Lecture 2

- Long-term solar variability
  - Grant minima/maxima
  - Total solar irradiance
- Spectral irradiance
  - Black body, gray body
- Internal structure of the Sun
  - Y-dependence
  - Intensity & radiation transport

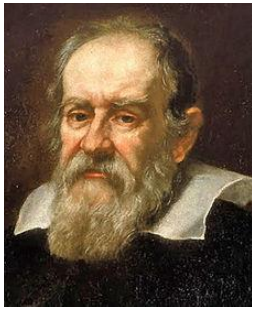
Summary of previous lecture

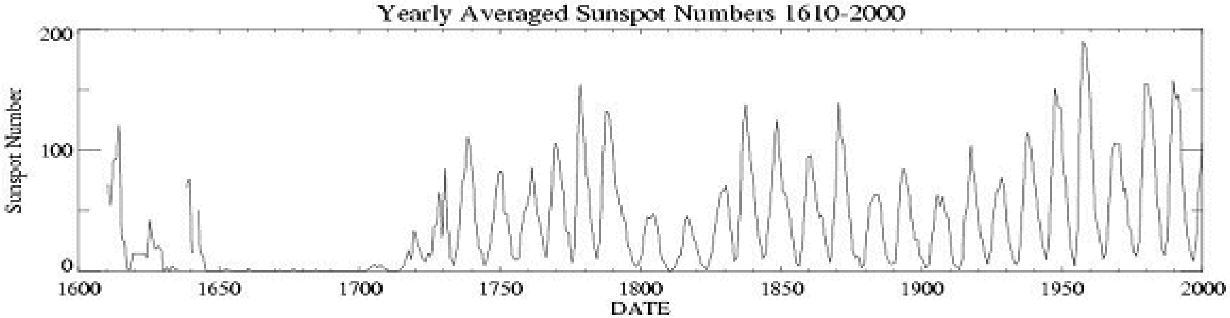
- Previous space weather events
  - Halloween storm, Carrington flare, etc
- Effect on aviation, GPS, radiation, GICs, etc
  - GPS stories: climbers on Mt Everest, Heathrow…
  - Biol. impact measured in

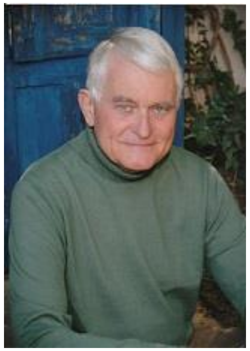
    (A) Grey, (B) Curie, © Sieverts, (D) rem?
- Kp index
- Sun's position in HR diagram (L=3.8x10^{26}W)

Long-term variability

Galileo was one of the first Europeans to observe sunspots, although Kepler had unwittingly observed one in 1607, but mistook it for a transit of Mercury. He also reinterpreted a sunspot observation from the time of Charlemagne, which formerly had been attributed (impossibly) to a transit of Mercury. The very existence of sunspots showed another difficulty with the unchanging perfection of



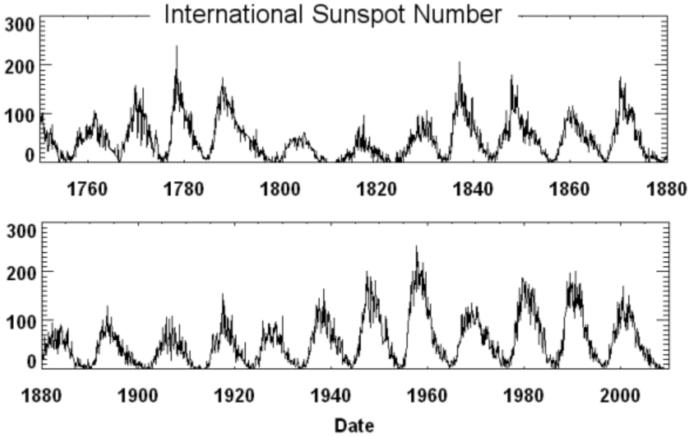




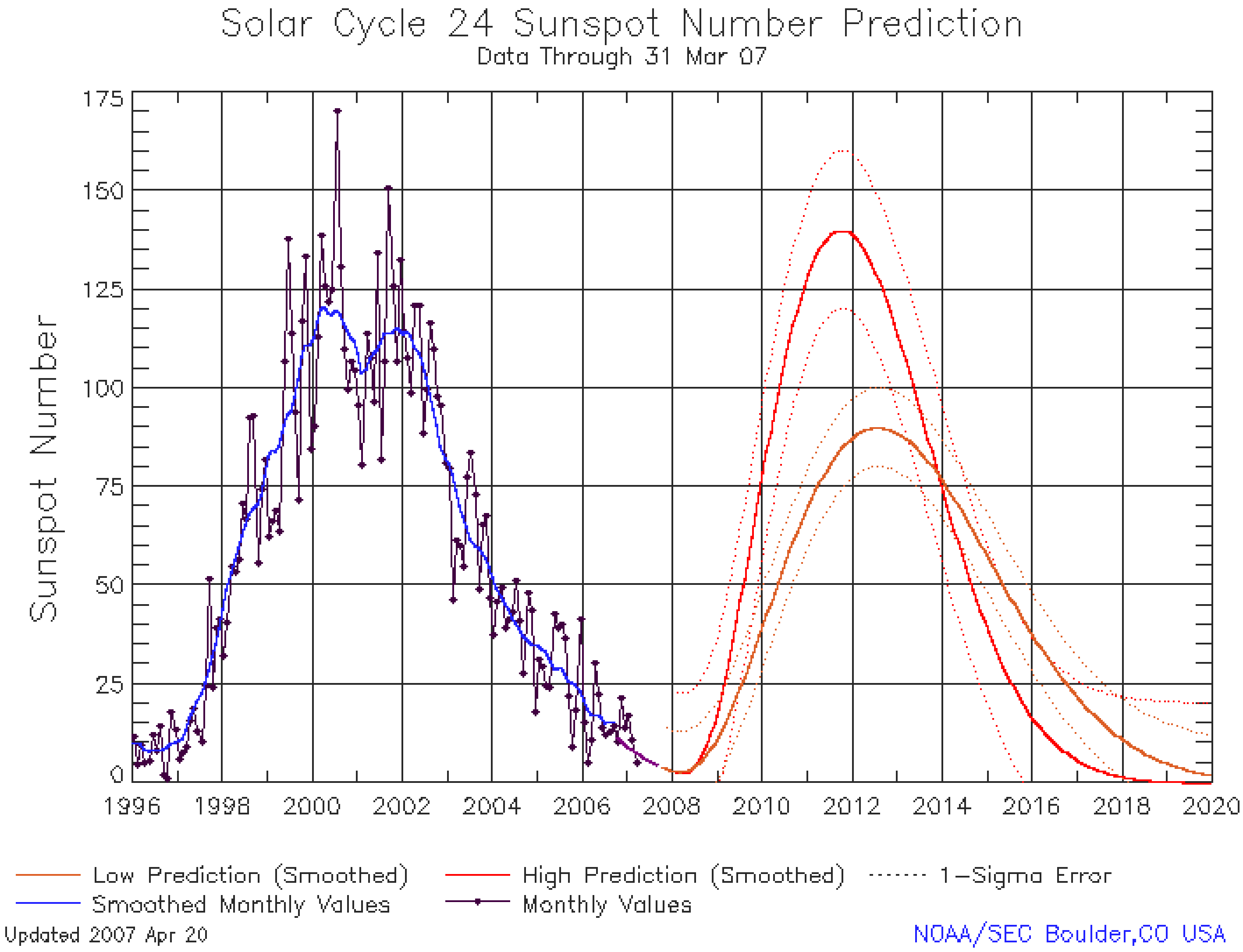
J. Eddy

E. Maunder

S. Schwaber

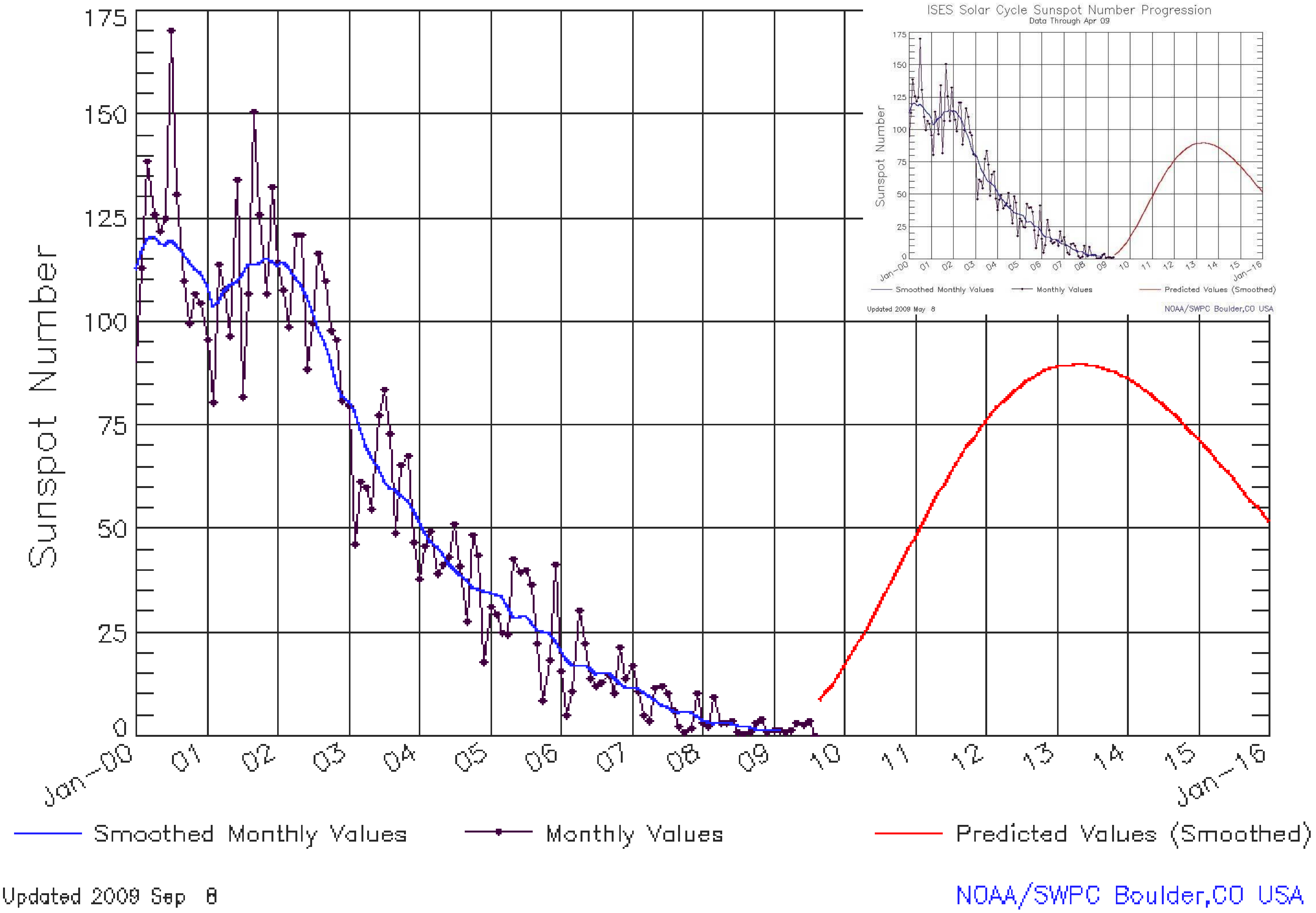


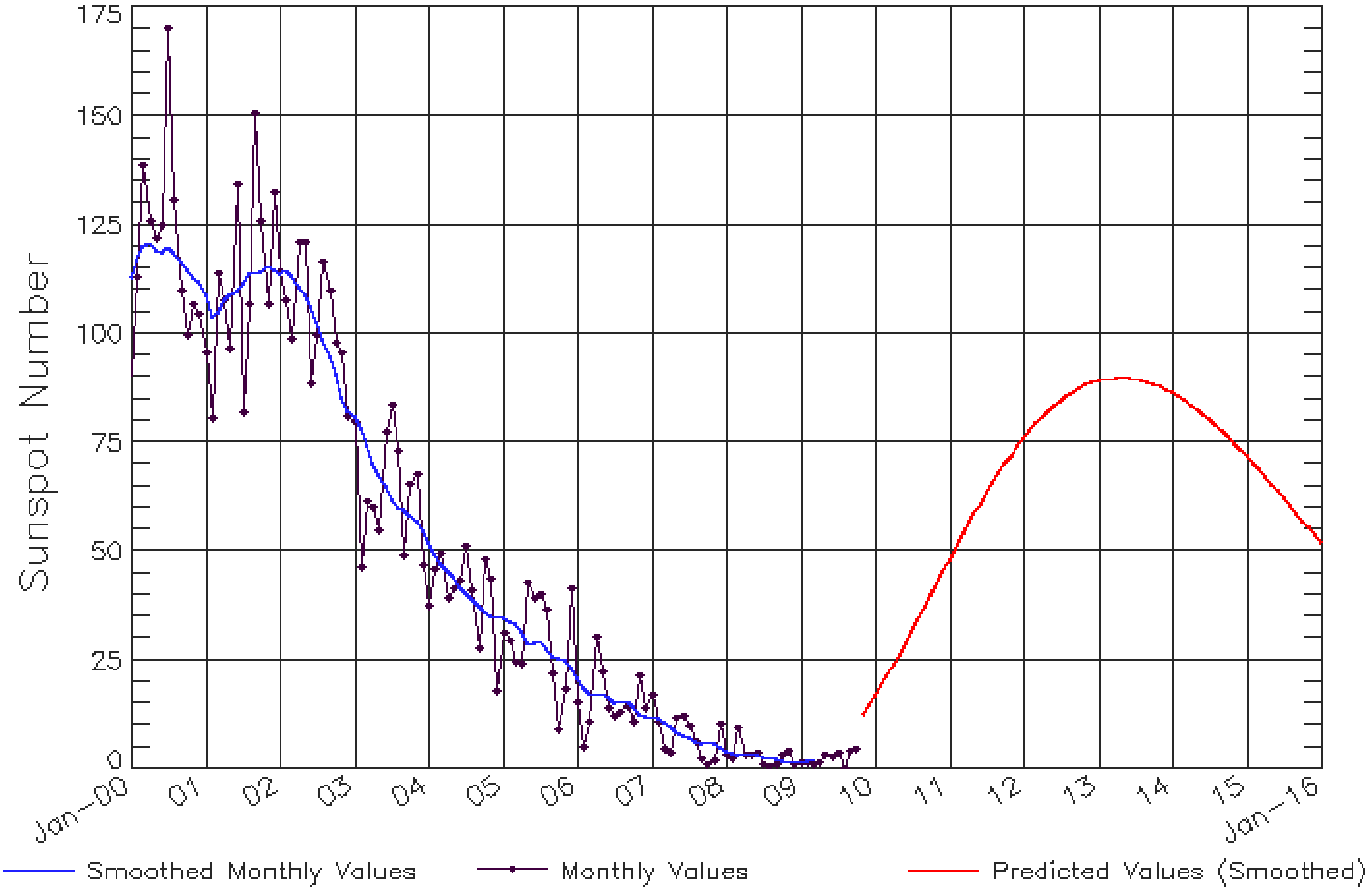
Past sunspot predictions



ISES Solar Cycle Sunspot Number Progression

Data Through Aug 09





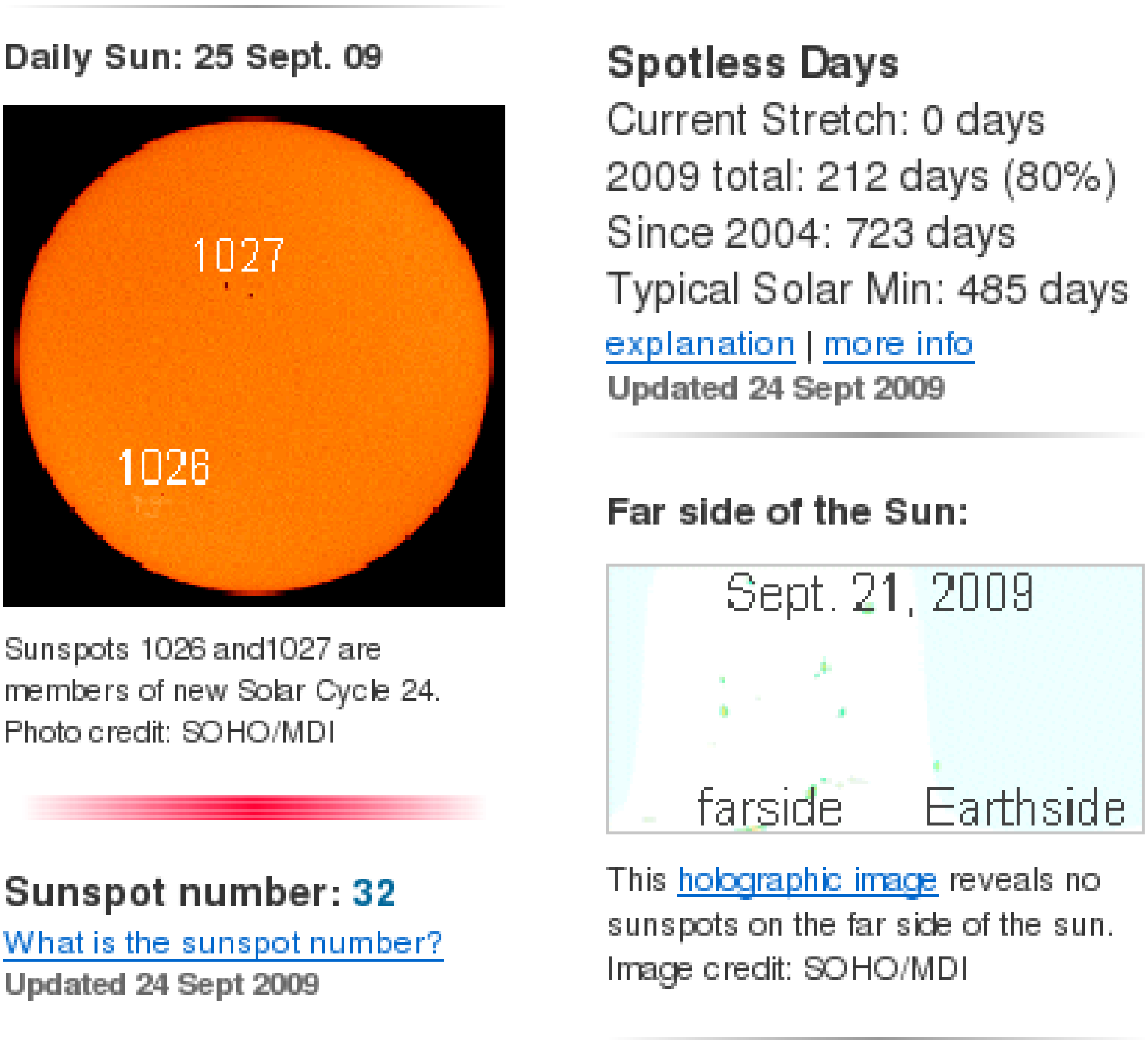
ISES Solar Cycle Sunspot Number Progression

Data Through Oct 09

Updated 2009 Nov 2

NOAA/SWPC Boulder,CO USA

http://spaceweather.com



Daily Sun: 25 Sept. 09

Sunspots 1026 and1027 are members of new Solar Cycle 24. Photo credit: SOHO/MDI

Sunspot number: 32

What is the sunspot number?

Updated 24 Sept 2009

Spotless Days

Current Stretch: 0 days
2009 total: 212 days (80%)
Since 2004: 723 days
Typical Solar Min: 485 days

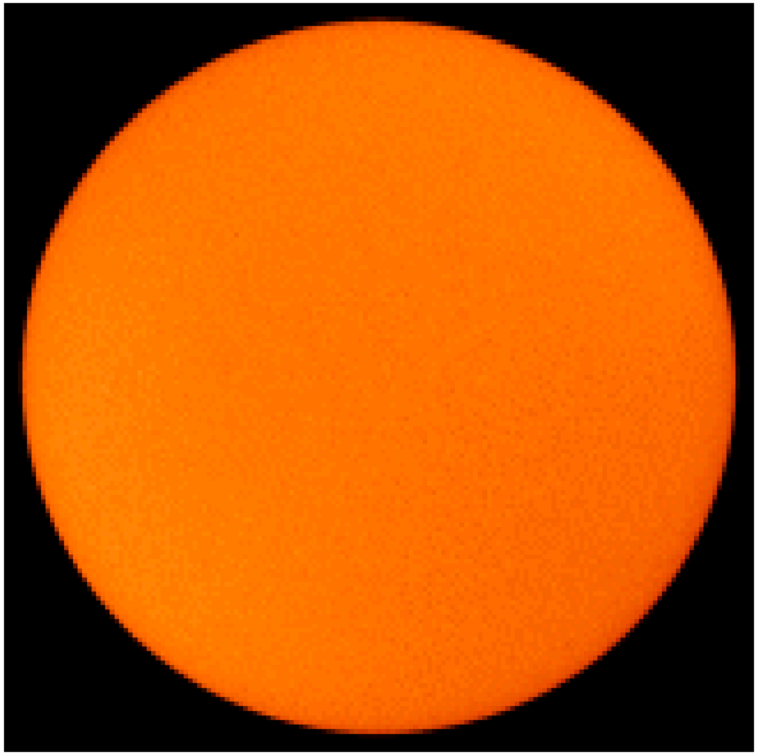
explanation | more info

Updated 24 Sept 2009

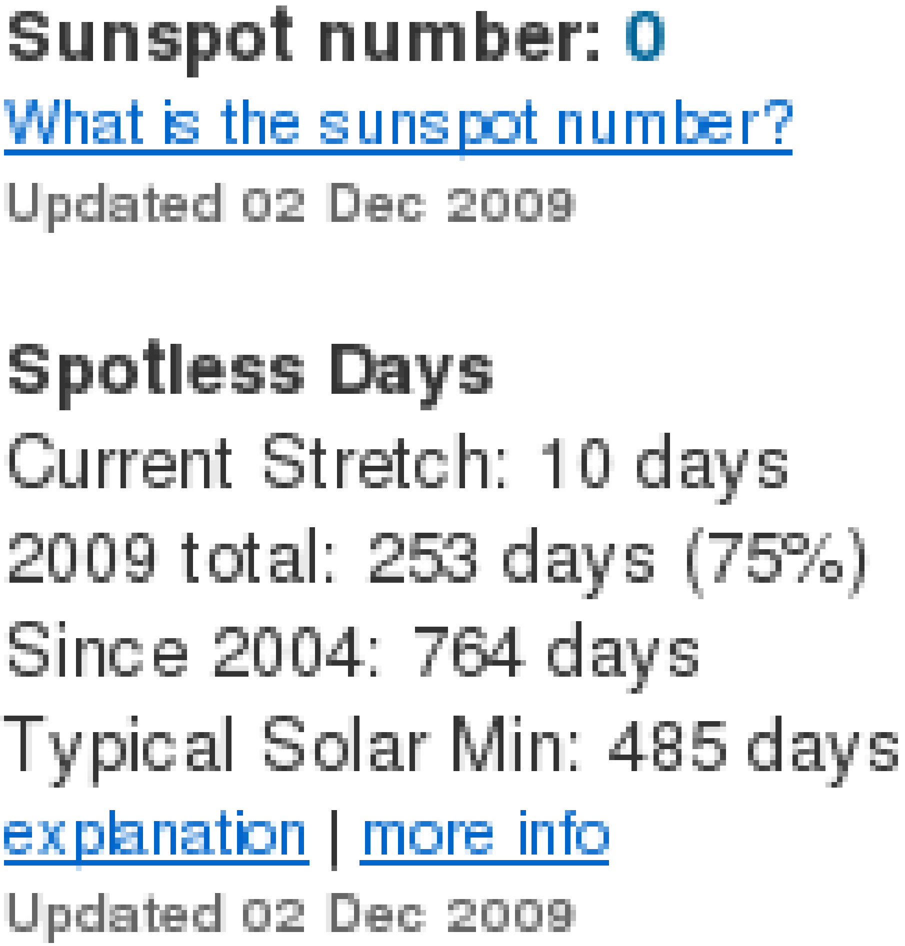
Far side of the Sun:

This holographic image reveals no sunspots on the far side of the sun. Image credit: SOHO/MDI

Daily Sun: 03 Dec. 09



The sun is blank--no sunspots.
Credit: SOHO/MDI



Sunspot number: 0

What is the sunspot number?

Updated 02 Dec 2009

Spotless Days

Current Stretch: 10 days

2009 total: 253 days (75%)

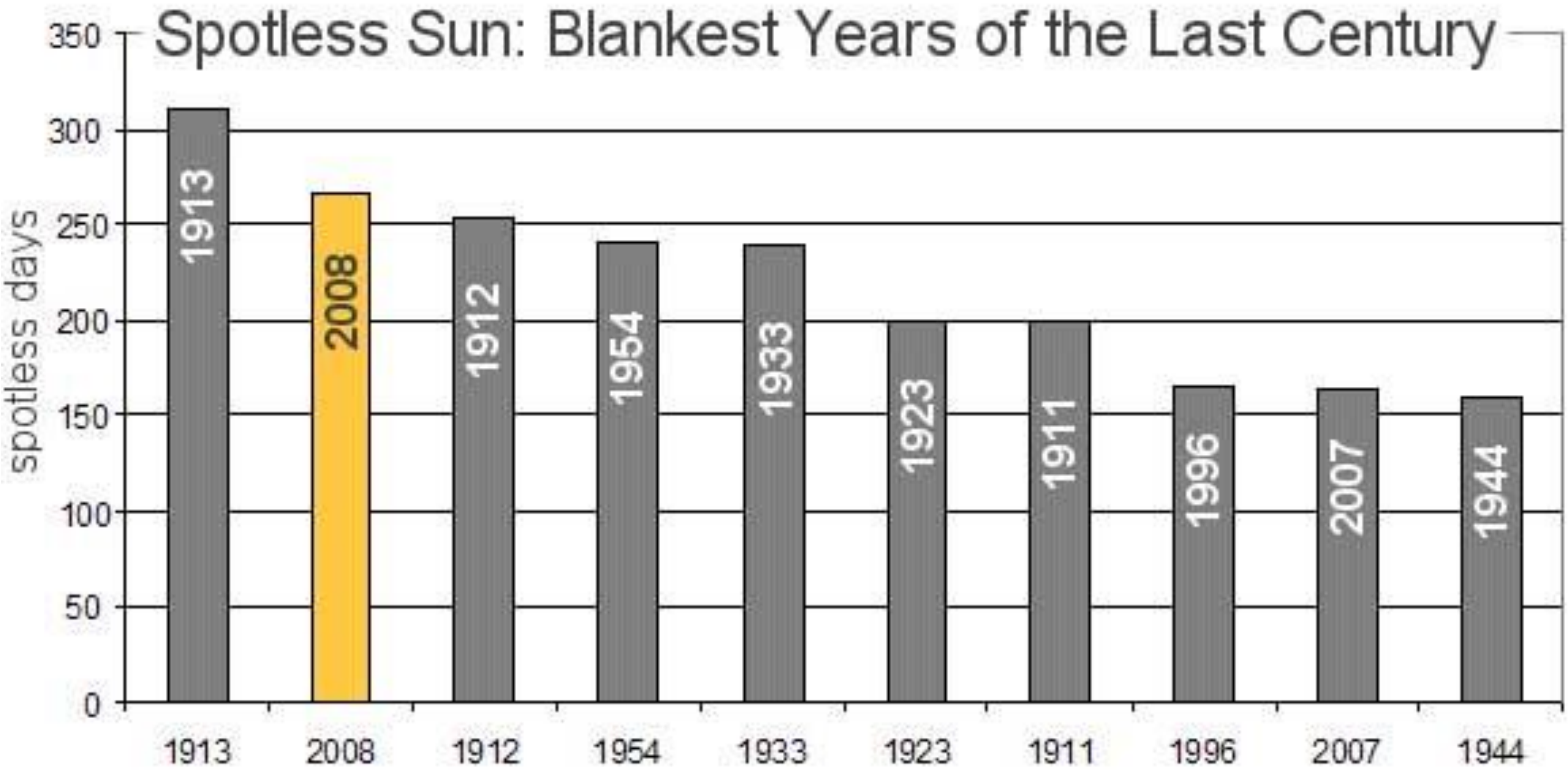
Since 2004: 764 days

Typical Solar Min: 485 days

explanation | more info

Updated 02 Dec 2009

Low, but not as low as 1913

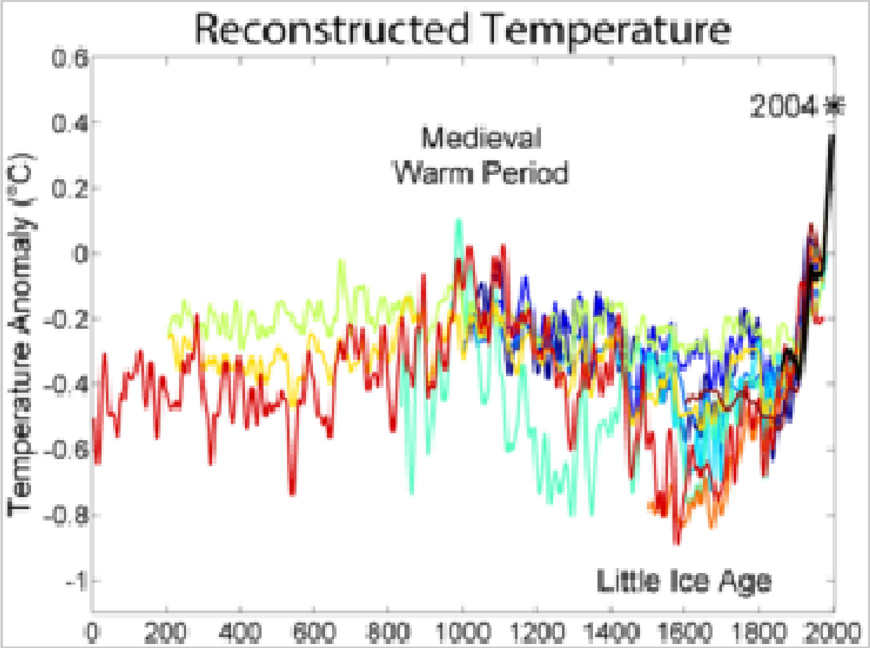


Little Ice Age

From Wikipedia, the free encyclopedia

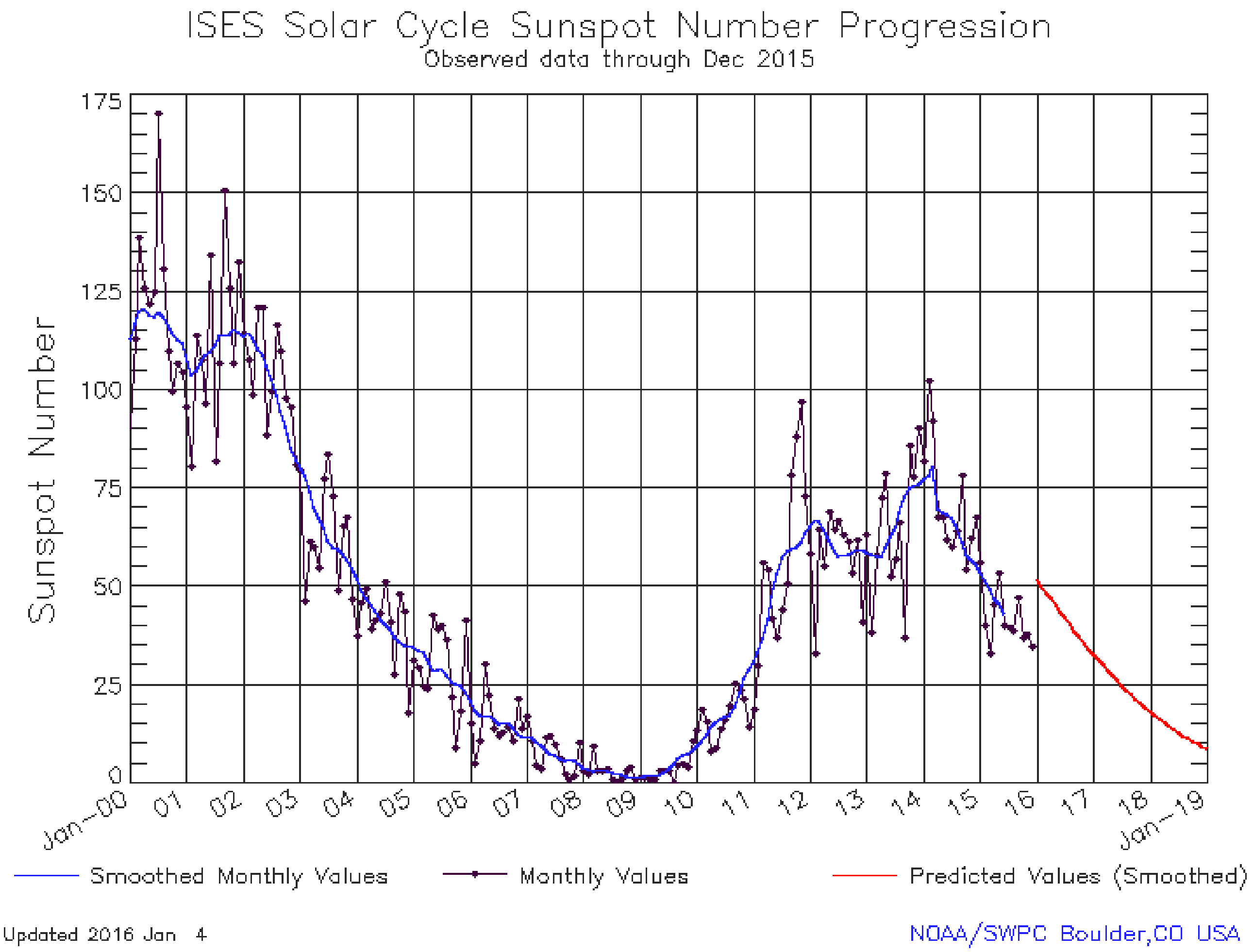
For the most recent period much colder than present and with significant glaciation, see Last glacial period.

The **Little Ice Age** (LIA) was a period of cooling that occurred after the Medieval Warm Period (Medieval Climate Optimum).[1] While it was not a true ice age, the term was introduced into the scientific literature by François E. Matthes in 1939.[2] It has been conventionally defined as a period extending from the sixteenth to the nineteenth centuries,[3][4][5] or alternatively, from about 1300[6] to about 1850,[7][8][9] although climatologists and historians working with local records no longer expect to agree on either the start or end dates of this period, which varied according to local conditions. The NASA Earth Observatory notes



The reconstructed depth of the Little Ice Age varies between different studies (anomalies shown are from the 1950–80 reference period)

Cycle progression as of now

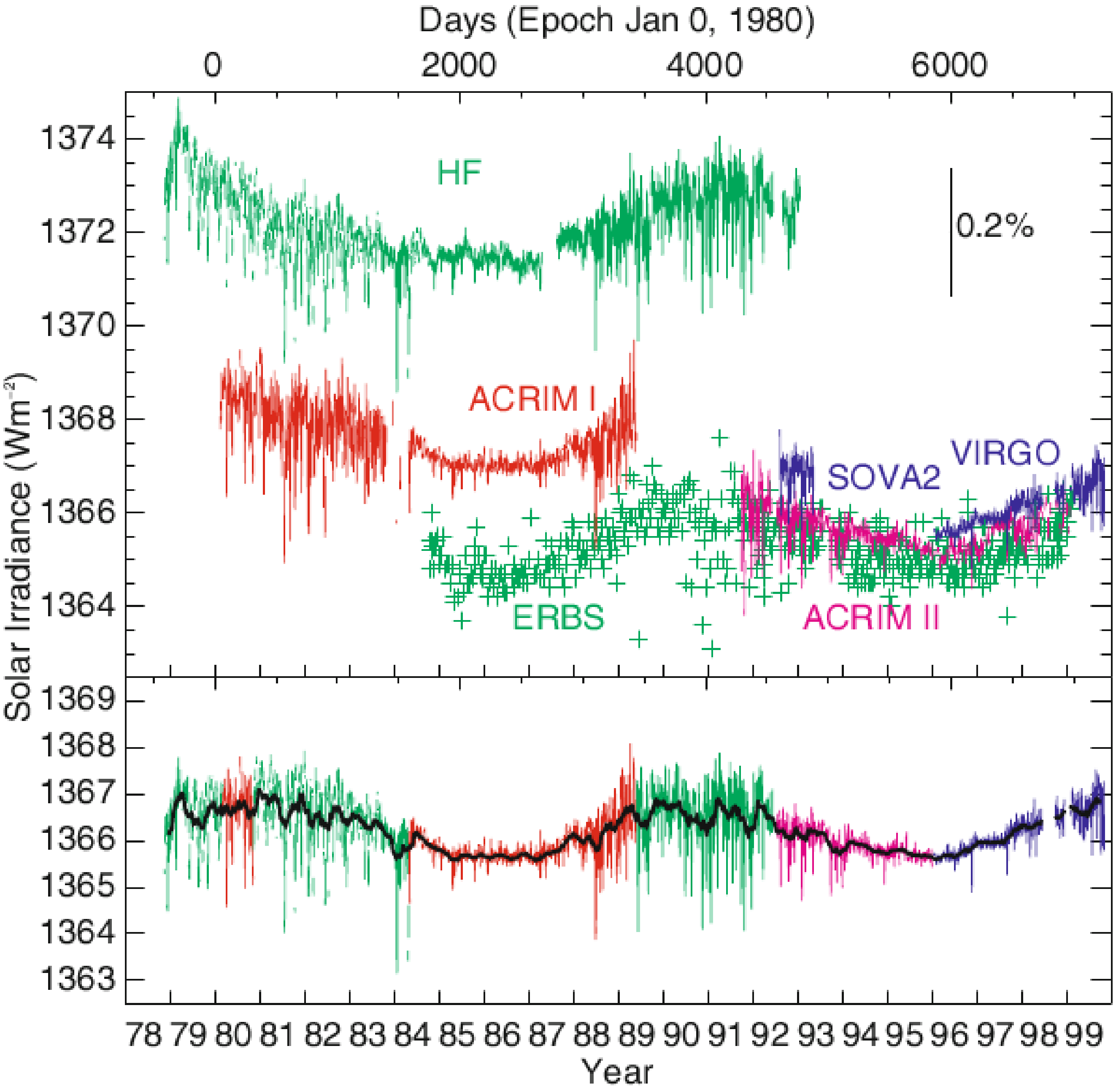


Total solar irrradiance

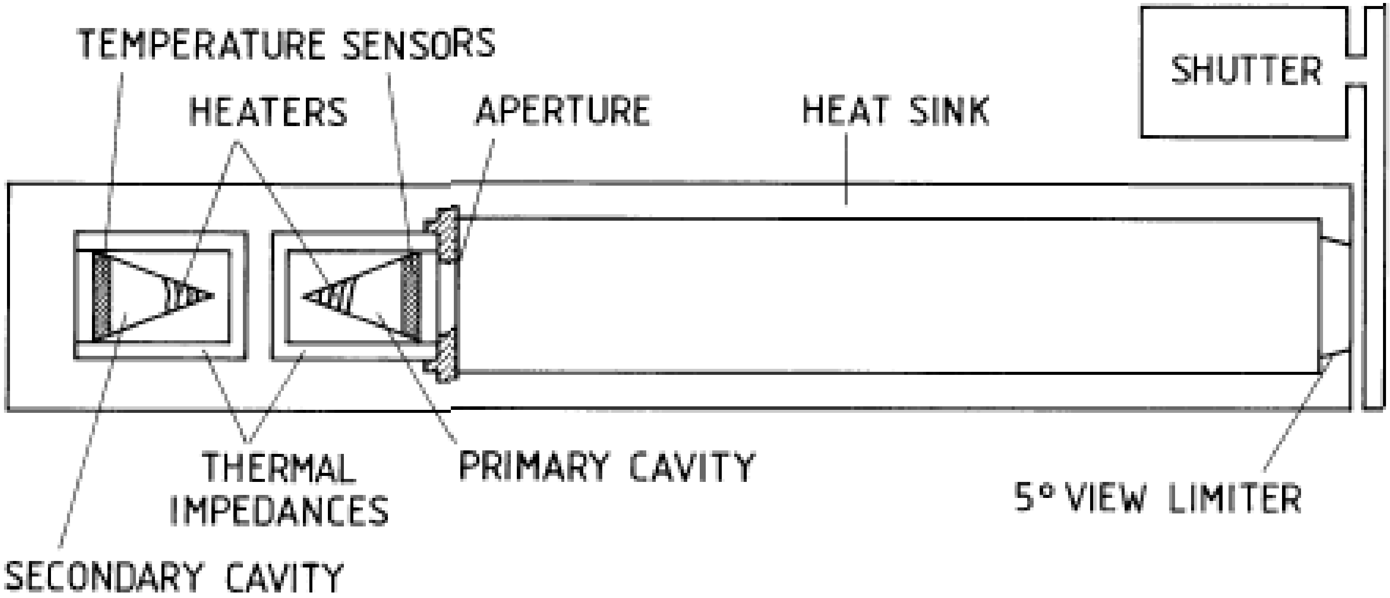
Integrated flux
Over all λ

$$L = 4\pi r^2 F$$

$$r = 1\text{AU}$$



Pyrheliometer



Conversion of spectral distribution function

$$F(T) = \int I_\nu(\nu, T)\, d\nu$$

or

$$F(T) = \int I_\lambda(\lambda, T)\, d\lambda$$

$$\nu(\lambda) = \frac{c}{\lambda}$$

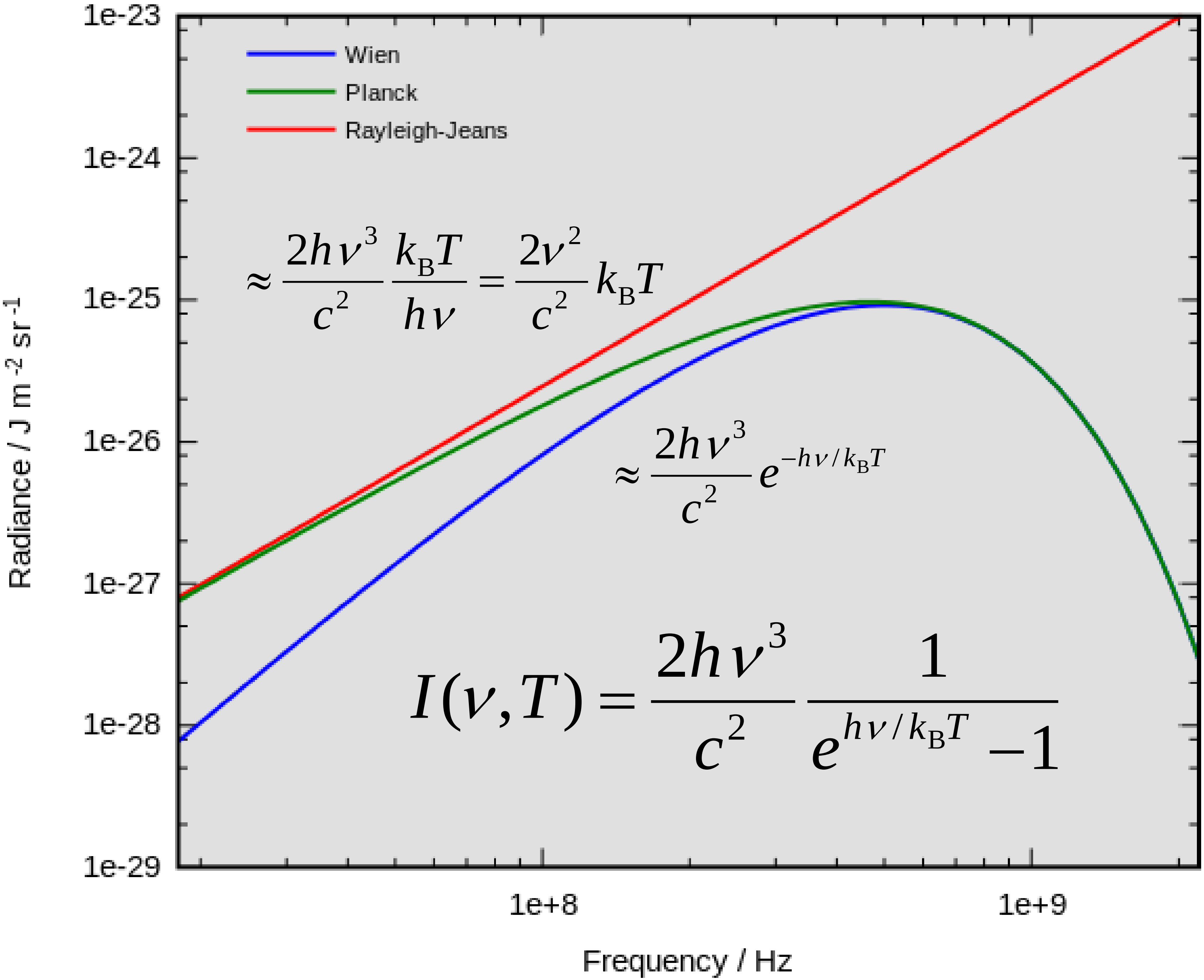
Hint: compute $\dfrac{d\nu}{d\lambda}$

Dimensional analysis

$$\left[I_\nu(\nu, T) \right] = \frac{\mathrm{W}}{\mathrm{m^2 Hz}}$$

$$I_\nu(\nu, T) = \nu^a T^b c^c k_\mathrm{B}^d$$

$$k_\mathrm{B} = 1.38 \times 10^{-23} \, \frac{\mathrm{J}}{\mathrm{K}}$$


Wien
Planck
Rayleigh-Jeans
$\approx \frac{2h\nu^3}{c^2}\frac{k_B T}{h\nu} = \frac{2\nu^2}{c^2}k_B T$
$\approx \frac{2h\nu^3}{c^2}e^{-h\nu/k_B T}$
$I(\nu,T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{h\nu/k_B T}-1}$
1e-23
1e-24
1e-25
1e-26
1e-27
1e-28
1e-29
1e+8
1e+9
Frequency / Hz
Radiance / J m $^{-2}$ sr $^{-1}$

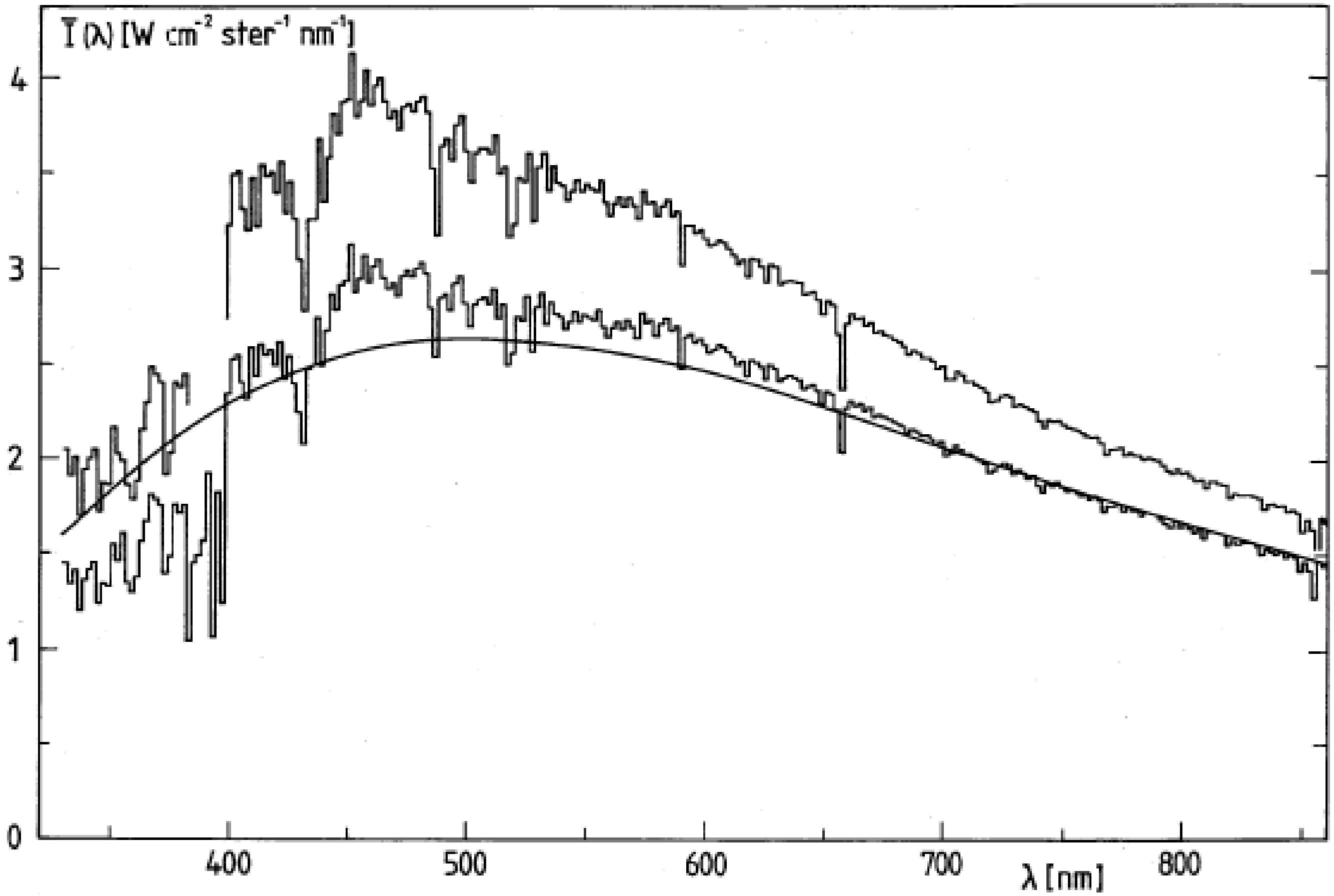
Rayleigh-Jeans law

$$I_\nu(\nu,T) = \frac{2\nu^2}{c^2} k_\mathrm{B} T$$

$$I_\lambda(\lambda,T) = I_\nu(\nu,T)\frac{c}{\lambda^2} = \frac{2\nu^2}{c^2}\frac{c}{\lambda^2} k_\mathrm{B} T$$

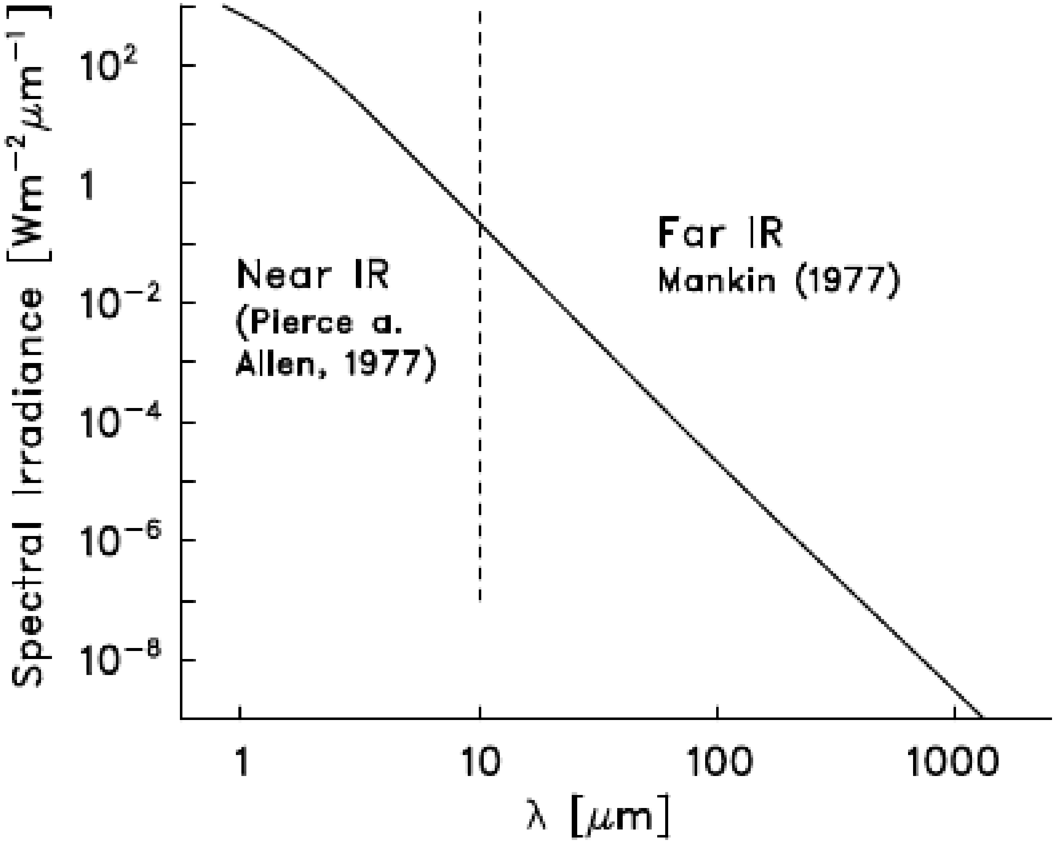
$$= \frac{2c}{\lambda^4} k_\mathrm{B} T$$

Visible spectrum: most of energy



$$B_\lambda = \frac{2hc^2}{\lambda^5(\mathrm{e}^{hc/\lambda kT} - 1)}\ , \qquad \text{i.e.,} \quad B_\lambda \simeq \frac{2ckT}{\lambda^4}$$

Infrared: λ^{-4} law

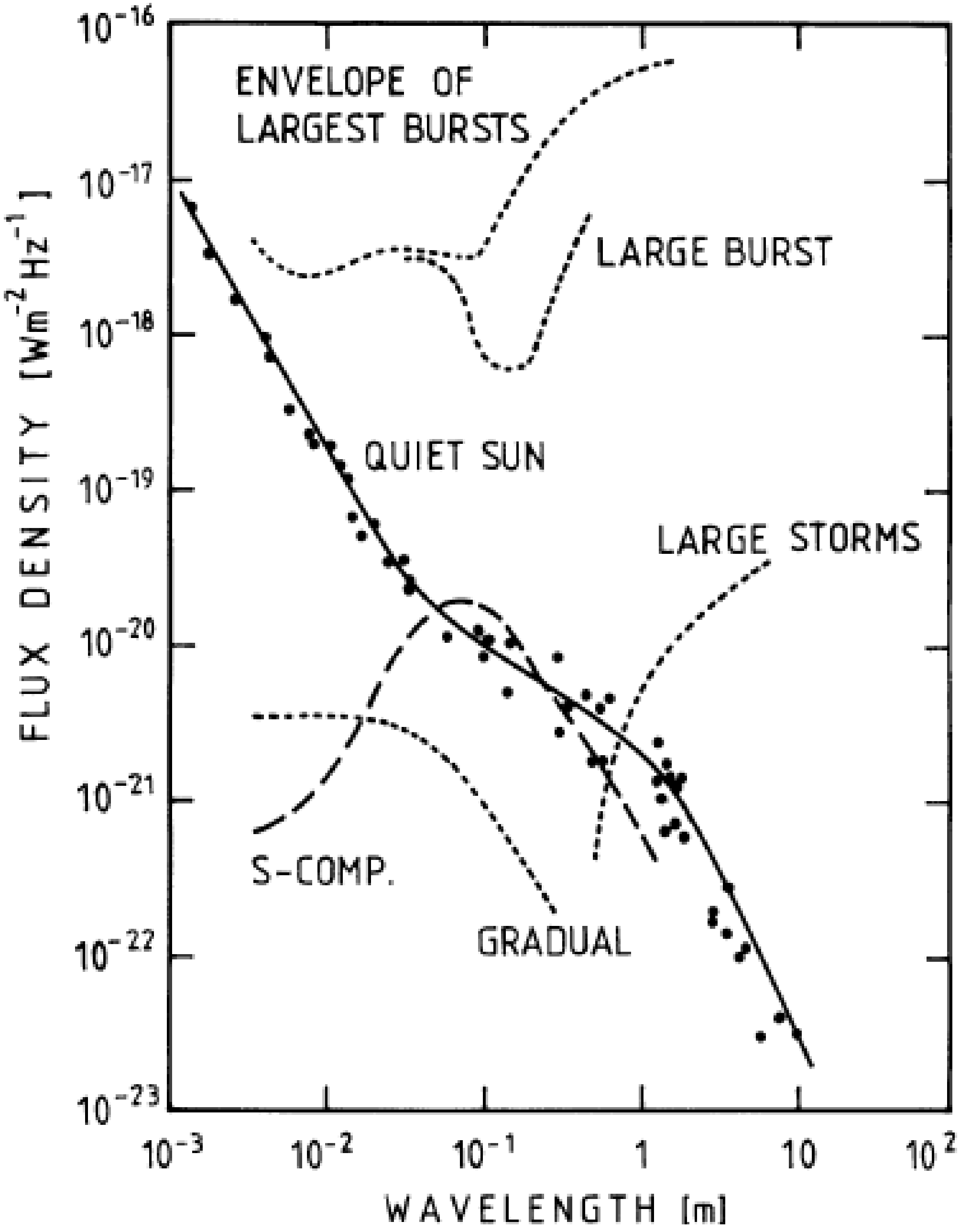


$$S(\lambda) \simeq 2\pi ckT\lambda^{-4}(r_{\odot}/A)^2$$

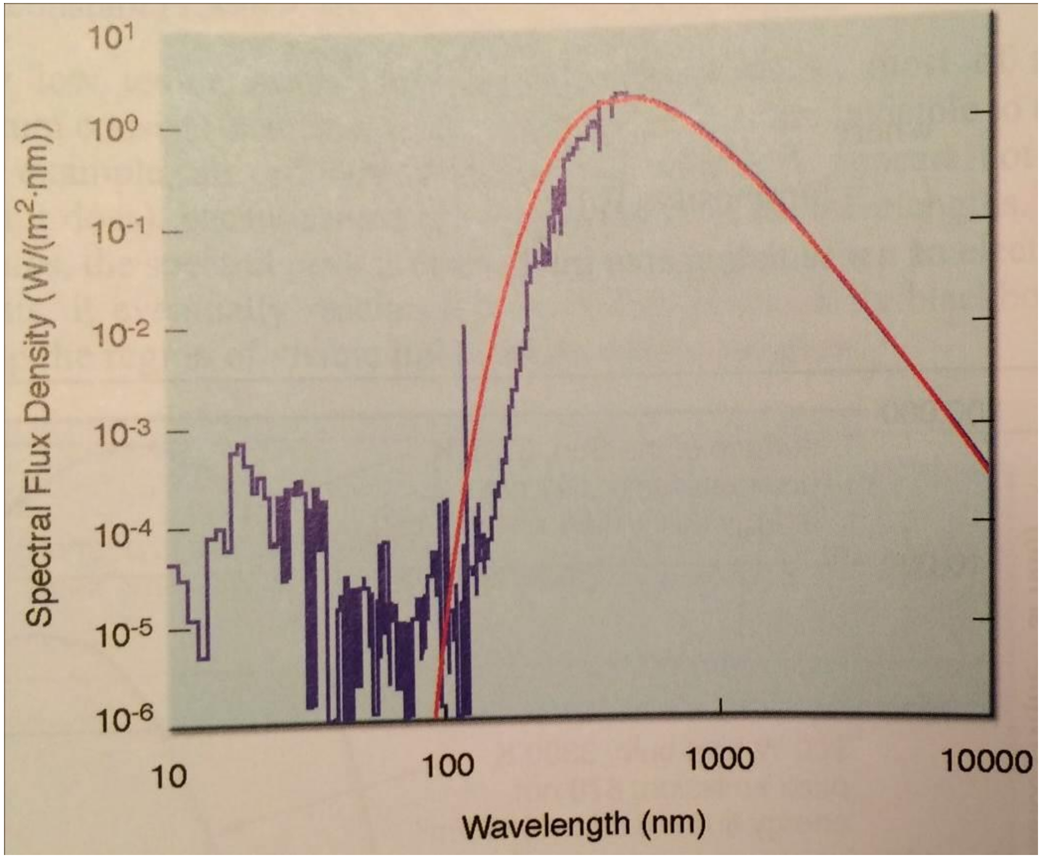
Radio: interesting break

- Clue about hot corona
- Brightness temperature

$$S(\lambda) \simeq 2\pi c k T \lambda^{-4} (r_\odot / A)^2$$



“Gray body” at short wavelengths



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Knipp (2011)

Internal structure of the Sun

- Seeing deeper
  - Different wavelengths
  - Ca, Fe lines (slightly higher up)
  - infrared (slightly deeper)
- Helioseismology
- Neutrinos
- Theory (depends on Y and mixing length)
  - $X+Y+Z=1$

Dependence on Y

- Solve time-dependent stellar structure eqns
- Produce more *Y*

$$\ln L = \ln L_\odot + a(Y_0 - Y_{0\odot}) + b(\alpha - \alpha_\odot)$$

$$\ln r = \ln r_\odot + c(Y_0 - Y_{0\odot}) + d(\alpha - \alpha_\odot)\ ,$$

R and *L* grow (faint sun paradox)

$$a \equiv \frac{\partial \ln L}{\partial Y_0} = 8.6 \qquad b \equiv \frac{\partial \ln L}{\partial \alpha} = 0.04$$

$$c \equiv \frac{\partial \ln r}{\partial Y_0} = 2.1 \qquad d \equiv \frac{\partial \ln r}{\partial \alpha} = -0.13$$

More on intensity

$$I_\nu(\mathbf{x}, \hat{\mathbf{n}}, t)$$

depends also
on direction

for each ray path…

$$\frac{dI_\nu}{ds} = -\rho\kappa_\nu (I_\nu - S_\nu)$$

$$\hat{\mathbf{n}} \cdot \nabla I_\nu = -\rho\kappa_\nu (I_\nu - S_\nu)$$

or

$$\frac{dI_\nu}{d\tau} = I_\nu - S_\nu$$

with $d\tau_\nu = -\rho\kappa_\nu ds$

optical depth

3. A Not-So-Ordinary Differential Equation. Consider a one-dimensional "slab" of gas that starts at $x = 0$ and ends at $x = D$, and is surrounded by empty space. A ray of light with intensity I_0 hits the slab at $x = 0$ and shines through it parallel to the x axis. Inside the slab, the intensity obeys

$$\frac{dI}{dx} = \alpha\,(S - I)$$

where α and S are constants.

(a) Solve this equation for $I(x)$ at all points between $x = 0$ and $x = D$.

(b) Define the quantity $\tau = \alpha D$. Give an approximate solution for the "emergent intensity" $I(D)$ under the three limiting cases:

- $\tau \ll 1$.
- $\tau \gg 1$ and $S \gg I_0$.
- $\tau \gg 1$ and $S \ll I_0$.

(c) Each of the three above cases matches with one of the following three physical analogies. Which do you think corresponds to which, and why?

- Shining a flashlight through a piece of dark smoky quartz.
- Shining a flashlight through the bright flame of a welder's torch.
- Shining a flashlight through a glass window pane.

Hint: The quantity τ can be thought of as the "optical depth" or opaqueness of the slab—i.e., how efficiently does the gas absorb (or otherwise eliminate) the incoming beam. The quantity S is a "source function" that describes how the gas in the slab generates its own light.