National Observatory of Athens (NOA)

INSTITUTE FOR ASTRONOMY, ASTROPHYSICS, SPACE APPLICATIONS & REMOTE SENSING
(formerly INSTITUTE OF ASTRONOMY & ASTROPHYSICS)
National Observatory of Athens

IAASARS

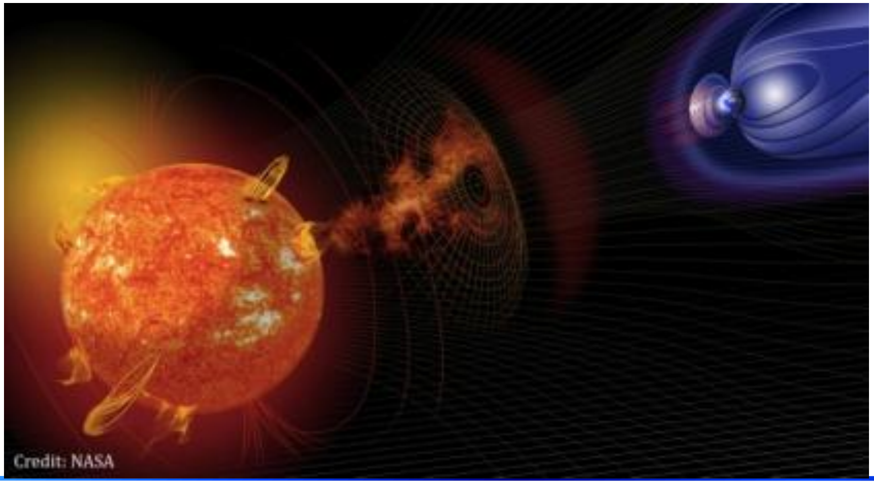
HESPERIA SUMMER SCHOOL

# Introduction to SPACE WEATHER

# The 'HESPERIA' project


**Olga E. Malandraki**

*IAASARS, National Observatory of Athens, Greece*


**'Understanding Solar Eruptions and Extreme Space Weather Events. The physics behind'**

'HESPERIA Summer School'

Kiel, Germany
29 Aug-2 Sept 2016

# The term '*Space Weather*' refers to

**variable conditions on the Sun, throughout space,
in the Earth's magnetic field and upper atmosphere
that can influence the performance and reliability of space-borne and ground-based technological systems and *endanger human life and health*.**

**Adverse conditions in the space environment can cause disruption of satellite operations, communications, navigation and electric power distribution grids, leading to a variety of socioeconomic losses and impacts on our society**

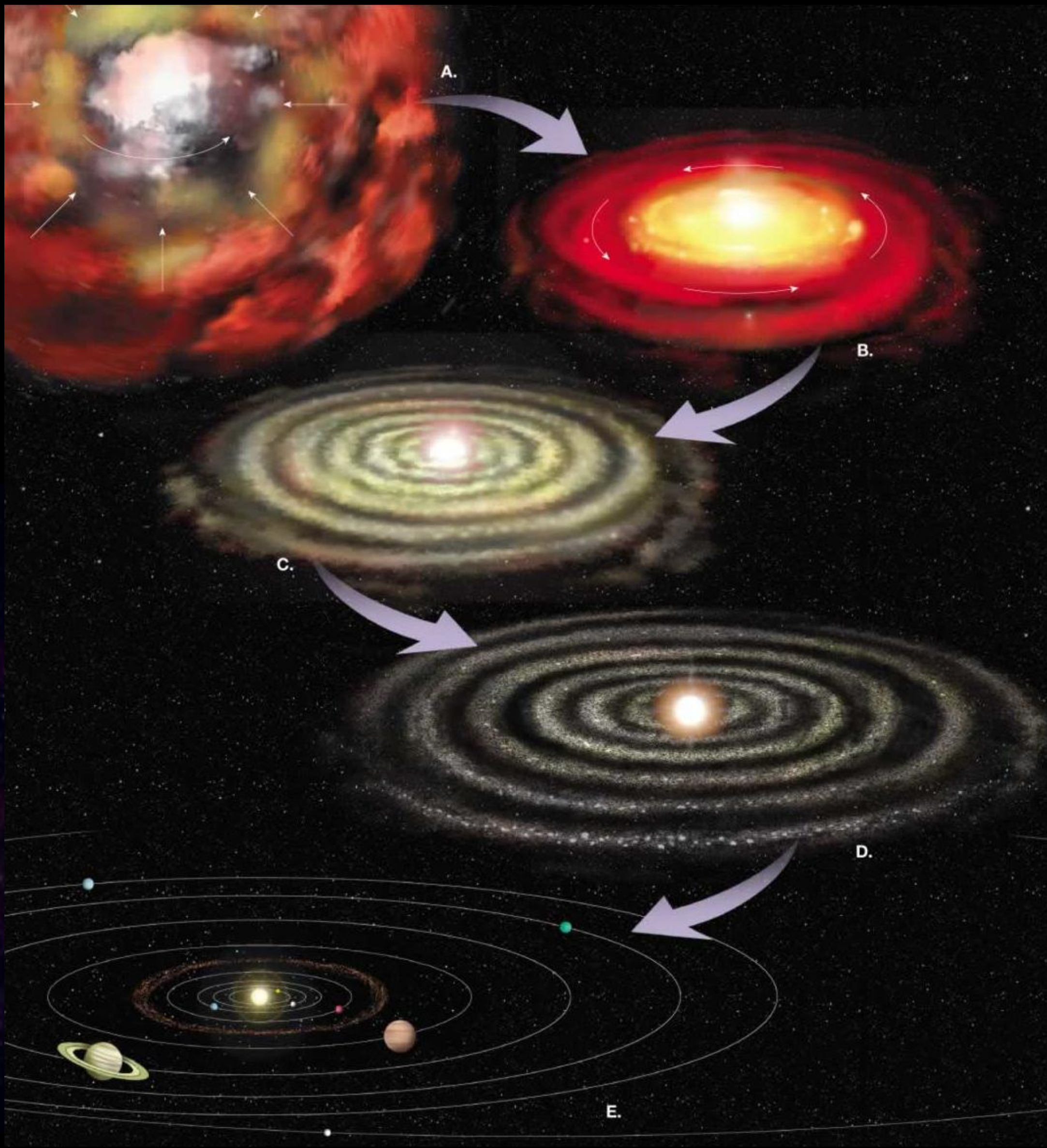
UOC\revosore.mov


*National Space Weather Program Council, Washington, DC, June 2010*

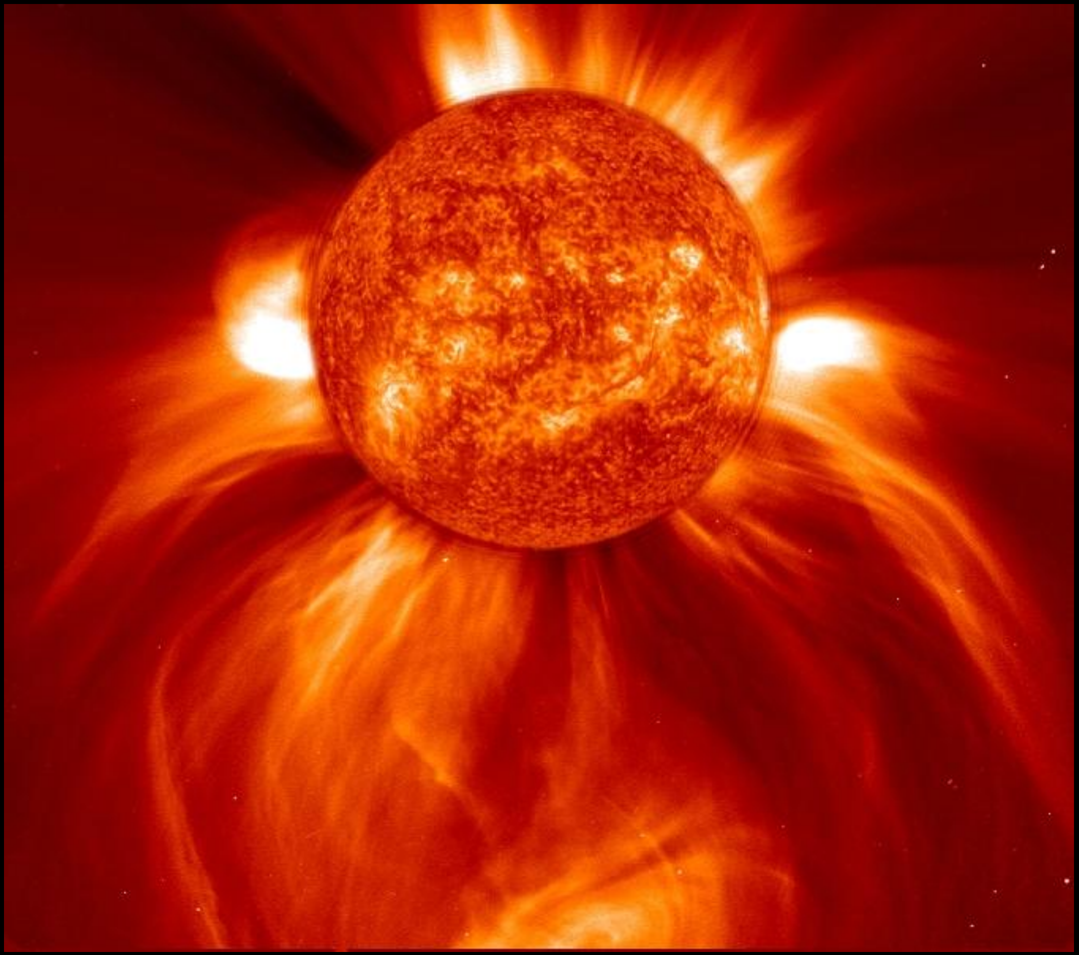
# Space Weather
# can harm humans in space


# *THE SCIENTIFIC UNDEPINNINGS OF SPACE WEATHER*

OUR SUN IS BORN
~ 5 BILLION YEARS AGO



# OUR SUN:
# A STAR THAT IS CONSTANTLY CHANGING



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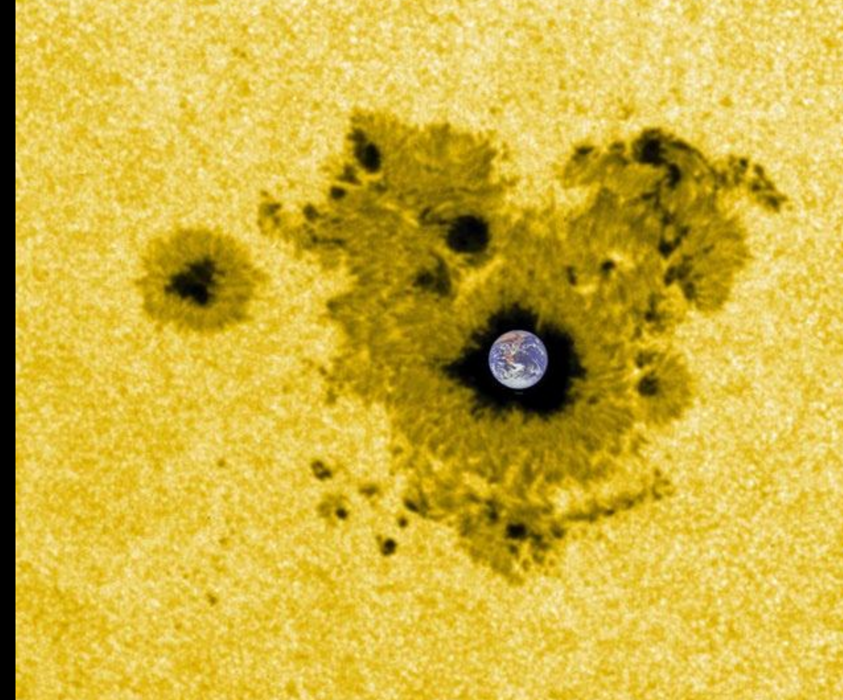
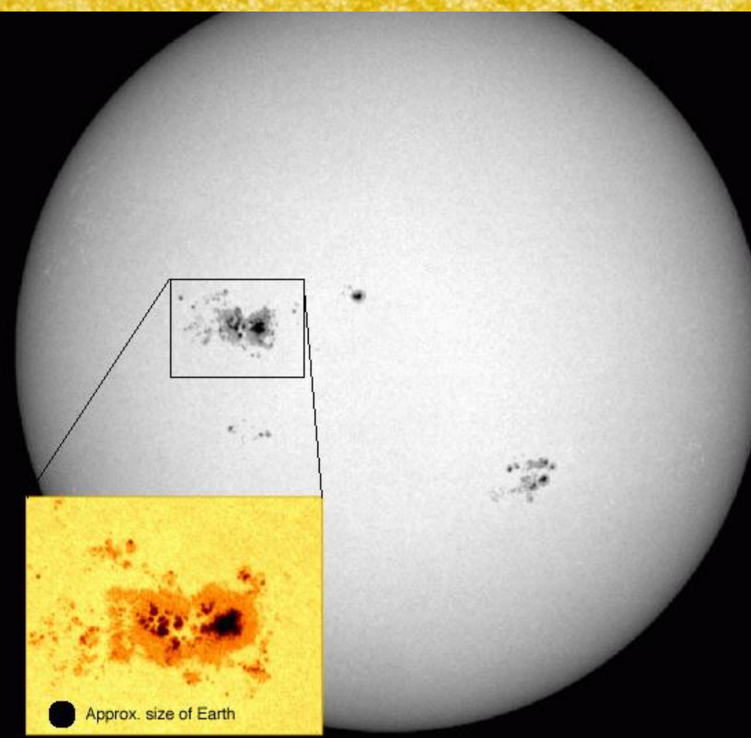
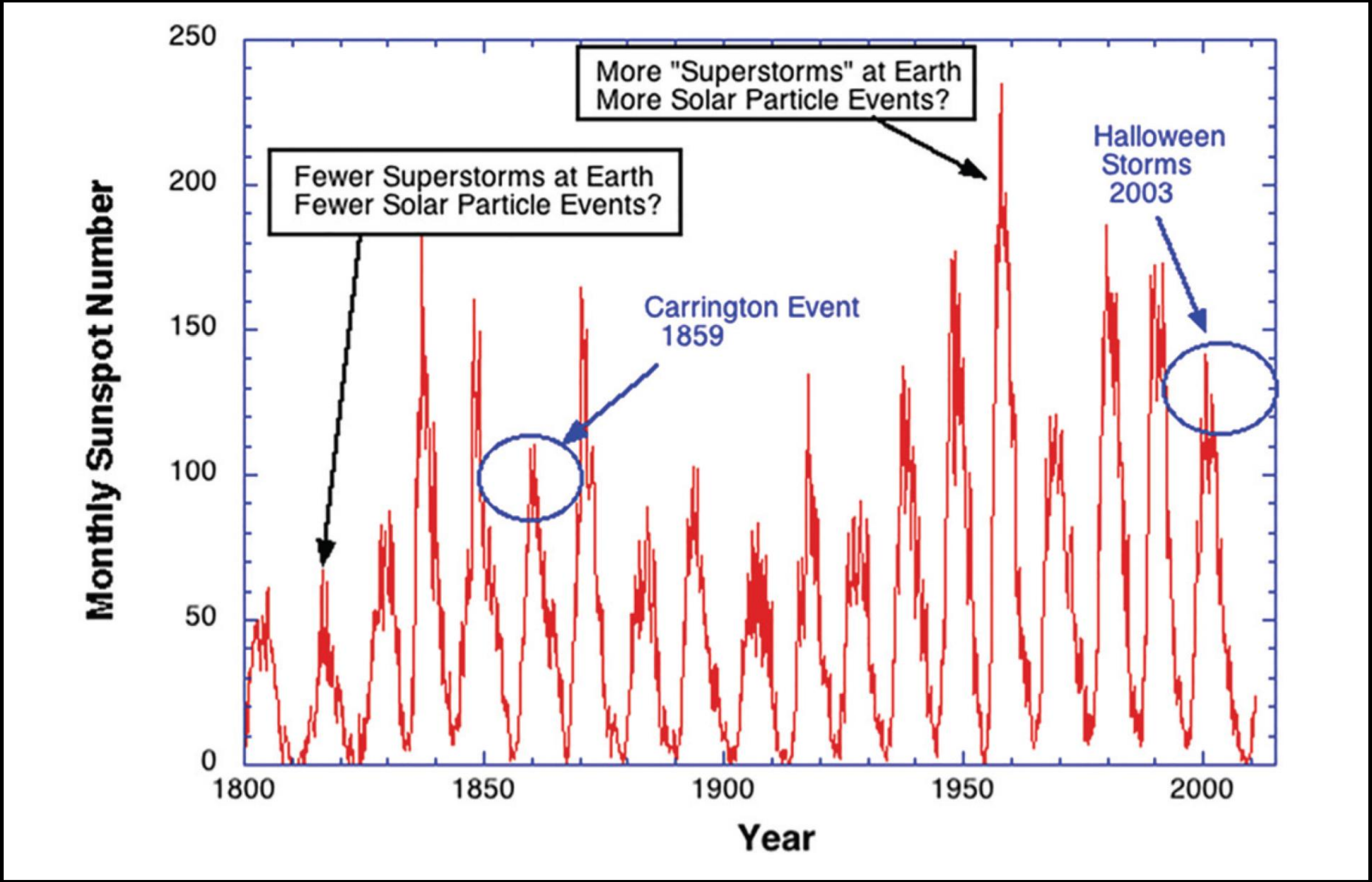
# SOLAR SUNSPOTS


Play Spinning Sun_1 Movie





# SOLAR SUNSPOT NUMBER (SNN)




Baker, 2012

# Definition of a plasma

- An ionised gas consisting of positively and negatively charged particles with approximately equal charge densities

- Deviations from charge neutrality are small, as soon as charge imbalance develops, large **E** are produced to restore charge neutrality

# Characteristic parameters of a plasma

- Number density $n_s$ for each species

- Temperature of particles of type s is directly proportional to their average random kinetic energy

$$\frac{1}{2} m_s v_s^2 = \frac{3}{2} k_B T_s$$

- Debye length $\lambda_D$: gives the spatial scale over which particles in a plasma exert electrostatic forces on each other,

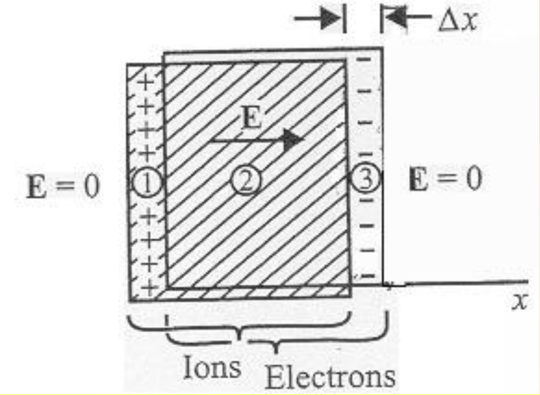
$$\lambda_D << L$$

- Number $N_D$ of particles inside a Debye cube

$$N_D = n_e \lambda_D^3$$

$$N_D >> 1$$ plasma approximation

- Electron Plasma Frequency




$$\omega_{pe}^2 = \frac{n_o e^2}{\varepsilon_o m_e}$$

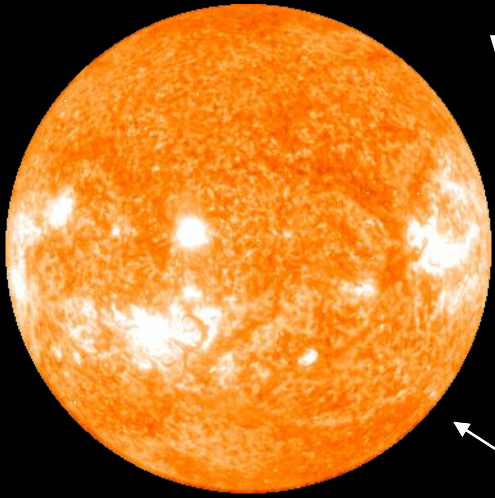
- Cyclotron frequency

$$\omega_c = \frac{|q|B}{m}$$

# Plasmas in Space

- Ionosphere
- Magnetosphere
- Heliosphere – Voyagers

# What is an Astronomical Unit (AU)??

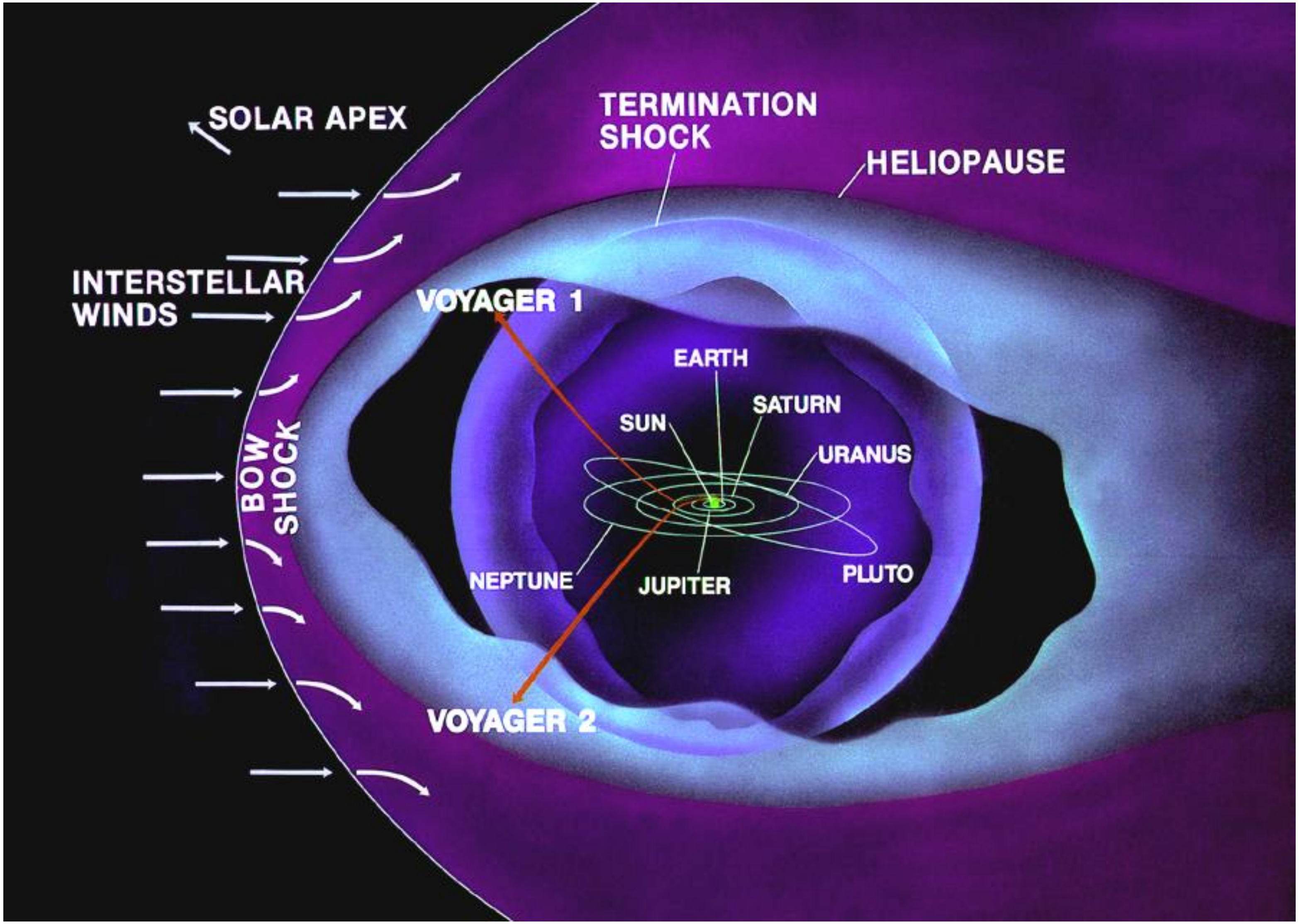


Distance between Sun and Earth

About 150 million km

Light needs 8 minutes and 20 sec to reach the Earth.
With an airplane you would need 17 year to reach the Sun!
How old would you be? And how old when you got back?
If you went by car, 100 km/h, you would need 170 years!
With a horse, 13 km/h, it would take you 1317 years and
if you like walking you would need 3424 years!!!

# The Voyager Odyssey



# Single particle motions

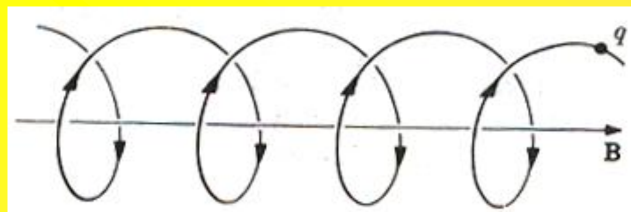
- Motion in a static uniform magnetic field

$$m\frac{d\mathbf{v}}{dt} = q(\mathbf{v}\times\mathbf{B})$$ Lorentz force

$$m\mathbf{v}\cdot\frac{d\mathbf{v}}{dt} = \frac{d}{dt}\left(\frac{1}{2}mv^2\right) = q\mathbf{v}\cdot(\mathbf{v}\times\mathbf{B}) = 0$$

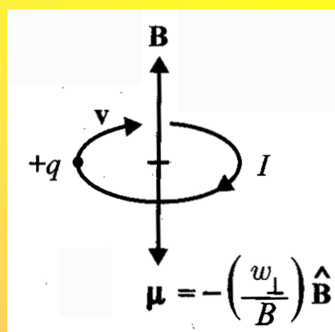
$$\mathbf{v} = \mathbf{v}_{||} + \mathbf{v}_{\perp}$$

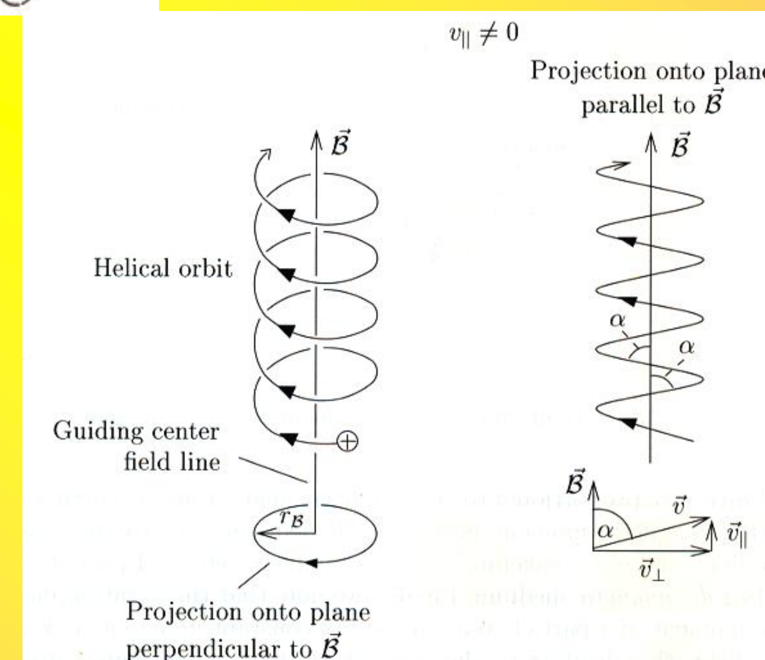
$$r_c = \frac{mv_{\perp}}{|q|B} \qquad \omega_c = \frac{|q|B}{m}$$




μ=I A

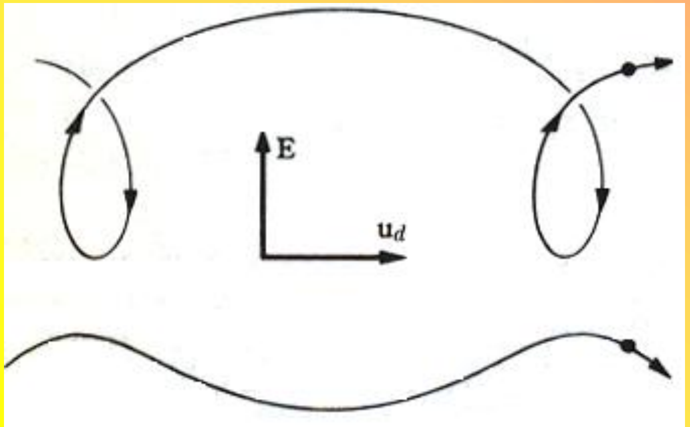
$$\mu = \frac{mv_{\perp}^2}{2B} = \frac{w_{\perp}}{B}$$



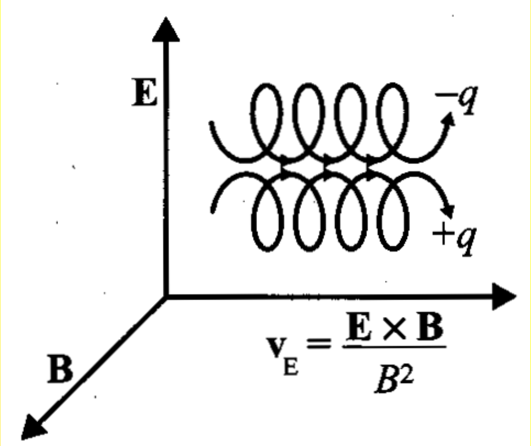



- Motion in perpendicular electric and magnetic fields

$$\mathbf{u_d} = \frac{\mathbf{E}\times\mathbf{B}}{B^2}$$



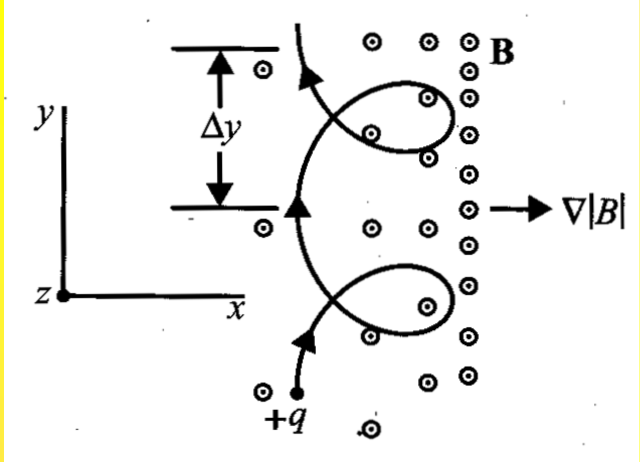

Since electrons and protons drift into the same direction,
NO CURRENT RESULTS



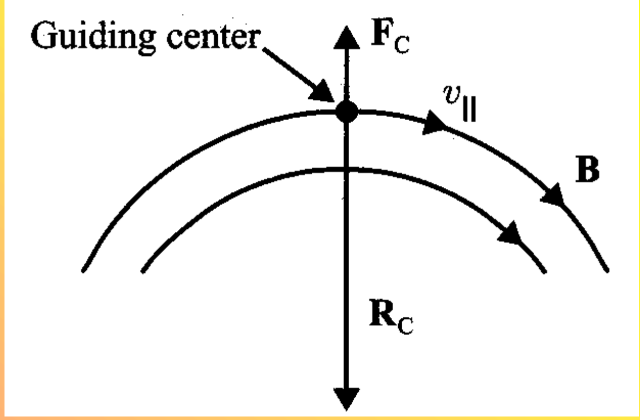
- Motion of particles in inhomogeneous magnetic fields



Both Charge Dependent and can lead to currents in the plasma

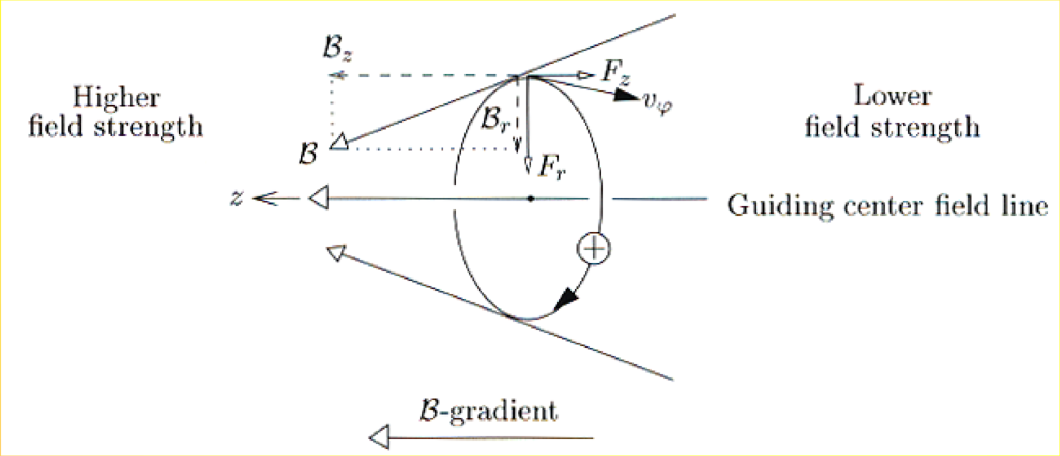



$$\mathbf{v}_G = \frac{w_\perp}{qB}\left[\frac{\hat{\mathbf{B}} \times \nabla \mathbf{B}}{B}\right]$$



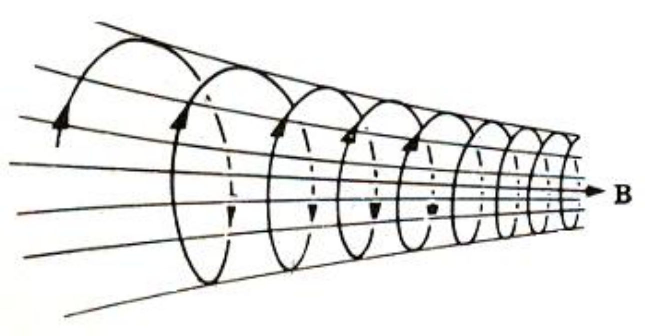

$$\mathbf{v}_C = \frac{2w_\parallel}{qB}\left[\frac{\hat{\mathbf{B}} \times \mathbf{R_C}}{R_C}\right]$$

# • Motion in a magnetic mirror field

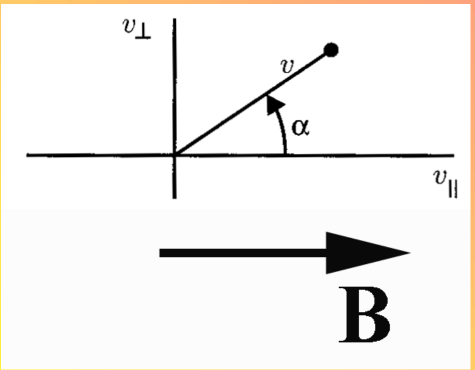



$$\frac{1}{2}mv^2 = \frac{1}{2}m(v_{\parallel}^2 + v_{\perp}^2) = const$$

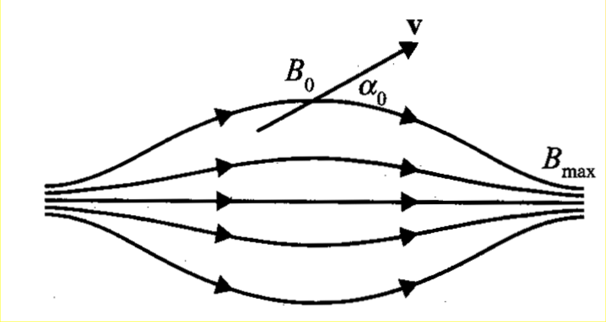
$$\frac{1}{2}mv^2 = \frac{1}{2}mv_{\parallel}^2 + \mu B$$



$$\mu = \frac{mv_{\perp 1}^2}{2B_1} = \frac{mv_{\perp 2}^2}{2B_2}$$

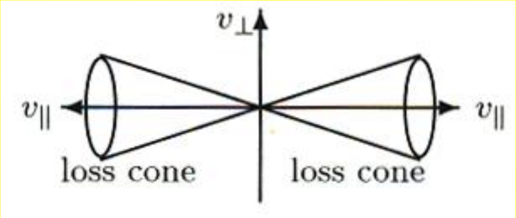



$$\frac{v_1^2 \sin^2\alpha_1}{B_1} = \frac{v_2^2 \sin^2\alpha_2}{B_2}$$

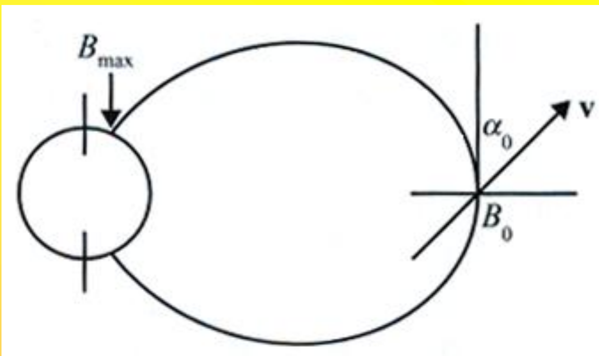


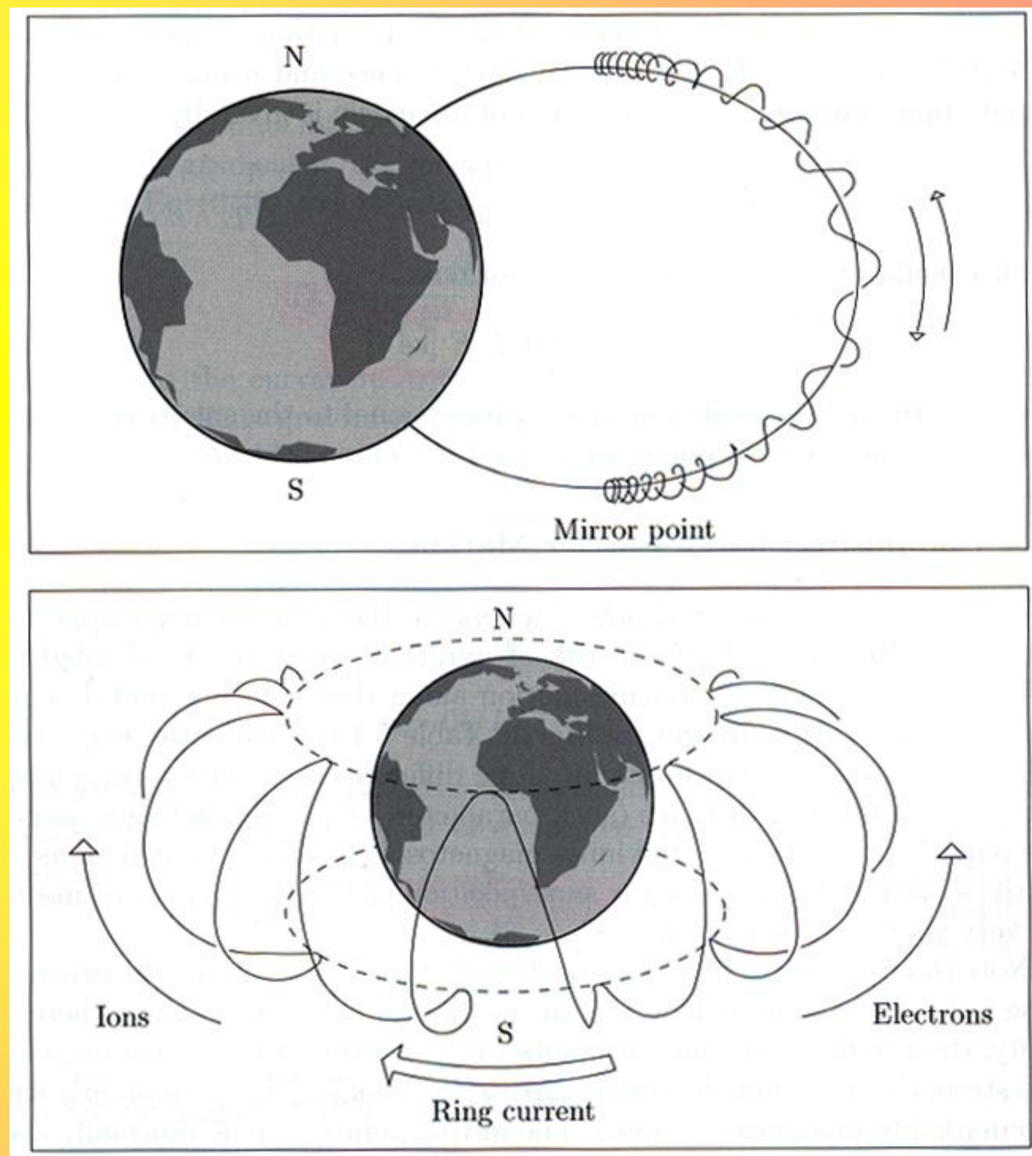

$$\frac{2\mu}{mv^2} = \frac{\sin^2\alpha_1}{B_1} = \frac{\sin^2\alpha_2}{B_2}$$

$$\sin^2\alpha_o = \frac{B_o}{Bmax}$$



# Charged particles trapped in the radiation belts – Ring Current



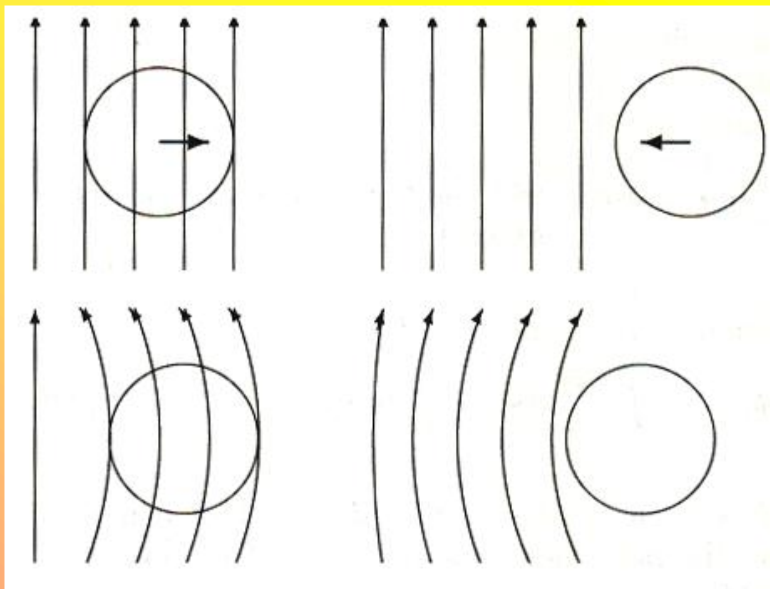
James Van Allen kissing goodbye Explorer 4

# Magnetohydrodynamics (MHD)

$$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\mathbf{v} \times \mathbf{B}) + \frac{1}{\mu_O \sigma} \nabla^2 \mathbf{B}$$

$$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\mathbf{v} \times \mathbf{B})$$

frozen-in frozen-out

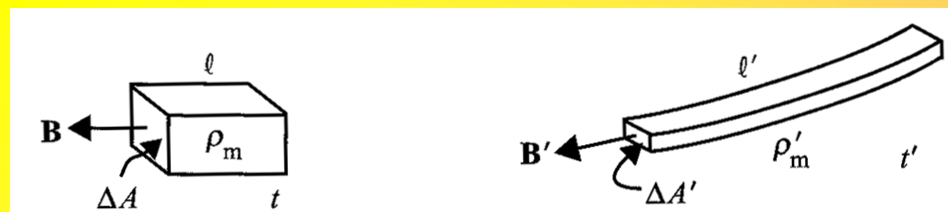


Neutron star

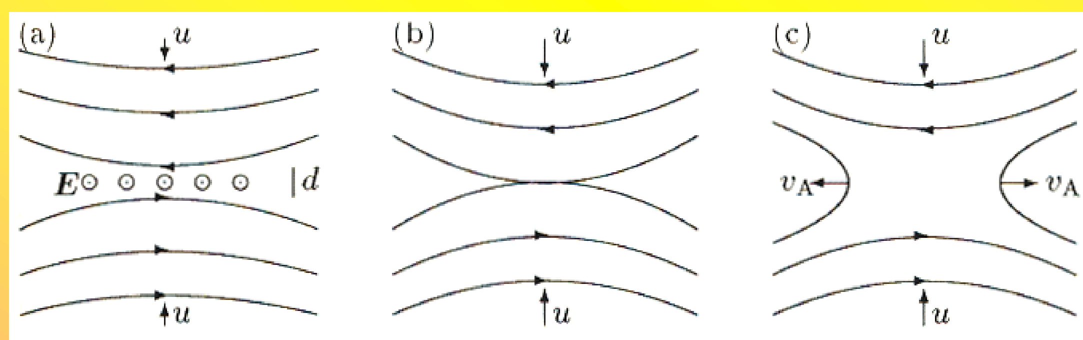
$$B' = B\left(\frac{\rho'_m}{\rho_m}\right)\left(\frac{\ell'}{\ell}\right)$$

$$\rho'_m \sim 1/\ell'^3$$

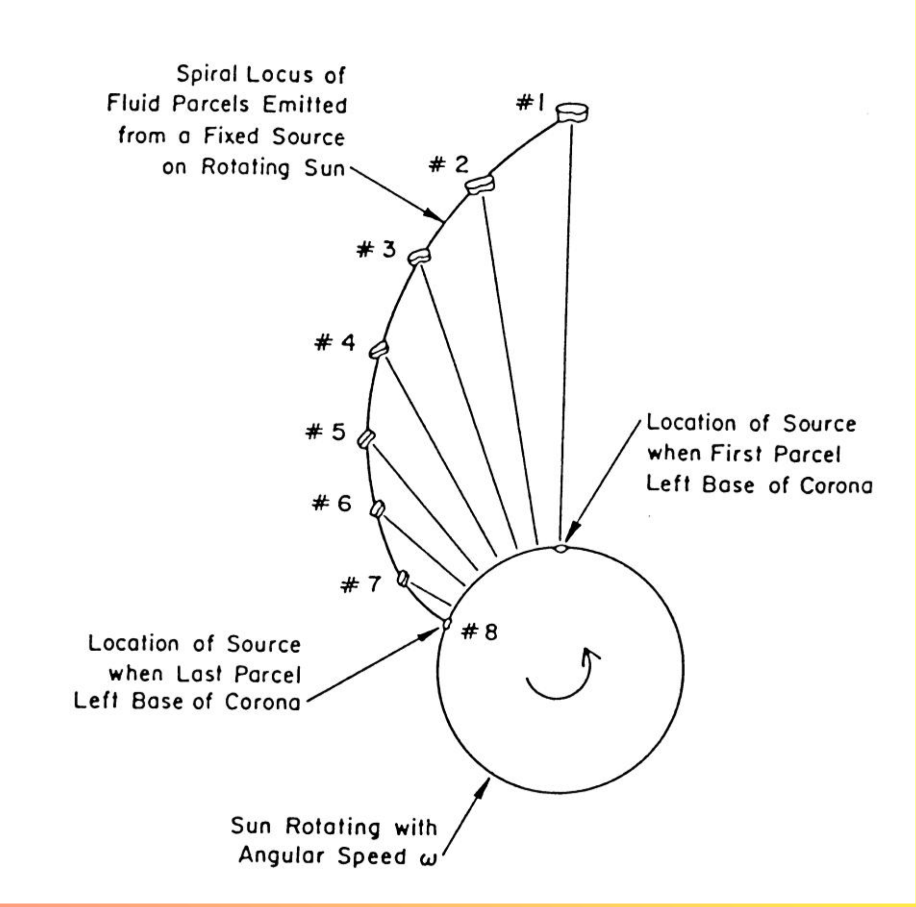
$$B \sim \left(\frac{\ell}{\ell'}\right)^2$$

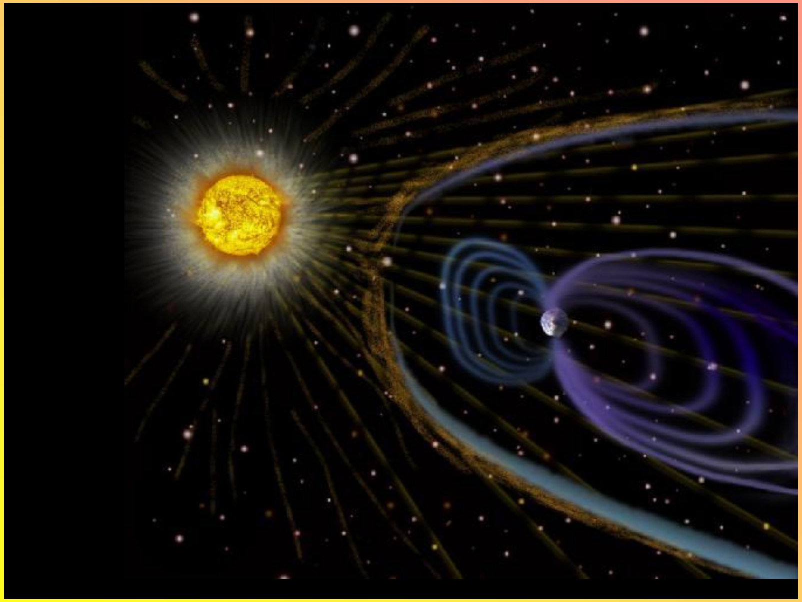


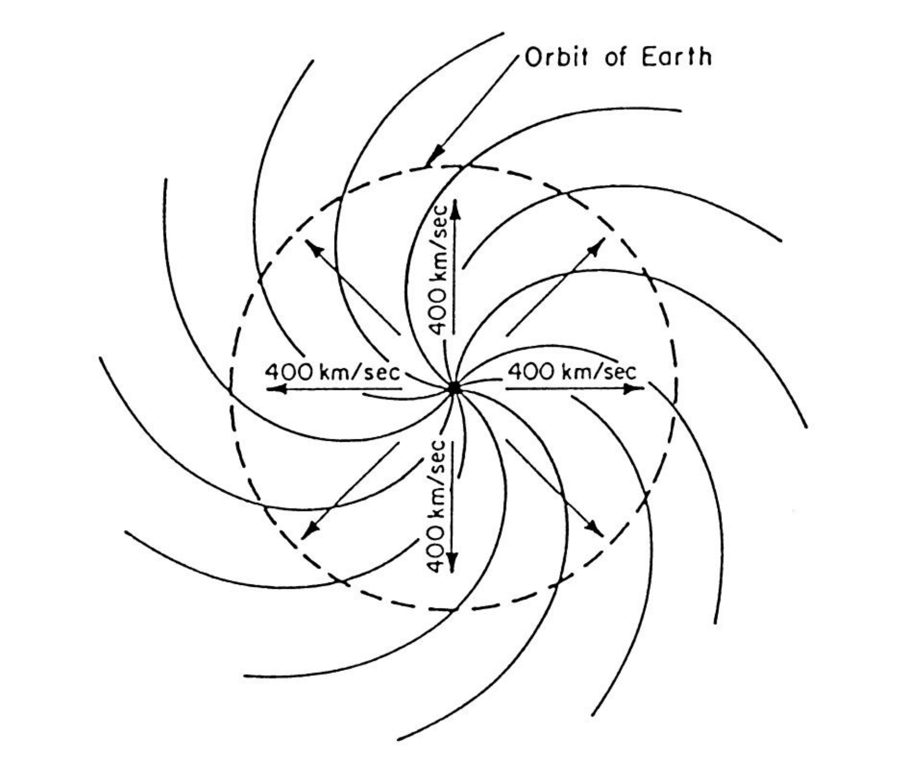

$$\frac{\partial \mathbf{B}}{\partial t} = \frac{1}{\mu_O \sigma} \nabla^2 \mathbf{B} \qquad T = \mu_O \sigma L^2$$



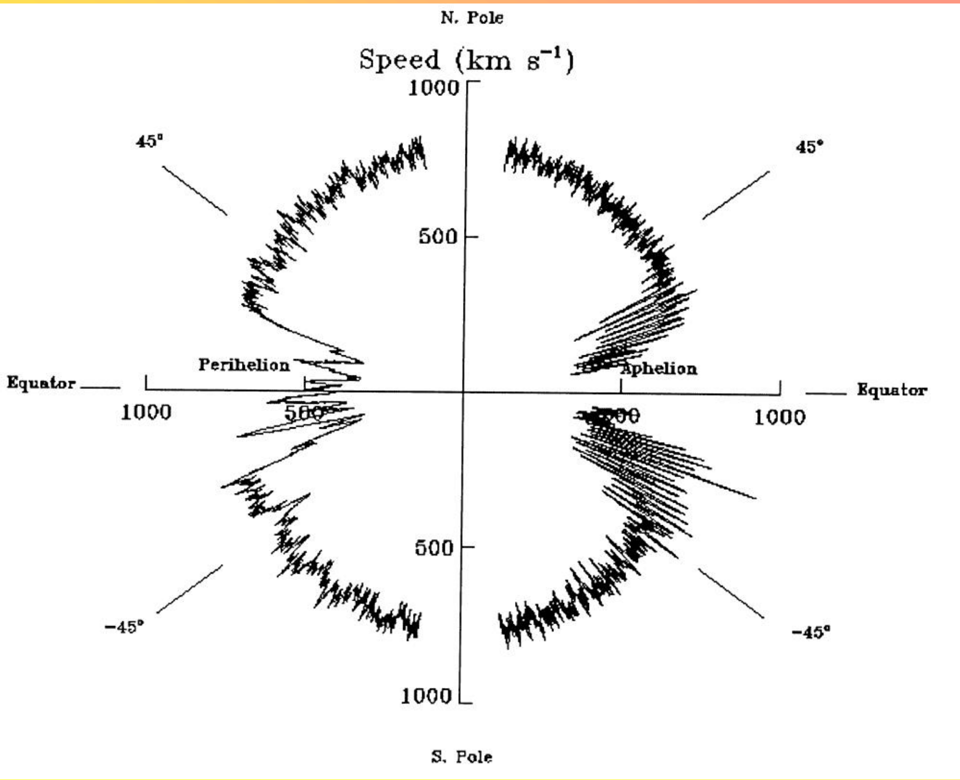
# The Solar Wind

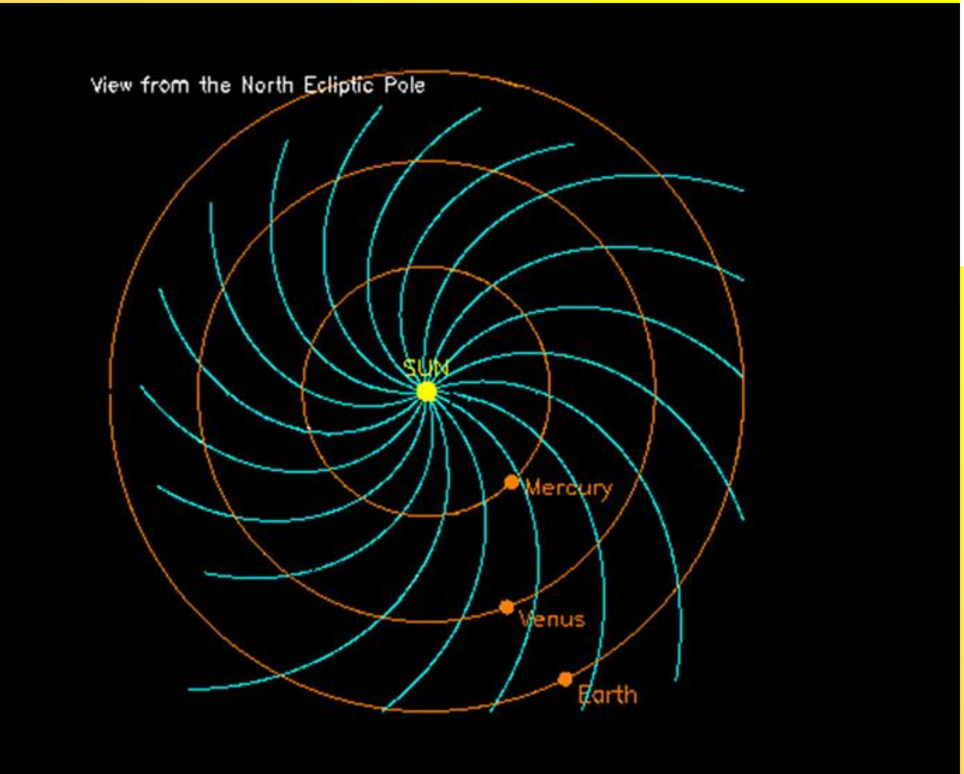


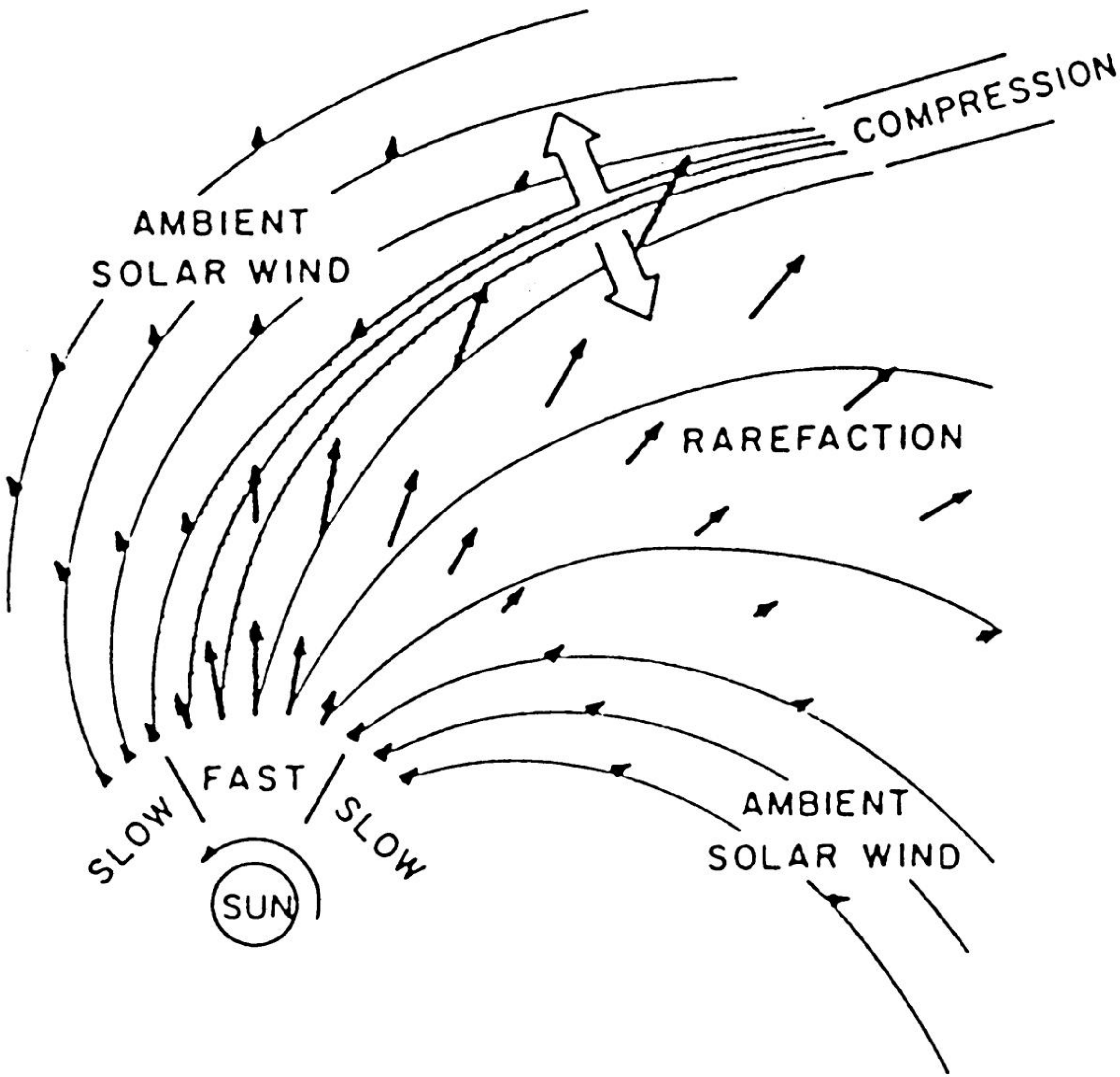


# The Solar Wind - cntd



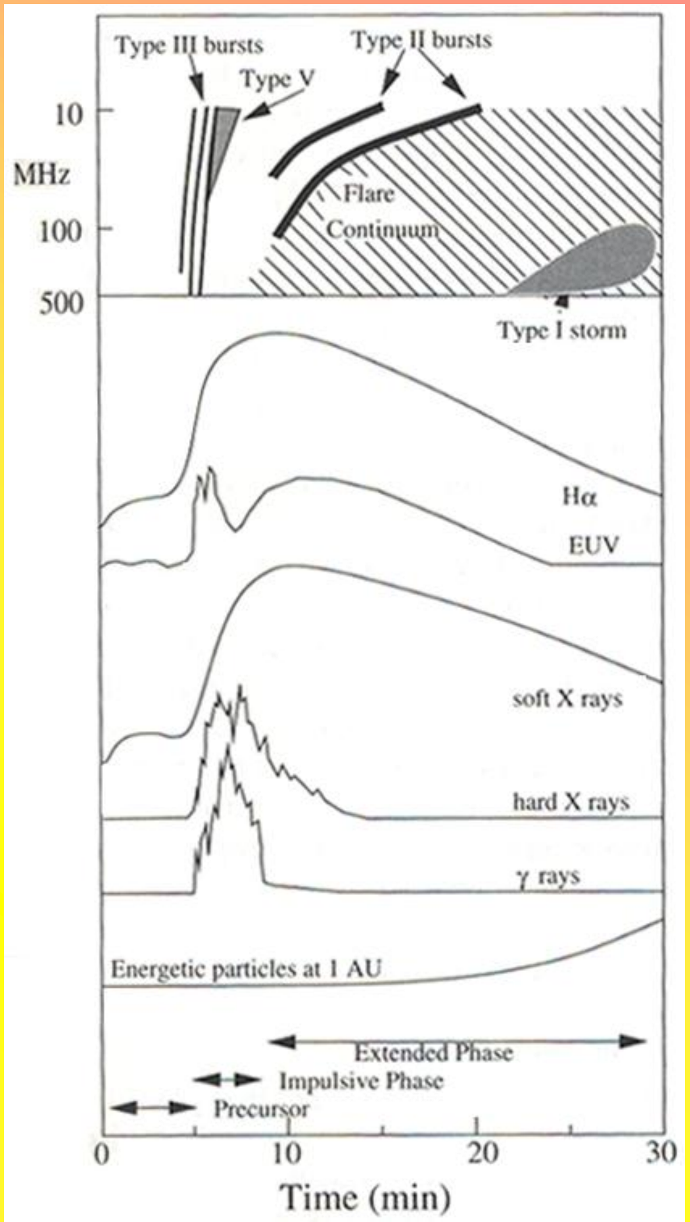
# Corotating Interaction Region - CIR



# Solar Eruptive Events

- **Solar Flares**

Outbursts in electromagnetic radiation covering an immense wavelength (from radio waves to Gamma-rays)



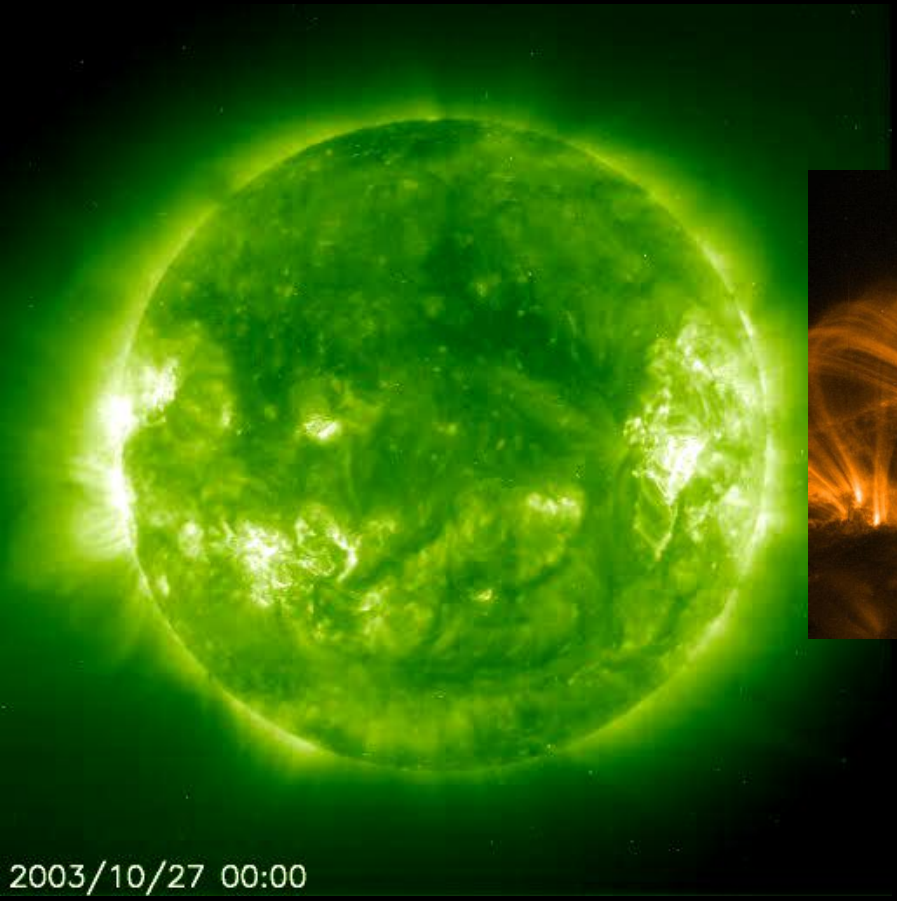

- **Coronal Mass Ejections - CMEs**

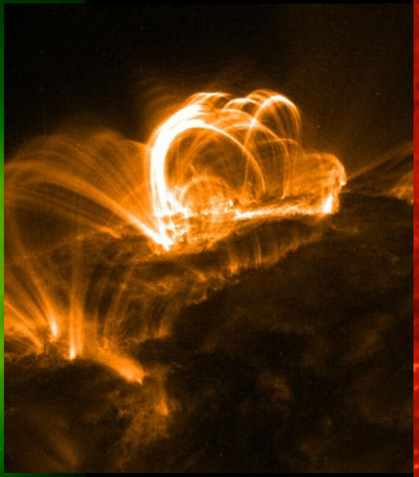
Gigantic clouds of ionized gas ejected into interplanetary space

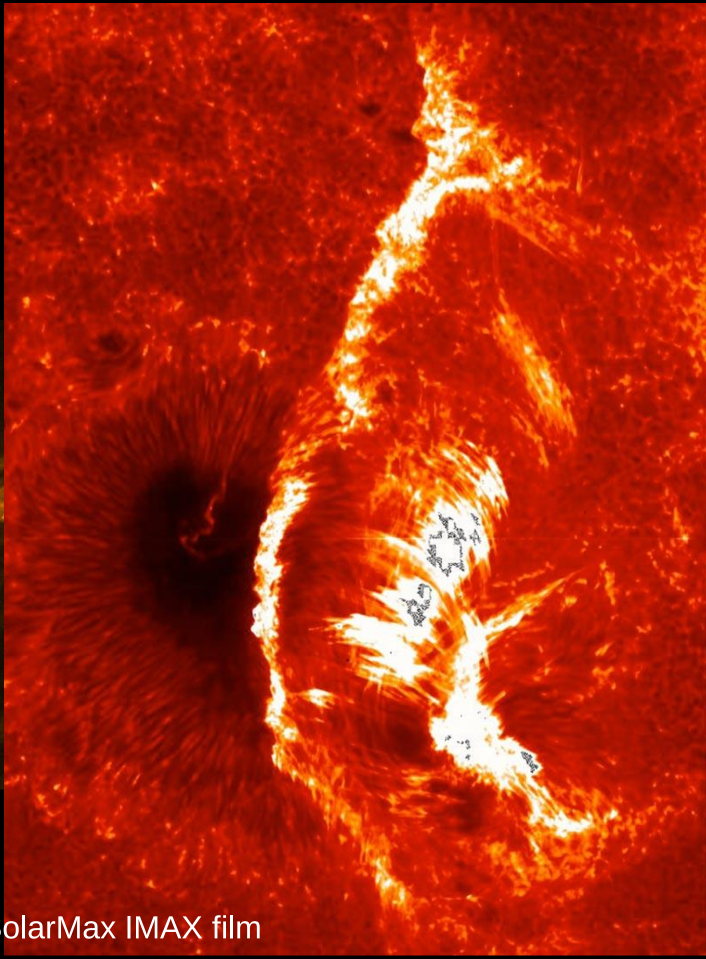
- **Solar Energetic Particles - SEPs**

Accelerated to near-relativistic energies during major solar events-can severely endanger traveling astronauts

# SOLAR ERUPTIONS
# 1) Solar flares



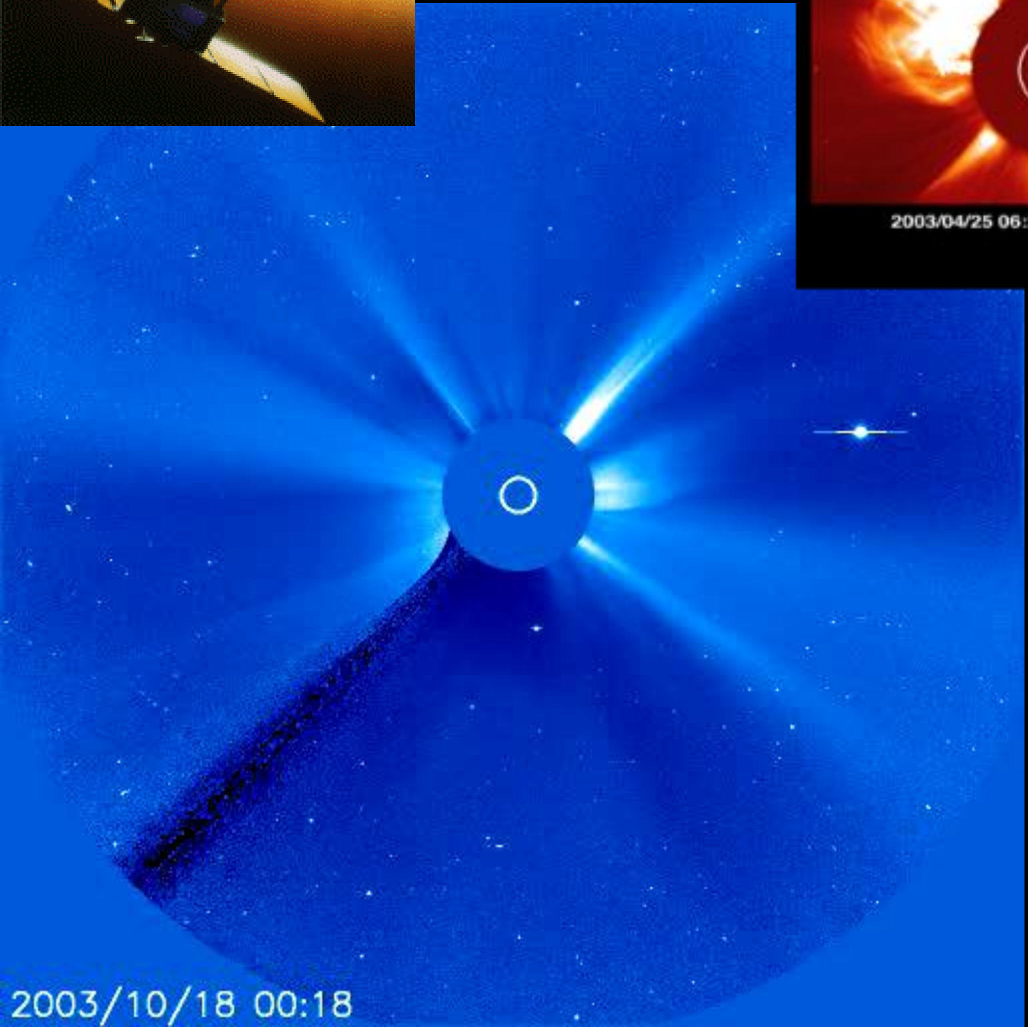


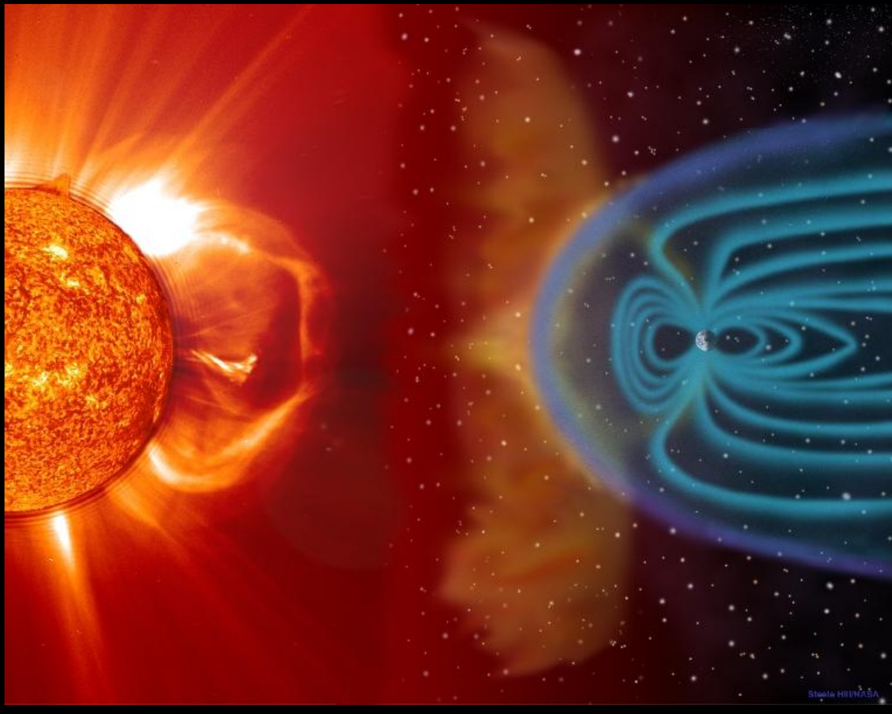
Video credit: SolarMax IMAX film

[978-1-4614-0570-2\sun-earth-presentation\Loops.mov]

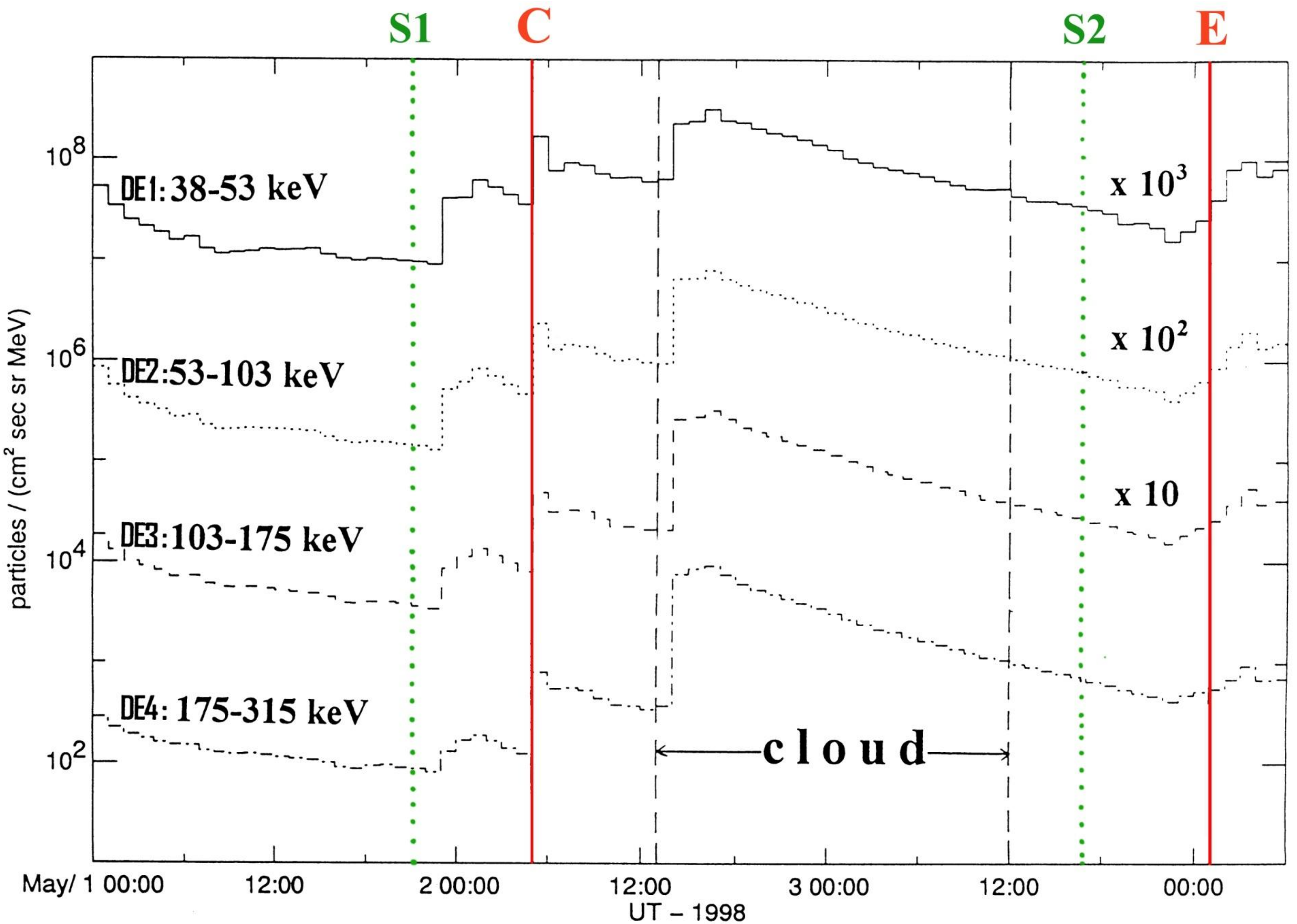
# 2) Coronal Mass Ejections (CMEs)

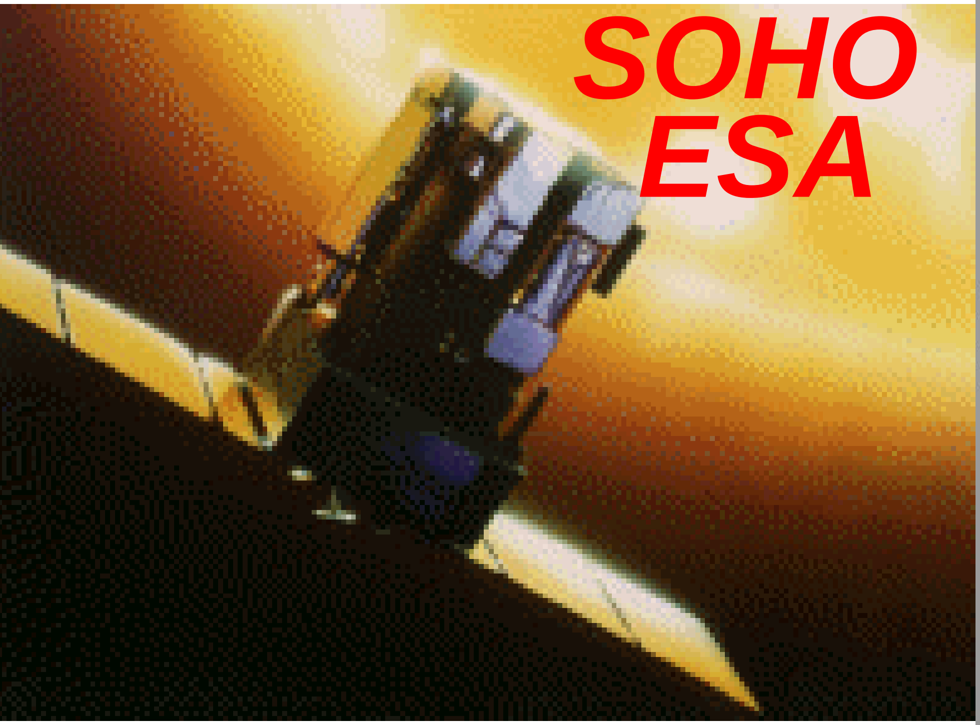




# Interplanetary CME

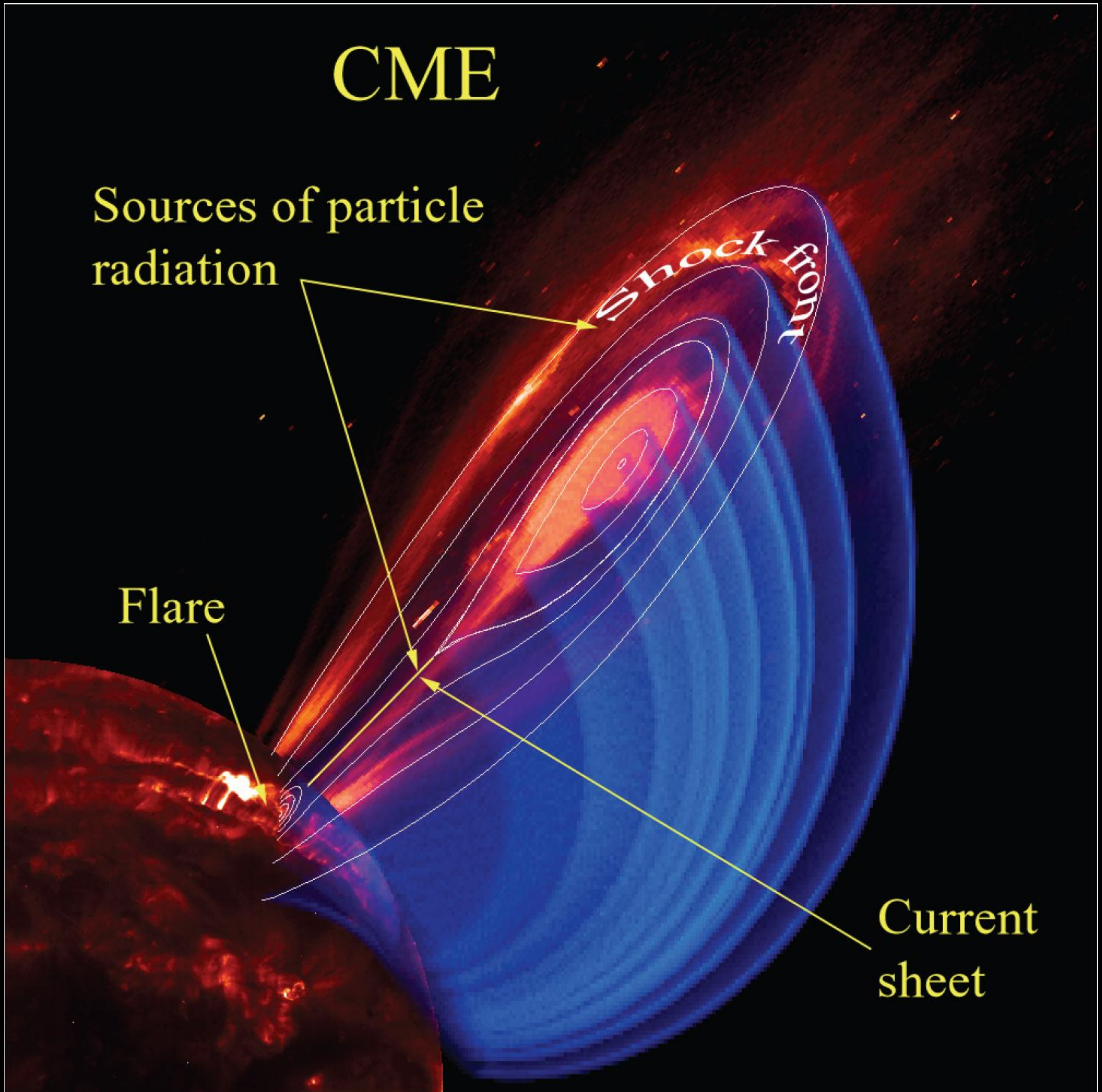




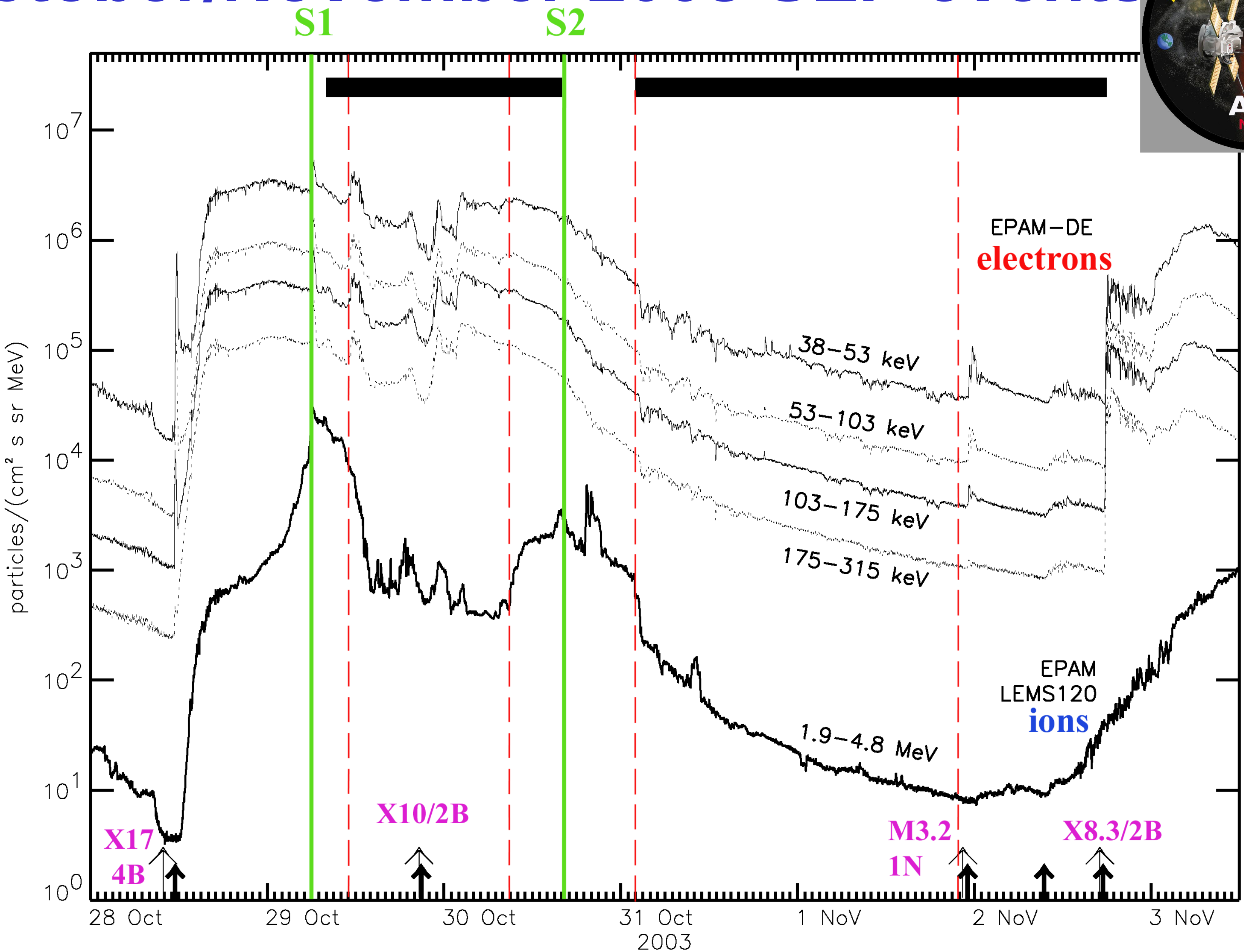


LAGRANG.MOV`

# 3) Solar Energetic Particles, (SEPs)

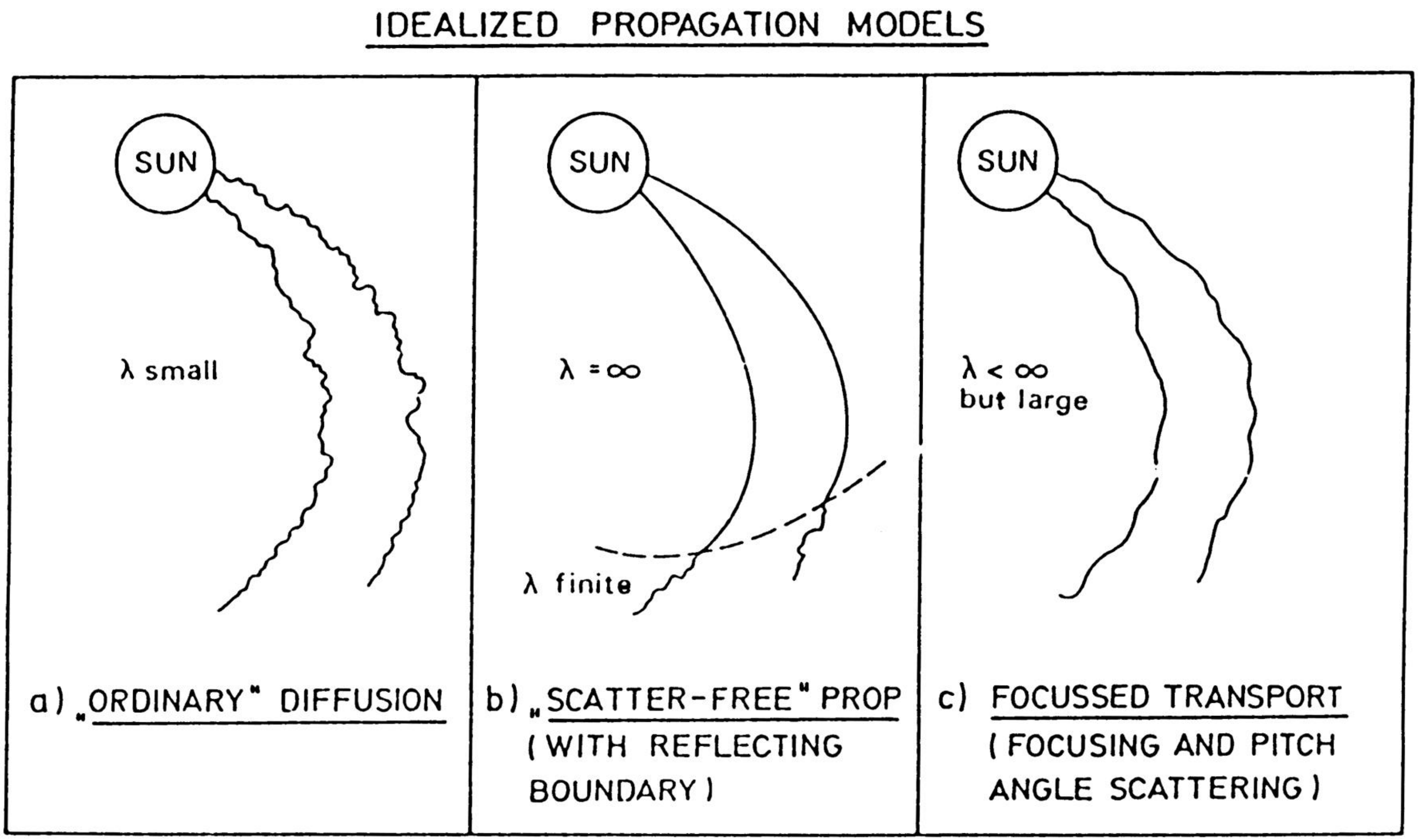


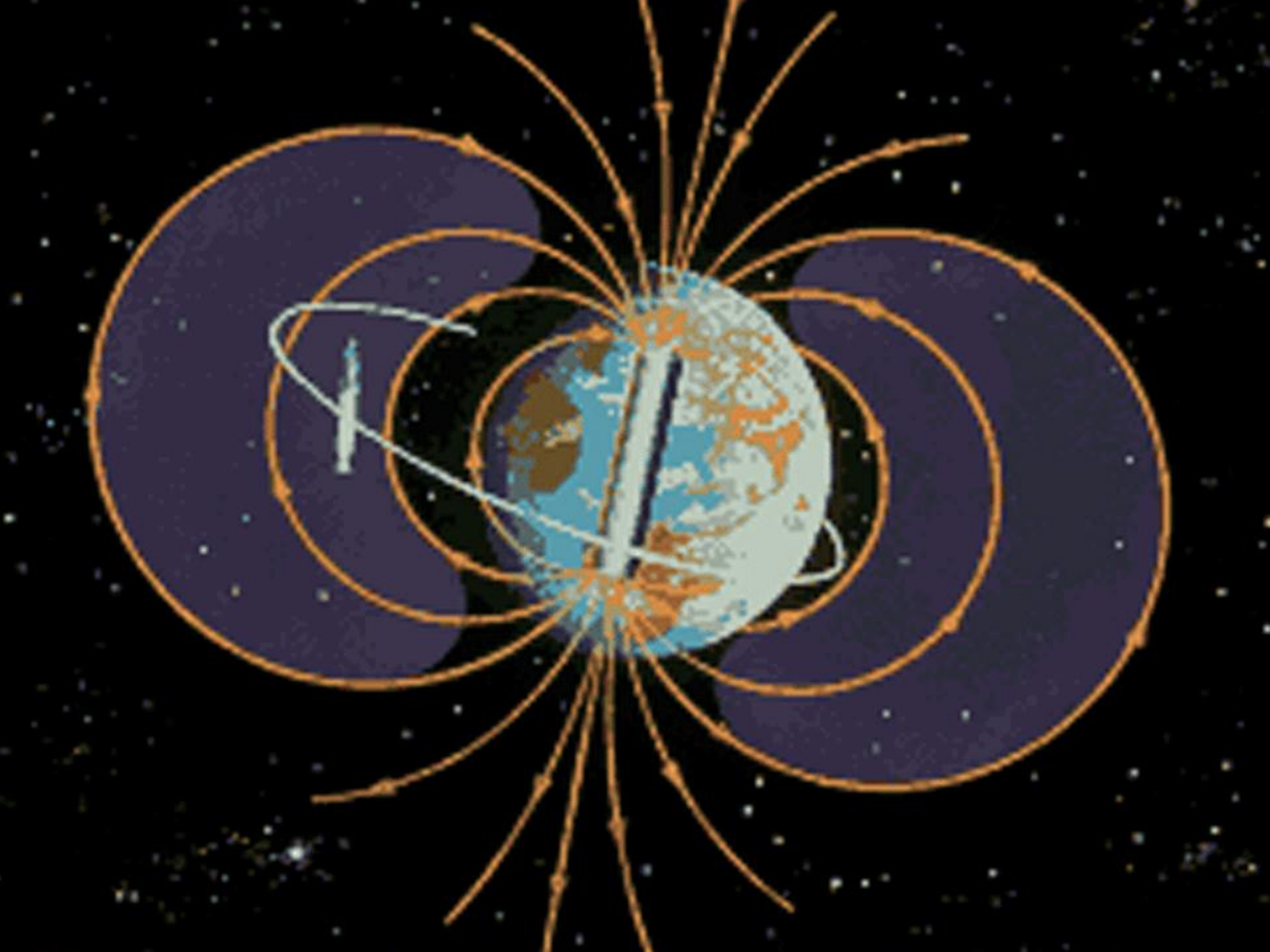
# October/November 2003 SEP events

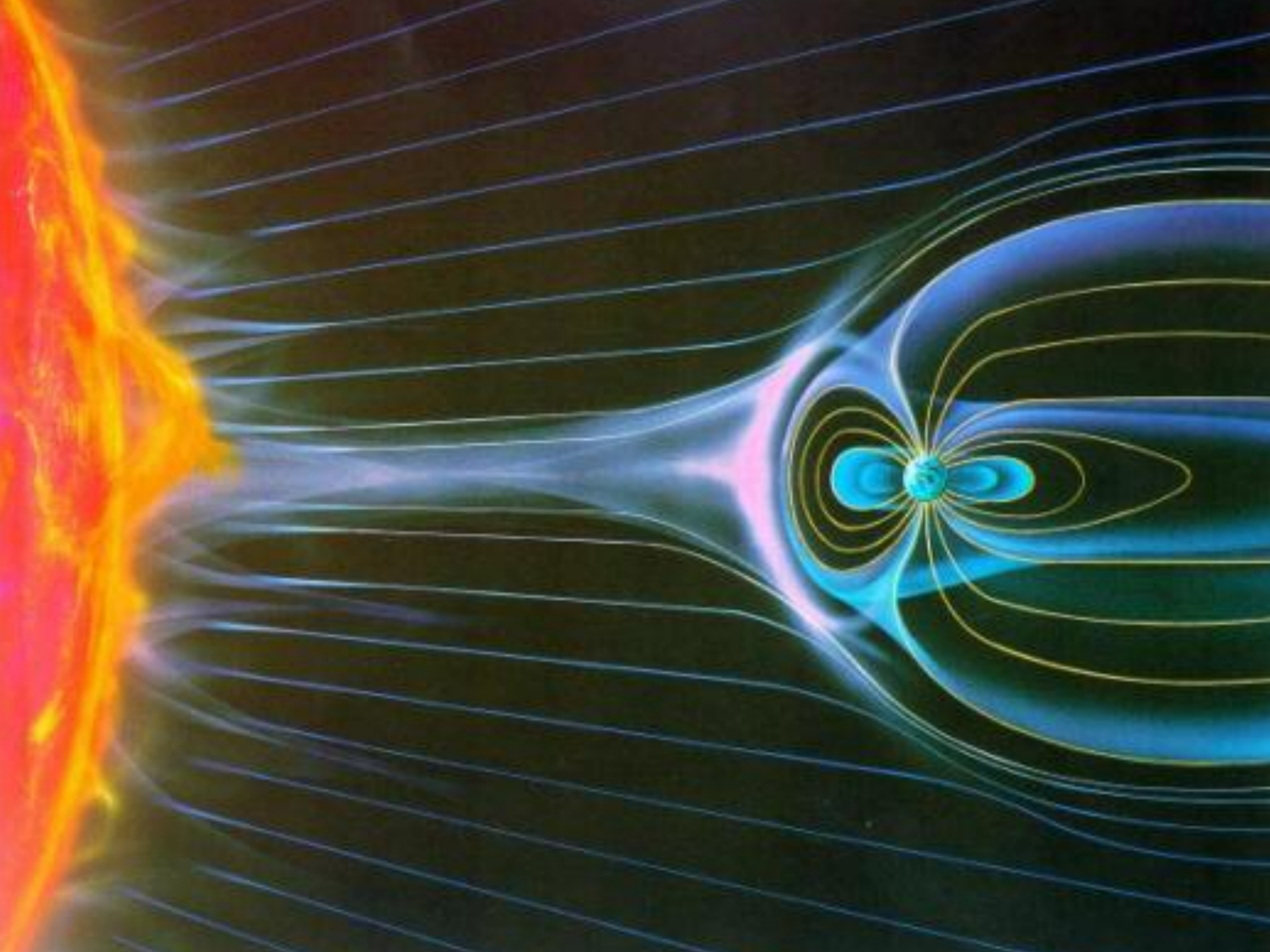


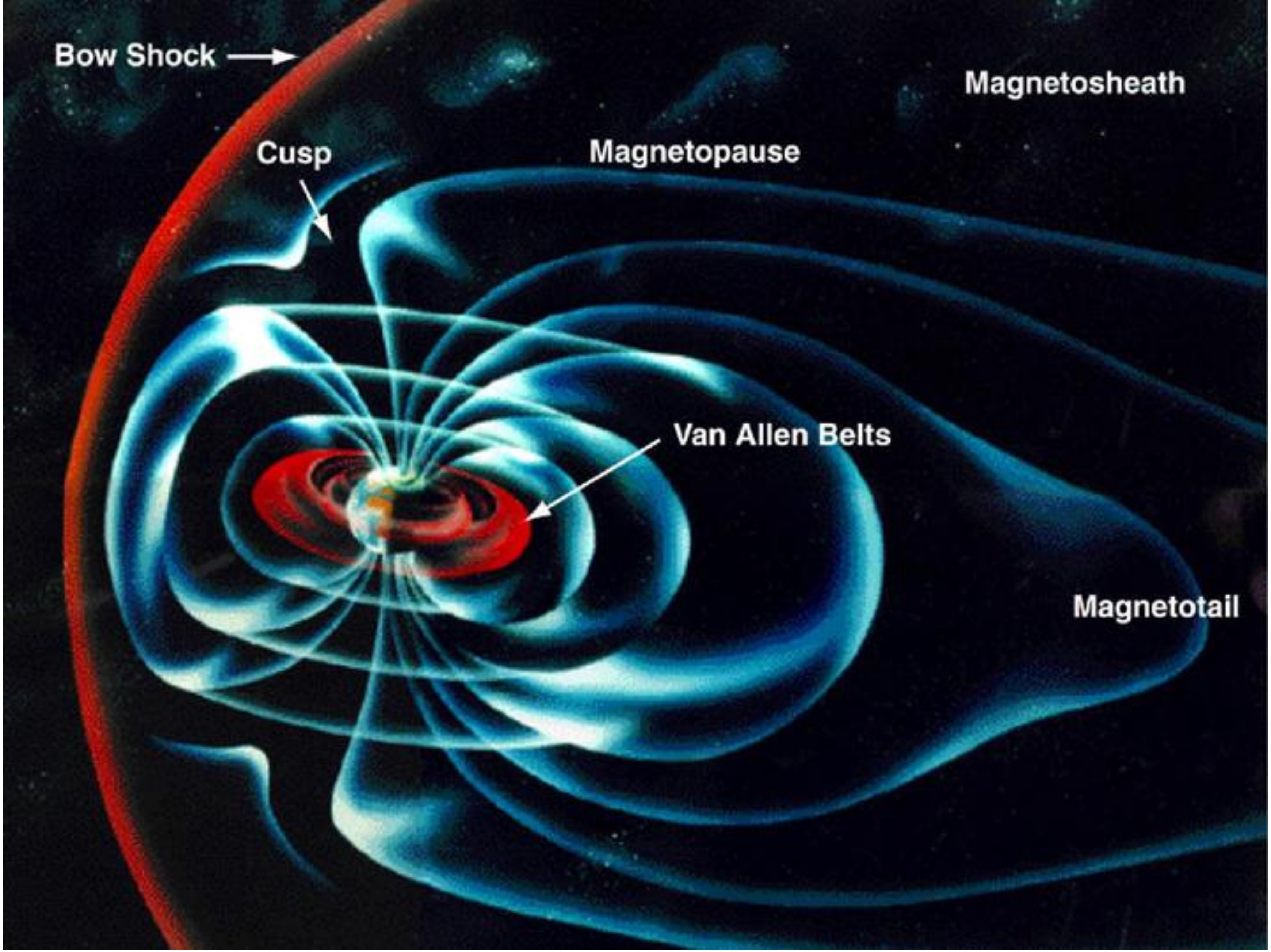

Malandraki et al., J. Geophys. Res, 2005

# SEP propagation







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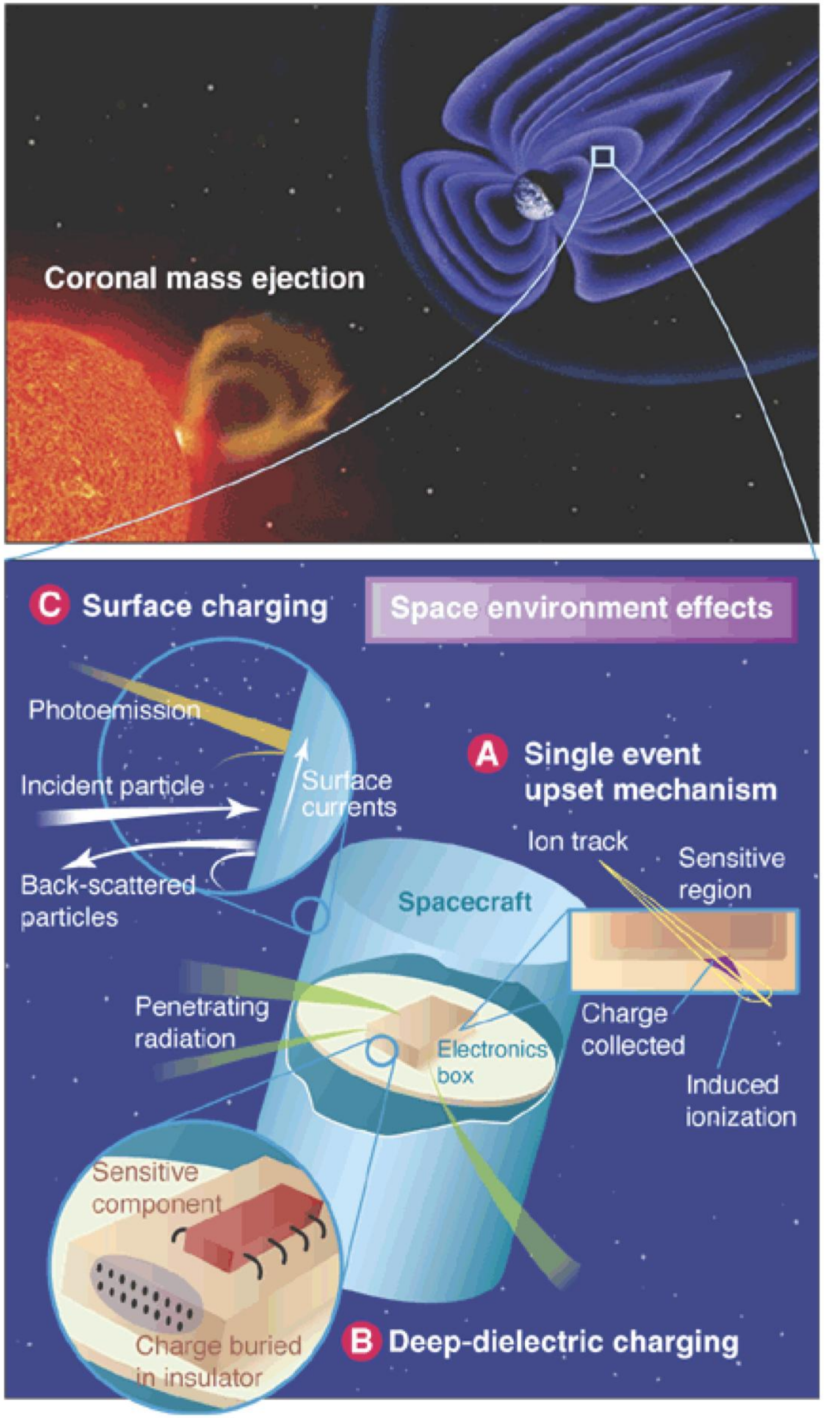
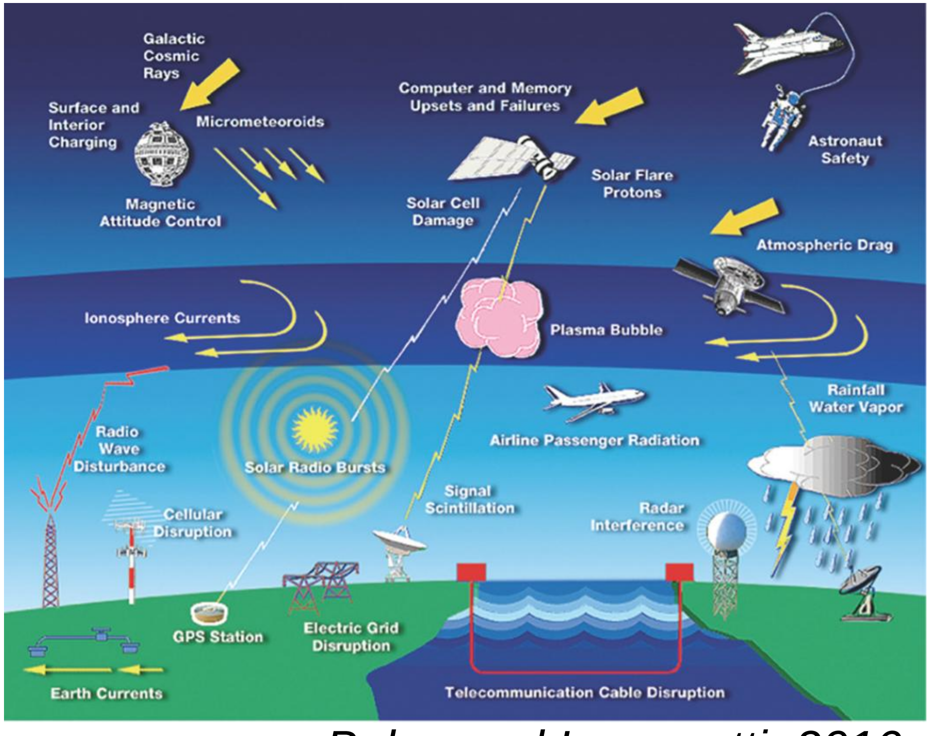
Space\film5.mov

# SPACE WEATHER IMPACT AND EFFECTS

## *Near-Earth environments*

***'Space Radiation Hazards and the Vision for Space Exploration:*** *Report of a Workshop, National Research Council, 2006*

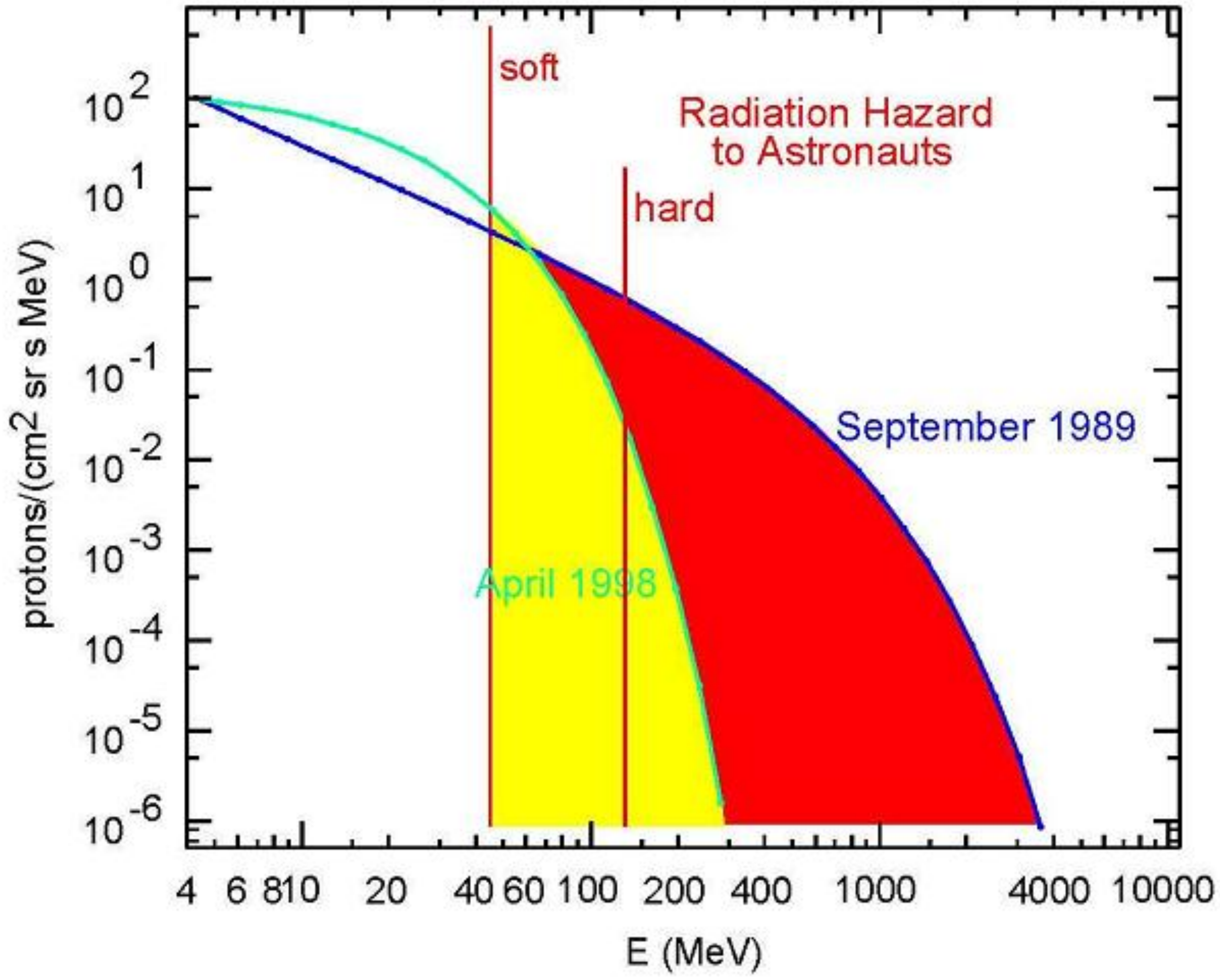



*Baker and Lanzerotti, 2016*

# SPACE WEATHER IMPACT AND EFFECTS

## *Interplanetary Space*




Solar Proton Events
SPEs

***'Managing Radiation Riks in the new era of Space Exploration,*** *National Research Council, 2008*

HESPERIA SUMMER SCHOOL

# The '*HESPERIA*' HORIZON 2020 Project: *'HIGH ENERGY SOLAR PARTICLE EVENT FORECASTING AND ANALYSIS'*

# PROTEC-1-2014 'Space Weather'
# High Energy Solar Particle Events Forecasting and Analysis

✓ **Solar energetic particles (SEPs)** are of prime astrophysical interest, but are also a space weather hazard motivating the development of predictive capabilities.

✓The project is funded through the **European Union's HORIZON 2020** research and Innovation Programme (Contract No 637324) and coordinated by the National Observatory of Athens in Greece **(Project Coordinator: Dr. Olga Malandraki)** .

✓It will combine data and knowledge from **9 European partners** and several collaborating parties from US and Russia.

HESPERIA SUMMER SCHOOL

# Team Members

- Olga Malandraki [National Observatory of Athens, NOA, Greece]
  Project Coordinator
- Ludwig Klein [Observatoire de Paris, OBSPARIS, France]
- Rami Vainio [Turun Yliopisto, UTU, Finland]
- Neus Agueda [Universitat de Barcelona, UB, Spain]
- Marlon Nunez [Universidad de Malaga, UMA, Spain]
- Bernd Heber [Cristian-Albrechts-Universitaet zu Kiel, CAU, Germany]
- Rolf Buetikofer [Universitaet Bern, UBERN, Switzerland]
- Christos Sarlanis [ISNet, Greece]
- Norma B. Crosby [Inst. d'Aeronom. Spat. De Belgique, IASB-BIRA, Belgium]

# External Collaborators

- Galina Bazilevskaya [Lebedev Physical Institute of Russian Academy of Sciences, Moscow, Russia]
- Veronica Bindi [University of Hawai at Manoa, Honolulu, USA]
- Ron Murphy [Naval Research Laboratory, Washington DC, USA]
- Allan Tylka [Washington DC, USA]
- Juan Rodriguez [NOAA, USA]

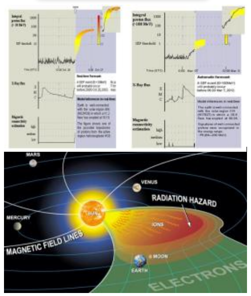
# HESPERIA

## WP1

leader NOA

MANAGEMENT

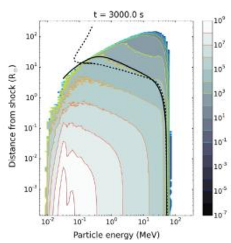
## WP2




leader UMA

FORECASTING OF SOLAR RADIATION STORMS

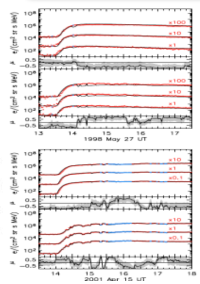
## WP3




leader UTU

MODELING OF SHOCK-ACCELERATED EVENTS

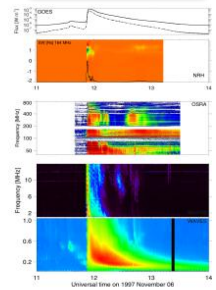
## WP4



leader UB

INVERSION METHODS

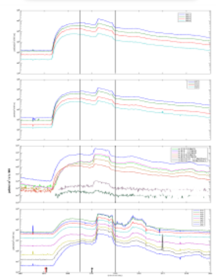
## WP5



leader OBSPARIS

SCIENTIFIC DATA ANALYSIS: GAMMA-RAYS, RADIO SEPS

## WP6



leader NOA

SEP RADIATION IMPACT

## WP7

leader ISNet

SERVER DEVELOPMENT

## WP8

leader NOA

DISSEMINATION AND EXTERNAL COORDINATION

The HESPERIA 'High Energy Solar Particle Events Forecasting and Analysis' project is:

✓ **producing two novel forecasting tools** based upon proven concepts **(UMASEP, REleASE).**

✓ **advancing our understanding of the physical mechanisms** that result into high-energy solar particle events (SEPs) exploiting novel datasets **(FERMI/LAT/GBM; PAMELA; AMS)**

National Observatory of Athens (NOA)

INSTITUTE FOR ASTRONOMY, ASTROPHYSICS, SPACE APPLICATIONS & REMOTE SENSING
(formerly INSTITUTE OF ASTRONOMY & ASTROPHYSICS)
National Observatory of Athens

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# HESPERIA Public Website

hesperia-space.eu

HESPERIA Partners   info@hesperia-space.eu   Username   Password

HOME | PARTNERS | PUBLICATIONS | RESULTS | MEETINGS | NEWS | OUTREACH | INTERNAL

KICK-OFF MEETING

HESPERIA Kick-Off Meeting, 21-22 May 2015, Athens, Greece

read more

FUNDING

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 637324.

IAASARS

l'Observatoire de Paris

Turun yliopisto University of Turku

Universitat de Barcelona

C A U

ISNet Intelligent Systems Networks

aeronomie.be

STAY CONNECTED

STATISTICS

*$1^{st}$ HESPERIA Progress Meeting, Barcelona 19-20 October 2015*

*HESPERIA Review Meeting, Turku 2-4 May 2016*

# HESPERIA Overall Objectives

1. To develop two novel SEP forecasting systems based upon proven concepts (UMASEP, REleASE)

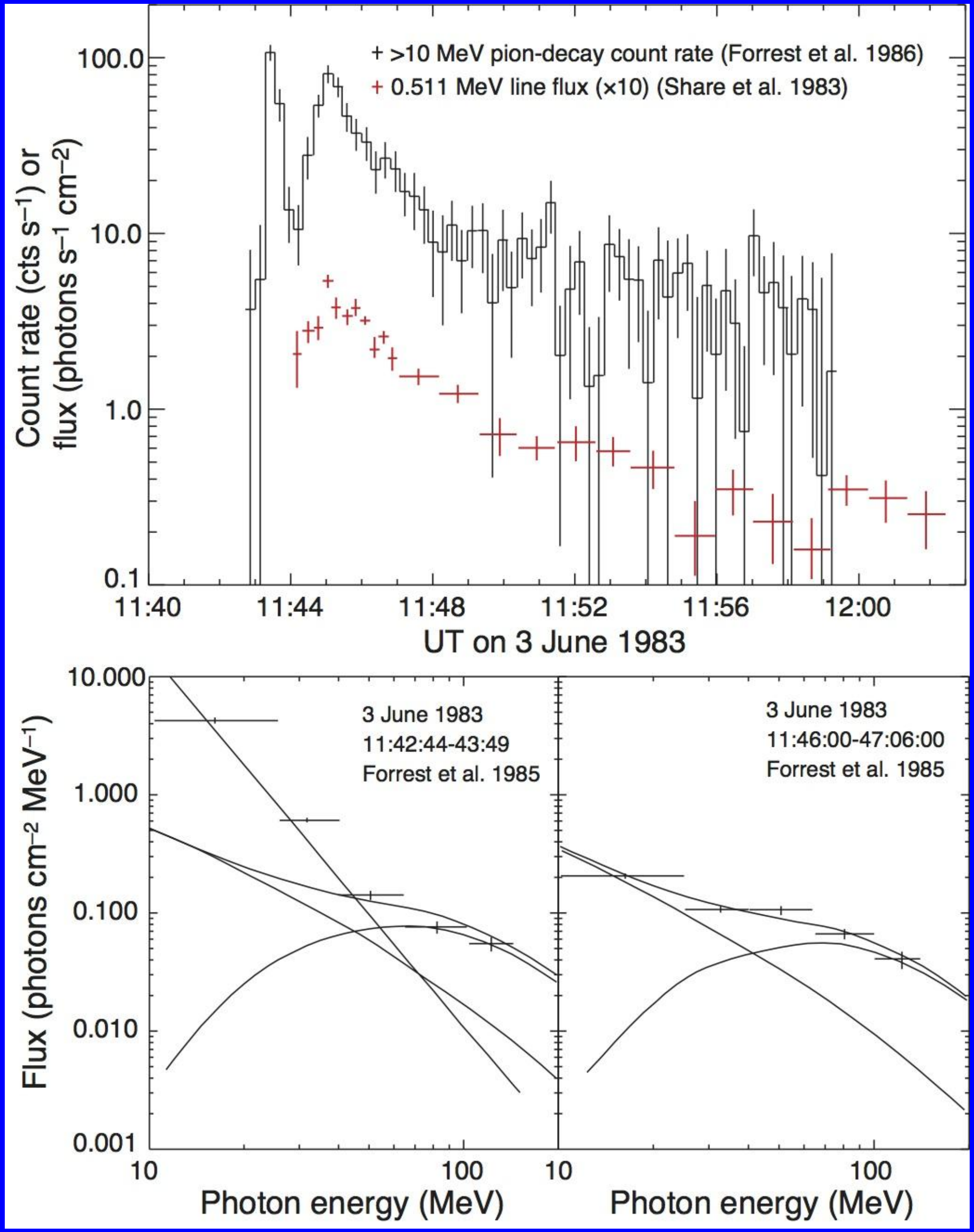
2. To develop SEP forecasting tools searching for electromagnetic proxies of the gamma-ray emission in order to predict large SEP events

3. **To perform systematic exploitation of the novel high-energy gamma-ray observations of the FERMI mission together with in situ SEP measurements near 1 AU**

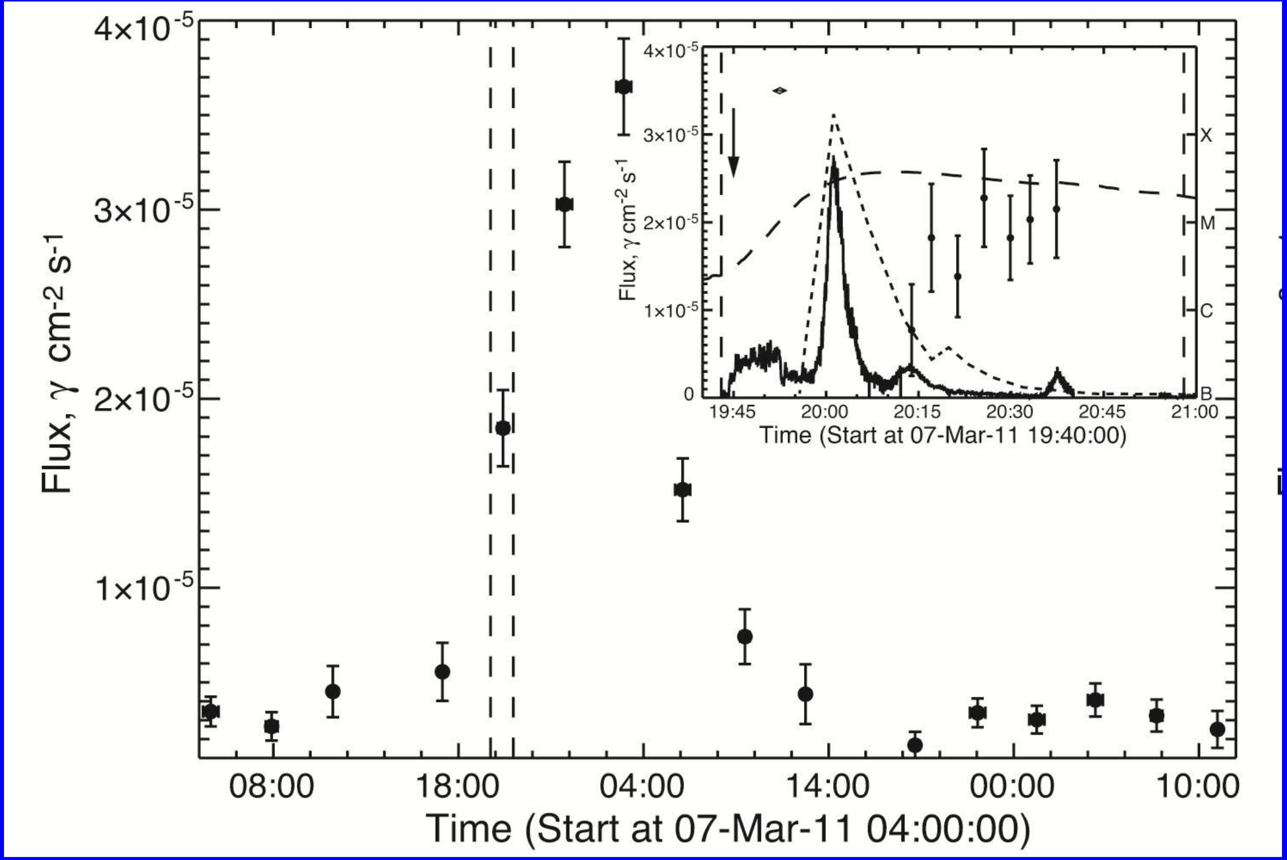
- *Fermi detection of sustained >100 MeV gamma-ray emission following solar flares (Ackermann et al. 2014). Most likely origin is from neutral and charged pions produced when >300 MeV protons interact deep in the solar atmosphere. Long Duration Gamma-Ray Flares (Ryan 2000).*
- *Twenty-six Fermi events studied from 2008 to 2015: numbers of protons, spectral indices, onset times and durations. Comparisons with flares and SEPs.*

*Gerald H. Share (private communication, 2015)*

Observations of high-energy emission from the 1982 June 3 flare made by the SMM/GRS. a) Time history of the pion-decay γ-ray count rate revealing two clear phases of emission. b) γ-ray spectra observed during the impulsive phase (left panel) and during the second phase (right panel). The solid curves show the different components of the spectrum, including: bremsstrahlung from primary electrons and electrons and positrons from pion-decay and neutral pion-decay bump. Shown in red, and scaled arbitrarily, is the count rate observed in the 511 keV annihilation line

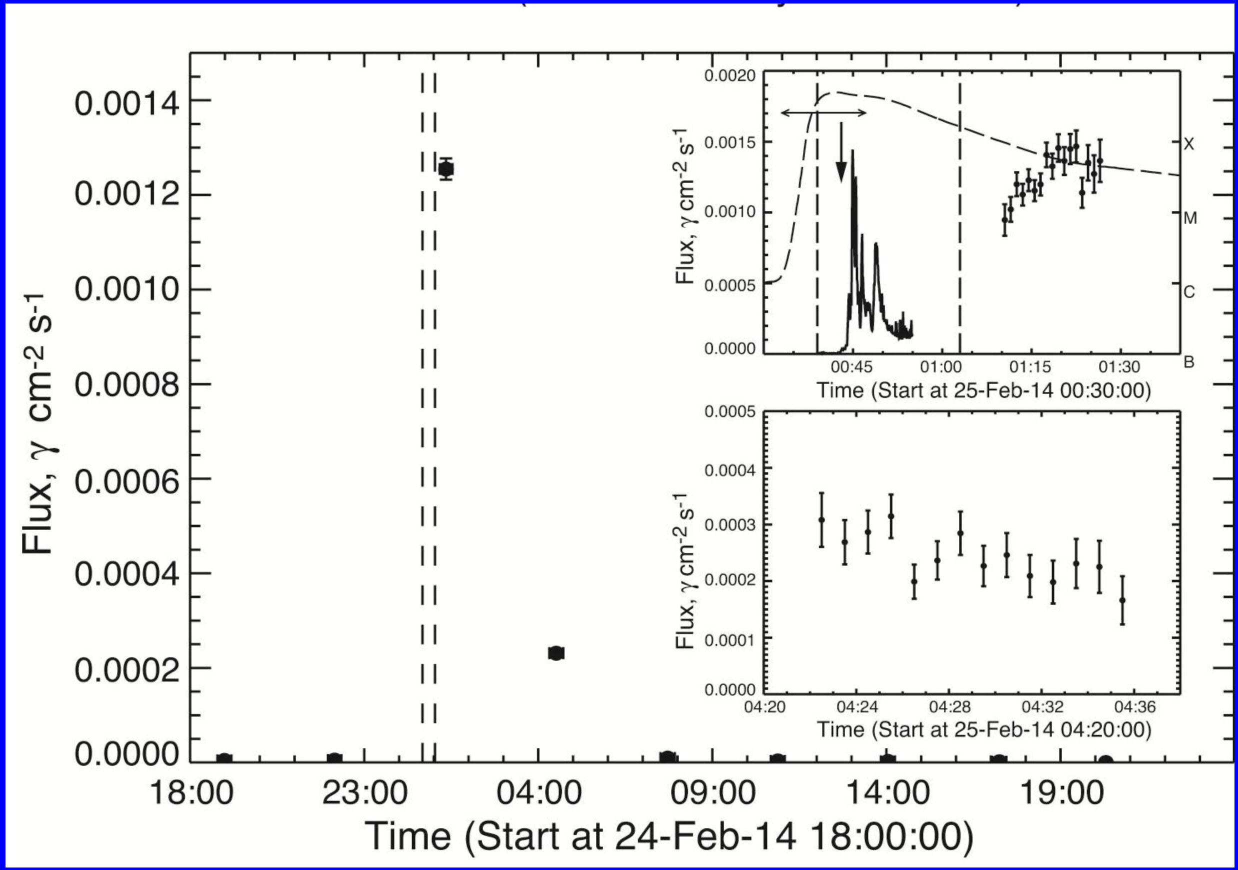



*Gerald H. Share (private communication, 2015)*




The first LDGRF observed by Fermi and reported by the Fermi/LAT team in Ackermann et al. (2014). Note that the flare was only an M3.7. Plot made using a 'light-bucket' analysis technique different than the Maximum Likelihood technique used by LAT team. Emission lasted at least 14 hrs. Dashed lines show extent of soft X-ray flare; details in inset: 100-300 keV rate, 4 min LAT data suggesting the emission begins within 15 min of HXR peak. Dotted curve 1991 June 11 profile. No 2.223 MeV or nuclear line emission during impulsive phase ➔ estimate of >100 MeV γ-rays. Spectral softening observed in protons >300 MeV at Sun. Is the gamma-ray onset associated with the SEP release time?

*Gerald H. Share (private communication, 2015)*

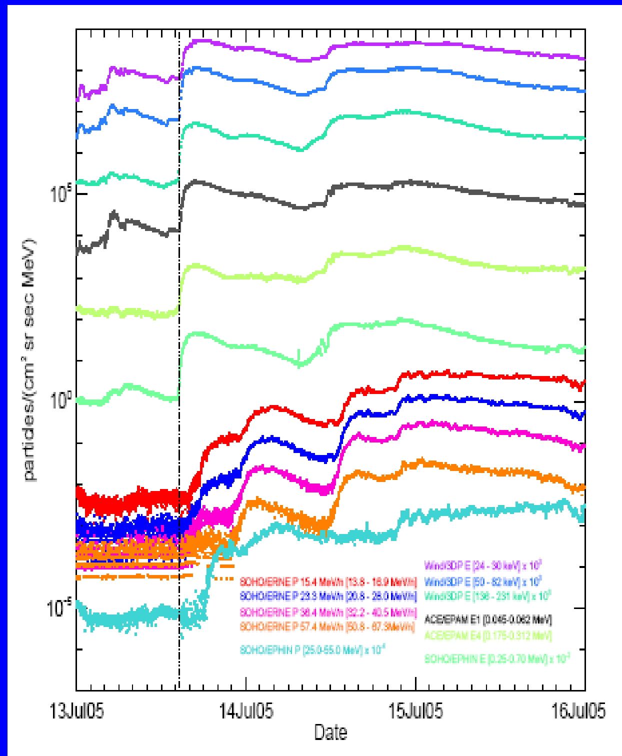


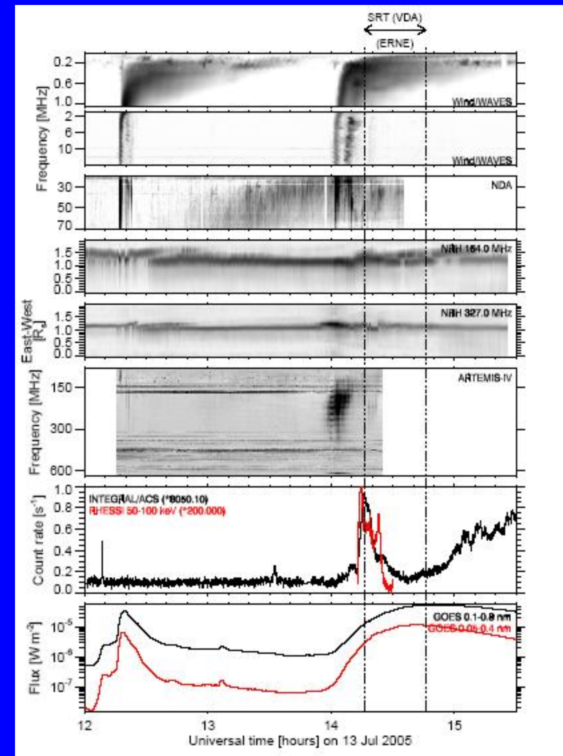

>100 MeV time profile of 2014 Feb. 25 event, one of most intense LAT events. Inset shows high-time resolution rise and fall. Strong nuclear line radiation during the impulsive phase but no LAT solar exposure. Spectral softening with time again observed in >300 MeV protons producing gamma rays. Can estimate >100 MeV gamma-ray emission during impulsive phase using 2.2 MeV capture line or LLE data where available.

*Gerald H. Share (private communication, 2015)*

## Particle Observations

## EM Observations




*Malandraki et al., Sol. Phys., 2012*

- *How the long-lasting gamma-ray emission is physically related to other radiative signatures of eruptive solar flare especially Hard X-rays and radio wavelengths*
- *AMS/PAMELA provide unique observations of >300 MeV protons in space; these are the same energies producing the pion-decay radiation observed by Fermi.*
- *Search for proxies of proton acceleration that can be used for forecasting purposes at times when no adequate gamma-ray detectors are available*

# HESPERIA Overall Objectives

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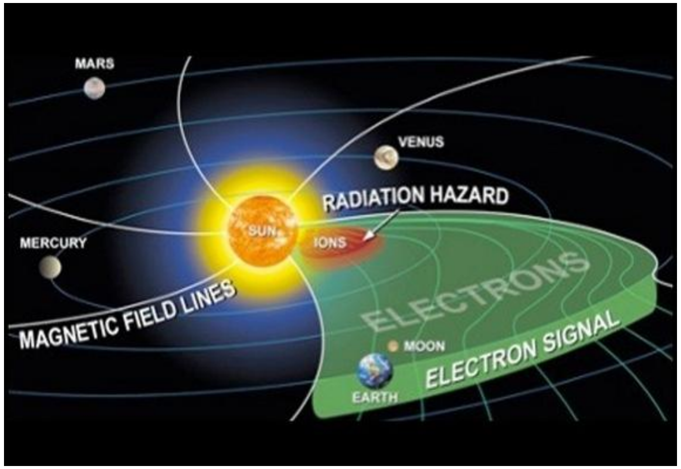
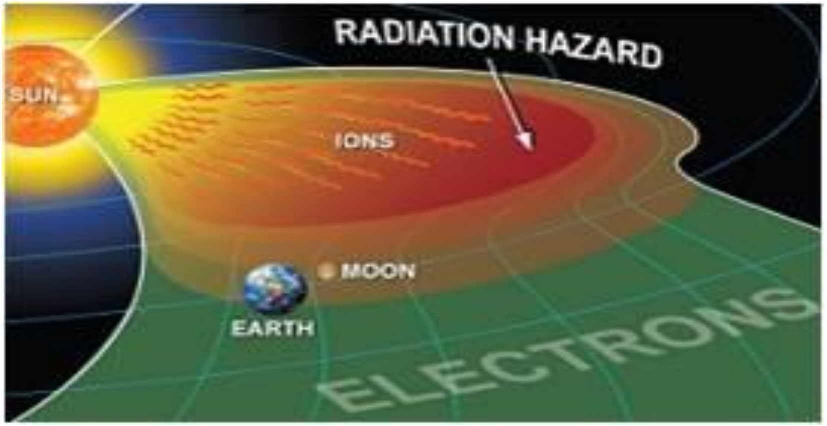
# Real-time tool for predicting 30-50 MeV SEP events by using the RELeASE scheme



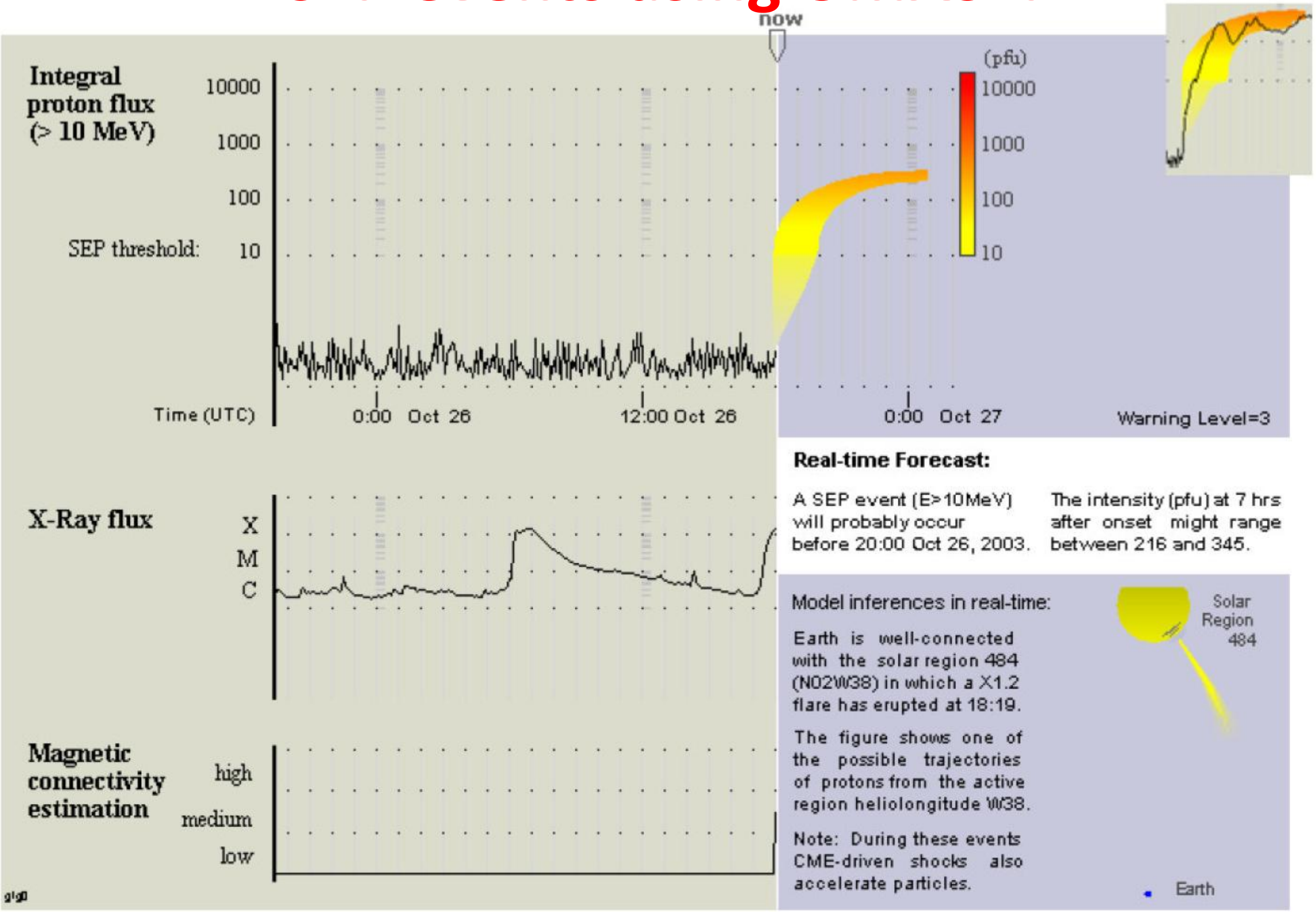




This task is implementing/adapting and evaluating **a near-realtime SEP predictor** by using the **RELeASE** scheme (Posner 2007)

The implemented model will infer the proton time profiles at 30-50 MeV based on both near-relativistic and relativistic electron intensity time profiles measured by **SOHO/EPHIN & ACE/EPAM.**

# Real-time tool for predicting >500 MeV SEP events using UMASEP

- Example of the output of the **UMASEP** system for >10 MeV



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# Facts & Figures:

THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION HORIZON 2020

✓ The project has started on **May 1, 2015** and will last **24 months**.

**http://hesperia-space.eu**

The most significant milestones are planned as follows:

- **The first forecasting results published via the Consortium Server in May 2016**
- **The results on the SEP simulation modelling for Fermi/LAT events as well as the inversion software for GLE events will be posted online in October 2016.**
- **The web-based front-end of the four SEP prediction tools will be released in the HESPERIA Server in April 2017**

✓A **scientific Workshop**, open to the community, **on SEP event analysis** will be organised in Paris end of February 2017.

✓ In addition the consortium will provide **educational** and **outreach material** on solar eruptions and space environment on its website

# FOR FURTHER READING ON SPACE PHYSICS, SPACE WEATHER AND ITS EFFECTS

1. ***An Introduction to Space weather*, M. Moldwin, Cambridge, UK, 2008**

**2. *Understanding Space Weather and the physics behind it*, by Delores Knipp, edited by M. McYada & D. Kirkpartick, McGraw Hill Companies, 2011.**

**3. *Managing Radiation Riks in the new era of Space Exploration,*** *National Research Council, 2008*

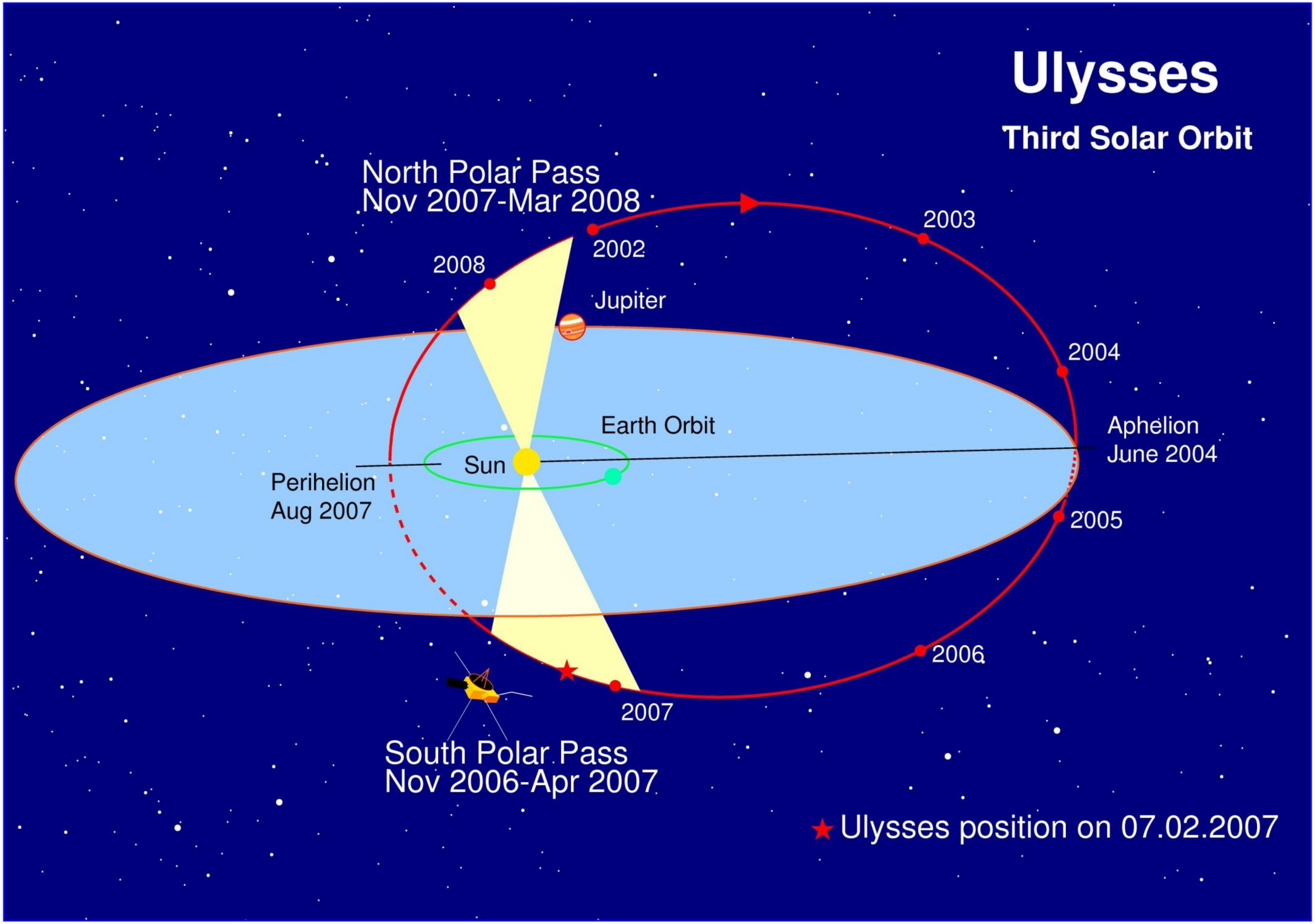
# FOR FURTHER READING ON SPACE PHYSICS, SPACE WEATHER AND ITS EFFECTS

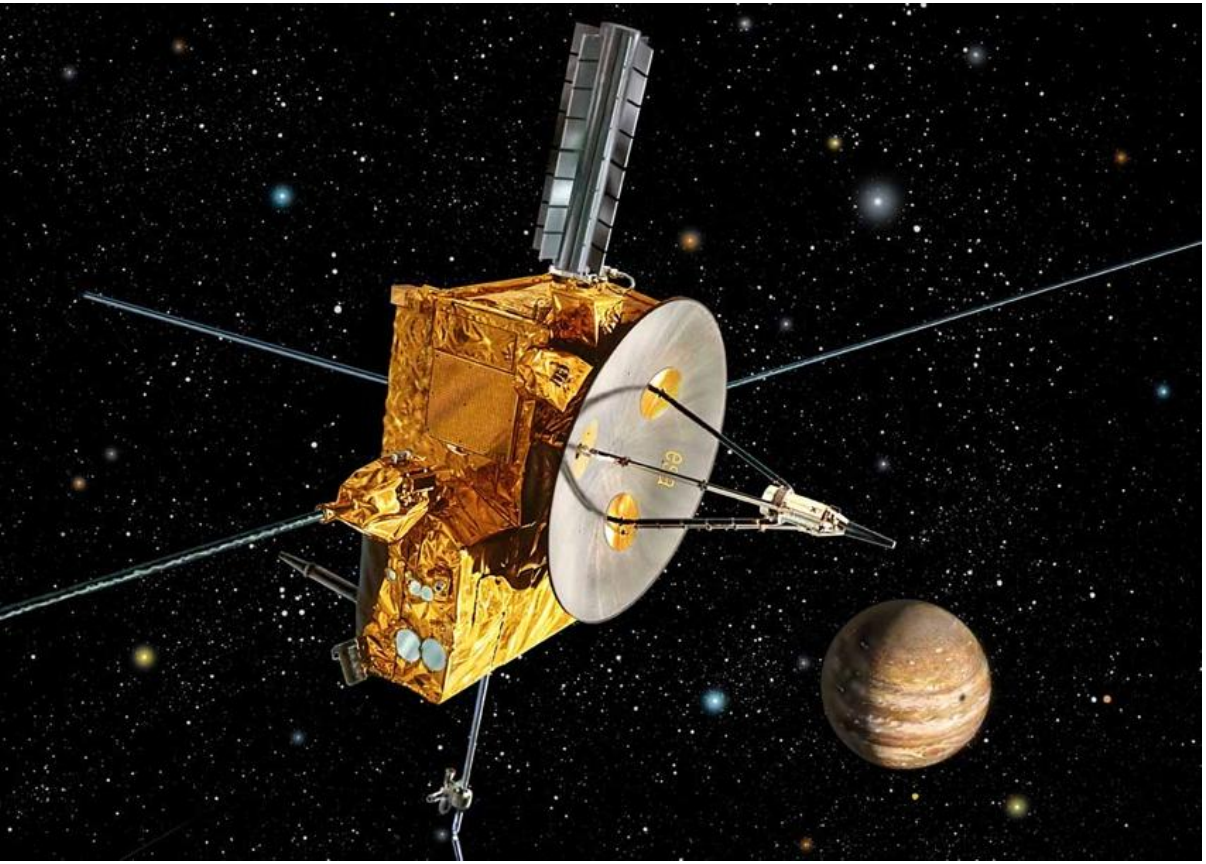


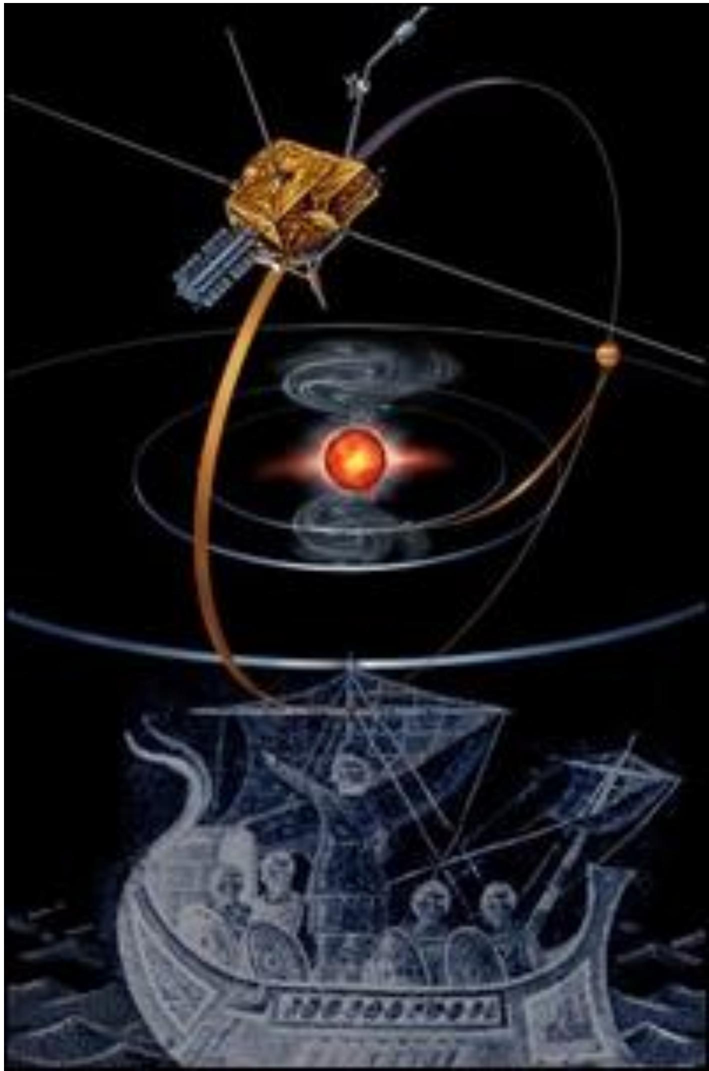
**4. *Space Radiation Hazards and the Vision for Space Exploration:*** *Report of a Workshop, National Research Council, 2006*

**5. *Introduction to Space Physics*, ed. by Luhmann & Russel, Cambridge University Press, 2016**

**6. Baker and Lanzerotti, *Space Weather*, Am. J. Phys., 84 (3), 2016, (186 references (books, published articles etc)**

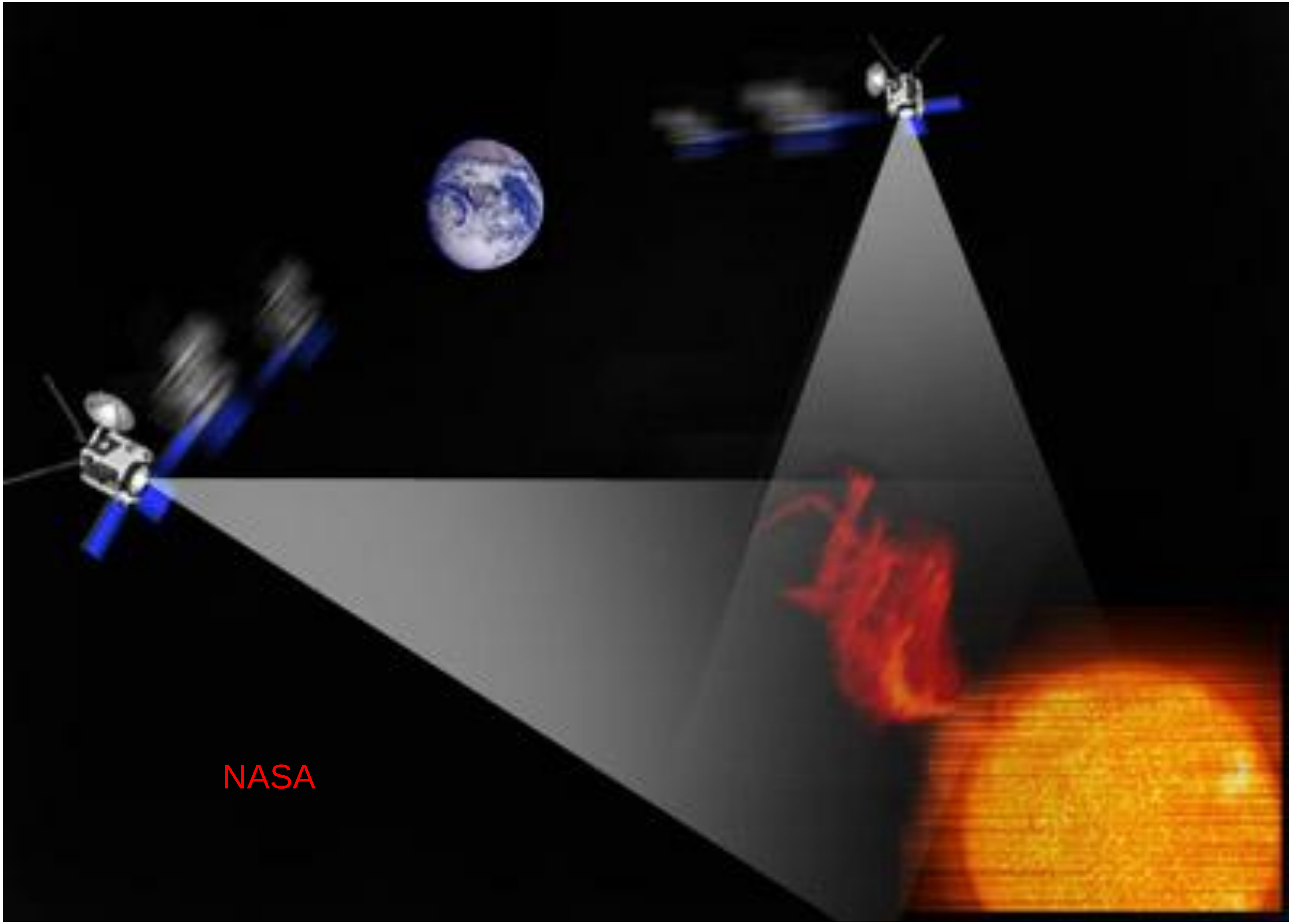

Ulysses
Third Solar Orbit
North Polar Pass
Nov 2007-Mar 2008
2002
2003
2008
Jupiter
2004
Earth Orbit
Aphelion
June 2004
Sun
Perihelion
Aug 2007
2005
2006
2007
South Polar Pass
Nov 2006-Apr 2007
Ulysses position on 07.02.2007

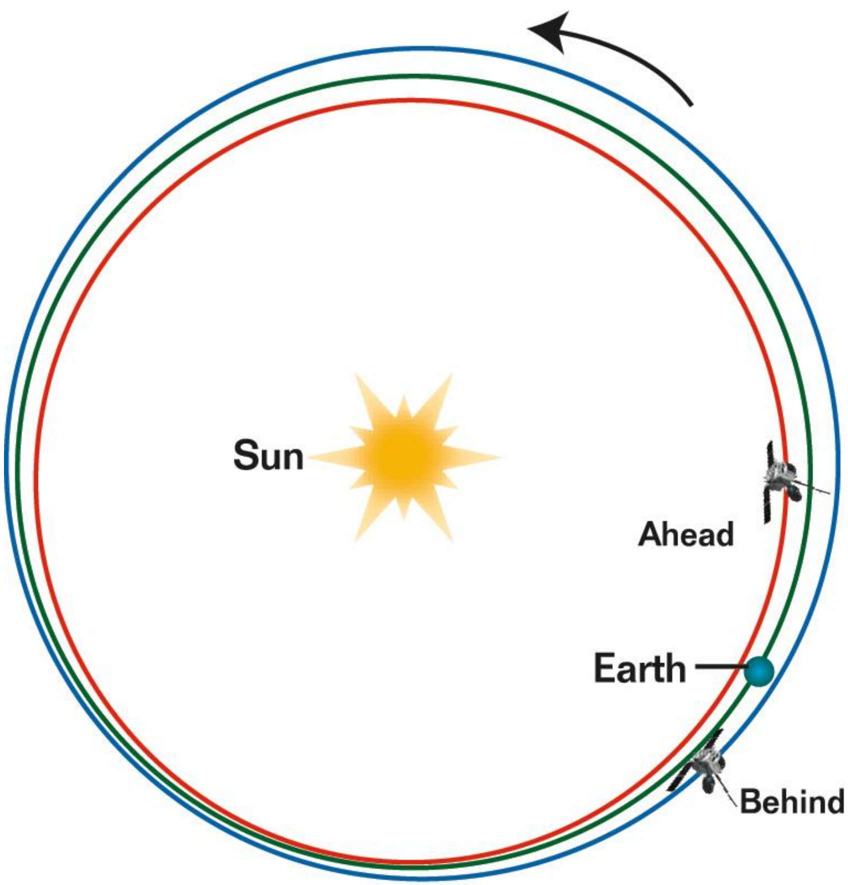




**ESA/NASA**

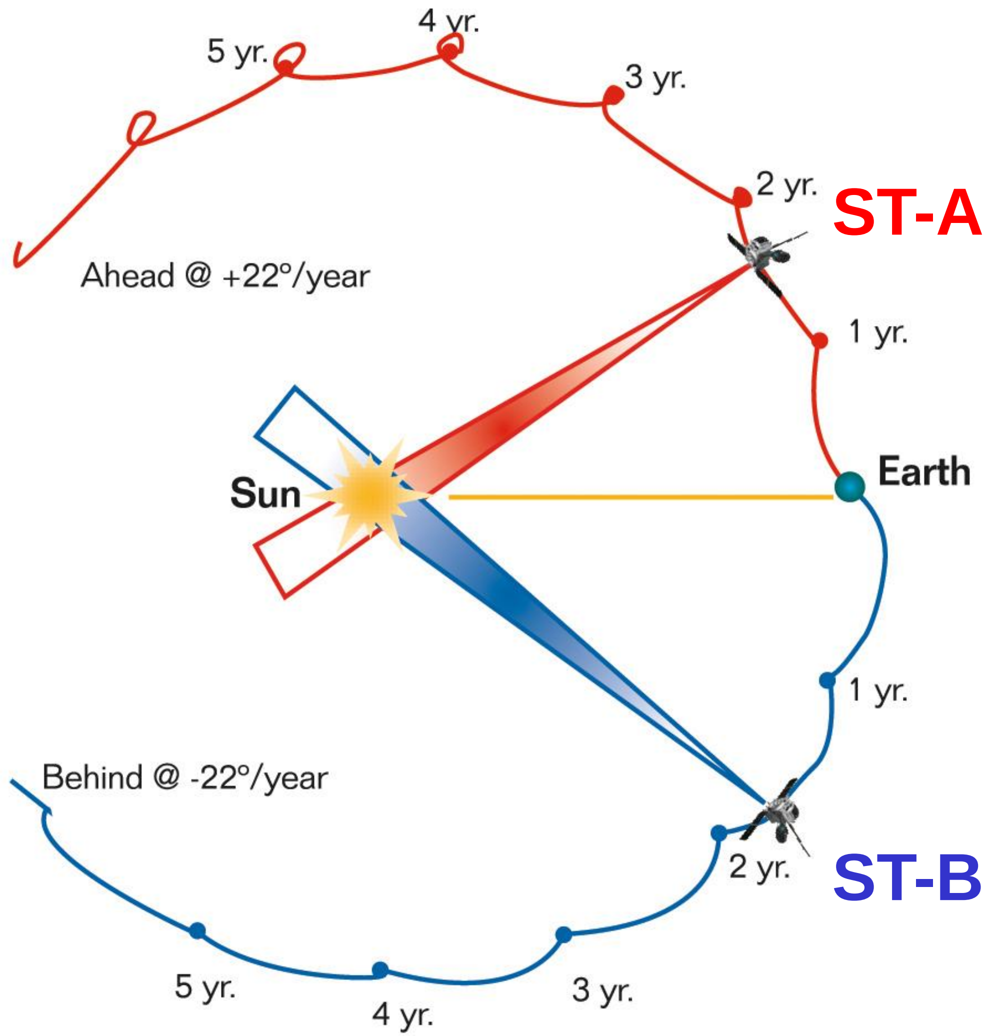
# STEREO A & B twin spacecraft





Sun
Ahead
Earth
Behind


NASA



5 yr.
4 yr.
3 yr.
2 yr.
ST-A
Ahead @ +22°/year
1 yr.
Sun
Earth
1 yr.
Behind @ -22°/year
2 yr.
ST-B
5 yr.
4 yr.
3 yr.