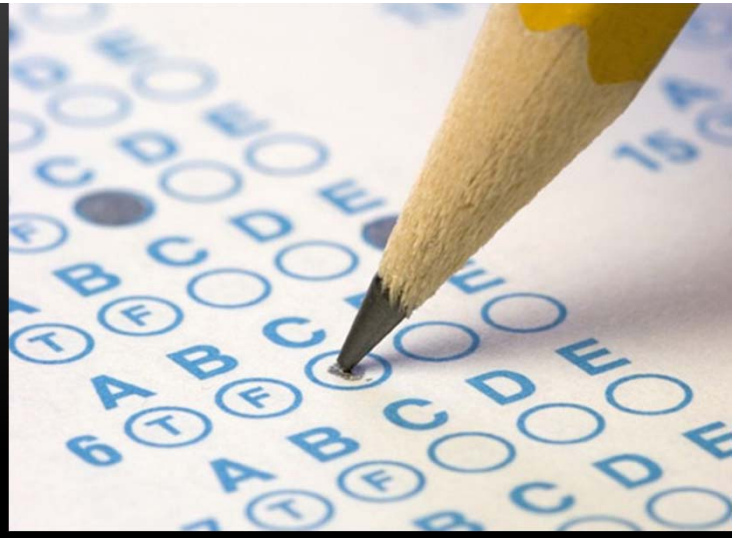
TEST MONDAY



- Chapters 6-10
- Same format as the first test
  - Bring pencils, eraser, your student ID#
  - No need for calculator or phone
- Example test posted on the homework page again
  - So you can practice, and get a feel for what sort of questions get asked
  - “can you figure out what’s going on” style questions, not so much “memorize this factoid or number”
  - Look at the “summary of key concepts” page at the end of each chapter

HOW ARE METEORITES RELATED TO ASTEROIDS?

Fig.9.5

METEORS

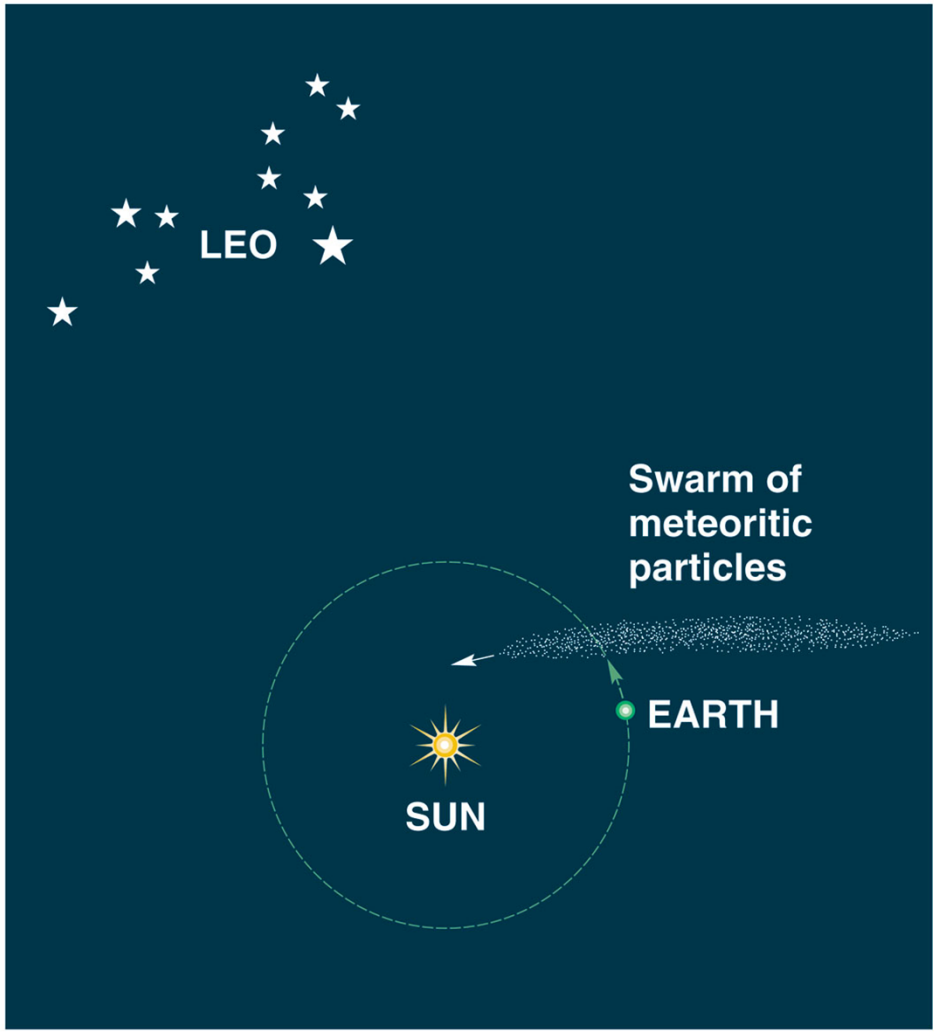
A Leonid meteor seen by Ryan Poling
Nov. 18 2001

- "Shooting Stars"
- Small bit of space junk burning up in the Earth's atmosphere
- If it hits the ground, it's called a *meteorite*
- Floating in space, called a *meteoroid*
- Most are chunks of asteroids or flakes of comets

METEORS

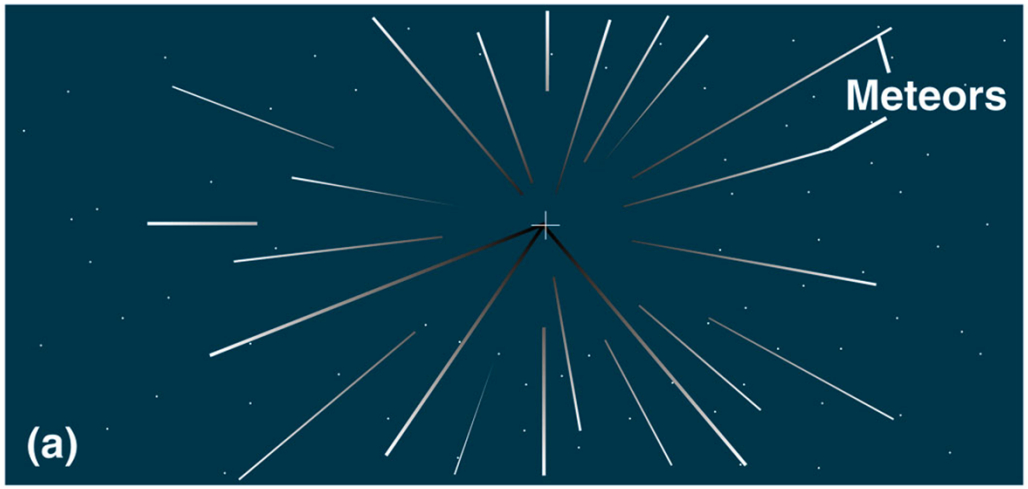
- Most start as grain-of-sand to marble-sized meteoroids
  - Traveling 10-70 km/sec
  - Burn up from 130 to 80 km high
  - Can be seen by people in a ~100mi radius
  - You will see 5-8/hour in a given hour with dark skies
- Called a “fireball” if especially bright

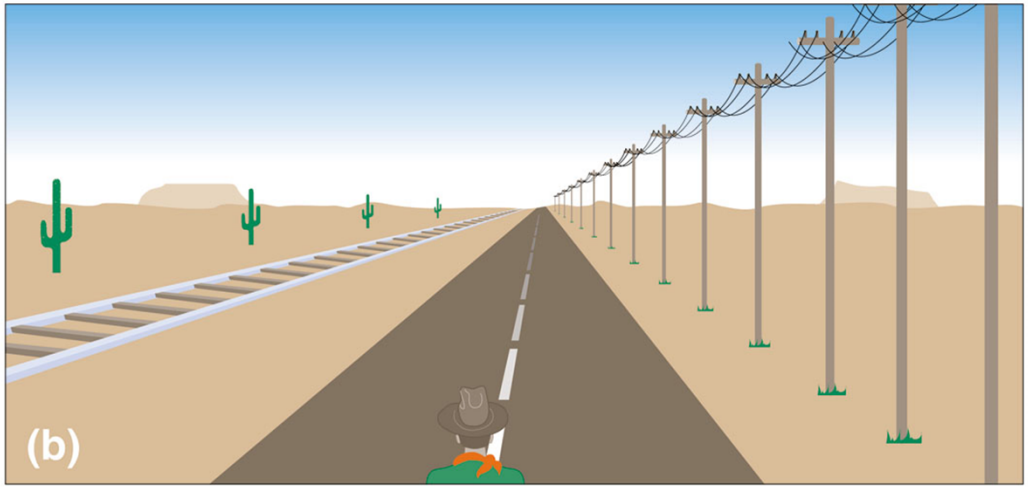
METEOR SHOWERS



- Sometimes, Earth runs through a cloud of comet leftovers
- Many small bits of dust hit the atmosphere
- Observers see many more meteors than usual

RADIANTS AND SHOWER NAMES





- If Earth was headed towards the constellation Leo when it ran over the dust trail
- Meteors will appear to be coming from the same direction
  - In this case, Leo
  - Called the “Leonid” Meteor Shower

RADIANTS AND SHOWER NAMES

b This digital composite photo, taken in Australia during the 2001 Leonid meteor shower, shows meteors as streaks of light (with stars and nebulae visible in the background). The large rock is Uluru, also known as Ayers Rock.

- If Earth was headed towards the constellation Leo when it ran over the dust trail
- Meteors will appear to be coming from the same direction
  - In this case, Leo
  - Called the “Leonid” Meteor Shower

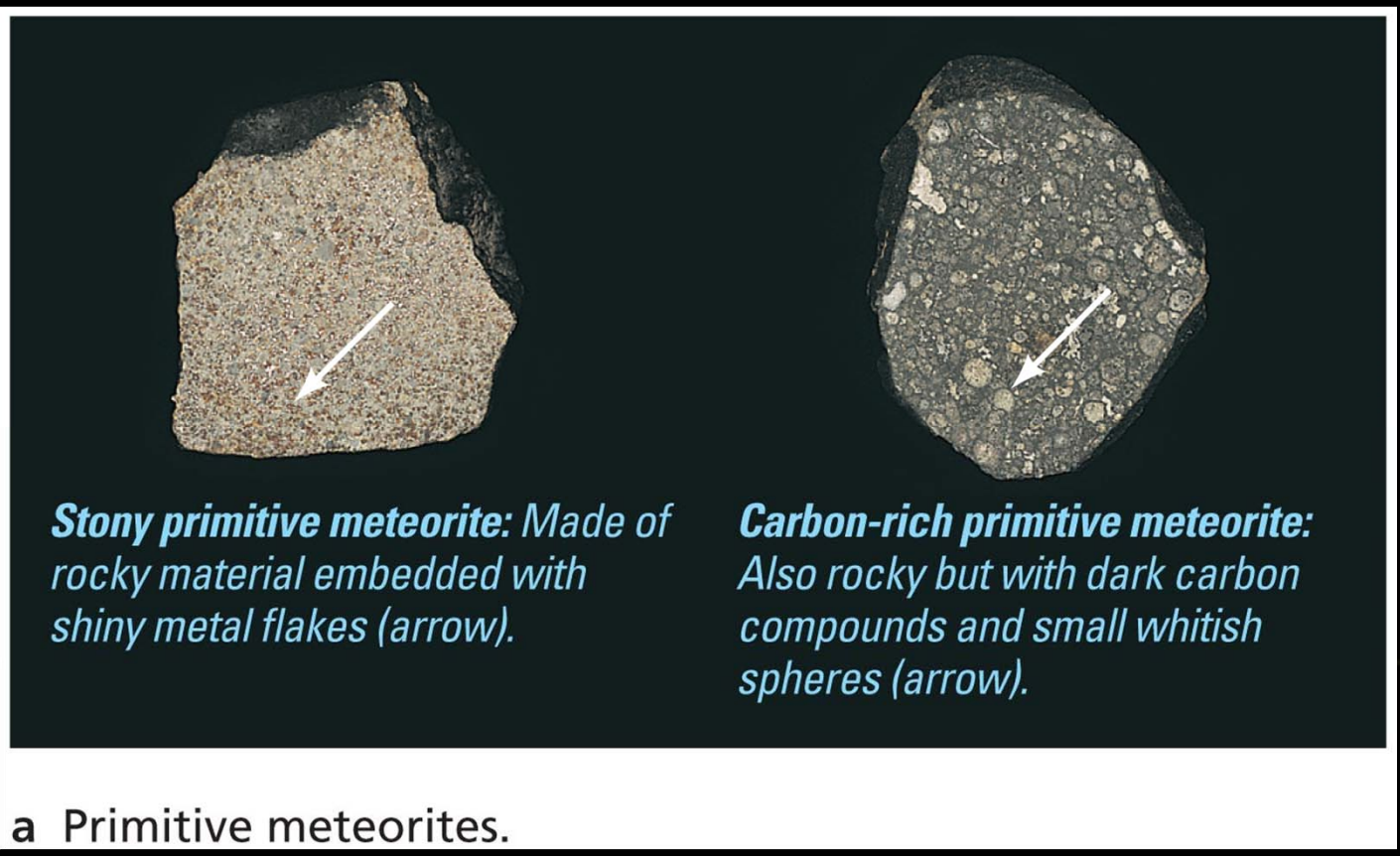
Fig.9.14b

METEORITES

- Meteors big enough to make it to the ground are meteorites
  - Most are asteroid bits

PRIMITIVE METEORITES

- Primitive: Unchanged in composition since they first formed 4.6 billion years ago



a Primitive meteorites.

Fig.9.9a

PROCESSED METEORITES

- Processed: Younger, have experienced processes such as volcanism or differentiation

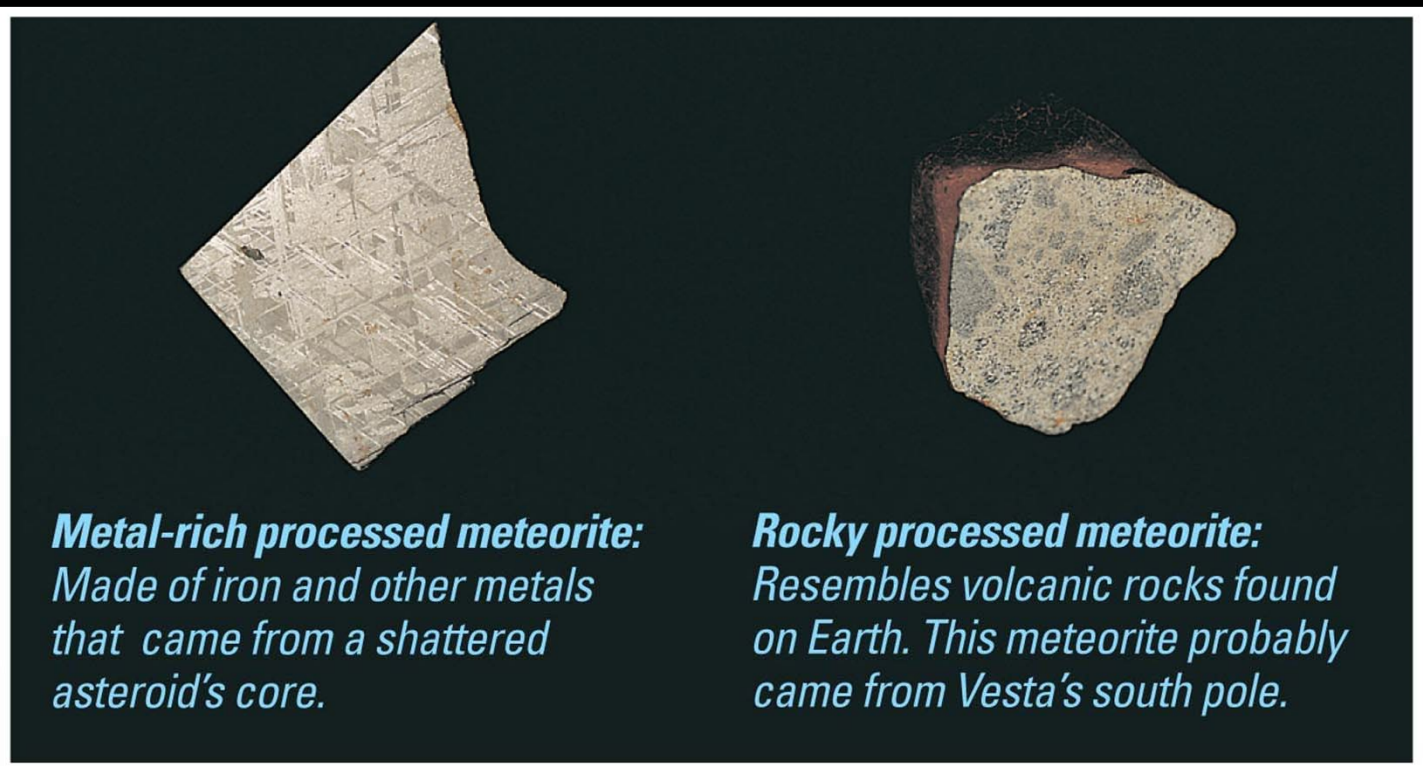


Fig.9.9b

b Processed meteorites.

METEORITES FROM THE MOON & MARS

- A few meteorites arrive on Earth from the Moon and Mars.
- Composition differs from the asteroid fragments.
- This is a cheap (but slow) way to acquire moon rocks and Mars rocks.
- *Question: why do we not see more Venus rocks?*

COMETS

Fig.9.2a

a Comet Hyakutake.

COMETS

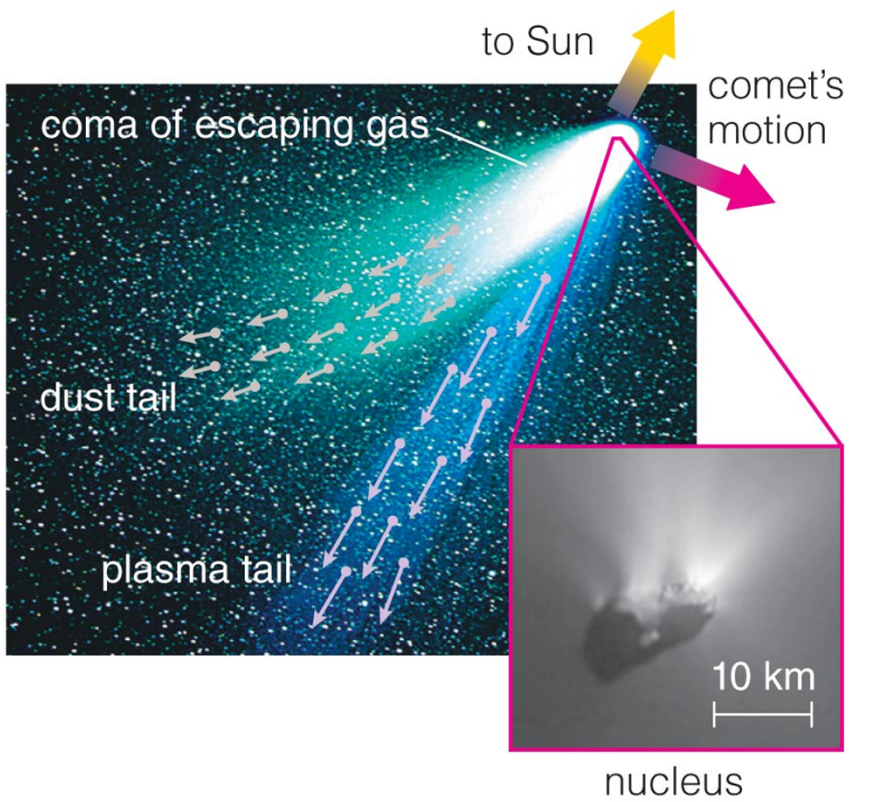
Fig.9.2b

b Comet Hale–Bopp, photographed over Phoenix.

COMETS

- Formed beyond the frost line, comets are icy counterparts to asteroids.
- The nucleus of a comet is like a "dirty snowball."
- Comets do not have tails most of the time
  - Most comets remain perpetually frozen in the outer solar system.
  - Only comets that enter the inner solar system grow tails when they get close enough to the sun.

ANATOMY OF A COMET

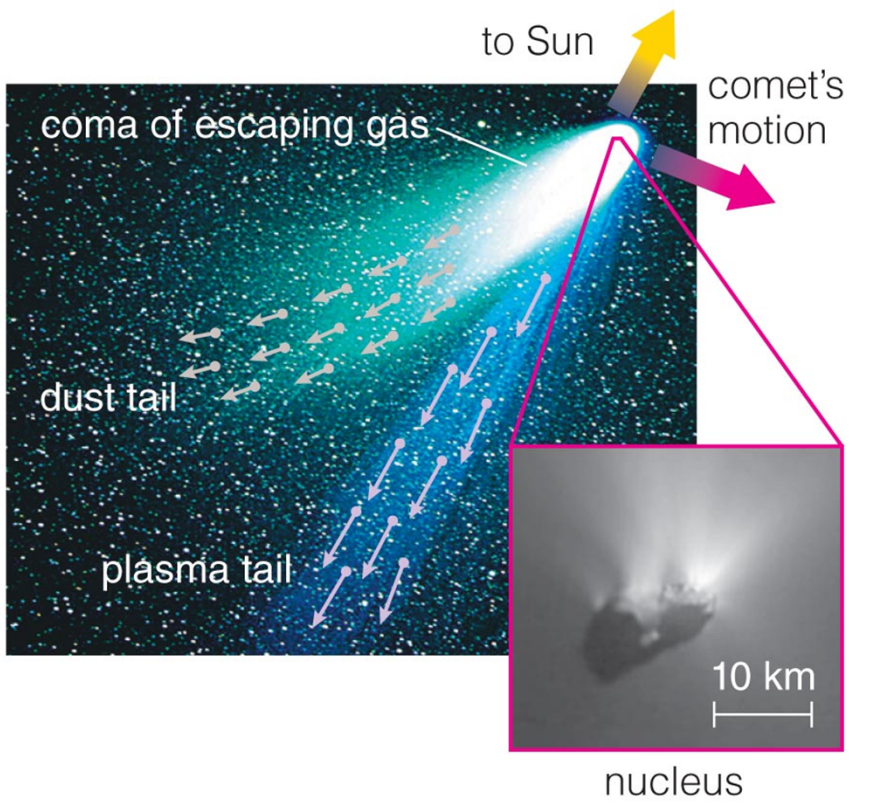


b Anatomy of a comet. The larger image is a ground-based photo of Comet Hale–Bopp. The inset shows the nucleus of Halley's Comet photographed by the *Giotto* spacecraft.

- Nucleus:
  - A "dirty snowball"
  - Source of material for comet's tail

Fig.9.12b

ANATOMY OF A COMET

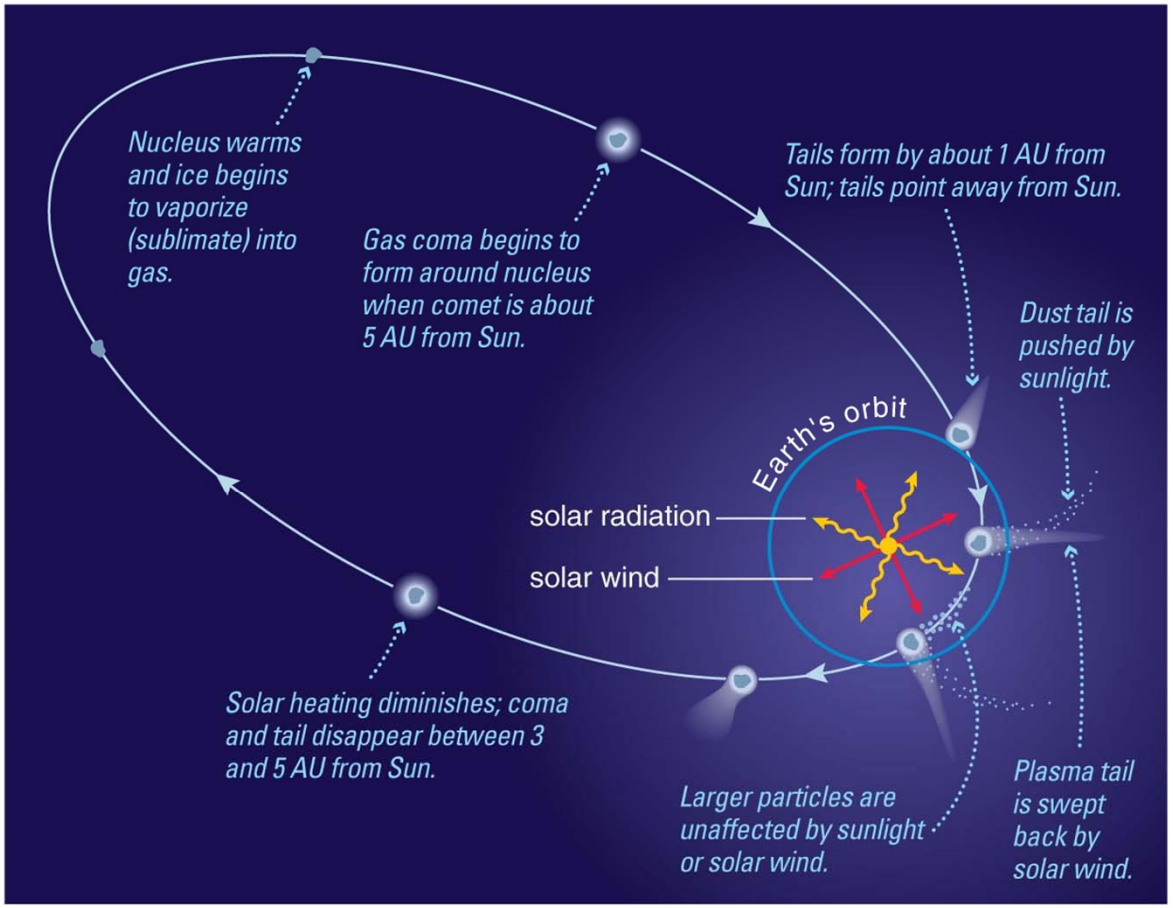


b Anatomy of a comet. The larger image is a ground-based photo of Comet Hale–Bopp. The inset shows the nucleus of Halley's Comet photographed by the *Giotto* spacecraft.

- Coma is atmosphere that comes from heated nucleus.
- Plasma tail is gas escaping from coma, pushed by solar wind.
- Dust tail is pushed by sunlight
  - Doesn't get pushed as fast as plasma tail

Fig.9.12b

GROWTH OF TAIL

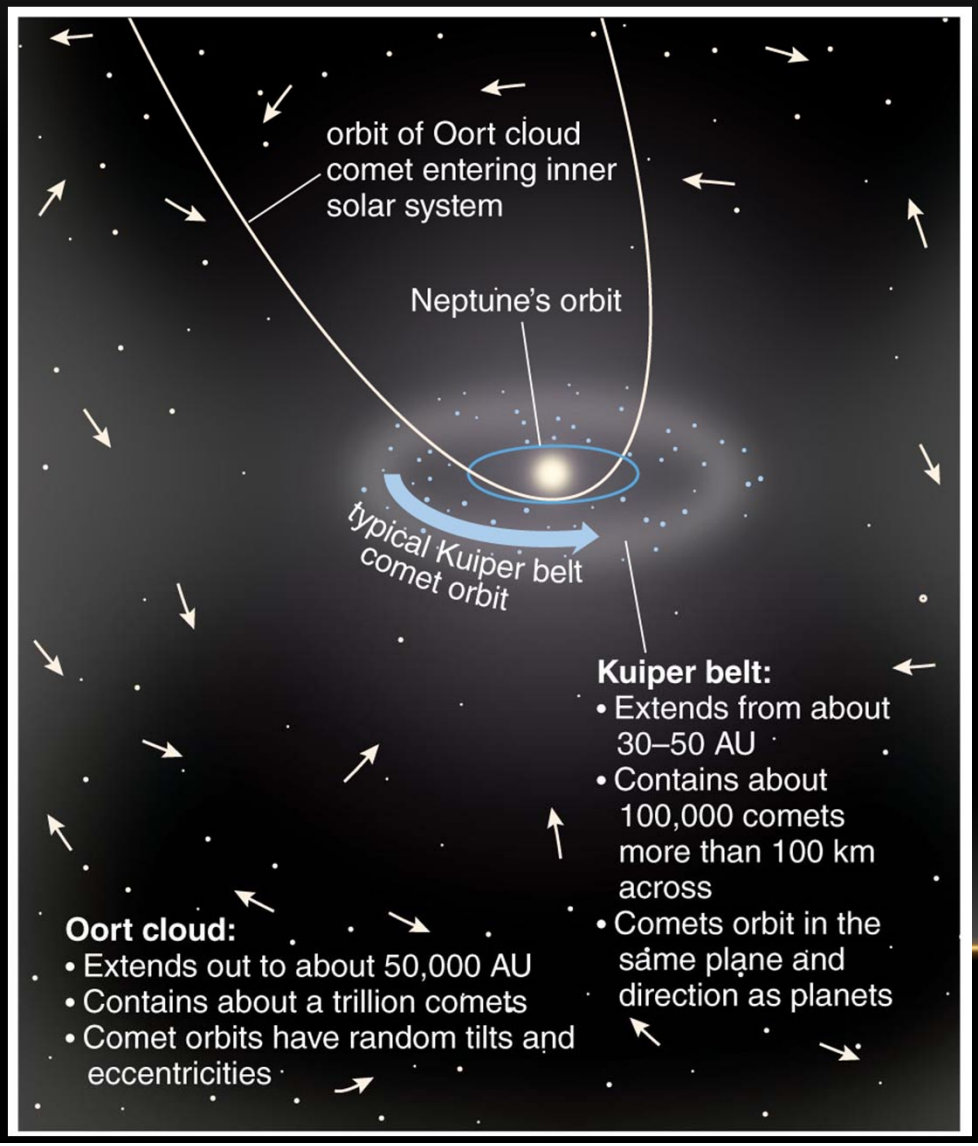


a This diagram (not to scale) shows the changes that occur when a comet's orbit takes it on a passage into the inner solar system.

- Tail only appears when comet gets close enough to the sun to start boiling stuff away

Fig.9.12a

WHERE DO COMETS COME FROM?



Only a tiny number of comets enter the inner solar system; most stay far from the Sun.

Oort Cloud:
Comets on random orbits extending to about 50,000 AU

Kuiper Belt:
Comets on orderly orbits at 30-100 AU in disk of solar system

Fig.9.15

HOW DID THEY GET THERE?

- Kuiper Belt comets formed in the Kuiper Belt.
  - Flat plane aligned with the plane of planetary orbits
  - Orbiting in the same direction as the planets
- Oort Cloud comets were once closer to the Sun, but they were kicked farther out by gravitational interactions with Jovian planets.
  - Spherical distribution
  - Orbiting in any direction

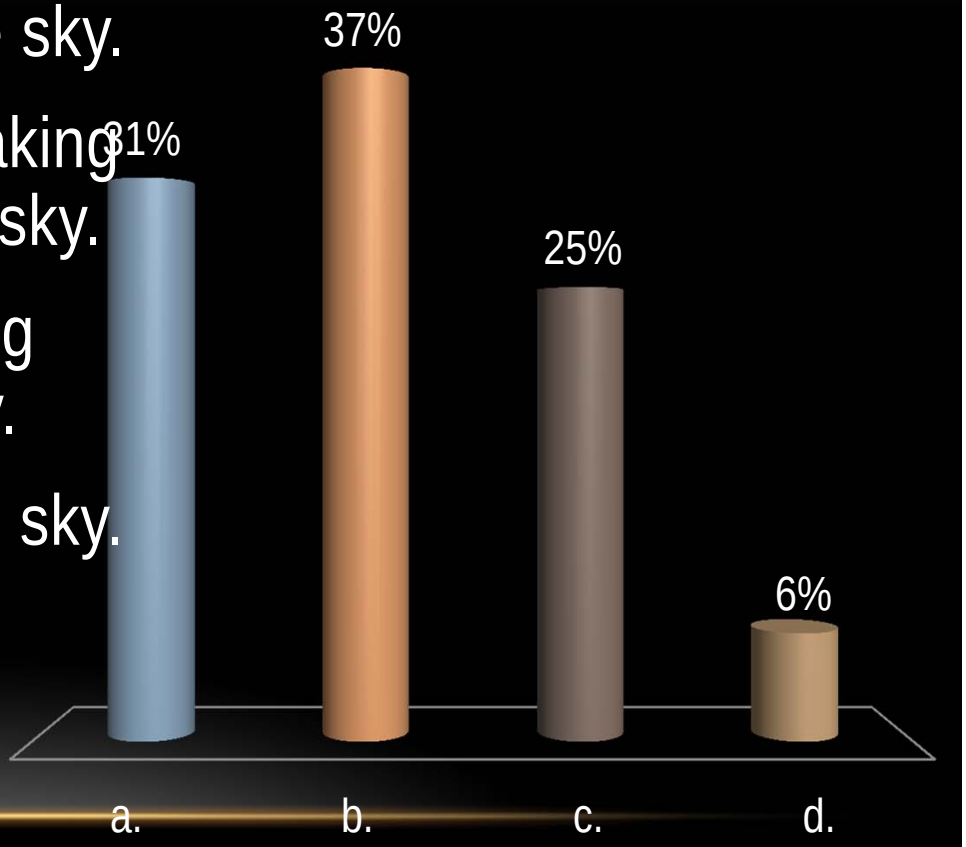
SEEN FROM EARTH, HOW DOES A COMET APPEAR TO MOVE THROUGH THE SKY?

a. It's just like a shooting star, taking seconds to cross the sky.

b. It moves like an airplane, taking minutes to cross the entire sky.

c. It moves like a planet, taking days to cross the entire sky.

d. It doesn't move through the sky.



TWO COOL MISSIONS

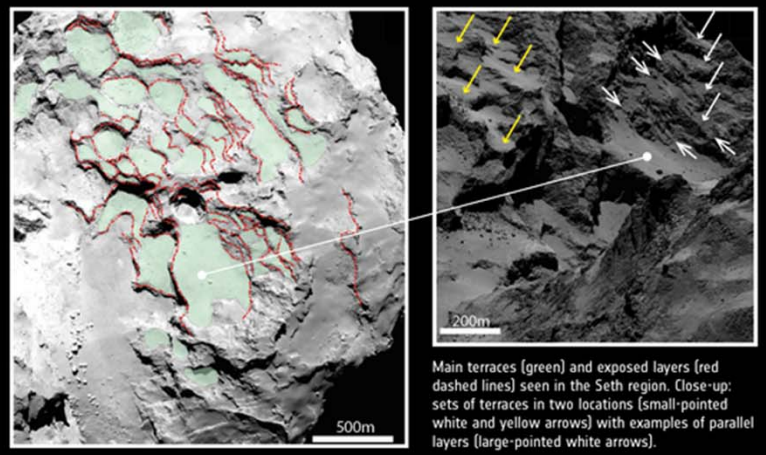
- July 4 2005, “Deep Impact” smashes a probe into comet Tempel 1

  - Earth-based scopes watched carefully to see what flew out
- Rosetta spacecraft and Philae lander
  - Lands on comet 67P/Churyumov–Gerasimenko 12 Nov. 2014
  - Falls into shadow of a cliff, powers down a few days later
  - Powered back up as the comet got closer to the sun! (*now lost again*)

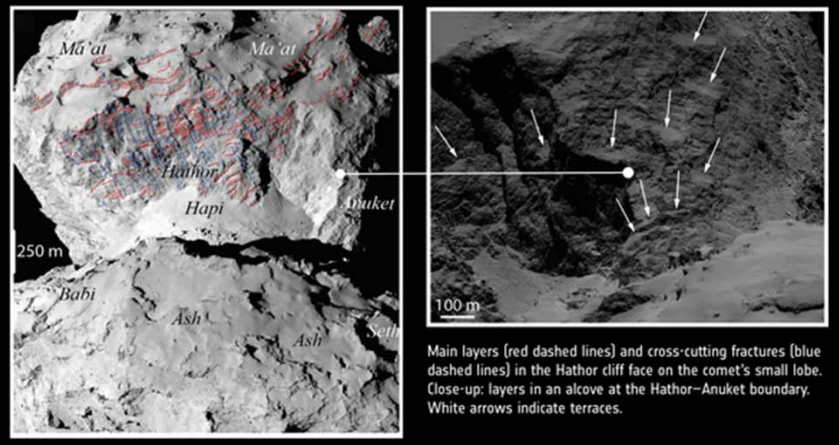
FUNNY SHAPE DUE TO LOW-SPEED COLLISION LONG AGO?

→ COMET 67P/CHURYUMOV–GERASIMENKO'S LAYERS

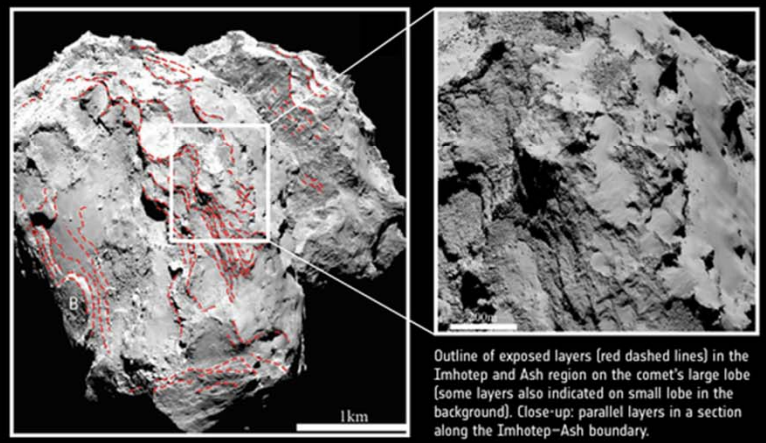
esa



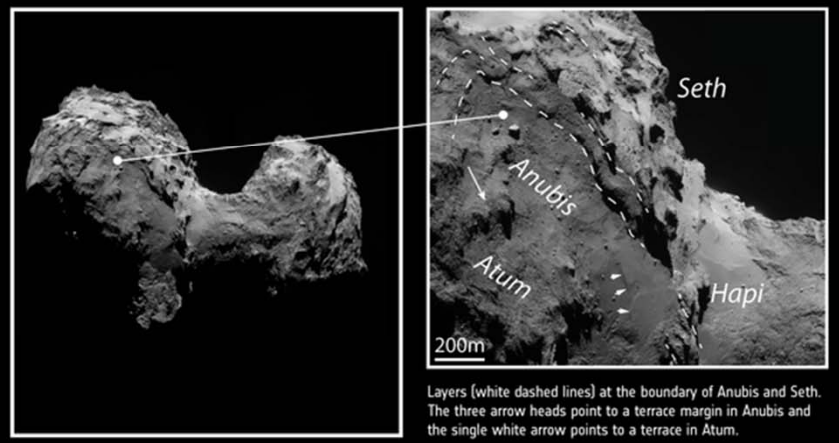
Main terraces (green) and exposed layers (red dashed lines) seen in the Seth region. Close-up: sets of terraces in two locations (small-pointed white and yellow arrows) with examples of parallel layers (large-pointed white arrows).



Main layers (red dashed lines) and cross-cutting fractures (blue dashed lines) in the Hathor cliff face on the comet's small lobe. Close-up: layers in an alcove at the Hathor–Anuket boundary. White arrows indicate terraces.



Outline of exposed layers (red dashed lines) in the Imhotep and Ash region on the comet's large lobe (some layers also indicated on small lobe in the background). Close-up: parallel layers in a section along the Imhotep–Ash boundary.



Layers (white dashed lines) at the boundary of Anubis and Seth. The three arrow heads point to a terrace margin in Anubis and the single white arrow points to a terrace in Atum.

www.esa.int

ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA; M. Massironi et al. (2015).

European Space Agency

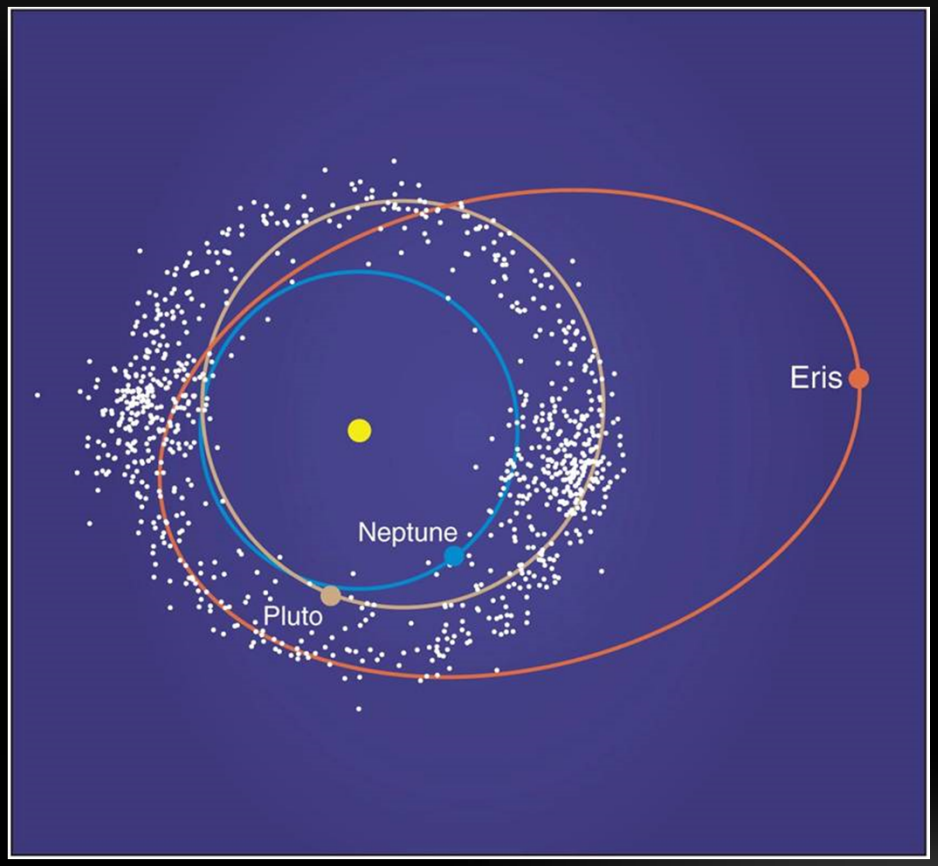
PLUTO 

And other dwarf planets

DWARF PLANETS

Fig.9.4

KUIPER BELT OBJECTS



- These large, icy objects have orbits similar to the smaller objects in the Kuiper Belt that become short period comets.
- So are they very large comets or very small planets?

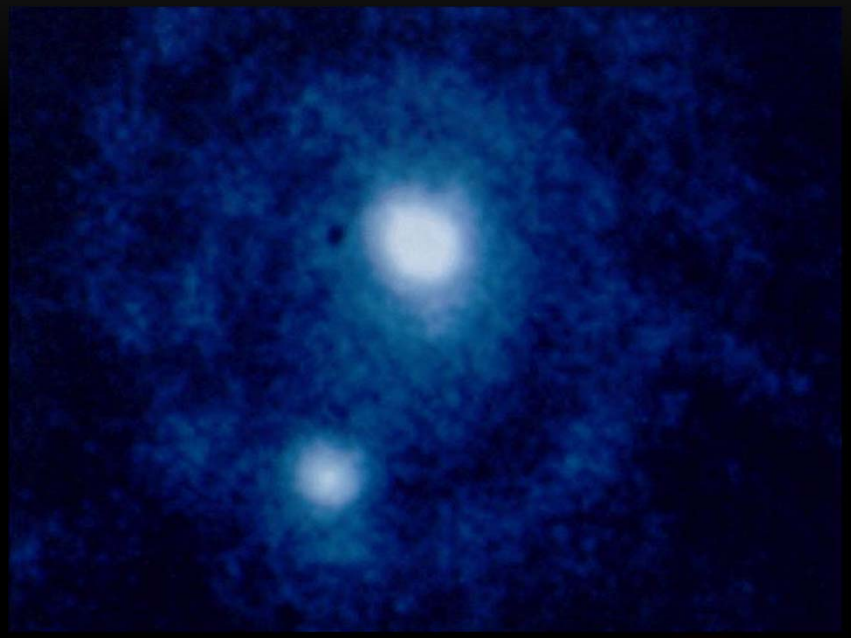
PLUTO

- Following success at Neptune's discovery
  - Lowell looks at irregularities in Neptune's orbit
  - See if these are due to another planet

Clyde Tombaugh

- Works for Lowell Observatory
- Does blink comparisons of star fields
- Discovers Pluto in 1930
- Happy accident – Pluto too small to influence Neptune!

PLUTO FROM EARTH



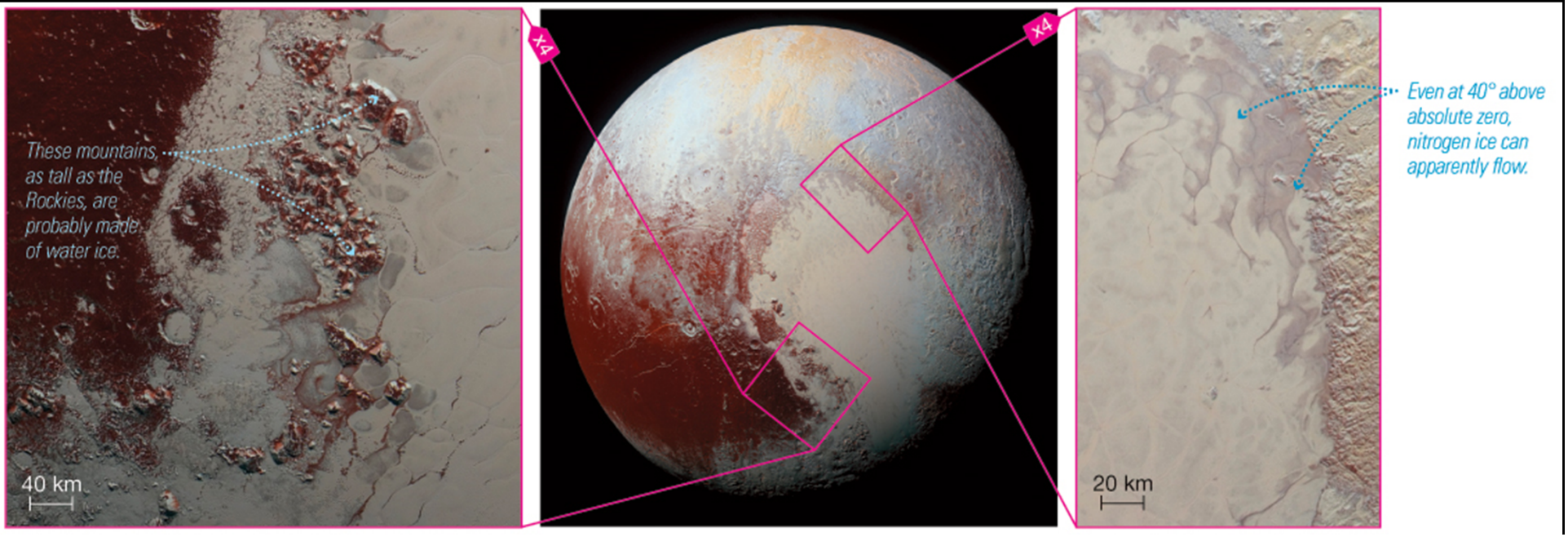
- a=40 AU
  - p=248 years
  - Orbit very eccentric
    - Distance from Sun varies from 30 to 50 AU
    - Closer than Neptune sometimes!
  - At 17^{o} angle to ecliptic!
    - No other planet more than 7^{o} off
- Very small, faint

Pluto and its moon Charon
Seen by HST

NEW HORIZONS

- In 2015, the New Horizons probe raced by Pluto and took great pictures

Fig.9.18



DENSITY, COMPOSITION?

- Diameter is 0.18 of Earth's, Mass 0.0022 Earths (0.178 of the Moon)
- Combining diameter and mass as usual gives:
  - Density of 1.87 g/cm^3
  - Comparable in size and density to large, icy moons of Jovian planets
    - ~30% ice, 70% rock
  - So it is likely similar in composition and structure

PLANET?

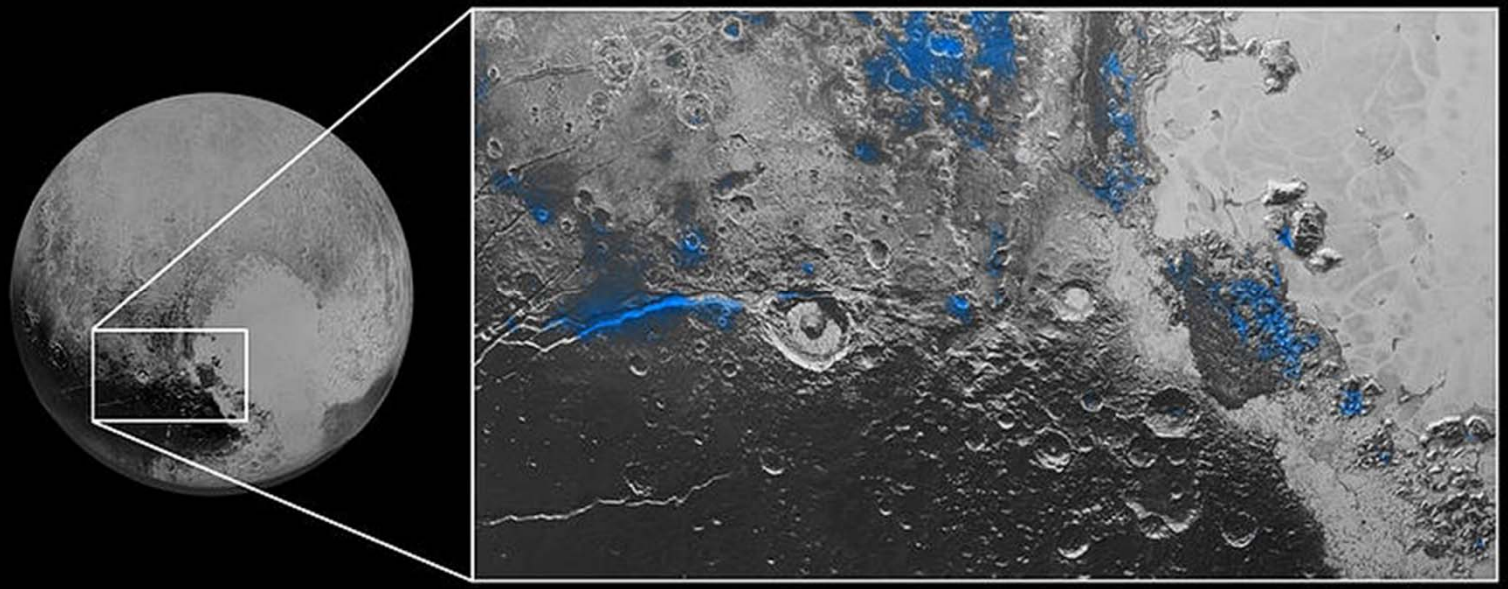
- In 2006, the IAU decided that there were enough smaller “not quite a planet” things to give them their own category: Dwarf Planet
- Big enough to be round from their own gravity
- Not big enough to have enough gravity to keep other stuff out of their orbits

SURFACE

- Covered mostly by nitrogen ice
- Coloring is methane and carbon monoxide ice

EVEN SOME WATER ICE

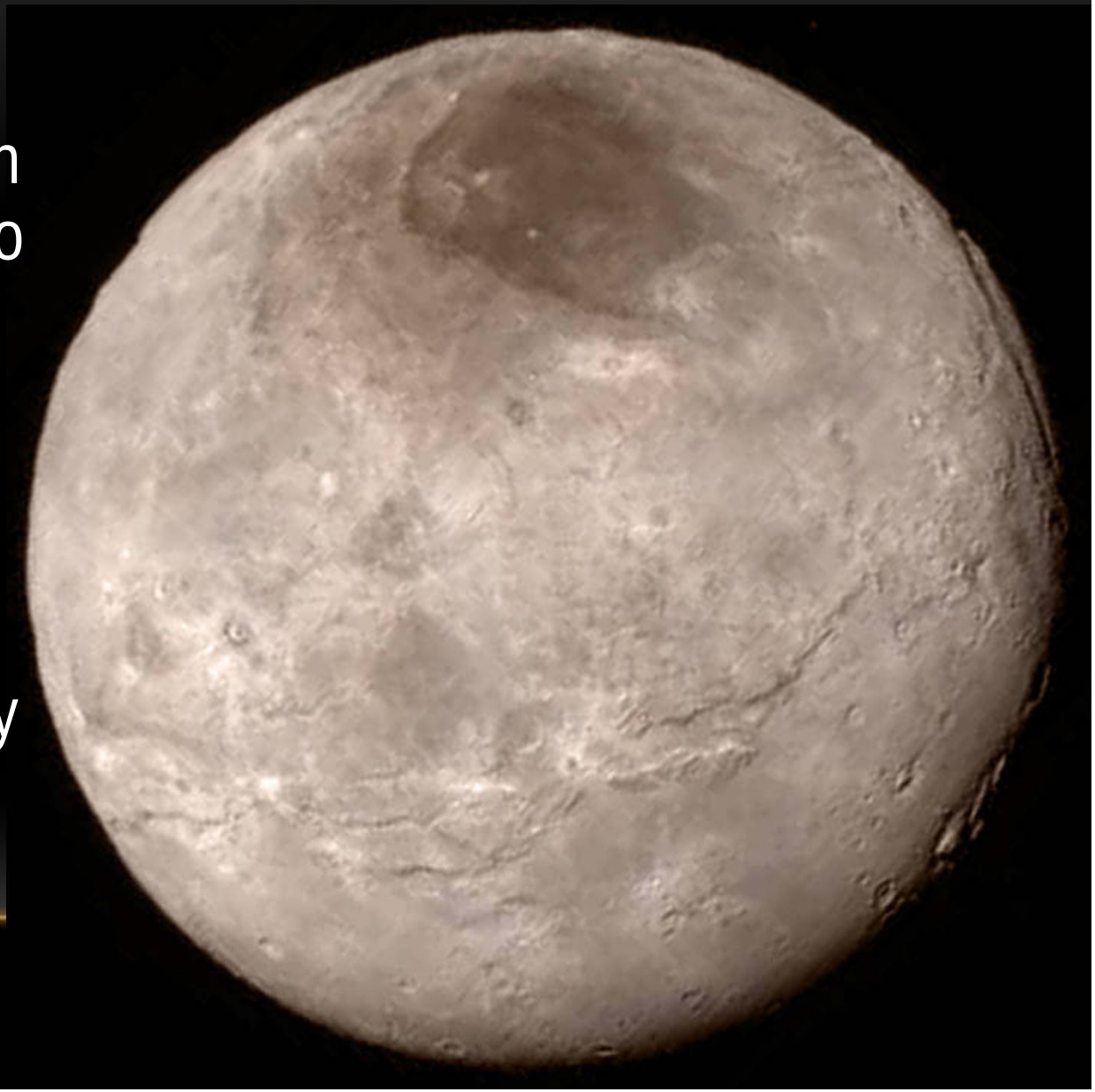
- Pluto also probably stayed warm enough long enough to chemically differentiate
  - Could have a layer of liquid water deep down there



Blue is where water ice was seen

CHARON

- Very large moon in comparison to its planet
  - Both bodies are tidally locked to each other
- 4 other small icy moons



HOW RARE OR COMMON ARE IMPACTS OF ASTEROIDS AND COMETS INTO EARTH?

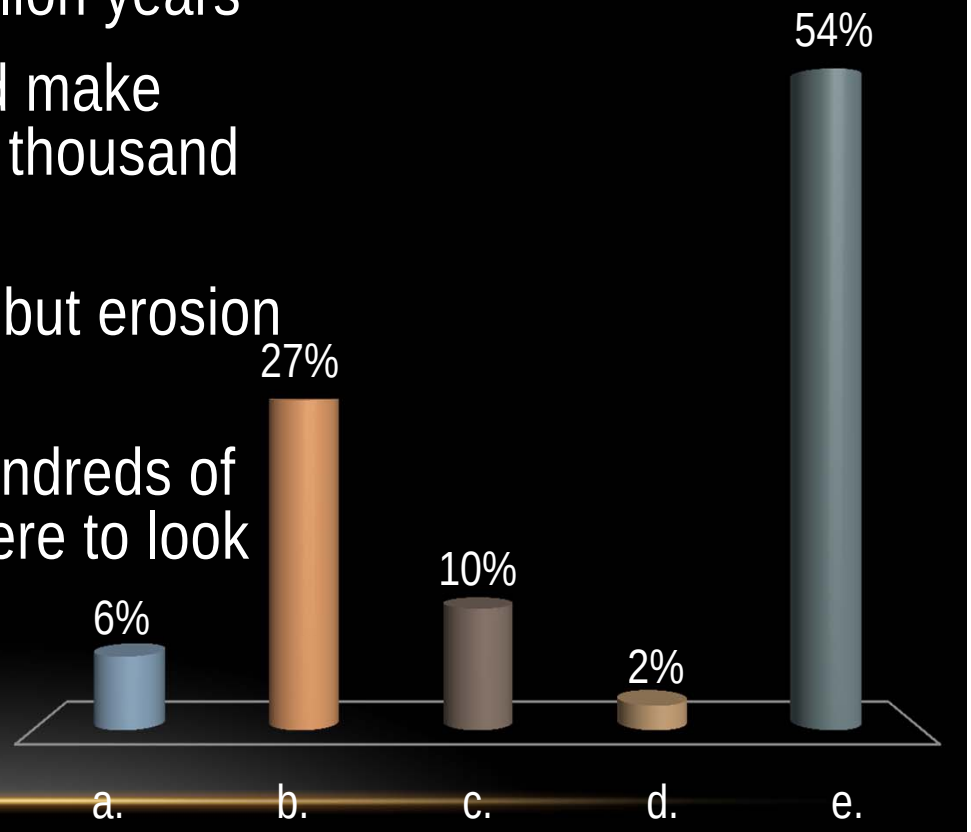
a. Ones big enough to kill off all life on Earth–maybe once in 100 million years

b. Smaller impacts, which would make mile-sized craters--every few thousand years

c. As common as on the Moon, but erosion has warn away old craters

d. Pretty common. Earth has hundreds of large craters–if you know where to look

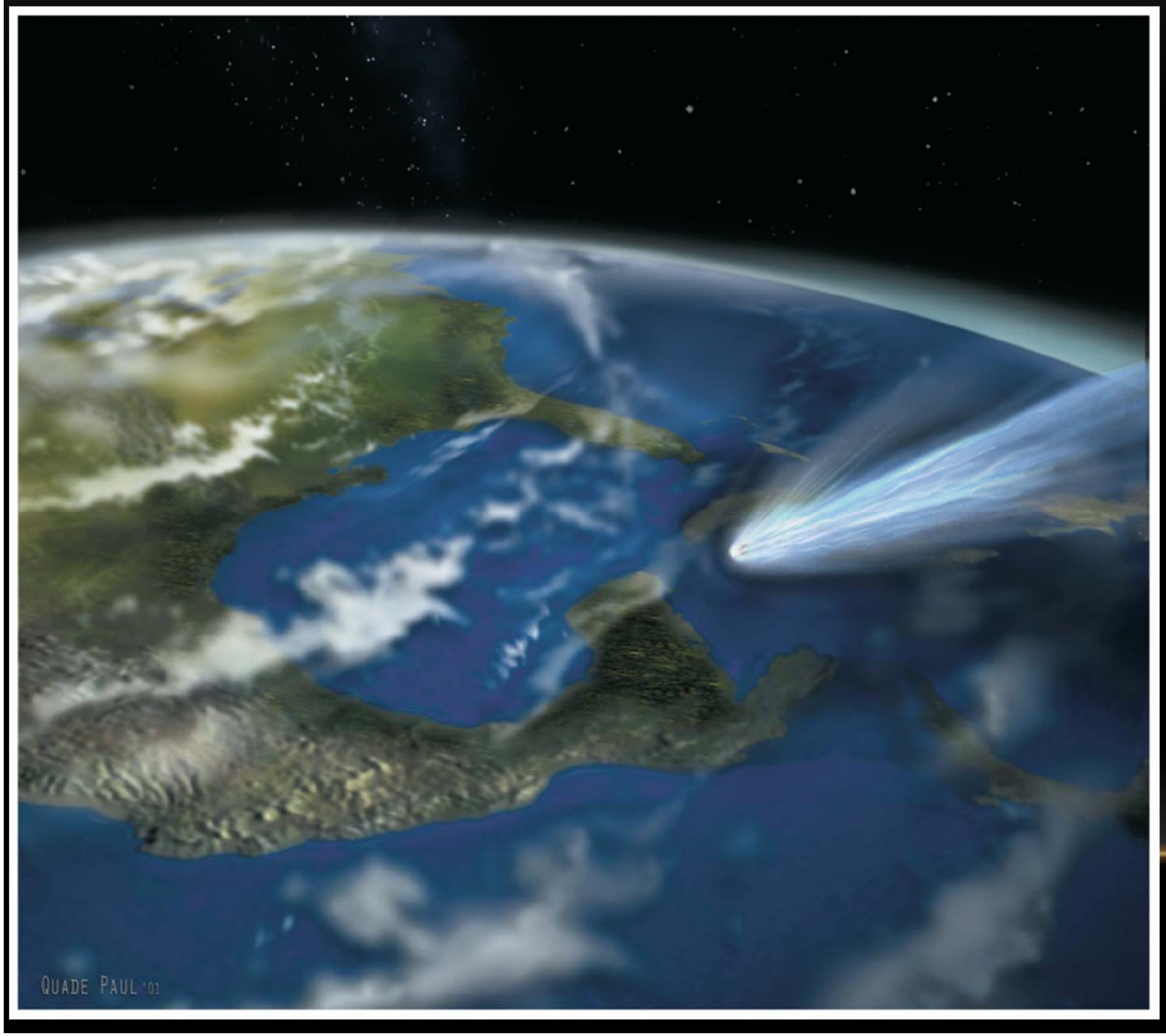
✓ e. All of the above



IMPACTS

- So small things impact the Earth all the time
  - Those meteors from earlier!
  - About 100 tons of stuff total per day
- What about bigger things that make a mark?

DINOSAURS, FOR EXAMPLE



- 65 million years ago, something did in 99% of life on the planet (and 75% of all species went extinct)

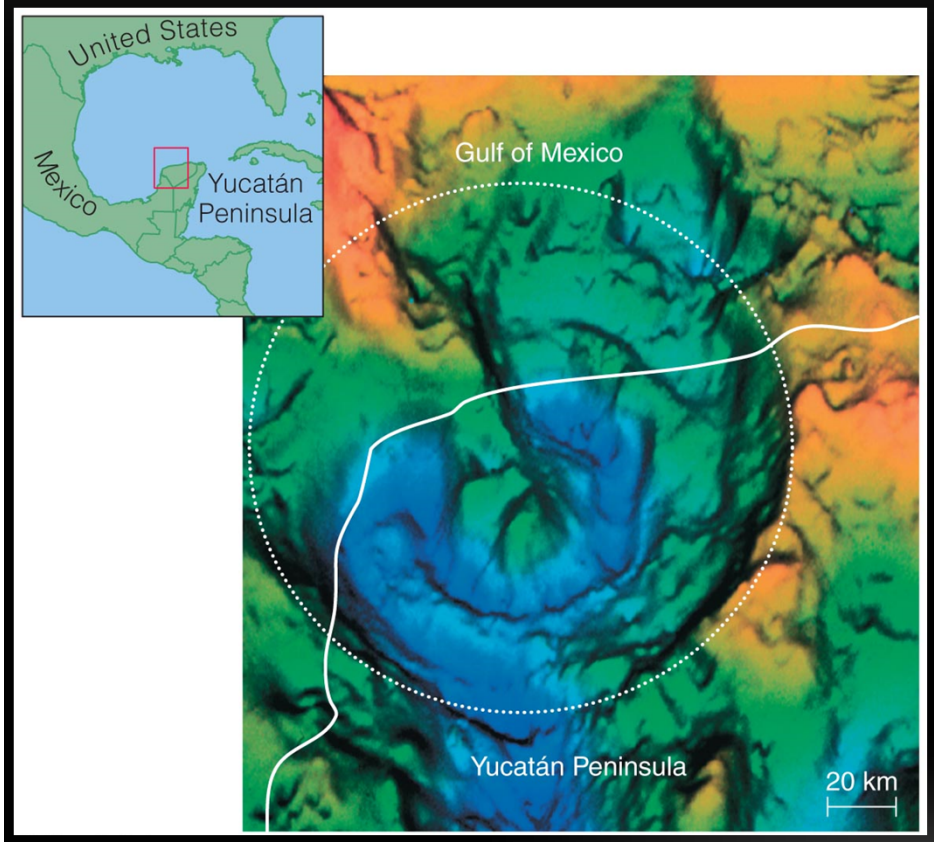
Fig.9.24

AN IMPACT?

Exposed rocks in the badlands of Alberta at boundary of Cretaceous-Tertiary periods

- Thin layer of extra Iridium ID'd worldwide in rocks at that extinction boundary
  - An element mostly found in meteorites
- Dust, soot from impact worldwide would have stifled all the plants that didn't just plain die

AN IMPACT?



- 180 km wide crater from that time ID'd
  - Chicxulub crater just off the coast of the Yucatan
- A 10 km wide asteroid could do this

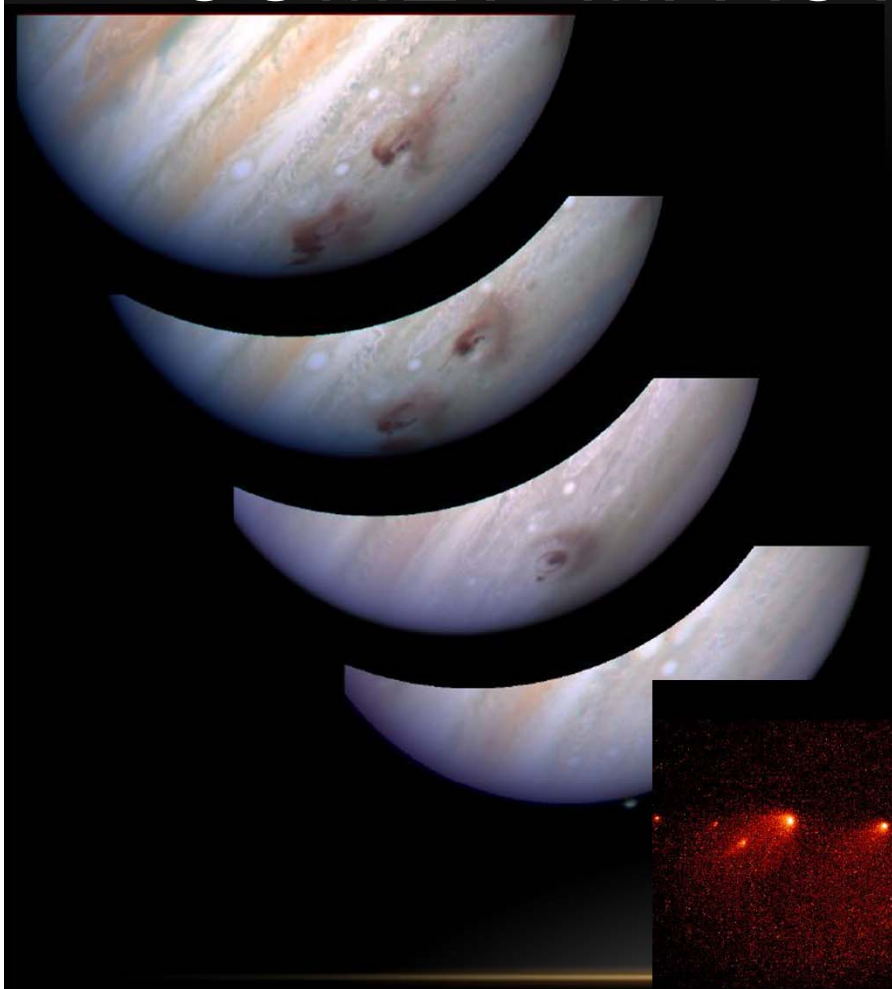
Fig.9.23

BARRINGER CRATER

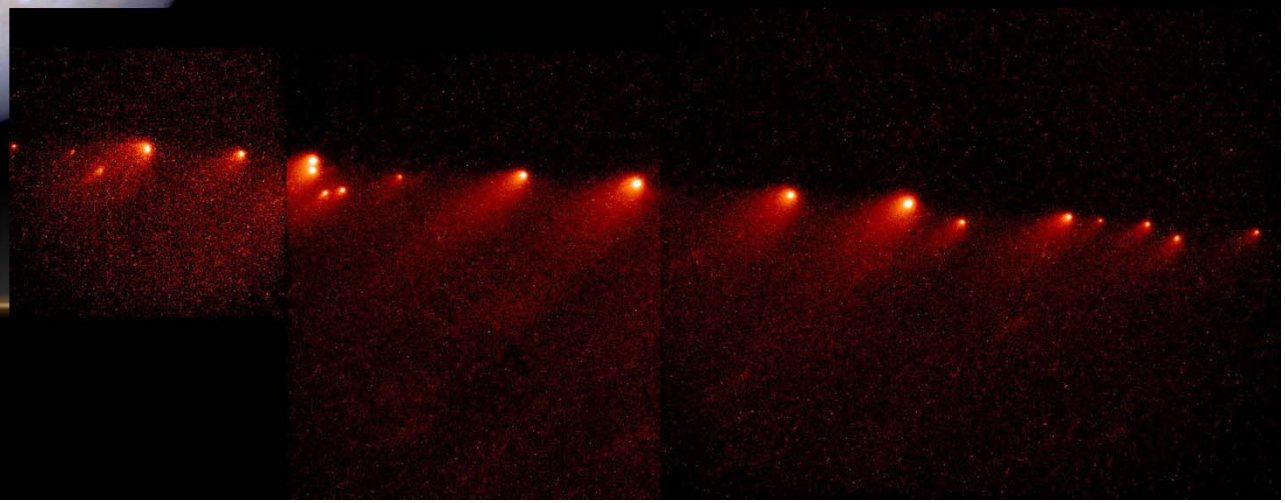
- 49,000 year old impact crater
  - “Meteor Crater” in Arizona
  - 1.2 km wide
- First recognized impact crater on Earth
- Estimated 45 meter, 300,000 ton small asteroid
  - 25 tons iron recovered
  - Energy of 25-megaton bomb

More recently and way smaller
So recent that it hasn’t had a chance to erode away

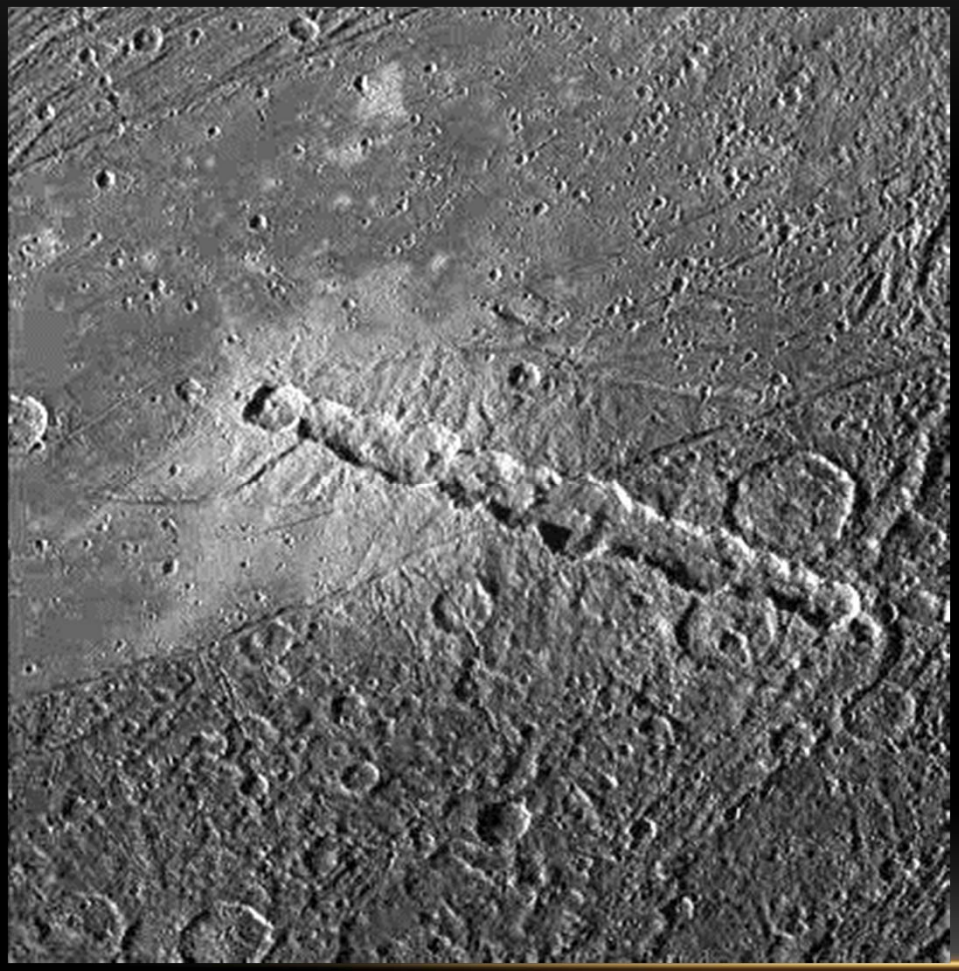
COMET IMPACT



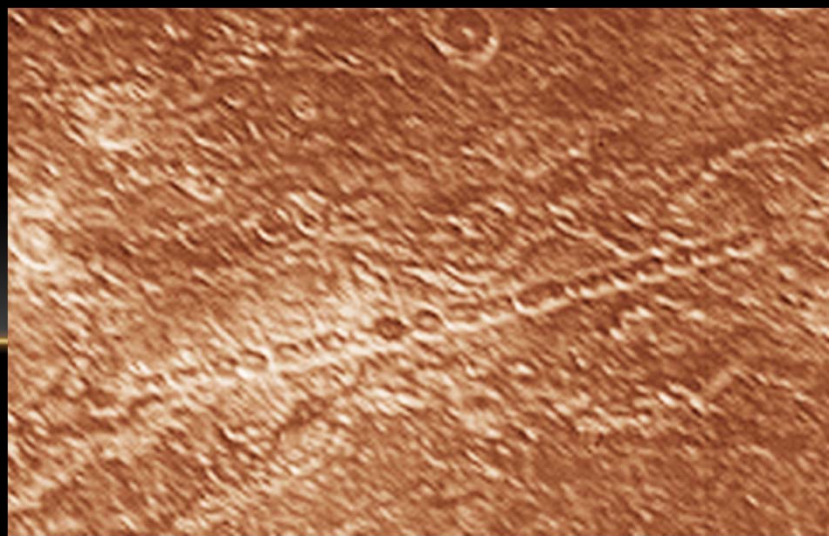
- In July 1994, comet Shoemaker-Levy 9 hits Jupiter's night side
- Previously broken up by Jupiter's tidal action during a close pass



NOT SO UNUSUAL



- A Galileo photo of Ganymede reveals
  - A 120-mile long crater chain
- A 620 km chain on Callisto is below



IMPACT IN 1908?

- Something hit near the Tunguska River in Siberia 17 June 1908
  - Boom and quake measured around Europe
  - Estimated power of 3-5 megatons of TNT (directed downward)

Years later (1929), the forest was still wrecked

Fig.9.25

IMPACT IN 1908?

- No crater
  - but 70x55km area clobbered
  - No human casualties
- Best guess: air burst of an asteroid 6-10km up in the air

Years later (1929), the forest was still wrecked

Fig.9.25

MORE RECENTLY

- Chelynabinsk, Russia, Feb. 15 2013
  - 500-kton kerpow caused by a 10,000 ton asteroid moving 60,000 km/hr

Again an airburst – fragments recovered

1000 people injured by broken glass

Good thing it came in at such an angle!

Fig.9.26