Solar Modulation in AMS-02

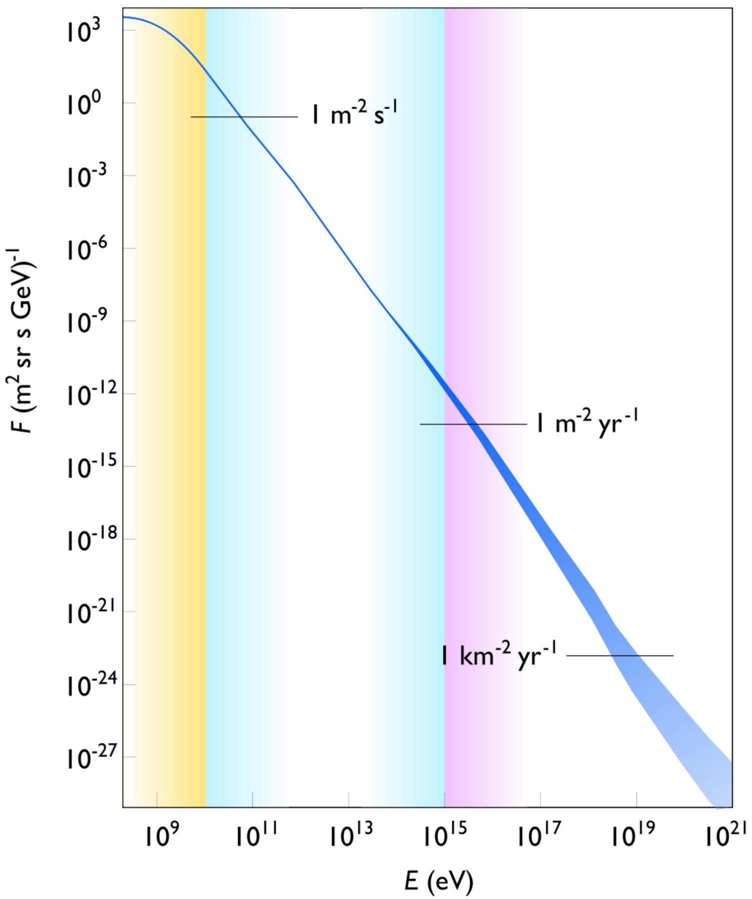
Luís Batalha
batalha@lip.pt

Fernando Barão
barao@lip.pt

Summary

- What is Solar Modulation?
- The agents of Solar Modulation
- Parker Model
- Force-Field Approximation
- 1D Full Numerical Solution
- Measuring Fluxes with AMS-02
- Conclusions and Next Steps

Solar Modulation



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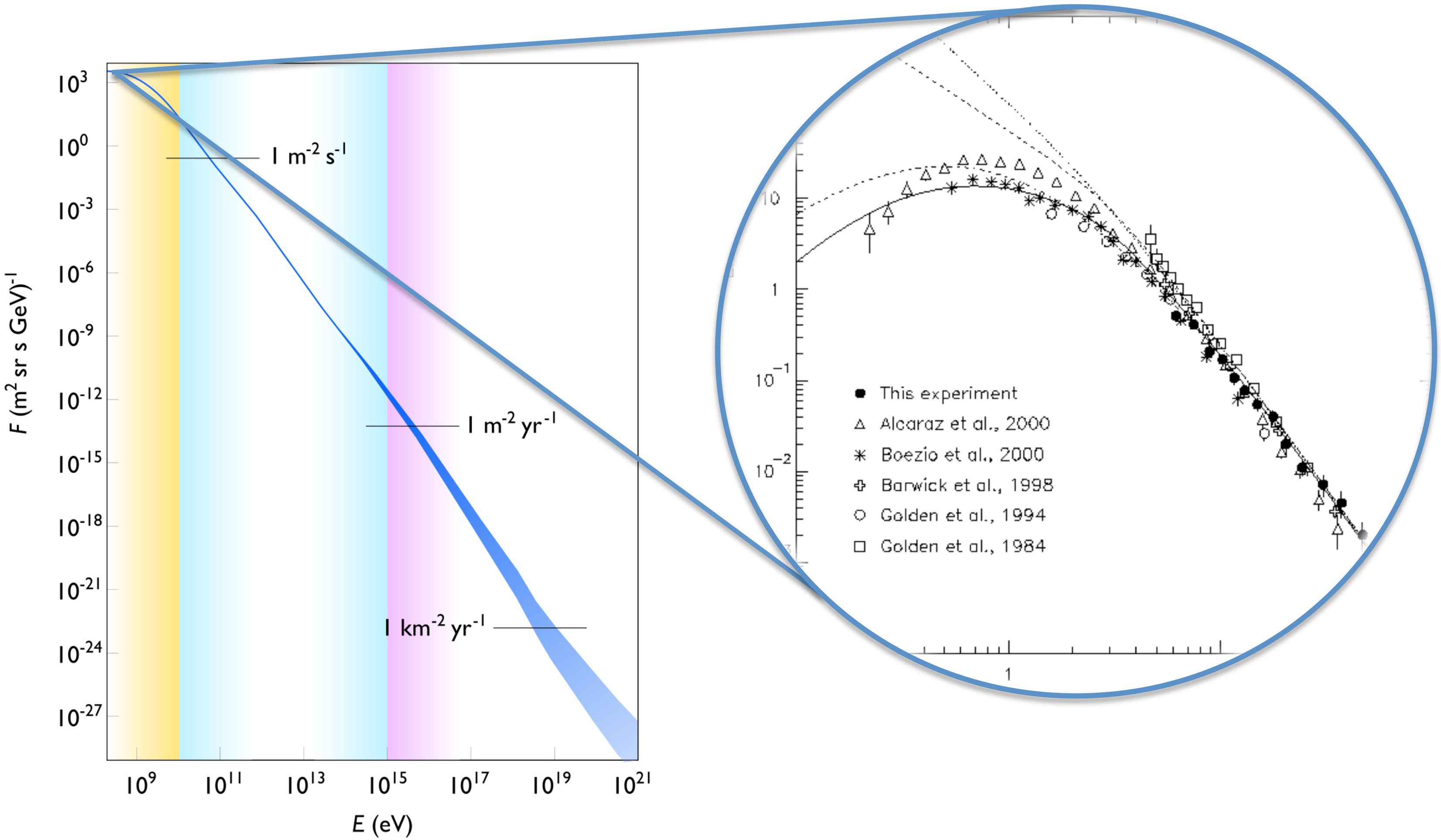
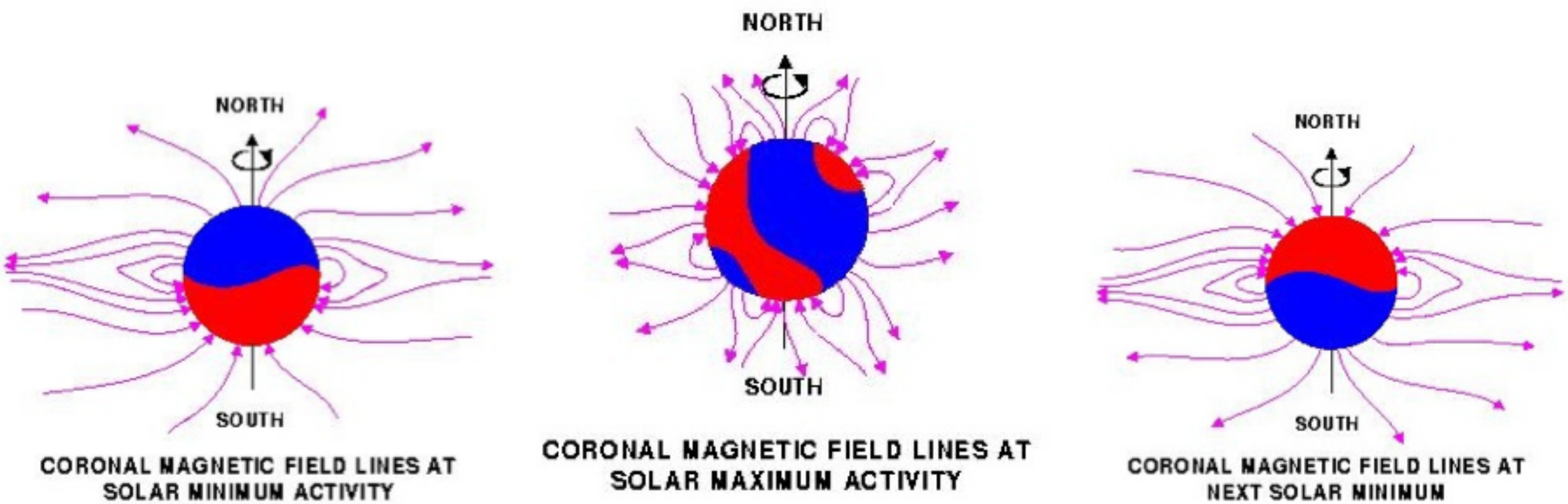


The agents of Solar Modulation

- **The magnetic field of the Sun**



(a) $A > 0$ (b) (c) $A < 0$

Solar Activity Cycle – 11 years

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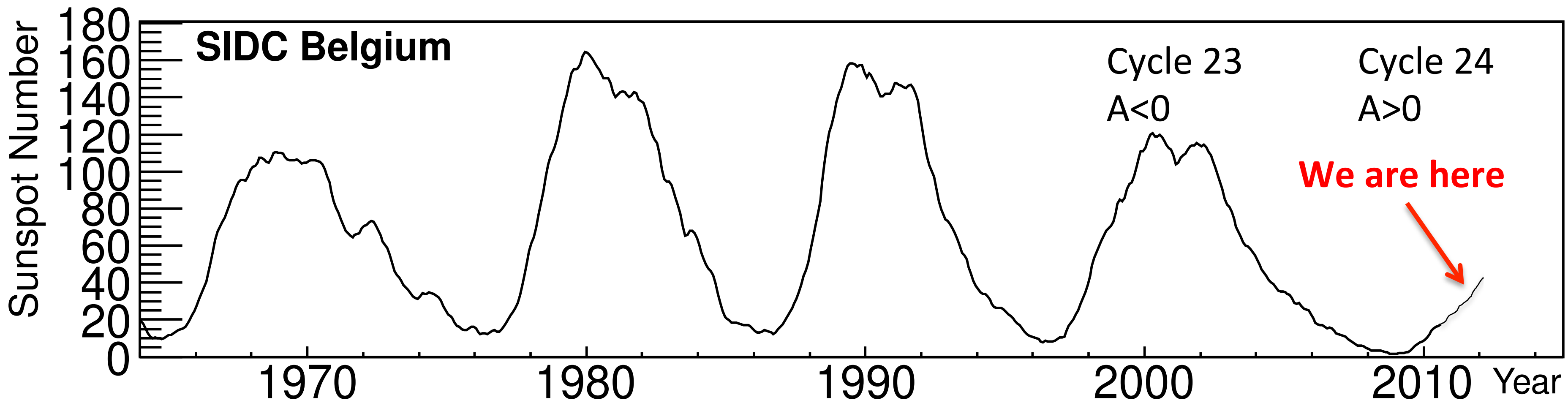

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The agents of Solar Modulation

- **Solar Wind**
- The Sun emits charged particles (p,e^-)
- The magnetic field of the Sun is "frozen" into the Solar Wind
- The Heliosphere is the zone where the solar wind is dominant

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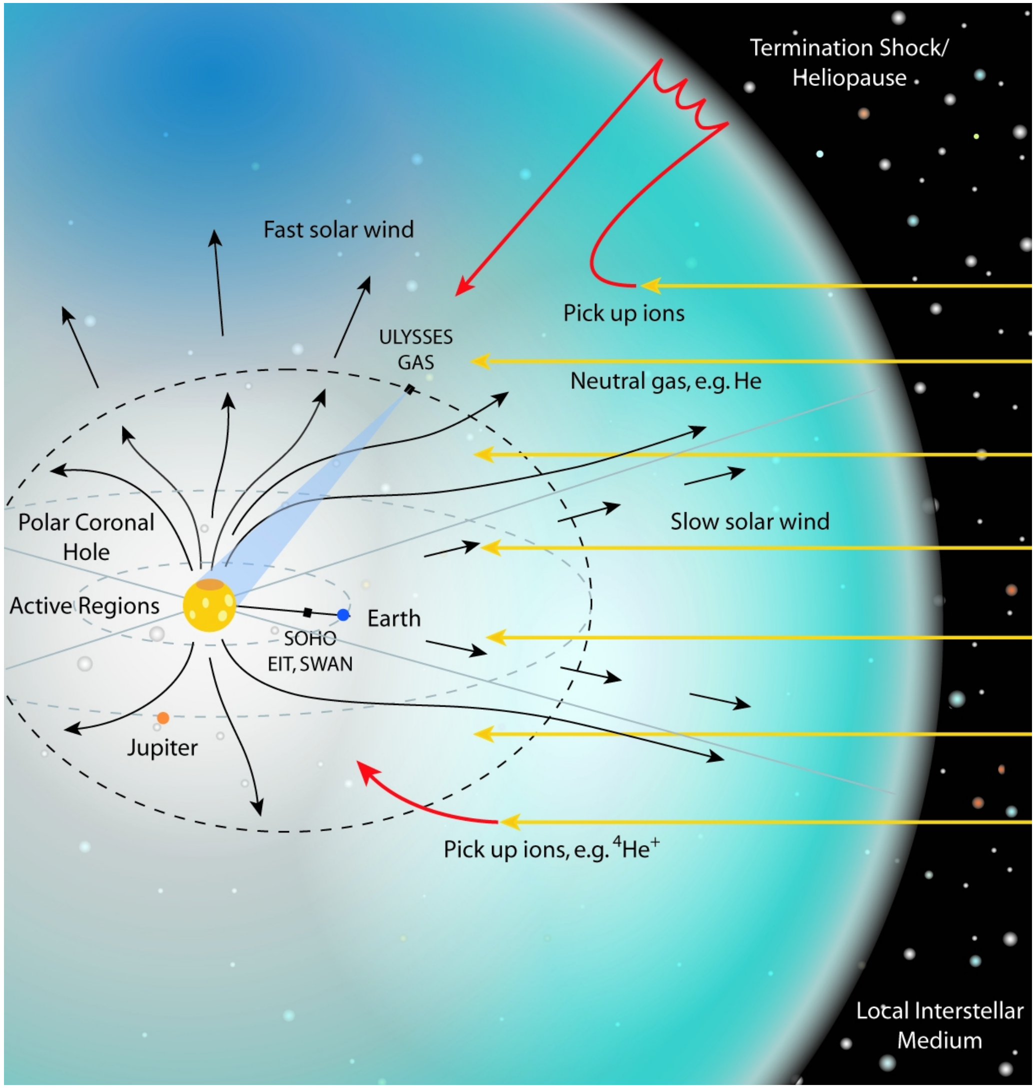

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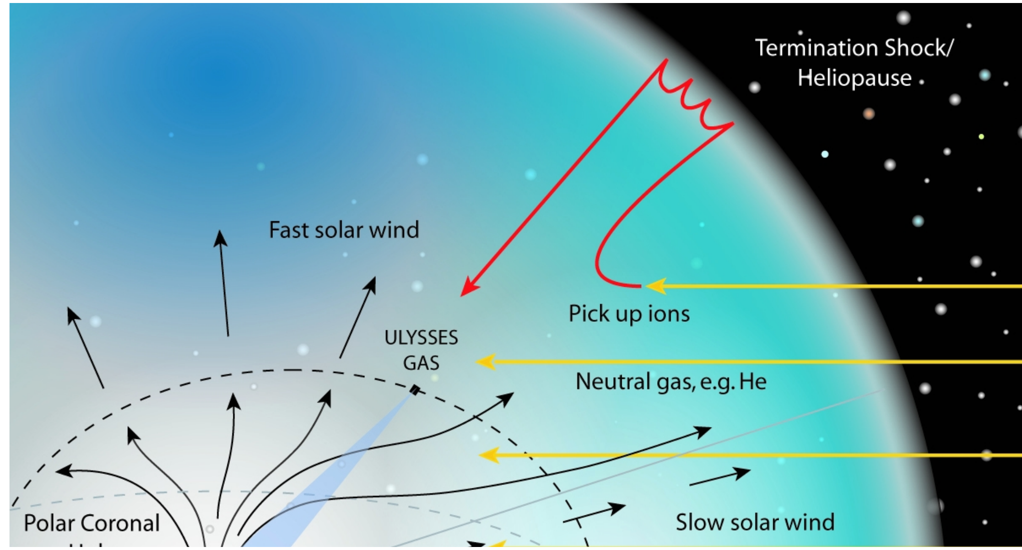
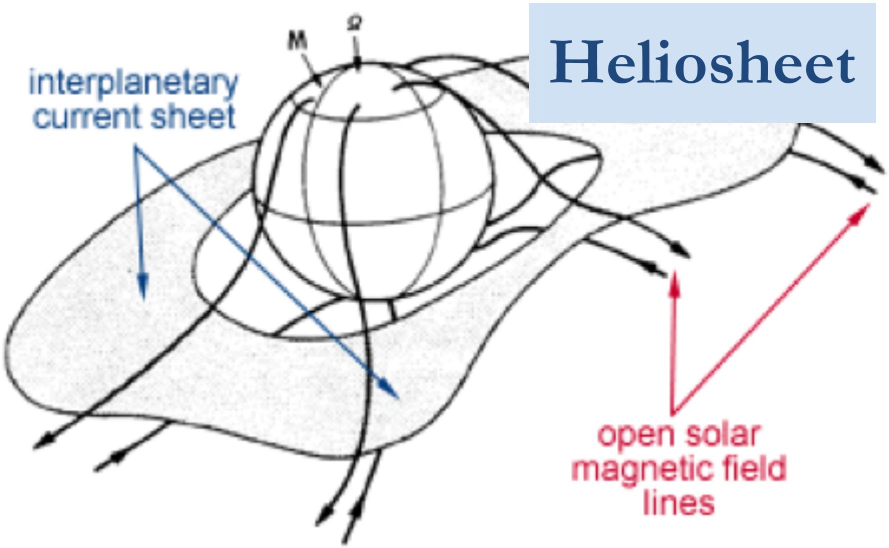
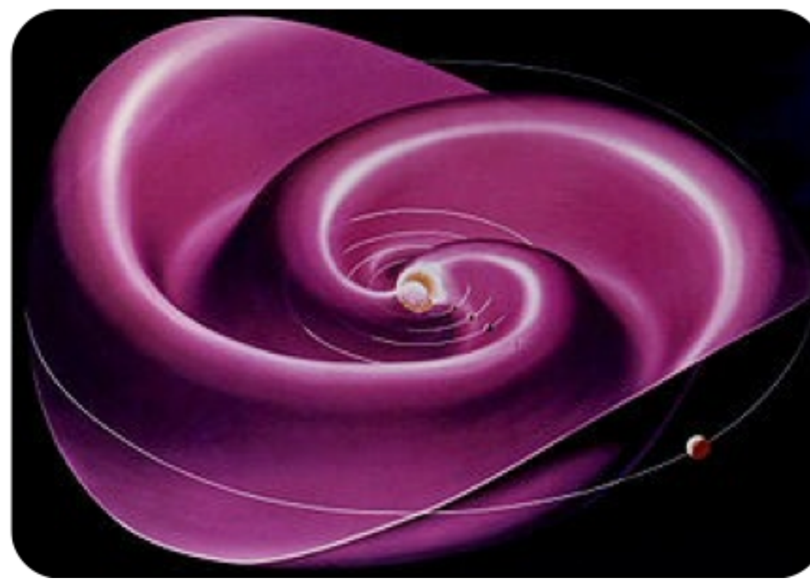


Heliosheet





Parker Model – (Parker 1964)

- **A particle entering the heliosphere faces:**
- The Solar Wind 1
- The magnetic field irregularities 2
- The Large scale magnetic field 3
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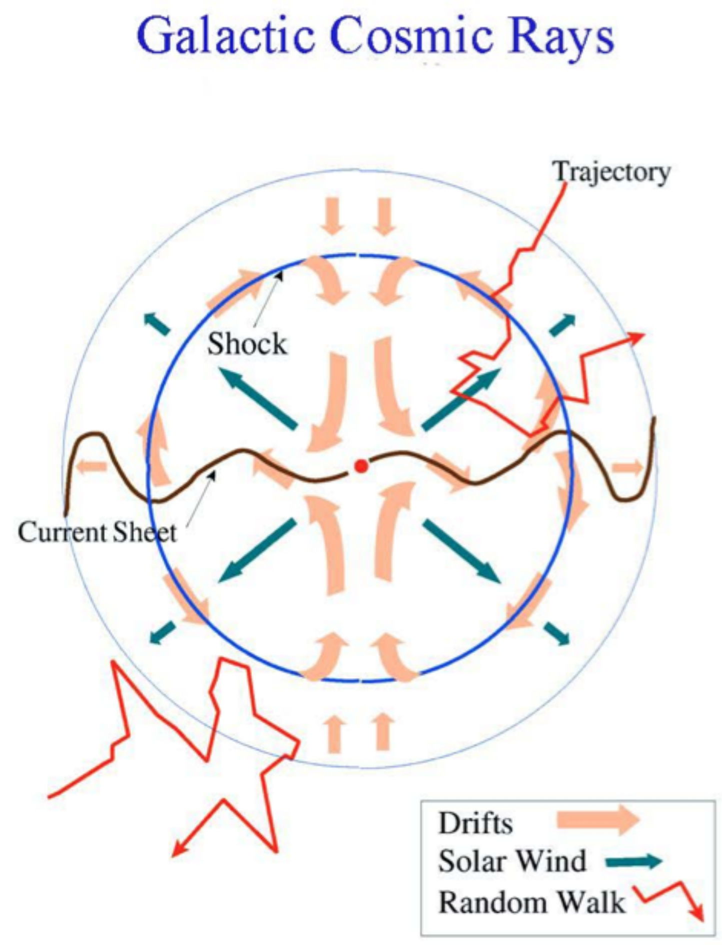

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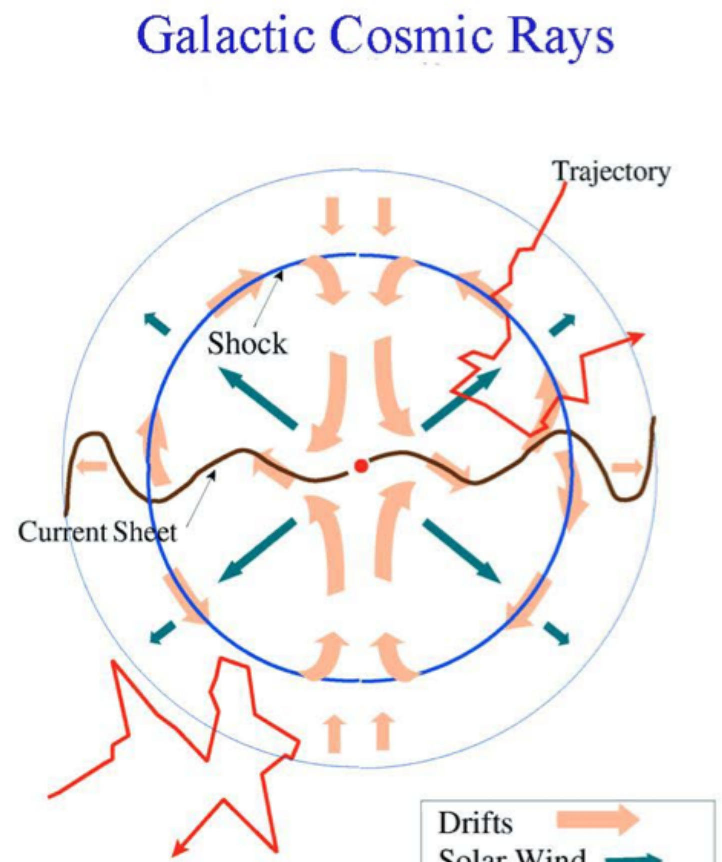

Parker Equation

$$\frac{\partial f}{\partial t} + \underbrace{\vec{V}_{SW}}_{1} \cdot \nabla f - \nabla \cdot \underbrace{(K \cdot \nabla f)}_{2\,3\,4} - \frac{1}{3} \nabla \cdot \underbrace{\vec{V}_{SW}}_{1} p \frac{\partial f}{\partial p} = 0$$

where the differential flux is $J = p^2 f$

Force Field Approximation

- Simplifications (Gleeson e Axford 1968)
  - Solar Wind moves radially with constant velocity ;
  - The heliosphere is spherically symmetric;
  - The drift terms are not considered;
  - Steady-state;

Parker equation is now: $V\frac{\partial f}{\partial r} - \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 k\frac{\partial f}{\partial r}\right) - \frac{1}{3r^2}\frac{\partial}{\partial r}(r^2V)\frac{\partial f}{\partial lnp} = 0$

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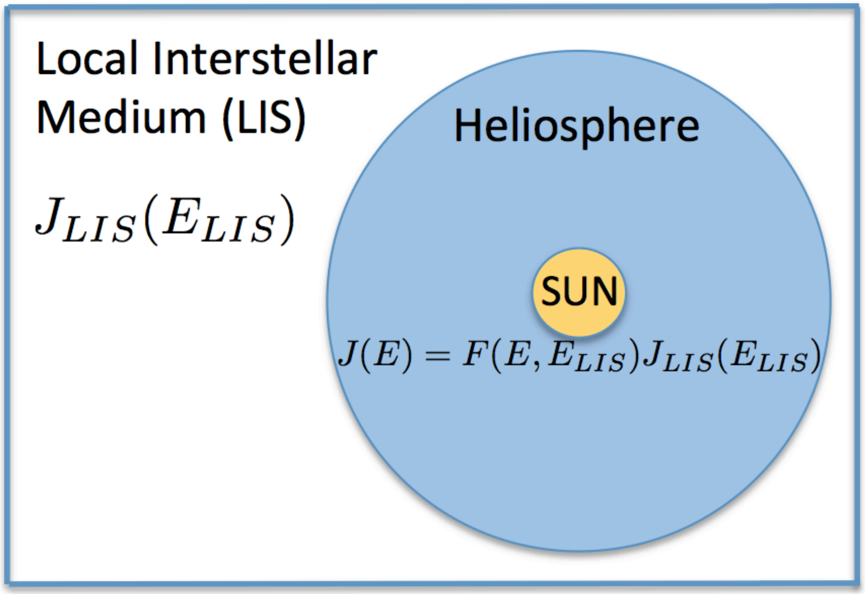

Parker equation is now: $V\frac{\partial f}{\partial r} - \frac{1}{r^2}$

Solution: $$\boxed{J(E) = F(E, \phi_{SM})J_{LIS}(E_{LIS}) = \frac{E^2 - m^2}{(E + |Z|e\phi_{SM})^2 - m^2} J_{LIS}(E_{LIS})}$$

$$E = E_{LIS} - |Z|e\phi_{SM}$$

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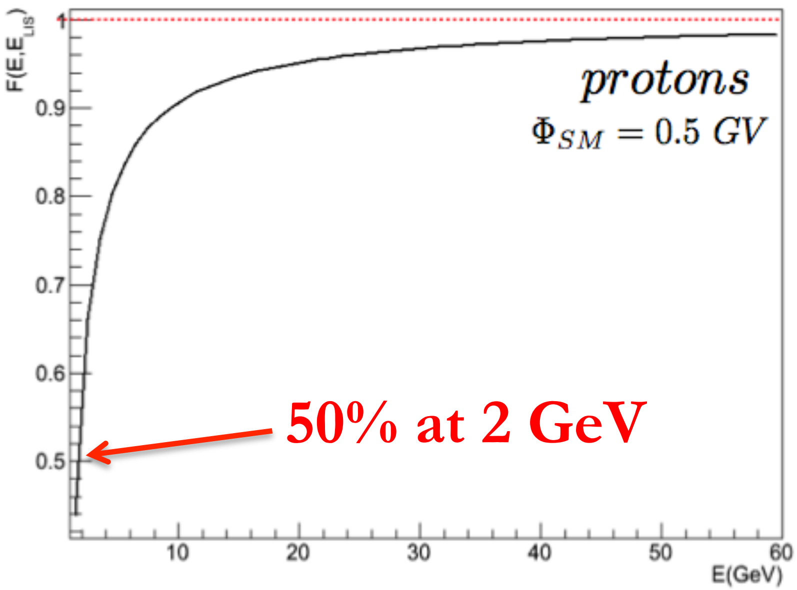

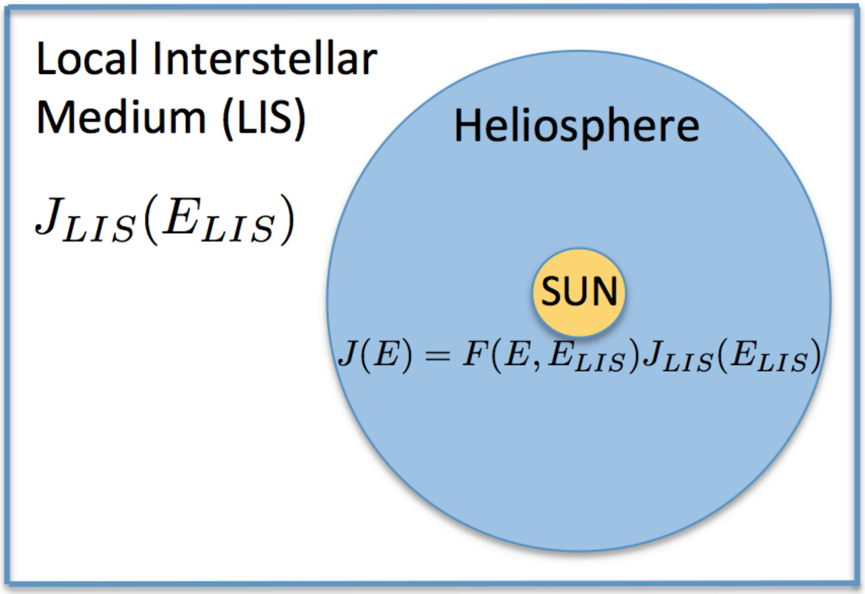

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$$E = E_{LIS} - |Z|e\phi_{SM}$$

Disadvantages of Force Field

- Only good for monthly analysis of the fluxes;
- Is not applicable for very low energies;
- As it doesn't take into account the drift terms it will not explain the fluxes during a period of solar maximum;

Conclusions: To fully understand the effects of solar modulation **we need to solve the equation numerically**

1D solution of Parker Equation

- The equation to solve is $V\frac{\partial f}{\partial r} - \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 k \frac{\partial f}{\partial r}\right) - \frac{1}{3r^2}\frac{\partial}{\partial r}(r^2 V)\frac{\partial f}{\partial lnp} = 0$

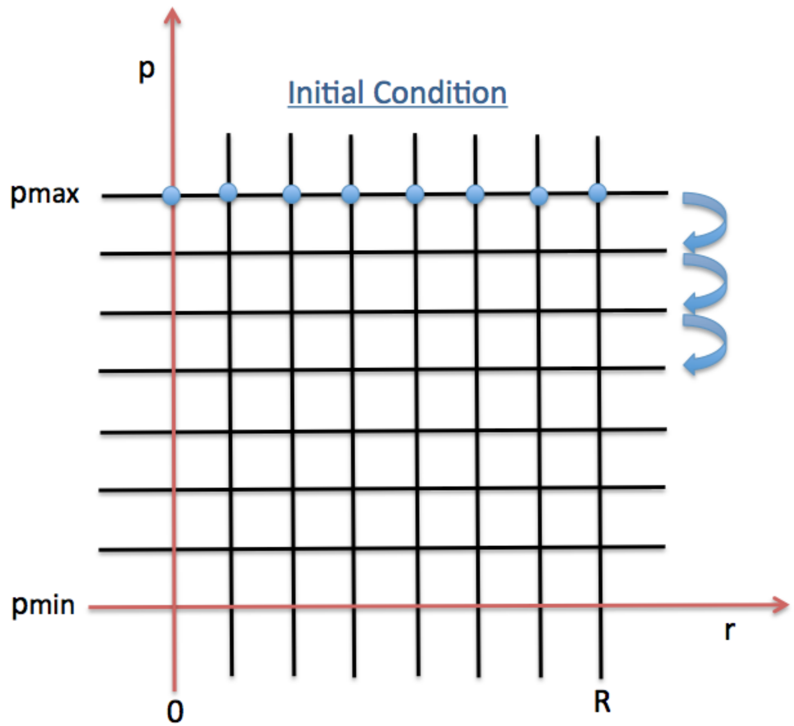
$$k = 4.38 \times 10^{22} \beta P(GV) \ \mathrm{cm^2/s}$$

$$V = 400[1 - e^{-13.3(r-r_0)}] \ \mathrm{km/s}$$

LIS fluxes (Webber and LockWood 2001):

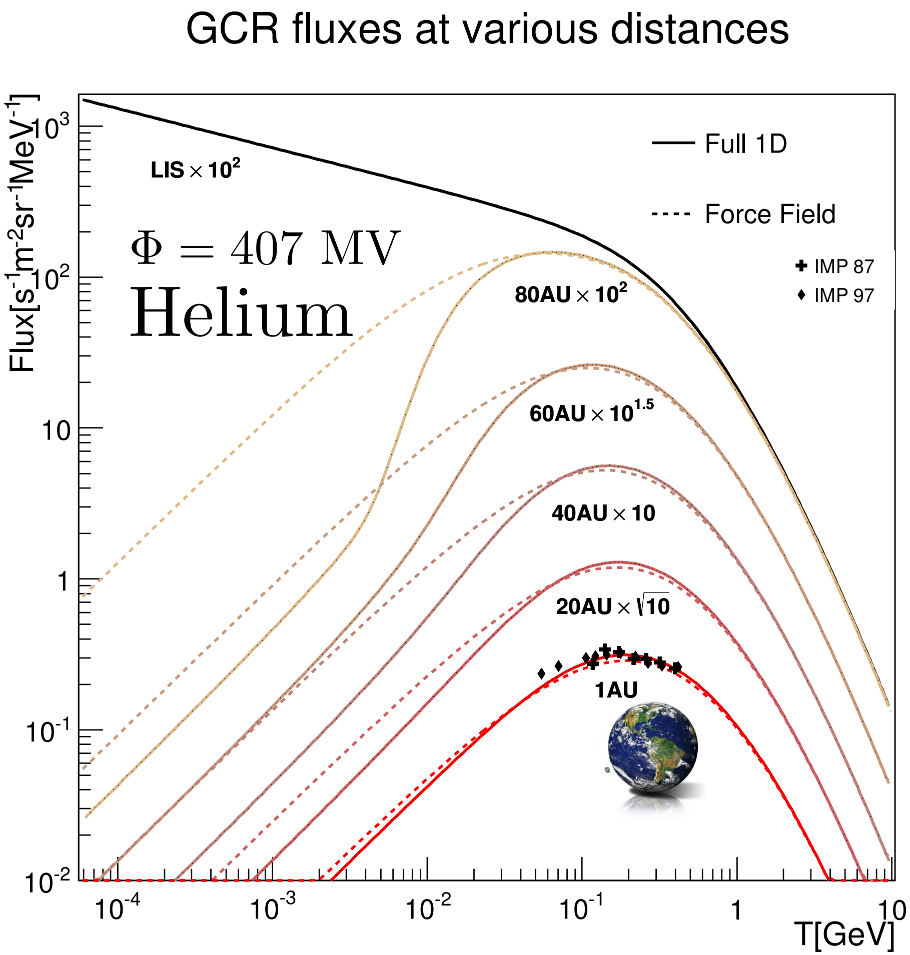
$$J_{LIS}(H) = 21.1 \frac{T^{-2.8}}{1 + 5.85T^{-1.22} + 1.18T^{-2.54}} [\mathrm{s^{-1} m^{-2} sr^{-1} MeV^{-1}}]$$

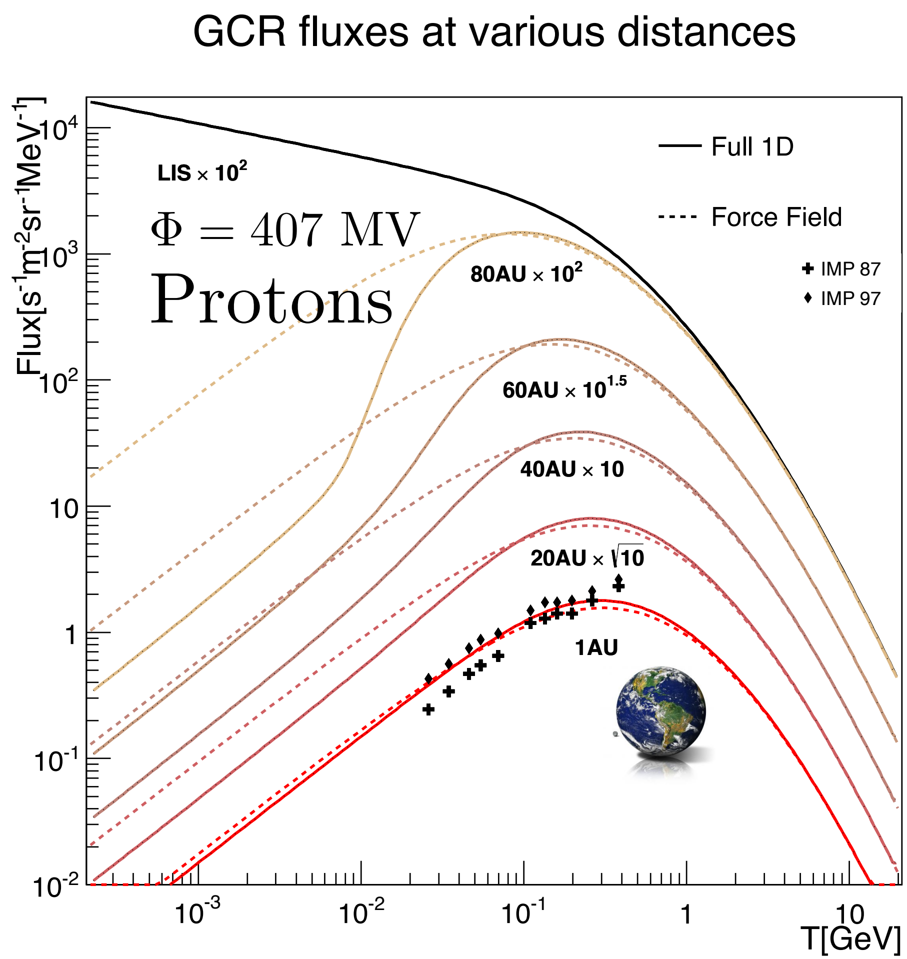
$$J_{LIS}(He) = 1.075 \frac{T^{-2.8}}{1 + 3.91T^{-1.09} + 0.90T^{-2.54}} [\mathrm{s^{-1} m^{-2} sr^{-1} MeV^{-1}}]$$



Solution is done using Crank Nicholson scheme

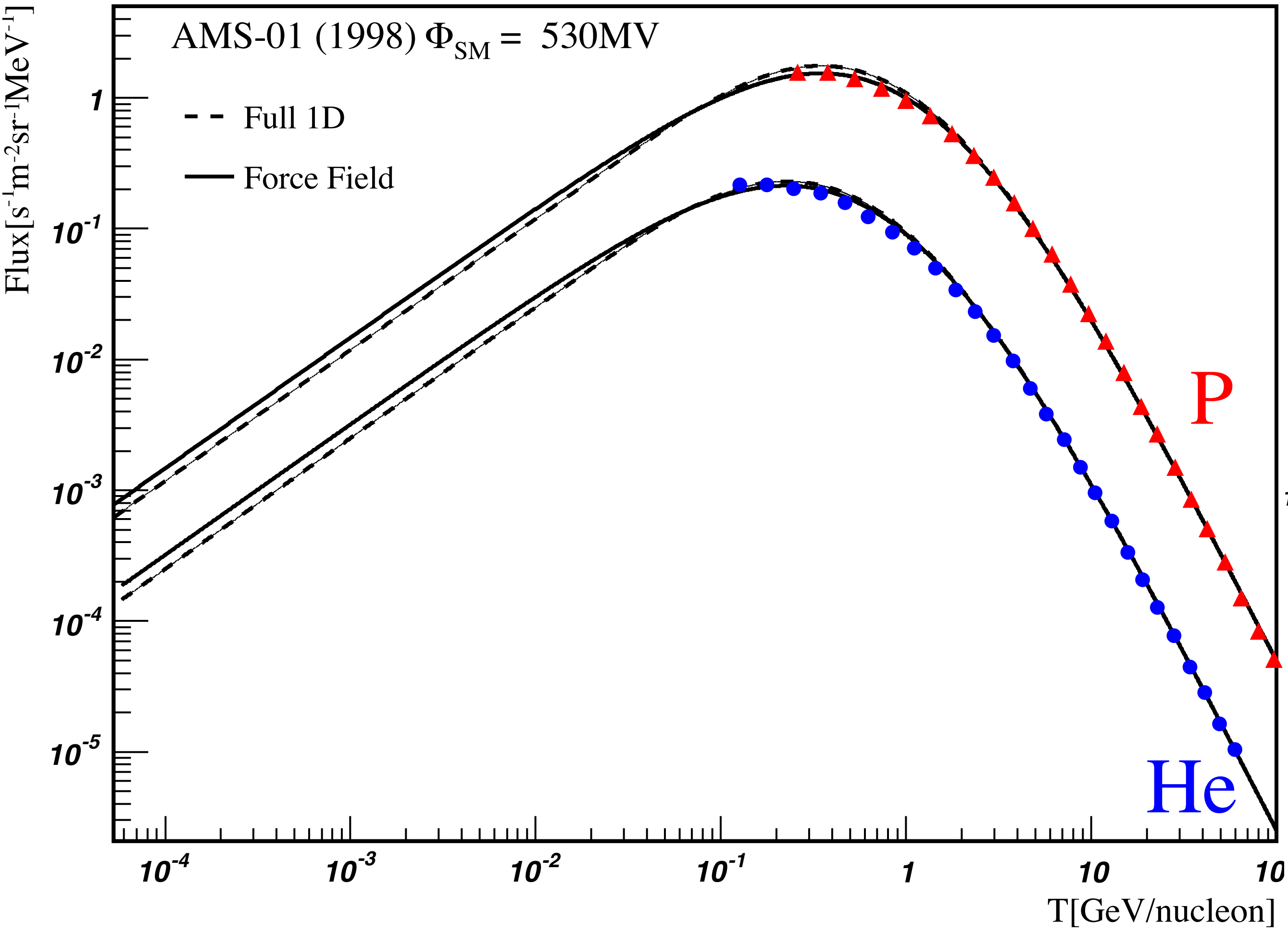
1D solution of Parker Equation



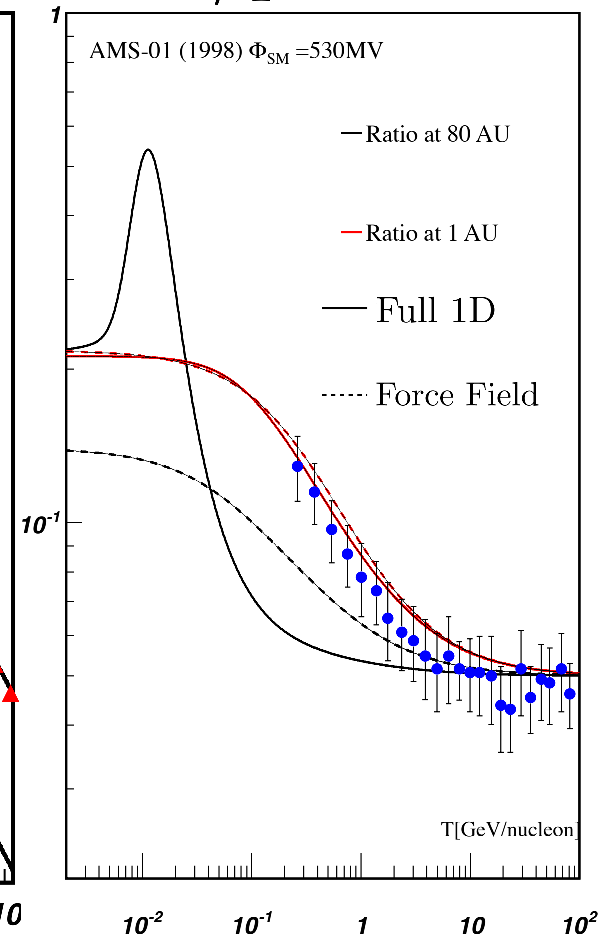


Force Field fails at low energies where the adiabatic energy losses are not taken into account correctly

1D solution of Parker Equation



He/p Ratio



Flux Calculation in AMS-02

$$\Phi_P(E) = \frac{dN}{dE}\frac{1}{\Delta t(E)}\frac{1}{Acc(E)}$$

- The number of events is just the integrated rate

$$dN = \int_{\Delta E} R_0(t)dt$$

- The rate of detected events is different from the rate of events that reach the detector, and so it we define livetime (L)

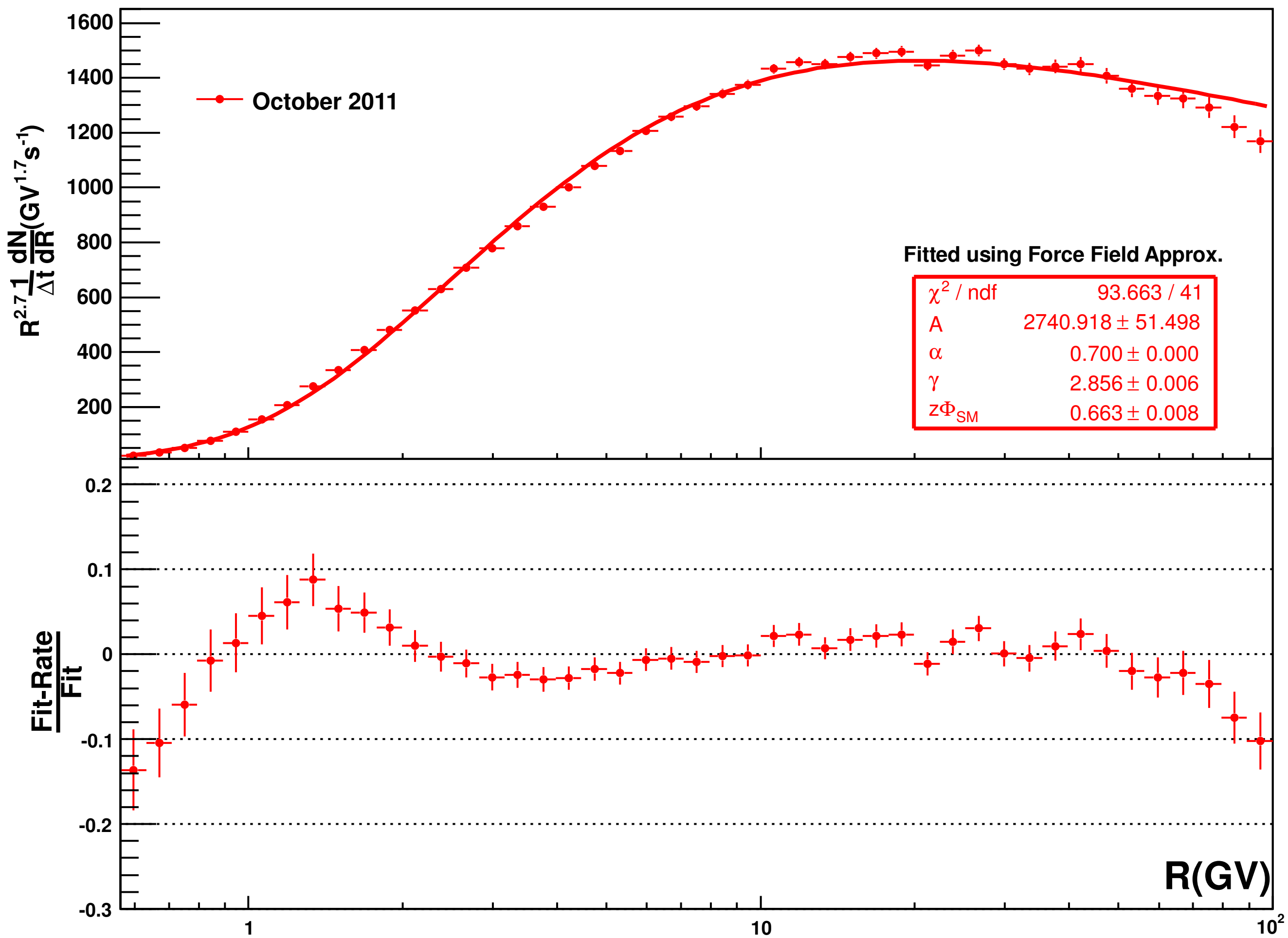
$$L(t) = \frac{R(t)}{R_0(t)} \qquad dN = \int_{\Delta E}\frac{R(t)}{L(t)}dt = \sum_{i=1}^{N(\Delta E)}\frac{1}{L_i(t)}$$

$$\boxed{\Phi_P(E) = \frac{\sum_{i=1}^{N(\Delta E)}\frac{1}{L_i(t)}}{dE}\frac{1}{\Delta t(E)}\frac{1}{Acc(E)}}$$

Things to calculate before determining the flux:

- ✓ **Detector Acceptance**– Acc (E) (using the Monte Carlo)
- ✓ **Exposition Time** – Δ t(E) Daq
- ✓ **Count Primary Events**

Force Field applied to AMS-02 data



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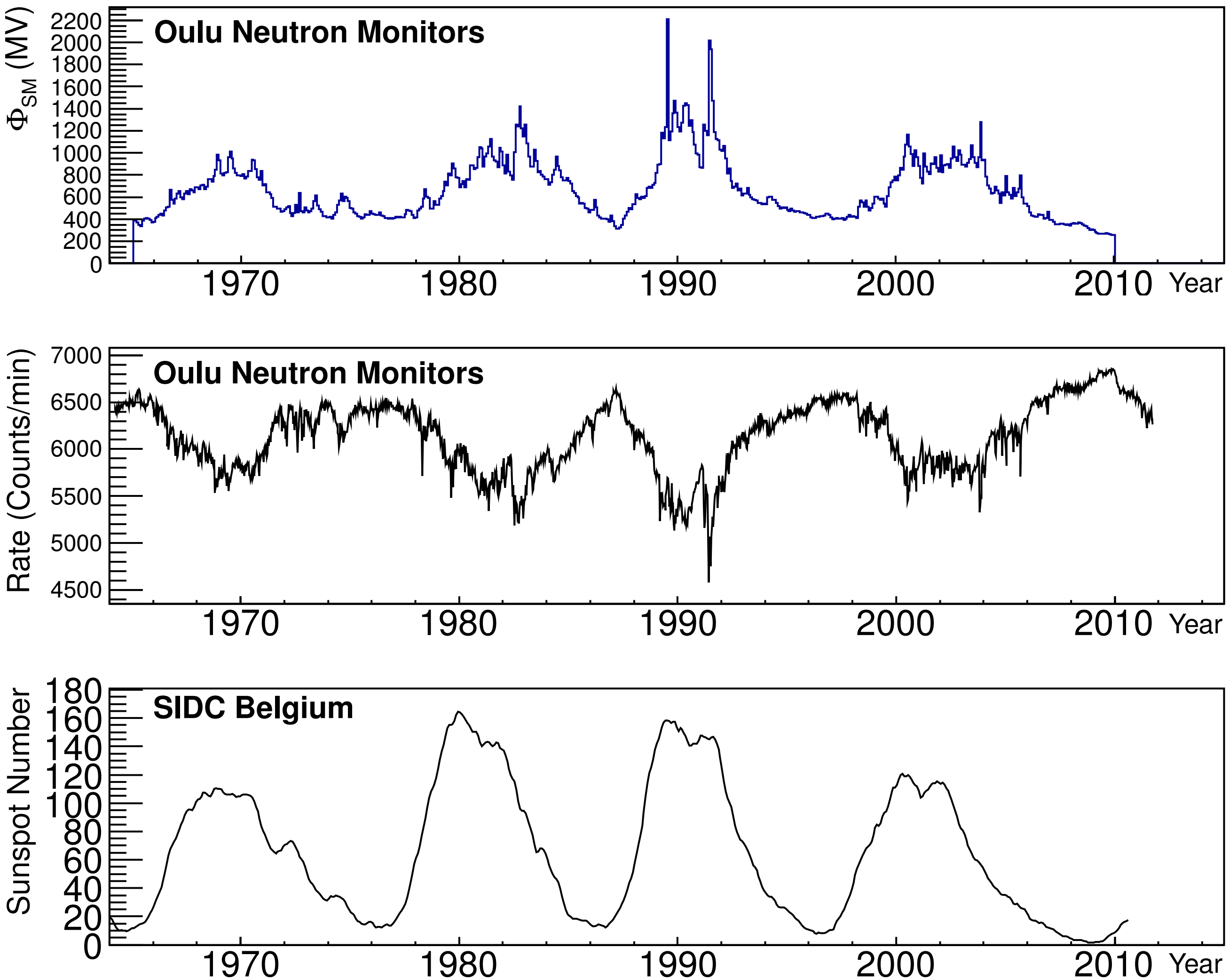

Next Steps

- AMS-02 is acquiring data at a rate, that has never been achieved before, which allows a hourly monitorization of solar activity
  - Solar Flares observation;
  - Forbush decreases;
- Study of the parameters of the models that describe Solar Modulation: Force Field, 1D, 2D
- Variations of the fluxes depending on Solar Activity

Thank You