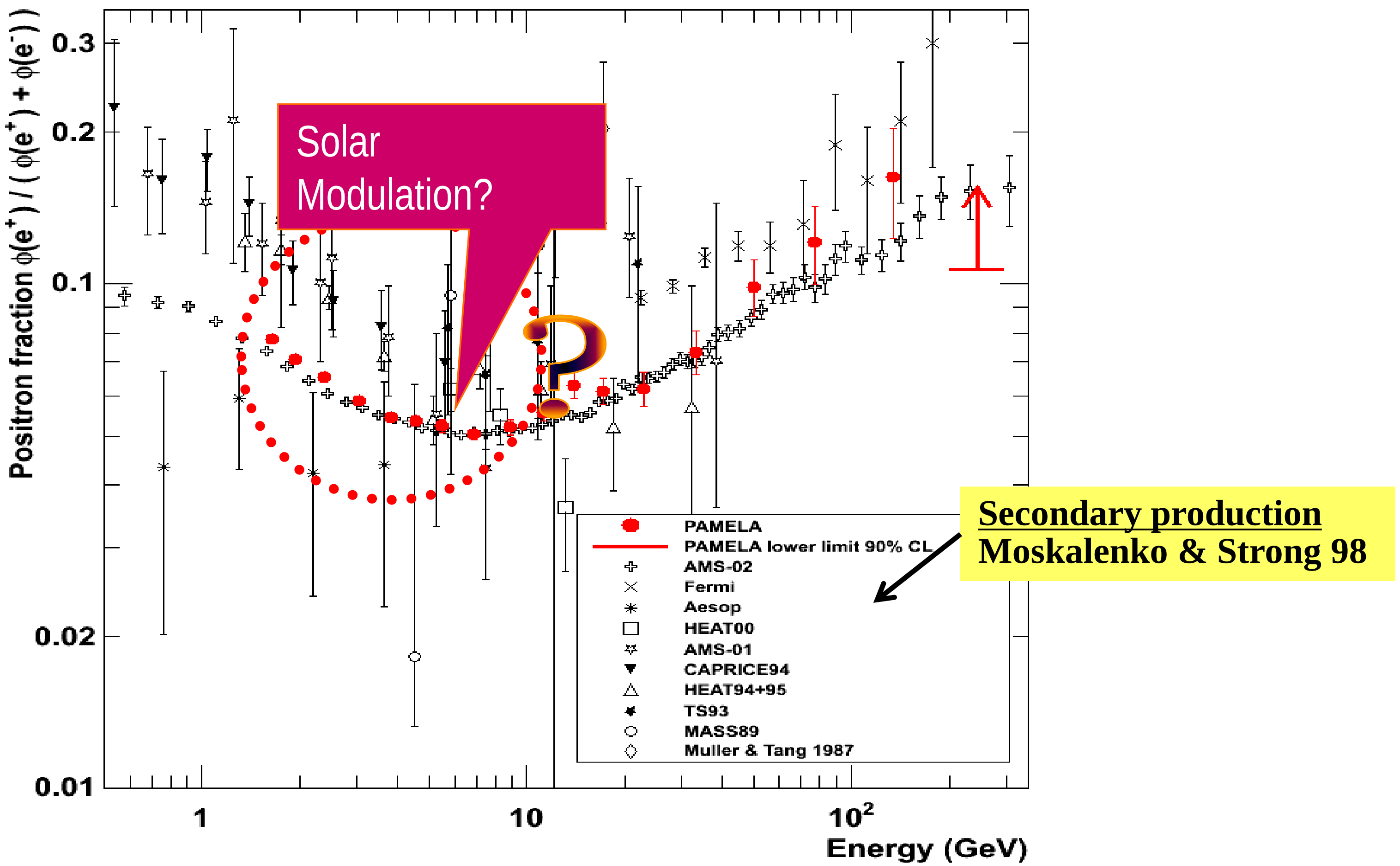
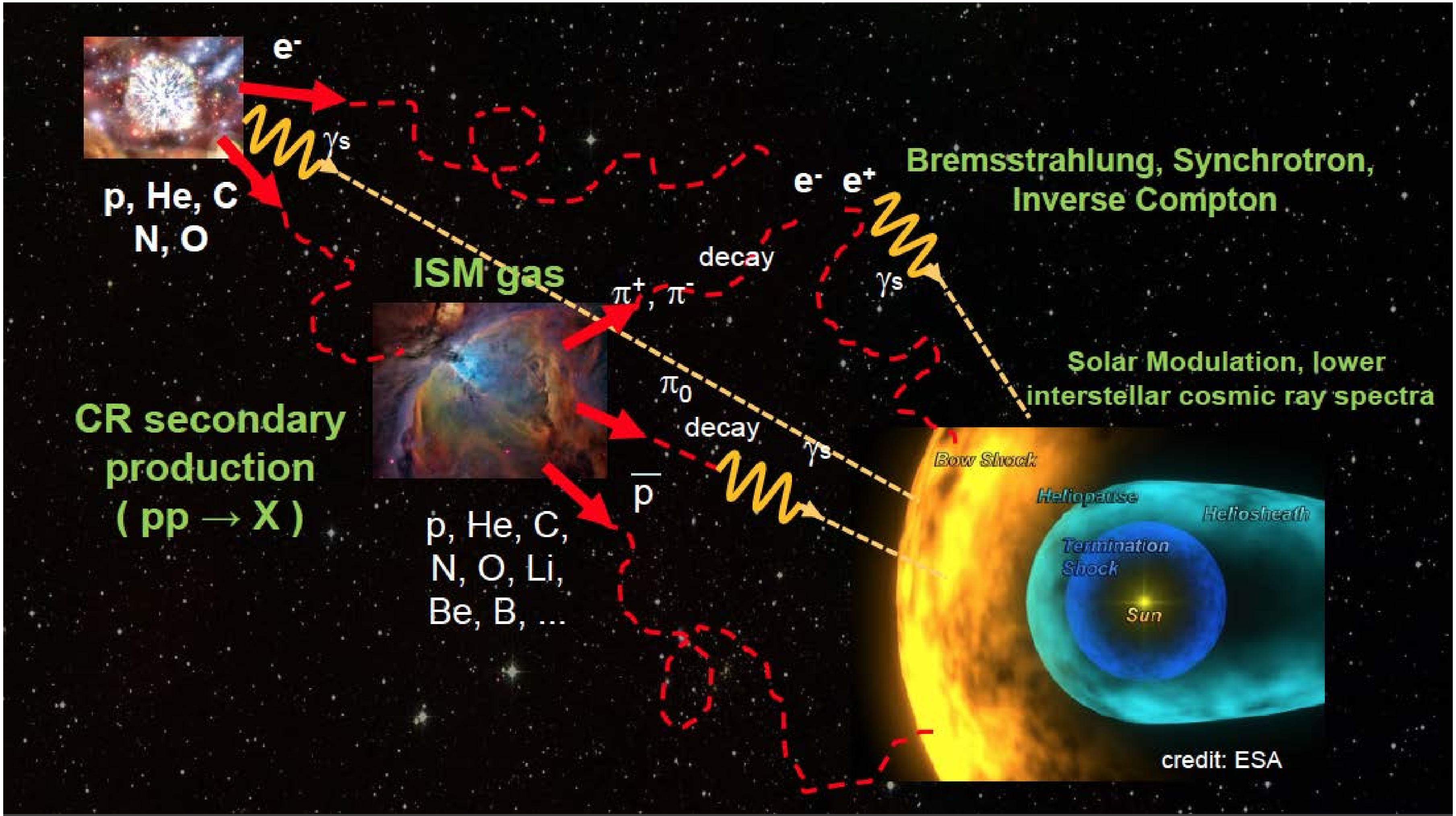
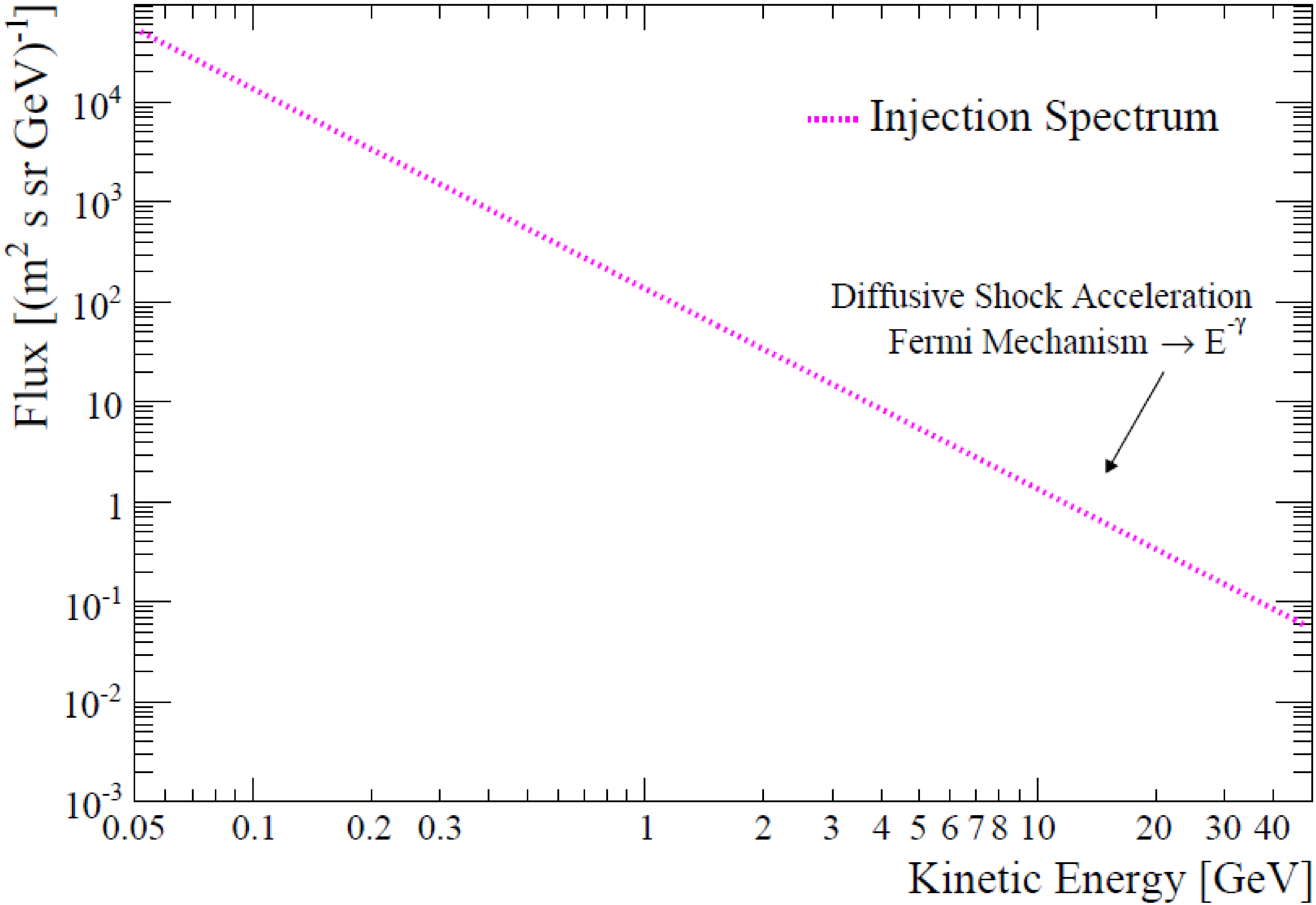
Positron to Electron Fraction



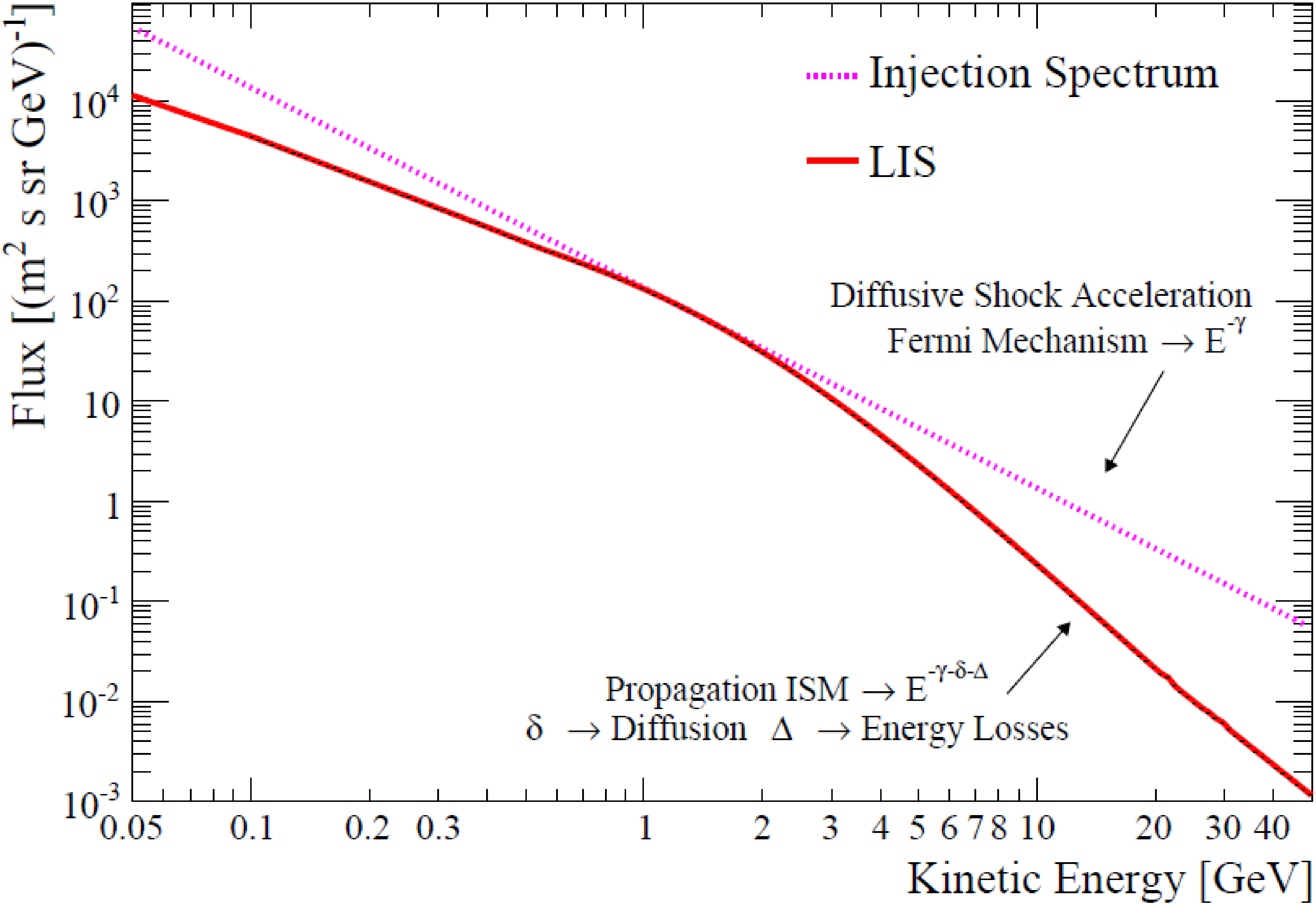
Adriani et al, Astropart. Phys. 34 (2010) 1;
arXiv:1001.3522 [astro-ph.HE]



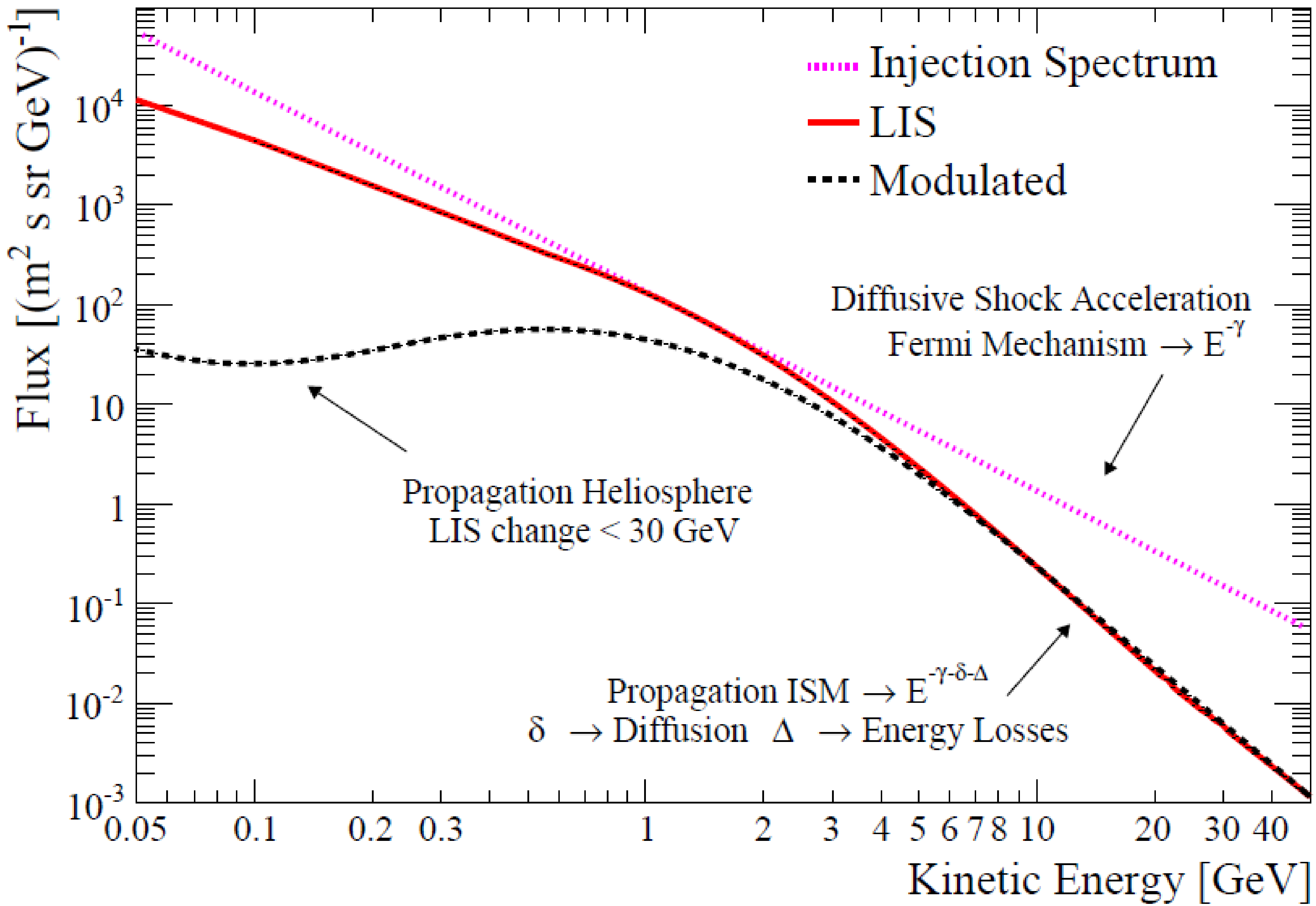
Cosmic rays in the heliosphere



Flux [(m^2 s sr GeV)$^{-1}$]
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
Injection Spectrum
Diffusive Shock Acceleration
Fermi Mechanism $\rightarrow E^{-\gamma}$
0.05
0.1
0.2
0.3
1
2
3
4
5
6
7
8
10
20
30
40
Kinetic Energy [GeV]

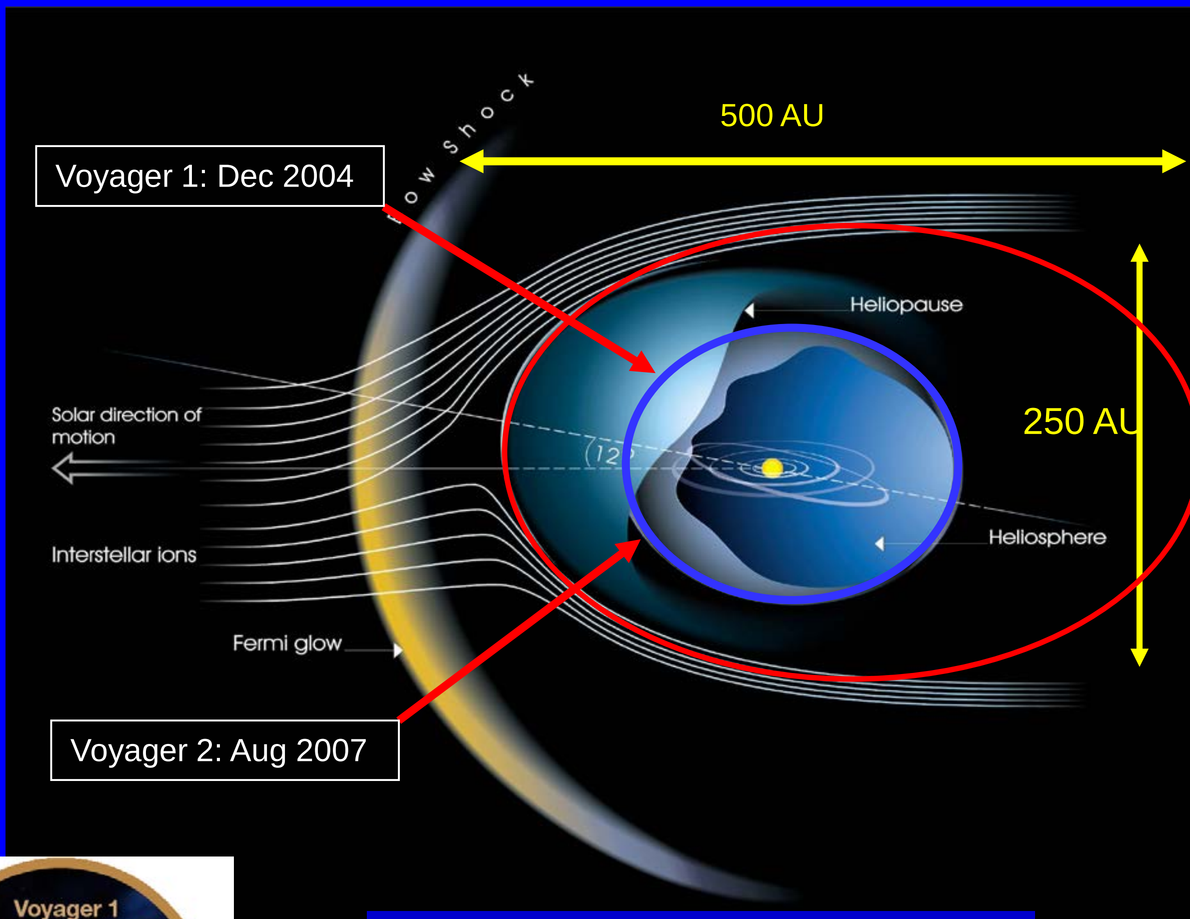


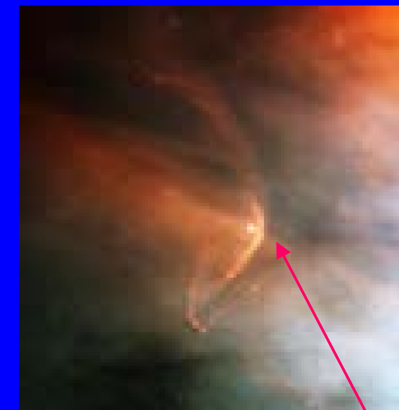
Flux [(m² s sr GeV)⁻¹]
10⁴
10³
10²
10
1
10⁻¹
10⁻²
10⁻³
Injection Spectrum
LIS
Diffusive Shock Acceleration
Fermi Mechanism → E^-γ
Propagation ISM → E^-γ-δ-Δ
δ → Diffusion Δ → Energy Losses
0.05
0.1
0.2
0.3
1
2
3
4
5
6
7
8
10
20
30
40
Kinetic Energy [GeV]



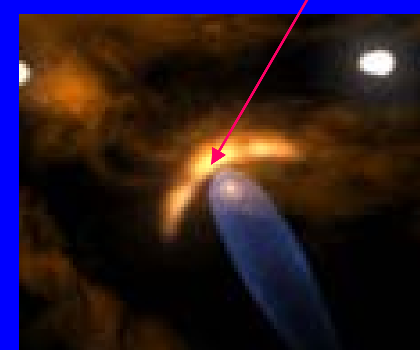
Flux [(m² s sr GeV)⁻¹]
Injection Spectrum
LIS
Modulated
Diffusive Shock Acceleration
Fermi Mechanism → E^-γ
Propagation Heliosphere
LIS change < 30 GeV
Propagation ISM → E^-γ-δ-Δ
δ → Diffusion Δ → Energy Losses
Kinetic Energy [GeV]

Heliospace: The Heliosphere





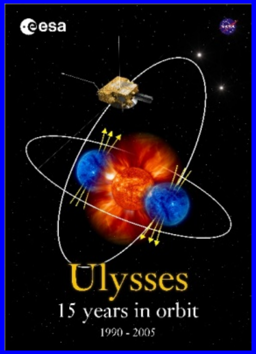
Bow Shocks

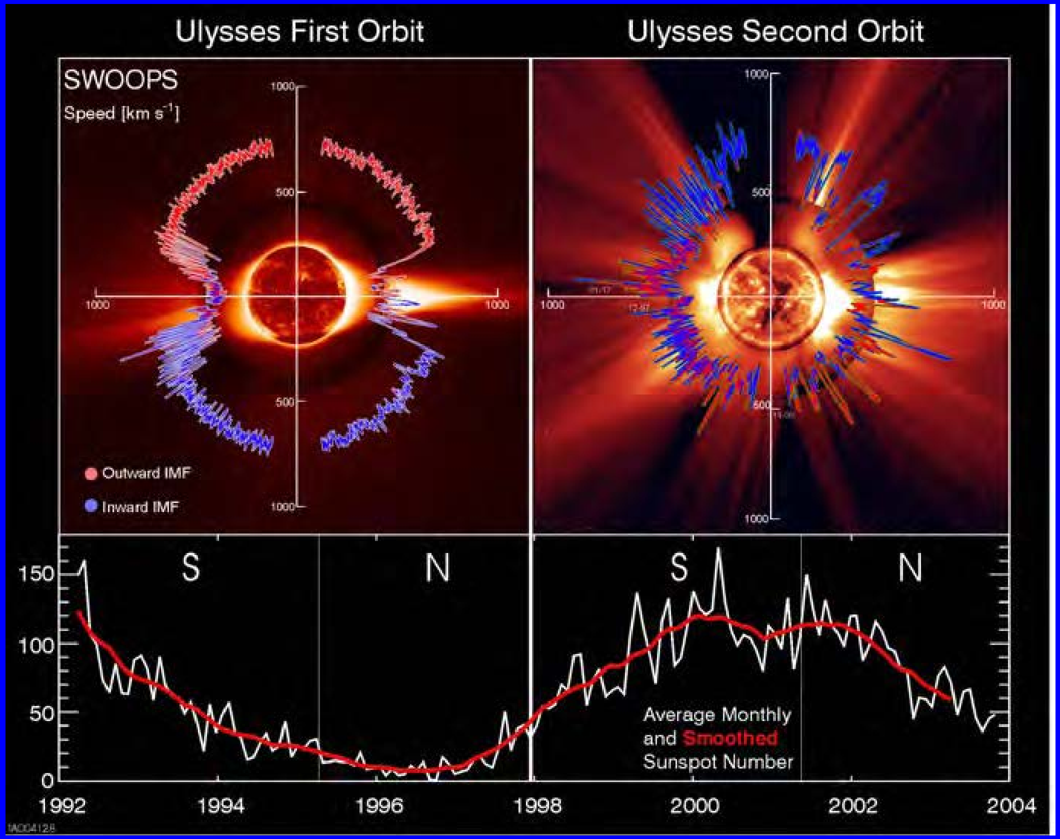


- Launched in 1977
- Voyager 1: ~ 121 AU
- Voyager 2: ~ 99 AU

Cortesy of M. Potgieter

The Solar Wind

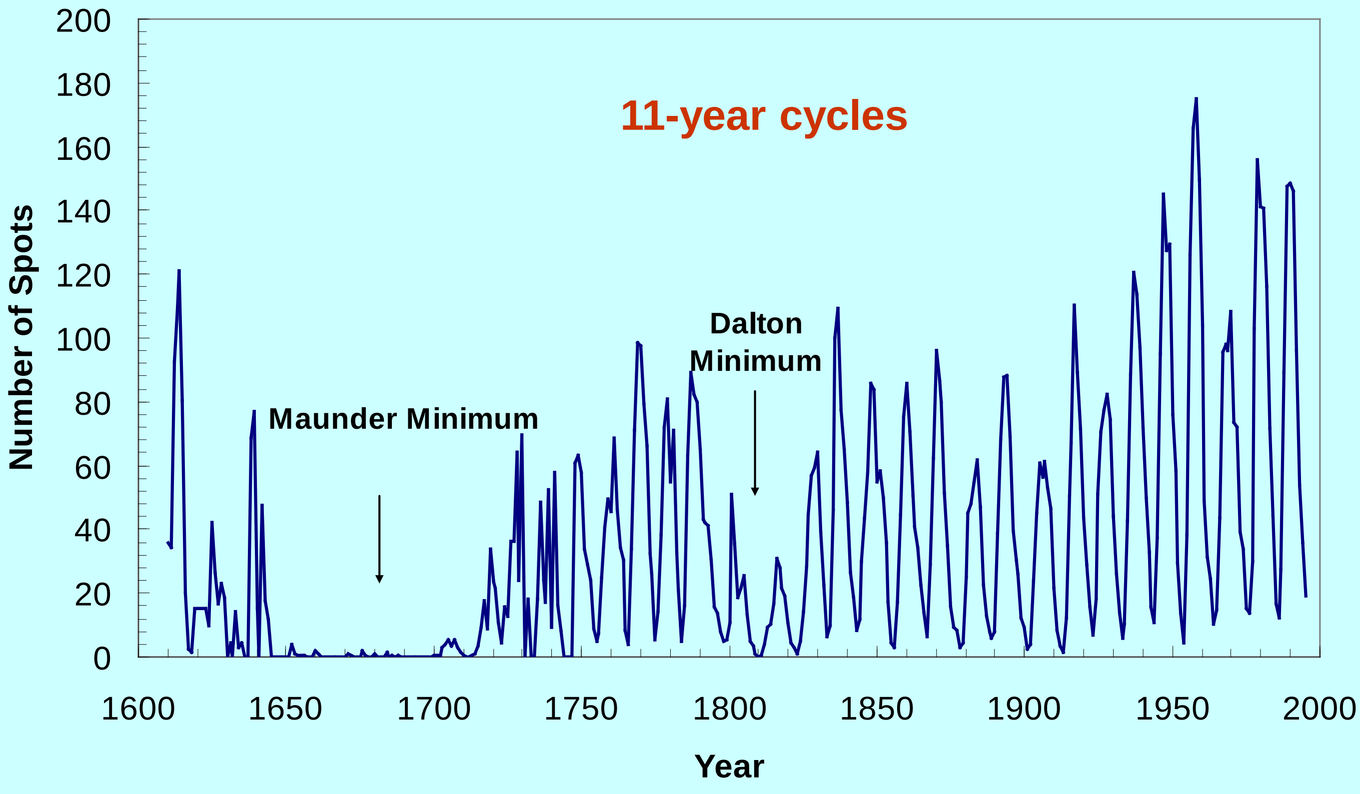




Strong latitude dependence at solar minimum

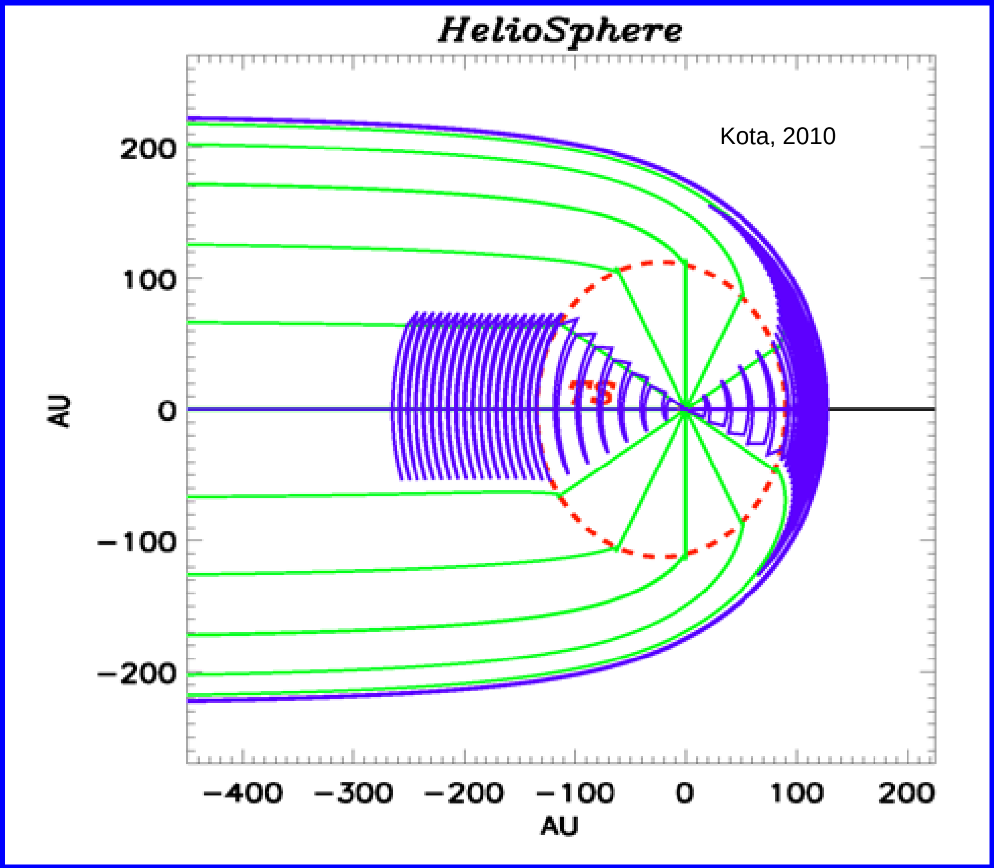
Cortesy of M. Potgieter

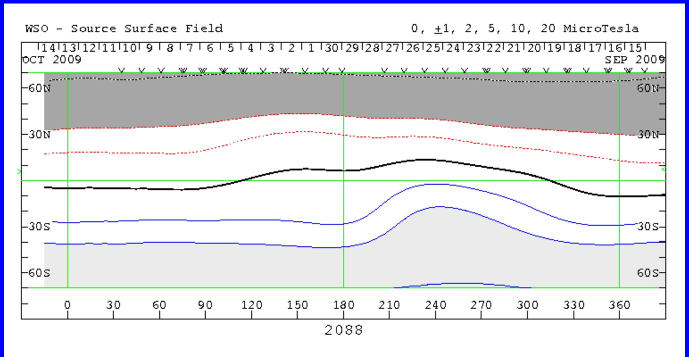
Solar Activity and Sunspot Numbers

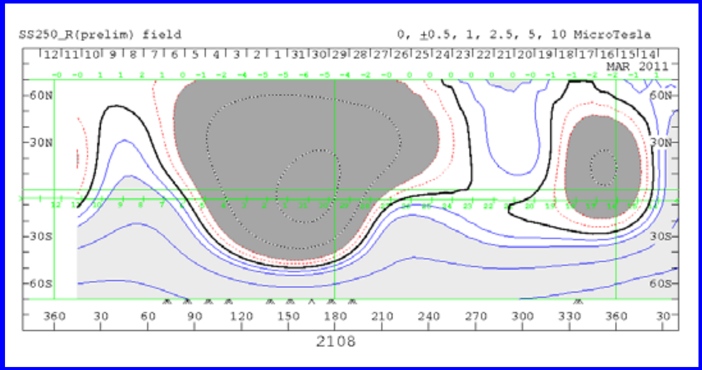


Cortesy of M. Potgieter

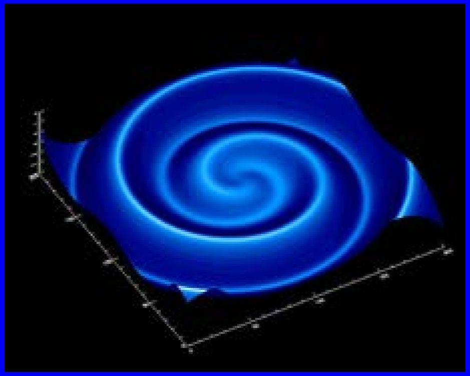
Wavy Heliospheric Current Sheet







Conceptual wavy HCS



Cortesy of M. Potgieter

Magnetic flux freezing

- *The equation of continuity*

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{v}) = 0 ,$$

where ρ is the mass density and $\boldsymbol{v}$ is the velocity at a point in the fluid.

- *Force equation*

$$\rho \frac{\mathrm{d}\boldsymbol{v}}{\mathrm{d}t} = -\nabla p + \boldsymbol{J} \times \boldsymbol{B} + \boldsymbol{F}_{\mathrm{v}} + \rho \boldsymbol{g} ,$$

where p is the pressure, $\boldsymbol{J}$ is the current density, $\boldsymbol{B}$ is the magnetic flux density, $\boldsymbol{F}_{\mathrm{v}}$ represents viscous forces and $\boldsymbol{g}$ is the gravitational acceleration.

Maxwell's equations:

$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t} ,$$

$$\nabla \times \boldsymbol{B} = \mu_0 \boldsymbol{J} ,$$

$$\nabla \cdot \boldsymbol{B} = 0 ,$$

$$\nabla \cdot \boldsymbol{E} = \frac{\rho_{\mathrm{e}}}{\epsilon_0} .$$

Slow varying phenomena -> no displacement term $\partial \boldsymbol{D}/\partial t$, hence no space charge effects

Ohm's law

$$\boldsymbol{J} = \sigma(\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B}) \,,$$

where σ is the electrical conductivity of the plasma. Now substituting for $\boldsymbol{E}$

$$\nabla \times (\boldsymbol{J}/\sigma - \boldsymbol{v} \times \boldsymbol{B}) = -\frac{\partial \boldsymbol{B}}{\partial t} \,.$$

Now, eliminating $\boldsymbol{J}$

$$\nabla \times \left(\frac{\nabla \times \boldsymbol{B}}{\sigma \mu_0} - \boldsymbol{v} \times \boldsymbol{B} \right) = -\frac{\partial \boldsymbol{B}}{\partial t} \,.$$

Therefore,

$$\frac{\partial \boldsymbol{B}}{\partial t} = \nabla \times (\boldsymbol{v} \times \boldsymbol{B}) - \frac{\nabla \times (\nabla \times \boldsymbol{B})}{\sigma \mu_0} \,.$$

We now use the identity $\nabla \times (\nabla \times \boldsymbol{B}) = \nabla(\nabla \cdot \boldsymbol{B}) - \nabla^2 \boldsymbol{B}$. Since $\nabla \cdot \boldsymbol{B}$ is always zero, we find

$$\frac{\partial \boldsymbol{B}}{\partial t} = \nabla \times (\boldsymbol{v} \times \boldsymbol{B}) + \frac{1}{\sigma \mu_0} \nabla^2 \boldsymbol{B} \,.$$

Infinite conductivity $\sigma \to \infty$:

$$\frac{\partial \boldsymbol{B}}{\partial t} = \nabla \times (\boldsymbol{v} \times \boldsymbol{B})\,. \tag{11.47}$$

consider a current loop S in the plasma and the two contributions to changes in the magnetic flux density ϕ through it with time. First, there may be changes in the magnetic flux density due to external causes, and second, there is an induced component of the flux density due to motion of the loop. The first contribution is

$$\int_S \frac{\partial \boldsymbol{B}}{\partial t} \cdot \mathrm{d}\boldsymbol{S}\,. \tag{11.48}$$

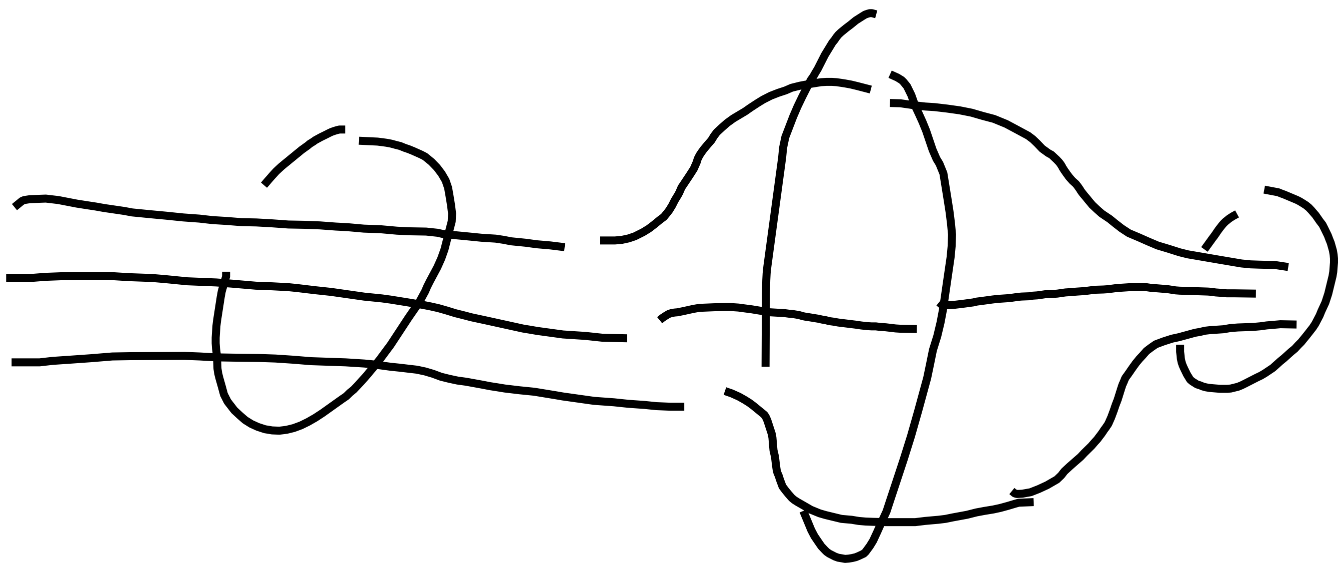
The second contribution results from the fact that, because of the motion of the loop, there is an induced electric field $\boldsymbol{E} = \boldsymbol{v} \times \boldsymbol{B}$. Because $\nabla \times \boldsymbol{E} = -\partial\phi/\partial t$, there is an additional contribution to the total magnetic flux through the loop,

$$-\int_S \nabla \times (\boldsymbol{v} \times \boldsymbol{B}) \cdot \mathrm{d}\boldsymbol{S}\,. \tag{11.49}$$

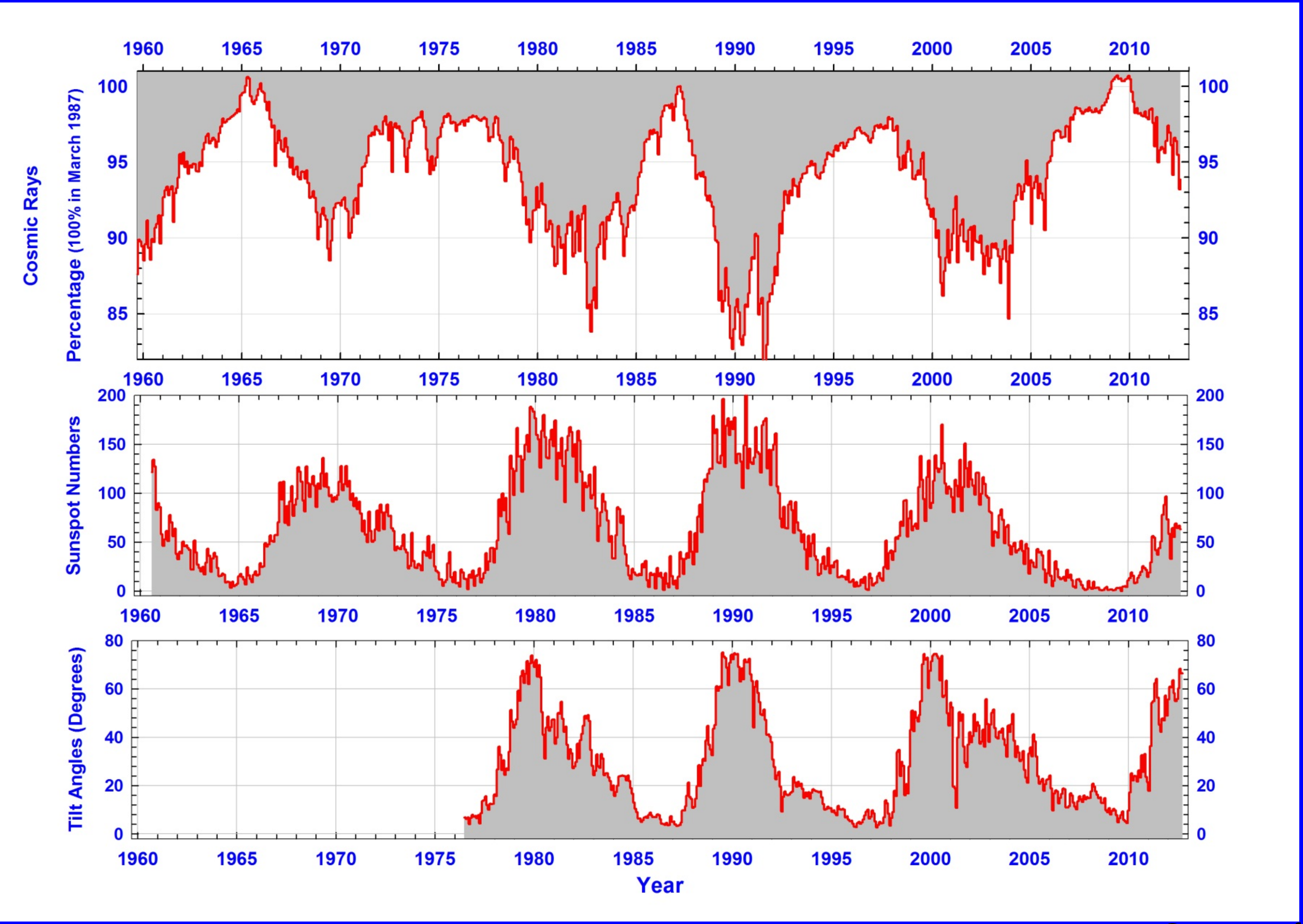
Adding together both contributions, we obtain

$$\begin{aligned}\frac{\mathrm{d}}{\mathrm{d}t}\int_S \boldsymbol{B} \cdot \mathrm{d}\boldsymbol{S} &= \int_S \frac{\partial \boldsymbol{B}}{\partial t} \cdot \mathrm{d}\boldsymbol{S} - \int_S \nabla \times (\boldsymbol{v} \times \boldsymbol{B}) \cdot \mathrm{d}\boldsymbol{S} \\ &= \int_S \left(\frac{\partial \boldsymbol{B}}{\partial t} - \nabla \times (\boldsymbol{v} \times \boldsymbol{B})\right) \cdot \mathrm{d}\boldsymbol{S} = 0\,,\end{aligned}$$

$$\frac{d}{dt}\int_S \boldsymbol{B}\cdot\boldsymbol{dS} = 0$$

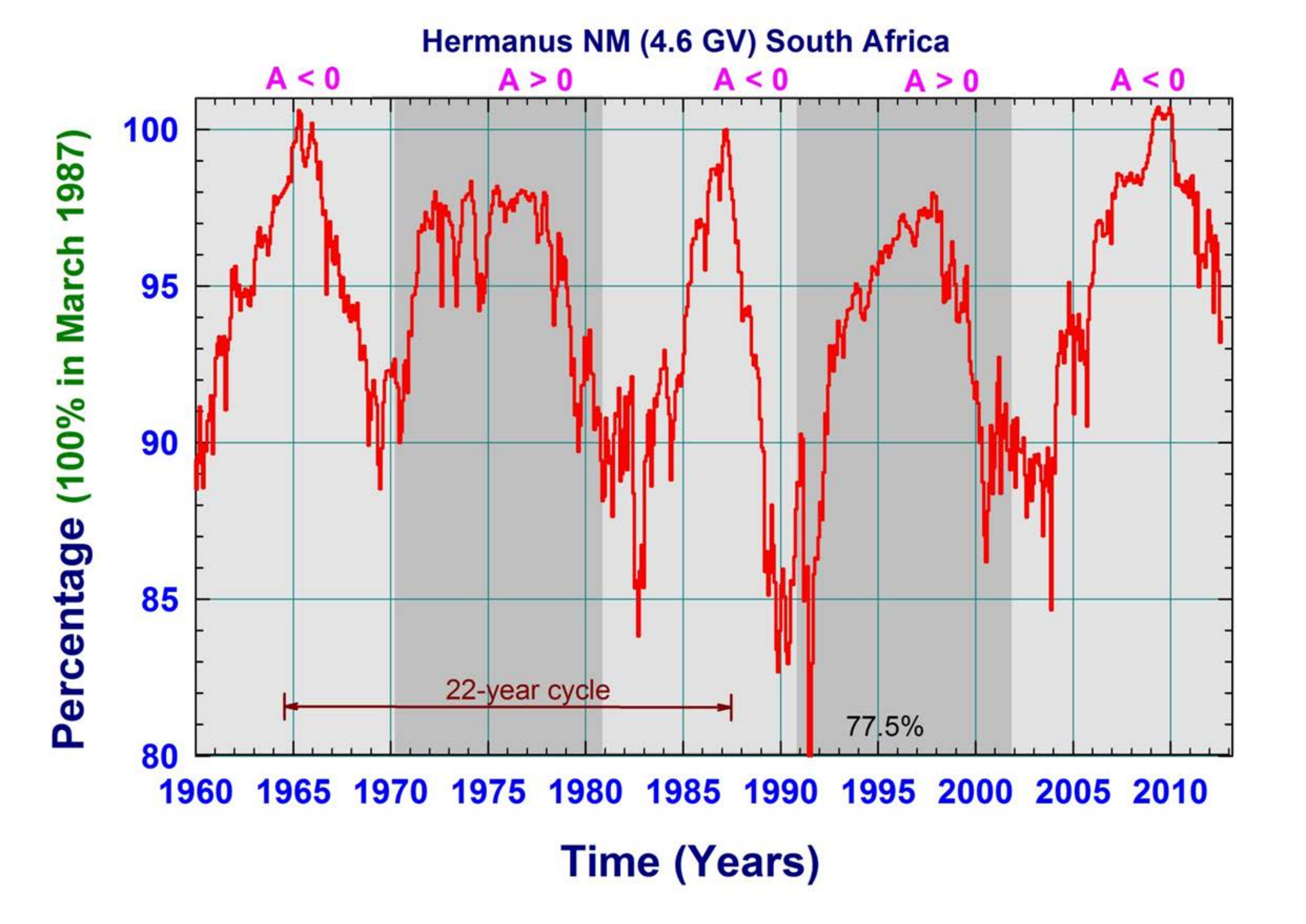


Solar Activity and Cosmic Rays



Cortesy of M. Potgieter

Cosmic rays as indicators of heliospheric conditions
Modulation of galactic CRs at Earth at NM energies (E > 10GV)



Cortesy of M. Potgieter

Transport equation for the transport, modulation and acceleration of cosmic rays in the heliosphere

$$\frac{\partial f}{\partial t} = \nabla \cdot [\mathbf{K} \cdot \nabla f] - \boldsymbol{V} \cdot \nabla f - \langle \boldsymbol{v}_D \rangle \cdot \nabla f + \frac{1}{3}(\nabla \cdot \boldsymbol{V})\frac{\partial f}{\partial \ln p} + Q(r,p,t)$$

Time-dependent, pitch-angle-averaged distribution function

Diffusion

Convection with solar wind

Particle Drifts

Adiabatic energy changes

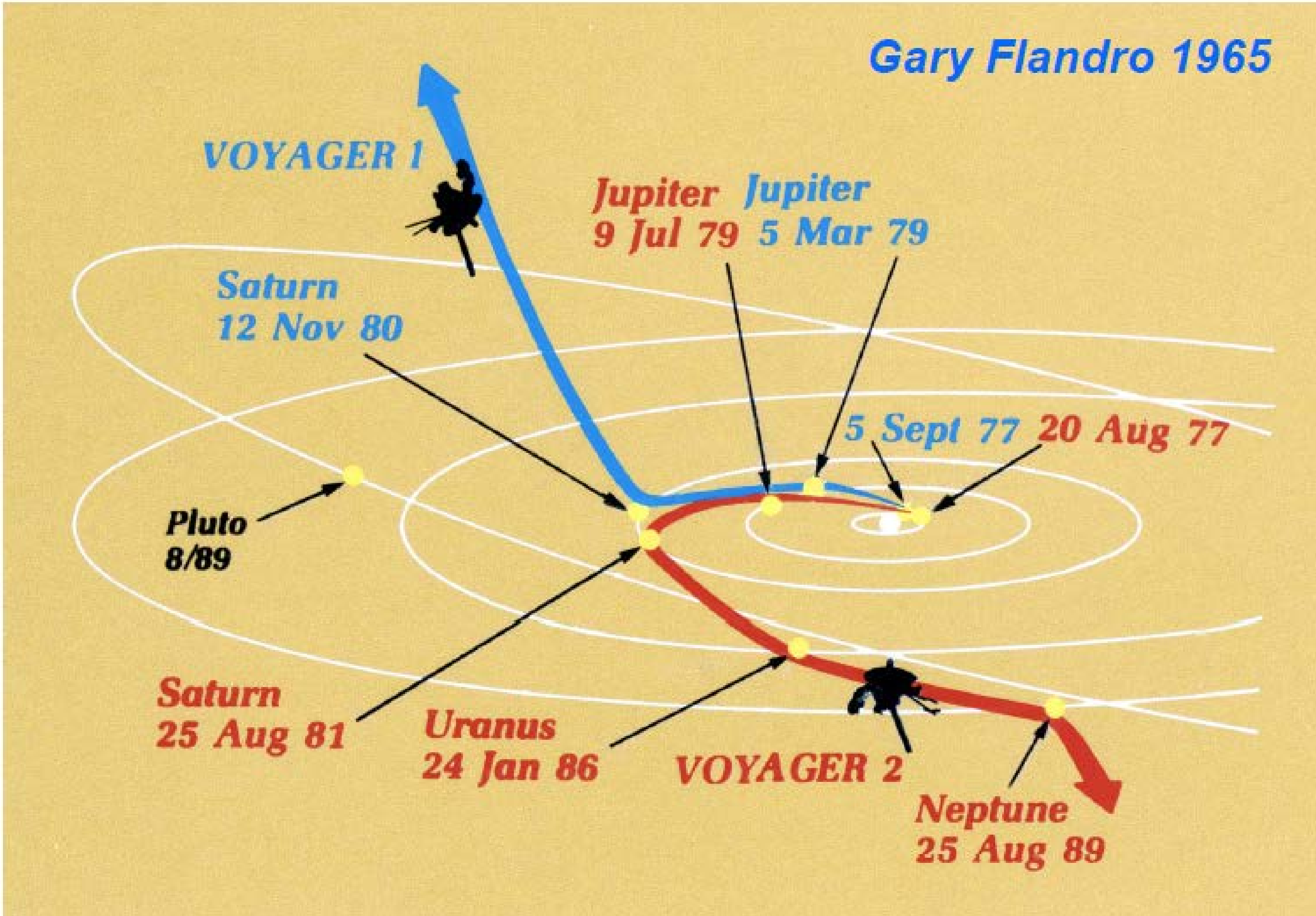
Any local source

$$\ldots = \ldots + \frac{1}{p^2}\frac{\partial}{\partial p}\left(p^2 D_{pp}\frac{\partial f}{\partial p}\right)$$

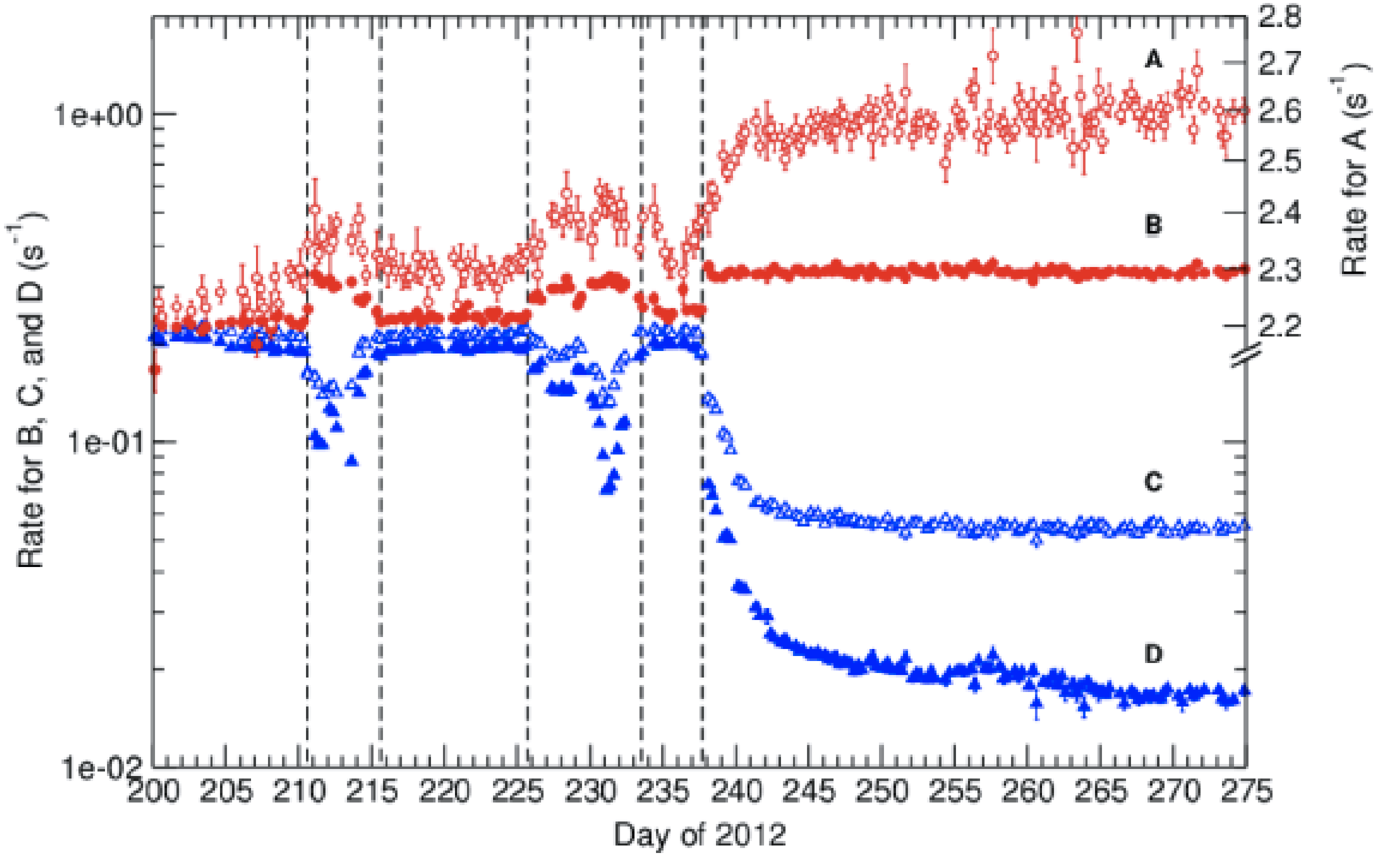
Second order Fermi acceleration

Parker (Planet. Space Science, 13, 9,1965)

Cortesy of M. Potgieter



Gary Flandro 1965
VOYAGER 1
Jupiter
9 Jul 79
Jupiter
5 Mar 79
Saturn
12 Nov 80
5 Sept 77
20 Aug 77
Pluto
8/89
Saturn
25 Aug 81
Uranus
24 Jan 86
VOYAGER 2
Neptune
25 Aug 89



From outside:

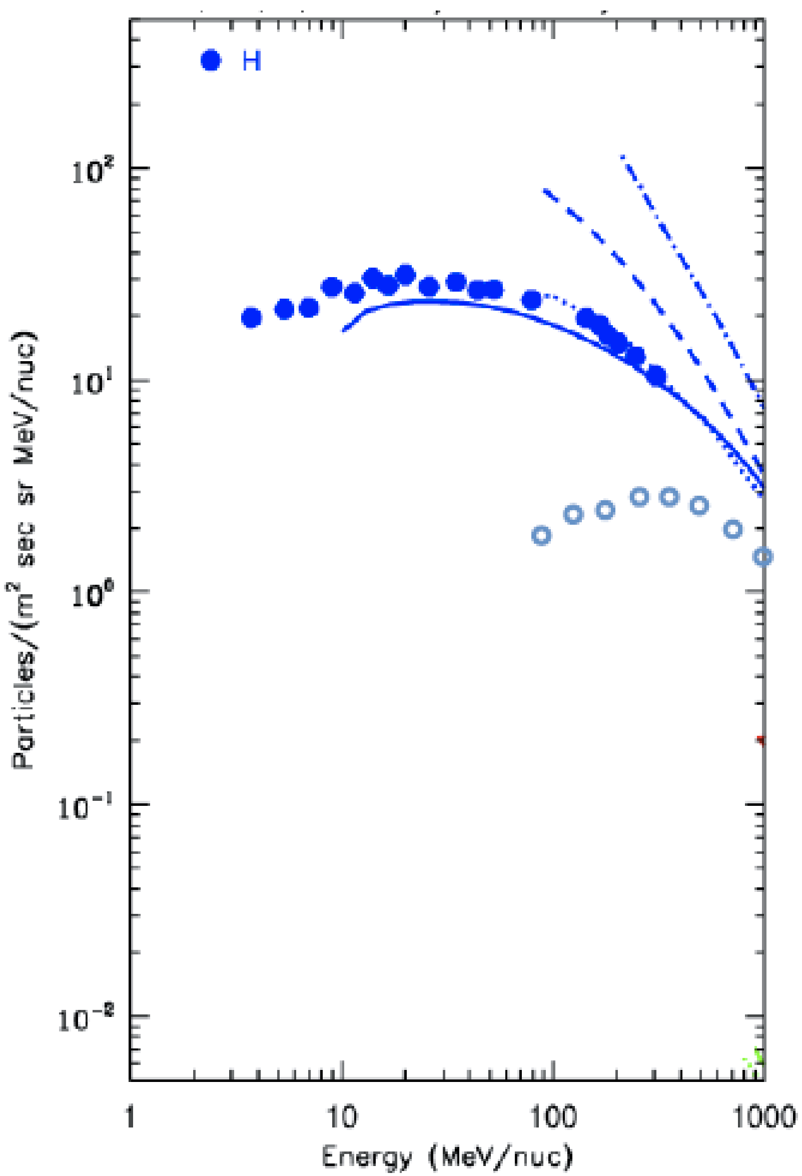
GCR protons
>70 MeV

GCR electrons
7 to ~100 MeV

From inside:

ACR protons
7 to 60 MeV

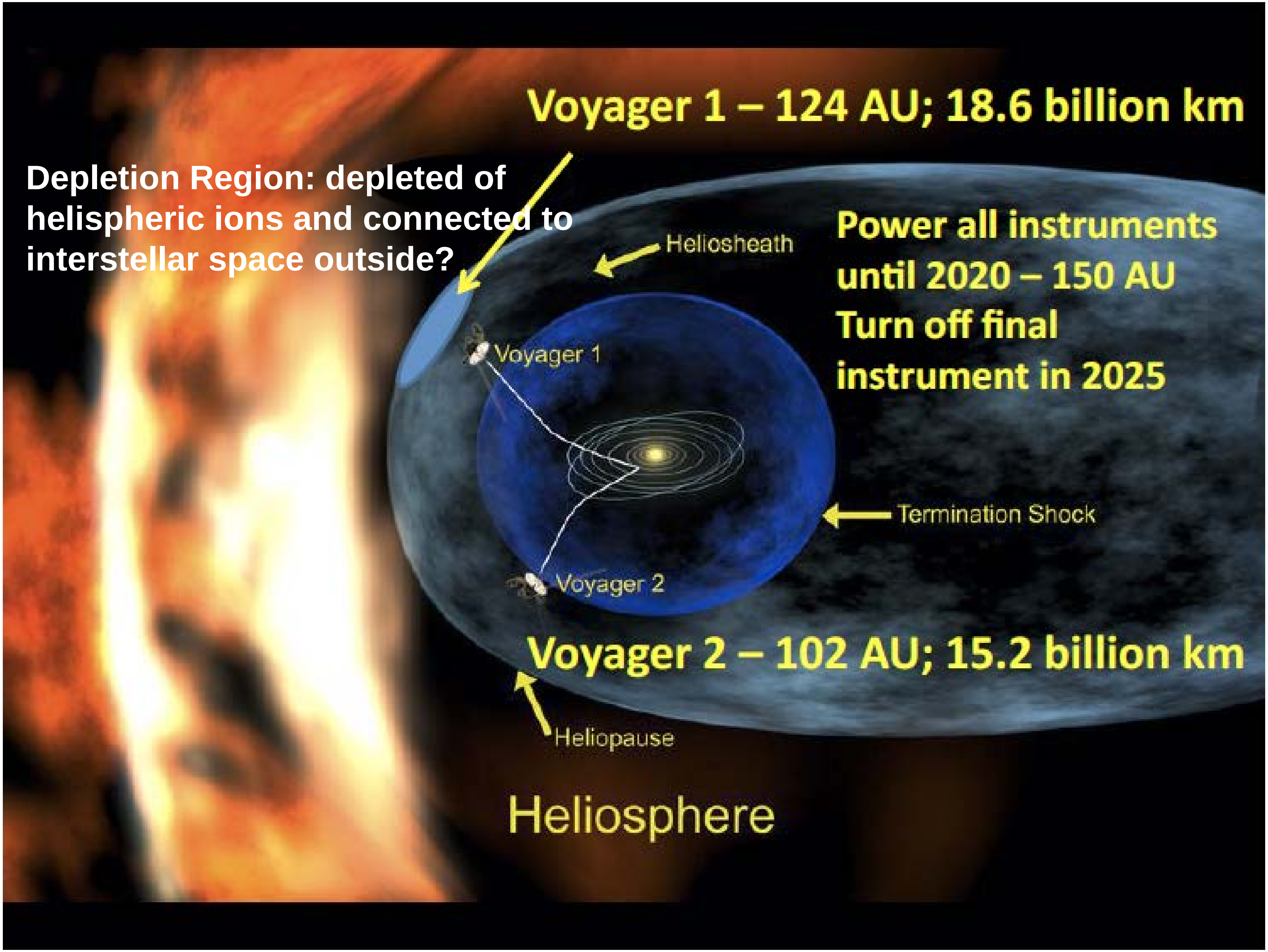
TSPs
0.5 to 30 MeV



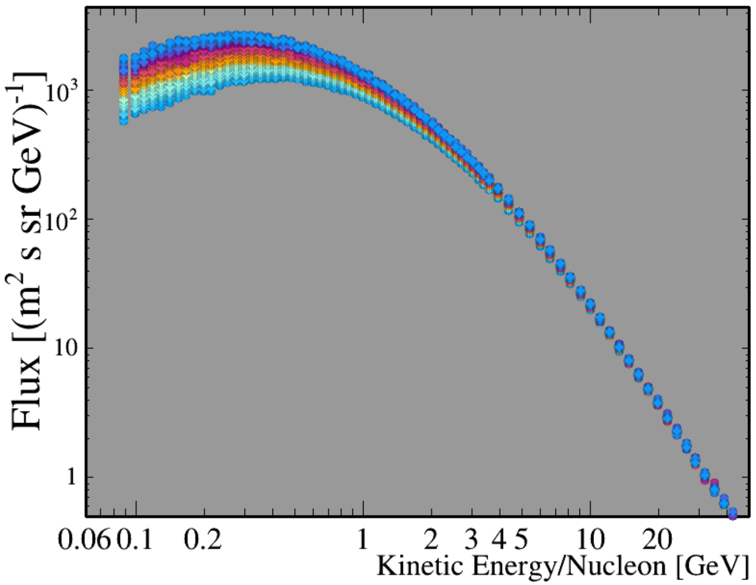
V1 H spectra
2012/342 to 2013/161

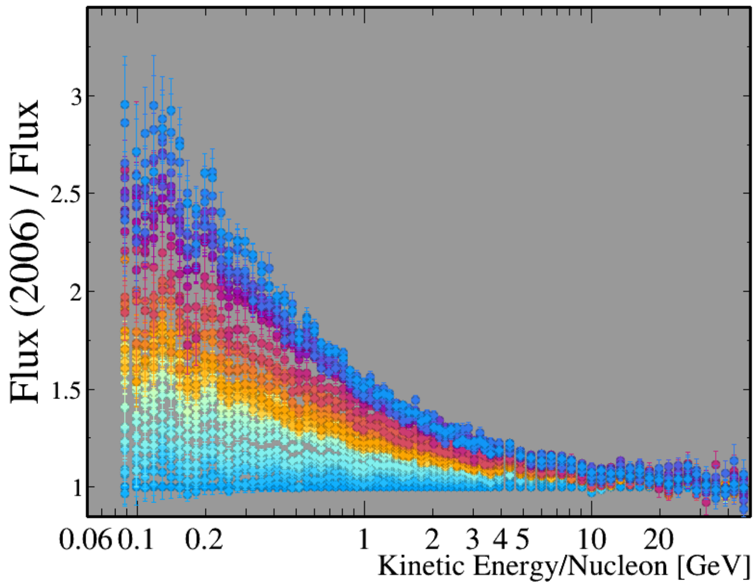
PAMELA H solar minimum spectrum at 1 AU
2009/340 to 2010/1

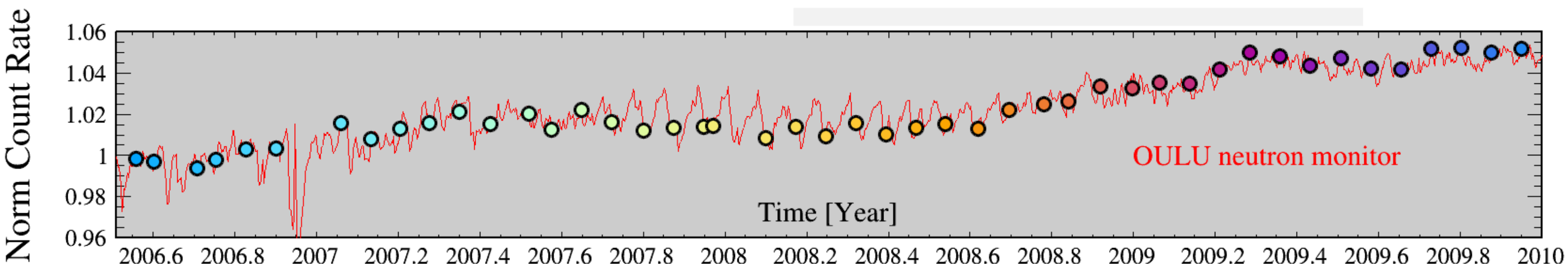
GALPROP
tuned to ACE by Lave et al ApJ 2013
and Poster 793 (July 7&8)


Voyager 1 – 124 AU; 18.6 billion km
Depletion Region: depleted of helispheric ions and connected to interstellar space outside?
Heliosheath
Power all instruments until 2020 – 150 AU
Turn off final instrument in 2025
Voyager 1
Termination Shock
Voyager 2
Voyager 2 – 102 AU; 15.2 billion km
Heliopause
Heliosphere

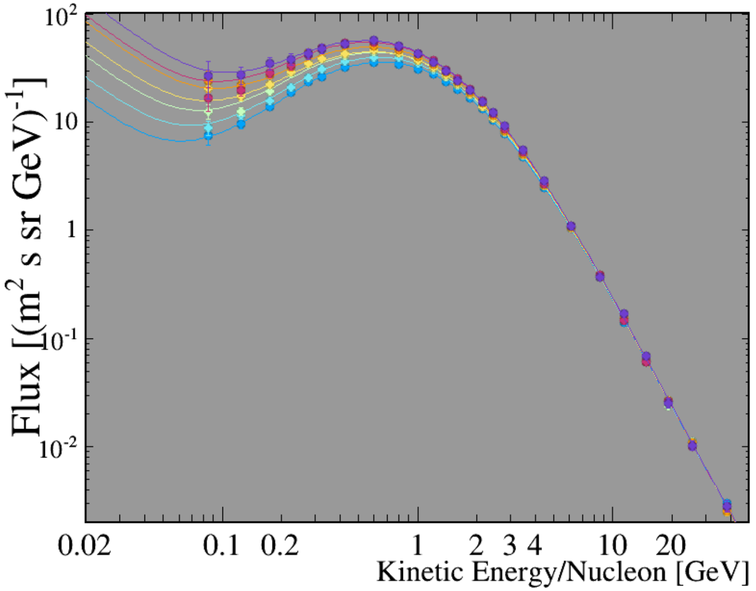
Time dependence - Proton flux

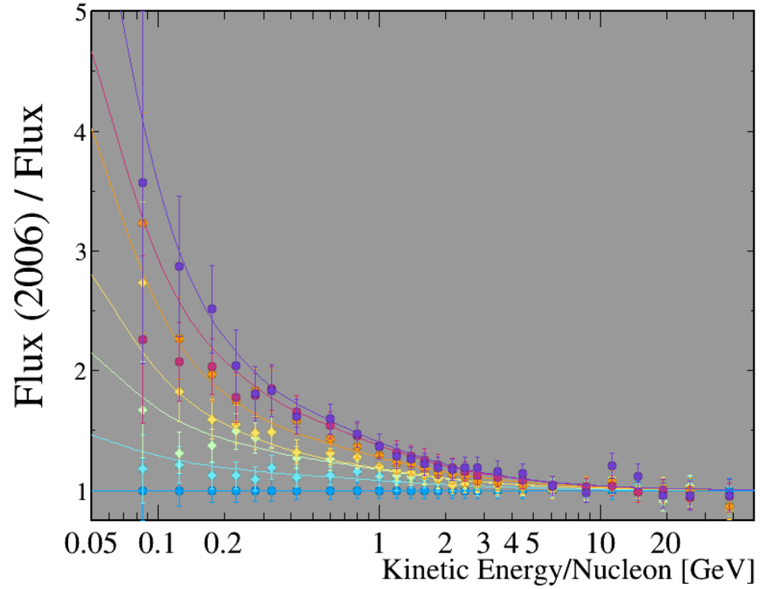


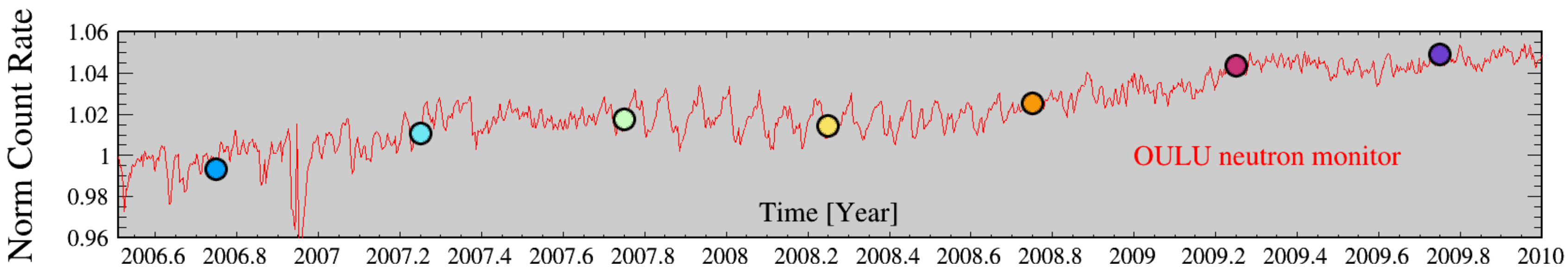




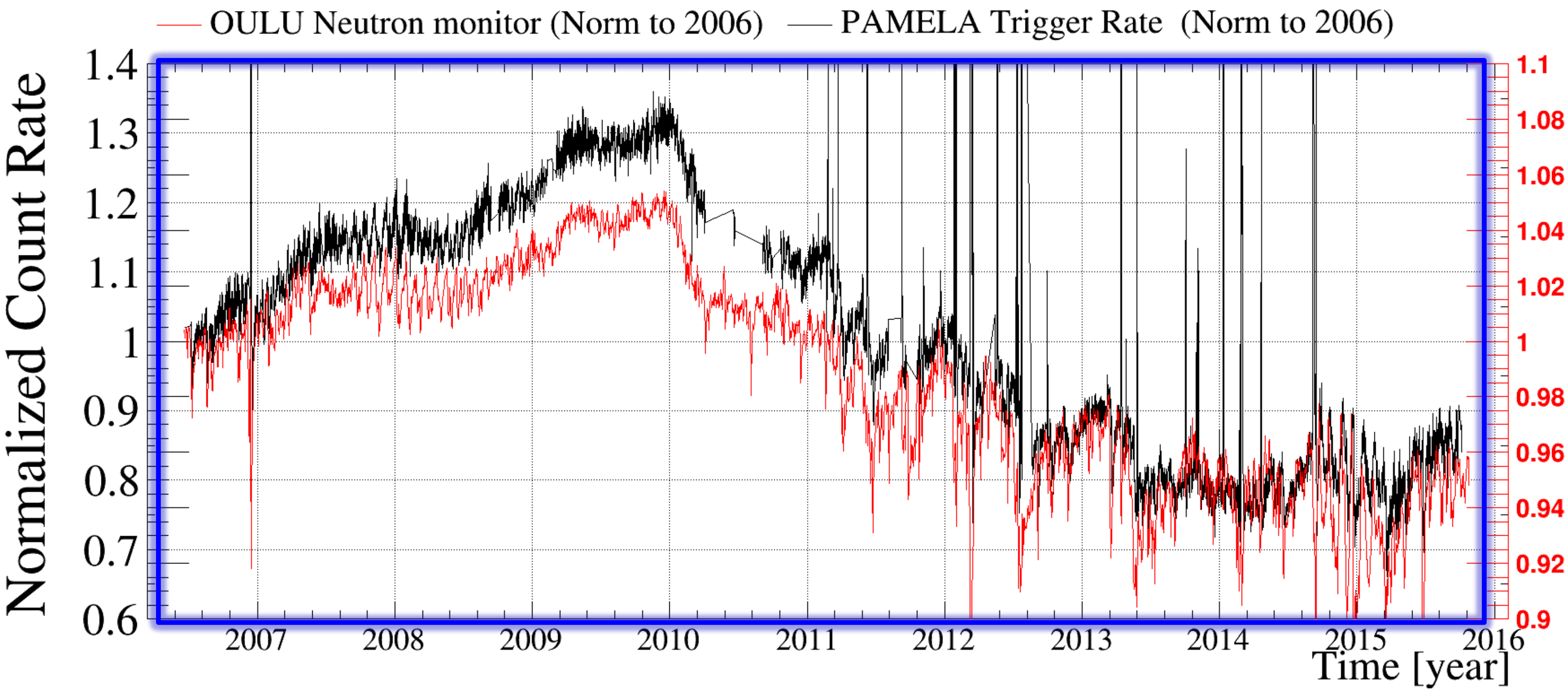
Time dependence - Electron flux







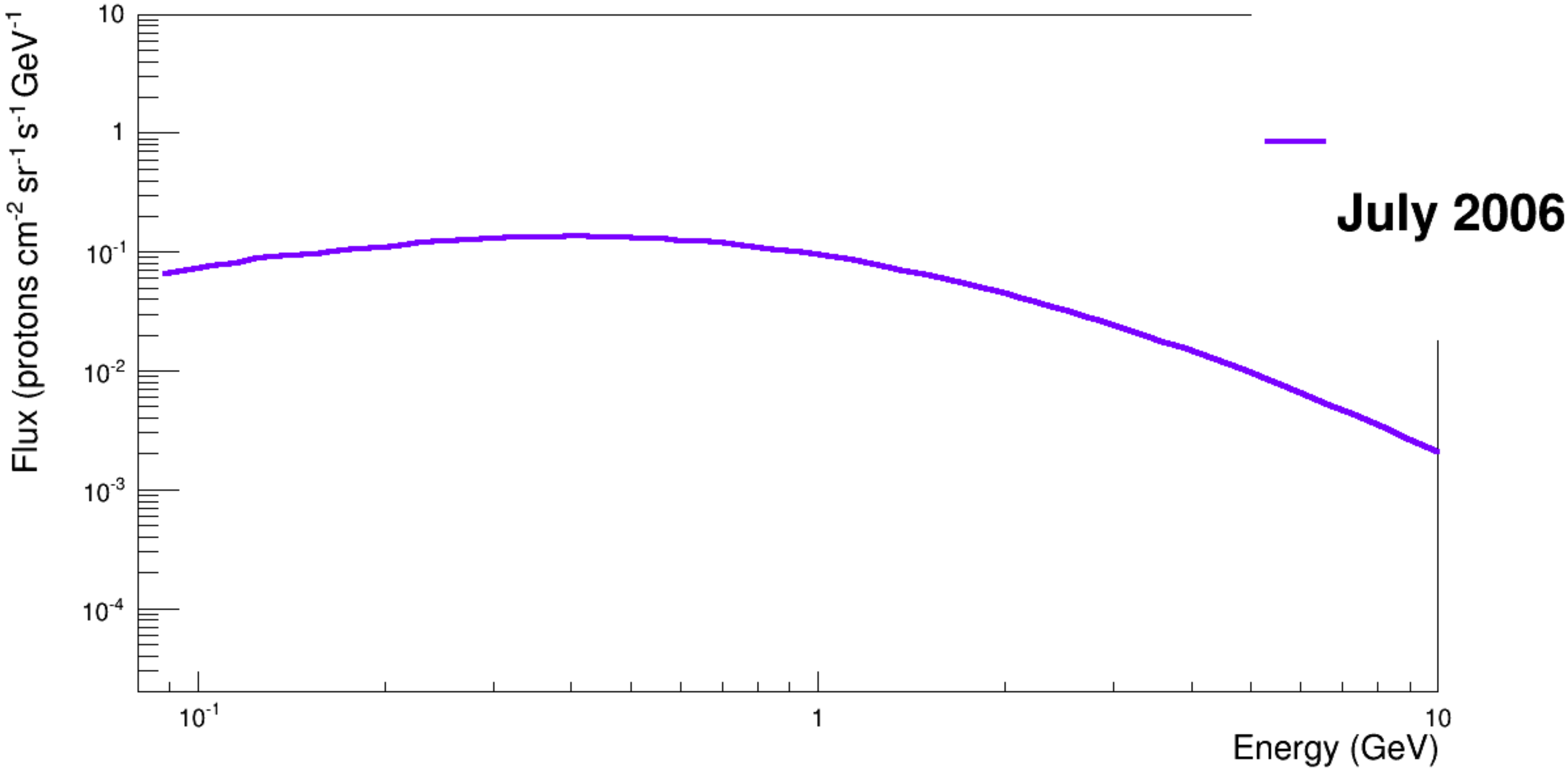
Heliospheric conditions during PAMELA observations



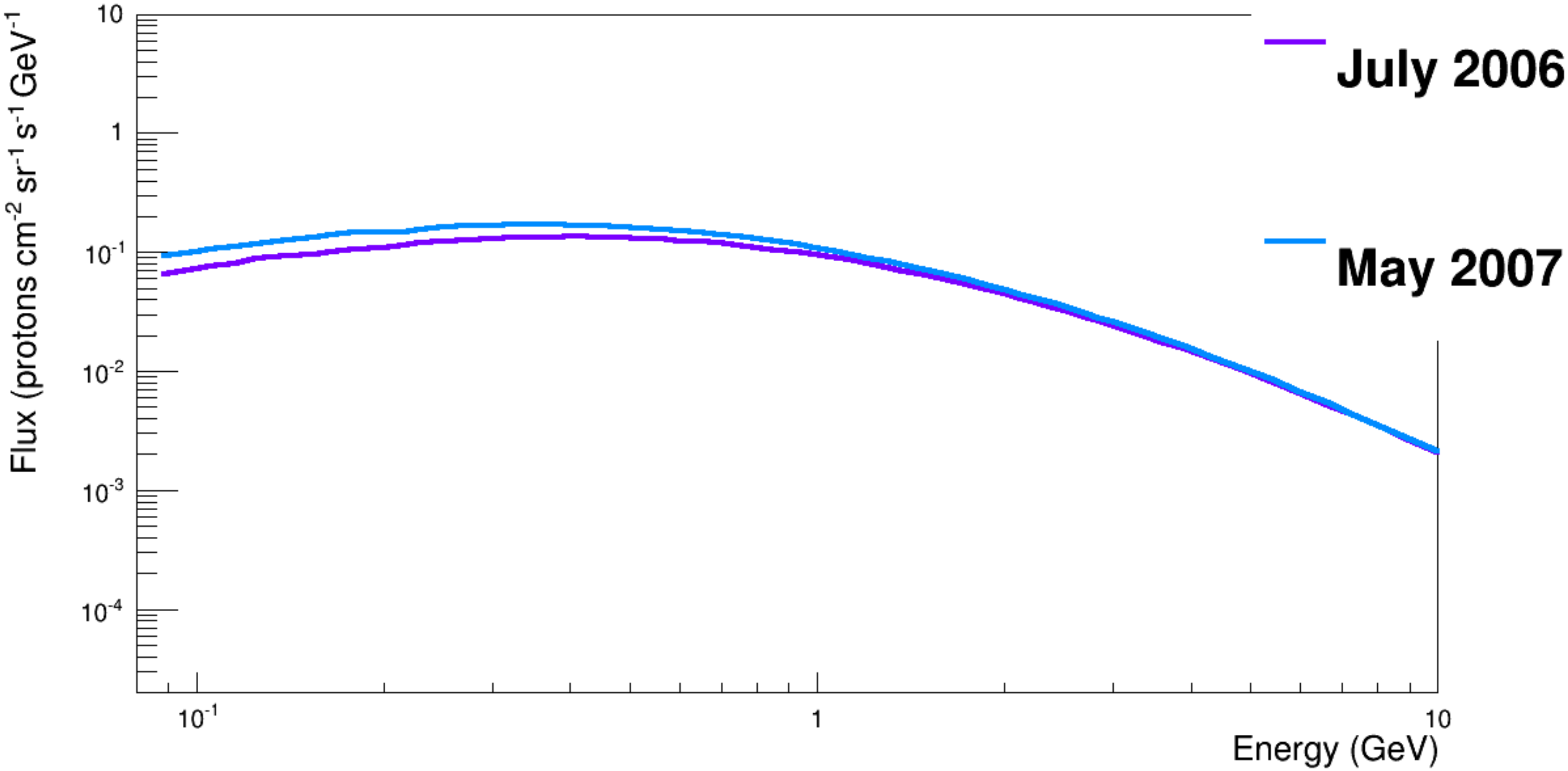
Neutron Monitor counts data from
http://cosmicrays.oulu.fi/

PAMELA observations covers ~ one solar cycle

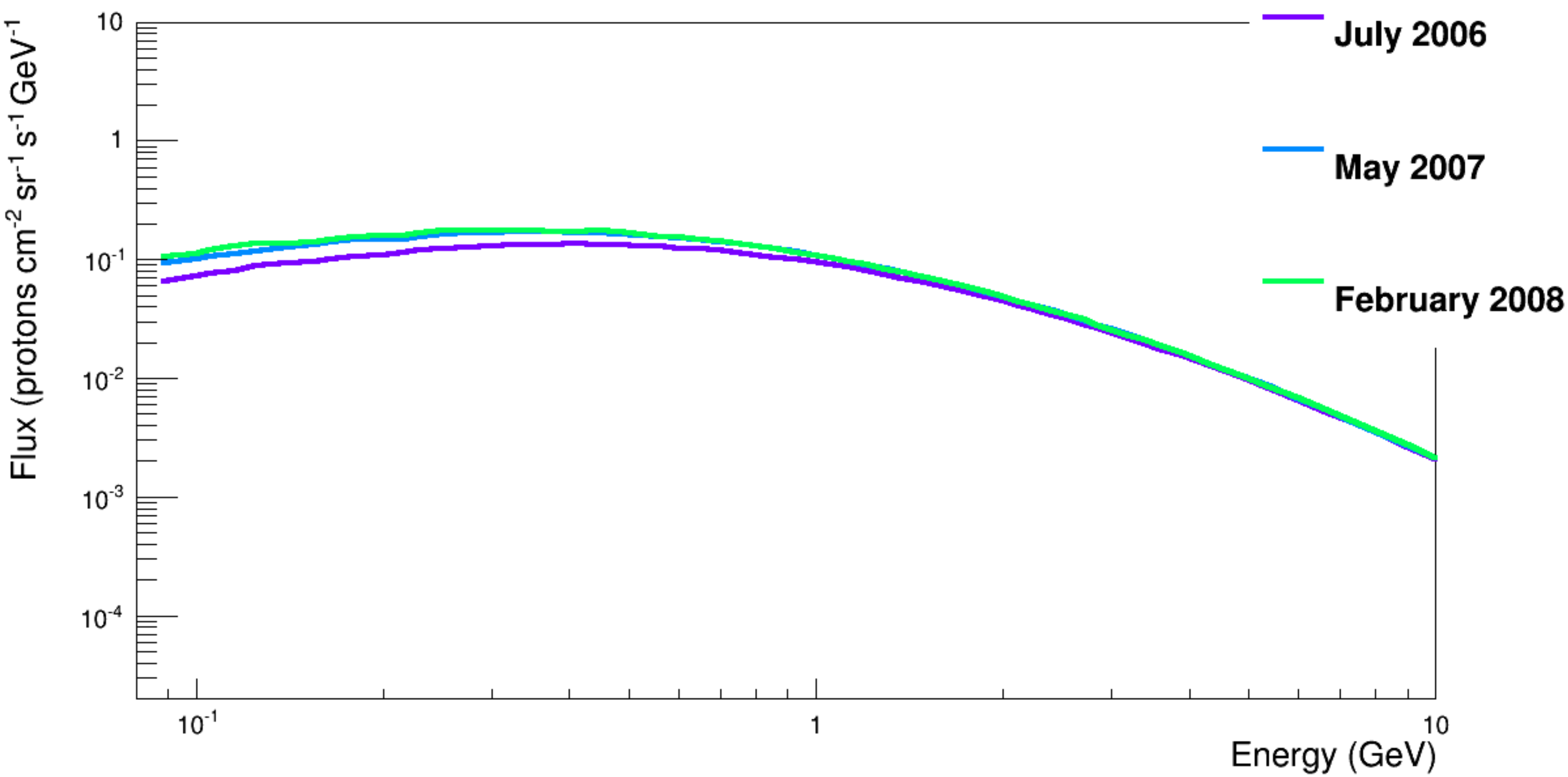
Time dependance of the proton flux July 2006-January 2014



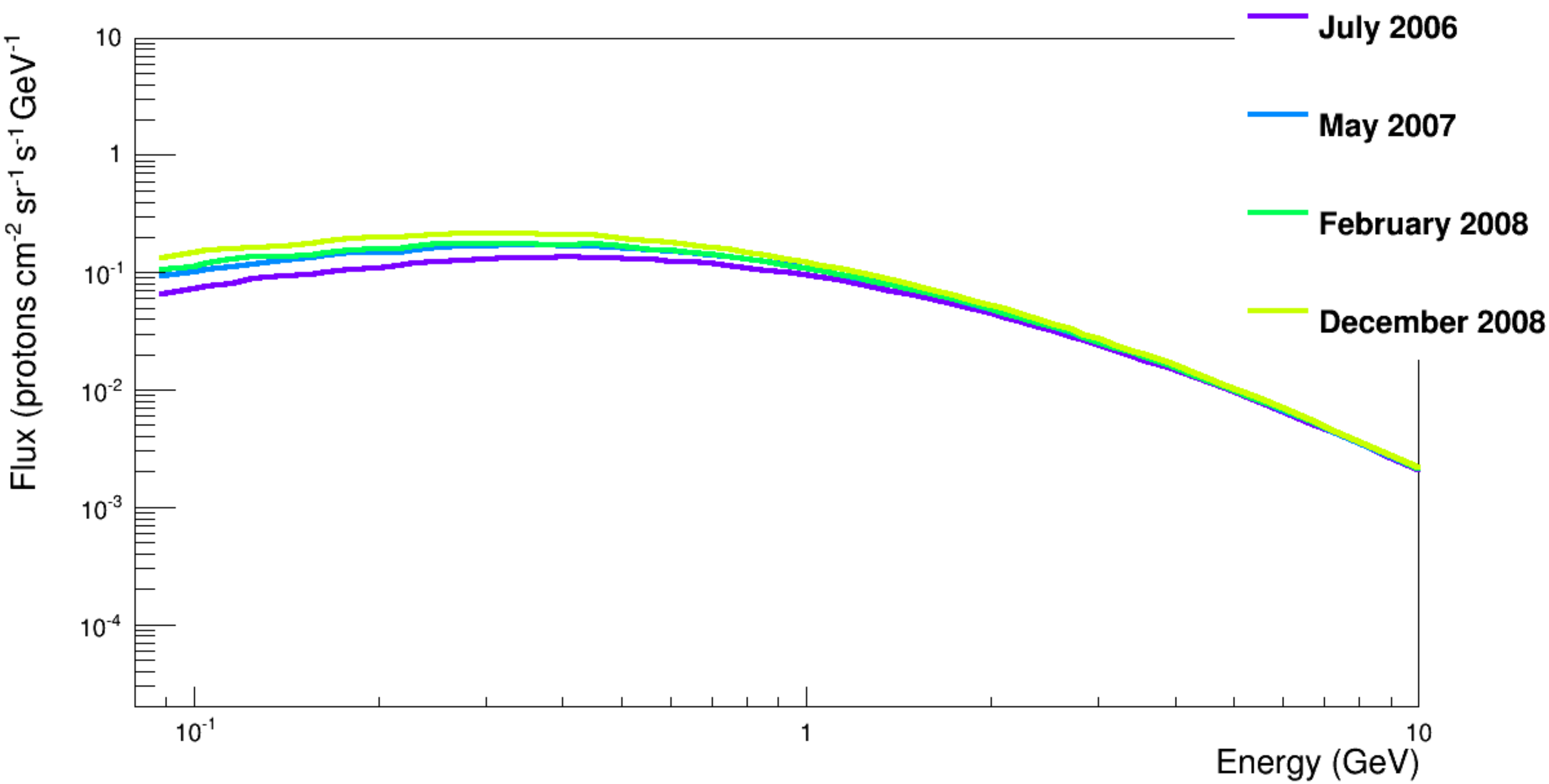
Time dependance of the proton flux July 2006-January 2014



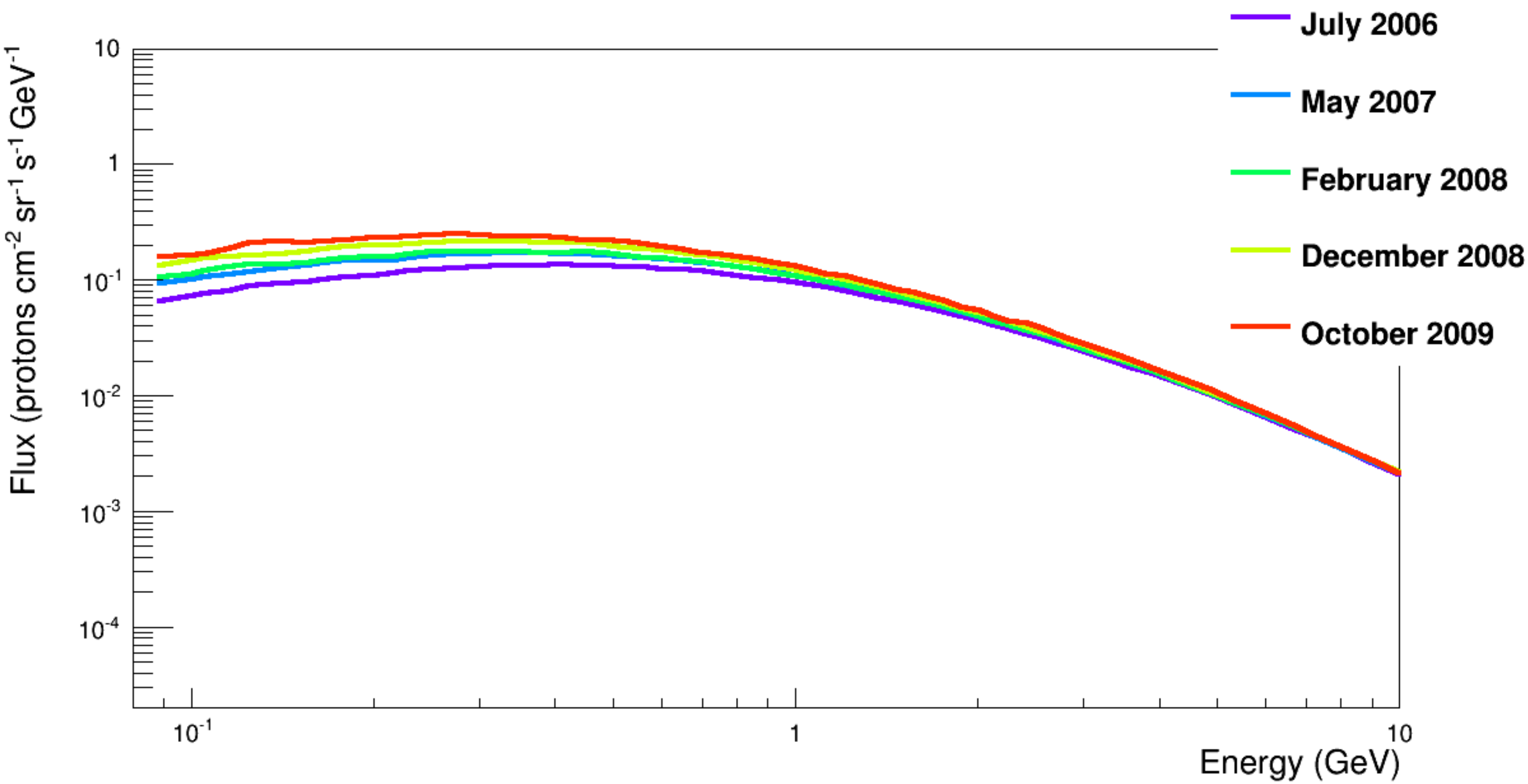
Time dependance of the proton flux July 2006-January 2014



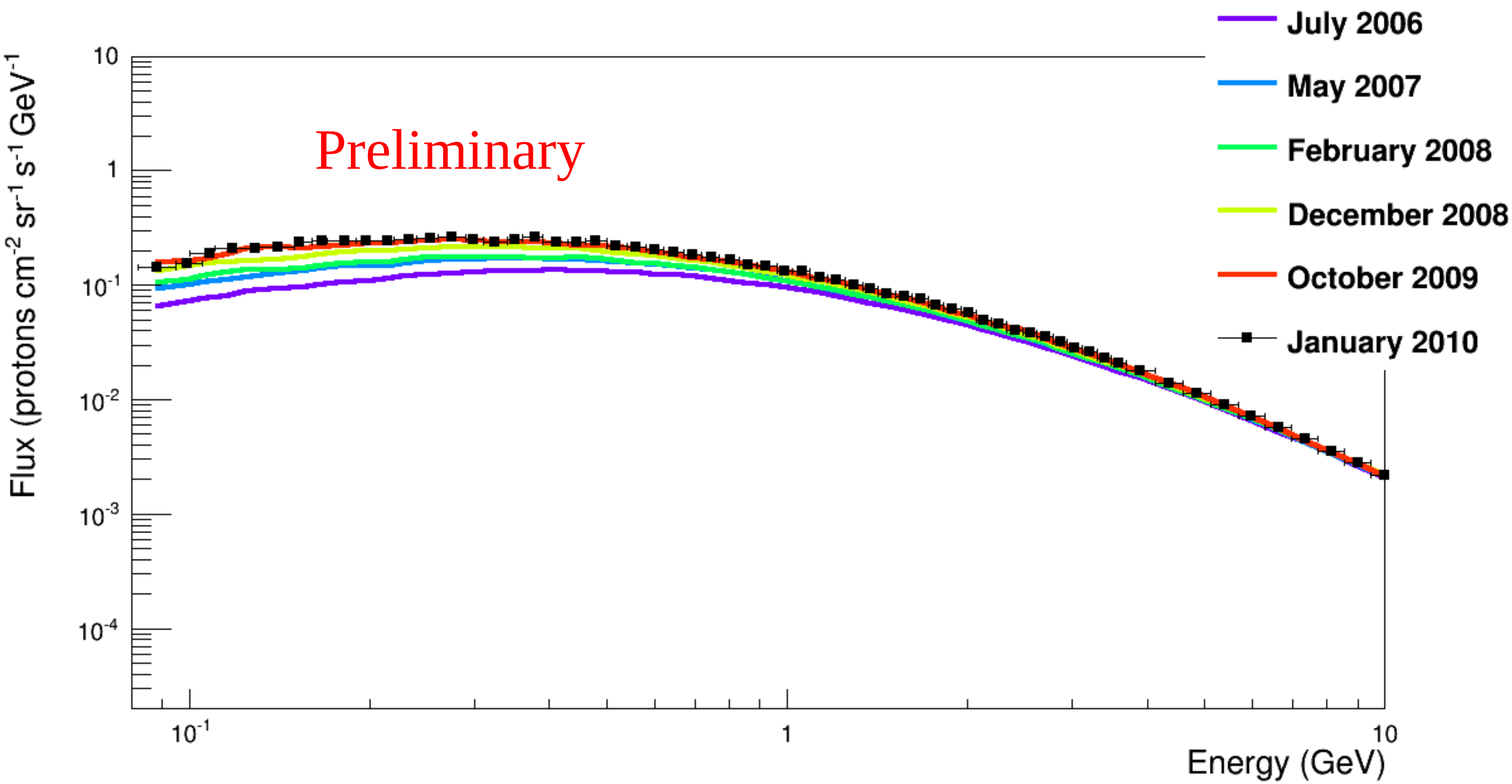
Time dependance of the proton flux July 2006-January 2014



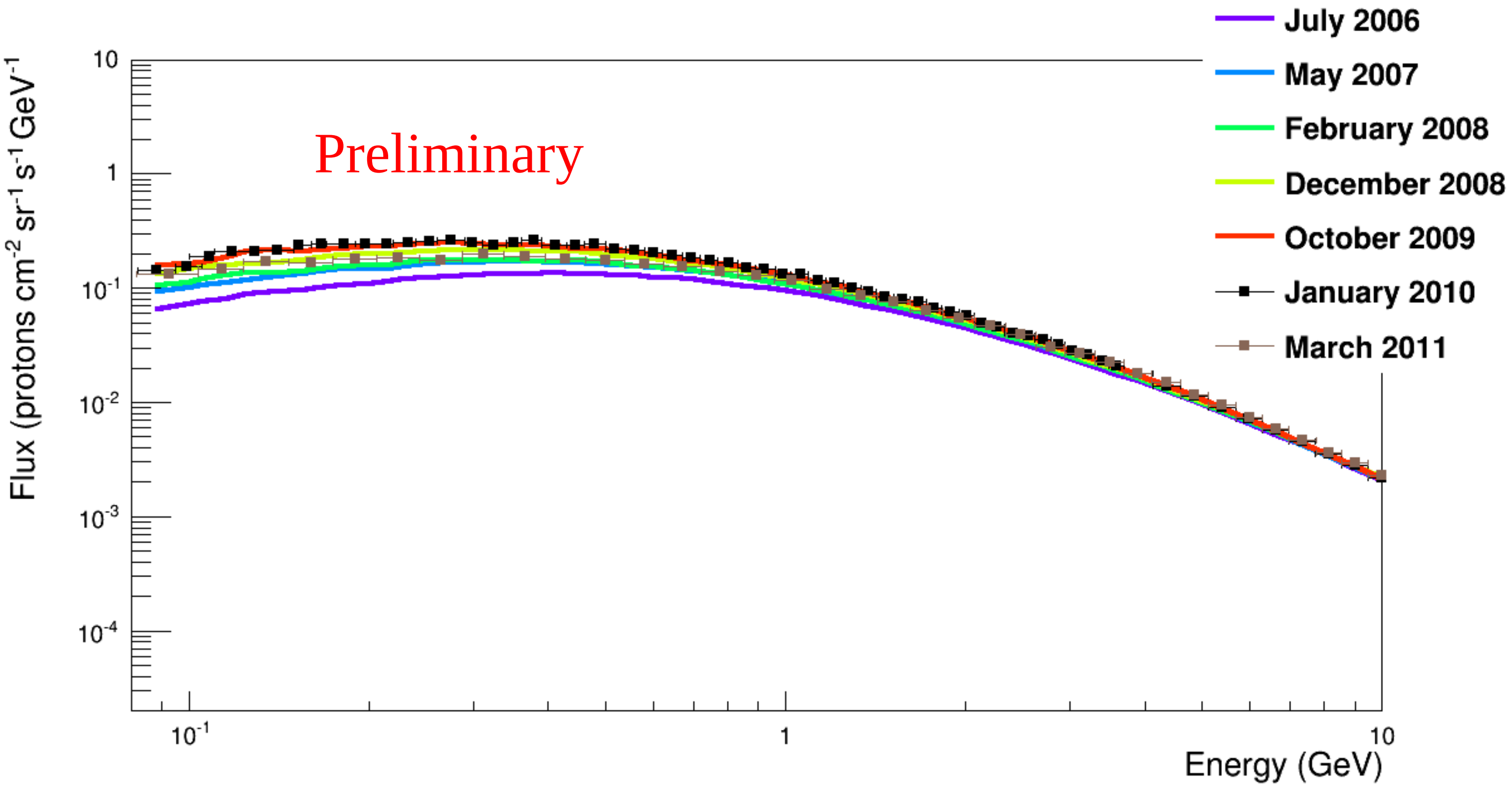
Time dependance of the proton flux July 2006-January 2014



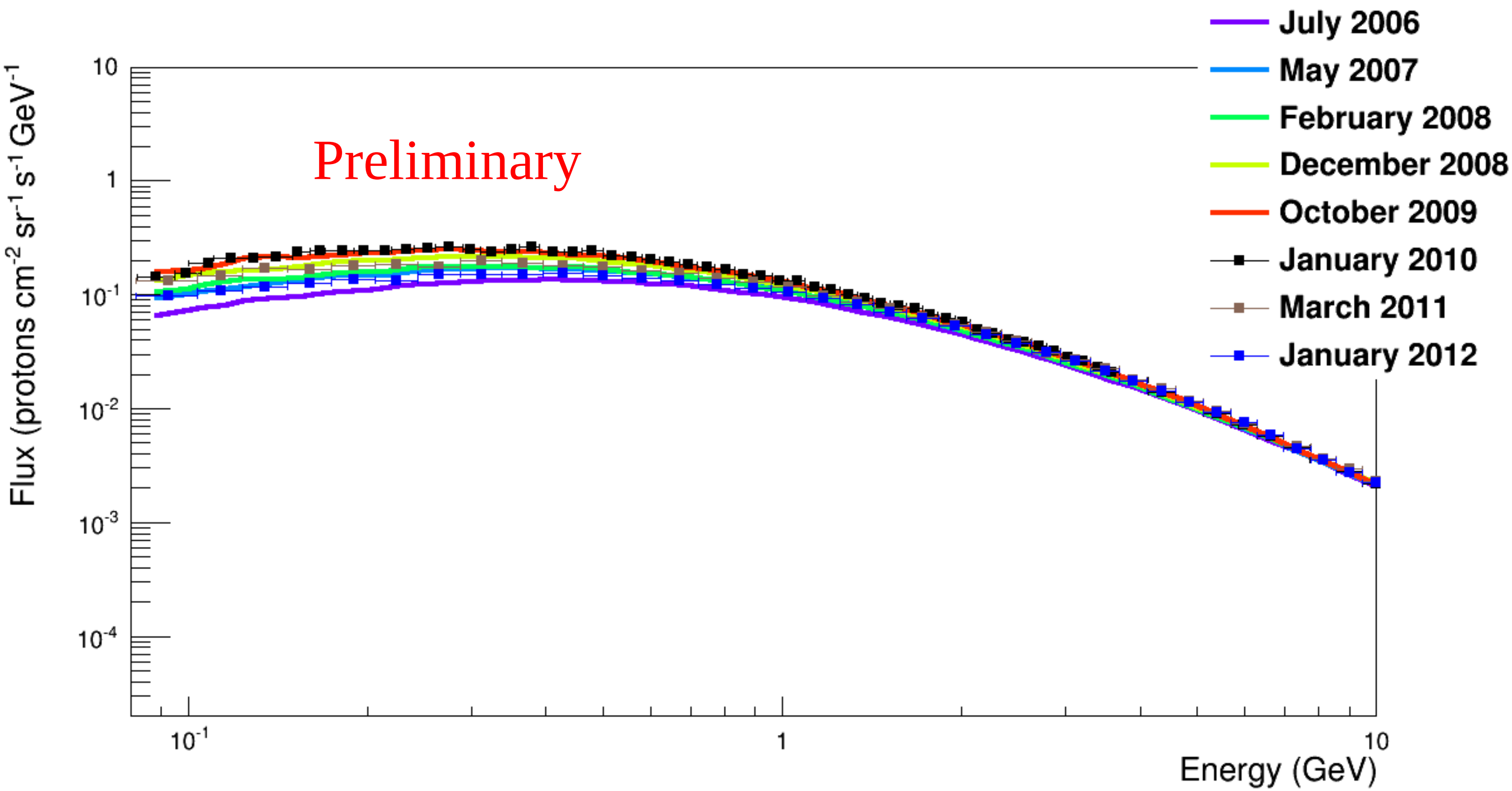
Time dependance of the proton flux July 2006-January 2014



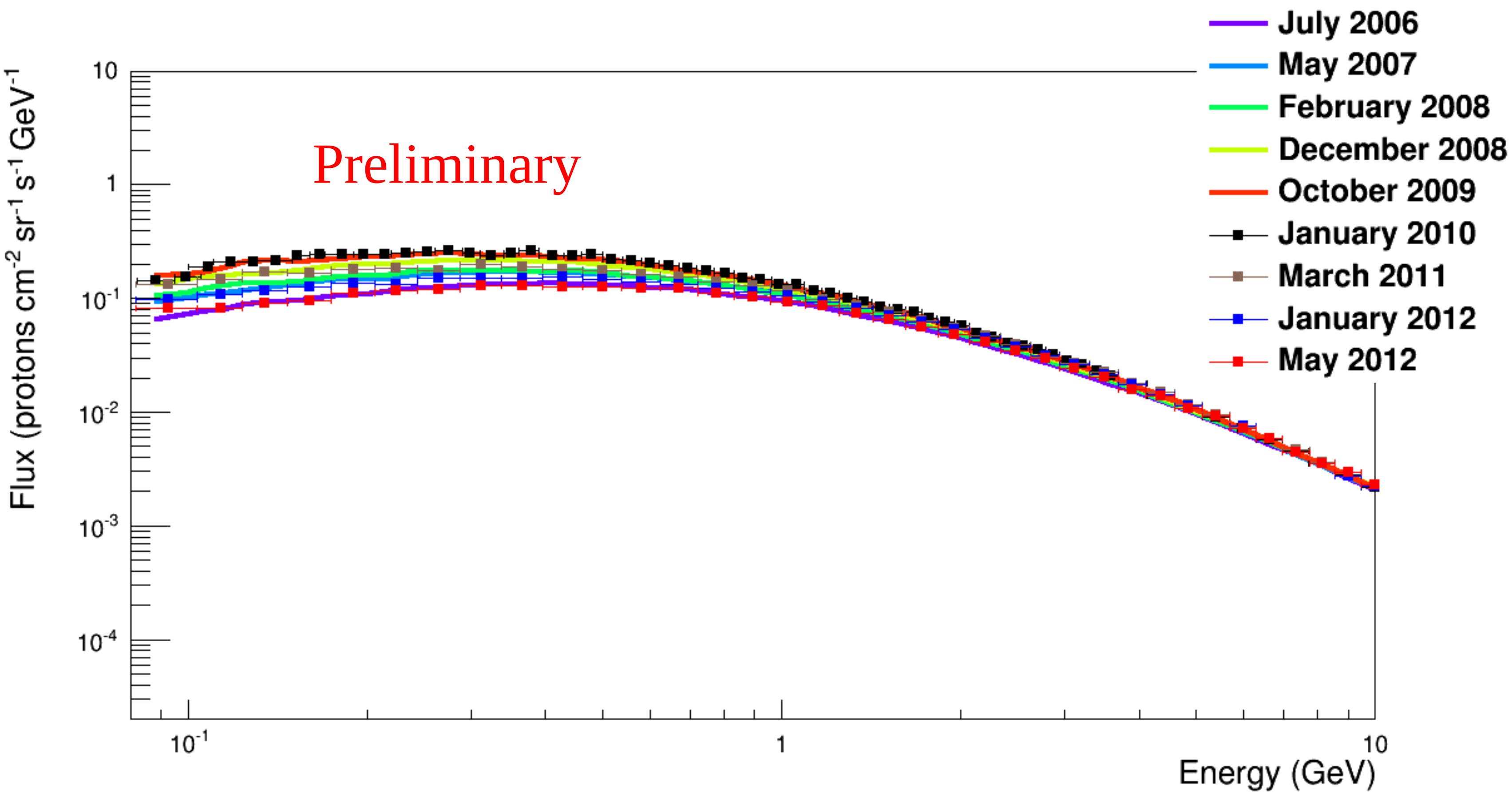
Time dependance of the proton flux July 2006-January 2014



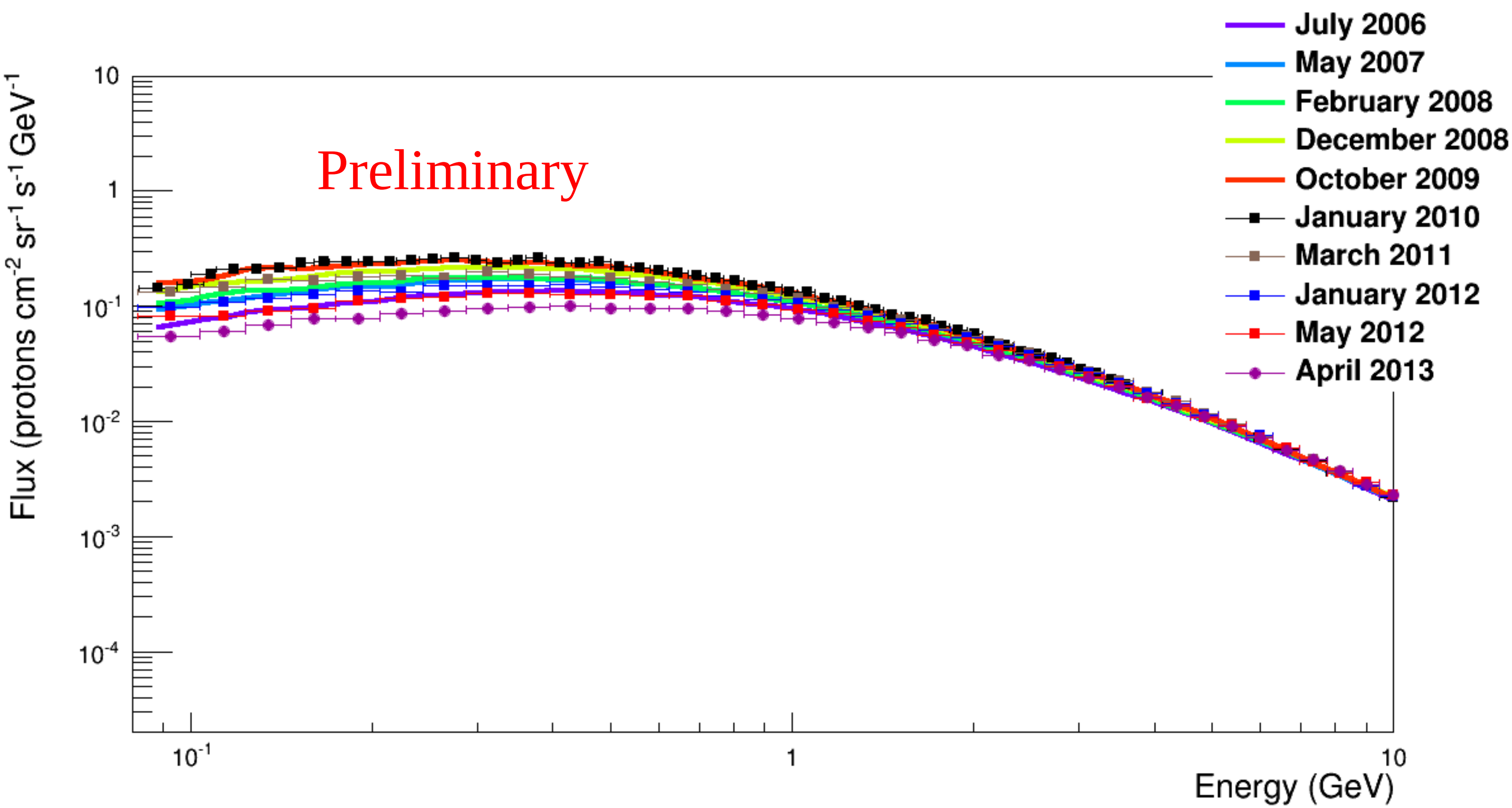
Time dependance of the proton flux July 2006-January 2014



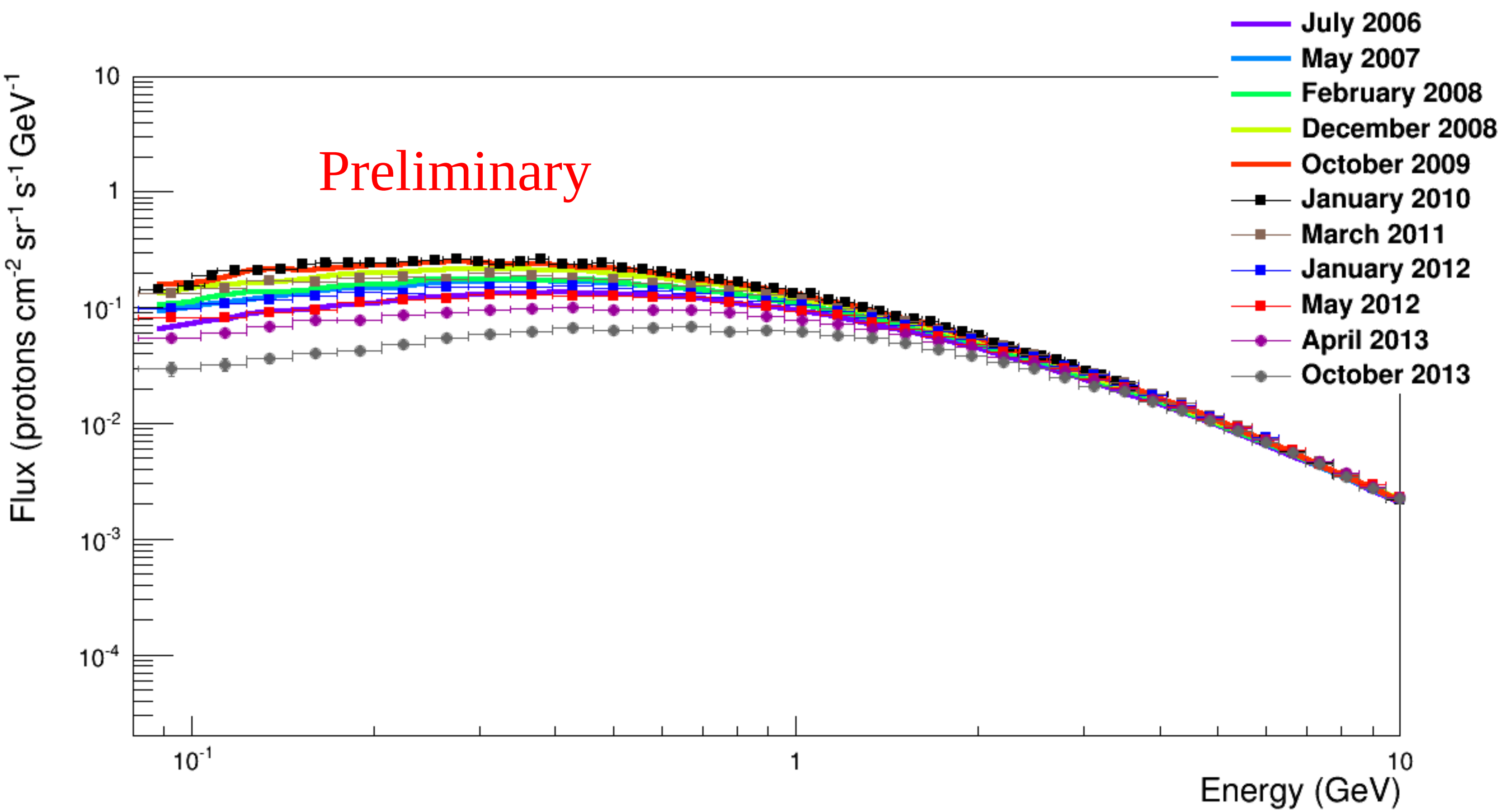
Time dependance of the proton flux July 2006-January 2014



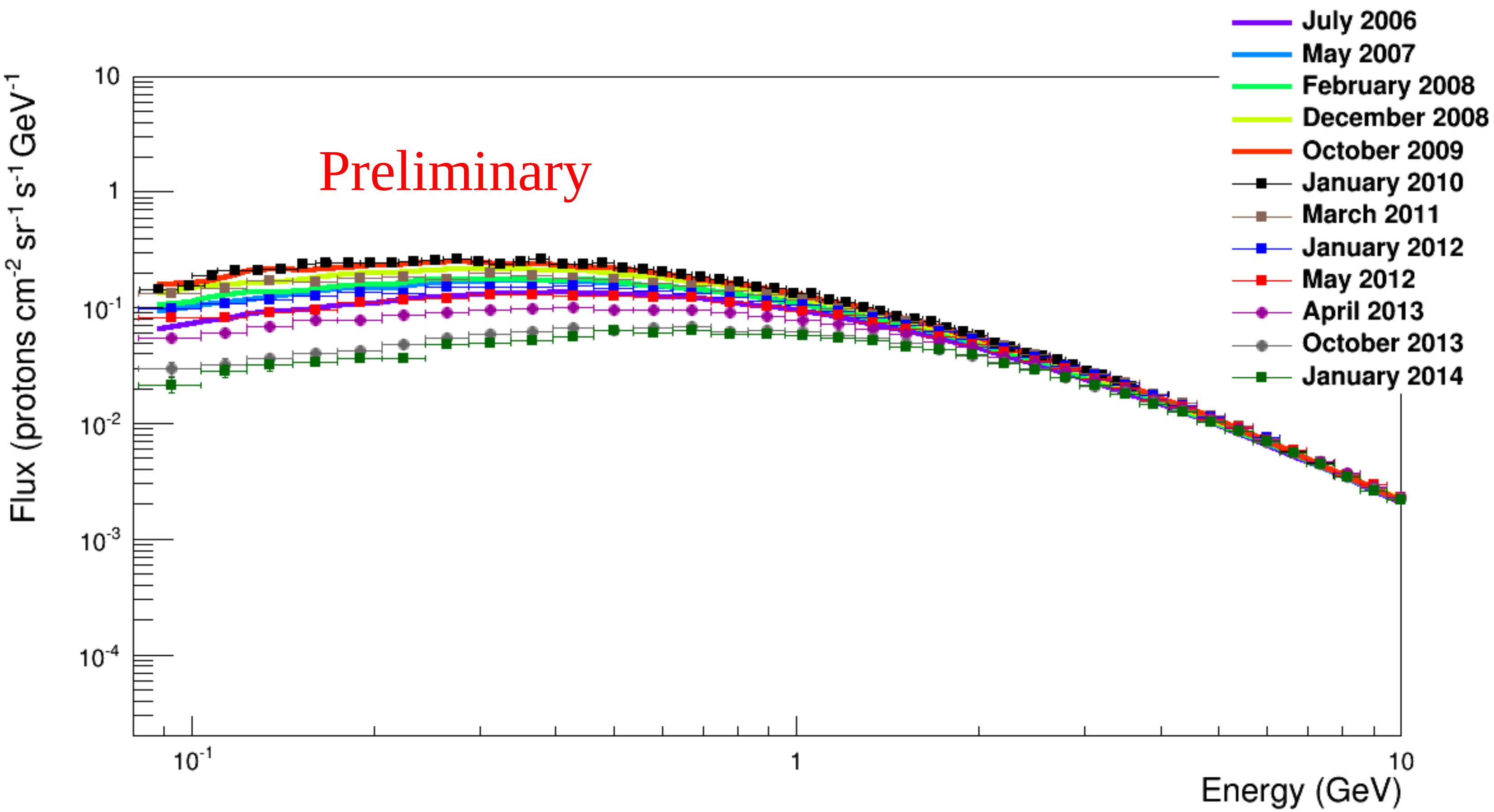
Time dependance of the proton flux July 2006-January 2014



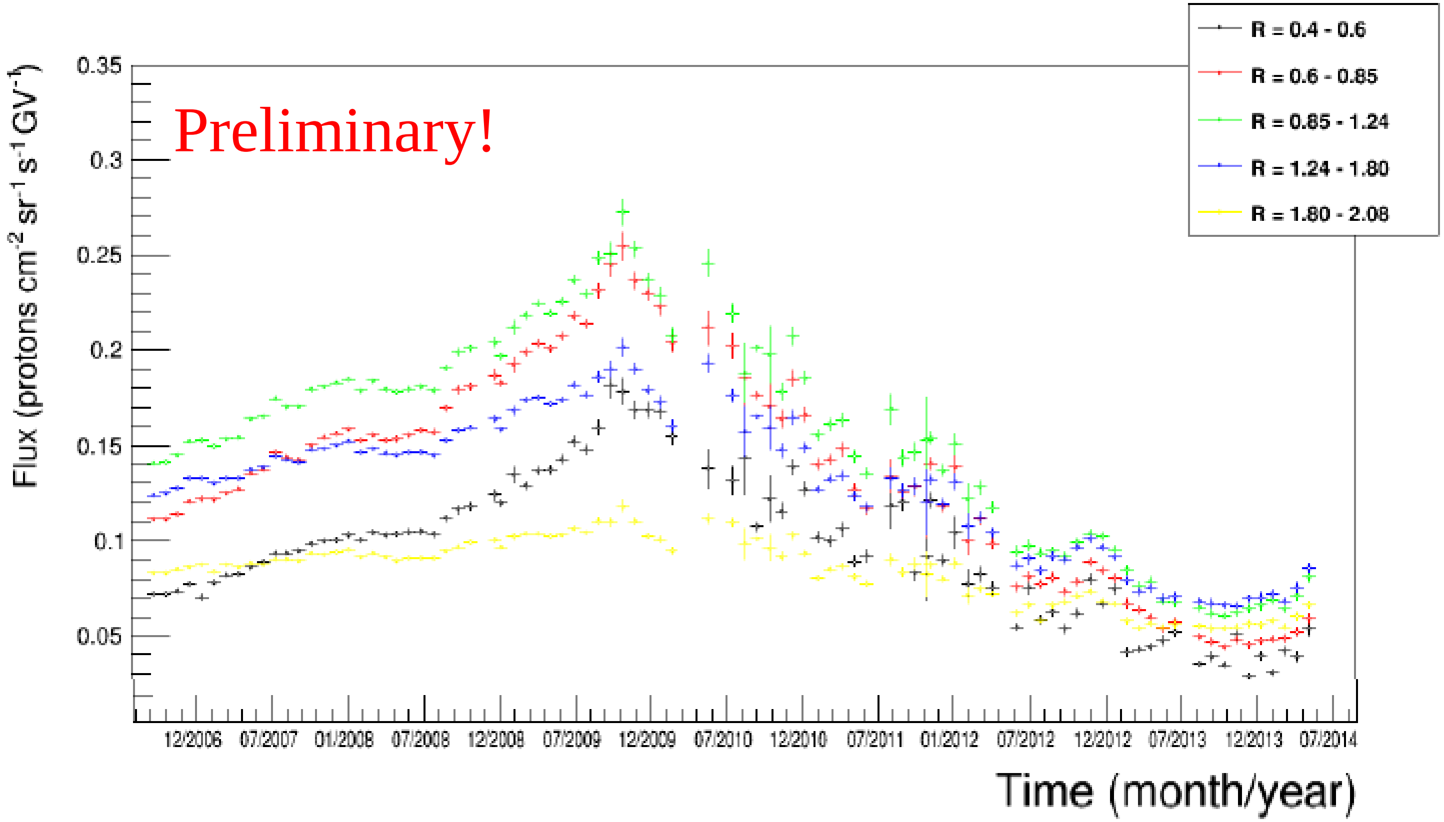
Time dependance of the proton flux July 2006-January 2014

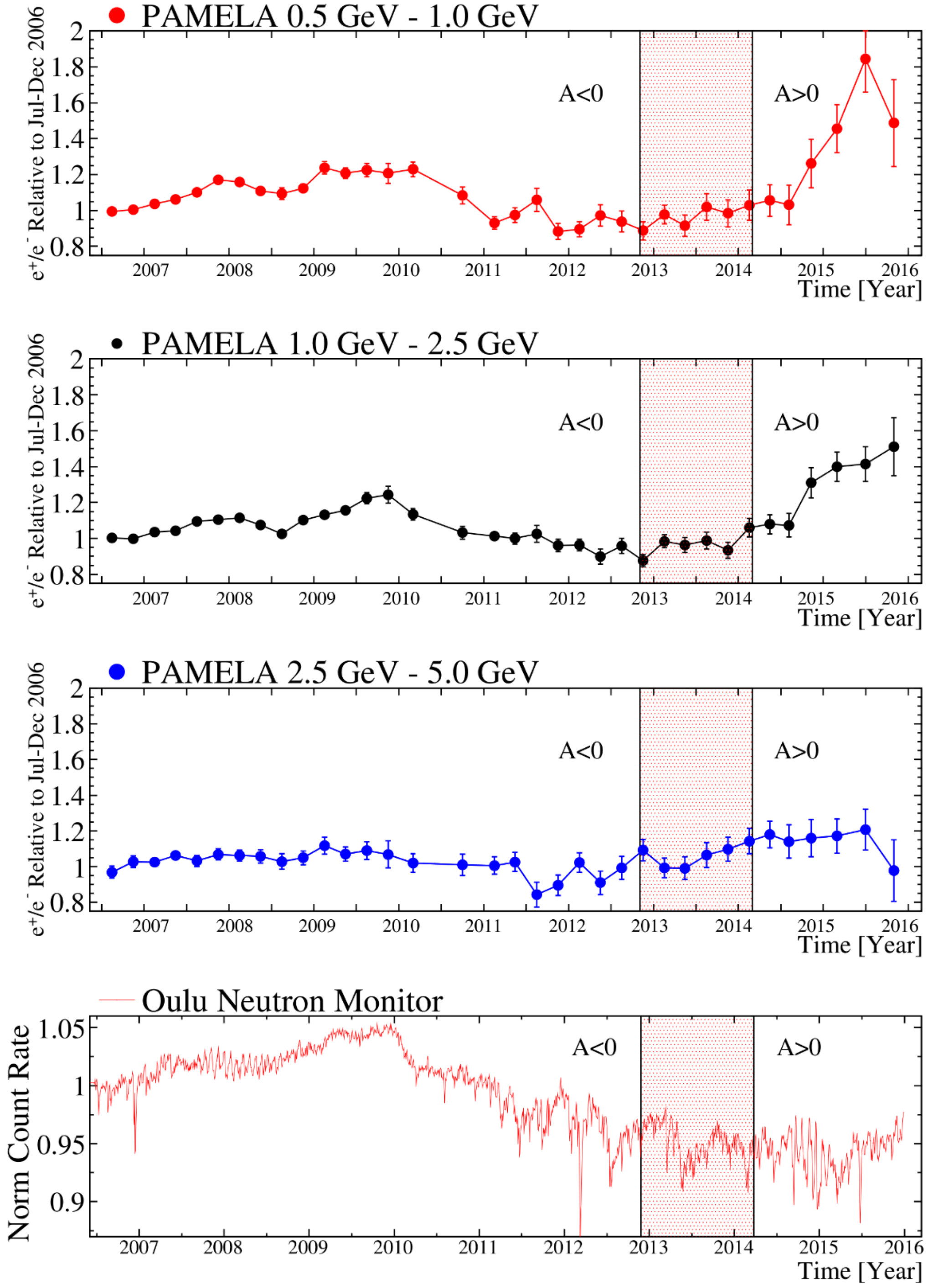


Time dependance of the proton flux July 2006-January 2014



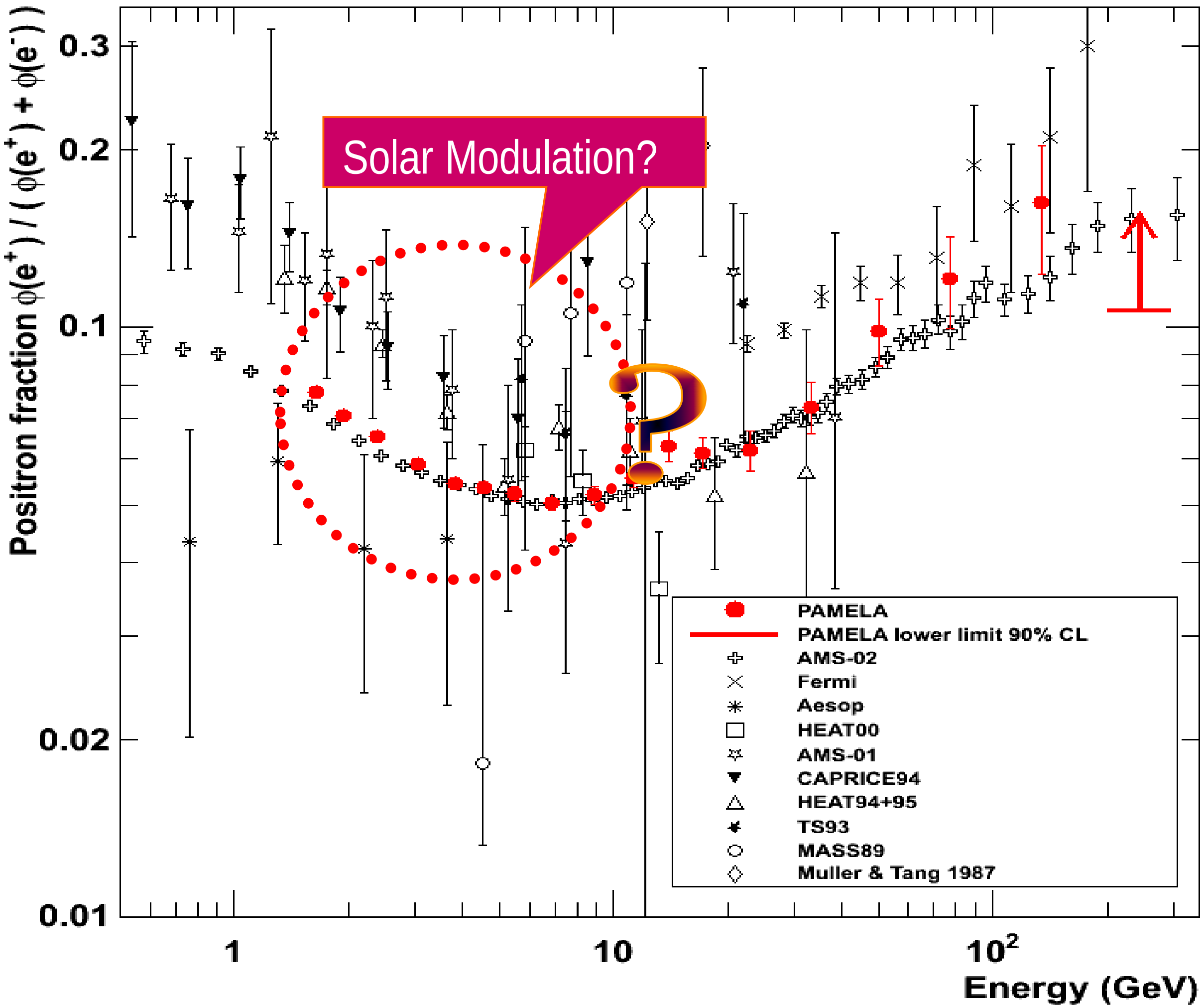
Time dependance of the proton flux July 2006-January 2014



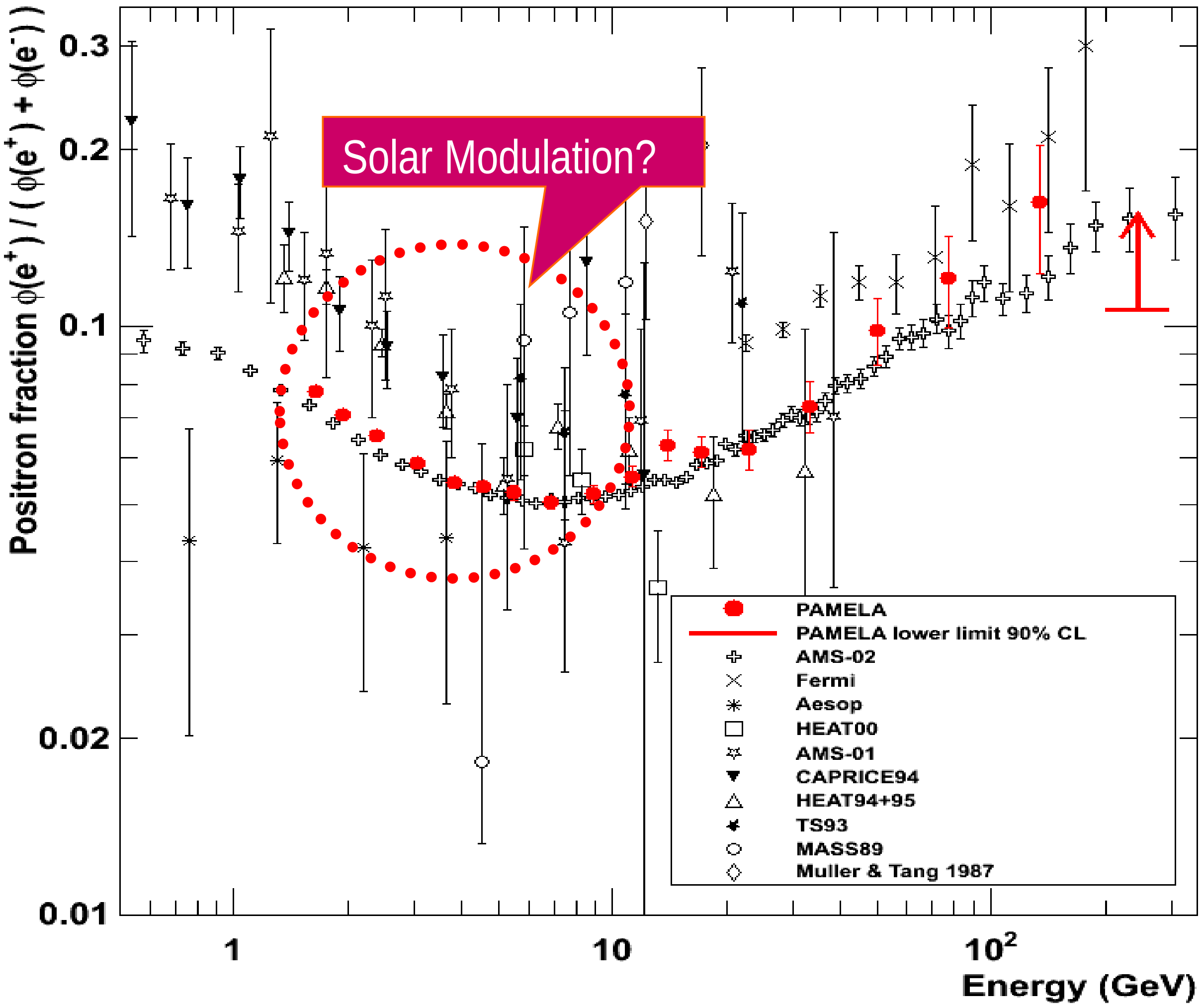


Time dependance of the electron and positron **fluxes**

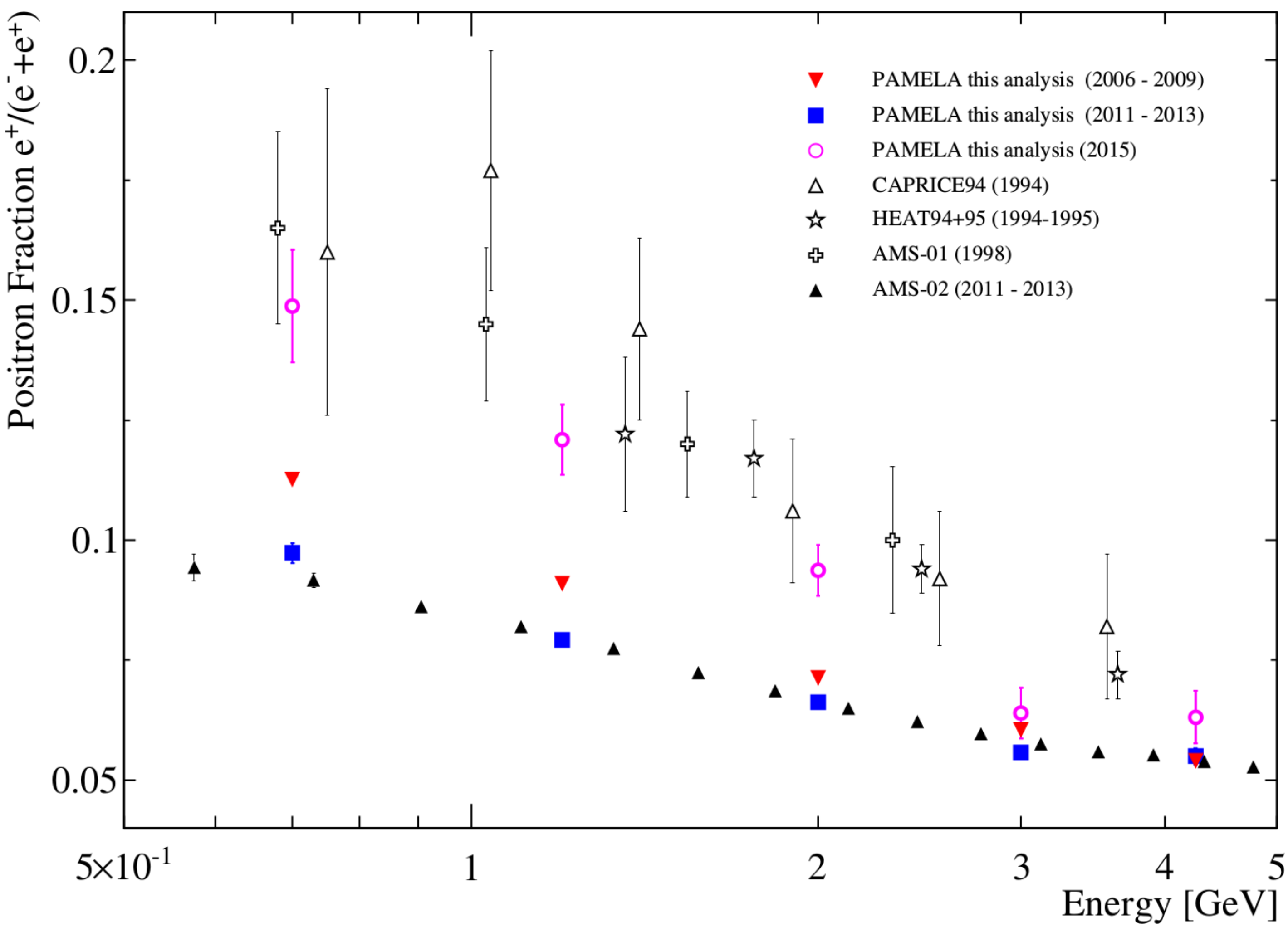
Positron to Electron Fraction



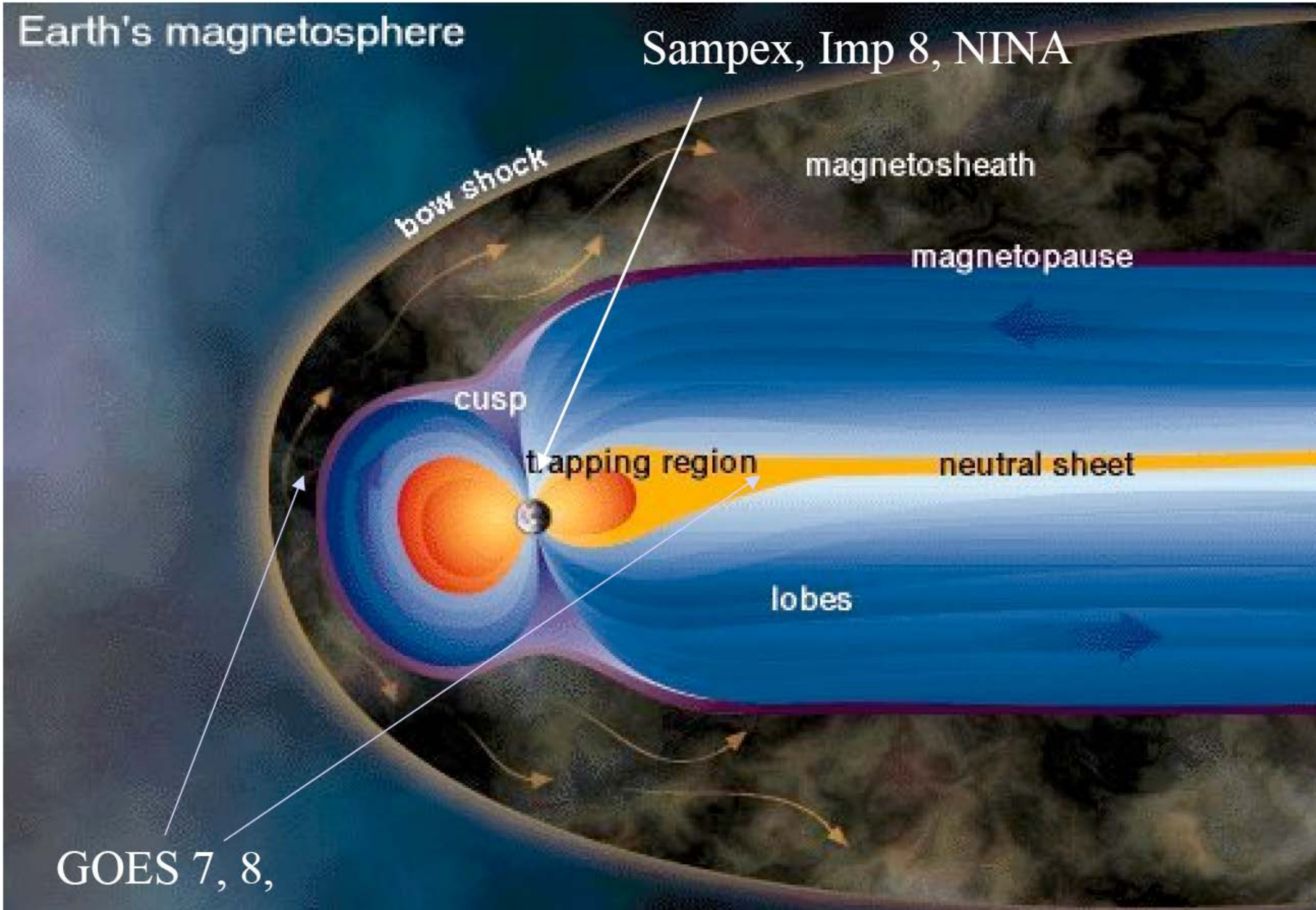
Positron to Electron Fraction



Time dependance of the electron and positron fluxes

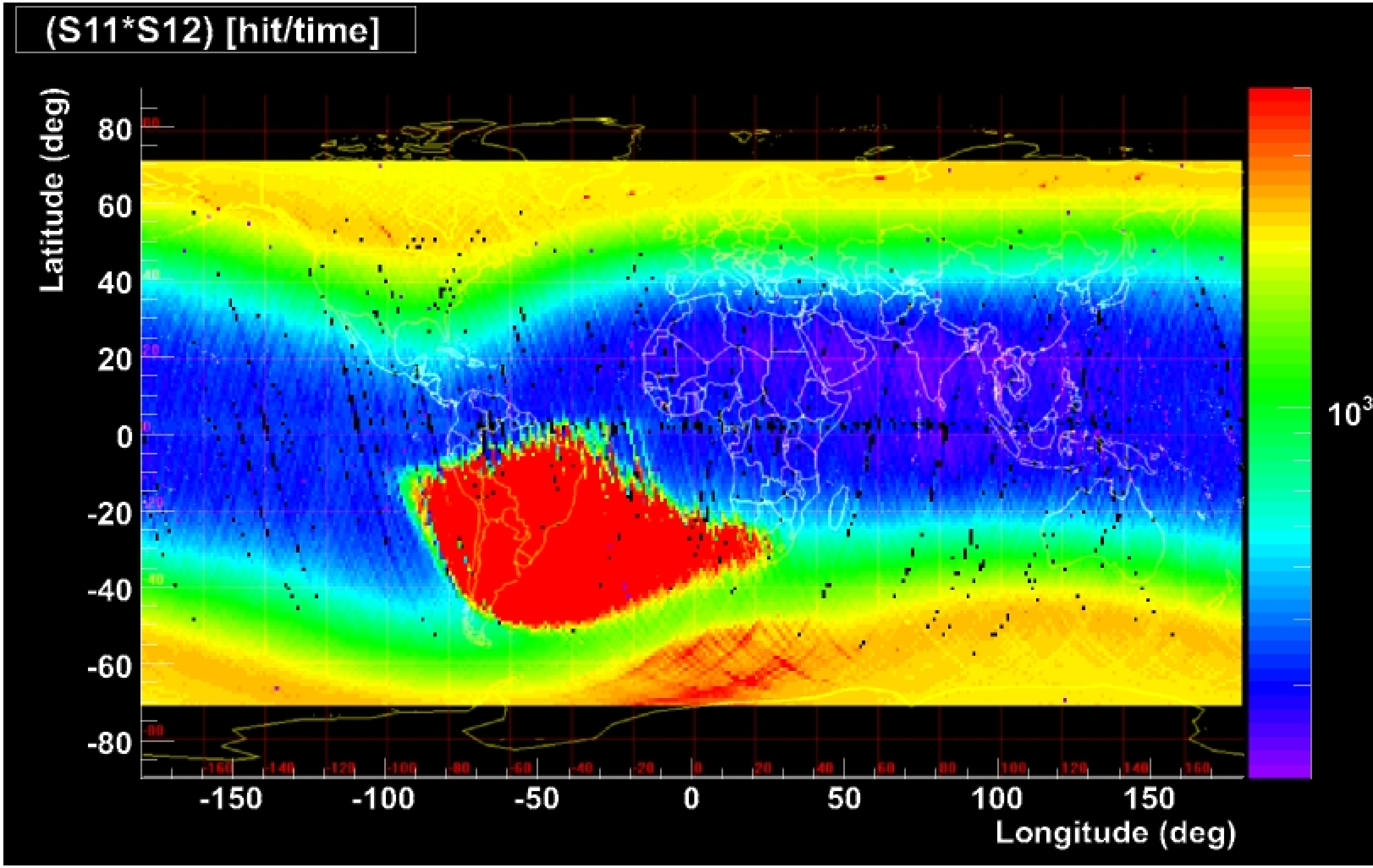


Earth Magnetosphere



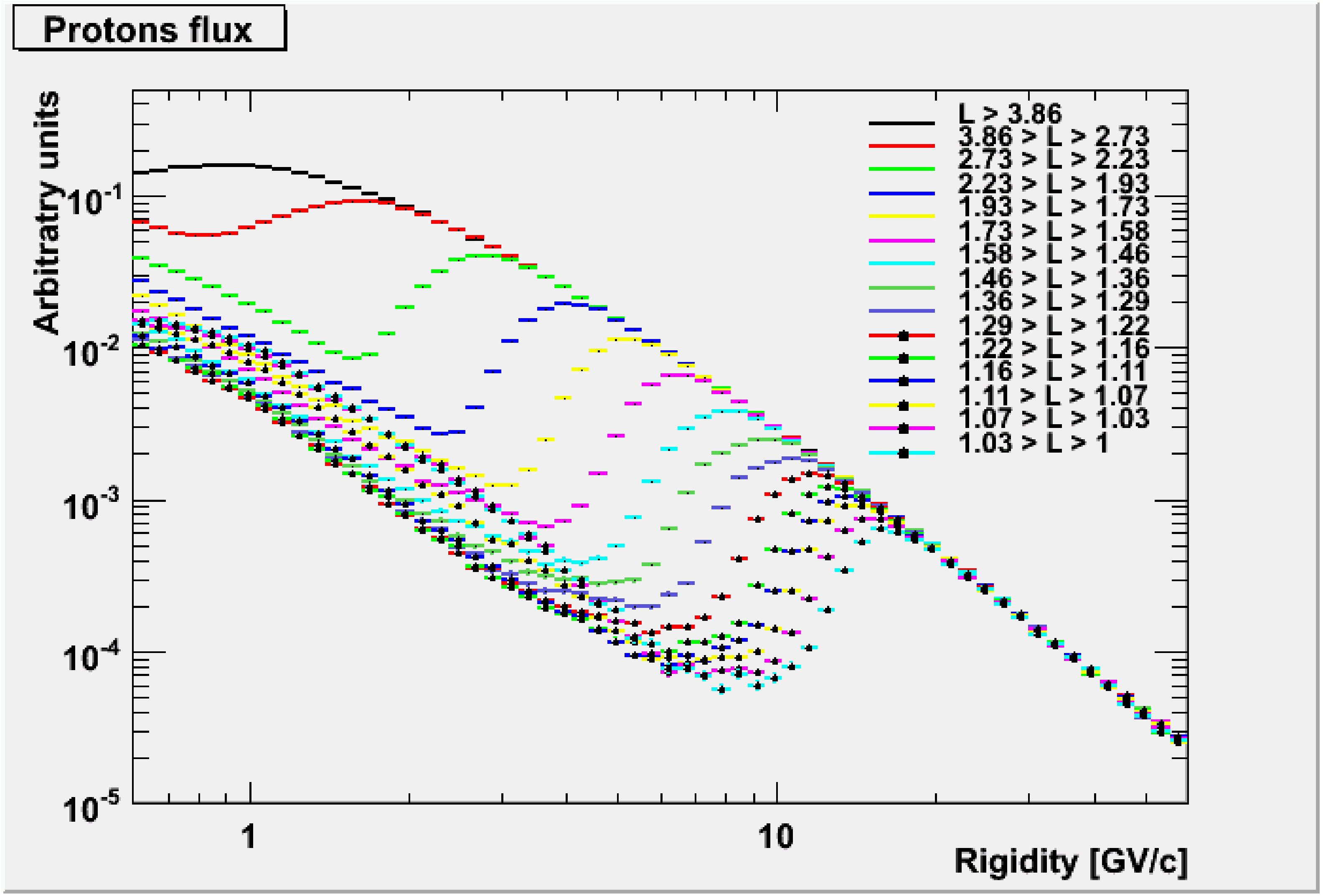
Earth's magnetosphere
Sampex, Imp 8, NINA
bow shock
magnetosheath
magnetopause
cusp
trapping region
neutral sheet
lobes
GOES 7, 8,

Pamela World Maps: 350 – 650 km alt

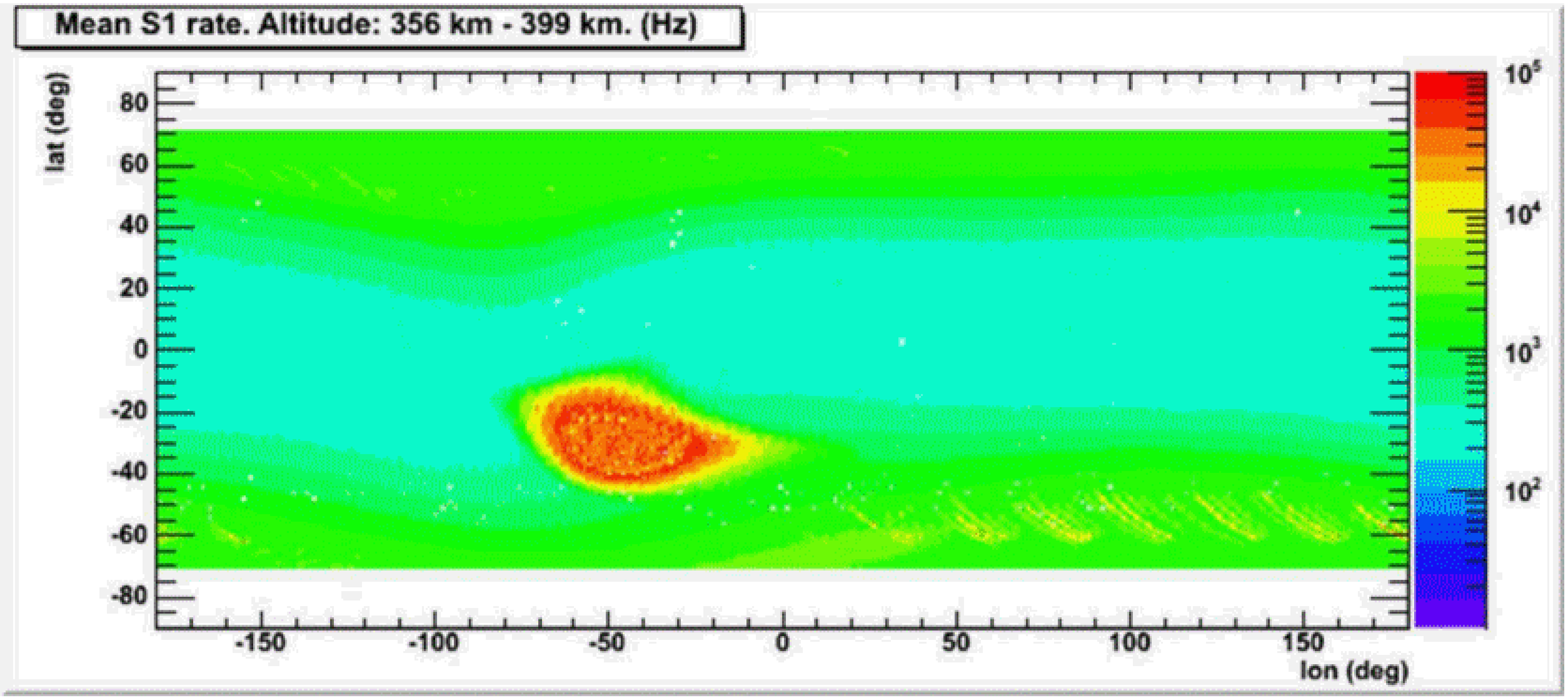


36 MeV p, 3.5 MeV e^-

Subcutoff particles

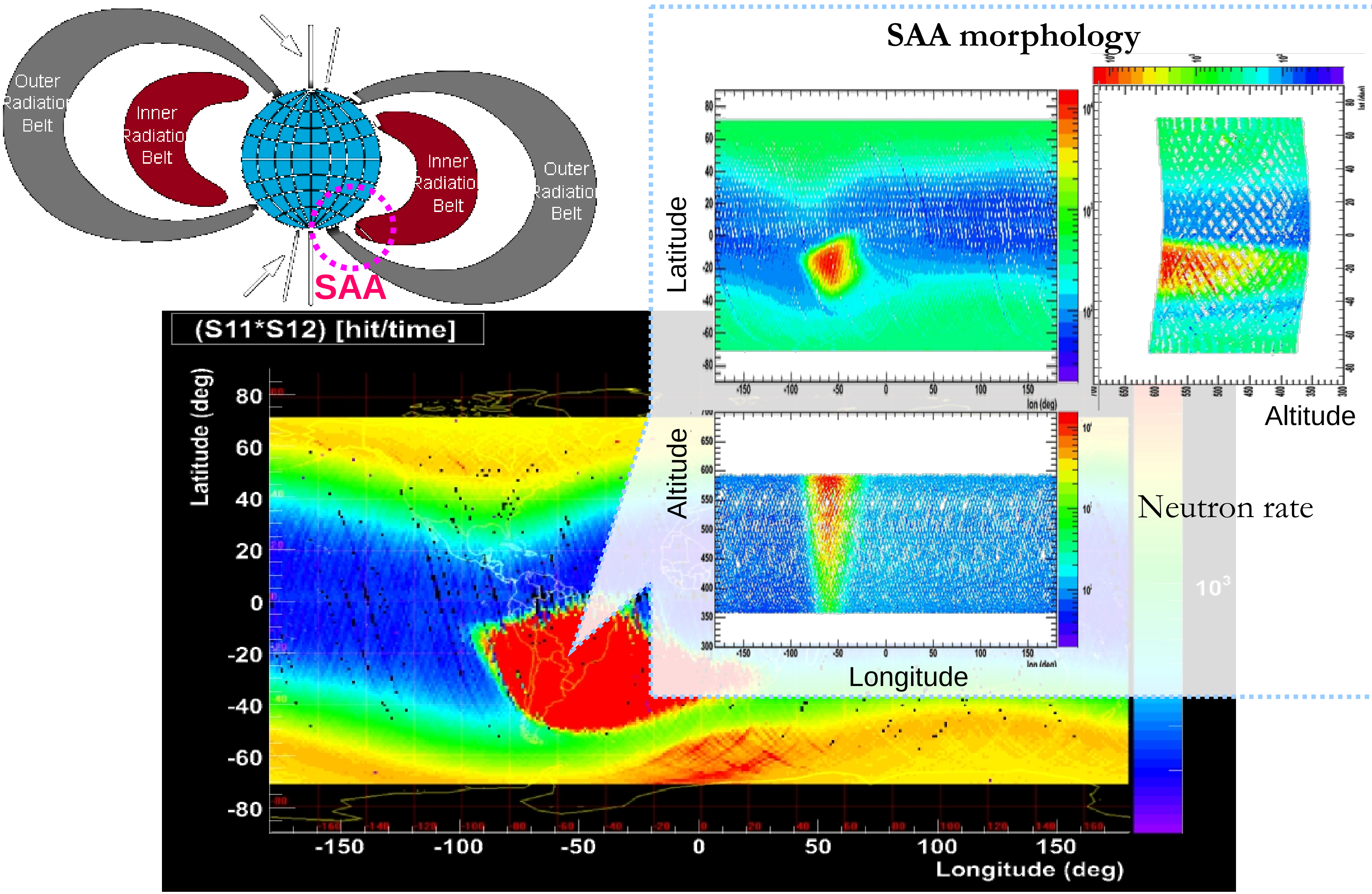


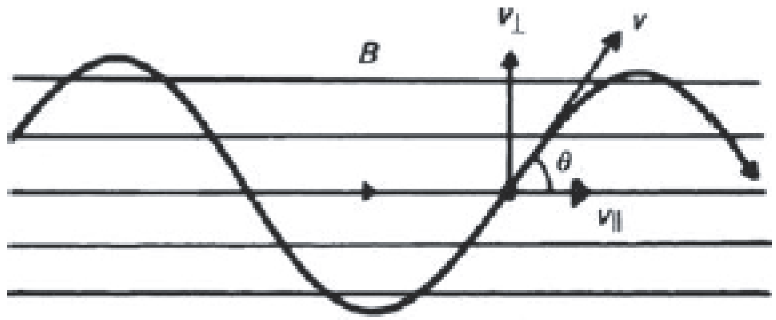
Pamela maps at various altitudes



Altitude scanning

South-Atlantic Anomaly (SAA)





$$r = \frac{\gamma m_0 v \sin\theta}{ZeB} = \left(\frac{pc}{Ze}\right)\frac{\sin\theta}{Bc}$$

A charged particle gyrating about its guiding centre in a magnetic field is equivalent to a current loop. The equivalent current is the rate at which charge passes a particular point in the loop per second, $i = zev_\perp/2\pi r$. The area of the loop is $A = \pi r^2$ and so the magnetic moment μ of the current loop is

$$\mu = iA = \frac{zev\sin\theta}{2\pi r}\pi r^2 = \frac{zev_\perp}{2}r\ .$$

In the non-relativistic limit, $r = m_0 v_\perp/zeB$, and therefore

$$\mu = \frac{m_0 v_\perp^2}{2B} = \frac{w_\perp}{B}\ , \qquad (7.7)$$

where $w_\perp$ is the kinetic energy of the particle in the direction perpendicular to the guiding centre.

Magnetic mirroring

$$\Delta B \neq 0 \; and \; \frac{\Delta B}{B} \ll 1 \rightarrow emf = A\frac{dB}{dt} = \xi$$

Work done on the particle per orbit by emf:

$$Ze\xi = Ze\pi r^2 \frac{dB}{dt} = Ze\pi r^2 \frac{\Delta B}{\Delta T}, \Delta T = \frac{2\pi r}{v_\perp}$$

Change in kinetic energy:

$$\Delta w_\perp = \frac{zerv_\perp}{2}\Delta B = \frac{m_0 v_\perp^2}{2B}\Delta B = \frac{w_\perp}{B}\Delta B \, .$$

The corresponding change in the magnetic moment of the current loop is

$$\Delta\mu = \Delta\left(\frac{w_\perp}{B}\right) = \frac{\Delta w_\perp}{B} - \frac{w_\perp \Delta B}{B^2} = \frac{\Delta w_\perp}{B} - \frac{\Delta w_\perp}{B} = 0 \, ,$$

that is, the magnetic moment of the particle is an *invariant* provided the field is slowly varying. There are other ways of expressing this important result. As illustrated by (7.8), $\Delta\mu = 0$ is equivalent to $\Delta(w_\perp/B) = 0$. Since $w_\perp = p_\perp^2/2m_0$, this is the same as

$$\Delta(p_\perp^2/B) = 0 \, .$$

Magnetic mirroring

$$\Delta\left(\frac{p_\perp^2}{B}\right) = 0$$