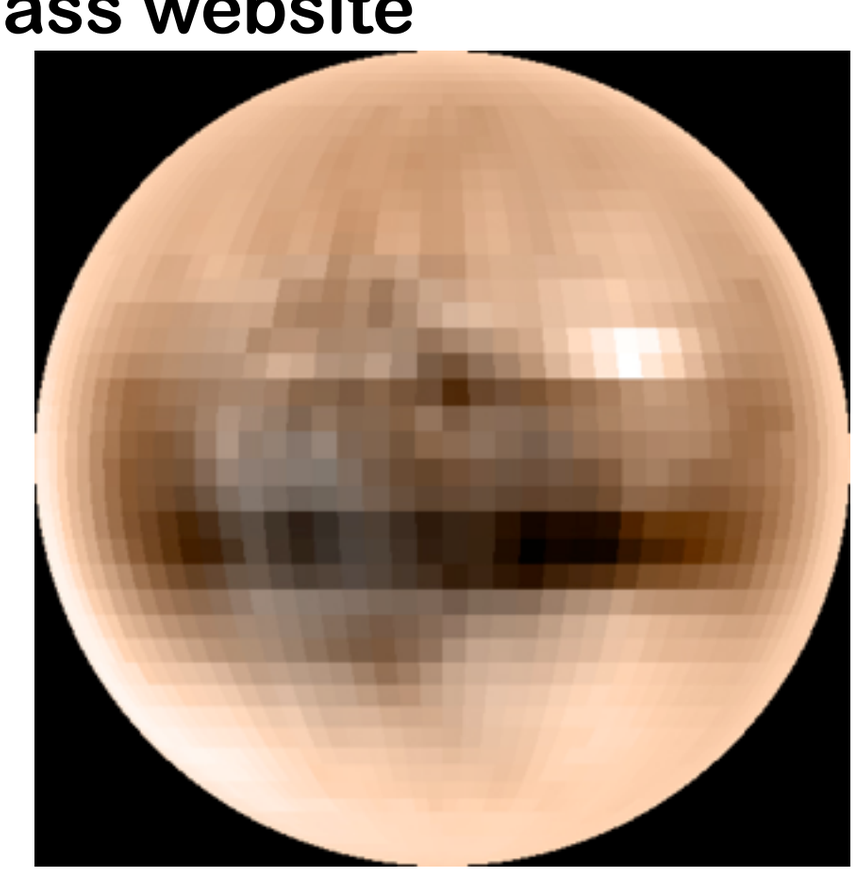
Astronomy 150: Killer Skies
Lecture 7, February 1

Last time: Asteroids and Comets

Today: Pluto; Origin of the Solar System

Assignments:

- HW 2 due Friday at 1pm
  - Office hours after class today
- Planetarium shows this week and next; info and reservations on class website



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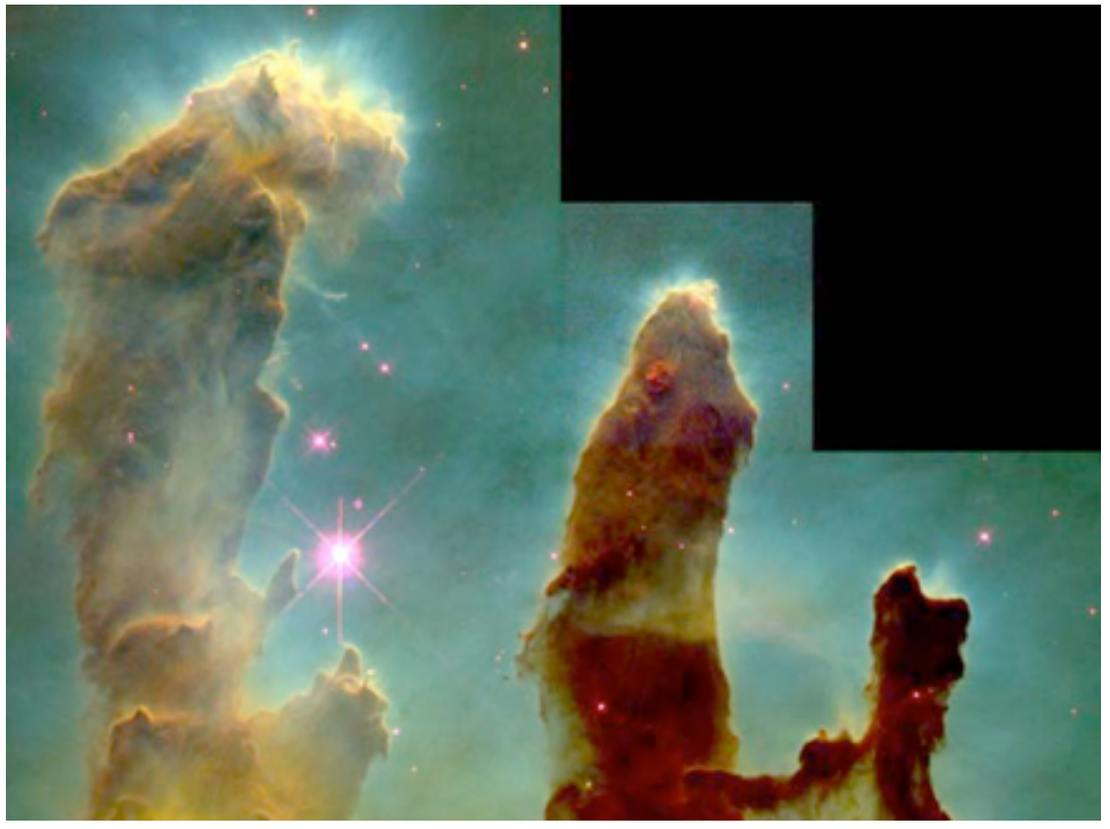

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Comets: Who's Who

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

Q: how are these different?

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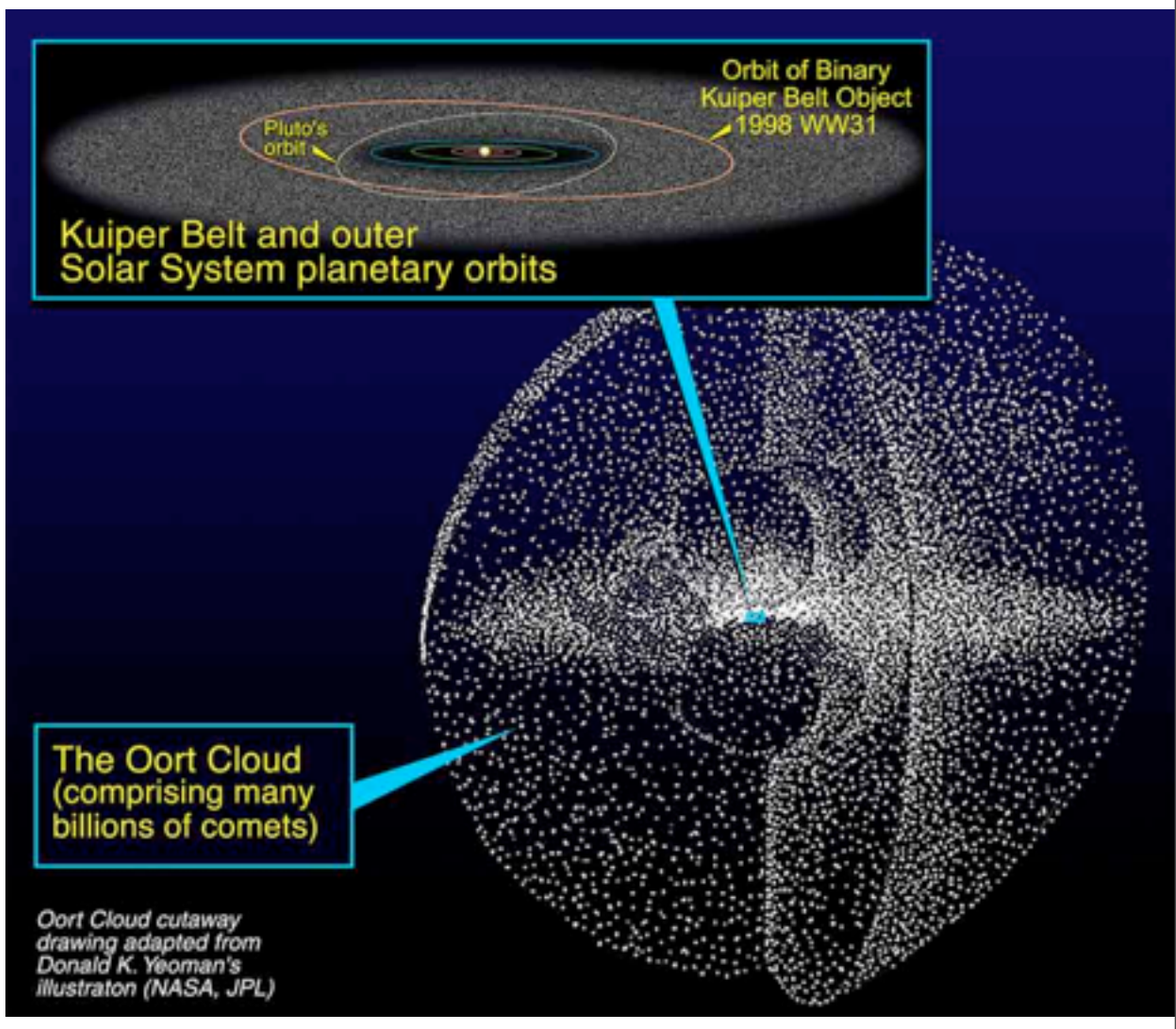
Kuiper Belt

- **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 (Eclptic) though somewhat tilted**



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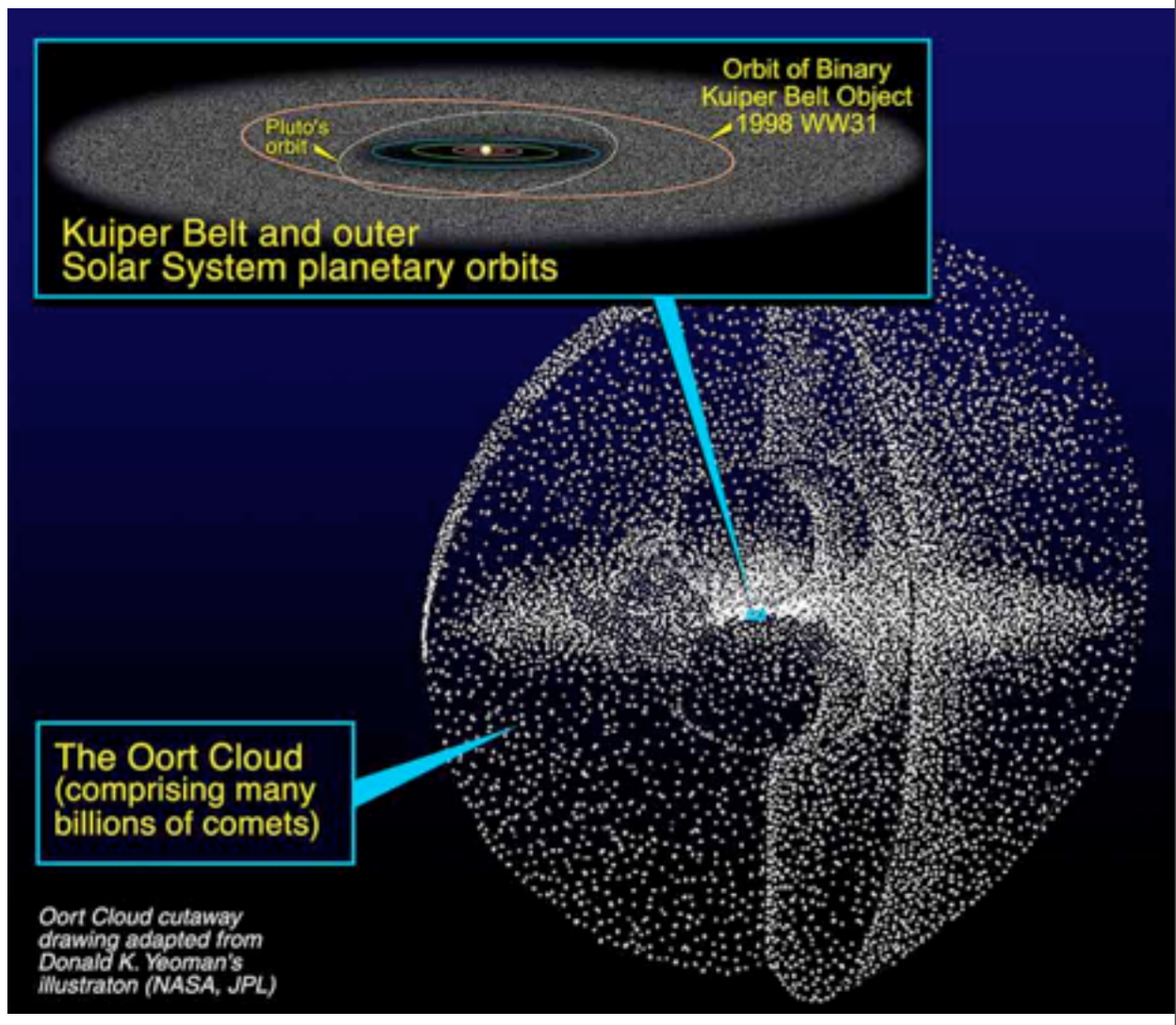
Oort Cloud

- **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**



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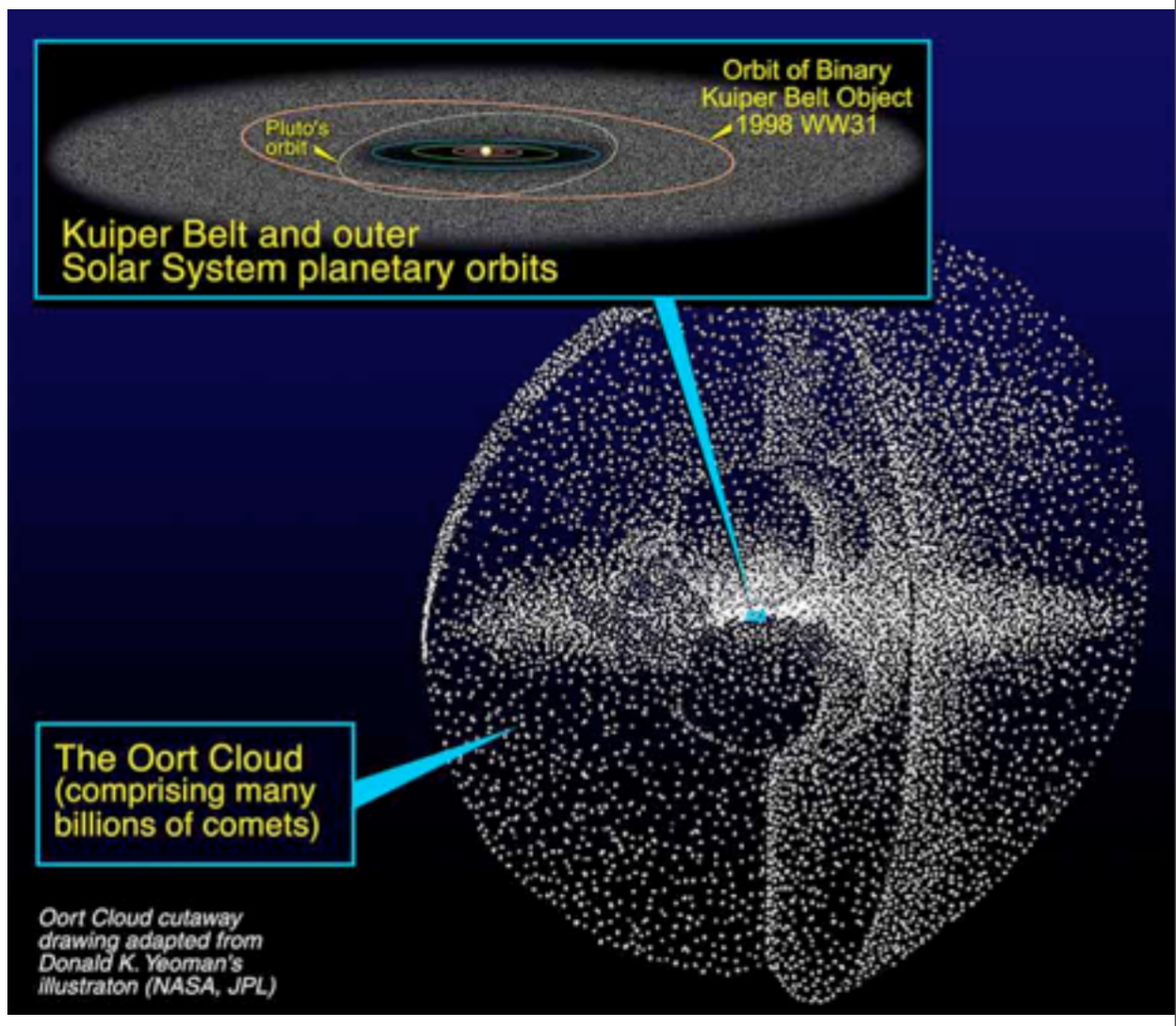


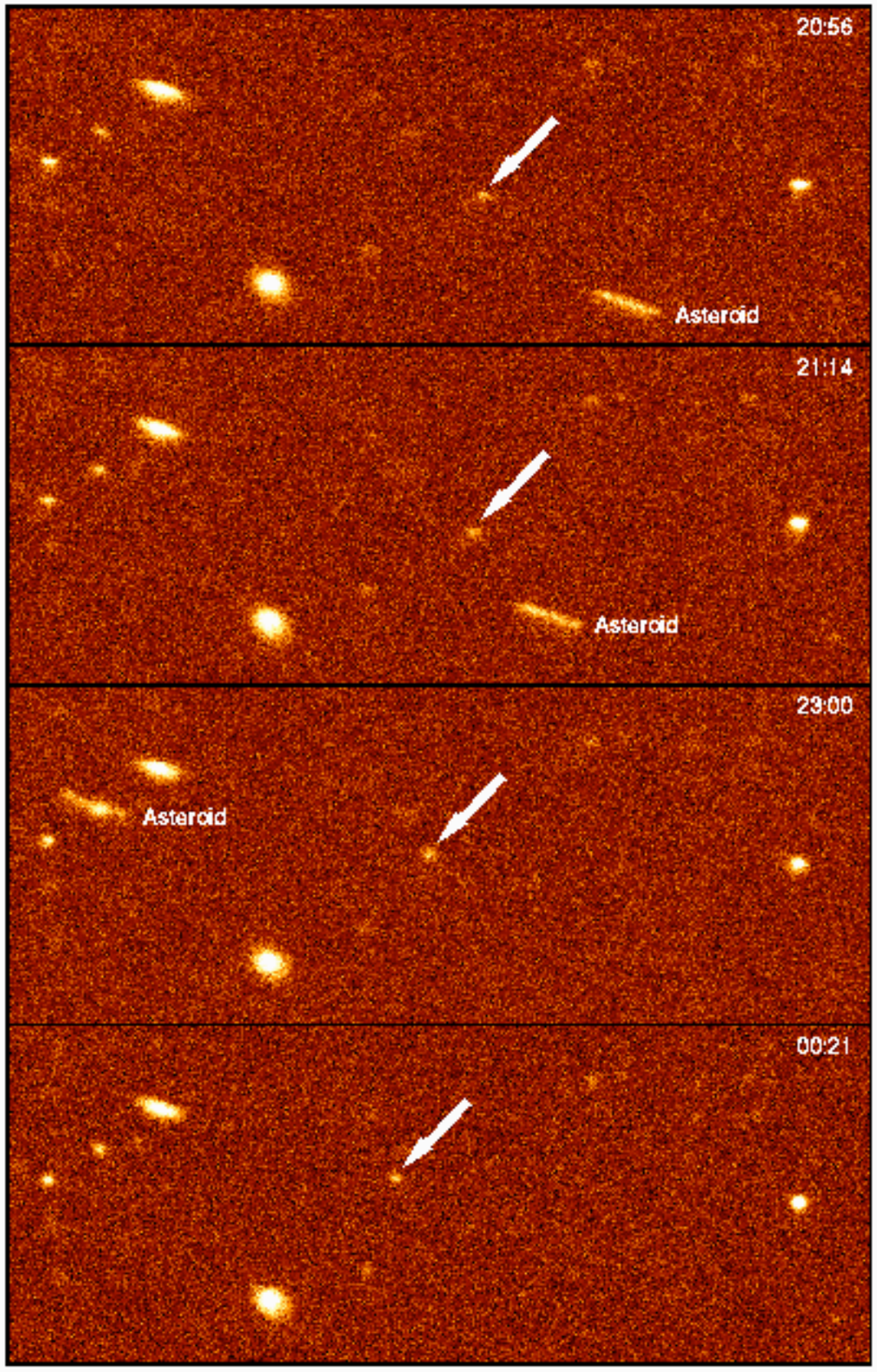
We will want to understand these differences!

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

Kuiper Belt Discovery

first object detected in orbit at location of Kuiper belt in 1992, beyond Neptune

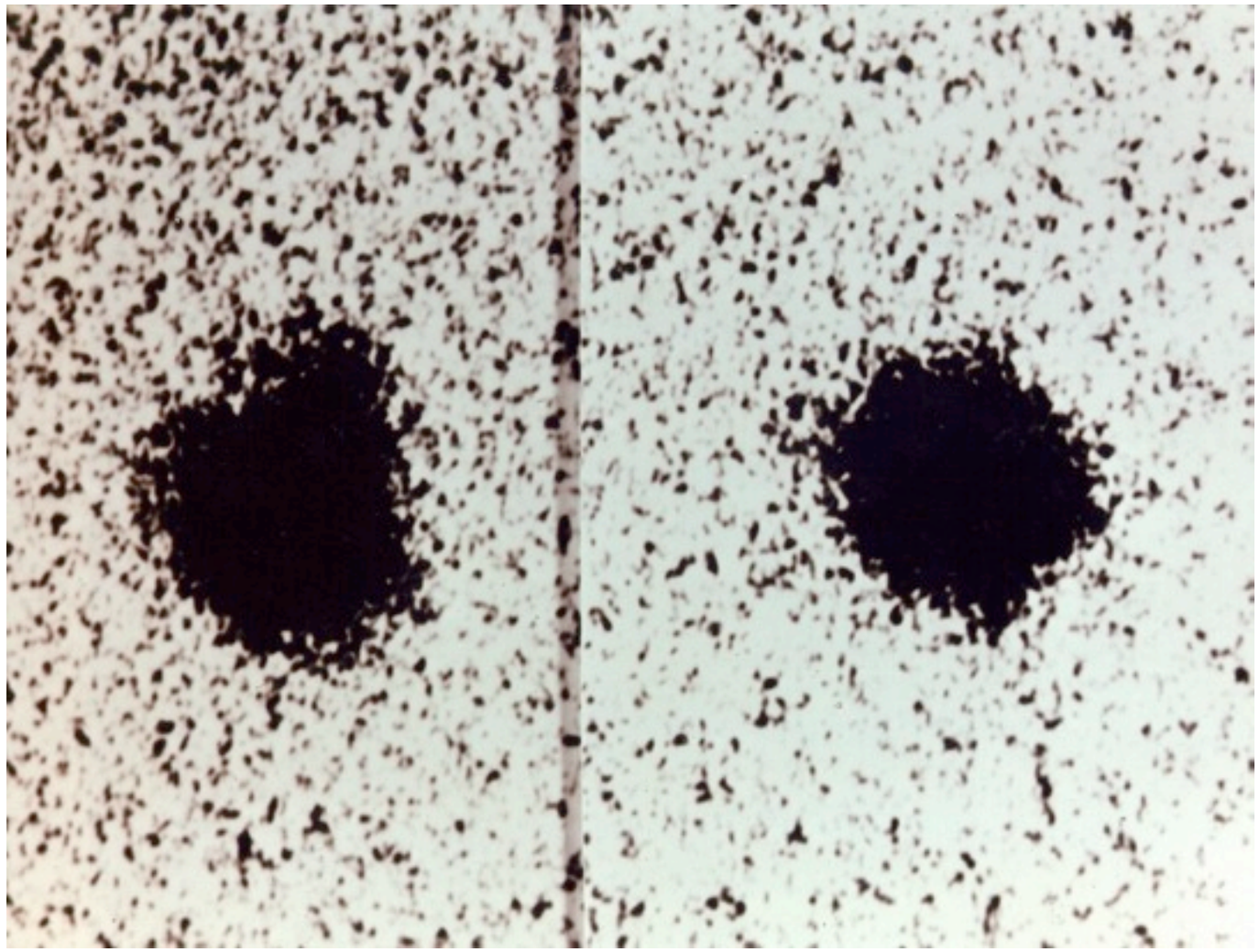
- KB objects also called Trans-Neptunian objects
- today, tally of KB objects is hundreds
- typically small iceballs, <10% size of Pluto
- estimates: 70,000 KBO's total mass ~ $0.1M_{Earth}$



Discovery Image http://www2.ess.ucla.edu/~jewitt/images/qb1.gif

Pluto

Best images of Pluto circa 1978



Pluto's Orbit:

- a = 39.5 AU so P = 285 yr!
- eccentricity e = 0.25
  larger than all planets

Composition:

- surface icy, rocky

Shape: spherical

Q: notice anything funny in these images?

Pluto has moons!

Largest: Charon

- more discovered in recent years

Note Pluto's similarity to comet nucleus, Kuiper belt objects

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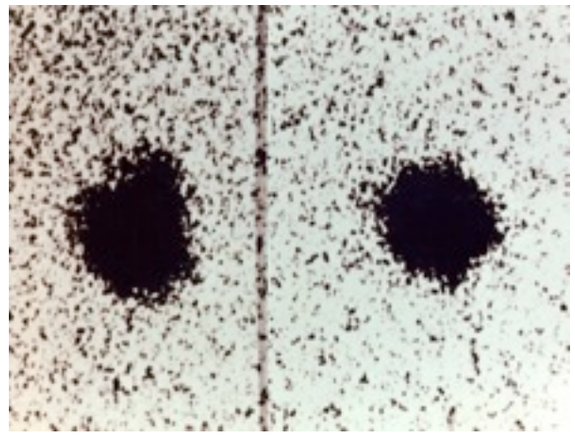

Hubble Telescope, 1994

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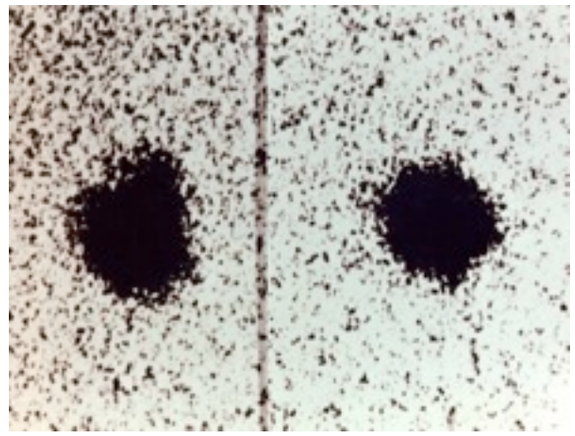

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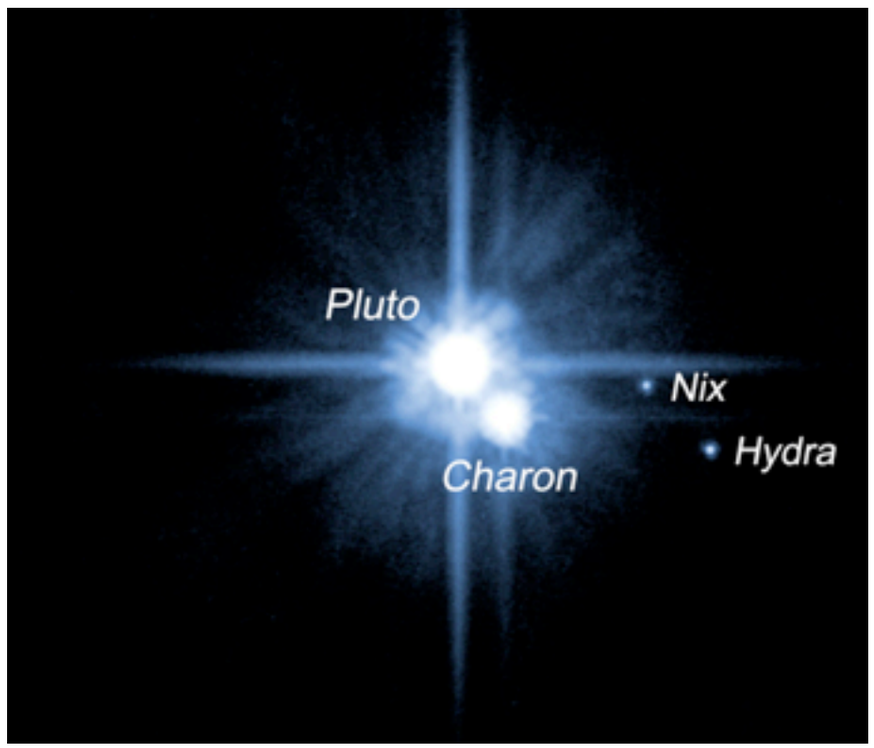


Hubble Telescope, 2006

Pluto: History and Status

Clyde Tombaugh -- born in Streator IL!

- 1930: Pluto discovered in sky scan
- totally unlike its neighbors: Uranus, Neptune

1930's-1950's: Kuiper belt idea proposed

1990's: Kuiper belt objects discovered

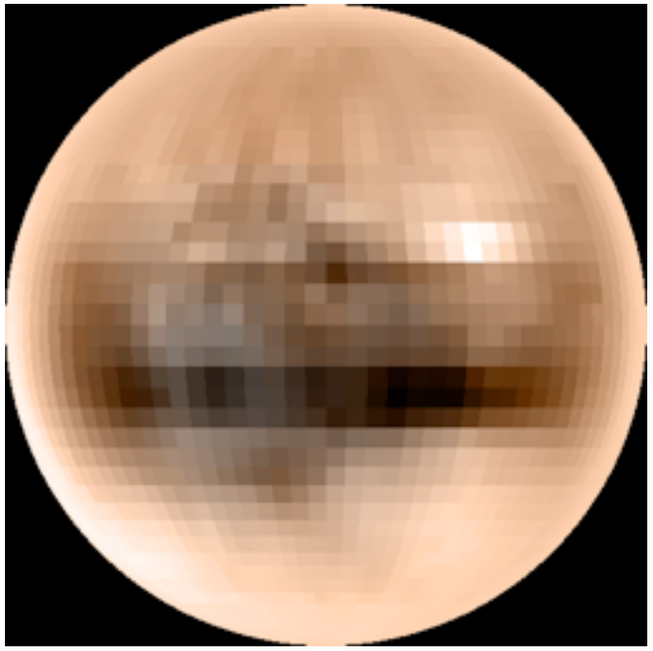
2002–present: more large outer solar system objects

- Quaoar ("Kwawar") ≈ 60% Pluto size
- Sedna ≈ 70% Pluto size
- "Xena" → Eris: more massive, and maybe larger than Pluto!!

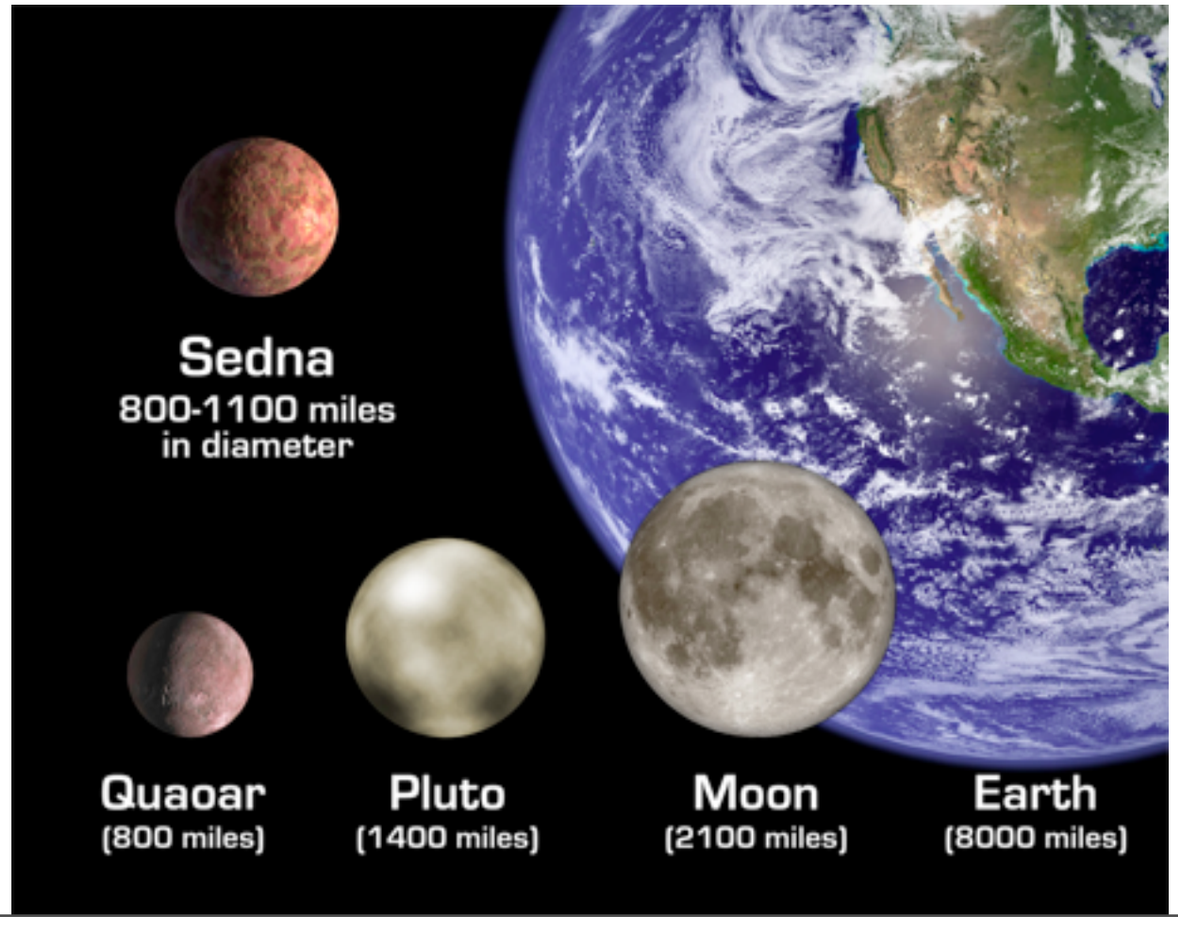
all these are spherical rocky iceballs

largest of huge population of objects beyond Neptune

- orbits more elliptical than planets, but still near ecliptic
- "transneptunian objects" or Kuiper belt objects (KBOs)
- smaller Kuiper belt members sometimes scatterer → comets



Pluto: mapped by Hubble



iClicker Poll:
Pluto: Planet or Plan-not?

2006: International Astronomical Union redefines "planet"

Pluto demoted to "dwarf planet"

along with Ceres (asteroid belt),

and KBO's Eris + 2 others

Vote your conscience!

Is Pluto a full-fledged, non-dwarf planet?

A. No way! Good riddance! And I've got my eye on you, Neptune!

B. Umm, probably not?

C. Umm, probably so?

D. Yes way! Pluto was robbed! Long live Pluto!

Where are These Rocks From?

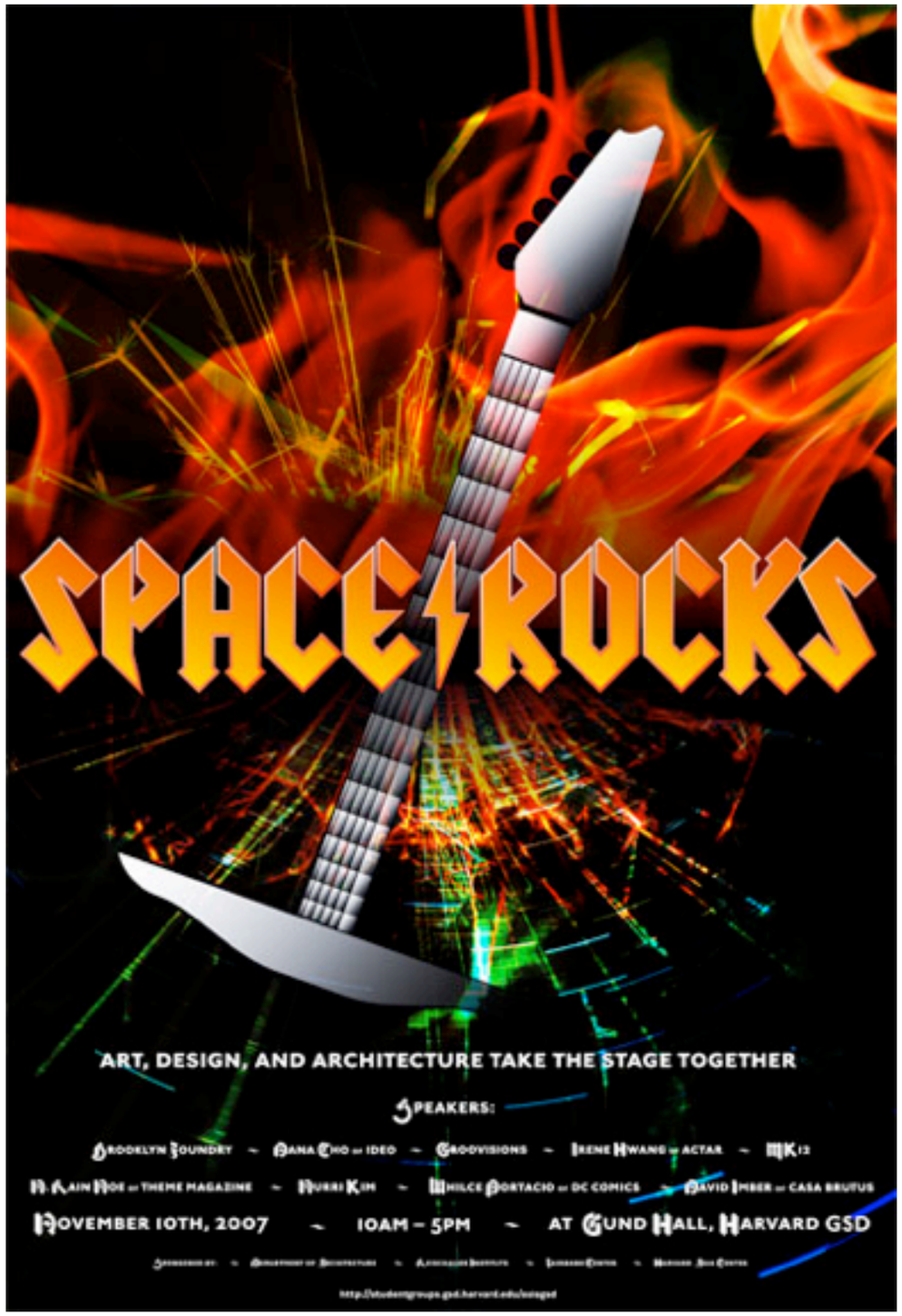
Asteroids

Meteoroids

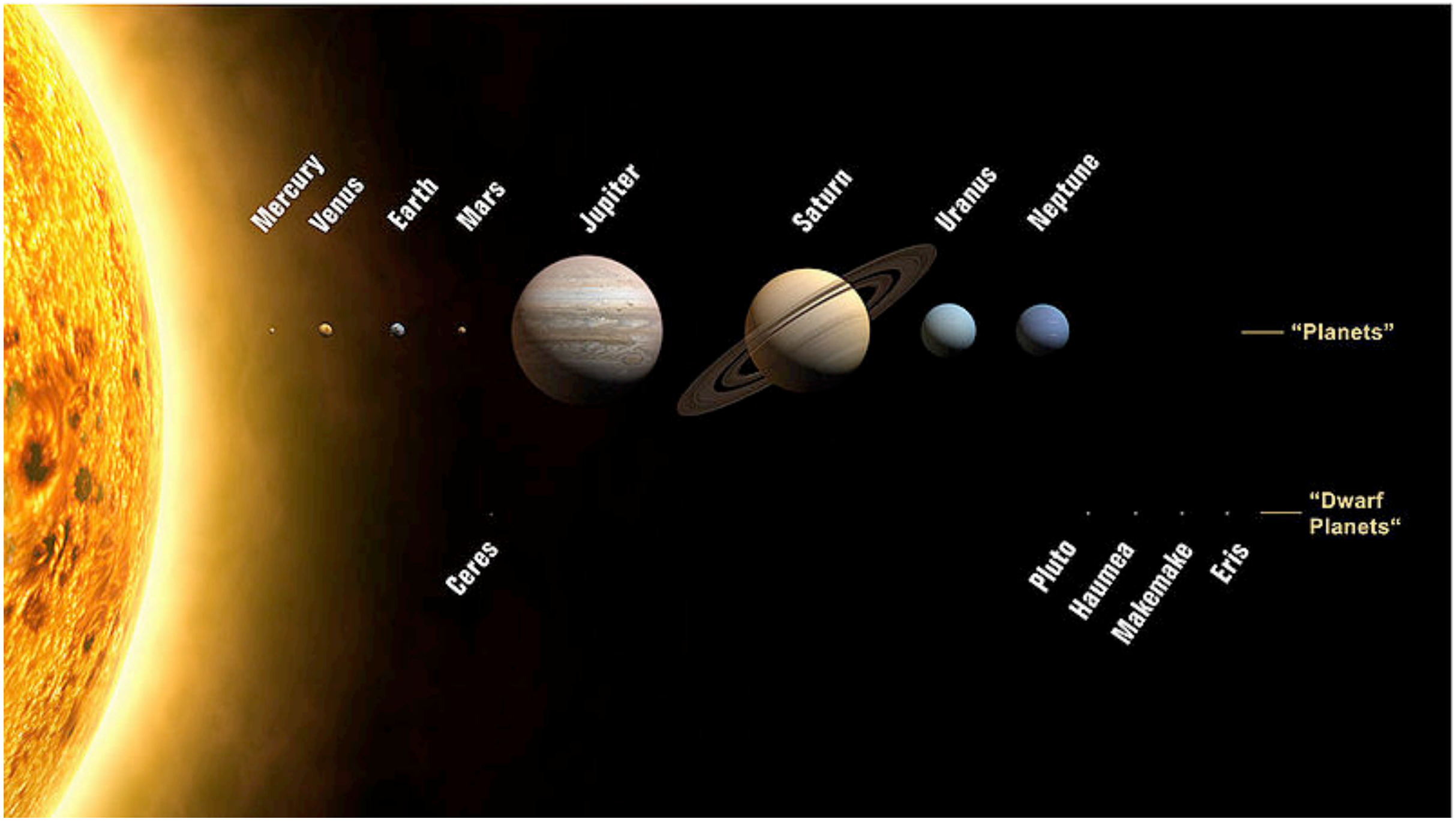
Comets

… 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

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

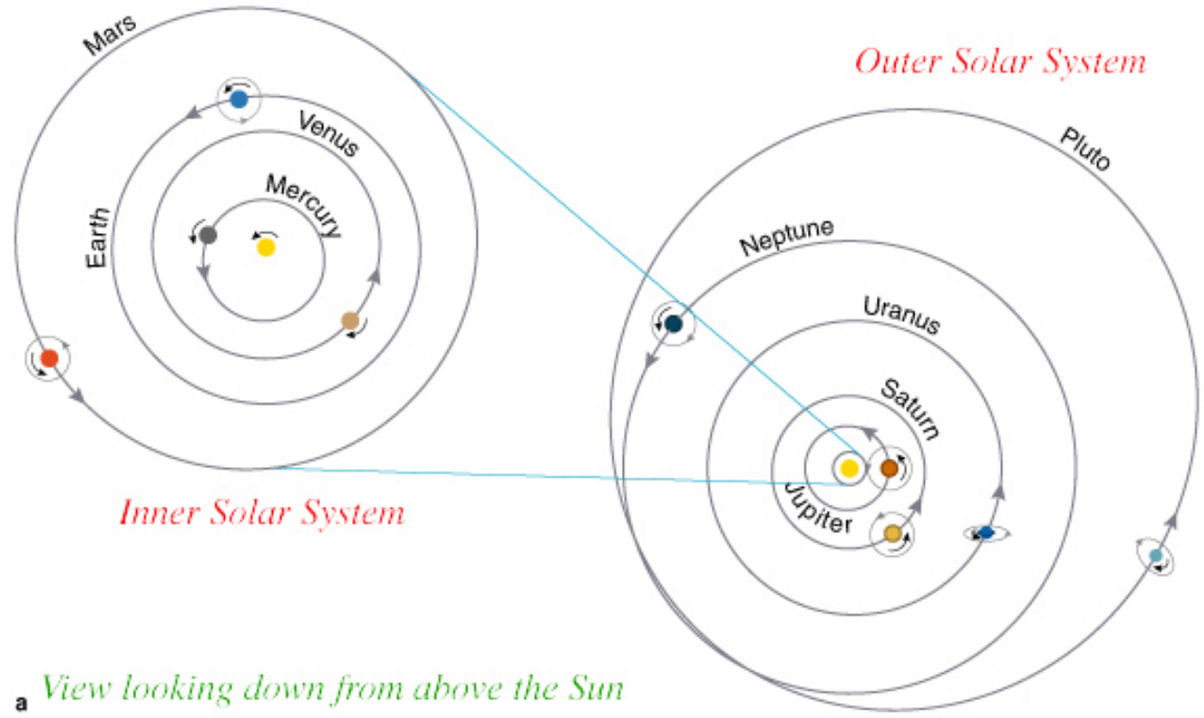
1. Patterns of Motion
2. Two Types of Planets
3. Asteroids and Comets

Clue 1.
Patterns of Motion

Kepler I:

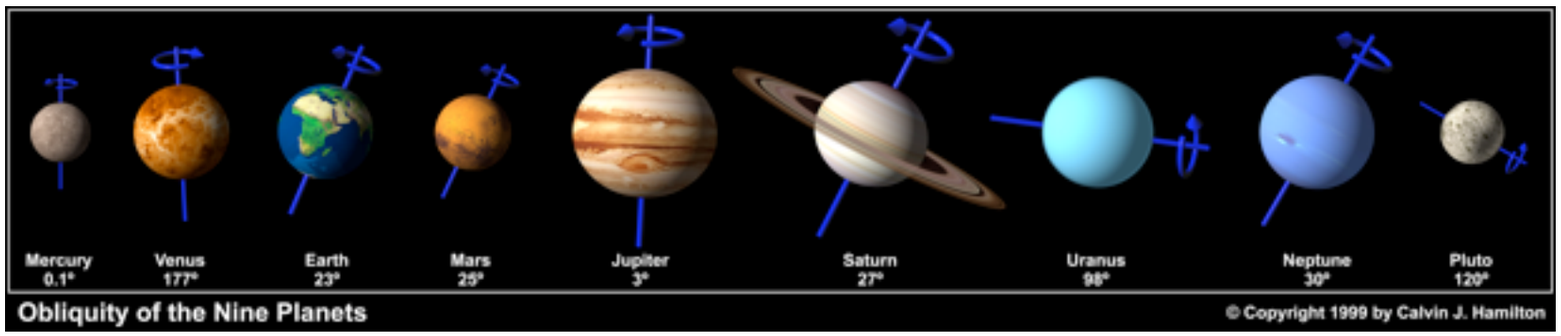
every object moves around Sun in ellipse: every orbit lies in a plane

Earth orbit plane: "Ecliptic"

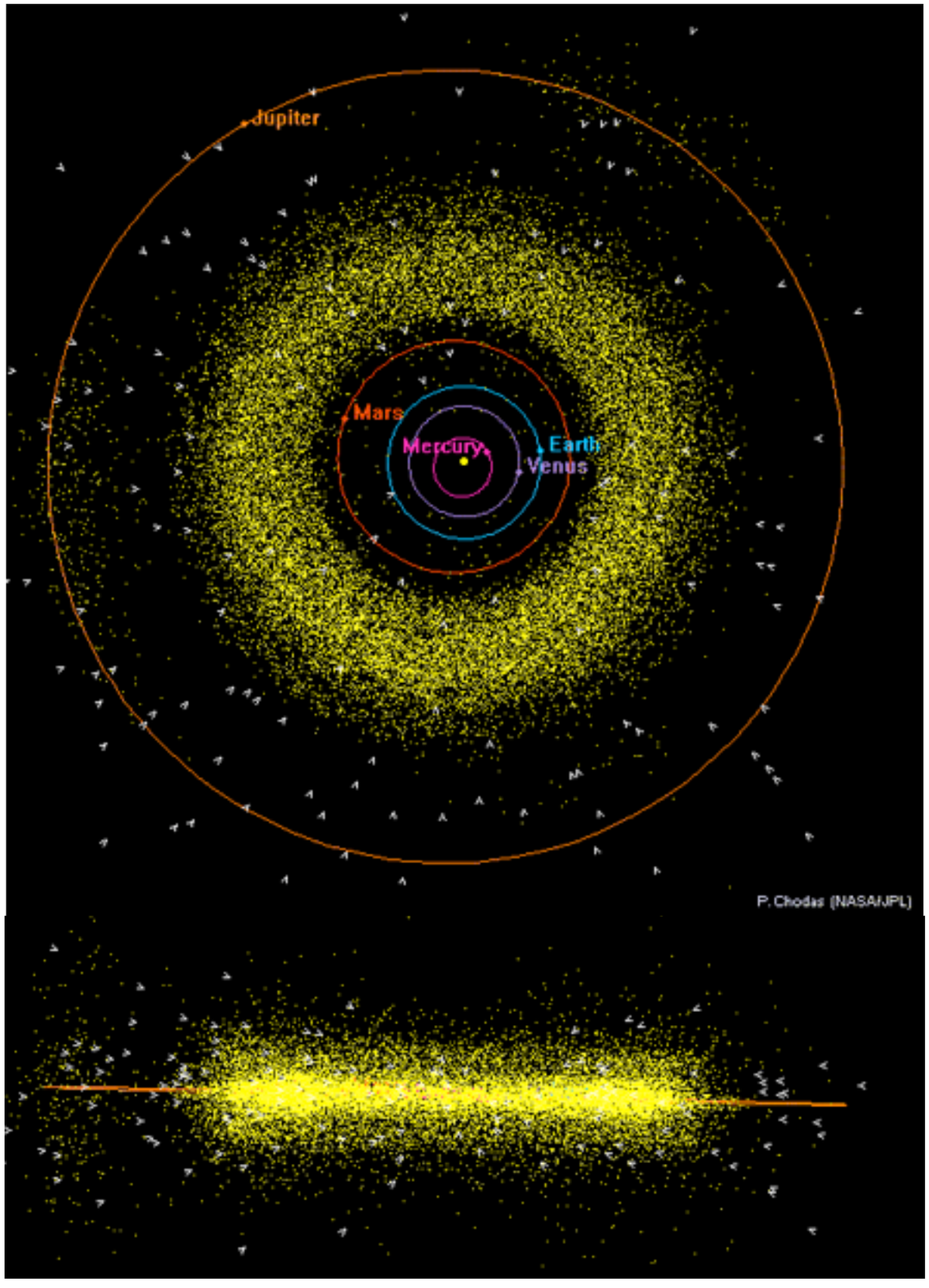


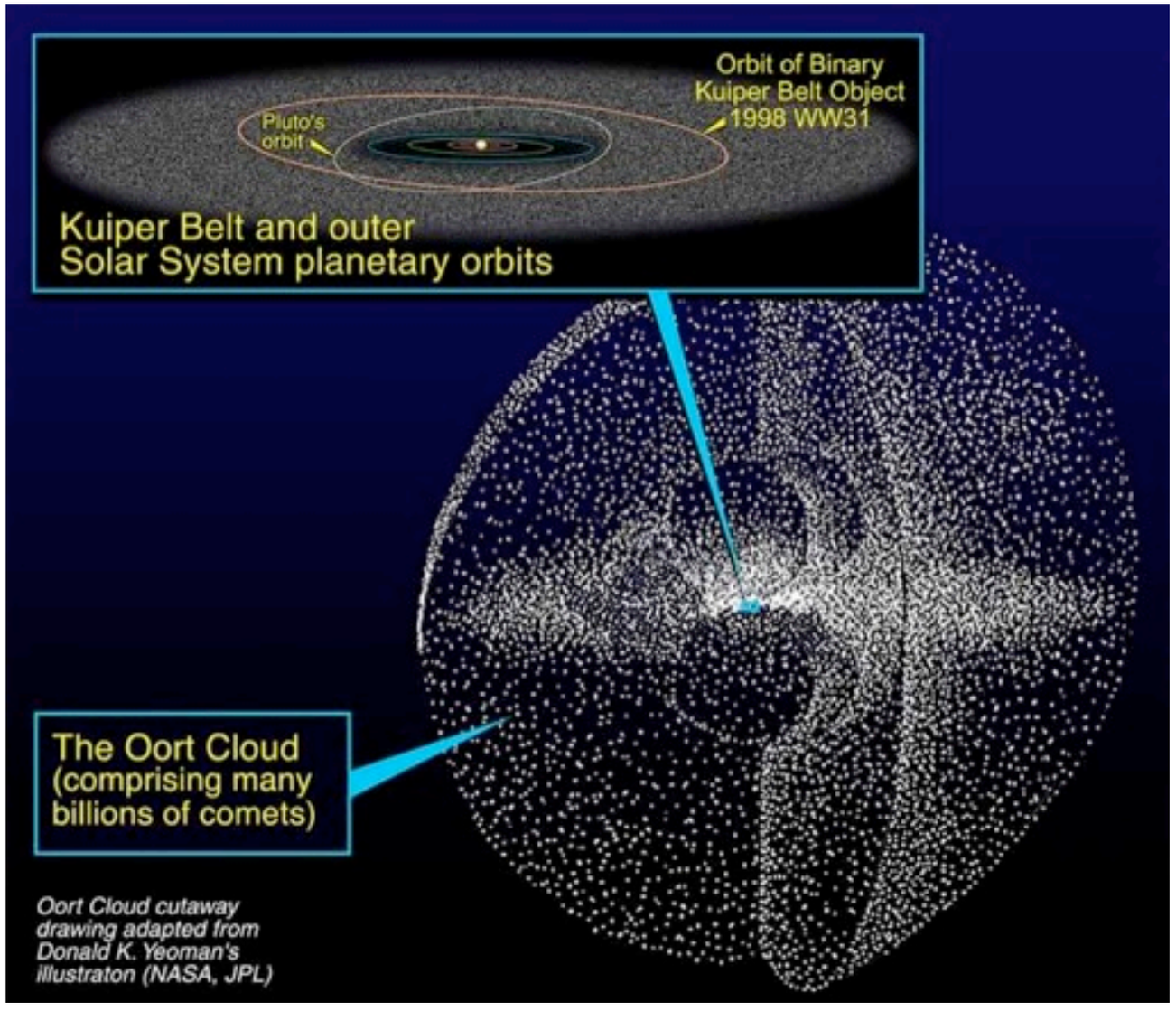
Key fact I:
all large bodies in the solar system orbit in the same direction and in nearly the same plane

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



Asteroid and Comet Orbits





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

The Terrestrials: Earth-Like

Mercury

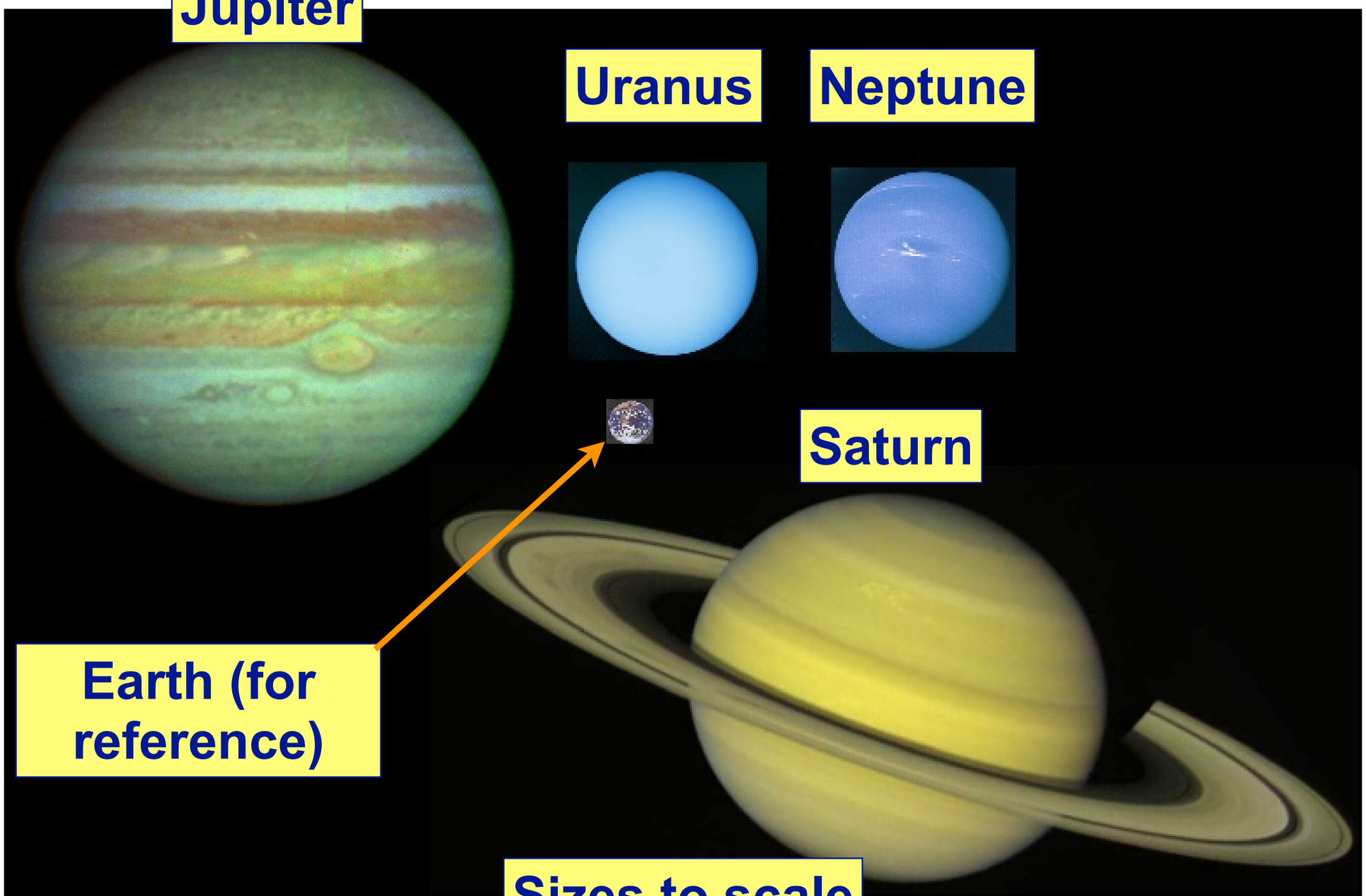
Venus

Earth

Mars

Sizes to scale
Distances are not!

The Jovians: Jupiter-Like



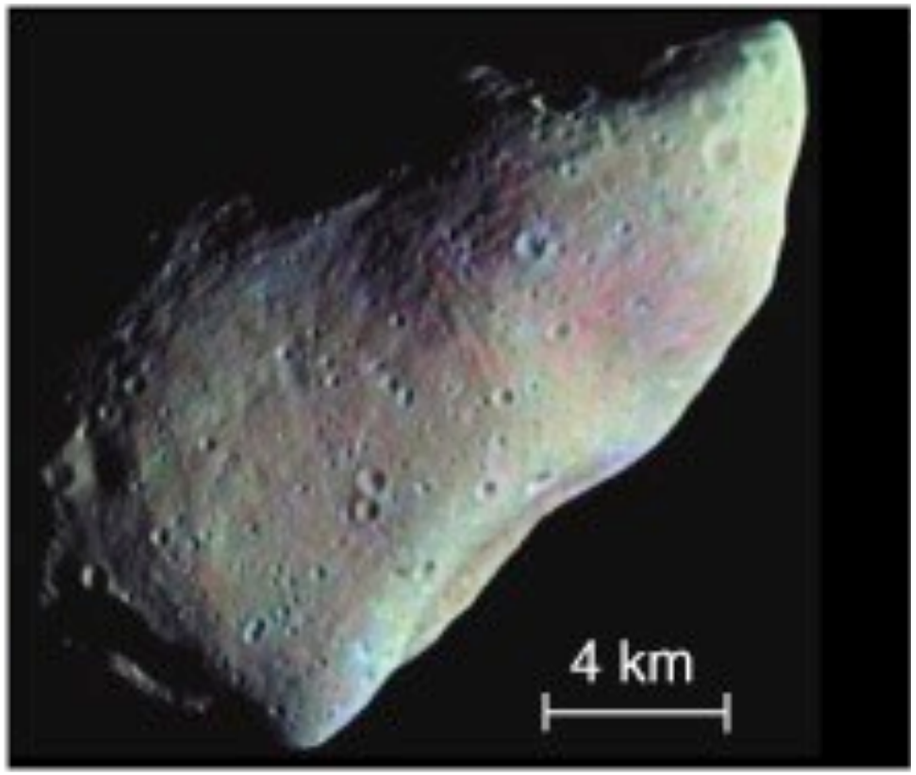
Clue 3.
Debris: Asteroids and Comets

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



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Age of the Solar System

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Earth:

- oldest rocks are 4.4 billion yrs

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Age of Solar System is probably around
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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

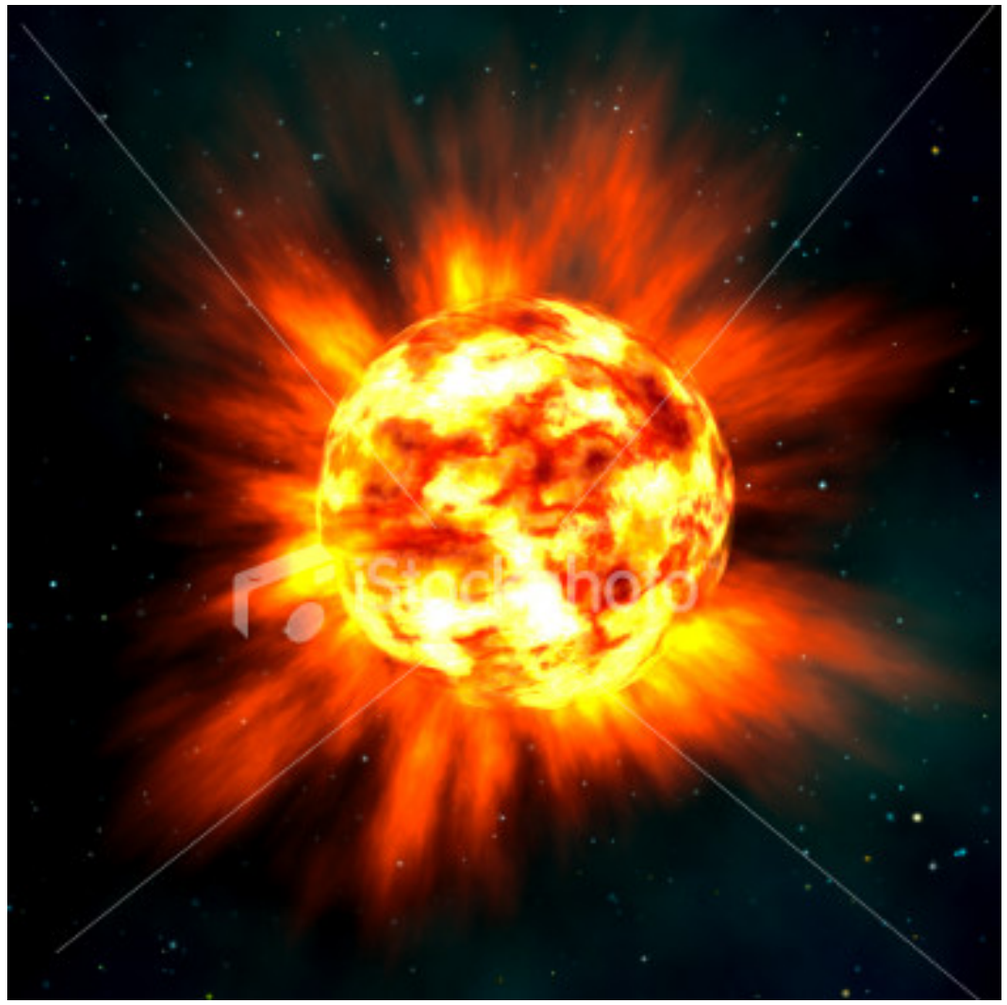
- sequence of events, predictions for evolution up to present
- allows us to construct a "story of what happened"
- makes predictions for new observations

The Early Days

We'll come back to this, but the Universe is around 13.7 billion years old.

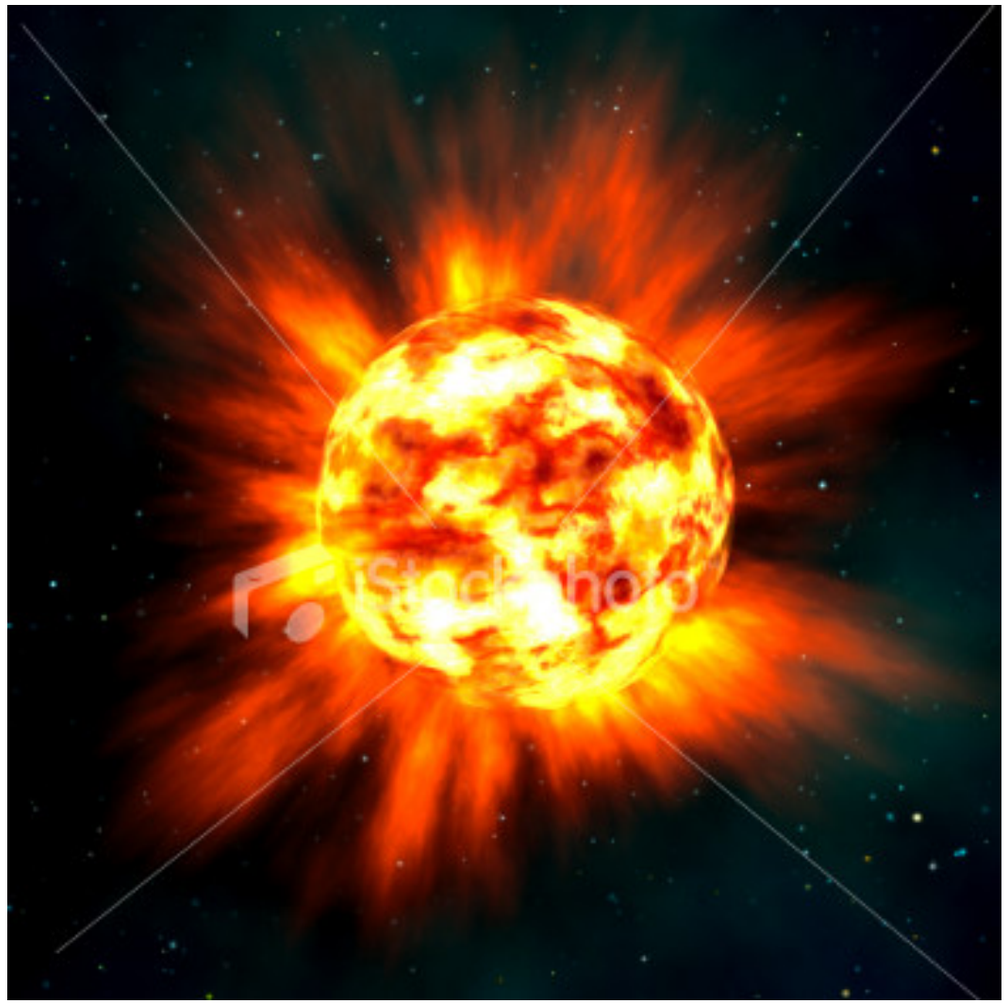
3 minutes after the big bang (we'll come back to this), the Universe was mostly hydrogen (75% by mass) and helium (25%) with no heavy elements

Making Heavy Elements



Making Heavy Elements

The first stars were born and died.



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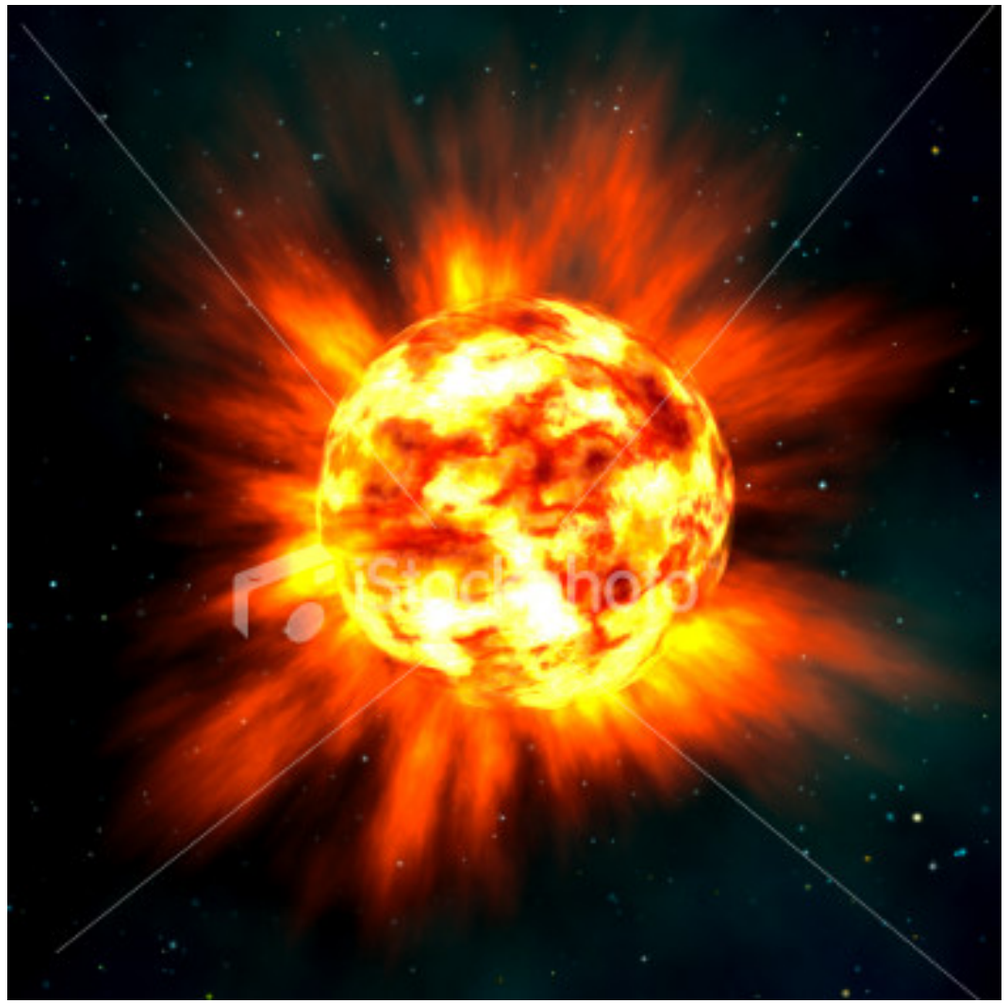

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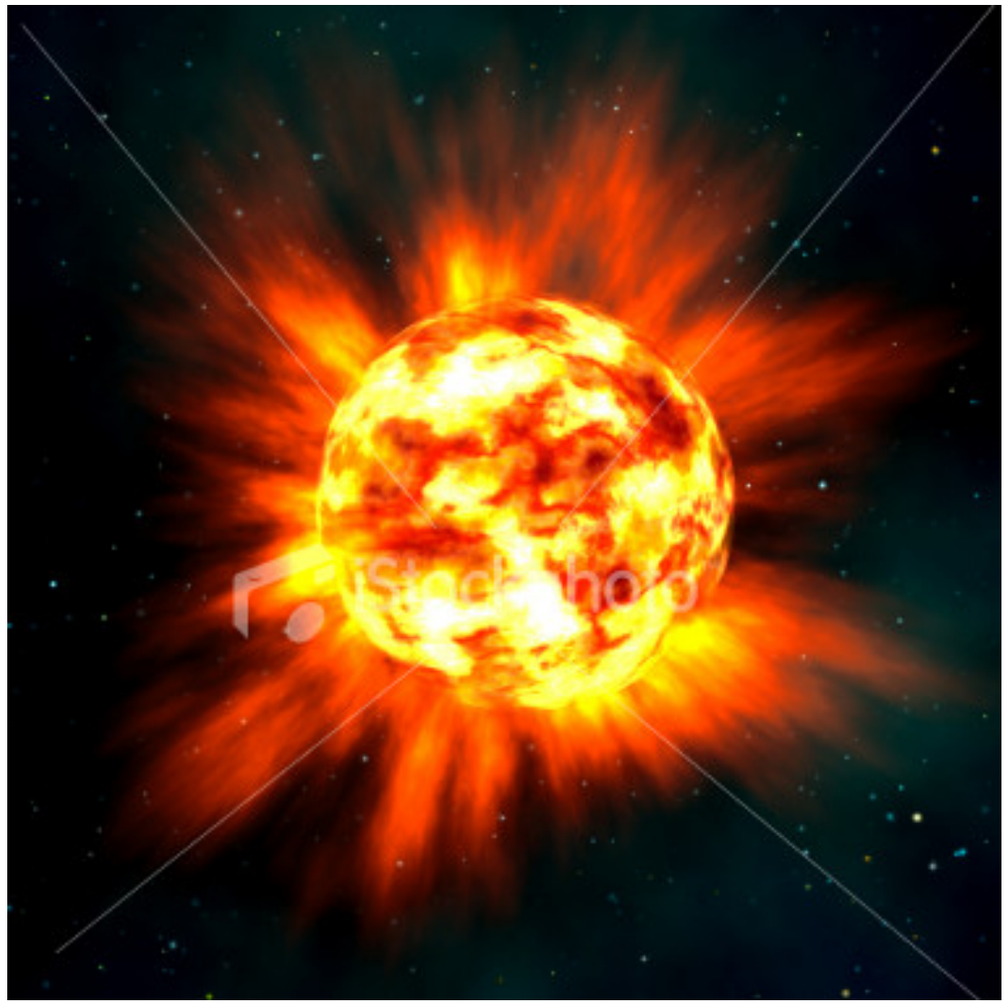

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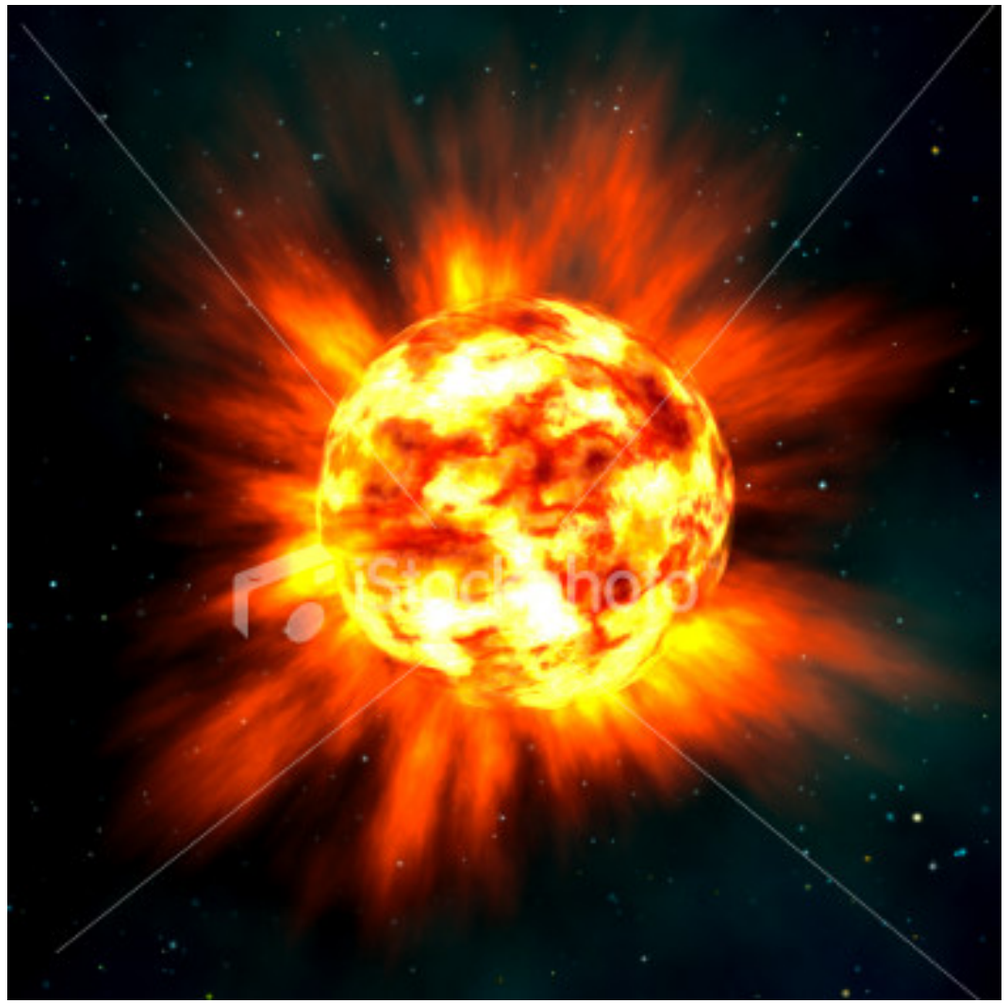

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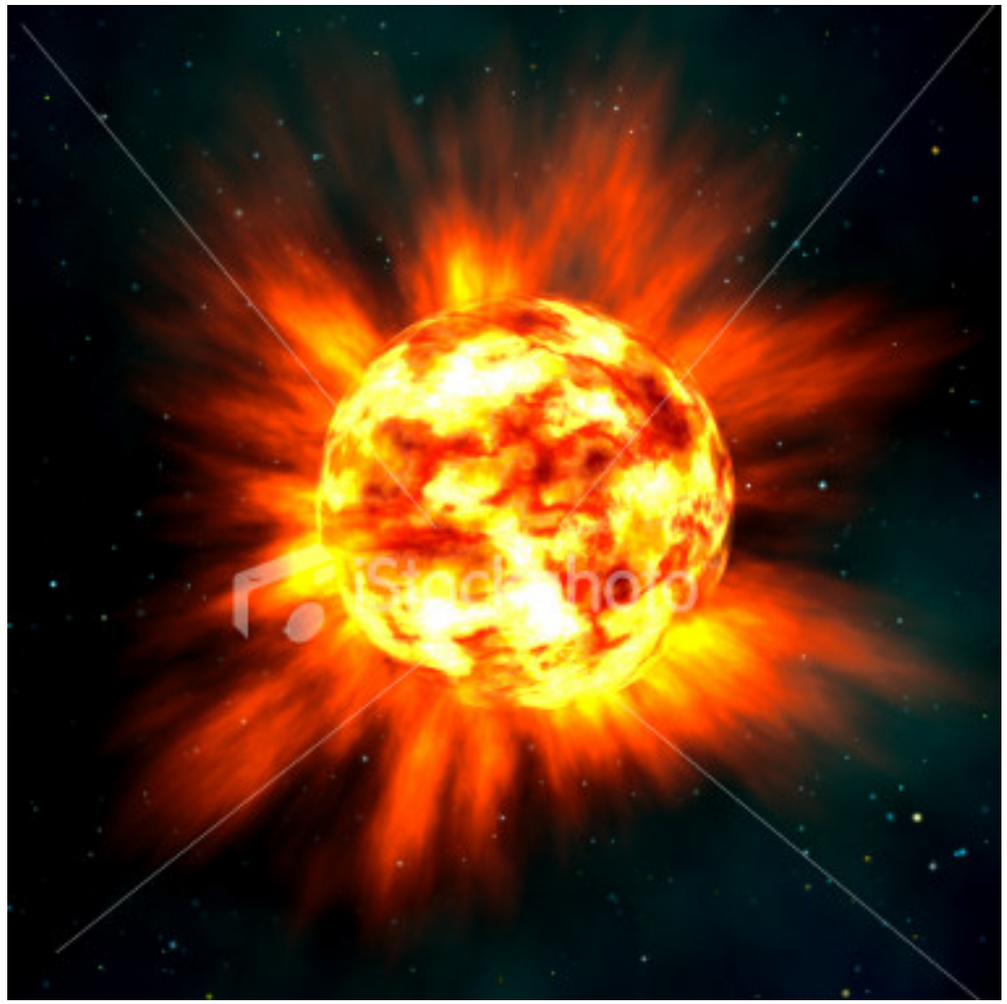

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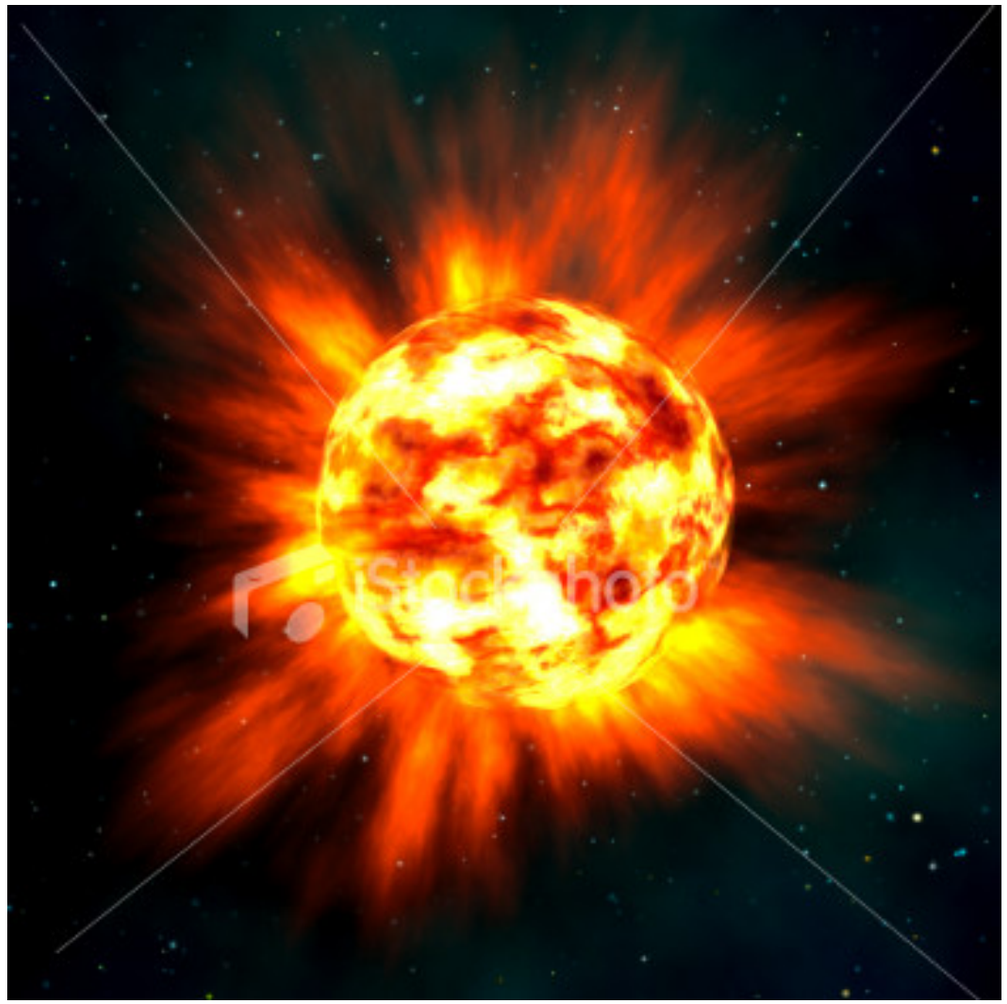
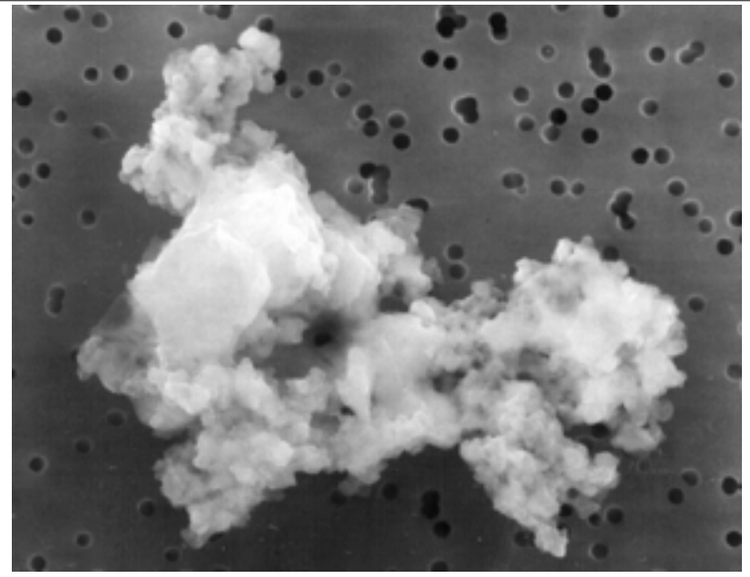


The Stuff Between the Stars:
The Interstellar Medium



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

Keyhole Nebula

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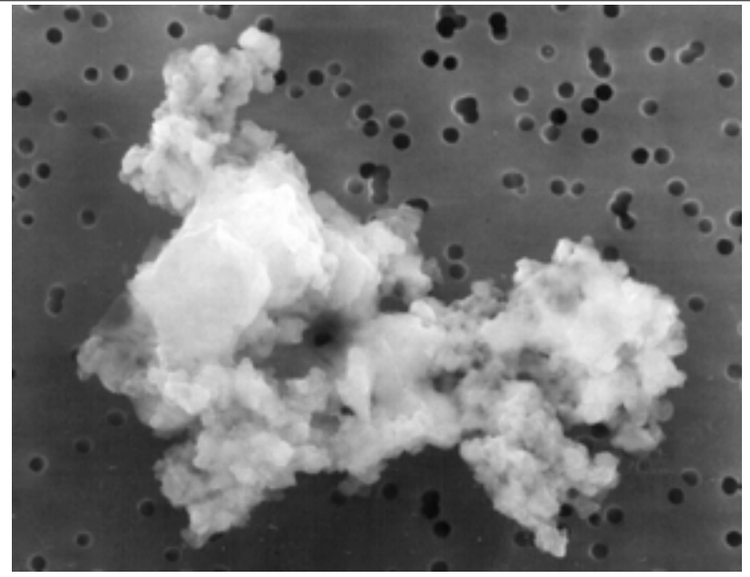

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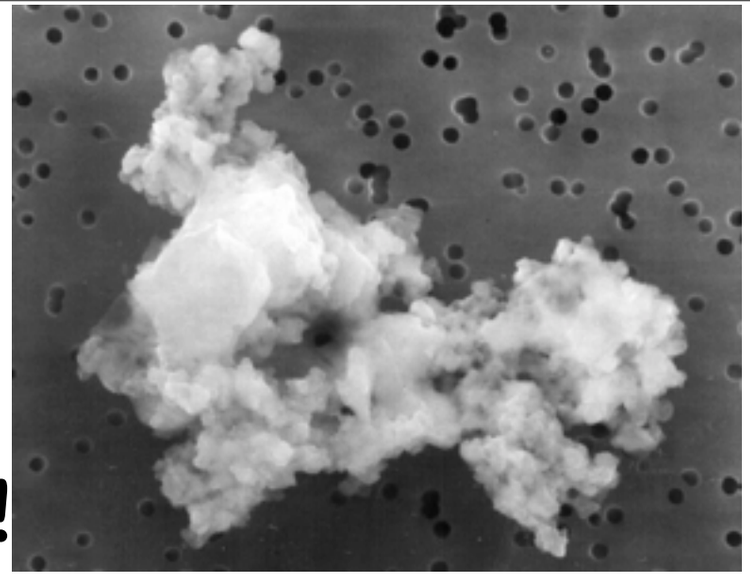

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here is stuff between the stars in a galaxy!

- 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"

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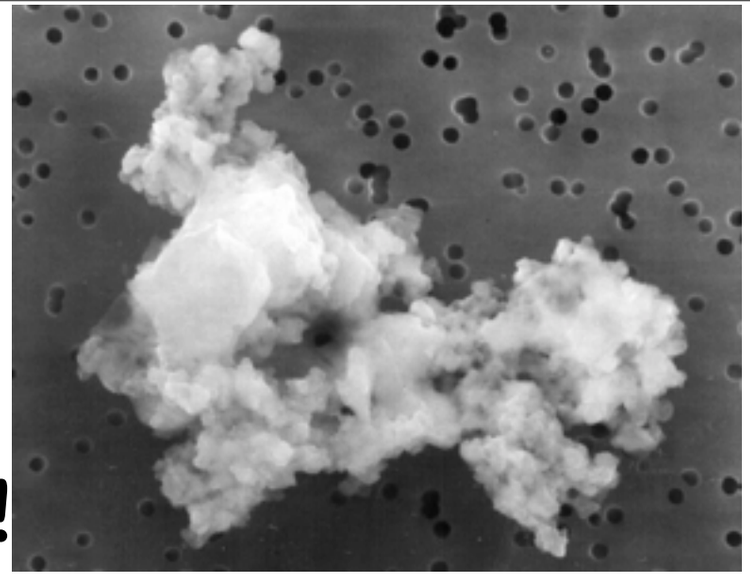

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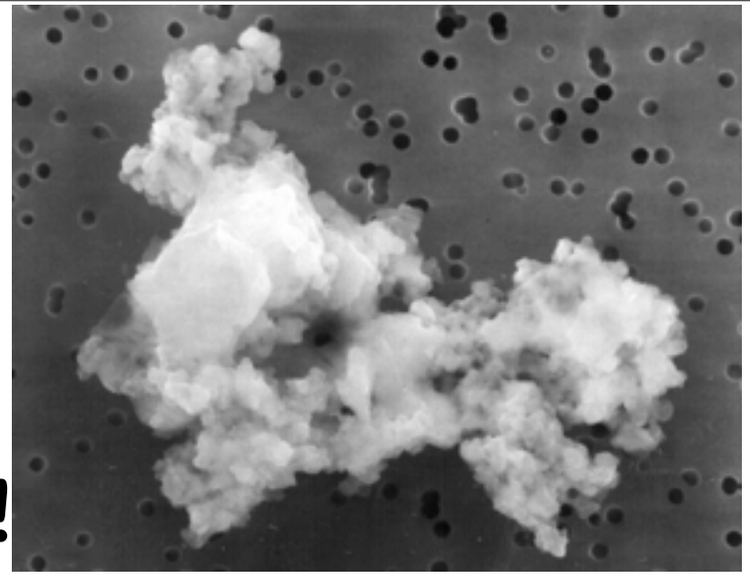

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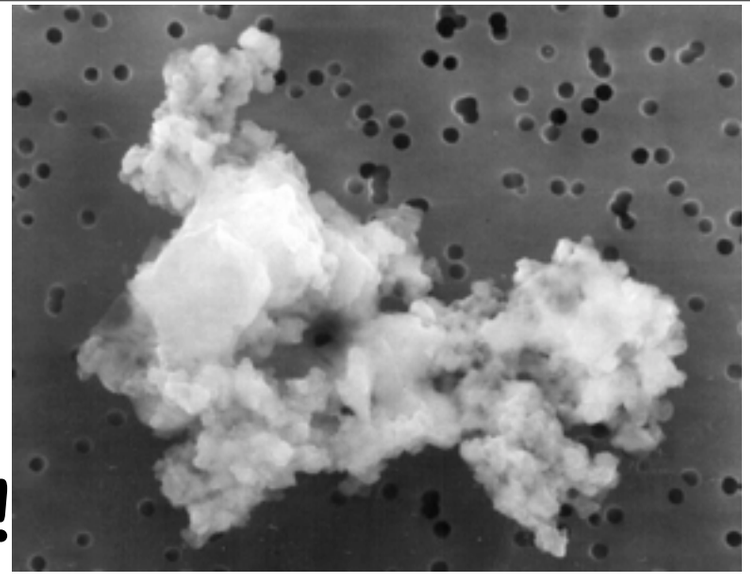

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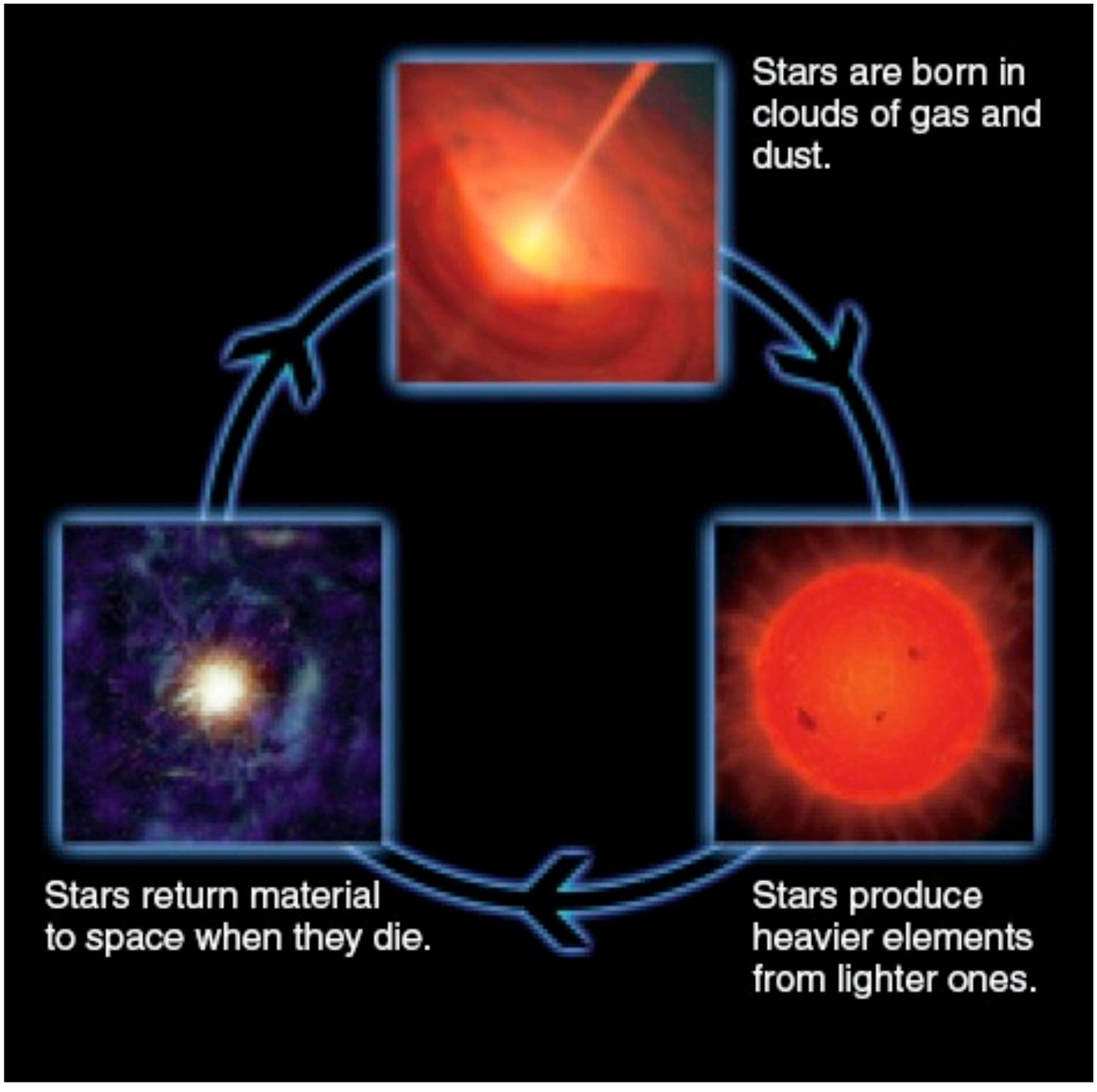
xists as either

- Diffuse Interstellar Clouds
- Molecular Clouds

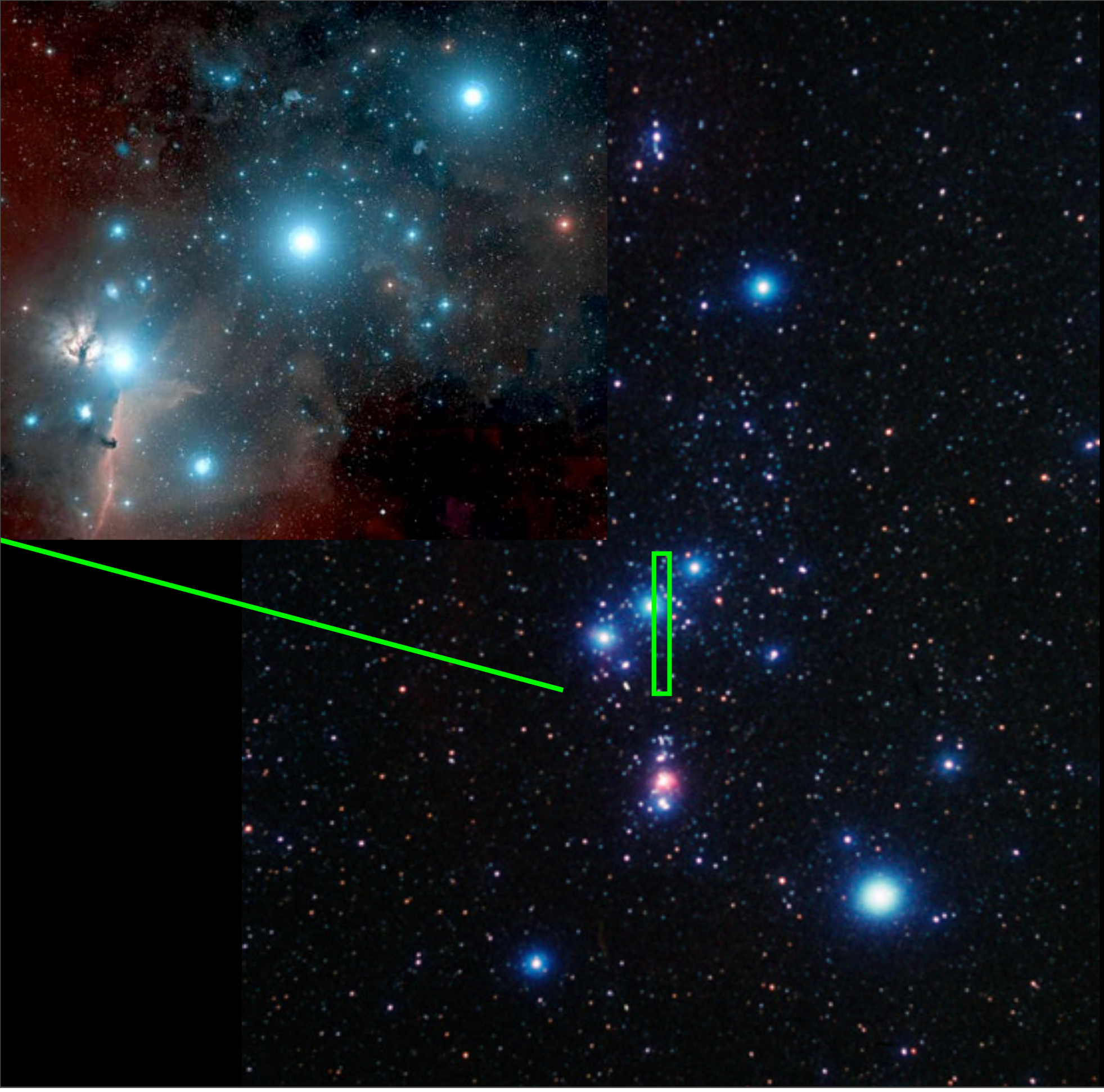
Keyhole Nebula

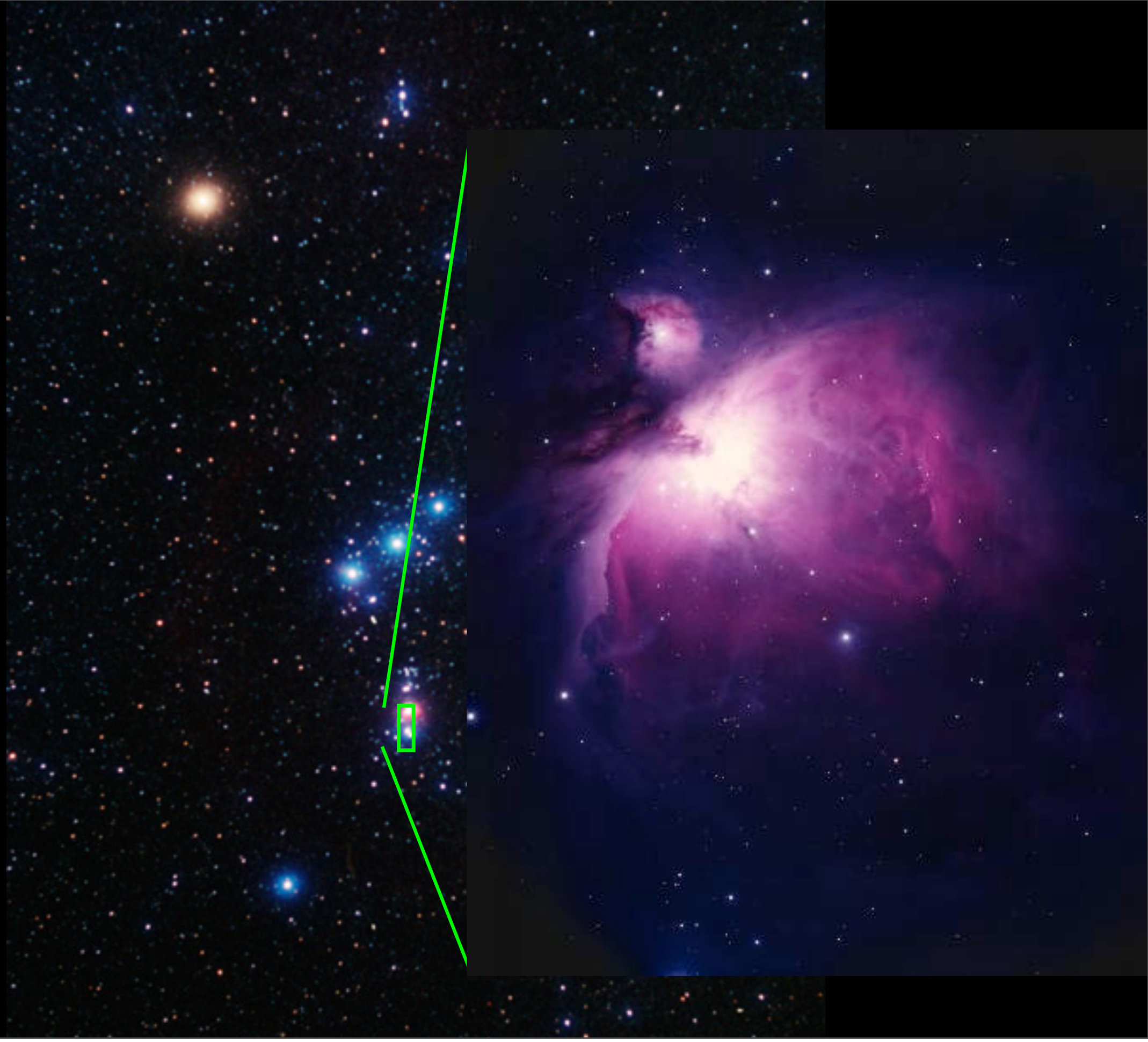
Where did the solar nebula come from?

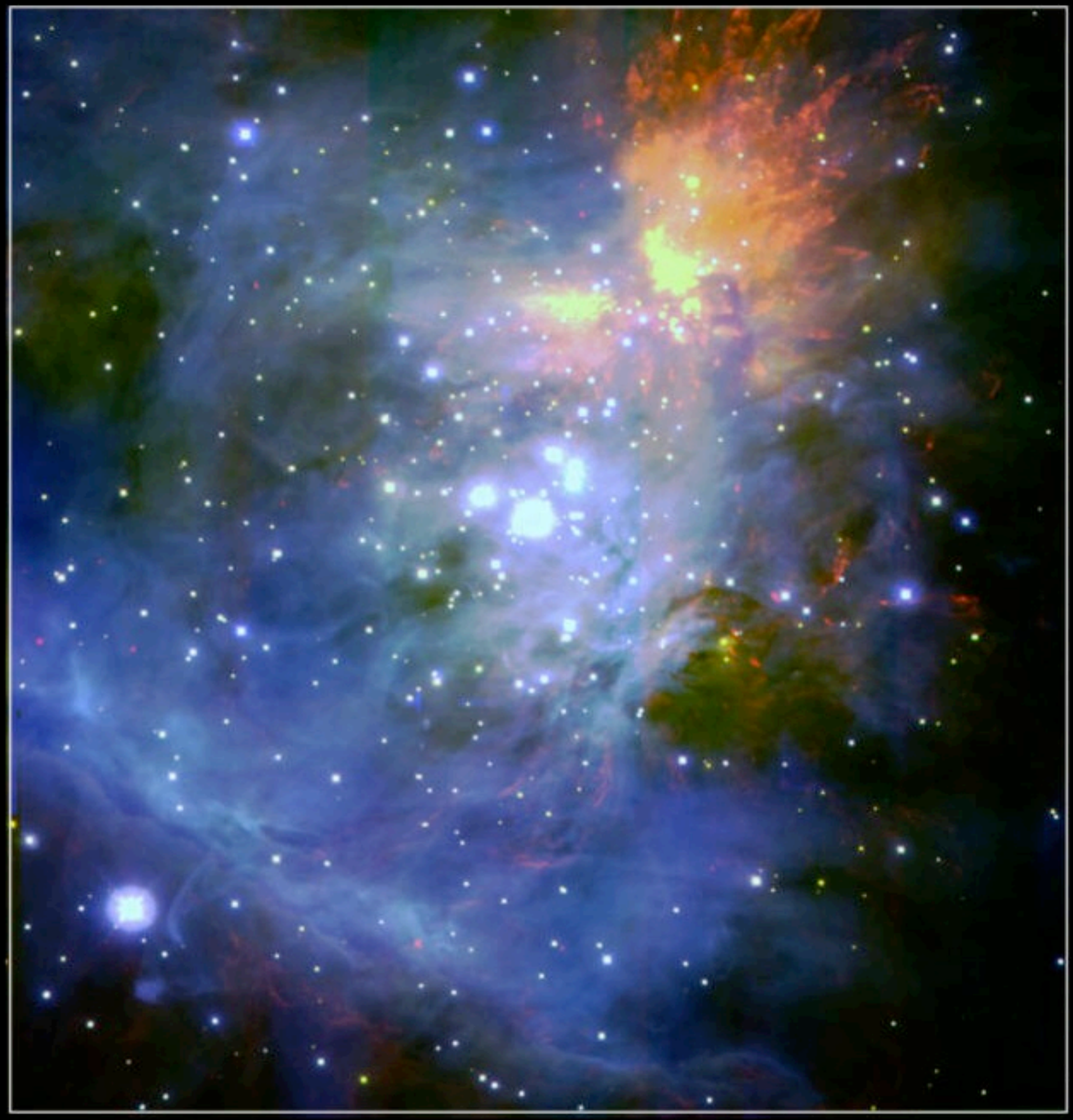


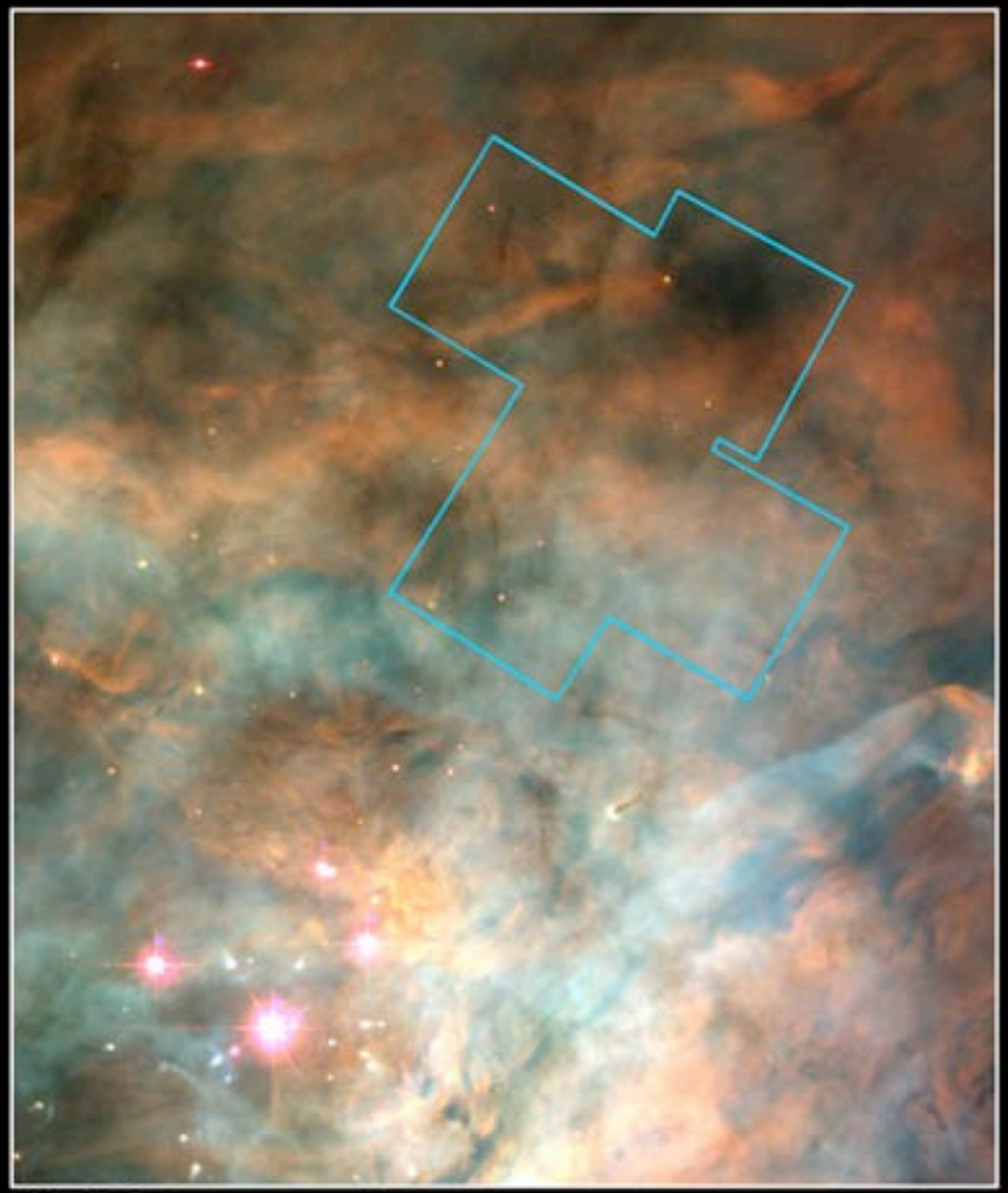
The cloud of gas that gave birth to our solar system resulted from the recycling of gas through many generations of stars within our galaxy

Wednesday, February 1, 2012

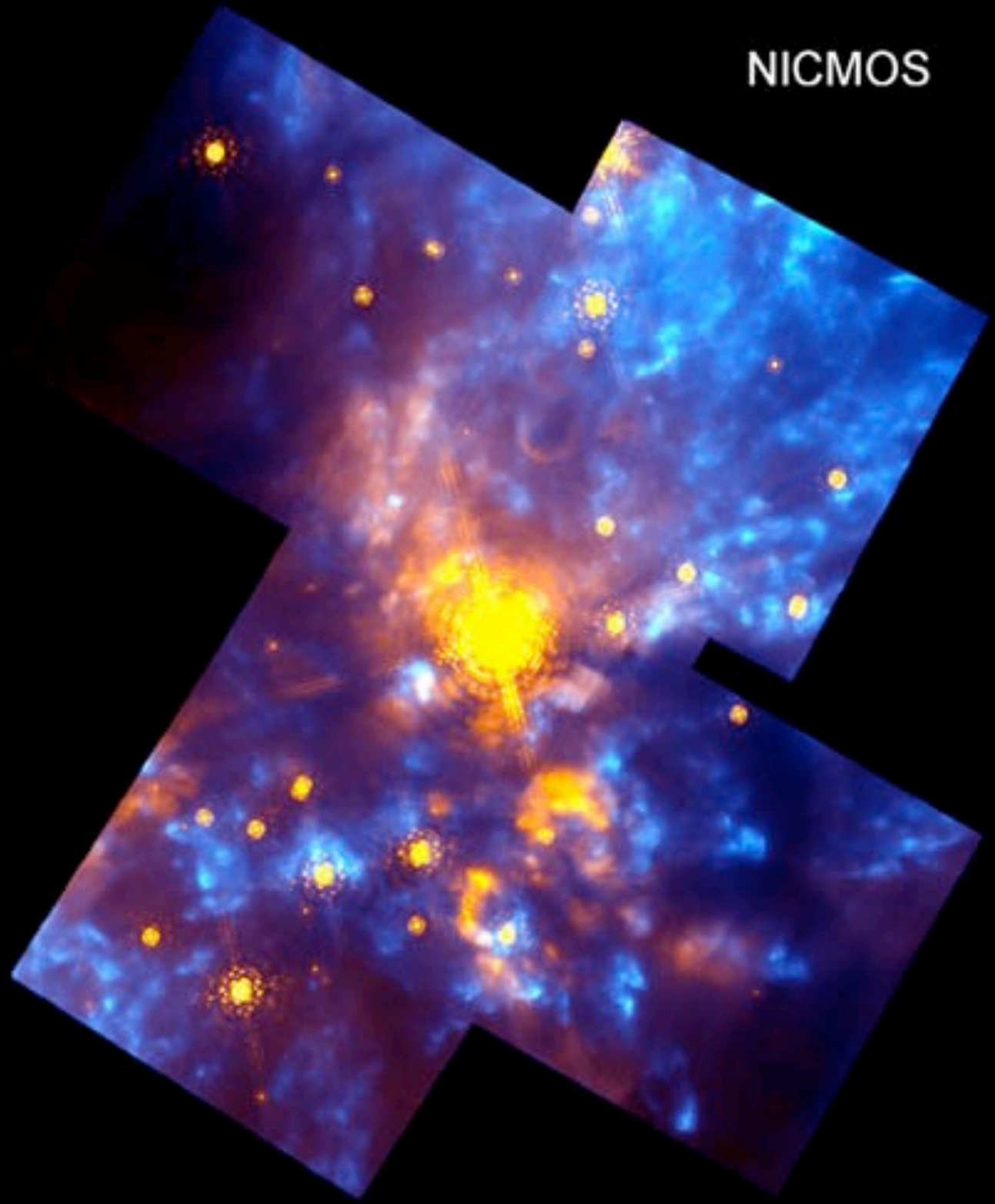








WFPC2



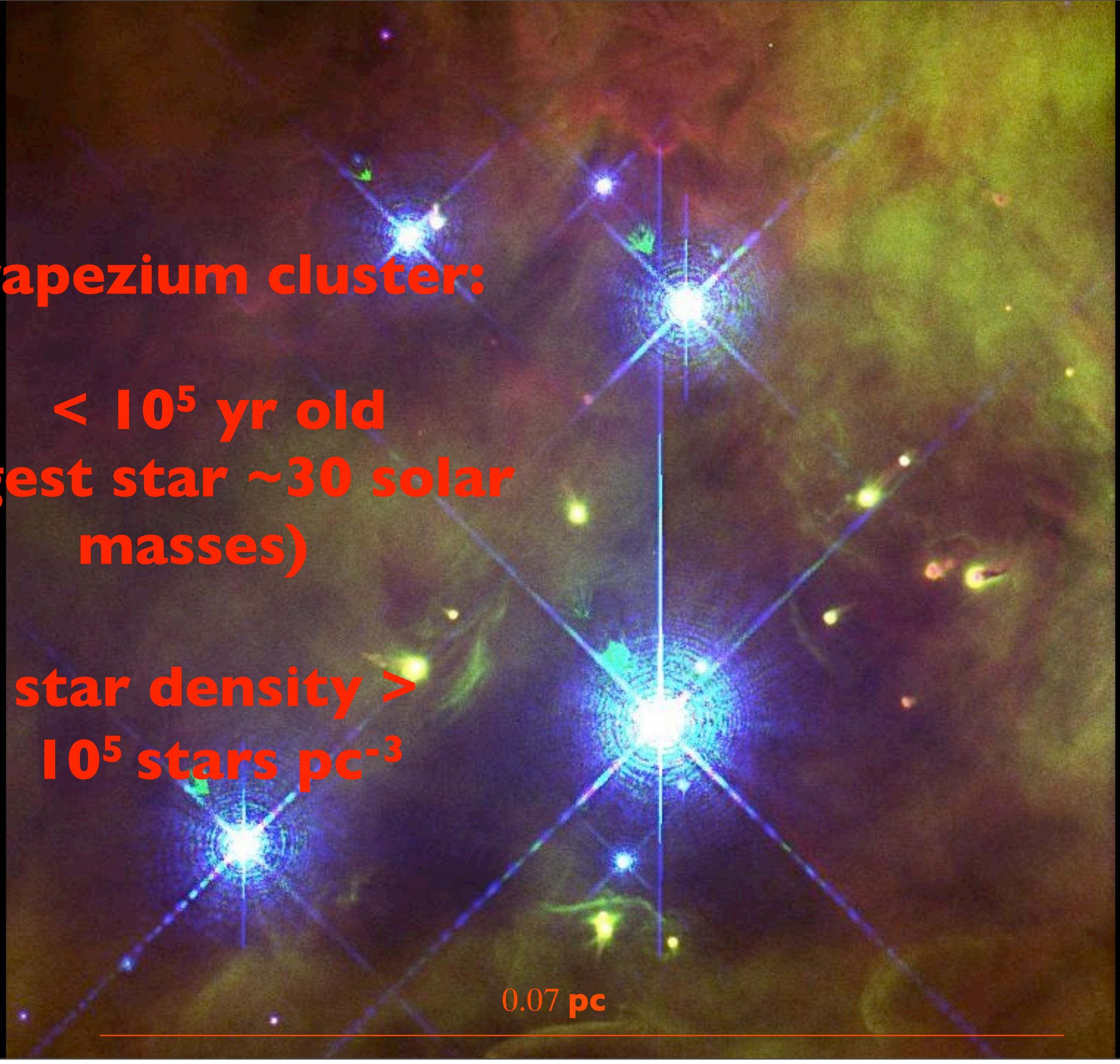
NICMOS

Orion Nebula • OMC-1 Region

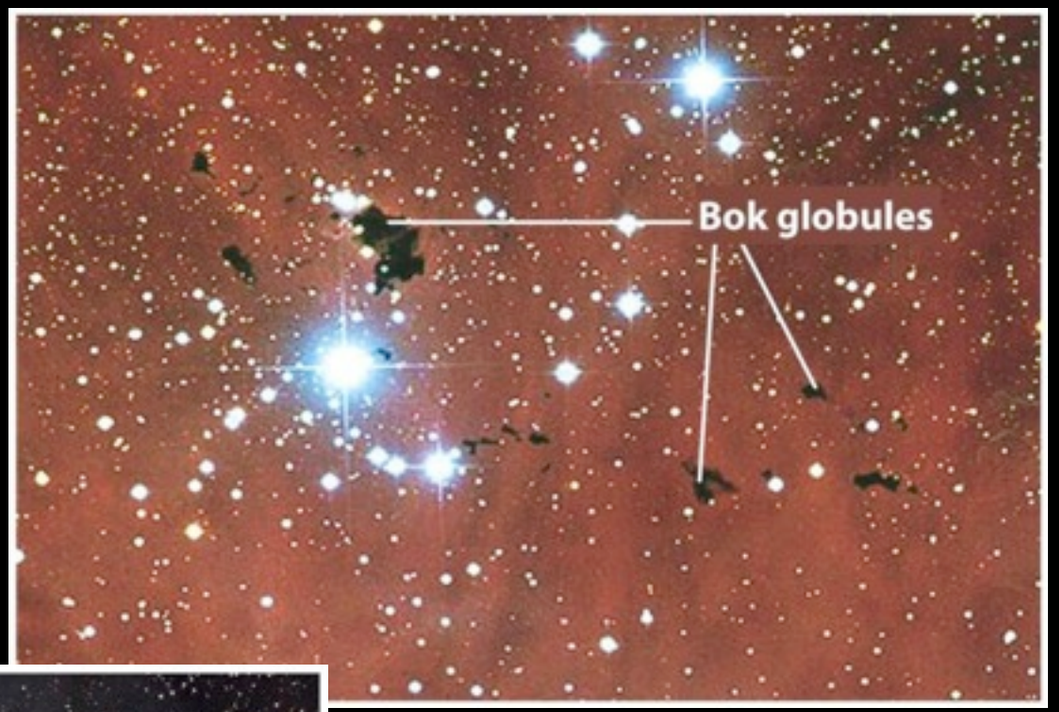
PRC97-13 • ST ScI OPO • May 12, 1997

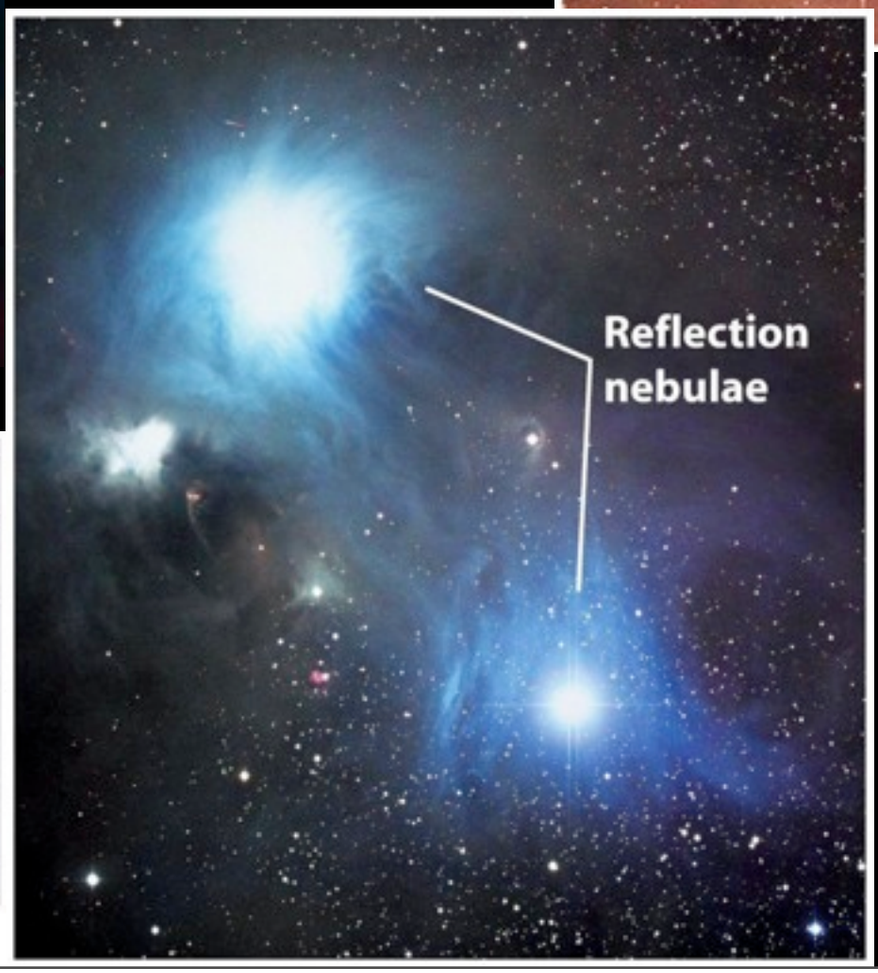
R. Thompson (Univ. Arizona), S. Stolovy (Univ. Arizona), C.R. O'Dell (Rice Univ.) and NASA

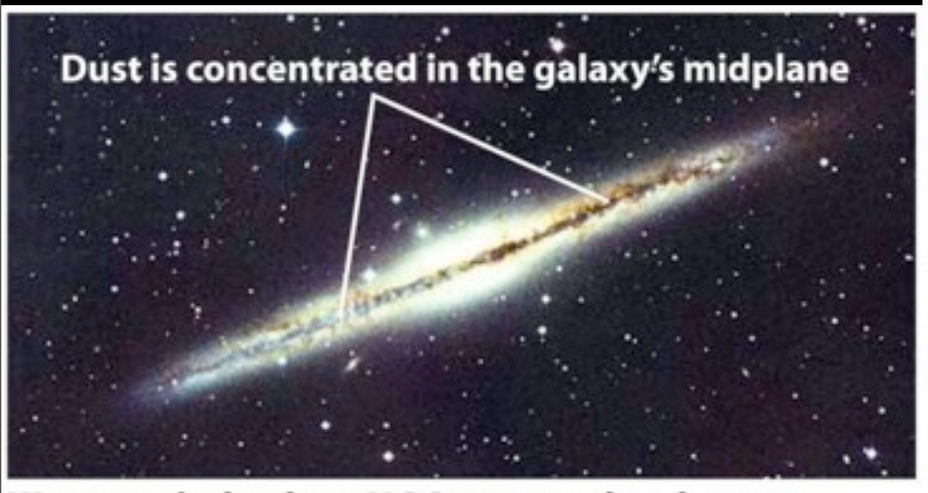
Hubble Space Telescope


Trapezium cluster:
< 10^5 yr old
(largest star ~30 solar masses)
star density > 10^5 stars pc^{-3}
0.07 pc

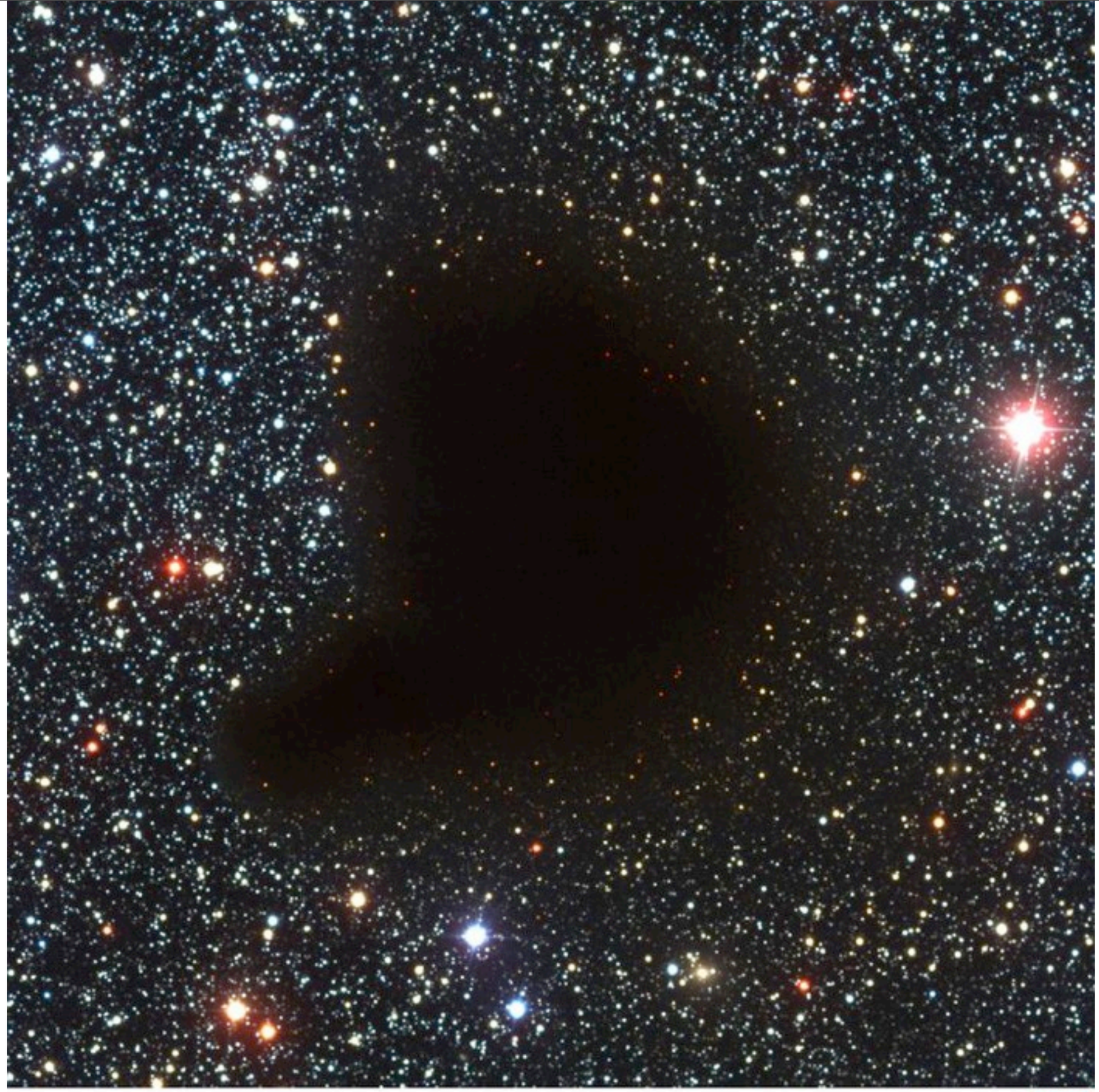
Molecular Clouds





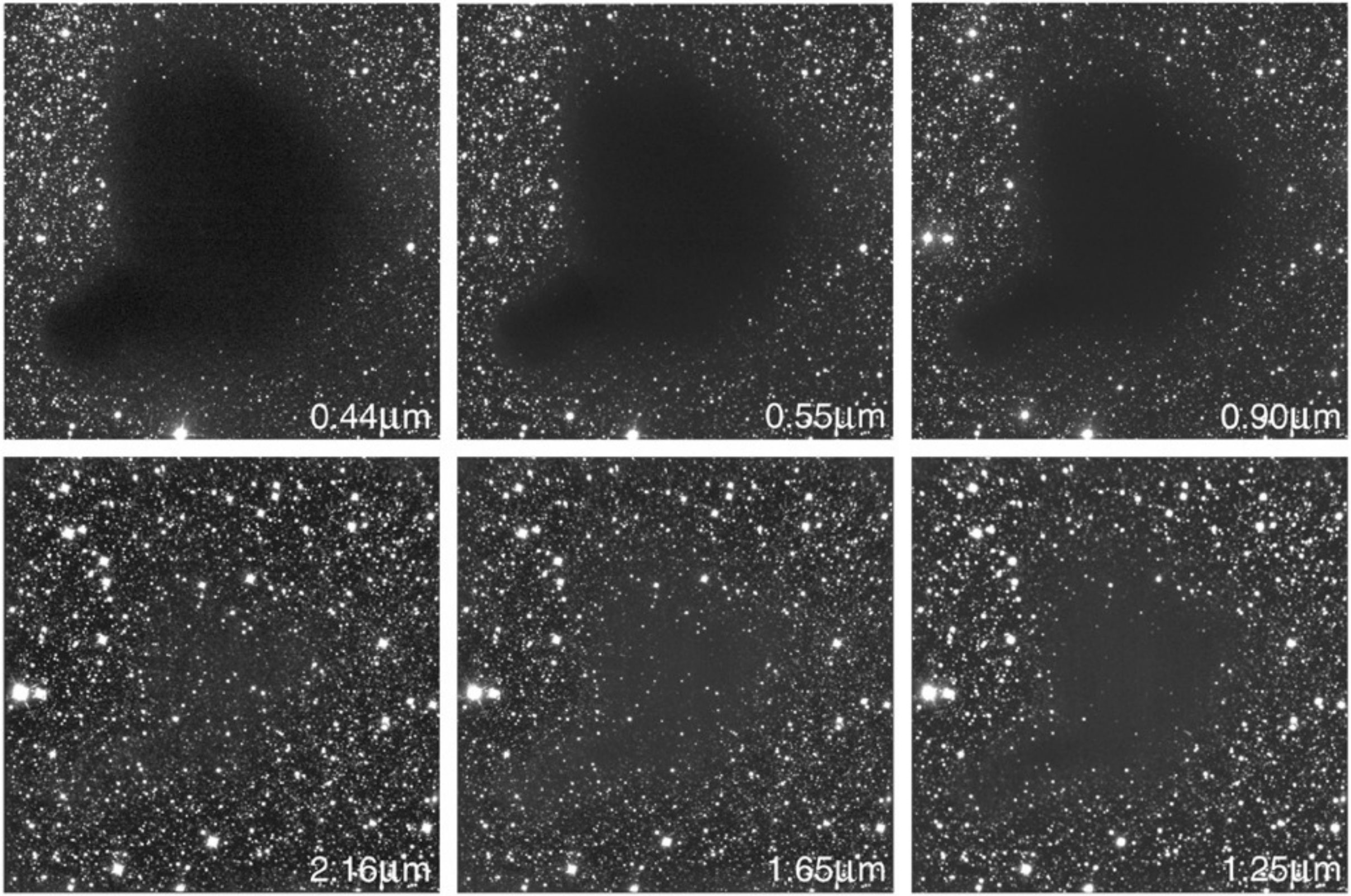


We see spiral galaxy NGC 891 nearly edge-on



The "Black Cloud" B68
(VLT ANTU + FORS1)

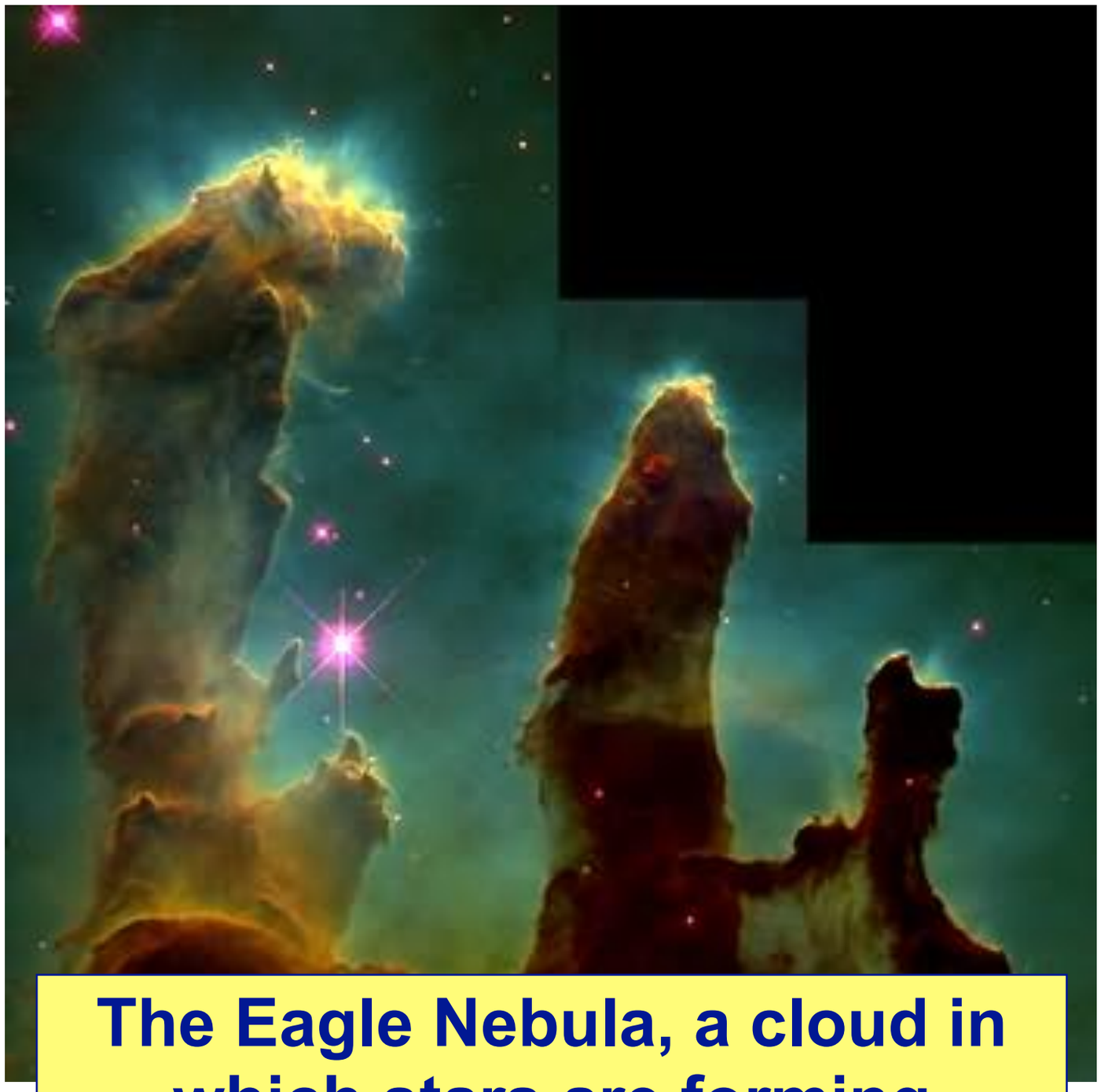
ESO PR Photo 20a/99 (30 April 1999)



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?

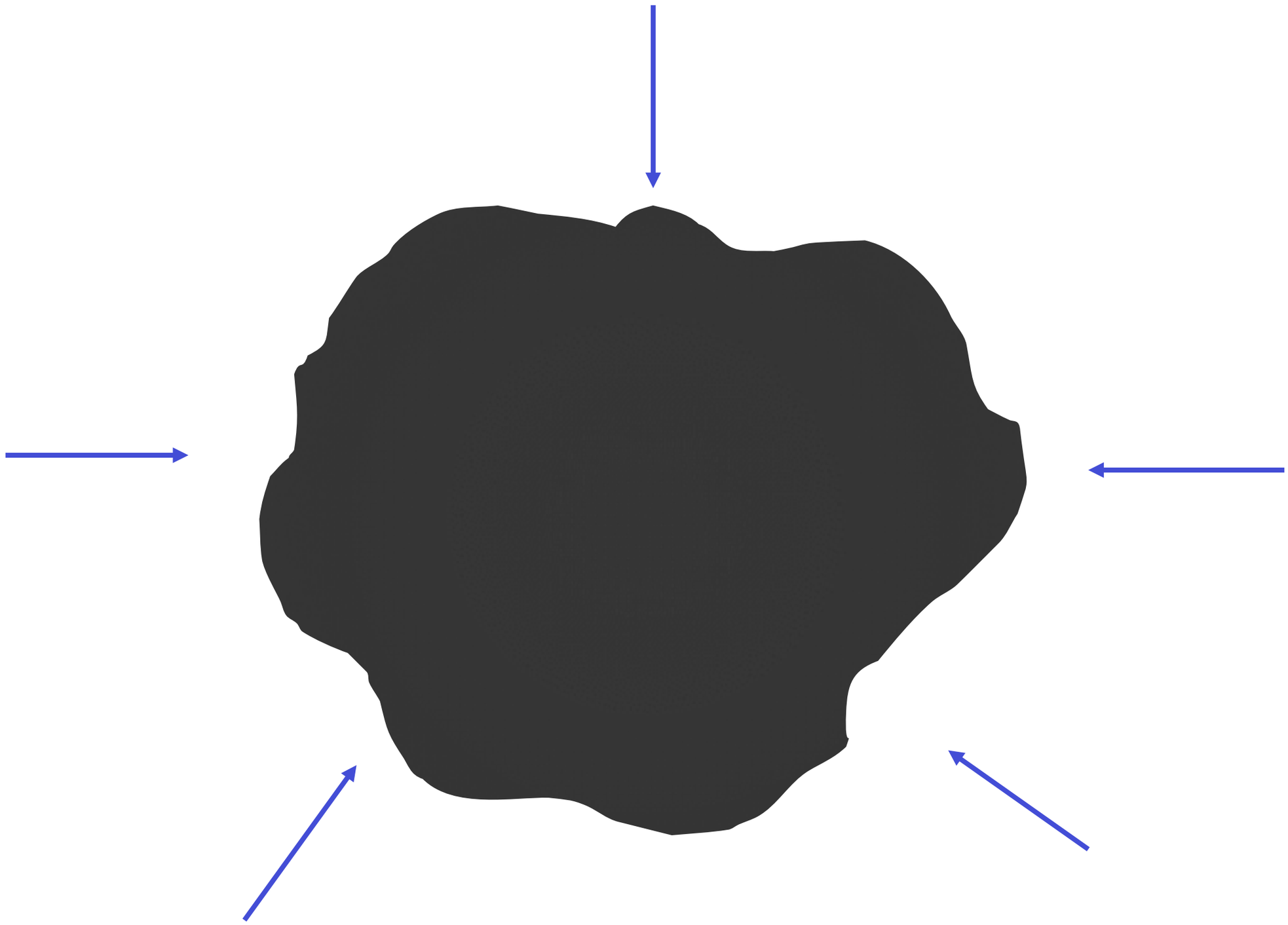
A. gravity force weaker

B. gravity force same

C. gravity force stronger

Q: and so what eventually happens?

Gravitataional Contraction



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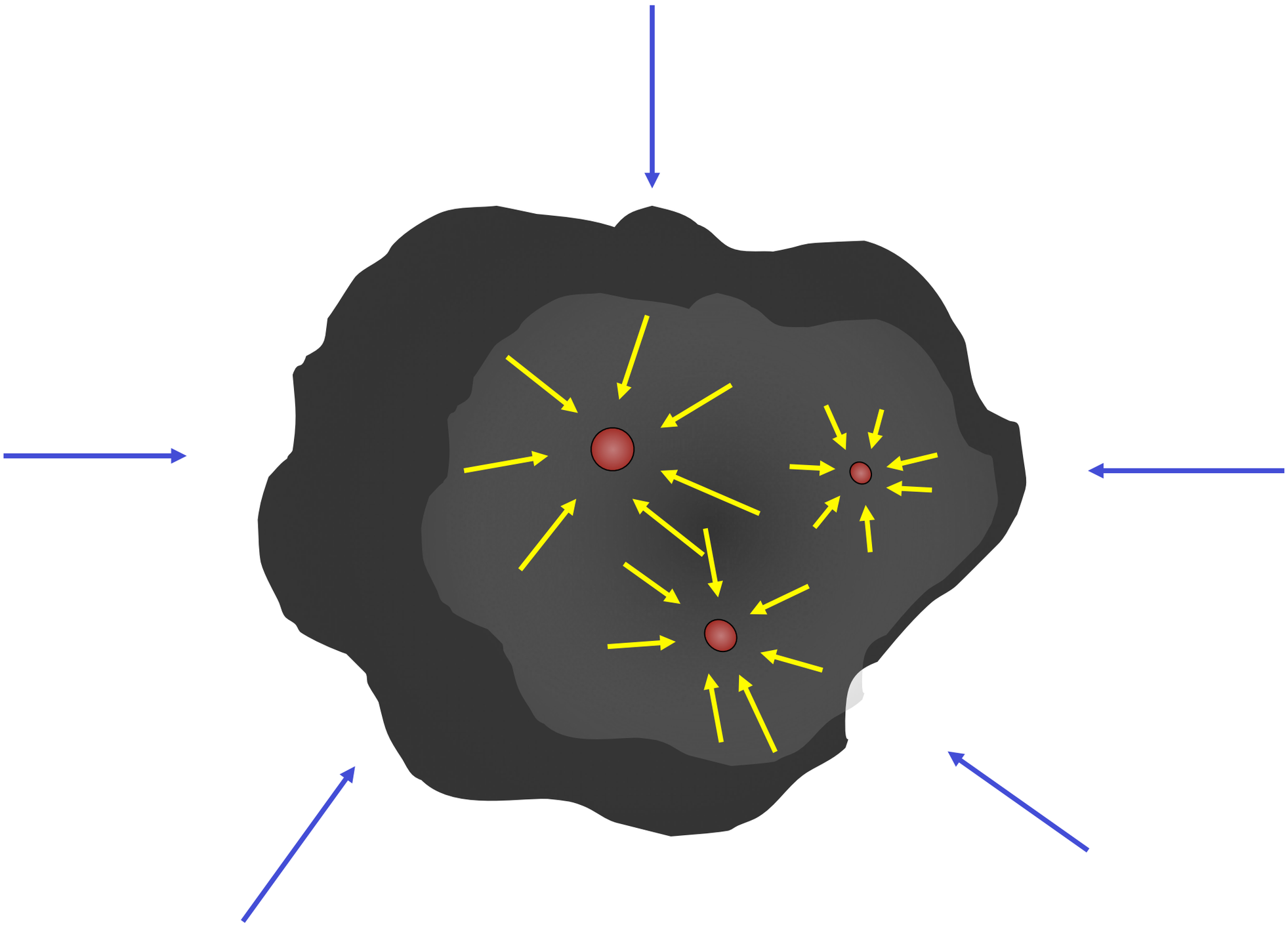


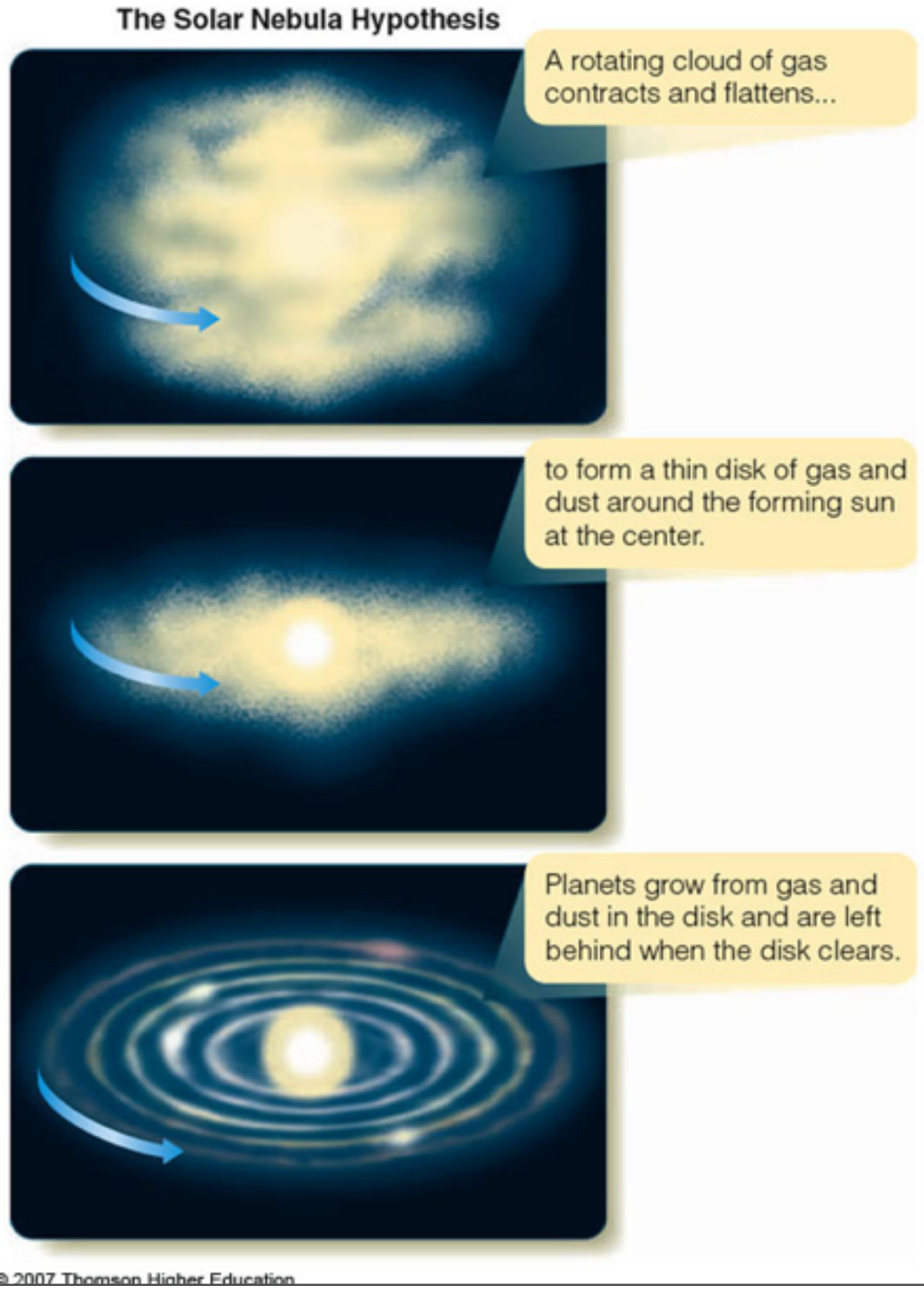
Why do large bodies in our solar system have orderly motions?

The solar nebula began to collapse due to its own gravity

As it collapsed, it began to spin faster and faster

Sun forms at the center, surrounded by a flattened disk

Planets form from gas and dust in the disk



Gravitational Contraction

http://www.birthingthefuture.com/AllAboutBirth/americanway.php

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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.

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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.

http://www.birthingthefuture.com/AllAboutBirth/americanway.php

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

$$\text{ang. mom.} = \left(\begin{array}{c}\text{orbit}\\ \text{speed}\end{array}\right) \times \left(\begin{array}{c}\text{distance}\\ \text{to orbit axis}\end{array}\right)$$

Interlude: Angular Momentum

Spinning or orbiting objects in closed system have angular momentum.

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Angular momentum is a single, constant number

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Move closer to axis → speed up!

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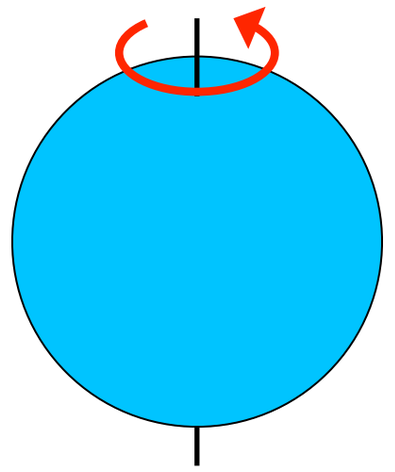
Taking The Solar System for a Spin

Solar nebula competition:
Gravity vs Angular Momentum

- If fall perpendicular to spin axis



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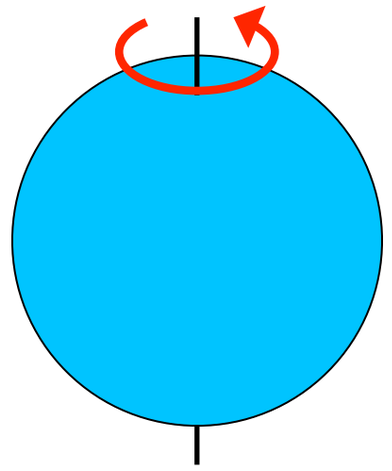

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  Need to speed up
  → resistance: centrifugal force

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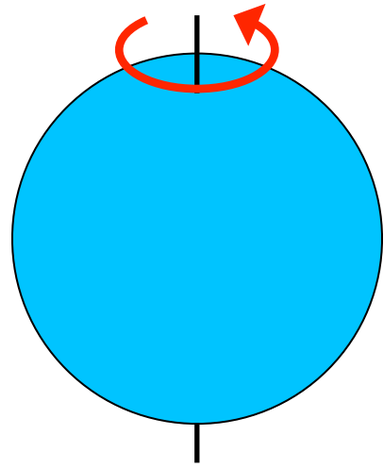

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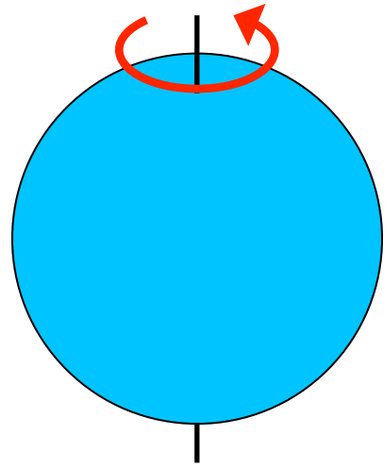

- If fall perpendicular to spin axis
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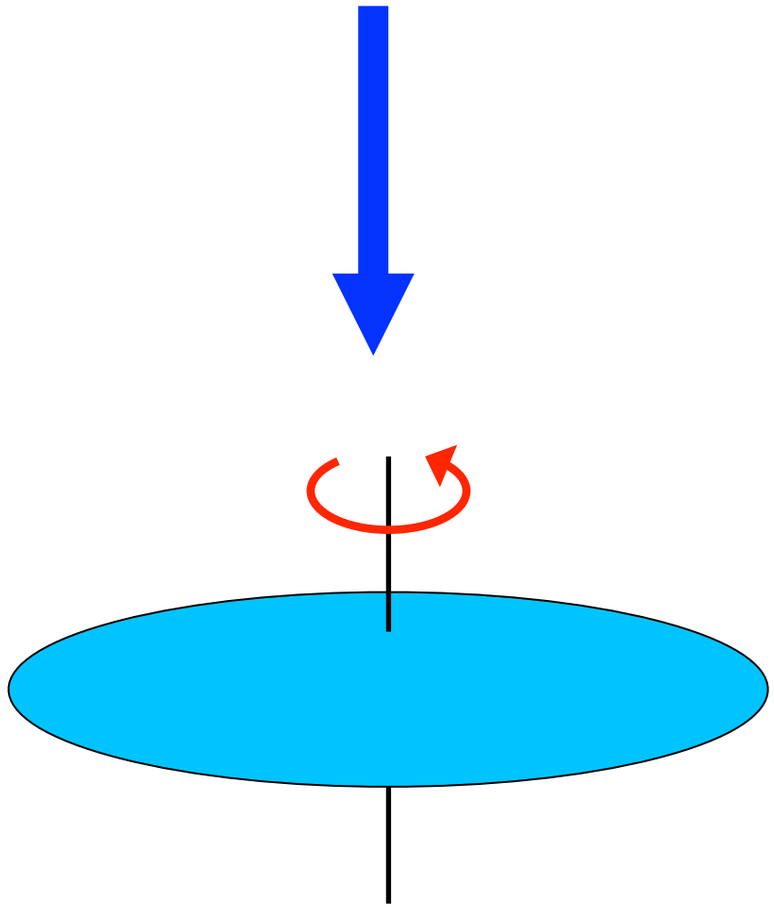
- If fall parallel to spin axis:
  same speed, so no resistance
  → forms protoplanetary disk
  swirling gas and dust
  raw material for planets



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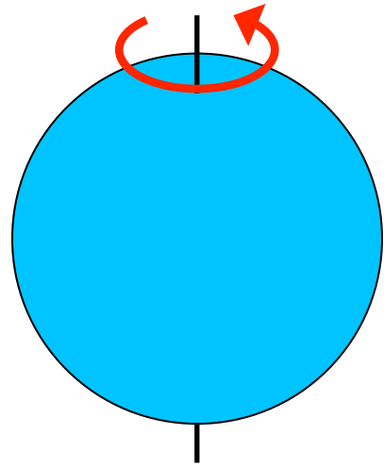

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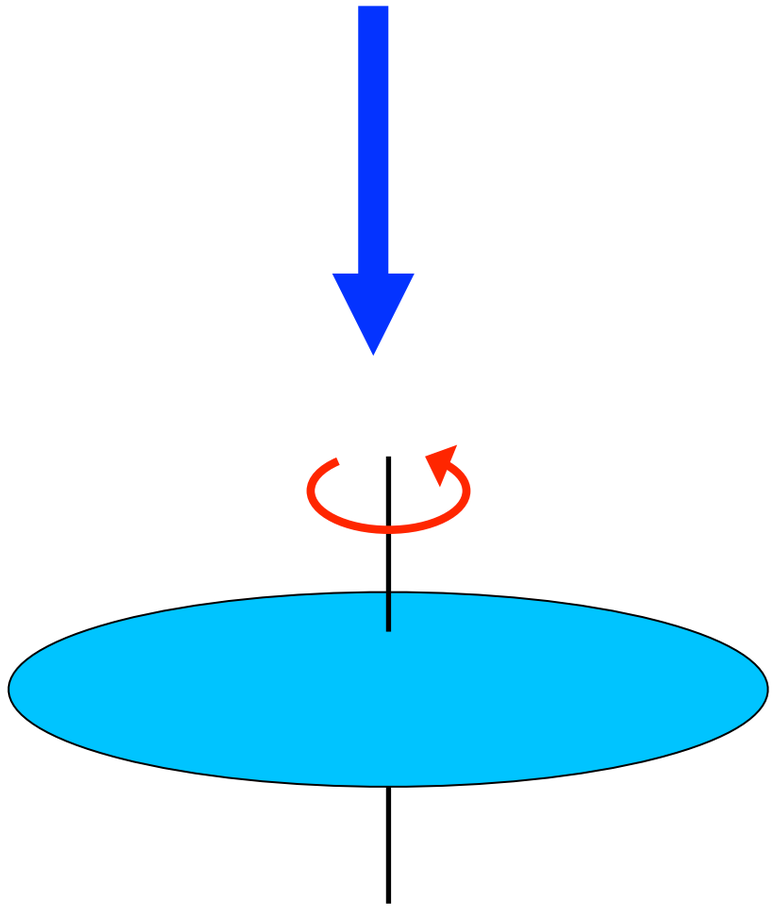

– Origin of planet's orbits!
– Origin of Ecliptic plane
– Organizes spins along initial spin axis

Taking The Solar System for a Spin

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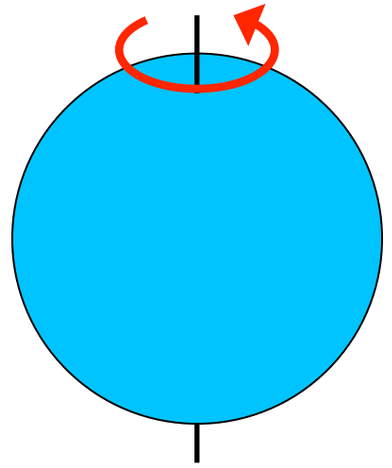

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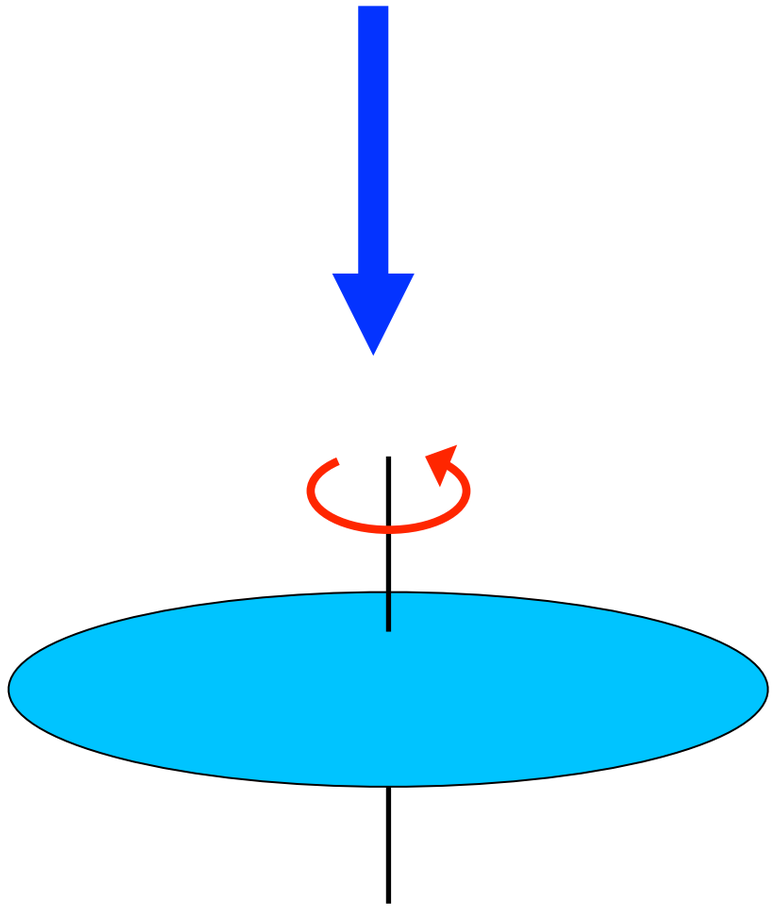

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Q: how can we test if these ideas are right?