Forbush decreases observed with GRAPES-3

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Outline

- (Quick intro to) Coronal Mass Ejections (CMEs) from the Sun

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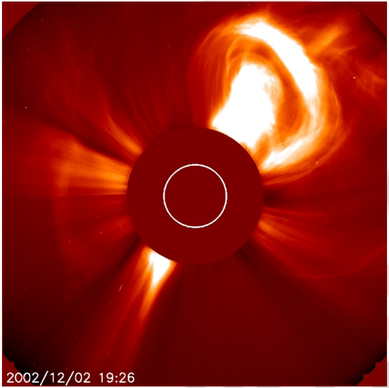
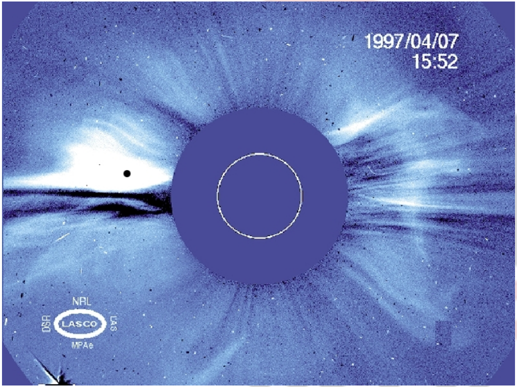
- (Quick intro to) Forbush Decreases (FDs)
- Main Q we try to answer: What are Forbush decreases (predominantly) due to: (near-Earth manifestations of) CMEs or their associated shocks?
- This work is a followup to Subramanian et al 2009, and is part of Arun Babu's PhD thesis

CME



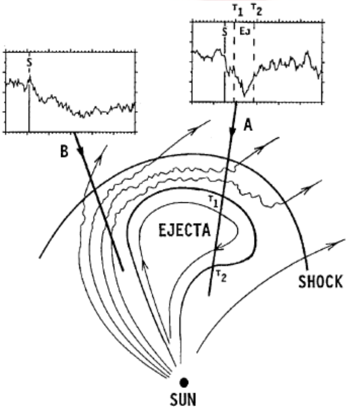
Plane-of-sky CME (from LASCO/SOHO)

CME



Halo (Earth-directed) CME (from LASCO/SOHO)

Forbush Decrease



Forbush decreases (from Cane 2000)

Cutoff Rigidity

- Rigidity $Rg\,(\mathrm{volts}) \equiv P\,c/Z\,e = 300\,B\,(\mathrm{Gauss})\,r_{\mathrm{L}}\,(\mathrm{cm})$

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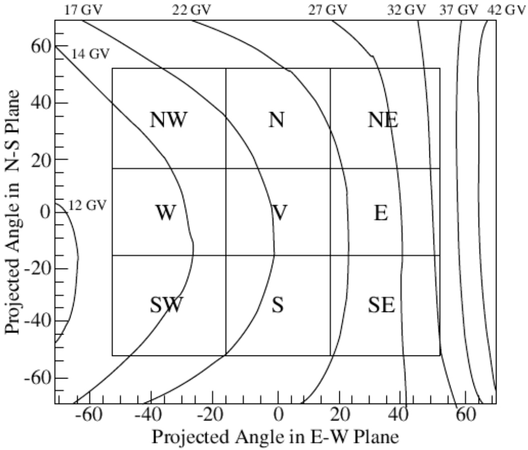
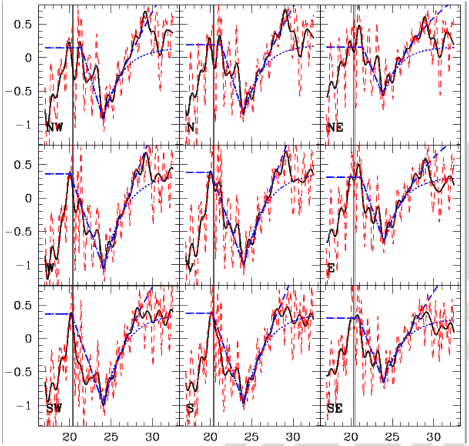
- The cutoff rigidity is very dependent on the B field geometry;
  $\rightarrow$ 0 for a nearly vertical field,
  $\rightarrow \infty$ for nearly horizontal field;
  i.e., its dependent on the viewing direction (different for East, West, North, South)

9 directional bins make GRAPES-3 a multi-rigidity instrument



FD on 20 Nov 2003



Forbush decrease on Nov 20 2003 observed with GRAPES-3

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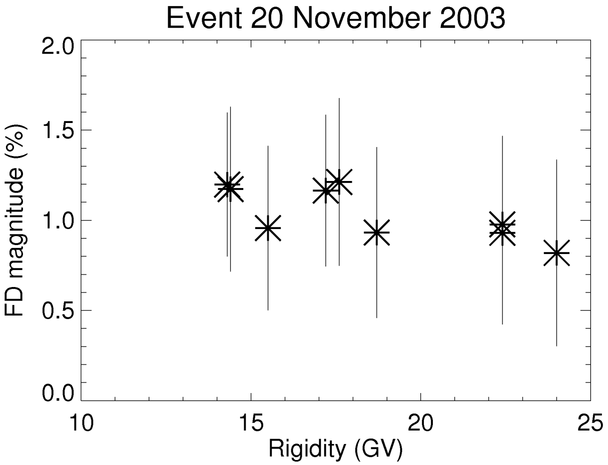
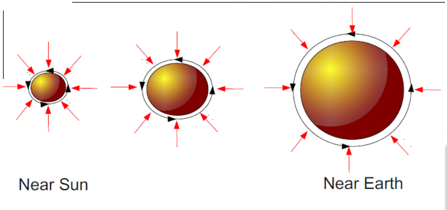


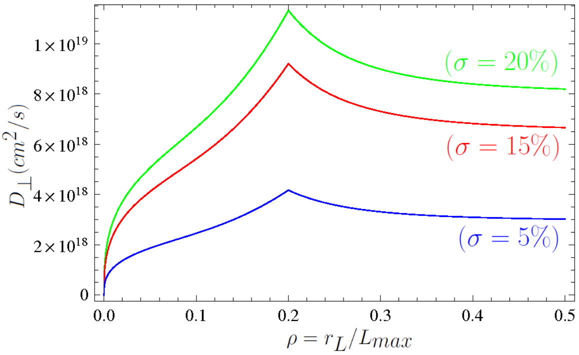
Forbush decrease on Nov 20 2003 observed with GRAPES-3

The CME-only model (following Subramanian et al 2009)



High energy galactic (*not of solar origin*) cosmic rays progressively diffuse into the expanding, propagating CME bubble, across the B fields bounding it. At the earth, the density contrast between the CME interior & outside (in high energy CR protons) is manifested as the Forbush decrease. The diffusion coefficient $D_{\perp}$ depends upon the CR proton rigidity Rg and the turbulence level σ^2 near the CME. $D_{\perp}$ is taken from analytical fits to Monte Carlo simulations of charged particle diffusion in turbulent B fields (Candia & Roulet 2004).

$D_\perp(Rg\,,\sigma^2)$: Candia & Roulet (2004)



$\rho \equiv r_{\rm L}/L_{\rm max}$ (similar to proton rigidity). $L_{\rm max} \equiv$ largest lengthscale in the problem. $r_{\rm L}$ is proton gyroradius. Turbulence level near CME $\sigma^2 \equiv \langle B^2_{\rm turb}/B^2_0 \rangle$

The CME-only model: details

Flux of protons entering CME is

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- $\partial N_a/\partial r \approx N_a/L_{\mathrm{CR}} = N_a/\kappa\, r_{\mathrm{L}}^{0.33}$. $L_{\mathrm{CR}} \rightarrow$ cosmic ray density variation lengthscale (O'Gallagher 1967).

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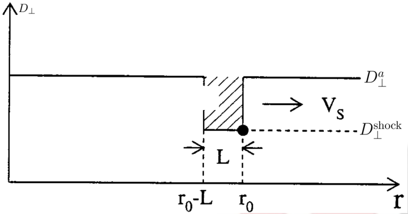
- Turbulence level near CME $\sigma^2 \equiv \langle B_{\mathrm{turb}}^2/B_0^2\rangle$.

The shock-only model (following Wibberenz et al 1998)



The Forbush decrease is due to the shock - a propagating, diffusive barrier. The B field enhancement at the shock acts as an "umbrella" against galactic cosmic rays.

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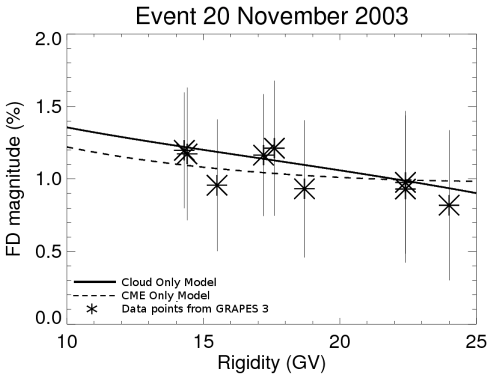
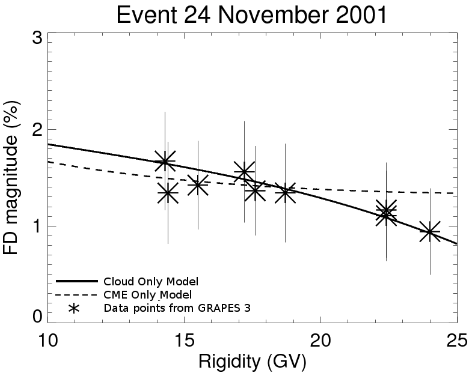
- Turbulence level $\sigma^2_{\rm shock}$ taken to be twice $\sigma^2_{\rm ambient}$

Results - I



For CME-only model, $\sigma = 5$ %,
while for shock-only model $\sigma_{\mathrm{ambient}} = 25$ %.
Typical quiet sun turbulence level σ (at $15 - 50\ R_{\odot}$) $\approx$ 6–15 % (Spangler 2002).

Results - II



For CME-only model, $\sigma = 8\%$,
while for shock-only model $\sigma_{\mathrm{ambient}} = 100\ \%$!
Typical quiet sun turbulence level σ (at $15 - 50\ R_{\odot}$) $\approx$ 6–15 % (Spangler 2002).

Conclusions

We have fitted CME-only and shock-only models to multi-rigidity data of FDs for the first time. We use a couple of representative, well observed events, and use as many observed parameters as possible. Our main fitting parameter is the turbulence level σ. On this basis, we find that the low density (CR) bubble/CME is the major contributor to the observed FD, as opposed to the shock/umbrella driven by it.

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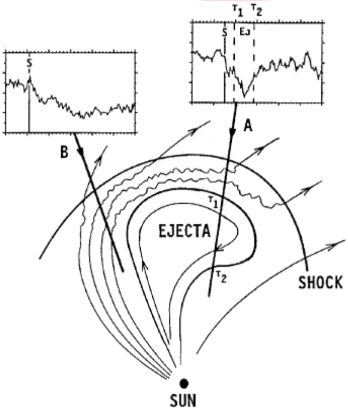

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We have fitted CME-only and shock-only models to multi-rigidity data of FDs for the first time. We use a couple of representative, well observed events, and use as many observed parameters as possible. Our main fitting parameter is the turbulence level σ. On this basis, we find that the low density (CR) bubble/CME is the major contributor to the observed FD, as opposed to the shock/umbrella driven by it. This represents a paradgim shift in our understanding of FDs.