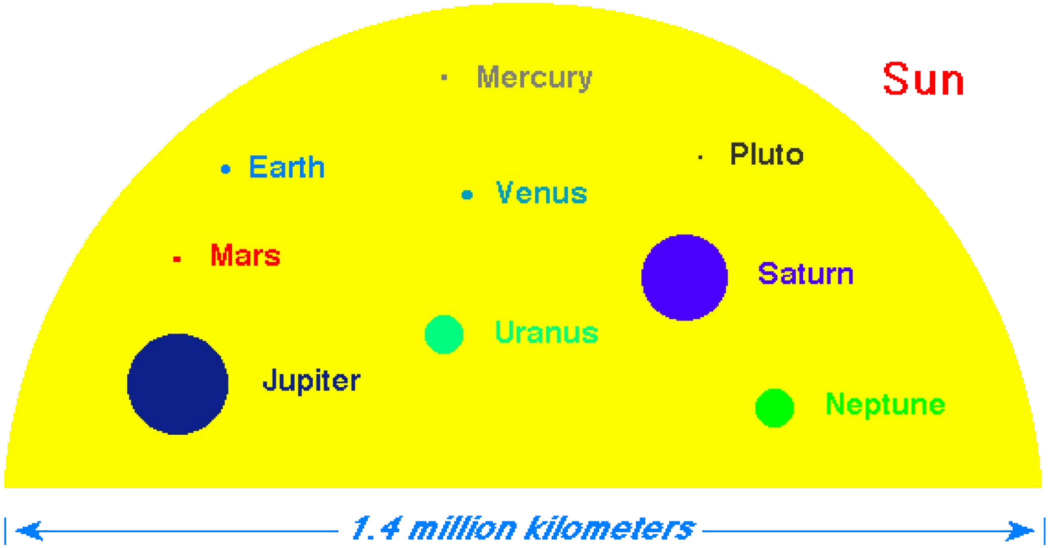
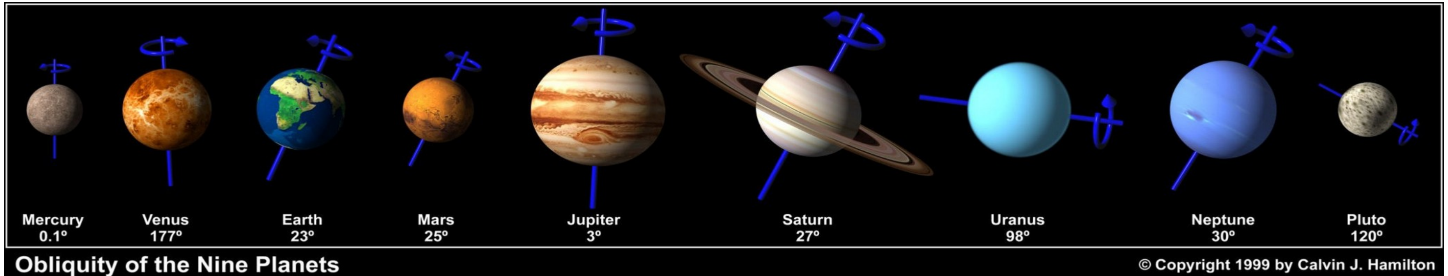
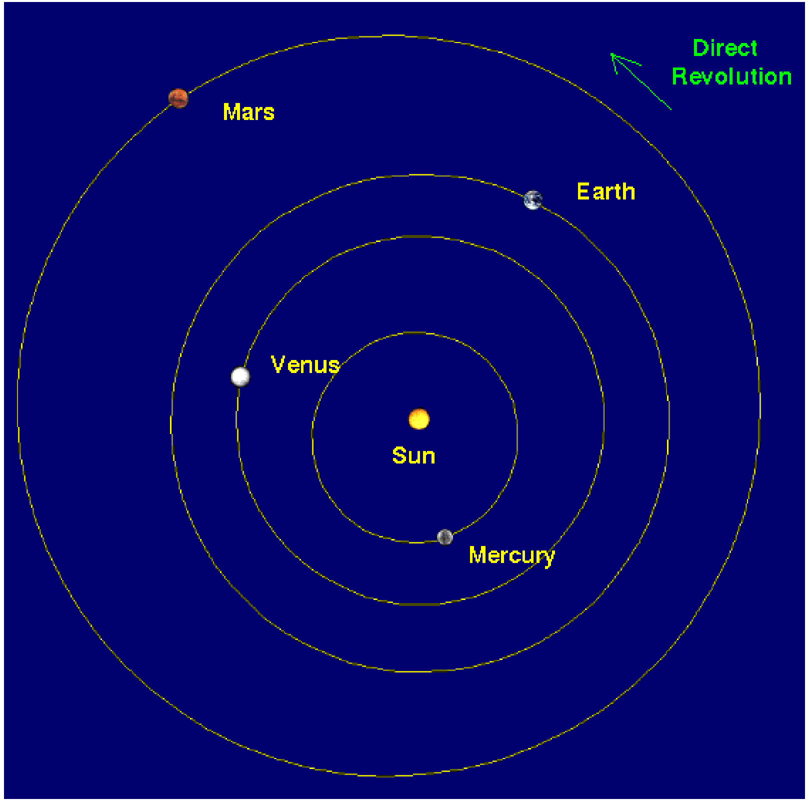
Lecture 2 : The Sun and Starlight

The Solar System



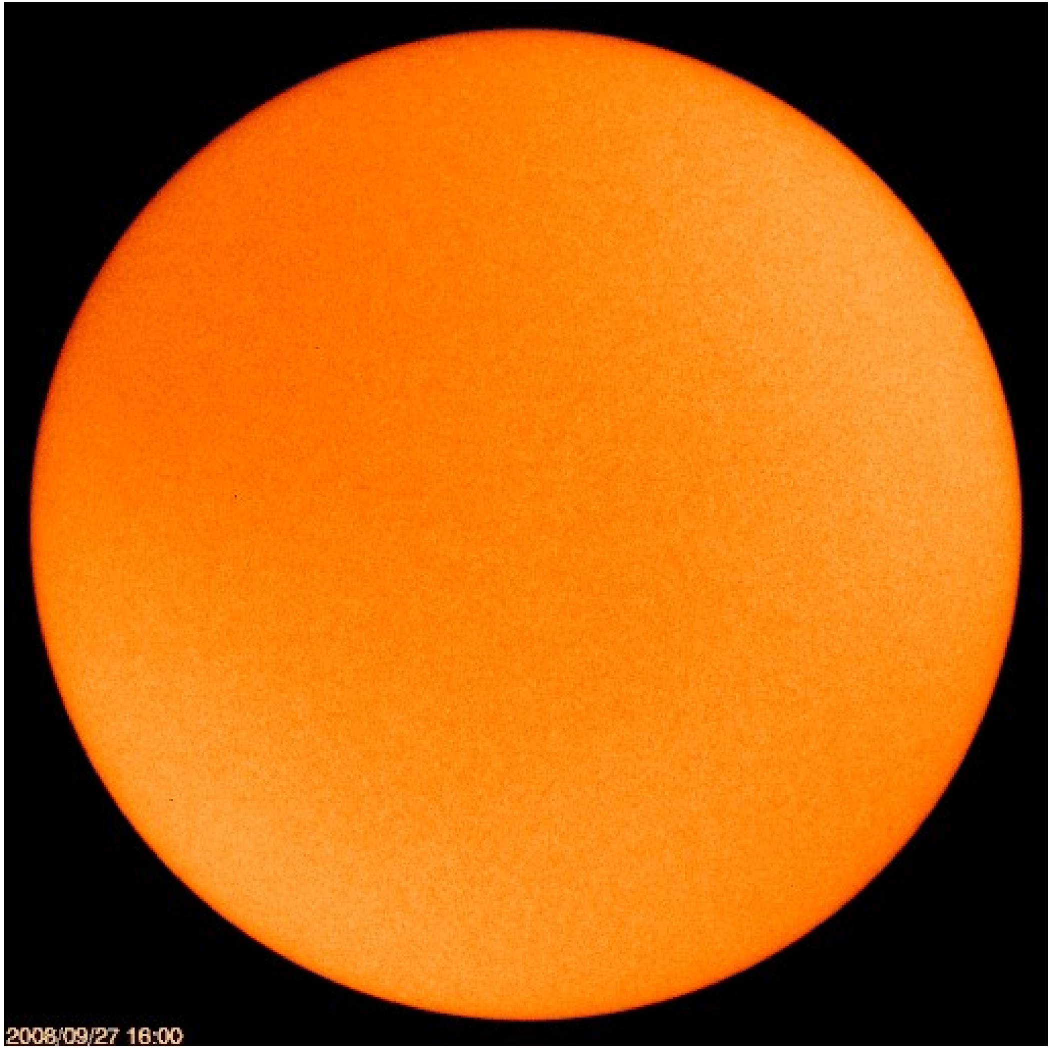


The Solar System



The Sun

- Properties
- Lifetime
- Energy Source
- Solar Atmosphere



science.nasa.gov

Basic parameters

- Mass = 2 x 10^{30} kg = 1 $M_{¤}$
  - (Kepler’s Law – later in the course)
- Distance = 1.5 x 10^{11} m = 1 au
  - (Kepler’s Law)
- Radius = 7 x 10^{8} m = 1 $R_{\odot}$
  - (angular size and distance)
- Luminosity = 4 x 10^{26} W = 1 $L_{\odot}$
  - (Flux and distance)

Lifetime

- Geological evidence

  → at least 5 x 10^9 years
- Stellar evolution theory

  10 x 10^9 years
- Energy required

$$E = L\tau$$

$$= 4.10^{26} \times 10.10^{9} \times 3.10^{7}$$

$$= 1.10^{44}\ \text{J}$$

Nuclear Fusion

- In the core of the Sun
  T=1 x 10^7 K
  P=10^9 atmospheres
- Sufficient for fusion of hydrogen into helium

$$4\,{}^{1}\mathrm{H} \rightarrow {}^{4}\mathrm{He} + \nu + \gamma$$

- Energy arises from mass difference

$$m(4\,{}^{1}\mathrm{H}) - m({}^{4}\mathrm{He}) = 0.0286\ \mathrm{amu}$$

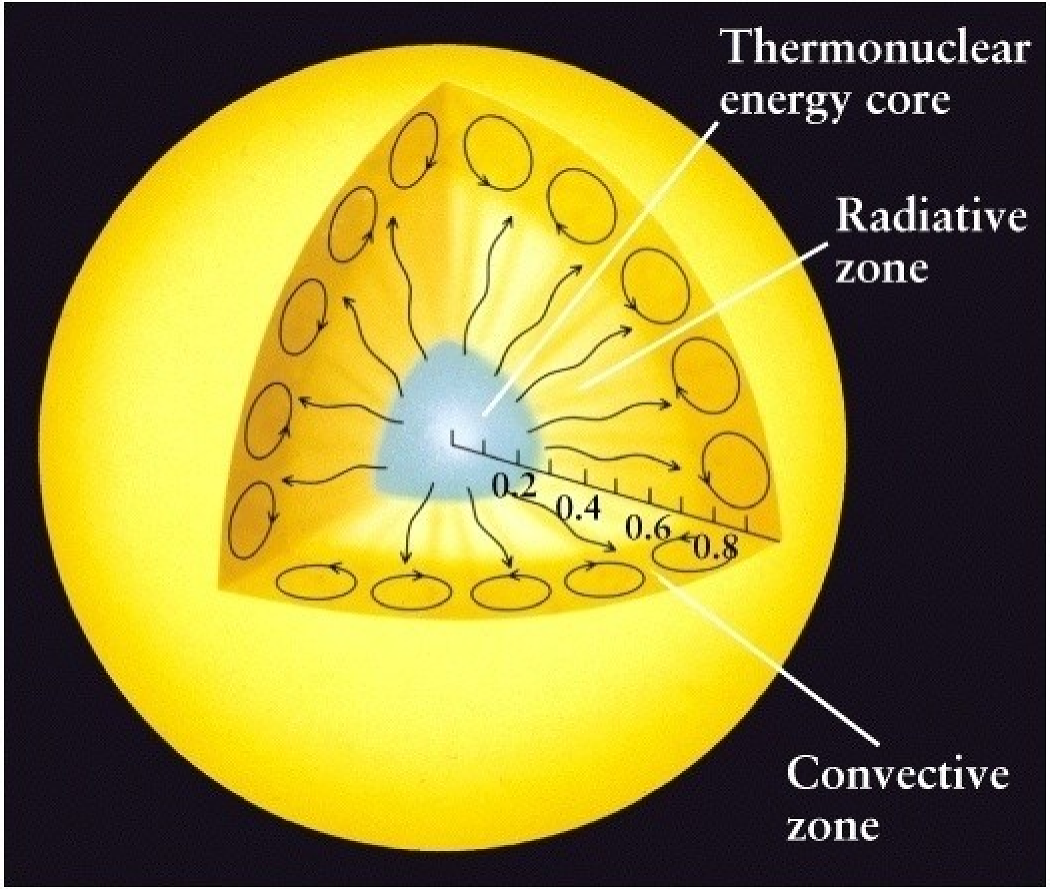
or 0.7% of the mass.

- Core of the Sun contains about 10% of the total mass
- Total

$$= \Delta m c^2$$

$$= 0.10 \times 0.007 \times 2 \times 10^{30} \times \left(3 \times 10^{8}\right)^2$$

$$= 1 \times 10^{44}\ \mathrm{J}$$



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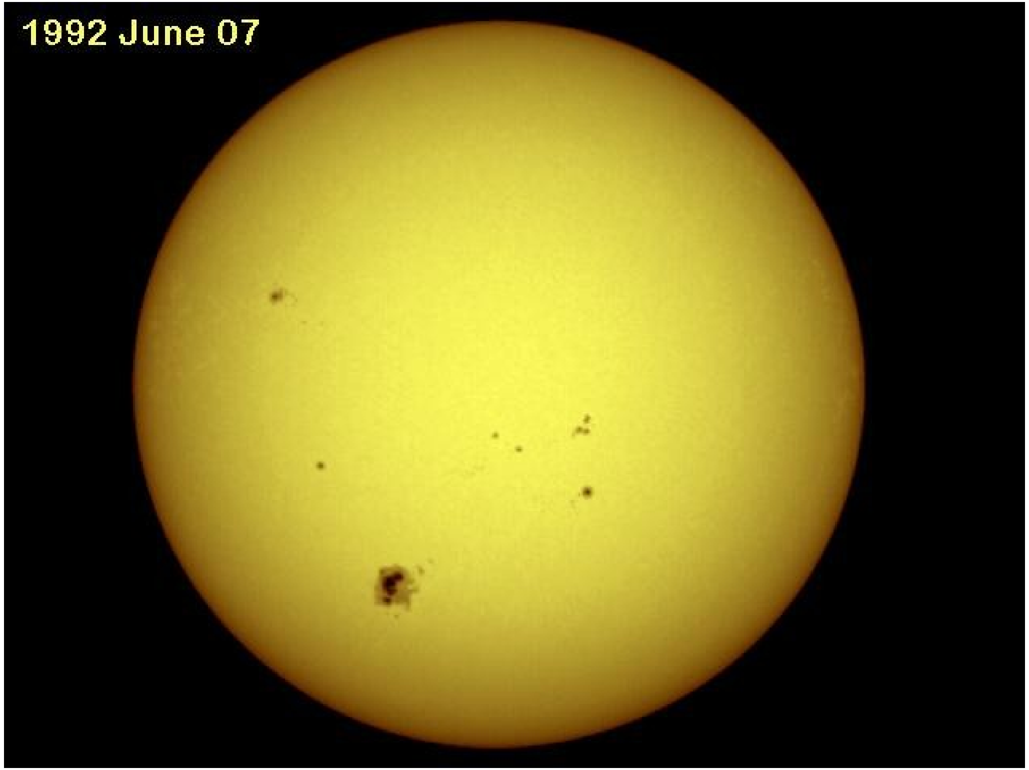
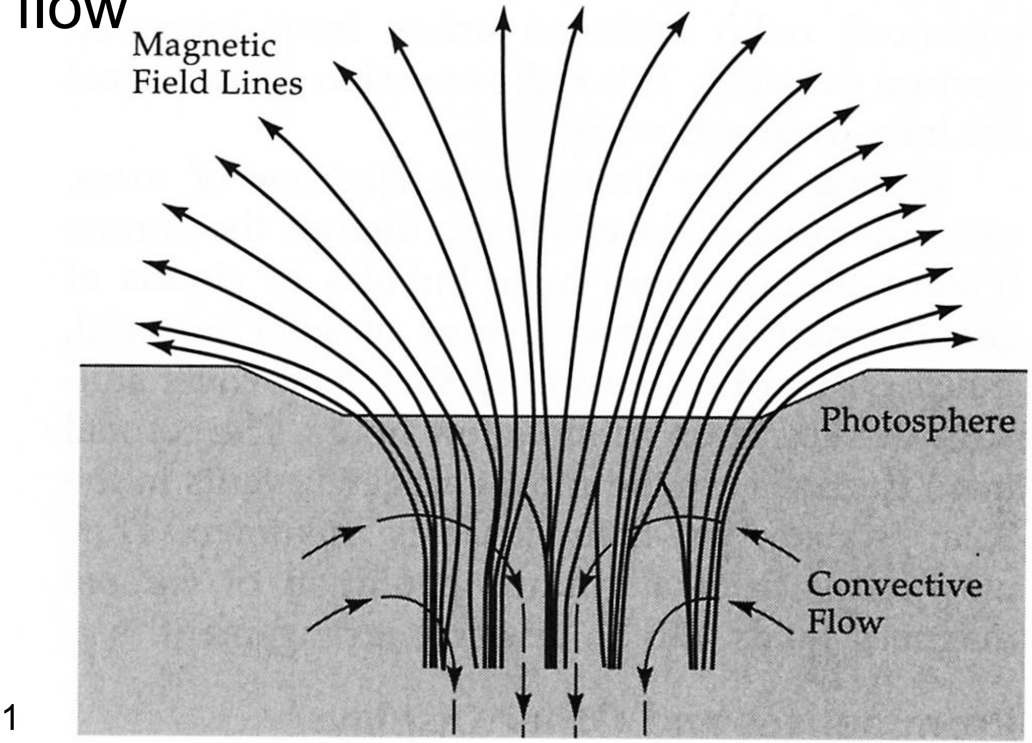
Sunspots

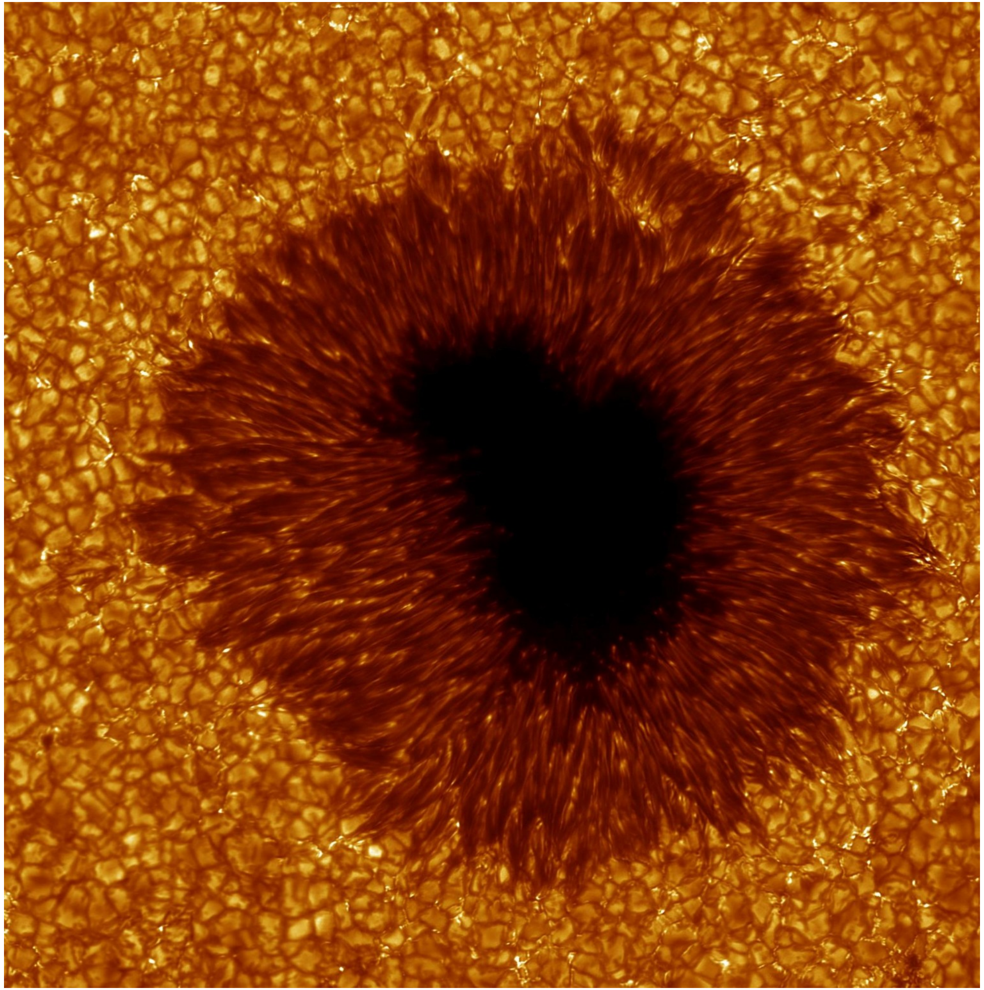


http://solarscience.msfc.nasa.gov/

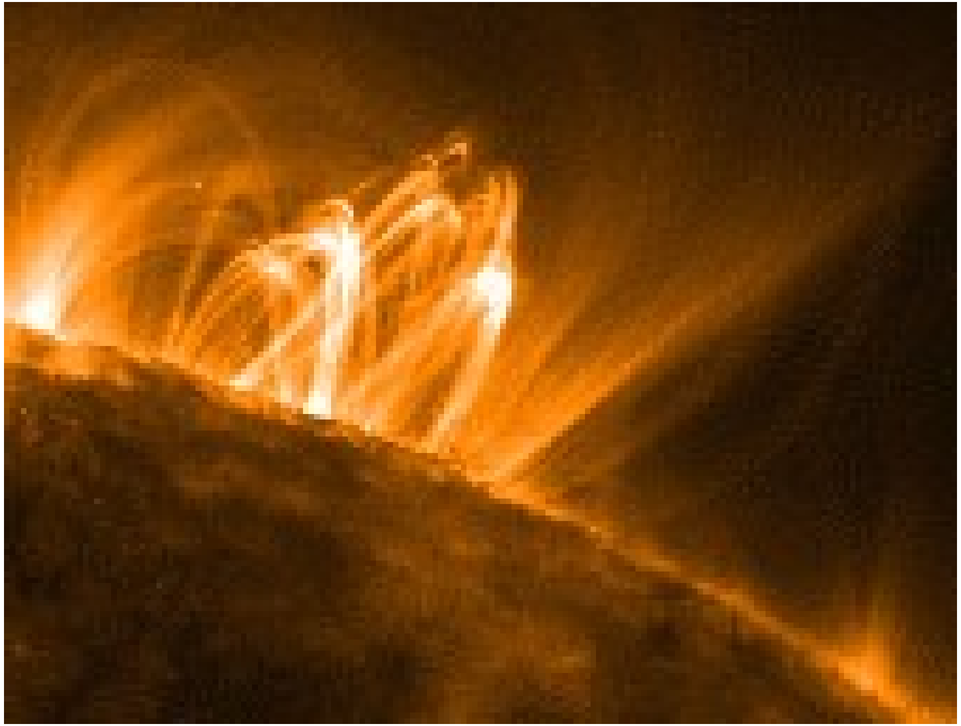
- Spot cooler and lower than surroundings
- Strong (B~0.1T) vertical magnetic field prevents heat transfer from convective flow



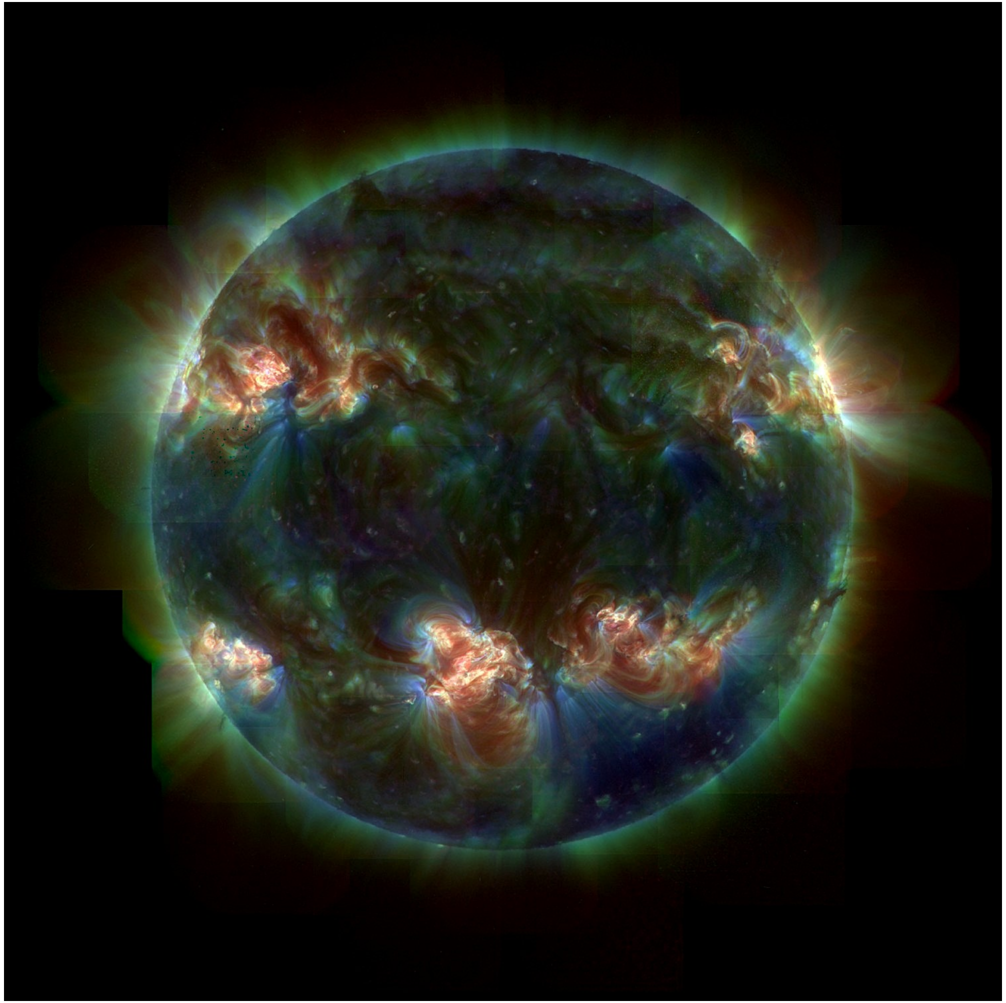
Zeilik & Gregory Fig 10-21


Close-up of sunspot. Credit: Royal Swedish Academy of Sciences www.solarphysics.kva.se

- Pairs of spots usually linked by loop of hot, magnetic plasma



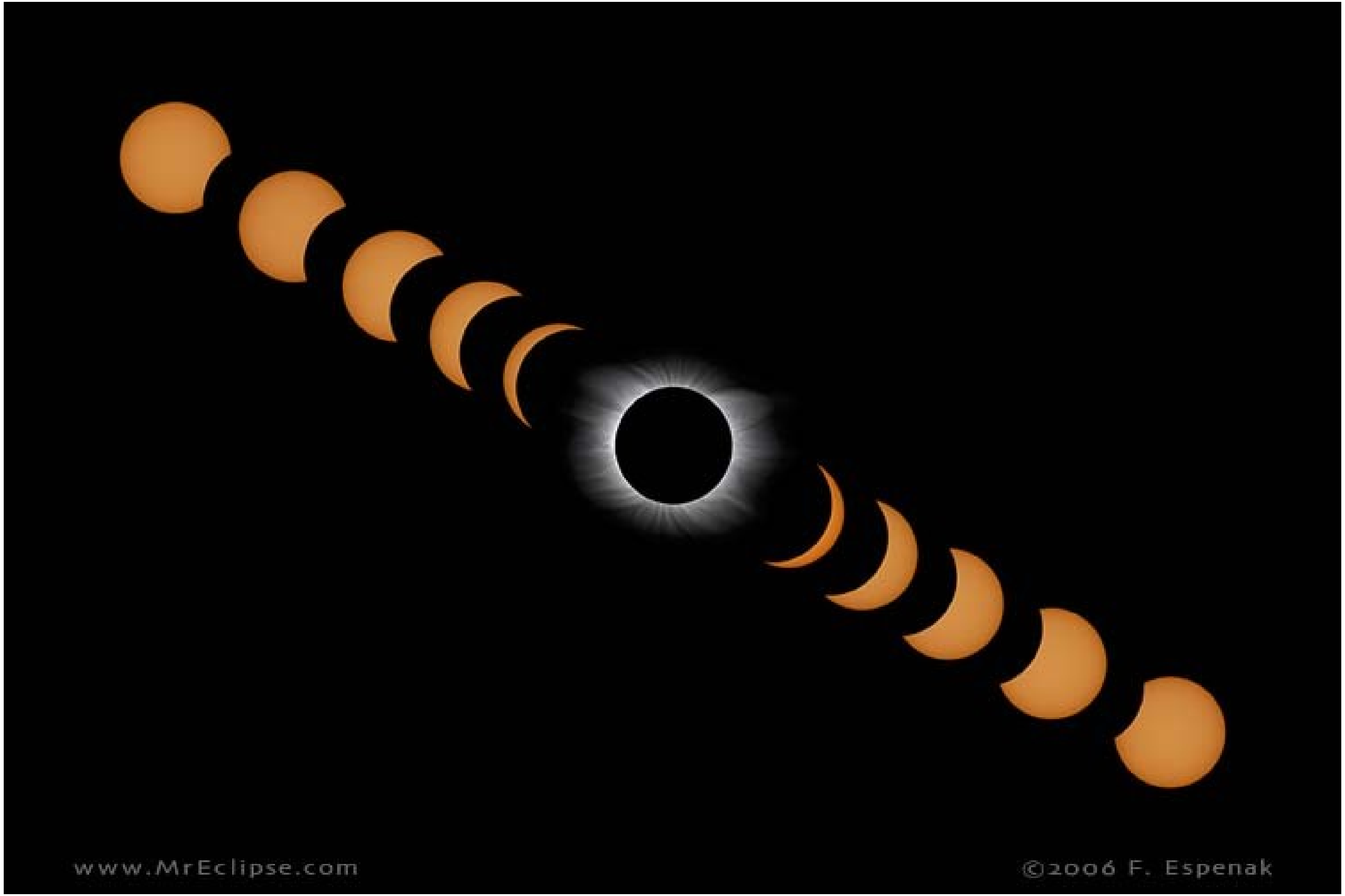
TRACE Satellite Stanford-Lockheed Institute for Space Research & NASA (trace.lmsal.com/POD/images)



TRACE Satellite Stanford-Lockheed Institute for Space Research & NASA (trace.lmsal.com/POD/images)

Corona

- The outer atmosphere of the Sun is very hot ($T \sim 10^6$ K) and tenuous
- White halo seen during eclipses extends several solar radii
- Also emits strongly in UV and X-rays observed from satellites and at radio wavelengths


www.MrEclipse.com
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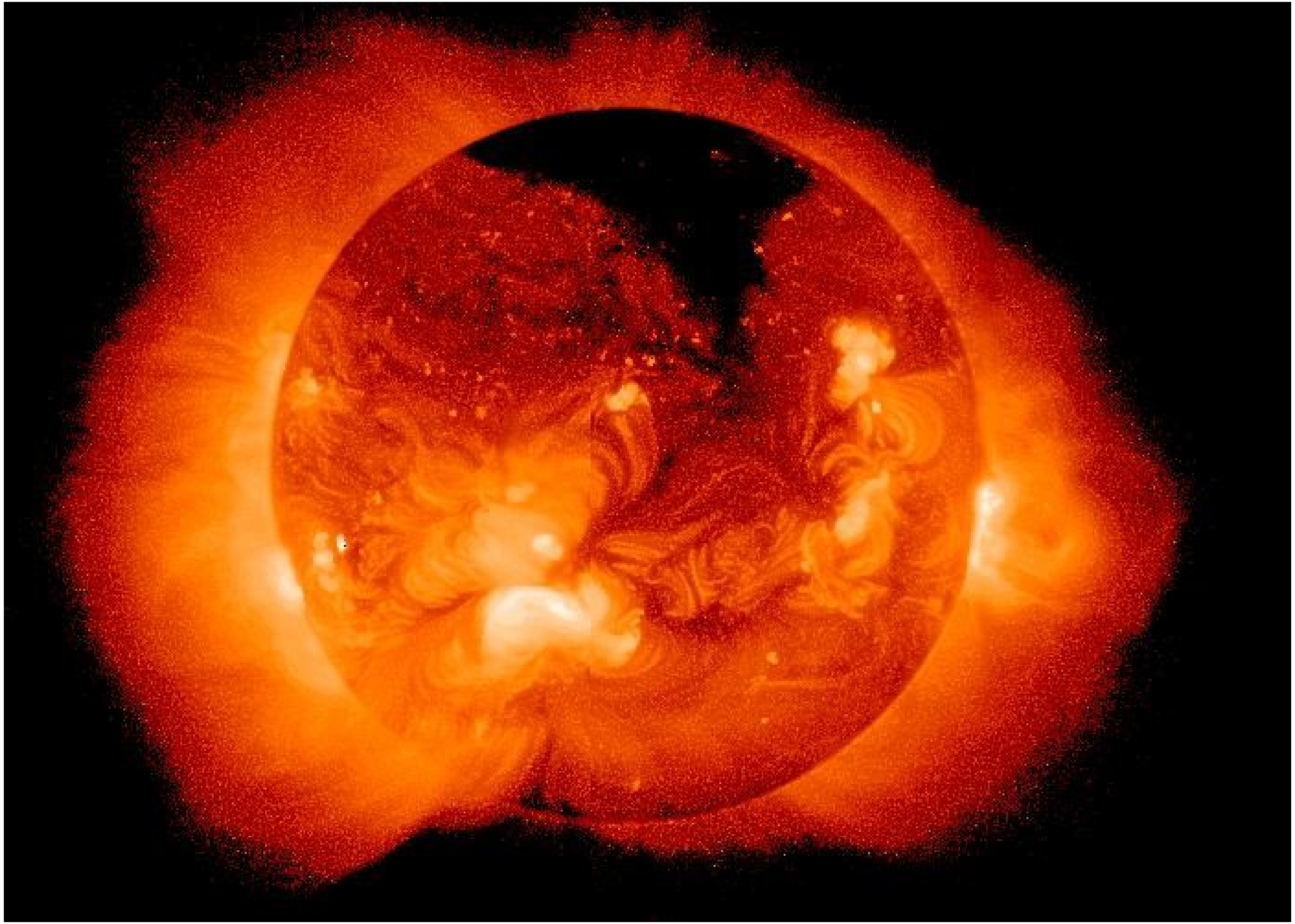

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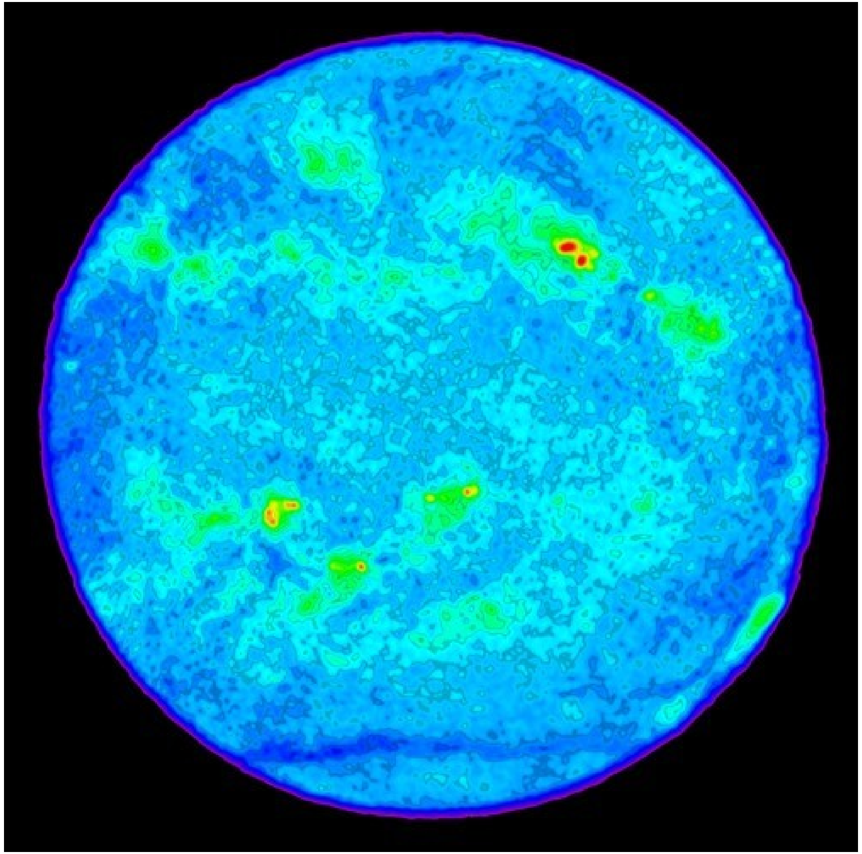


VLA radio image at 5 GHz
http://images.nrao.edu/506

The Sun: Summary

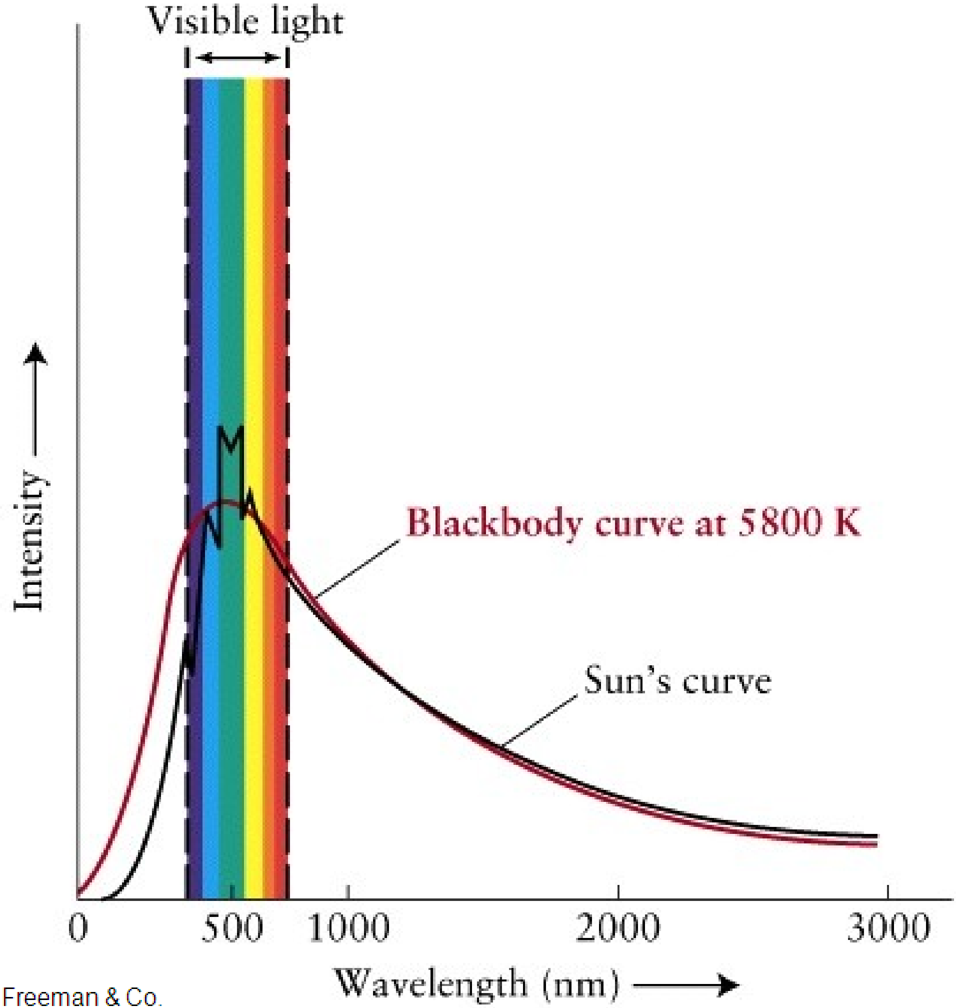
- The Sun is a very average star about half way through its 10 billion year lifetime
- Energy generated in core by nuclear fusion is transported by radiation and convection to the photosphere
- Surface activity is powered by magnetic fields generated by dynamo action through convection and differential rotation

Starlight

- Continuum spectrum
- Blackbody radiation
- Wien’s Displacement Law
- Luminosity and Flux

Continuum Spectrum

- The intensity of light from the Sun peaks at a wavelength λ=500nm
- Falls off rapidly towards the blue and more steadily to the red
- Continuum spectrum is approximately that of a perfect blackbody with T=5800 K



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Blackbody Radiation

- A *blackbody* is a body which emits and absorbs radiation perfectly.
- The intensity of radiation from a perfect blackbody is described by the *Planck function*

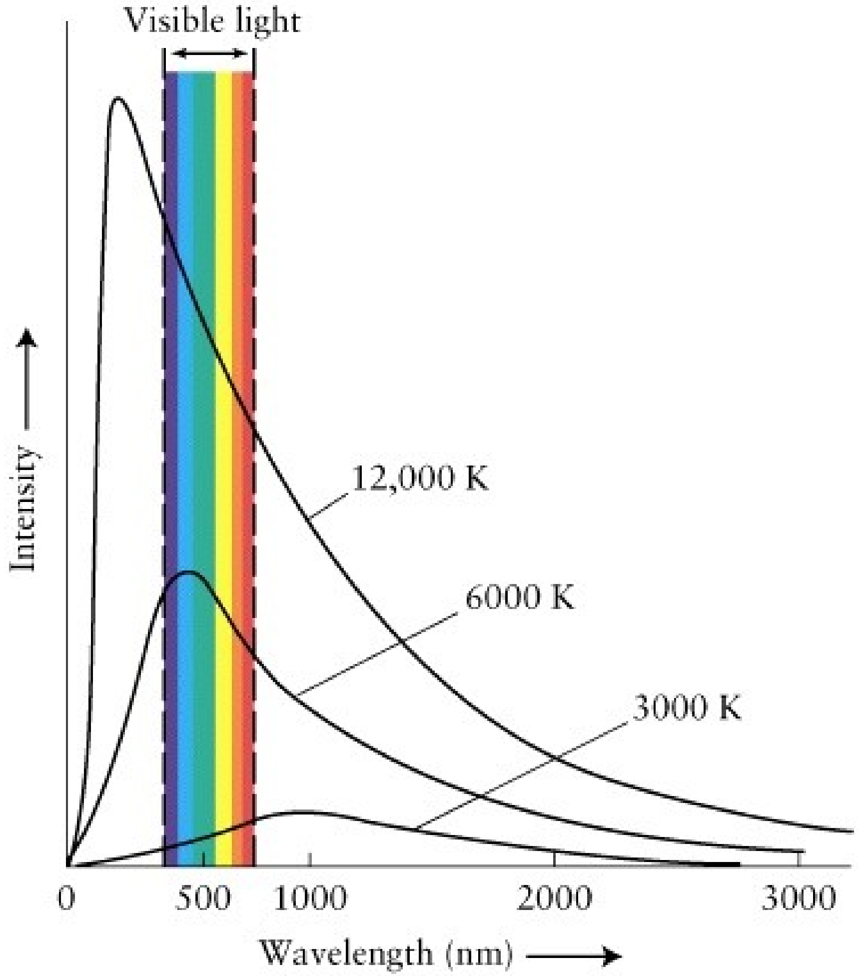
$$B_\lambda(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1}$$

Wien Displacement Law

- The wavelength of the peak of the emission from a blackbody of temperature *T* is given by

$$\lambda_{\max} = \frac{3.10^{-3}}{T}$$

- The hotter the blackbody the shorter the wavelength of the peak emission



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Luminosity of a Blackbody

- The total power in the radiation from a sphere of radius *R* emitting blackbody radiation with temperature *T* is

$$L = 4\pi R^2 \sigma T^4$$

where σ is the Stefan-Boltzmann constant

Effective Temperature

- The *effective* temperature of a star is the surface temperature that a spherical blackbody with the star's radius would have to have, to provide the star's luminosity. i.e.

$$L = 4\pi R^2 \sigma T_{eff}^4$$

Luminosity and Flux

- We can also determine the luminosity of the Sun (or any star) by finding the total flux of radiation reaching Earth as long as we also know the distance
- When we observe the spectrum of a star we are measuring the flux of radiation as a function of wavelength

Monochromatic Flux

- monochromatic flux of radiation f_λ is defined as the amount of energy crossing a unit area per unit time per unit wavelength interval ($Js^{-1}m^{-2}m^{-1}$ or $Wm^{-2}\mu m^{-1}$)

Total Flux

- The flux of radiation, *f*, is defined as the amount of energy crossing a unit area per unit time ($Js^{-1}m^{-2}$ or Wm^{-2})
- It is the sum of the monochromatic fluxes over all wavelengths

$$f = \int_0^\infty f_\lambda \, d\lambda$$

- At a distance, *d*, from the Sun it is given by

$$f = \frac{L}{4\pi d^2}$$

- Note that flux falls with the inverse square of the distance
- Hence, the luminosity can be found from

$$L = 4\pi d^2 f$$

Starlight: Summary

- The Sun and stars radiate from their surfaces very much like a blackbody
- The effective temperature of a star can be found using Wien’s law
- The luminosity of a star can be found by measuring its flux and using the inverse square law