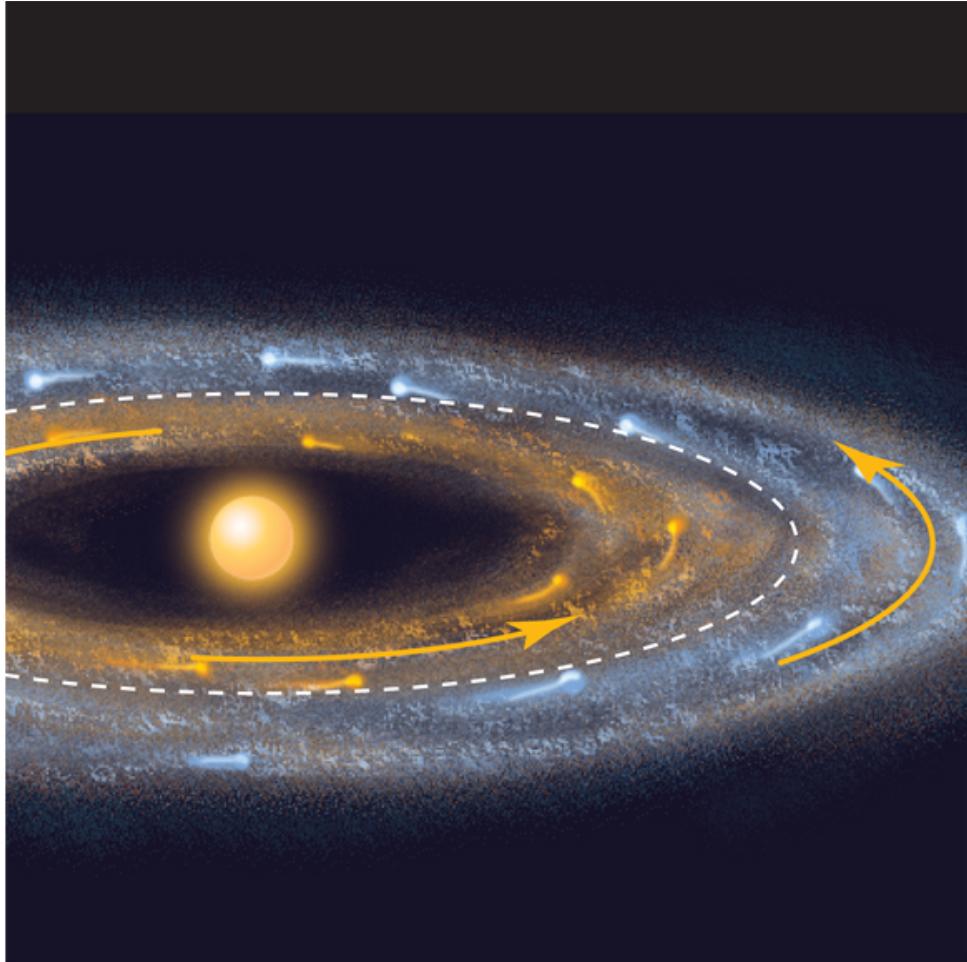


The formation & evolution of solar systems



Content expectations

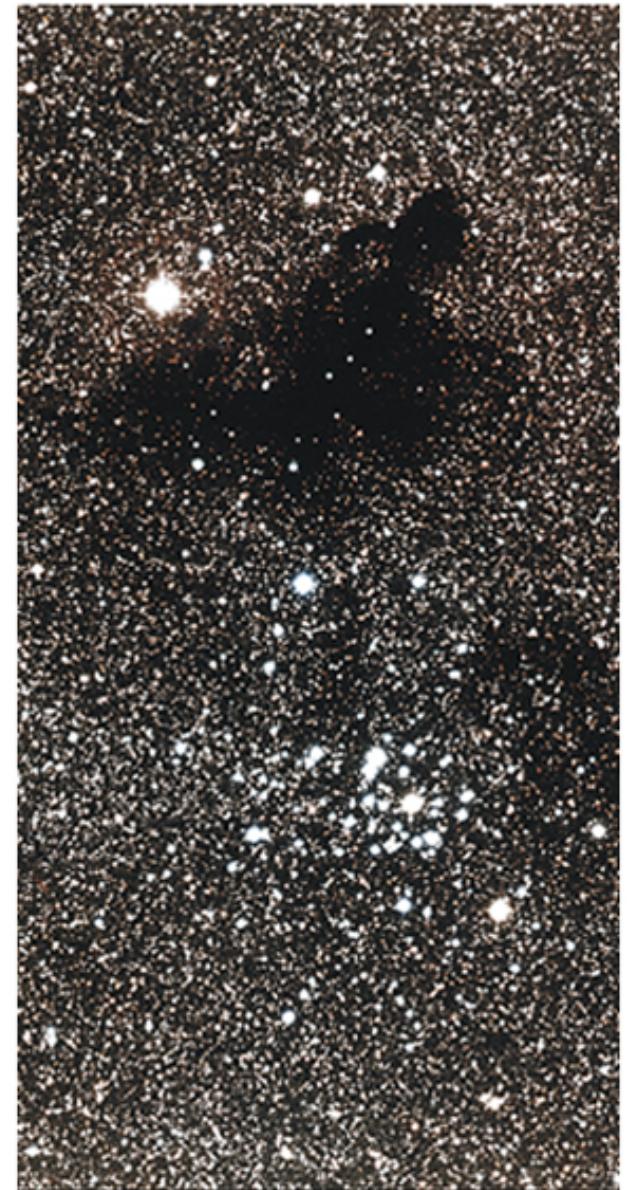
E5.3 Earth History and Geologic Time

The solar system formed from a nebular cloud of dust and gas 4.6 Ga (billion years ago). The Earth has changed through time and has been affected by both catastrophic (e.g., earthquakes, meteorite impacts, volcanoes) and gradual geologic events (e.g., plate movements, mountain building) as well as the effects of biological evolution (formation of an oxygen atmosphere). Geologic time can be determined through both relative and absolute dating.

- E5.3A** Explain how the solar system formed from a nebula of dust and gas in a spiral arm of the Milky Way Galaxy about 4.6 Ga (billion years ago).
- E5.3B** Describe the process of radioactive decay and explain how radioactive elements are used to date the rocks that contain them.
- E5.3C** Relate major events in the history of the Earth to the geologic time scale, including formation of the Earth, formation of an oxygen atmosphere, rise of life, Cretaceous-Tertiary (K-T) and Permian extinctions, and Pleistocene ice age.
- E5.3D** Describe how index fossils can be used to determine time sequence.

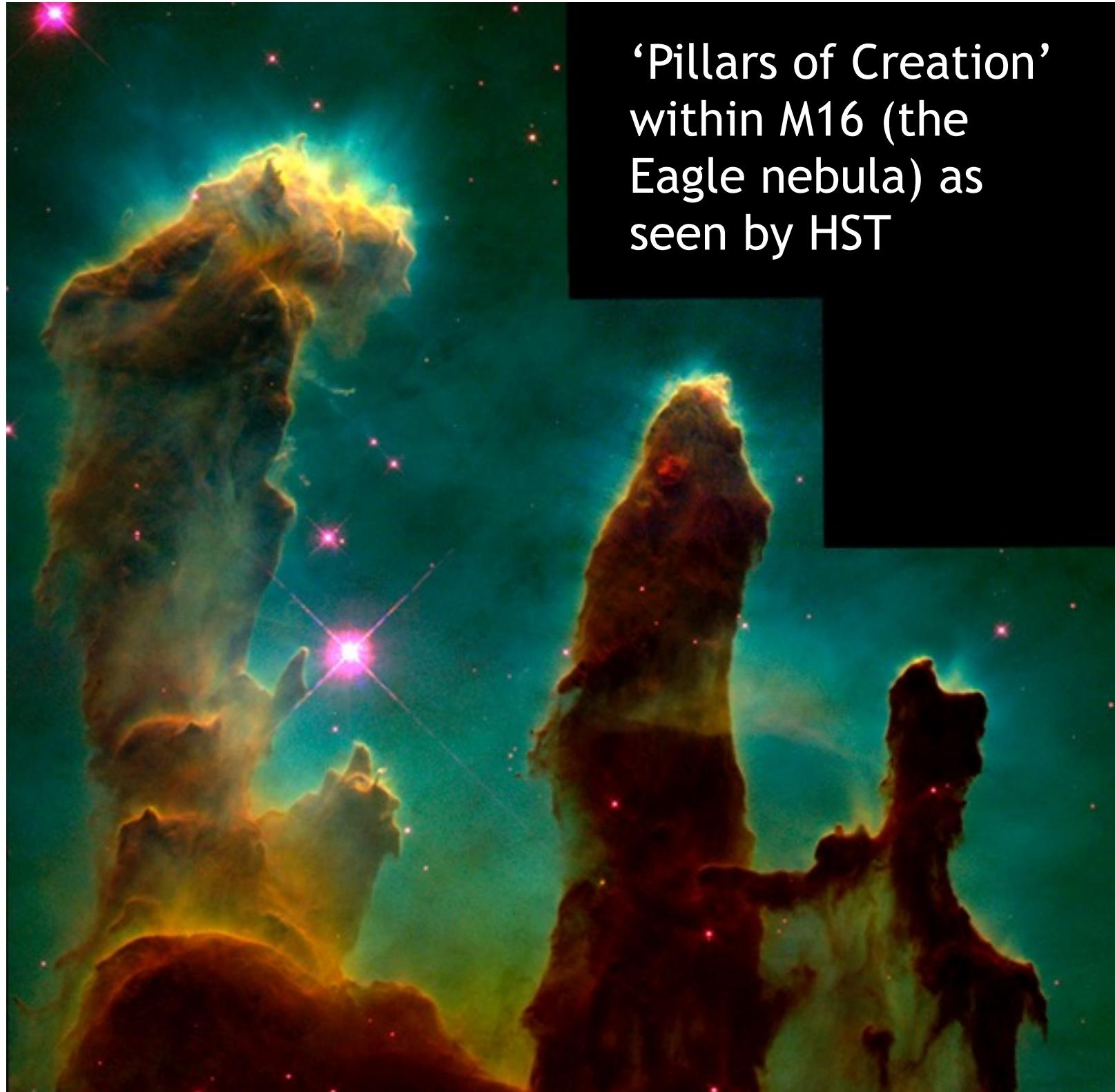
Birth of the Solar System

- What did the material that eventually became the Sun and planets look like originally?
- *Interstellar clouds* like the one at right are found throughout much of the Galaxy.
 - Many have similar proportions of elements to the Sun.
 - At these cold temps, heavier elements are mostly bound into *dust grains* up to several micrometers in size.



Stellar nurseries

We have observed young stars burning within giant clouds (e.g. M16, right): these are *stellar nurseries*.

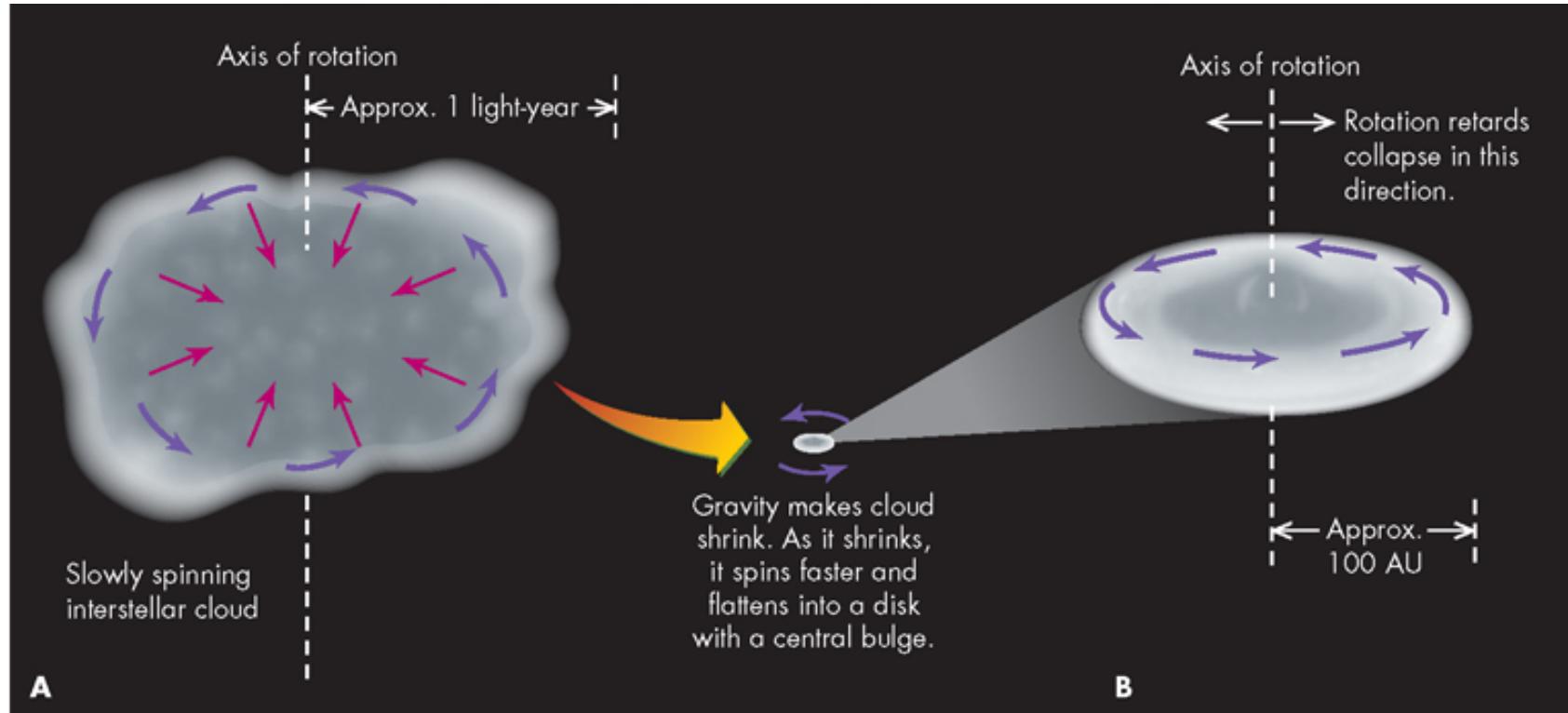


'Pillars of Creation' within M16 (the Eagle nebula) as seen by HST

The Horsehead Nebula



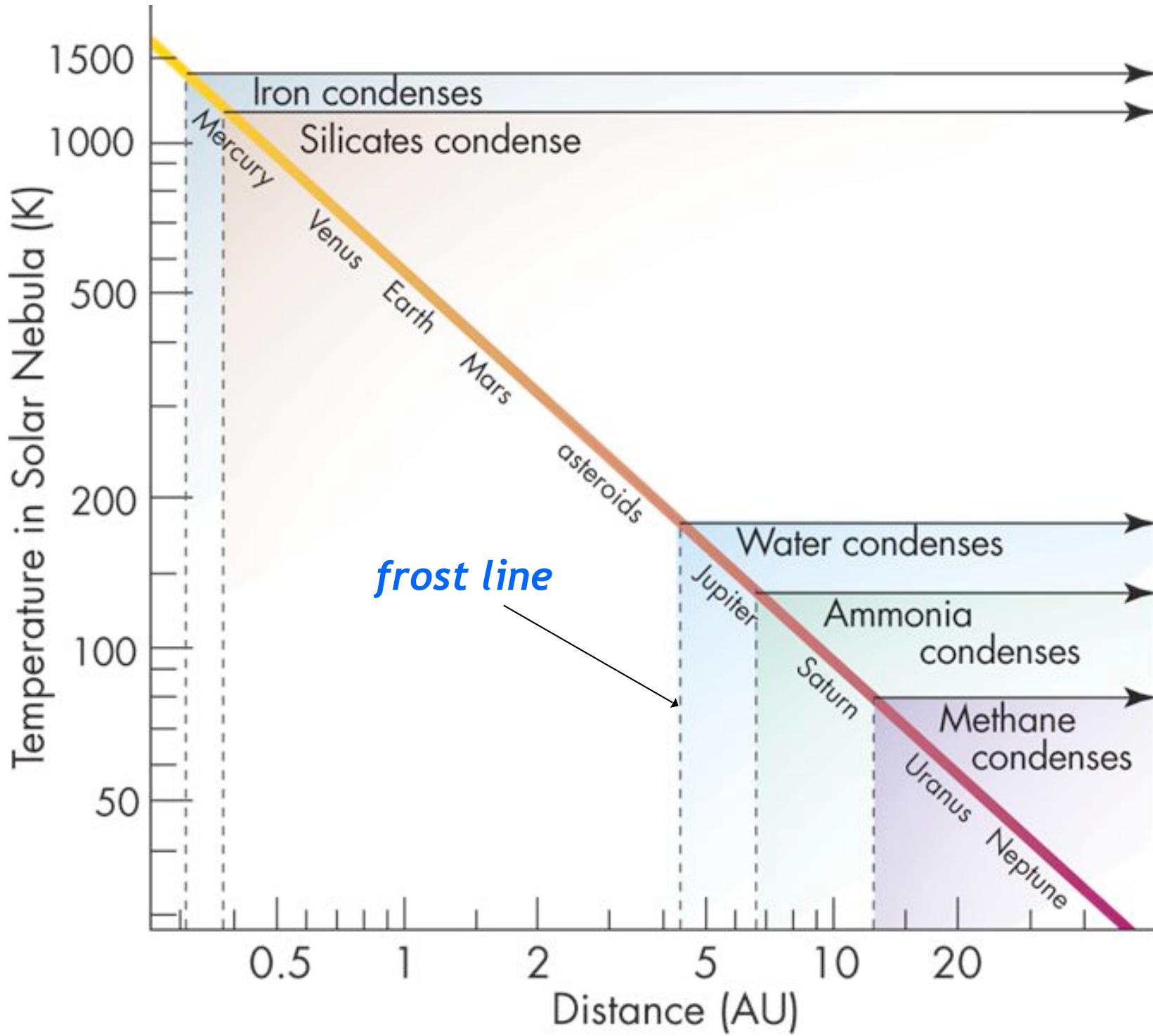
Molecular cloud
where stars form



- The primordial Solar System is thought to have been a *rotating* cloud *collapsing* under its own gravity.
- The central part of the cloud heats up due to gravitational collapse
 - Eventually becomes hot enough for **nuclear reactions** (the Sun is born).
- The outer parts of the disk cannot fall inward and eventually form the **planets** and their **satellites**, and the **asteroids**.

The Primordial Solar System

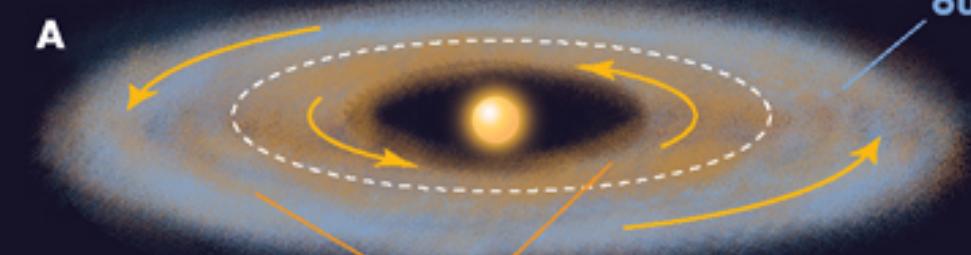
- *Next phase:* the young Sun burns in the center of a flattened, rotating cloud.
- How warm is the Solar System, and where?
 - Nearly everywhere: iron, silicates, etc. condense out as tiny solid particles.
Condensation: a gas turns to a liquid or a solid when its molecules are moving slowly enough to stick together.
 - Hydrogen, helium stay as gases.
 - Outer Solar System: ‘volatiles’ (water, ammonia, methane) also condense out - mostly as solids.
 - Inner Solar System: too warm, these compounds stay as gases.



Dust Grains to Planetesimals to Planets

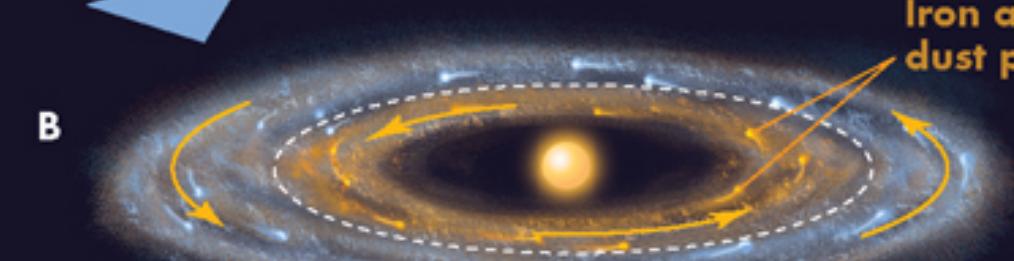
Solar radiation heats up the inner solar system.

A

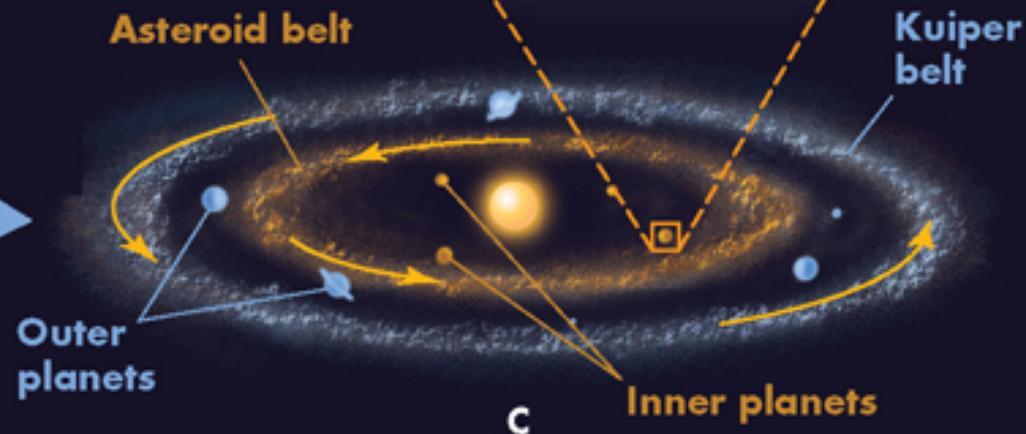


Water-ice only in outer parts of disk

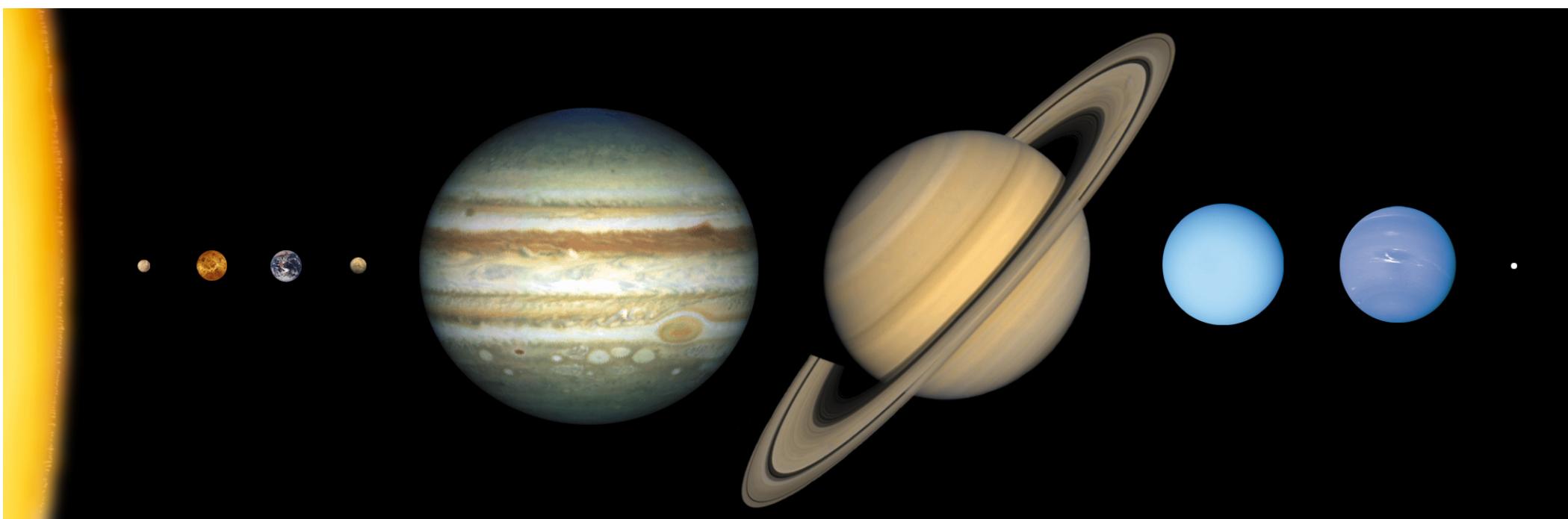
B

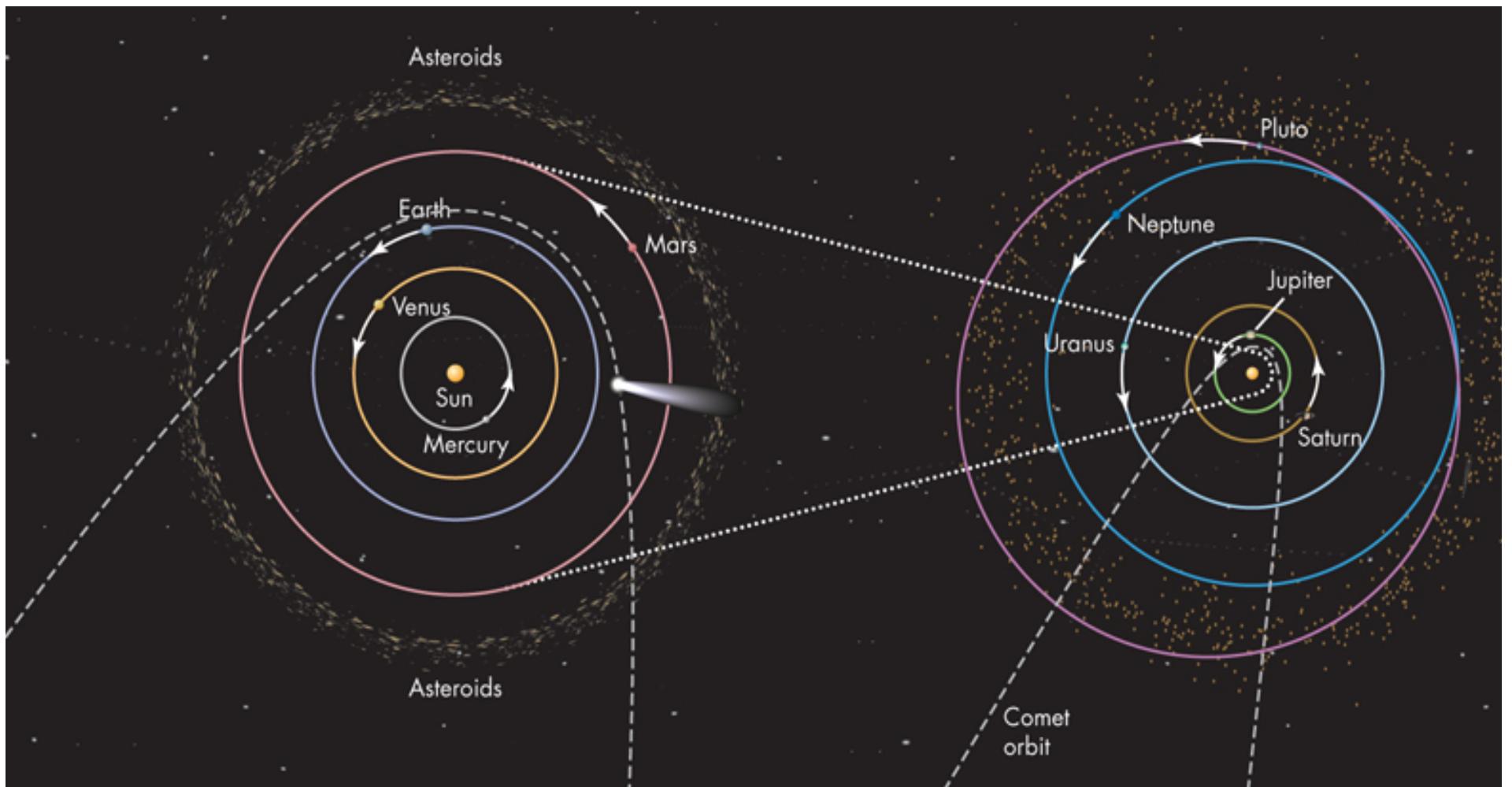


D



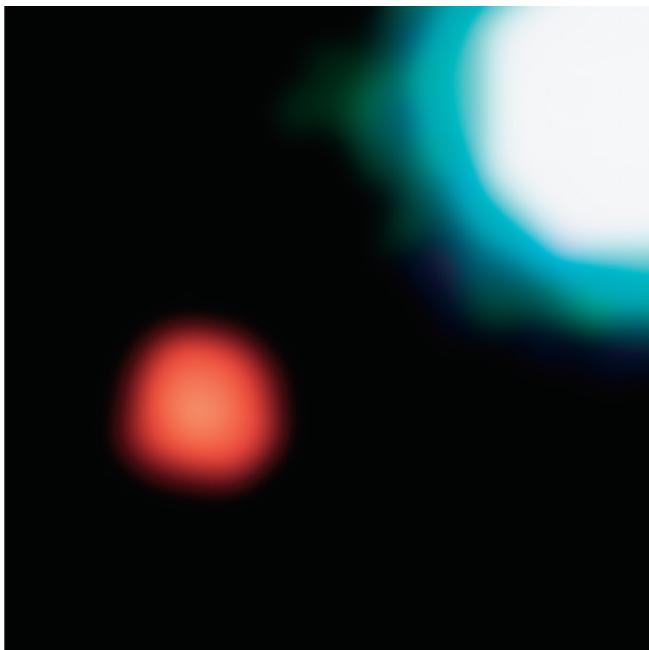
Sun and planet sizes to scale (distances between planets NOT to scale)





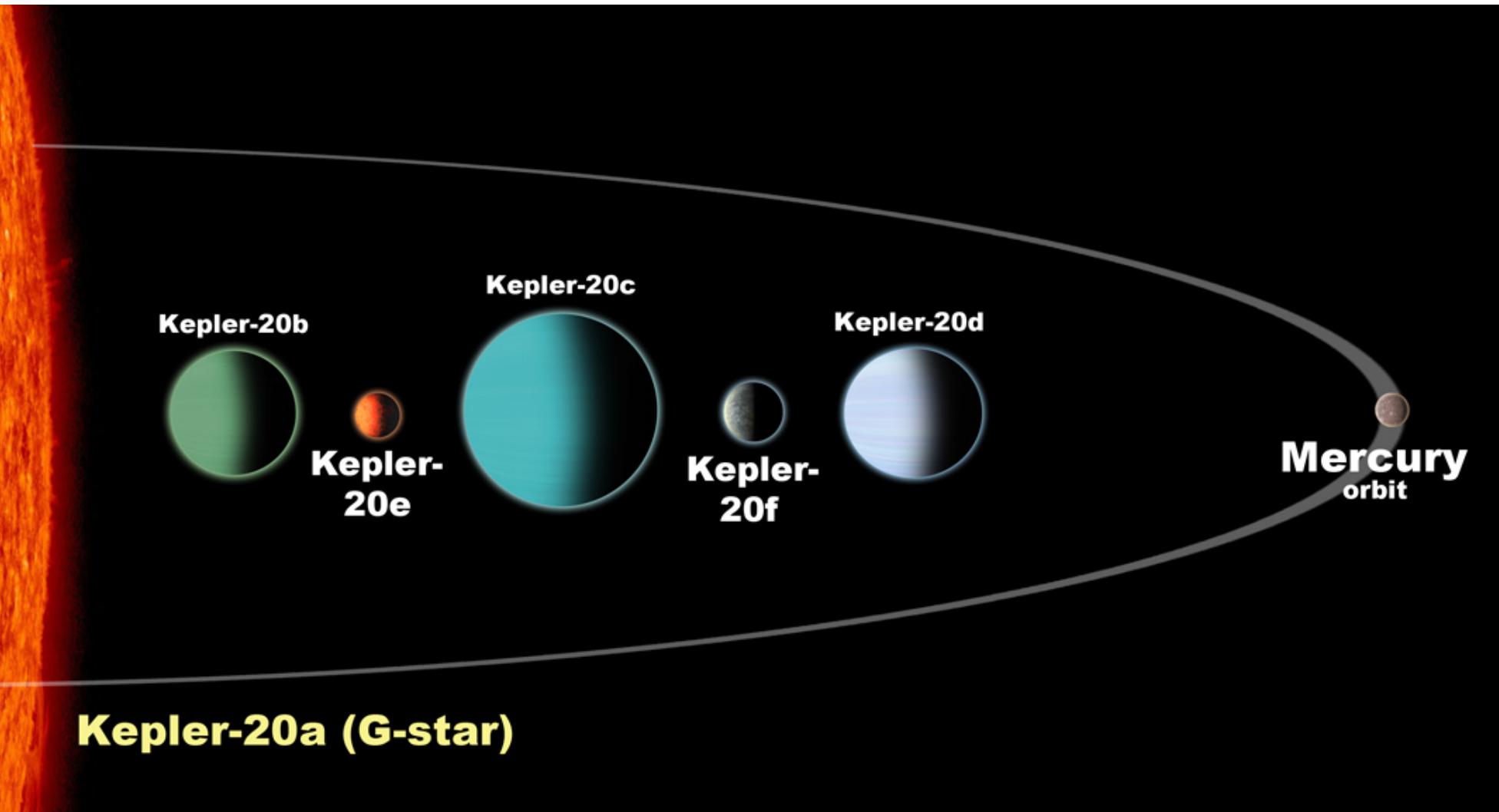
Planet orbits are roughly in the same plane and are nearly circular

Other planetary systems



- First extra-solar planet (exoplanet) was discovered in 1992
- Leaps forward in discovering exoplanets in the last 10 years or so
- Number from exoplanets.org
 - * Confirmed exoplanets = 1523
 - * Unconfirmed exoplanets = 3303
 - * Total = 4826!

NASA's Kepler space telescope is finding the most new solar systems....here's one example:

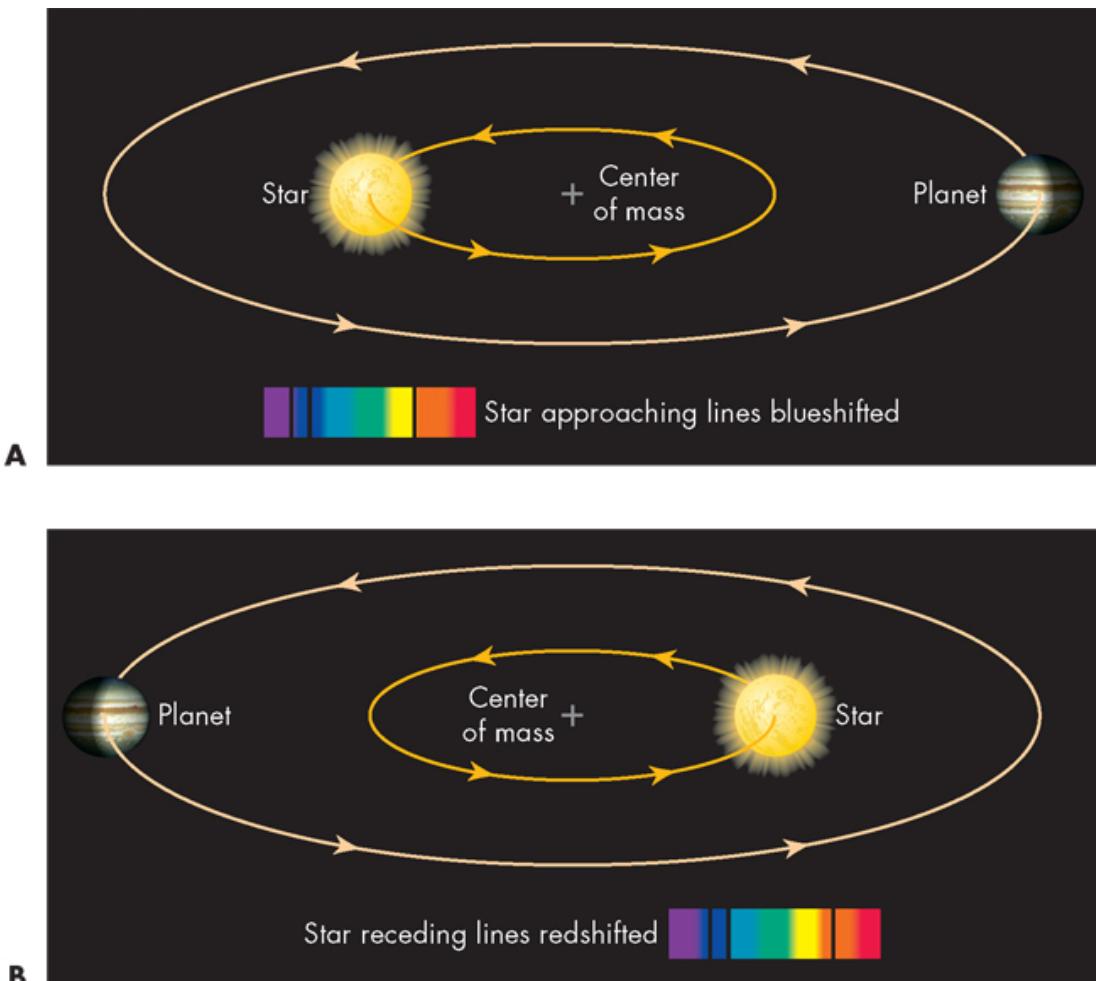


Methods for detecting exoplanets

- 1.Doppler shift (radial velocity) method
- 2.Transit method - most successful so far
- 3.Gravitational microlensing

Doppler shift (radial velocity) method

- Everything in a planetary system orbits the system's center of mass, **including the star**.
- This comes from Newton's 3rd law (equal and opposite force)
- Thus the star **wobbles** a little as the planet goes around it.
- We can detect the wobble by looking for a regularly **varying Doppler shift of the star's spectral lines**.
- Favors detecting planets with strong gravity (gas giants).
- Also in close orbits.
- Allows an estimate of planet's mass.
- Lots of 'hot Jupiters'

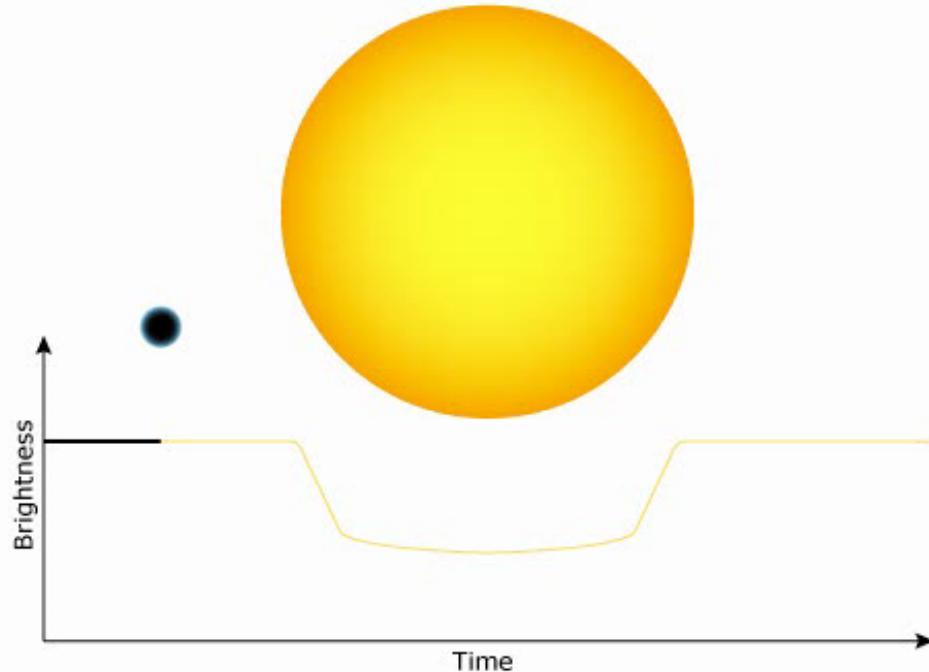


Play external animation now.....

Transit method

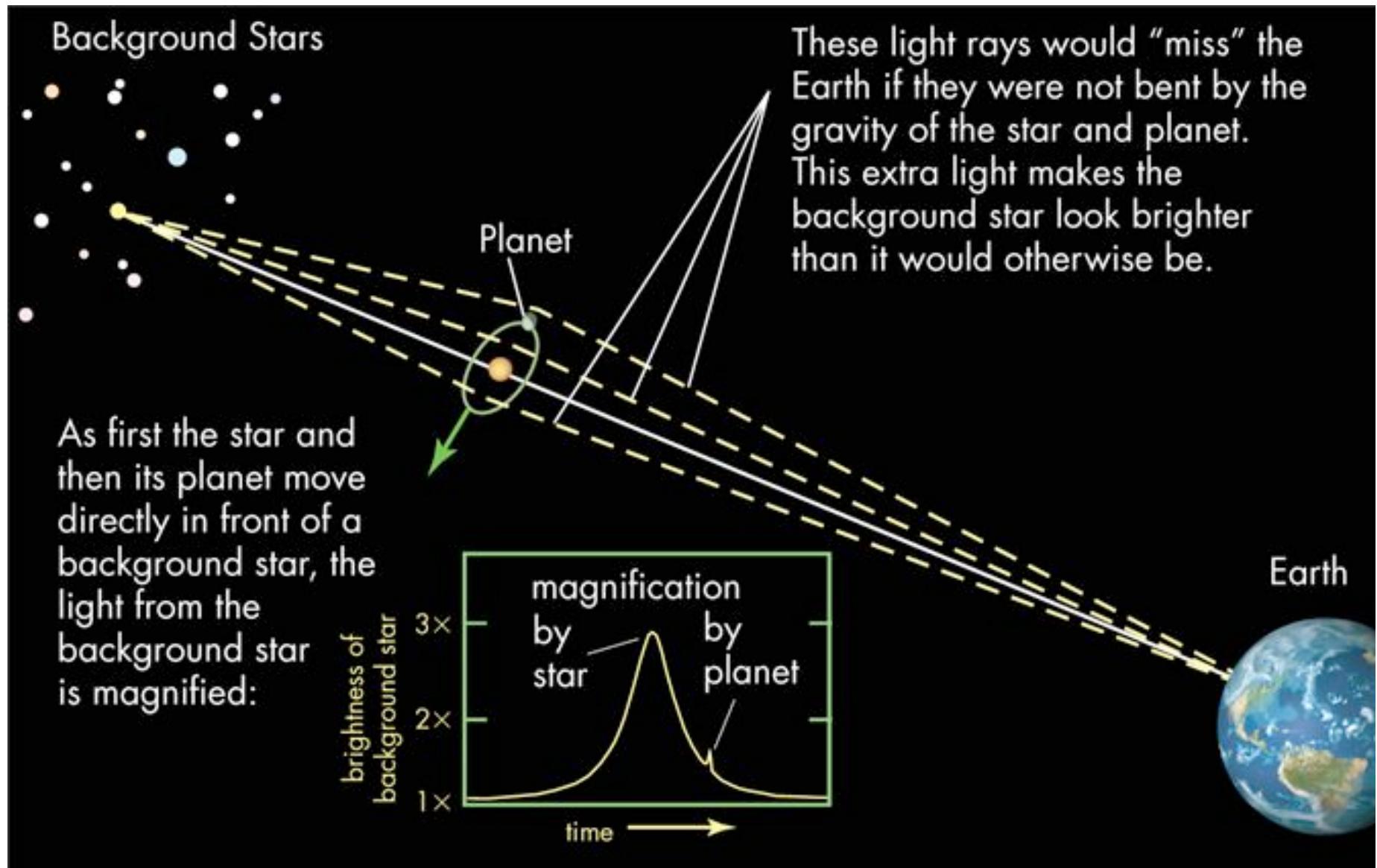
- Planet passing in front of star dims its light.
- Brightness vs. time shows regular dips due to transits.

Light Curve of a Star During Planetary Transit



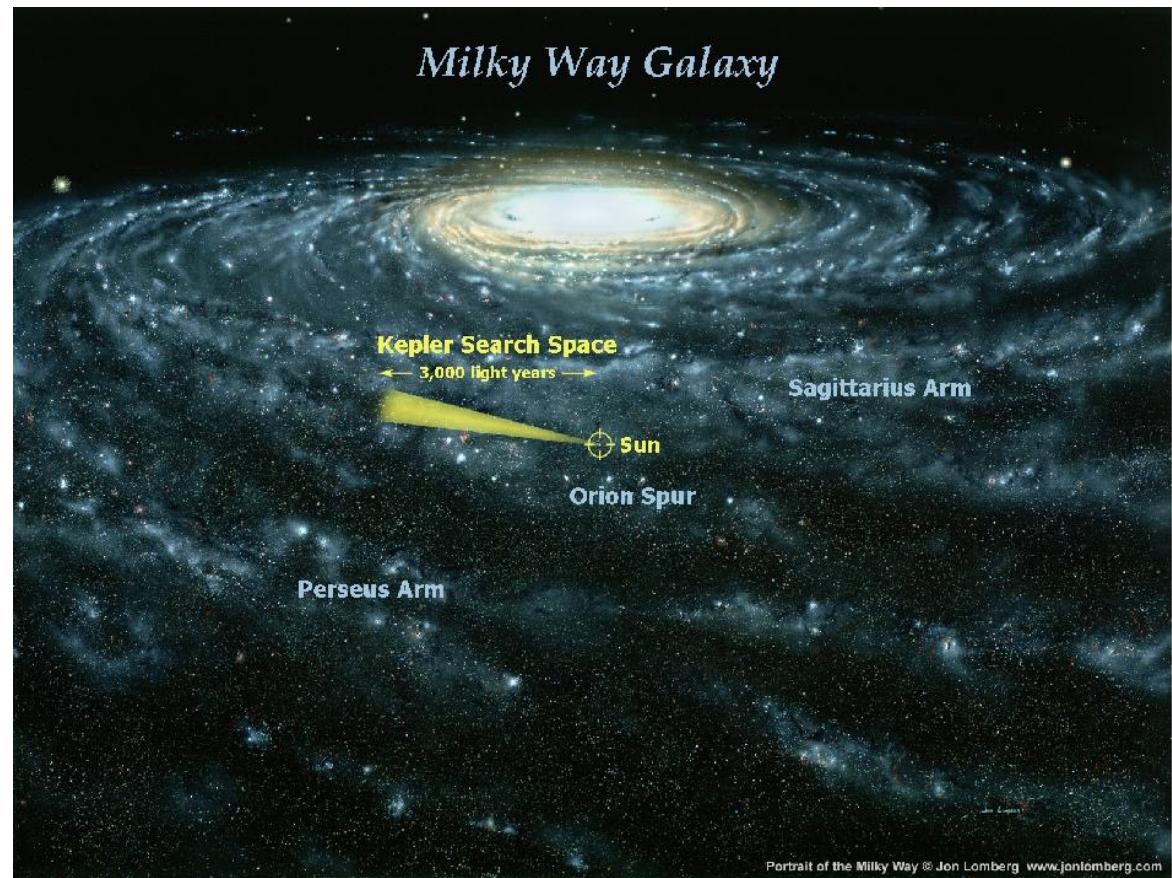
- Probability of detecting a planet around a given star like this is low because orbit lineup unlikely - the key is to look at many, many stars
- Also favors detecting giant planets (smaller planets block less light).

Gravitational microlensing

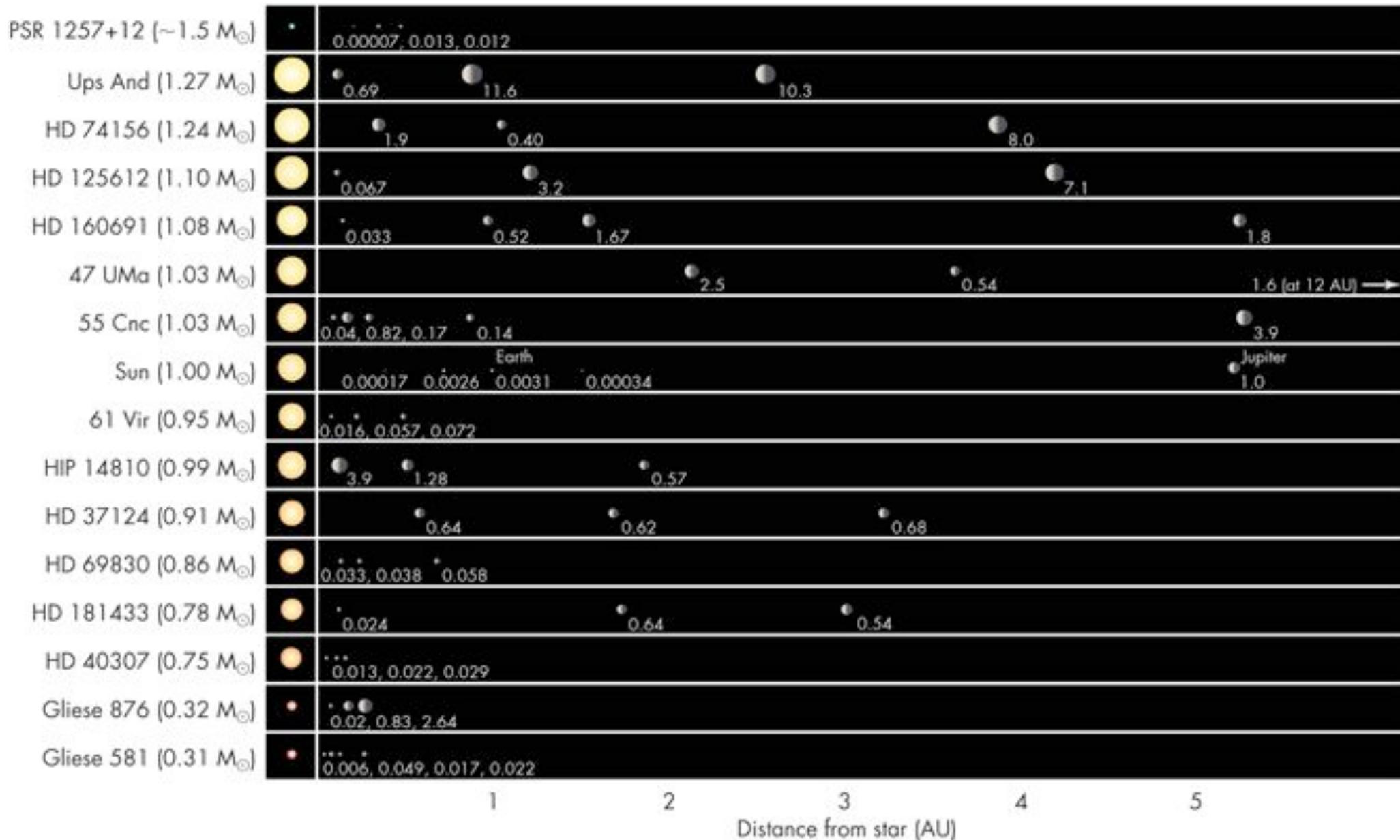


NASA's Kepler mission

- Launched in 2009
- Designed to search for habitable planets via the **transit method**
- Stares at the same patches of sky constantly
- Has found over 4000 candidates



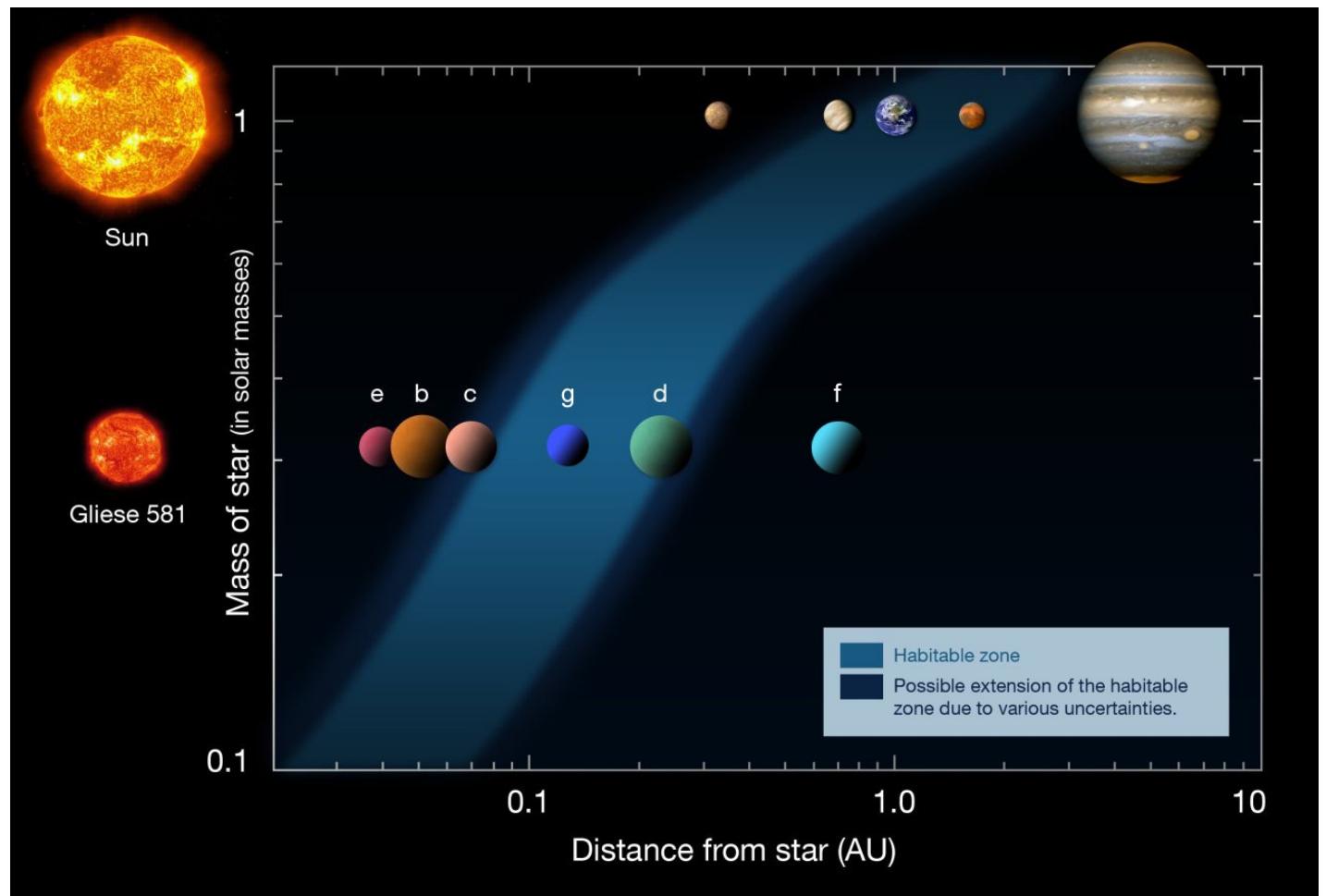
Each planetary system is unique...



Habitable exoplanets?

- A few exoplanets have been discovered with masses of **about a few Earths**.
- One or two may be in their star's habitable or '**Goldilocks**' zone (not too cold, not too hot, but just right!)
- Goldilocks zone: where temperatures allow liquid water.

- e.g. Gliese 581d
(discovered
2007, 20 l.y.
distant)
- Gliese 581g is
also in
Goldilock's zone
but its existence
is not yet
confirmed



Summary

- Solar systems form from the collapse of large, cold, molecular clouds
- Planets and star form from the same cloud
- Many exoplanets now detected, mostly via
 - 1.Doppler shift method
 - 2.Transit method
- Both are most sensitive to big planets, close to star, hence many '**hot Jupiters**' discovered