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[A personal perspective]

ENERGETIC PARTICLES NEAR EARTH: relations to Space Weather studies

CORRELATED TOPICS:

- Terrestrial effect of cosmic rays (Flueckiger talk)
- Long-term variations of galactic cosmic rays … (Muscheler talk)
- Energetic particle observation … (Marsden talk)

Many contributed papers of SESSION 2

ECRS 2010

agenzia spaziale italiana

ENERGETIC PARTICLES NEAR EARTH

WEATHER CONCEPT

CLASSICAL METEOROLOGY

[lower atmosphere]

PARAMETERS

Wind, Pressure, Temperature, Relative humidity, Precipitation, …

STRUCTURES

Clouds, Thunderstorms, Lightning, Hurricanes, Cyclones, …

TERRESTRIAL WEATHER

NEW METEOROLOGY ?

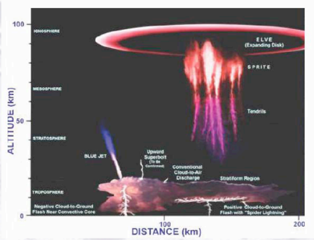
[the complete atmosphere*]

INCLUDED STRUCTURES

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

SPACE WEATHER

[the terrestrial environment
+
near-Earth free space]



* WITH PARTICULAR ATTENTION TO THE OZONE LAYER

CR RELEVANCE – WHY?

THE THIRD INGREDIENT OF THE HELIOSPHERE

PROBE OF THE HELIOSPHERIC STATUS

Storini, ECRS2006

CR signatures for forecast/nowcast

(INDIRECT DATA USE)

CR interaction with matter

PLANET'S ATMOSPHERE

GROUND & SPACE DEVICES

BIOLOGICAL BODIES

(DIRECT DATA USE)

INTERNATIONAL ALERT SERVICES

CONTENT

- Basic Knowledge
- Geoeffective Alerts
- SEP Forecasting
- Some Topics to be improved
- Examples
- Personal conclusions

BASIC SEP CHARACTERISTICS

DATA SOURCES: Instruments on Balloons, Satellite & Spacecraft and Ground-based.

DATA INFO: intensity-time profiles (depending on the magnetic connection of the acceleration site with the observation point). Particle energy channels, SEP particle composition and anisotropies. **MAXIMUM ENERGY:** ~ 30 GeV for protons ? ; ~ 100 MeV for electrons ? **BULK ENERGY:** at low energies (only 70 GLEs were identified), particularly for electrons.

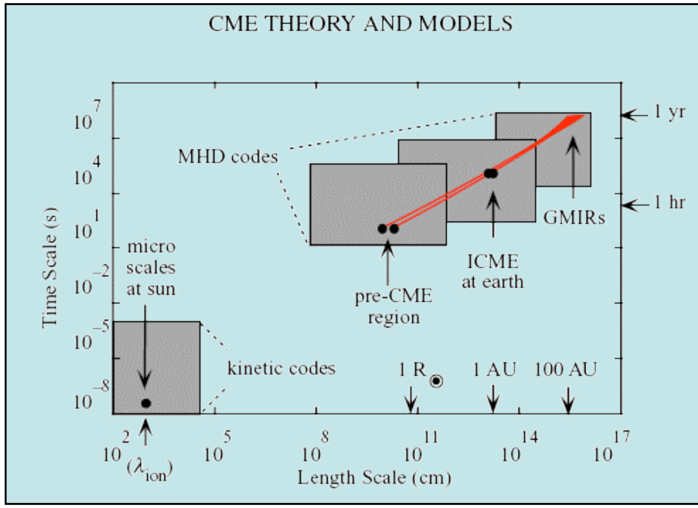
ARRIVAL AT THE EARTH: electrons before middle energy protons but relativistic protons before electrons.

PRESENT SEP CLASSIFICATION (impulsive & gradual events - not satisfactory): oversimplified.

DATA BASES FROM MULTISPACECRAFT: require data calibration before their use (e.g. IMP & GOES series).

ANISOTROPIES: large at low solar latitudes (hence Earth) but small at high-latitudes. **LINKS WITH SOURCE REGION & ACCELERATION/PROPAGATION PROCESSES**: more difficult for electrons than ions.

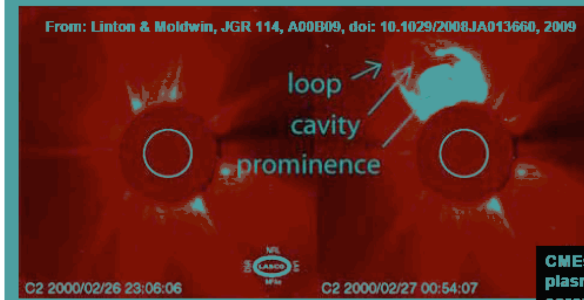
DEPENDENCE ON THE INTERPLANETARY MEDIUM CHARACTERISTICS: quite time; traveling interplanetary perturbations → simple or complicated IMF structures.

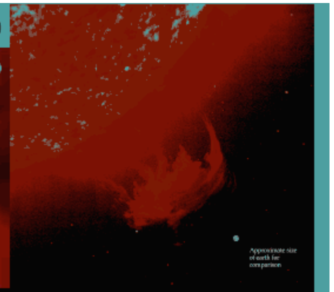


FORBES et al., SSRev 123, 251, 2006

BASIC KNOWLEDGE

CME -----> ICME M. Storini / Torino - 22/10/2009





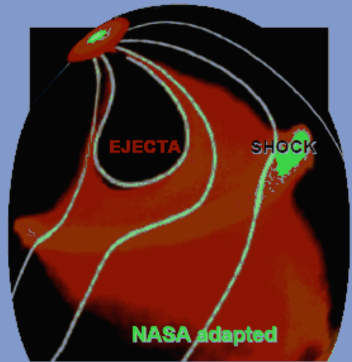
CMEs are dynamics events in which the plasma, initially contained in closed coronal magnetic structures, is ejected into the interplanetary medium. They originate from active regions (ARs), filament (FR) and transequatorial (TEqR) interconnecting regions.

- Coronal Shock → Interplanetary Shock
- Bright frontal loop → Sheat
- Dark cavity → Magnetic Cloud/Ejecta/Flux Rope
- Embedded bright (prominence) core → Pressure Plug (cool prominence material)

CME associated features: (1) SIGMOIDS [pre-eruptive, bright S- or inverse-S shaped features in ARs; (2) ARCADE EVENTS [post-eruptive event]; (3) DIMMINGS [transient CHs – dark regions that form near arcade events, signaling mass loss during CME eruption]; (4) EIT waves [global-scale disturbances, propagating from compact arcade regions in ARs. – supposed to be related to MORETON WAVES in the chromosphere]

THE HELIOSPHERIC ENVIROMENT

M. Storini / Torino – 20/10/2009



TRANSIENT STREAMS

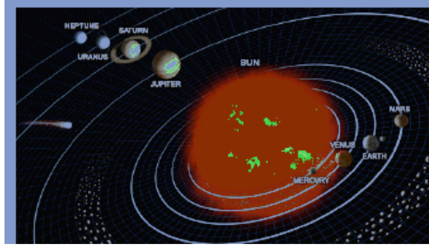
Ingredients:

- shock wave followed by a sheet (compression region) and ejecta (MCloud)
- shock wave without ejecta
- interplanetary CME

COMPOUND STREAMS

Ingredients:

- two corotating streams
- corotating stream + transient stream
- two transient streams



Towards the outer heliosphere:

MERGED STREAM INTERACTION REGIONS

GLOBAL MERGED INTERACTION REGION

GEOEFFECTIVE ALERTS from ground-based data

THE HELIOSPHERIC ENVIROMENT

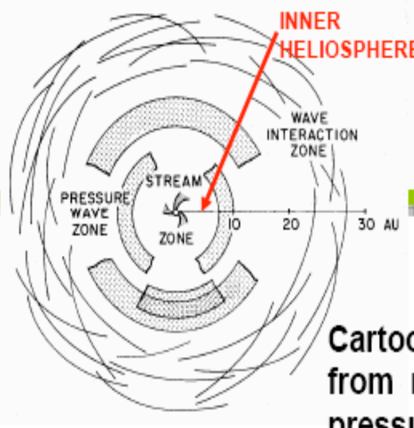
M. Storini / Torino – 23/10/2009

Storini, 2000 (ICRC 1999)

HELIOSPHERIC STRUCTURES

	FROM THE SUN:
- SW streams (SWSs) + interaction regions (IRs) (transient and/or corotating; CIRs for corotating IRs)	≤ 5 - 10 AU
- merged interaction regions (MIRs) (local, transient and/or corotating)	≥ 5 - 10 AU
- global merged-interaction regions (GMIRs)	≥ 10 - 20 AU
- heliospheric boundary region:	> 50 AU

SW termination shock
heliosheath
heliopause
heliospheric bow shock.



Cartoon to emphasize the individual stream zone from regions of concentric shells where pressure waves dominate the structure.

(see Burlaga L.F. et al., GRL 10, 413-416, 1983.)

PRECURSORS BASED ON:

(**Neutron monitor hourly data [loss cone: up to 9h; enhanced variance: up to 4 h];**

(**Neutron monitor 5-min data [Wavelet technique: up to 9h];**

(**Muon data [Global Muon Detector Network & URAGAN hodoscope: up to 15 h];**

(**+ SEVAN array (Armenia).**

NOTE:

Background flux has contributions from: 1) SW; 2) pickup ions; 3) prominence material; 4) pre-accelerated particles by SW; 5) suprathermal particles from previous events.

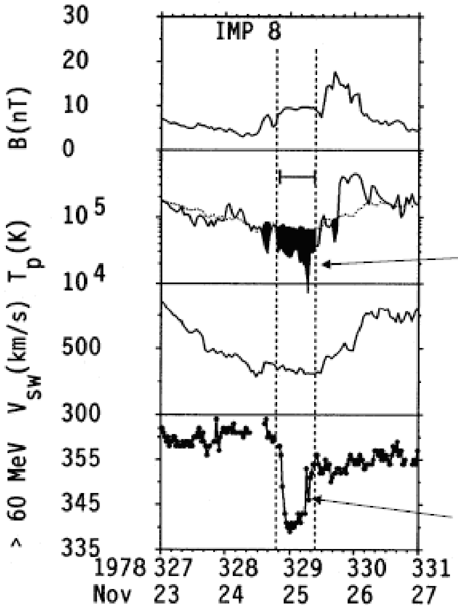
SOME GEOEFFECTIVE PRECURSORS IN SPACE

TRANSIENT SOLAR WIND STREAM EFFECTS ON CRs - Cane & Lario, S.S. Rev. 123, 45-56, 2006

COSMIC RAYS

M. Storini / Torino – 22/10/2009

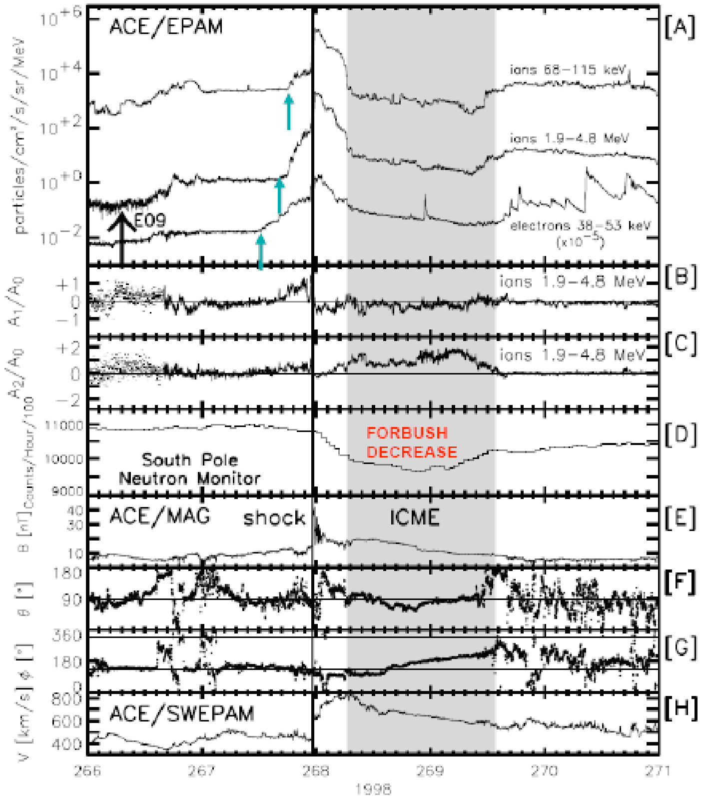
PROBE OF THE HELIOSPHERIC ENVIRONMENT



Energetic particles to probe the magnetic topology of ejecta

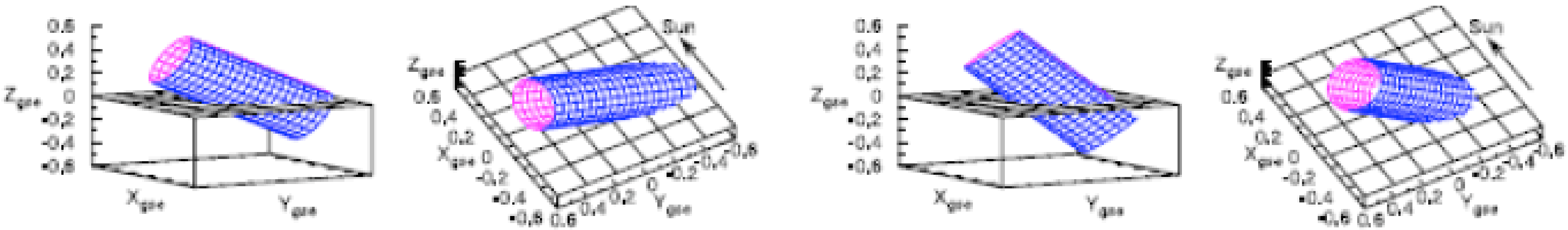
See:

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



Kuwabara et., JGR 114, 2009

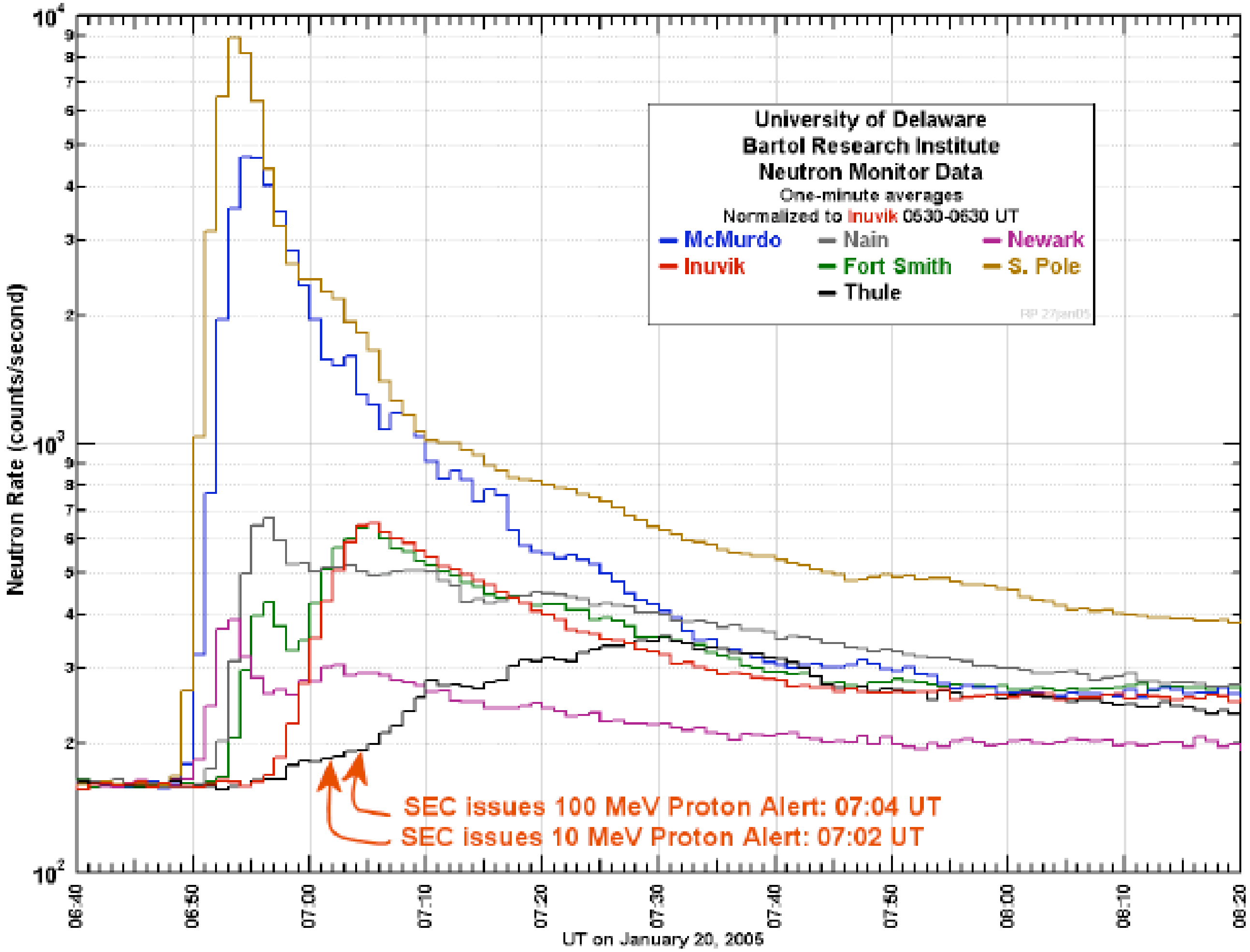
29/30 Oct. 2003 ICME



ICME/flux rope geometry in GSE coordinates deduced from CR (left panels) & force-free cylindrical flux rope (right panels) models.

SEP FORECASTING

Alert from Neutron Monitors



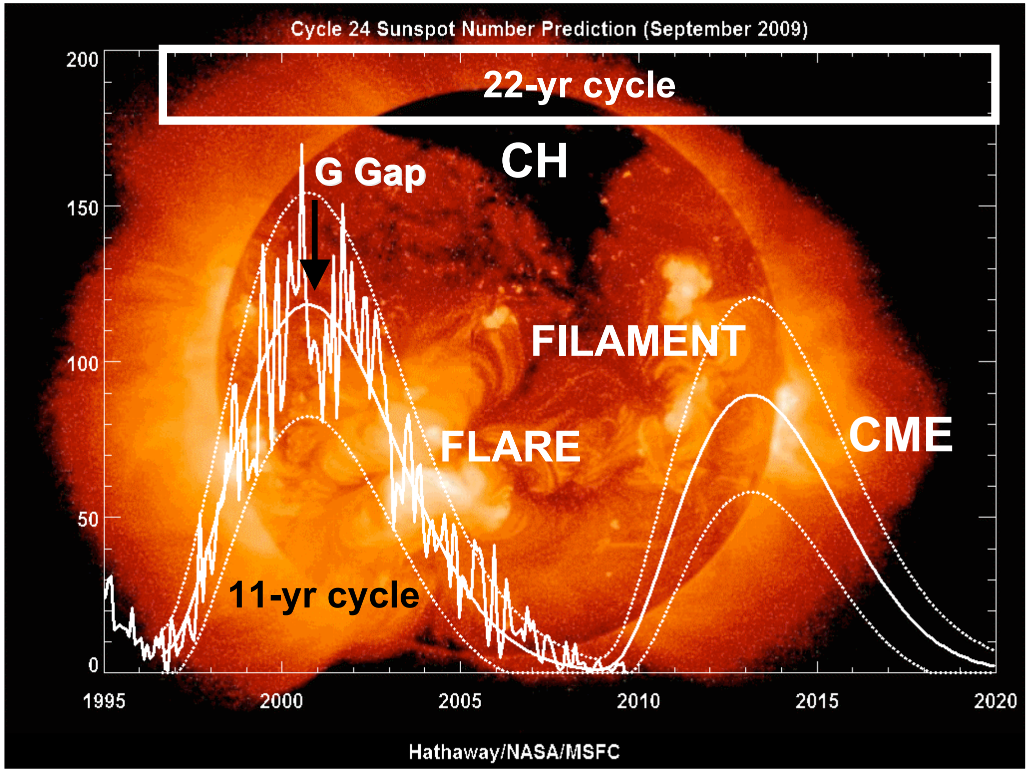
In the January 20, 2005 GLE, the earliest neutron monitor onset preceded the earliest Proton Alert issued by the Space Environment Center by 14 minutes.

J.W. BIEBER

ICRC'07 WORKSHOP

OTHER METHODS: NOAA; Posner, 2007; Laurenza et al., 2009; NMDB resources (ATHENS, IZMIRAN, ESO,...) [see also Vainio et al., 2009]

SOME TOPICS TO BE IMPROVED for SW



ROLE OF PERIODICITIES T > 22 yr

• to be established from further studies

RADIATION HAZARDS:

- Atmospheric ionization (quite and disturbed times)
- Radiation doses (particularly from SEP incoming)

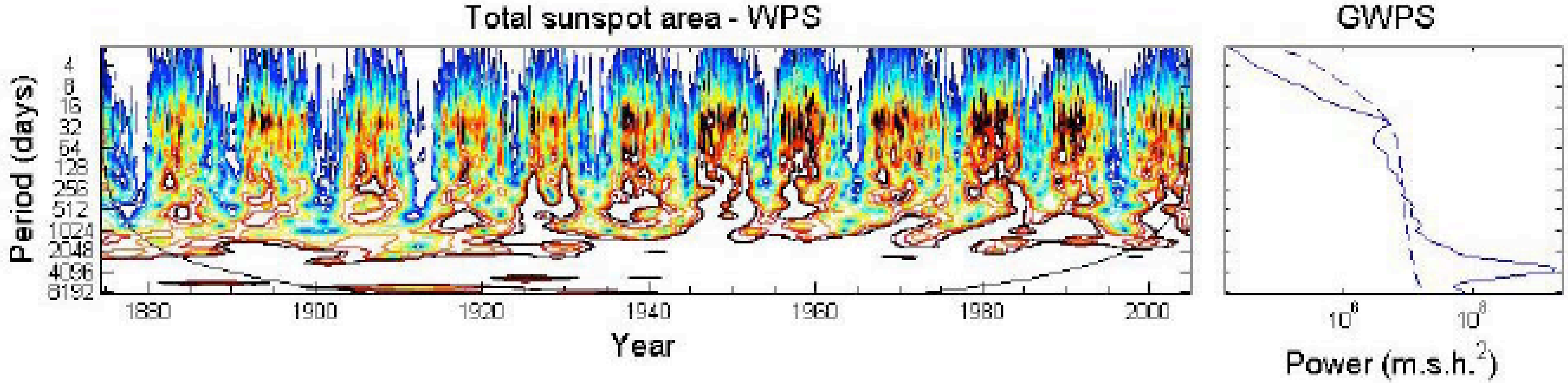
A) Cosmic ray variabilities and their relationship with solar activity (Space Climatology)

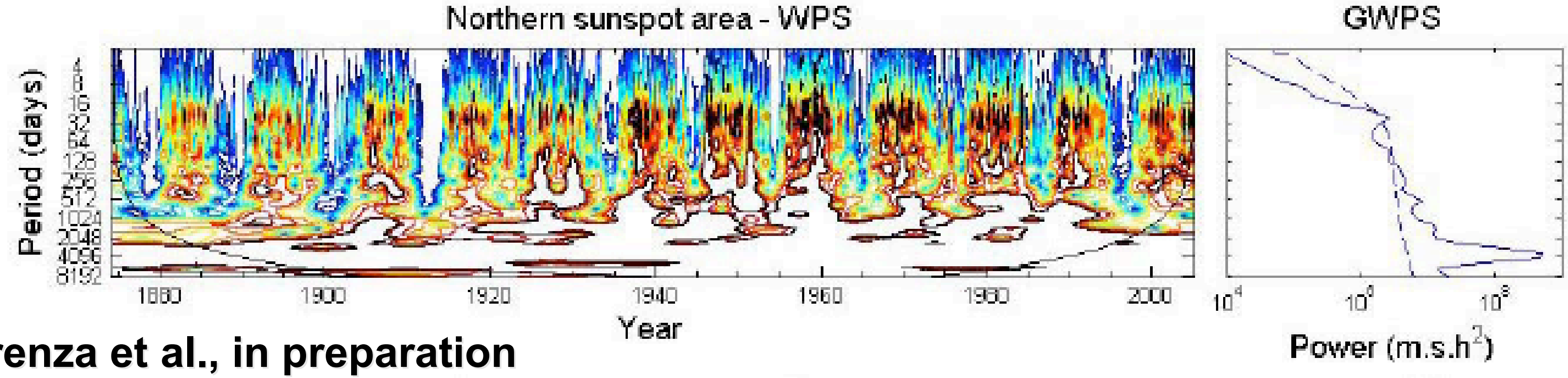
B) Cosmic ray periodicities during quite and perturbed time intervals

C) Particle spectra or at least geographic latitude flux curves (for different altitudes) on monthly and daily basis [useful for radiation hazard events (e.g. anomalies and failures on space vehicles; biological bodies on flights or at mountain heights)]

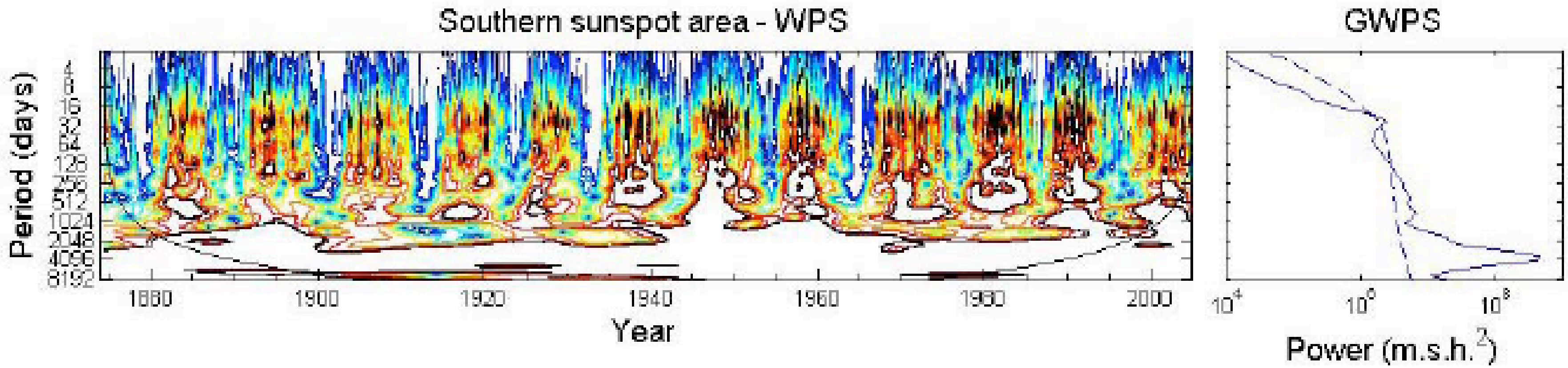
D) Role of geomagnetic field during interplanetary perturbation passage [SW/magnetospheric coupling]: CR transmissivity, CR trajectories in the terrestrial environment with appropriate field models

EXAMPLE I: Solar activity parameters



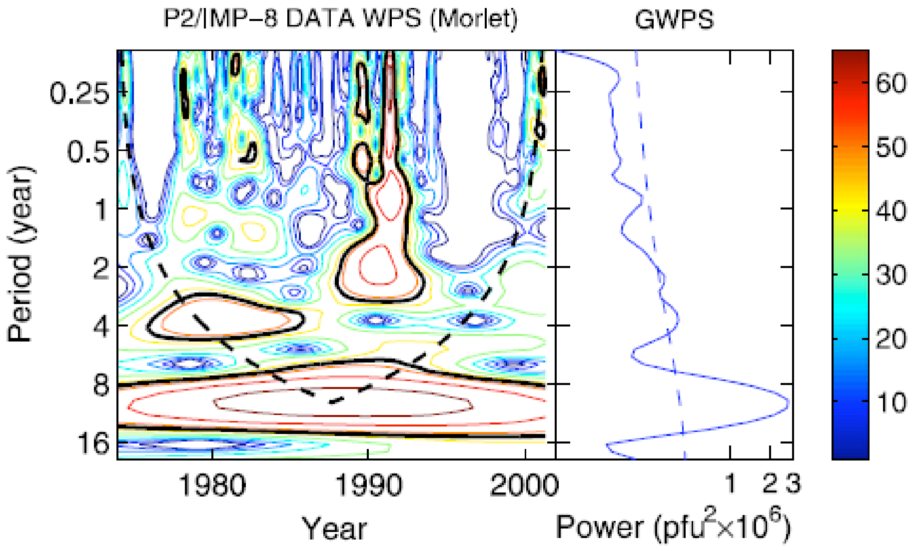


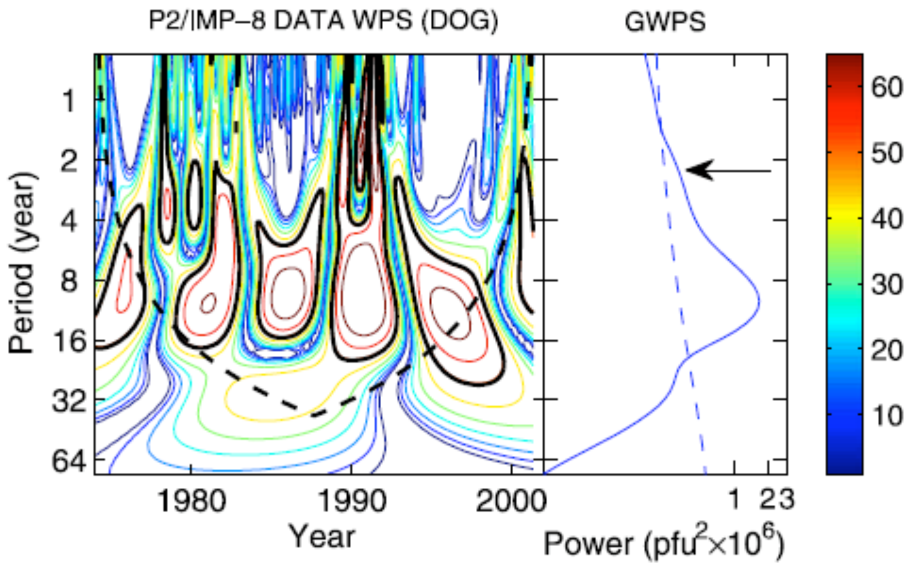
Laurenza et al., in preparation



EXAMPLE II: Solar electrons and protons

Laurenza et al., JGR 114, A01103, 2009





Chowdhury & Ray, MNRAS 373, 1577,2006

E > 0.6 MeV and E > 2 MeV (IMP8)

~ 152d – cycle 21

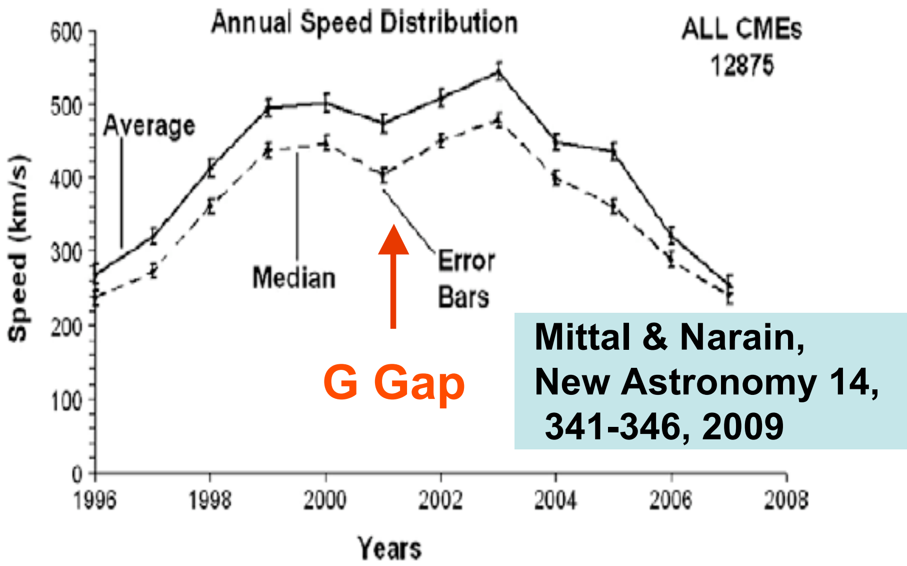
~ 330d, ~604d – cycle 22

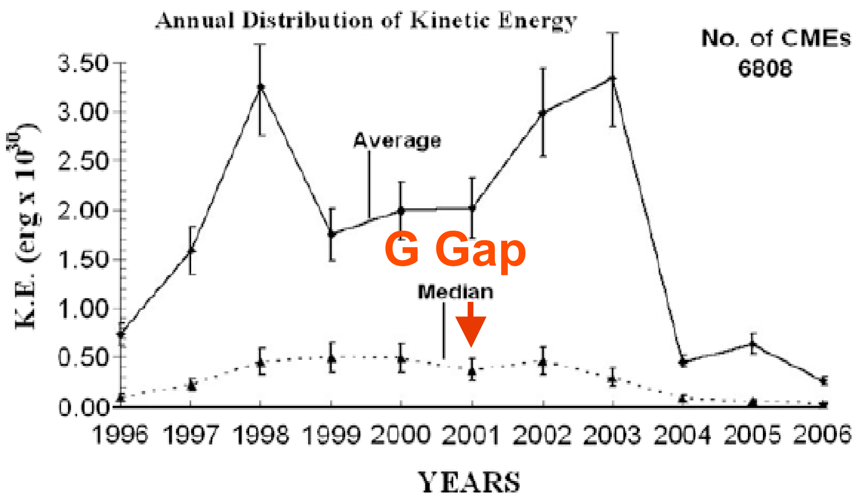
~ 152d, ~176d – cycle 23

ELECTRON ACCELERATION SOURCES:

- **solar flares;**
- **accel. & released in conjunction with CMEs;**
- **high corona**
- **with radioemission phenomena (e.g. Type III bursts)**

EXAMPLE III: G Gap





See also: Cremades & St. Cyr, JASR 40, 1042, 2007; Li et al., Solar Phys. 257, 149-154, 2009.

The Astrophysical Journal Letters, 709:L1–L5, 2010 January 20 doi:10.1088/2041-8205/709/1/L1

QUASI-BIENNIAL MODULATION OF SOLAR NEUTRINO FLUX AND SOLAR AND GALACTIC COSMIC RAYS BY SOLAR CYCLIC ACTIVITY

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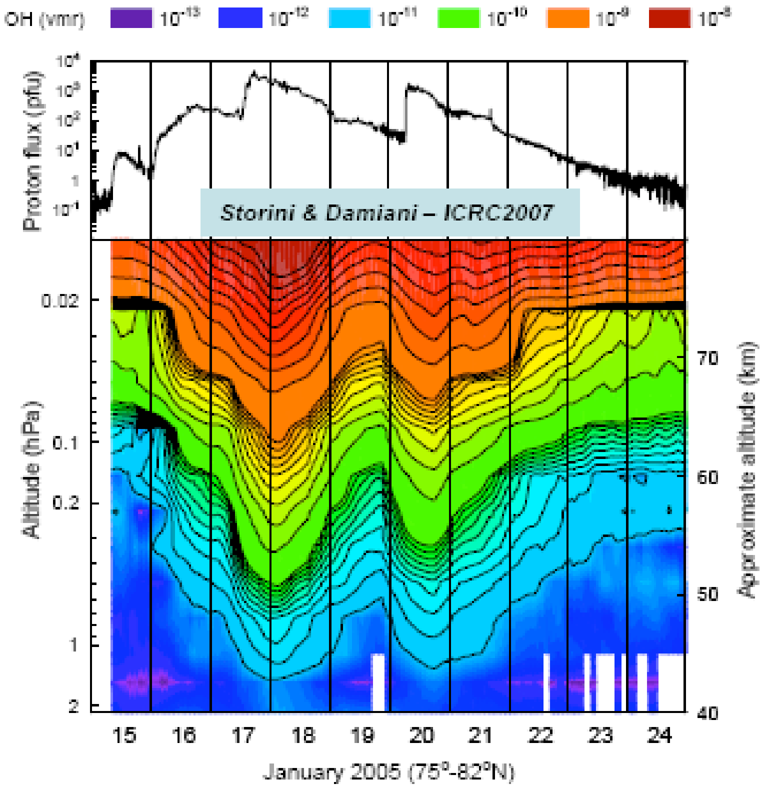
ABSTRACT

Using some solar activity indicators such as sunspot areas and green-line coronal emission during the period 1974–2001, we find that the quasi-biennial periodicity is a fundamental mode of solar variability. We provide evidence for the quasi-biennial modulation of the solar neutrino flux, thus supporting the hypothesis of a connection between solar neutrinos and solar magnetic fields, probably through direct interaction with the neutrino magnetic moment. The same periodic modulation has been detected when fluxes of solar energetic protons and galactic cosmic rays are investigated. These modulation results significantly correlate to that of the neutrino flux. Finally, the superposition of the quasi-biennial cycle to the eleven-year cycle can explain the Gnevyshev Gap phenomenon.

EXAMPLE IV: SEPs & ATMOSPHERE

OH radicals / MLS-AURA: Selected Geographic band



75° - 82° (towards the pole)

- suitable region to perform investigations by using ***zonal means*** on a daily basis;
- completely located inside the ***polar cap*** (geomagnetic latitude greater than 60°);
- mainly outside the ***auroral belt***;
- the ***winter night*** is roughly maintained for many months;
- region inside the core of the ***polar vortex***;
- region less disturbed by ***planetary waves***.

NOTE:

1. *Low background values at nighttime for the mesospheric hydroxyl (OH) radical.*
2. *GOES data for the proton flux level.*

Discovery of the mesospheric trail of SEP events!

[see also: Usoskin et al., Acta Geophys. 57(1), 88-101, 2009]

EXAMPLE V: Inside the Earth

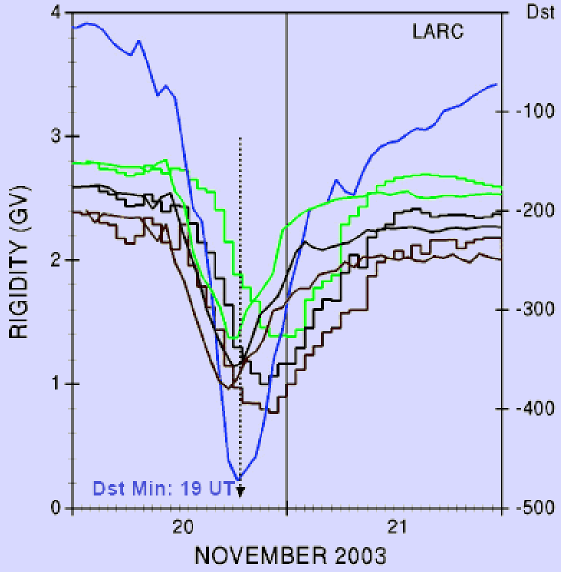
M. Storini, K. Kudela, P. Diego, R. Bucik, EGU2006, SESSION ST5.6 , ABSTRACT EGU06-A-05876

VERTICAL CUT-OFF CHANGES DURING NOVEMBER 20-21, 2003

GREEN: Upper Cut-off
BLACK: Effective Cut-off
RED: Lower Cut-off
BLUE: Dst index

Staircase: Ts89Kp/Dst (Boberg et al., GRL 22 (9), 1133, 1995).

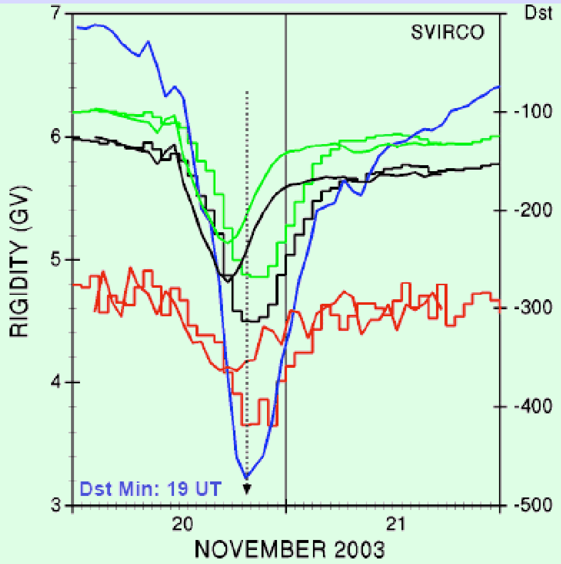
Continuous line: Ts04 (Tsyganenko & Sitnov, JGR 110, 2005, A03208, doi:10.1029/2004JA010798).



ABSOLUTE RIGIDITY

Cut-off	LOWER	UPPER	EFFECTIVE
Ts89Kp/Dst	0.77: 22 UT -	1.38:24 UT -	1.00:21 UT
Ts04	0.96:18 UT -	1.37:18 UT -	1.14:18 UT

• Results from Ts04 gave stable time for minimum rigidity cut-off (18 UT), preceding 1 h the Dst minimum, while the ones for Ts89Kp/Dst follow the Dst minimum from 2 to 5 h.



ABSOLUTE RIGIDITY

Cut-off	LOWER	UPPER	EFFECTIVE
Ts89Kp/Dst	3.66:19 UT -	4.86:20 UT -	4.49:20 UT
Ts04	4.09:18 UT -	5.13:17 UT -	4.82:17 UT

• Results from Ts04 gave the time for minimum rigidity cut-off, preceding 1 or 2 h the Dst minimum, while the ones for Ts89Kp/Dst coincide or follow the Dst minimum 1 h.

Different models for the geomagnetic field provide different results for CR cutoffs at different observational sites.

LARC: King George Isl. (Antarctica) – Chile/Italy collaboration.

SVIRCO: Rome (Italy) – INAF/UNIRoma Tre collaboration.

PERSONAL CONCLUSIONS

• The relation between SW and CRs is not completely investigated, particularly at fine scales [seconds/minutes; see also poster by Laurenza et al.].

• CR periodicities contain relevant info on space variabilities (probe of the heliosphere; see also poster by Storini et al.; Diego and Storini, ICRC2009).

• CR measurements at high mountains (fine scale acquisition) should be complementary of the ones obtained from balloons and satellites. The atmosphere response (particularly of its minor components and radionuclides) to CR flux deserves special attention for SW.

• Data calibration is a heavy task!

Much work ahead!


Thank you!
Approx. size of Earth