Outlook

- Read Chapter 13 – More details on neutron stars and black holes than we talked about in class
- Coming Up:
  Chapter 4-8: Solar System, Planets
- Midterm: October 29
  covers Chapters 3 (Telescopes) and 9-12 (Sun, Stars, Interstellar Medium, Stellar Evolution)
- After midterm: Extrasolar Planets and planetary highlights, Galaxies and Cosmology

Astronomy 103

The Solar System,
Planets, Moons, Asteroids, Comets

Read Chapter 4-8

Extrasolar Planets (Chapter 4.4)
coming up after mid-term

An Inventory of the Solar System

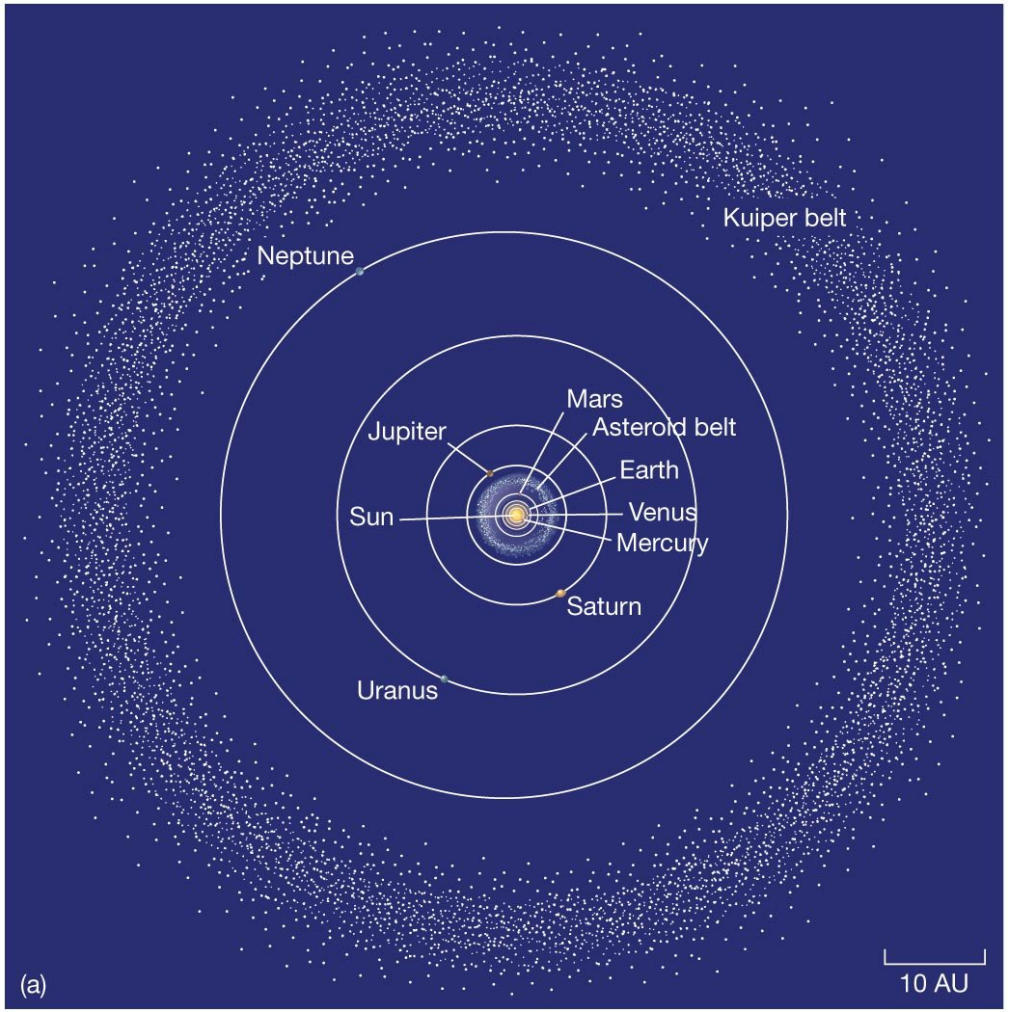
Early astronomers knew Moon, stars, Mercury, Venus, Mars, Jupiter, Saturn, comets, and meteors.

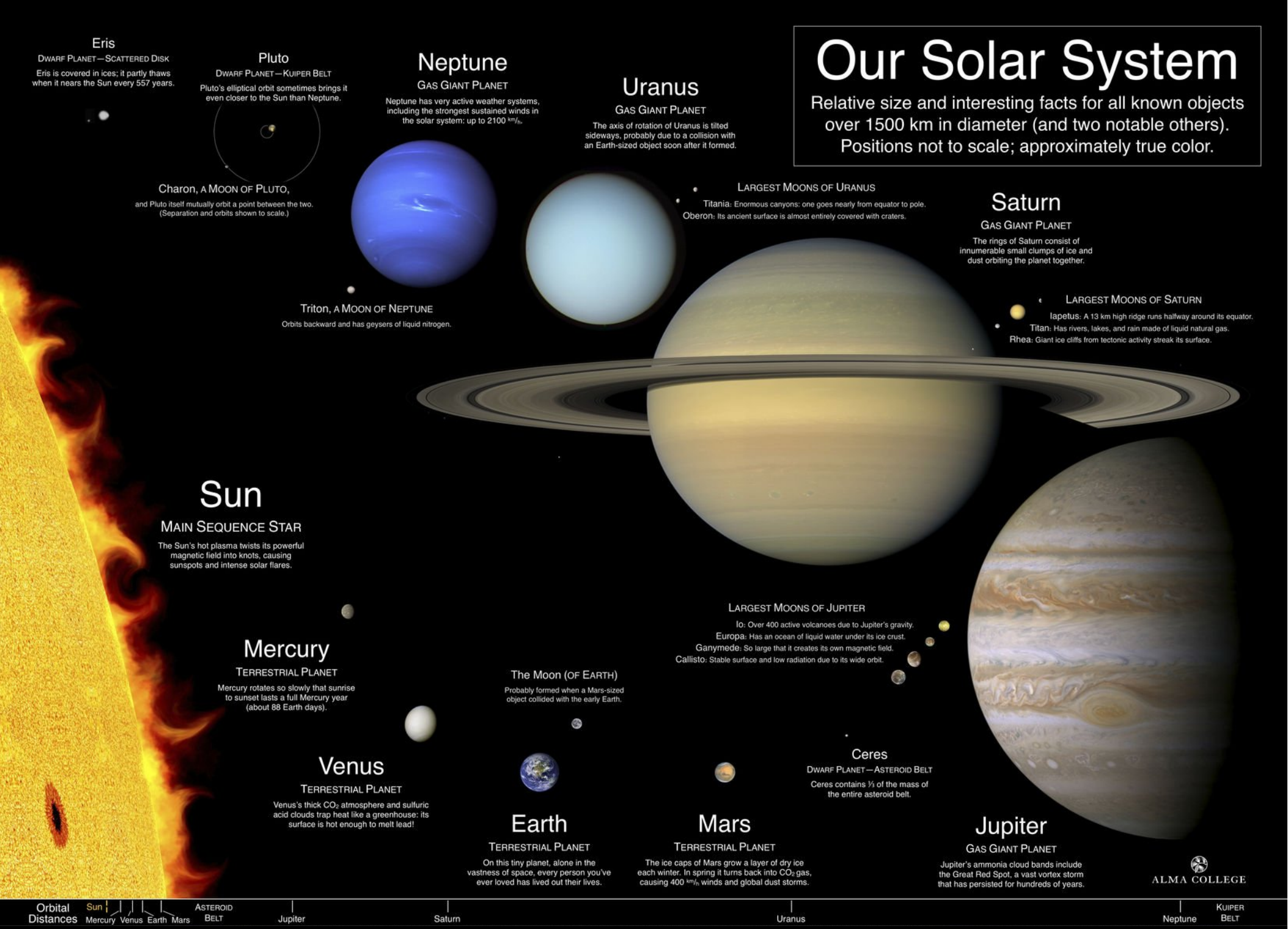
An Inventory of the Solar System

Early astronomers knew Moon, stars, Mercury, Venus, Mars, Jupiter, Saturn, comets, and meteors.

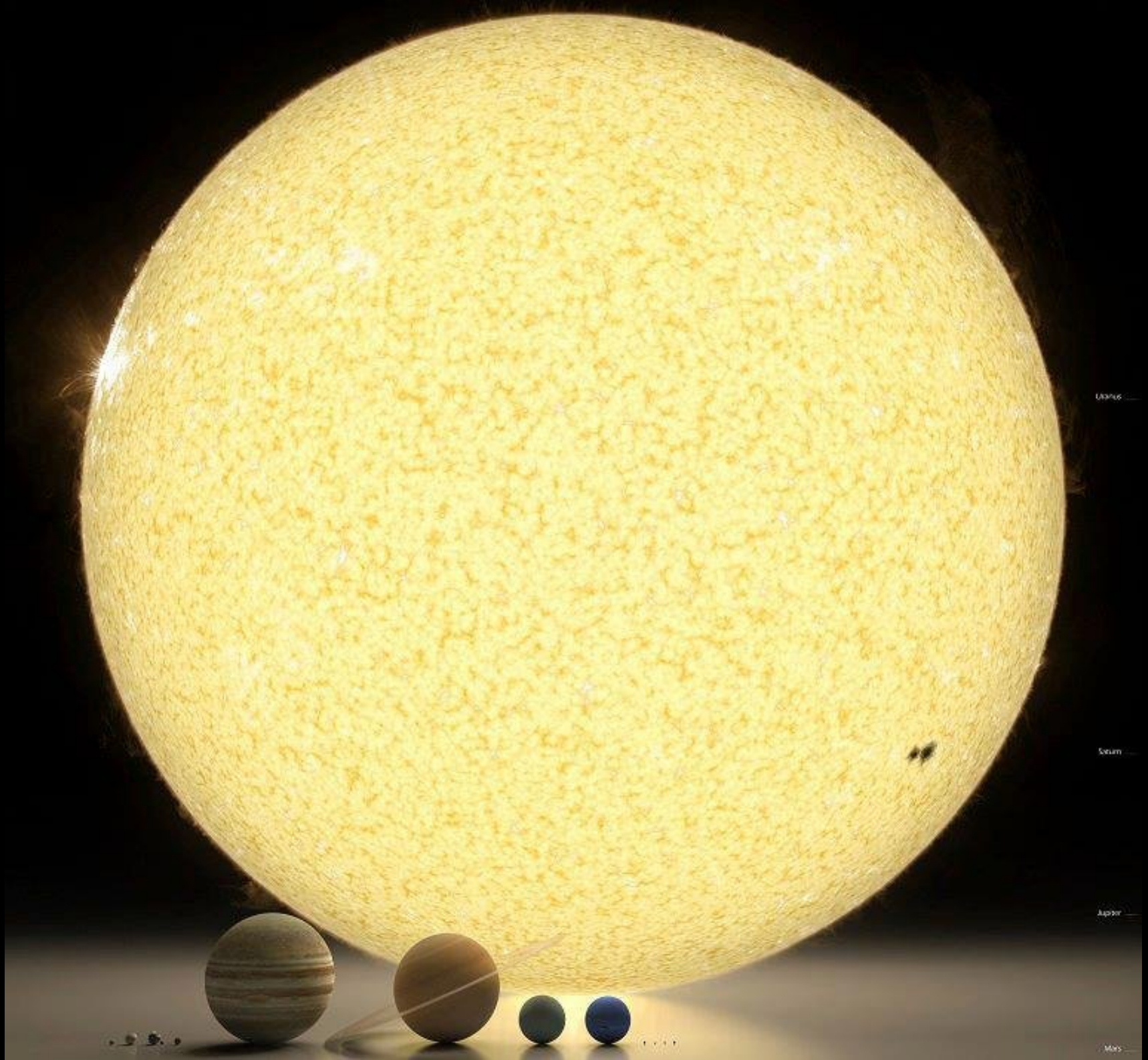
Now:

- 1 star
- 8 planets (add Uranus & Neptune)
- 166 moons
- >660,000 asteroids
- comets, meteoroids
- ~50 dwarf planets,
- Kuiper Belt objects



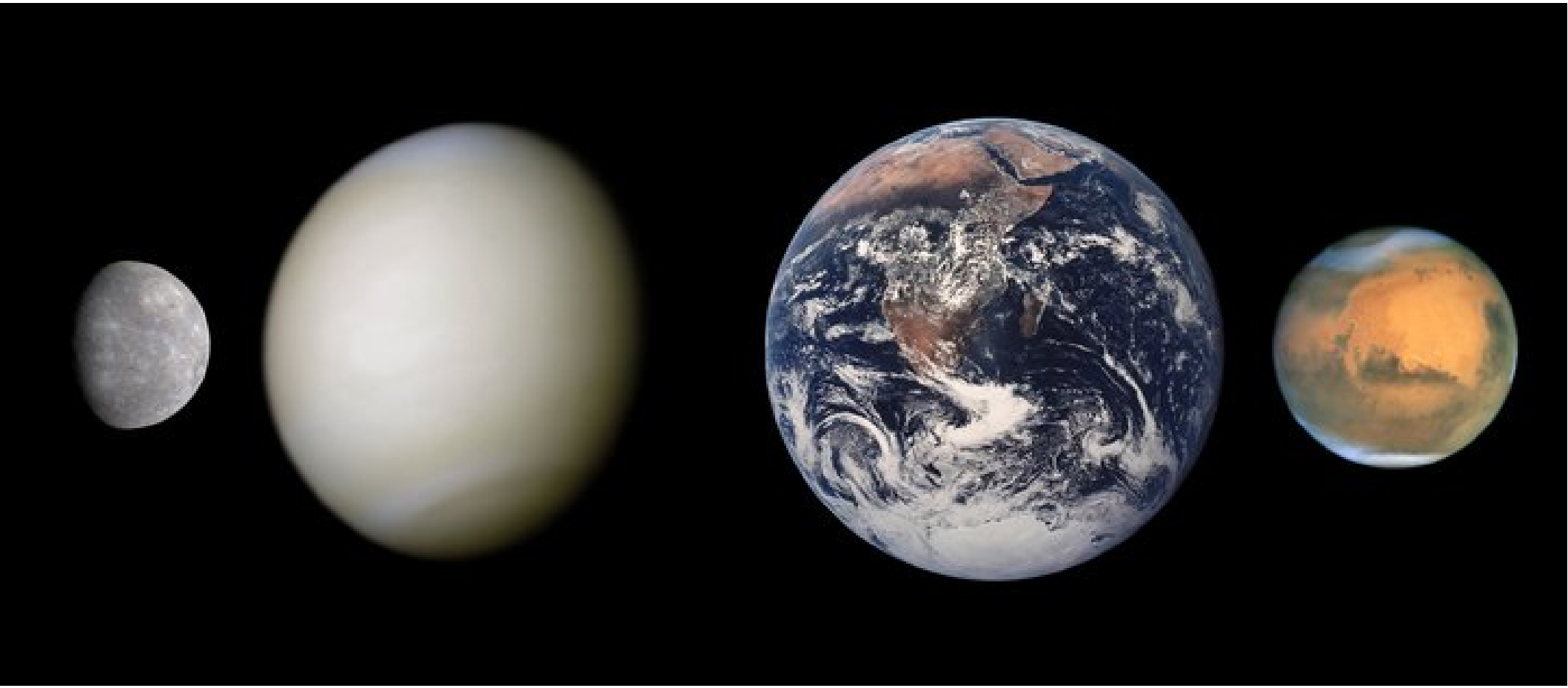


Source: http://www.slimy.com/~steuard/teaching/solarsystem/


Uranus
Saturn
Jupiter
Mars

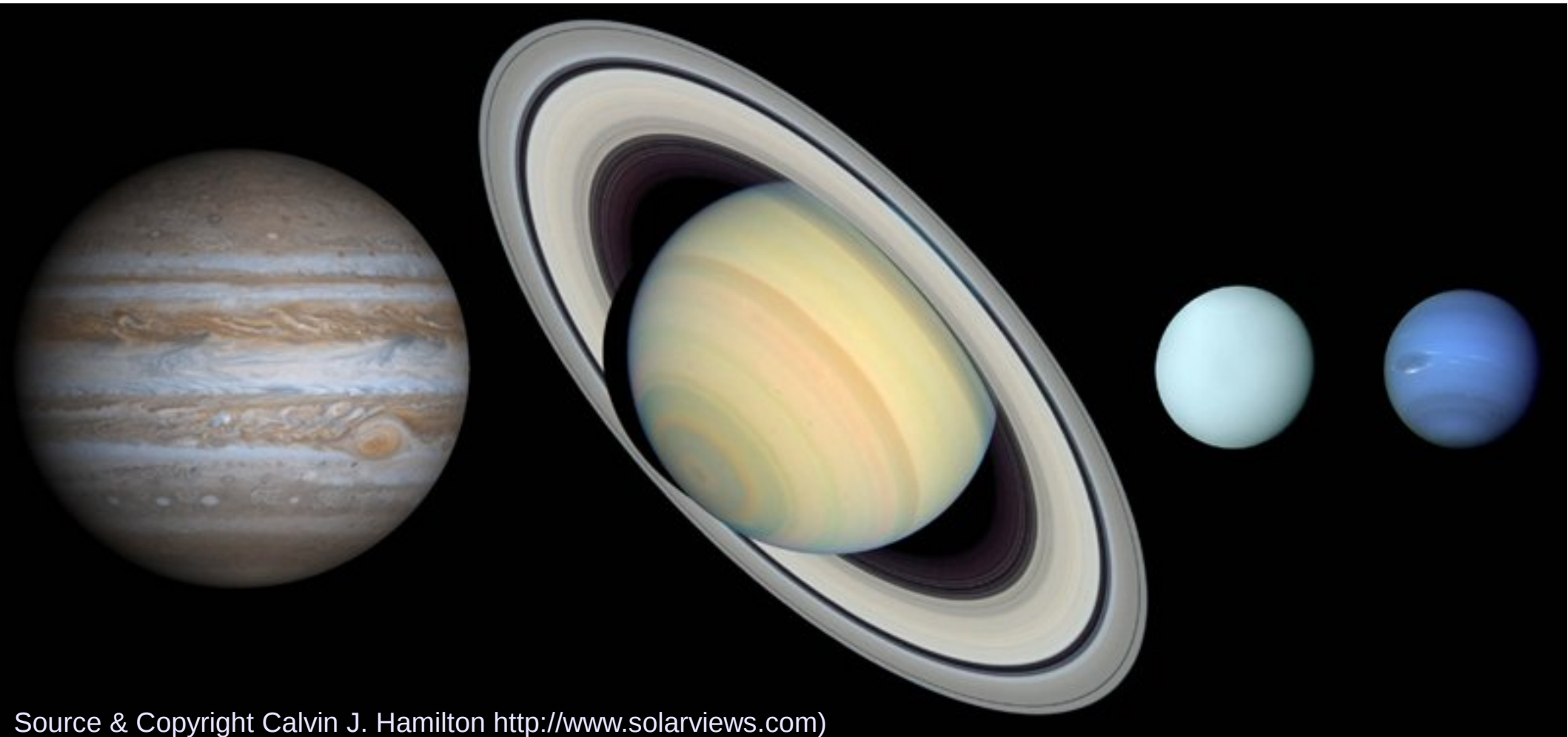
Terrestrial Planets

- Close to the Sun
- Made of rocks (silicon) and iron
- High density
- Small (~10000 km in diameter)



Jovian Planets

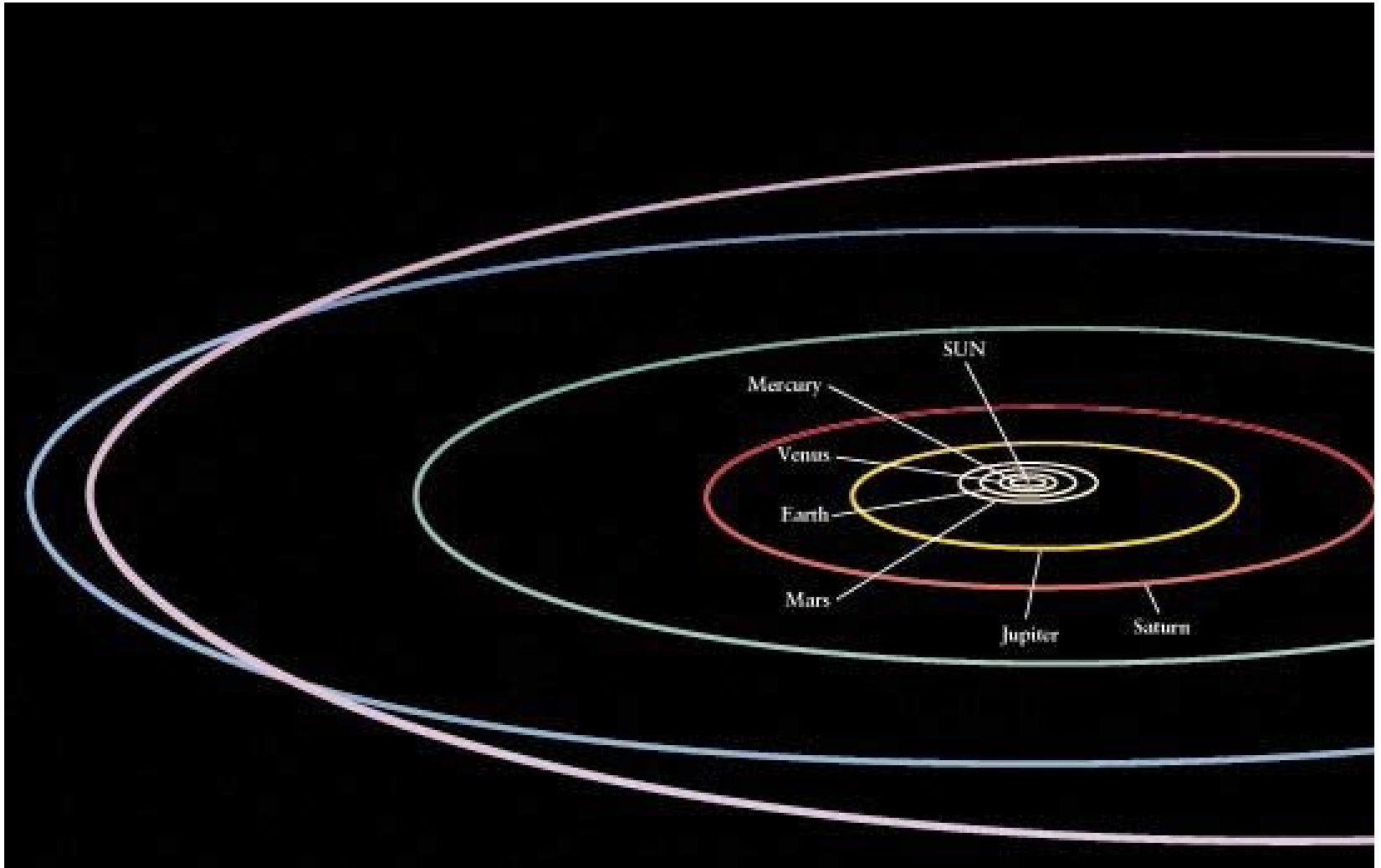
- Farther from the Sun
- Made of gases (hydrogen, helium, methane, water, ammonia)
- lower density
- large (~100,000 km in diameter)



Source & Copyright Calvin J. Hamilton http://www.solarviews.com)

An Inventory of the Solar System

The planets orbit the sun from W to E along the plane of the ecliptic – looking down from Earth's North pole, planets orbit counterclockwise.



An Inventory of the Solar System

- The planets orbit the sun from W to E along the plane of the ecliptic – looking down from Earth's North pole, planets orbit counterclockwise.
- Orbits are nearly circular – yes, Kepler says that they are ellipses, and they are, but they are nearly perfectly circular ellipses
- Nearly all in the same plane – without Pluto, they are perfect to 1%
- Inner planets are called **terrestrial planets**
- Outer planets are called **Jovian planets**

Formation of the Solar System

Can we develop a model for the formation of the solar system that explains these properties?

- The **nebular hypothesis** suggests that the planets formed from a gas cloud which collapsed into a disk.
- This gas cloud has roughly the same composition as the Sun (mostly hydrogen, helium, + a trace of carbon, oxygen, nitrogen, iron etc)

The Nebular Hypothesis or Theory

The idea that the planets form from a disk is called the **nebular hypothesis.**

This idea was proposed by many people, one of which was Pierre Simon Laplace, a mathematician in 18th century France

However, this was not the only idea

Alternatives to the nebular hypotheses

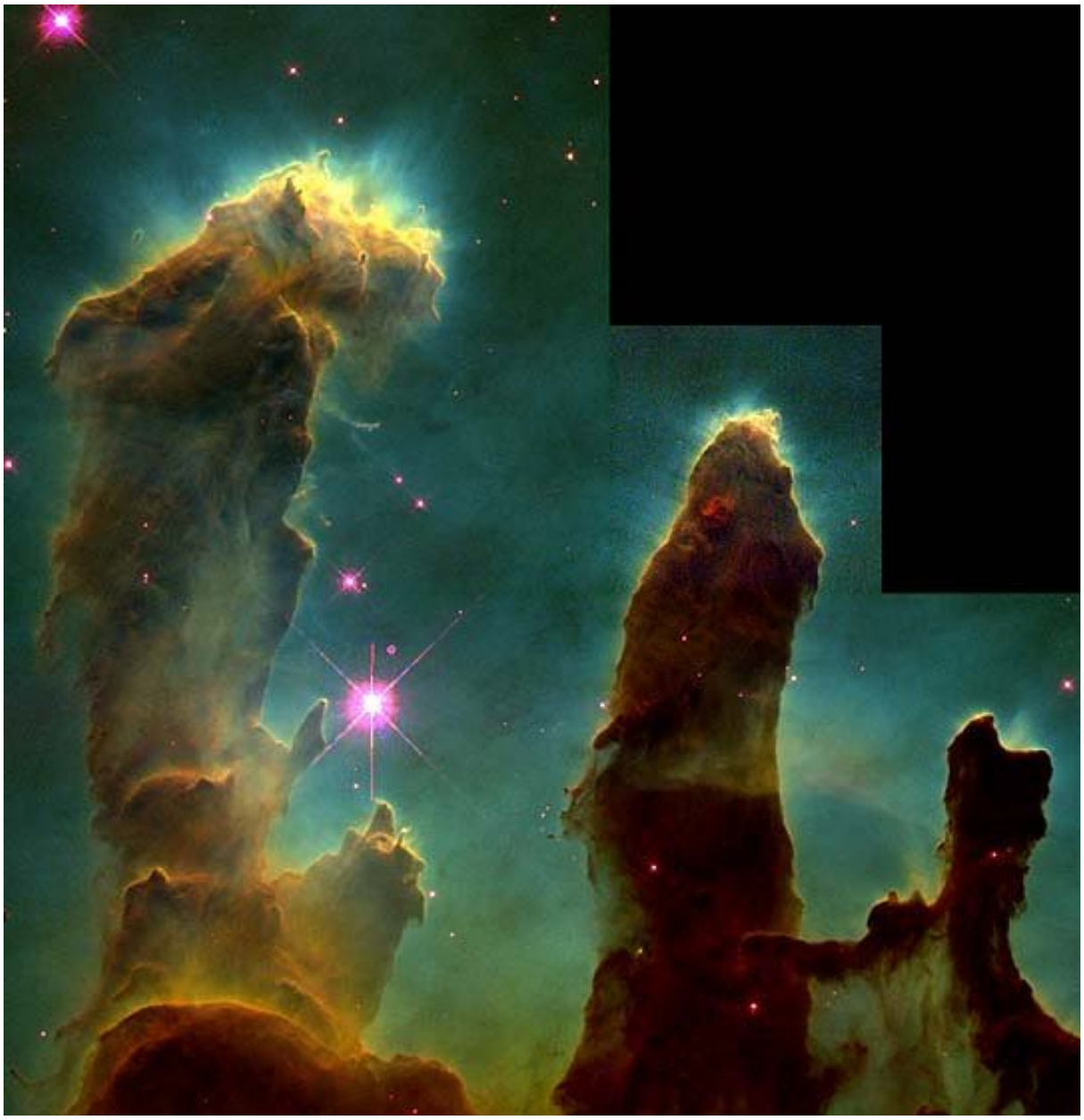
- **Tidal model:** a passing star ripped material from the Sun and that material collapsed to form the planets
- **Capture model:** The sun and planets formed separately, but the planets were captured later by the Sun
- **Accretion model:** The sun moved through a gas cloud, got some gas and that gas formed the planets

However, the nebular hypothesis eventually won out over all competitors because of the many observations of disks around young stars

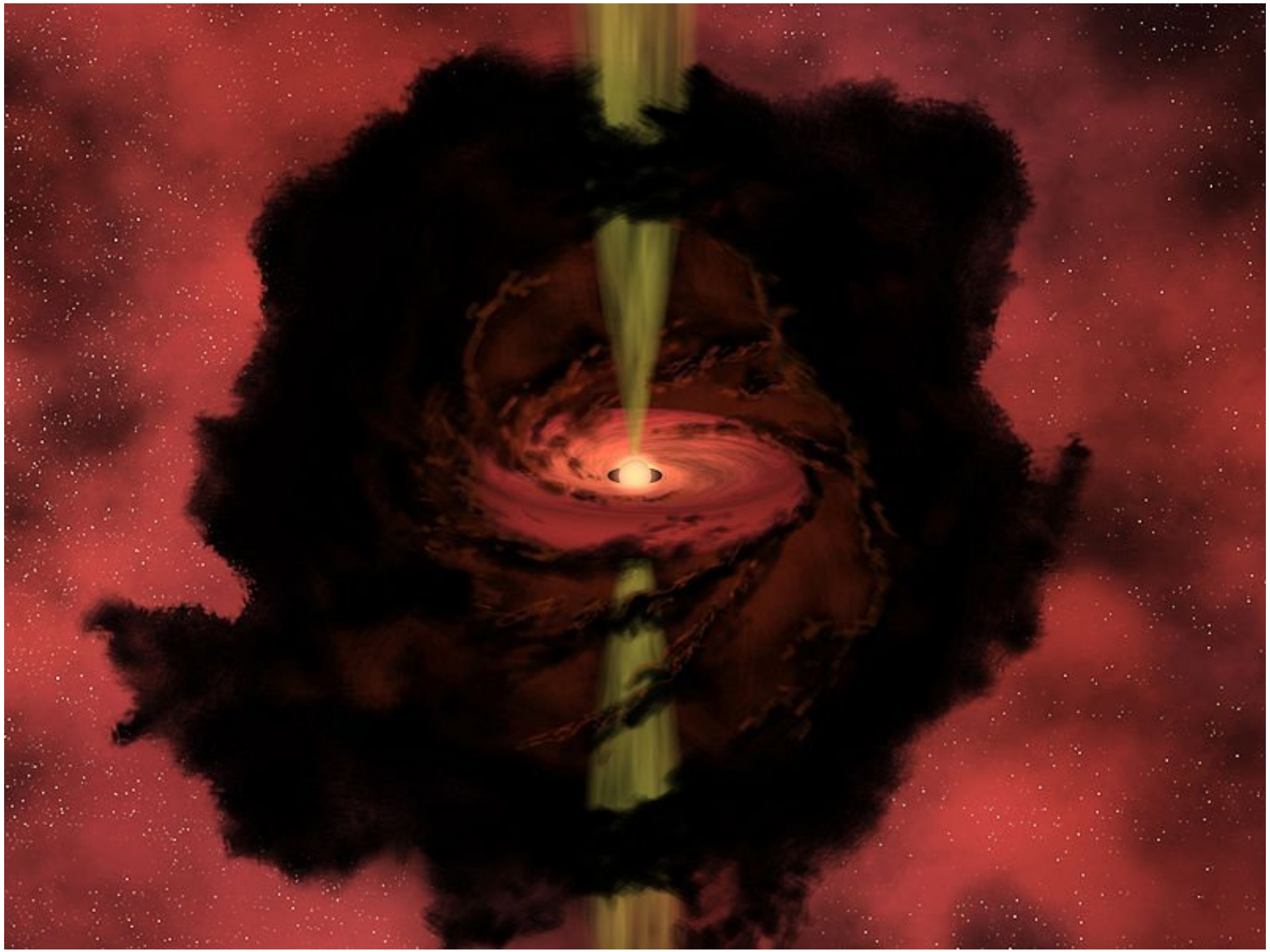
Formation of the Sun

Remember that most of the mass of the solar system is in the Sun. So the formation of the solar system is a footnote to the formation of the Sun.

Recall that stars form from molecular clouds.



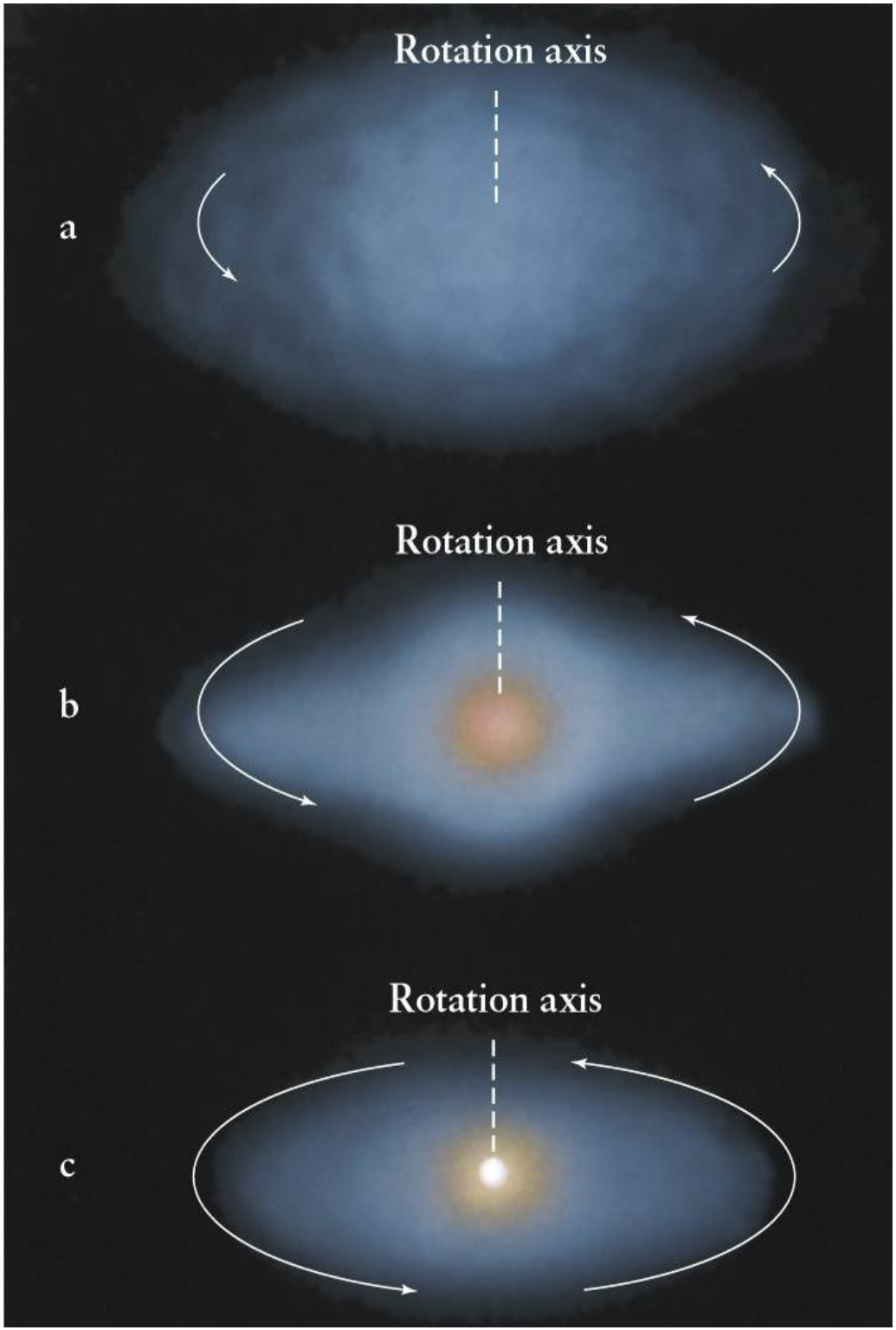
The protostar



The collapse of one of these clouds forms a **protostar** and the disk of gas that surrounds it

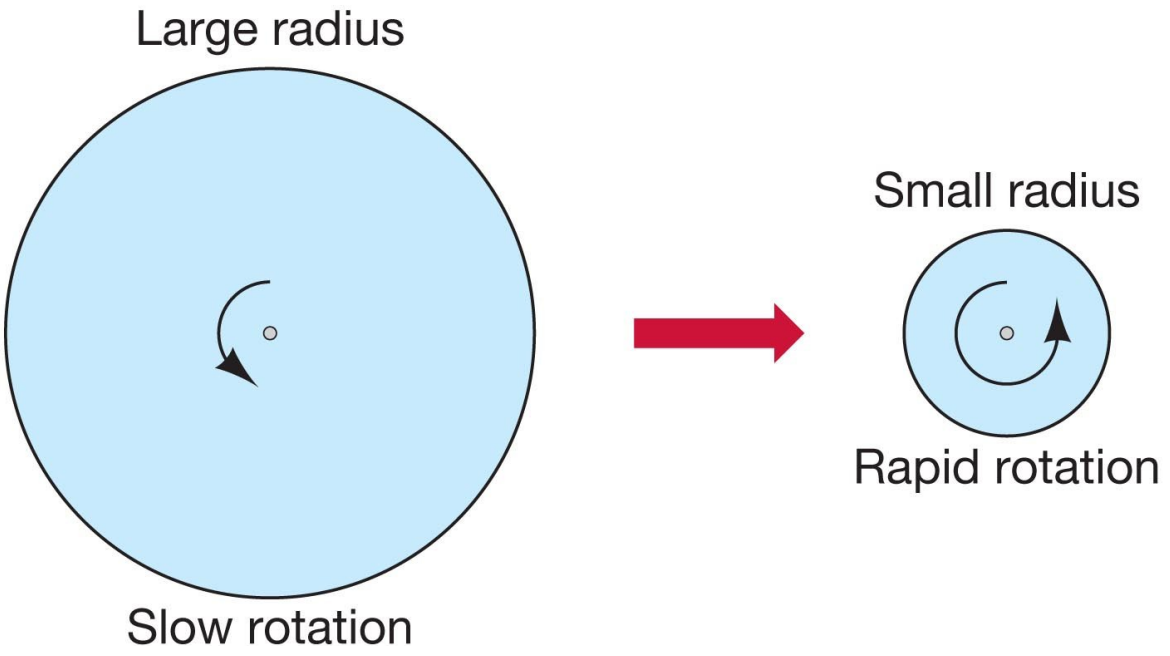
Disk Formation

- As the cloud collapses, the angular momentum in the gas makes it spin faster and faster until the the gas moves fast enough to orbit the protostar.
- This is a general principle in astronomy. Collapse of stuff leads to the formation of a disk due to angular momentum



The Concept of Angular Momentum

Angular momentum: **spinning things keep spinning**, and in the same direction



Conservation of angular momentum says that product of radius and rotation rate must be constant.

→ **Therefore, as a dust cloud collapses, its rate of rotation will increase.**

Formation of the disk

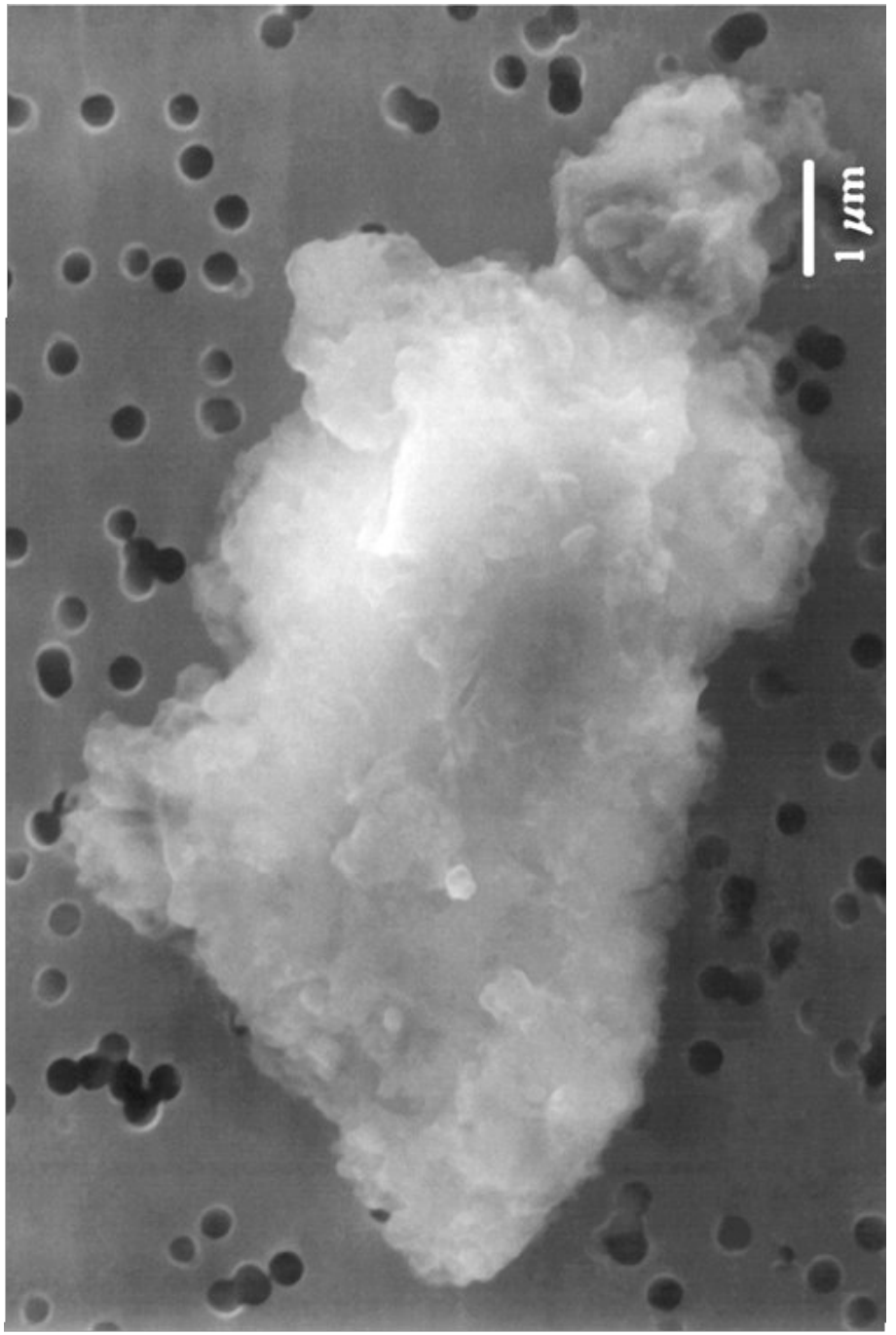
One way to look at this in action is to look at an ice skater as she moves her arms in. The ice skater spins faster as a result of angular momentum causing her to spin up.

Condensation of the planets

- Gas does not condense (because it remains gas), but **dust** can gather – tiny chunks of rocky and icy matter, with sizes of about 10-5 m
- Dust grains form in cool atmospheres of old stars, are ejected, grow by accumulating molecules from interstellar gas
- Dust collects into larger bodies: dust bunnies!

Forming dust bunnies

- Dust bunnies or dust coagulations are stuck together by molecular forces.
- Small grains stick together to make larger grains which stick together to make even larger grains.



Condensation of the planets

- Clumps of dust grow larger, become able to sweep up more and more material: this process is called **accretion**
- Eventually we get objects a few hundred km in size, which have gravity strong enough to affect their neighbors and sweep up even more material: **planetesimals**
- Eventually nearly all material swept up into **protoplanets**
- Stuff that escapes capture and is left over becomes **asteroids** and **comets**
- Also: **high-speed collisions** between protoplanets and planetesimals

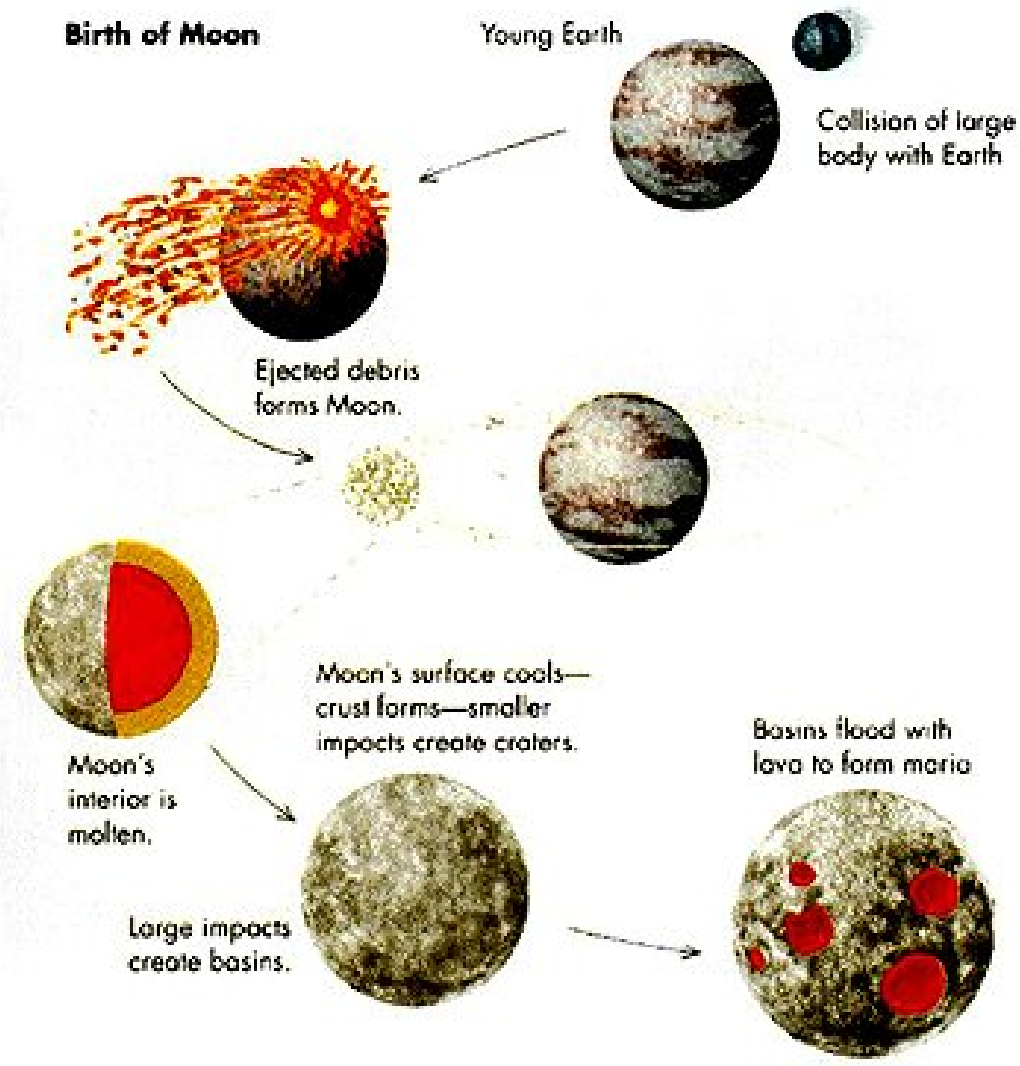
Forming the Moon

One of these high-speed collisions is thought to be responsible for the formation of Earth's Moon.

Forming the Moon

During the formation of the Earth, the young Earth suffered a collision with a Mars-sized body that threw up material into orbit that condensed to form the Moon.

This is a rare event, and Earth is the only terrestrial planet with a large moon



Scenario I: Slow, big impact

Source: https://www.youtube.com/watch?v=Fwl_JBQtH9o

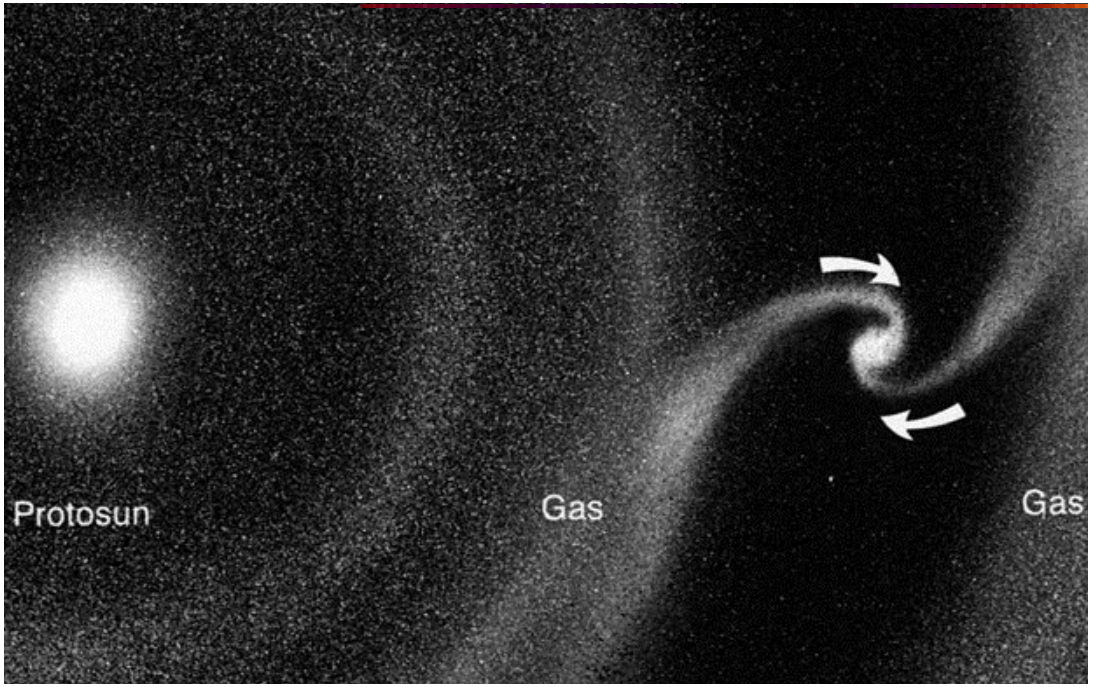
Scenario II: Small, fast impact

Source: https://www.youtube.com/watch?v=3JNNKQrfXzk

Forming Jupiter and Company

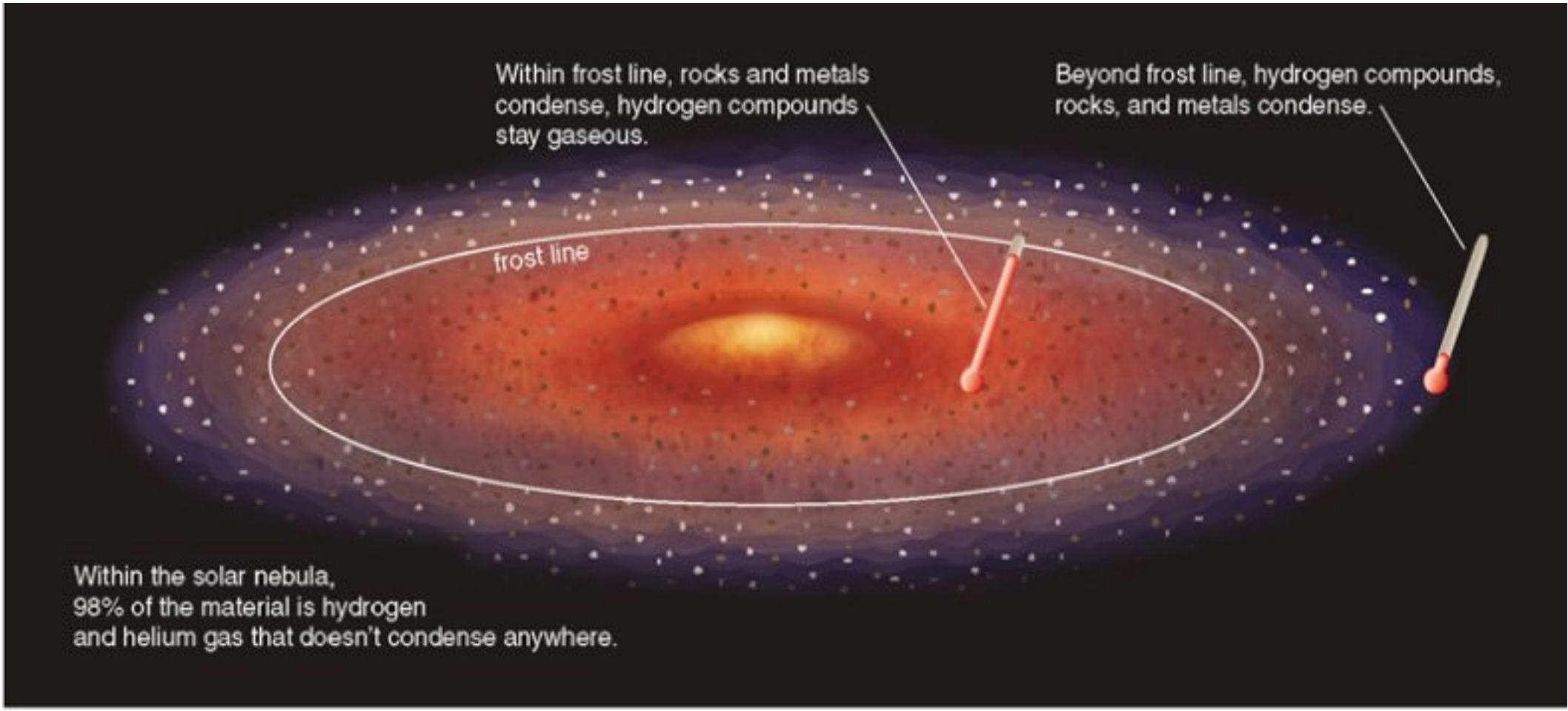
Up to this point, the story has produced rocky bodies, perfect for terrestrial planets, but the Jovian planets are different because they are gaseous.

To form the Jovian planets, we need one more stage of planet formation in which the gas accretes onto these rocky cores



However, to accrete gas we need a big core

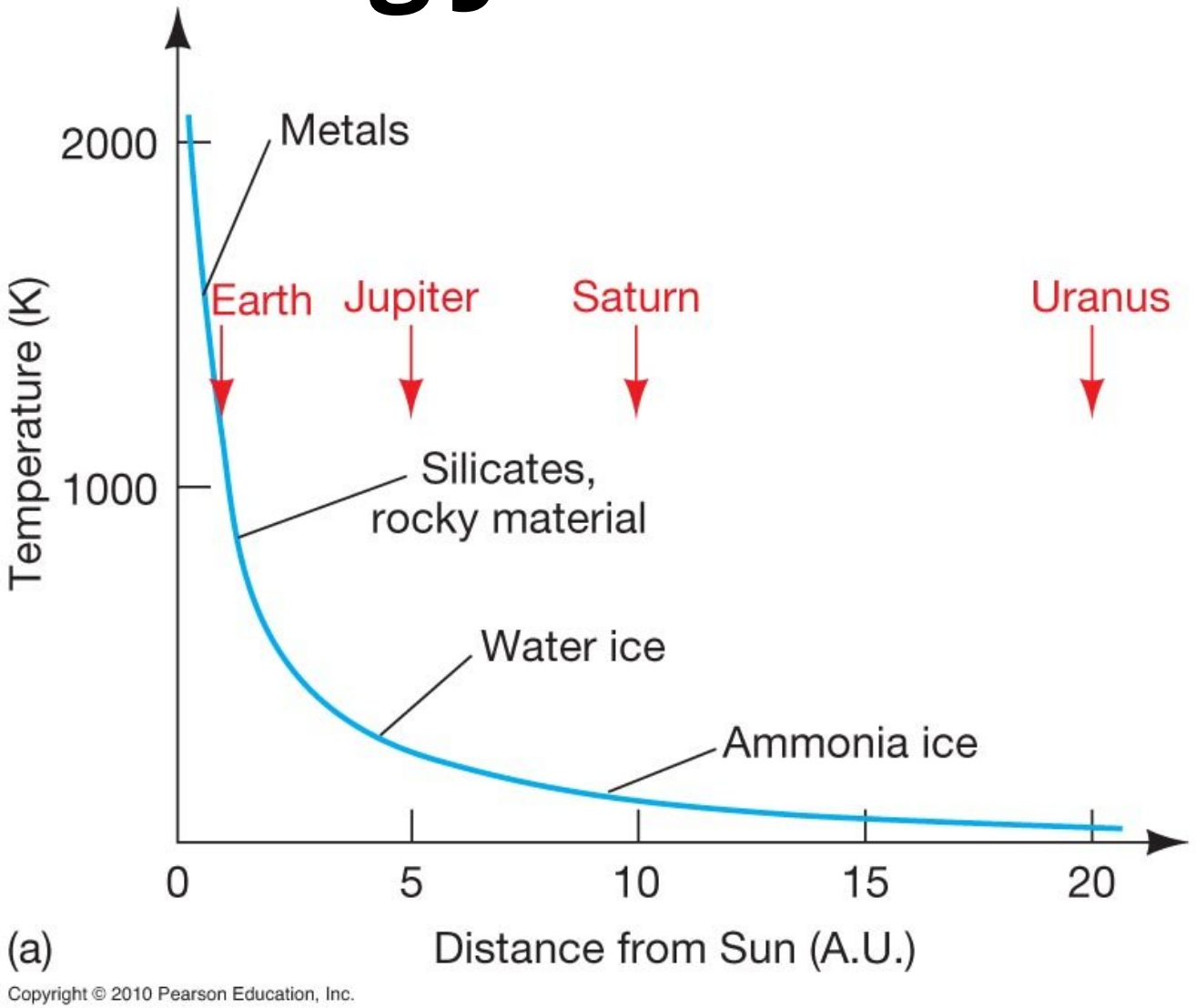
Forming Jovians



Bigger cores are possible if you can gather more material. In regions where the gas is so cold that ices form – beyond the **snow line** or **frost line** – we have the extra stuff to make this possible.

Forming Jovians

This plot shows the types of material that could condense at different radii as the solar system was forming.

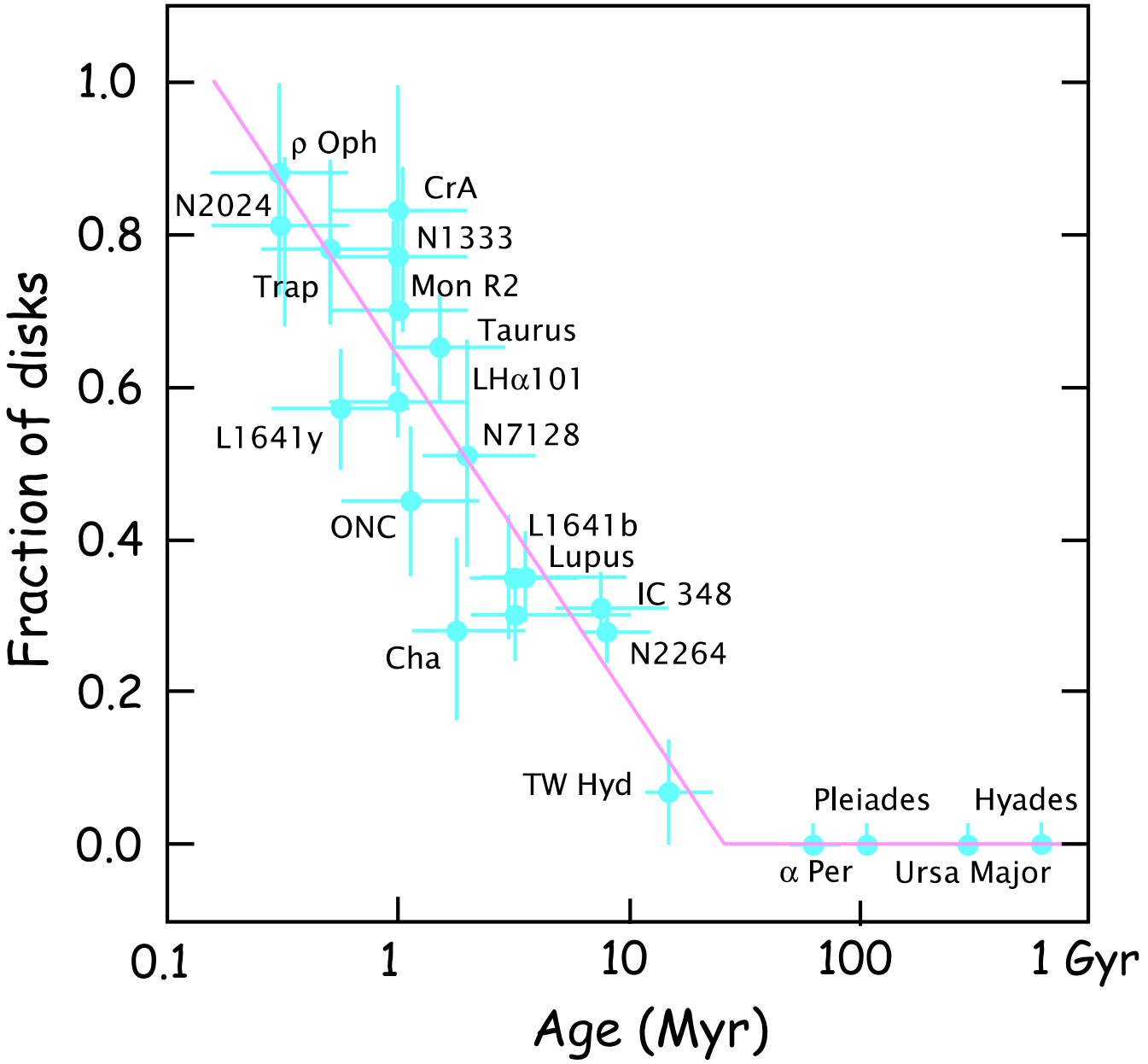


In the early solar system, the snow line was roughly at the position of Jupiter today!

End of planet formation

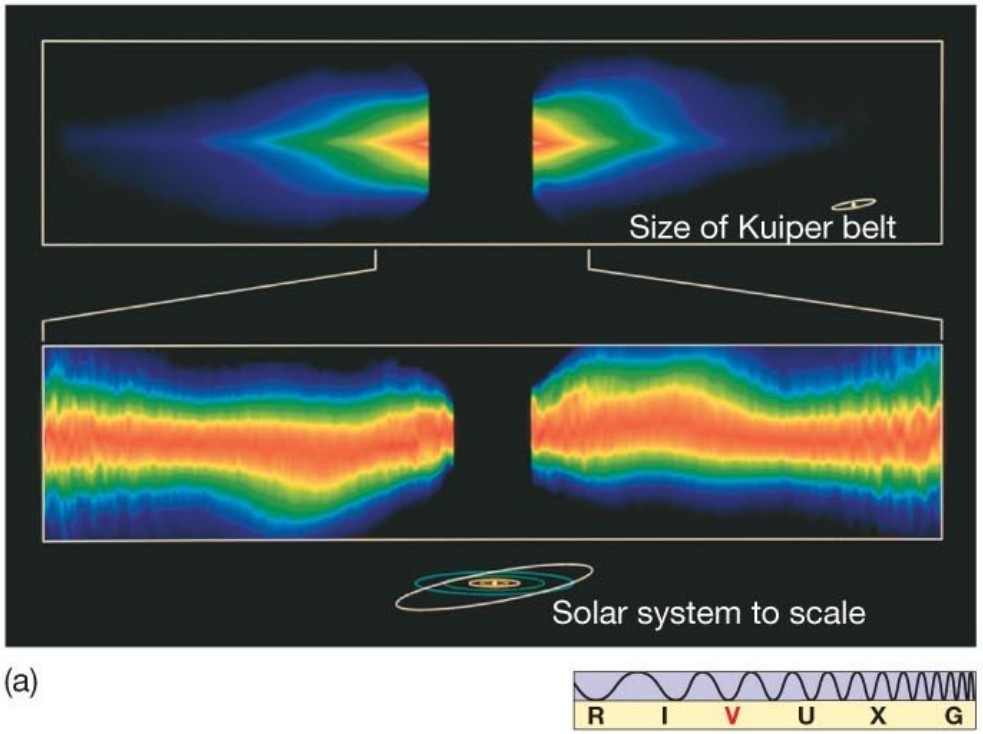
We see this process in action in observations of young protostars with disks.

This plot shows that as protostars get older, they are less likely to have a disk – probably because it has condensed into planets.

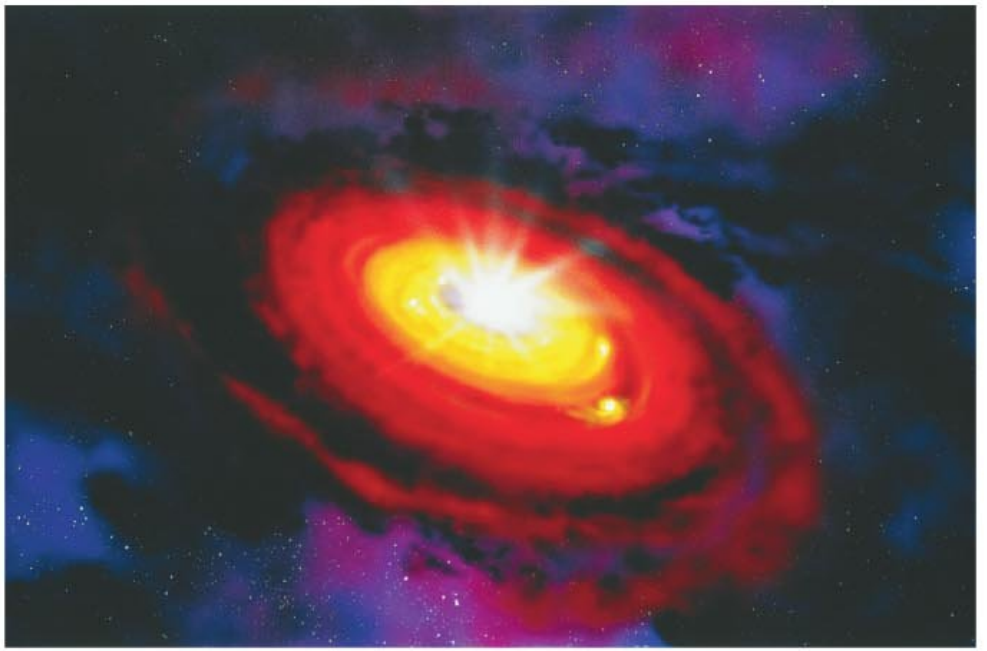


Disks around other stars

The star Beta Pictoris is surrounded by a disk of warm matter, which may indicate planetary formation.

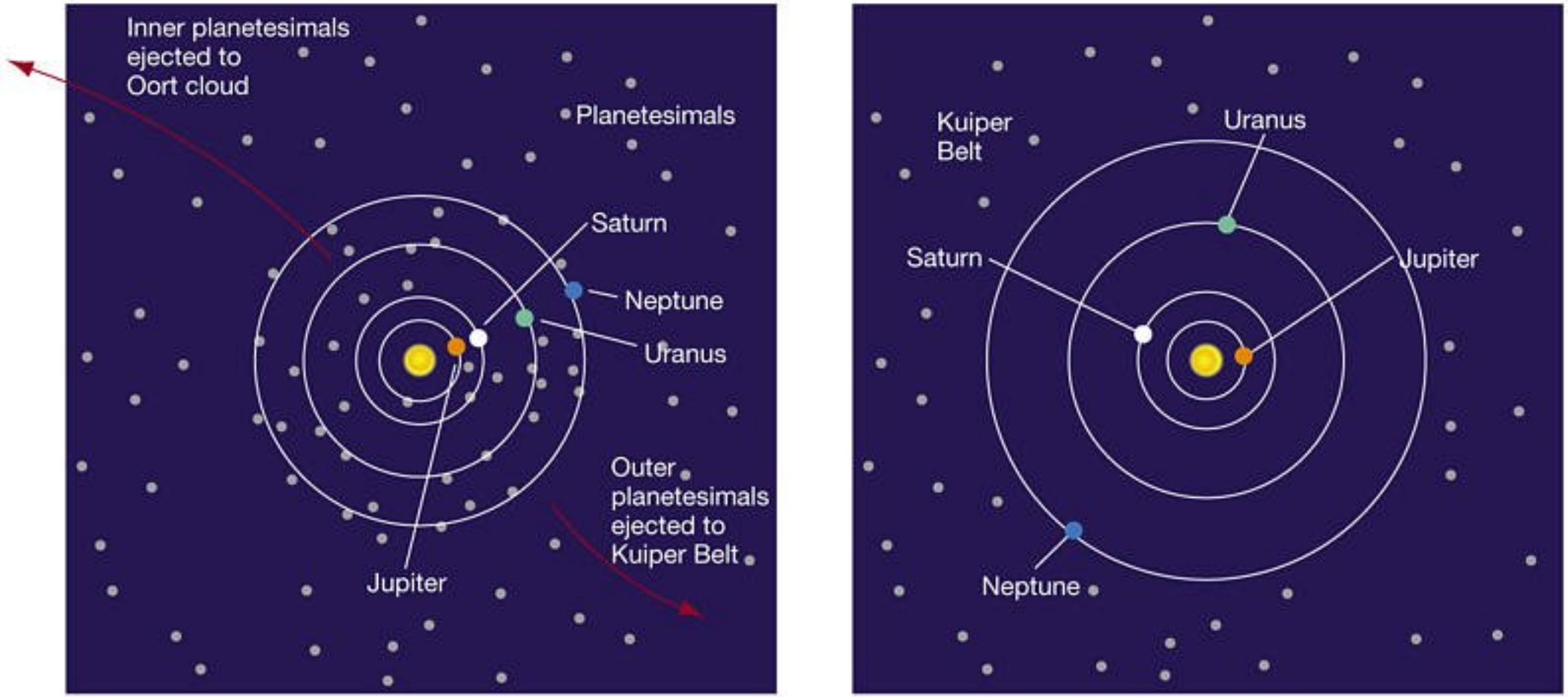


(a)



(b)

Scattering and Ejection



The early solar system was filled with debris that was ejected by the planets (mainly Jupiter).

Scattering and Ejection

The larger pieces of this debris in the early solar system are called planetesimals. The ejection and scattering of planetesimals allowed the planets to change their orbits.

Generally Neptune, Uranus and Saturn move outward at the expense of Jupiter, which moves inward.

Jupiter being the biggest planet tends to fling stuff out of the solar system, causing it to move inward, while the other three planets tend to move planetesimals inward – so they move outward.

The Nebular Hypothesis and the Solar System

- **Planets form in a rotating disk**
  - Planets are all (nearly) in a plane to about 1%
  - All orbit in a counterclockwise direction and nearly all rotate in the same direction as well.
  - Orbits are nearly circular
- **Planets are relatively isolated – far away from their neighbors**
  - Planets accrete all the material in their neighboring orbits
- **The composition of the planets differ**
  - The presence of the snow line allows different materials to condense onto forming protoplanets.
- **Space between planets is relatively empty**
  - Planets scatter small bodies

Density of Planets

Density of a object is:

Density = mass / volume

Density of some common materials:

- Water ~ 1000 kg/$m^{3;}$
- Rock ~ 2000-3000 kg/m^3
- Iron ~ 8000 kg/m^3

- For objects like the Sun, Jupiter, Saturn: density is ~ 1000 kg/m^3
- For terrestrial bodies like Earth, Mercury, Venus: density is around 5000 kg/m^3

Compared with terrestrial planets, Jovian planets have all of the following characteristics EXCEPT

A Low density

B Many moons

C Larger size

D Slower rotation

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History of the Solar System

We want to understand the history of the solar system

However, large bodies like planets evolve

Volcanism, erosion, plate tectonics…

So it is important to look at things that hold a better record of the past: small bodies that don't change much

The small bodies that have the best clues are **asteroids, comets, meteoroids** (coming from asteroids and comets) and **plutoids**

The age and chemical composition of these things can tell us about the early solar system

Asteroids

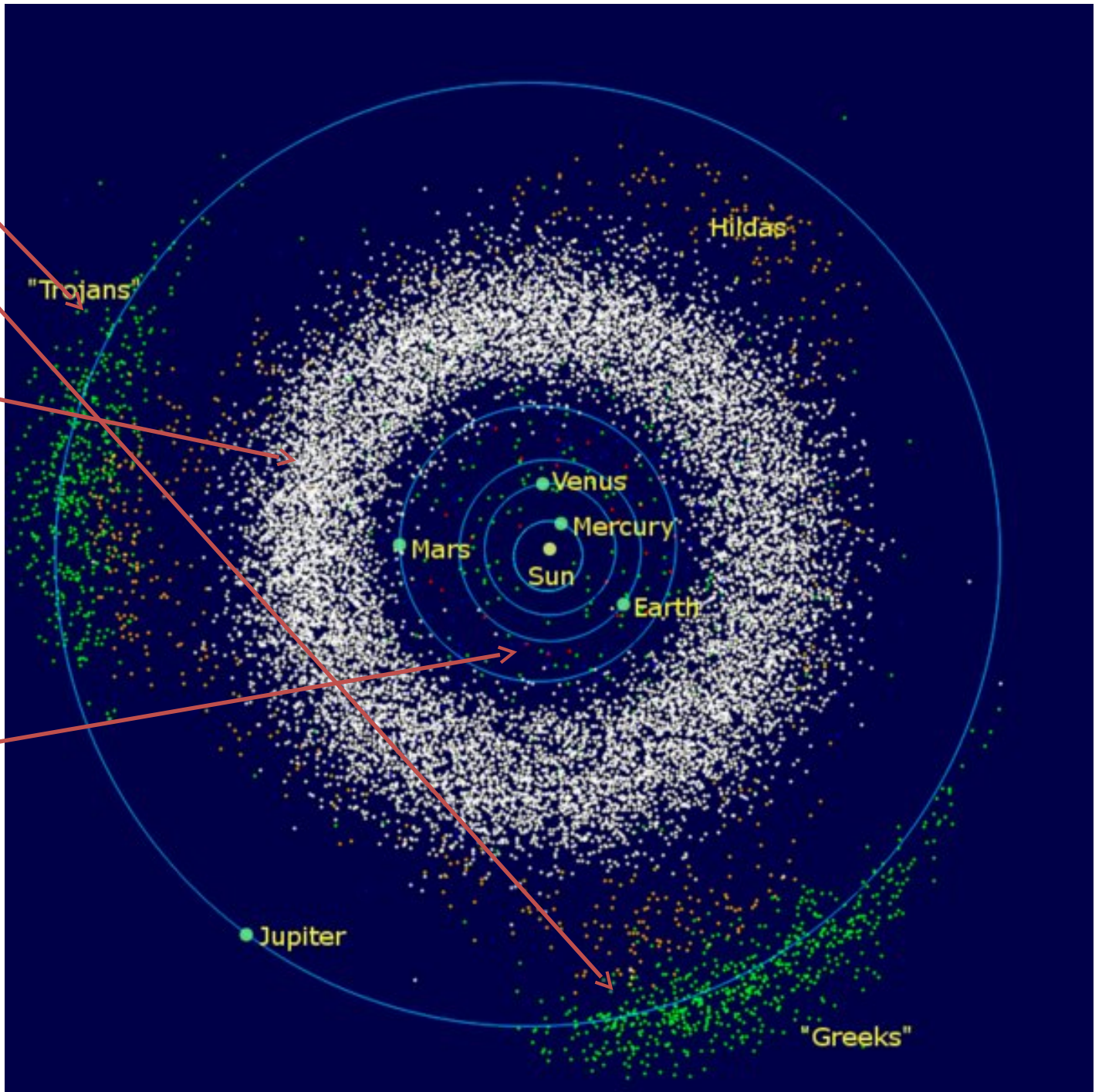
- Rocky bodies that are held together by gravity and internal forces
- Most live in a belt between Mars and Jupiter at 2.8 A.U. called the asteroid belt
- about 100,000 rocky objects bigger than 1 km exist
- Ceres is the largest asteroid with a diameter of ~1000 km
- A few thousand have orbits that cross Earth's orbit – called near-Earth asteroids (NEAs)
- Some are near Jupiter (60 degrees ahead and behind) and are called Trojans

Asteroids

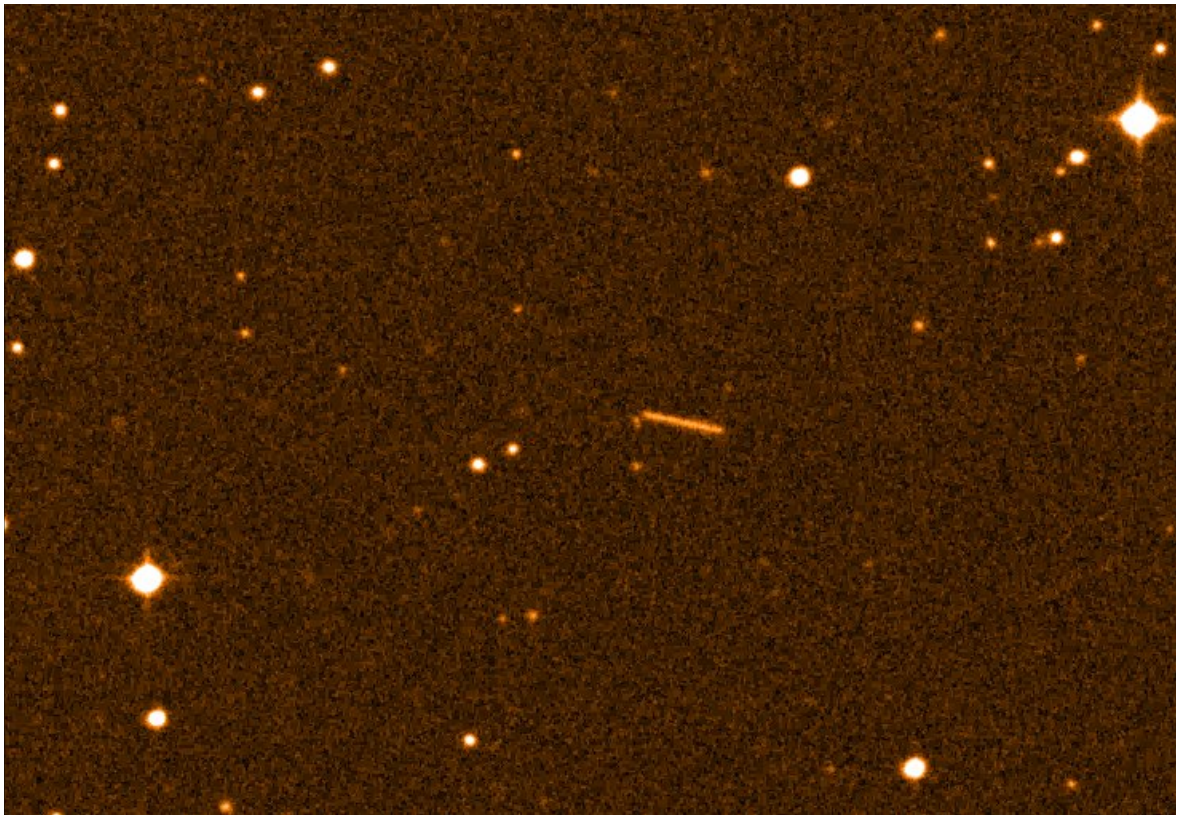
Trojans

Asteroid Belt

Near Earth Asteroids



Asteroids are faint because they shine only in reflected light and they are small. But they can be differentiated from stars because they move.



Over a long exposure, they appear as streaks.

Searching for asteroids at UW

Small team at WIYN Observatory and UW-Madison and follow up near-earth objects to refine orbits

Detect new asteroids in same data

Asteroids

- Their composition is not well known, but it is believed that some of them have iron cores and rocky or icy exteriors, or are rocky all the way through.
- Some are dark and have lots of water ices and organic material on the surface – known as carbonaceous asteroids
- Others are more reflective and are mainly bare rock – known as silicate asteroids
- Total amount of mass in asteroids is about the mass of the Moon

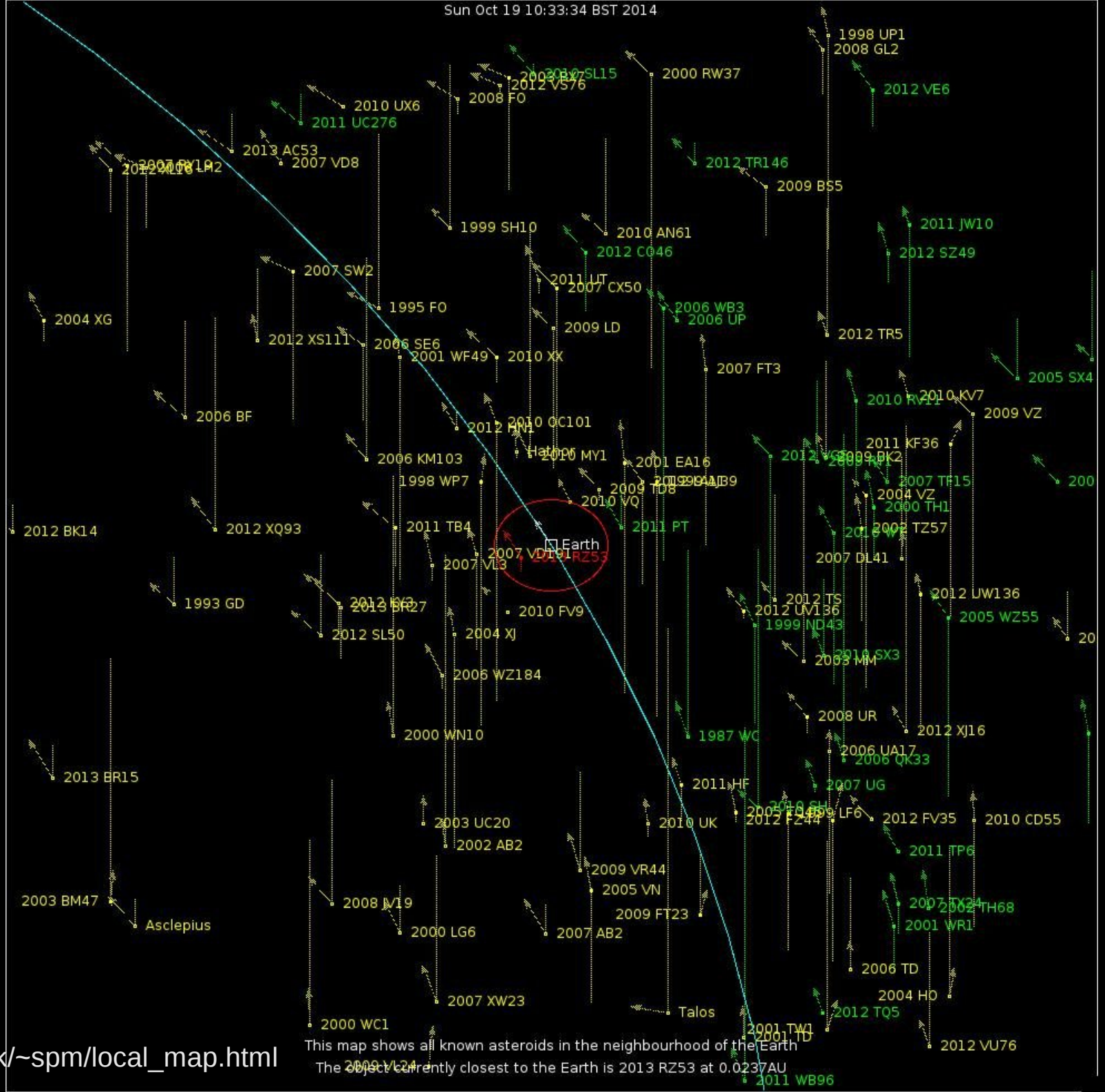
Asteroids – Why do we care?

- Asteroids are left-over material from formation of the solar system
  → ideal laboratory to study formation of earth and other planets
- Potential source of water on earth

Asteroids – Why do we care?

- Derive orbits to predict close encounters to earth and prevent armageddon.

Source: http://www.kotaku.com.au/2013/05/japan-has-an-insane-number-of-armageddon-flicks/



Source:
http://szyzyg.arm.ac.uk/~spm/local_map.html

Asteroids in the Inner Solar System

Green dots represent objects which do not approach the Earth at present e.g. Main Belt asteroids

Yellow dots represent objects which approach the Earth but do not cross its orbit e.g. Amor asteroids

Red dots represent objects which cross the Earth's orbit e.g. Aten and Apollo asteroids

Source: http://www.arm.ac.uk/neos/anim.html


Barringer Crater, Arizona: 1 km across, from a 50 m
iron meteor landing about 50,000 years ago

The Manicouagan reservoir in Quebec

Giant Impact: Tunguska

Tunguska explosion 1908: result of a 30 m meteor which exploded above the ground.

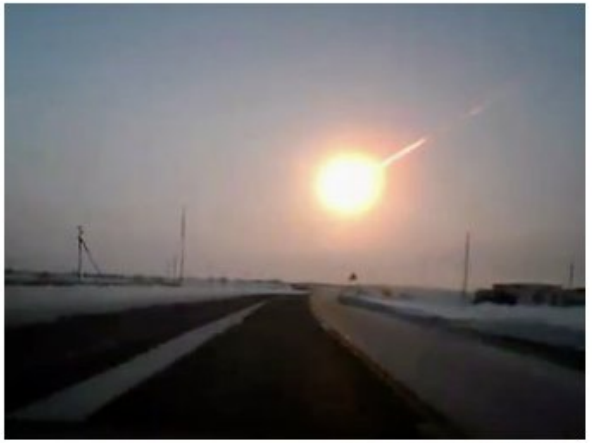
Exploded with the power of a 10 megaton nuclear bomb.

Fortunately hit in Siberia.

Russian meteor of February 15, 2013

The New York Times

Friday, February 15, 2013 Last Update: 9:42 AM ET



www.ng.kz, via Associated Press

Pieces of Possible Meteorite Hit Siberia

By ELLEN BARRY and ANDREW E. KRAMER 8:48 AM ET

Hundreds of injuries were reported after bright objects streaked through the sky in Chelyabinsk, above, accompanied by a loud boom that damaged buildings.

· The Lede: Video of Object Believed to Be Meteorite 6:13 AM ET

LIVE VIDEO, 10 AM ET

Richard P. Binzel, a Massachusetts Institute of Technology professor, discusses the event in western Siberia.

theguardian

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Breaking news: Flights canceled as strikes hit 2 Gerr

Meteor explodes dramatically over Russian Urals, injuring 950 – live updates

LIVE Reports conflict over whether it was a single meteor or a meteor shower that struck over Chelyabinsk region, breaking windows

231 comments

Hundreds hurt in meteor explosion over Chelyabinsk

The Washington Post

41° Washington, DC February 15, 2013 Edition: U.S. | Regional Make us y

ival Triumph Eye implant Chuck Hagel Oscar Pistorius

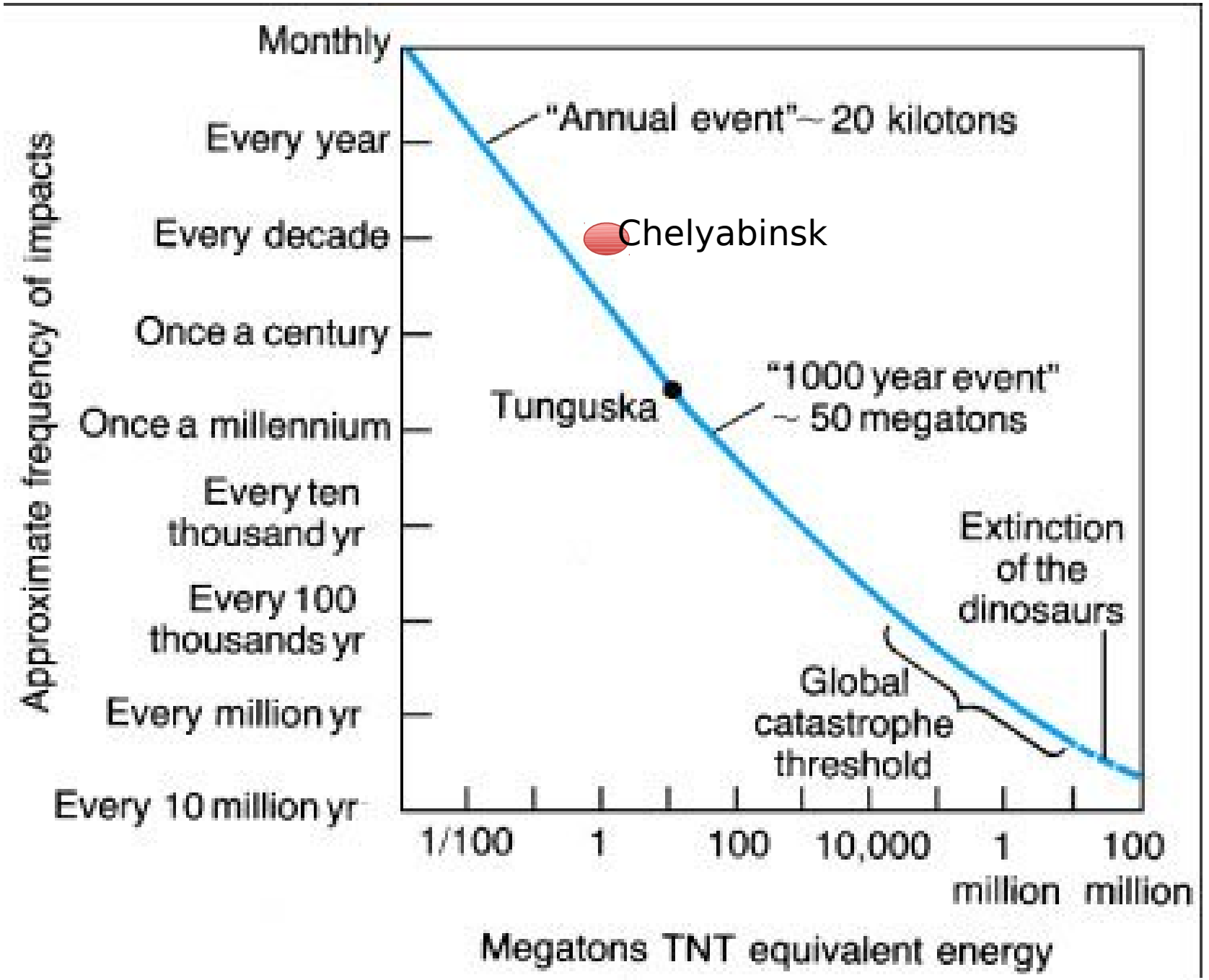
Sonic blast injures more than 900

Will Englund 8:13 AM ET

Windows shattered and roofs collapsed as an apparent 10-ton meteor streaked across the sky at up to 12 miles per second.

· 'We saw a big burst of light'

Giant Impacts and Mass Extinctions

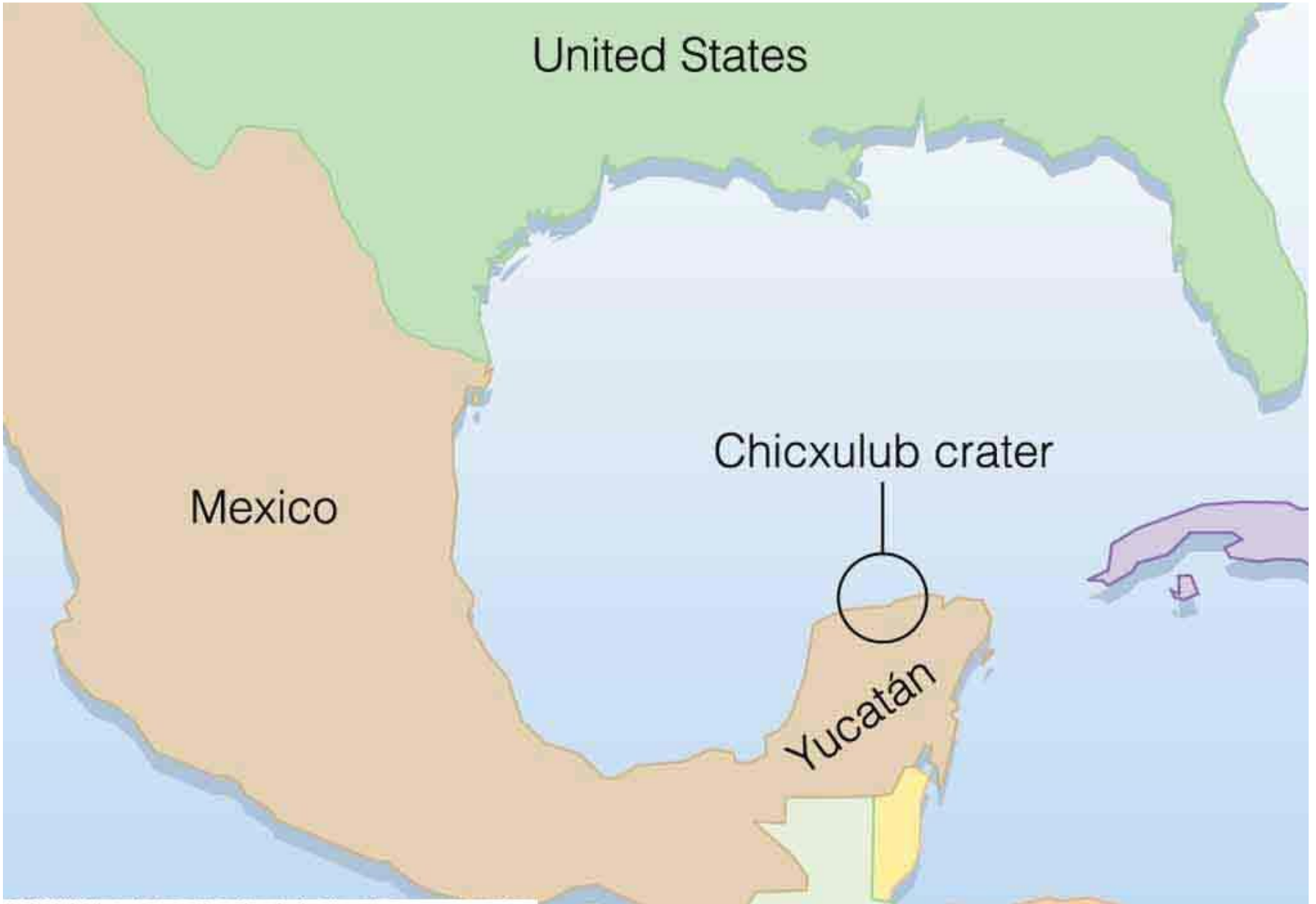


Giant Impacts and mass extinctions

A widely accepted hypothesis is that an impact of a 10 km asteroid hit the Earth 65 million years ago and killed off the dinosaurs.

A layer of iridium is found in 65 million year old rock sediments worldwide – iridium is rare on Earth because it sank to the center, but found in meteorites

A crater of the right age and size has been found in the Yucatan peninsula in Mexico: the **Chicxulub crater**.



Giant Impacts and mass extinctions

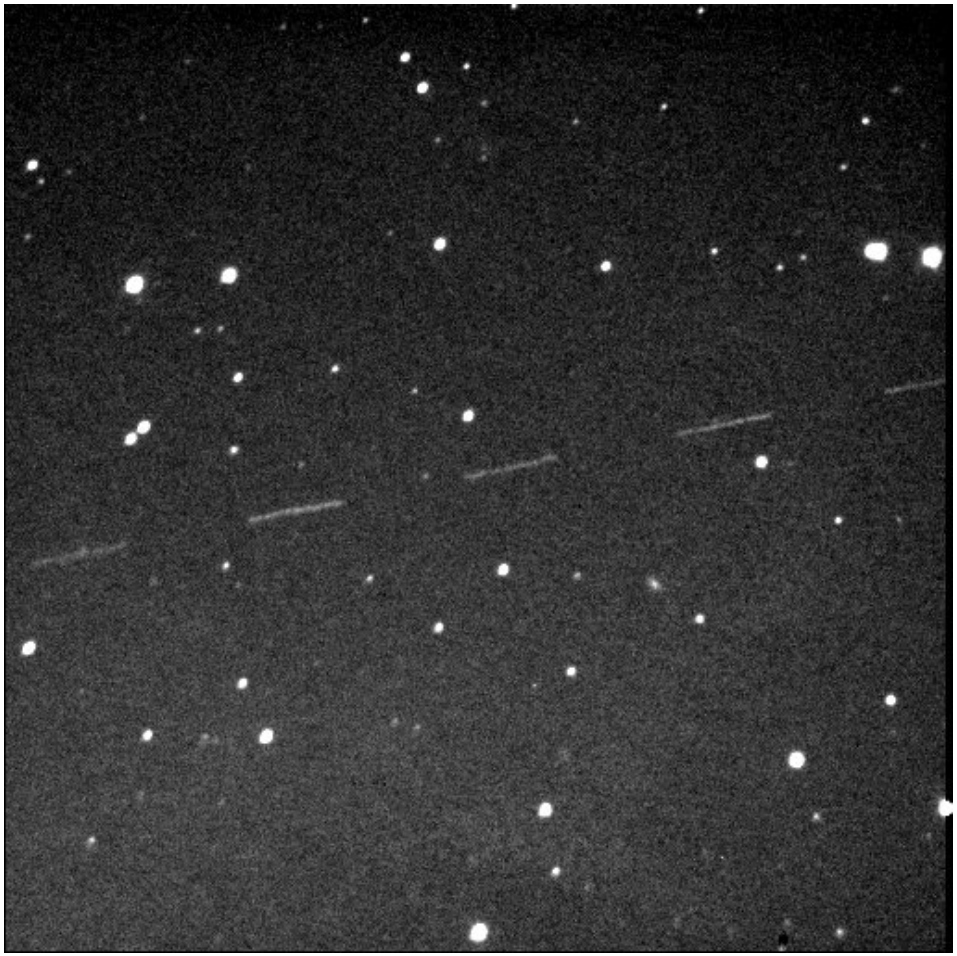
- Such an impact would have generated mega-tsunamis kilometers high – seen in fractured rocks that are piled in regions around the impact site
- Material thrown up from the impact would re-enter the Earth's atmosphere around the world and heat the surface up to a temperature of 400+ degrees – triggers world-wide forest fires
- Production of dust and sulfate would block out the sun for years and bathe the Earth in acid rain – death of many plant species, and bad news for the food chain

Giant Impacts

- To help understand the threat of Earth-crossing objects, we need to find all of them.
- One such effort is the Catalina sky survey being run in Arizona
- Uses a bunch of (relatively) small telescopes to look for near-Earth asteroids.

Giant Impacts

- First detection of an rock that actually hit the earth (2008 TC3)
- Detected it on Oct 6 2008 – 20 hours before impact.



Giant Impacts

- Hit the earth on Oct 7, 2008 in Northern Sudan
- Exploded with a force of 2.1 kilotons (1/5 of the Hiroshima bomb)
- The fragments were collected by geologists who flew into the area

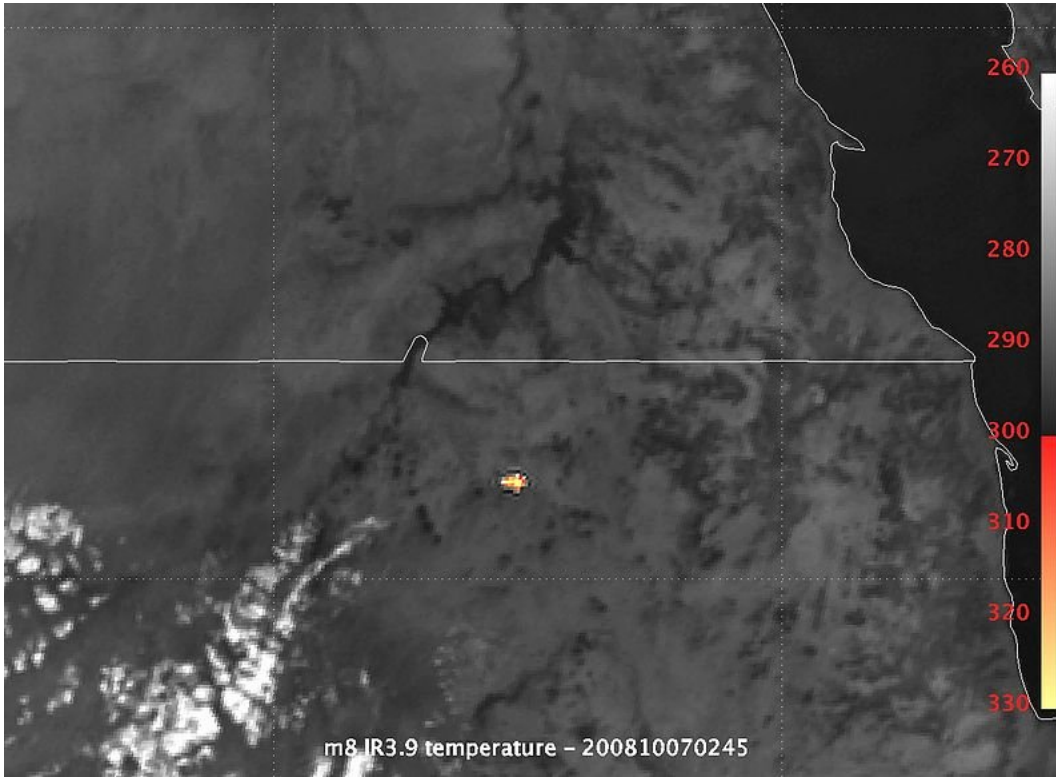


Image Source: Wikipedia