ASTR 150

- Homework 2 due Monday
  - Office hour today
- Planetarium shows this week
- Next Monday/ Wednesday no lectures
  - Time for asteroid lab
- Last time: Asteroids and Comets
- Today: Solar System Formation

Music: *Fly Away* – Lenny Kravitz

Comets: Who's Who

Recall--two comet groups: Kuiper belt, Oort cloud

Q: how are these different?

Kuiper Belt

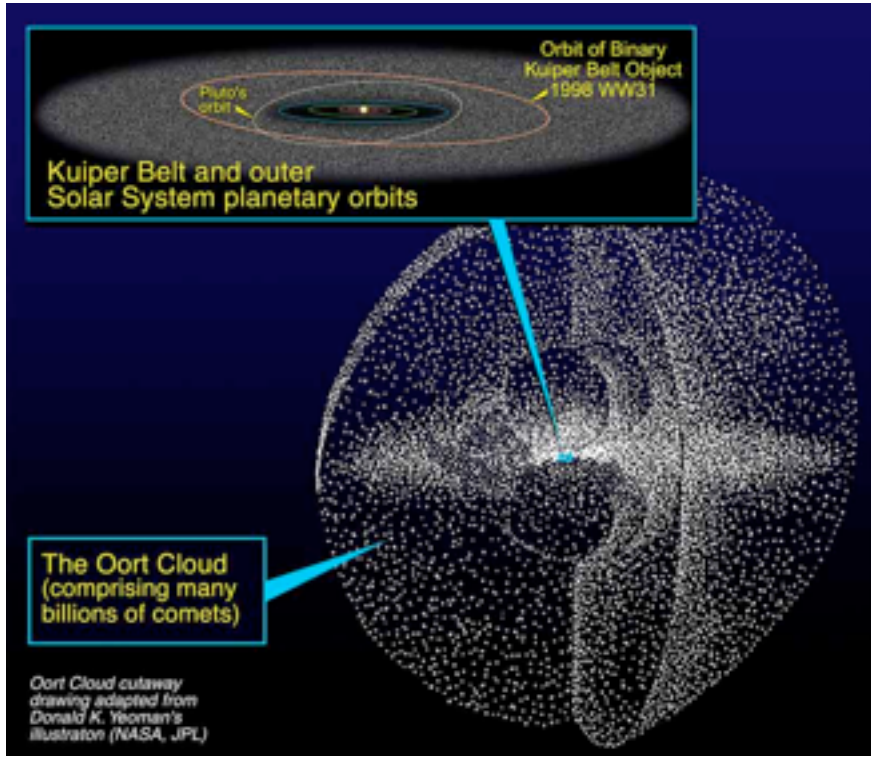
- **short periods < 200 years**

  can see repeatedly over written history, predict return visits
- **distances 30-100 AU = just beyond Neptune**
- **orbits directions mostly same as planets, but eccentricities larger (ellipses more elongated)**
- **orbit planes mostly near Earth-Sun orbit plane (Ecliptic) though somewhat tilted**

Oort Cloud

- **long periods up to million years**

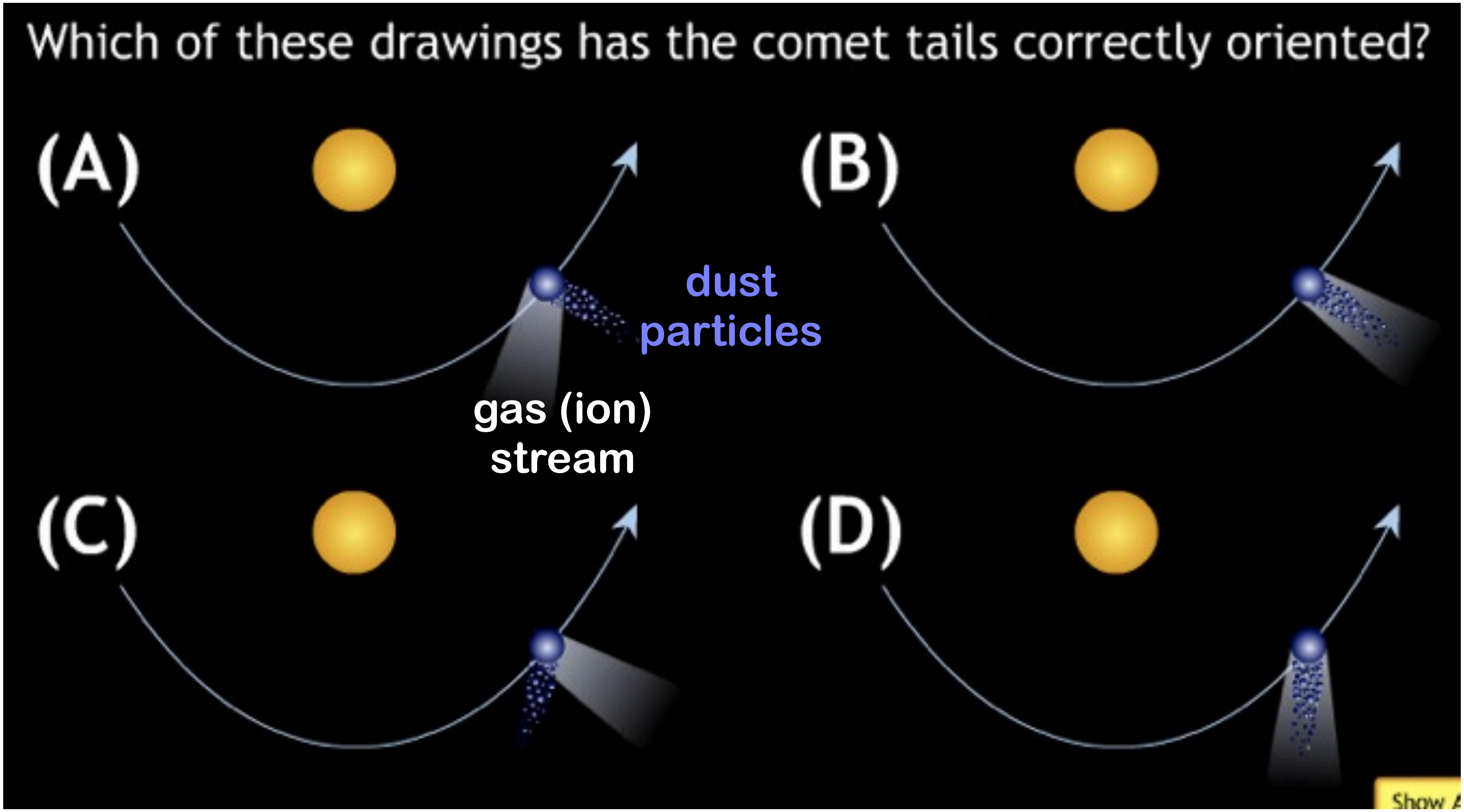
  no record of last visits, cannot predict new visits
- **distances up to 100,000 AU: edge of Solar System!**
- **orbit directions and planes randomly oriented**



We will want to understand these differences!

Also note: until 20 years ago, both Kuiper Belt and Oort Cloud hypothetical--guessed they exist to supply the comets that visit the inner solar system

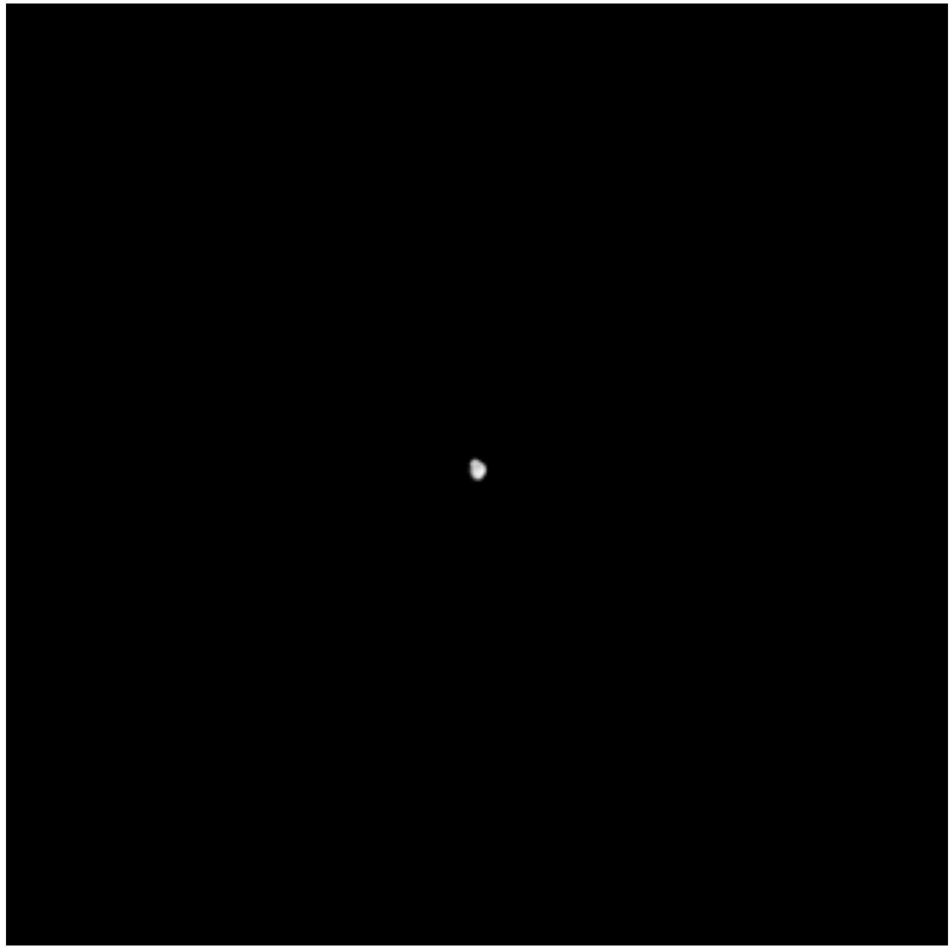
iClicker Poll



Answer C

Deep Impact

- On July 4, 2005, NASA sent part of the Deep Impact probe on a collision course with Comet Tempel 1



Deep Impact

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- Material excavated by the impact contained more dust and less ice than had been expected

Initial results were surprising. The material excavated by the impact contained more dust and less ice than had been expected.
In addition, the material was finer than expected; scientists likened it to talcum powder rather than sand.
Analysis of data from the Swift X-ray telescope showed that the comet continued outgassing from the impact for 13 days, with a peak five days after impact.
A total of 250,000 tonnes of water was lost.

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Deep Impact: The Movie

Movie trailer for Deep Impact

After many orbits, a comet can break up completely, as Comet 73P did in 2006

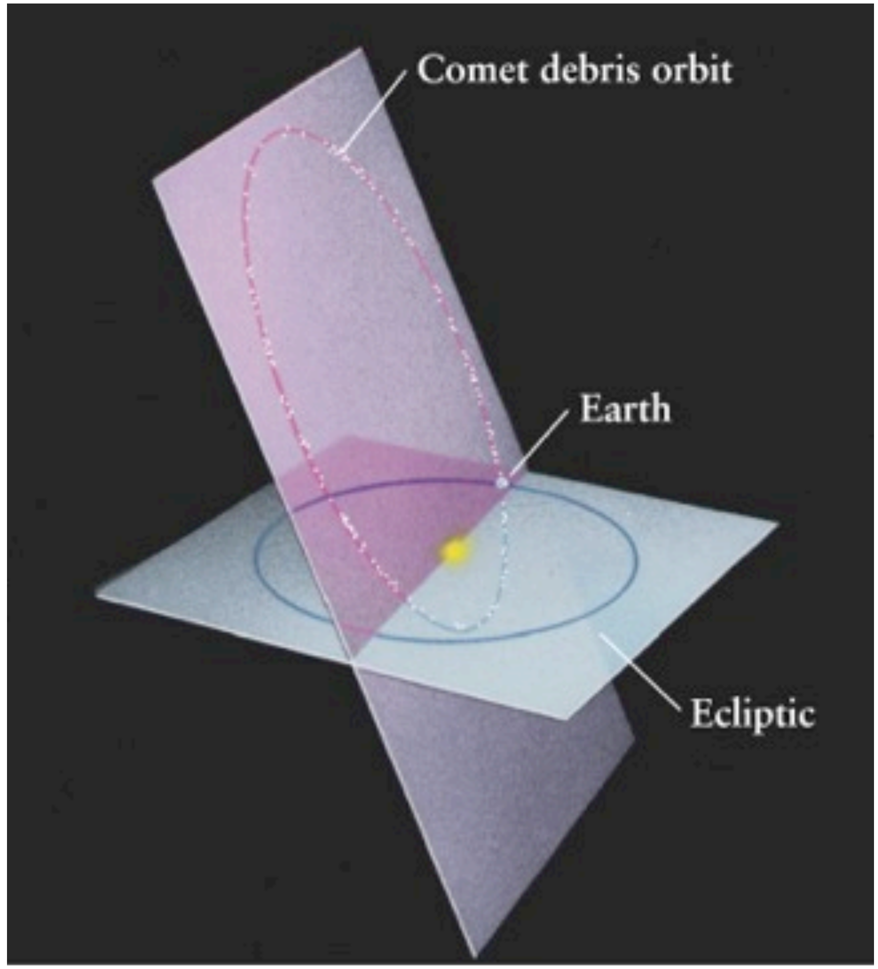
Comet debris produces meteor showers

Over time a comet leaves trail of dust along its orbit

Comets lose mass every orbit

If the Earth passes through the comet's orbit, we pass through dust, get a meteor shower

Since Earth crosses the comet orbit every year, meteor showers are periodic, annual events



Lets Make a Comet!

Ingredients:

- 2 cups water, 2 cups dry ice, 2 spoonfuls of sand, a dash of ammonia, and a dash of organic material (dark corn syrup)

http://www.youtube.com/watch?v=tYc25Jt5RSk

Where are These Rocks From?

Asteroids

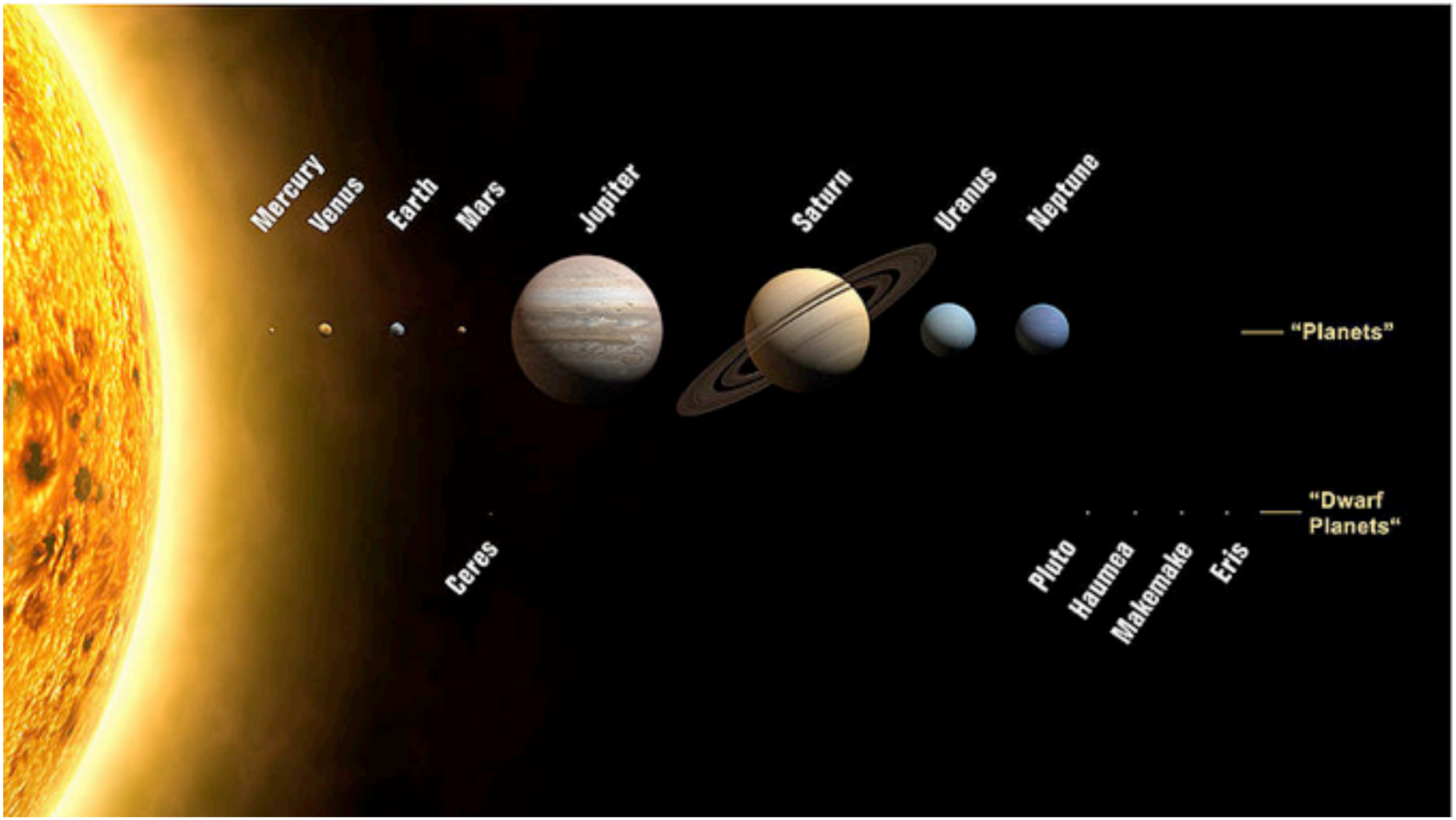
Meteoroids

Comets

… yes, but why are they so old and where are they from?

step back, look at the bigger picture

Our Solar System



Sizes to scale, distances NOT to scale

The solar system is our home in the universe. As humans are an intelligent species, we have the right and the responsibility to wonder what we are. Our kind has inhabited this solar system for at least a million years. However, only within the last hundred years have we begun to understand what a solar system is. Today we know Solar system has: 1 star, 8 planets, 5 dwarf planets, 139+ moons, countless small solar system bodies. Let's study the planets, comparing them to one another, looking for patterns among the planets. Studying other worlds in this way tells us about our own Earth.

What features of our solar system provide clues to how it formed?

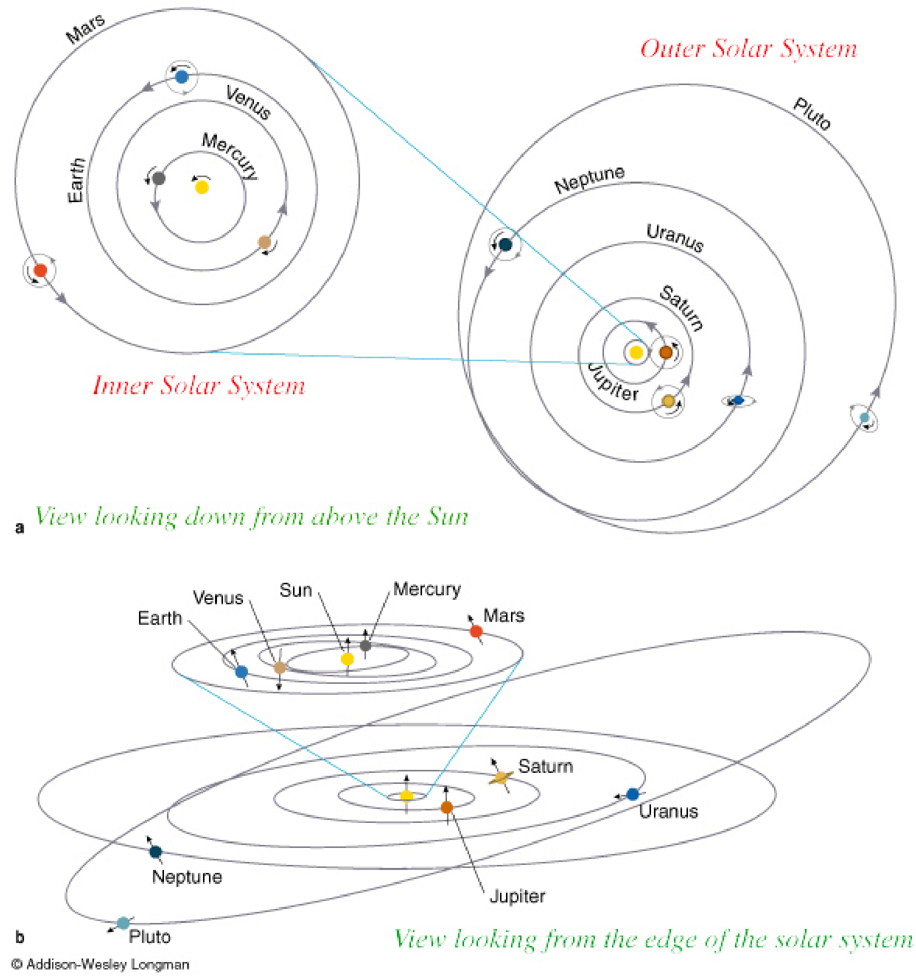
1. Patterns of Motion
2. Two Types of Planets
3. Asteroids and Comets

Clue 1.
Patterns of Motion

Kepler I:

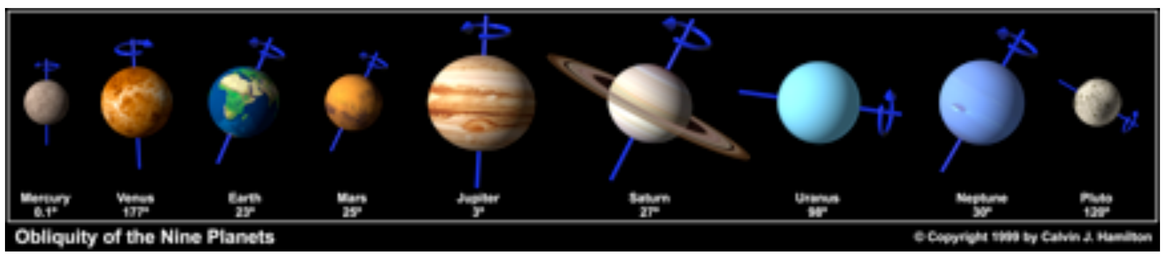
every object moves around Sun in ellipse: every orbit lies in a plane

Earth orbit plane: "Ecliptic"



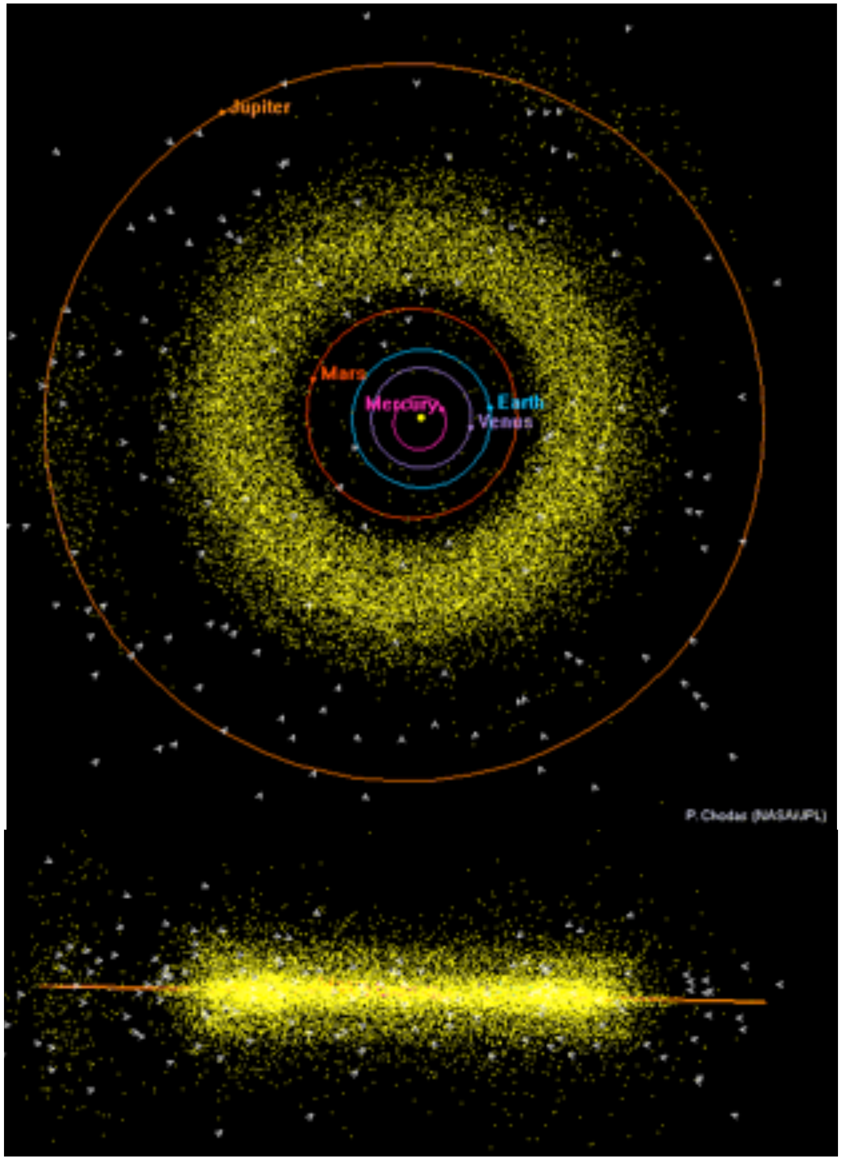
Key fact I:
all large bodies in the solar system orbit in the same direction and in nearly the same plane

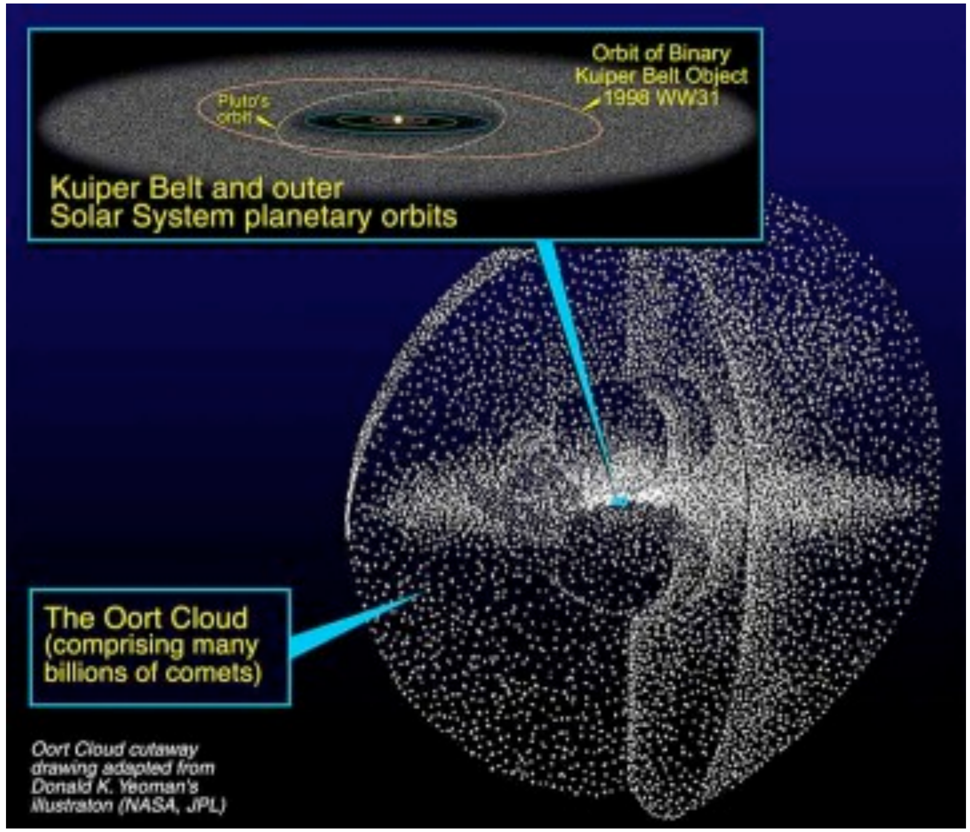
Key fact II:
Spins are almost all in the same direction, which is also the same sense as the orbits



Sun rotates counter-clockwise. All the planets orbit the Sun counter-clockwise. Most planets rotate counter-clockwise (except Venus, Uranus, and Pluto). Most large moons orbit their planets in the direction their planet rotates (except Triton of Neptune).

Asteroid and Comet Orbits





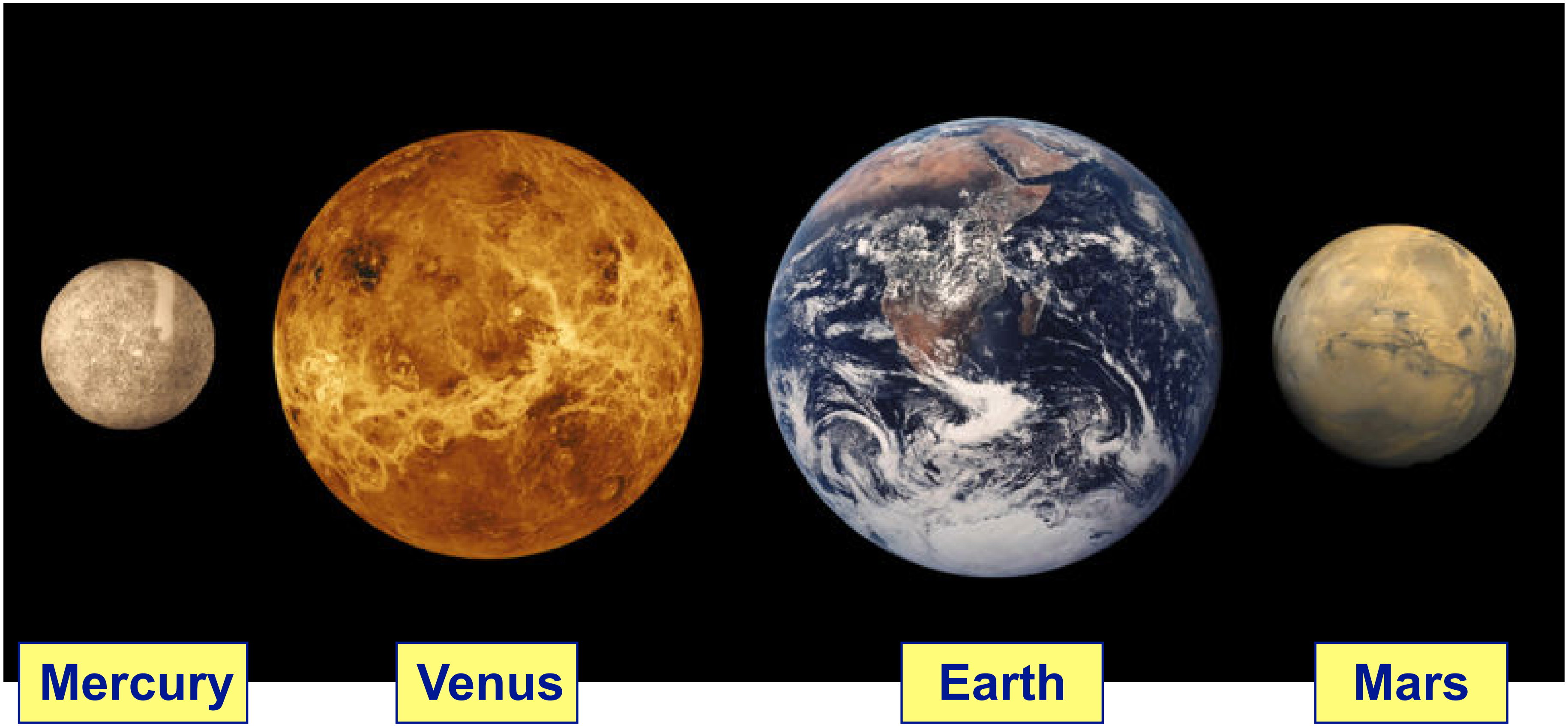
~150,000 asteroids have been charted
Most orbit in a belt between Mars and Jupiter
~3,000 on orbits that bring them into the inner solar system
Asteroids orbit in a thick disk

Clue 2.
Two Types of Planets

Terrestrial Planets	*Jovian Planets*
Smaller size and mass	Larger size and mass
Higher density	Lower density
Made mostly of rock and metal	Made mostly of hydrogen, helium, and hydrogen compounds
Solid surface	No solid surface
Few (if any) moons and no rings	Rings and many moons
Closer to the Sun (and closer together), with warmer surfaces	Farther from the Sun (and farther apart), with cool temperatures at cloud tops

Terrestrials (or rocky planets): Closest to the Sun, Largely composed of rock
Mercury, Venus, Earth and Mars
Jovians (or gas giants): Further from the Sun, Planets largely made up of gaseous material, Much more massive than terrestrials, All have many moons & rings
Jupiter, Saturn, Uranus, and Neptune

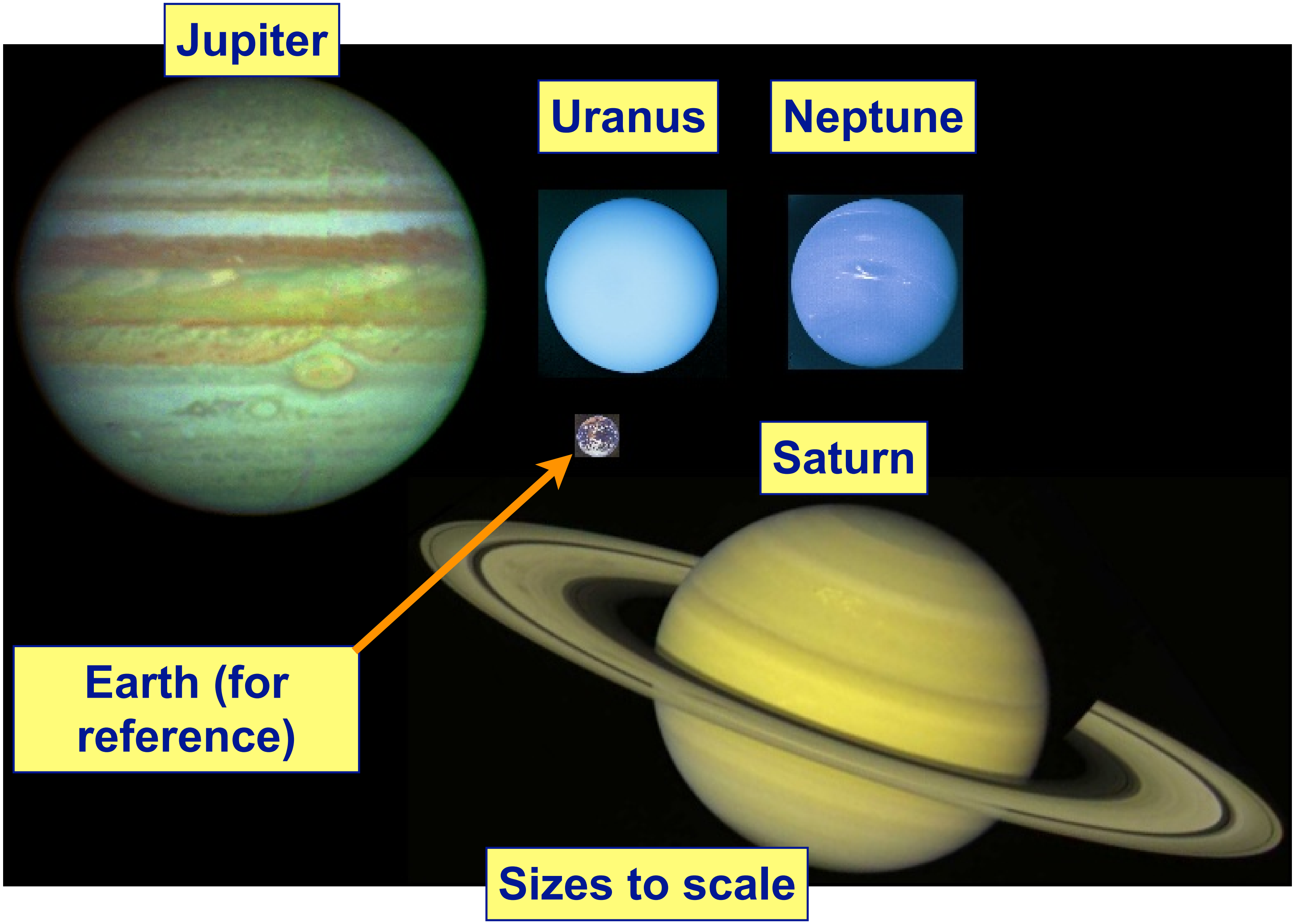
The Terrestrials: Earth-Like



Sizes to scale
Distances are not!

Small size
Low Mass
Higher density
Mostly rock
Few, if any moons, no rings

The Jovians: Jupiter-Like



Large size
Massive
Low density
Mostly gas
All have many moons and rings

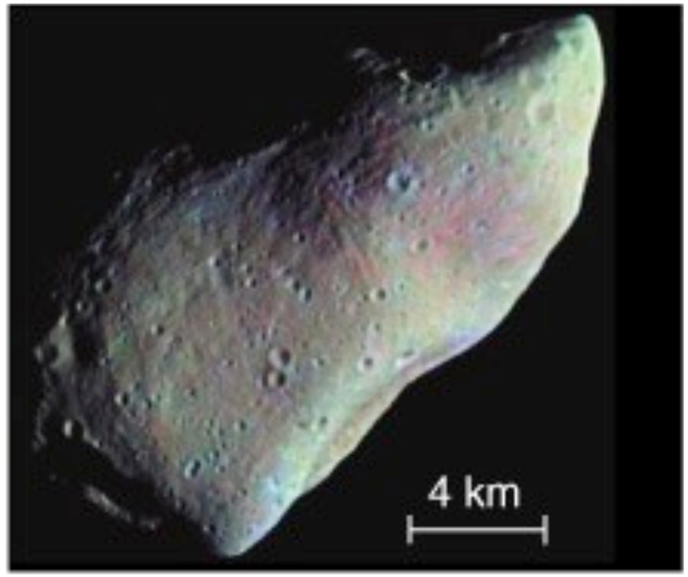
Clue 3.
Debris: Asteroids and Comets

Two types of small solar system bodies

- Rocky asteroids between Mars & Jupiter
- Icy objects in vicinity of Neptune and beyond-- a few visit us as comets

Far outnumber the planets and their moons

But they are NOT most of the mass



Another clue:
Age of the Solar System

Earth:
- oldest rocks are 4.4 billion yrs

Moon:
- oldest rocks are 4.5 billion yrs

Mars:
- oldest rocks are 4.5 billion yrs

Meteorites:
- oldest are 4.6 billion yrs

Age of Solar System is probably around
4.6 billion years old

Origin of the Solar System: Building A Theory

These patterns cry out for explanation!

Want to organize, and explain in a scientific way

Building a Scientific Model

How? the test of all scientific knowledge is observation.

- Experiment is the final judge of scientific truth.

If experiment is the Judge, then the Court is the Scientific Method:

observation & experiment → tentative model

→ predictions → further experiment

→ refined model → repeat ↑

end product: theory

Building Theories

Scientific Models must:

- explain observations
- predict future observations
- change or even be abandoned if in conflict with any observations

"The scientific method is a way of finding what works.

The first principle is that you must not fool yourself–and you are the easiest person to fool."

--Richard Feynman

A Theory for the Origin of the Solar System

Inputs: Data and Laws

- data: observed patterns in the Solar System
  - motions, planet types, debris types
- laws of nature
  - like F=ma
  - discovered (mostly) in labs on Earth

Output: Model

- sequence of events, predictions for evolution up to present
- allows us to construct a “story of what happened”
- makes predictions for new observations

The Early Days

We’ll come back to this, but the Universe is around 13.8 billion years old.

3 minutes after the big bang(we’ll come back to this), the Universe was mostly hydrogen (75% by mass) and helium (25%) with no heavy elements

Making Heavy Elements

The first stars were born and died.

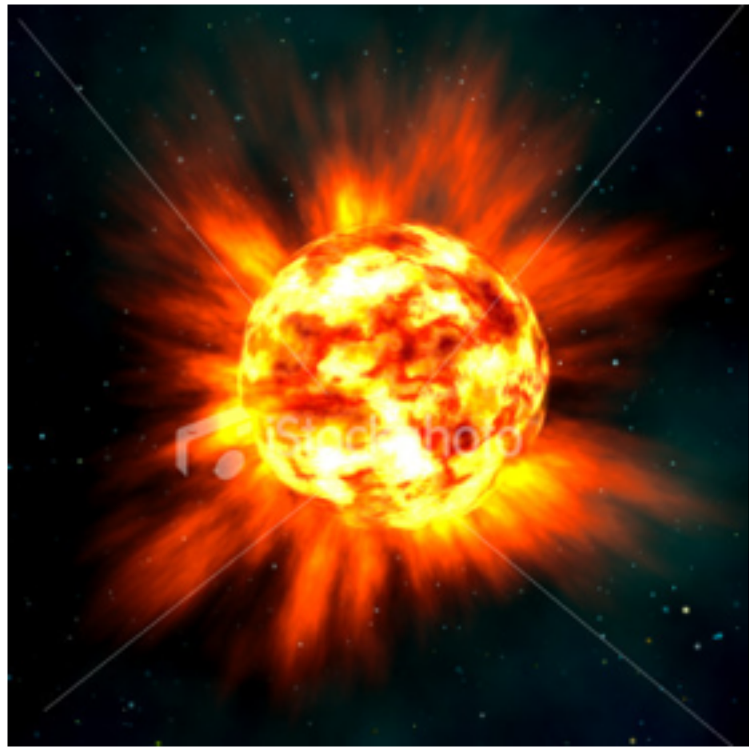
When a massive star dies, it goes supernova and explodes. (We'll come back to this.)

When it does this, the elements forged during its life enrich space.

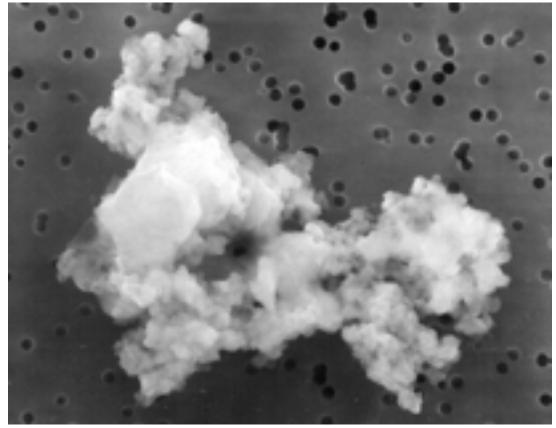
Supernovae provide much of the building blocks for planets… and us!

We are recycled supernova debris!

We are Star stuff.



The Stuff Between the Stars:
The Interstellar Medium



microscope image of interplanetary dust
http://apod.nasa.gov/apod/ap010813.html

Interstellar space is not empty!

There is stuff between the stars in a galaxy!

- Very dilute (less dense than best lab vacuum)
- Mostly gas (98% of mass), of which most is hydrogen
- But 2% is microscopic solid bodies: "dust"

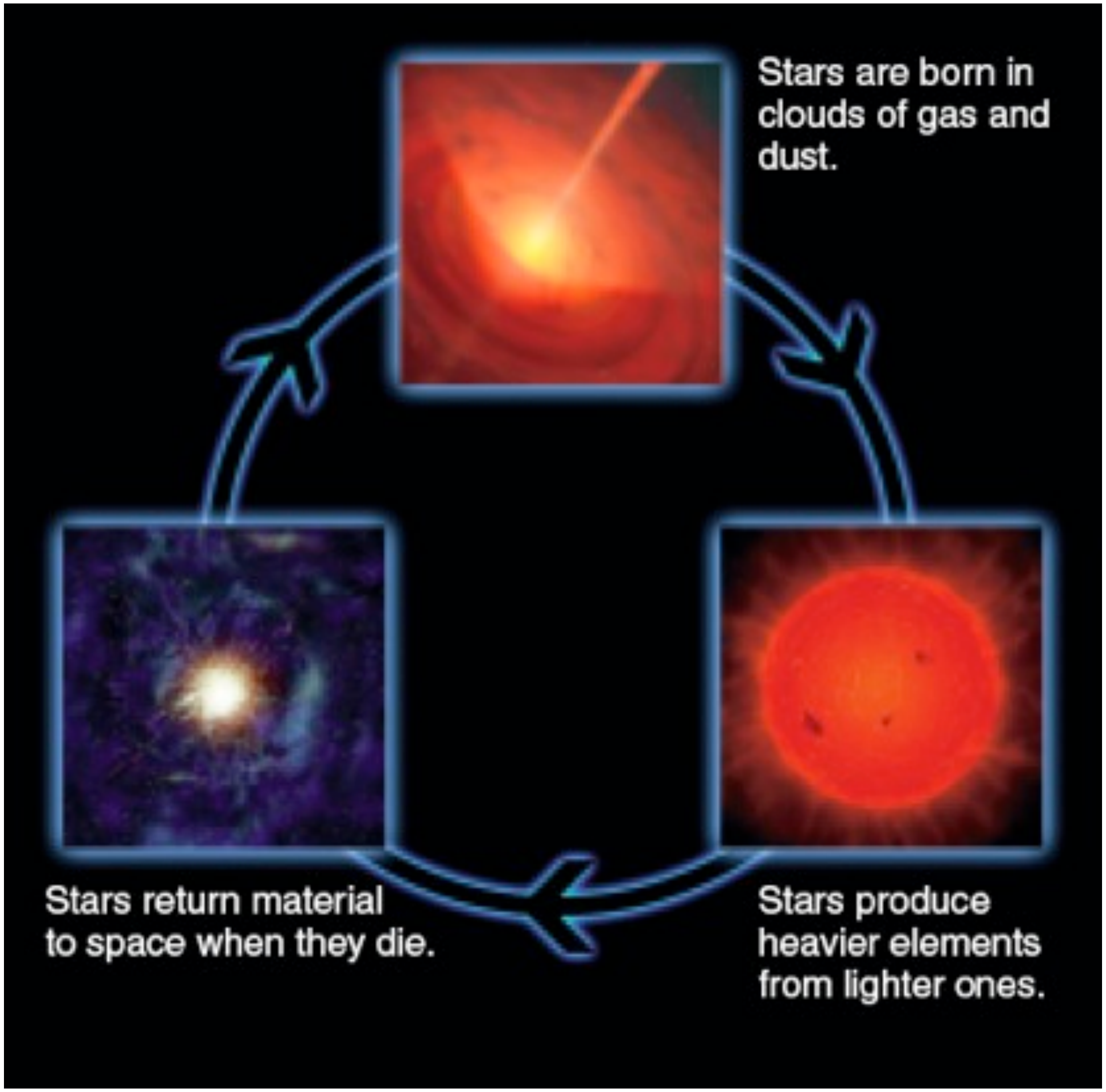
Every star and planet, and maybe the molecules that led to life, were formed in the dust and gas of clouds.

Exists as either

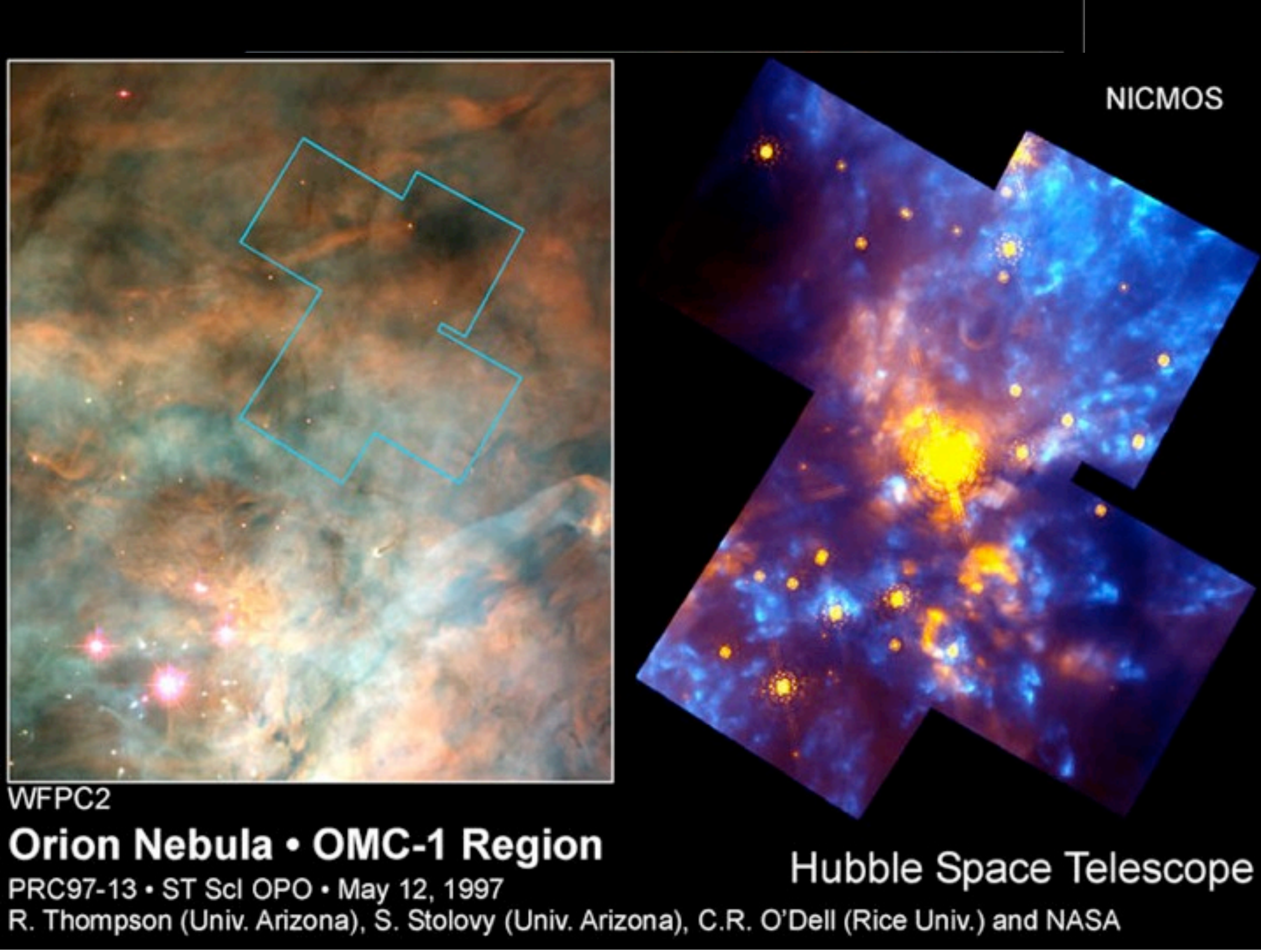
- Diffuse Interstellar Clouds
- Molecular Clouds

Keyhole Nebula

Where did the solar nebula come from?



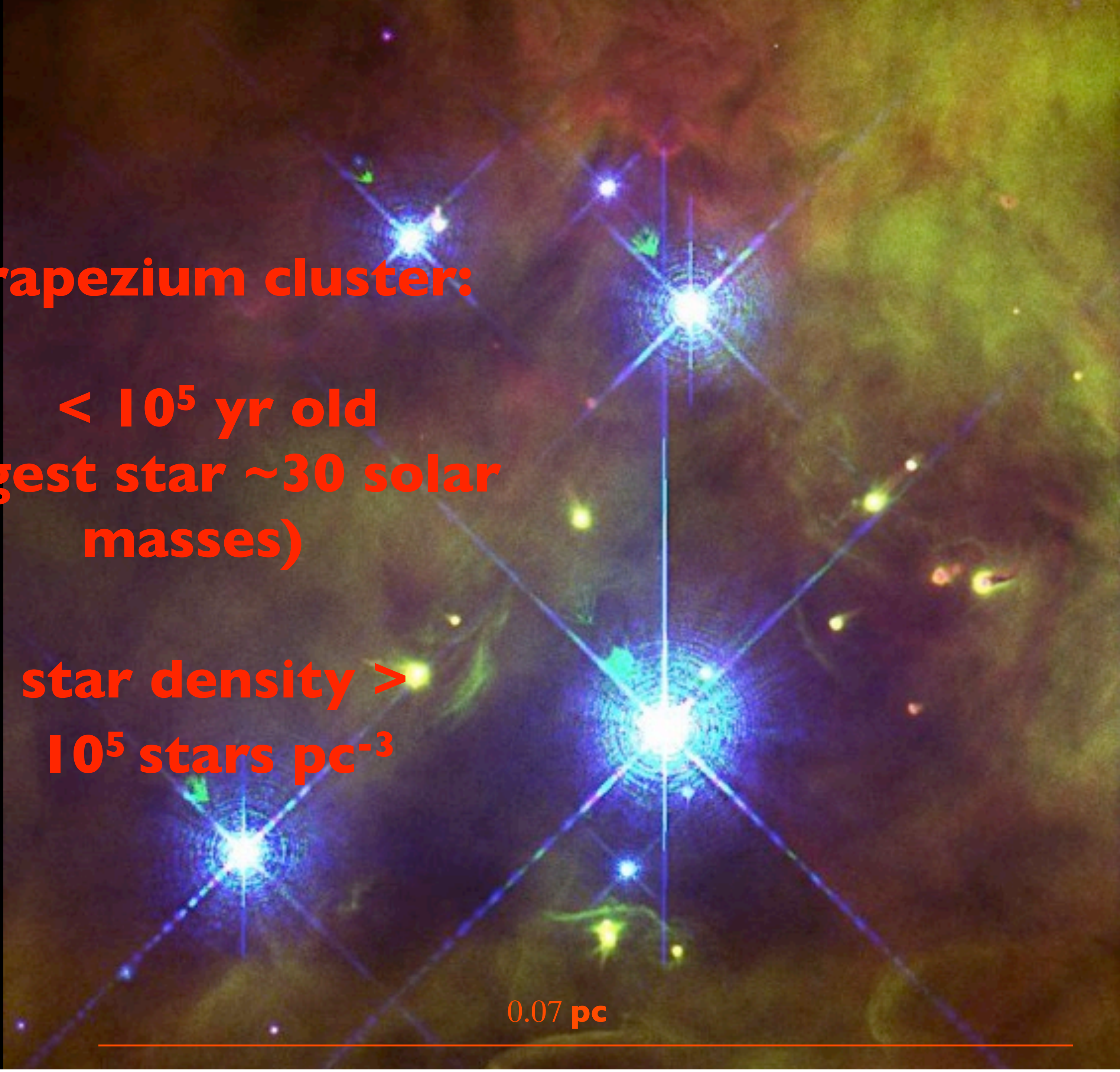
The cloud of gas that gave birth to our solar system resulted from the recycling of gas through many generations of stars within our galaxy


NICMOS
WFPC2
Orion Nebula • OMC-1 Region
Hubble Space Telescope
PRC97-13 • ST ScI OPO • May 12, 1997
R. Thompson (Univ. Arizona), S. Stolovy (Univ. Arizona), C.R. O'Dell (Rice Univ.) and NASA

Trapezium cluster:

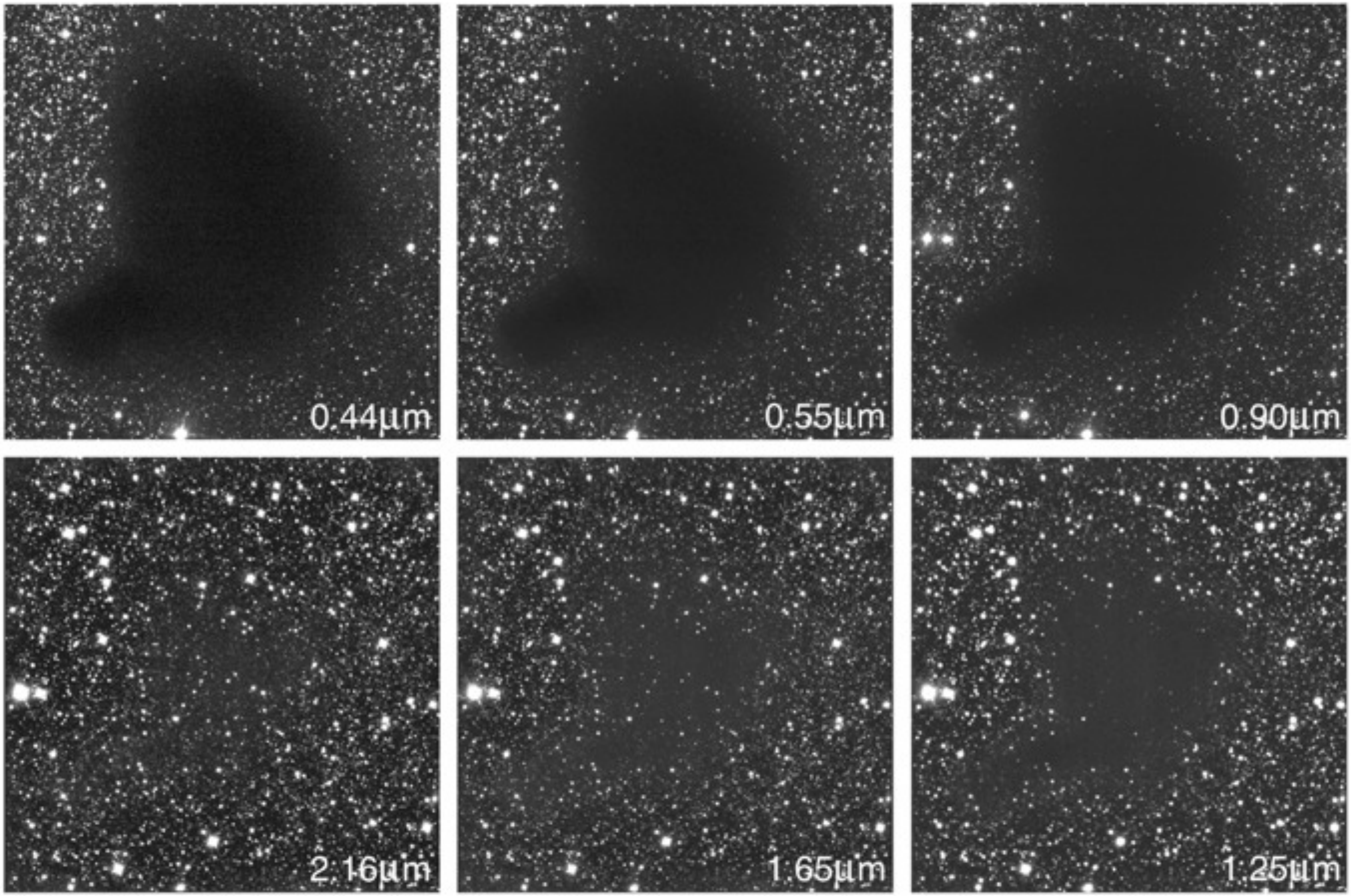
< 10^5 yr old
(largest star ~30 solar masses)

star density > 10^5 stars pc^{-3}



Molecular Clouds

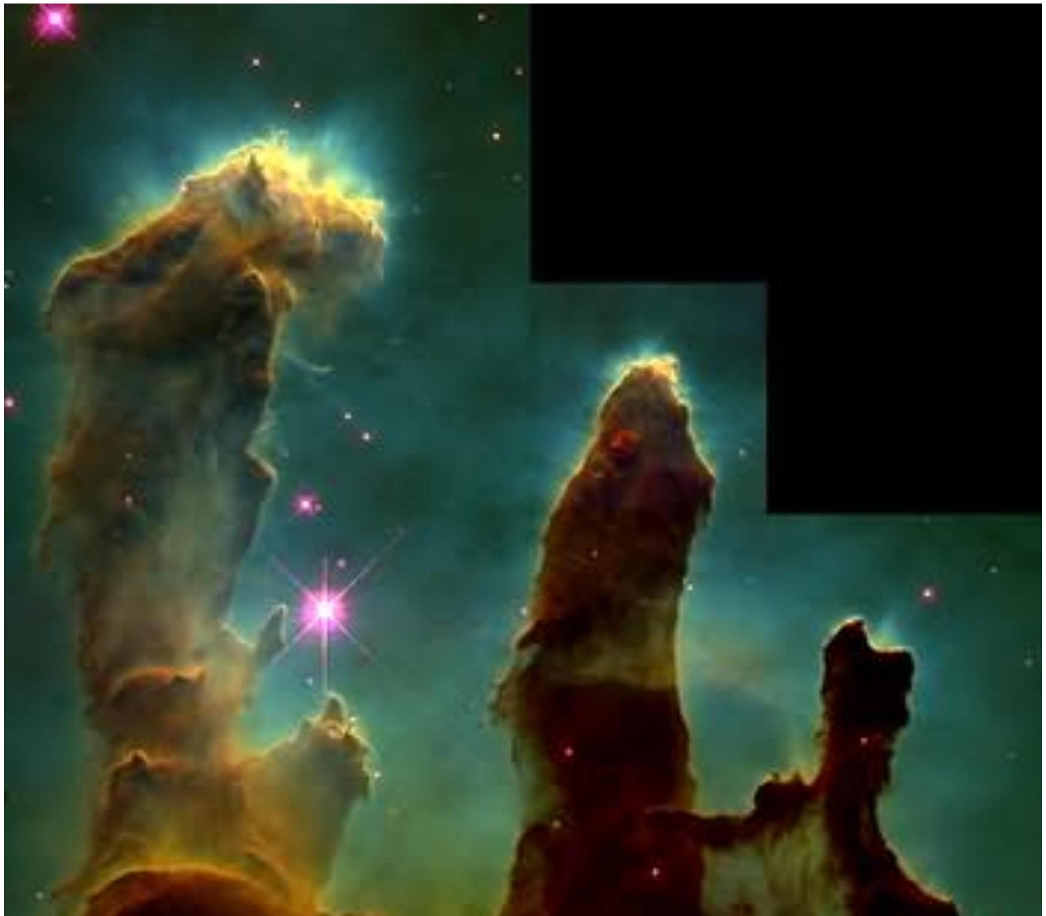
We see spiral galaxy NGC 891 nearly edge-on



The Dark Cloud B68 at Different Wavelengths (NTT + SOFI)

ESO PR Photo 29b/99 (2 July 1999)

What theory best explains the features of our solar system?



The Eagle Nebula, a cloud in which stars are forming

solar nebula theory
our solar system formed from a **giant, gently spinning cloud** of interstellar gas and dust

(nebula = cloud)

iClicker Poll: Gravity and Cloud Compression

consider a cold cloud begins at rest

but then compressed by its own gravity

without losing or gaining mass

for each point in the cloud

How does the gravity force change after compression?

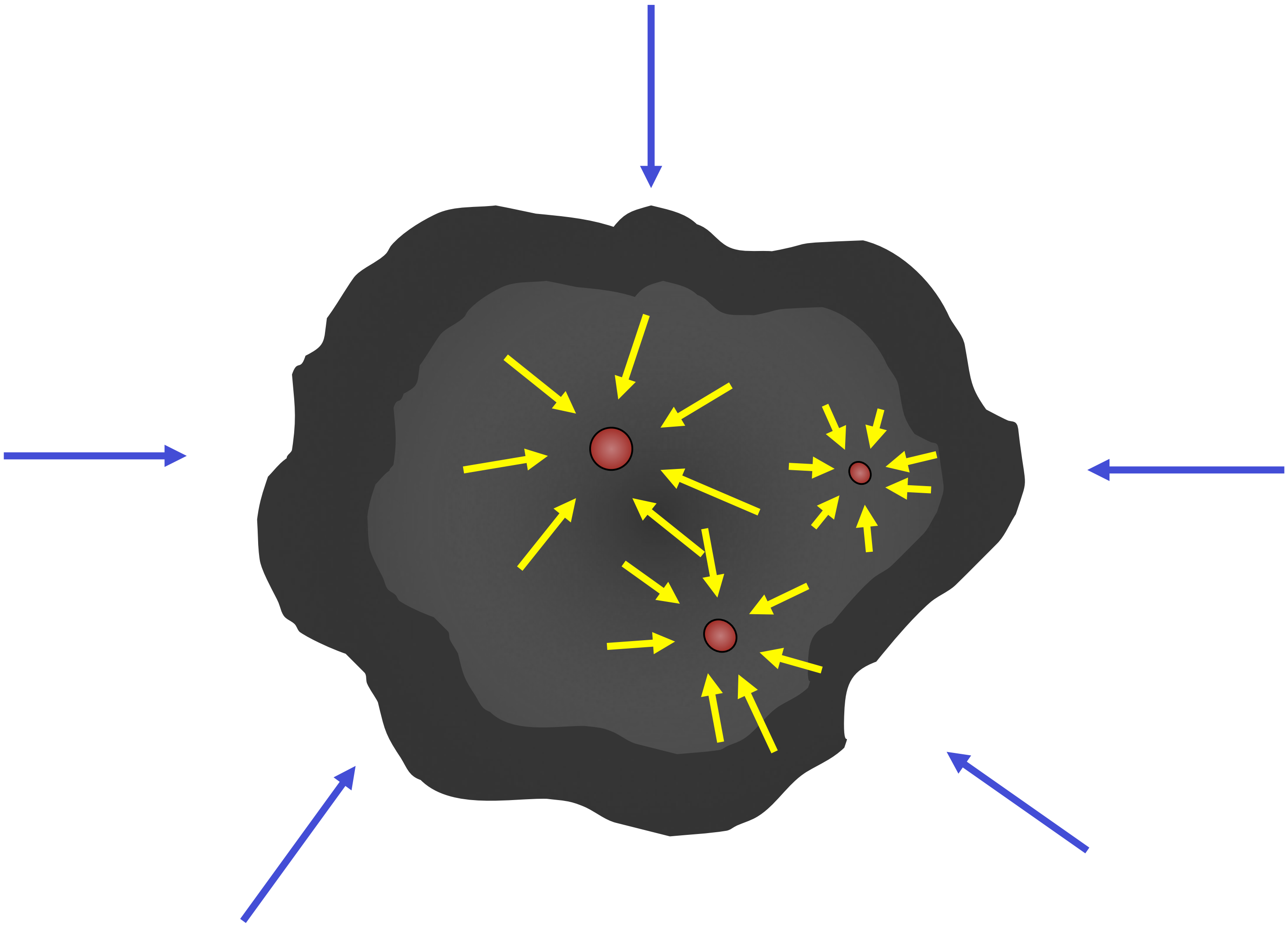
A. gravity force weaker

B. gravity force same

C. gravity force stronger

Q: and so what eventually happens?

Gravitational Contraction



Gravitational Contraction

- The gravity of the gas and dust clumps pushes the cloud together, but there is some resistance from pressure and magnetic fields to collapse.
- Probably as the cloud core collapses, it fragments into blobs that collapse into individual stars.
- Cloud becomes denser and denser until gravity wins, and the clumps collapse under their own mass– a protostar = a baby star = “embryo” of Sun

But..

- Not all mass falls in directly (radially). Why?

- All gas has a small spin that preferentially causes the formation of a flattened structure
  - time for an interlude.

http://homepages.igrin.co.nz/moerewa/Pages/

Interlude: Angular Momentum

Spinning or orbiting objects in closed system have angular momentum.

$$\text{ang. mom.} = \begin{pmatrix} \text{orbit} \\ \text{speed} \end{pmatrix} \times \begin{pmatrix} \text{distance} \\ \text{to orbit axis} \end{pmatrix}$$

Angular momentum is a single, constant number = conserved!

Keep same dist. to axis → speed same

Move closer to axis → speed up!