Today's Weather Forecast

"Today's weather will be cloudy (as it has been for as long as anyone can remember).

Temperatures will range from the low to high 900s, Fahrenheit.

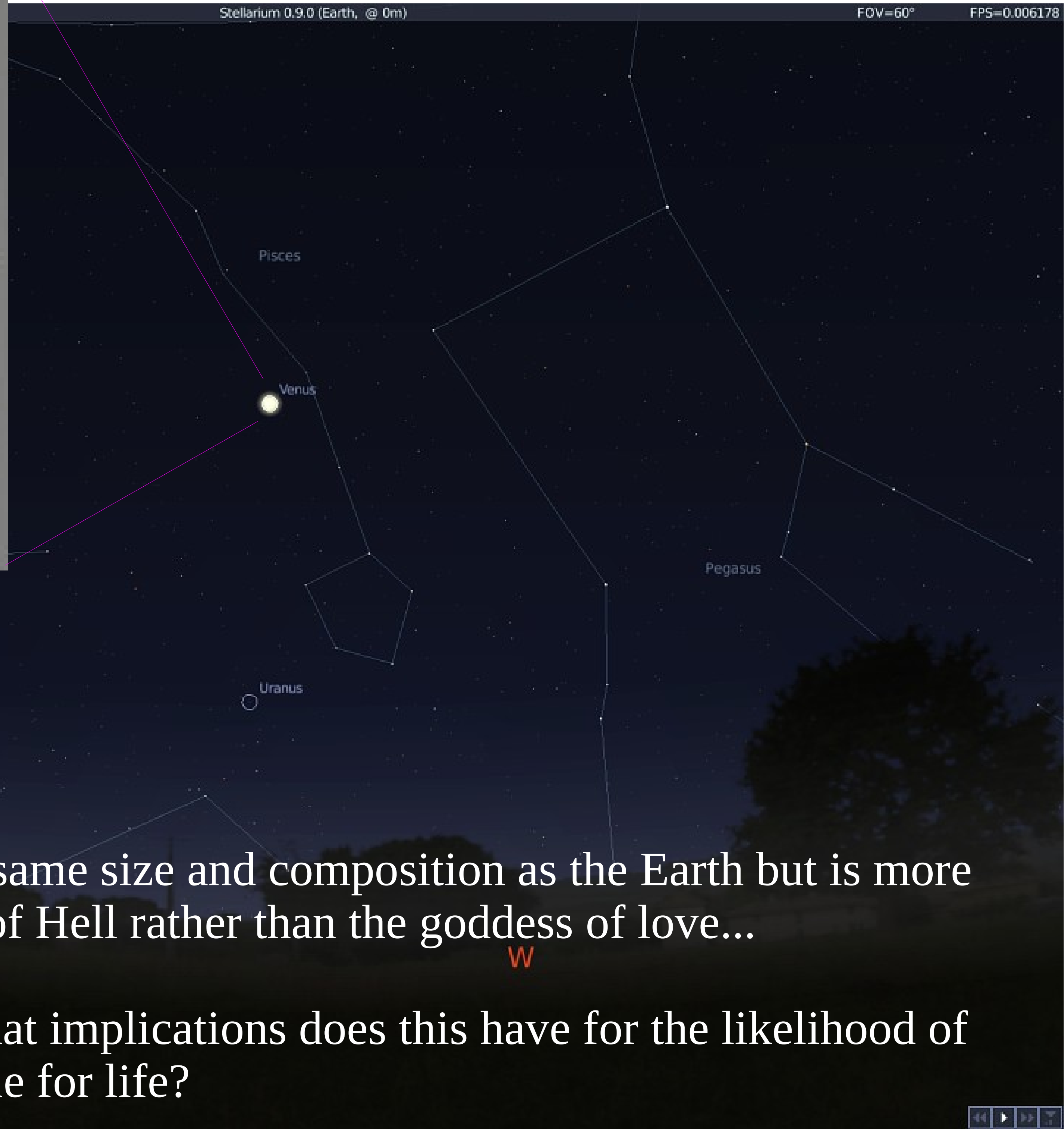
Atmospheric pressure will continue to be high — about 90 times higher than on Earth.

Winds will average around four miles per hour (but may still be able to knock you over because of the extremely high pressure), and there is the usual chance of a misty precipitation of sulfuric acid.

The Sun will set in the East about two months after sunrise."

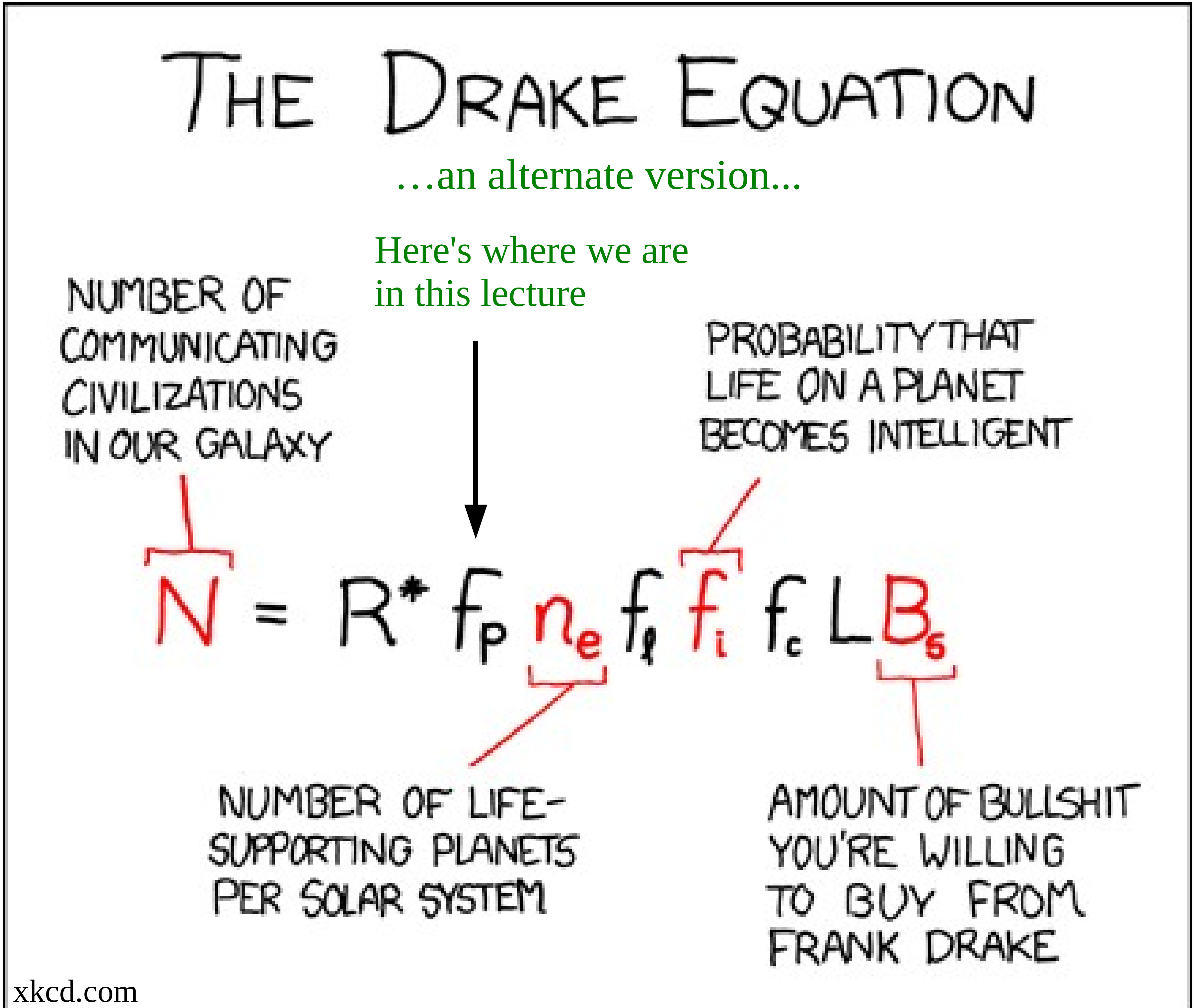
Where are you?

Venus is visible in the early evening this month



Venus has nearly the same size and composition as the Earth but is more like the embodiment of Hell rather than the goddess of love...

What happened? What implications does this have for the likelihood of finding planets suitable for life?



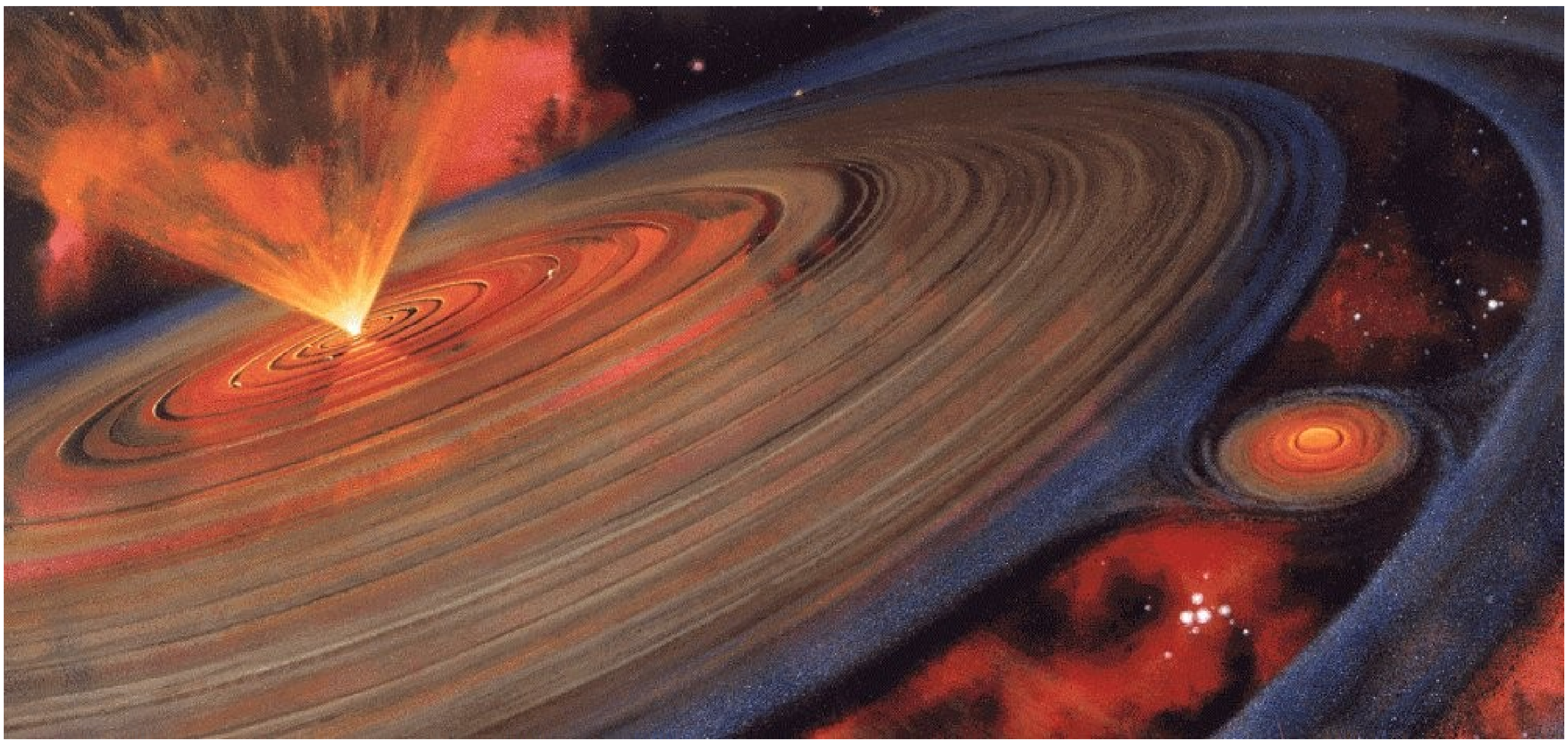
…an alternate version...

Here's where we are in this lecture

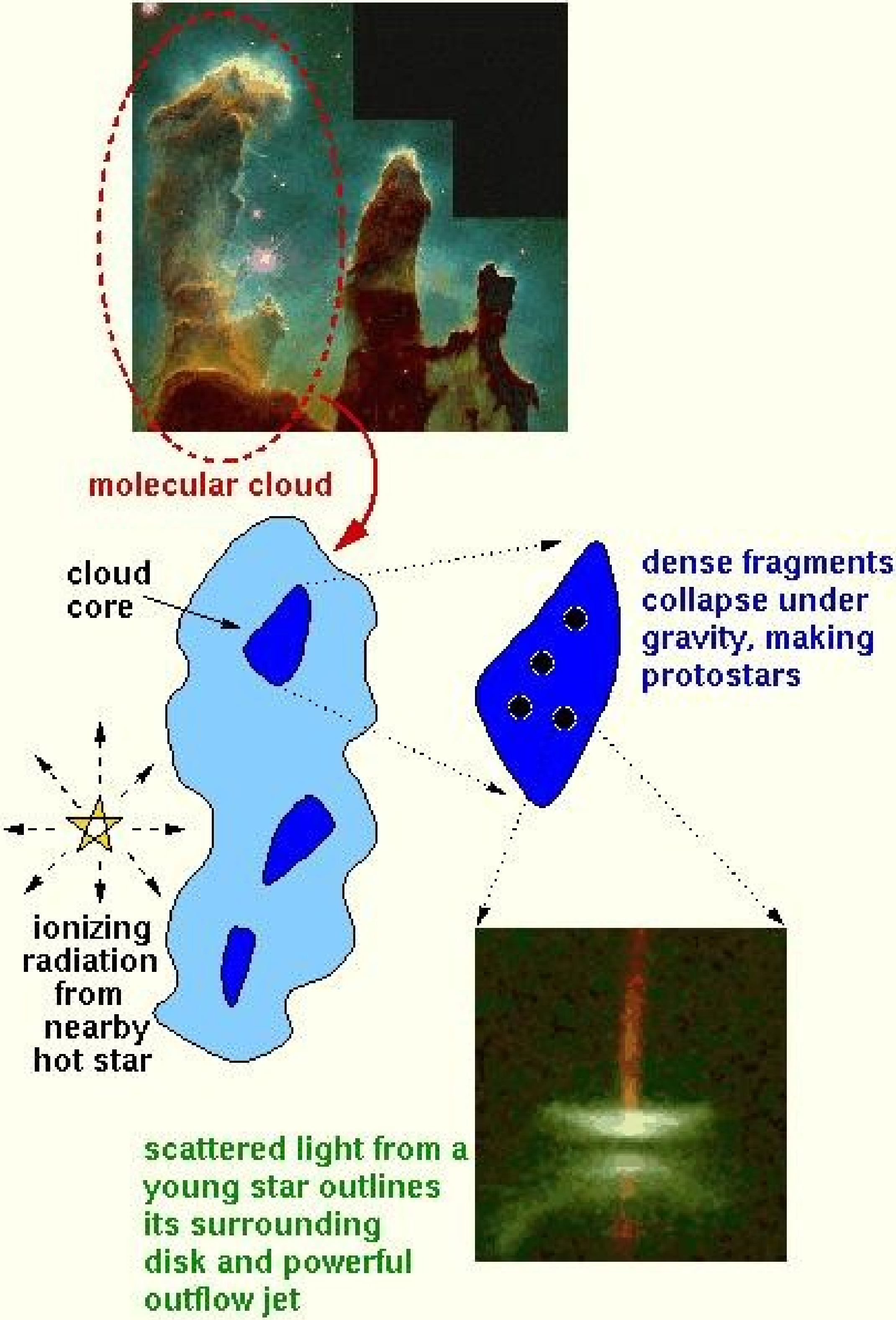
xkcd.com

Planet Formation

Readiness Question:
"Name and describe three evolutionary stages of star formation."



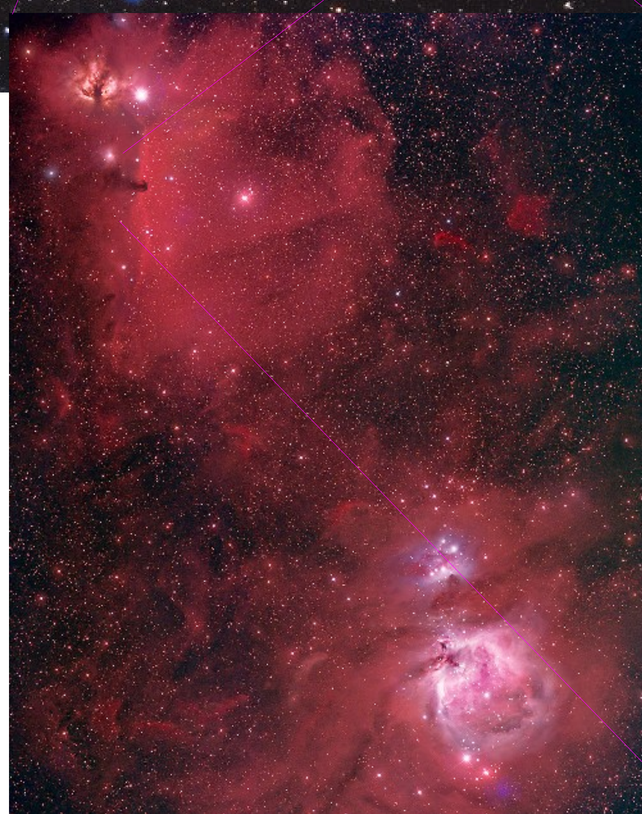
Notes at.... http://loke.as.arizona.edu/~ckulesa/astr202/



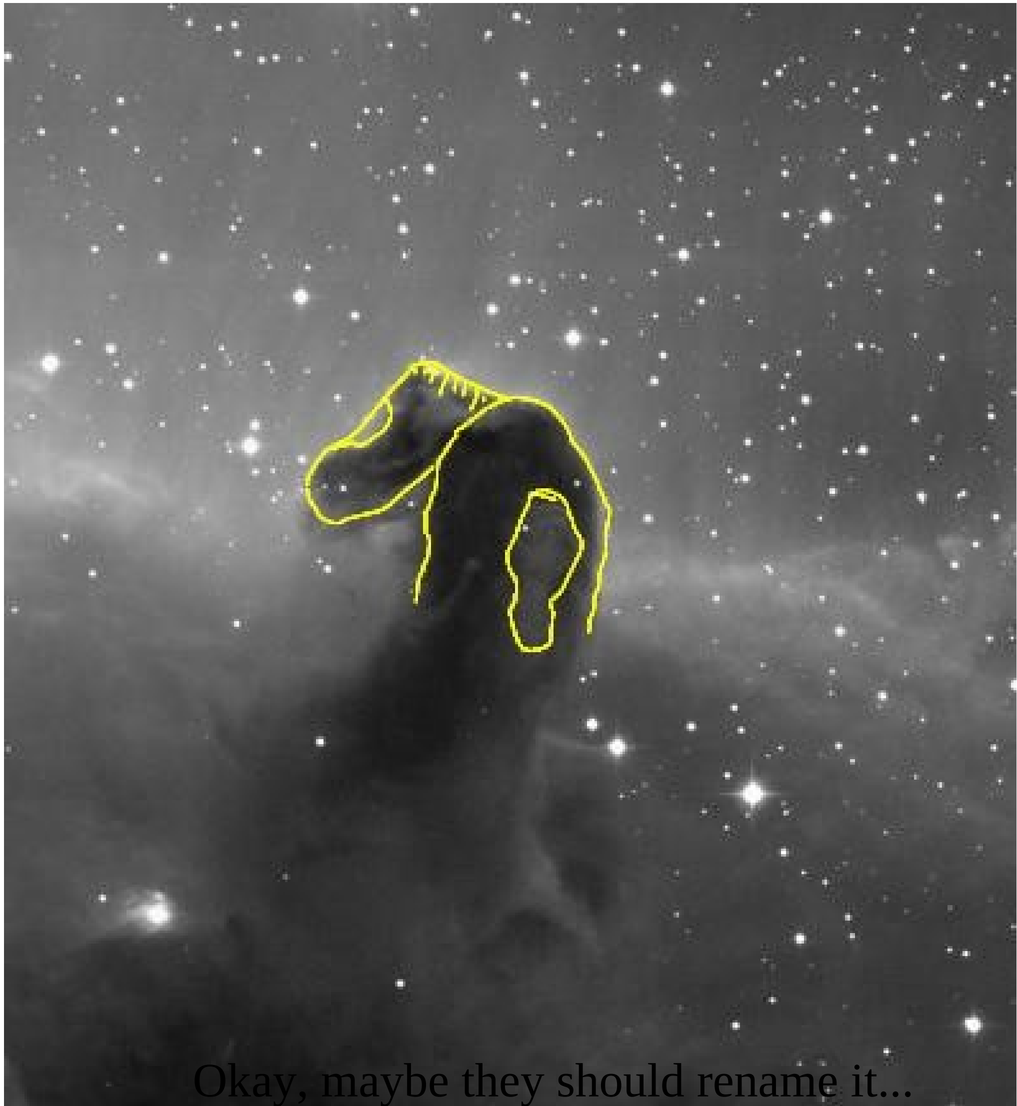
Review of Star Formation

- Molecular cloud
- Loss of magnetic support, cloud collapse, infall of material
- molecular outflows
- Formation of a protostar
- formation of a circumstellar disk
- formation of planets in the disk

constellation of Orion



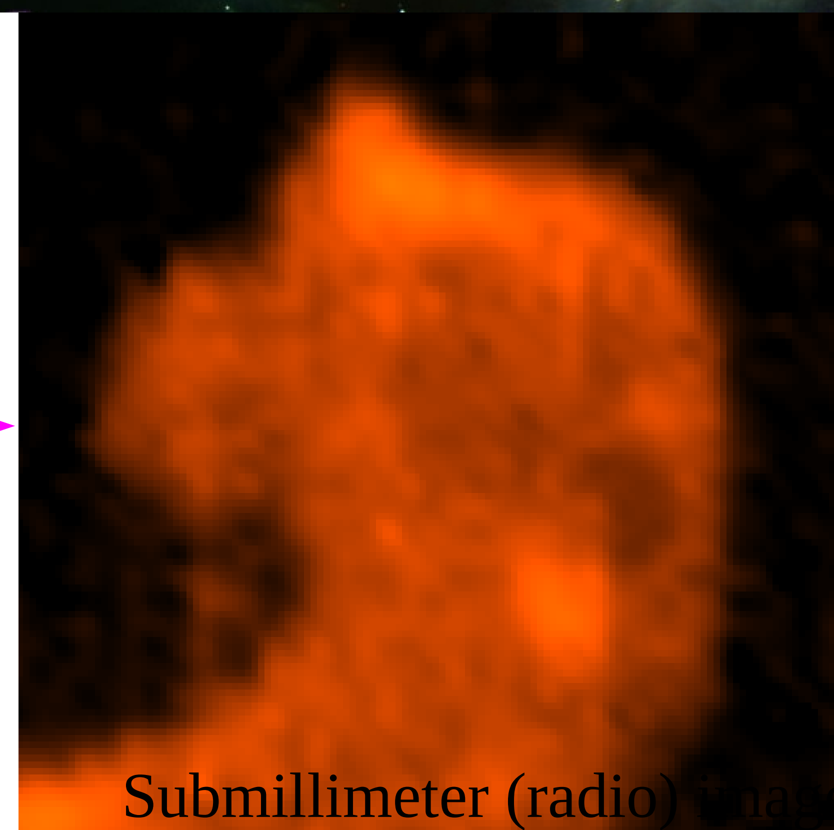
Horsehead Nebula in Orion


Okay, maybe they should rename it...


NGC 2024 – the Flame Nebula
Visible light


Infrared light

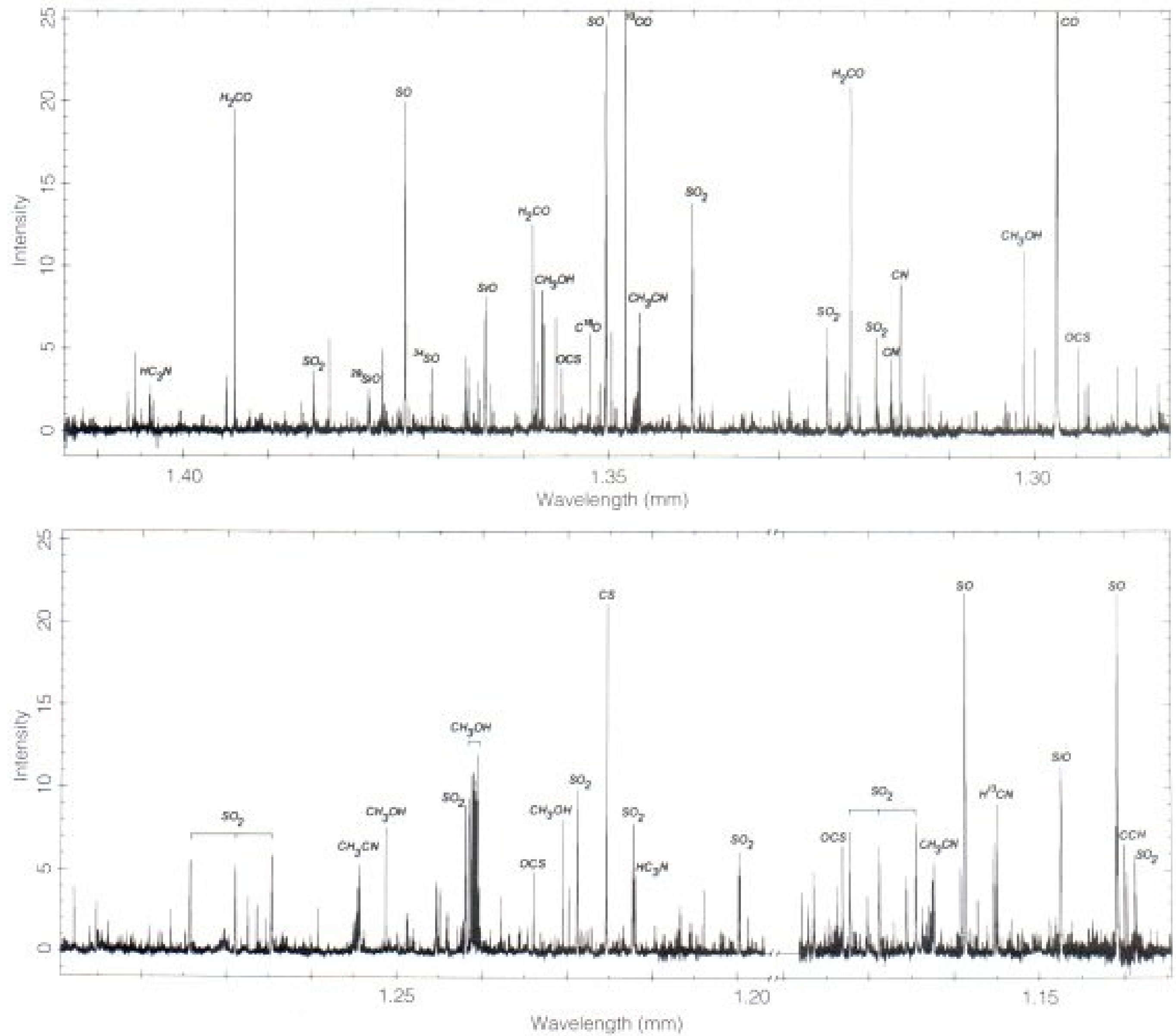

Visible light

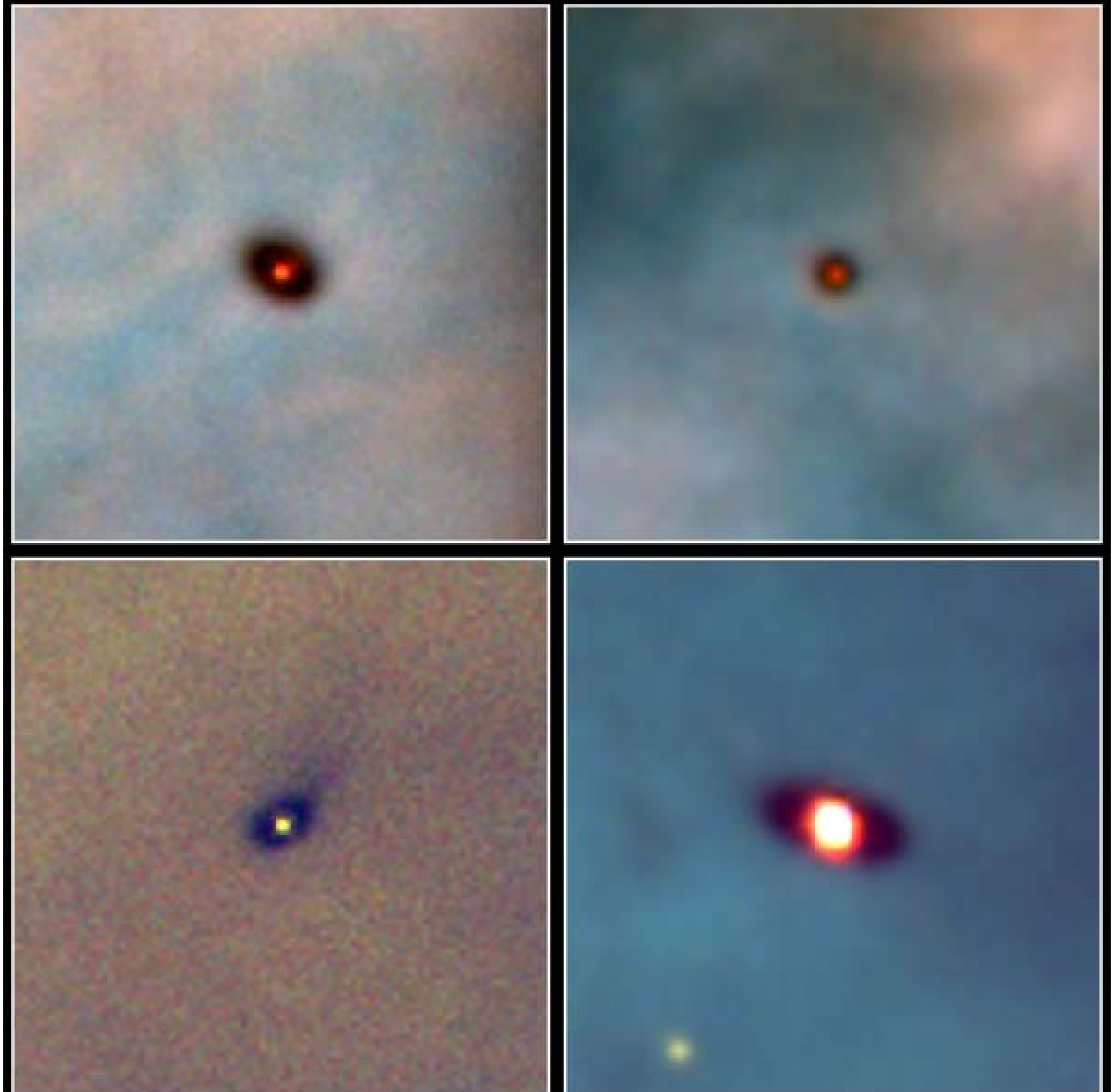

Submillimeter (radio)

There are over 900 features from >70 different molecules in this single radio spectrum!

Some of them are fairly familiar...

For example, anyone know what CH_2CH_3OH is?



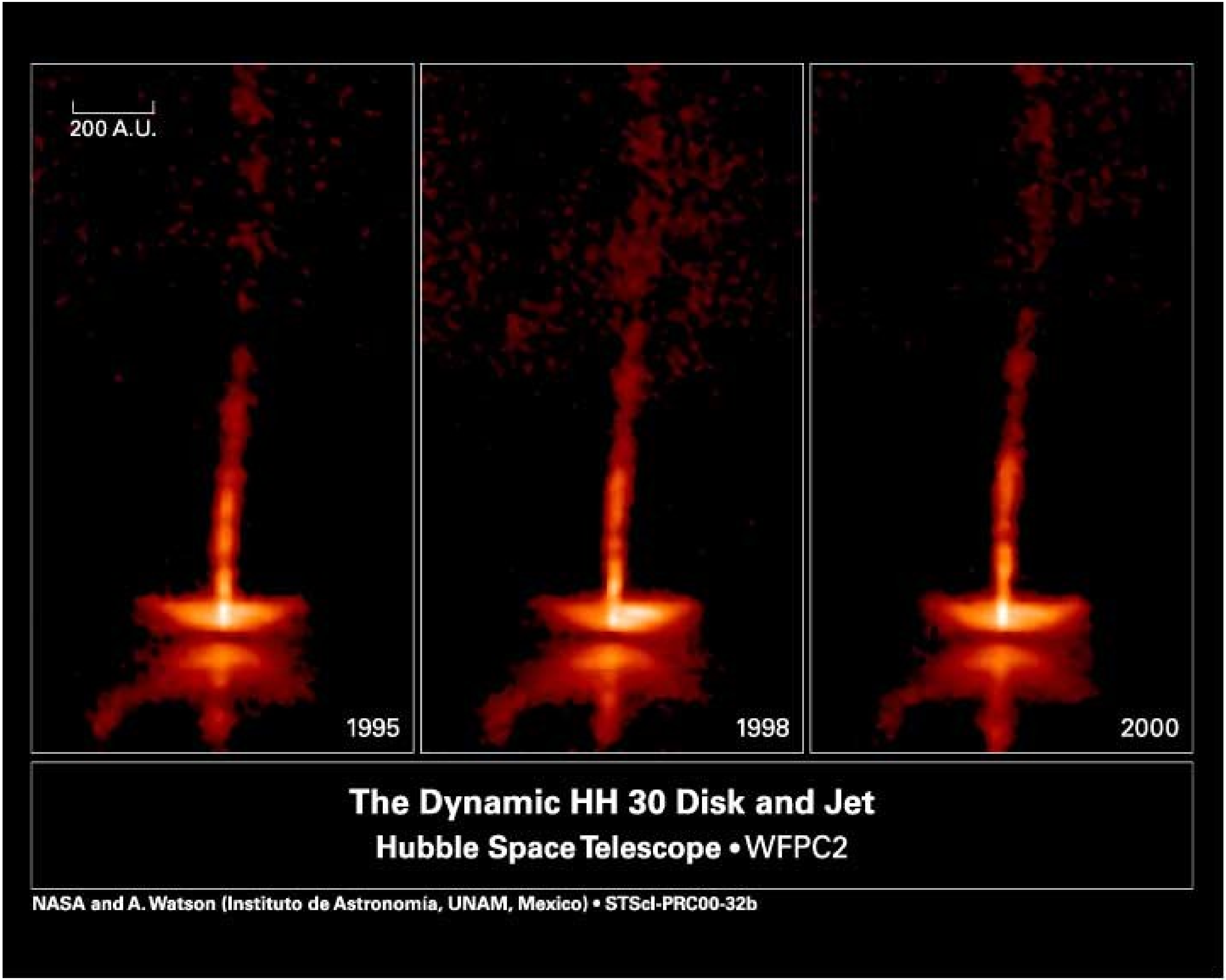


Protoplanetary Disks
Orion Nebula

HST • WFPC2

PRC95-45b • ST ScI OPO • November 20, 1995

M. J. McCaughrean (MPIA), C. R. O'Dell (Rice University), NASA

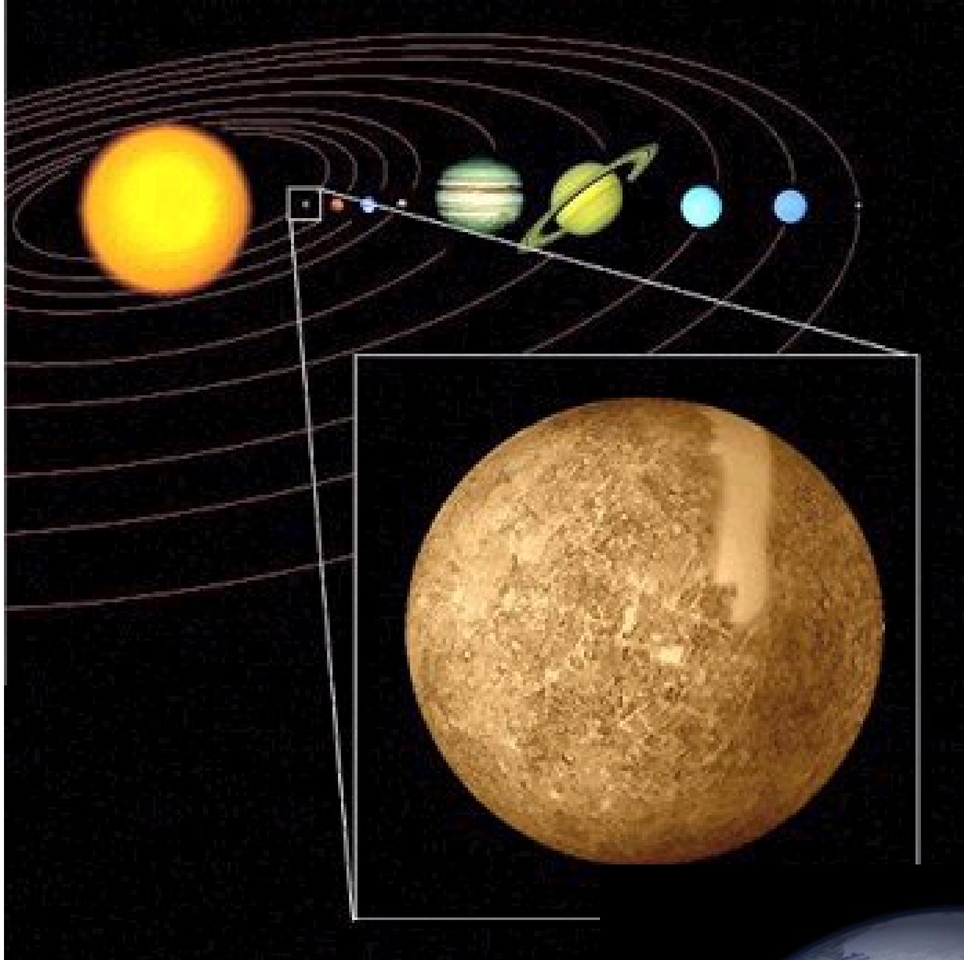

200 A.U.
1995
1998
2000
The Dynamic HH 30 Disk and Jet
Hubble Space Telescope • WFPC2
NASA and A. Watson (Instituto de Astronomia, UNAM, Mexico) • STScI-PRC00-32b

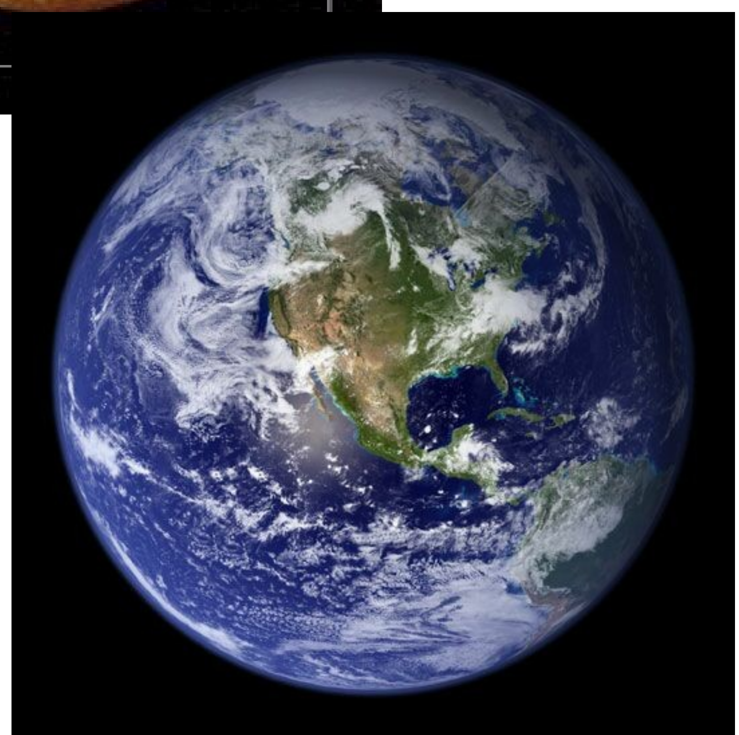
Will a circumstellar disk form a companion star or a planet?

- If $M_{disk} > M_{star}$ (i.e. a massive disk), then the disk is unstable and will fragment into another star
- If $M_{disk} < M_{star}$, then the disk will tend to be stable and will form planets and **not** another star

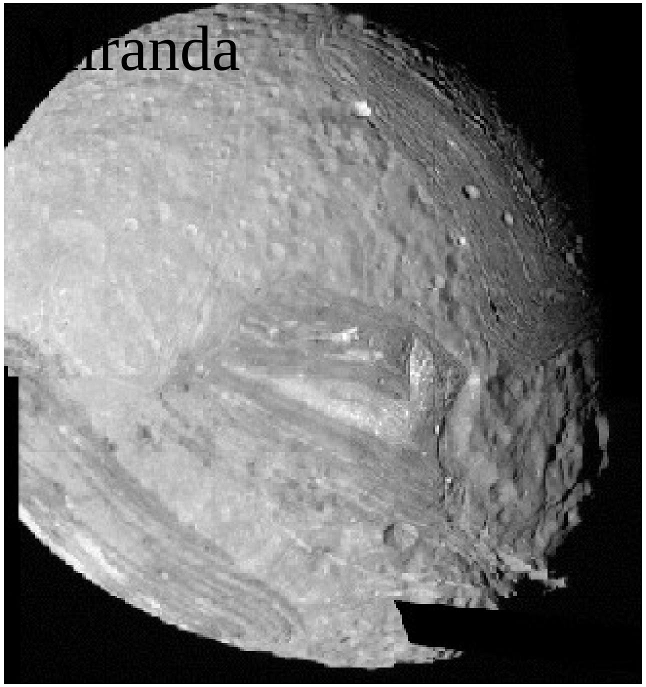
Basic Theory of Planet Formation

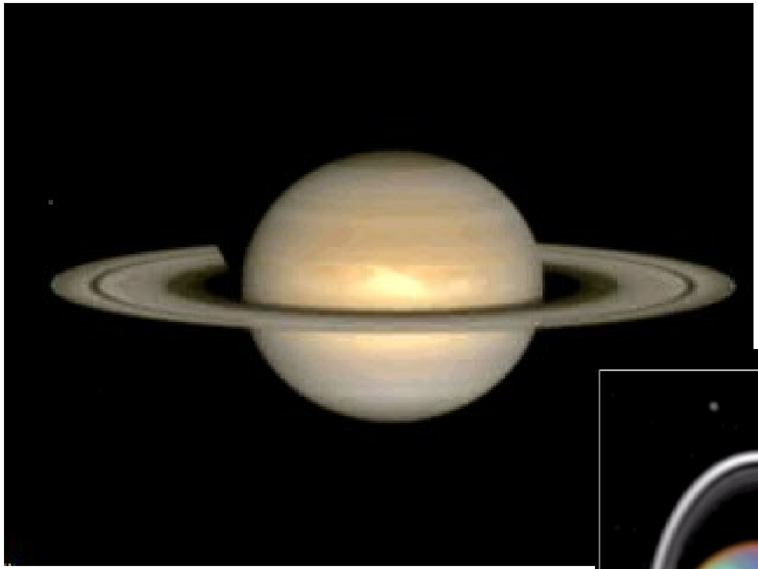
- How can we explain with a **single theory** how the varied kinds of objects in the Solar System formed?



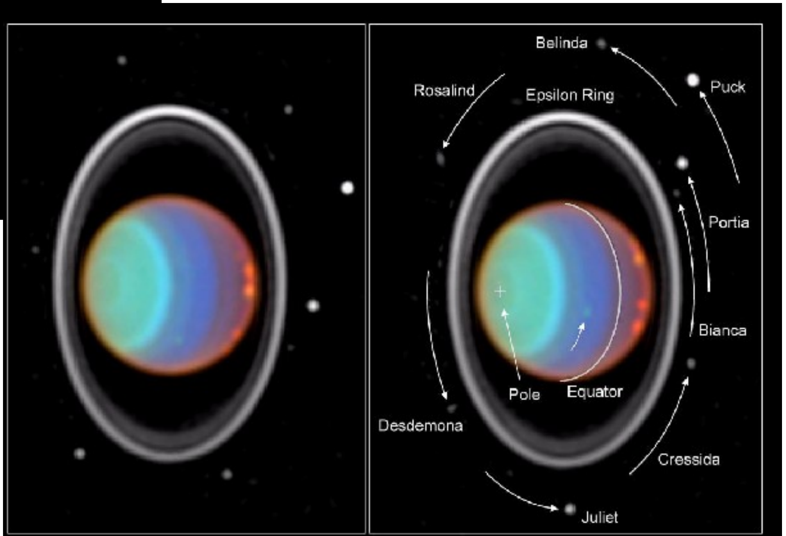


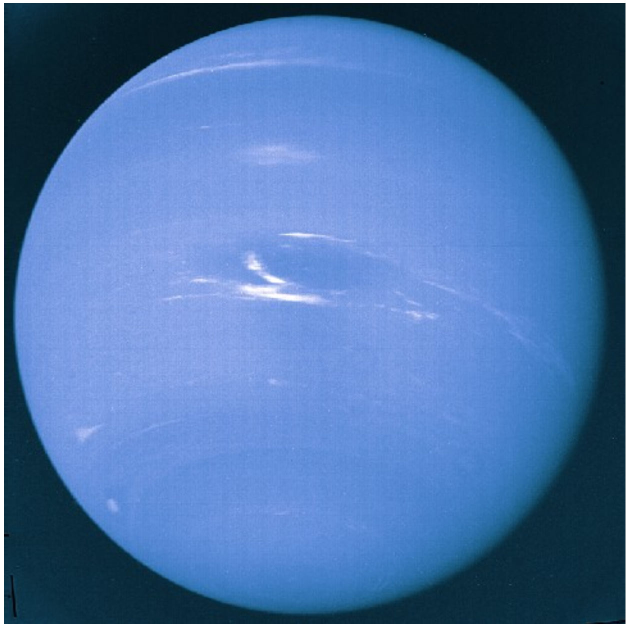
terrestrial
planets

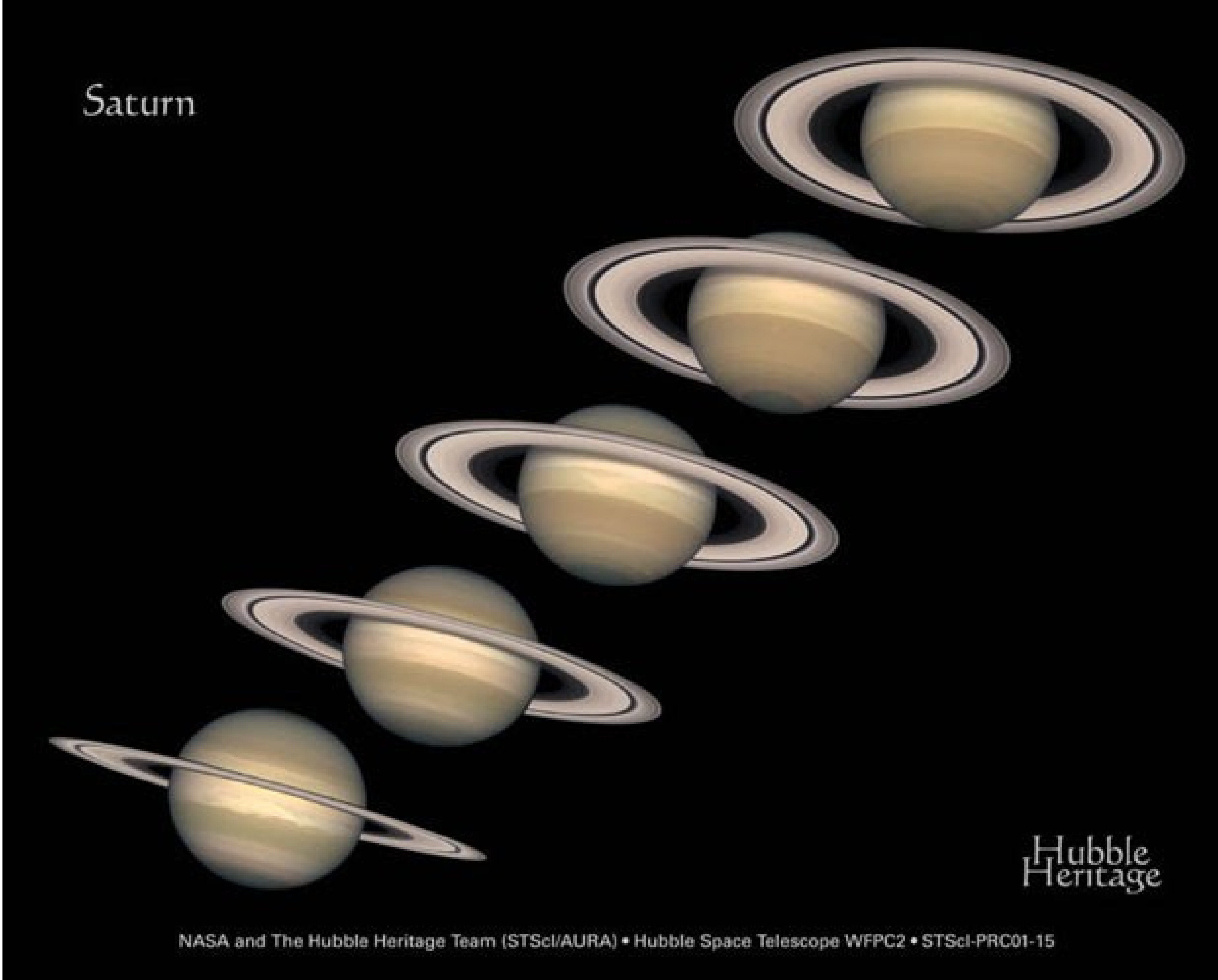




outer Solar System



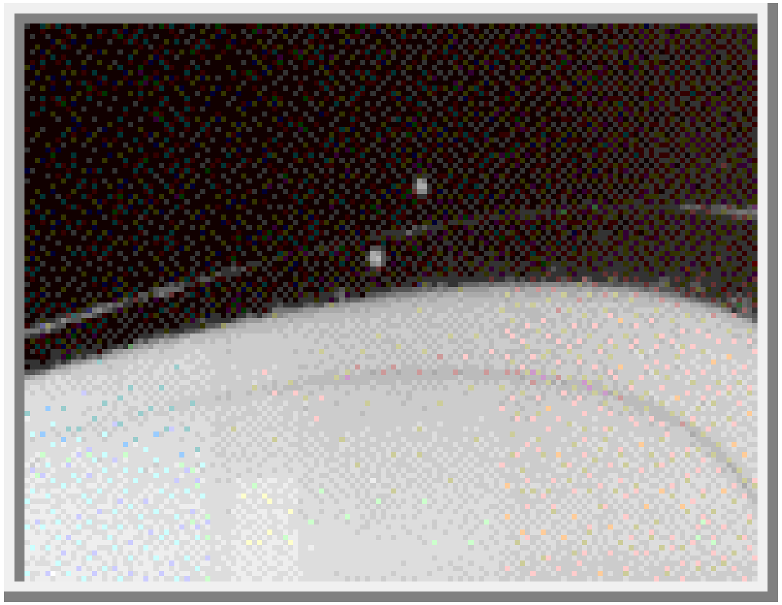



Saturn
Hubble Heritage
NASA and The Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope WFPC2 • STScI-PRC01-15

Rings have gaps -- largest one called “Cassini Division”,

Rings are comprised of snowball-like objects that range from the size of pingpong balls to houses

“F ring” is braid-like and is “shepherded” by two moons

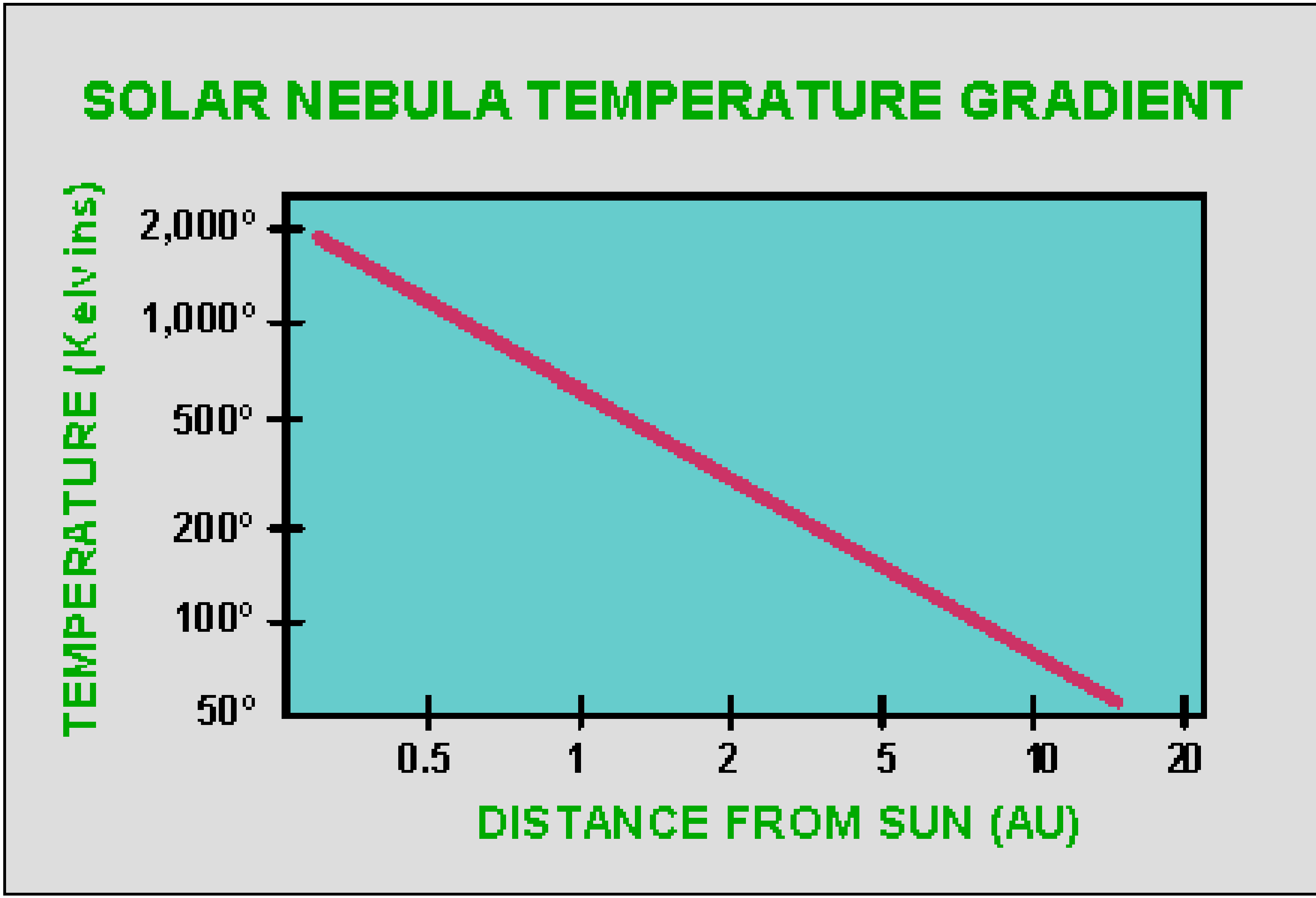


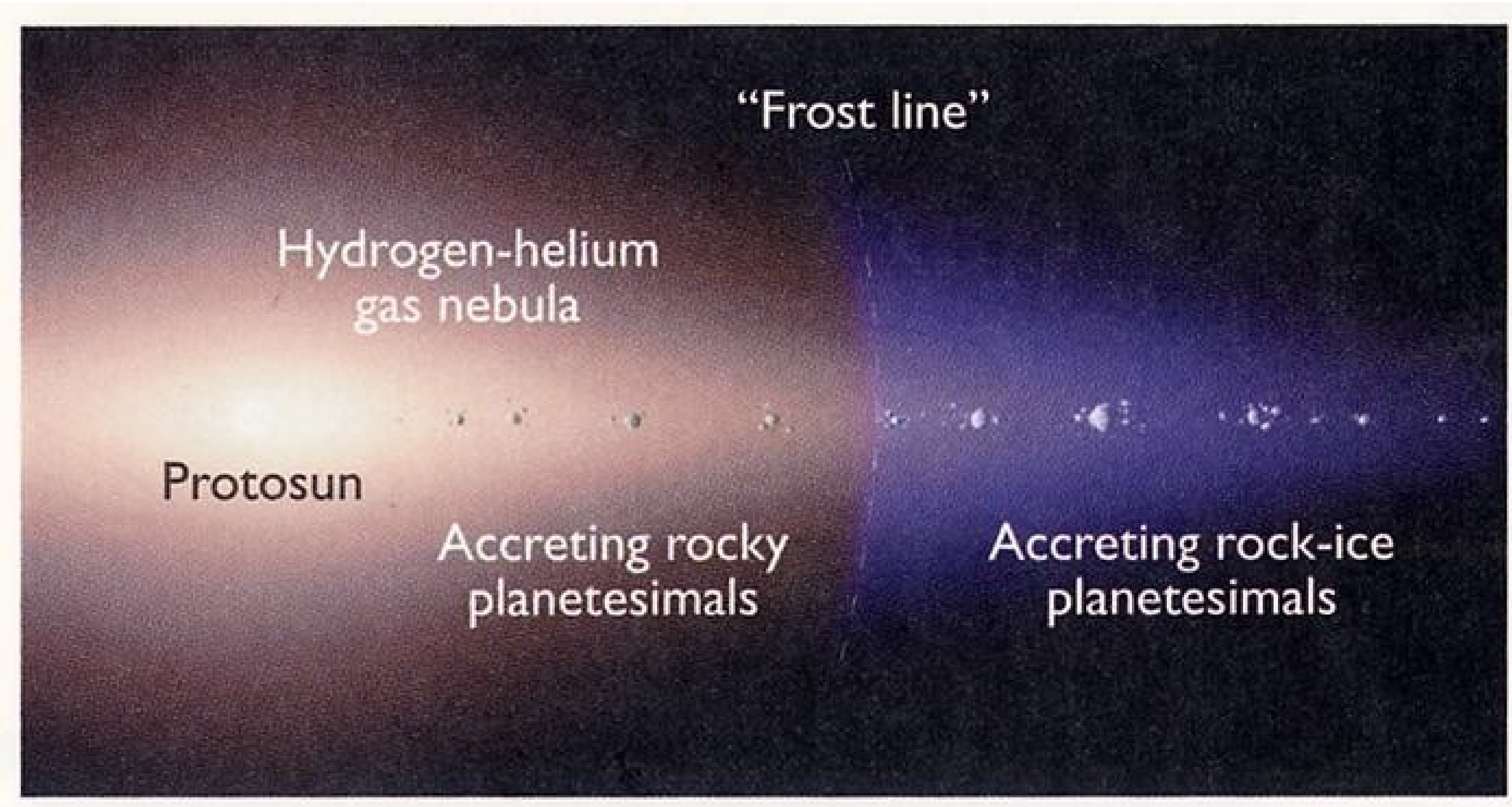
shepherd moons

Basic Theory of Planet Formation

- Collisional model of planet formation (also called "core accretion" model)
- "Condensation sequence": as temperature dropped, metallic elements formed solid particles; ex. $MgSiO_3$ = magnesium silicate
- rocky "**planetesimals**" thus formed from dense regions of a disk
- these "planetesimals" are the seeds from which planets accumulate

Temperature Profile in Solar Nebula




"Frost line"
Hydrogen-helium
gas nebula
Protosun
Accreting rocky
planetesimals
Accreting rock-ice
planetesimals

Common Planet forming materials

Gases

Hydrogen (H)
Helium (He)
Neon (Ne)

Ices (condense @100-300K)

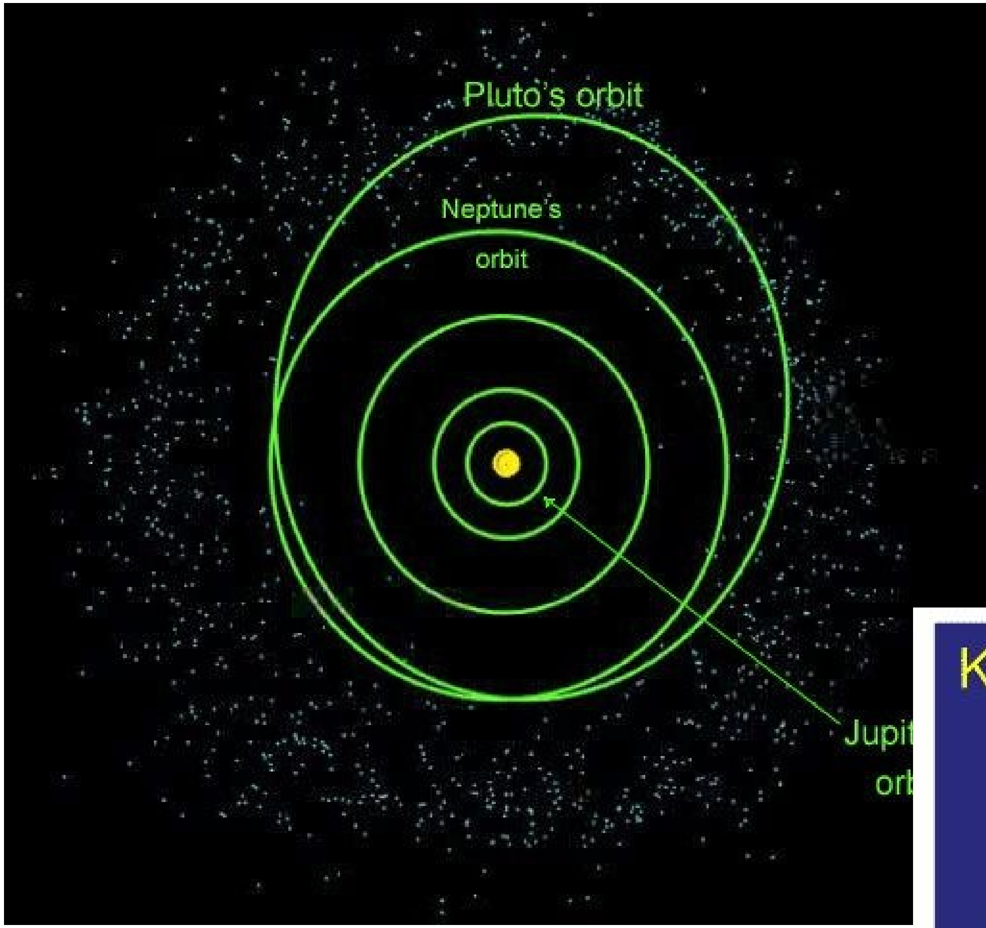
Water (H_2O)
Methane (CH_4)
Ammonia (NH_3)
Carbon Dioxide (CO_2)

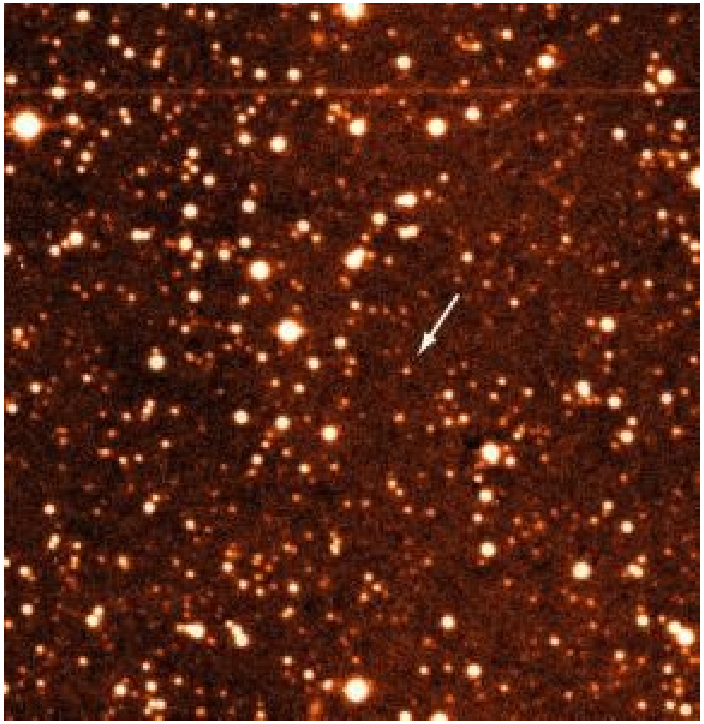
Solids (condense ~1400K)

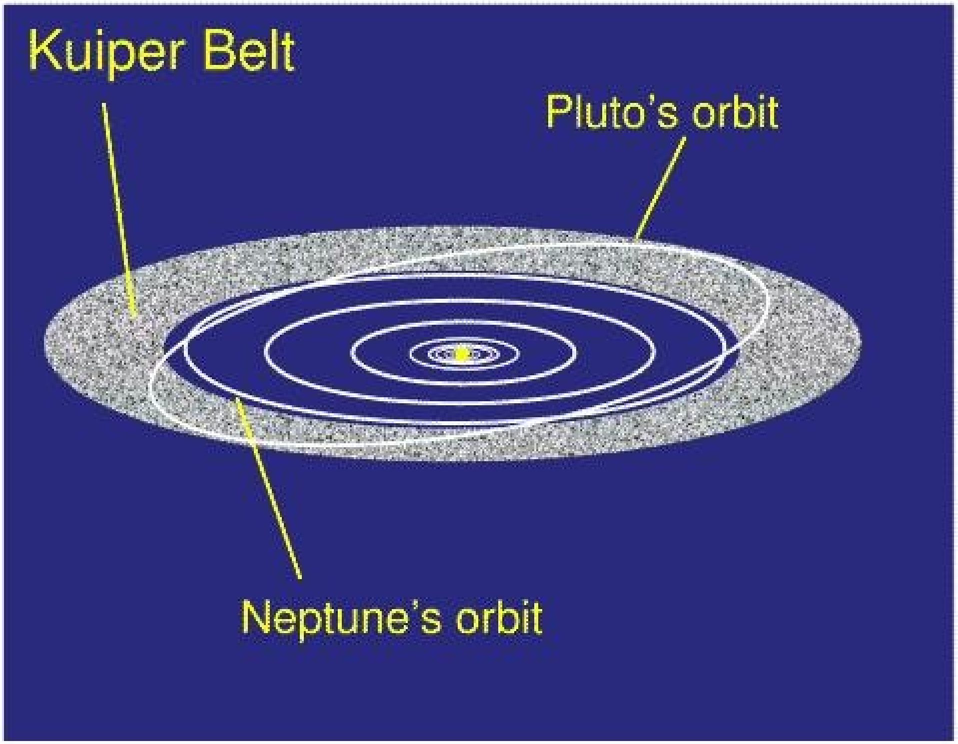
Iron (Fe)
Iron Sulfide (FeS)
Olivine ($(MgFe)SiO_4$)
Pyroxine ($CaMgSi_2O_6$)

Formation of Jovian Planets

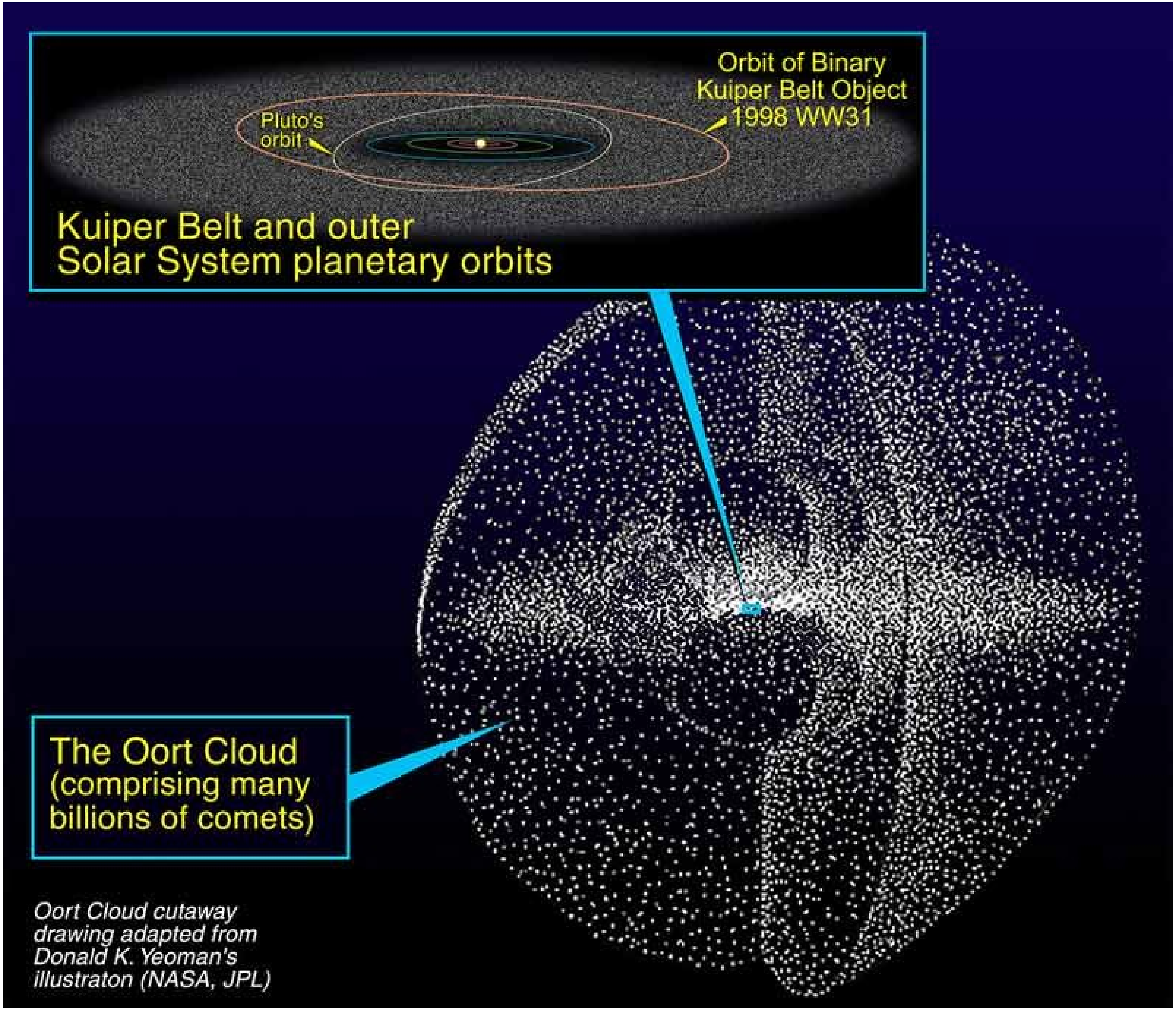
- Formation is similar to the smaller rocky terrestrial planets, but they can also accumulate ICE!   (frost line)
- Once they get to ~15 times Earth's mass, they can gravitationally attract hydrogen and helium gas too!
- Thus we get massive gas-giant planets in the outer Solar System
- Leftovers are comets, asteroids (Kuiper Belt and Oort Cloud)


Pluto's orbit
Neptune's
orbit



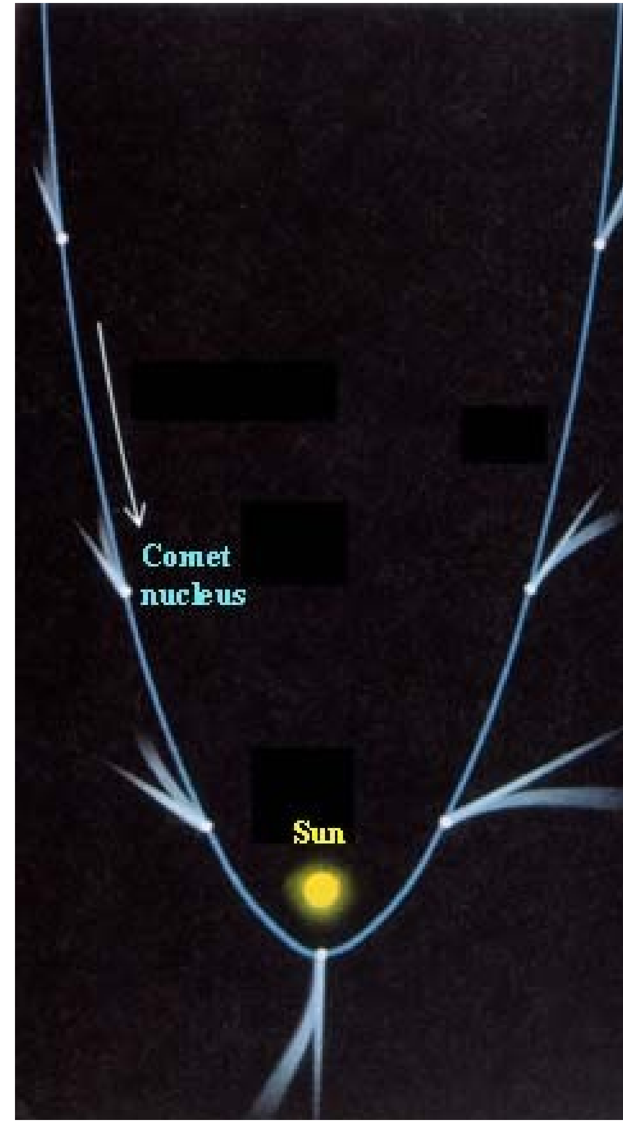

Kuiper Belt
Pluto's orbit
Neptune's orbit

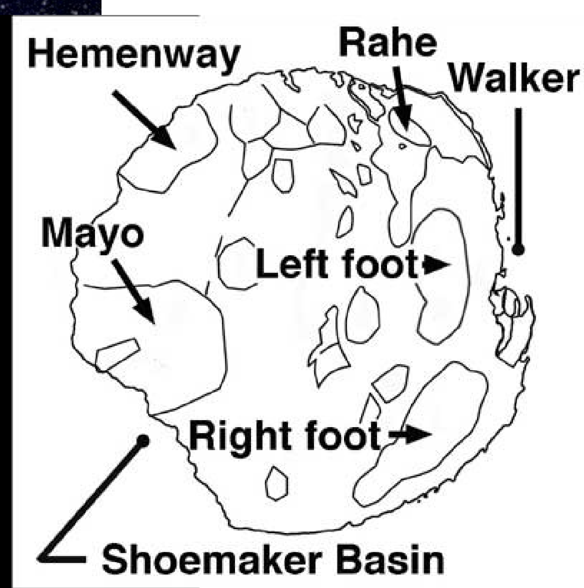
Kuiper Belt



Oort cloud – pieces of the primordial Solar Nebula in a “Deep Freeze”... home of most comets

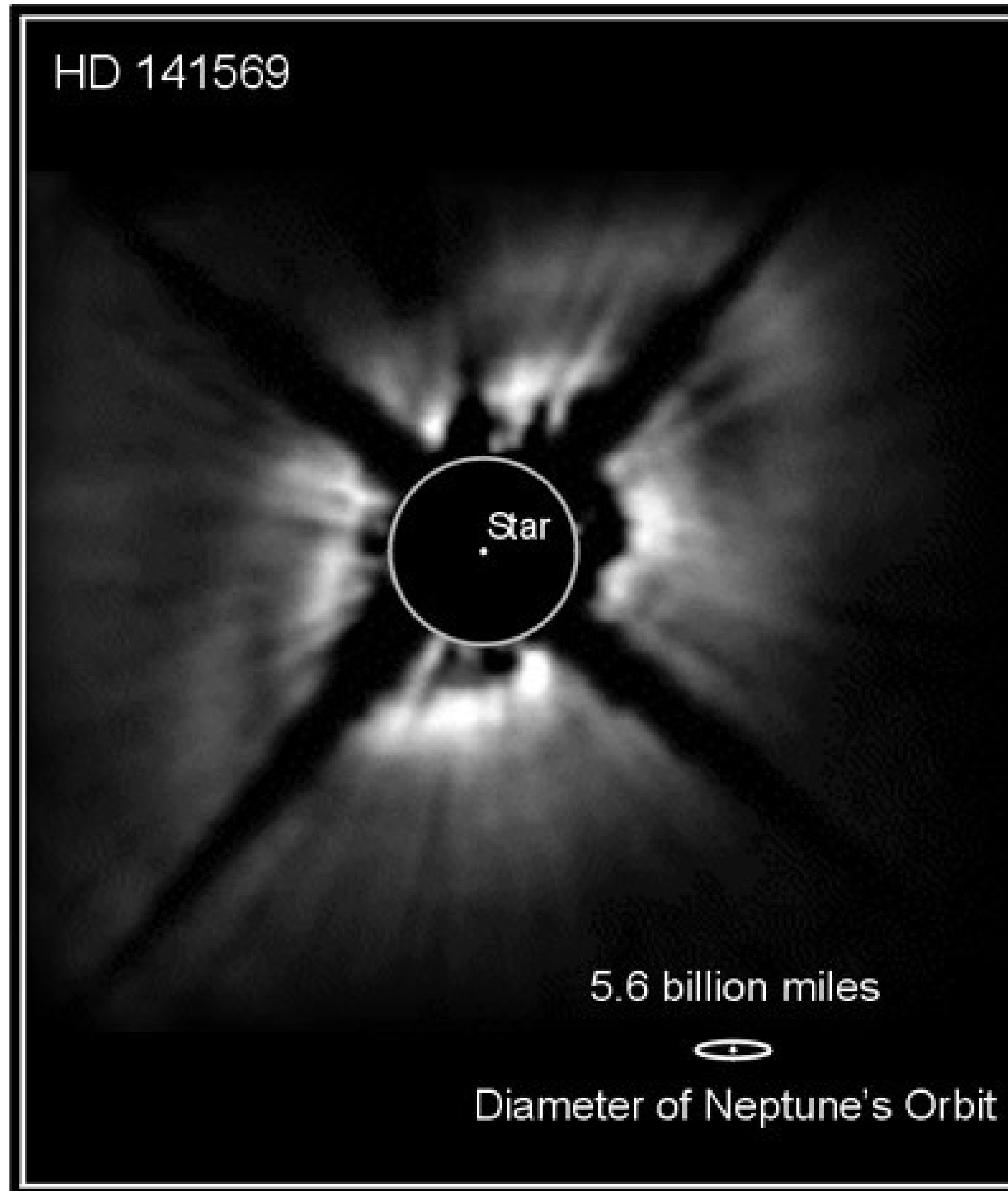
Comets – dirty snowballs of the outer solar system





Observational Tests of this Theory

other young stars seem to have large disks of material like our own Kuiper Belt



Evidence #2: Collisions dominated the early Solar System

Callisto, moon of Jupiter

Meteor Crater, Arizona
~50,000 years ago
iron meteorite about the size of a large bus

Large-scale collisions can affect life on Earth – think of the demise of the dinosaurs!

We are trying to find all Earth Crossing Asteroids

Catalina Sky Survey 60” telescope on Mt. Lemmon

36 and 72” Spacewatch telescopes on Kitt Peak

composition of meteorites tell us that the Sun formed from a cloud that was compressed by a nearby stellar explosion!