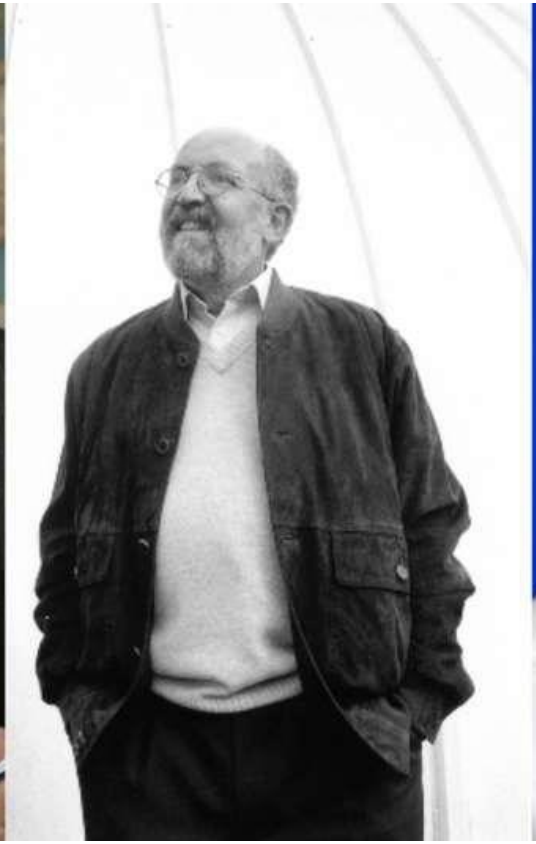
2019 Nobel Prize in Physics … and Astronomy

James Peebles
(Princeton U.)



Michel Mayor
(U. of Geneva)

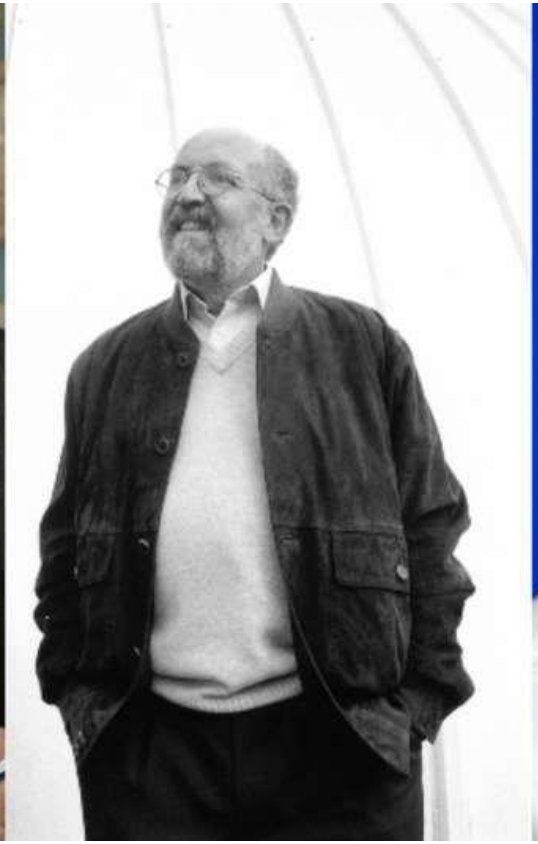
Didier Queloz
(U. of Geneva)

[Image credits: Royal Swedish Academy of Sciences; University of Geneva]

2019 Nobel Prize in Physics … and Astronomy

James Peebles
(Princeton U.)

Big Bang theory,
dark matter & energy



Michel Mayor
(U. of Geneva)

Didier Queloz
(U. of Geneva)

Discovery of first star-based **exo-planet** (in 1995)

[Image credits: Royal Swedish Academy of Sciences; University of Geneva]

2019 Nobel Prize in Physics … and Astronomy

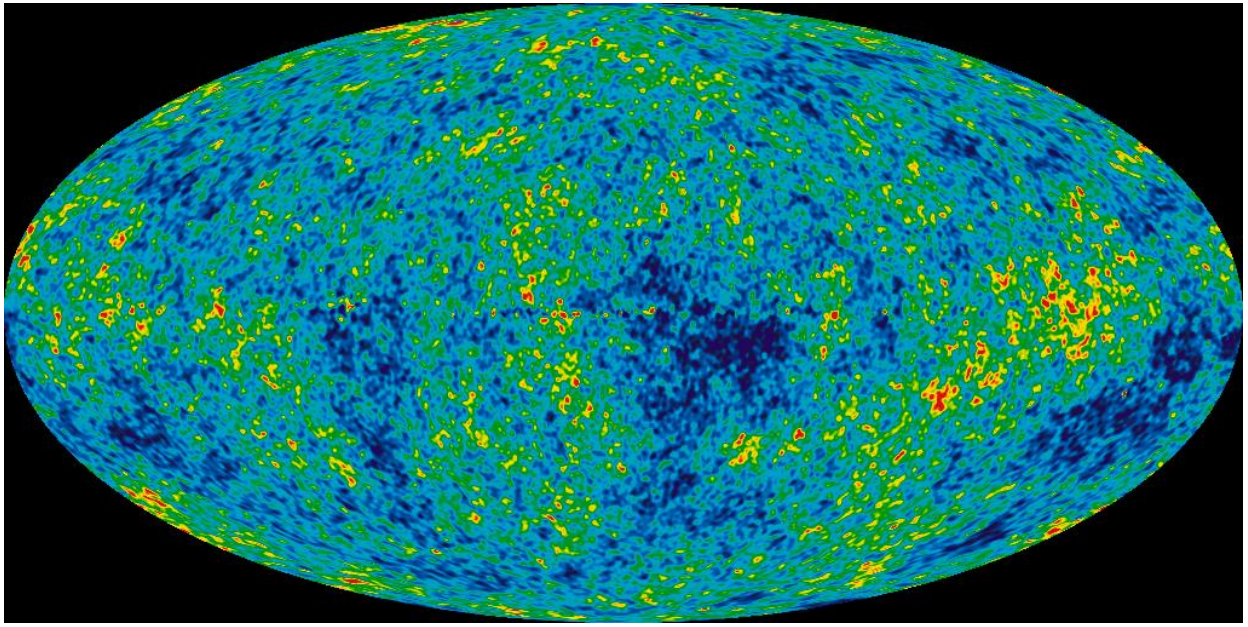
- **Cosmic Microwave Background** (CMB) is the remnant blackbody radiation from the Big Bang.
- This radiation used to much more energetic, but it has been "Doppler-shifted" by the expansion of the universe. Apparent temperature is **T = 2.726 K** (peak at λ = 1 mm).

James Peebles
(Princeton U.)

[Image credits: Royal Swedish Academy of Sciences; University of Geneva]

2019 Nobel Prize in Physics … and Astronomy

- **Cosmic Microwave Background** (CMB) is the remnant blackbody radiation from the Big Bang.
- This radiation used to much more energetic, but it has been "Doppler-shifted" by the expansion of the universe. Apparent temperature is **T = 2.726 K** (peak at λ = 1 mm).
- **Spatial/angular variations of CMB** (~ 0.01% level) are thought to have given rise to galactic superclusters, galaxies, and stars.



[https://map.gsfc.nasa.gov/media/121238/index.html]

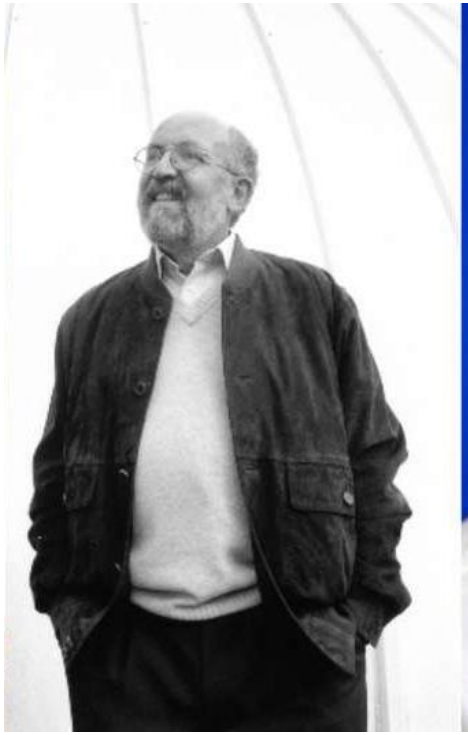
Spatial variations in the Cosmic Microwave Background (WMAP).

James Peebles
(Princeton U.)

[Image credits: Royal Swedish Academy of Sciences; University of Geneva]

2019 Nobel Prize in Physics … and Astronomy

- **1995: First discovery of a planet orbiting another star** (51 Pegasi) at about 50 ly.
  → *Pegasus constellation.*
- Discovered by seeing the **Doppler shift** in the star's light caused by orbiting the center-of-mass of the star-planet system.
- Planet is 0.5 lighter than Jupiter, but with a 4 day orbit (i.e. closer than Mercury)

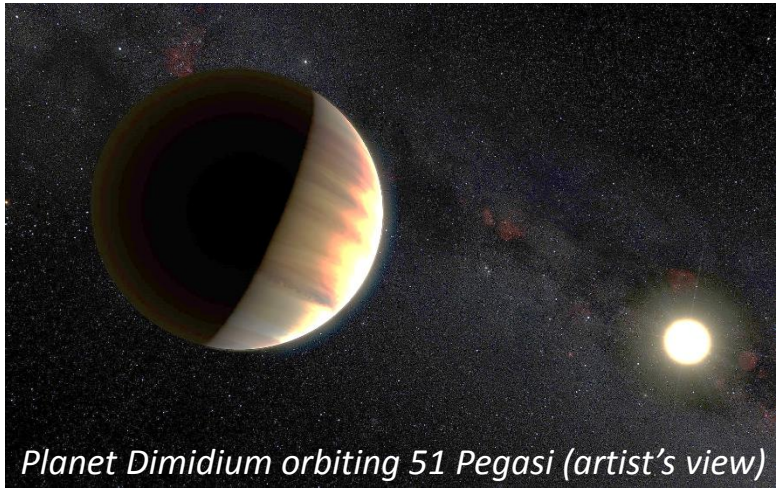


Michel Mayor
(U. of Geneva)

Didier Queloz
(U. of Geneva)

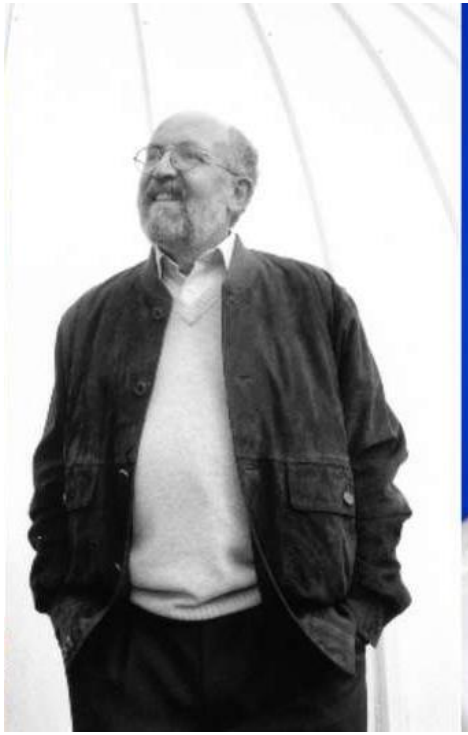
2019 Nobel Prize in Physics … and Astronomy

- **1995: First discovery of a planet orbiting another star** (51 Pegasi) at about 50 ly.
  → *Pegasus constellation.*
- Discovered by seeing the **Doppler shift** in the star's light caused by orbiting the center-of-mass of the star-planet system.
- Planet is 0.5 lighter than Jupiter, but with a 4 day orbit (i.e. closer than Mercury)



Planet Dimidium orbiting 51 Pegasi (artist's view)

[Wikipedia: ESO/M. Kornmesser/Nick Risinger (skysurvey.org) - ESO website]



Michel Mayor
(U. of Geneva)

Didier Queloz
(U. of Geneva)

Discovery launched exo-planet astronomy.
→ ~ 4000 exo-planets discovered so far.

Today's Topics

Wednesday, October 9, 2019 (Week 6, lecture 17) – Chapter 8.

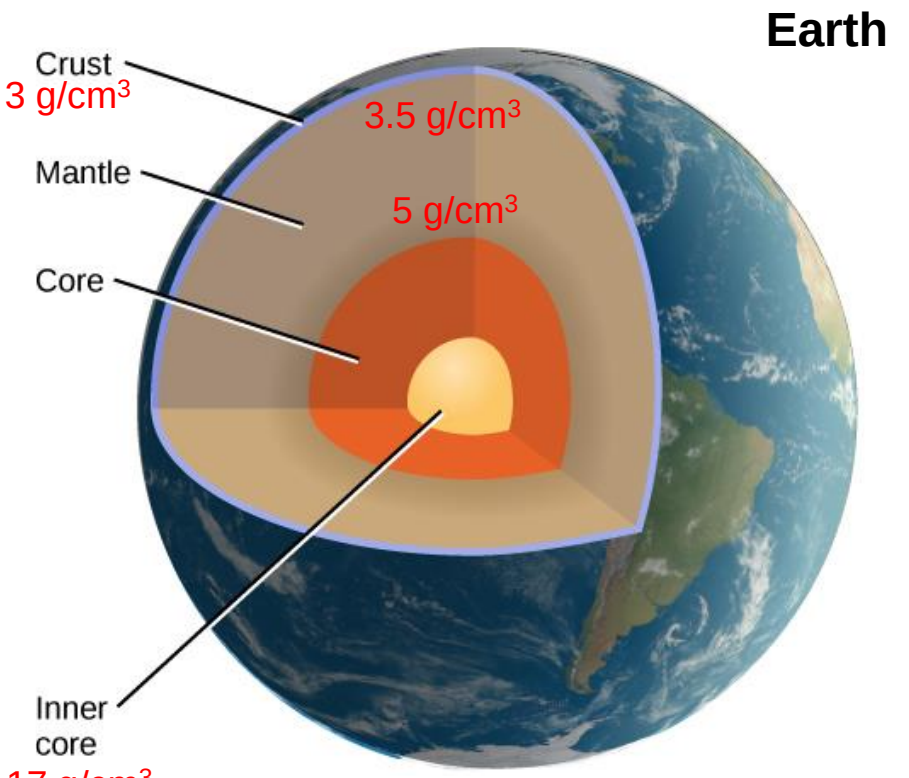
1. Earth as a Planet
2. Interior of Earth
3. Magnetosphere

Earth as a Planet

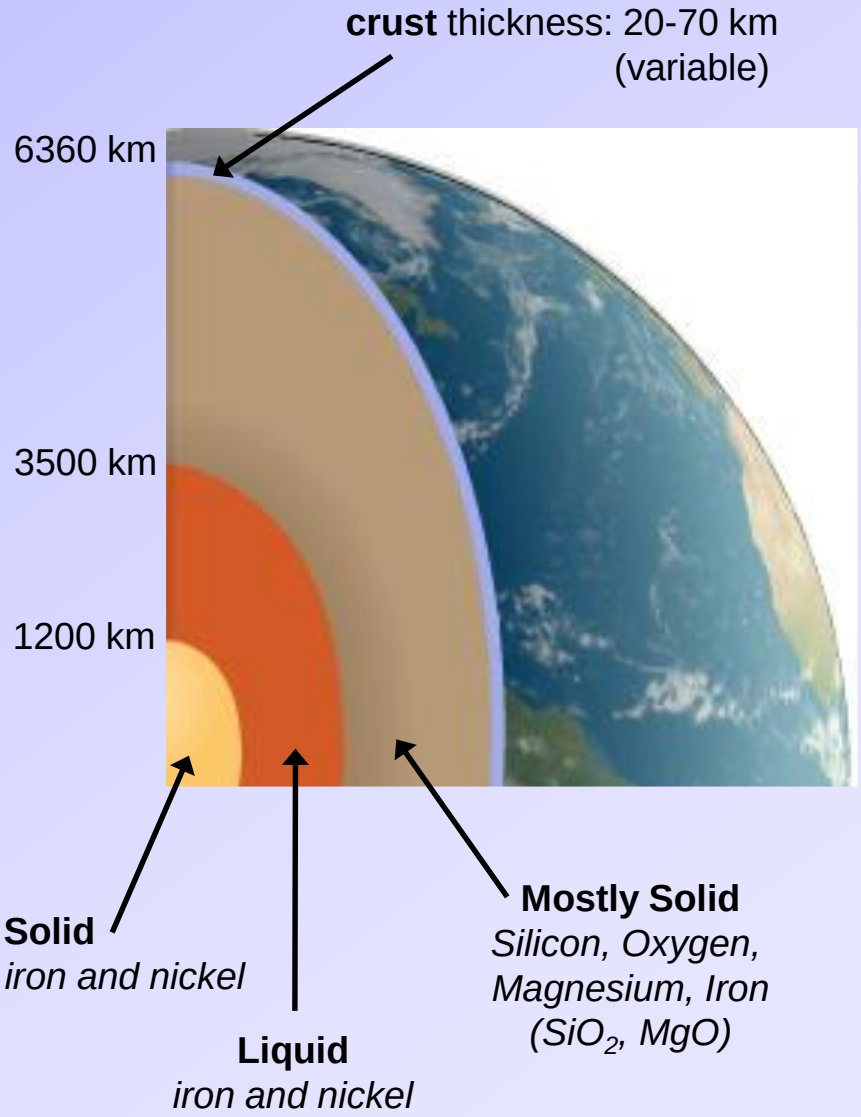
- Interior of Earth
  - → Geology
- Magnetosphere
  - → Aurora.
- Atmosphere
  - → Life's effect on Earth.
  - → Greenhouse effect.
- Asteroids impacts

Earth as seen from Apollo 17

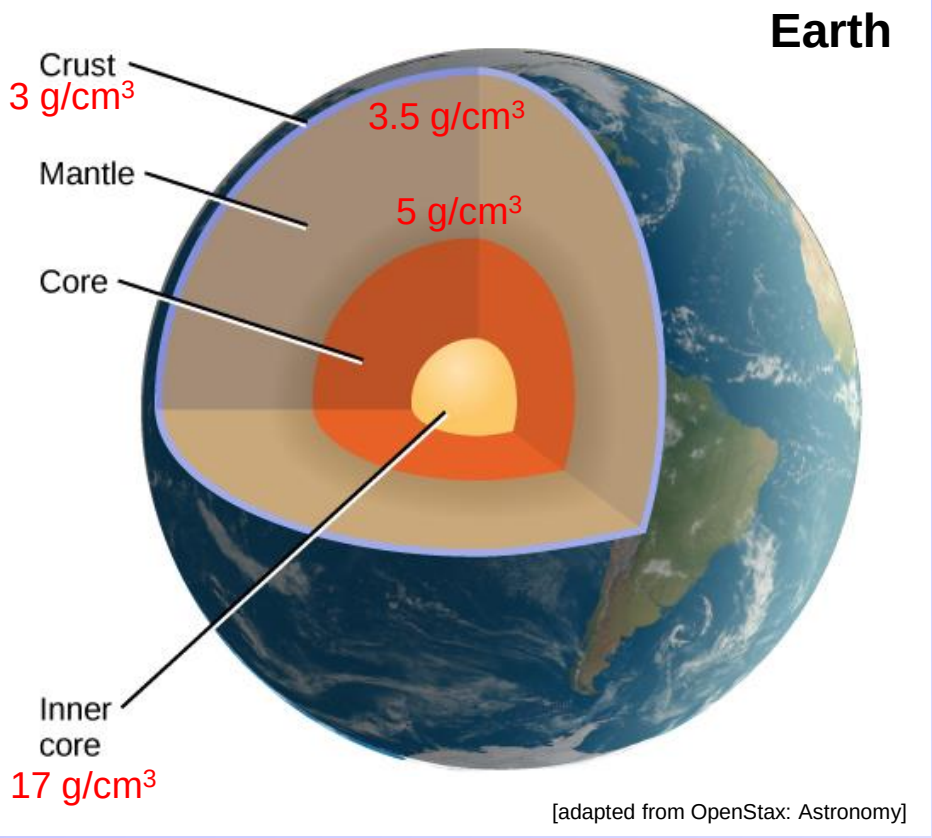
Earth's Interior

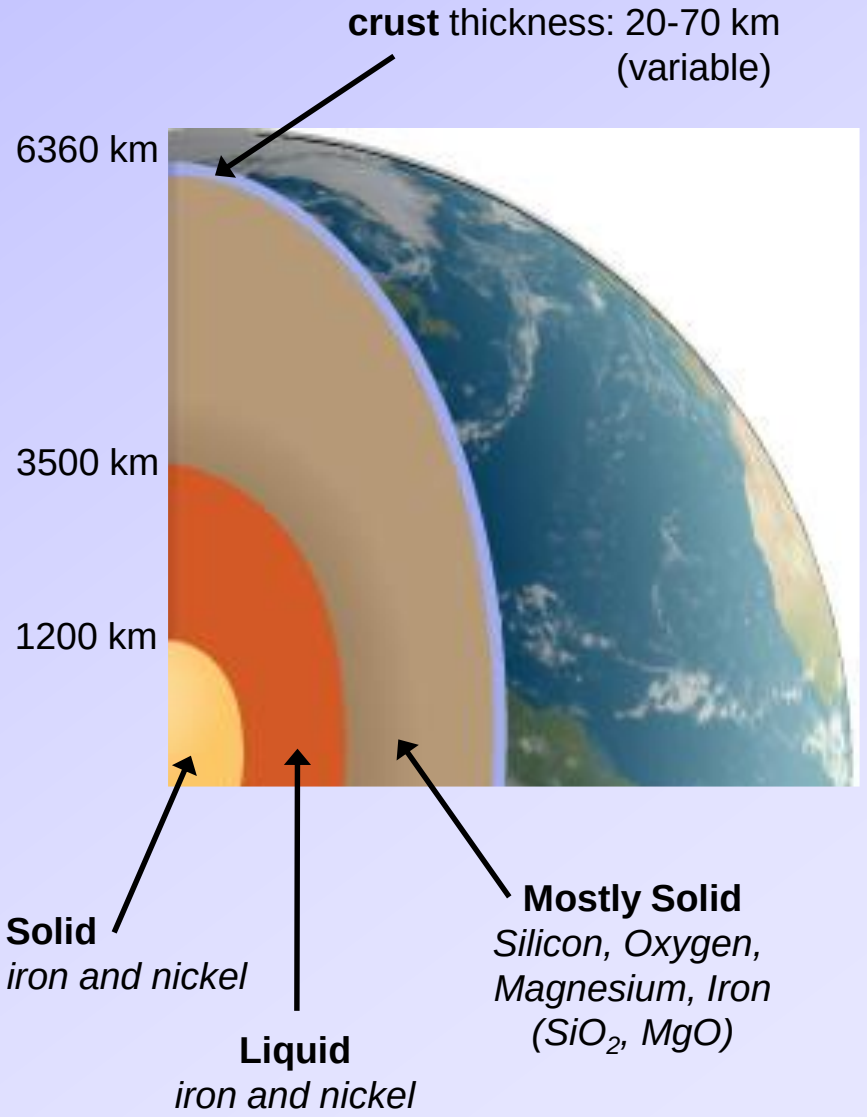


[adapted from OpenStax: Astronomy]



Earth's Interior

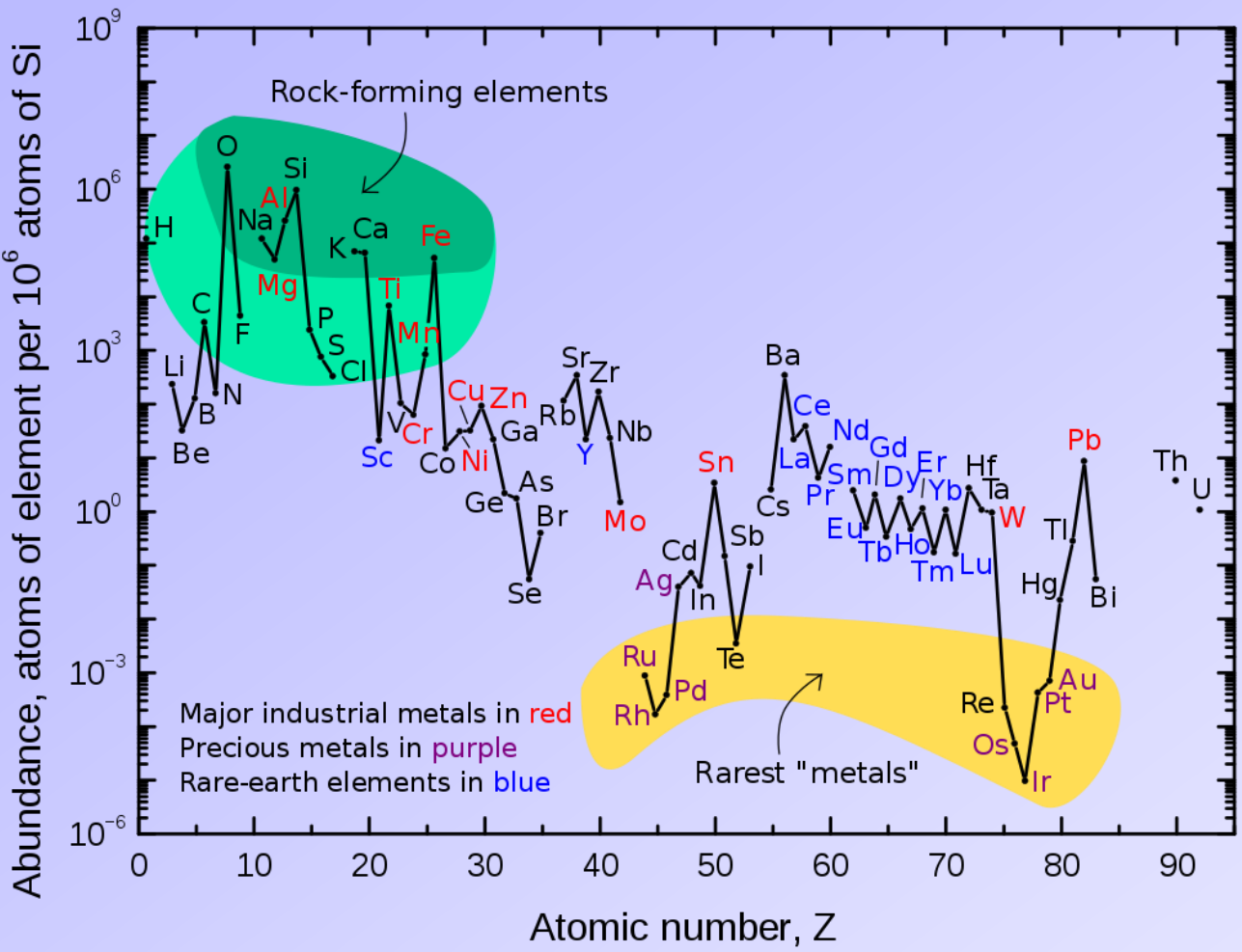




Where does the Earth's interior heat come from ?

- Residual heat from formation of planet.
- Radioactive decay (uranium, thorium, K-40).
- *Differentiation (denser material sinking).*

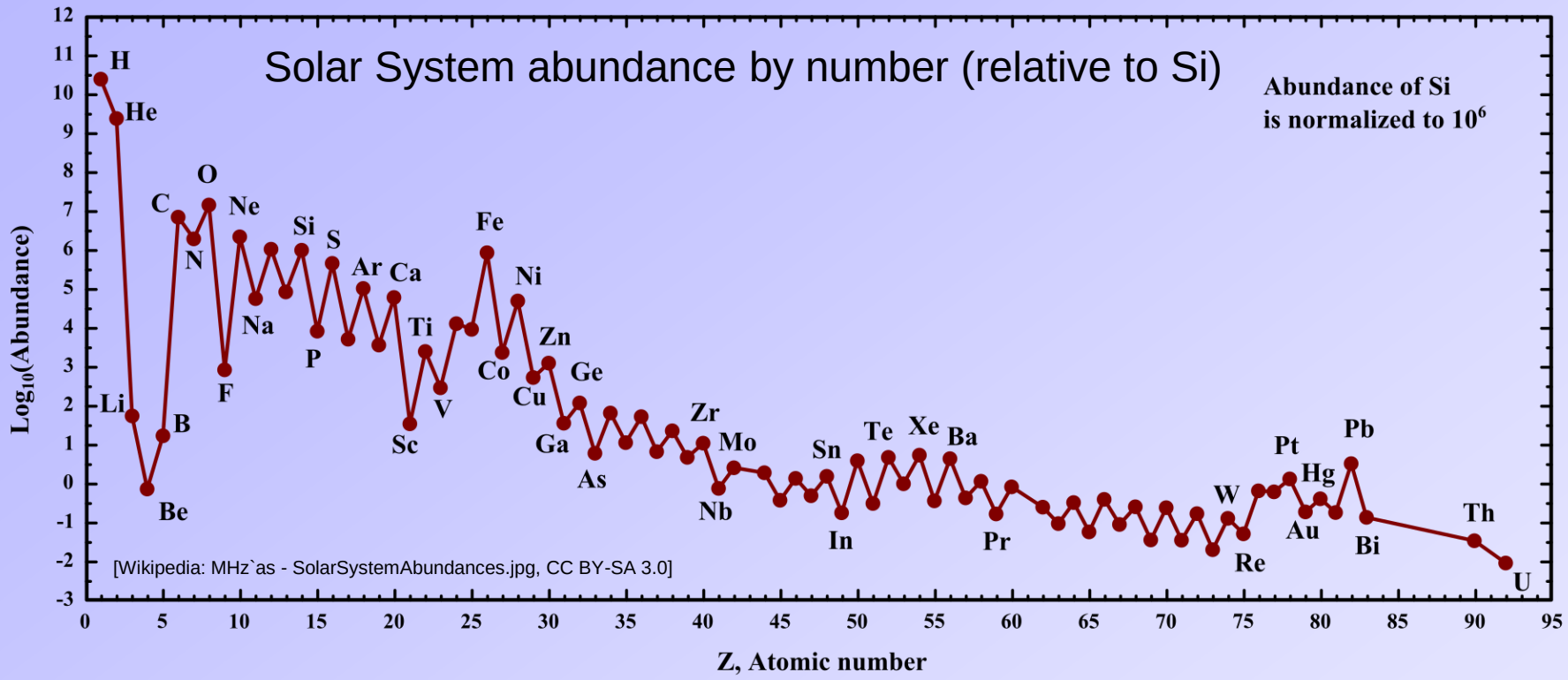
Elements in Earth's Crust



- Lots of **oxygen** and **silicon**.
- Some <u>hydrogen</u>.
- Not much <u>helium</u>.
- Decent amounts of **iron** and **aluminum**.
- *Significantly less heavy elements (past Fe = iron)*

[Wikipedia: Gordon B. Haxel, Sara Boore, and Susan Mayfield from USGS; vectorized by User:michbich - http://pubs.usgs.gov/fs/2002/fs087-02/]

Solar System's Elements



- Dominated by **hydrogen** (H) and **helium** (He).
- Very little lithium (Li), beryllium (Be), and boron (B).
- Decent amounts of **carbon** (C), **oxygen** (O), and **nitrogen** (N).
- *Steady decline in abundance for heavier elements.*
- Significant amounts of **iron** (Fe) and some **nickel** (Ni).

Measuring Earth's Interior

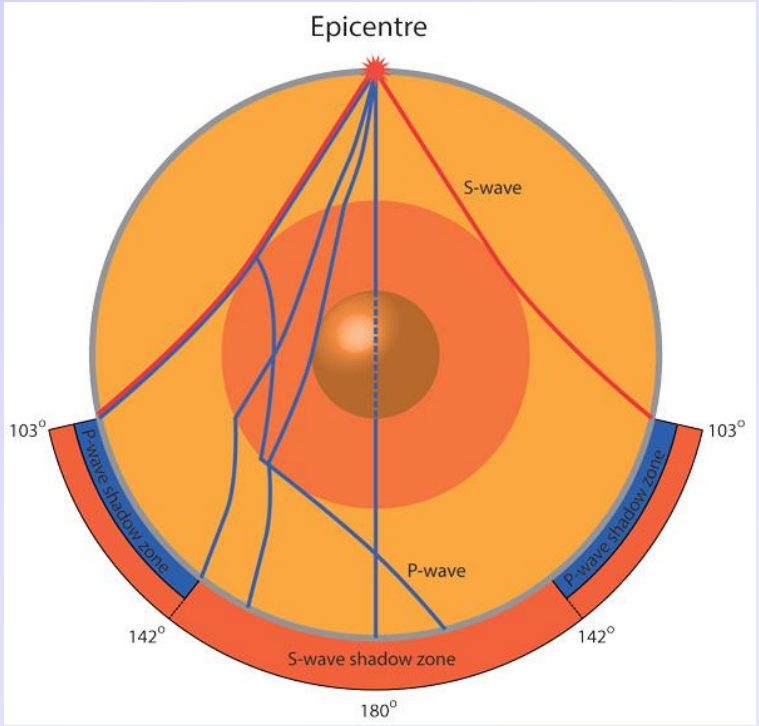
- How can we determine what's underneath the crust?
  - → Ground penetrating radar can go about 30 m deep.
  - → The deepest holes that we have drilled are ~12 km deep.
  - → Earth's crust is roughly 20-70 km thick.
- Drilling our way to an answer is really hard !!!

Measuring Earth's Interior

- How can we determine what's underneath the crust?
  - → Ground penetrating radar can go about 30 m deep.
  - → The deepest holes that we have drilled are ~12 km deep.
  - → Earth's crust is roughly 20-70 km thick
- Drilling our way to an answer is really hard !!!

Answer: Seismic waves

- The **shadowing** and **deviation** of seismic waves by the Earth's interior can be used to probe it.
- Seismic waves are **vibrational waves.**
  → *Primary waves are **compression** waves.*
  → *Secondary waves vibrate **perpendicular** to propagation.*
- They are generated by **earthquakes** or large explosions.



[Source: https://www.bgs.ac.uk/discoveringGeology/hazards/earthquakes/structureOfEarth.html]

Earth's Crust: Tectonic Plates

[OpenStax: Astronomy]

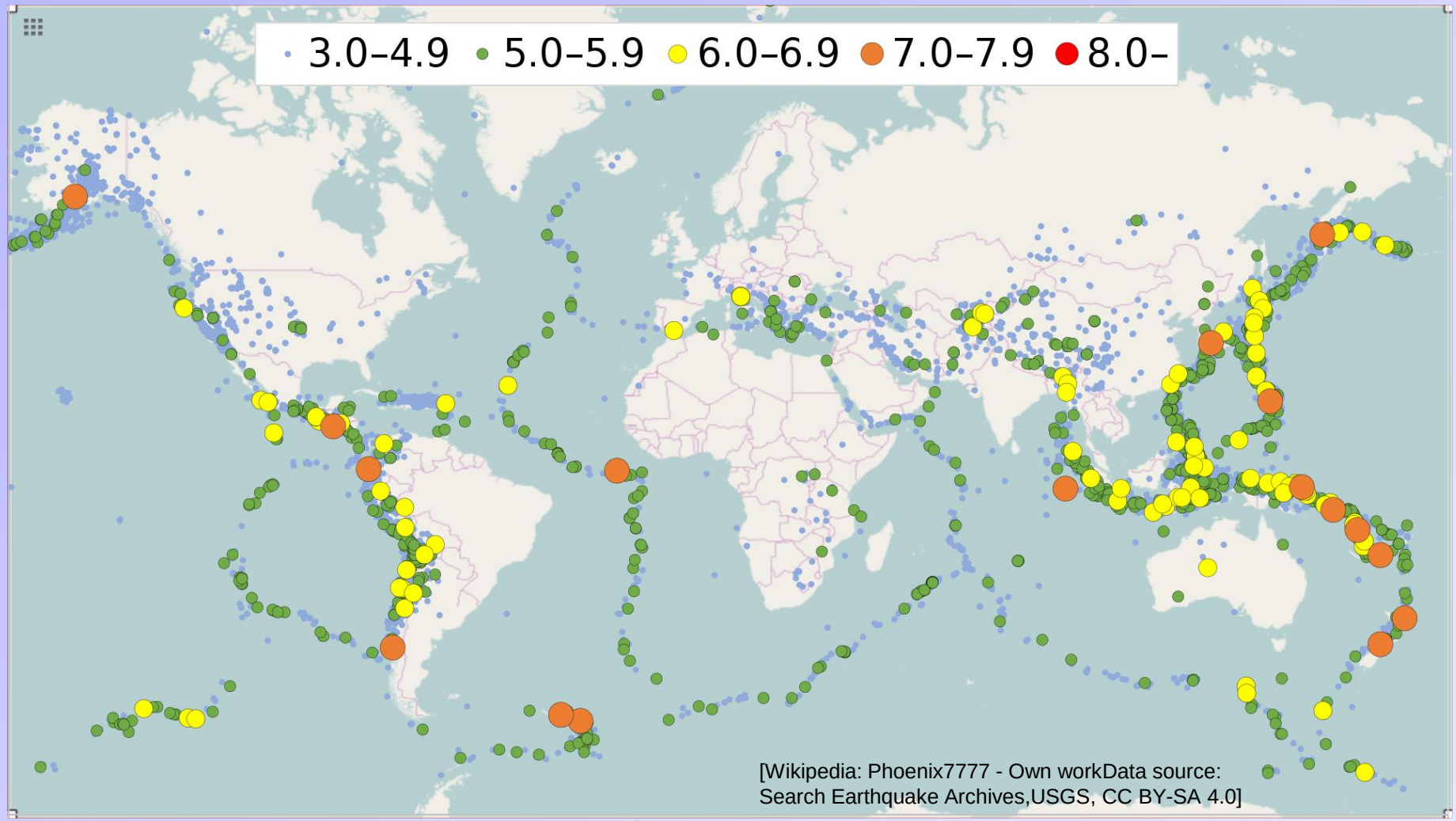
- Earth's crust is broken in up into **tectonic plates** that "drift" on top of mantle.
- Plates are generated in **rifts zones** (←→) and removed in **subduction zones** (→←).

Earth's Crust: Tectonic Plates

[OpenStax: Astronomy]

- Earth's crust is broken in up into **tectonic plates** that "drift" on top of mantle.
- Plates are generated in **rifts zones** (←→) and removed in **subduction zones** (→←).
- These zones typically show **mountain growth** and **volcanic activity**.
- Alfred Wegener first proposed theory in 1910-15: idea was slow to gain acceptance.

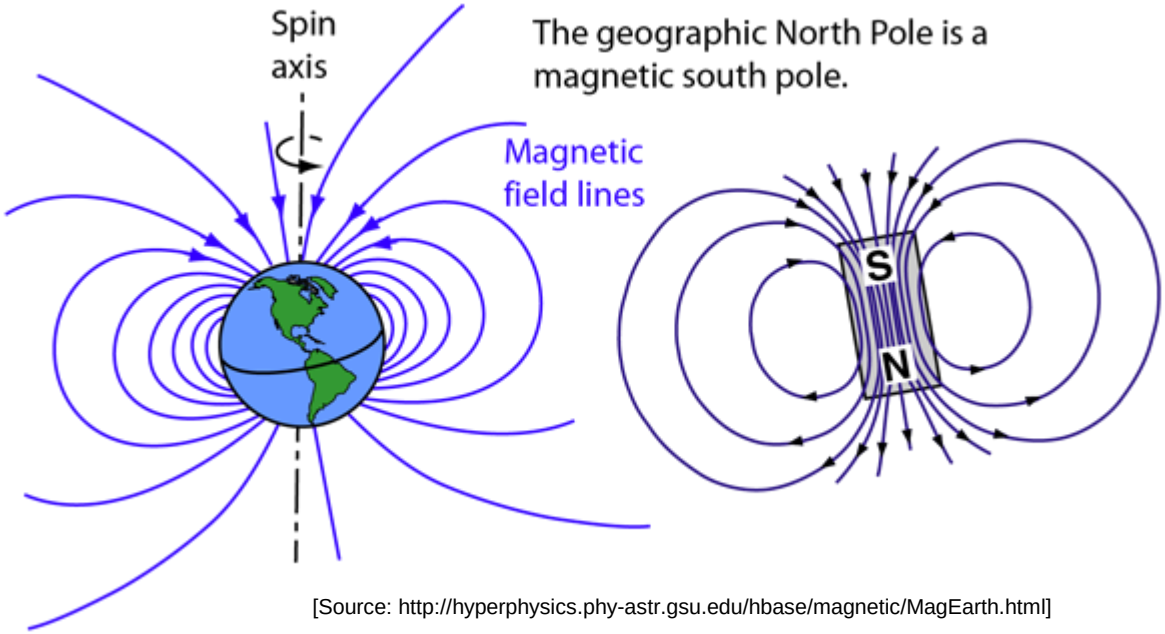
Map of Earthquakes in 2016



Earthquakes and volcanoes typically occur at tectonic plate boundaries

Earth's Magnetic Field

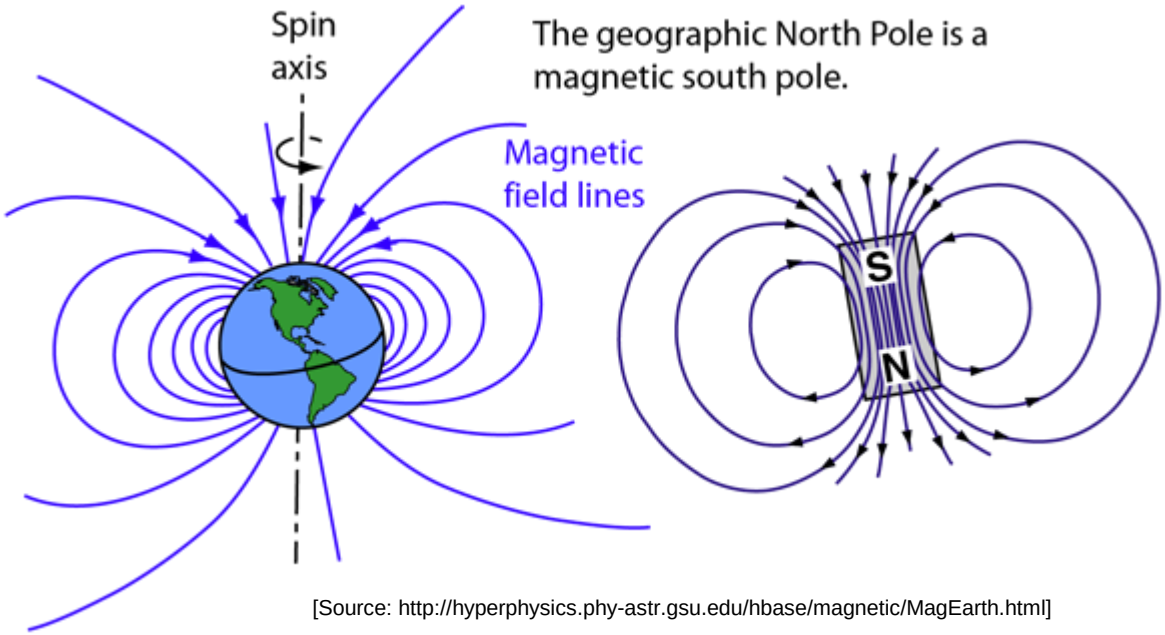
- Earth has a magnetic field generated by **electrical current in its core**.
- The magnetic is **not** aligned with Earth's rotation axis.
- 0.3-0.5 Gauss at surface.



[Source: http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/MagEarth.html]

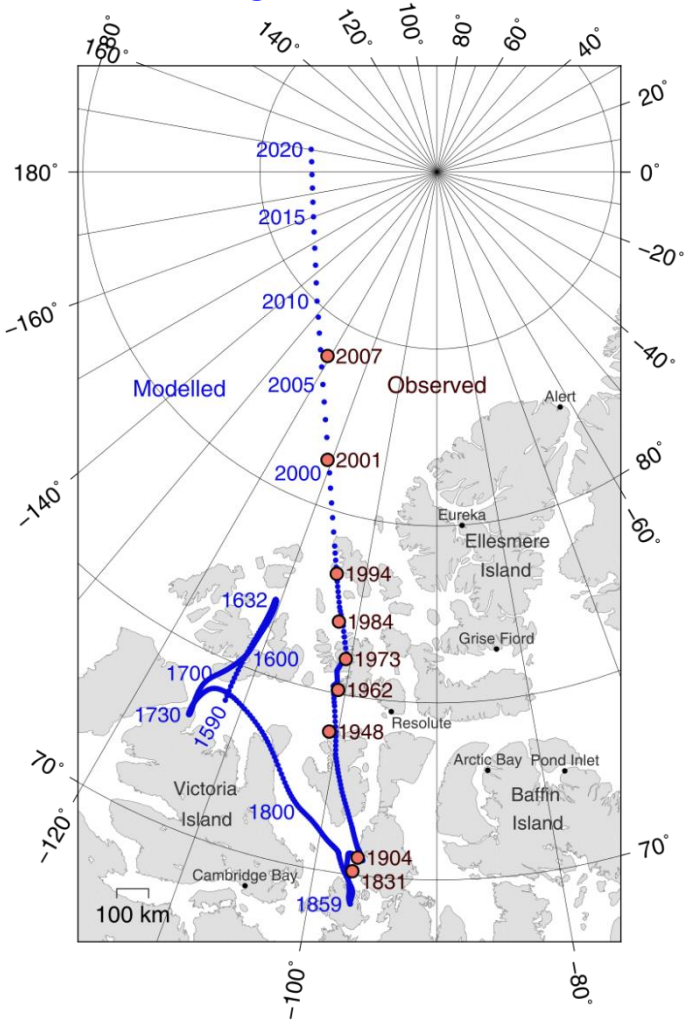
Earth's Magnetic Field

- Earth has a magnetic field generated by **electrical current in its core**.
- The magnetic is **not** aligned with Earth's rotation axis.
- 0.3-0.5 Gauss at surface.
- The magnetic pole **drifts** over time and **flips** on a time scale of 0.1 – 1 million years.



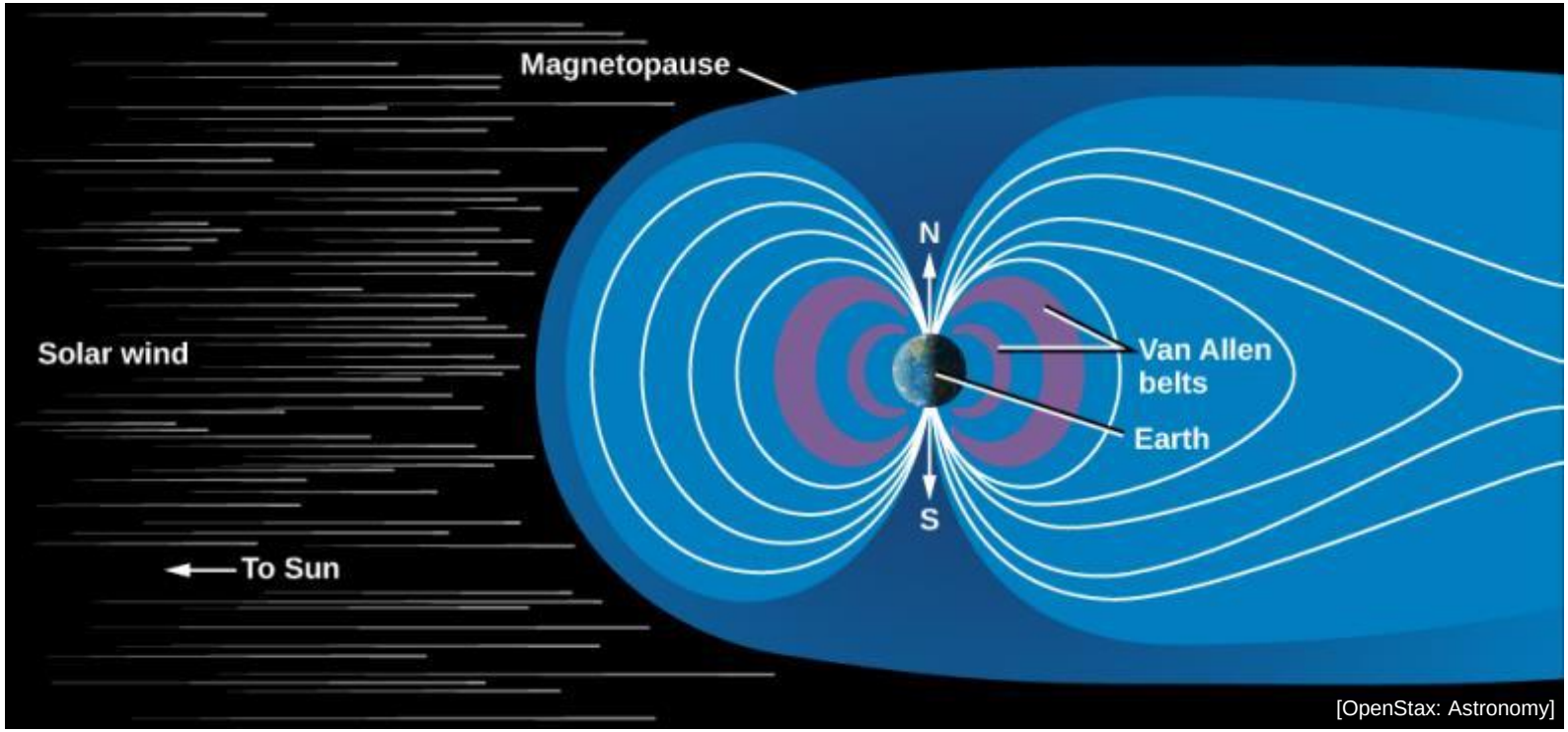
[Source: http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/MagEarth.html]

Earth's magnetic north vs time



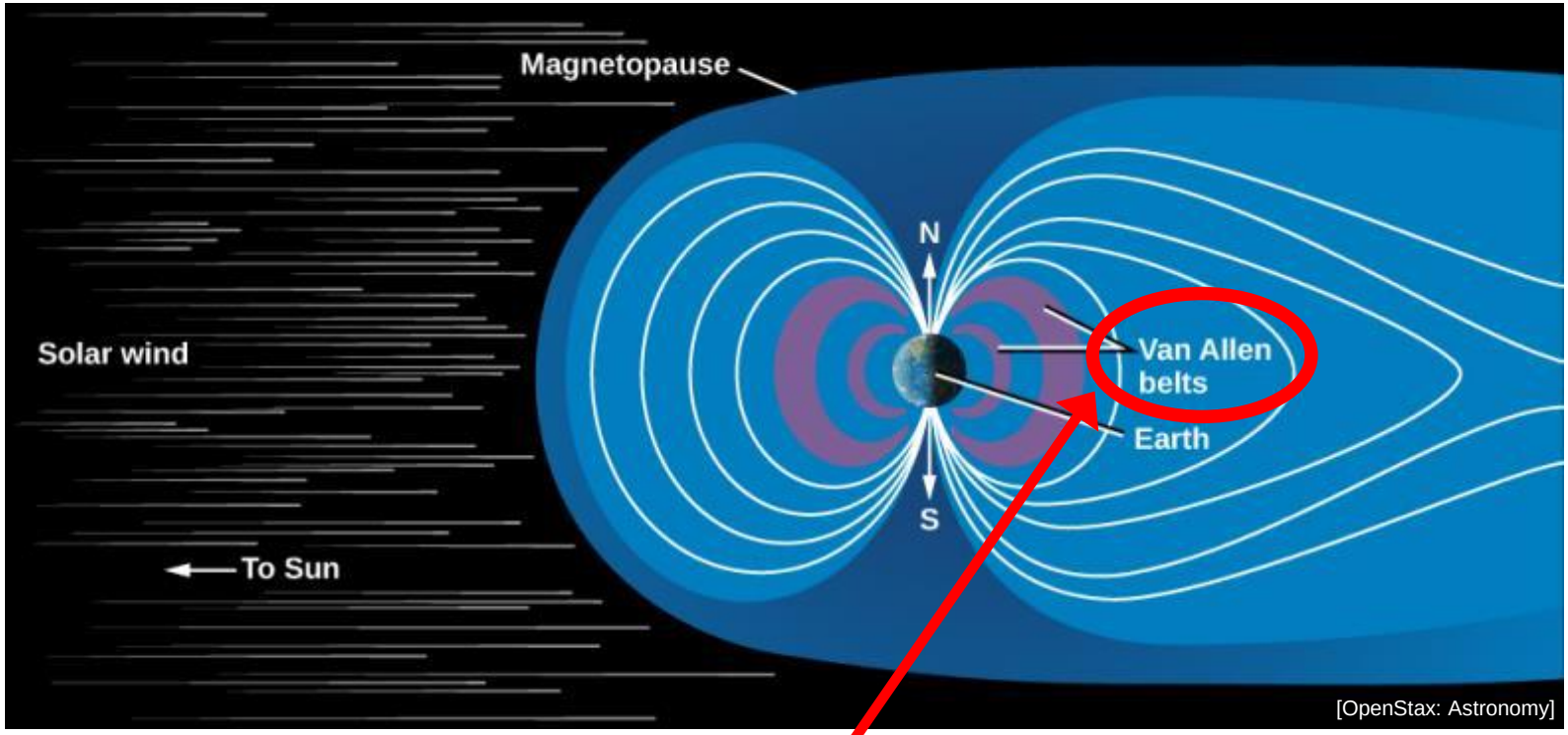
[Wikipedia: By Cavit - Own work:
Observed pole positions taken from Newitt et al., "Location of the North Magnetic Pole in April 2007", Earth Planets Space, 61, 703–710, 2009 Modelled pole positions taken from the National Geophysical Data Center, "Wandering of the Geomagnetic Poles"Map created with GMT, CC BY 4.0]

Magnetosphere



- Earth's magnetic field **screens** the planet from **charged particles** emitted by the Sun (i.e. **solar wind**).
- The Earth's magnetic field **deflects** the charged particles into **spiral trajectories** and slows them down.

Magnetosphere



Charged particles are trapped by magnetic field in the Van Allen radiation belts.

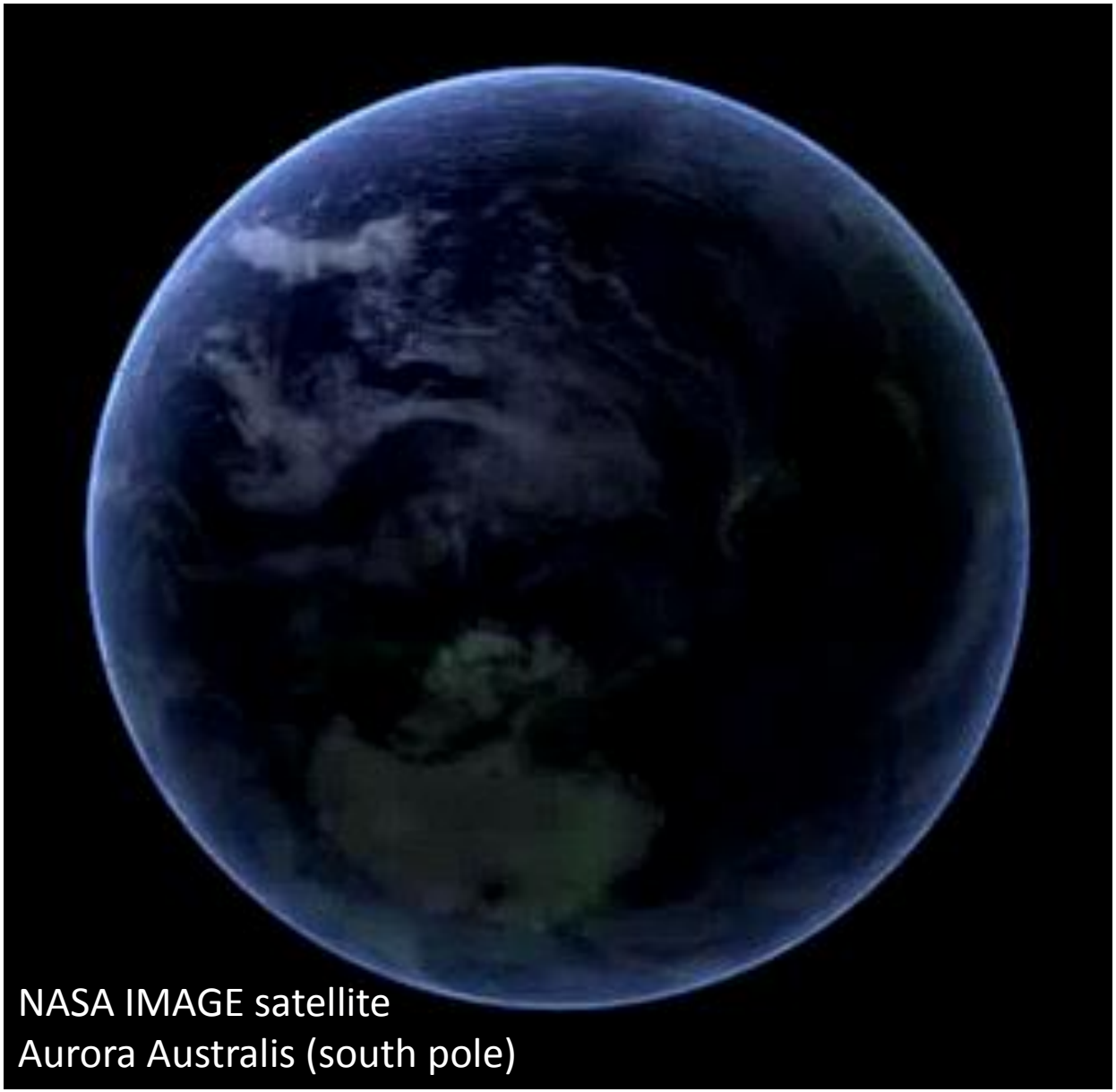
- Earth's magnetic field **screens** the planet from **charged particles** emitted by the Sun (i.e. **solar wind**).
- The Earth's magnetic field **deflects** the charged particles into **spiral trajectories** and slows them down.

Aurora Borealis

Basic physics

- Solar wind charged particles are directed by the Earth's magnetic field into the atmosphere.
- Atmosphere molecules/atoms are ionized, excited, and generate light (red: H, green: O).

Aurora Australis



NASA IMAGE satellite
Aurora Australis (south pole)