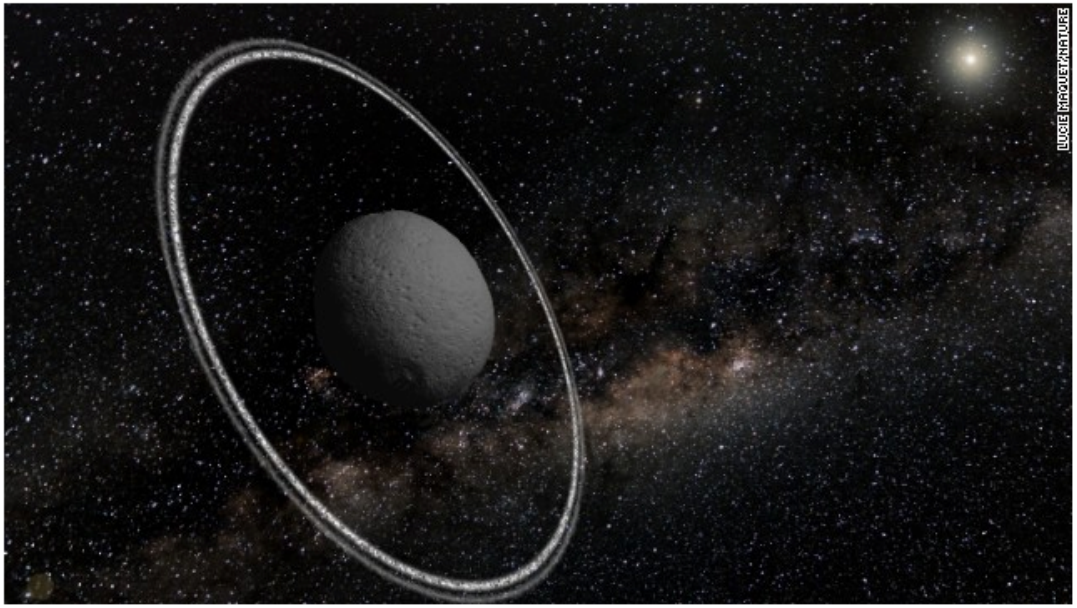
Announcements

- Midterm grades soon…
- Quiz 8B on Chapter 13 due tonight
- Now: the **Solar System**
  - Upcoming schedule:
  - Today: Chapter 4 Sections 4.2 and 4.3 (we'll do Section 4.4 on extrasolar planets later)
  - Wednesday April 3: Terrestrial planets (Chapter 6, a bit of Chapter 5)

New things in the solar system

Astronomers find first asteroid with rings

By **Elizabeth Landau**, CNN
updated 4:59 PM EDT, Wed March 26, 2014 | Filed under: Innovations



This is an artist's interpretation of the ring system around asteroid Chariklo.

STORY HIGHLIGHTS

- South American telescope observations found rings around an asteroid

(CNN) -- Quick -- name a planet with rings. Easy, right?

But Saturn and others are not alone: Now scientists have added another celestial body to the short list of objects in our solar system

New things in the solar system

U.S. INTERNATIONAL 中文网

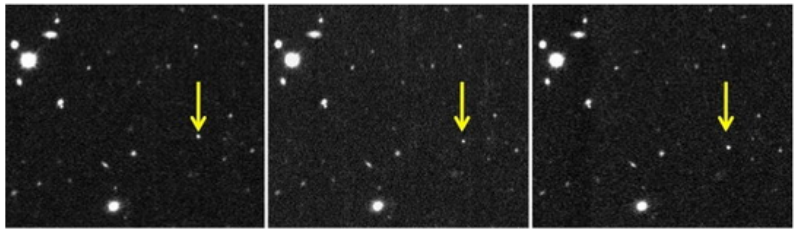
The New York Times

SPACE & COSMOS

Discovery of Planetoid Hints at Bigger Cousin in Shadows

By KENNETH CHANG MARCH 26, 2014

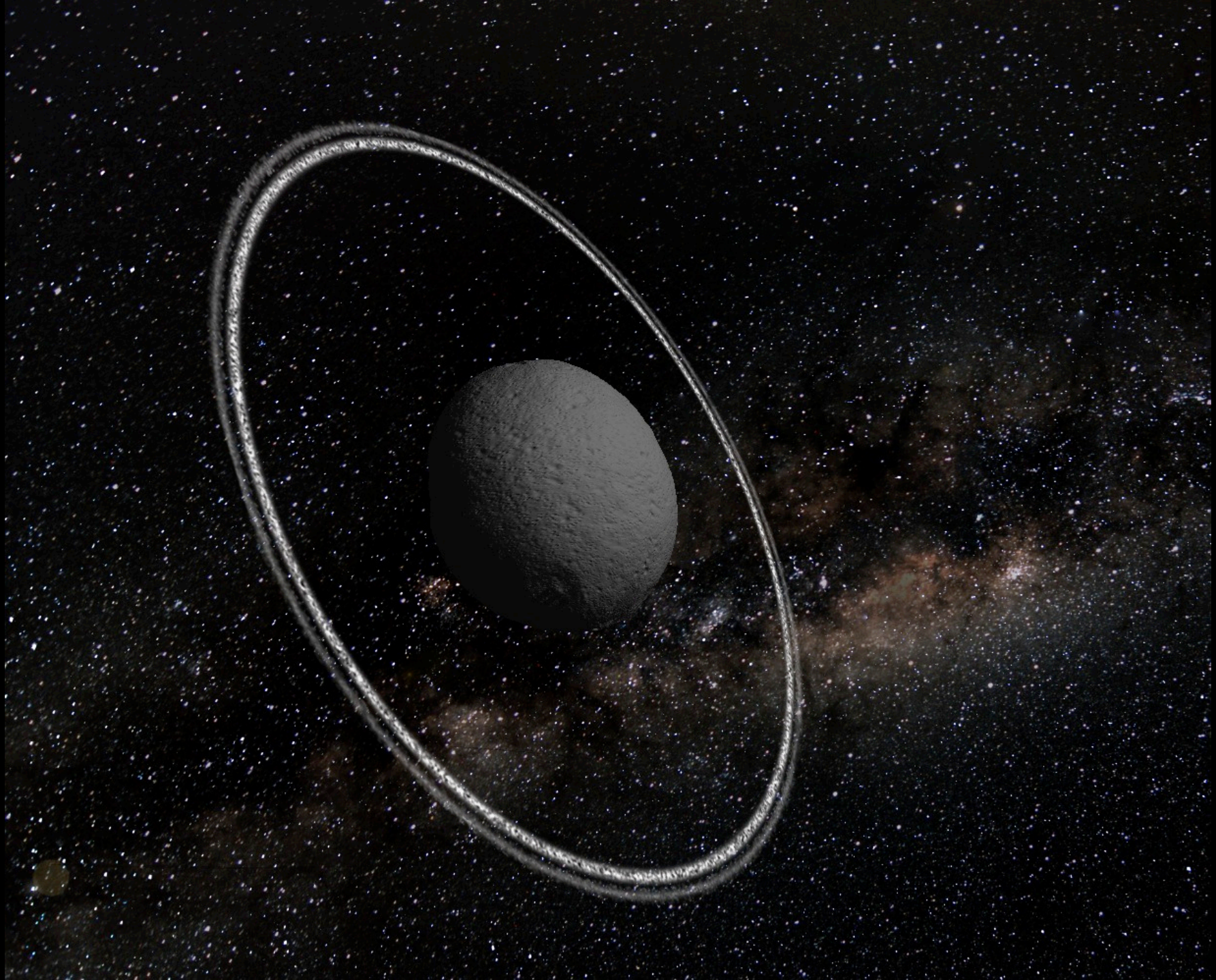
Astronomers have discovered a second icy world orbiting in a slice of the solar system where, according to their best understanding, there should have been none.



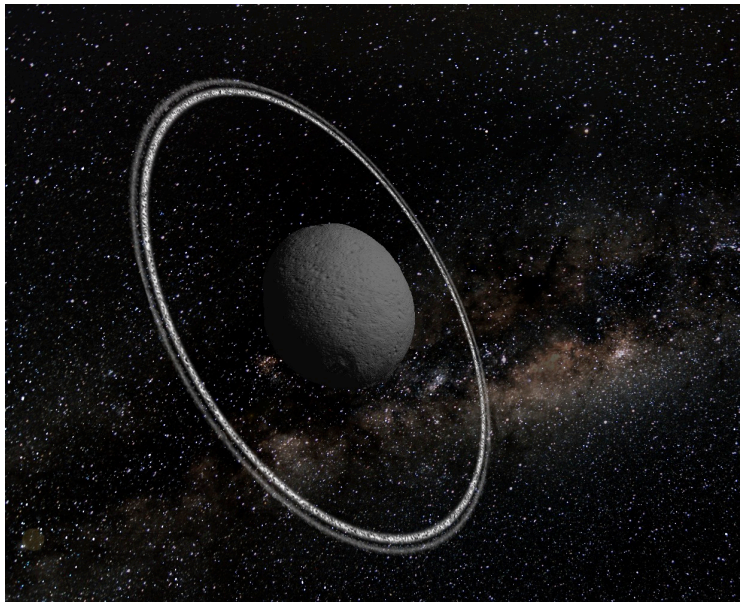
Three images of a newly discovered planetoid called 2012 VP113 taken at two-hour intervals in 2012. Scott S. Sheppard/Carnegie Institution for Science

"They're in no man's land," Scott S. Sheppard, of the Carnegie Institution for Science in Washington, said of the objects, which orbit far beyond the planets and even the ring of icy debris beyond Neptune known as the Kuiper belt.

Intriguingly, the astronomers said that details of the orbits hint at perhaps an unseen planet several times the size of Earth at the solar system's distant outskirts.



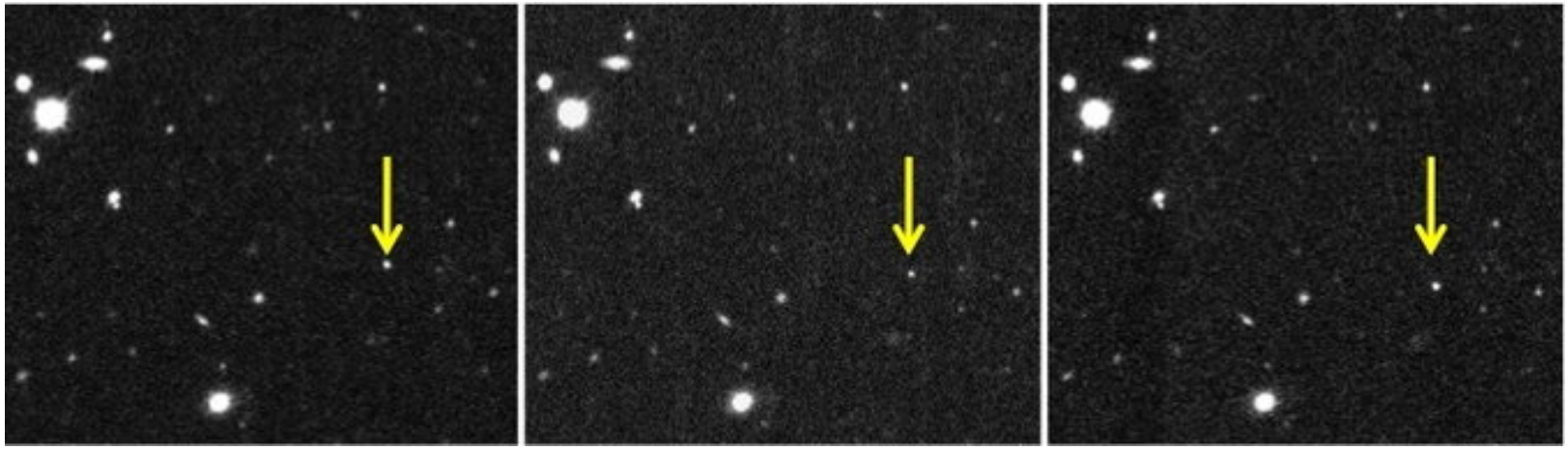
An asteroid with rings



Artist's conception

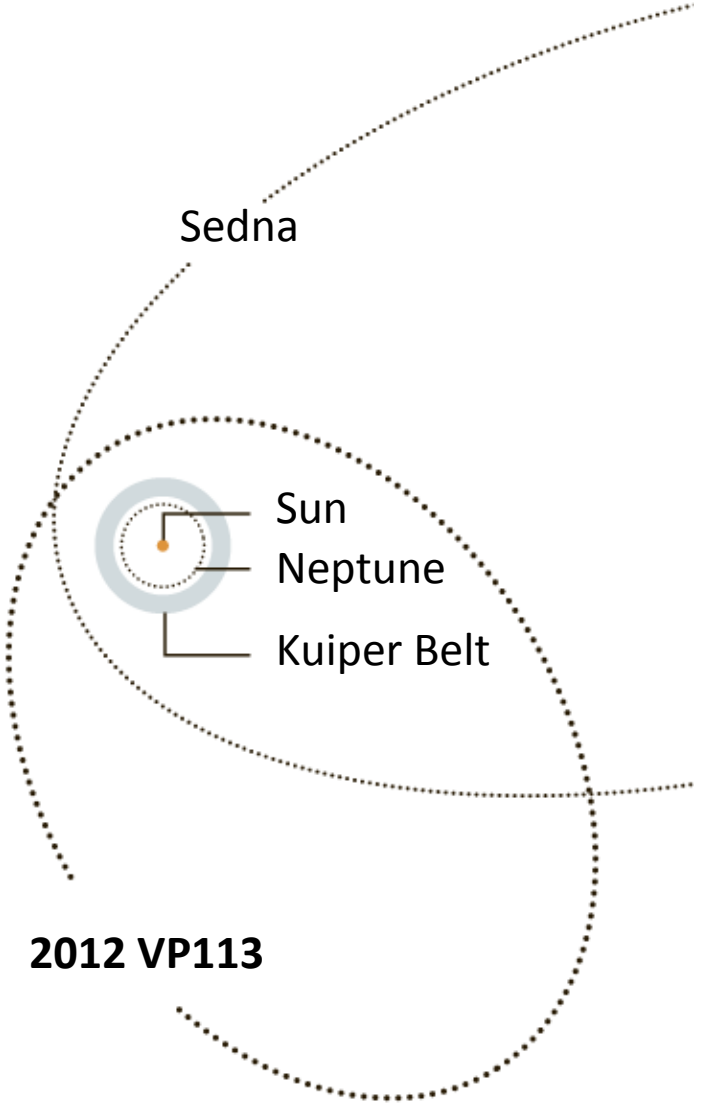
- Chariklo, orbits between Saturn and Uranus
- 155 miles across, biggest in the neighborhood
- Rings discovered when asteroid eclipsed a star
- Two rings: inner about 4 miles wide, outer about 2 miles, made partially of water ice
- First rings known around a non-planet
- How did they get there? Debris from a collision?

A new dwarf planet



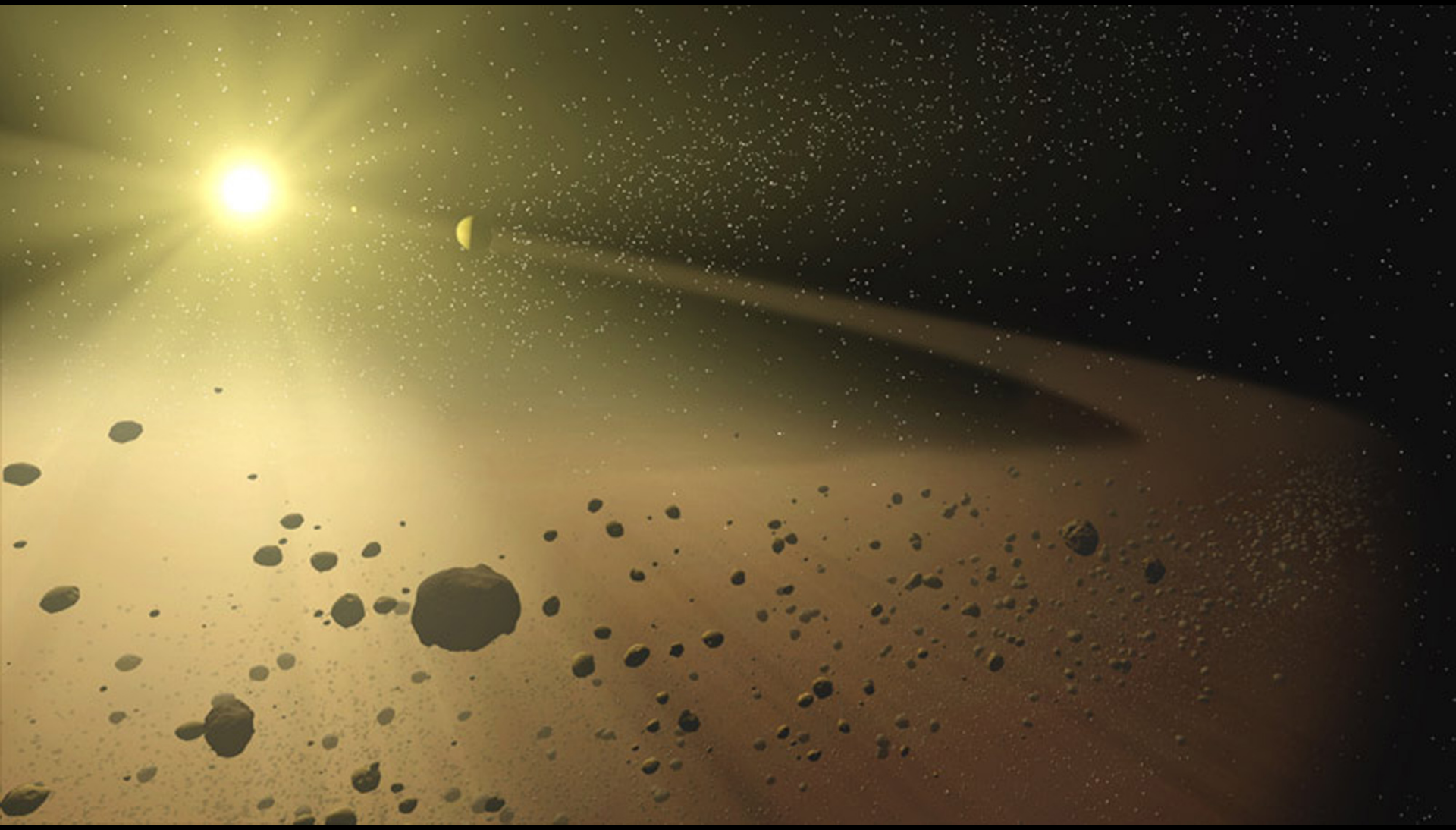
- 2012 VP113 (“Biden”): found in Kuiper Belt, far beyond Neptune
- About 250 miles across
- Called a “Sednoid,” after another similar object called Sedna
- How did it get out there?
- Does orbit indicate an unseen planet in outer solar system??

A new dwarf planet



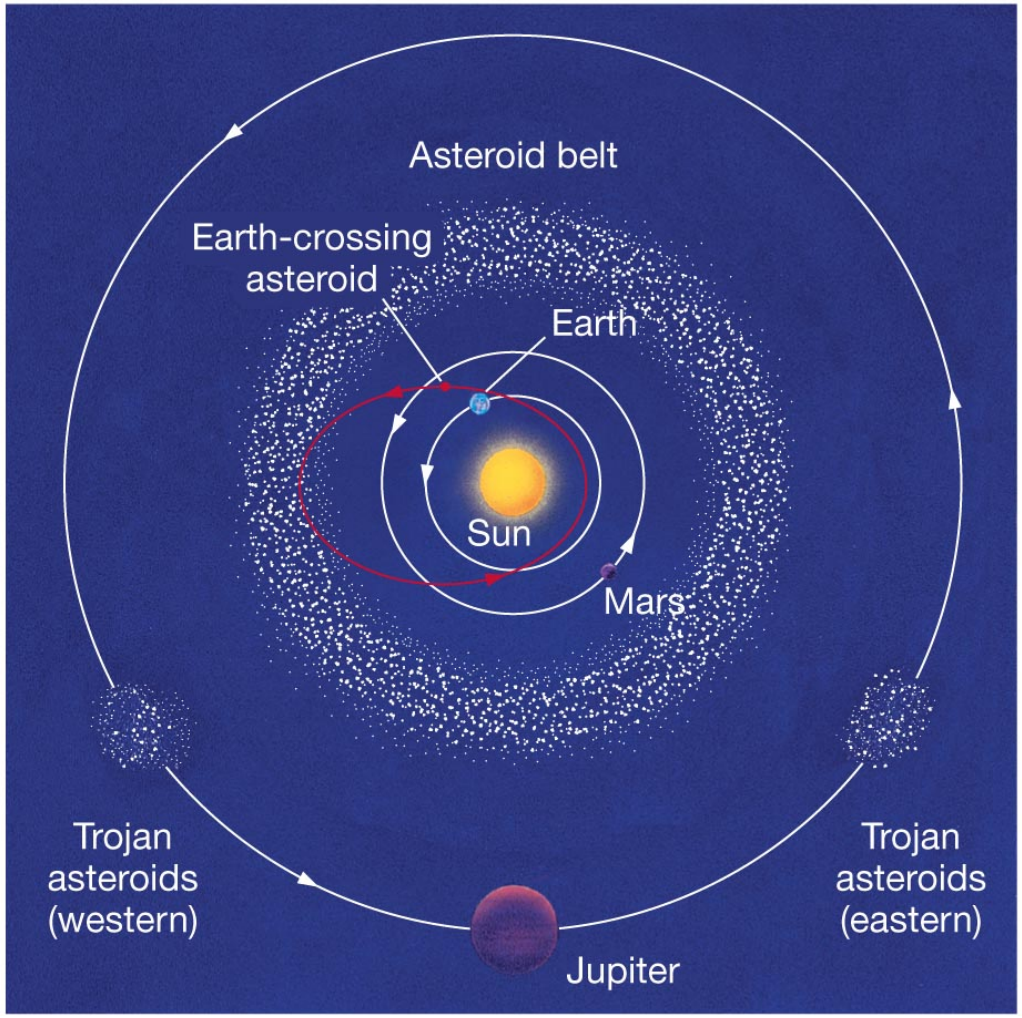
Graphic from the New York Times

Small Things in the Solar System: Recap



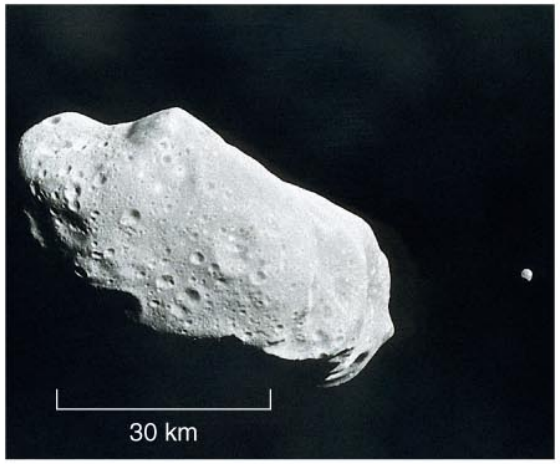
Asteroids

- Small, low density, loosely packed rocky bodies
- Mostly found in belt between Mars and Jupiter
- Some cross Earth's orbit



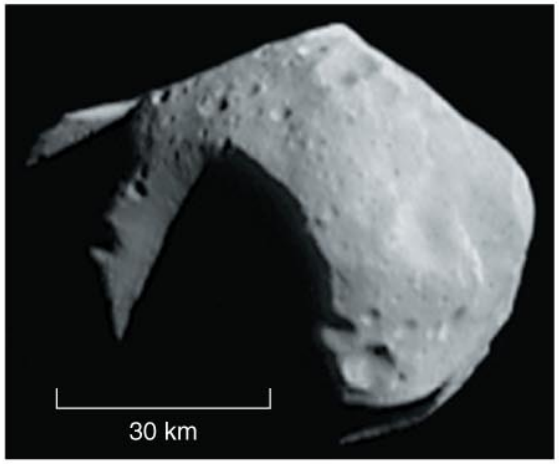
Asteroids and Meteoroids

Asteroids and meteoroids have rocky composition; asteroids are bigger.

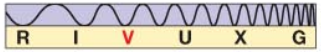


(b)

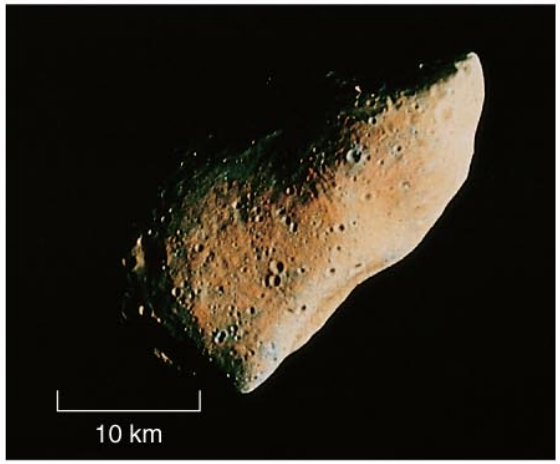
(below) Asteroid Gaspra



(c)



(above) Asteroid Ida with its moon, Dactyl



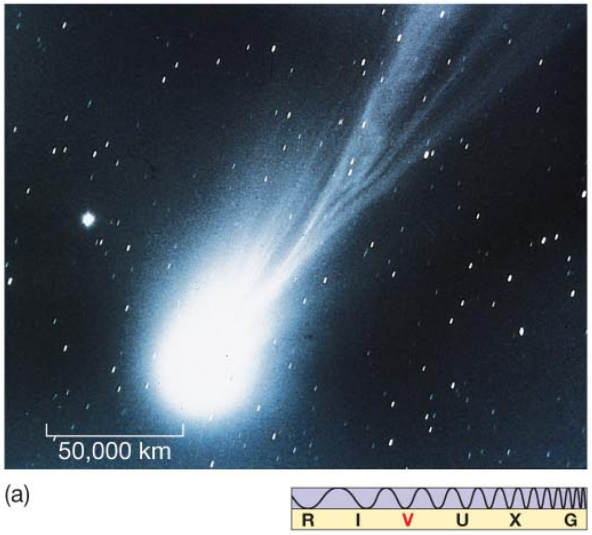
(a)

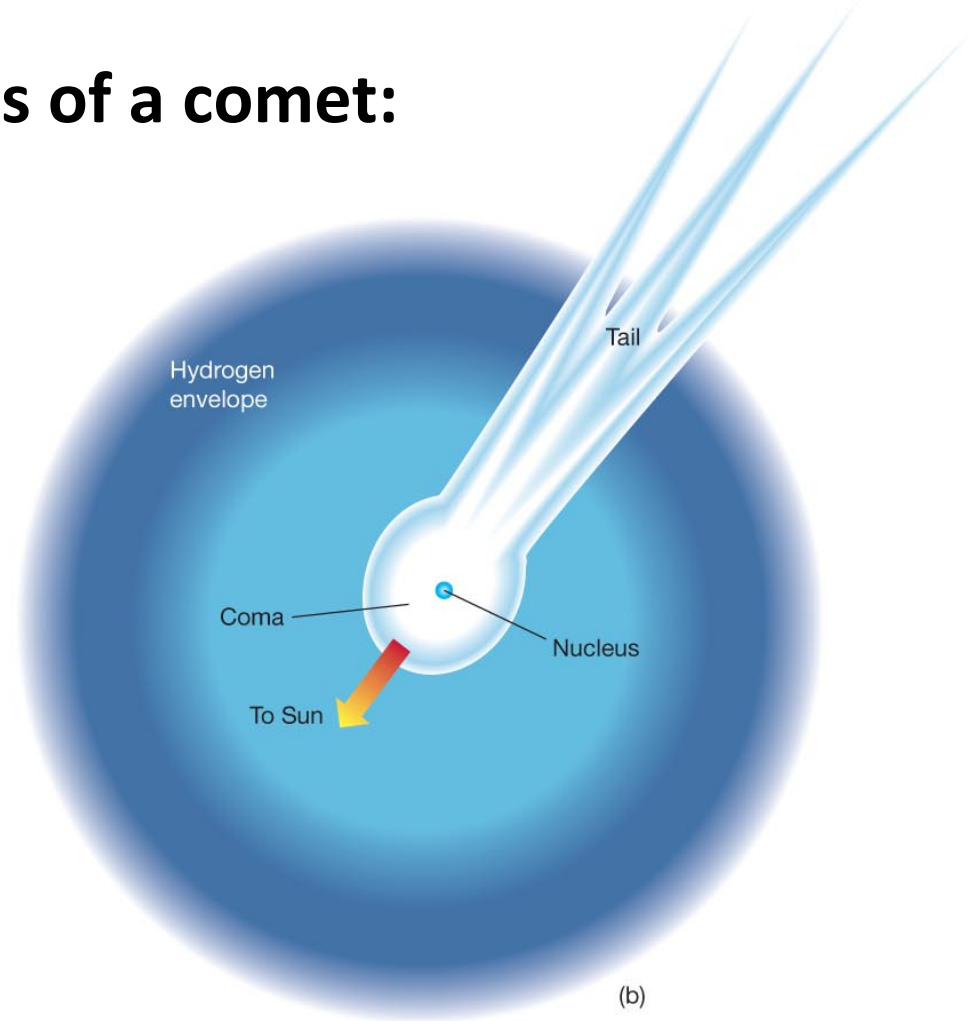
(above) Asteroid Mathilde

Comets

Comets are icy, with some rocky parts, and very low density

The basic components of a comet: nucleus, coma, tail



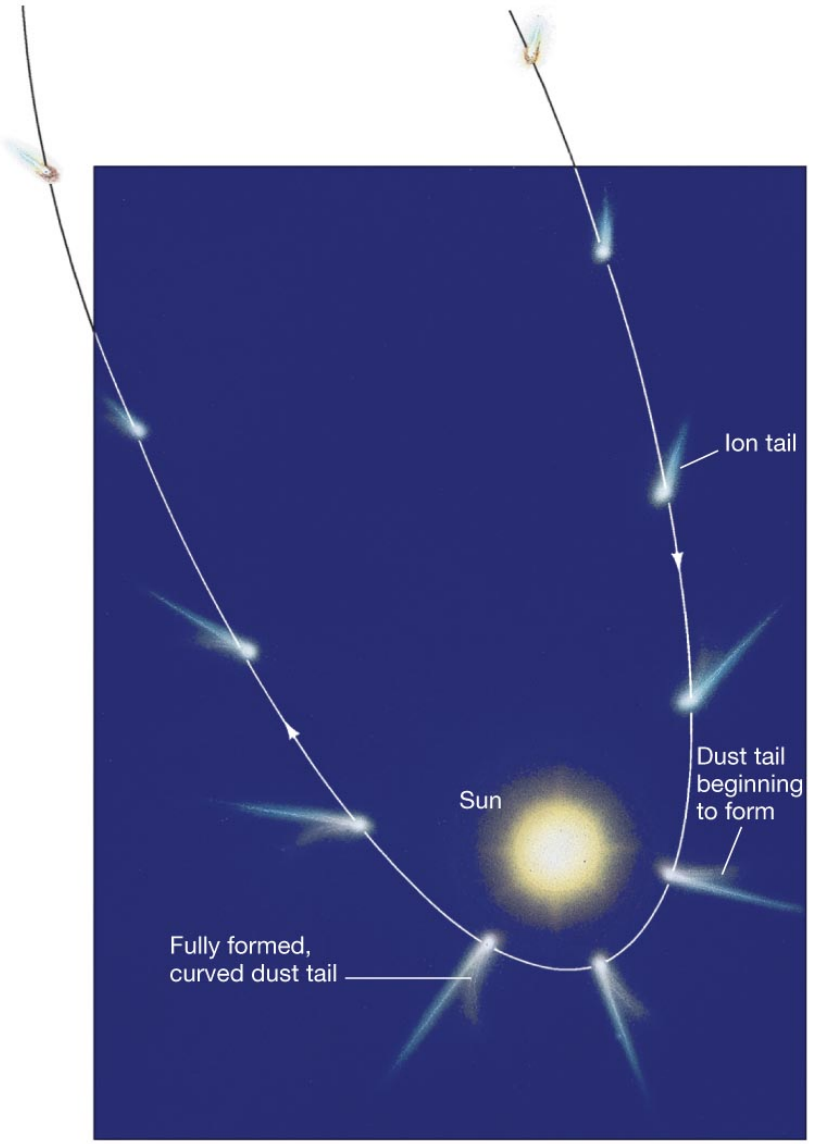


Comets

Comets sublimate (parts of them turn from solid to gas) when they come near the Sun, producing the tail.

The solar wind means the ion tail always points away from the Sun.

The dust tail also tends to point away from the Sun, but the dust particles are more massive and lag somewhat, forming a curved tail.



Meteoroids

- Small rocks in the solar system
- **Asteroid: >100 m in size**
- **Meteroid: <100 m in size**
- If they enter the Earth's atmosphere and burn up they are called **meteors**
- **Meteorites** are meteors that penetrate though the atmosphere to hit the ground

The **asteroid belt** is evidence of

A

a planet that once orbited the Sun but was later destroyed

B

ancient material from the formation of the solar system

C

a collision between Jupiter and one of its larger moons

D

comets that were trapped by Jupiter's gravitational field

The **asteroid belt** is evidence of

A

a planet that once orbited the Sun but was later destroyed

B

ancient material from the formation of the solar system

C

a collision between Jupiter and one of its larger moons

D

comets that were trapped by Jupiter's gravitational field

Meteorites: Meteors that do not burn up in the atmosphere and hit the Earth


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

The Manicouagan reservoir in Quebec

Sudbury Basin, Ontario, Canada

Formed from the impact of a 10-15 km diameter asteroid 1.8 billion years ago.

Area is extremely rich in minerals, especially iron. Canada is mining asteroids!

Giant Impacts

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

Exploded with the power of a 10 megaton nuclear bomb.

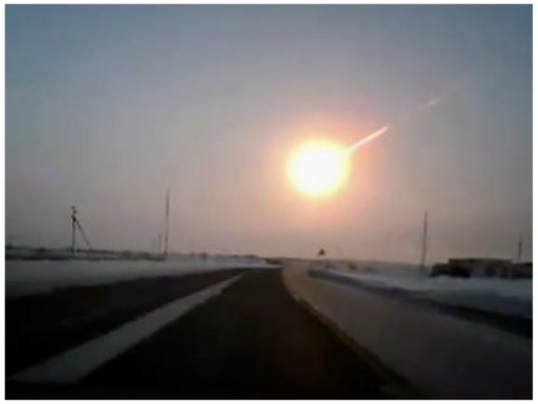
Fortunately hit in Siberia.

Russian meteor of February 15, 2013

The New York Times

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

Capital One 360 Follow Us SAVE 50% Limited-T



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

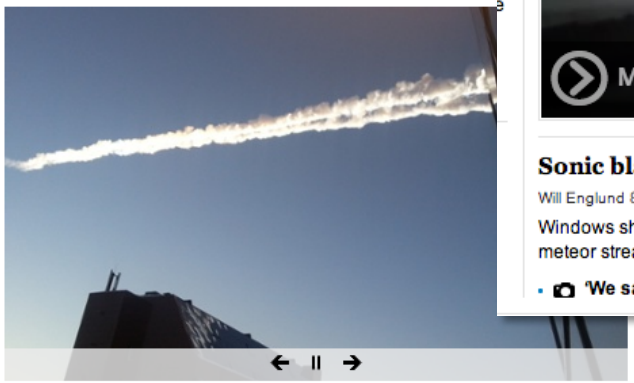
Richard P. Binzel, a Massachusetts Institute of Technology professor, discusses the event in western Siberia.

theguardian

News | US | World | Sports | Comment | Culture | Bu

News | US news blog | UK | Gun control | Manning

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

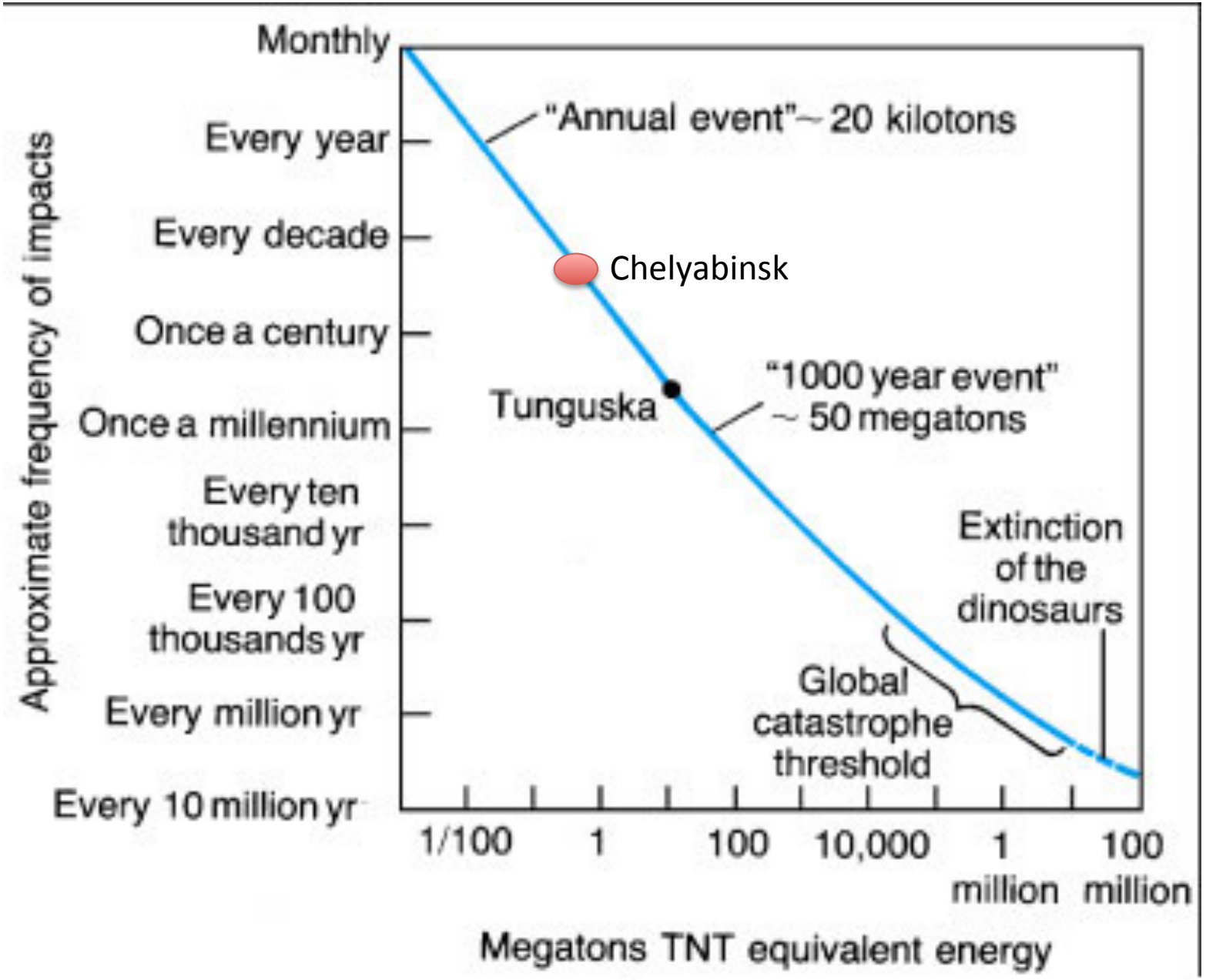
Windows shattered and roofs collapsed as an apparent 10-ton meteor streaked across the sky at up to 12 miles per second.

· 'We saw a big burst of light'

Russian meteor of February 15, 2013

- Largest known object to have entered Earth's atmosphere since Tunguska event – exploded over Chelyabinsk, Russia
- Not detected before explosion
- Estimated mass 11,000 tons, size 17-20 m in diameter, speed when entering atmosphere 18 km/s (40,000 mph)
- Total energy before impact equivalent to ~440 kilotons of TNT, 20-30 times more energy than atomic bombs of Hiroshima and Nagasaki
- Explosion generated flash of light, small fragmentary meteorites, powerful shock wave
- Not all energy released in form of explosion – about 20% of energy emitted as visible 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**.

- 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

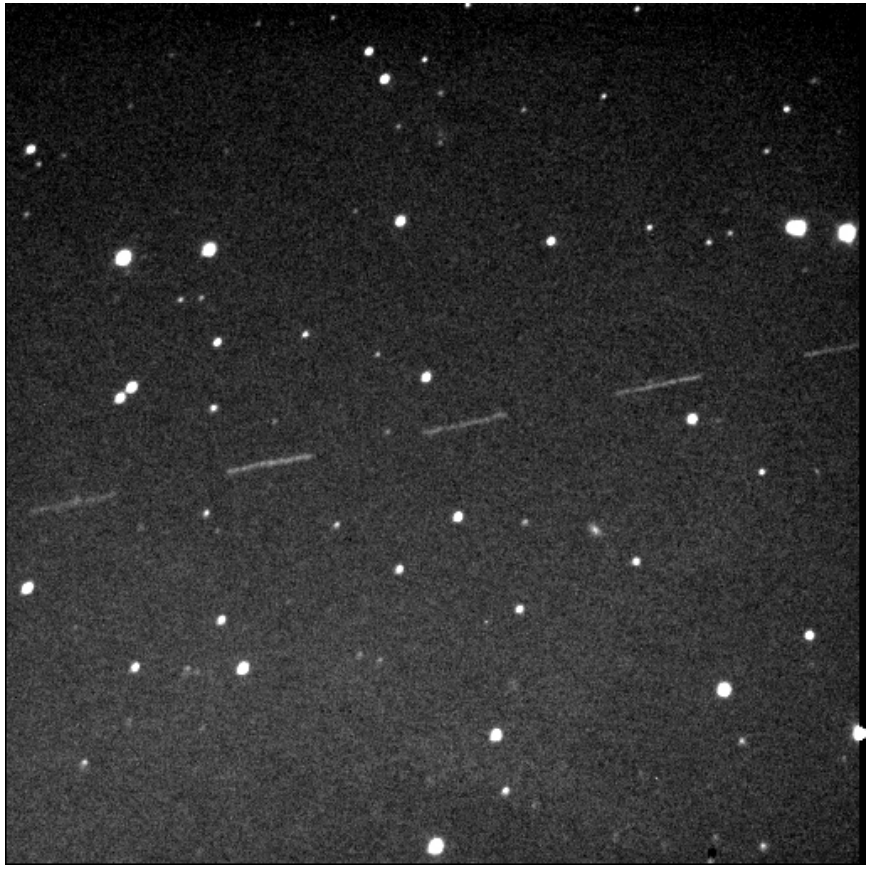
Giant Impacts

- 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

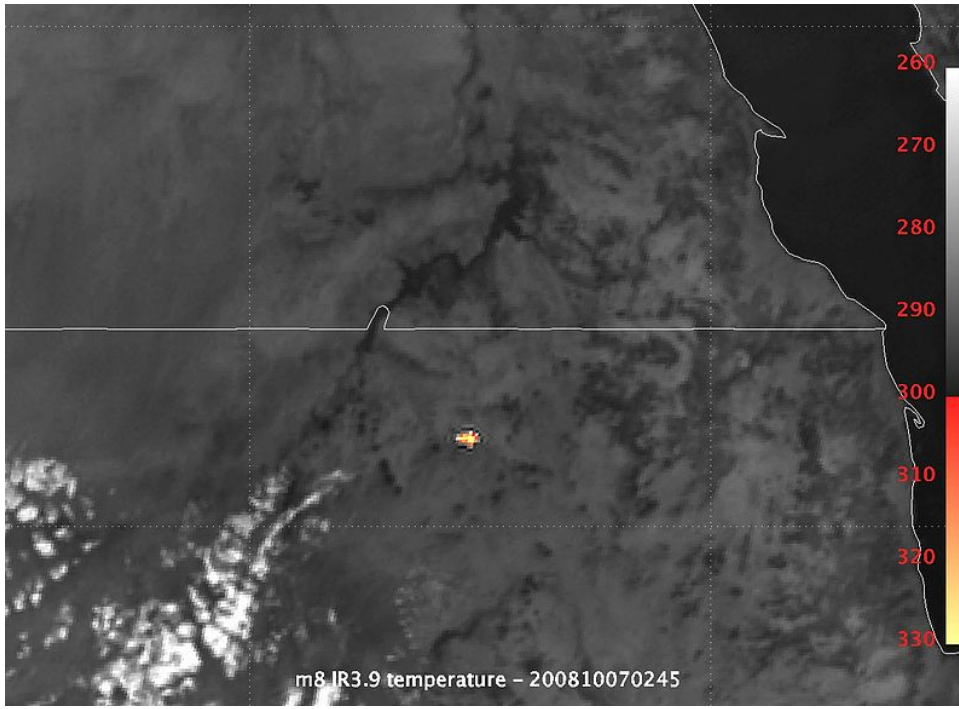
- First detection of an rock that actually hit the earth (2008 TC_3)

- 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.



Astronomy 103

Formation of the Solar System

Please read Chapter 4

Features of the solar system

- Planets are all (nearly) in a plane to about 1%
- All orbit in a counterclockwise direction (as viewed from Earth's N pole) and nearly all rotate in the same direction as well
- Orbits are nearly circular
- Planets are relatively isolated – far away from their neighbors
- Space between the planets is relatively empty

	Distance from Sun	Composition	Mass	Radius	Density	Spin	Number of moons
Terrestrial	close	rock and iron	Earth or less	Earth or less	high (rock)	slow	few or none
Jovian	far	Gas: H, He, H_20, NH_4, CH_4	larger	larger	low	fast	many

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

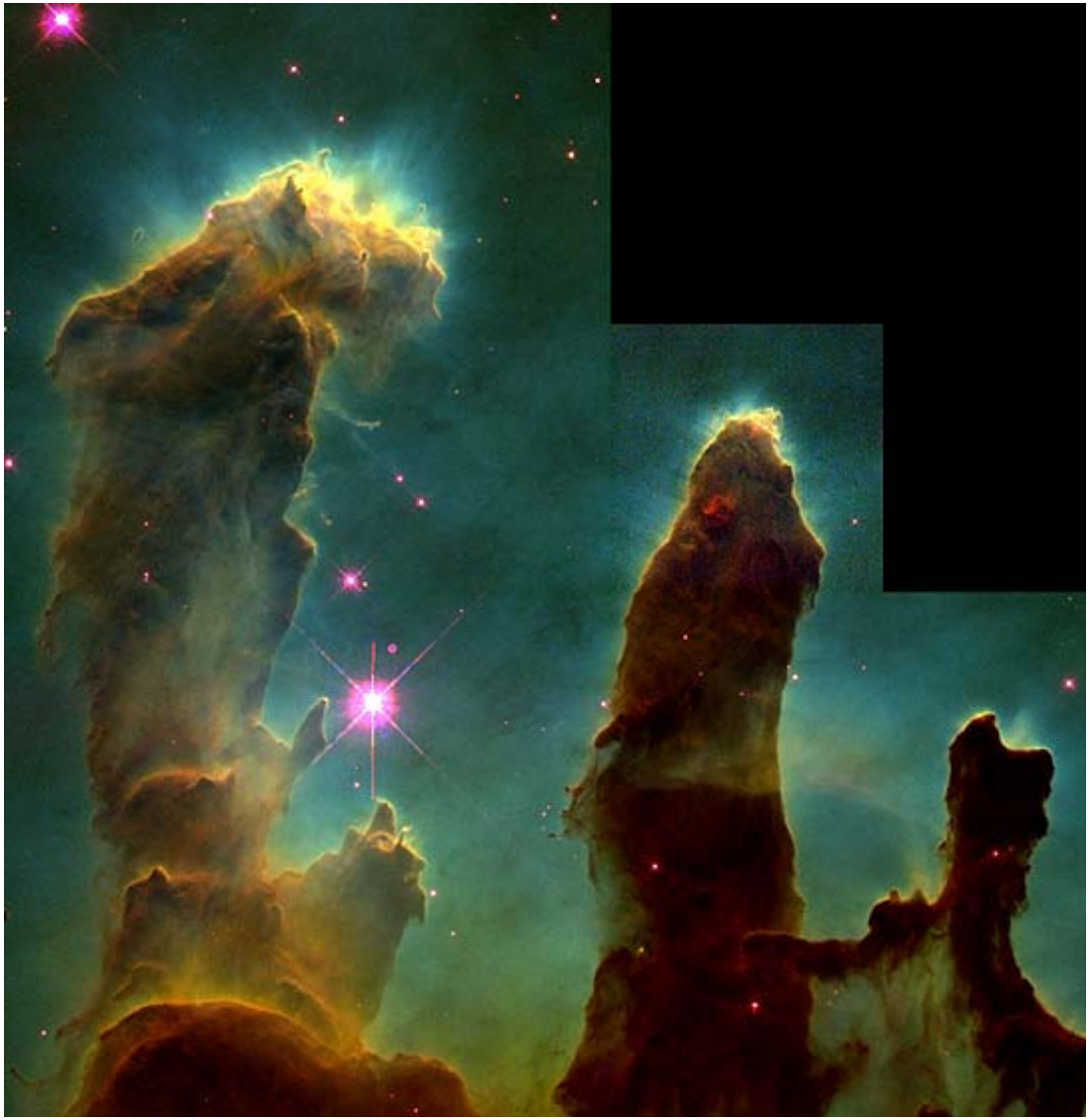
Other Alternatives

- Alternatives to the nebular hypothesis
  - 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

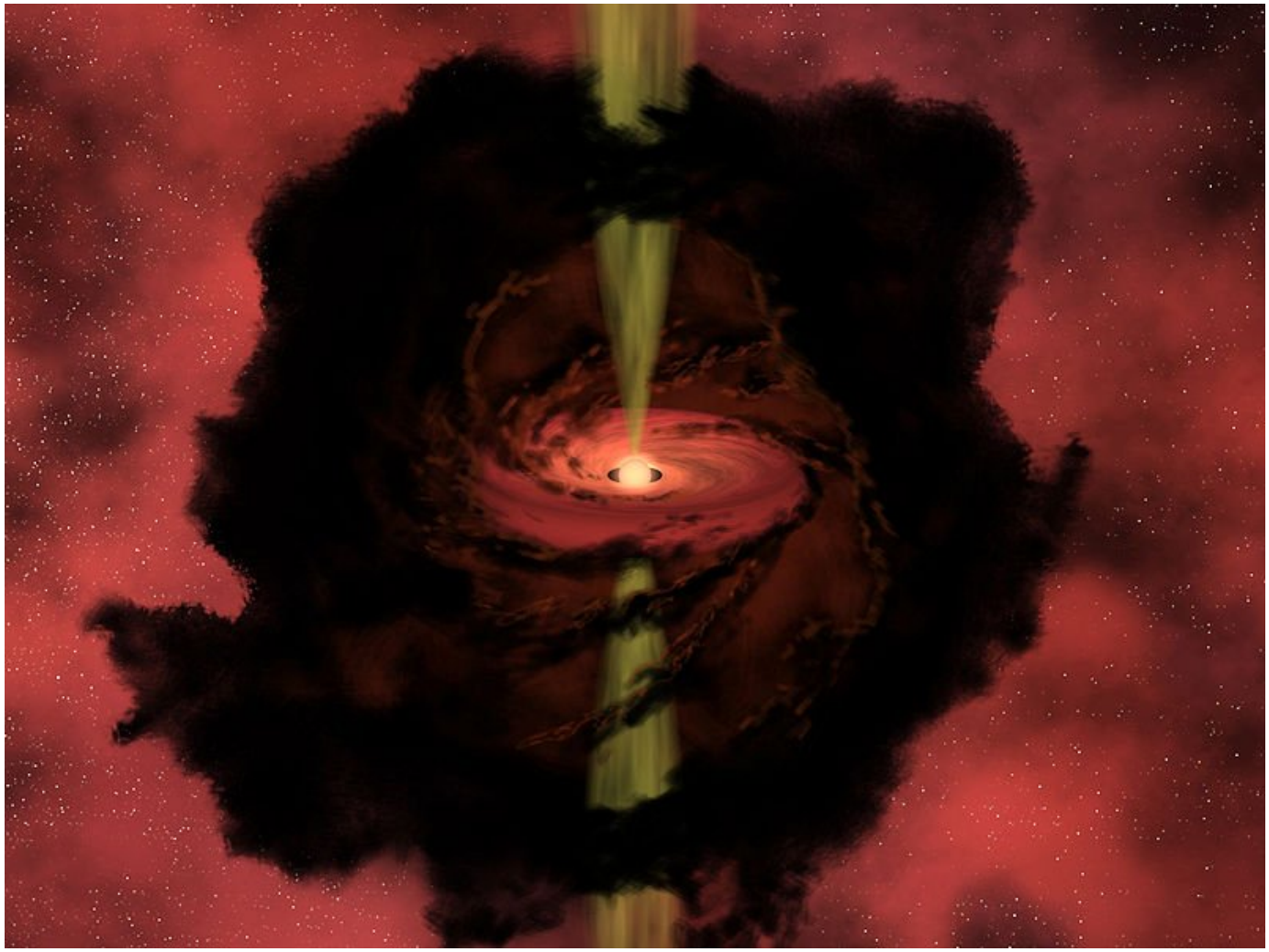
Formation of the Sun

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

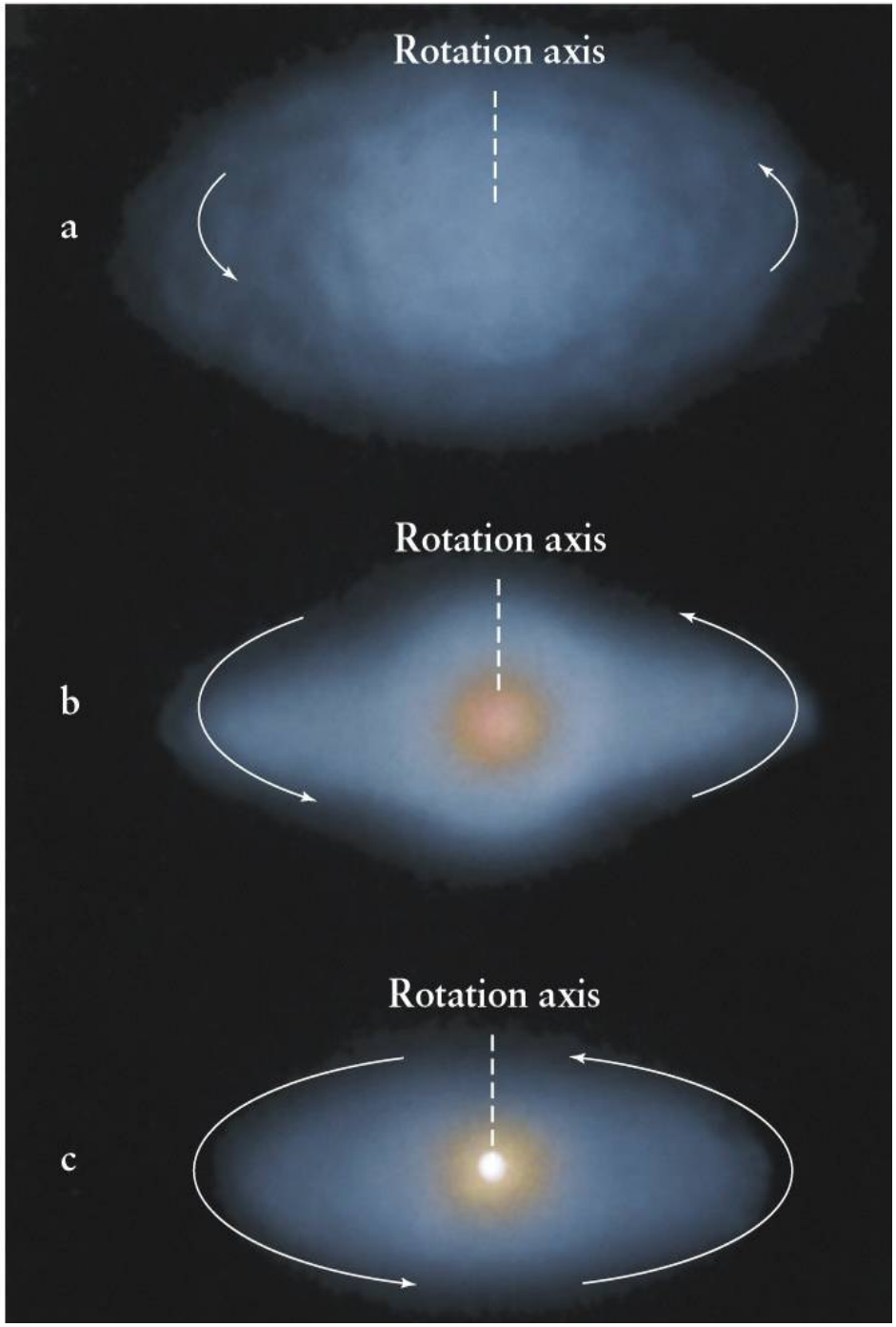


The collapse of one of these clouds forms a **protostar** and the disk of gas that surrounds it

Formation of the disk

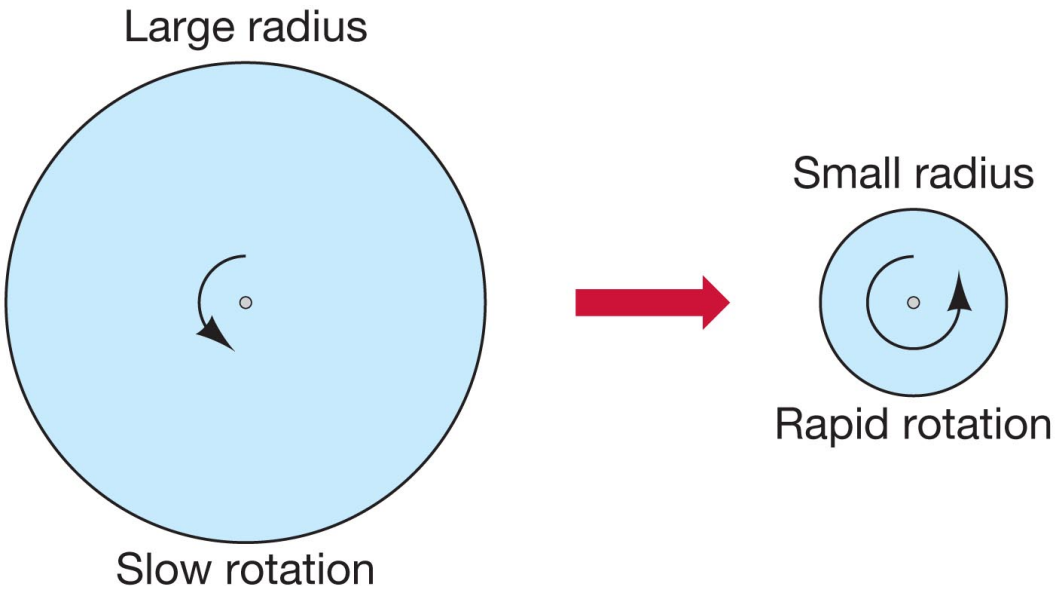
As the cloud collapses, the angular momentum in the gas makes it spin faster and faster until the the gas moves fast enough to orbit the protostar.

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

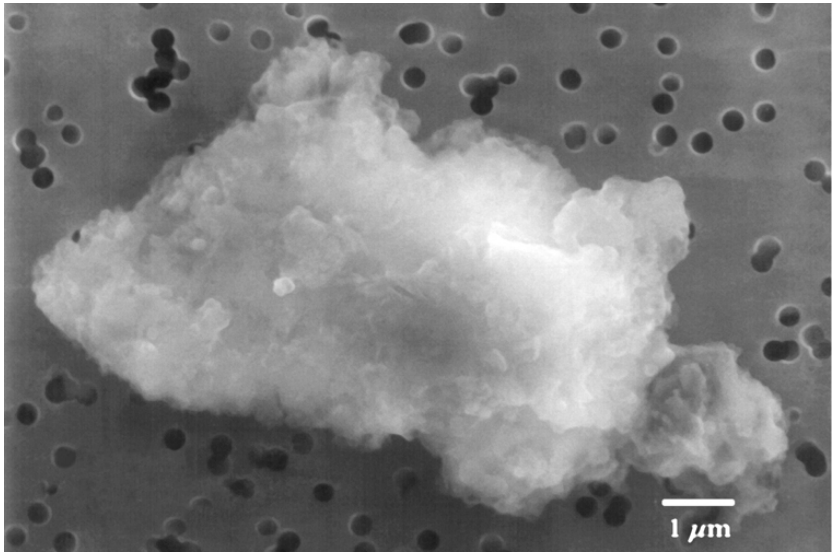
One way to look at this in action is to look at an ice skater as she moves her arms in. The ice skater spins faster as a result of angular momentum causing her to spin up.

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

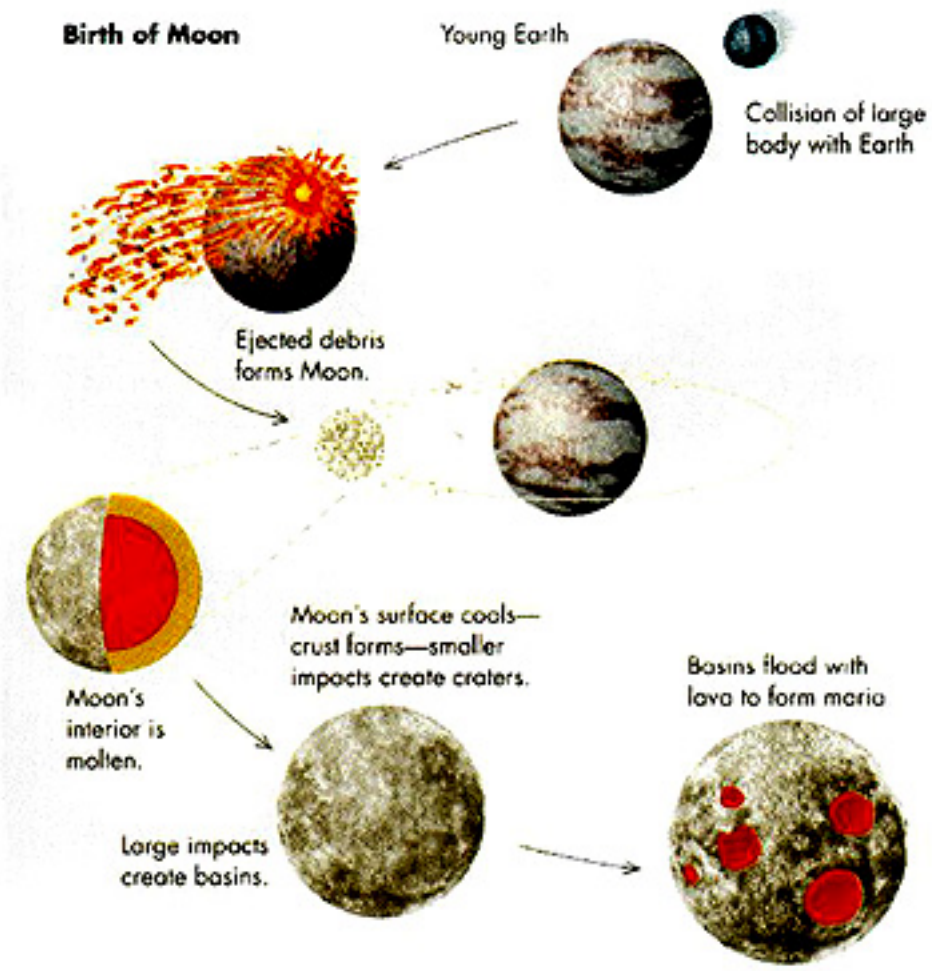
- Clumps of dust grow larger, become able to sweep up more and more material: this process is called **accretion**
- Eventually we get objects a few hundred km in size, which have gravity strong enough to affect their neighbors and sweep up even more material: **planetesimals**
- Eventually nearly all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

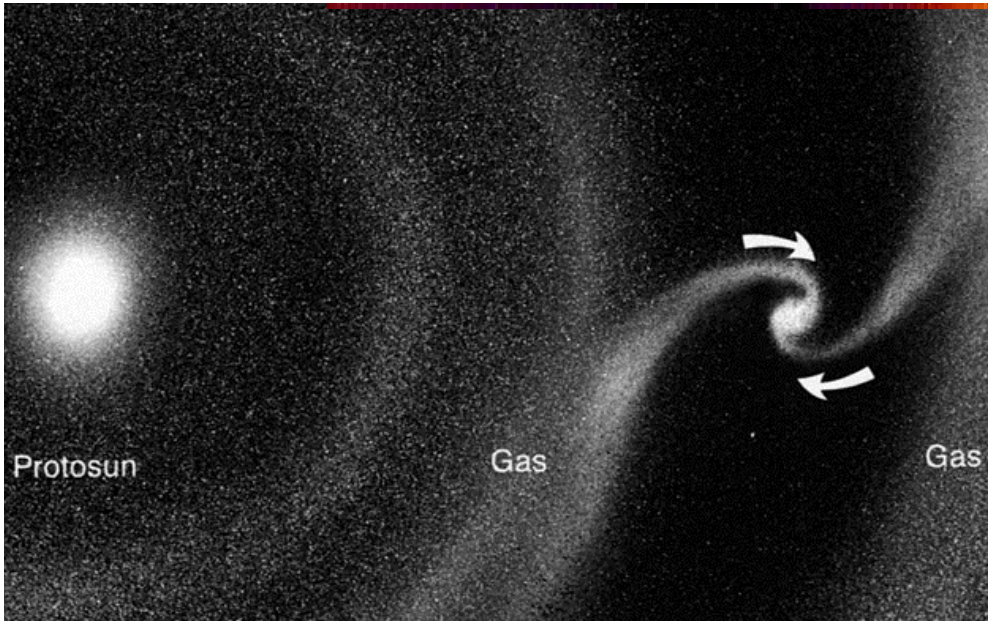
- During the formation of the Earth, the young Earth suffered a collision with a Mars-sized body that threw up material into orbit that condensed to form the Moon.
- This is a rare event, and Earth is the only terrestrial planet with a large moon



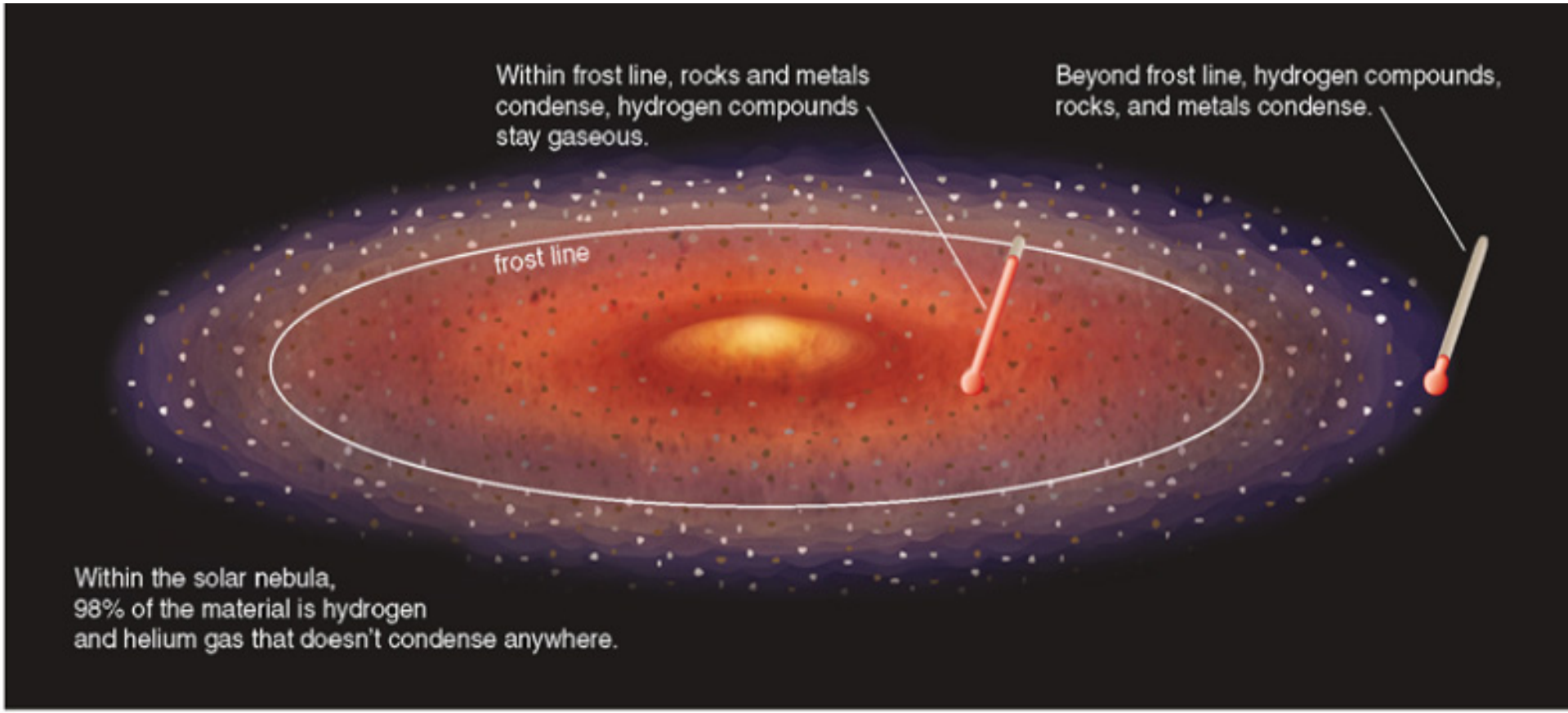
Forming Jupiter and Company

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



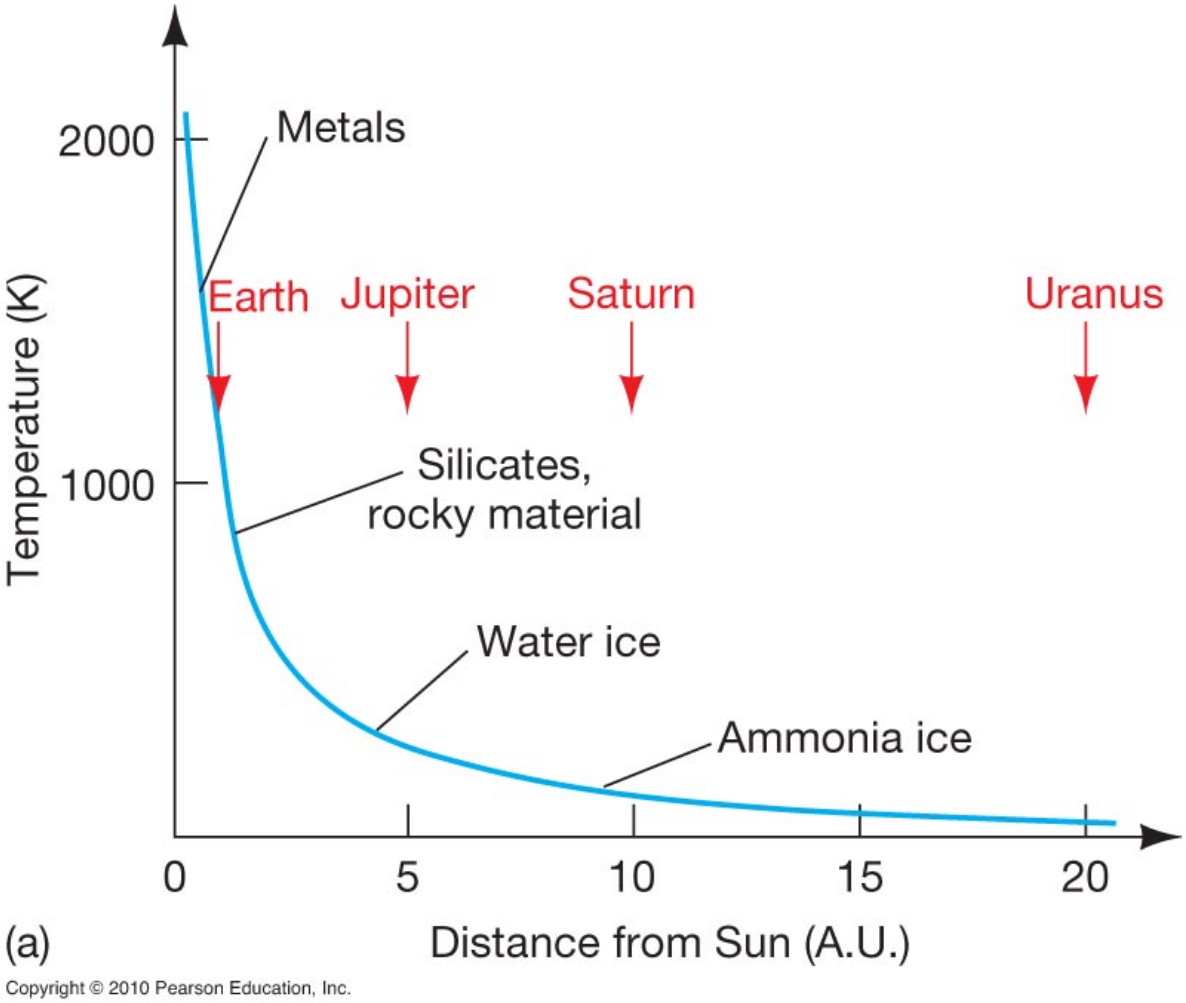
Forming Jovians



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.

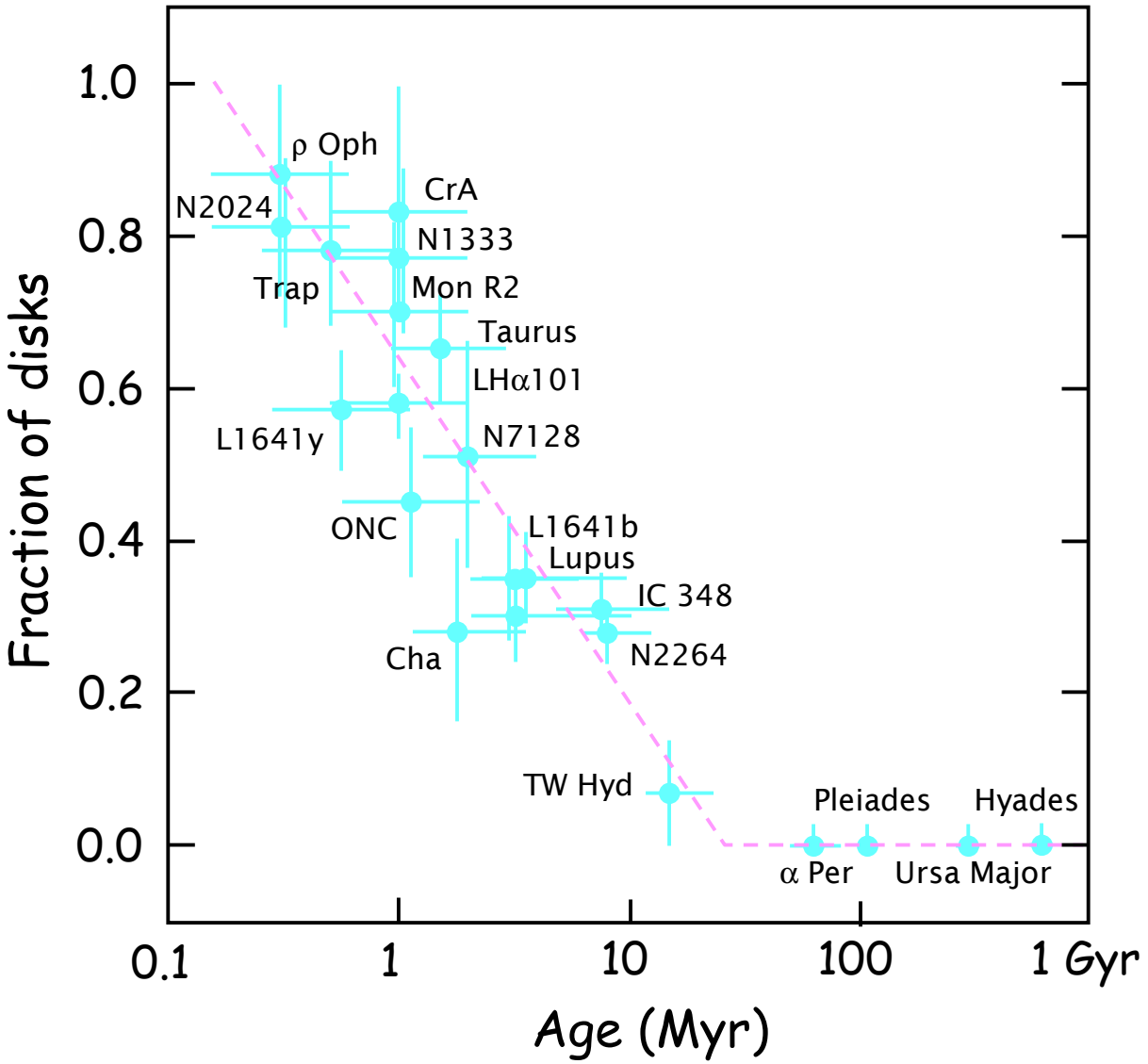


In the early solar system, the snow line was roughly at the position of Jupiter today!

End of planet formation

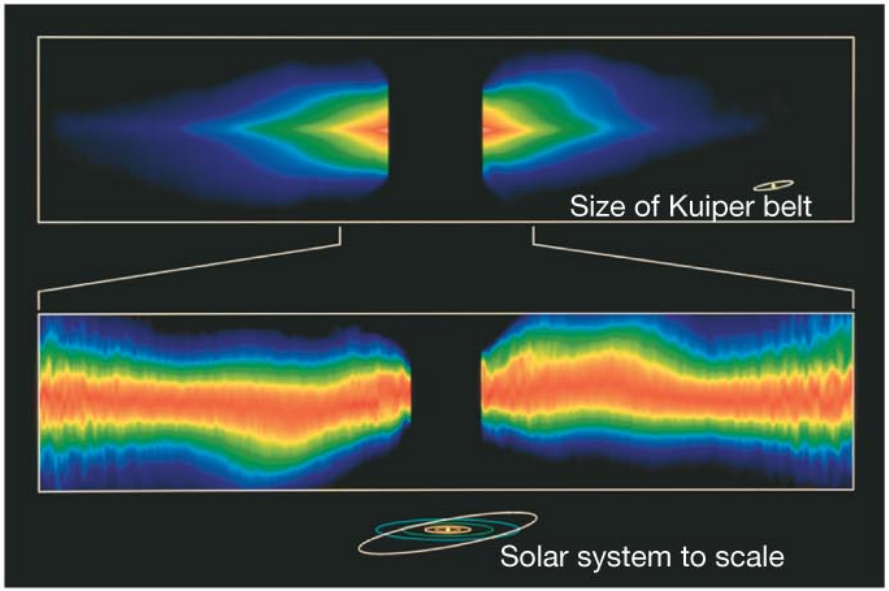
We see this process in action in observations of young protostars with disks.

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

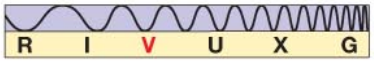


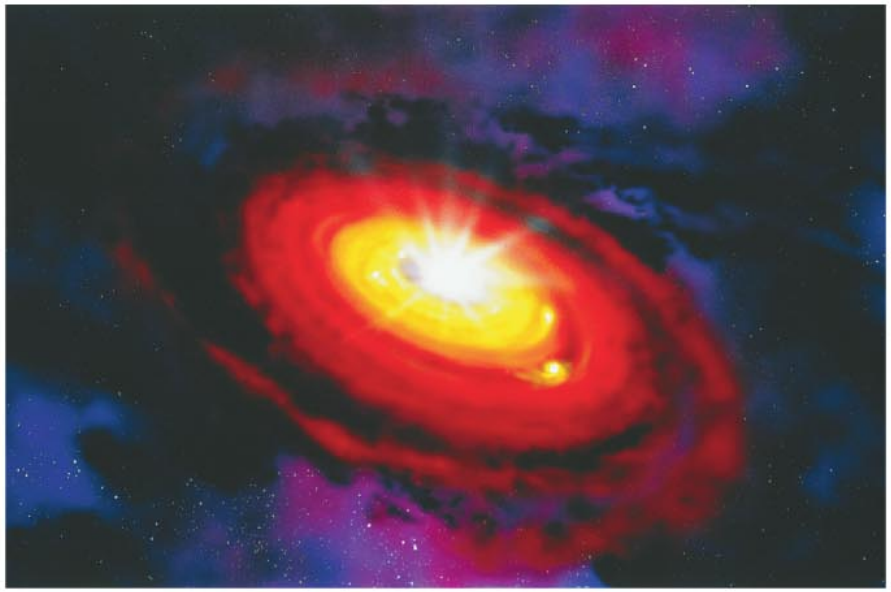
Disks around other stars

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



(a)

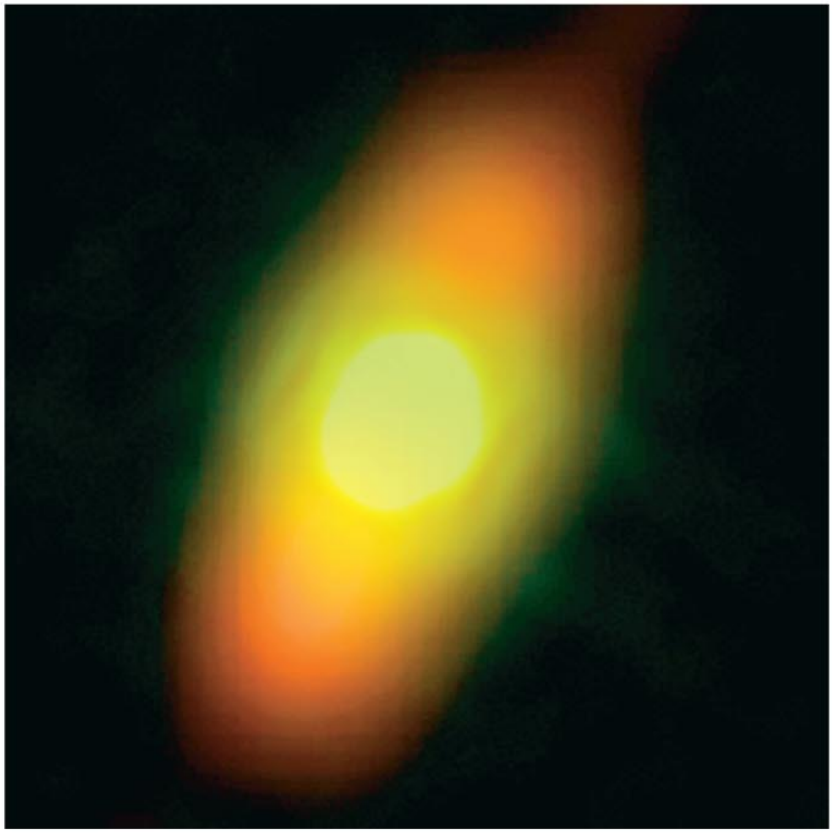




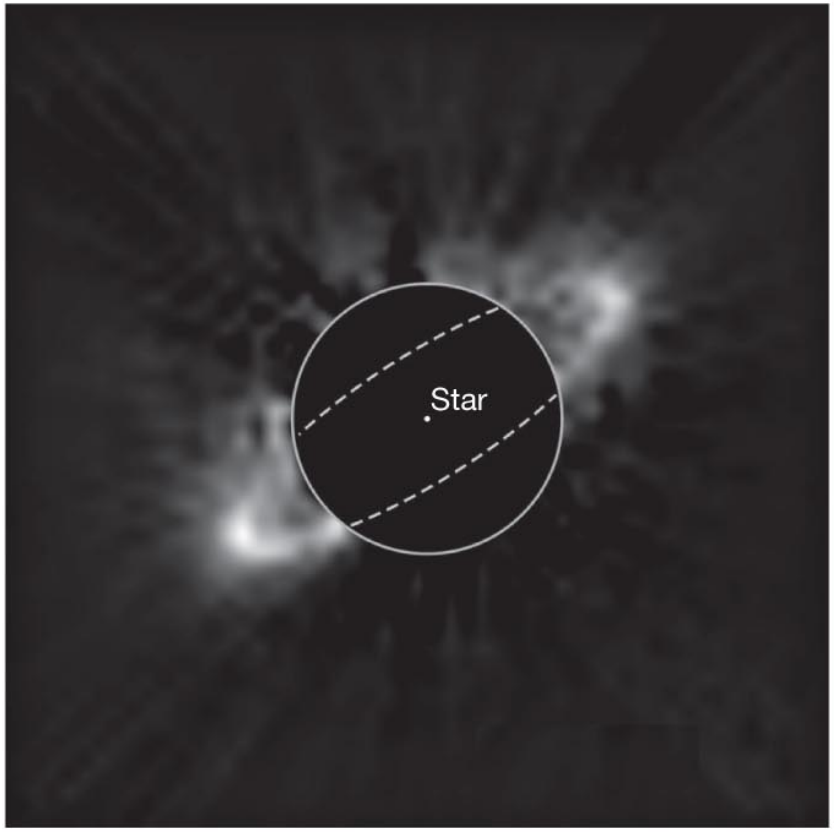
(b)

Disks around other stars

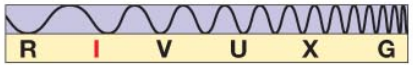
These images show possible planetary systems in the process of formation – disks around the stars Fomalhaut and HR4796A.



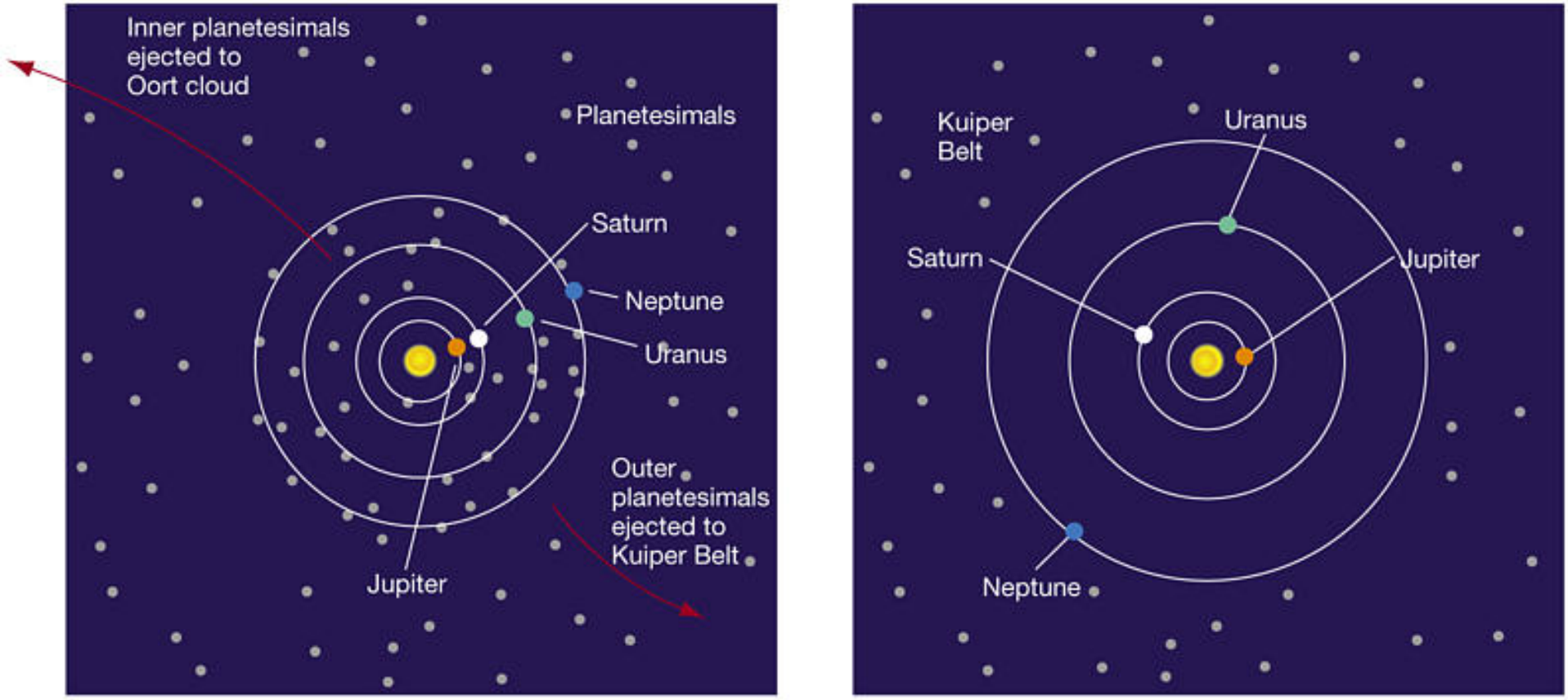
(a)



(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