P3-010

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CALET による太陽磁気圏の観測

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CALET Mission on ISS

Purposes and Expected Results

Long-term and Short-term Variation of
Electron and Proton Flux in 1-10 GeV Energy Range

* Cosmic Ray Transport in the Heliosphere
  Diffusion, Convection, and Drift in Solar B-Field
  Charge Sign Dependence of Modulation
* Forbush Decreases

CALET Solar Physics　Measurements and Objectives

Cosmic Ray Transport

▶ **Force−Field Approximation**

Heliosphere ∼ Potential Field?

＊ Diffusion Coefficient(D) and Energy Dependence $D \propto E^{\alpha}$

⇒ *Energy Index α = "1" or smaller ?*

▶ **Drift Dominated Model**

How is Drift effective ?

＊ Charge Sign Dependence of Modulation :

⇒ *Occurs in Both Solar Min and Max ?*

Forbush Decreases

＊ What determines the magnitude of Fds?

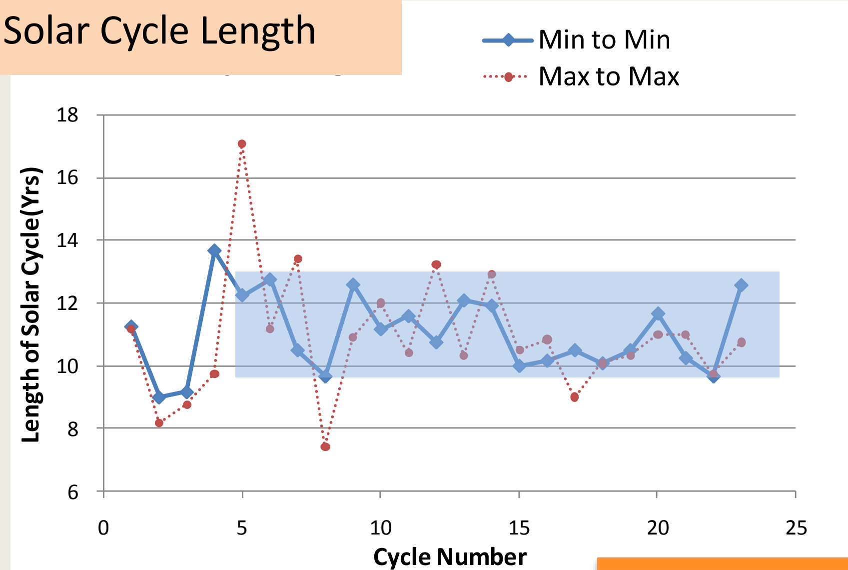
⇒ *Shocks or CMEs ? or Both ?*

＊ Charge sign differences of Fd profiles in electron (negative) flux

⇒ *Compared with those in Proton flux or NM profiles*

Sunspot Number

Solar Cycle Length

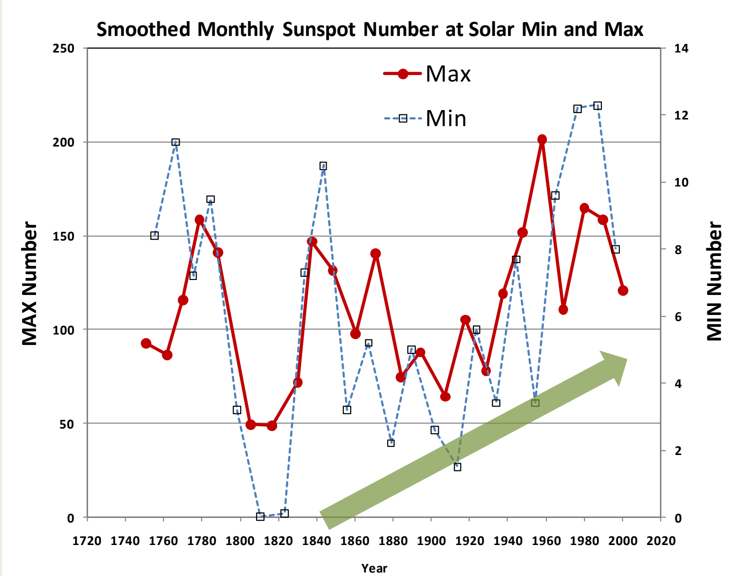


MIN to MIN ：～10 – 13 yrs

★ 23rd Cycle
Min(Start) 1996.3 – 1996.10
Max 2000.4 – 2001.1

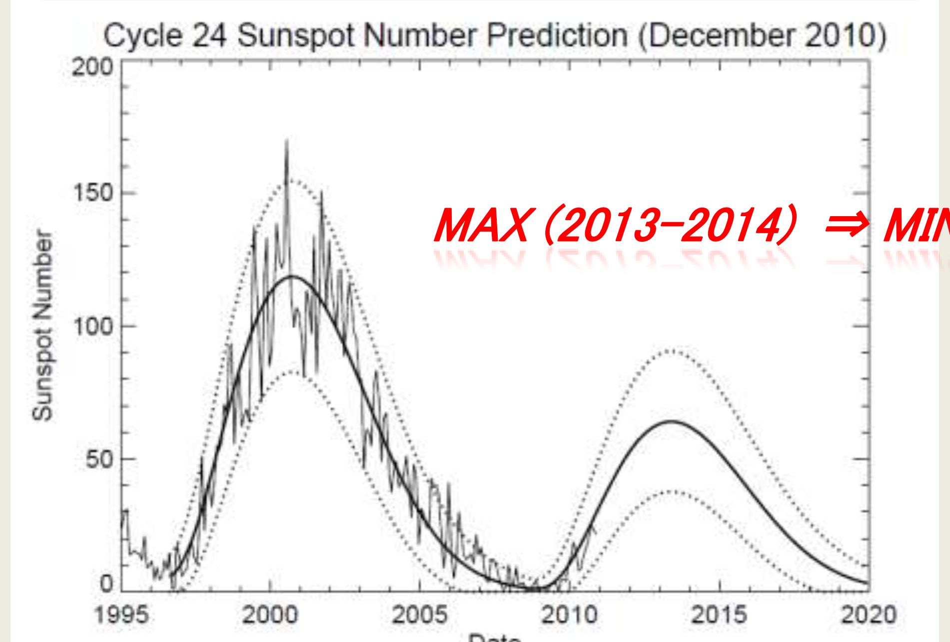
☆ 24th Cycle
Min(Start) 2008.12
Max(Prediction) 2013.6
http://www.swpc.noaa.gov/SolarCycle/SC24/

Max & Min Number from 1700



Gradually increase from 1800

Prediction of Solar Activity after 2010



http://solarscience.msfc.nasa.gov/predict.shtml

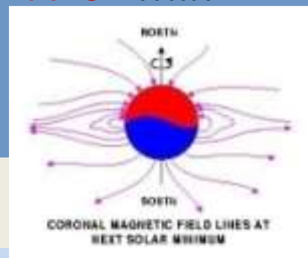
GCR Electron Transport in the Heliosphere

Long-term Variation Profile in A>0

2000 | 2010 | 2020

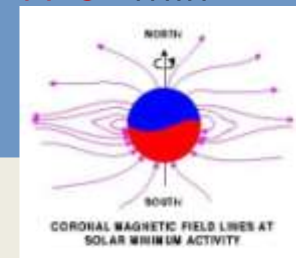
Solar Magnetic Field

A<0 Min



Max

A>0 Min



http://www.sp.ph.ic.ac.uk/~forsyth/reversal/

◇ GCR Electrons

Diffuse in the solar magnetic field, and are

Convected by solar wind in the heliosphere.

Force-Field Approximation

Energy Dependence of Transport

Diffusion Coefficient

$D \propto E^{\alpha}$

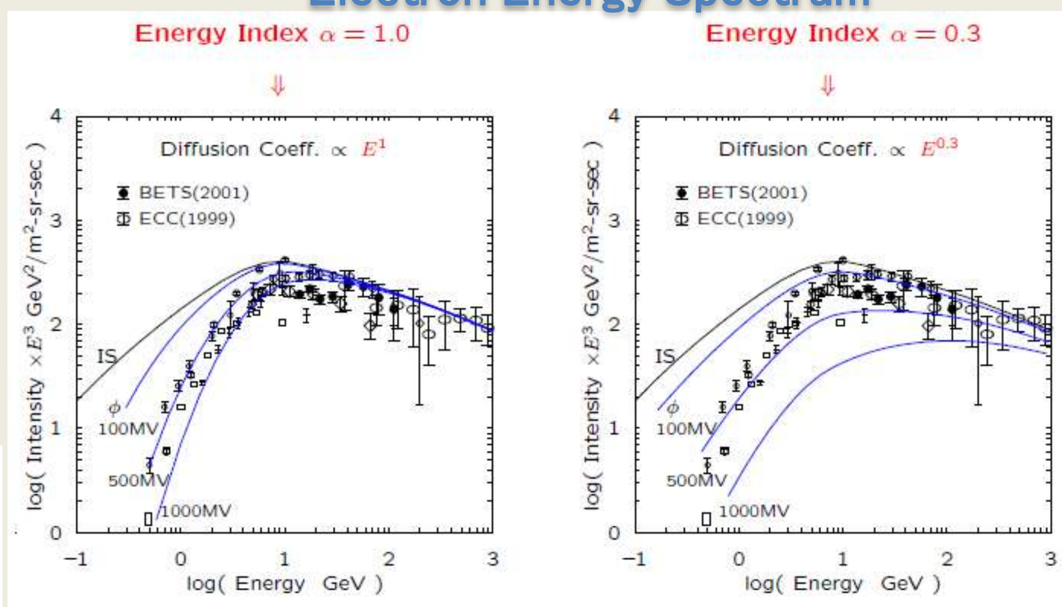
Modulation Parameter

Φ MeV $\sim E^{1-\alpha}$

Figure 2. Expected electron modulated spectra with the energy dependence of diffusion coefficient of 0.3, 1. ϕ[MV] represents the parameter including the boundary of solar magnetosphere and the solar wind speed and is related with the energy part of the diffusion coefficient $D_2(E)$ of $\Phi \sim (p/D_2)\phi$.

Prediction

Electron Energy Spectrum



Φ − N relationship

Modulation MODELS and Charge Sign Dependence
Estimates from Long-term Variation Profile in A>0

ICE, IMP, BESS Results

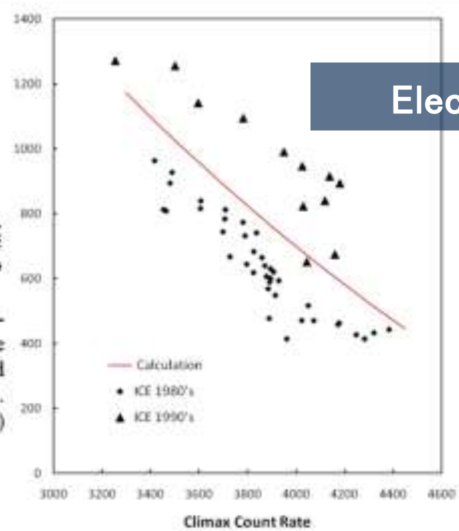


Fig. 2: The correlations between the modulation parameter Φ and the Climax neutron monitor counting rate. The Φ values of ICE 1.2 GeV electron data [3] are estimated from the local interstellar spectrum shown in Fig. 1. The calculation curve represents the formula of eq. (2) derived from FF approximation with $N_{max} = 5300$.

Electron

Proton , Helium

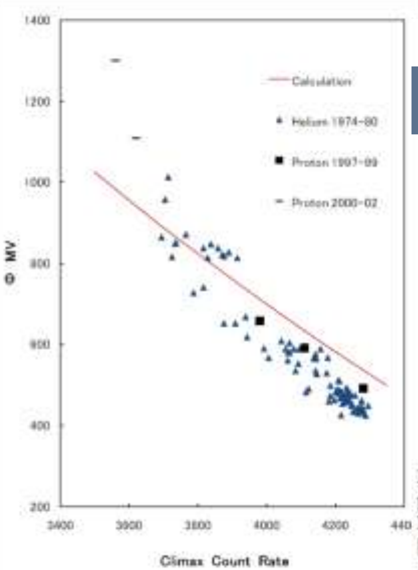


Fig. 3: Helium data of 70-95 MeV in 1973-1980(A>0) period are adopted from Fig. 4 in the paper of M. Garcia-Munoz et al. [21]. Proton data of the BESS experiments [22] have 0.2-20 GeV kinetic energy range in both 1997-1999(A>0) and 2000-2002(A<0) period. The curve is the same as in Fig. 2.

? Same or Different between electron and nuclear CRs ?

<BASIC Curve>
Force-Field Approximation

Slope

Min term
−0.5 ～ −0.6

Max term
−0.7 ～ −0.8

Prediction

Drift Model expects "Steeper" slope in A>0 Solar Min Peiod.

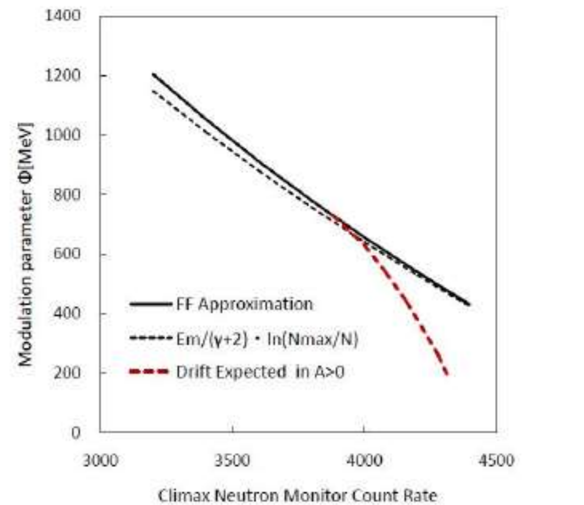


Fig. 2. Relationship between the modulation parameter Φ MeV and the Climax NM counting rate N. The solid line is estimated by the FF approximation at the response energy 11 GeV (Eq. (2)), while the dashed line is the expected curve, determined by the drift model, for negative particles in the solar quiet period of A>0, which is just estimated qualitatively. (The dotted line is an approximate expression of Eq. (3) and is good agreement with the solid line.)

Negative/Positive CR Ratio from Observations

Long term variations of solar modulation

Charge sign dependent modulation

It is widely recognized the ratio of negative to positive particles in the A<0 period is higher than that in the A>0 period.

e/He, e/p

Bieber JW, et al. PRL, 83, 4, 1999

IMP-8

Ulysses

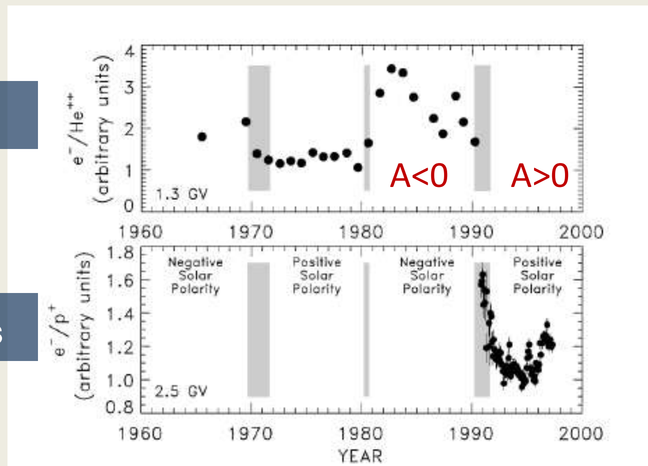
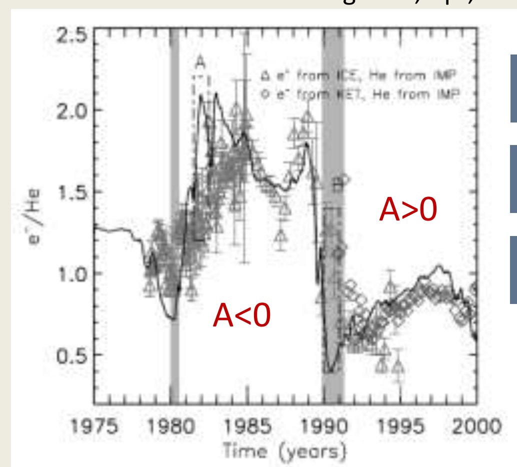


FIG. 1. Ratio of (top) cosmic electrons to cosmic helium at 1.3 GV rigidity and (bottom) cosmic electrons to cosmic protons at 2.5 GV rigidity. Shaded areas delimit time periods when the Sun's poloidal magnetic field was reversing. Positive and negative solar polarity refer to epochs when the magnetic field emerging from the Sun's north pole points, respectively, outward and inward.

S. E. S. Ferreira and M. S. Potgieter , ApJ, 603:744–752, 2004



ISEE3/ICE

IMP-8

Ulysses

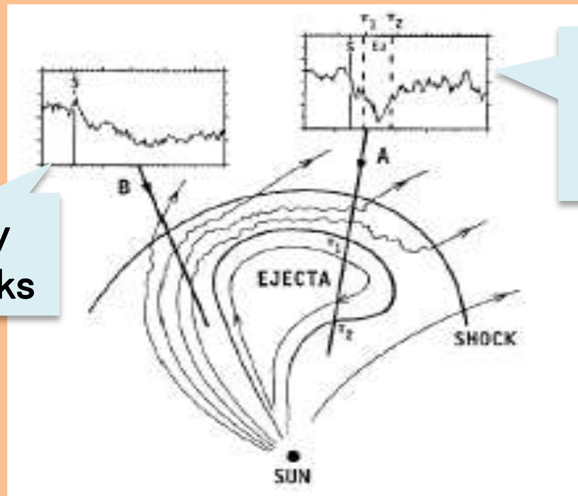
Fig. 6.—Computed 1.2 GV e=He at Earth for 1976–2000 in comparison with the observed e=He obtained from electron measurements from ICE (Clem et al. 1996; Evenson 1998), helium measurements from IMP (e.g., McDonald 1998; McDonald et al. 2001), and electron measurements from KET (Clem et al. 2002). Two periods with relatively large differences between the computed ratios and the observations are selected (A and B). The shaded areas correspond to the period when there was not a well-defined HMF polarity.

CALET simultaneously observe electrons and protons in the 1-10 GeV energy range and investigate the charge sign dependence of solar modulation.

Forbush Decreases (Fds)

Two-step decrease : through the passages of
the forward shock and the coronal mass ejection

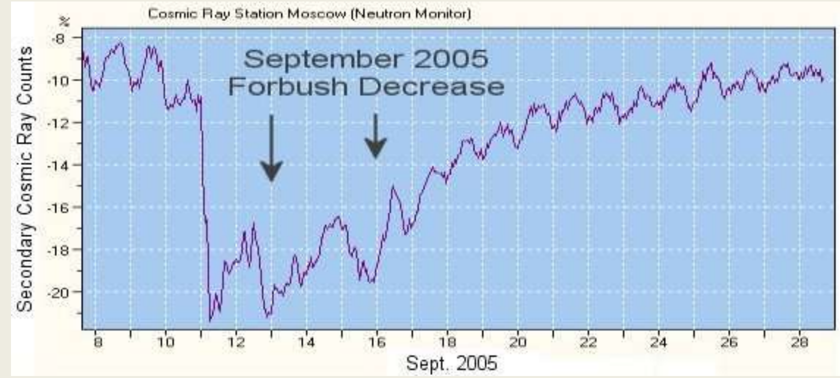
Only Shocks



Shocks and Ejecta

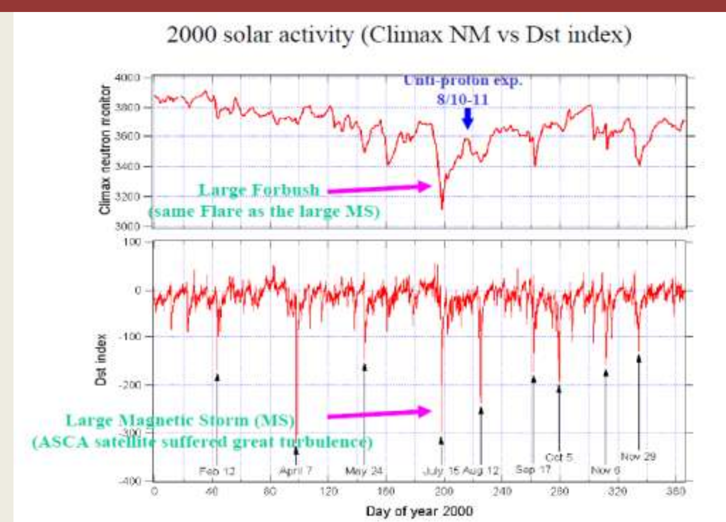
(Cane H.V. Space Science Reviews 2000)

http://science.nasa.gov/science-news/science-at-nasa/2005/07oct_afraid/



Above: Neutron counts from a cosmic ray monitoring station in Moscow. Radiation levels dropped in early Sept. during a period of intense solar activity.

Observations of Fds are very Important !
Electron(−) Fds will contribute
Background estimates of negative CR Measurements



Expected Number of Fds

Fds (> 4%) ～ 10 / 5 yrs

The Results in 2000–2004
Izmiran NM (55° N) & Climax NM (40° N)
～ 5 /yr, and 7–12 /yr in Solar Max

Electron (< 10 GeV) Measurements on ISS

ISS Orbit :
Inclination: 51.6°
Altitude: 350–400 km

At Highest Latitude : 50° N and 50° S ,
Observation Time : 5 min
Alternately N → S → N → S → N → ・・ every 46 min

- Long–Term Measurements
(Transport Models, Charge Sign Dependence)

The exposure factor :
40 m^2・sr・min
The modulation parameter
φ = 500 – 1000 MV ,

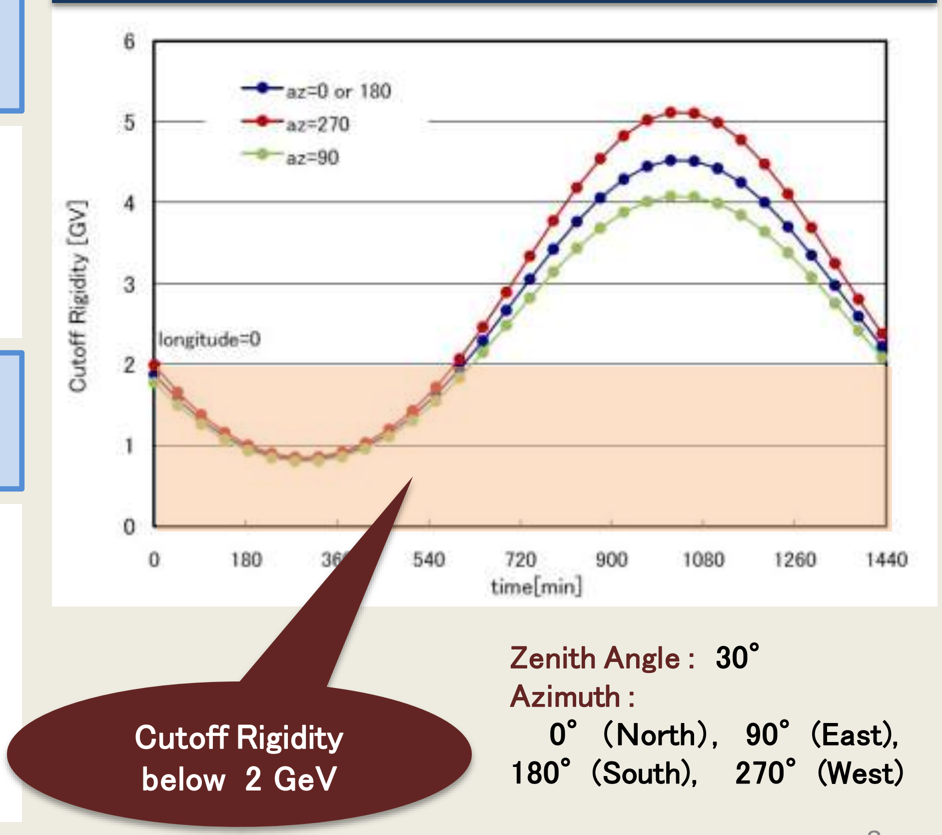
Electrons ～ 17,000
Three Energy Ranges,
Statistical Error ～ 1 – 2%

- Short–Term Measurements
(Forbush Decreases)

The exposure factor :
10 m^2・sr・min
The modulation parameter
φ = 500 – 1000 MV ,

Electrons ～ 2,000
Total number of
Northern and Southern Measurement,
Statistical Error < 2%.

Time Variation of Cutoff Rigidity



Zenith Angle : 30°
Azimuth :
0° (North), 90° (East),
180° (South), 270° (West)