On the role of the magnetic cloud topology on galactic cosmic-ray Forbush decreases at energies above 70 MeV

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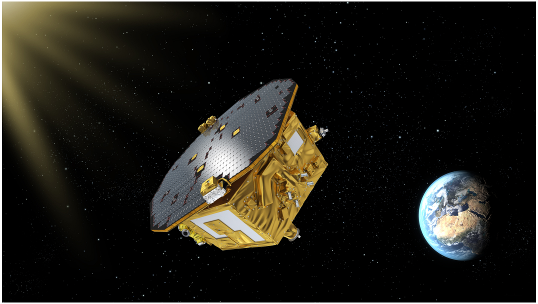
Outline

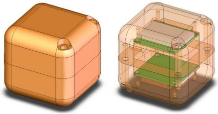
LISA Pathfinder

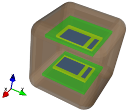


Orbit

- LPF orbit was around the Earth-Sun Lagrangian point L1 at about 1.5 million km from Earth
- The orbit was inclined at about 45 degrees on the ecliptic plane
- LPF took 6 months to complete the orbit
- The satellite spinned on its own axis in 6 months

Particle Detector



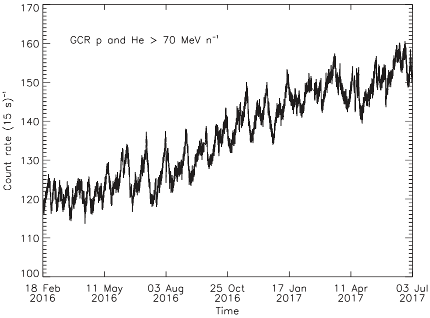


I Mateos, et al., Journal of Physics: Conference Series. Vol. 228. No. 1. IOP Publishing, 2010

Two silicon wafers 1.4x1.05x0.03 cm^3 inside a shielding copper box 6.4 mm thick

- Maximum allowed detector counting rate: 6500 counts s^{-1}
- Acquisition rate: 0.067 Hz (15 counts s^{-1})
- Integral proton and helium fluxes above 70 MeV n^{-1}

Particle Detector Data

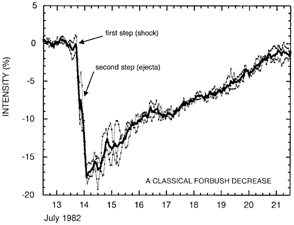


M. Armano et al., The Astrophysical Journal 854.2 (2018): 113

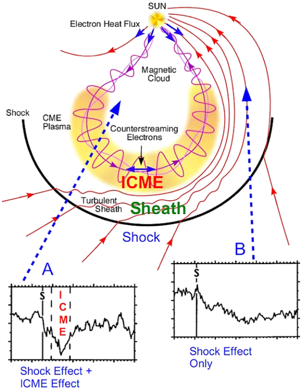
- LPF Particle Detector data from 2016 February 18 to 2017 July 3
- Hourly averaged data in order to limit the statistical uncertainty to 1%

Short Term Variations of Galactic Cosmic Rays

Less than 1 month



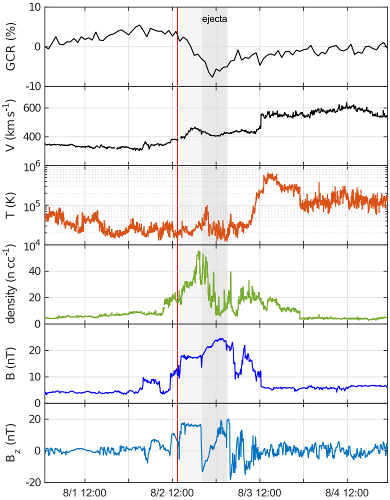
H. V. Cane, 2000, SSRv, 93, 55



I. G. Richardson and H. V. Cane, Solar Physics 270.2 (2011): 609-627

- The largest Forbush Decrease (FD) that LPF observed was between 2 and 3 August 2016

2016 August 2: Forbush Decrease



Disturbance Y/M/D (UT) (a)	ICME Plasma/Field Start, End Y/M/D (UT) (b)	
2016/08/02 1400	2016/08/02 1400	2016/08/03 0300

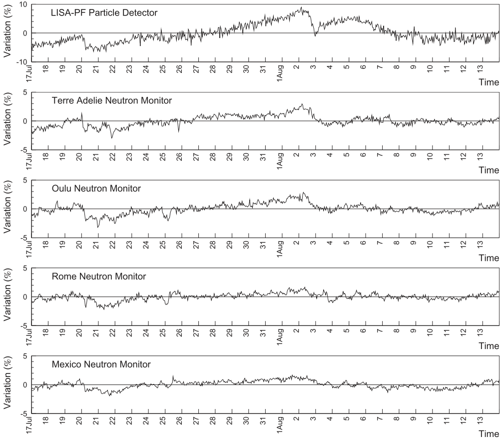
Richardson and Cane (http://www.srl.caltech.edu/ACE/ASC/DATA/level3/icmetable2.htm)

No.	Time Range
2683	2016/08/02 21:00 ~ 2016/08/03 02:55

Zheng and Hu (http://fluxrope.info/index.html)

- $V_{ICME} = 420$ km/s
- $V_{MAX} = 460$ km/s
- $< B > = 22.89$ nT
- $B_{max} = 25.48$ nT

Comparison with Neutron Monitors



While the GCR fractional variation observed with LPF above 70 MeV n^{-1} is of about 10%, it goes down to a maximum of 3% in near-polar stations and to a maximum of 2% at increasing latitudes

M. Armano et al., The Astrophysical Journal 854.2 (2018): 113

Grad-Shafranov Reconstruction

- For 2D quasi-stationary magnetic field structure, in a reference frame moving with the structure, the equilibrium equation can be written as a Grad-Shafranov (GS) plane equation (Hau and Sonnerup, 1999)

$$\frac{\partial^2 A}{\partial x^2} + \frac{\partial^2 A}{\partial y^2} = -\mu_0 \frac{d}{dA} \underbrace{\left(p + \frac{B_z^2}{2\mu_0}\right)}_{P_t}$$

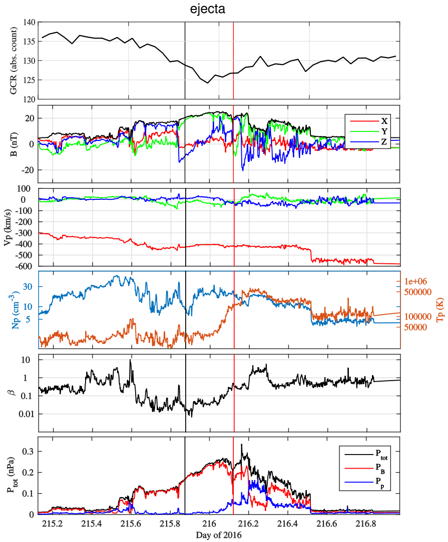
  where $\hat{z}$ is the invariant direction, $\partial / \partial z = 0$

- $\boldsymbol{B} = \left(\partial A/\partial y, -\partial A/\partial x, B_z(A)\right)$
- By choosing $\hat{x}$ along the velocity of the structure $-V_0$, $\hat{x}$ represents the path of the s/c
- Velocity estimation through the de Hoffmann-Teller analysis
- Optimization procedure based on P_t as a function of A only is used to determine the orientation of the invariant axis
- Fixed the reference frame, P_t is fitted with a proper analytical function and the right term of the GS plane equation is evatuated

References:

Q Hu, BUÖ Sonnerup, Journal of Geophysical Research: Space Physics 107.A7 (2002)
C Möstl et al., Sol. Phys. 256 (2009) 427–441

2016 August 2: Wind Data



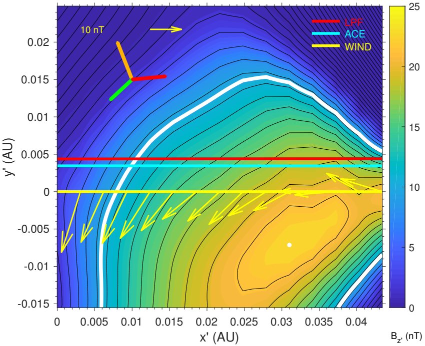
LISA Pathfinder

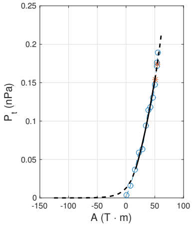
GCR intensity

WIND

B, V_p, N_p, T_p, β and P

Grad-Shafranov Reconstruction





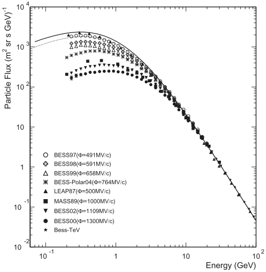
Fit residue: $R_f = 0.03$

X GSE Y GSE Z GSE

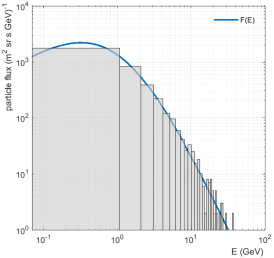
- dHT velocity $[-413.69, -27.94, 11.64]$ km/s
- GS orientation: latitude -19.68°, longitude 229.54°
- Max $|B_z| = 23.1$ nT
- MC diameter ~ 0.07 AU

A simple Particles Simulation

- Simulation of a relativistic proton and helium propagation through the 2.5D magnetic structure obtained from the Grad-Shafranov reconstruction
- Energies of the random selected particles are extracted from the 2016 August 2 energy spectrum extrapolated at the 21:00 UT (beginning of the MC region)



M. Armano et al., The Astrophysical Journal 854.2 (2018): 113



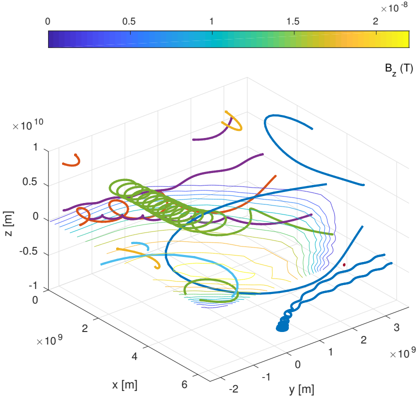
Energy Spectrum of particles used in the simulation

$$F(E) = A(E+b)^{-\alpha} E^{\beta}$$

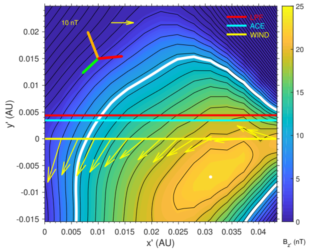
$$A = 18000,\ b = 1.034,\ \alpha = 3.66,\ \beta = 0.869$$

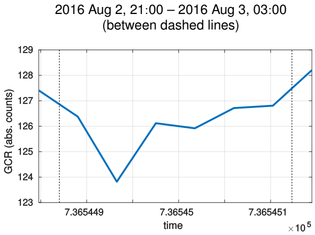
A simple Particles Simulation

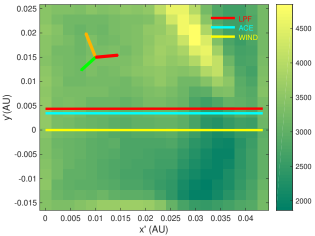
- $E_{min} = 70 MeV$
  $E_{max} = 100 GeV$
- The simulation space is divided in cells where the crossing particles are counted and the output is a count matrix

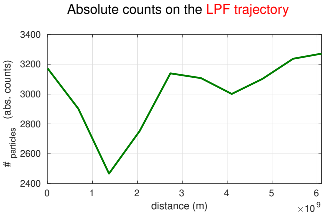


Conclusions and future work









Conclusions and future work

- Generally, the shock/sheat region and the magnetic cloud have comparable effects on the GCR modulation. Indeed LPF measured a 7% variation during the shock/sheat part and a 3% variation due to the magnetic cloud transit.
- In the numerical simulation the particle count variation along the LPF path is about 20% with an isotropic flux of particles entering the magnetic cloud from all directions with zero magnetic field outside.
- The profile of GCR variation observed on LPF is well reproduced by the simulation, this seem to be addressed by the magnetic configuration of the region explored by the s/c.