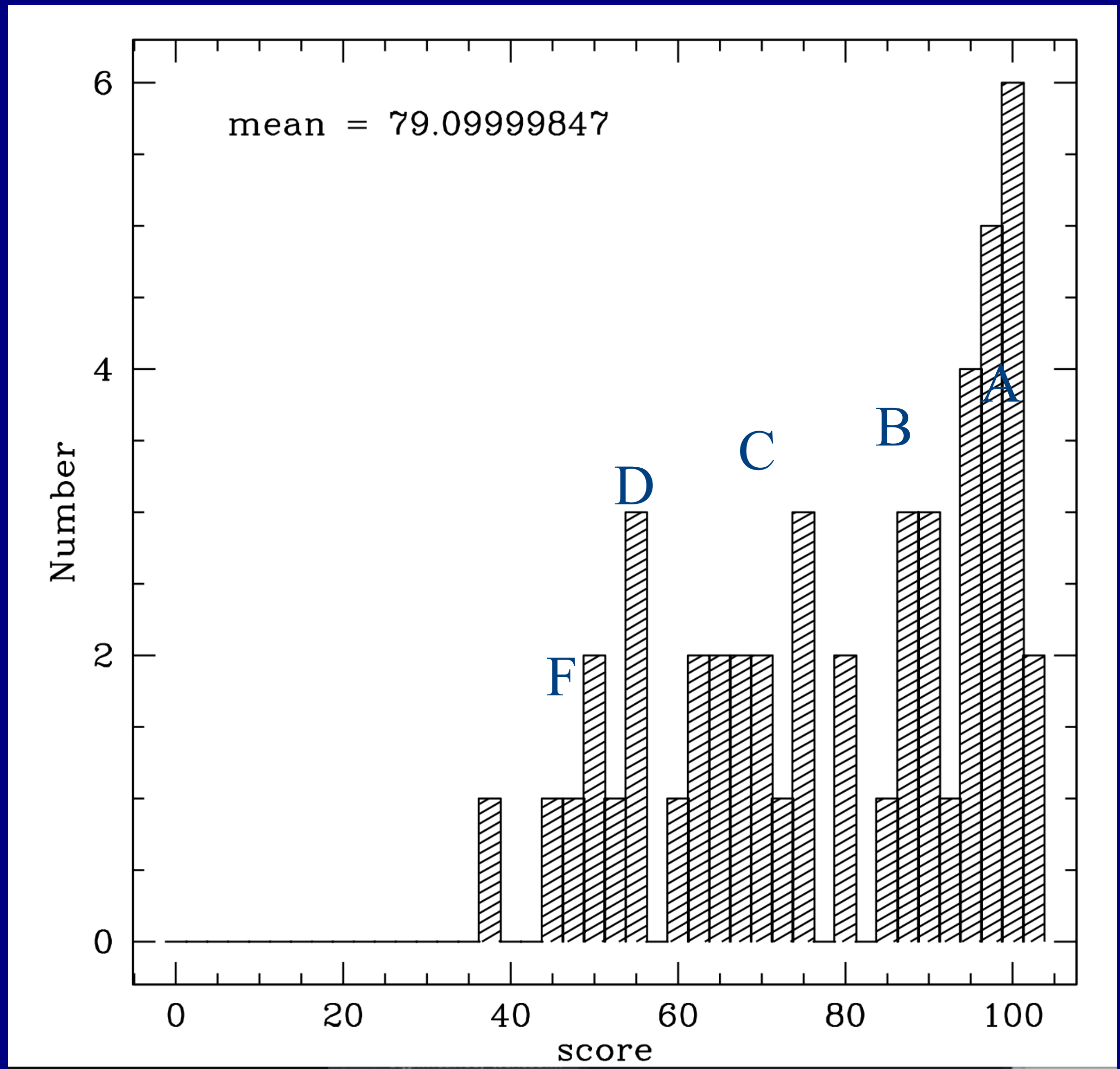
Test #1 Results

90 – 100: A
80 – 89: B
60 – 79: C
50 – 59: D
< 50   : F



How did the Solar System Form?

We weren't there. We need a good theory. Check it against other forming solar systems. What must it explain?

- Solar system is very flat.

- Almost all moons and planets orbit and spin in the same direction. Orbits nearly circular.

- Planets are isolated in space.

- Terrestrial - Jovian distinction (esp. mass, density, composition).

- Leftover junk and its basic properties (comets, asteroids, TNOs).

Not the details and oddities – such as Venus' and Uranus' retrograde spin.

General theory – the Nebular Model

- Interstellar cloud of dust and gas
- Slow rotation, original spherical shape
- Gravitational collapse, dissipation into a plane due to conservation of angular momentum
- Differing temperature environments

A cloud of interstellar gas

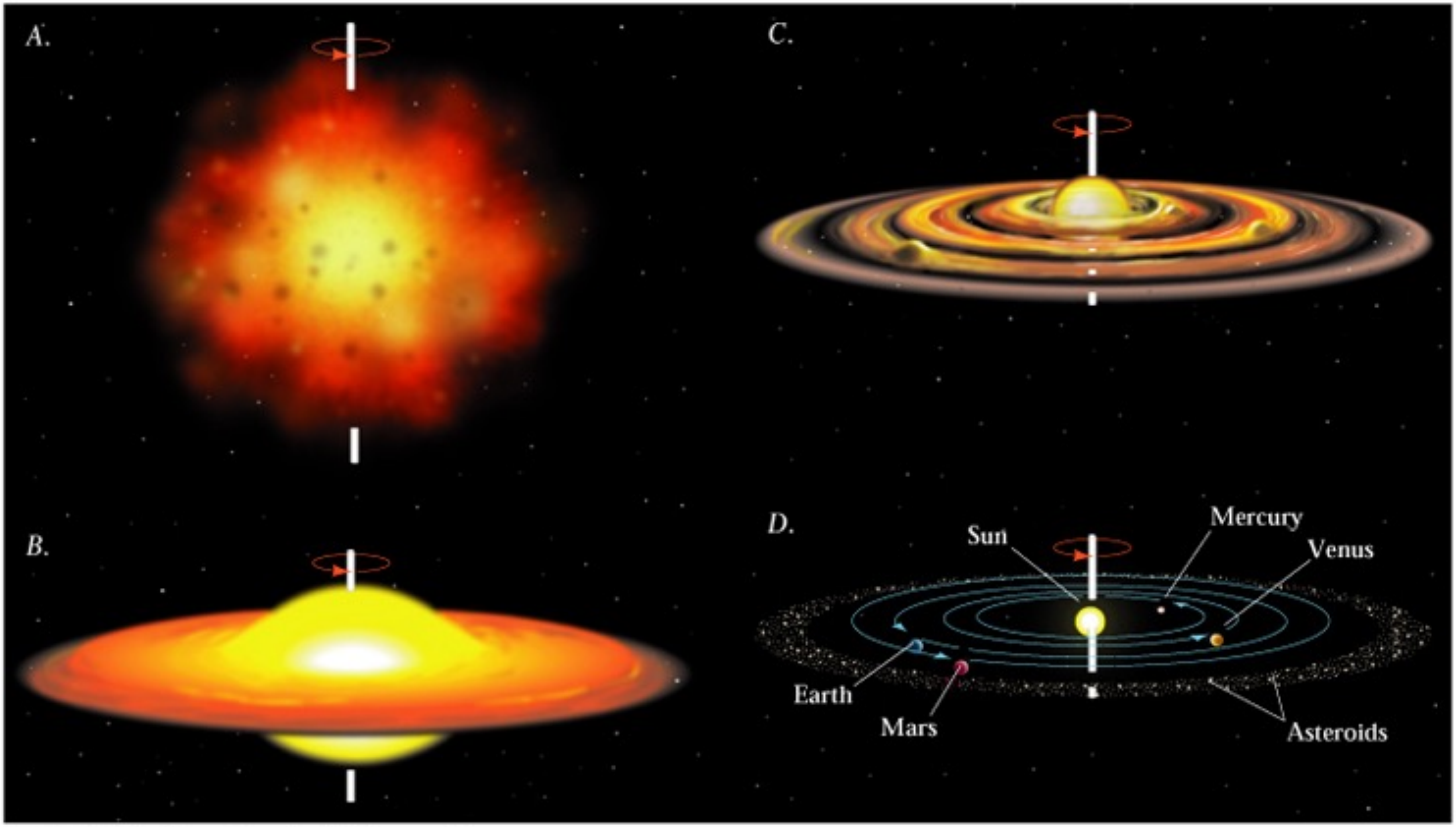
a few pc,
or about 1000
times bigger than
Solar System

The associated dust blocks starlight. Composition mostly H, He.

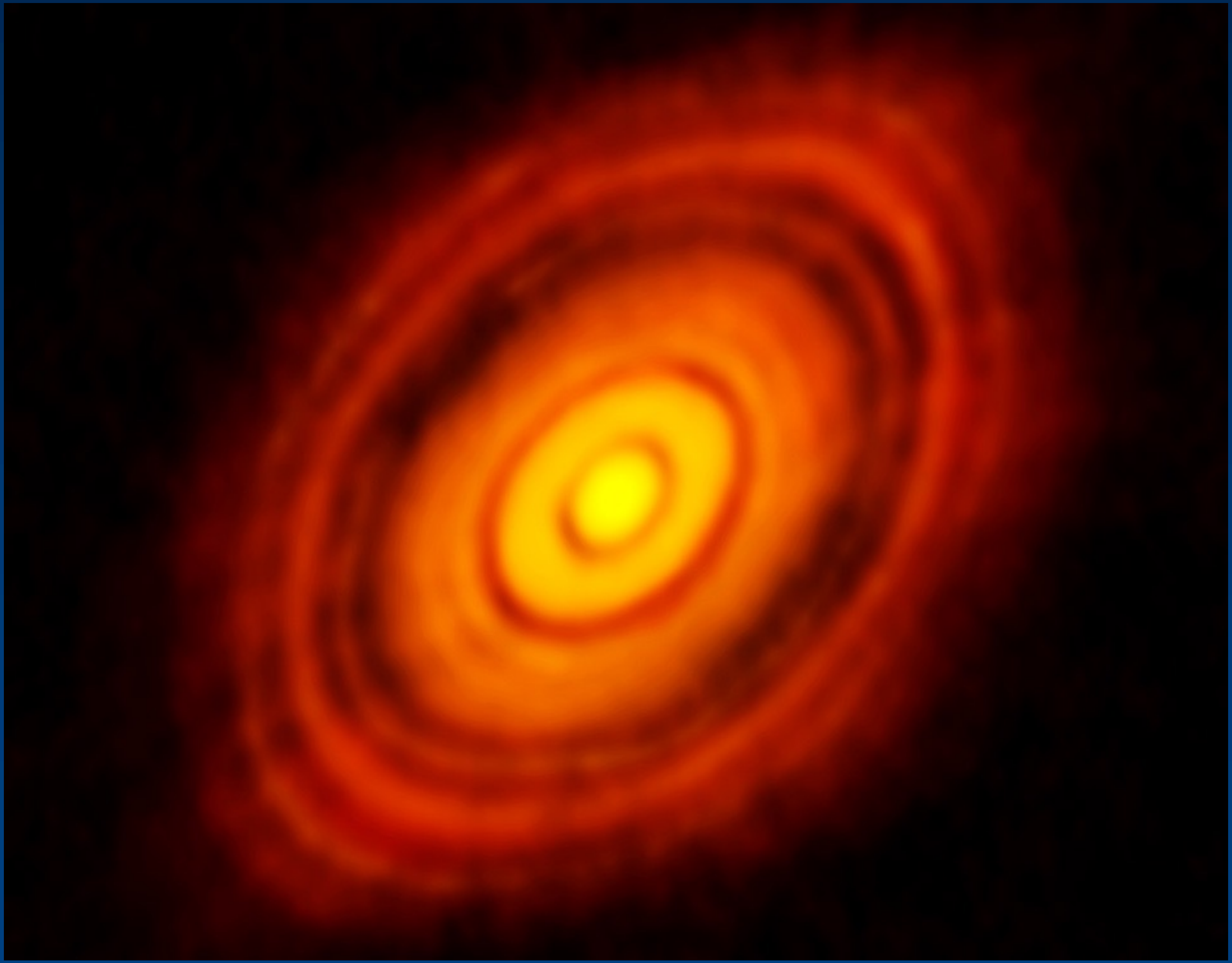
Molecular. Cold. But collisions still cause rotational transitions in molecules – observe at mm wavelengths. Doppler shifts of lines indicate clouds rotate at a few km/s.

Some clumps within clouds collapse under their own weight to form stars or clusters of stars. Clumps spin at about 1 km/s.

Solar System Formation



HL Tau Protoplanetary Disk



So how can you get a flat, rapidly rotating Solar System?

Conservation of Angular Momentum

For a spinning object: $$L = I\Omega$$

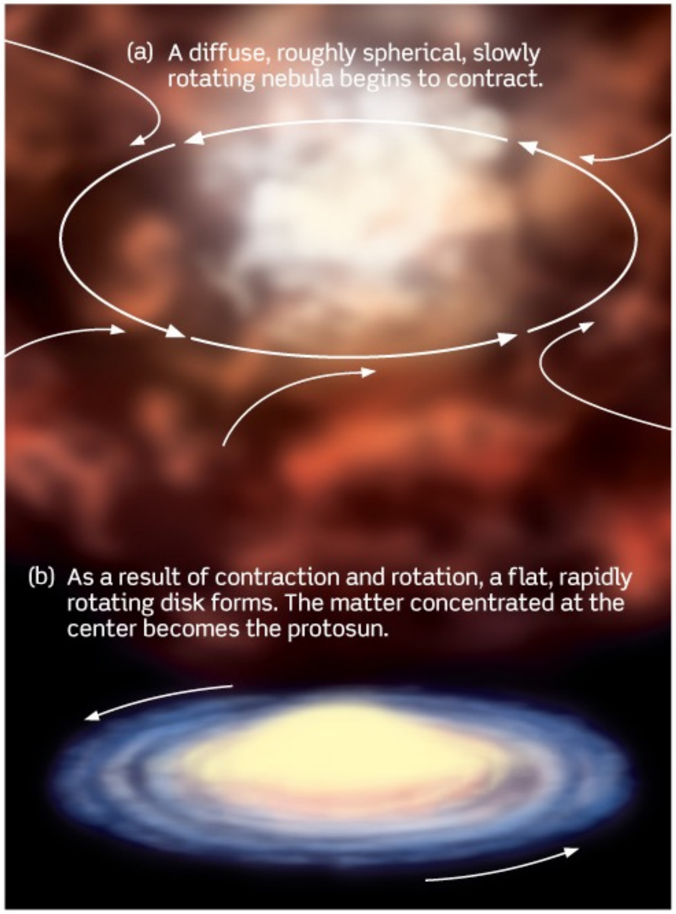
where L is angular momentum, I is moment of inertia, and Ω is angular rotation rate (of spinning or orbiting object).

For uniform density sphere, $$I = \frac{2}{5}MR^2$$

In general $$L \propto MR^2\Omega$$

So if R decreases, Ω increases.

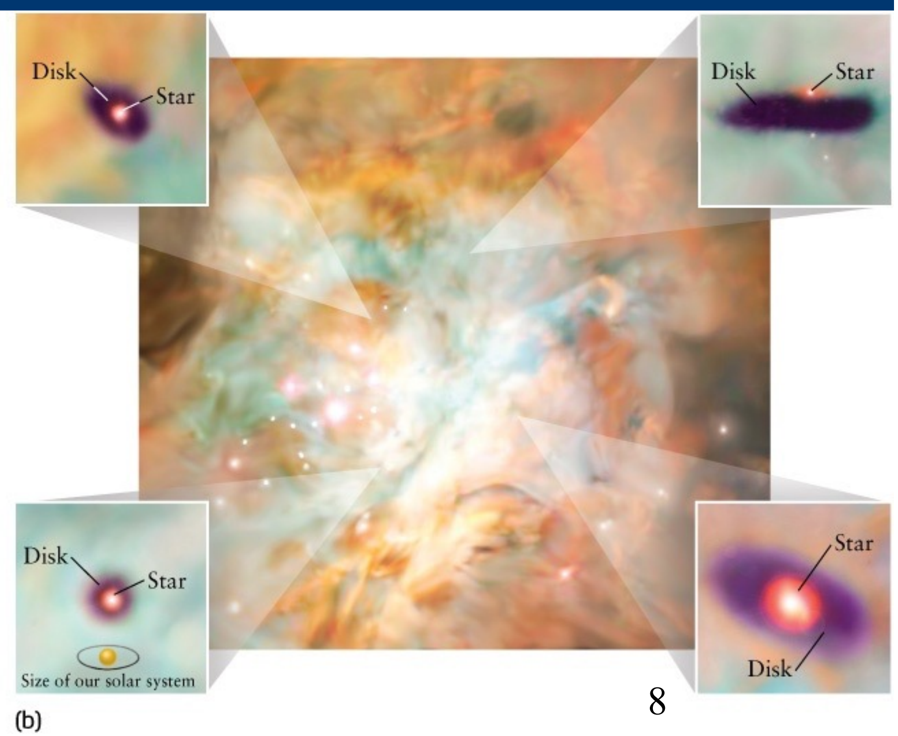
(For orbiting object, $L = MR^2\Omega$ is conserved.)



Cloud starts collapsing under its own gravity. Its pressure cannot support it.

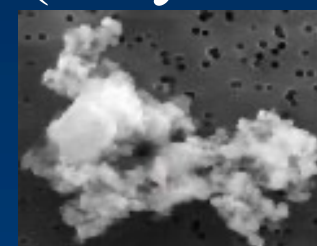
The cloud spins more rapidly as it collapses (conservation of angular momentum), and forms a disk.

We observe these now in star forming regions, using HST



How does the nebular model explain planets and "debris"?

- Solar Nebula composed of 71% H (by mass), 27% He, traces of heavier elements in gas, and dust grains (only about 2% of mass).



- After collapse, now so dense that solid material can grow by collisions and accretion. In warm inner nebula, growth of dust grains.

- Further from Sun, ice chunks, and ice mantles on dust grains, formed readily (lots of gas to make ice from => much more solid material). But most matter still gas.

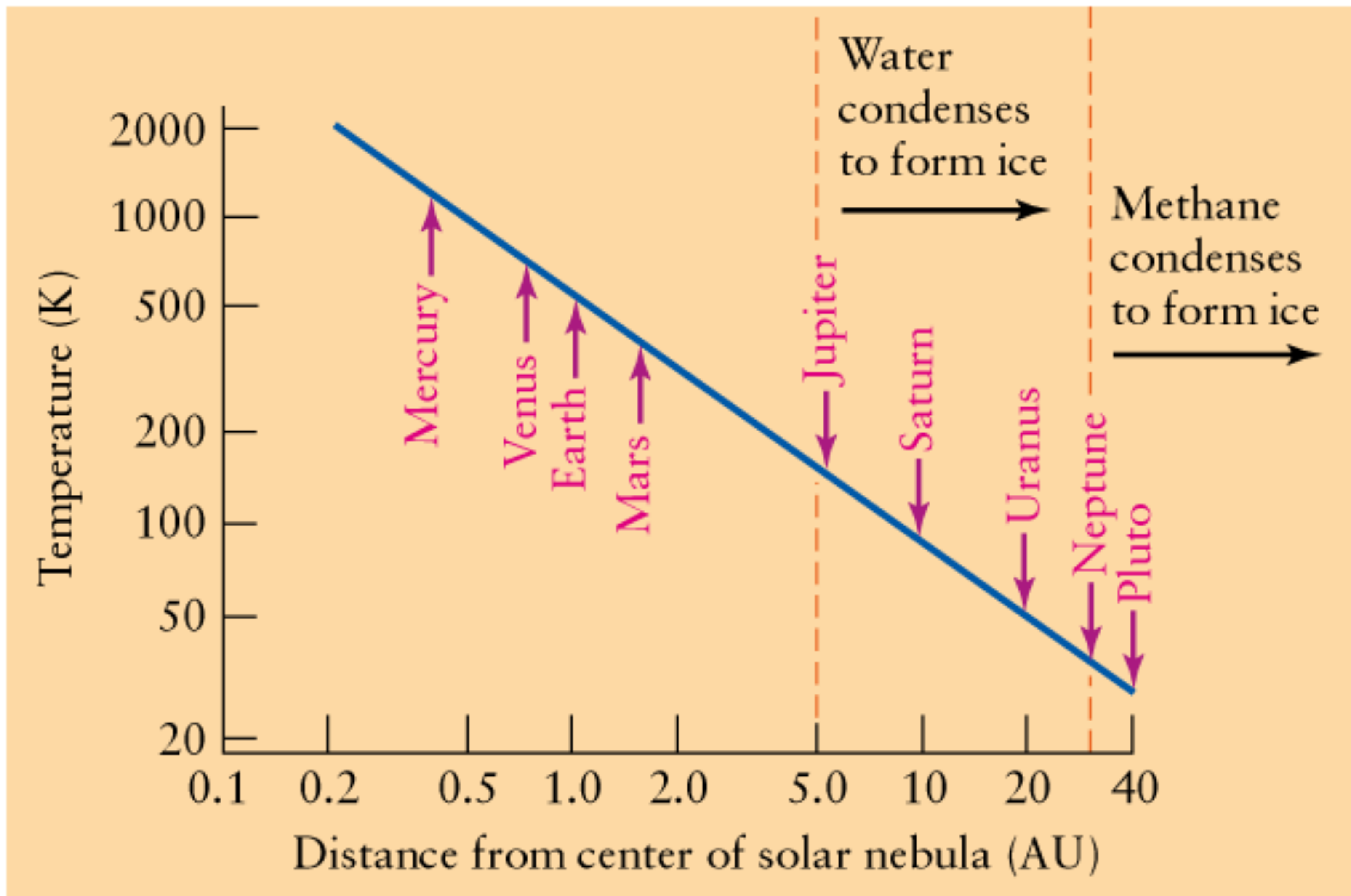
Condensation temperature

Temp (K)	Elements	Condensate
>2000 K	All elements gaseous	
1600 K	Al, Ti, Ca	Mineral oxides
1400 K	Fe, Ni	Metallic grains
1300 K	Si	Silicate grains
300 K	C	Carbonaceous grains
300-100 K	H, N	Ices (H_2O, CO_2, NH_3, CH_4)

The "frost line"

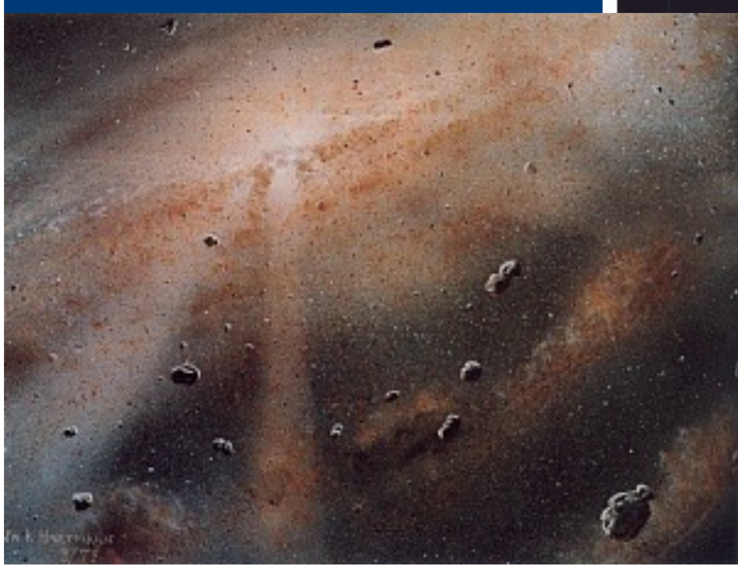
- Rock and metals form when T<1300 K
- Carbon grains and ices form when T<300 K
- Inner Solar System is too hot for ices and carbon grains. Only materials with high condensation temps can remain solid
- In the outer Solar System carbon grains and ices form beyond the "frost line"

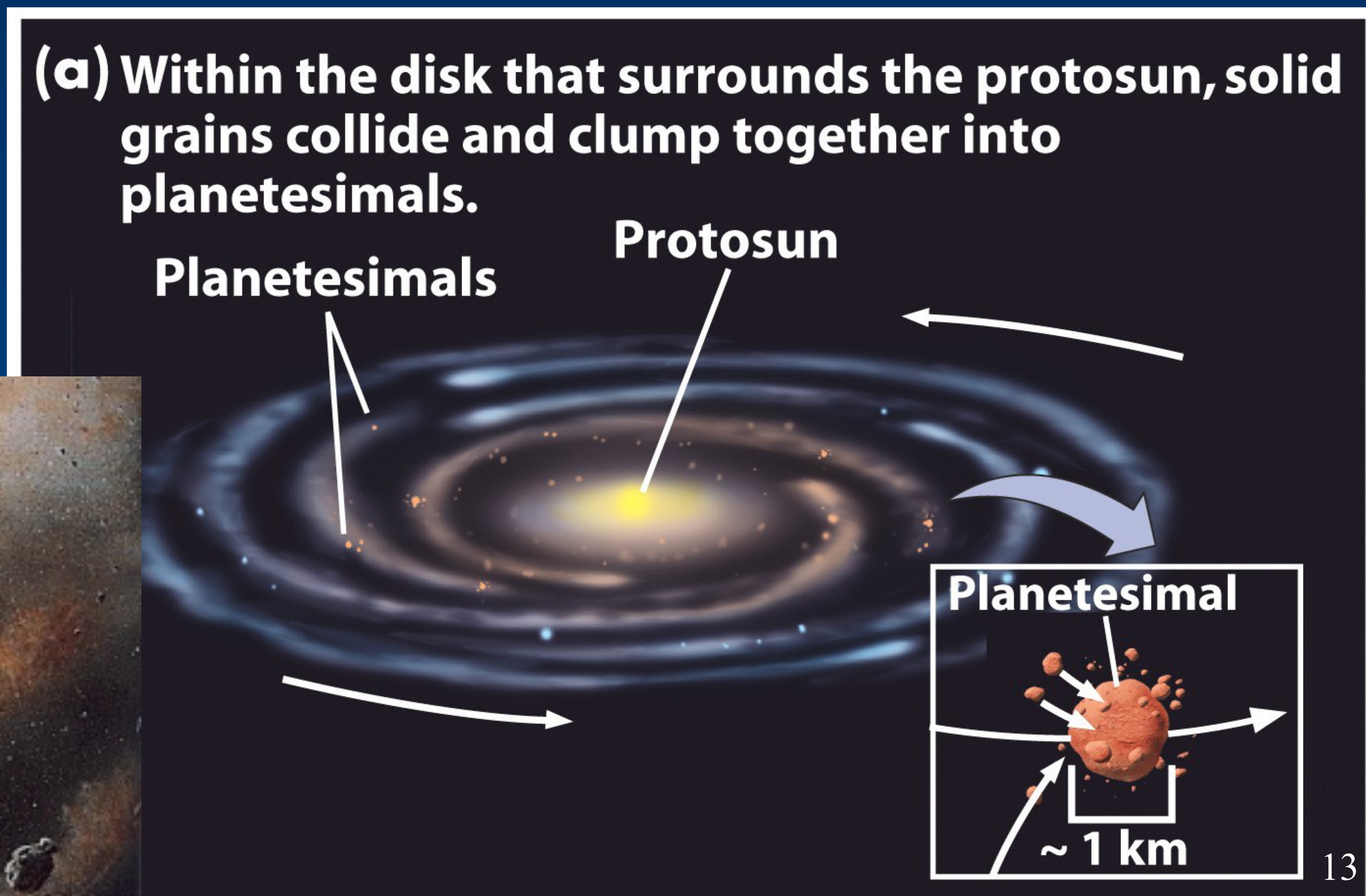
Temperature distribution in Solar Nebula at time of formation of the planets

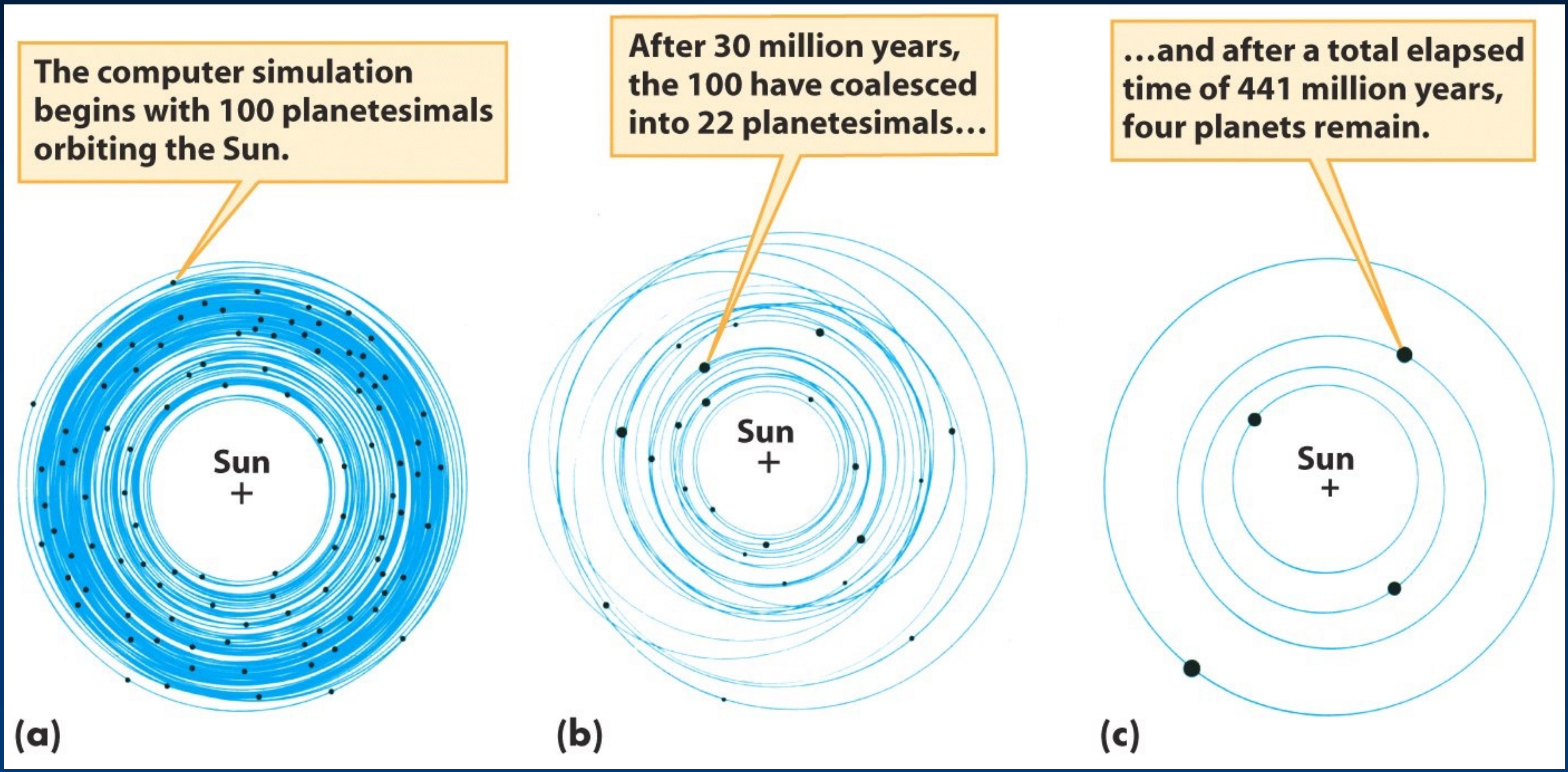


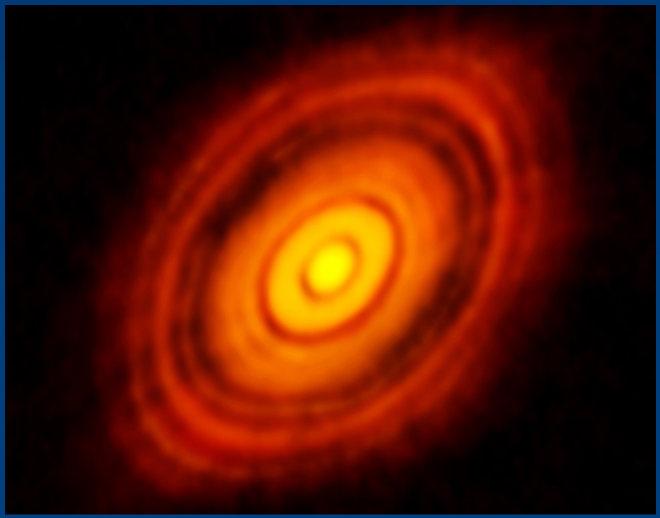
Grains => planetesimals => protoplanets

The planets formed by the collision and sticking of solid particles, leading to km-scale planetesimals (few 10^6 yrs). Collisions of planetesimals enhanced by gravity, growth of proto-planets. Larger ones grew faster – end result is a few large ones.









ALMA observation of disk around young star with ring structure. Unseen planets sweep out gaps

Terrestrial planets

- Only rocky planetesimals inside the frost line
- Energy of collisions heats growing protoplanets. Along with heat from radioactivity, they become molten
- Hotter close to the Sun => protoplanets cannot capture H, He gas and retain thick atmosphere
- Solar wind also dispersing nebula from the inside, removing H & He

=> Rocky terrestrial planets with few ices

Jovian planets

- Addition of ices increases masses of grains - large proto-planets of rock and H compounds result (few to 15 M_{Earth})
- Larger masses & colder temps: can accrete H & He gas from the solar nebula
- Planets with biggest cores grow fast, thereby increasing gas accretion

⇒Form large Jovian planets with massive cores of rock and ice and heavy H, He atmospheres

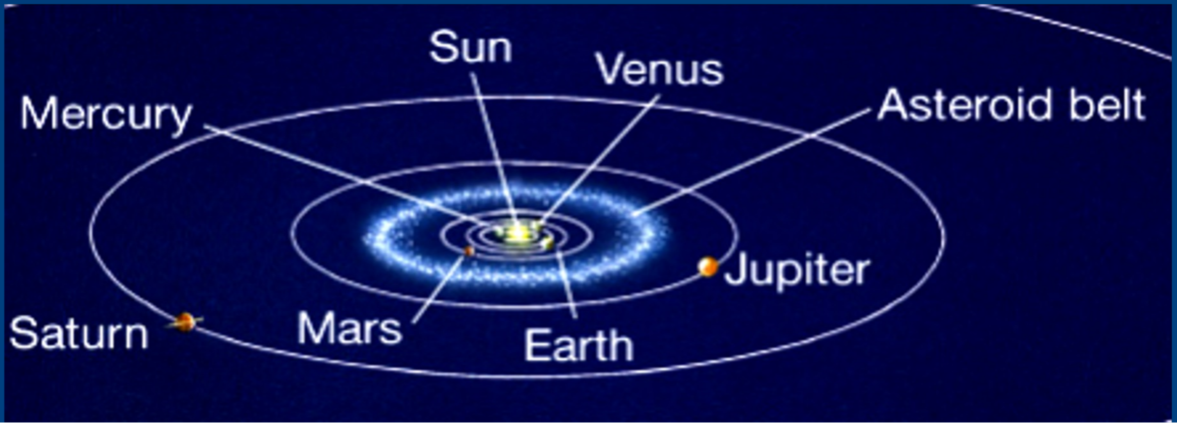
- Alternative: formed directly and rapidly by gravitational collapse in disk. Denser material sunk to center. Should take 100's to 1000's of years only!

Moons & Asteroids

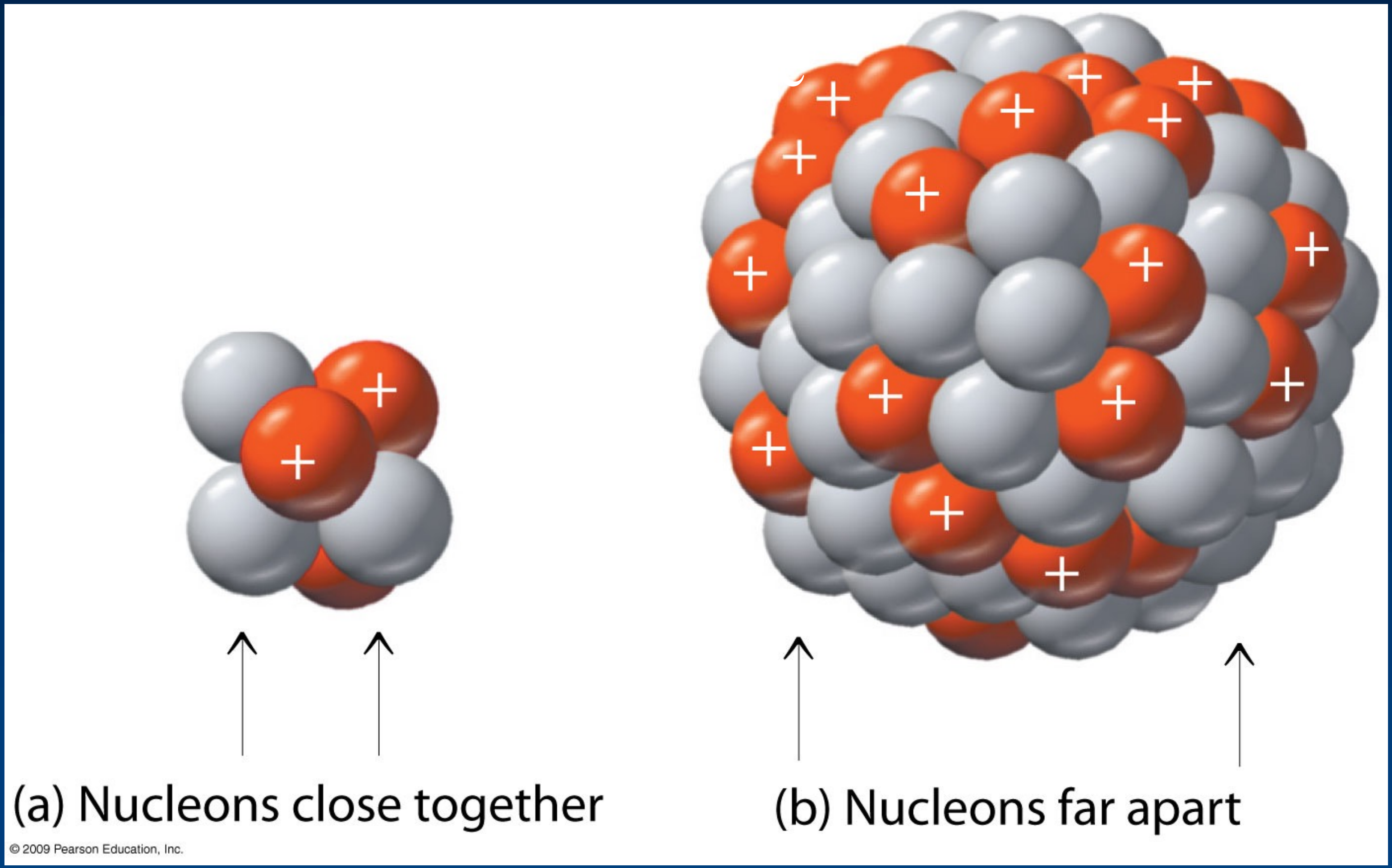
Some gas attracted to proto-Jovians formed disks:

- Mini solar nebula around Jovians
- Rocky/icy moons form in these disks
- Later moons added by asteroid/comet capture

Asteroid Belt: perhaps a planet was going to form there. But Jupiter's strong gravity disrupted planetesimals' orbits, ejecting them from this zone. The Belt is the few left behind.

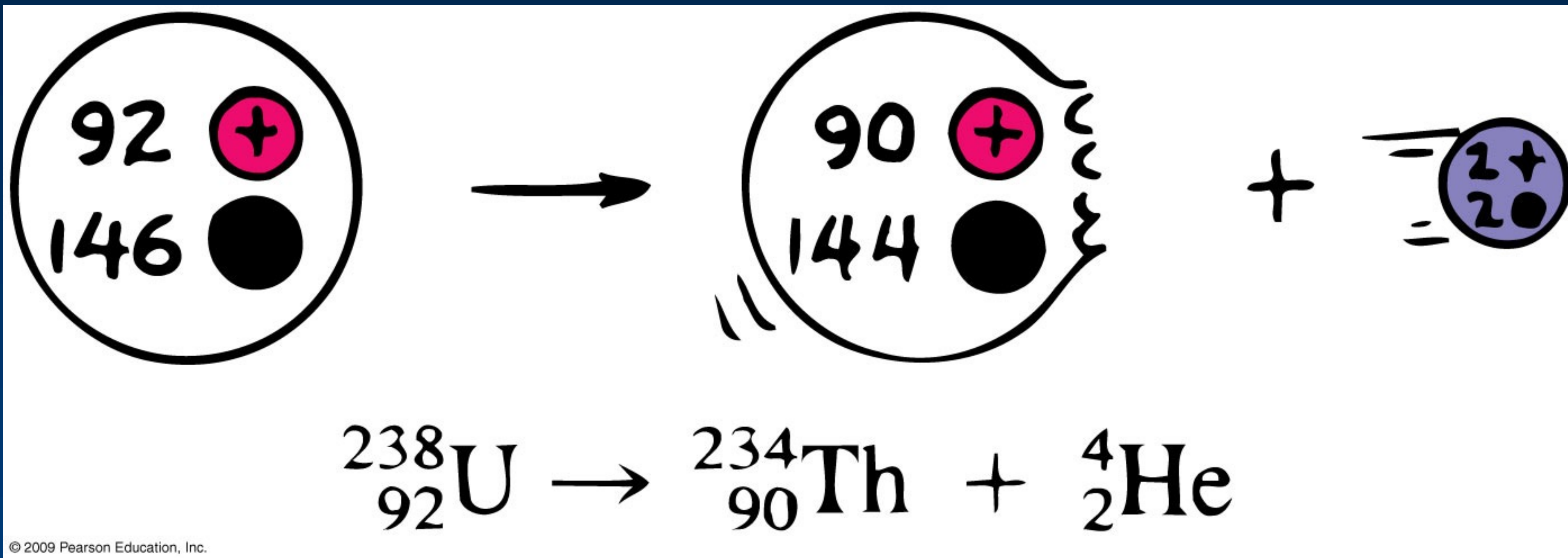


Why are some materials Radioactive?



Big nucleii are unstable due to the limited range of the strong force that holds them together

What Happens?



Uranium 238 spontaneously decays to Thorium 234 and an alpha particle

What is this transmutation of heavy to light elements called?

What Happens?

Uranium 238 spontaneously decays to Thorium 234 and an alpha particle

Thorium decays to Protactinium and so on, all the way down to lead

Various byproducts are alpha, beta and gamma radiation

Particles (and gamma rays) leave the nucleus with a lot of energy (high speed)

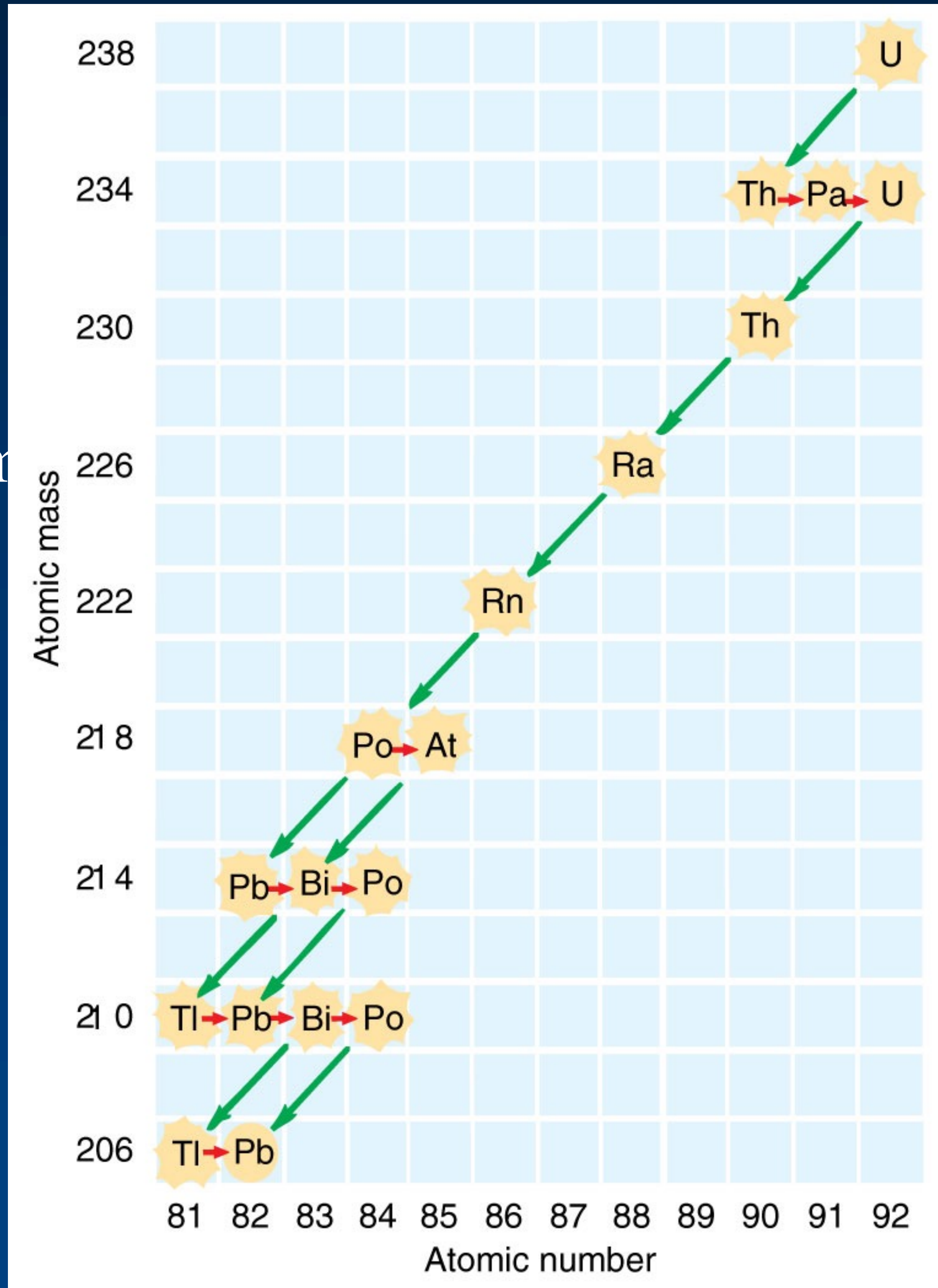
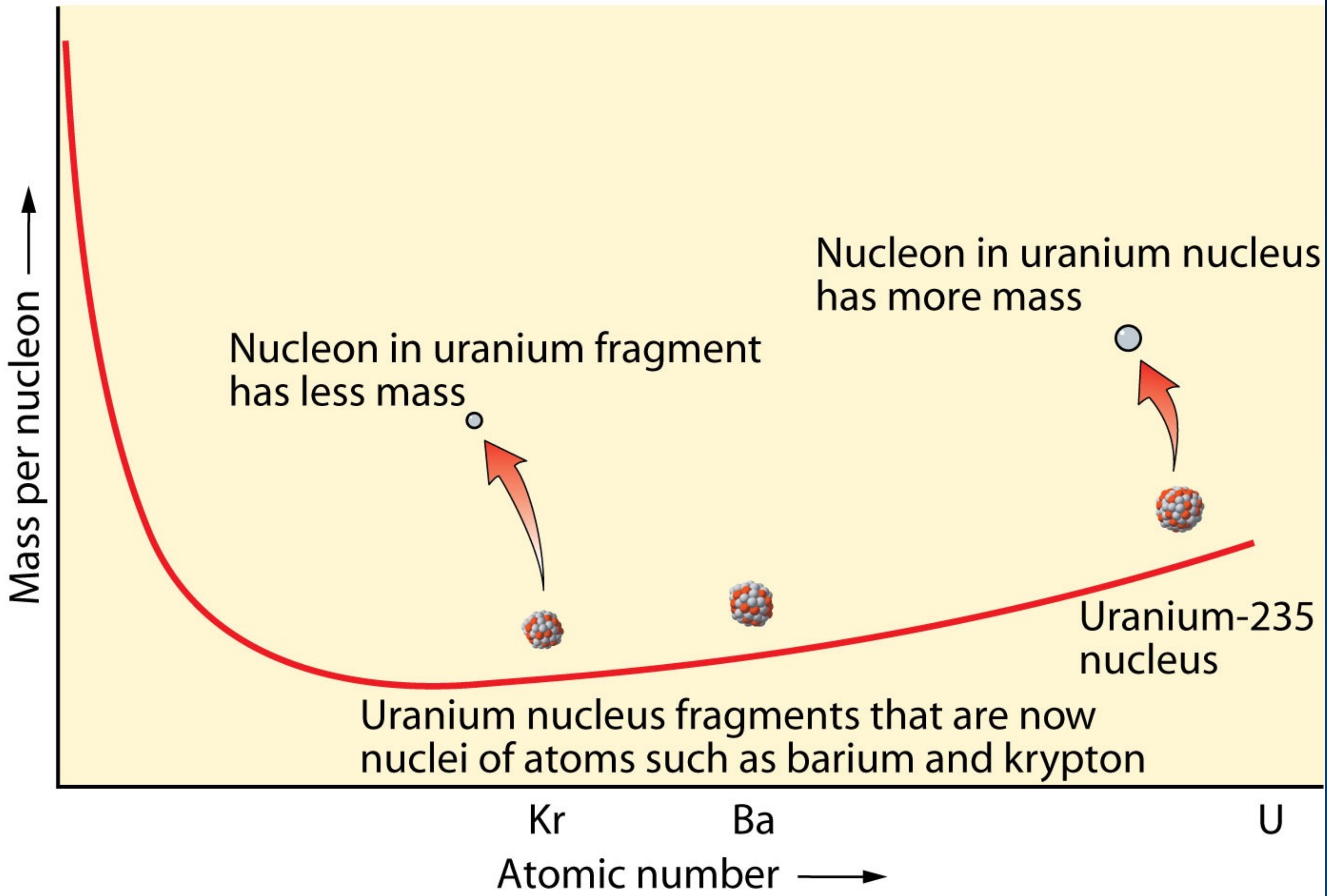
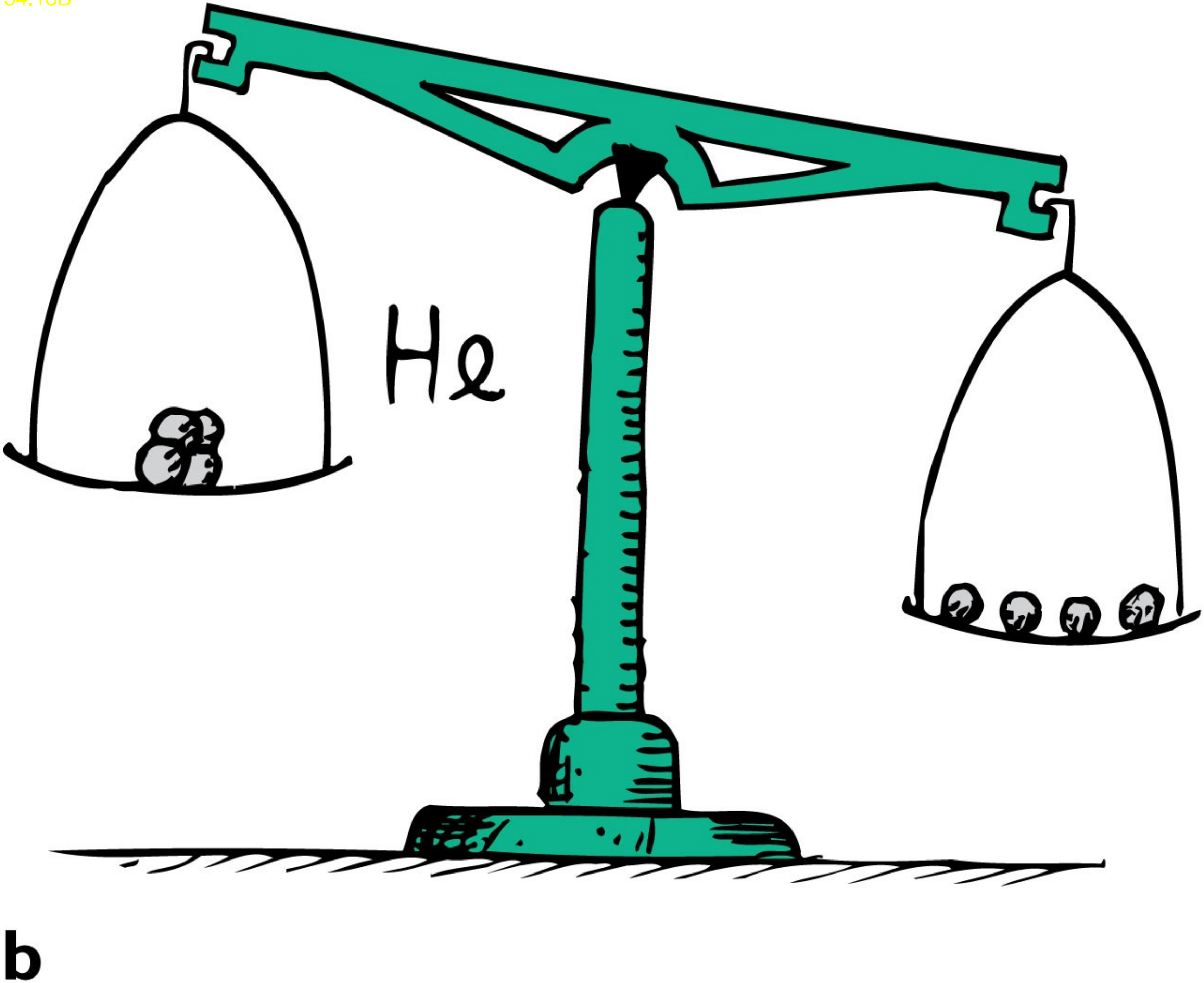


Figure 34.17



Mass per nucleon
Nucleon in uranium nucleus
has more mass
Nucleon in uranium fragment
has less mass
Uranium-235
nucleus
Uranium nucleus fragments that are now
nuclei of atoms such as barium and krypton
Kr
Ba
U
Atomic number

Figure 34.18B



Some Materials can become radioactive

Radioactive waste products

HIGH: spent fuel rods

low: containment materials, pipes, suits

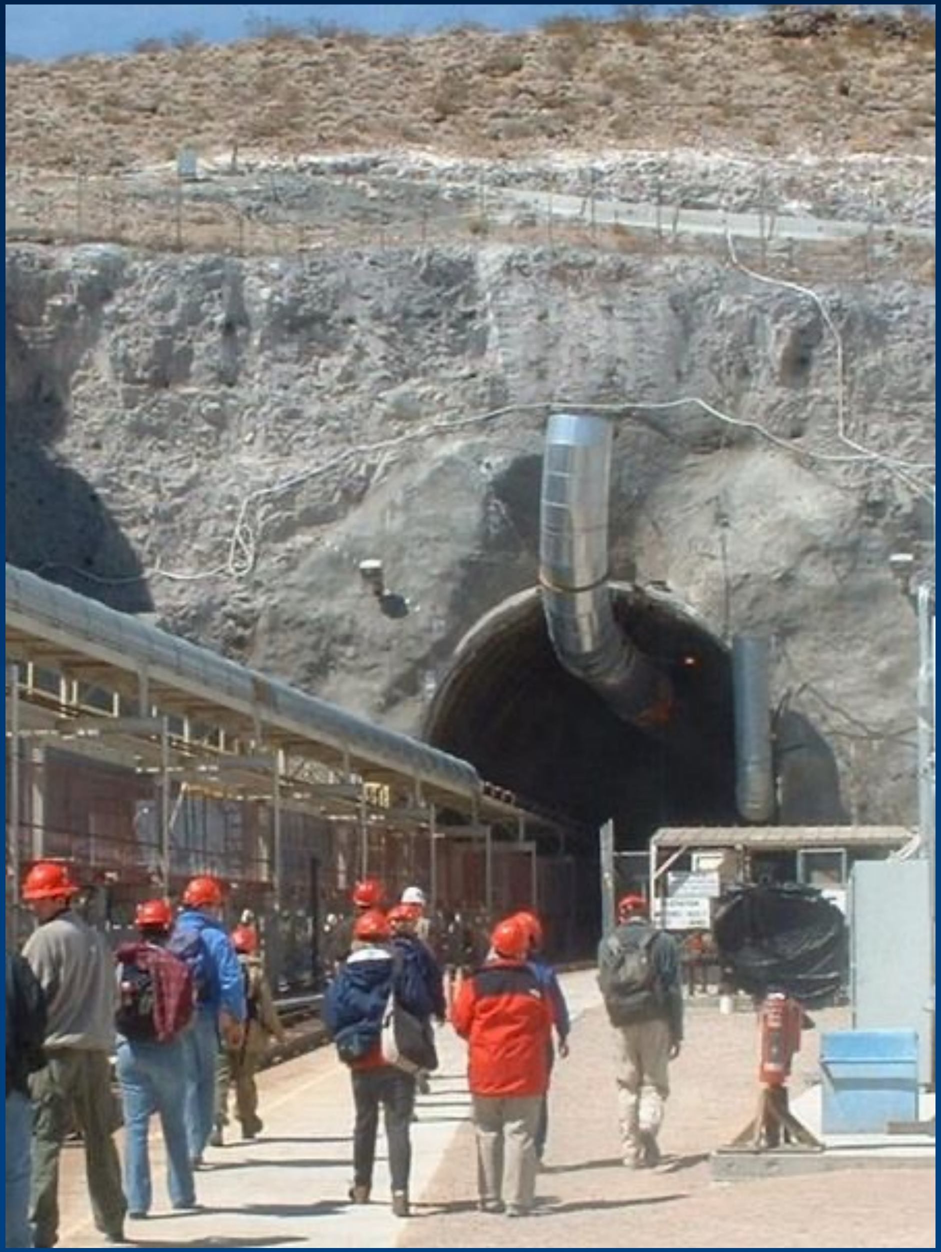
Current total US waste: 100 million gallons + 2500 tons solid waste

Bombardment of nuclei with high energy particles can increase the number of unstable isotopes

Yucca Mountain

80 miles North of Las Vegas
Studies began in 1978
Under construction since 2002
$9 Billion spent preparing it
Defunded in 2010

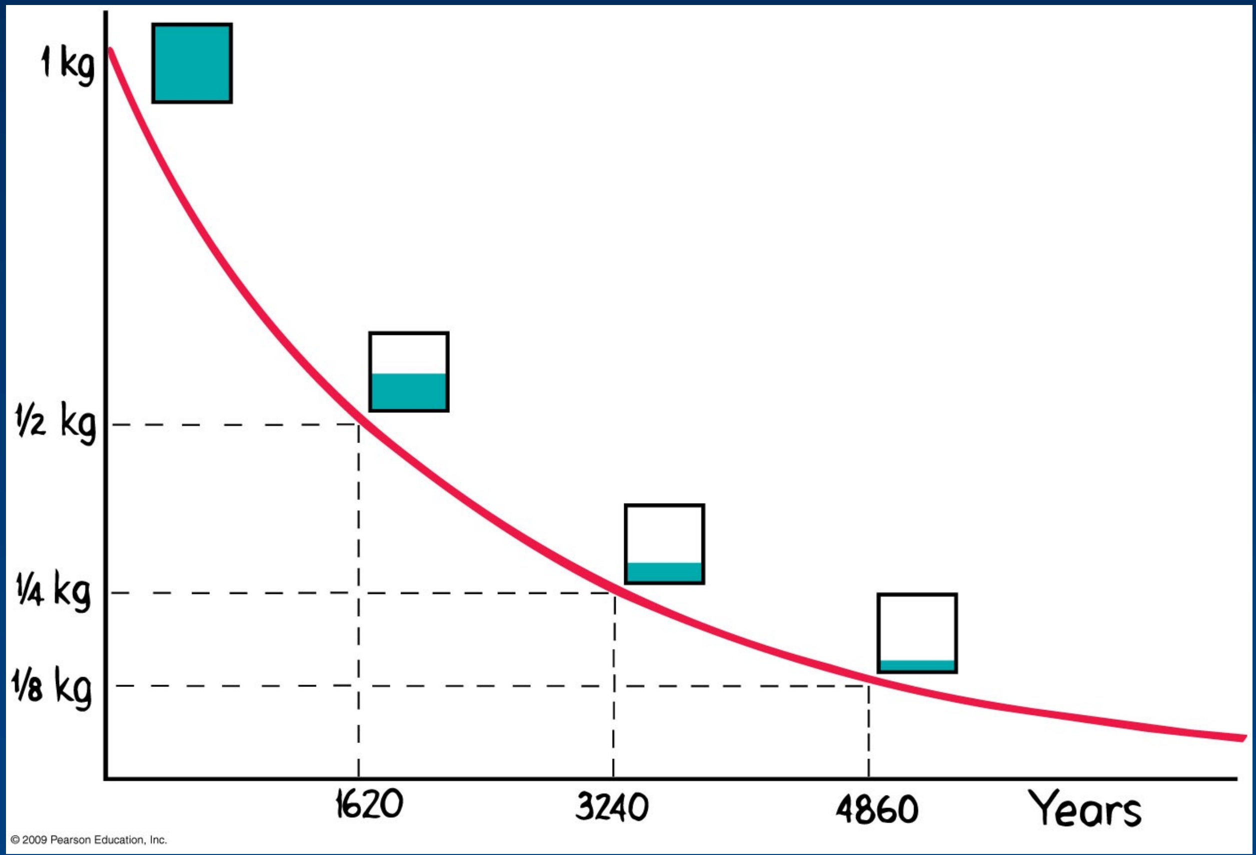
WIPP in New Mexico
Operating since 1998
Shut down due to accident in
February 2014
re-opened in Jan 2017



Radioactive Decay

Its an "exponential" decay
Half of the radioactive material will transmutate in a set amount of time
This amount of time is called the "half-life"

$$N(t) = N_0 e^{-t/\tau}$$
$$\tau = t_{1/2} / \ln(2)$$
$$\tau = 1.44\ t_{1/2}$$



Half-life for radium 226 is 1620 y

^{14}C dating

^{14}C decays to ^{12}C with a half life of 5730 years. ^{14}C is taken in by plants and animals while they are alive and then decays after they die so measuring the isotope ratio can tell you how long ago they lived.

$$N(t) = N_0 e^{-t/\tau}$$

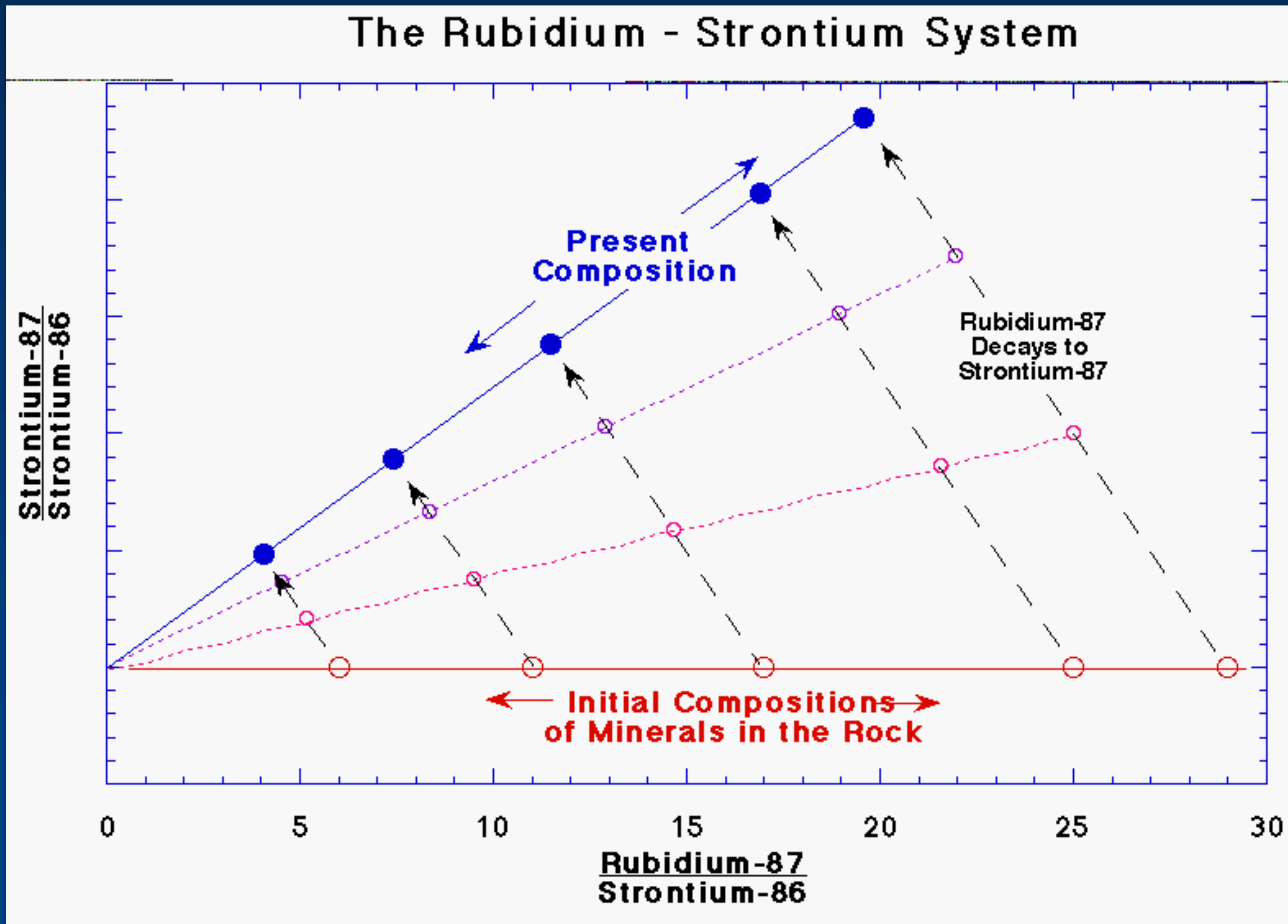
$$\tau = t_{1/2} / \ln(2)$$

$$\tau = 1.44\, t_{1/2}$$

WS10: In 1935 UNM archeologist Frank Hibben claimed to have discovered "Sandia Man" in a cave above Los Huertes Creek, and estimated that Sandia Man lived in the cave 25,000 years ago based on layering of deposits in the cave. This would have made Sandia Man the oldest human in North America. A bone fragment is found in the bottom layer with a ^{14}C to ^{12}C isotope ratio of 0.66. How long ago did Sandia Man really live?

Rock Clocks

At creation rubidium and strontium ratios are equal
rubidium-87 decays to strontium-87 with a half-life of 49 billion years

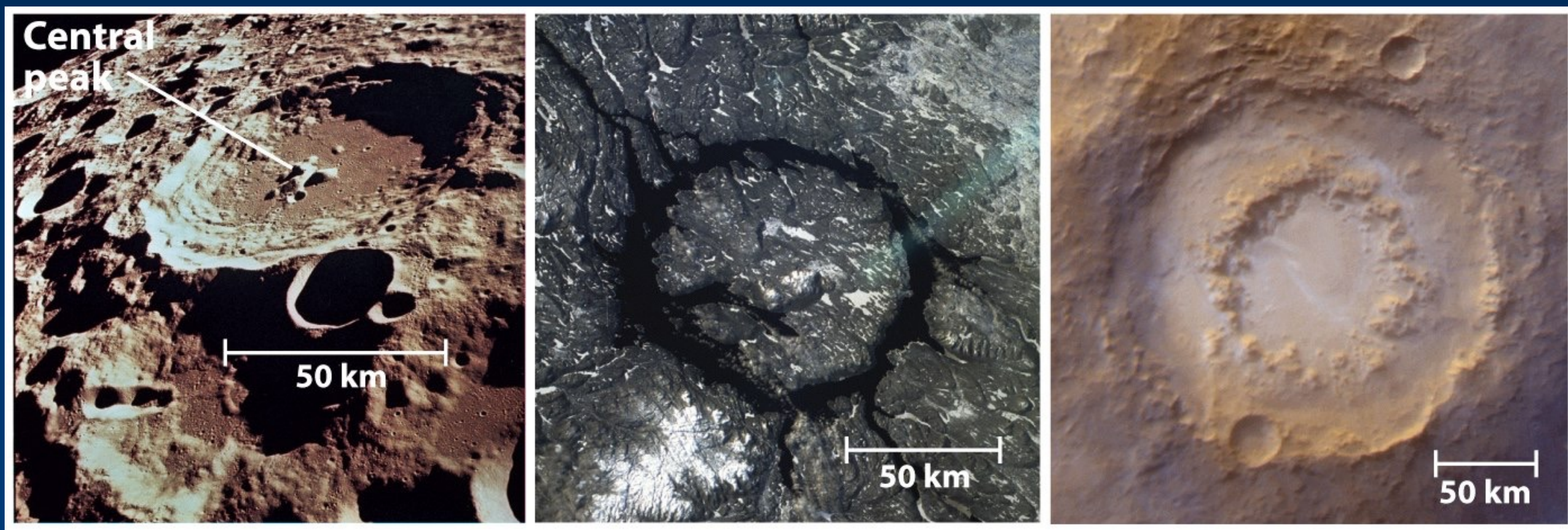


Rock Clocks

Nuvvuagittuq greenstone belt, exposed on the eastern shore of Hudson Bay in northern Quebec. 4.28 billion y old

Cratering on terrestrial planets

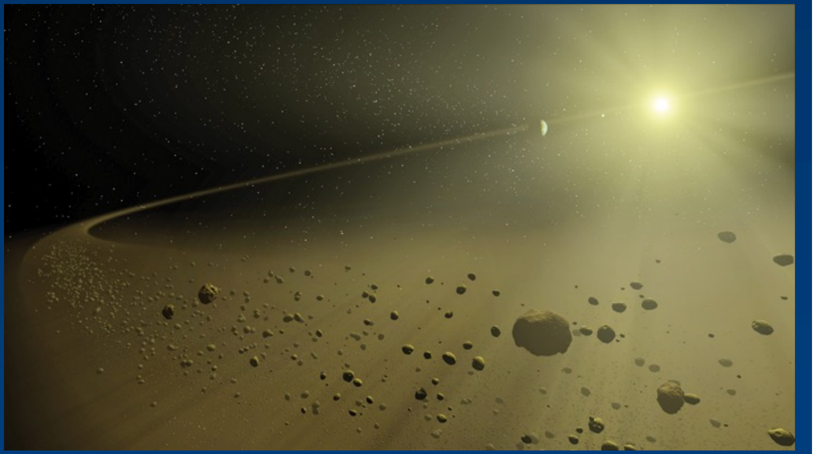
- Result of impacts from interplanetary debris



- Geological activity =>
  - Many craters means old surface and low geological activity
  - Smaller objects lose heat faster: more cratered

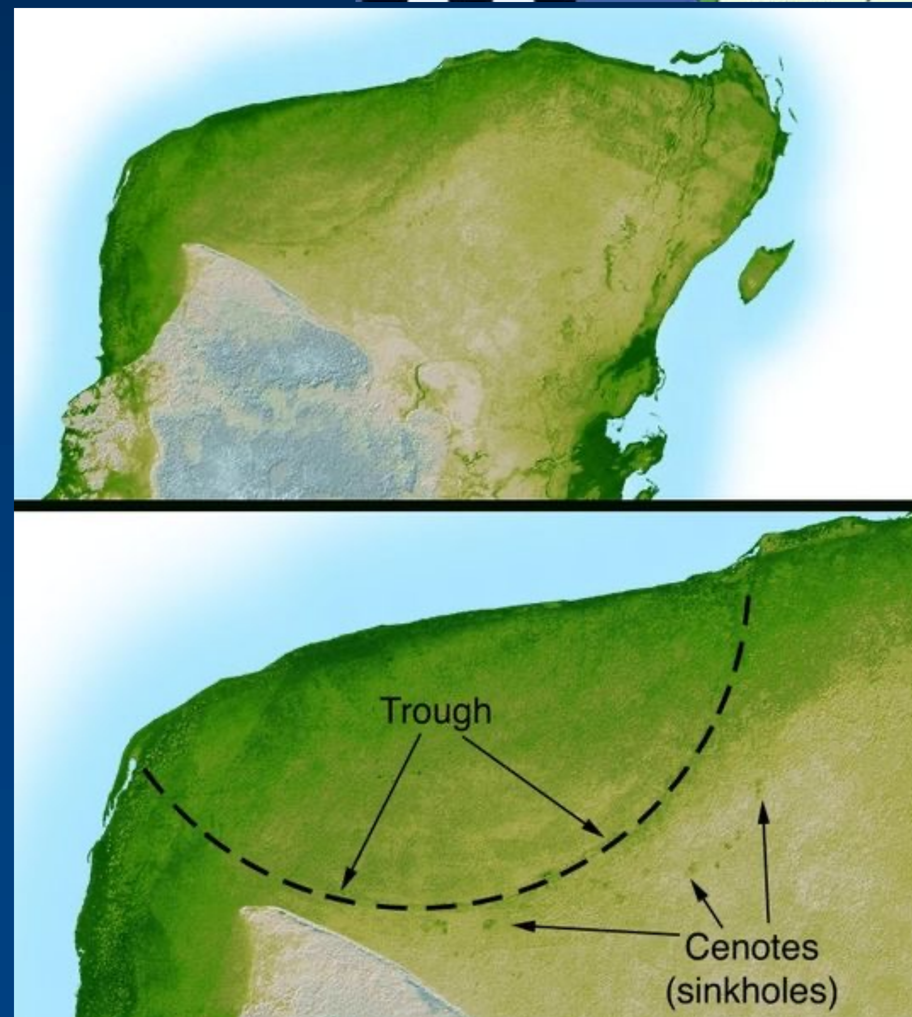
Icy bodies and comets

- Leftover bodies from planet building in Jovian planet zone. Hence more icy than asteroids.
- Gravitational encounters with giant planets flung them outwards beyond Neptune.



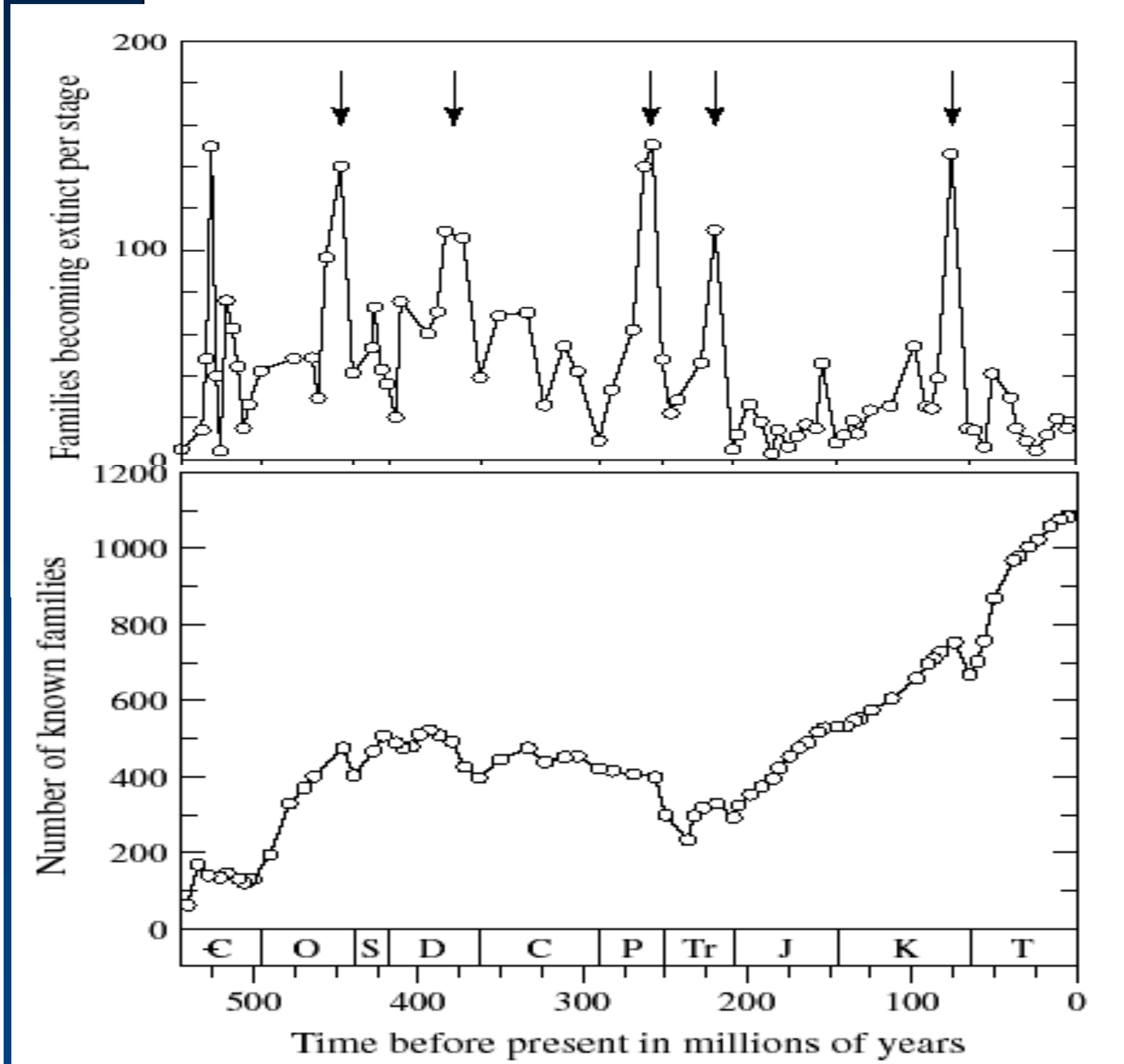
- Result is TNOs, some of which encounter Neptune and sent into inner Solar System, where they appear as comets.

Dinosaur Killer Impact 65 million years ago



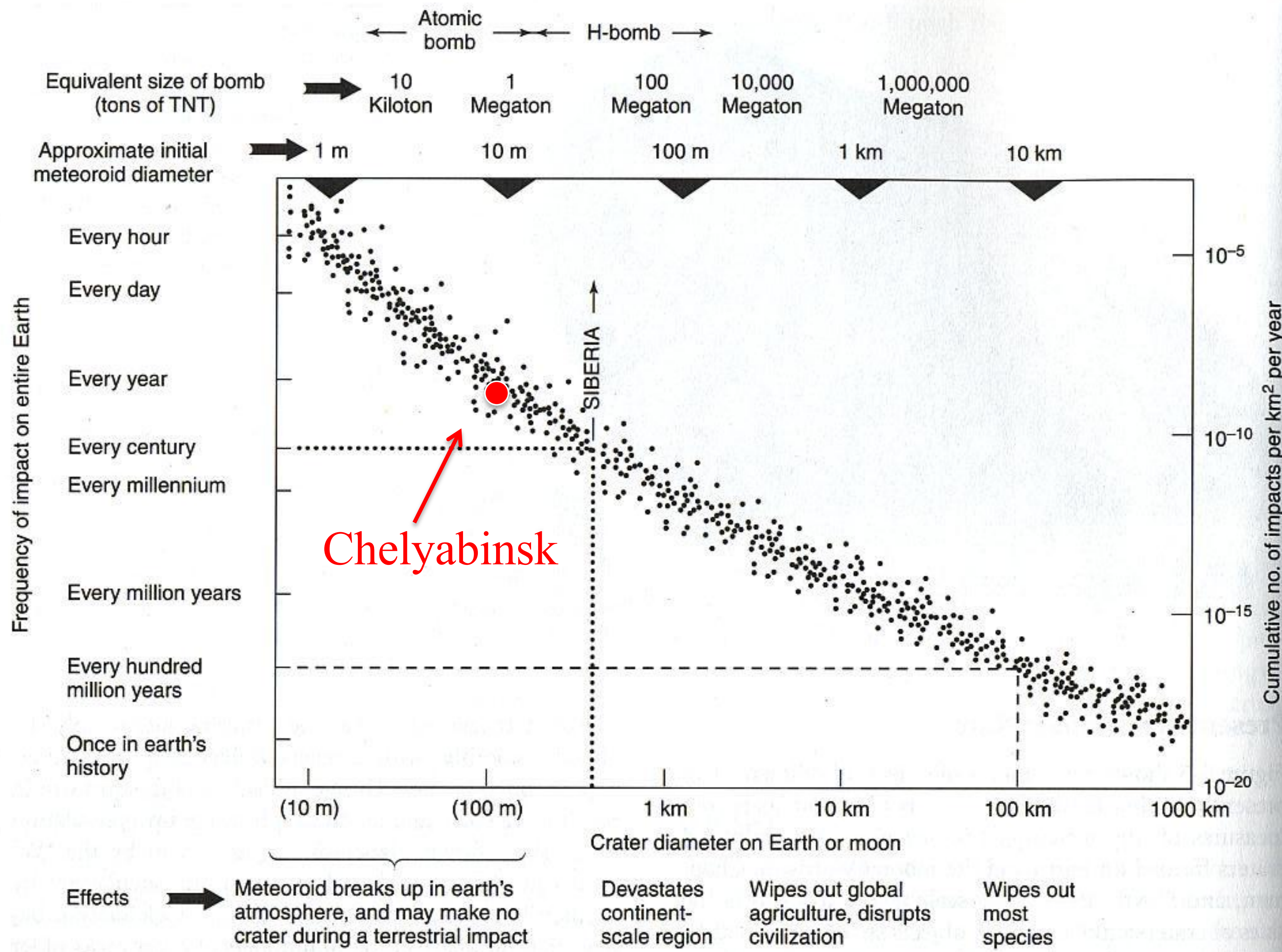
High levels of iridium in Raton Pass (I25)

The Fossil Record is Marked by Mass Extinction Events



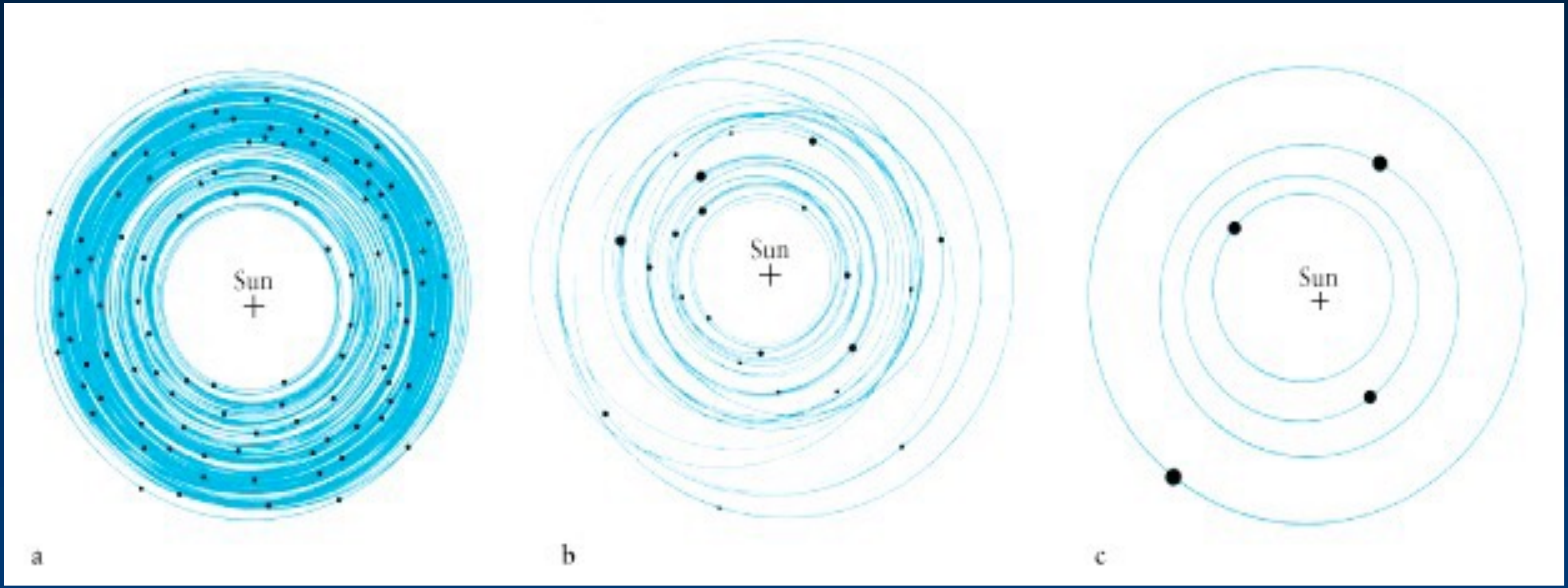
Extinction	Genus loss
End Ordovician	60%
End Devonian	57%
End Permian	82%
End Triassic	53%
End Cretaceous	47%

From Solé & Newman 2002



Atomic bomb
H-bomb
Equivalent size of bomb (tons of TNT)
10 Kiloton
1 Megaton
100 Megaton
10,000 Megaton
1,000,000 Megaton
Approximate initial meteoroid diameter
1 m
10 m
100 m
1 km
10 km
Every hour
Every day
Every year
Every century
Every millennium
Every million years
Every hundred million years
Once in earth's history
Frequency of impact on entire Earth
SIBERIA
Chelyabinsk
10–5
10–10
10–15
10–20
Cumulative no. of impacts per km2 per year
(10 m)
(100 m)
1 km
10 km
100 km
1000 km
Crater diameter on Earth or moon
Effects
Meteoroid breaks up in earth's atmosphere, and may make no crater during a terrestrial impact
Devastates continent-scale region
Wipes out global agriculture, disrupts civilization
Wipes out most species

Result from computer simulation of planet growth



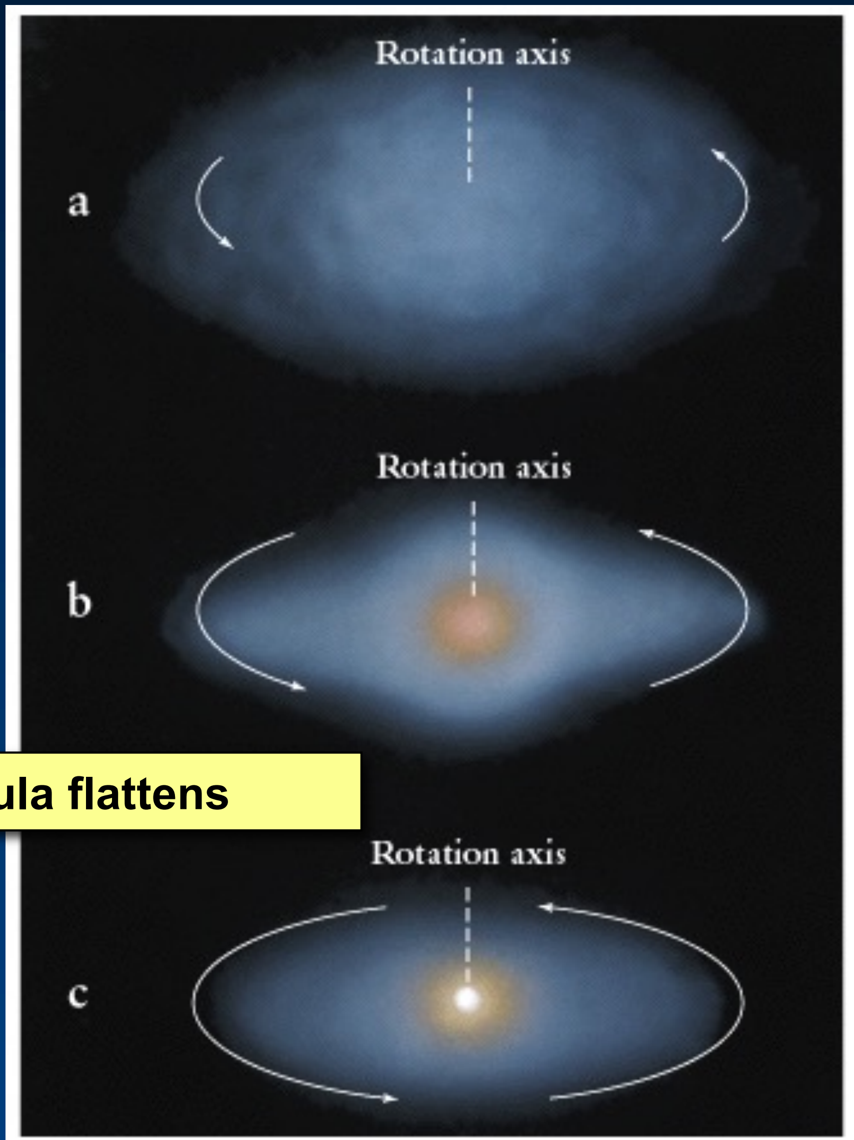
Shows growth of terrestrial planets. If Jupiter's gravity not included, fifth terrestrial planet forms in Asteroid Belt. If Jupiter's gravity included, orbits of planetesimals there are disrupted. Almost all ejected from Solar System.

Simulations also suggest that a few Mars-size objects formed in Asteroid Belt. Their gravity modified orbits of other planetesimals, before they too were ejected by Jupiter's gravity.

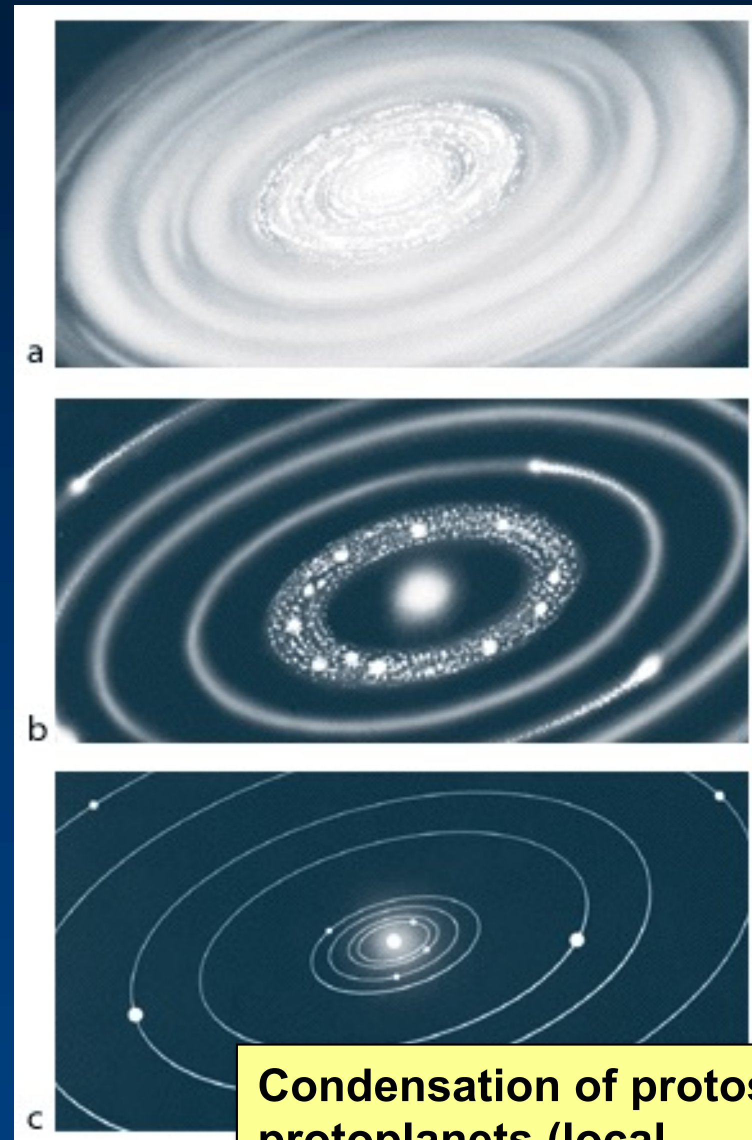
Asteroid Ida

Solar System Planetary Migration – a model

- Jupiter, Saturn, Uranus and Neptune formed closer in, between ~5.5 – 17 AU
- Interactions with disk of small rocky, icy planetesimals lying from orbit of outermost giant planet to ~35 AU caused planets to move out, planetesimals to move in
- Planetesimals eventually interact with Jupiter (huge mass), many get ejected to far out solar system, Jupiter moves in a bit
- In some runs of simulation (but not all), Neptune and Uranus even change places



Nebula flattens

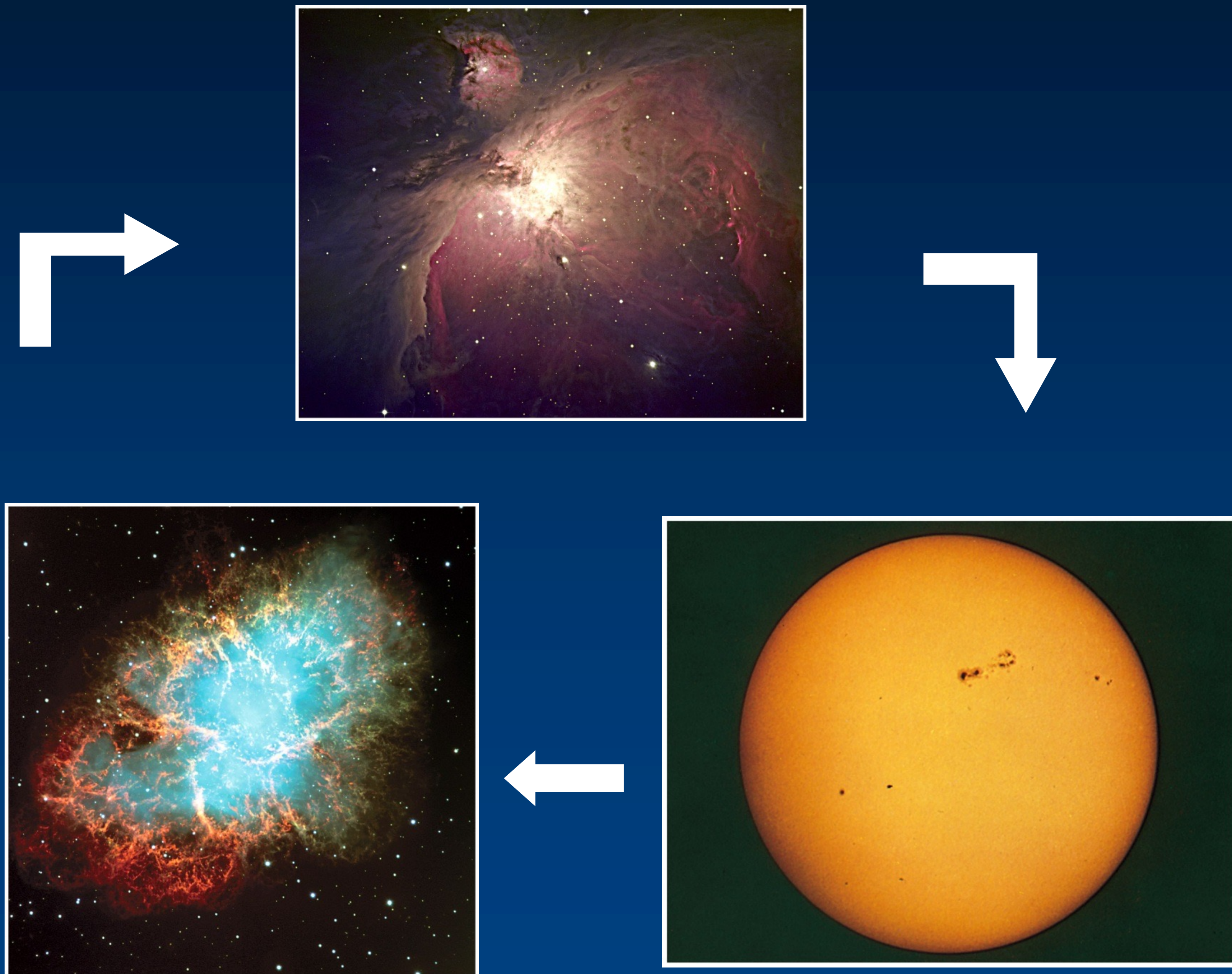


Condensation of protosun and protoplanets (local gravitational instabilities)

- After ~10^7 years the protosun's temperature became high enough to ignite nuclear reactions => a star

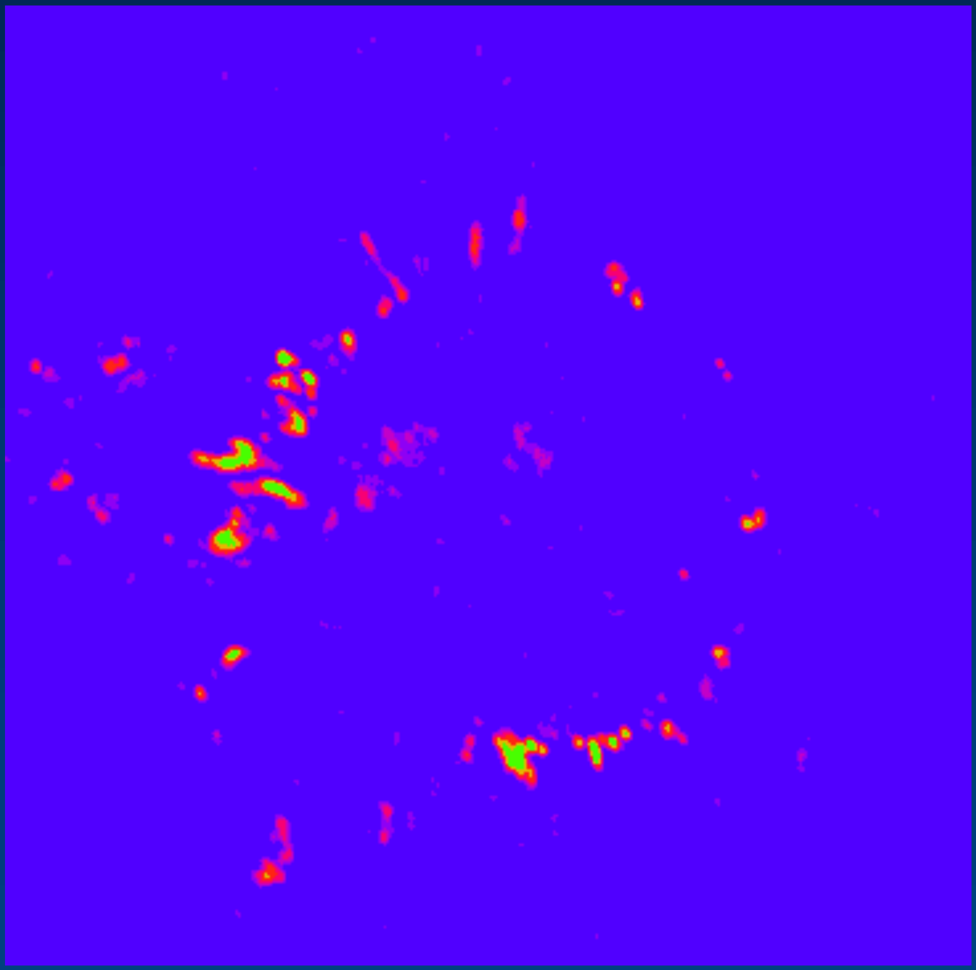
…how was the Solar Nebula formed?

- Abundances of elements are determined by cosmic processes
- H, He created in the Big Bang
- Heavier elements created by stars:
  - Thermonuclear reactions
  - Supernova explosions

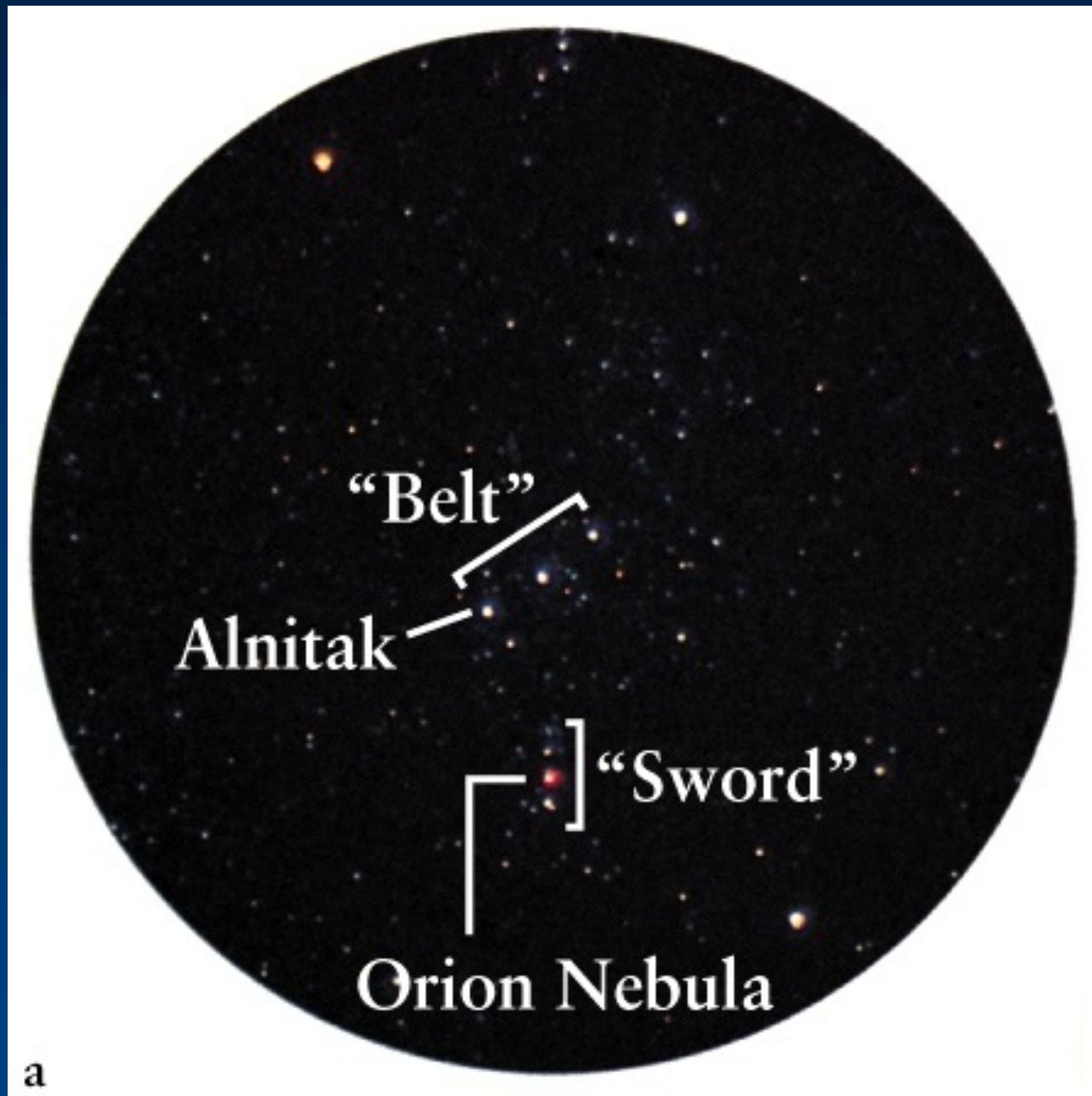


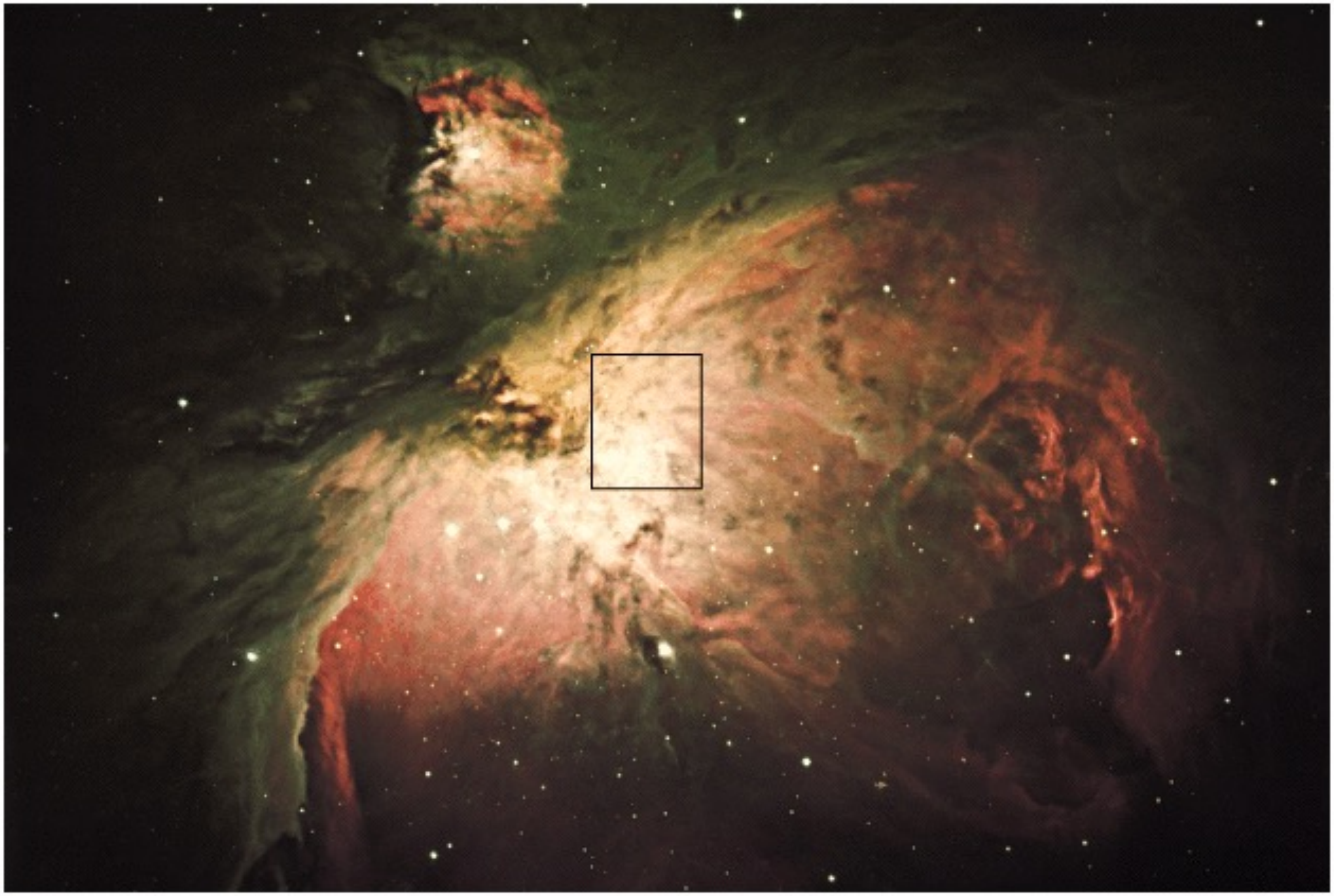
Ejection of stellar material

- Tx Cam - a Mira variable



Superwind from Antares


"Belt"
Alnitak
"Sword"
Orion Nebula
a


b


Eagle Nebula