The Relevance of Cosmic Rays to Space and Earth Weather

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2001 - 2006

1998 - 2006

1991 - 2006

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COST 724

OUTLINE

- WEATHER CONCEPT
- CR RELEVANCE – WHY?
- CRs: PROBE OF THE HELIOSPHERIC ENVIRONMENT
- CRs: INTERACTION WITH MATTER
- PLANET's ATMOSPHERE
- GROUND AND SPACE DEVICES
- BIOLOGICAL BODIES
- GEOMAGNETIC FIELD ROLE
- THE RELEVANCE OF HIGH-MOUNTAIN RESEARCH
- CONCLUSIONS

WEATHER CONCEPT

CLASSICAL METEOROLOGY

[lower atmosphere]

PARAMETERS

Wind, Pressure, Temperature, Relative humidity, Precipitation, ...

STRUCTURES

Clouds, Thunderstorms, Lightning, Hurricanes, Cyclones, ...

SPACE WEATHER

[the terrestrial environment
+
near-Earth free space]

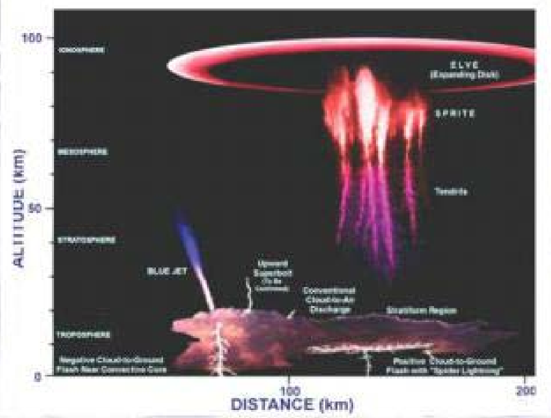
TERRESTRIAL WEATHER

NEW METEOROLOGY ?

[the complete atmosphere*]

INCLUDED STRUCTURES

Sprites (red ↑ and blue ↓ emissions), Blue Jets, Auroras,...



* WITH PARTICULAR ATTENTION TO THE OZONE LAYER

CR RELEVANCE – WHY?

THE THIRD INGREDIENT OF THE HELIOSPHERE

PROBE OF THE HELIOSPHERIC STATUS

CR signatures for forecast/nowcast

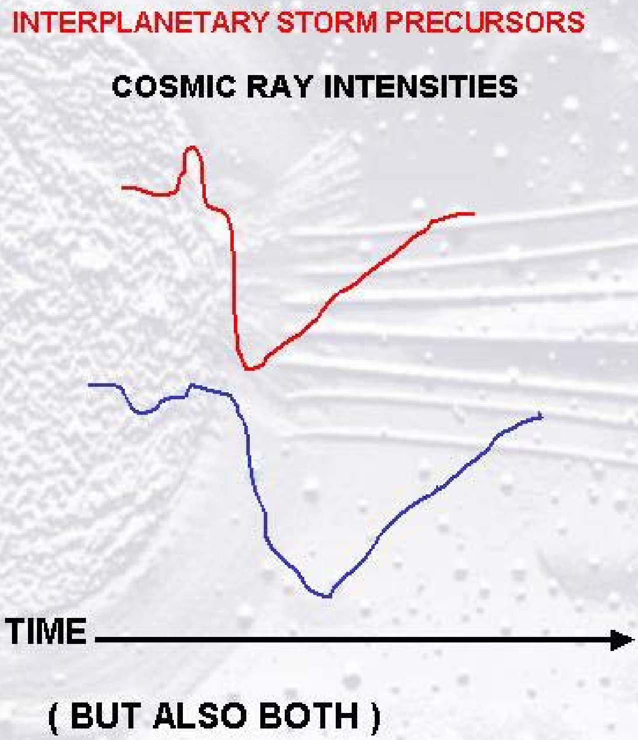
(INDIRECT DATA USE)

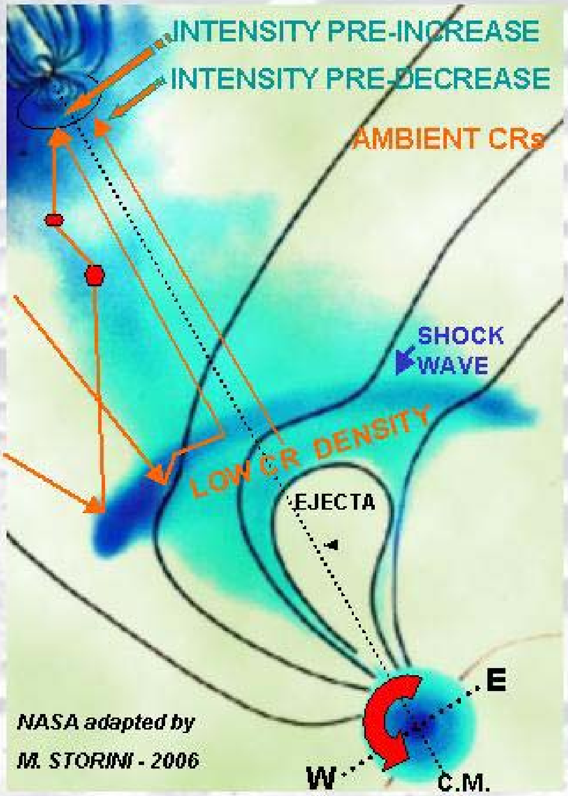
CR interaction with matter

- PLANET'S ATMOSPHERE
- GROUND & SPACE DEVICES
- BIOLOGICAL BODIES

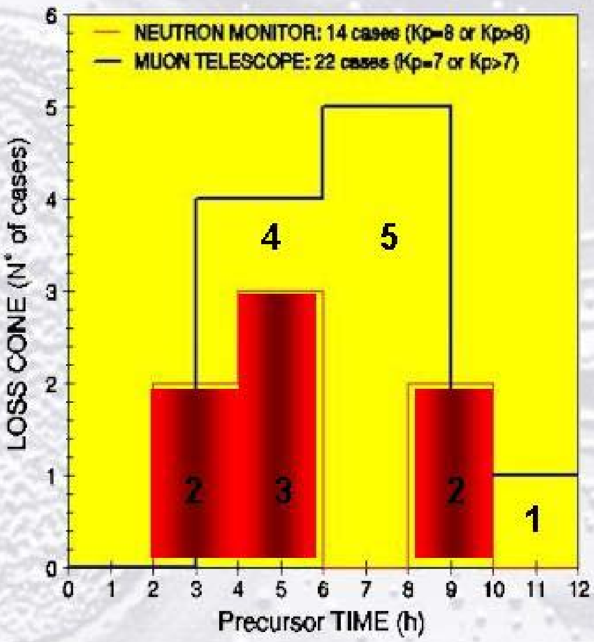
(DIRECT DATA USE)

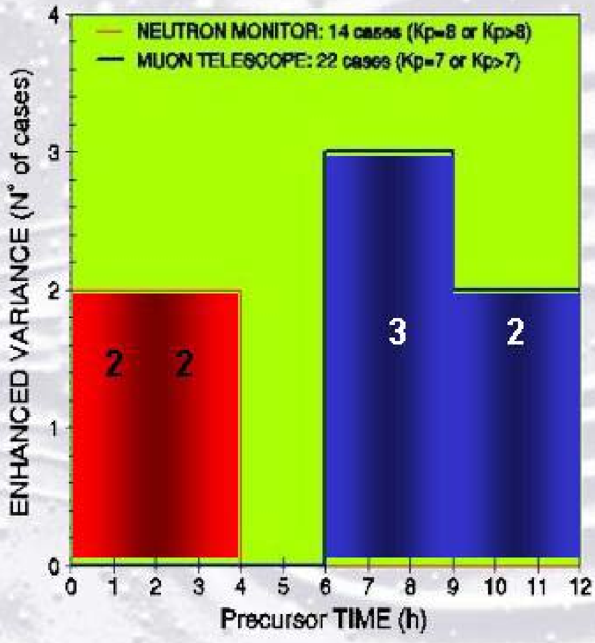
PROBE OF THE HELIOSPHERIC ENVIRONMENT





CRs / OUTSTANDING GEOMAGNETIC STORMS



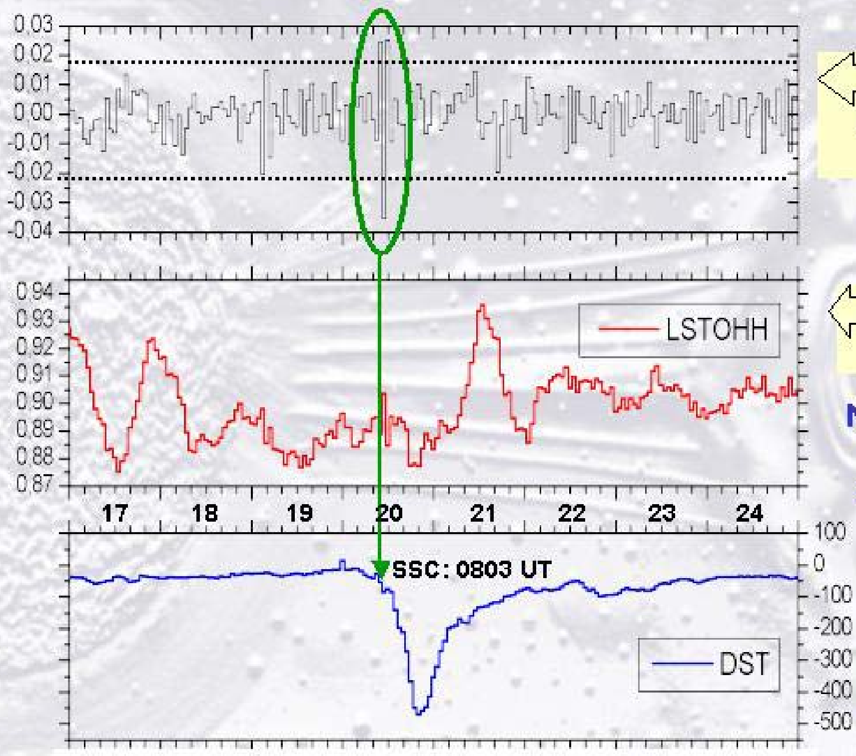


[Hours before SSC event ; red: 11/14 events ; blue: 15/22 events]

Storini et al. – EGU 2006

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

CR NOWCAST / OUTSTANDING GEOMAGNETIC STORMS



November 17-24, 2003

LS/HH Derivate (taken from 2 h before and 1 h after)

Ratio between the counting rate (LS/HH)

Nowcast from two NMs with opposite asymptotic longitudes (LS: L-Stit & HH:Haleakala)

Kudela & Storini, Adv. Space Res. 2006.

REAL-TIME CR MONITORING SYSTEM

SPACE WEATHER, VOL. 4, S08001, doi:10.1029/2005SW000204, 2006

By T. Kuwabara et al.

Published 15 August 2006

We have developed a real-time system to monitor high-energy cosmic rays for use in space weather forecasting and specification. Neutron monitors and muon detectors are used for our system, making it possible to observe cosmic rays with dual energy range observations. In large solar energetic particle (SEP) events, the ground level enhancement (GLE) can provide the earliest alert for the onset of the SEP event. The loss cone precursor anisotropy predicts the arrival of interplanetary shocks and the associated interplanetary coronal mass ejections (ICMEs), while the occurrence of bidirectional cosmic ray streaming indicates that Earth is within a large ICME. This article describes a set of real-time Web displays that clearly show the appearance of the GLE, loss cone precursor, and other space weather phenomena related to cosmic rays.

Examples of other resources:

- **Cosmic ray indices & List of cosmic ray storms (IZMIRAN group)**
- **Space weather prediction by cosmic rays, H. Mavromichalaki et al. / Advances in Space Research 37 (2006) 1141–1147.**

…

ESO RESOURCES

Forecasting of radiation hazard: 1. Alerts on great FEP events beginning; probabilities of false and missed alerts; on-line determination of solar energetic particle spectrum by using spectrographic method, L.I. Dorman et al. / Advances in Space Research 37 (2006) 1124–1133

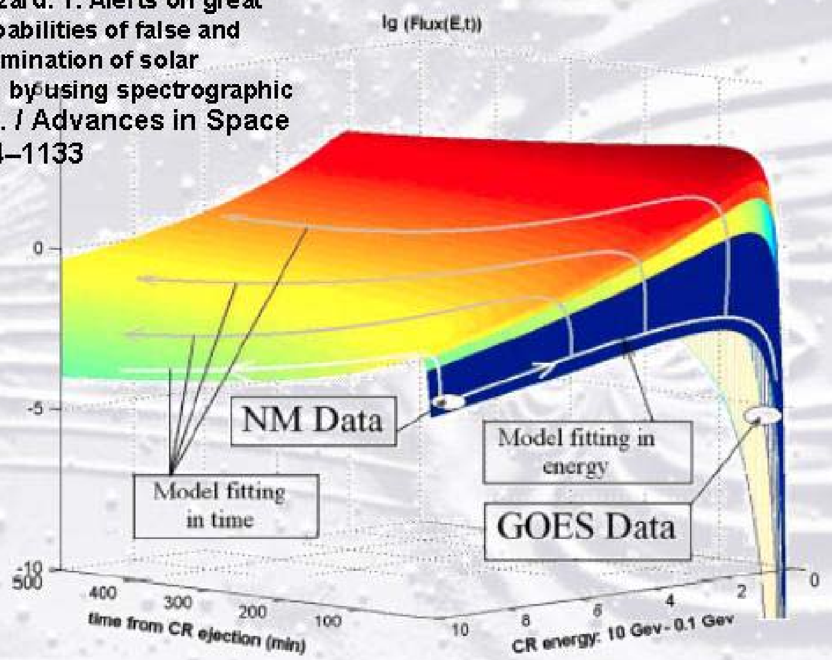


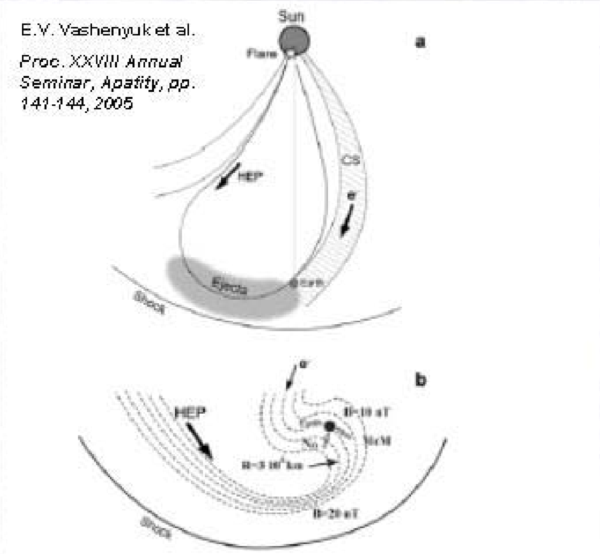
Fig. 5. Illustration of the idea of the FEP forecasting method by using on-line NM and satellite data.

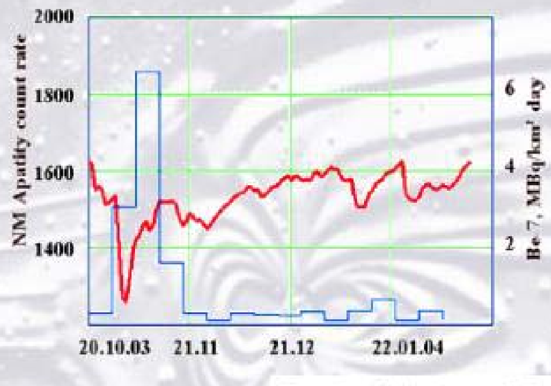
Forecasting of radiation hazard: 2. On-line determination of diffusion coefficient in the interplanetary space, time of ejection and energy spectrum at the source; on-line using of neutron monitor and satellite data, L.I. Dorman et al. / Advances in Space Research 37 (2006) 1134–1140

PROBE OF THE HELIOSPHERIC ENVIRONMENT

E.V. Vashenyuk et al.

Proc. XXVIII Annual Seminar, Apatity, pp. 141-144, 2005





N.A. Melnik et al.

Proc. XXVIII Annual Seminar, Apatity, pp. 126-129, 2005

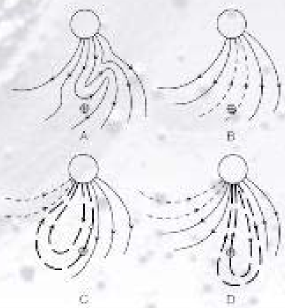
Fig. 8. Variations of Be-7 concentration in atmospheric precipitations related to the events SCR in the period from 20 October 2003 to 10 February 2004.

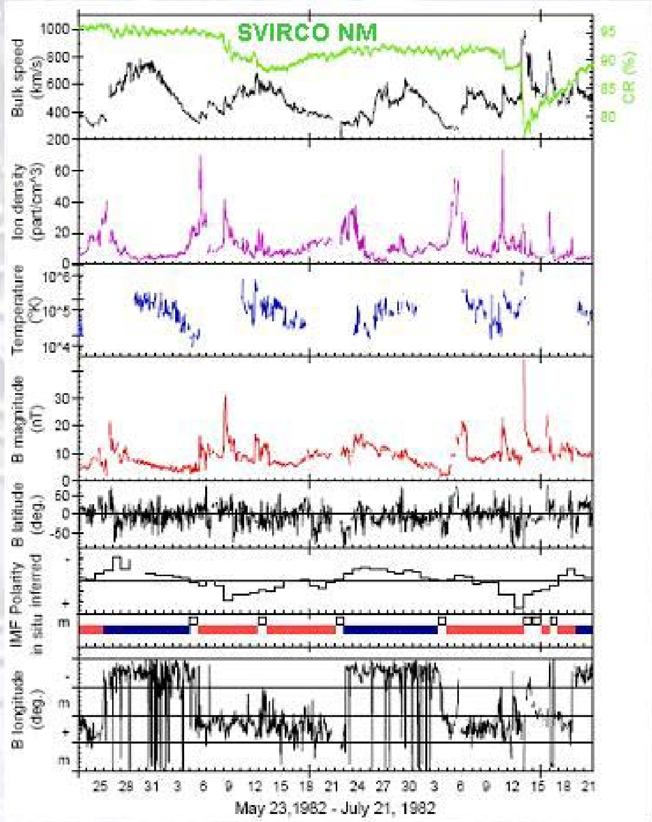
Fig. 2. a. The proposed model for the IMF structure during the 28 October, 2003 SPE. The Earth is at the boundary area between the ejecta from the flare of October 26 and corotating stream (CS) commenced to the Earth shortly before the event. By means of the looped IMF structure inside the ejecta, the Earth is connected to the flare site in the eastern part of the solar disc. High energy solar protons (HEP) come to the Earth from the antisunward direction. At the same time, the subrelativistic electrons can arrive at the Earth from a source in the western part of the solar disk along the Parker spiral IMF line, connected with a corotating stream.
b. The spatial structure of the IMF near the Earth during the 28 Oct 2003 GLE, reconstructed using IMF and solar wind data. The dotted lines are the IMF field lines and arrows are average directions of relativistic proton flux registered by neutron monitors in Mc Murdo (McM) and Norilsk (No). An essential detail here is a sharp kink of

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. Laurenza et al., JGR 109, A06103, doi:10.1029/2003JA010323, 2004. Laurenza et al., IJMPA 20(29), 6802-6804, 2005.





INTERACTION WITH MATTER

COSMIC RAYS
(type of Interactions)

NUCLEAR INTERACTIONS

IONISATION/EXCITATION
of atoms or molecules

DESTRUCTION
of crystal structures
or molecular chains

PLANET's ATMOSPHERE

FOLLOWS:

- Cascade of secondary CRs
- Direct ionization of the target
- Relevance of the ionization losses
- Relevance of the transferred energy to the target

⇨ IMPROVED IONIZATION MODELS (COST 724 ACTION)

⇨ BERN GROUP (Desorgher and co-authors)

⇨ OULU GROUP (Usoskin and co-authors)

⇨ SOFIA GROUP (Velinov and co-authors)

VARIABILITIES: Latitude, Longitude, Altitude, Solar cycle phase, Charged-particle spectrum, Contemporary geomagnetic field.

PLANET's ATMOSPHERE - 2

IONS IN AIR ⇨ IMPACT ON ATMOSPHERIC PROCESSES THROUGH:
[e.g. Bazilevskaya et al., JASTP 62 (2000), 1577-1586]

🕮 Charge-dependent chemical reactions [e.g. for minor atmospheric constituents ⇨ OZONE ISSUE AND INVOLVED CATALITIC PROCESSES]

🕮 Charge-dependent droplet and crystal formation [MICROPHYSICS OF CLOUDS]

🕮 Influence on the current flowing in the global terrestrial electric circuit [THUNDERSTORM CLOUD EVOLUTION]

OTHER OBSERVED FUTURES IN THE ATMOSPHERE
(Tinsley and co-workes & Stozhkov and co-workers)

FDs ⇨ VAI & PRECIPITATION Decrease

SEP ⇨ VAI & PRECIPITATION Increase

PLANET's ATMOSPHERE - 3

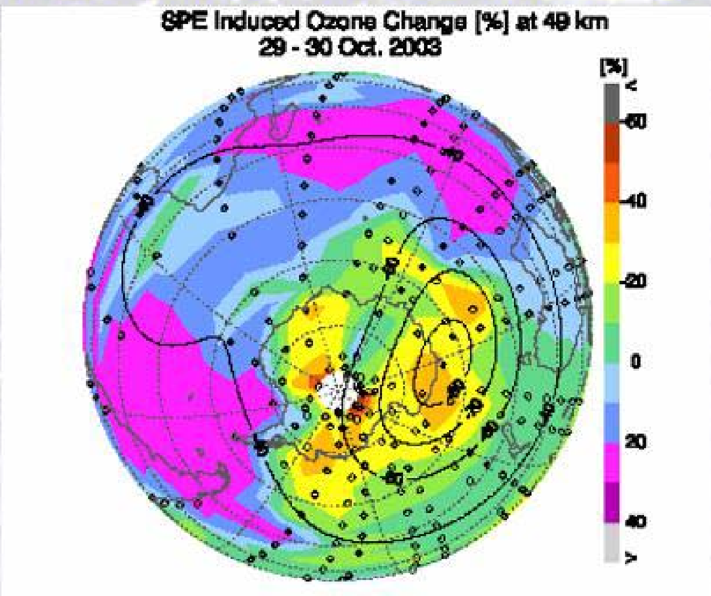


Fig. 7. In the Southern hemisphere, evident changes of the ozone concentrations can only be observed in a period from 29 to 30 October 2003. The ozone depletion is mainly located where the solar particles

FROM SCIAMACHY LIMB SPECTRA (Envisat satellite) :

Rohen et al., Adv. Space Res. 37 (2006), 2263-2268

GROUND AND SPACE DEVICES

CRs can 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 IN MEMORY BANKS

GROUND AND SPACE DEVICES - 2

CRs can induce negative effects on spacecraft systems

They:

- can damage solar panels
- confuse optical trackers
- deposit harmful charges into sensitive electronic components

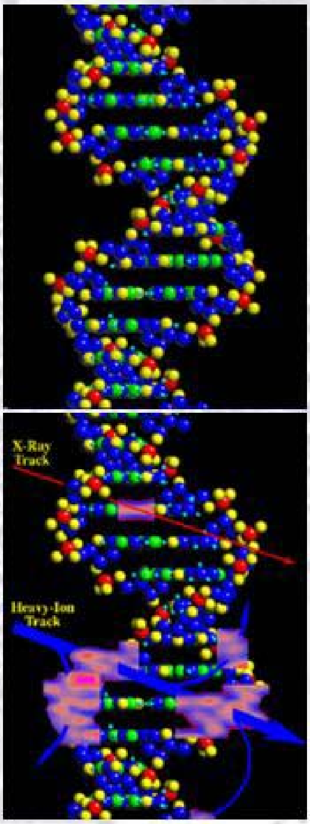
… ⇨

"ANOMALIES"

(also SPACECRAFT FAILURES)

(e.g. Iucci et al., SPACE WEATHER 3, S01001, doi:10.1029/2003SW000056,2005 and Pilipenko et al., Adv. Space Res. 37 (2006) 1192-1205 for recent work).

BIOLOGICAL BODIES



EXPECTED RISKS

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

ACUTE EFFECTS

- SKIN-REDDENING
- VOMITING/NAUSEA
- DEHYDRATION

BIOLOGICAL BODIES - 2

NEAR-EARTH EXPOSURE SOURCES OF THE COSMIC ORIGIN

Component ⇒ Property ⇓	Galactic	Solar	Radiation belts
Origin	Deep Space	Sun	Earth's trapped
Composition	86% p, 12% He, up to U	99% p	p, e^-
Energy	$\leq 10^{20}$ eV, $\Phi \sim E^{-2.6}$	variable, >1 GeV rare	p <100 MeV, $e^- < 1$ MeV
Distribution	isotropic	variable, flares	inner, ~3000 km, outer, ~22000 km
Particularity	solar modulated	intensity nor energy predictable	South Atlantic anomaly (SAA)
H*(10) in open space	0.4 – 1.2 Sv per year	< 10 Sv, mostly much lower	p(SAA) < 4 Sv/y, $e^- \sim 10^5$ Sv/y

František Spurný

BEOBAL 3rd Training Seminar - 2006

BIOLOGICAL BODIES - 3

František Spurný – BEOBAL 3rd Training Seminar - 2006

Doses from GCR (1977 solar minimum) and/or SPE shield 10 g.cm^{-2}

GCR Sv/year	Open space	0.59
	Moon	0.29
	Mars	0.12
GCR Sv	Mission to Moon (190 days)	0.18
	Mission to Mars (947 days)	0.92
SPE*); Sv	Open space	1.3
	Lunar surface	0.6
	Mars surface	0.25

*) worst scenario – GLE 23/05/56 with 10times higher flux than that of GLE of 29/09/89

BIOLOGICAL BODIES - 4

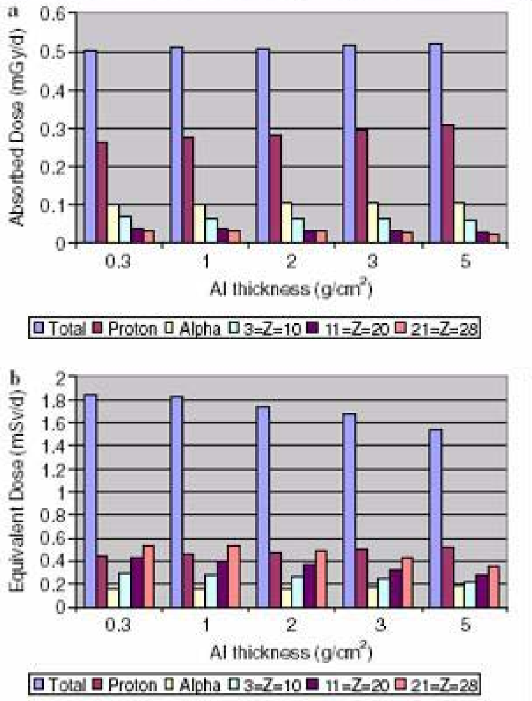


Fig. 3. Skin-averaged absorbed dose (in mGy/day, panel a) and equivalent dose (in mSv/day, panel b) calculated with the mathematical phantom for solar minimum GCR. For each Al thickness value, the six bars (from left to right) represent the contributions from the following components of the GCR primary spectrum: all primary particles, protons, alpha particles, and heavier ions with $3 \leqslant Z \leqslant 10$, $11 \leqslant Z \leqslant 20$, $21 \leqslant Z \leqslant 28$.

F. Ballarini et al., Advances in Space Research 37 (2006) 1791–1797

BIOLOGICAL BODIES - 5

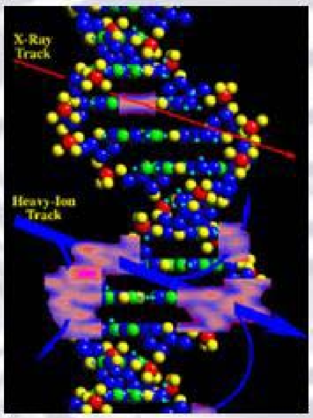
Short-lived hazard: solar CR events

←··

Long-lived hazard: continuous galactic CRs

··→

RELEVANT PARAMETERS: Exposure time, Exposure place

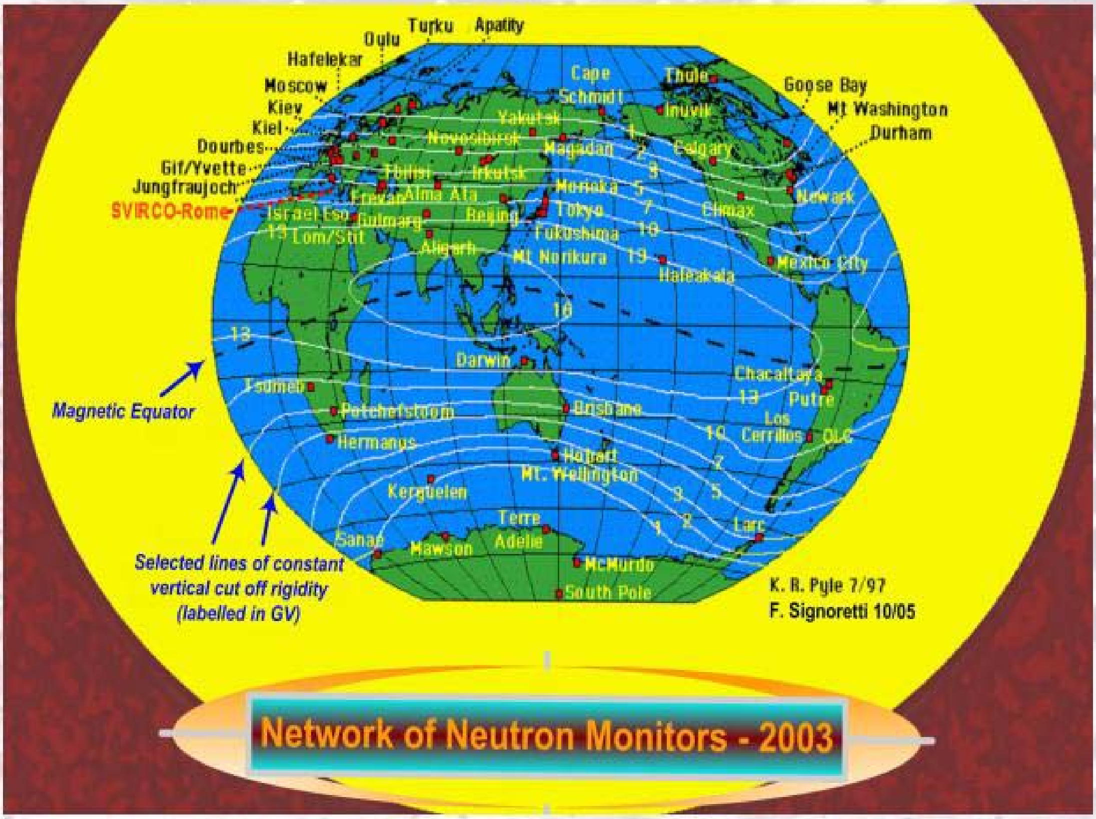


Ronald Turner (ANSER/U.S.) said:

" 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

STRONGLY IMPROVED
SPACE-CHARGE DOSIMETERS
experimental work
[type/weight/size/power]

GEOMAGNETIC FIELD ROLE



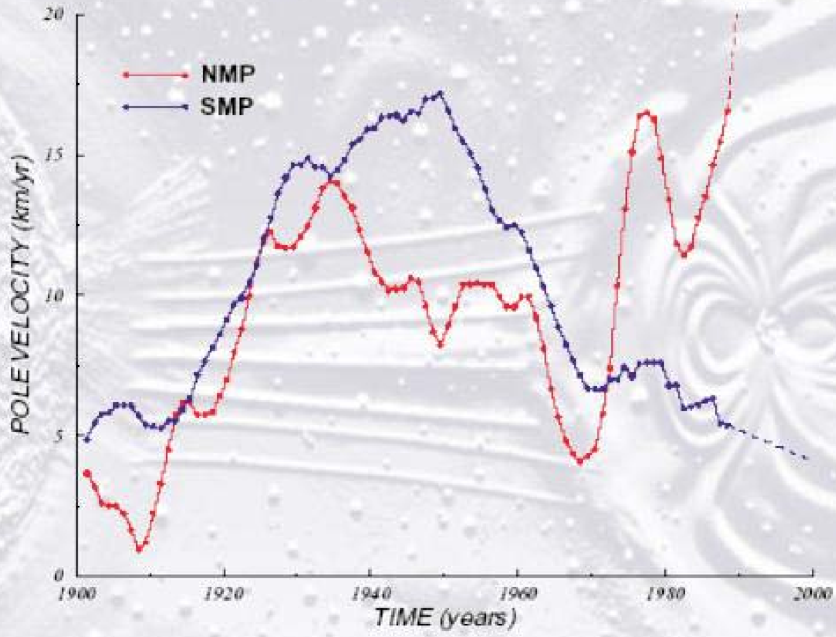
GEOMAGNETIC FIELD ROLE - 2

GEOMAGNETIC CUTOFF RIGIDITIES ARE NOT STATIC

- LONG-TERM CHANGES (centuries) can be evaluated from the GUFM (1600-1990: Jackson et al., Phil. Trans. R. Soc. Lond. 358, 957-990, 2000) and IGRF (Mandea and MacMillan, Earth Planets Space 52, 1119-1124, 2000) field models.
- THERE IS A DIPOLE MOMENT DECAY OVER THE LAST FOUR CENTURIES
- THE DIPOLE TILT ANGLE IS RAPIDLY INCREASING TOWARDS 90° (axial direction) SINCE ~ 1950
- THE NON-DIPOLE COMPONENTS ARE FASTLY CHANGING
- THE MAGNETIC DIP POLES MOVE INDEPENDENTLY OF ONE ANOTHER

Several published papers on the topic

GEOMAGNETIC FIELD ROLE - 3

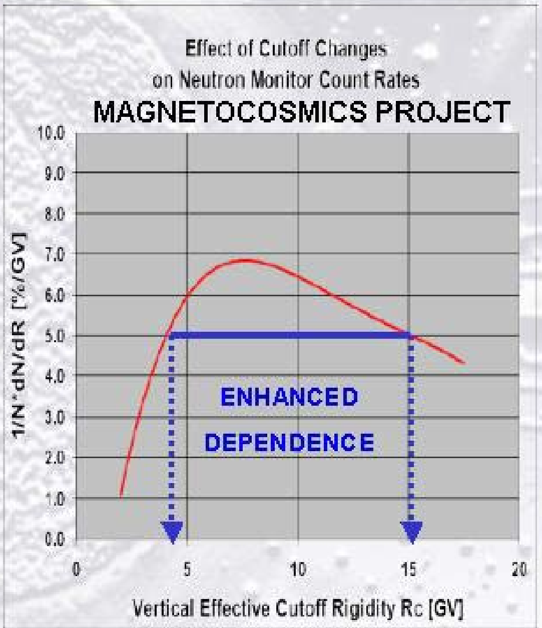


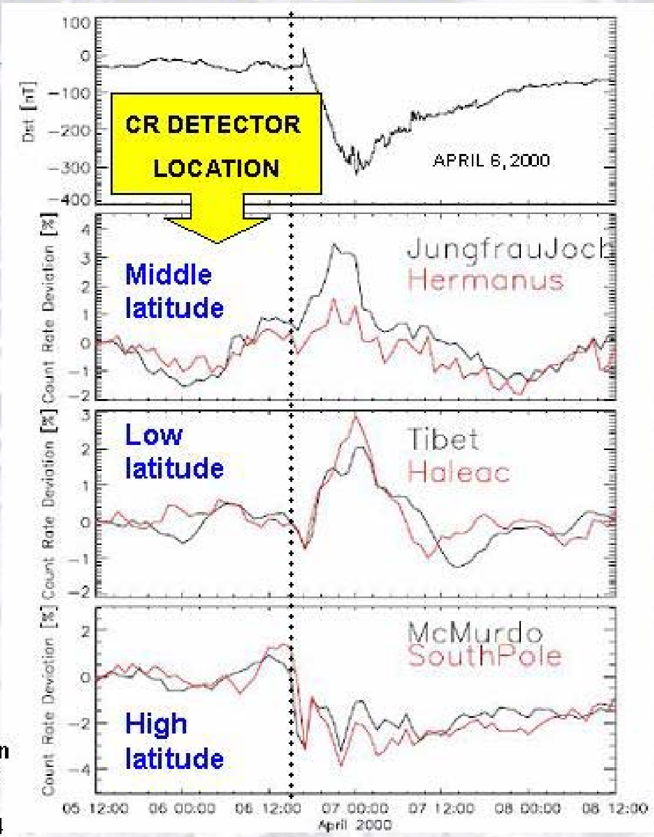
Mandea & Dormy, Asymmetric of magnetic dip poles, Earth Planets Space 55, 153-157, 2003

CAUTION FOR SHORT-TERM PERIODS

Flückiger and Desorgher, 2005

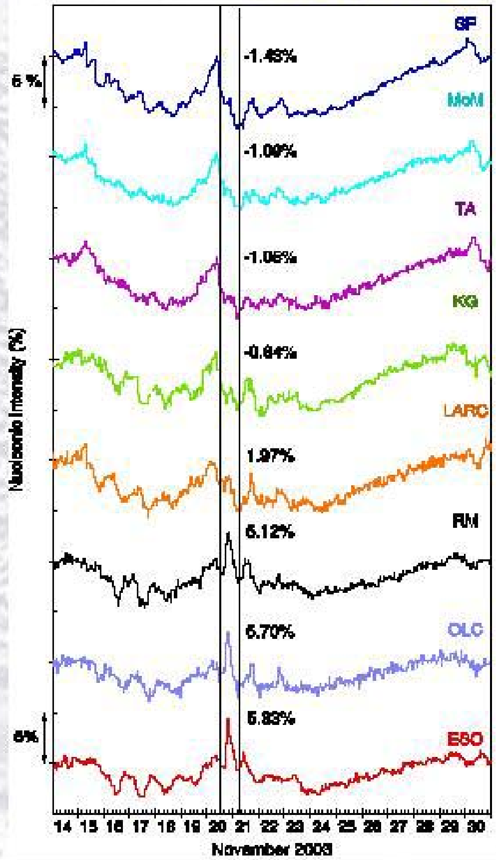
COST 724 – WG2 (Athens)

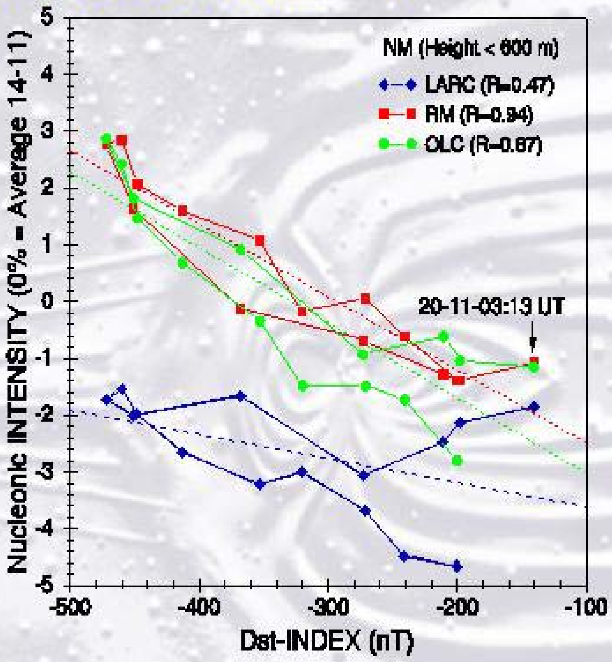




Desorgher, L., MAGNETOCOSMICS: Geant4 application for simulating the propagation of cosmic rays through the Earth's magnetosphere, http://reat.space.qinetiq.com/septimess/magcos/, 2004

GEOMAGNETIC FIELD ROLE - 4





Scatter plot for 15 hourly averages of NM data vs. Dst-index from November 20, 2003 at 13 UT (R: correlation coefficient).

Storini et al. – EGU 2006

THE RELEVANCE OF HIGH-MOUNTAIN RESEARCH

CONCLUSIONS

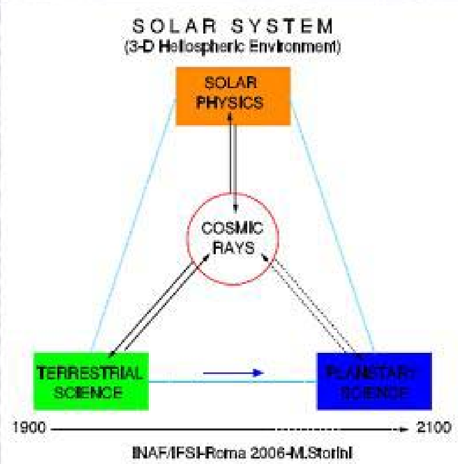


Fig. 4. The expected interlacement of CR physics with other science branches during the current century. The horizontal arrow refers to the knowledge transfer from Terrestrial Science to Planetary Science. Cross-disciplinary relations are shown by double arrows to indicate a continuous learning flow, traveling in both directions.

- The role of CRs to Space and Earth weather (in the broad context) is certainly relevant
- The world-wide network of CR detectors is essential for forecast/nowcast work.
- Multidisciplinary high-mountain research is required to test and improve models.
- The environments of the planets and moons are exposed to and interact with solar wind and CRs. It is expected that the acquired knowledge from the global solar-terrestrial physics will be transferred to the solar-planetary physics, by developing the ability to scale the appropriate relations.

END

PLANETOCOSMICS

http://cosray.unibe.ch/~laurent/planetocosmics/

L. Desorgher, M. Gurtner, and E.O. Flückiger
Physikalisches Institut, University of Bern

Thank you!