

Introductory space physics and solar-planetary relationships - II

Lecture 3

W.K. Tobiska

Space Environment Technologies

Class announcements

Contributions

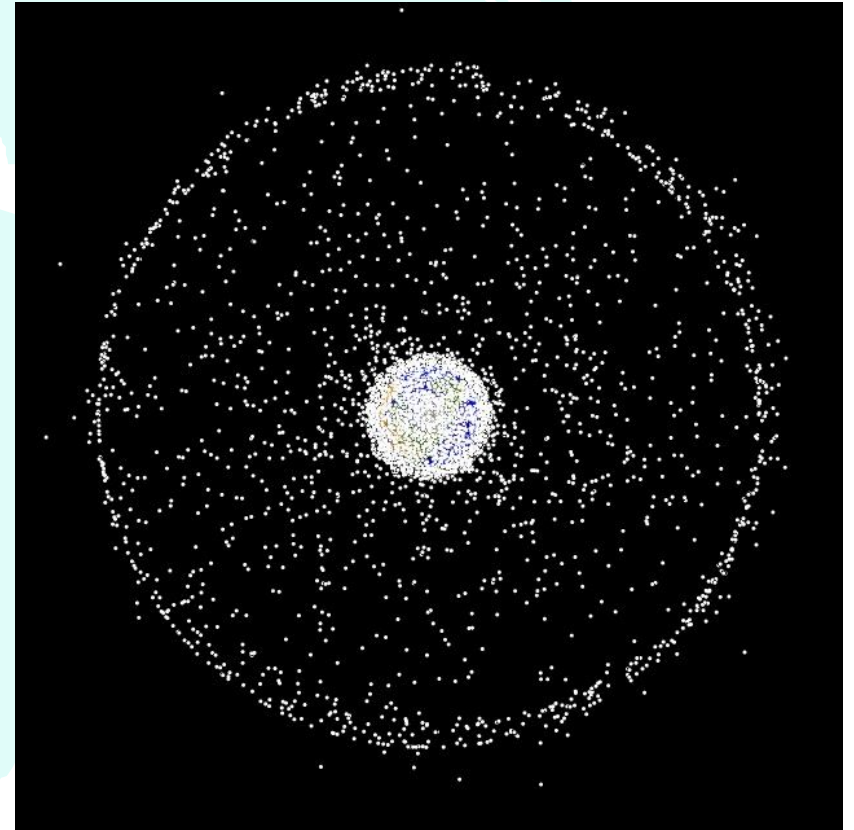
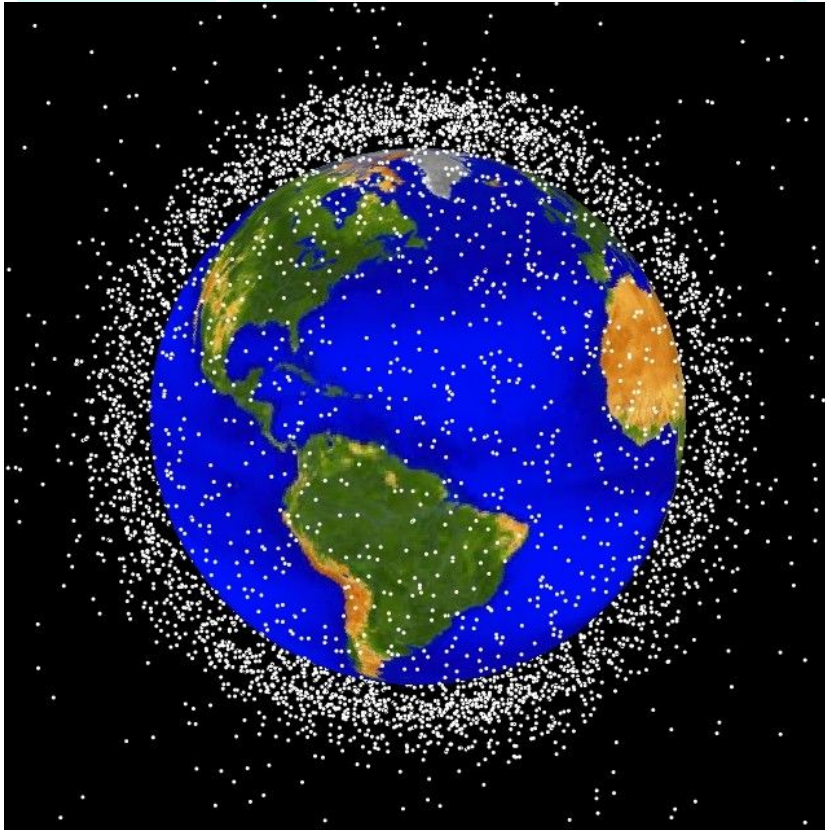
- ◆ Distant Star's Sound Waves Reveal Cycle Similar to the Sun's at <http://www.sciencedaily.com/releases/2010/08/100826141219.htm>
- ◆ Shrinking Atmospheric Layer Linked to Low Levels of Solar Radiation at <http://www.sciencedaily.com/releases/2010/08/100826152217.htm>
- ◆ Solar flare at <http://www.spaceweather.com/archive.php?view=1&day=06&month=09&year=2010>
- ◆ Extreme Ultraviolet "Rainbow" on the Sun, Sept 5, 2010, 720p HD at <http://www.youtube.com/watch?v=fl0PMBerCvQ>
- ◆ Why we study the Sun (NASA MSFC site) <http://solarscience.msfc.nasa.gov/whysolar.shtml>
- ◆ SOHO: Flares http://sohowww.nascom.nasa.gov/hotshots/2003_10_28/

Class announcements

Contributions

- ◆ SOHO: Venus crossing Sun
http://sohowww.nascom.nasa.gov/hotshots/2004_06_08/
- ◆ Alfven waves provide energy into the corona
http://www.space.com/scienceastronomy/070830_sun_waves.html
- ◆ Death Rays From Space: How Bad Are They?
<http://www.space.com/scienceastronomy/090827-cosmic-rays.html>
- ◆ SETI signal? <http://www.seti.org/seti-institute/a-seti-signal>
- ◆ How scientists predict the solar corona during the August 2017 eclipse <https://www.nasa.gov/feature/goddard/2018/how-scientists-predicted-corona-s-appearance-during-aug-21-2017-total-solar-eclipse>

Contributions



Lecture Overview

The interplanetary space environment

The Sun

- Fields - solar gravitational field

- Fields - solar magnetic fields

- Particles - the solar wind

- Particles - solar electrons and protons

Nonsolar

- Particles - Galactic cosmic rays

- Particles - Interplanetary material

 - Comets and asteroids

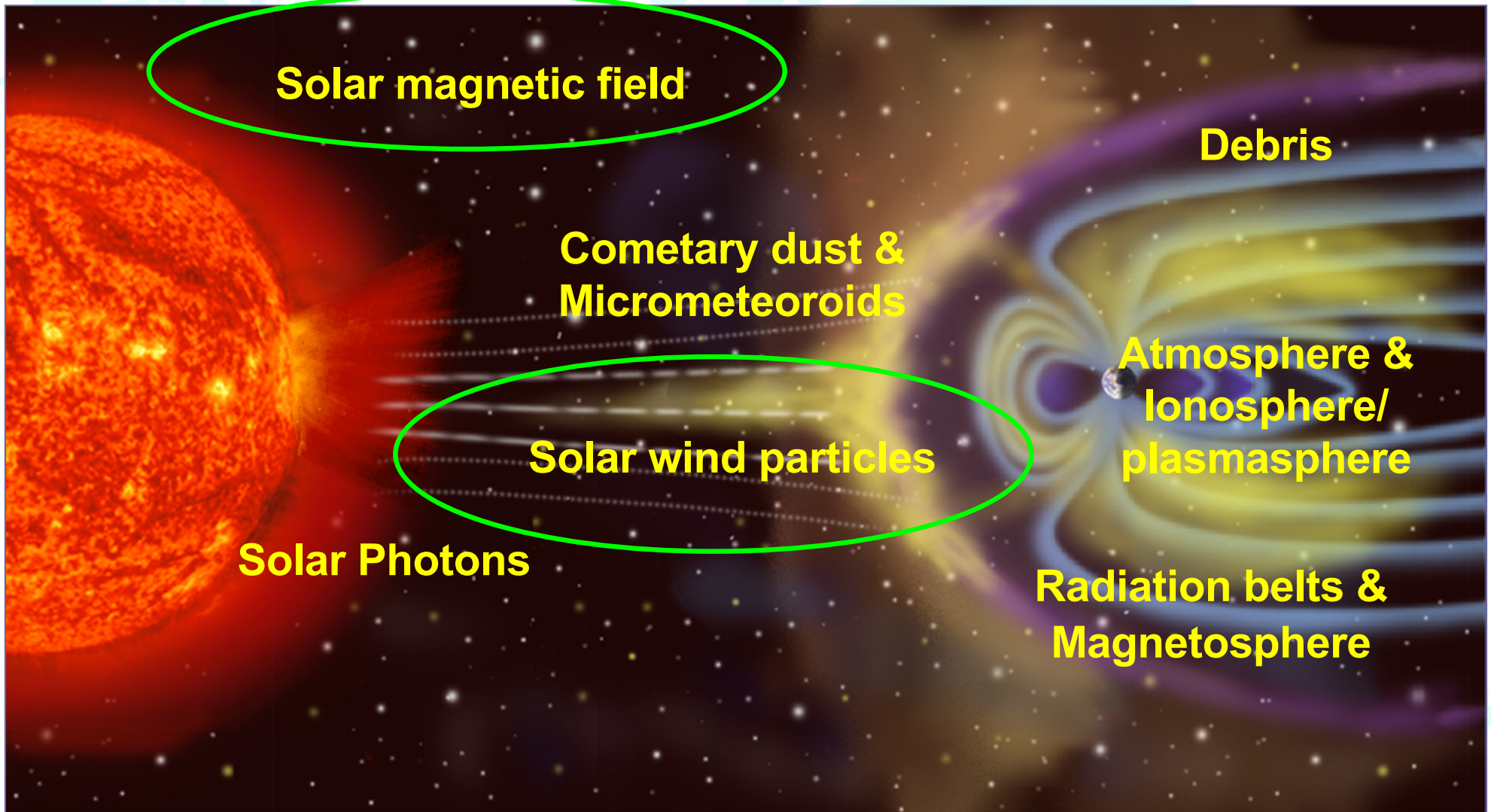
 - Gas and dust

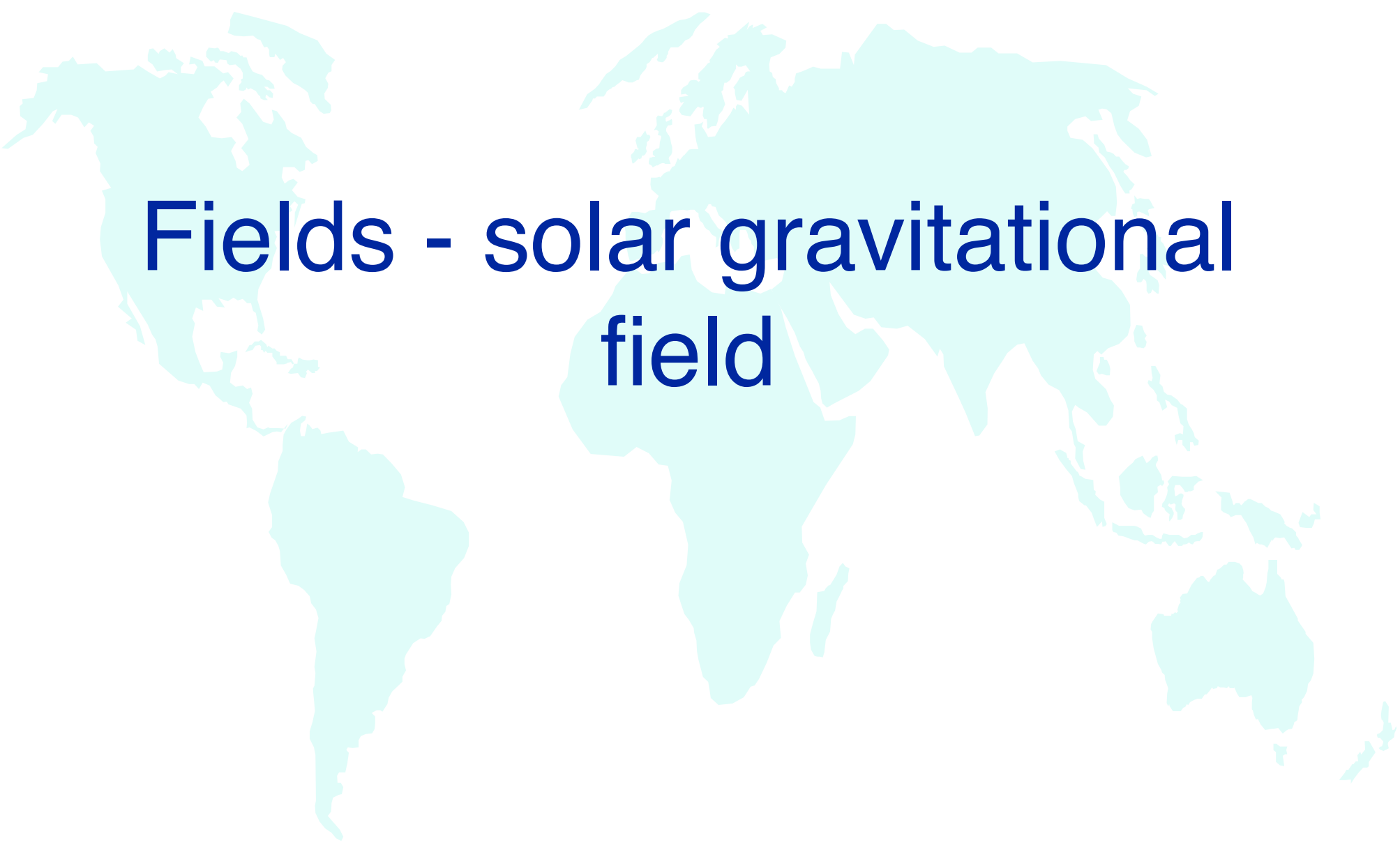
Homework

A light blue world map is centered in the background of the slide.

The interplanetary space environment

The space environment



A light blue world map is centered in the background of the slide, showing the continents of North America, South America, Europe, Africa, Asia, and Australia.

Fields - solar gravitational field

Solar gravitational field

Newton's Law of Gravitation

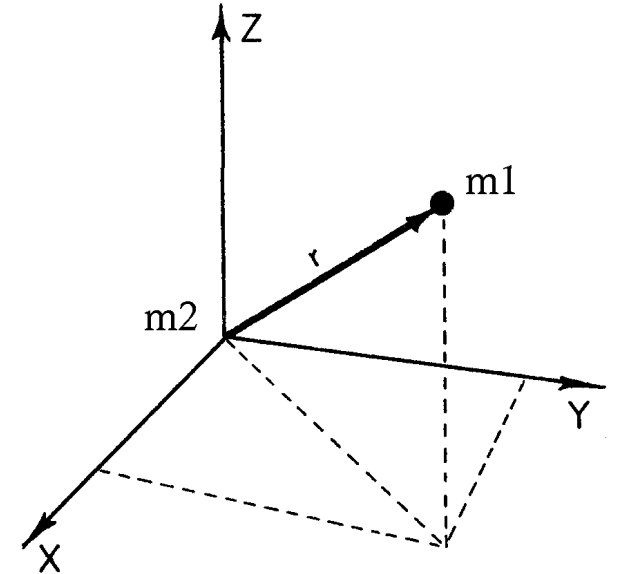
$$\mathbf{F}_{21} = \frac{Gm_1m_2(\mathbf{r}_1 - \mathbf{r}_2)}{|\mathbf{r}_1 - \mathbf{r}_2|^3} \quad (3-1)$$

where force F_{21} is the force exerted on system 1 by system 2 (m_2 is the larger mass)

$$G = 6.672\,59 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$$

$$\mathbf{r} = \mathbf{r}_1 - \mathbf{r}_2$$

$$\mu = (1/m_2)(m_2 + m_1) \text{ (dimensionless reduced mass)}$$



Credit: Tobiska

Solar gravitational field

Heliocentric system

Gm_2 from equation 3-1 is the heliocentric gravitational constant, let $m_2 = M_{\odot}$

$$M_{\odot} = 1.9891 \text{E}30 \text{ kg}$$

$$GM_{\odot} = 1.327 \ 124 \ 40 \ \text{E}20 \ \text{m}^3 \ \text{s}^{-2}$$

$GM_{\odot} = k^2$ (definition) and it can be shown

$$k_{\odot} = 0.01720209895 \ (\text{AU})^{3/2} \ \text{day}^{-1} \ \text{for}$$

$$1 \ \text{AU} = 149 \ 597 \ 870 \ 691 \ \text{m}$$

Credit: Tobiska

Kepler's Third Law

Effect of solar gravitational field on bodies in the solar system

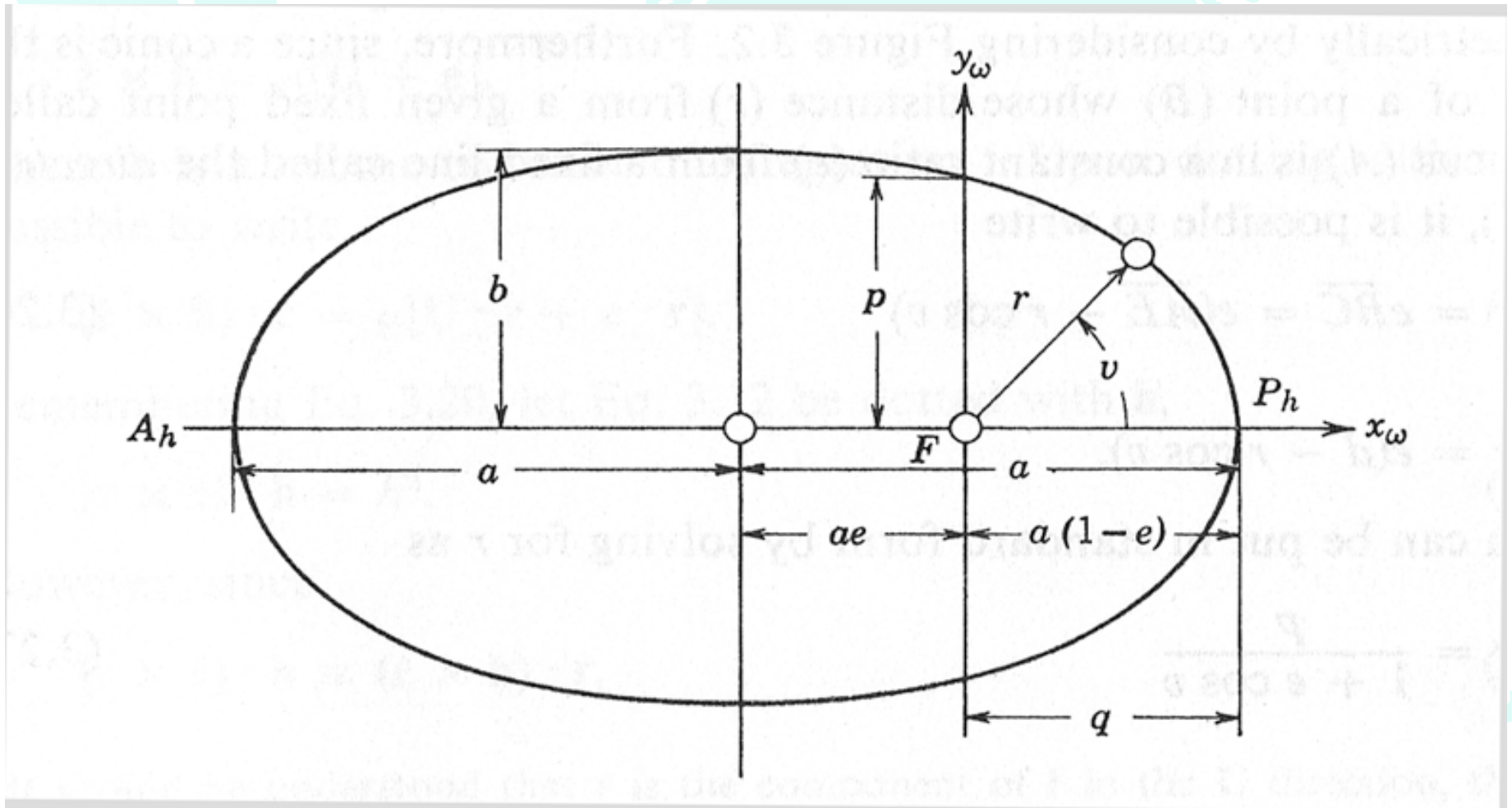
Kepler's Third Law

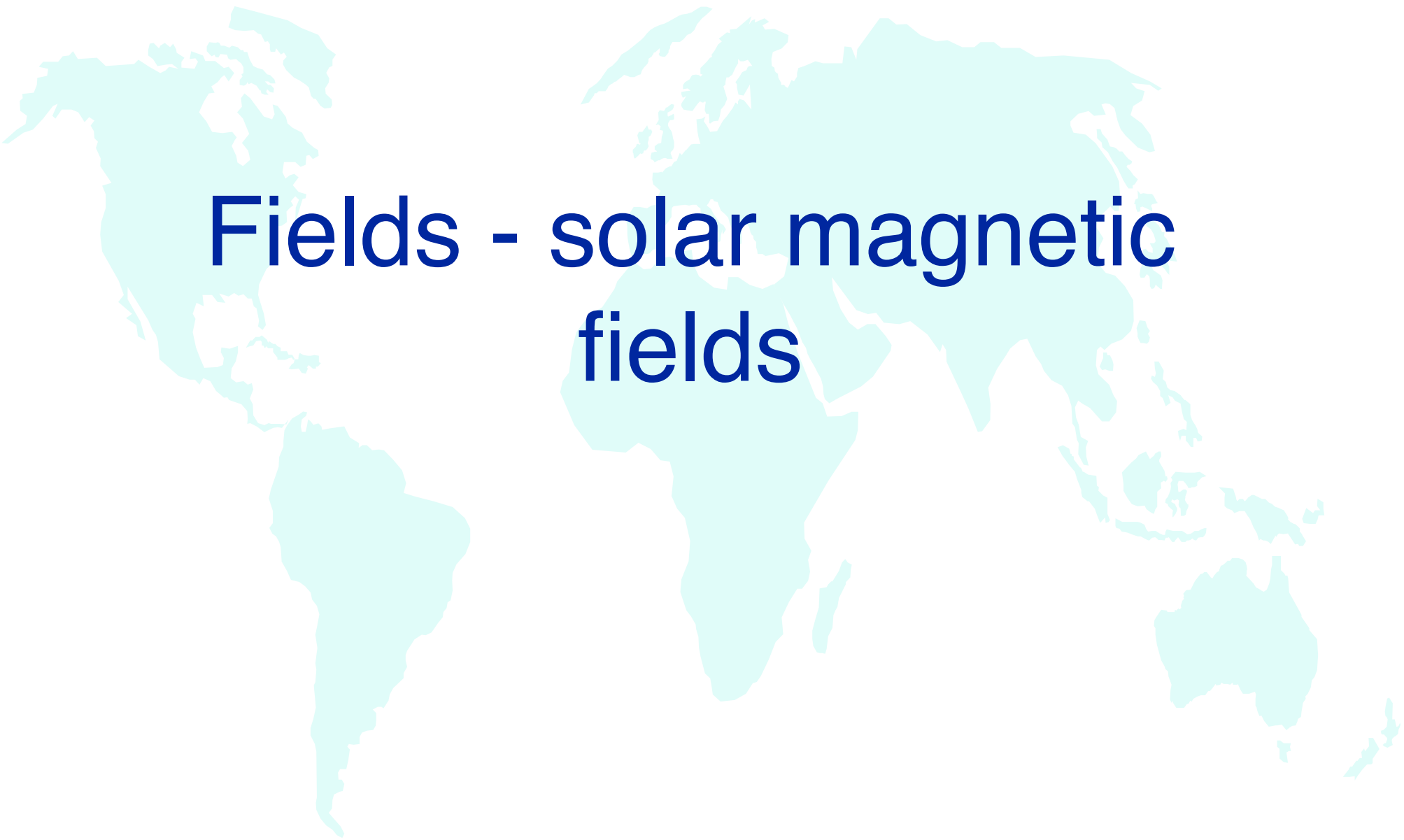
$$P^2 = \frac{(2\pi)^2}{k^2 \mu} a^3 \quad (3-2)$$

where ***P*** is the orbit period of the body, ***k*²** is the gravitational constant, ***μ*** is the dimensionless reduced mass, and ***a*** is the semi-major axis of the orbit; this formulation is useful for solving 2-body problems in orbit determination

Credit: Tobiska

Geometry of any orbit



A light blue world map is centered in the background of the slide, showing the continents of North America, South America, Europe, Africa, Asia, and Australia.

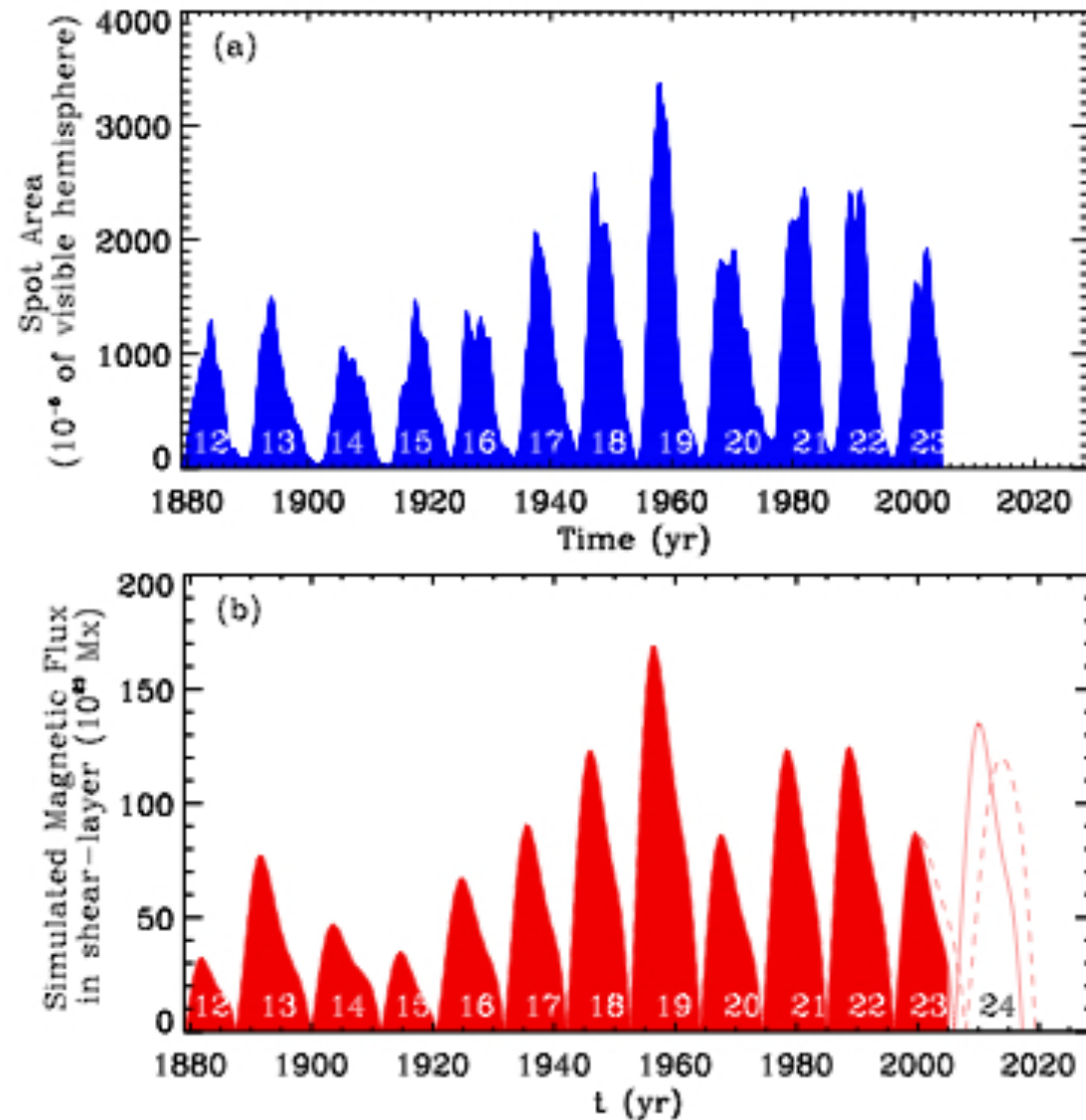
Fields - solar magnetic fields

Solar dynamo

- ◆ **A successful model for the solar dynamo must explain several observations:**
 - 1) the 11-year period of the sunspot cycle
 - 2) the equatorward drift of the active latitude as seen in the butterfly diagram
 - 3) Hale's polarity law and the 22-year magnetic cycle
 - 4) Joy's law for the observed tilt of sunspot groups
 - 5) the reversal of the polar magnetic fields near the time of cycle maximum as seen in the magnetic butterfly diagram

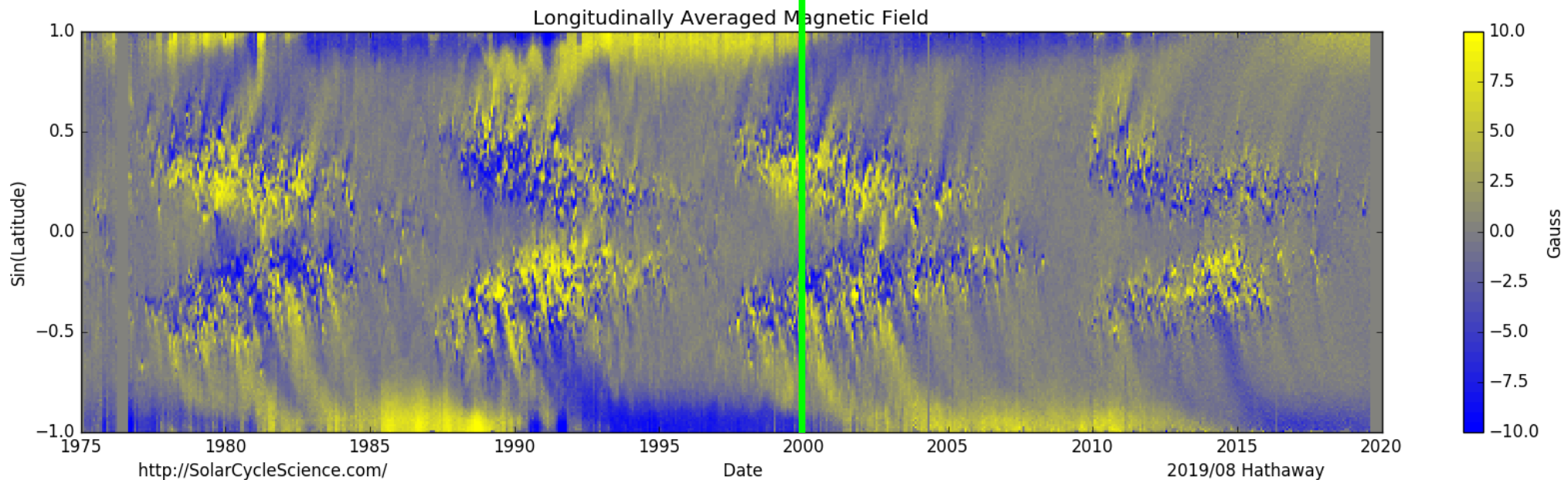
Credit: Tobiska

Flux transport dynamo model



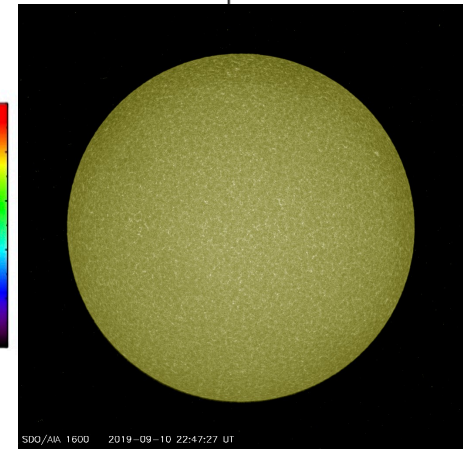
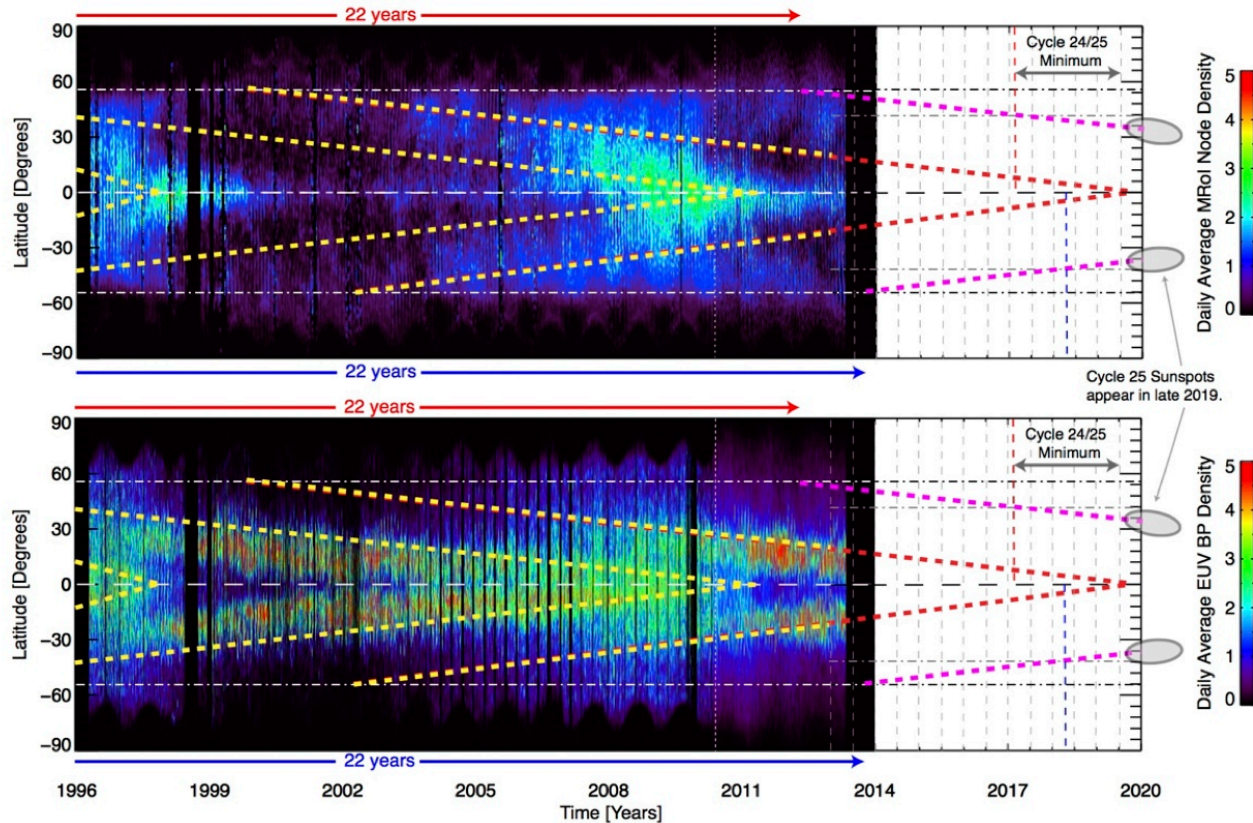
Solar dynamo – August 2019

CR1959



Forecasting?

Cycle 25 has already appeared at high latitude of Northern hemisphere. The Southern hemisphere is 18-24 months behind and slower. Based on a linear progression of the chevrons (using observed cycle 22/23 behavior) we anticipate solar minimum condition onset by 2017. It is VERY likely that this minimum will be extremely weak and VERY asymmetric. It is HIGHLY likely (based on the lengthening overlap and decrease of magnetic flux present) that the system is slowing down - this is a progression into a significantly extended activity minimum.



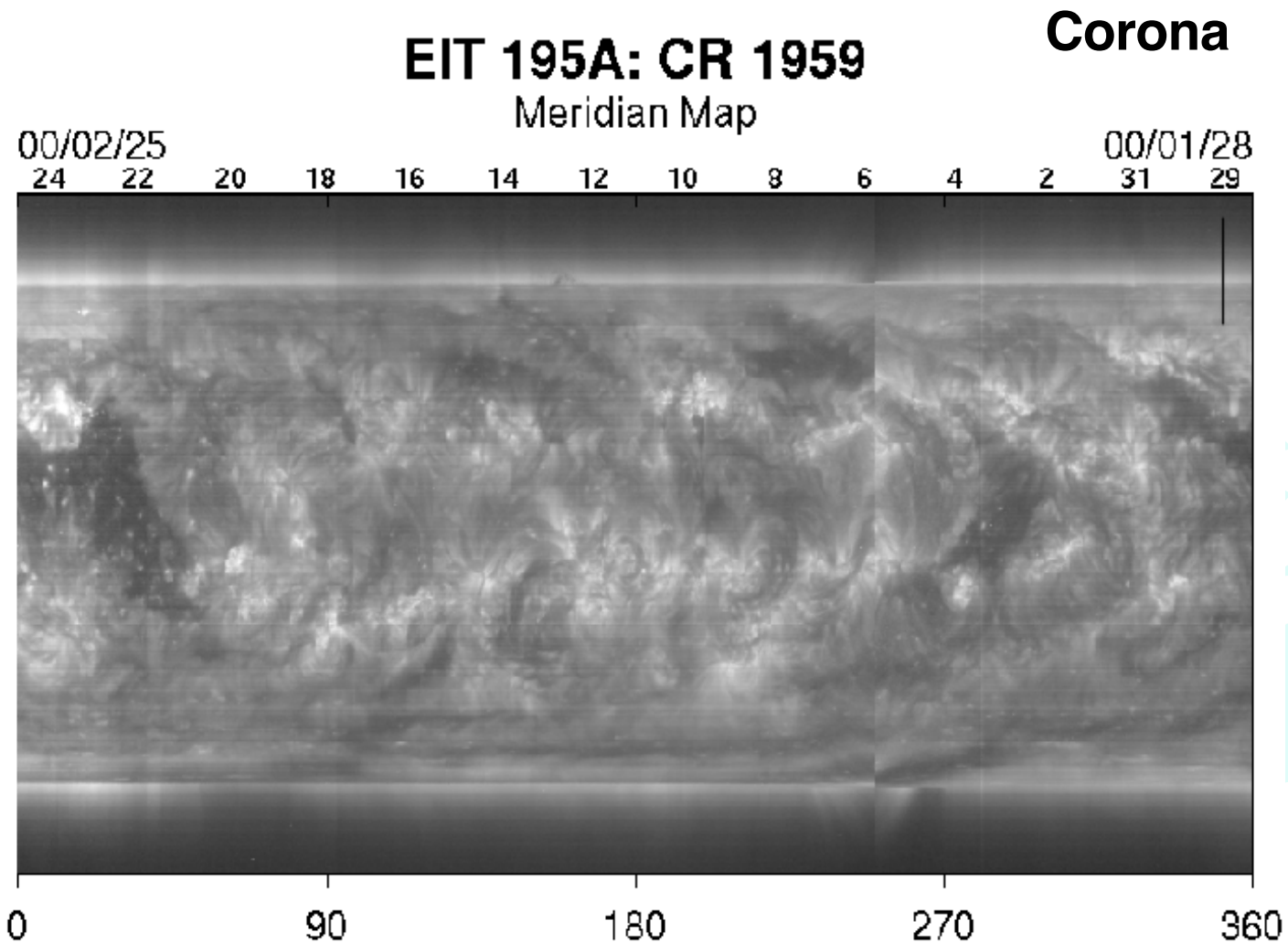
Predicting the future!

Using only a linear approximation and assuming that the circulation rate does not change....



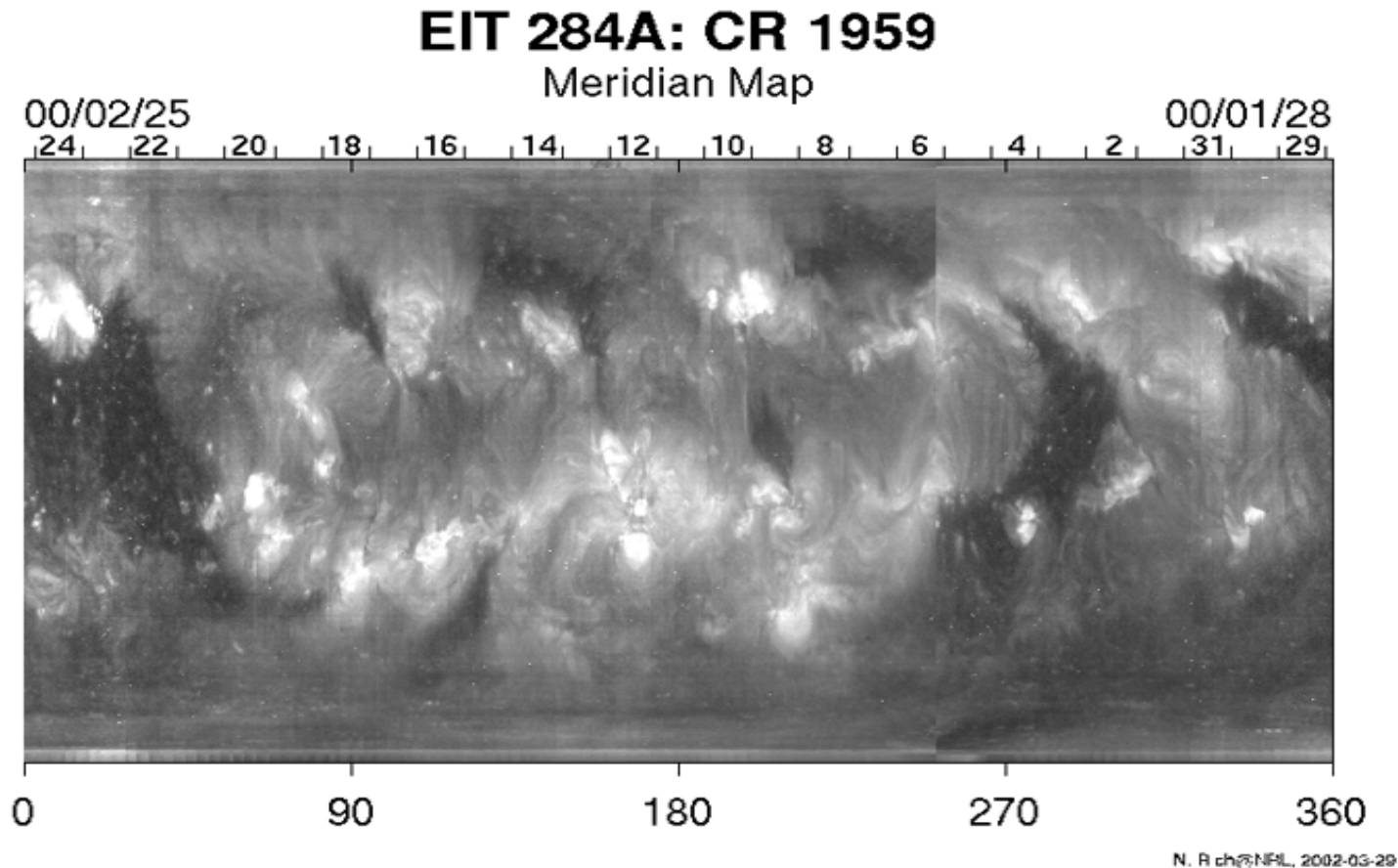
Scott McIntosh - mscott@ucar.edu - NJF '13 Presentation

Example of CR1959



Example of CR1959

Transition region

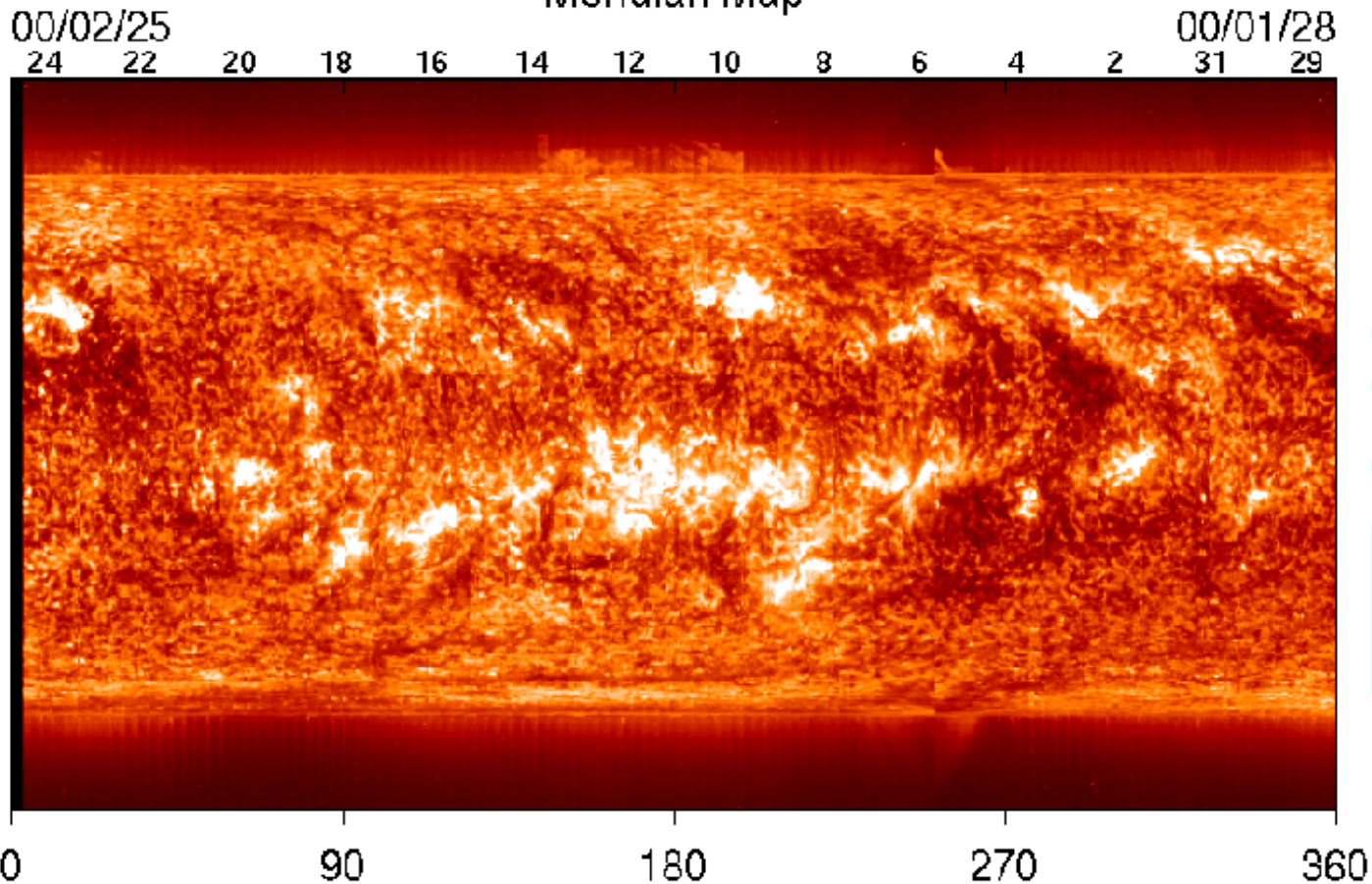


Example of CR1959

Chromosphere

EIT 304A: CR 1959

Meridian Map



3D MHD physics basis

- ◆ MHD equations explain the dynamo physics: conservation of angular momentum & continuity

1. *Momentum equation with rotation* in a reference frame

$$\rho \frac{\partial \mathbf{U}}{\partial t} + \rho(\mathbf{U} \cdot \nabla) \mathbf{U} = -2\rho\boldsymbol{\Omega} \times \mathbf{U} - \nabla P - \rho \mathbf{g} + \mathbf{j} \times \mathbf{B} + \mu(\nabla^2 \mathbf{U} + \frac{1}{3} \nabla(\nabla \cdot \mathbf{U})) \quad (3-3)$$

Differential rotation

where ρ is the density, P is the gas pressure, $\mathbf{U}$ is the velocity in the rotating frame, $\mathbf{g}$ is the gravitational acceleration, $\mathbf{j}$ is the current density, $\mathbf{B}$ is the magnetic field and μ is the dynamic coefficient of viscosity (assumed constant)

Credit: Tobiska

3D MHD physics basis

2. Continuity equation

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{U}) = 0 \quad (3-4)$$

combines with the *induction equation*

$$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\mathbf{U} \times \mathbf{B}) - \eta \nabla \times (\nabla \times \mathbf{B}) \quad (3-5)$$

contains poloidal
and toroidal terms

where η is the magnetic diffusivity (constant).
Assumed solenoidal magnetic field

$$\nabla \cdot \mathbf{B} = 0 \quad (3-6)$$

Credit: Tobiska

Helicity - twist and writhe of magnetic field

Ideal MHD assumes steady turbulence, homogenous and isotropic conditions

$$\overline{u' \times b'} \quad (3-7)$$

but with a dependence on helicity

$$\mathbf{u} \cdot \nabla \times \mathbf{u} \quad (3-8)$$

where η (magnetic diffusivity, e.g., eddy) approaches 0

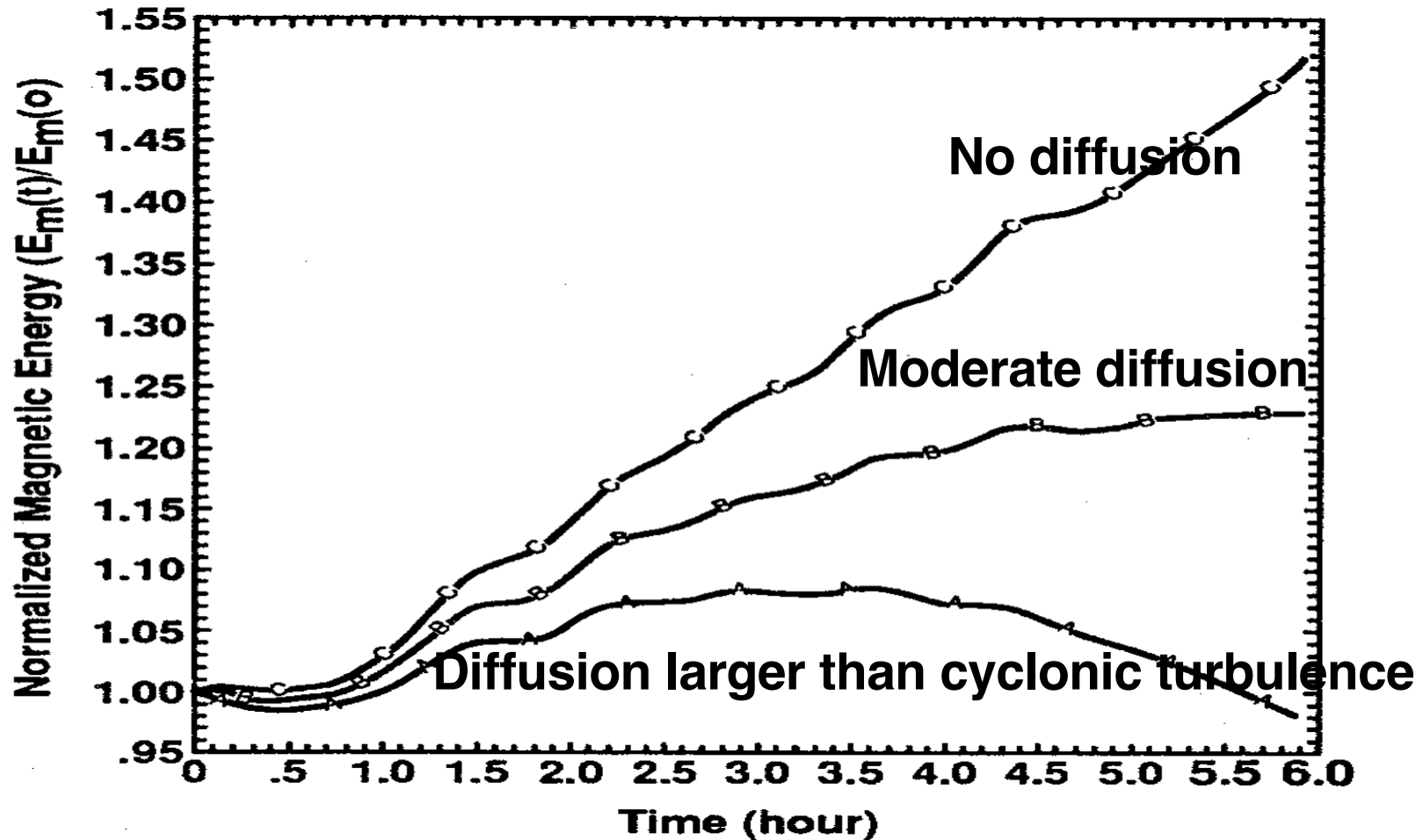
Manifested in filaments, coronal arcades, sigmoidal coronal loops, sunspot whorls

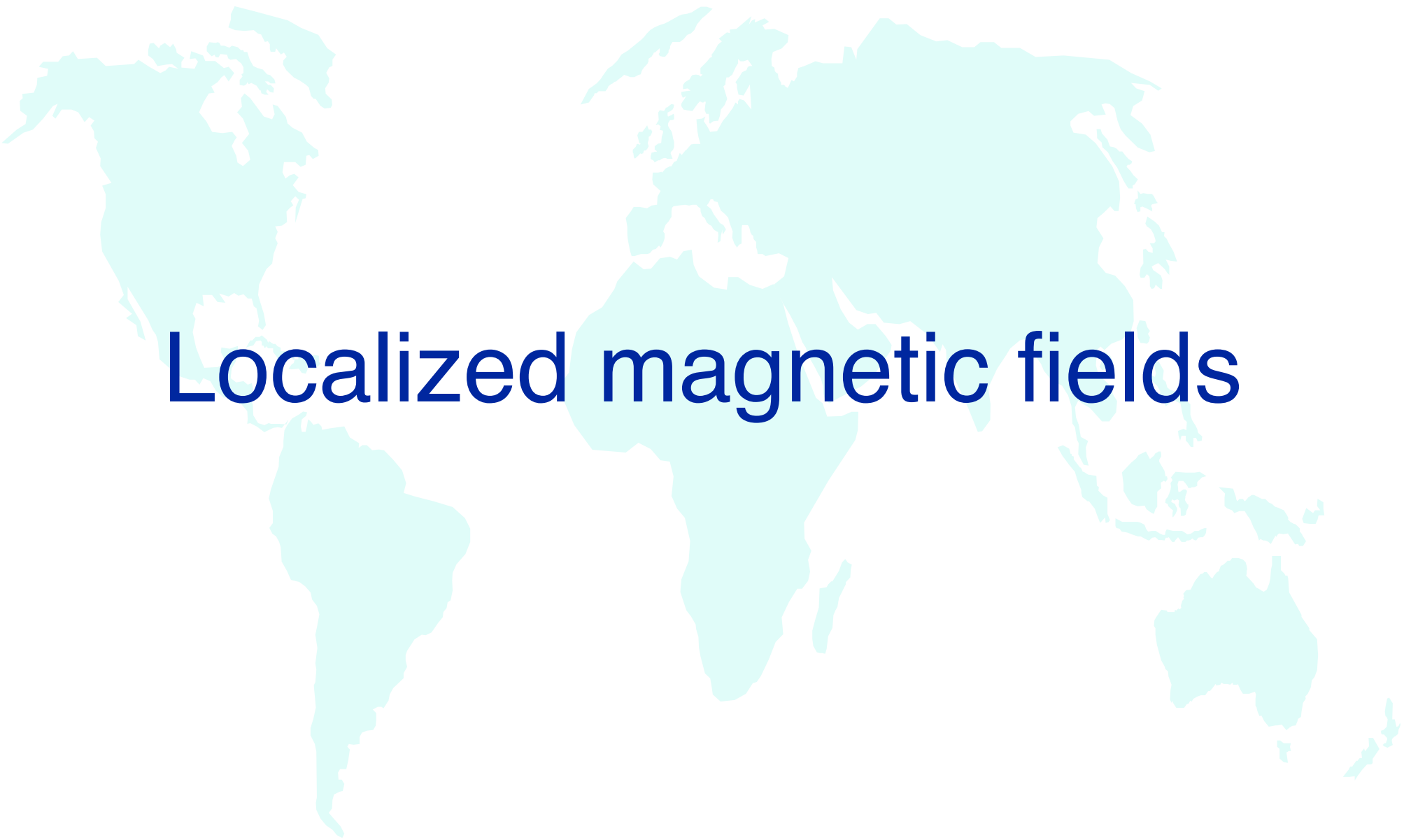
Credit: Tobiska

Helicity - characteristics

- ◆ Helicity, the wrapping of a magnetic field around itself, is global quantity and expresses the velocity for steady state turbulence
- ◆ conserved even in resistive MHD
- ◆ helicity pattern is cycle-invariant and would incessantly accumulate unless Sun gets rid of it
- ◆ Helicity is continuously generated
 - in toroidal flux layer and tachocline by differential rotation and helical motions
 - brought up by emergence of buoyant twisted flux tubes
 - increased by surface differential rotation and localized shearing foot-point motions

MHD diffusion effects

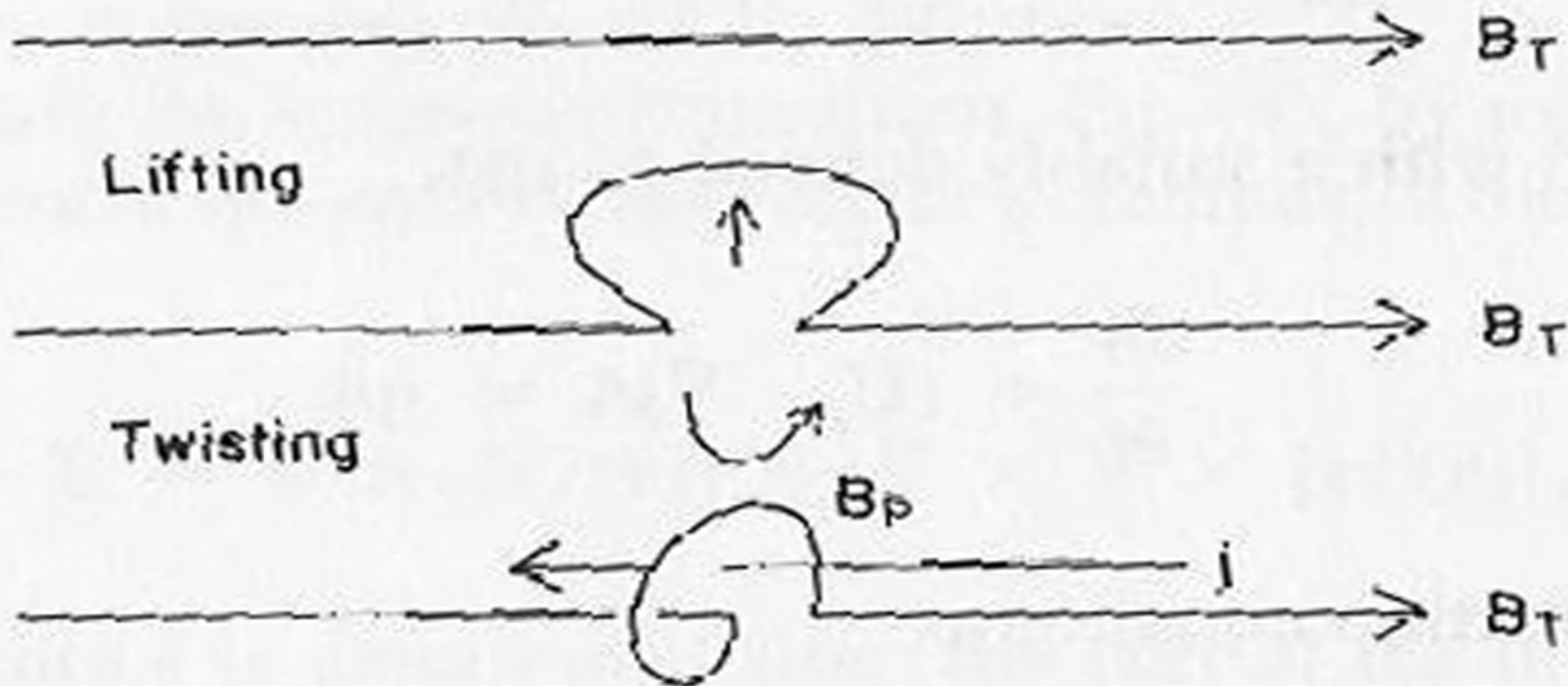


A light blue world map is centered in the background of the slide.

Localized magnetic fields

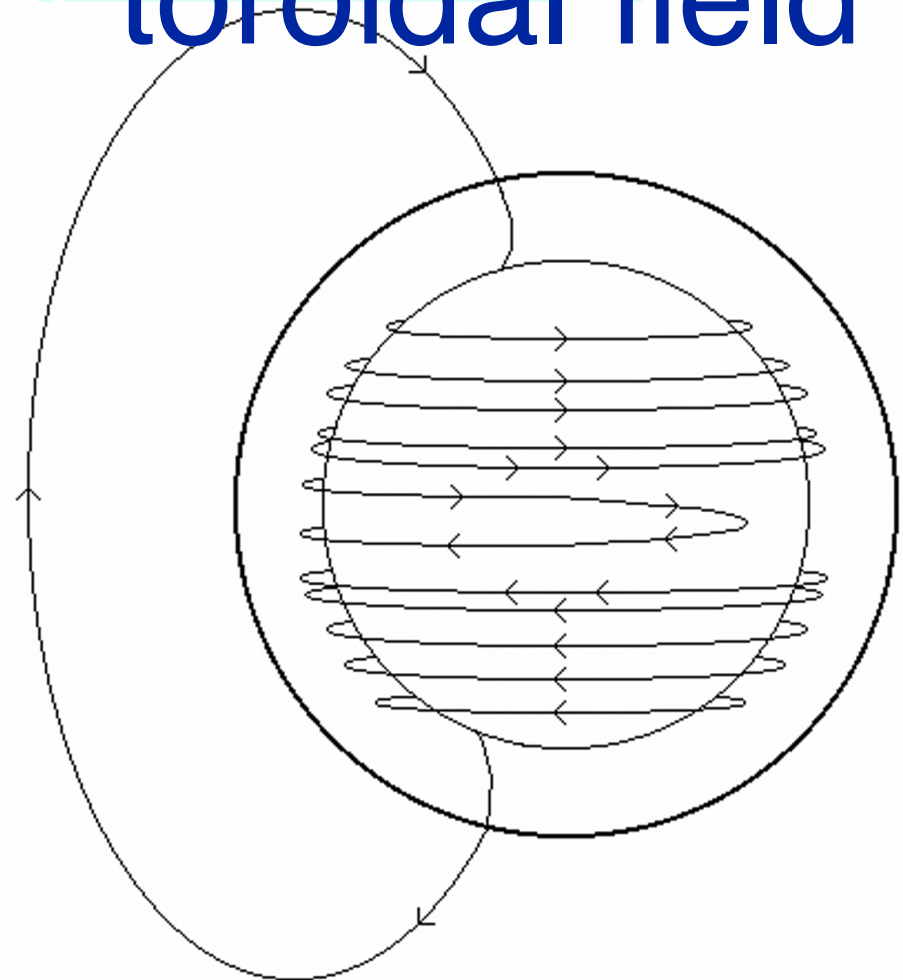
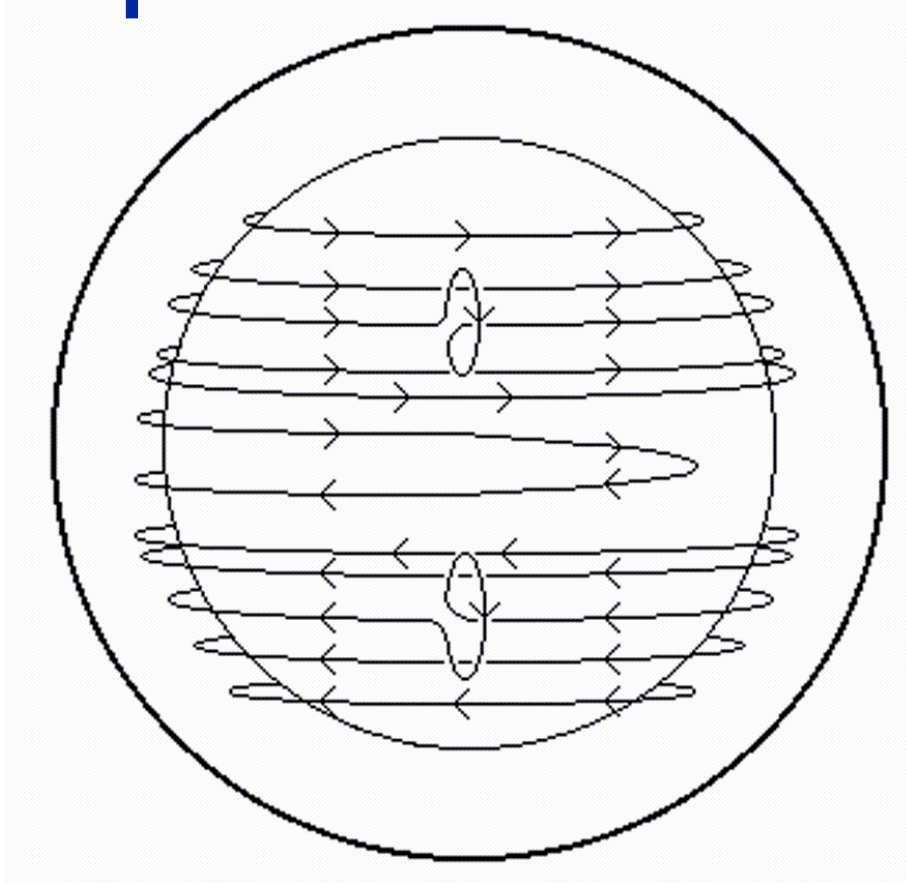
Poloidal induction

INDUCTION OF POLOIDAL FIELD B_p FROM
TOROIDAL FIELD B_T VIA THE α EFFECT



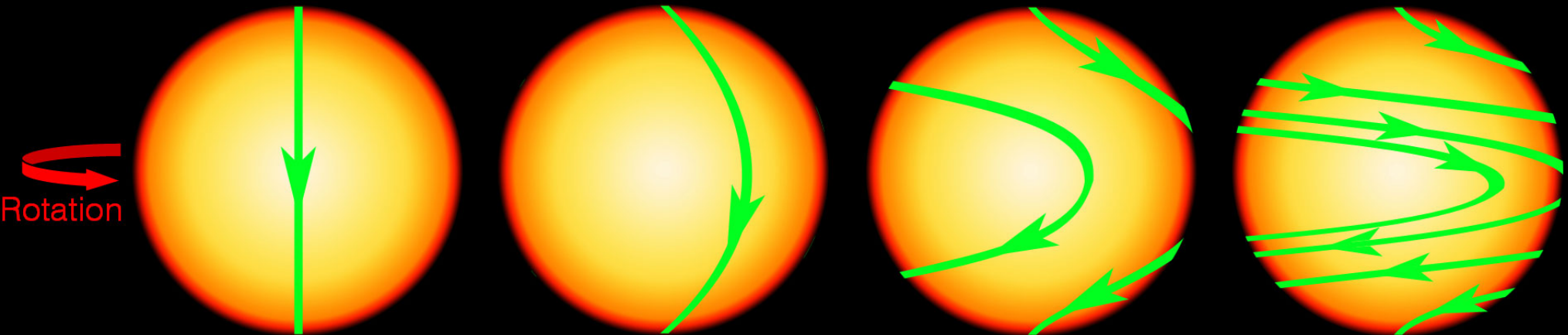
α -effect
poloidal field

ω -effect
toroidal field



Omega Effect

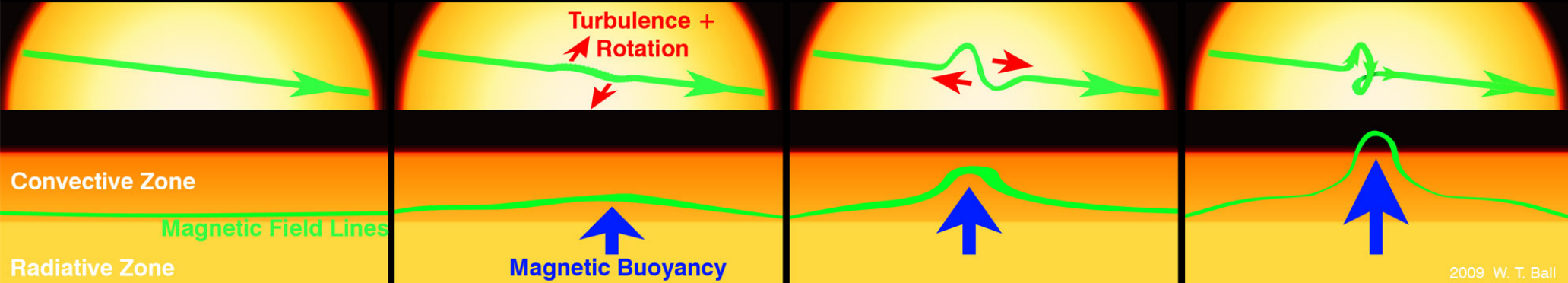
— Magnetic Field Lines



2009 W. T. Ball

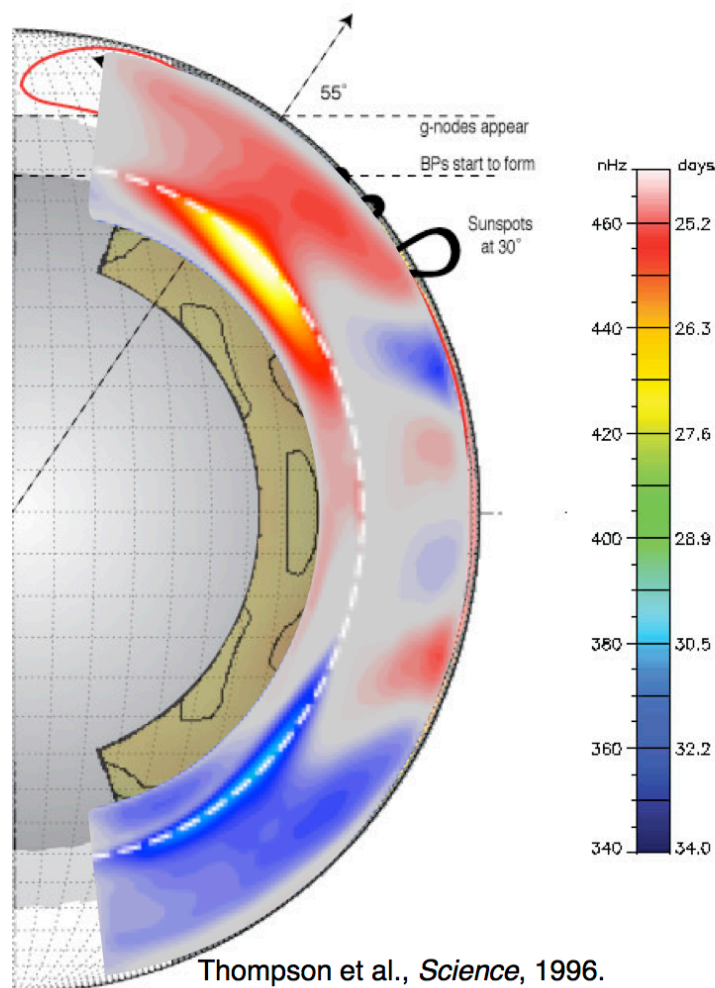
Alpha Effect

— Magnetic Field Lines



2009 W. T. Ball

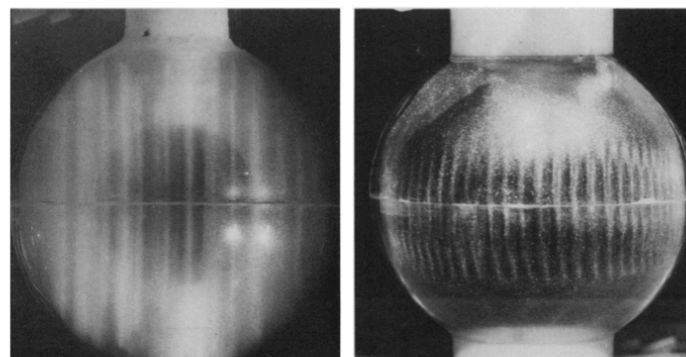
Cartoon Progression



(Toroidal) magnetic flux appears to form at the tachocline at the projected latitude of the driven differential rotation ($\sim 55^\circ$).

Some of that flux rises and is caught in the polar circulation, the rest is caught in the equatorial flow.

The “g-nodes” and BPs appear to outline giant cell convection - organized in “banana cells” by RZ rotation.



Busse & Carrigan, *Science* (1976)
“Laboratory Simulation of Thermal Convection in Rotating Planets and Stars”

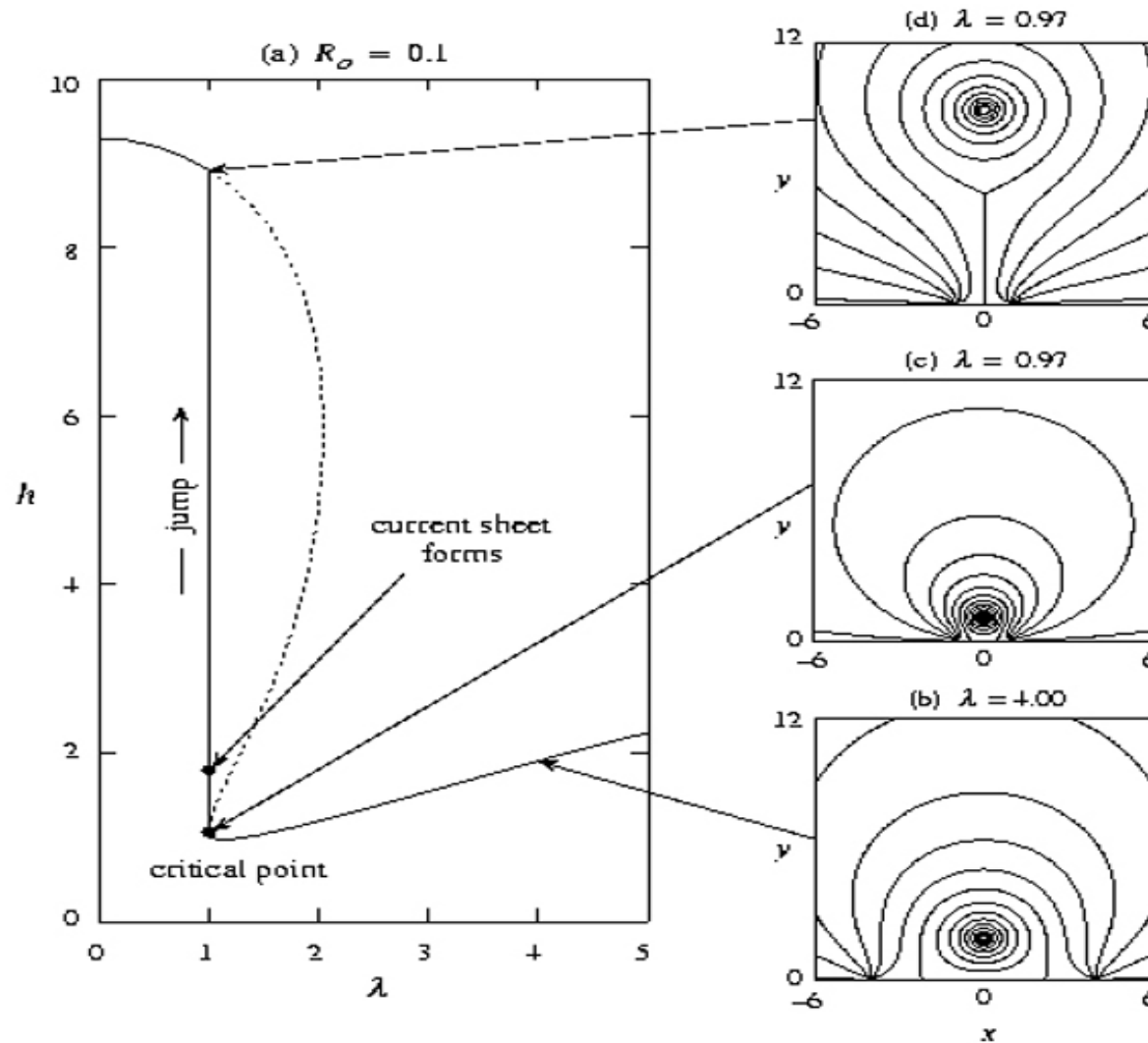
High latitudinal dependence of surface pattern based on RZ source.

Thompson et al., *Science*, 1996.
Racine et al., *ApJ*, 2011.

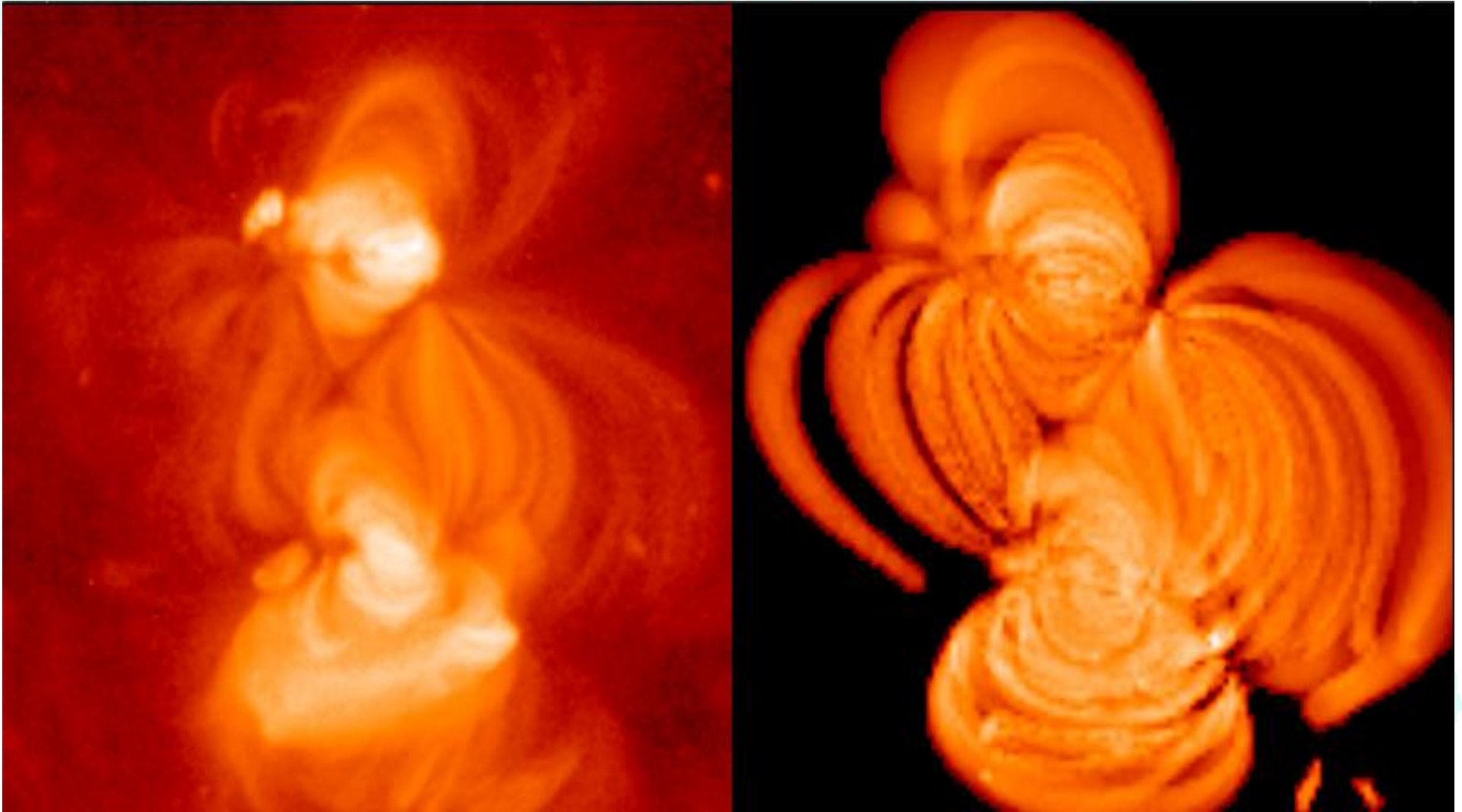
Scott McIntosh - mscott@ucar.edu - NJF '13 Presentation

HAO

Ideal MHD case



Example of flux tube model



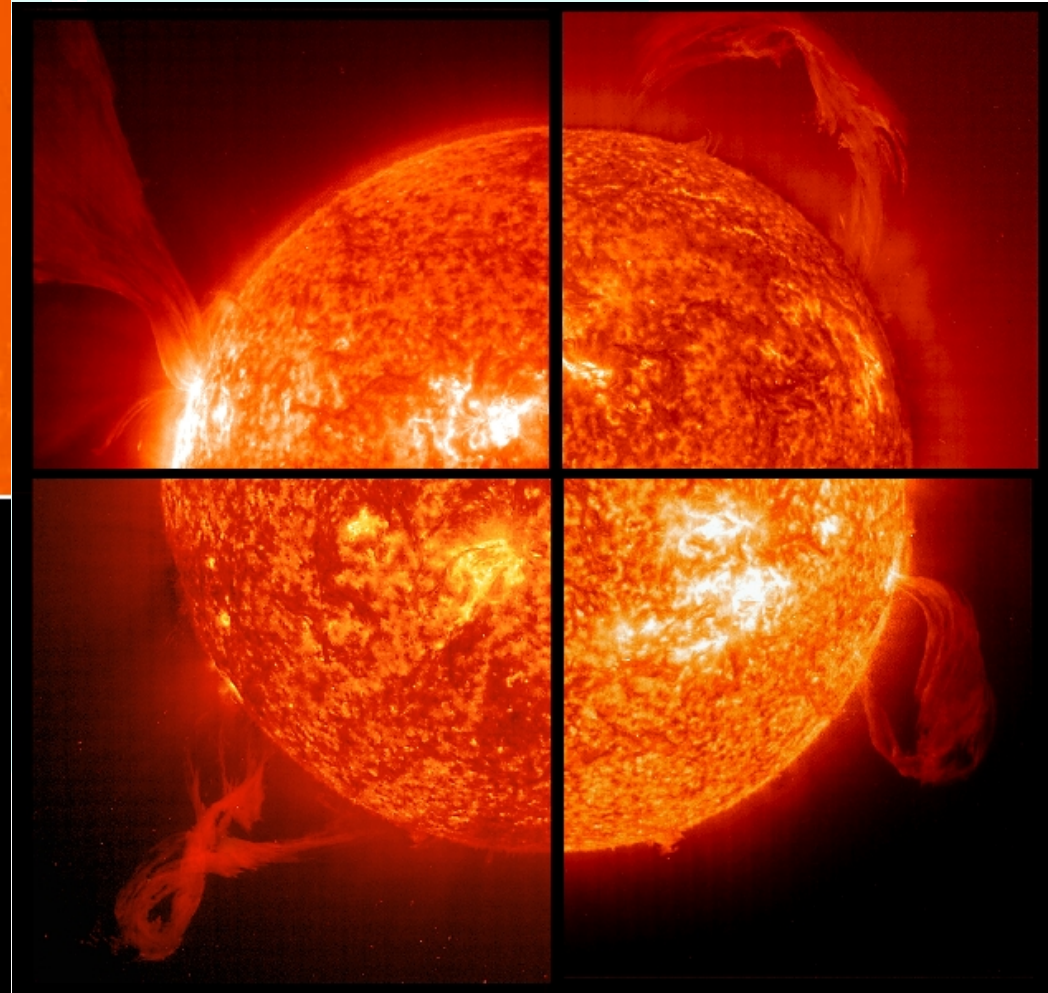
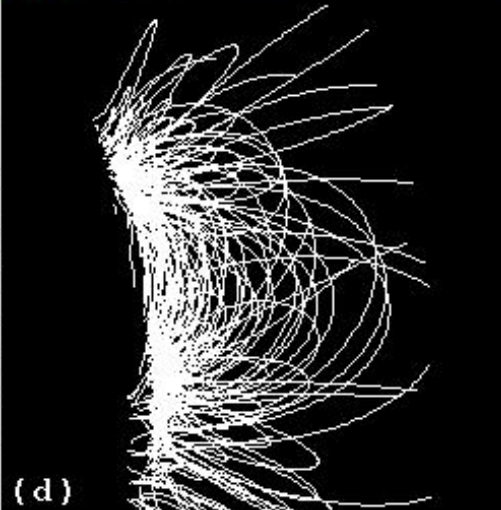
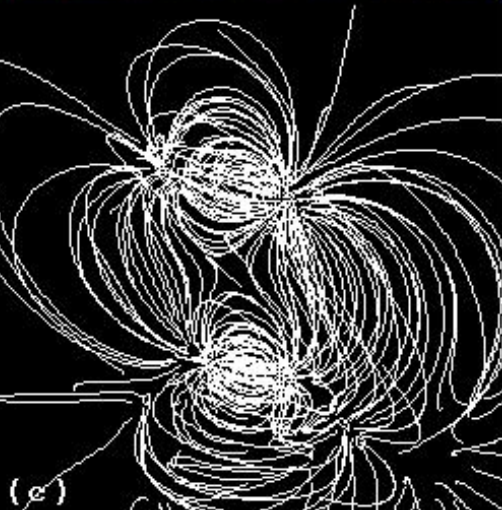
Example of flux tube model

Corona

LOS B-field

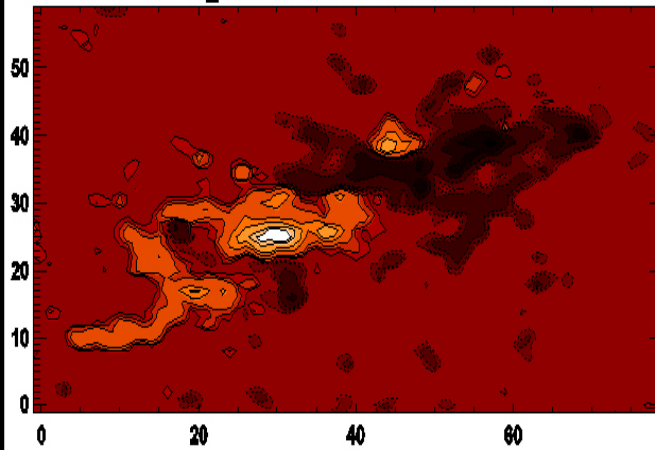
(a)

(b)

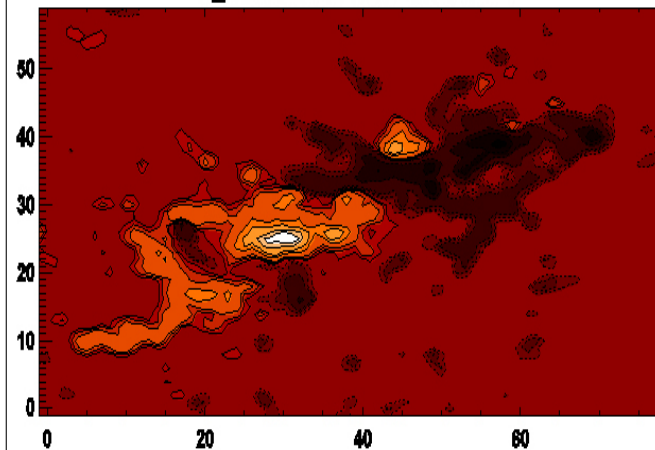


Bipolar magnetic fields

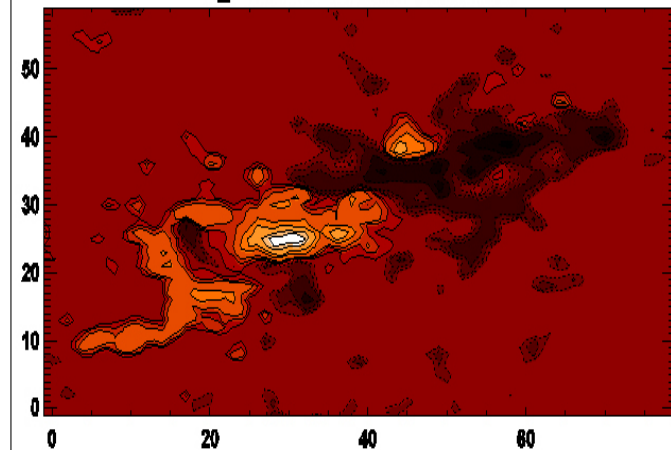
B_r Contour at 01:39 1997/11/02



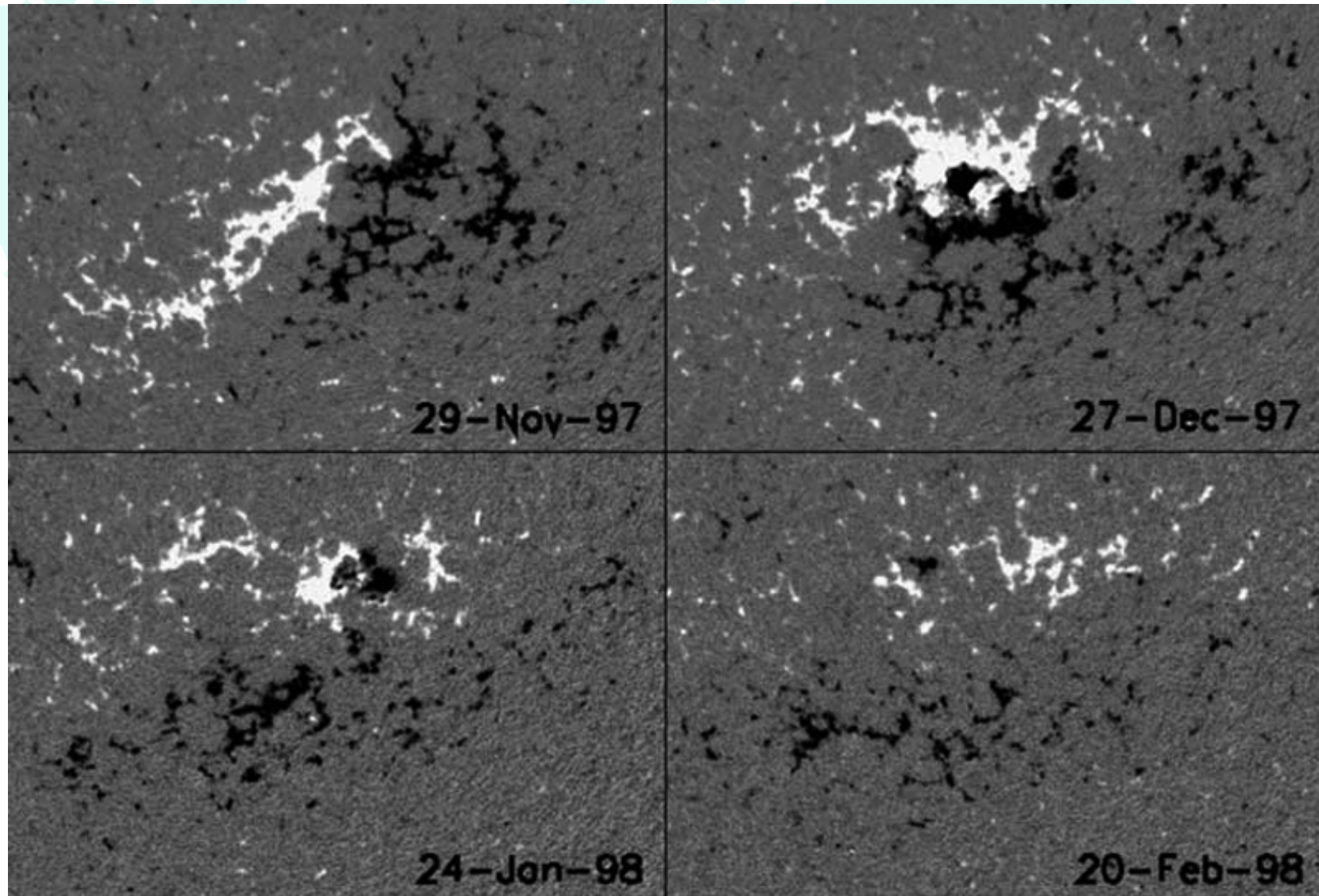
B_r Contour at 03:15 1997/11/02



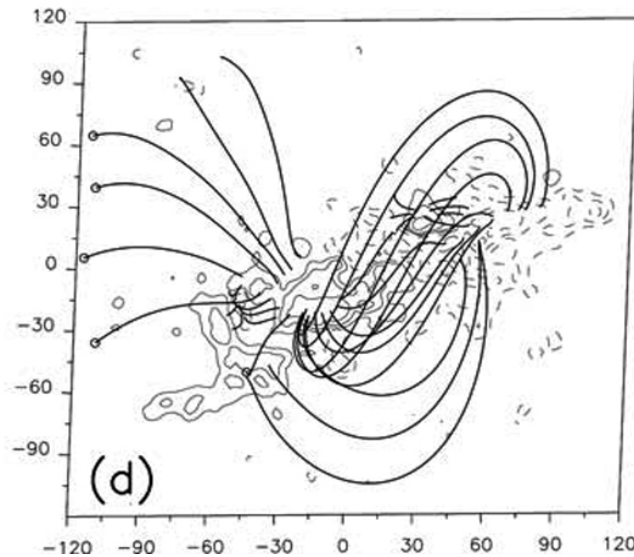
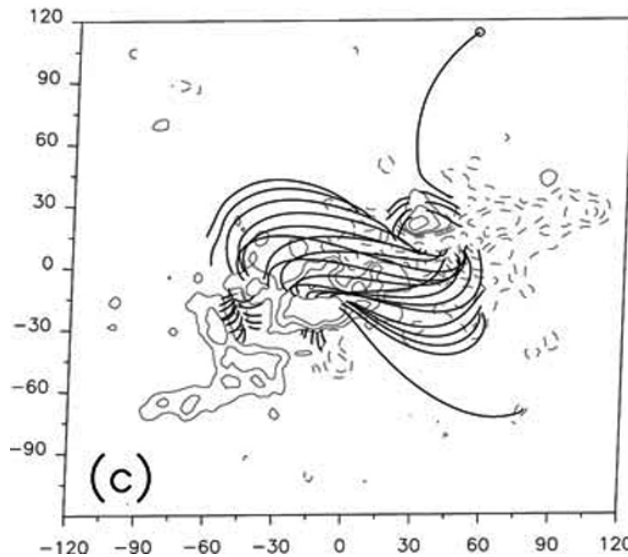
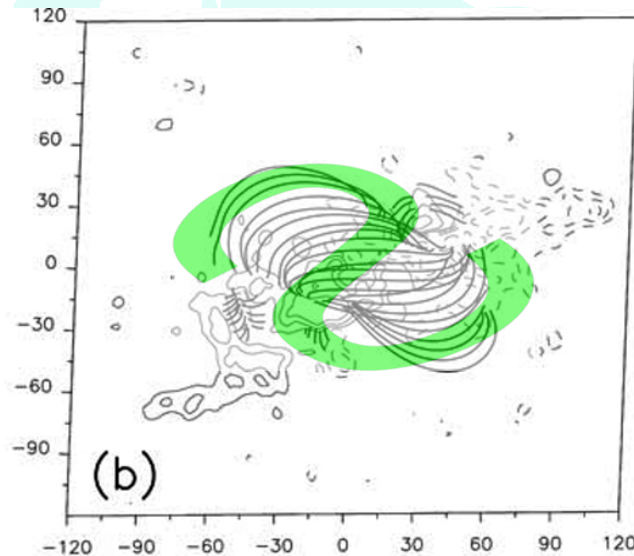
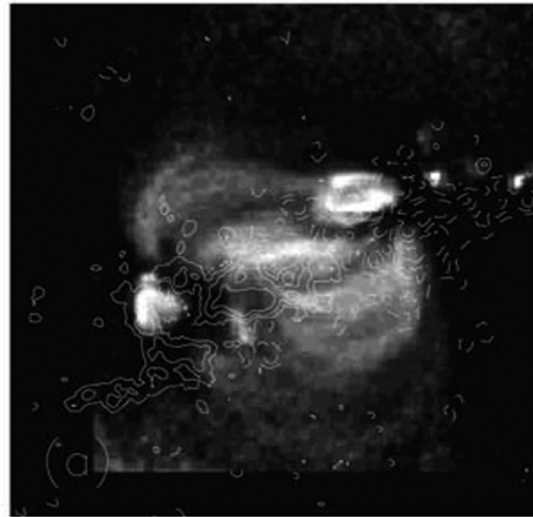
B_r Contour at 04:51 1997/11/02



Example of AR8100



Example of AR8100



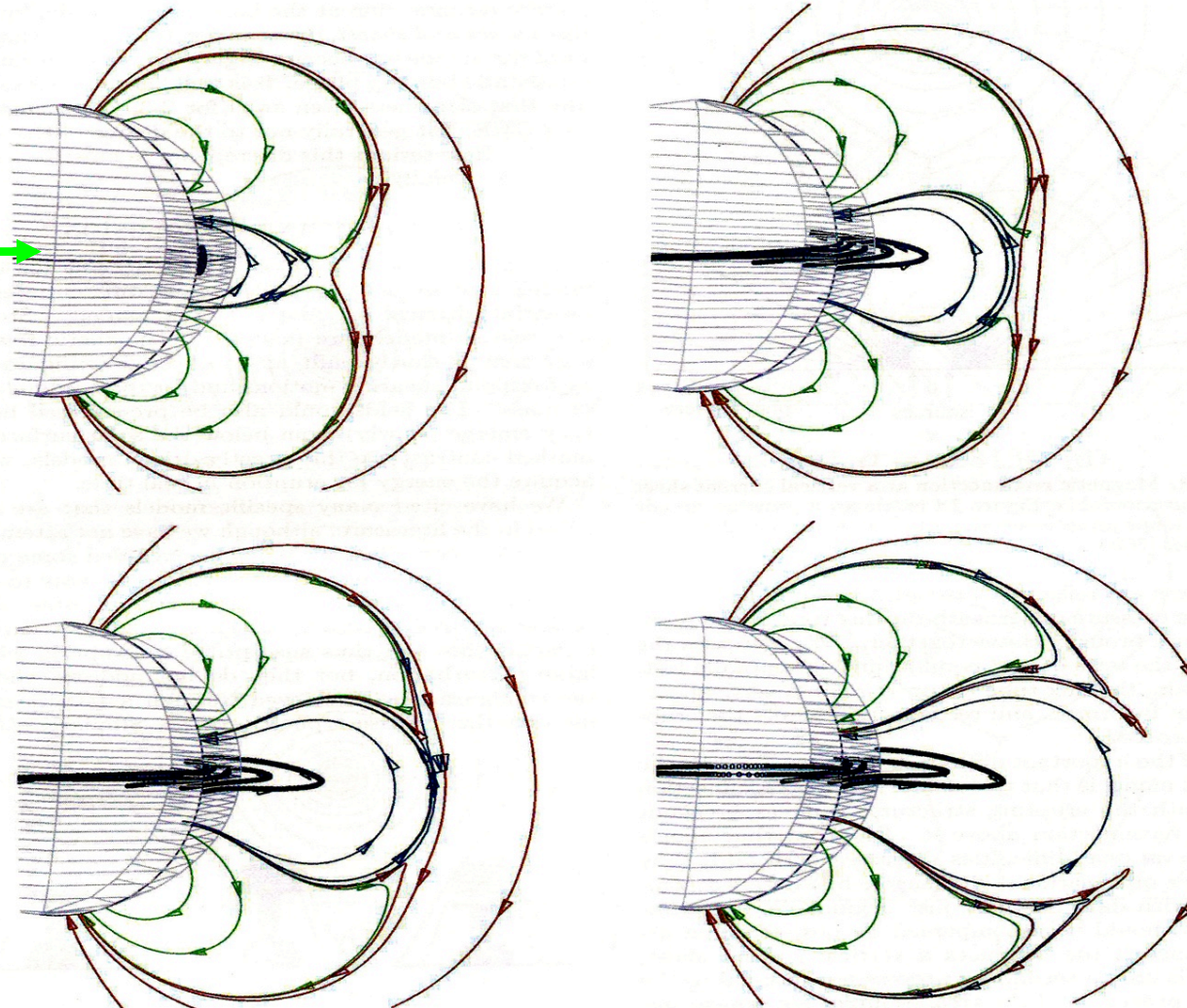


CMEs and Flares

- ◆ **Necessary conditions for CMEs**
 - eruptive flare occurrence, complex mag topology
 - filament eruption, high helicity
- ◆ **Conditions for large-scale trans-equatorial CMEs**
 - having the same sign of helicity
 - eruptive events at either footpoint
- ◆ ***similarities* between confined flares and CMEs - liberate magnetic energy**
- ◆ ***differences* between confined flares and CMEs - closed vs open field lines**

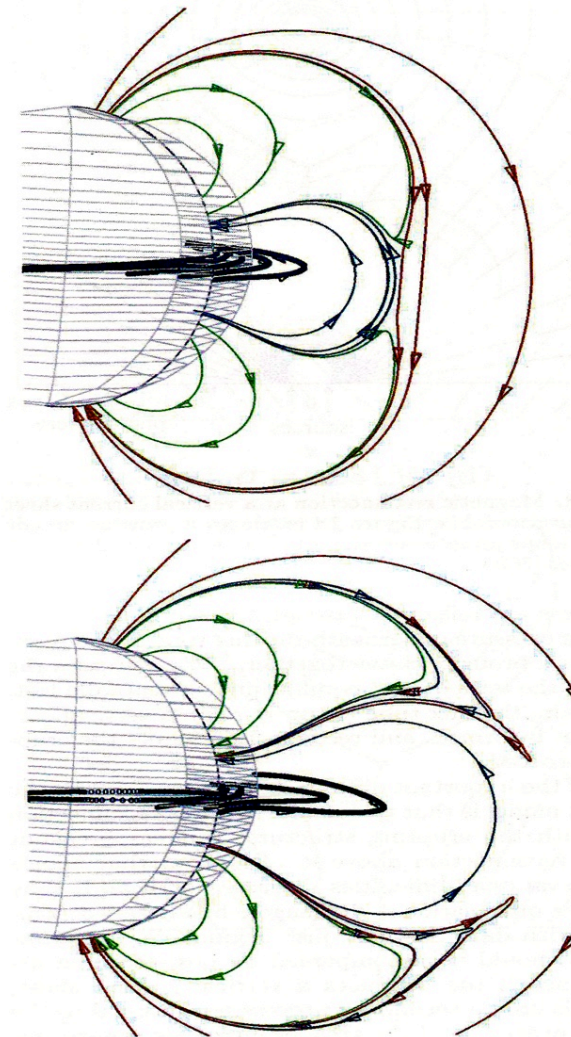
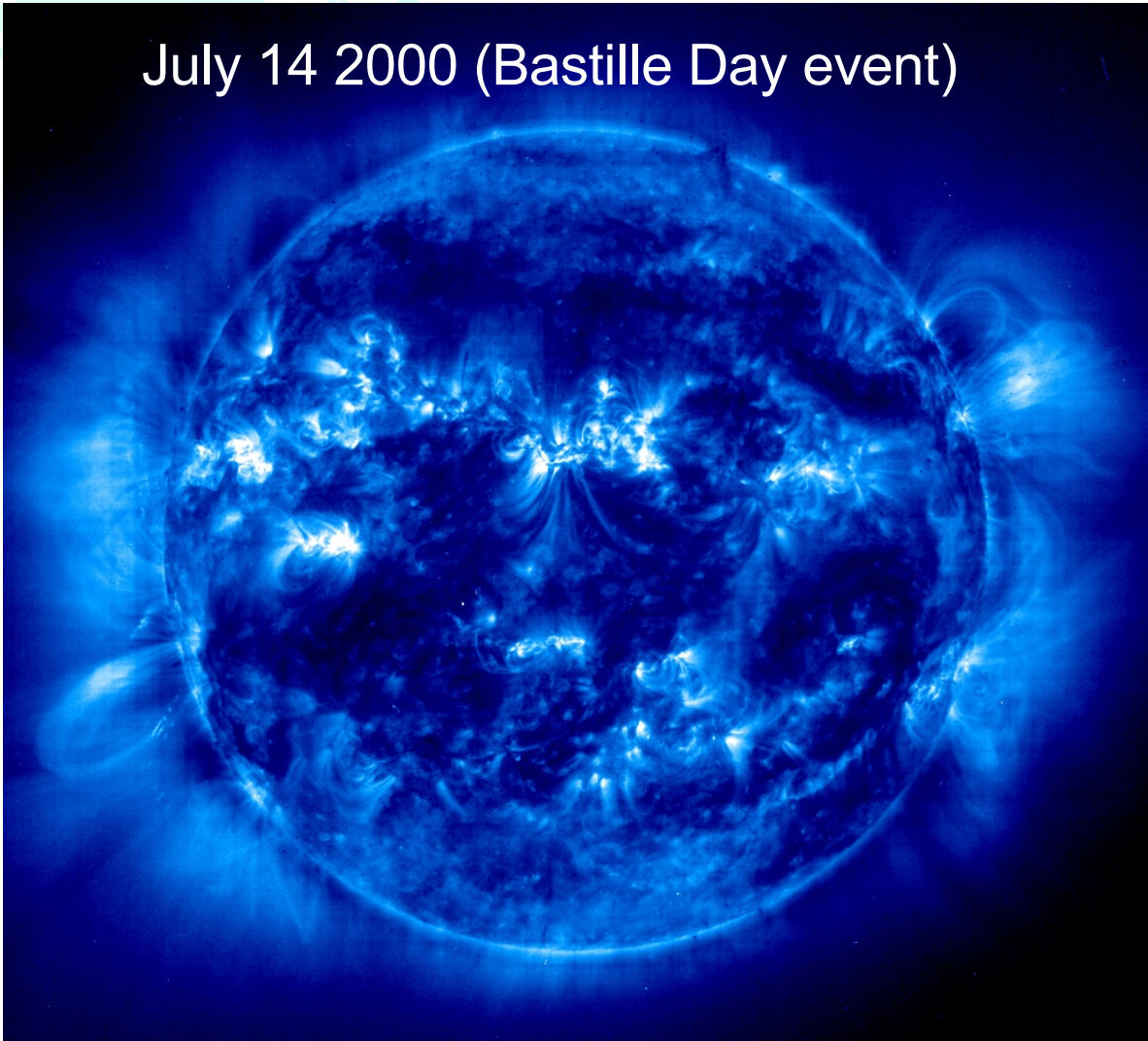
Breakout CME model

Neutral line = equator

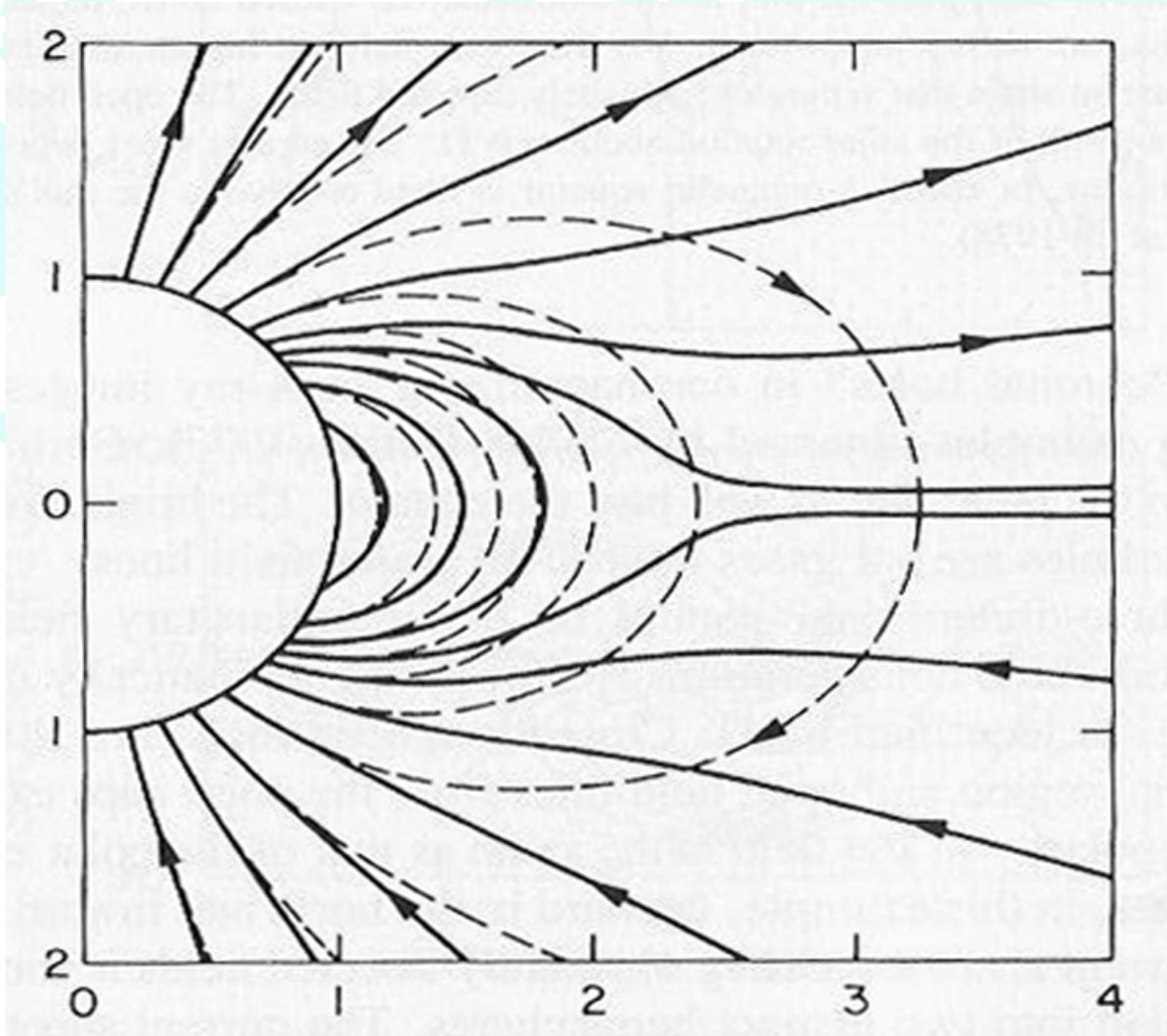


CME

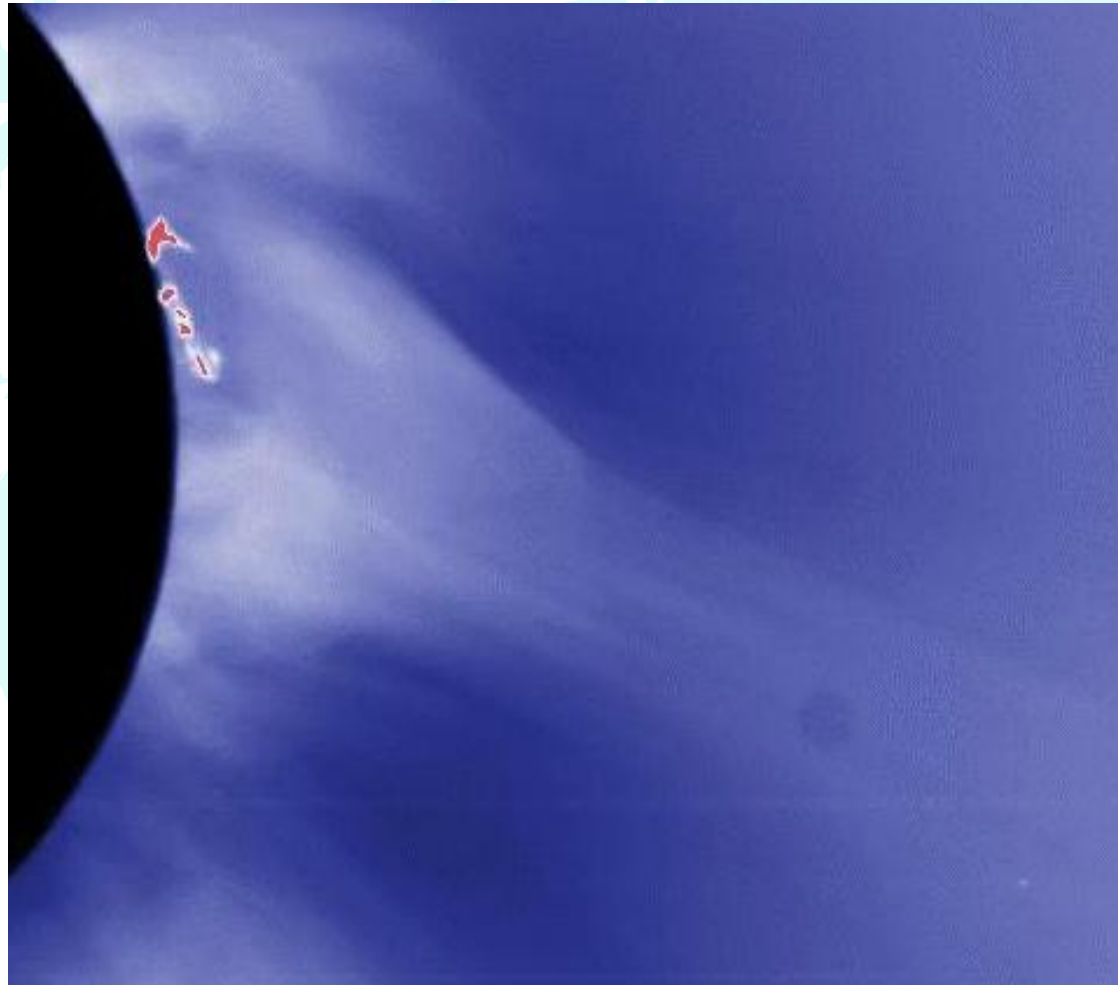
July 14 2000 (Bastille Day event)



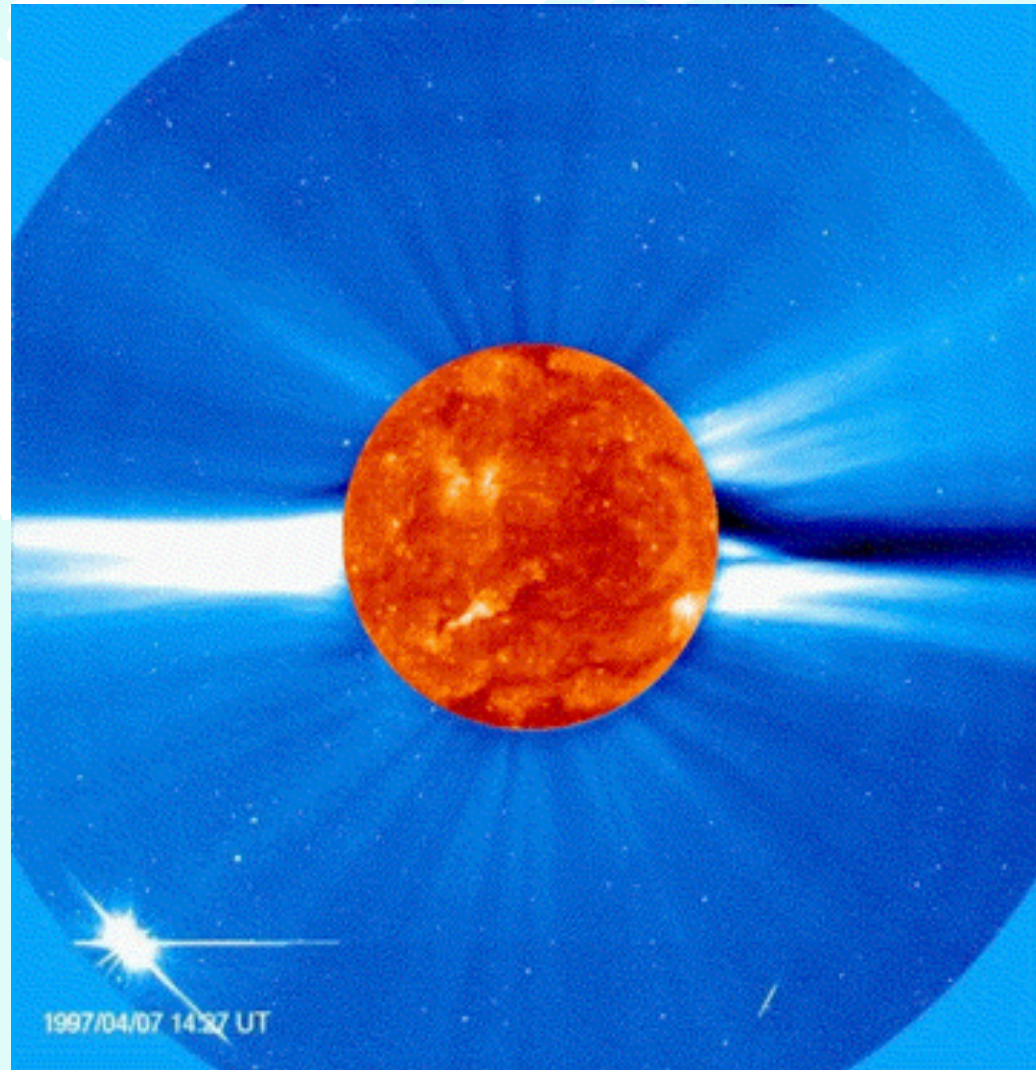
Solar-coronal magnetic field



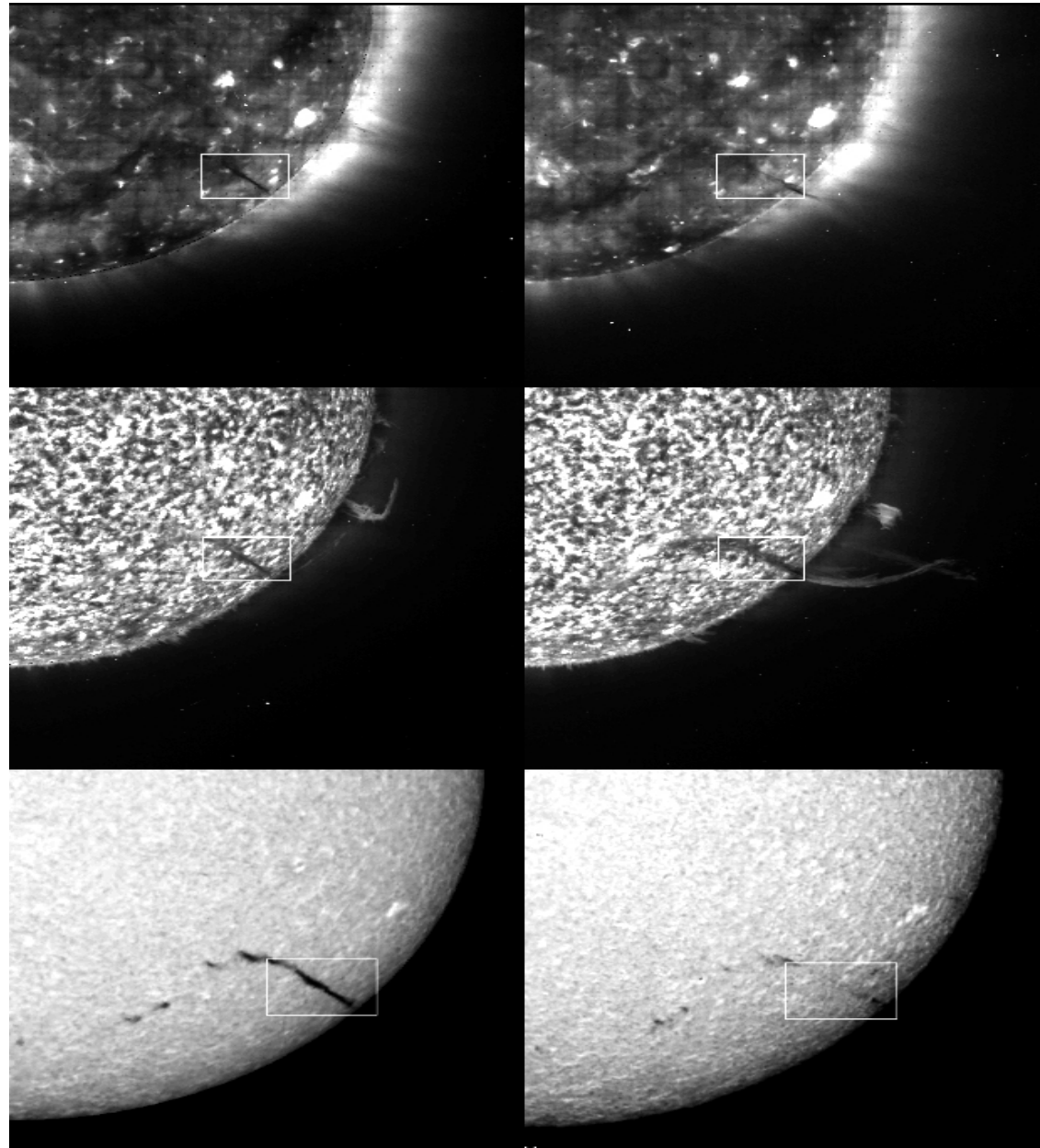
Helmet streamers



CMEs and halo events



Filament



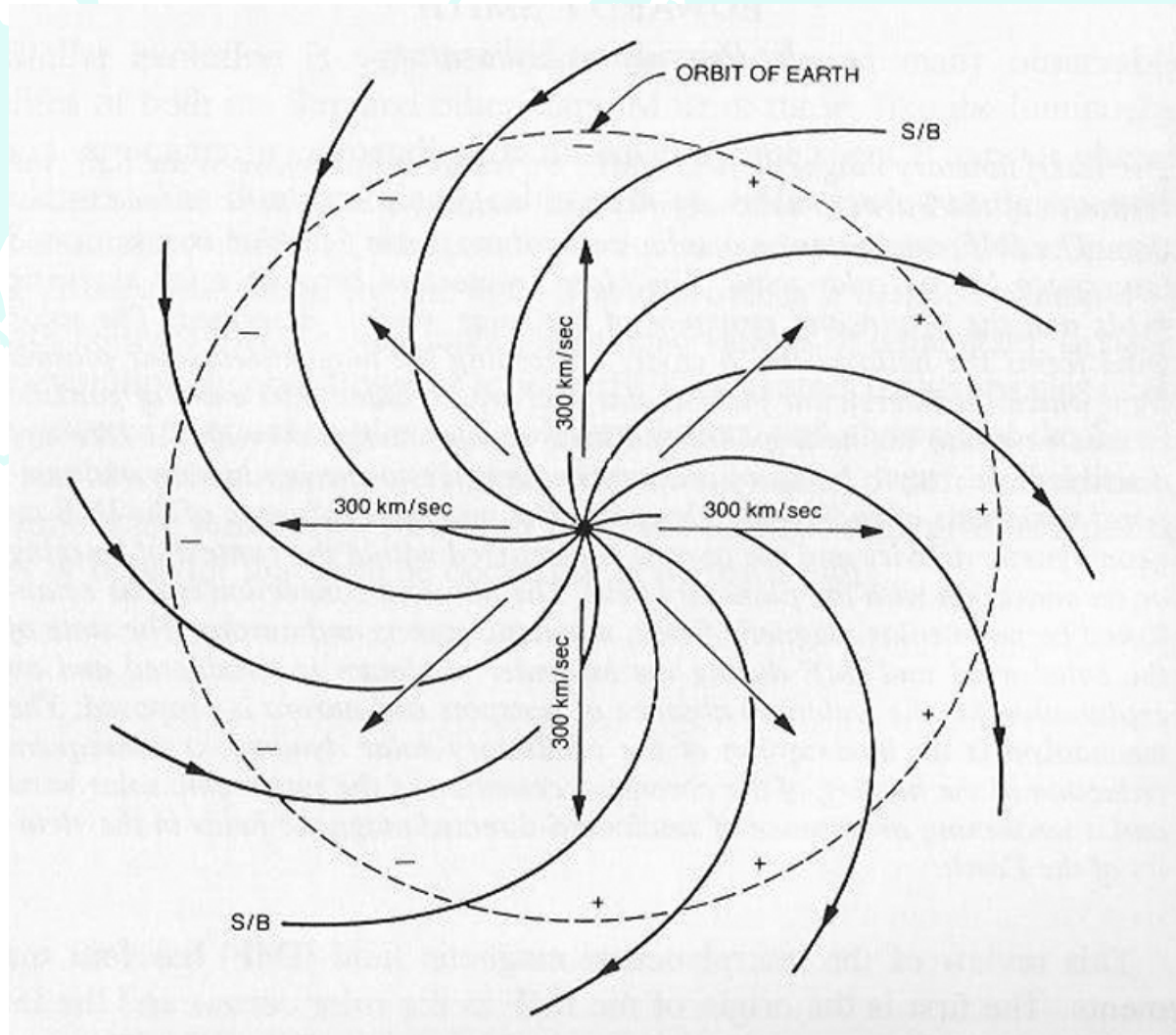


BREAK

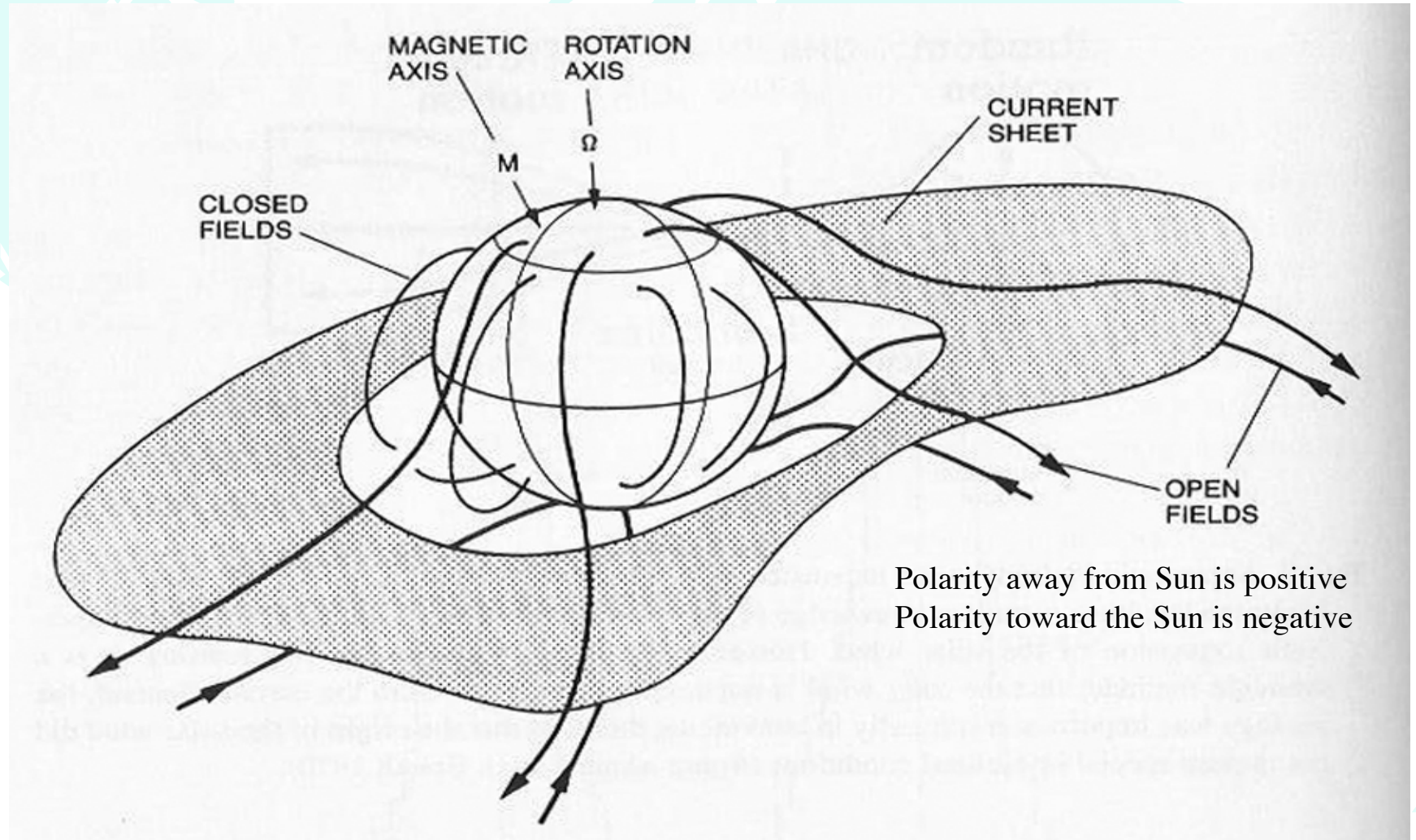
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Particles - the solar wind

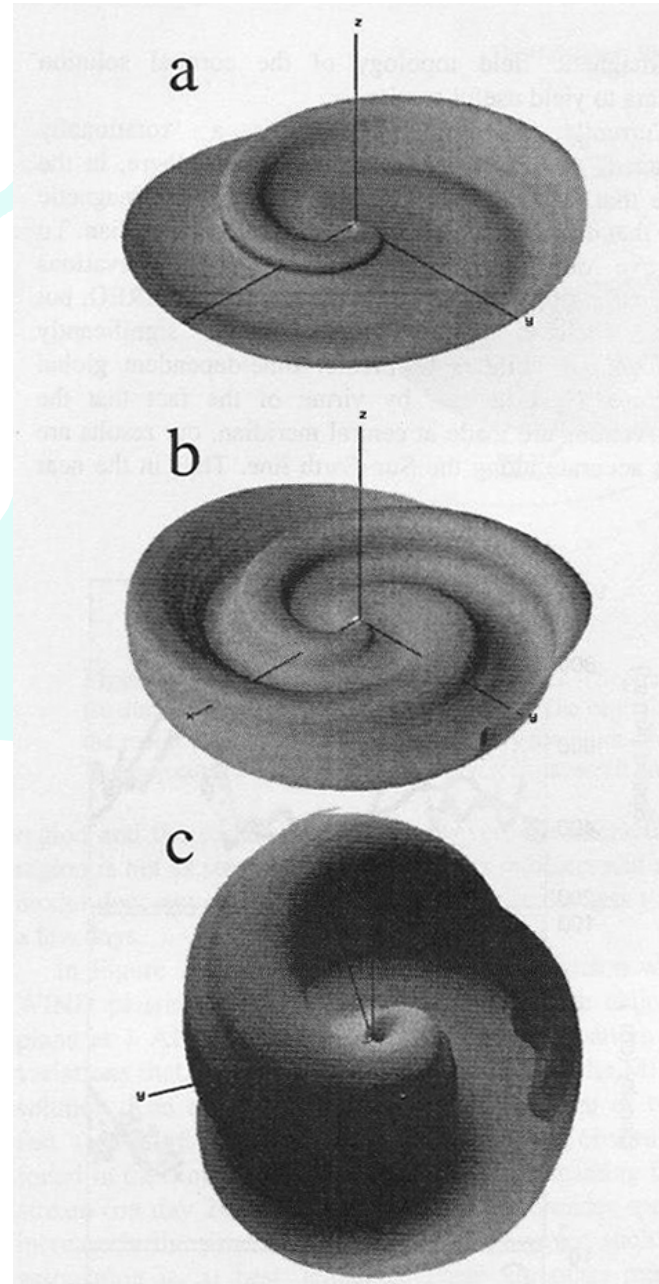
Interplanetary magnetic field



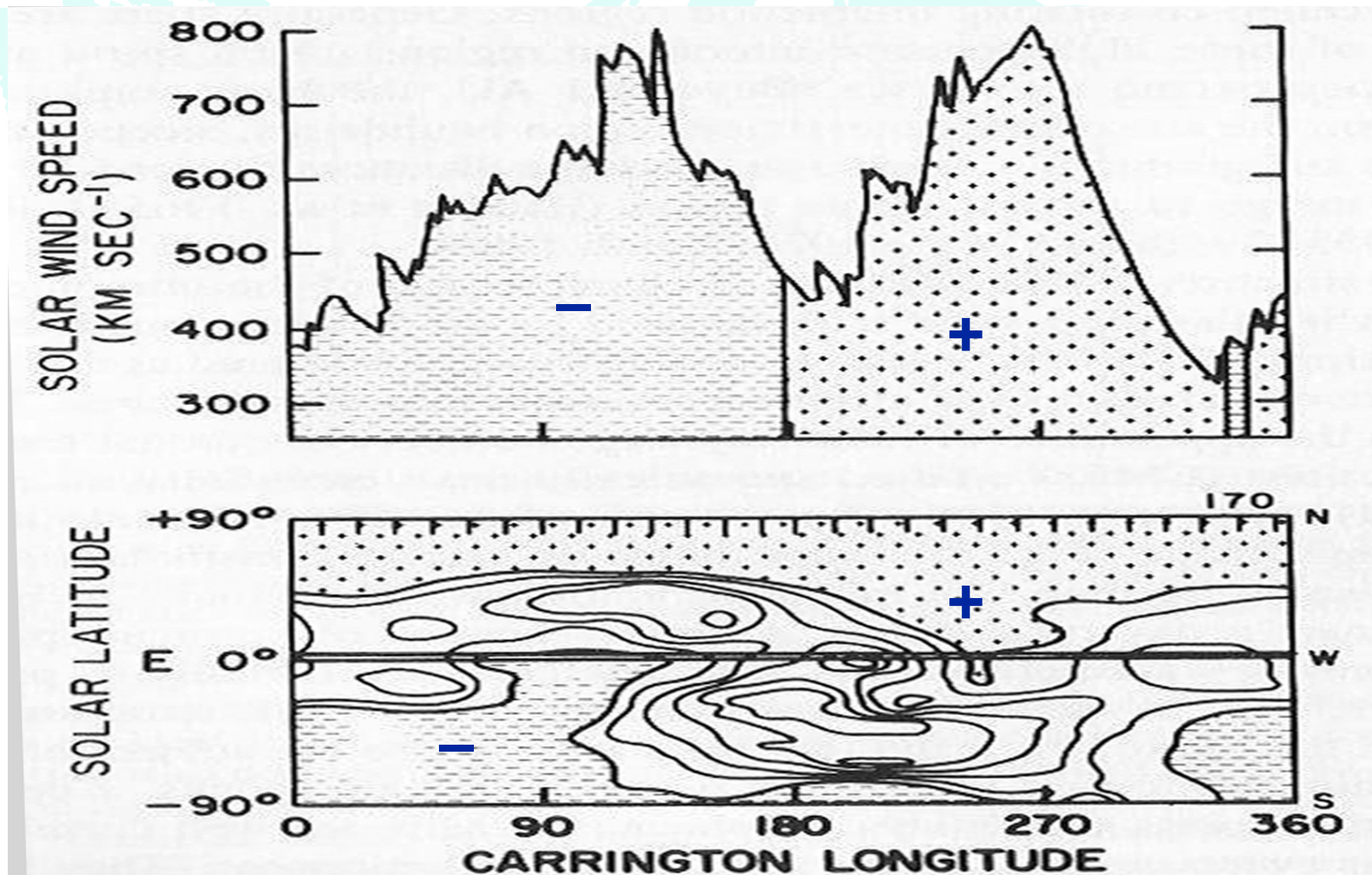
Current sheet



Current sheet and solar cycle dependence

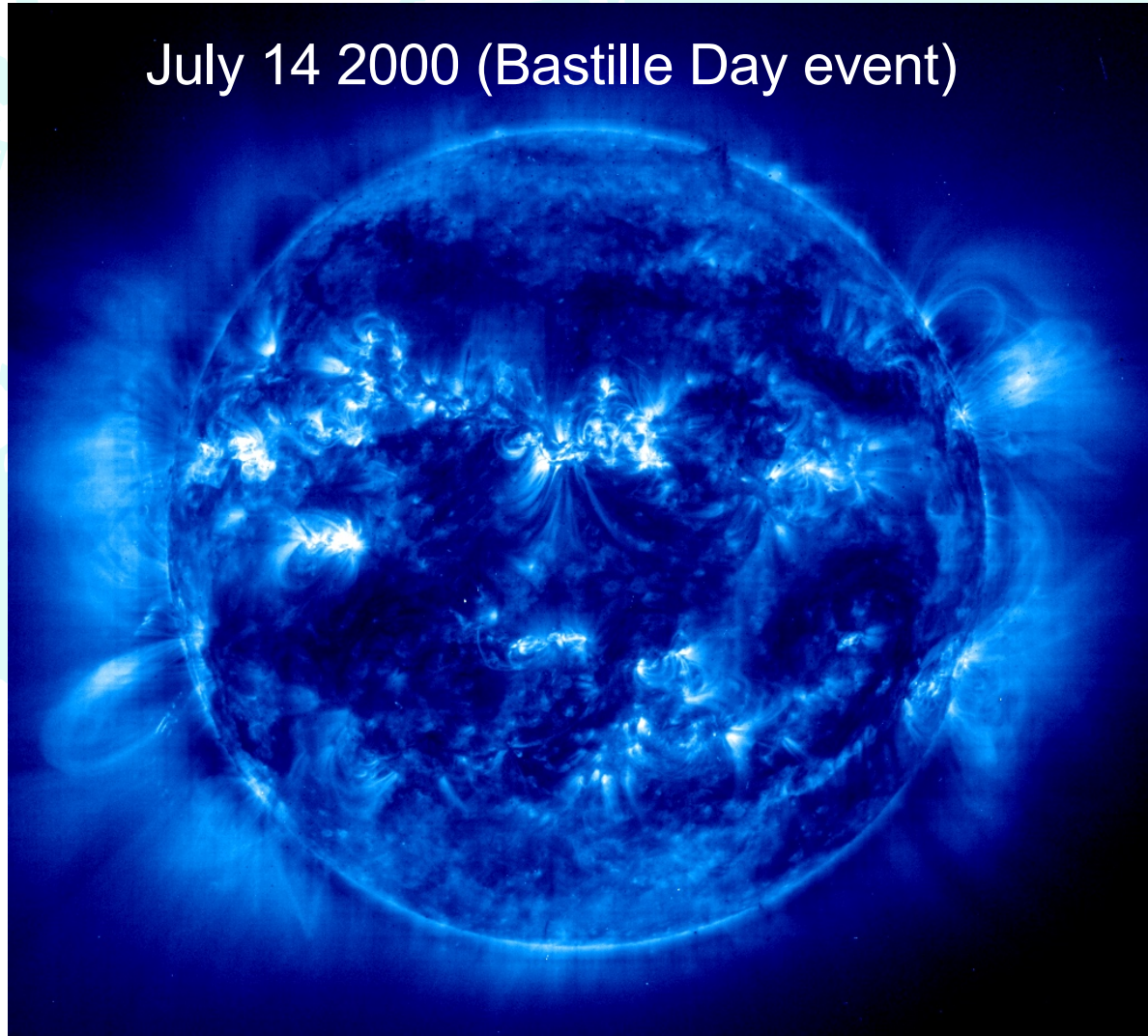


Solar wind and coronal holes

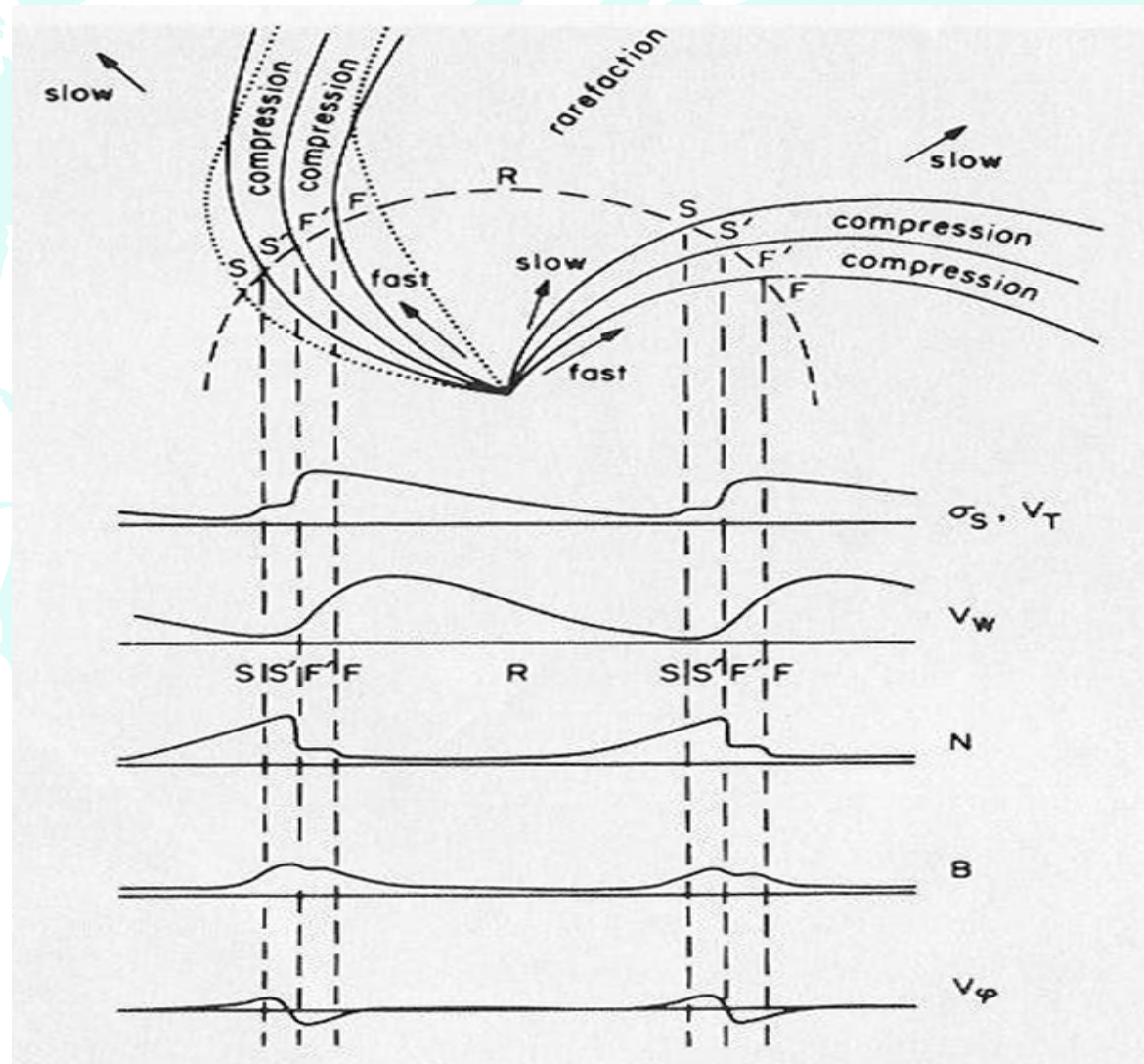


Coronal holes

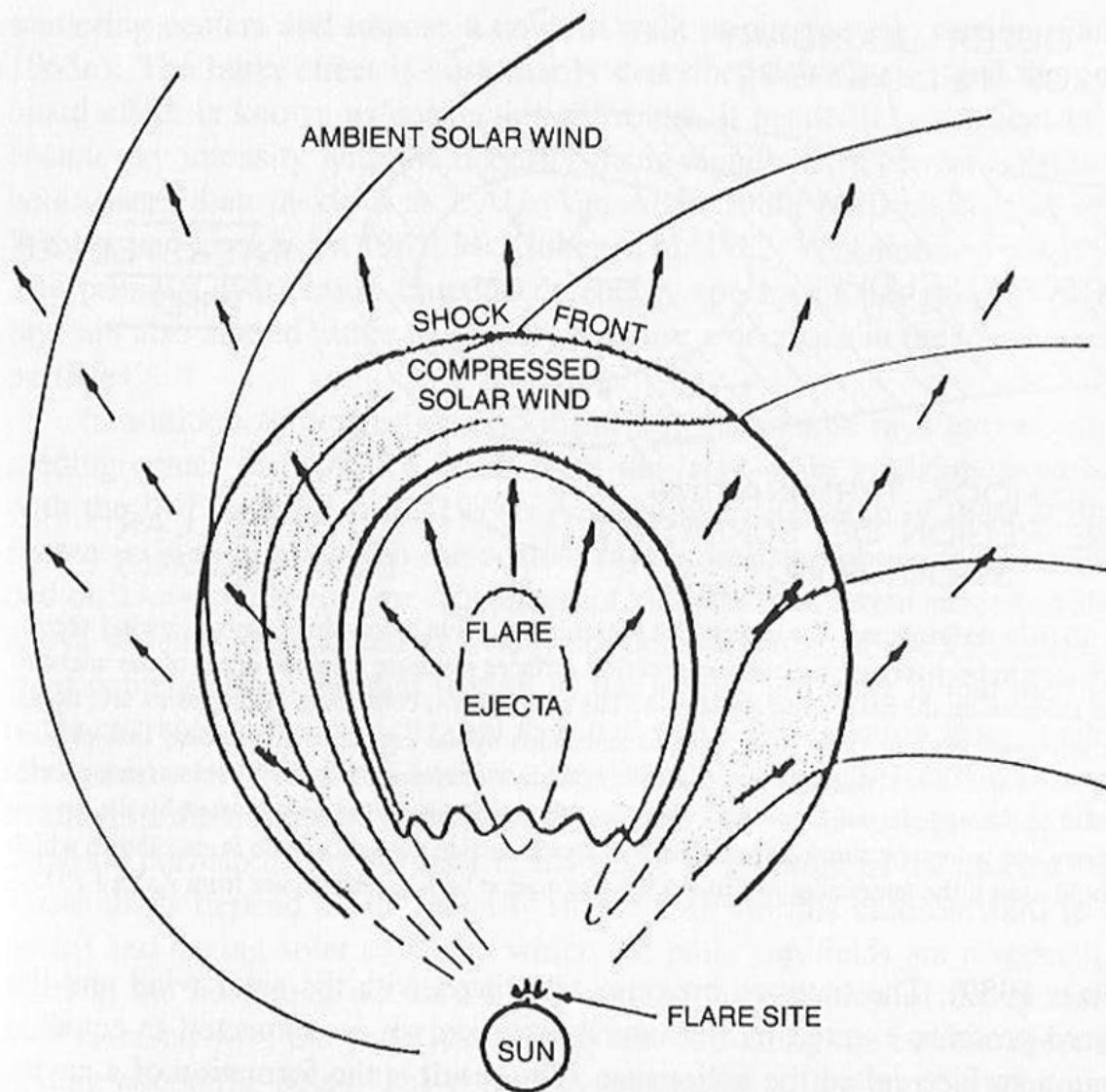
July 14 2000 (Bastille Day event)



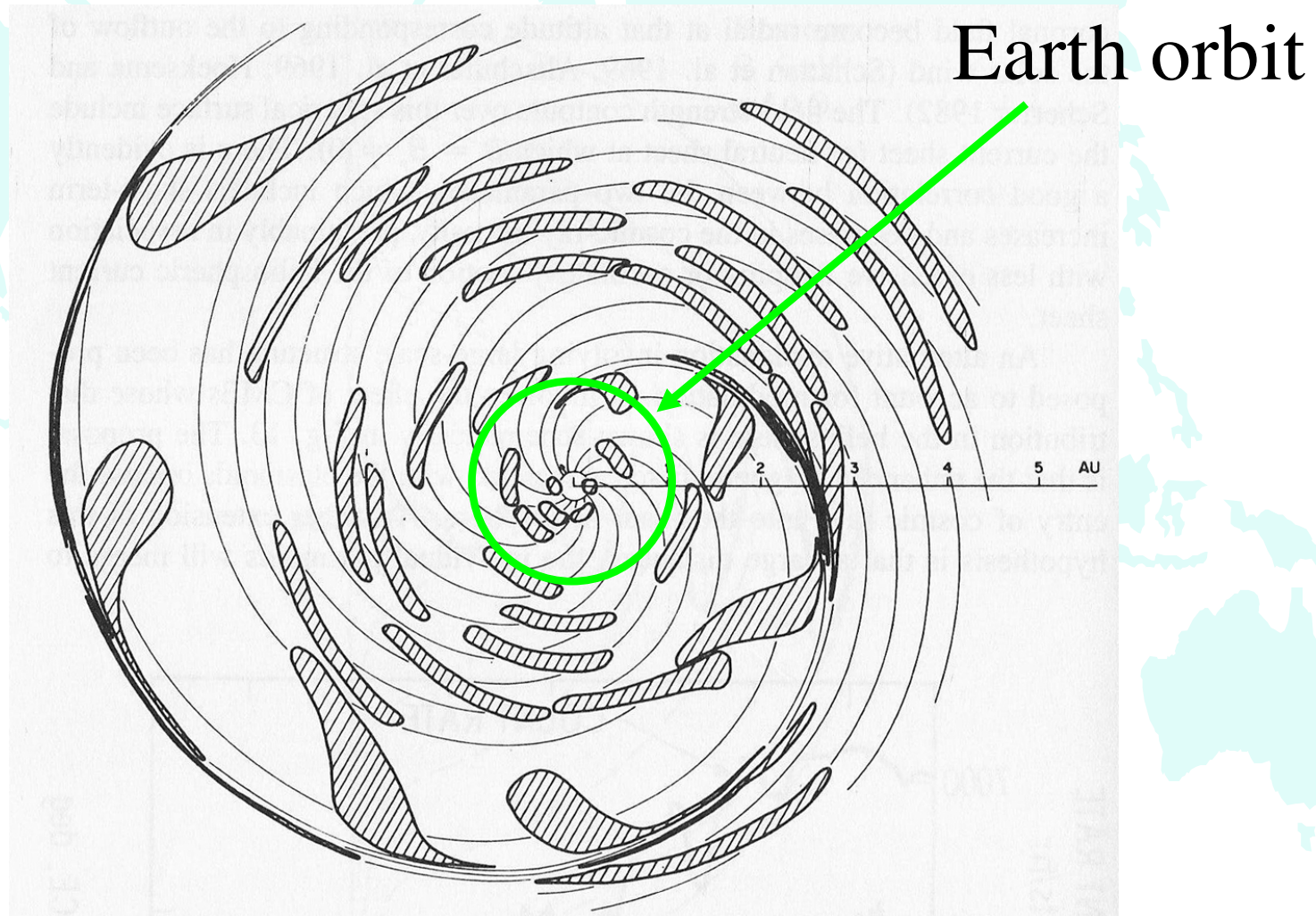
Corotating interacting regions



CME/solar wind interaction



CME distribution

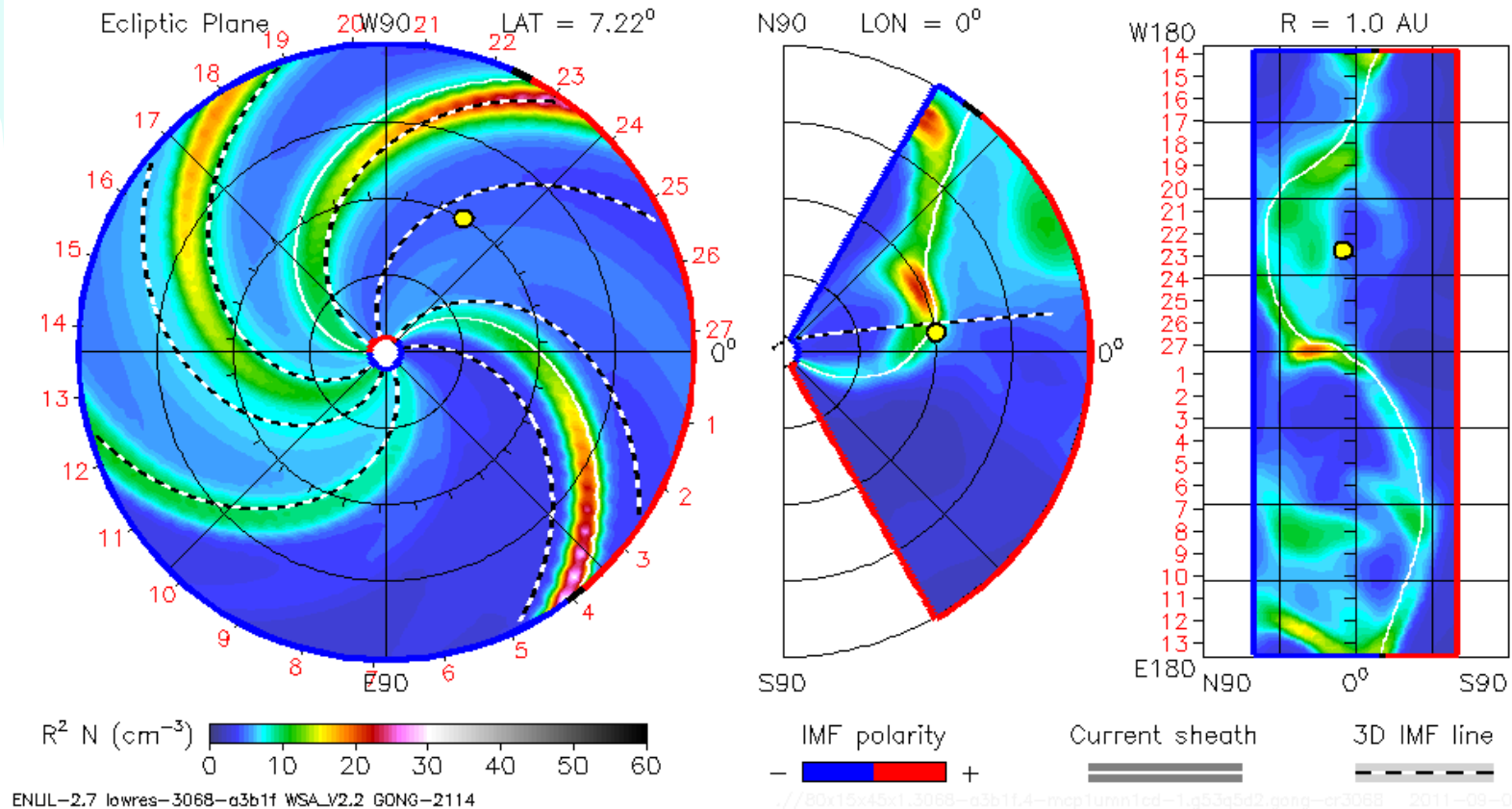


ENLIL: Interplanetary Magnetic Field (IMF)

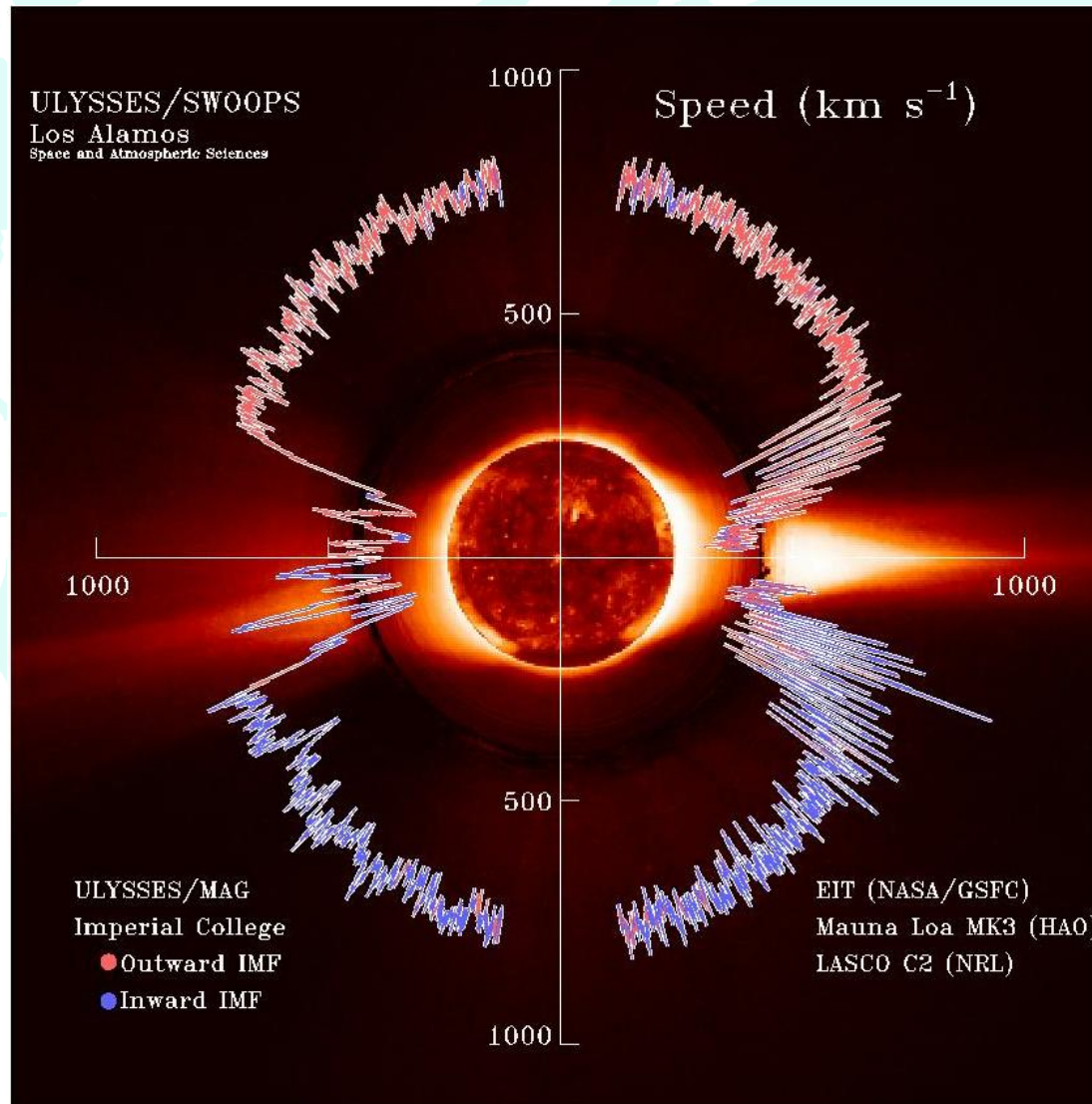
2011-09-06T05:00

2011-08-14T11 +22.73 days

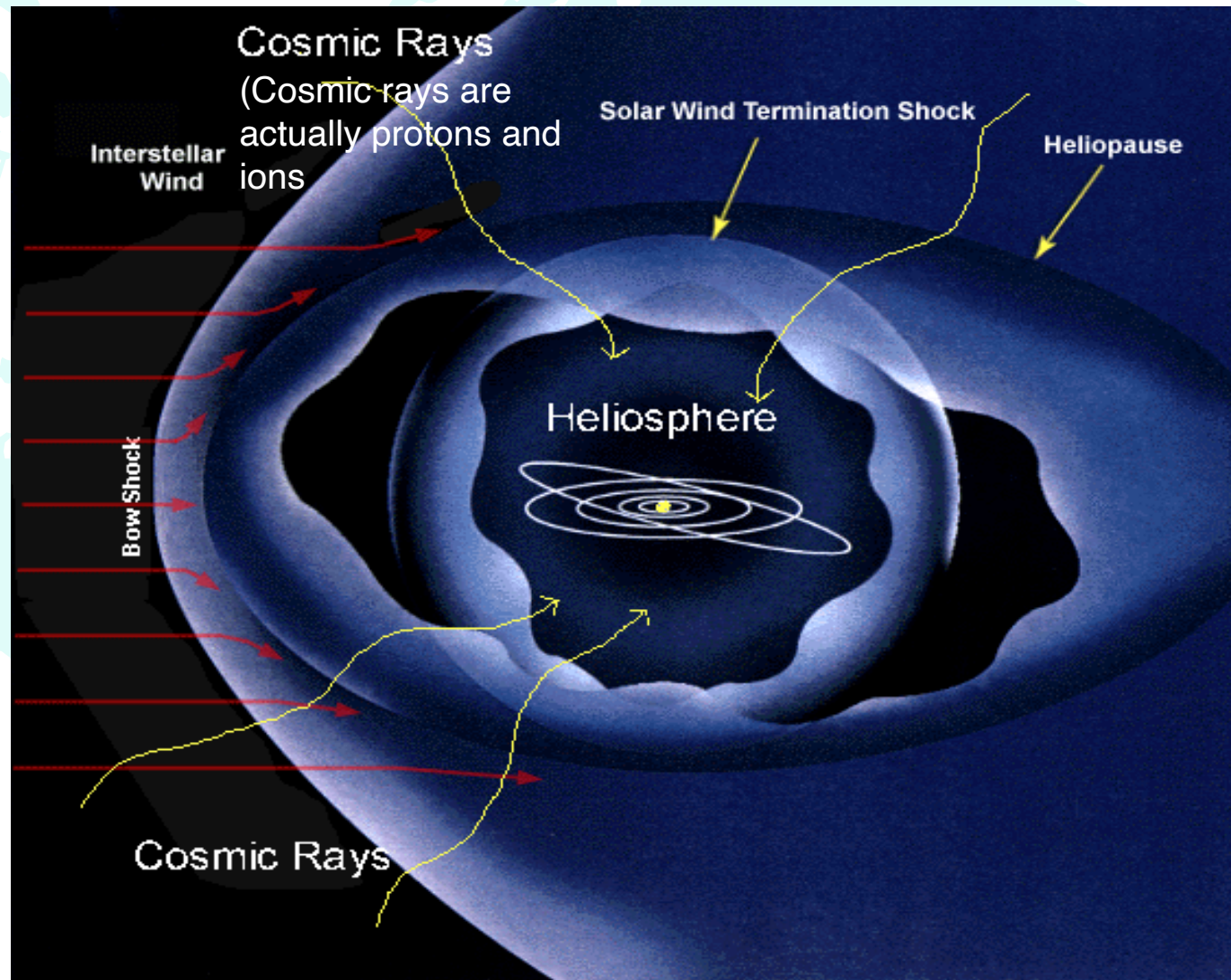
● Earth

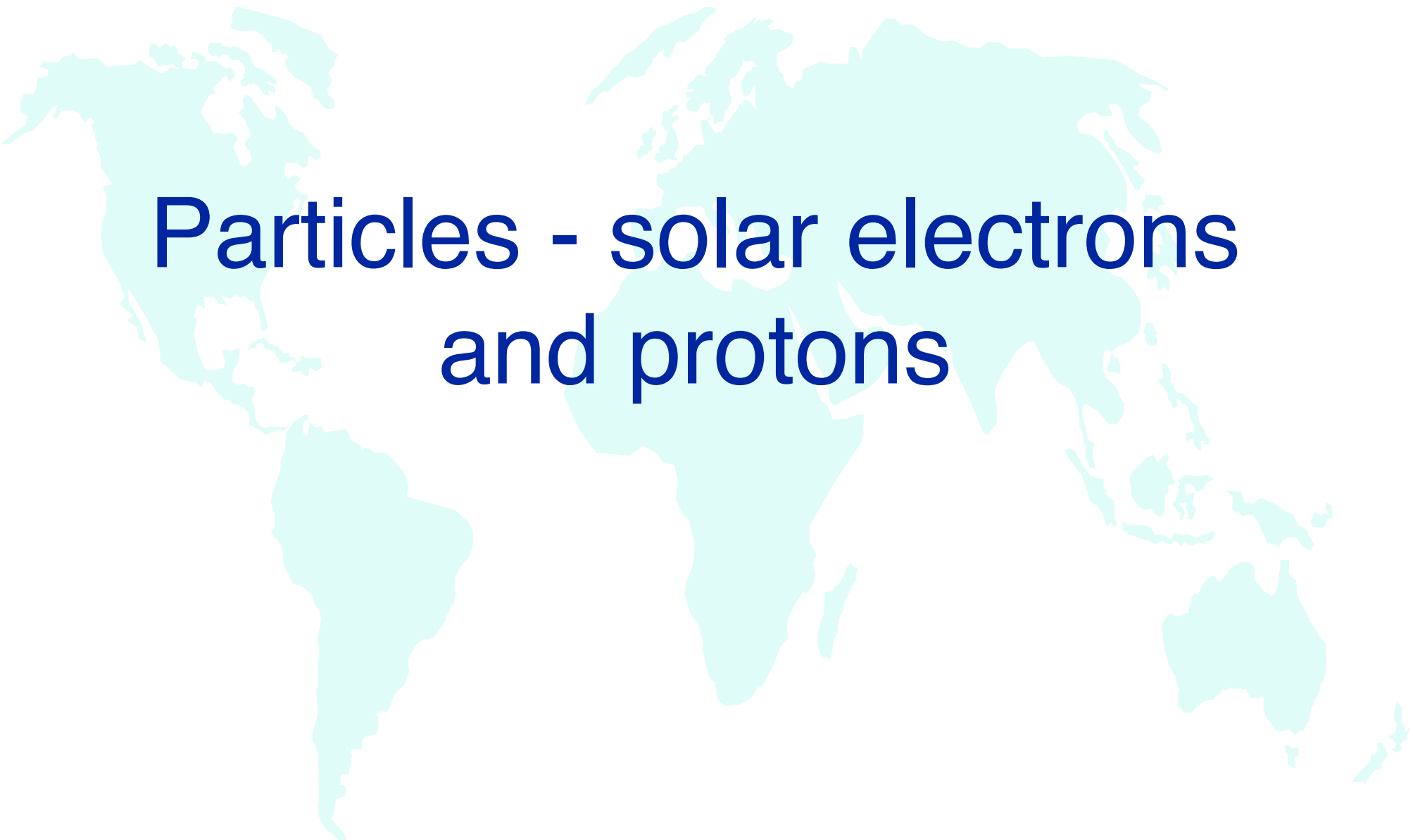


Particles - the solar wind



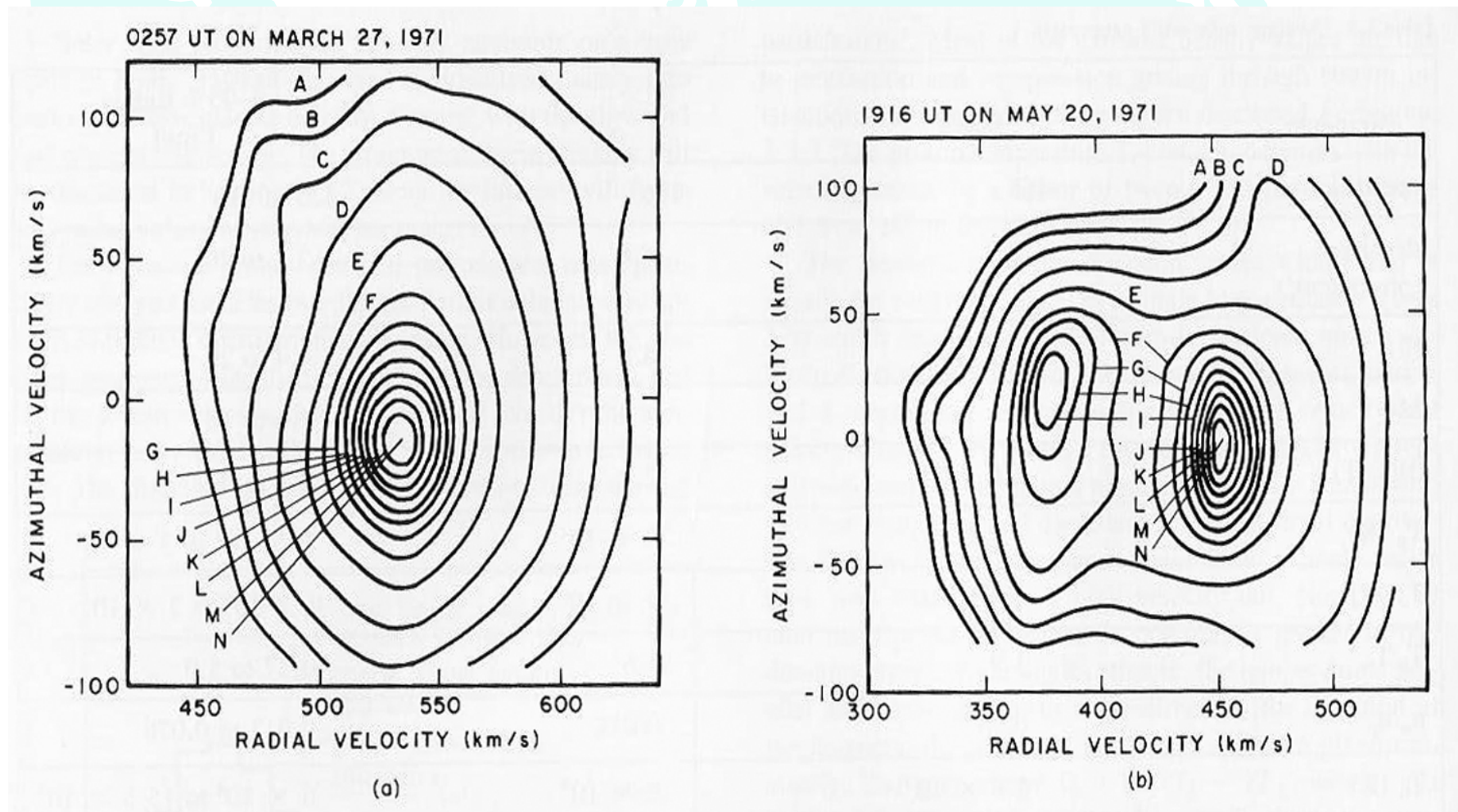
Heliosphere



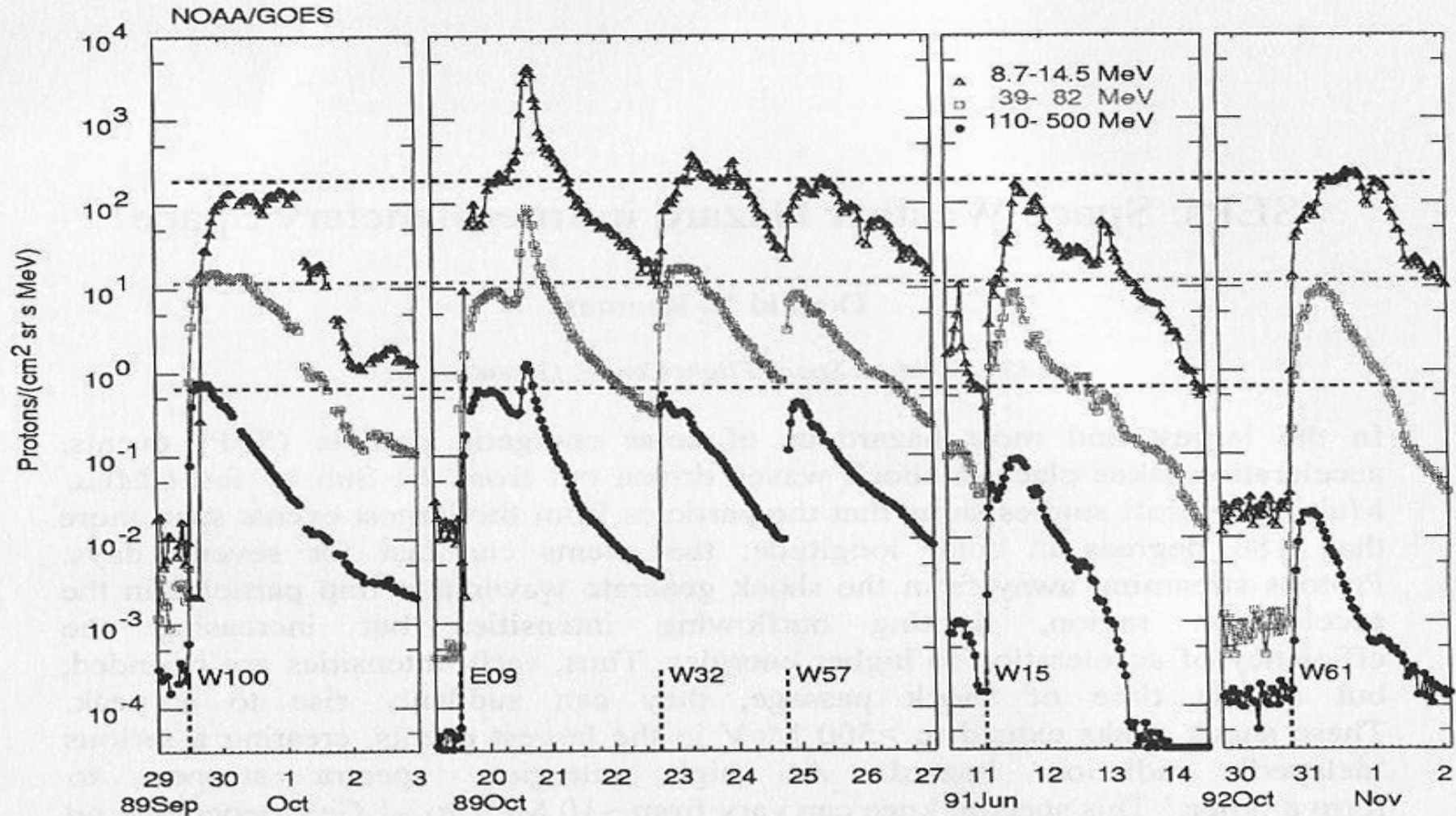
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Particles - solar electrons and protons

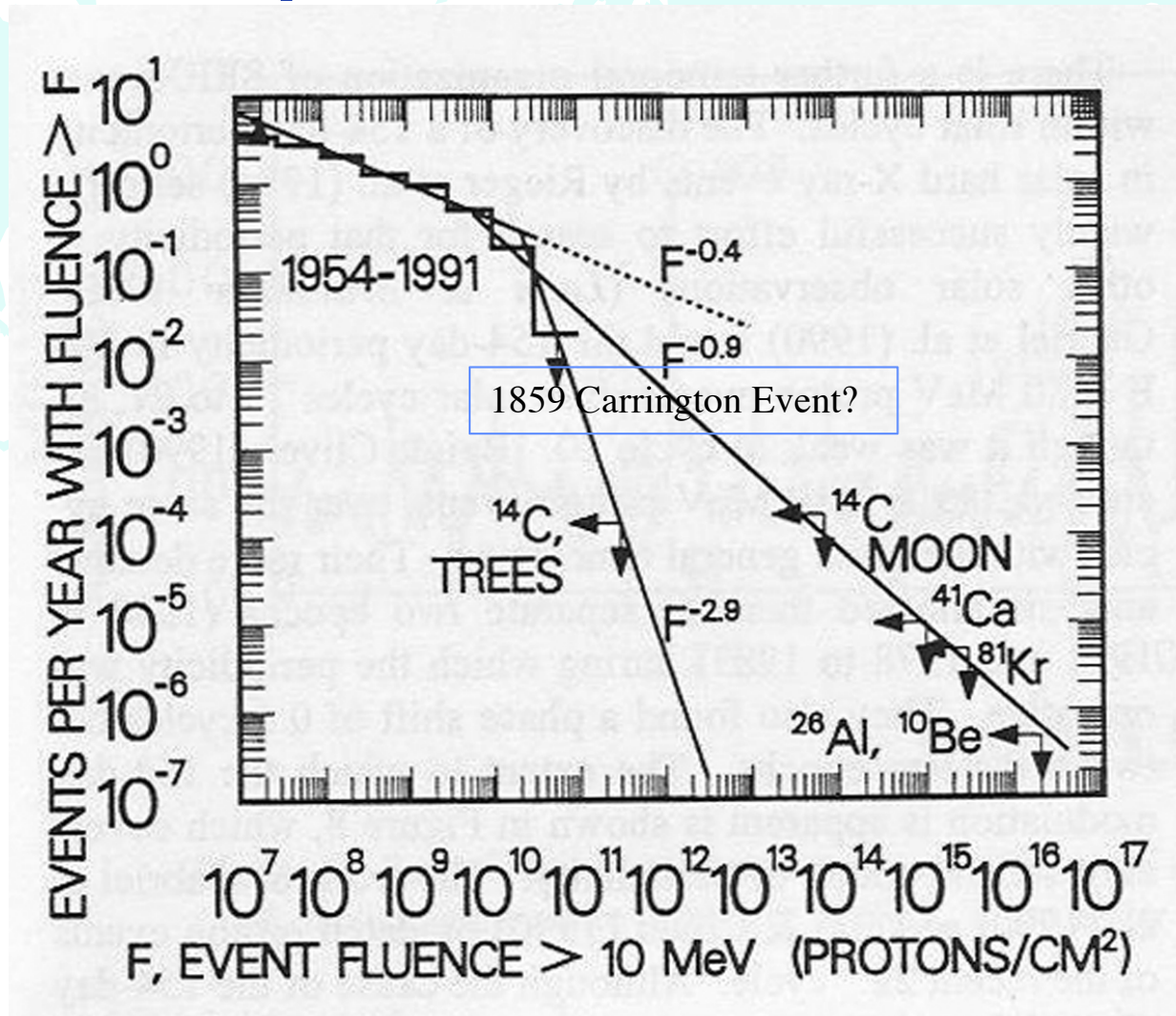
Particles - solar protons



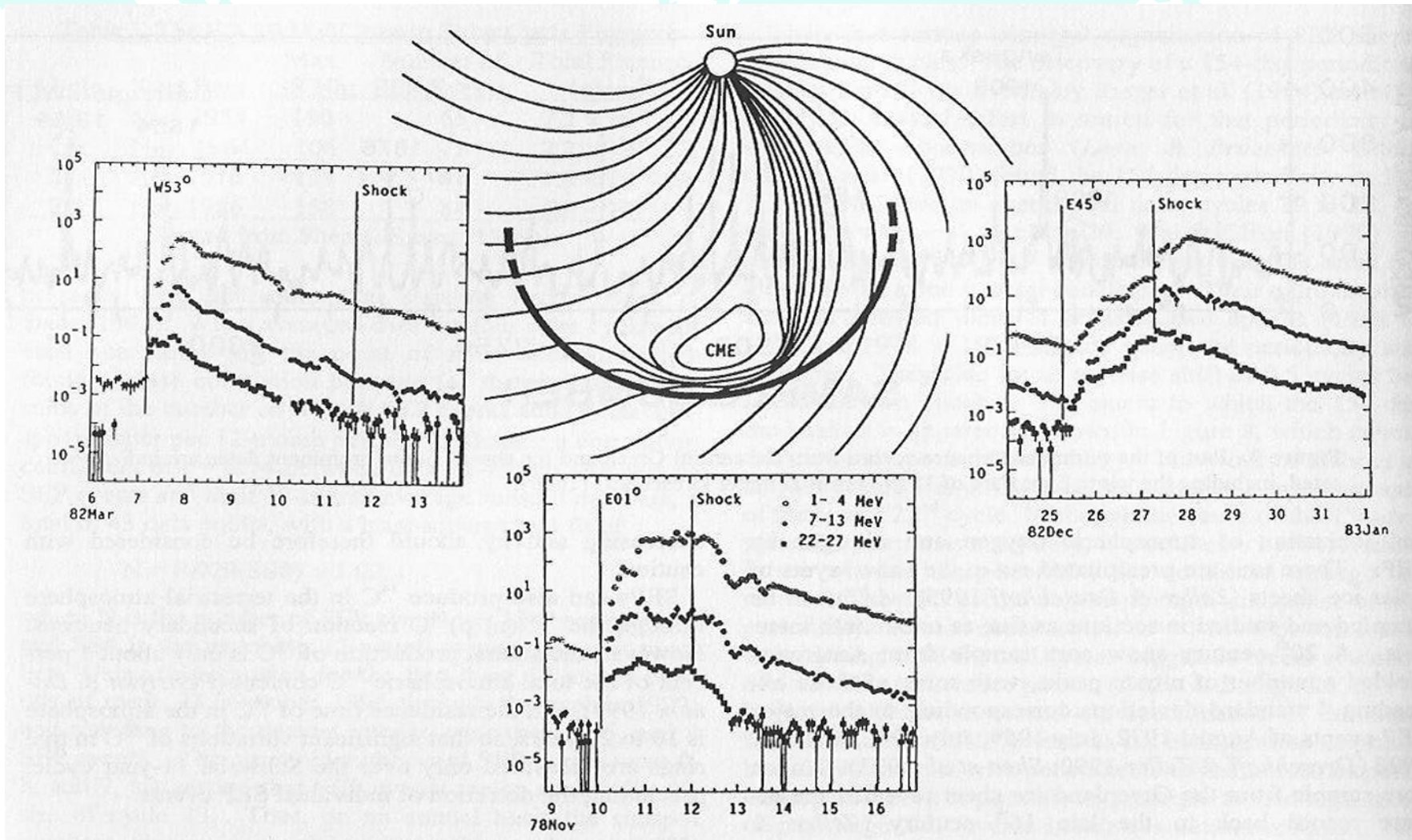
Particles - solar protons



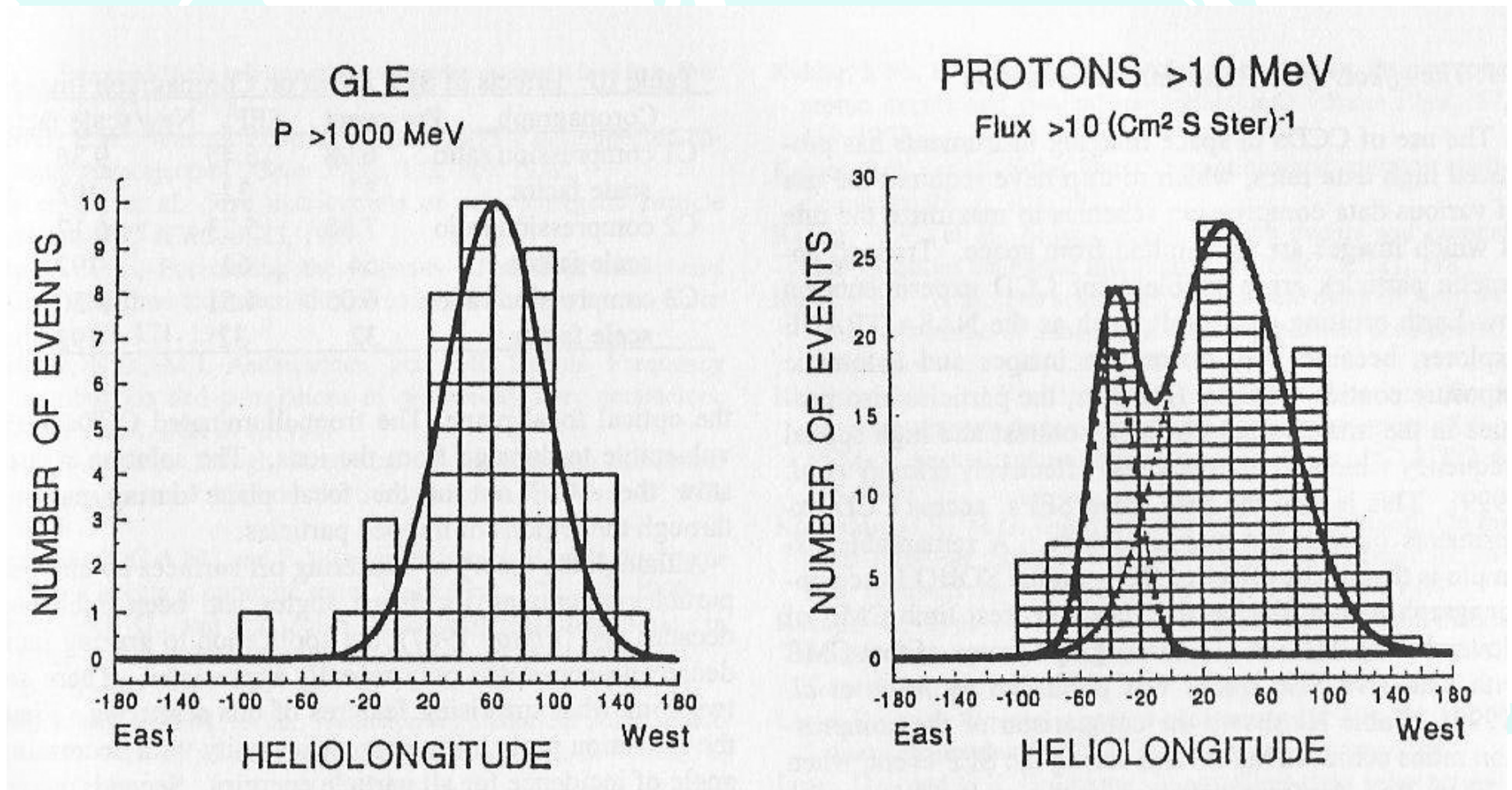
Solar proton fluences



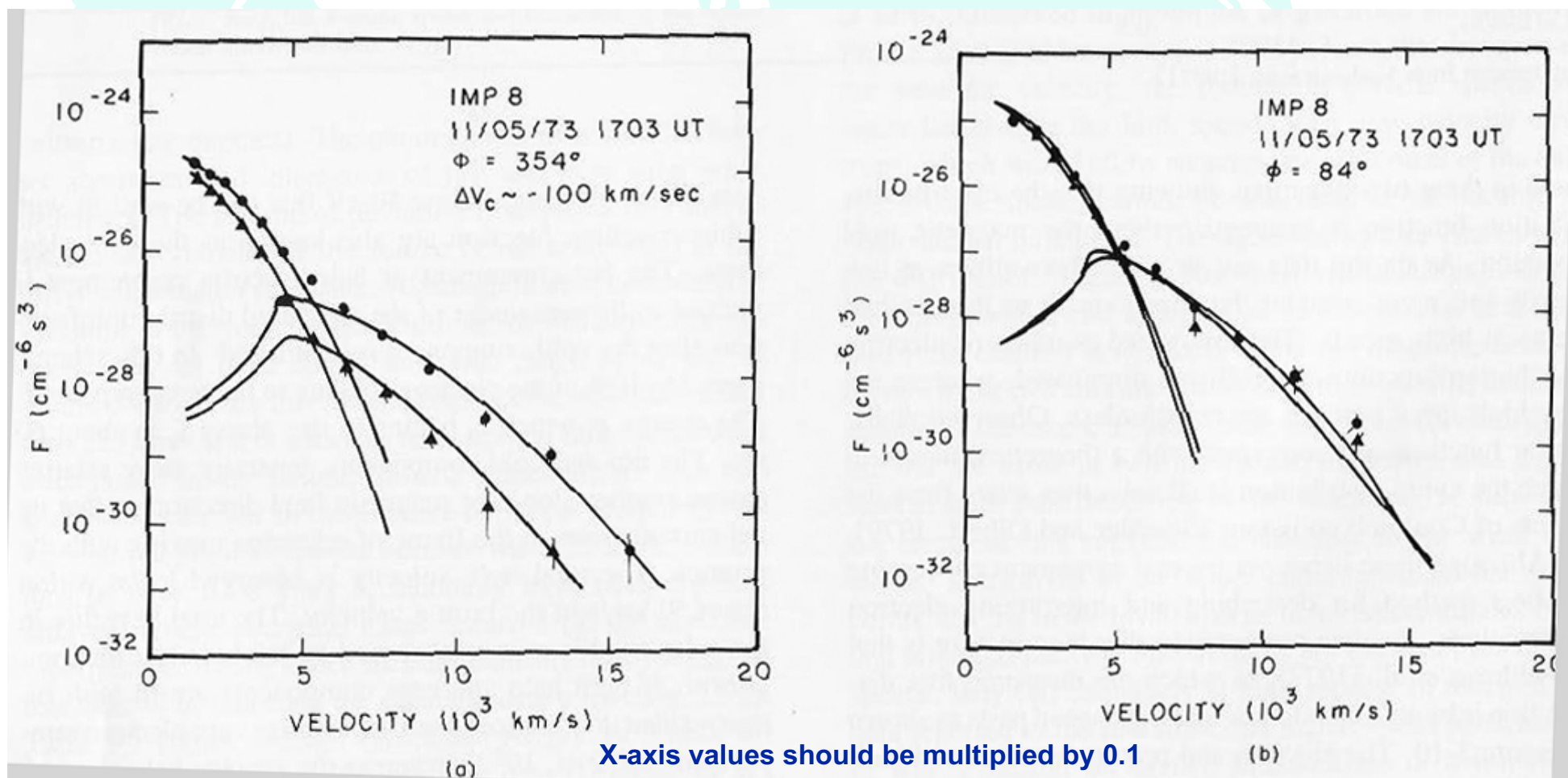
SEP geometry



SEP source longitudes



Particles - solar electrons



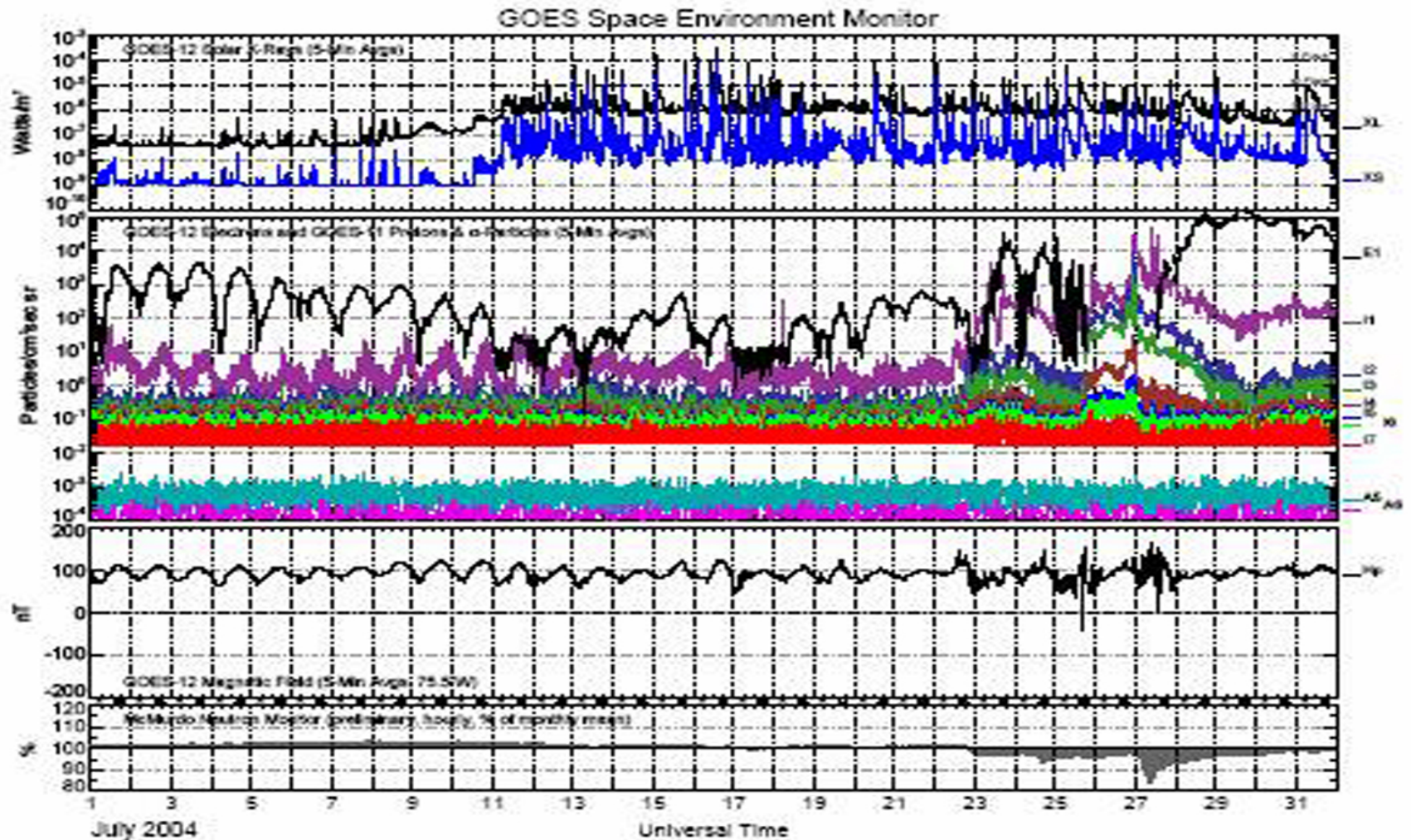
Interplanetary medium

Xrays

e

B_z

V_T



Geoeffectiveness of high speed solar wind

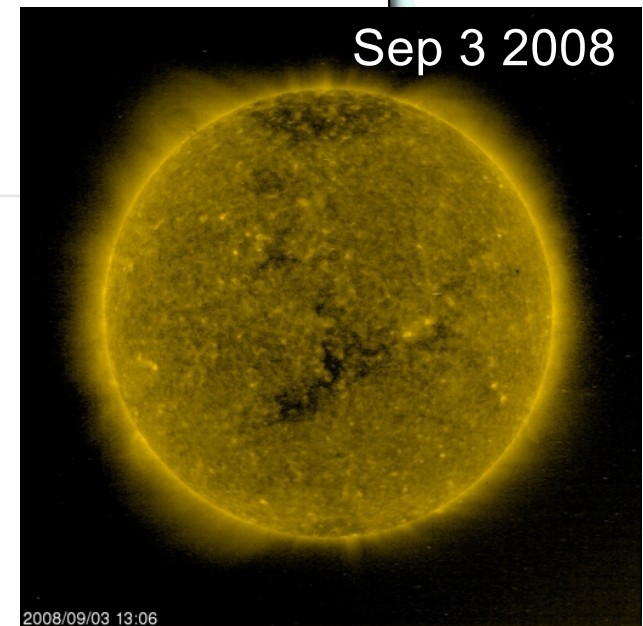
From: <swpc.products@noaa.gov>
Subject: **ALERT: Electron 2 MeV Integral Flux exceeded 1,000 pfu**
Date: September 4, 2008 5:14:05 PM GMT+00:00
To: <ktobiska@spaceenvironment.net>

Space Weather Message Code: ALTEF3
 Serial Number: 1580
 Issue Time: 2008 Sep 04 1711 UTC

ALERT: Electron 2MeV Integral Flux exceeded 1000pfu
 Threshold Reached: 2008 Sep 04 1655 UTC
 Station: GOES12
 Observed Yesterday: No

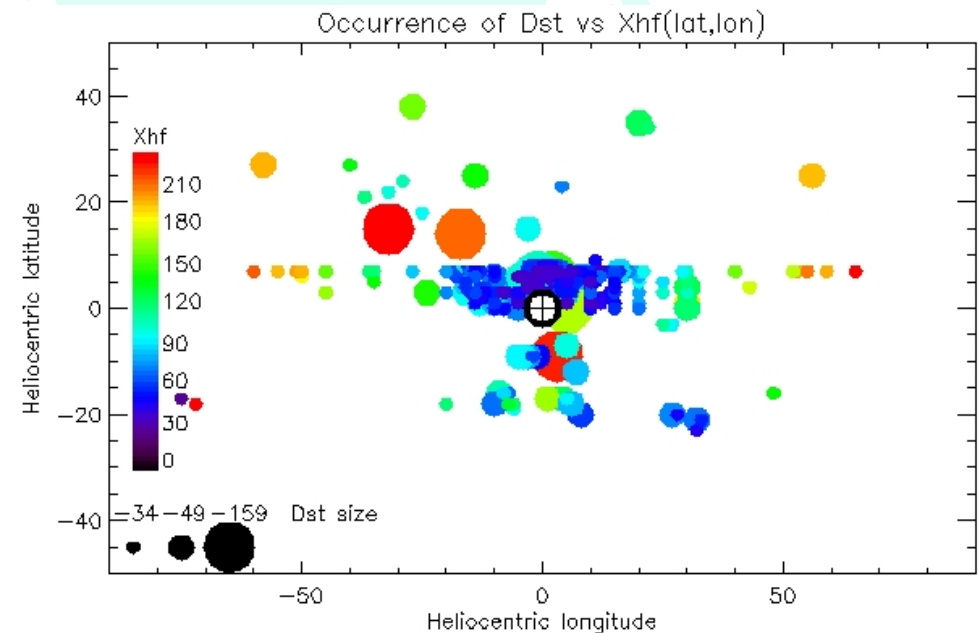
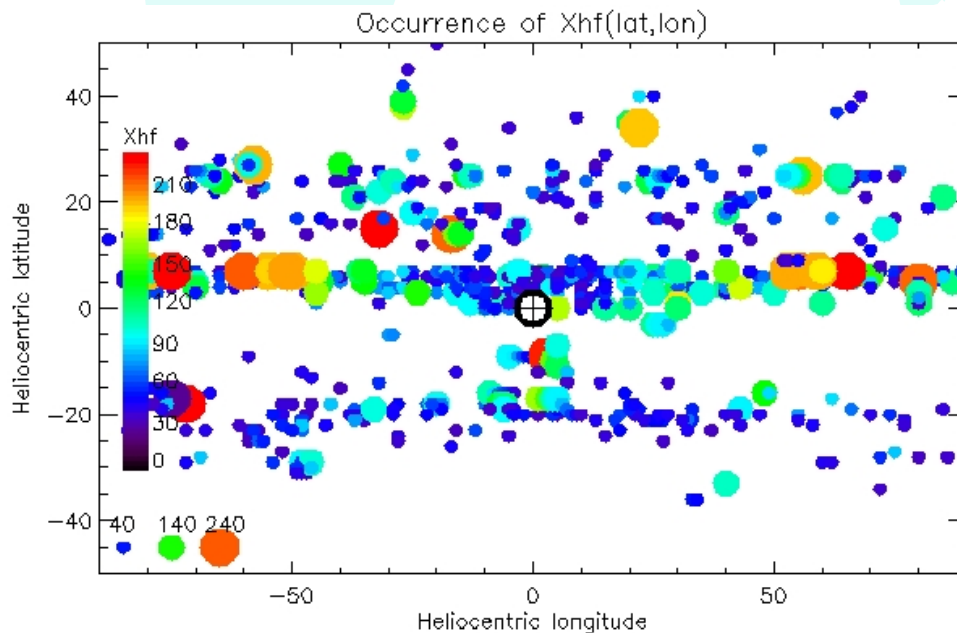
NOAA Space Weather Scale descriptions can be found at
www.swpc.noaa.gov/NOAA scales

Thank you for using the Product Subscription Service. If you would like to remove a product subscription or update the personal information in your account, go to: <https://pss.swpc.noaa.gov>. For problems, contact: <mailto:pss.help@noaa.gov>.



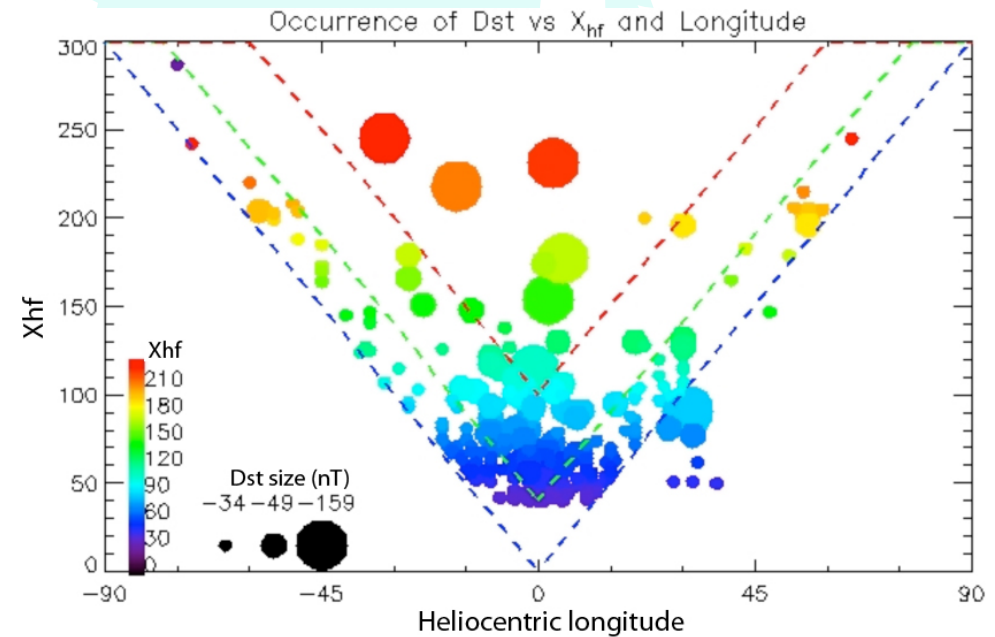
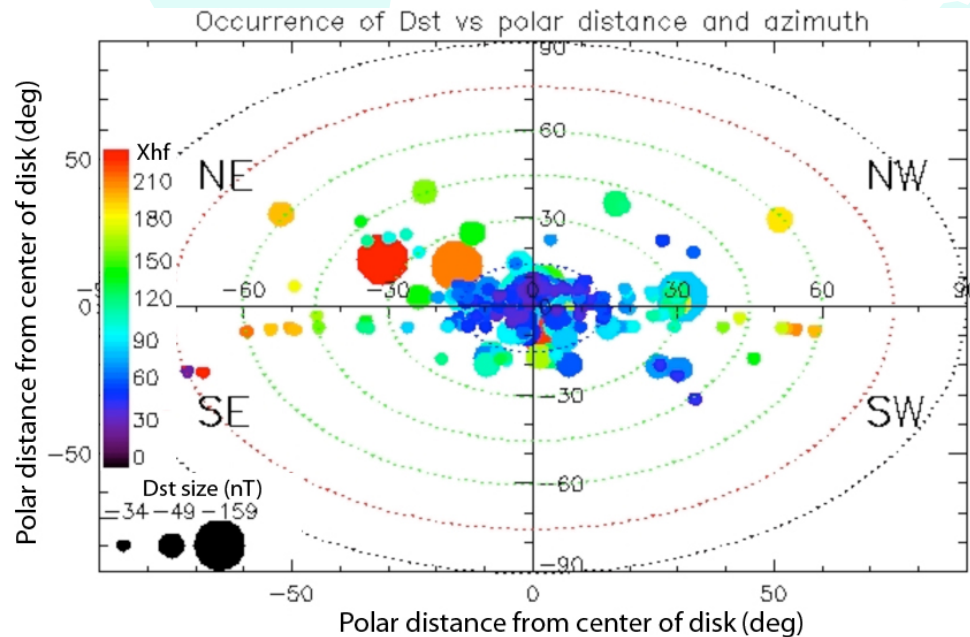
Credit: Tobiska

Geoeffectiveness of solar particles creating Dst



http://sol.spacenvironment.net/~sam_ops/Docs/Anemomilos_SWJ.pdf

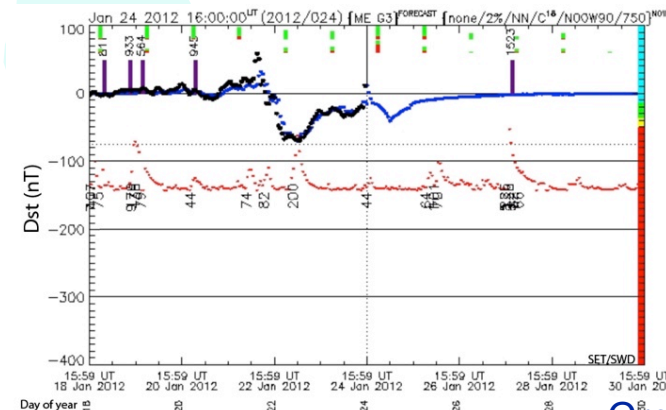
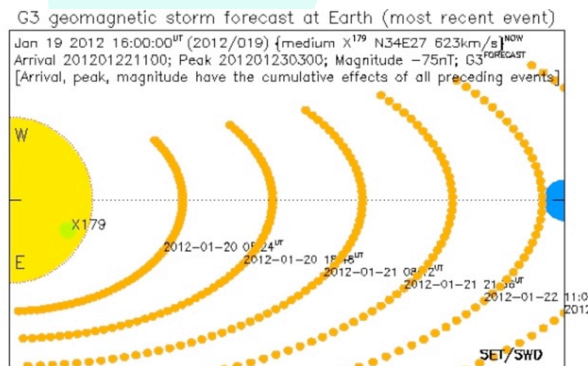
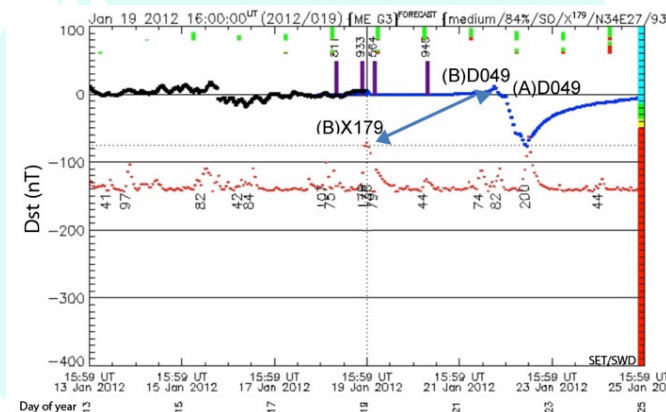
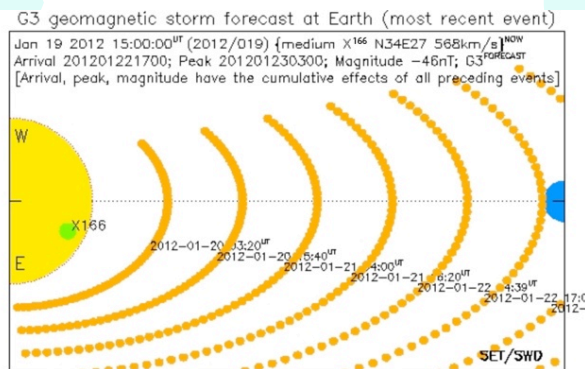
Geoeffectiveness of solar particles creating Dst



http://sol.spacenvironment.net/~sam_ops/Docs/Anemomilos_SWJ.pdf

Credit: Tobiska

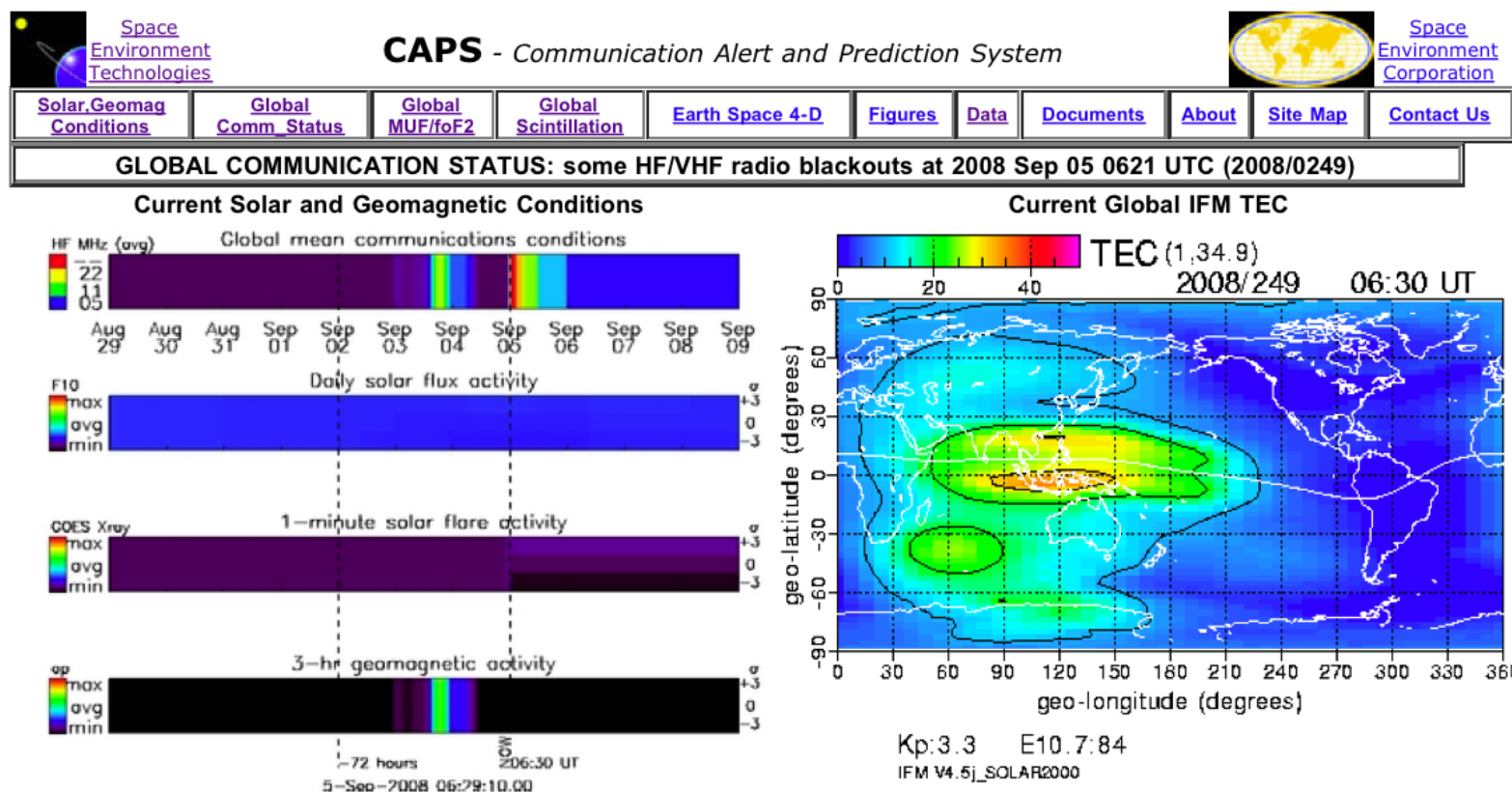
Geoeffectiveness of solar particles creating Dst



Credit: Tobiska

Solar photons and particles

(CAPS: <http://sol.spaceenvironment.net/~ionops/index.html>)



[\(click image for solar/geomagnetic conditions\)](#)

[\(click image for Regional Conditions\)](#)

SET proprietary site; SET and SEC proprietary data- not for use without written consent

Last Website Update: 8 May 08 (nowcasts updated every 15 Minutes)

Credit: Tobiska



Geosynchronous charging environment (shaded)

solid white ring & dots = current epoch
outer edge = +3 days
inner edge = -2 days
- is negative charge
+ is positive charge

Current epoch:
Oct 29 2003 23:35 UT

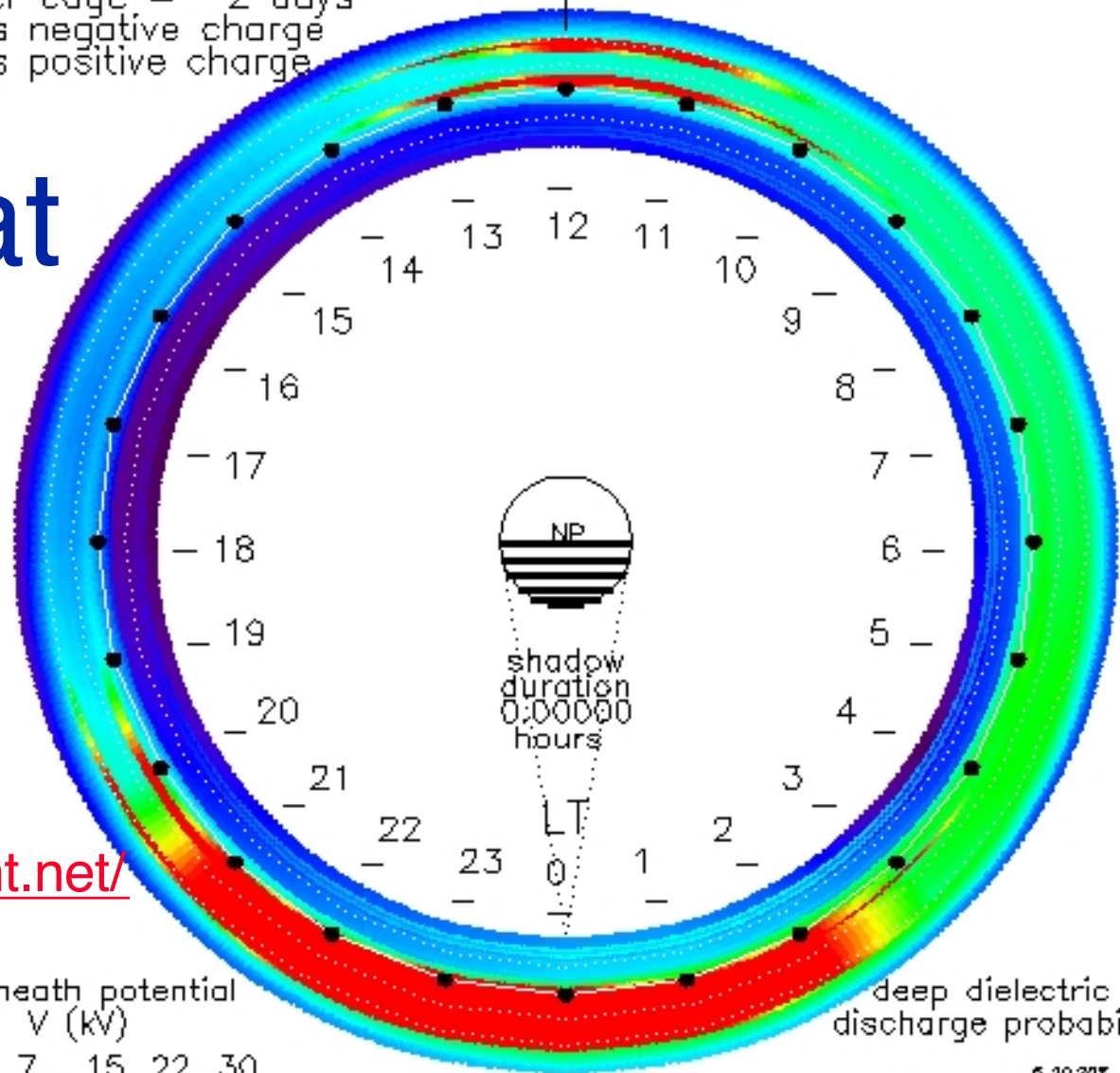
Charging at GEO

(GAPS:

<http://sol.spacenvironment.net/gapops/index.html>)

thick sheath potential
V (kV)
0 7 15 22 30

Space Environment Technologies
GAPS v1.40

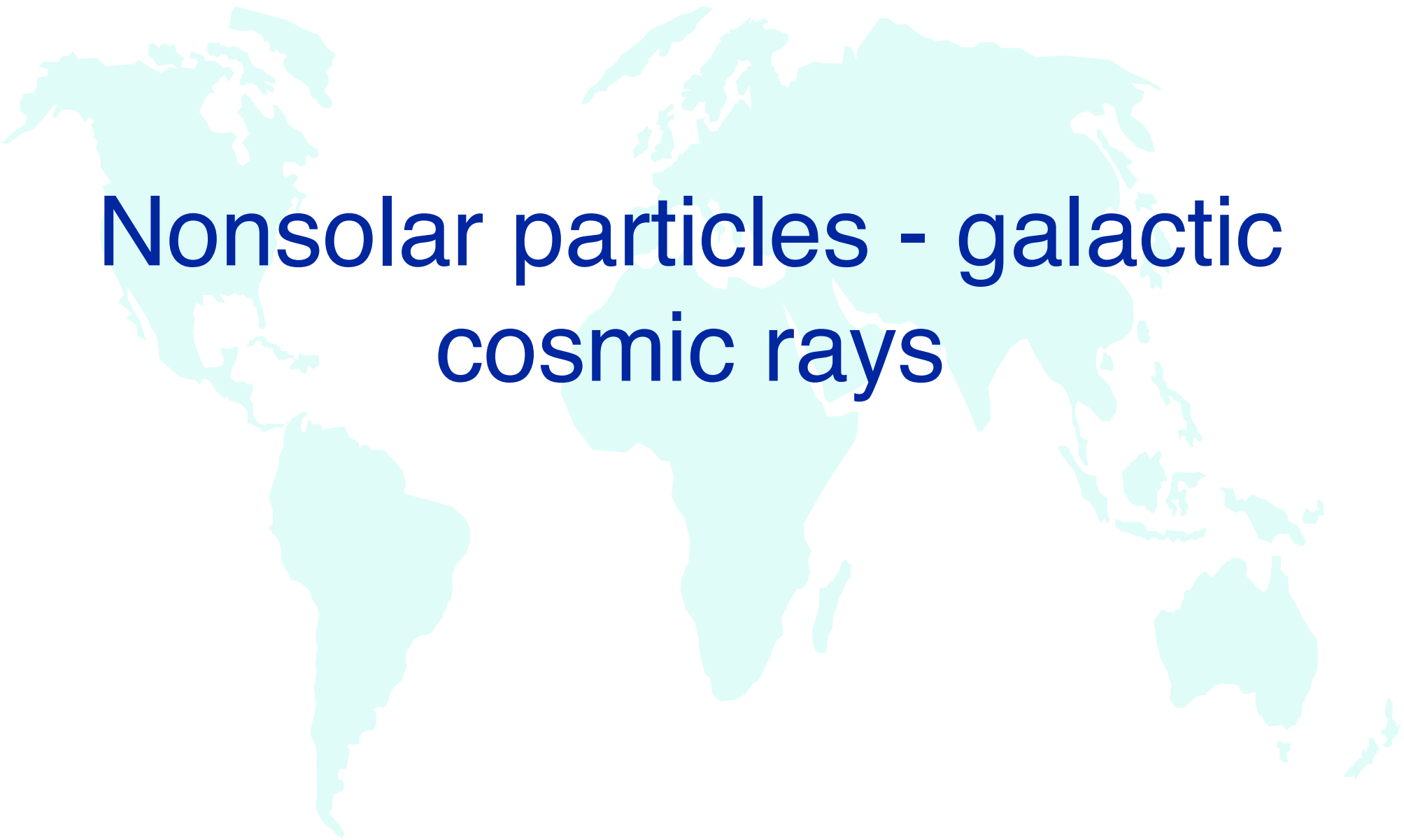


4% probability
1.2E9 electrons cm^{-2} past 24hr
for 4π fluence at GOES-13

5 10 20%
2.1E9
1.0E10
3.6E10

Credit: Tobiska

<https://Spac>

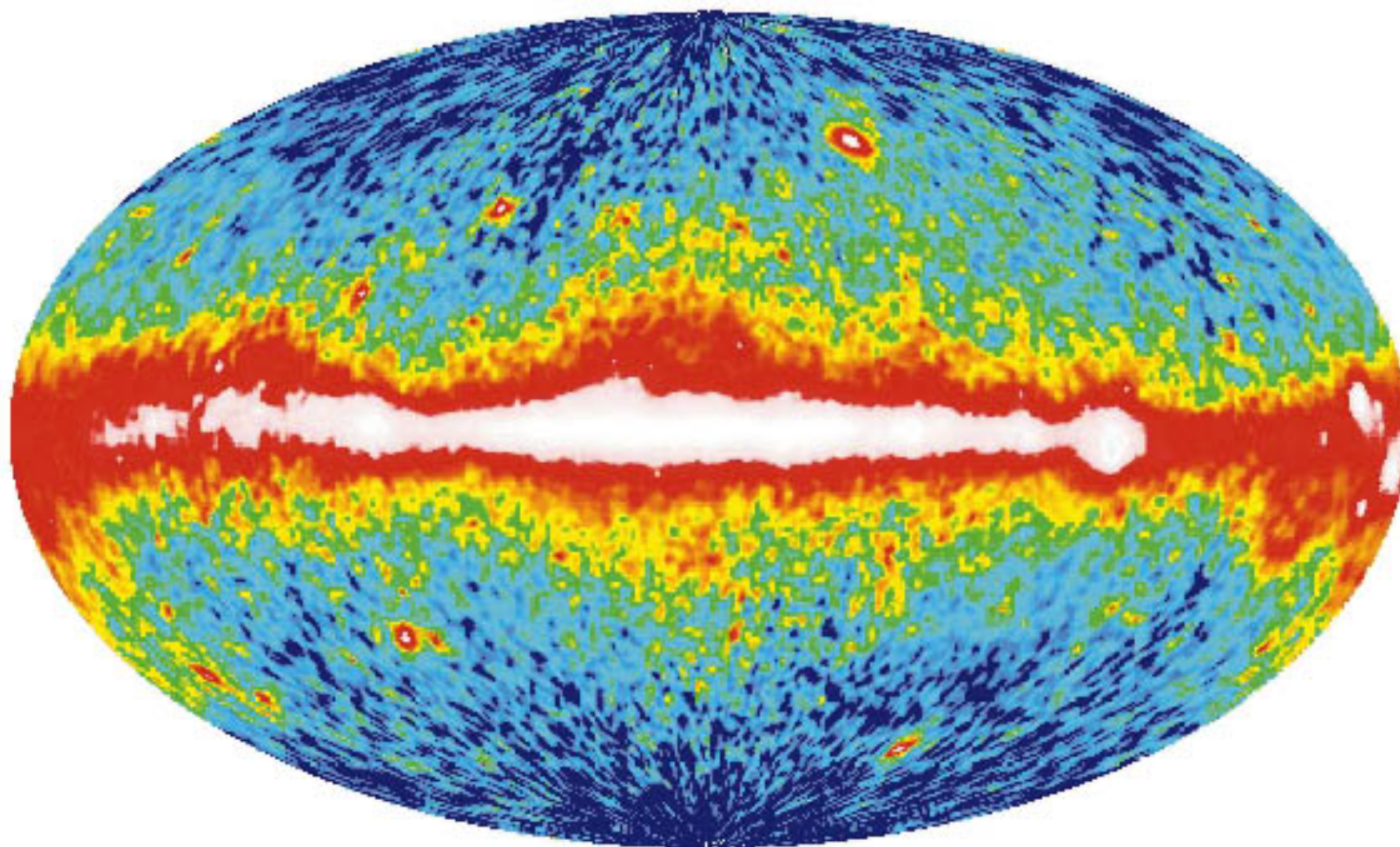
A light blue world map is centered in the background of the slide, showing the continents of North America, South America, Europe, Africa, Asia, and Australia.

Nonsolar particles - galactic cosmic rays

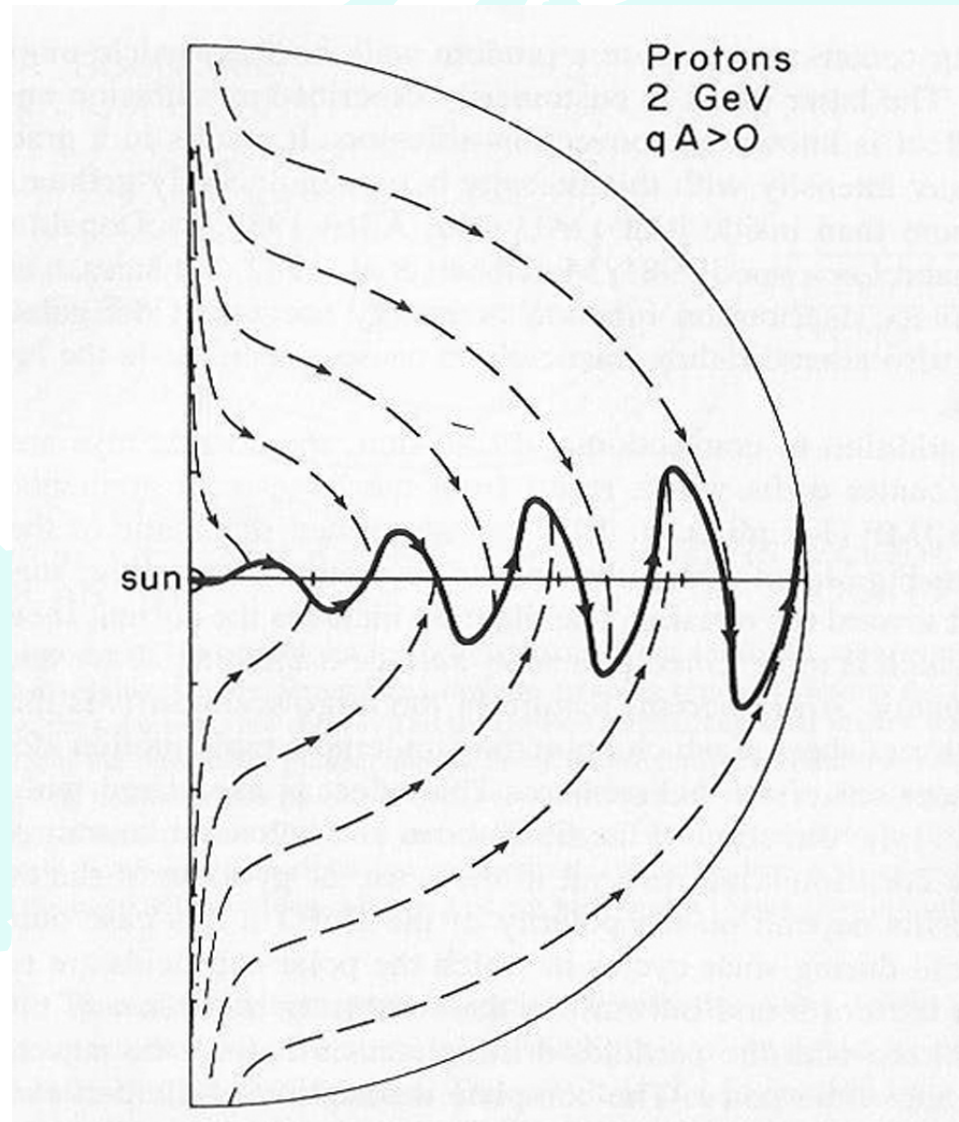
Supernova



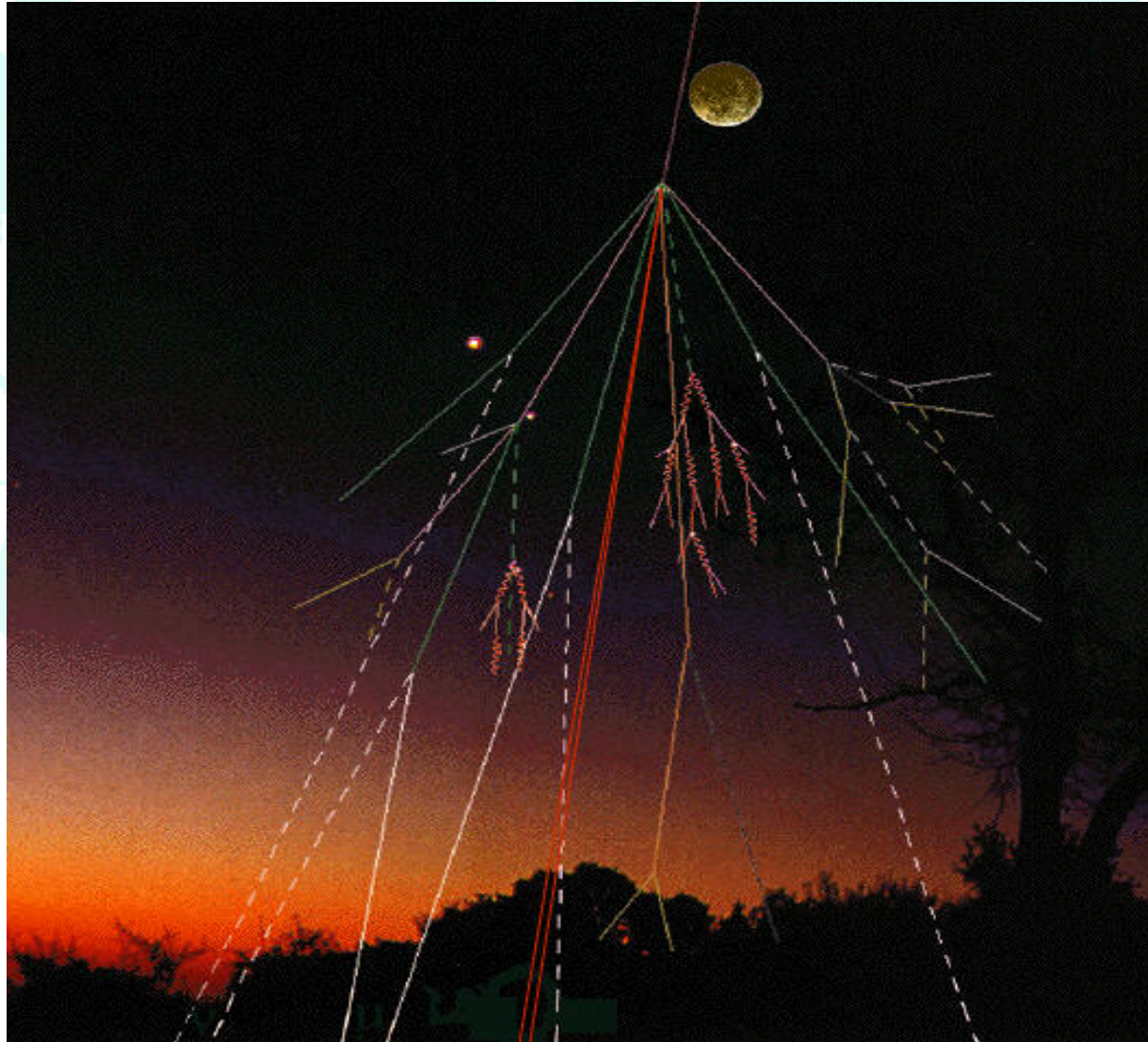
Sources of GCRs



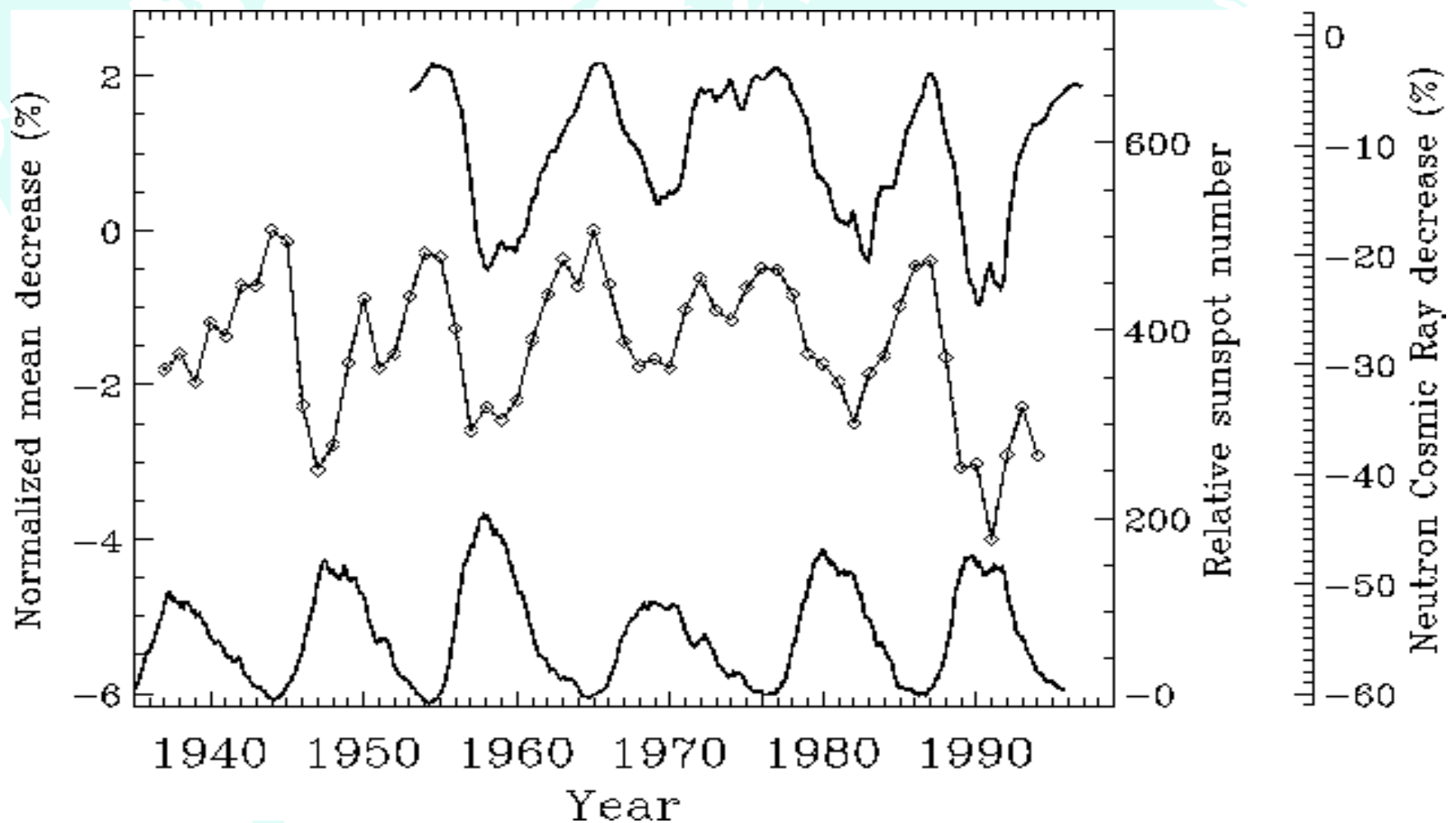
GCR drift trajectories



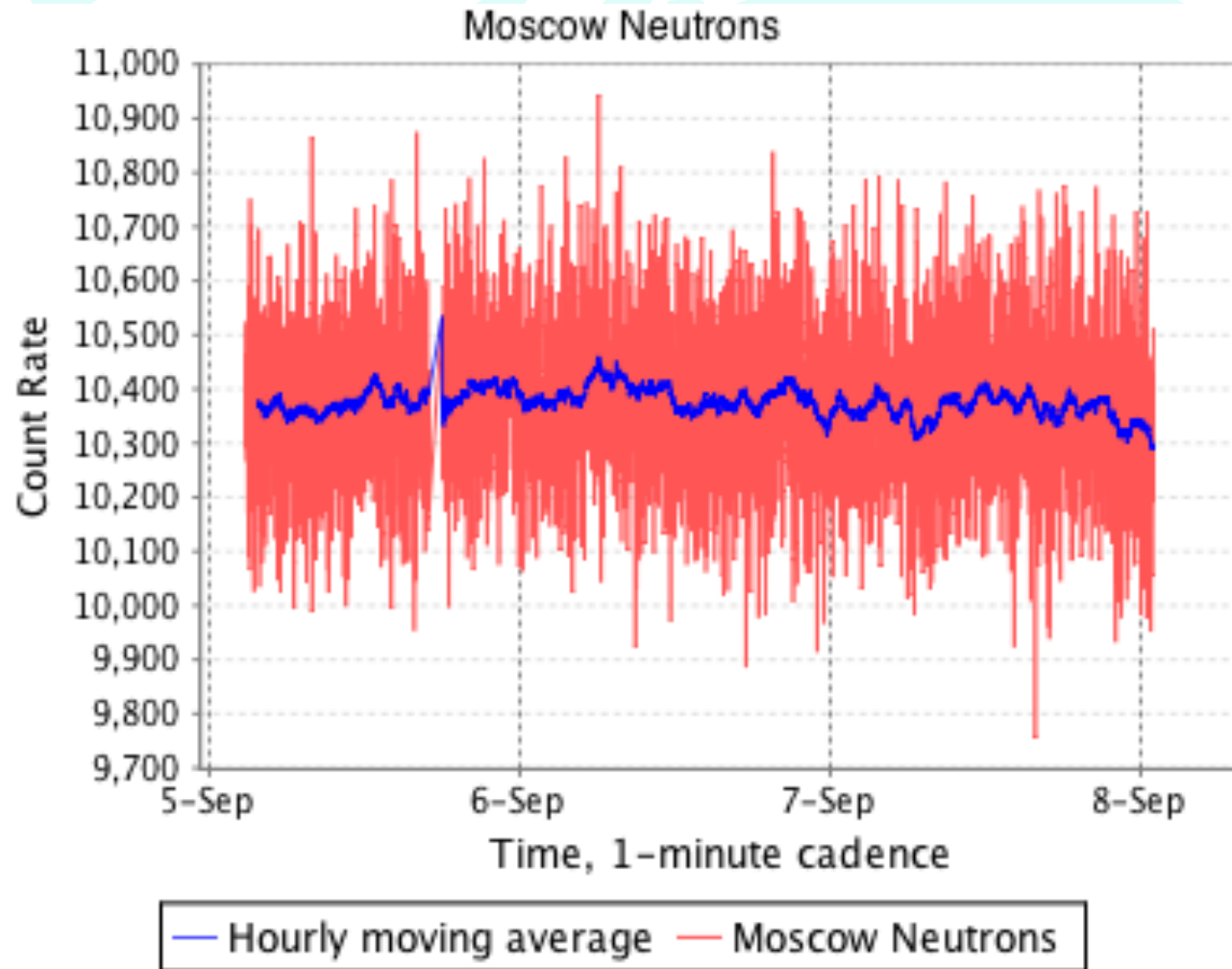
GCRs at Earth



GCR count rates



GCR count rates

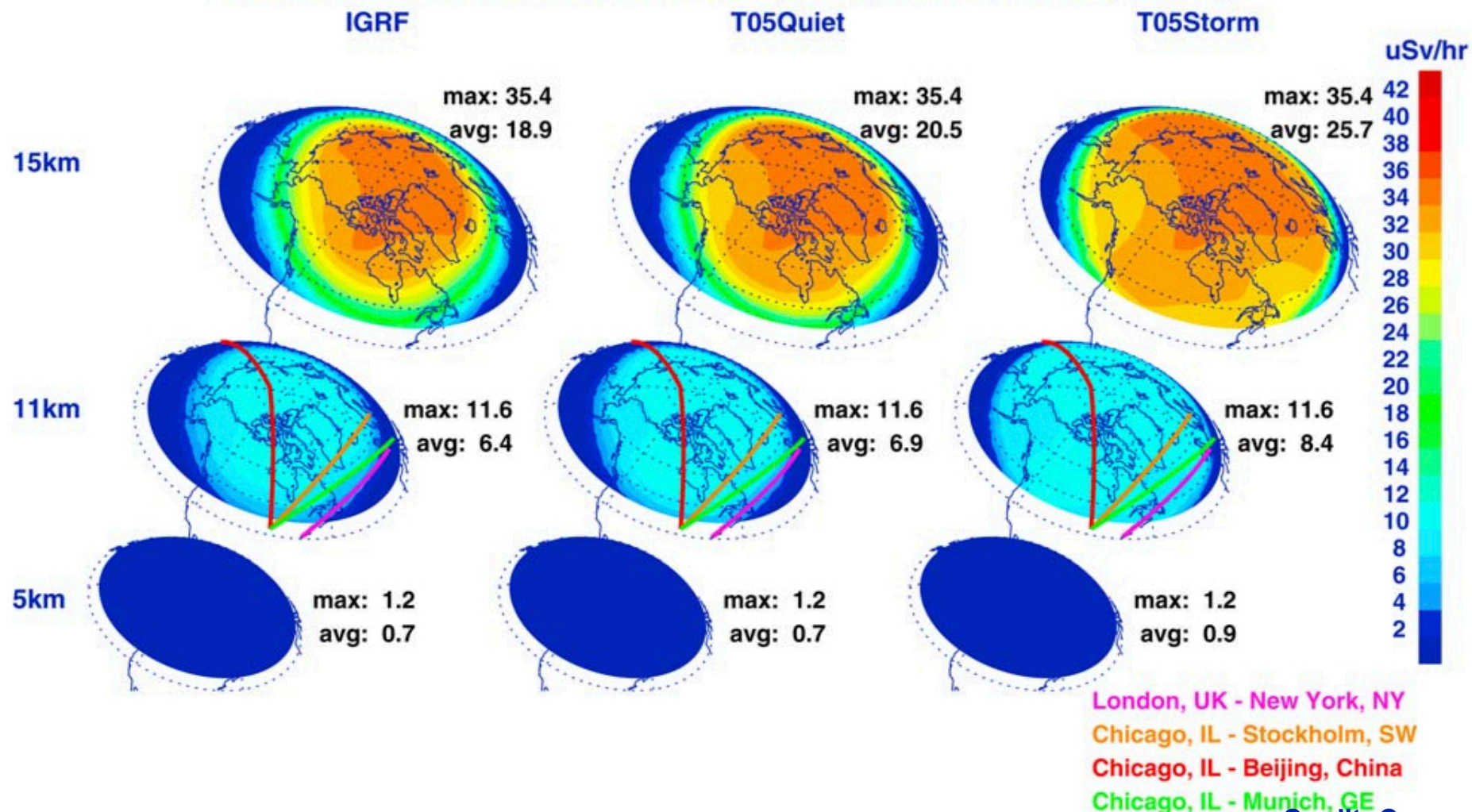




Effects at aviation altitudes

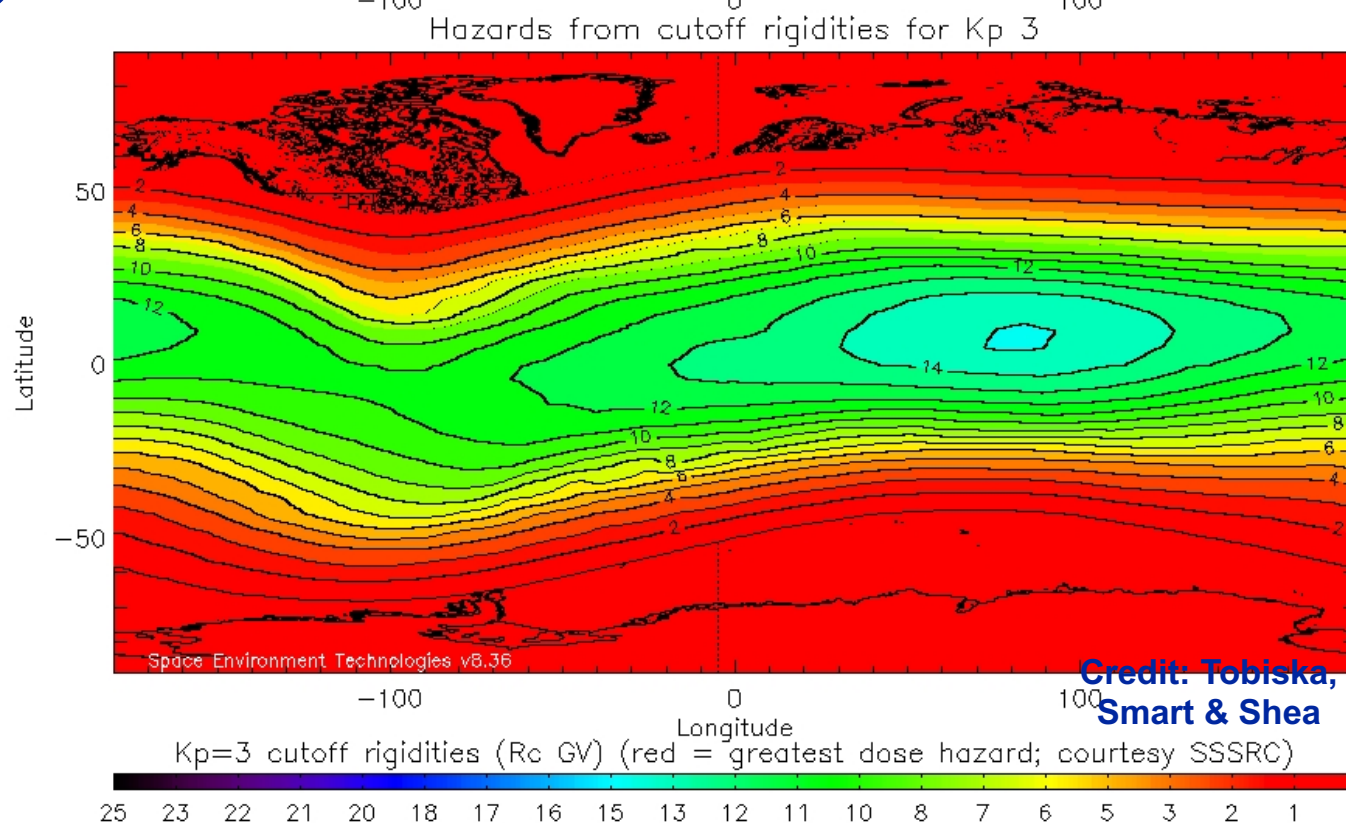
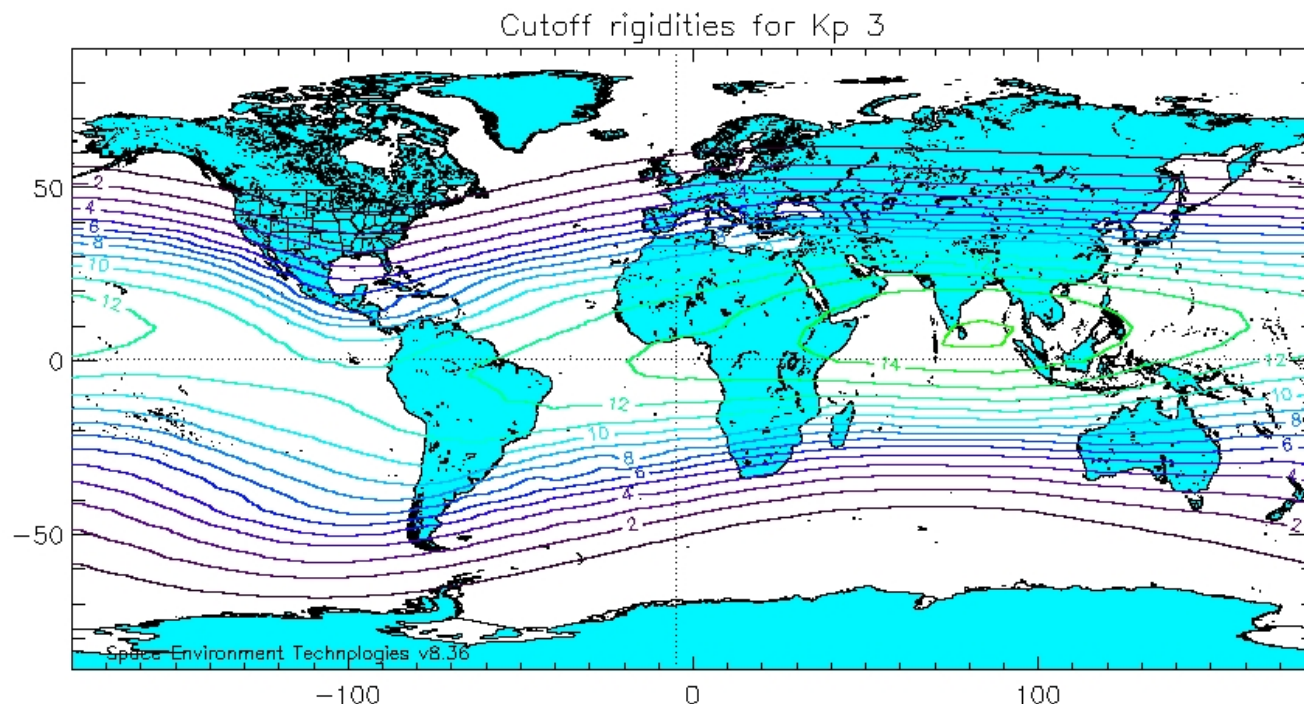
(MAPS: <http://sol.spacenvironment.net/~nairas/index.html>)

Effective Dose for Halloween 2003 SEP (10/29 (2100 UT) - 10/31 (2400UT))



Cutoff rigidities (Rc) at Earth

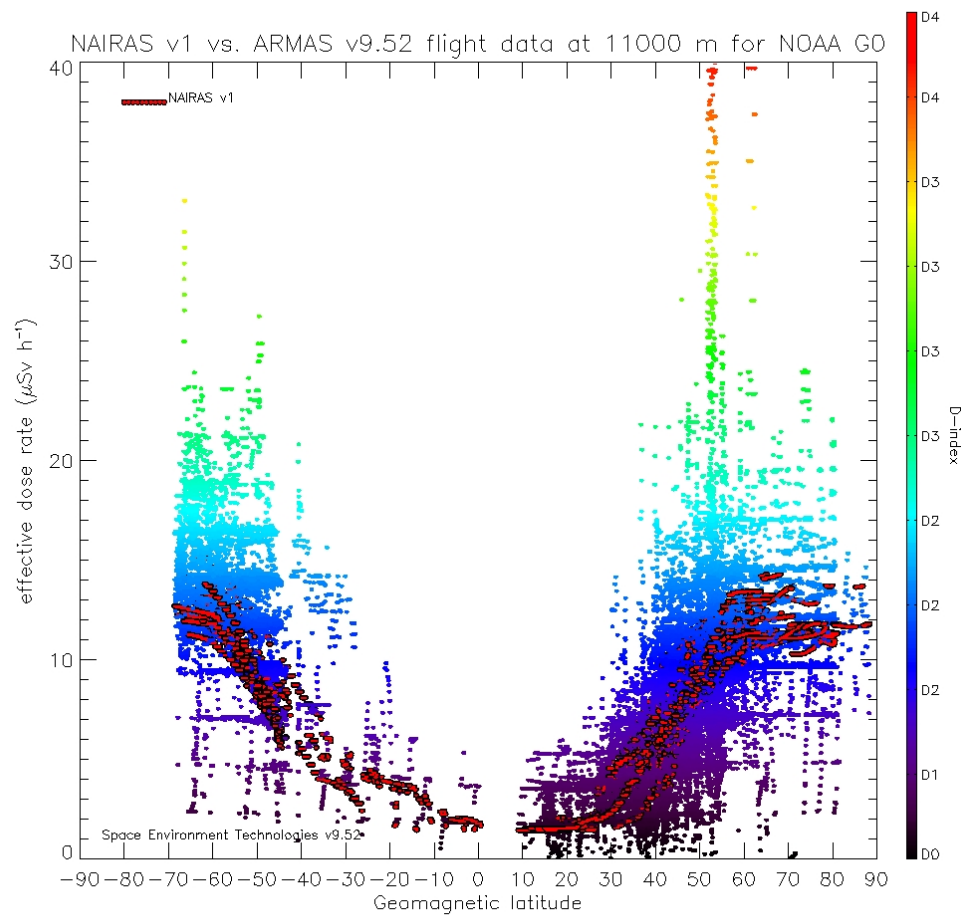
<https://SpaceWx.com>



Credit: Tobiska,
Smart & Shea

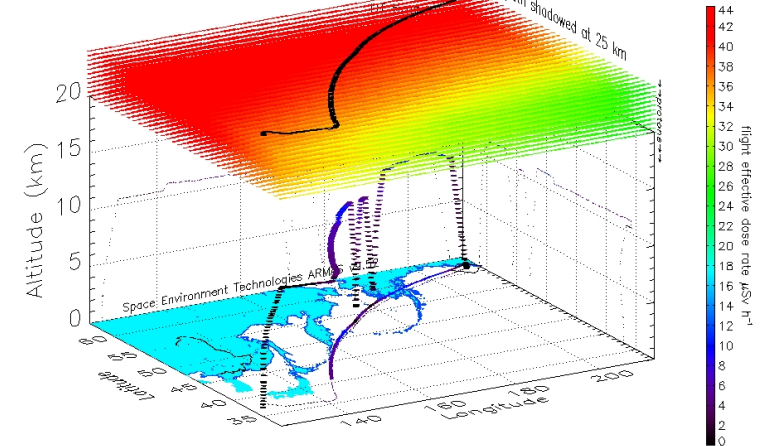
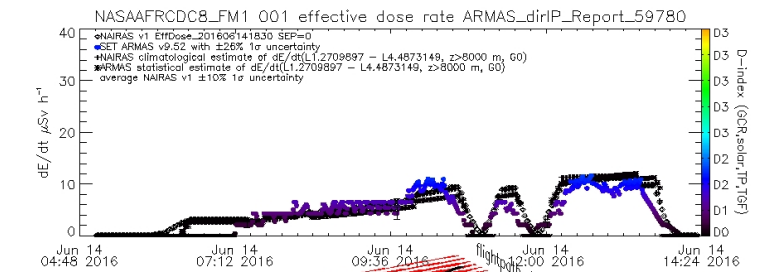


Effects on aviation by Rc

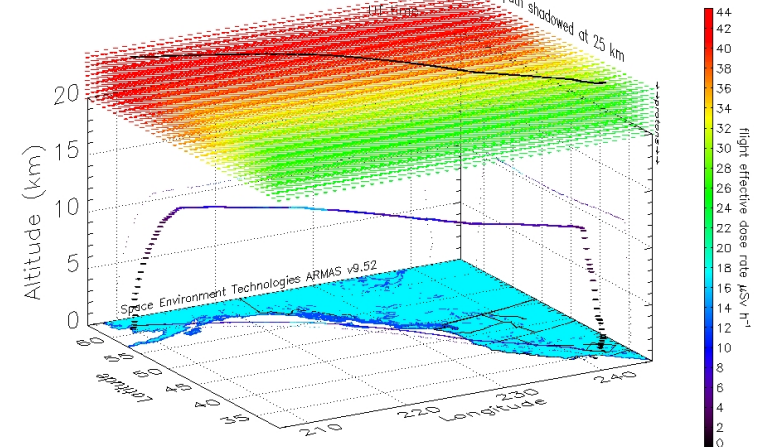
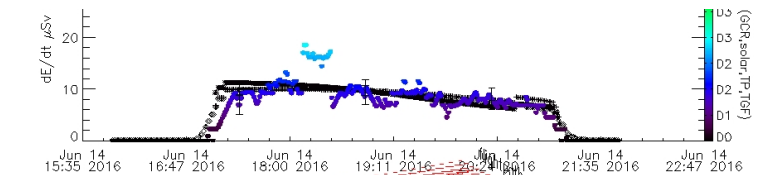


<https://SpaceWx.com>

W. Kent Tobiska <ktobisk>



Kp=3 with cutoff rigidity (R_c) >25 km (GV: red = greatest dose hazard; courtesy SSSRC)

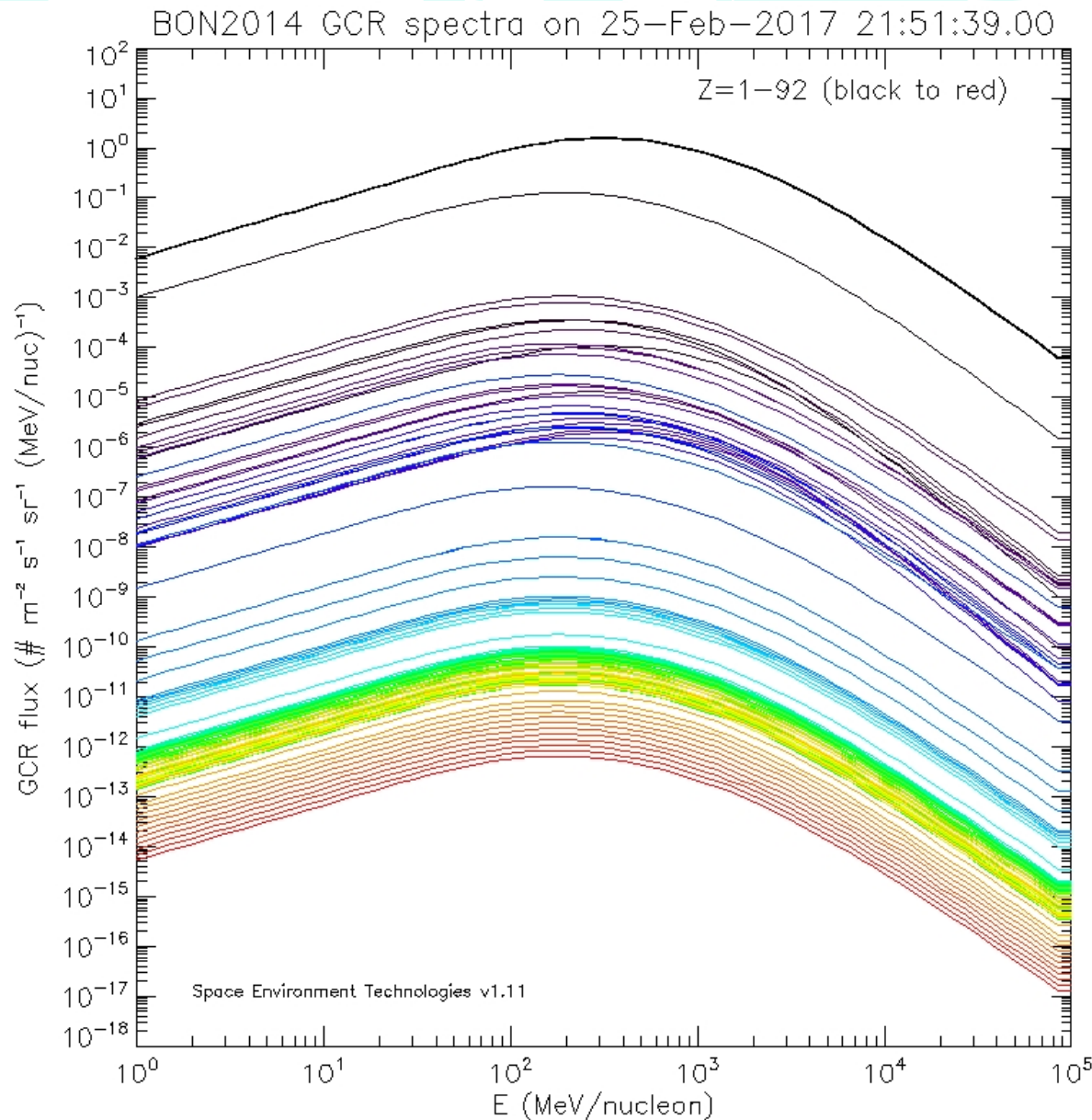


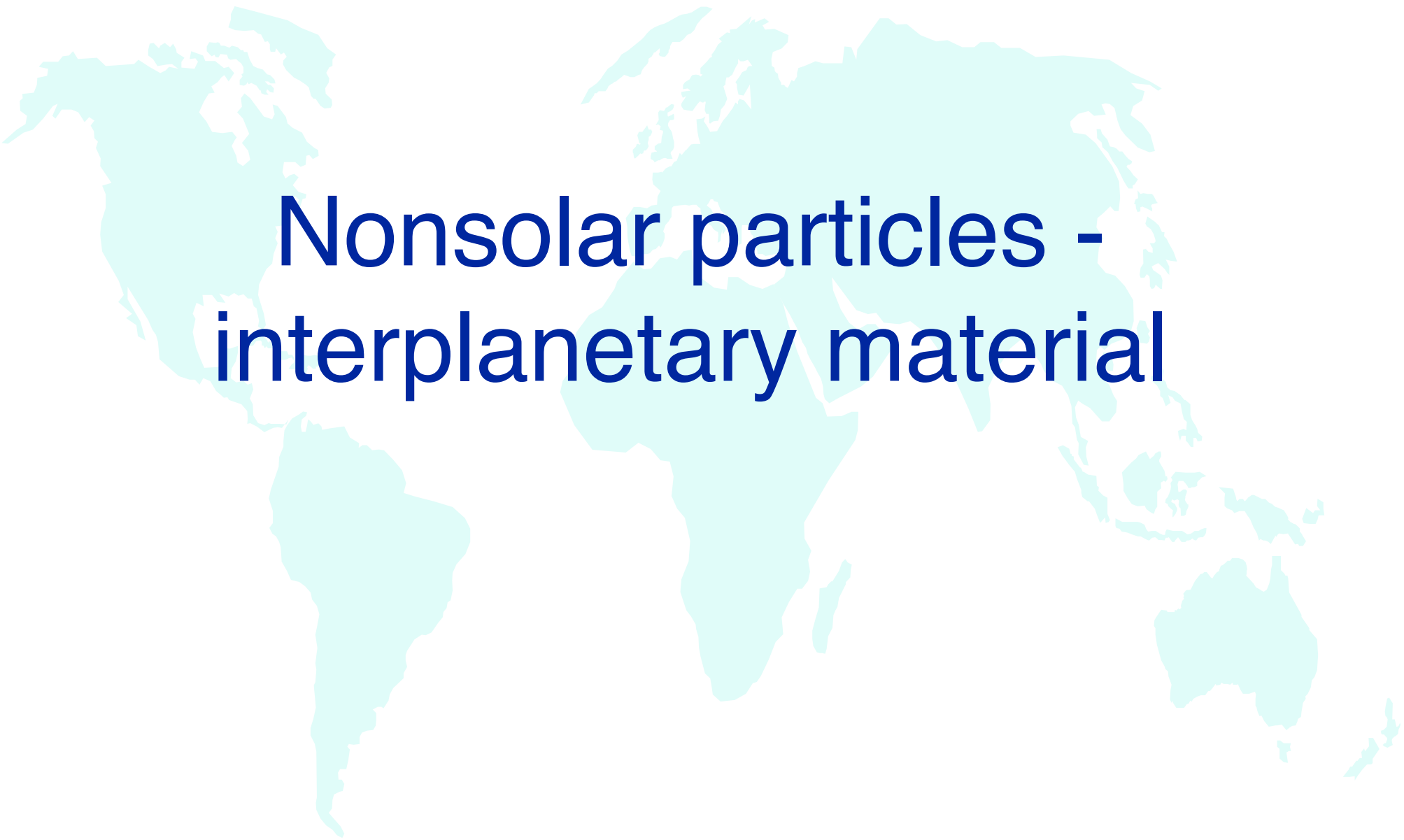
Kp=3 with cutoff rigidity (R_c) >25 km (GV: red = greatest dose hazard; courtesy SSSRC)

ISO 15390 GCR standard

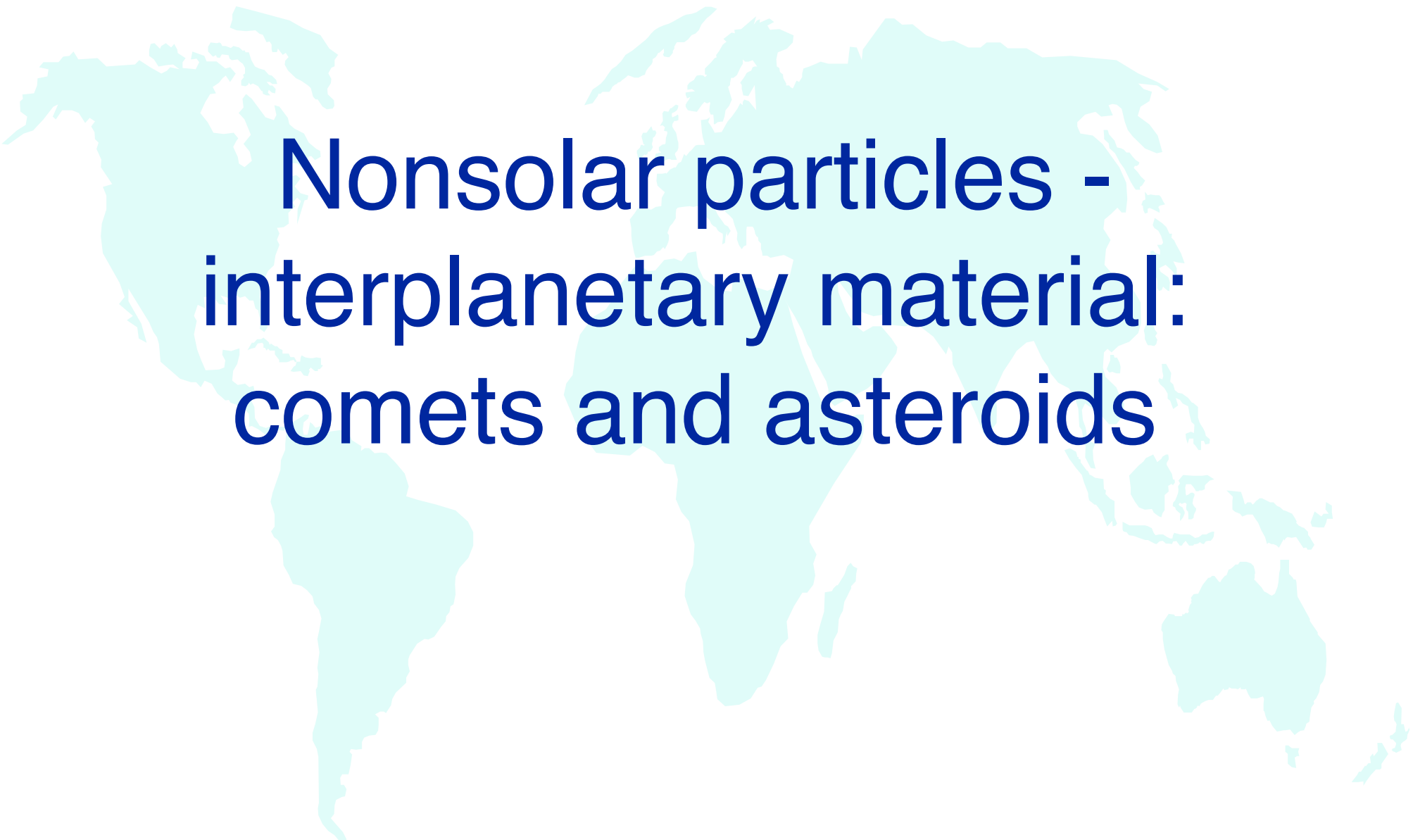
- specifies a model for estimating the radiation impact of galactic cosmic rays (GCR) on hardware and on biological and other objects when in space.
- can also be used in scientific research to generalize the available experimental evidence for GCR fluxes.
- establishes the model parameters and characteristics of variations in the 101 MeV to 105 MeV GCR particles (electrons, protons, and $Z = 2$ to 92 nuclei in the near-Earth space beyond the Earth's magnetosphere)

GCRs produced for operational models



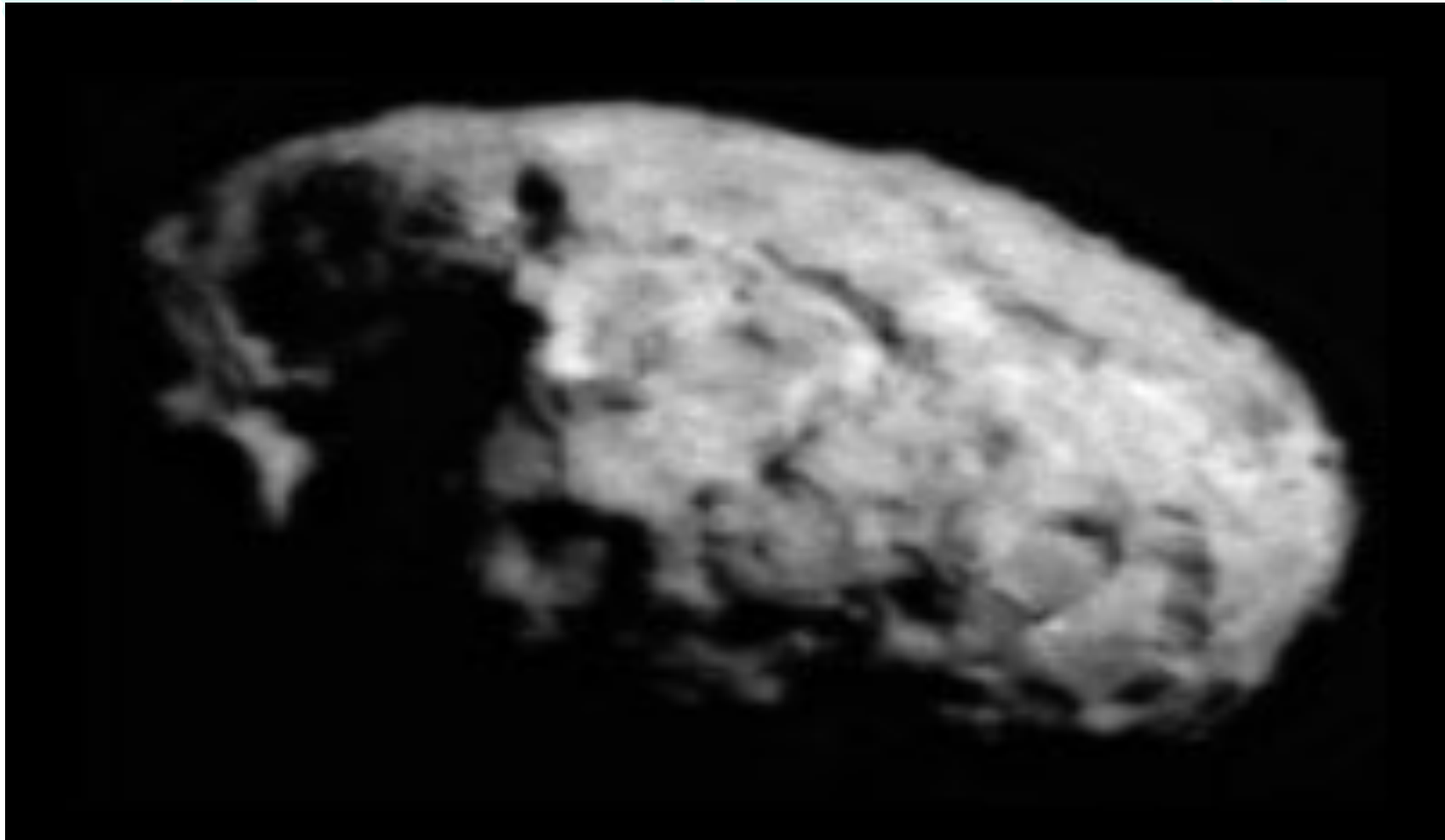
A light blue world map is centered in the background of the slide.

Nonsolar particles - interplanetary material

A faint, light blue world map is visible in the background of the slide, centered behind the main text.

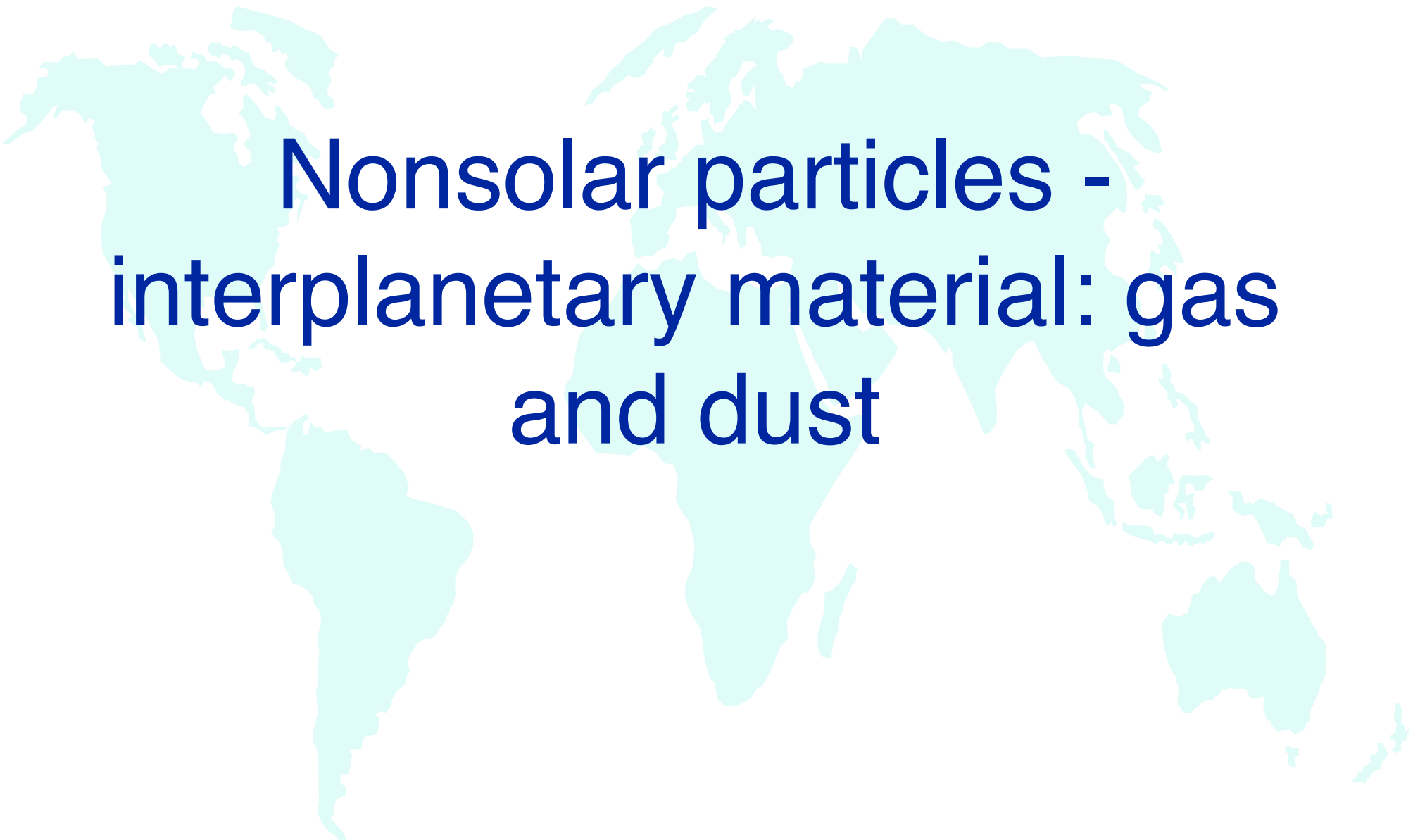
Nonsolar particles - interplanetary material: comets and asteroids

Comet Wild-2



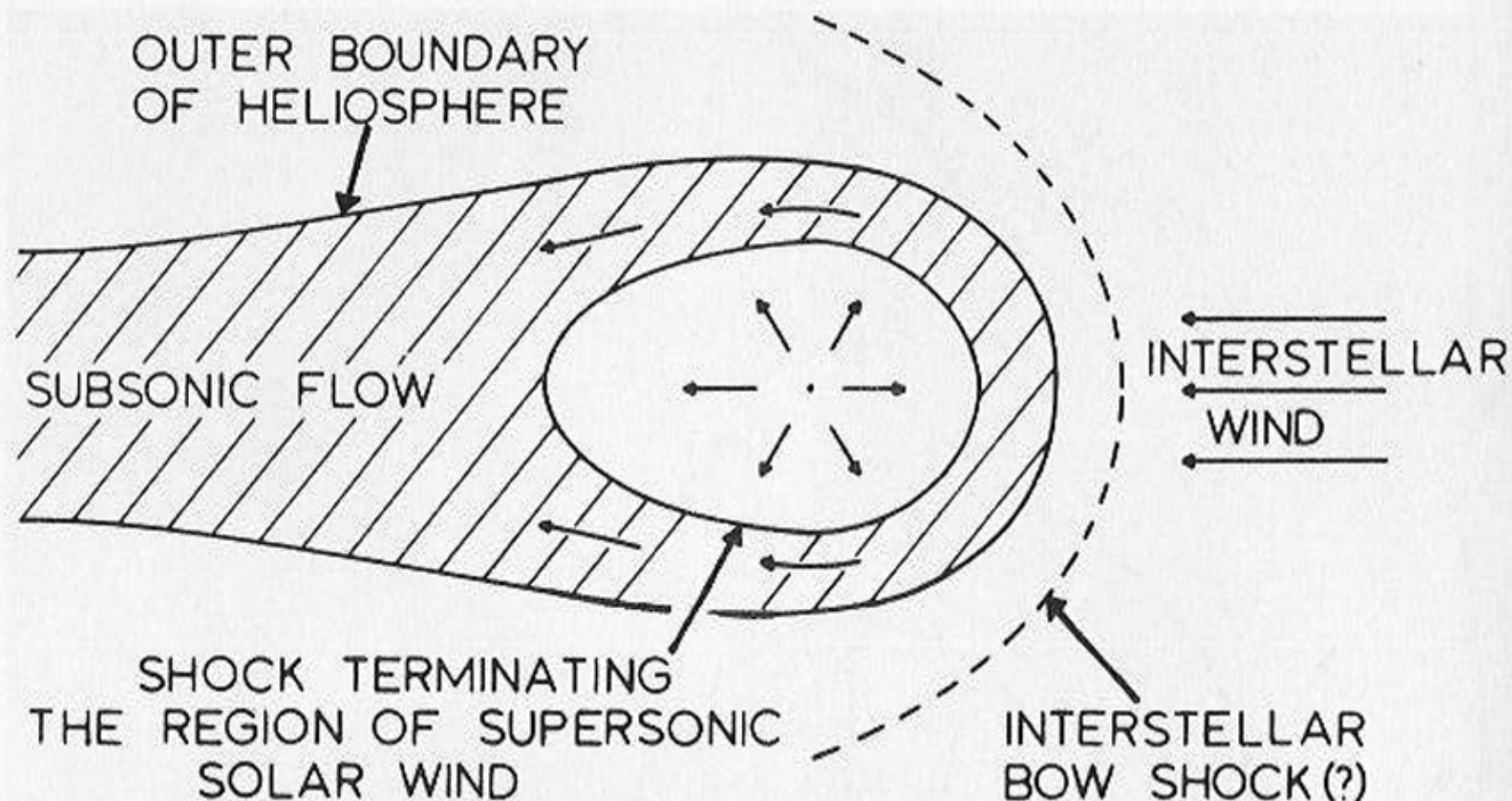
Asteroids: IDA and Dactyl



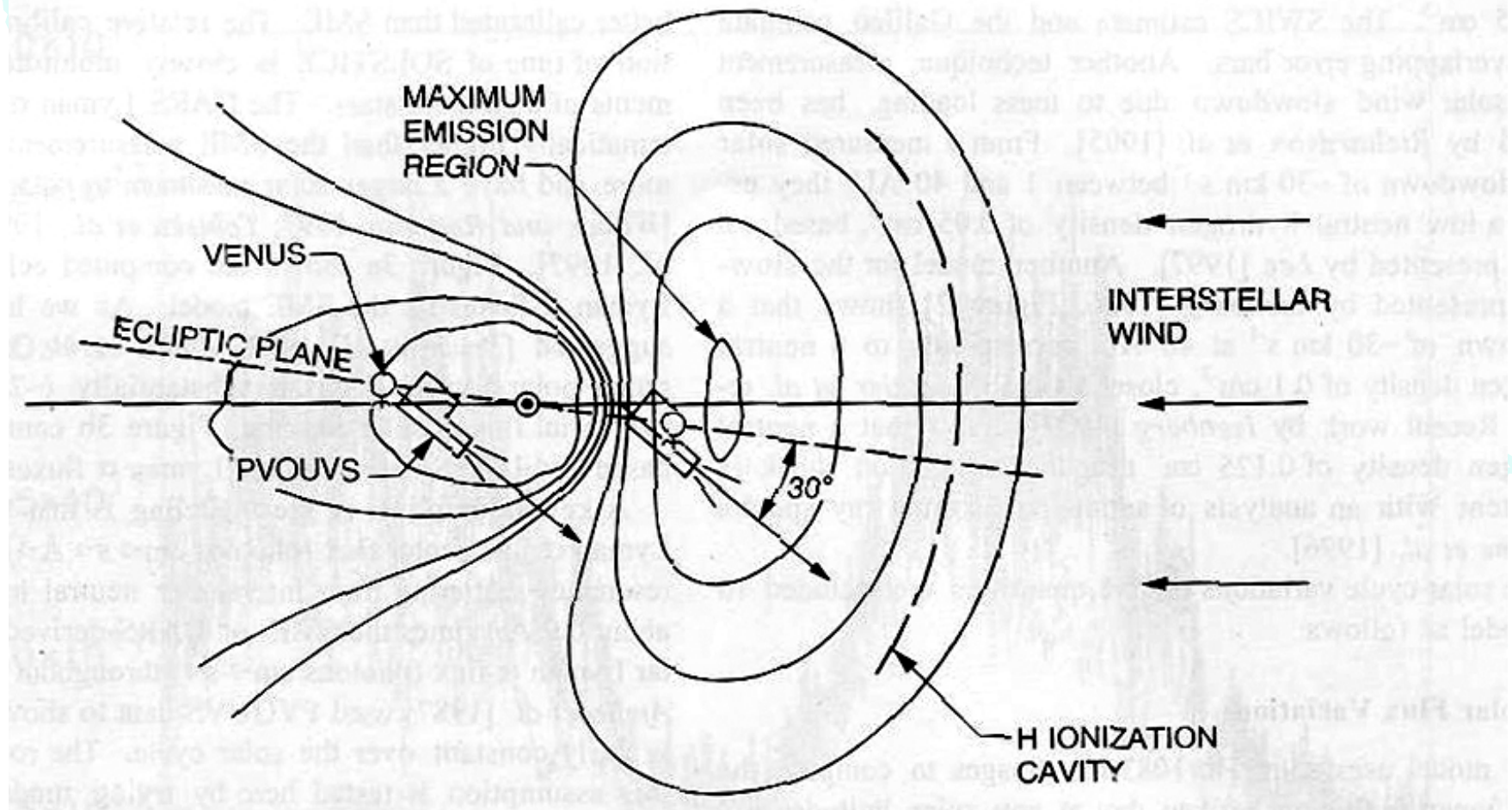
A faint, light blue world map is visible in the background of the slide, centered behind the main title text.

Nonsolar particles - interplanetary material: gas and dust

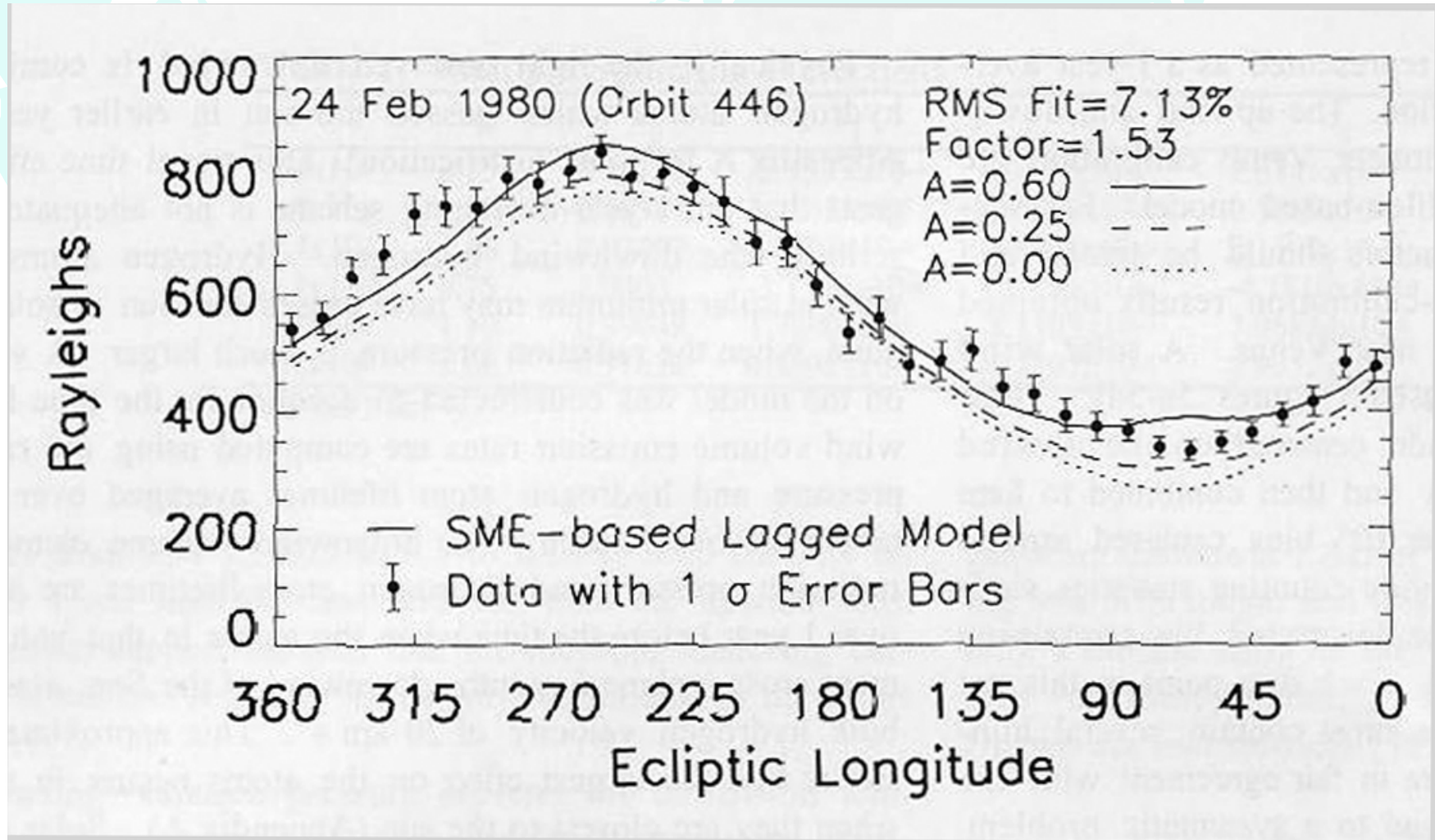
Heliosphere



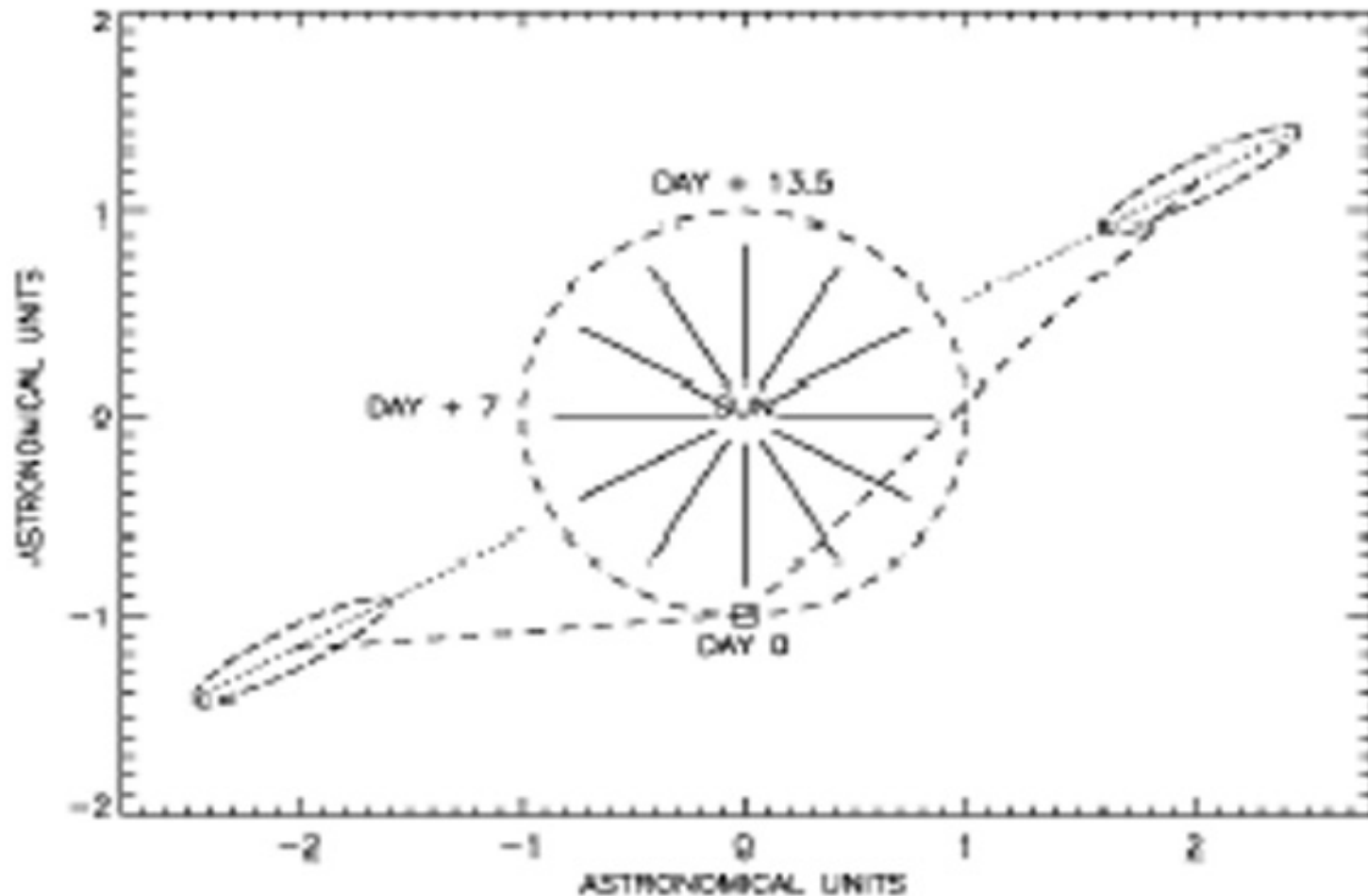
Interstellar H geometry



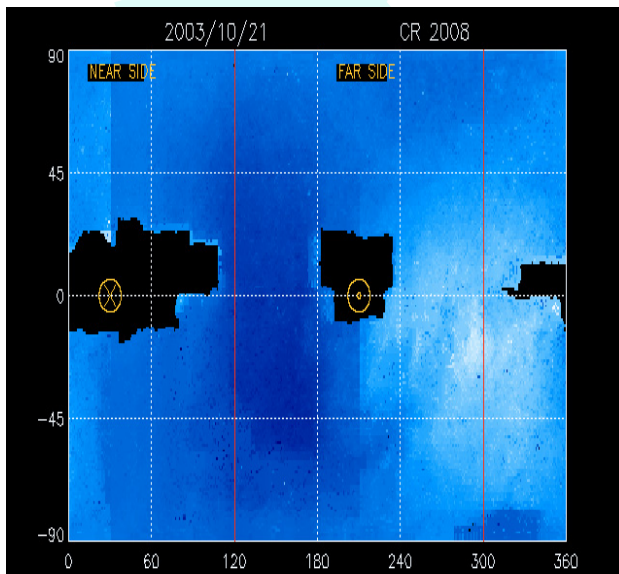
Interstellar H by longitude



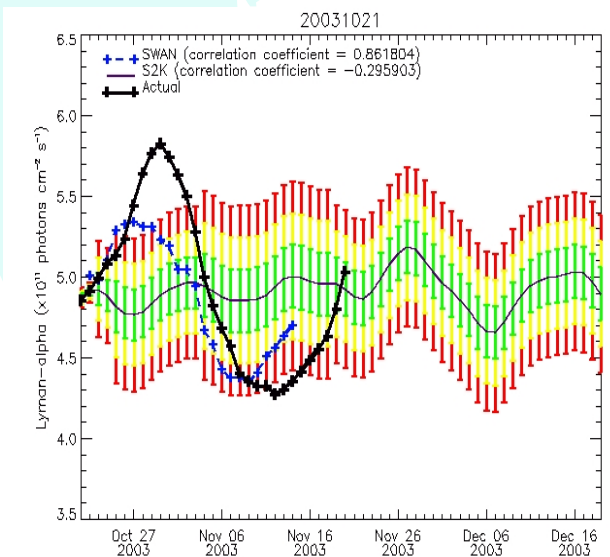
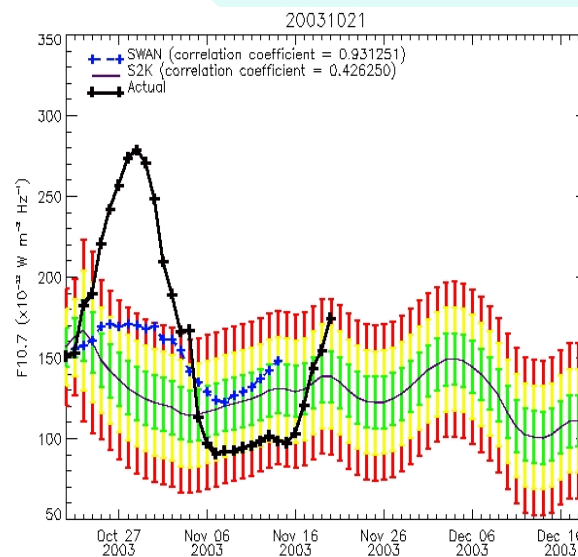
SOHO SWAN forecasts



Forecast Oct 21 2003



Images courtesy of SOHO SWAN team and Eric Quemerais



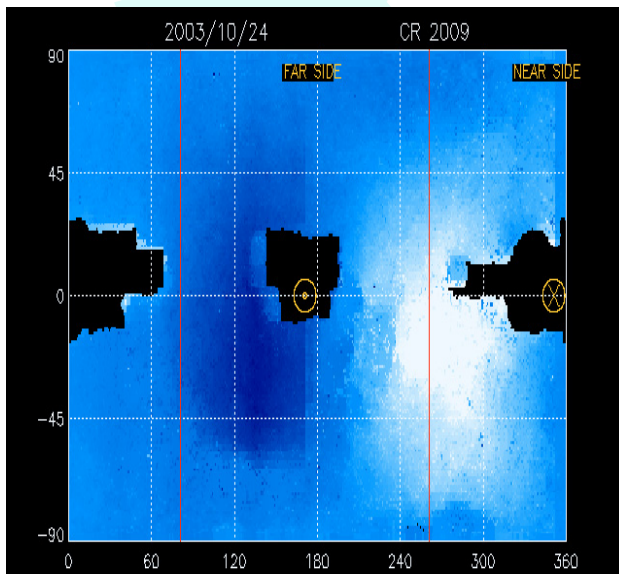
Heavy Black line = post-facto measurements

Heavy Blue line = SWAN prediction

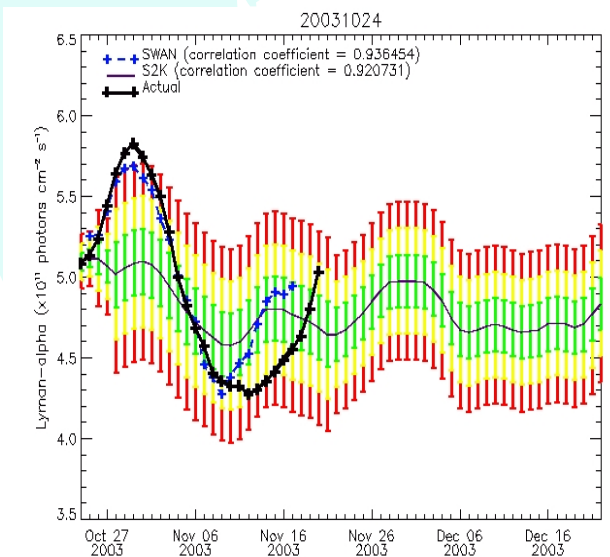
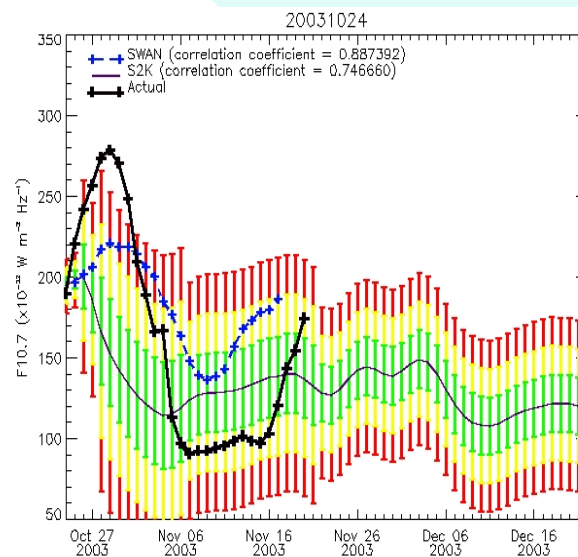
Light Black line = S2K FGen 1X prediction (with 1,2,3- σ error)

Credit: Tobiska

Forecast Oct 24 2003



Images courtesy of SOHO SWAN team and Eric Quemerais



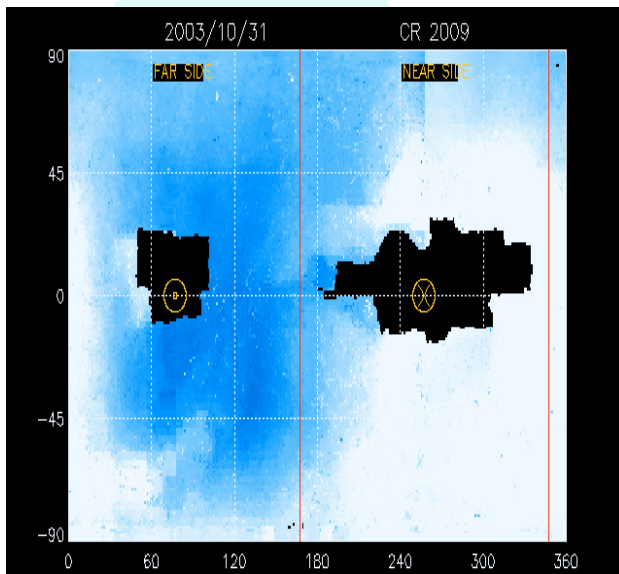
Heavy Black line = post-facto measurements

Heavy Blue line = SWAN prediction

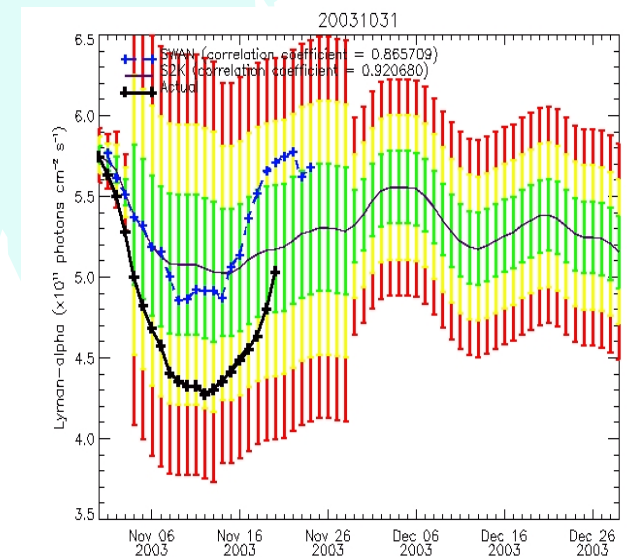
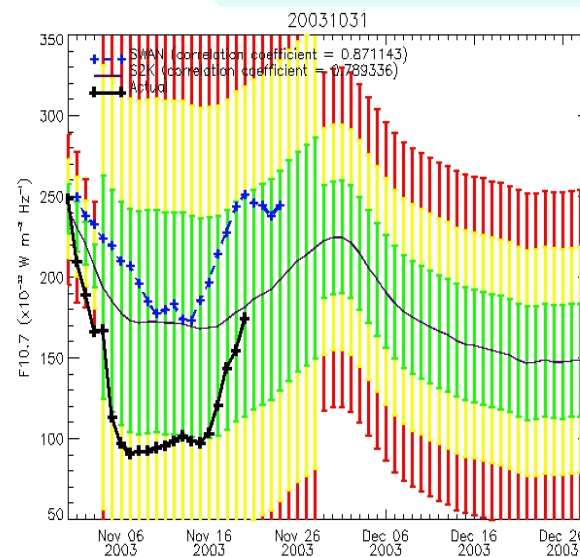
Light Black line = S2K FGen 1X prediction (with 1,2,3- σ error)

Credit: Tobiska

Forecast Oct 31 2003



Images courtesy of SOHO SWAN team and Eric Quemerais



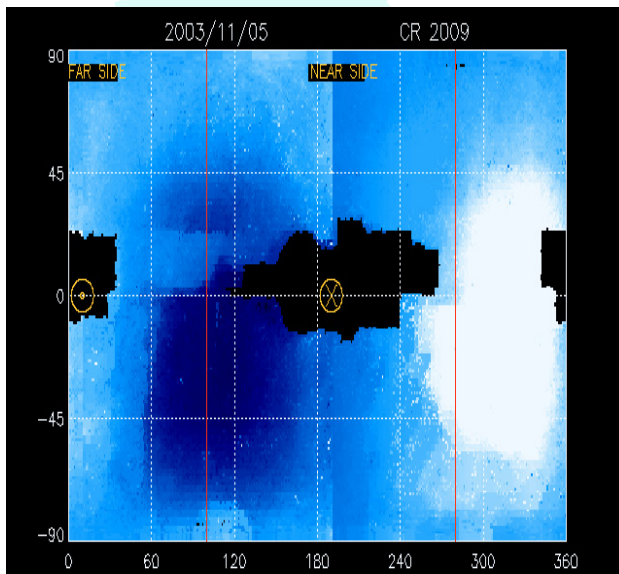
Heavy Black line = post-facto measurements

Heavy Blue line = SWAN prediction

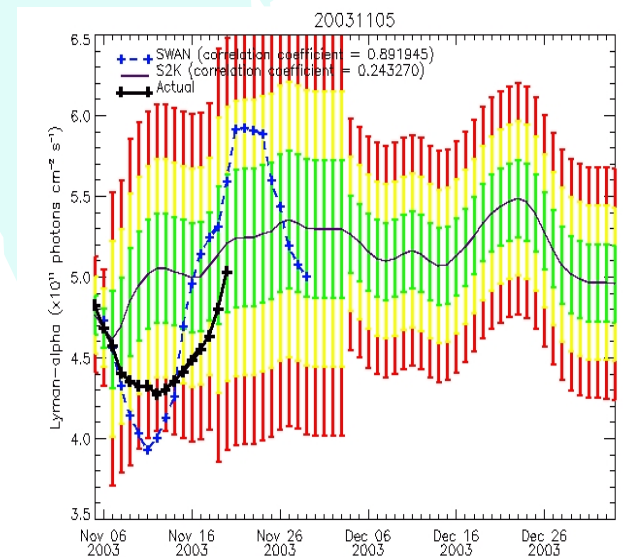
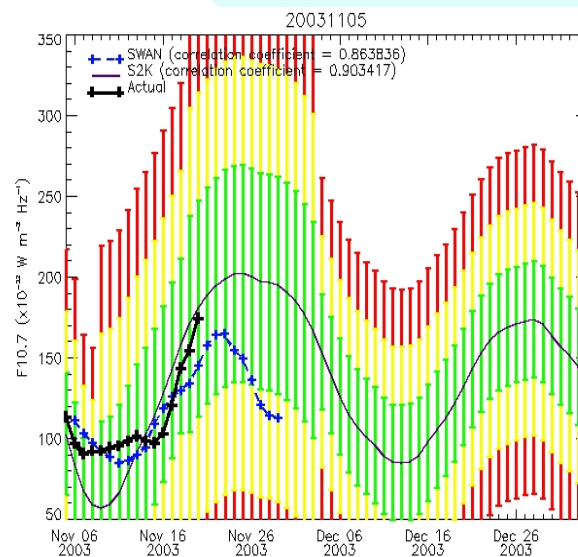
Light Black line = S2K FGen 1X prediction (with 1,2,3- σ error)

Credit: Tobiska

Forecast Nov 05 2003



Images courtesy of SOHO SWAN team and Eric Quemerais



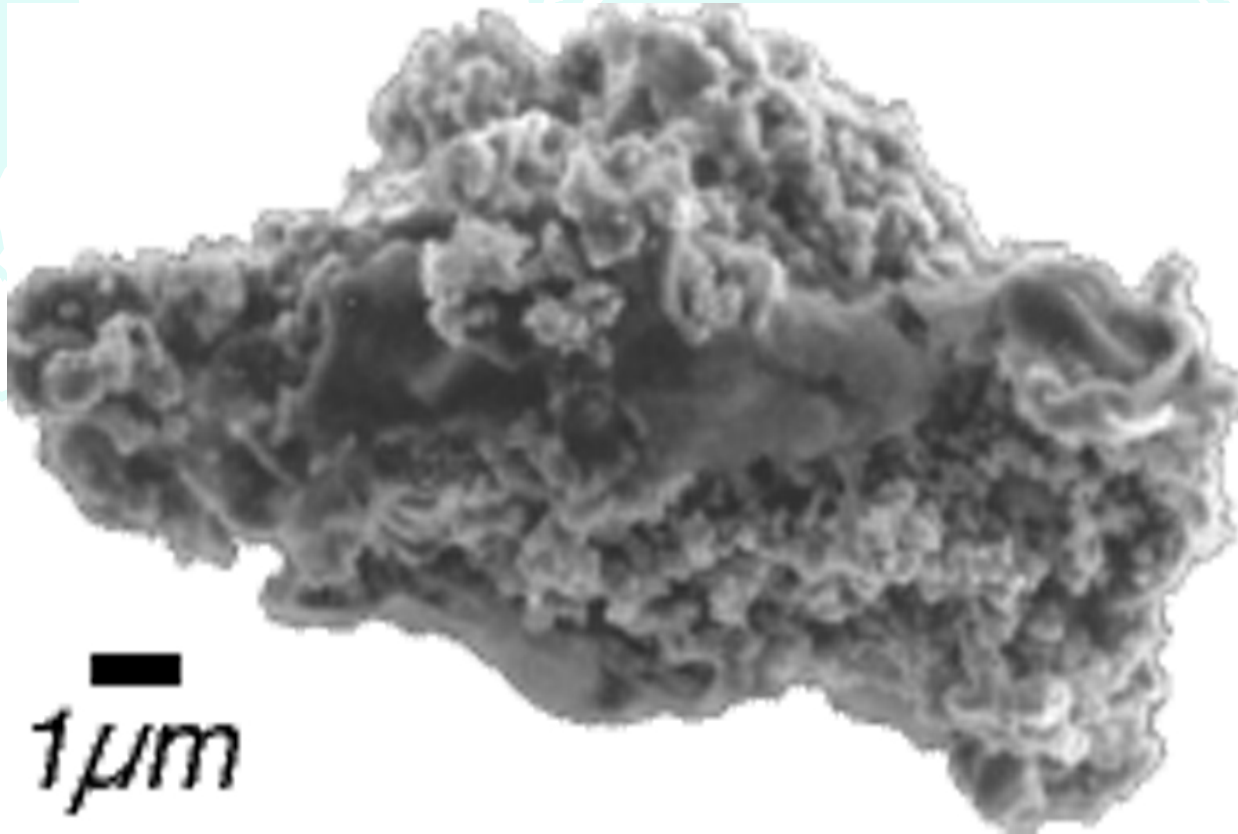
Heavy Black line = post-facto measurements

Heavy Blue line = SWAN prediction

Light Black line = S2K FGen 1X prediction (with 1,2,3- σ error)

Credit: Tobiska

Interplanetary Dust



Zodiacal light is dust



Zodiacal Light over the Qinghai Radio Observatory, Qinghai, central China, 1998

Summary

✓ The interplanetary space environment

✓ The Sun

- ✓ Fields - solar gravitational field
- ✓ Fields - solar magnetic fields
- ✓ Particles - the solar wind
- ✓ Particles - solar electrons and protons

✓ Nonsolar

- ✓ Particles - Galactic cosmic rays
- ✓ Particles - Interplanetary material
 - ✓ Comets and asteroids
 - ✓ Gas and dust