Today's Topics

Wednesday, March 5, 2025 (Week 6, lecture 15) – Chapters 15, 16.

A. The Sun: a visual introduction

B. Surface of the Sun

C. Internal structure

D. Solar fusion

Reminder: Problem Set #5 is due on ExpertTA on Friday, March 7, by 9:00 am.

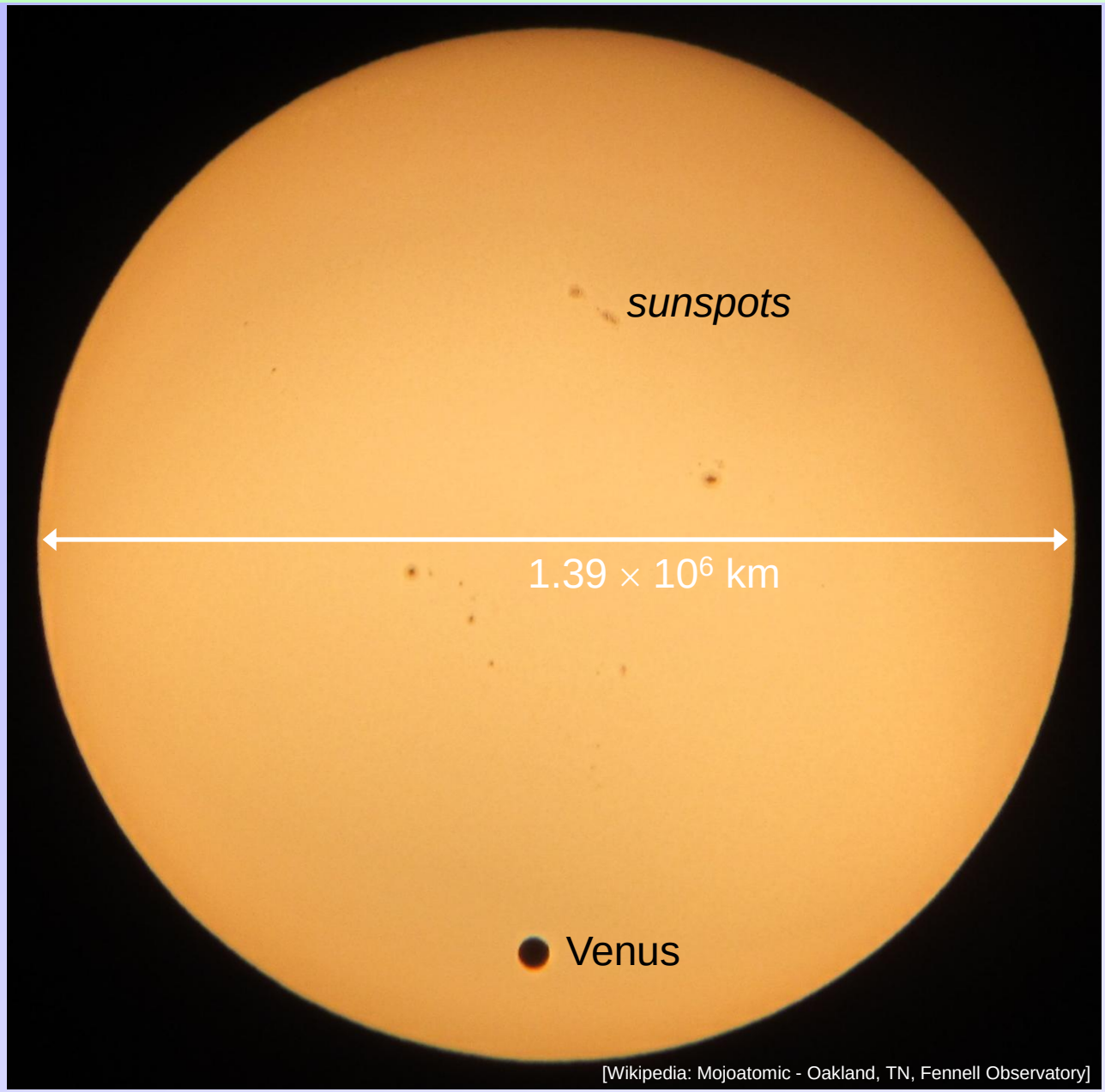
Our Sun

[OpenStax: Astronomy]

Our Sun

[Wikipedia: Mojoatomic - Oakland, TN, Fennell Observatory]

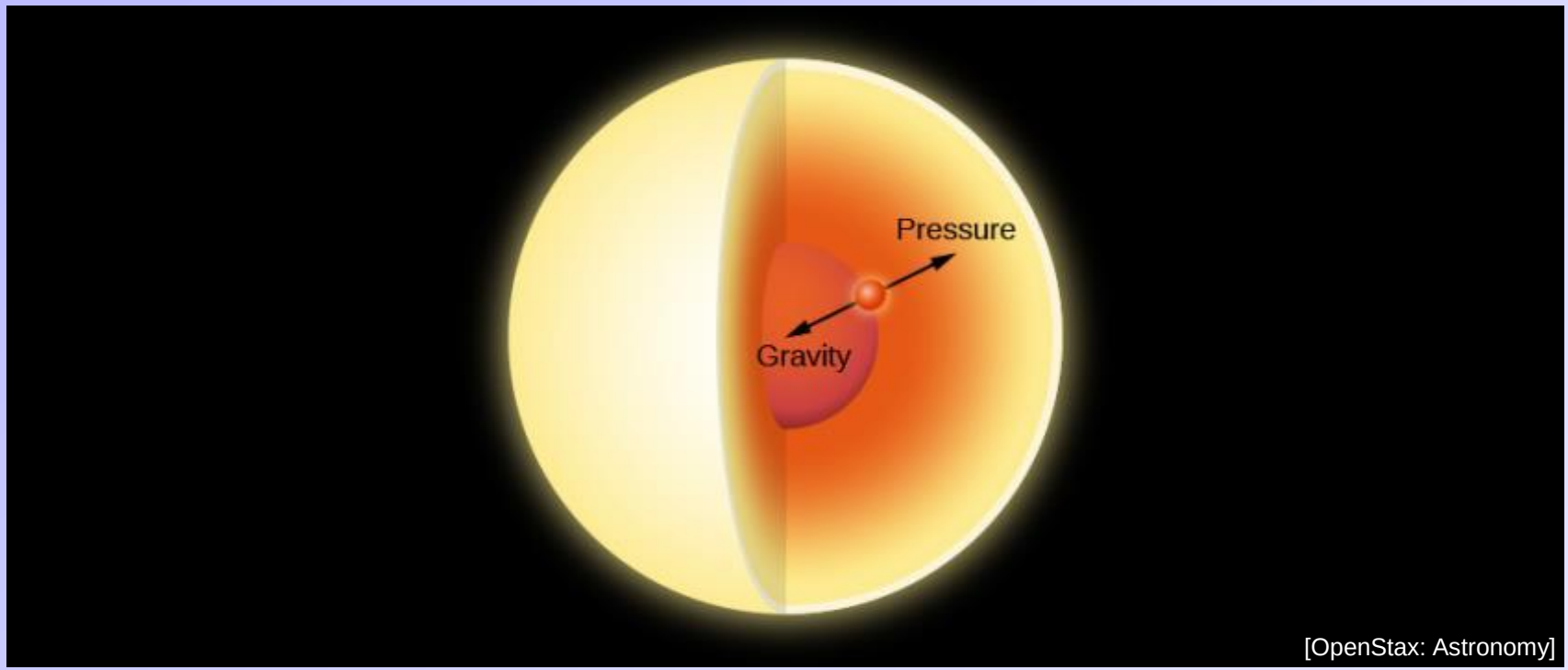
Our Sun



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

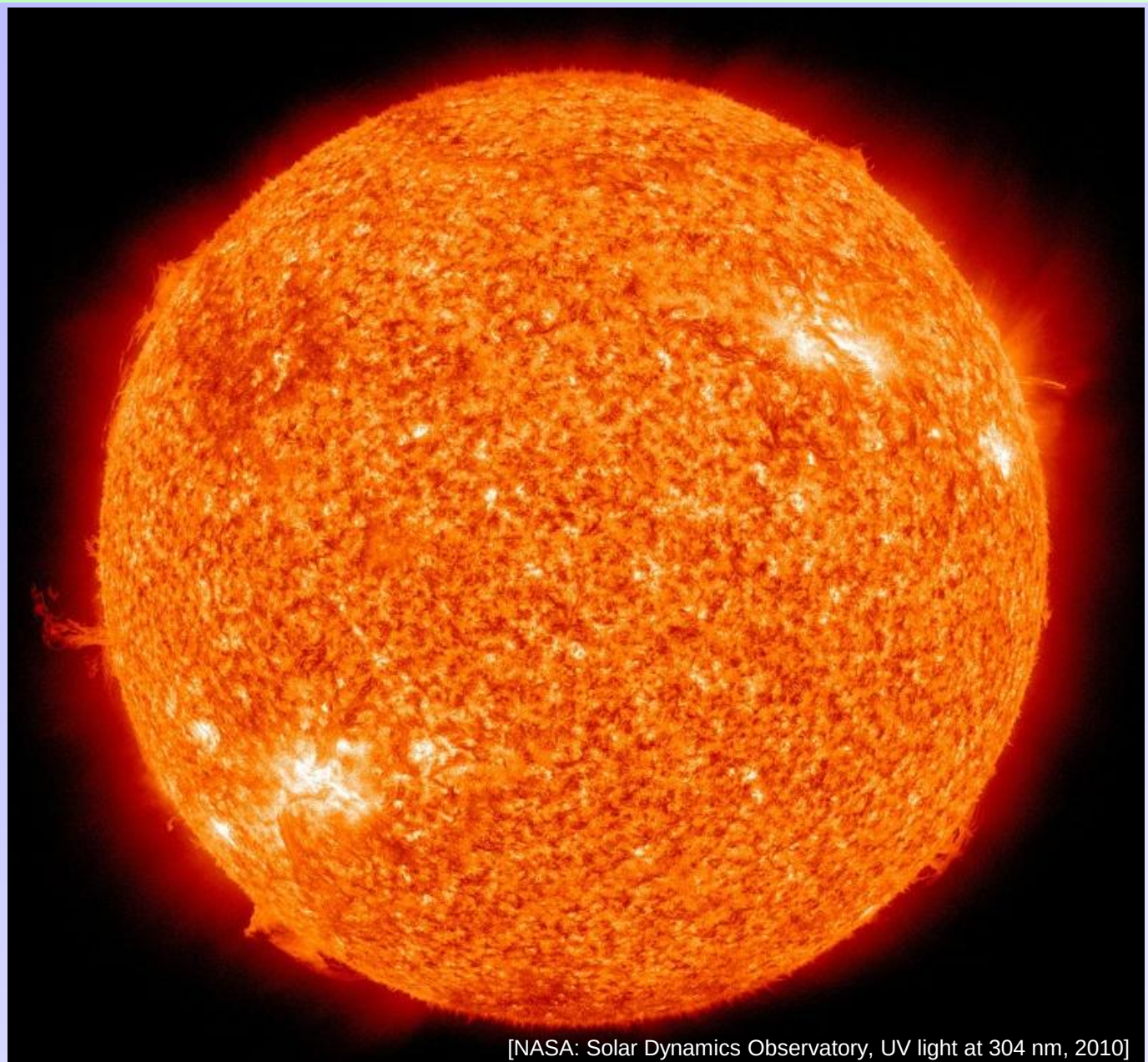
Solar Equilibrium

Gravity vs Fusion Heat



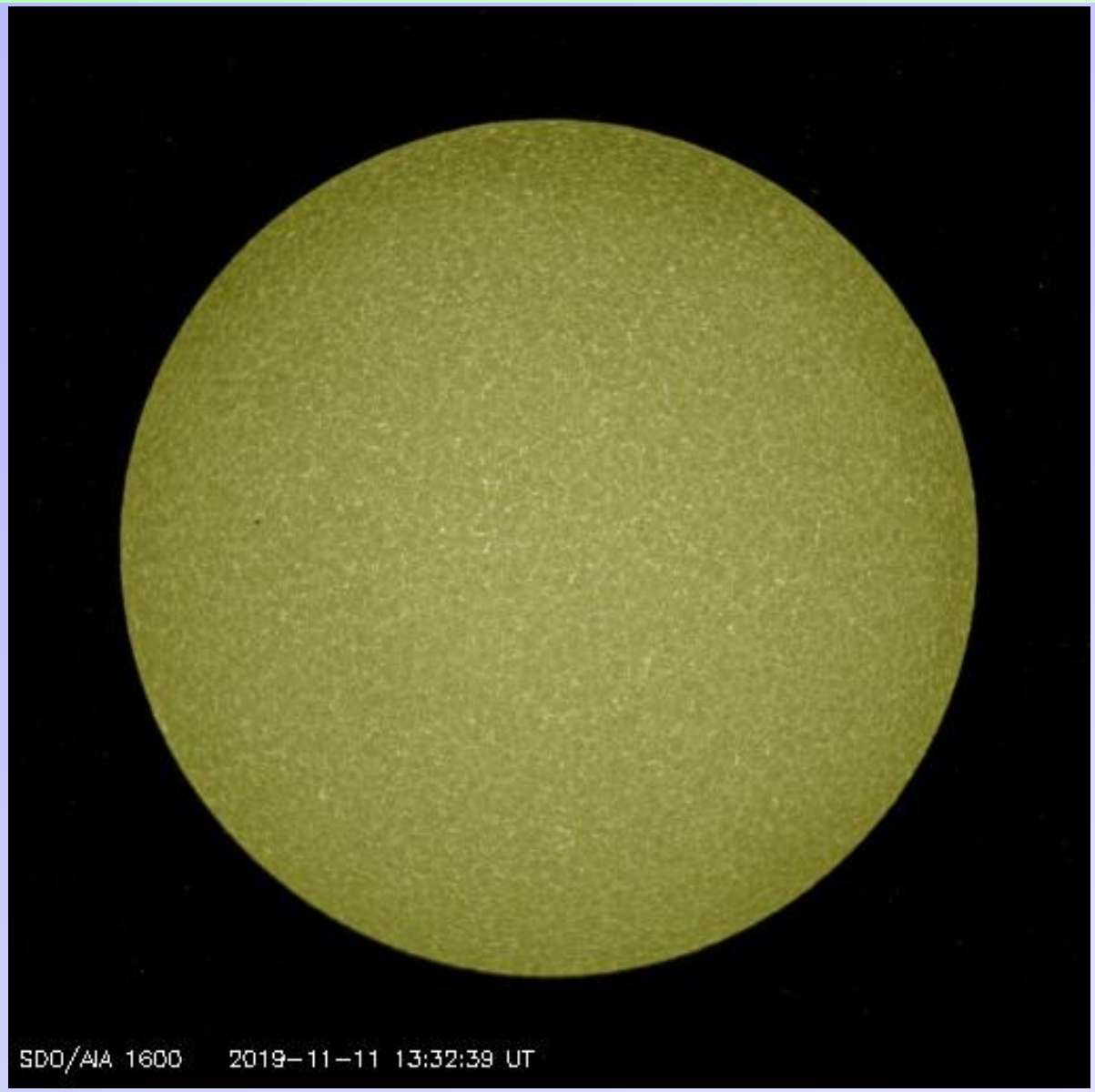
Hydrostatic Equilibrium: In the Sun (and any star), the **inward force of gravity** is ***exactly balanced*** at each point by the **outward force of gas pressure** due to **heat** from nuclear fusion.

Our Sun



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

The Sun is Gigantic



Transit of Mercury, November 11, 2019

Sun view at 1600 nm.

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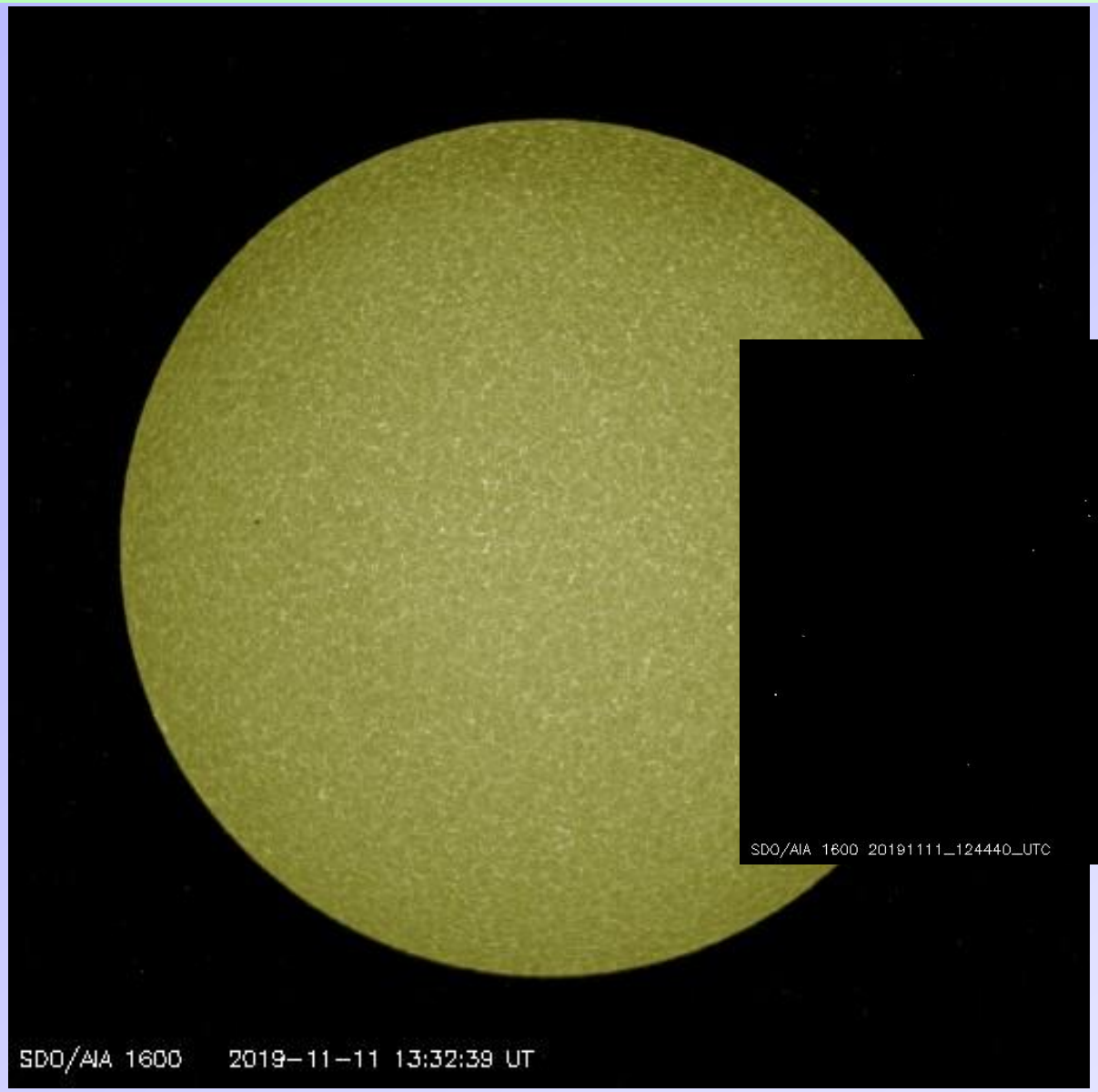

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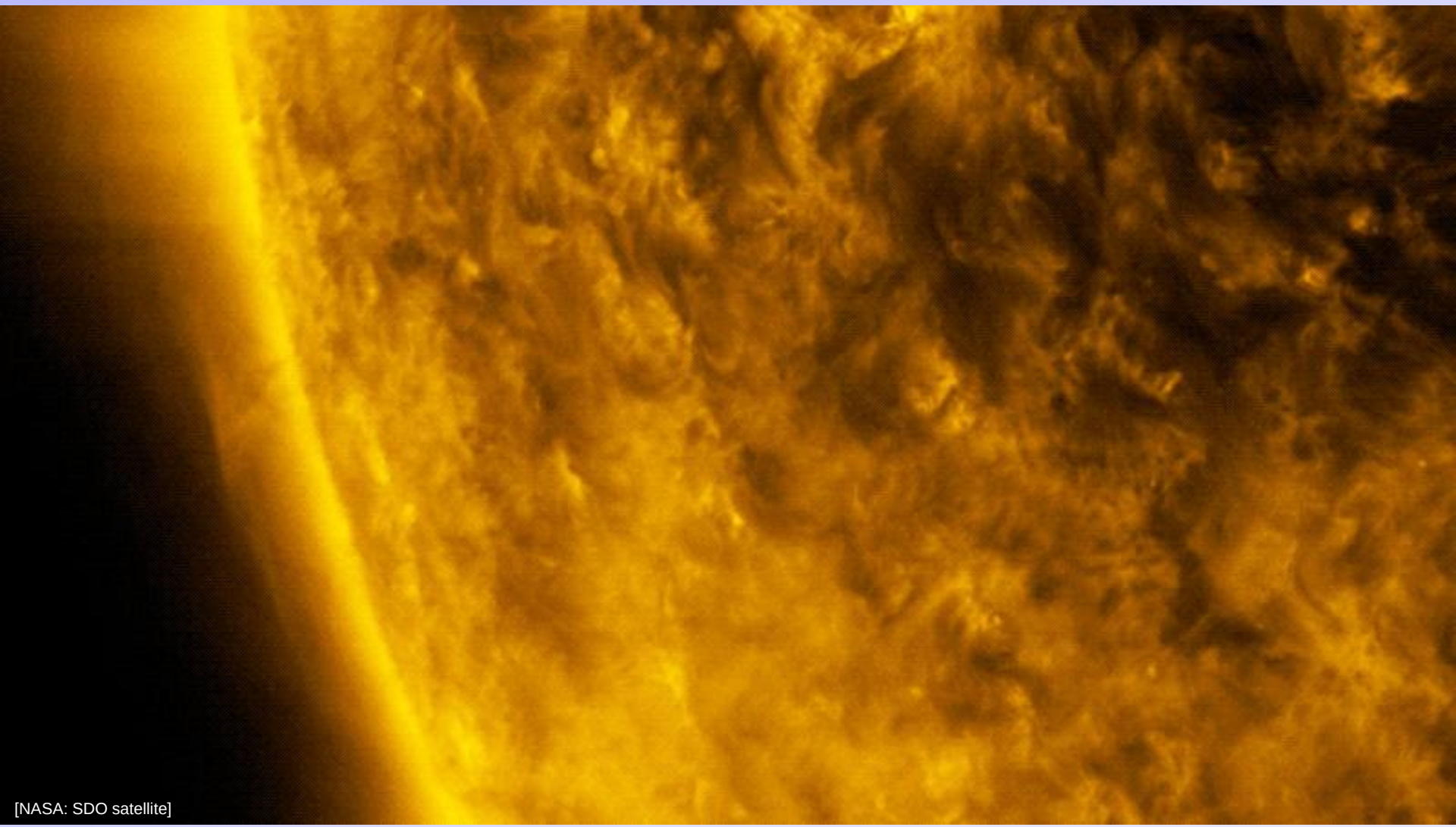


[NASA: SDO satellite]

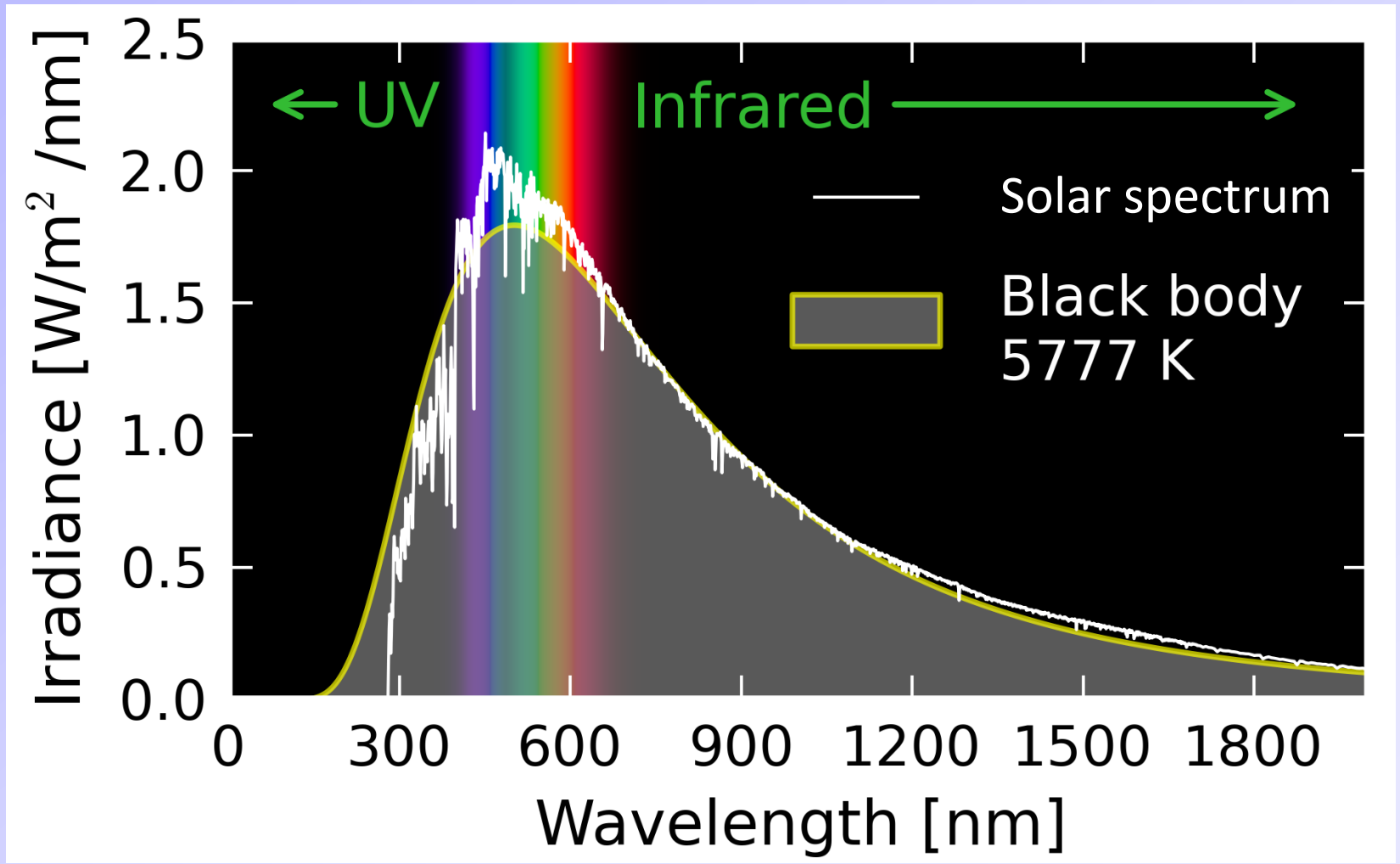
Transit of Mercury, May 9, 2016

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

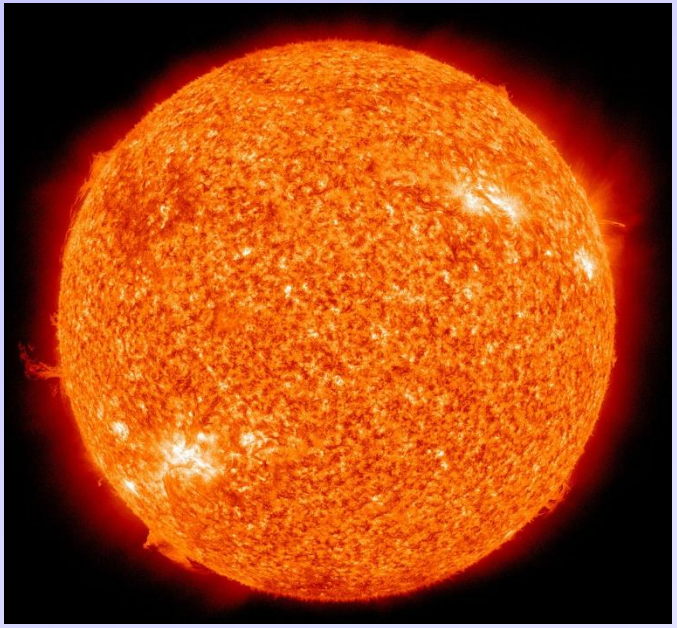


[Wikimedia Commons: Danmichaelo,public domain]

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: $T_{equator}$ = 25 days, T_{poles} = 34 days.
- Rotation axis tilt: 7.25° with respect to ecliptic.



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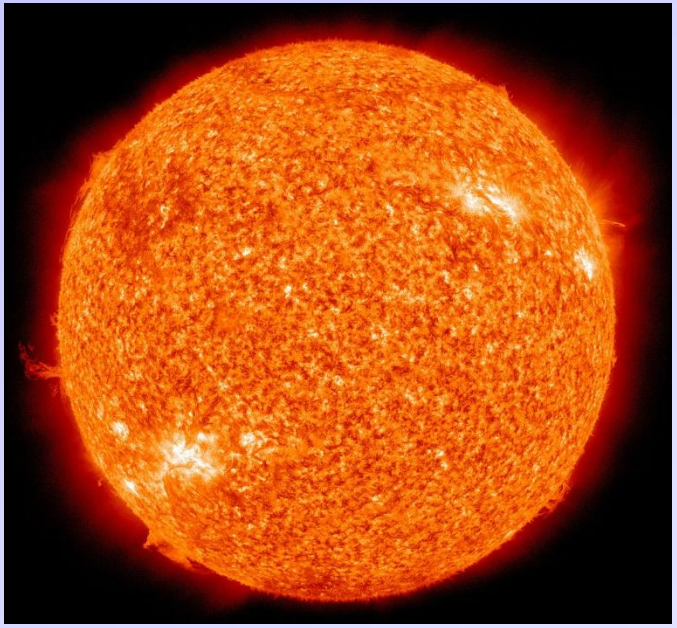

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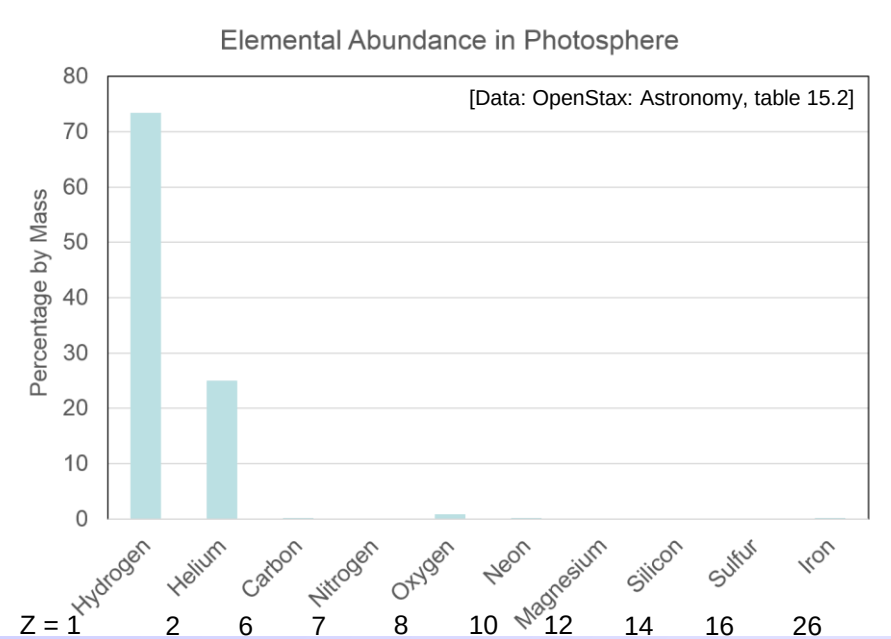
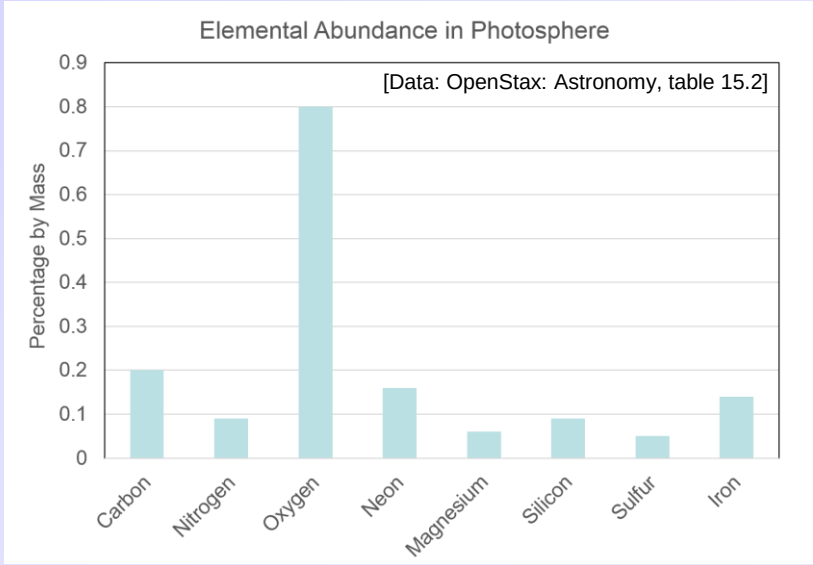




Solar Wind

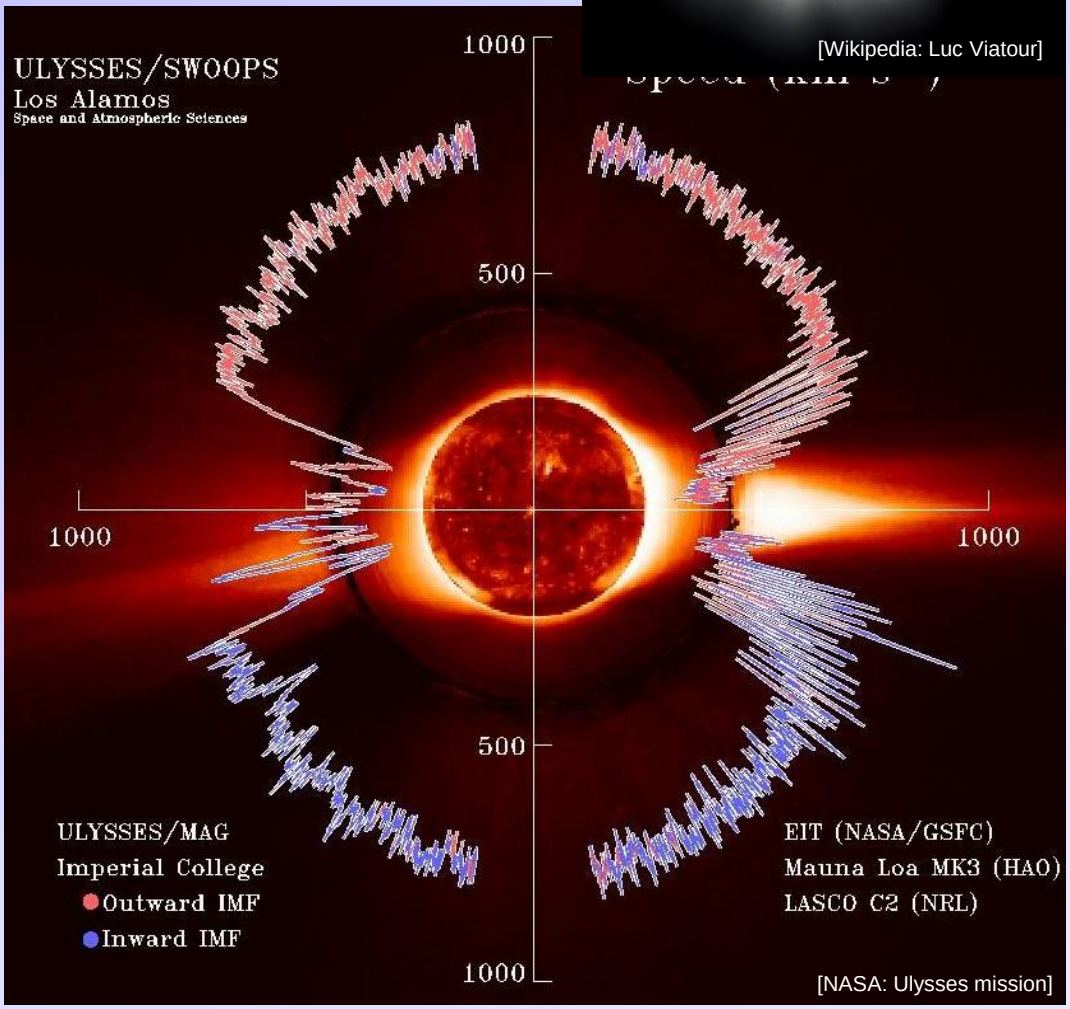
Extension of the Corona

Solar Wind

Extension of the Corona


[Wikipedia: Luc Viatour]

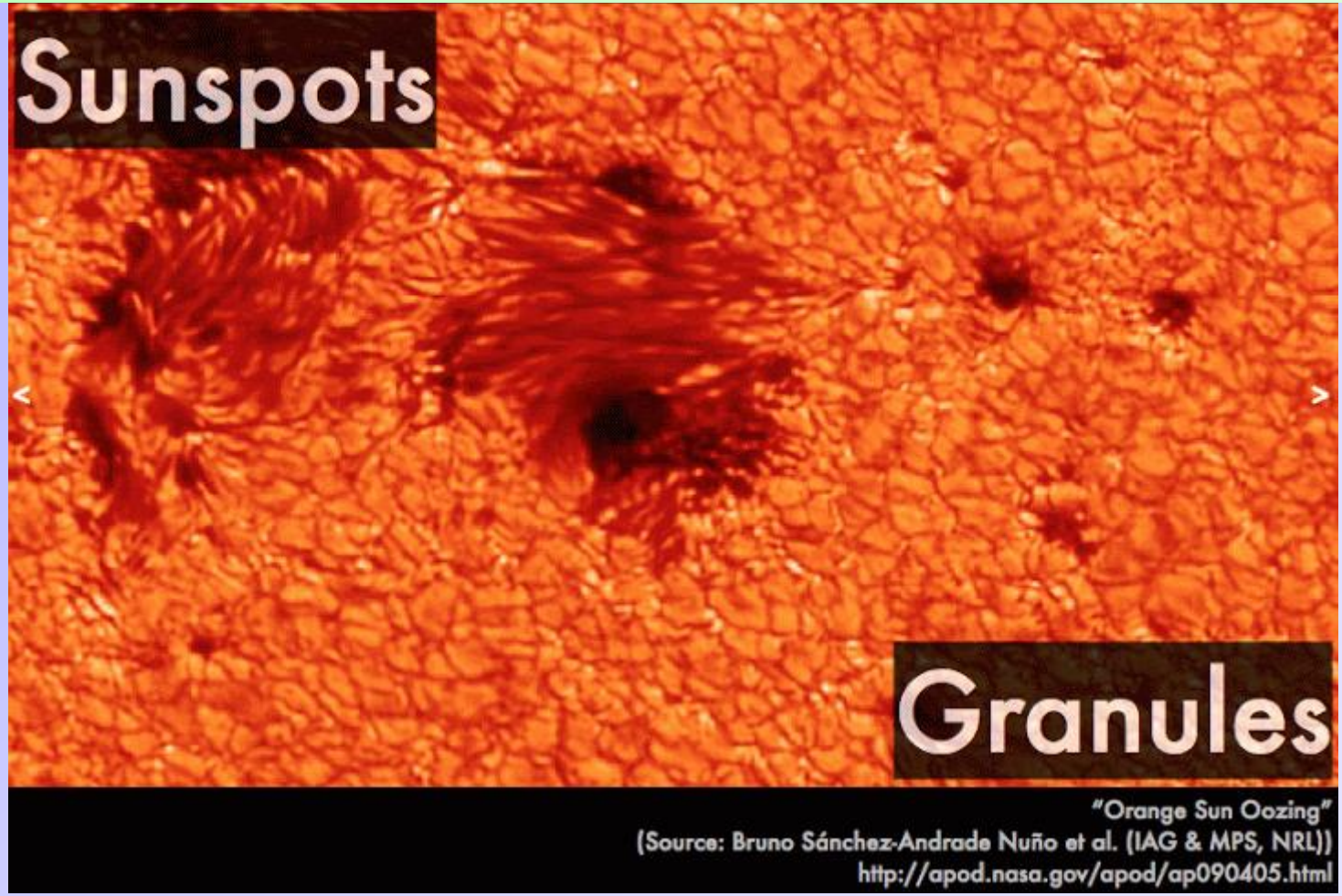
- Corona is very hot: 1 million Kelvin
- Solar wind consists of:
  - protons
  - electrons
  - alpha particles (He nuclei)
- Energy range: 0.01 – 10 keV
- Solar wind speed: 400 – 750 km/s
- Strongest emission is from coronal holes.



[NASA: Ulysses mission]

Our Sun's Surface

Our Sun: Sunspots & Granules



Sunspot size ~ 10,000-20,000 km

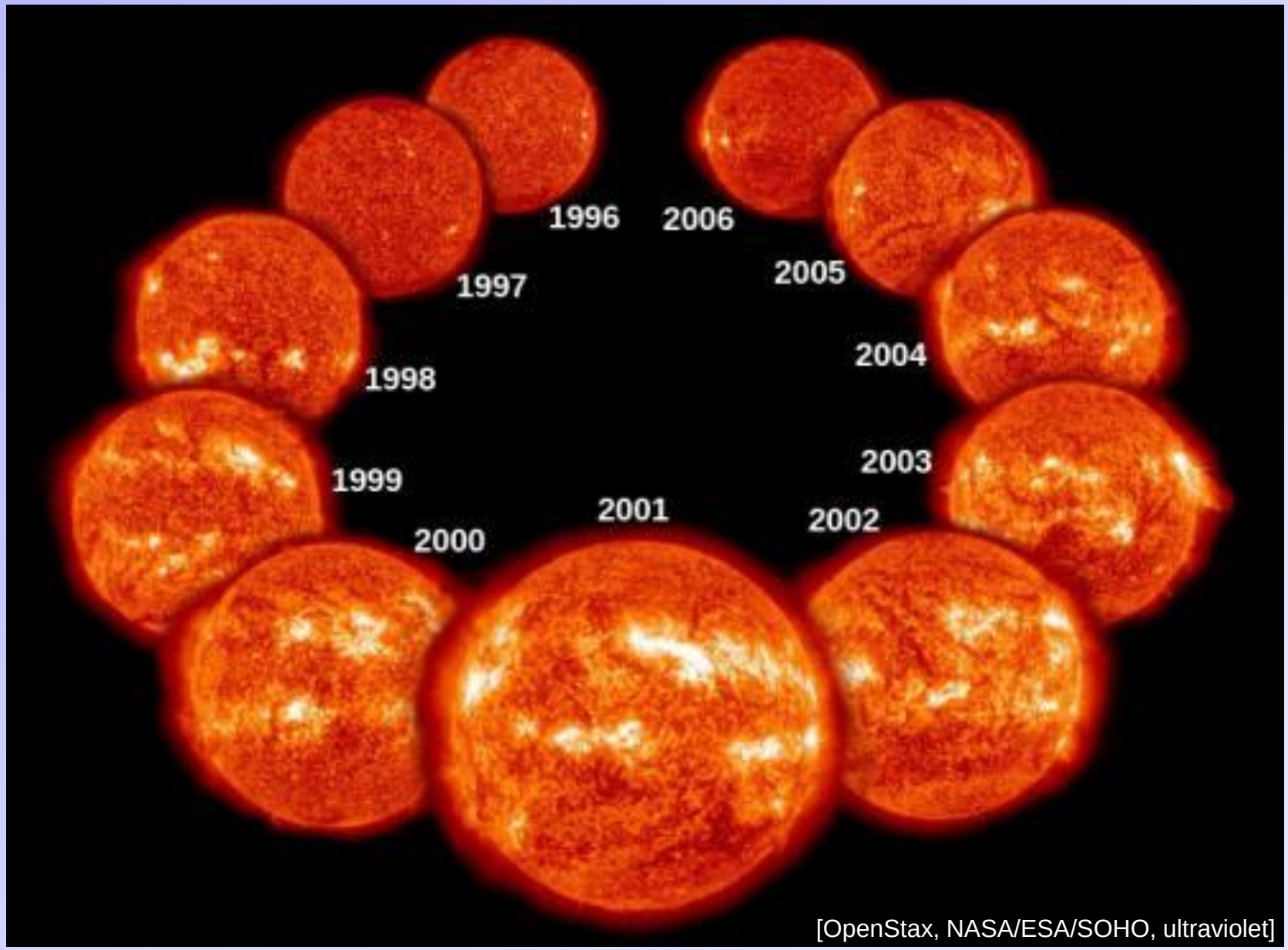
Sunspot = cooler surface region with strong magnetic field.

→ convection is impede by magnetic field.

Granule size ~ 1500 km

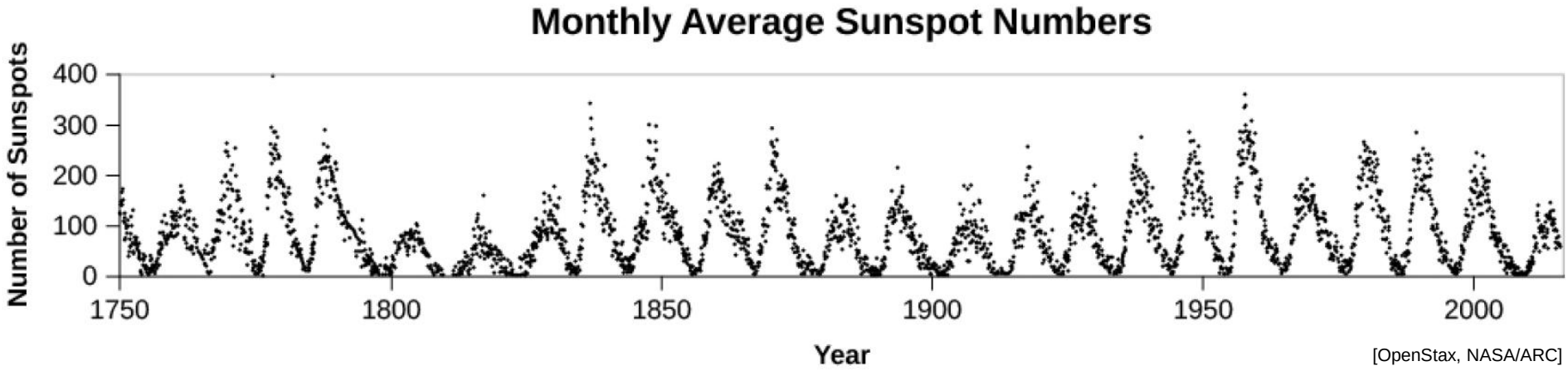
granule = convective cell

Solar Cycle: 11 year period



[OpenStax, NASA/ESA/SOHO, ultraviolet]

Sunspots: 11 year cycle



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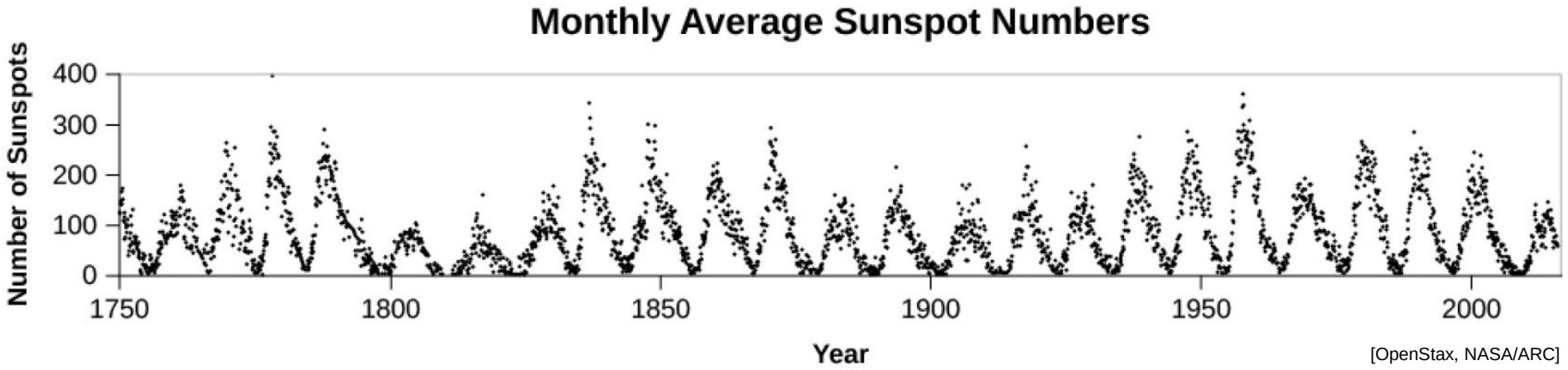
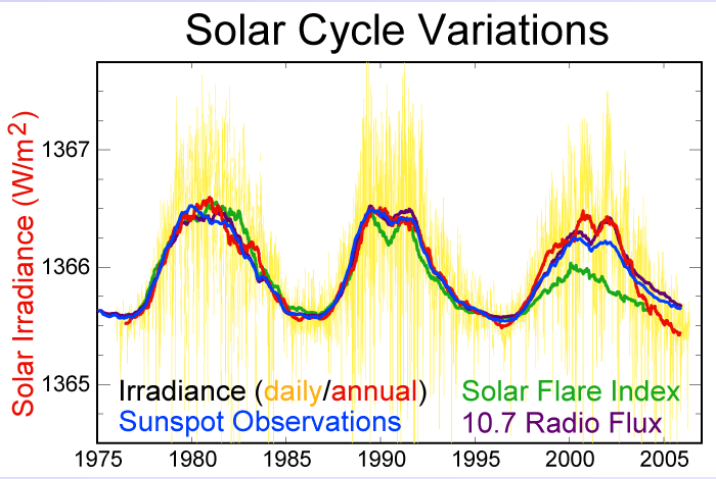


[OpenStax, NASA/ARC]

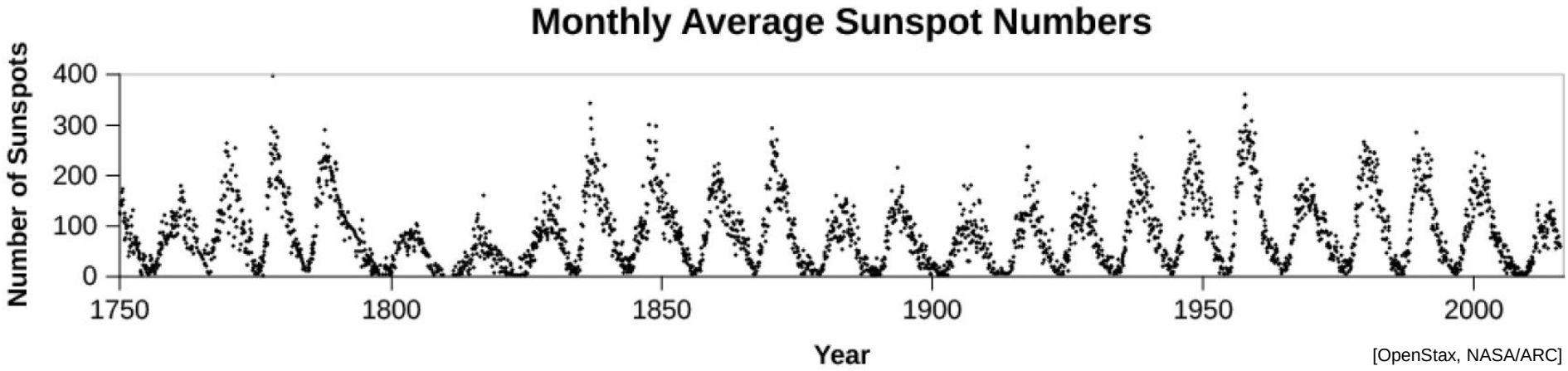
The following all vary in-sync with the solar cycle:

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



[Wikipedia]

Sunspots: 11 year cycle



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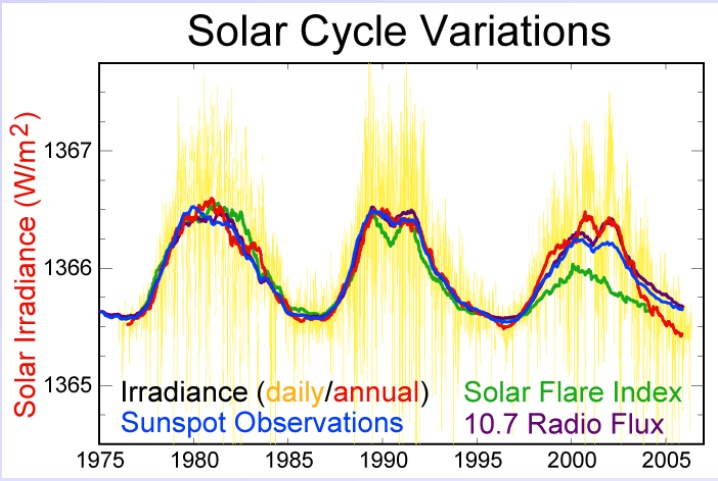
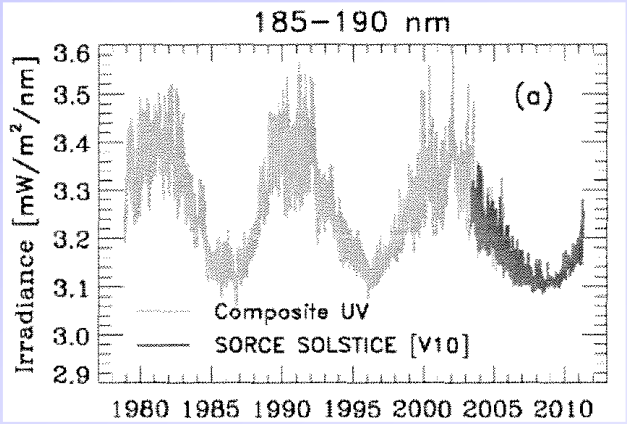


[Wikipedia]



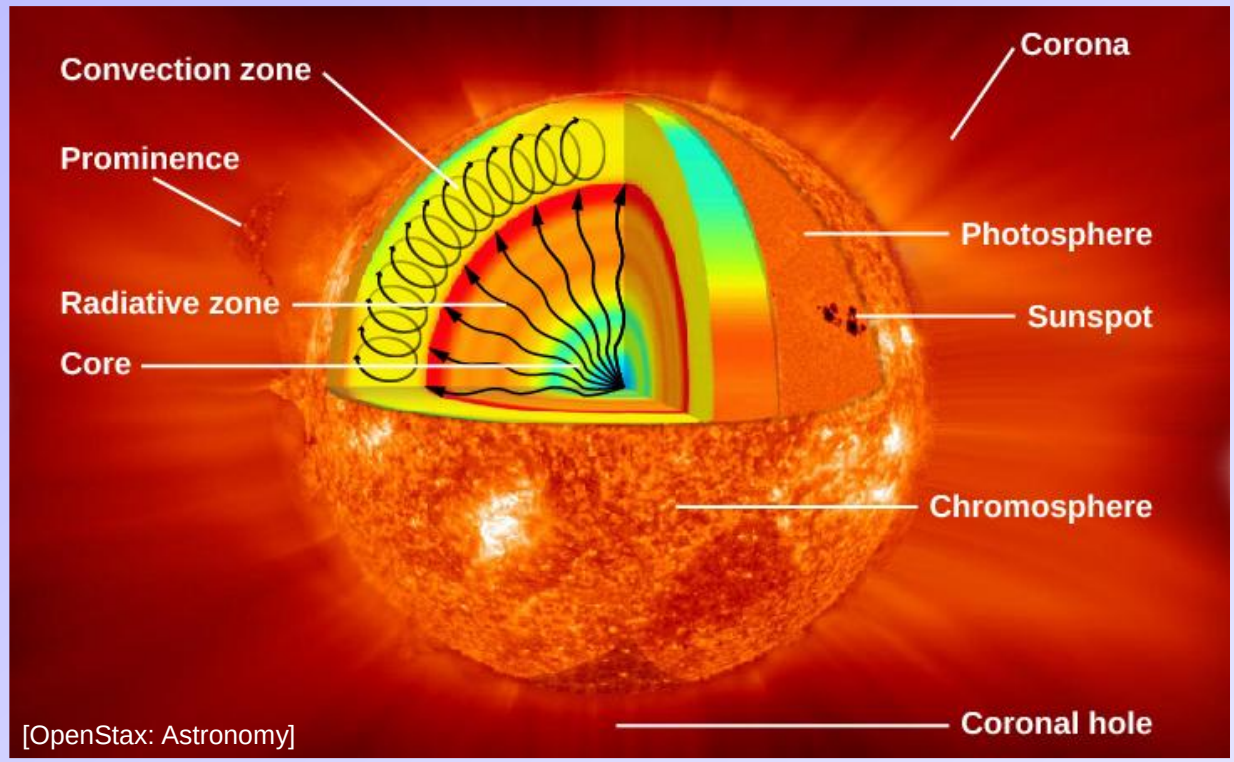
[M. T. DeLand and R. P. Cebula, "Solar UV Variations during the decline of cycle 23", *J. Atmos. Sol.-Terr. Phy.* **77**, 225 (2011)]

PollEv Quiz: **PollEv.com/sethaubin**

Our Sun: Structure

Structure determined from:

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



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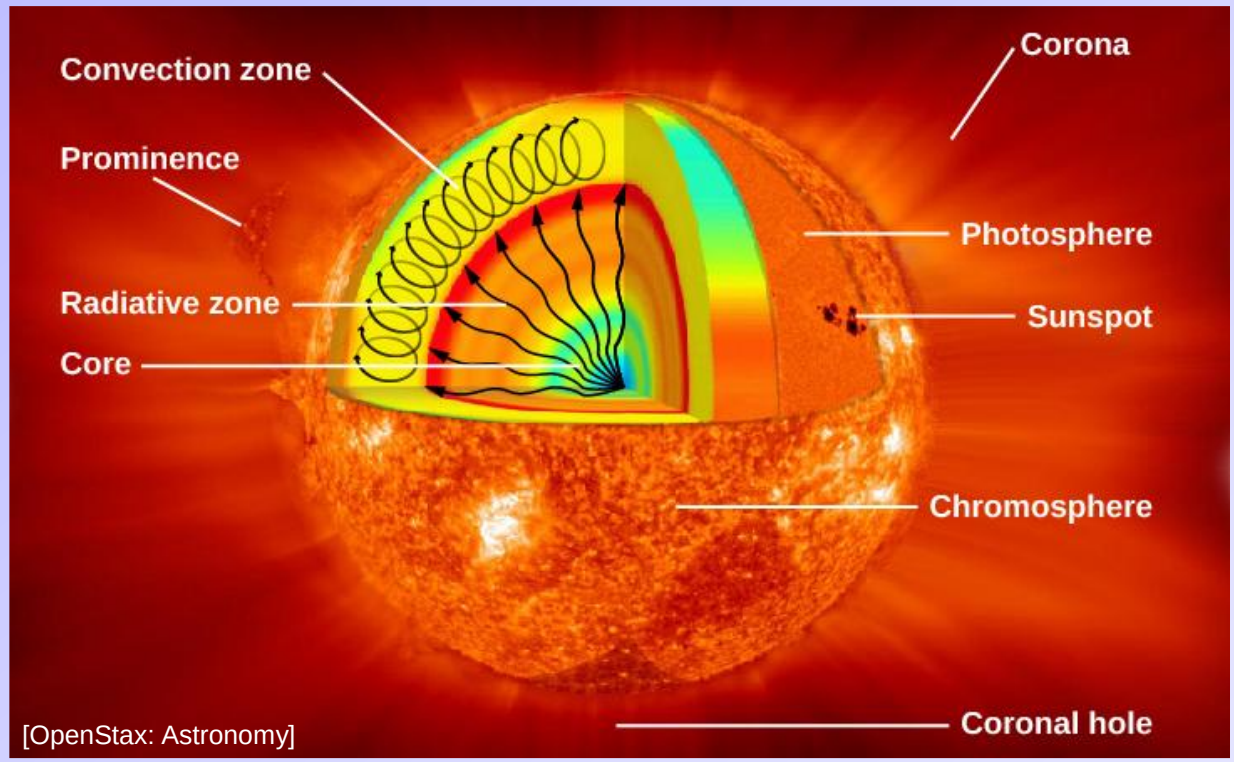
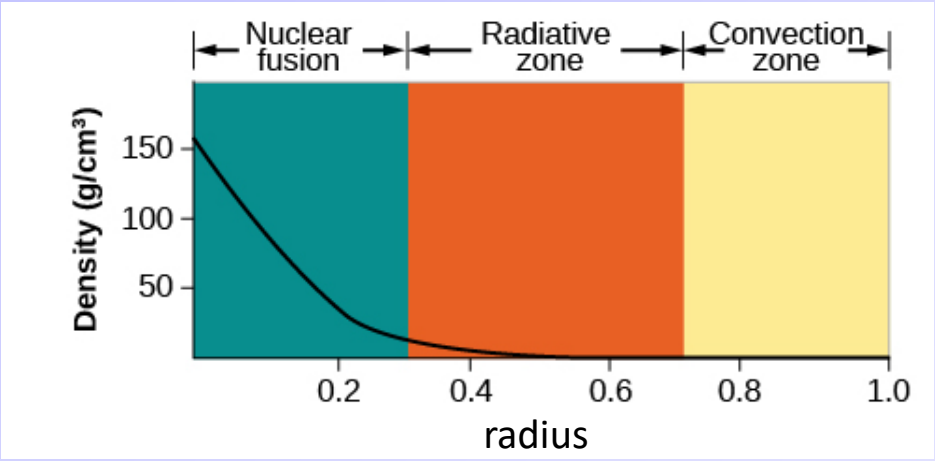
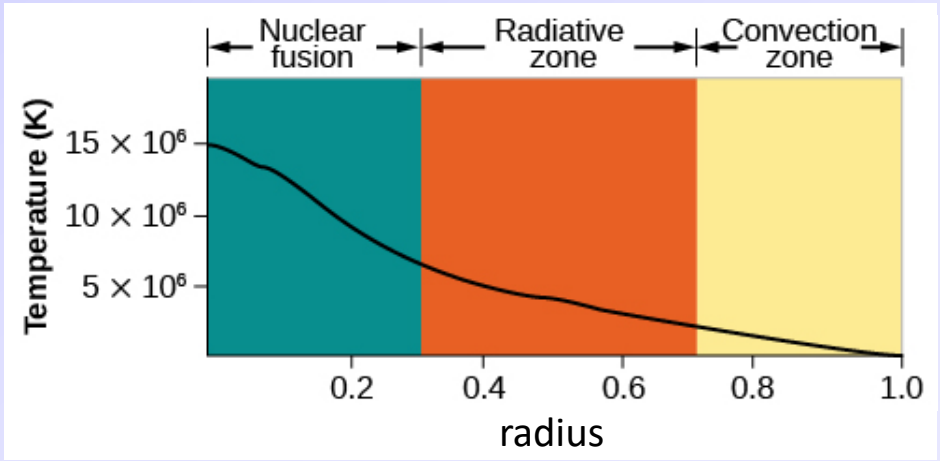
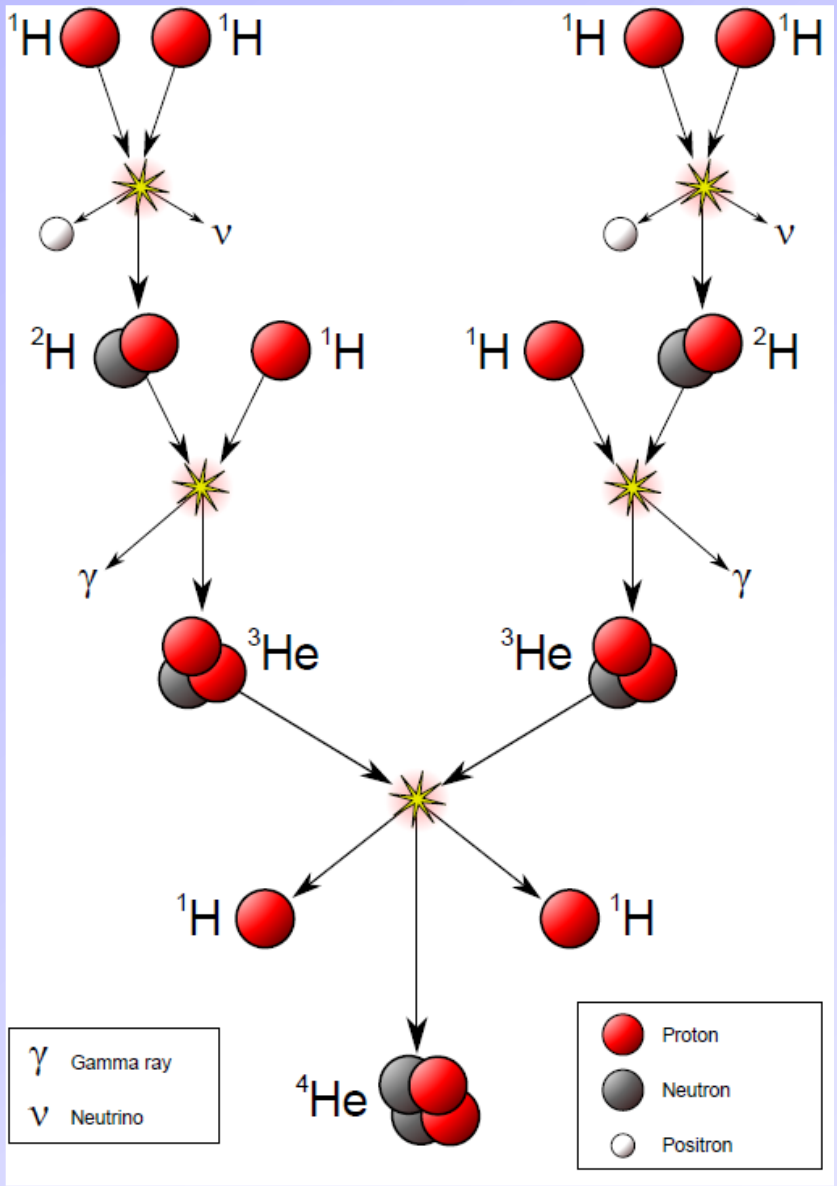






Solar Fusion: proton-proton chain



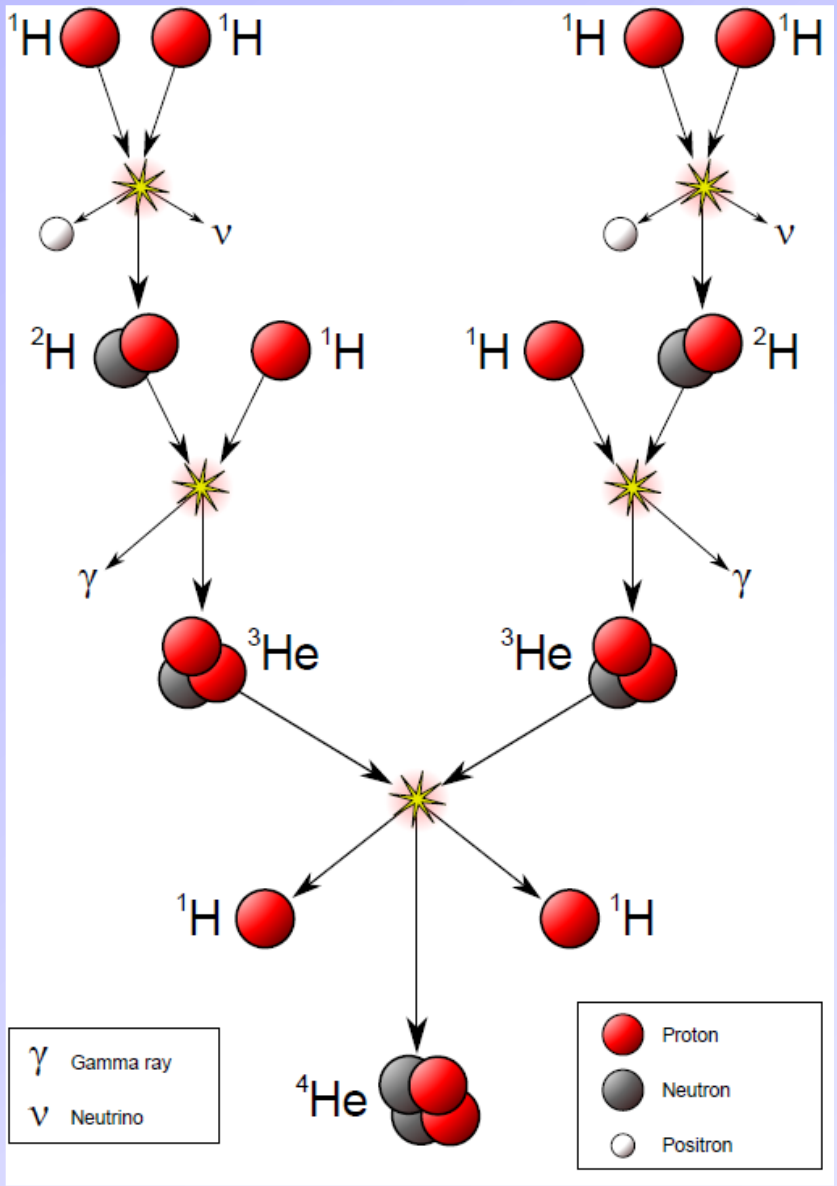
(see also Feb. 17 lecture)

By Sarang - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=51118538

Solar Fusion: proton-proton chain

(Note: 1 eV = 1.602×10^{-19} J)

9 billions years
weak force



2×1.442 MeV

(see also Feb. 17 lecture)

Solar Fusion: proton-proton chain

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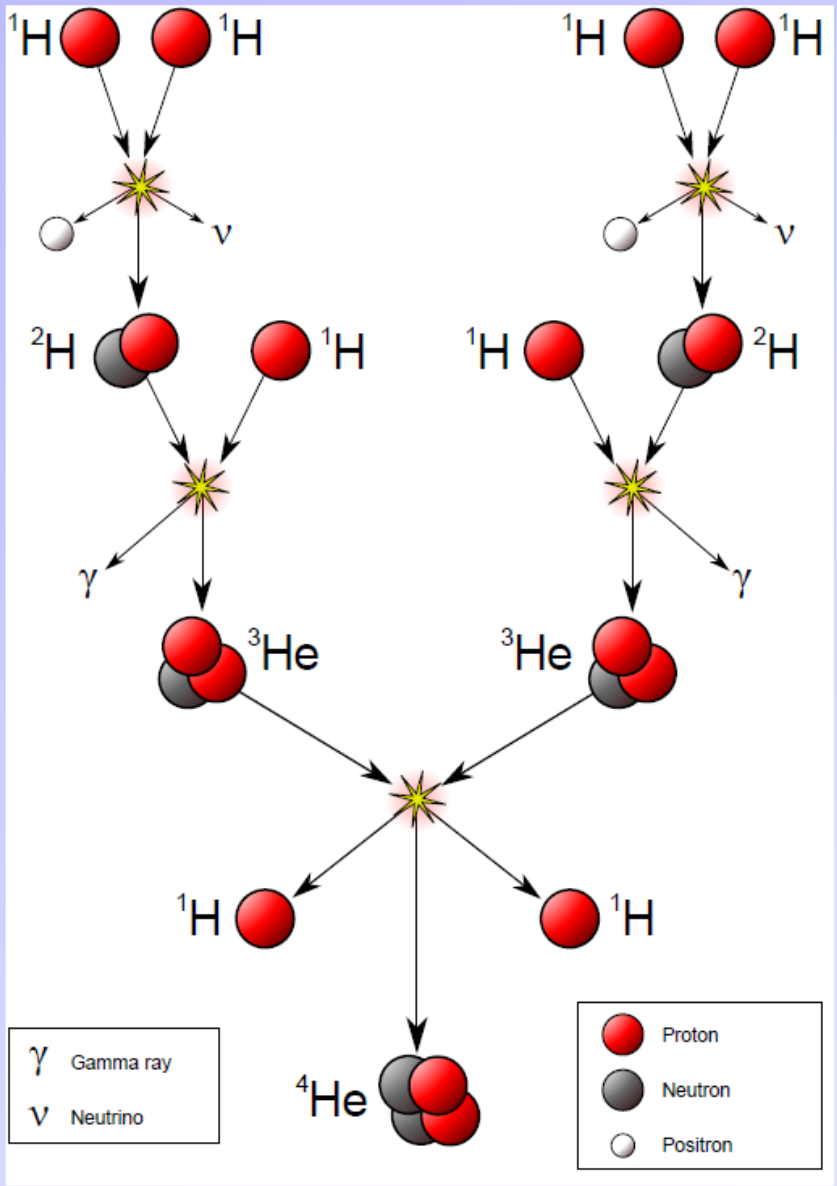
4 seconds
strong force



2×1.442 MeV

\+ 2×5.49 MeV

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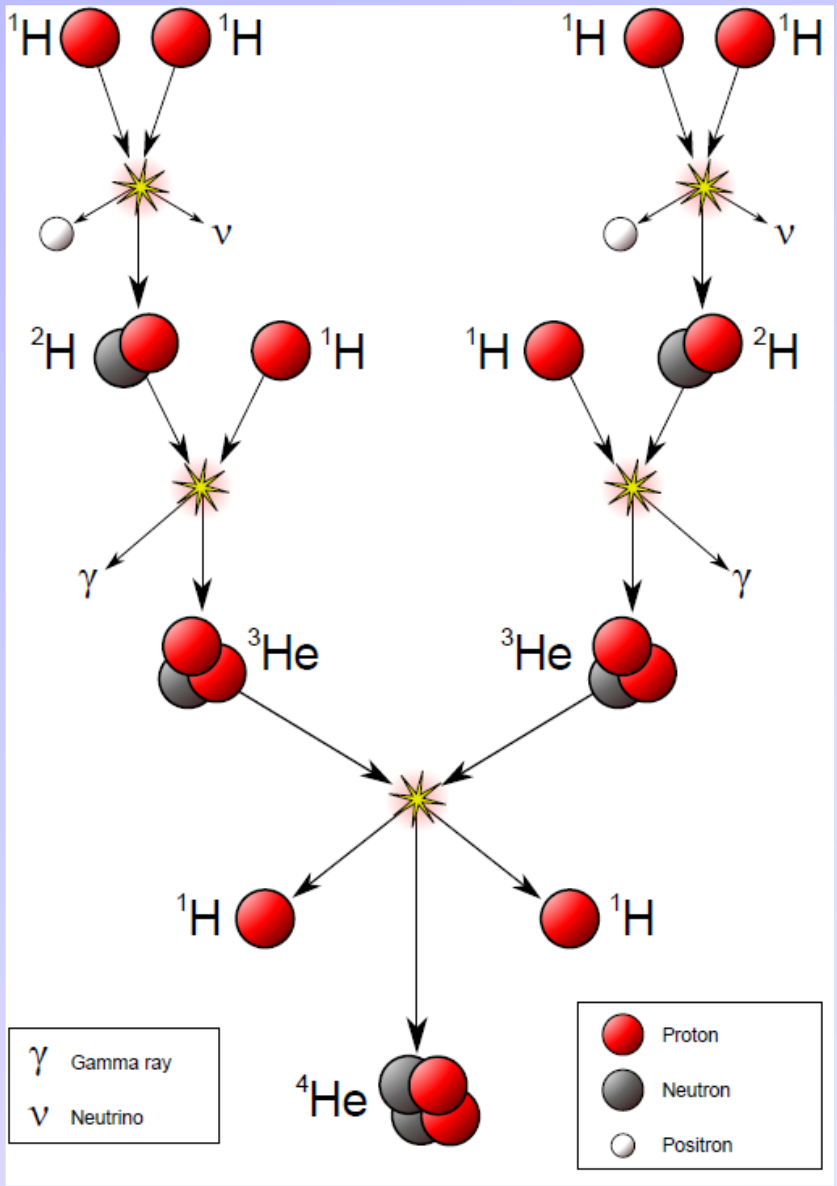

2×1.442 MeV

\+ 2×5.49 MeV

\+ 12.86 MeV

= 26.7 MeV total

= 4.28×10^{-12} J

(see also Feb. 17 lecture)

Einstein: Mass & Energy

$$Energy = E = mc^2$$

mass

c = speed of light

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Example: Mass converted to energy in p-p fusion

$$m = \frac{E}{c^2} = \frac{4.28\times10^{-12}}{(3\times10^8)^2} = 4.76 \times 10^{-29} \text{ kg}$$

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

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= 0.7 % of the mass of 4 protons

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

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

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

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

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

Note:

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

difference is due to two positrons !