CALET Mission on ISS

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
Charge sign differences of Fd profiles in electron (negative) flux
⇒ Compared with those in Proton flux or NM profiles

What determines the magnitude of Fds?
⇒ Shocks or CMEs? or Both?

Diffusion Coefficient (D) and Energy Dependence
D \propto E^\alpha
⇒ Energy Index \alpha = “1” or smaller?

Drift Dominated Model
How is Drift effective?

Charge Sign Dependence of Modulation:
⇒ Occurs in Both Solar Min and Max?

Force-Field Approximation
Heliosphere \sim Potential Field?

Forbush Decreases

Cosmic Ray Transport

CALET Solar Physics Measurements and Objectives
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/

Sunspot Number

Max & Min Number from 1700

Gradually increase from 1800

Prediction of Solar Activity after 2010

MAX (2013–2014) ⇒ MIN

http://solarscience.msfc.nasa.gov/predict.shtml
GCR Electrons
Diffuse in the solar magnetic field, and are Convected by solar wind in the heliosphere.

Prediction

Electron Energy Spectrum

Energy Dependence of Transport
Diffusion Coefficient
\[ D \propto E^\alpha \]
Modulation Parameter
\[ \Phi \text{ MeV} \sim E^{1-\alpha} \]

Figure 2. Expected electron modulated spectra with the energy dependence of diffusion coefficient of 0.3, 1. \( \phi \text{[MV]} \) 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 \( \Phi \sim (p/D_2)\phi \).
Fig. 2. The correlations between the modulation parameter $\Phi$ and the Climax neutron monitor counting rate. The $\Phi$ 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 $N_{\text{max}} = 5300$.

ICE, IMP, BESS Results

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

Prediction

Drift Model expects “Steeper” slope in $A>0$ Solar Min Period.

$\Phi-N$ relationship

ICE, IMP, BESS Results

Electron

Proton, Helium

[basic curve]

Force-Field Approximation

Slope

Min term $-0.5 \sim -0.6$

Max term $-0.7 \sim -0.8$

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Drift Model expects “Steeper” slope in $A>0$ Solar Min Period.

? Same or Different between electron and nuclear CRs ?

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Fig. 2. Relationship between the modulation parameter $\Phi$ 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.*


**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.

**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.

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

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


Above: Neutron counts from a cosmic ray monitoring station in Moscow. Radiation levels dropped in early Sept. during a period of intense solar activity.
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 m²·sr·min
  - The modulation parameter: \( \varphi = 500 – 1000 \) MV
  - Electrons \( \sim 17,000 \)
  - Three Energy Ranges,
  - Statistical Error \( \sim 1 – 2\% \)

- **Short-Term Measurements**
  (Forbush Decreases)
  - The exposure factor: 10 m²·sr·min
  - The modulation parameter: \( \varphi = 500 – 1000 \) MV
  - Electrons \( \sim 2,000 \)
  - Total number of Northern and Southern Measurement,
  - Statistical Error < 2%.

Time Variation of Cutoff Rigidity

Electrons \( \sim 17,000 \)
Three Energy Ranges,
Statistical Error \( \sim 1 – 2\% \)

Atmospheric Cutoff Rigidity below 2 GeV

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