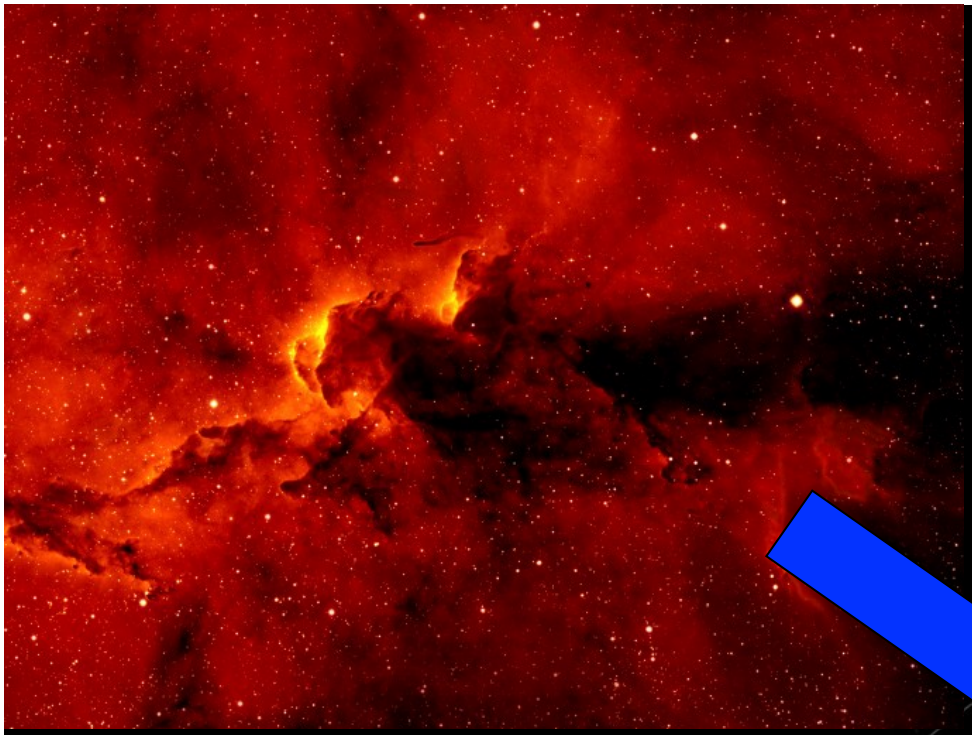
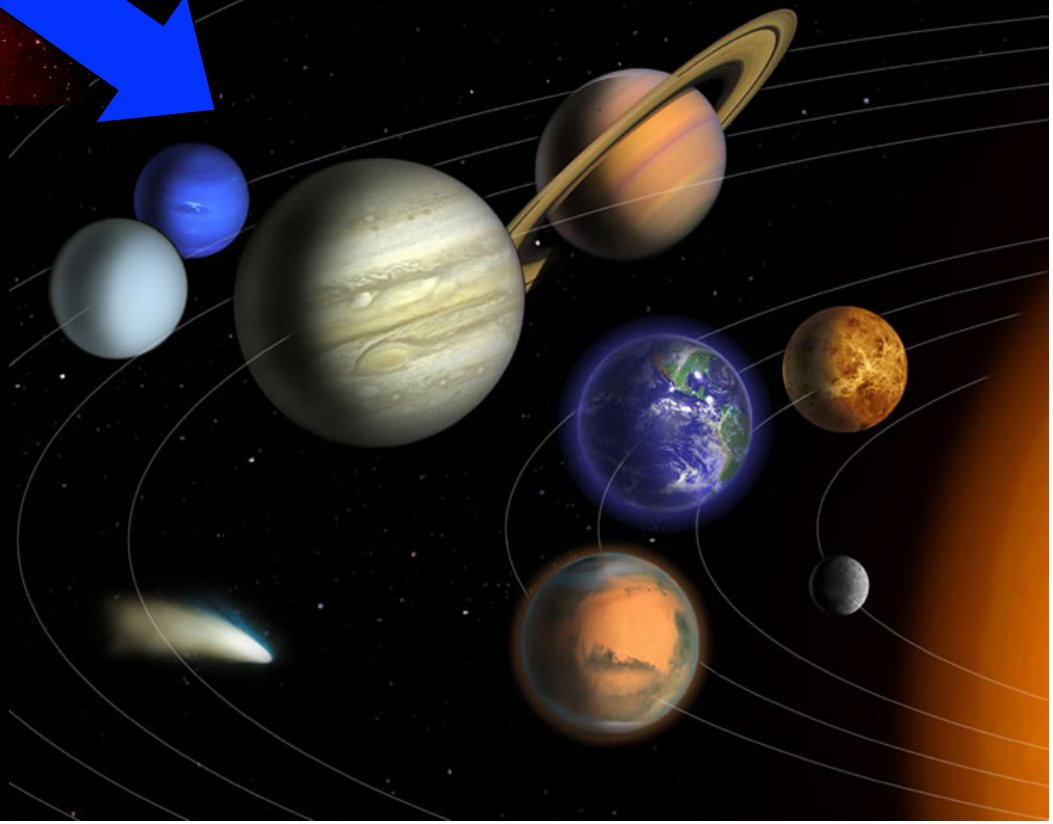
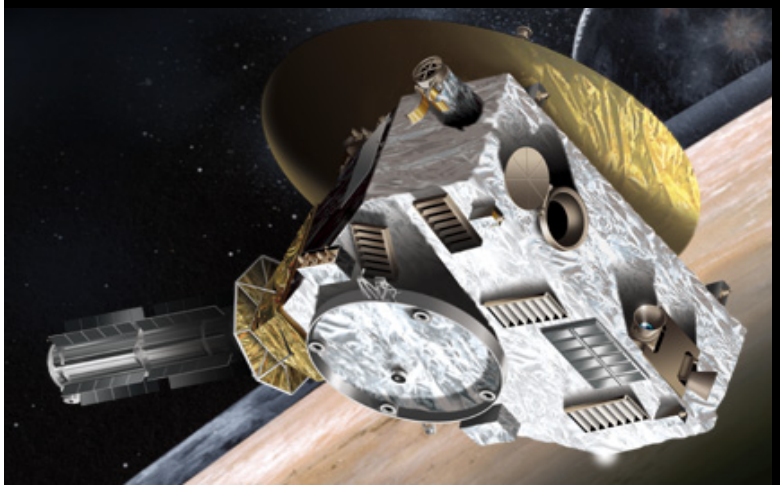


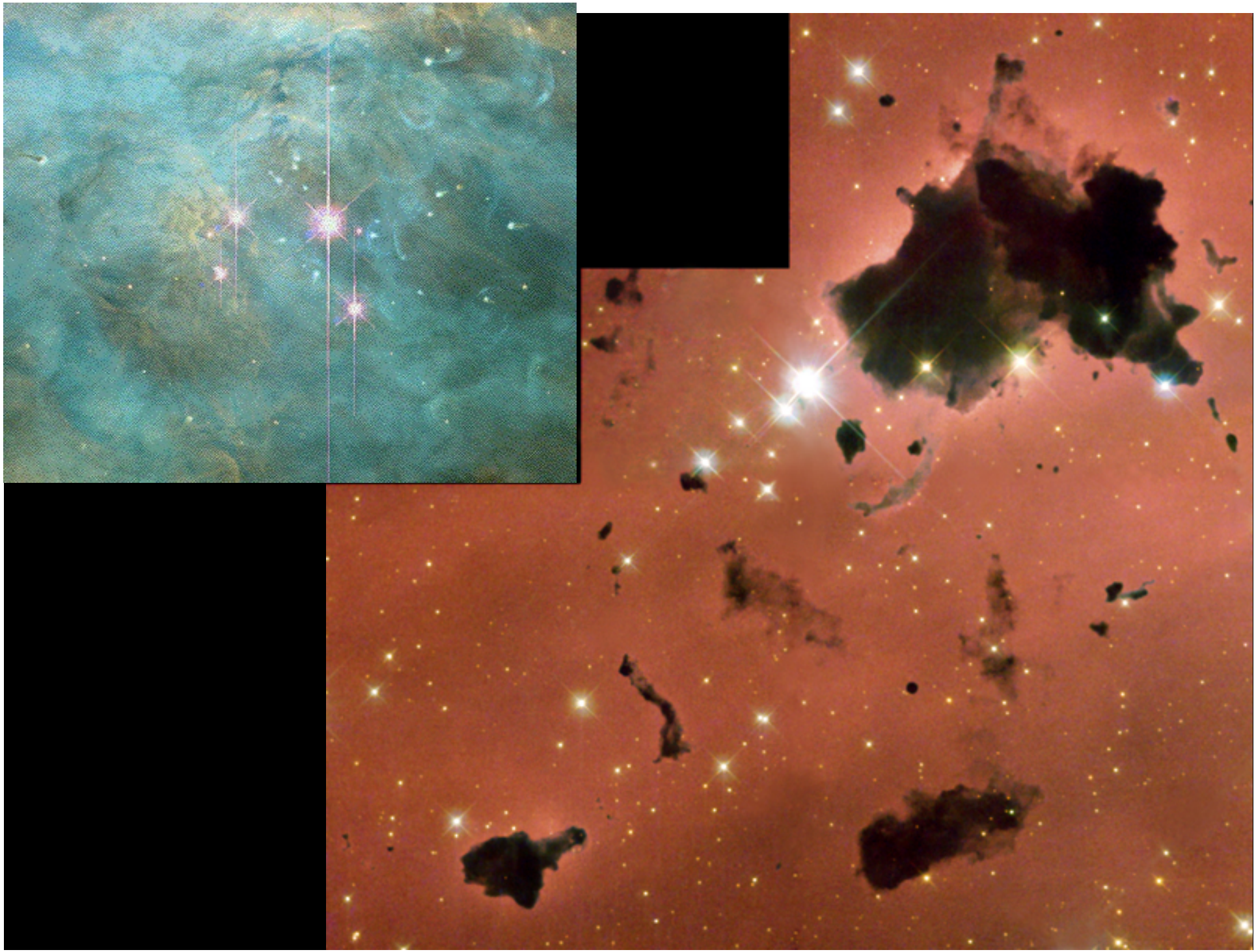
Fran Bagenal

Solar System Formation



New Horizons
Mission To Pluto

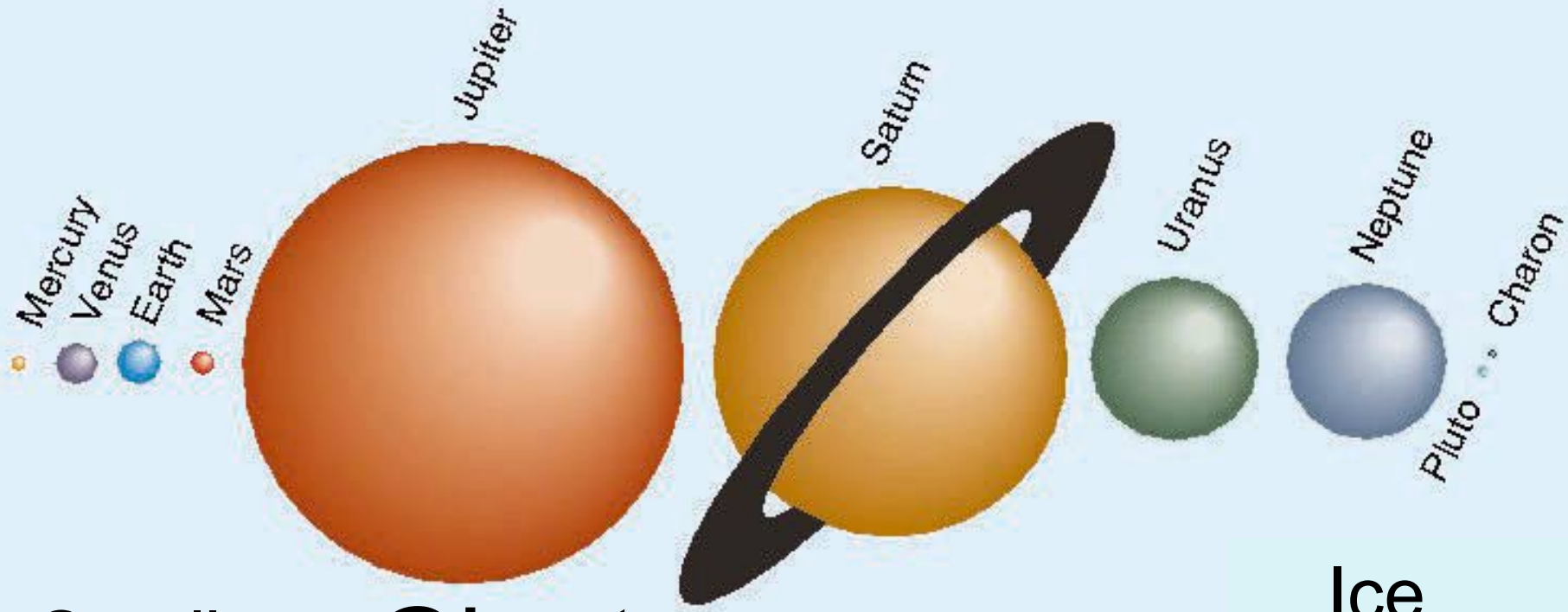




Protoplanetary Disks in the Orion Nebula
Hubble Space Telescope • WFPC2

NASA, J. Bally (University of Colorado), H. Throop (SWRI), and C.R. O'Dell (Vanderbilt University)
STScI-PRC01-13

The Planets at a Glance



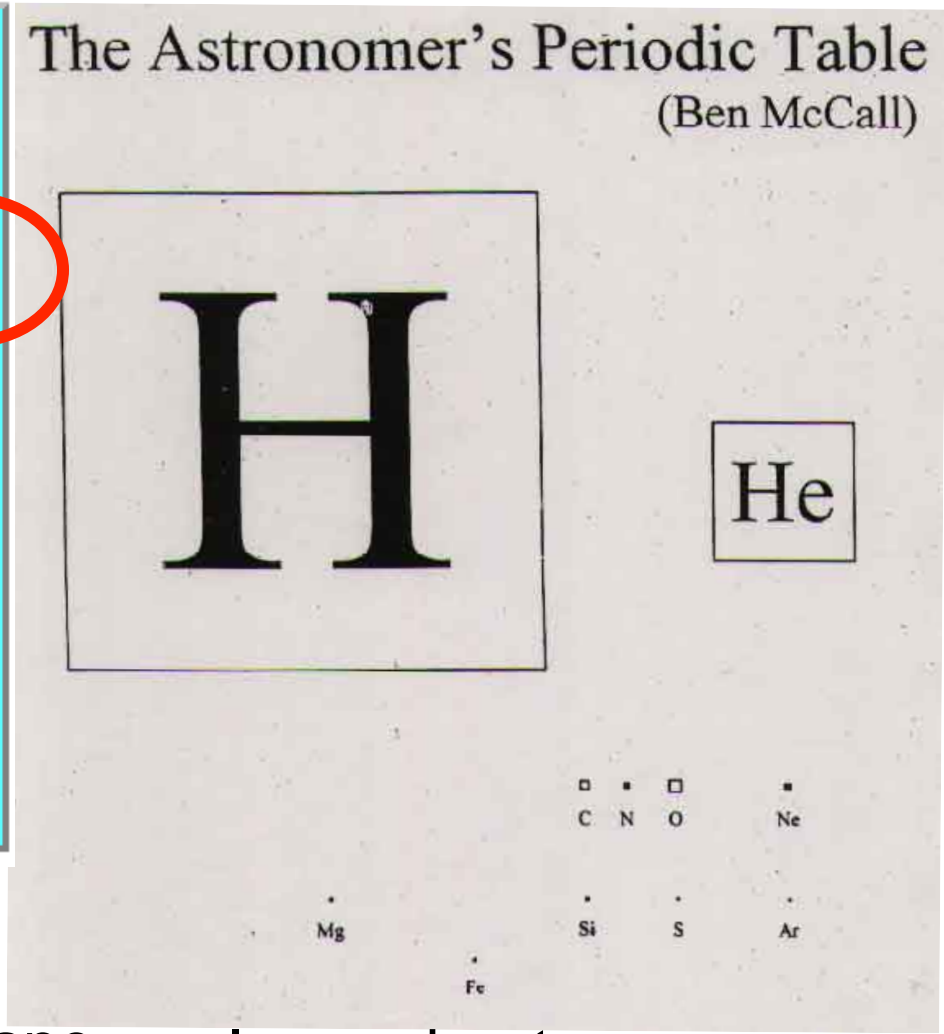
Small
Inner
Rocky
Planets

Giant
Outer
Gas
Planets

Ice
Dwarf
Planets

The Cosmic Abundance of Elements

Element	Symbol	Atomic Number	Number of Atoms per Million Hydrogen Atoms
Hydrogen	H	1	1,000,000
Helium	He	2	68,000
Carbon	C	6	420
Nitrogen	N	7	87
Oxygen	O	8	690
Neon	Ne	10	98
Sodium	Na	11	2
Magnesium	Mg	12	40
Aluminum	Al	13	3
Silicon	Si	14	38
Sulfur	S	16	19
Argon	Ar	18	4
Calcium	Ca	20	2
Iron	Fe	26	34
Nickel	Ni	28	2



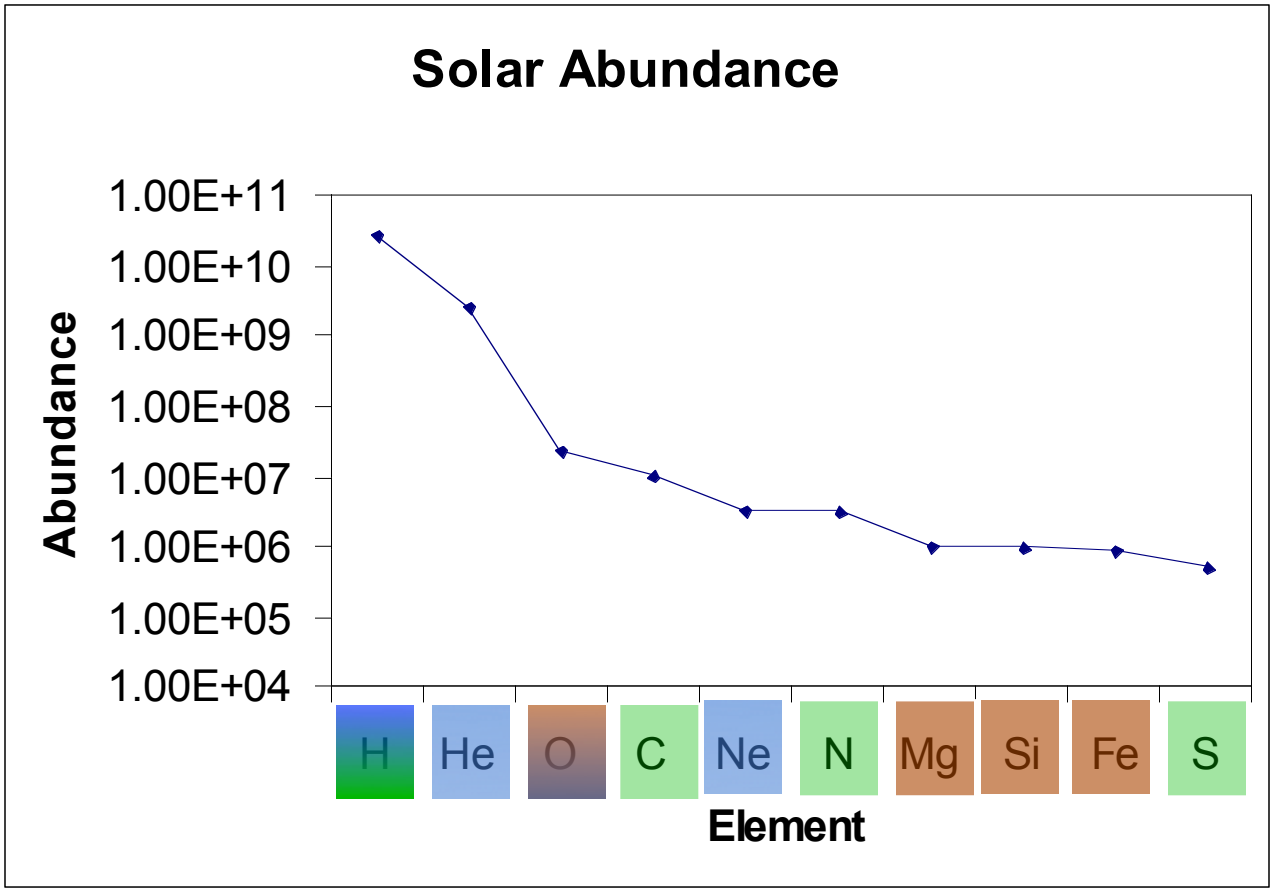
H_2O NH_3 CH_4

Water, **A**mmonia, **M**ethane

CO_2 CO N_2

Ignore inert gases
He, Ne, Ar

The Universe's Top Ten



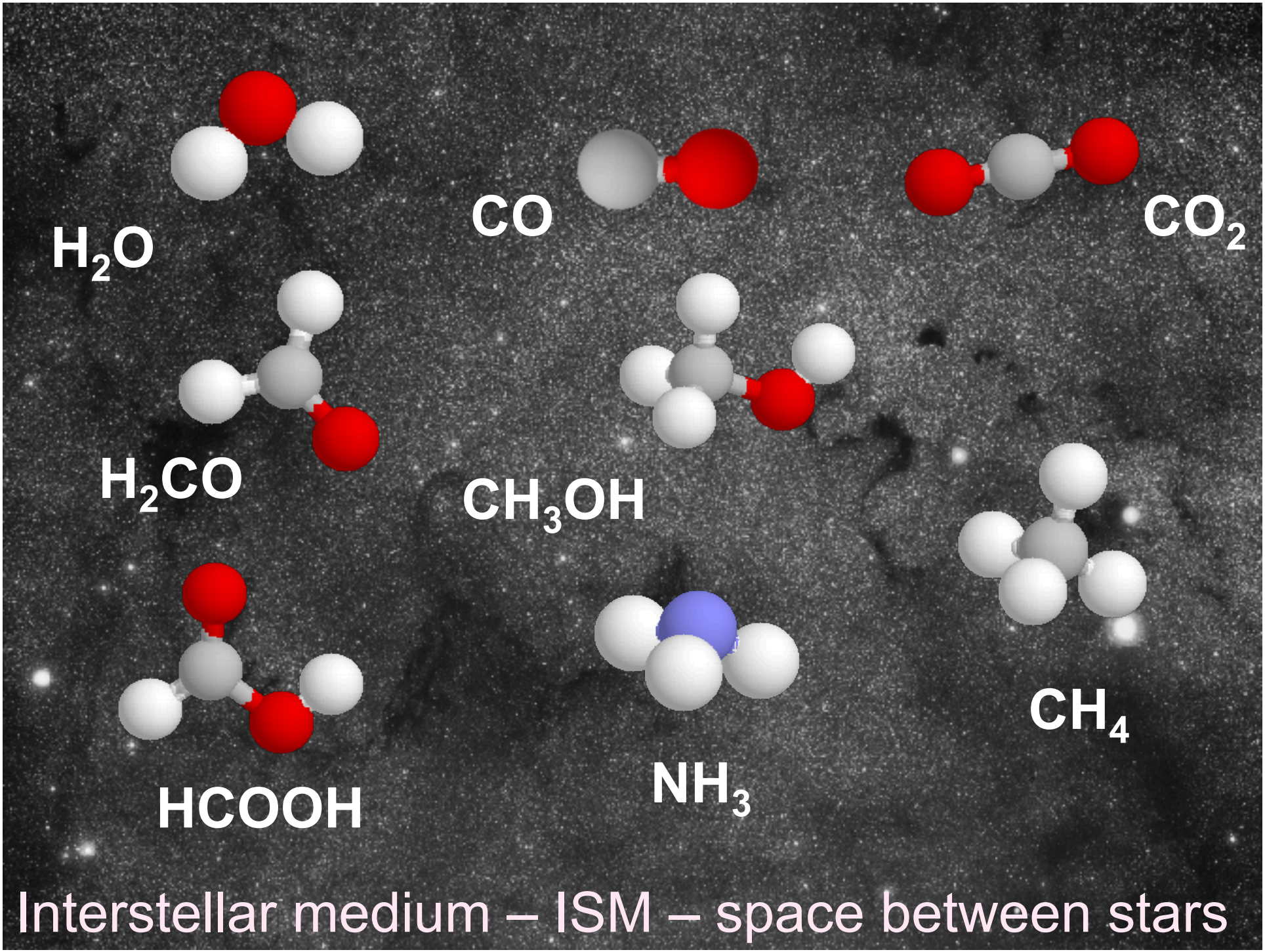
Noble gases

Water

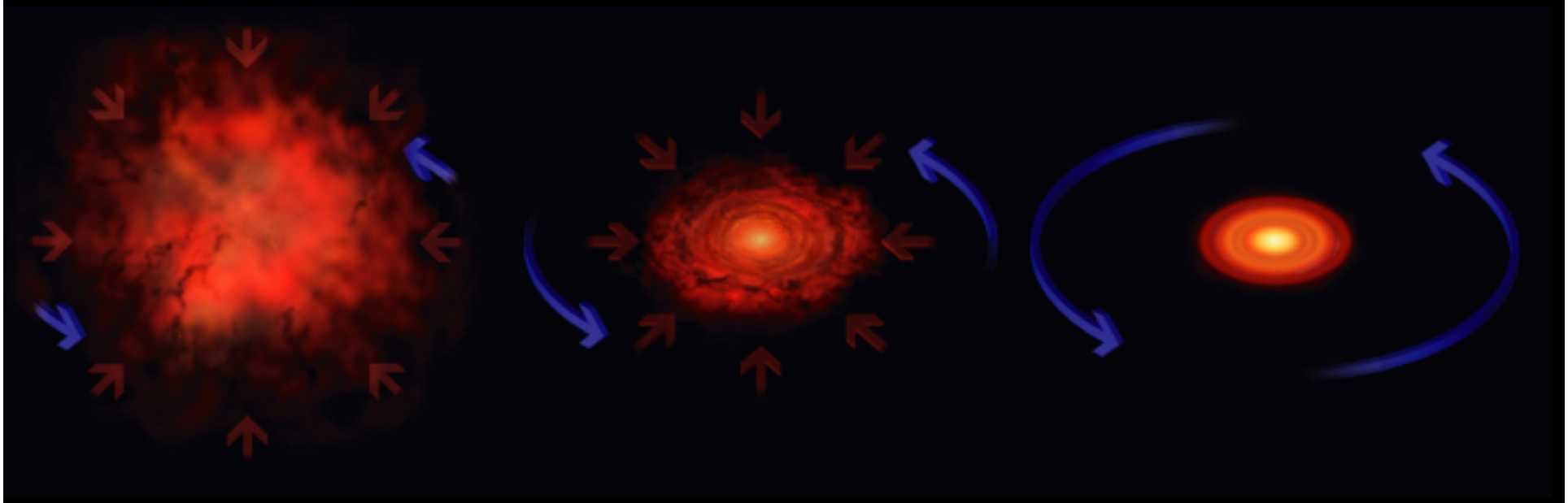
Avg. solid => 50/50 rock/ice

Rocks

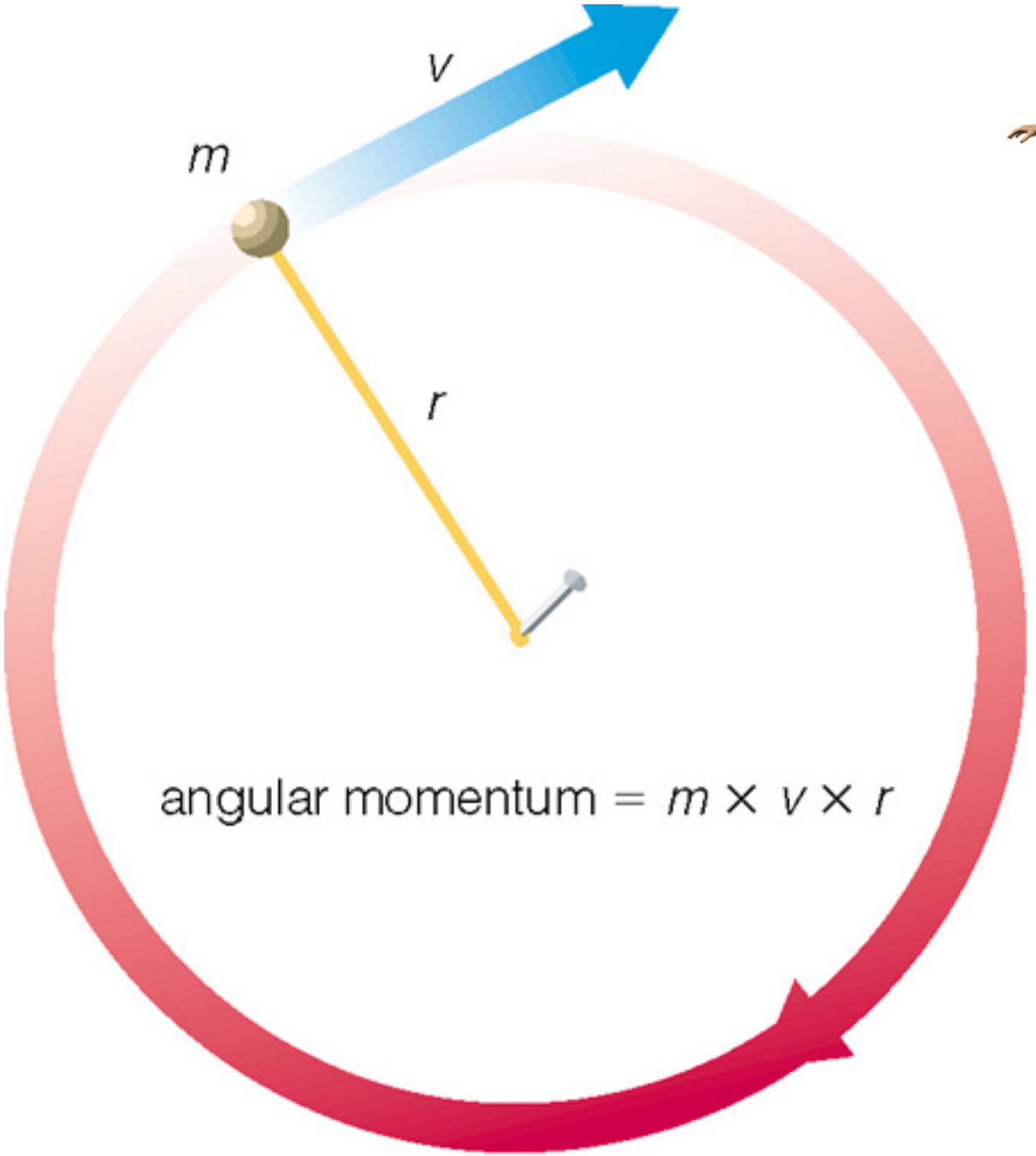
Life building blocks

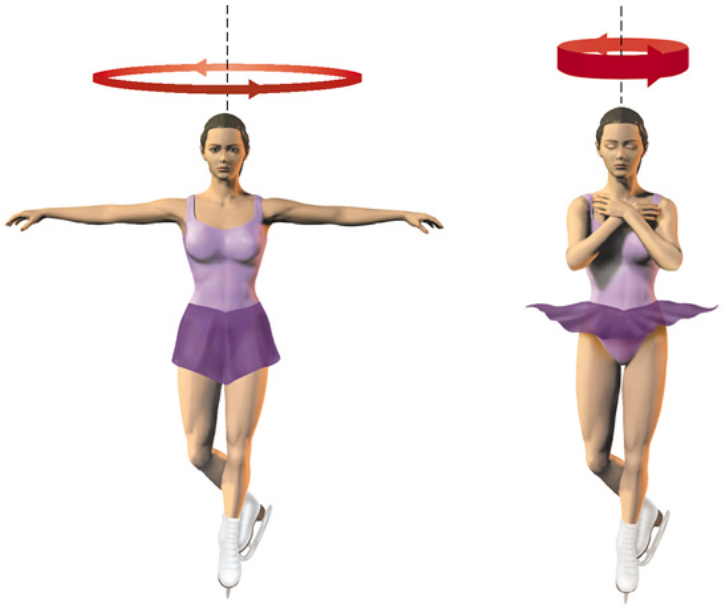

H_2O
CO
CO_2
H_2CO
CH_3OH
CH_4
HCOOH
NH_3
Interstellar medium – ISM – space between stars

Collapse of the Solar Nebula



Collapse Spin-up Form Disk





Conservation of Angular Momentum

MVR = Constant

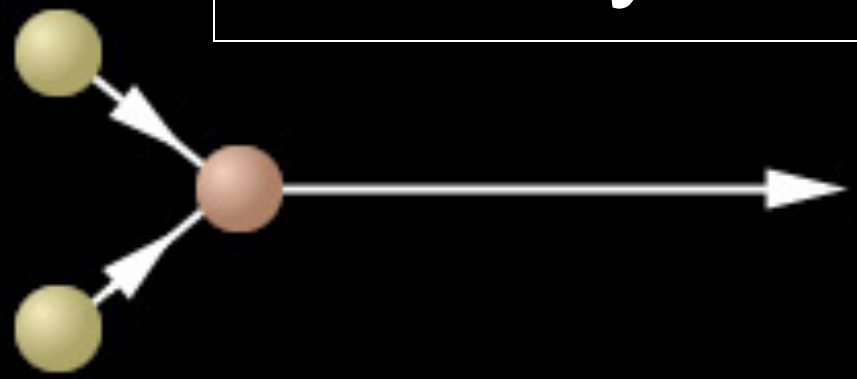
Where did the angular momentum come from???

Small random motions averaging out to a tiny bulk motion

- this bulk motion is then “amplified” (due to conservation of angular momentum) as the cloud collapses

Demonstration: Take a flat-bottomed bowl (preferably glass) and fill it to ~2" deep with water. Shake a little pepper into the water. Stab the water with a stick/pencil - not stir. Then wait. After about a minute or two you should see a slow bulk motion develop, rotating one direction or the other.

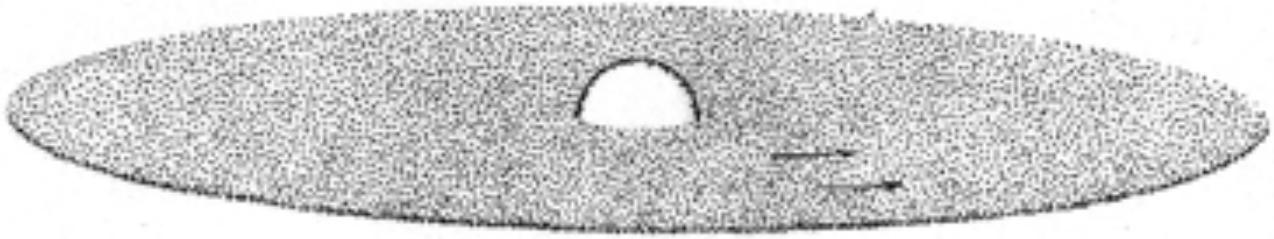
Why a Disk?



Oblique collisions ⇒ regular orbits

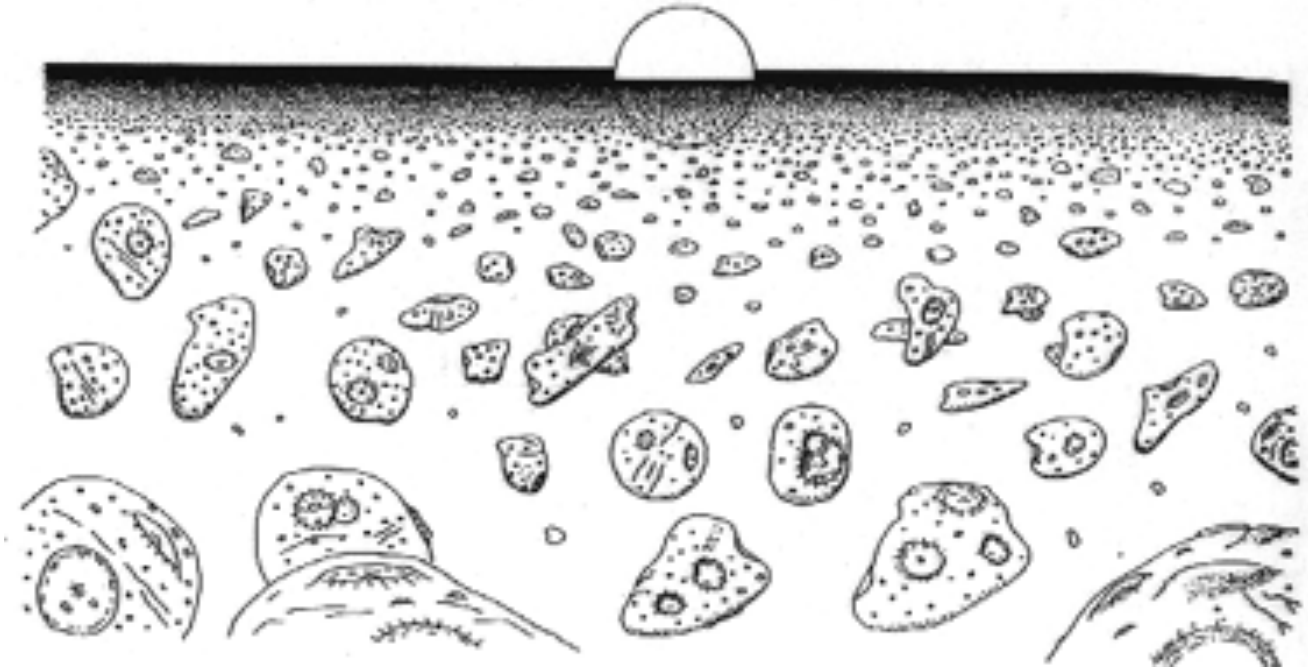
Head-on collisions ⇒ smaller object

- As the cloud collapses (due to gravity) the gases, dust and stuff orbit the central mass.
- On the timescale of an orbit, gravity still balances the centrifugal force.
- The disk is not formed by being “flung out into a disk”.
- Nor does gravity of the disk “pull the material down onto a disk”.
- These are common misconceptions.

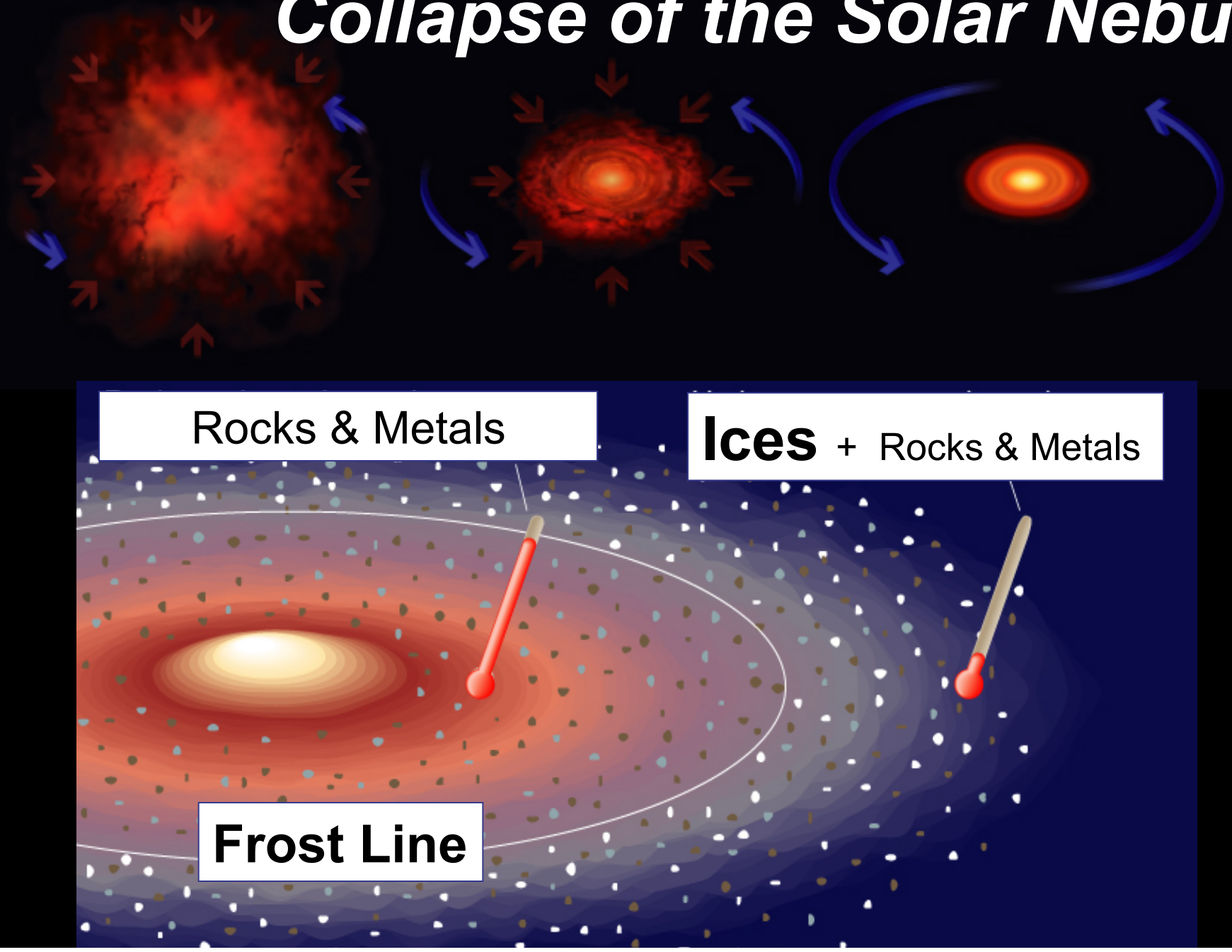


Go with the flow or crash to oblivion

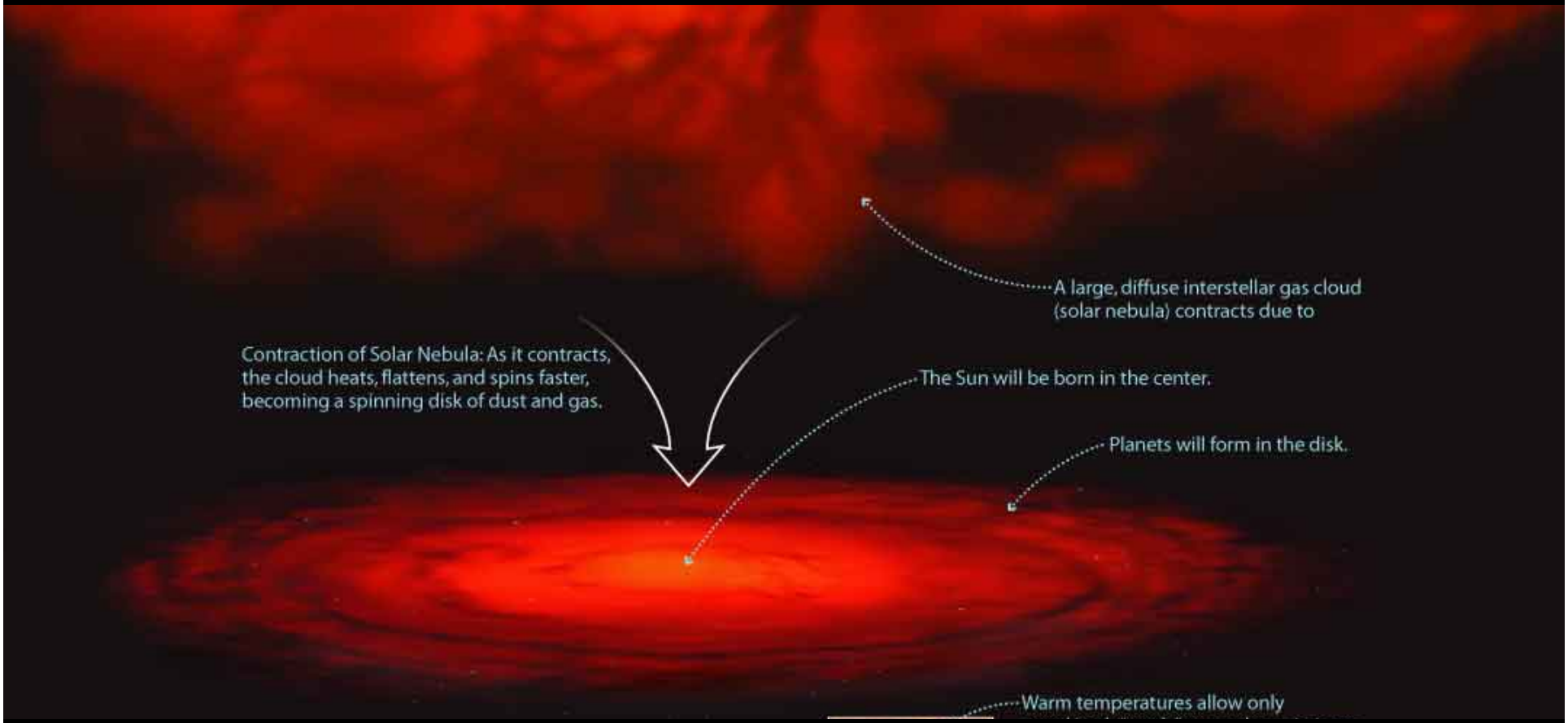
- Extreme Conformism!



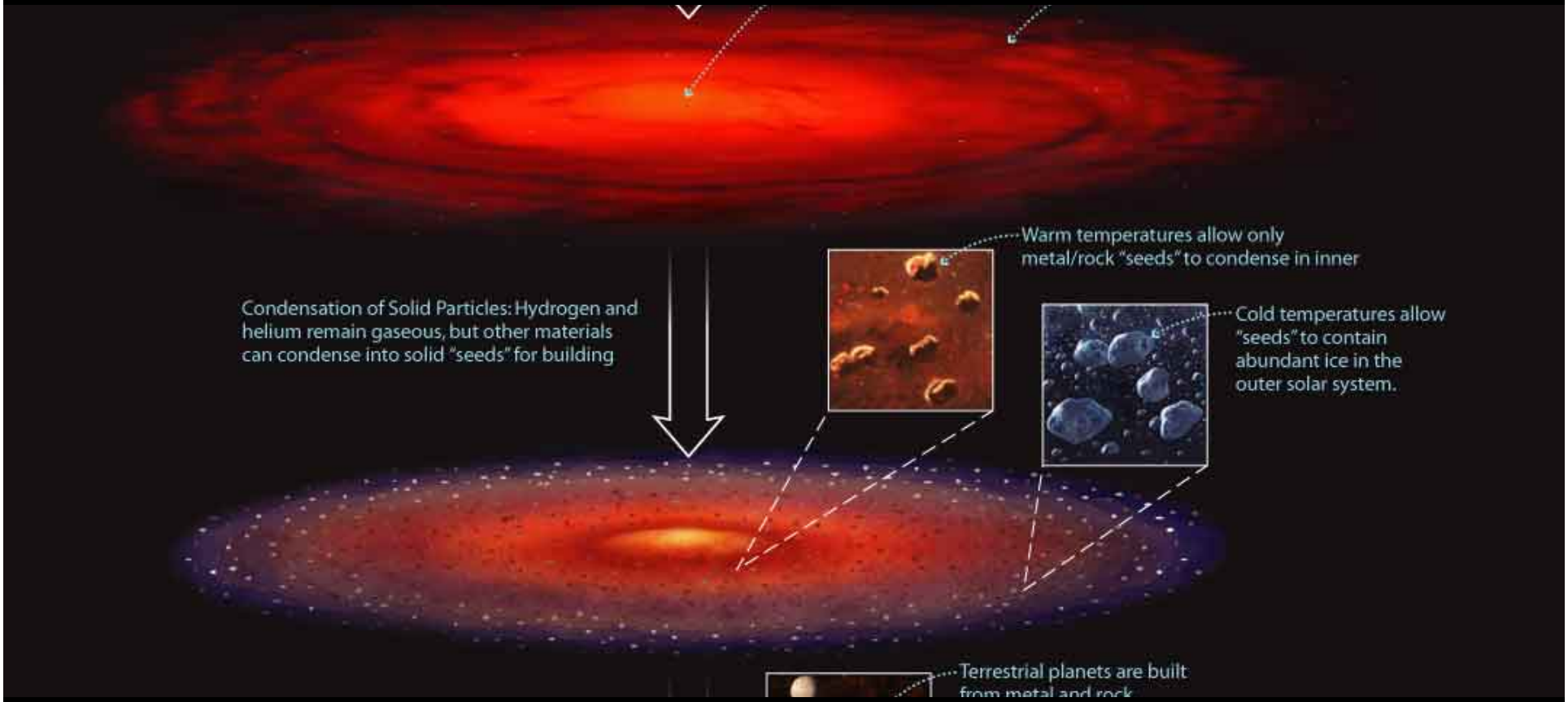
Collapse of the Solar Nebula

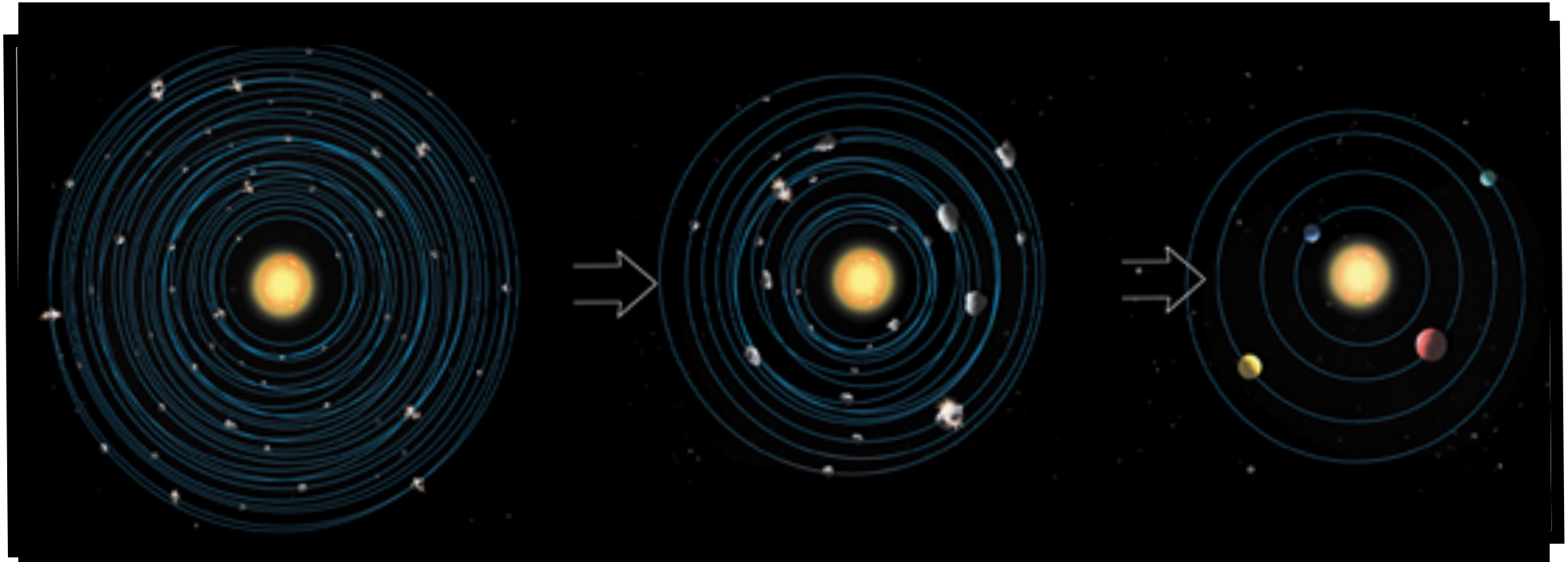


Summary of Solar System Formation - Part 1



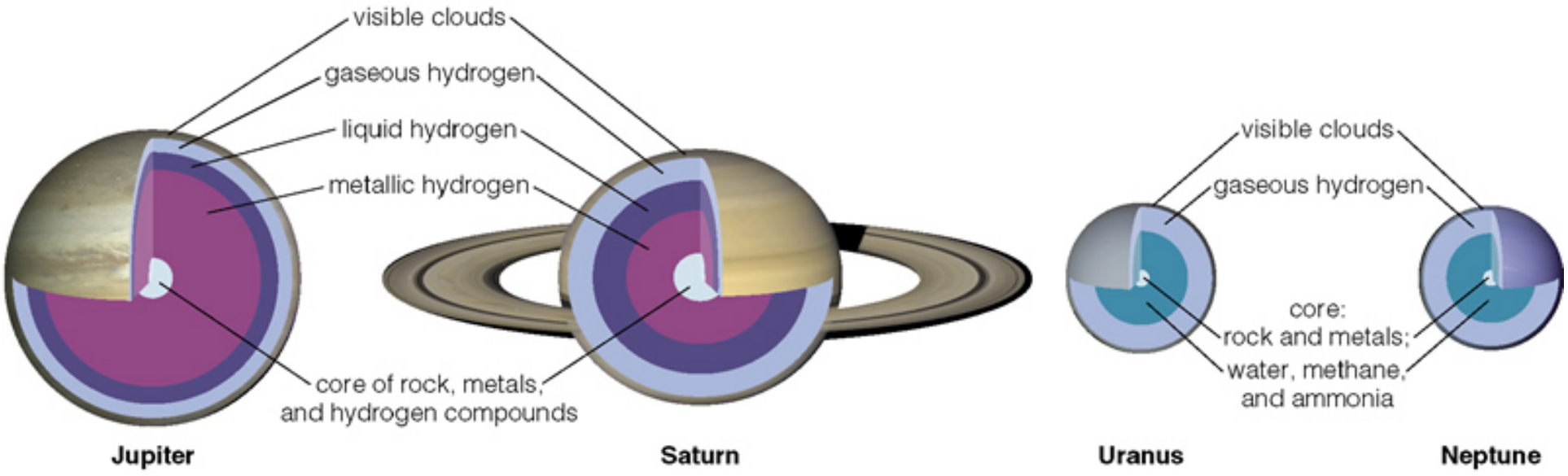
Summary of Solar System Formation - Part 2



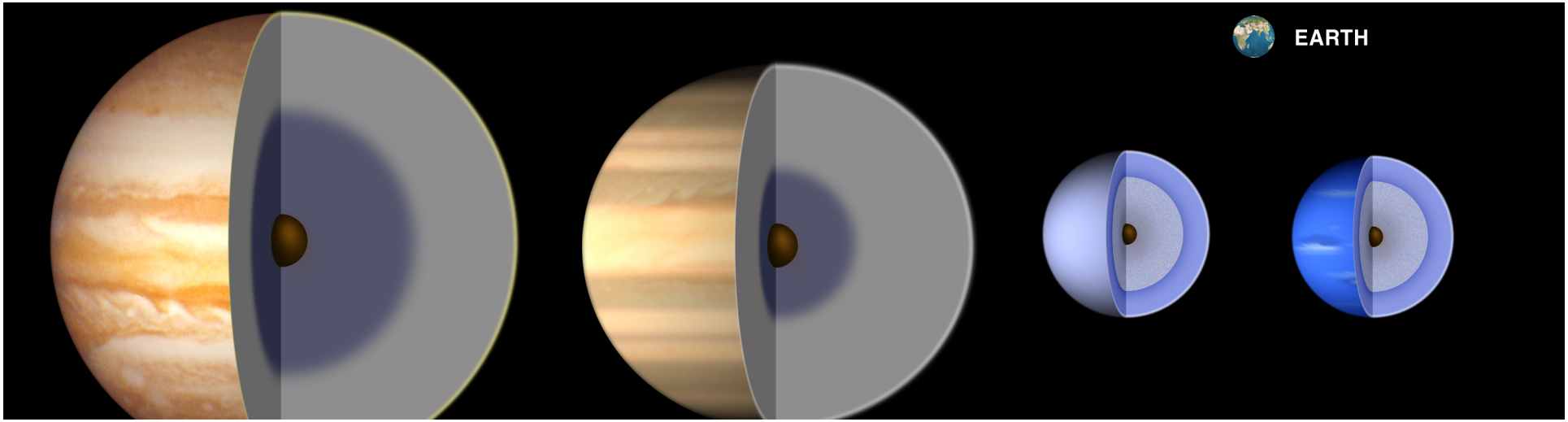


Planetesimals

- ***Oligarchic growth*** - the bigger get bigger
- REALLY big planetesimals (~20 x Earth) strong gravity pulls in hydrogen - the most abundant gas - and become GIANT.



Hydrogen envelopes over cores of rock, metals and **W**ater, **A**mmonia, **M**ethane



Why 3 Types of Planets?

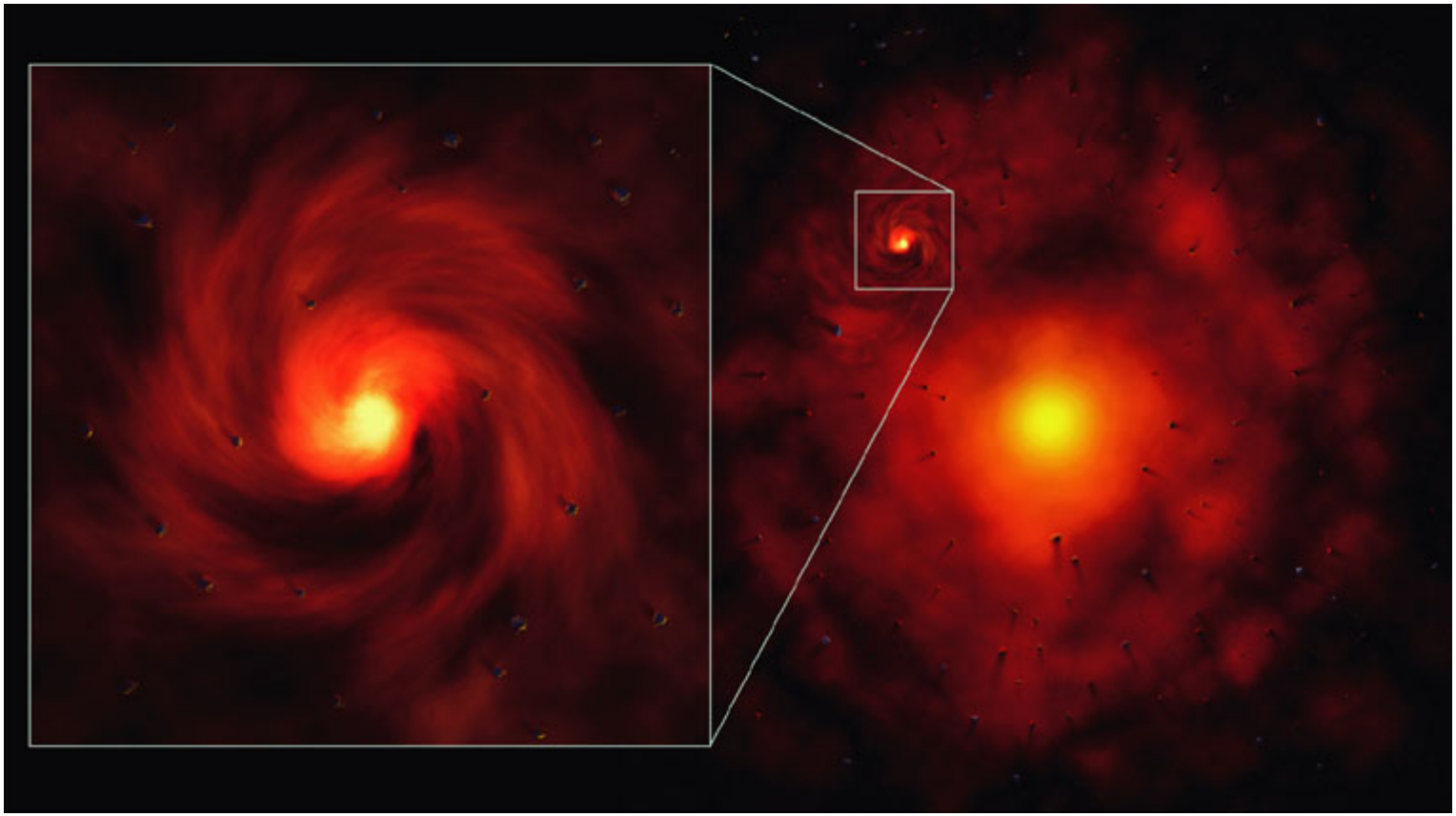
1. **Cosmic Abundance of Elements**
2. **Temperature Colder Farther from Sun**

- Ø Abundant ices condense beyond frost line
- Ø Snowballs -> bigger snowballs
- Ø Giant snowballs have enough gravity to hold H - most abundant element - > giant gas planets - *Jupiter, Saturn, Uranus, Neptune*
- Ø Small amounts of rock & metal-> terrestrial planets - *Mercury, Venus, Earth, Mars*
- Ø Ice dwarfs, comets, asteroids = leftovers

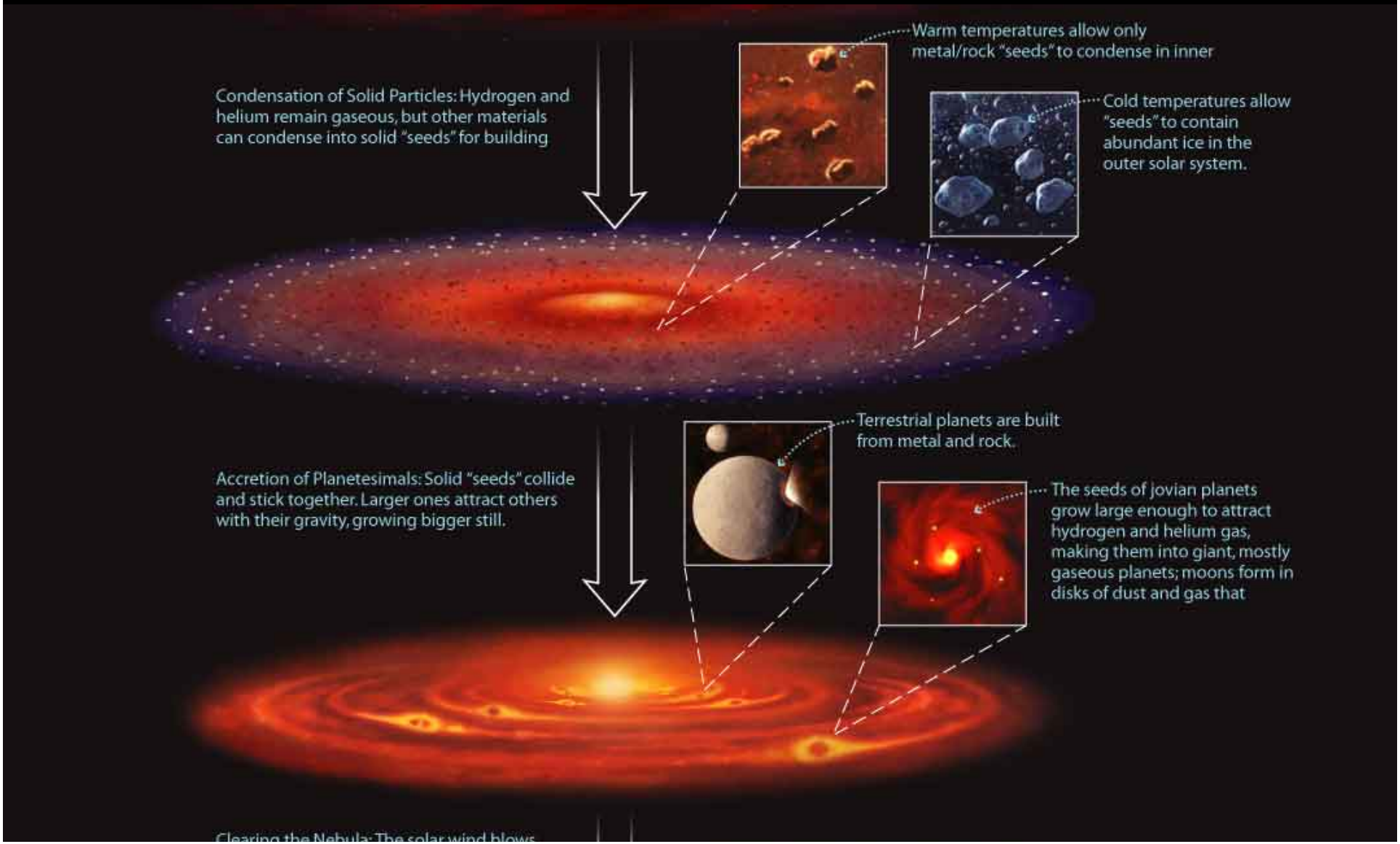
- Pluto, Xena, and ?

Building the Planets

- Each jovian planet formed its own “miniature” solar nebula.
- Moons formed out of the disk.



Summary of Solar System Formation - Part 3



But there's still (a) gas and (b) junk between planets

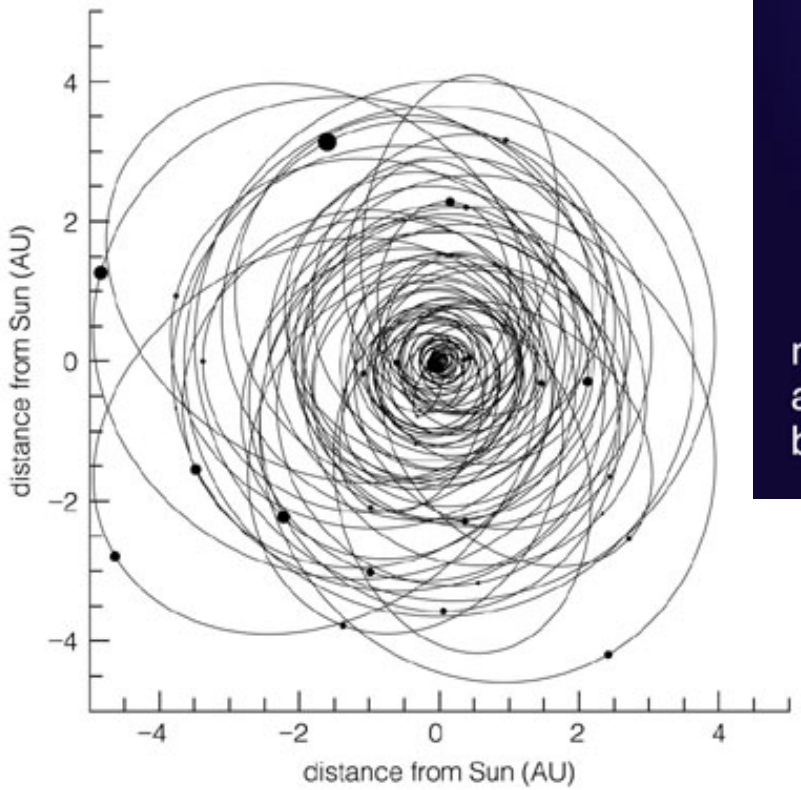
What happens to the gas?

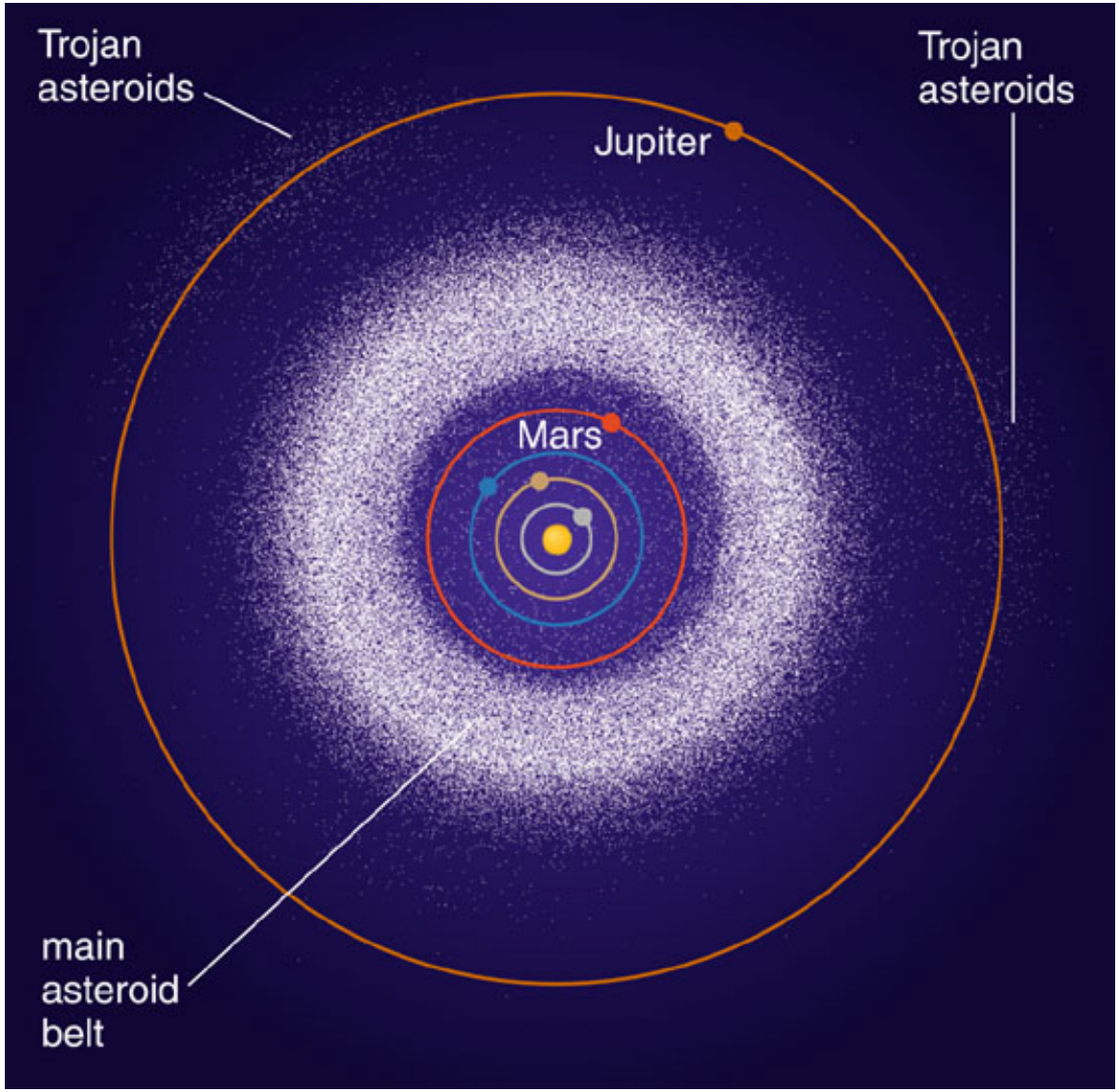
Young stars go through phase of very strong solar wind - blows away gas

But there's still (a) gas and (b) junk between planets

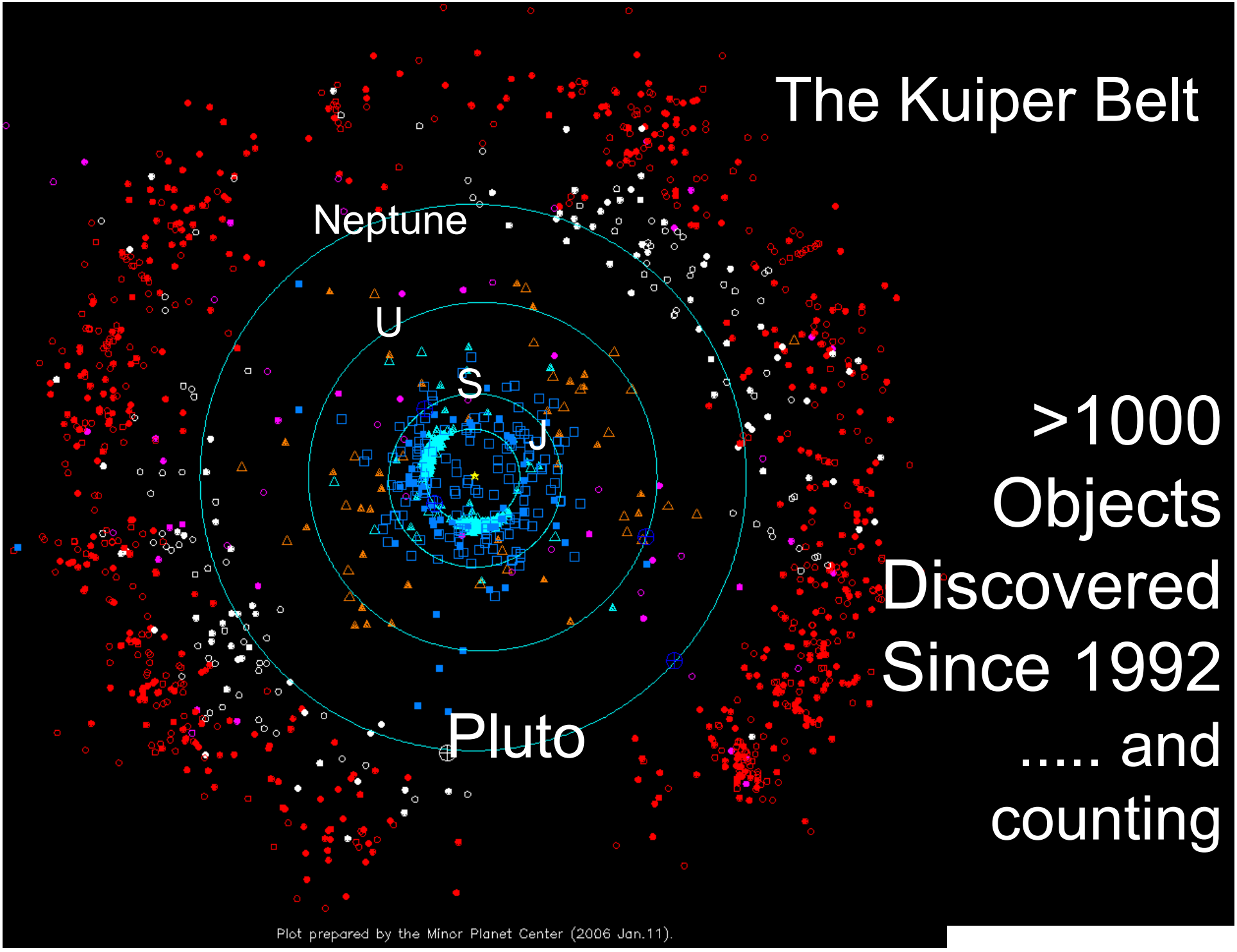
What happens to the junk?

- Gets kicked about - mostly by JSUN
- Kicked out of solar system
- Herded - asteroid belt, Kuiper Belt
- Captured as moons
- Bashed into young planets -> Moon, Charon, others?
- Delivers water (+other volatiles) to Earth

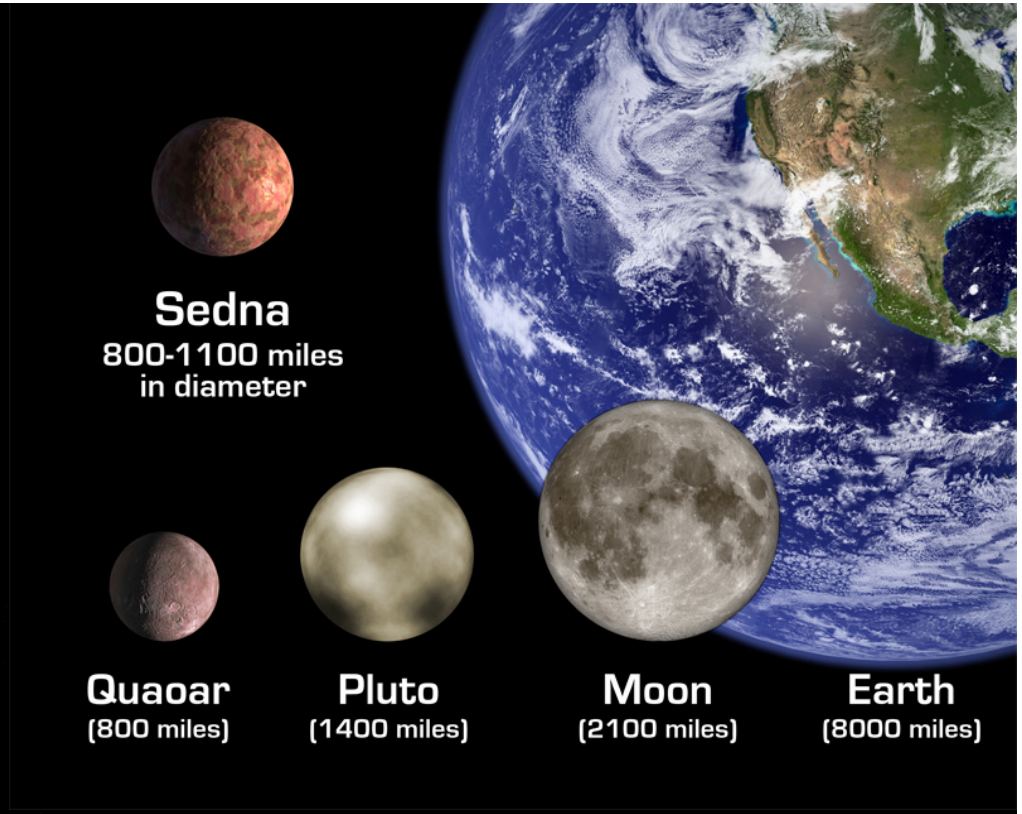




100s of thousands of asteroids
100s Near Earth Objects
100s Trojans ± 60° of Jupiter

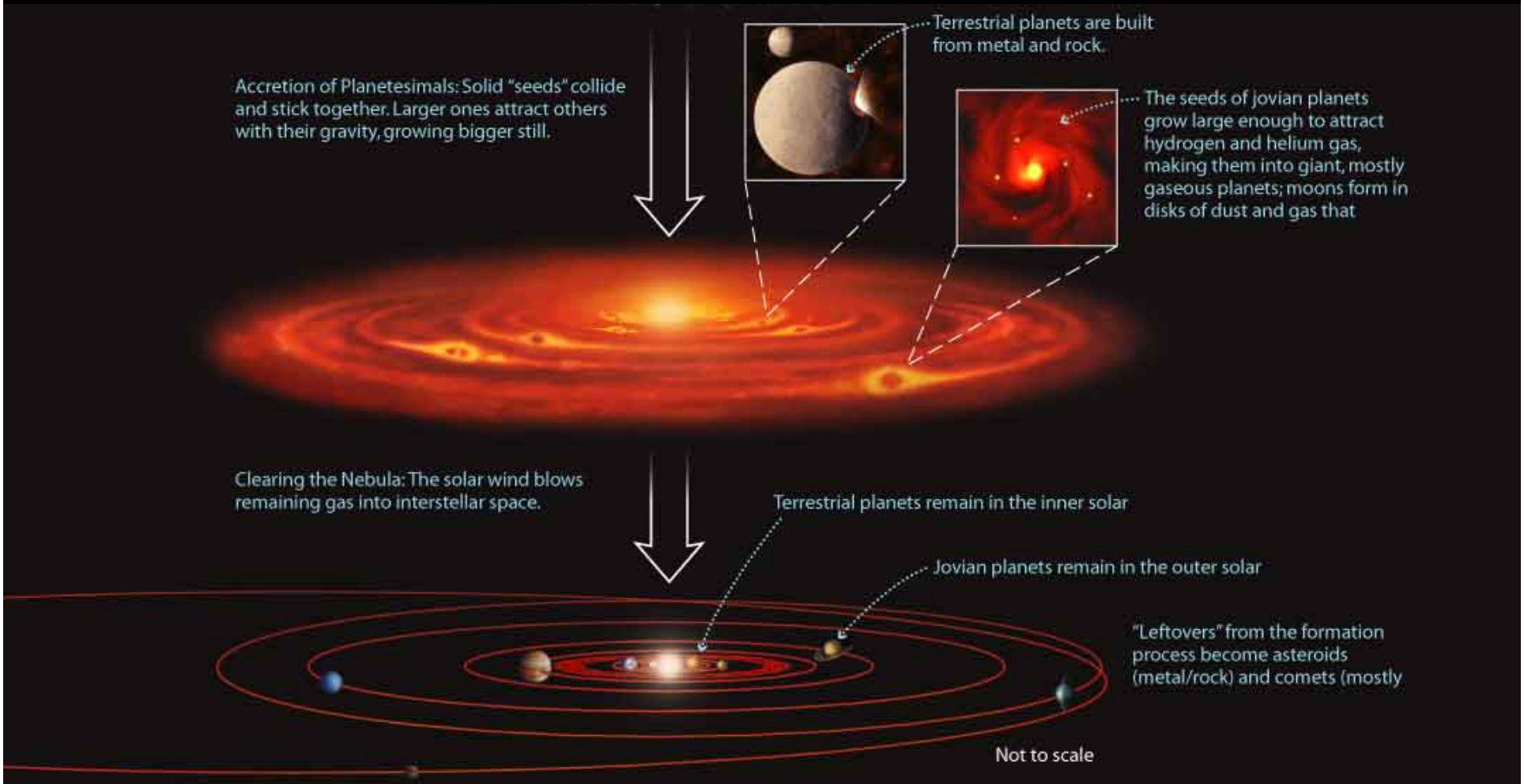

The Kuiper Belt
Neptune
U
S
J
Pluto
>1000
Objects
Discovered
Since 1992
..... and
counting
Plot prepared by the Minor Planet Center (2006 Jan.11).

Xena & Gabriella - 10th Planet?

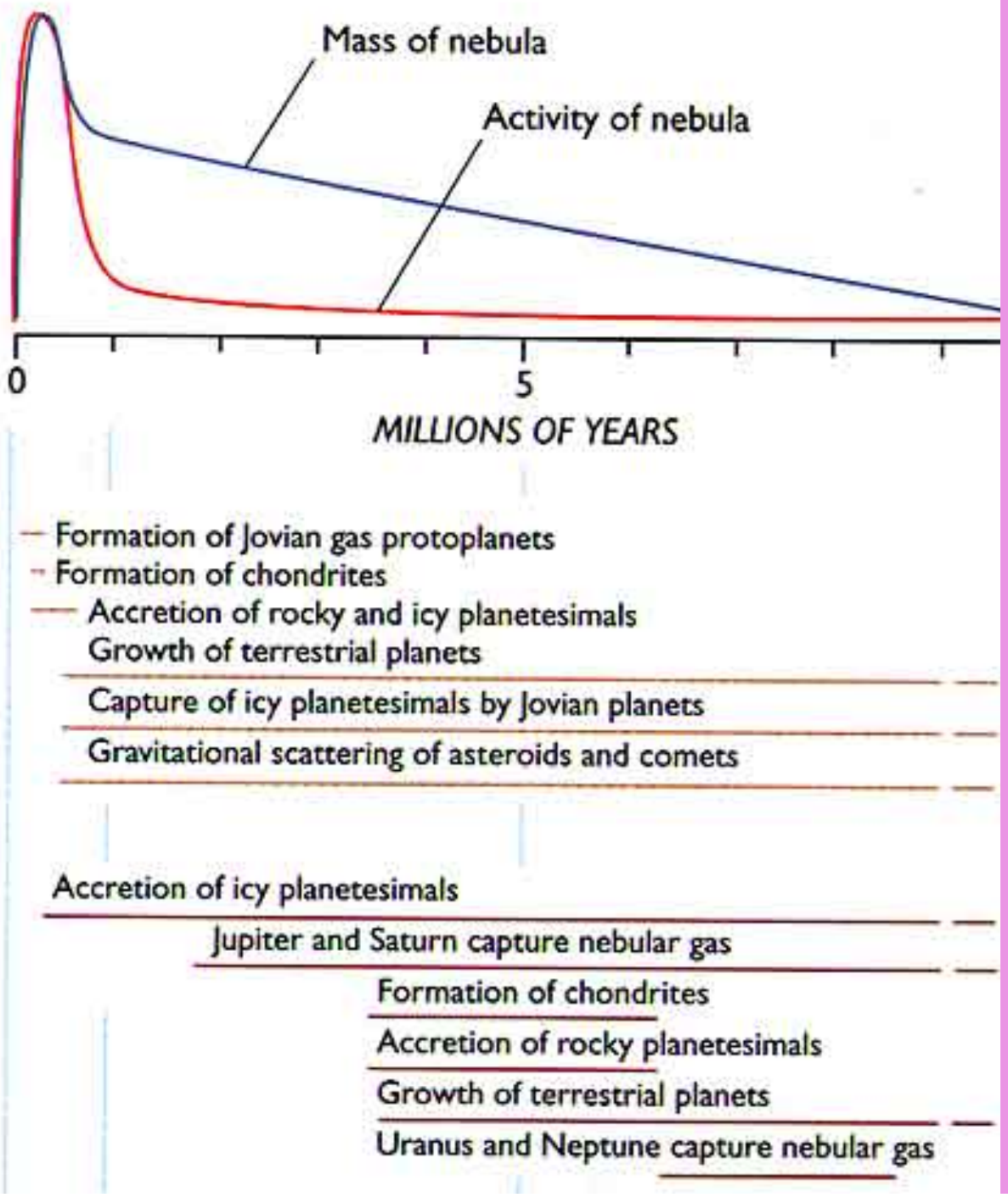


All the more reason to get out there and explore!

Summary of Solar System Formation - Part 4



How long does this whole process take?



How long did all this take?

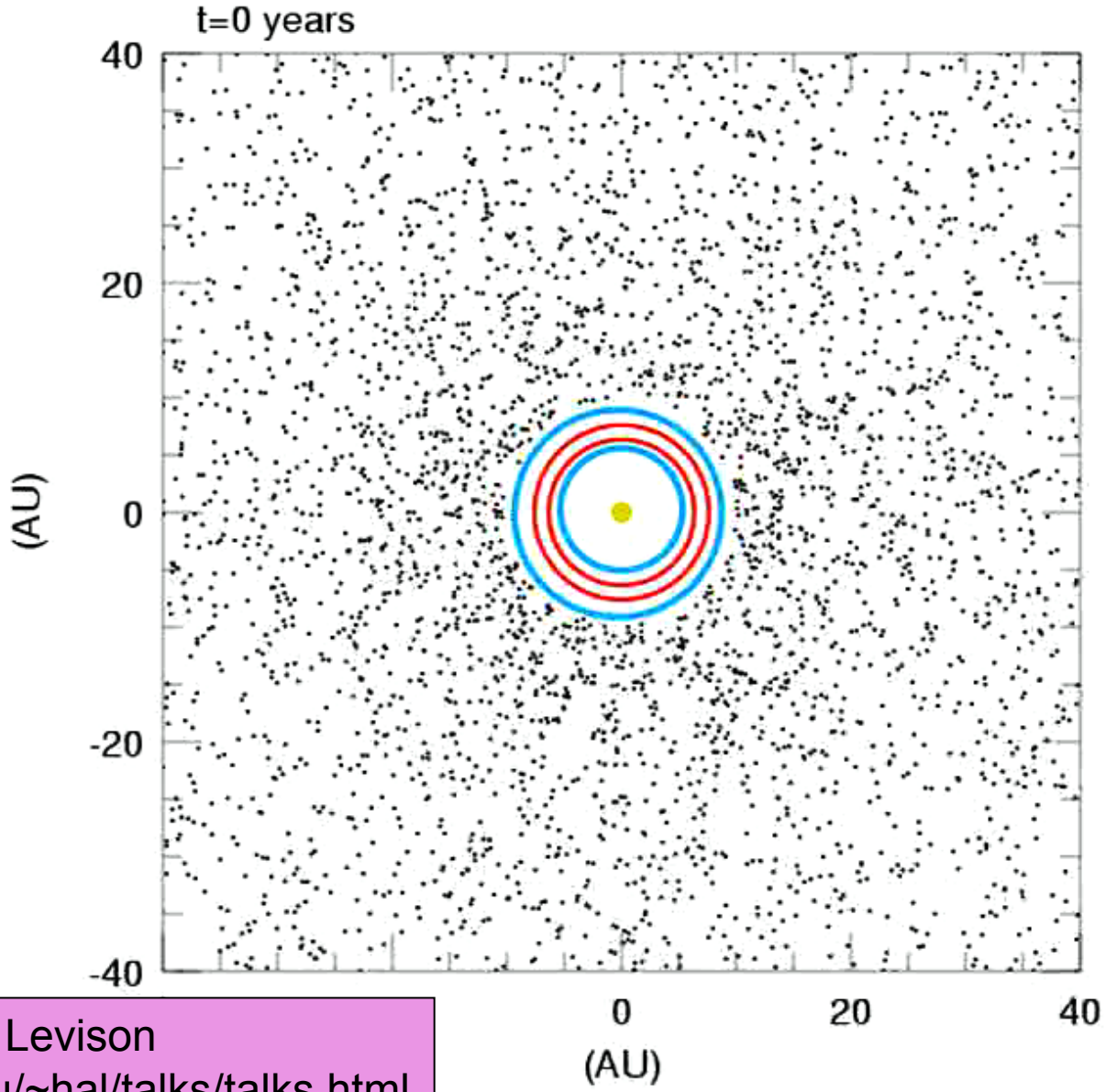
- Nebula collapse <1 MY
- planetesimal formation in 1MY
- J, S < 2 MY
- Terrestrials <4 MY
- Uranus & Neptune?

But it's not so simple…

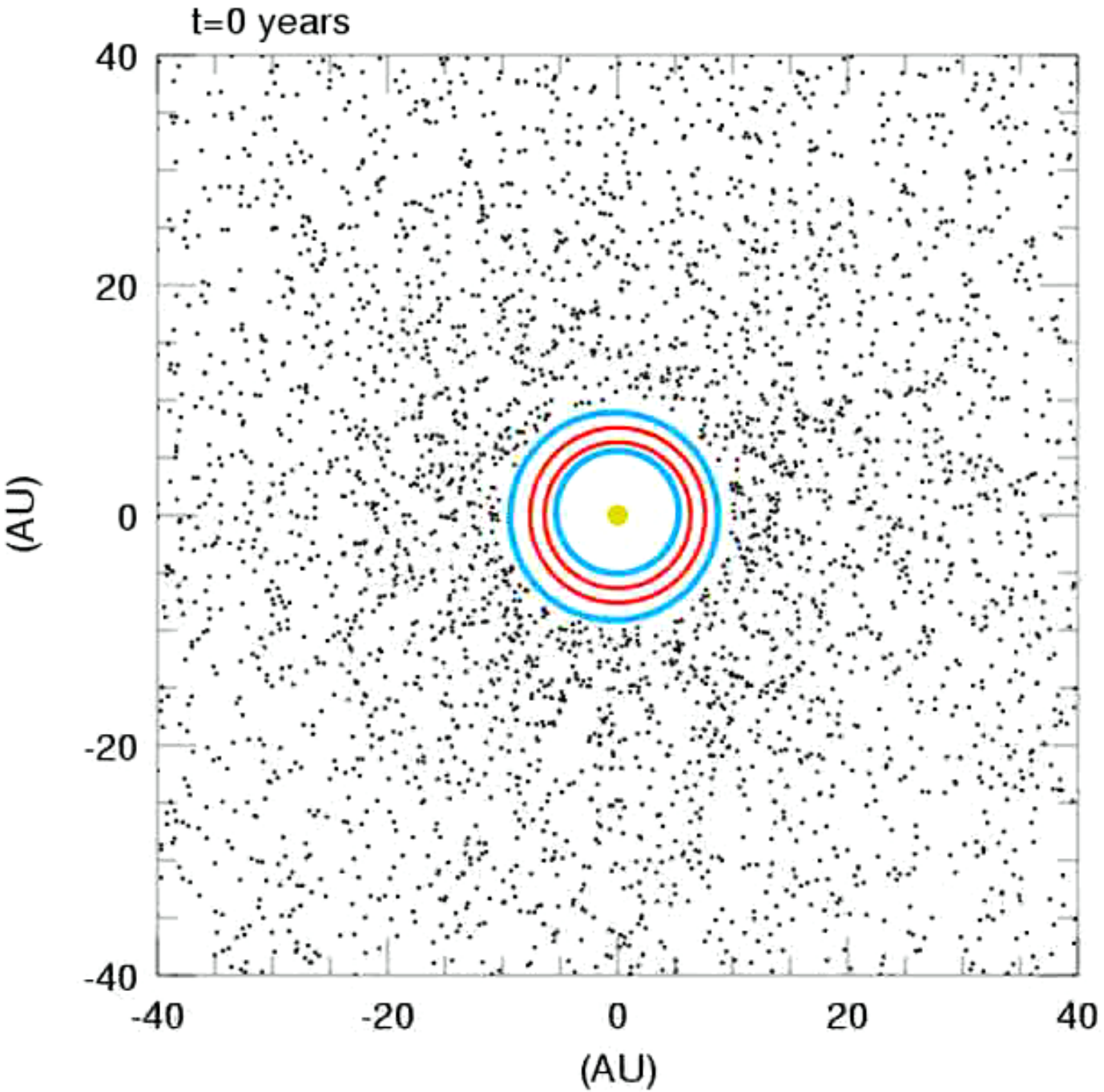
Jupiter & Saturn
& Neptune Uranus

- Hard to make U & N at present orbits
- Where did earth's oceans come from?
- How to make Kuiper Belt?

=> Migration?



See movies in talks by Hal Levison
http://www.boulder.swri.edu/~hal/talks/talks.html


t=0 years
40
20
0
-20
-40
(AU)
-40
-20
0
20
40
(AU)

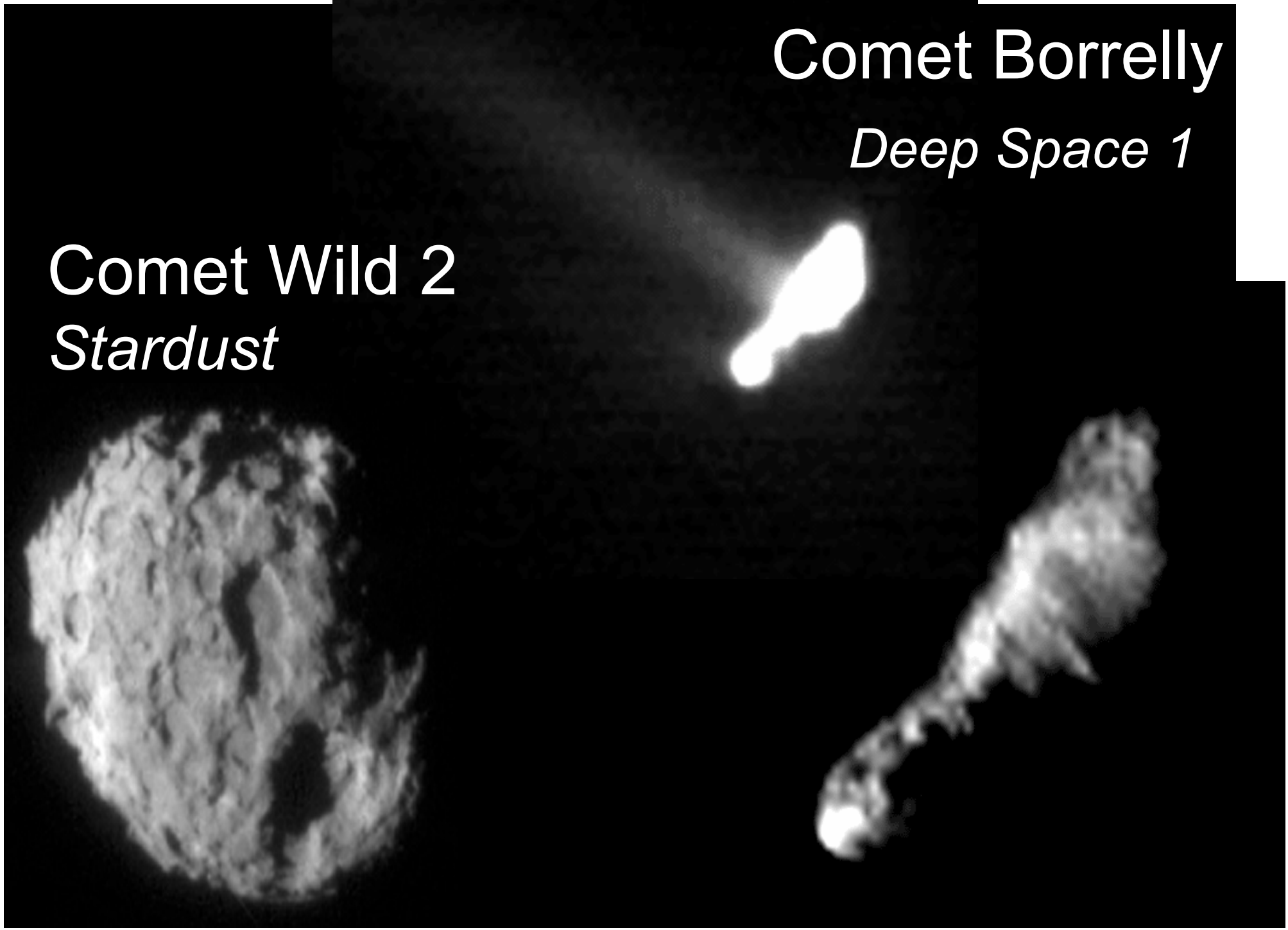
Comets contain the most primitive material - they tell us about the solar nebula composition and the earliest steps in the process

Nucleus of Comet 19P/Borrelly
8 x 3.2 km in diameter
Imaged by Deep Space 1 2001

~43 m/pixel

Nucleus of Comet 1P/Halley
x 8 km in diameter
Imaged by Giotto, 1986

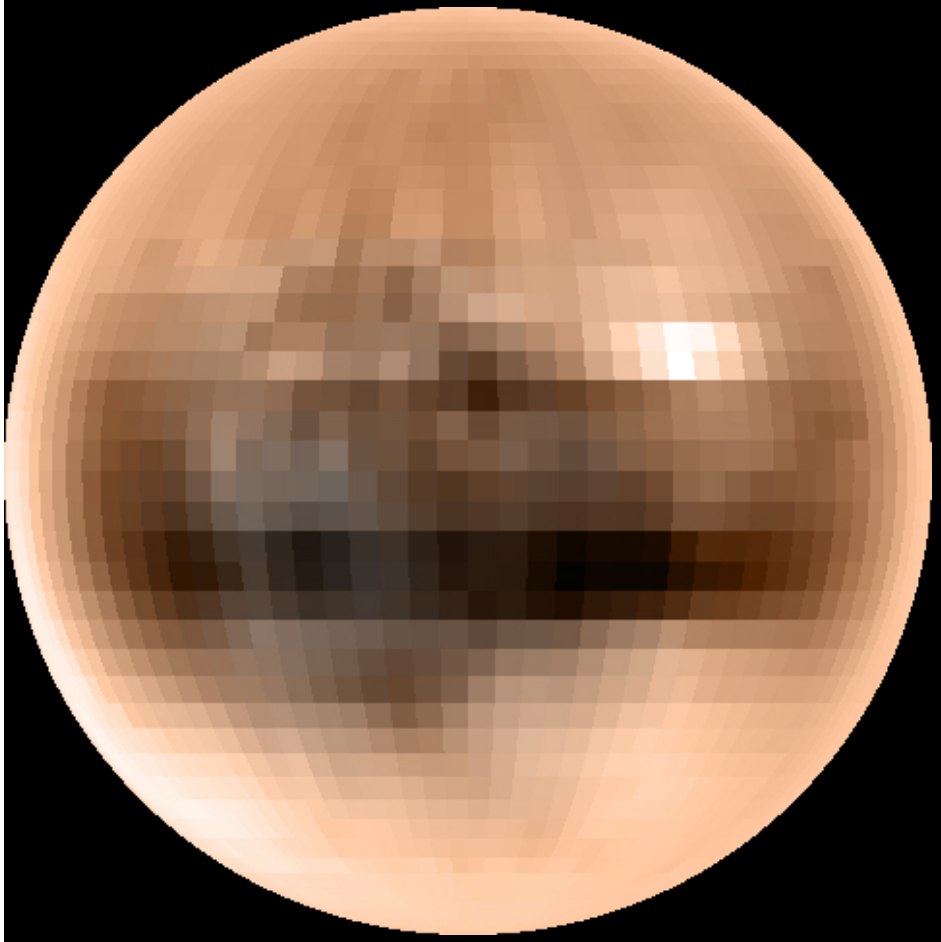
~100 m/pixel (but only at top left)


Comet Borrelly
Deep Space 1
Comet Wild 2
Stardust

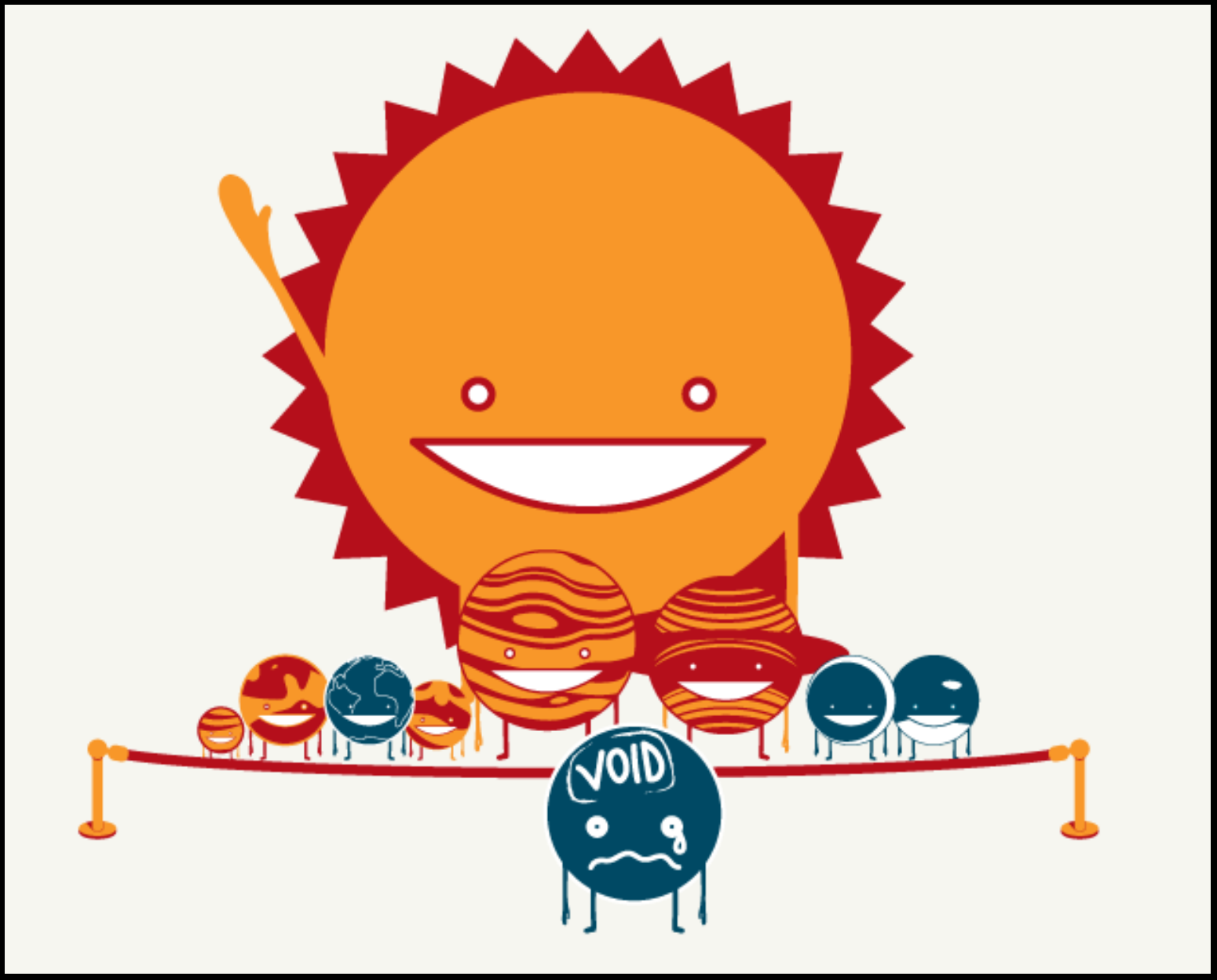
Pandora - moon of Saturn
114 x 84 x 62 km

Asteroid Itokawa

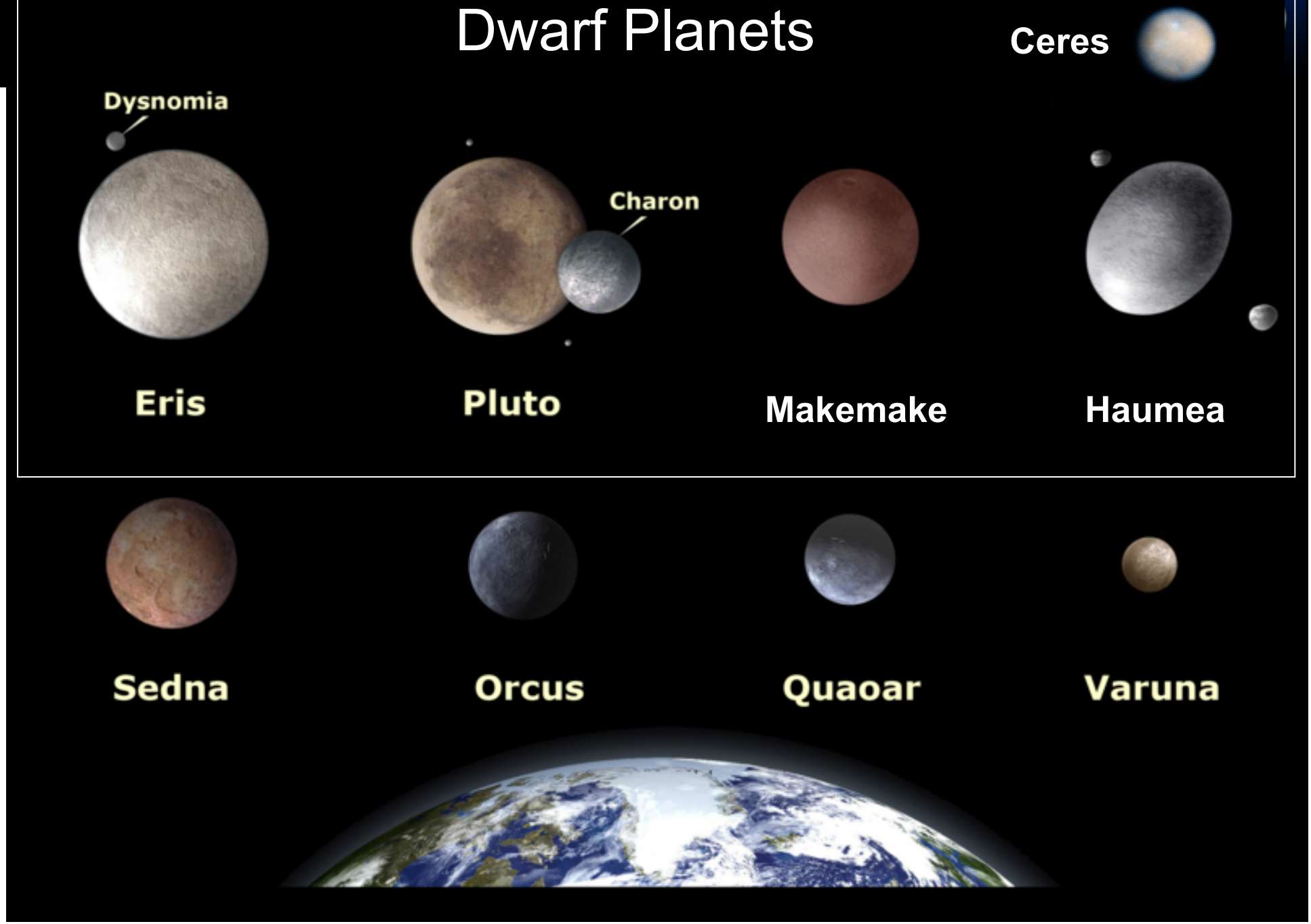
Hayabusa



Objects like Pluto - planetesimals or planetary embryos - tell us about planetary growth stages


VOID

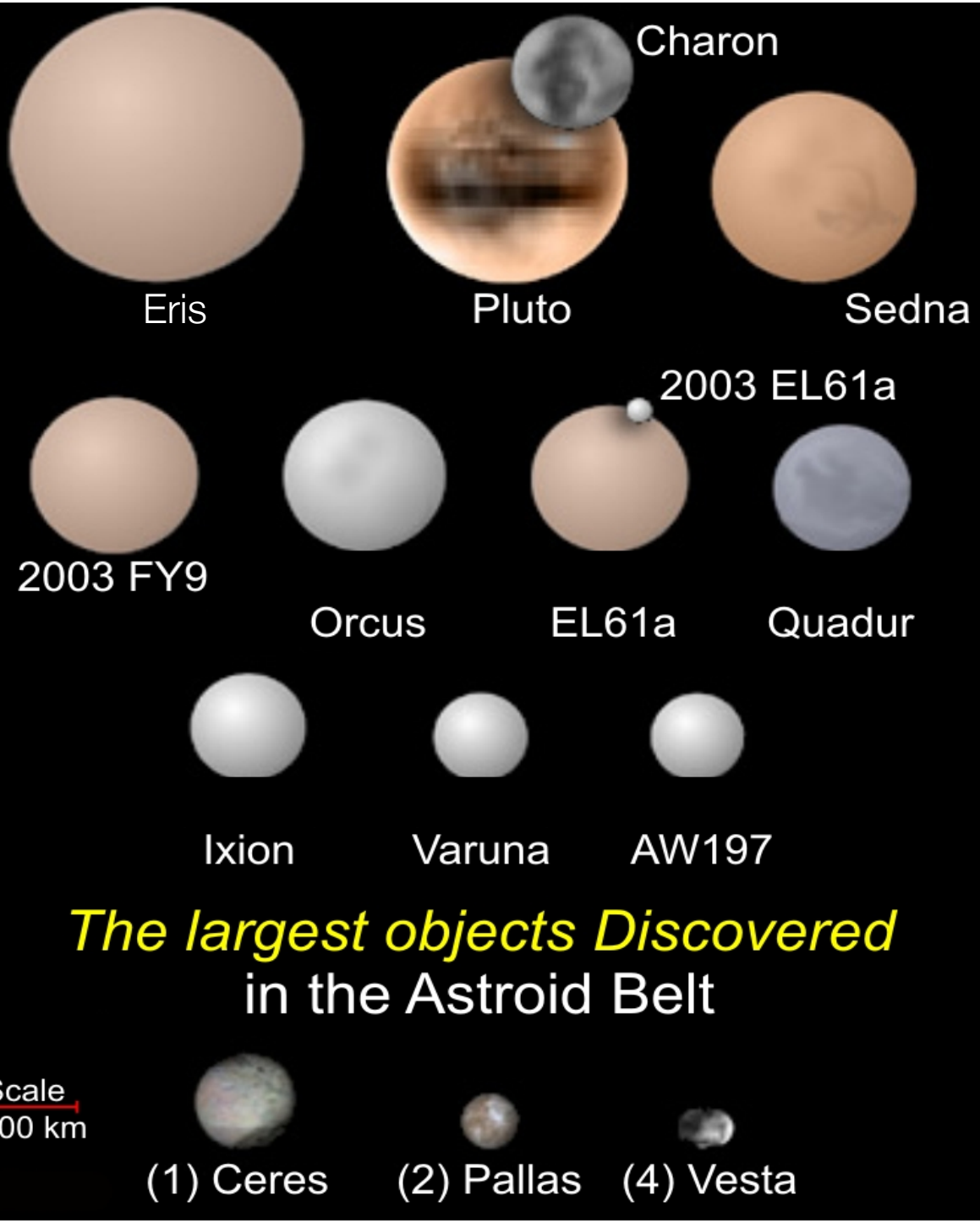
Dwarf Planets

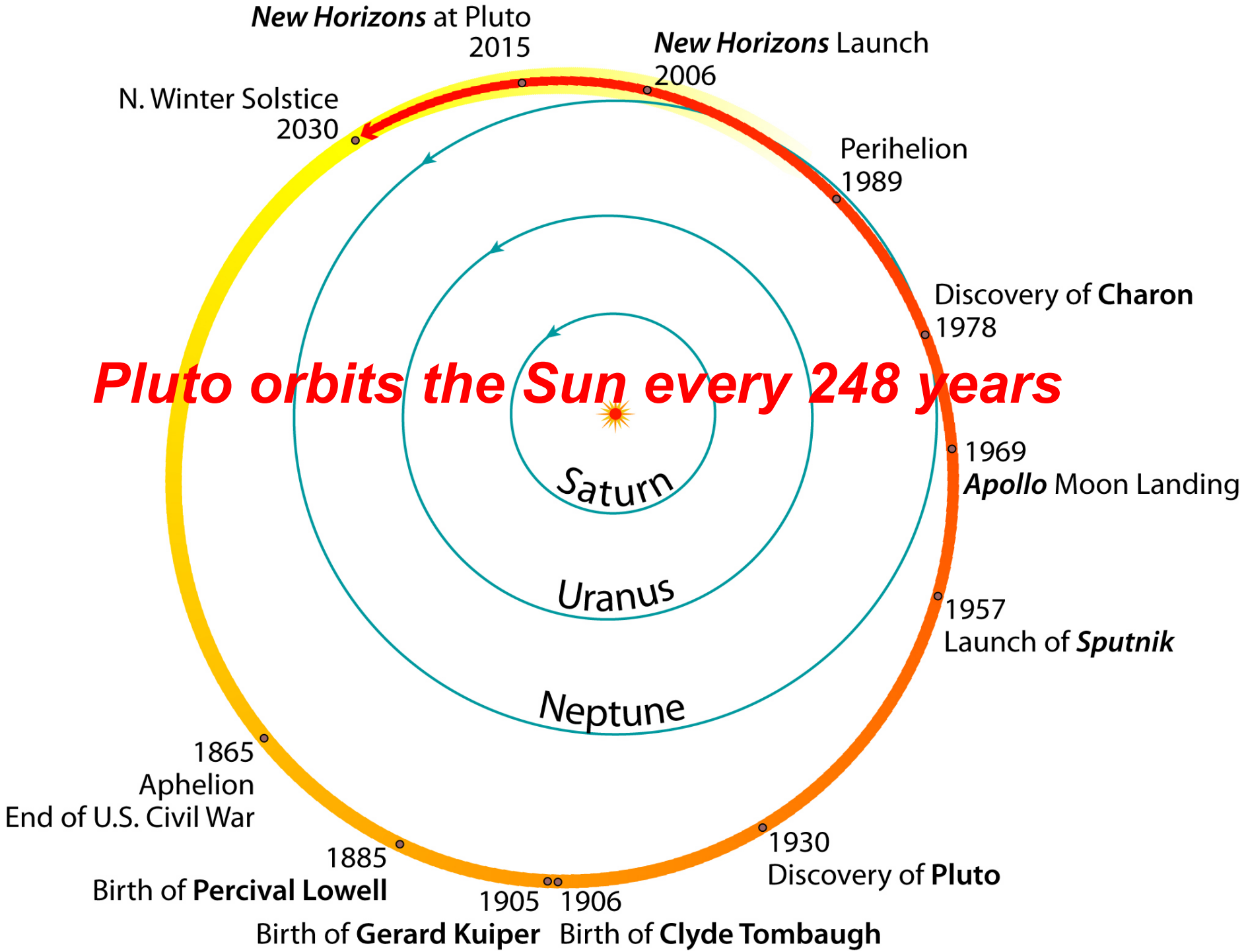


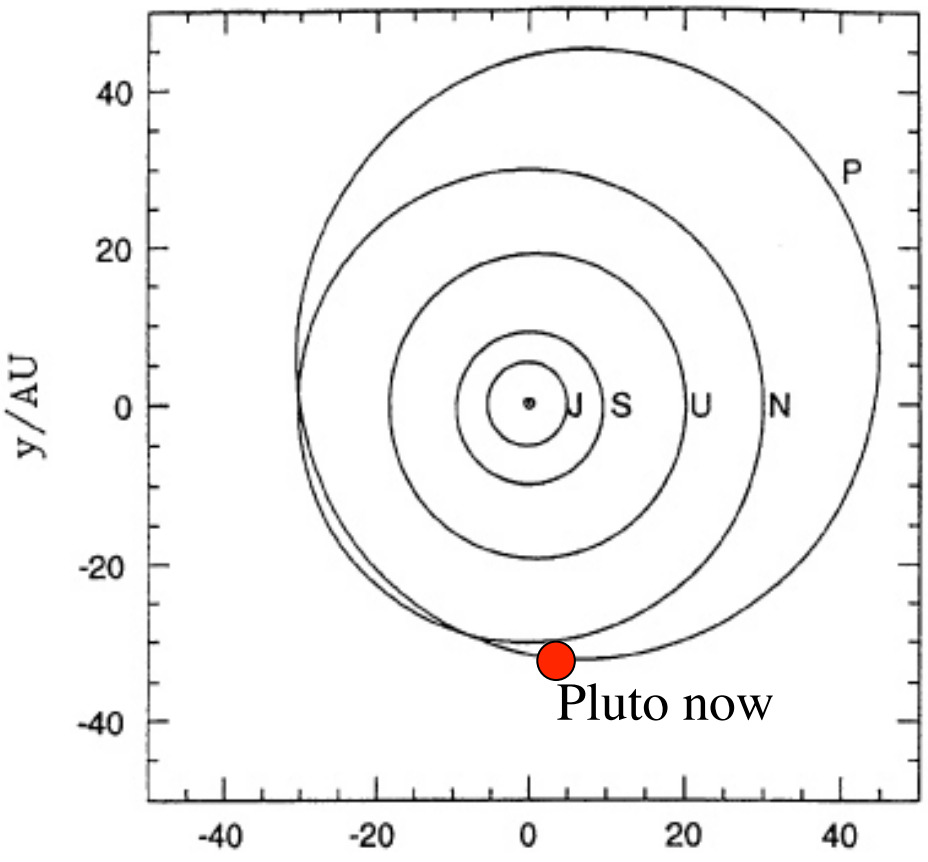
Dwarf Planets: The Most Populous Class of Planet

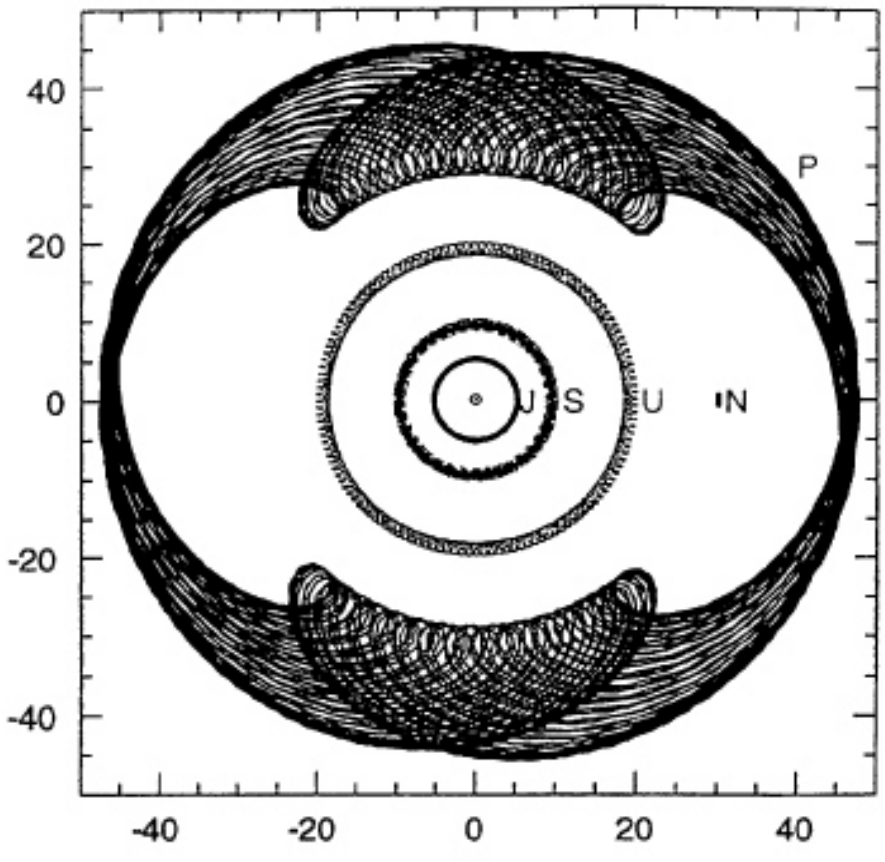
The Kuiper Belt

- Different sizes and colors
- Bigger than the largest asteroids



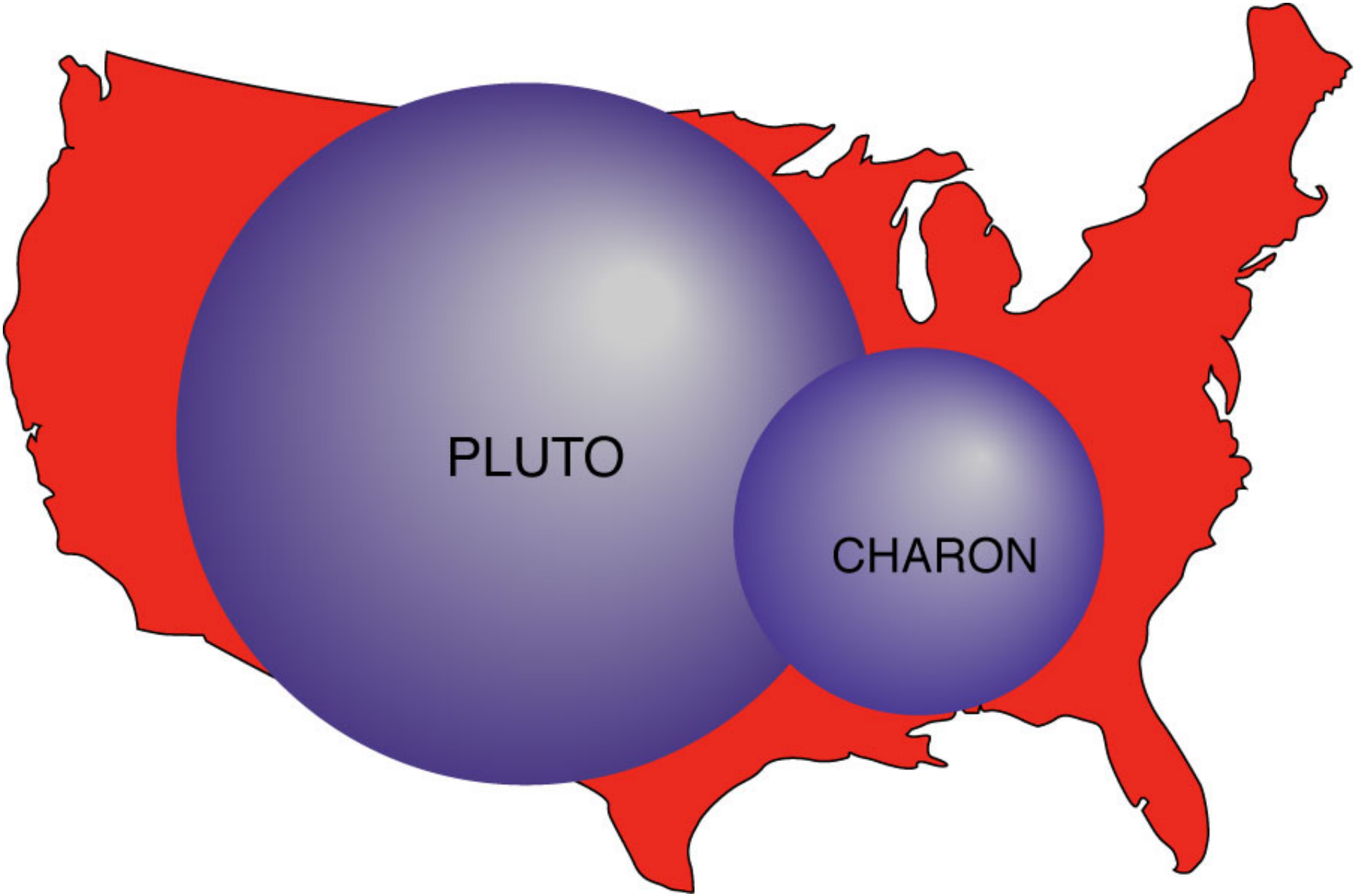

New Horizons at Pluto
2015
New Horizons Launch
2006
N. Winter Solstice
2030
Perihelion
1989
Discovery of **Charon**
1978
Pluto orbits the Sun every 248 years
1969
Apollo Moon Landing
Saturn
Uranus
1957
Launch of ***Sputnik***
Neptune
1865
Aphelion
End of U.S. Civil War
1885
Birth of **Percival Lowell**
1930
Discovery of **Pluto**
1905
Birth of **Gerard Kuiper**
1906
Birth of **Clyde Tombaugh**

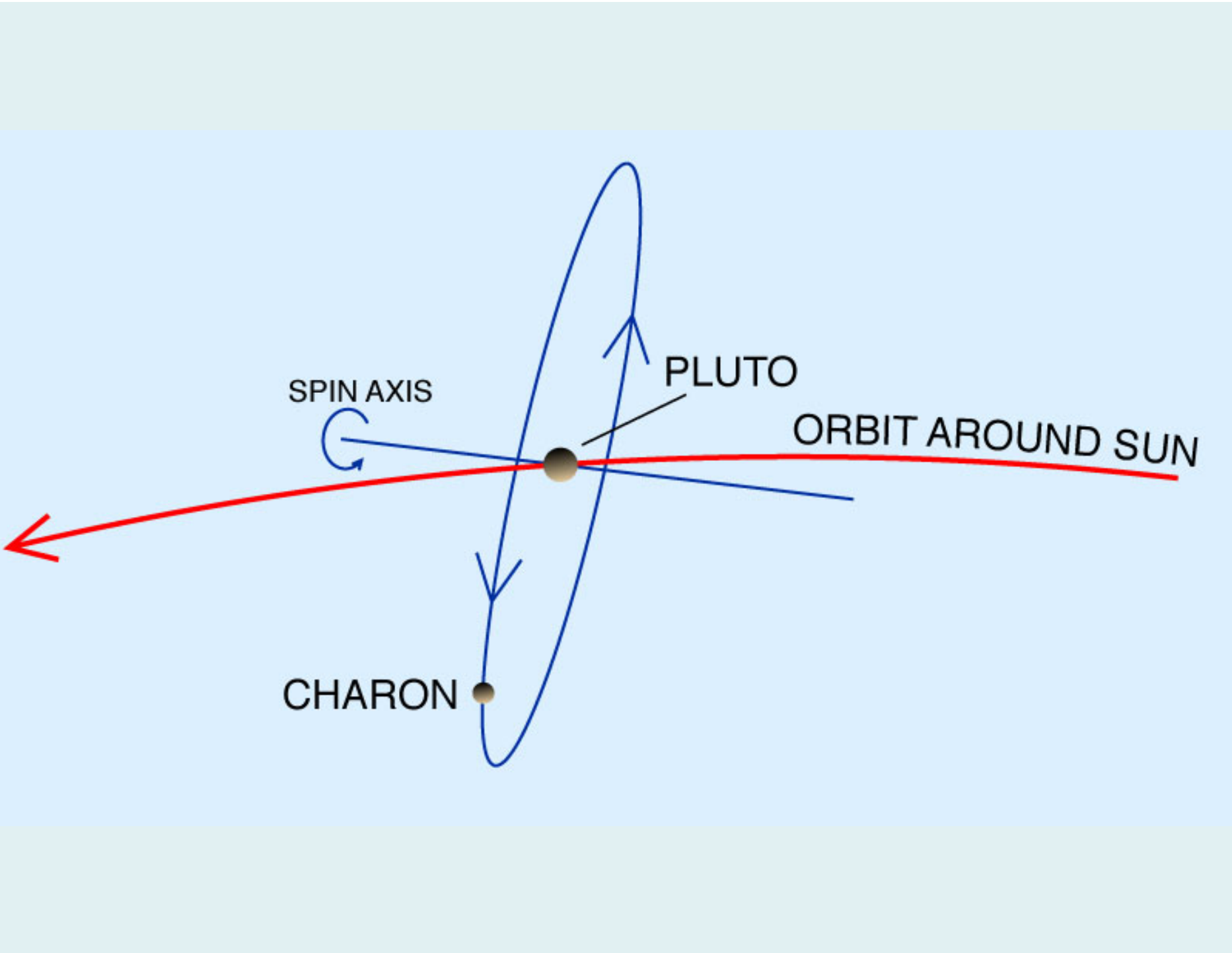




Neptune and Pluto dance together

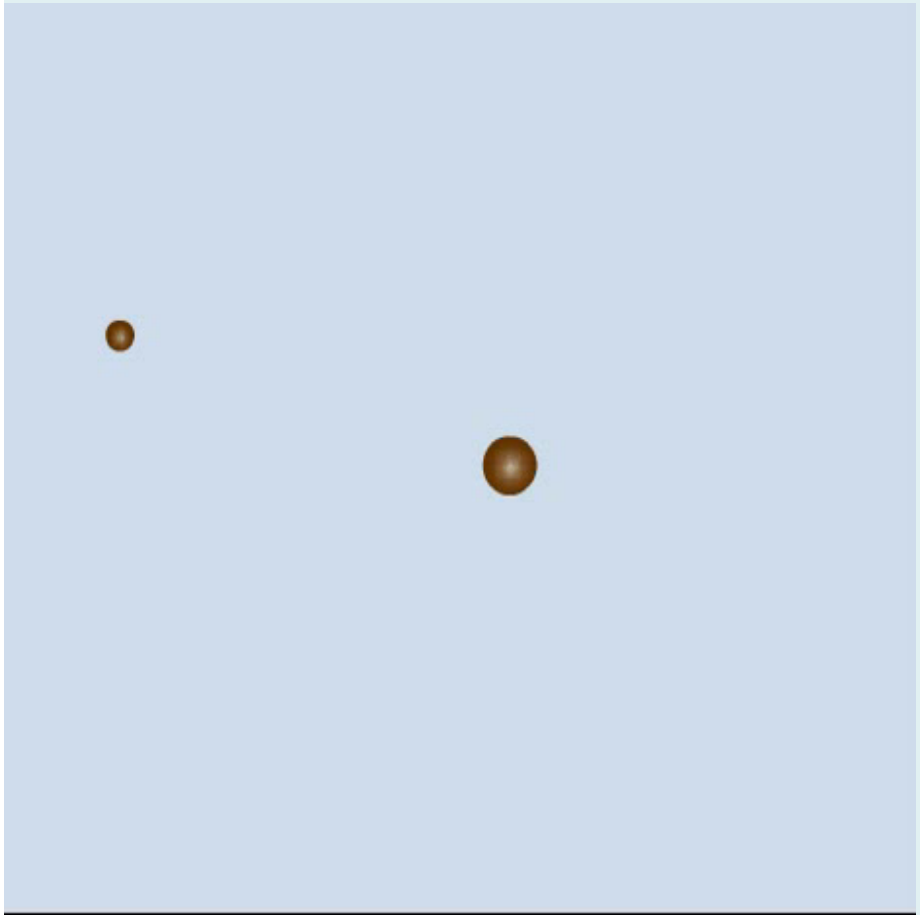
- but never get close

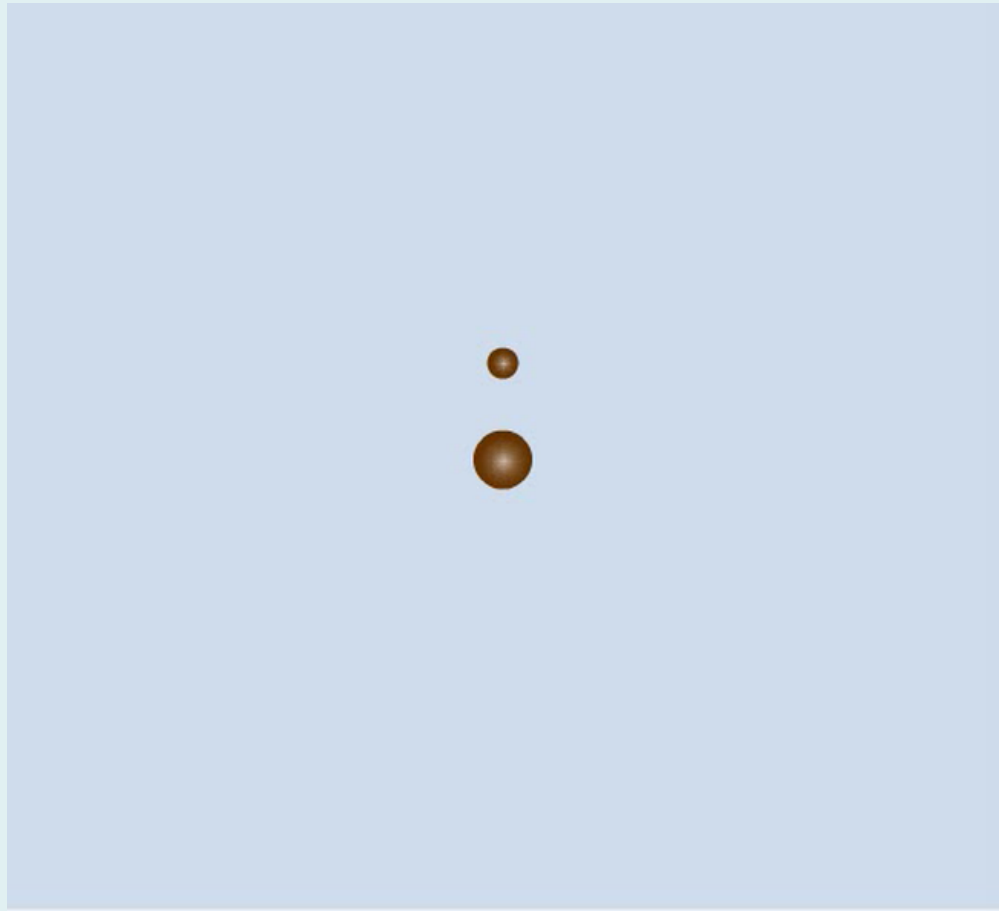

PLUTO
CHARON


SPIN AXIS
PLUTO
ORBIT AROUND SUN
CHARON

Binary Planet System

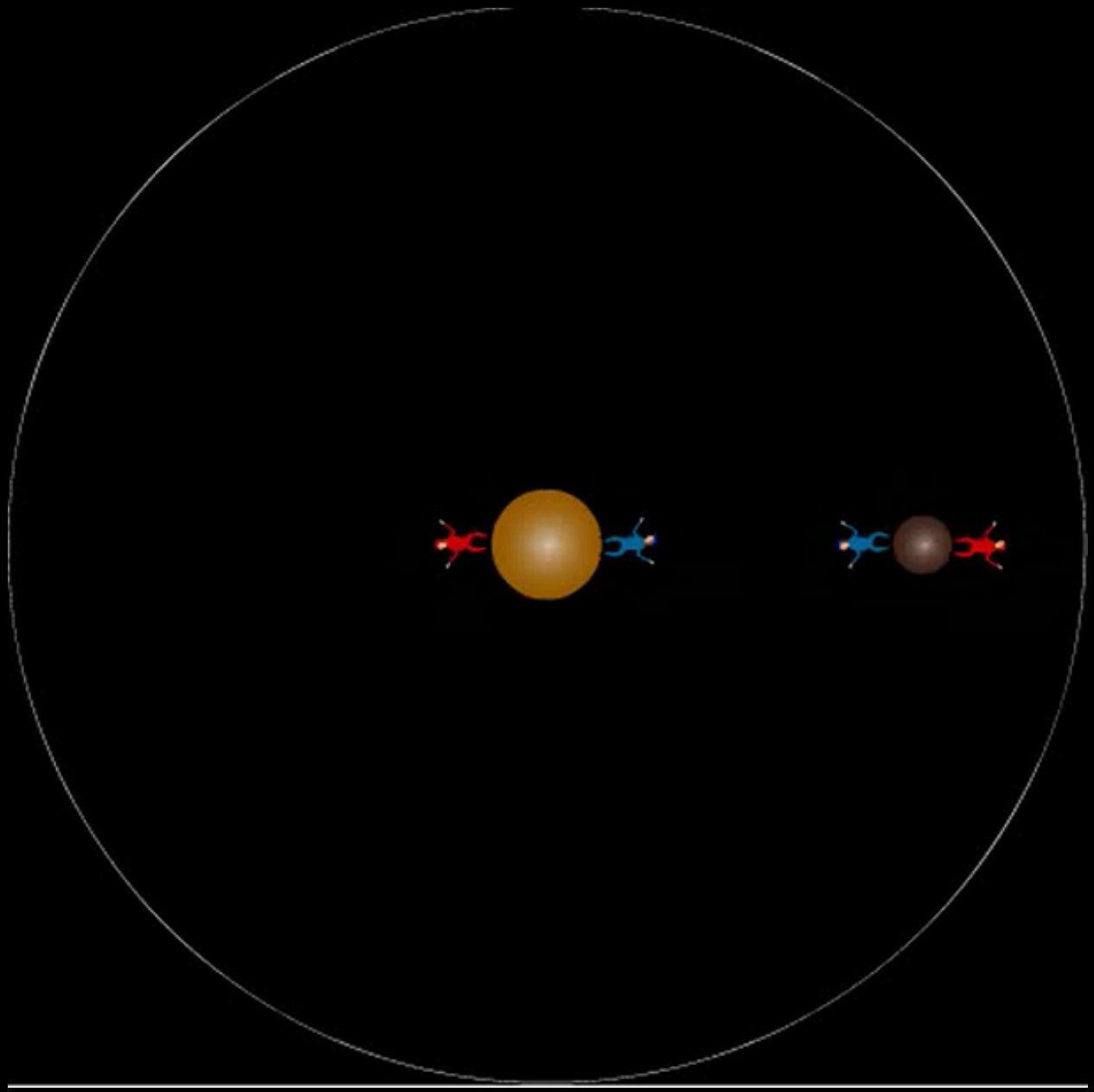
Mass of Pluto ~ 6 x Mass of Charon

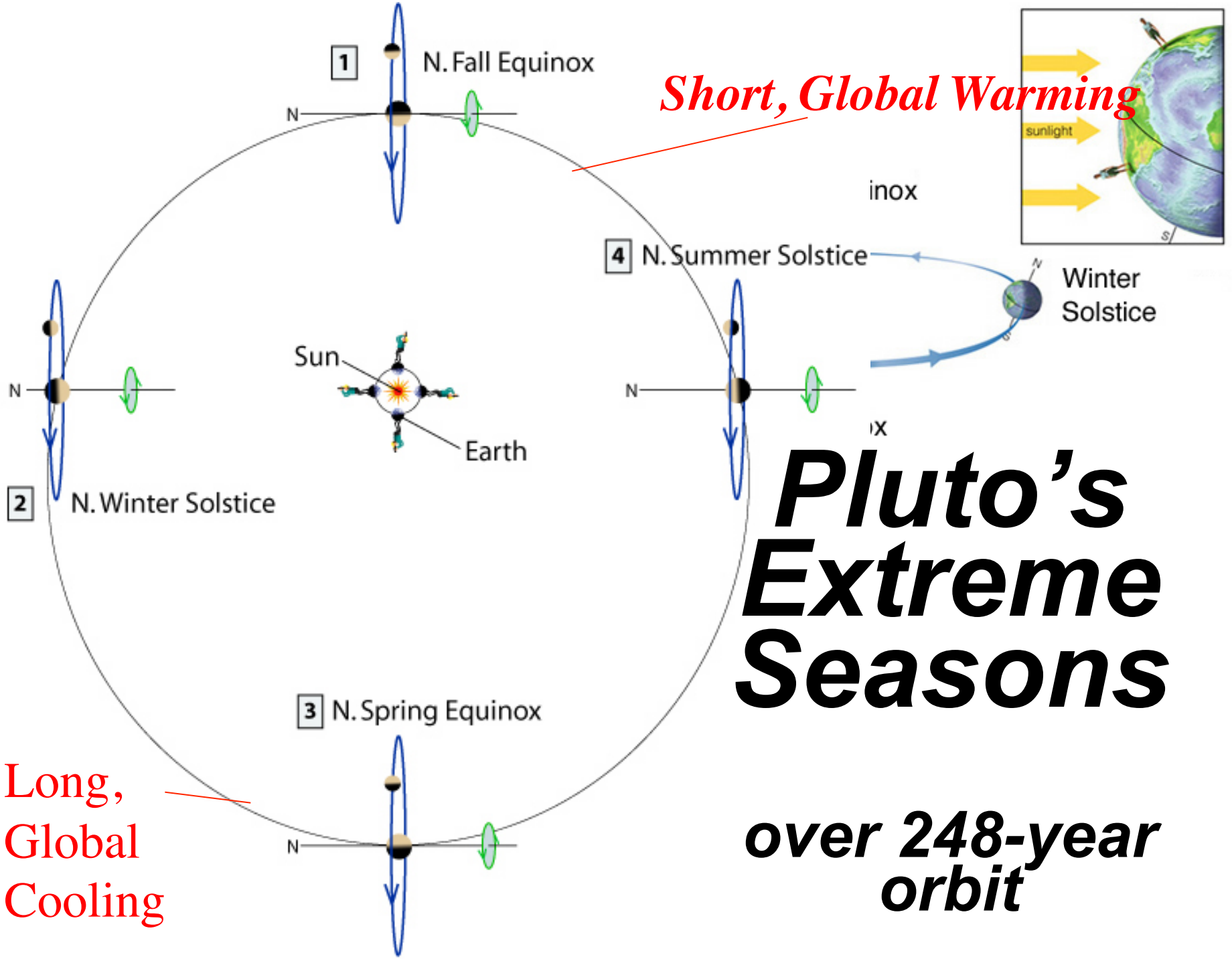




Spin-Orbit Phase Lock

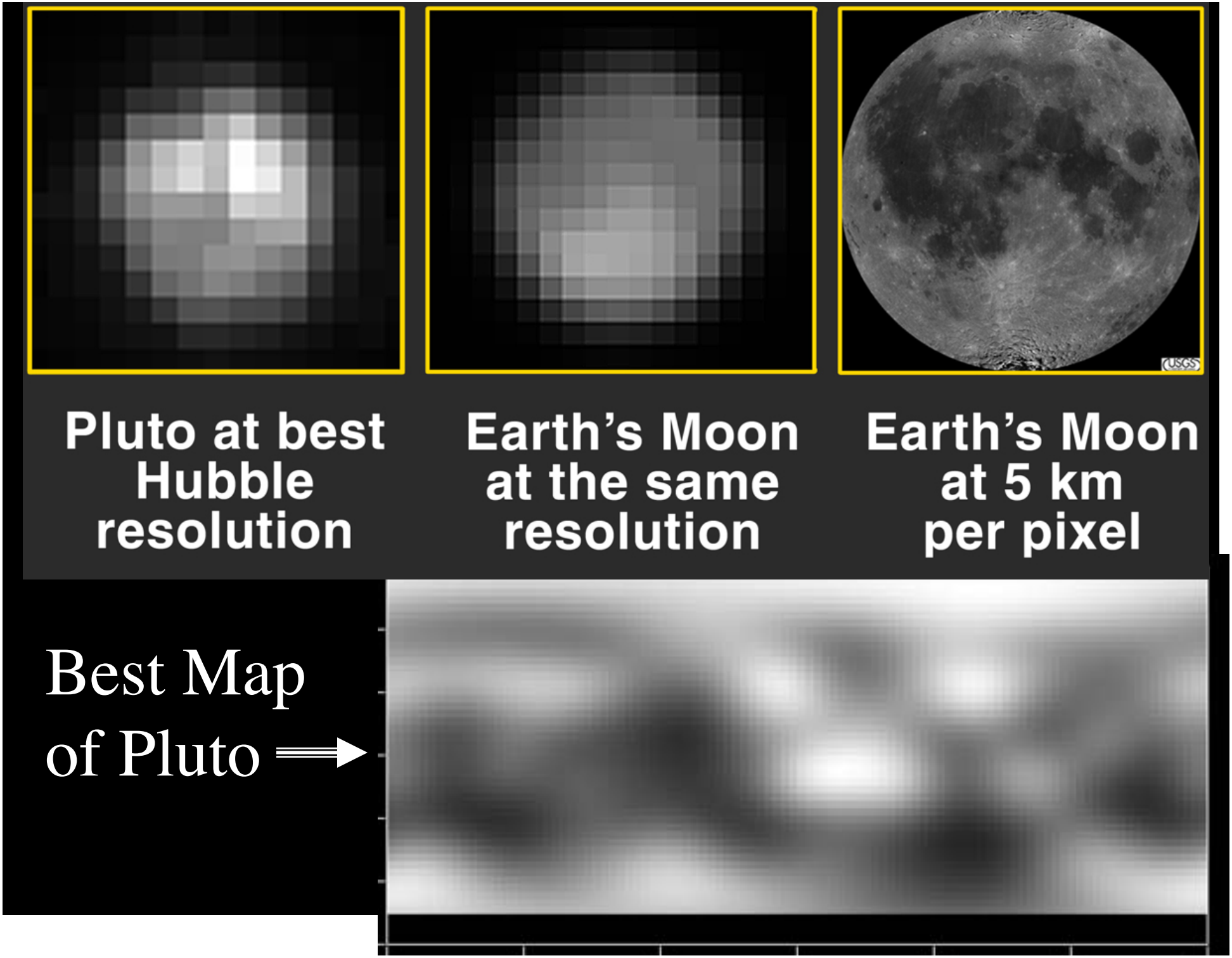
Pluto & Charon both spin and orbit every 6.4 days

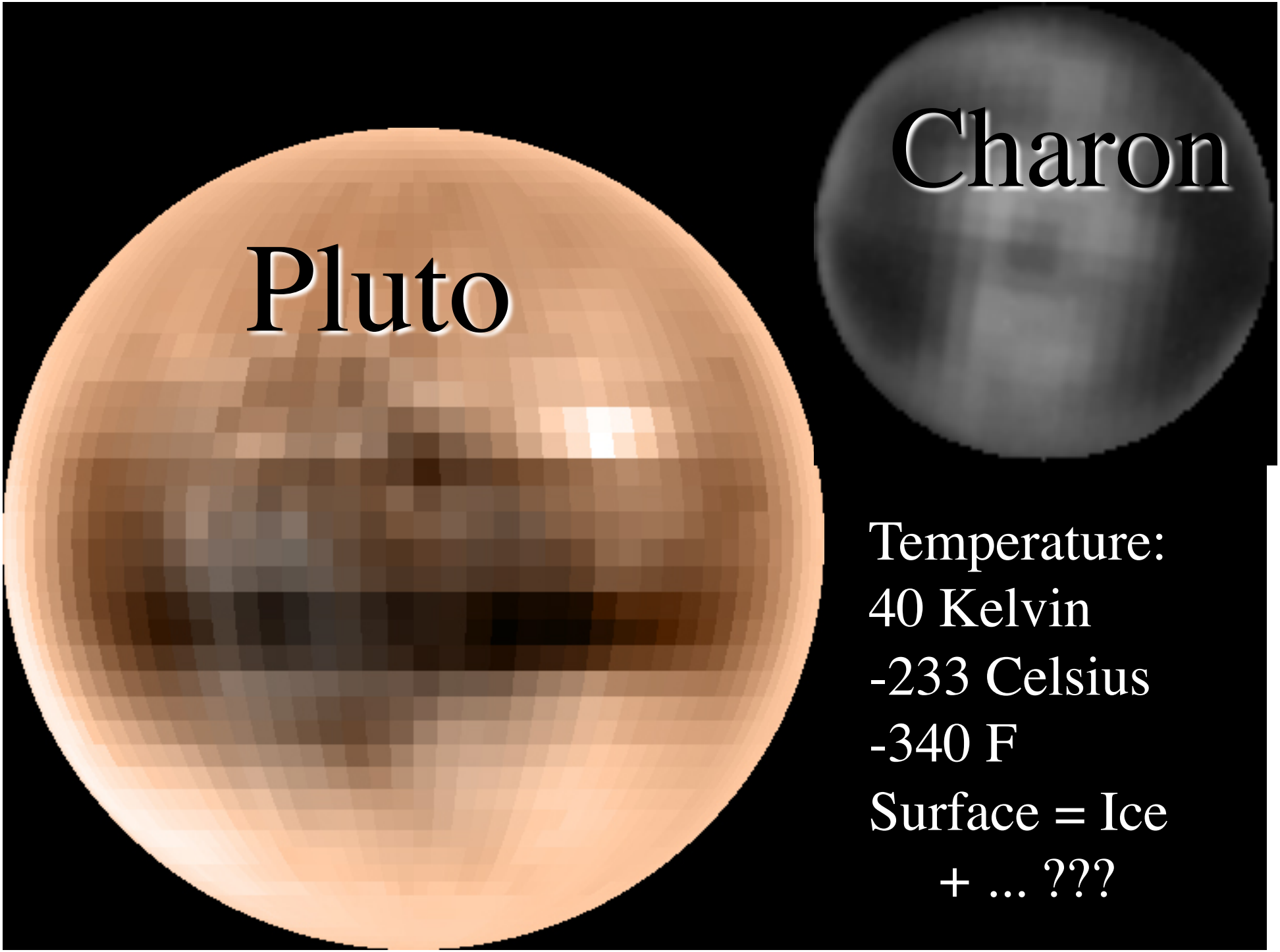


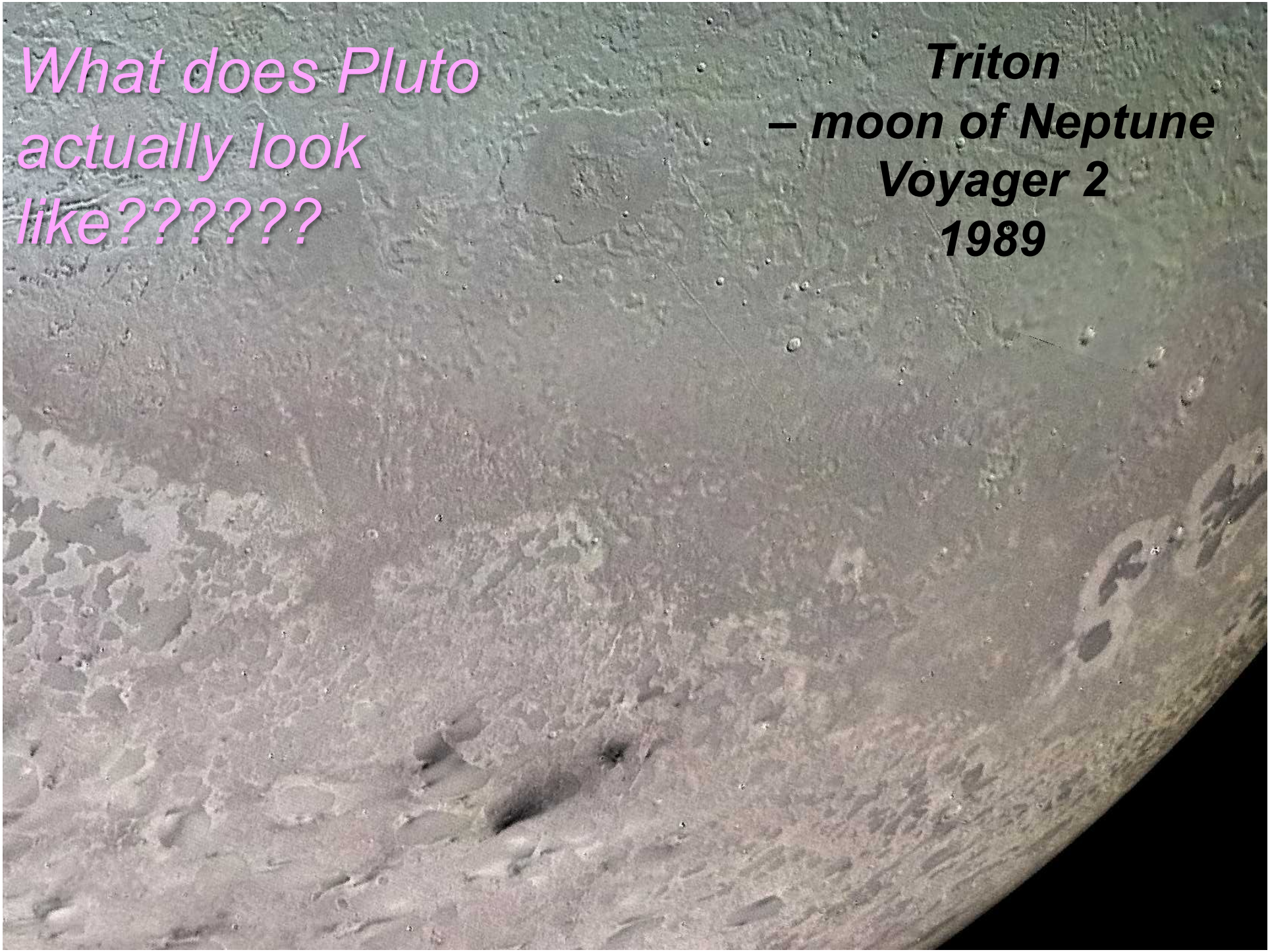


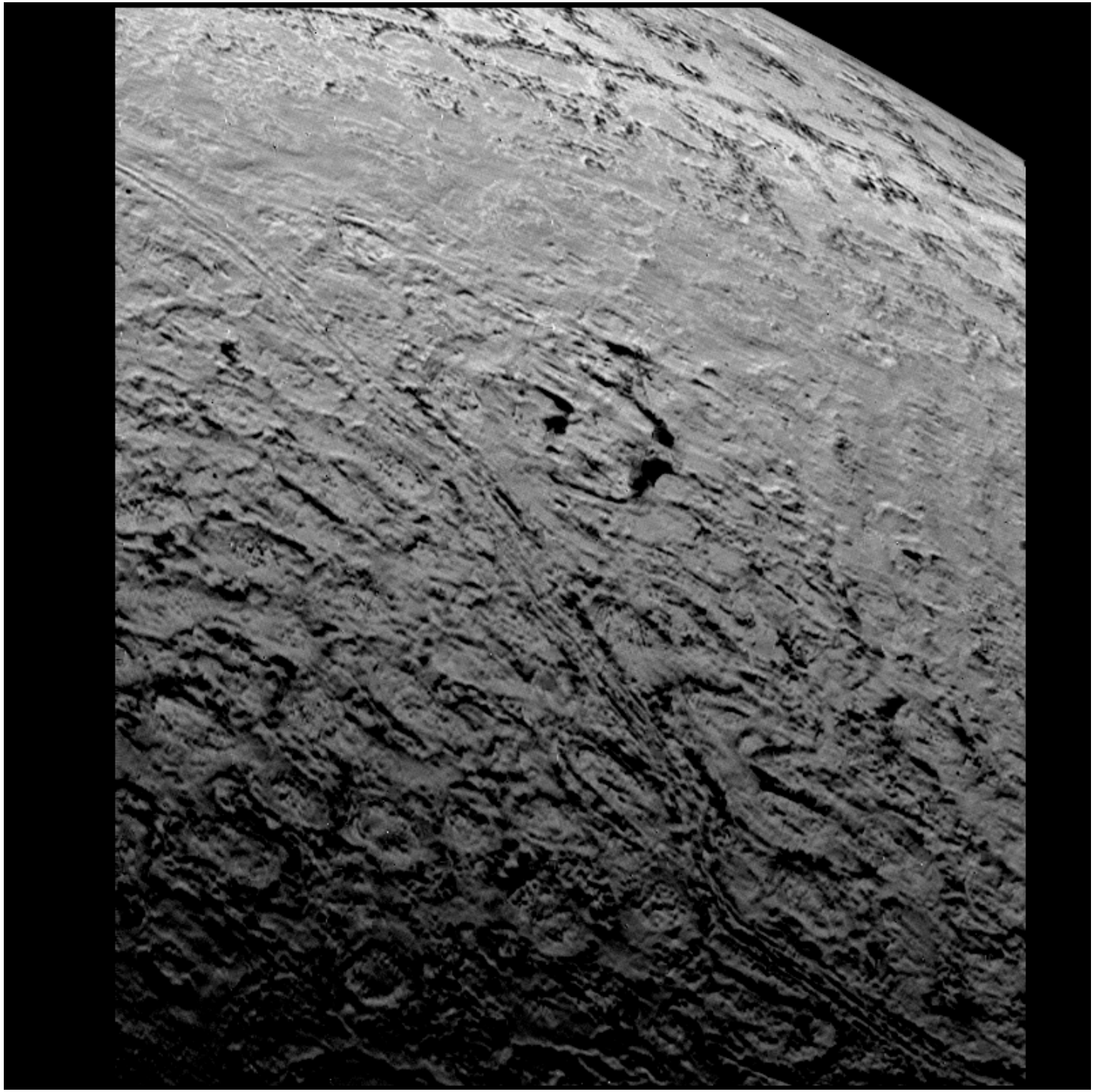
Pluto's Extreme Seasons

over 248-year orbit


Pluto at best Hubble resolution
Earth's Moon at the same resolution
Earth's Moon at 5 km per pixel
USGS
Best Map of Pluto


Pluto
Charon
Temperature:
40 Kelvin
-233 Celsius
-340 F
Surface = Ice
+ ... ???


What does Pluto actually look like??????
Triton
– moon of Neptune
Voyager 2
1989



Cantaloupe terrain:

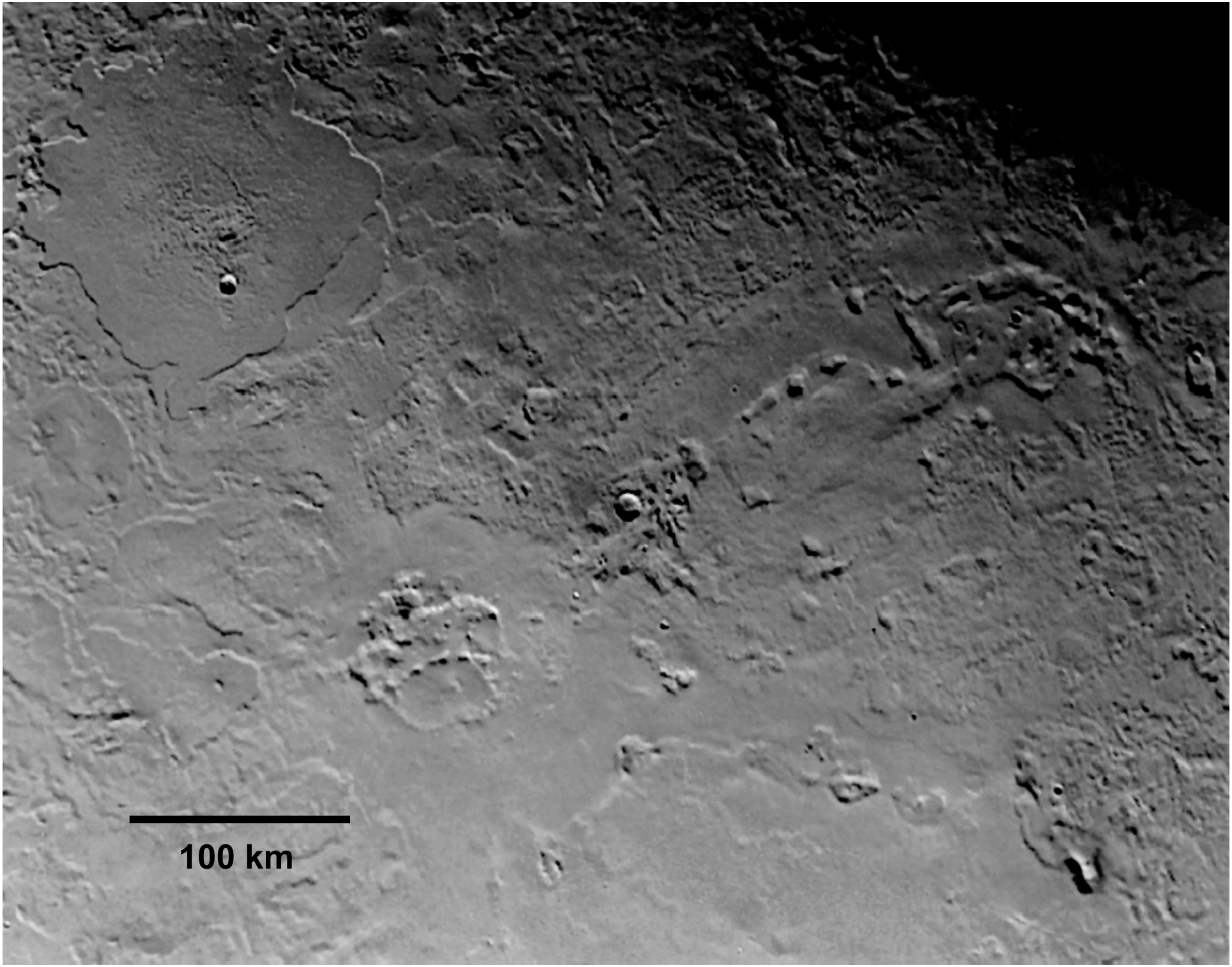
Cavi (dimples), ~25-35 km across

cross-cutting ridges

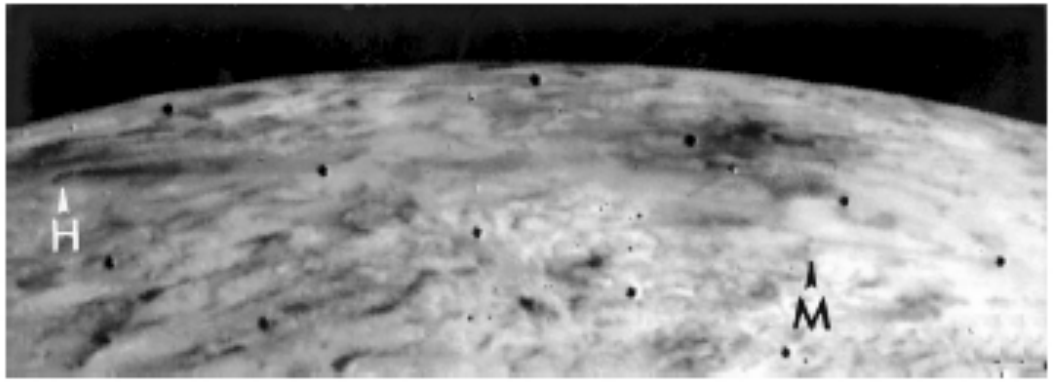
& polar terrain at top

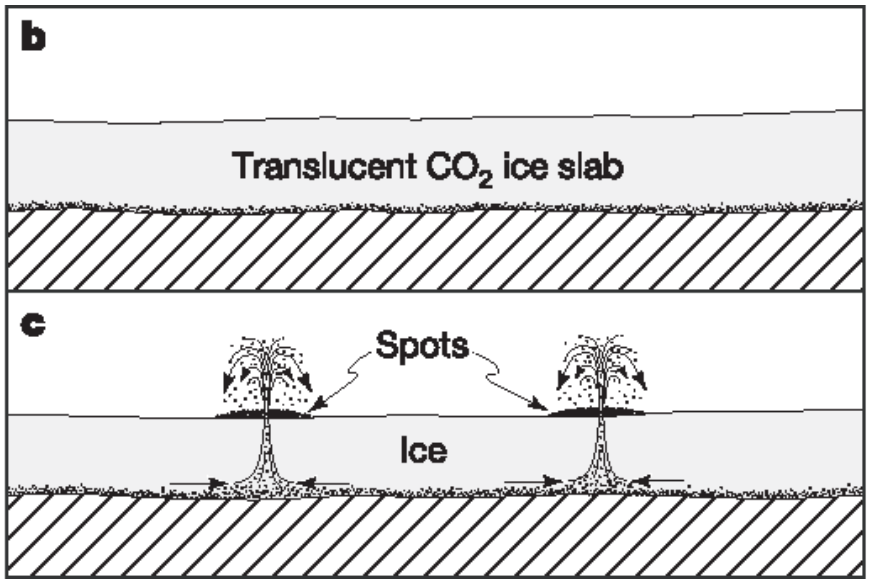
Oldest terrain?

Where are the craters?

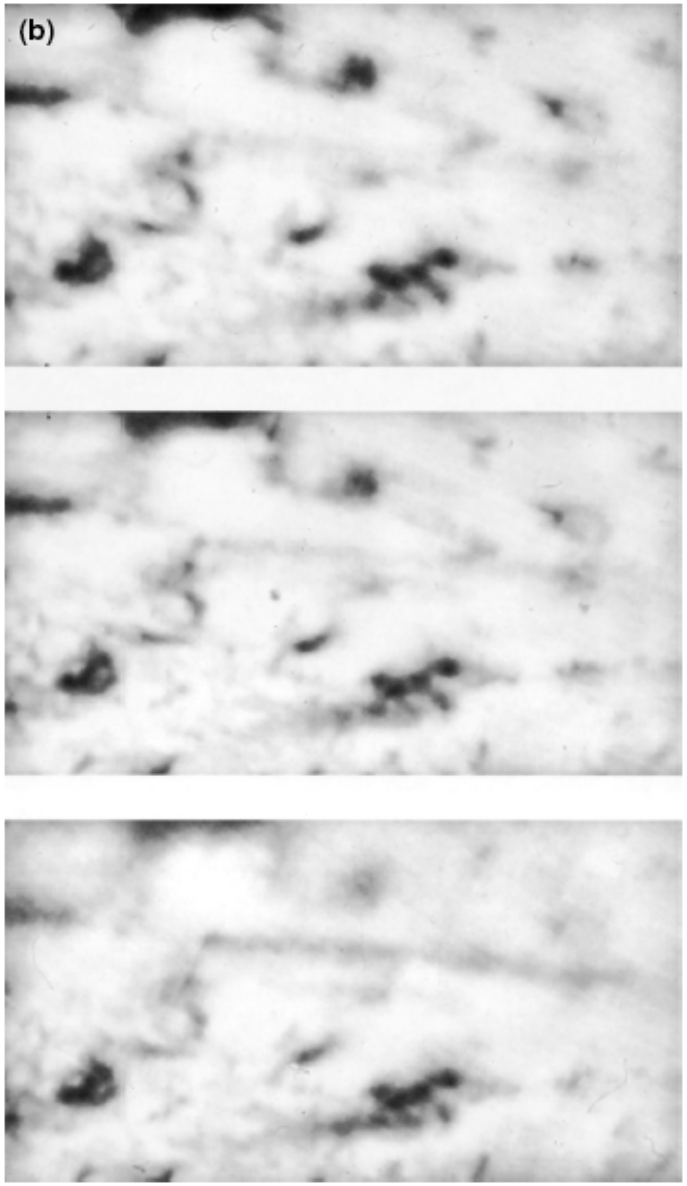

100 km

Nitrogen Plumes (or Geysers)

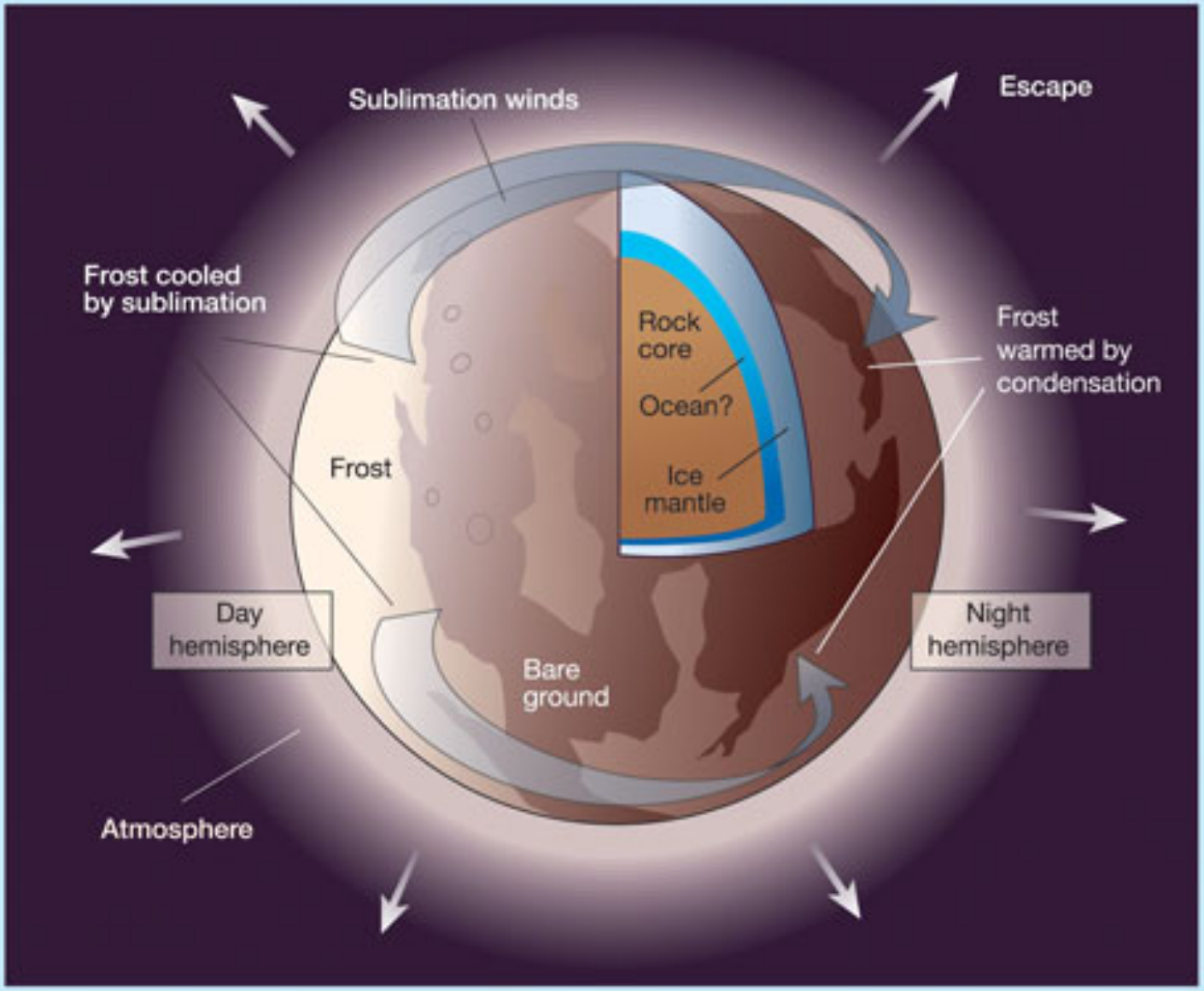




Kieffer et al. 06; Mars “spiders”

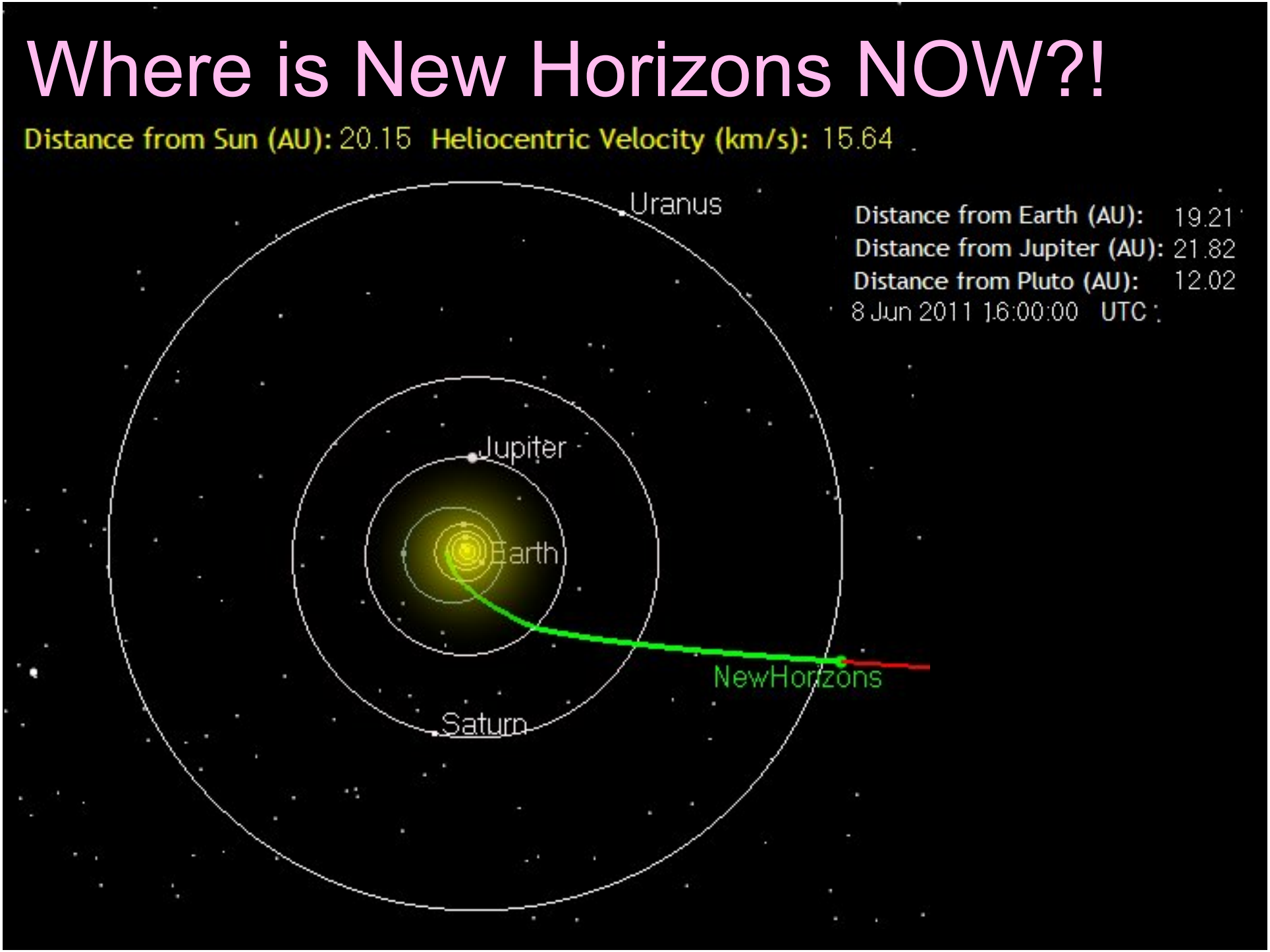


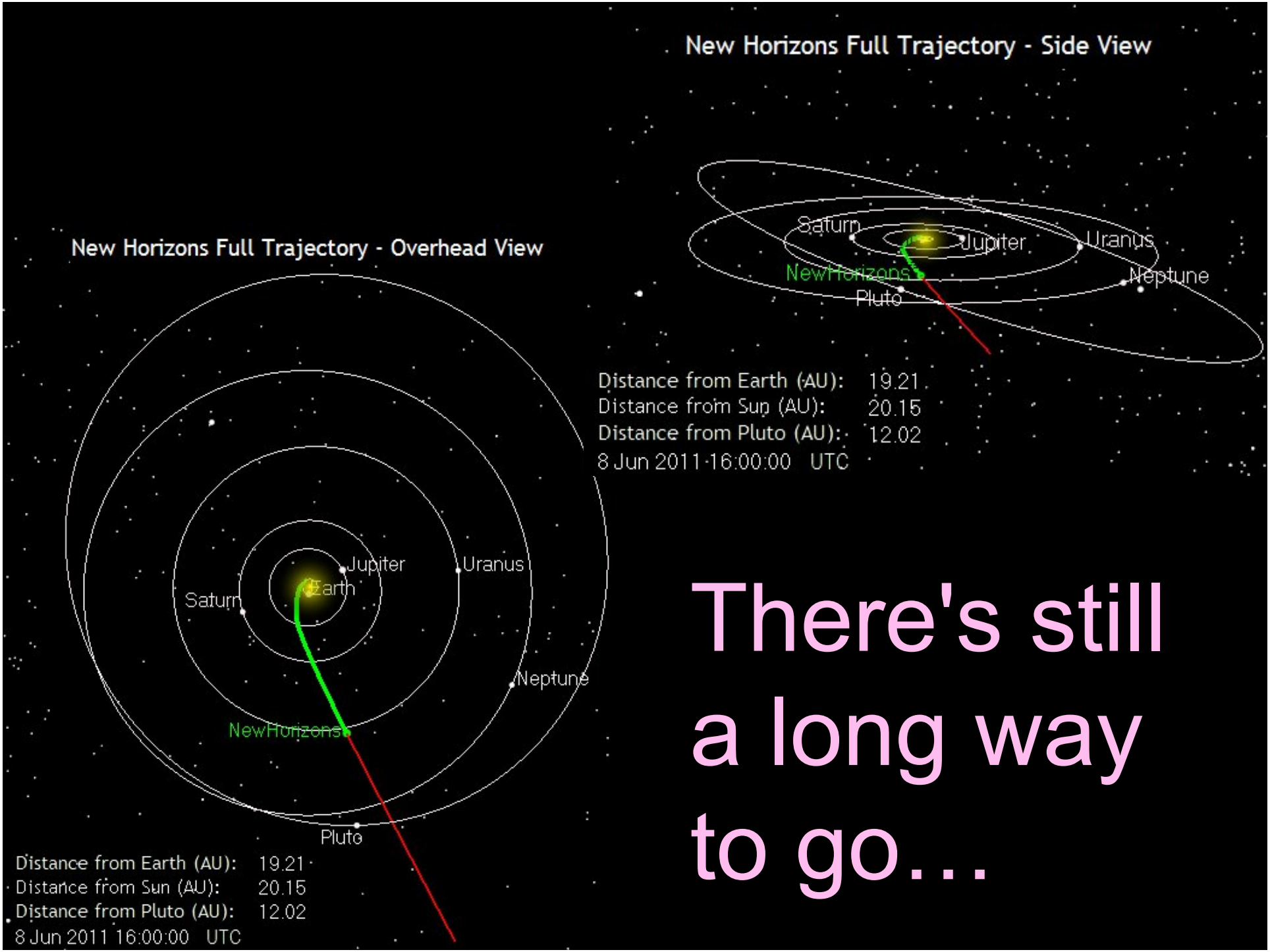
Pluto?


Sublimation winds
Escape
Frost cooled by sublimation
Rock core
Ocean?
Ice mantle
Frost warmed by condensation
Frost
Day hemisphere
Night hemisphere
Bare ground
Atmosphere


New Horizons
Mission To Pluto

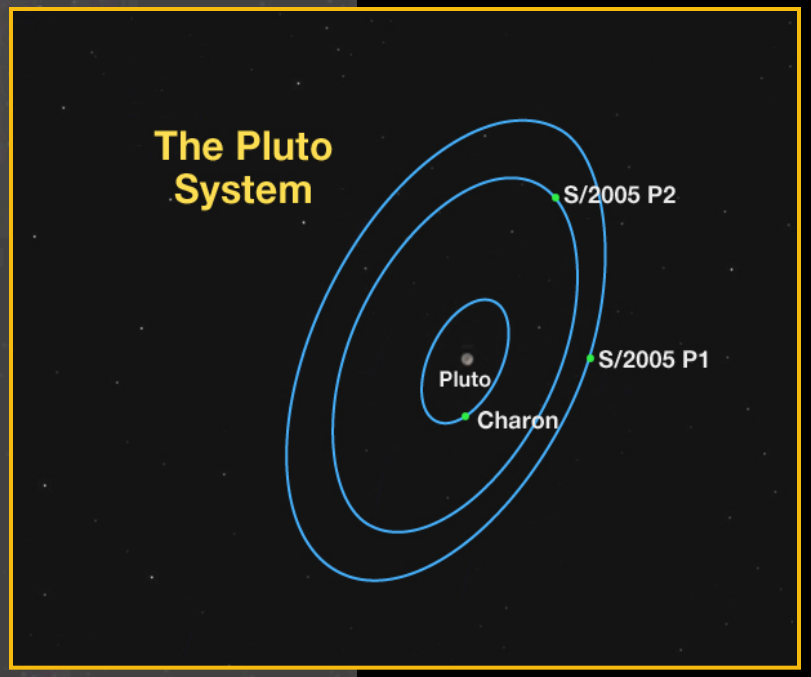
Where is New Horizons NOW?!



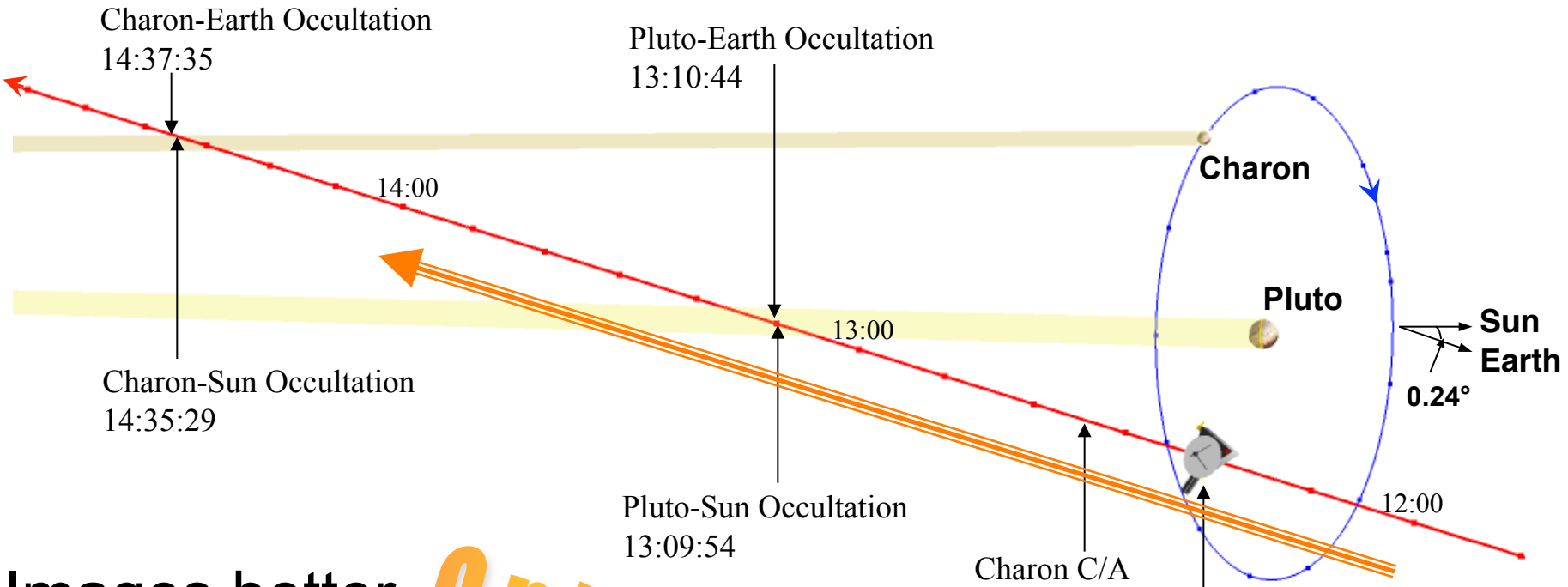

New Horizons Full Trajectory - Side View
Saturn
Jupiter
Uranus
NewHorizons
Neptune
Pluto
Distance from Earth (AU): 19.21
Distance from Sun (AU): 20.15
Distance from Pluto (AU): 12.02
8 Jun 2011 16:00:00 UTC
New Horizons Full Trajectory - Overhead View
Jupiter
Uranus
Saturn
Earth
Neptune
NewHorizons
Pluto
Distance from Earth (AU): 19.21
Distance from Sun (AU): 20.15
Distance from Pluto (AU): 12.02
8 Jun 2011 16:00:00 UTC
There's still a long way to go…

And then in 2015…

Pluto:
The Main Attraction



Pluto-Charon Encounter Geometry
Arrival July 14, 2015



Images better than Hubble >150 days before arrival

Only 2 Hours

Let's talk money…..

For example, how much does NASA's New Horizons mission to Pluto cost?

But first… What do you think is the fraction of the federal budget that goes to NASA?

A. 0.05%
B. 0.5%
C. 1%
D. 5%
E. 10%

How much does NASA's New Horizons mission to Pluto cost?

How many people in the US today? http://www.census.gov/

About 310 million ~ 3×10^8

What is total US federal budget? http://www.gpoaccess.gov/usbudget/fy11/index.html

About \$3.8 trillion ~ $\$4 \times 10^{12}$

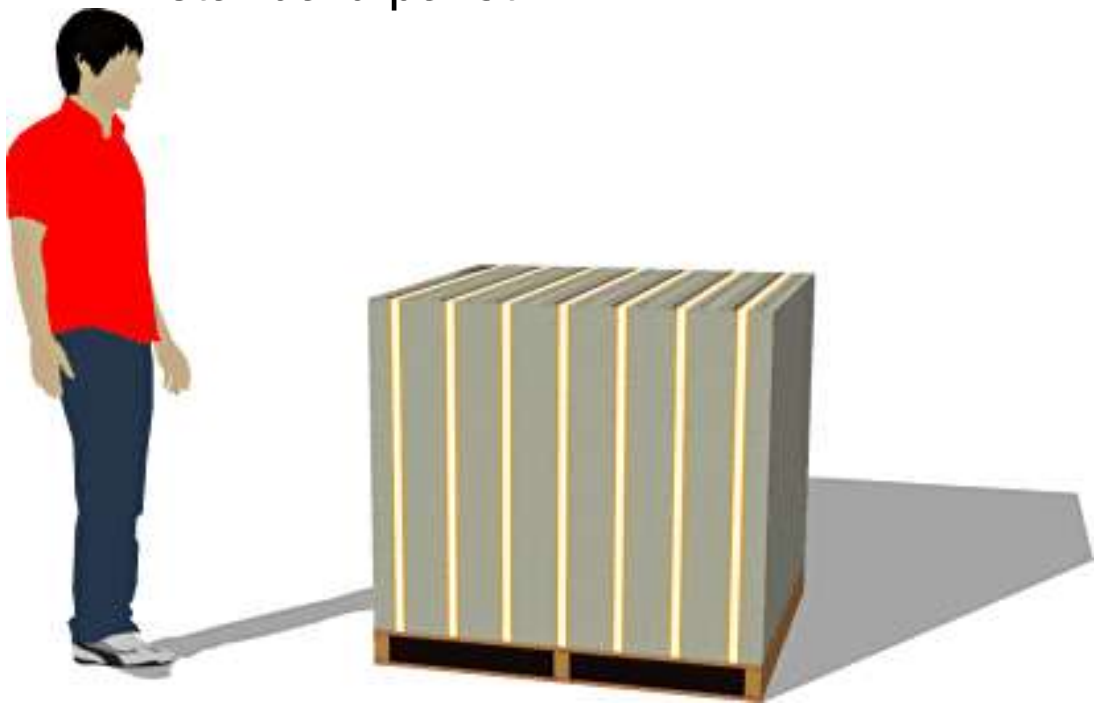
How much is 1 trillion bucks?

Let's start with a $100 dollar bill. I's currently the largest US denomination in general circulation. They're guaranteed to make friends wherever they go.

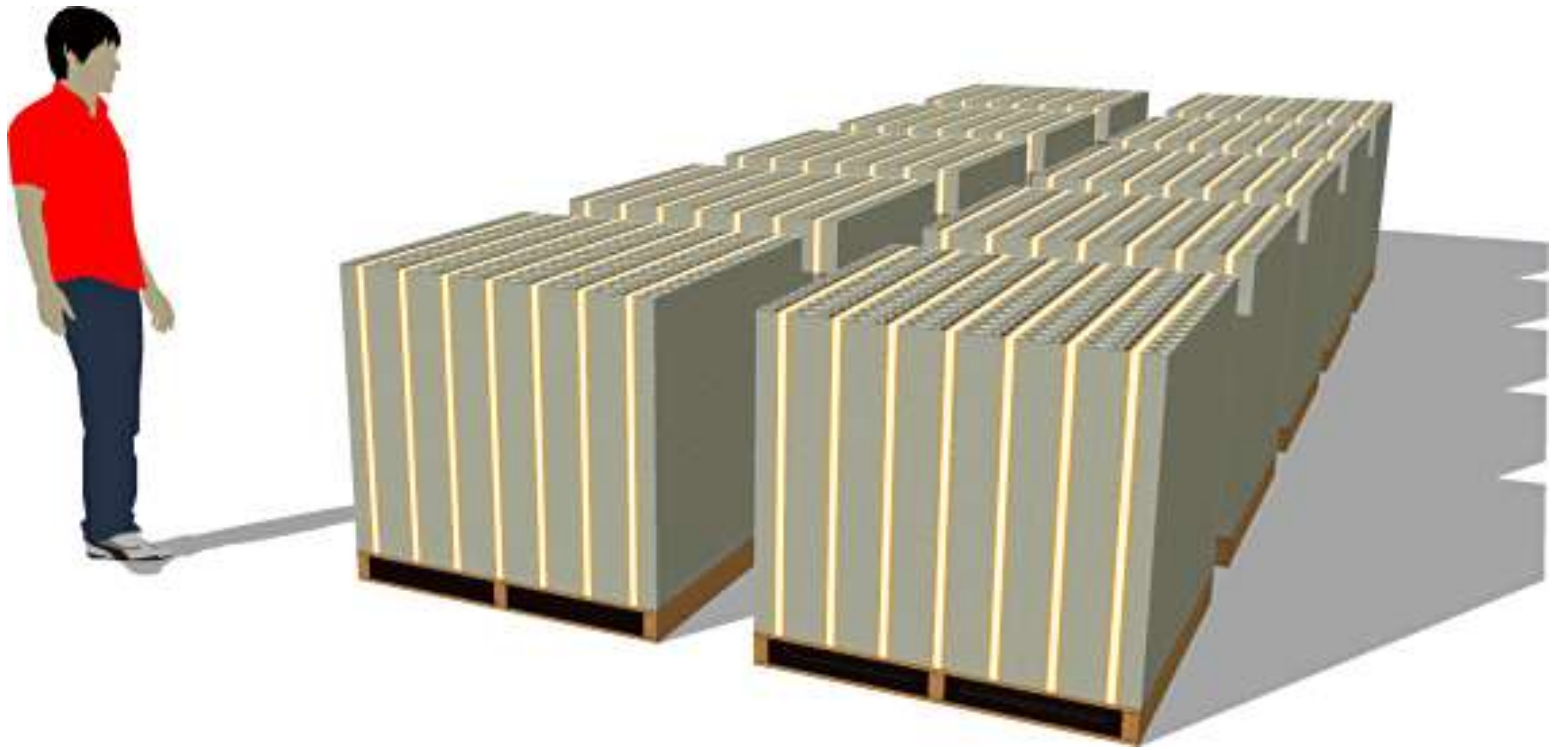
A packet of one hundred $100 bills is less than 1/2" thick and contains $10,000. It fits in your pocket and is more than enough for week or two fun.

Believe it or not, this next little pile is $1 million (100 packets of $10,000). You could stuff that into a grocery bag and walk around with it.

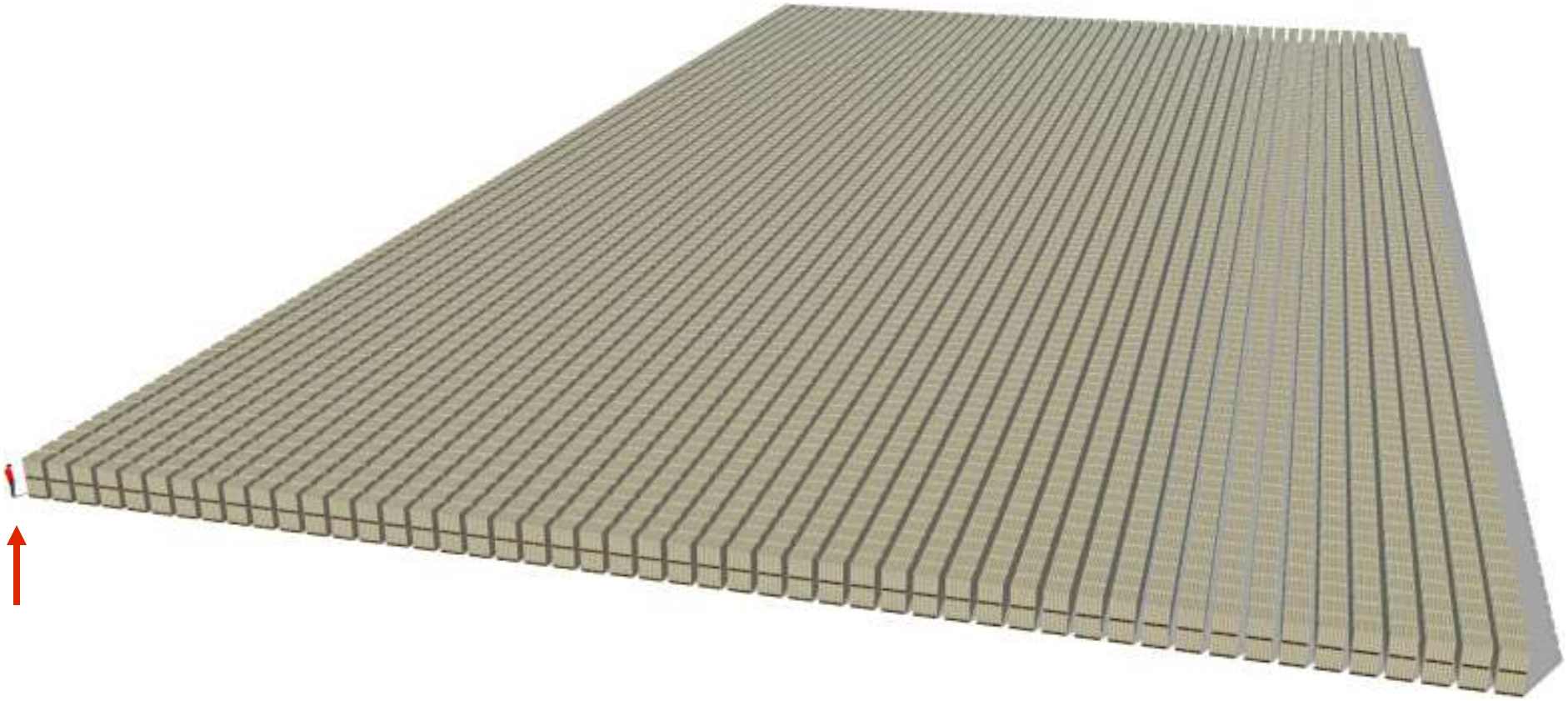
While a measly $1 million looked a little unimpressive, $100 million is more respectable. It fits neatly on a standard pallet.



And here's $1 *billion* which is really impressive.



Okay, so let's look at *one trillion dollars*. It's the number we're been hearing so much about. What is a trillion dollars? Well, it's a million million. It's a thousand billion. It's a one followed by 12 zeros. Are you ready for this?



notice that those pallets are *double stacked*

US federal budget $3.5 trillion

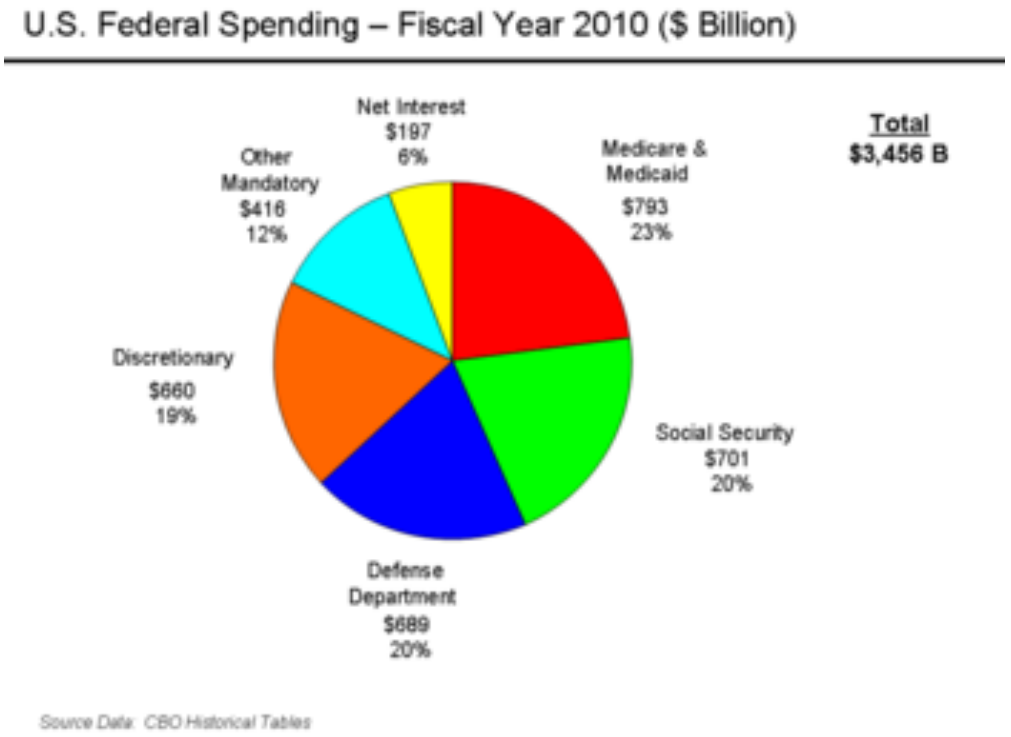
~ $4 x 10^{12}

How much is that per person?

$\frac{\$4 \times 10^{12}}{3 \times 10^{8}}$ ~ $12,000

How much is NASA's budget?

About $19 billion ~ $2 x 10^{10}



What fraction of federal budget goes to NASA?

$\frac{\$2 \times 10^{10}}{\$4 \times 10^{12}}$ ~ 1/200 ~ 0.5%

How much is this per person?

$\frac{\$2 \times 10^{10}}{3 \times 10^{8}}$ ~ $61

http://www.nasa.gov/news/budget/index.html

How much does NASA's New Horizons mission to Pluto cost?

About $1 billion ~ $1 x 10^9

Over 10-year mission, how much is this per person?

About $\frac{\$1 \times 10^9}{3 \times 10^8}$ ~$3