El Sol y el Sistema Tierra

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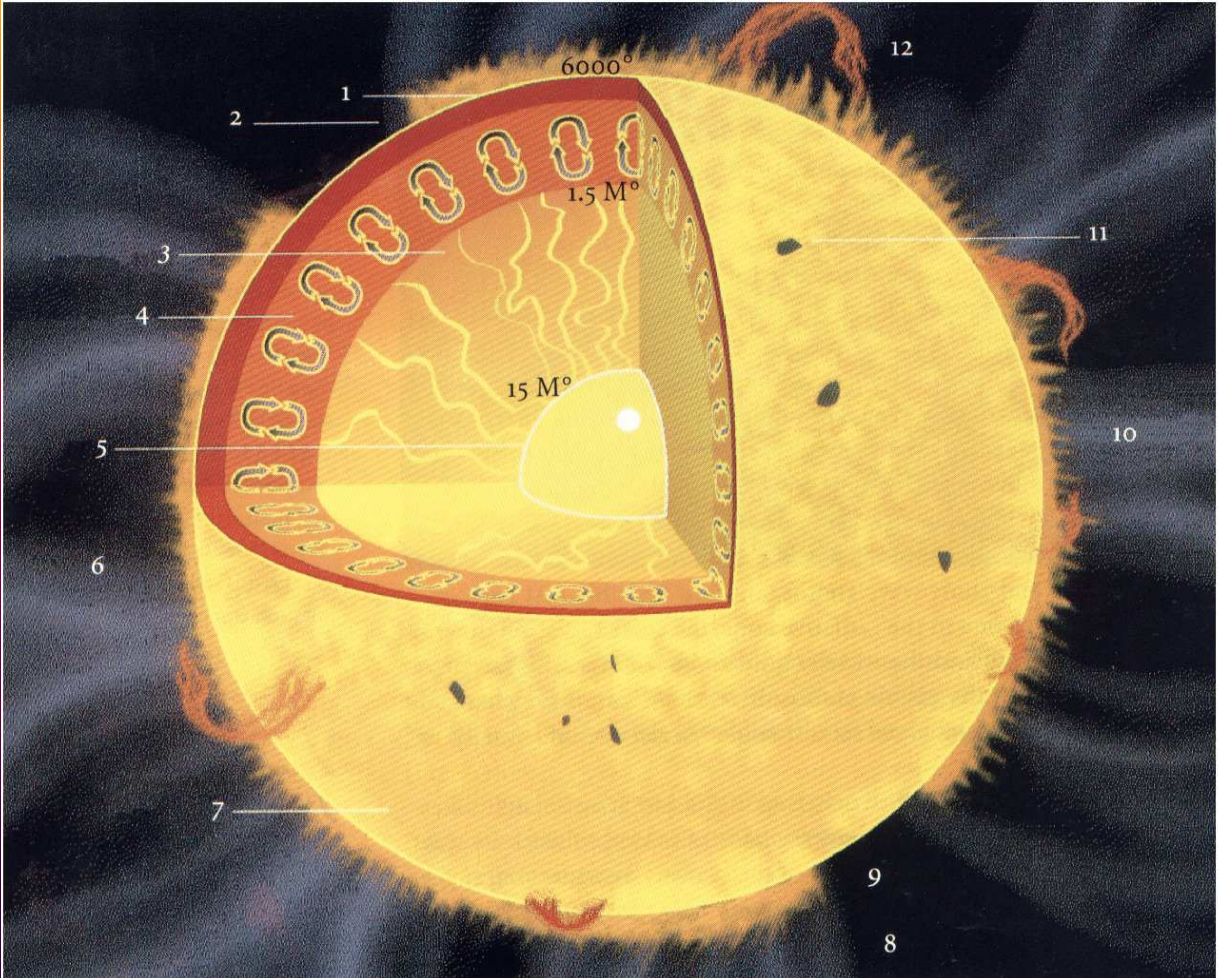
- La estructura del Sol
- Actividad solar
- Variaciones en la actividad solar y sus efectos
- Entono galáctico
- Final del Sol y la Tierra
- Insolación y estaciones

PARTE I

LA ESTRUCTURA DEL SOL


6000°
1
2
1.5 M°
3
4
15 M°
5
6
7
8
9
10
11
12

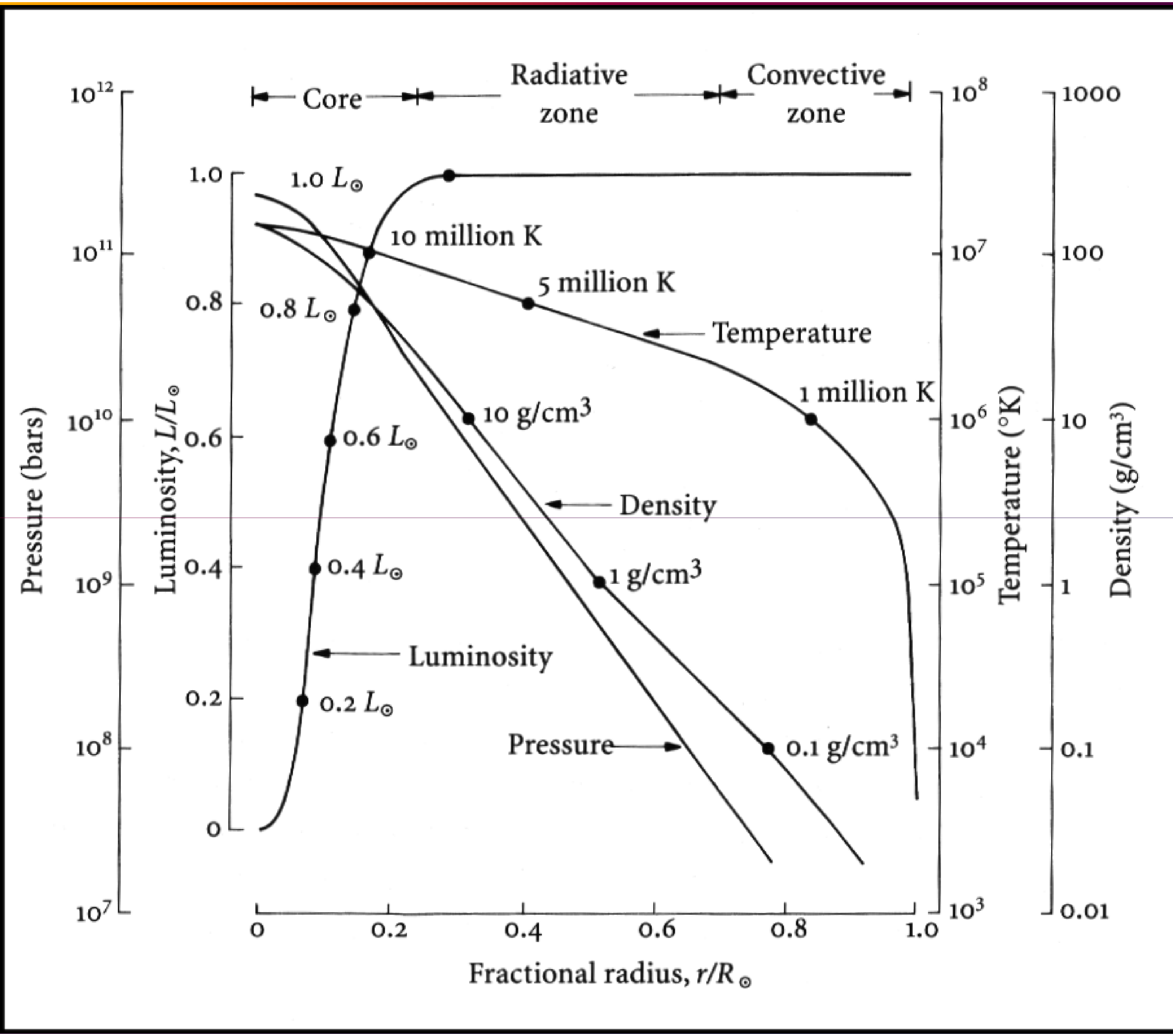
ECUACIONES PARA EL INTERIOR DEL SOL

Stellar theory[a]

Conservation of mass	$\frac{dM_r}{dr} = 4\pi\rho r^2$	(9.60)	r M_r ρ	radial distance mass interior to r mass density
Hydrostatic equilibrium	$\frac{dp}{dr} = \frac{-G\rho M_r}{r^2}$	(9.61)	p G	pressure constant of gravitation
Energy release	$\frac{dL_r}{dr} = 4\pi\rho r^2\epsilon$	(9.62)	L_r ϵ	luminosity interior to r power generated per unit mass
Radiative transport	$\frac{dT}{dr} = \frac{-3}{16\sigma}\frac{\langle\kappa\rangle\rho}{T^3}\frac{L_r}{4\pi r^2}$	(9.63)	T σ $\langle\kappa\rangle$	temperature Stefan–Boltzmann constant mean opacity
Convective transport	$\frac{dT}{dr} = \frac{\gamma - 1}{\gamma}\frac{T}{p}\frac{dp}{dr}$	(9.64)	γ	ratio of heat capacities, c_p/c_V

[a] For stars in static equilibrium with adiabatic convection. Note that ρ is a function of r. κ and ϵ are functions of temperature and composition.

P = Prad + Pgas



Core
Radiative zone
Convective zone
Pressure (bars)
Luminosity, L/L⊙
Temperature (°K)
Density (g/cm3)
1.0 L⊙
0.8 L⊙
0.6 L⊙
0.4 L⊙
0.2 L⊙
10 million K
5 million K
1 million K
Temperature
10 g/cm3
1 g/cm3
0.1 g/cm3
Density
Luminosity
Pressure
Fractional radius, r/R⊙

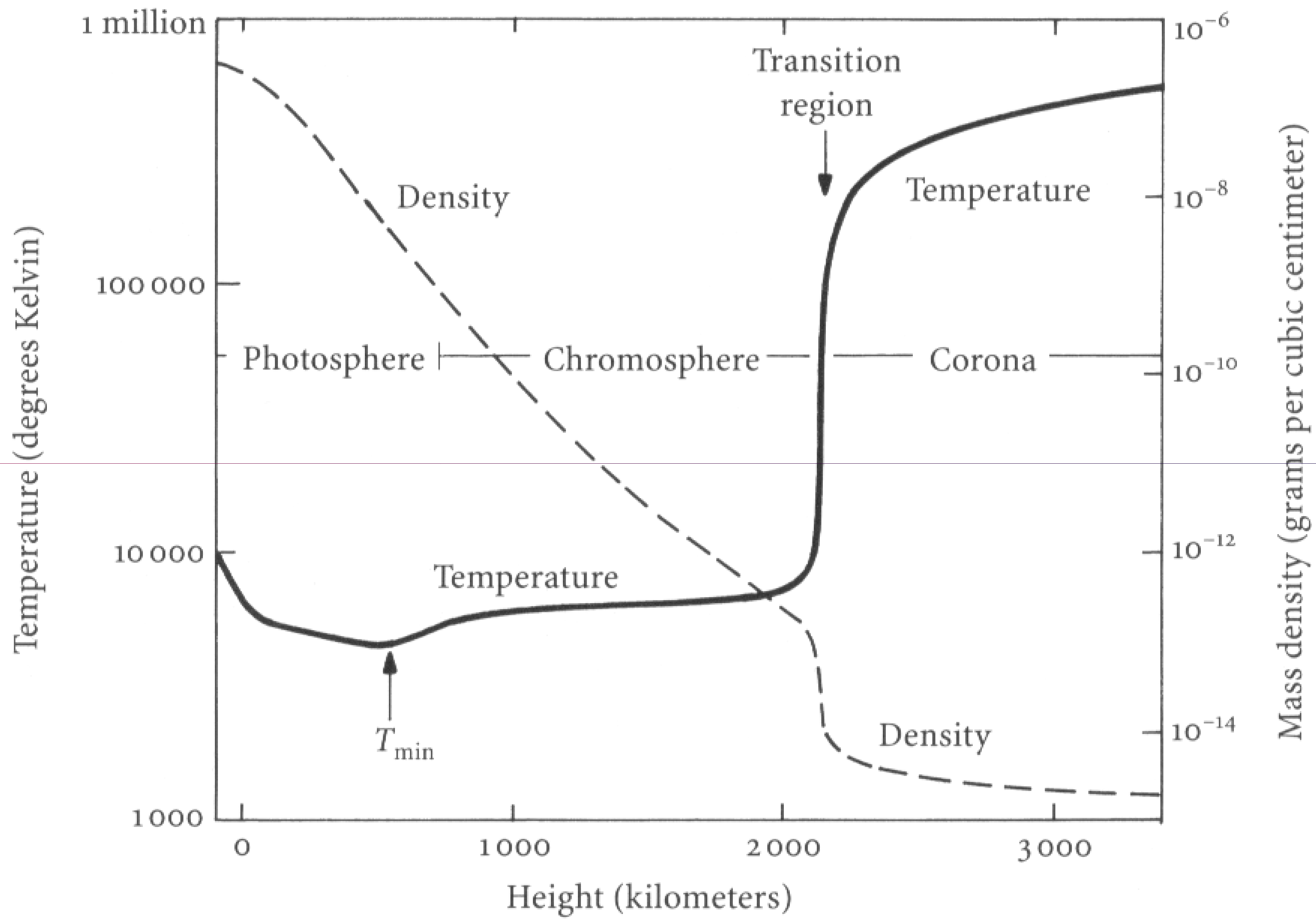
INTERIOR

- núcleo
- zona radiativa
- zona convectiva

ATMÓSFERA

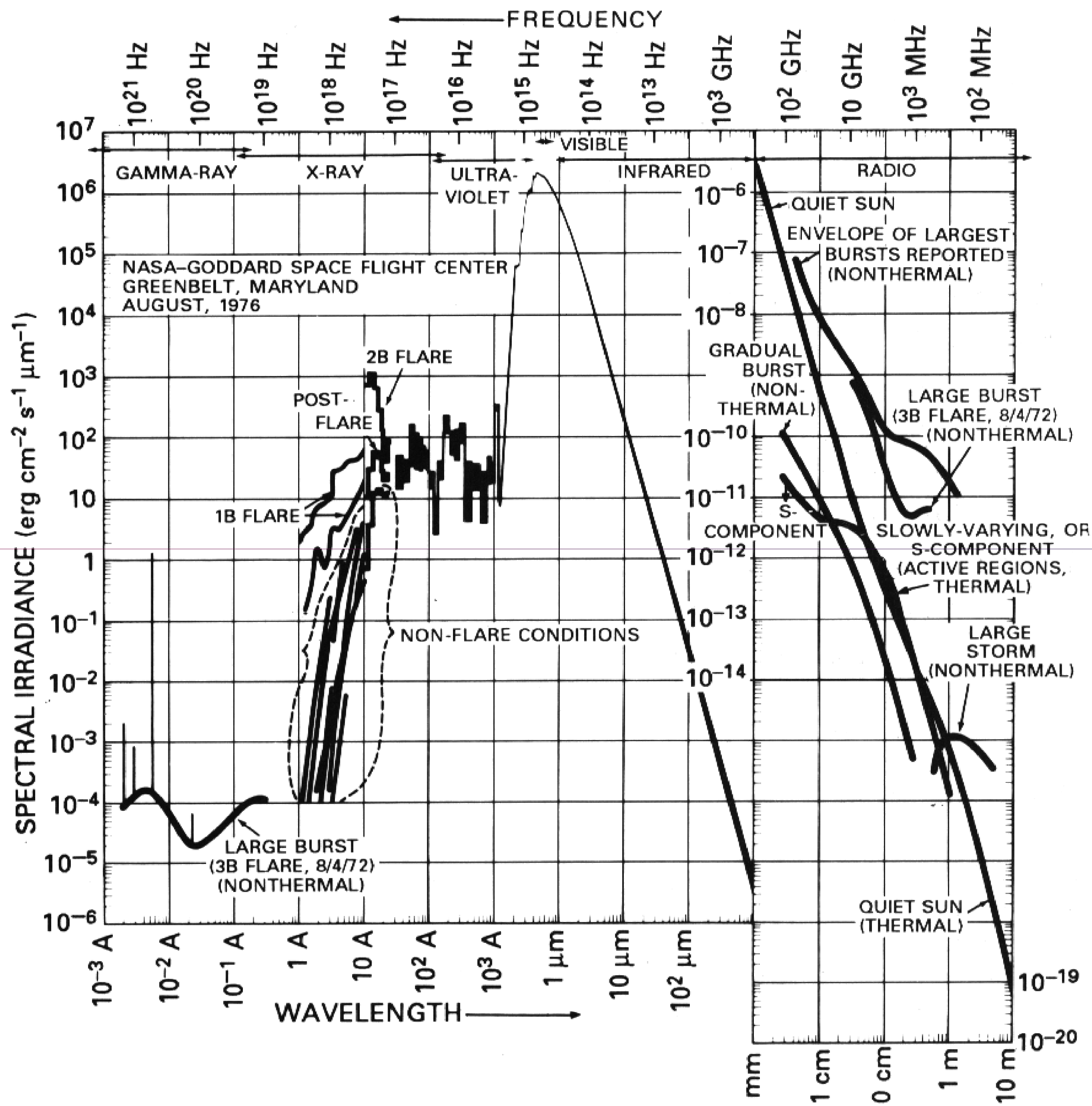
- fotósfera
- cromósfera
- corona

VIENTO SOLAR

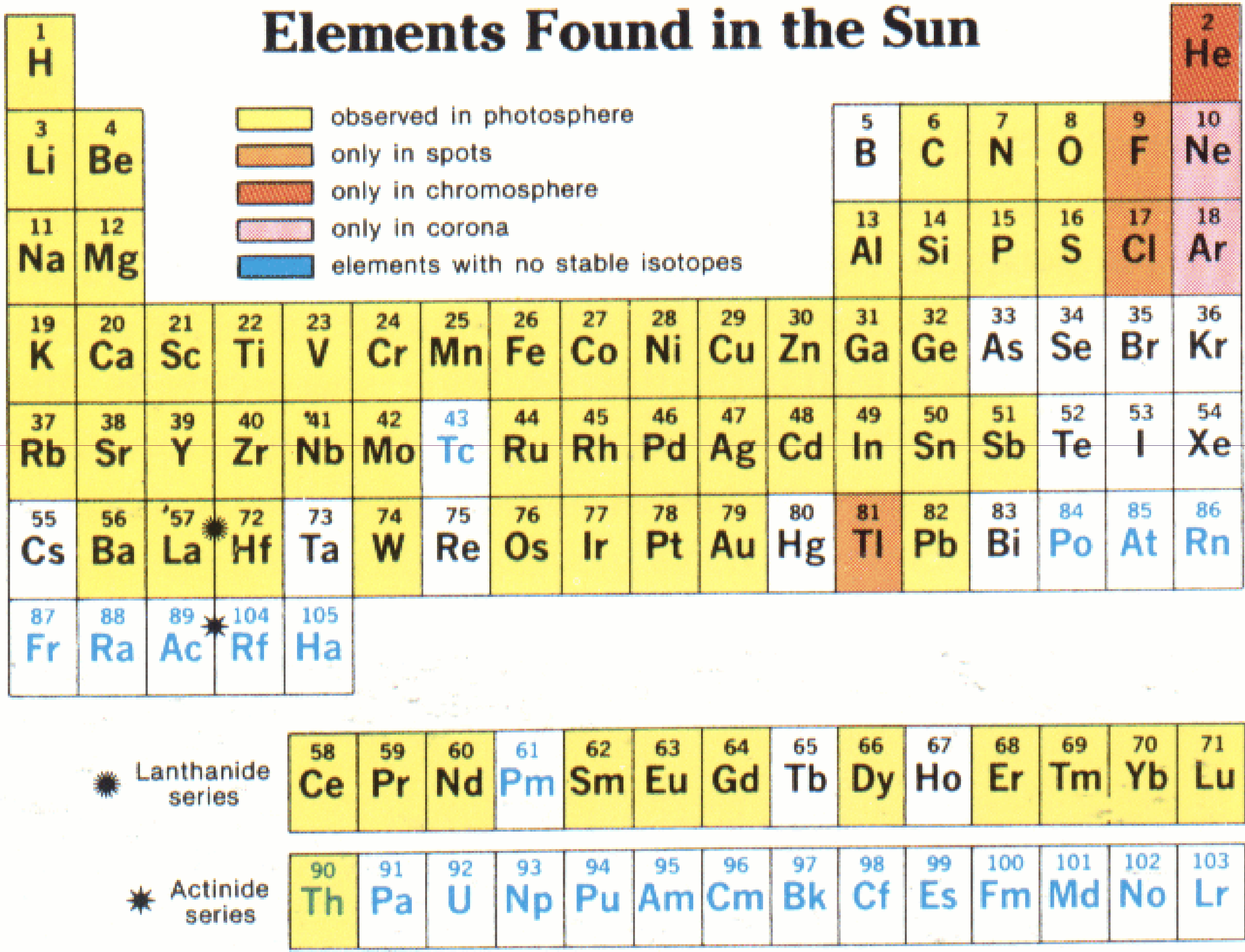


1 million
100 000
10 000
1000
Temperature (degrees Kelvin)
0
1000
2000
3000
Height (kilometers)
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
Mass density (grams per cubic centimeter)
Transition region
Density
Temperature
Photosphere
Chromosphere
Corona
Temperature
T_{min}
Density

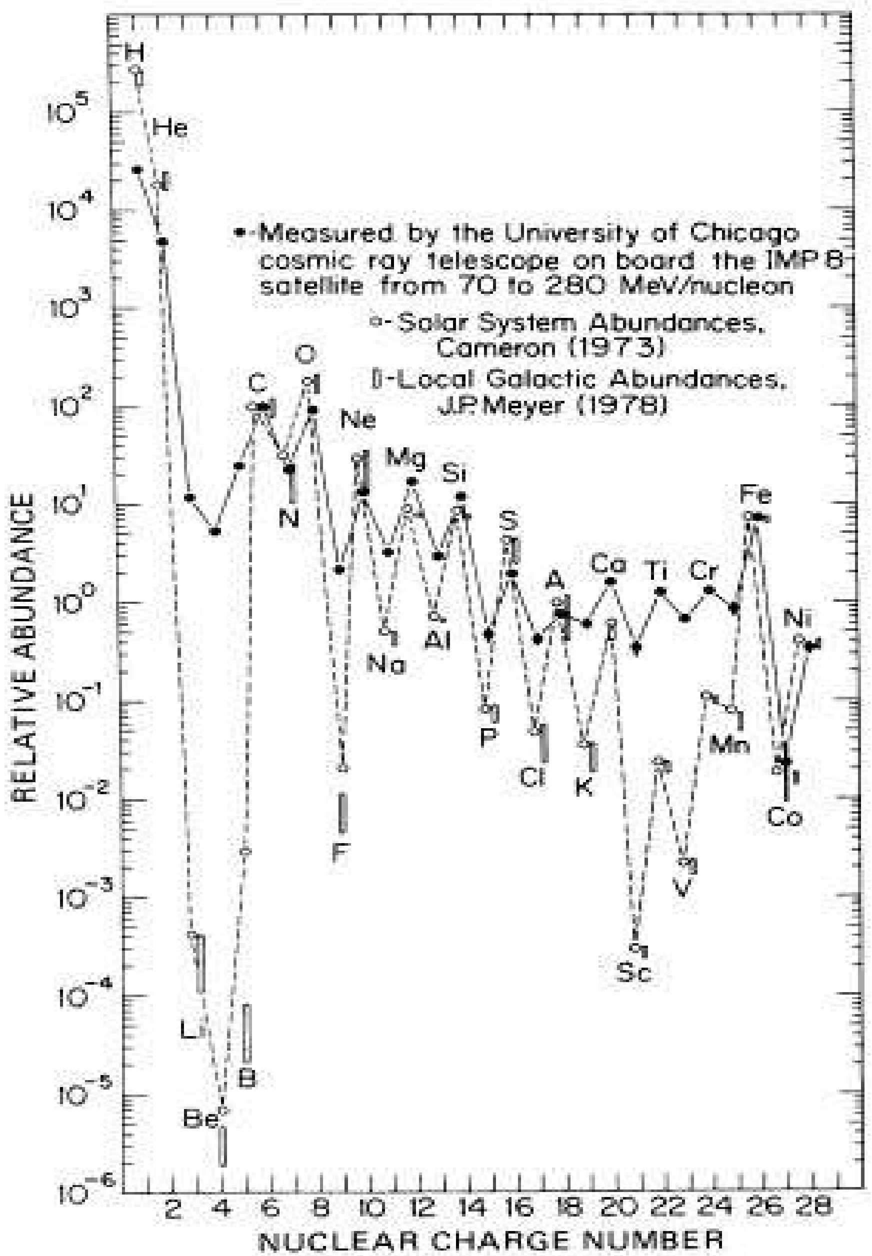
(Courtesy H. Malitson and the National Space Science Data Center.)

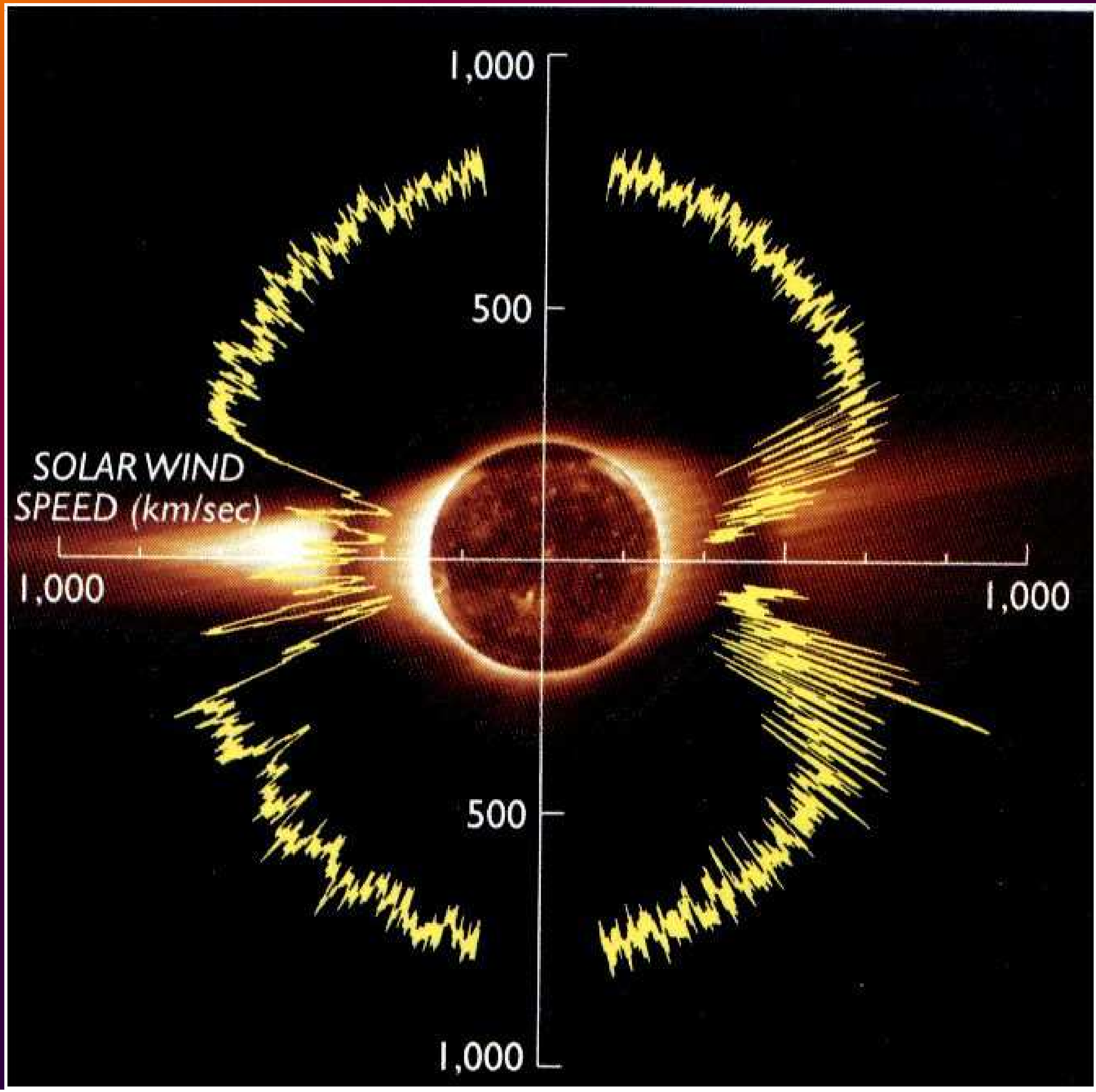


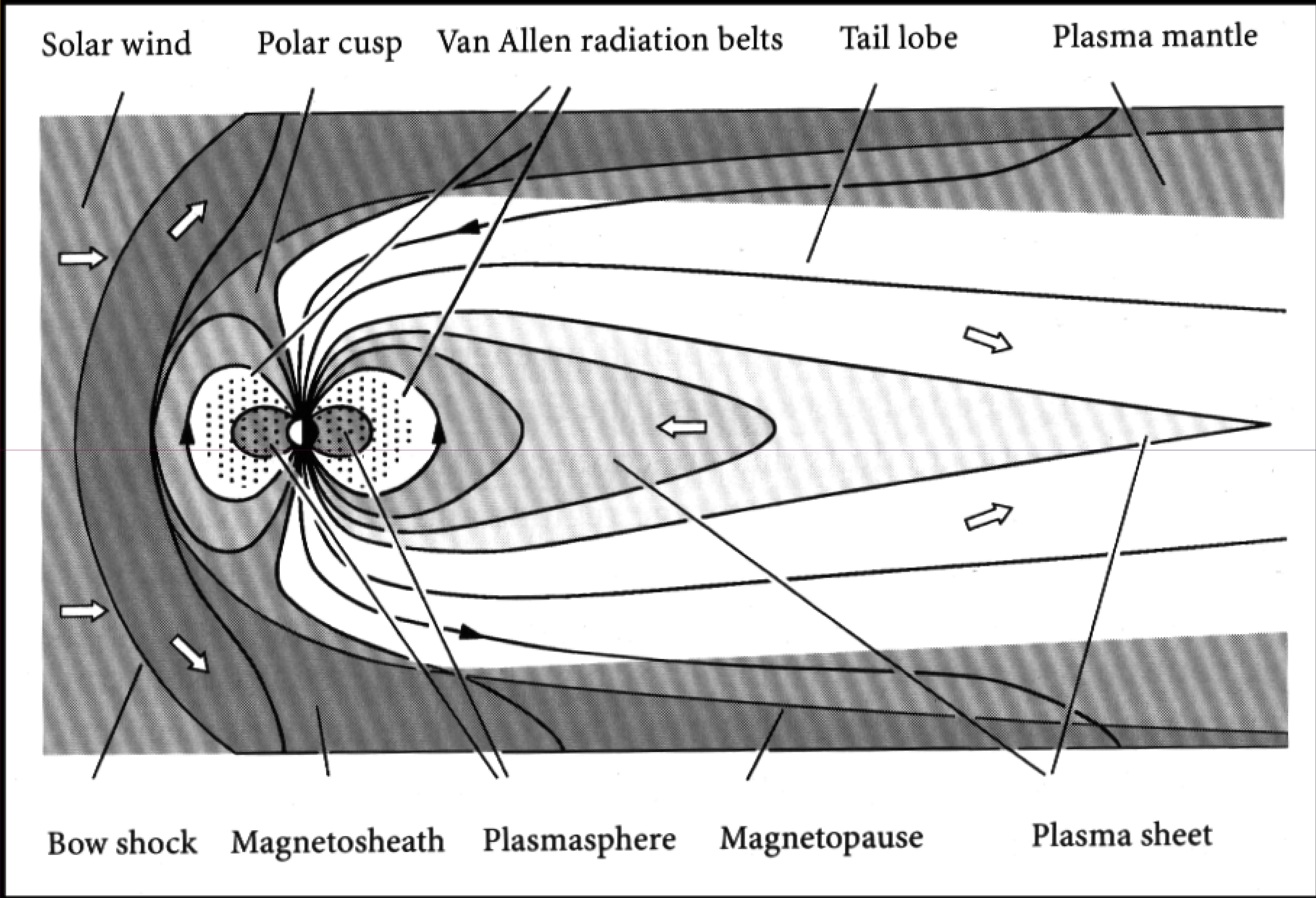
Elements Found in the Sun



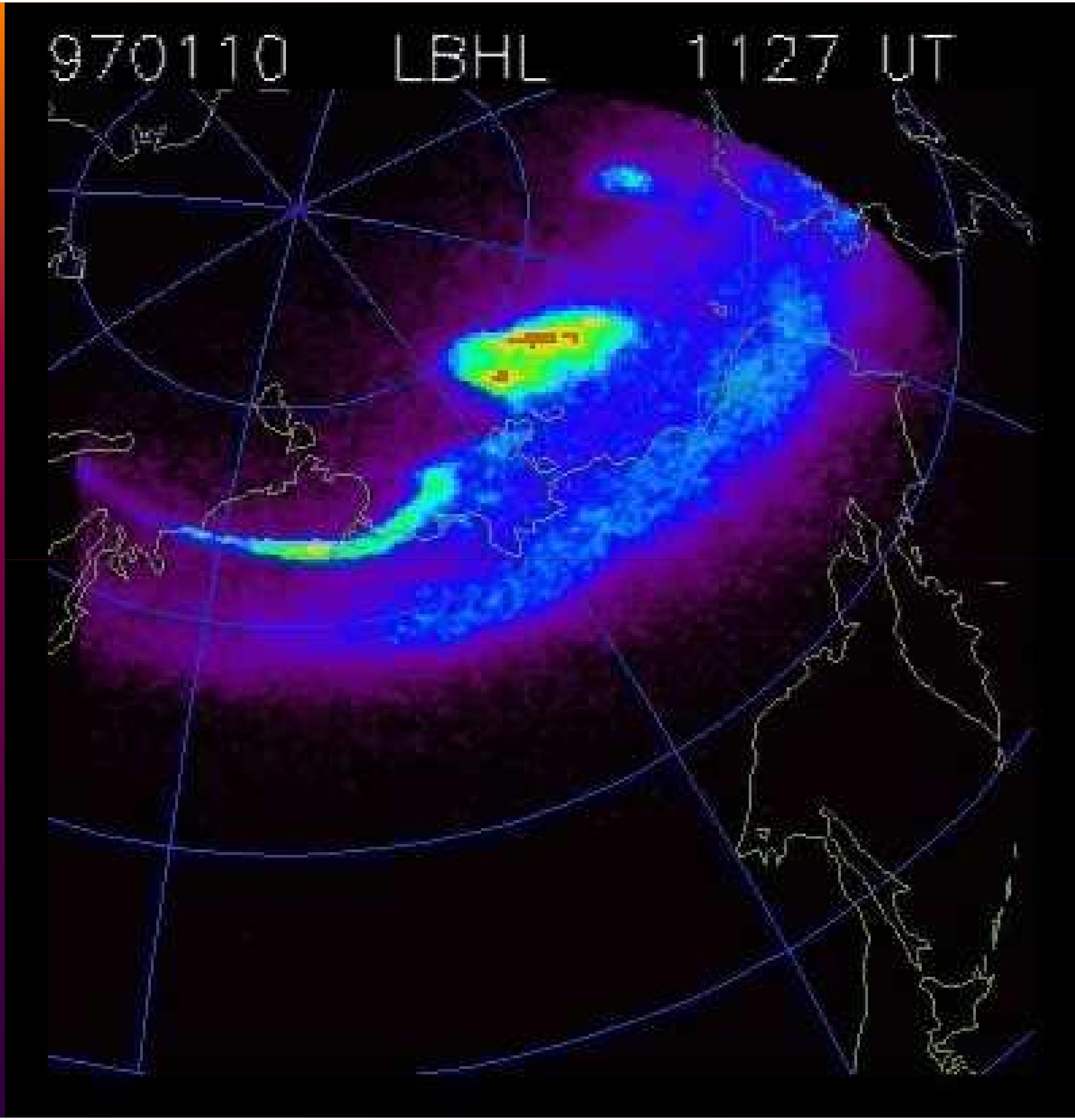
Comparison of the abundances of the elements in the galactic cosmic rays with the solar abundances (normalized to C). (Courtesy of C. Meyer, University of Chicago.)

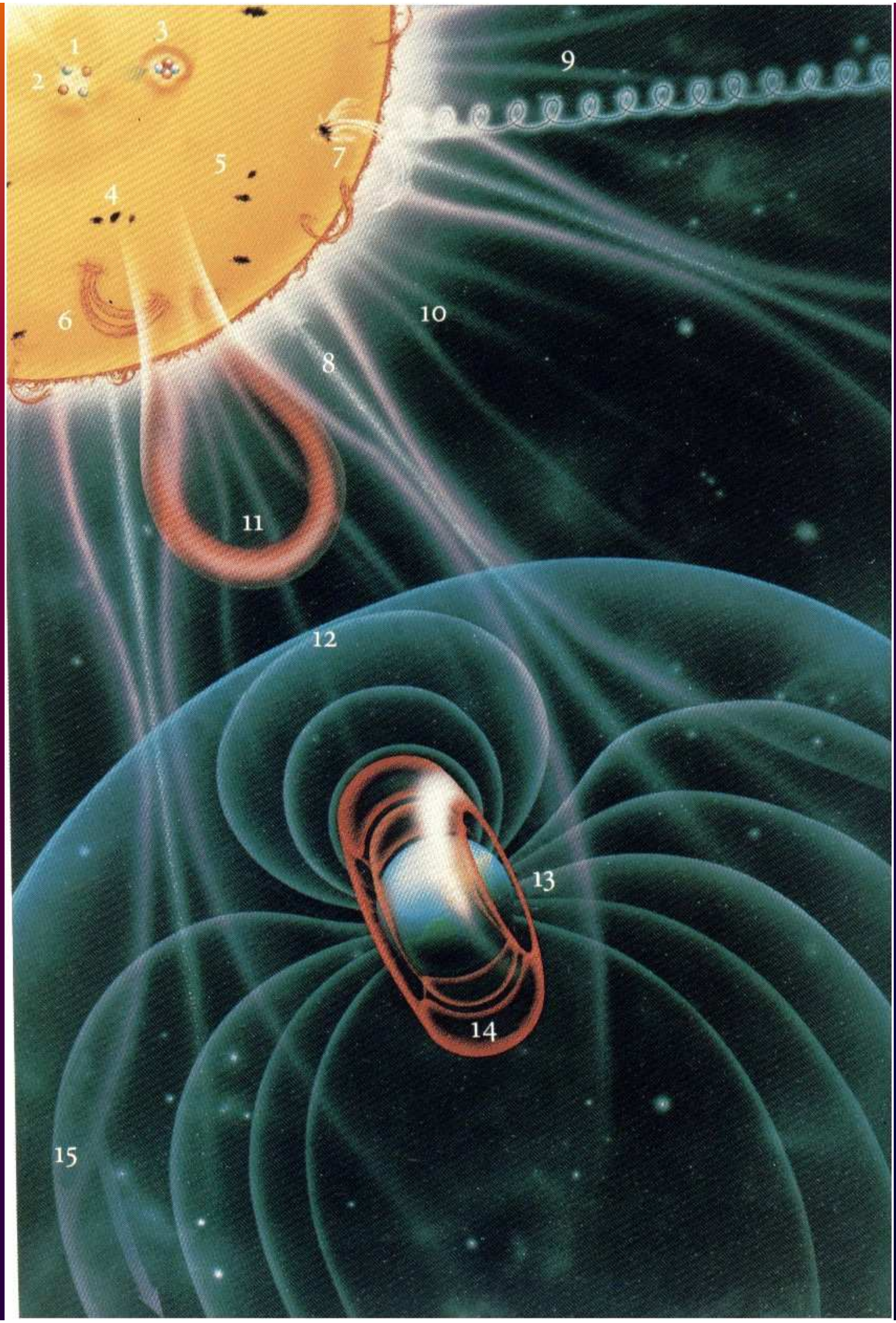


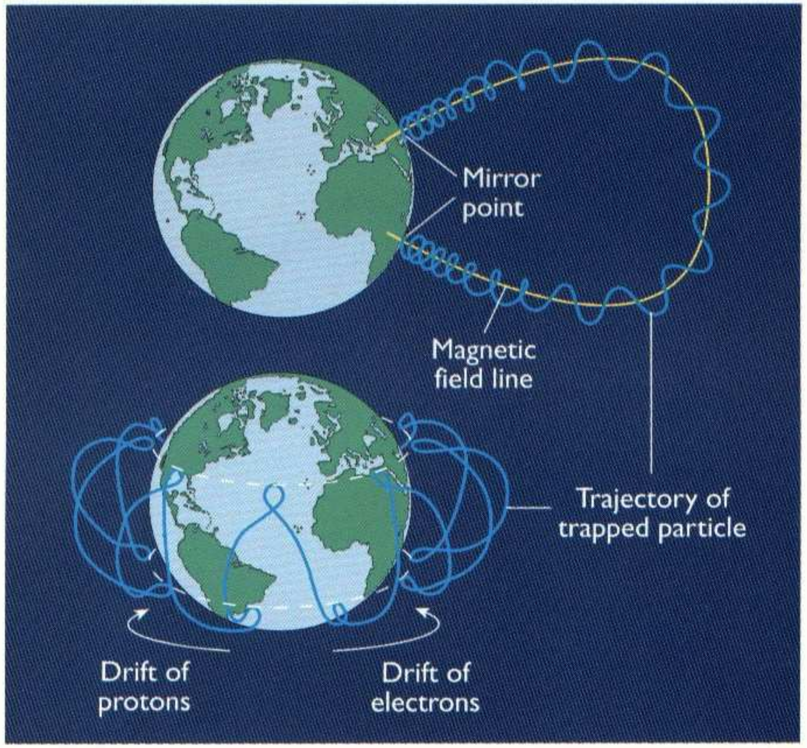

1,000
500
SOLAR WIND
SPEED (km/sec)
1,000
1,000
500
1,000

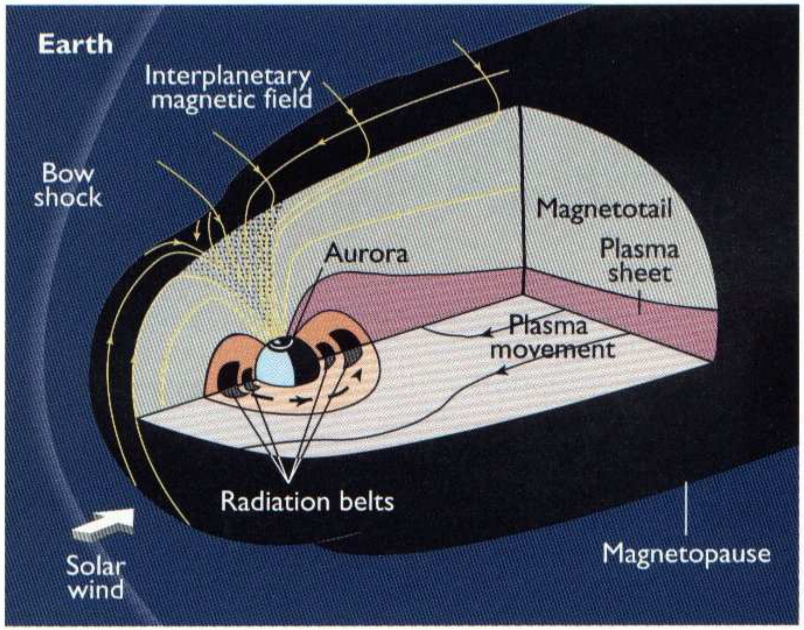

Solar wind
Polar cusp
Van Allen radiation belts
Tail lobe
Plasma mantle
Bow shock
Magnetosheath
Plasmasphere
Magnetopause
Plasma sheet

(JAN CURTIS)

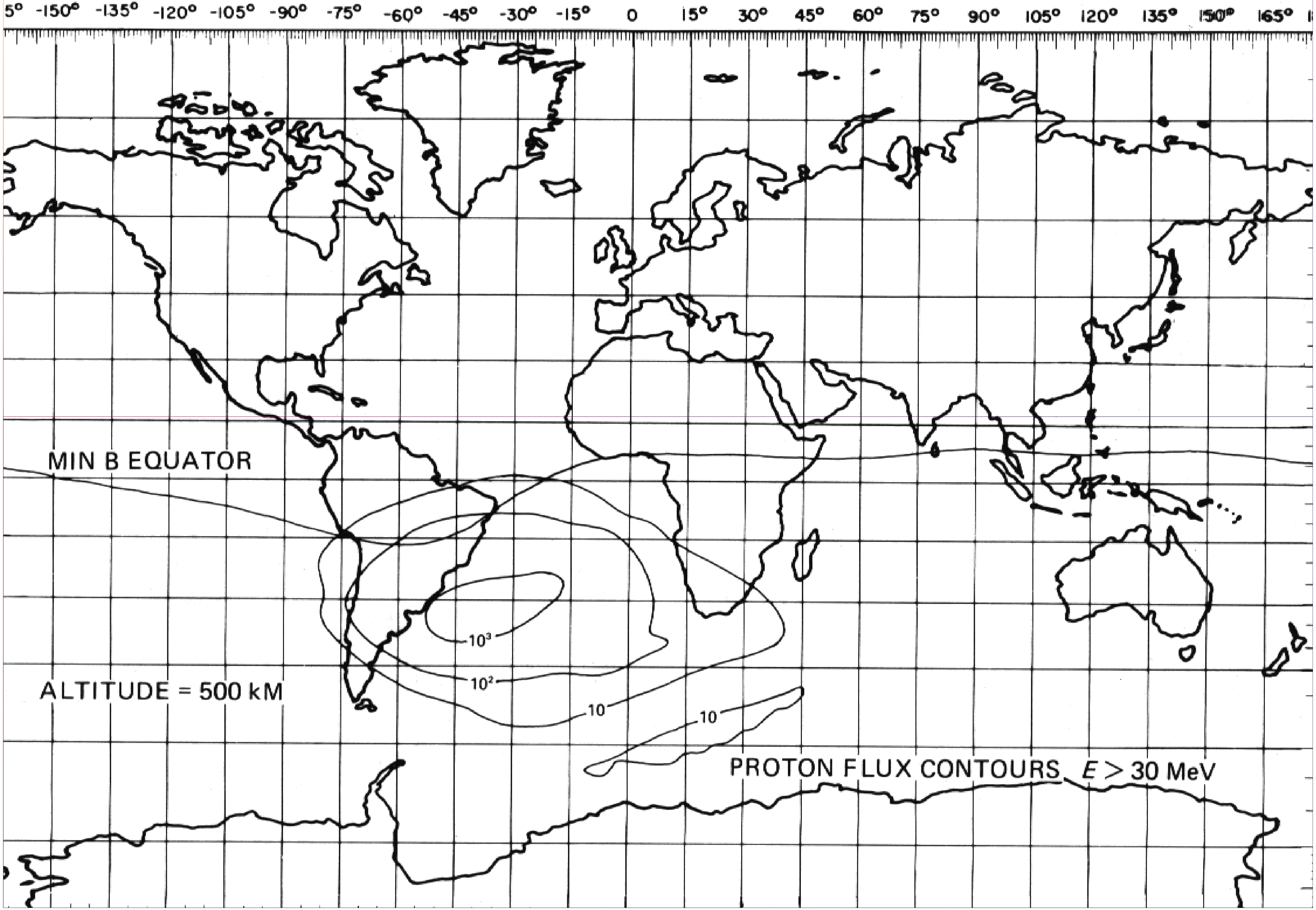

970110 LBHL 1127 UT

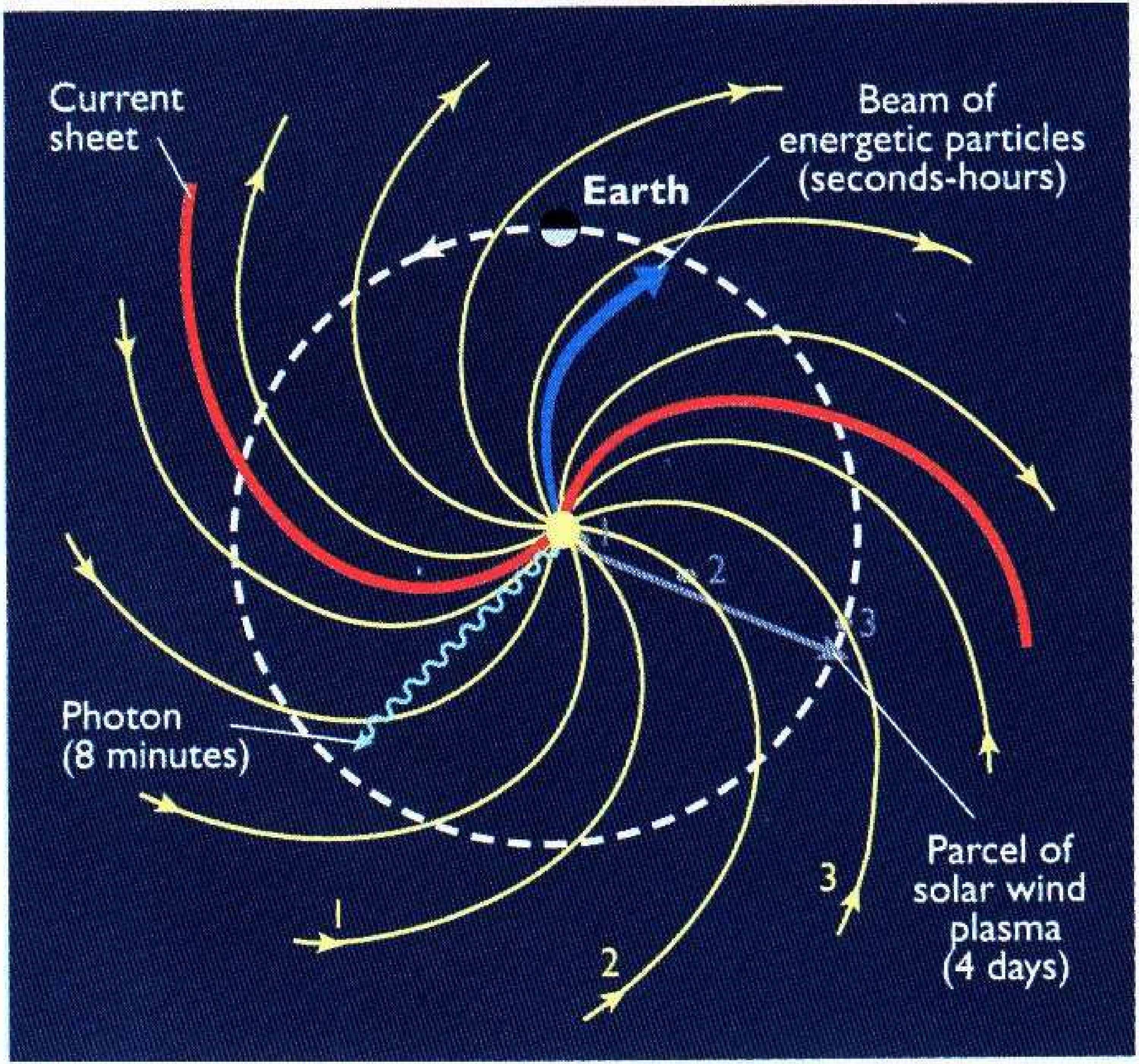

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

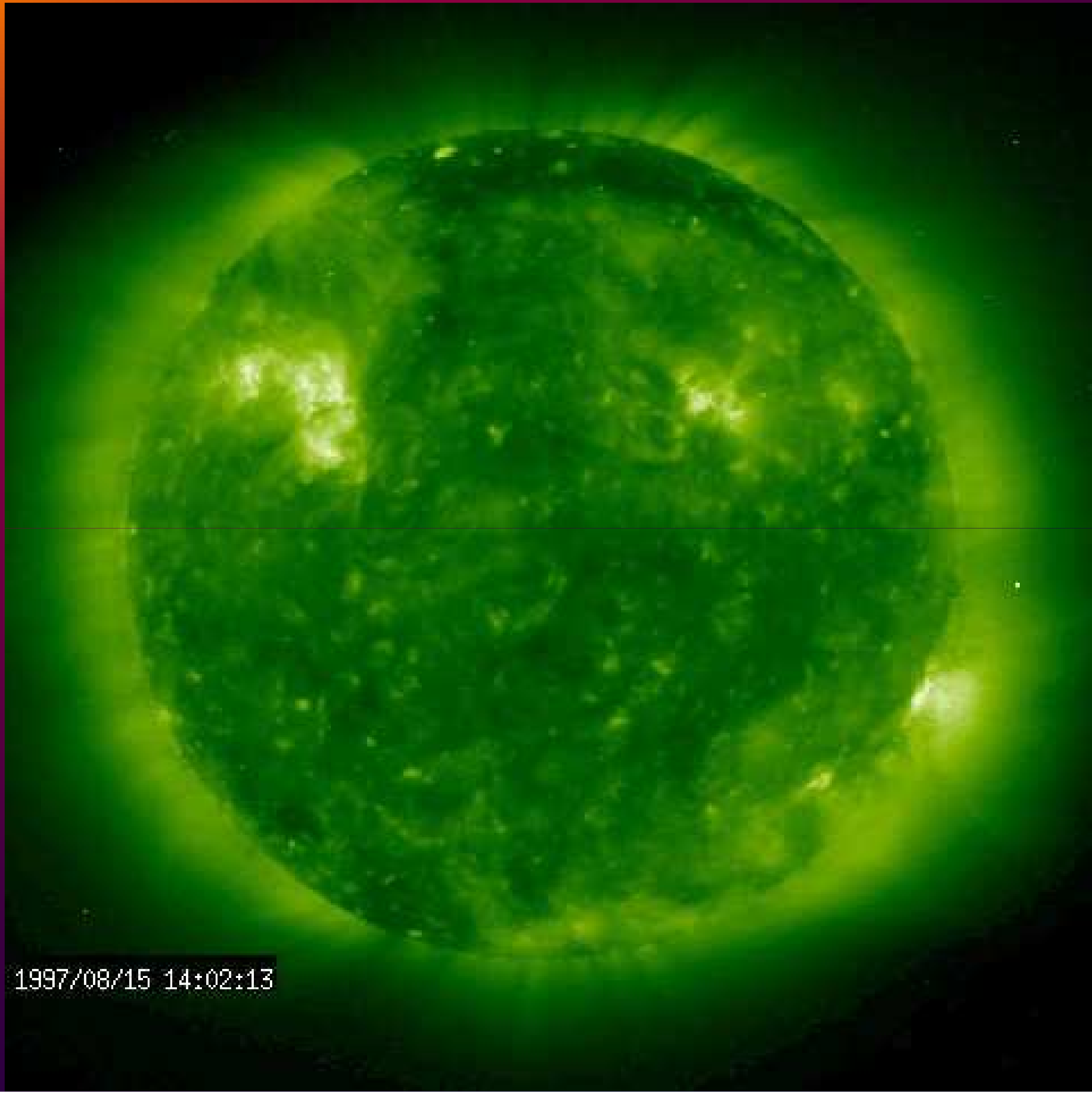

Mirror
point
Magnetic
field line
Trajectory of
trapped particle
Drift of
protons
Drift of
electrons

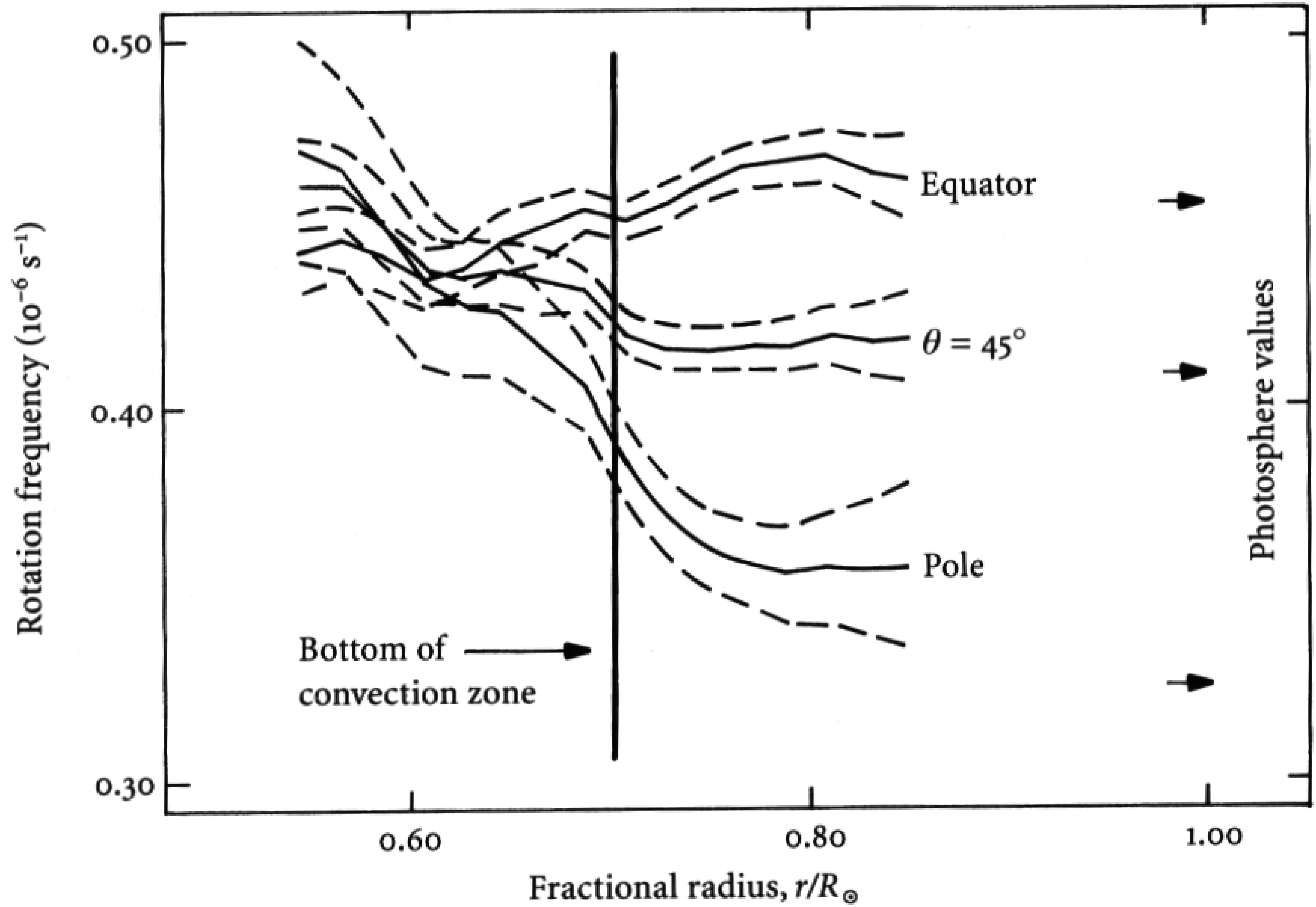

Earth
Interplanetary
magnetic field
Bow
shock
Magnetotail
Plasma
sheet
Aurora
Plasma
movement
Radiation belts
Magnetopause
Solar
wind

...ectional flux in protons cm⁻² s⁻¹. (Adapted from Stassinopoulos, E. G., *World Maps of Constant B, L* ...*ntours*, NASA SP-3054, 1970.)

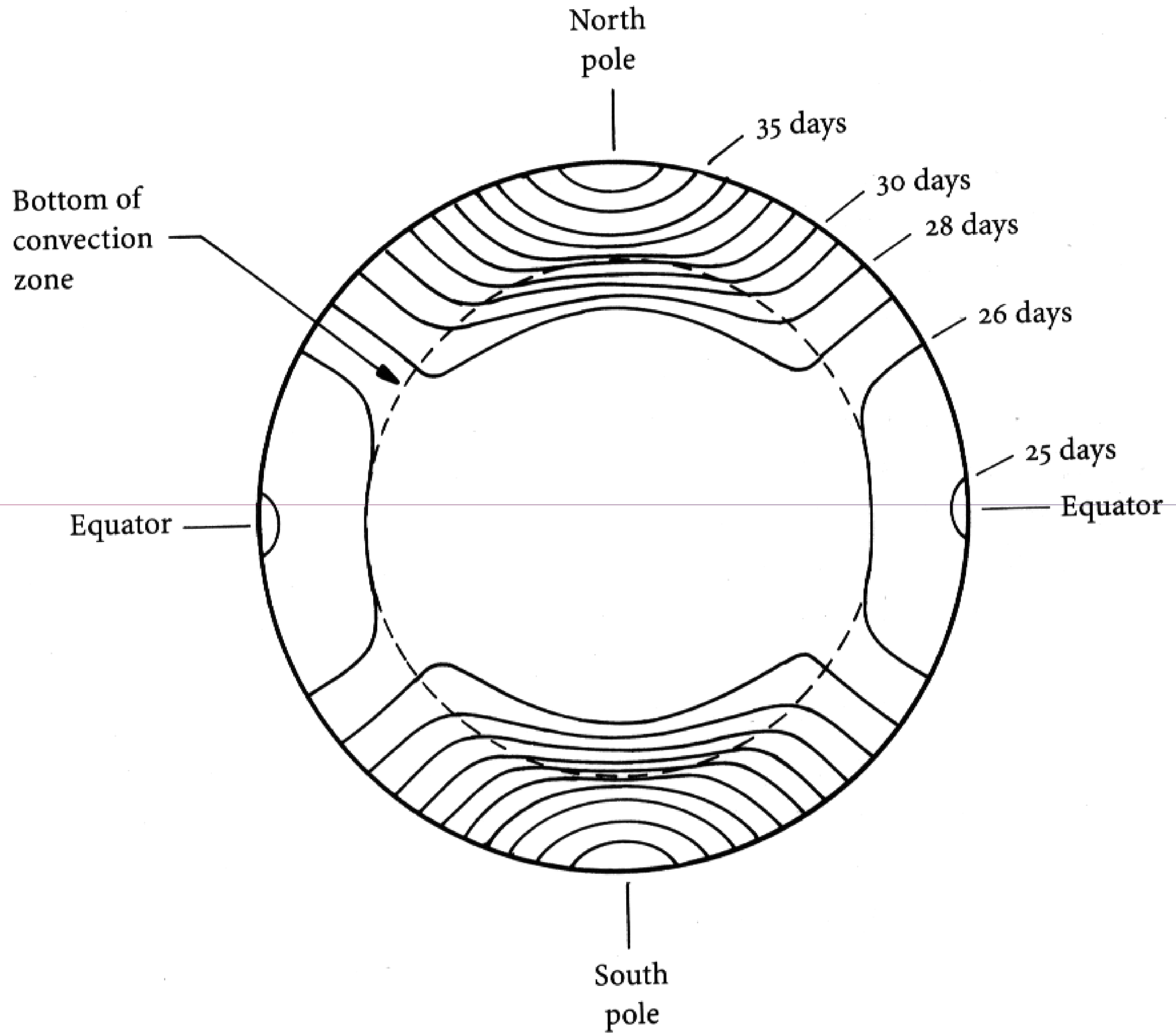



Current sheet
Earth
Beam of energetic particles (seconds-hours)
Photon (8 minutes)
Parcel of solar wind plasma (4 days)
1
2
3
1
2
3

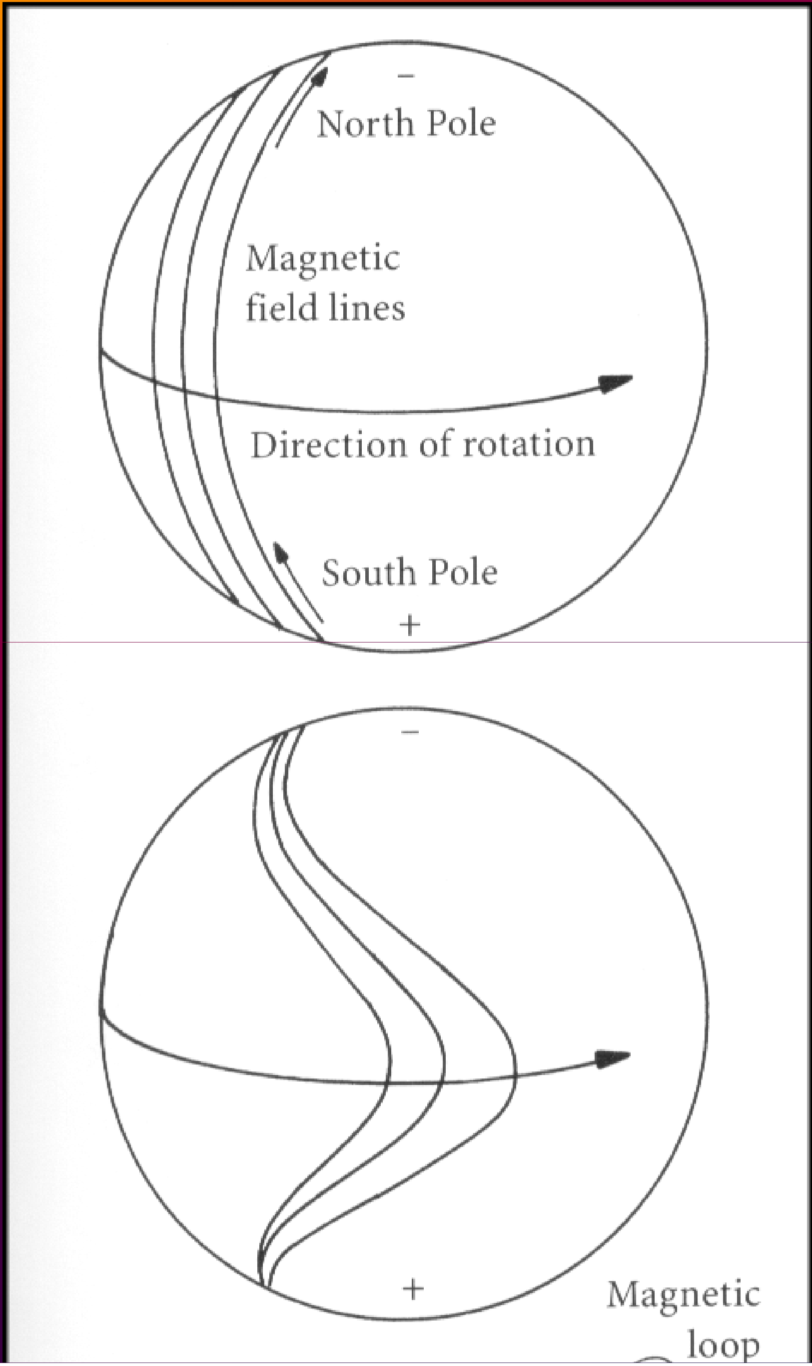

1997/08/15 14:02:13

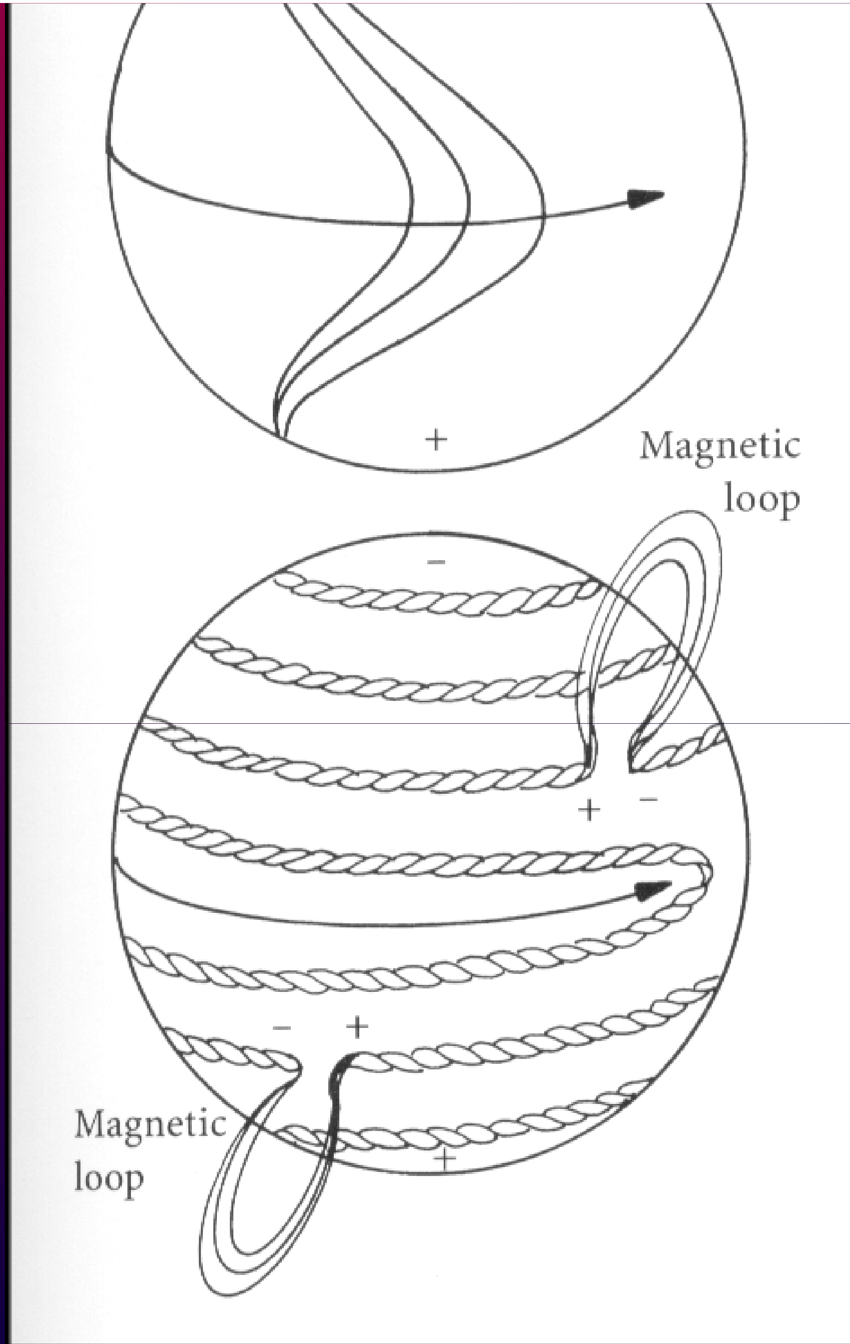


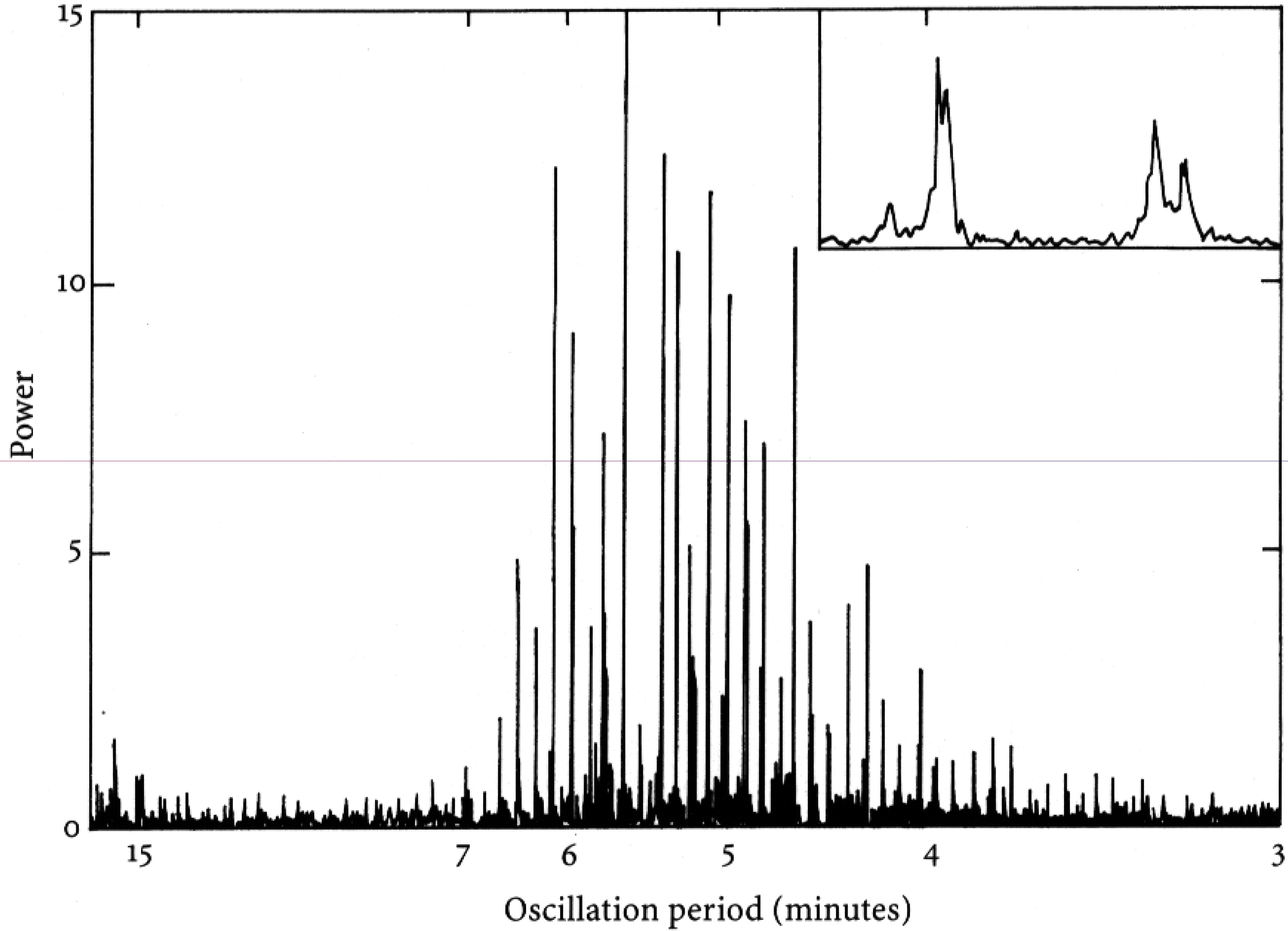
0.50
0.40
0.30
Rotation frequency (10^{-6} s^{-1})
Equator
$\theta = 45°$
Pole
Bottom of
convection zone
Photosphere values
0.60
0.80
1.00
Fractional radius, $r/R_\odot$



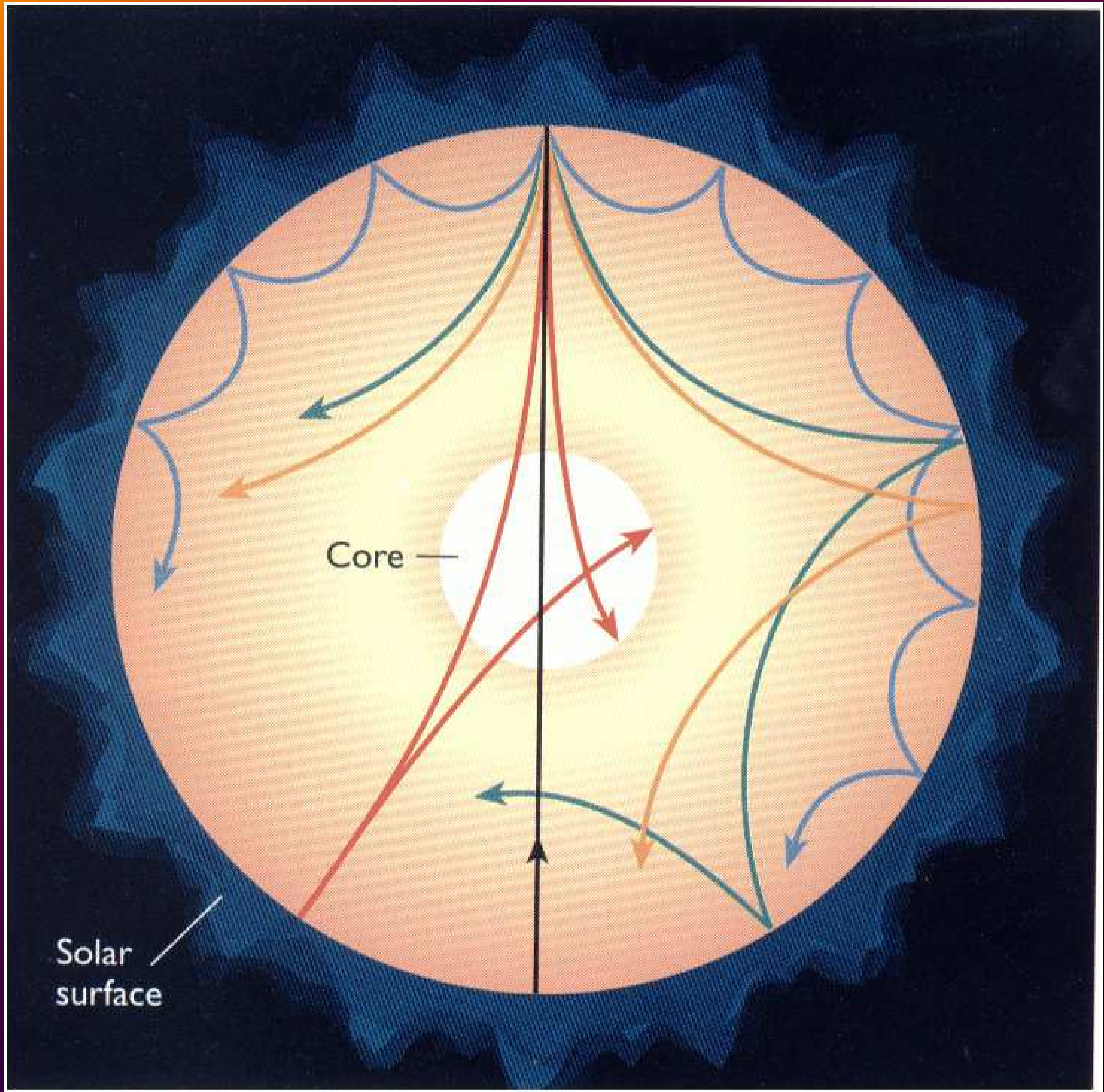
North pole
35 days
30 days
28 days
26 days
25 days
Bottom of convection zone
Equator
Equator
South pole

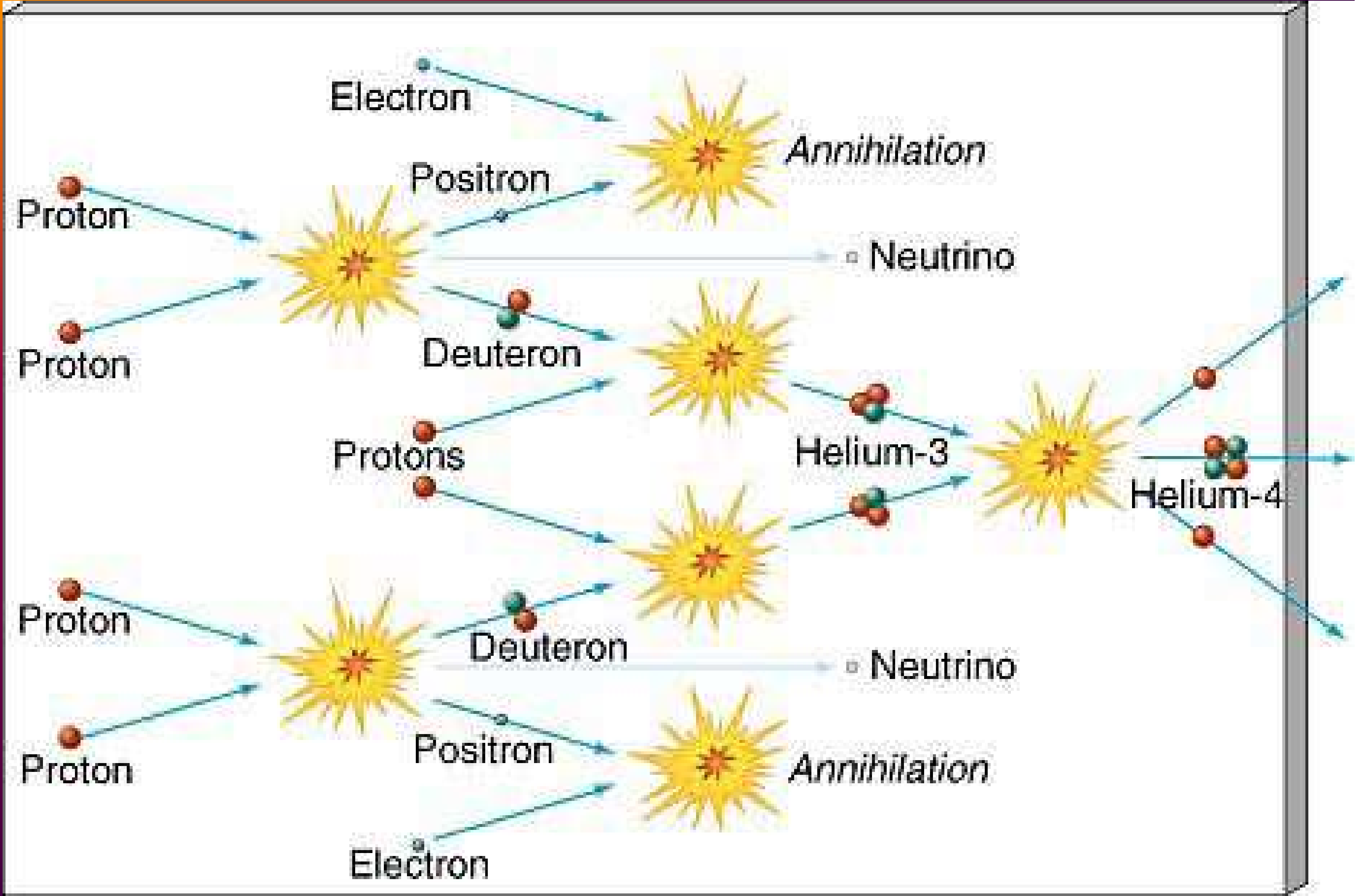

–
North Pole
Magnetic
field lines
Direction of rotation
South Pole
+
–
+
Magnetic
loop


+
Magnetic
loop
–
+
–
–
+
Magnetic
loop
+



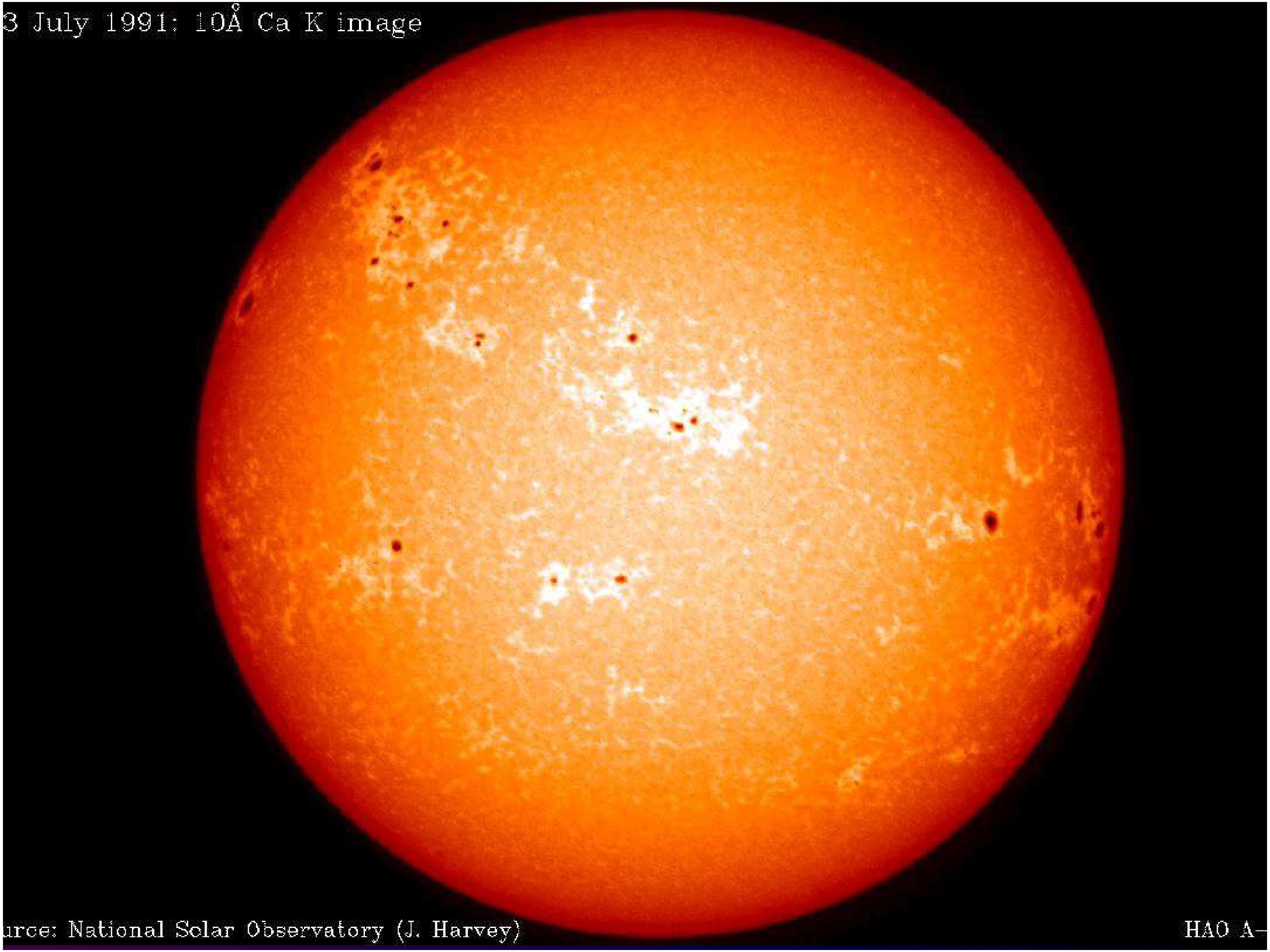
15
10
5
0
Power
15
7
6
5
4
3
Oscillation period (minutes)

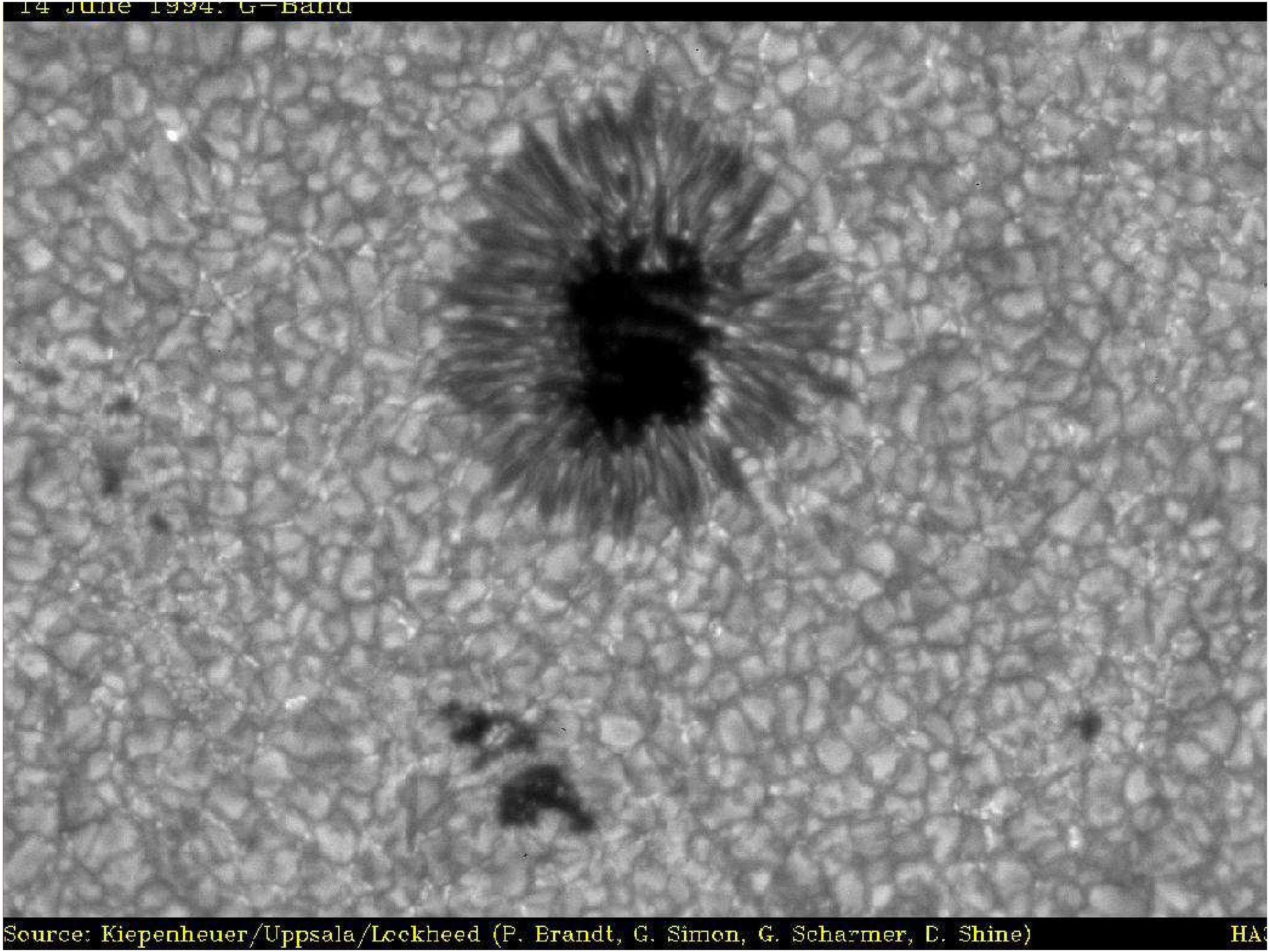

Core
Solar surface

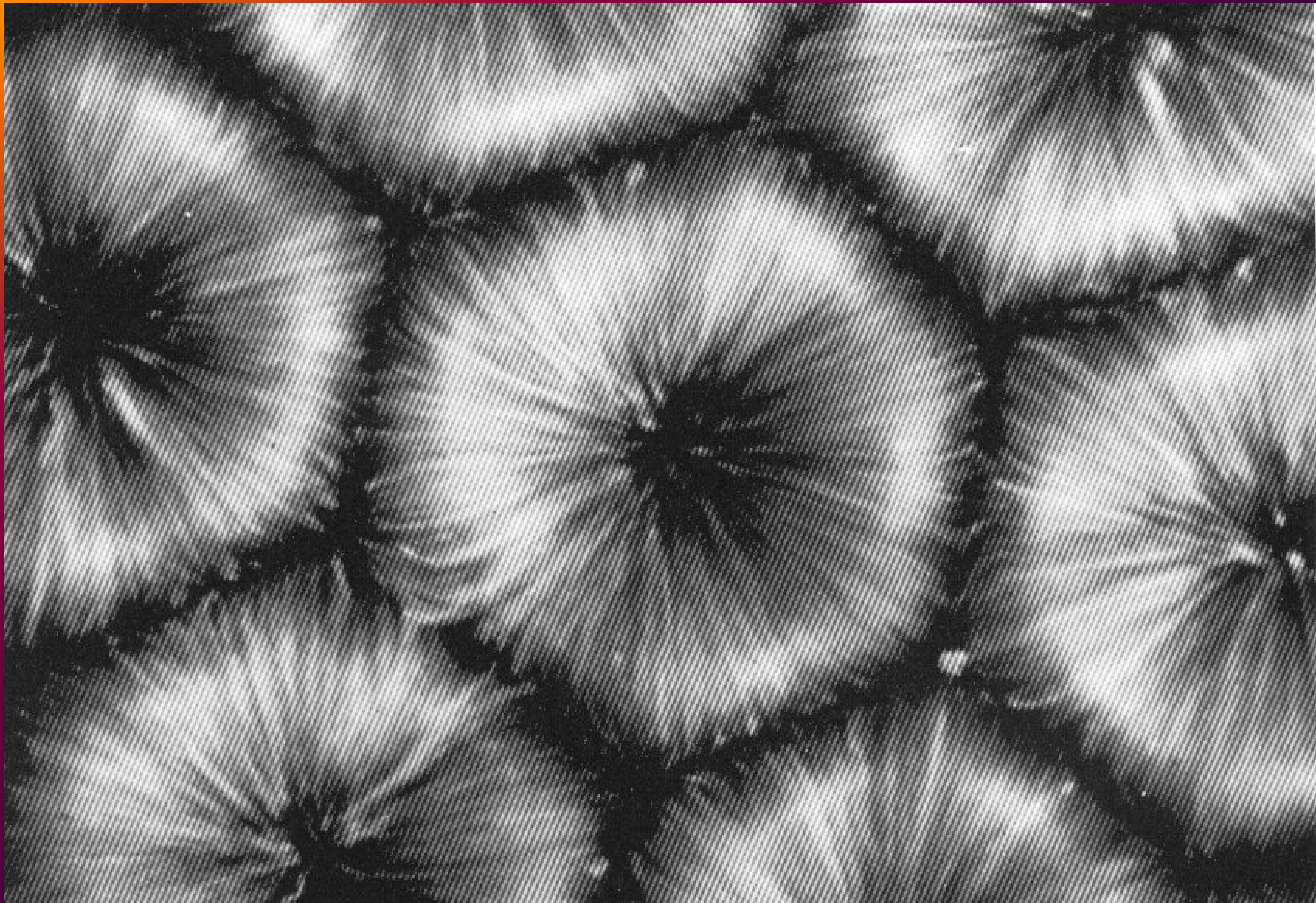

Electron
Annihilation
Positron
Proton
Neutrino
Proton
Deuteron
Protons
Helium-3
Helium-4
Proton
Deuteron
Neutrino
Proton
Positron
Annihilation
Electron

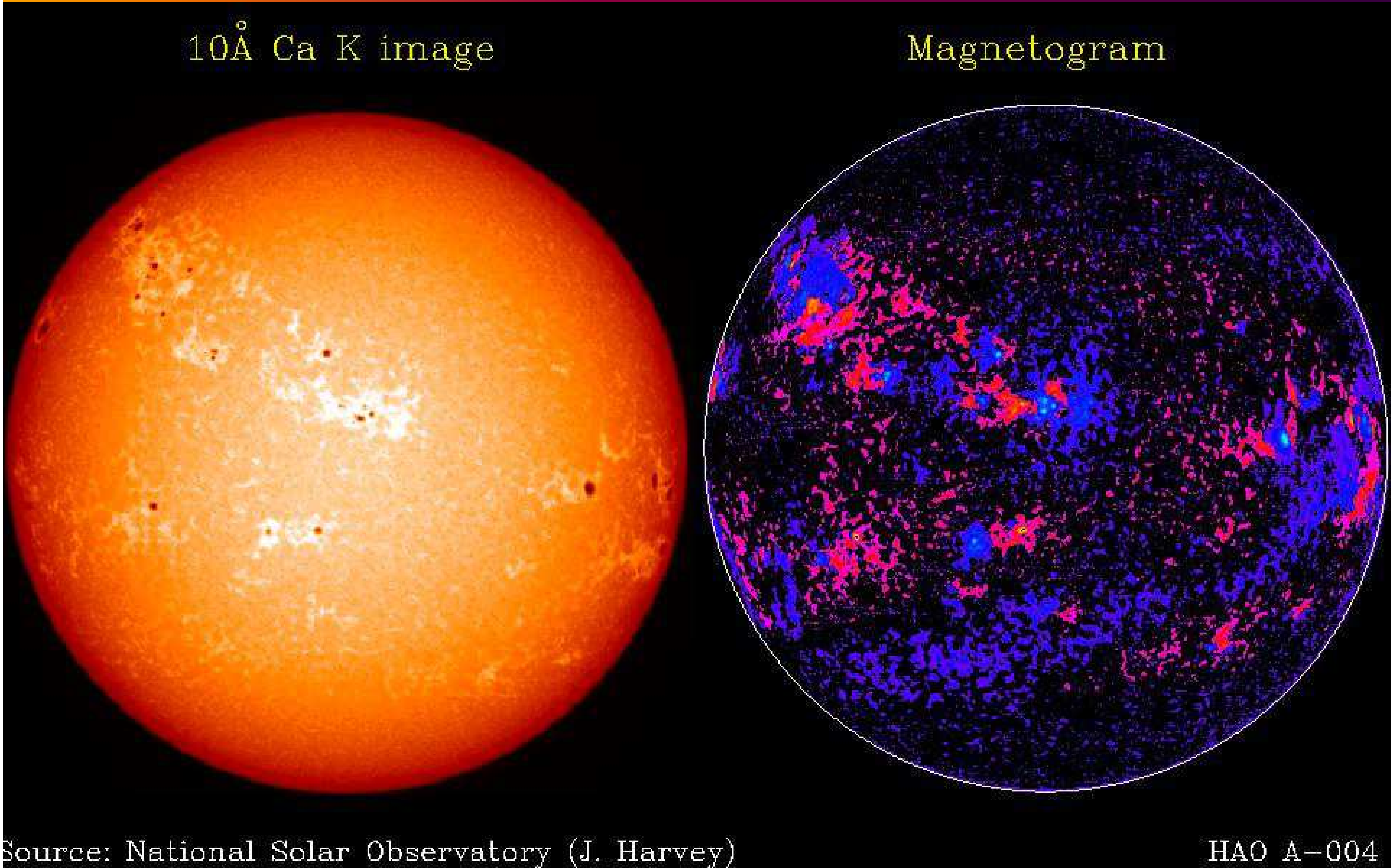
PARTE II

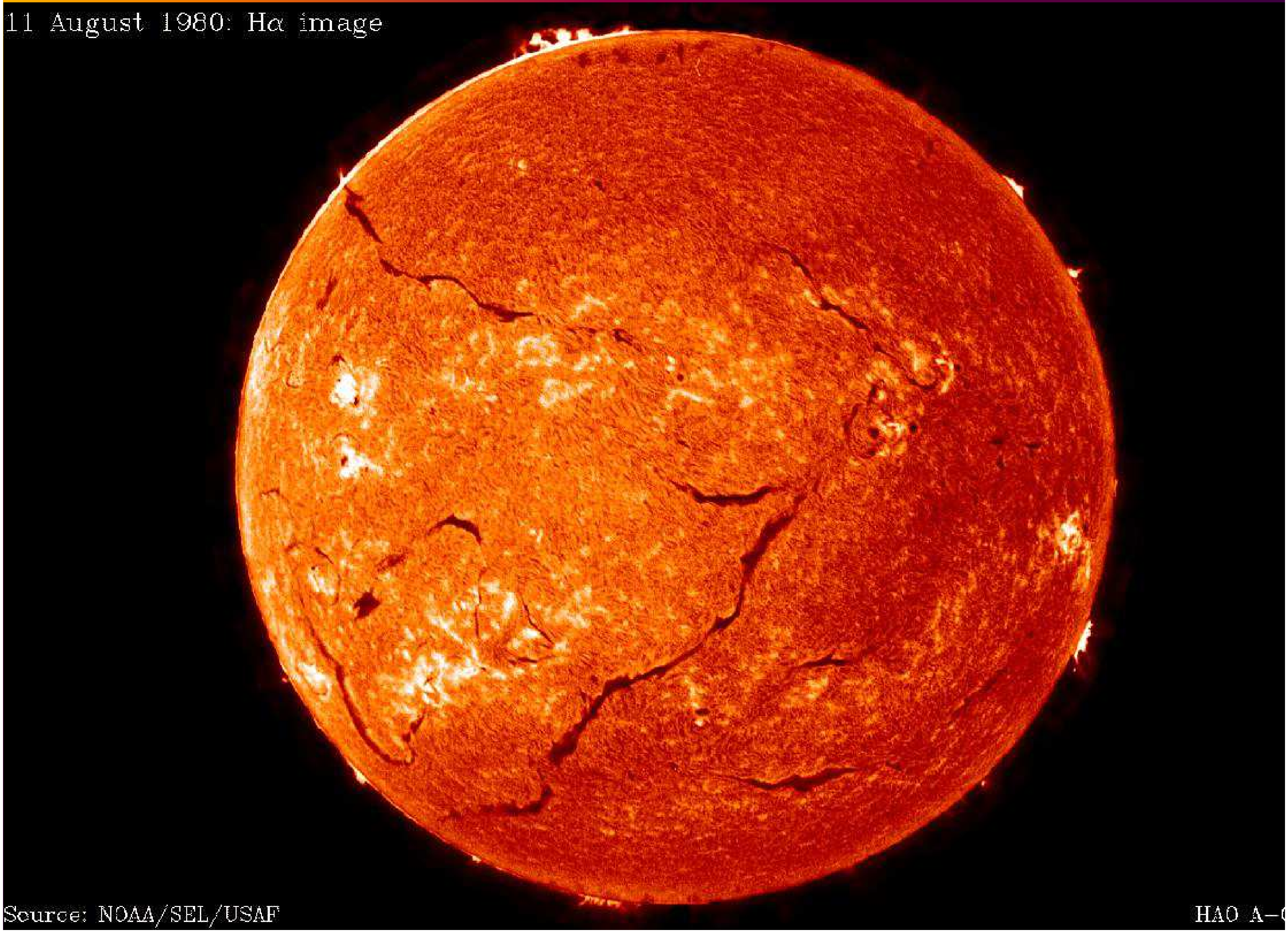
ACTIVIDAD SOLAR

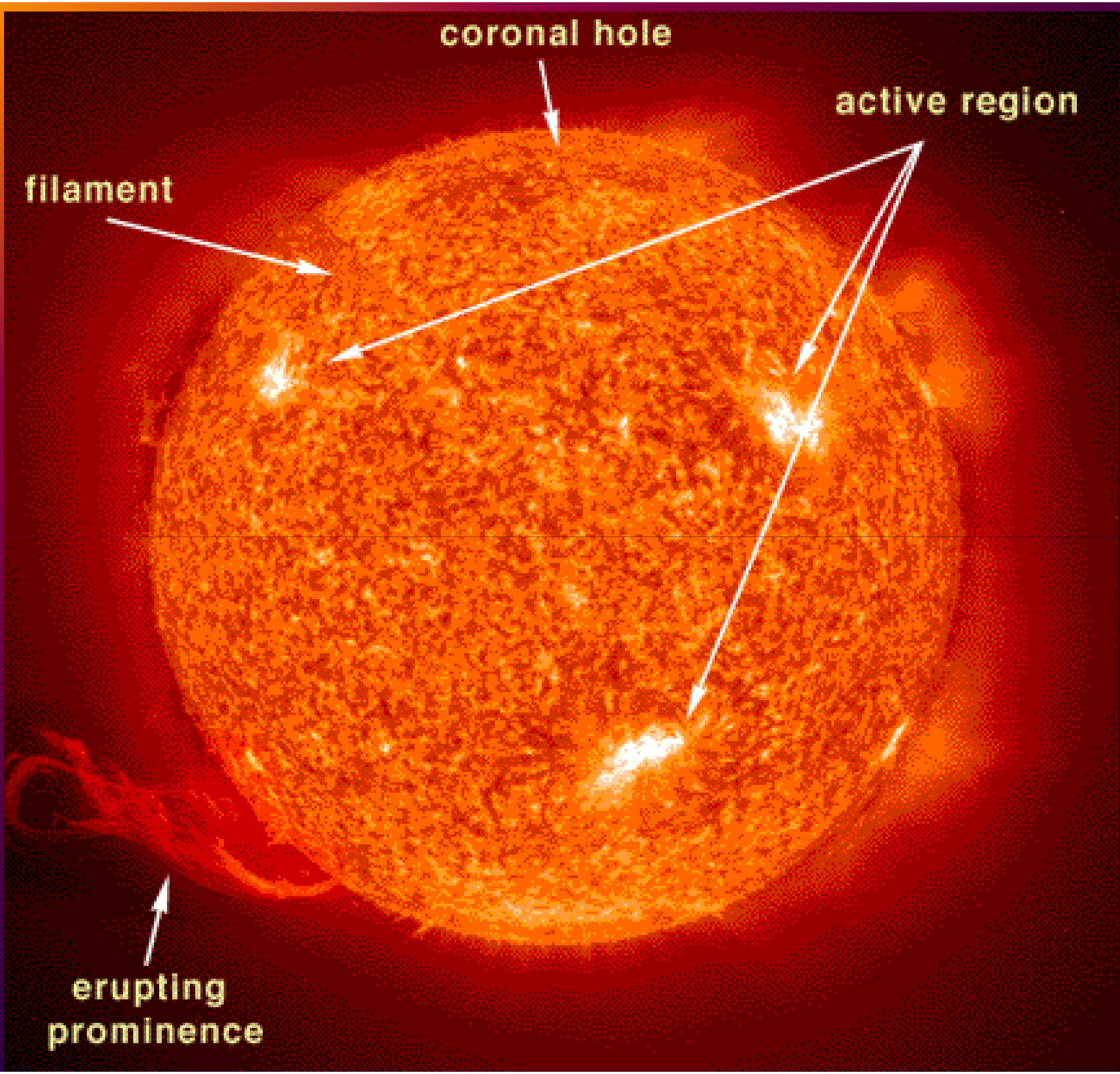

3 July 1991: 10Å Ca K image
urce: National Solar Observatory (J. Harvey)
HAO A-

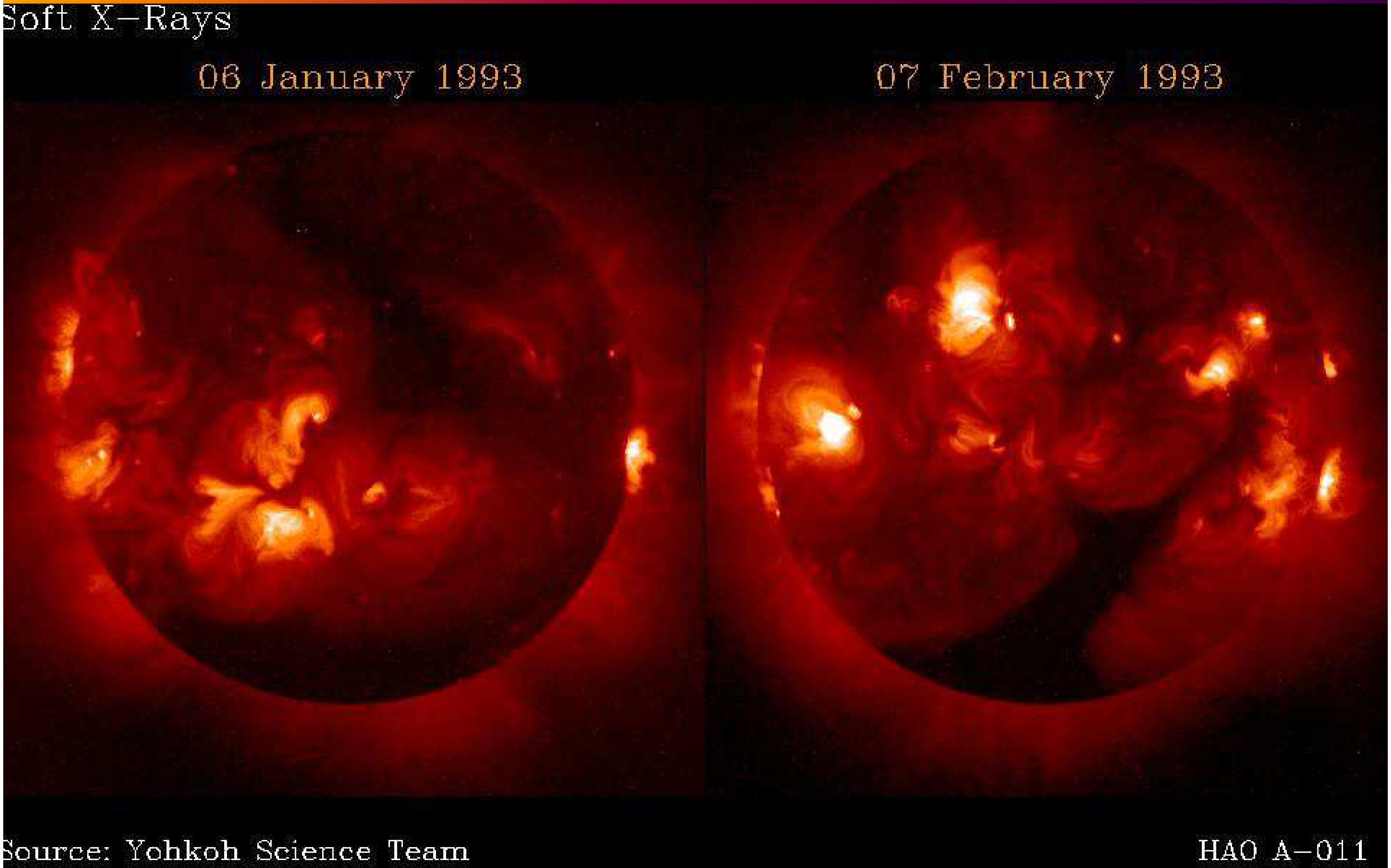

14 June 1994: G-Band
Source: Kiepenheuer/Uppsala/Lockheed (P. Brandt, G. Simon, G. Scharmer, D. Shine)

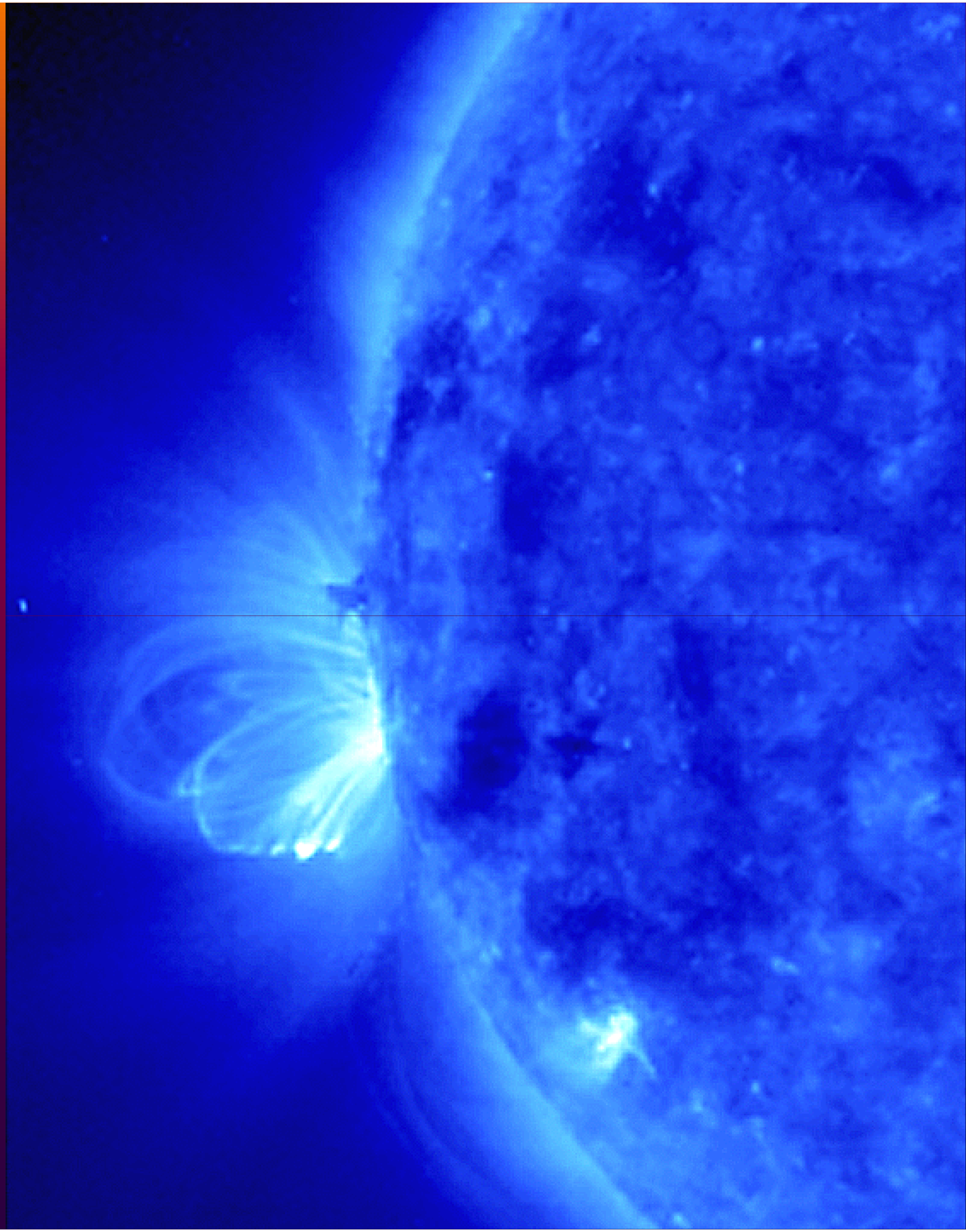


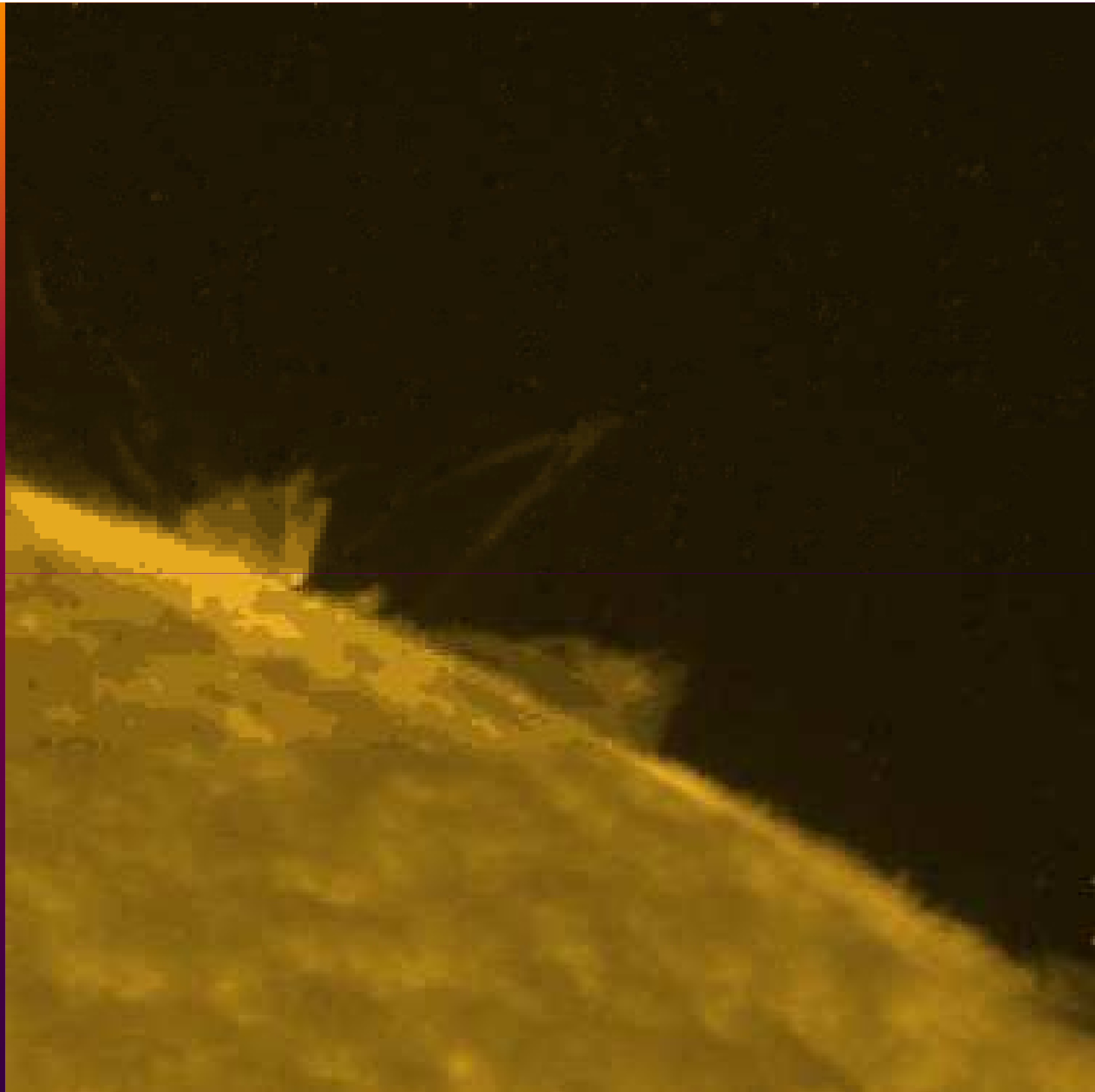

10Å Ca K image
Magnetogram
Source: National Solar Observatory (J. Harvey)
HAO A-004

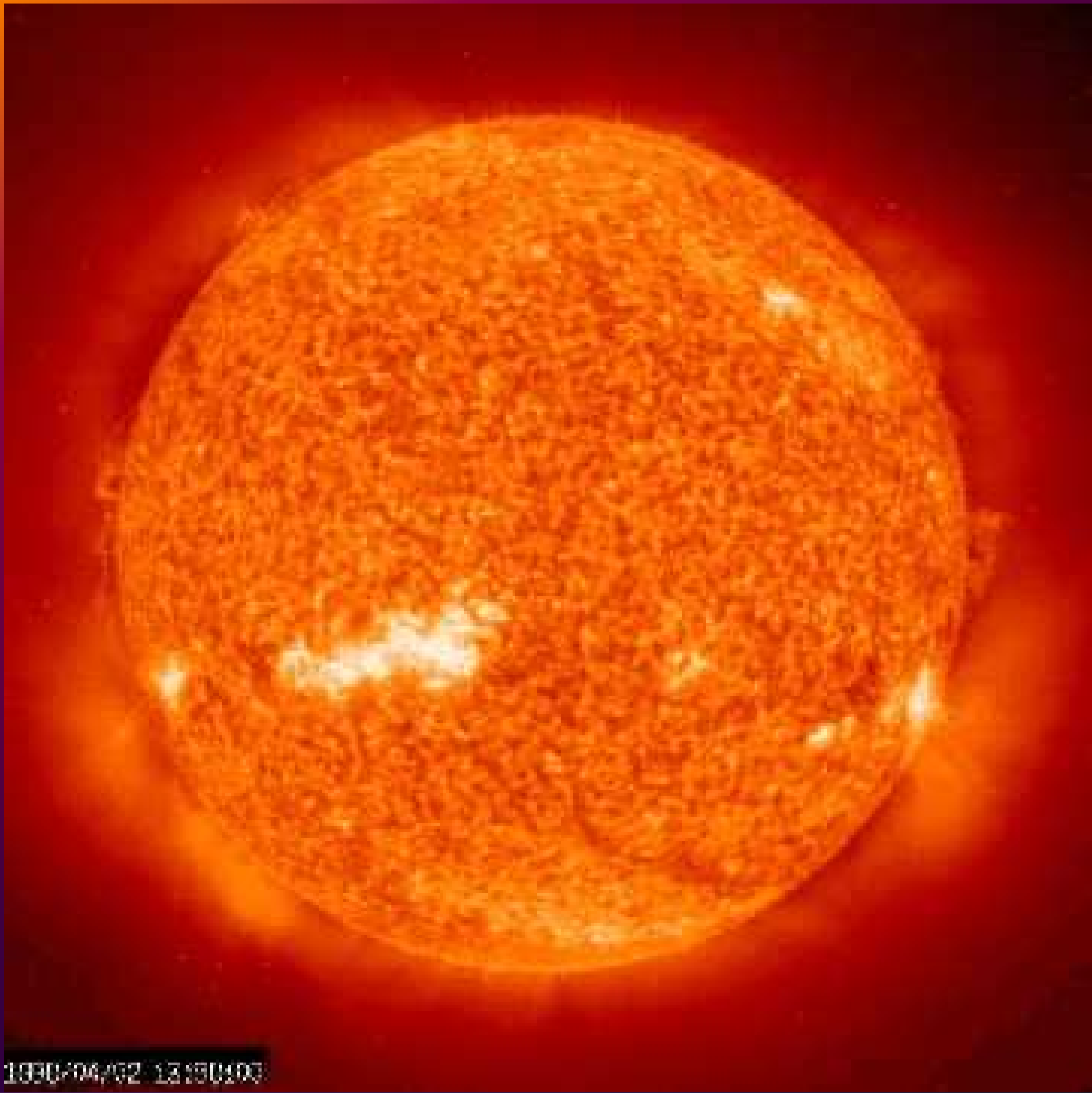

11 August 1980: Hα image
Source: NOAA/SEL/USAF
HAO A-

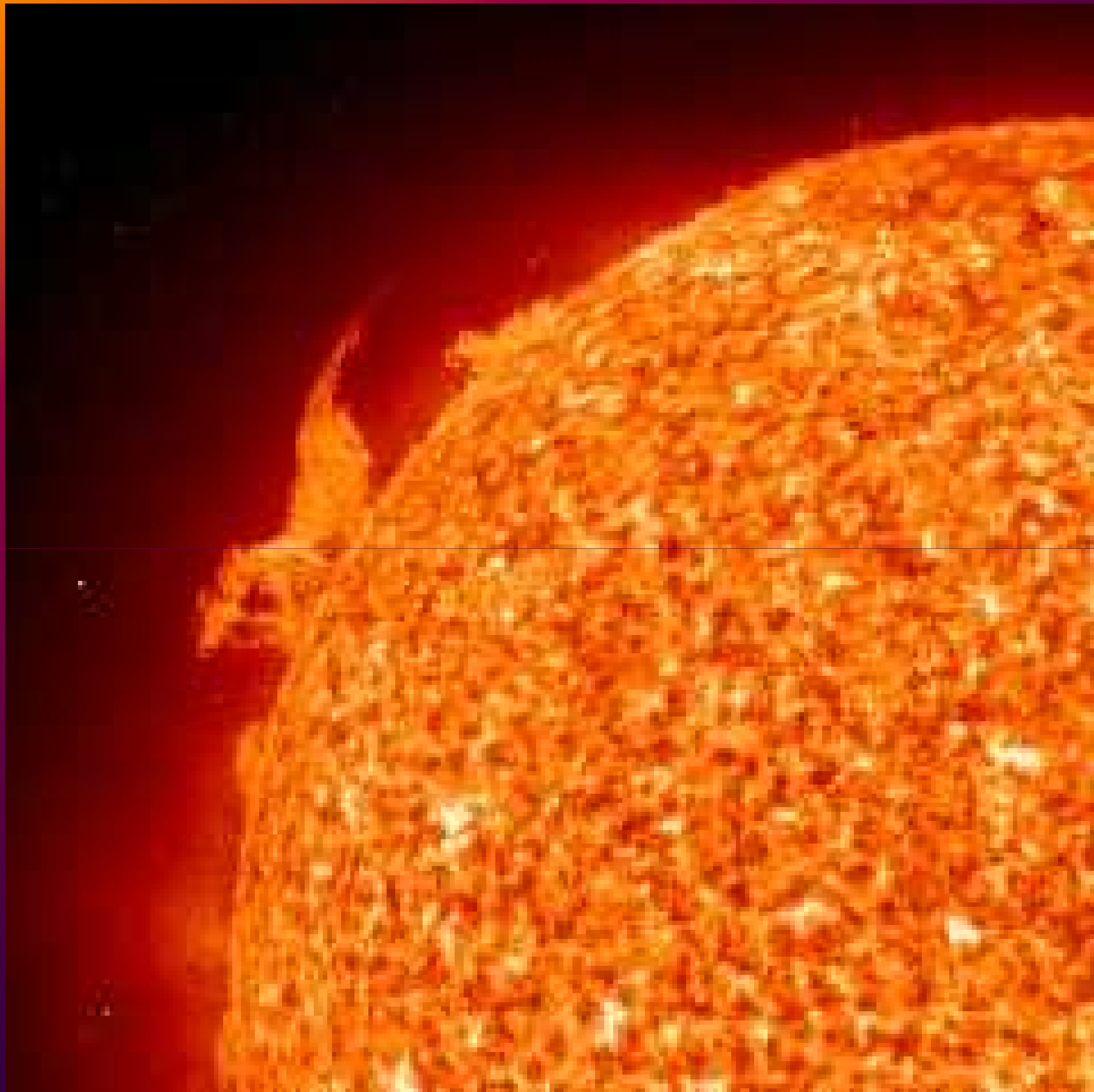

coronal hole
active region
filament
erupting
prominence

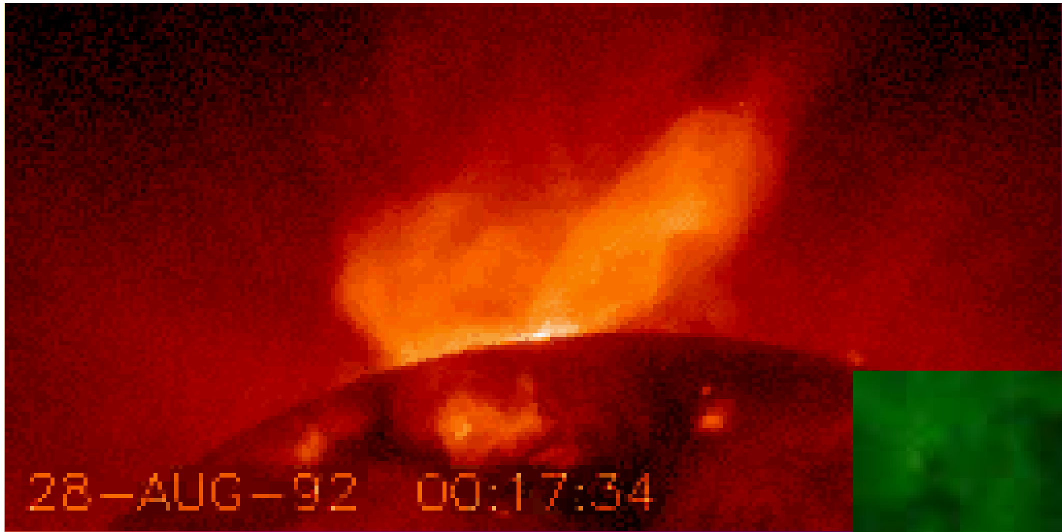

Soft X-Rays
06 January 1993
07 February 1993
Source: Yohkoh Science Team
HAO A-011

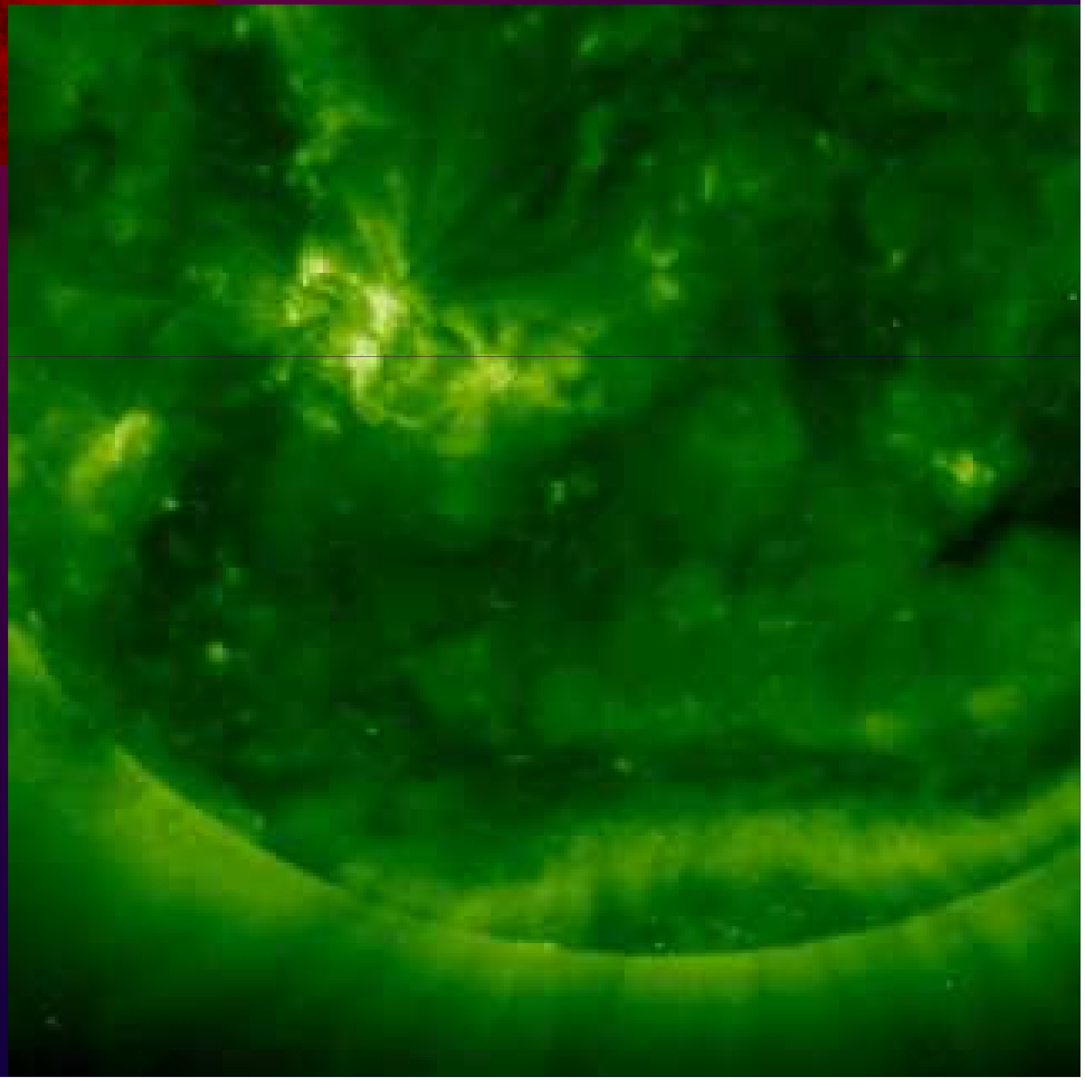


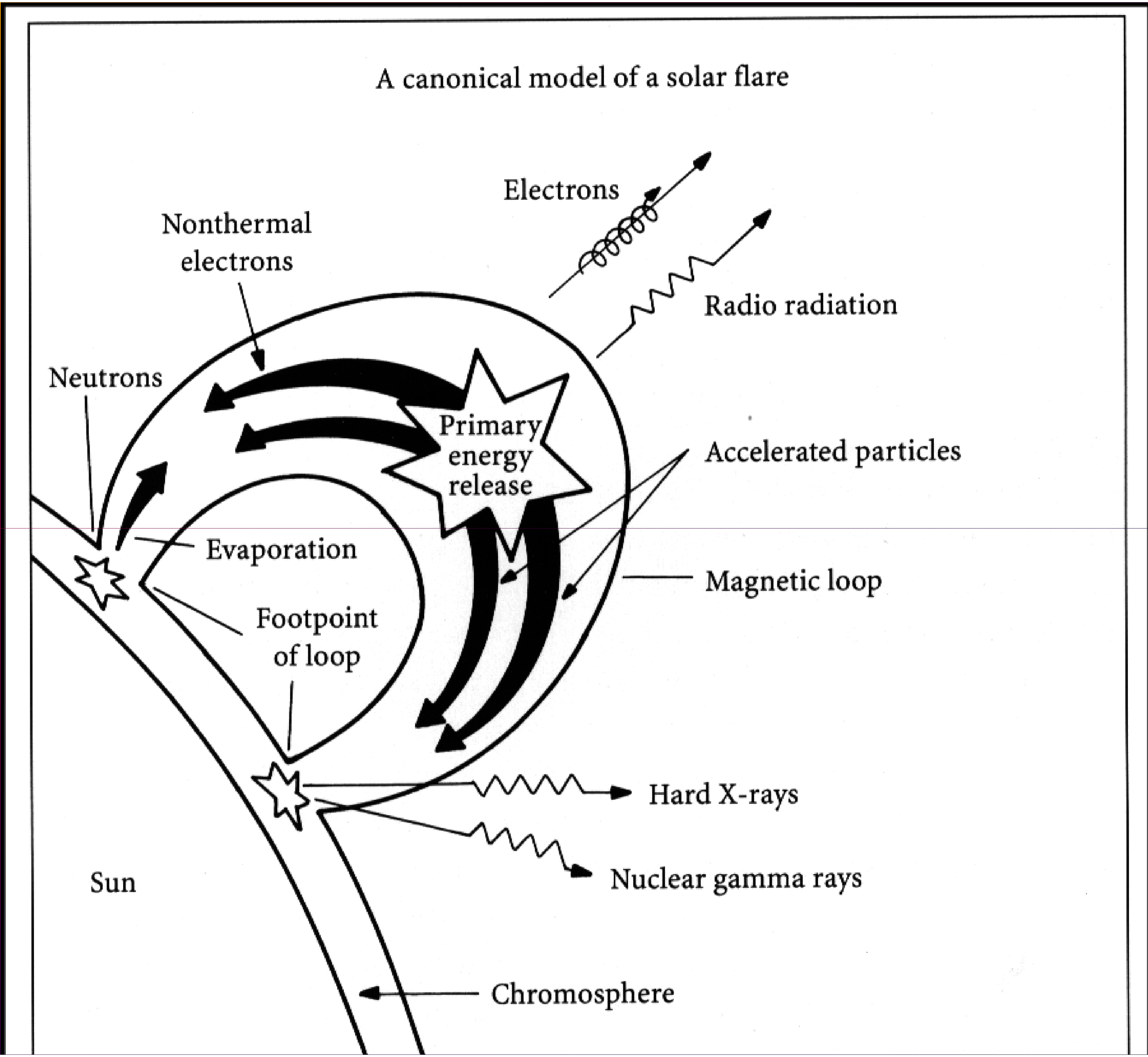


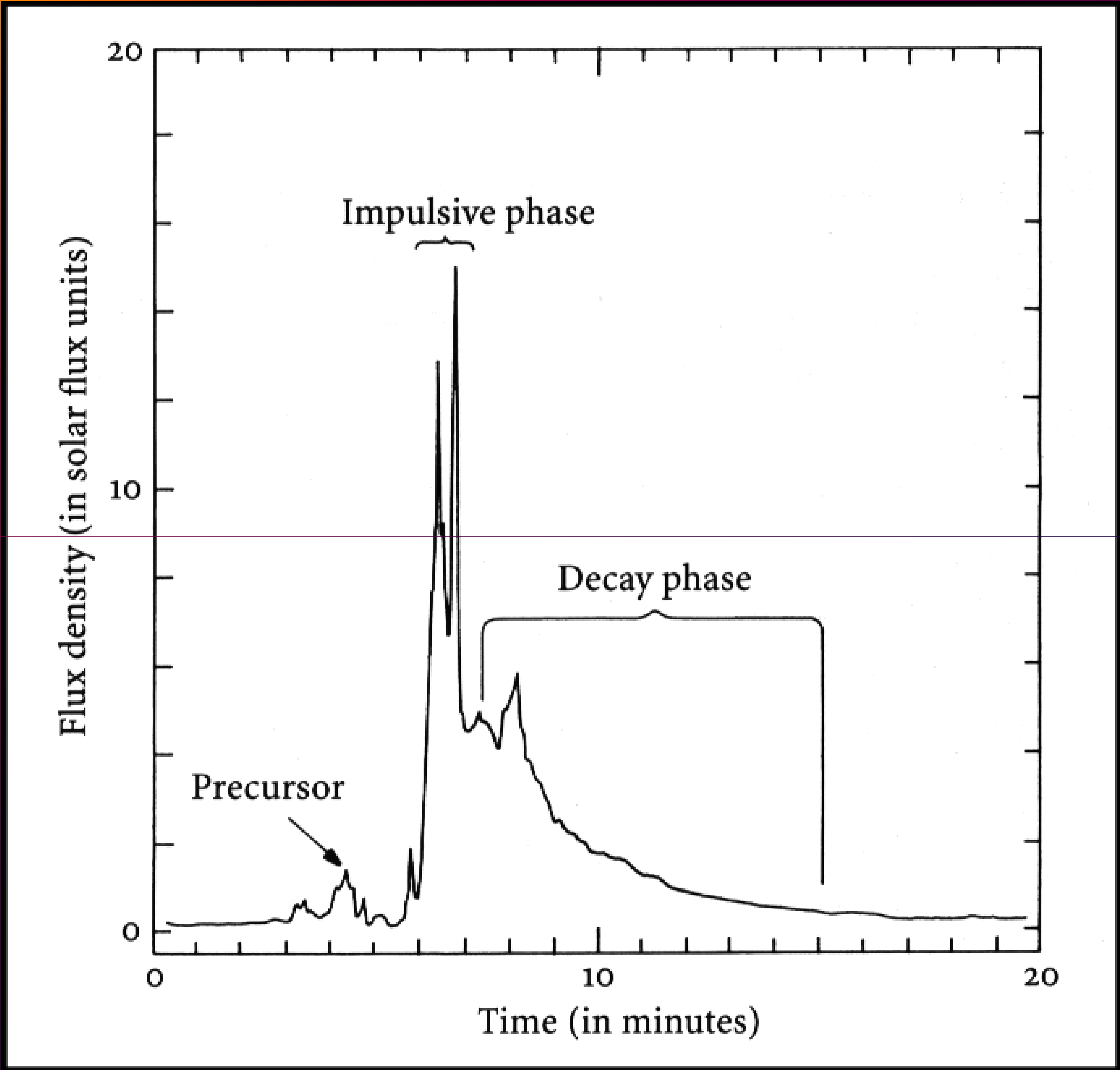




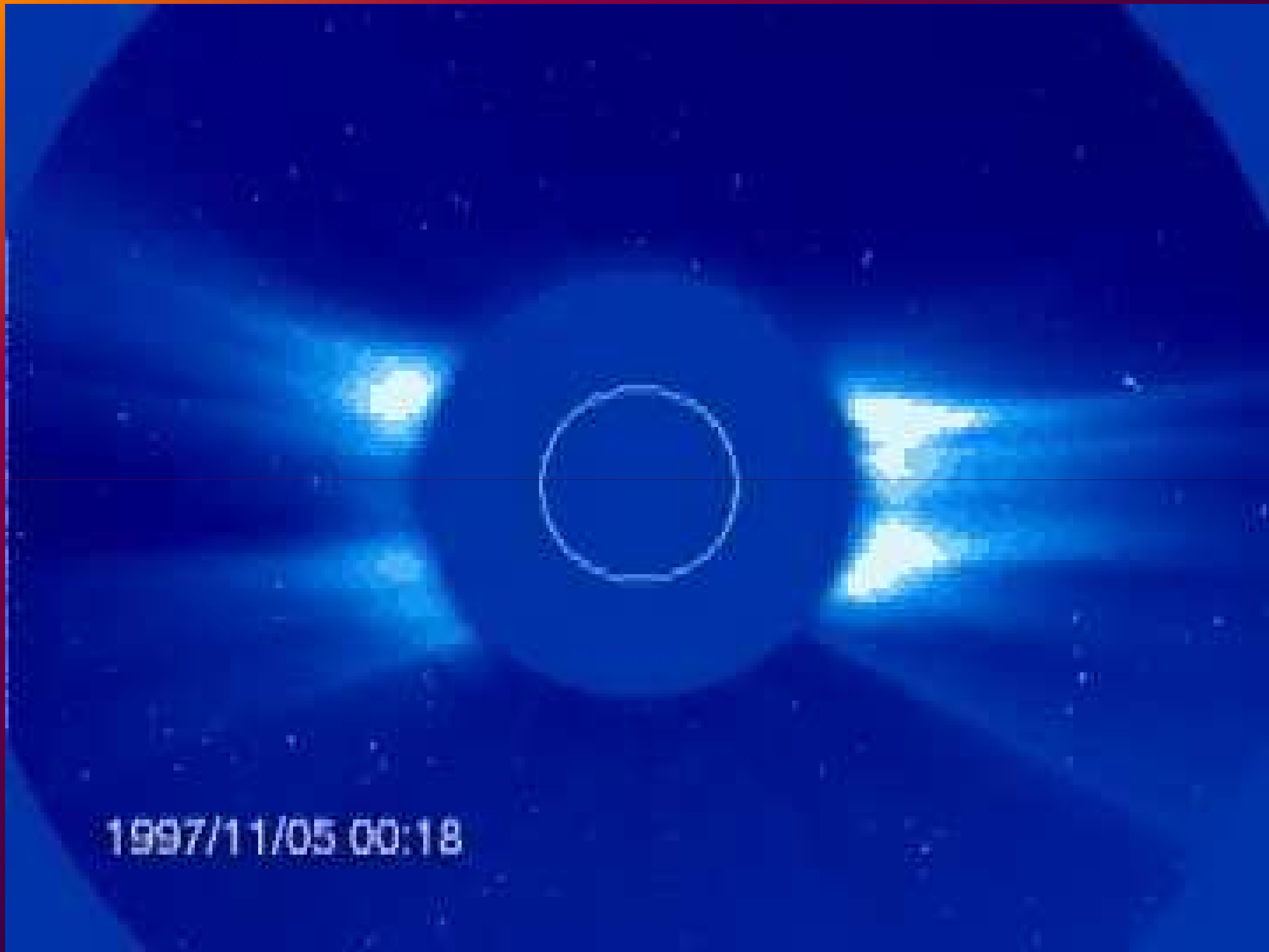

28-AUG-92 00:17:34

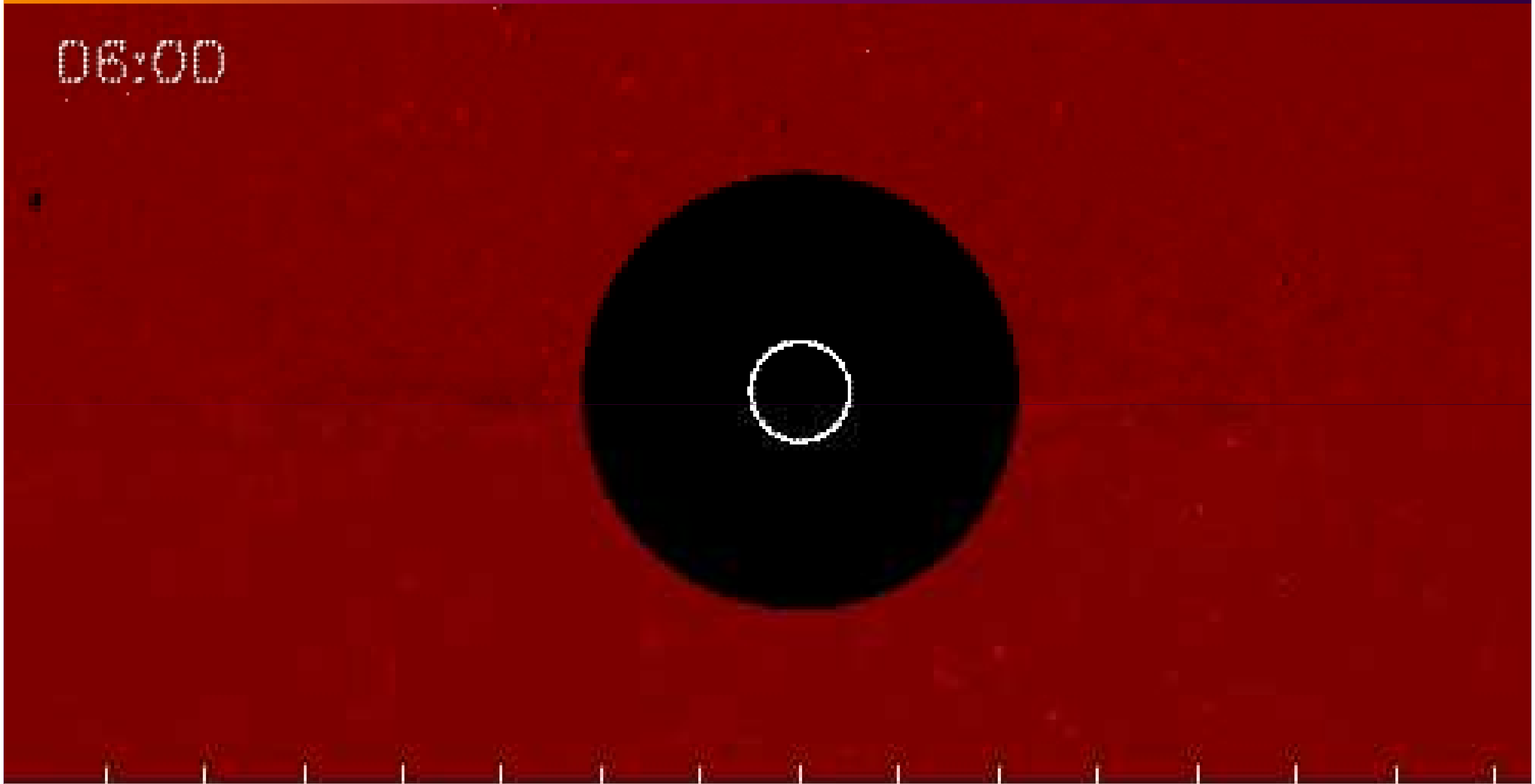


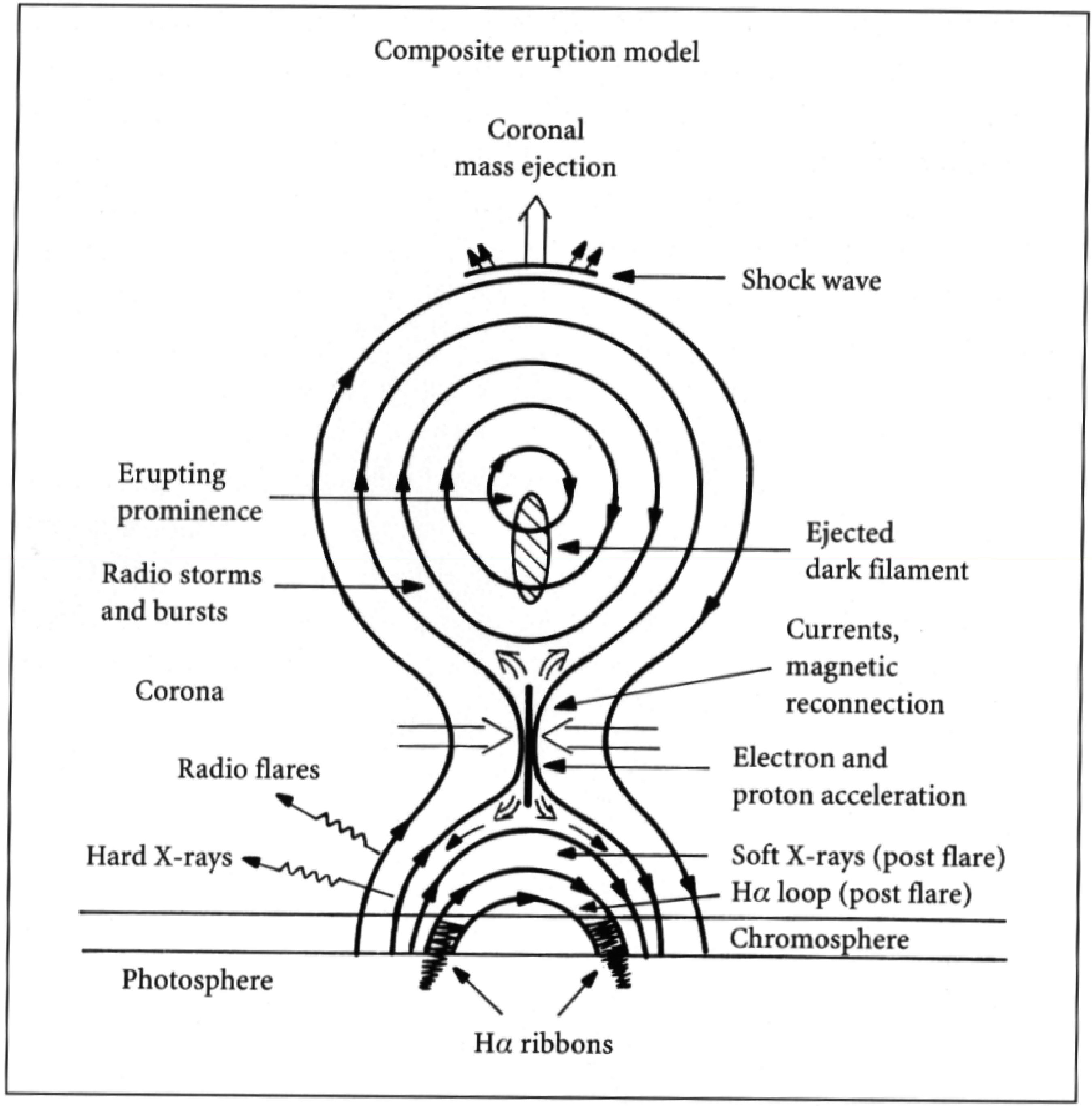

A canonical model of a solar flare
Electrons
Nonthermal
electrons
Radio radiation
Neutrons
Primary
energy
release
Accelerated particles
Evaporation
Magnetic loop
Footpoint
of loop
Hard X-rays
Nuclear gamma rays
Sun
Chromosphere

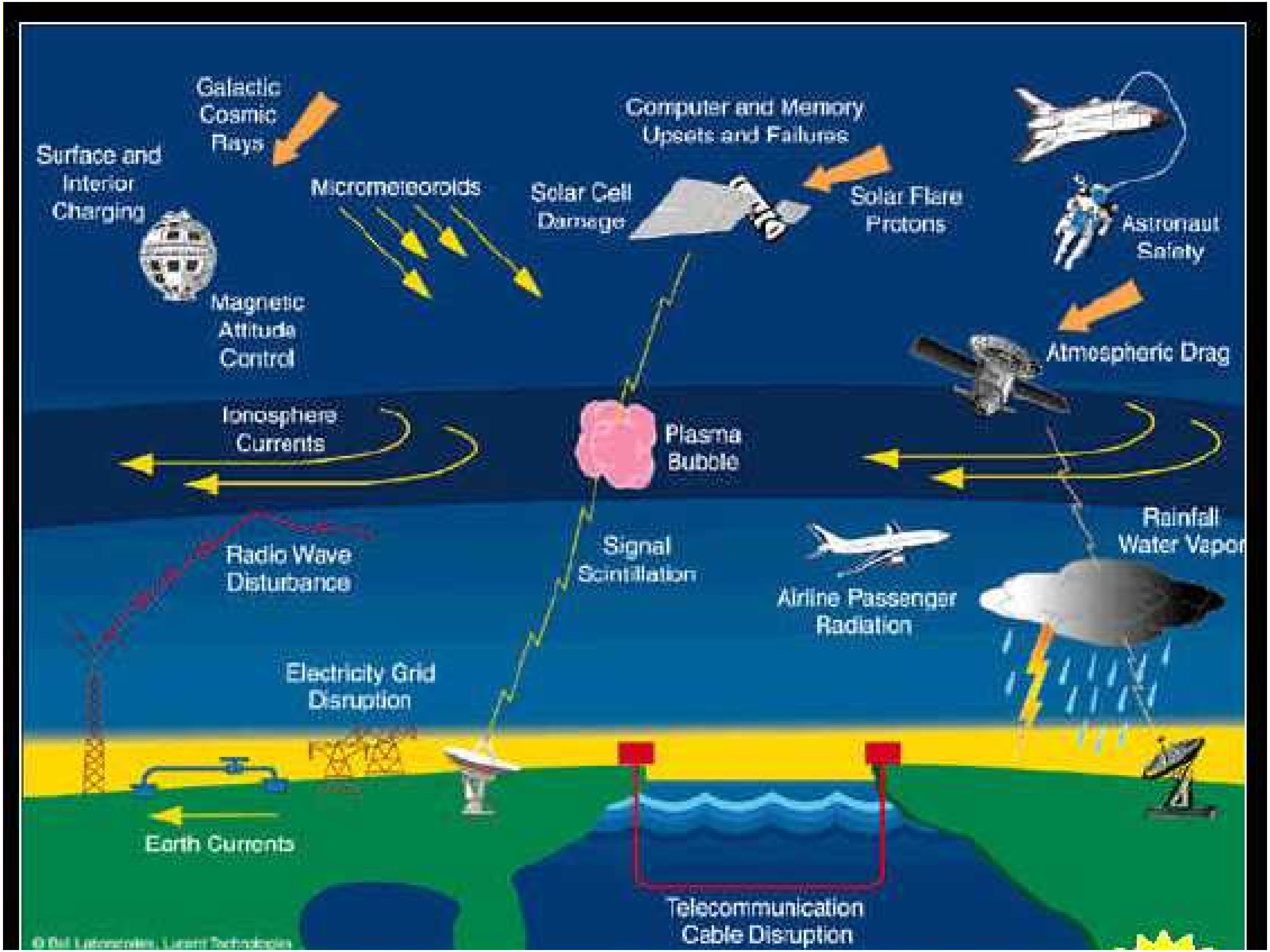


Impulsive phase
Decay phase
Precursor
Flux density (in solar flux units)
Time (in minutes)
20
10
0
0
10
20

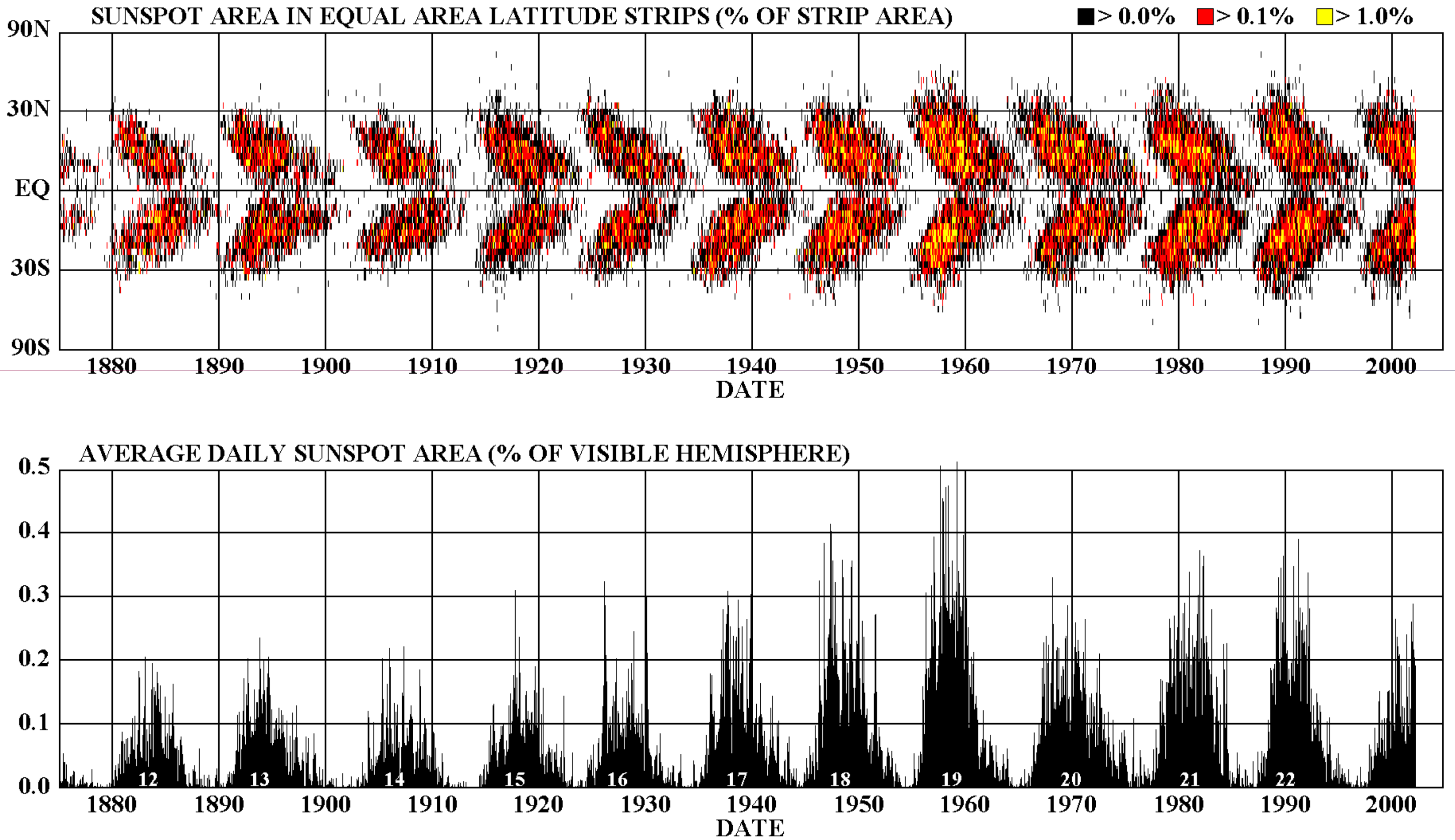

1997/11/05 00:18


06:00


Composite eruption model
Coronal
mass ejection
Shock wave
Erupting
prominence
Ejected
dark filament
Radio storms
and bursts
Currents,
magnetic
reconnection
Corona
Electron and
proton acceleration
Radio flares
Soft X-rays (post flare)
Hard X-rays
Hα loop (post flare)
Chromosphere
Photosphere
Hα ribbons


Galactic Cosmic Rays
Surface and Interior Charging
Micrometeoroids
Solar Cell Damage
Computer and Memory Upsets and Failures
Solar Flare Protons
Astronaut Safety
Magnetic Attitude Control
Atmospheric Drag
Ionosphere Currents
Plasma Bubble
Radio Wave Disturbance
Signal Scintillation
Airline Passenger Radiation
Rainfall Water Vapor
Electricity Grid Disruption
Earth Currents
Telecommunication Cable Disruption

DAILY SUNSPOT AREA AVERAGED OVER INDIVIDUAL SOLAR ROTATIONS

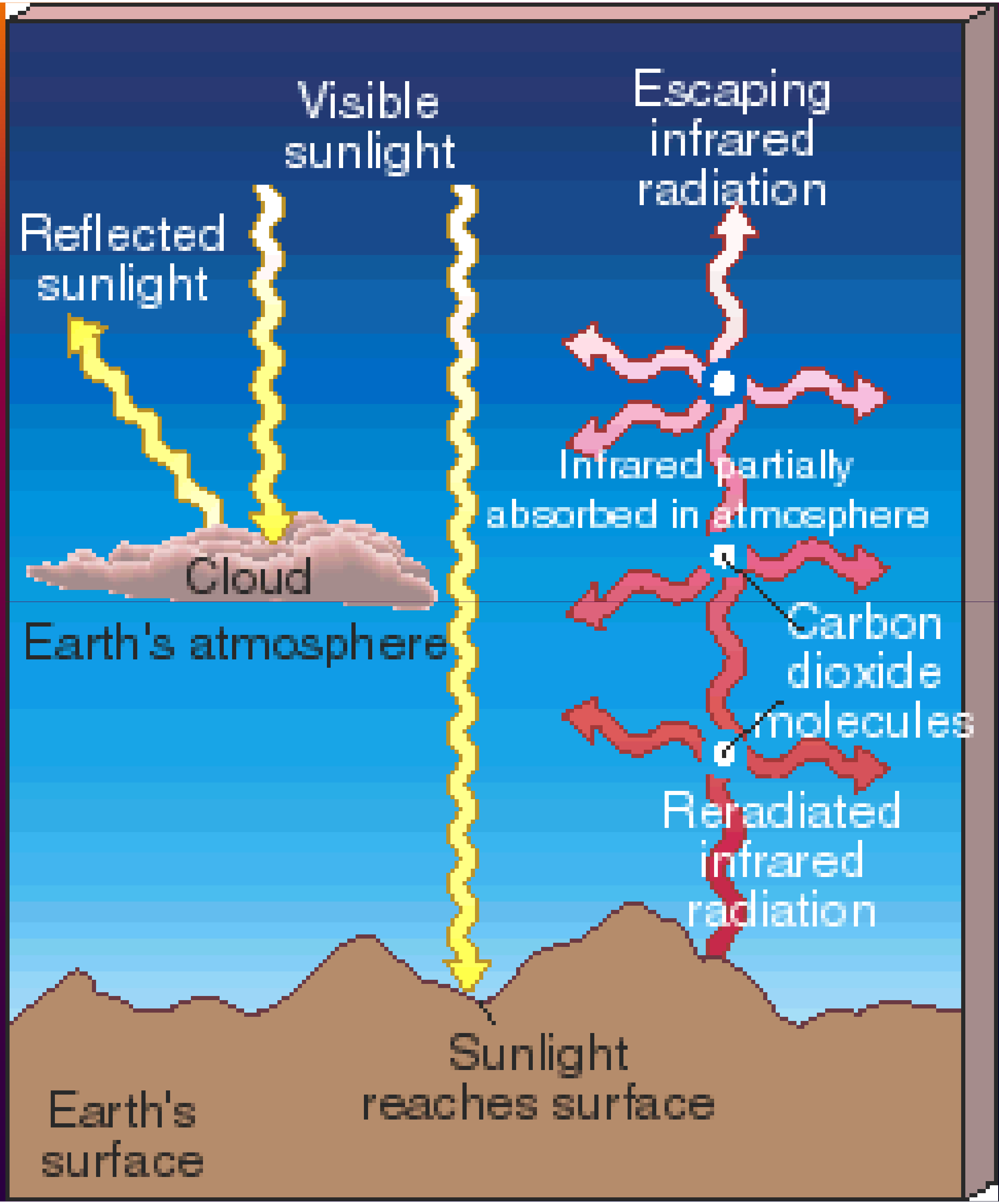


http://science.msfc.nasa.gov/ssl/pad/solar/images/bfly.gif

NASA/NSSTC/HATHAWAY 02/2002

PARTE III

VARIACIONES EN LA ACTIVIDAD SOLAR Y SUS EFECTOS


Visible sunlight
Escaping infrared radiation
Reflected sunlight
Infrared partially absorbed in atmosphere
Cloud
Earth's atmosphere
Carbon dioxide molecules
Reradiated infrared radiation
Sunlight reaches surface
Earth's surface

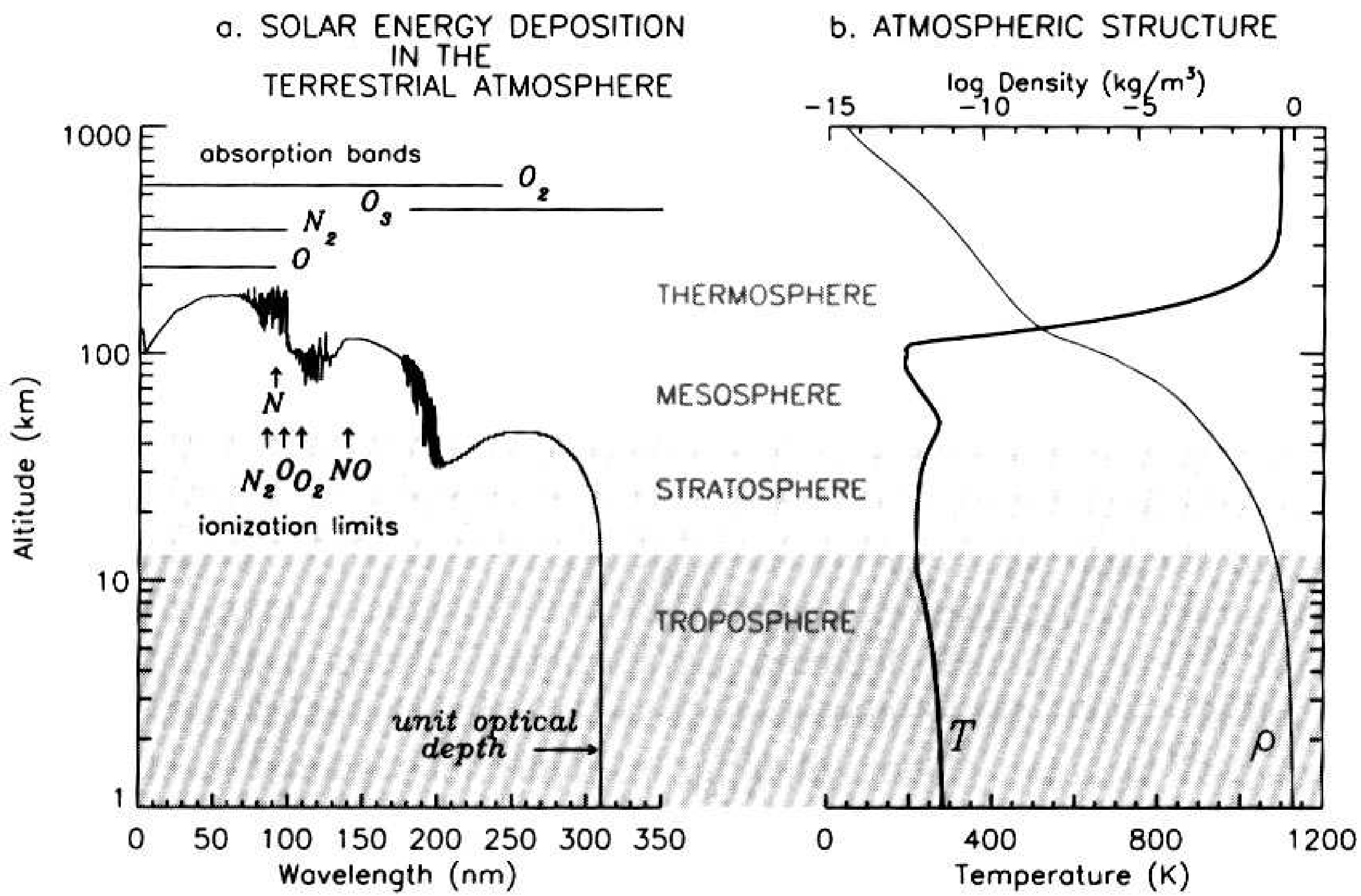
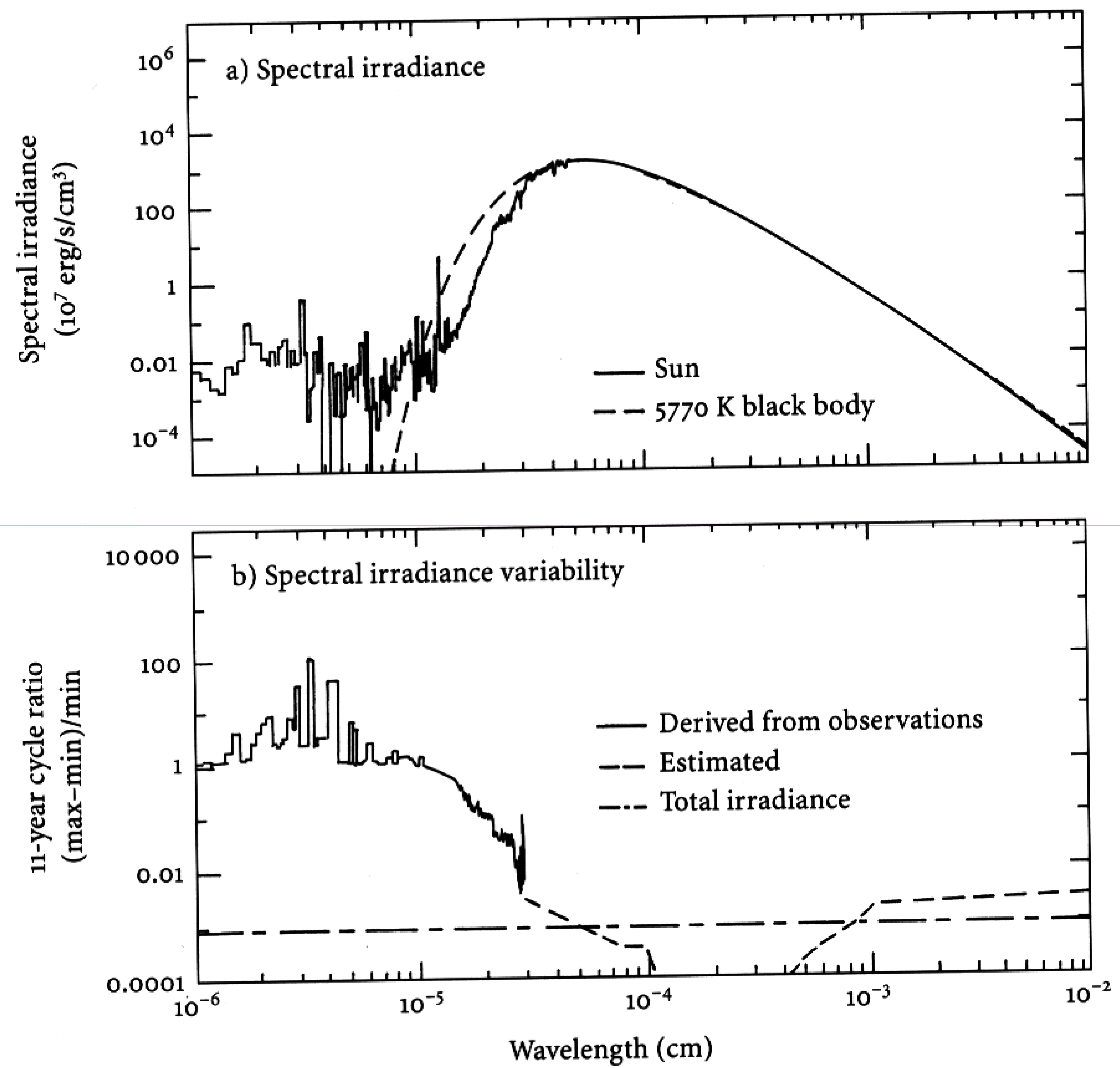


Figure 7 Different regions of the solar spectrum penetrate to different altitudes in the Earth's atmosphere because atmospheric species absorb radiation at different wavelengths. Shown in (*a*) is the altitude at which the Earth's atmosphere attenuates incident radiation from an overhead Sun by a factor of $1/e$ (Meier 1991). Deposited solar energy determines the atmosphere's temperature profile (T) in (*b*), on which atmospheric regions are based.



a) Spectral irradiance
Spectral irradiance
(10^7 erg/s/cm^3)
10^6
10^4
100
1
0.01
10^-4
Sun
5770 K black body
b) Spectral irradiance variability
11-year cycle ratio
(max–min)/min
10 000
100
1
0.01
0.0001
Derived from observations
Estimated
Total irradiance
10^-6
10^-5
10^-4
10^-3
10^-2
Wavelength (cm)

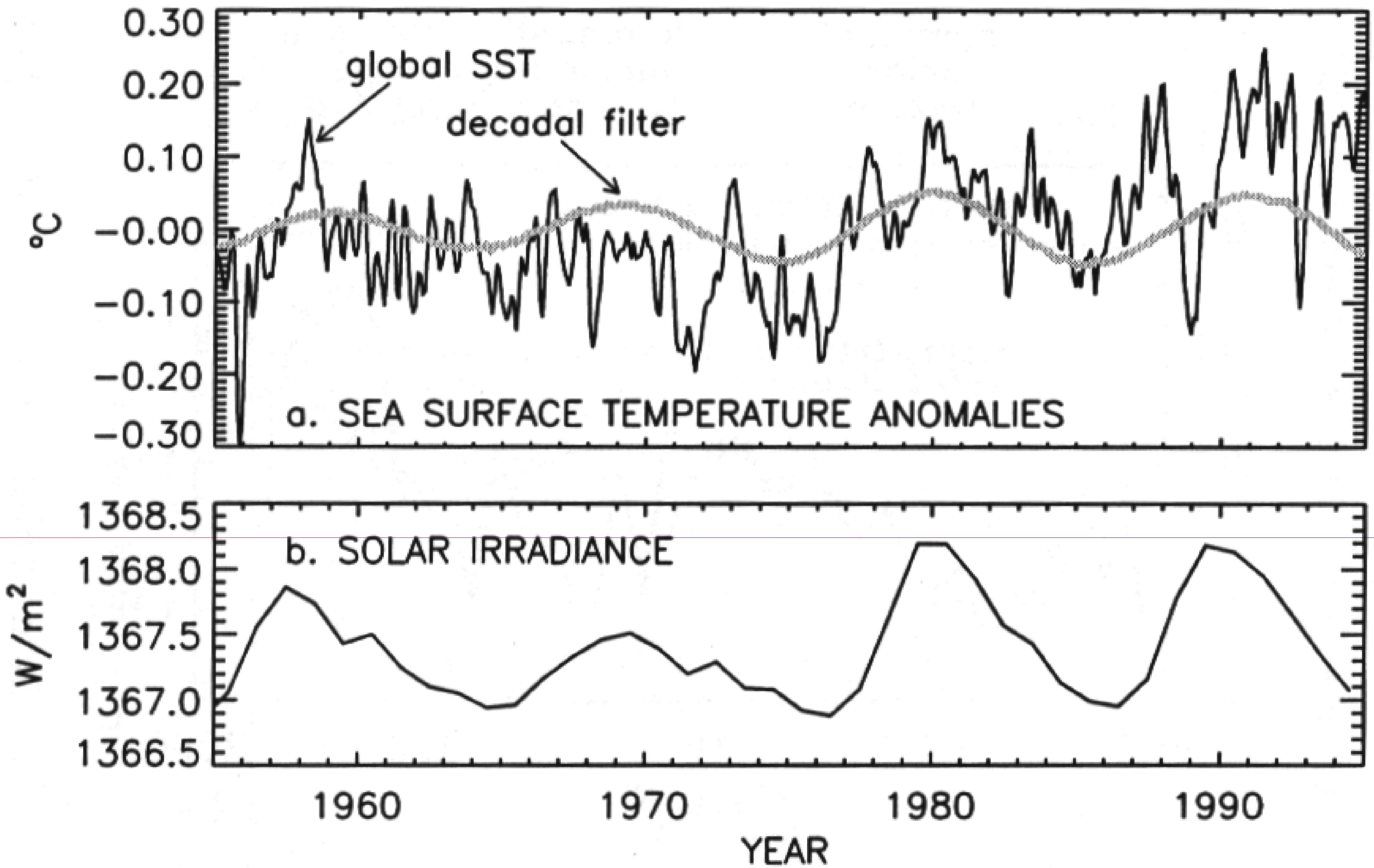


Figure 11 White et al (1997) identified in globally averaged sea surface temperature anomalies compiled from bathythermographs (BT), significant annual and interannual variability including a decadal component shown in (*a*) that tracks solar irradiance reconstructed by Lean et al (1995), shown in (*b*).

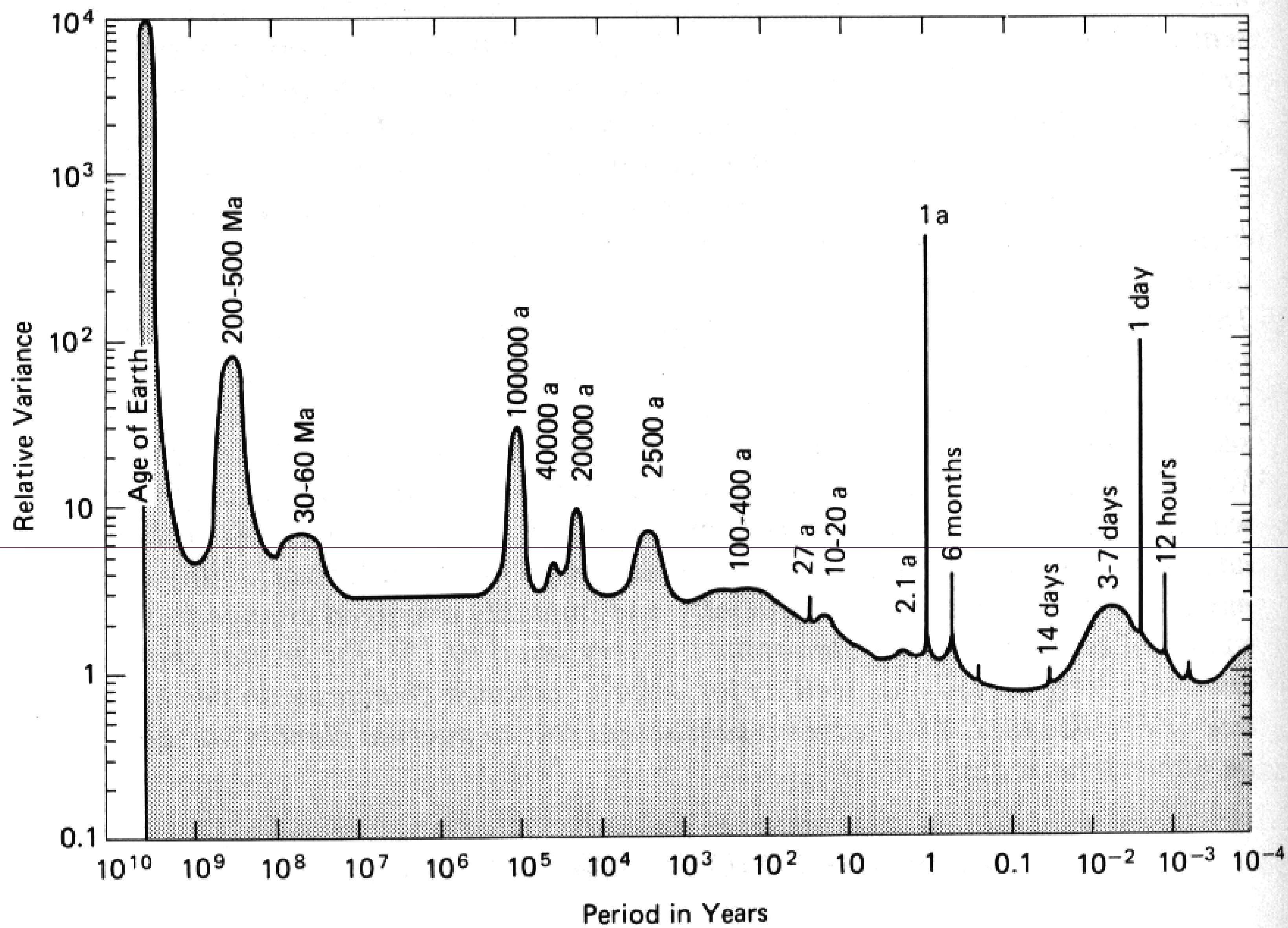
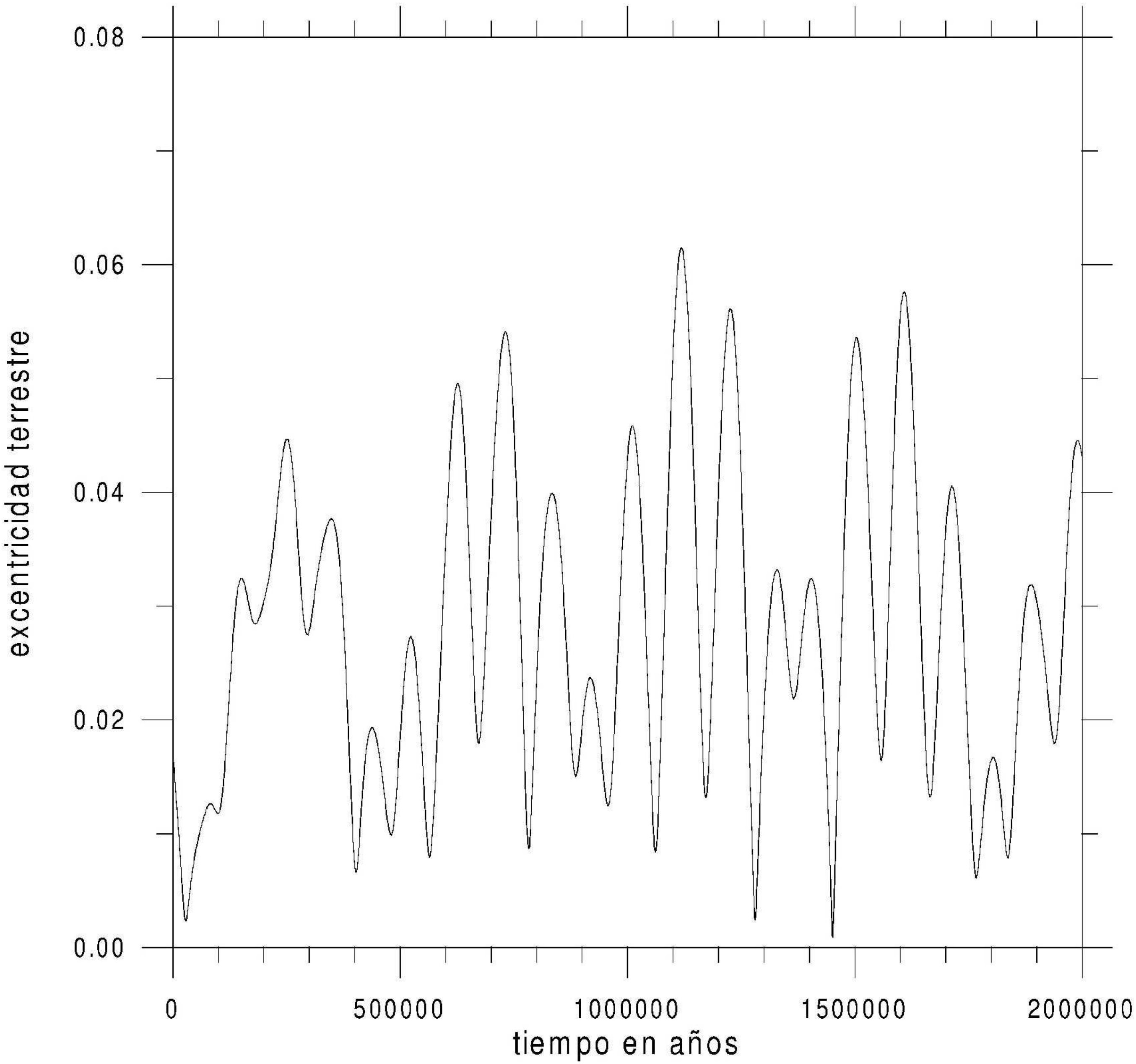
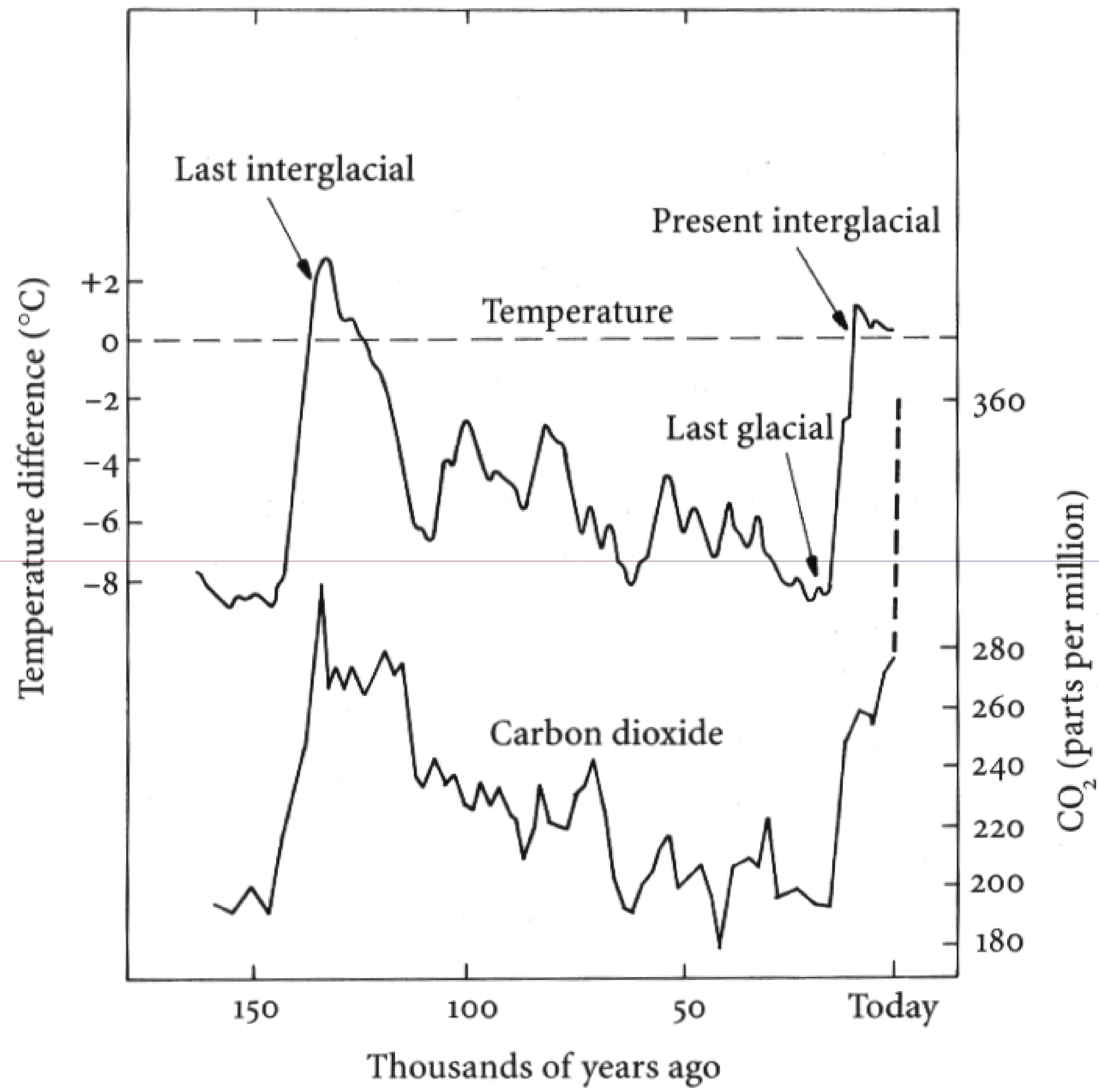
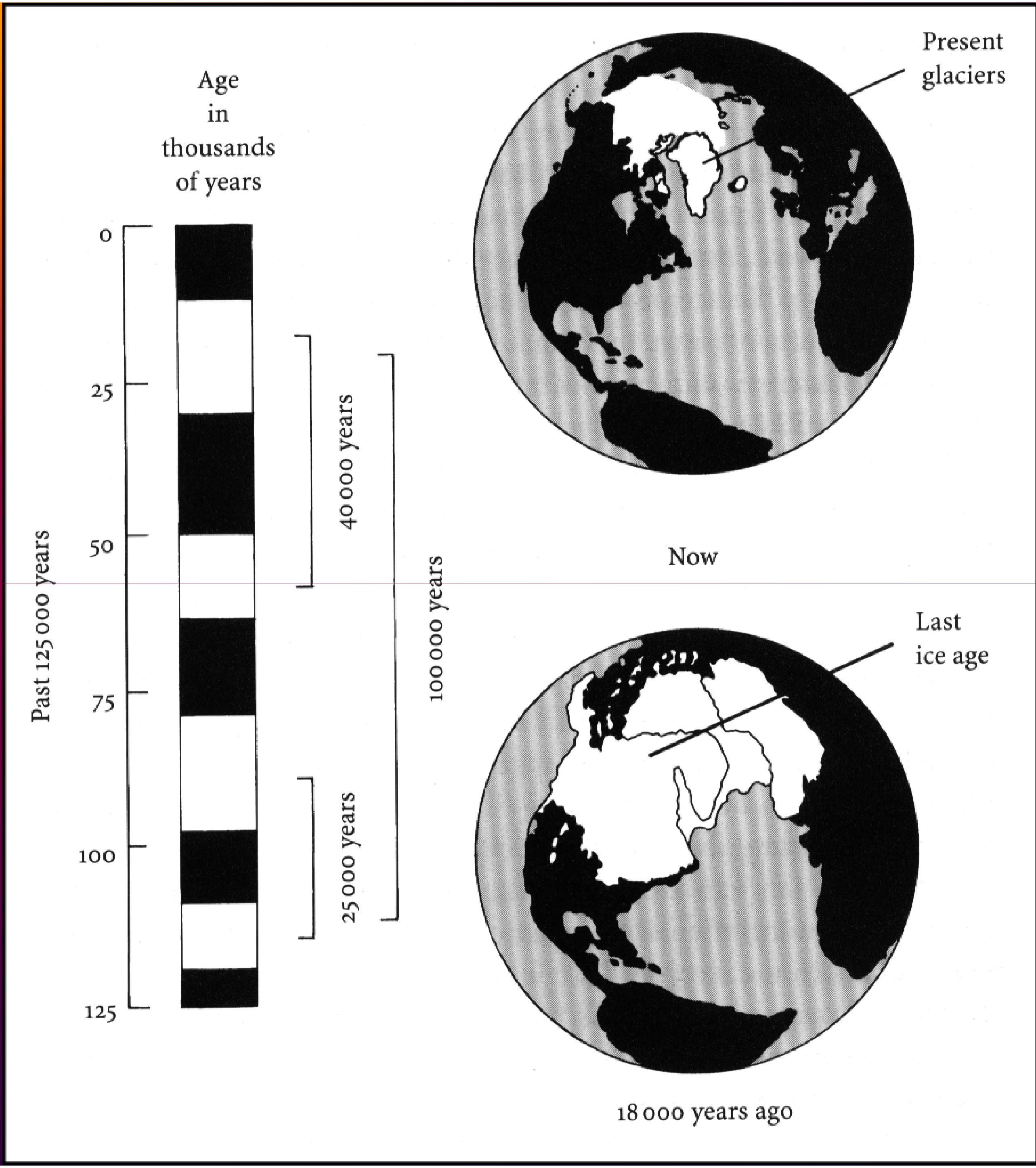


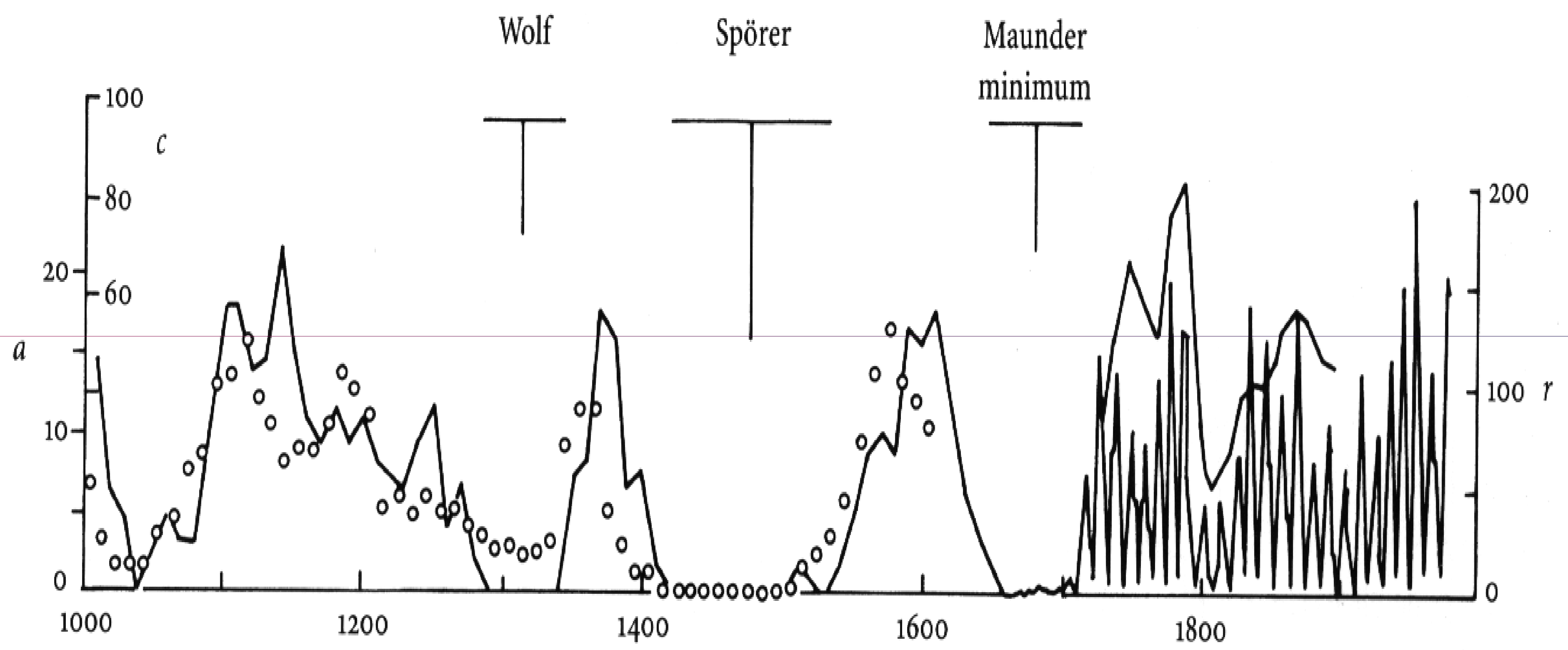
Fig. 1. Estimate of global climatic variability on all time scales (figure after Mitchell 1976). The position of the peaks indicated is relatively well known, but not their relative height and width. Units of time are abbreviated as 1 year = 1a and 10^6 years = 1Ma.


0.08
0.06
0.04
0.02
0.00
excentricidad terrestre
0
500000
1000000
1500000
2000000
tiempo en años


Last interglacial
Present interglacial
Temperature
Last glacial
Carbon dioxide
Temperature difference (°C)
+2
0
−2
−4
−6
−8
CO_2 (parts per million)
360
280
260
240
220
200
180
150
100
50
Today
Thousands of years ago



Age
in
thousands
of years
0
25
50
75
100
125
Past 125 000 years
40 000 years
25 000 years
100 000 years
Present
glaciers
Now
Last
ice age
18 000 years ago


Wolf
Spörer
Maunder
minimum
100
c
80
60
20
a
10
0
200
100 r
0
1000
1200
1400
1600
1800

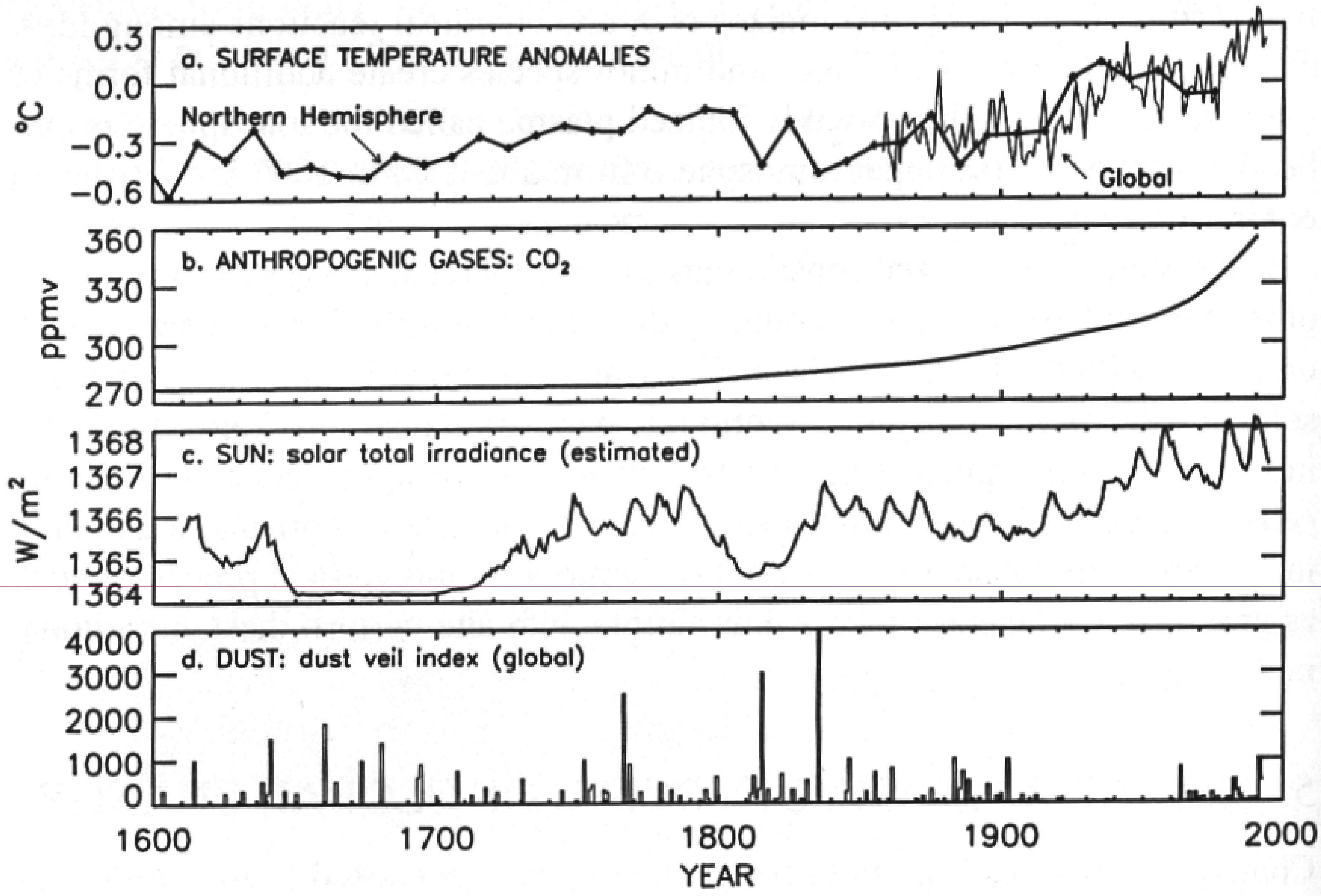


Figure 8 Compared in (*a*) are the Bradley & Jones (1993) reconstructed record of decadal NH surface temperature since 1600 (*solid line with plus signs*) and the IPCC (1992) global instrumental record since 1850 (*thin line*). Both natural and anthropogenic influences may have contributed to the observed surface warming since 1850. Shown are (*b*) annual averages of the concentration of CO_2 (Boden et al 1994), (*c*) estimated solar total irradiance (Lean et al 1995), and (*d*) volcanic aerosol loading according to the global dust veil index (Lamb 1977, Robuck & Free 1995).

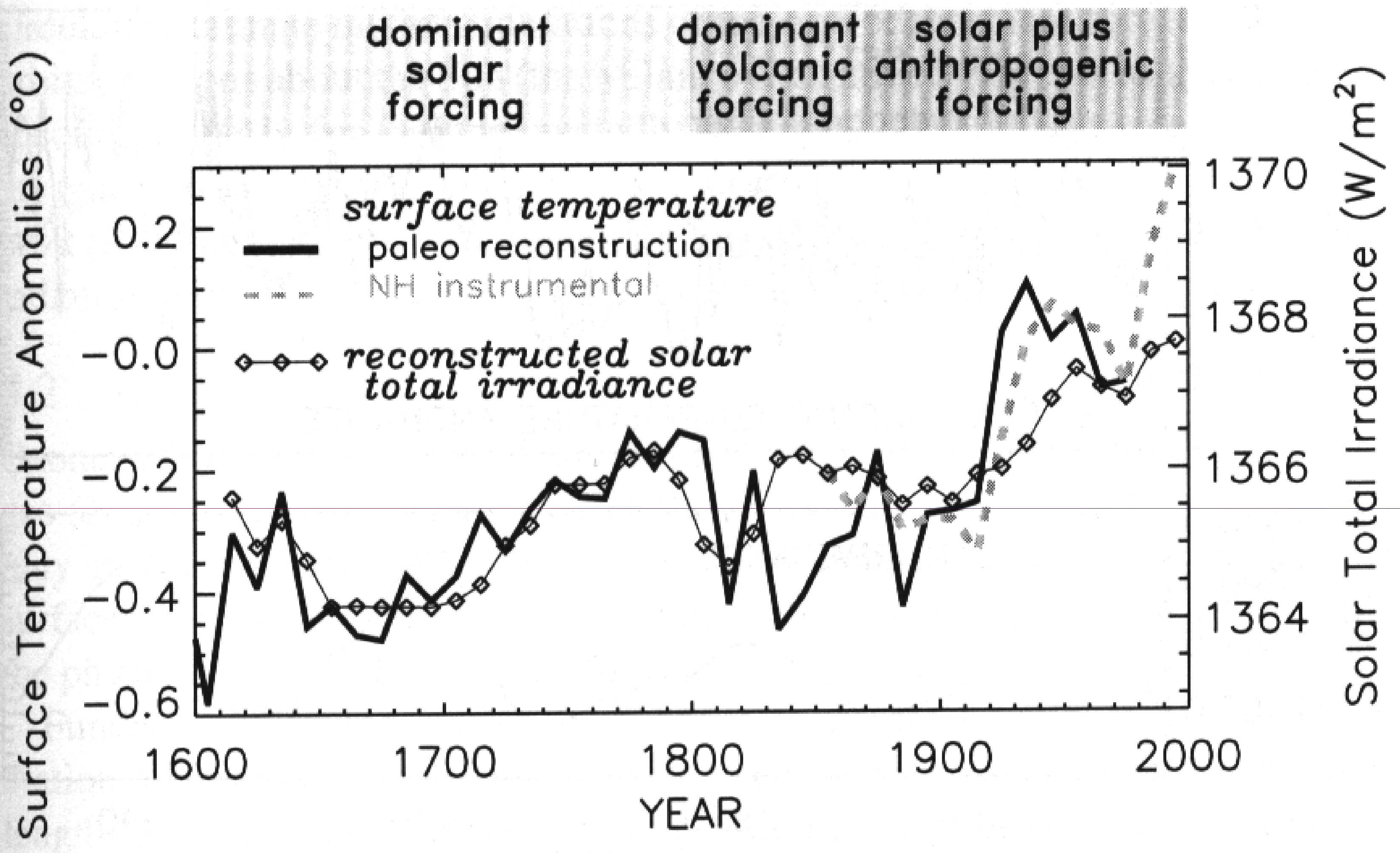


Figure 10 Compared are decadally averaged values of solar total irradiance reconstructed by Lean et al (1995) and NH summer temperature anomalies from 1610 to the present. The dark solid line is the Bradley & Jones (1993) NH summer surface temperature reconstruction from paleoclimate data (primarily tree rings), scaled to match the NH instrumental data (IPCC 1992) (*gray dashed line*) during the overlap period. (Updated from Lean et al 1995.)

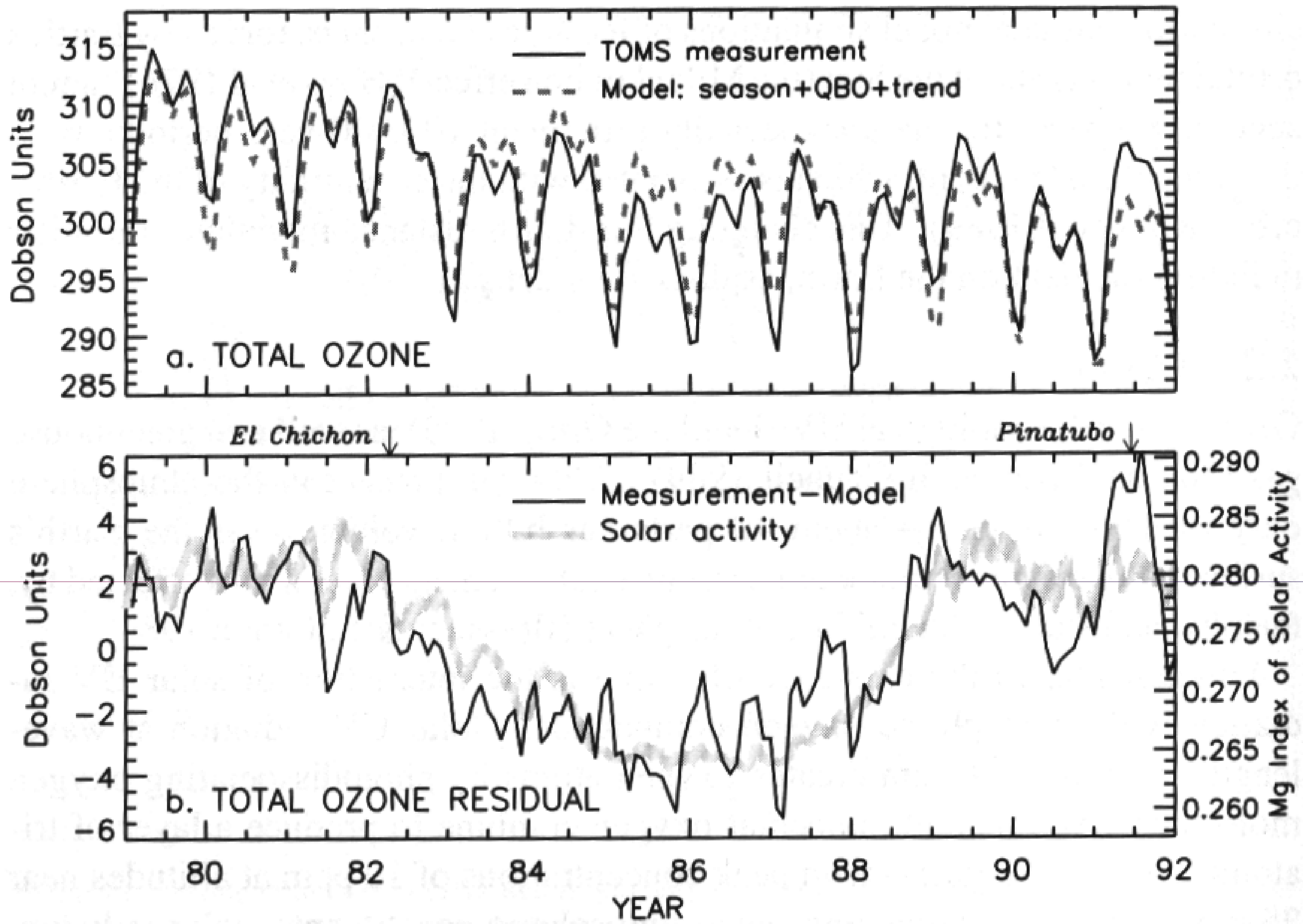
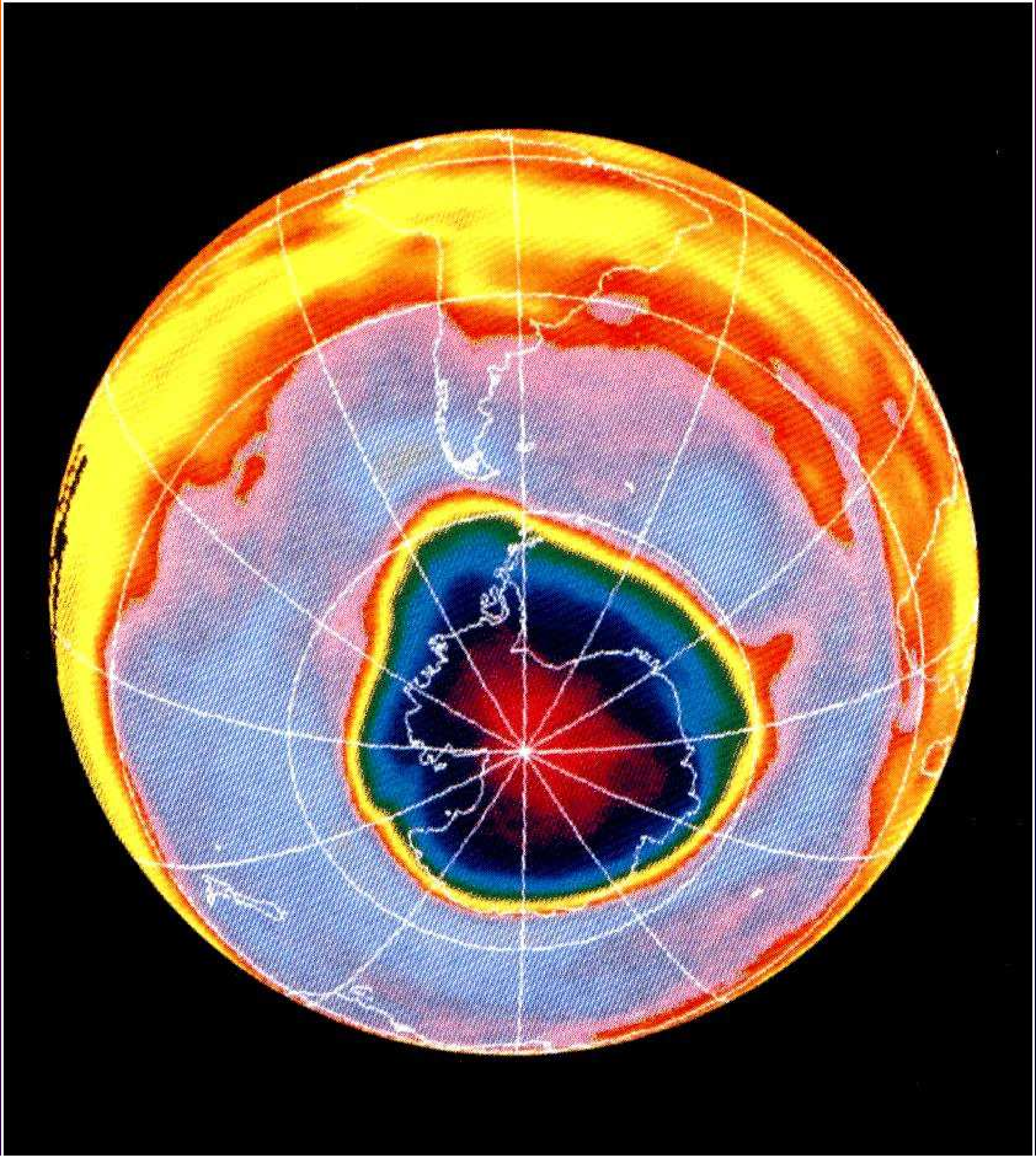
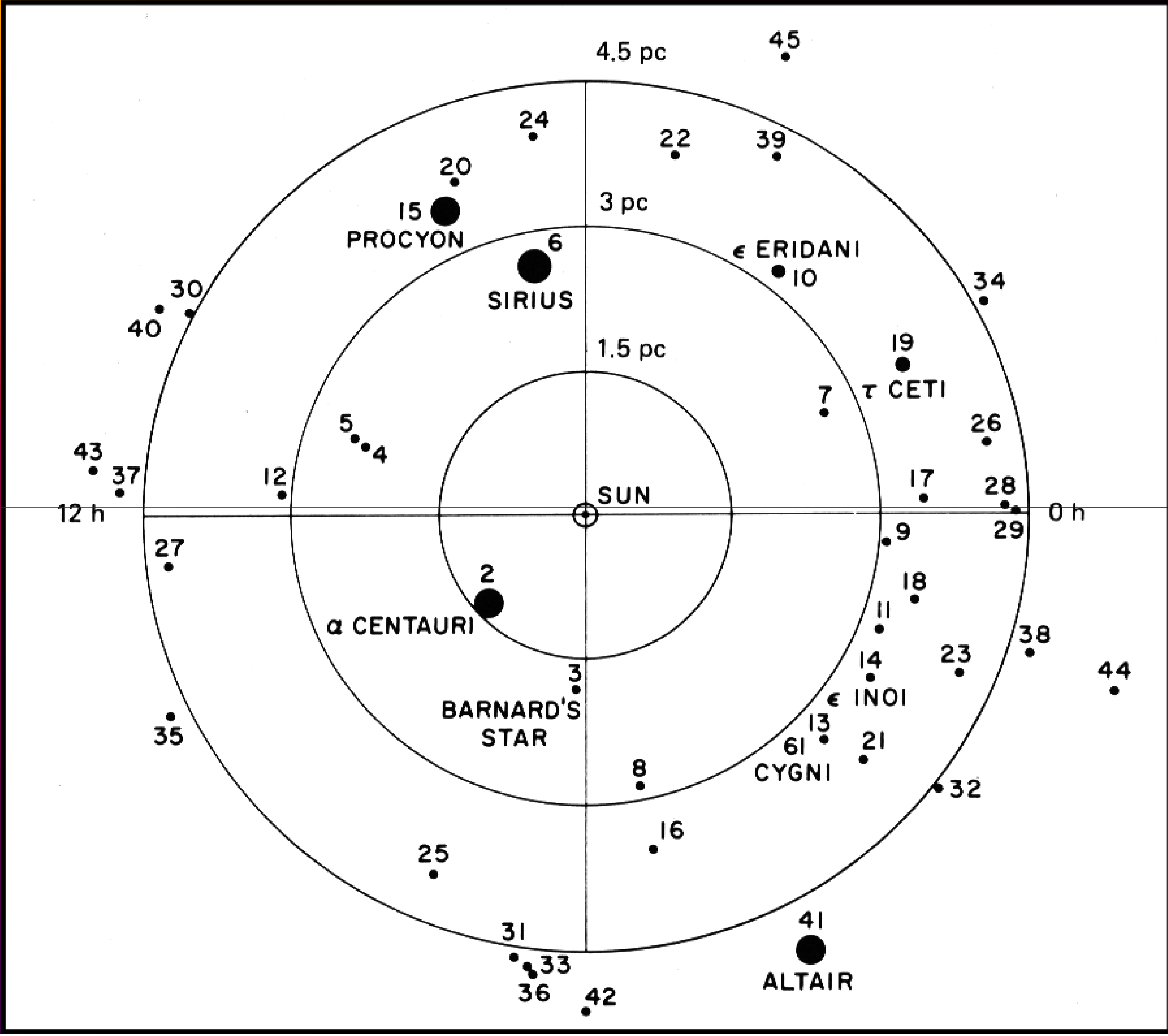


Figure 12 Shown are the results of an analysis of the variability modes evident in global column ozone since 1978, by Hood & McCormack (1992). The Total Ozone Mapping Spectrometer ozone measurements in (*a*) (*solid line*) are compared with a fitted statistical model of seasonal, linear trend, and quasibiennial oscillation terms (*gray dashed line*). The residual of the measured minus model ozone is shown in (*b*) to track the Mg index of solar activity (provided by L Puga, NOAA).



PARTE IV

EL ENTORNO GALACTICO


4.5 pc
3 pc
1.5 pc
SUN
12 h
0 h
PROCYON
SIRIUS
ε ERIDANI
τ CETI
α CENTAURI
BARNARD'S STAR
ε INDI
61 CYGNI
ALTAIR
45
24
22
39
20
15
6
10
34
30
40
19
7
26
5
4
43
37
12
17
28
29
9
27
2
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44
14
3
13
21
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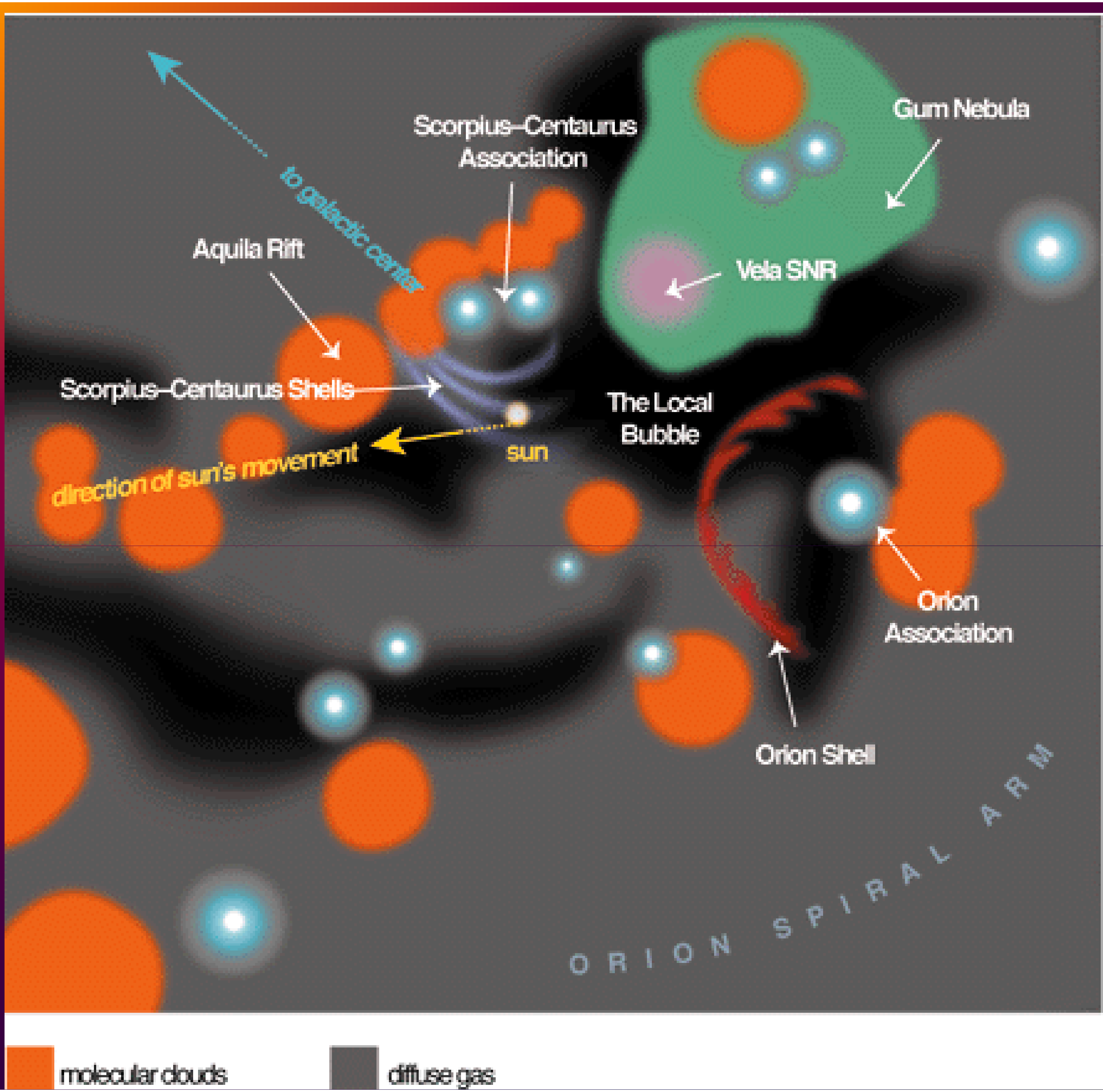
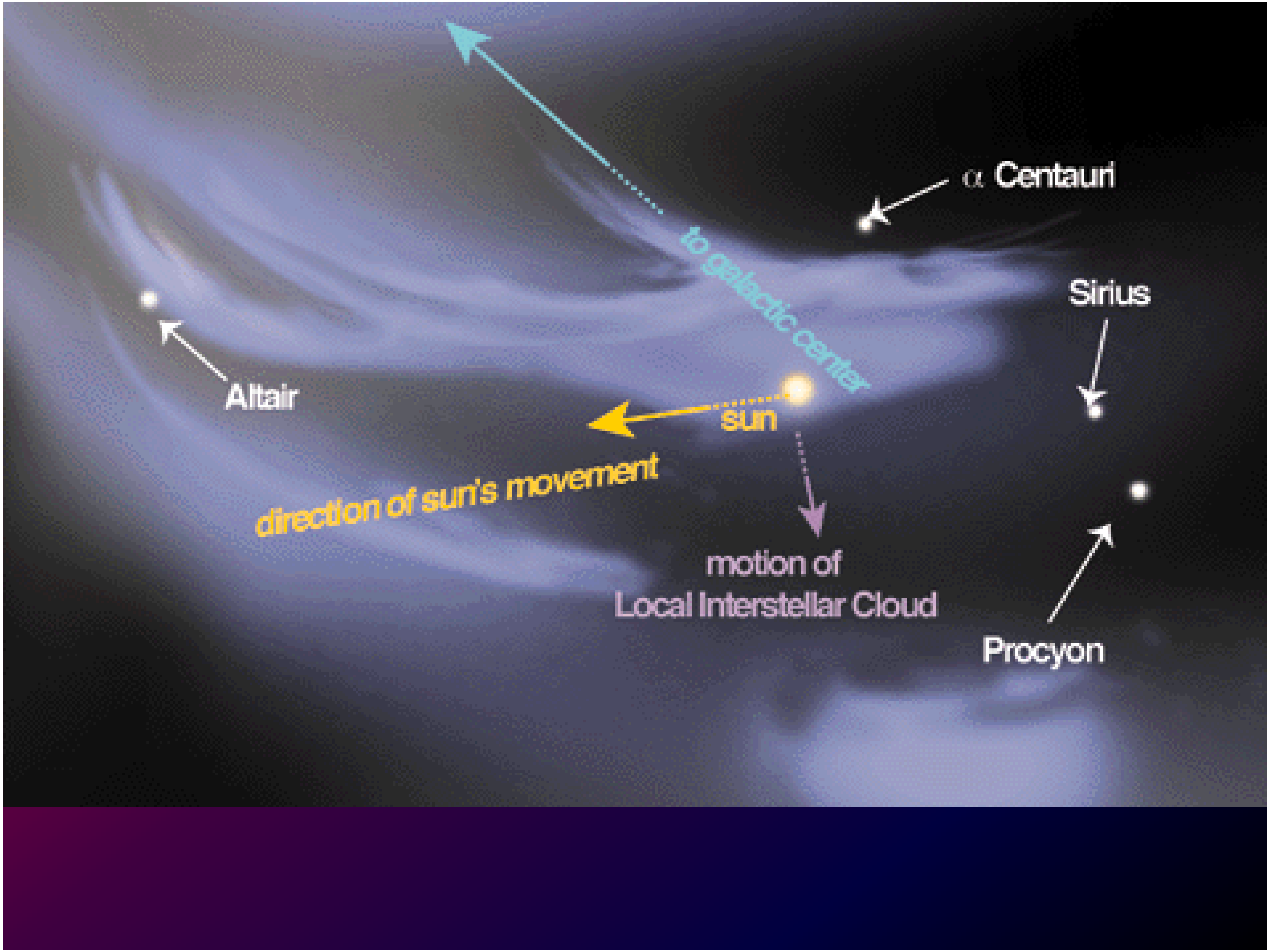
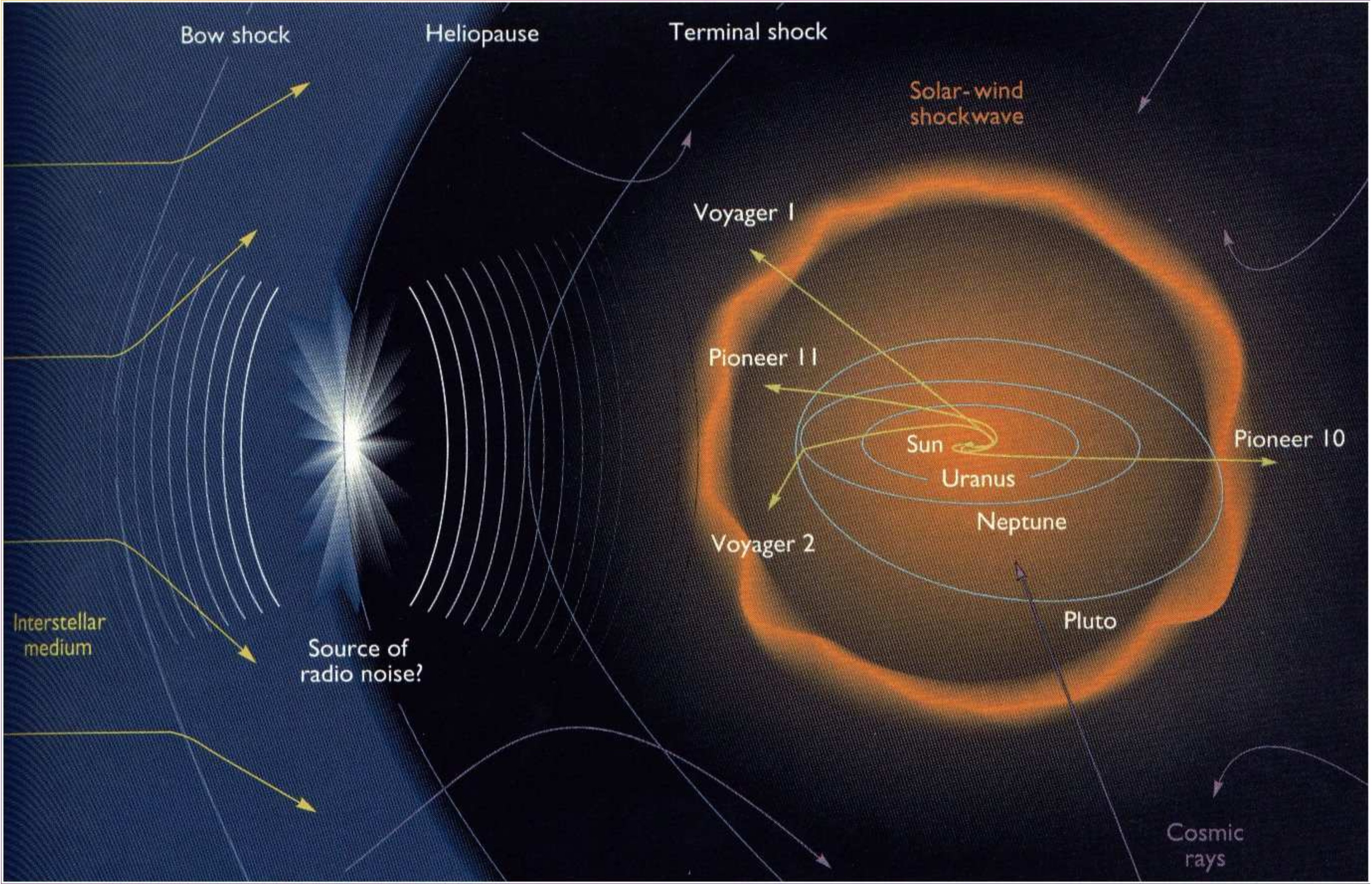
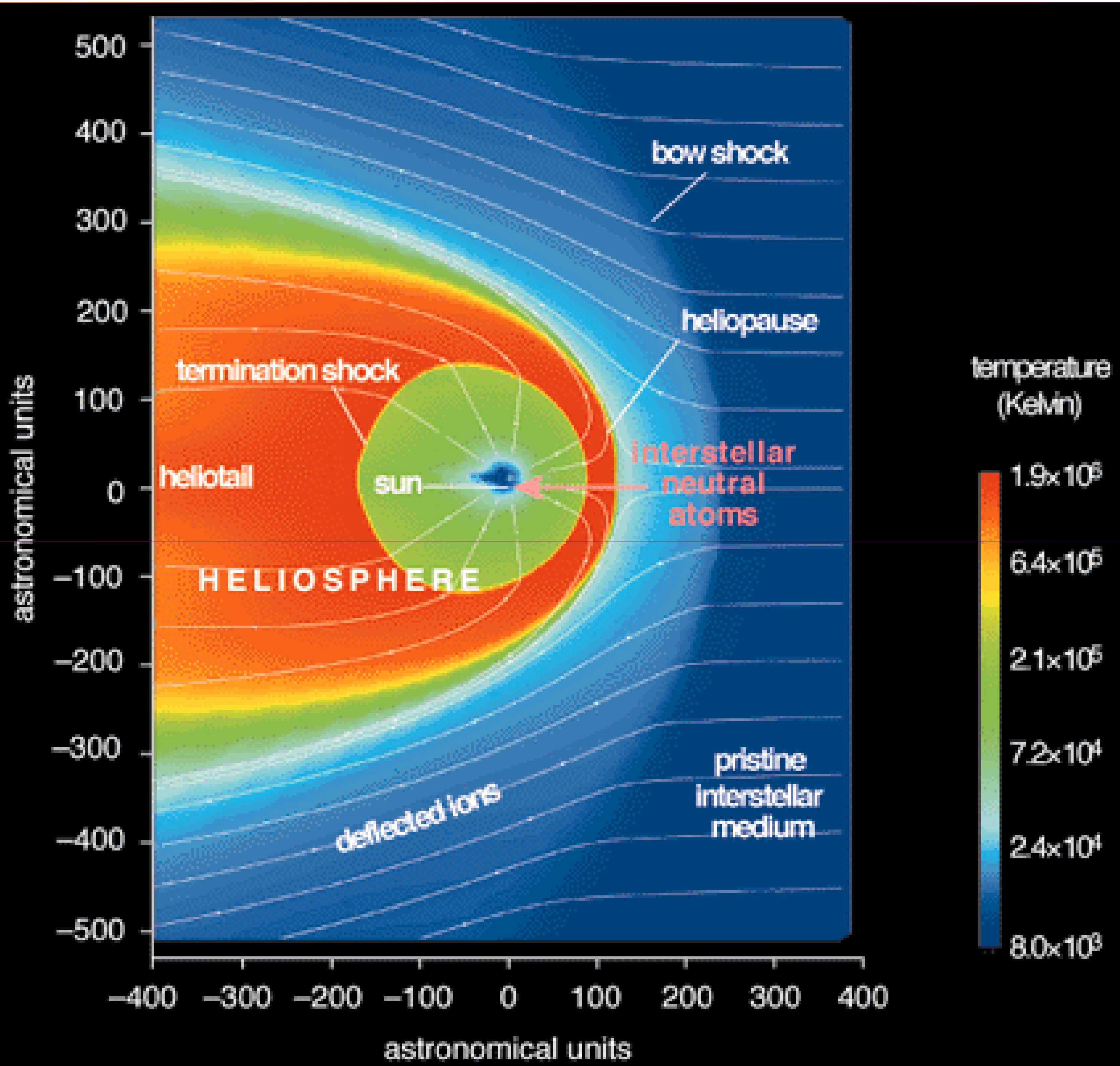
8
32
16
25
41
31
33
36
42



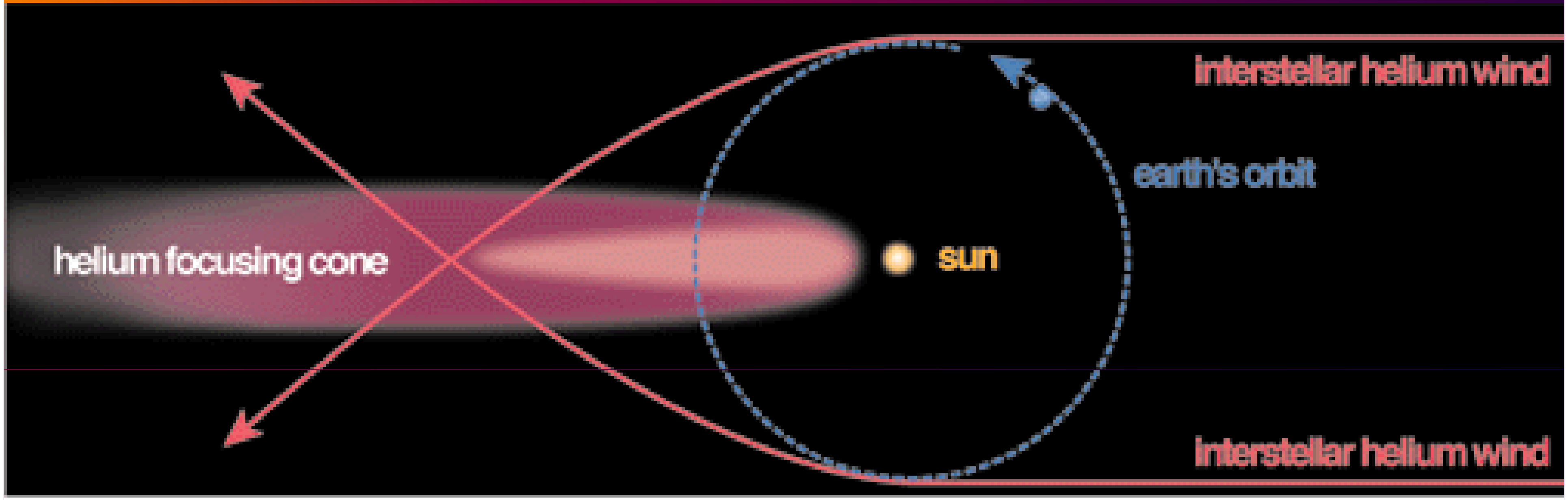
to galactic center
Scorpius–Centaurus Association
Gum Nebula
Aquila Rift
Vela SNR
Scorpius–Centaurus Shells
The Local Bubble
sun
direction of sun's movement
Orion Association
Orion Shell
ORION SPIRAL ARM
molecular clouds
diffuse gas

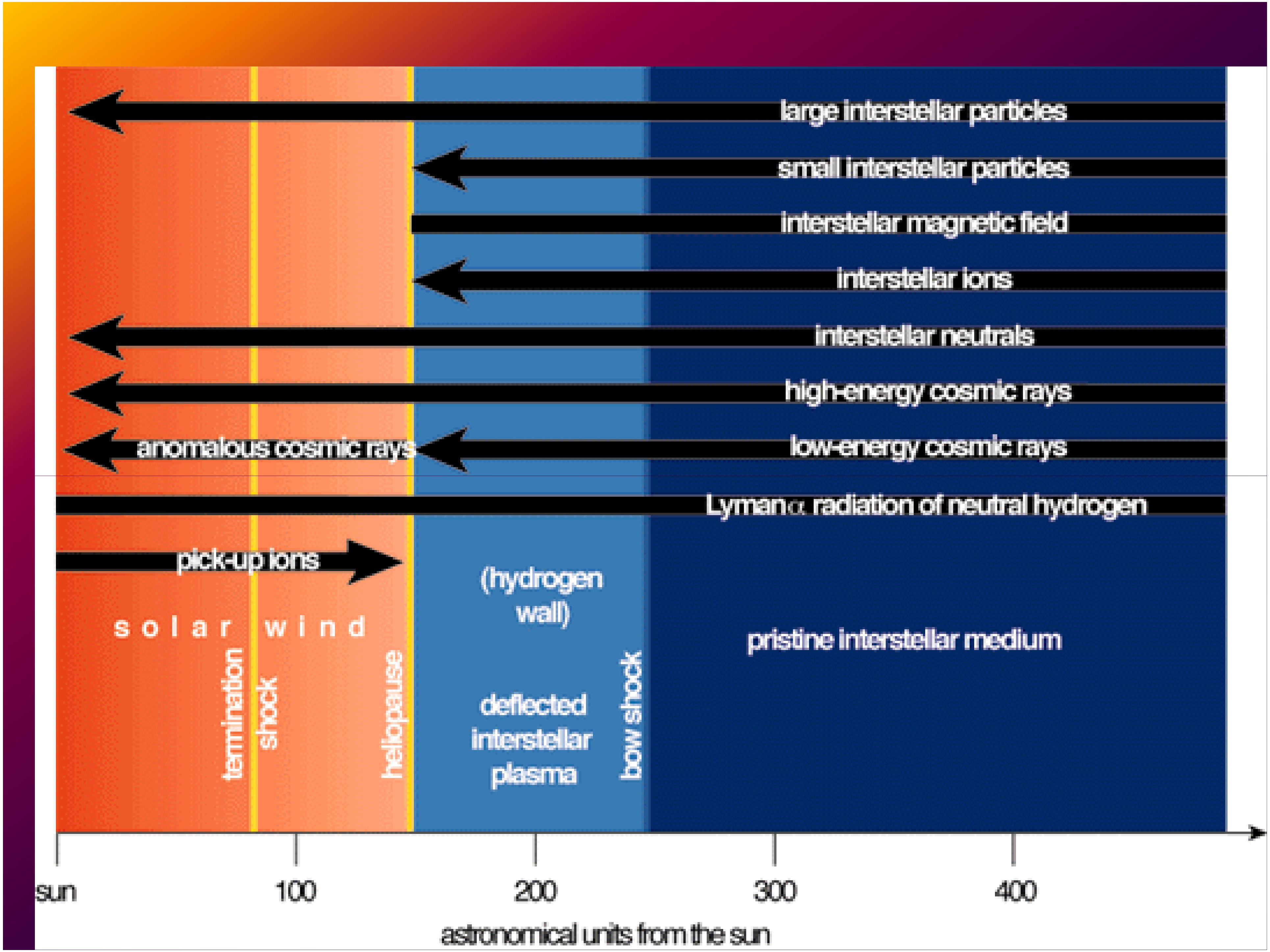

to galactic center
α Centauri
Sirius
Altair
sun
direction of sun's movement
motion of
Local Interstellar Cloud
Procyon


Bow shock
Heliopause
Terminal shock
Solar-wind shockwave
Voyager 1
Pioneer 11
Sun
Uranus
Neptune
Pioneer 10
Voyager 2
Pluto
Interstellar medium
Source of radio noise?
Cosmic rays



bow shock
heliopause
termination shock
heliotail
sun
interstellar neutral atoms
HELIOSPHERE
deflected ions
pristine interstellar medium
temperature (Kelvin)
1.9×10^6
6.4×10^5
2.1×10^5
7.2×10^4
2.4×10^4
8.0×10^3
astronomical units
astronomical units
500
400
300
200
100
0
−100
−200
−300
−400
−500
−400
−300
−200
−100
0
100
200
300
400

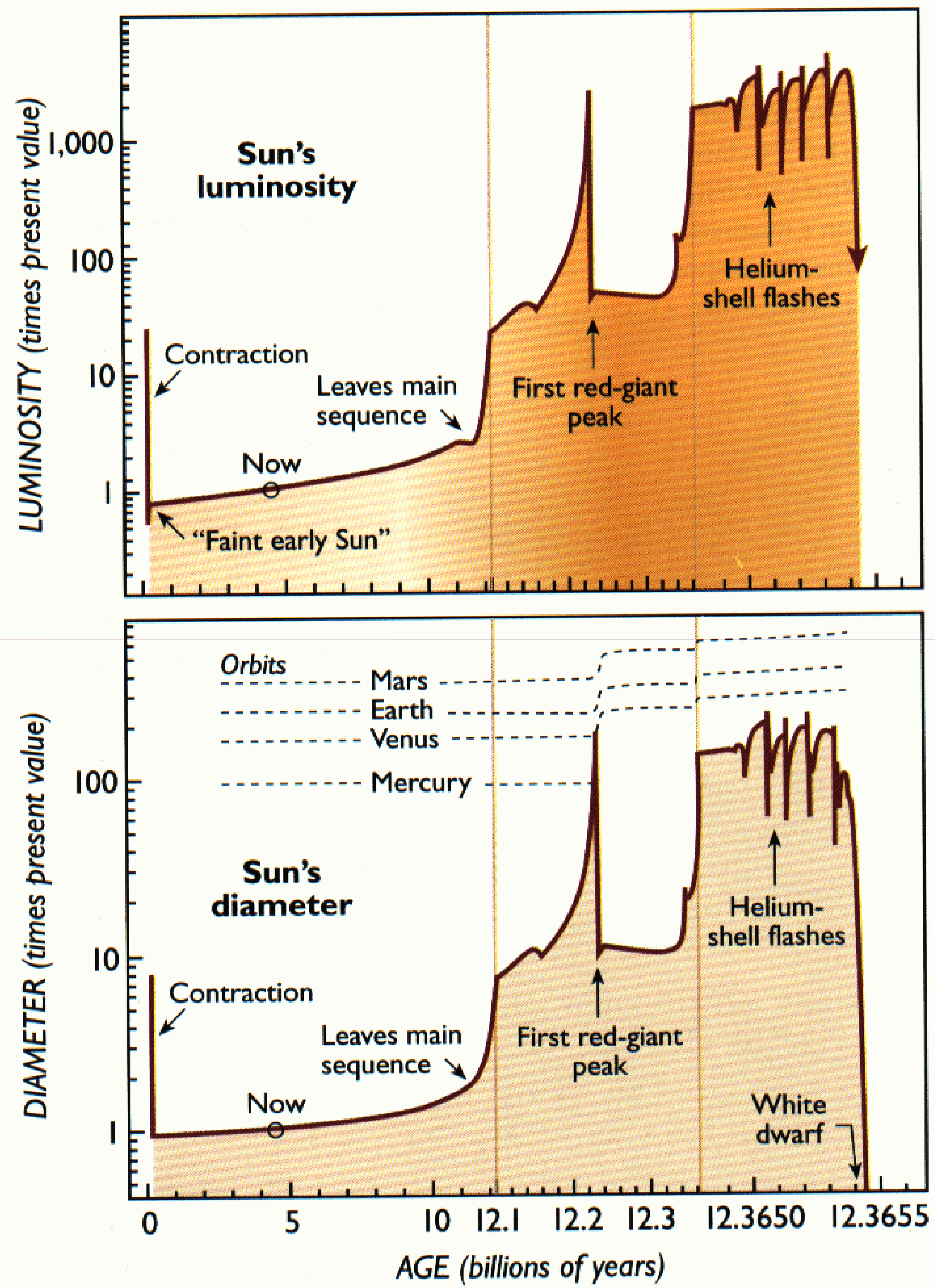

interstellar helium wind
earth's orbit
helium focusing cone
sun
interstellar helium wind



large interstellar particles
small interstellar particles
interstellar magnetic field
interstellar ions
interstellar neutrals
high-energy cosmic rays
anomalous cosmic rays
low-energy cosmic rays
Lyman α radiation of neutral hydrogen
pick-up ions
(hydrogen wall)
solar wind
termination shock
heliopause
deflected interstellar plasma
bow shock
pristine interstellar medium
sun
100
200
300
400
astronomical units from the sun

PARTE V

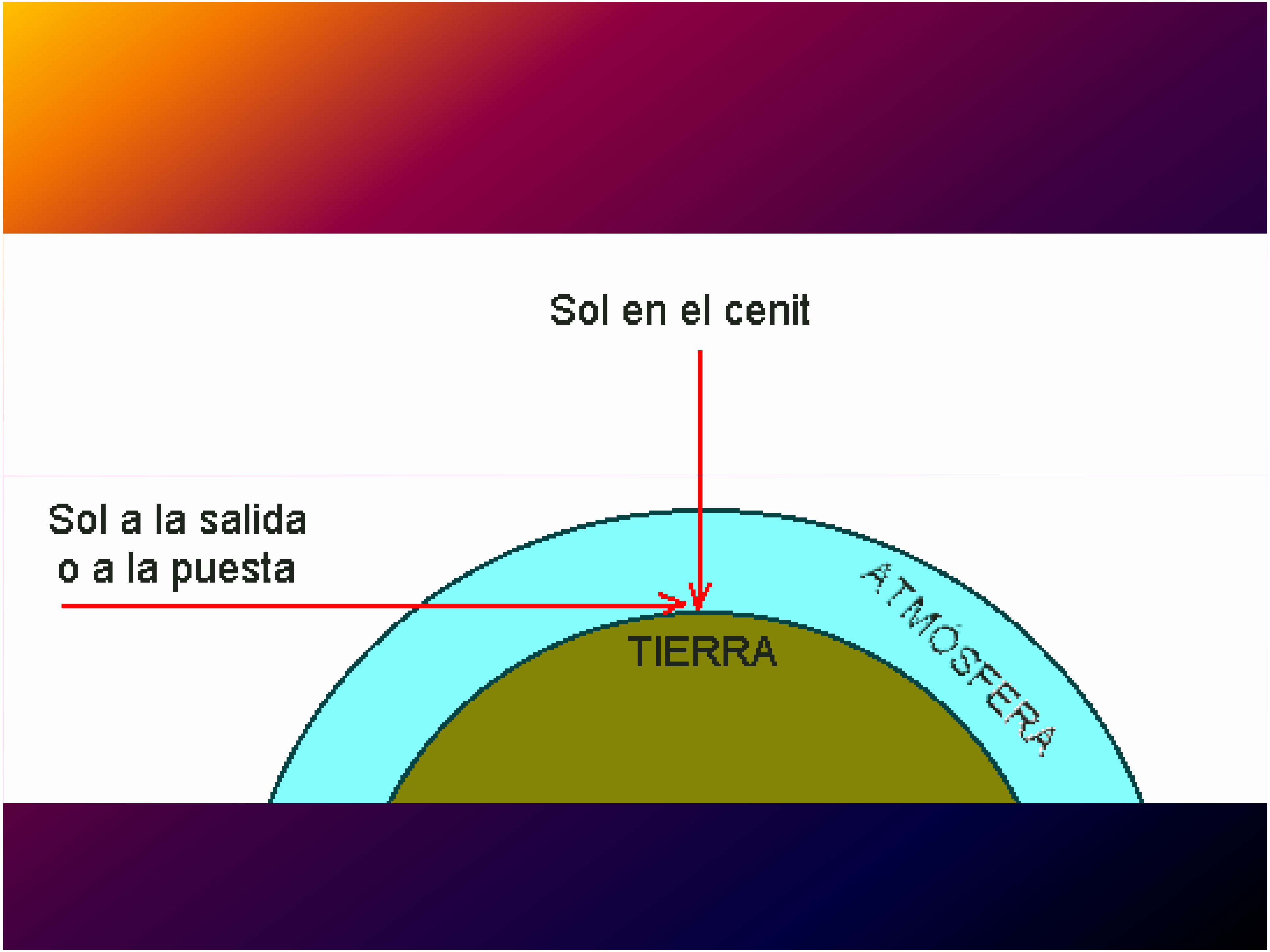
EL FINAL DEL SOL Y LA TIERRA

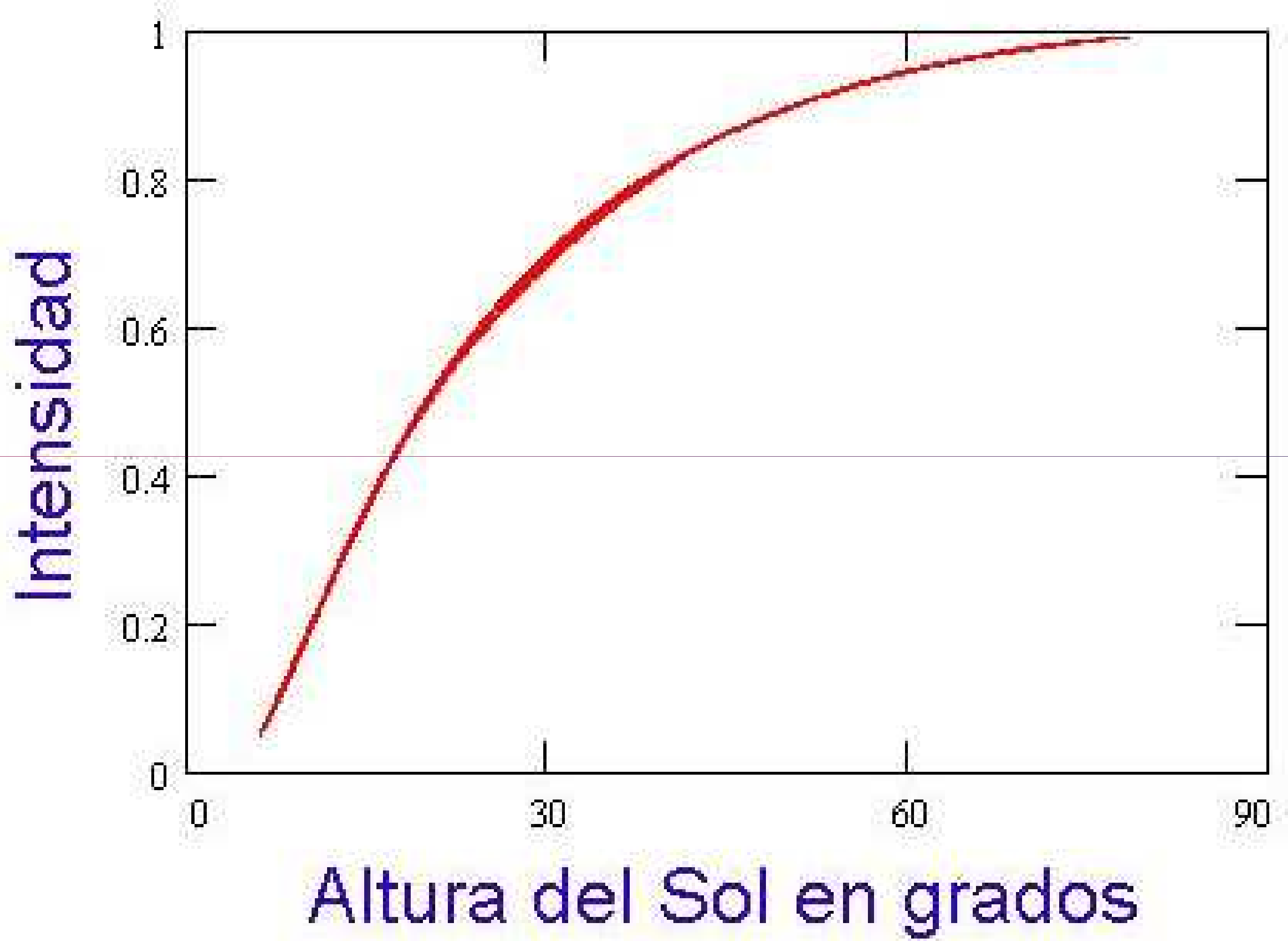


Sun's luminosity
LUMINOSITY (times present value)
1,000
100
10
1
Contraction
Leaves main sequence
Now
"Faint early Sun"
First red-giant peak
Helium-shell flashes
Orbits
Mars
Earth
Venus
Mercury
Sun's diameter
DIAMETER (times present value)
100
10
1
Contraction
Leaves main sequence
Now
First red-giant peak
Helium-shell flashes
White dwarf
0
5
10
12.1
12.2
12.3
12.3650
12.3655
AGE (billions of years)

PARTE VI

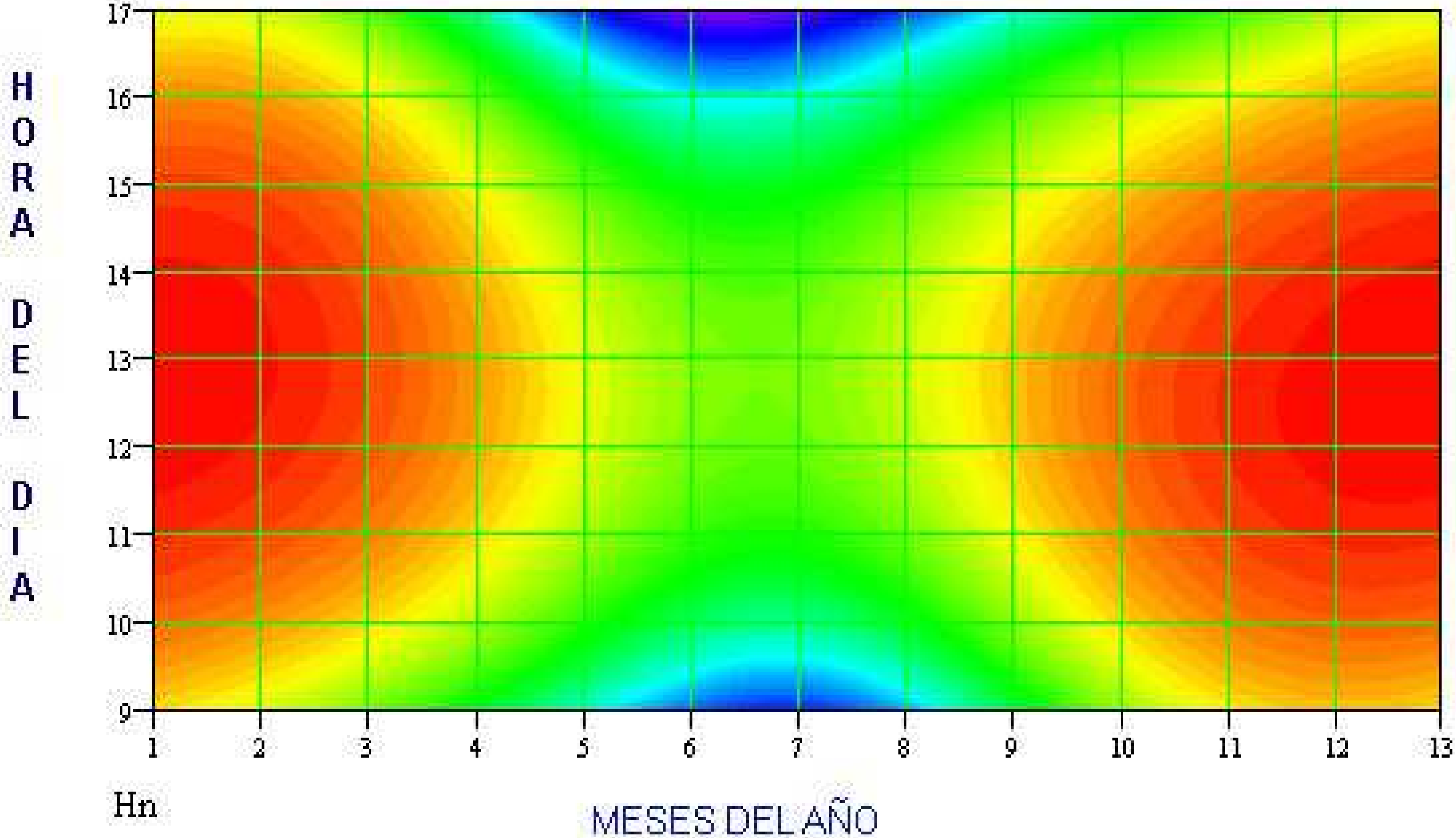
INSOLACION Y ESTACIONES

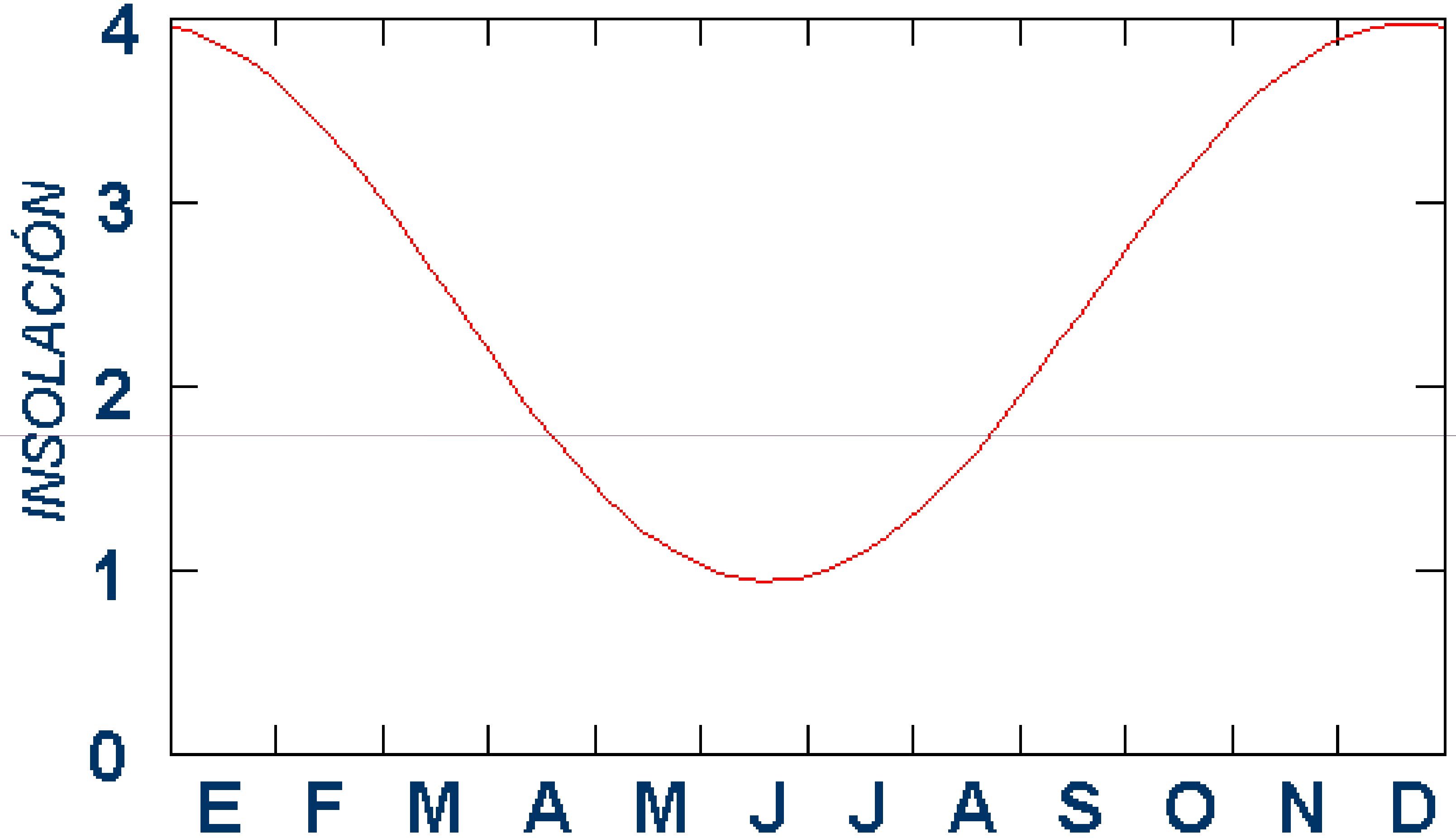

Sol en el cenit
Sol a la salida
o a la puesta
TIERRA
ATMÓSFERA



Intensidad
1
0.8
0.6
0.4
0.2
0
0
30
60
90
Altura del Sol en grados

INTENSIDAD DE LOS RAYOS SOLARES DURANTE EL 2000




INSOLACIÓN
4
3
2
1
0
E
F
M
A
M
J
J
A
S
O
N
D

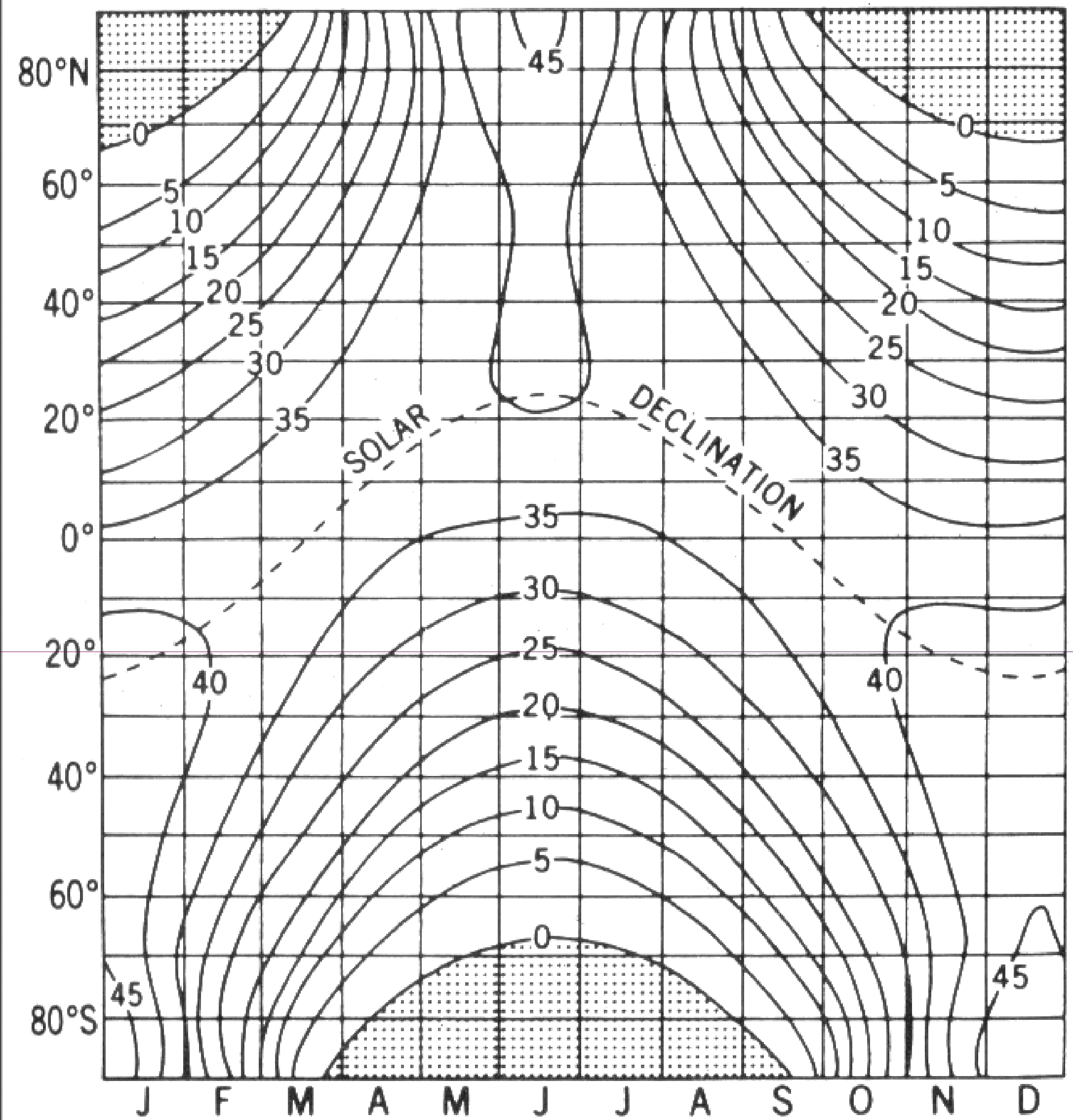


Figure I13 Daily total and latitudinally averaged insolation at the top of the atmosphere (TOA) as a function of latitude and date in $10^6\ J\ m^{-2}$ ($10^6\ J\ m^{-2}$ is about 11.6 $W\ m^{-2}$). Shaded areas represent those regions not illuminated by the Sun. The Sun's declination is also shown (after Peixoto and Oort, 1992).

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•American Scientist

• Charbonneau and White:*“The Sun, a Pictorial Introduction”* (www.hao.ucar.edu)

•Imamura: *“Physics 208: Introduction to Astrophysics”*

•SOHO