Forbush decreases associated to Stealth CMEs

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Outline

- Motivation
- A long detour: Modulation of galactic cosmic rays
- Short term effects
    - Forbush decreases and the interplanetary counterpart of a CME
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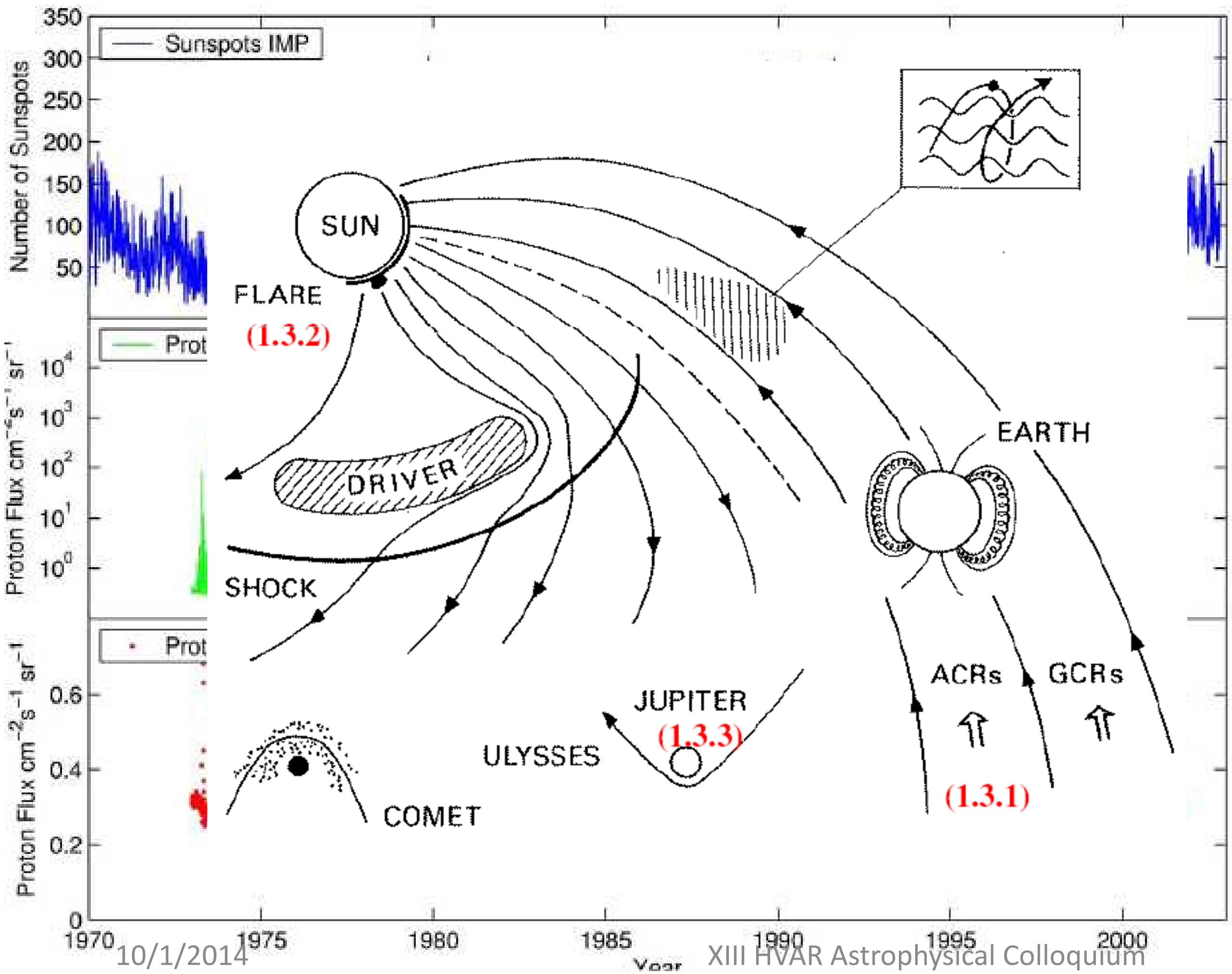
- Summary and Conclusion

Why are we interested in energetic particles and its variation?



Because the phenomena exists!
Unique possibility to investigate astrophysical plasma particle interaction, particle acceleration and injection "in-situ"

Kallenrode, 2010

Kunow et al., 1991

Impact on deep space travel

Relativistic Electrons: ~10

50 MeV Protons: 30-80 Minutes

'My God, space is radioactive!'

Ernie Ray, 1958

(member of Van Allen's Explorer I team)

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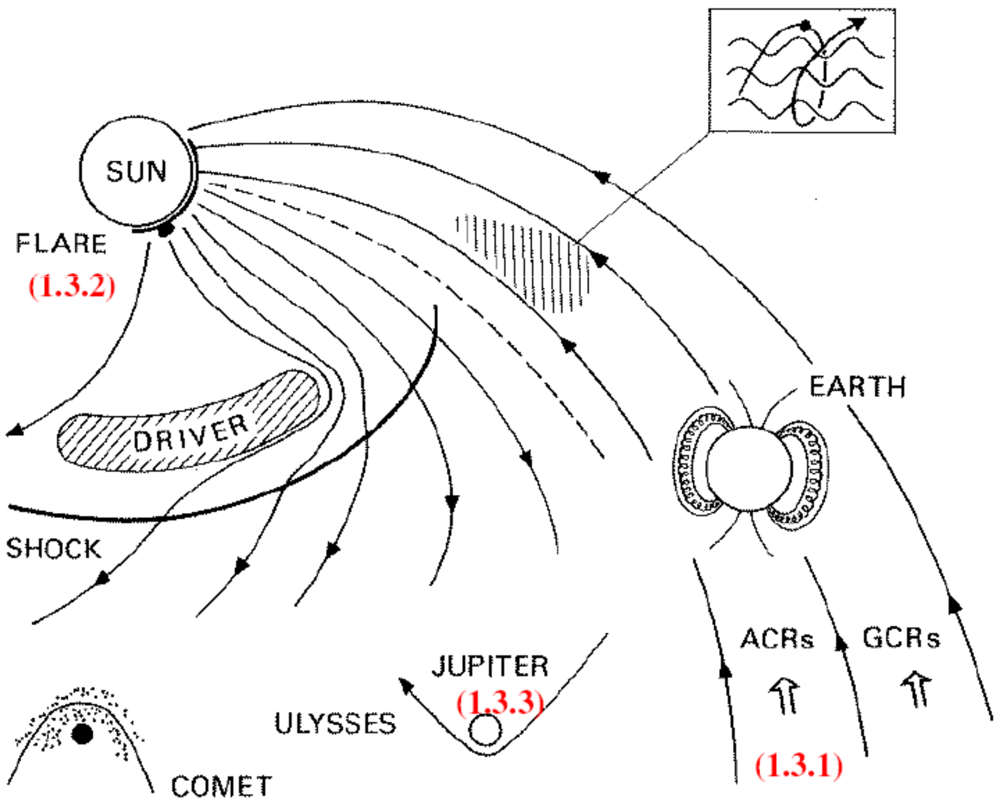
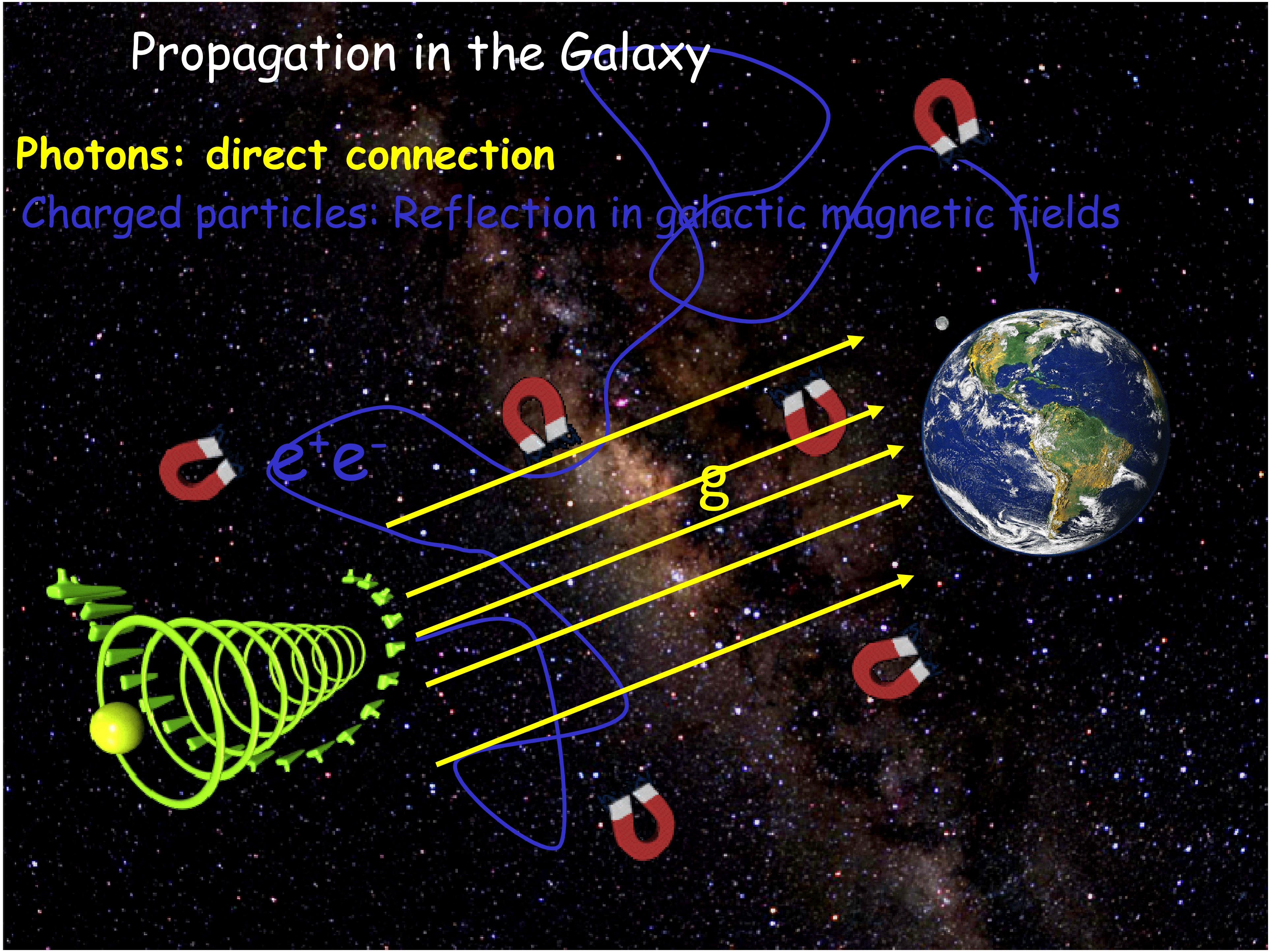
Sources inside and outside of the heliosphere

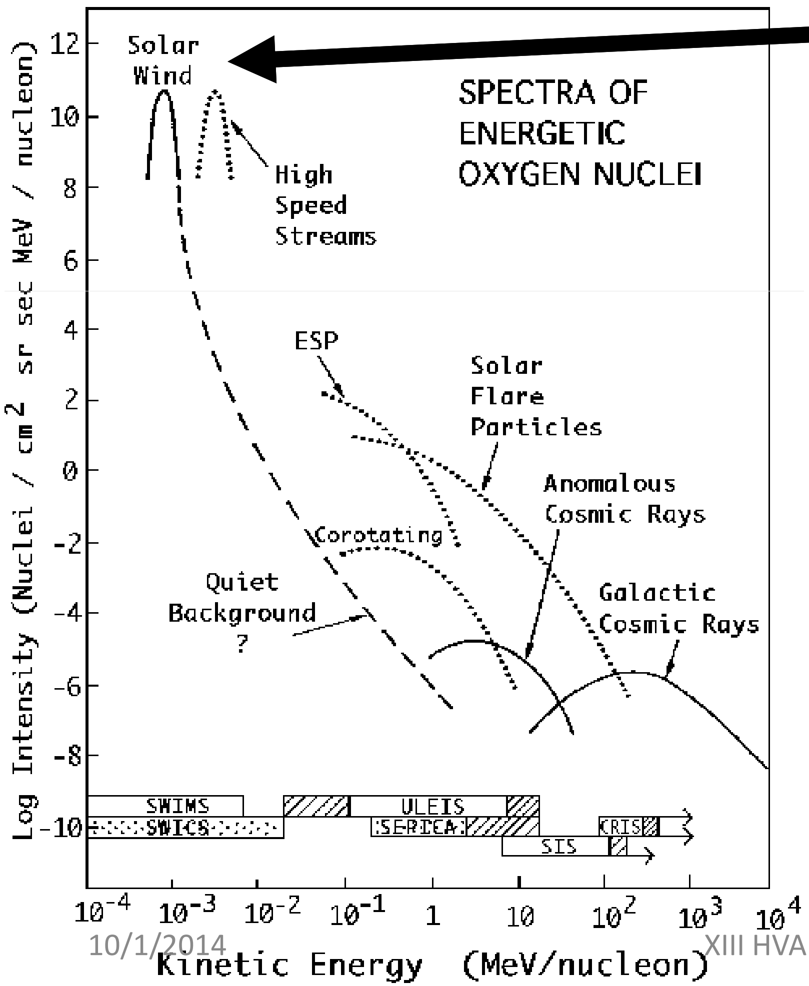


Kunow et al., 1991

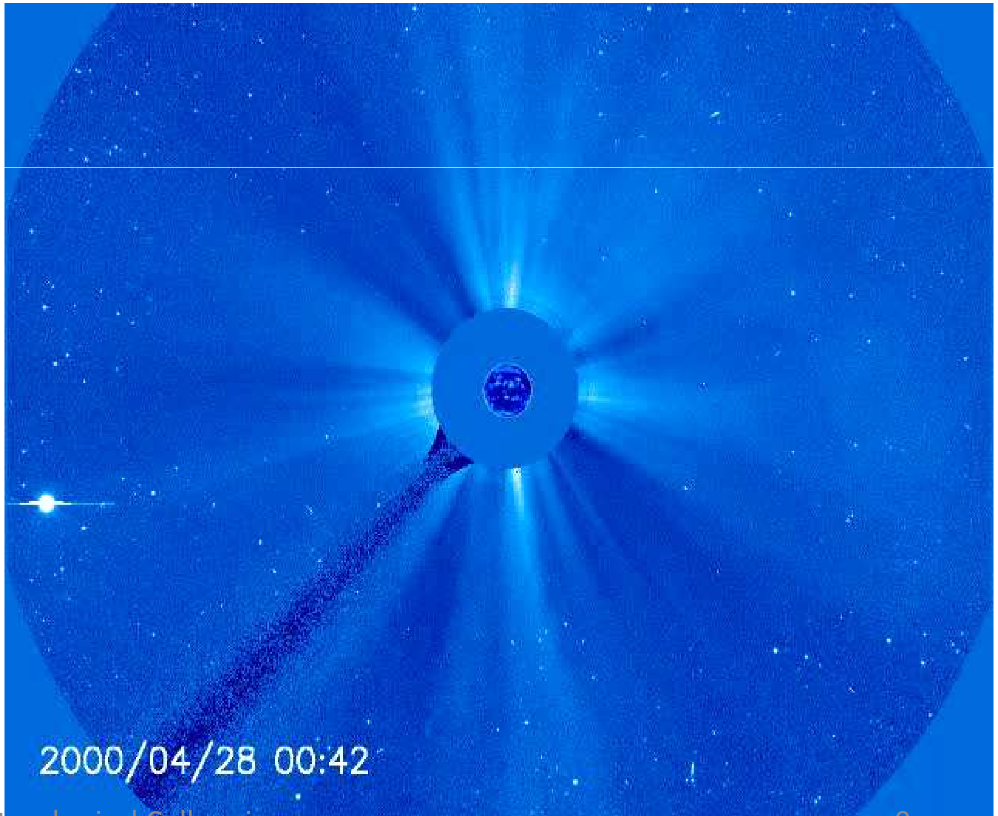
- **Galactic cosmic rays**
- **Planetary magnetospheres and shocks**
- **Anomalous cosmic rays**
- **Solar energetic particles**
- **Energetic storm particles**
- **Corotating, or traveling shocks**


Propagation in the Galaxy
Photons: direct connection
Charged particles: Reflection in galactic magnetic fields
e^+e^-
g

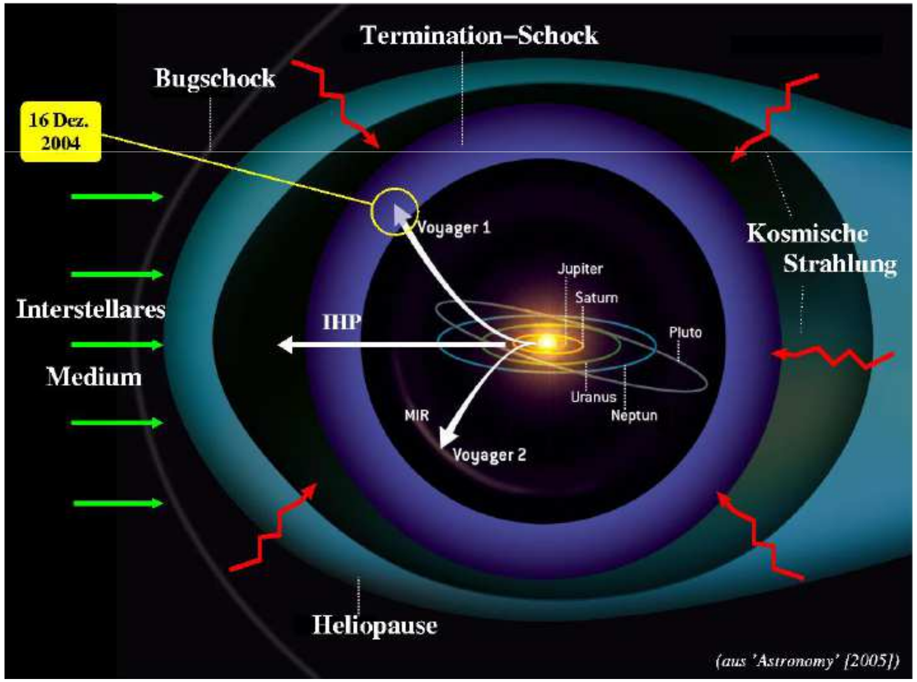
The solar wind extends into interstellar space

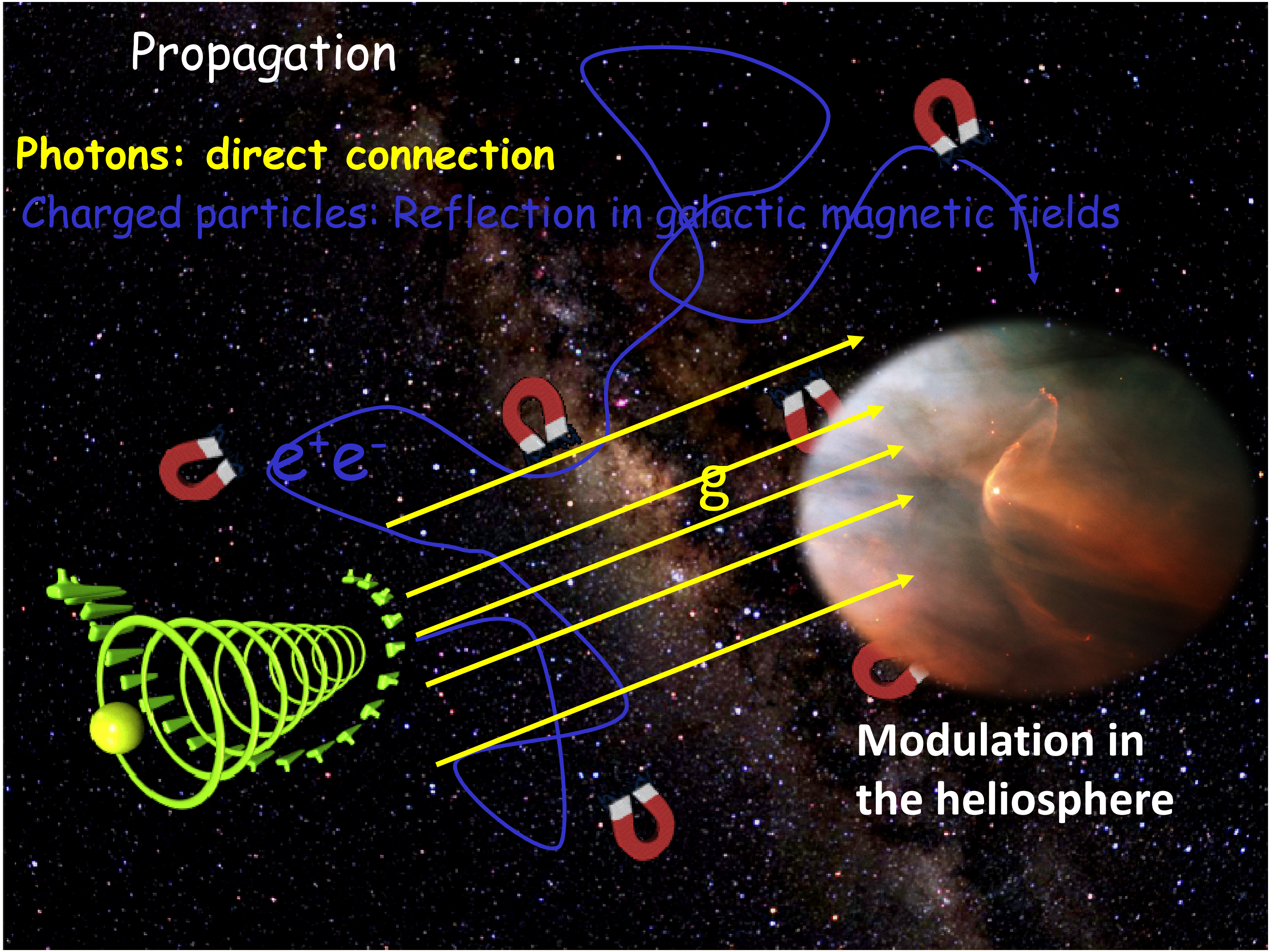


Slow and high speed wind



- The Atmosphere of the Sun extends into interstellar space
- Forming the heliosphere
- Termination shock (90 AU)
- Heliopause (120 AU)
- Bow shock (350 AU)




Propagation
Photons: direct connection
Charged particles: Reflection in galactic magnetic fields
e+e-
g
Modulation in
the heliosphere

Parker’s Transport model

f is the differential CR number density with respect to p:

$$\begin{aligned} \frac{\partial f}{\partial t} &= \nabla \cdot \left(\kappa^{(S)} \cdot \nabla f\right) && \text{diffusion} \\ &- \vec{V} \cdot \nabla f && \text{convection} \\ &+ \frac{1}{3}\left(\nabla \cdot \vec{V}\right) \frac{\partial f}{\partial \ln p} && \text{ad. energy change} \\ &+ Q && \text{Source term} \end{aligned}$$

Diffusion approximation

- Force field solution:

$$J_i(T, \phi) = J_{\mathrm{LIS},i}(T + \Phi) \frac{(T)(T + 2T_r)}{(T + \Phi)(T + \Phi + 2T_r)},$$

Solar modulation at minimum of solar cycle XXIII years 2006-2008

$F_{is} = 1.54\ \beta_{is}^{0.7}\ R_{is}^{-2.76}$

p/(cm² s sr GV)

Spectral index

2.76 ±0.01

$$J(r,E,t) = \frac{E^2 - E_0^2}{(E^2+\Phi(t))^2 - E_0^2} J(\square, E+\Phi(t))$$

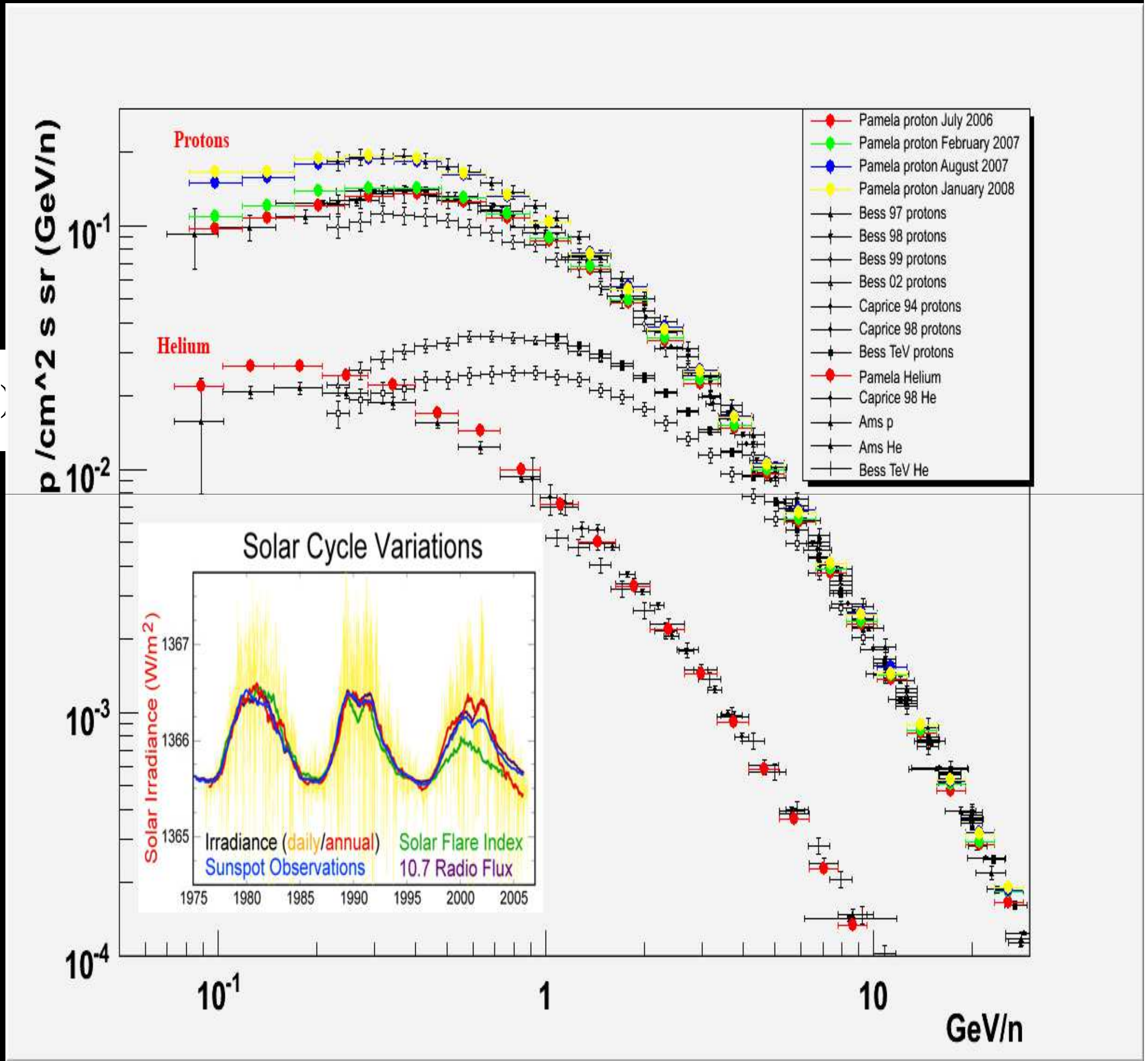
Solar modulation parameter ϕ(GV)

JUL06: 5.81-01 ± 2e-03

DEC07: 5.00-01 ± 2-03

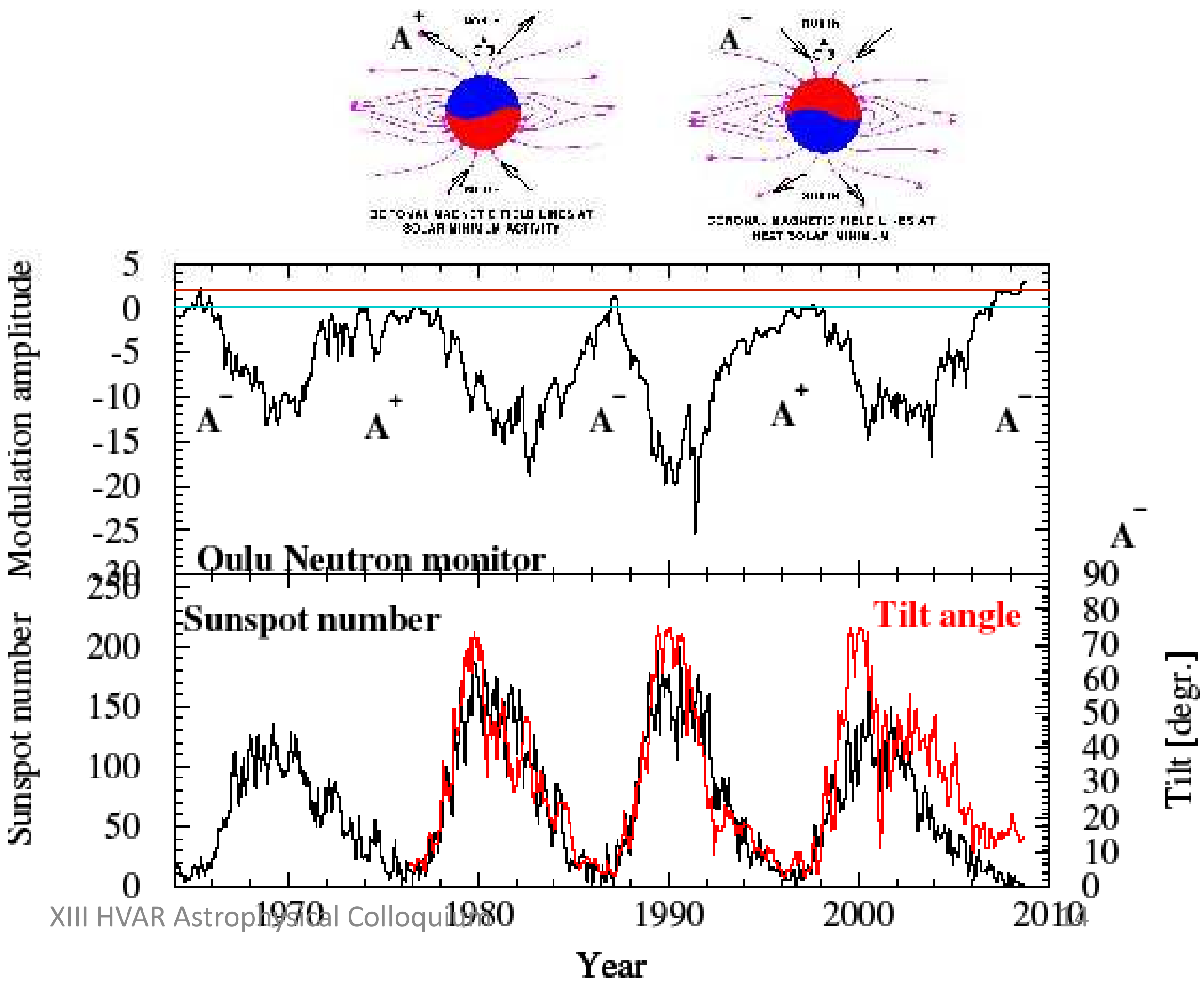
DEC08: 4.82-01 ± 3-03

Different models by Alankrita

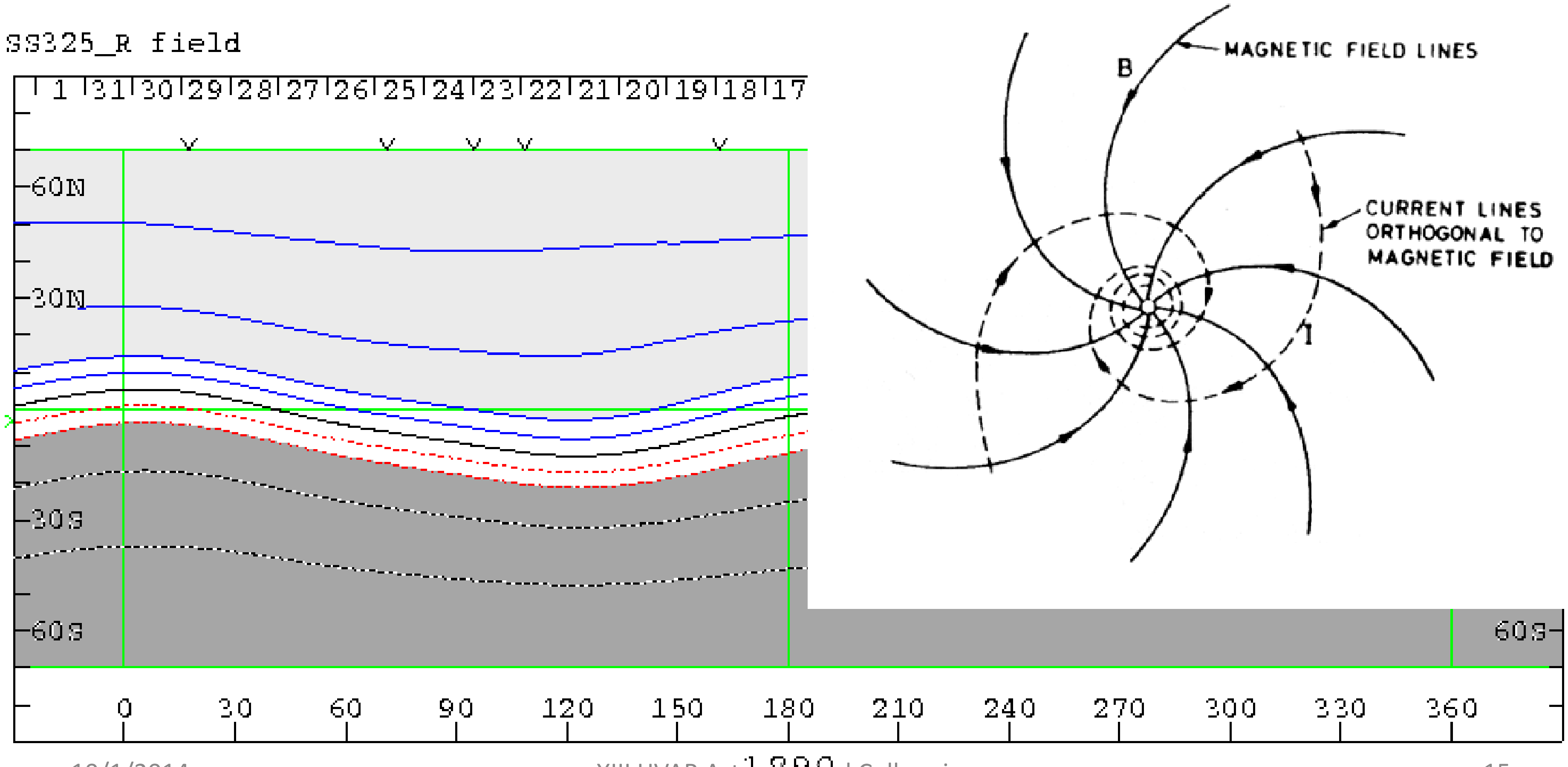


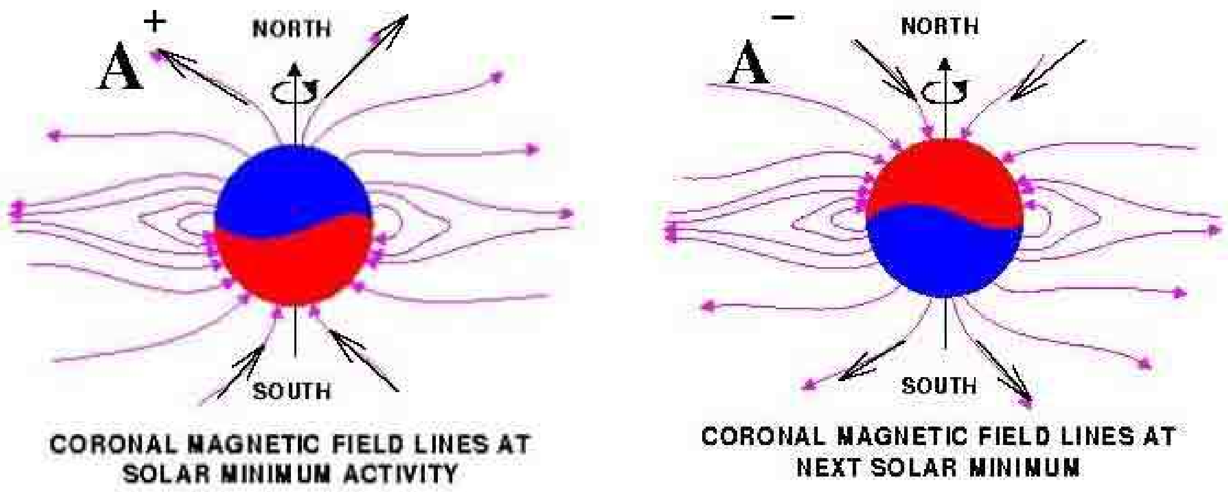
Observations of galactic cosmic rays in the heliosphere: Solar modulation at neutron monitor energies

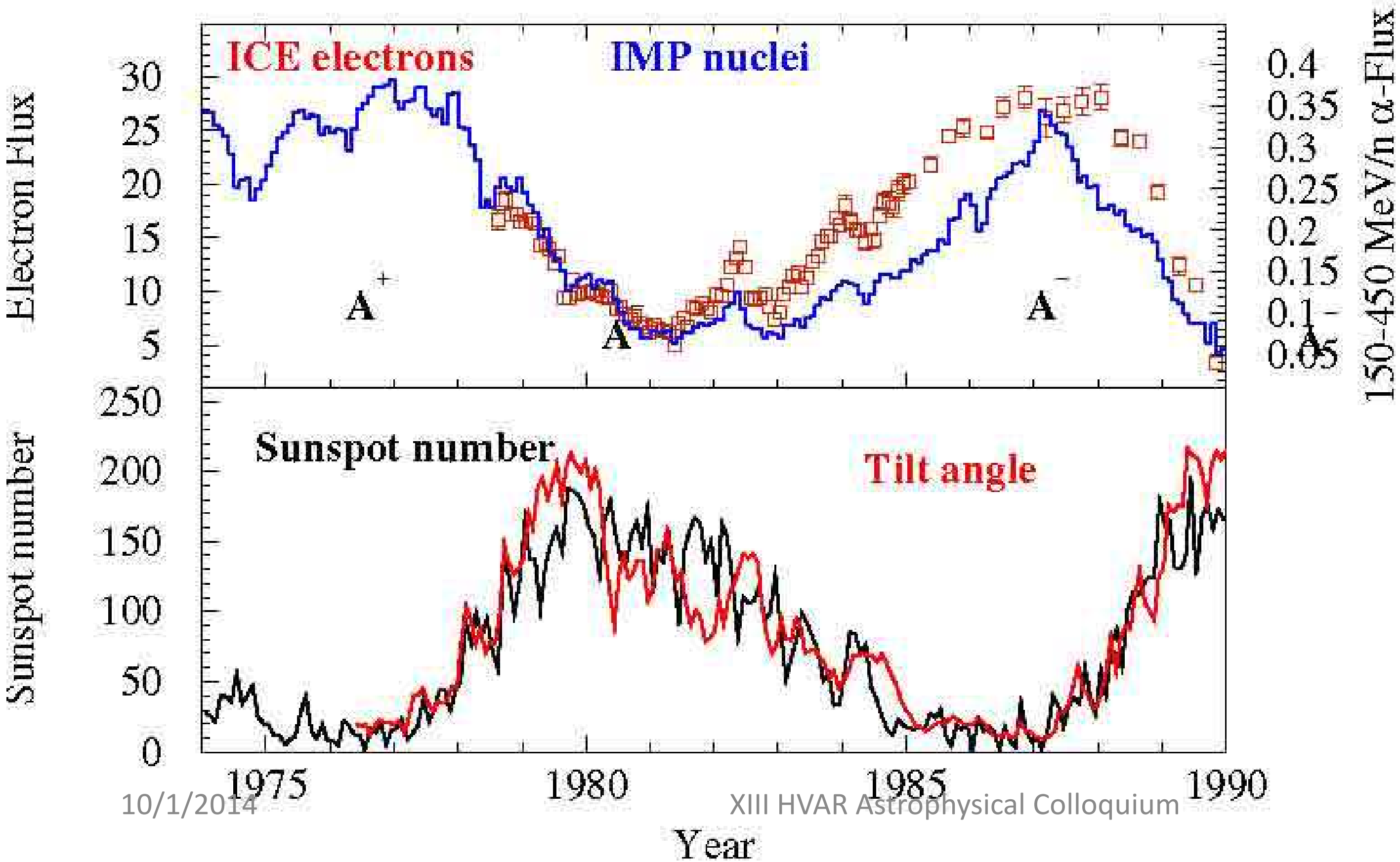
- Variations with the 11-year solar magnetic cycle



The heliospheric magnetic field

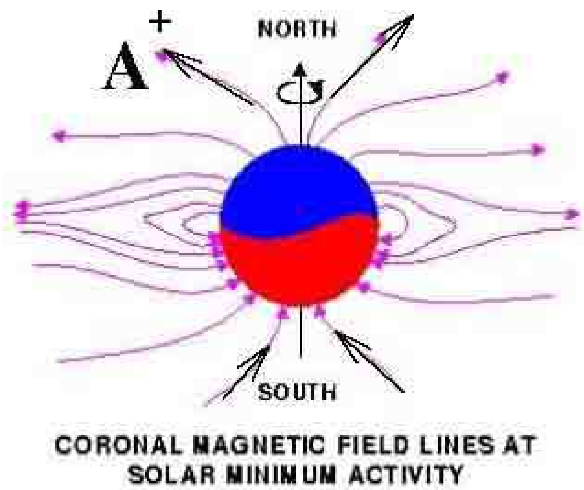


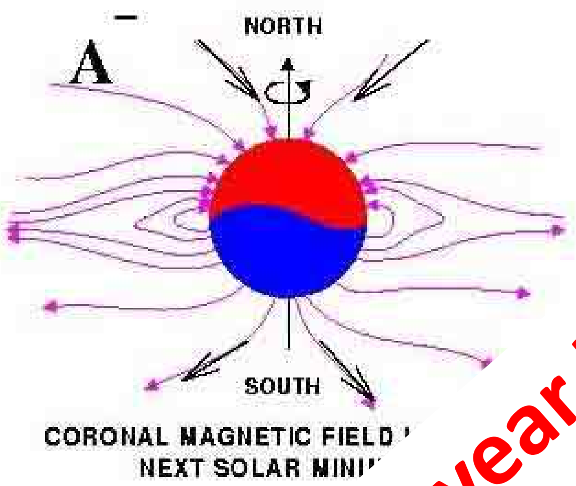


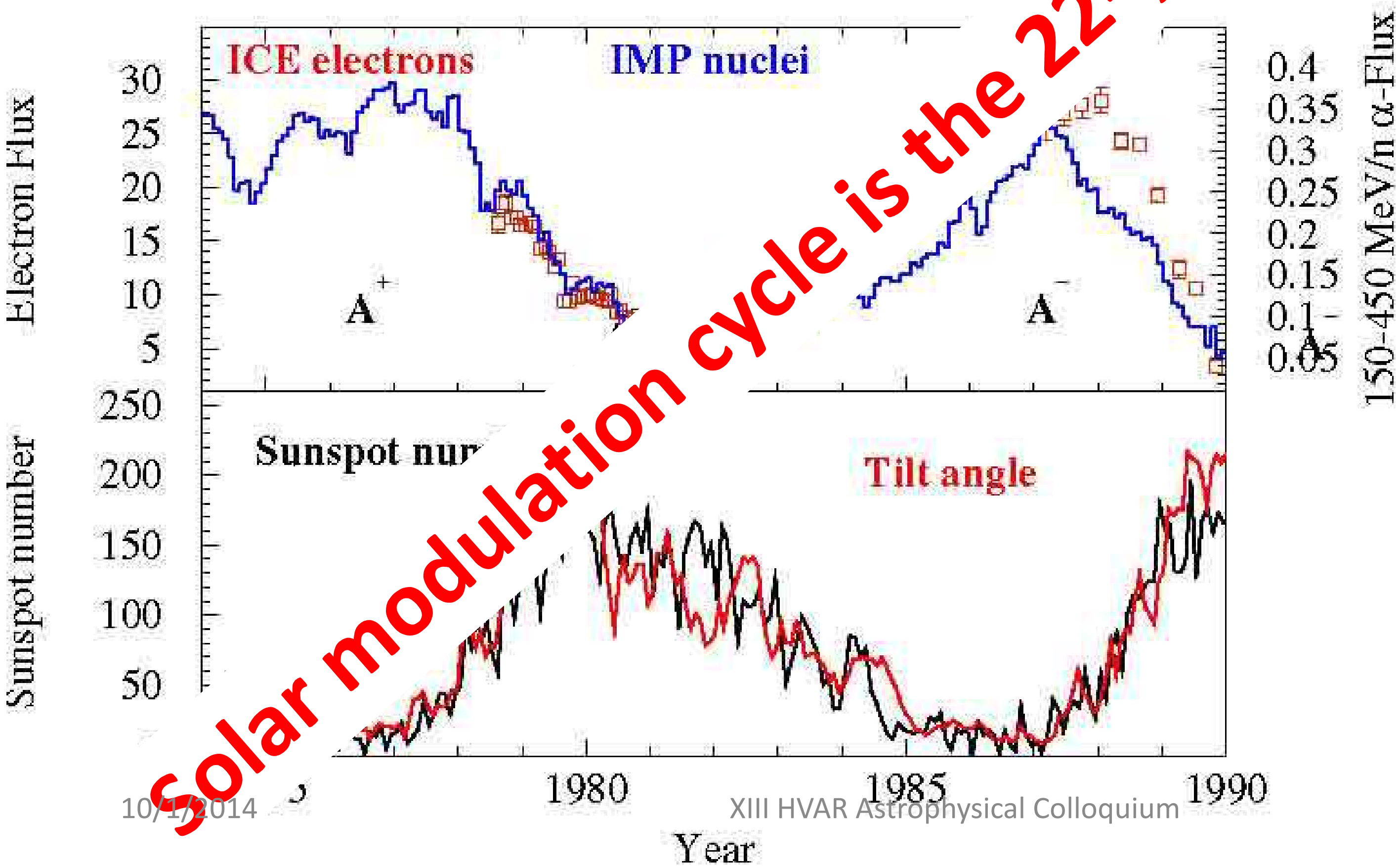


Shape and amplitude depend on particle charge sign and rigidity (=momentum/ charge)

Solar modulation cycle is the 22-year Hale cycle







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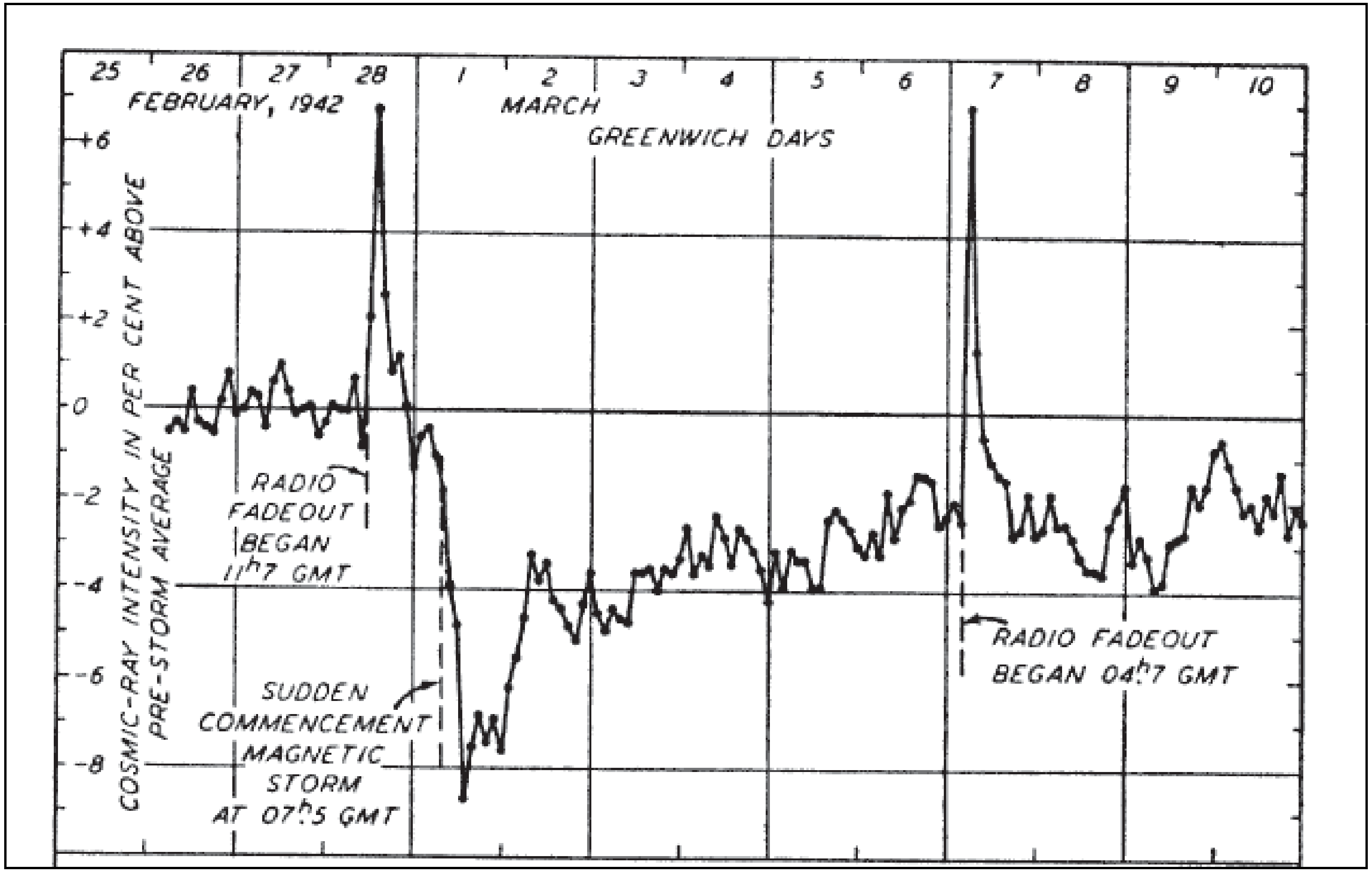
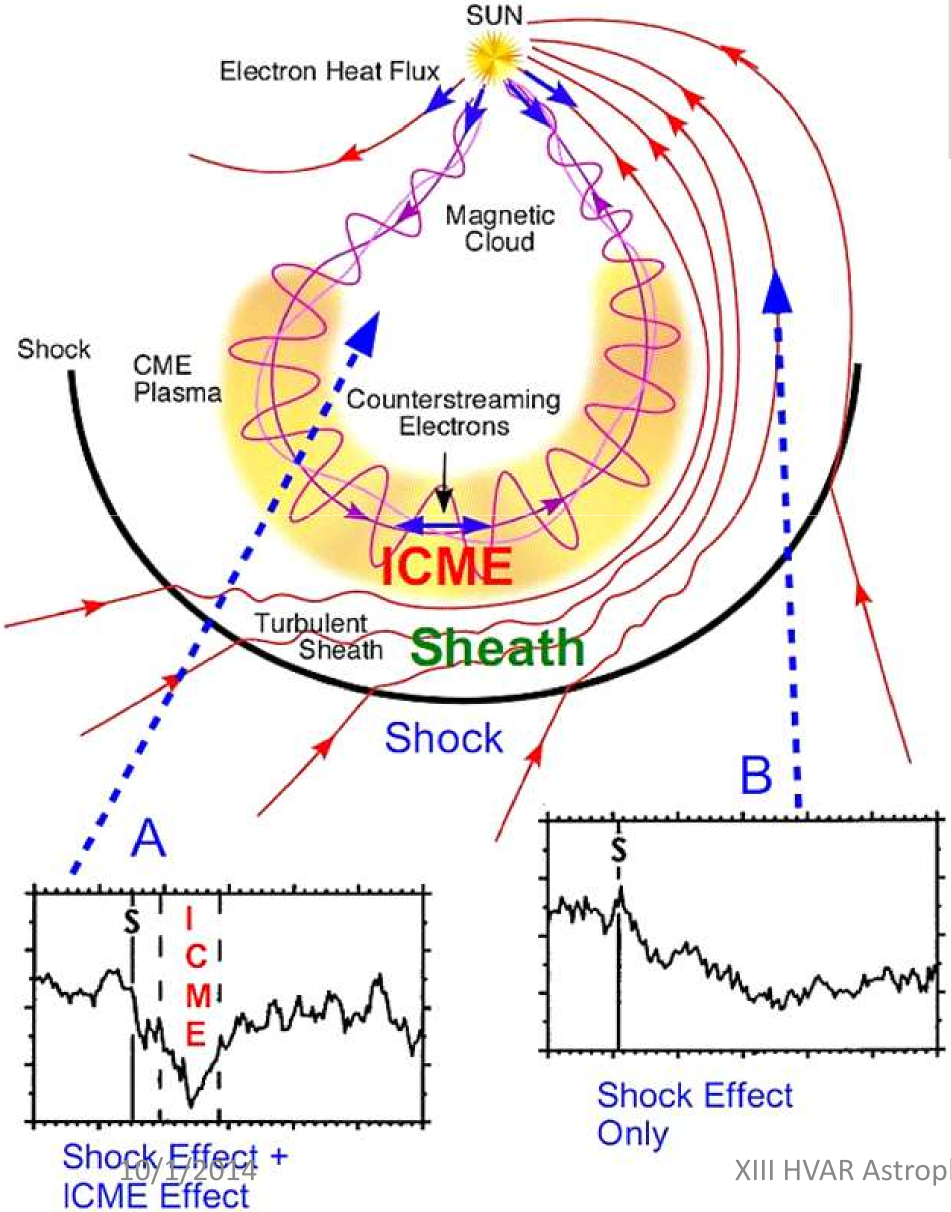
Forbush Decrease



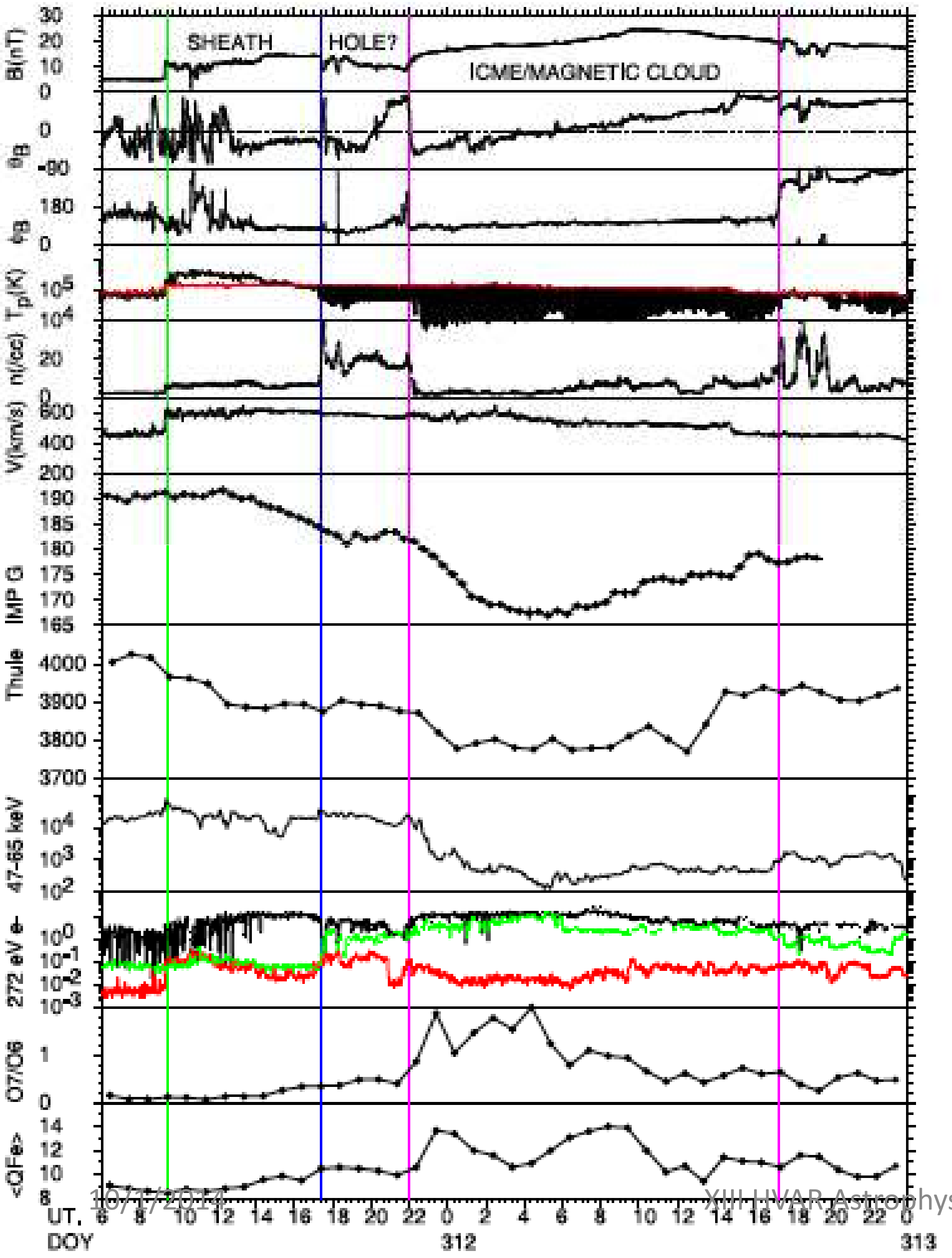
Lange & Forbush, 1942; Forbush, 1946

Forbush decreases



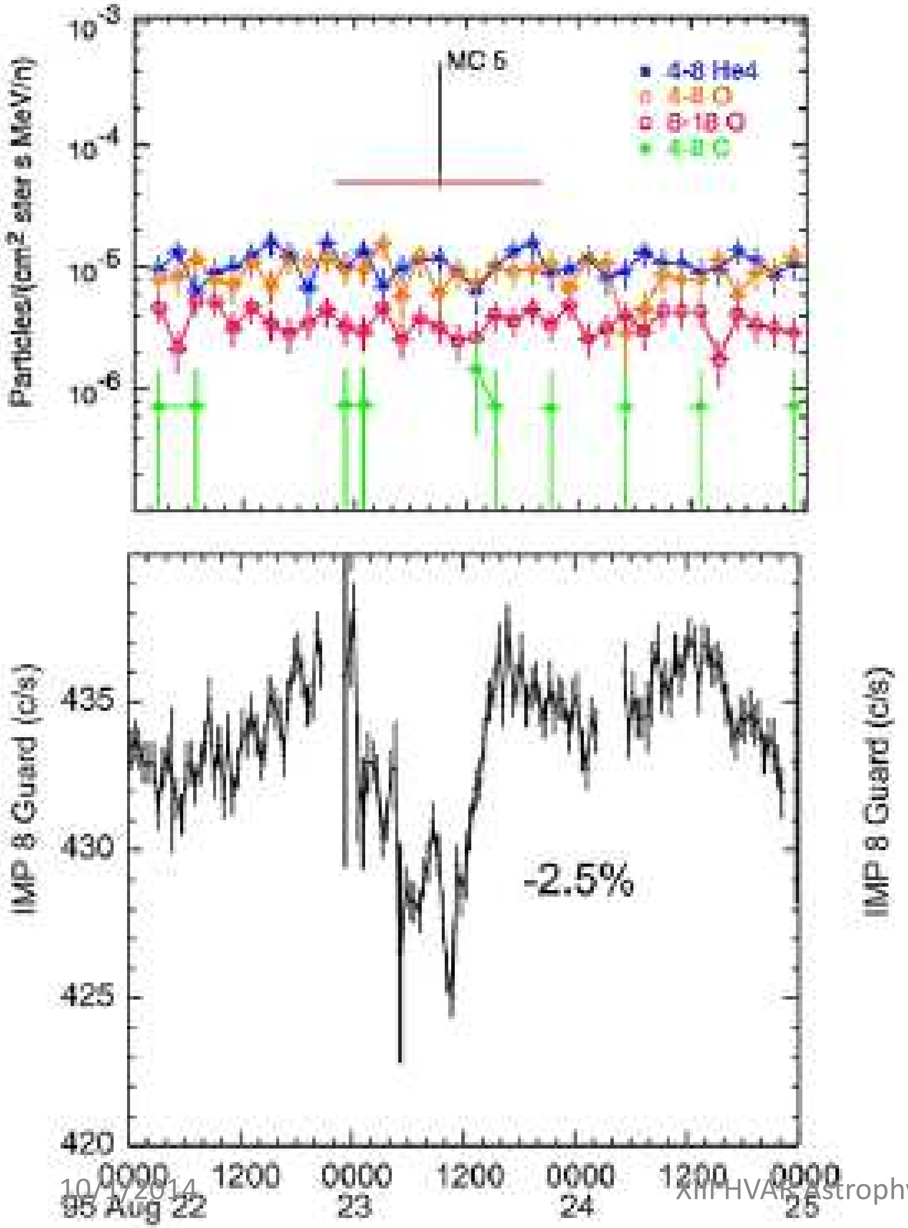
Schematic of an interplanetary coronal mass ejection driving a shock ahead of it and the associated variations in the galactic cosmic ray intensity along trajectories that do (A) or do not (B) encounter the ICME (from Richardson and Cane, 2011)

Forbush decreases



From the top: IMF intensity, polar and azimuthal angles, solar wind proton temperature, density and speed, GCR guard (G; counts s−1) , Thule neutron monitor (counts/hr), 47 – 65 keV ion intensity, solar wind suprathermal (272 eV) electron distribution function ~ parallel (black), anti-parallel (green) and perpendicular (red) to the IMF direction, solar wind O7/O6 ratio and mean Fe charge state.

Forbush decreases



Magnetic cloud event (Reames, Kahler, and Tylka, 2009) .The lower panel of each pair shows the IMP 8 guard counting rate.(Richardson and Cane, 2011). No sheath effect with confined FD for the time of the MC passage.

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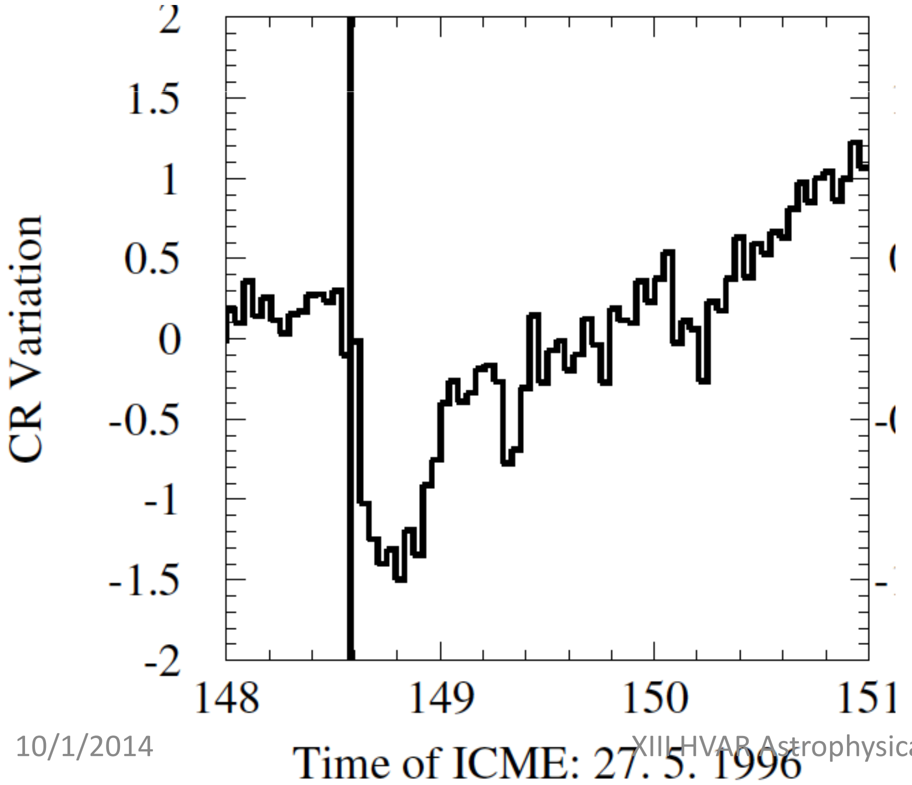
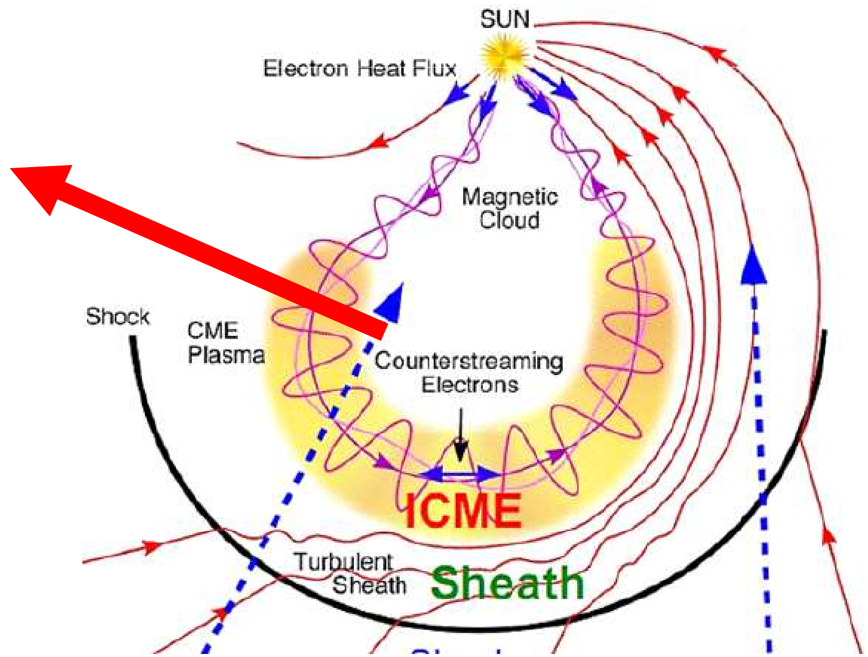
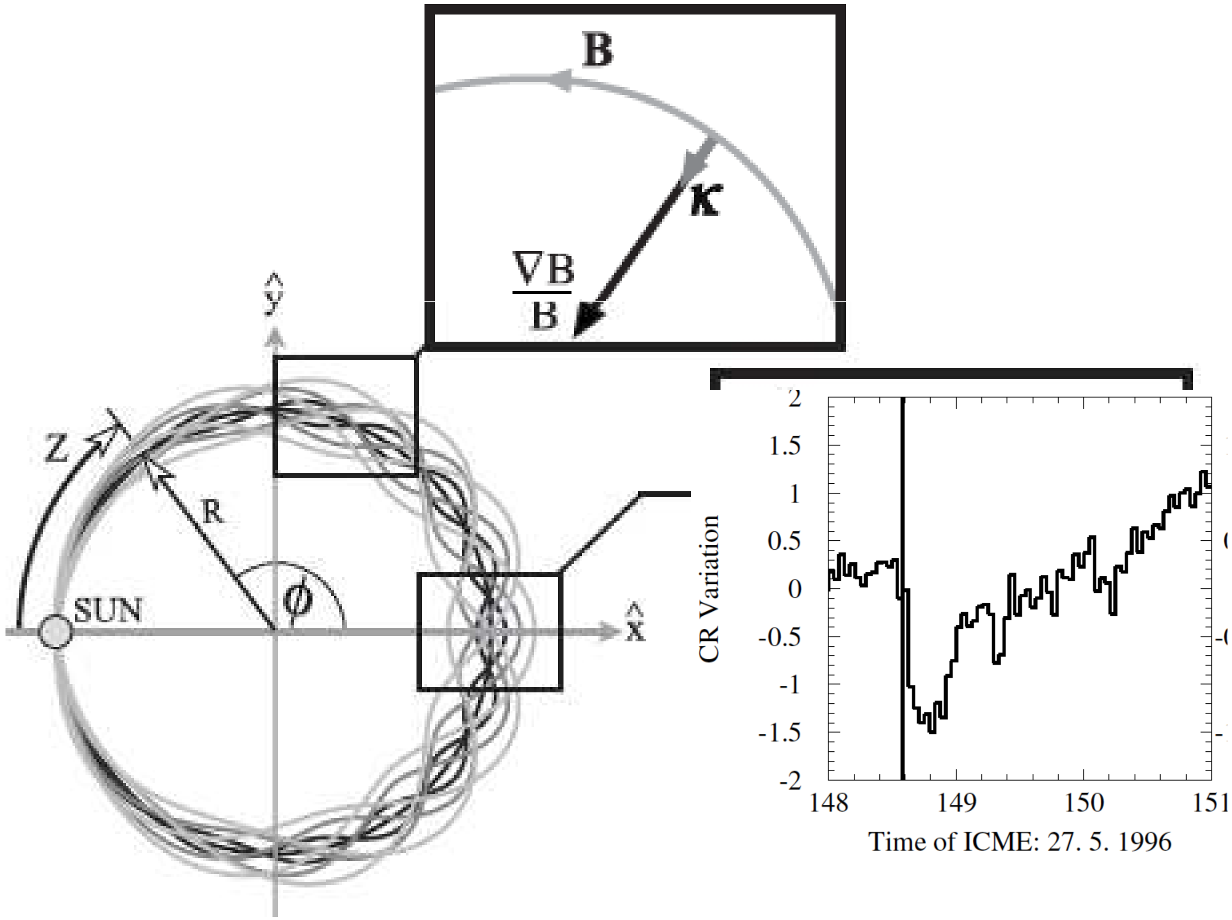
Can we understand Forbush decreases caused by magnetic structures with basic physics?



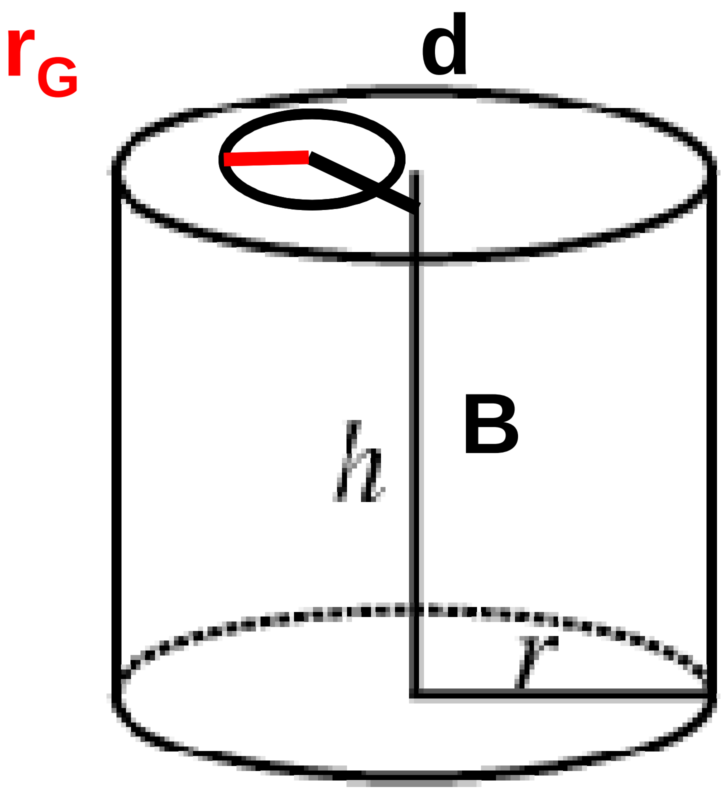


Idea of the project



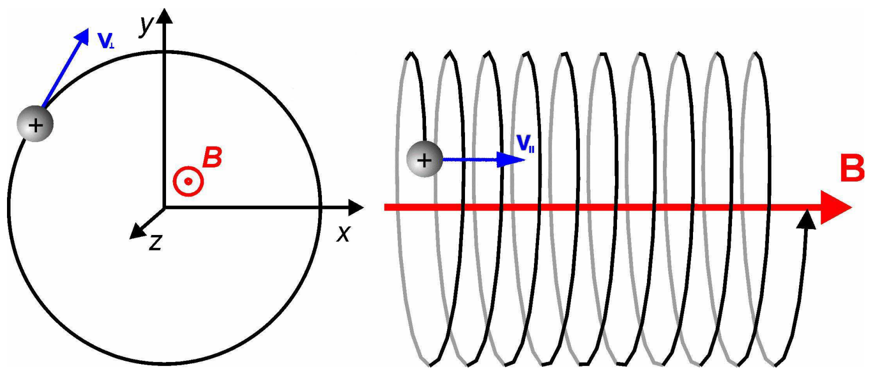
Follow the idea from Krittinatham & Ruffolo (2009): Search Forbush events without sheath influence but with close magnetic structure. Set up a flux rope model. Perform a particle transport code and compare to real data.

Test of idea



Use an infinite long cylinder with an uniform magnetic field B inside the cylinder and no field outside. Particles that are not making it into the cylinder are those that stay in the cylinder when injected inside.

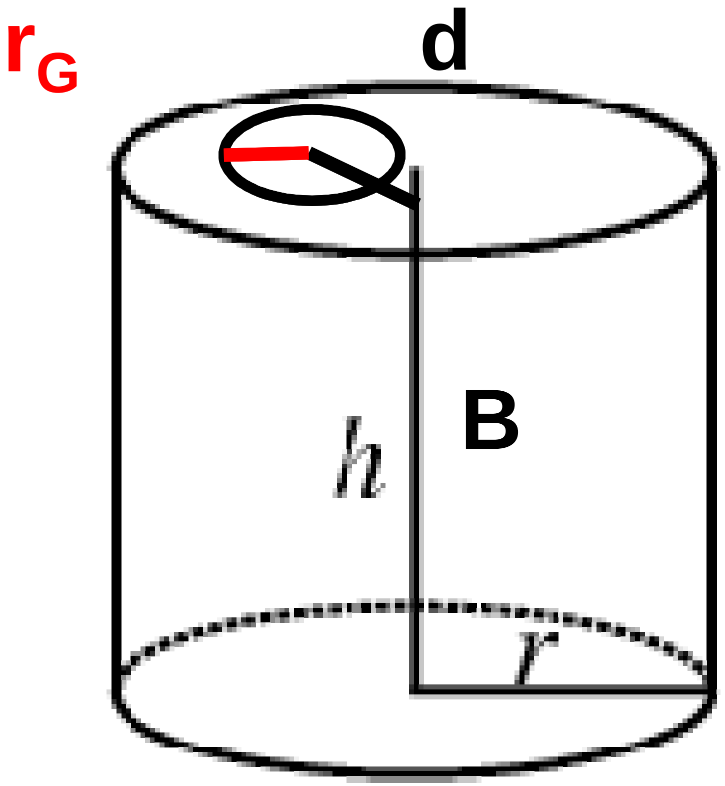
Cosmic rays in uniform magnetic fields



Particle trajectory is a helix around the guiding center magnetic field line.
The radius depends on the velocity and the pitch angle:

$$r = \frac{m_0 \cdot \gamma \cdot v_\perp}{|q| \cdot B} = \frac{m_0 \cdot \gamma \cdot v \cdot \sin(\alpha)}{|q| \cdot B}$$

Test of idea

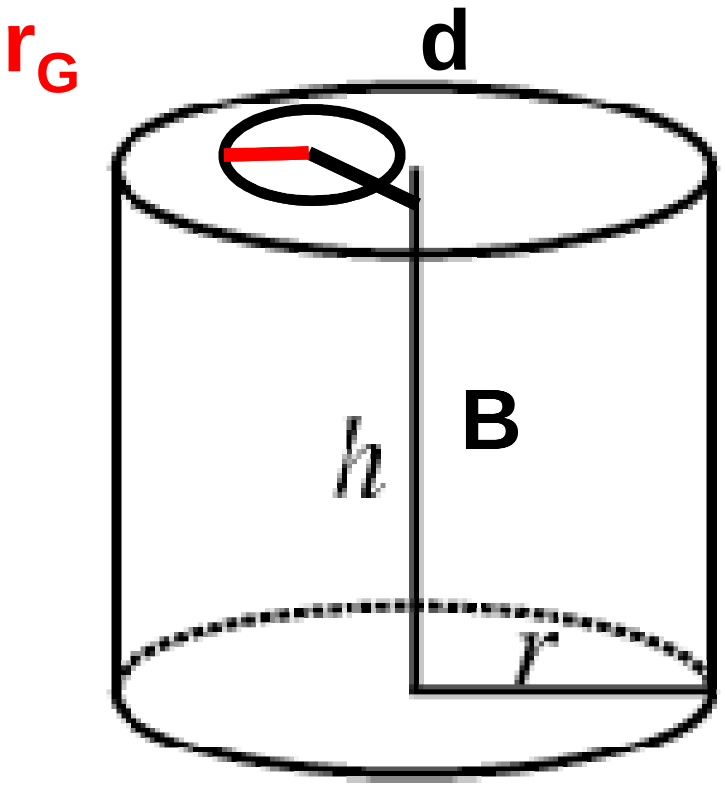


Use an infinite long cylinder with an uniform magnetic field B inside the cylinder and no field outside.

Particles are confined if
$r < r_G + d$
otherwise the escape.

Needs r_G as function of pitch angle cosine μ and energy.

Test of idea



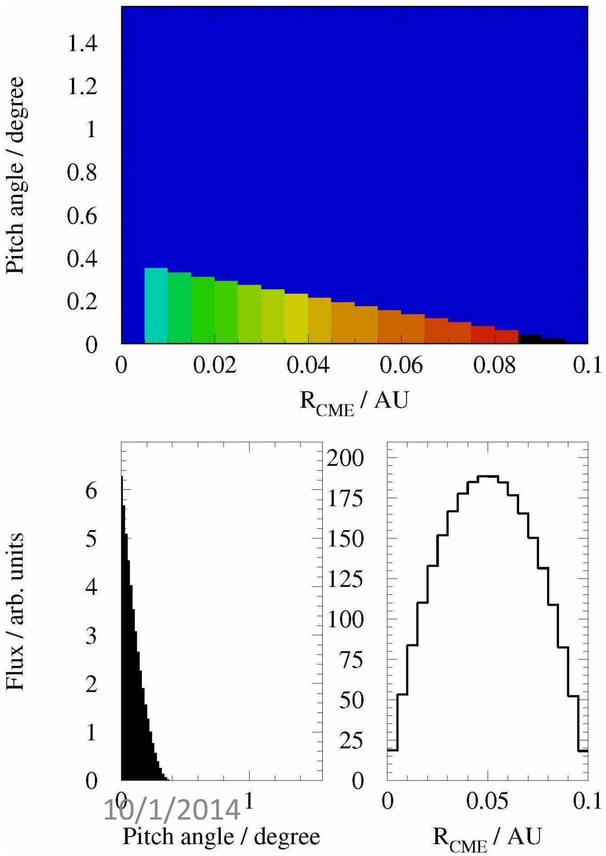
Assume an uniform pitch angle (μ-) distribution.

For fixed energies E, cylinder radius, and magnetic field strength the number of confined particles depend only on μ.

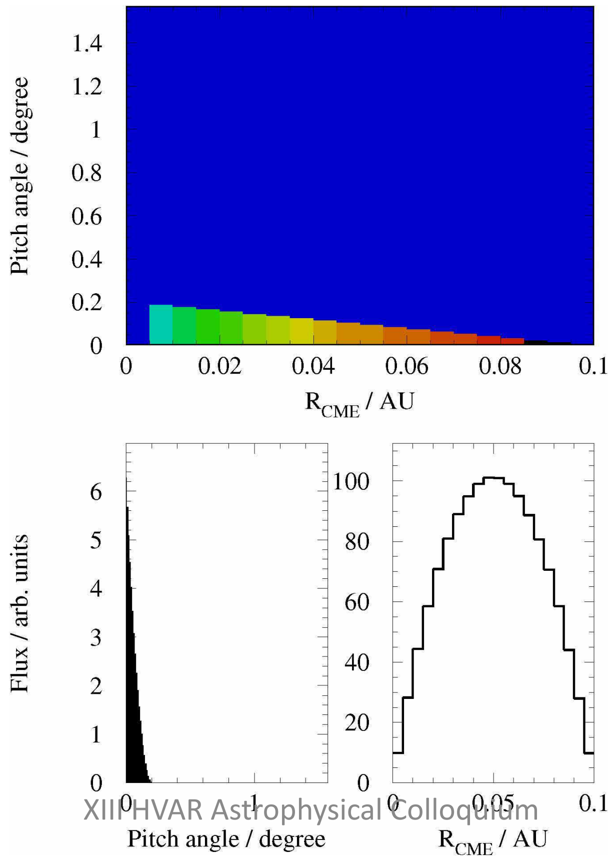
Case study B=20 nT and r_{CME}=0.1 AU

Test of idea

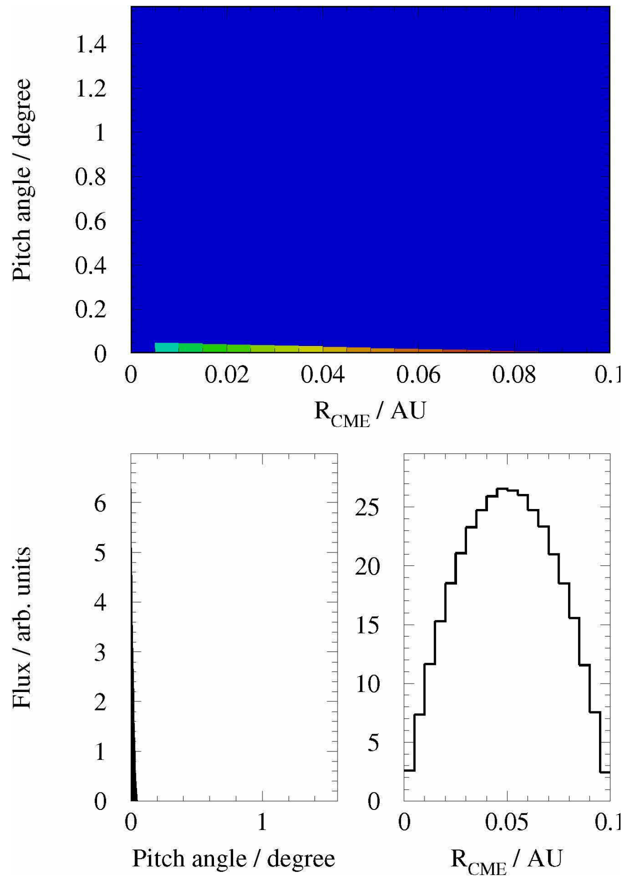
E_k = 30 MeV



E_k = 100 MeV



E_k = 1000 MeV

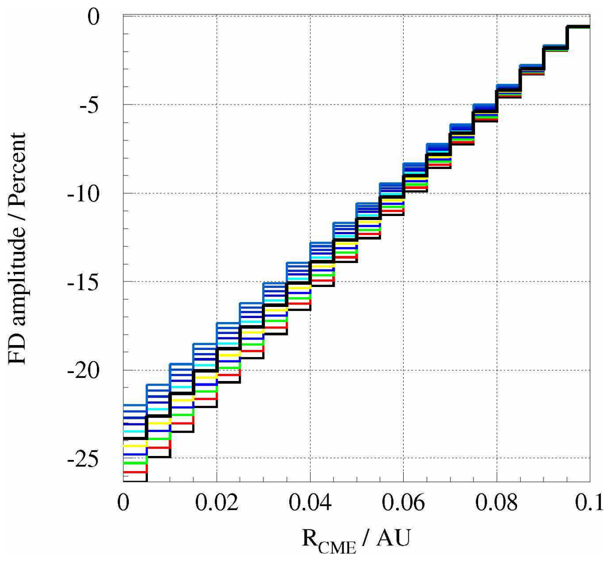


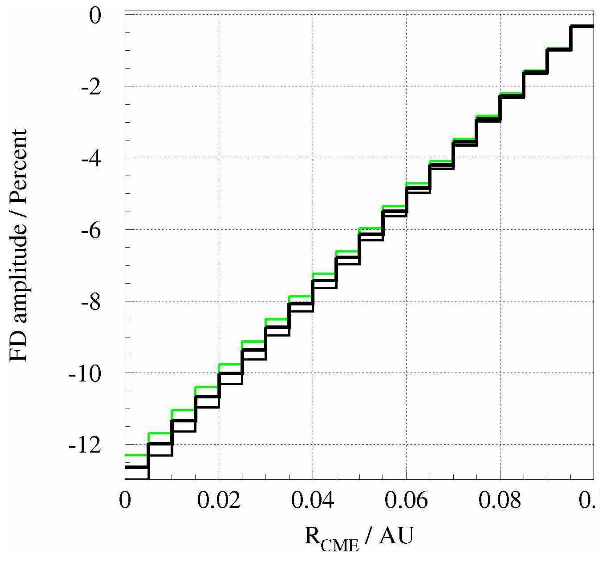
Test of idea

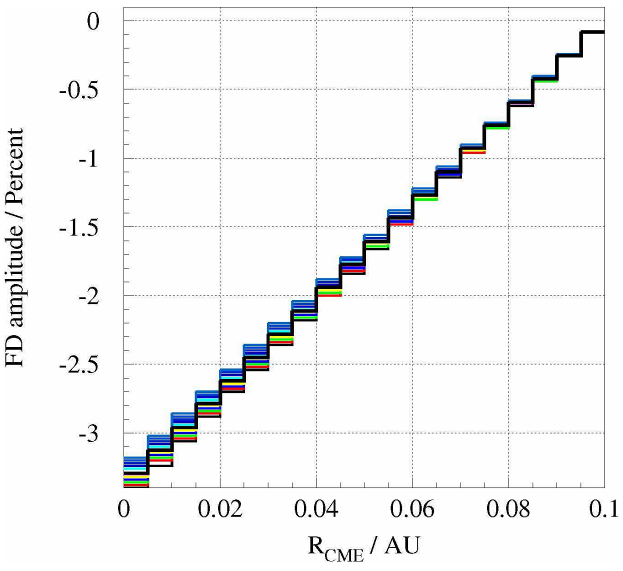
E_k = 30 MeV

E_k = 100 MeV

E_k = 1000 MeV



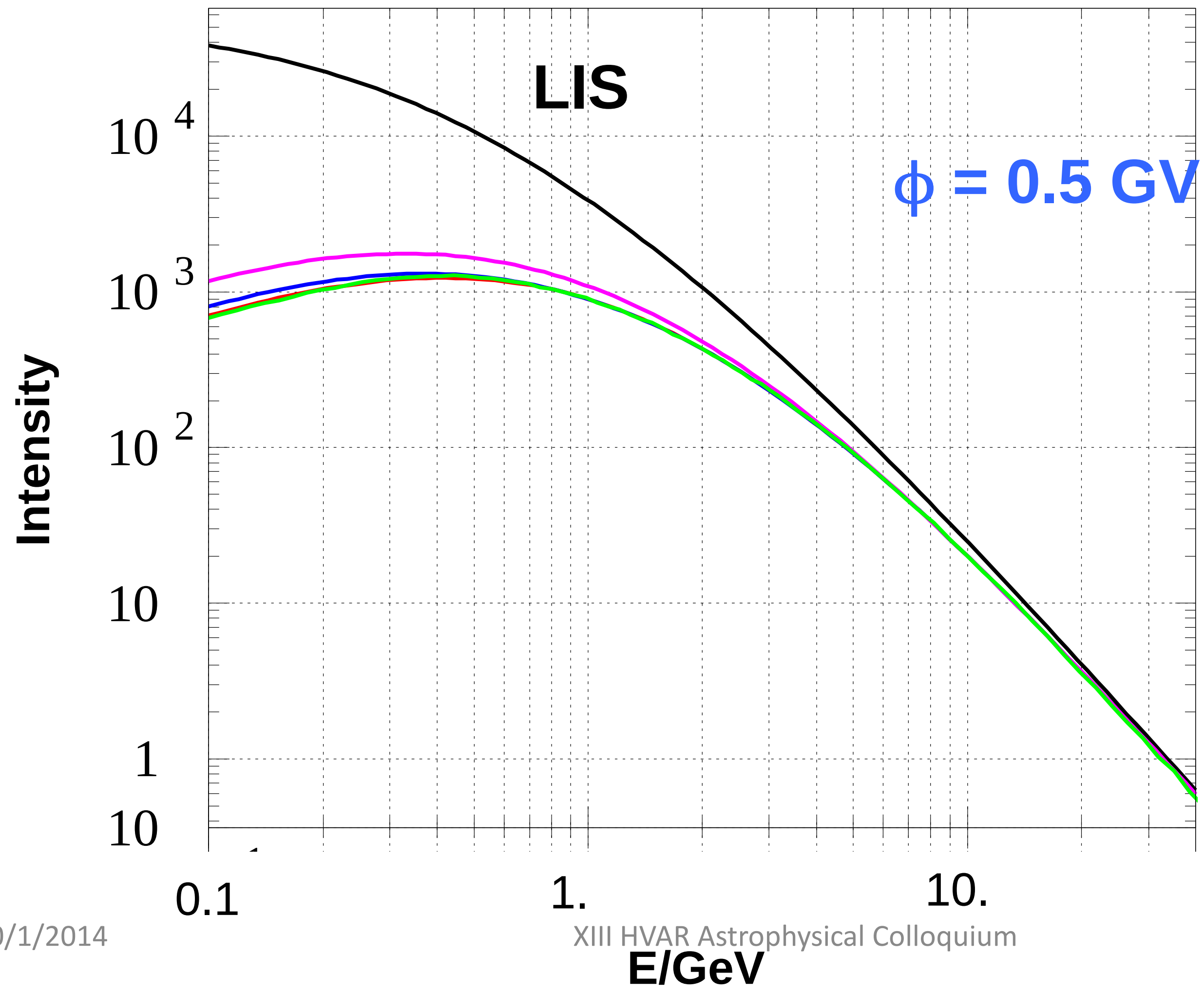




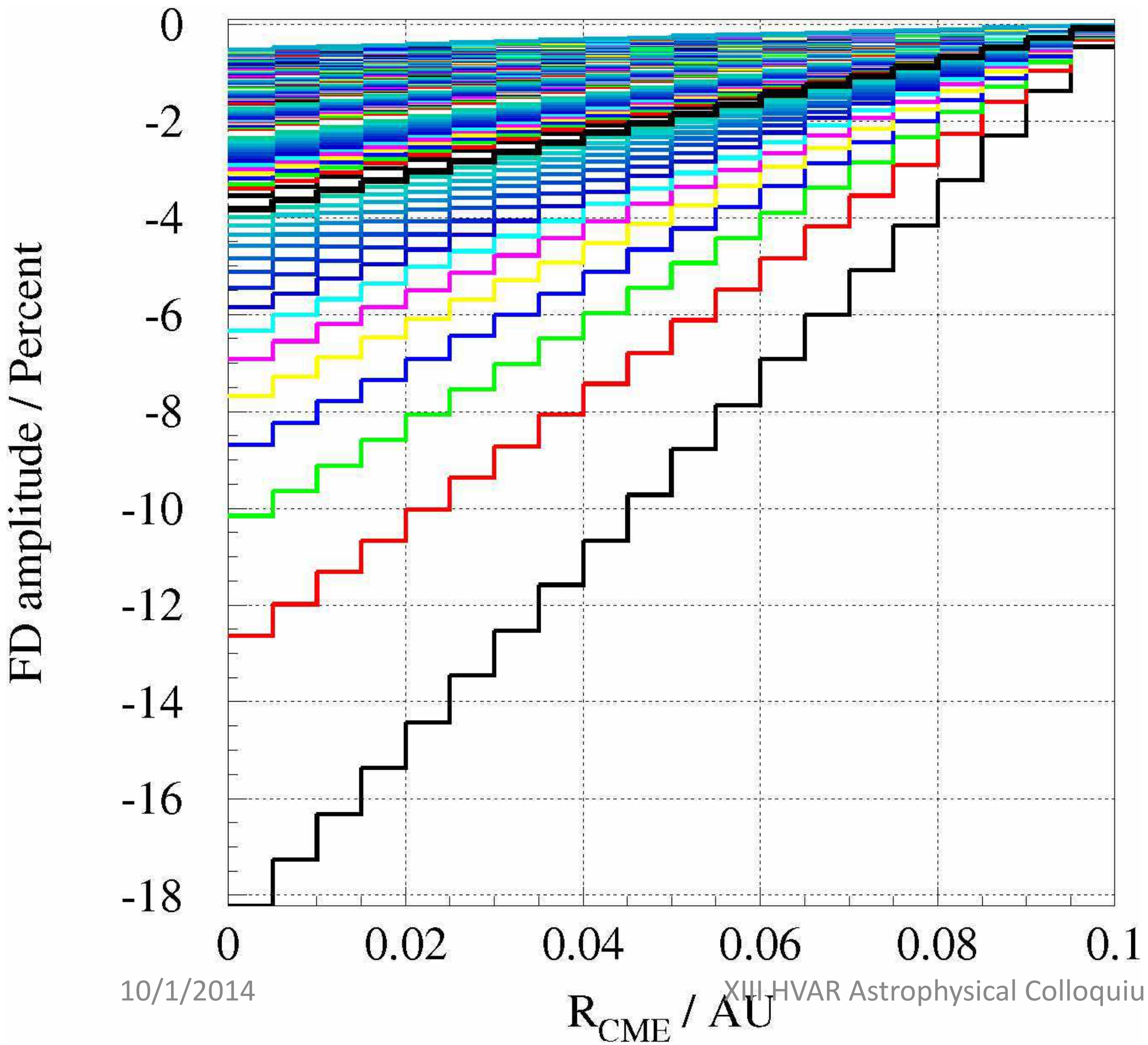
FD Amplitude varies from:

24% @ 30 MeV to 3.5% @ 1000MeV

Test of idea / Force field solution



Test of ideas / Result



FD in a magnetic structure with

- **R_{CME} = 0.1 AU**
- **B = 20 nT**
- **Isotropic pitch angle distribution**
- **Force field solution for ϕ = 0.5 GV**

- **A_{FD} = 3.8 %**

Experimental check

1. Forbush effects are small amplitude variations of the GCR flux ➔ high statistics and in space. Very accurate instrumentation is needed.
2. CME should not drive a sheath region ➔slow CMEs (stealth CMEs are good candidates)

- Question does every magnetic ICME structure drive a Forbush effect?
- What are the limits of detection?

Instrumentation

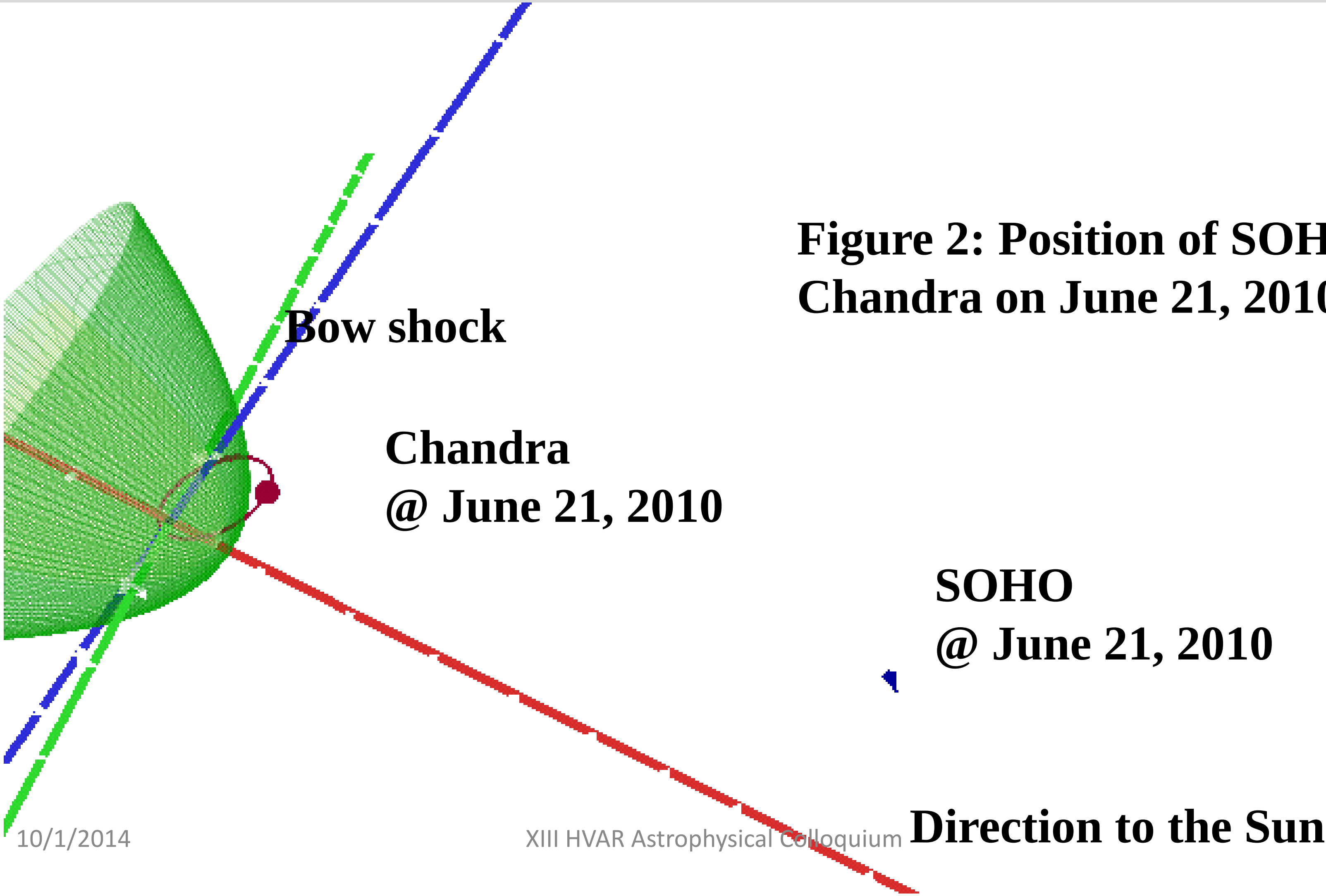
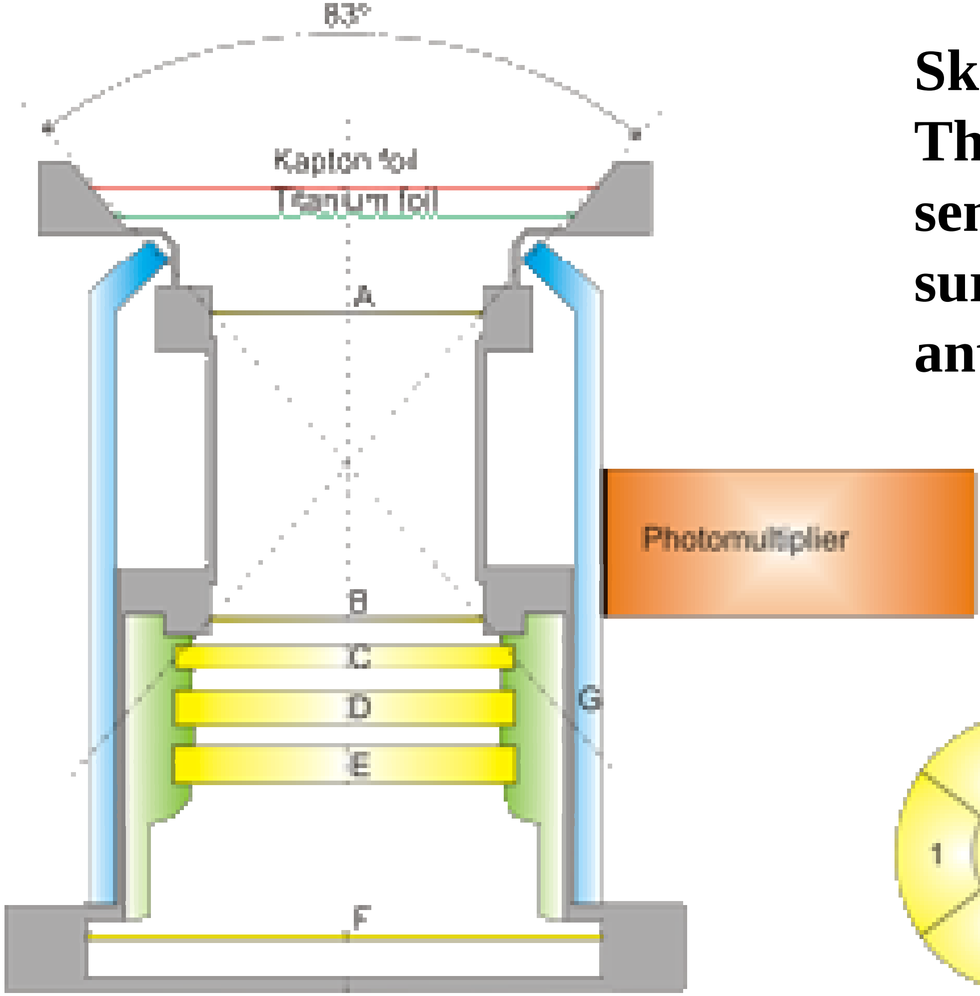
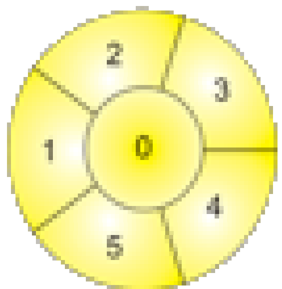


Figure 2: Position of SOHO and Chandra on June 21, 2010

Instrumentation



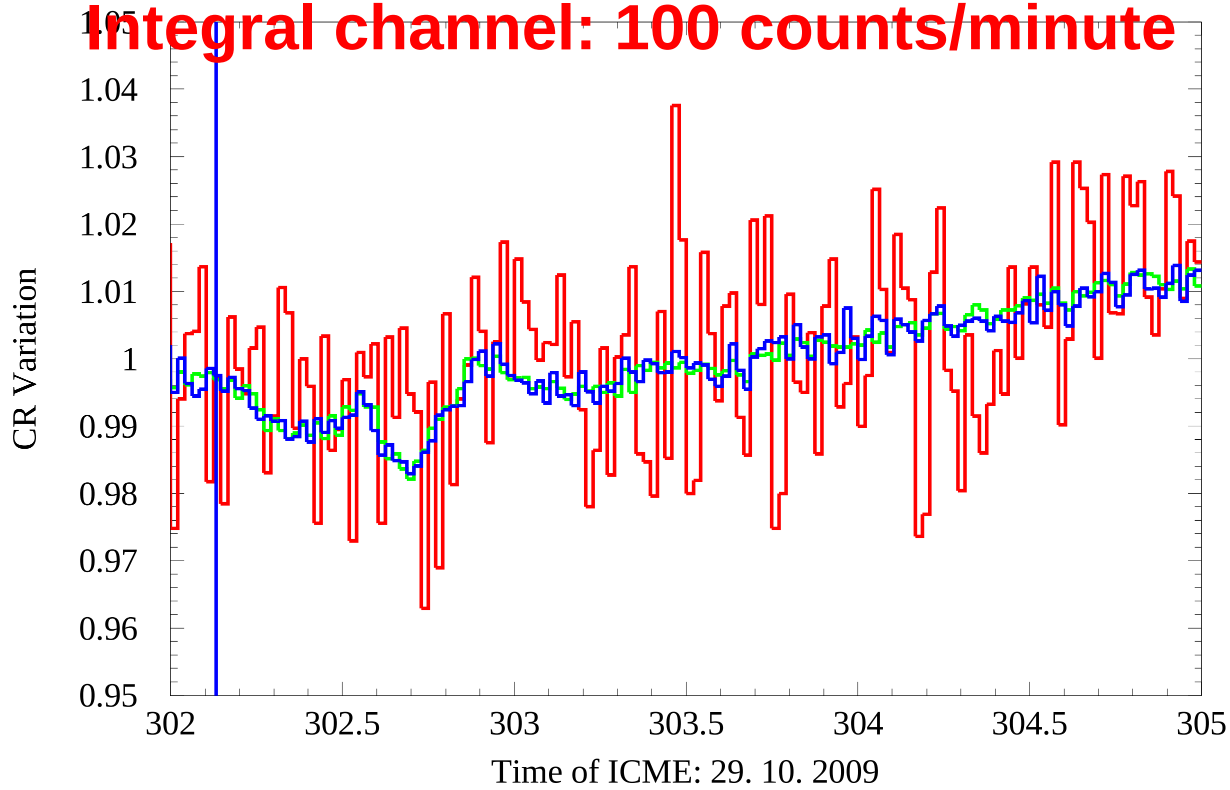
Sketch of the EPHIN sensor. The sensor consists of 6 semiconductor detectors surrounded by an anticoincidence cylinder (A).

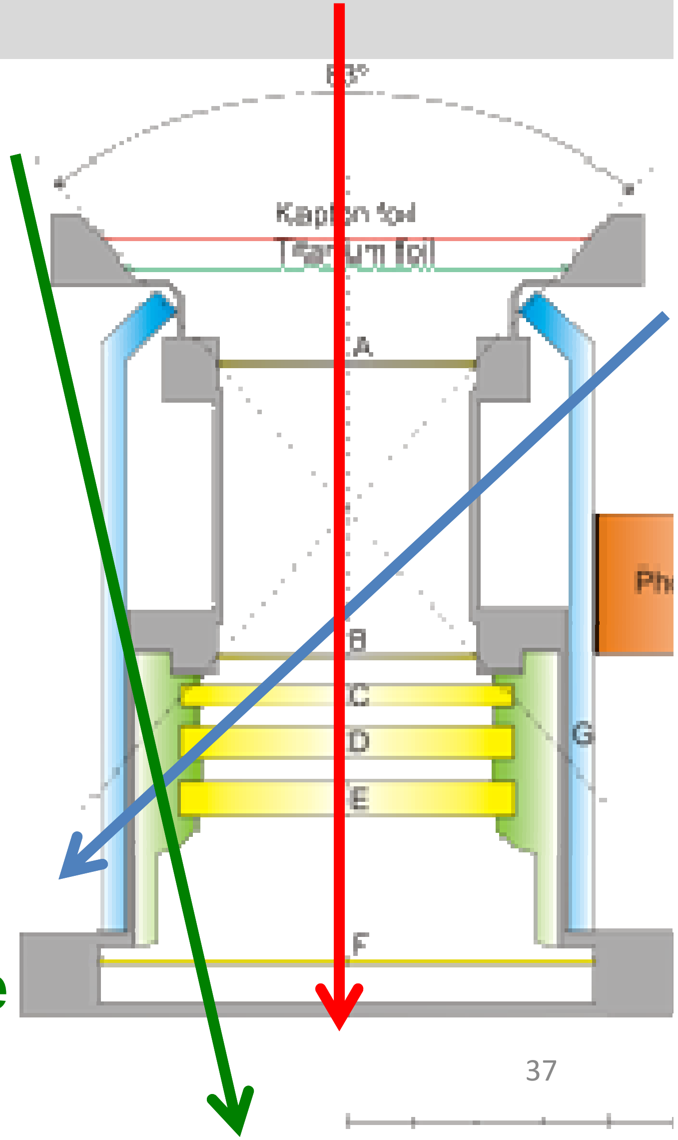


A and B detectors

Instrumentation

Integral channel: 100 counts/minute

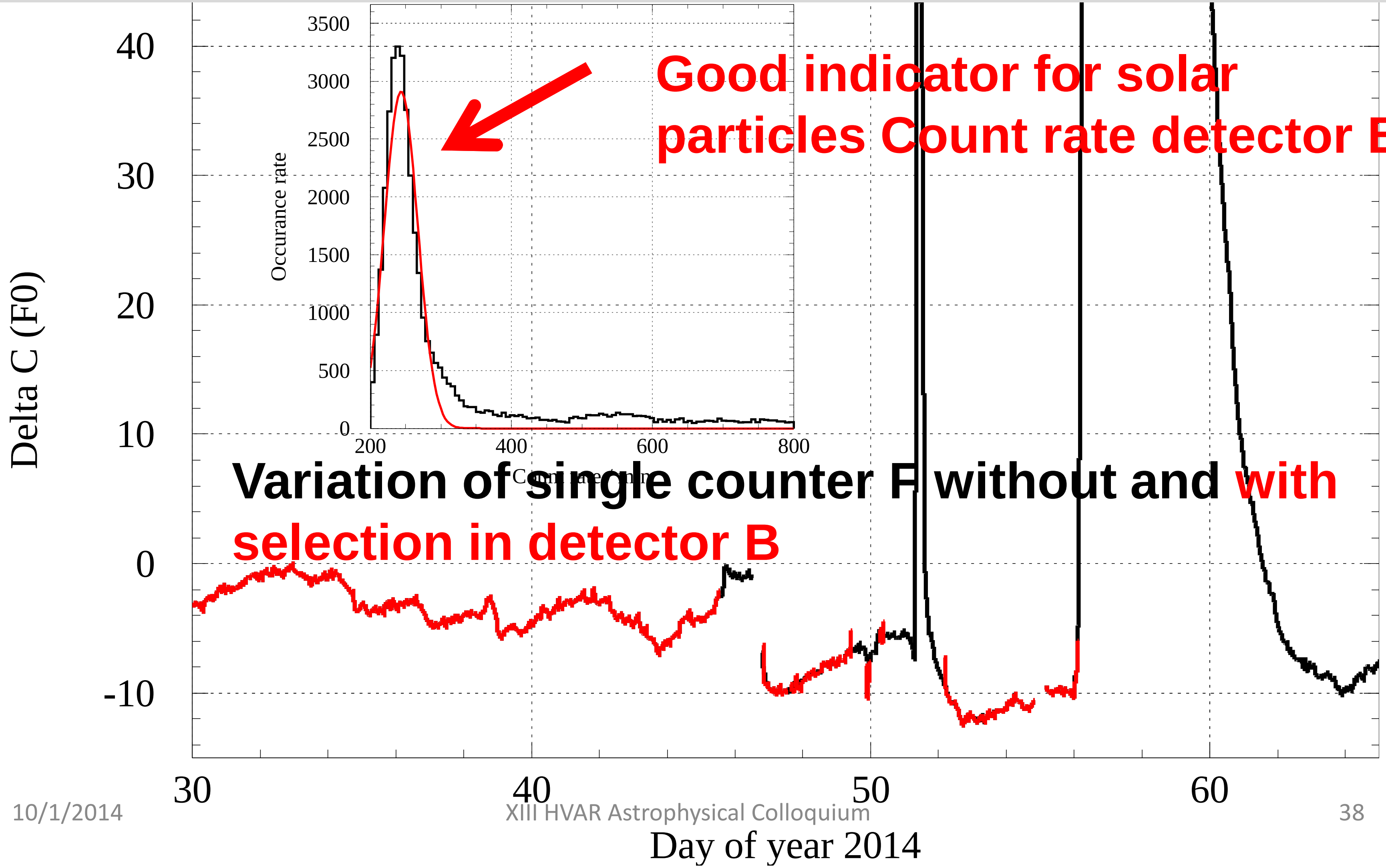




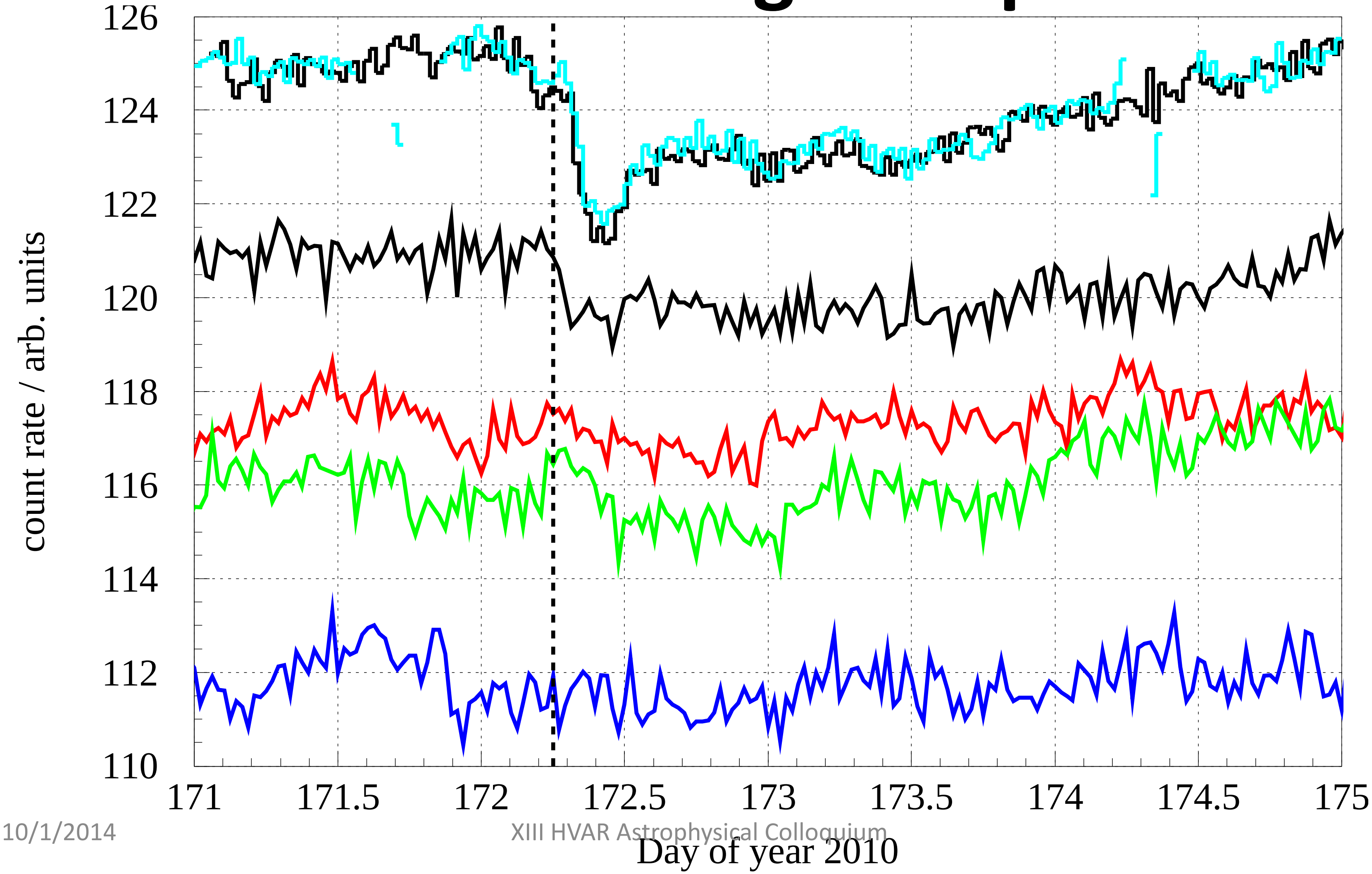
Single counter: F ~ 15000 counts/minute

G ~ 24000 counts/minute

Data selection



… not only … but also being out of the Earth magnetosphere



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- Question does every magnetic ICME structure drive a Forbush effect?
- What are the limits of detection?

It is not "stealth" if I can see it!

- CMEs have low corona signatures: flares, filament eruption, coronal waves and dimmings associated with CMEs.
- "Stealth" CMEs do not have these attributes: harder to detect on the disk?
- But unambiguous signature in coronagraphs
- "Stealth" CMEs originate from areas of weak magnetic field.

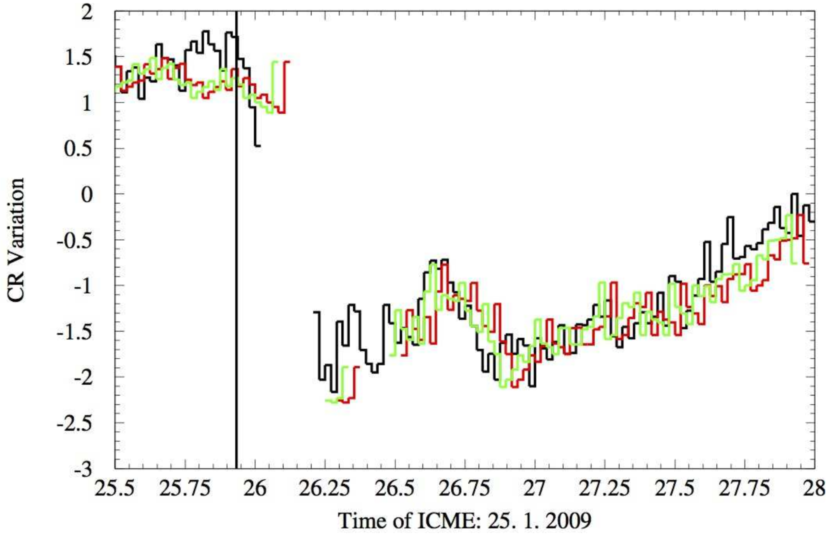
- **Thus they are ideal candidates for our study**

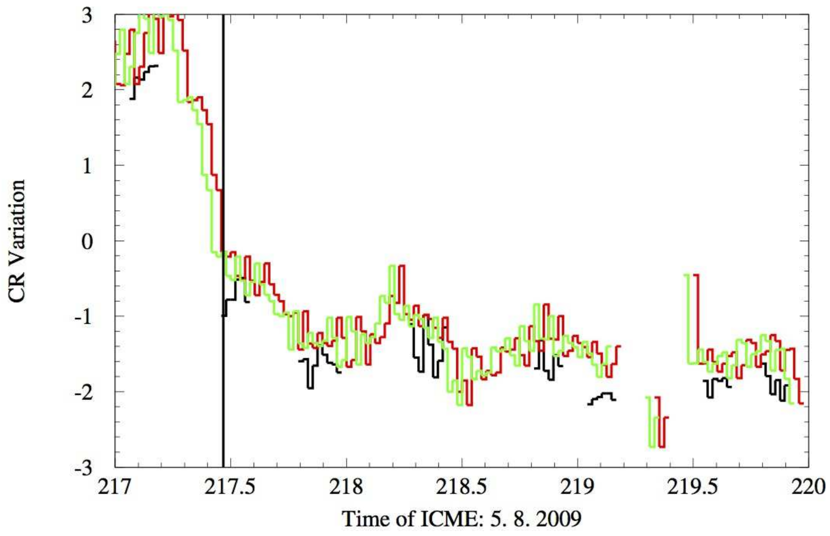
List of events by Mierla et al. (2013)

No.	ICME start (dd-mm-yyyy/hh:mm)	ICME speed (km/s)	CME start (dd-mm-yyyy/hh:mm)	CME speed (km/s)	Longitude (FM)	Latitude (FM)	CME morphology
1	02-01-2009/06:05	437	28-12-2008/~04:30	360 (B)	W08	N08	COR2-A: faint, unstructured COR2-B: narrow CME
2	25-01-2009/22:24	333	21-01-2009/<22:00	390 (B)	W19	S04	COR2-A: diffuse, partial halo COR2-B: FR CME
3	04-02-2009/00:00	385	30-01-2009/~09:00	302 (B)	W09	N07	COR2: faint flows
4	21-07-2009/02:00	335	15-07-2009/<17:00	280 (A)	W22	S02	COR2: narrow, jet-like
5	05-08-2009/11:14	411	31-07-2009/09:00	300 (B)	W08	N14	COR2: faint, unstructured
6	30-08-2009/08:36	429	25-08-2009/10:30	300 (A)	E46	N11	COR2-A: FR CME COR2-B: faint, diffuse CME
7	10-09-2009/10:25	310	03-09-2009/07:30	230 (B)	W34	N01	COR2-A: FR CME COR2-B: FR CME
8	30-09-2009/06:34	361	25-09-2009/~17:00	340 (B)	W03	N02	COR2: narrow, jet-like
9	29-10-2009/03:08	377	23-10-2009/~13:00	-	-	-	COR2-A: FR CME Data gap
10	12-12-2009/22:05	293	06-12-2009/<14:00	190 (B)	E08	S06	COR2-A: FR CME COR2-B: FR CME
11	21-06-2010/06:00	410	16-06-2010/14:50	360 (B)	E30*	N03*	COR2-A: FR CME COR2-B: FR CME

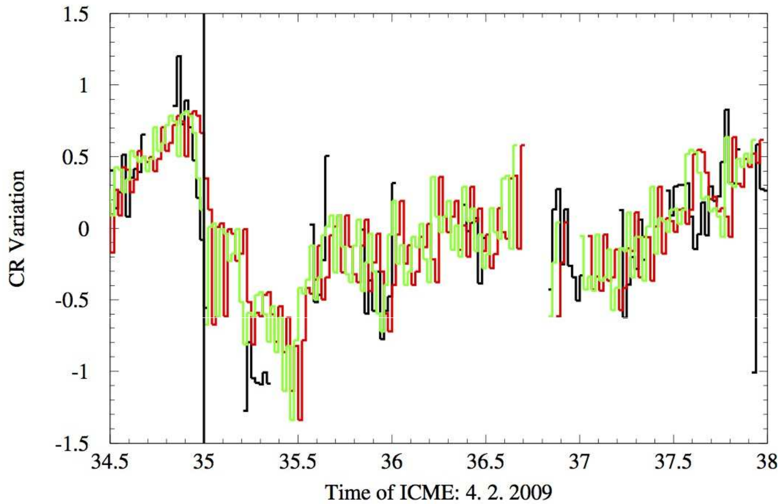
Example of a stealth CME

Pure sheath FDs

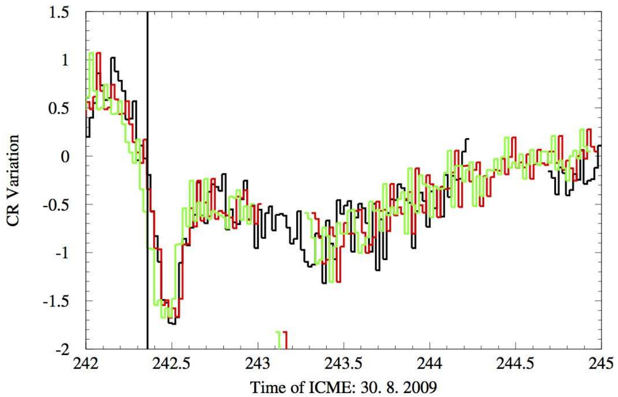


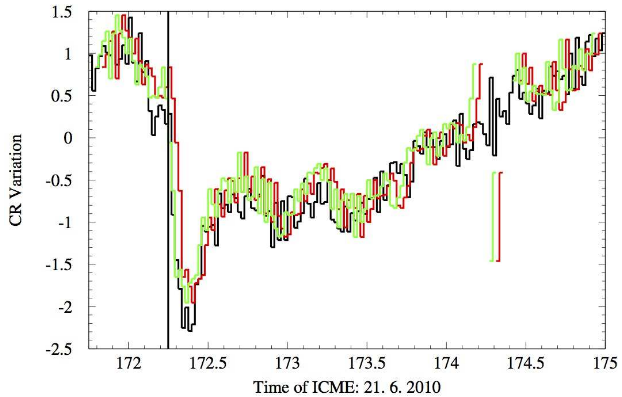


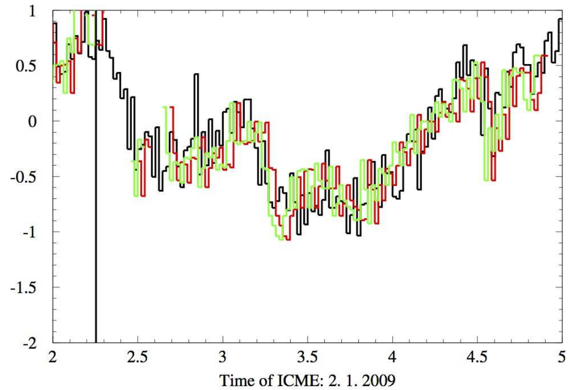
Example of a stealth CME



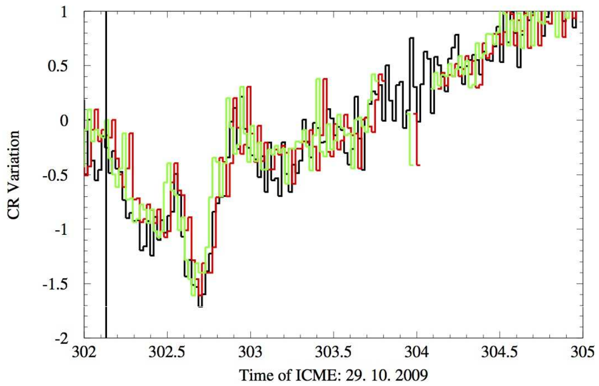
Mixture

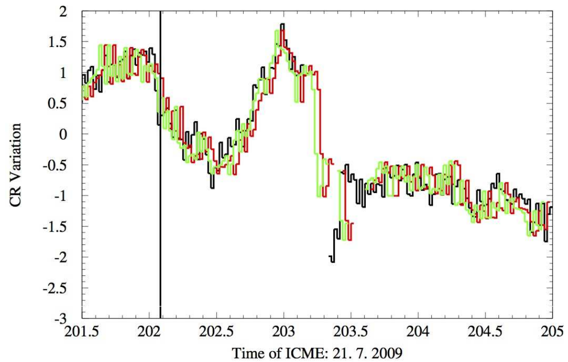


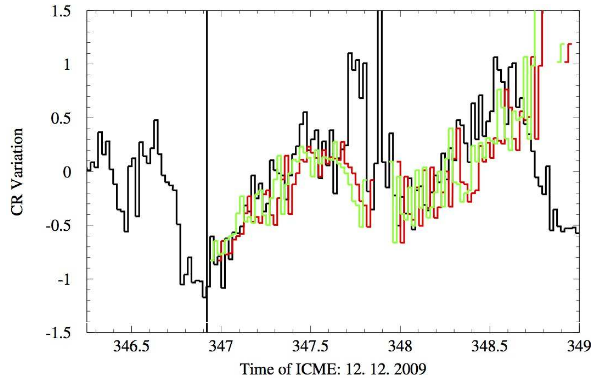


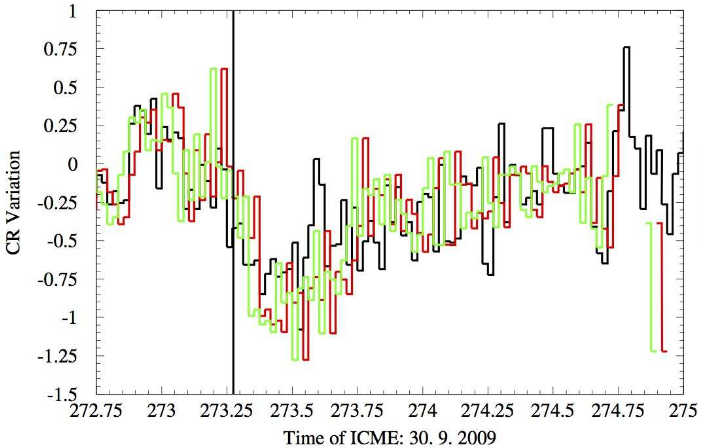


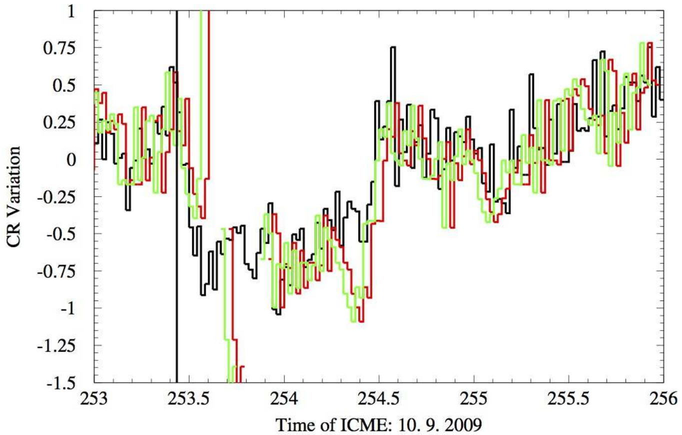
Example of a stealth CME











MC - dominated FDs

Summary

1. Galactic cosmic ray are modulated by several processes and on different time scales.
2. The EPHIN aboard SOHO/Chandra allow investigation of GCR variation of less than 0.5% when no accelerated particles are there.
3. Stealth CMEs are ideally suited to study short term modulation (Forbush like effects) in interplanetary space.
4. A simple cylinder model has shown that the FD amplitudes depends on B and R_{CME}.

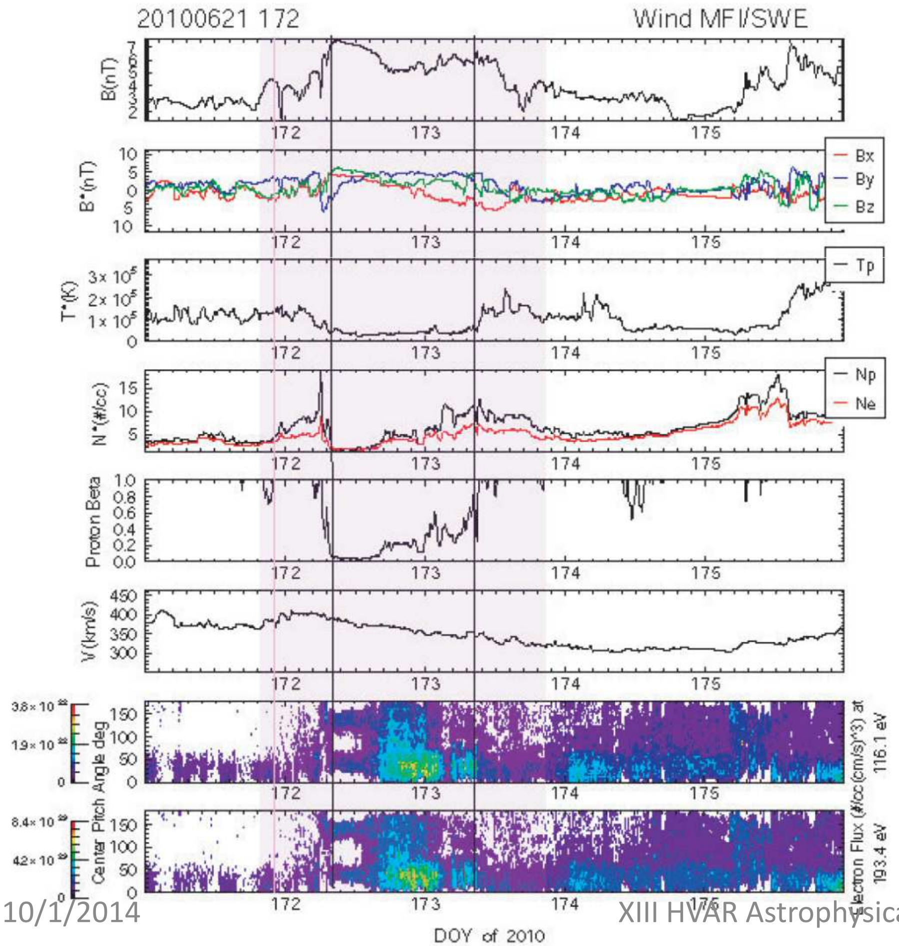
To do ...

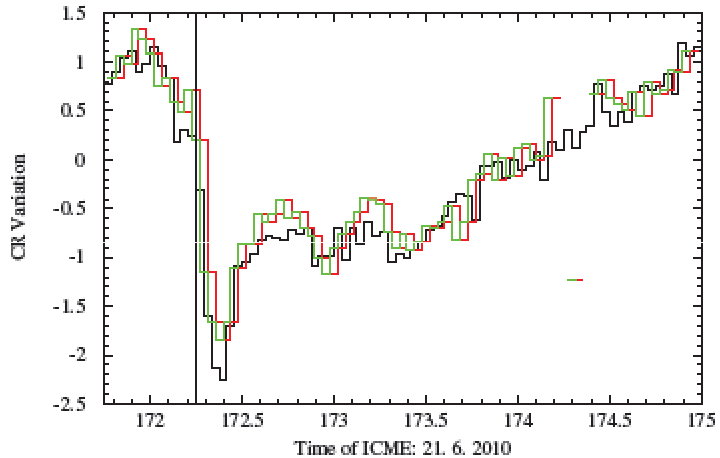
1. Systematic investigation of the “toy model”
2. Correlation of measured and model amplitudes for much as many CMEs we find.
3. Investigation of the FD amplitude rigidity dependence
4. Implementation of a more sophisticated CME - flux rope model.
5. Detailed comparison with plasma structures
6. Extension to the sheath region

Acknowledgement

1. BV and MD acknowledge financial support by Croatian Science Foundation under the project 6212 „Solar and Stellar Variability“.
2. The SOHO/EPHIN project is supported under Grant 50 OC 1302 by the German Bundesministerium für Wirtschaft through the Deutsches Zentrum für Luft- und Raumfahrt (DLR). We acknowledge the NMDB database (www.nmdb.eu) founded under the 213007), and the PIs of individual neutron monitors for providing data.

Example of a stealth CME





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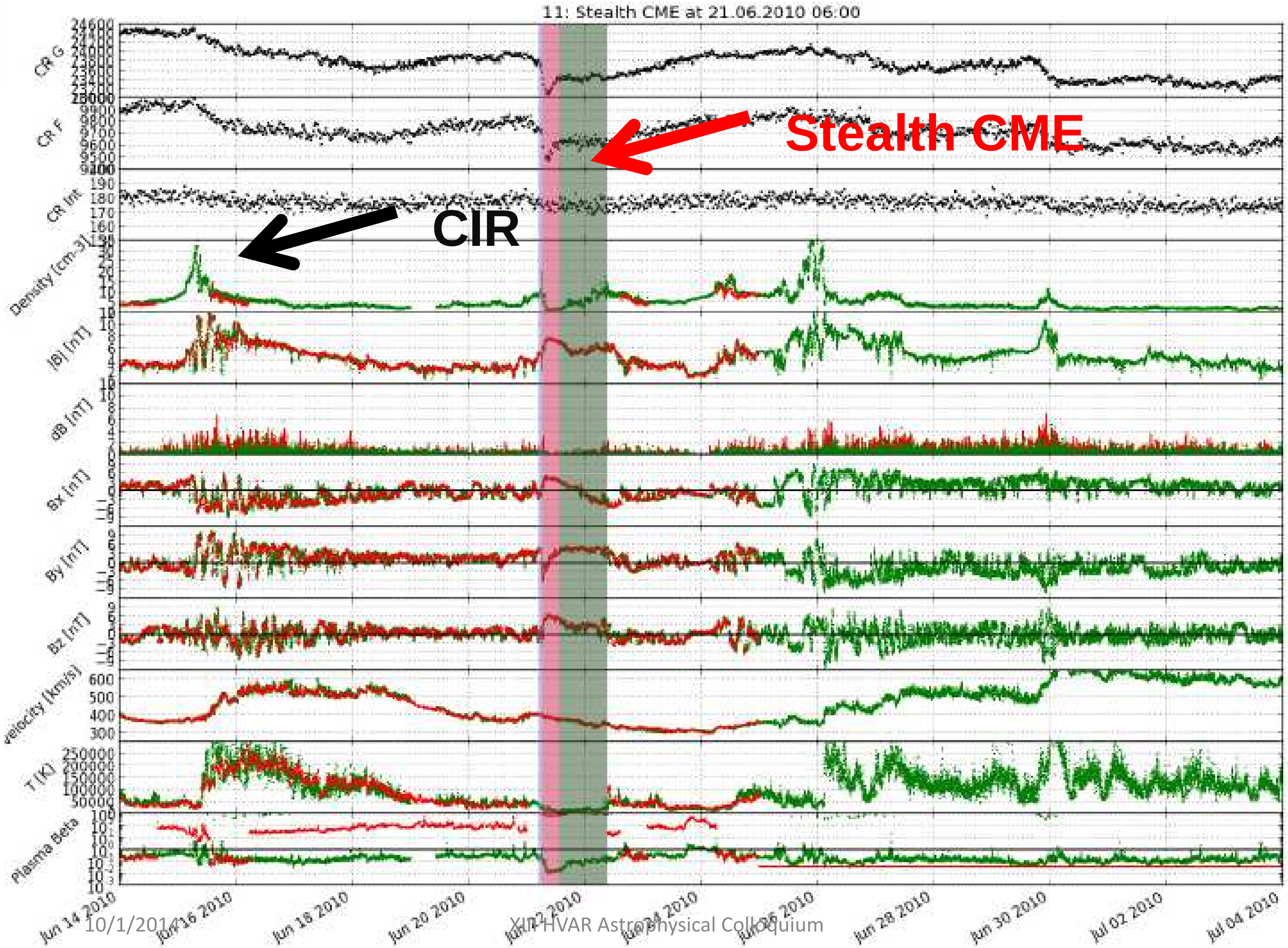
11: Stealth CME at 21.06.2010 06:00
Stealth CME
CIR
CR G
CR F
CR Int
Density [cm-3]
|B| [nT]
dB [nT]
Bx [nT]
By [nT]
Bz [nT]
velocity [km/s]
T [K]
Plasma Beta
Jun 14 2010
Jun 16 2010
Jun 18 2010
Jun 20 2010
Jun 22 2010
Jun 24 2010
Jun 26 2010
Jun 28 2010
Jun 30 2010
Jul 02 2010
Jul 04 2010

Stealth CMEs and Coronal Holes