

Today's Topics

Friday, February 27, 2026 (Week 5, lecture 15) – Chapters 15, 16.

A. CCD cameras

B. Telescopes by wavelength

C. The Sun: a visual introduction

D. Surface of the Sun

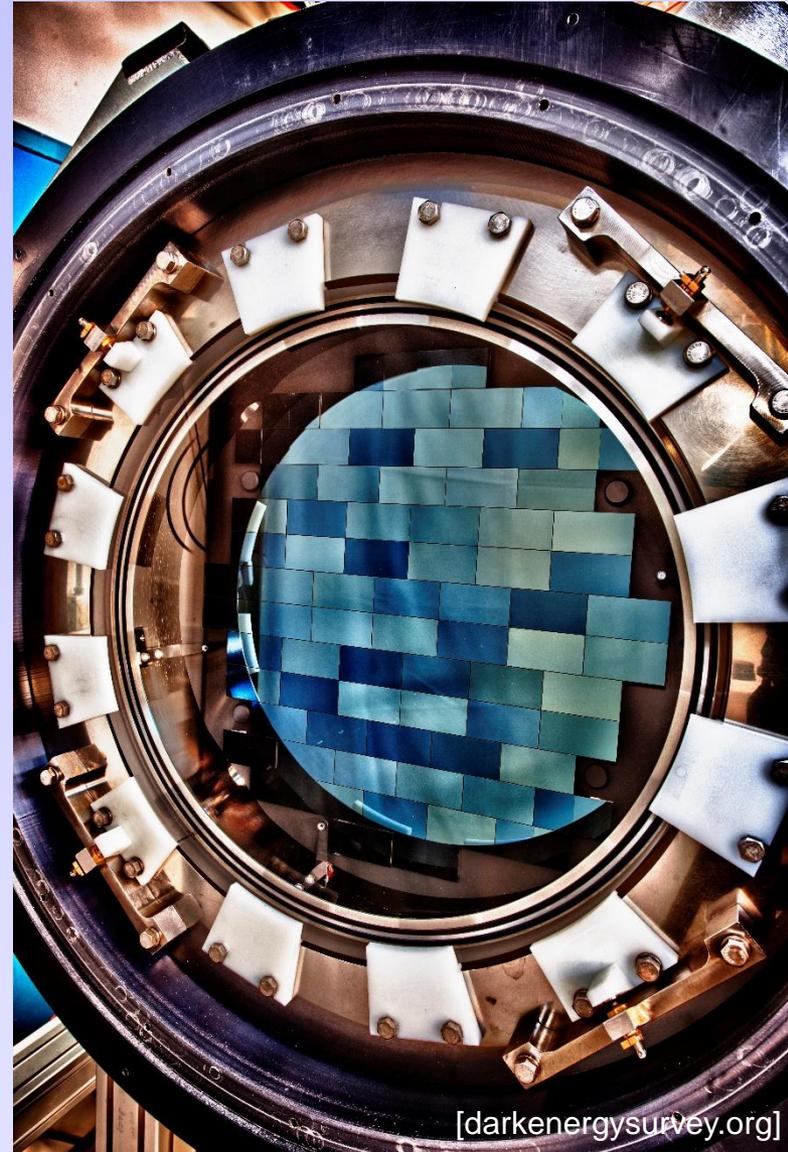
E. Internal structure

F. Solar fusion

Reminder: Problem Set #5 part 1 is due on ExpertTA on Friday, March 7, by 9:00 am.
Problem Set #5 part 1 is due in class on Friday, March 7 (hardcopy).

CCD Cameras

- CCD = Charge Coupled Device
- Standard digital camera sensor
- Wavelength
 - can cover X-ray to IR.
- **Efficiency:** 30-90% of photons detected (human eye ~ 20% in dark).
- Data is stored on a computer for later analysis (often made public).
- Often combined with a **spectrometer**.
- Does not work for microwaves and radio-waves (antenna sensor)...yet.

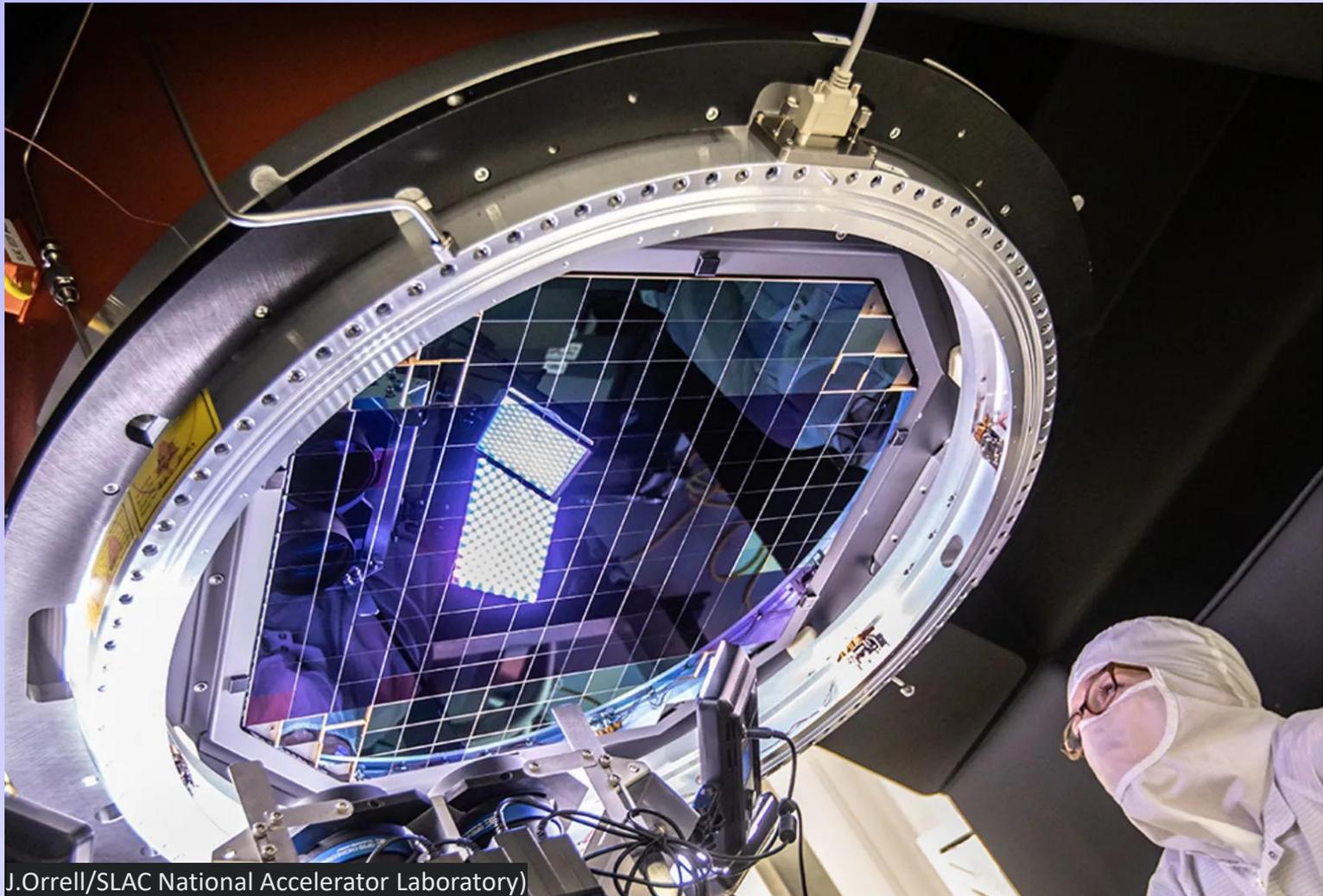


[darkenergysurvey.org]

CCD array for Dark Energy Survey camera

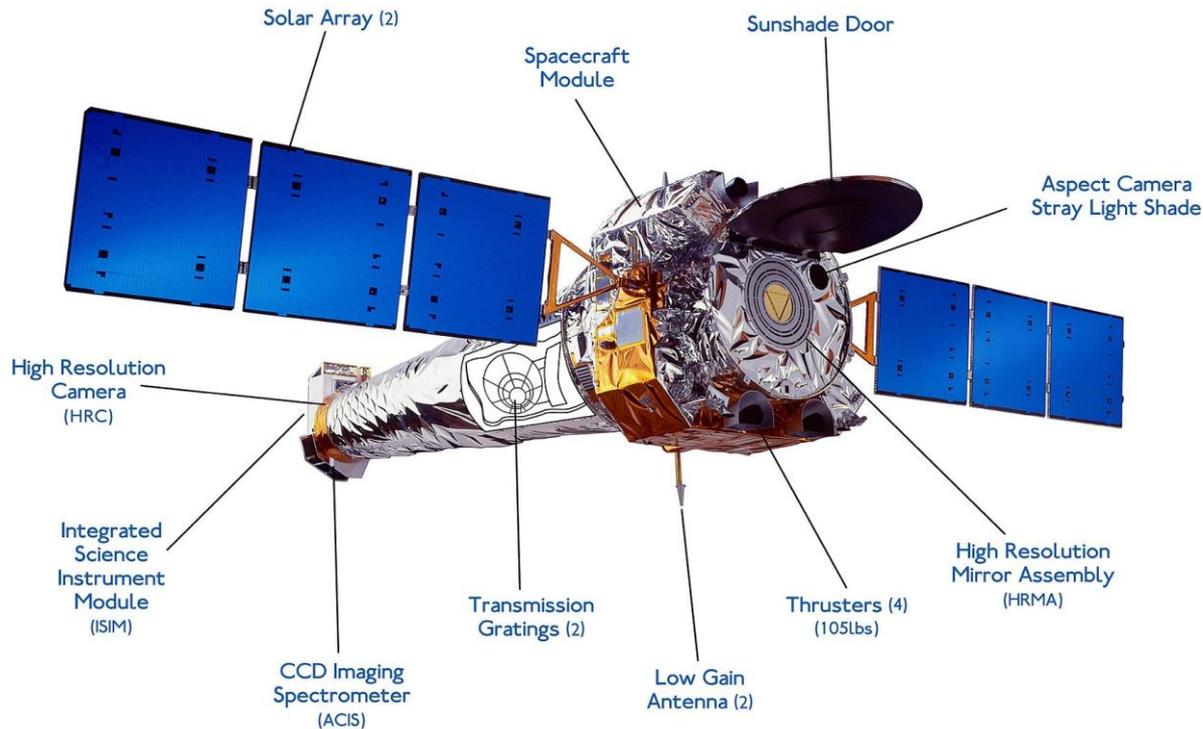
Largest CCD camera in the world !!

The Vera Rubin telescope has 3,200 Megapixels (189 CCD sub-arrays).

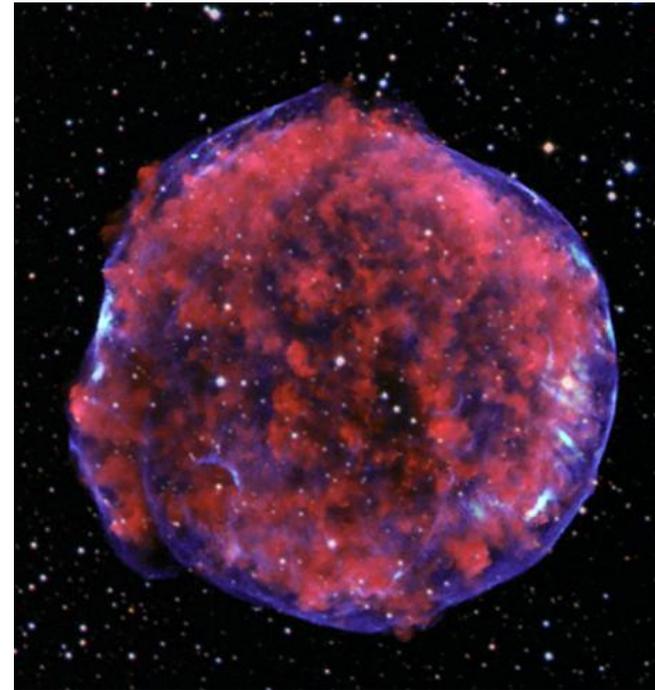


J.Orrell/SLAC National Accelerator Laboratory)

Chandra X-ray Telescope



[NASA/CXC/NGST - <http://chandra.harvard.edu>]



Tycho's supernova (1572 AD).
X-ray: red & blue. Stars are optical.

Hubble Space Telescope



Wavelengths: near-IR, visible, ultraviolet.

Main mirror diameter: $D = 2.4 \text{ m}$

Angular resolution: $\theta_{min} \sim 0.05'' = 50 \text{ mas}$



“pillars of creation” in the Eagle Nebula
(Serpens constellation, northern hemisphere)

James Webb Space Telescope

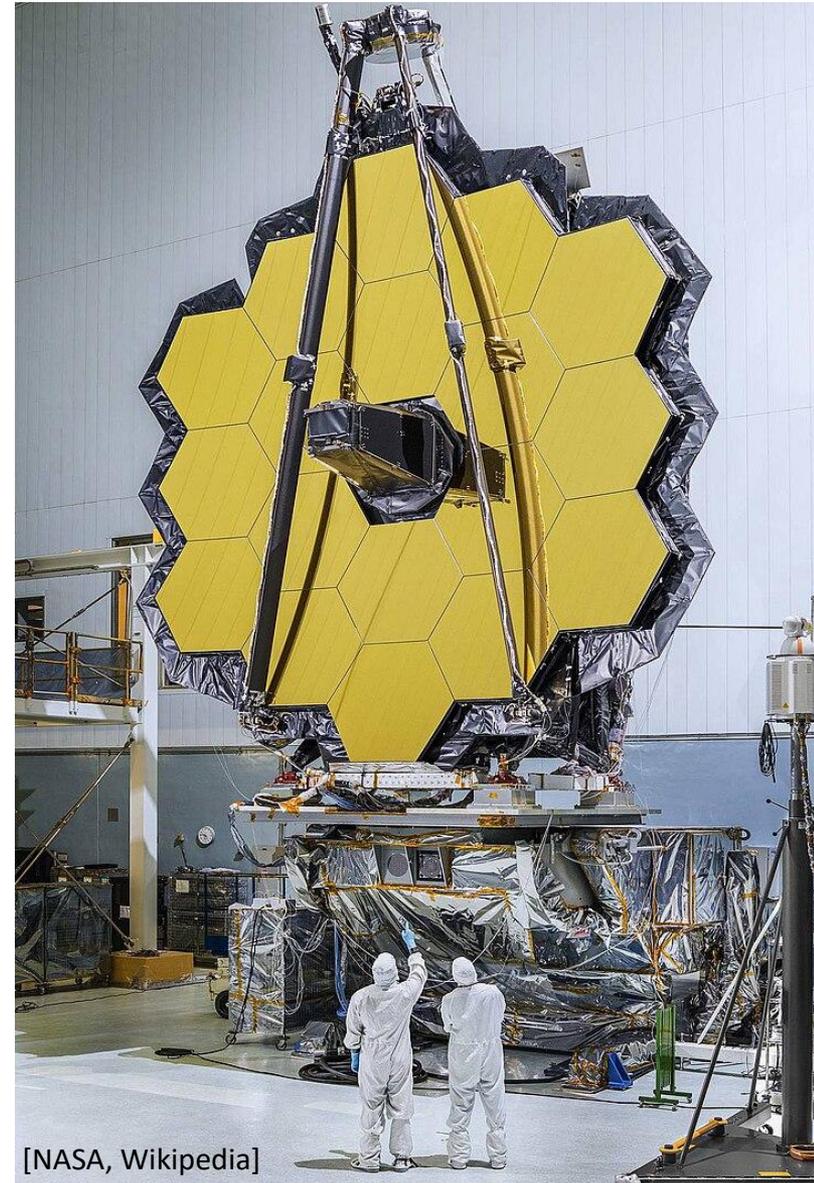


Full size mock-up model [NASA/Goddard, Wikipedia]

Wavelengths: near-IR, mid-IR (0.6-28 microns).

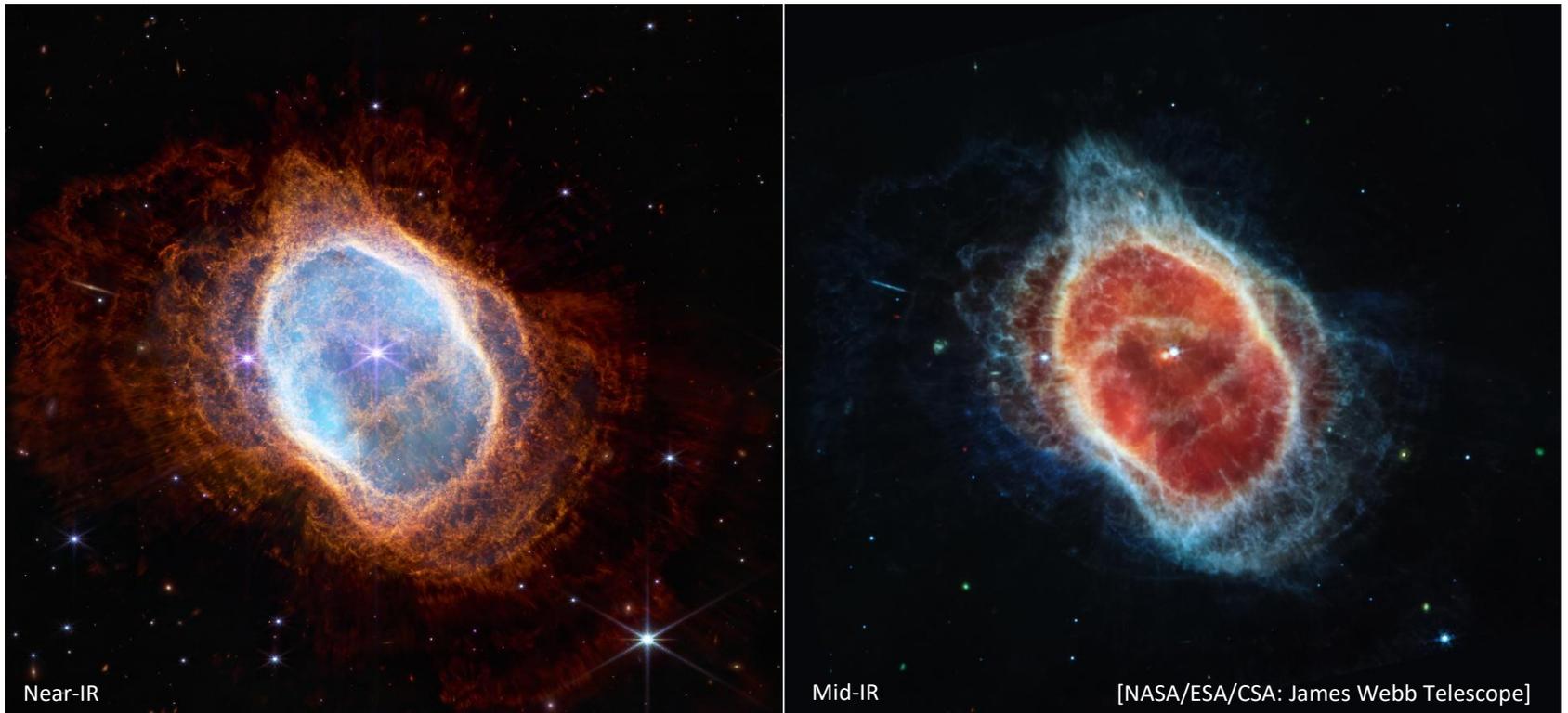
Main mirror diameter: $D = 6.5 \text{ m}$

Angular resolution: $\theta_{min} \sim 0.1'' = 100 \text{ mas}$



[NASA, Wikipedia]

James Webb Space Telescope



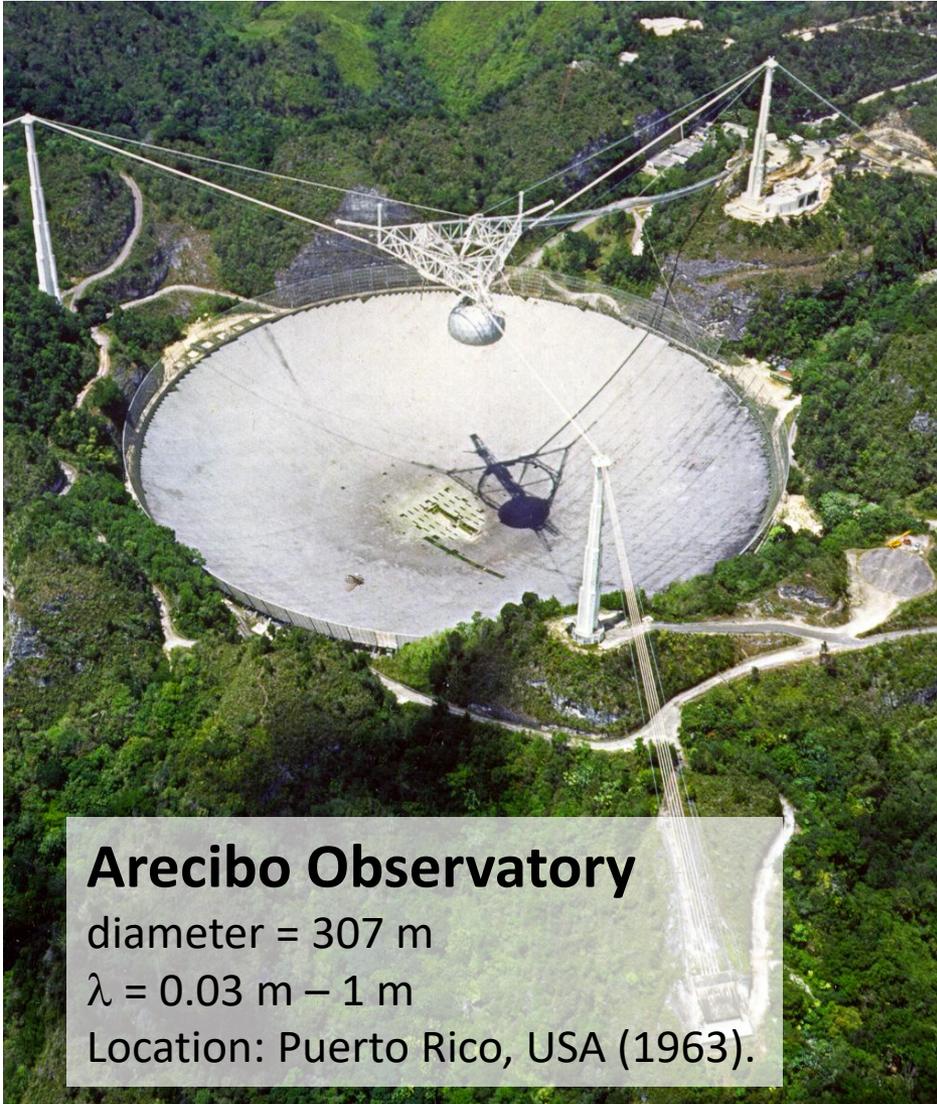
Southern Ring Nebula, constellation of Vela

Wavelengths: near-IR, mid-IR (0.6-28 microns).

Main mirror diameter: $D = 6.5 \text{ m}$

Angular resolution: $\theta_{min} \sim 0.1'' = 100 \text{ mas}$ (at $\lambda = 2 \text{ microns}$)

Arecibo Radio Telescope



Arecibo Observatory

diameter = 307 m

$\lambda = 0.03 \text{ m} - 1 \text{ m}$

Location: Puerto Rico, USA (1963).

[source: naic.edu]

FAST Radio Telescope



[source: Wikipedia, Xinhua News]

Tianyan FAST Telescope

“Five-hundred-meter Aperture Spherical Telescope”

$\lambda = 0.1 \text{ m} - 10 \text{ m}$

Location: Guizhou, China (operational in 2020).

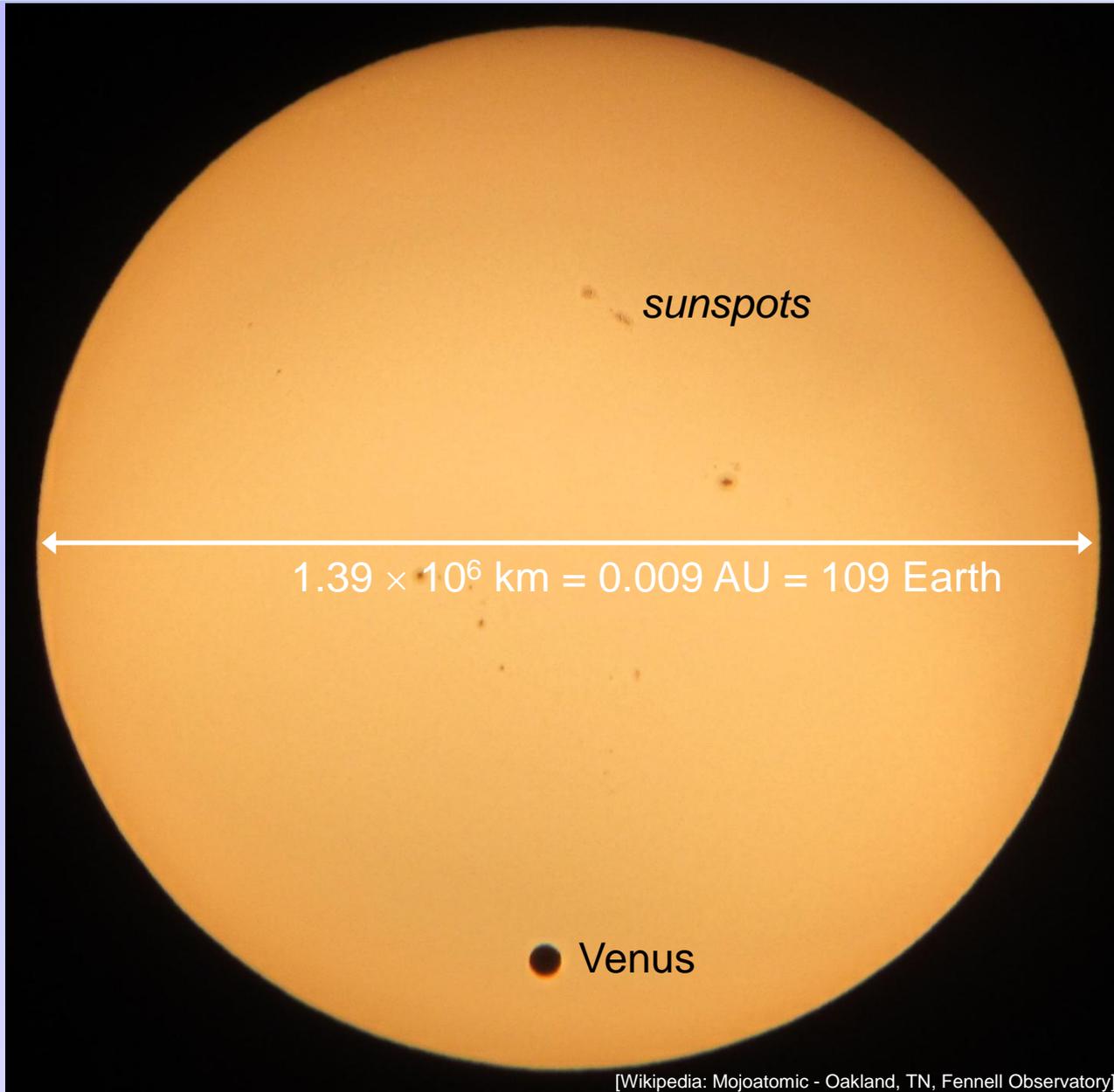
Our Sun



Our Sun



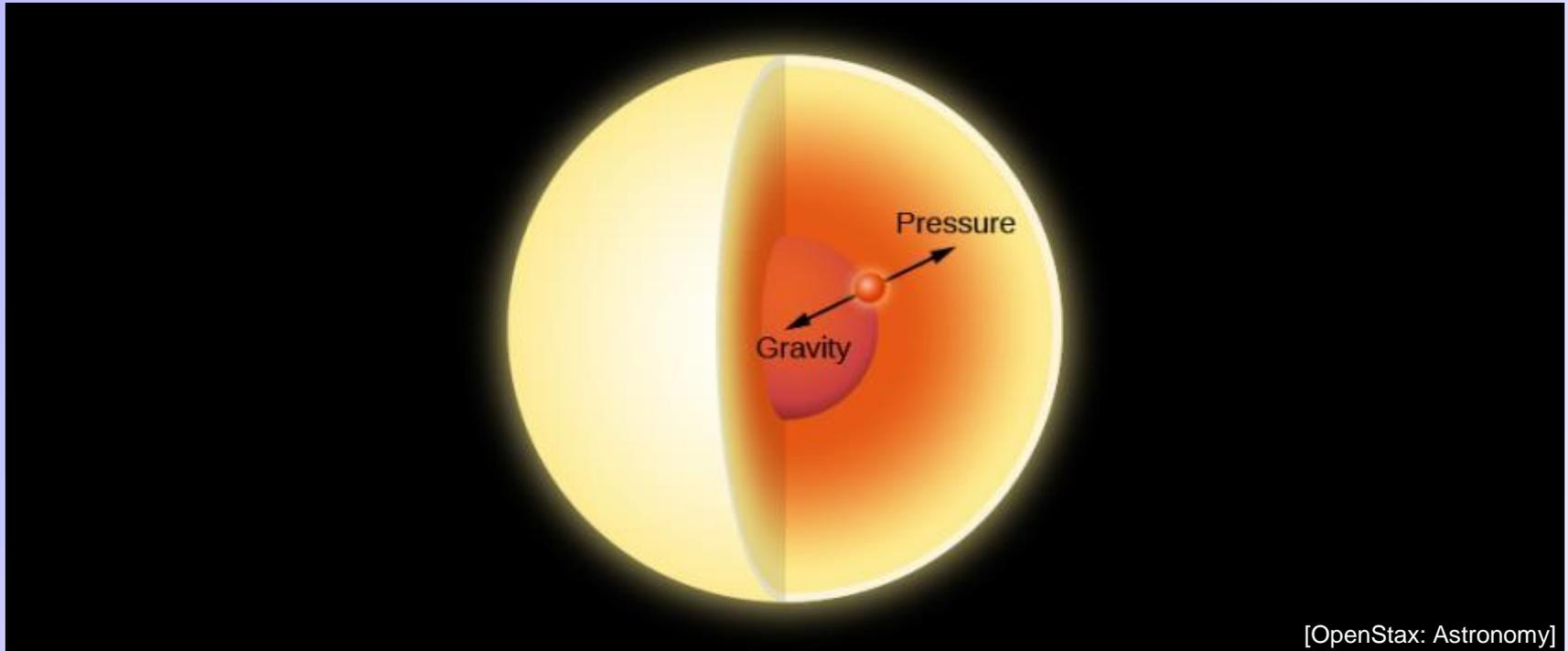
Our Sun



Transit of
Venus, 2012.
(*visible light*)

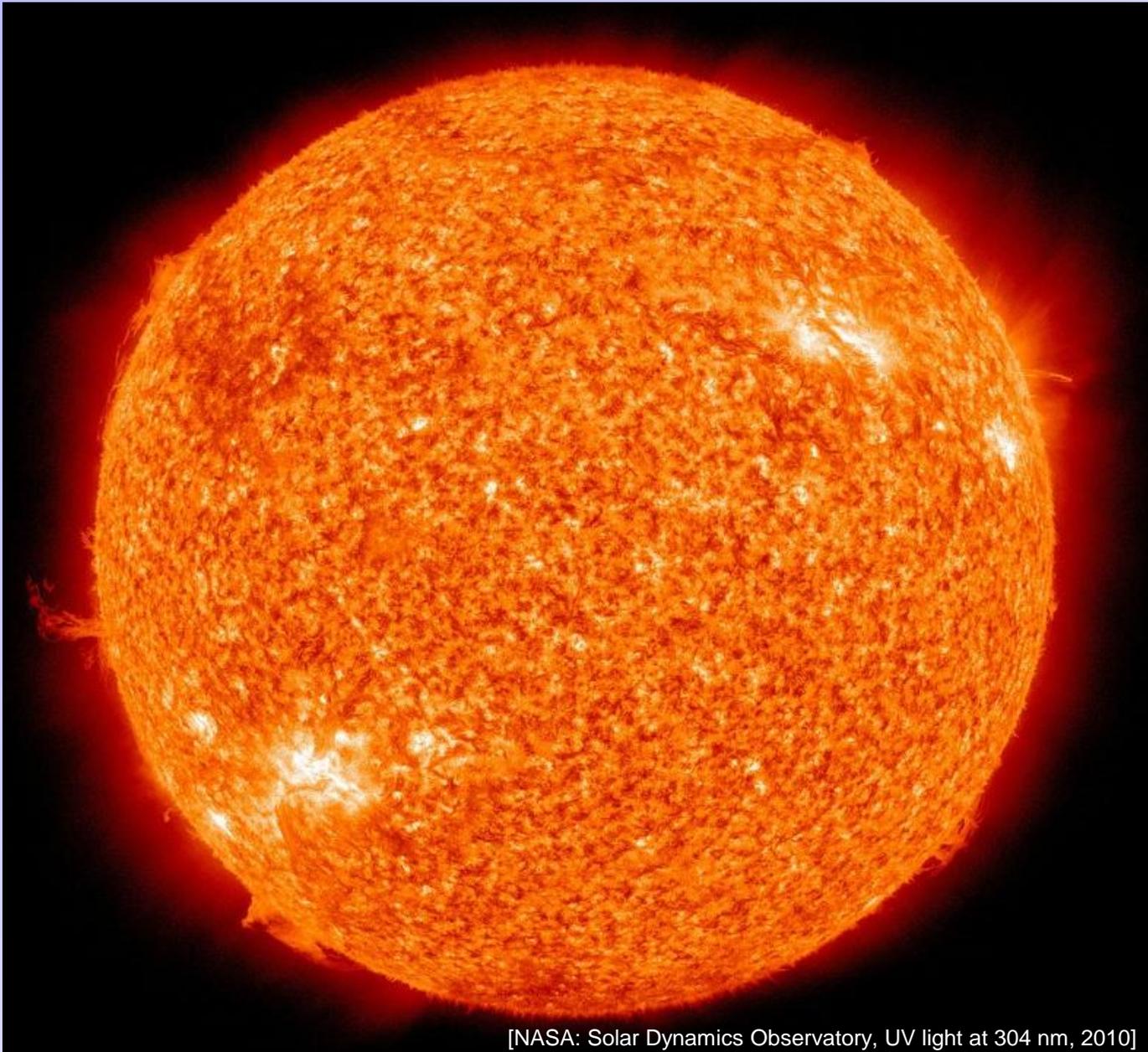
Solar Equilibrium

Gravity vs Fusion Heat



Hydrostatic Equilibrium: In the Sun (and any star), the **inward force of gravity** is ***exactly balanced*** at each point by the **outward force of gas pressure** due to heat from nuclear fusion.

Our Sun



[NASA: Solar Dynamics Observatory, UV light at 304 nm, 2010]

The Sun is Gigantic

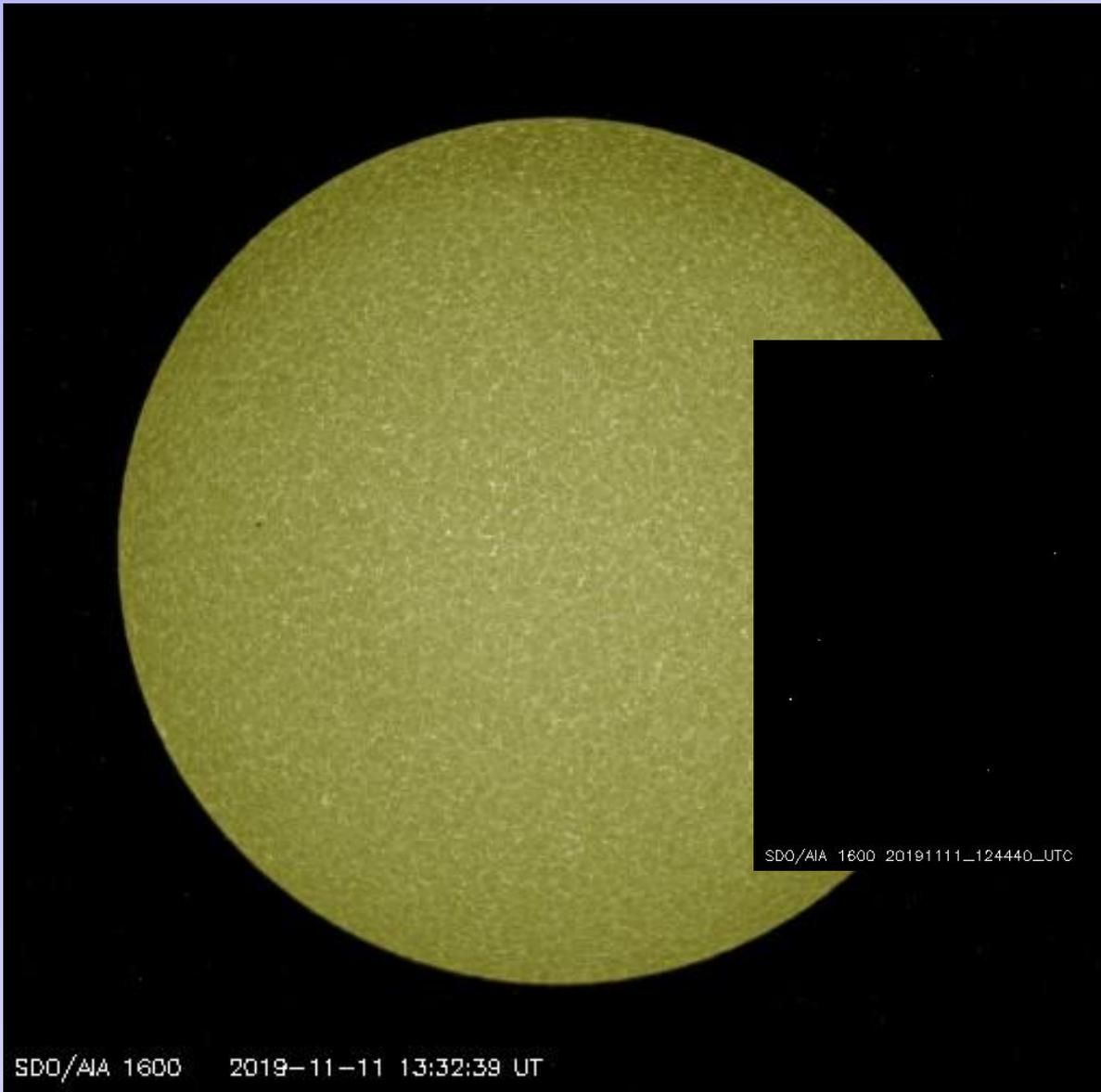


Sun view at 1600 nm.

SDO/AIA 1600 2019-11-11 13:32:39 UT

Transit of Mercury, November 11, 2019

The Sun is Gigantic



Sun view at 1600 nm.

Transit of Mercury, November 11, 2019

The Sun is Gigantic



[NASA: SDO satellite]

Transit of Mercury, May 9, 2016

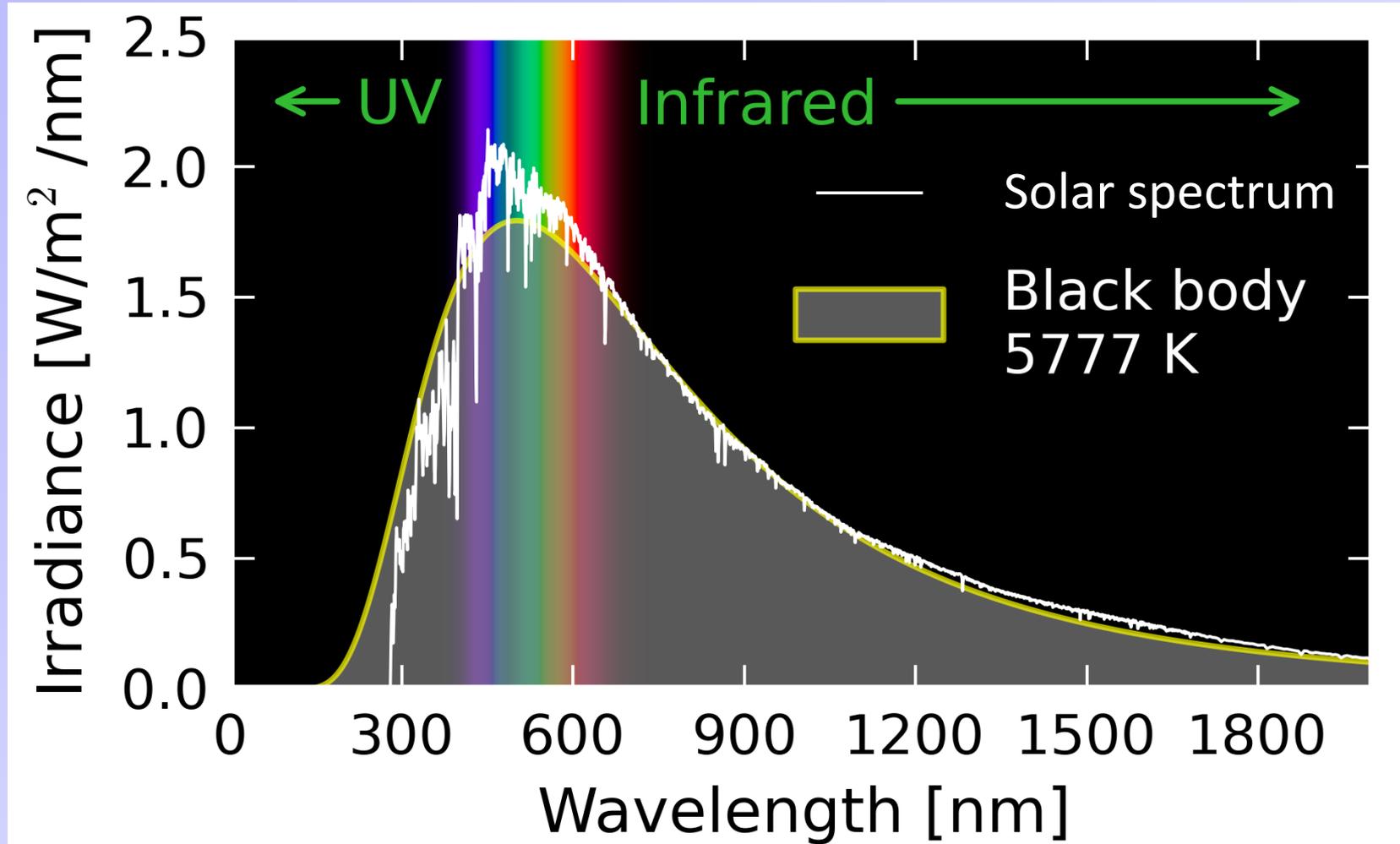
The Sun is Gigantic



June 26, 2019 | The International Space Station passes in front of the sun as seen from Gyöngyös, Hungary. (Peter Komka/EPA-EFE/Shutterstock)

Our Sun

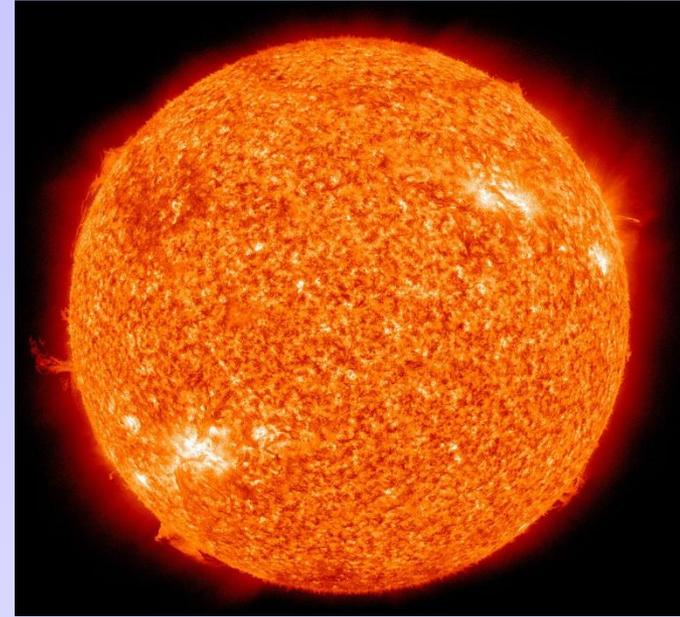
Blackbody Radiation Source



Our Sun: Surface (photosphere)

Properties

- Temperature = 5777 K (surface/photosphere)
- Substance: Plasma (electrons & nuclei are dissociated).
- Magnetosphere: ~ 1 Gauss at surface.
(*exception: sunspots at 3000 G*)
- Rotation period: $T_{\text{equator}} = 25$ days, $T_{\text{poles}} = 34$ days.
- Rotation axis tilt: 7.25° with respect to ecliptic.

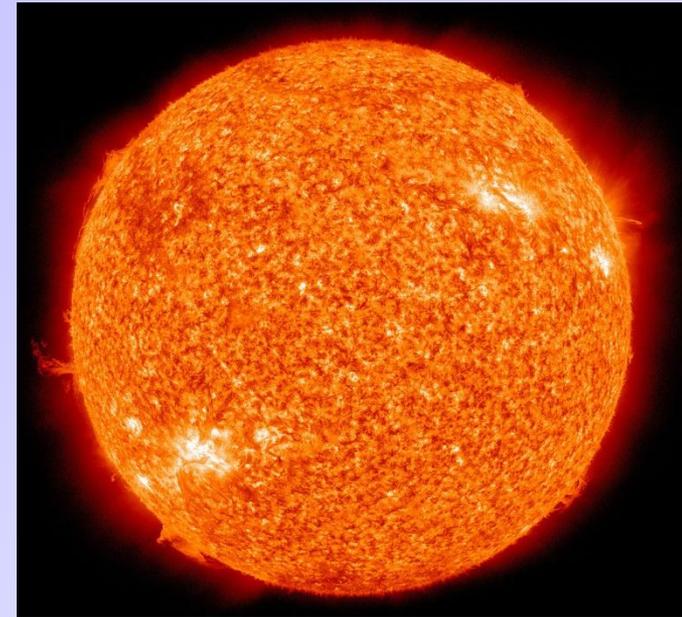


[NASA: Solar Dynamics Observatory, UV light at 304 nm, 2010]

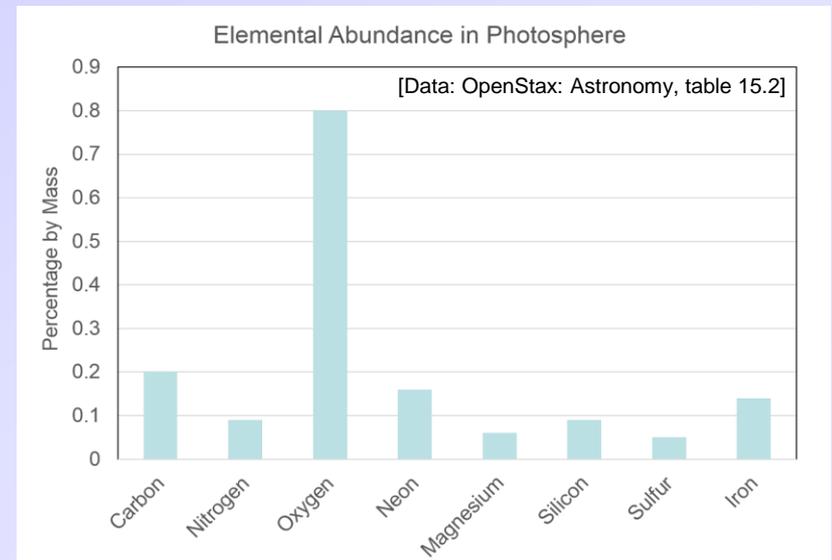
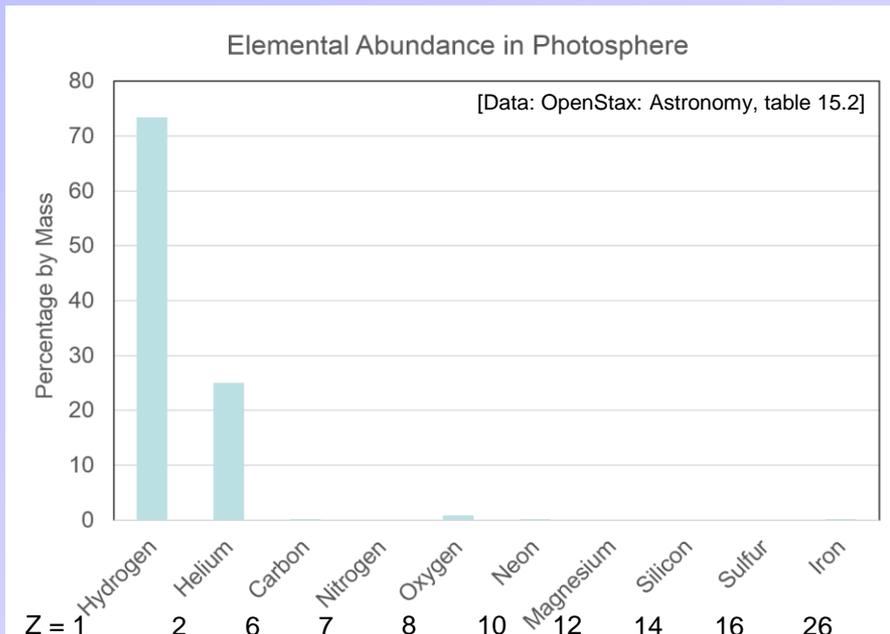
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Solar Wind

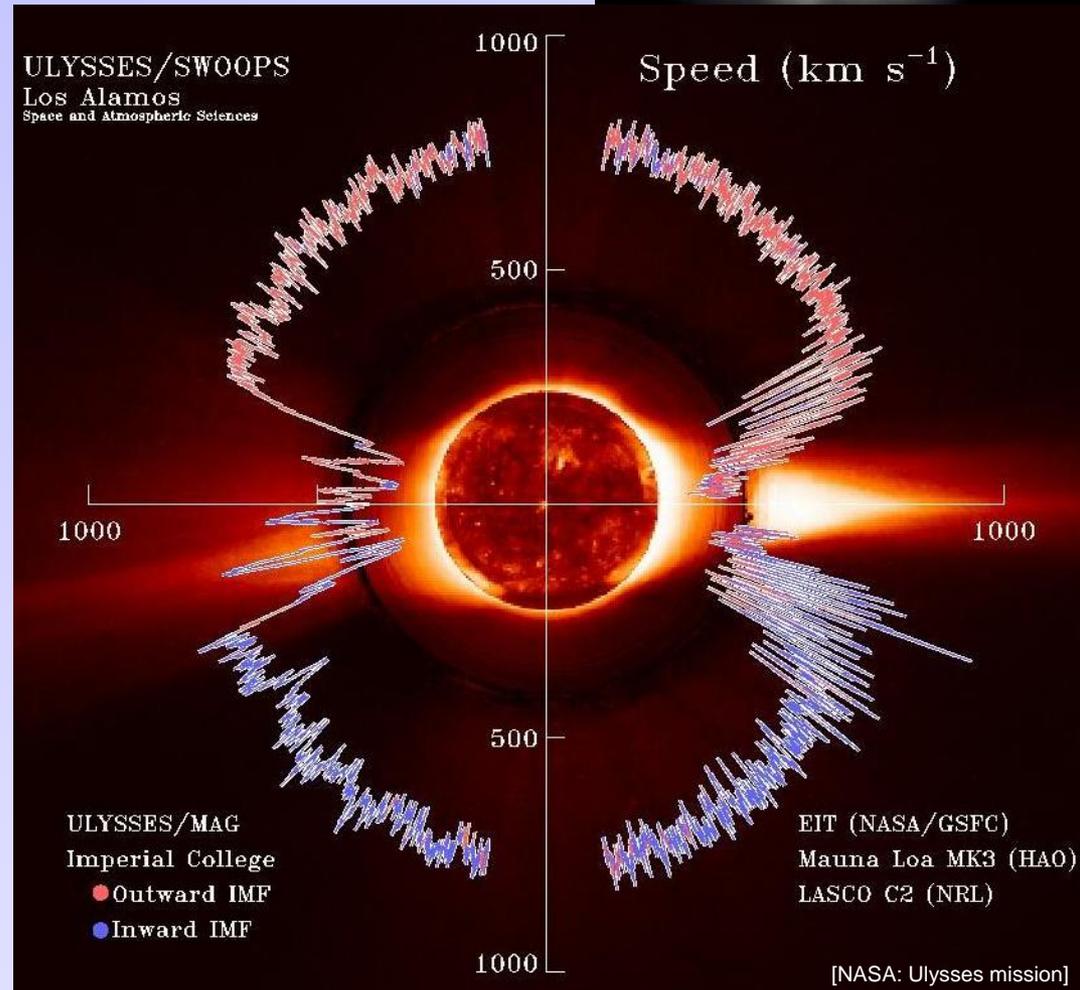
Extension of the Corona



Solar Wind

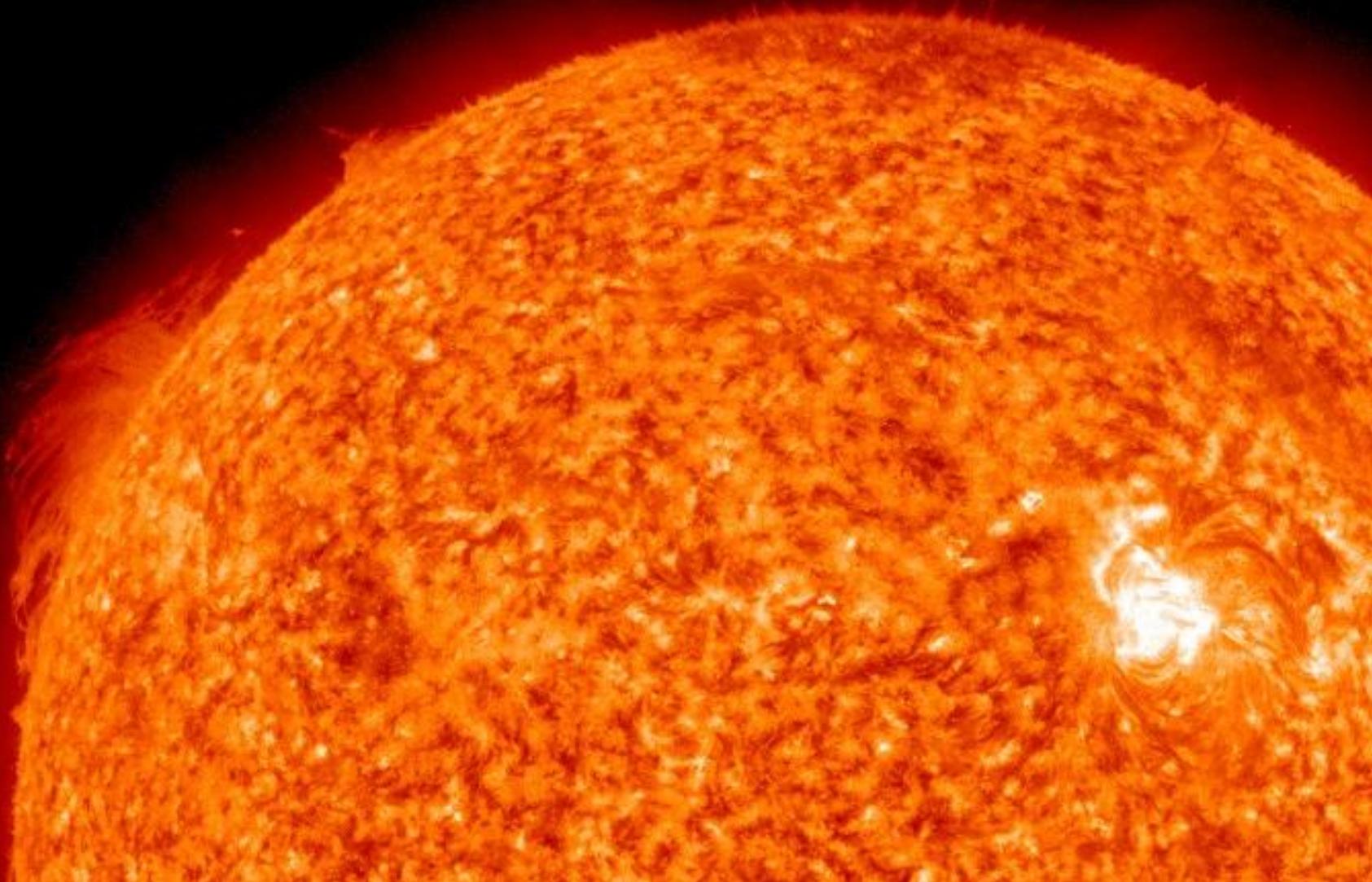
Extension of the Corona

- Corona is very hot: 1 million Kelvin
- Solar wind consists of:
 - protons
 - electrons
 - alpha particles (He nuclei)
- Energy range: 0.01 – 10 keV
- Solar wind speed: 400 – 750 km/s
- Strongest emission is from coronal holes.

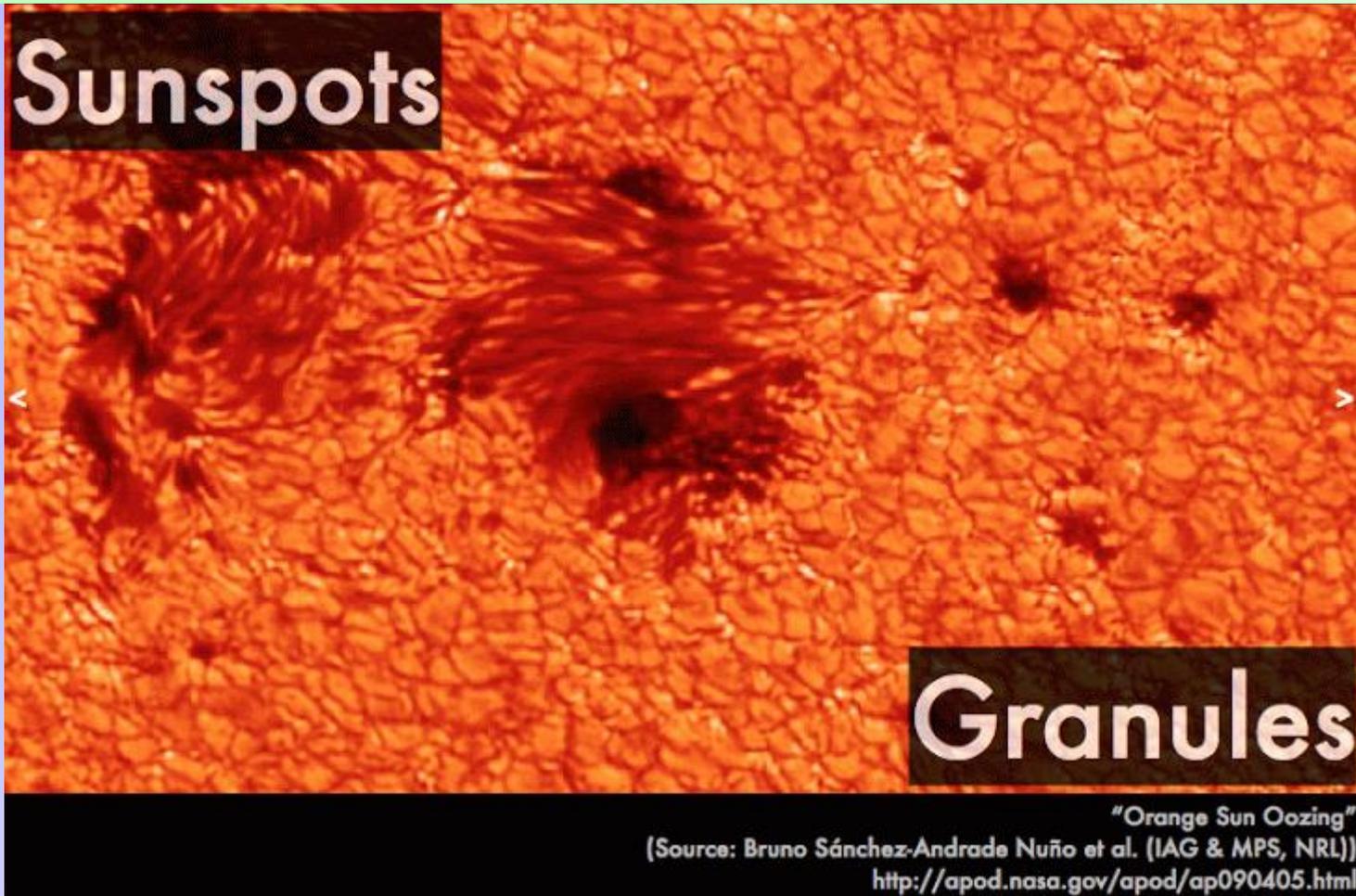


Our Sun's Surface

[NASA: Solar Dynamics Observatory, October 18, 2010]



Our Sun: Sunspots & Granules



Sunspot size ~ 10,000-20,000 km

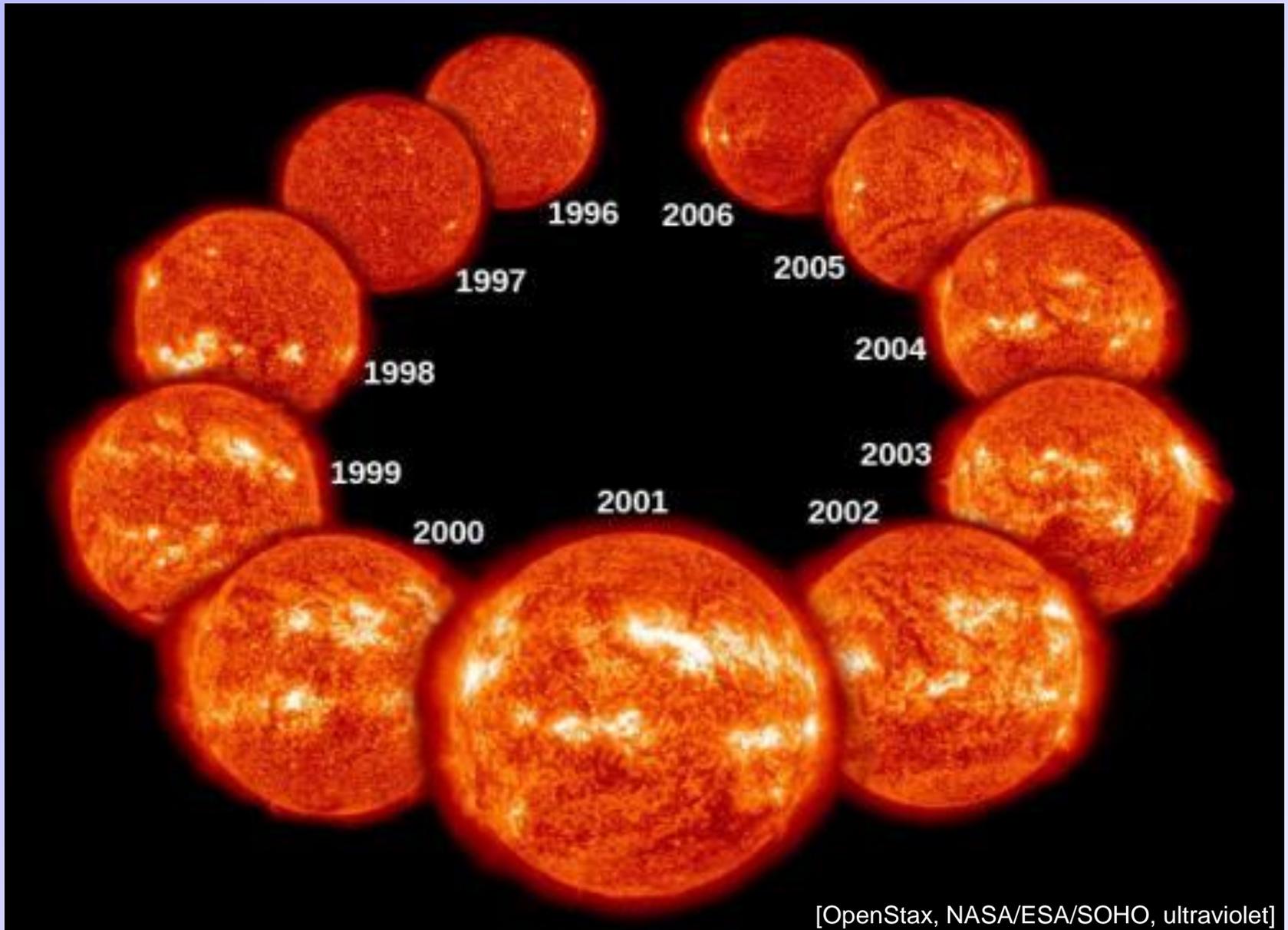
Sunspot = cooler surface region with strong magnetic field.

→ convection is impede by magnetic field.

Granule size ~ 1500 km

granule = convective cell

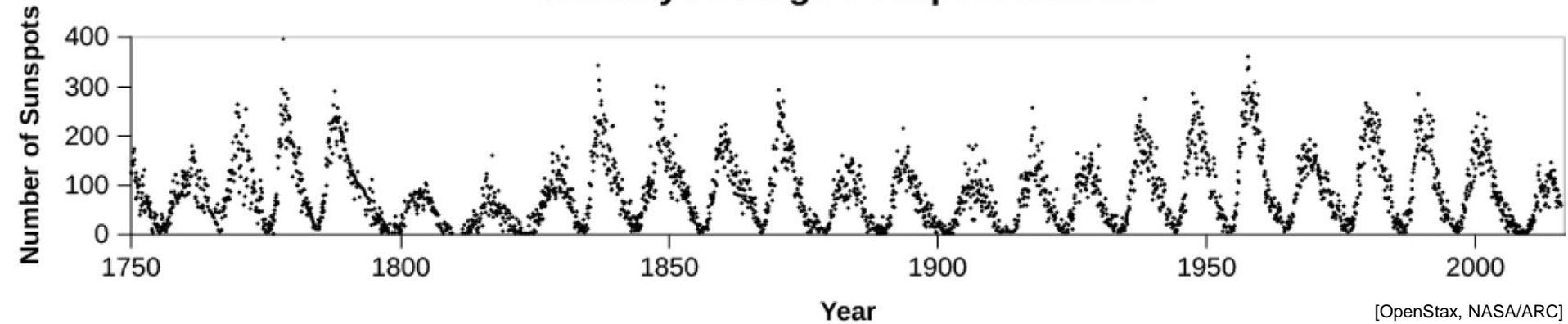
Solar Cycle: 11 year period



[OpenStax, NASA/ESA/SOHO, ultraviolet]

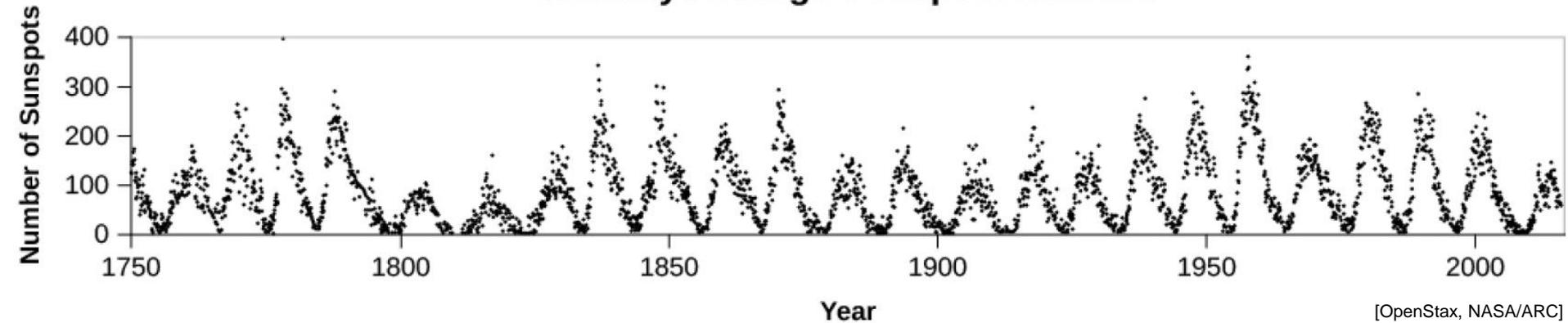
Sunspots: 11 year cycle

Monthly Average Sunspot Numbers



Sunspots: 11 year cycle

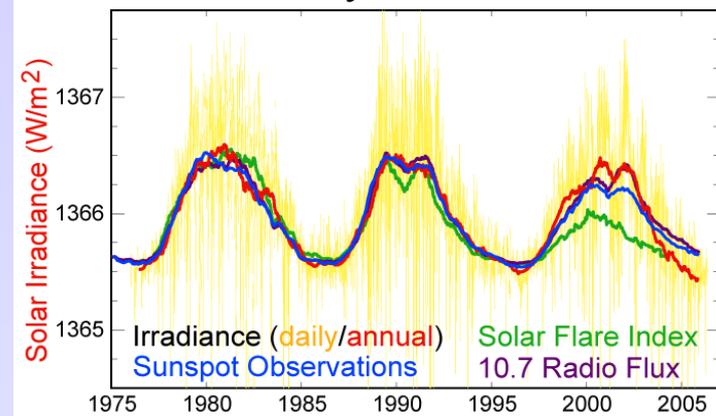
Monthly Average Sunspot Numbers



The following all vary in-sync with the solar cycle:

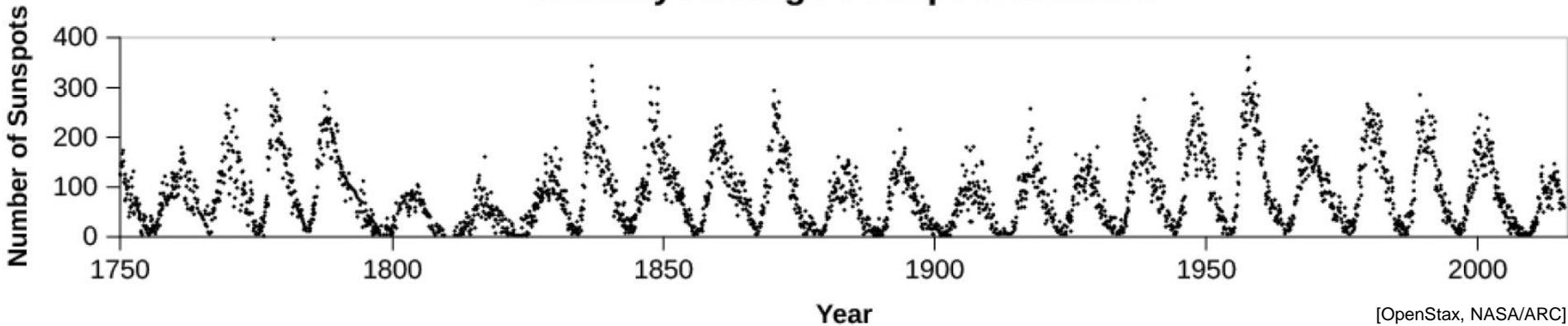
- Number of **sunspots**.
- Solar **flares** and **coronal mass ejections**.
- Total solar irradiance (but only by 0.1 %).
- Solar **UV irradiance**.

Solar Cycle Variations



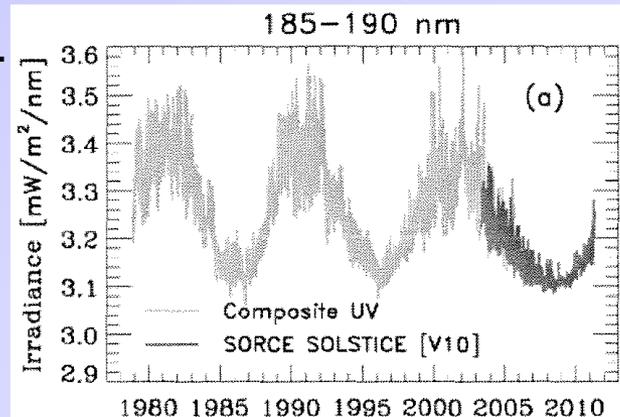
Sunspots: 11 year cycle

Monthly Average Sunspot Numbers



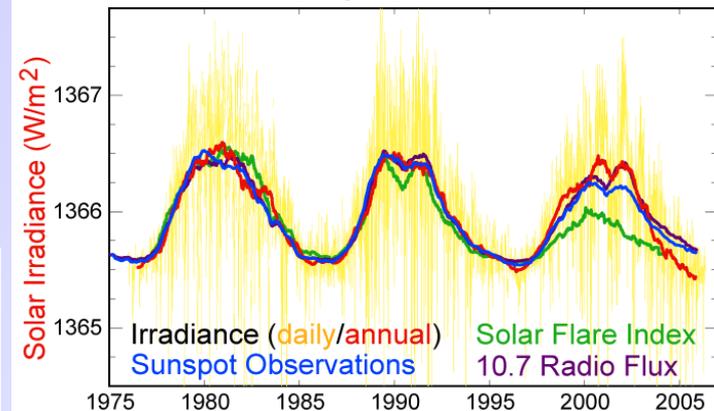
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[M. T. DeLand and R. P. Cebula, "Solar UV Variations during the decline of cycle 23", *J. Atmos. Sol.-Terr. Phys.* **77**, 225 (2011)]

Solar Cycle Variations



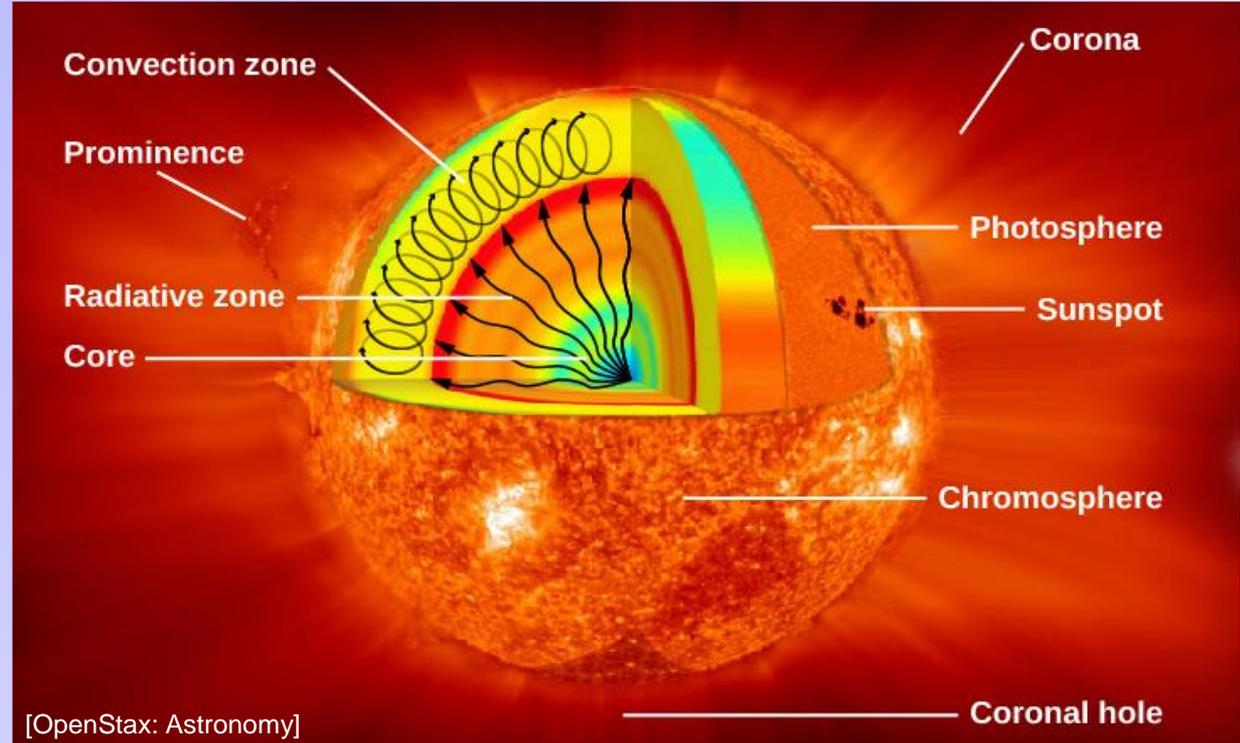
[Wikipedia]

PolleEv Quiz: PolleEv.com/sethaubin

Our Sun: Structure

Structure determined from:

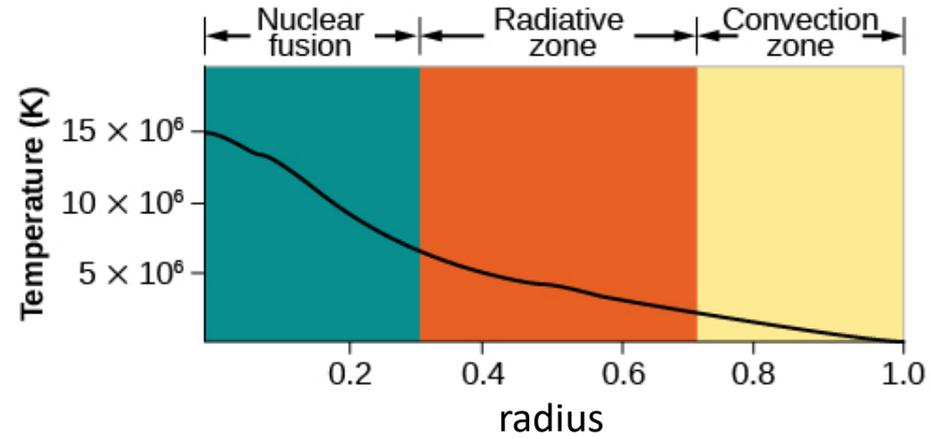
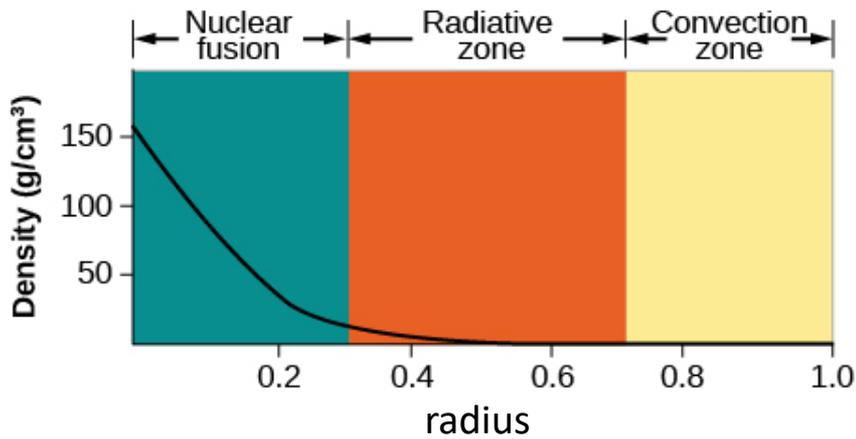
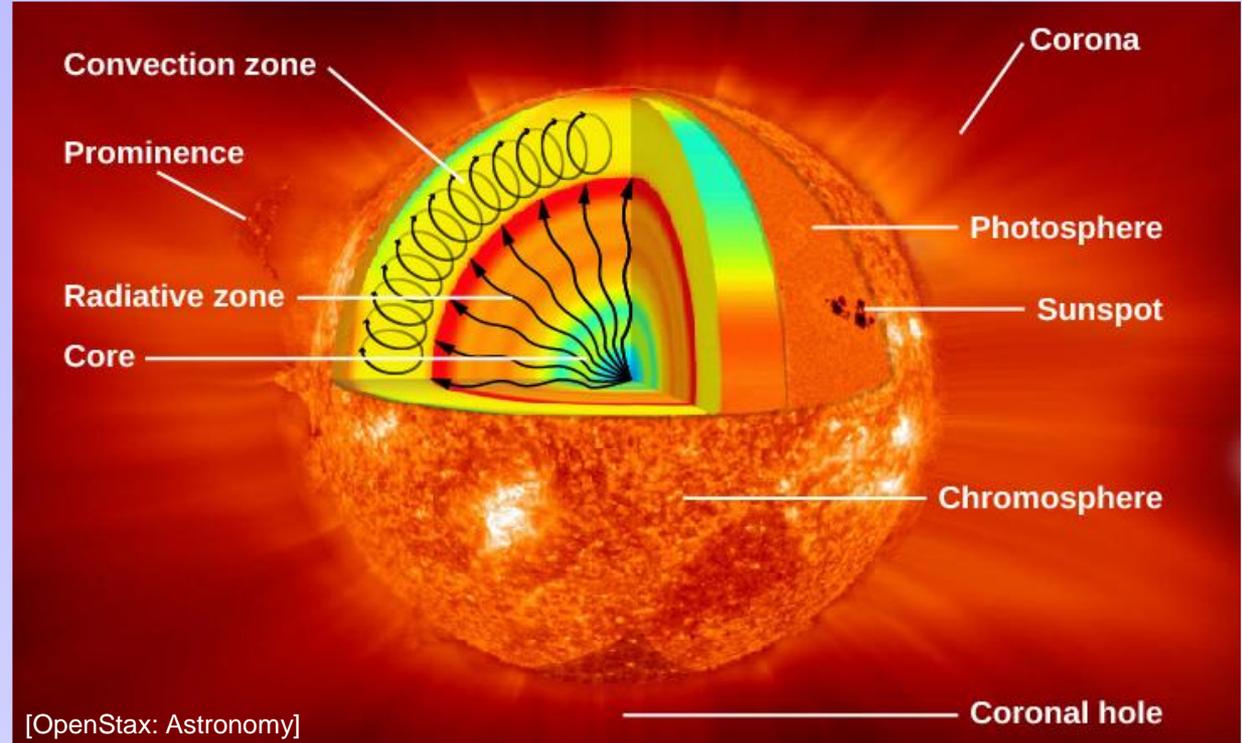
- Computer modelling.
- Helioseismology.
- **Neutrino** measurements.



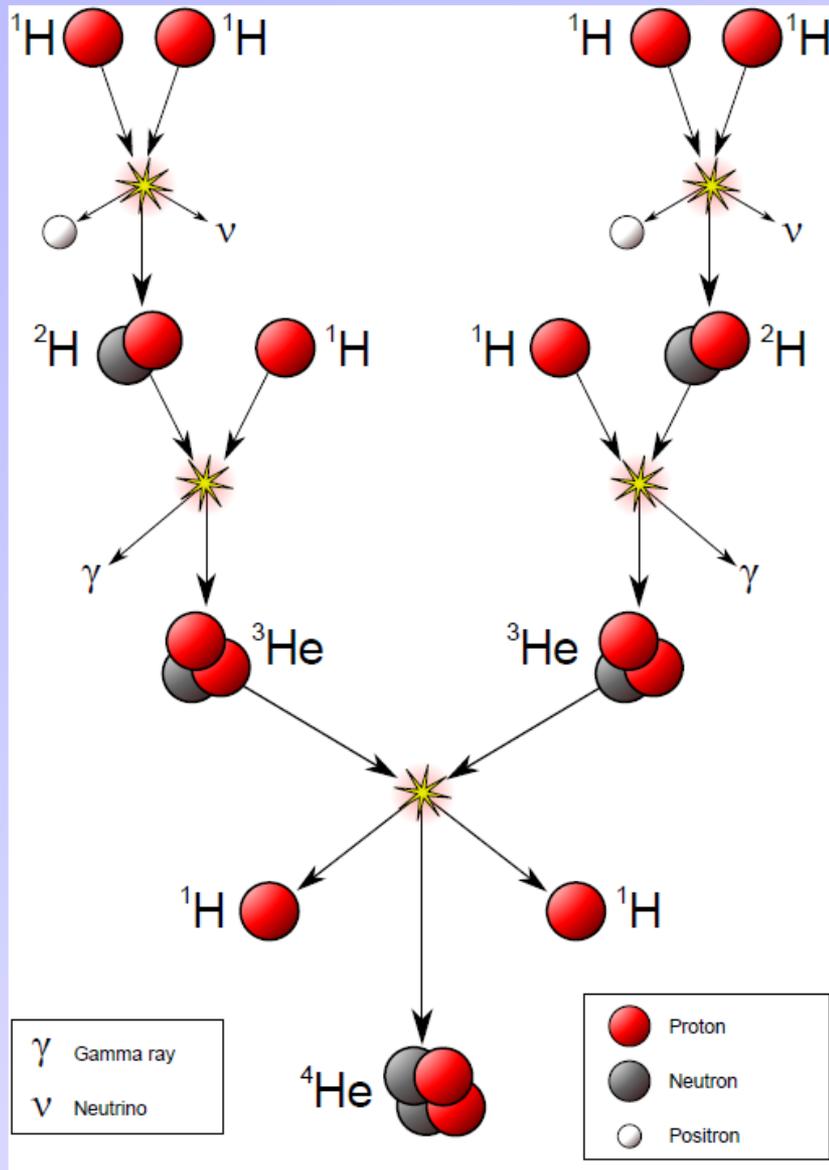
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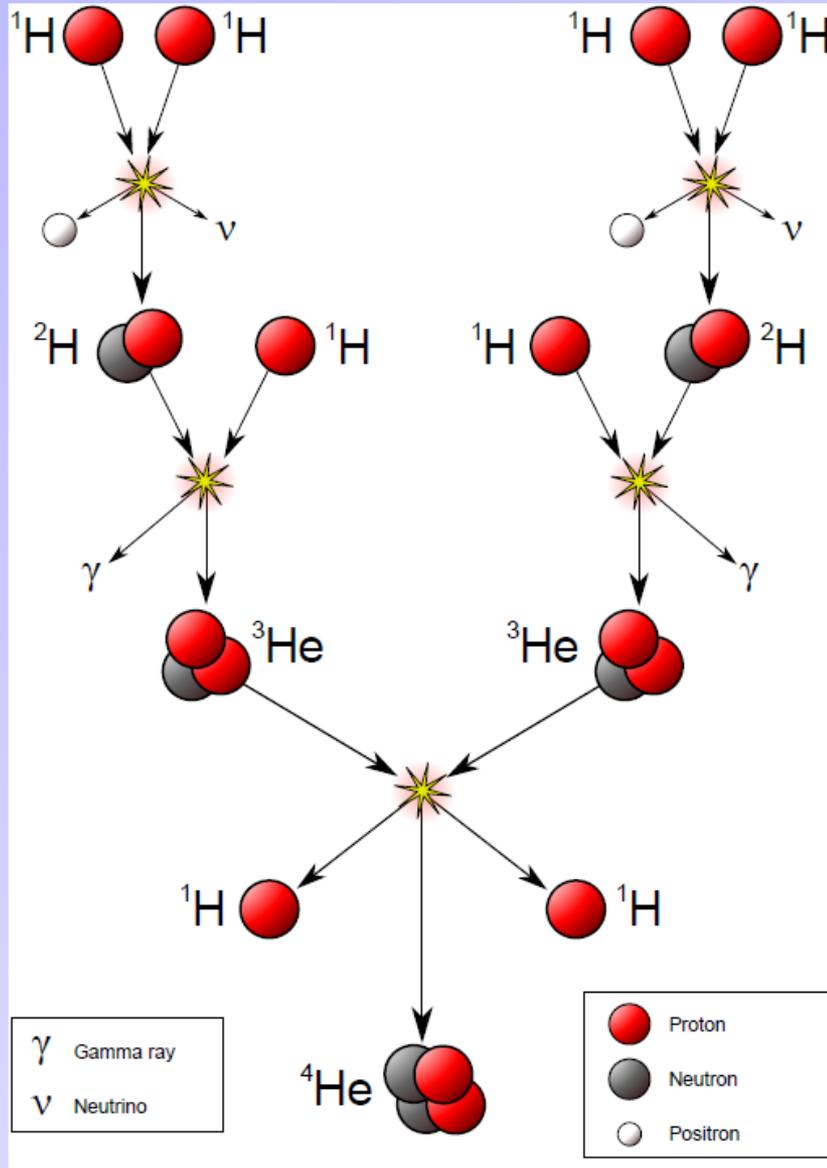
Solar Fusion: proton-proton chain



(see also Feb. 16 lecture)

Solar Fusion: proton-proton chain

9 billions years
weak force

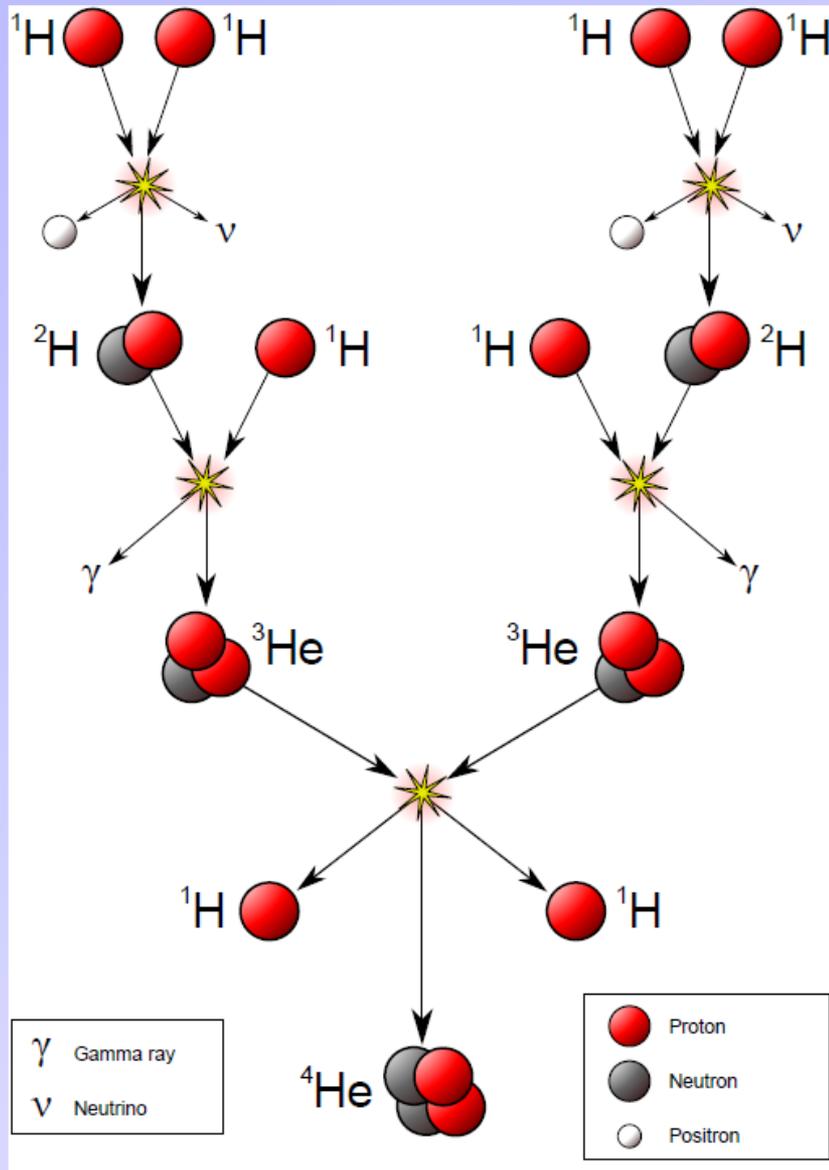


(Note: $1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$)

$2 \times 1.442 \text{ MeV}$

(see also Feb. 16
lecture)

Solar Fusion: proton-proton chain



(Note: $1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$)

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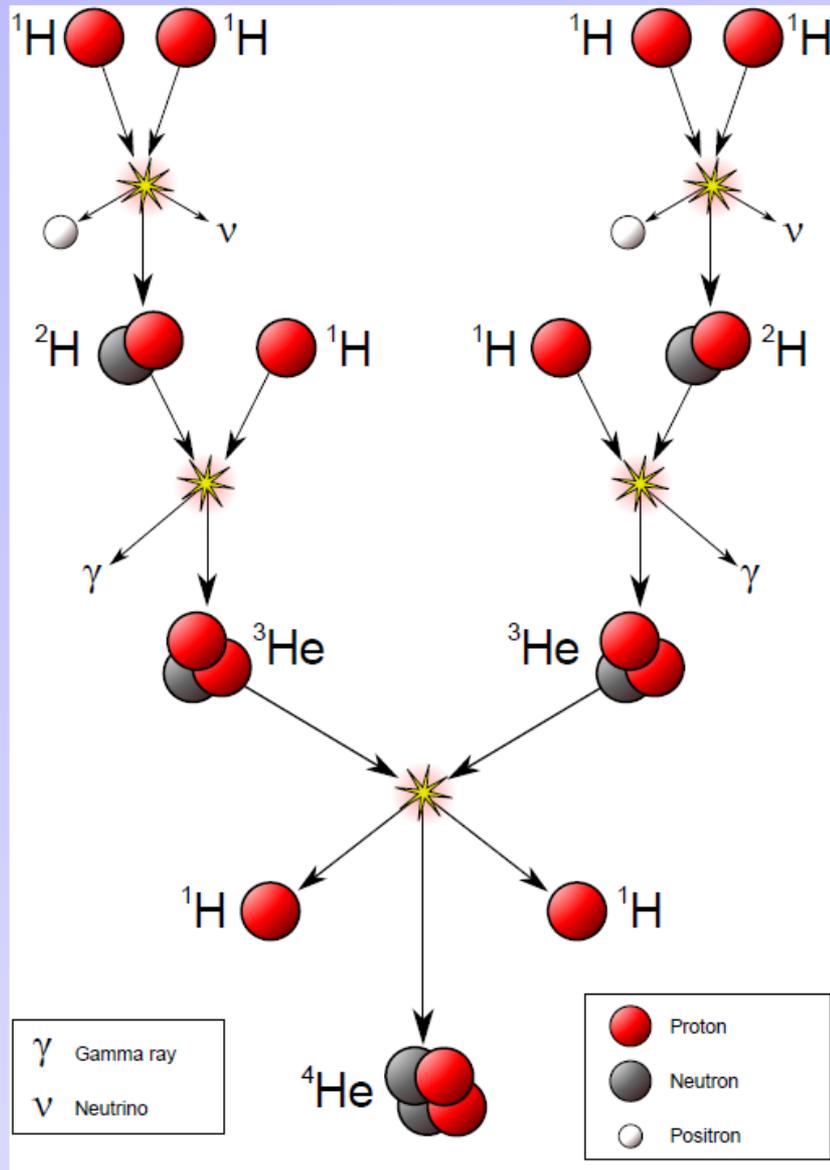
4 seconds
strong force

$$2 \times 1.442 \text{ MeV}$$

$$+ 2 \times 5.49 \text{ MeV}$$

(see also Feb. 16
lecture)

Solar Fusion: proton-proton chain



9 billions years
weak force

4 seconds
strong force

400 years
strong force

(see also Feb. 16
lecture)

(Note: $1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$)

$$2 \times 1.442 \text{ MeV}$$

$$+ 2 \times 5.49 \text{ MeV}$$

$$+ 12.86 \text{ MeV}$$

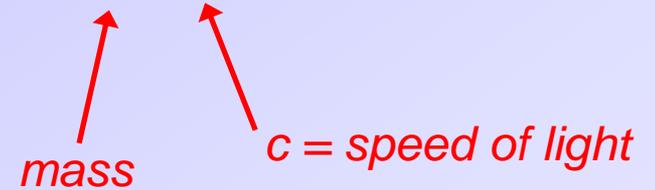
$$= 26.7 \text{ MeV total}$$

$$= 4.28 \times 10^{-12} \text{ J}$$

Einstein: Mass & Energy

$$\textit{Energy} = E = mc^2$$

mass *c = speed of light*



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mass *c = speed of light*

Example: Mass converted to energy in p-p fusion

$$m = \frac{E}{c^2} = \frac{4.28 \times 10^{-12}}{(3 \times 10^8)^2} = 4.76 \times 10^{-29} \text{ kg}$$

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$$m = \frac{E}{c^2} = \frac{4.28 \times 10^{-12}}{(3 \times 10^8)^2} = 4.76 \times 10^{-29} \text{ kg} = 2.8 \% \text{ of the mass of proton}$$

Mass of a proton: $m_p = 1.6726 \times 10^{-27} \text{ kg}$

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= 0.7 % of the mass of 4 protons

Mass of a proton: $m_p = 1.6726 \times 10^{-27} \text{ kg}$

Mass of 4 protons: $4 \times m_p = 6.6905 \times 10^{-27} \text{ kg}$

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Mass of a proton: $m_p = 1.6726 \times 10^{-27} \text{ kg}$

Mass of 4 protons: $4 \times m_p = 6.6905 \times 10^{-27} \text{ kg}$

Mass of ^4He nucleus: $m_{\text{He}} = 6.6447 \times 10^{-27} \text{ kg}$

Note:

$$4m_p - m_{\text{He}} = 4.65 \times 10^{-29} \text{ kg}$$

difference is due to two positrons !