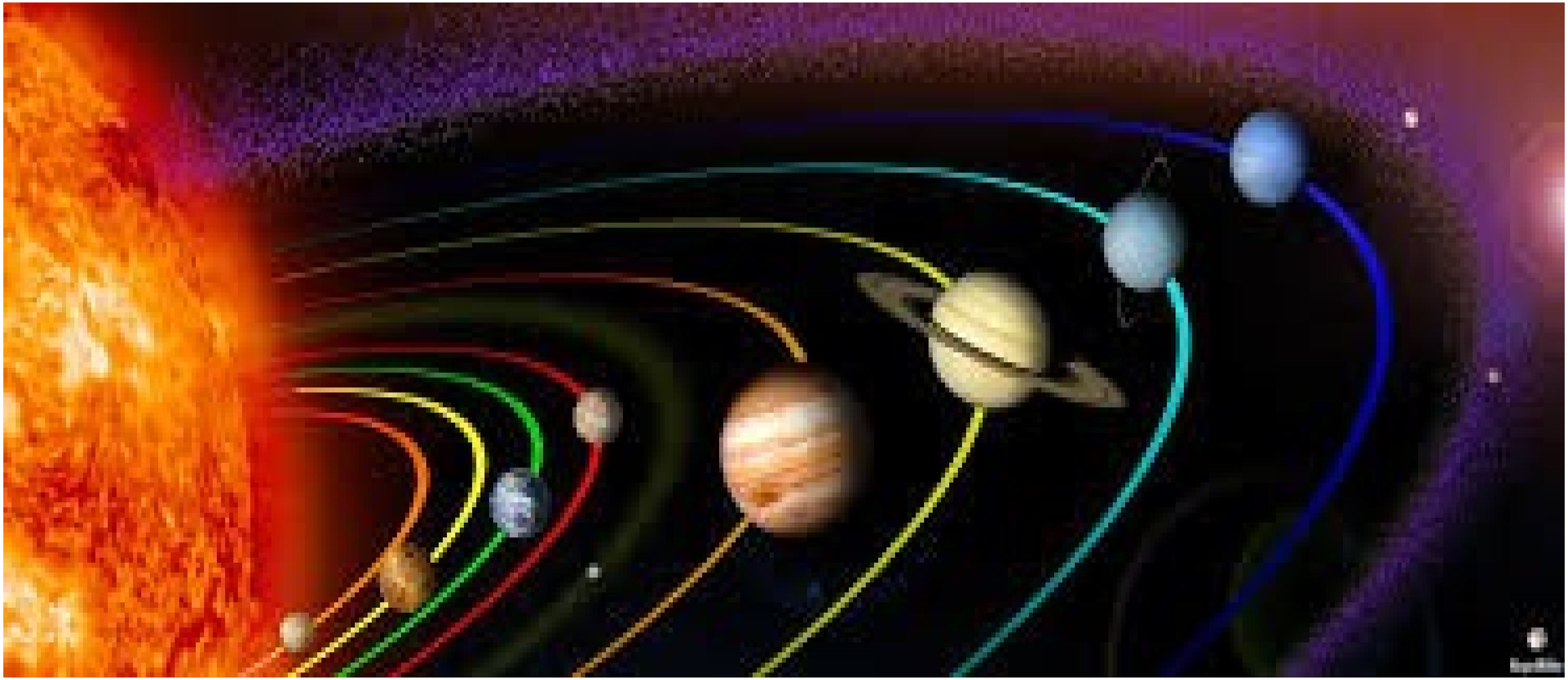
Origin of the Solar System



Dr Priya Hasan
Asst Professor in Physics
Maualana Azad National Urdu University
Hyderabad
priyashasan@yahoo.com

Possible Theories...

1) Catastrophic hypotheses

Example: passing star hypothesis:

Star passing the sun closely tore material out of the sun, from which planets could form (no longer considered)

Catastrophic hypotheses predict: Only few stars should have planets!

2) Evolutionary hypotheses

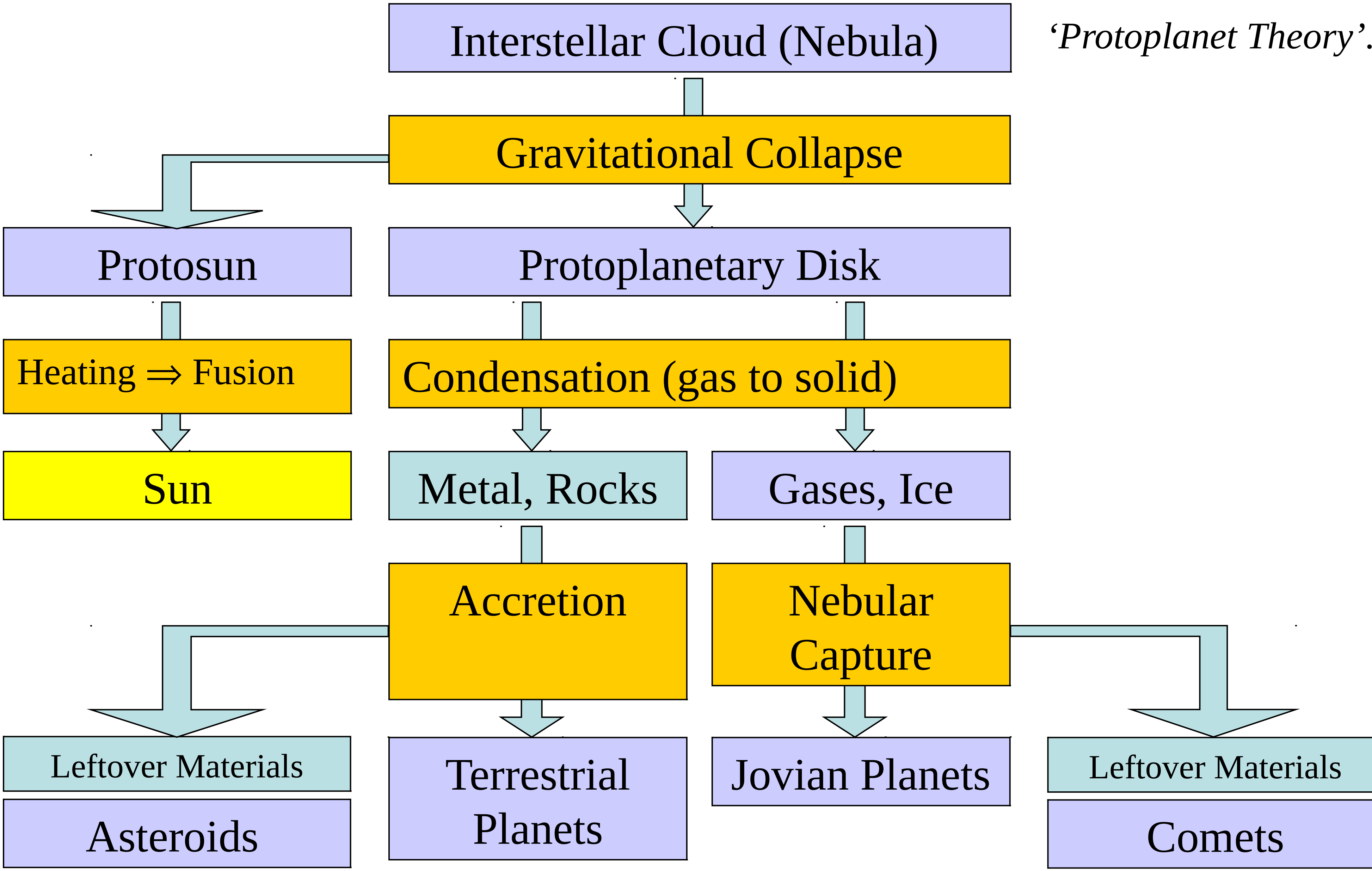
Example: Laplace's nebular hypothesis:

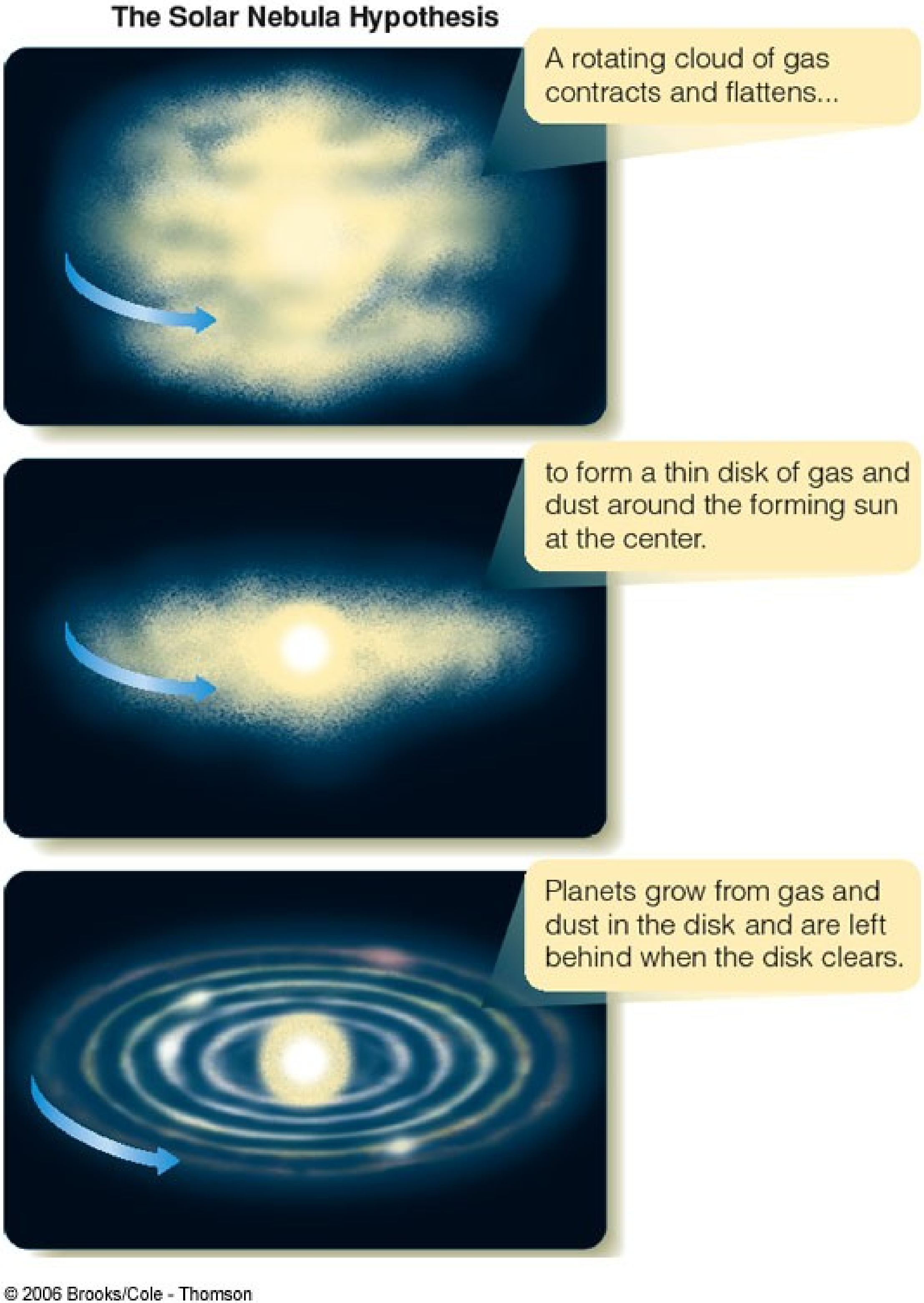
Rings of material separate from the spinning cloud, carrying away angular momentum of the cloud → cloud could contract further (forming the sun)

Evolutionary hypotheses predict: Most stars should have planets!

The Nebular Theory* of Solar System Formation

'Protoplanet Theory'.





The Solar Nebula Hypothesis

Immanuel Kant (1755) and Pierre-Simon Laplace (~1790)

Planets form at the same time from the same cloud as the star.

Planet formation sites observed today as dust disks of T Tauri stars.

Sun and our solar system formed ~ 5 billion years ago.

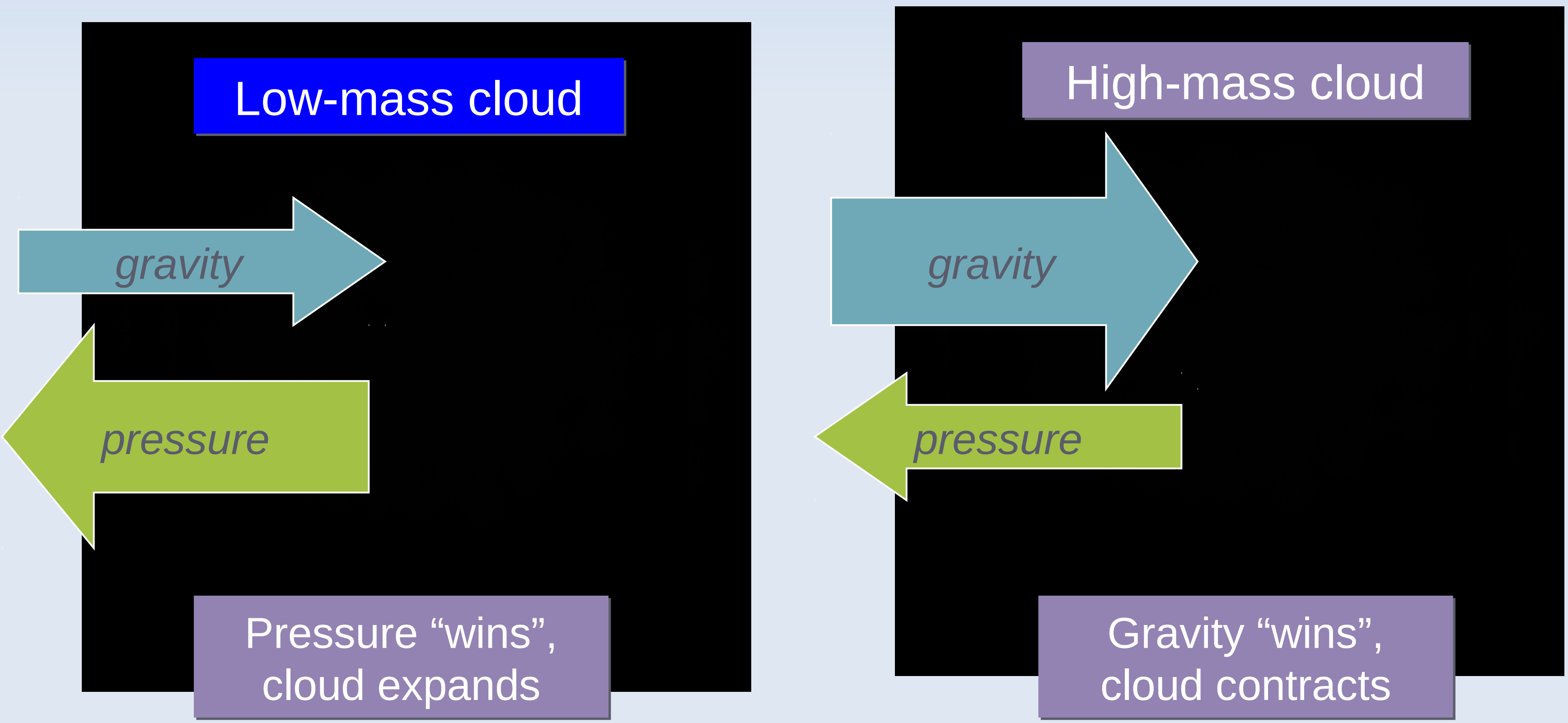
Solar nebula hypothesis

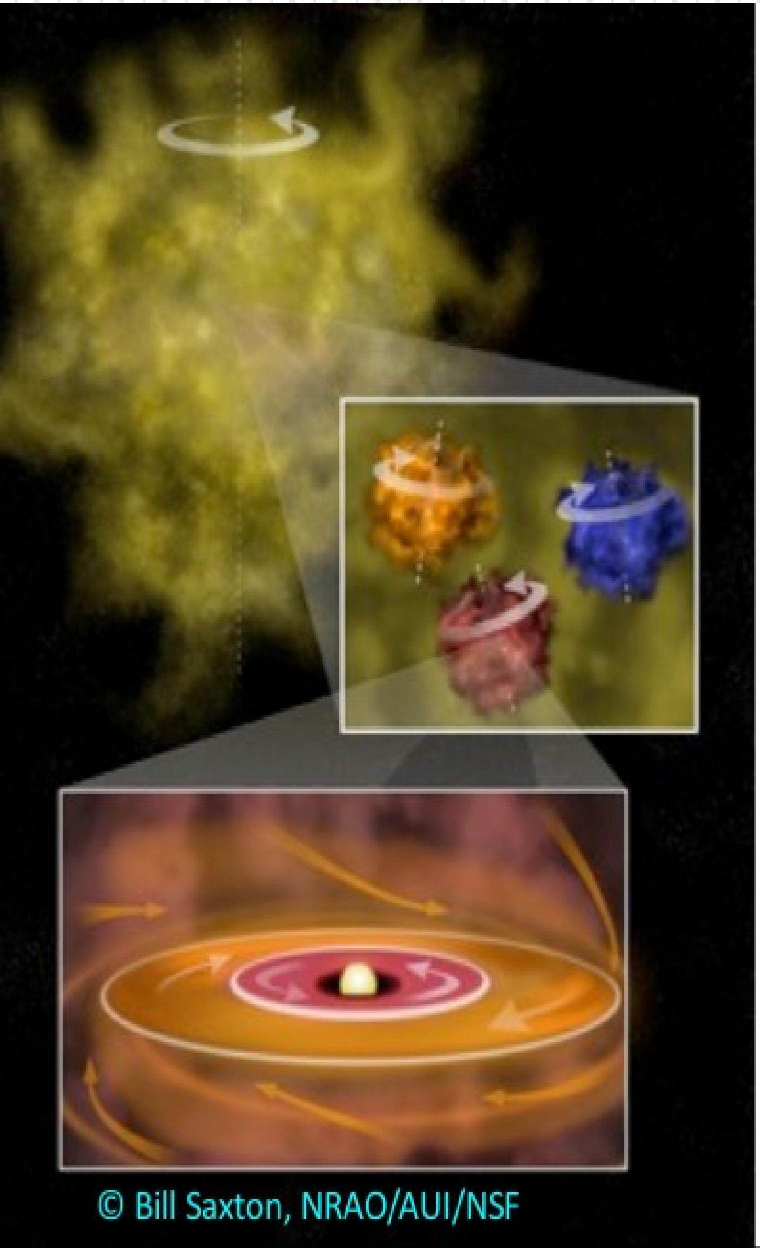
Planets formed within the disk of gas (mainly hydrogen) and fine ‘dust’ particles of heavier elements and molecules left over from earlier cycles of stellar evolution. As the relevant gas cloud collapses, initiated by complex processes of interstellar shock waves, the gas and dust falls into a giant flattened, circulating, pancake-like ‘protoplanetary’ disk.

Star Formation

- Giant Molecular clouds
- Very thin, low-density cloud (10,000 atoms per cm^3)
- Very cold, T~10-20 K, so molecules can form --> molecular cloud
- Made mostly of H (75%) and He (23-25%) gas and a bit of heavier atoms (<2%).

If a nebula contains enough mass, it may begin to collapse because of gravity. Whether it succeeds in collapsing depends on the mass: pressure within the gas and dust opposes the collapse.

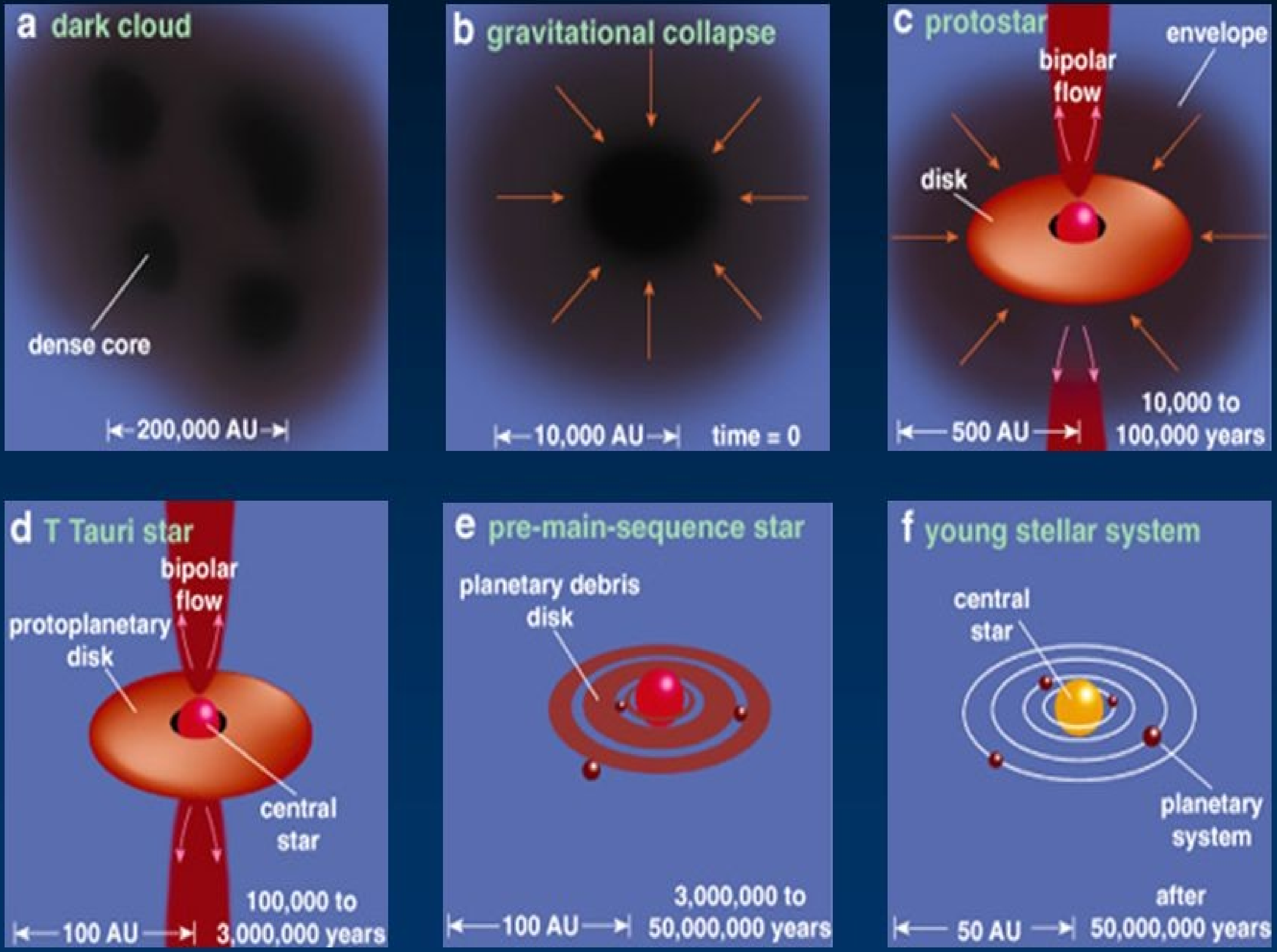




Star and planet formation (sketch)

- Collapse of a molecular cloud
  - under its own gravitation
  - fragmentation
- Conservation of angular momentum
  => increase of rotation
- Formation of a disk
- Planet formation in the disk
  - from the dust and gas in the disk

Obligatory star & planet formation slide



M. Liu (IfA/Hawaii)

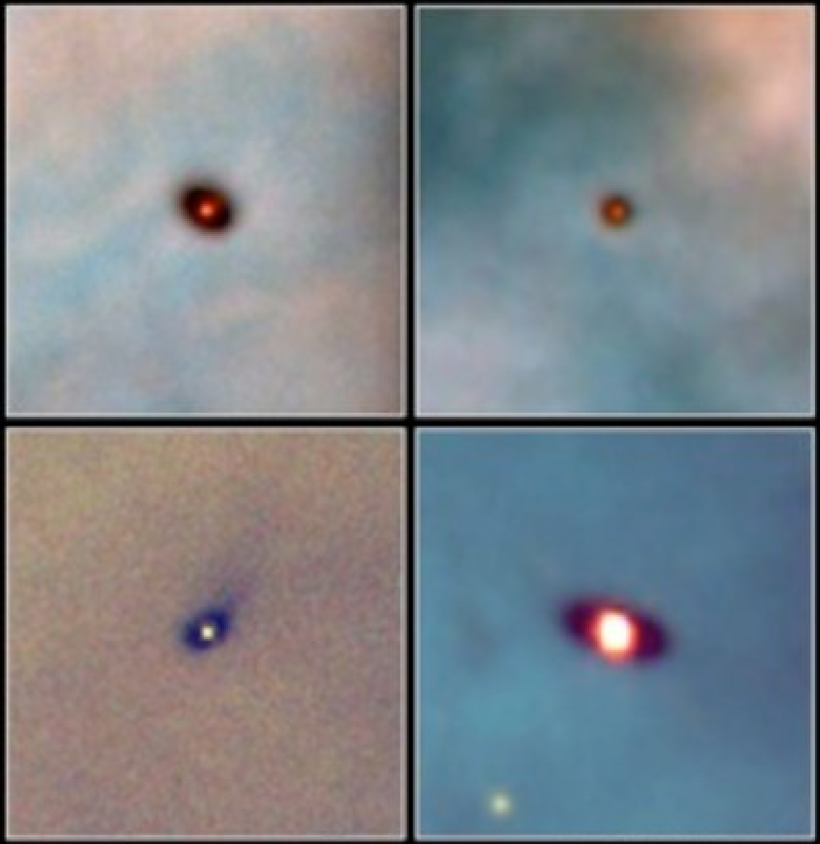
Star forming regions

Orion nebulae

Orion Nebula Mosaic HST • WFPC2

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

C. R. O'Dell and S. K. Wong (Rice University), NASA



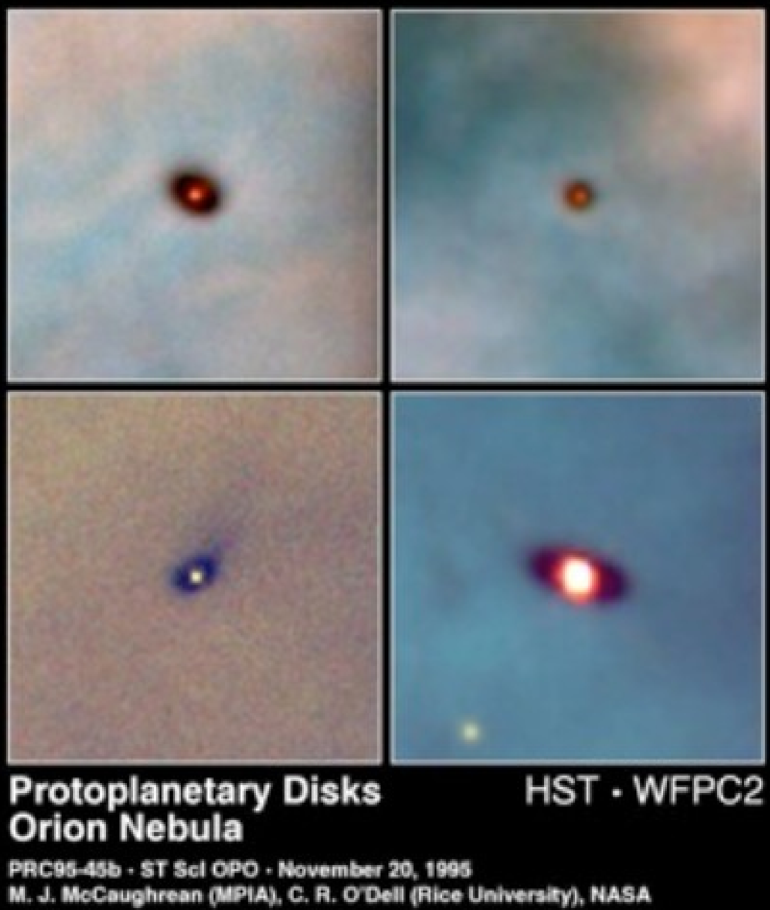
Protoplanetary Disks
Orion Nebula HST • WFPC2

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

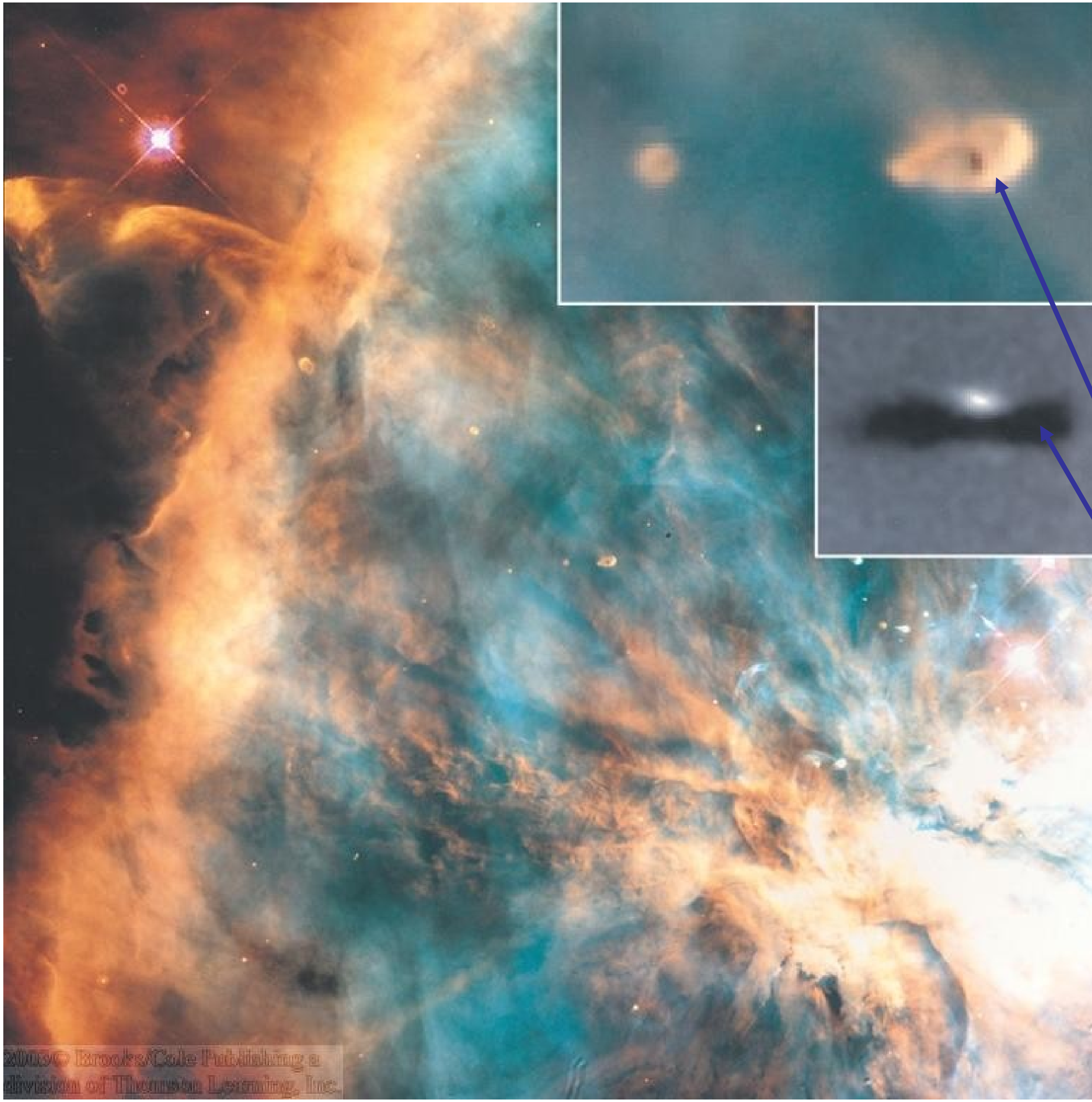
M. J. McCaughrean (MPIA), C. R. O'Dell (Rice University), NASA

Star forming regions – image of protoplanetary disks

Orion nebulae

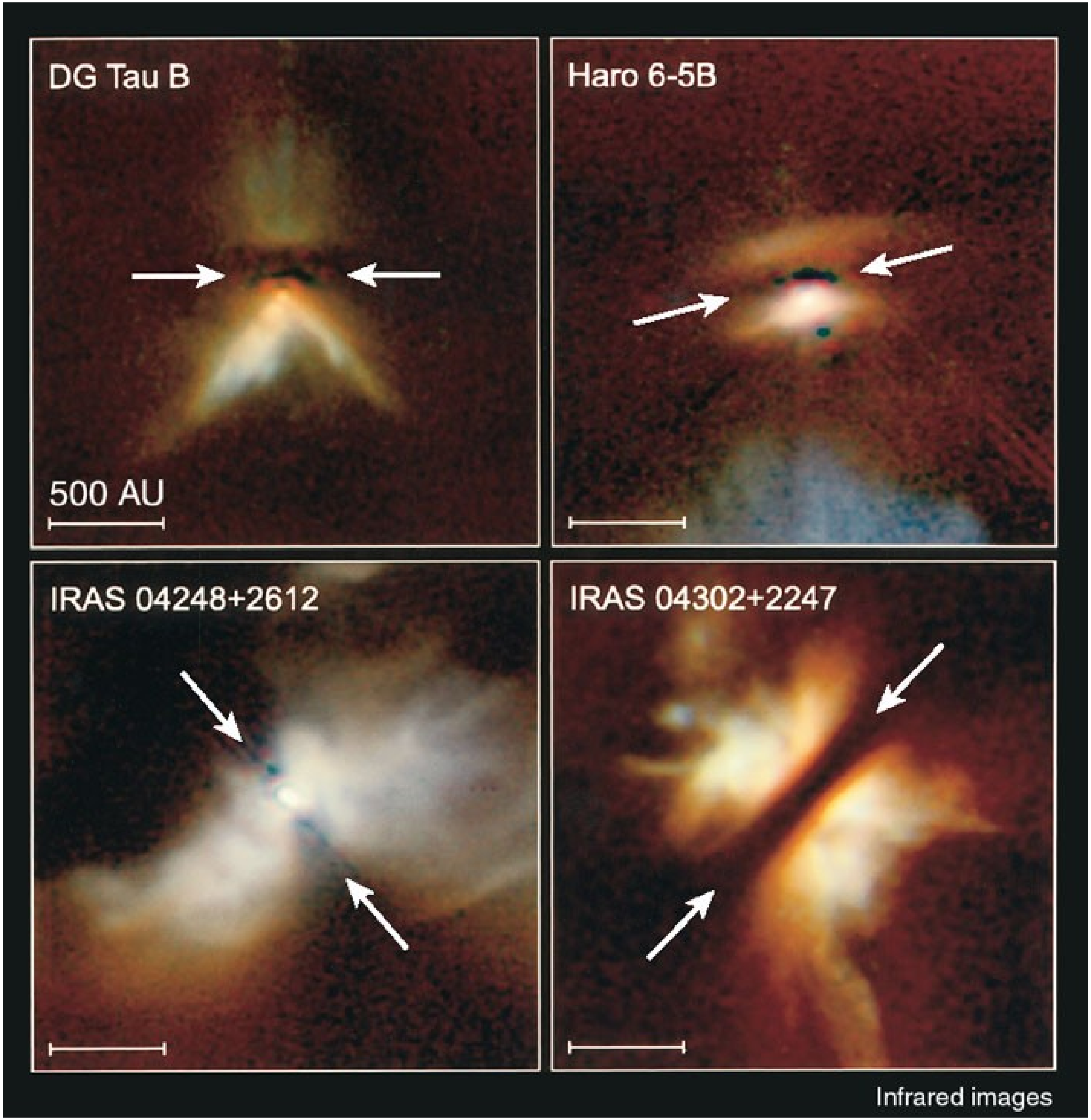


Evidence for Ongoing Planet Formation



Many young stars in the Orion Nebula are surrounded by dust disks:

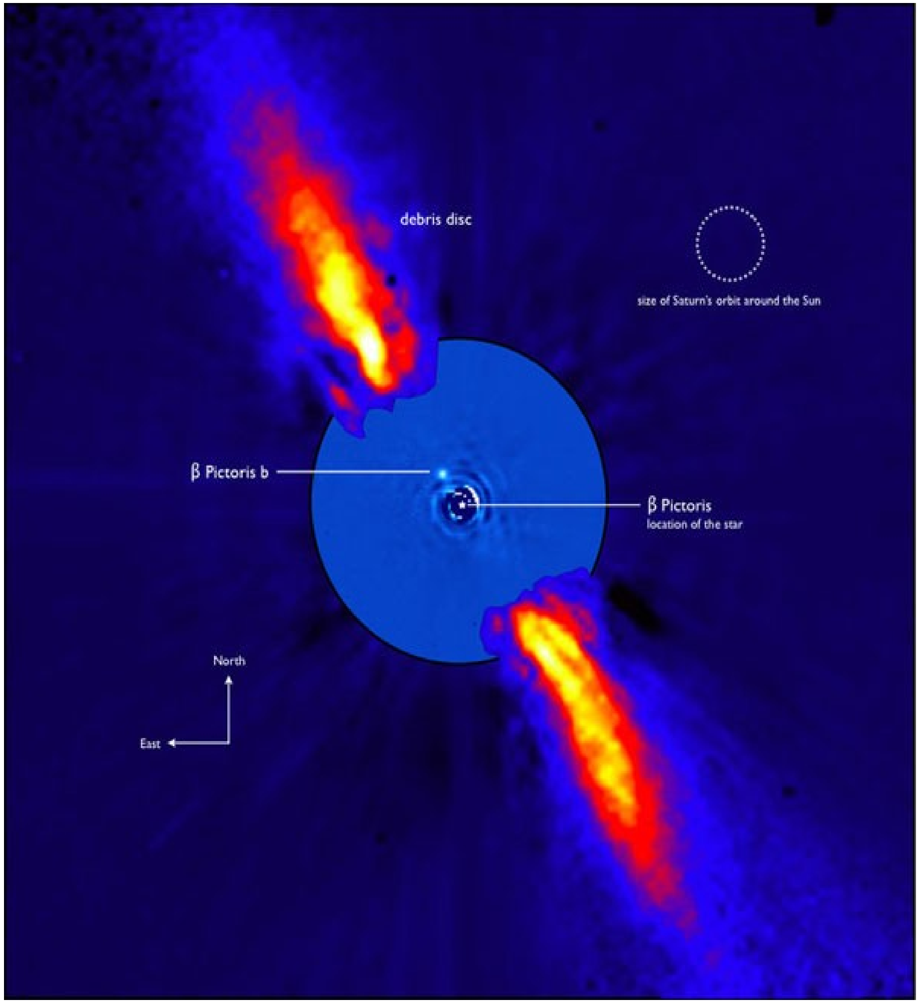
Probably sites of planet formation right now!



Dust Disks around Forming Stars

Dust disks around some T Tauri stars can be imaged directly (HST).

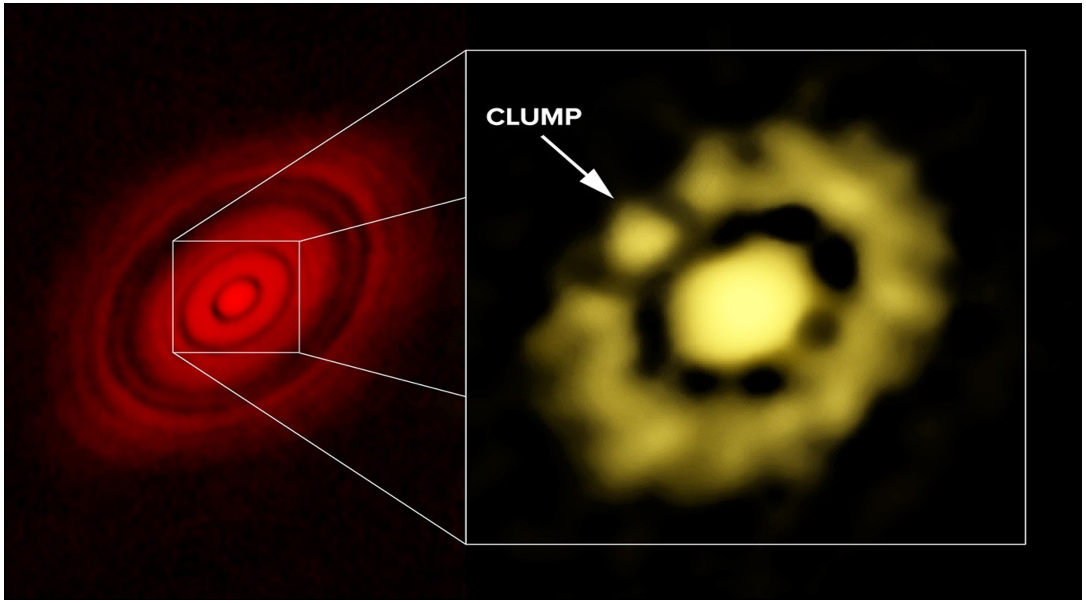
Beta Pectoris dust disk



The planet Beta Pictoris b is visible orbiting its host star in this composite image from the European Southern Observatory's (ESO) 3.6-m telescope and the NACO instrument on ESO's 8.2-m Very Large Telescope.

ESO / A-M. Lagrange et al.

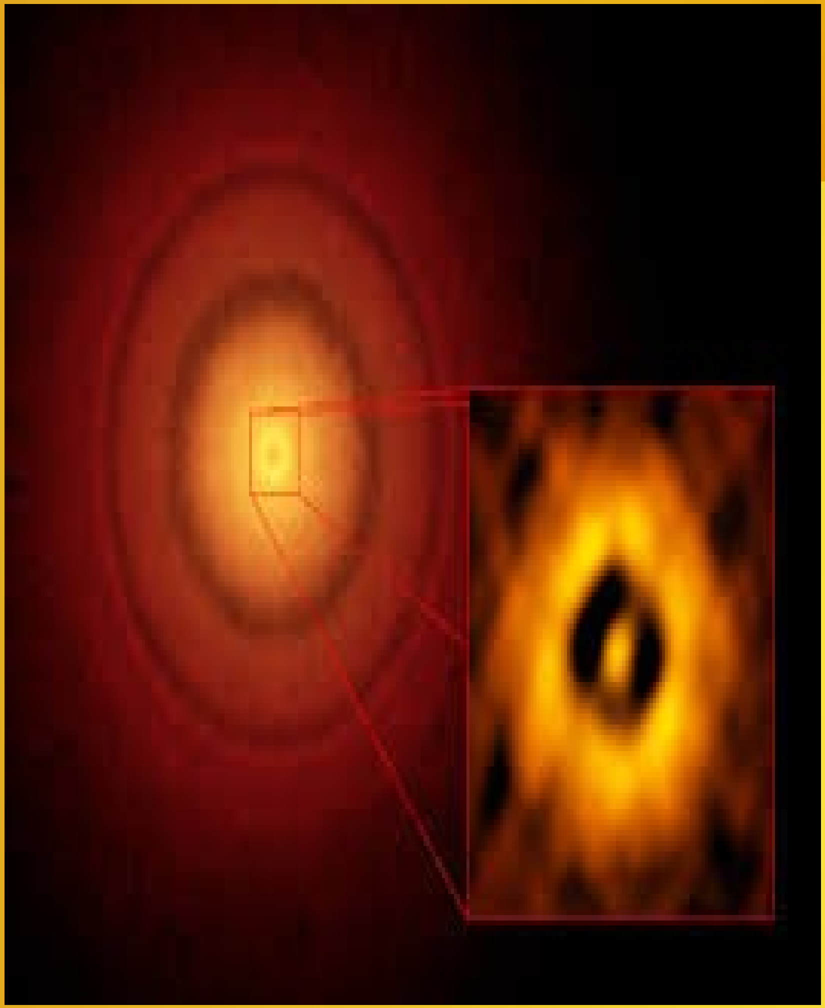
VLA reveals earliest stages of planet formation



ALMA image of HL Tauri(450 light-years)

left; VLA image, showing clump of dust, at right.

Image credit: Carrasco-Gonzalez, et al.; Bill Saxton, NRAO/AUI/NSF.

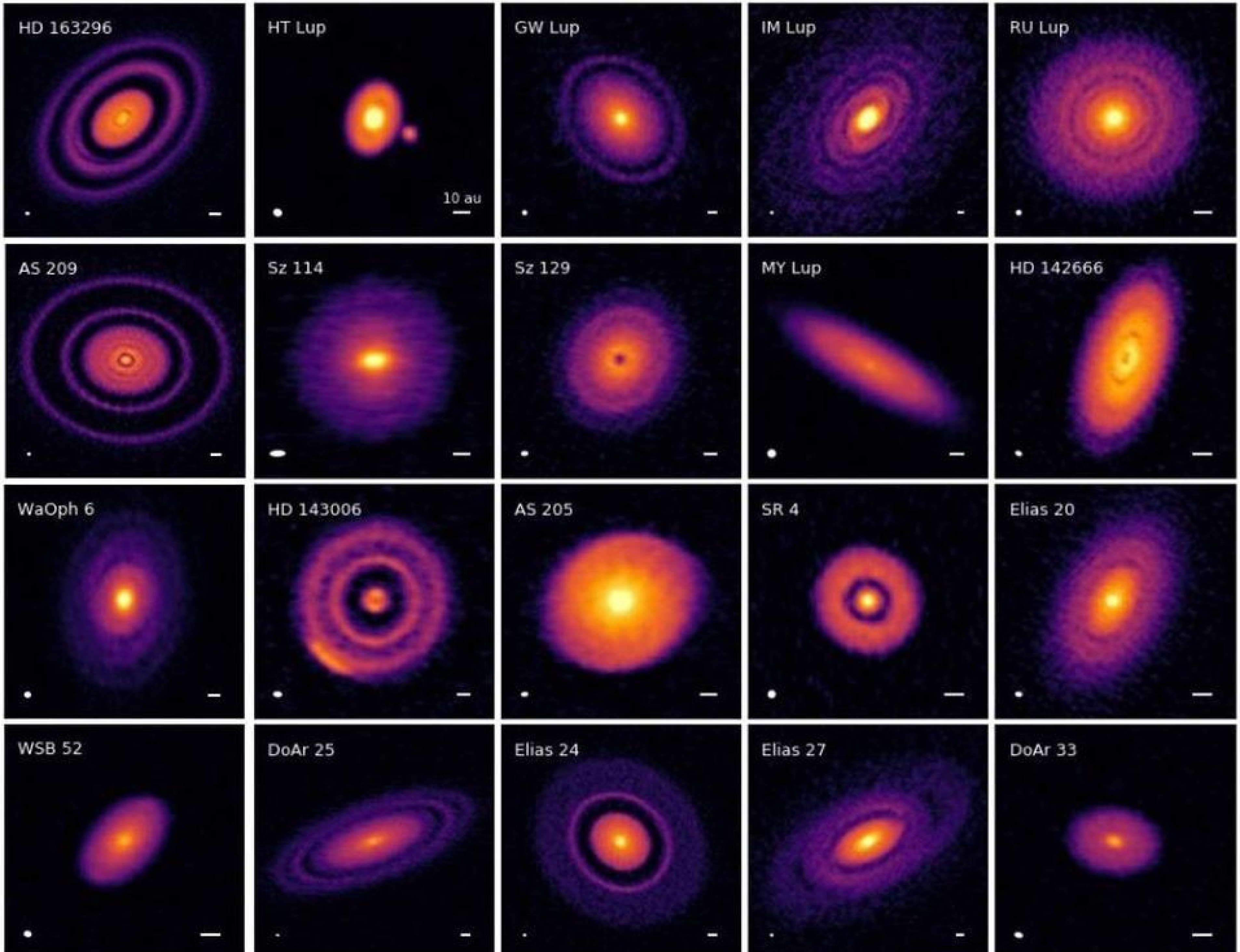


ALMA image of TW Hydrae

Zooms in on the gap nearest to the star, which is at the same distance as the Earth is from the Sun, suggesting an infant version of our home planet could be emerging from the dust and gas.

The additional concentric light and dark features represent other planet-forming regions farther out in the disk.

Credit: S. Andrews (Harvard-Smithsonian CfA), ALMA (ESO/NAOJ/NRAO)

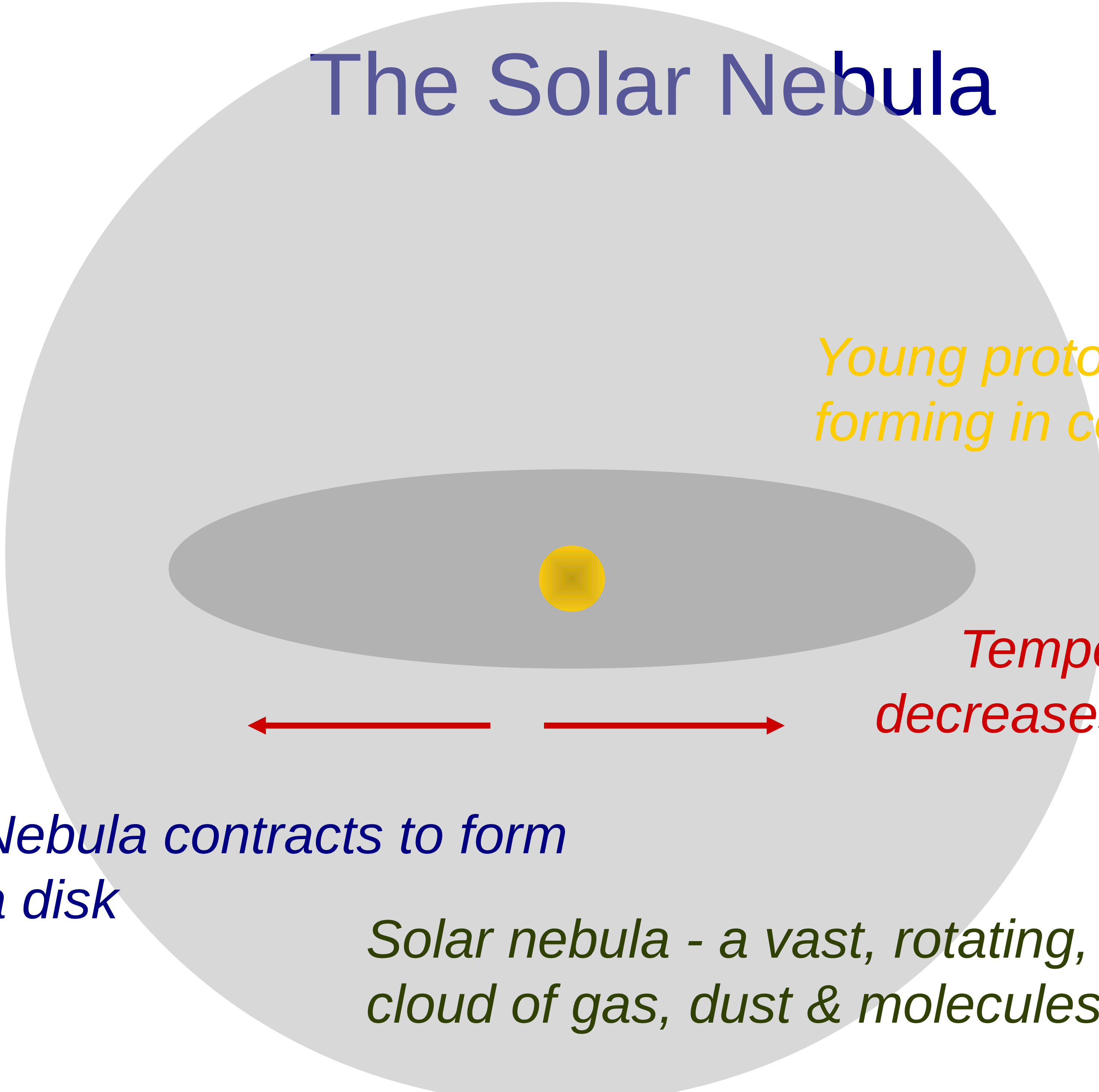

HD 163296
HT Lup
10 au
GW Lup
IM Lup
RU Lup
AS 209
Sz 114
Sz 129
MY Lup
HD 142666
WaOph 6
HD 143006
AS 205
SR 4
Elias 20
WSB 52
DoAr 25
Elias 24
Elias 27
DoAr 33

Planetary Formation is a by product of Star Formation

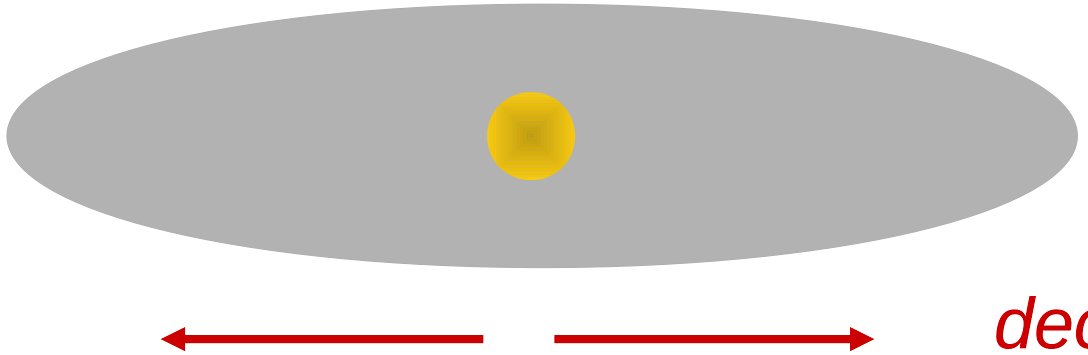
Planets are Common!!

Almost every star has planet(s)

The Solar Nebula

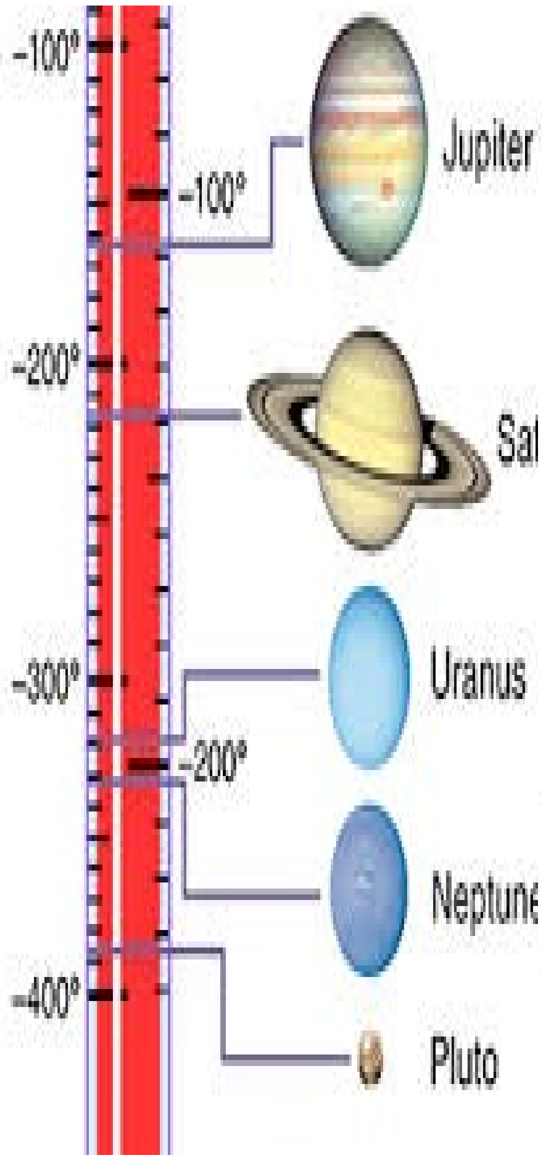


The conditions believed to exist in the Solar Nebula, whether a substance existed as a solid or as a gas depended on the local temperature



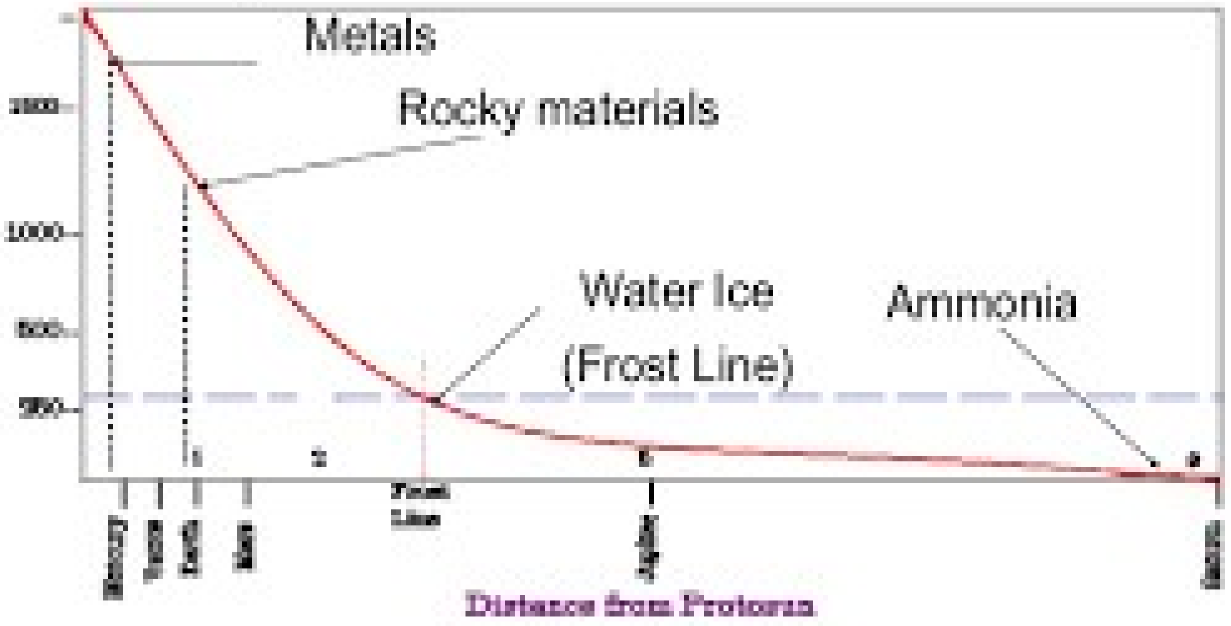
Temperature decreases from centre

As the Solar Nebula radiated off its energy it gradually cooled, and so different molecules started to form and “condense out” onto dust grains. Different substances have different “condensation temperatures”.



2) Condensation: The process of going from a gas to a solid or liquid. This temperature is different for different materials!!

- In general, denser materials can condense at higher temperatures.



Accretion

Accretion is growing by colliding and sticking
The growing objects formed by accretion – planetesimals (pieces of planets)

Small planetesimals came in a variety of shapes, reflected in many small asteroids
Large planetesimals (>100 km across) became spherical due to the force of gravity

Inner solar system: only rocks and metals condensed and only small bodies formed

Nebular Capture

Nebular capture – growth of icy planetesimals by capturing larger amounts of hydrogen and helium
It led to the formation of the Jovian planets

Numerous moons were formed by the same processes that formed the protoplanetary disk
Condensation and accretion created mini solar systems around each Jovian planet

The Solar Wind

Solar wind is a flow of charged particles ejected by the Sun in all directions
It was stronger when the Sun was young

The wind swept out a lot of remaining gas and interrupted the cooling of the nebula

If the wind were weak, the ices could have condensed in the inner solar system

Leftover Planetesimals

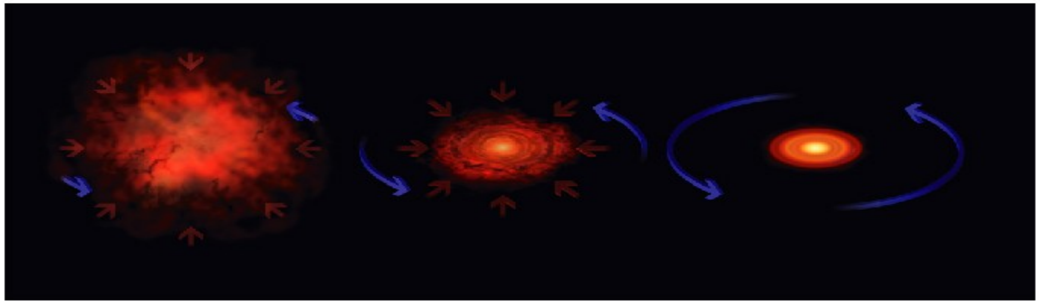
lanetesimals remained from the clearing became comets and asteroids

They were tugged by the strong gravity of the jovian planets and got more elliptical orbits

Rocky leftovers became asteroids
Icy leftovers became comets

Collapse of the Solar Nebula

Gravitational Collapse



Denser region in a interstellar cloud, maybe compressed by shock waves from an exploding supernova, triggers the gravitational collapse.

1. **Heating** ⇒ Prototsun ⇒ Sun
   In-falling materials loses gravitational potential energy, which were converted into kinetic energy. The dense materials collides with each other, causing the gas to heat up. Once the temperature and density gets high enough for nuclear fusion to start, a star is born.
1. **Spinning** ⇒ Smoothing of the random motions
   Conservation of angular momentum causes the in-falling material to spin faster and faster as they get closer to the center of the collapsing cloud. ⇒ demonstration
1. **Flattening** ⇒ Protoplanetary disk. ***Check out the animation in the e-book!***
   The solar nebular flattened into a flat disk. Collision between clumps of material turns the random, chaotic motion into a orderly rotating disk.

This process explains the orderly motion of most of the solar system objects!