Today's Topics

Wednesday, October 21, 2020 (Week 9, lecture 26) – Chapters 15, 16.

A. The Sun: a visual introduction

B. Surface of the Sun

C. Internal structure

D. Solar fusion

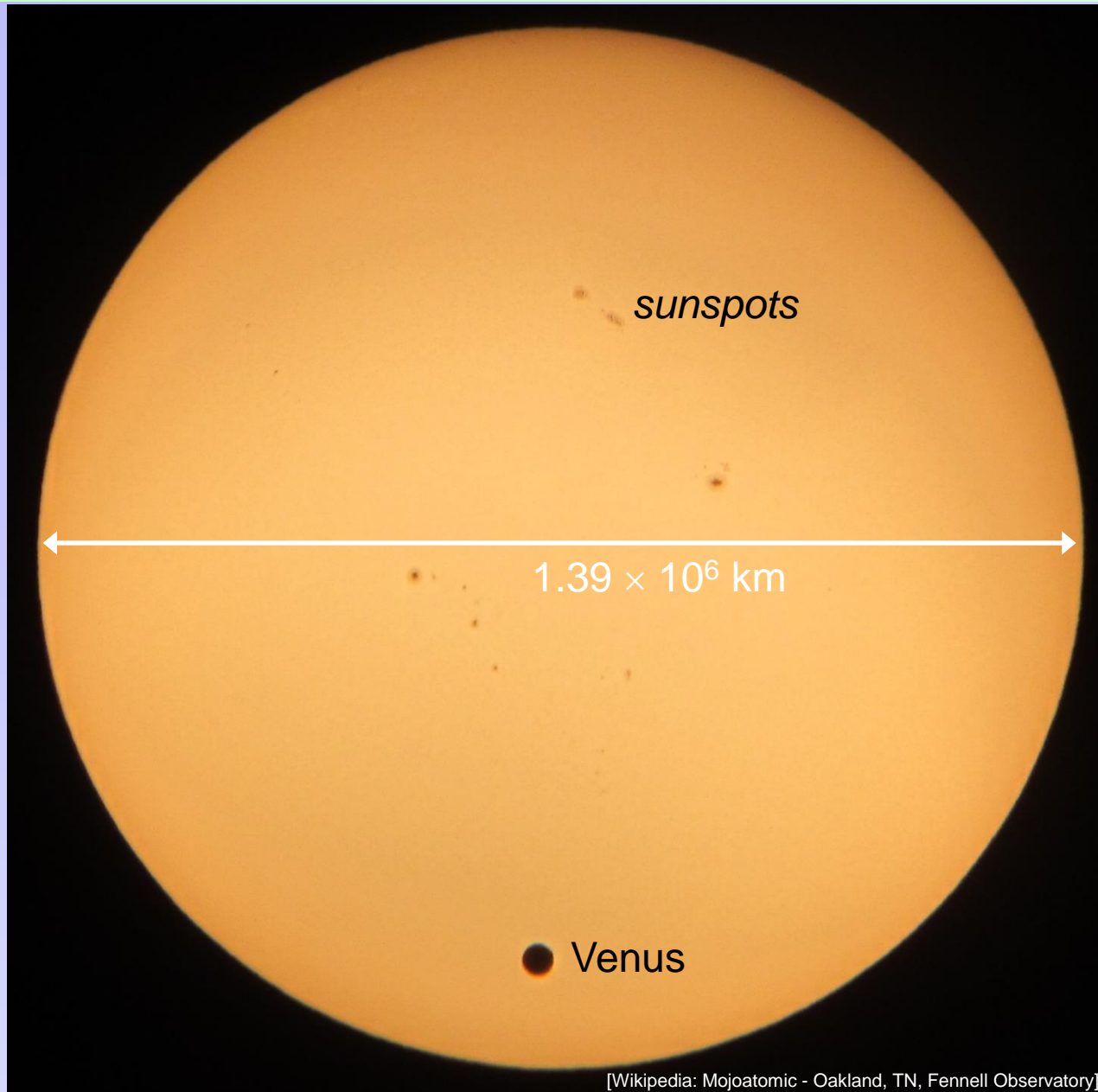# Our Sun

Our Sun

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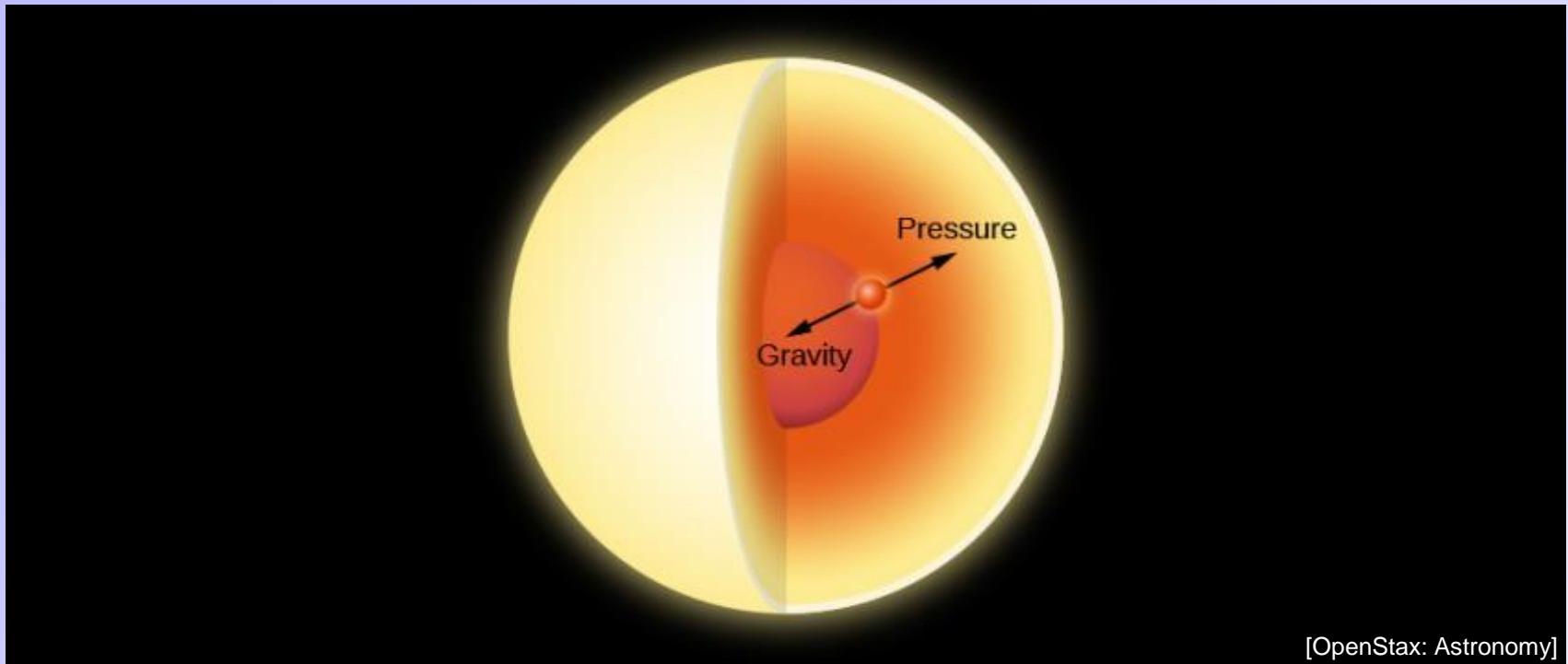
Our Sun

sunspots

1.39×10^6 km

Venus

Transit of
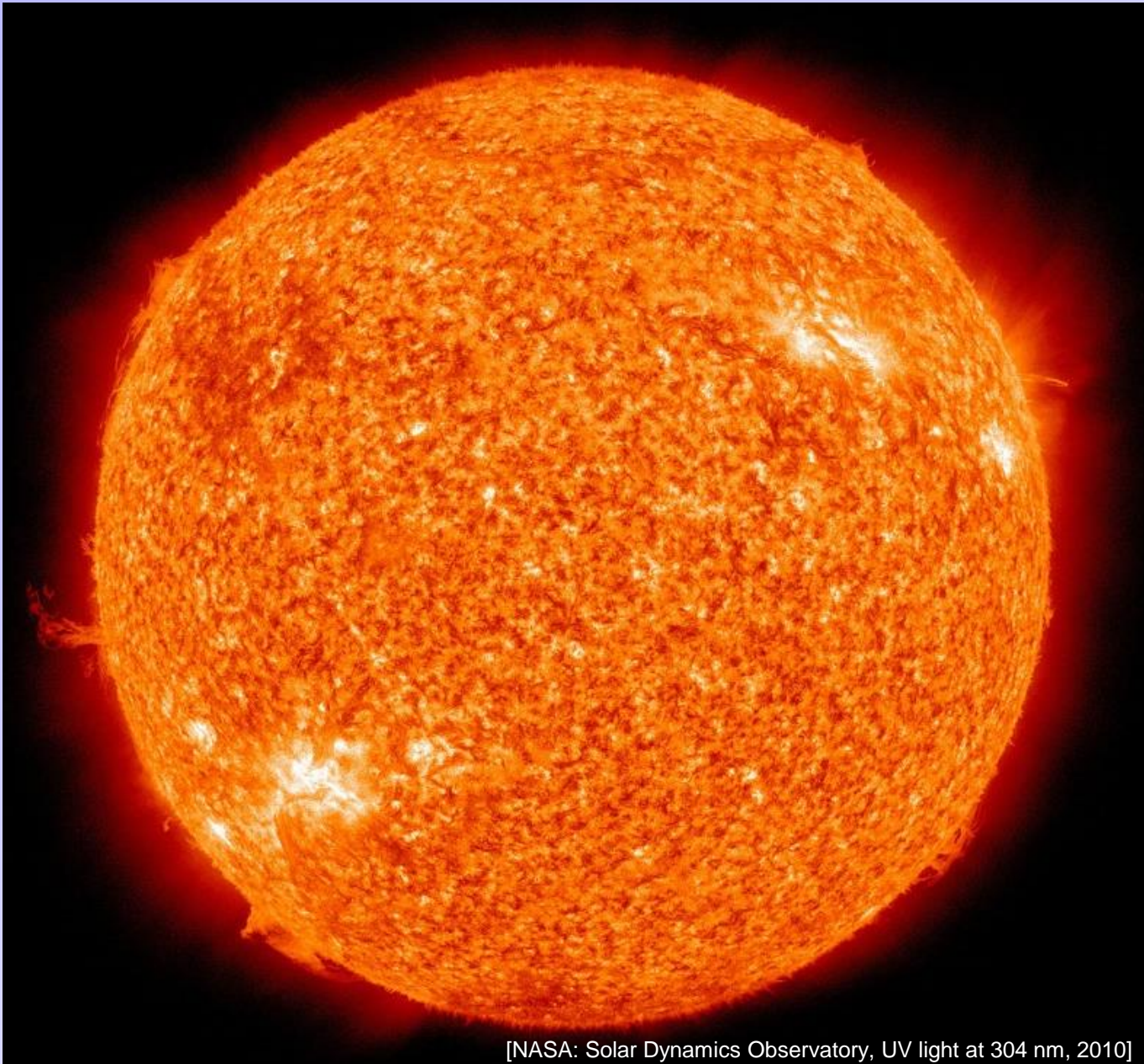Venus, 2012.
(visible light)

Solar Equilibrium

Gravity vs Fusion Heat

[OpenStax: Astronomy]

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 <u>nuclear fusion</u>.

Our Sun

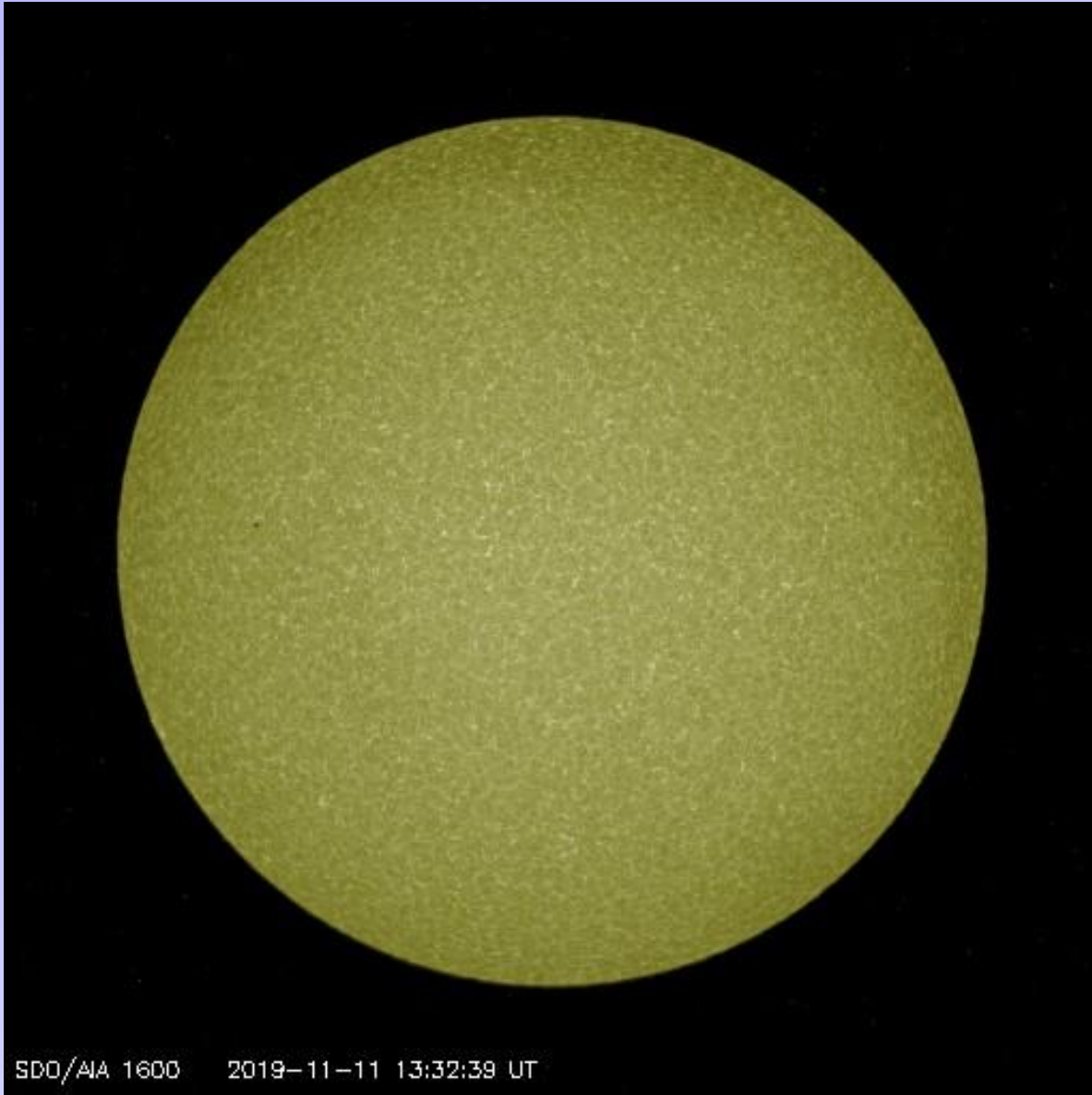[NASA: Solar Dynamics Observatory, UV light at 304 nm, 2010]

The Sun is Gigantic

[NASA: SDO satellite]

Transit of Mercury, May 9, 2016
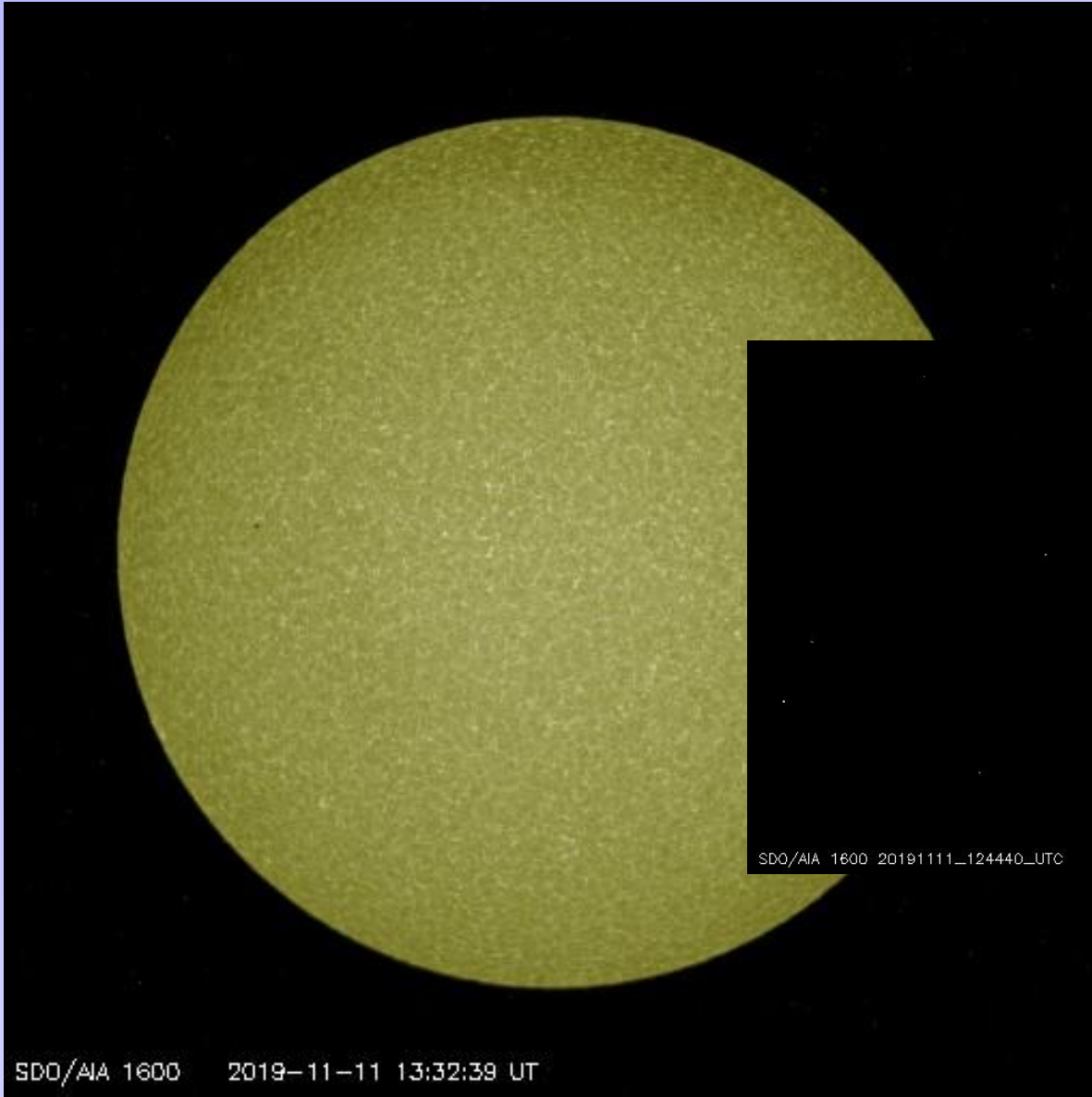
The Sun is Gigantic

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

Sun view at 1600 nm.

Transit of Mercury, November 11, 2019 (i.e. right now)

The Sun is Gigantic

SDO/AIA 1600 20191111_124440_UTC

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

Sun view at 1600 nm.

Transit of Mercury, November 11, 2019 (i.e. right now)

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)
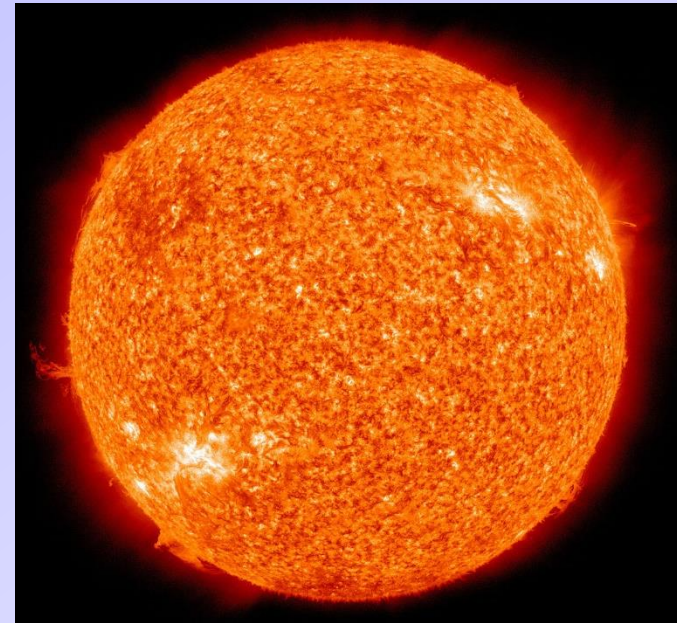
Our Sun

Blackbody Radiation Source
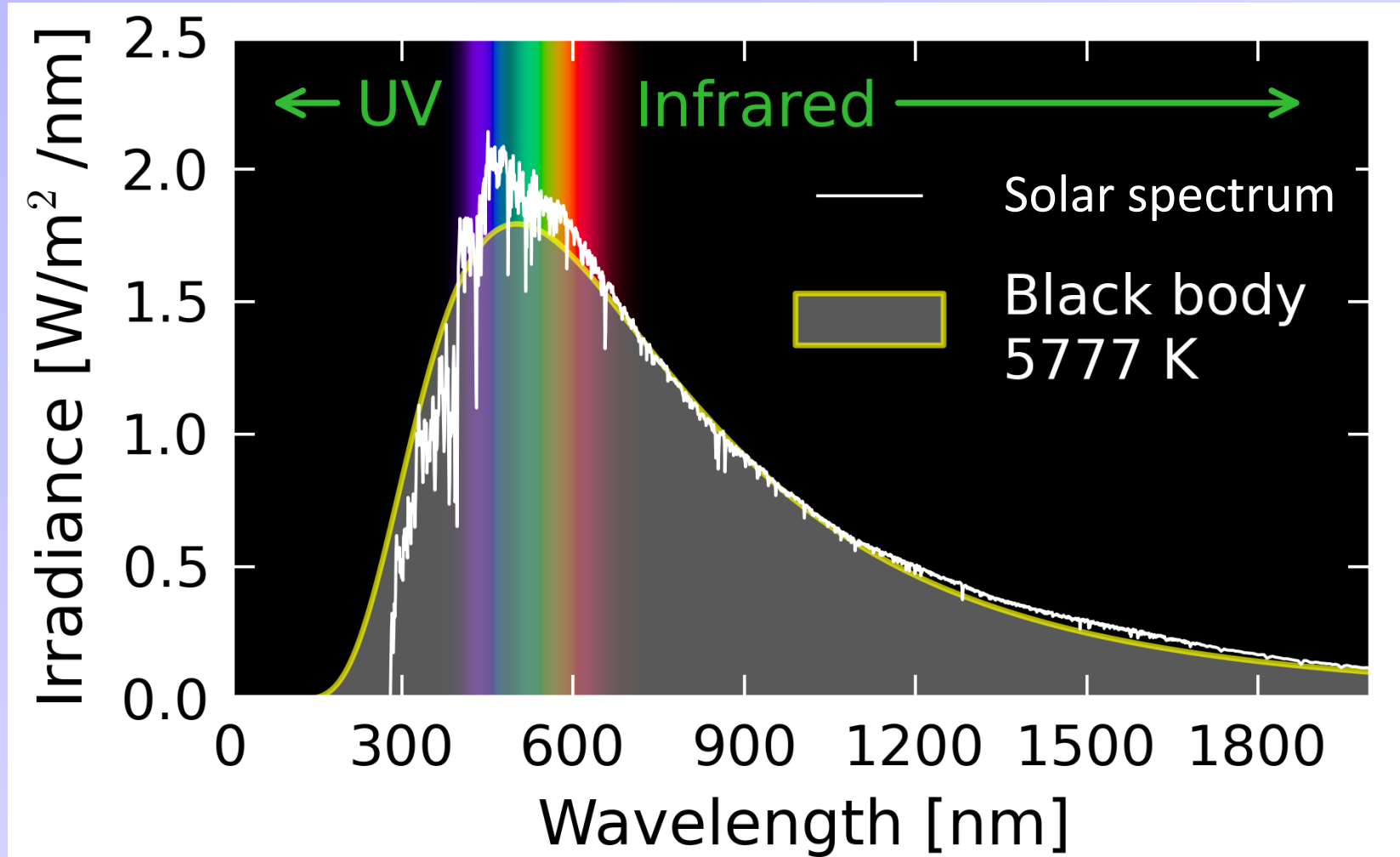
Our Sun: Surface (photosphere)

Properties

- Temperature = 5777 K (surface/photosphere)

- Substance: Plasma (electrons & nuclei are dissociated).

- Magnetosphere: ~ 1 Gauss at surface.
      (exception: sunspots at 3000 G)

- Rotation period: $T_{equator}$ = 25 days, T_{poles} = 34 days.

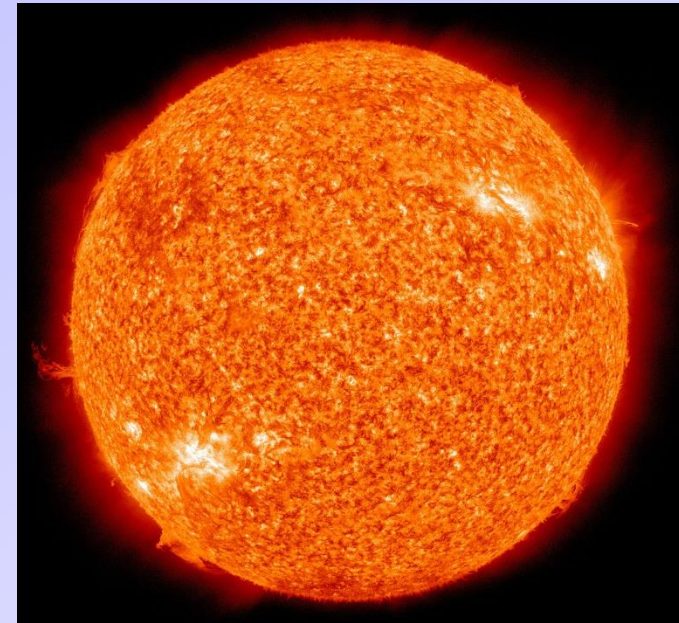- Rotation axis tilt: 7.25° with respect to ecliptic.

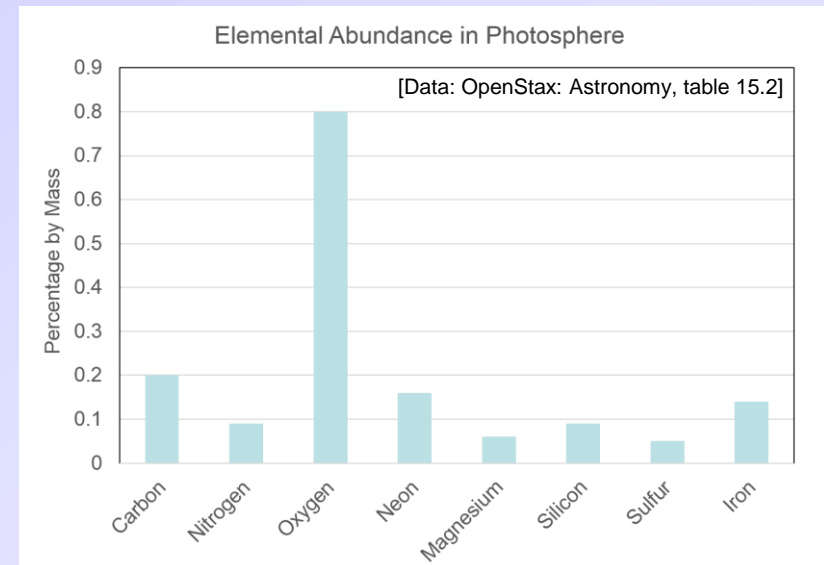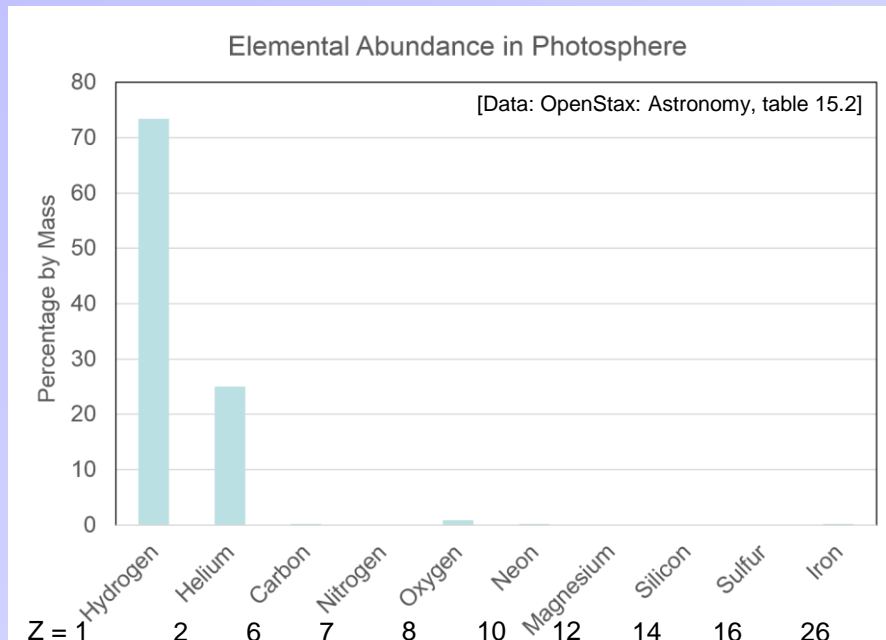[NASA: Solar Dynamics Observatory, UV light at 304 nm, 2010]

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.

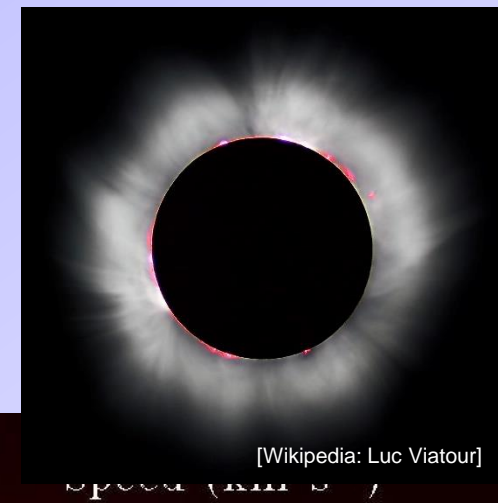[NASA: Solar Dynamics Observatory, UV light at 304 nm, 2010]

Elemental Abundance in Photosphere

[Data: OpenStax: Astronomy, table 15.2]

Elemental Abundance in Photosphere

[Data: OpenStax: Astronomy, table 15.2]

Solar Wind

Extension of the Corona

[Wikipedia: Luc Viatour]

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
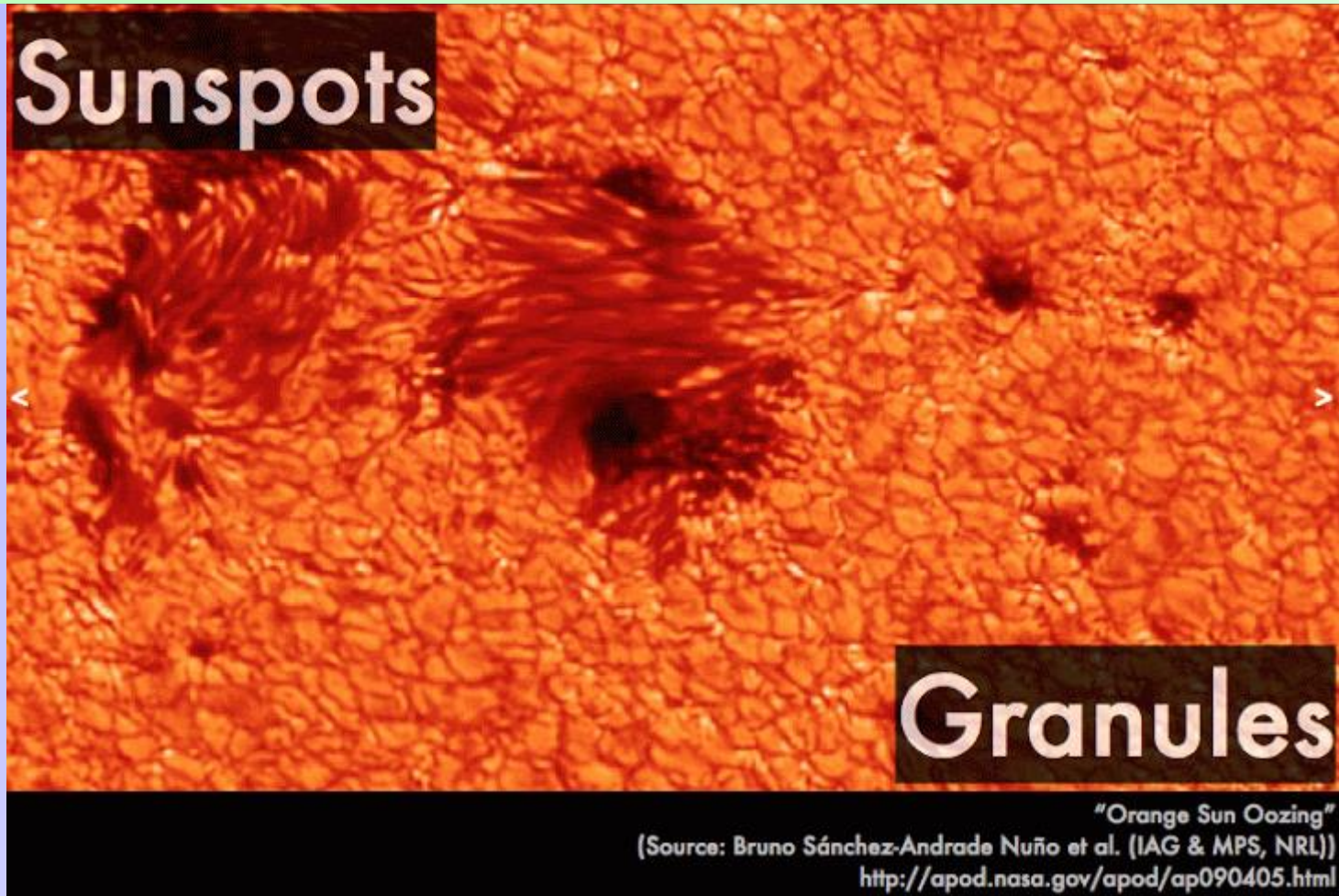
- Strongest emission is from coronal holes.

ULYSSES/SWOOPS
Los Alamos
Space and Atmospheric Sciences

1000

500

1000

1000

500

ULYSSES/MAG
Imperial College
● Outward IMF
● Inward IMF

EIT (NASA/GSFC)
Mauna Loa MK3 (HAO)
LASCO C2 (NRL)

1000

[NASA: Ulysses mission]
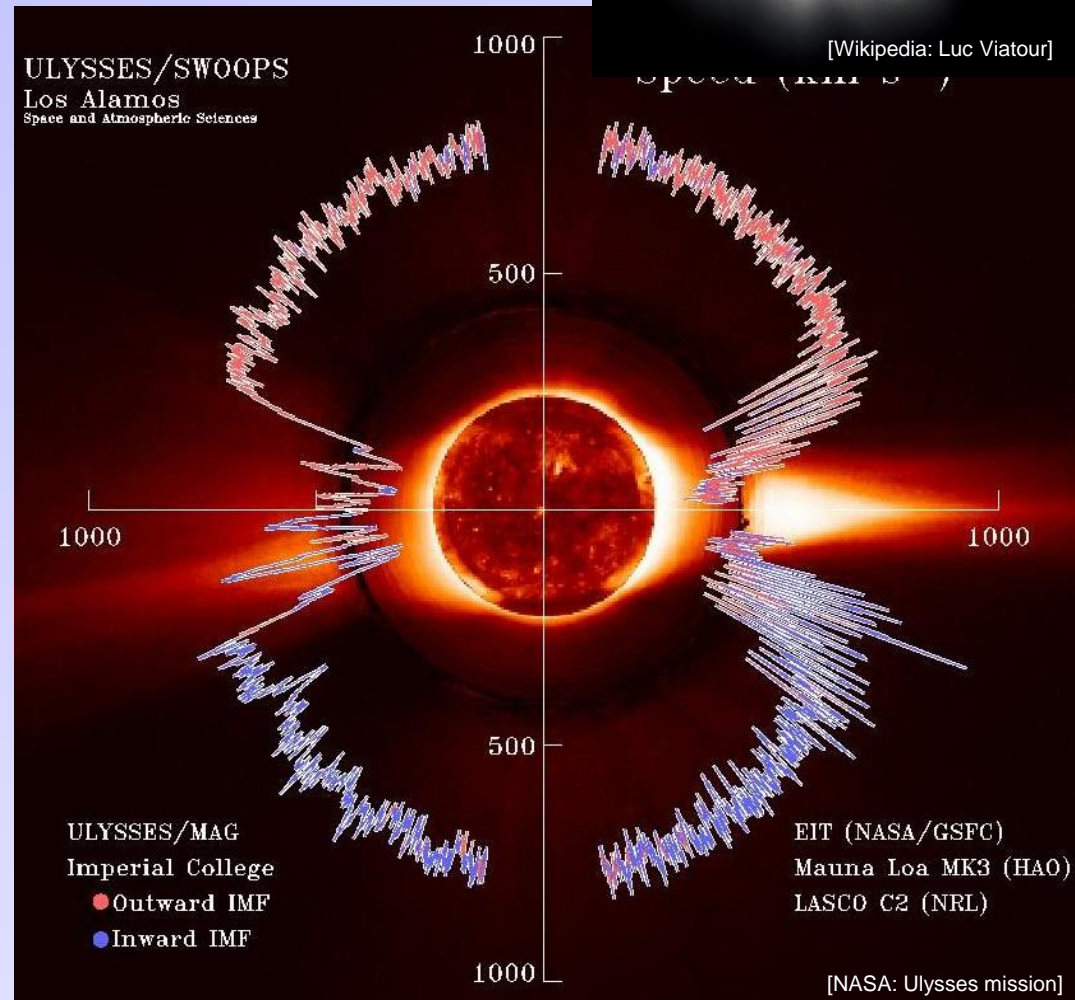
Our Sun's Surface

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

Our Sun: Sunspots & Granules

"Orange Sun Oozing"
(Source: Bruno Sánchez-Andrade Nuño et al. (IAG & MPS, NRL))
http://apod.nasa.gov/apod/ap090405.html

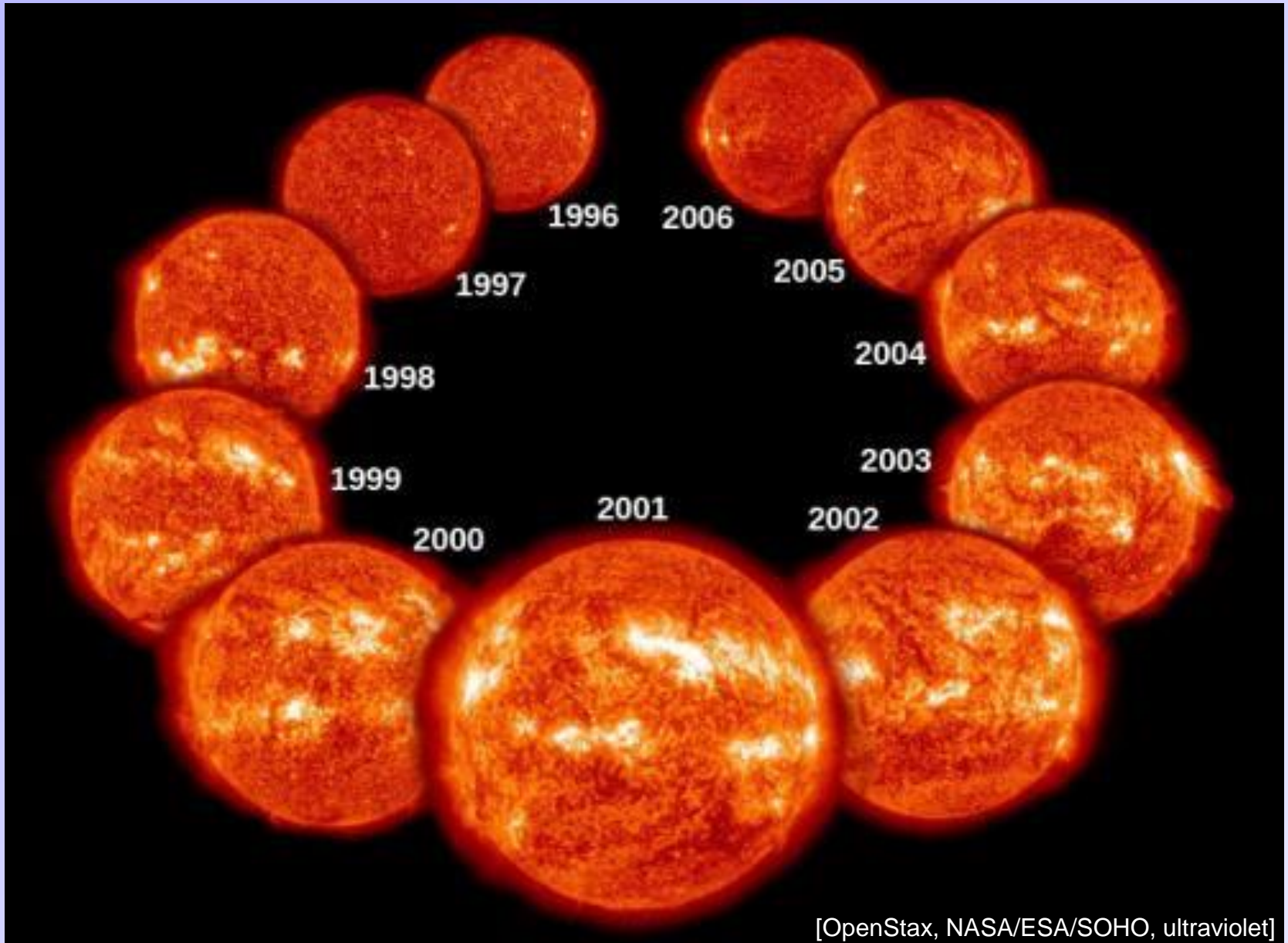Sunspot size ~ 10,000-20,000 km
Sunspot = cooler surface region with strong magnetic field.

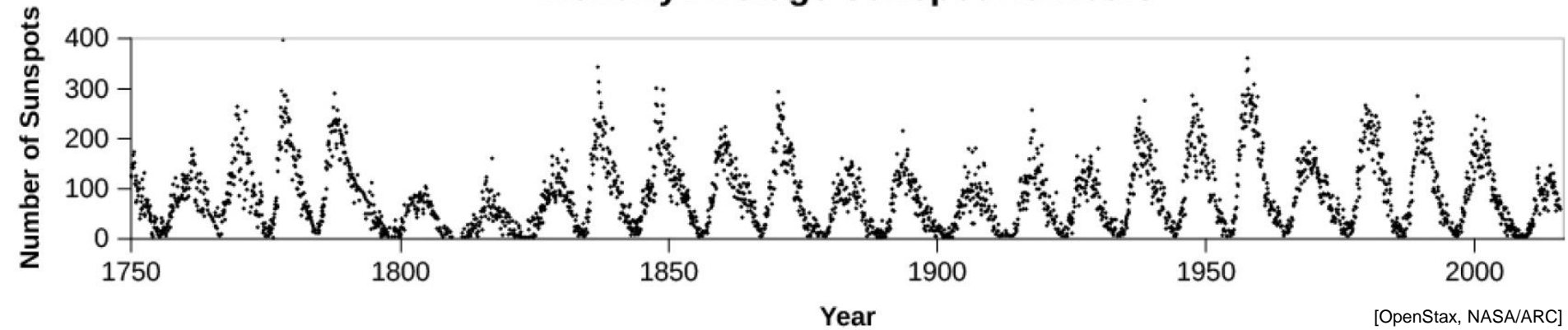→ *convection is impede by magnetic field.*

Granule size ~ 1500 km
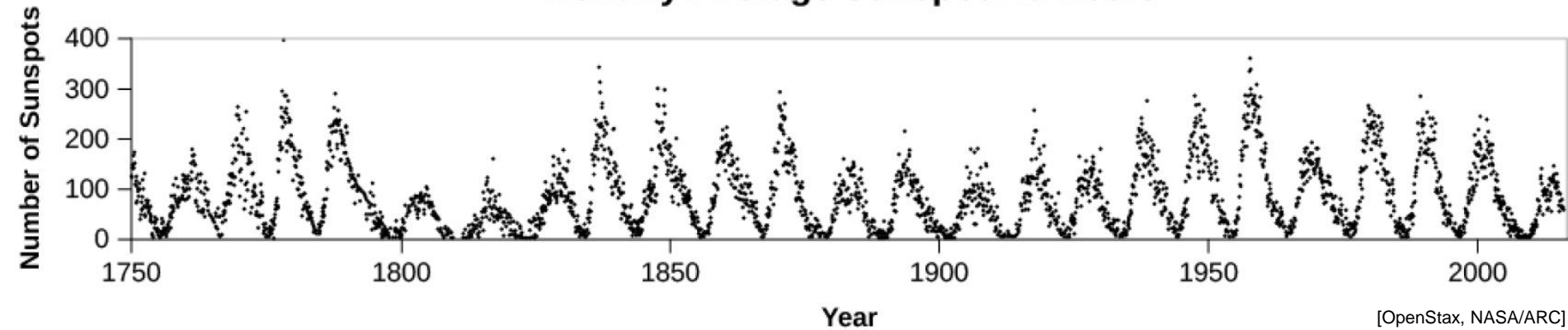*granule = convective cell*

Solar Cycle: 11 year period

[OpenStax, NASA/ESA/SOHO, ultraviolet]

Sunspots: 11 year cycle

Monthly Average Sunspot Numbers

[OpenStax, NASA/ARC]
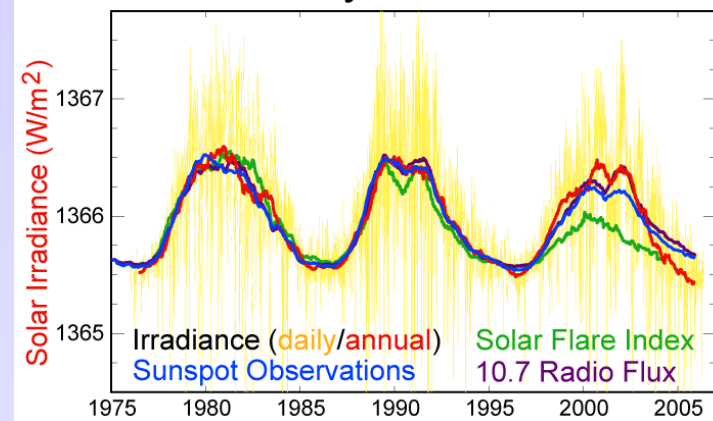
Sunspots: 11 year cycle

Monthly Average Sunspot Numbers

[OpenStax, NASA/ARC]

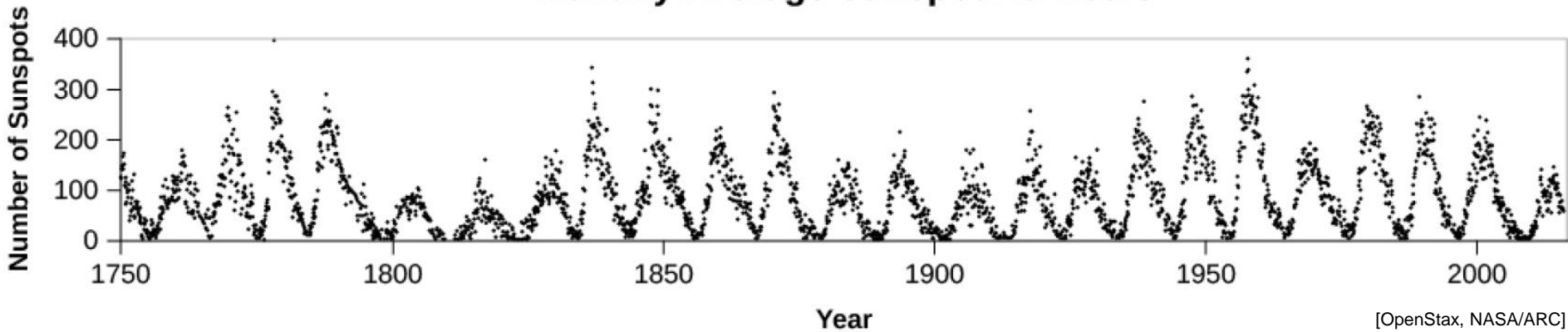The following all vary in-sync with the solar cycle:

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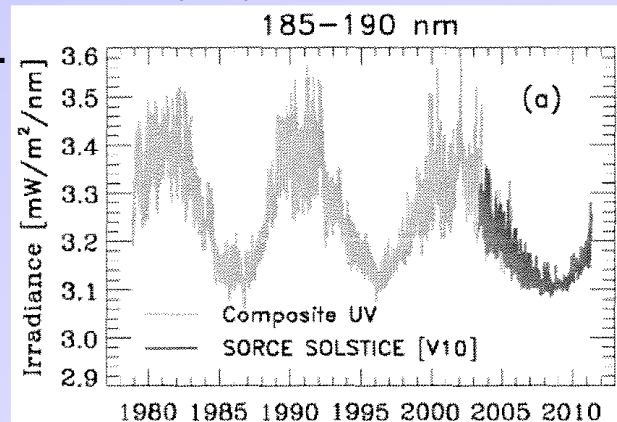- Solar **UV irradiance**.

Solar Cycle Variations

Irradiance (daily/annual)   Solar Flare Index
Sunspot Observations   10.7 Radio Flux

[Wikipedia]

Sunspots: 11 year cycle

Monthly Average Sunspot Numbers


[OpenStax, NASA/ARC]

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

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

Solar Cycle Variations

Irradiance (daily/annual)   Solar Flare Index
Sunspot Observations   10.7 Radio Flux

[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)]
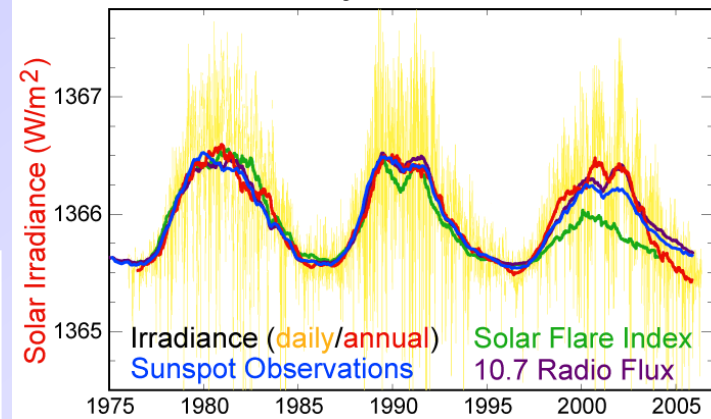
Our Sun: Structure

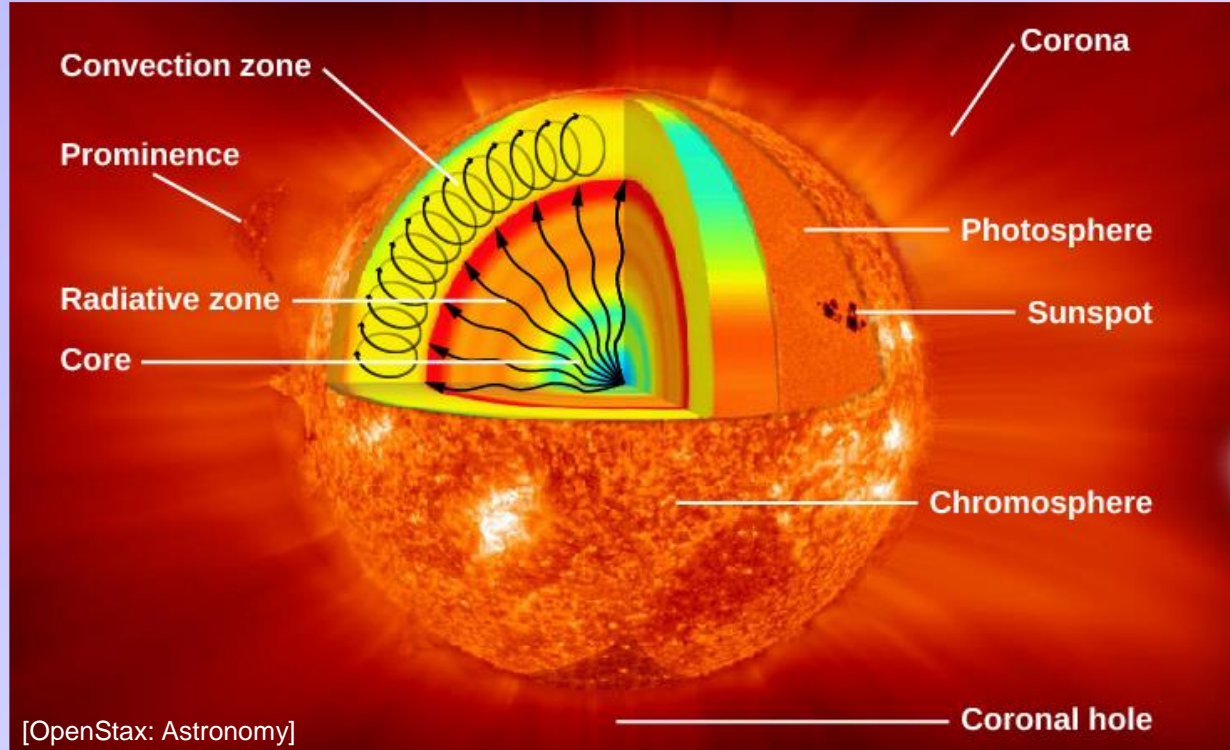Structure determined from:

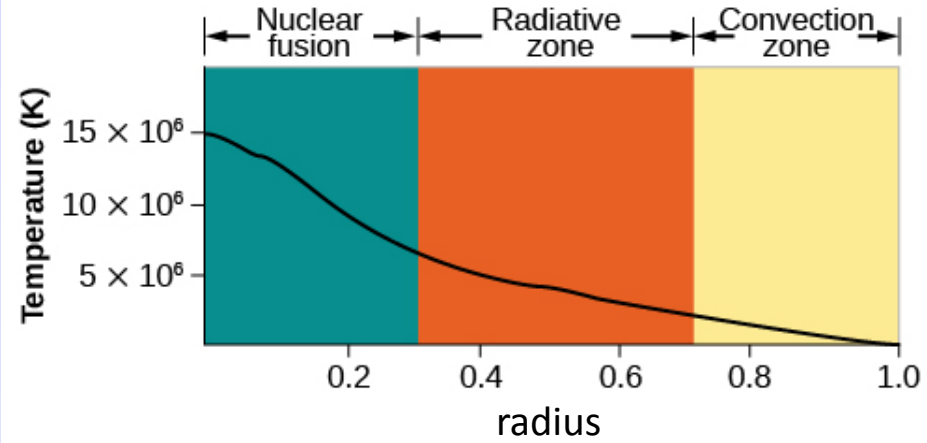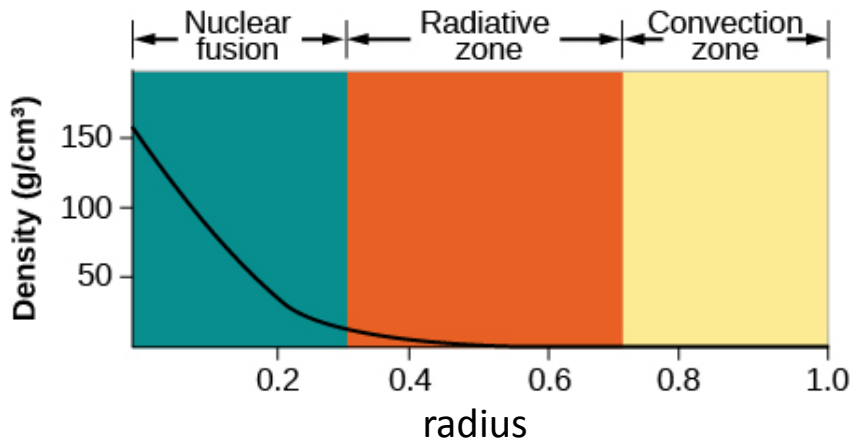- Computer modelling.

- Helioseismology.

- **Neutrino** measurements.

[OpenStax: Astronomy]

Our Sun: Structure

Structure determined from:

- Computer modelling.
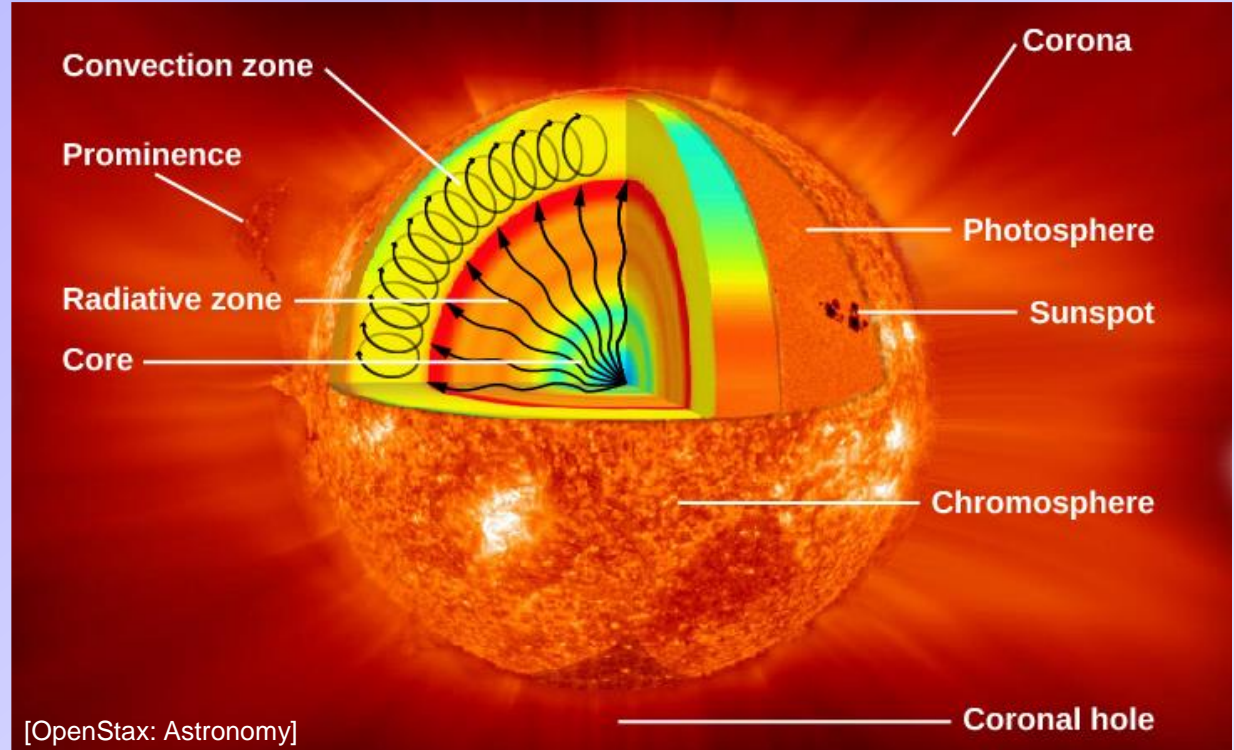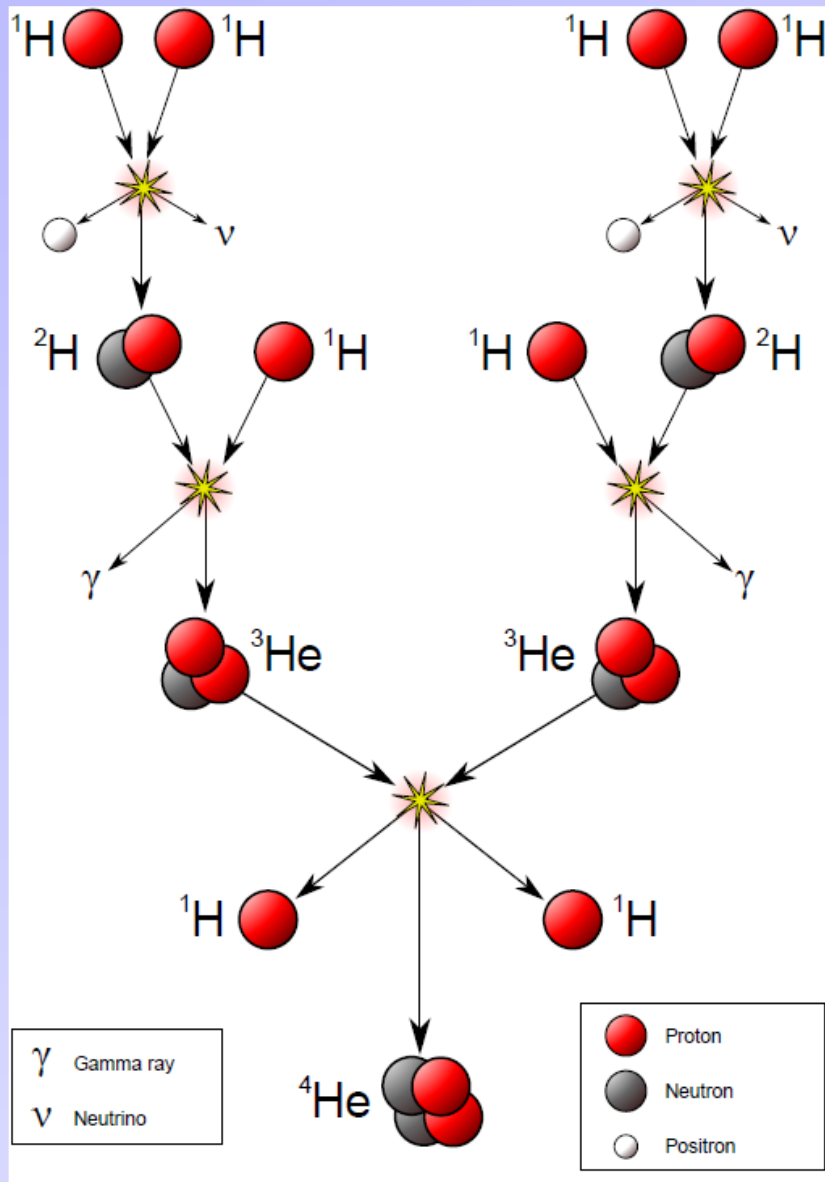
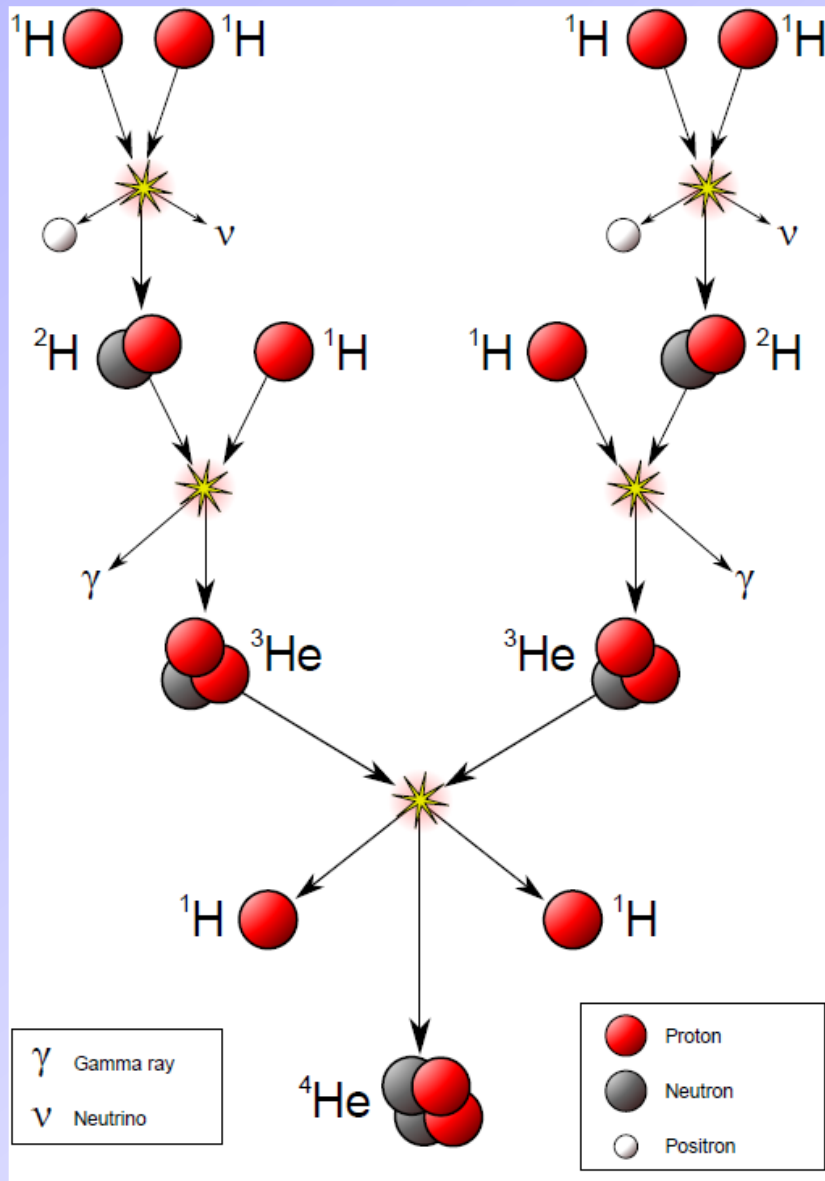- Helioseismology.

- **Neutrino** measurements.

[OpenStax: Astronomy]

Solar Fusion: proton-proton chain

(see also Sept. 9 lecture)

Solar Fusion: proton-proton chain

(Note: 1 eV = 1.602×10^{-19} J)

9 billions years
weak force

2×1.442 MeV

| γ | Gamma ray |
| ν | Neutrino |

●	Proton
●	Neutron
○	Positron

(see also Sept. 9 lecture)

Solar Fusion: proton-proton chain

(Note: 1 eV = 1.602×10^{-19} J)

9 billions years
weak force

4 seconds
strong force

2×1.442 MeV

+ 2×5.49 MeV

(see also Sept. 9 lecture)

¹H ¹H   ¹H ¹H

²H ¹H   ¹H ²H

γ   γ

³He   ³He

¹H   ¹H

⁴He

γ Gamma ray
ν Neutrino

Proton
Neutron
Positron

Solar Fusion: proton-proton chain
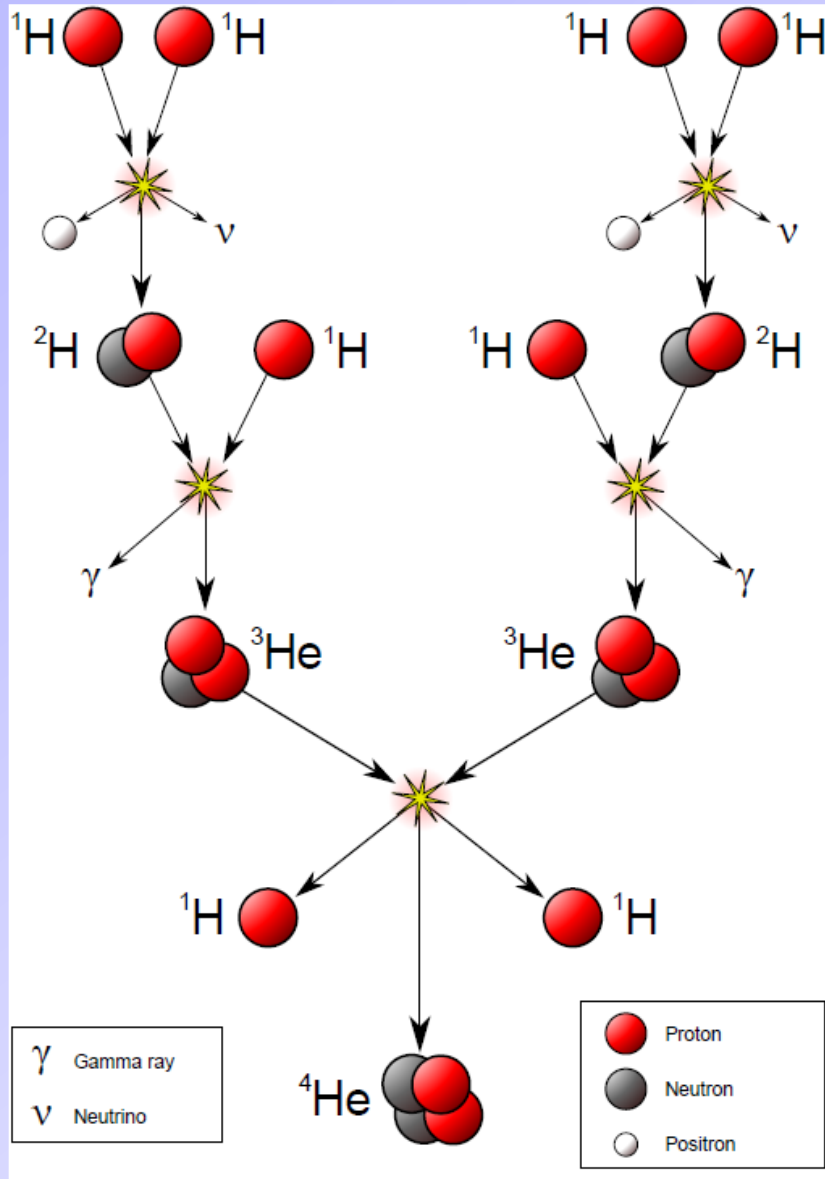
9 billions years
weak force

4 seconds
strong force

400 years
strong force

(see also Sept. 9 lecture)

(Note: 1 eV = 1.602×10^{-19} J)

2×1.442 MeV

$+ \quad 2 \times 5.49$ MeV

$+ \quad 12.86$ MeV

$= 26.7$ MeV total

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

| γ | Gamma ray |
| ν | Neutrino |

	Proton
	Neutron
	Positron

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

Einstein: Mass & Energy

$$Energy = E = mc^2$$

mass

c = speed of light