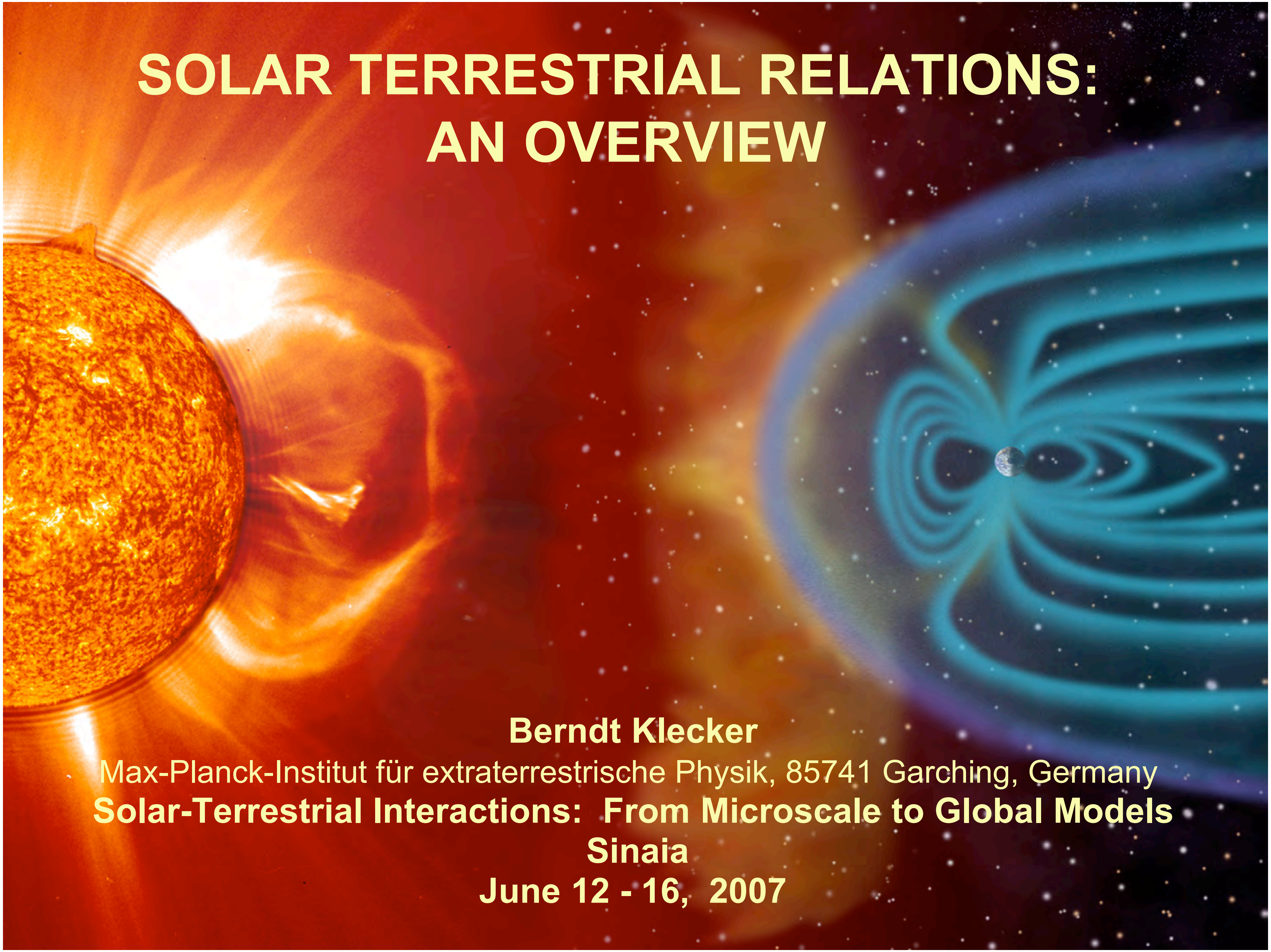
SOLAR TERRESTRIAL RELATIONS: AN OVERVIEW



Berndt Klecker
Max-Planck-Institut für extraterrestrische Physik, 85741 Garching, Germany

Solar-Terrestrial Interactions: From Microscale to Global Models

Sinaia

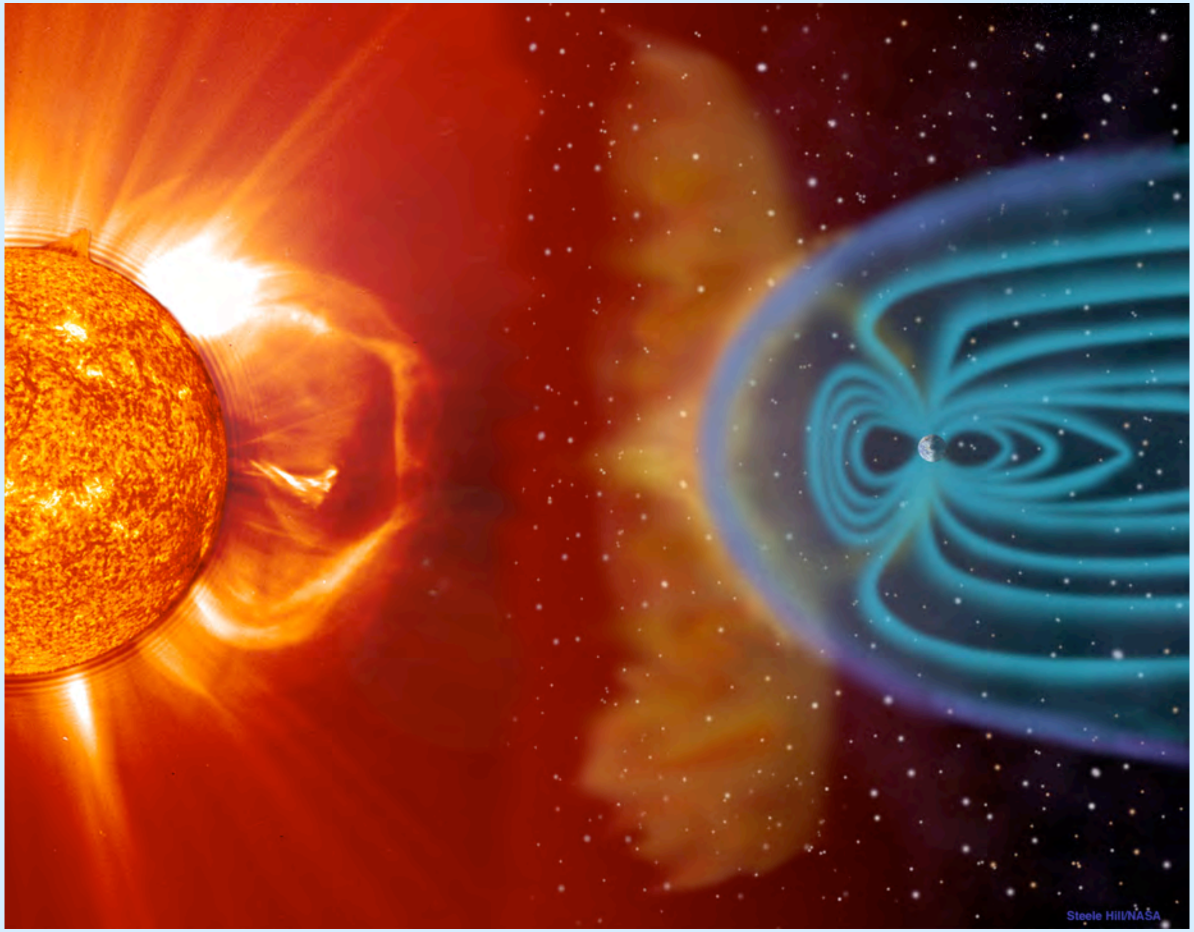
June 12 - 16, 2007

OVERVIEW

- Introduction

  Solar - Terrestrial Relations
- The Variability of the Sun
- Effects in the Near - Earth Environment
- Future Missions

Solar - Terrestrial - Relations



Effects of solar Variability to:

- Atmosphere
- Ionosphere
- Magnetosphere

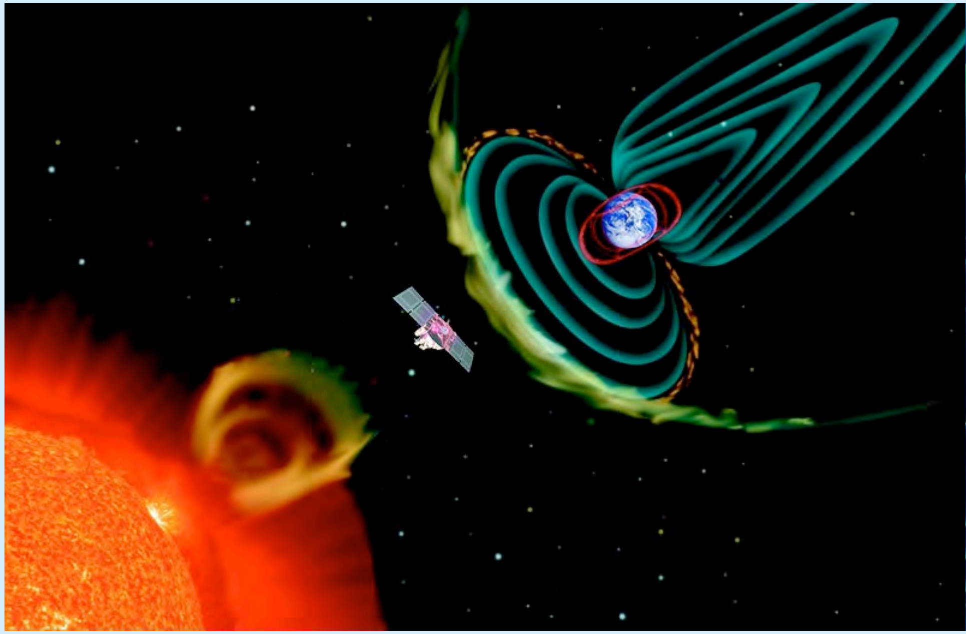
Variability of the Sun

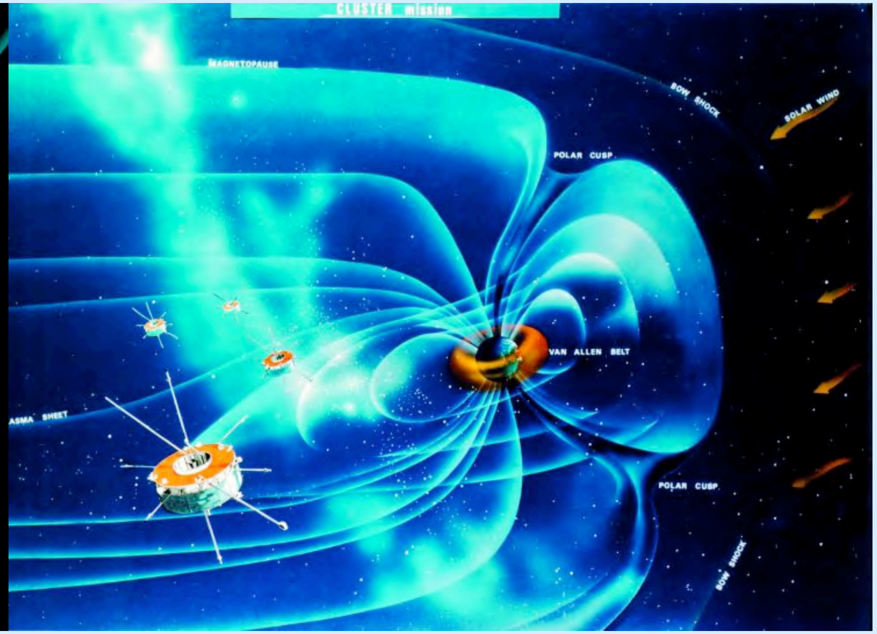
- Flares
- CMEs
- Solar Wind / CIRs
- Sunspot-Cycle
- Long - period Variations

ACTIVE MISSIONS

SUN + INTERPLANETARY SPACE

MAGNETOSPHERE





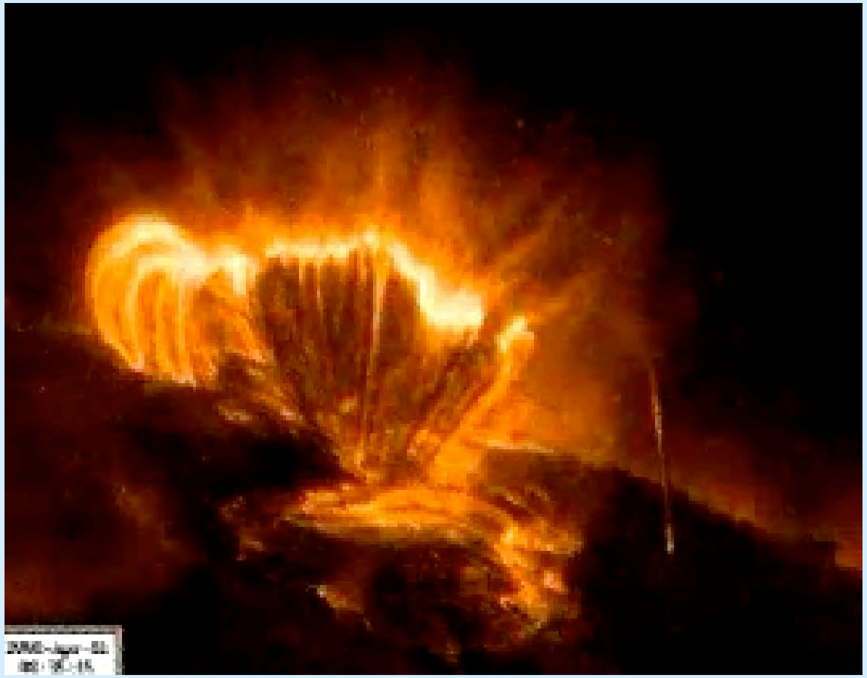
Yohkoh (1991), Wind (1994), SOHO (1995) ACE (1997), TRACE (1998), Hinode (2006), STEREO (2006)

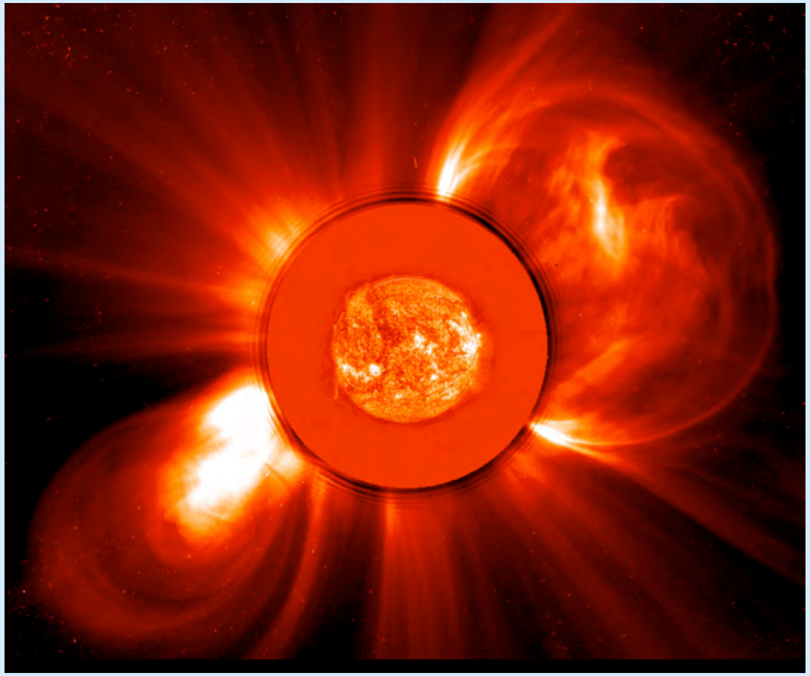
Polar (1996), FAST (1997), Cluster (2000), Double Star (2004), THEMIS (2007)

TIME SCALES

• Short Time scales	Flares, Solar Wind Variations, CMEs (Seconds - Hours - Days)
• Intermediate Timescales	Solar Rotation
• Long Time Scales	Solar Cycle (11y, 22 y)
• Earth Orbital Time Scales	~ 23 ky, ~41ky, ~100 ky (Milankovic - Cycles)
• Galactic Timescales	Motion of the Solar System and nearby Clouds

THE VARIABILITY OF THE SUN
Flares and Coronal Mass Ejections

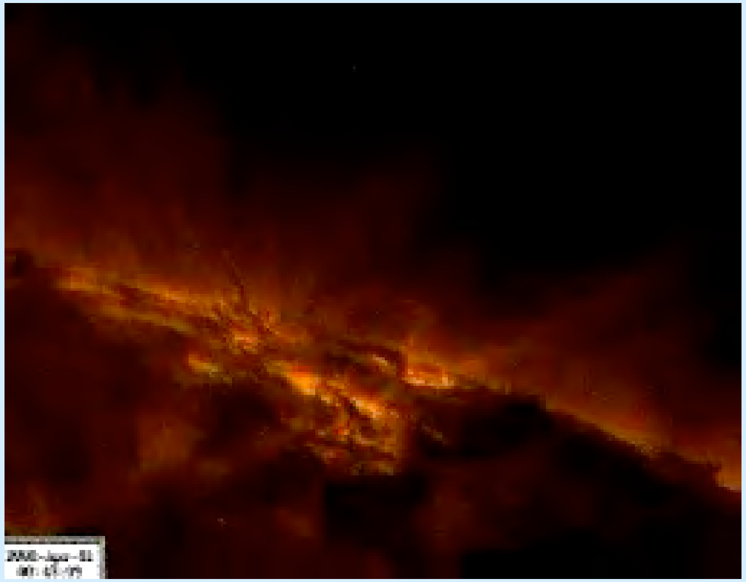




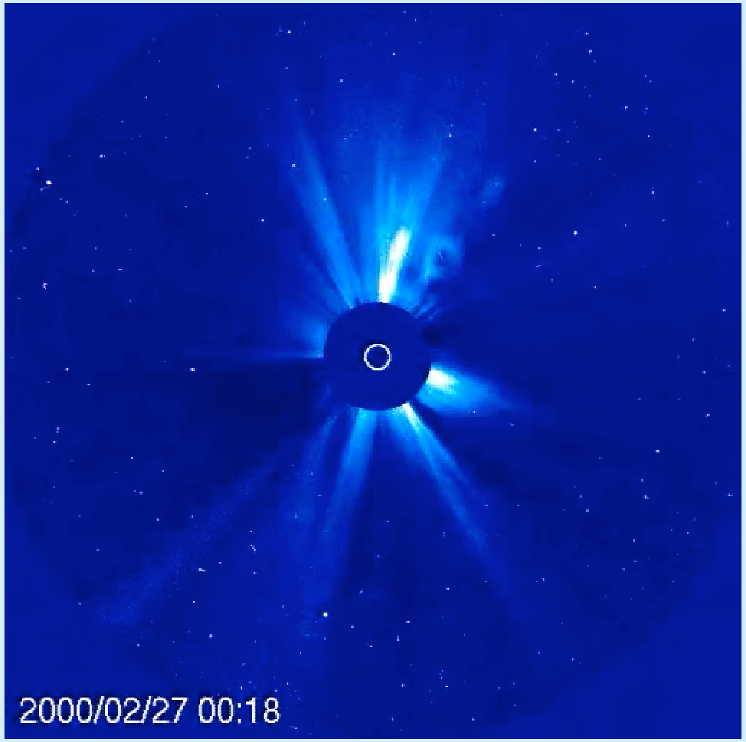
Solar Flare
TRACE / NASA

Coronal Mass Ejection (CME)
SOHO / ESA

THE VARIABILITY OF THE SUN
Flares and Coronal Mass Ejections

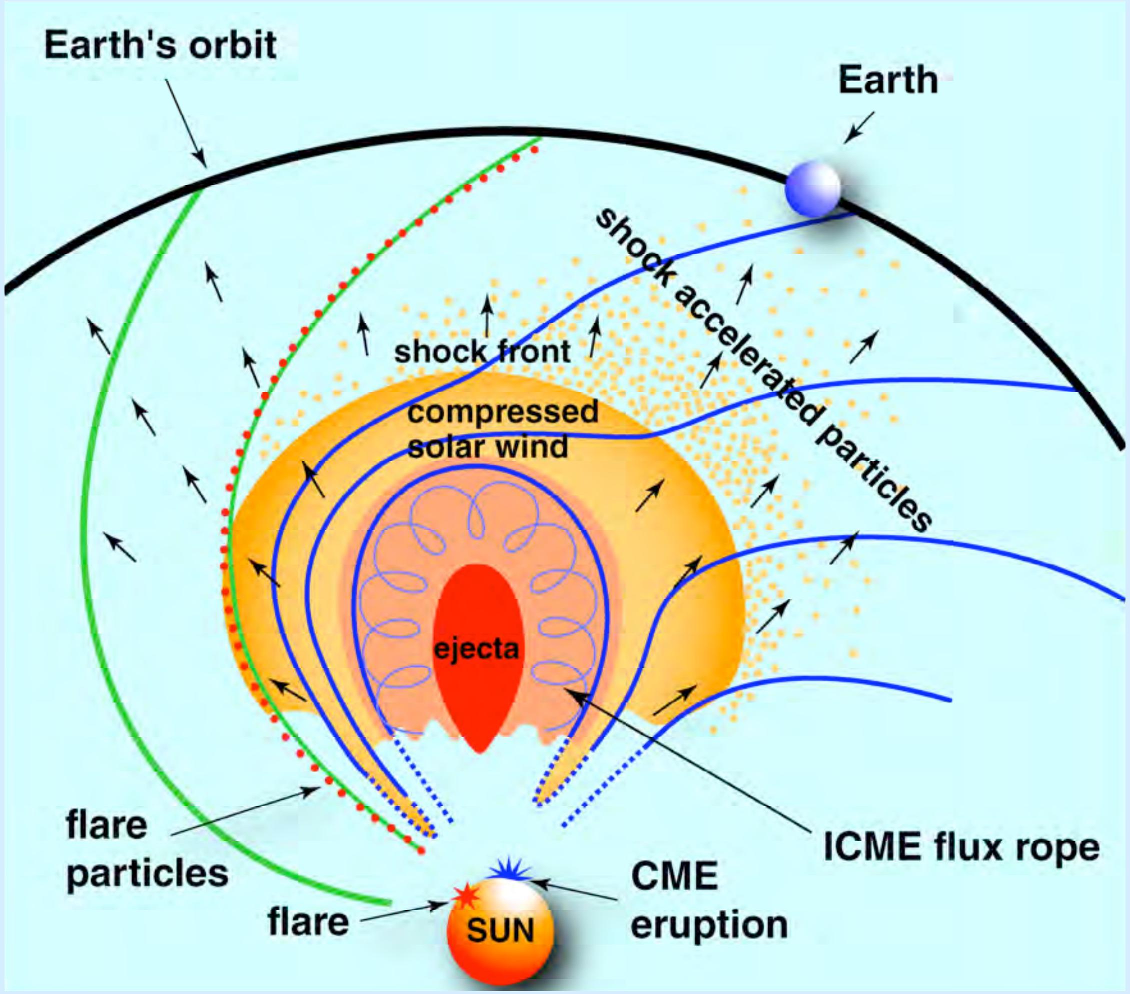


Solar Flare
TRACE / NASA



Coronal Mass Ejection (CME)
SOHO / ESA

THE VARIABILITY OF THE SUN
Solar Energetic Particles (SEP)



Flares:

Energetic Particles are observed in a narrow range of solar longitudes; low Intensity

Composition: large 3He/4He and heavy ion abundances

Ionic Charge: High; Source in the low corona

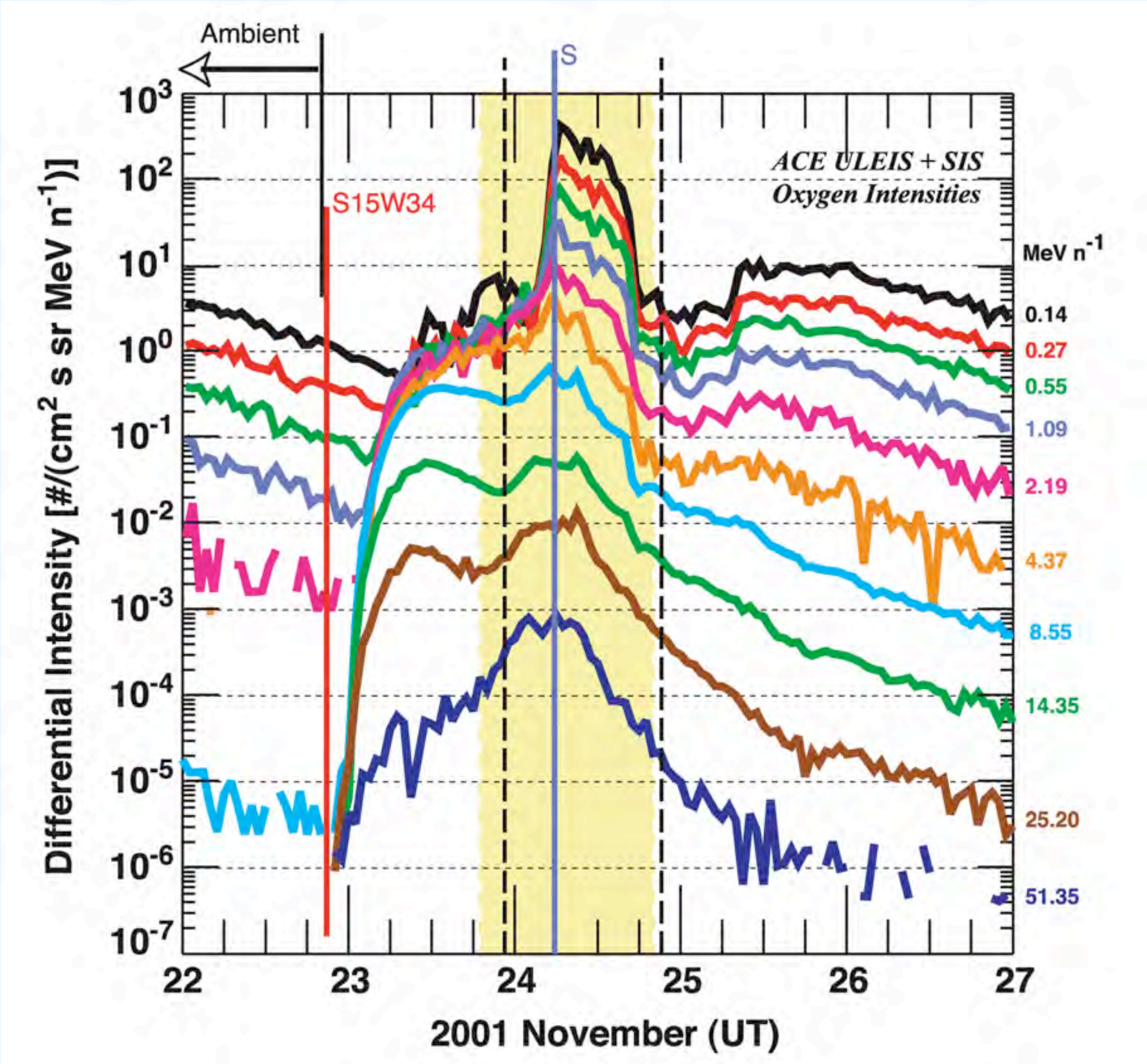
Coronal / Interplanetary Shocks:

High intensity of SEPs ;

Wide range of solar longitude

Composition and charge states similar to Solar Wind

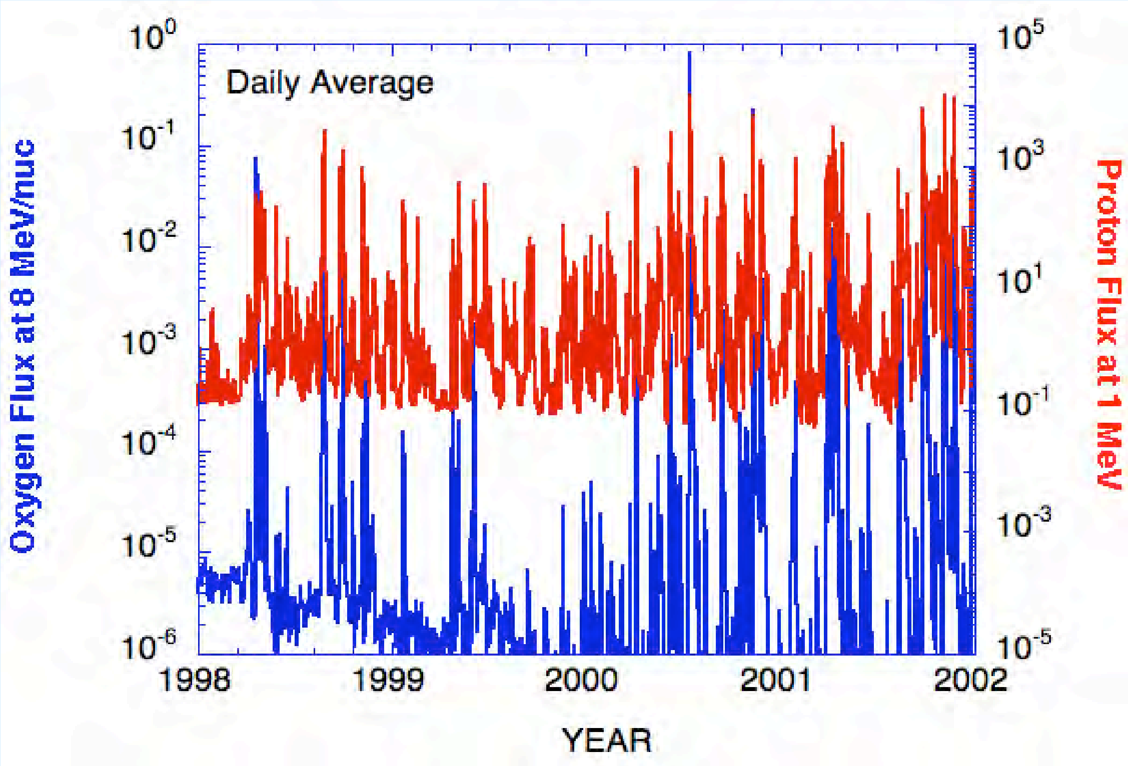
THE VARIABILITY OF THE SUN
Solar Energetic Particles (SEP)



Typical Example for Event with Coronal / Interplanetary Acceleration

Desai et al., 2003

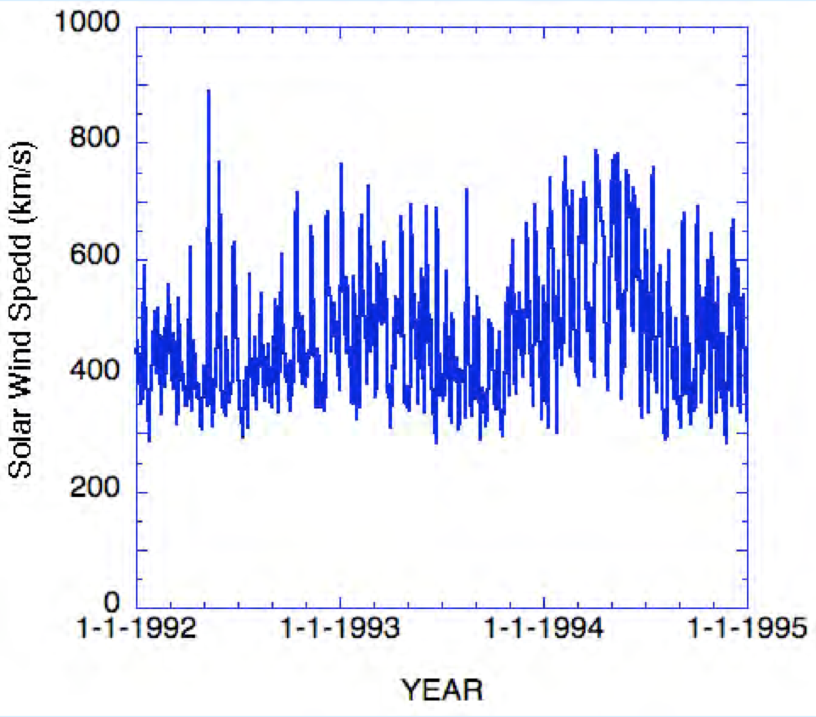
THE VARIABILITY OF THE SUN
Interplanetary Particle Intensities



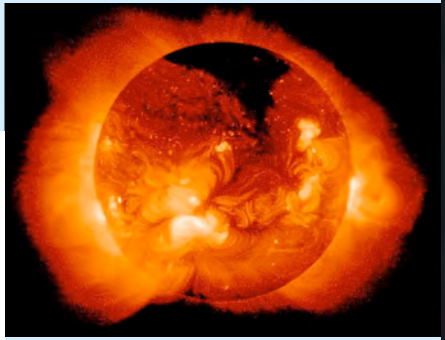
Data from ACE / EPAM (p) and ACE / SIS (O)

THE VARIABILITY OF THE SUN
High-Speed Streams in the Solar Wind

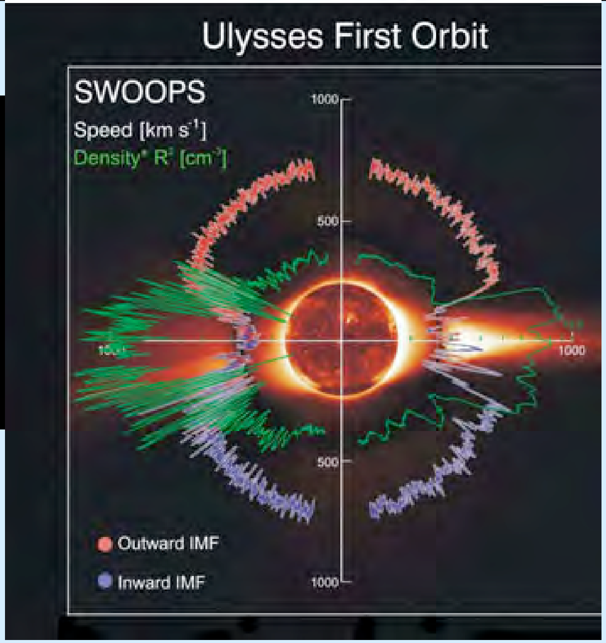
Daily Average of Solar Wind Speed



NASA COHOWEB



Yohkoh

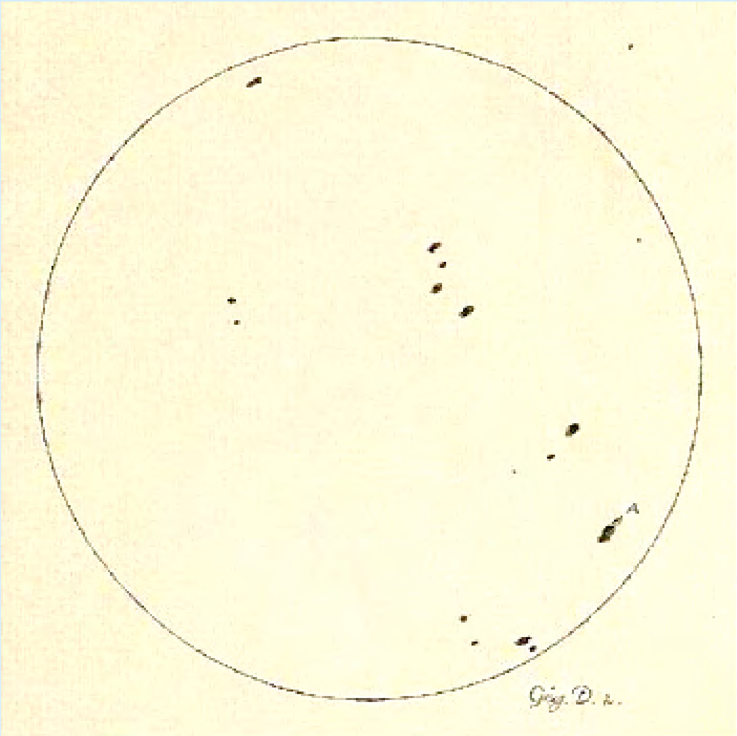


CIRs: Corotating Interaction Regions

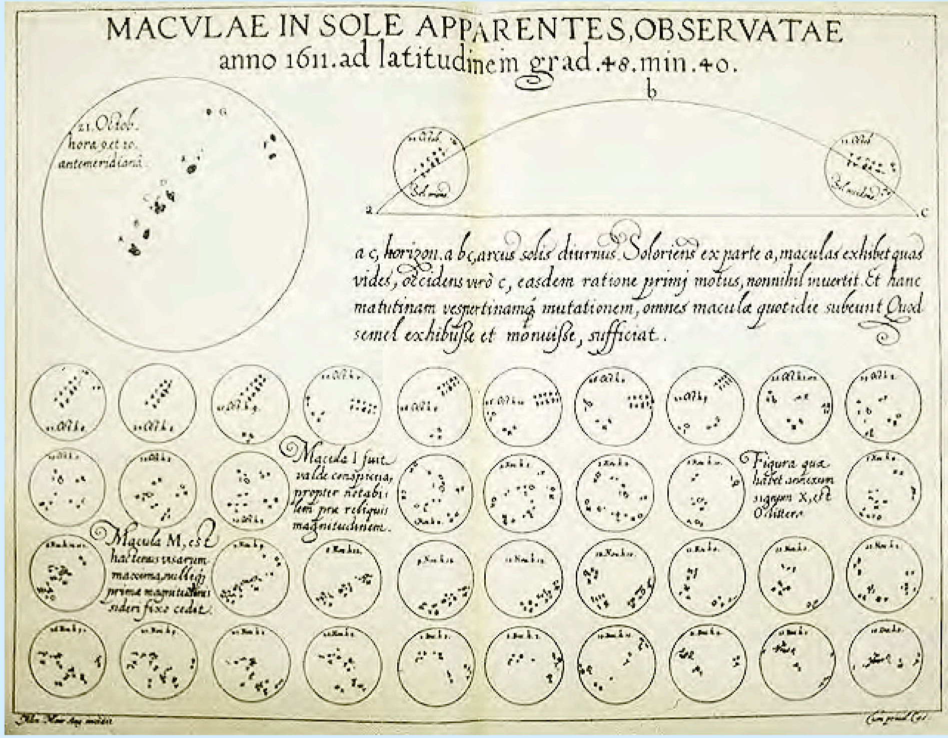
- Acceleration of particles in interplanetary space
- Compression of the Magnetosphere by high-speed solar wind
- acceleration of electrons to ~MeV energies in the Magnetosphere

Long Time Scales: Sunspot Cycle

First Sunspot Observations



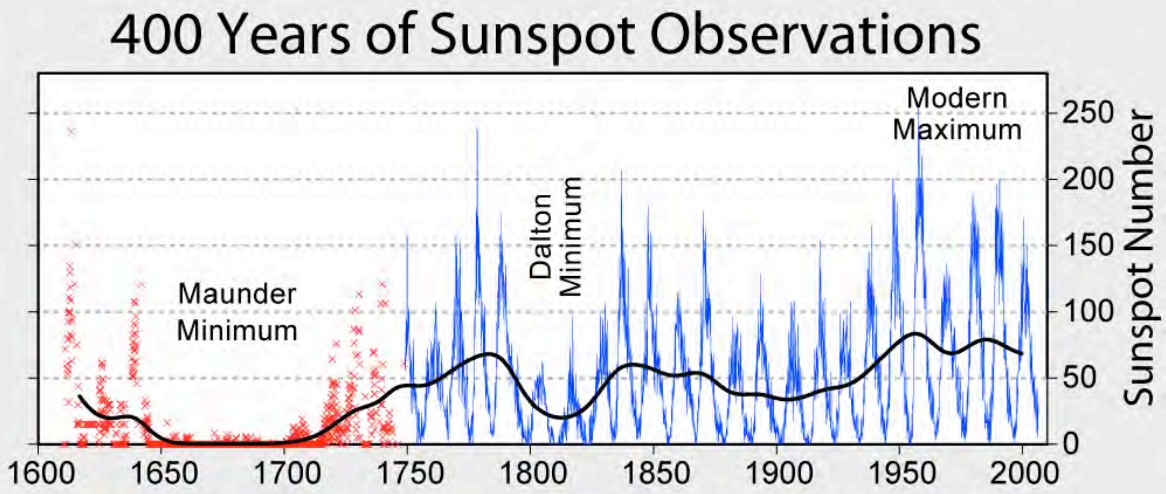
Galileo (1612)



Scheiner (1611)

THE VARIABILITY OF THE SUN

Long Time Scales: Sunspot Cycle



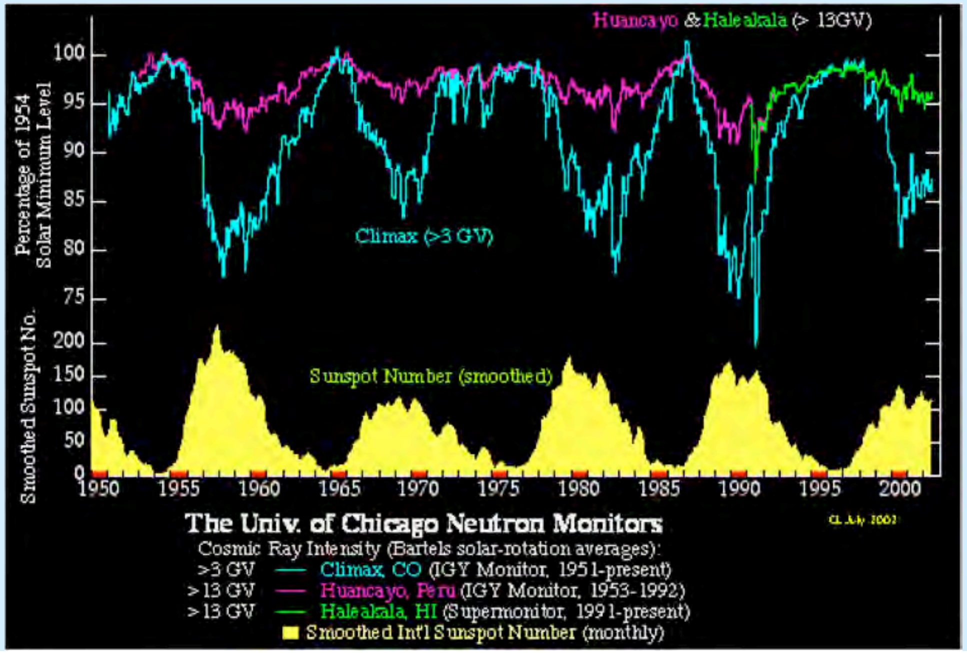
Large Variation of Solar Activity during Solar Cycle:

Number of Sunspots, Flares, CMEs vary strongly with Solar Cycle

Indirect Effect:

Galactic Cosmic Ray Modulation

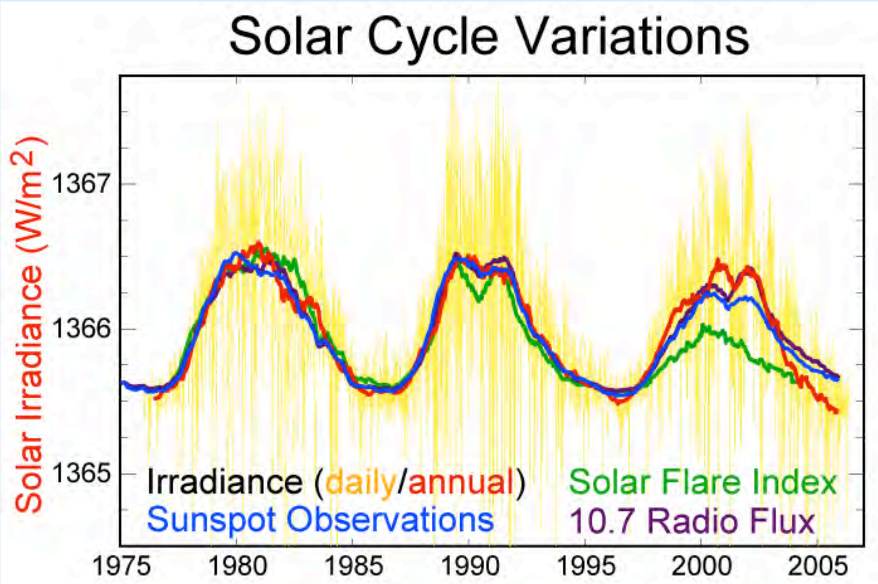
Sunspot Number for 1950 - 2000

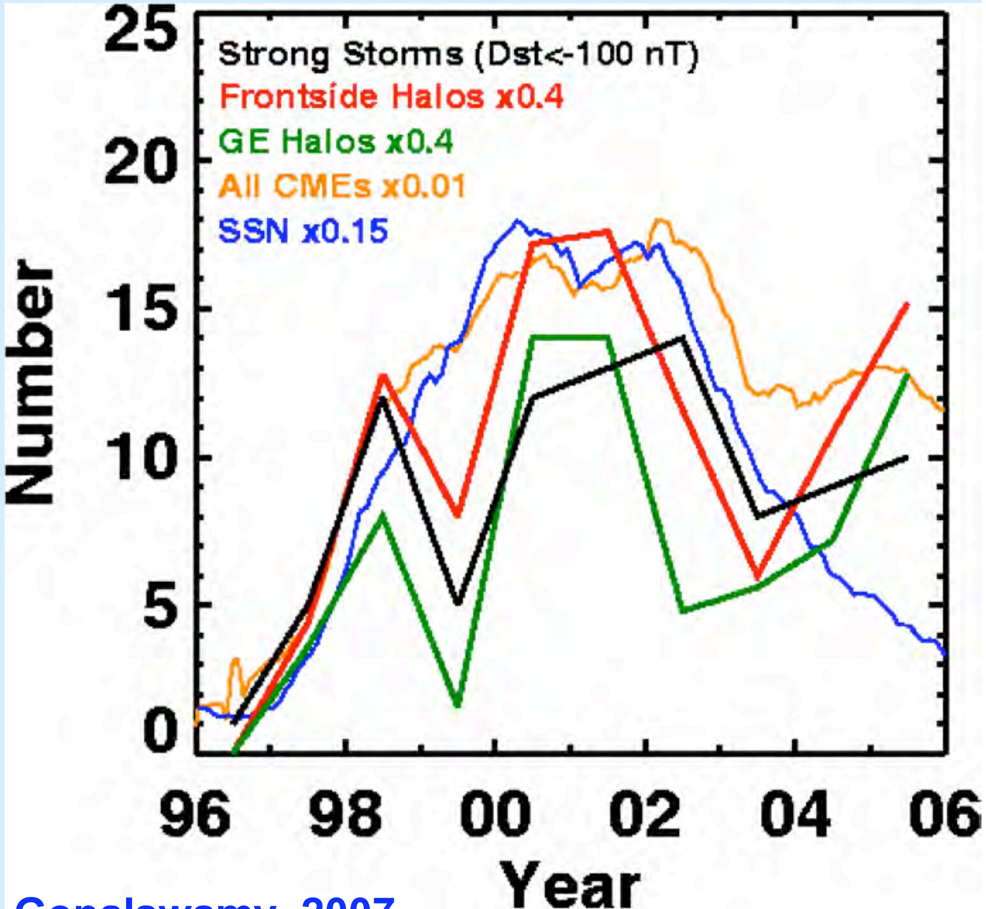


THE VARIABILITY OF THE SUN

Solar Cycle Variations: Radiation

But: Large variation of Flares, CMEs, SEPs, CIRs, …





Solar Cycle variation of total irradiance is small ~0.2%

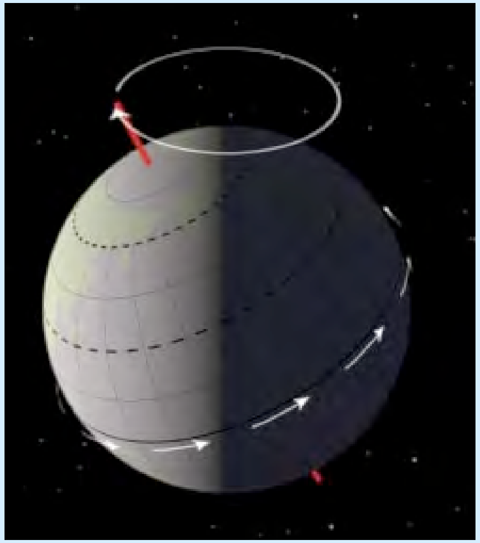
Lean & Fröhlich, 1998

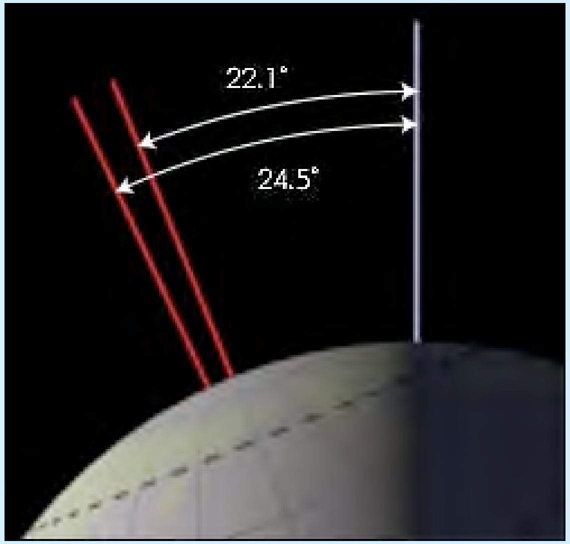
Fröhlich & Lean, 2004

Gopalswamy, 2007

VARIABILITY OF THE SUN-EARTH SYSTEM

Earth Orbital Time Scales: Milankovic Cycle





Variation of the

Eccentricity of the orbit of the Earth:

$\varepsilon \sim 0.005 - 0.05$

Precession

~21 ky

Axial Tilt Variation

~41 ky

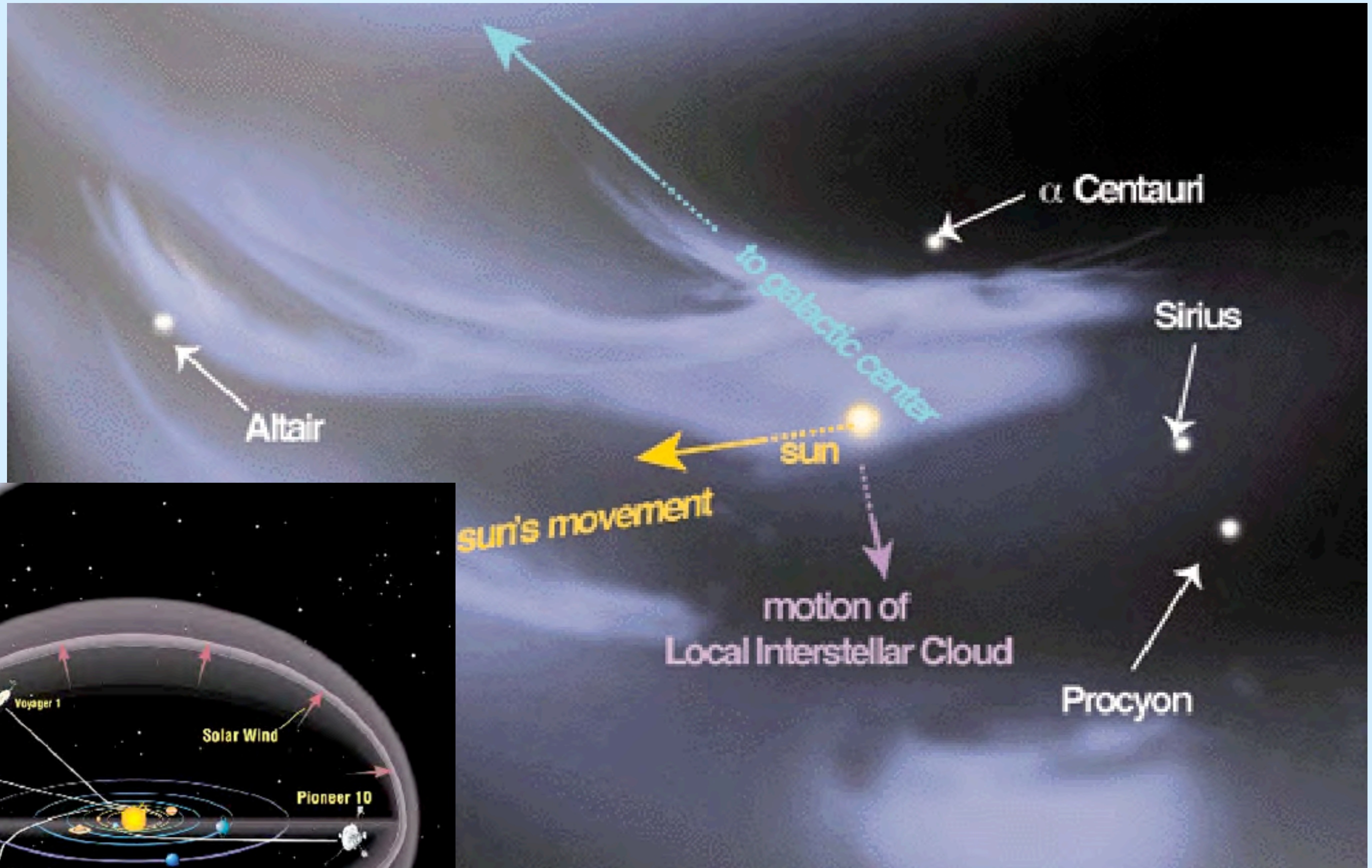
Eccentricity Variation

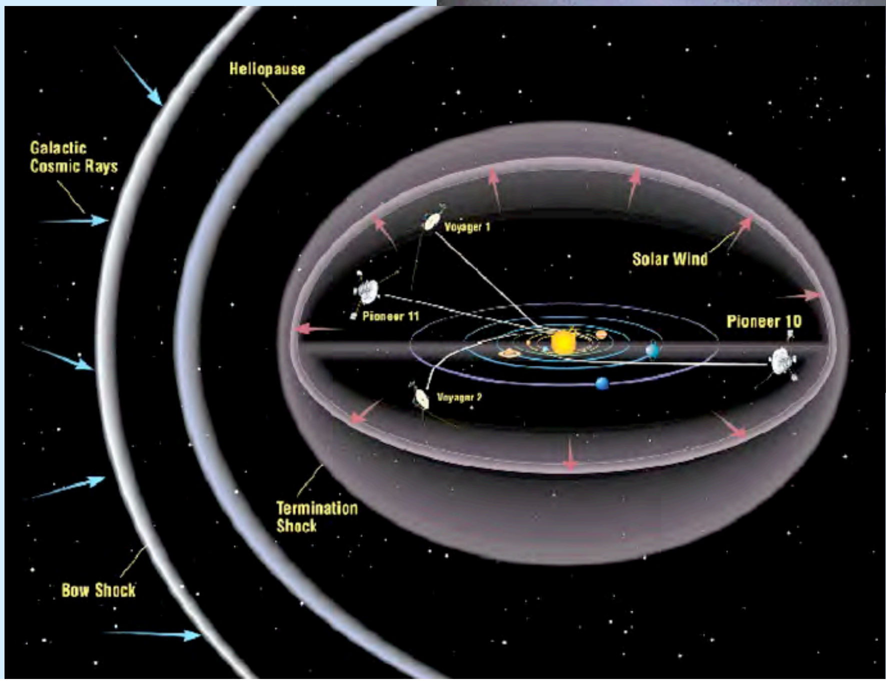
~100 ky, 400 ky

MILANKOVIC CYCLE

THE VARIABILITY OF THE SUN

Galactic Time Scales: The Motion of the Sun



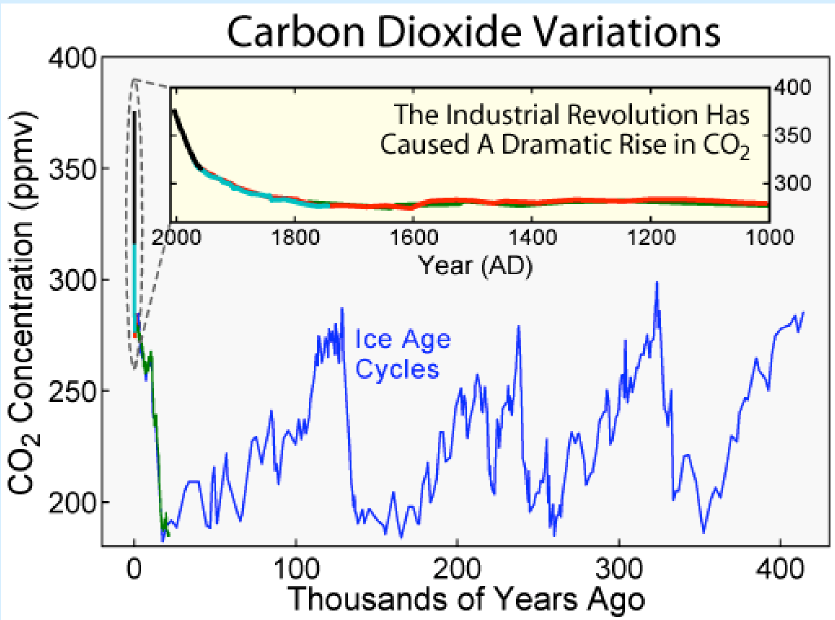


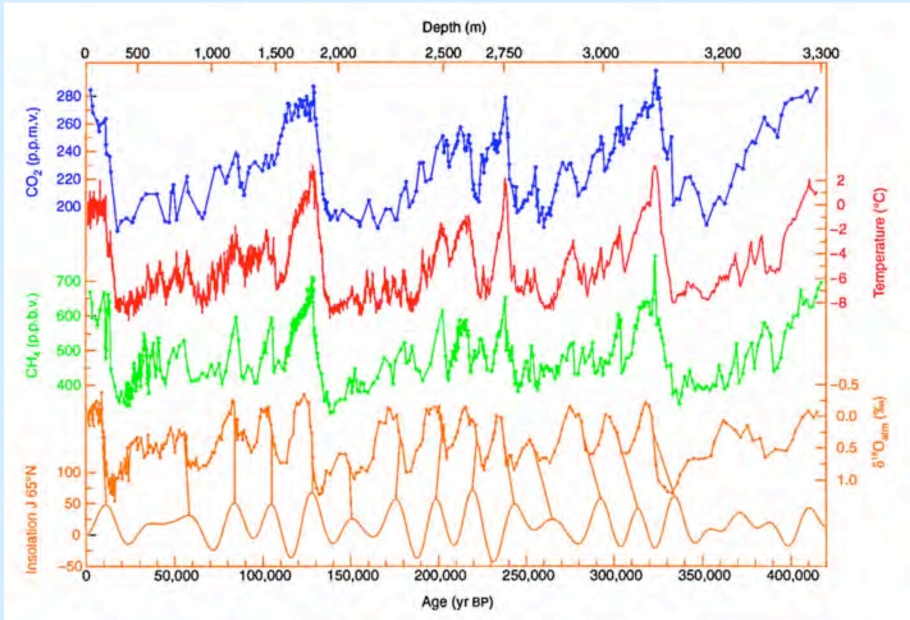
Size and Shape of Heliosphere depends on N, B outside

Effects at Earth and in the Near-Earth Environment
Long Time Scales

Galactic Time Scale
- *Size and Shape of the Heliosphere depends on the Interstellar Medium (N, B)*
- *Intensity of GCR inside the Heliosphere depends on the distance to the outer boundary*

Earth Orbit Time Scales (Milankovic Cycles)
- *Milankovic cycle time scales can be found in Climate Records*





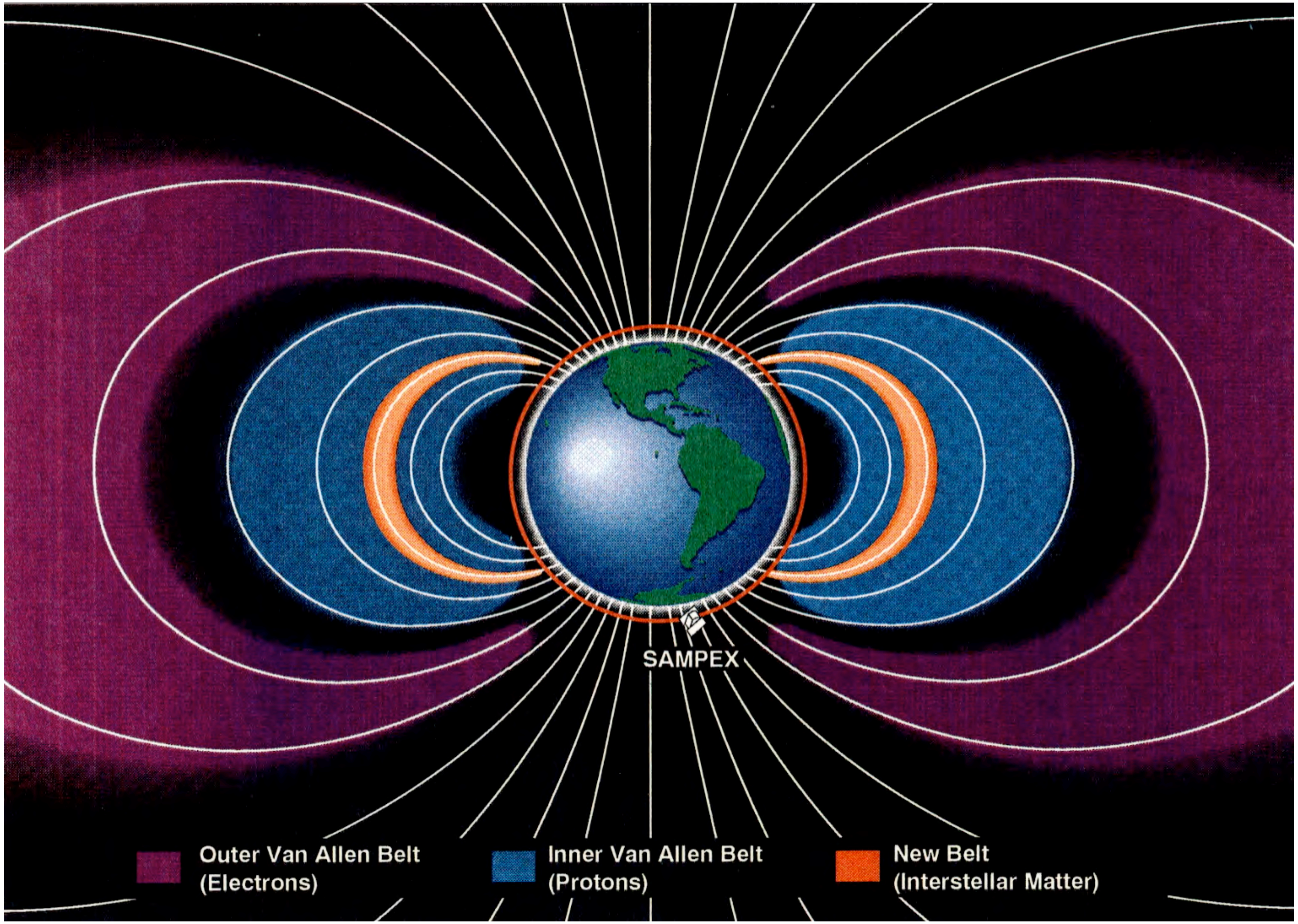
Effects at the Earth and in the Near-Earth Environment

Short- to Solar Cycle Time Scales

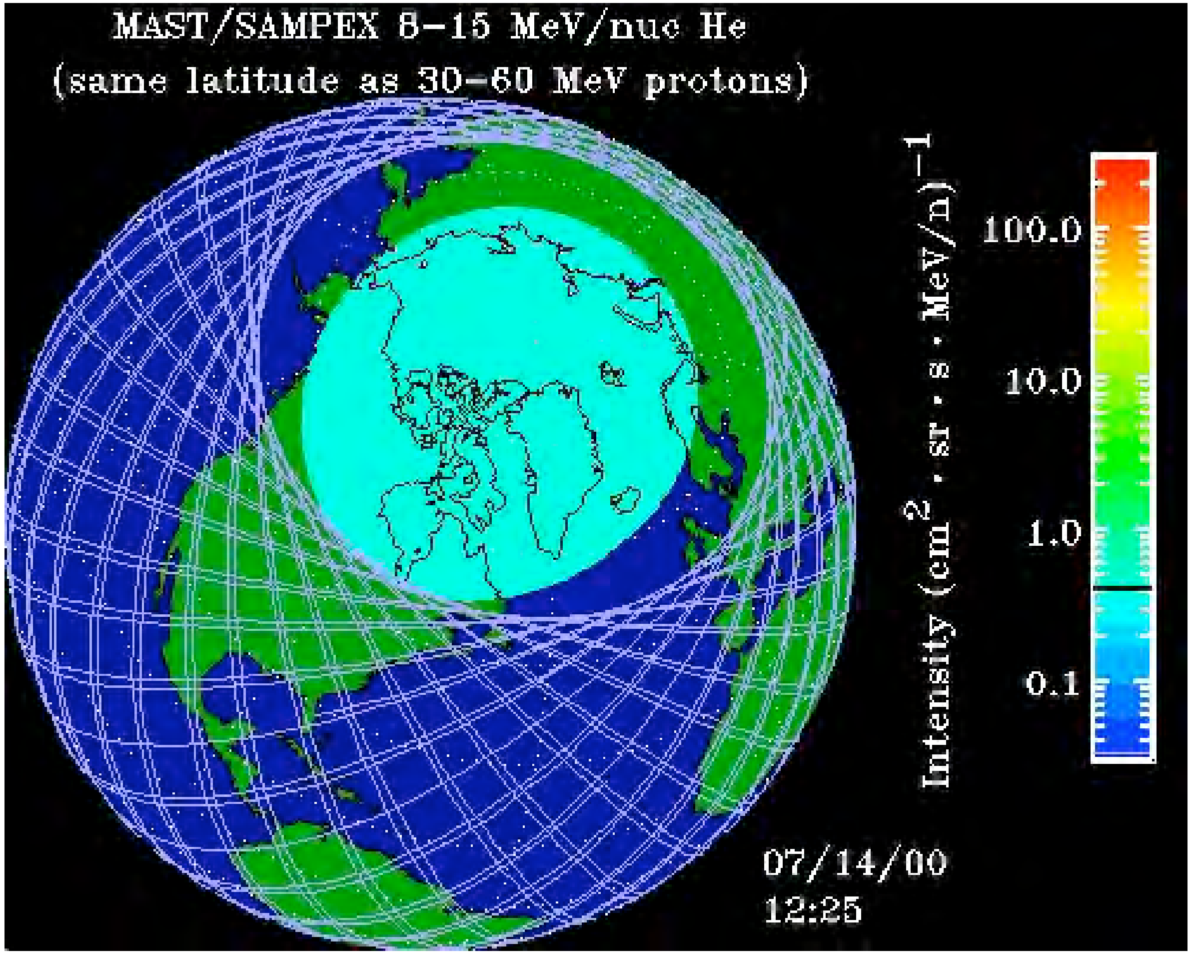
Solar Flares, CMEs, CIRs

- Increase of particle fluxes, in particular in the polar regions (Minutes, hours, days after the event at the Sun, depending on Energy)
- Massive disturbance of the magnetic field of the Earth by the impact of an Interplanetary Shock or High-Speed Stream (Magnetic Storm) (for a shockwave with 1000 - 2000 km/s ~ 20 h - 42 h after the event at the Sun)
- Variability of V_{SW}, B_z, B_y - Reconnection, Magnetic Storms, Substorms
- Acceleration of ions and electrons in the magnetosphere
- Increase of Auroral Activity
- Increase of ion outflow
- Variation of Total Electron Content (TEC) of Ionosphere (e.g. degradation of GPS signal, wireless connections, etc)
- Induced currents in pipelines, increased corrosion of pipelines, etc

THE INNER MAGNETOSPERE
RADIATION BELTS



VARIATION OF THE GEOMAGNETIC CUTOFF AT THE ISS ORBIT



Polar Cap

Geomagnetic Cutoff of

P: 30-60 MeV

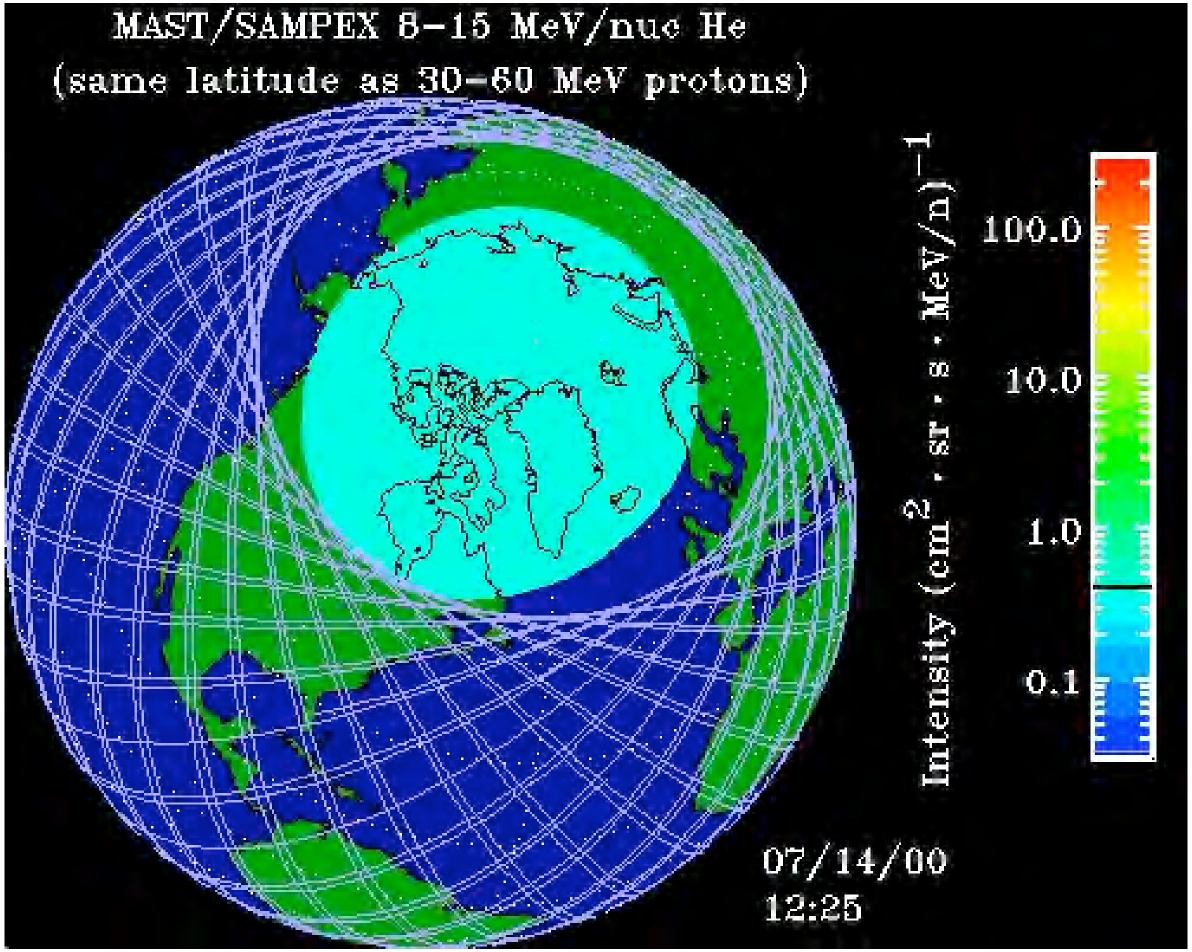
He: 8-15 MeV

Light blue: ISS Orbit

1. **Before a magnetic Storm**

R. Leske, Caltech

VARIATION OF THE GEOMAGNETIC CUTOFF AT THE ISS ORBIT



Polar Cap

Geomagnetic Cutoff of

P: 30-60 MeV

He: 8-15 MeV

Light blue: ISS Orbit

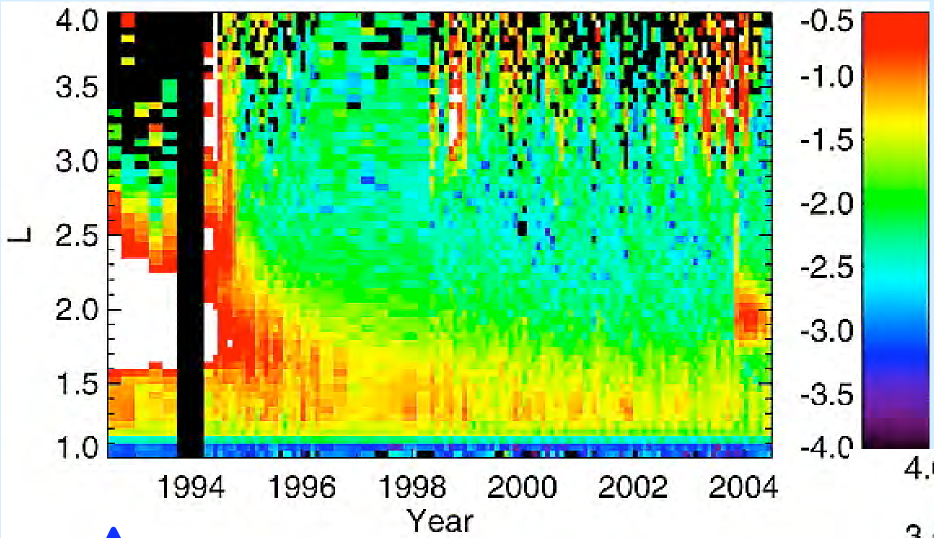
2. During a magnetic Storm

R. Leske, Caltech

VARIABILITY OF THE RADIATION BELTS

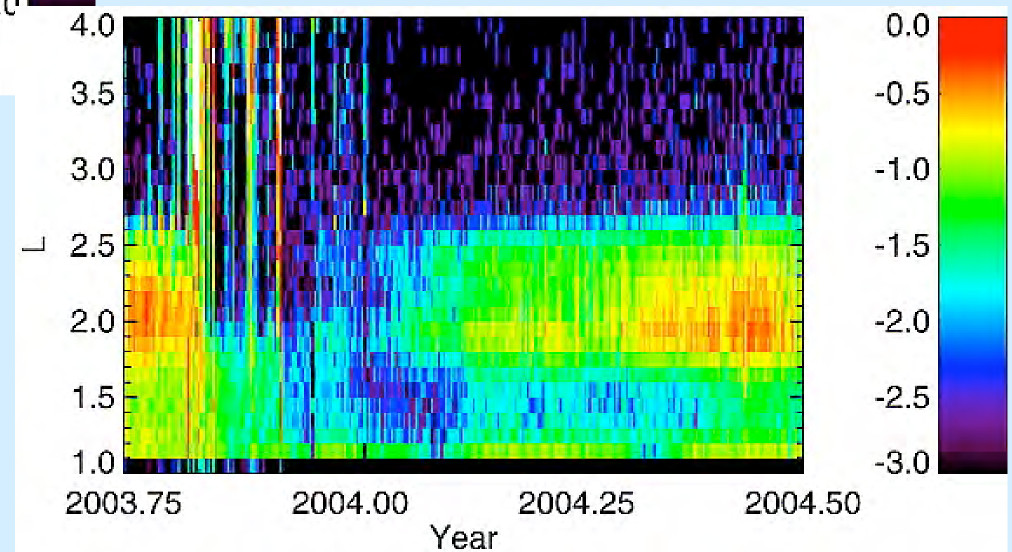
New Belts at Low Altitudes

SAMPEX 1992 - 2004, Electrons 10 - 20 MeV



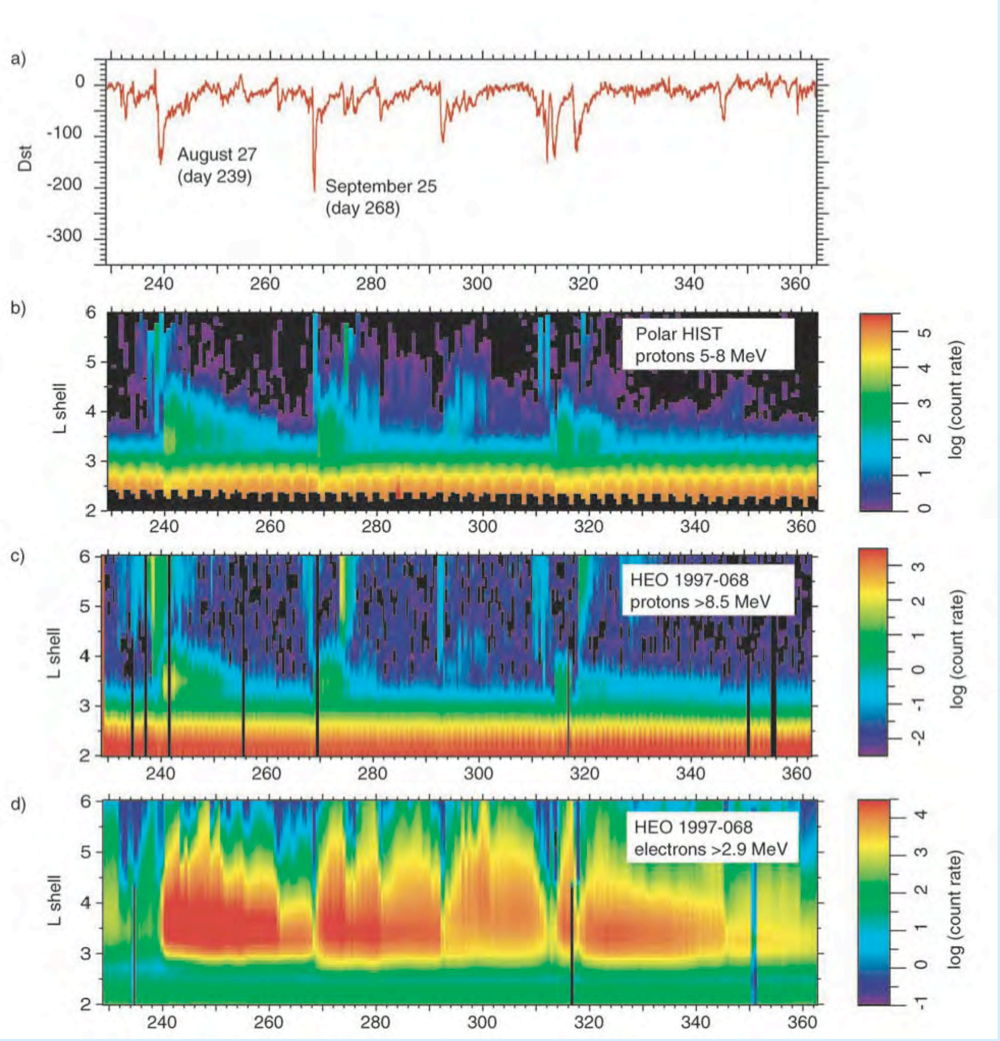
Injection in March 1991

SAMPEX, Protons 19 - 29 MeV



Looper et al., 2004

ENERGETIC PARTICLES IN THE MAGNETOSPHERE OF THE EARTH



Lorentzen et al., 2001

1998

DST

POLAR

Protons 5- 8 MeV

HEO 1997-068

Protons > 8.5 MeV

HEO 1997-068

Electrons > 2.9 MeV

ACCELERATION OF ELECTRONS

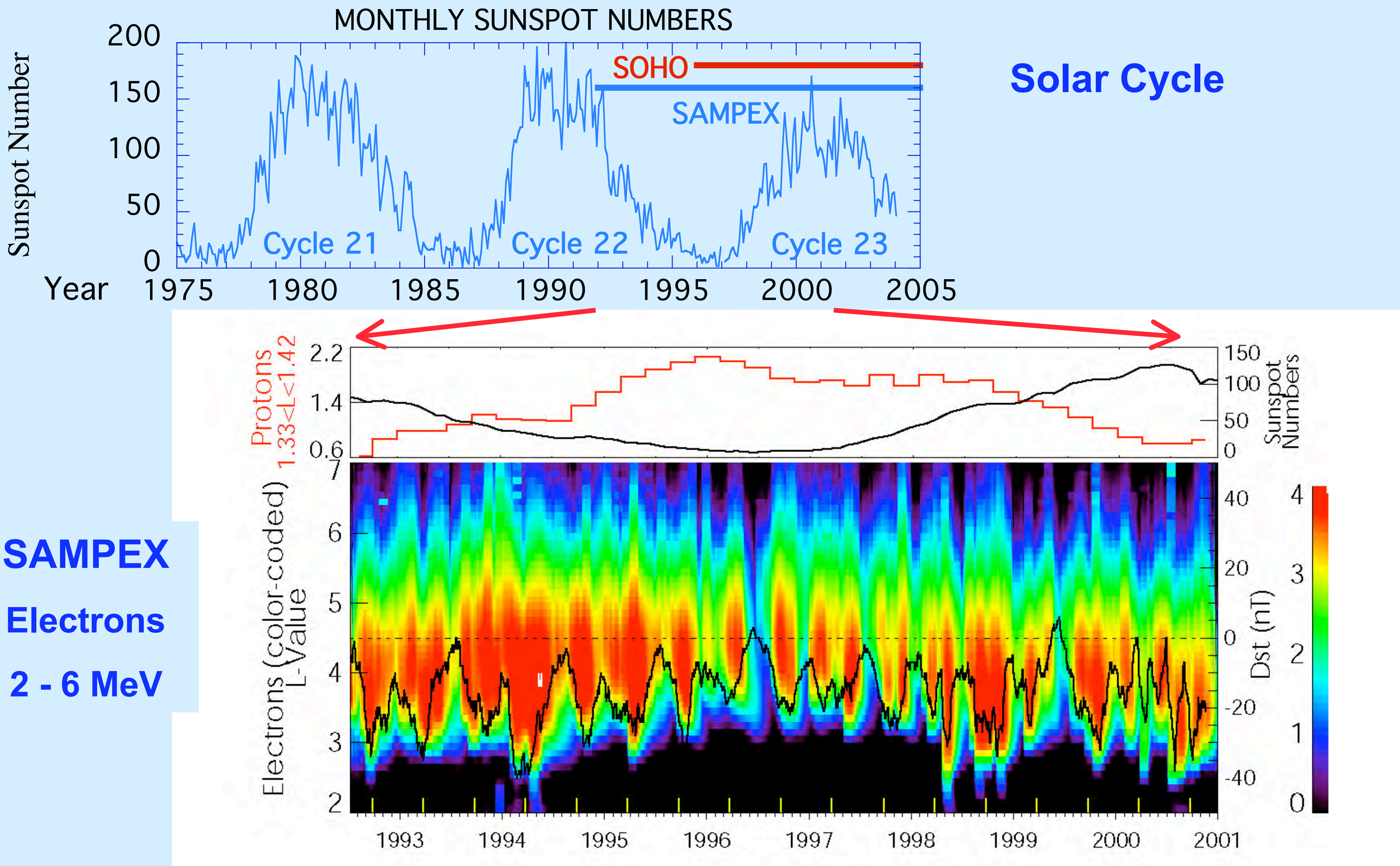
Intermediate Time Scales: CIR - High-Speed Solar Wind

Solar Cycle

SAMPEX

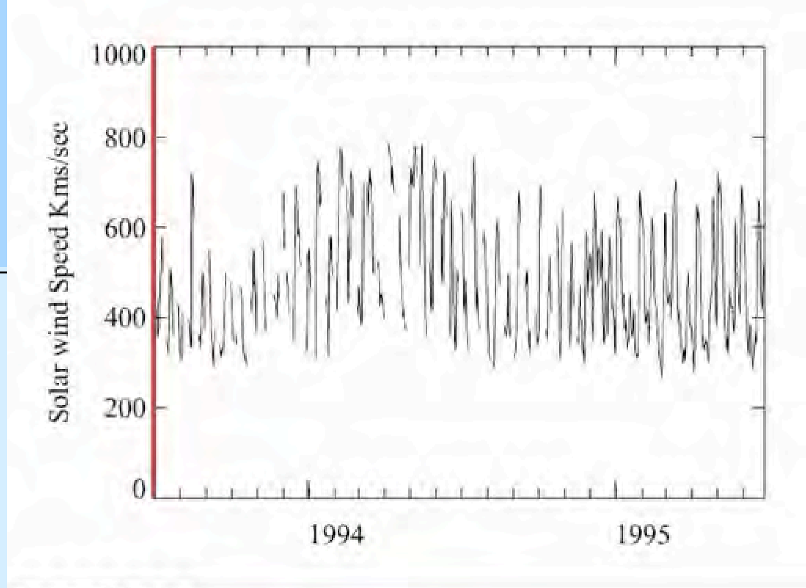
Electrons

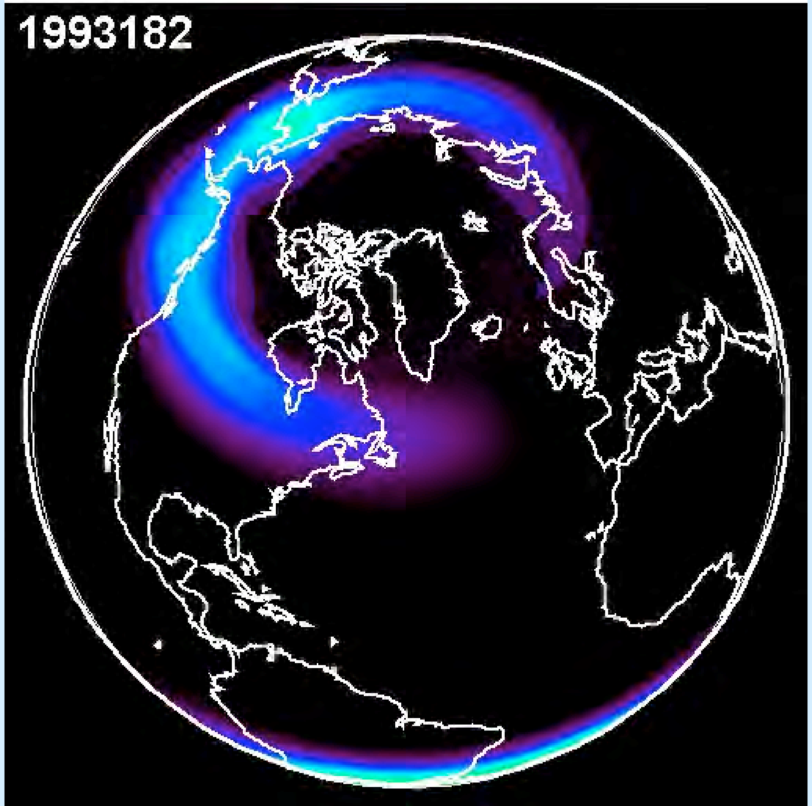
2 - 6 MeV



Li et al., 2001

Dynamic Radiation Belts: 1993-1995

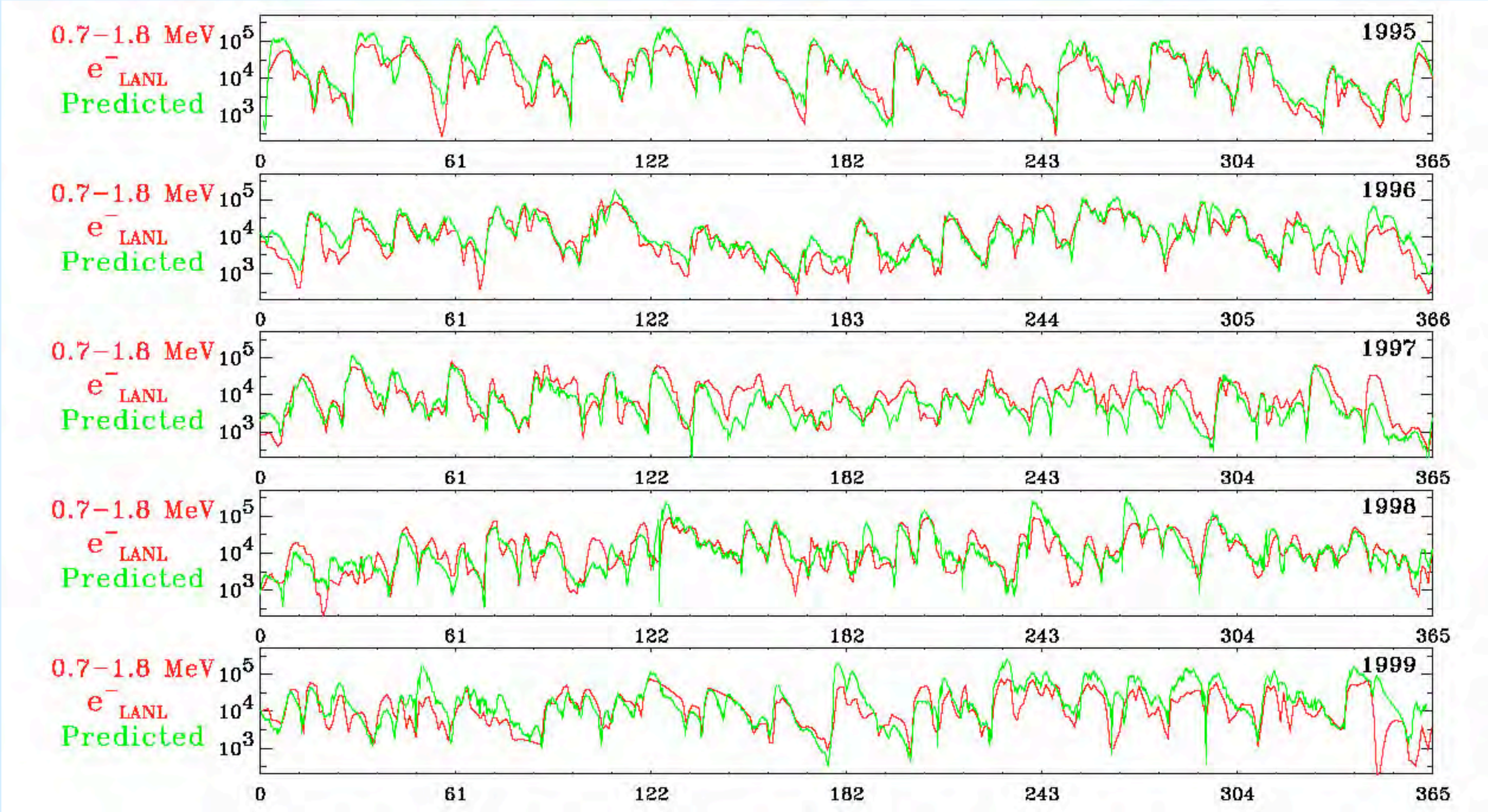




Relativistic electrons observed with SAMPEX in low altitude (600 km) polar orbit

MODEL FOR THE PREDICTION OF

Relativistic Electrons in Geostationary Orbit



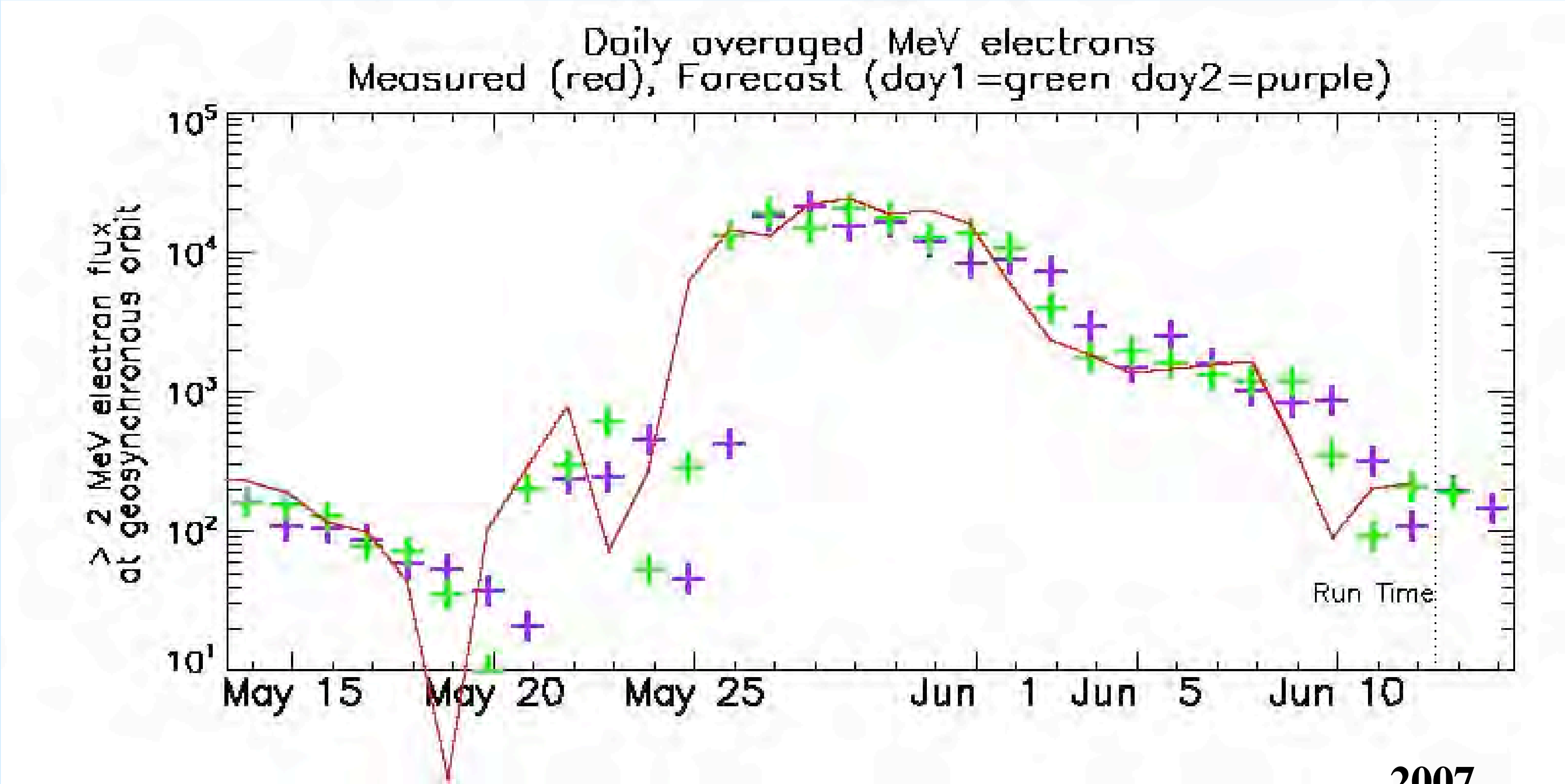
Modell: $\frac{\partial f}{\partial t} = L^2 \frac{\partial}{\partial L}\left(\frac{D_{LL}}{L^2}\frac{\partial f}{\partial L}\right) - \frac{f}{\tau},$ $D_{LL} = D_o\,(L/6.6)^{10}$

$$D_0 = C\left(\frac{v}{v_0}\right)^{\gamma_1}\left[1+((v_x b_z + |v_x b_z|)/\alpha)^2\right]^{\gamma_2}\left[\left(\frac{\triangle v^2}{\triangle t}\right)^2/\beta\right]^{\gamma_3}$$

ST

Li et al., 2001

ONLINE PREDICTION

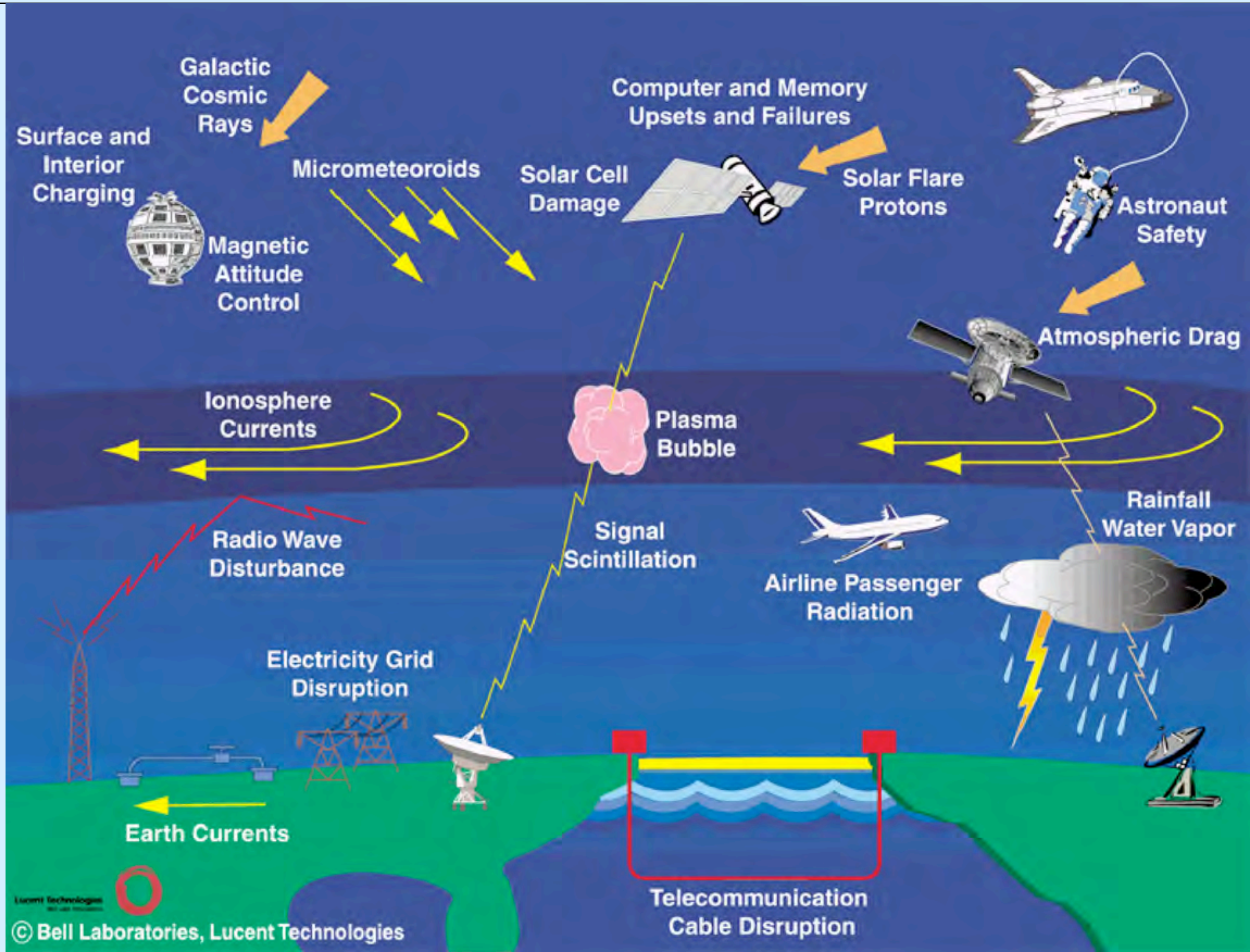


2007

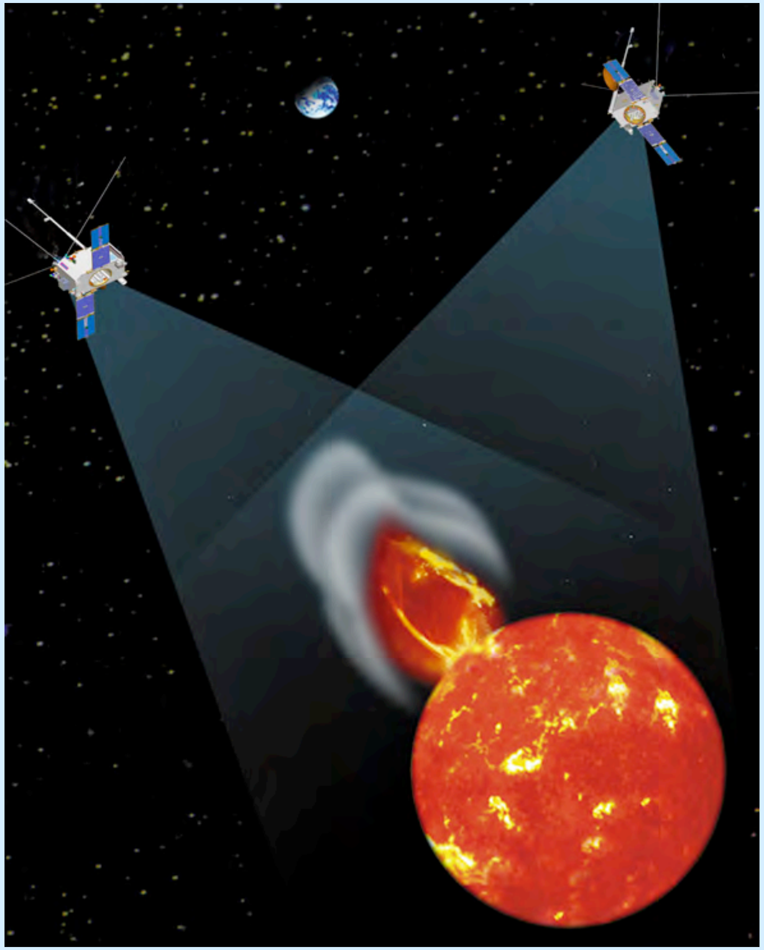
http://lasp.colorado.edu/space_weather/xlf3/xlf3.html

Li et al., 2001

SPACE WEATHER EFFECTS
Overview



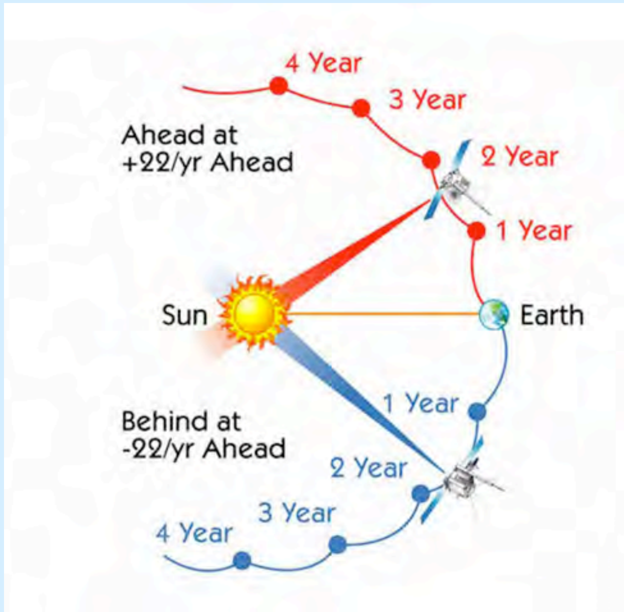
FUTURE MISSIONS
THE STEREO MISSION (NASA)



STEREO

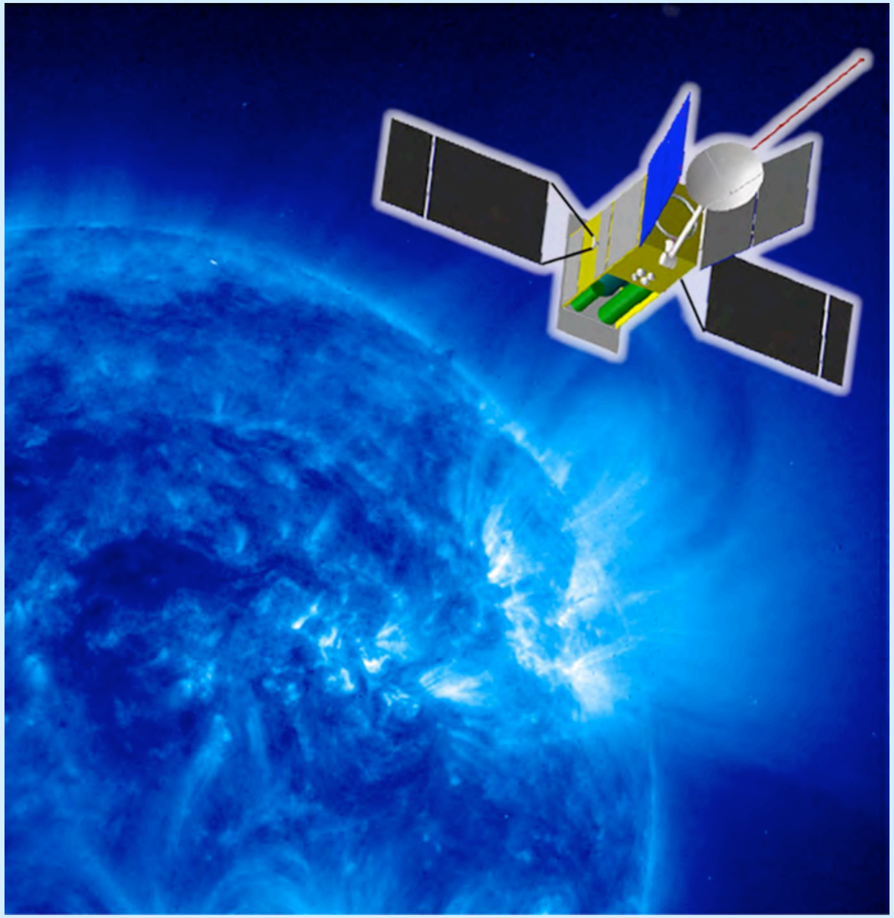
Solar Terrestrial Relations Observatory

Stereoscopic Observations of the Sun and of CMEs with 2 Observatories



Launch: 26 October 2006 KSC / Florida

THE MORE DISTANT FUTURE - ESA
SOLAR ORBITER



ESA Mission

Launch: ~ 2015

Perihelion: ~ 0.22 AU (45 R_S)

Sun-synchronous in Perihelion

Cruise Phase: ~ 3.5 y

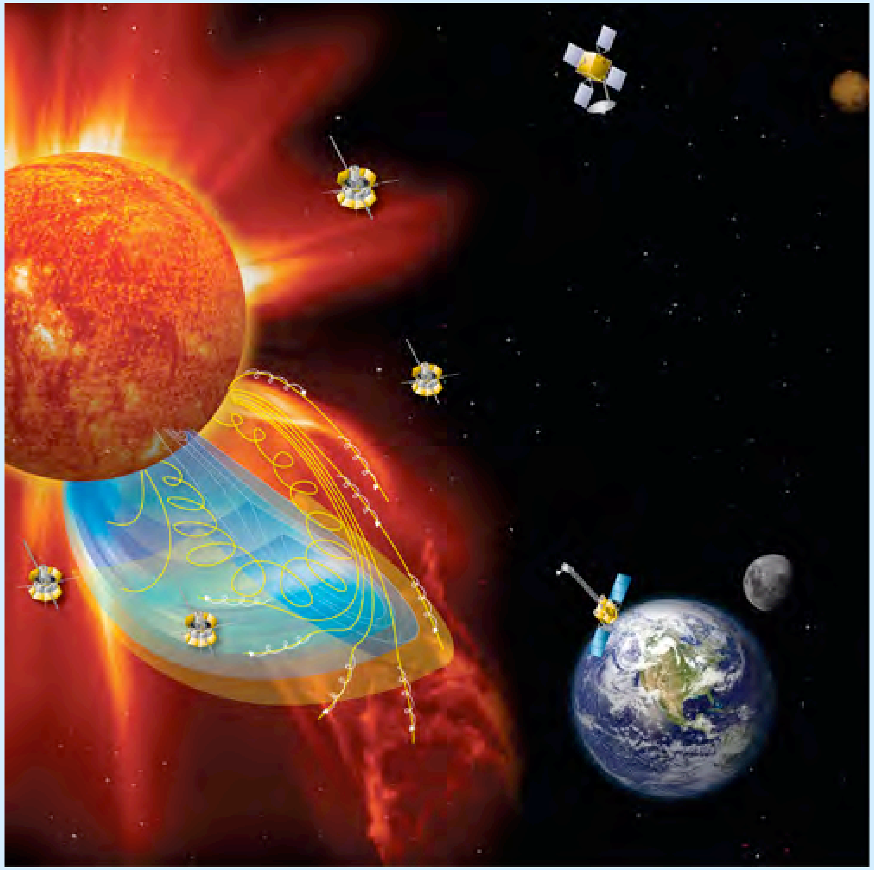
Orbit: ~ 150 d

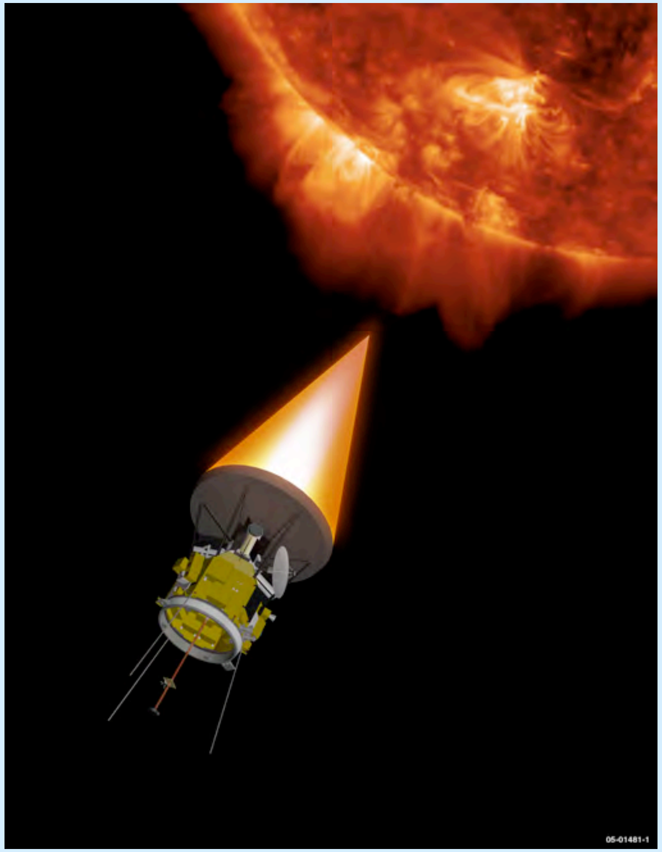
Max- Sol. Latitude: ~ 30°

THE MORE DISTANT FUTURE - NASA

SENTINELS

SOLAR PROBE

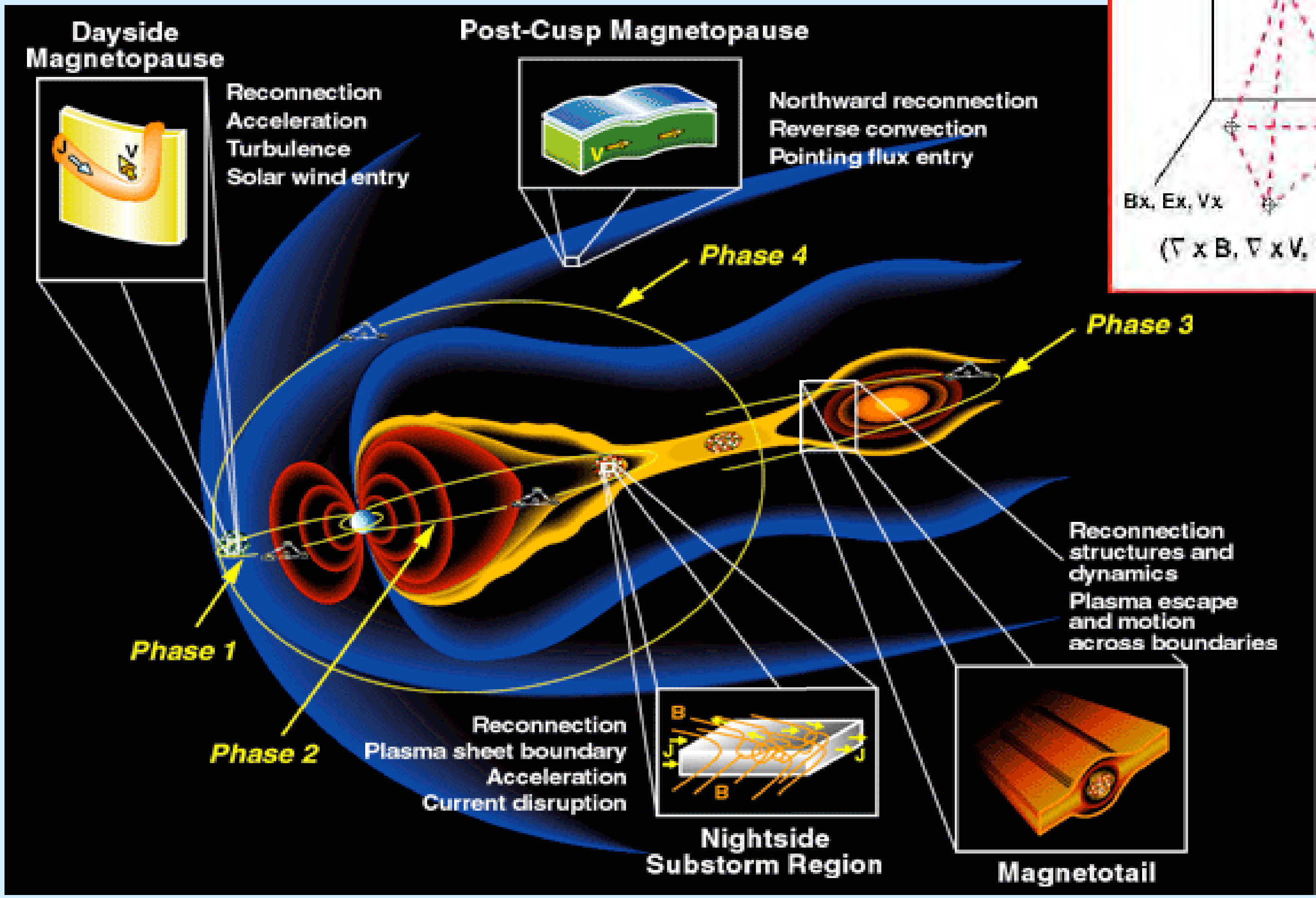


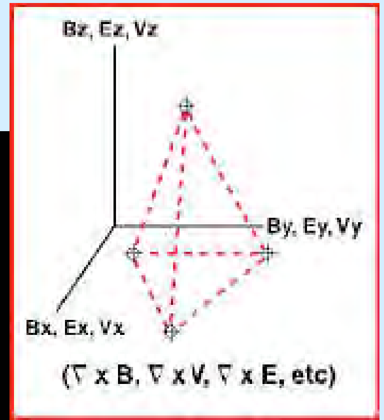


Fleet of 6 Spacecraft (4 IHS: 0.25 - 0.75 AU)
Status: Study (Launch: > ~ 2012)

Flight through the Corona at ~3 R_S
Status: Study Phase (Launch: ?)

MAGNETOSPHERIC MULTISCALE MISSION (MMS)





THE END