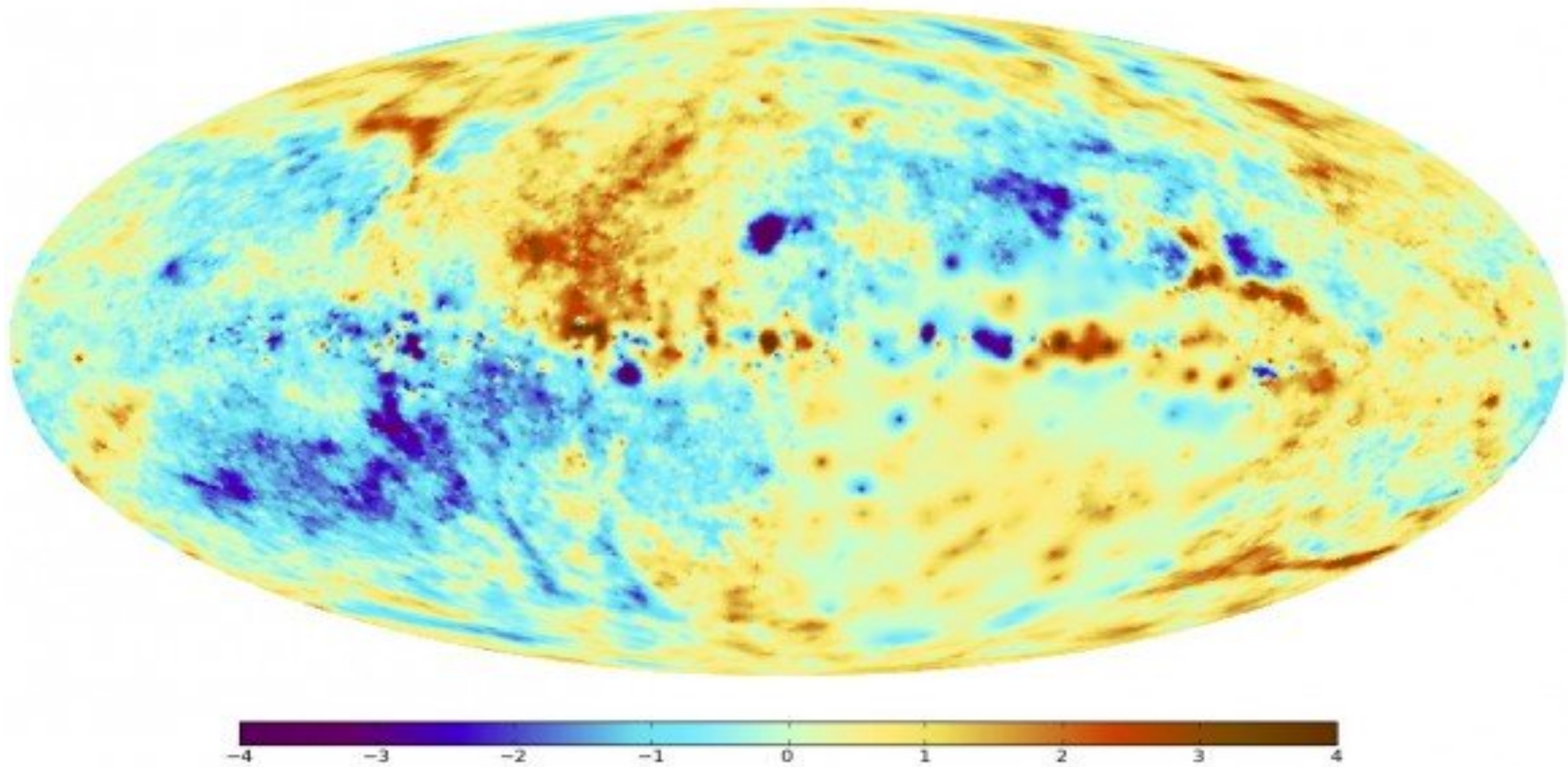


Pshirkov et al, **arXiv:1103.0814**

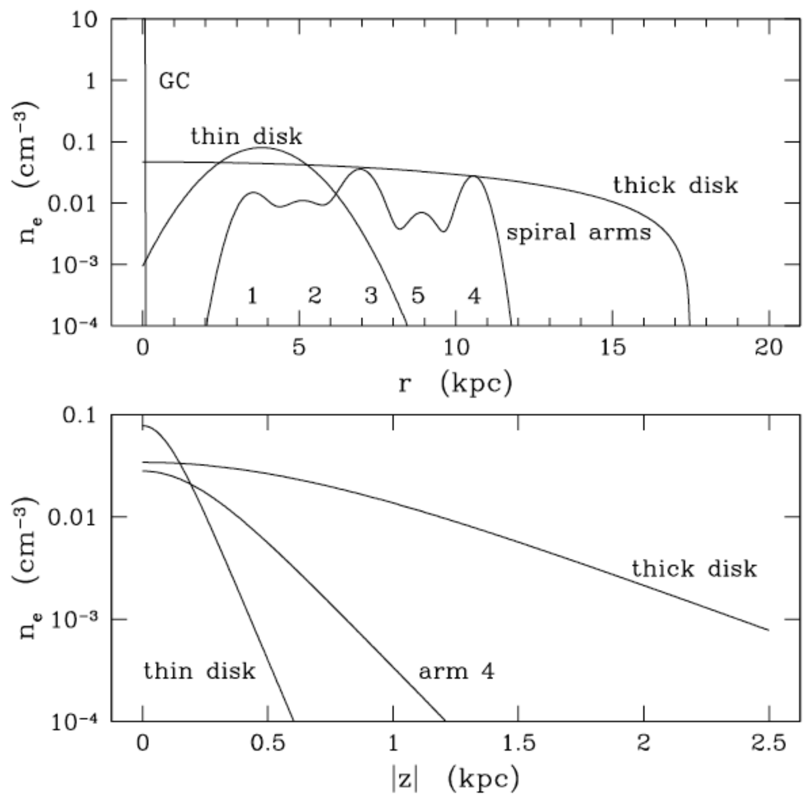
Galactic magnetic field measurement: RM dominated by disk



Galactic magnetic field halo measurement: RM



Free electrons 2001 model



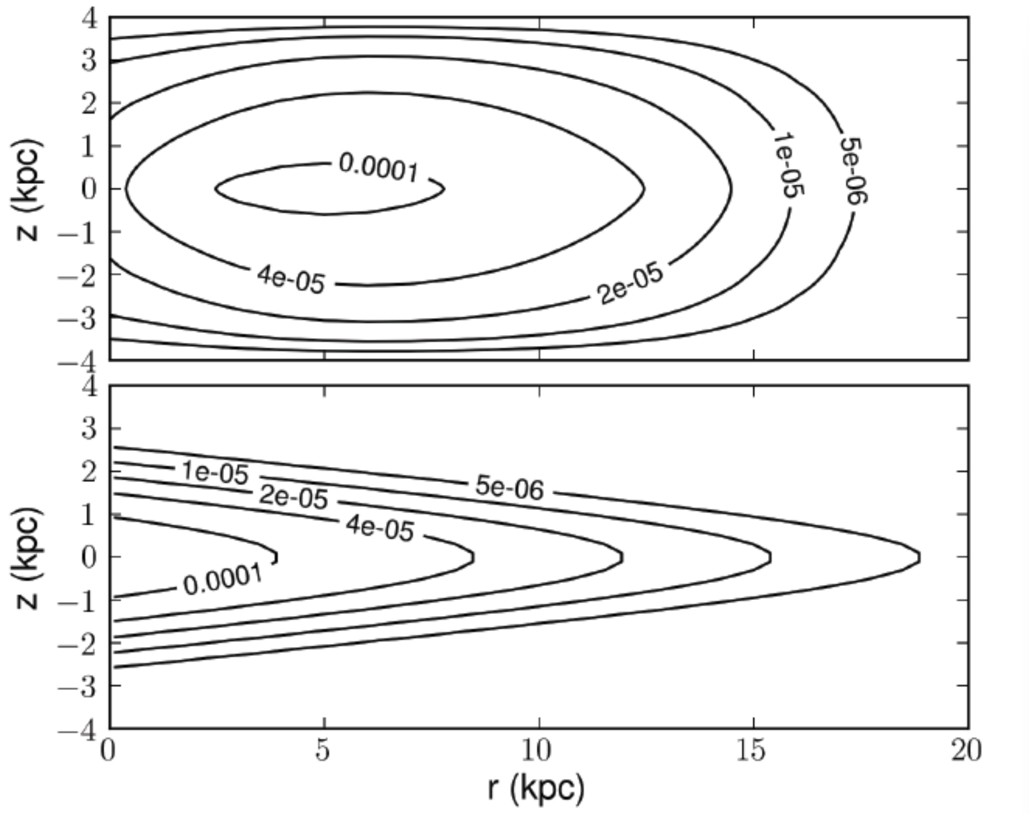
J.Cordes and T.Lazio, **astro-ph/0207156**

Polarized synchrotron emission

$$j_\nu \propto n_{cre} B_\perp^{\frac{1+s}{2}} \nu^{\frac{1-s}{2}} .$$

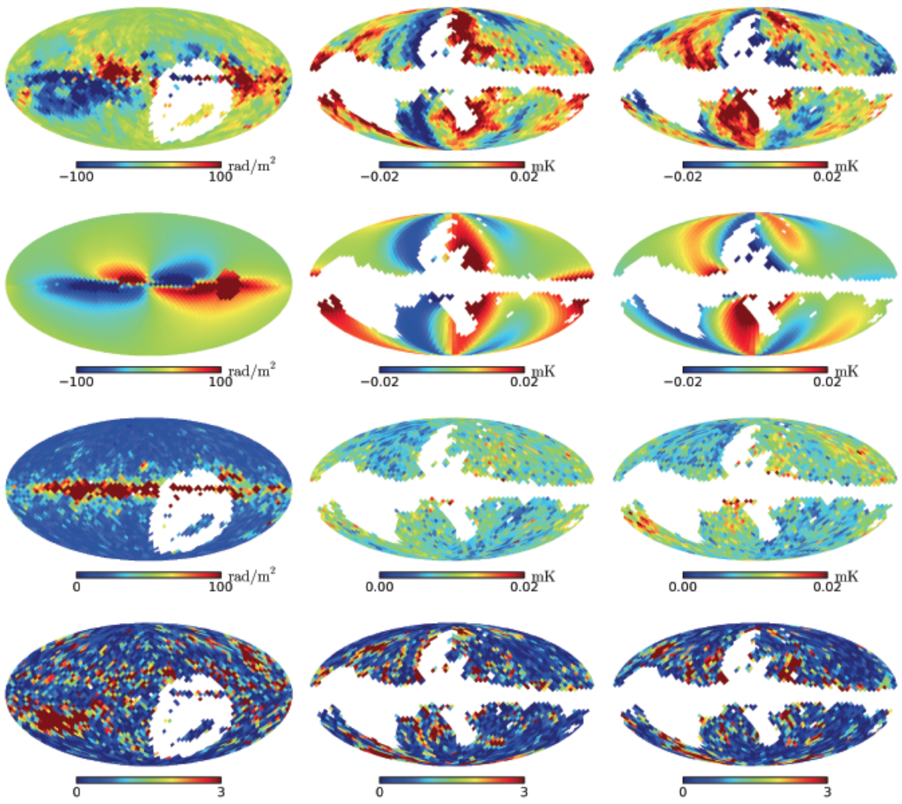
$$s = 3$$

Relativistic electrons



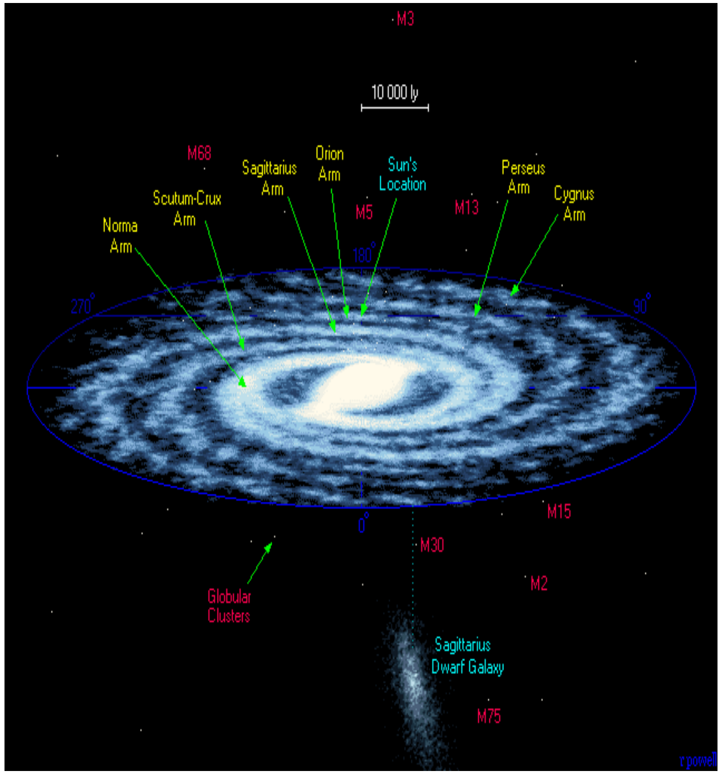
From R.Jansson & G.Farrar, arXiv:1204.3662

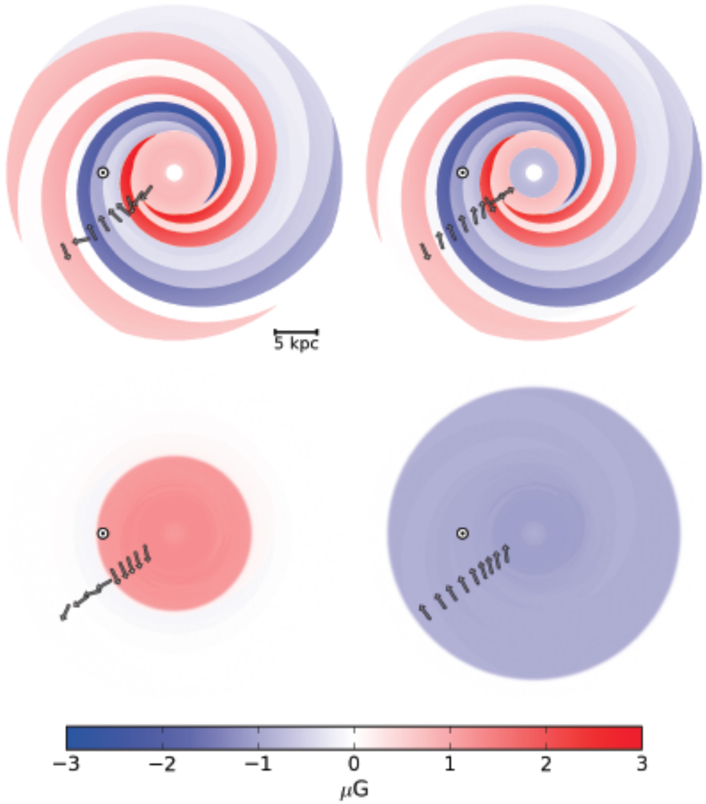
Synchrotron/RM maps



From R.Jansson & G.Farrar, arXiv:1204.3662

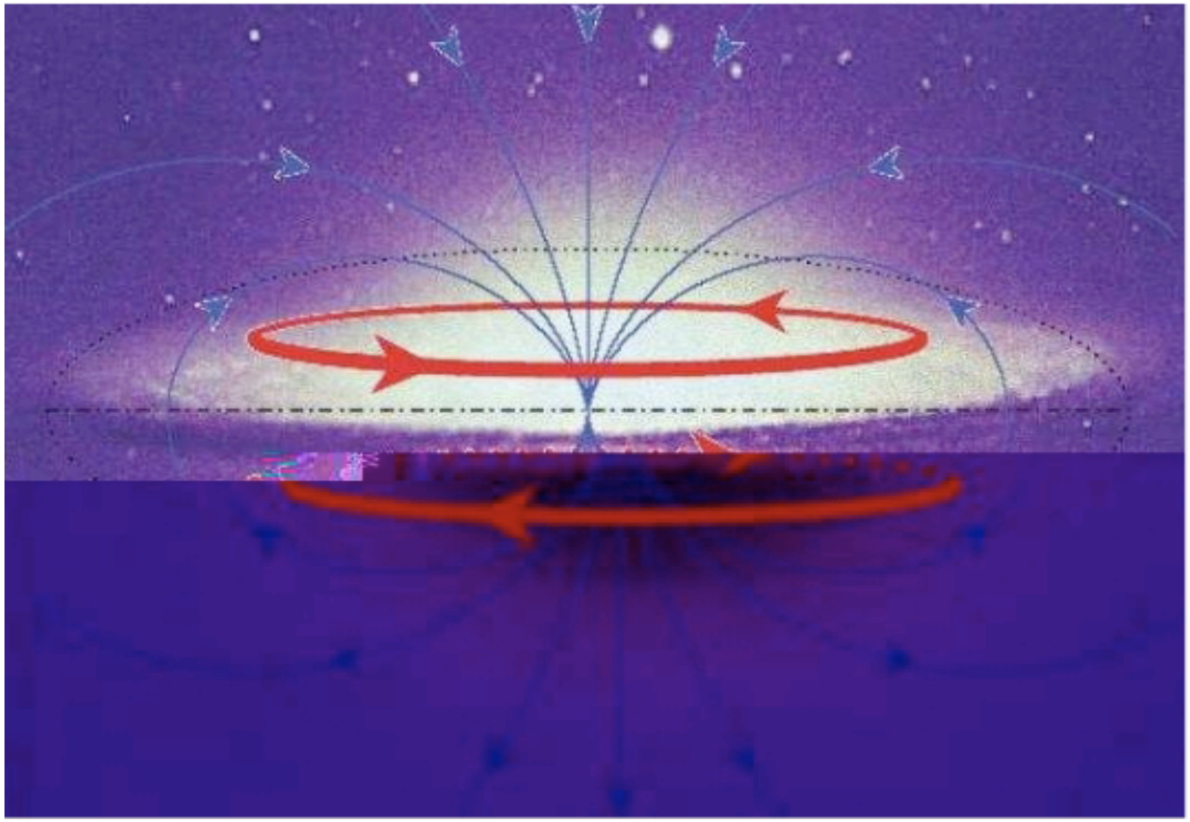
Galactic magnetic field: disk





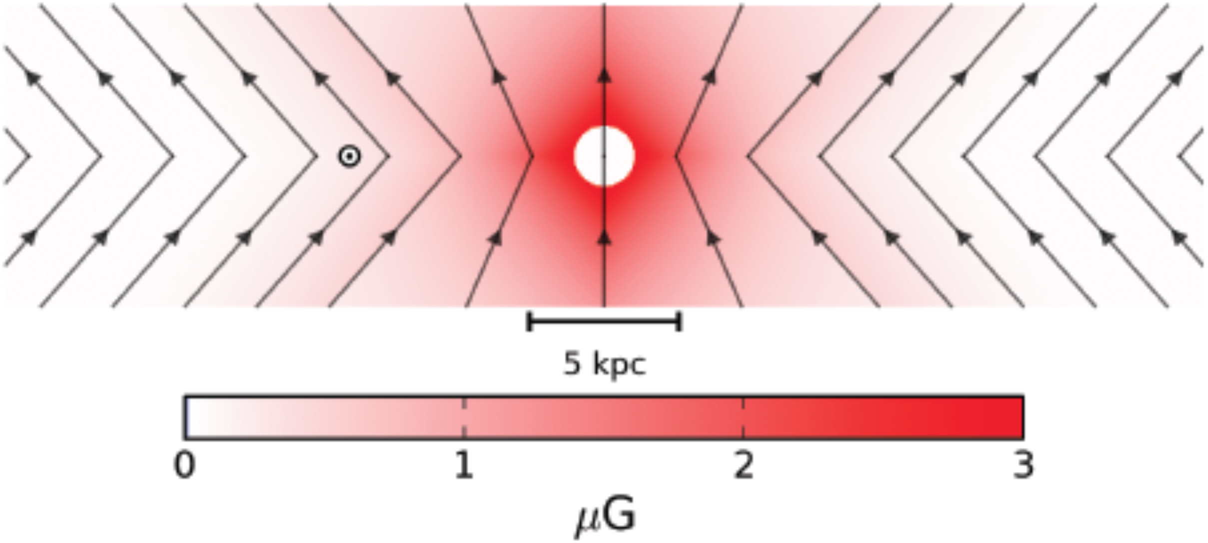
R.Jansson & G.Farrar, arXiv:1204.3662

Galactic magnetic field: halo



J-L. Han et al, **arXiv:0901.0040**

Galactic magnetic field halo: x-shape



R.Jansson & G.Farrar, arXiv:1204.3662

GMF parameters

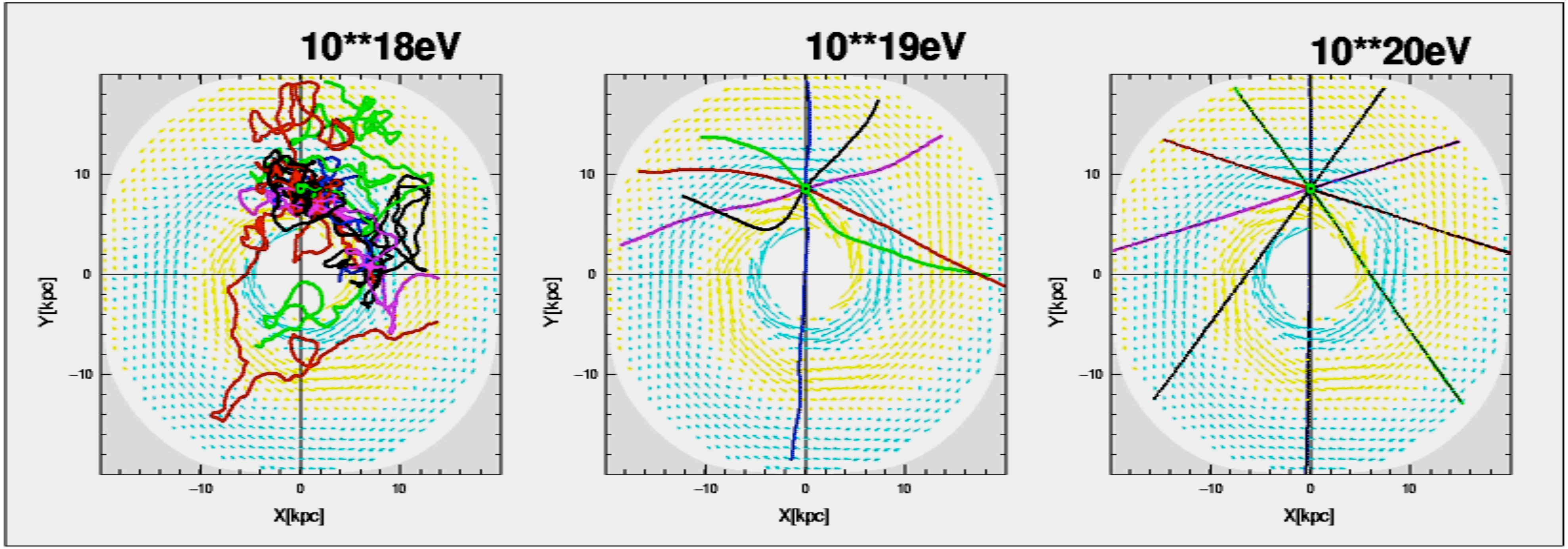
Table 1
Best-fit GMF parameters with $1-\sigma$ intervals.

Field	Best fit Parameters	Description
Disk	$b_1 = 0.1 \pm 1.8\,\mu$G	field strengths at $r = 5$ kpc
	$b_2 = 3.0 \pm 0.6\,\mu$G	
	$b_3 = -0.9 \pm 0.8\,\mu$G	
	$b_4 = -0.8 \pm 0.3\,\mu$G	
	$b_5 = -2.0 \pm 0.1\,\mu$G	
	$b_6 = -4.2 \pm 0.5\,\mu$G	
	$b_7 = 0.0 \pm 1.8\,\mu$G	
	$b_8 = 2.7 \pm 1.8\,\mu$G	inferred from $b_1, ..., b_7$
	$b_{\rm ring} = 0.1 \pm 0.1\,\mu$G	ring at 3 kpc $< r <$ 5 kpc
	$h_{\rm disk} = 0.40 \pm 0.03$ kpc	disk/halo transition
	$w_{\rm disk} = 0.27 \pm 0.08$ kpc	transition width
Toroidal halo	$B_{\rm n} = 1.4 \pm 0.1\,\mu$G	northern halo
	$B_{\rm s} = -1.1 \pm 0.1\,\mu$G	southern halo
	$r_{\rm n} = 9.22 \pm 0.08$ kpc	transition radius, north
	$r_{\rm s} > 16.7$ kpc	transition radius, south
	$w_{\rm h} = 0.20 \pm 0.12$ kpc	transition width
	$z_0 = 5.3 \pm 1.6$ kpc	vertical scale height
X halo	$B_{\rm X} = 4.6 \pm 0.3\,\mu$G	field strength at origin
	$\Theta^0_{\rm X} = 49 \pm 1°$	elev. angle at $z = 0, r > r^c_{\rm X}$
	$r^c_{\rm X} = 4.8 \pm 0.2$ kpc	radius where $\Theta_{\rm X} = \Theta^0_{\rm X}$
	$r_{\rm X} = 2.9 \pm 0.1$ kpc	exponential scale length
striation	$\gamma = 2.92 \pm 0.14$	striation and/or $n_{\rm cre}$ rescaling

R.Jansson & G.Farrar, arXiv:1204.3662

UHECR propagation in Milky Way

- Deflection angle ~ 1-2 degrees at 10^{20}eV for protons
  - Astronomy by hadronic particles?



Galactic magnetic field

- B = B_disk (regular) + B_disk (turbulent) + B_halo(regular) + B_halo (turbulent)

Galactic magnetic field: turbulent component

- Field with $\langle B(r)\rangle = 0 \qquad \langle B(r)^2\rangle \equiv B_{\rm rms}^2 > 0.$
- Power spectrum $\mathcal{P}(k) \propto k^{-\alpha}, \qquad |B(k)|^2 \propto k^{-\alpha-2}$
- With index $\alpha = 5/3,\ 3/2$ for Kolmogorov/Kraichnan cases
- Correlation length

$$L_c = \frac{L_{\rm max}}{2}\,\frac{\alpha-1}{\alpha}\,\frac{1-(L_{\rm min}/L_{\rm max})^{\alpha}}{1-(L_{\rm min}/L_{\rm max})^{\alpha-1}}\,.$$

- Where
- $L_{\rm min} = 1\,{\rm AU} \qquad L_{\rm max} = 100-300\,{\rm pc}.$

Galactic magnetic field: turbulent component

- Profile 1

$$B_{\rm rms}(r,z) = B(r)\exp\left(-\frac{|z|}{z_0}\right)$$

$$B(r) = \begin{cases} B_0 \ \exp\left(\frac{5.5}{8.5}\right) & \text{, if } r \leq 3\,\text{kpc (bulge)} \\ B_0 \ \exp\left(\frac{-(r-8.5\,\text{kpc})}{8.5\,\text{kpc}}\right) & \text{, if } r > 3\,\text{kpc} \end{cases}$$

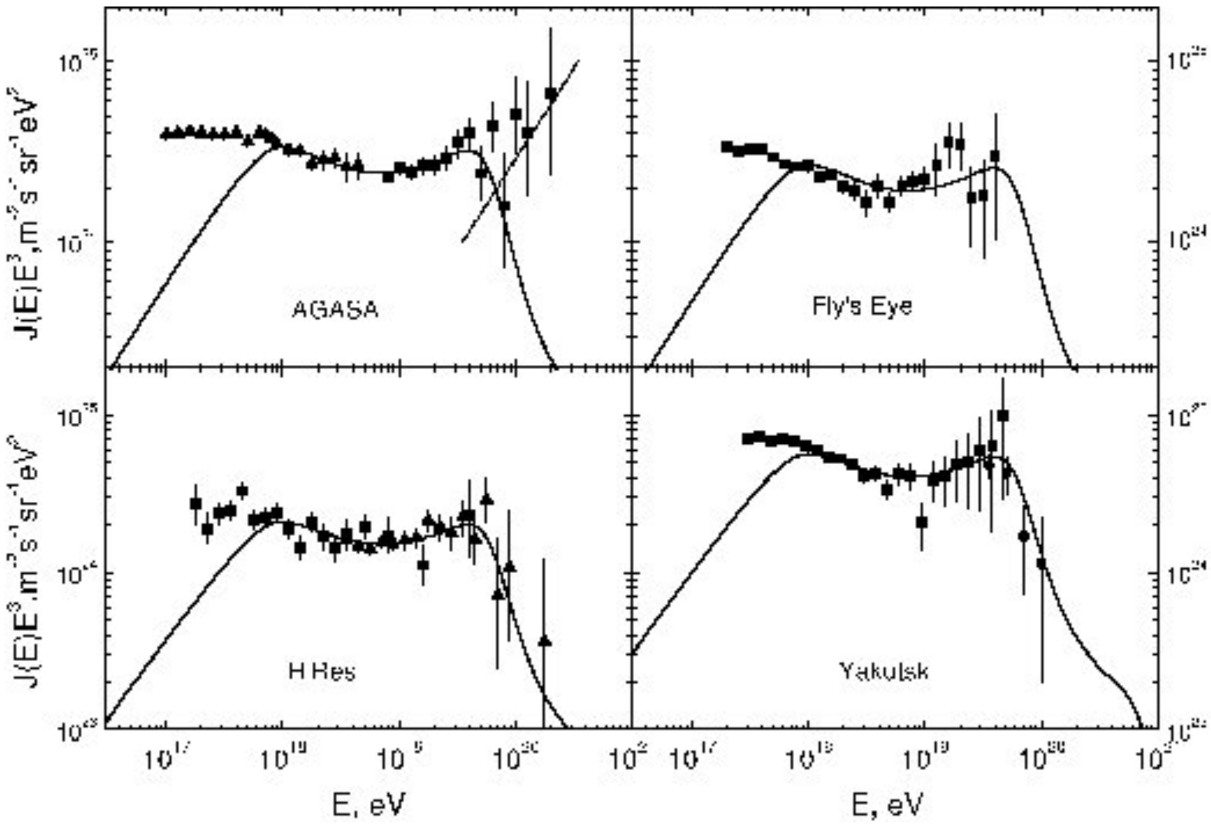
- Profile 2

$$B_{\rm rms}(r,z) = \begin{cases} B_0 & \text{, if } r \leq 20\,\text{kpc and } |z| \leq z_0 \\ 0 & \text{, if } r > 20\,\text{kpc or } |z| > z_0 \end{cases}$$

G.Giacinti et al, arXiv:1112.5599

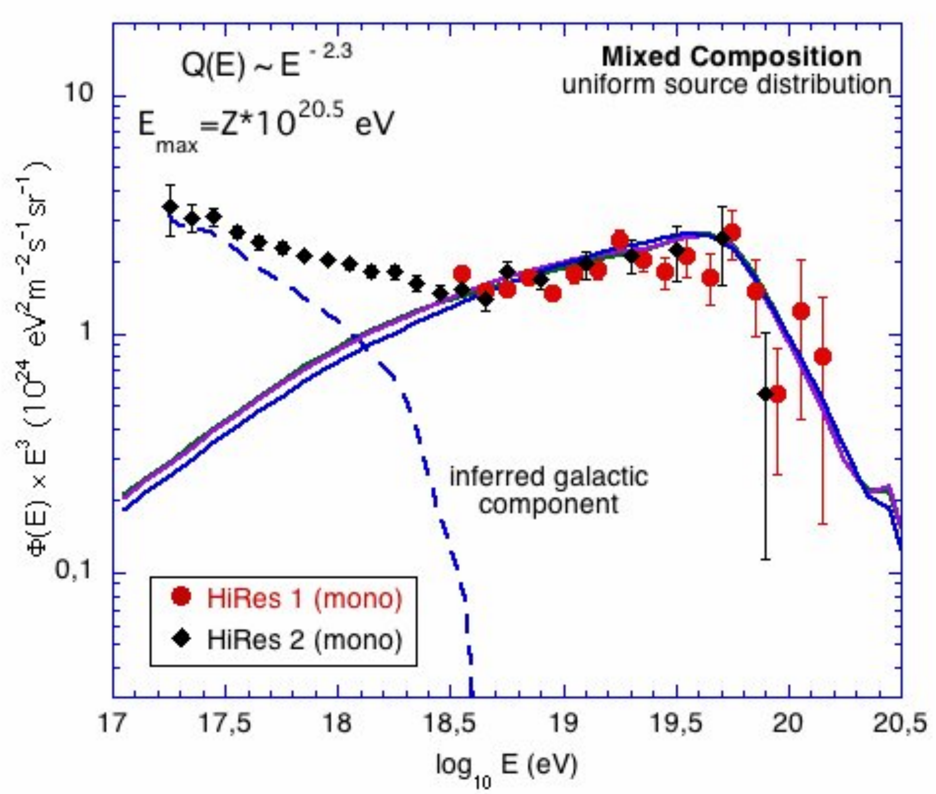
Transition from galactic to extragalactic cosmic rays

Dip model: Protons can fit UHECR data



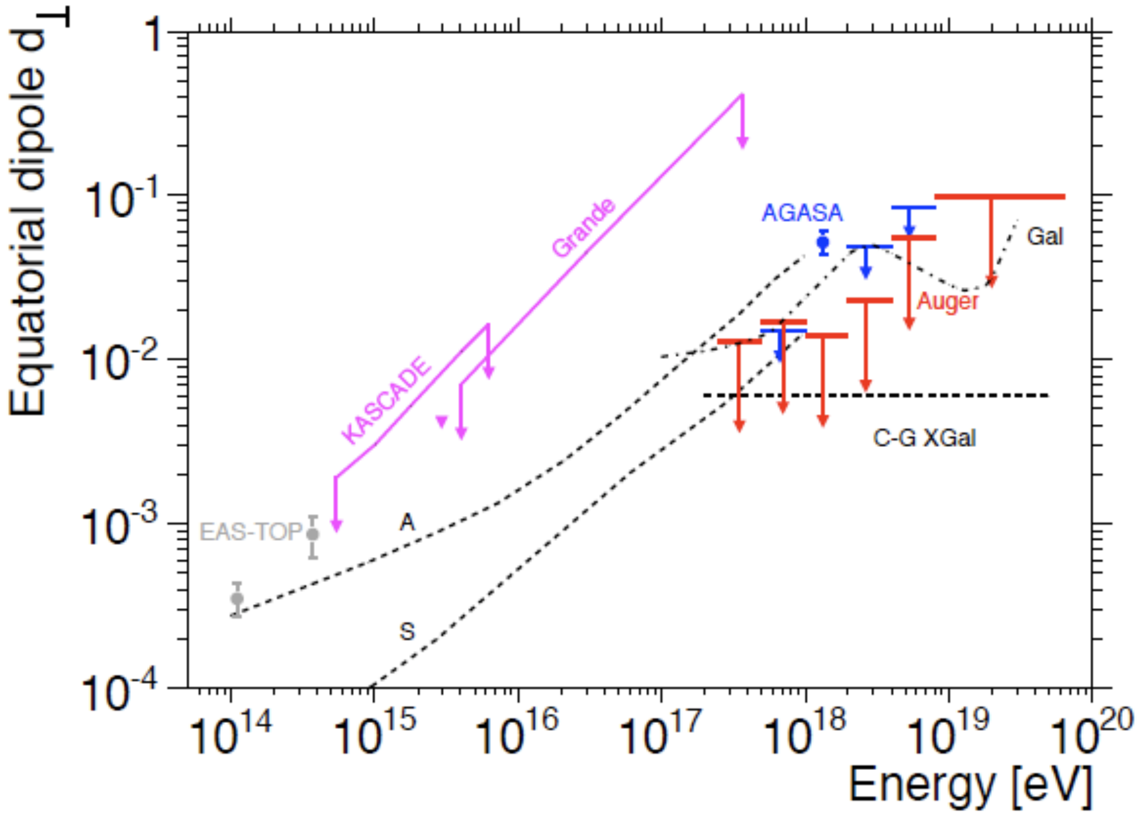
V.Berezinsky , astro-ph/0509069

Mixed composition model



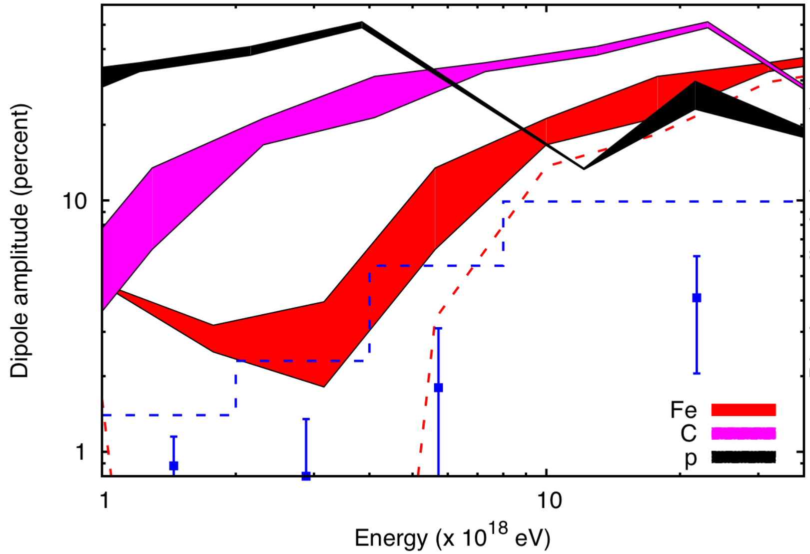
D.Allard, E.Parizot and A.Olinto, astro-ph/0512345

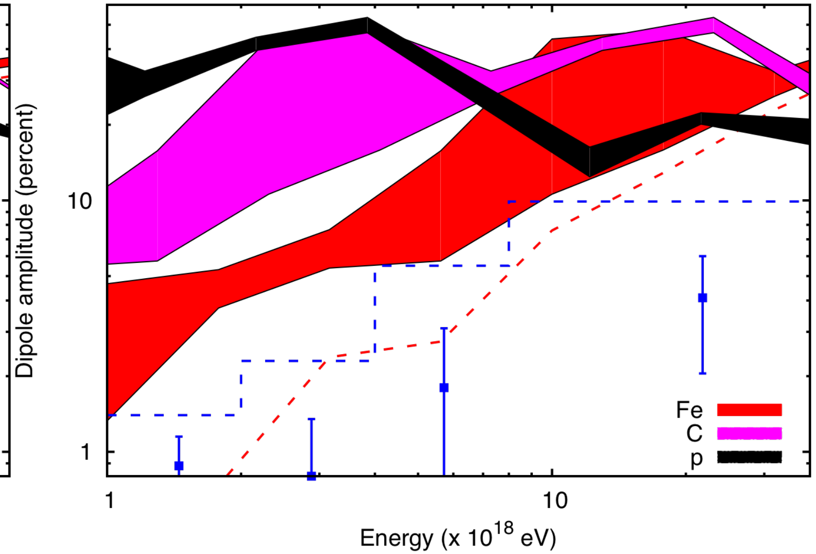
Anisotropy towards Galactic plane



Pierre Auger Collaboration, arXiv:1103.2721

Dependence on parameters



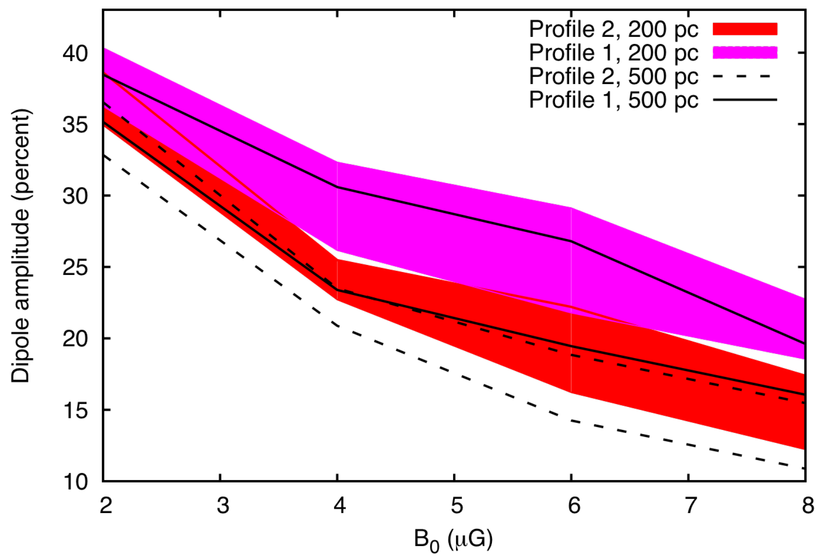


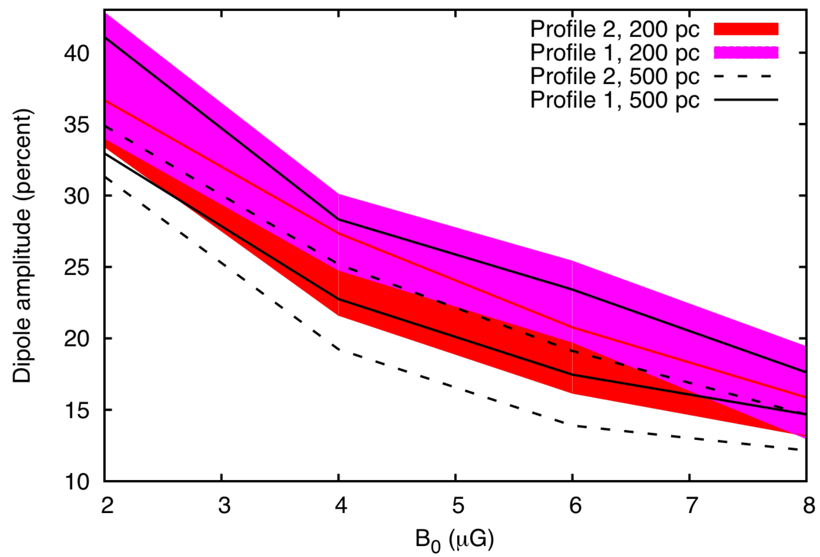
Turb. Magn. Field spectrum
Kolmogorov/Kraichnan

Lmax = 100-300 pc

G.Giacinti et al, arXiv:1112.5599

1 EeV protons from galactic sources



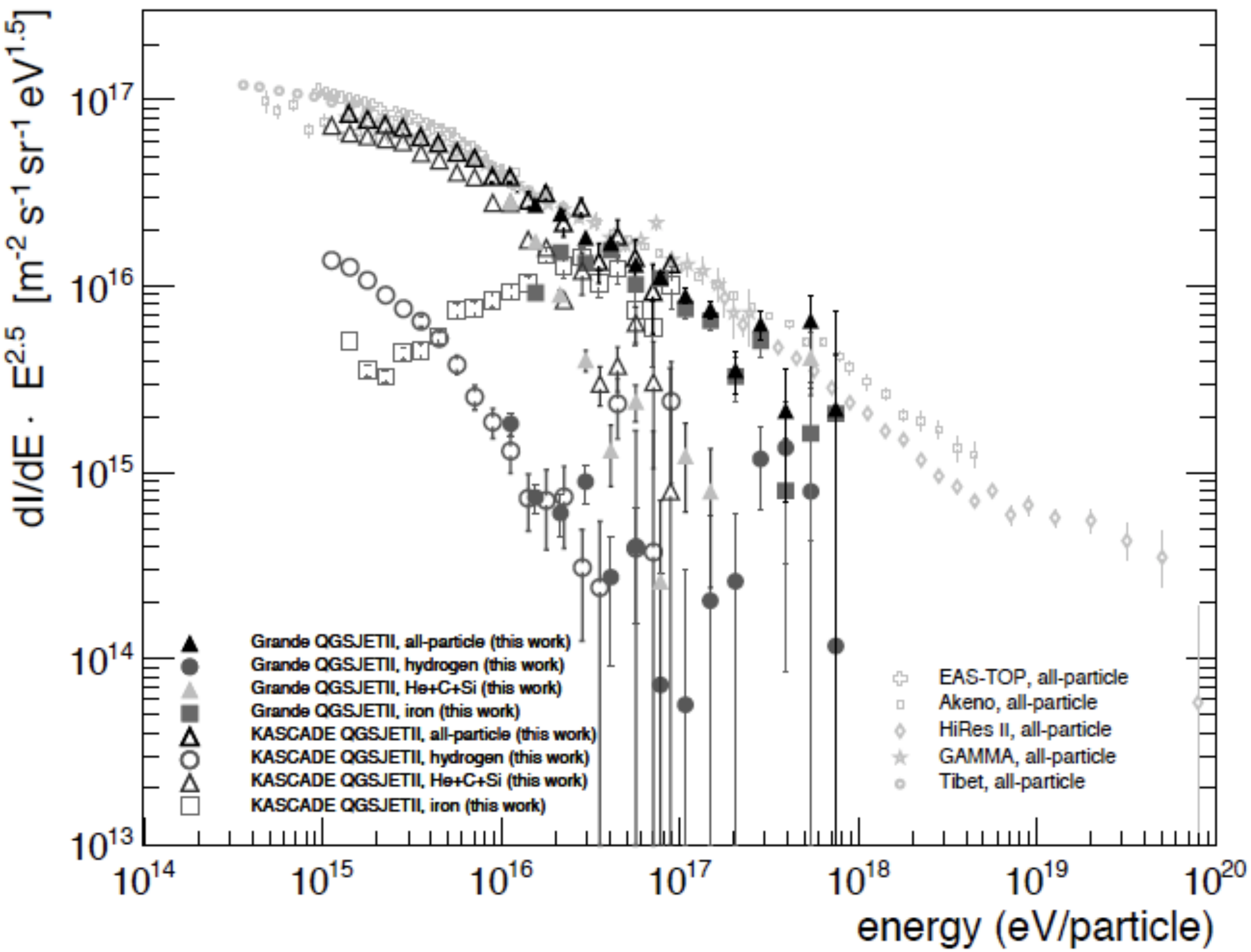


Turb. Magn. Field spectrum Kraichnan

Turb. Magn. Field spectrum Kolmogorov

G.Giacinti et al, arXiv:1112.5599

KASCADE-Grande protons



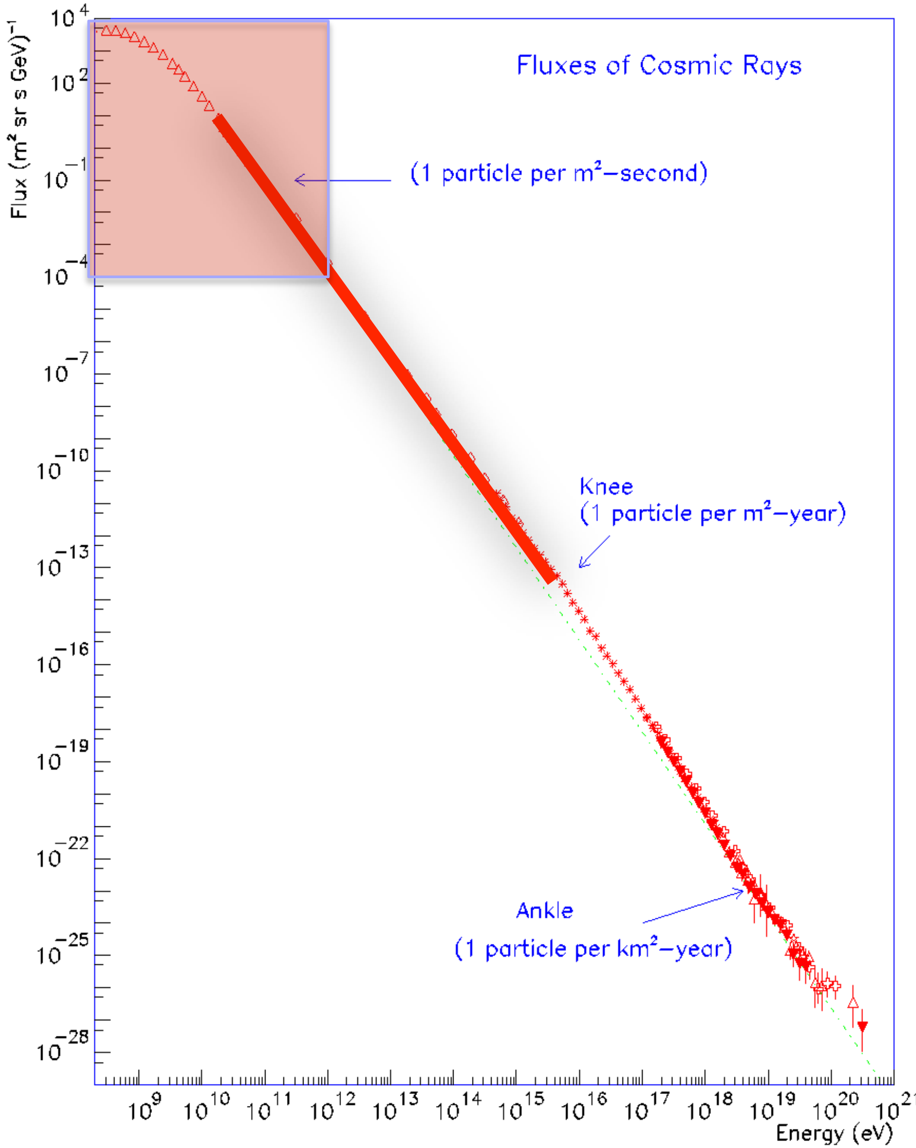
ICRC 2011 arXiv: 1111.5436

Cosmic rays below TeV

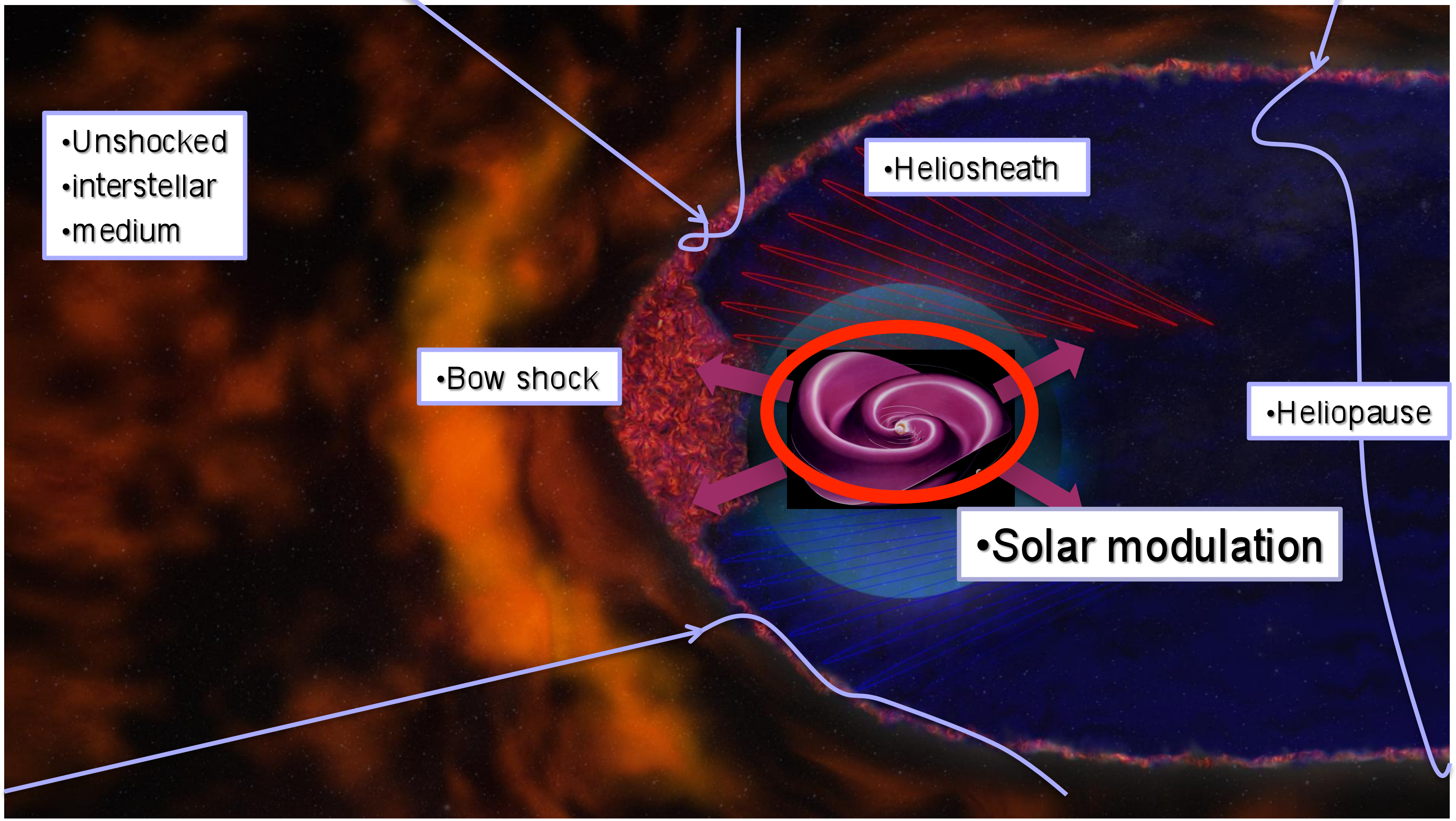
- CR flux at the energies <100 GeV is affected by the interplanetary magnetic field and depends on the solar activity

$$R_L = \frac{E_{CR}}{ZeB} \approx 2\left[\frac{E_{CR}}{10^{11}\,\mathrm{eV}}\right]\left[\frac{B_{IPM}}{10^{-5}\ \mathrm{G}}\right]^{-1} \mathrm{AU}$$

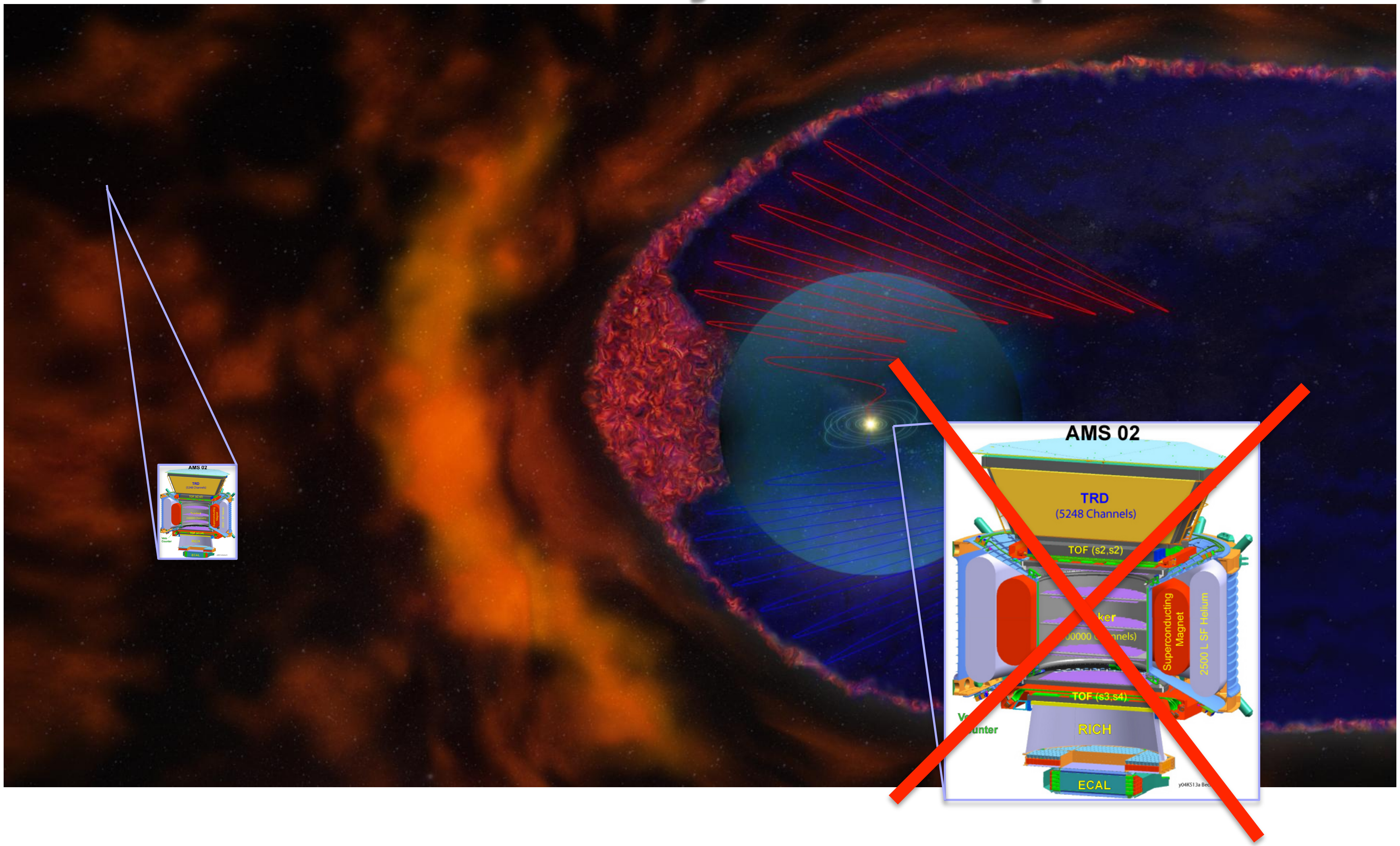
- At the lowest energies (< 10 GeV) Solar modulation is observed



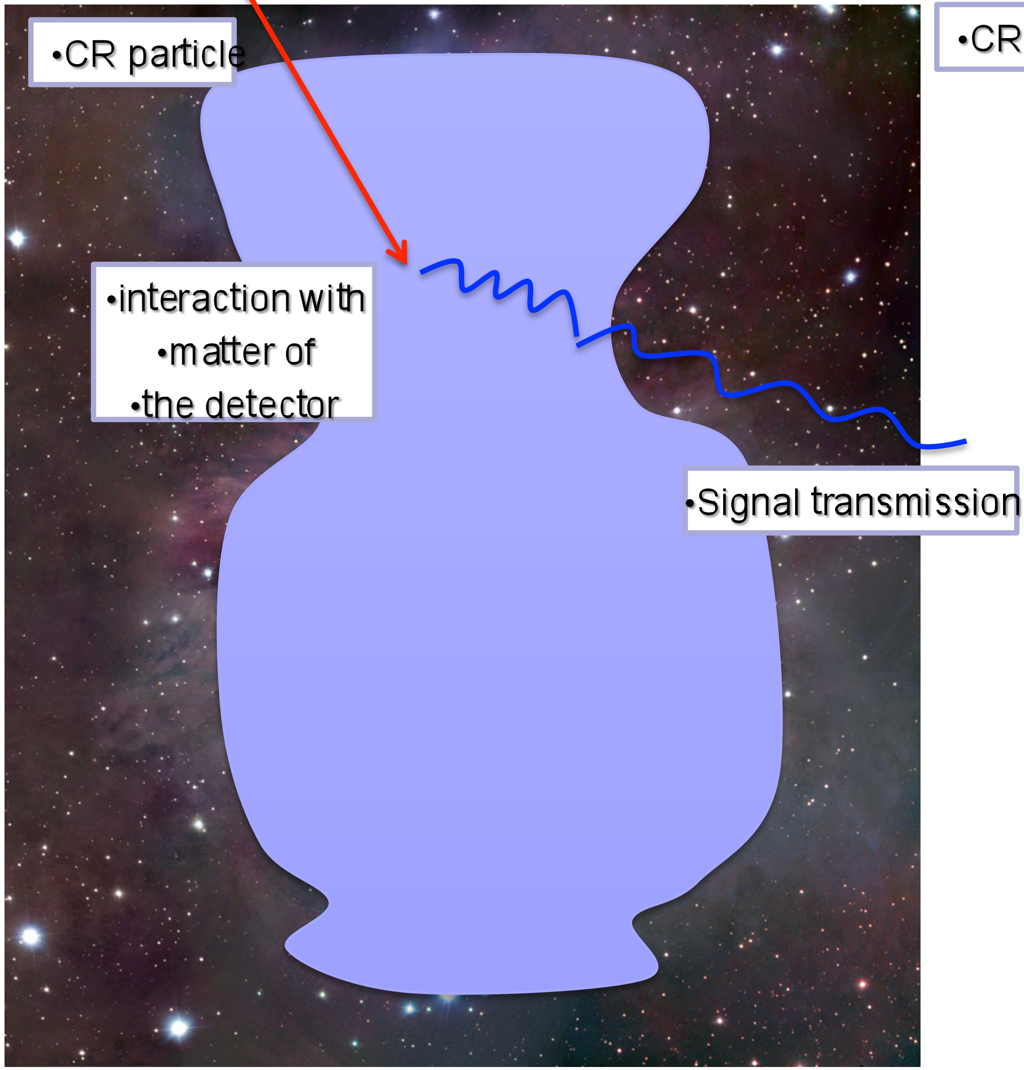
•Cosmic Rays in the Solar system

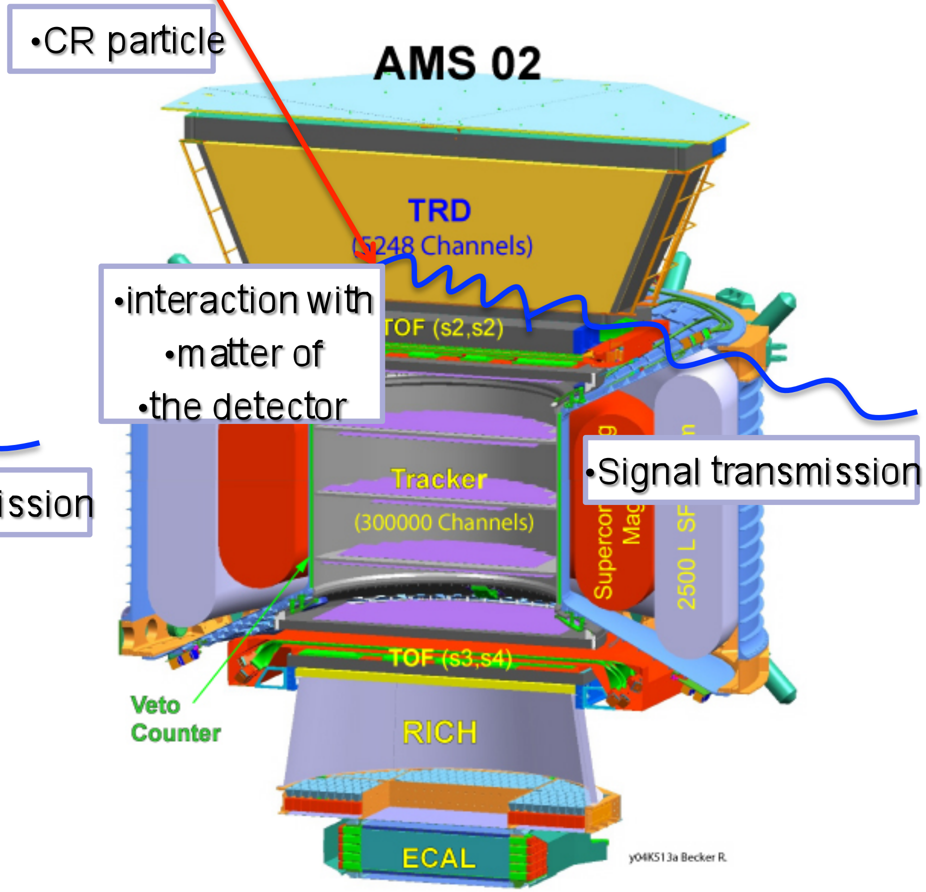


•Measurement of CR spectrum unaffected by the Heliosphere



•CR detectors outside the Heliosphere





•Large mass concentrations in the ISM could be used as "natural" CR detectors. Such mass concentrations are e.g. nearby Giant Molecular Clouds (GMC).

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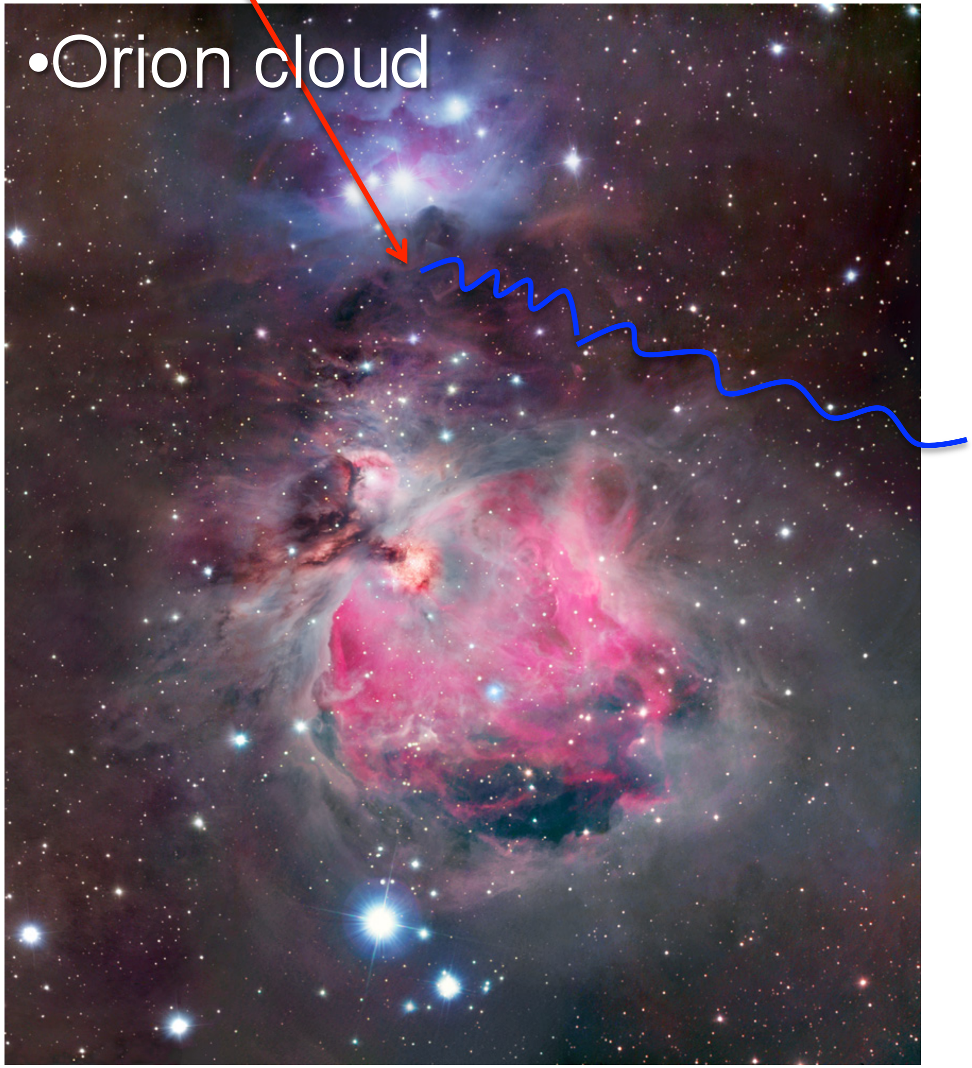
•CR detectors outside the Heliosphere



F.Aharonian book

•GMCs are objects of the mass $\sim 10^5\ M_{Sun}$ and size ~ 10 pc, i.e. of the matter density $n \sim 10^3 - 10^4$ cm^{-3}.

•CRs diffusing through the ISM cross the GMCs on the time scales of $t \sim 10^3 - 10^4$ yr.

•During this time CRs interact with the GMC matter with probability $p \sim ct\sigma n \sim 0.1$.

•CR interaction in the GMCs lead to the gamma-ray emission (from neutral pion production and decay).

•Large mass concentrations in the ISM could be used as "natural" CR detectors. Such mass concentrations are e.g. nearby Giant Molecular Clouds (GMC).

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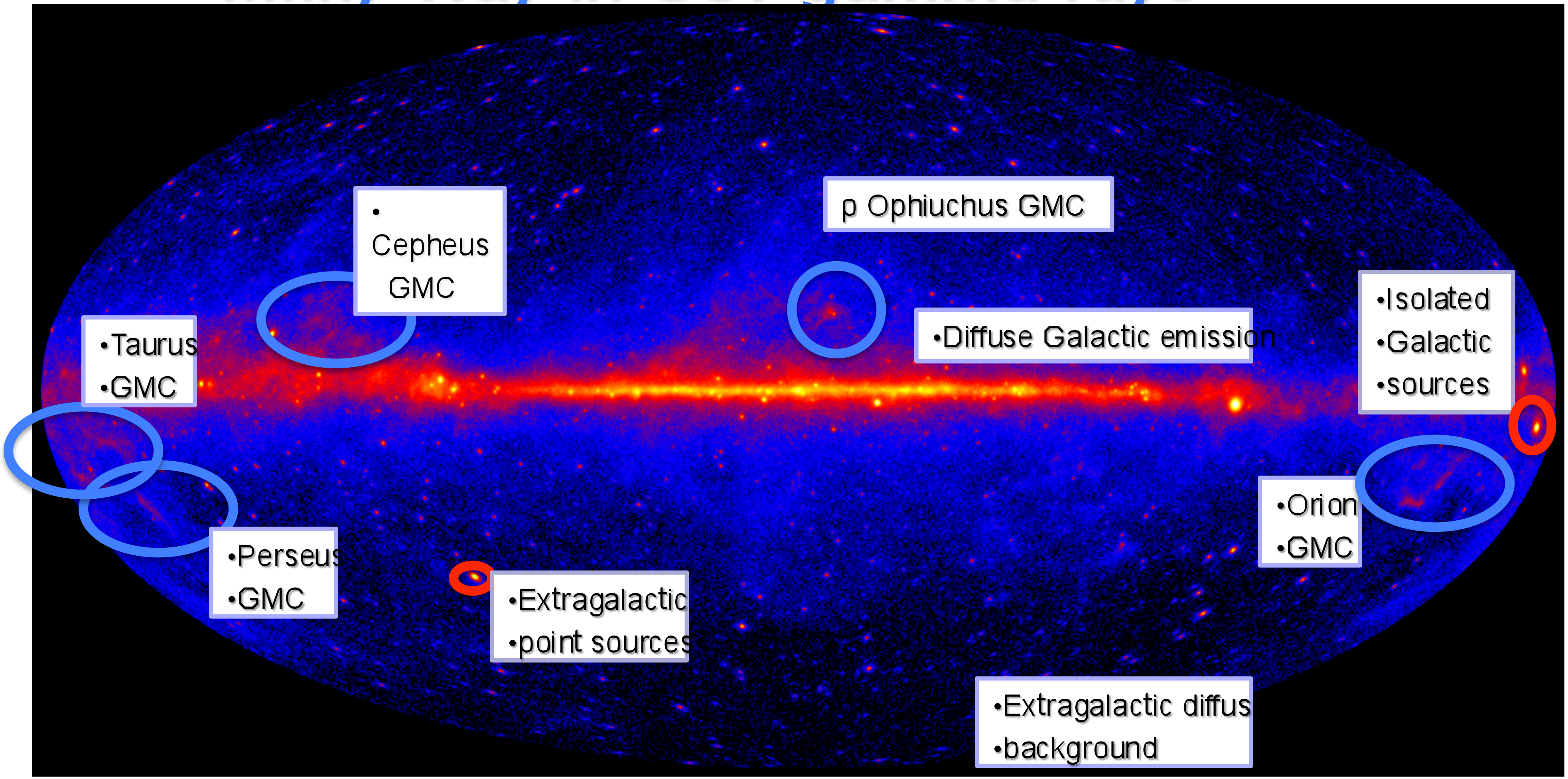
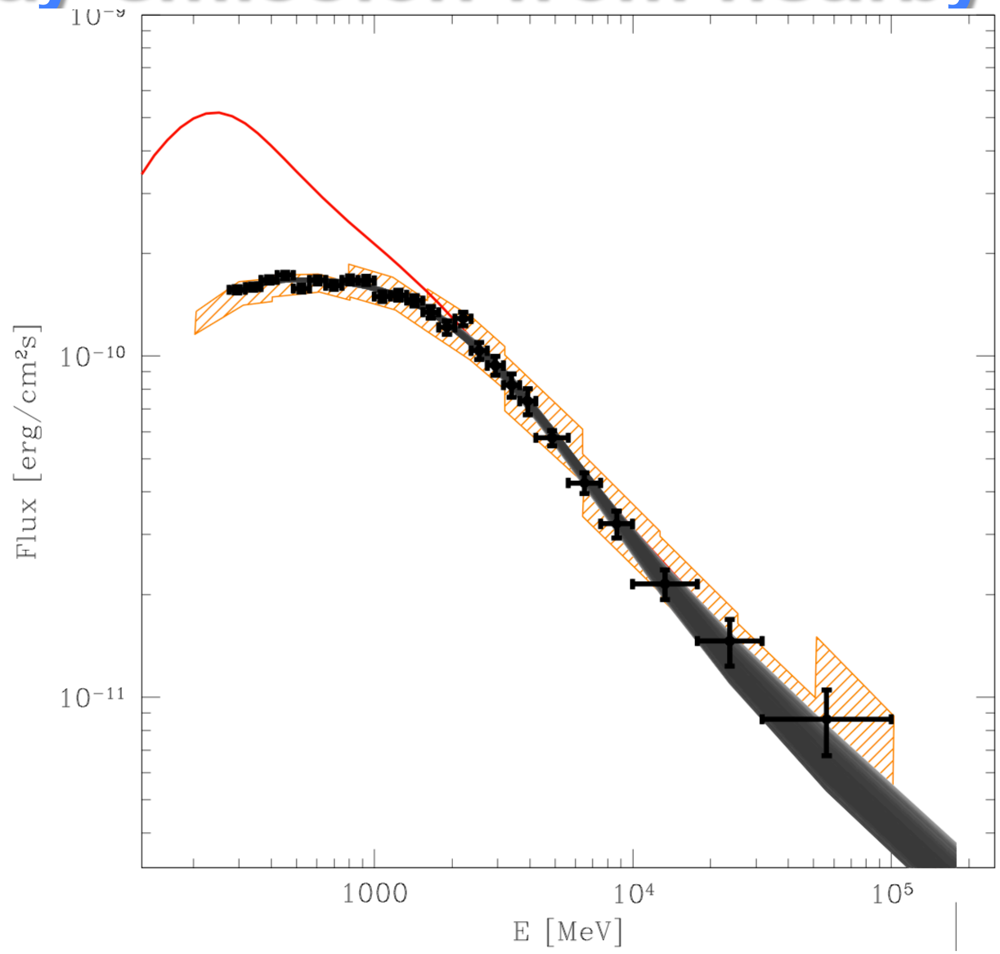
Milky Way in GeV gamma-rays



•Nearby GMCs are rather strong gamma-ray sources, first detected by CosB, later by EGRET and most recently by Fermi/LAT.

•Gamma-ray emission from nearby GMCs



•The gamma-ray spectrum of GMCs repeats the spectrum of emission from local ISM (diffuse Galactic emission at high Galactic latitudes).

•Gamma-ray emission from nearby GMCs

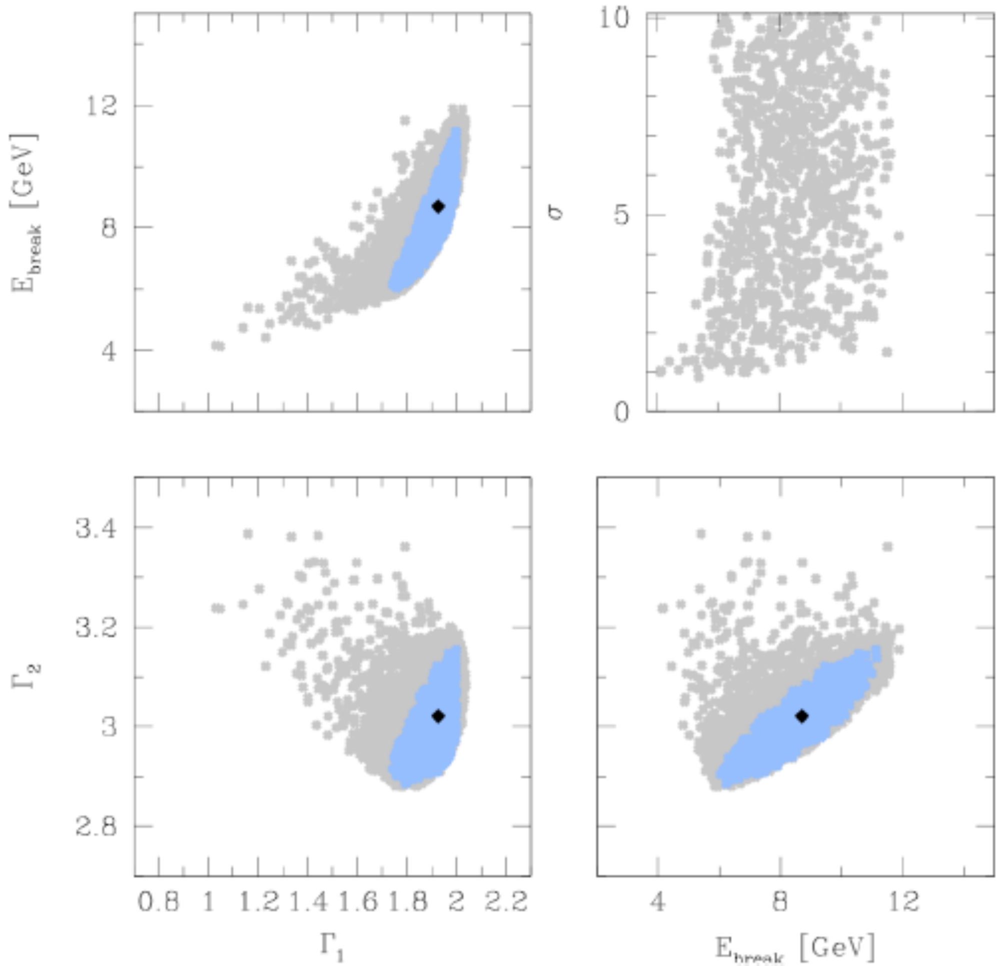
$$dN_{\rm CR}/dE = N_0\, E^{-\bar{\beta}_{\rm CR}}$$

$$\begin{aligned}
\frac{E_\gamma^2\, dN_\gamma}{dE_\gamma} &\propto E_\gamma^2 \int_{E_\gamma}^{E_{\max}} dE' \,\frac{dN_{\rm CR}}{dE'}\, \frac{d\sigma^{pp\to\gamma}(E', E_\gamma)}{dE_\gamma} \\
&\propto E_\gamma^{2-\beta_{\rm CR}} \int_0^1 dx_E\, \frac{x_E^{\beta_{\rm CR}-1}\, d\sigma^{pp\to\gamma}(E_\gamma/x_E, x_E)}{dx_E} \\
&\equiv E_\gamma^{2-\beta_{\rm CR}}\, \tilde{Z}_\gamma(E_\gamma)\,, \qquad (1)
\end{aligned}$$

$$x_E = E_\gamma/E'$$

T. Kamae, N. Karlsson, T. Mizuno, T. Abe, T. Koi, Astrophys. J. **647** (2006) 692; Erratum-ibid. **662** (2007) 779; N. Karlsson and T. Kamae, *ibid.* **674** (2008) 278.

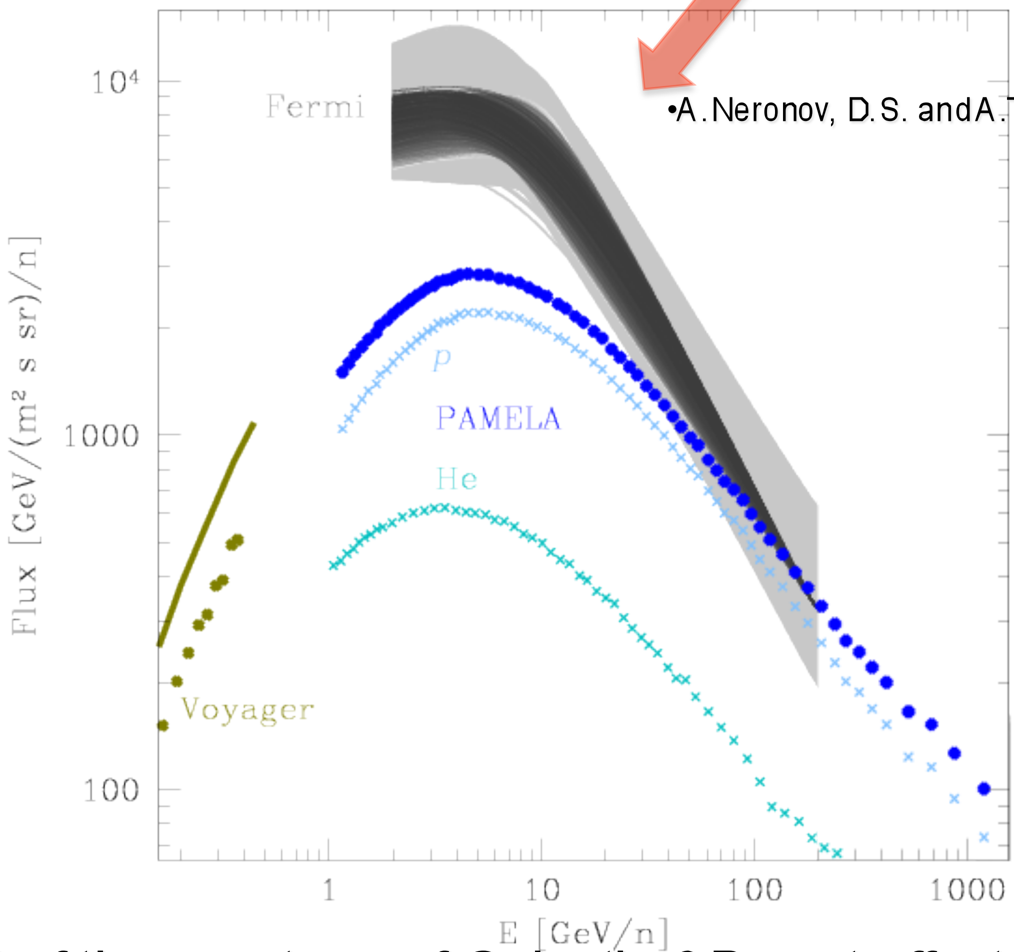
Parameters of the break in the CR spectrum



Gamma-ray data can be fitted with 2 power-laws with break

$$dN_{CR}/dE \sim \quad (E/E_{Br})^{\Gamma_1} \Big/ (1+(E/E_{break})^{\sigma})^{(\Gamma_2+\Gamma_1)/\sigma}$$

•Galactic cosmic ray spectrum

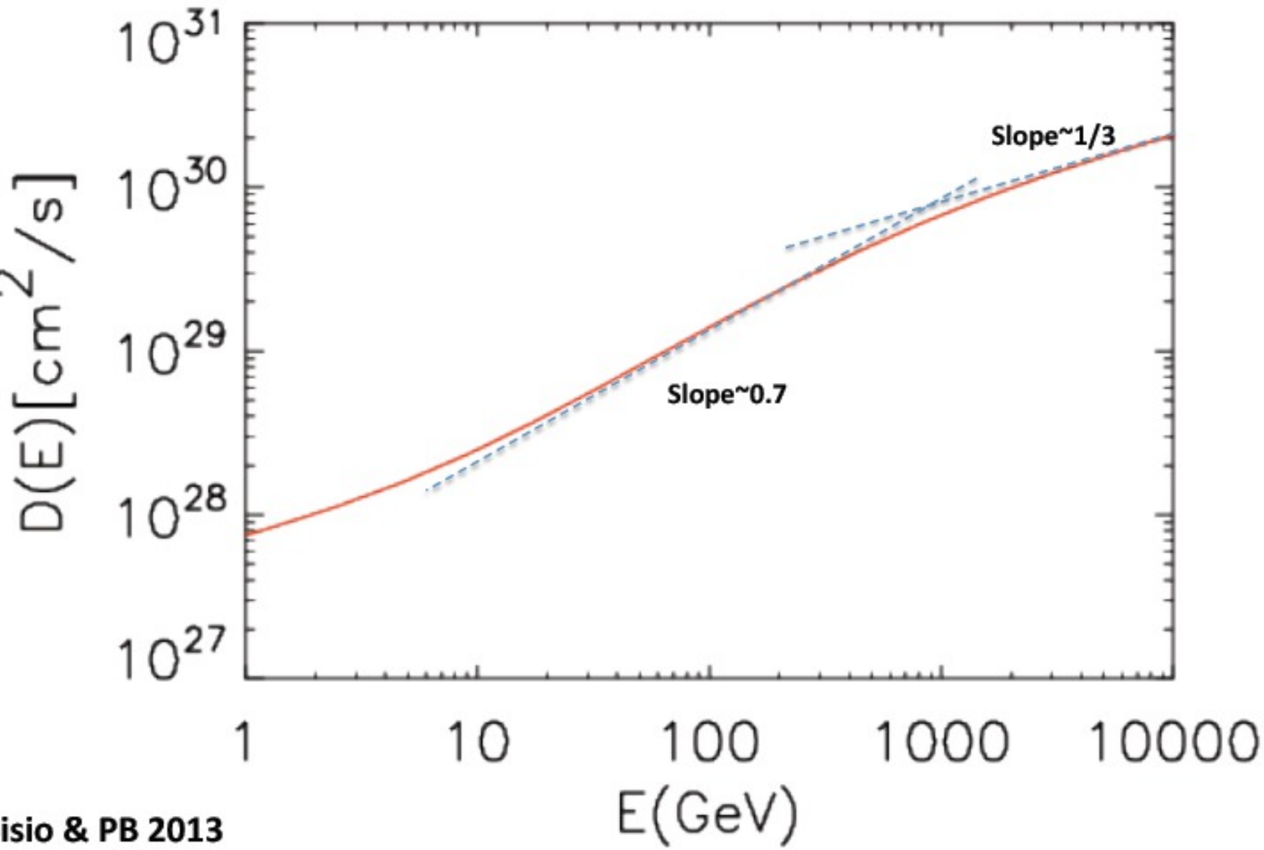


•A.Neronov, D.S. and A.Taylor, PRL, 108, 051105 (2012)

•Measurement of the spectrum of Galactic CRs not affected by the Heliospheric effects could be deduced from the gamma-ray spectrum of the clouds.

•Galactic cosmic ray spectrum has a strong break at the energy ~ 10 GeV.

DIFFUSION COEFFICIENT



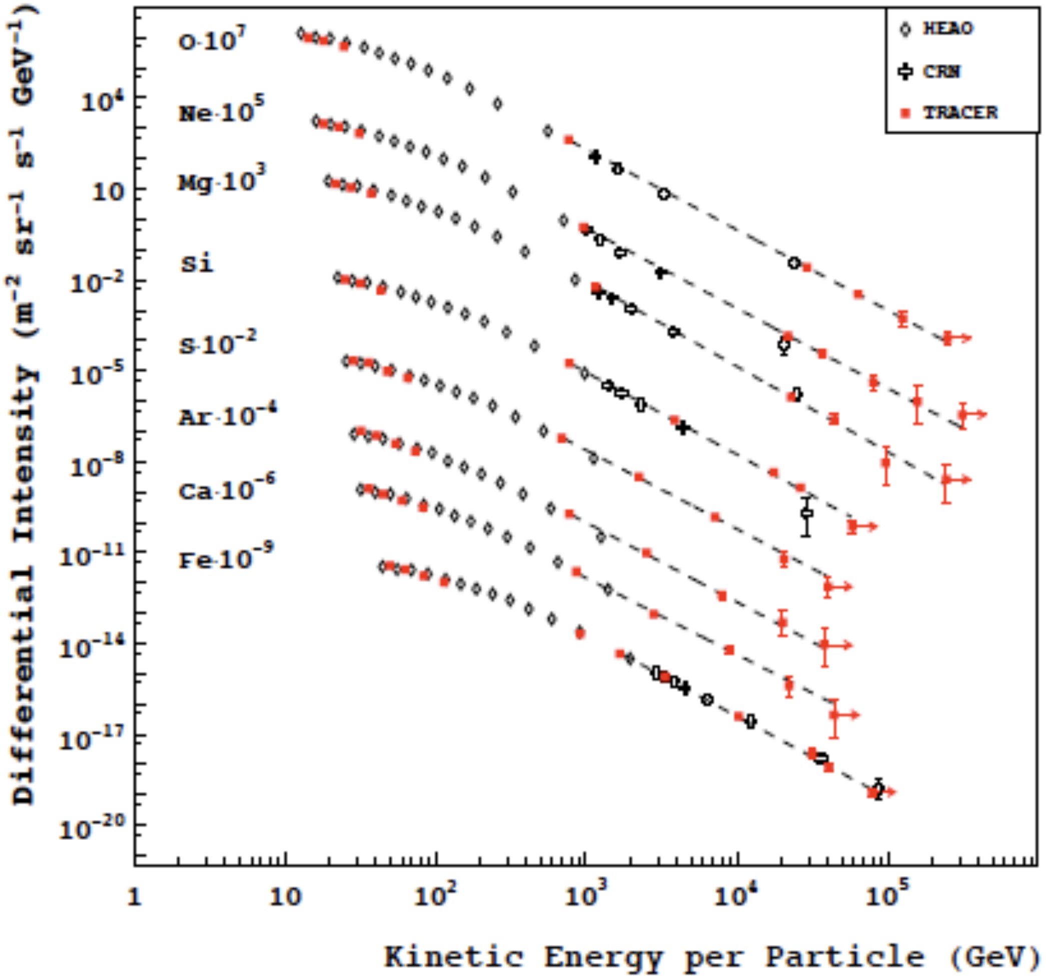
Aloisio & PB 2013

From P.Blasi talk Paris workshop Dec. 2012

Summary below 1 TeV

- Two new breaks at 10 GeV and 200 GeV indicate existence of new component in low energy Galactic CR
- Detailed comparison of global all-sky analysis of Fermi data with new results needed to find if this component is local at 500 pc / 1000 pc?
- Cosmic ray acceleration and propagation mechanism has to be modified

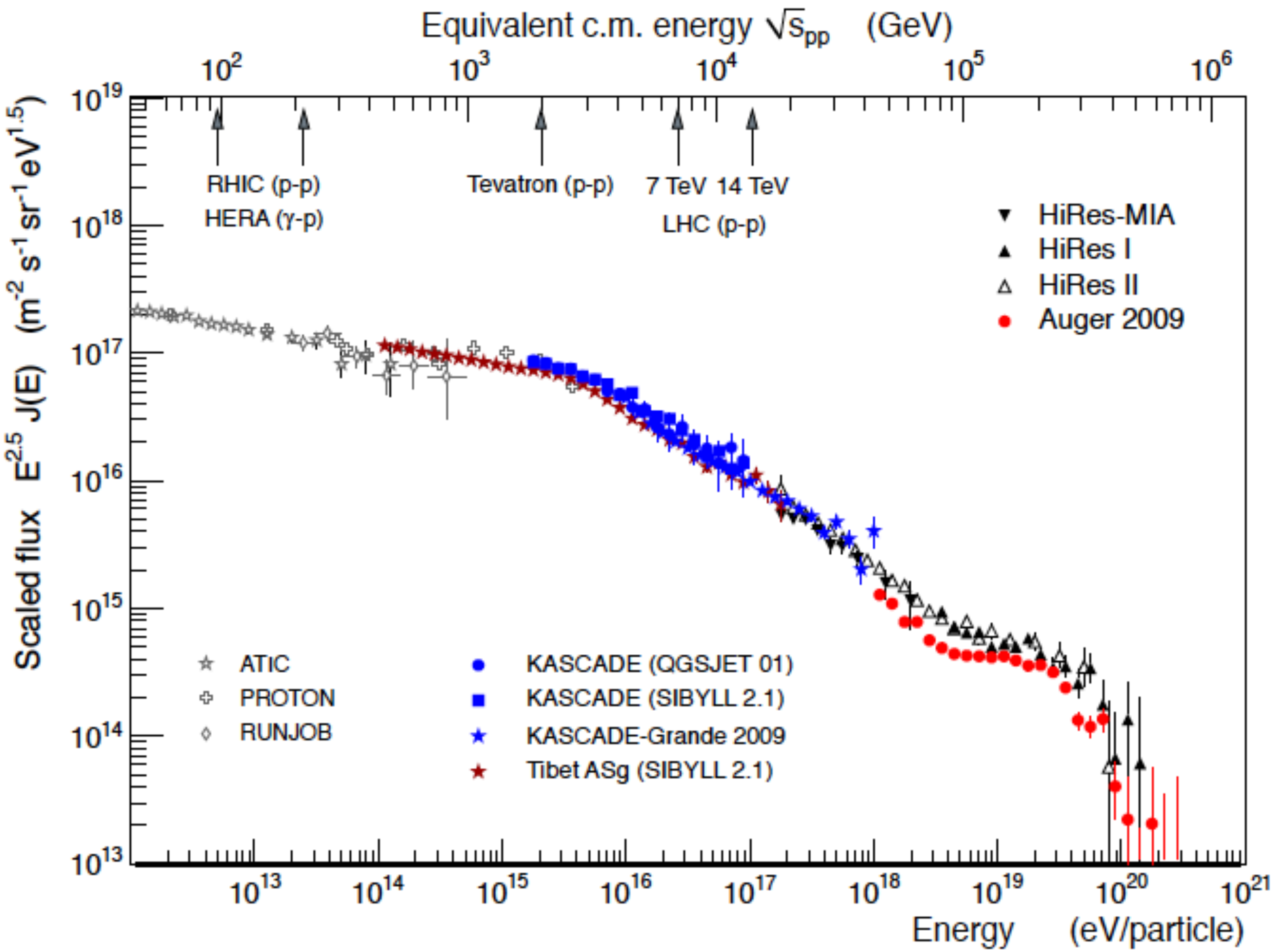
Mass composition below knee



Knee in the cosmic ray spectrum

Cosmic Ray Knee

steepening $\Delta\gamma \simeq 0.4$ at few $\times 10^{15}$ eV



Cosmic Ray Knee

KASCADE experiment

40000 m² 10^{15}-10^{17} eV

Measure electron and muon size at Karlsruhe, Germany (near sea level).
Energy spectra of 5 primary mass groups are obtained from two dimensional Ne-Nμ spectrum by unfolding method (P,He,CNO,Si,Fe).

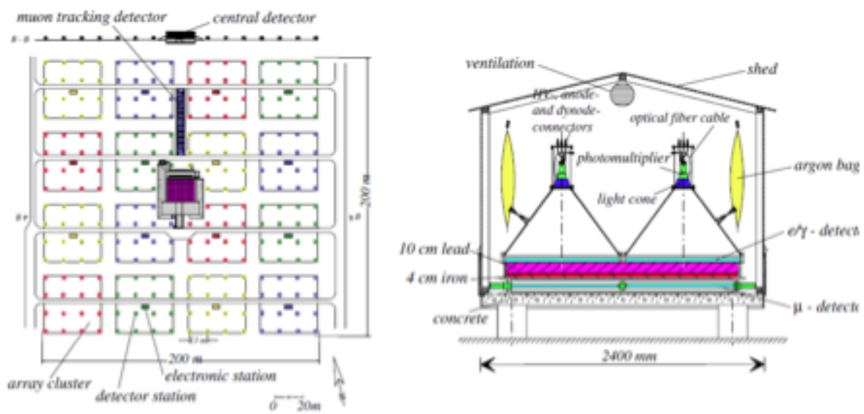


Fig. 1. Left: layout of the KASCADE air shower experiment; Right: sketch of a detector station with shielded and unshielded scintillation detectors.

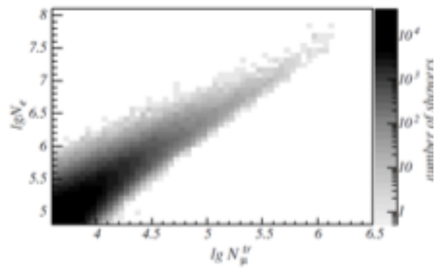
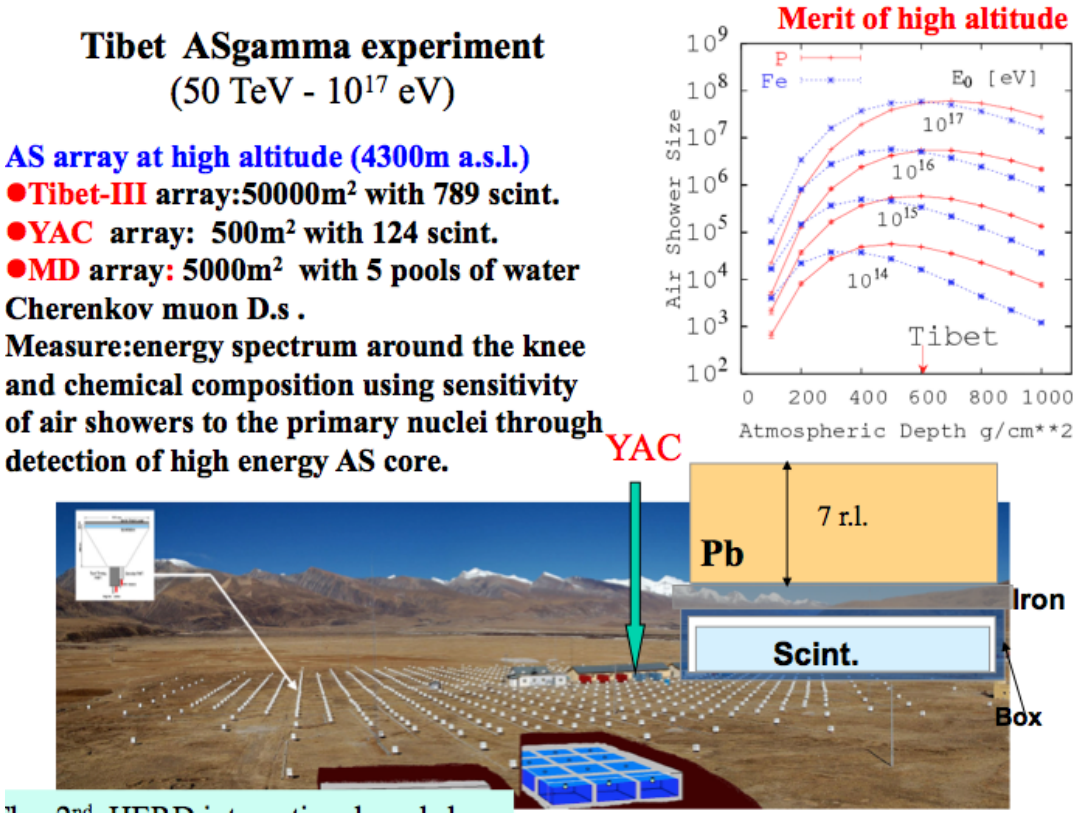


Fig. 2. Two-dimensional shower size spectrum used in th analysis. The range in $\lg N_e$ and $\lg N_\mu^{tr}$ is chosen to avoi influences of inefficiencies.

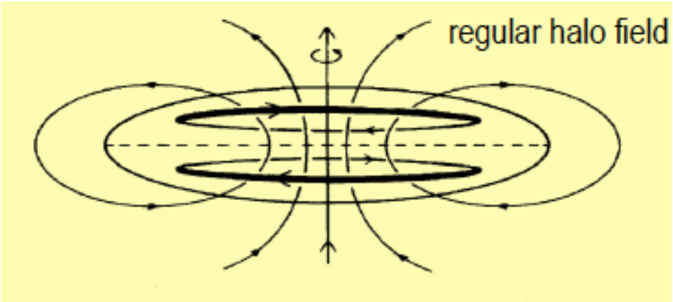
Cosmic Ray Knee

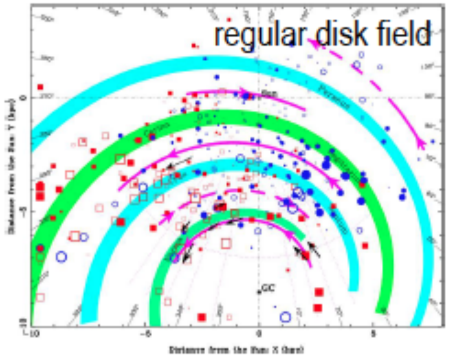


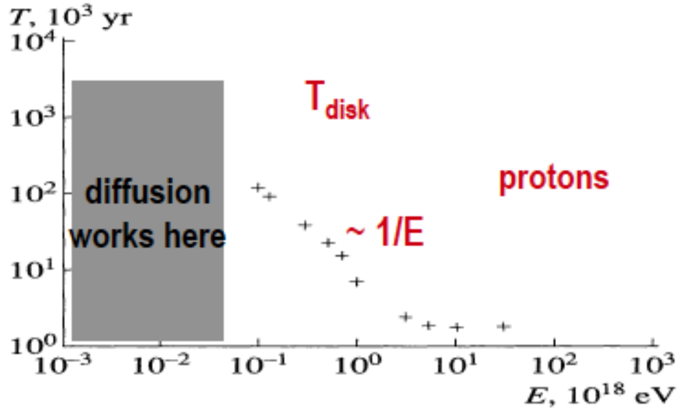
Cosmic Ray Knee

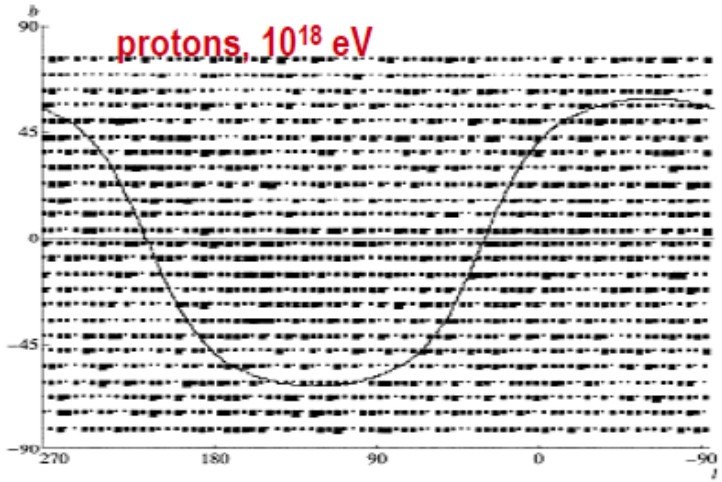
extension of propagation model till 10^{19} eV: trajectory calculations

Syrovatsky 1971, Berezinsky et al. 1991, Gorchakov et al 1991, VP et al 1993, Lampard et al 1997, Zirakashvili et al 1998, Hörandel et al. 2005



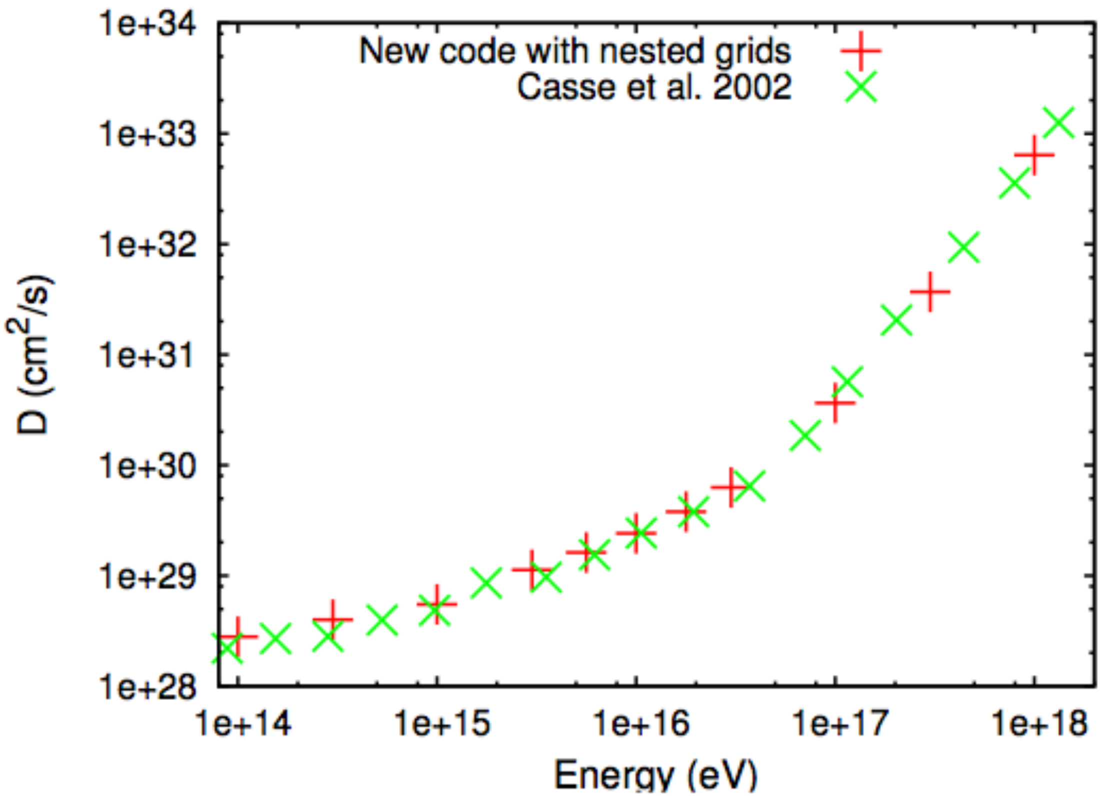






From V.Ptuskin

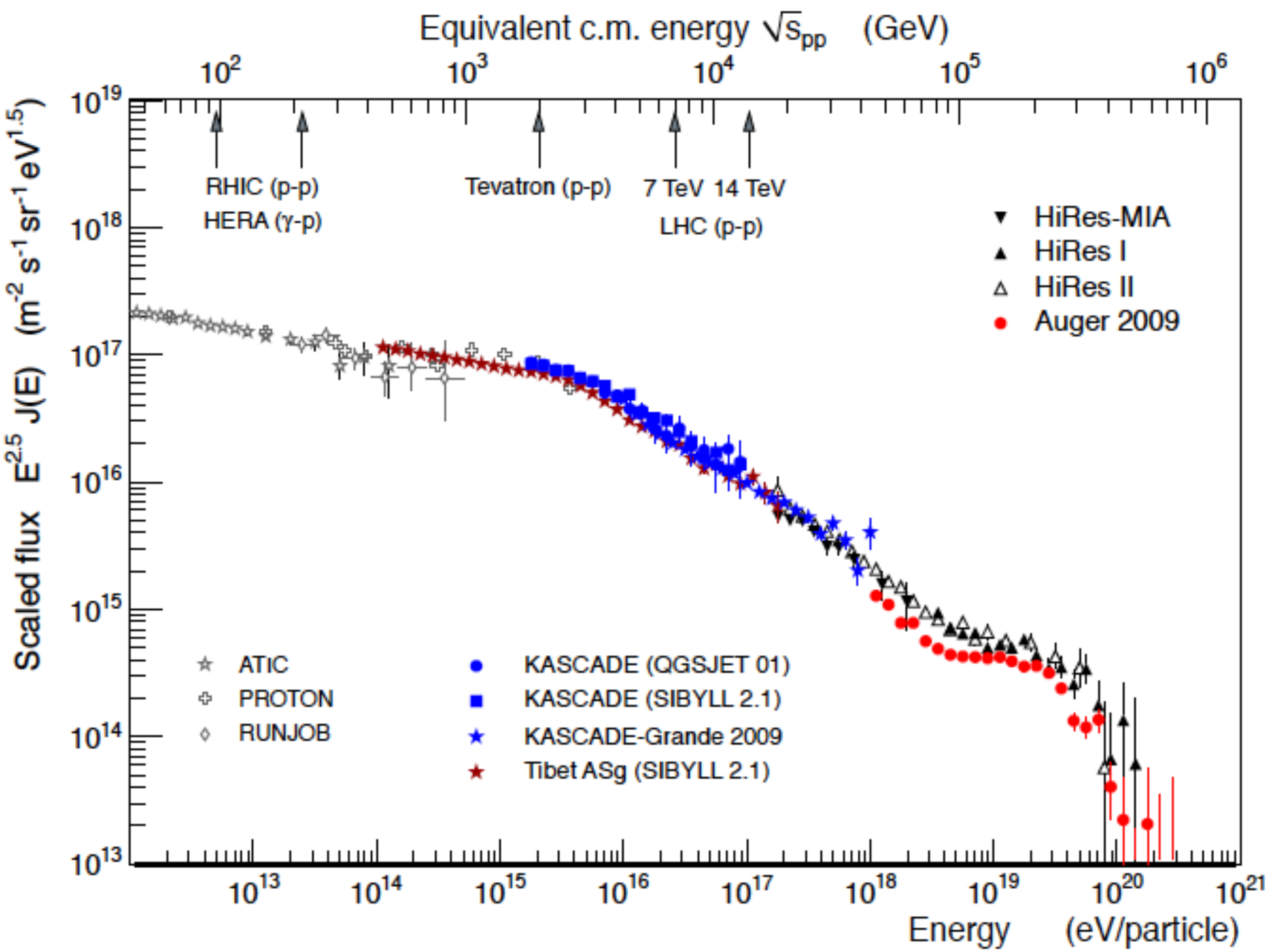
Only turbulent diffusion



G.Giacinti et al, arXiv:1112.5599

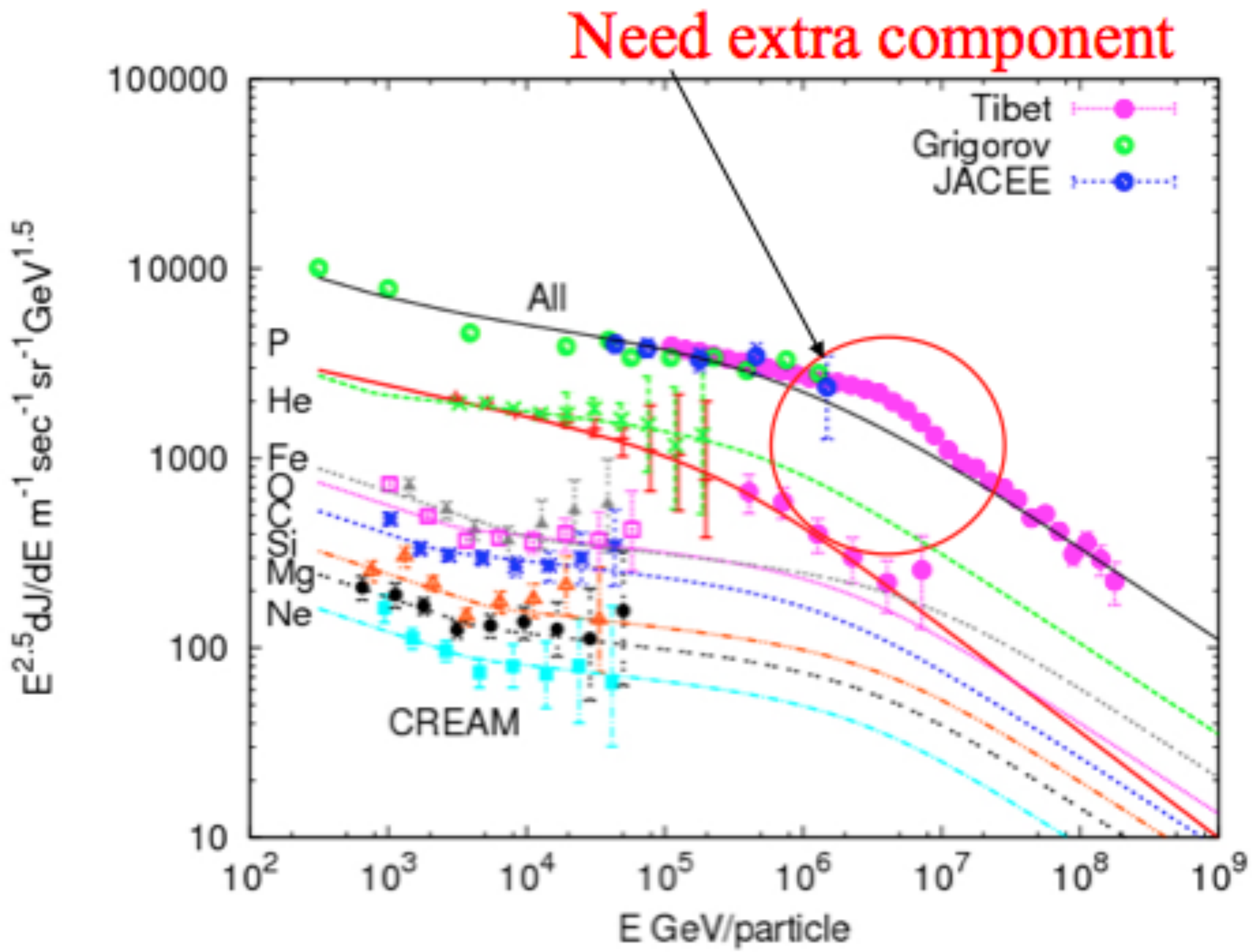
Cosmic Ray Knee

- change of interactions at multi-TeV energies: excluded by LHC



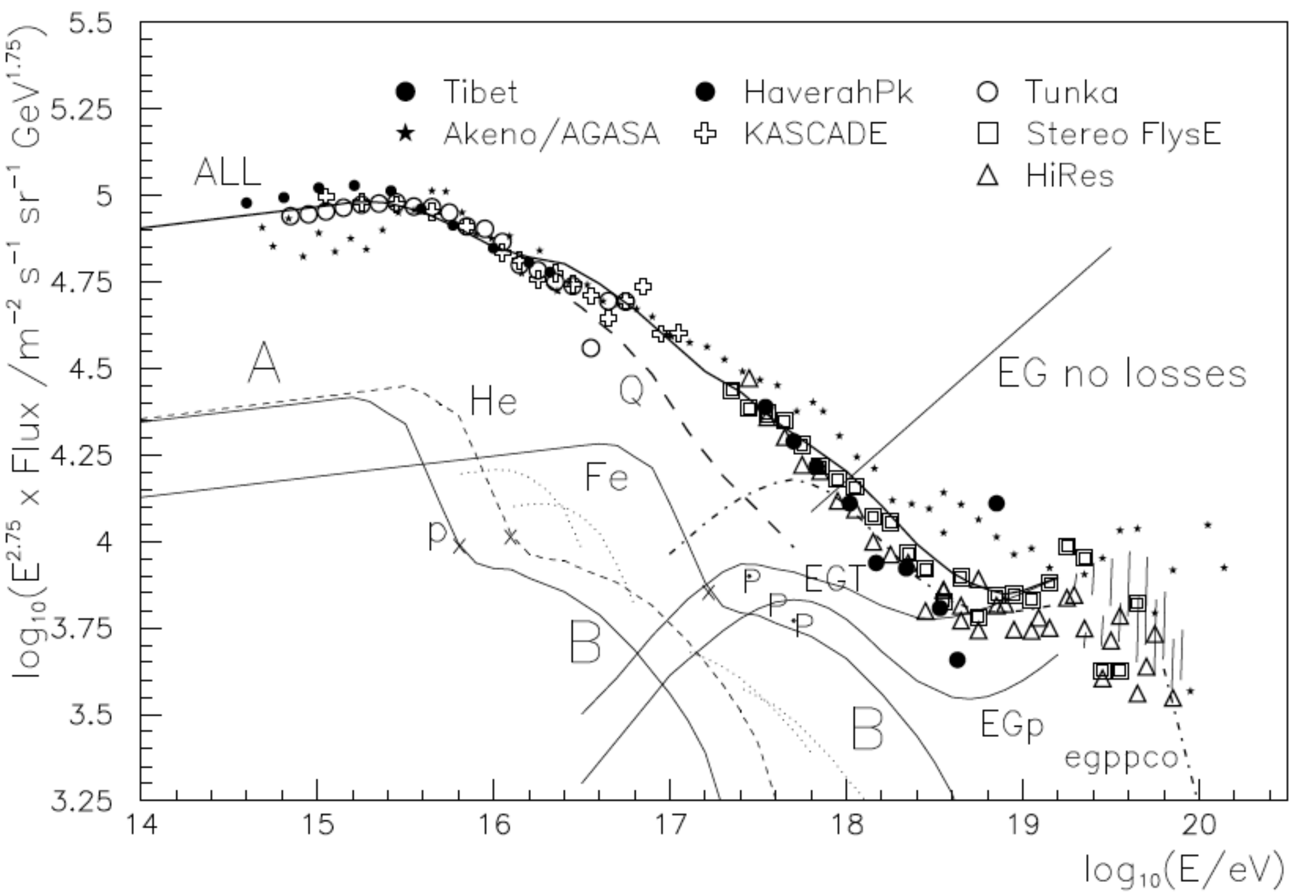
Cosmic Ray Knee

Tibet: Nearby source?



Cosmic Ray Knee

Hillas model



Cosmic Ray Knee

.

- change of interactions at multi-TeV energies: excluded by LHC
- maximal energy of dominant CR sources – Hillas model
- knee at $R_L(E/Z) \simeq l_{\rm coh}$:

  $\Rightarrow$ change in diffusion from $D(E) \sim E^{1/3}$ to
  - Hall diffusion $D(E) \sim E$
  - small-angle scattering $D(E) \sim E^2$
  - something intermediate?

Cosmic Ray Knee

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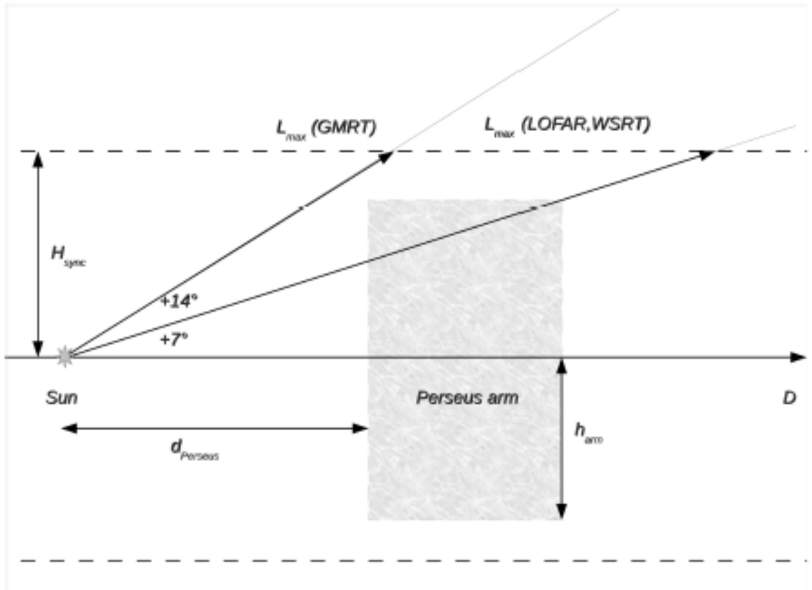
  - something intermediate?

our approach:

- use model for Galactic magnetic field
- calculate trajectories $\boldsymbol{x}(t)$ via $\boldsymbol{F}_L = q\boldsymbol{v} \times \boldsymbol{B}$.

LOFAR measurement of maximum scale of turbulent GMF



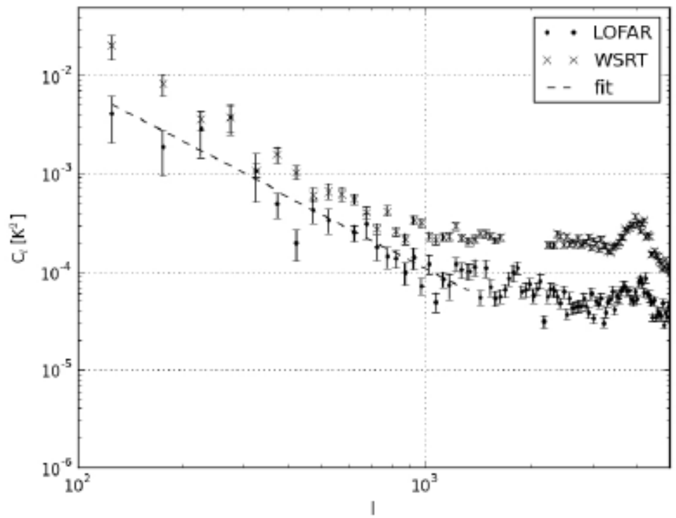


Fig. 9. Power spectra of total intensity from the LOFAR (dots) and WSRT (crosses) observations. The error bars indicate statistical errors at 1σ. The fitted power law (dashed line) with a spectral index $\alpha = -1.84 \pm 0.19$ for $\ell \in [100, 1300]$ is also shown.

arXiv: 1308.2804

Lmax ~ 20 pc +-6 pc in disk

Cosmic Ray Knee

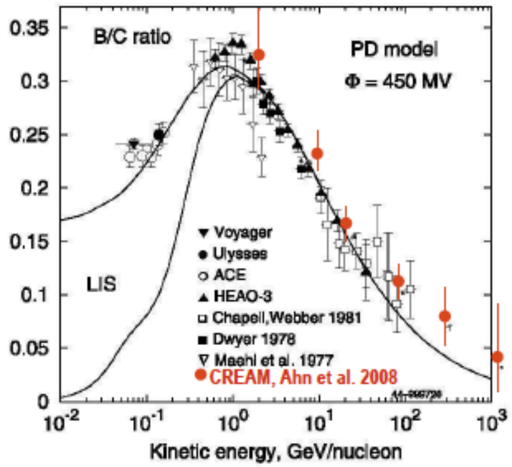
- $l_{\rm coh}$ and regular field $\boldsymbol{B}(\boldsymbol{x})$ fixed from observations
- determine magnitude of random $\boldsymbol{B}_{\rm rms}(\boldsymbol{x})$ from grammage $X(E)$

B to C ratio

B/C ratio in three models of cosmic ray propagation

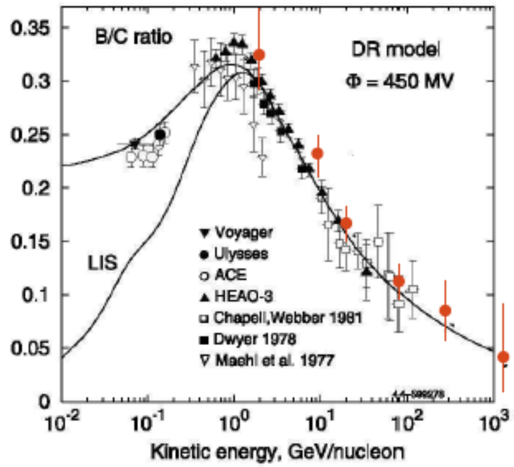
plain diffusion, "unphysical" break

$D \sim (p/Z)^{0.6}$
$Q_{cr} \sim (p/Z)^{-2.1}$



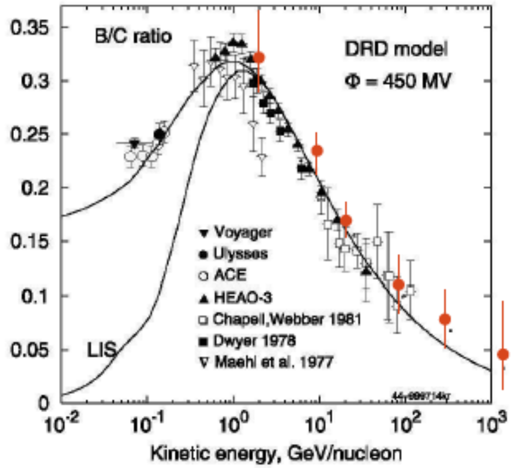
diffusion (Kolmogorov) + reacceleration

$D \sim (p/Z)^{0.3}$
$Q_{cr} \sim (p/Z)^{-2.4}$



diffusion (Kraichnan) + reac. + damping on CR

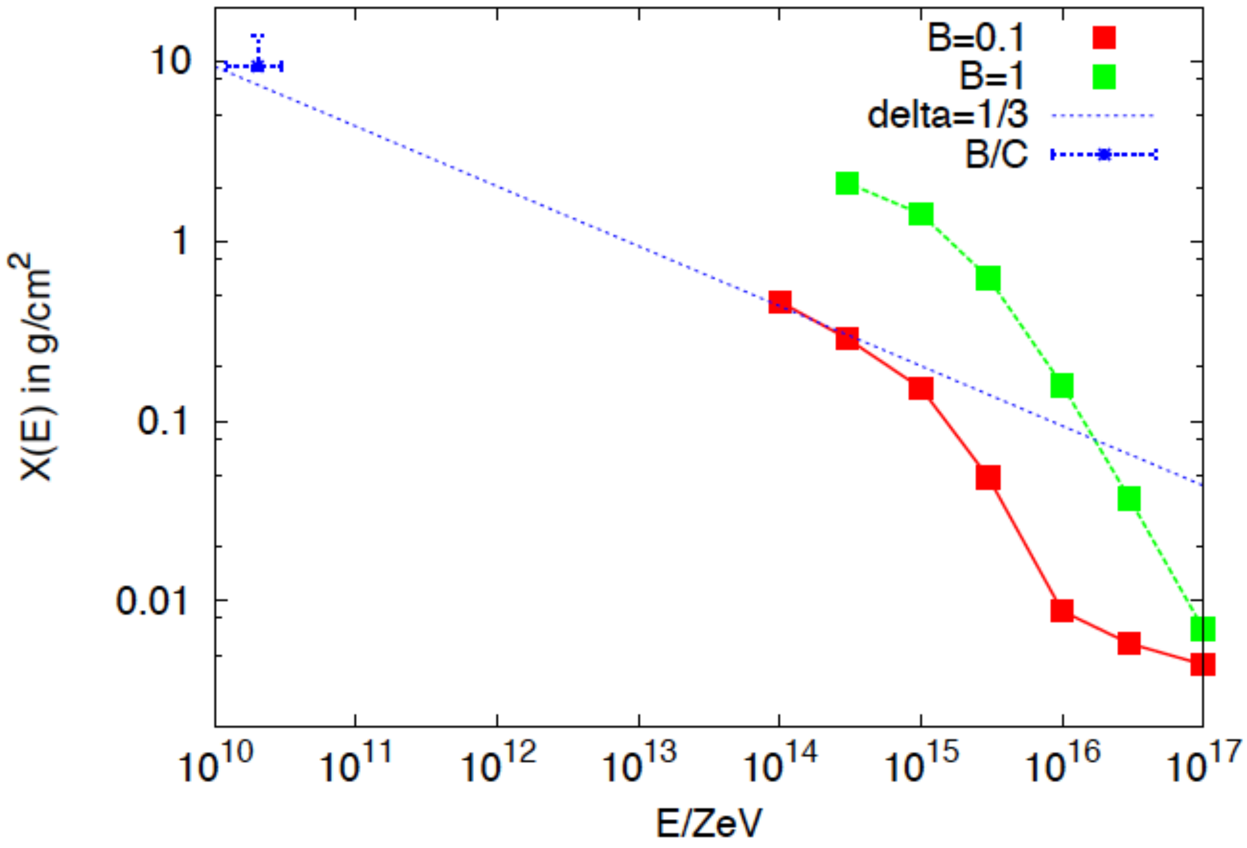
$D \sim (p/Z)^{0.5}$
$Q_{cr} \sim (p/Z)^{-2.2}$



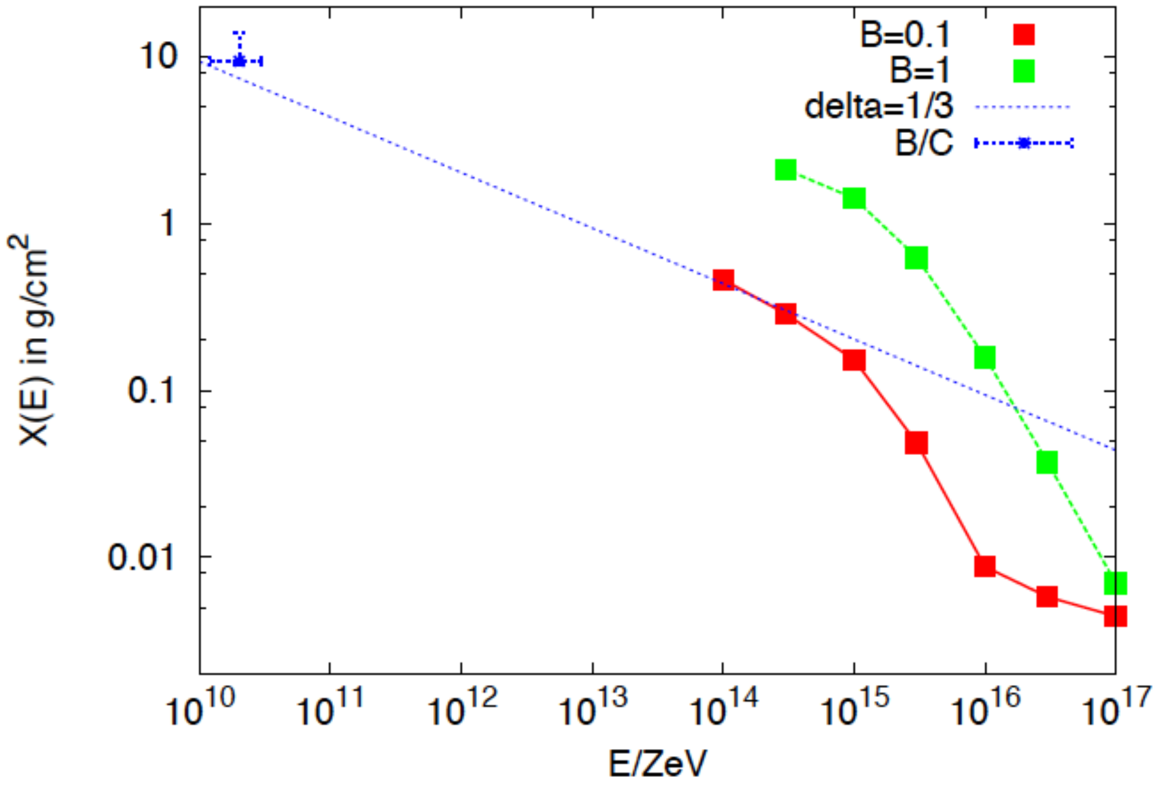
derived exponent of source spectrum at high energies 2.1...2.2 or 2.4

Cosmic Ray Knee

- $l_{\rm coh}$ and regular field $\boldsymbol{B}(\boldsymbol{x})$ fixed from observations
- determine magnitude of random $\boldsymbol{B}_{\rm rms}(\boldsymbol{x})$ from grammage $X(E)$



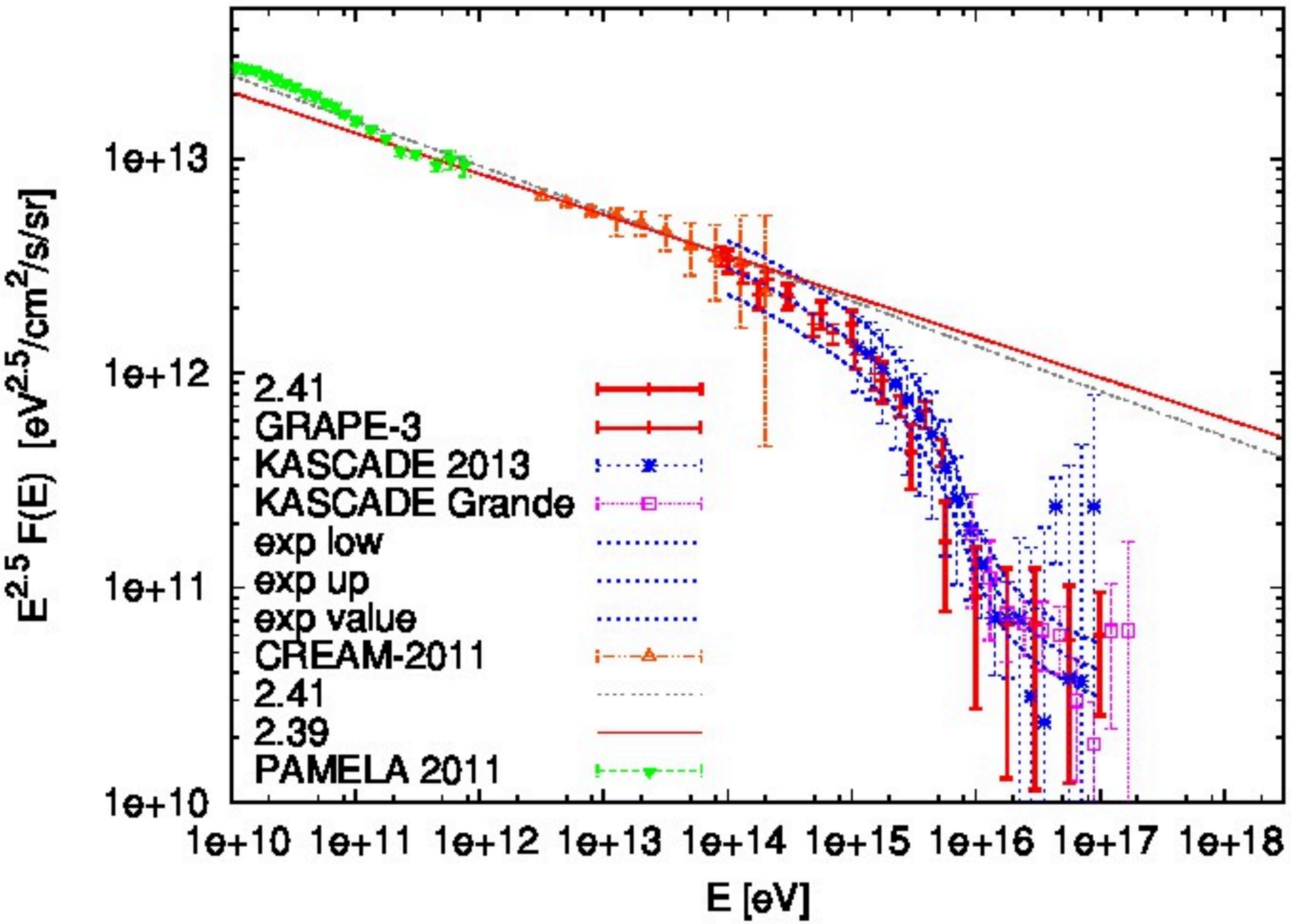
Cosmic Ray Knee



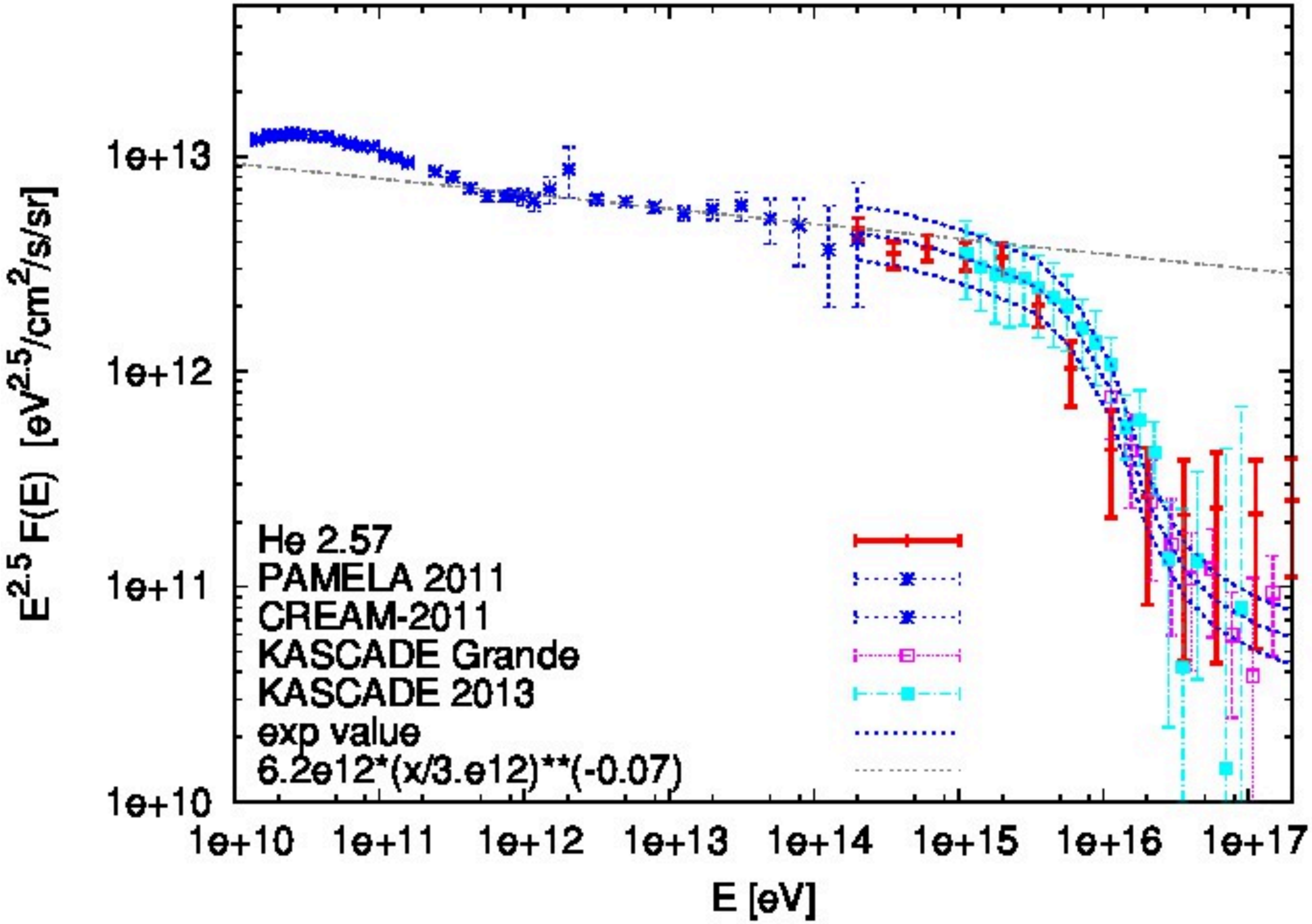
$\Rightarrow$ prefers weak random fields

$\Rightarrow$ fluxes $I_A(E)$ of all isotopes fixed by low-energy data

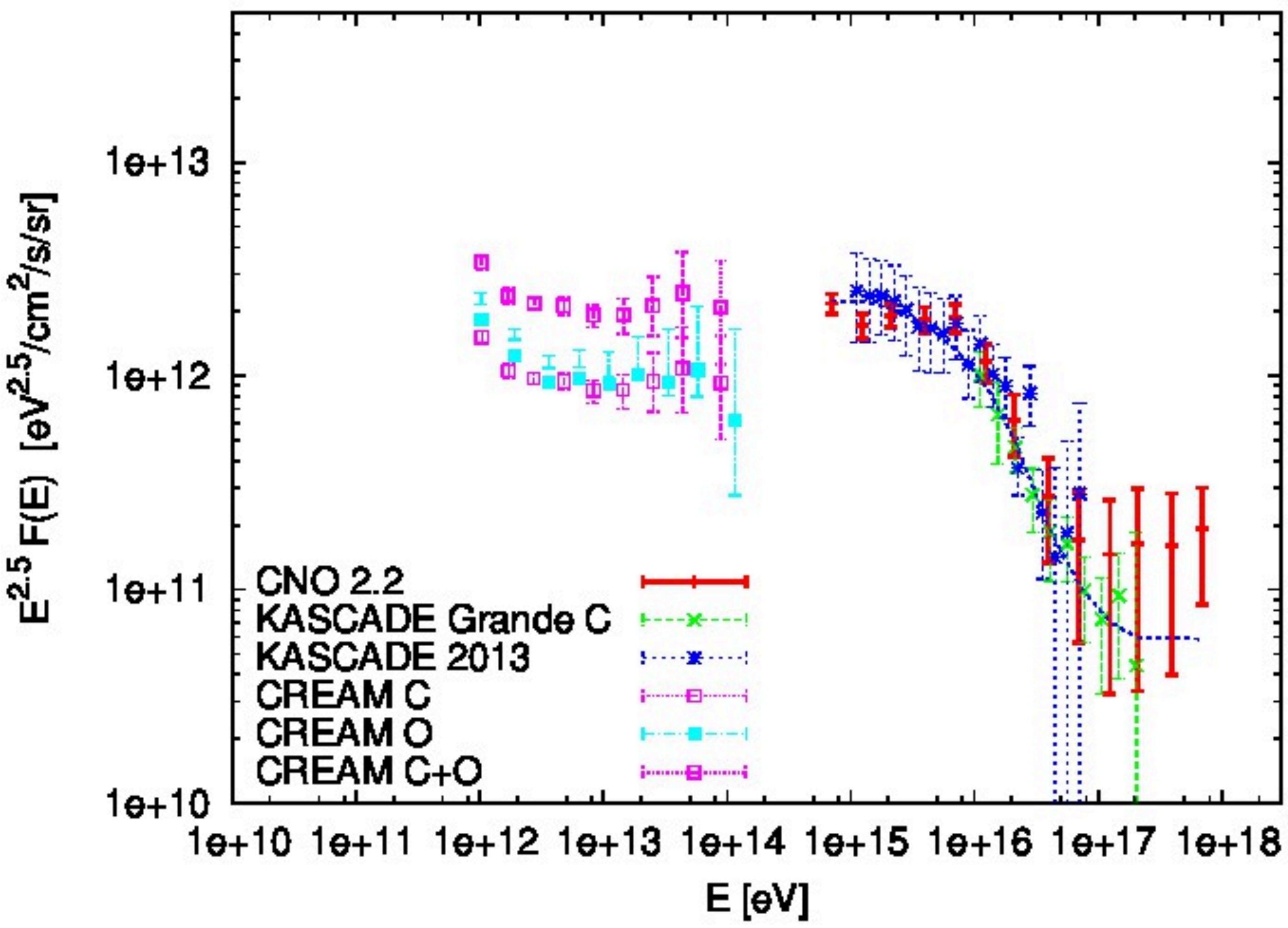
Cosmic Ray Knee: protons



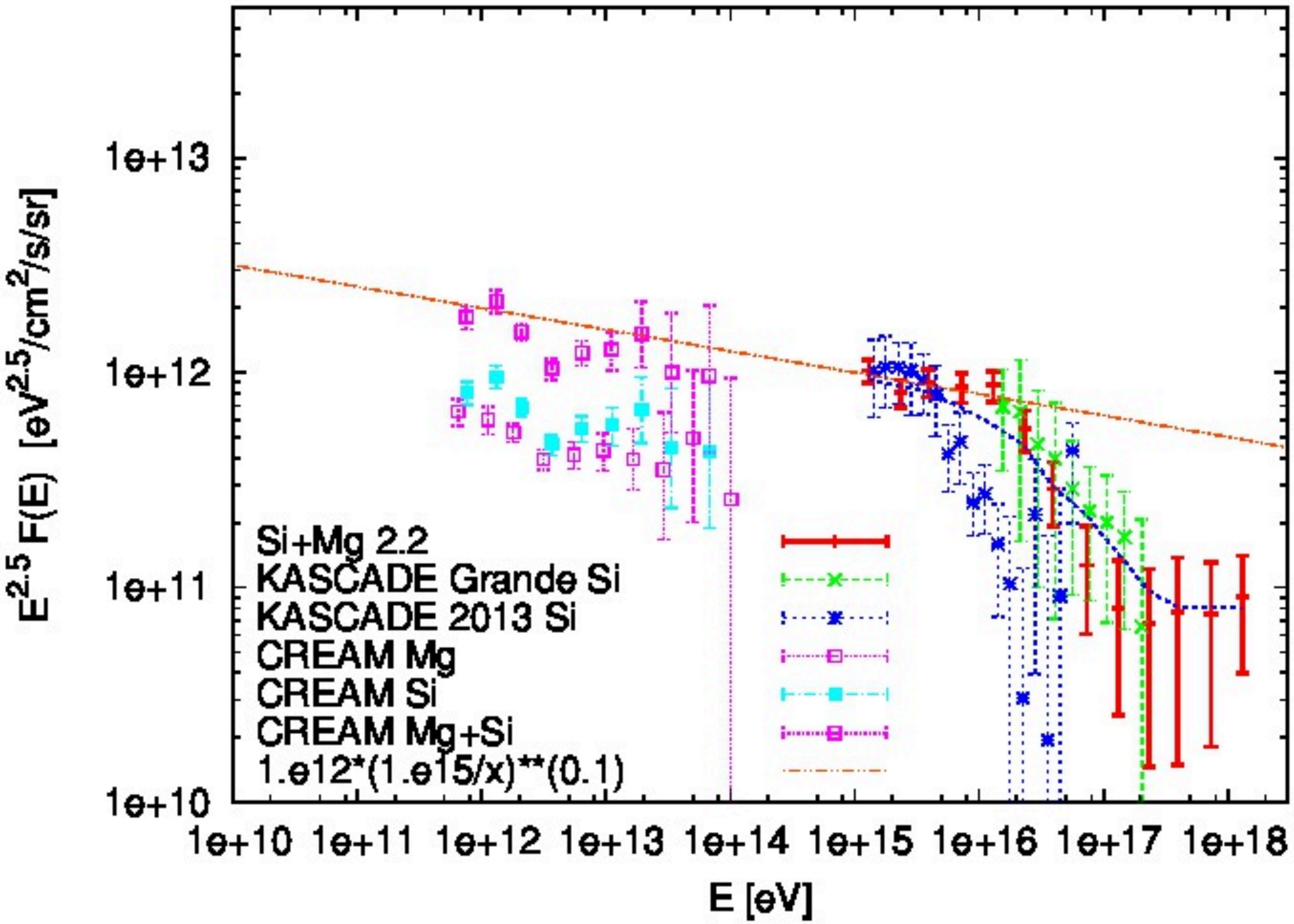
Cosmic Ray Knee: He



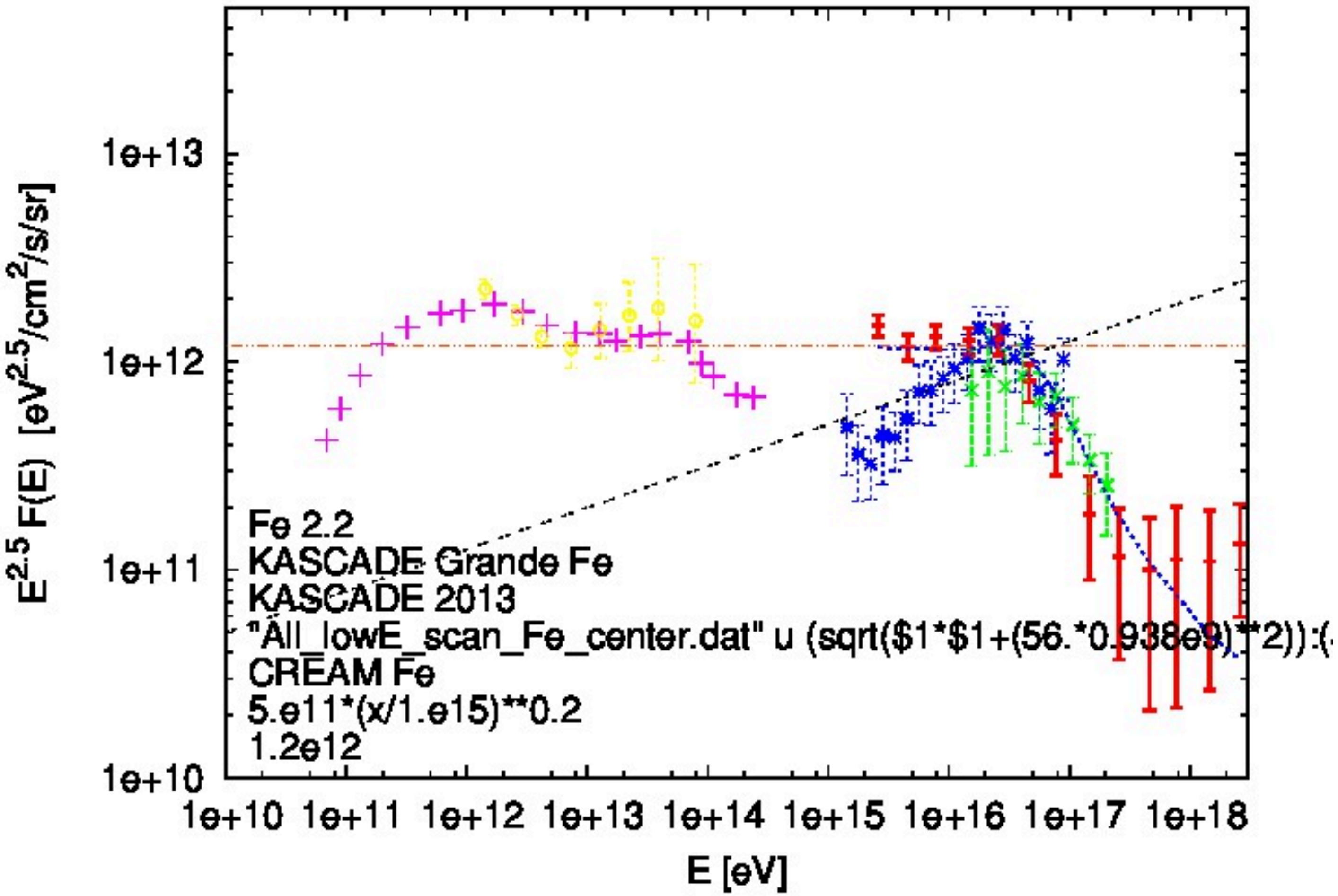
Cosmic Ray Knee: CNO



Cosmic Ray Knee: Si



Cosmic Ray Knee: Fe

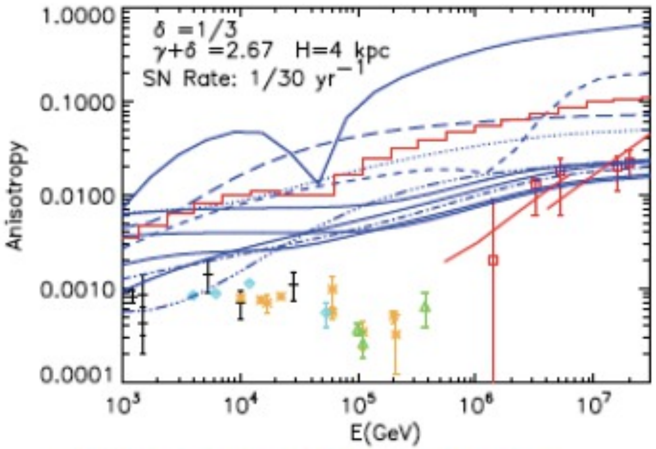


Anisotropy in arrival directions

Dipole anisotropy due to nearby sources

LARGE SCALE CR ANISOTROPY

ANISOTROPY DOMINATED BY NEARBY AND MOST RECENT SOURCES.



Naïve expectation:

$$\delta_A = \frac{3}{2^{3/2}} \frac{1}{\pi^{1/2}} \frac{D(E)}{Hc}$$

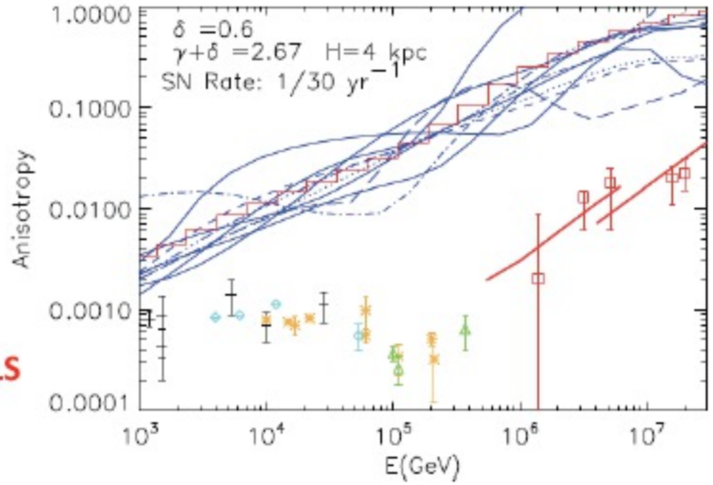
proportional to E^{δ}

REACCELERATION MODELS

$\delta=1/3$

$\delta=0.6$

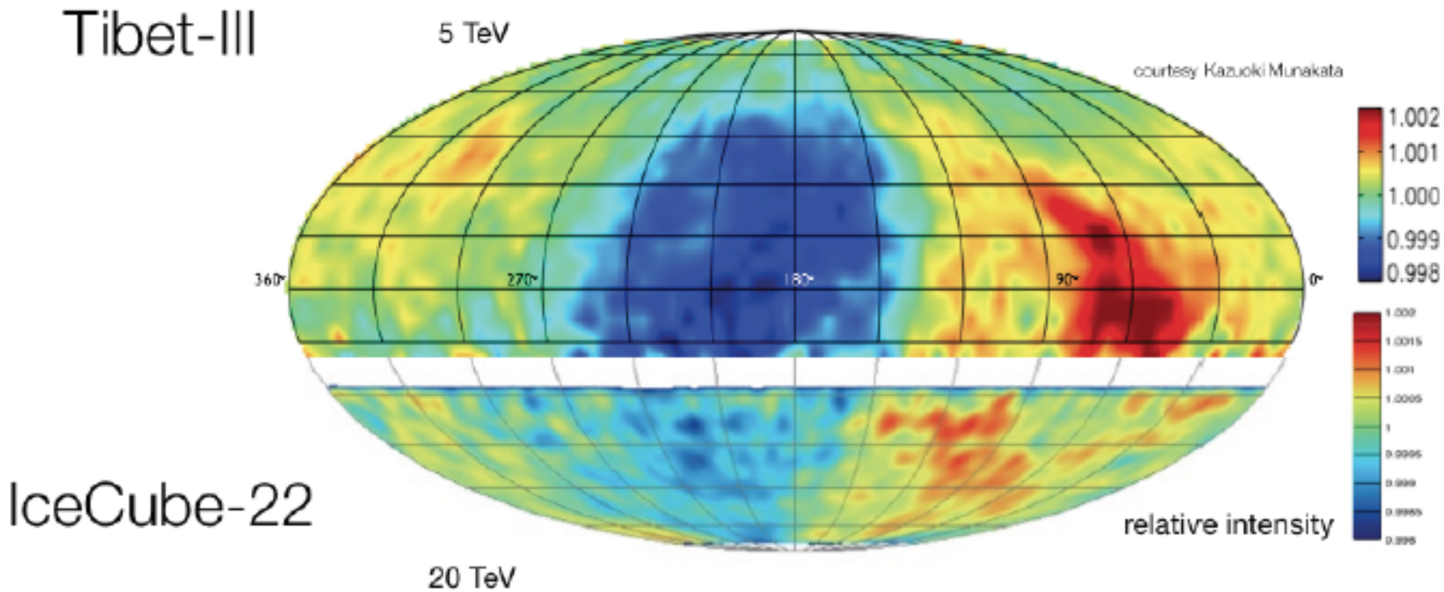
DIFFUSION MODELS



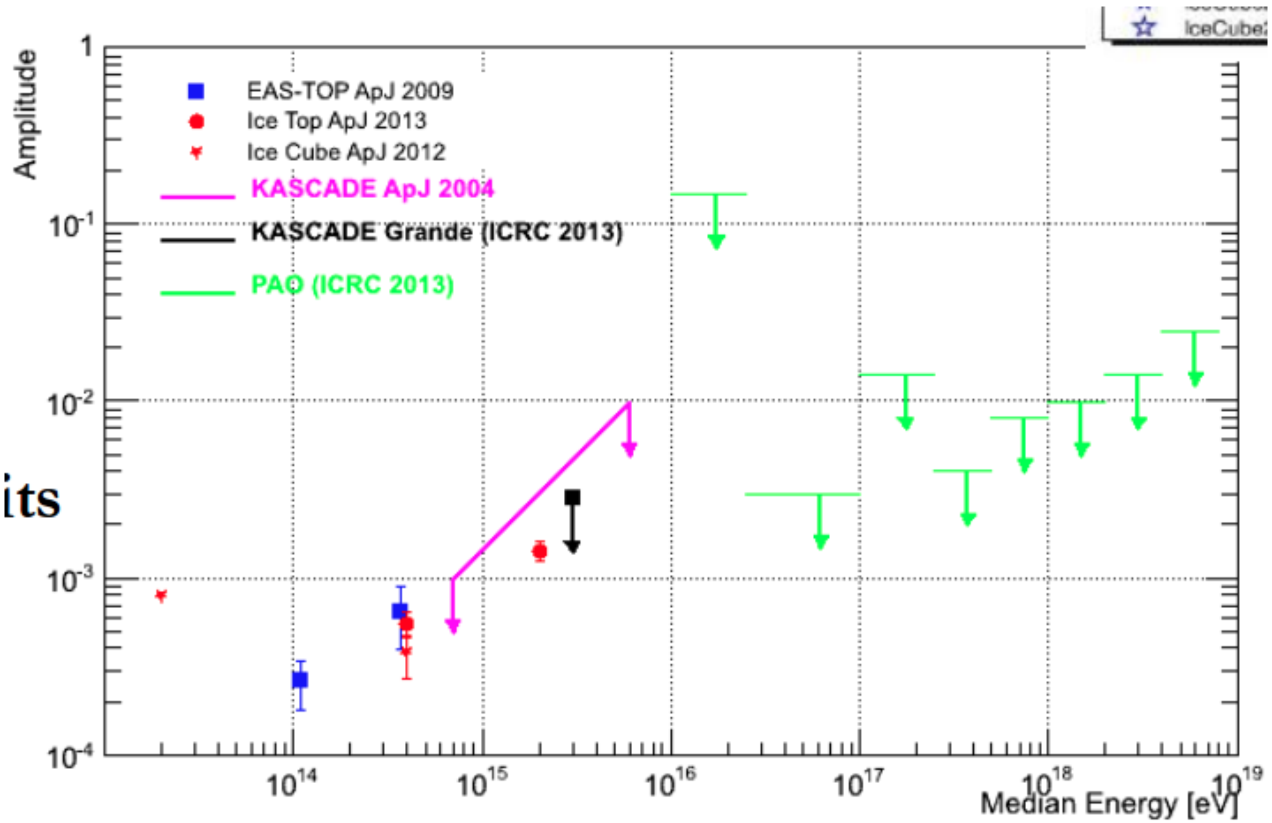
Blasi & Amato 2011

Large-Scale Anisotropy

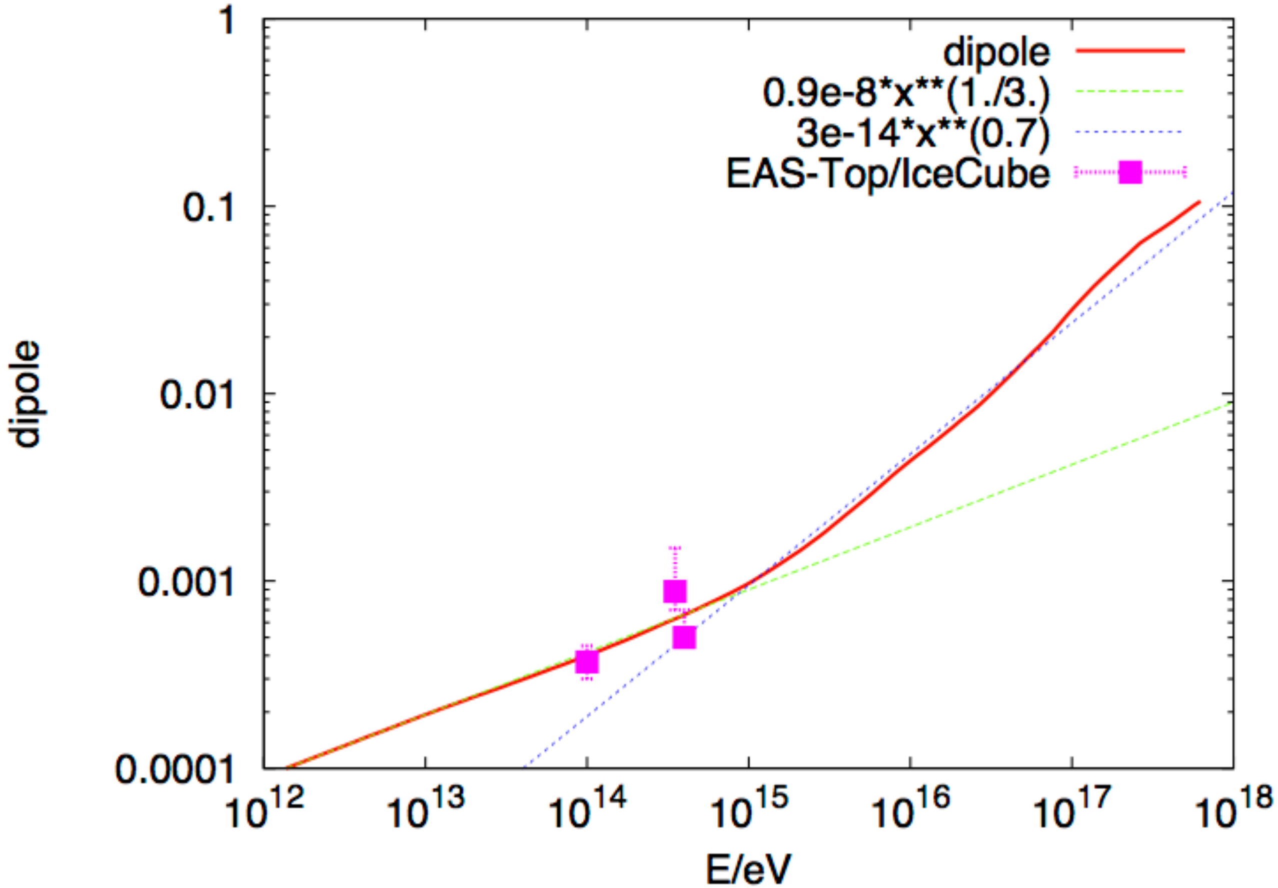
- IC22, 4×10^{9} events, median energy 20 TeV
- Sufficient statistics to observe 10^{-3} anisotropy
- Anisotropy matched in northern hemisphere



Cosmic Ray Knee: anisotropy



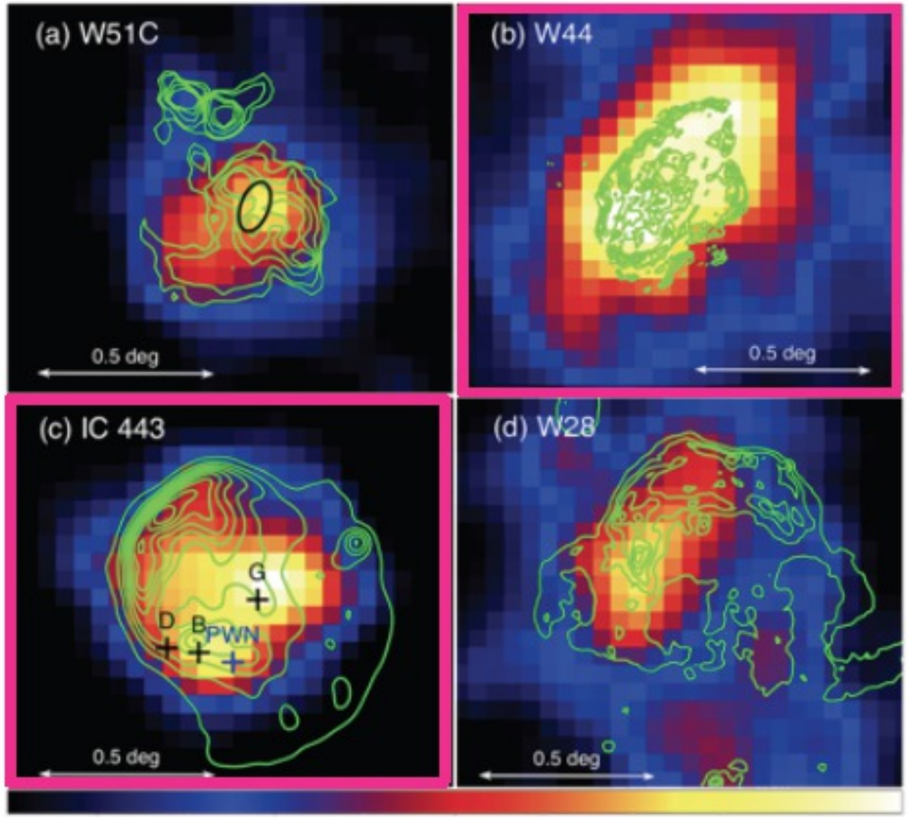
Cosmic Ray Knee: anisotropy



Cosmic ray propagation from single cosmic ray source

LAT Observations of MC-SNRs

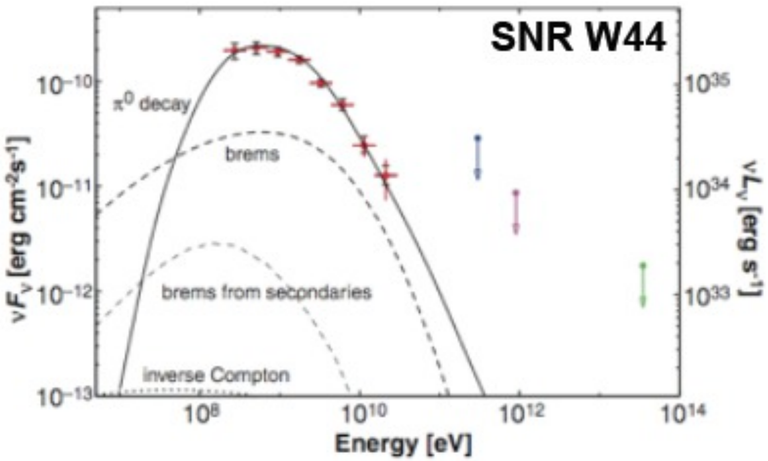
Fermi-LAT Collaboration (Uchiyama+) 2011



2.5 yr count maps (>2 GeV, front-converted)

Intense, extended GeV emission has been discovered from several SNRs that interact with molecular cloud (MC).

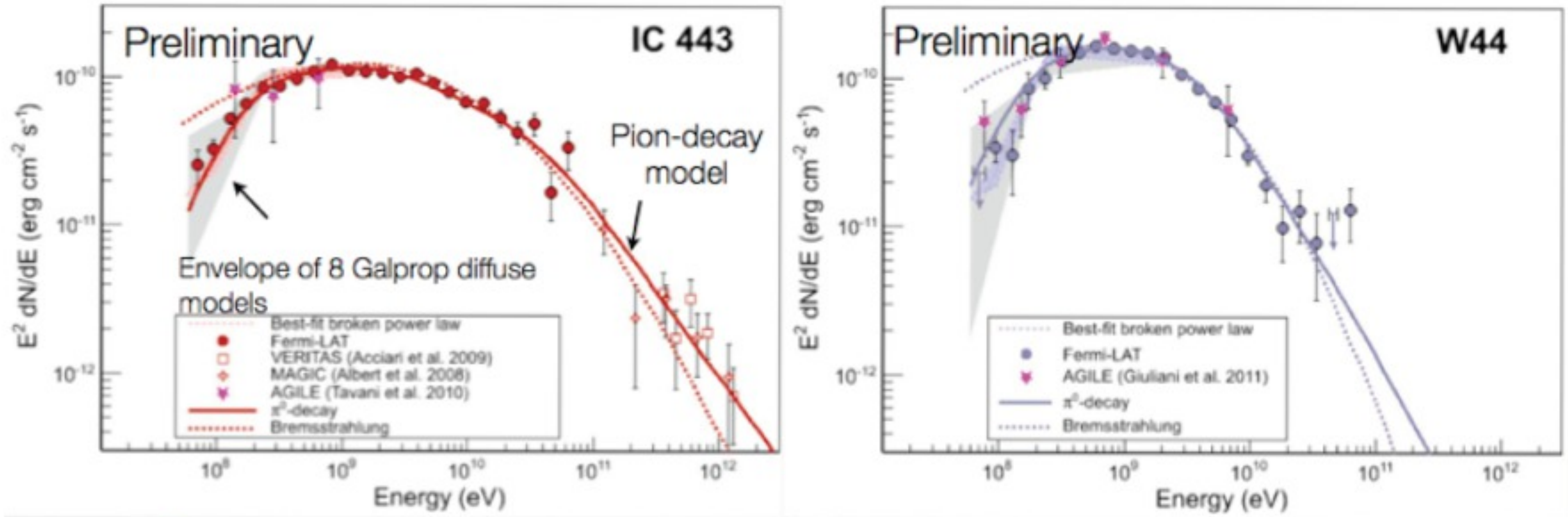
Spectral break in the GeV band
➜ GeV-bright objects
(GeV > TeV in energy flux)



The GeV emission has been interpreted as being π^0-decay γ-rays.

Fermi LAT Spectra of SNRs W44 & IC443: Signature of π^0-decay γ-rays

Fermi-LAT Collaboration 2012 (Funk, Tanaka, Uchiyama) Science in press



- ☑ Our previous papers reported spectra only >200 MeV.
- ☑ Here we report spectra down to 60 MeV thanks to:
  - Recent update ("Pass-7") of event reconstruction, which largely improved effective area at low energies.
  - Increased exposure time: 1 yr ➜ 4 yr

CR interactions in Galaxy

- Cosmic rays interact in galaxy at the rate

$$t_{pp} = (c\sigma_{pp} n_{ISM})^{-1} \simeq 3 \times 10^7 \left[\frac{n_{ISM}}{1 \text{ cm}^{-3}}\right]^{-1} \text{ yr},$$

- where cros-section is

$$\sigma_{pp} \simeq 4 \times 10^{-26} \text{ cm}^2$$

CR from one source

- Local measurements of primary and secondary nuclei give diffusion coeficient:

$$D = D_{28} \times 10^{28} \, [E_{CR}/4 \text{ GeV}]^{-\delta} \ \text{cm}^2/\text{s},$$

with

$$\delta = 0.4 \pm 0.1$$

Diffusion region has bound exp(-r^2/r_s^2)

Radius of region around source is

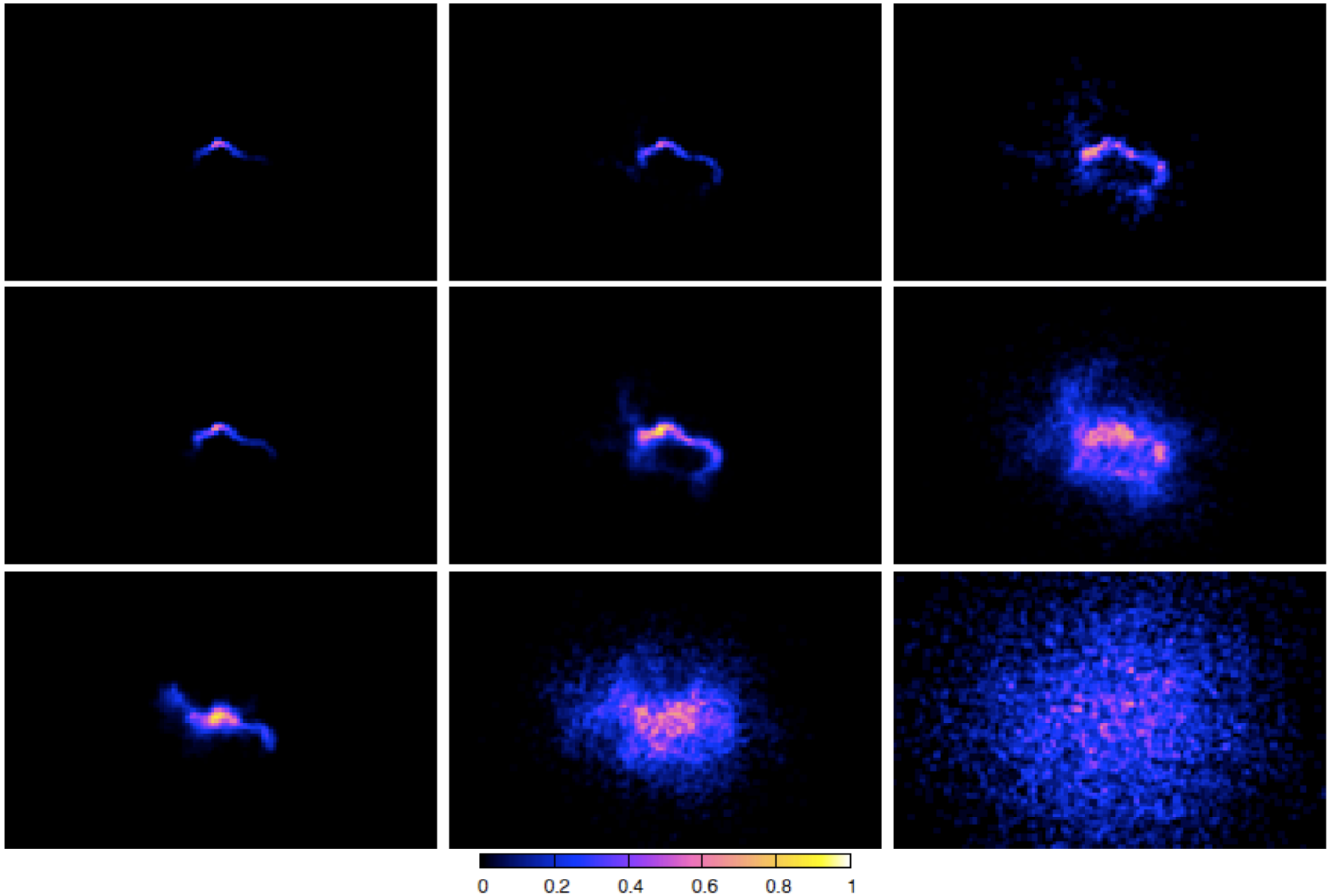
$$r_s \simeq 2\sqrt{DT_s} \simeq 80 \ D_{28}^{1/2} \left[\frac{T_s}{10 \text{ kyr}}\right]^{1/2} \left[\frac{E_{CR}}{1 \text{ TeV}}\right]^{\delta/2} \ \text{pc}.$$

Diffusion of protons from single source

100 TeV

1 PeV

10 PeV



500 yr | 2 kyr | 7 kyr

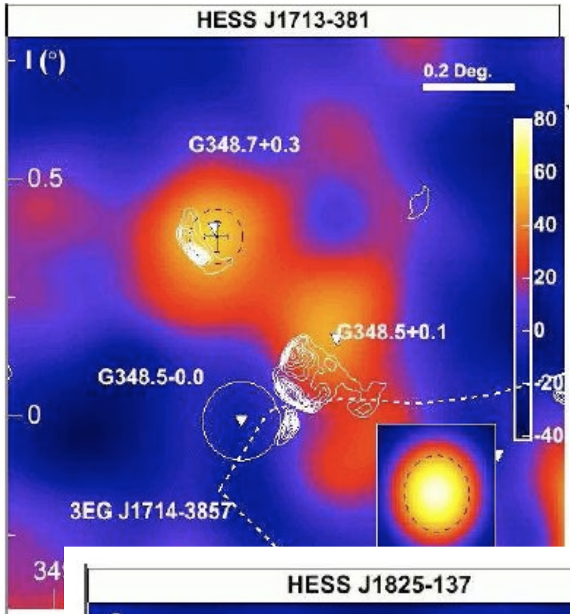
Time needed to come in 3-d diffusion regime

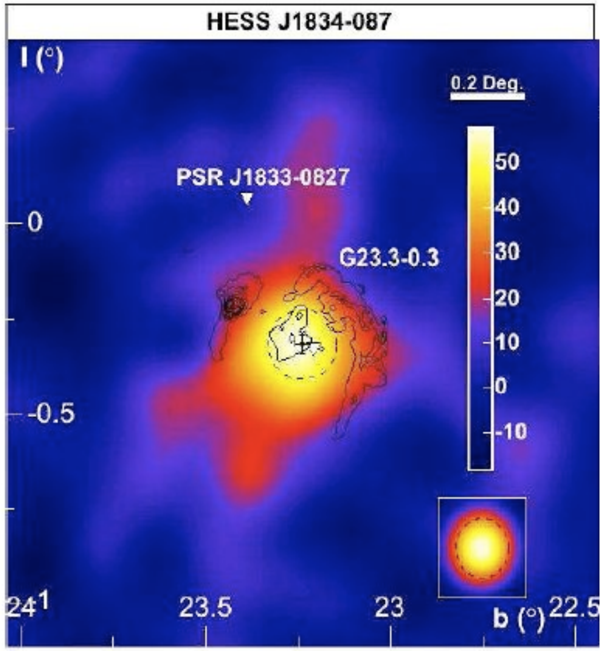
$$t_* \sim 10^4\,\mathrm{yr}\;\; (l_{\max}/150\,\mathrm{pc})^{\beta}\,(E/\mathrm{PeV})^{-\gamma}\,(B_{\mathrm{rms}}/4\,\mu\mathrm{G})^{\gamma}$$

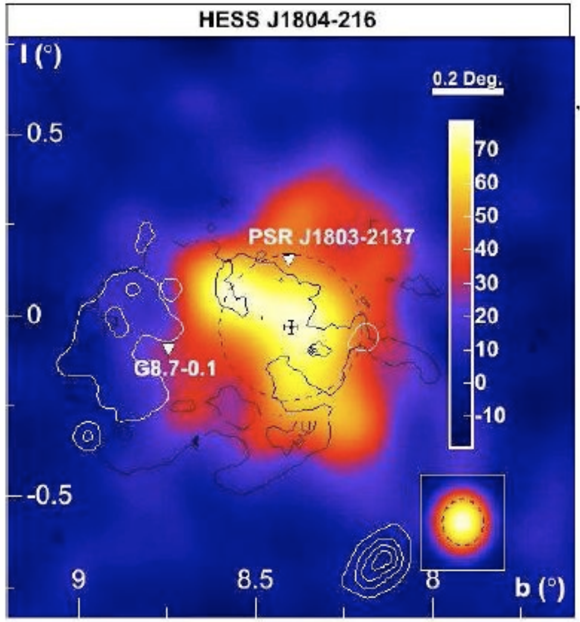
$\beta \simeq 2$ and $\gamma = 0.25$–0.5 for Kolmogorov turbulence

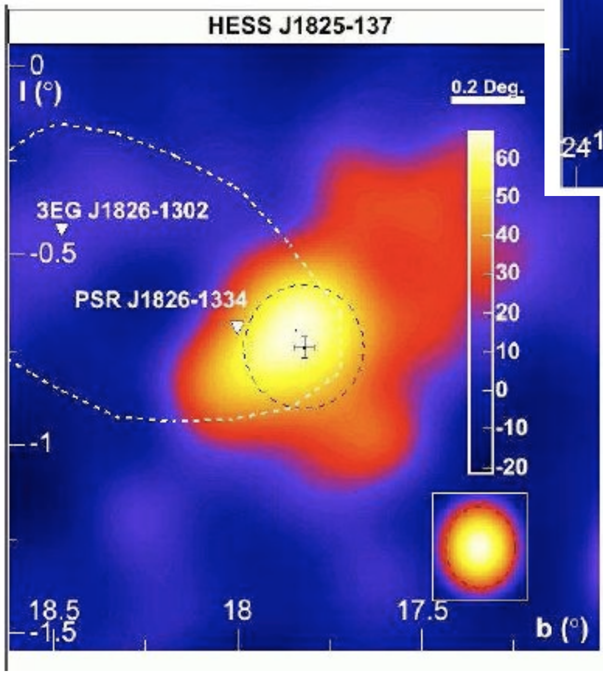
G.Giacinti, M.Kachelriess and D.S., **arXiv:1204.1271**

Examples of observed HESS sources

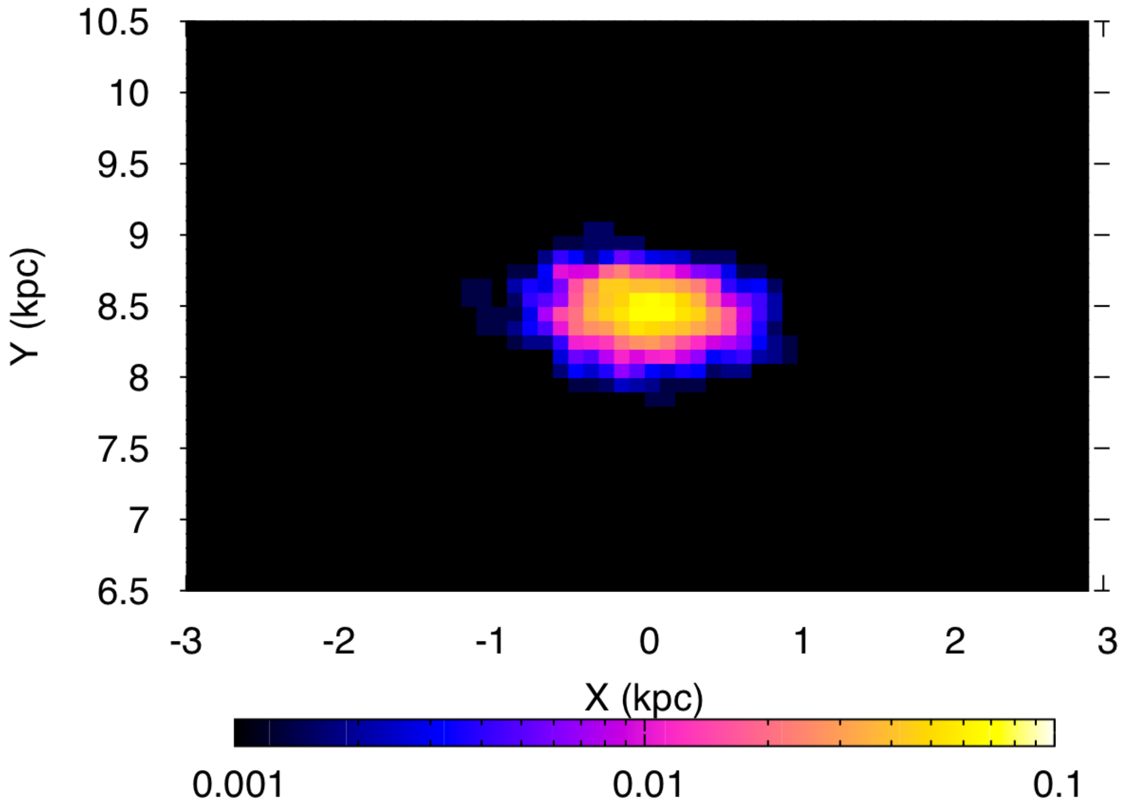




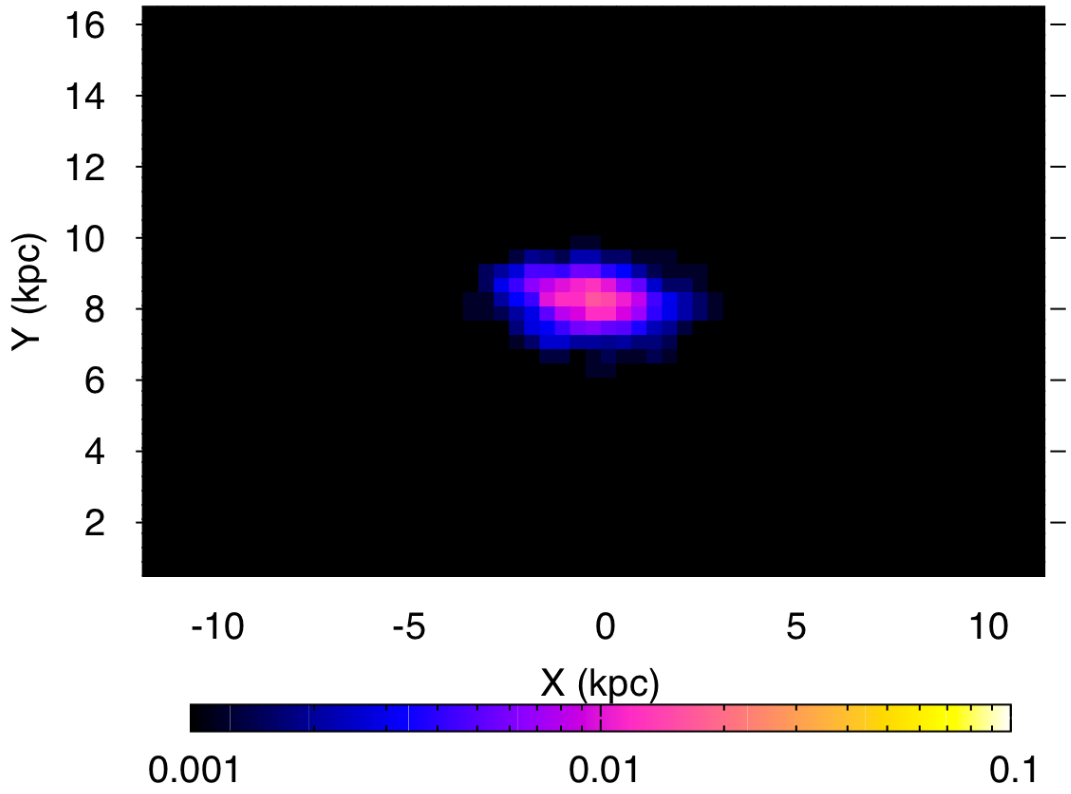




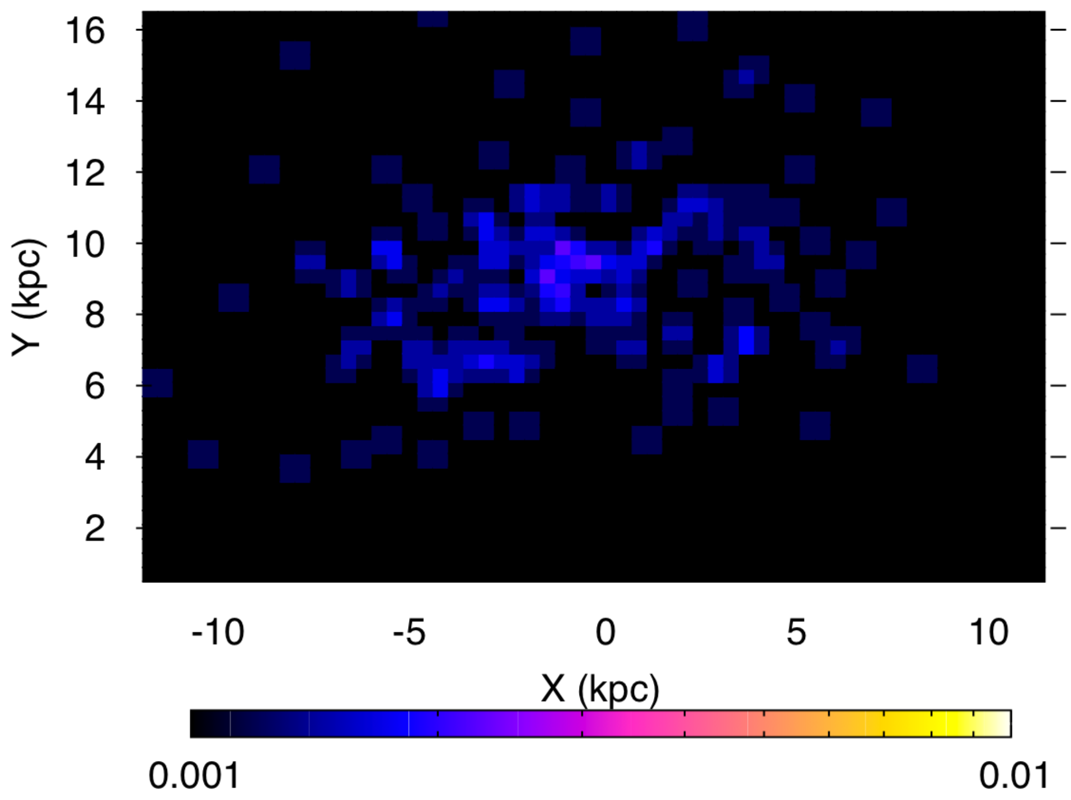
40 PeV protons from single source: 10 kyr (77%)



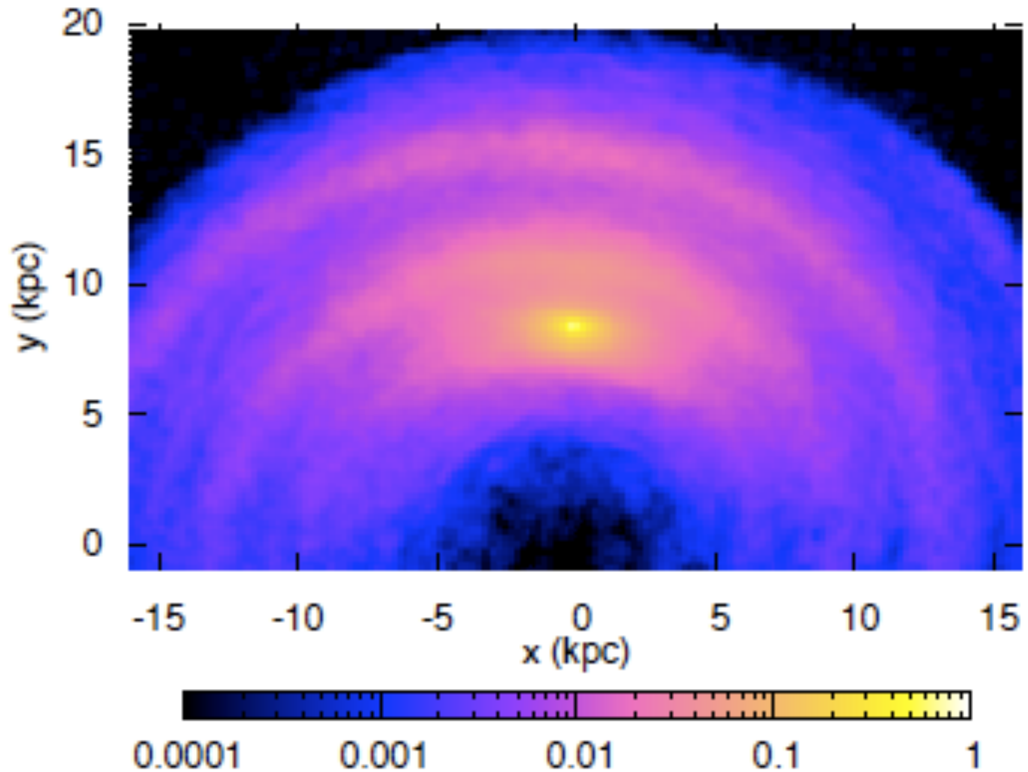
40 PeV protons from single source: 100 kyr (33%)



40 PeV protons from single source: 1 Myr (12%)



40 PeV protons from single source: all times (up to several Myr)



G.Giacinti et al, **arXiv:1112.5599**

Secondary gamma-rays from CR

- To explain observed CR flux each source release

$$E_s \sim 3 \times 10^{50} \left[\mathcal{R}_{SN}/10^{-2}\ \mathrm{yr}\right]$$

In form of cosmic rays

Then luminosity in gamma-rays is

$$L_\gamma \sim \frac{\kappa E_s}{t_{pp}} \sim 2 \times 10^{34} \left[\frac{\kappa}{0.2}\right] \left[\frac{E_s}{10^{50}\ \mathrm{erg}}\right] \left[\frac{n_{ISM}}{1\ \mathrm{cm}^{-3}}\right]\ \mathrm{erg/s},$$

Secondary gamma-rays from one source

- Then flux of gamma-rays from one source is

$$F_s = \frac{L_\gamma}{4\pi R_s^2} \simeq 10^{-11} \left[\frac{R_s}{5 \text{ kpc}}\right]^{-2} \left[\frac{n_{ISM}}{1 \text{ cm}^{-3}}\right] \left[\frac{\kappa}{0.2}\right] \frac{\text{erg}}{\text{cm}^2\text{s}}.$$

and angular size of source is

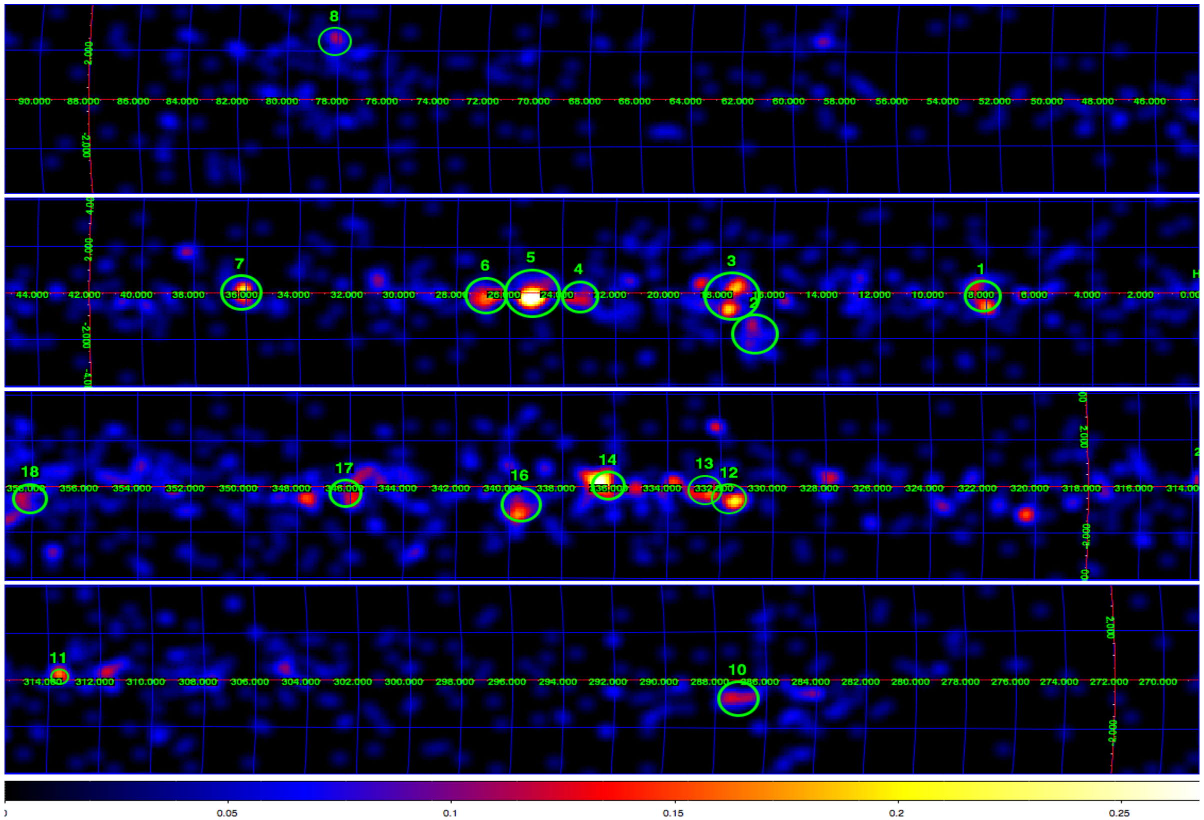
$$\theta_s \sim \frac{r_s}{R_s} \simeq 0.8^\circ D_{28}^{1/2} \left[\frac{R_s}{5 \text{ kpc}}\right]^{-1} \left[\frac{T_s}{10 \text{ kyr}}\right]^{1/2} \left[\frac{E_{CR}}{1 \text{ TeV}}\right]^{0.2}$$

Expected number of sources

- Expected number of sources in the nearby inner part of Galaxy: N_tot* Slocal/Stotal
- N_tot = R_SN *3*10^4 yr = 300
- We should see about 10-20 sources within 5 kpc towards inner galaxy

Fermi LAT observation of Galaxy at E>100 GeV

Fermi LAT Galactic plane at E>100 GeV



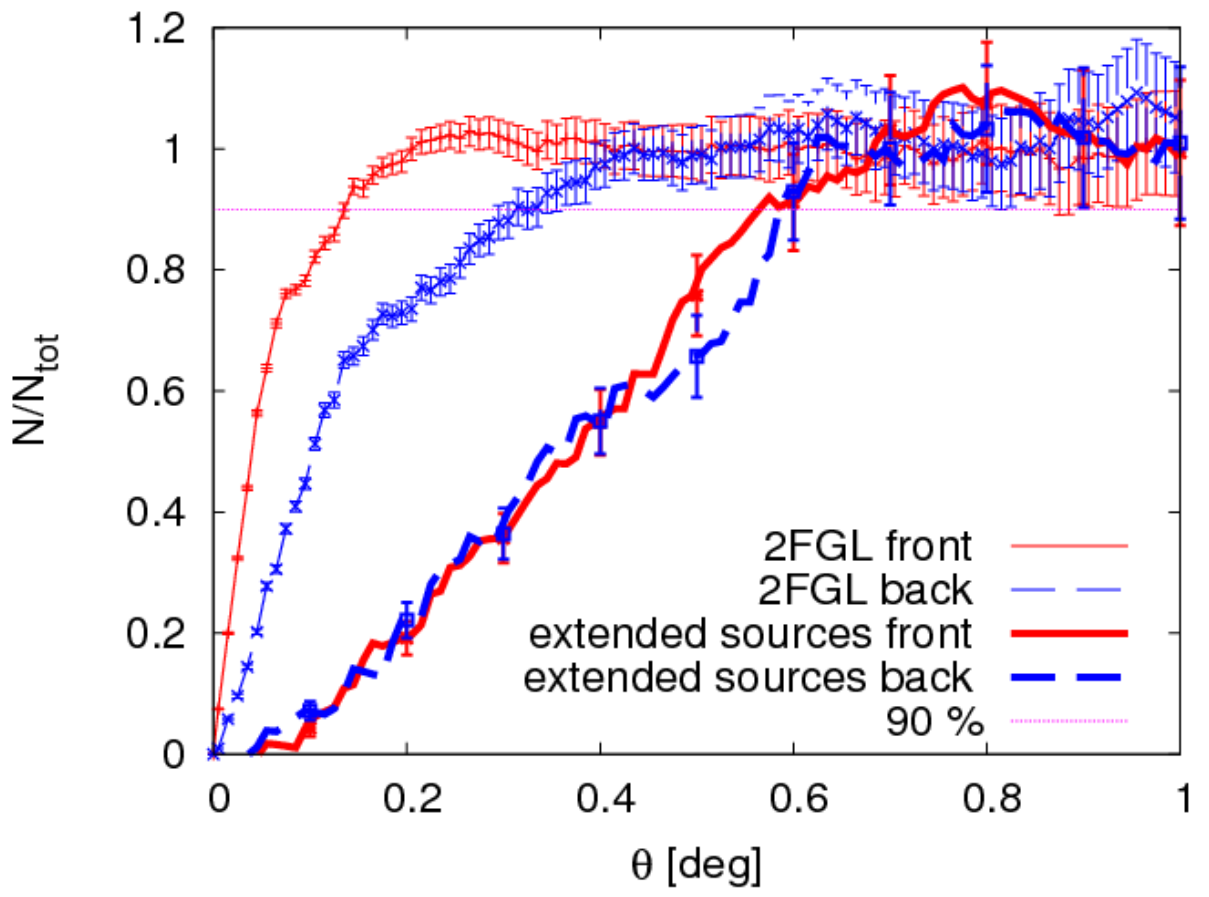
A.Neronov and D.S., **arXiv:1201.1660**

Fermi LAT point sources in Galactic plane at E>100 GeV

	2FGL	l	b	N_{ph}	P	type	Name
1	1837.3-0700c	25.09	-0.08	4	1.e-4		**HESS J1837-069**
2	J2001.1+4352	79.06	-7.12	2	1.e-3	BLZ	**MAGIC J2001+435**
3	J2323.4+5849	111.74	-2.11	2	1.e-3	SNR	**Cas A**
4	J2347.0+5142	112.88	-9.90	4	6.e-8	BLZ	**1ES 2344+514**
5	J0035.8+5951	120.97	-2.96	5	4.e-8	BLZ	**1ES 0033+595**
6	J0110.3+6805	124.70	5.29	2	6.e-4		VCS J0110+6805
7	J0240.5+6113	135.67	1.08	4	2.e-6	GRLB	**LS I+61 303**
8	J0521.7+2113	183.6	-8.70	4	2.e-5	AGU	**VCS J0521+2112**
9	J0534.5+2201	184.55	-5.78	28	0	PWN	**Crab**
10	J0617.2+2234e	189.05	3.03	4	7.e-5	SNR+CCO	**IC443**
11	J0648.9+1516	198.99	6.35	4	4.e-7	AGU	**VER J0648+152**
12	J1030.4-6015	286.28	-2.03	2	1.e-3		
13	J1124.6-5913	292.2	-2.03	2	1.e-3	PWN	PSR J1124-5916
14	J1603.8-4904	332.15	2.56	5	5.e-7		AT20G J160350-49

A.Neronov and D.S., **arXiv:1201.1660**

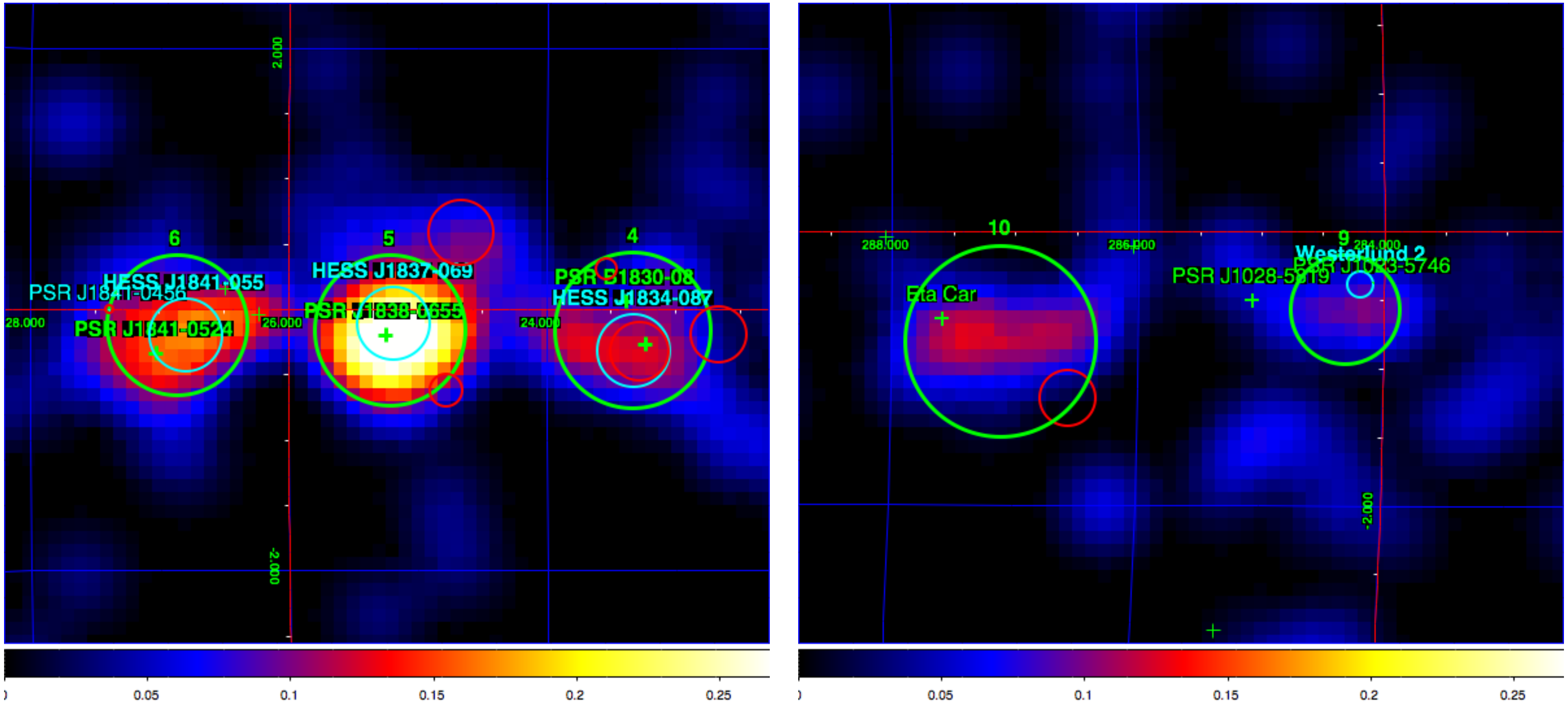
Fermi LAT point PSF and extended sources at E>100 GeV



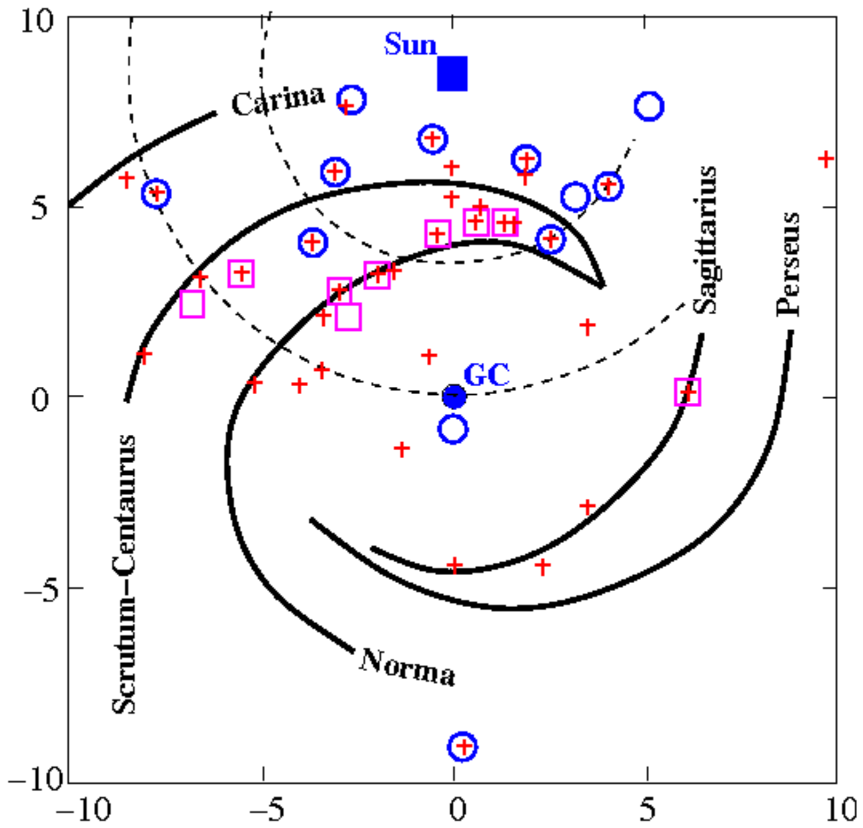
Fermi LAT diffuse sources in Galactic plane at E>100 GeV

	l	b	θ_{50}	θ_{90}	P_{90}	N_{ph}	F	Comments	SNR	PSR	R_s	T_s
1	8.15	-0.14	0.47	0.65	1.e-5	12	4.6 ± 1.3	**HESS 1804-216**	W30	B1800-21	3.9	1.6
2	16.74	-1.79	0.46	0.83	1.e-6	12		**LS 5039**				
3	17.58	-0.14	0.6	1. 0	1.e-3	13	5.2 ± 1.4	**HESS J1825-137**		B1823-13	4.1	2.1
4	23.32	-0.16	0.5	0.6	2.e-2	8	3.4 ± 1.2	**HESS J1834-087**	W41	CXOU J183434.9-084443 B1830-08?	4	~ 10 3.5
5	25.21	-0.16	0.43	0.58	1.e-5	15	6.4 ± 1.5	**HESS J1837-069**		J1838-0655		2.3
6	26.87	-0.12	0.39	0.54	2.e-4	11	4.6 ± 1.4	**HESS J1841-055**		J1841-0524	4.9	3.0
7	36.20	0.02	0.23	0.37	1.e-6	11	4.6 ± 1.4	**HESS J1857+026**		J1856+0245	10.3	2.0
8	78.09	2.54	0.33	0.38	1.e-5	7	2.3 ± 0.9	**VER J2019+407**	γCyg	J2021+4026		7.7
9	284.32	-0.57	0.32	0.42	7.e-3	4	1.3 ± 0.7	**Westerlund 2**		J1023-5746		0.5
10	287.12	-0.80	0.46	0.74	2.e-4	9	2.9 ± 1.0	near Eta Car				
11	313.56	0.11	0.2	0.32	8.e-6	8	2.6 ± 1.0	**Kookaburra**		J1420-6048	7.7	1.3
12	331.66	-0.58	0.27	0.64	7.e-4	11	3.7 ± 1.1	**HESS 1614-518**		J1614-5144		
13	332.57	-0.18	0.34	0.63	1.e-3	10	3.3 ± 1.0	**HESS J1616-508**		J1617-5055	6.5	0.8
14	336.25	0.04	0.37	0.59	1.e-6	16	5.4 ± 1.3	**HESS J1632-478**		J1632-4757	7.0	24
15	339.56	-0.79	0.37	0.72	3.e-3	10	3.4 ± 1.0	**Westerlund 1**		J1648-4611	5.7	11
16	344.90	0.23	0.72	1.05	3.e-2	8	2.8 ± 1.1	**HESS J1702-420**		J1702-4128?	5.2	5.5
17	346.20	-0.31	0.37	0.57	1.e-2	7	2.7 ± 1.0	**HESS 1708-410**		J1706-4009?	3.8	0.9
18	358.06	-0.54	0.57	0.63	1.e-4	10	3.7 ± 1.2	**HESS J1745-303**				

Fermi LAT extended sources at E>100 GeV

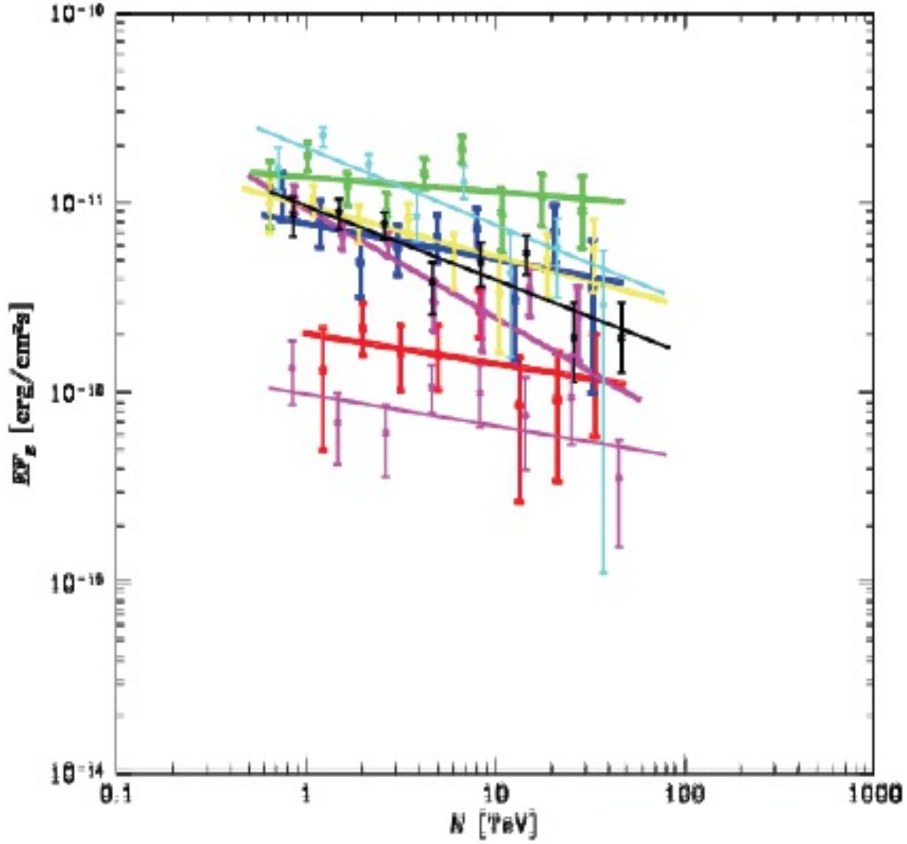


Pulsars with T<30 kyr



A.Neronov and D.S., **arXiv:1201.1660**

Nature of the extended sources



Spectra of all the extended sources are powerlaws in the energy range 1-30 TeV with the slopes $dN_\gamma/dE \sim E^{-2.1 \dots -2.4}$ consistent with the possibility of gamma-rays from CR interactions in the ISM.

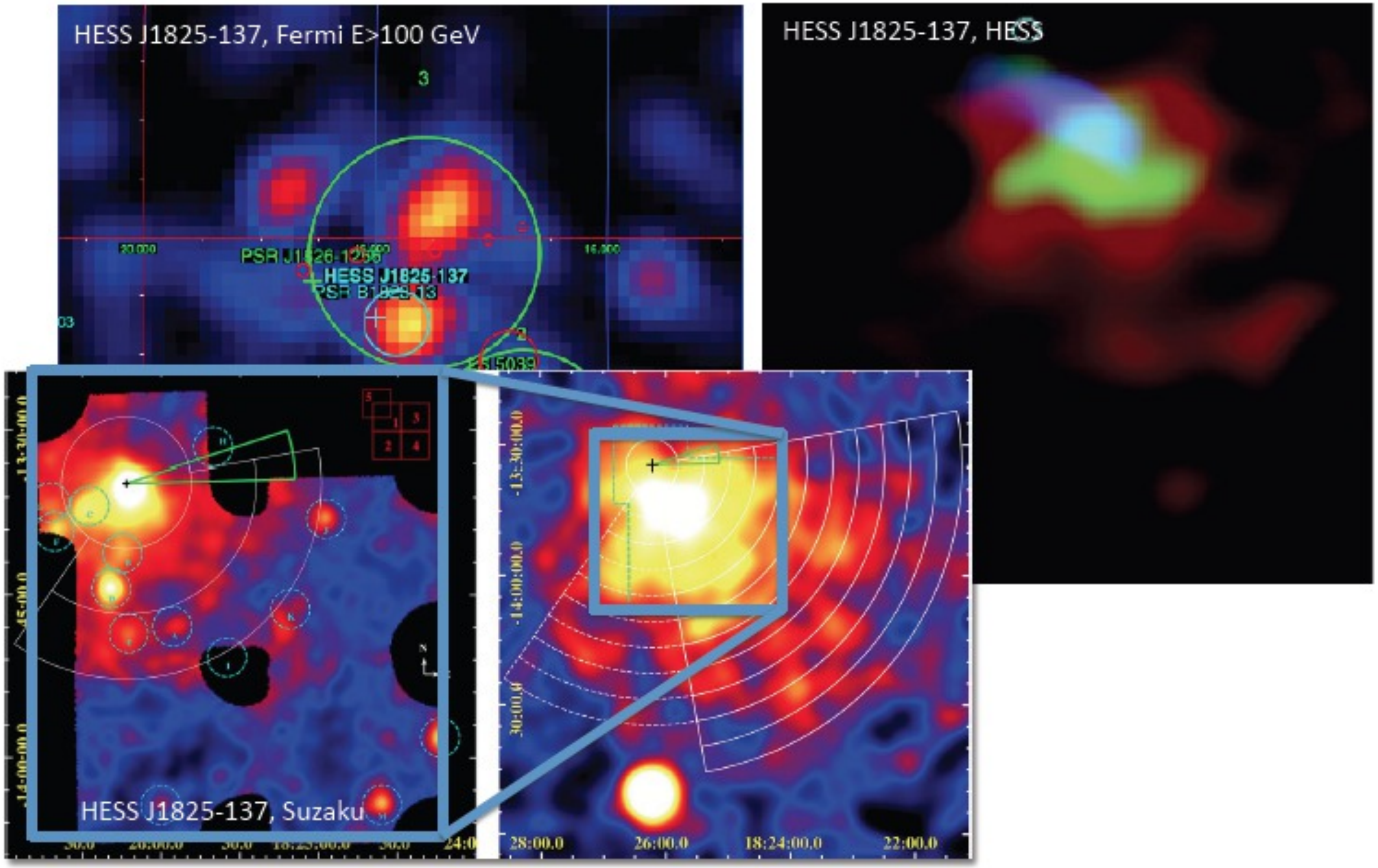
Pulsars

$$E_{NS} = \frac{I\Omega_{ini}^2}{2} \simeq 3 \times 10^{50} \left[\frac{P_{ini}}{10 \text{ ms}}\right]^{-2} \text{erg}$$

$$P \sim t^{1/(n-1)}$$

A.Neronov and D.S., **arXiv:1201.1660**

Extended sources: electron of CR proton/nuclei powered?



At least a part of the flux of extended 100 pc-scale sources could come from inverse Compton scattering by electrons, rather than from CR proton/nuclei interactions.

Summary galactic sources below TeV

- We expect to see 10^{th} of 100 pc CR sources with 100 GeV gamma-rays if SN are responsible for them
- With Fermi LAT we found 18 sources with 90% radius 0.3-1 degree, which give real size about 100 pc. Most of sources associated with pulsars with age T<30 kyr
- None of sources associated with SN shell without pulsar.
- Those sources can be sources of electrons
- If not pulsars are needed for CR acceleration? Energy requirement is OK.

Conclusions

- Two new breaks at 10 GeV and 200 GeV indicate existence of new component in Galactic CR
- We expect to see 10th of 100 pc CR sources with 100 GeV gamma-rays if SN are responsible for them. With Fermi LAT we found 18 sources with 90% radius 0.3-1 degree, which give real size about 100 pc. Most of sources associated with pulsars with age T<30 kyr
- Auger limits on the anisotropy of UHECR does not restrict existence of galactic iron component up to ankle or even up to 10^19 eV, depending on parameters of galactic magnetic fields.

Conclusions

- Existing limits on anisotropy forbid large (conservatively 10% or more) fraction of Galactic protons at 1 EeV. This mean that quickly rising proton fraction below 1 EeV in KASCADE-Grande has extragalactic origin
- Present GMF models for turbulent field are in contradiction with B/C measurements.
- Knee can be explained by escape of cosmic rays from sources, if average turbulent GMF is 5-10 times smaller then in models. Can be sign of anisotropic turbulence.