The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific
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International Atomic
Energy Agency

310/1749-33

ICTP-COST-USNSWP-CAWSES-INAF-INFN
International Advanced School
on
Space Weather
2-19 May 2006

Effects in the Heliosphere

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M. Storini – INAF/IFSI_Rome Trieste - 5 May 2006

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ICTP-COST-CAWSES-INAF-INFN
International Advanced School on Space Weather

Lecture 3. EFFECTS IN THE HELIOSPHERE

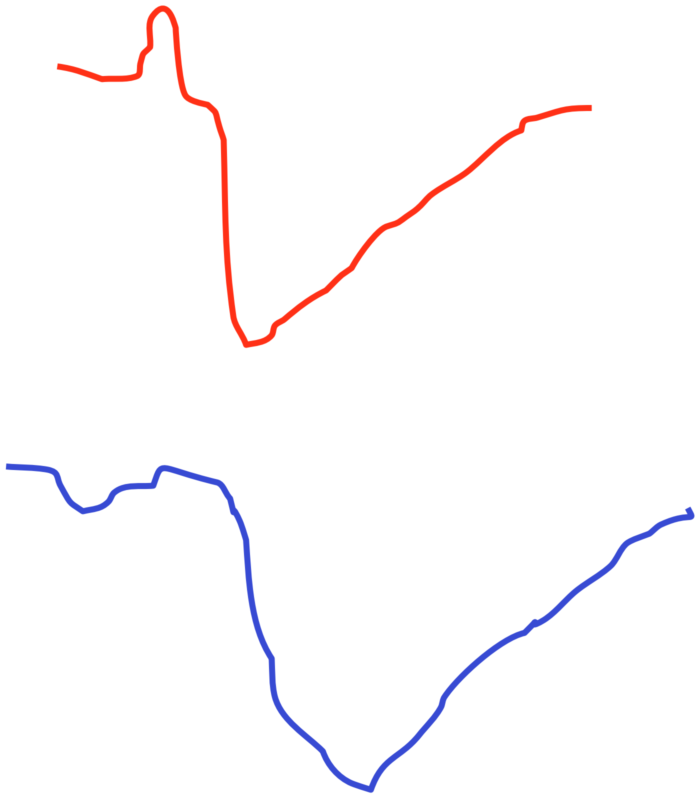
- CRs:
  Probe of the heliospheric environment (EXAMPLES)
- CRs:
  Hazard for space vehicles and life
- CRs and Planets

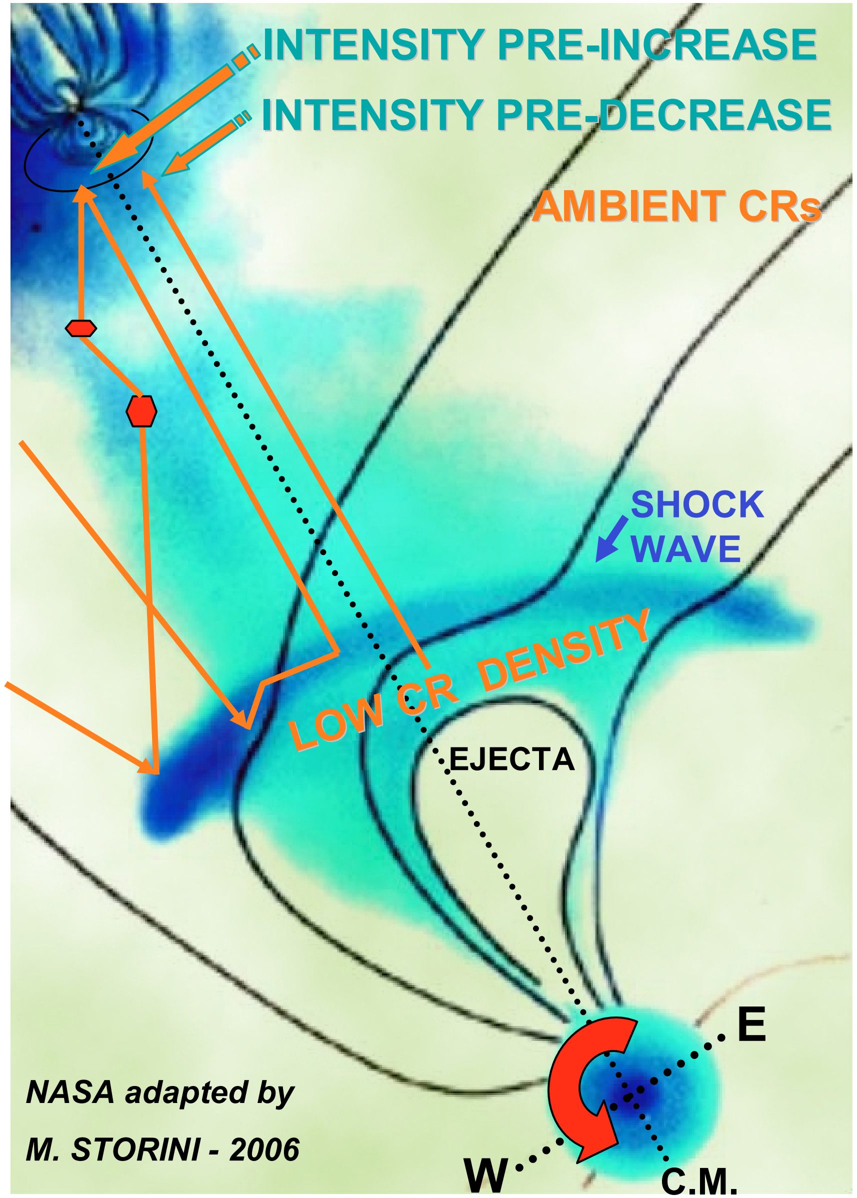
COSMIC RAYS

M. Storini / Trieste - 5 May 2006

PROBE OF THE HELIOSPHERIC ENVIRONMENT

INTERPLANETARY STORM PRECURSORS





BUT ALSO BOTH

COSMIC RAYS

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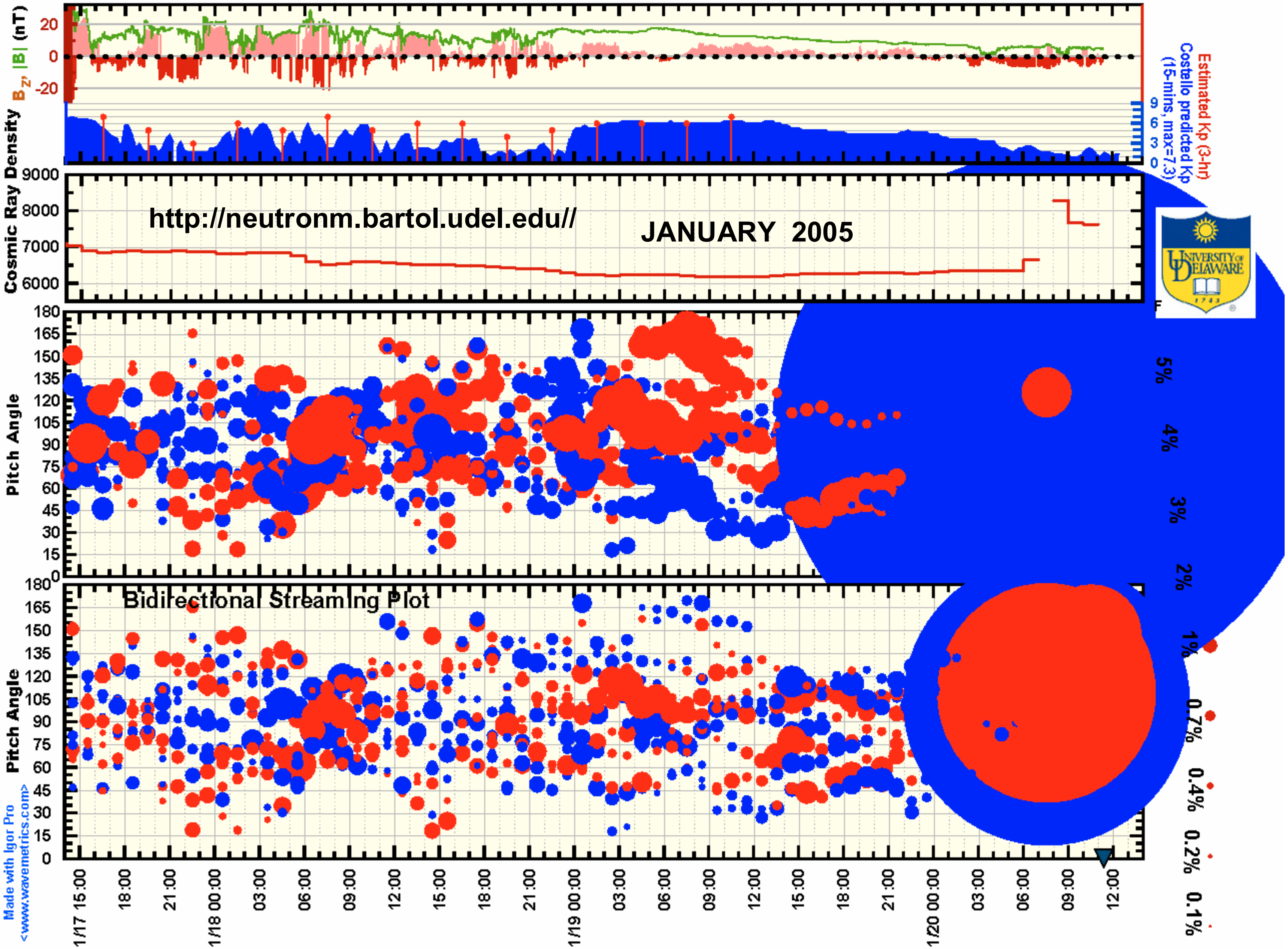
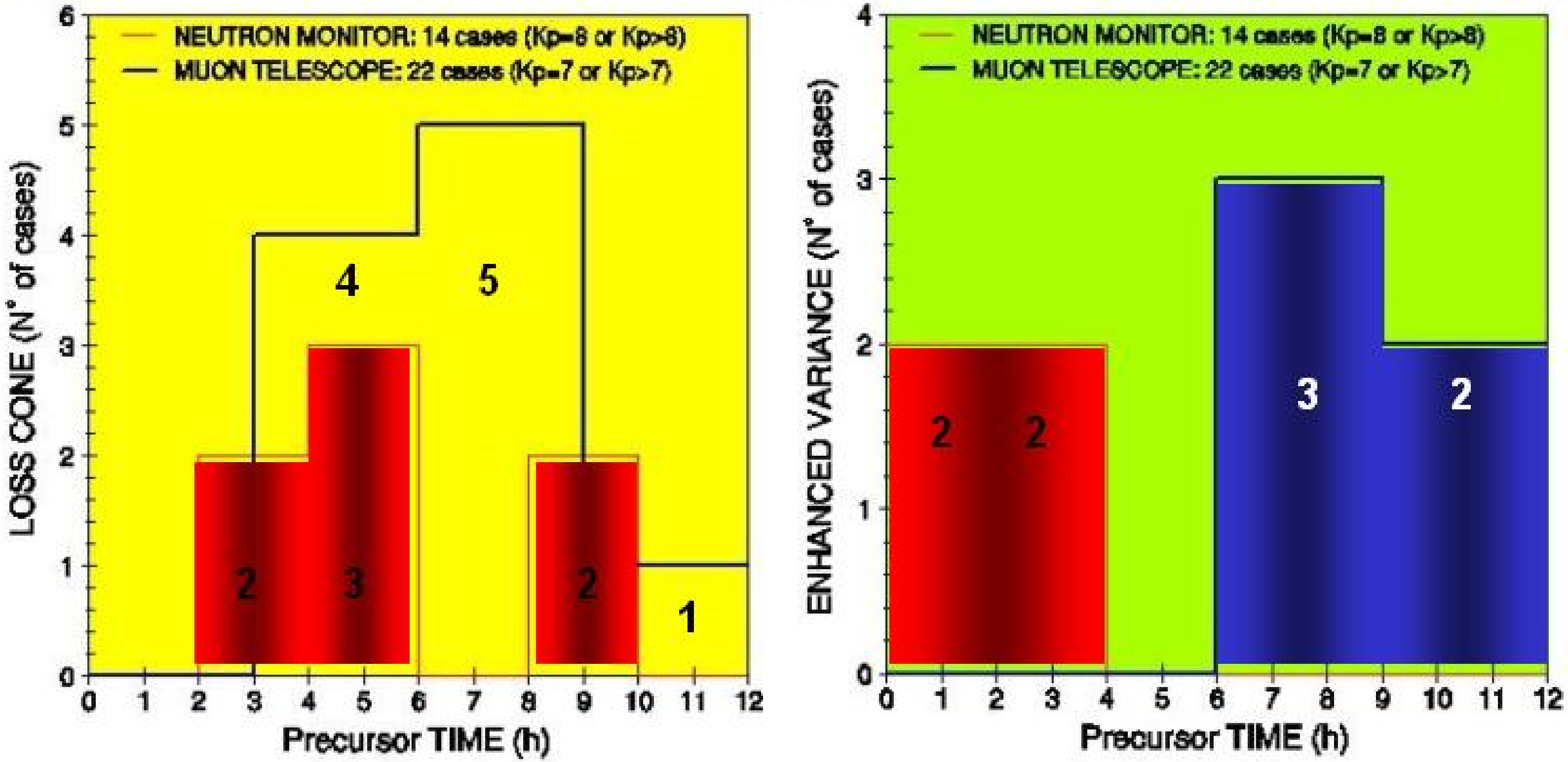


PROBE OF THE HELIOSPHERIC ENVIRONMENT

CR PRECURSORS FOR OUTSTANDING GEOMAGNETIC STORMS



[Hours before SSC event ; red: 11/14 events ; blue: 15/22 events]

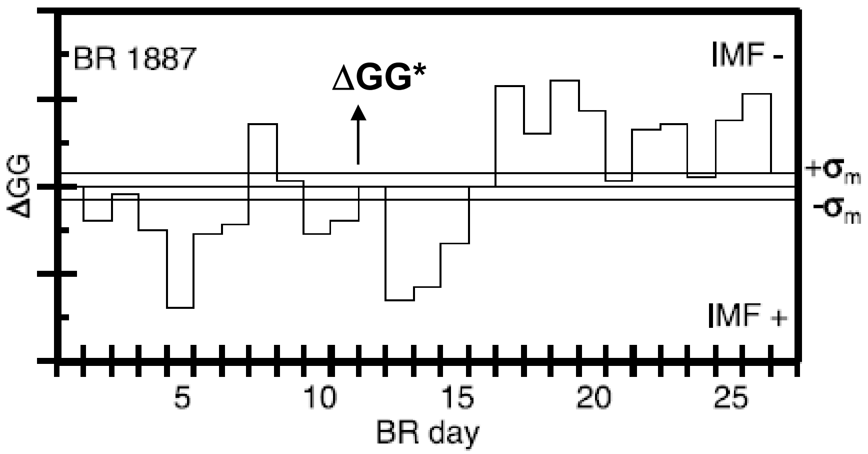
Derived from Munakata et al., JGR 105, 27457, 2000 & Belov et al., Proc. ICRC 2001, 3507, 2001.

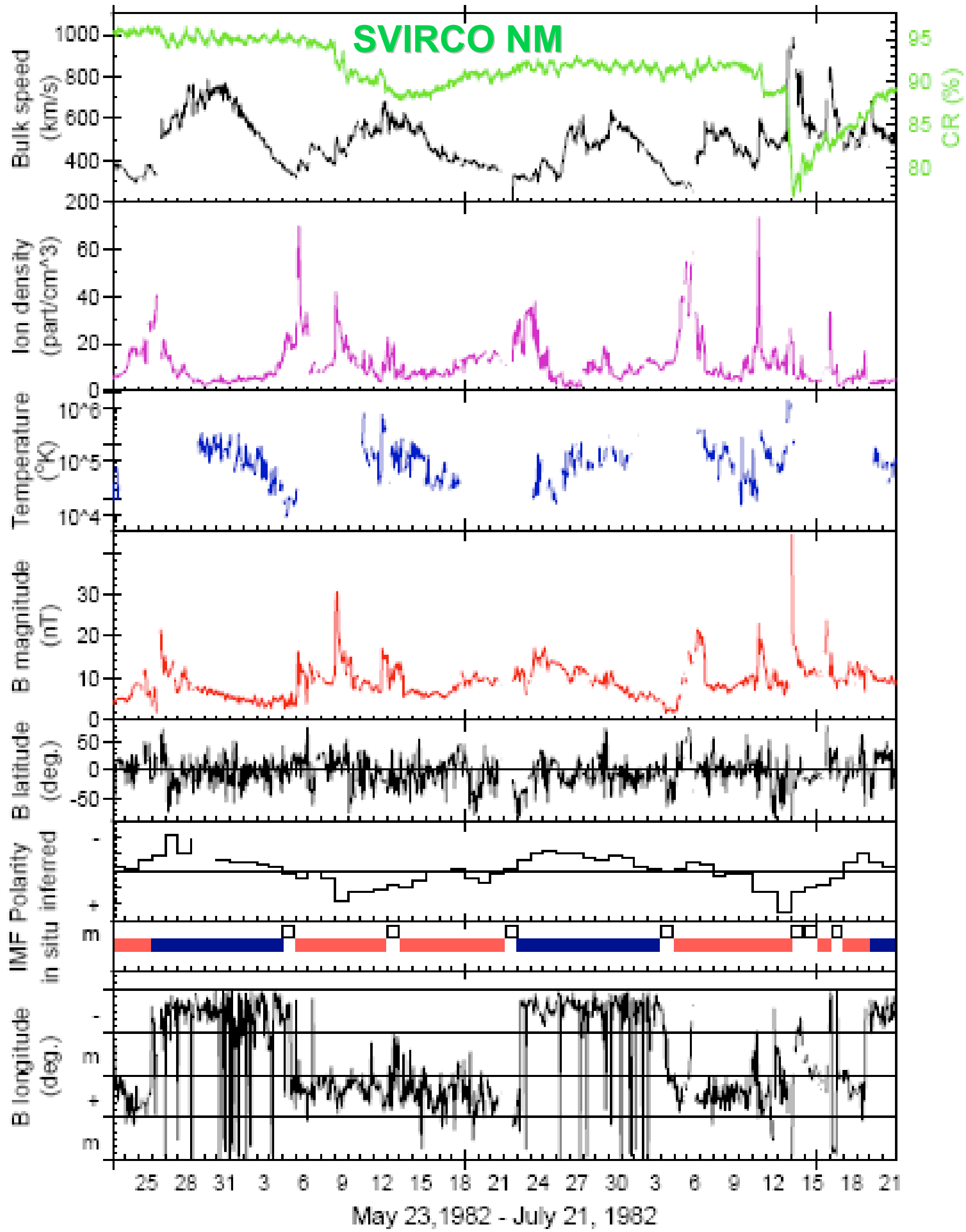
Storini et al. – EGU 2006

PROBE OF THE HELIOSPHERIC ENVIRONMENT

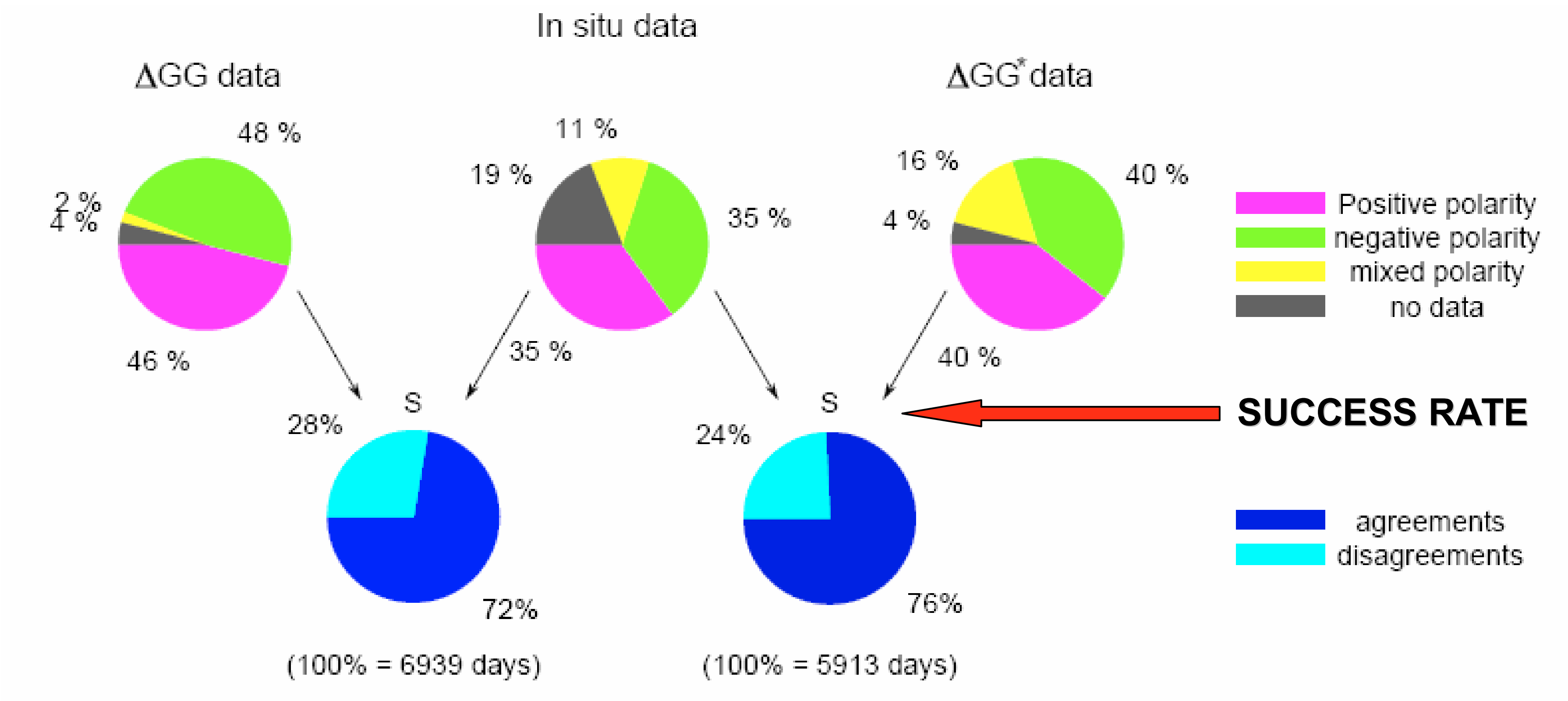
DAYLY IMF POLARITY

Swinson [1969] showed that at the Earth's location, during a positive IMF sector, the galactic CR flow is directed northward, whereas during a negative sector, the CR flow is directed southward. A daily index (GG), describing the CR anisotropy, is derived from the differences between the responses in the northern (N) and southern (S) viewing directions of the muon telescope at the Nagoya Observatory, Japan (see :
Storini M. et al., 28th Int.Cosmic Ray Conf., Universal Academic Press Inc., pp.3949-3952, 2003 & Laurenza et al., JGR 108 (A2), 1069, SSH 4-1, 4-7, 2003.





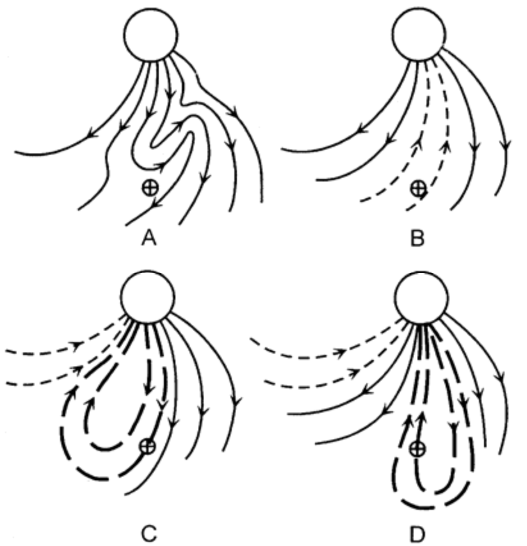
PROBE OF THE HELIOSPHERIC ENVIRONMENT



CR method gives the best results for periods of high-speed solar-wind streams (B <<), in particular during the declining phase of a solar cycle.

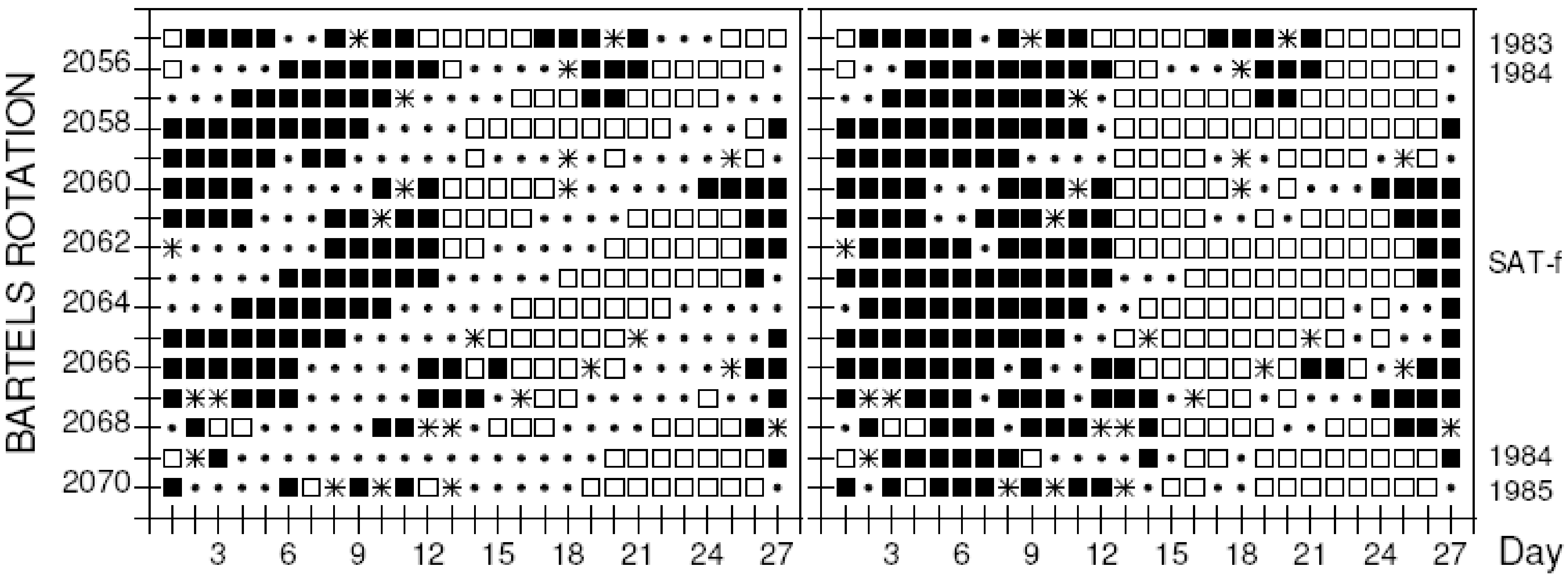
Storini M. et al., 28th Int.Cosmic Ray Conf., Universal Academic Press Inc., pp.3949-3952, 2003

PROBE OF THE HELIOSPHERIC ENVIRONMENT

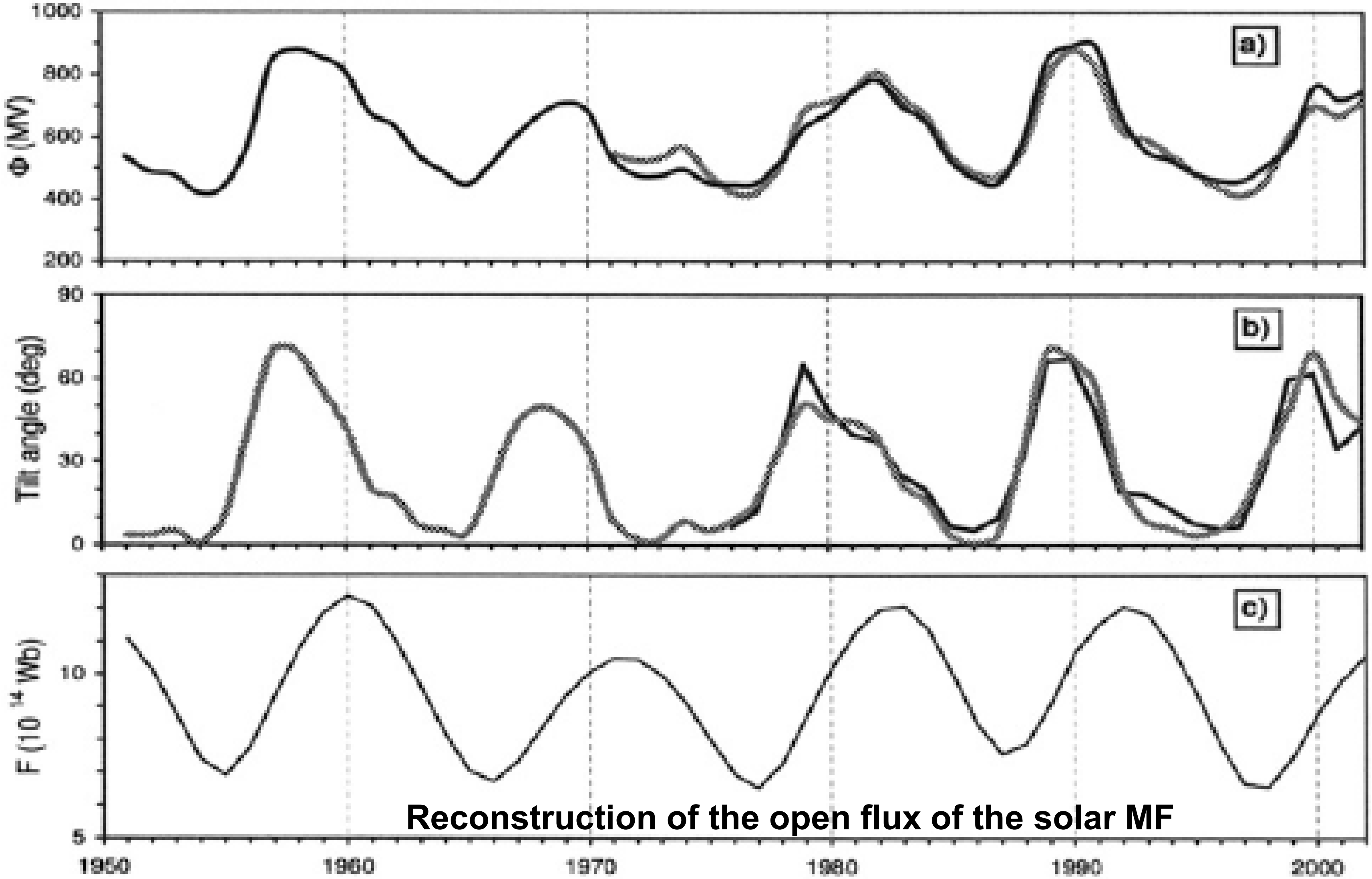


Kahler S.W., in Coronal Mass Ejections, Crooker et al. (eds.), Geophys. Monograph 99, 197-204, 1997.

Filling example - Laurenza et al., IJMPA 20(29), 6802-6804, 2005

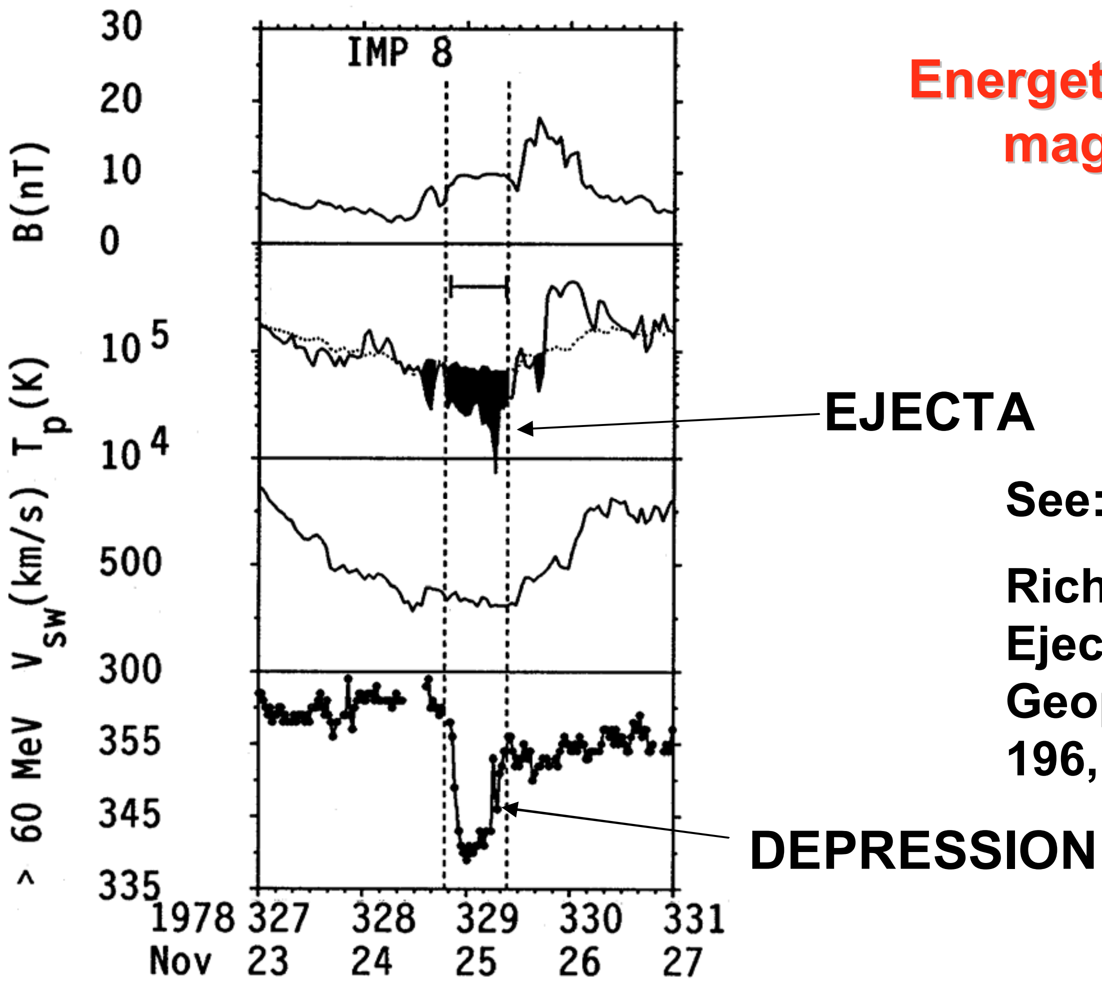


PROBE OF THE HELIOSPHERIC ENVIRONMENT



Taken from Munakata, K., Proc. 28th CR Conf. – Invited, Rapporteur and Highlight papers, Universal Academy Press, 251-276, 2004 (Usoskin et al., SH3.2.4 – ICRC2003)

PROBE OF THE HELIOSPHERIC ENVIRONMENT



Energetic particles to probe the magnetic topology of ejecta

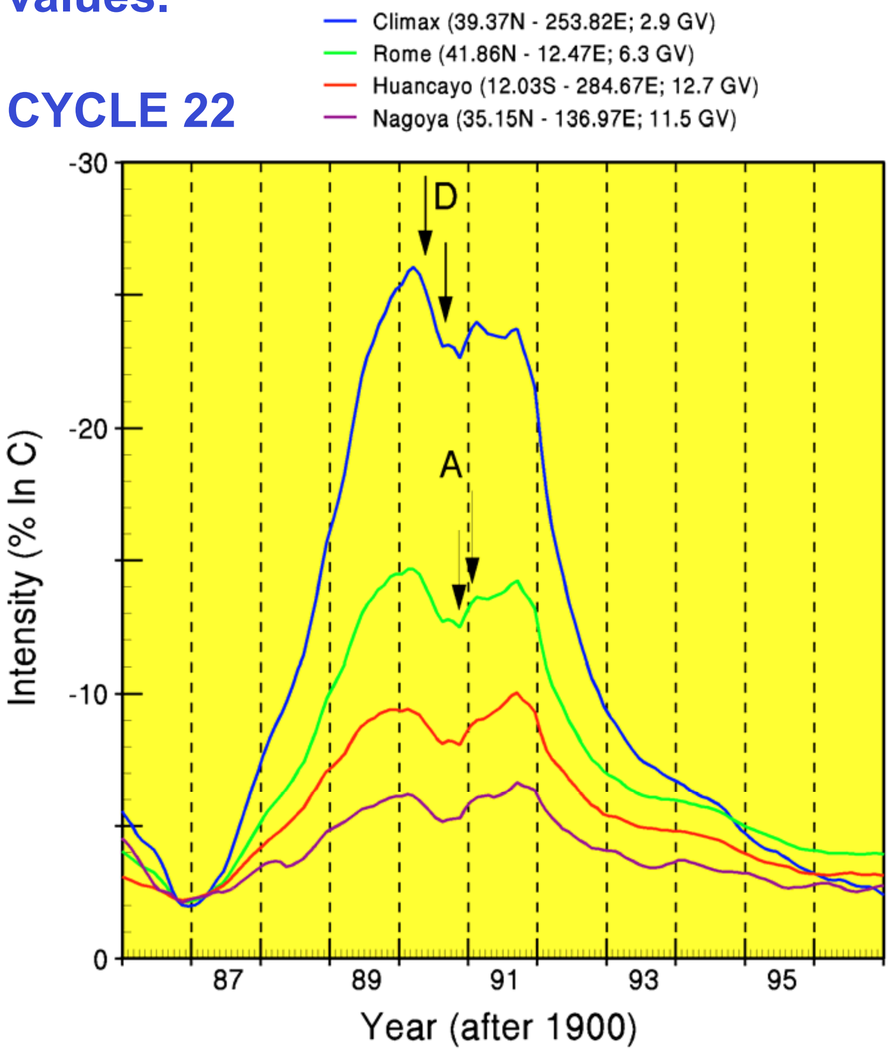
See:

Richardson I.G. in Coronal Mass Ejections, Crooker et al. (eds.), Geophys. Monograph 99, 189-196, 1997.

PROBE OF THE HELIOSPHERIC ENVIRONMENT

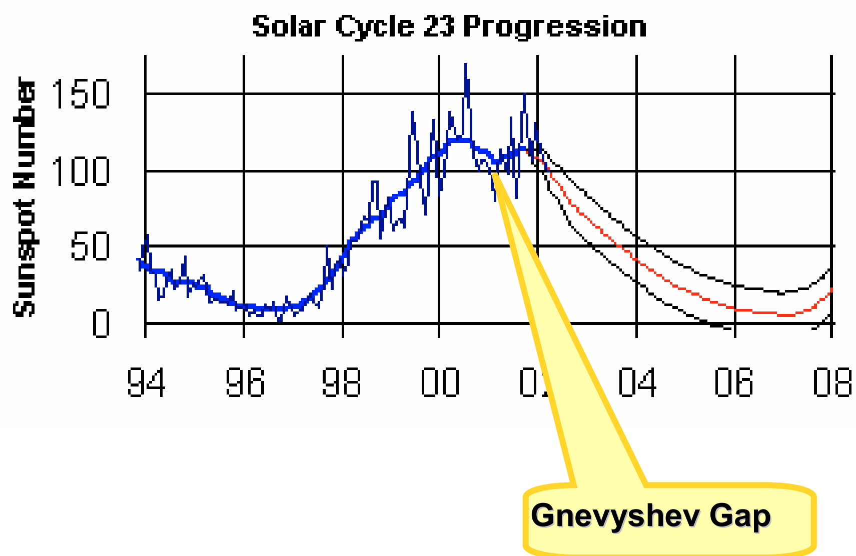
CR DATA : 13-month running averages after superposing the November 1986 values.

CYCLE 22



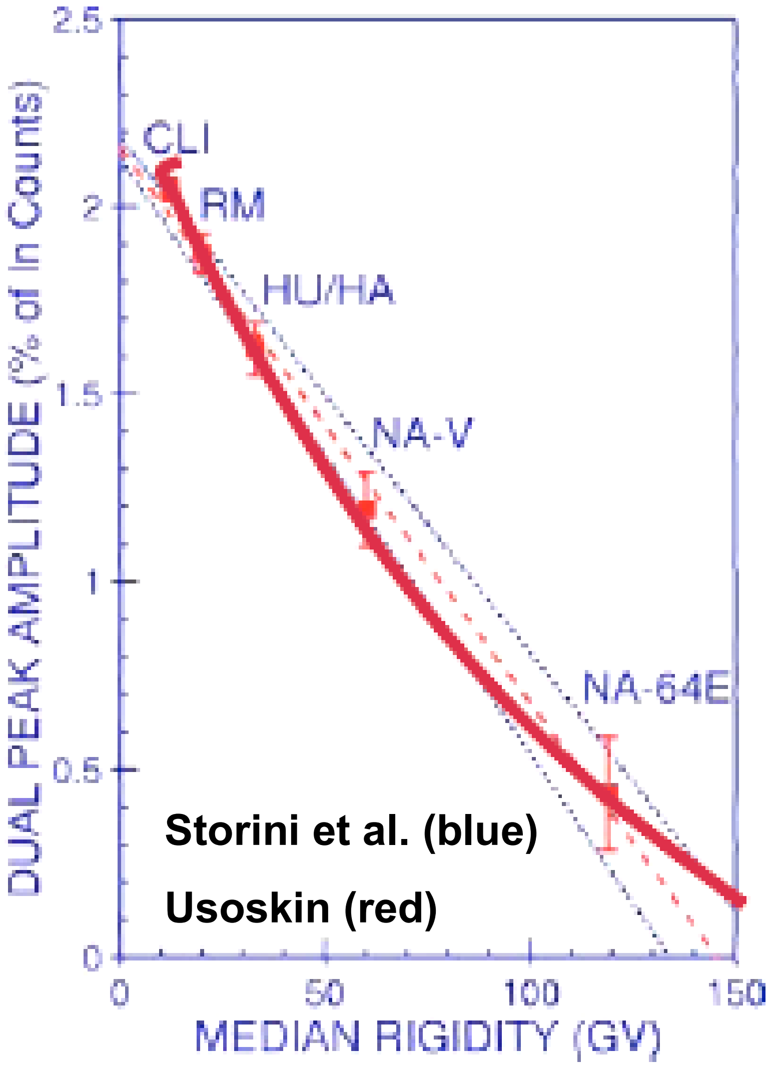
THE GNEVYSHEV GAP

The Gnevyshev Gap is a solar phenomenon related to a peculiar period of the maximum solar activity phase, for which energetic phenomena seem to be negligible or of low entity (see Storini M. et al., Adv. Space Res., 31 (4), 895-900, 2003, and references therein).



Storini et al., ICRC2003, Univ. Acad. Press Inc., pp.4049-4052, 2003

PROBE OF THE HELIOSPHERIC ENVIRONMENT



Gnevyshev Gap (G Gap) in CR power spectrum
(Storini et al. & Usoskin - ICRC2003)

It seems that G Gap can influence also at TEV region (Tibet Collaboration) !!!

Modulation strength …

relevant for space mission planning!

COSMIC RAYS

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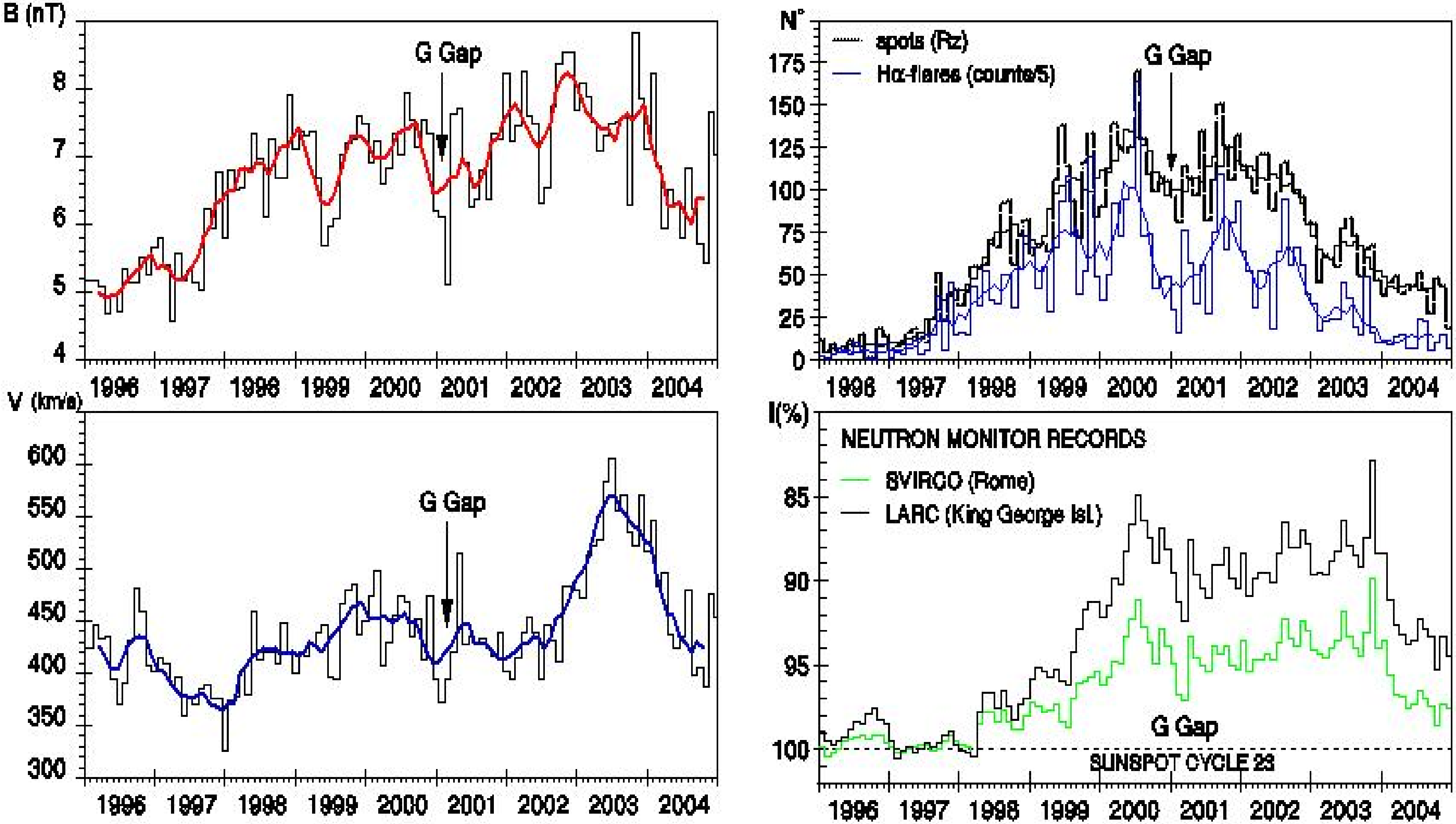
PROBE OF THE HELIOSPHERIC ENVIRONMENT

THE GNEVYSHEV GAP – CYCLE 23



Storini M. /INAF_IFSI-Roma 2006

Hazard for space vehicles and life

• **CRs induce soft errors in computer chips** :

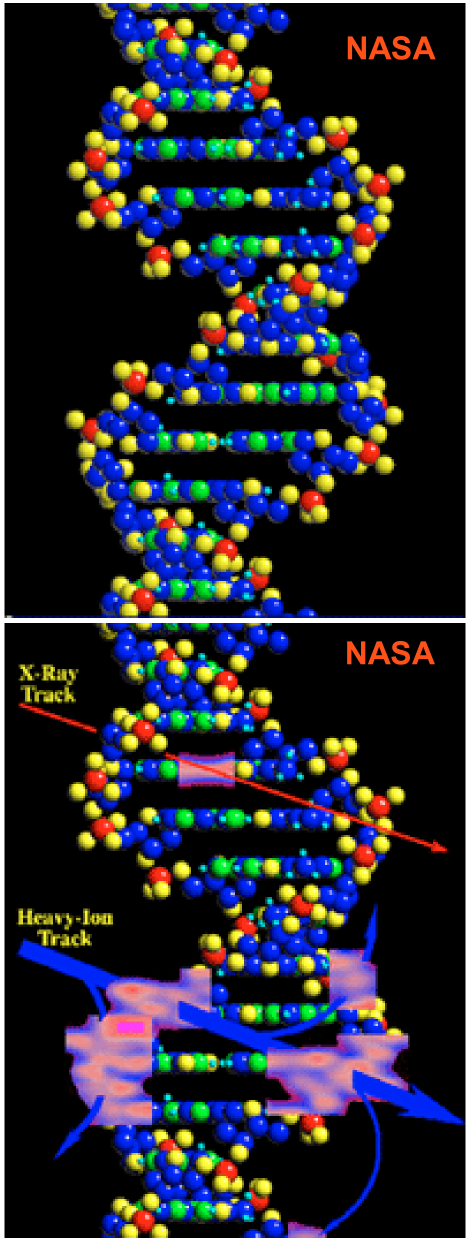
IBM Journal of Research and Development 40 (1), 1996.

(Terrestrial cosmic rays and soft errors)

hazard for space vehicles

Testing many see level particles, they found that neutrons and pions cause significant problems.

- Fracture of the silicon nucleus into a star of exploding fragments. Each generates a stream of electrical charges which can “upset” a circuit.



Hazard for space vehicles and life

Ronald Turner (ANSER/U.S.) said:

" It is extremely important that we really understand how the space weather environment outside a spacecraft can translate into what astronauts actually experience inside their vessel and inside their body"

Excerpt from Space Weather Quartely, 3 (1), 10, 2005

WHY ?

Crew
- → **short-lived hazard: solar CR events**
- → **long-lived hazard: continuous galactic CRs**

⇒ SPACE-CHARGE DOSIMETER

experimental work [type/weight/size/power]

Hazard for space vehicles and life

RISKS

- skin penetration
- free radicals generation
- DNA damage
- chronic illness (certain cancers)
- cataracts (lens clouding of eyes)

ACUTE EFFECTS

- SKIN-REDDENING
- VOMITING/NAUSEA
- DEHYDRATION

Hazard for space vehicles and life

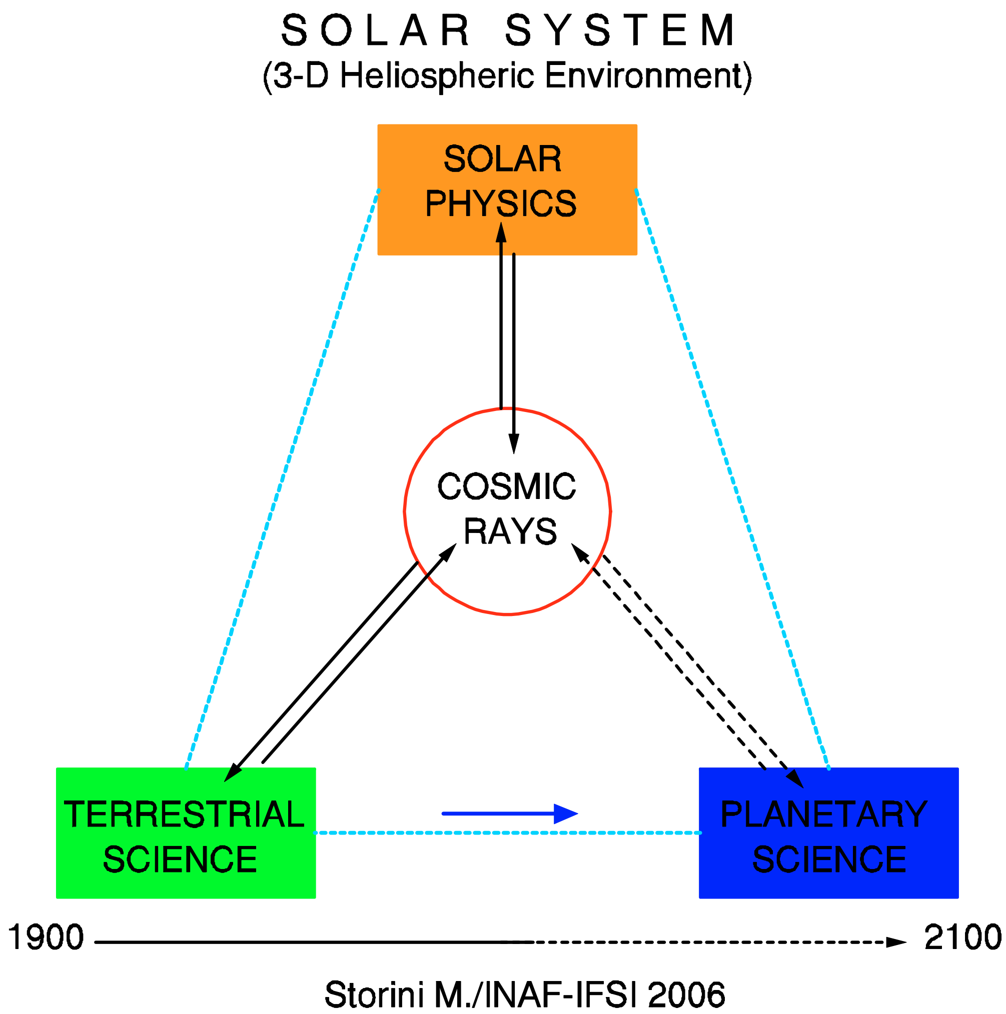
FUTURE MAN-MANED MISSIONS INTO DEEP SPACE NEED:

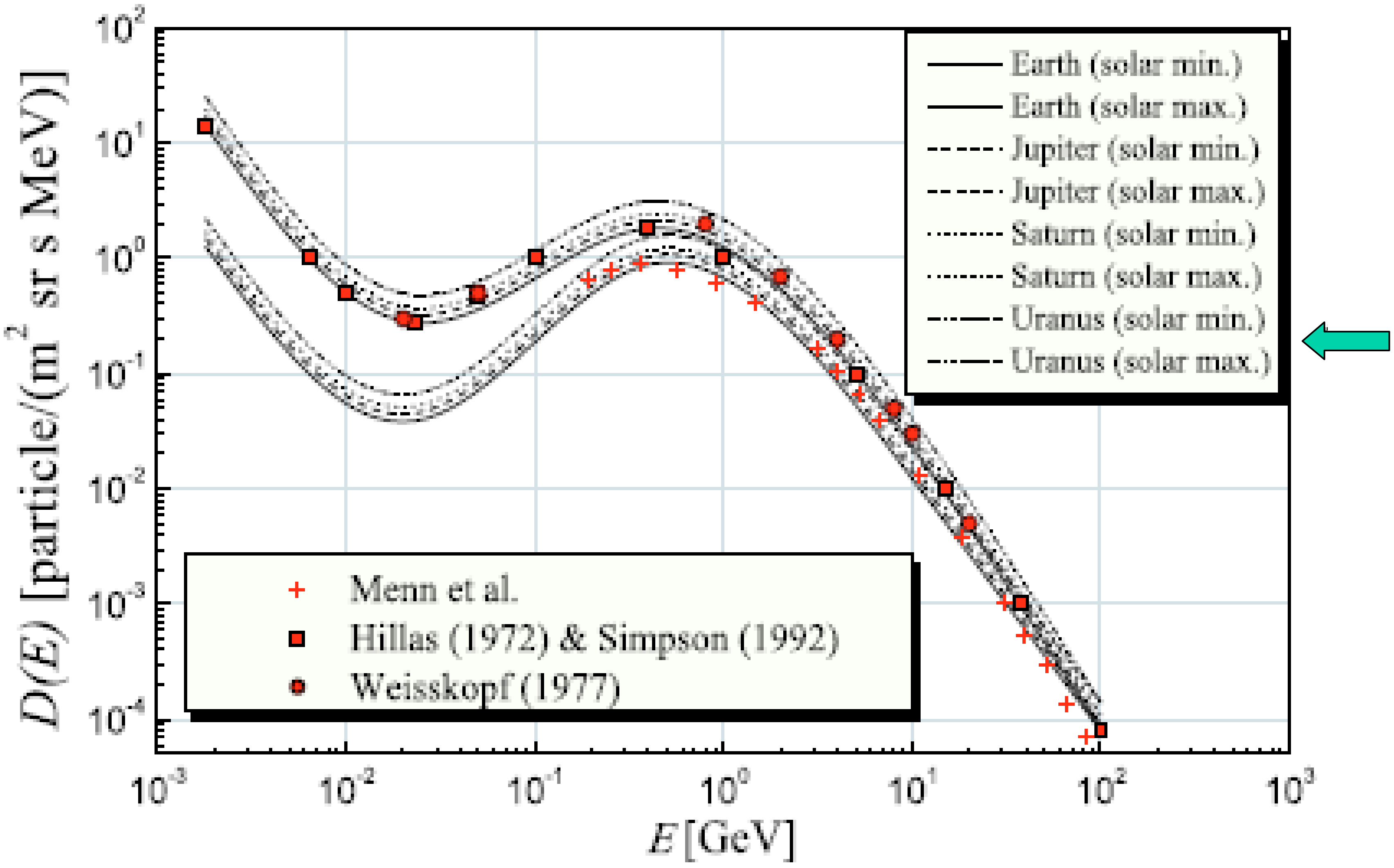
- a close collaboration between scientists, engineers and informatics people to develop:
  - arrays of detectors connected with on-board computer
  - hardware/software for computer generation of continuous 3-D dose maps
  - display devices for risk areas inside the vehicle
  - alert codes (normal, enhanced, outstanding doses)
  - studies for protected rooms to eliminate low energy particles and attenuate high energy particles
- to improve our knowledge on Space Climate

See http://space-env.esa.int/R_and_D/TN5.pdf

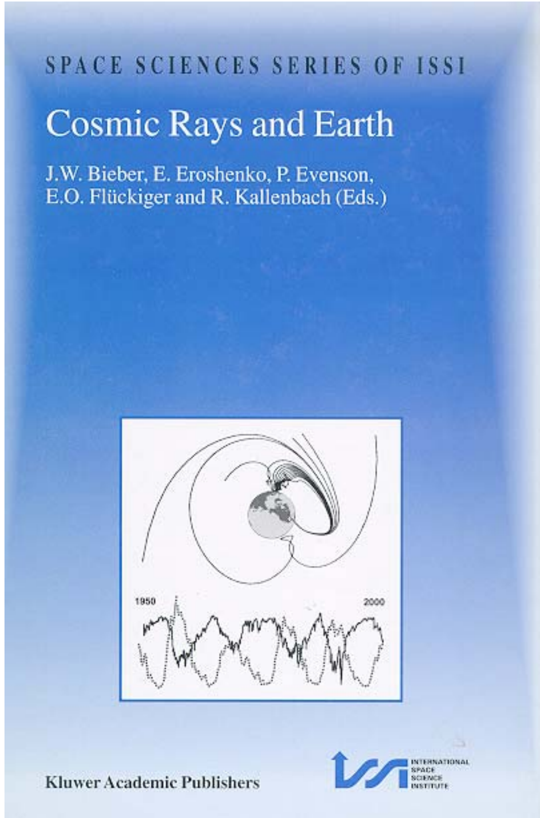
Taken from: Kumar, Mohi**,** *Space Weather,* Vol. 3, S12001, 10.1029/2005SW000214

COSMIC RAYS AND PLANETS





Buchvarova M. et al., IJMPA 20(29), 6681-6683, 2005



INGREDIENTS

- ❑ ATMOSPHERE
- ✐ VARIABILITY WITH HEIGHT
- ❑ GEOMAGNETIC FIELD
- ✐ VARIABILITY WITH THE GEOMAGNETIC COORDINATES

See Kudela K. Lectures

CR variability in the terrestrial environment can be described by Dorman equation:

atmospheric effects geomagnetic effects

$$\frac{\delta I_C^i(h_0)}{I_C^i(h_0)} = \int_{R_c}^{\infty} \frac{\delta m^i(R,h_0)}{m^i(R,h_0)} w_c^i(R,h_0) dR - \delta R_c(R,h_0).w_c^i(R,h_0)$$

Primary CR effects

$$+ \int_{R_c}^{\infty} \frac{\delta D(R)}{D(R)}.w_c^i(R,h_0).dR$$

Where I is the intensity of i-type at a given point [R: rigidity, h_0: atm. depth, D: differential rigidity spectrum]

integral multiplicity

$$w_c^i(R,h_0) = \frac{m^i(R,h_0).D(R)}{I_c^i(h_0)}$$

Known as coupling function

Dorman L.I., Cosmic Rays, Variations and Space Explorations, North-Holland Pub. Co., Amsterdam-Oxford-New York, 1974.

Name	Symbol	Equatorial diameter relative to the Earth	Equatorial diameter (km)	Flattening	Mass relative to the Earth[1]	Mean density	Surface gravity (in ms^{-2})	Escape velocity (in $km\,s^{-1}$)	Inclination of the equator to the orbital plane	Principal atmospheric components
Mercury	☿	0.382	4 878	0	0.055	5.44	3.78	4.25	0°	H, He, Ne (solar wind)
Venus	♀	0.949	12 104	0	0.815	5.25	8.60	10.36	2°07′	CO_2 (97%)
Earth	♁	1	12 756	0.003 353	1	5.52	9.78	11.18	23°26′	N_2 (78%) O_2 (21%)
Mars	♂	0.533	6 794	0.005	0.107	3.94	3.72	5.02	23°59′	CO_2 (95%)
Jupiter	♃	11.19	142 800	0.062	317.80	1.24	24.8	59.64	3°04′	H, He, CH_4, NH_3
Saturn	♄	9.41	120 000	0.0912	95.1	0.63	10.5	35.41	26°44′	H, He, CH_4, NH_3
Uranus	⛢	3.98	50 800	0.06	14.6	1.21	8.5	21.41	98°	H, He, CH_4, NH_3
Neptune	♆	3.81	48 600	0.02	17.2	1.67	10.8	23.52	29°	H, He, CH_4, NH_3
Pluto	♇	0.18	2 274		0.002	1.94		1.25	119.6	N_2

Taken from Encrenaz et al., The Solar System (3rd. Ed.), Springer, 2004.

Table 1.7. Planetary magnetic fields and magnetospheres

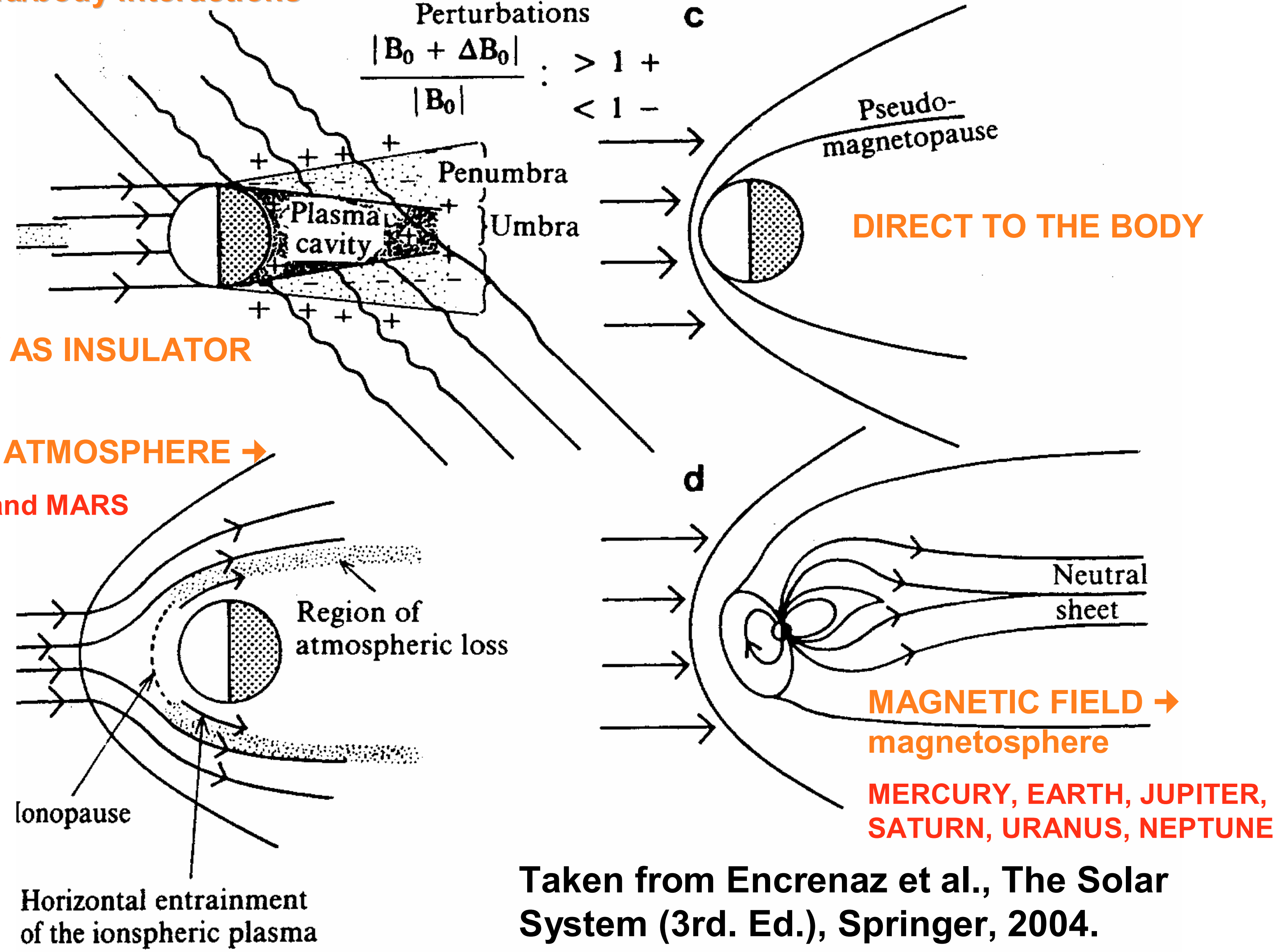
Planet	Dipolar moment ($G \cdot km^3$)	Field at the equator (G)	Inclination $[B,\Omega]$ & direction (°)	Typical radius of the magnetopause (km)	(R_P)
Mercury	5×10^7	0.003	+14	3 700	1.5
Venus	$< 3 \times 10^7$	≤ 0.0003	–	~ 6 100	~ 1
Earth	8×10^{10}	0.31	+11.7	64 000	10
Mars	$< 2 \times 10^6$	< 0.00005	–	~ 3 400	~ 1
Jupiter	1.6×10^{15}	4.3	– 9.6	4 300 000	60
Saturn	4.6×10^{13}	0.21	– 0	1 200 000	20
Uranus	4.1×10^{12}	0.23	–58.6	470 000	18
Neptune	2.1×10^{12}	0.14	–46.9	570 000	23

Taken from Encrenaz et al., The Solar System (3rd. Ed.), Springer, 2004.

COSMIC RAYS AND PLANETS

M. Storini / Trieste - 5 May 2006

Solar wind/body interactions



Taken from Encrenaz et al., The Solar System (3rd. Ed.), Springer, 2004.


PLANETOCOSMICS
http://cosray.unibe.ch/~laurent/planetocosmics/
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Physikalisches Institut, University of Bern