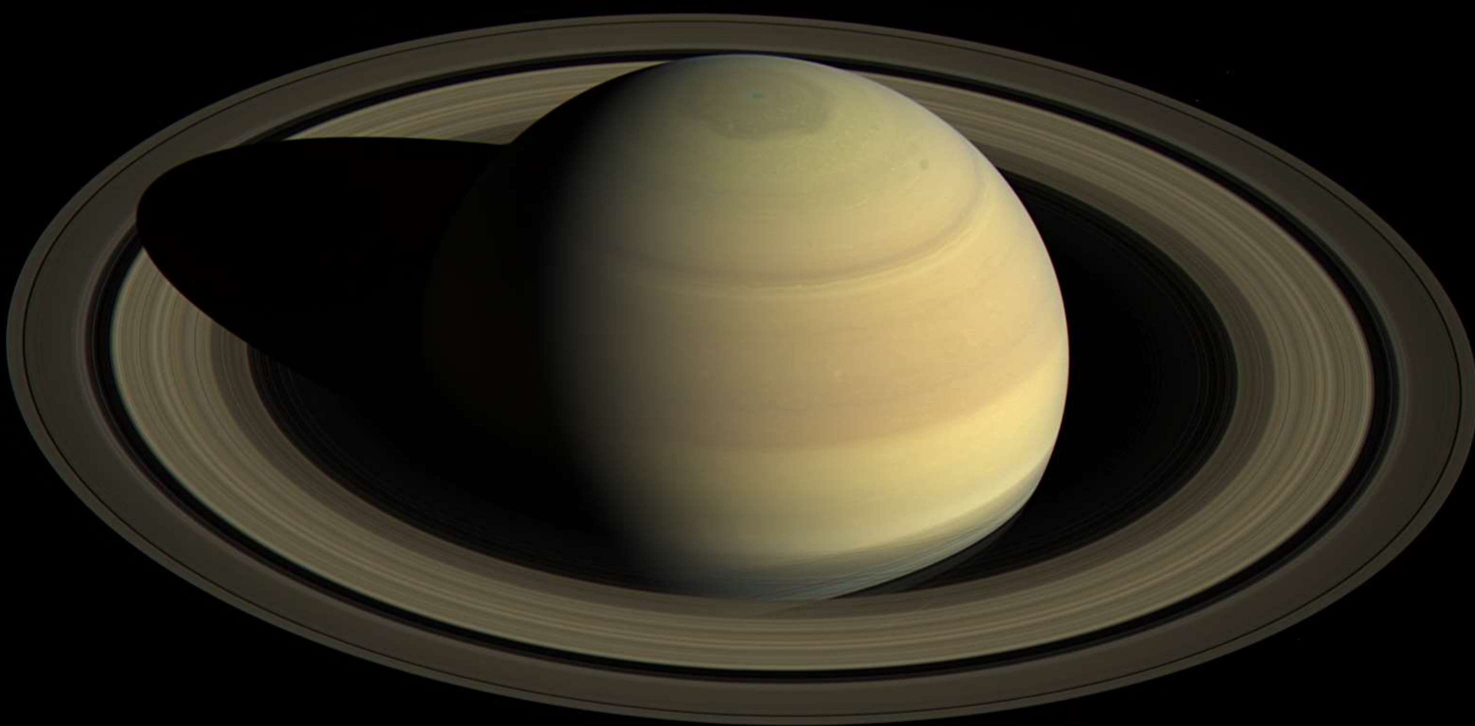
AST 2002
Introduction to Astronomy



A Few Quick Things…

E-mailing me: Must have AST2002 in the subject

Mary Hinkle, Graduate Teaching Assistant:
Office Hours: Mon 1:30-3:00pm. PSB 316

My office hours: Mon 3:00-4:00pm. PSB 308
Tue 3-4 pm. PSB 308

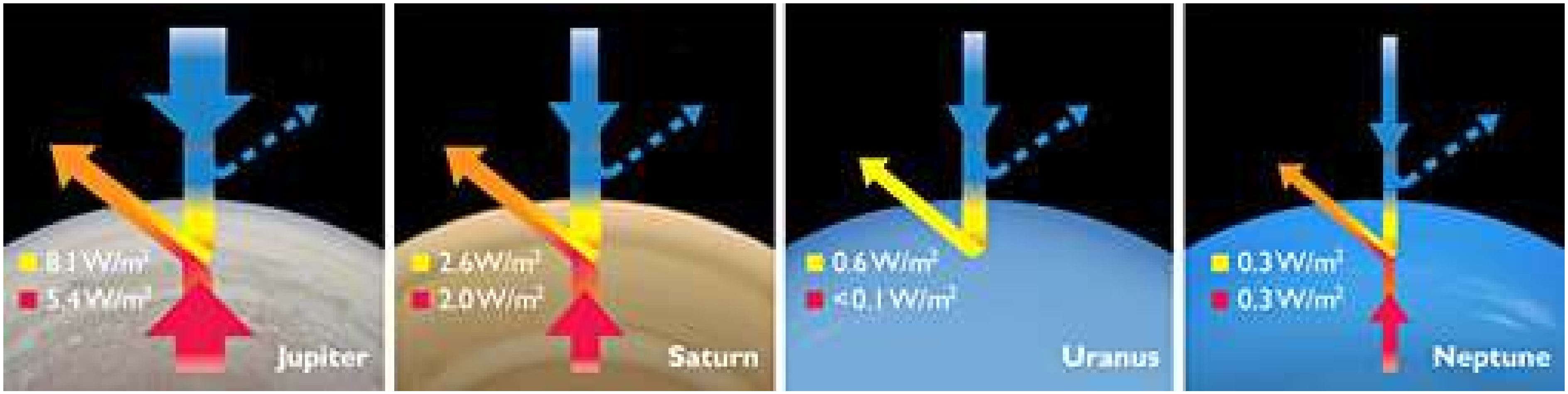
First Mid-term : Will be having more regular homework
Will start going over some of the exam questions…

Next Mid-Term: Wed 7th March

Next Knights Under the Stars Event – Wed 28th Feb 7:30-9:00pm

New Slide

Heat Fluxes of the Jovian Planets



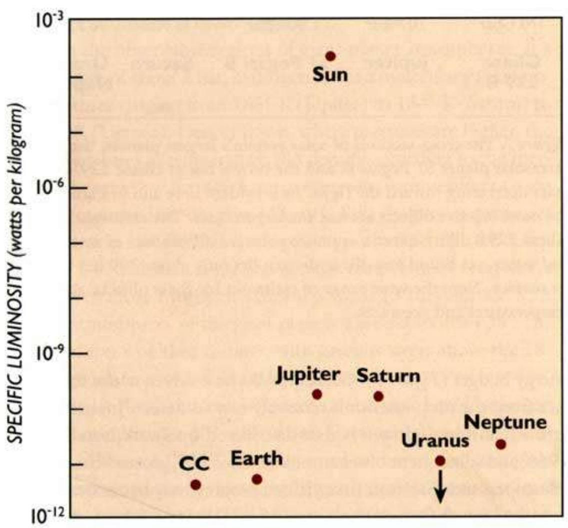
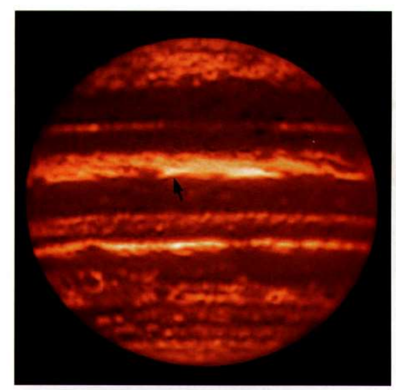


Figure 9. With the exception of Uranus, the Jovian planets emit more energy per unit of mass than other solar-system bodies do. The value labeled *CC* (carbonaceous chondrite) is that expected for a body of approximately chondritic (rocky) composition.

	Jupiter	Saturn	Uranus	Neptune
Heat Emitted / Sunlight Absorbed	2.5	2.3	~1.1	2.7

Seems that the Jovian planets (except Uranus?) all have significant internal heat sources (glow in infrared)

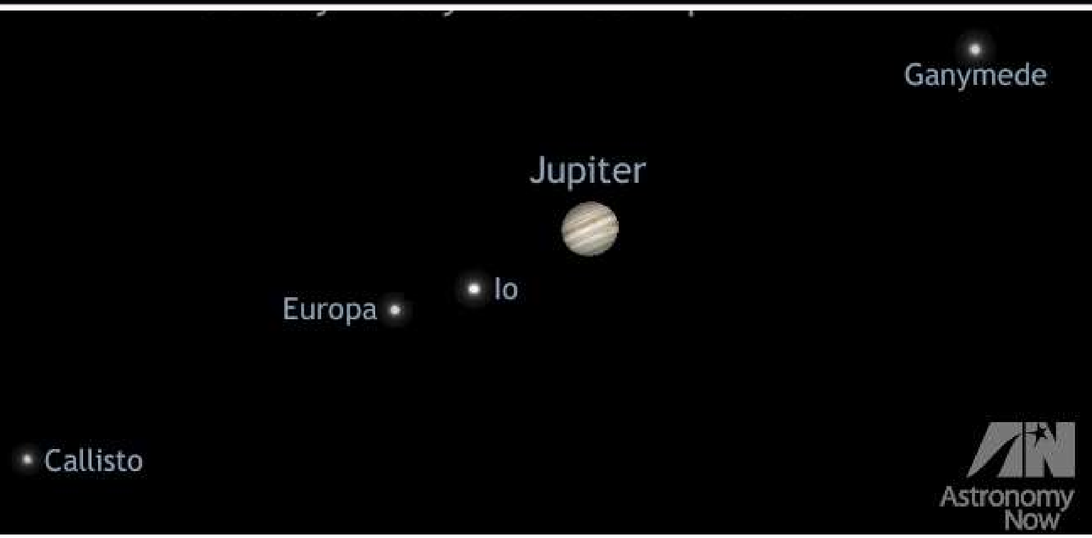
Not currently understood why, possibly due to Helium rain (differentiation)



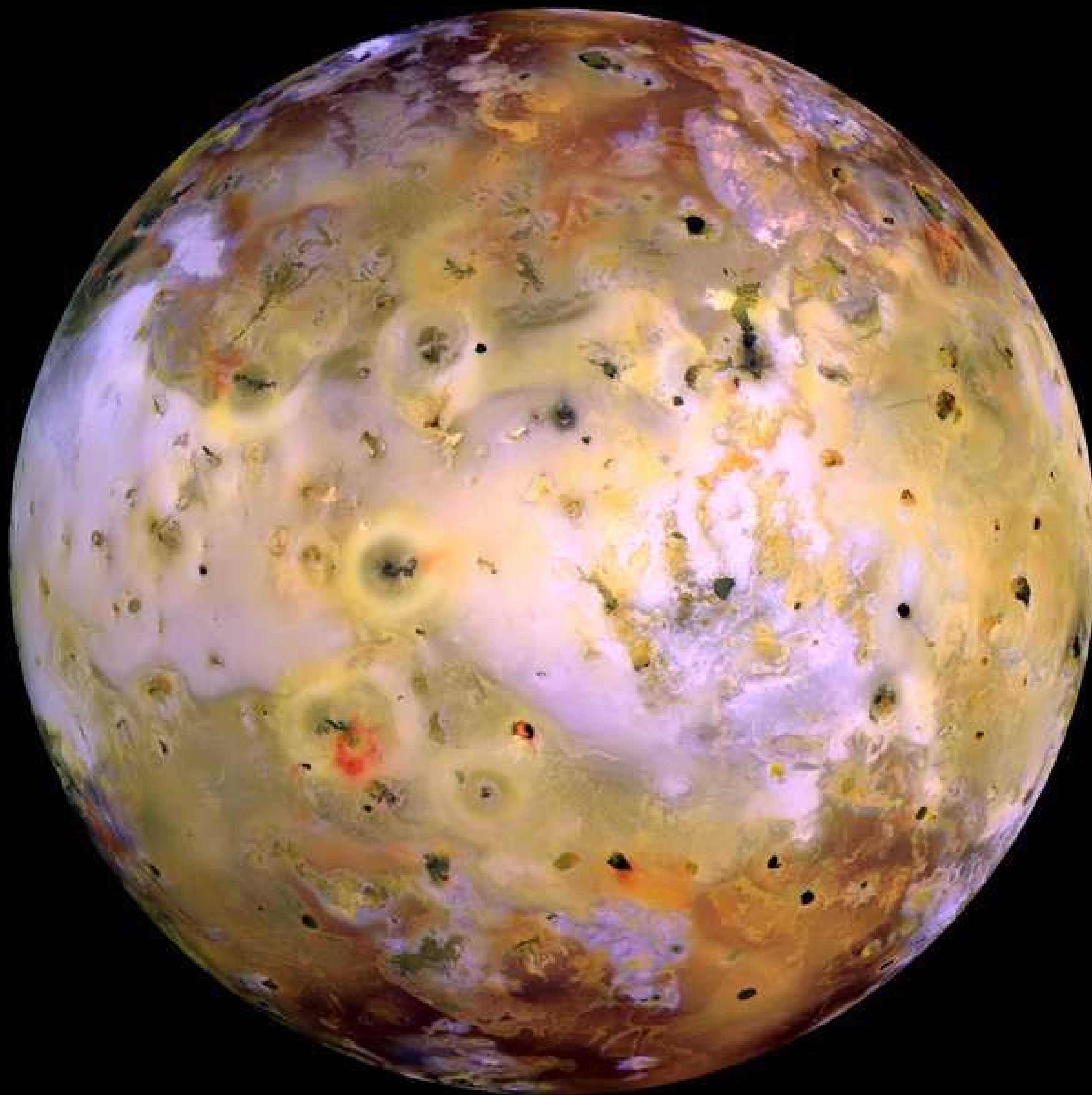
Medium and Large Moons

- Medium-sized moons (300–1500 km)
  - Geological activity in past
- Large moons (> 1500 km)
  - Ongoing geological activity
- Enough self-gravity to be spherical
- Have substantial amounts of ice
- Formed in orbit around jovian planets
- Circular orbits in same direction as planet rotation

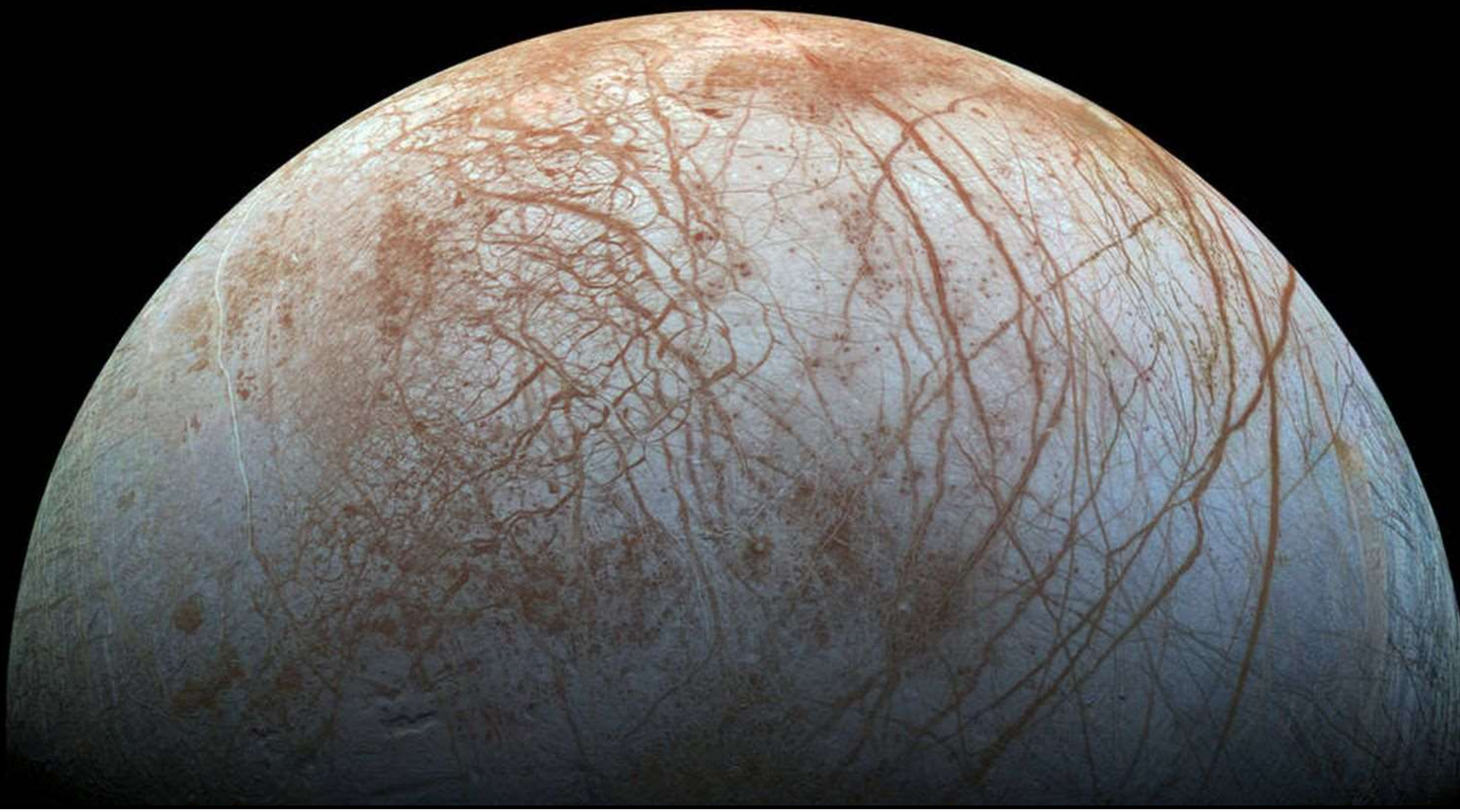
Jupiter's Galilean moons



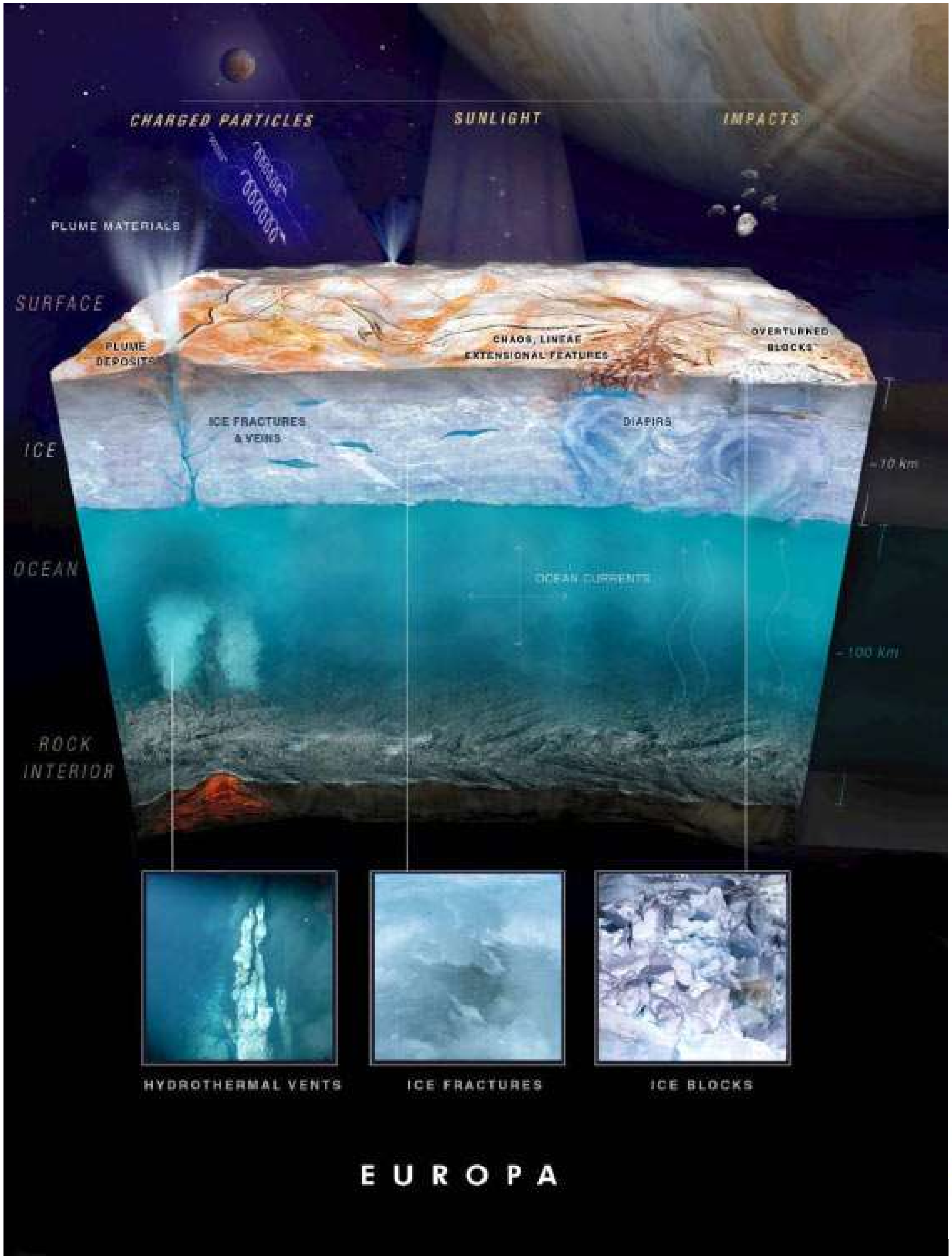
Io.

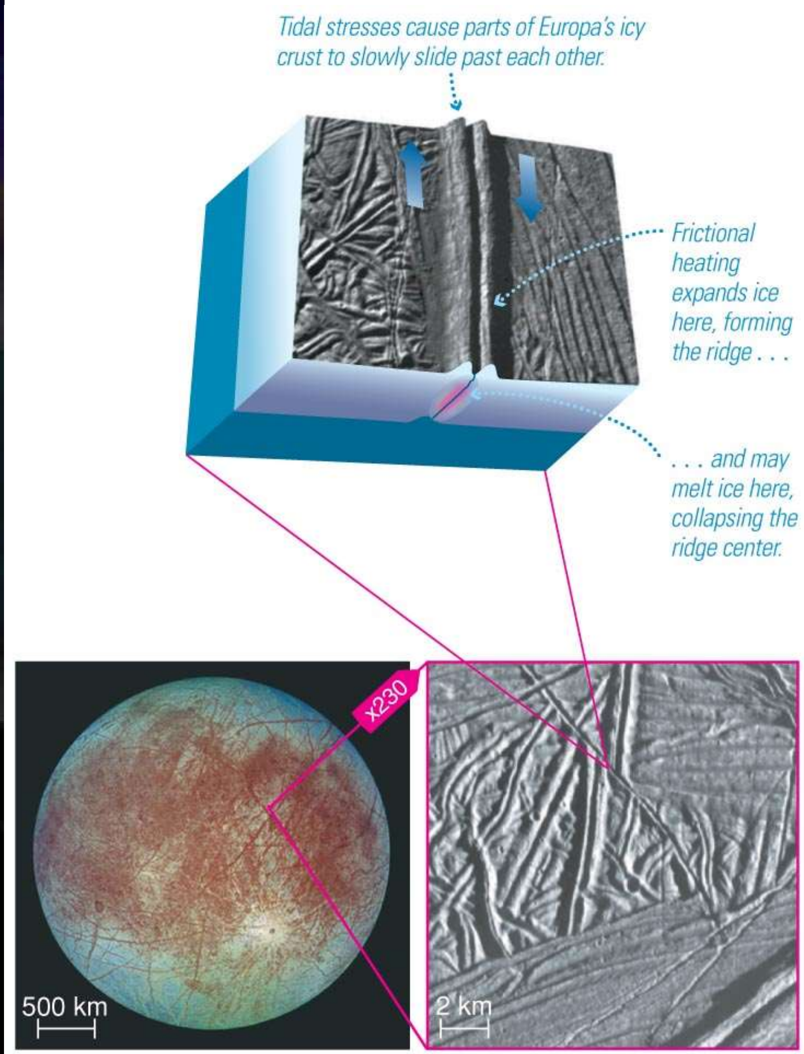


Jupiter’s 2nd Moon, Europa



Triple Bands

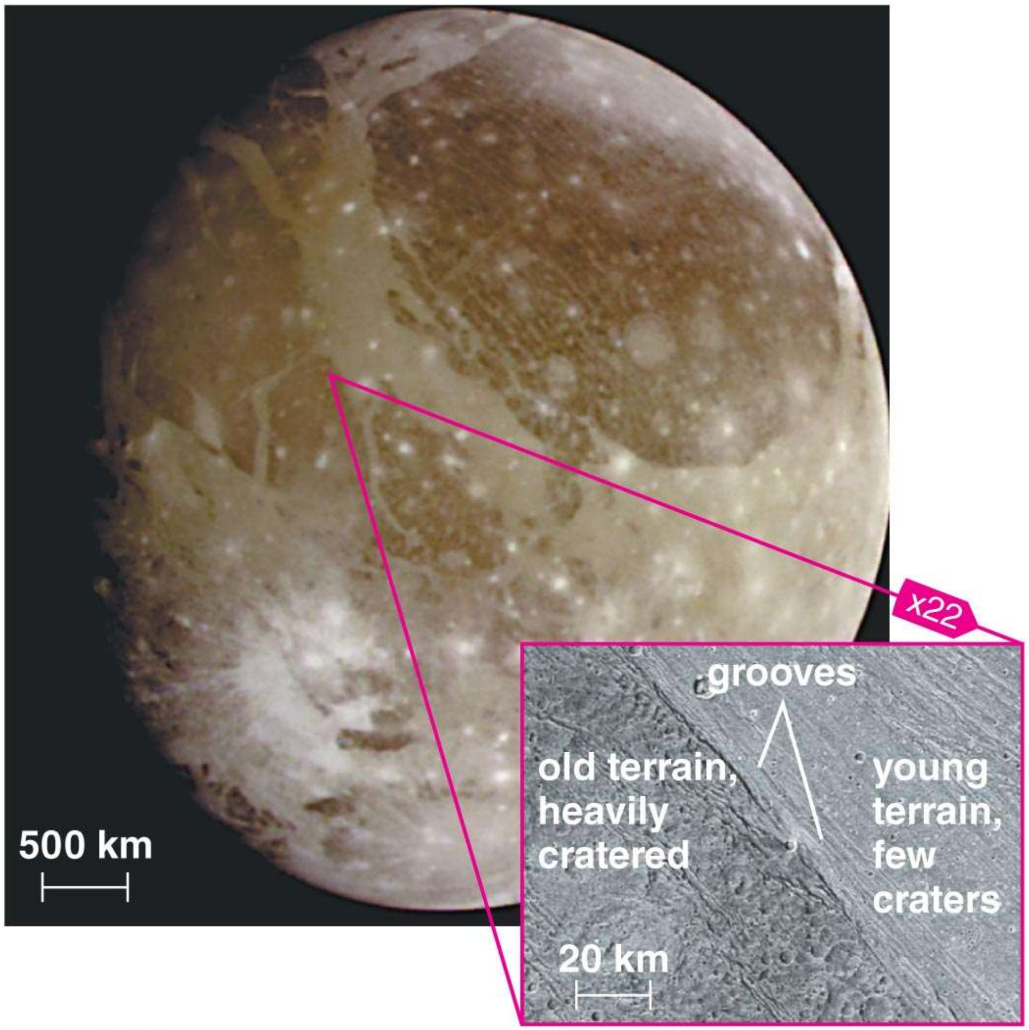




Europa's surface appears heavily cracked even from a distance.

Close-up photos show double-ridged cracks, best explained by an icy crust moving upon a soft or liquid layer below.

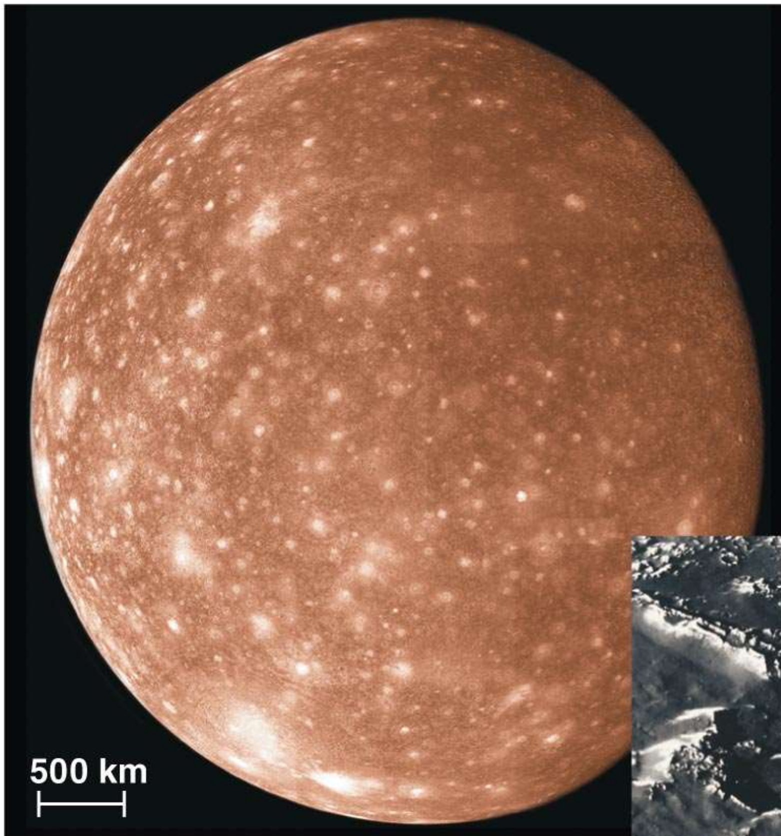
Jupiter's 3rd Moon - Ganymede



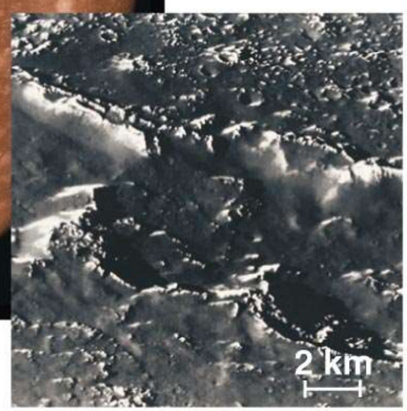
- Largest moon in the solar system
- Clear evidence of geological activity
- Tidal heating plus heat from radio-active decay?
- Has a reasonably strong Magnetosphere
- Planetary Dichotomy
  - Half of the surface is young
  - Half of the surface is old

New Slide

Jupiter's 4th Moon - Callisto



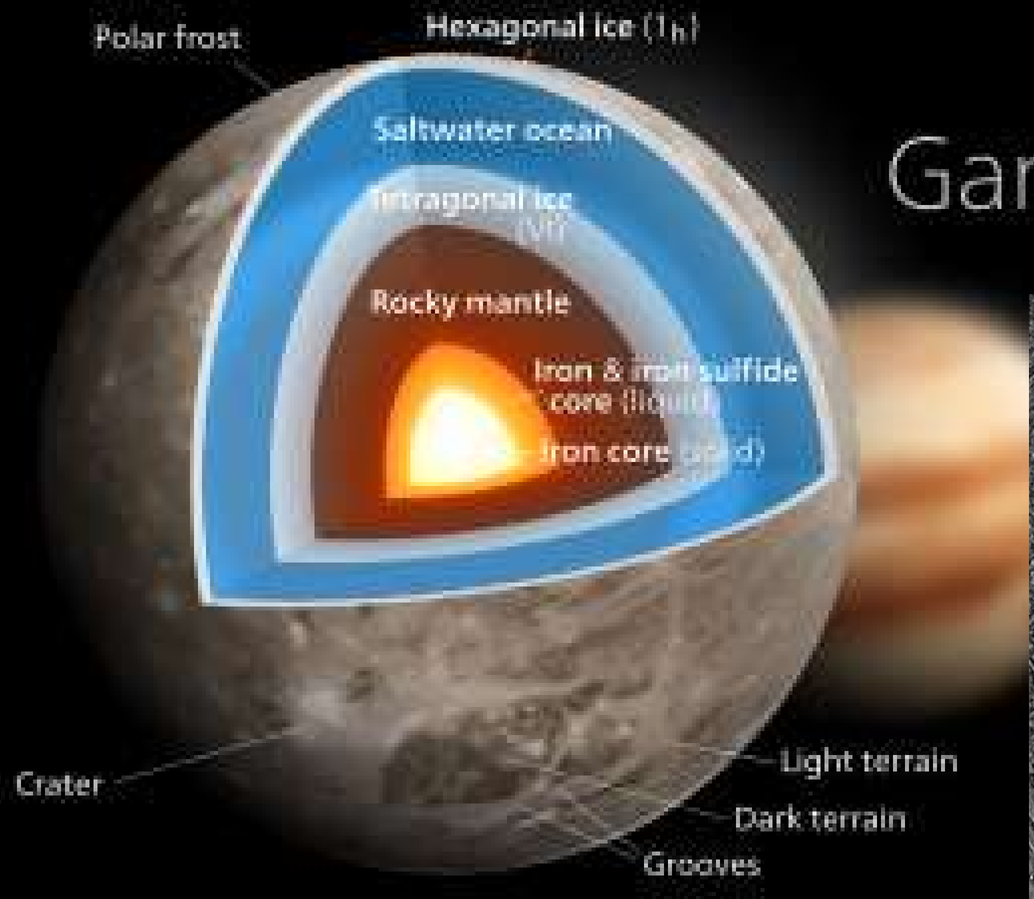
Callisto is heavily cratered, indicating an old surface that nonetheless may hide a deeply buried ocean.



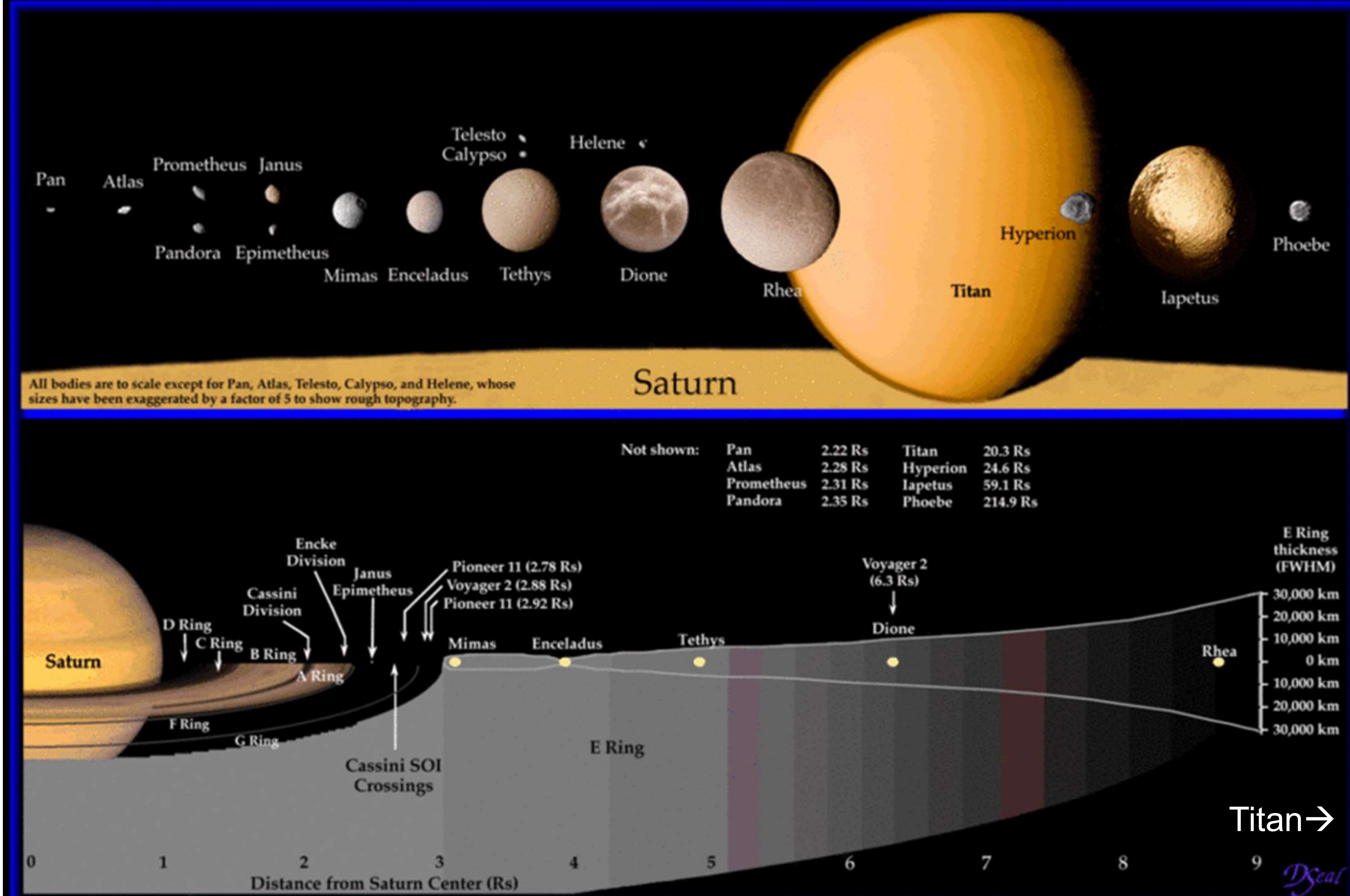
Close-up photo shows a dark powder overlaying the low areas of the surface.

- "Classic" cratered iceball (ancient surface)
- No tidal heating, no orbital resonances
- But it has magnetic field!?

Magnetosphere: Salty Ocean or Liquid Metallic Core?

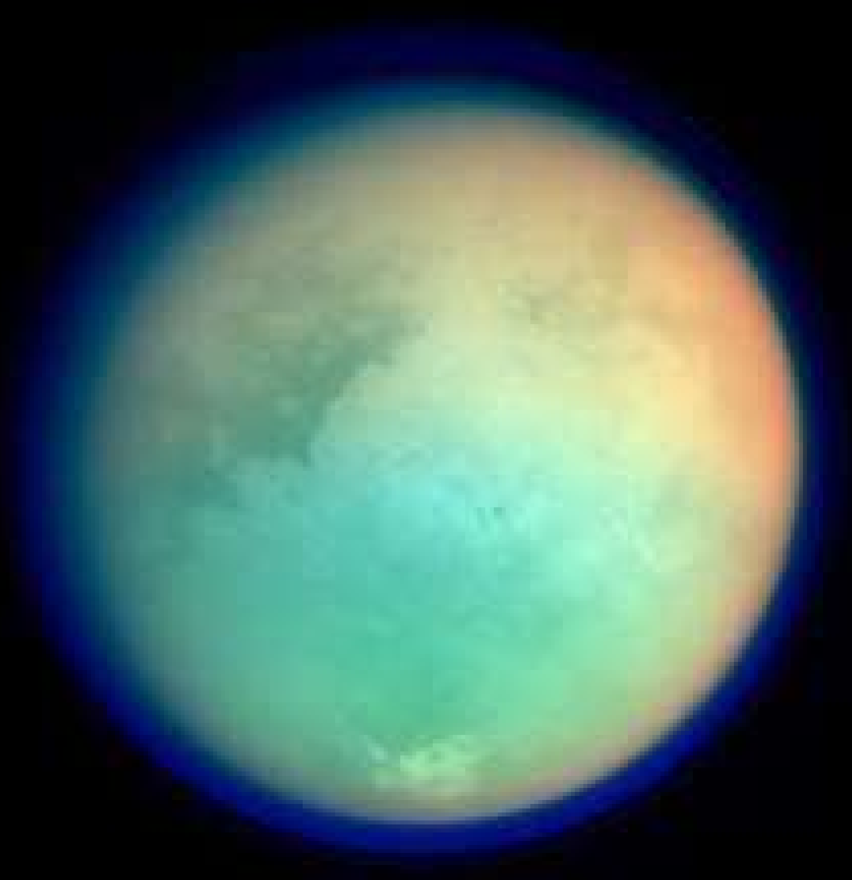


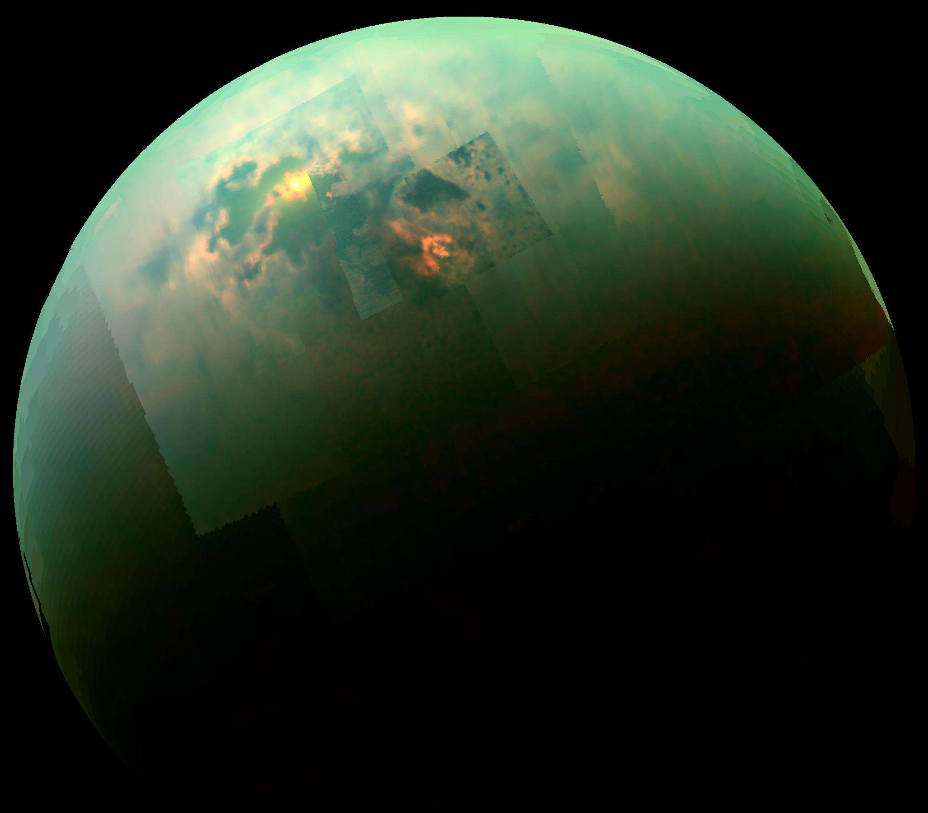
Saturn's Satellites and Ring Structure



This graphic is available in color if required.

Saturn's Largest Moon - Titan





Titan's Atmosphere

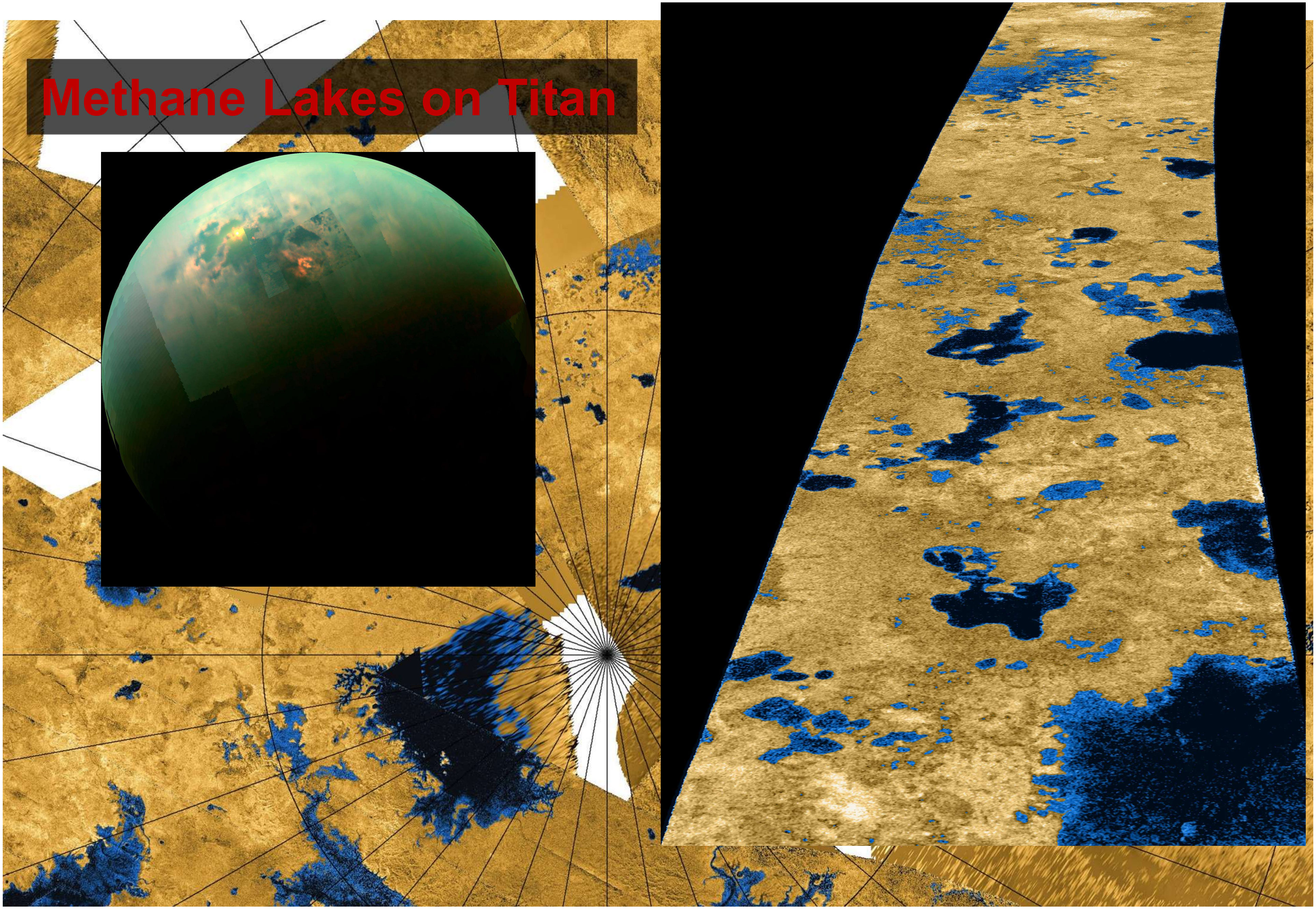
Titan is the only moon with a thick smoggy atmosphere (1.5× Earth)

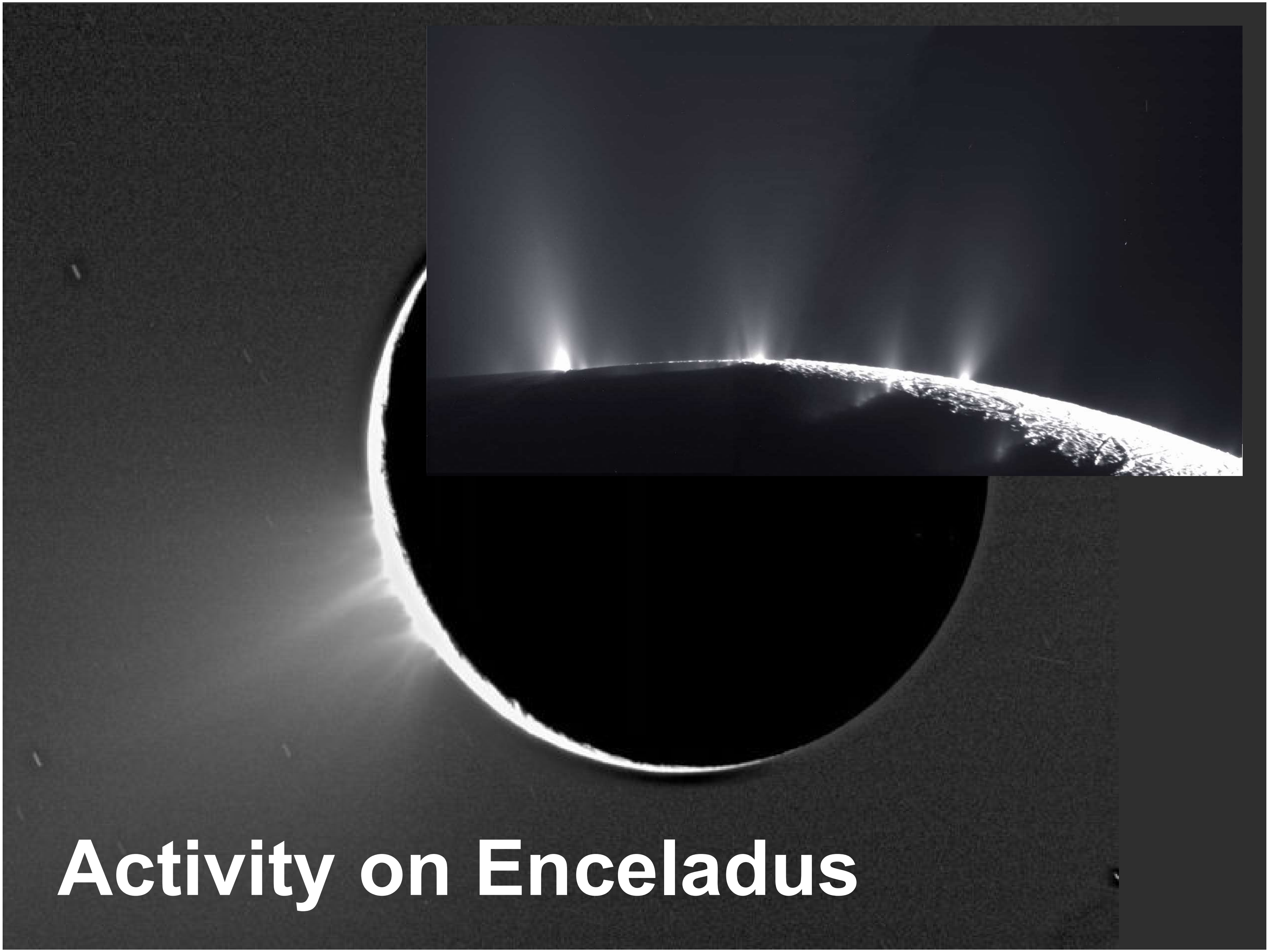
~95 % N_2 (similar to Earth)

Haze is caused by interaction of UV, solar wind and charged particles interacting with methane (CH_4) clouds to generate larger hydrocarbons such as ethane (C_2H_6), and larger species that contribute to the smog

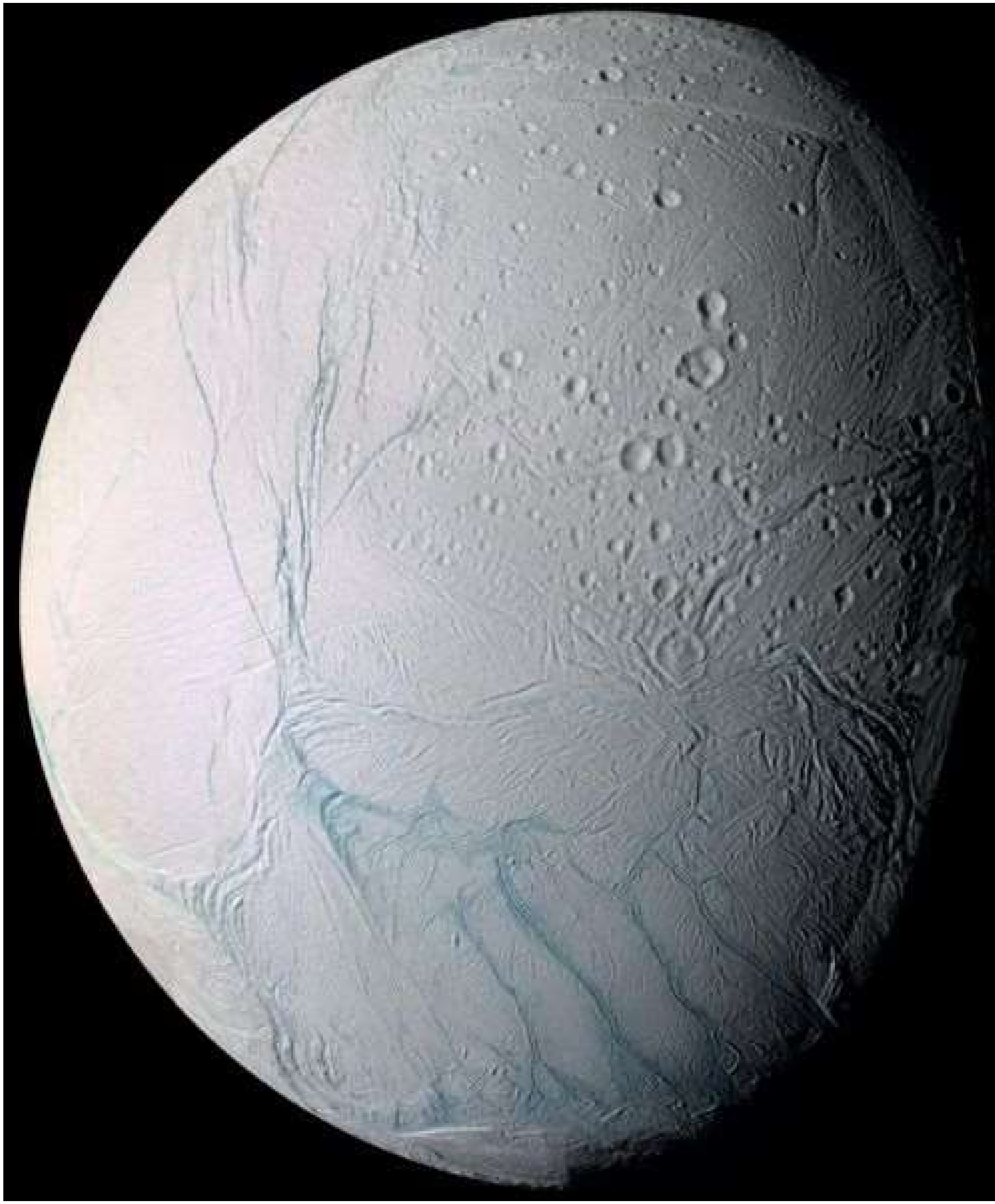
Clouds indicate rain and lakes may exist on Titan

Methane Lakes on Titan





Activity on Enceladus

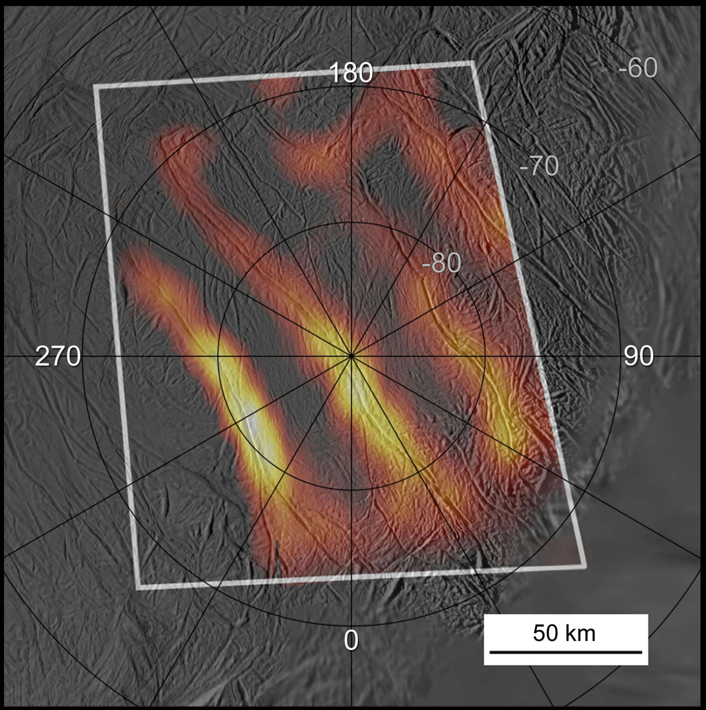


Enceladus

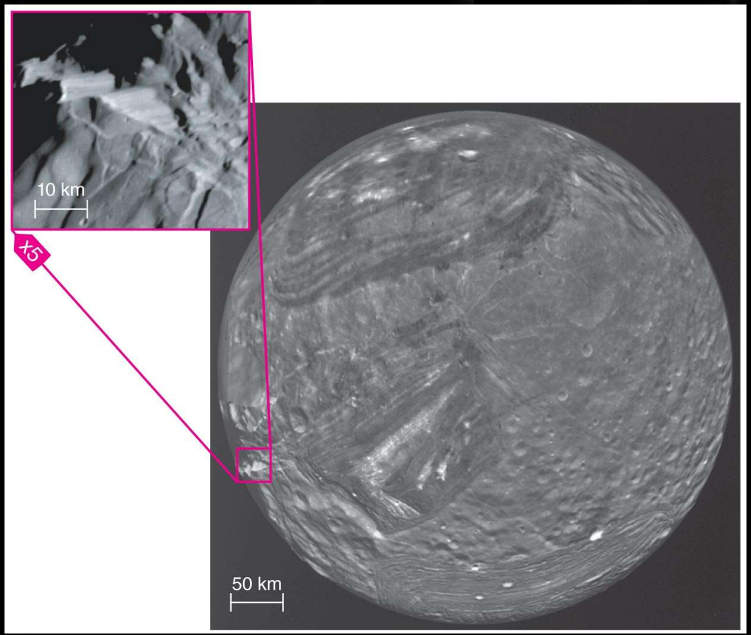
About the size of England

Seems to have geological activity…

"Tiger Stripes" Region



Close-up of Miranda



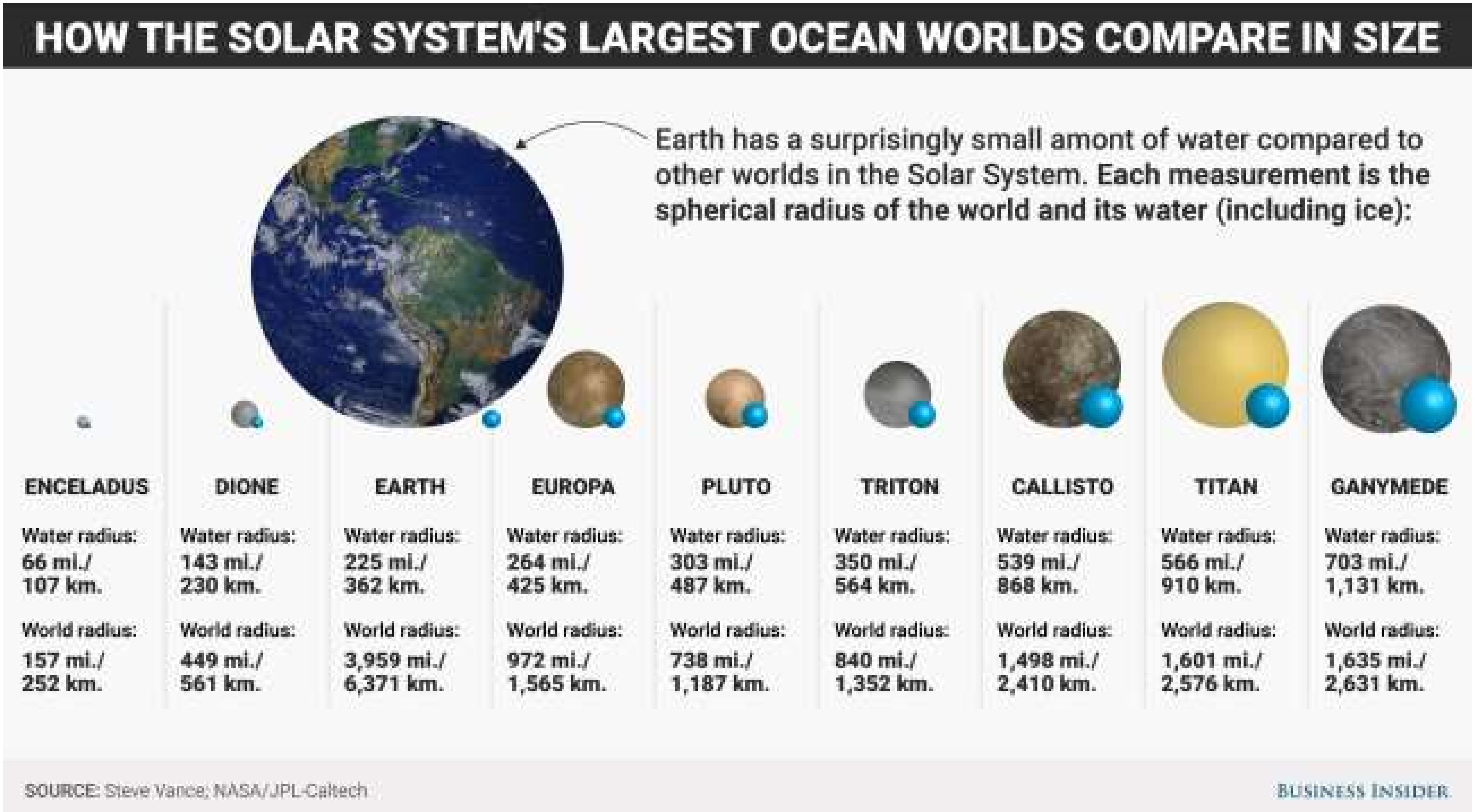
Moons of Uranus

All seem to show evidence of tectonic activity and few craters

No mission to Uranus currently planed (only have images from Voyager 2 flyby!)

Neptune only has 1 large moon

Icy Water Worlds
Many have more water than Earth!



Geological activity on small moons

- Hot interiors are necessary for geological activity.
- Tidal heating is not a major energy source for rocky planets, but it is for icy satellites…
- In the case of Io, tidal heating is large enough to melt rocky materials.
- *Ice deforms more easily than solid rock, so less internal heat is required, and smaller objects can be geologically active*

What have we covered, and what is next?

Chapter 8: Jovian Planet Systems

8.1. A Different Kind of Planet

- What are Jovian Planets made of?
- What is the weather like on Jovian planets?

8.2. A Wealth of Worlds: Satellites of Ice and Rock

- What kinds of moon orbit the Jovian Planets?
- Why are Jupiter's Galilean moons geologically active?
- What geological activity do we see on Titan and other moons?
- Why are Jovian moons more geologically active than small rocky planets?

8.3. Jovian Planet Rings

- What are Saturn's rings like?
- Why do Jovian planets have rings?

iClicker Question

Question: Jupiter is about three times as massive as Saturn, but only slightly larger. Why?

A. It is made of stronger material.
B. It is made of weaker material.
C. Adding mass increases gravity and compresses the gases in the atmosphere.
D. Because they have different compositions.
E. None of the above.

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Question: Titan is the only moon with a thick atmosphere, and its surface:

A. Has never been seen.
B. Has been seen by infrared light and spacecraft
C. Is warmed by a greenhouse effect
D. Has oceans of methane and ethane
E. All except a

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Mid-Term #1 Solutions

If we say that the Sun is “in” the constellation Taurus, then it mans that

A. Taurus is directly behind the Earth, away from the Sun, so visible at midnight.

B. Taurus is directly behind the Sun, so not visible during the day.

C. The constellation Taurus orbits the Sun for one Month.

D. The Sun is physically moving through the stars of the constellation Taurus.

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If we say that the Sun is “in” the constellation Taurus, then it mans that

A. Taurus is directly behind the Earth, away from the Sun, so visible at midnight.

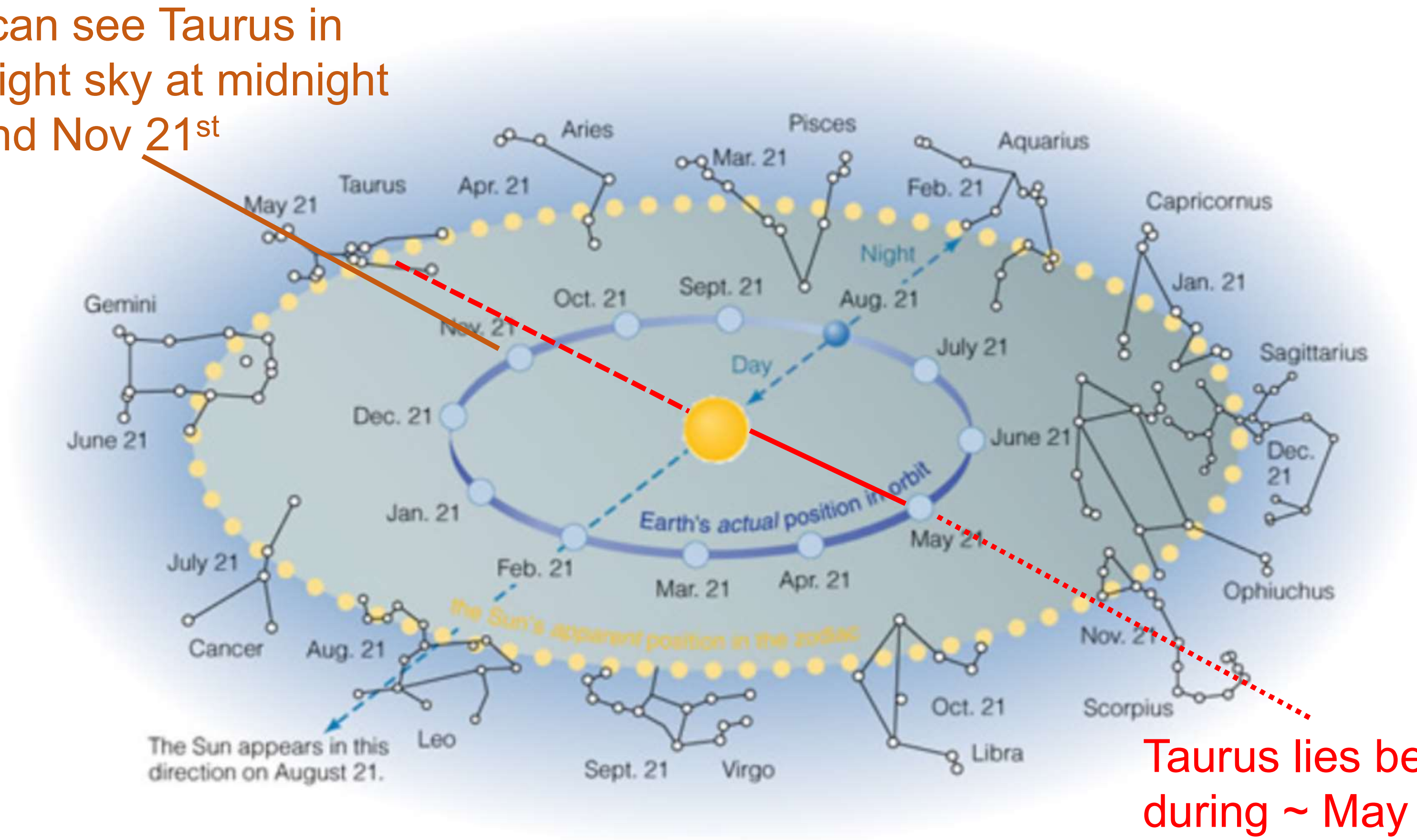
B. Taurus is directly behind the Sun, so not visible during the day. (~64% correct)

C. The constellation Taurus orbits the Sun for one Month.

D. The Sun is physically moving through the stars of the constellation Taurus.

If we say that the Sun is "in" the constellation Taurus, then it mans that…

You can see Taurus in the night sky at midnight around Nov 21st



Taurus lies behind the Sun during ~ May 21st so is "in" Taurus during this time

Taurus birthday Apr 20 – May 20 (remember, these are ~ 1 month off due to *precession*).

Mid-Term #1 Solutions

To calculate the masses of stars in a binary system, we must measure their _________

A. Spectral types and distance from Earth.
B. Orbital period and average orbital distance.
C. Absolute magnitudes and luminosities.
D. Luminosities and distance from Earth.

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Hint: It's the only one we have actually covered in class…

Mid-Term #1 Solutions

To calculate the masses of stars in a binary system, we must measure their _________

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Kepler's 3rd Law:

More distant planets orbit the Sun at slower average speeds, according to $p^2 = a^3$

Where p = orbital period, in years, a = the average distance from the Sun, in AU

In words: ***"The square of the orbital period of a planet (in years) is directly proportional to the cube of the semi-major axis of its orbit (in AU)."***

Newton's Version of Kepler's 3rd Law

$$p^2 = \frac{4\pi^2}{G(M_1 + M_2)} a^3$$

p = orbital period, in seconds

a = average orbital distance (between centers), in meters

$(M_1 + M_2)$ = sum of object masses, in kg

G is the gravitational constant, $6.67 \times 10^{-11} \frac{m^3}{kg \times s^2}$

Example: Use the fact that Earth orbits the Sun at an average distance of 1 AU over the period of 1 year to calculate the Sun's mass.

$$p_{Earth}^2 = \frac{4\pi^2}{G(M_{Sun} + M_{Earth})} a_{Earth}^3$$

$M_{Sun} + M_{Earth} \sim M_{Sun}$ ($> 3 \times 10^6\ M_{Earth}$)

1 AU = 1.5×10^{11} m

1 year = 3.15×10^7 seconds

Substitute:

$$p_{Earth}^2 \sim \frac{4\pi^2}{G \times M_{Sun}} a_{Earth}^3$$

Rearrange:

$$M_{Sun} \sim \frac{4\pi^2}{G \times p_{Earth}^2} a_{Earth}^3$$

Evaluate:

$$M_{Sun} \sim \frac{4\pi^2}{\left(6.67 \times 10^{-11} \frac{m^3}{kg \times s^2}\right) \times (3.15 \times 10^7\ s)^2} \times (1.5 \times 10^{11} m)^3 \quad \sim 2.0 \times 10^{30}\ kg$$

What have we covered, and what is next?

Chapter 9: Asteroids, Comets, and Dwarf Planets

9.1. Classifying Small Bodies

- How do we classify small bodies?

9.2. Asteroids

- What are asteroids like?
- What do meteorites tell us about asteroids and the early Solar System?
- Why is there an asteroid belt?

9.3. Comets

- Why do comets grow tails?
- Where do comets come from?

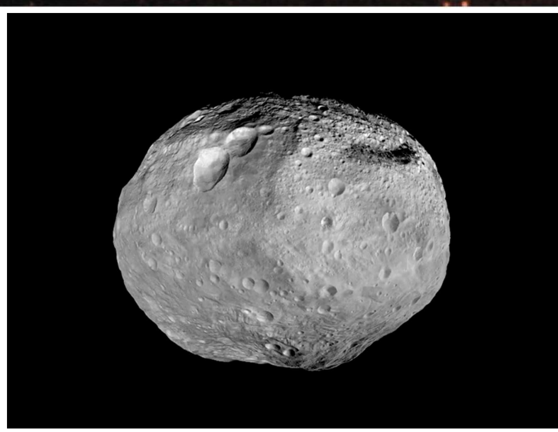
9.4. Pluto and the Kuiper Belt

- What is Pluto like?
- What do we know about other Kuiper Belt Objects

9.5. Cosmic Collisions: Small Bodies Versus the Planets

- Did an impact kill the dinosaurs?
- How great is the impact risk today?
- How do the Jovian planets affect impact rates and life on Earth?

Classification of Small Bodies
1. Asteroids



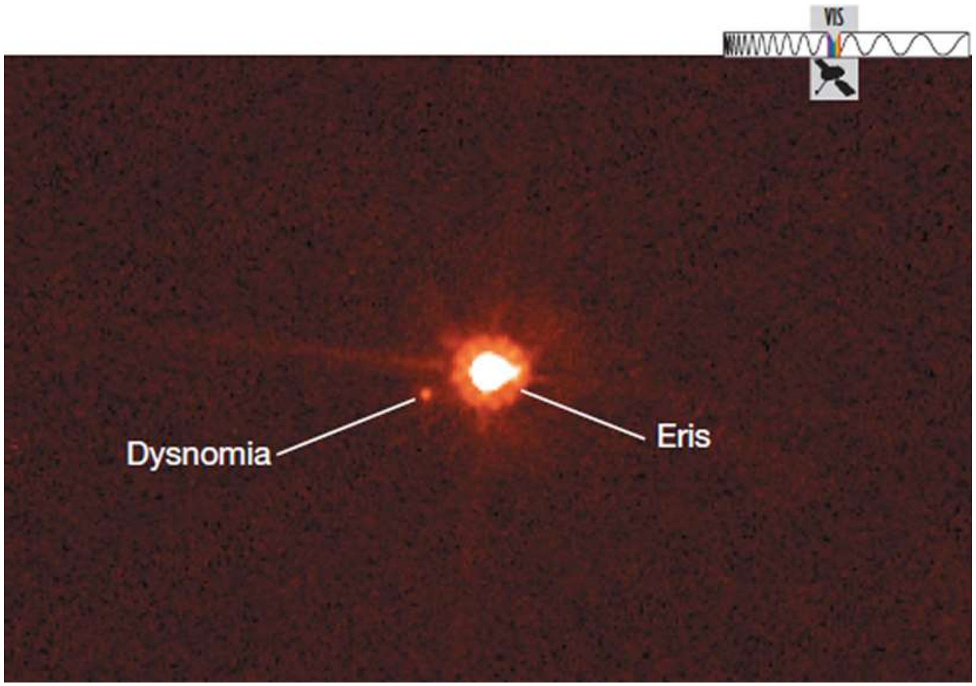
- Rocky, inner-solar system remnants.
- Asteroids leave trails in long-exposure images because of their orbital motion around the Sun.

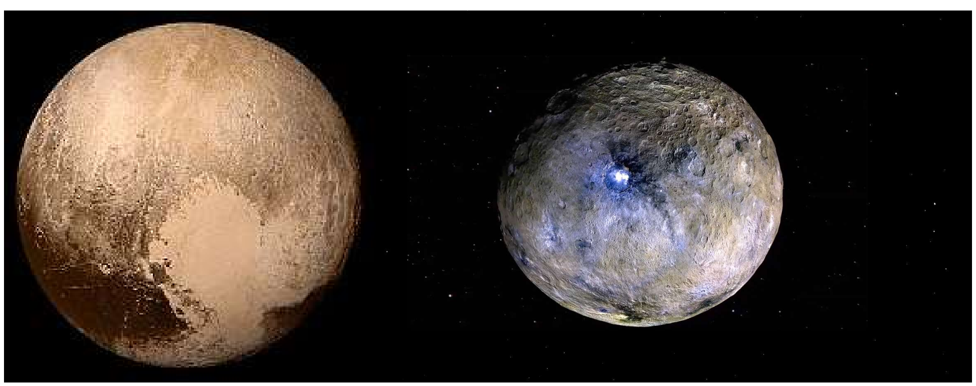
Classification of Small Bodies
2. Comets (or comet reservoirs)

Comet Hale-Bopp (1997)

- Icy, outer-solar system remnants.
- Though comets spend most of their time far from the Sun, they are best known for their spectacular appearance when they wander into the inner solar system.
- Typically only designated as 'comets' once active (i.e. have a tail)

Classification of Small Bodies
3. Dwarf Planets





- "Small bodies" that are large enough to be round.
- The discovery of Eris led to a debate about definitions and the eventual adoption of the dwarf planet category.
- Pluto (left) and Ceres (right) are the most well-known

Meteors, Meteoroids & Meteorites

Fukang meteorite (China)

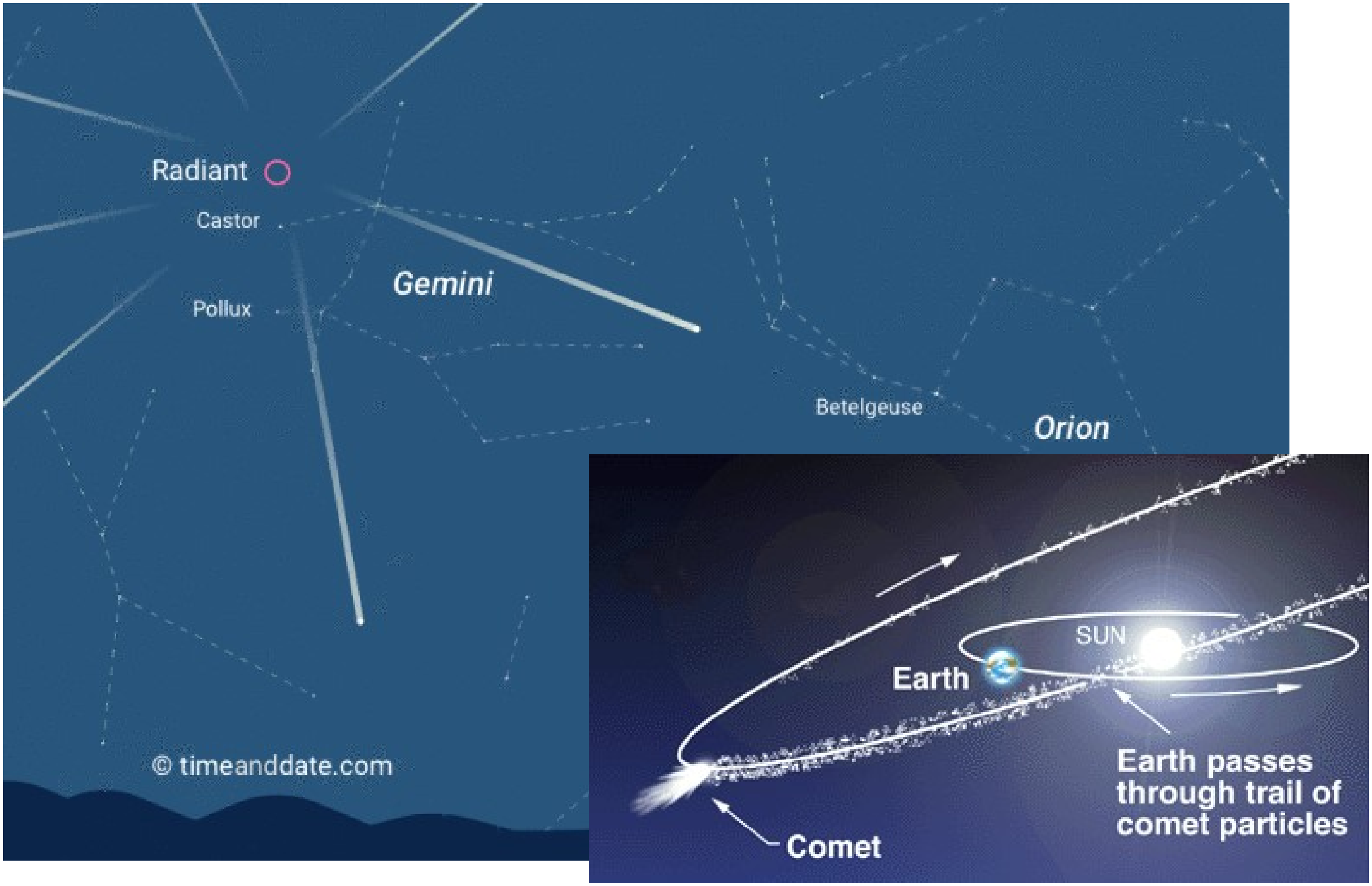
- A **meteor** is the flash of light produced as a small object enters the atmosphere. *"A thing in the air"*

  Shooting stars, meteor showers, etc.

- A **meteorite** is an object that survives its trip through the atmosphere and ends up on the ground. *"associated with meteors"*
- A **meteoroid** is the same object traveling in space – these are generally what astronauts are concerned about.

All of these may originate from asteroids, comets, the Moon, Mars, or even other bodies

Meteor Showers



Meteorite Falls

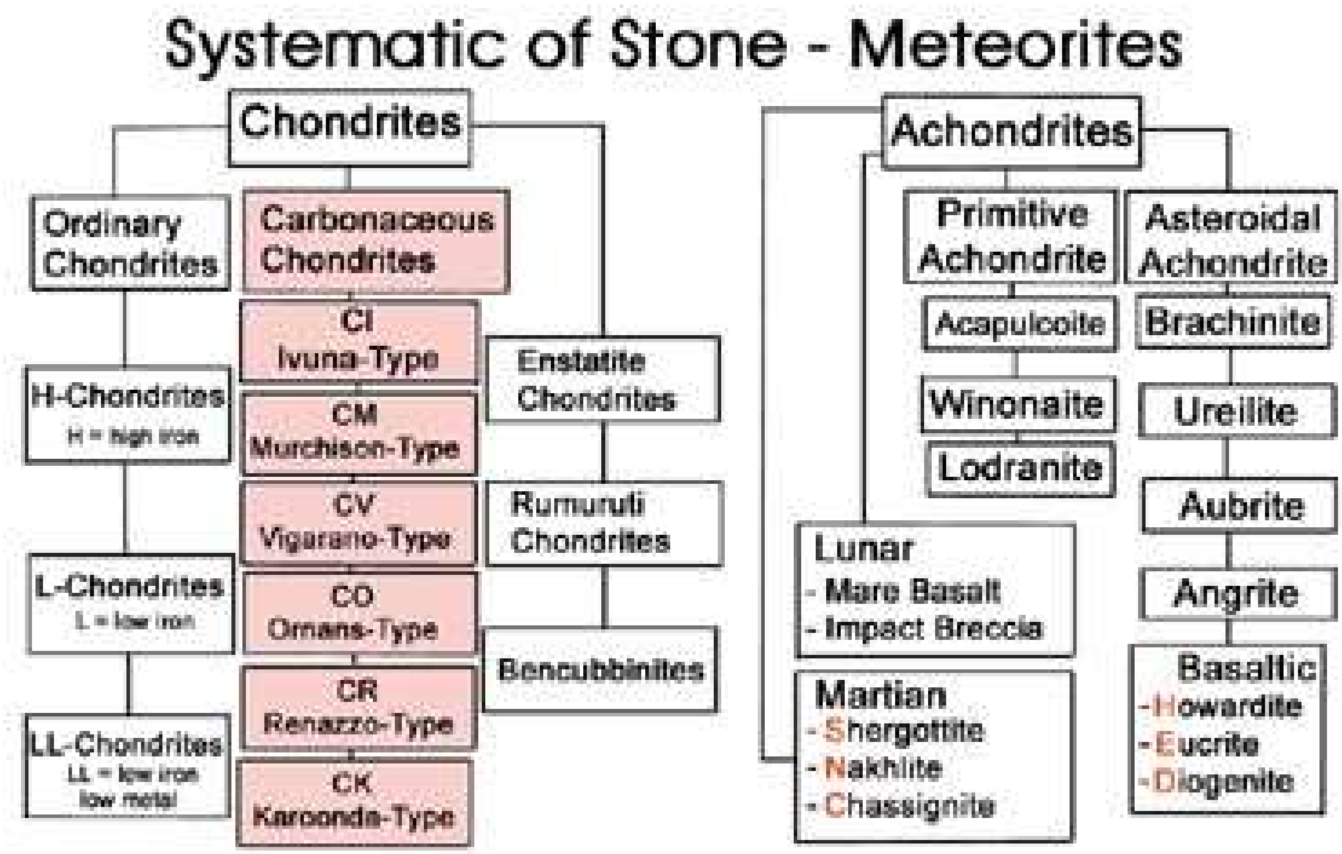
- Very rarely occur, can be dangerous.

Chelyabinsk meteor (Russia 2013)

How to Identify a Meteorite

- Usually surprisingly heavy – more dense than most terrestrial Rocks (which have undergone differentiation)
- Has a fusion crust from being burnt traveling through the atmosphere
    - May also have aerodynamic pits (lower picture)
- If stony or carbonaceous will have round 'chondrules' in it, and most will be covered with shiny metal flakes
- Often Magnetic

There are Many Classes of Meteorite



Some are primitive, some are processed.

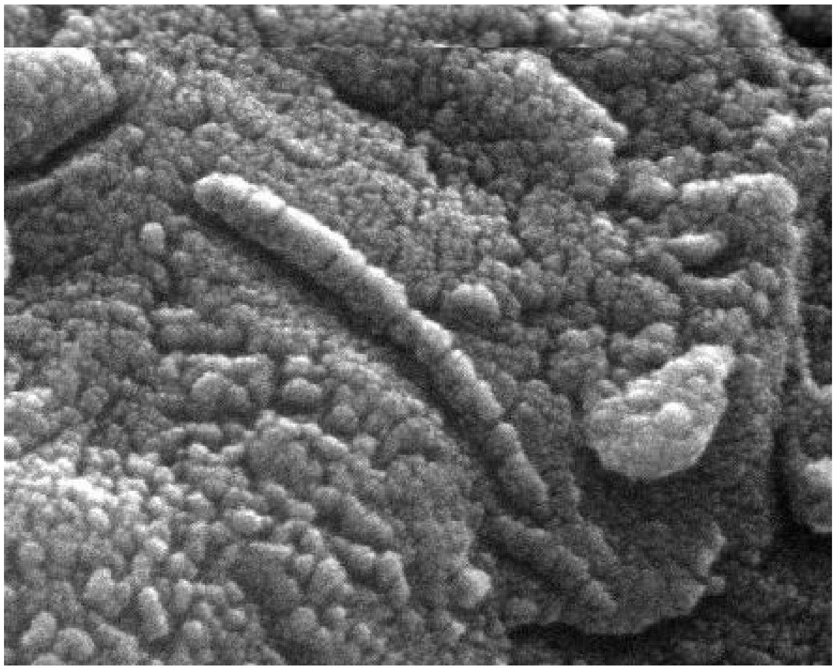
How do we know ALH84001 is from Mars?

This is Alan Hills 84001. The most famous Martian Meteorite. It was found in Antarctica in 1984 and thought to have originated from Mars ~4 billion years ago and only landed on Earth about 13,000 years ago.

But - How do we know it was from Mars??

There are trapped bubbles of gas inside and these match the composition and isotopic ratios of Mars!

Evidence of Life on Mars?



ALH84001 under a microscope reveals structures very similar to microfossils found 3.5 billion years ago on Earth (right).

These are made of magnetite, however.

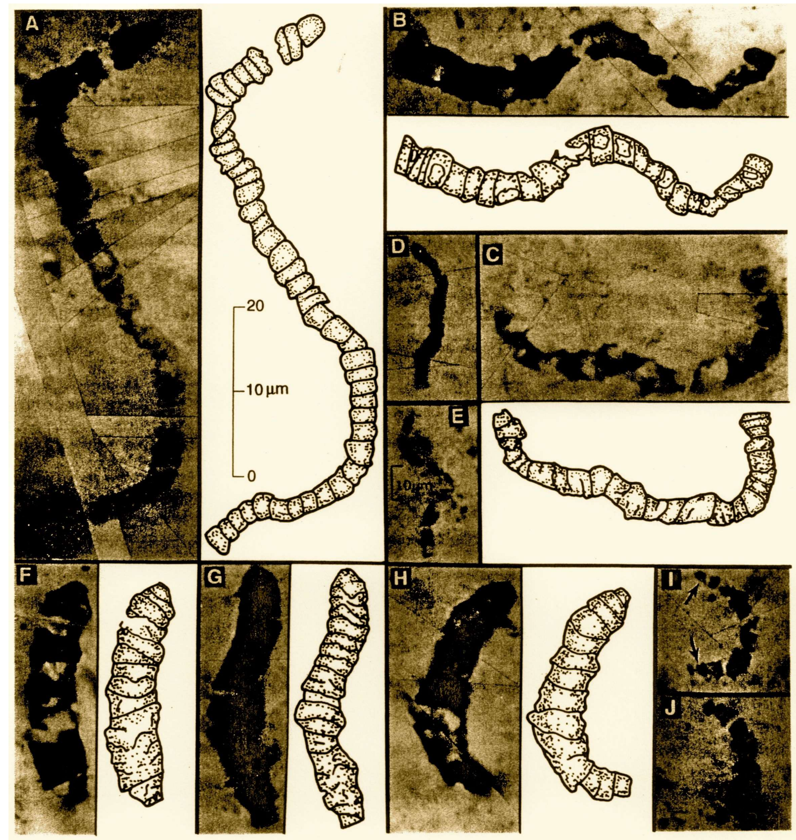


Fig. 4. Carbonaceous microfossils (with interpretive drawings) shown in thin sections of the Early Archean Apex chert of Western Australia. Magnification of (D, E, I, and J) denoted by scale in (E); magnification of all other parts shown by scale in (A). (A, B, C, and D) and (F, G, H, and I) show photomontages of the sinuous three-dimensional microfossils. (**A**, **B**, **C**, **D**, and **E**) *Primaevifilum amoenum* Schopf, 1992 (A, holotype) (*3*). (**F**, **G**, **H**, **I**, and **J**) *P. conicoterminatum* Schopf, 1992 (H, holotype) (*3*); arrows in (I) point to conical terminal cells.

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Carbonaceous Chondrites

- Up to a few % carbon (makes them dark)
- Have small round chondrules
- Mostly consist of a phyllosilicate (clay matrix

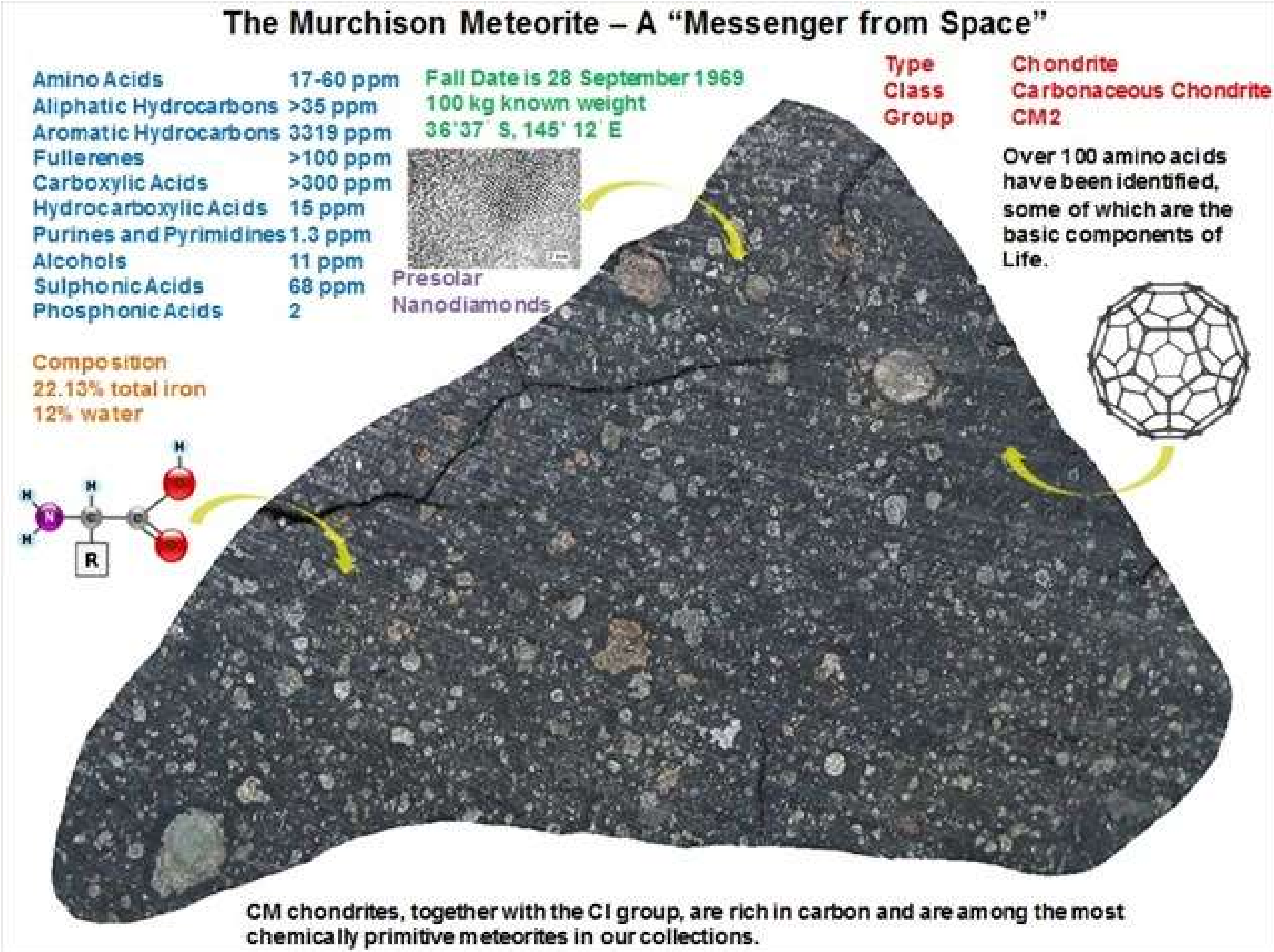
Represent only ~ 4% of falls

Most Famous are the Allende and Murchison meteorites…

Murchison ~ 100 kg fell in Australia in 1969. Allende same year > 2 tons

Over 8000 organic compounds have been identified in Murchison, including:

- Over 100 amino acids
- Nucleobases
- Polycyclic aromatic hydrocarbons
- Carboxylic acids
- Fatty lipids
- Hydroxy acids


The Murchison Meteorite – A "Messenger from Space"
Amino Acids 17-60 ppm
Aliphatic Hydrocarbons >35 ppm
Aromatic Hydrocarbons 3319 ppm
Fullerenes >100 ppm
Carboxylic Acids >300 ppm
Hydrocarboxylic Acids 15 ppm
Purines and Pyrimidines 1.3 ppm
Alcohols 11 ppm
Sulphonic Acids 68 ppm
Phosphonic Acids 2
Fall Date is 28 September 1969
100 kg known weight
36°37′ S, 145° 12′ E
Presolar
Nanodiamonds
Type Chondrite
Class Carbonaceous Chondrite
Group CM2
Over 100 amino acids have been identified, some of which are the basic components of Life.
Composition
22.13% total iron
12% water
H
H
N
H
C
C
R
H
CM chondrites, together with the CI group, are rich in carbon and are among the most chemically primitive meteorites in our collections.

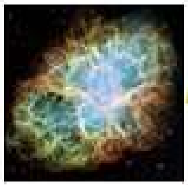
The Allende Meteorite – A "Messenger from Space"

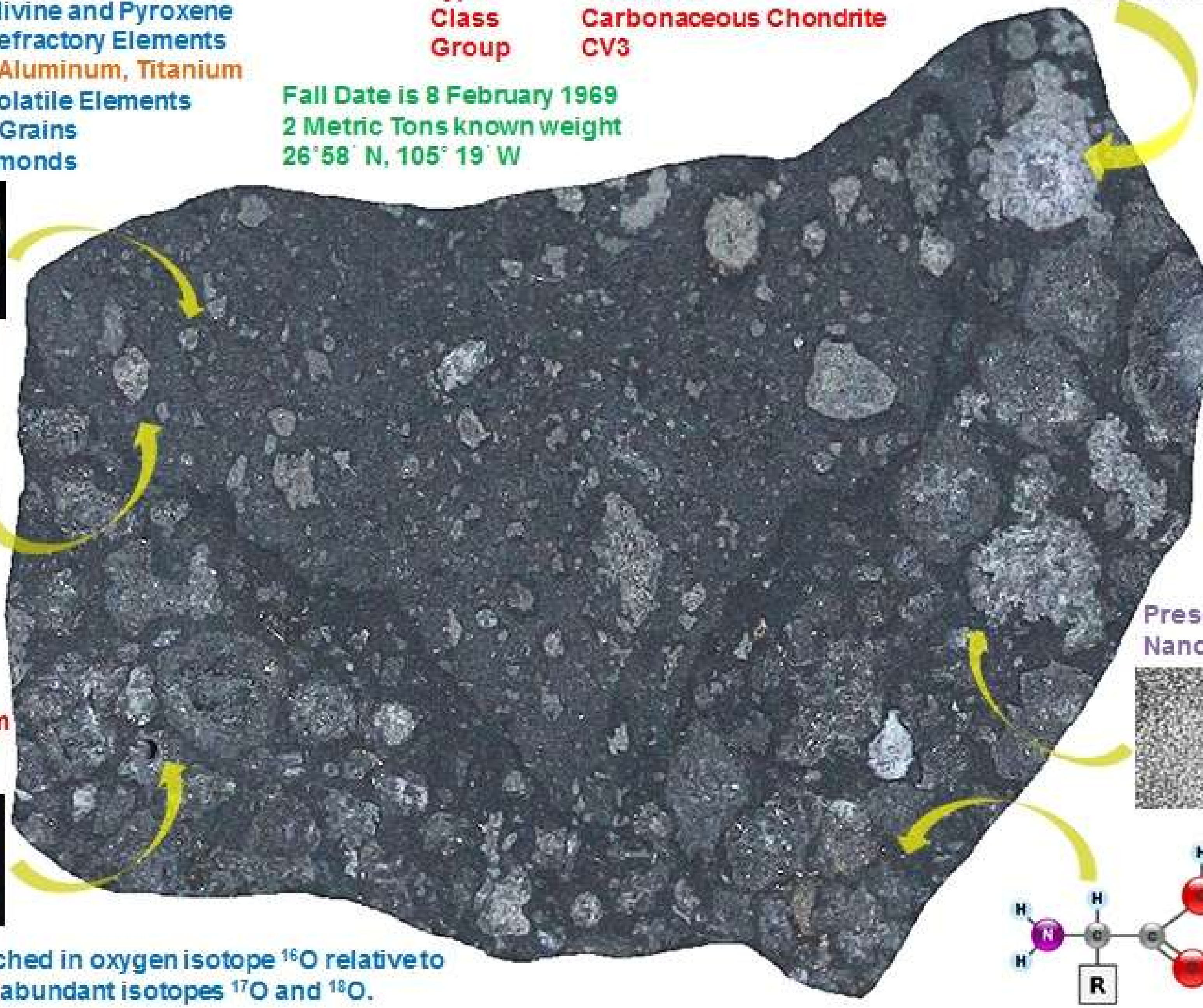
Matrix and Chondrules
Mostly Olivine and Pyroxene
Rich in Refractory Elements
Calcium, Aluminum, Titanium
Poor in Volatile Elements
Presolar Grains
Microdiamonds

Type	Chondrite
Class	Carbonaceous Chondrite
Group	CV3

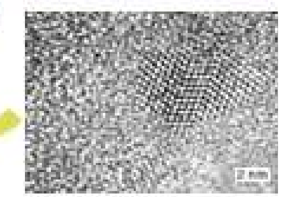
Fall Date is 8 February 1969
2 Metric Tons known weight
26˚58΄ N, 105˚ 19΄ W

Calcium-Aluminum Inclusions (CAI)





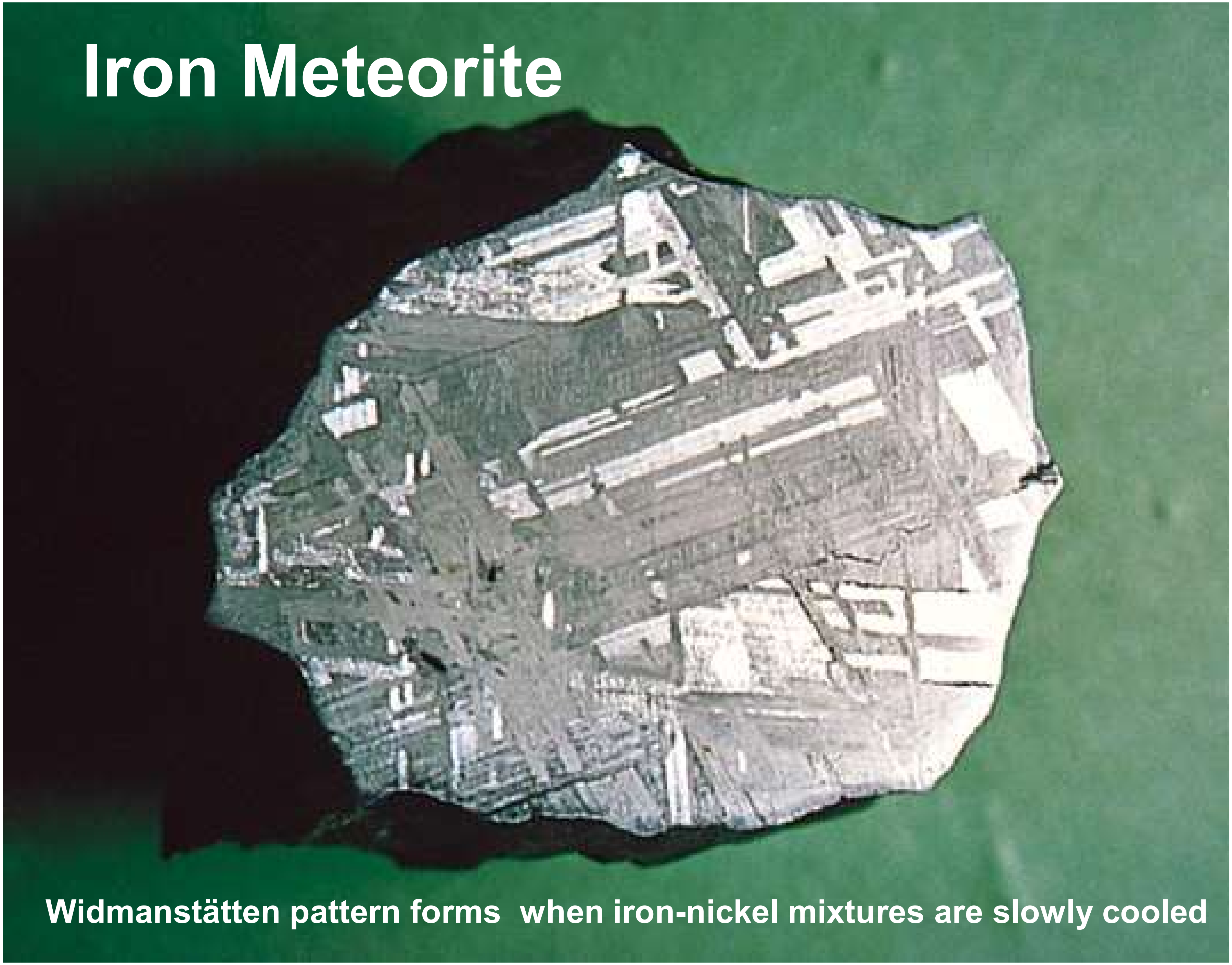
Presolar Nanodiamonds



Presolar Grains from Red Giant Stars

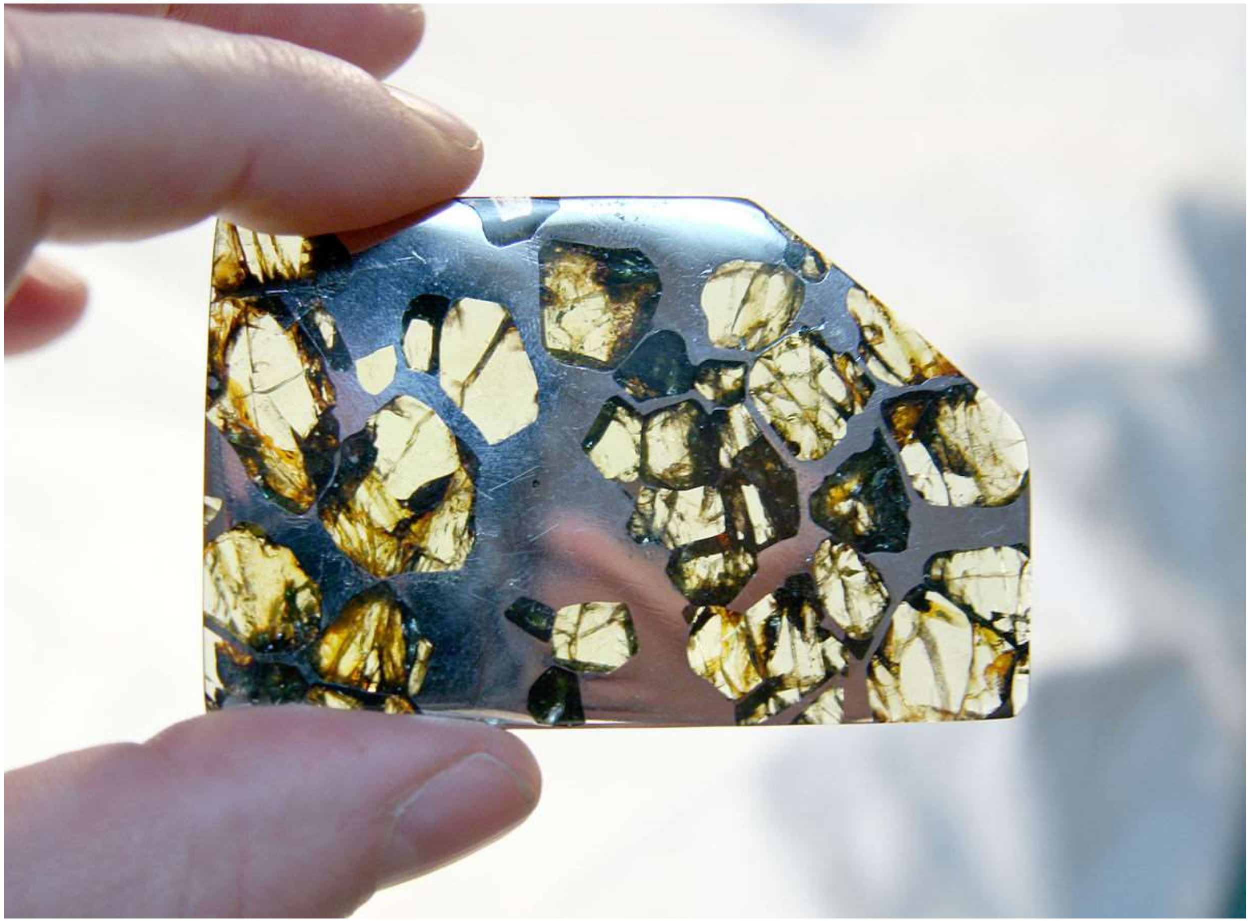
Enriched in oxygen isotope ^{16}O relative to less abundant isotopes ^{17}O and ^{18}O.

Stony Meteorite


Iron Meteorite
Widmanstätten pattern forms when iron-nickel mixtures are slowly cooled

HED Pallasites (mostly from Vesta)

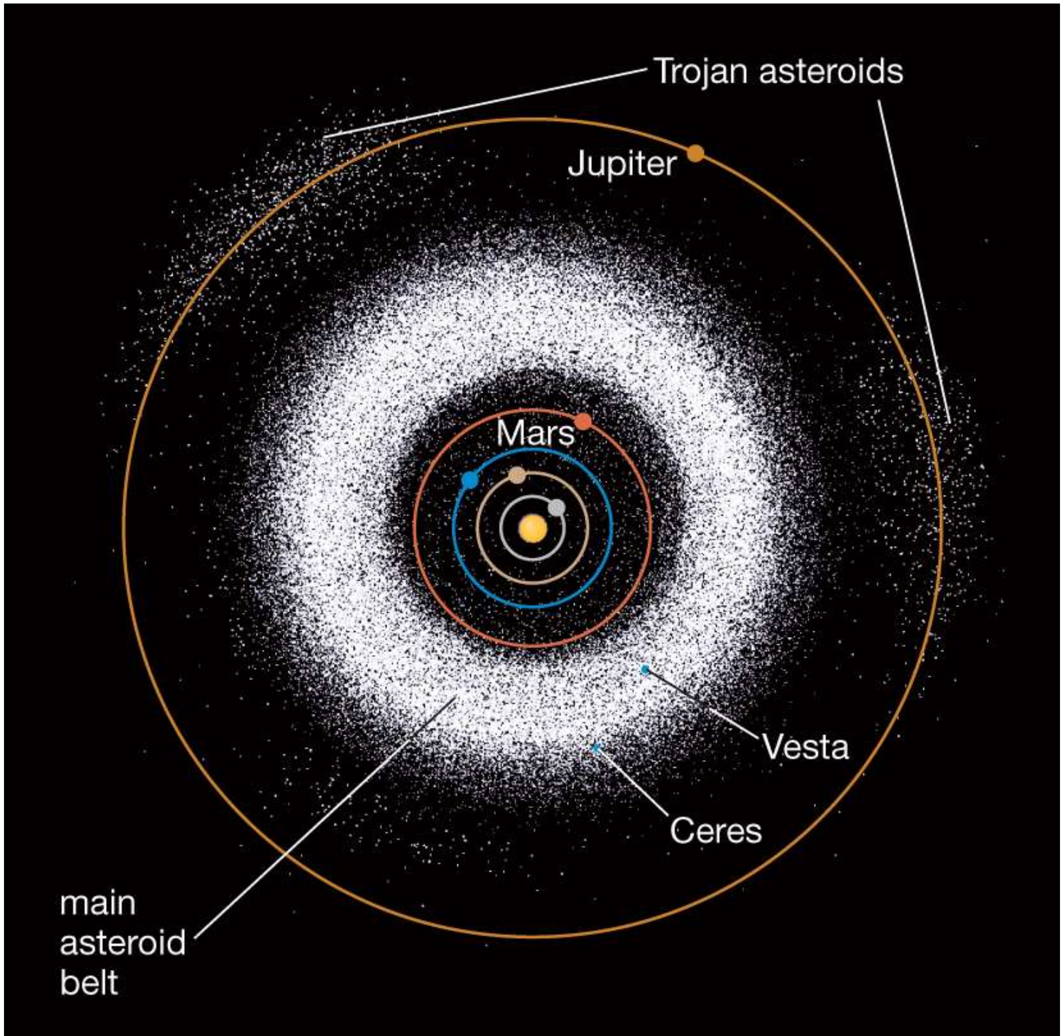
a snap-shot of differentiation



What can we learn from Meteorites?

- What the original planetesimals were like.
  - Many are thought to be close to their pristine state.
- When solar system formation began.
  - We can tell from their age and compositions.
- What asteroids are like on the inside.
  - What compounds they may have bought to the early Earth…
- Proof that differentiation and volcanism happened on asteroids.
  - Particularly from HED asteroids.

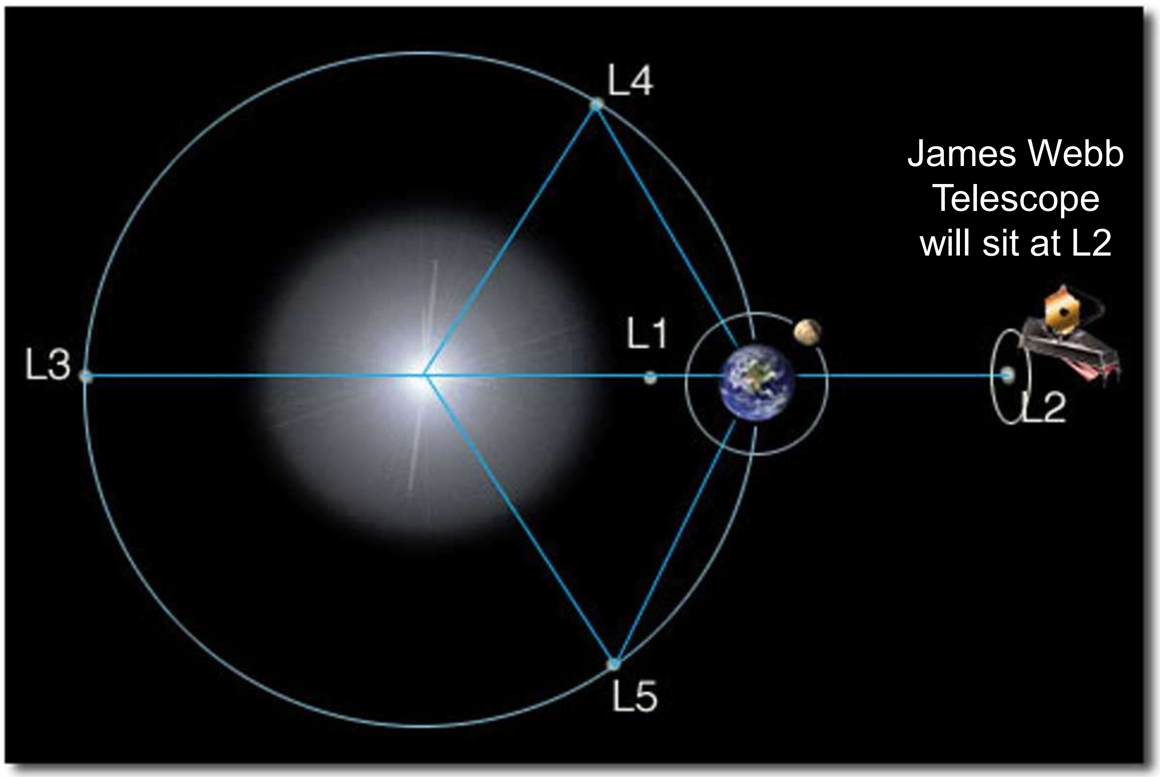
Asteroid Orbits



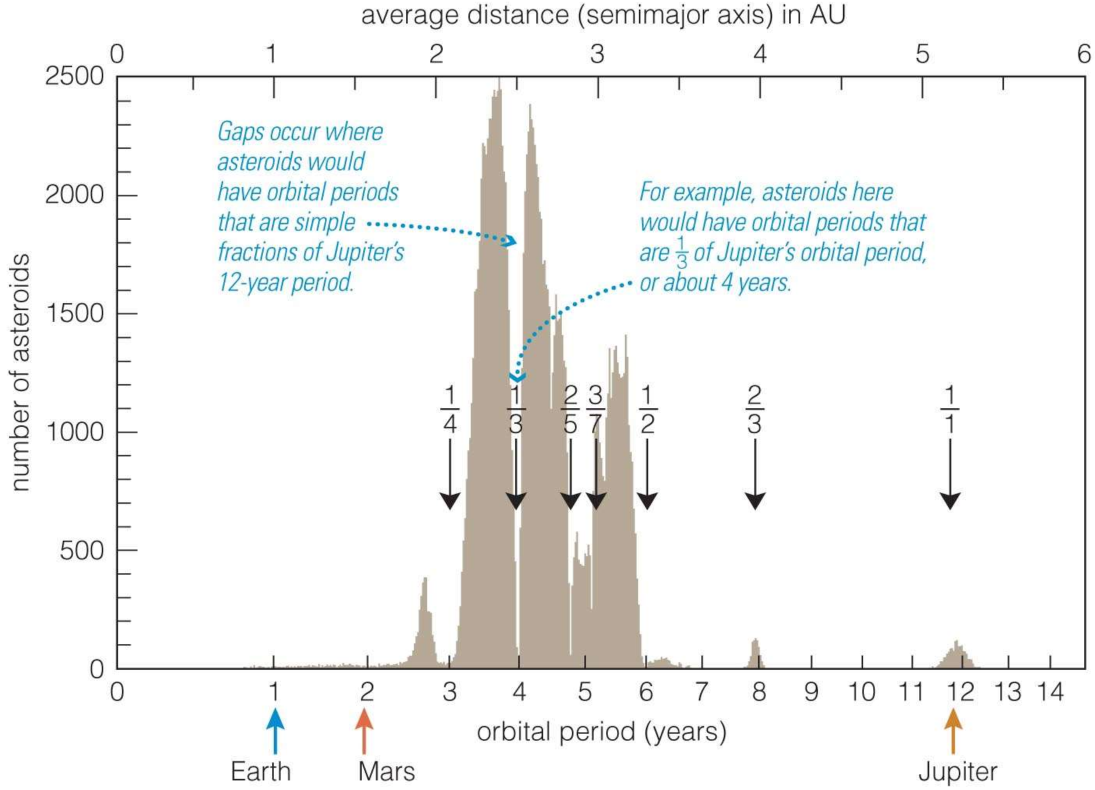
- Most asteroids orbit in a belt between Mars and Jupiter.
- *Trojan asteroids* follow Jupiter's orbit.
  - Lie in L4 and L5 Lagrangian points
- Orbits of *near-Earth asteroids* cross Earth's orbit.

Lagrangian points

- A Lagrange point is a location in space where the combined gravitational forces of two large bodies, such as Earth and the Sun or Earth and the moon, equal the centrifugal force felt by a much smaller third body.
- The interaction of the forces creates a point of equilibrium where a spacecraft may be "parked" to make observations.



Why didn't a Planet form in the Asteroid Belt?



Orbital Resonances

- Asteroids in orbital resonance with Jupiter experience periodic nudges.
- Eventually those nudges move asteroids out of resonant orbits, leaving gaps in the belt.
- Jupiter's gravity, through influence of orbital resonances, stirred up asteroid orbits and prevented their accretion into a planet.

End of Todays Lecture