Magnetic reconnection as the cause of cosmic ray excess from the heliospheric tail

Paolo Desiati[1,2] & Alexander Lazarian[2]

[1] IceCube Research Center
[2] Department of Astronomy

University of Wisconsin - Madison

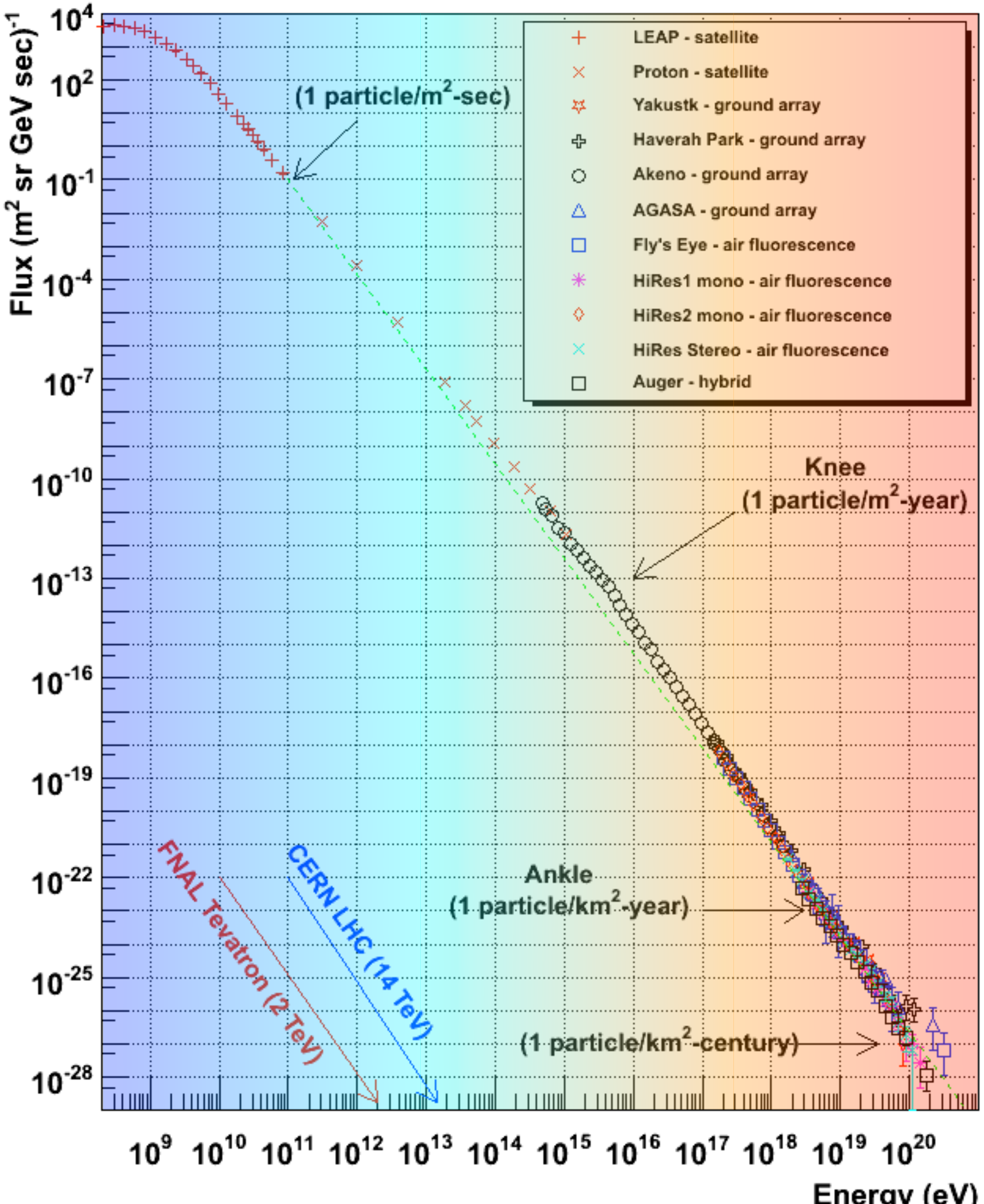
2010 AGU Fall Meeting
December 16, 2010

cosmic rays

- CR below the knee (~3×10^{15} eV) believed to be galactic
- CR below ~10^{18} eV believed to be predominantly galactic (transition to extra-galactic @ ~10^{18}-10^{19} eV)
- galactic CR believed to be accelerated in expanding shock waves initiated by supernova explosions
- galactic CR expected to be isotropic : scrambled by galactic magnetic field over very long time

$\Phi_{CR}(E)$

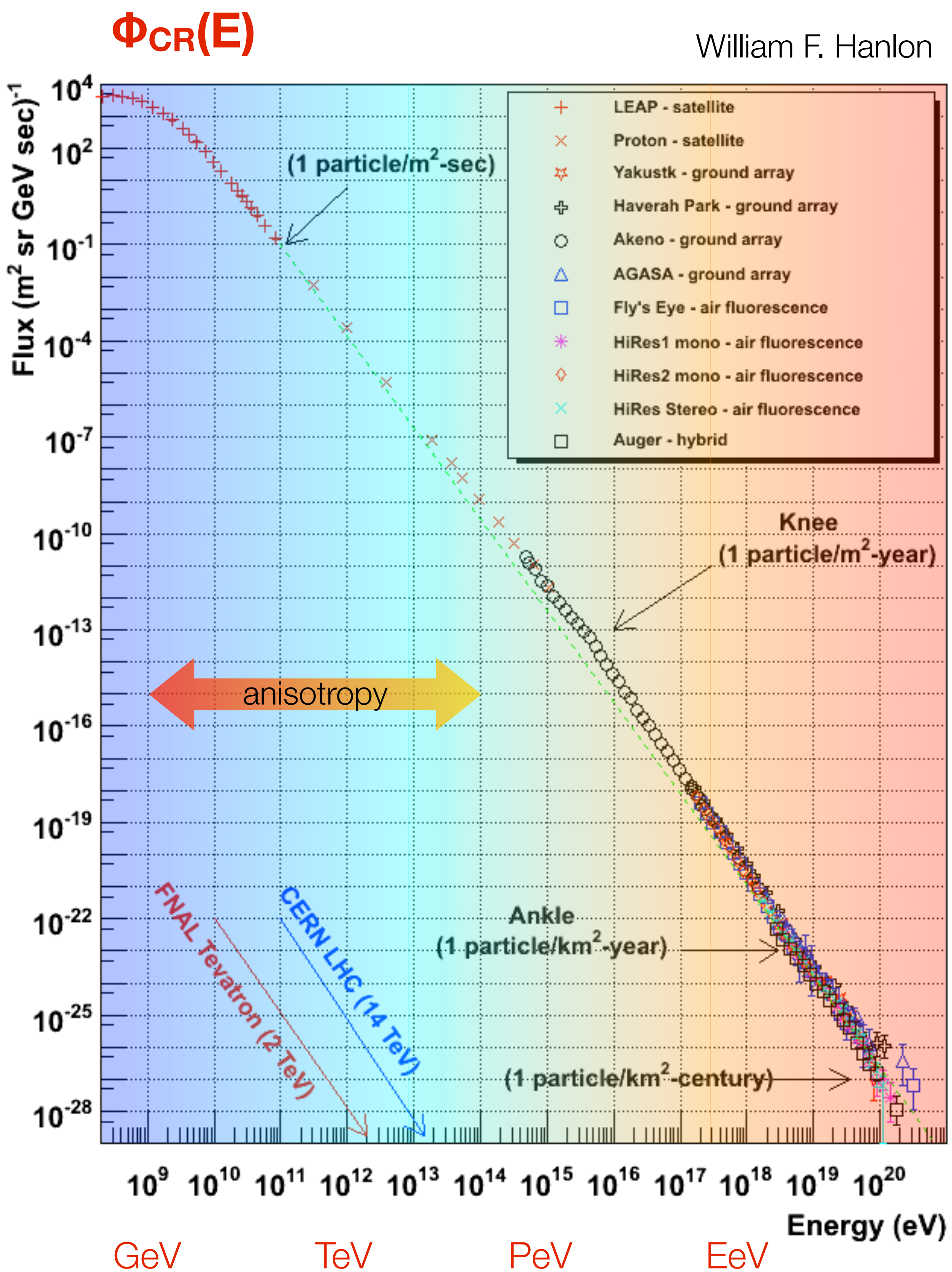
William F. Hanlon



GeV TeV PeV EeV

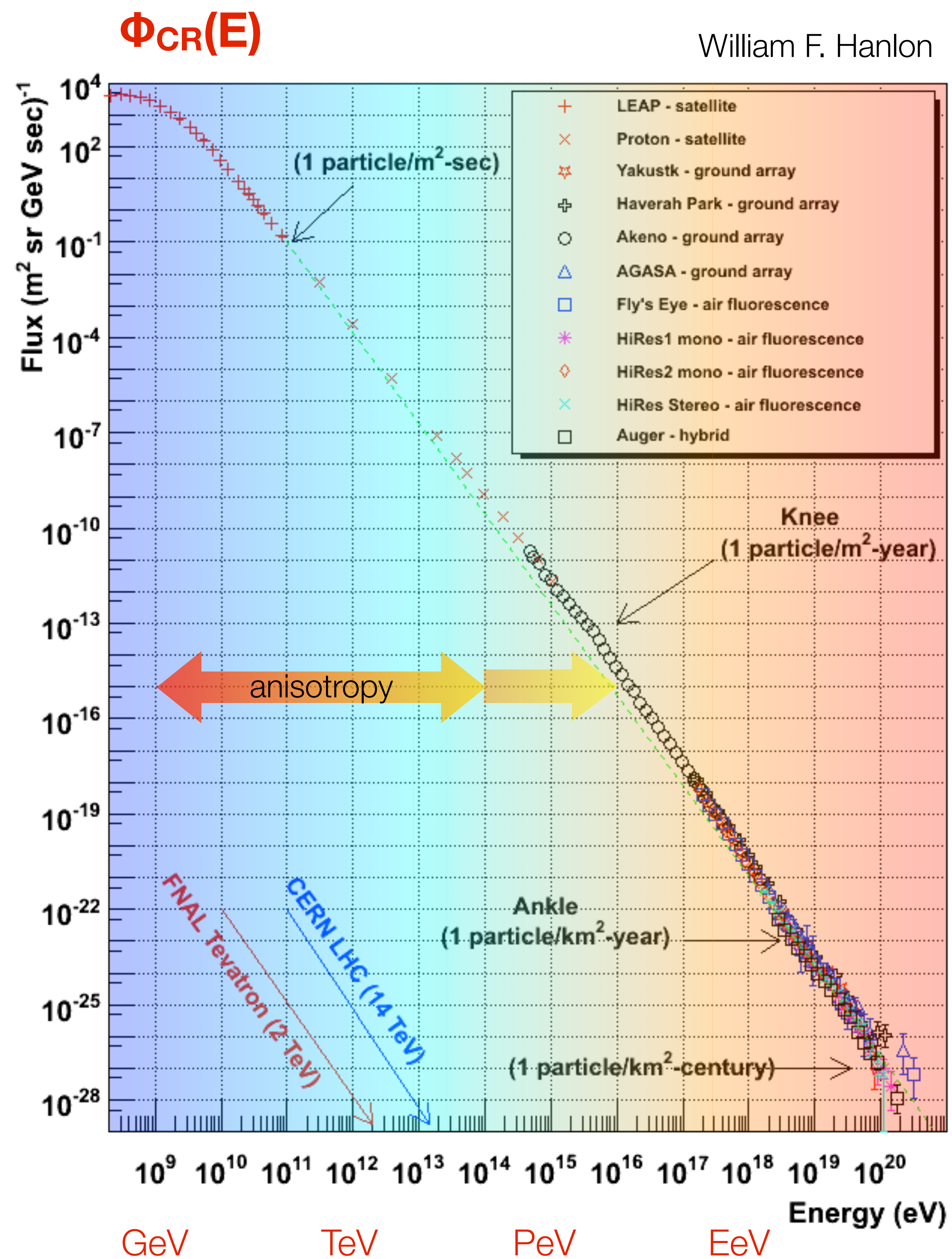
cosmic rays

- CR below the knee (~3×10^{15} eV) believed to be galactic
- CR below ~10^{18} eV believed to be predominantly galactic (transition to extra-galactic @ ~10^{18}-10^{19} eV)
- galactic CR believed to be accelerated in expanding shock waves initiated by supernova explosions
- galactic CR expected to be isotropic : scrambled by galactic magnetic field over very long time



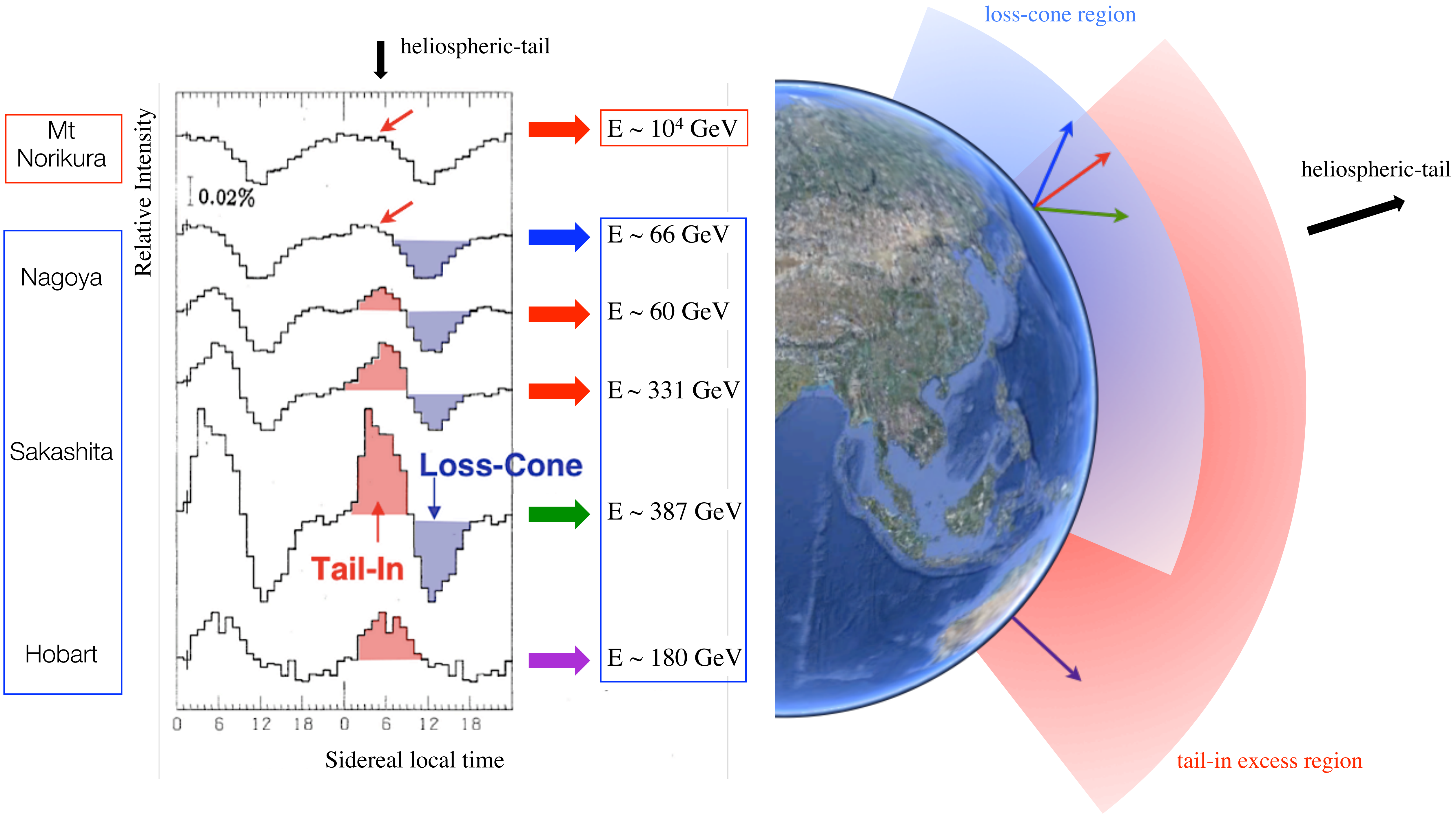
cosmic rays

- CR below the knee (~3×10^{15} eV) believed to be galactic
- CR below ~10^{18} eV believed to be predominantly galactic (transition to extra-galactic @ ~10^{18}-10^{19} eV)
- galactic CR believed to be accelerated in expanding shock waves initiated by supernova explosions
- galactic CR expected to be isotropic : scrambled by galactic magnetic field over very long time



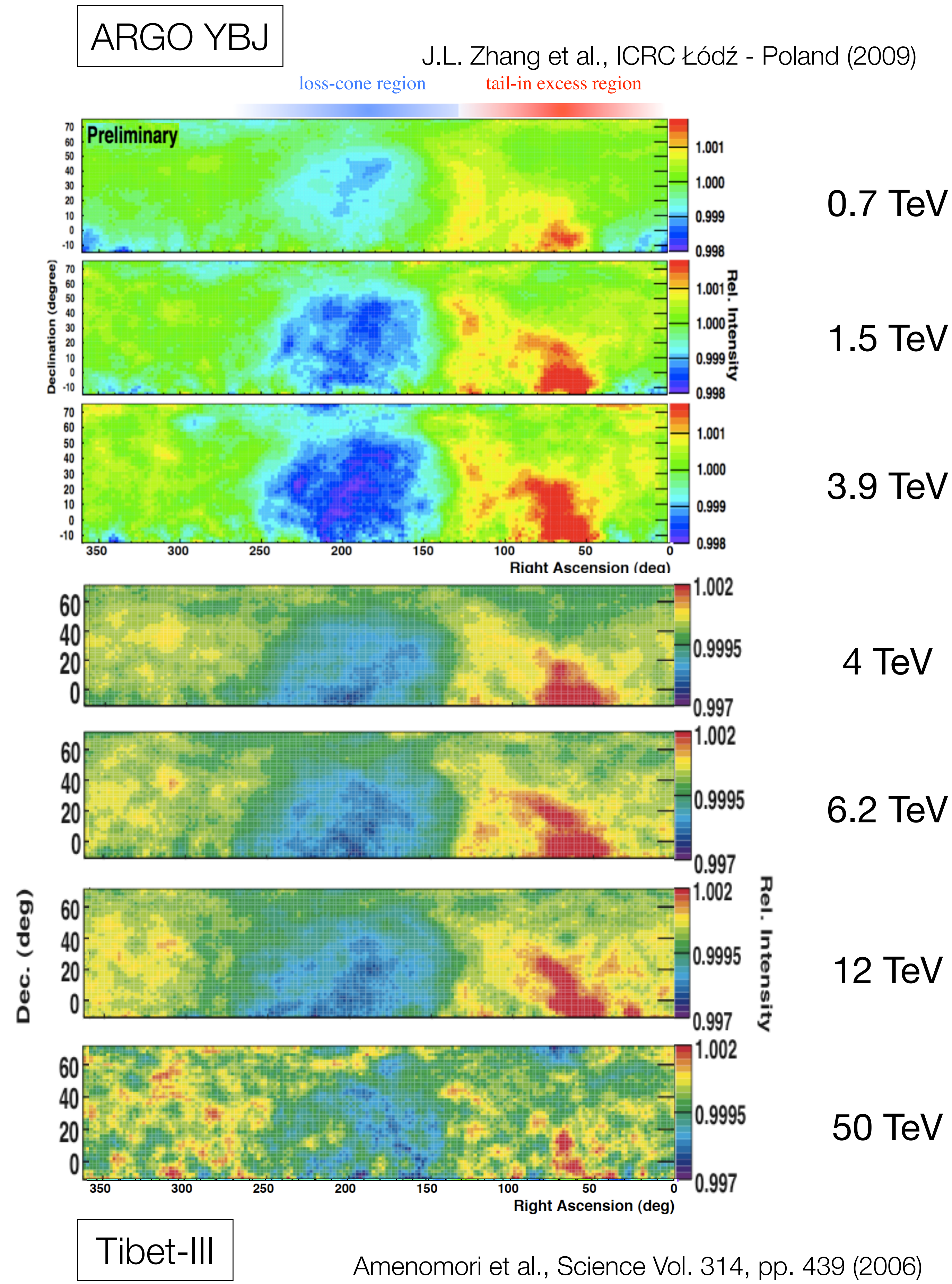
low energy cosmic ray anisotropy in arrival direction

Nagashima et al., J. Geophys. Res., Vol 103, No. A8, Pag. 17,429 (1998)



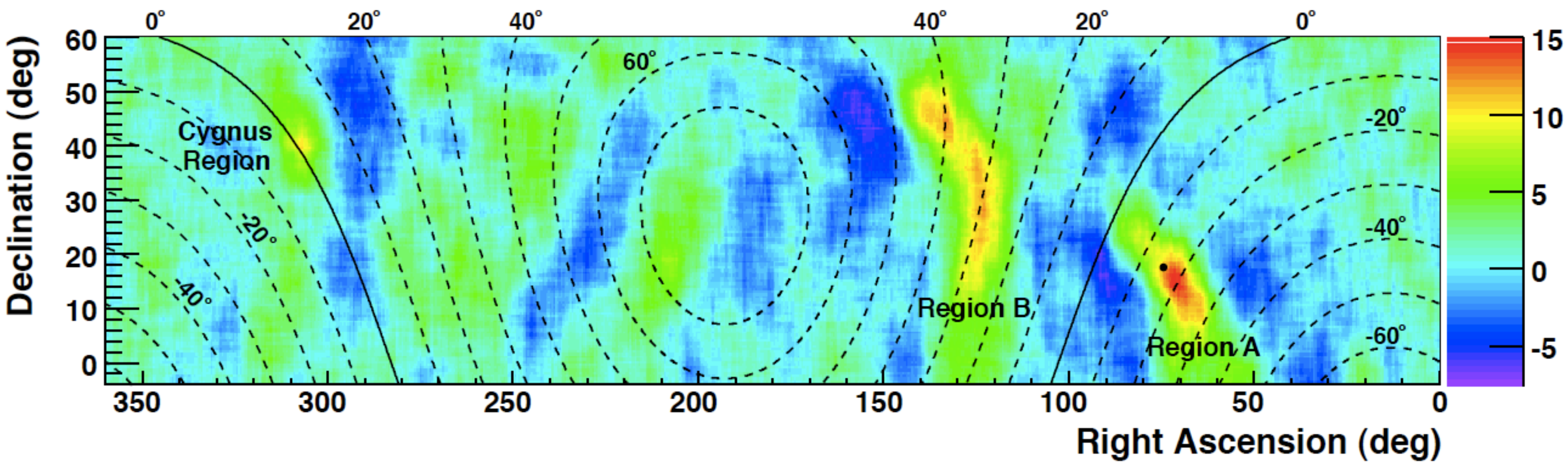
medium / small scale anisotropy

- global amplitude of large scale anisotropy increases with energy up to ~ 1-10 TeV and decreases above it
- large scale anisotropy shows smaller angular features, some of which highly significant
- origin of large scale anisotropy is unknown
- small angular features might reveal properties of the heliosphere or outer heliosphere that are not easily observed at low energy



medium / small scale anisotropy

Abdo A.A. et al., 2008, Phys. Rev. Lett., 101, 221101



2 hr = 30˚

Milagro

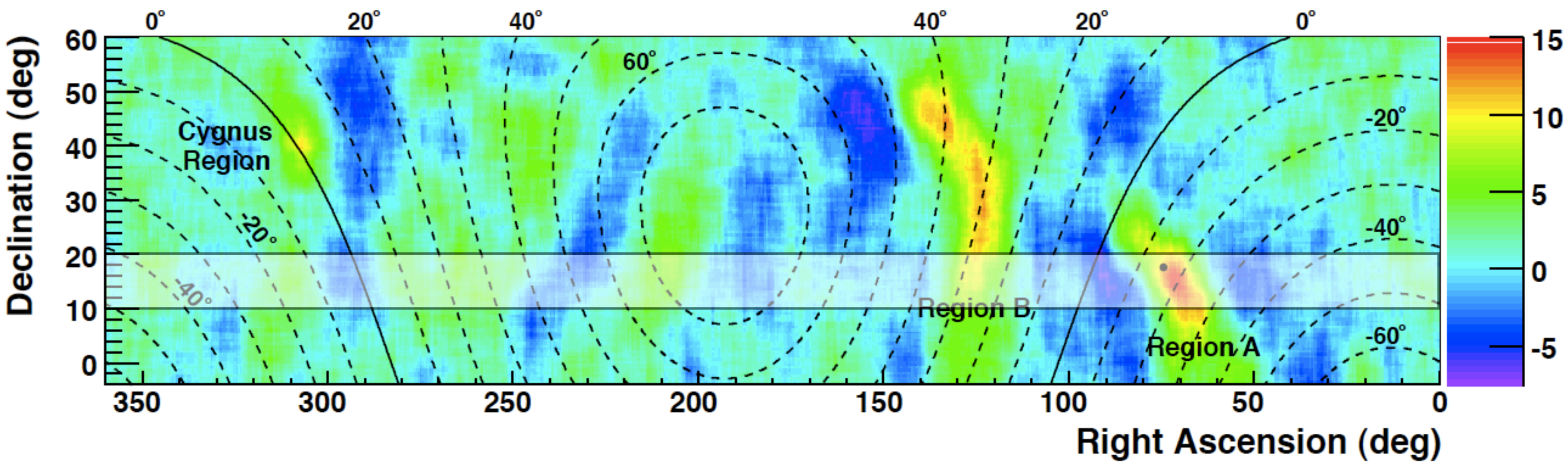
$2.2 \cdot 10^{11}$ events
median CR energy ~ 1 TeV
average angular resolution < 1^o

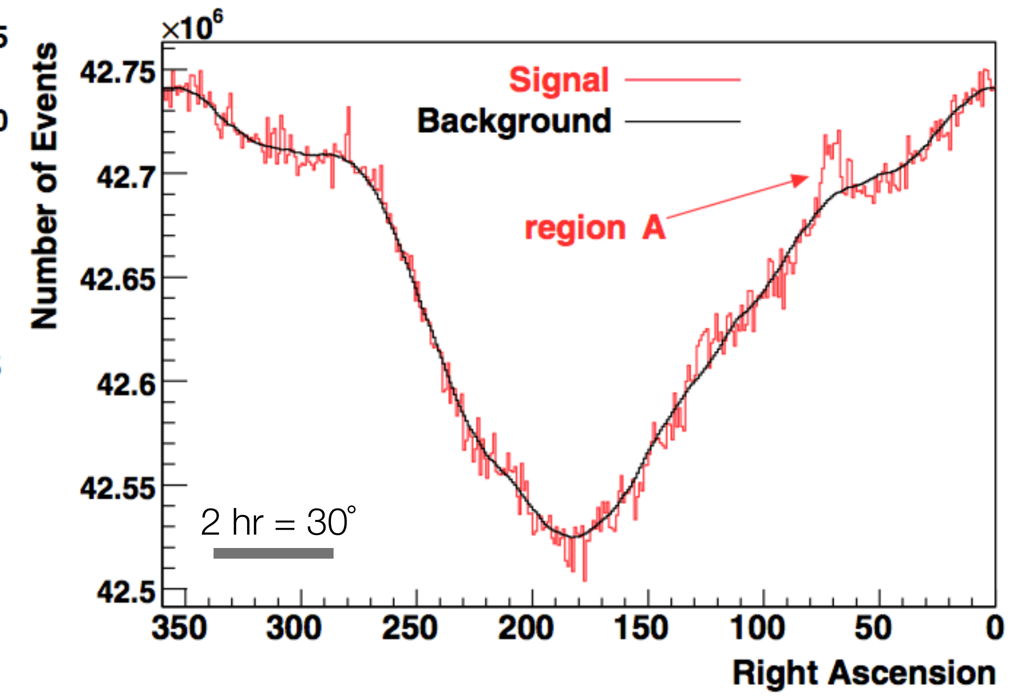
2hr time window
10˚ smoothing

- filter all angular features > 30˚
- technique used in gamma ray searches

medium / small scale anisotropy

Abdo A.A. et al., 2008, Phys. Rev. Lett., 101, 221101





Milagro

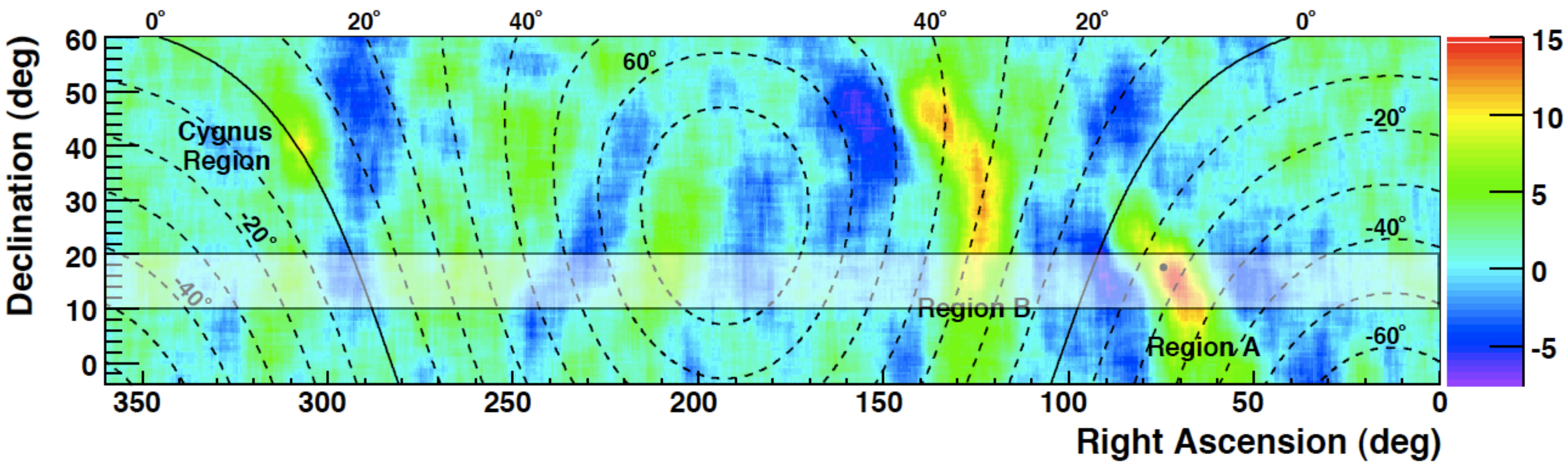
$2.2 \cdot 10^{11}$ events
median CR energy ~ 1 TeV
average angular resolution < 1°

2hr time window
10° smoothing

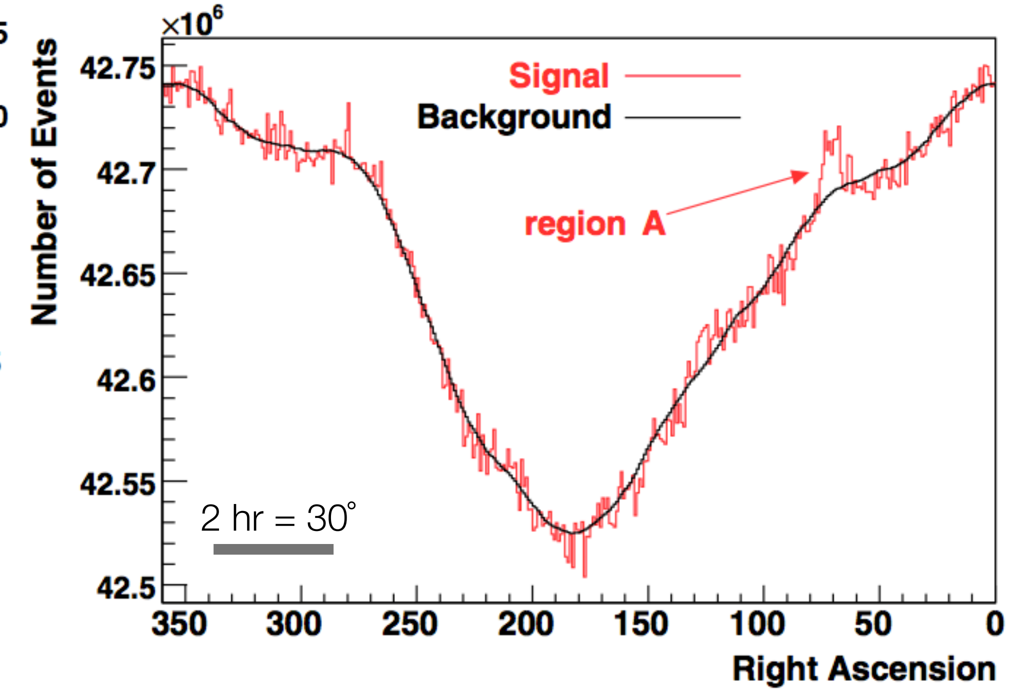
- filter all angular features > 30°
- technique used in gamma ray searches

medium / small scale anisotropy

Abdo A.A. et al., 2008, Phys. Rev. Lett., 101, 221101



2 hr = 30°

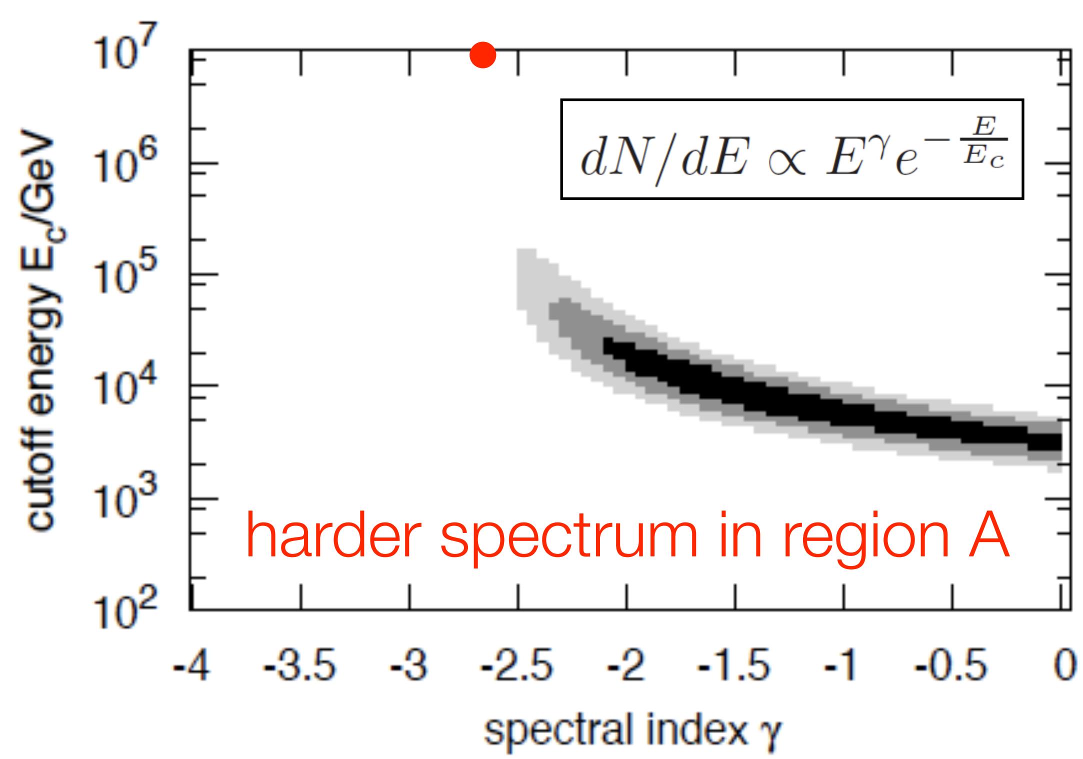


Milagro

$2.2 \cdot 10^{11}$ events
median CR energy ~ 1 TeV
average angular resolution < 1°

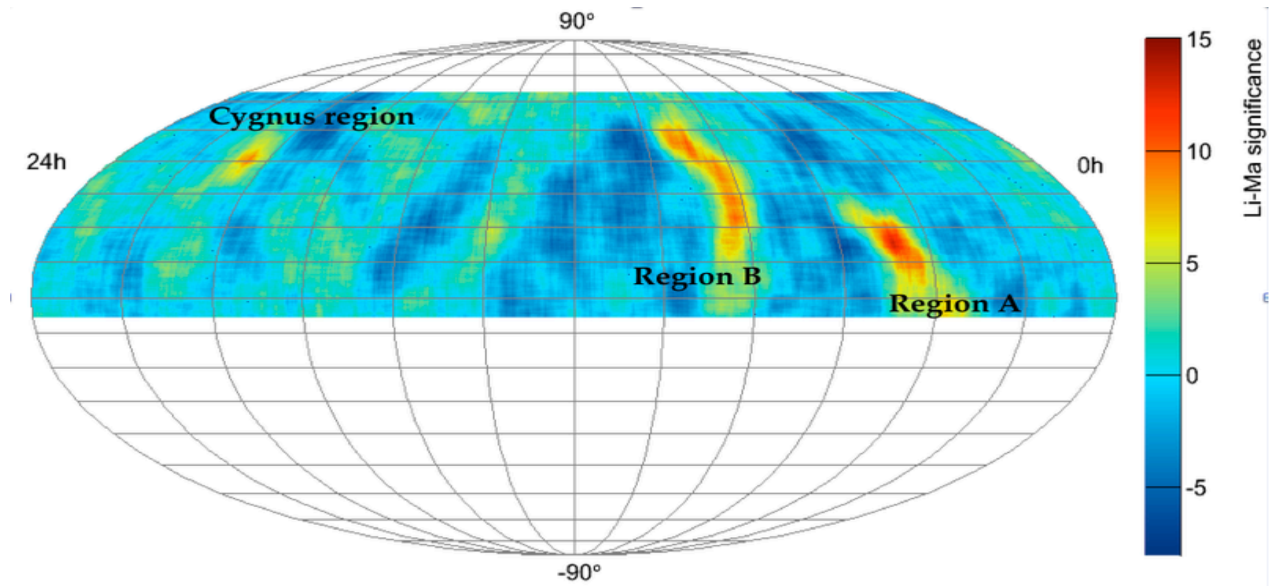
2hr time window
10° smoothing

- filter all angular features > 30°
- technique used in gamma ray searches

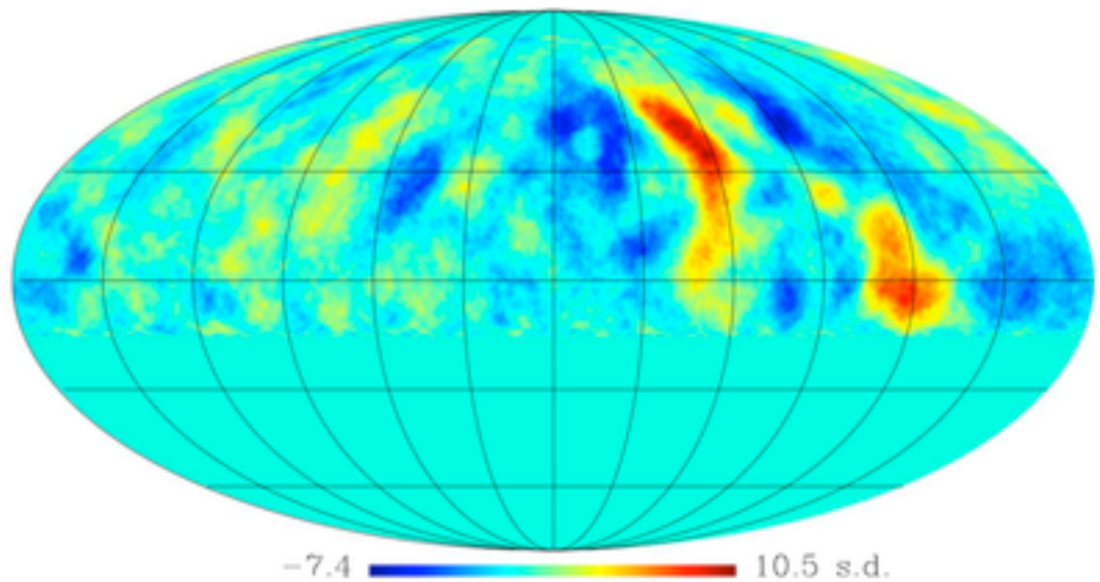


medium / small scale anisotropy for different experiments

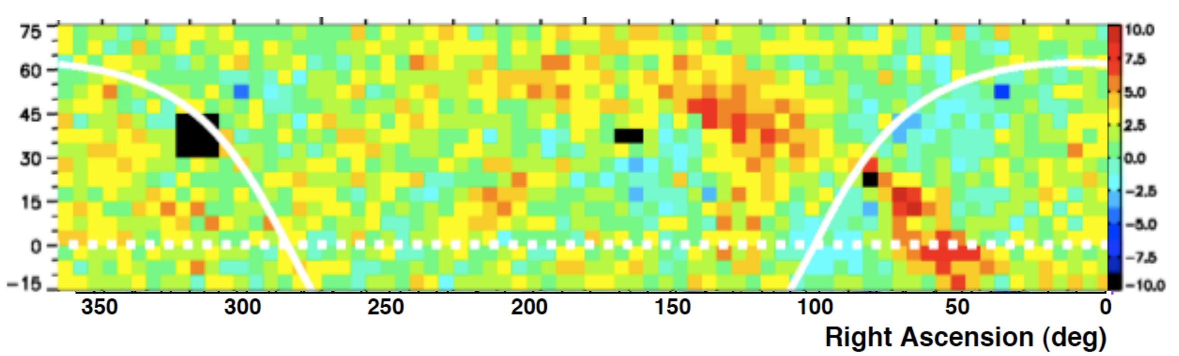
Milagro



ARGO-YBJ

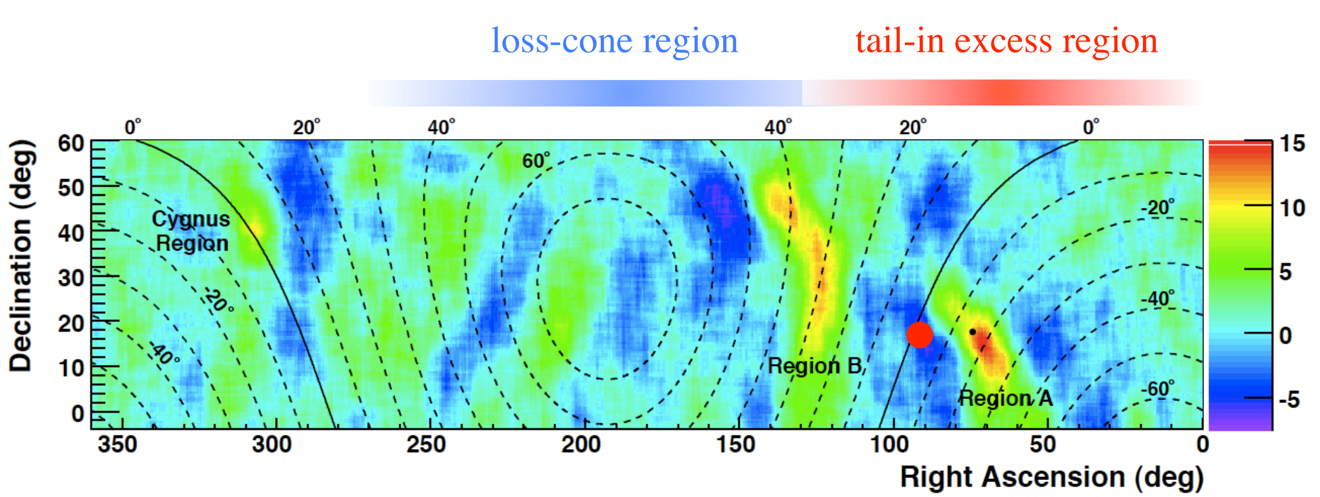


Tibet-III



origin of small scale anisotropy : astrophysics ?

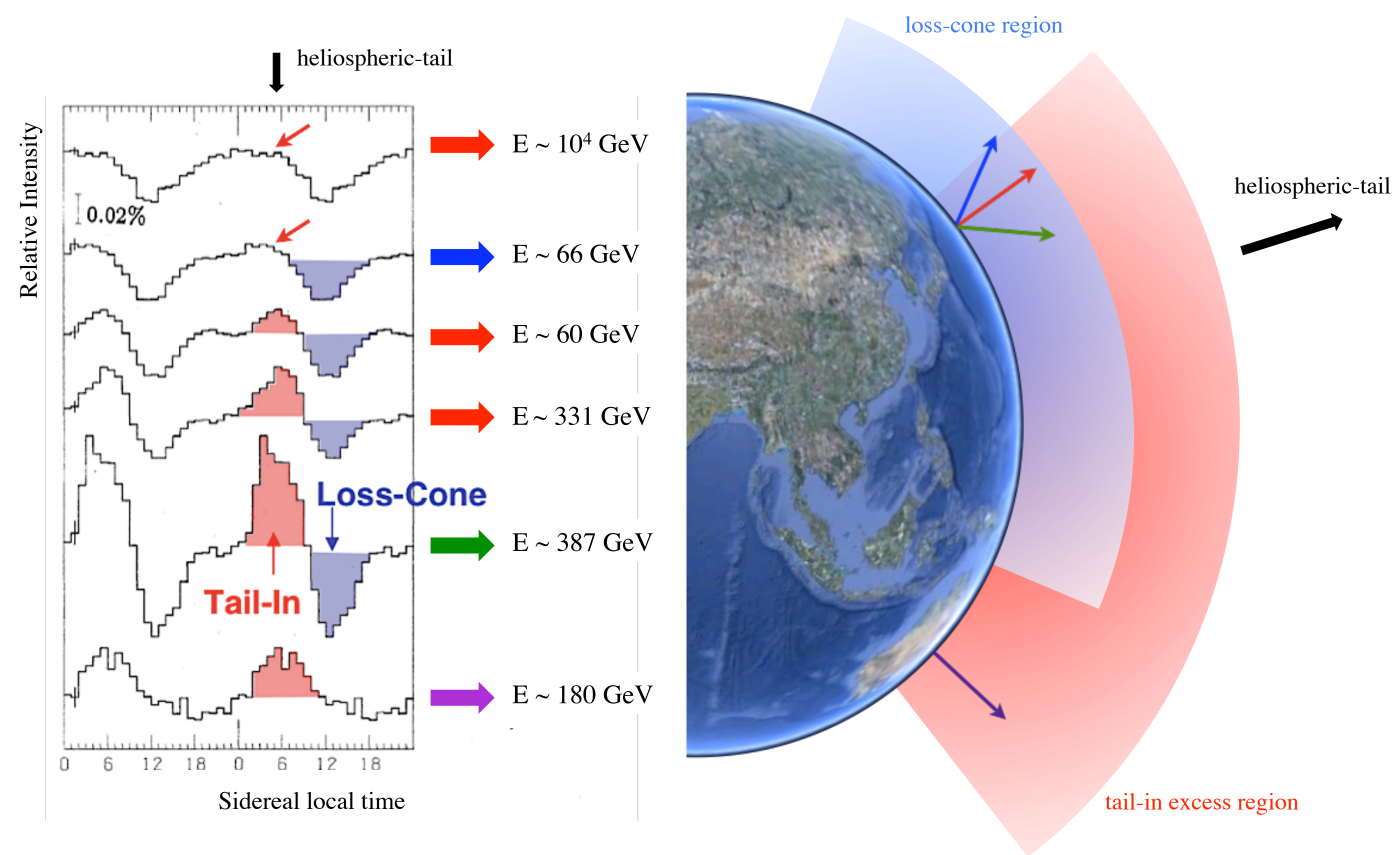
- localized excess of cosmic rays from nearby (~150 pc ~ 3×10^7 AU) recent (~ 350 kyr) supernova that gave birth to Geminga Pulsar
- fine tuning of propagation through interstellar medium
- incidentally requires magnetic connection
- small scale features likely from local processes



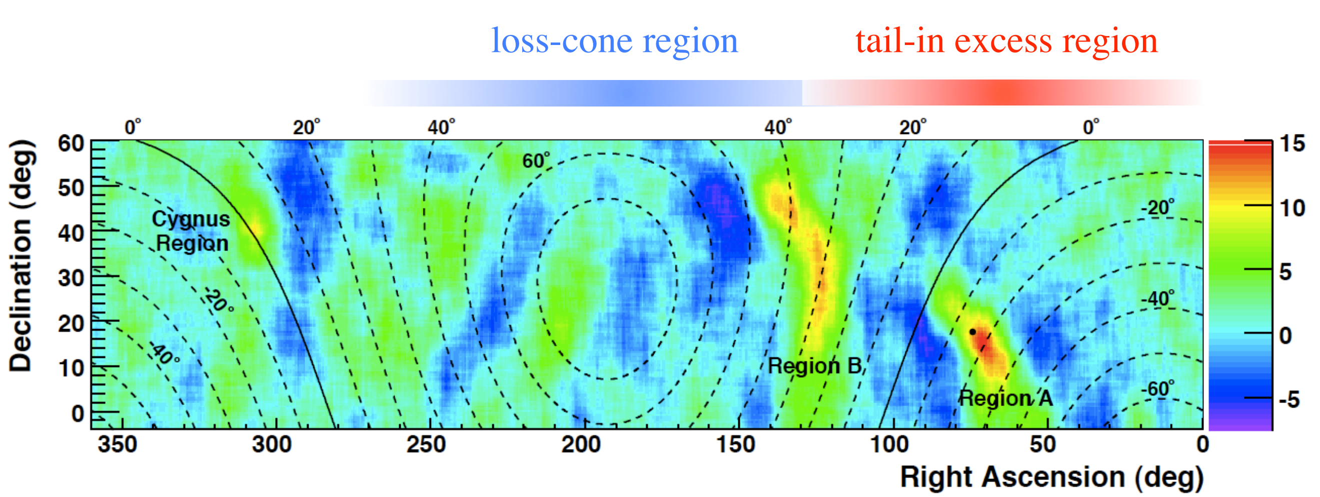
Abdo A.A. et al., 2008, Phys. Rev. Lett., 101, 221101

origin of tail-in anisotropy

- broad tail-in excess of **sub-TeV** cosmic rays attributed to heliotail
- localized excess of **multi-TeV** cosmic rays from the direction of the heliotail
- medium/small scale modulation to be connected to **nearby** perturbations
- first-order Fermi acceleration in magnetic reconnection regions in the heliotail



Nagashima et al., J. Geophys. Res., Vol 103, No. A8,17429, 1998

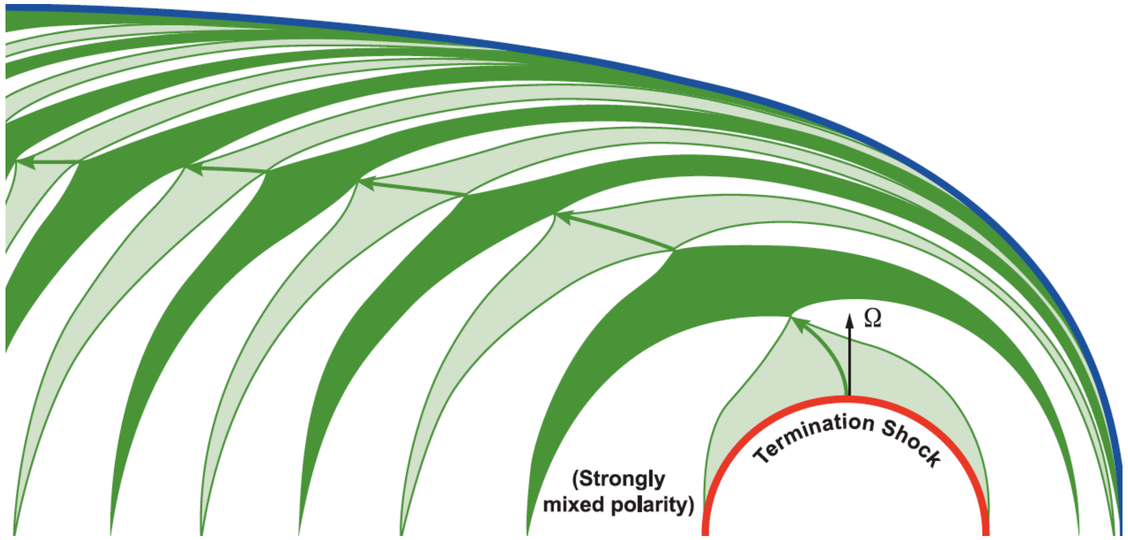


Abdo et al., Phys. Rev. Lett., 101, 221101, 2008

magnetic reconnection @ heliotail

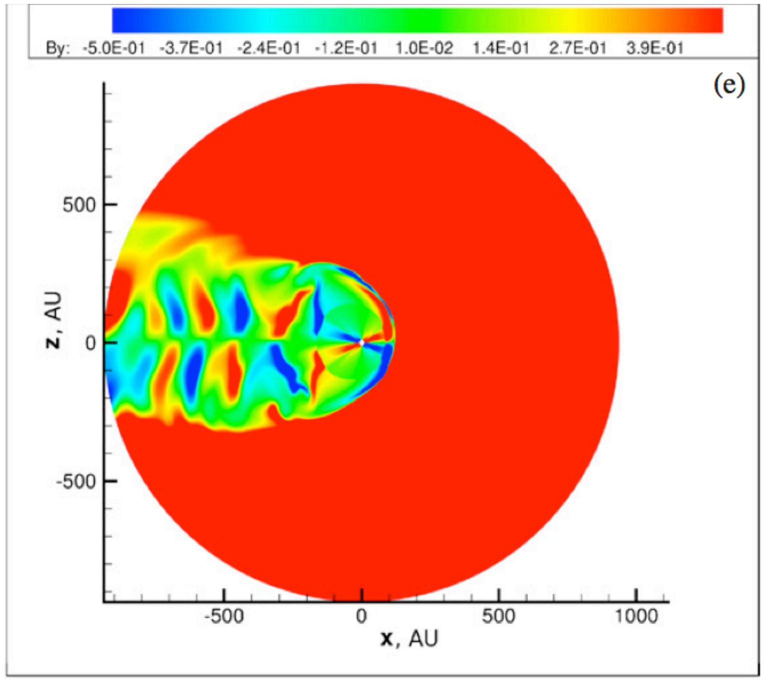
Lazarian & Desiati, ApJ, 722, 188, 2010

- magnetic polarity reversals due to the 11-year solar cycles compressed by the solar wind in the magneto-tail



Pogorelov et al., ApJ, 696, 1478, 2009

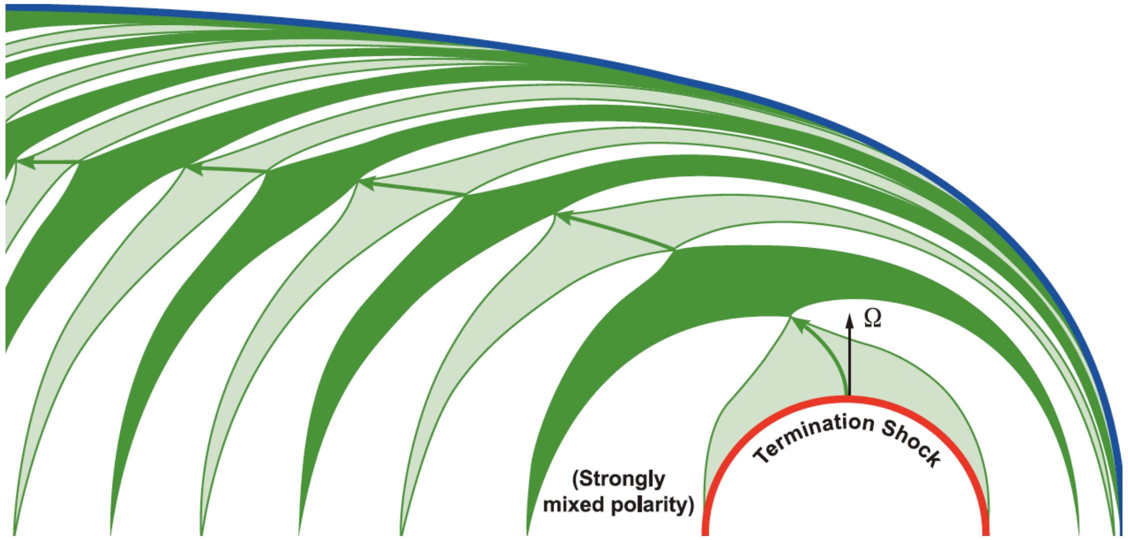
“realistic” numerical simulation of the turbulent heliosphere and heliotail



magnetic reconnection @ heliotail

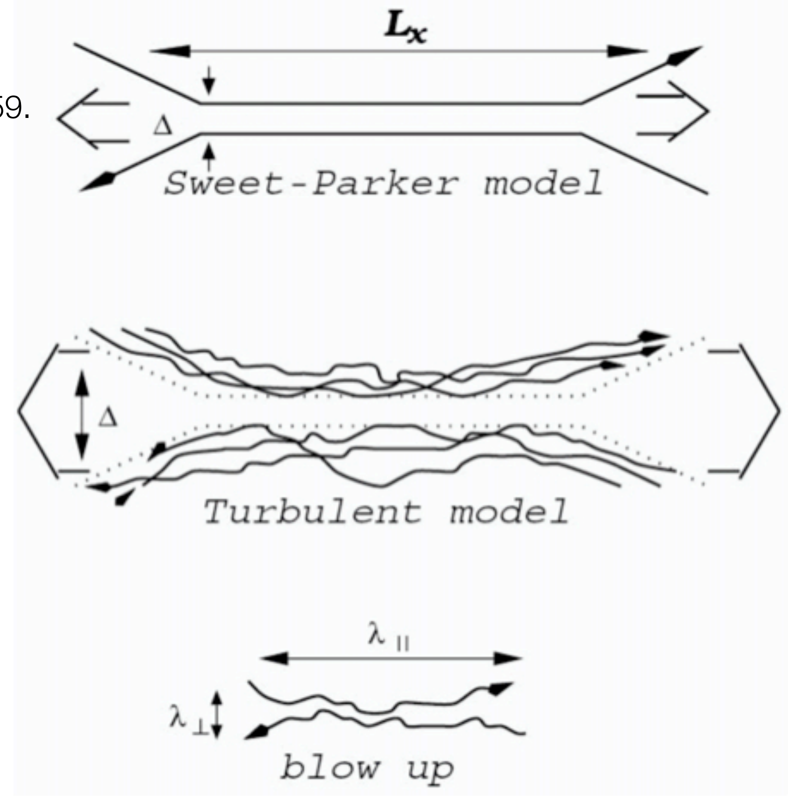
Lazarian & Desiati, ApJ, 722, 188, 2010

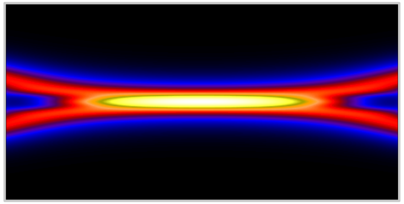
- magnetic polarity reversals due to the 11-year solar cycles compressed by the solar wind in the magneto-tail
- turbulence makes reconnection fast and not affected by ohmic dissipation

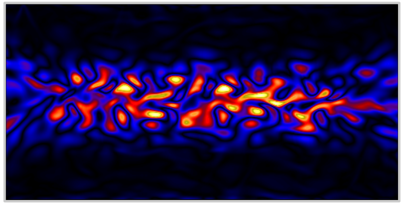


Sweet, IAU Symposium 6, Electromagnetic Phenomena in Cosmical Physics, 123, 1959.
Parker , J. Geophys. Rev., 62, 509, 1957

Lazarian & Vishniac, ApJ, 517, 700, 1999



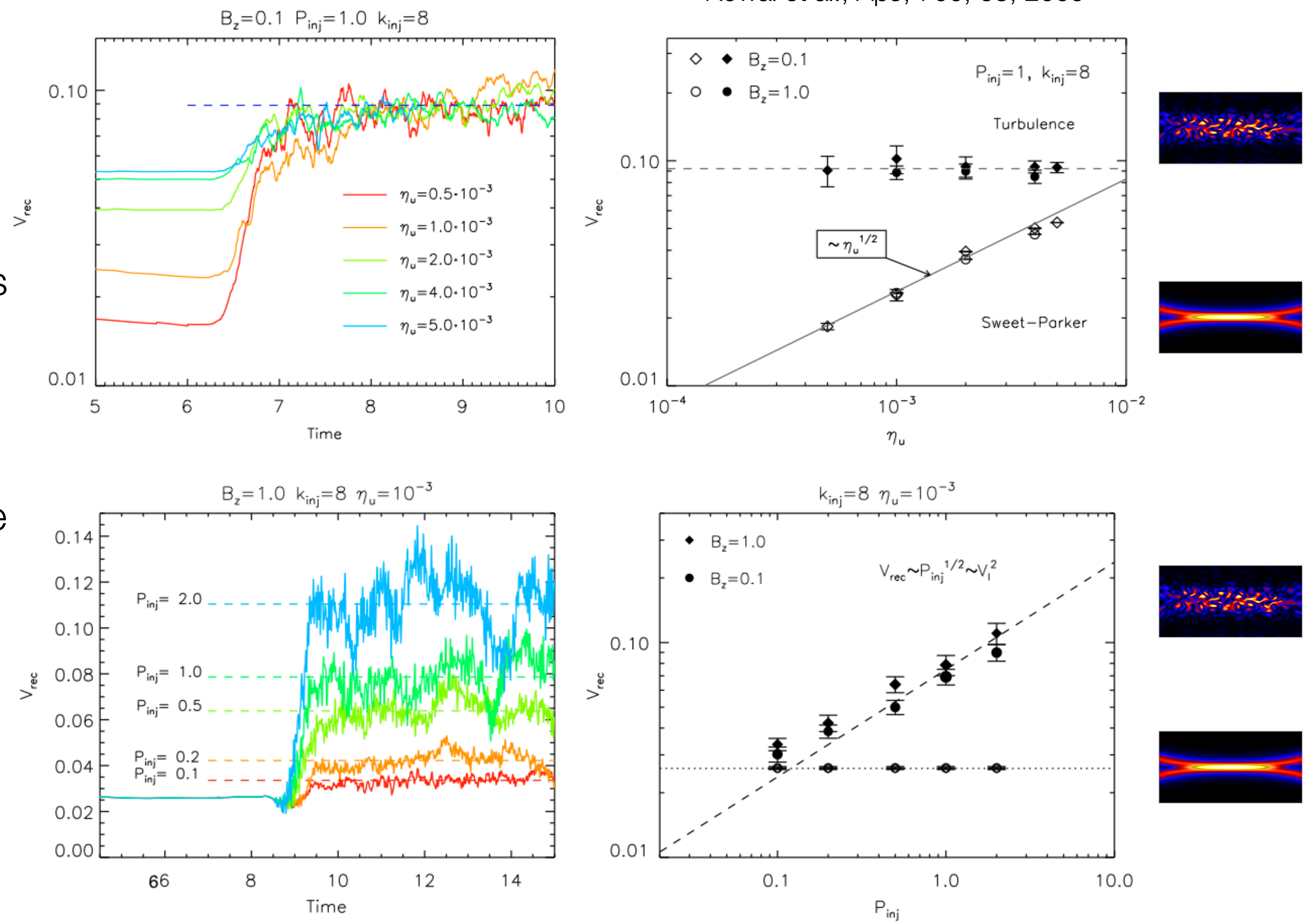




magnetic reconnection @ heliotail

- verification of Lazarian & Vishniac 1999 with numerical calculations
- reconnection speed does not depend on resistivity
- reconnection speed increases with turbulence injection power
- reconnection speed ~ local turbulent velocity

Kowal et al., ApJ, 700, 63, 2009



acceleration in reconnection regions

- first order Fermi acceleration from volume-filling magnetic reconnection

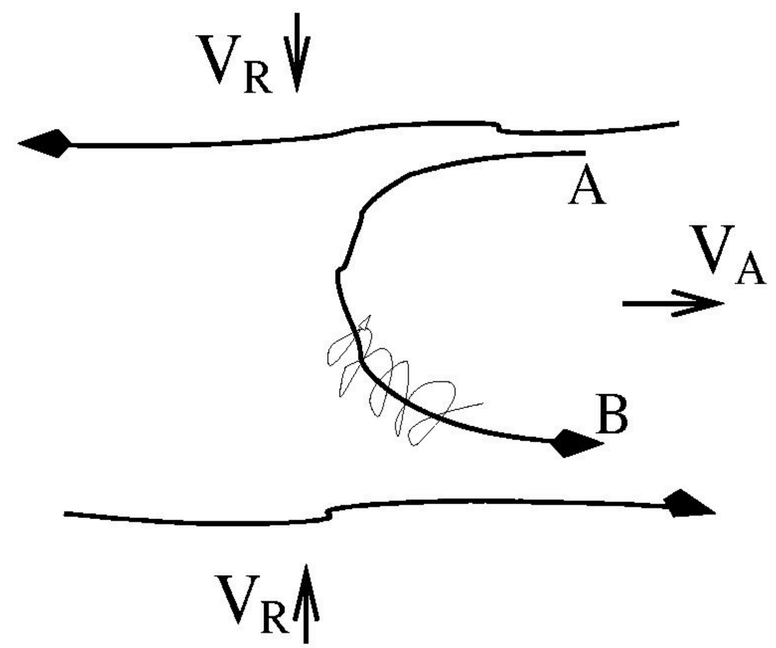
- magnetic mirror @ reconnection as site of acceleration

$$N(E)dE \sim E^{-5/2}dE$$

- magnetic tubes contraction leads to increase of particle energy as long as they are within the contracting magnetic loop

$$E_{max} \approx 10^{13}\ eV \cdot \left(\frac{B}{1\ \mu G}\right) \cdot \left(\frac{L_{zone}}{134\ AU}\right)$$

de Gouveia Dal Pino & Lazarian, 2003



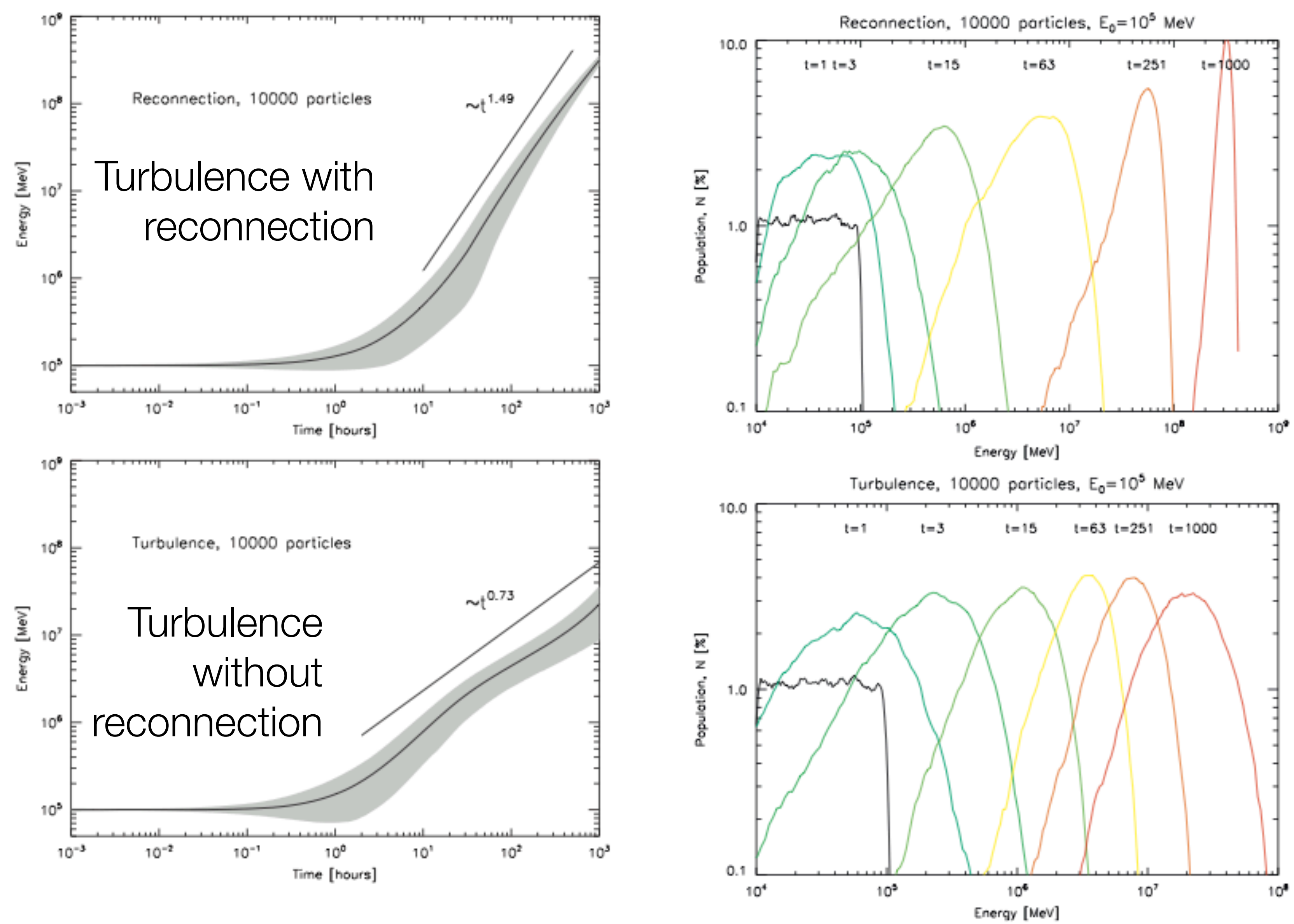
application to pulsars, microquasars, solar flares acceleration

de Gouveia Dal Pino & Lazarian, 2000, 2003, 2005
Lazarian, 2005

acceleration in weakly stochastic reconnection regions

Lazarian et al., Pl. and Sp. Sci. 2010

- verification of Lazarian & Vishniac 1999 with numerical calculations
- fast reconnection induces acceleration of cosmic rays



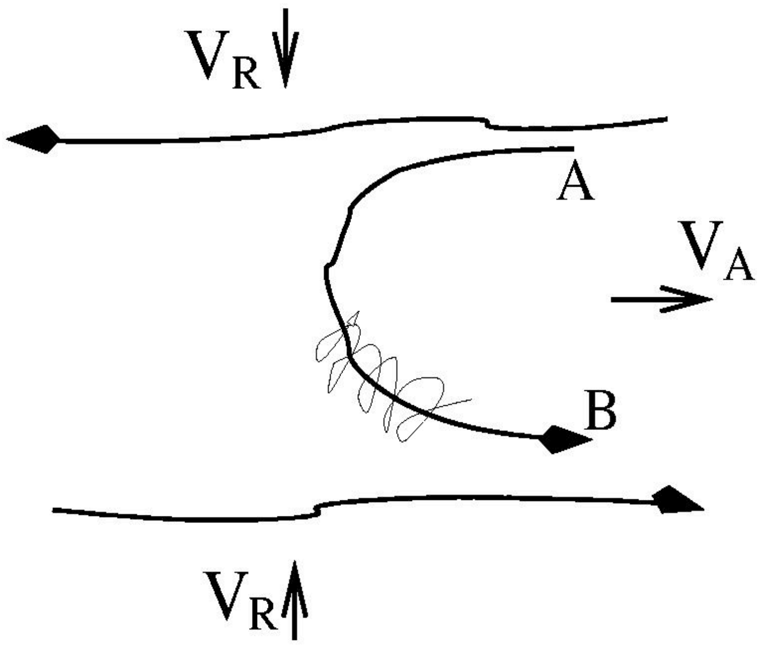
acceleration in reconnection regions

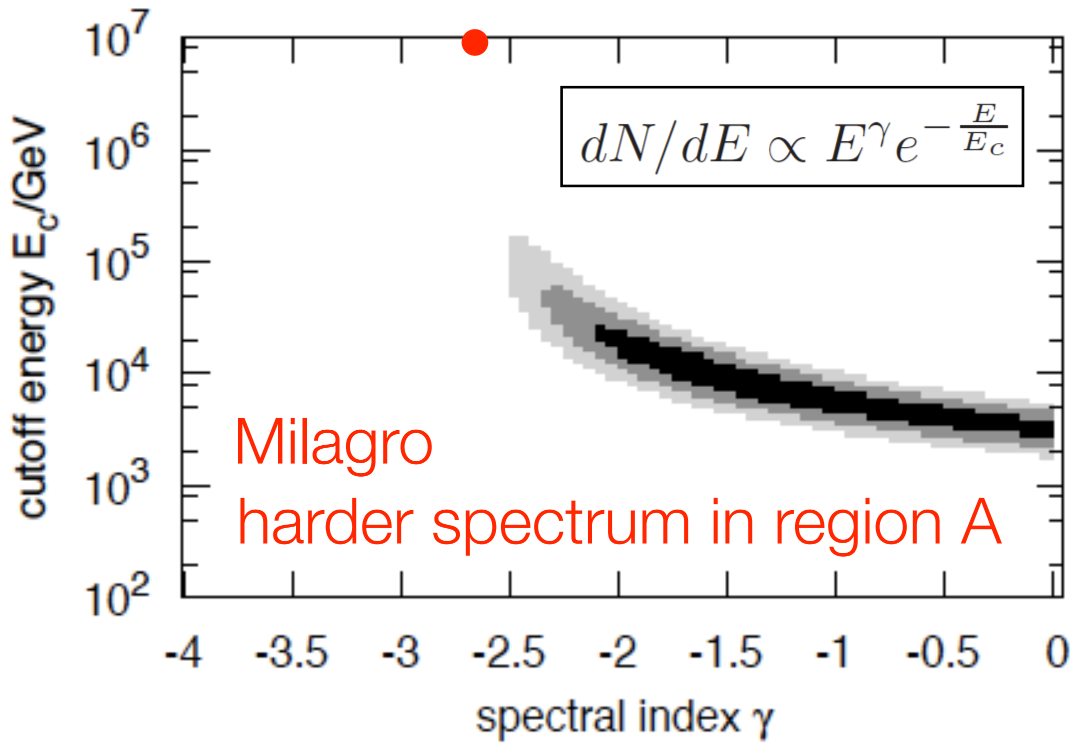
$$N(E)dE \sim E^{-5/2}dE$$

- harder spectrum if back reaction of accelerated particle

$$E_{max} \approx 10^{13}\ eV \cdot \left(\frac{B}{1\ \mu G}\right) \cdot \left(\frac{L_{zone}}{134\ AU}\right)$$

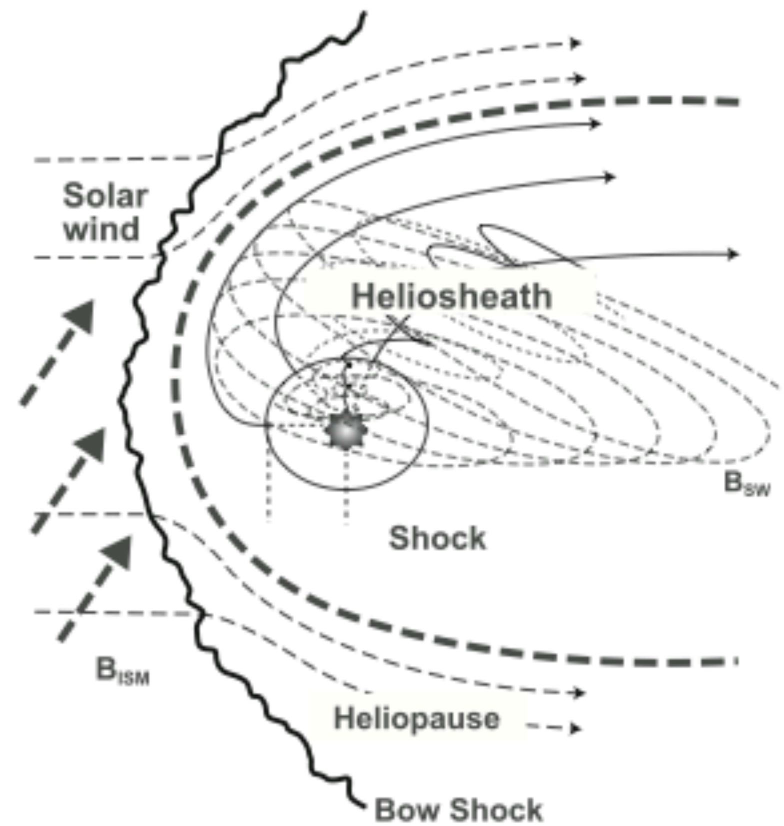
- solar wind < 450 km/sec
- $E_{max}(1\ \mu G) < 70$ TeV
- unlikely to expect energies > 10 TeV





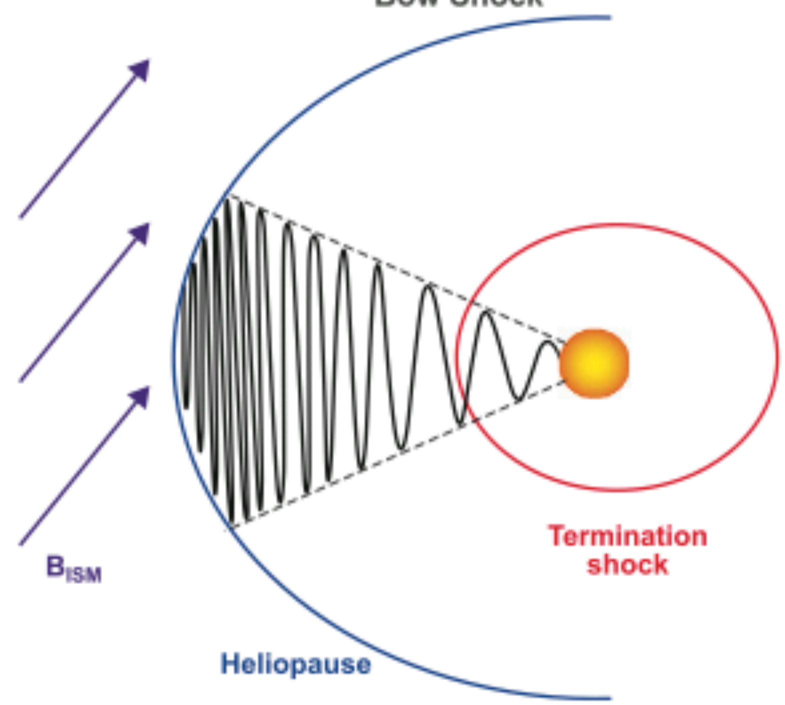
application on anomalous cosmic rays

Lazarian & Opher, ApJ 703, 8, 2009



- magnetic field reversals from Sun's rotation compress at the heliopause
- reconnection and acceleration induced in the heliosheath closer to the heliopause
- Voyager did not observe ACR passed the termination shock
- other models available as well

Drake et al., ApJ, 709, 963, 2010



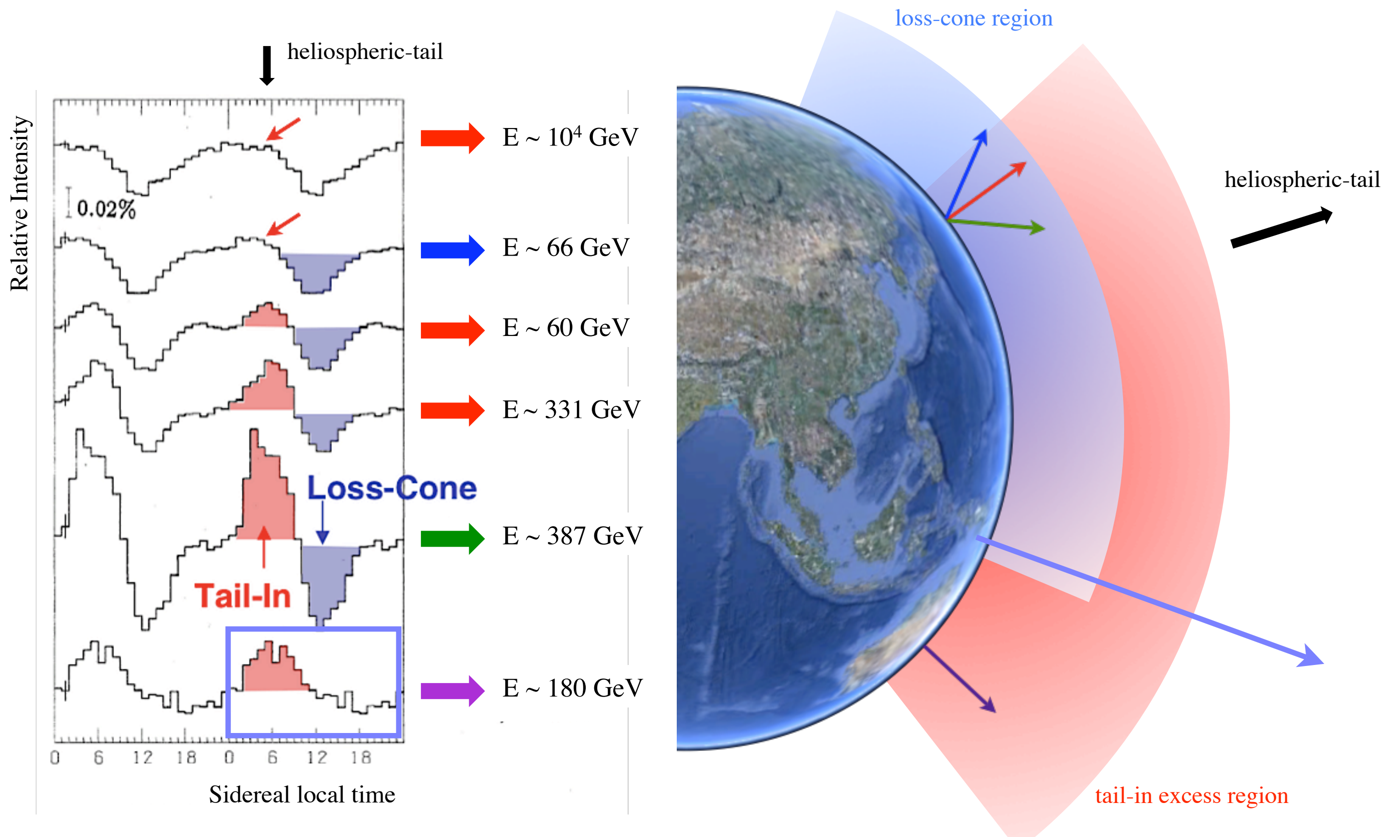
conclusions

- broad tail-in excess of **sub-TeV** cosmic rays and localized excess of **multi-TeV** cosmic rays from the direction of the heliotail could have a common origin
- 1^{st} order Fermi acceleration in magnetic reconnection regions in the heliotail
- HE cosmic rays excess related to reconnection site - LE cosmic rays smeared by scattering
- no need to tune interstellar medium properties

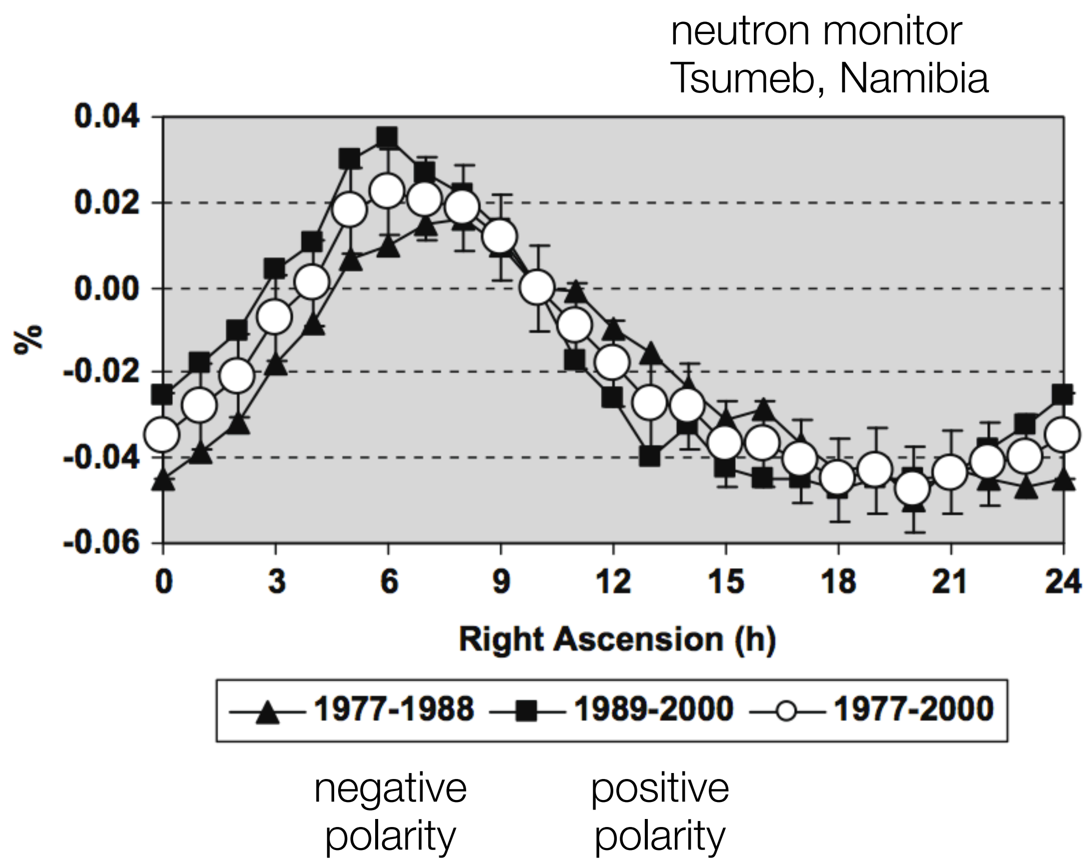
- numerical calculations to verify whether magnetic reconnection regions in the heliotail may be site of efficient acceleration
- model of acceleration in stochastic reconnection regions applied to other astrophysical systems

back up slides

origin of small scale anisotropy : heliospheric tail



Nagashima et al., J. Geophys. Res., Vol 103, No. A8, Pag. 17,429 (1998)

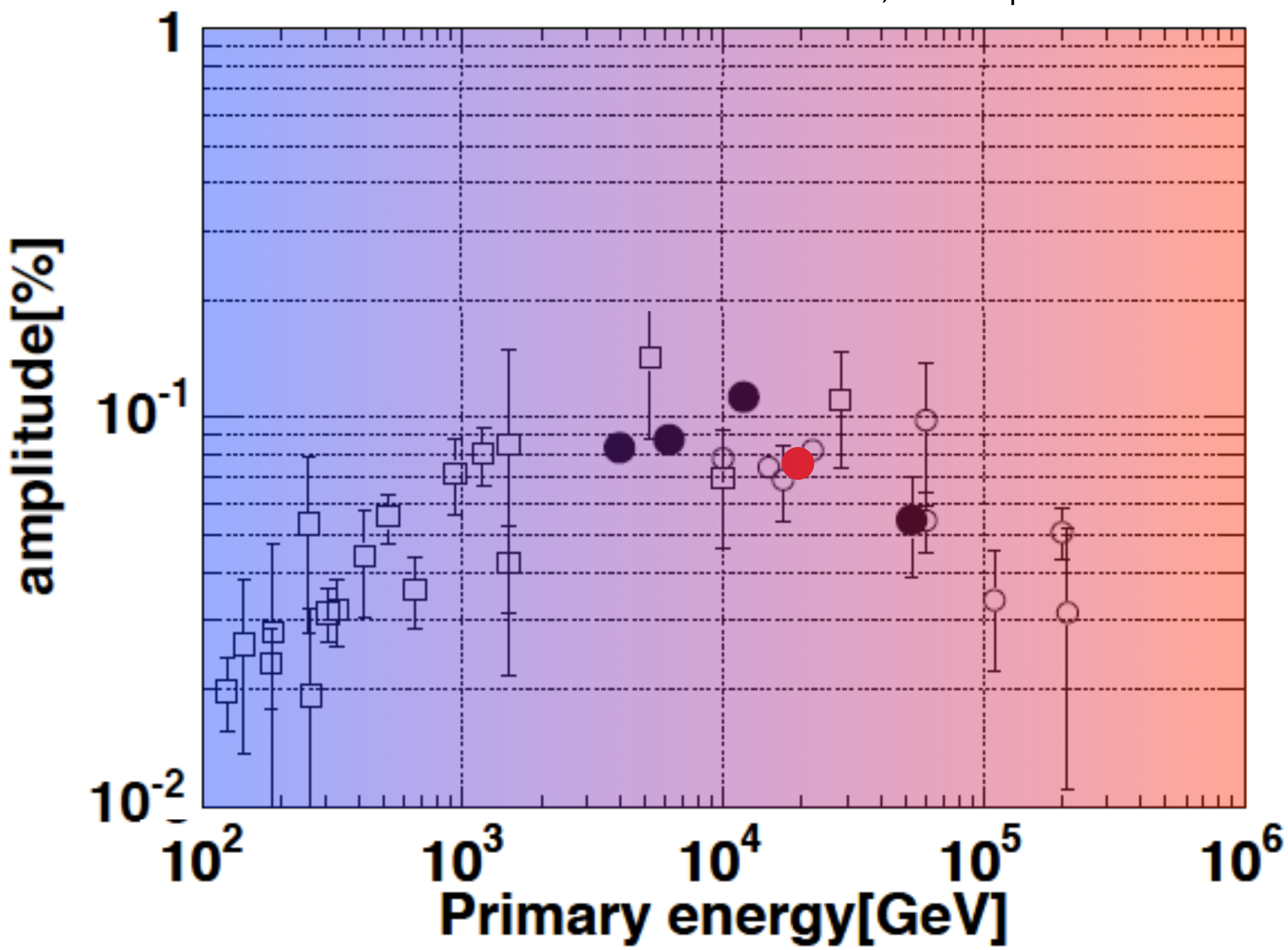


Karapetyan, Astrop. Phys., 33, 146, 2010

- sub-TeV cosmic ray tail-in excess by some unknown asymmetry caused by the heliotail
- solar magnetic field reversal should affect galactic anisotropy
- origin of excess is “heliospheric”

anisotropy vs energy : probing different causes

Amenomori et al., astro-ph/0505114



					(3 μG)
$3\cdot10^{-5}$	$3\cdot10^{-4}$	$3\cdot10^{-3}$	$3\cdot10^{-2}$	0.3	gyro-radius (pc)
7	70	700	7,000	70,000	gyro-radius (AU)

tail-in + galactic ← heliospheric influence   galactic influence →