Lecture 15 – 19 March 2009

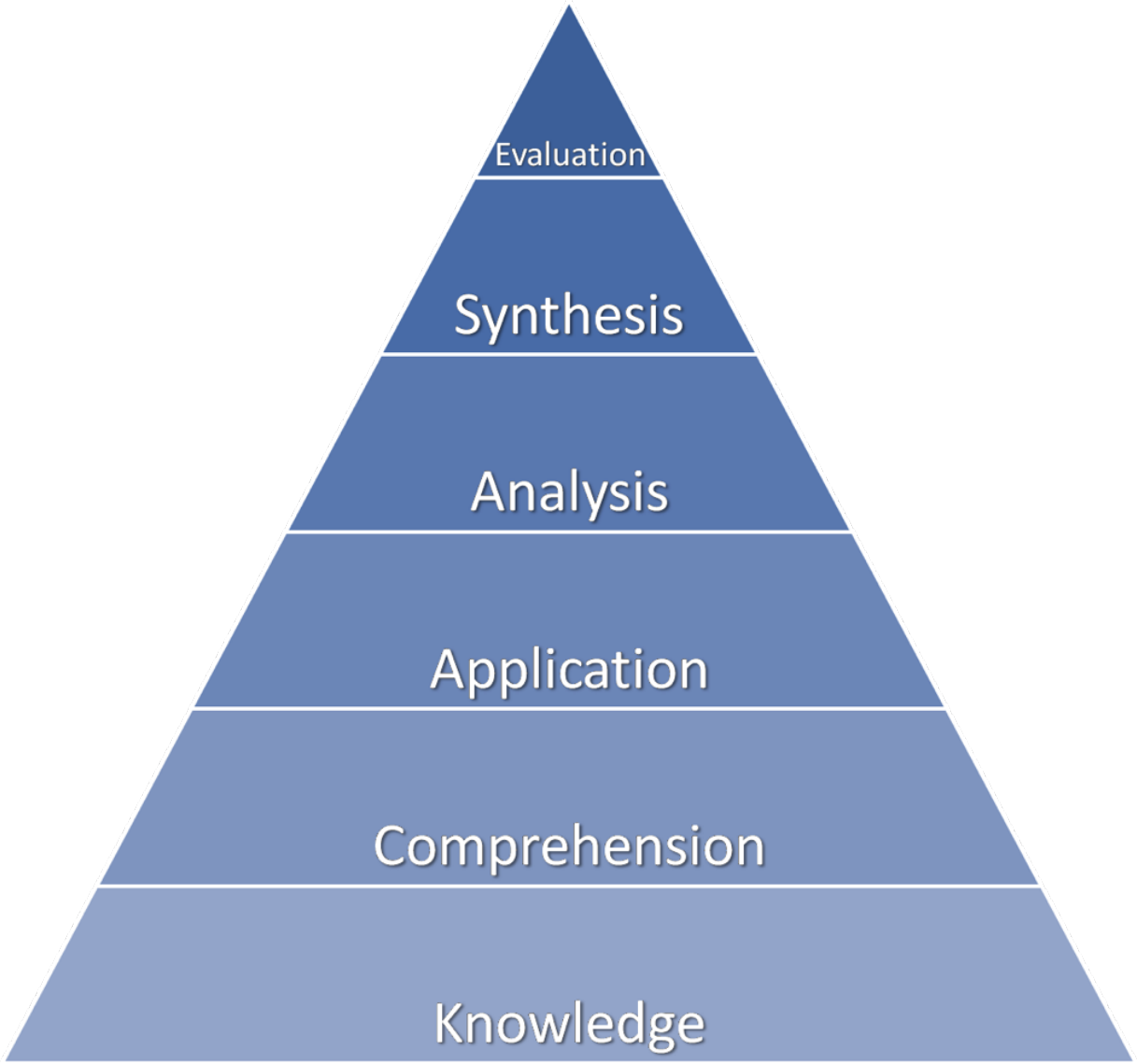
HOMEWORK 5: due next Tuesday, 24th March 2009, 11:59pm
COMPREHENSION 02: next Thursday, 26 March 2009

- **SCIENCE TOPICS**:
  Formation of the Sun and Solar System
  Extrasolar Planets
- **READING**
  Ch 4, sec 4.3 and 4.4
  Planets Beyond the Solar System
- **PRACTICE: Ch 7**
  Review: Ch.4, p.129, 9-11, 14, 15
  Self-test: Ch.4, p.130, 9, 10, 12, 13, 15

About Comprehension 2

- ***When and Where***: Thursday, 26 March 2009 in this classroom, during regular class time
- ***Format and Time Limit:***
  A passage of unseen text relevant to the course. 20 multiple choice questions; 1 mark per question. ***ALL*** the information you need to answer the questions will be provided in the text.
- ***What to Bring:***
  - **your PSU ID card**
  - #2 pencils and eraser
  - a calculator
- ***Other Rules and Regulations:***
  - closed book, closed notes
  - work on your own
  - items other than the above out of sight (*especially* cellphones)

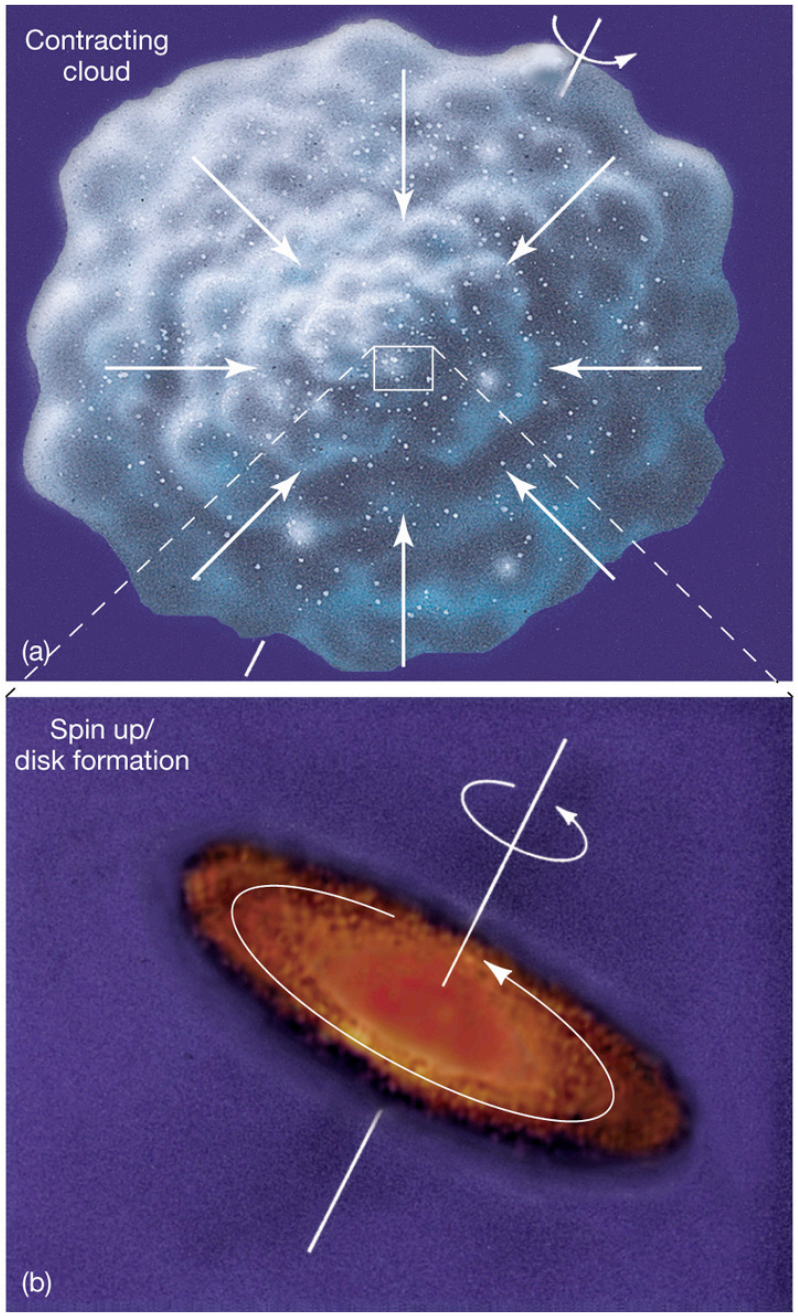
“Blooms Taxonomy”

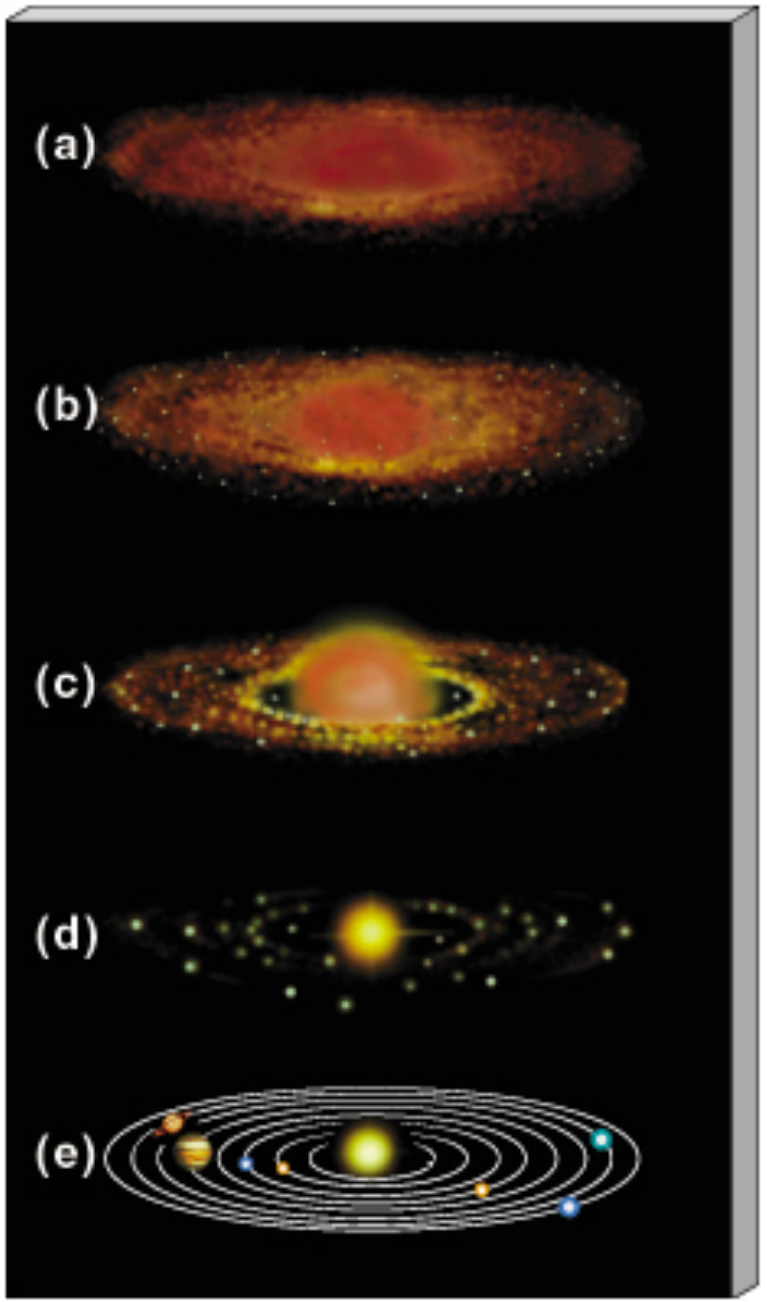


Formation of the Solar System

Properties of the Solar System that we need to explain:

1. Planets are widely spaced, not clustered together.
2. All orbits are nearly circular.
3. Planets orbit in the same plane.
4. All planets orbit in the same direction as the Sun rotates.
5. Most (but not all) planets rotate in the same direction as the Sun does.
6. Most moons orbit in the same direction as their planets rotate.
7. There are pronounced differences between the inner and outer planets in many properties, such as masses, density/ composition, moons, spacing, radii, presence of rings, and others ("differentiation" of the solar system).


Contracting cloud
(a)
Spin up/ disk formation
(b)


(a)
(b)
(c)
(d)
(e)

The **"Nebular Hypothesis"** in summary...

A) Gravitational Collapse of Interstellar Cloud ("Solar Nebula")

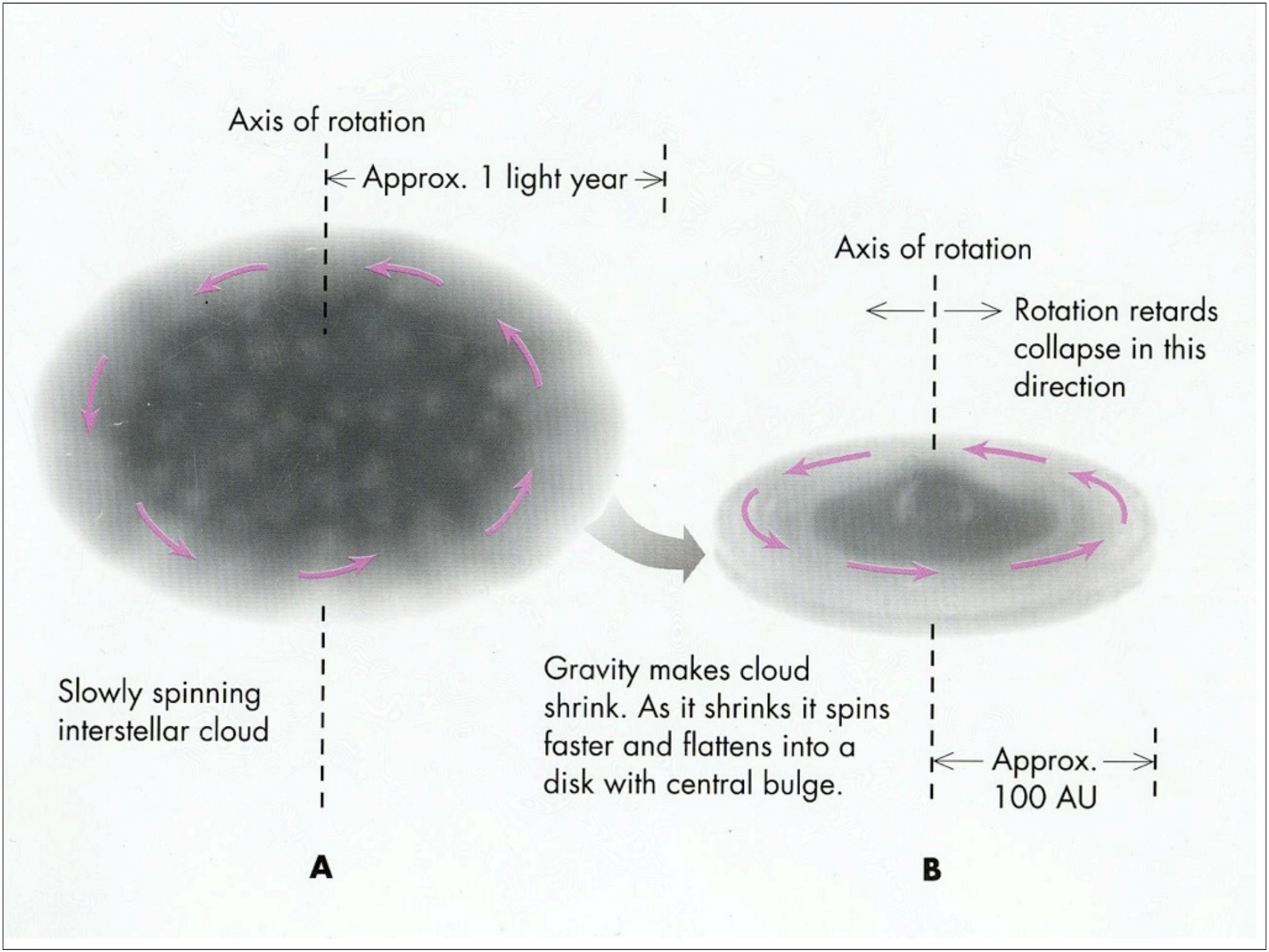
B) Temperature rises as cloud contracts and flattens. Sun forms at centre and nuclear fusion can start.

C) Little whirlpools might/can form in disk. *Accretion* starts.

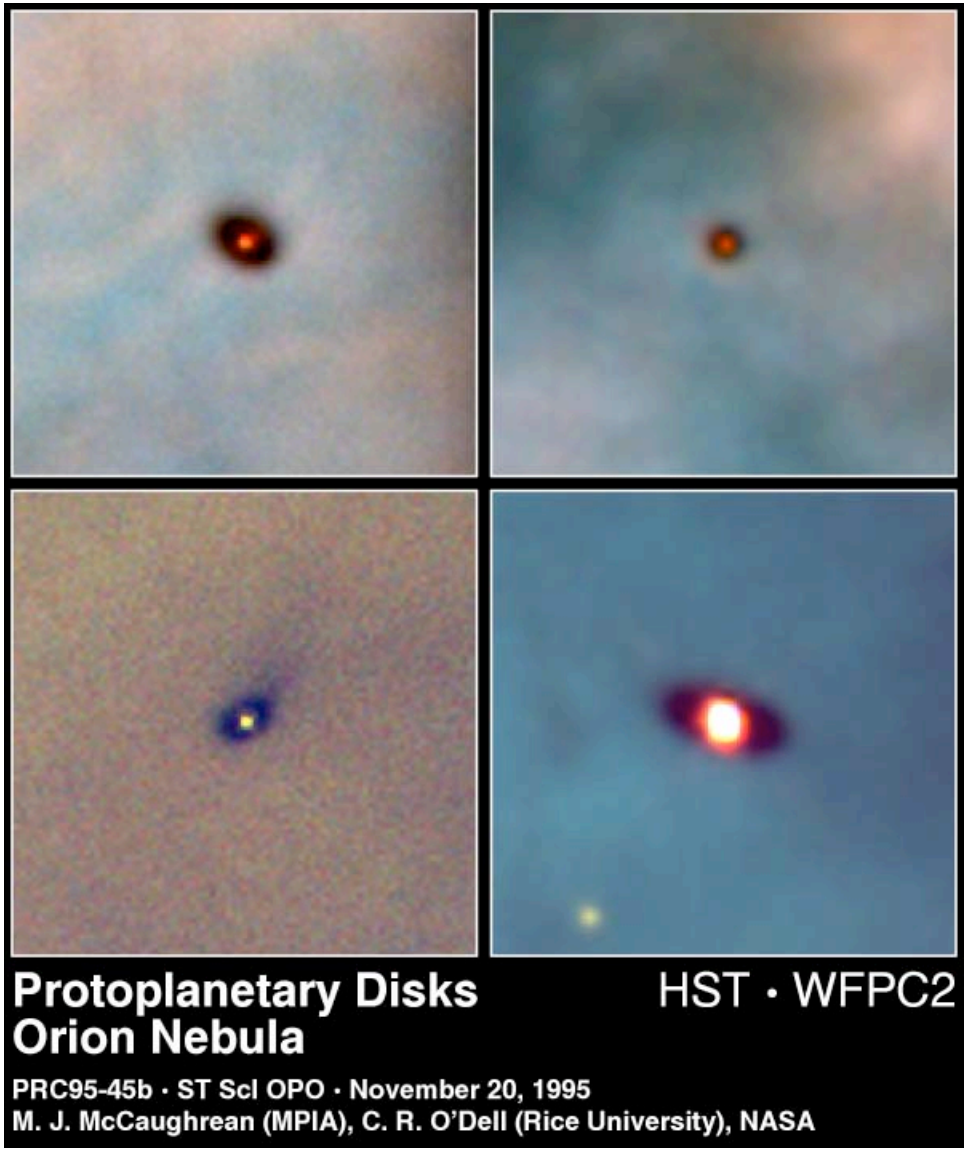
D) Nebula starts to cool. *Rocky* particles condense near the centre. *Ices* form in outer parts.

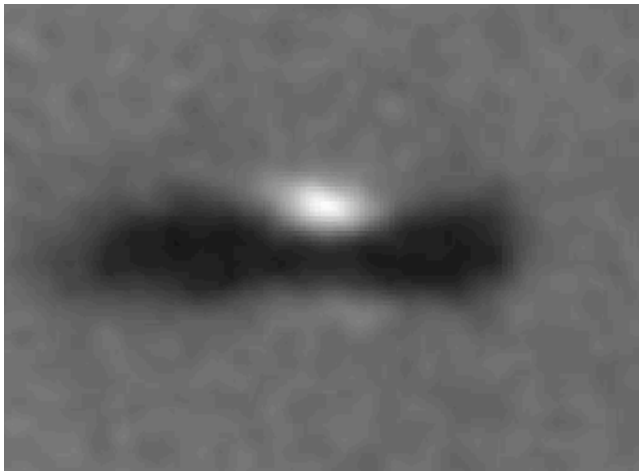
E) Collisions and gravity pull material together into *planetesimals* (embryonic planets, 1-10 km). Planetesimals collide to form large bodies, *protoplanets*.

F) "Clean-up" phase.

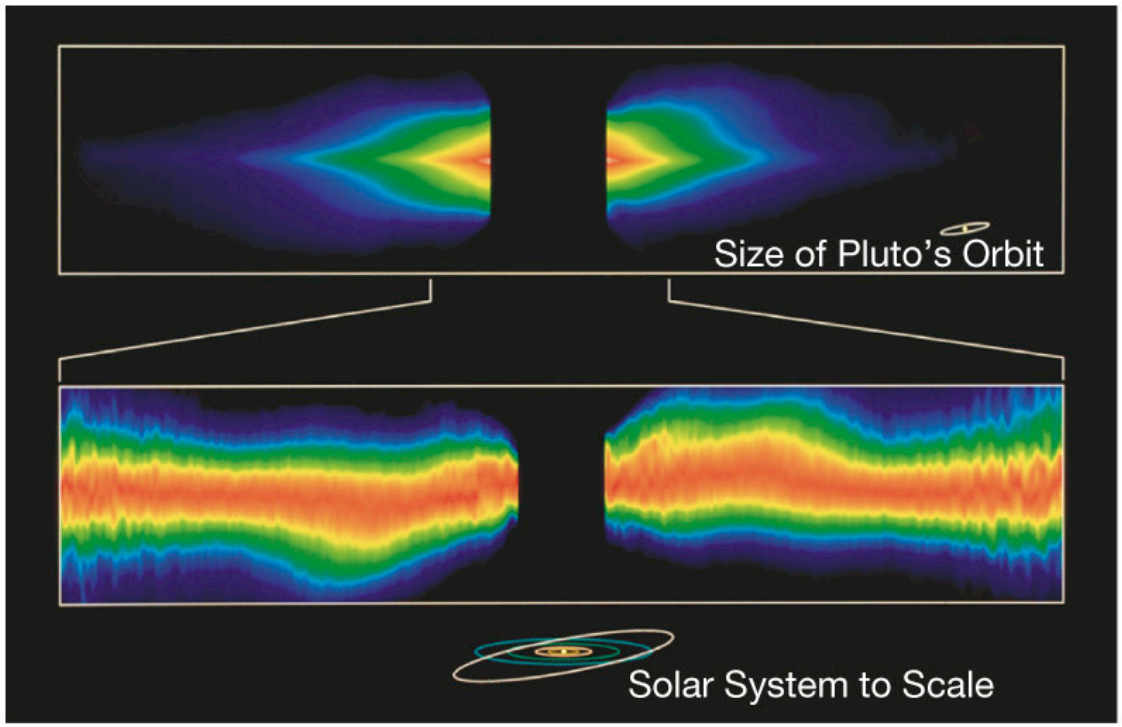

Axis of rotation
Approx. 1 light year
Axis of rotation
Rotation retards collapse in this direction
Slowly spinning interstellar cloud
Gravity makes cloud shrink. As it shrinks it spins faster and flattens into a disk with central bulge.
Approx. 100 AU
A
B

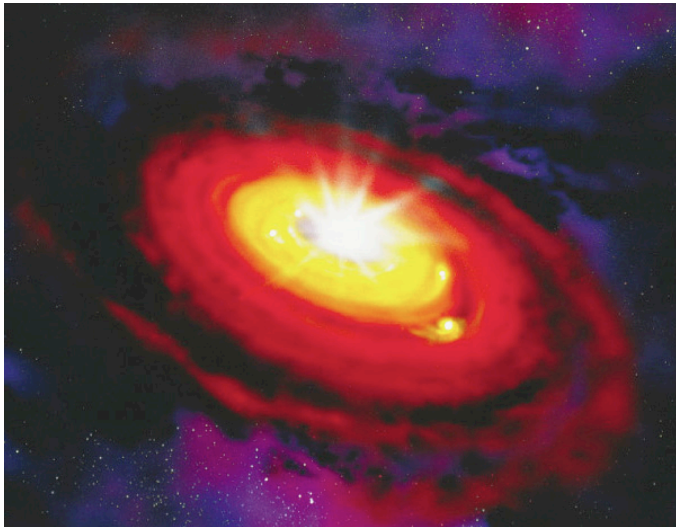
Protoplanetary Disks in Orion



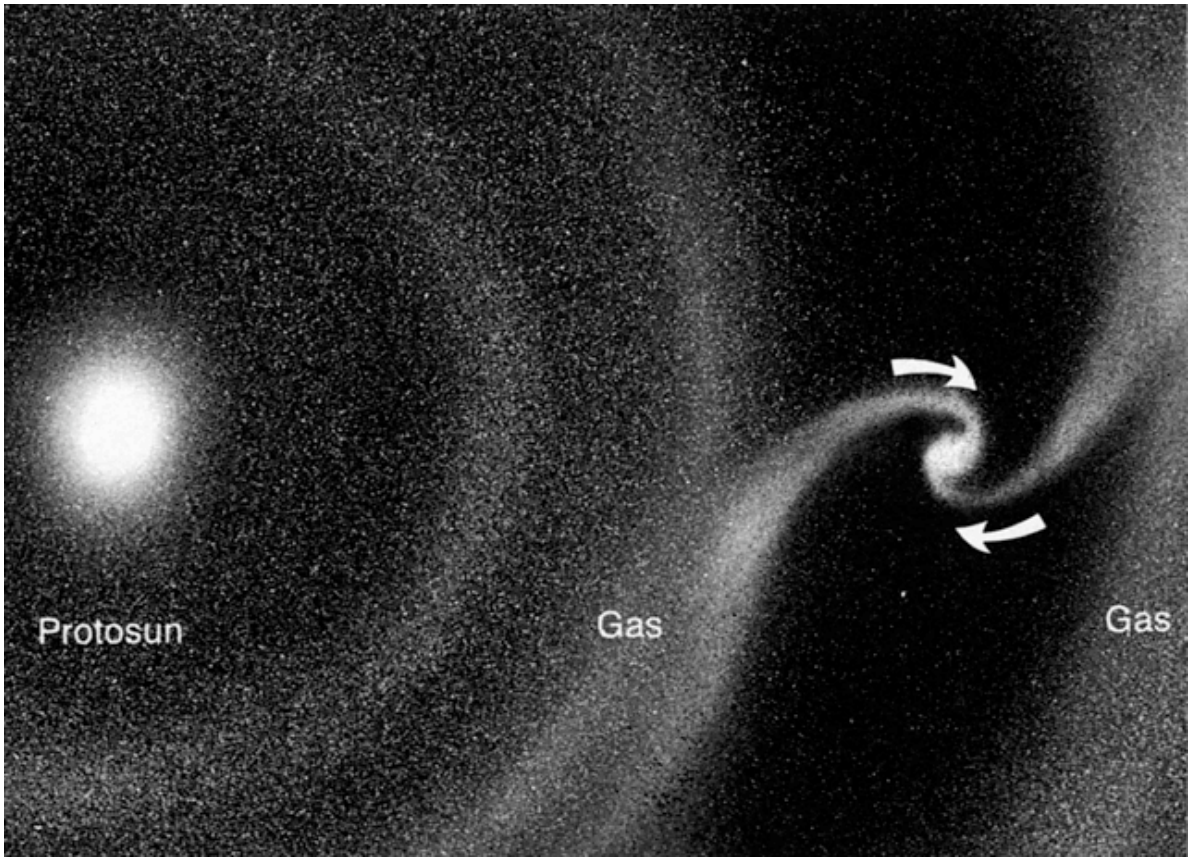


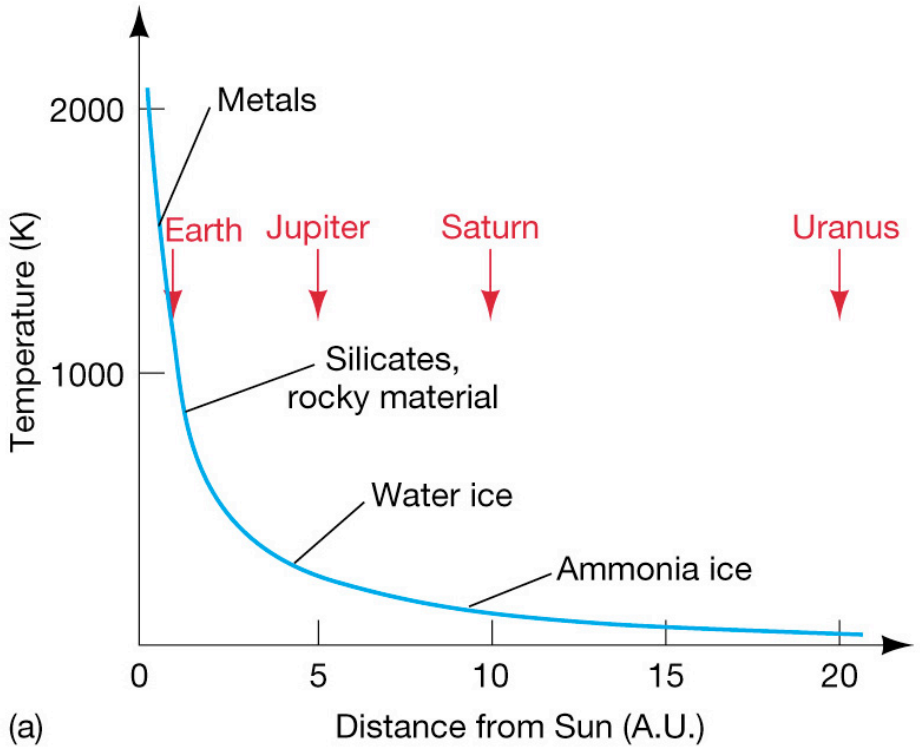
Disk of Beta Pictoris



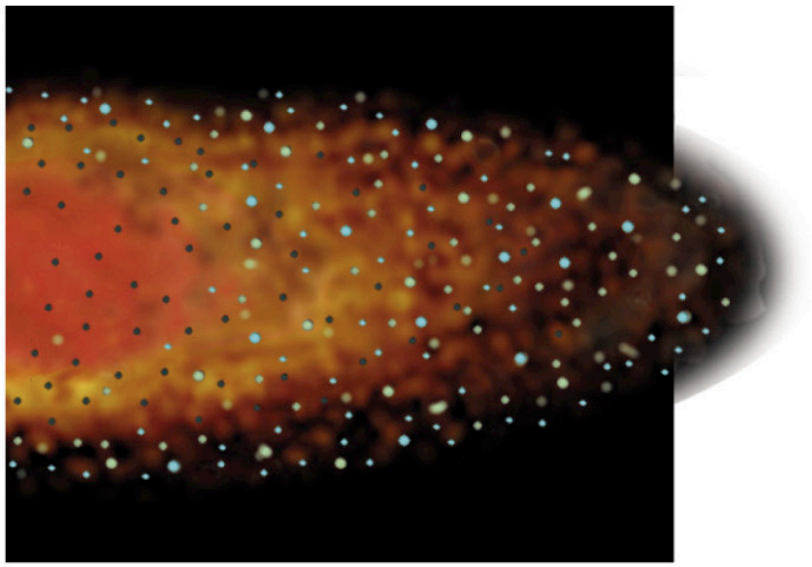


Whirlpools in protoplanetary disks




2000
1000
Temperature (K)
Metals
Earth
Jupiter
Saturn
Uranus
Silicates,
rocky material
Water ice
Ammonia ice
0
5
10
15
20
Distance from Sun (A.U.)

(a)



(b)

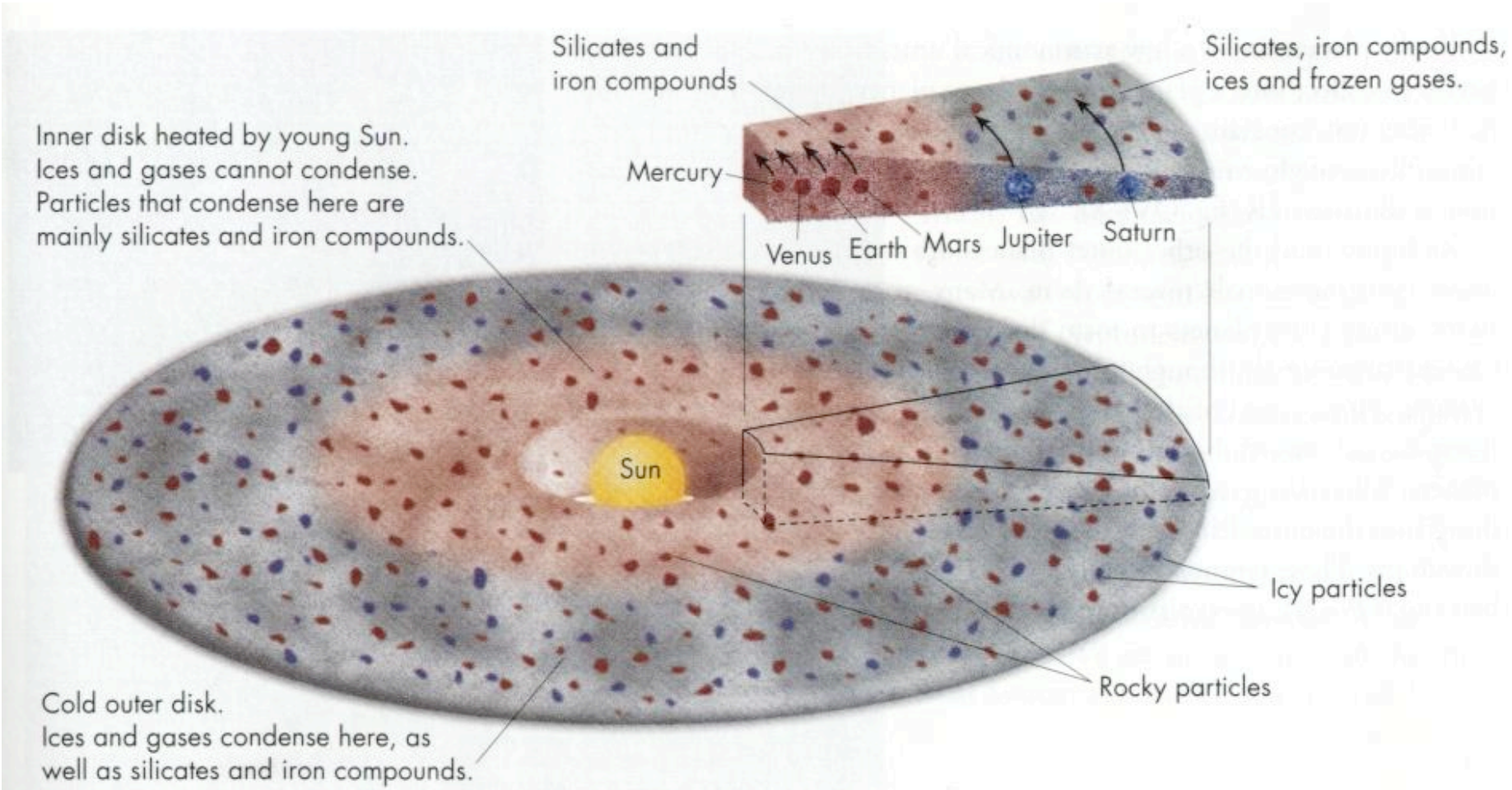
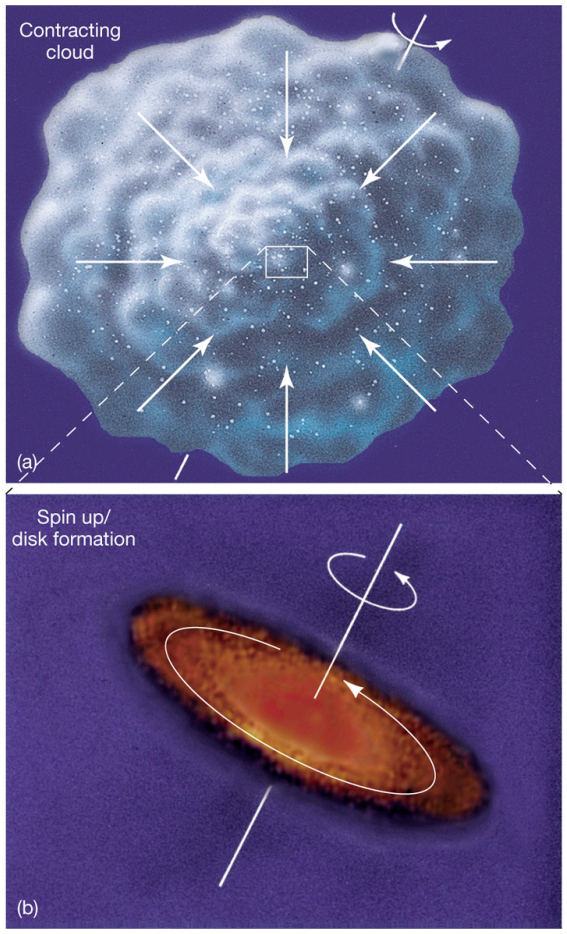


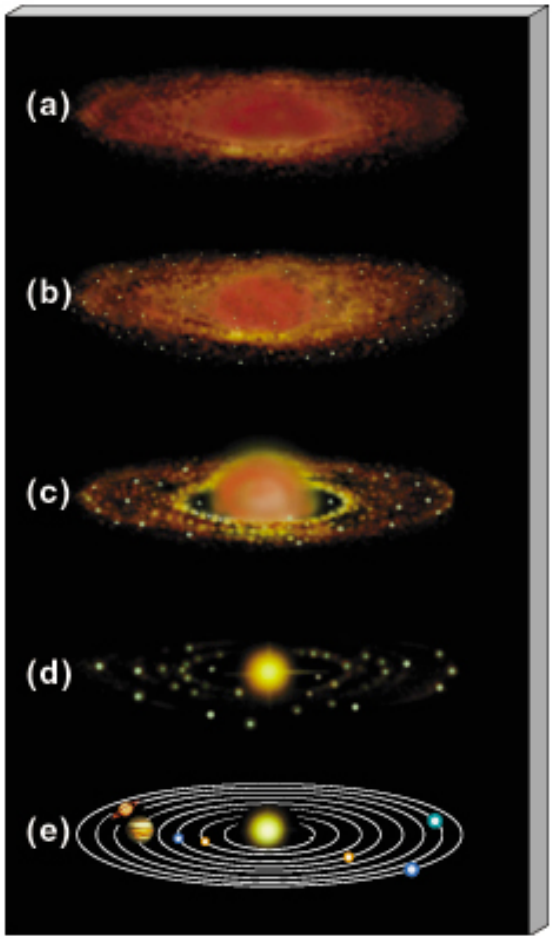
FIGURE OV4.6
Heat from the young Sun prevented ice from condensing in the inner parts of the Solar Nebula. The planetesimals—and ultimately the planets—that formed there are therefore composed mainly of rock and iron.

How long does it all take?

First stage of collapse

10^5 years





Entire process

10^8 years

Cf, lifetime of Sun and Solar System: 10^{10} years

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2. All orbits are nearly circular.
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5. Most (but not all) planets rotate in the same direction as the Sun does.
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7. There are pronounced differences between the inner and outer planets in many properties, such as masses, density/composition, moons, spacing, radii, presence of rings, and others ("differentiation" of the solar system).

A. Interstellar gas and dust cloud collapses to form a rotating disk.

B. Temperature gets higher closer to the center as the Sun forms.

C. Little whirlpools form in the disk.

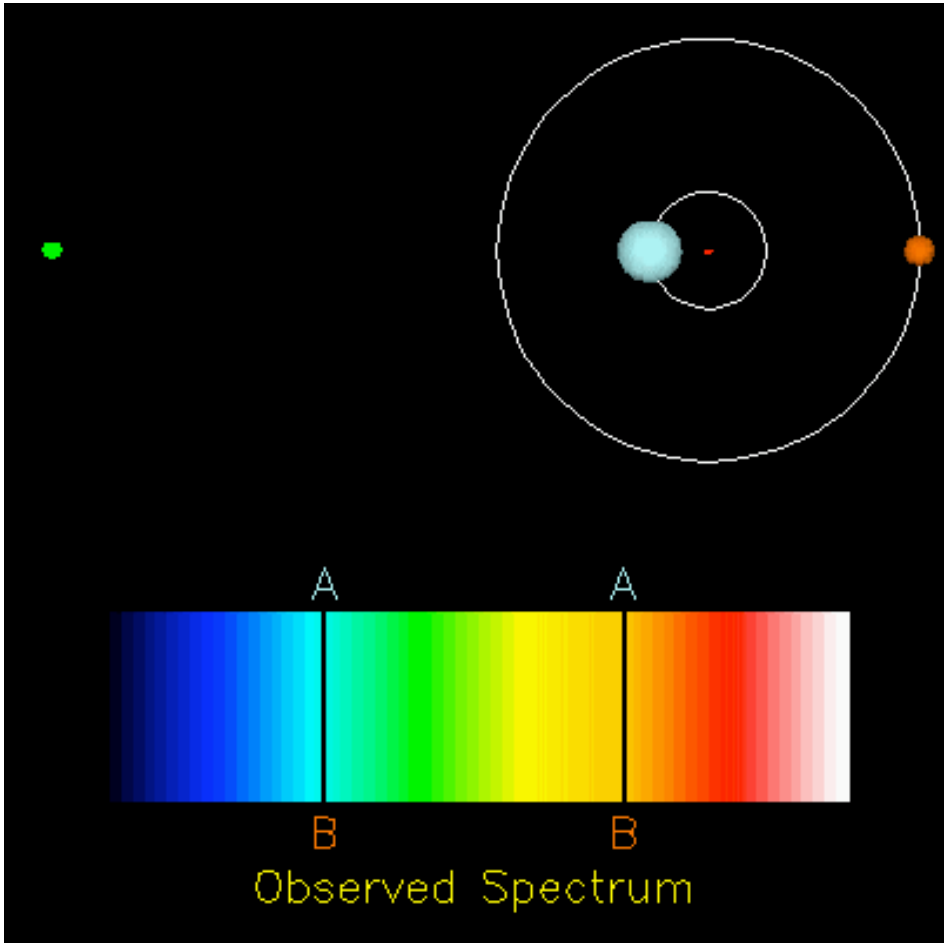
D. As the nebula cools, ices can form only far from the center. Rocks and metals can form close to the center as well as in the outer parts.

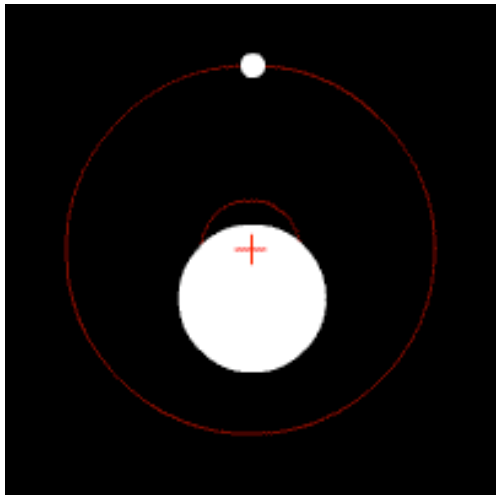
E. Collisions and gravity pull stuff together into planetesimals, which grow into protoplanets.

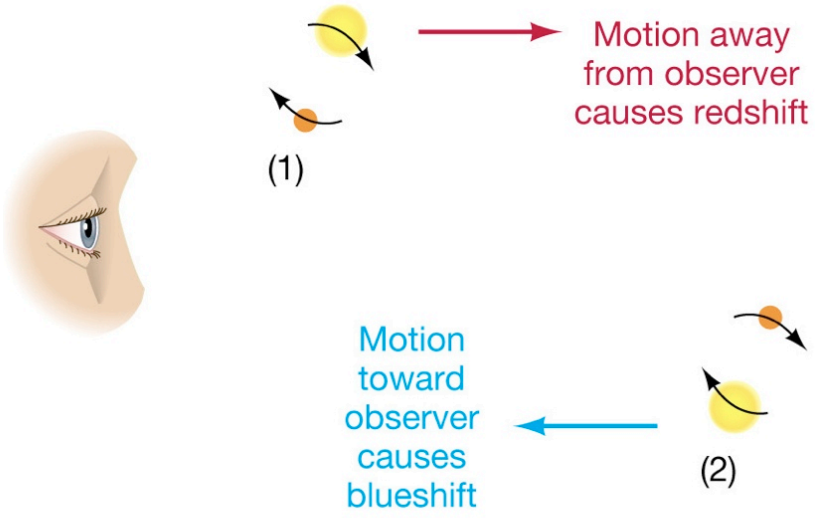
F. Cleanup phase.

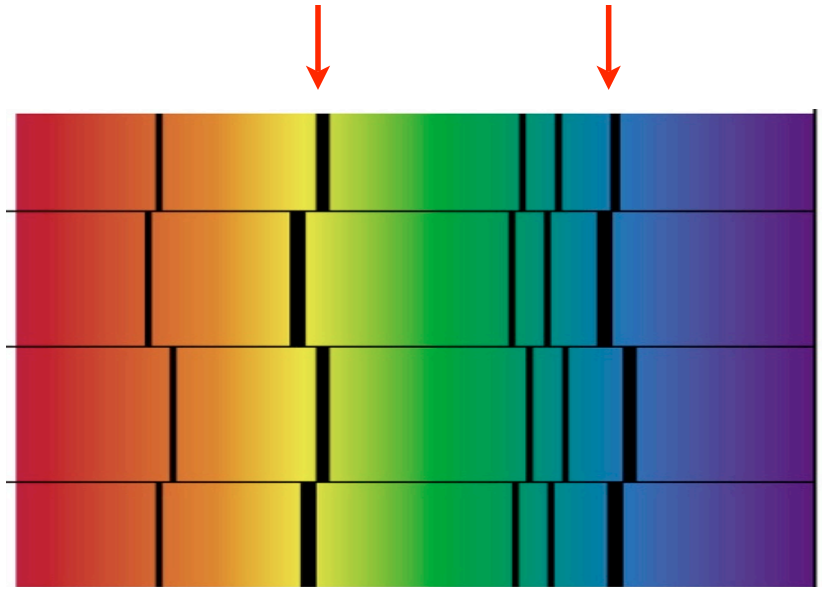
but this is really not the whole story...

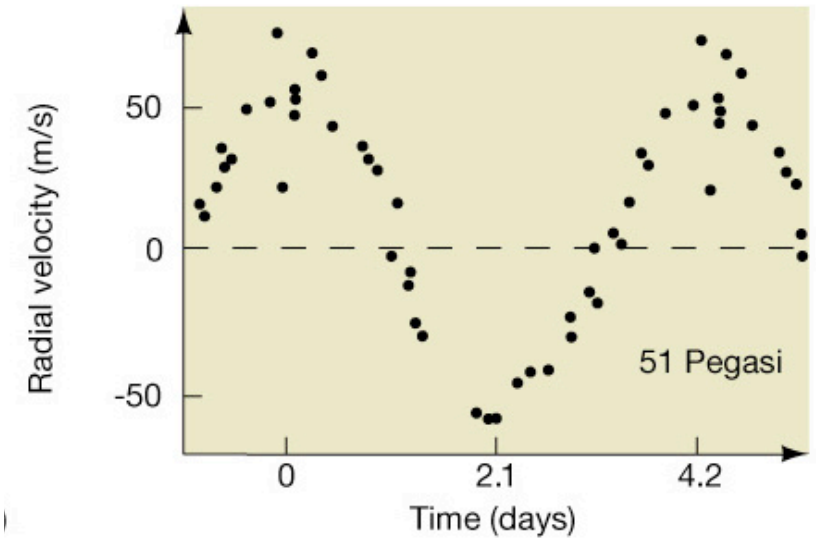
Extra-solar Planets ("Exoplanets")

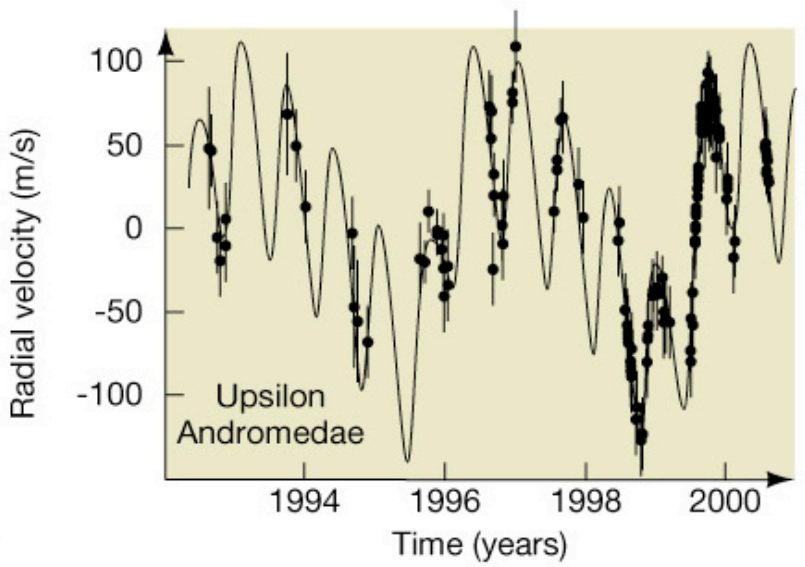

A
A
B
B
Observed Spectrum

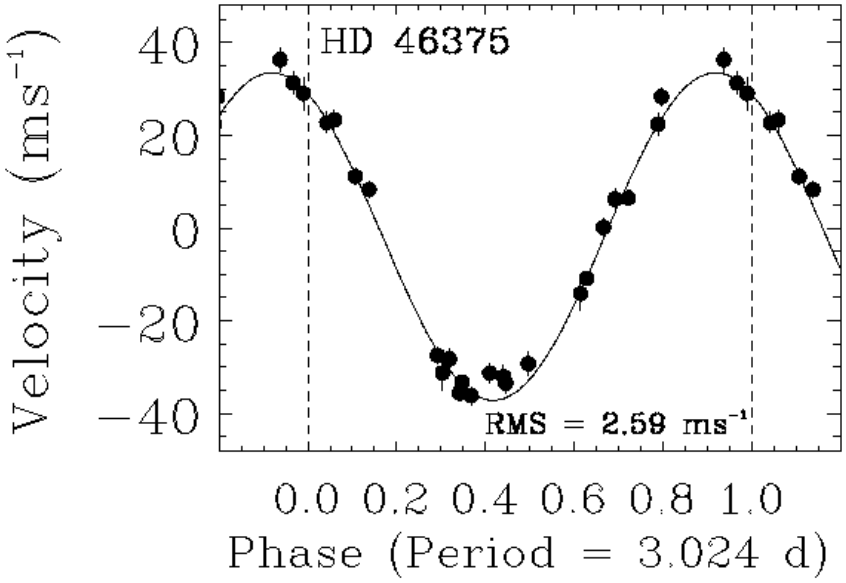


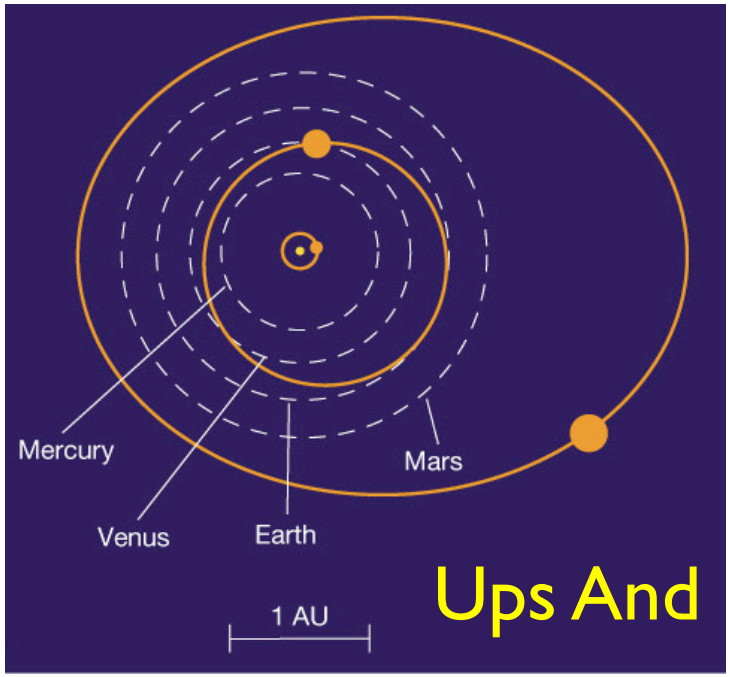

Motion away
from observer
causes redshift
(1)
Motion
toward
observer
causes
blueshift
(2)

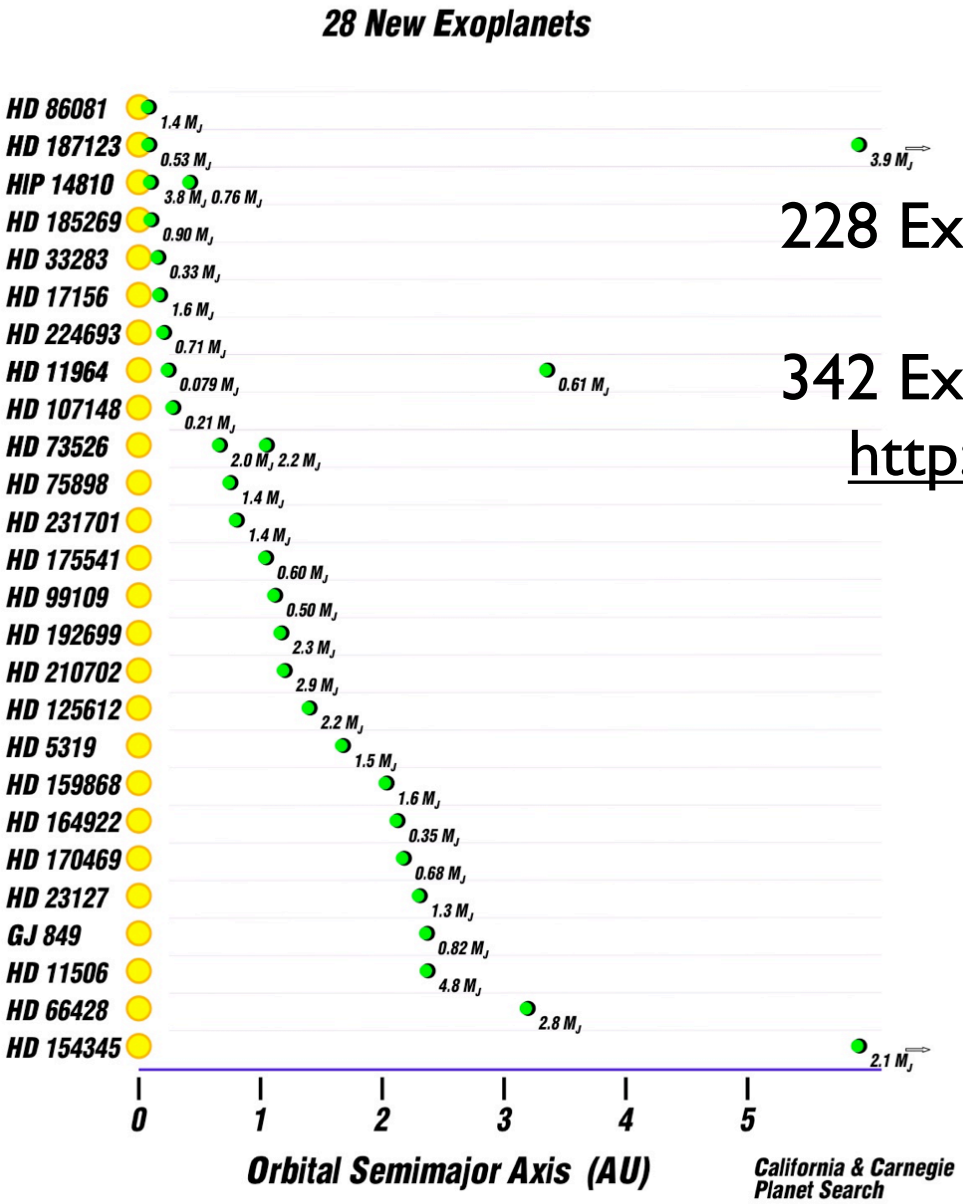



Radial velocity (m/s)
50
0
-50
51 Pegasi
0
2.1
4.2
Time (days)


Radial velocity (m/s)
100
50
0
-50
-100
Upsilon
Andromedae
1994
1996
1998
2000
Time (years)


Velocity (ms⁻¹)
40
20
0
−20
−40
HD 46375
RMS = 2.59 ms⁻¹
0.0 0.2 0.4 0.6 0.8 1.0
Phase (Period = 3.024 d)


Mercury
Venus
Earth
Mars
1 AU
Ups And



228 Extrasolar planets found so far
http://exoplanets.org
342 Extrasolar planets found so far
http://planetquest.jpl.nasa.gov/

smallest extrasolar planets known:
6-8 Earth masses

("super-Earths")

The missing ingredient from the planet formation scenario: Planetary Migration