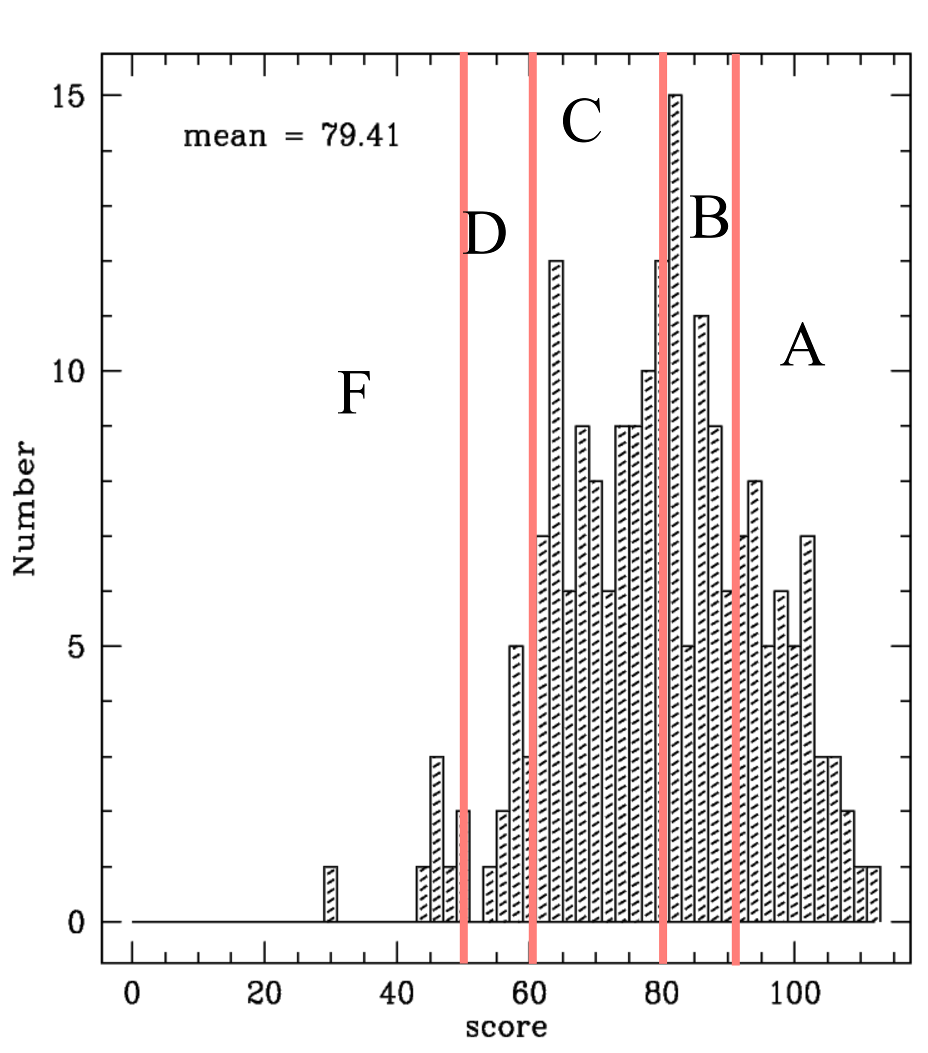
Announcements

The Albuquerque Astronomical Society (TAAS) is hosting a public lecture
SATURDAY, SEPTEMBER 17TH - 7:00pm
SCIENCE AND MATH LEARNING CENTER, UNM CAMPUS
Free and open to the public
“USA Total Solar Eclipse” of August 21, 2017 by Mike Molitor

HW #3 is Due on Thursday (September 22) as usual. Chris will be in RH111 on that day.

Exam 1 test results

Grades posted online in Learn



Clicker Question:

According to Newton's Law of Gravity, if the distance between two masses is doubled, the gravitational force between them is

A: half as strong

B: twice as strong

C: one fourth as strong

D: four times as strong

Clicker Question:

One arcsecond is equal to

A: 1/3600 degrees

B: 1/60 degrees

C: 60 arcminutes

D: 60 degrees

Clicker Question:

If the temperature of the Sun suddenly doubled from 6000 to 12000 K, but the size stayed the same, the luminosity would:

A: decrease by a factor of 4

B: increase by a factor of 2

C: increase by a factor of 4

D: increase by a factor of 16

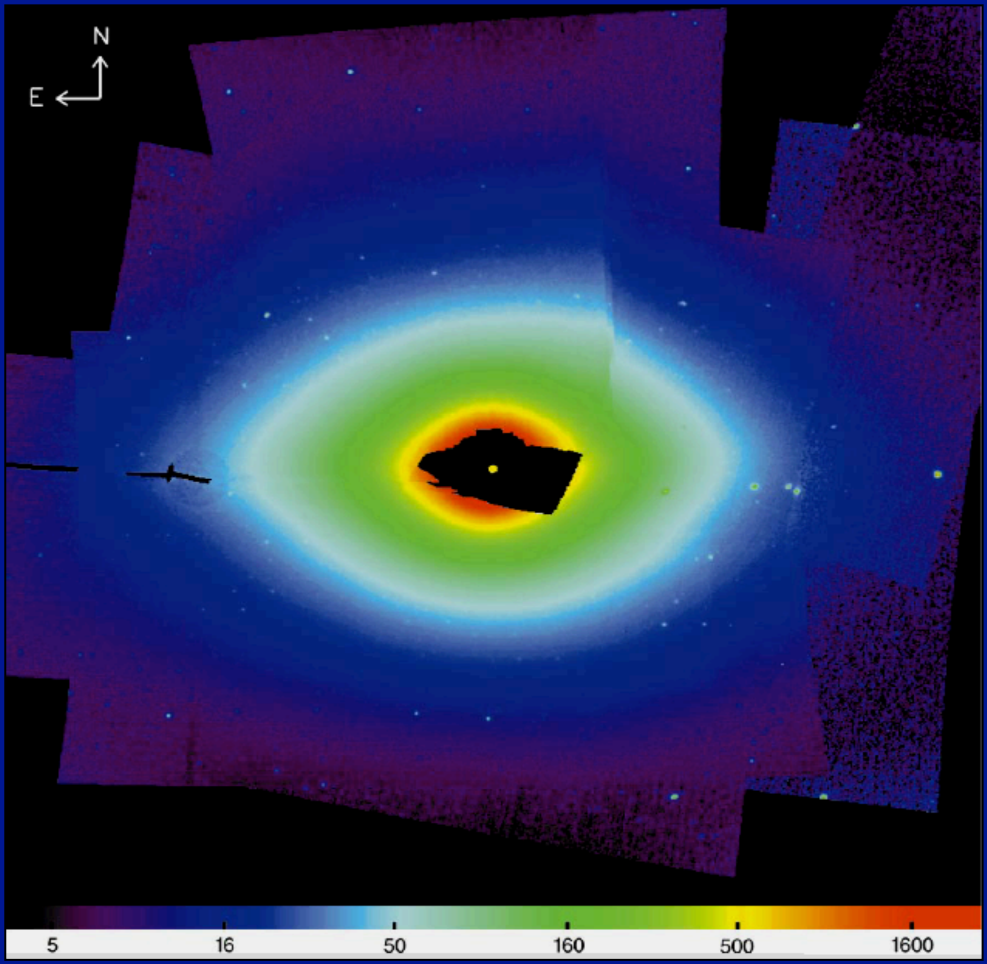
The Solar System

Ingredients?

- The Sun
- Planets
- Dust
- Moons and Rings
- Comets
- Asteroids (size > 100 m)
- Meteoroids (size < 100 m)
- Kuiper Belt
- Oort Cloud
- A lot of nearly empty space

Zodiacal Dust

Looking outwards (away from the sun)



Looking inwards (in infrared)

Zodiacal dust

Dust particles on the plane of the orbits of the planets. (size: 1 to 300 x 10^{-6} m)

Mon. Not. R. astr. Soc. (1974) 166, 439–448.

AN INVESTIGATION OF THE MOTION OF ZODIACAL DUST PARTICLES—I

RADIAL VELOCITY MEASUREMENTS ON FRAUNHOFER LINE PROFILES

T. R. Hicks, B. H. May and N. K. Reay

(Communicated by J. Ring)

(Received 1973 August 3)

SUMMARY

An experiment to record the spectrum of the Zodiacal Light in the neighbourhood of the Mg I absorption line (5183·6 Å) is described. Measurements were made of the Doppler shift imposed on the absorption line by the motion of the interplanetary dust particles. Observations were concentrated on the ecliptic plane, spectra being obtained at lower elongation angles from the Sun than previously achieved, and also over the entire range of high elongations including the Gegenschein.

The reduction methods applied to the data are described and compared, and the new results are presented.

1. INTRODUCTION

Several attempts have been made to measure the wavelength shifts, imposed by the motions of interplanetary dust particles on scattered solar Fraunhofer lines, in the Zodiacal Light (1)–(3).

The observations were made by examining the Zodiacal Light spectrum over a few Ångström units centred on a suitable Fraunhofer line, with high luminosity Fabry–Perot interferometers. Initially the Hβ 4861 Å line was used by Clarke *et al.* (1) and Reay & Ring (2), but a strong emission core detected at this wavelength (4), (5) caused James & Smeethe (3) to use the Mg I 5183·6 Å line. Because of the faintness of the Zodiacal Light, few accurate measurements have been made at elongations greater than 50°.

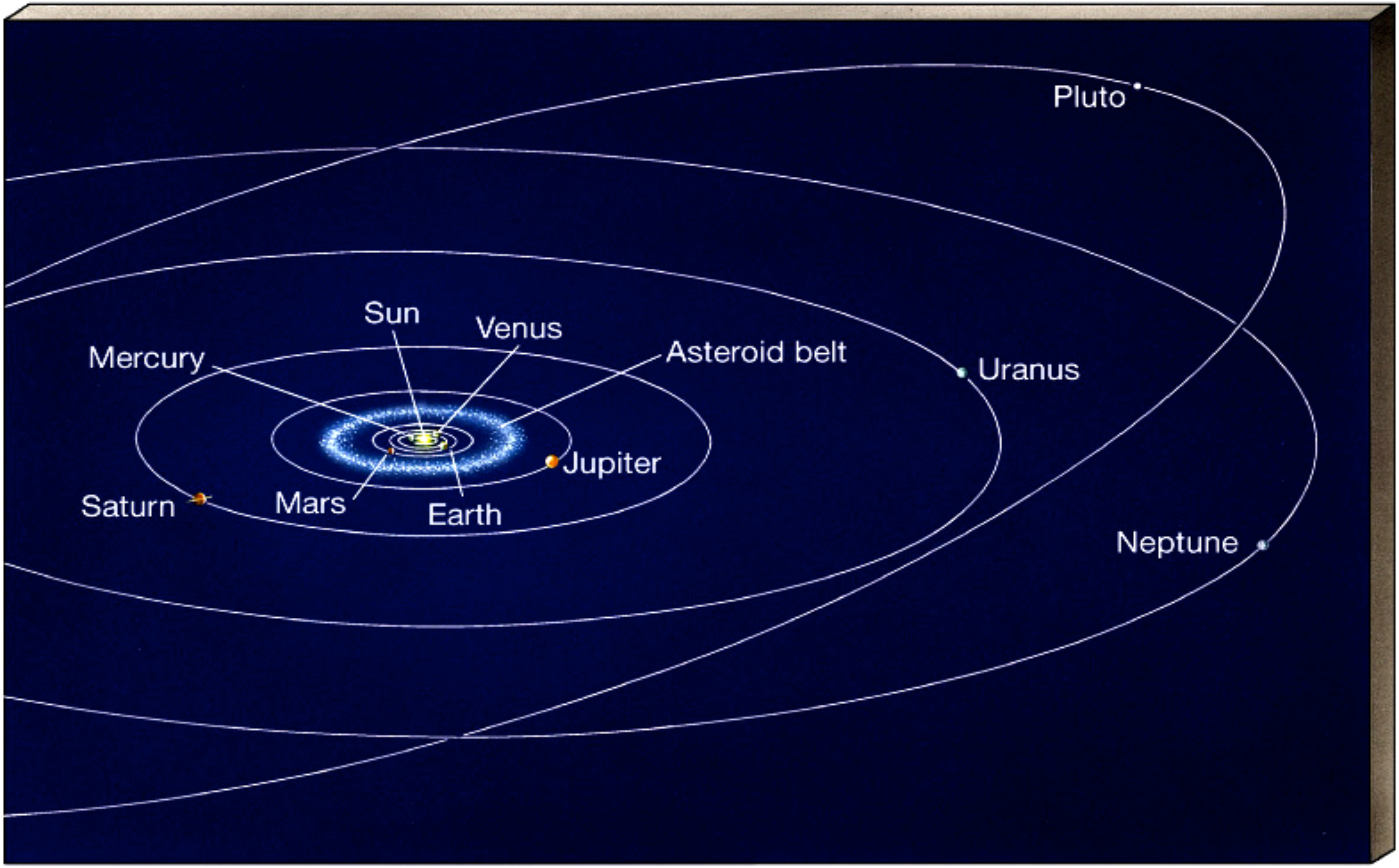
Models of the Zodiacal dust cloud have been constructed (6), (7) based on the available low elongation data, but the level of confidence placed in such models cannot be high until accurate data is obtained over the entire range of elongations.

For the last three years observations have been conducted by the Astronomy Group of Imperial College to obtain such accurate data, with the ultimate aim of constructing a model of the dust cloud. This follows a similar approach to that used by Reay & Ring (2) and later James & Smeethe (3). The measurements were made on the Mg I 5183·6 Å line from the 'Observatorio del Teide', Tenerife. Stringent precautions were taken to minimize errors in wavelength measurement and a large body of accurate data was collected, about 300 scans in all, during 1971 September–October and 1972 April.

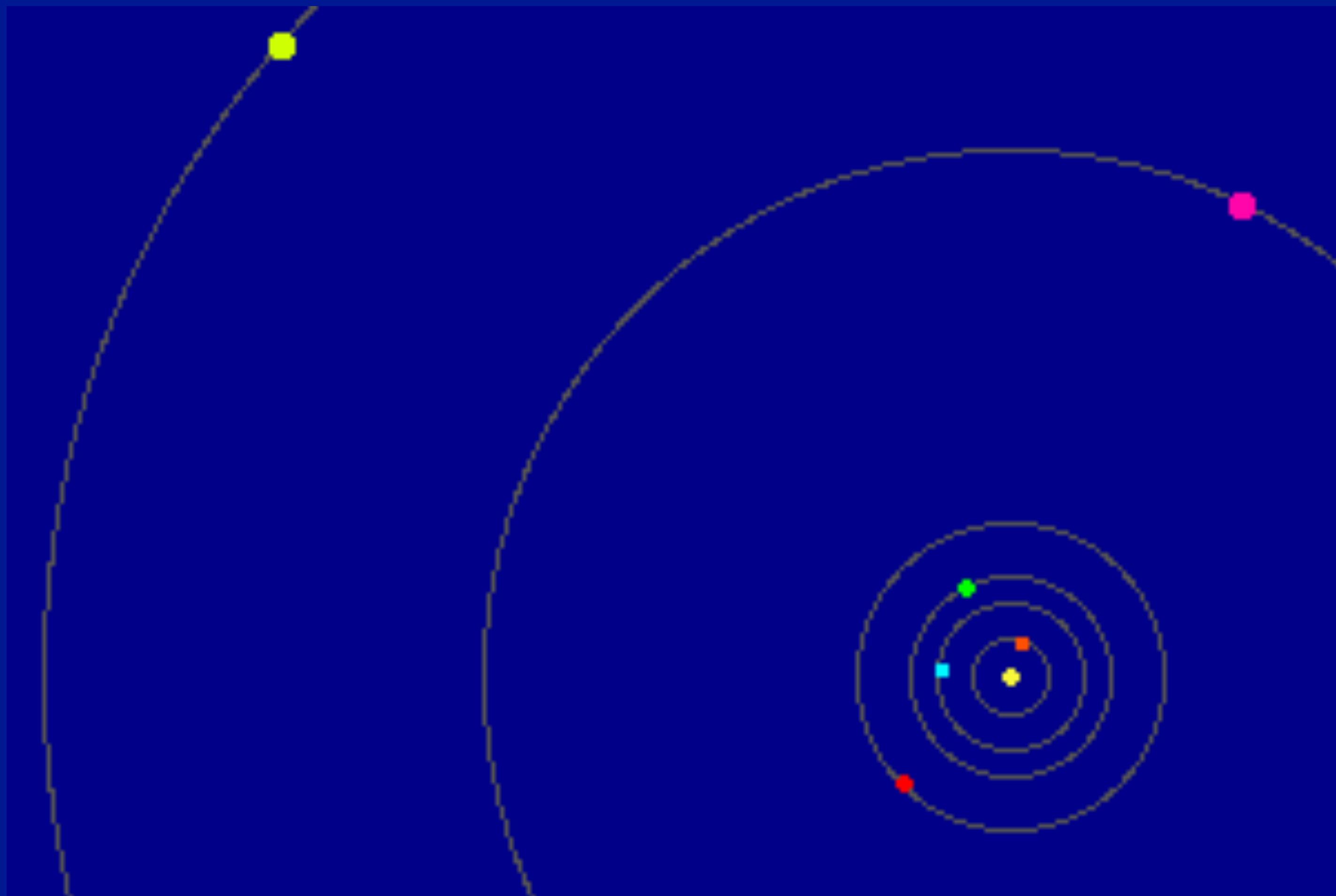
2. THE INSTRUMENT

Light was directed into the laboratory using a 6-in. aperture two-mirror coelostat, with a third mirror to produce a horizontal beam 48 in. from the floor.

Solar System Perspective



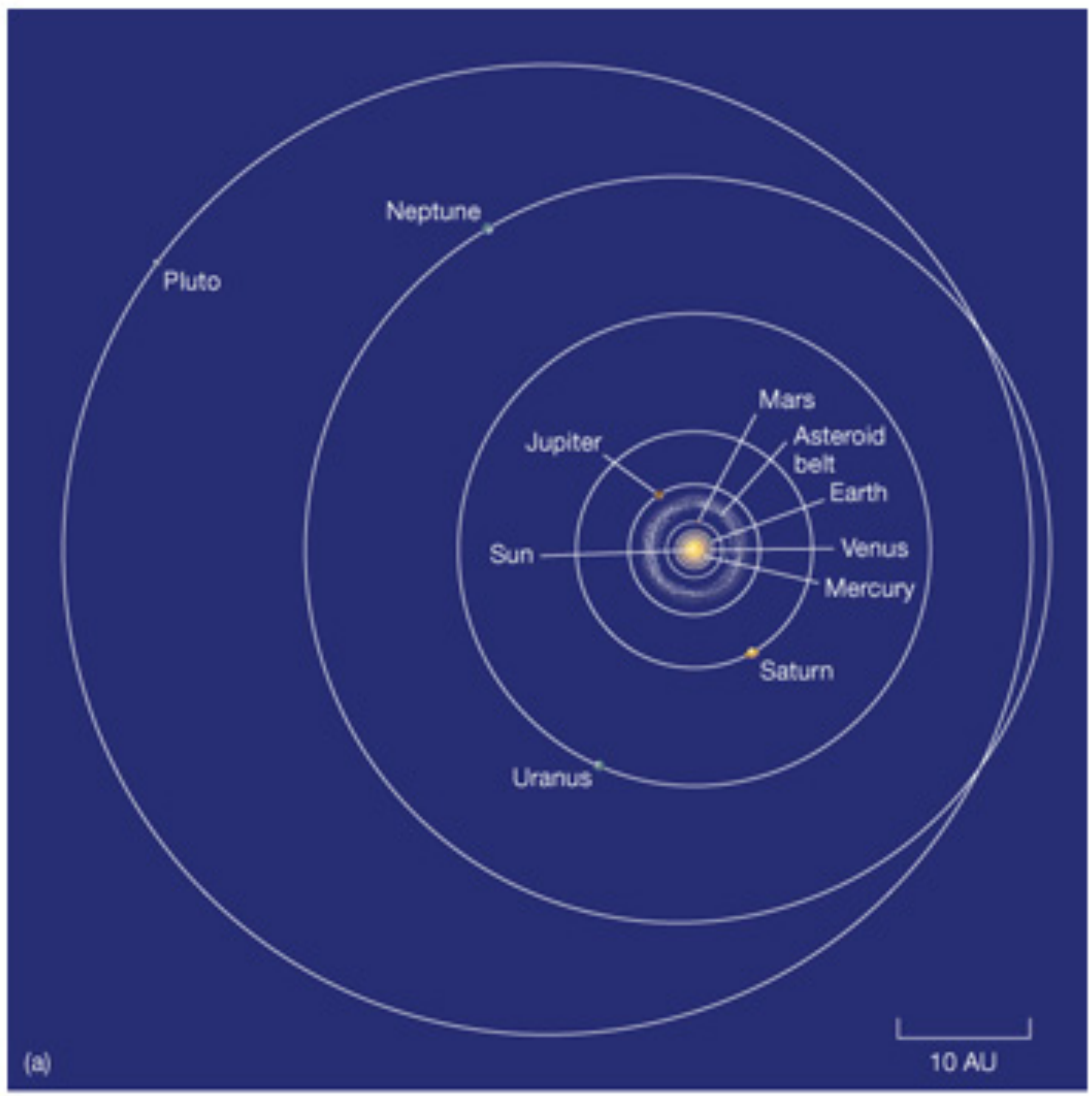
Orbits of Planets



All orbit in same direction.

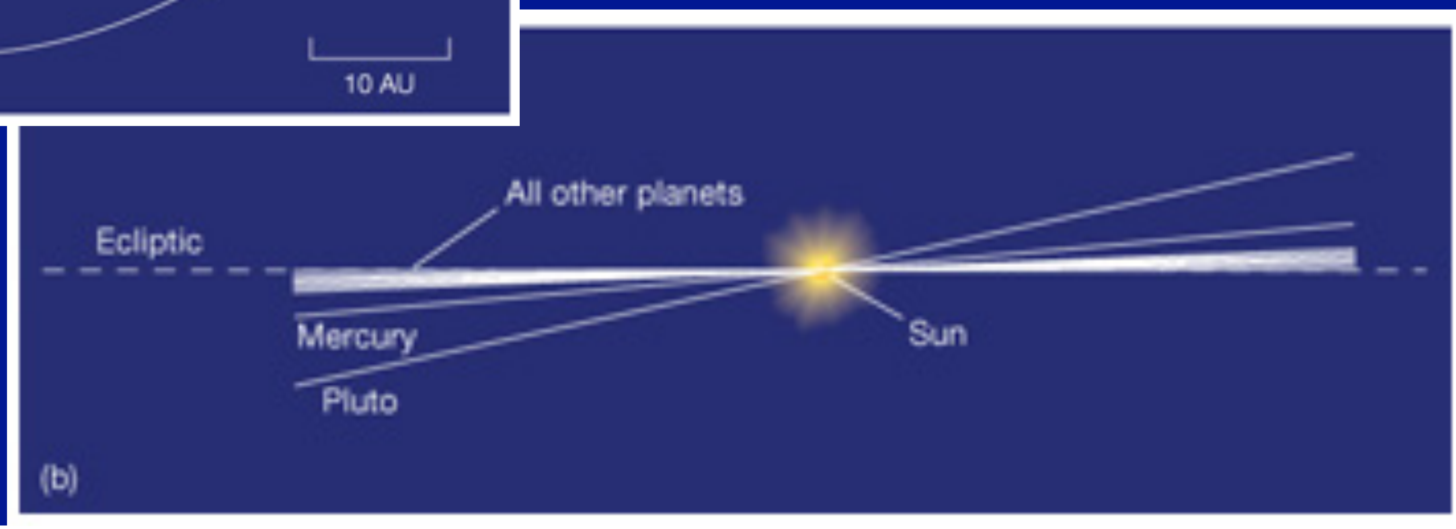
Most orbit in same plane.

Elliptical orbits, but low eccentricity for most, so nearly circular.

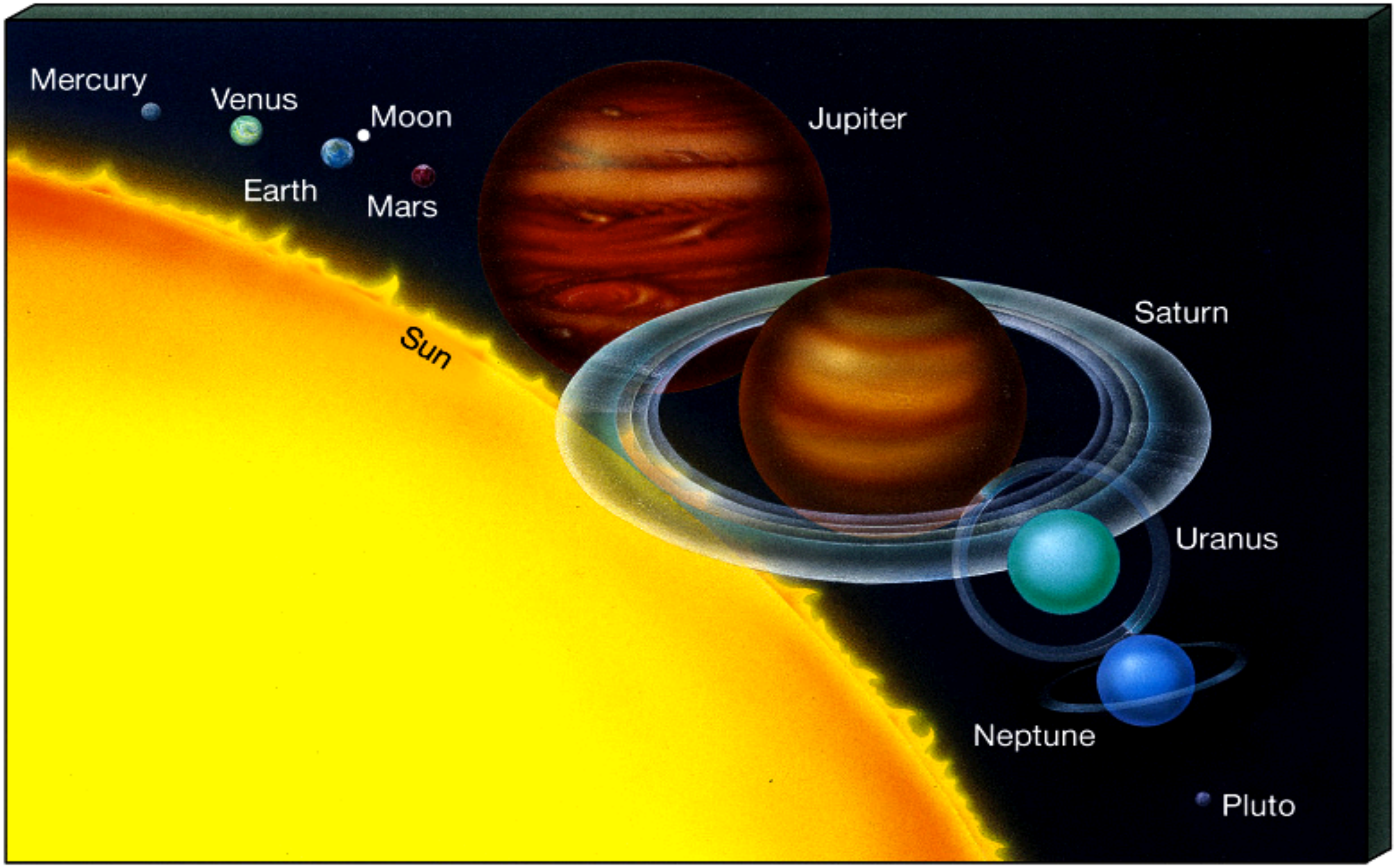


Exceptions:

Mercury	Pluto (no longer a planet)
orbital tilt 7°	orbital tilt 17.2°
eccentricity 0.21	eccentricity 0.25



Sun, Planets,our Moon and Pluto to scale (mostly)



Mistakes: Jupiter should have rings
Pluto should be smaller than Moon

DEMO: Bag of Planets

Two Kinds of "Classical" Planets

"Terrestrial"

Mercury, Venus,
Earth, Mars

Close to the Sun
Small
Mostly Rocky
High Density (3.3 -5.3 g/cm^3)
Slow Rotation (1 - 243 days)
Few Moons
No Rings
Main Elements Fe, Si, C, O, N

"Jovian"

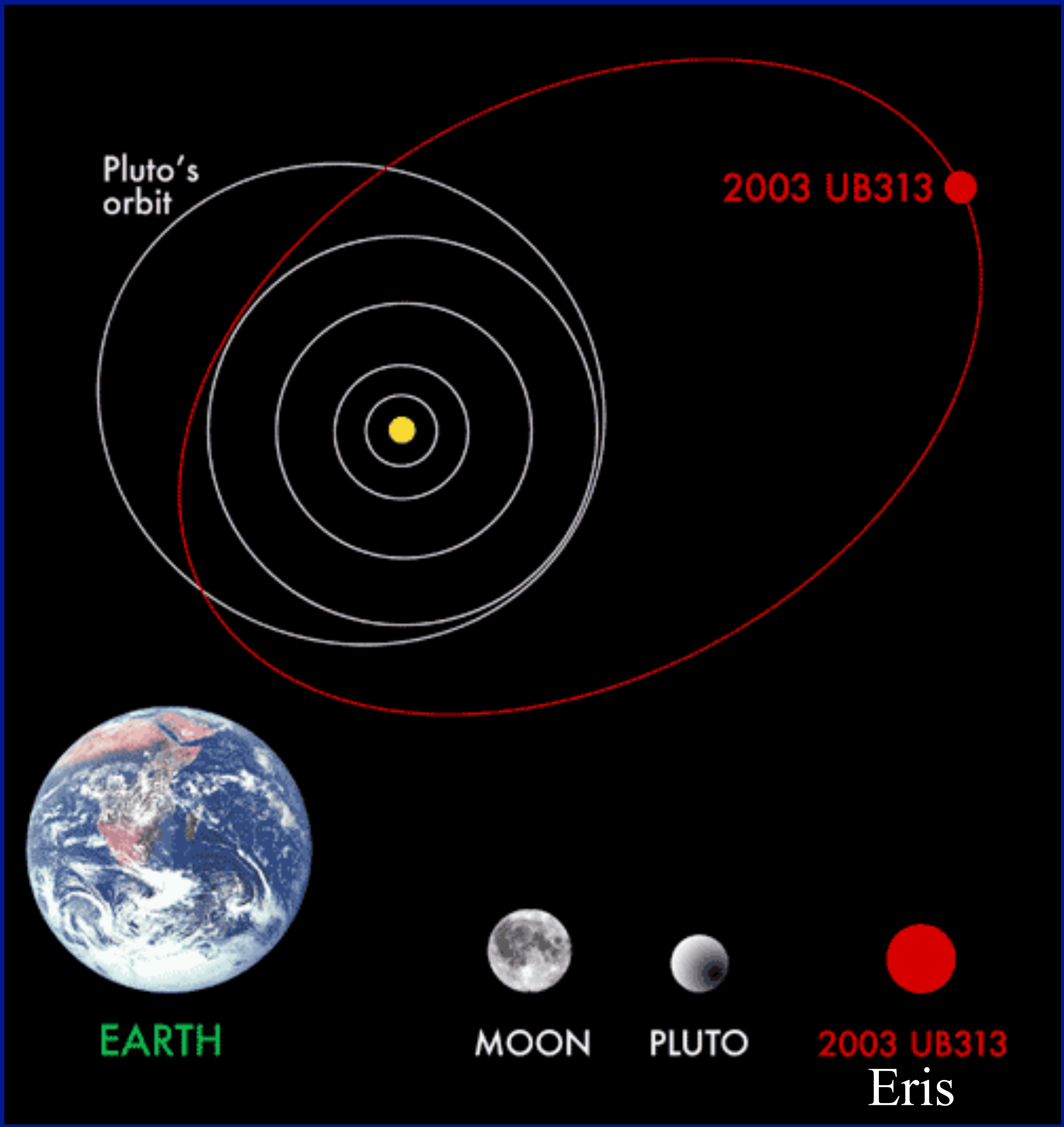
Jupiter, Saturn,
Uranus, Neptune

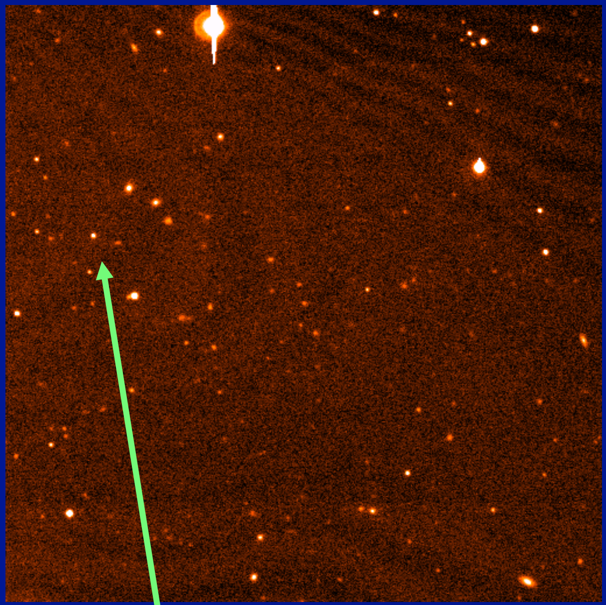
Far from the Sun
Large
Mostly Gaseous
Low Density (0.7 -1.6 g/cm^3)
Fast Rotation (0.41 - 0.72 days)
Many Moons
Rings
Main Elements H, He

Dwarf Planets compared to Terrestrial Planets

"Terrestrial"	Dwarf Planets
Mercury, Venus, Earth, Mars	Pluto, Eris, many others
Close to the Sun	Far from the Sun
Small	Very small
Mostly Rocky	Rock and Ice
High Density (3.3 -5.3 g/cm^3)	Moderate Density (2 - 3 g/cm^3)
Slow Rotation (1 - 243 days)	Rotation?
Few Moons	Few Moons
No Rings	No Rings
Main Elements Fe, Si, C, O, N	Main Elements Fe, Si, C, O, N
	And an icy surface

Dwarf planets continued





Sequence of discovery images

How did the Solar System Form?

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

- Solar system is very flat.
- Almost all moons and planets (and Sun) rotate and revolve in the same direction.
- Planets are isolated in space.
- Terrestrial - Jovian planet distinction.
- Leftover junk (comets and asteroids).

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

Early Ideas

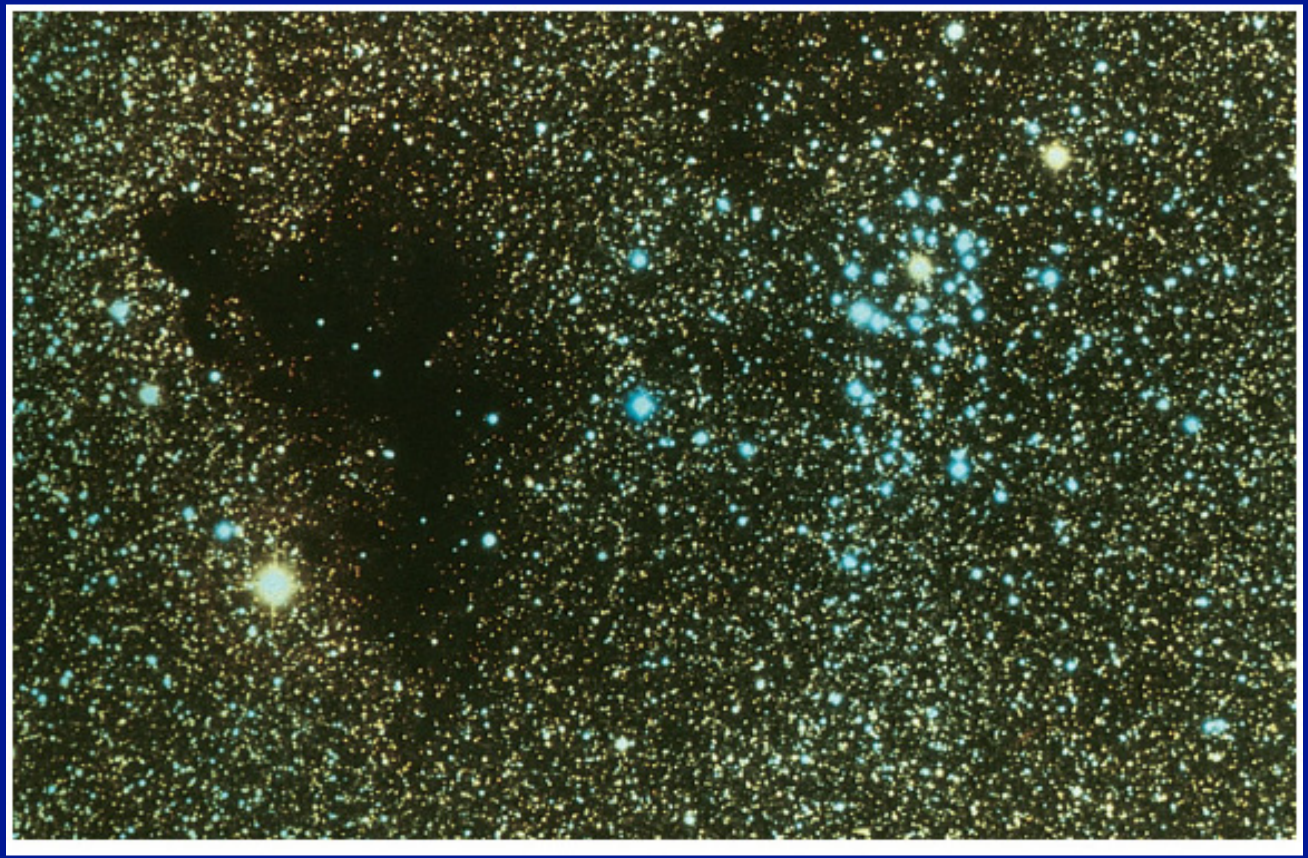
René Descartes (1596 -1650) <u>nebular theory</u>:

Solar system formed out of a "whirlpool" in a "universal fluid". Planets formed out of eddies in the fluid.
Sun formed at center.
Planets in cooler regions.
Cloud called "Solar Nebula".

This is pre-Newton and modern science. But basic idea correct, and the theory evolved as science advanced, as we'll see.

A cloud of interstellar gas

a few light-years, or about 1000 times bigger than Solar System

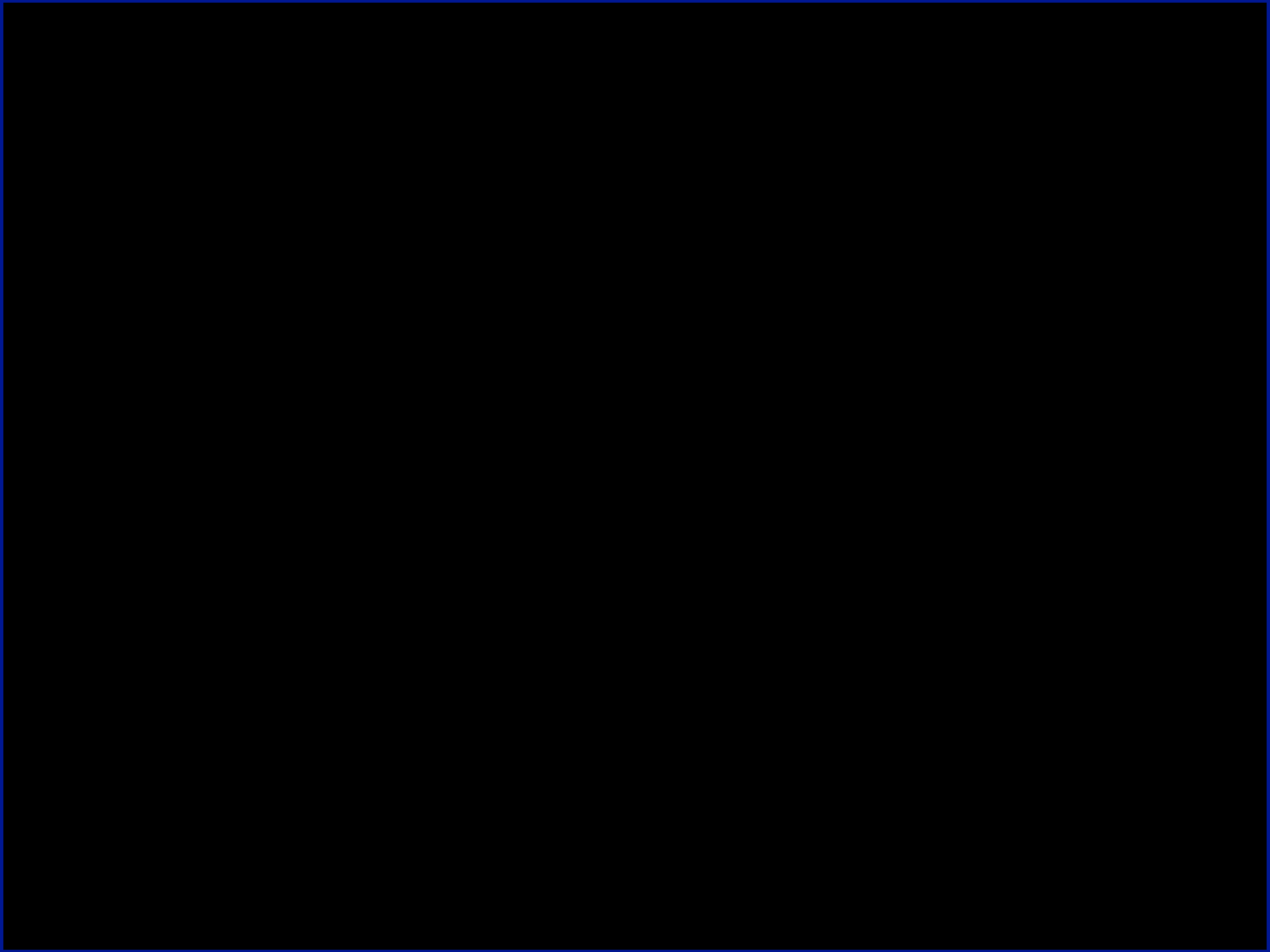


The associated dust blocks starlight. Composition mostly H, He.

Too cold for optical emission but some radio spectral lines from molecules. Doppler shifts of lines indicate clouds rotate at a few km/s.

Clumps within such clouds collapse to form stars or clusters of stars. They are spinning at about 1 km/s.

Solar System Formation Video



Clicker Question:

Which of the following is a Terrestrial planet:

A: Jupiter

B: Saturn

C: Mercury

D: Pluto

E: Neptune

Clicker Question:

In the leading theory of solar system formation, the planets:

A: were ejected from the Sun following a close encounter with another star.

B: formed from the same flattened, swirling gas cloud that formed the sun.

C: were formed before the Sun.

D: were captured by the Sun as it traveled through the galaxy.

But why is Solar System flat?

Pierre Laplace (1749 - 1827): an important factor is "conservation of angular momentum":

When a rotating object contracts, it speeds up.

"linear momentum" mass x velocity

"angular momentum" (a property of a spinning or orbiting object) mass x velocity x "size"

of spin or orbit

of spinning object or orbit

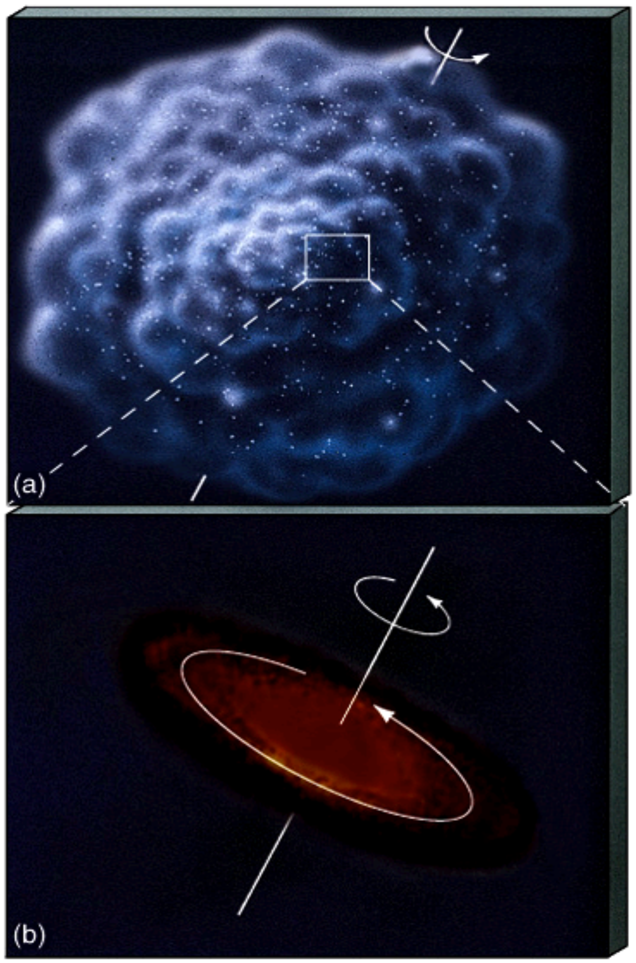
(Orban/Corbis/Sygma)

Well demonstrated by ice skaters . . .

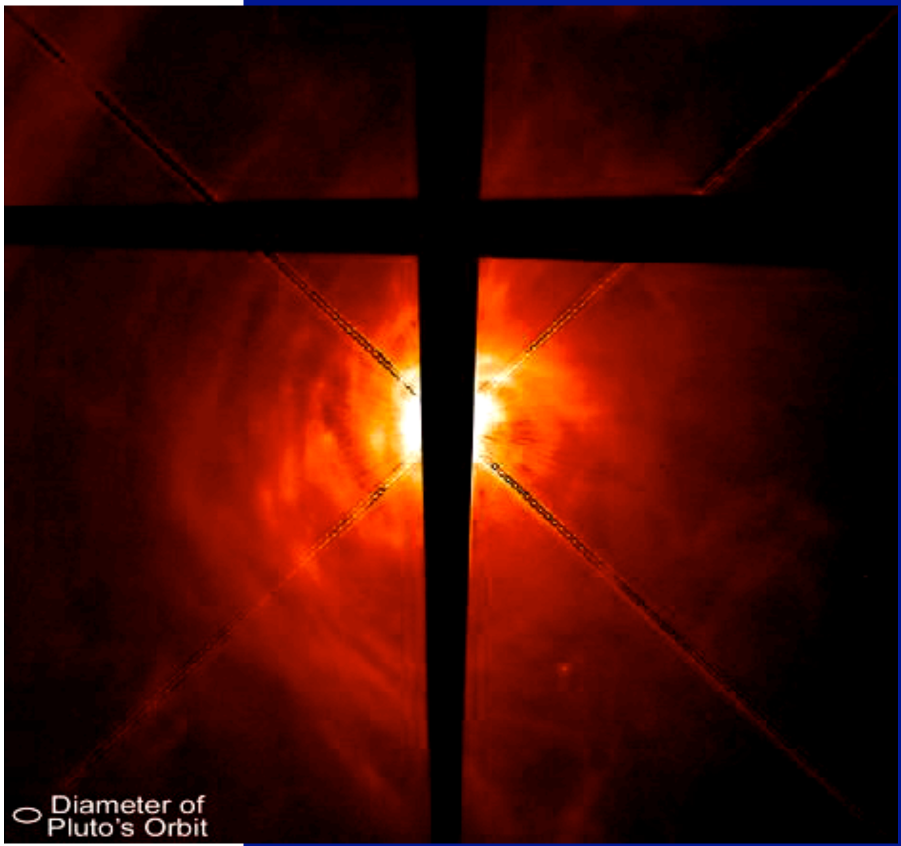
DEMO - Conservation of Angular momentum

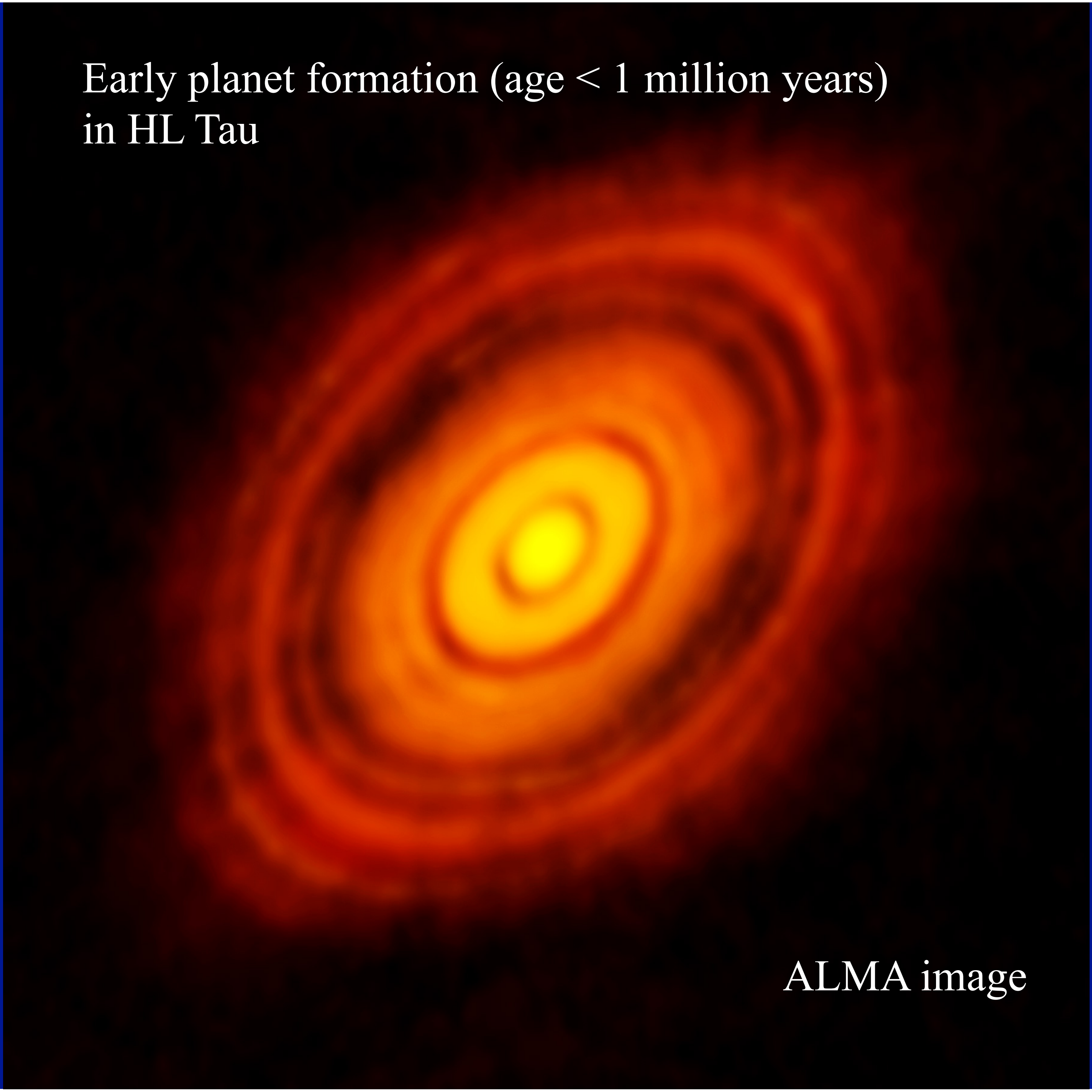
So, as nebula contracted it rotated faster.

Could not remain spherical! Faster rotation tended to fling stuff outwards, so it could only collapse along rotation axis => it became a flattened disk, like a pizza crust.



Hubble is seeing these now!




Early planet formation (age < 1 million years)
in HL Tau
ALMA image

Now to make the planets . . .

Solar Nebula:

98% of mass is gas (H, He)
2% in dust grains (Fe, C, Si . . .)

Condensation theory:

1) Dust grains act as "condensation nuclei": gas atoms stick to them => growth of first clumps of matter.

2) Accretion: Clumps collide and stick => larger clumps. Eventually, small-moon sized objects: "planetesimals".

3) Gravity-enhanced accretion: objects now have significant gravity. Mutual attraction accelerates accretion. Bigger objects grow faster => a few planet-sized objects.

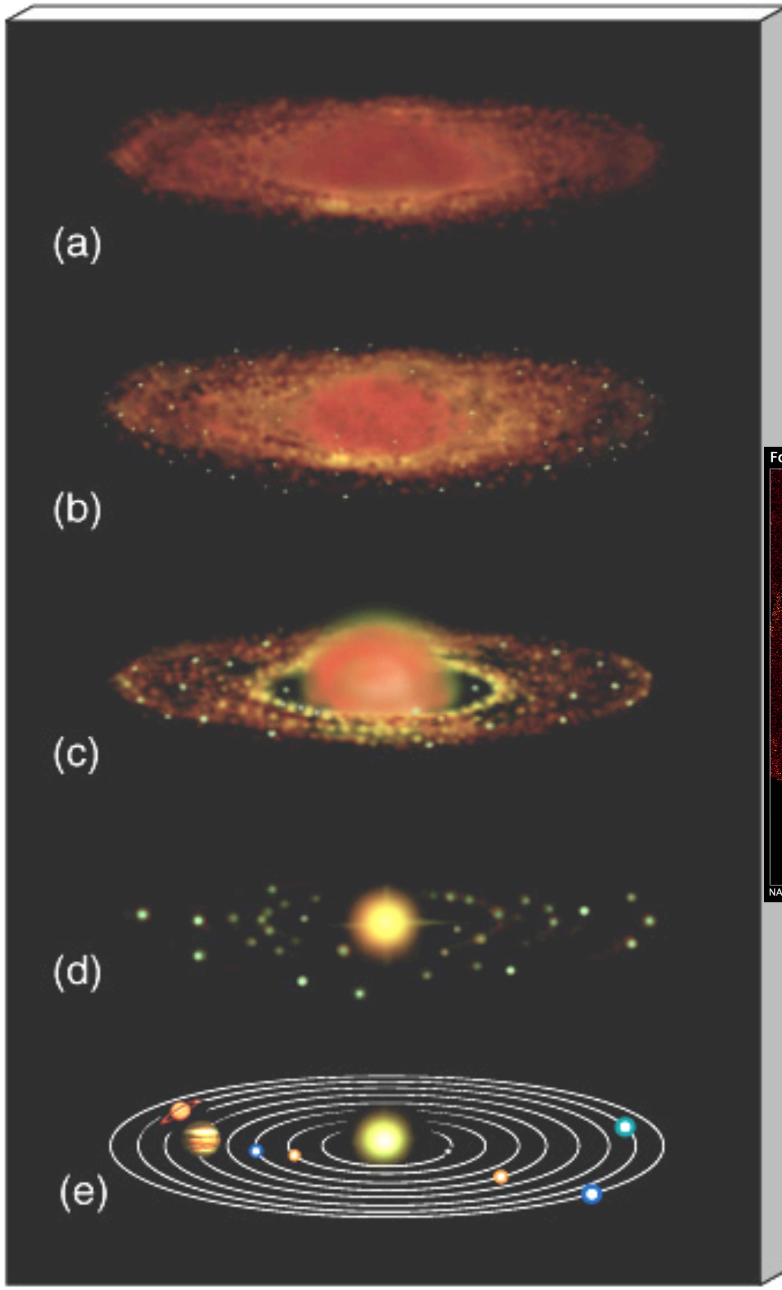
initial gas and dust nebula

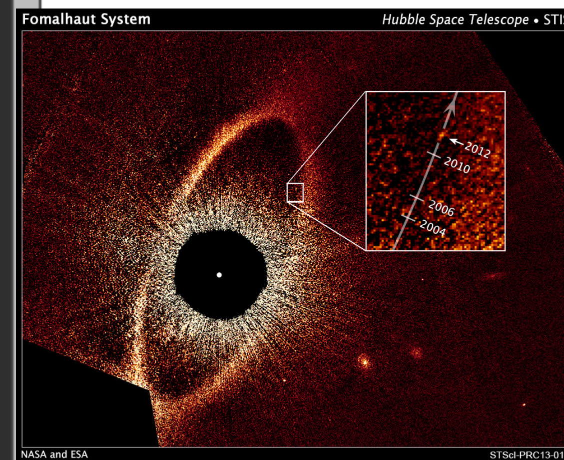
dust grains grow by accreting gas, colliding and sticking

continued growth of clumps of matter, producing planetesimals

planetesimals collide and stick, enhanced by their gravity

result is a few large planets





Hubble observation of disk and planet around the bright star Fomalhault

Terrestrial - Jovian Distinction

Inner parts of disk hotter (due to forming Sun): mostly gas. Accretion of gas atoms onto dust grains relatively inefficient.

Outer parts cooler: ices form (but still much gas), also ice "mantles" on dust grains => much more solid material for accretion => larger planetesimals => more gravity => even more material.

Jovian solid cores ~ 10-15 M_{Earth} . Strong gravity => swept up and retained large gas envelopes.

Composition of Terrestrial planets reflects that of initial dust – it is not representative of Solar System, or Milky Way, or Universe.

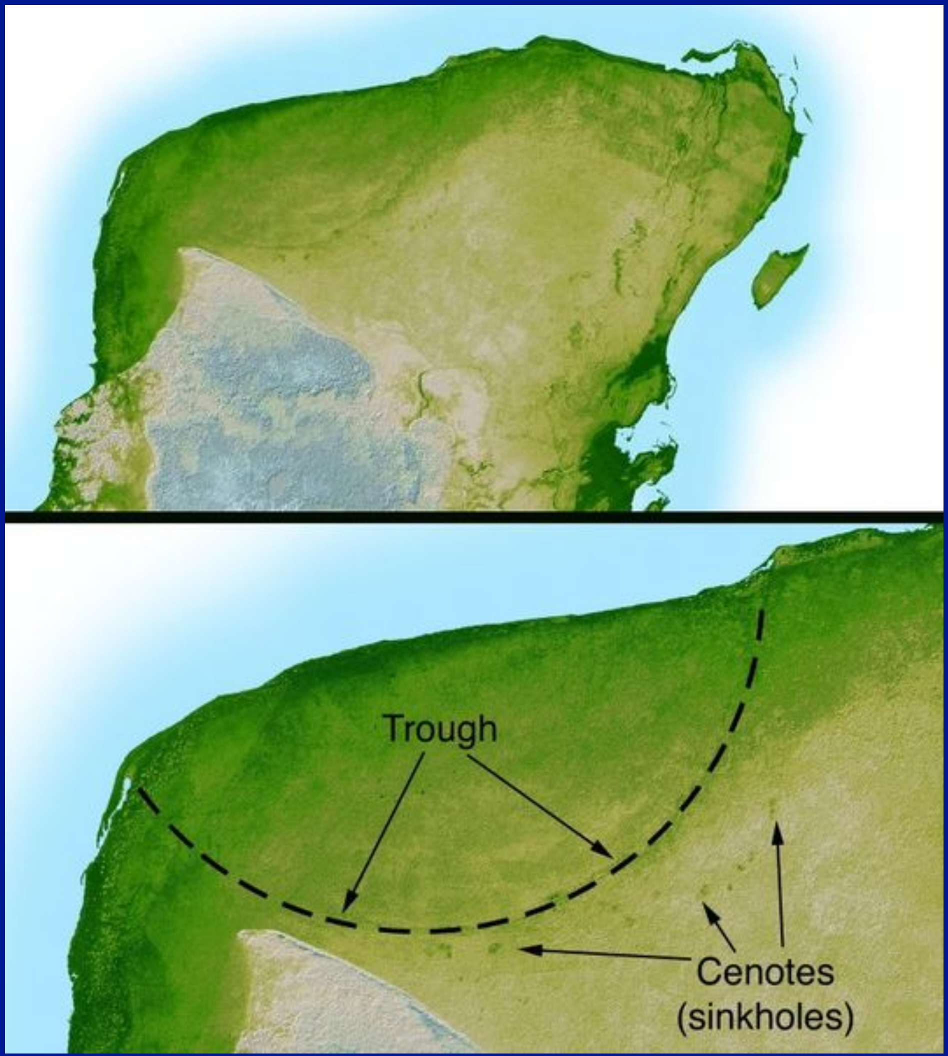
Asteroid Belt

Perhaps a planet was going to form there. But Jupiter's strong gravity disrupted the planetesimals' orbits, ejecting them out of Solar System. The Belt is the few left behind.

And Finally . . .

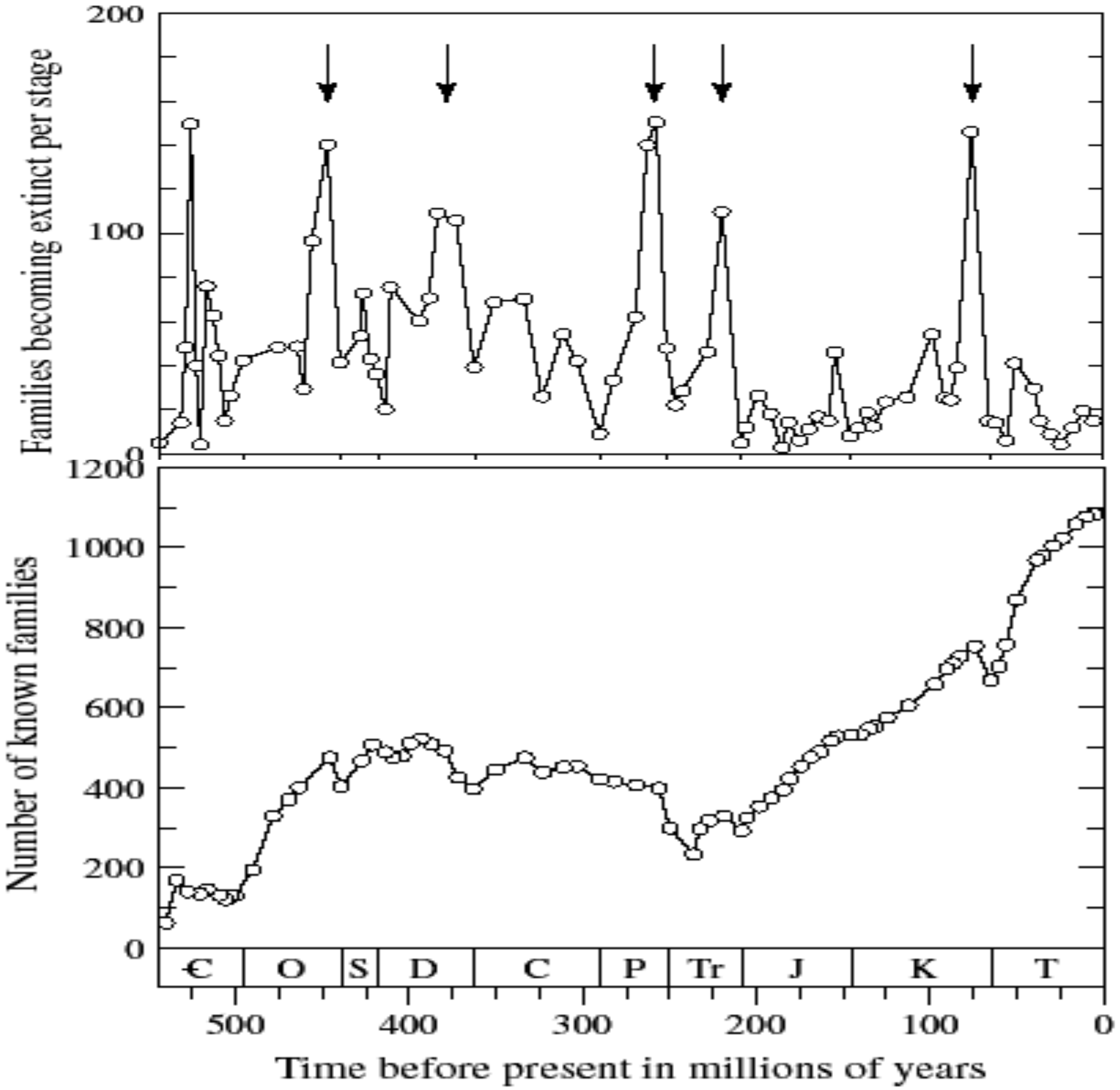
Remaining gas swept out by Solar Wind.

Dinosaur Killer Impact 65 million years ago



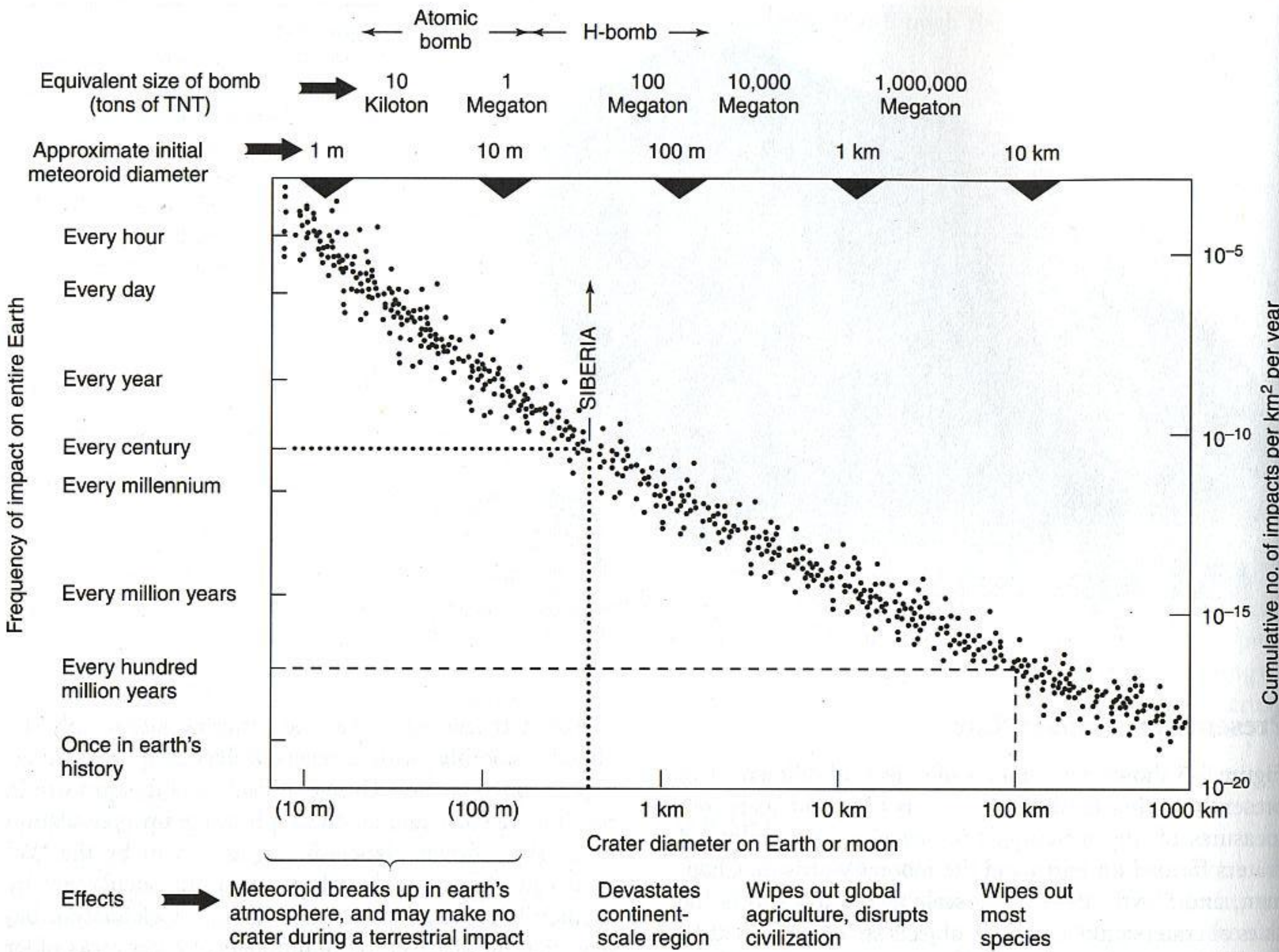
High levels of iridium in Raton Pass (I25)

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
Frequency of impact on entire Earth
Every hour
Every day
Every year
Every century
Every millennium
Every million years
Every hundred million years
Once in earth's history
SIBERIA
Cumulative no. of impacts per km² per year
10⁻⁵
10⁻¹⁰
10⁻¹⁵
10⁻²⁰
(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

Clicker Question:

We can tell something of the overall composition of the planets by looking at their:

A: spectra

B: temperature

C: mass and radius

D: magnetic fields

Clicker Question:

An asteroid impact like the one that killed off the dinosaurs is expected once every:

A: year

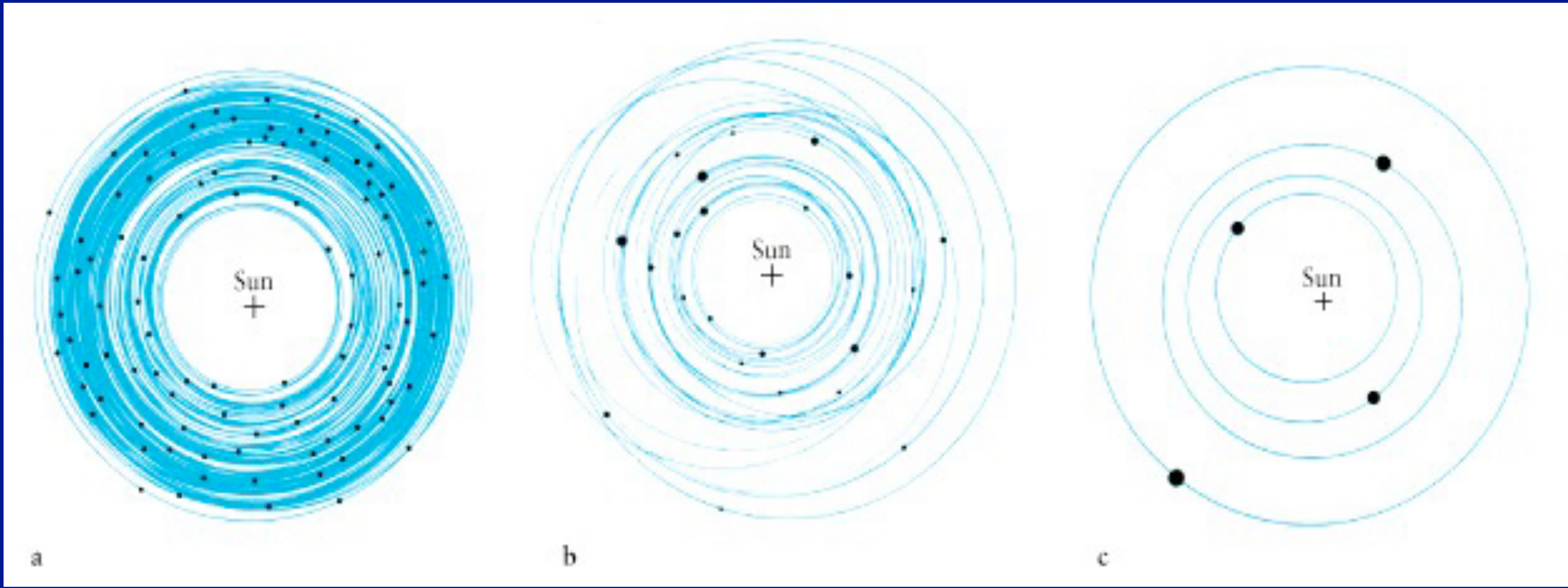
B: hundred years

C: thousand years

D: hundred thousand years

E: hundred million years

Result from computer simulation of planet growth

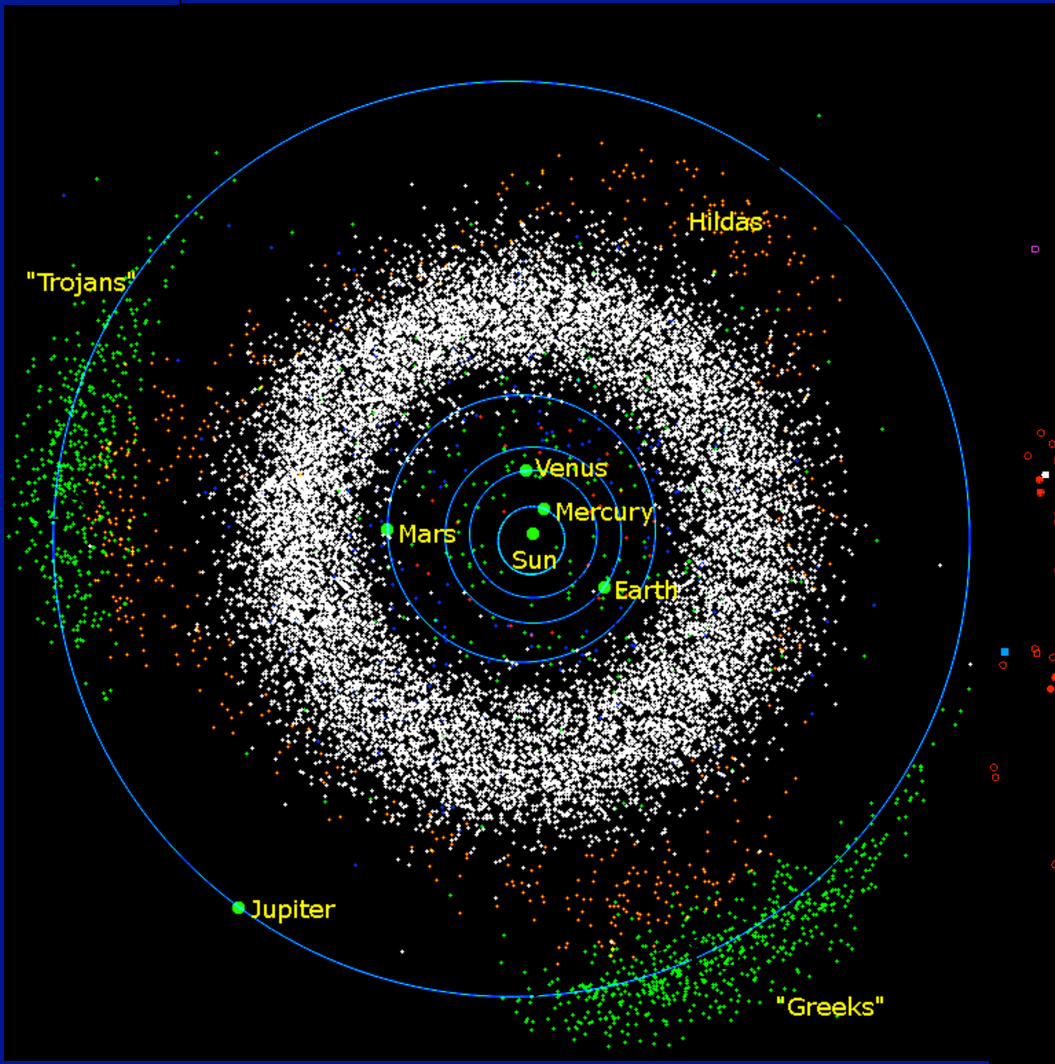


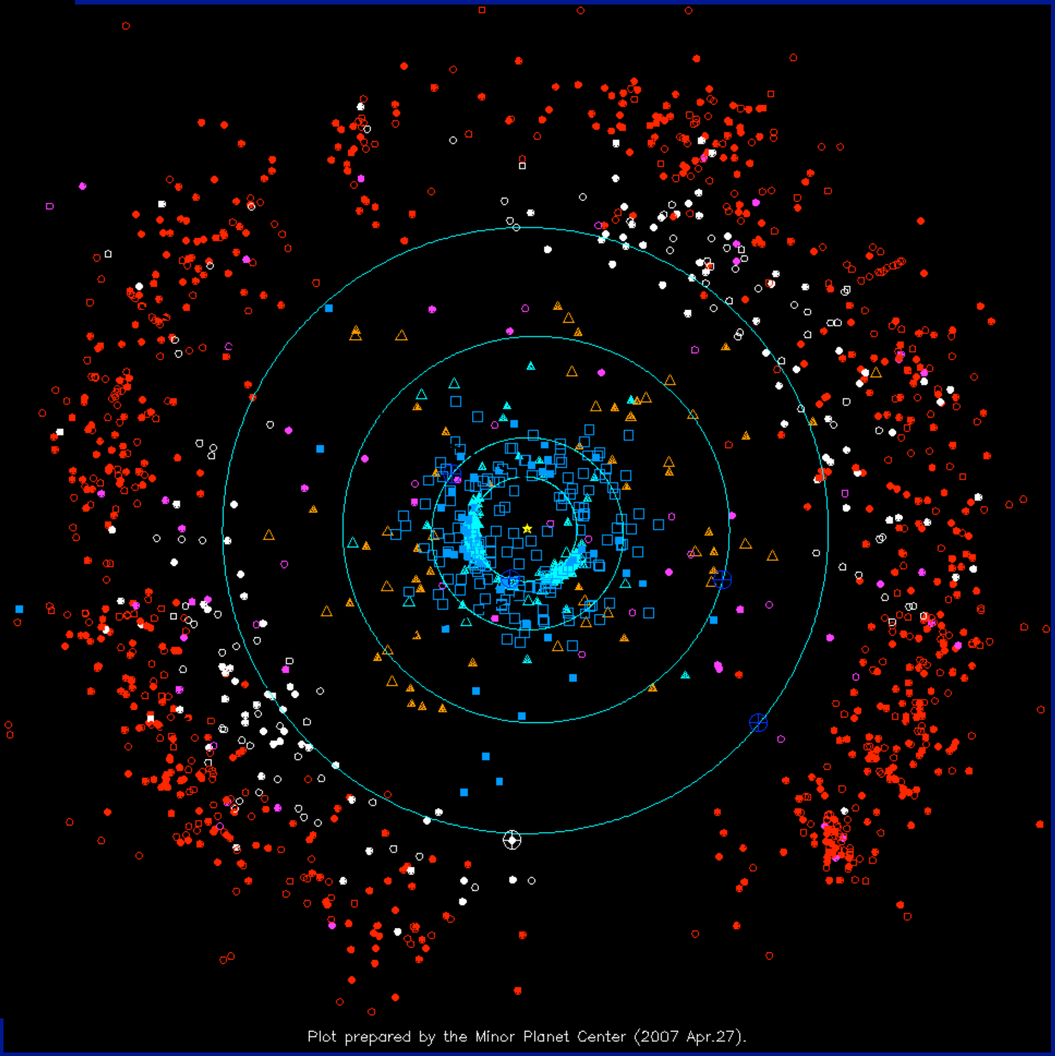
Shows growth of terrestrial planets. If Jupiter's gravity not included, fifth terrestrial planet forms in Asteroid Belt. If Jupiter's gravity included, orbits of planetesimals there are disrupted. Almost all ejected from Solar System.

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

The Structure of the Solar System





~ 5 AU

~ 45 AU

Lagrange Points