The formation of the Solar System

ASTR 407, spring 2018

Basic patterns needing explanation

All planets orbit Sun in same sense (counter-clockwise viewed from N)

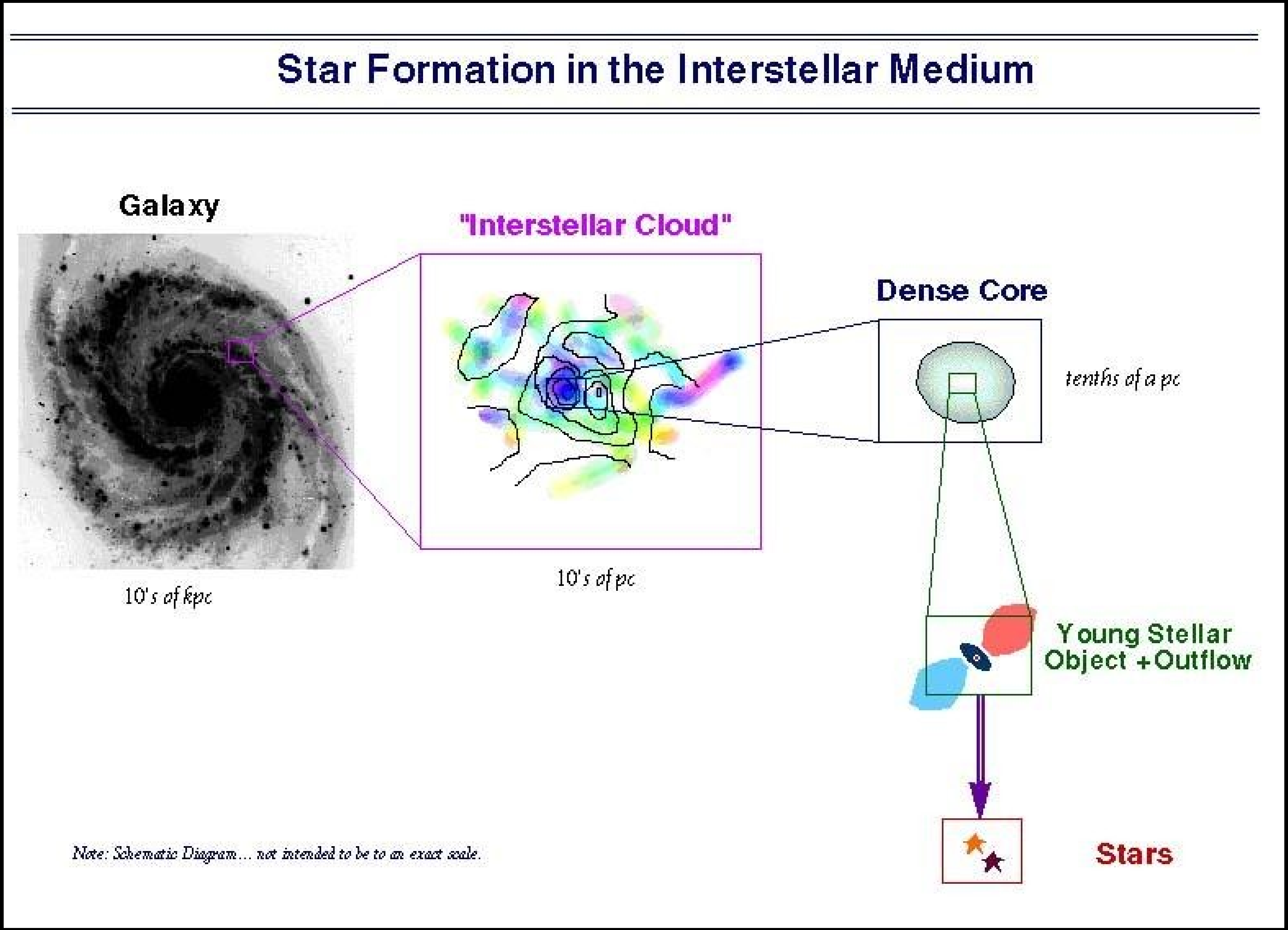
All planets orbit in almost same plane, with e~0

Sun contains 99.9% of Solar System's mass.

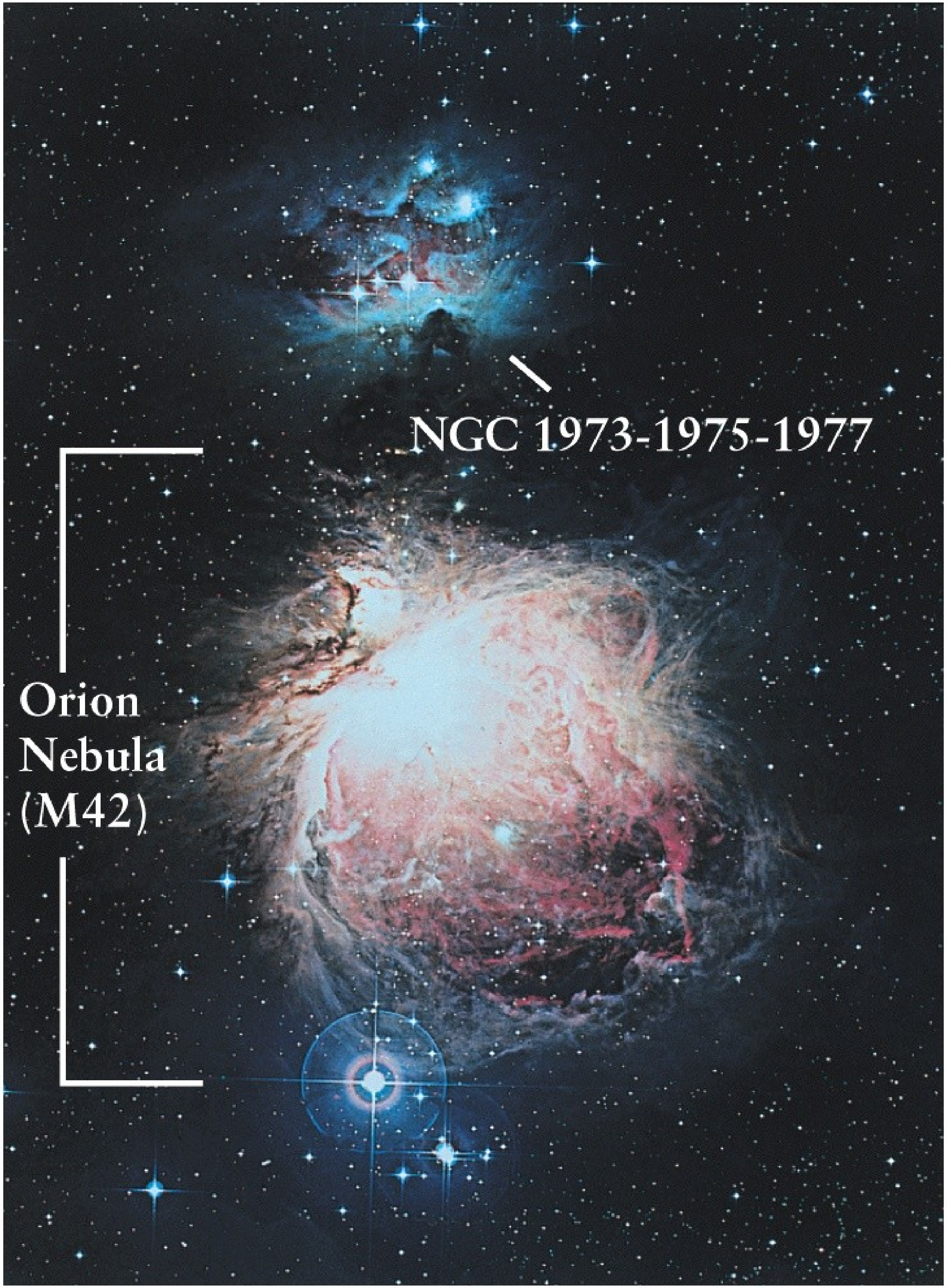
Inner planets rocky, outer planets/satellites icy or heavily gas-rich

Very similar isotopic ratios of certain elements

The framework - coupled to star formation



Young stars are found in our galaxy near regions of gas and dust.



Molecular cloud cores isolate/contract

- Interstellar clouds have mass densities of order $3x10^{-15}$ kg/m^3.
- The Jean's Mass is ~1 solar mass
- Free fall time of cloud t_{ff} ~ 300,000 yr
- Collapses to central condensation, with a surrounding disk ~100 au scale

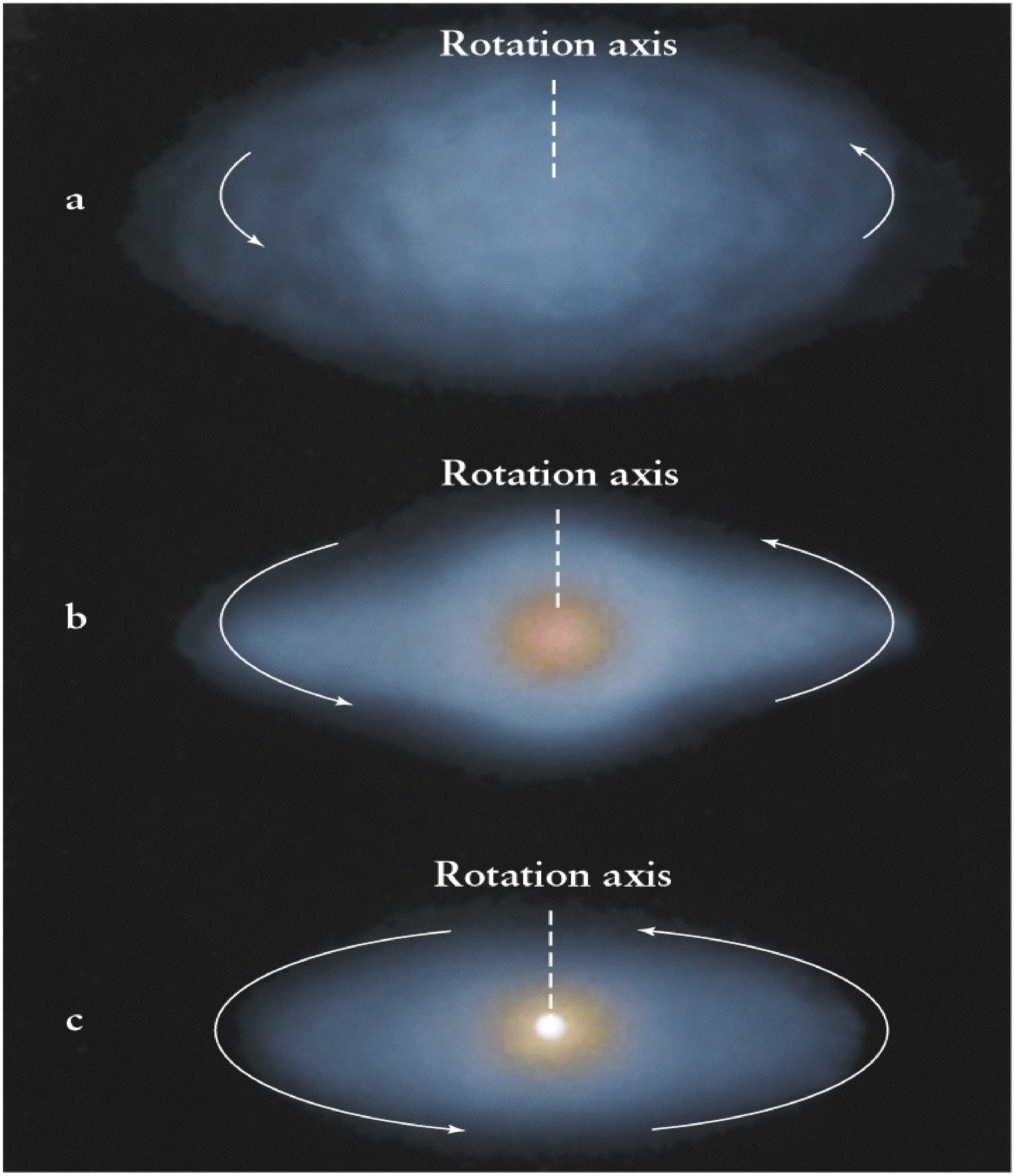
Cloud heats as it contracts.

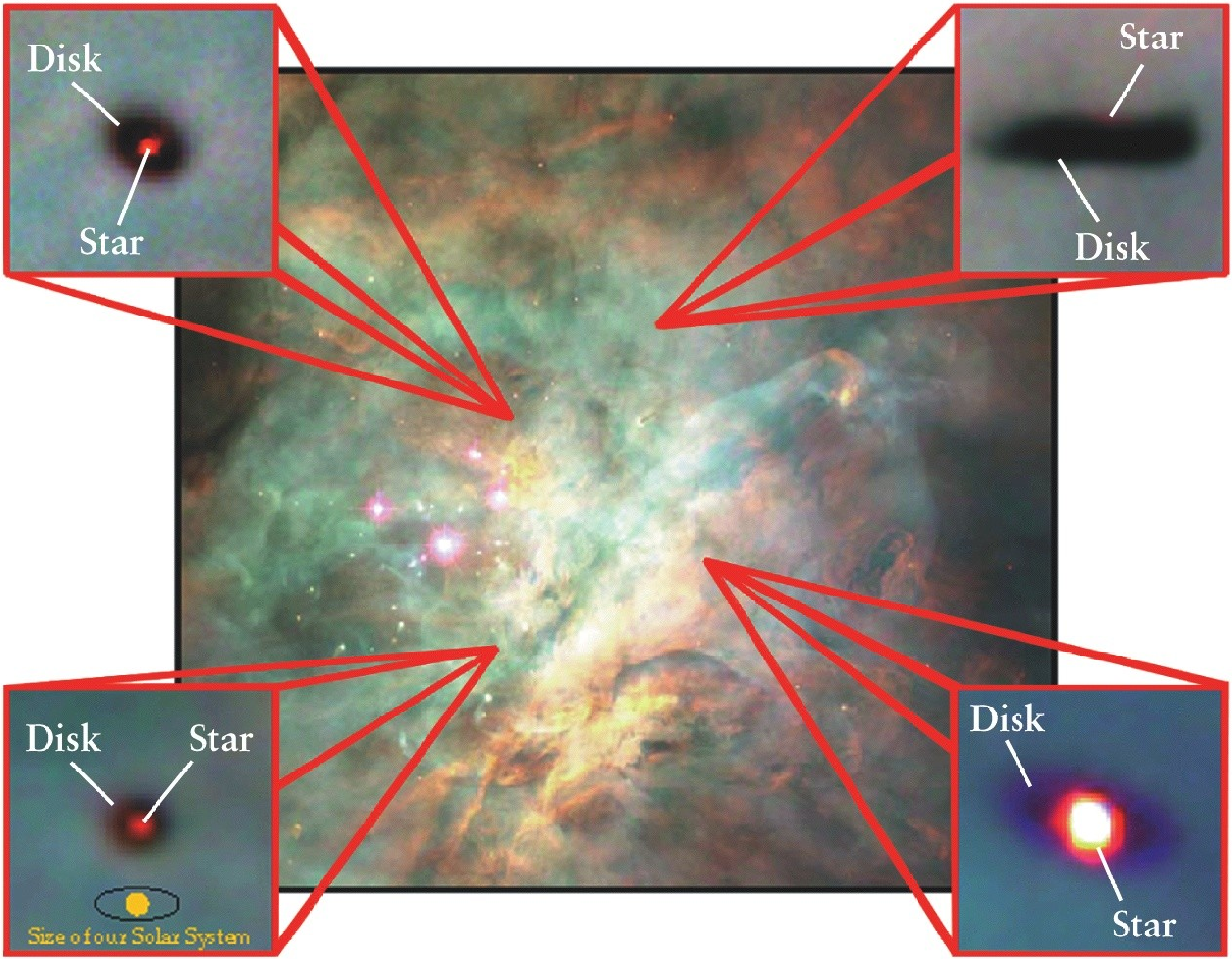
Kelvin-Helmhotz heating

(conservation of energy)

Spins faster

Conservation of angular momentum




Disk
Star
Star
Disk
Disk
Star
Size of our Solar System
Disk
Star

4 stages in star/planet formation

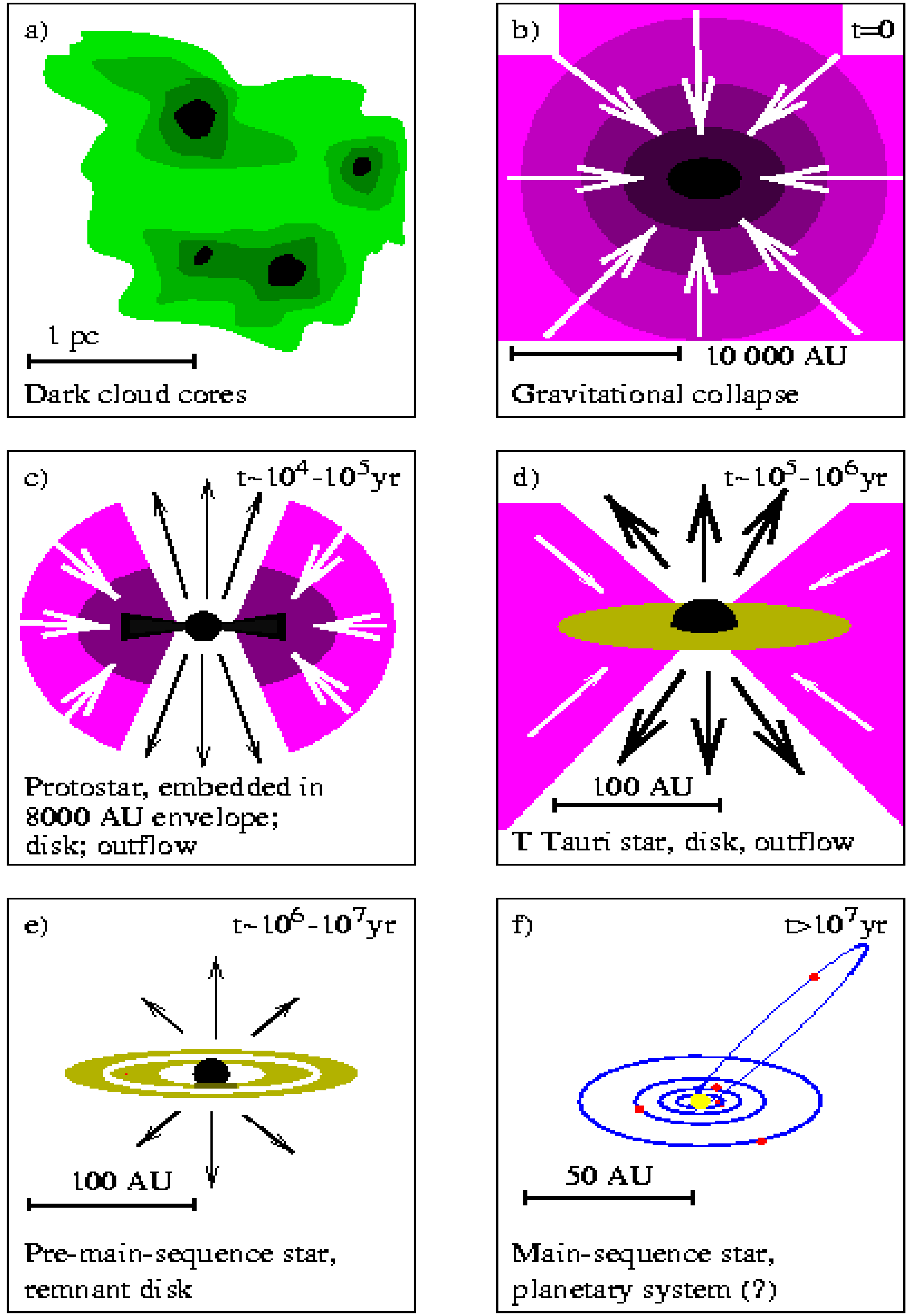
'Cores' form in molecular clouds, some collapse

Protostar and disk forms at center with while star is still cloaked inside infalling matter

Star eventually becomes powerful enough to create a 'wind' which breaks out along spin axis. Mass flows into star

Star blows away envelope, leaving disk in which planets form.

Timescales



Hogerheijde 1998, after Shu et al. 1987

The protoplanetary accretion disk STRUCTURE

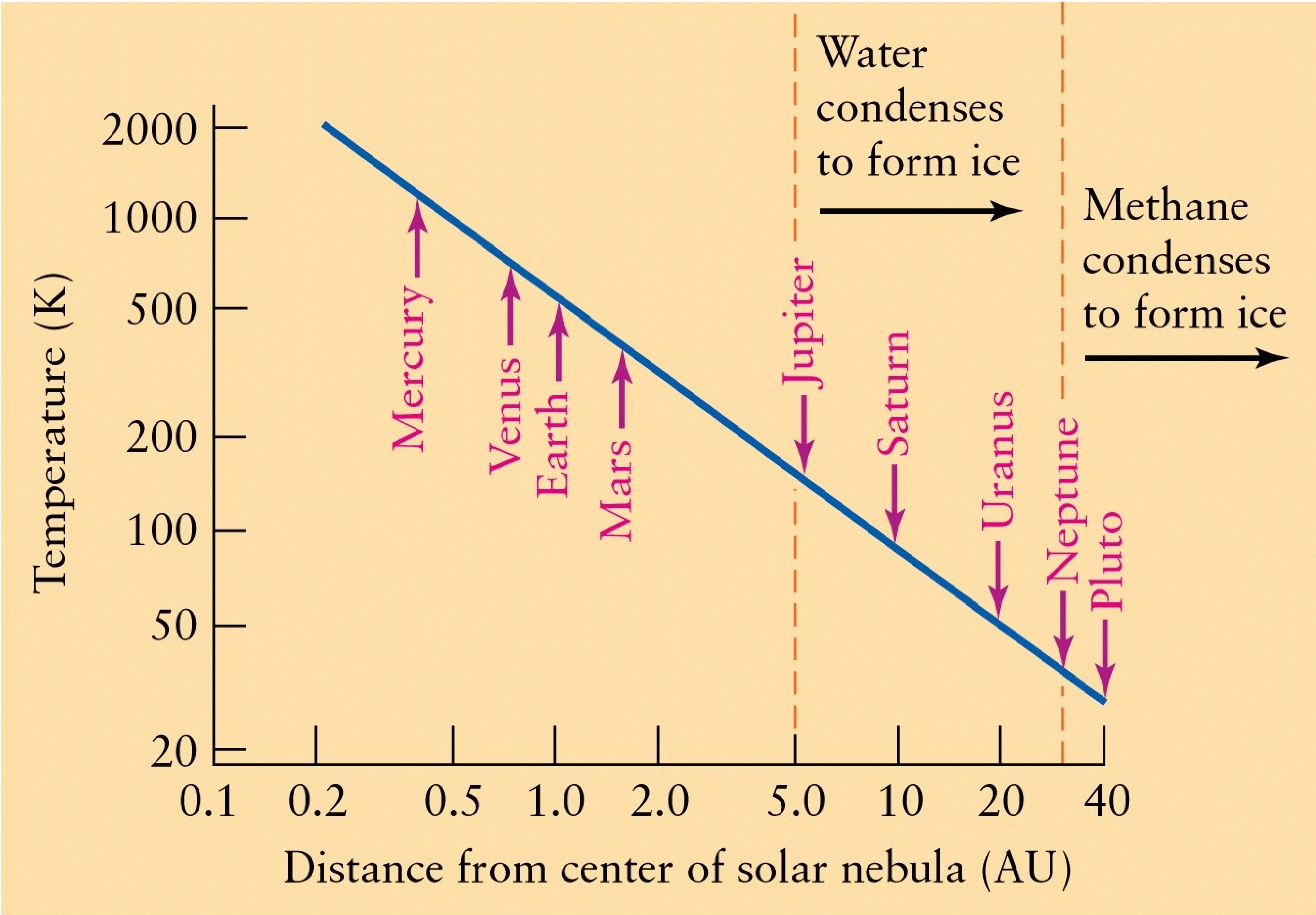
A turbulent ACCRETION DISK

Hotter near the star, cooler far away.

Disk denser near star

The 'snow line' or 'frost line' near the current distance of Jupiter (about 5 AU)

Temperature structure



The Lewis Model

Chemical condensation sequence at low pressure

As T drops, different chemical species can condense starting at 1600 K

Refractory Oxides and Metals first

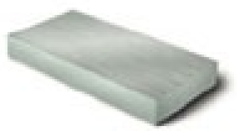
then Silicates (<1200 K)

then water ice (<160 K)

then ammonia and methane ice (<100K)

Condensation sequence

Table 9.1 Materials in the Solar Nebula A summary of the four types of materials present in the solar nebula, along with examples of each type and their typical condensation temperatures. The squares represent the relative proportions of each type (by mass).

	Metals	*Rock*	*Hydrogen Compounds*	*Hydrogen and Helium Gas*
				
Examples	iron, nickel, aluminum	various minerals	water (H_2O) methane (CH_4) ammonia (NH_3)	hydrogen, helium
Typical Condensation Temperature	1,000–1,600 K	500–1,300 K	<150 K	do not condense in nebula
Relative Abundance (by mass)	0.2%	0.4%	1.4%	98%

Lewis Model: Correct predictions

Rocky bodies closer to Sun, icy bodies farther out

Mercury: Large metal content

Venus/Earth/Mars sequence of more water (bulk)

'Wet' asteroids in the outer main belt.

Icy satellites of the giant planets

Planet formation

- How do planets form??
  - By what mechanism?

(Painting by William K. Hartmann. Used with permission.)

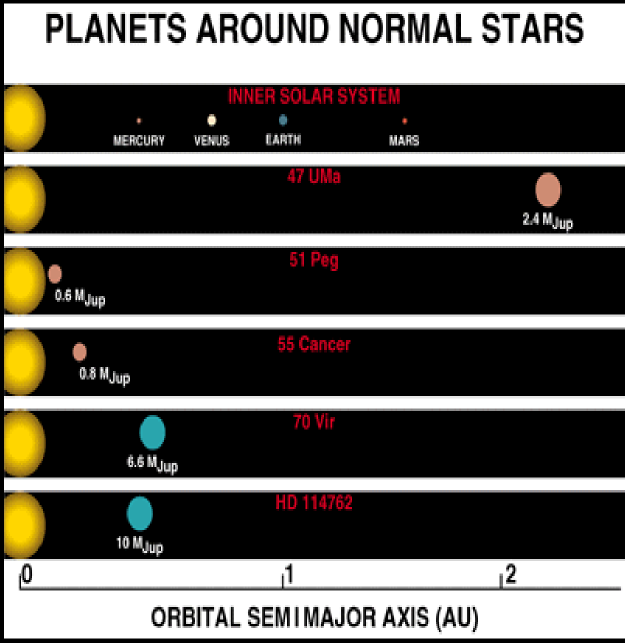
Planet formation

(Painting by William K. Hartmann. Used with permission.)

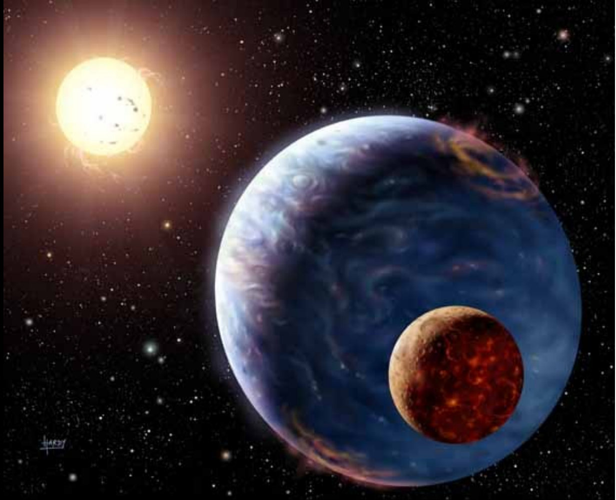
- How do planets form??
  - By what mechanism?
  - How long does it take?
    - Inner: tens of Myr
    - Outer : 10 --hundreds of Myr

Planet formation

- How do planets form??
  - By what mechanism?
  - How long does it take?
  - Is it the same for all planets?
    - for all planetary systems?



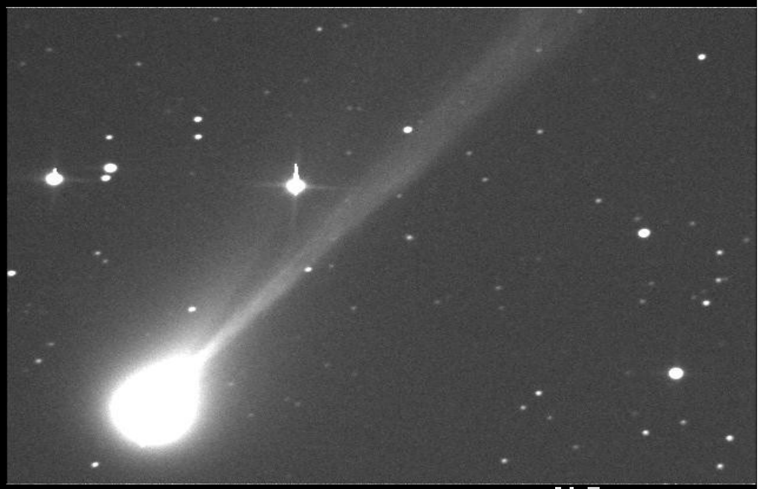
Planet formation



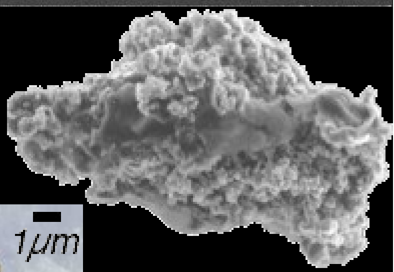
- How do planets form??
  - By what mechanism?
  - How long does it take?
  - Is it the same for all planets?
    - for all planetary systems?
- Where do we get constraints from?
  - properties of the planets (tough)
    - current positions/sizes/chemistry primordial? NO. Evolved. But some...

Constraints from small bodies

- Comets and Asteroids
  - much more primitive
  - Easier to sample



- Physical properties
- Orbital distribution



BOTH tell us about what was going on during planet formation