Introductory Lecture II: An Overview of Space Storms

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Overview

- Space weather and its storms.
- Super storms and the Sun.
- Geospace response.
- Heliospheric current sheet.
- “Cosmic” ray.
- Sun: solar storms.
- Heliosphere

Heliophysics: Sun + Solar Wind + Geospace + Planets + ...

Space Weather and Its Storms

What we "see"

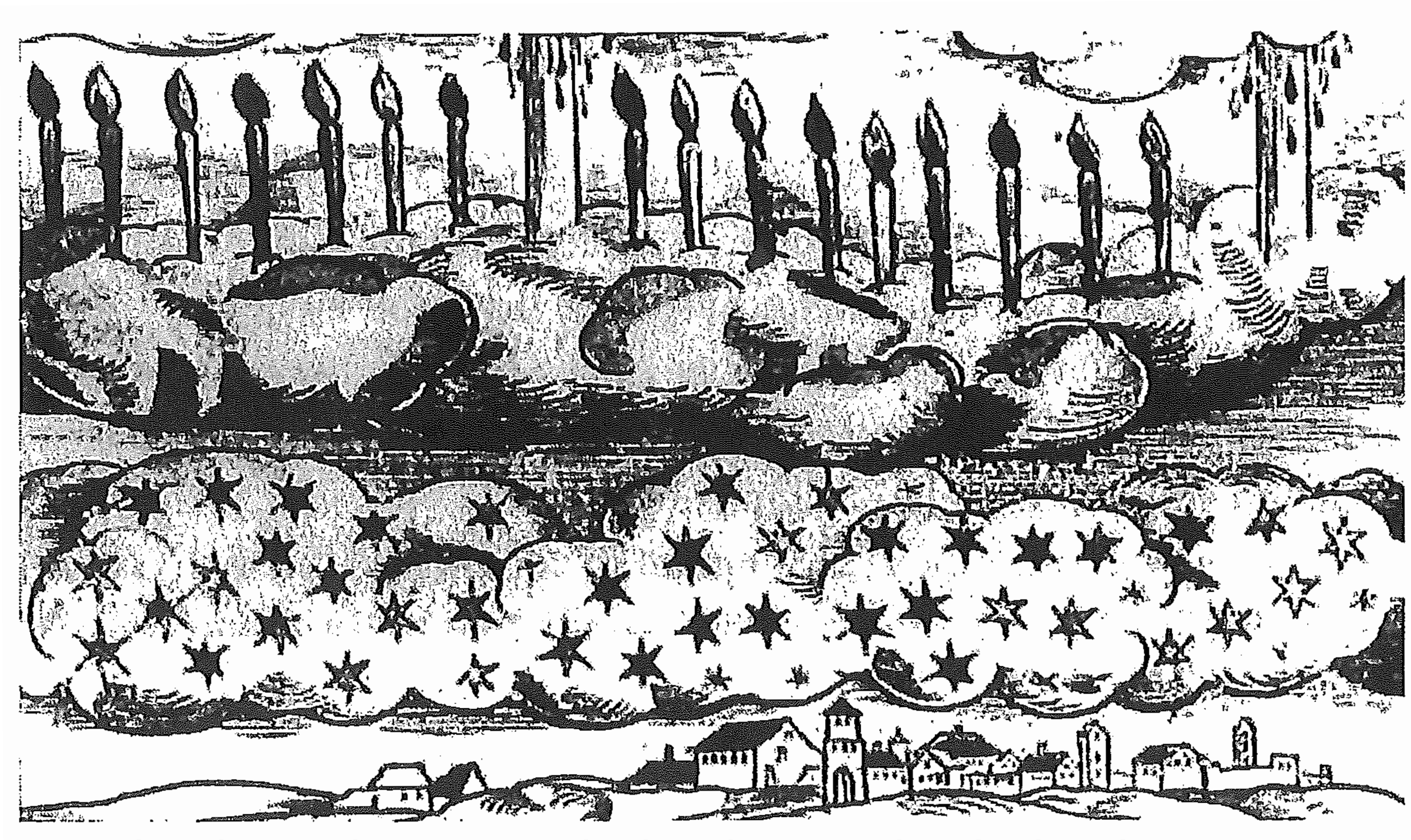
- Aurora "(Sun spots)"
- Magnetometer fluctuations
- Cosmic rays

Time Scales

- Minutes, seconds, hours, days
- Years - solar cycle
- Maunder periods

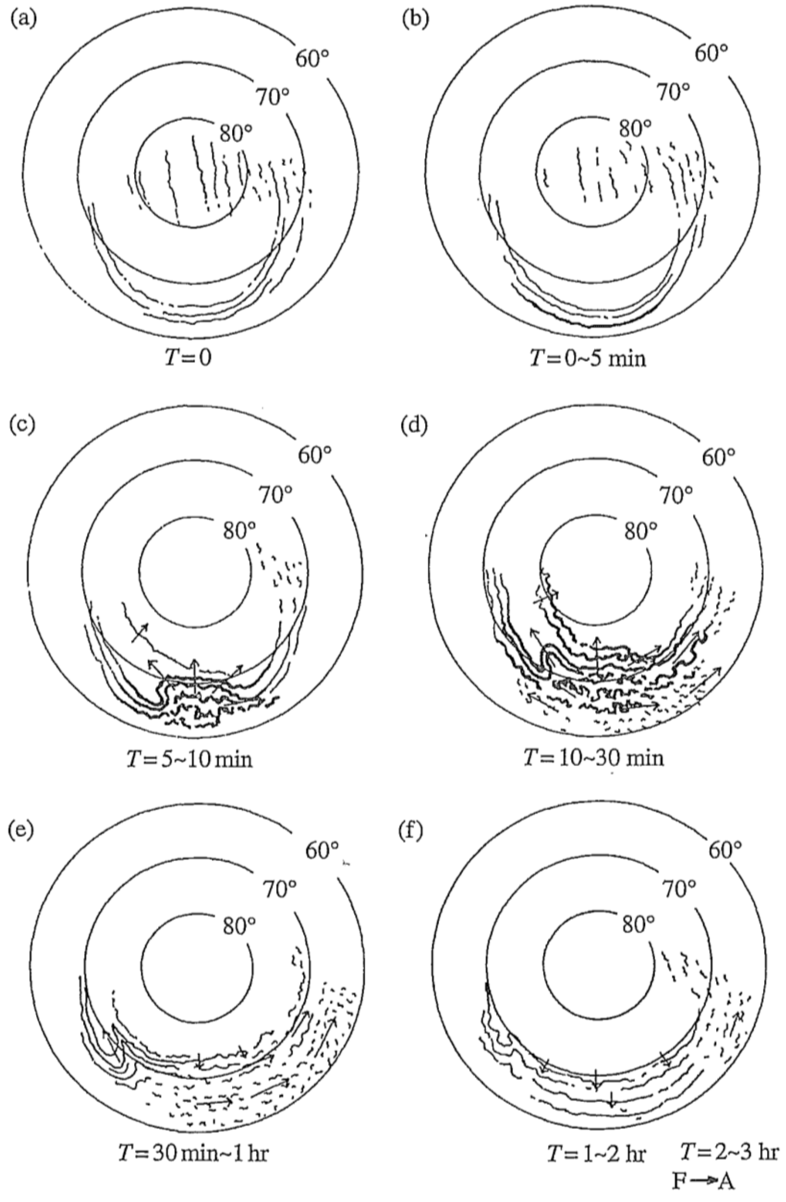
Space Scales

- High latitudes - OVAL
- Night time - all longitudes



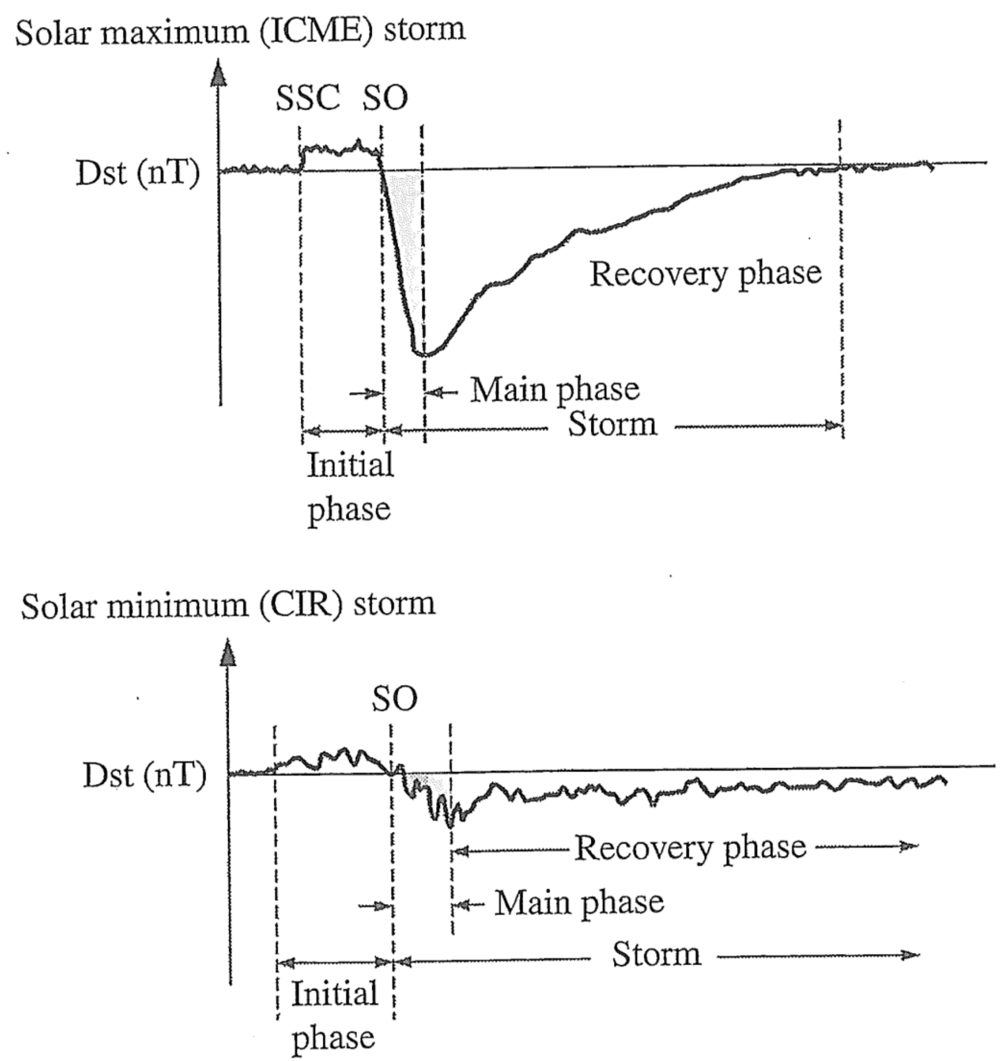
Early drawing of the aurora, depicted as candles in the sky; *c*. 1570
(Original print in Crawford Library, Royal Observatory, Edinburgh.)

Book 2, pp. 16.

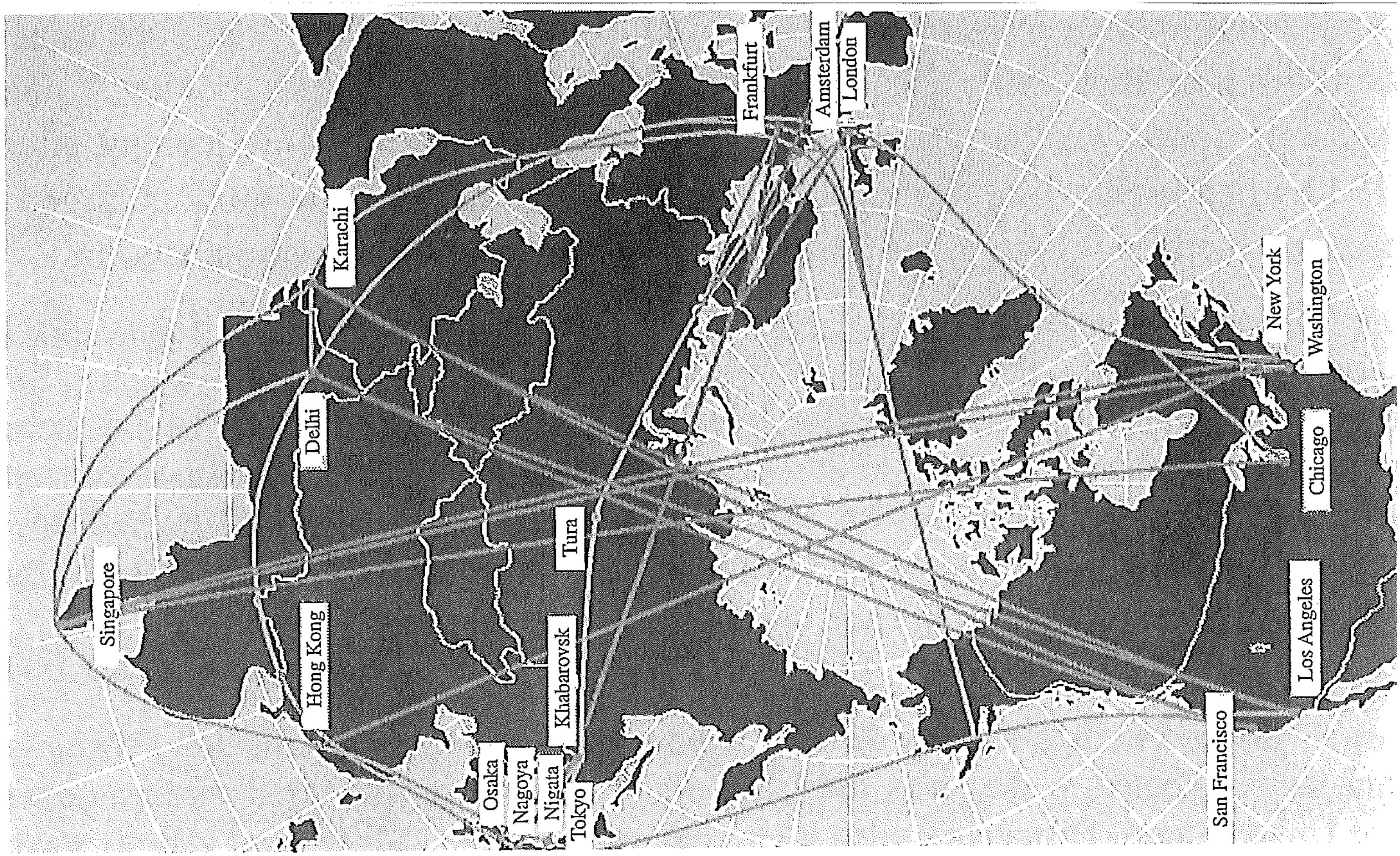


Schematic diagram of an auroral substorm. View from above the North Pole, circles of constant geomagnetic latitude, Sun toward the top (Akasofu, 1964).

Book 2, pp. 266



Schematic time history of geomagnetic field variation for two characteristic magnetic storms. Time range; several days. Vertical variation range: ~100–200 nT. SSC: storm sudden commencement. SO: storm onset. The top panel shows the storm development in response to a characteristic interplanetary coronal mass ejection (ICME), and the bottom panel that for the passage of a corotating intersection region (CIR). (Figure adapted from Tsurutani et al., 2006.) *Book 2, pp. 264.*



Polar airline routes used by United Airlines *c.* 2006 carrying 1500 flights per year. (Courtesy Hank Krakowski.)

Book 2, pp. 28.

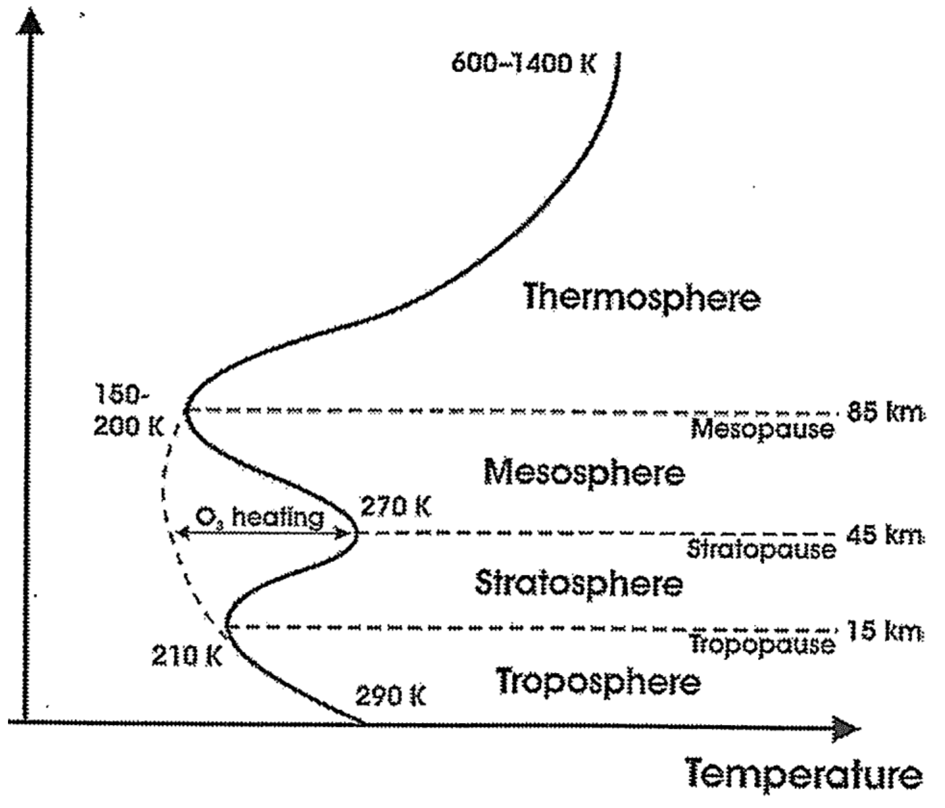
Back-of-the-Envelope Estimation

Given that United Airlines have 1500 polar crossing flights per year,

Estimate how many passengers take polar flights each year?

Note 1: you need to include an estimate for all airlines.

Note 2: Estimation means no calculators needed, no computers,…..



Average vertical temperature profile through Earth's atmosphere. The general shape of the temperature profile is reasonably consistent, to the point where it can be used to define the four main neutral-atmosphere "layers", from the troposphere to the thermosphere.

Book 1, pp. 327.

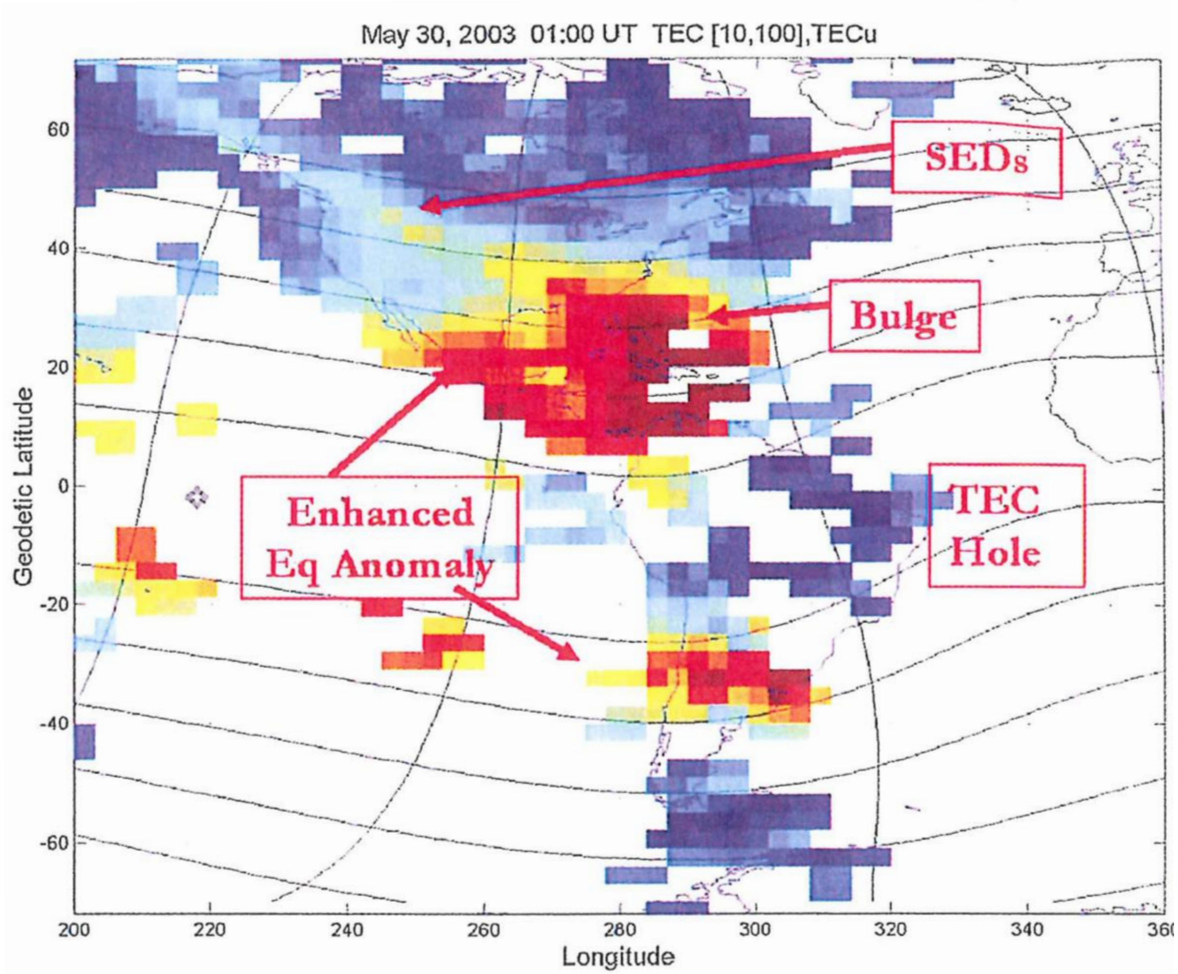


Illustration of the large enhancement “bulge” in TEC at mid-latitudes during a geomagnetic storm, and showing the plume of plasma (storm-enhanced density, or SED) connecting the bulge to the high latitudes. (Courtesy of J. Foster.) *Book 2, pp. 339.*

Back-of-the-Envelope Estimation

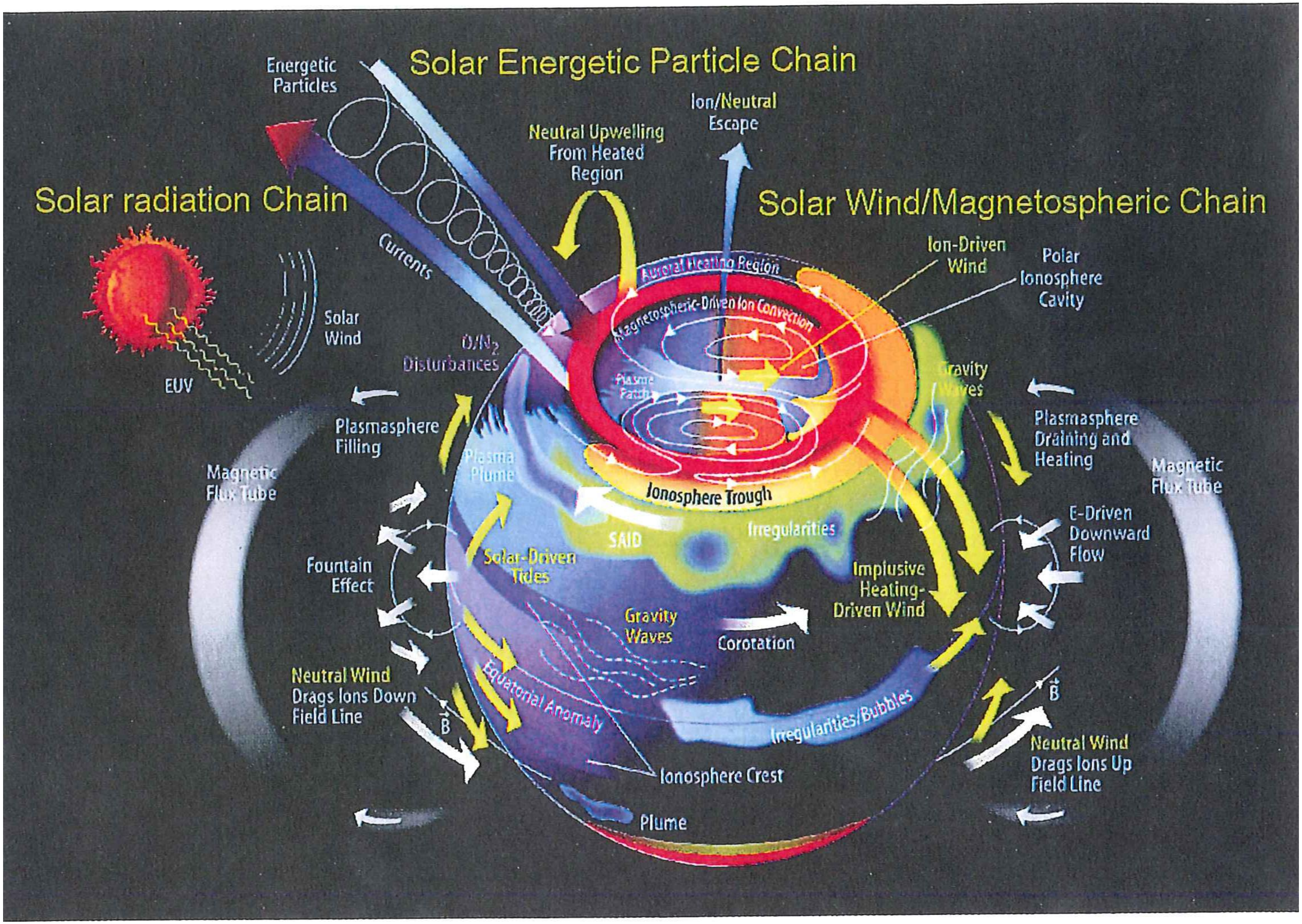
Given that the atomic oxygen ion is the dominant ion in the F-region, that the F-region is a layer 40km thick at an altitude of 300km above the Earth, and the layer density is 1×10^{12} m^{-3} on the dayside and 2×10^{11} m^{-3} on the night side,

Estimate the mass of the F-region?

Note 1: You need to estimate the total number of O^+ ions.

Note 2: Estimation means no calculators needed, no computers,…..

Note 3: Earth radius is 6371 km, mass of proton 1.6×10^{-27} kg


Solar Energetic Particle Chain
Energetic Particles
Ion/Neutral Escape
Neutral Upwelling From Heated Region
Solar radiation Chain
Solar Wind/Magnetospheric Chain
Currents
Auroral Heating Region
Magnetospheric-Driven Ion Convection
Ion-Driven Wind
Polar Ionosphere Cavity
Solar Wind
EUV
O/N2 Disturbances
Gravity Waves
Plasma Patch
Plasmasphere Filling
Plasmasphere Draining and Heating
Magnetic Flux Tube
Plasma Plume
Ionosphere Trough
Magnetic Flux Tube
E-Driven Downward Flow
SAID
Irregularities
Fountain Effect
Solar-Driven Tides
Impulsive Heating-Driven Wind
Gravity Waves
Corotation
Neutral Wind Drags Ions Down Field Line
Equatorial Anomaly
Irregularities/Bubbles
Neutral Wind Drags Ions Up Field Line
Ionosphere Crest
Plume

Book 1, pp. 350.

Super Storms and the Sun

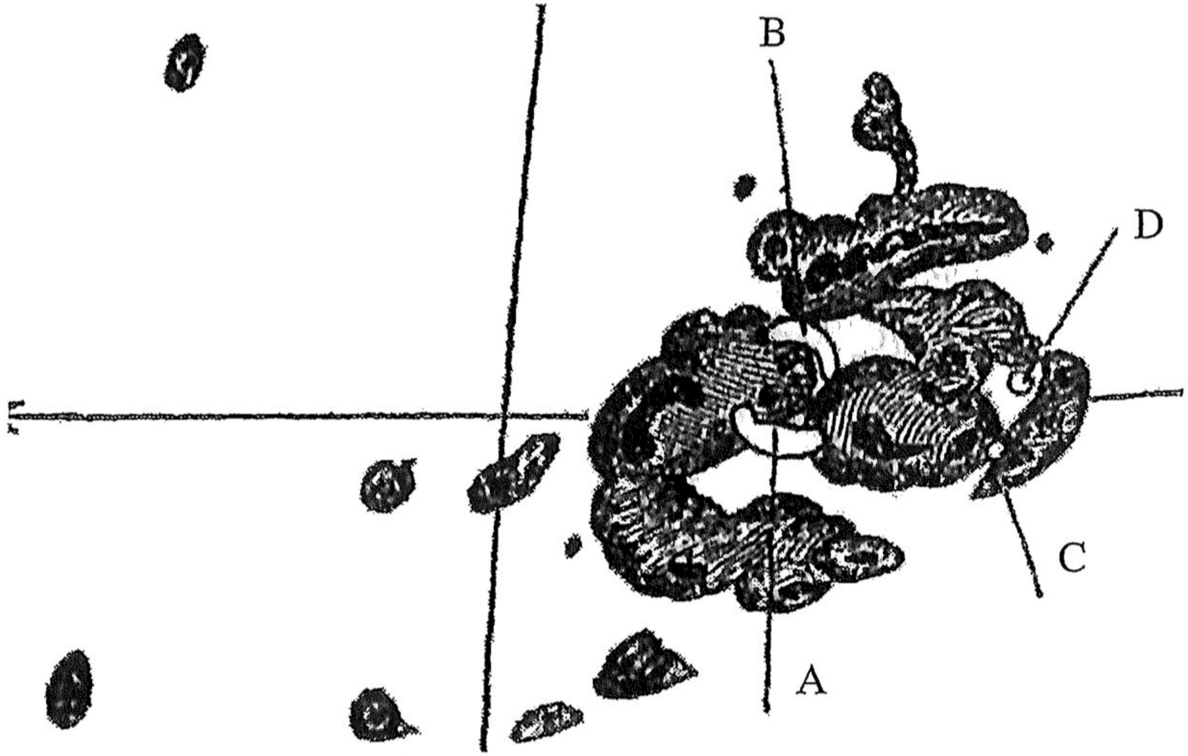
- Carrington White Light Flare

  1859, 1 September

- Coronal Mass Ejection (CME)

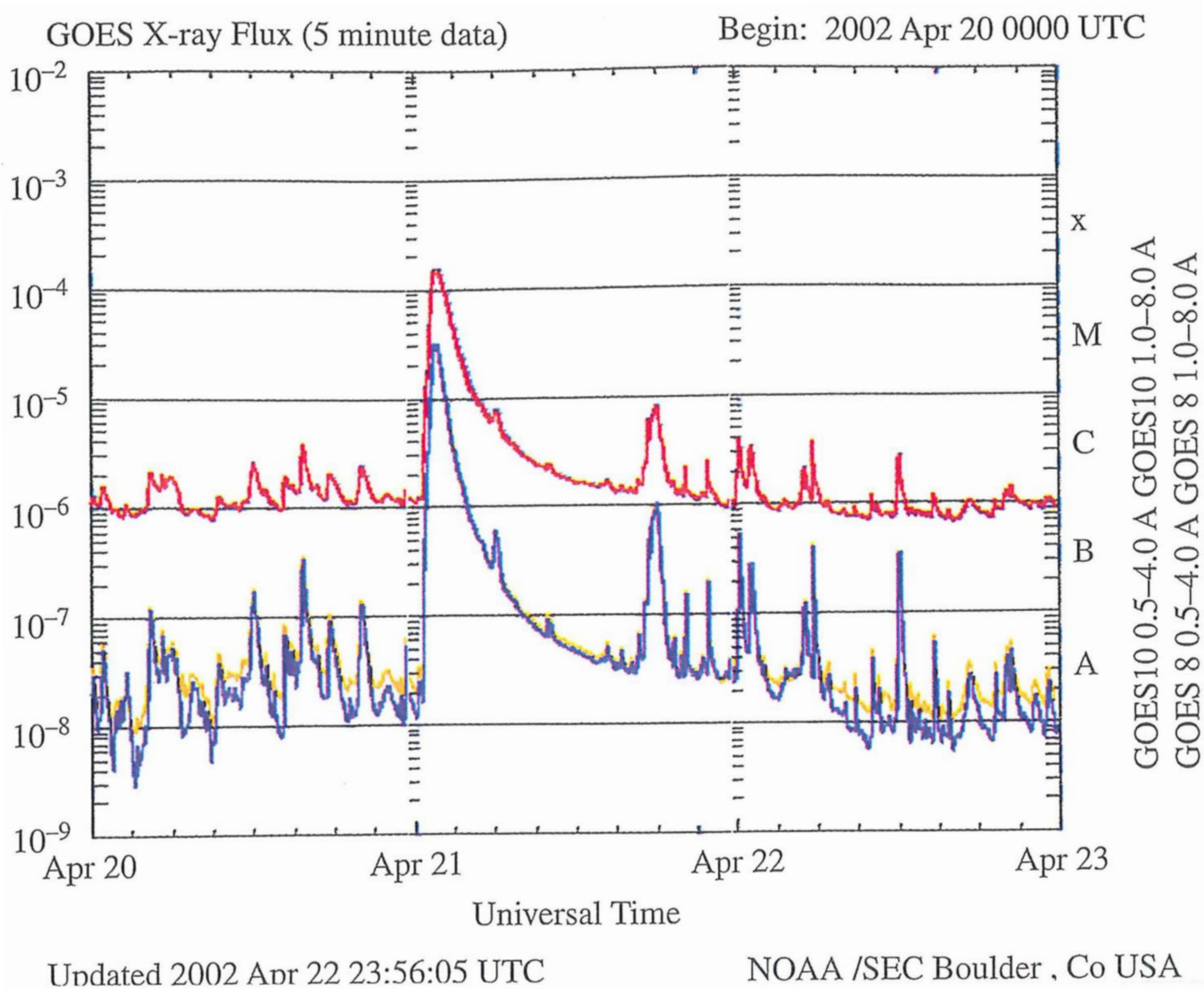
- High energy particles

- Time scales



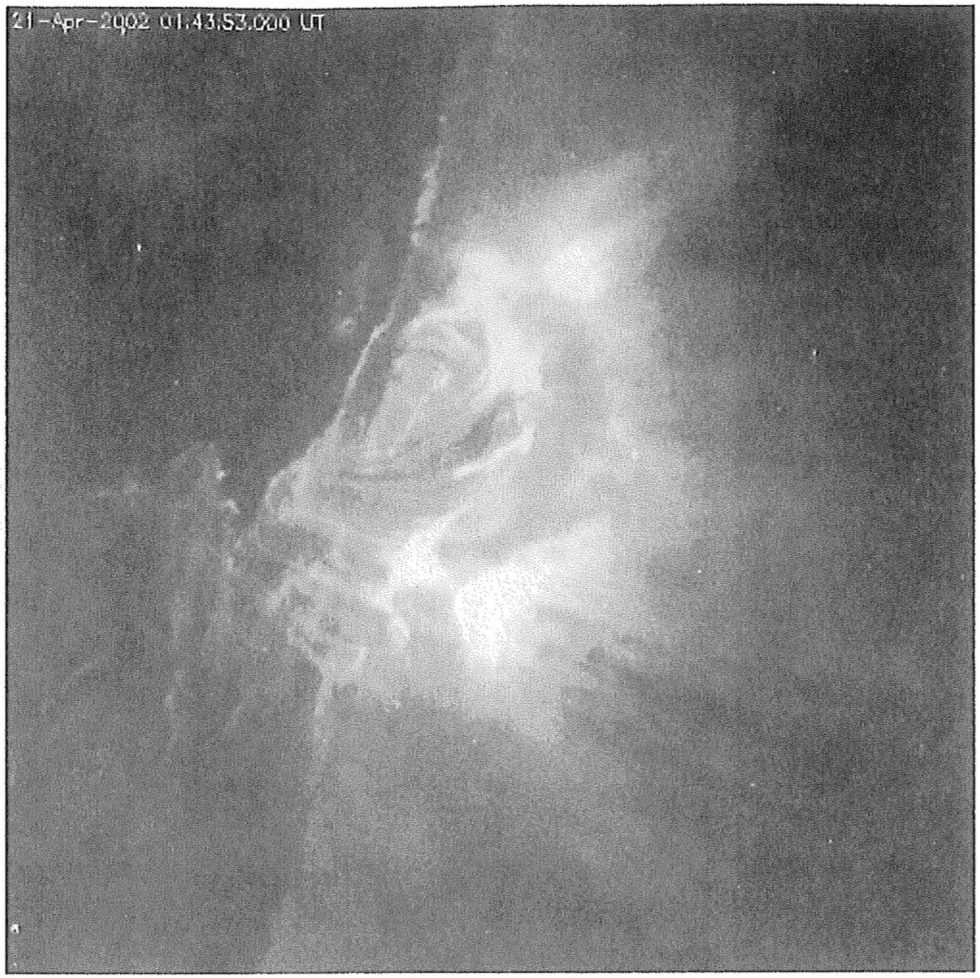
Carrington's sketch at 11:18 GMT on September 1, 1859, of the sunspot and the lettered (white) flaring regions. (From Carrington, 1859.)

Book 2, pp. 26.



Example of GOES XRS measurements during a large (X1.5) solar flare.

Book 2, pp. 347.



A TRACE observation of the 171Å, or 17.1 nm, EUV emission from the X1.5 solar flare (See Table 5.1 for the flare magnitude scale) on 21 April 2002. (From Gallagher et al., 2002.)

Book 2, pp. 86.

Back-of-the-Envelope Estimation

Given that light takes 8 minutes to travel from the Sun to the Earth,

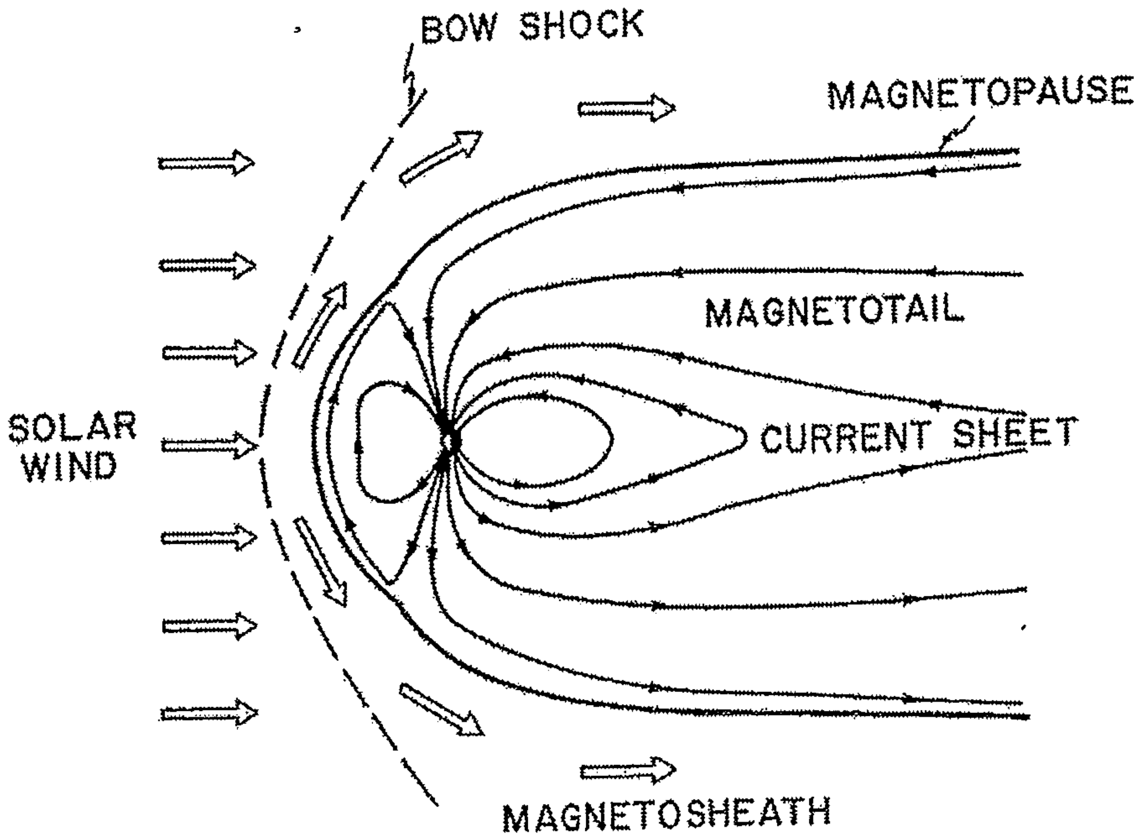
Estimate how far the Earth is from the Sun ?

Note 1: Answer in km.

Note 2: Estimation means no calculators needed, no computers,…..

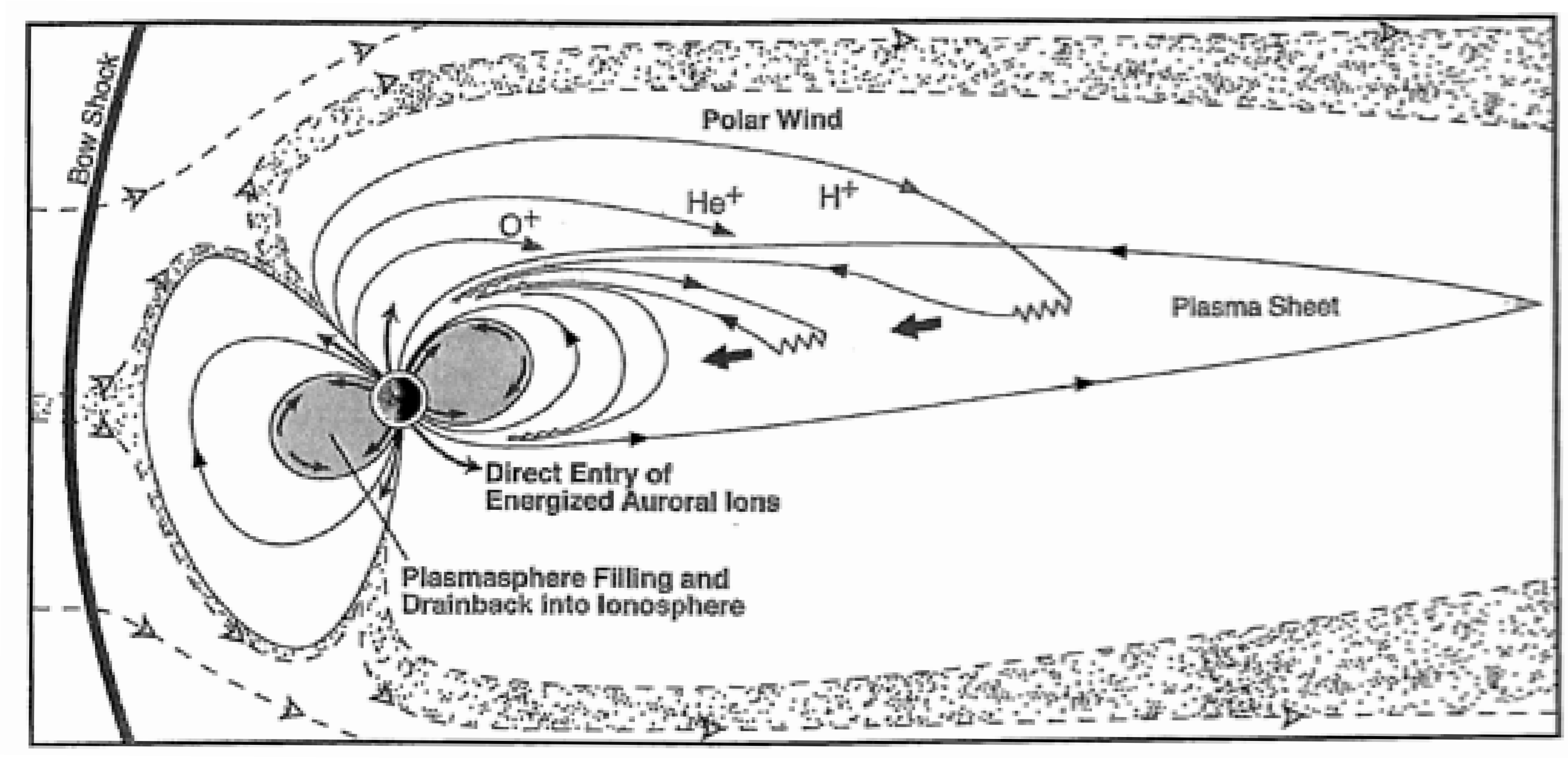
GEOSPACE Responses

- Energy, Momentum, Mass, $\vec{E}, \vec{B}, \vec{J}$
- Magnetosphere – Bow shock
  - – Magnetopause
  - – Magnetosheath
  - – Neutral sheet
  - – Plasma sheet
  - – Ring currents
- Plasmasphere – Plasmapause
  - – Radiation belts
- Ionosphere – Exosphere
  - – F-region, E-region, D-region
- Thermosphere – Atmosphere, mesopause
- Mesosphere – Stratopause
- Stratosphere –
- Troposphere –



Schematic view of a magnetically closed magnetosphere, cut in the noon-midnight meridian plane. Open arrows, solar wind bulk flow; solid lines within magnetosphere, magnetic field lines (directions appropriate for Earth).

Book 1, pp. 259.



Sources of plasma for the Earth's magnetosphere (after Chappell, 1988). The shaded and dotted area illustrates the boundary layer through which solar wind plasma enters the magnetosphere.

Book 1, pp. 369.

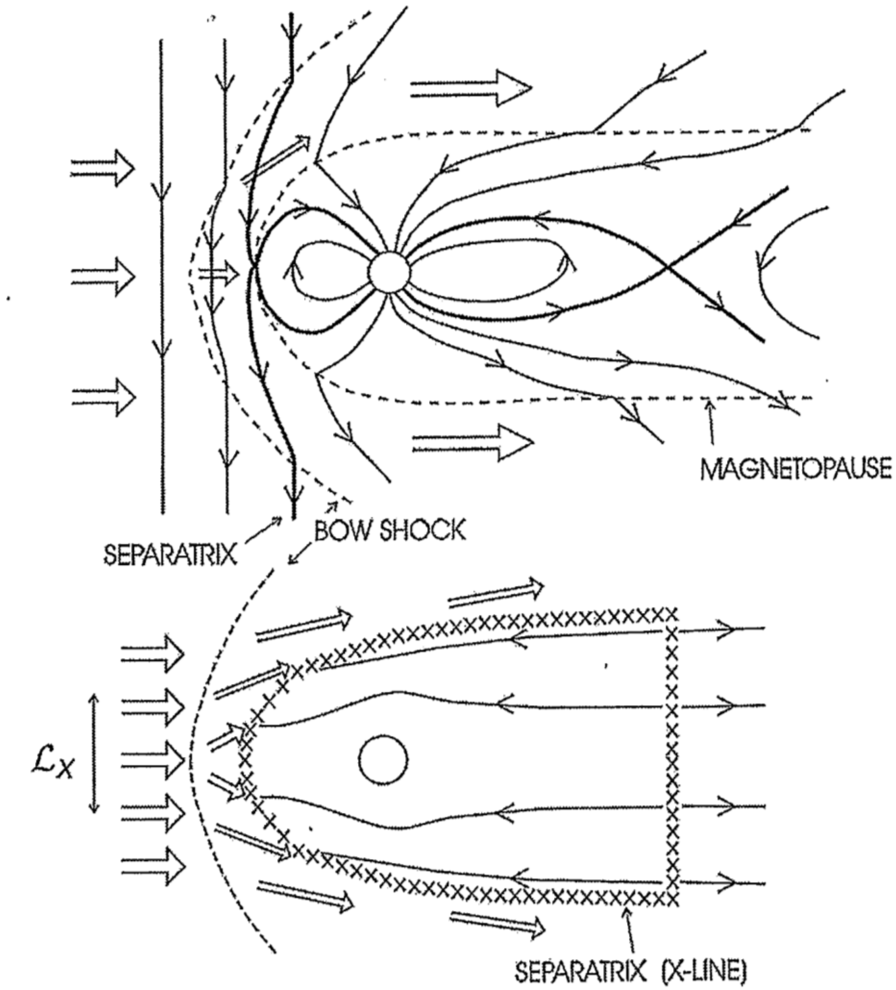
Back-of-the-Envelope Estimation

Given that the magnetosphere can be “viewed” as a cylinder that has a diameter of 10 Re and a length of 60 Re, and that its total proton content is approximately equal to the F-region O^+ content,

Estimate the average proton density in the magnetosphere?

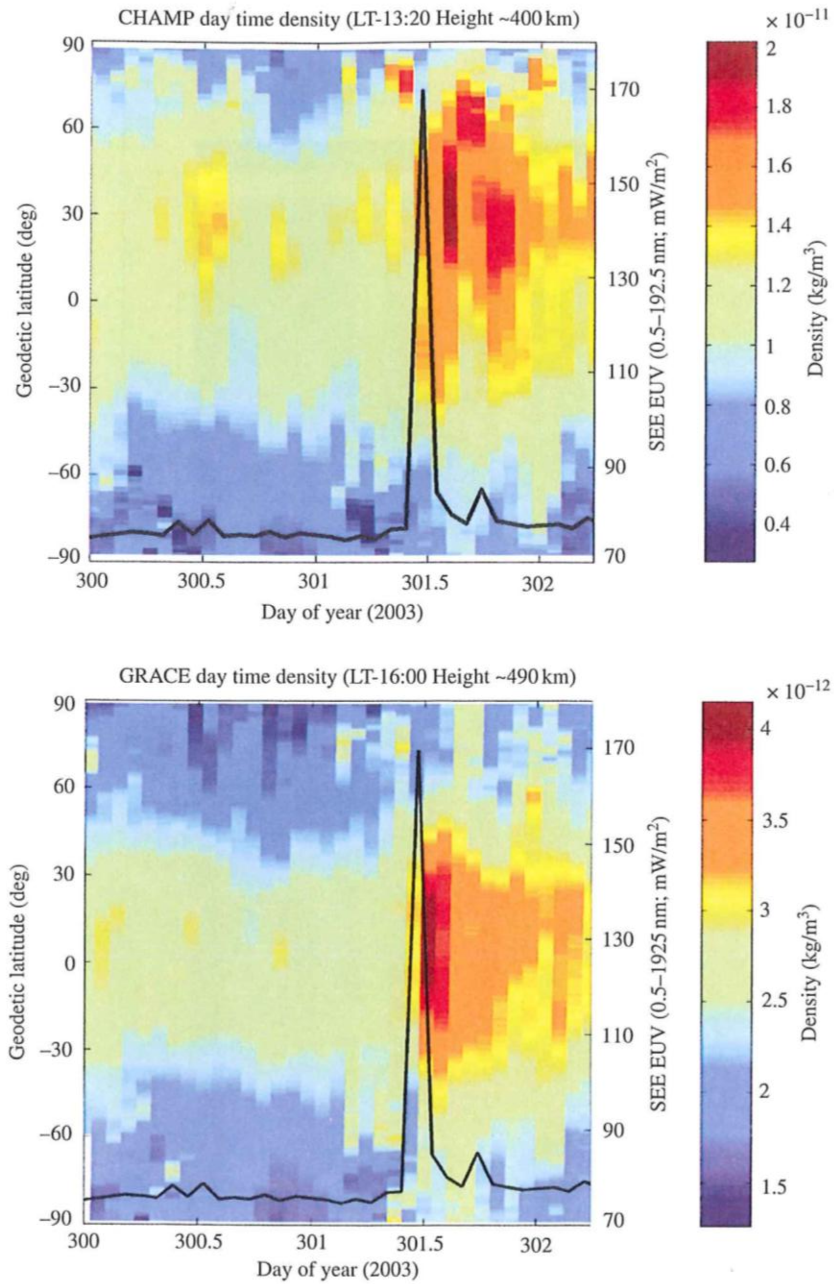
Note 1: Re is Earth radius.

Note 2: Estimation means no calculators needed, no computers,…..



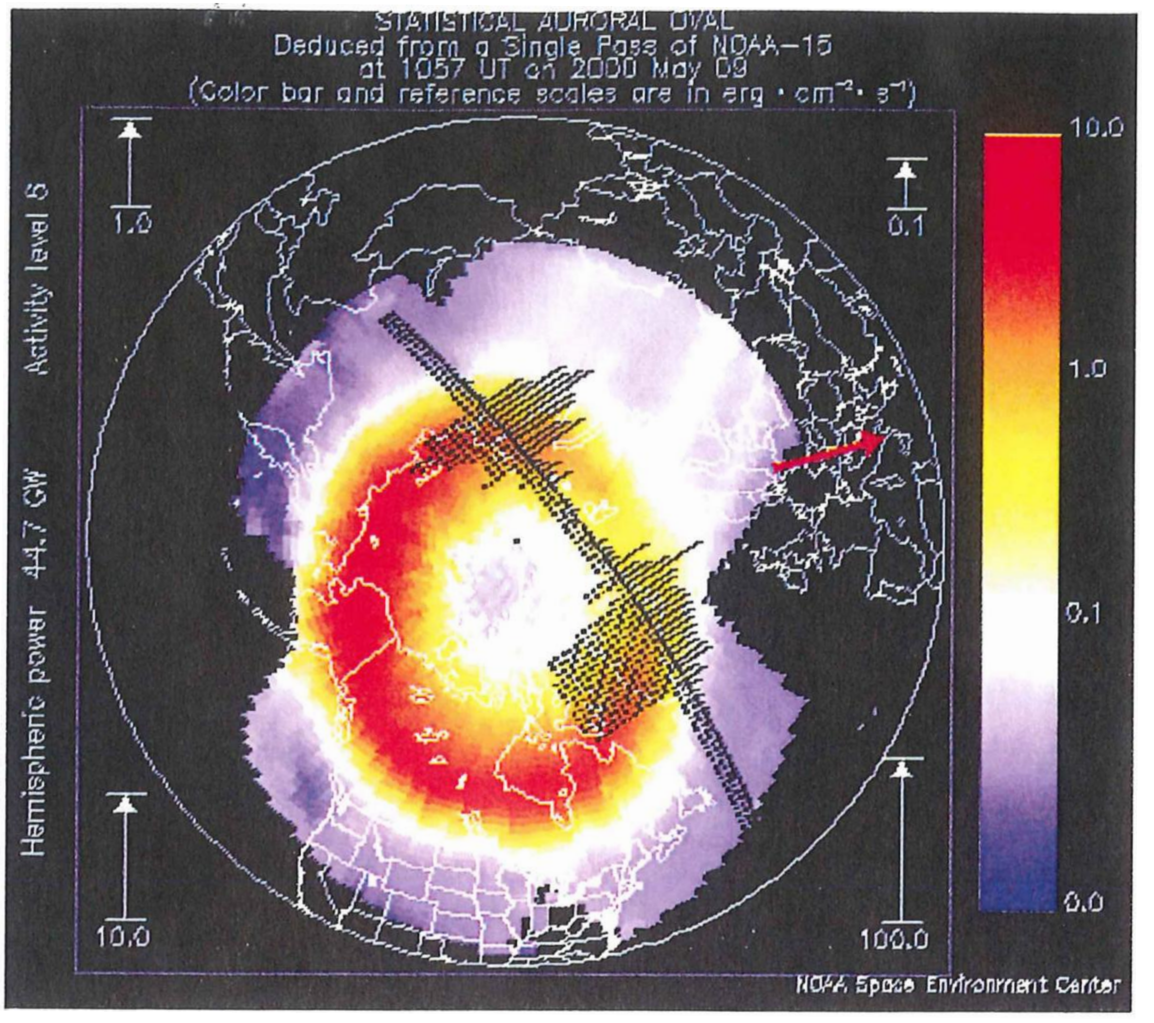
Schematic representation of a magnetically open magnetosphere. The upper panel shows a cut in the noon-midnight meridian plane; the bold lines are magnetic field lines within the separatrix surfaces separating open lines from closed lines or open lines from interplanetary field lines.

Book 1, pp.264.



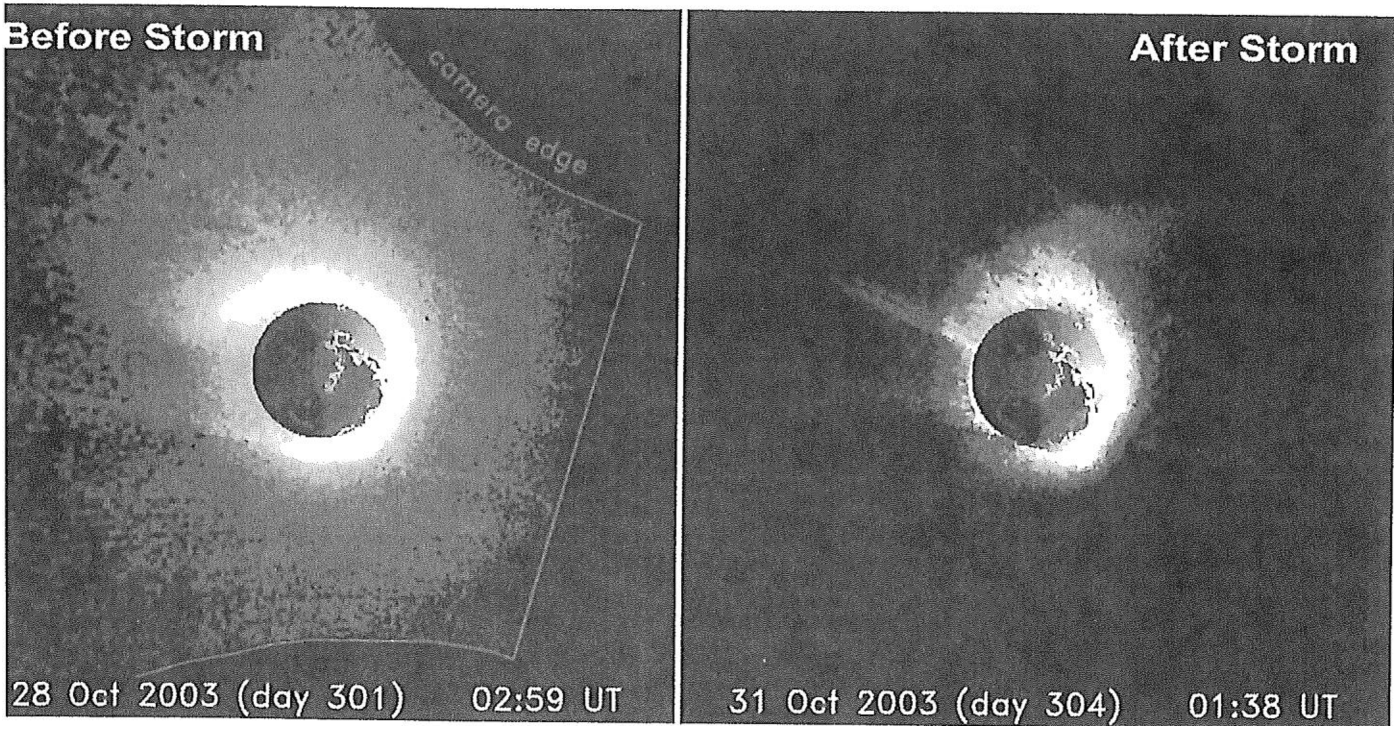
Thermospheric density enhancements measured by accelerometers on the CHAMP satellite (altitude ~400 km) and GRACE satellite (altitude ~490 km) during the October 28, 2003 flare. (Sutton et al., 2006.)

Book 2, pp. 355.



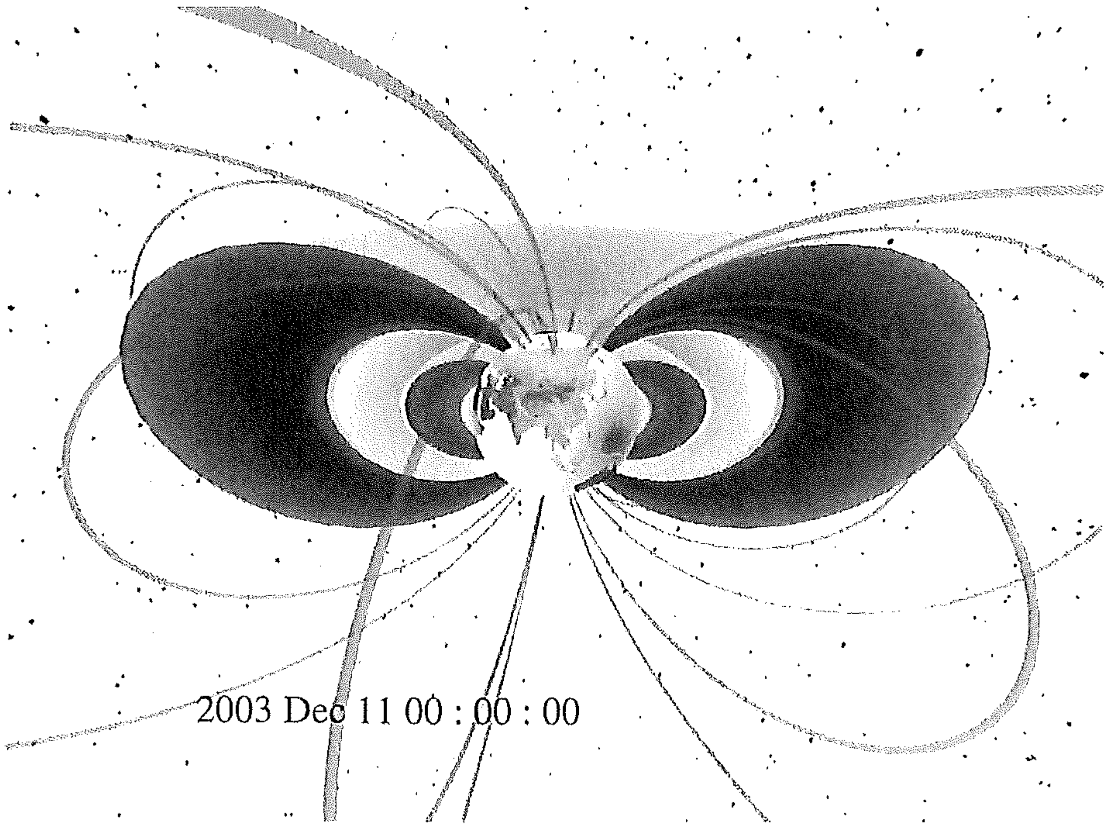
Statistical pattern of auroral energy input derived from TIROS/NPAA satellite data during a single transit of the polar region. (From Evans et al., 1988.)

From Book 2, pp. 328.



Satellite observations of the erosion of the plasmasphere during a storm, from observations by the IMAGE satellite before and after the Halloween storm of October 28, 2003. (Courtesy of J. Goldstein.) The plasmaspheric tail, or plume, can be seen in the dusk sector during the storm event.

Book 2, pp.341.

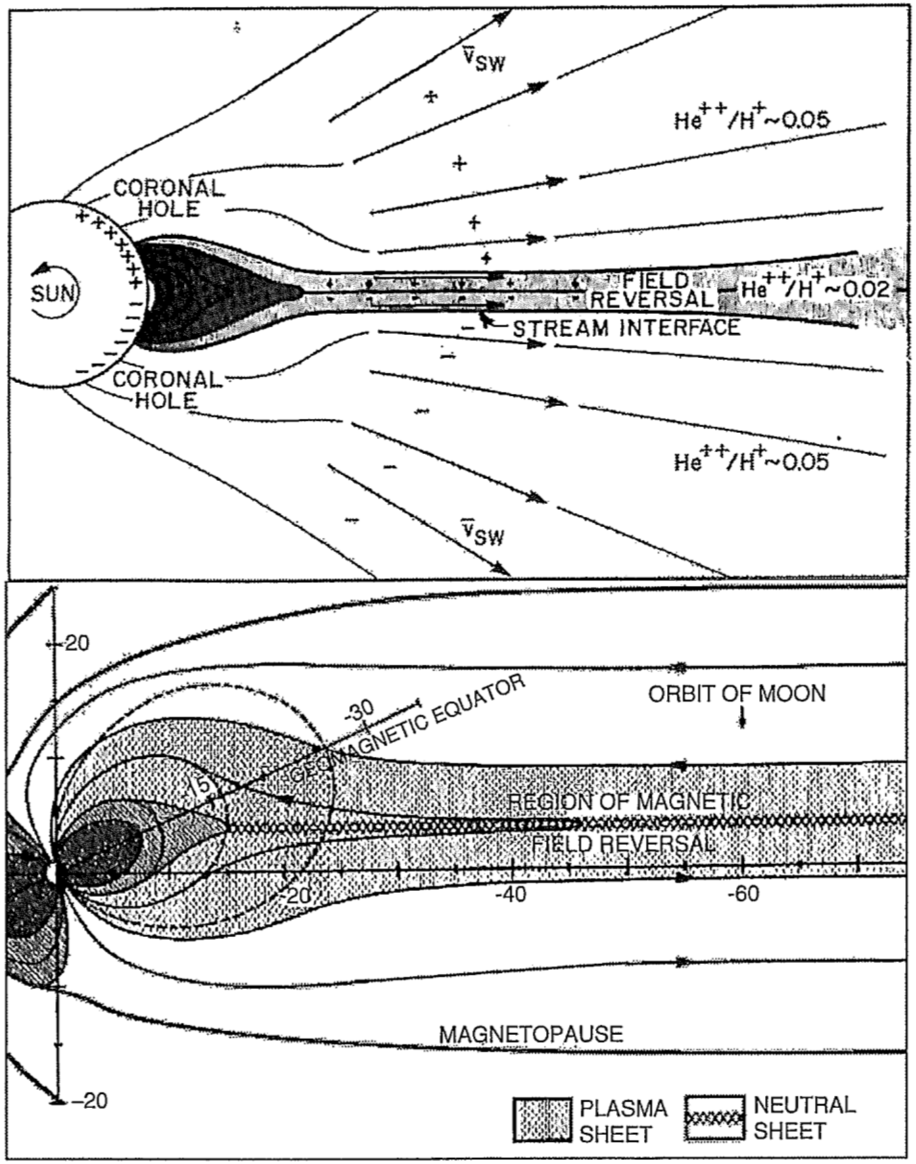


Schematic depiction of Earth's electron radiation belts. (Courtesy of the NASA/Goddard Space Flight Center Scientific Visualization Studies.)

Book 2, pp.294.

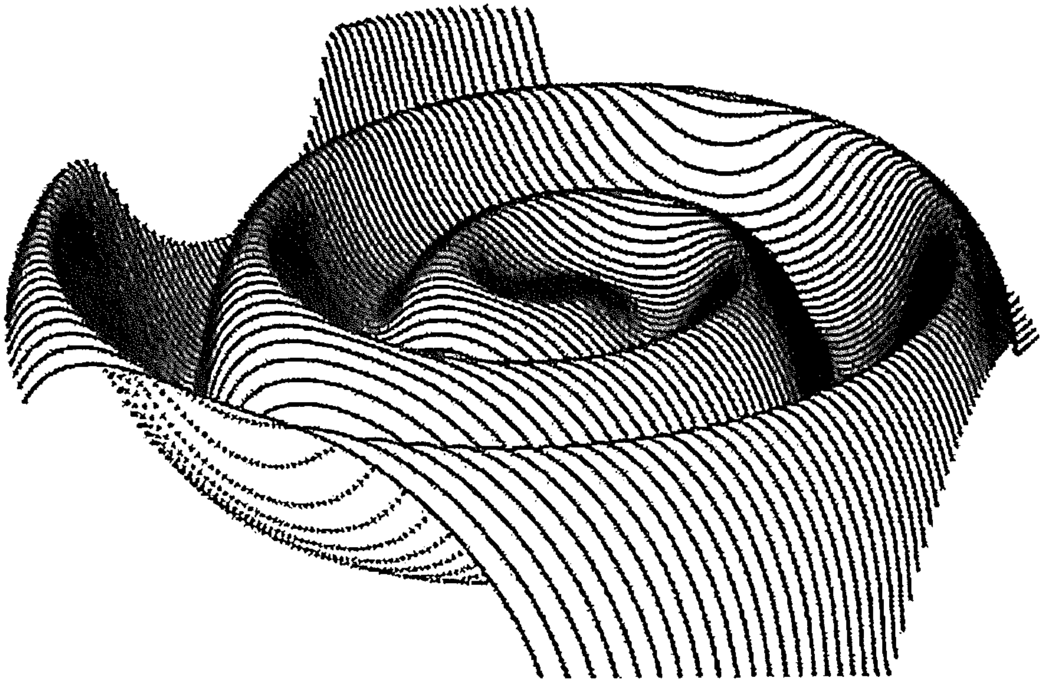
Heliospheric Current Sheet

- Solar wind
- Parker Spiral
- Solar rotation
- CME – Superstorm source



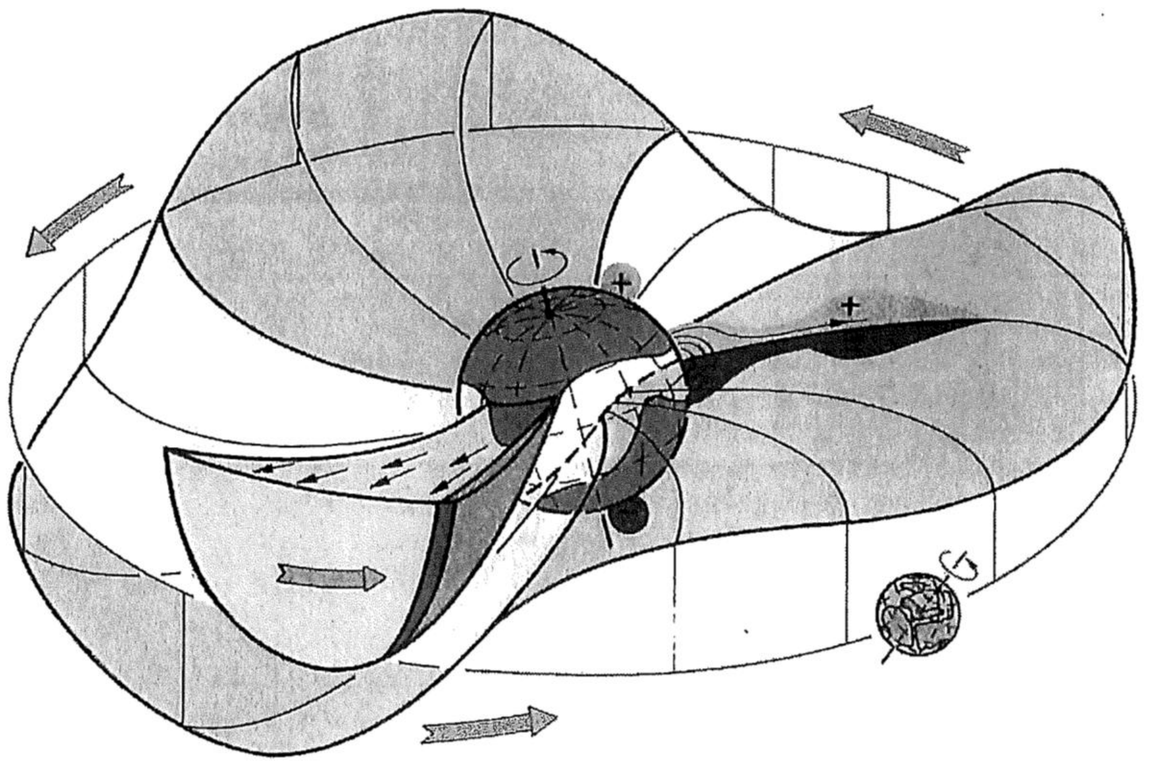
(Upper panel) The heliospheric current sheet, labeled “field reversal”, and its plasma sheet (Gosling et al., 1981) and (lower panel) the magnetospheric current sheet, here the “neutral sheet”, and its plasma sheet (Ness 1969.)

Book 1, pp. 144.



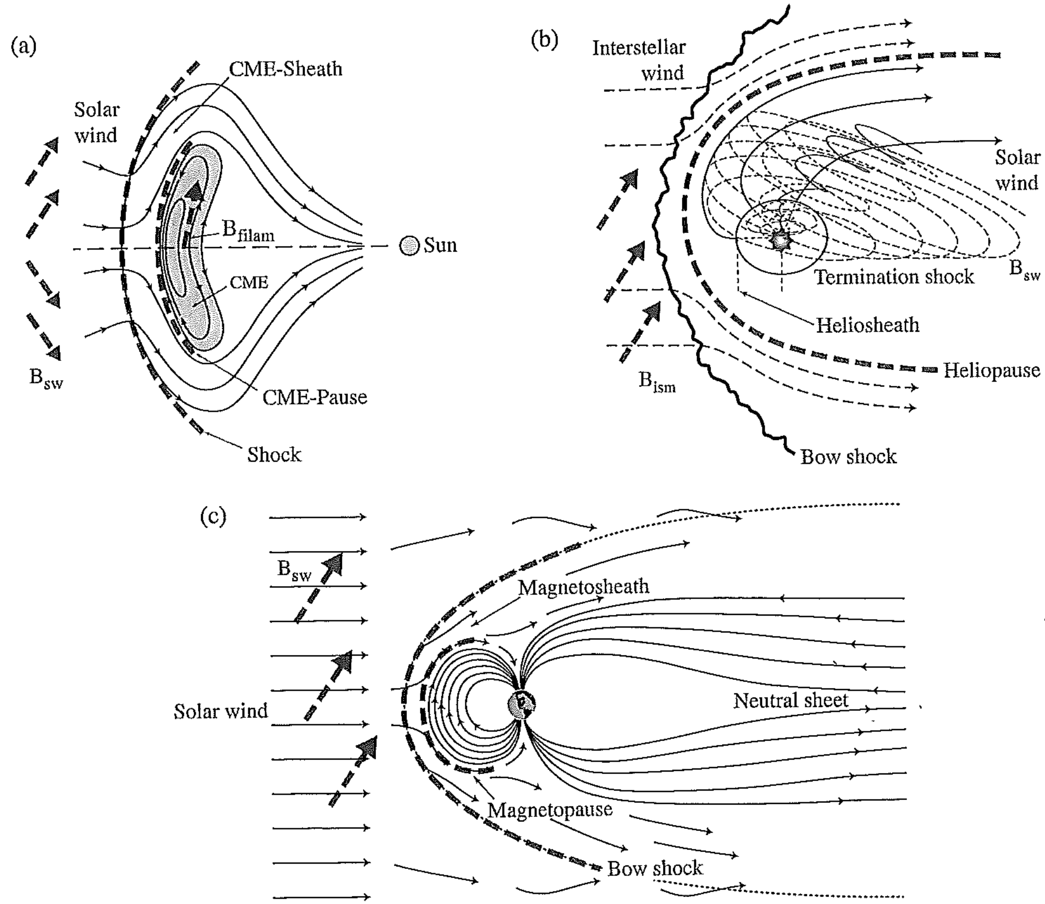
The heliospheric current sheet modeled for a 15☐° tilt of the solar magnetic equator. For a slow wind at 400 km/s, the figure is 25 AU across, extending to beyond Saturn’s orbit.

Book 1, pp. 143.



The heliospheric current sheet forms a warped, undulating structure extending from the top ridge of the helmet streamer belt (cf. Figs. 1.3 (top panel) and 8.1) that sweeps by the Earth as the Sun rotates once per 27 days (the synodic period).

Book 1, pp.234.



Schematic comparison of shocks around CMEs, the heliosphere, and the magnetosphere. The figure shows some of the types of shocks and sheaths that exist in the heliosphere and their universal basic structures; (a) a CME, (b) the outer heliosphere, and (c) Earth's magnetosphere.

Book 2, pp. 195.

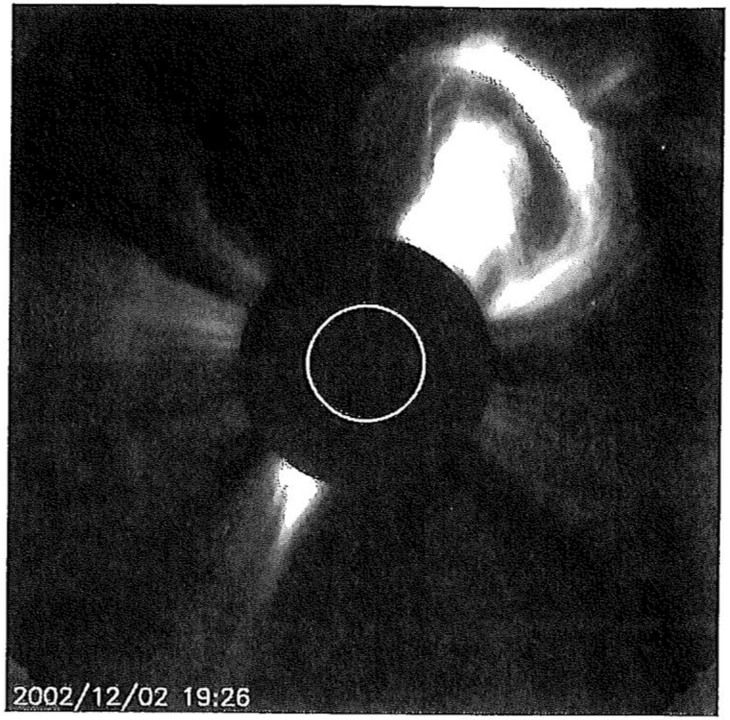
Back-of-the-Envelope Estimation

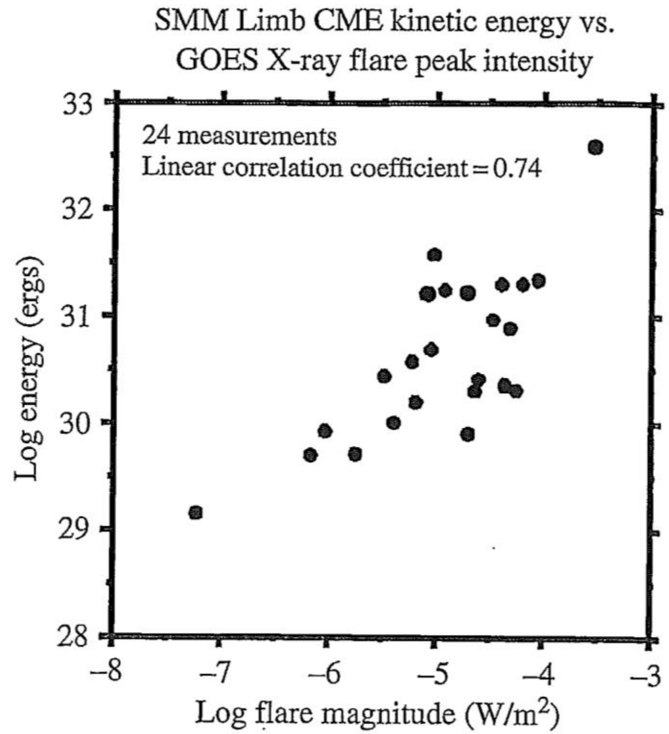
Given a fast CME has an Earthward velocity of 1000km/s,

Estimate how long it takes to reach the Earth?

Note 1: Answer in units of hours

Note 2: Estimation means no calculators needed, no computers,…..



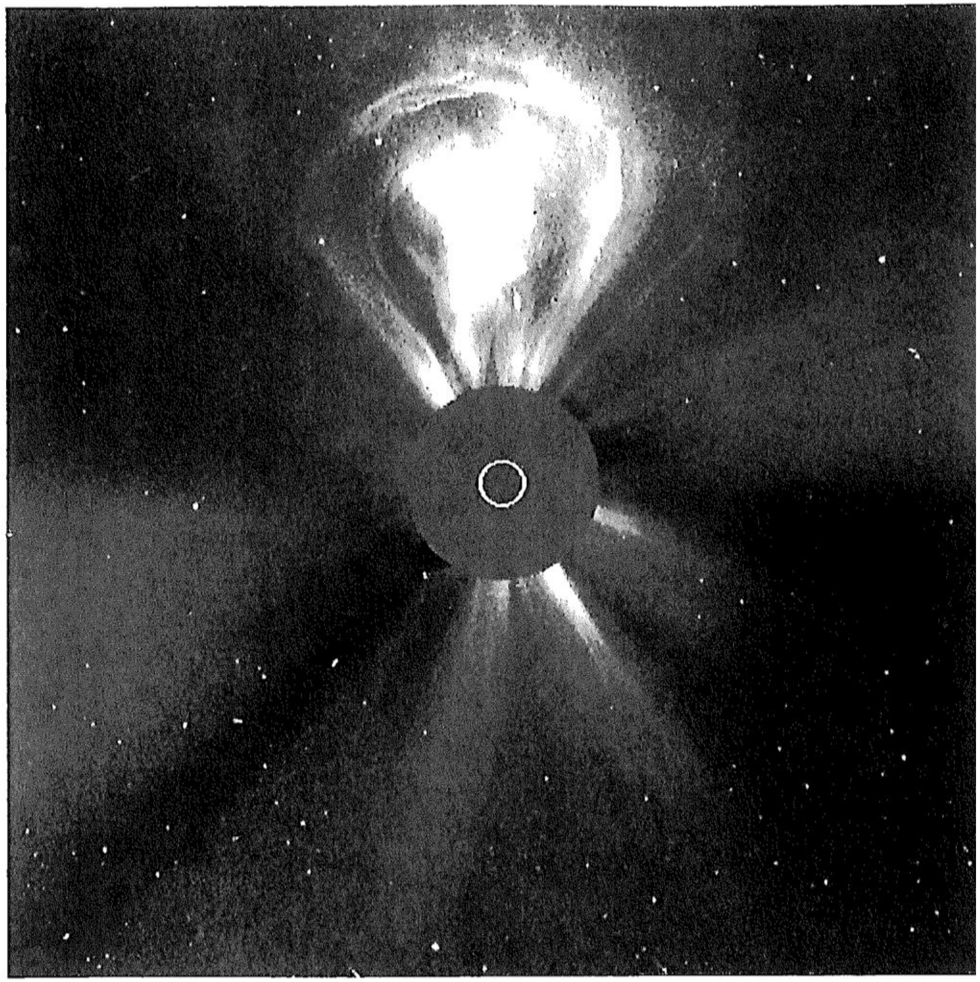


Coronagraph observation of a CME that nicely shows the three-part structure: front, cavity, and (the bright core) filament (this is a file image taken from the LASCO database, presented in a reverse grey scale). Right: Correlation between inferred CME kinetic energy and peak GOES soft X-ray flux. (From Burkepile et al., 2004.)

Book 2, pp. 136.

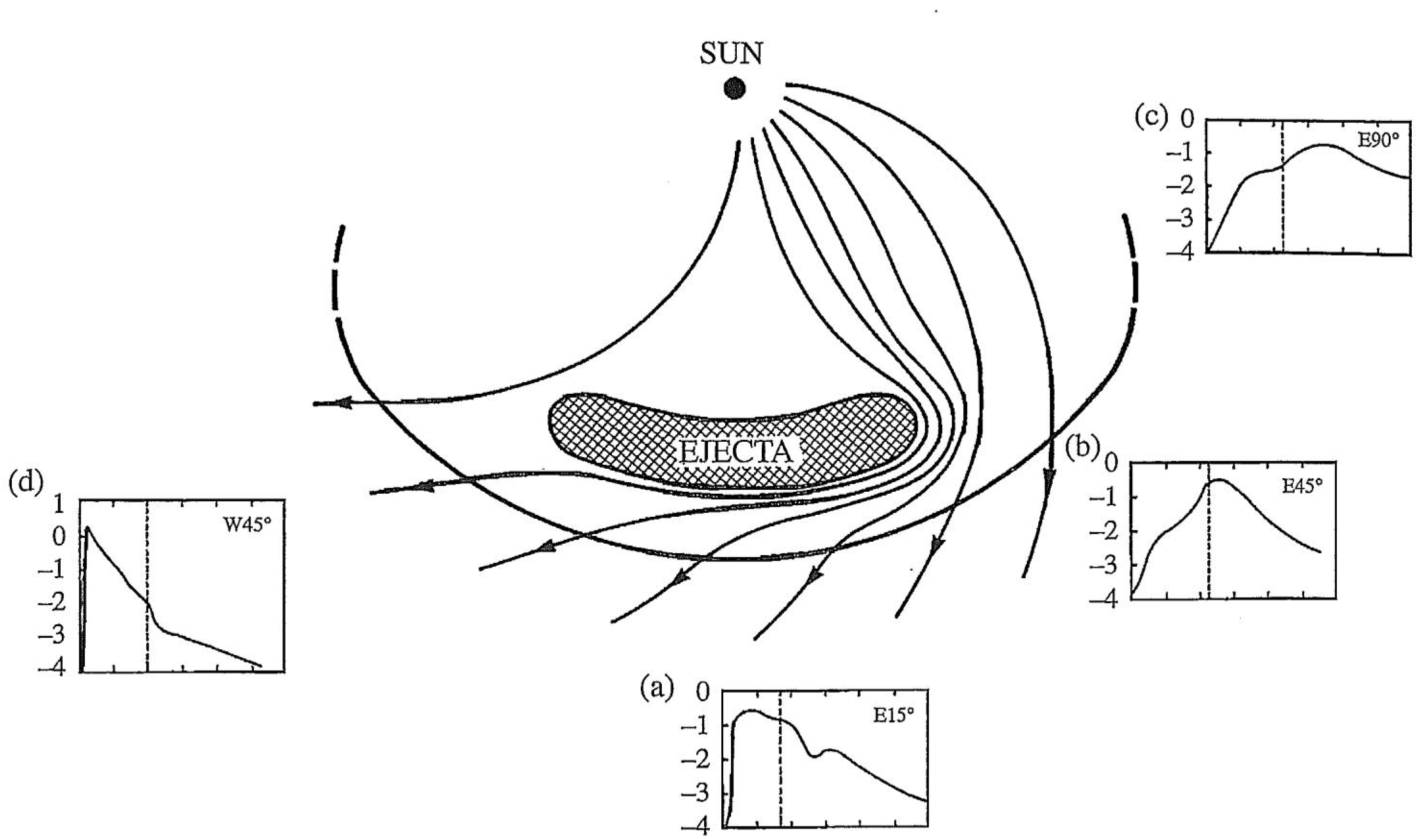
“Cosmic” Rays Energization

- Acceleration of charged particles occurs in the Sun, in the solar wind, and in geospace.
- Van Alan Radiation Belts.
- Shocks in solar wind (CME, CIRs).
- Solar events generated solar energetic particles.



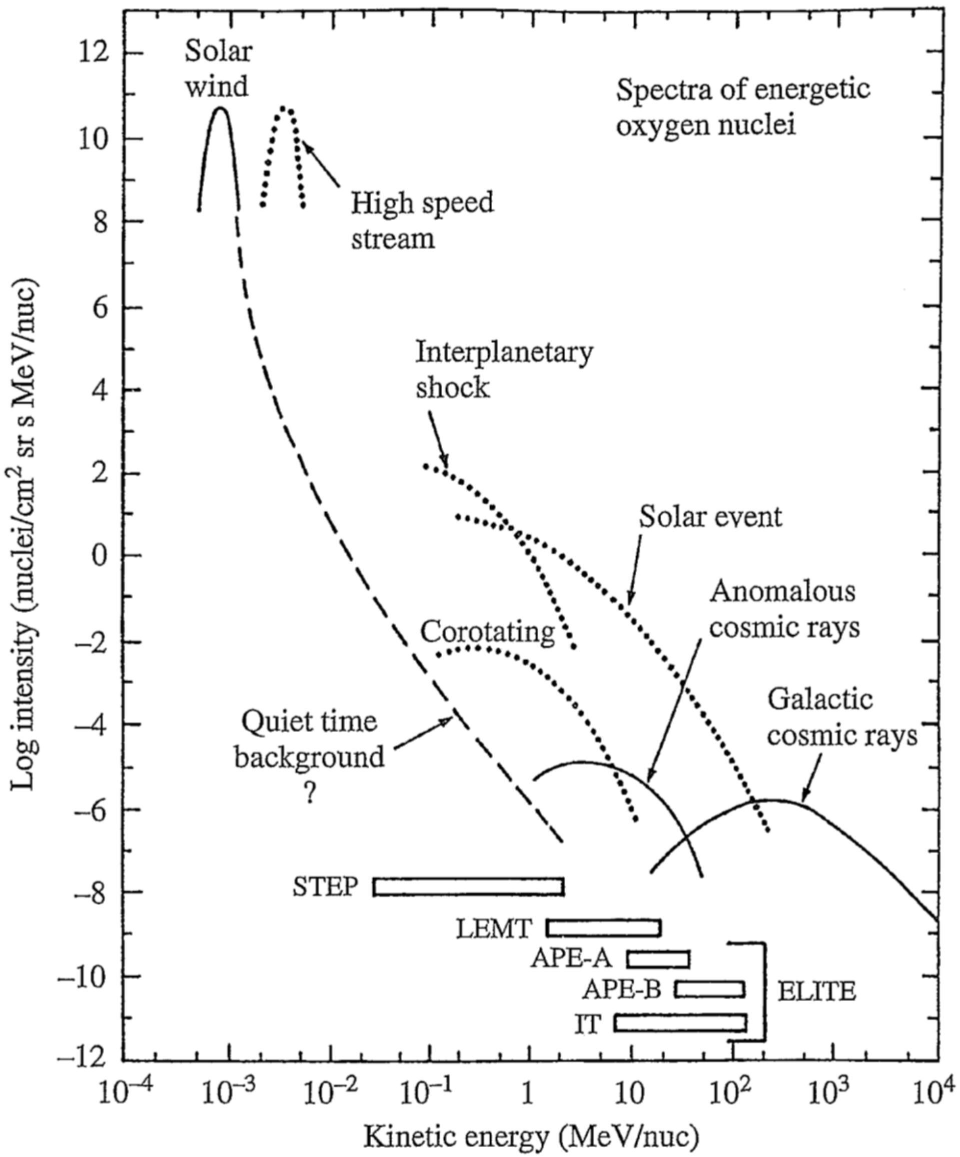
The explosive release of energy, mass, momentum, and magnetic field from (top panel, SOHO-ESA and NASA) the solar corona.

Book 1, pp. 37.



Representative profiles of 20 MeV proton events for different positions of the observatory with respect to a shock. The draping of the field lines around the ejecta is only a suggestion. (From Cane et al., 1988.)

Book 2, pp. 205.



An illustration of the energy spectrum of cosmic rays in the heliosphere based on spacecraft observations.

Book 2, pp.234.

Back-of-the-Envelope Estimation

Given a solar produced energetic proton has an energy of 10MeV,

Estimate how long it takes to reach the Earth?

Note 1: Answer in units of hours

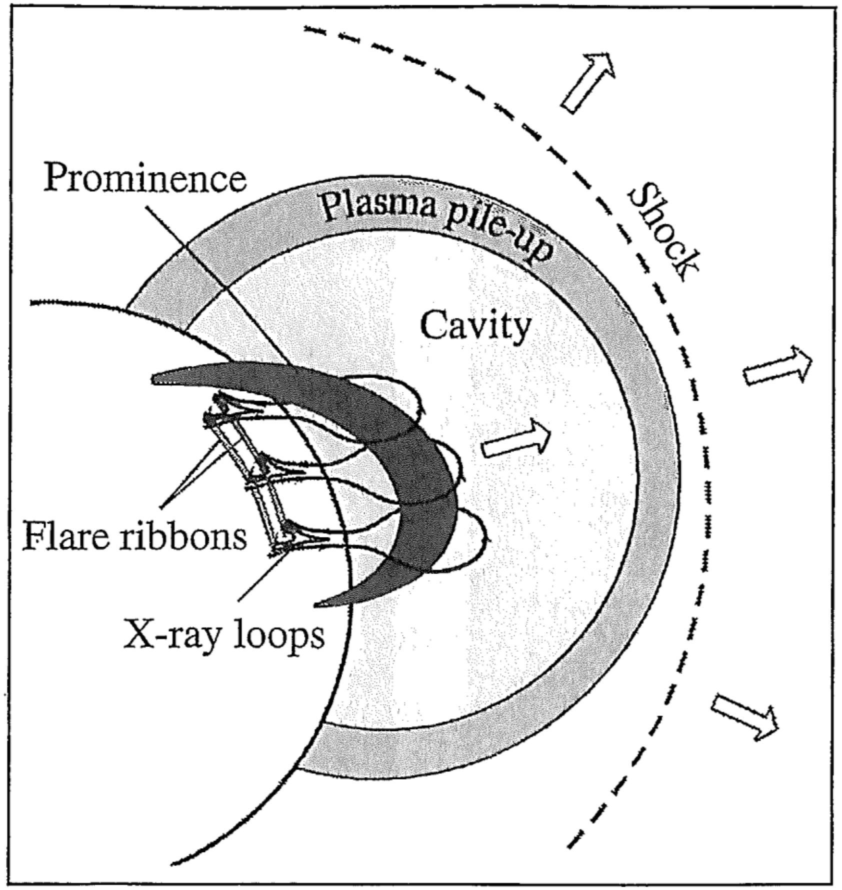
Note 2: Estimation means no calculators needed, no computers,…..

SUN: Solar Storms

- Solar origin of space storms

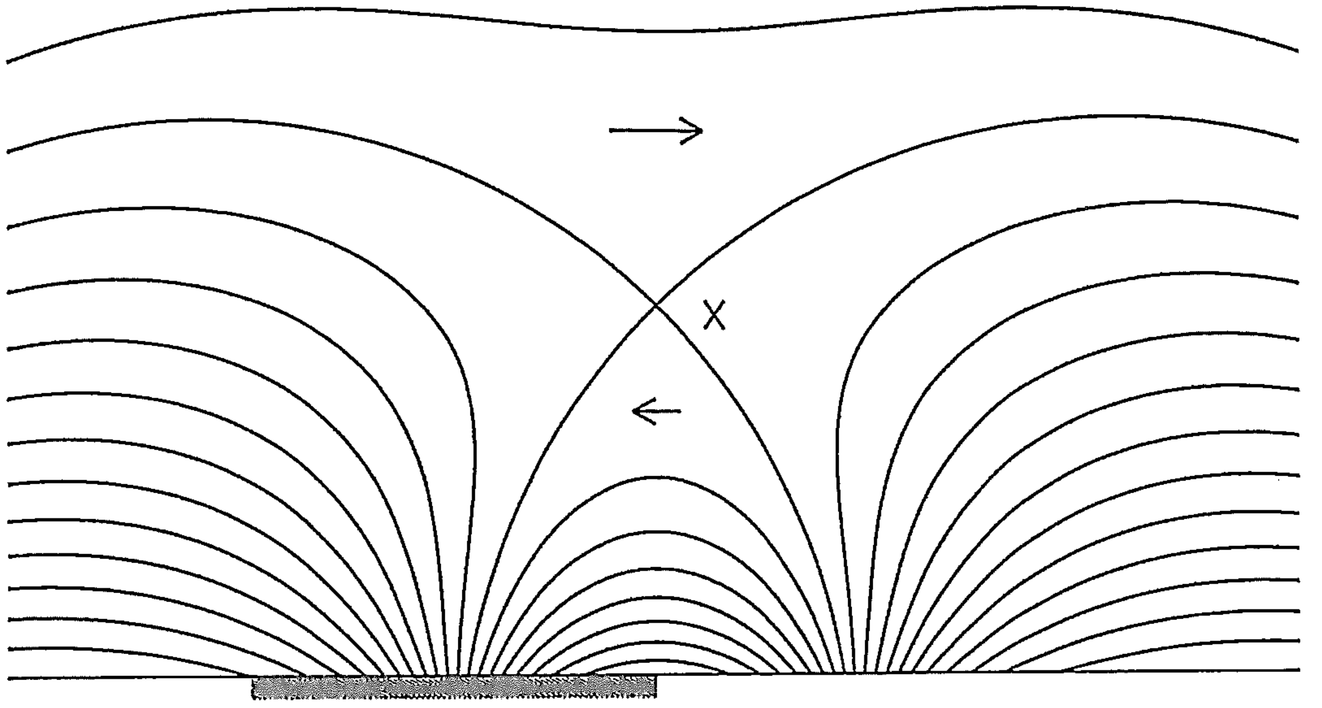
- Layers
  - Convection zone
  - Photosphere
  - Chromosphere
  - Corona

- Features
  - Sun spots
  - Prominence
  - Flare loops
  - Coronal mass ejections
  - Fast streams
  - Slow solar wind
  - Reconnection sites



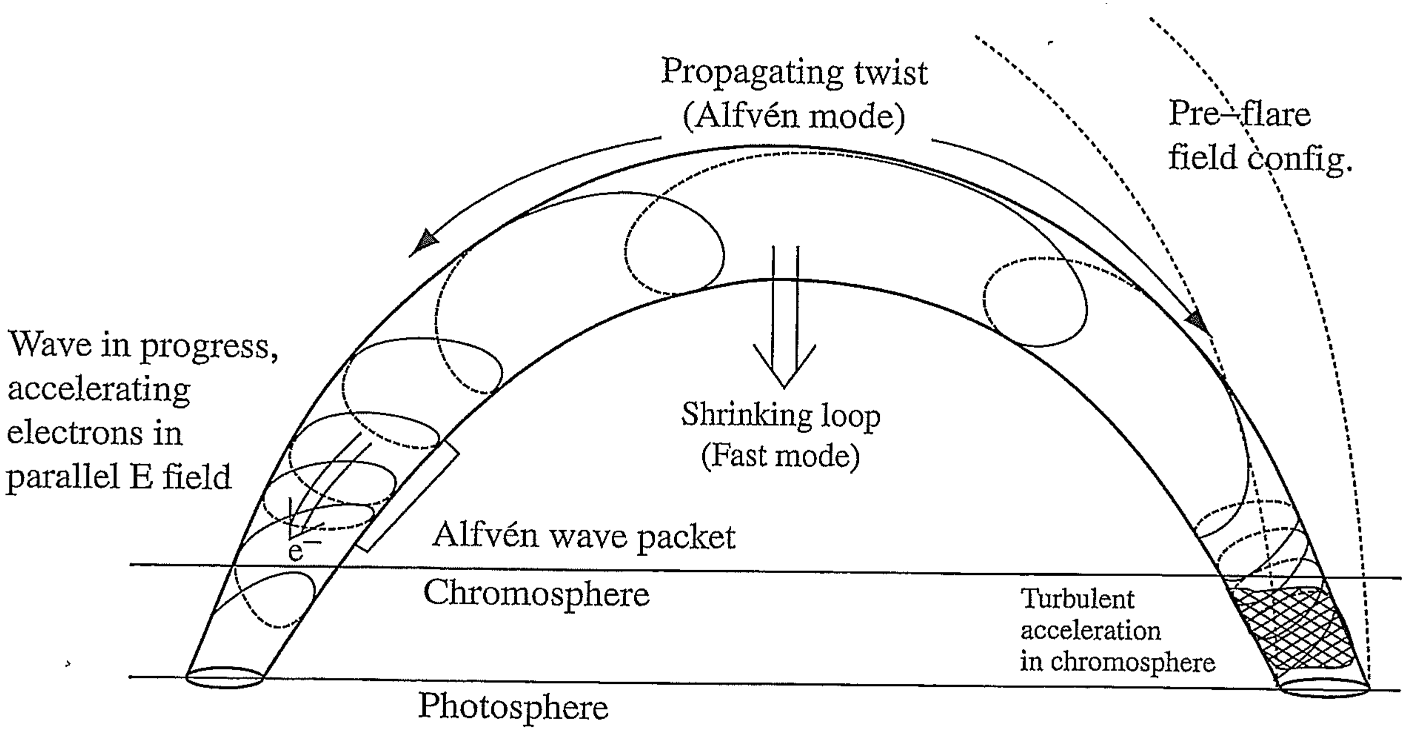
Idealized diagram showing the relation between the flare ribbons, flare loops, the CME shock, the CME shell (plasma pile-up region), the CME cavity, and the filament contained within the cavity.

Book 2, pp. 162.



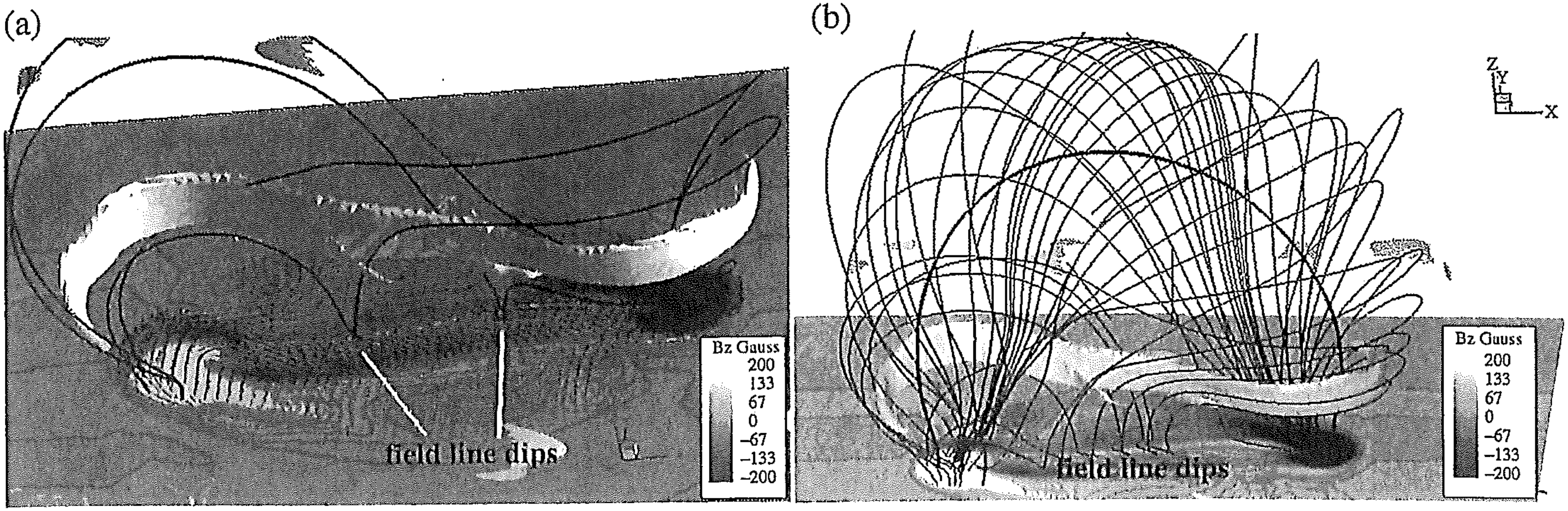
A simple model of a solar coronal magnetic arcade. Field lines connect a positive region (light shading) to a negative region (dark shading). The overlying large-scale field is oppositely directed. It is separated from this by separatrices from a single null point X.

Book 1, pp. 89.



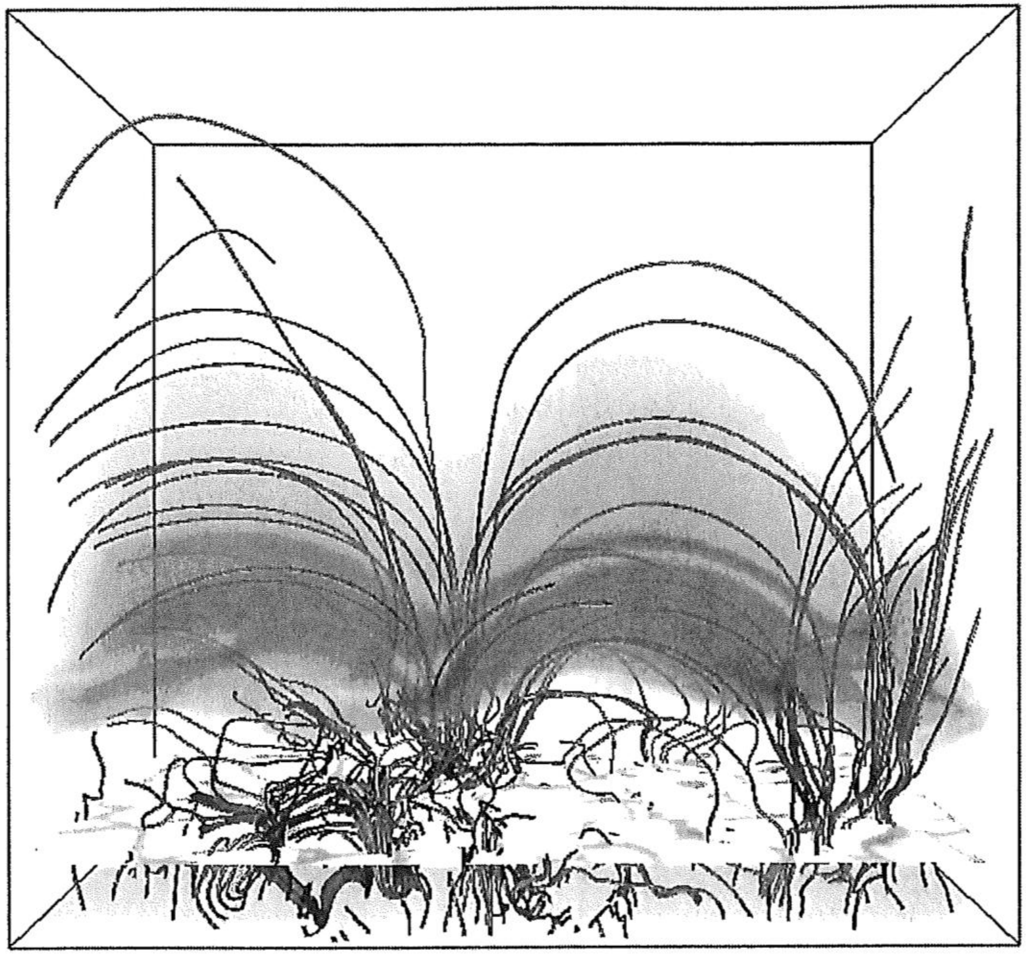
Model put forth by Fletcher and Hudson (2008), showing the extraction of stored coronal magnetic energy via the Poynting flux of waves excited by the restructuring that produces the flare. **Particle acceleration in this picture, as in other pictures, remains problematic**.

Book 2, pp.158.



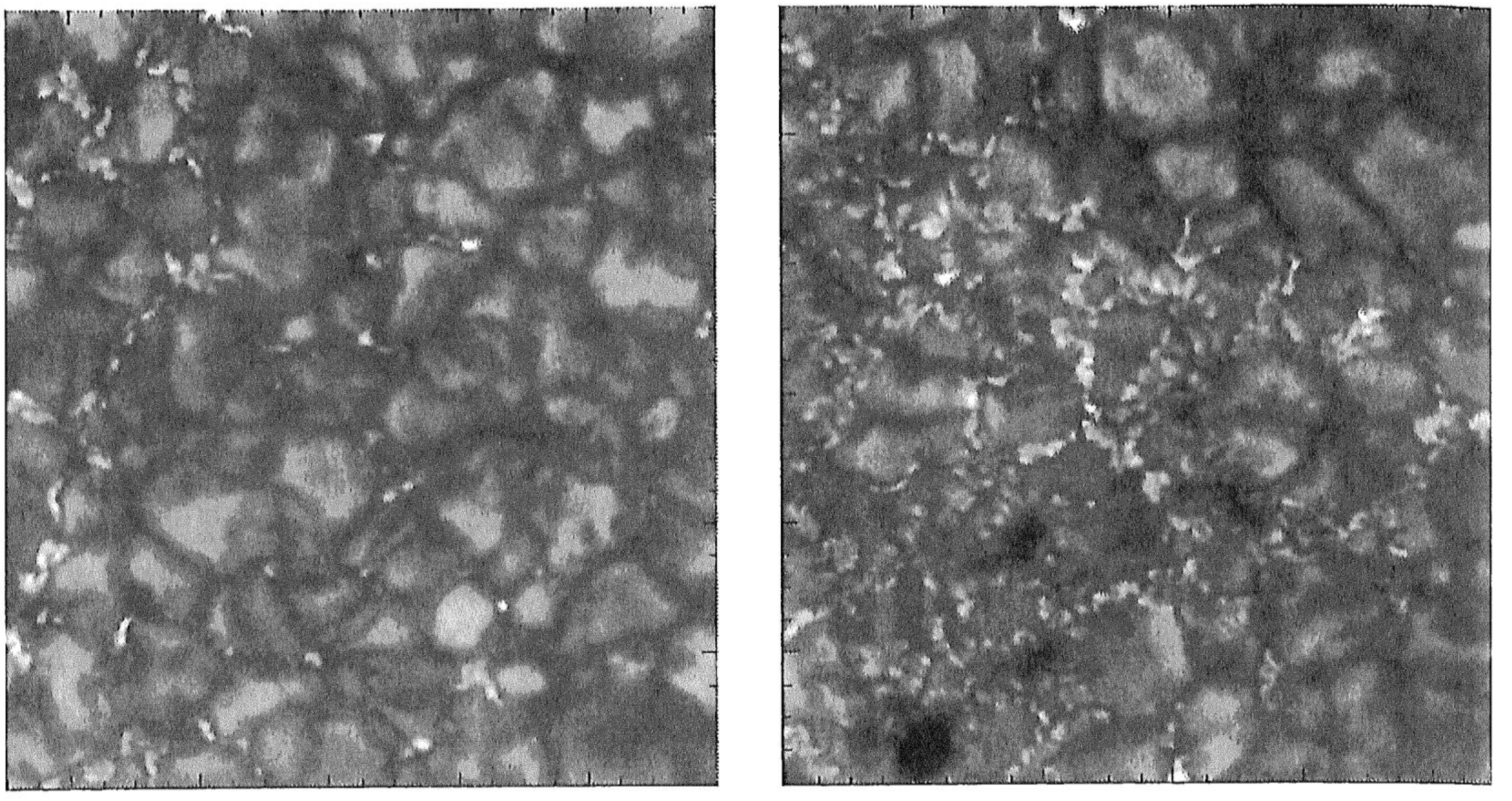
Two views of the magnetic field configuration and current density distribution at t = 72.8 in the simulation of Manchester et al. (2004b). (a) The view from above; (b) the view from an angle. The base surface is shaded according to the value of the normal magnetic field component. The black and grey curves show two magnetic field lines. The bright grey, ribbon-like structure shows the position of the current sheet that develops during the slow emergence of the flux into the corona.

Book 2, pp.189.



A 3D model of temperature and magnetic field. Shows the convection zone, photosphere,and chromosphere.

Book 1, pp. 219.



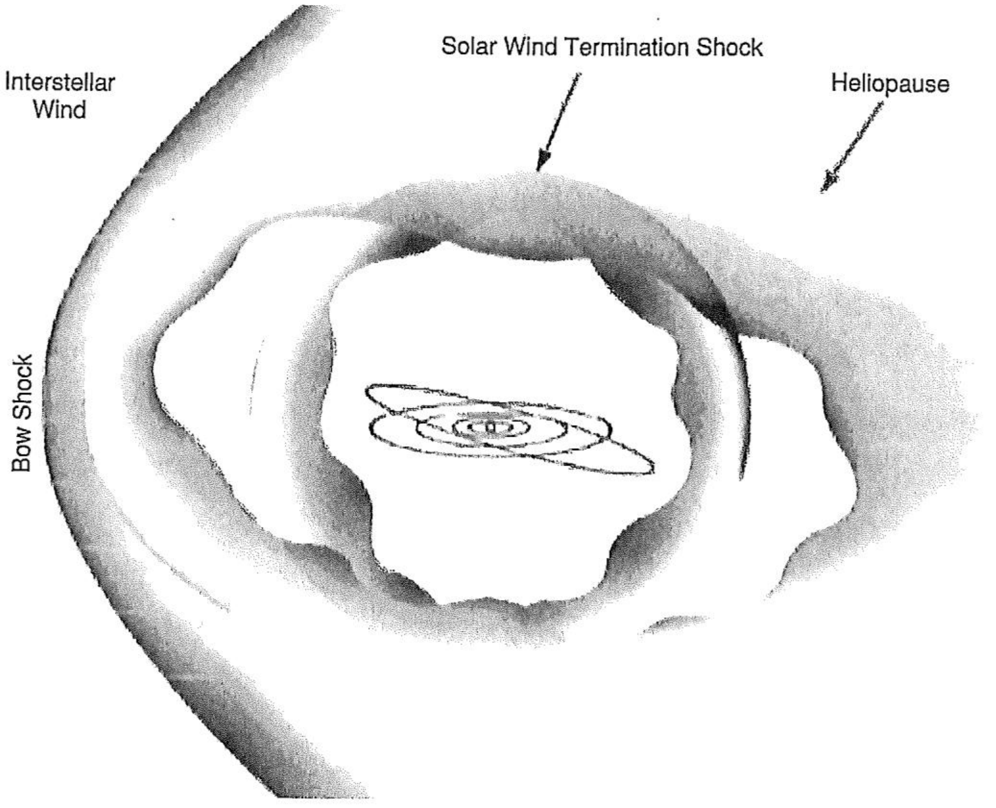
The image on the left shows a typical quiet photospheric region (a network region) observed in the G-band with the Swedish 1 meter Solar Telescope. The image on the right includes a plage region, where the total amount of magnetic flux penetrating the photosphere is larger. The axes of both panels are numbered in arcseconds measured on the Sun; 1 arcsec is approximately 725 km.

Book 1, pp.201.

Heliosphere

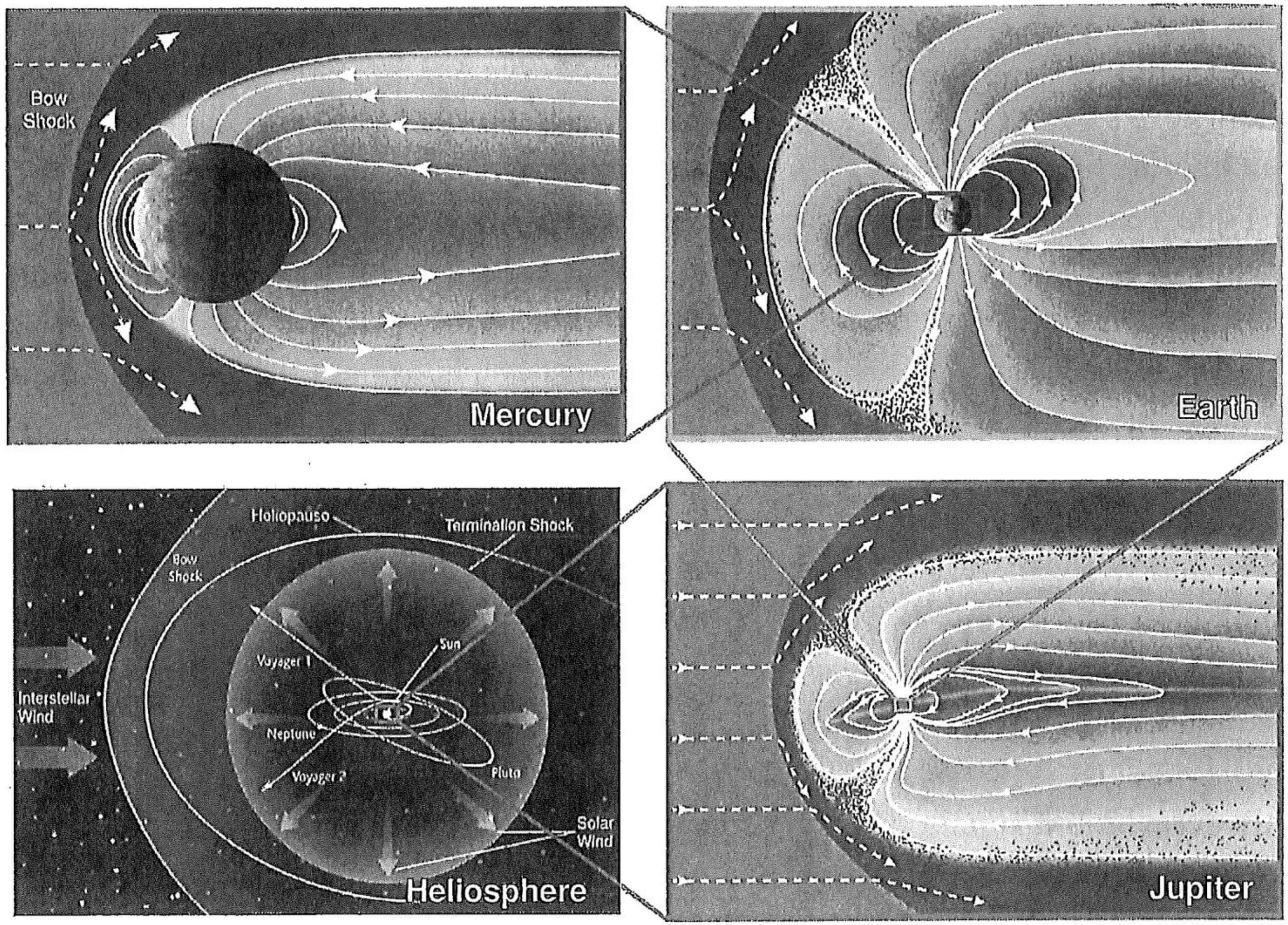
- Includes:
  - Sun
  - Solar wind
  - Geospace
  - Planets & other objects

- It has:
  - Heliopause
  - Bow shock
  - Interstellar wind



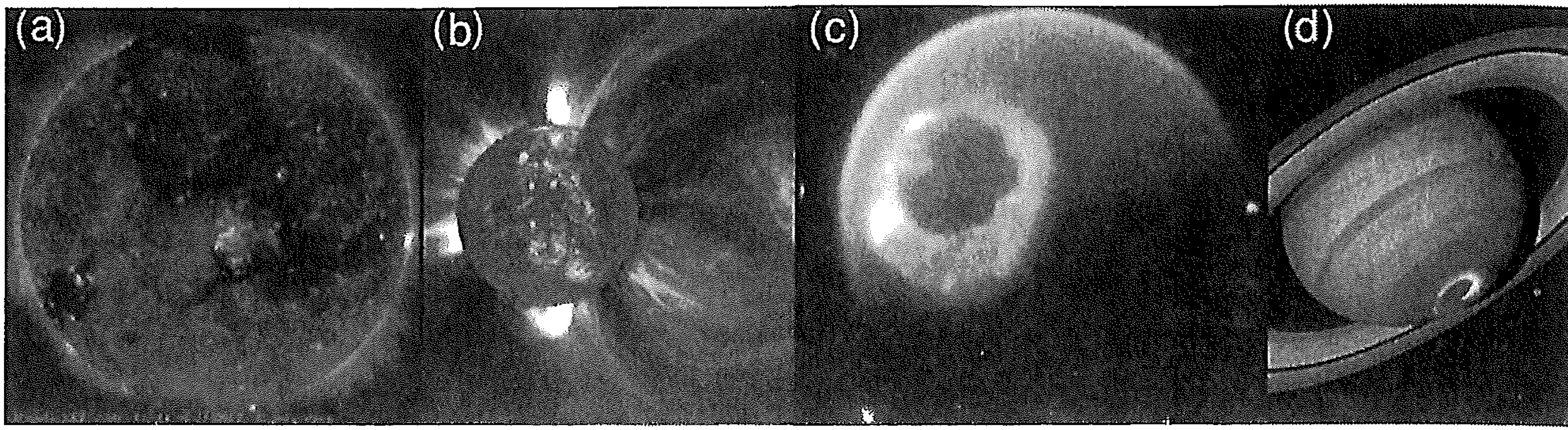
The heliosphere is the sphere of influence carved out by the Sun in the surrounding interstellar medium. The solar wind flows out incessantly in all directions, past the orbiting planets, and is finally halted at the termination shock (the innermost nested surface). The shocked solar wind material diffuses outward into the surrounding material forming the heliopause (the prolate spheroid that encloses the spherical termination shock.

Book 1, pp. 22.



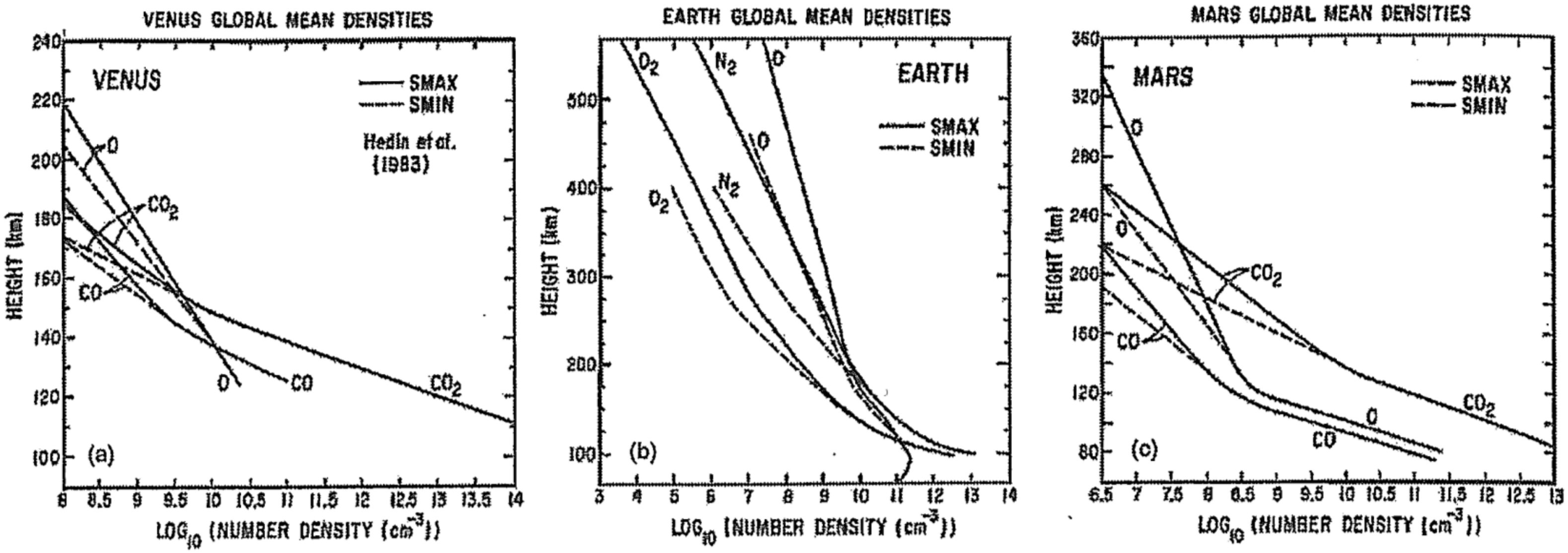
Magnetospheres (the regions defined by the field lines) surround all planets with magnetic fields.

Book 1, pp. 35.



(a) A Hinode X-Ray Telescope image of the Sun taken on 14 November 2007, showing coronal configuration resulting from the dynamic magnetic field, including large-scale dark regions called coronal holes. (b) a SOHO LASCO image of a coronal mass ejection on 8 January 2002. (c) Auroral storm on Earth on 15 July 2002 taken by the far-ultraviolet camera on the IMAGE spacecraft. (d) Auroral storm on Saturn taken by the Hubble spacecraft in October 1997. (Courtesy of nasaimages.org.)

Book 1, pp.16.



Comparison of the global mean vertical profiles of the major species in the neutral upper atmospheres of (a) Venus, (b) Earth, and (c) Mars for low and high solar activity (from Bougher and Roble, 1991).

Book 1, pp.331.

Table 5.1. *Comparison of plasma parameters in different environments (in MKS units, i.e. length scales in* m, *n in* m^{-3}, *T in* K, *B in tesla, electric fields in* $V\,m^{-1}$*)*

Parameter	Laboratory experiments[a]	Terrestrial magnetosphere[b]	Solar corona[c]	Solar interior[d]
L_e	10^{-1}	10^{7}	10^{8}	10^{7}
n	10^{20}	10^{5}	10^{15}	10^{29}
T	10^{5}	10^{7}	10^{6}	10^{6}
B	10^{-1}	10^{-8}	10^{-2}	10^{1}
λ_D	10^{-6}	10^{3}	10^{-3}	10^{-10}
R_{gi}	10^{-3}	10^{5}	10^{-1}	10^{-4}
λ_i	10^{-2}	10^{6}	10^{1}	10^{-6}
$\ln \Lambda$	11	33	19	3
λ_{mfp}	10^{-2}	10^{16}	10^{4}	10^{-9}
β	10^{-2}	10^{-1}	10^{-4}	10^{4}
$L_u\ (\approx R_m)$	10^{3}	10^{14}	10^{14}	10^{10}
E_D	10^{3}	10^{-13}	10^{-2}	10^{11}
$E_A\ (= v_A B)$	10^{4}	10^{-2}	10^{5}	10^{4}
$E_{SP}\ (= E_A/\sqrt{R_{me}})$	10^{2}	10^{-9}	10^{-3}	10^{-2}

[a] MRX at Princeton Plasma Physics Laboratory.
[b] Plasma sheet.
[c] Above a solar active region.
[d] Base of the solar convection zone.

Table 5.2. *Diffusion lengths (in meters) from the generalized Ohm's law*

Characteristic length	Laboratory experiments[a]	Terrestrial magnetosphere[b]	Solar corona[c]	Solar interior[d]
$L_{\mathrm{inertia}}(\lambda_e)$	10^{-4}	10^{4}	10^{-1}	10^{-8}
$L_{\mathrm{Hall}}(\lambda_i)$	10^{-2}	10^{6}	10^{1}	10^{-6}
L_{stress}	10^{-3}	10^{5}	10^{-3}	10^{-2}
$L_{\mathrm{collision}}$	10^{-4}	10^{-7}	10^{-7}	10^{-3}

[a] MRX at Princeton Plasma Physics Laboratory.
[b] Plasma sheet.
[c] Above a solar active region.
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