Terrestrial Planets

Week 4

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FD Adams 131C

Formation of our Solar System

In the beginning, the Big Bang created the simplest of atomic nuclei, **^{1}H**, **^{4}He**, traces of **^{2}H**, **^{3}He**, **^{3}H**, **^{7}Be**, **^{7}Li** and **^{6}Li** but nothing much else. All the more massive nuclei were created in the nuclear fires of stars and supernoval explosions.

Resulting from this nucleosynthesis, the elements that form our Earth and Solar System assembled into gases and mineral dusts.

From these our Earth, Sun and sister planets condensed.

Formation of our Solar System

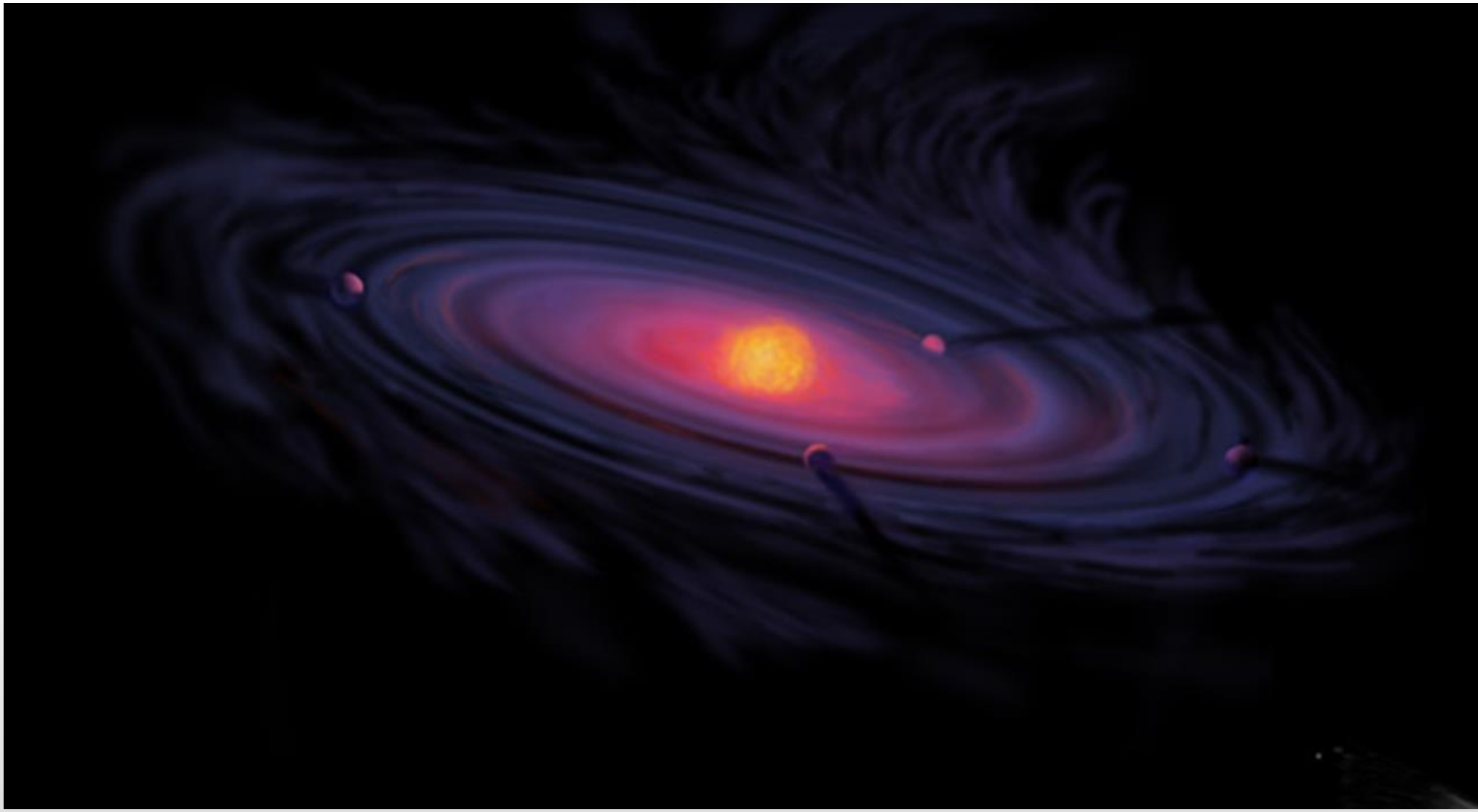
About 5×10^9 years ago, when the Universe was already, perhaps 8×10^9 years old, at some gravitational centre, material from the clouds of dust and gas left behind by supernoval explosions began to assemble the mass of our Solar System.

The gravitational condensation of the dispersed cloud may have been triggered by shock waves created in the explosion of a nearby low-mass core-collapse supernova.

Formation of our Solar System

All isotopes of elements known to still exist in our Solar System, except for those with short decay half-life, promethium, $^{141-156}$**Pm**, technitium $^{93-99}$**Tc** and the trans-bismuth elements, those with atomic numbers greater than 83, pre-existed in the condensing ***"molecular cloud".***

Formation of our Solar System



Artist's image of protoplanetary nebula: By NASA [Public domain], via Wikimedia Commons

https://en.wikipedia.org/wiki/Formation_and_evolution_of_the_Solar_System

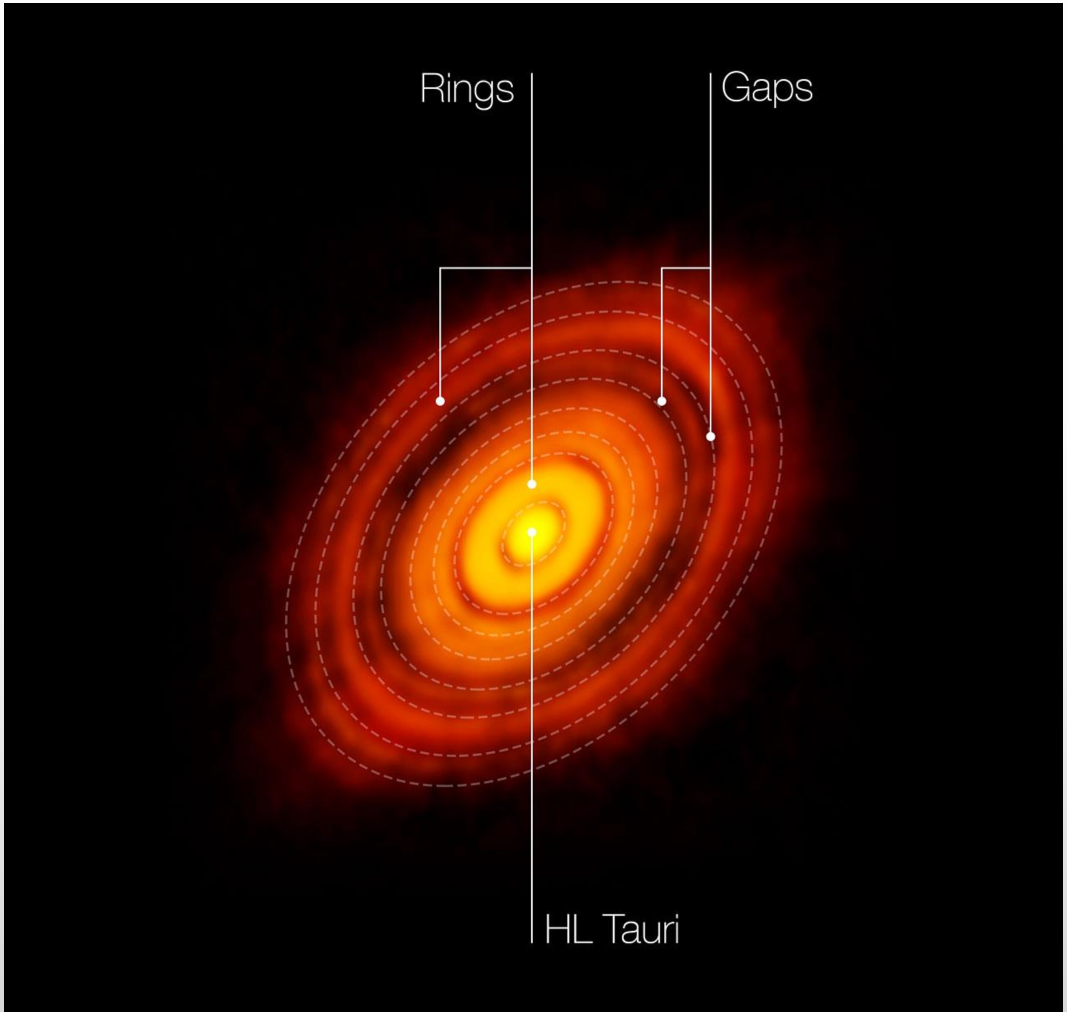
Molecular cloud: Orion Nebula

By Skatebiker at English Wikipedia [Public domain], via Wikimedia Commons

By C.R. O'Dell/Rice University; NASA [Public domain], via Wikimedia Commons

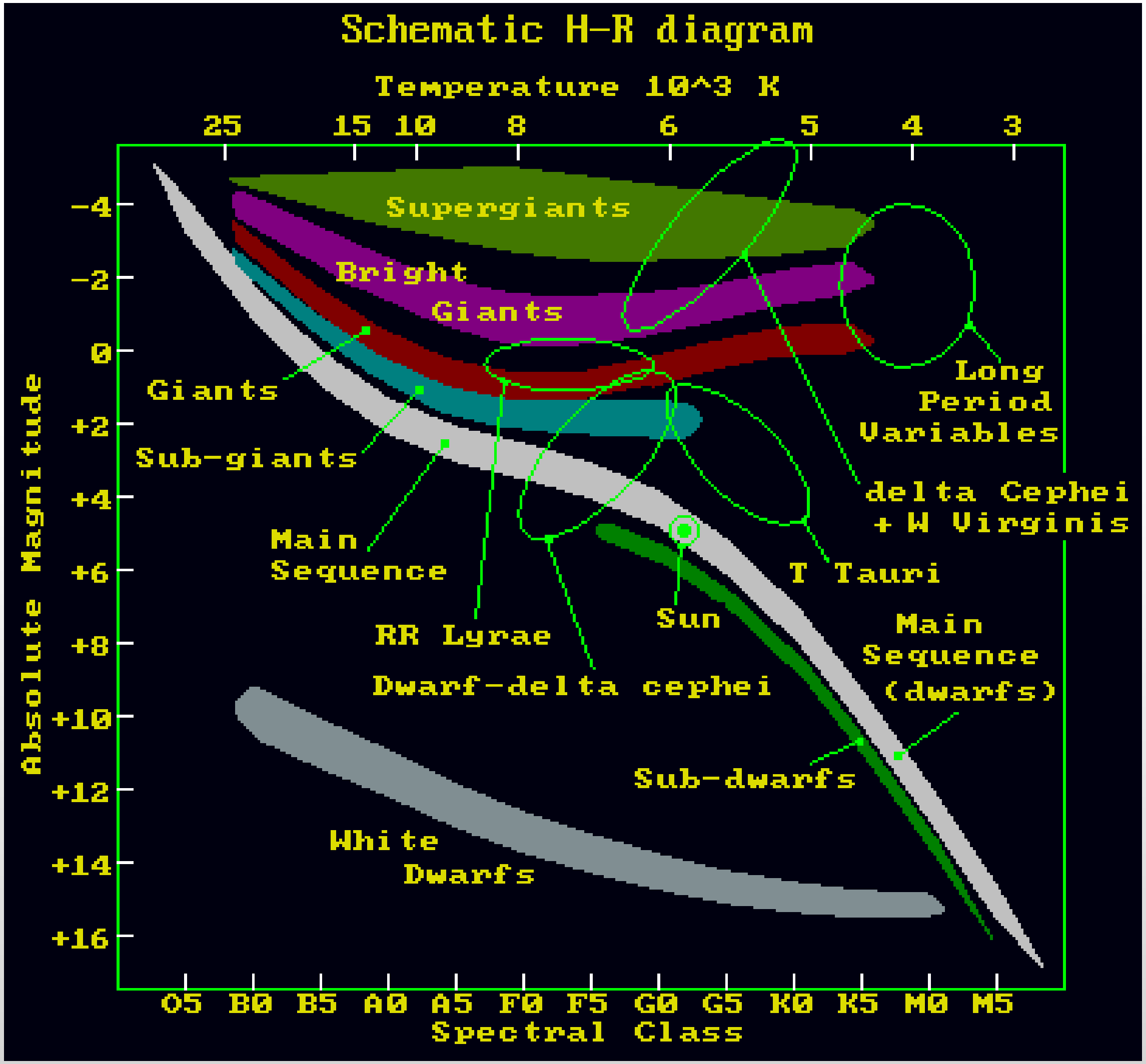
T-Tauri Molecular Cloud

T-Tauri Molecular Cloud



http://www.eso.org/public/archives/images/screen/eso1436c.jpg

T-Tauri and H-R Diagram



http://www.britastro.org/vss/whatstar.html

A video diversion

James Webb Infrared Telescope:
https://www.youtube.com/watch?v=L2d7joOgVLg

ALMA imaging:
https://www.youtube.com/watch?v=aqt7s0J10f8

National Geographic: Birth of the Solar System:
https://www.youtube.com/watch?v=kay2-F8uXPo

The Pleiades: a cluster of young stars

The Pleiades, an open cluster of young bright stars.
http://hubblesite.org/newscenter/archive/releases/2004/20/image/a/

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Temperature in the Solar System

The Sun, with its surface temperature of 5800K largely determines the temperature of materials distributed throughout the Solar System. Obviously, the farther we find ourselves from the warming Sun the colder our region of the Solar System is.

As the Sun forms and becomes radiant, the gases and dusts of the solar-planetary nebula become heated. Close to the radiant protosun, only **refractory minerals** (those silicates and metal oxides that make up our rocks) form. Minerals that melt at lower temperature (such as water and ammonia **volatiles** and **ices**) are driven to outer regions by the developing solar winds and radiation pressure.

Black-body Temperature

A ***"black body"*** is a body that absorbs all wavelengths of electromagnetic (microwave, light, X-ray, γ-ray) radiation incident upon it.

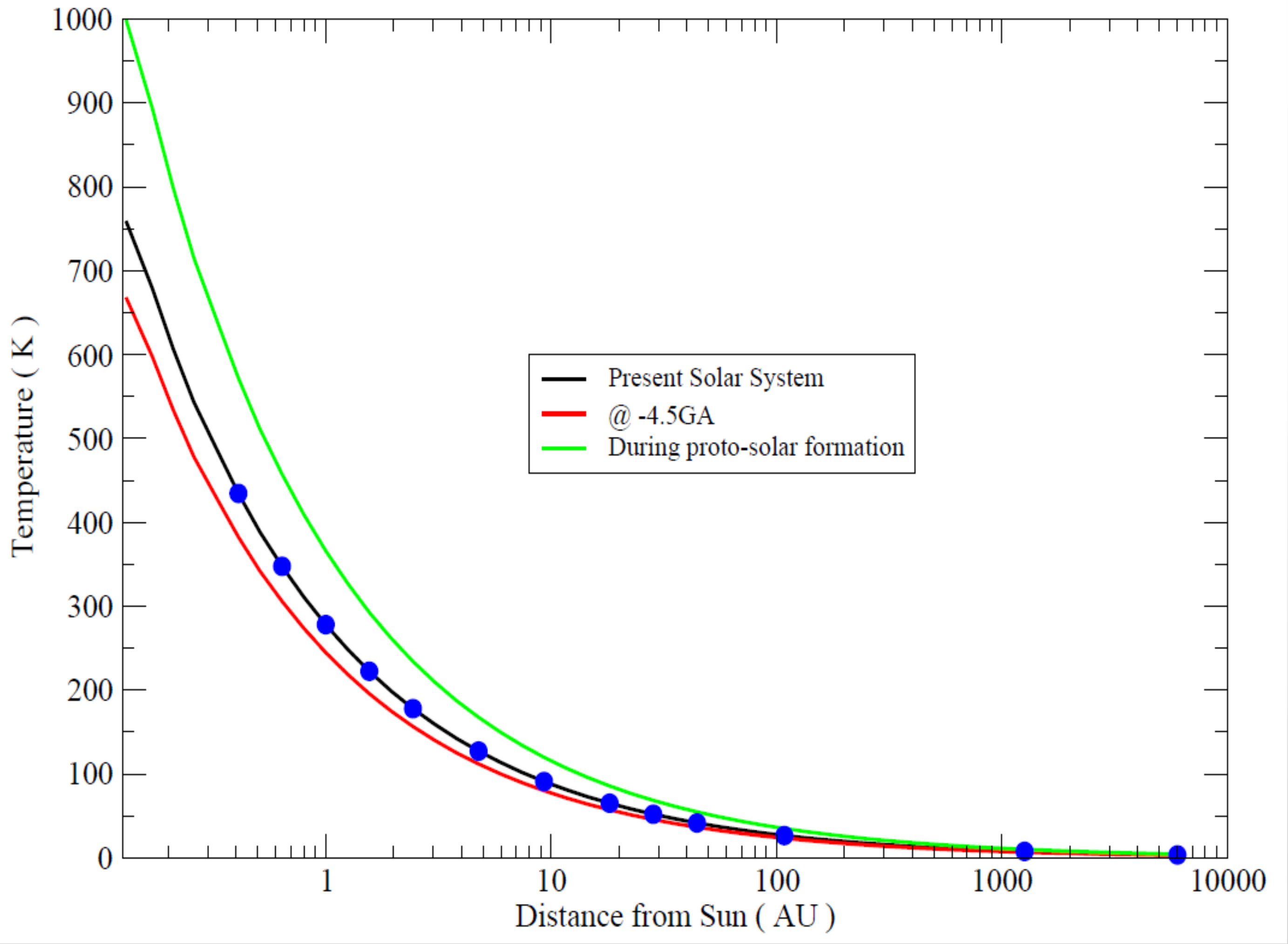
The surface of a black body comes to equilibrium at a temperature that is determined by the balanced in-flux and re-radiation of energy according to the Stefan-Boltzmann law:

$$\mathrm{R} = \boldsymbol{\sigma T^4},$$

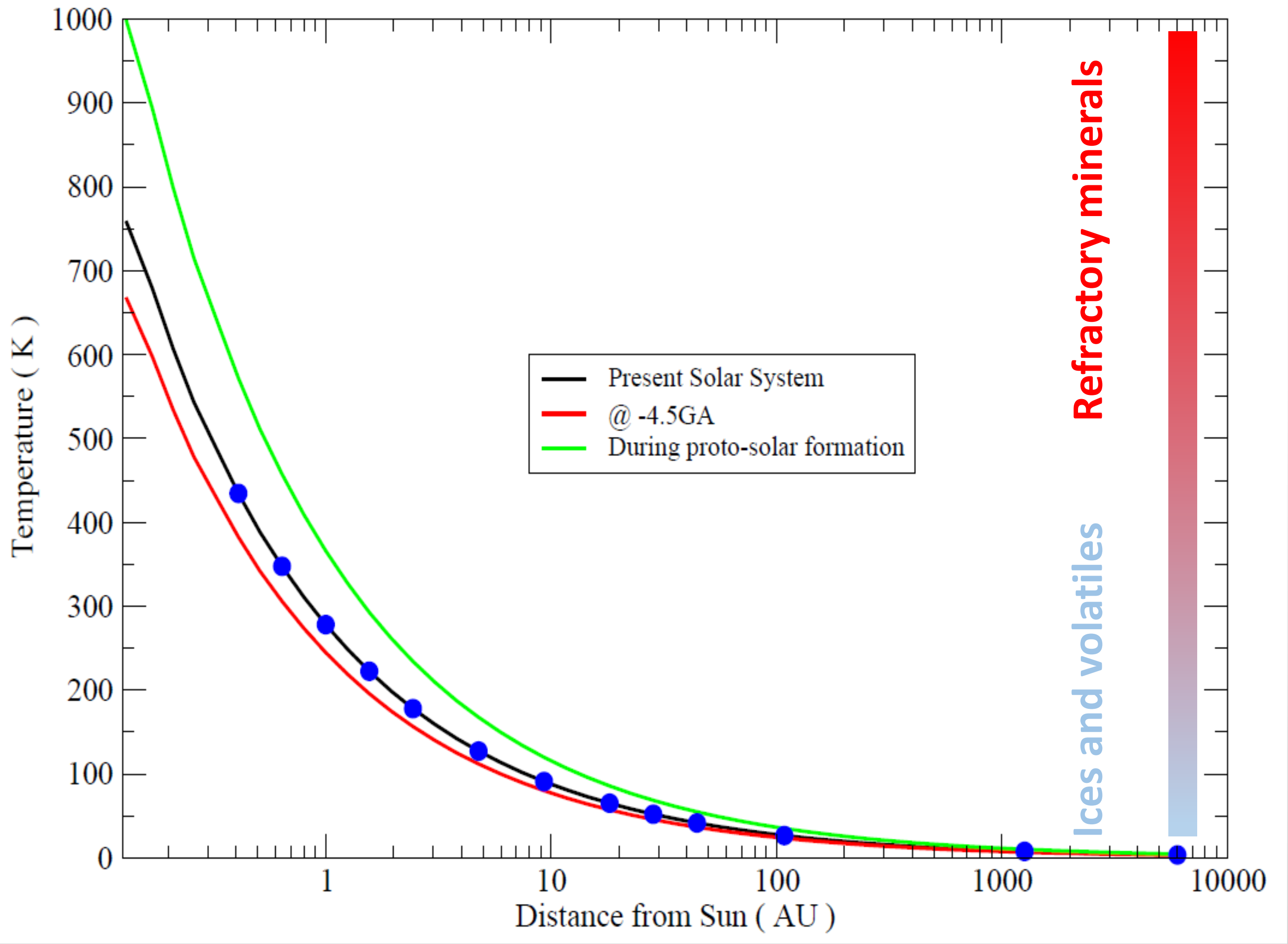
where $\mathbf{R}$ is the radiant energy measured in $\mathrm{W \cdot m^{-2}}$, $\boldsymbol{T}$ is the equilibrium temperature measured in K (kelvins) and

$\boldsymbol{\sigma} = \mathbf{5.670 \times 10^{-8}\ W \cdot m^{-2} \cdot K^{-4}}$, the **Stefan-Boltzmann constant**.

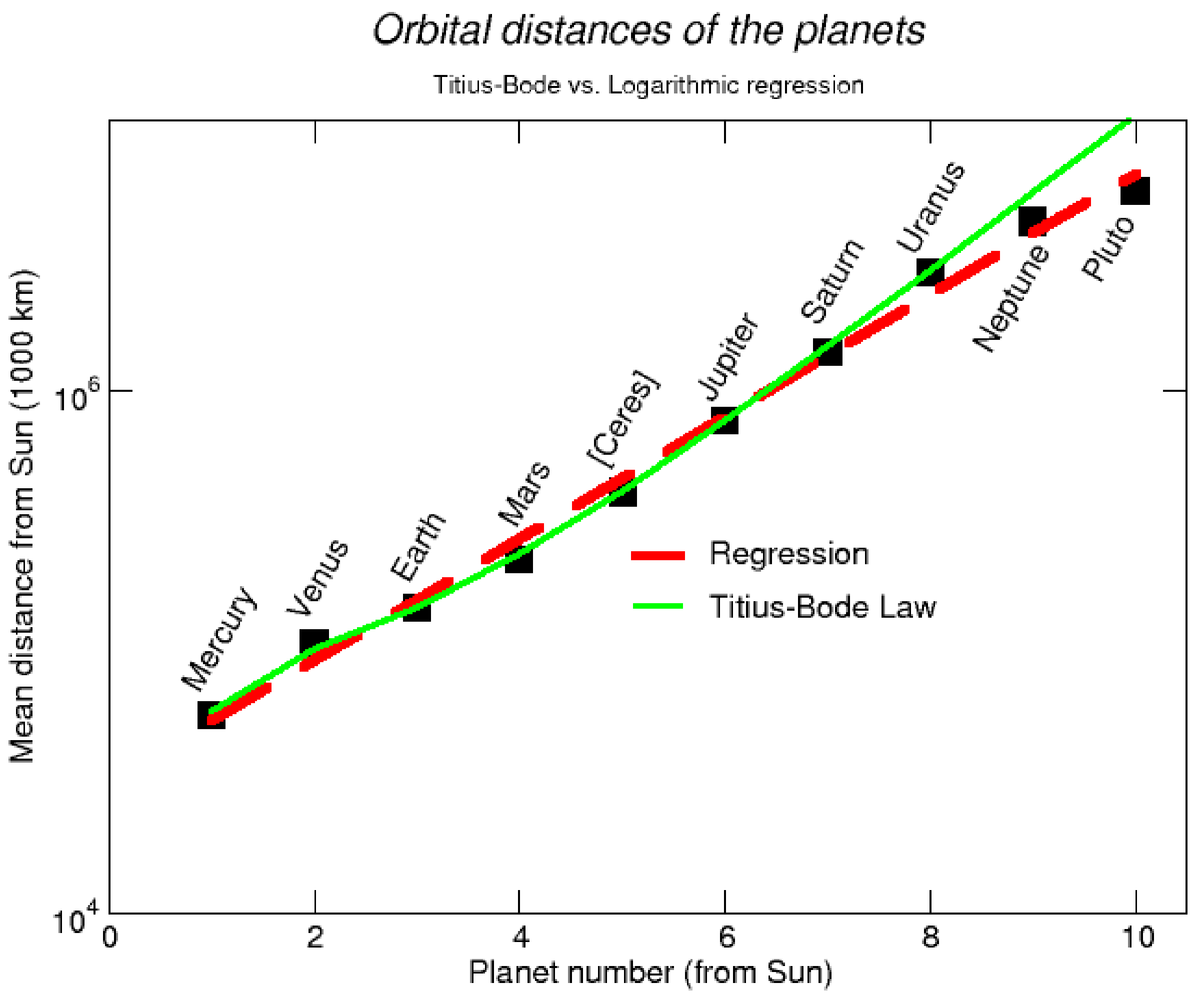
Black body T in Solar System



Black body T in Solar System



Distribution of Planets



Distribution of Planets

Bode in the late 1700s tried to understand the distribution of planets; that is, the organization of their distances from the Sun. He, with **Titius**, offered a law that seemed to "predict" the planetary positons. The law has been variously described by different mathematical relationships. The original form of the law:

$$\boldsymbol{a = 0.4 + 0.3 \times 2^{k-1}} \text{ AU}$$

where $\boldsymbol{k}$ is the planet number counting out from the Sun and $\boldsymbol{a}$ is its orbital semi-major axis.

Another simple regression relationship:

$$\boldsymbol{a = 0.9\, e^{0.54k}} \text{ AU}$$

Do these empirical laws really tell us anything about the distribution of planets about other stars or are they particular to our Solar System?

Search for ExoPlanets

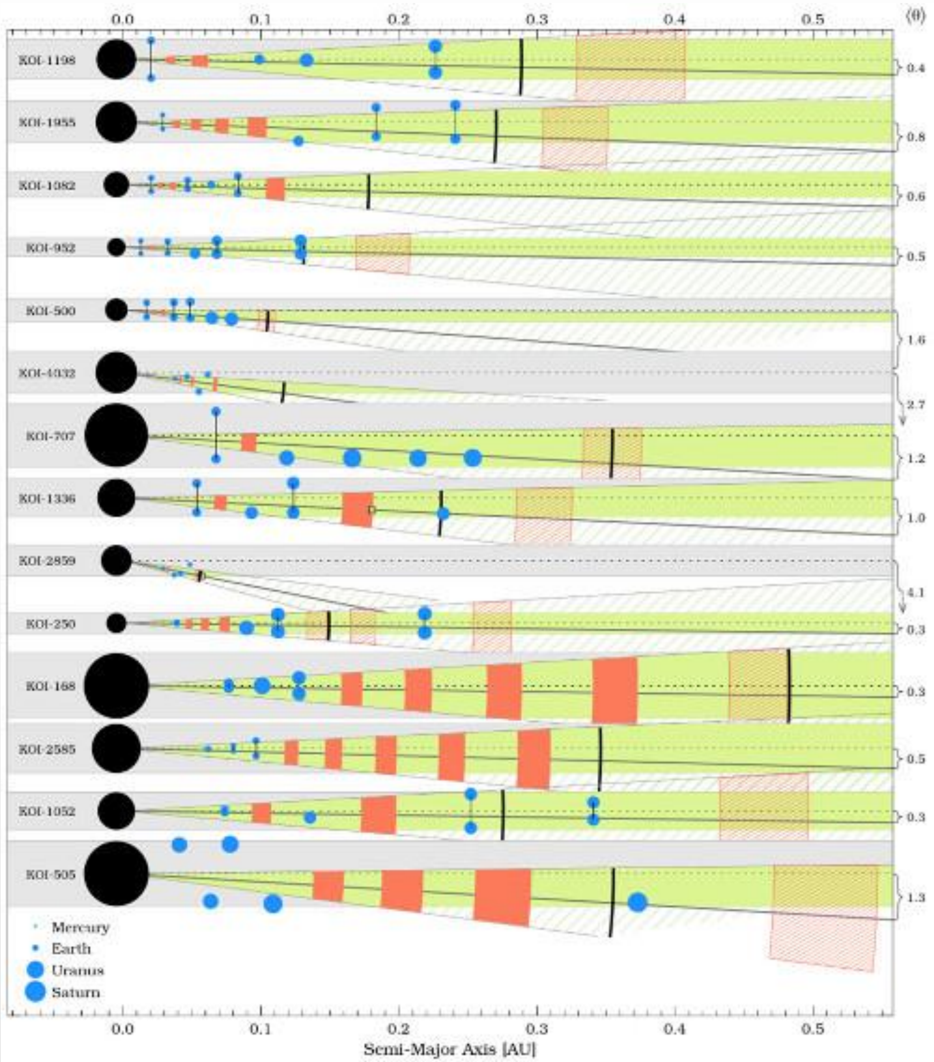
Since Gordon Walker and Bruce Campbell developed the Doppler technique to look for perturbations on stars that could be caused by very large planets in orbit about them in the 1980s, astronomers, using that technique and the more successful transit (eclipse) technique have confirmed more than 3000 planets in orbit about other stars. The Exoplanet Orbit Database lists another 3000 probable candidates. This exploration leads us to believe that almost all stars have planets. As we find evermore candidates, we begin to focus on those that might be life-habitable.

Distribution of ExoPlanets

As we now explore many other stellar-planetary systems, we see no strong evidence of such simplistic relationships. Still there may be something of a regular organization.

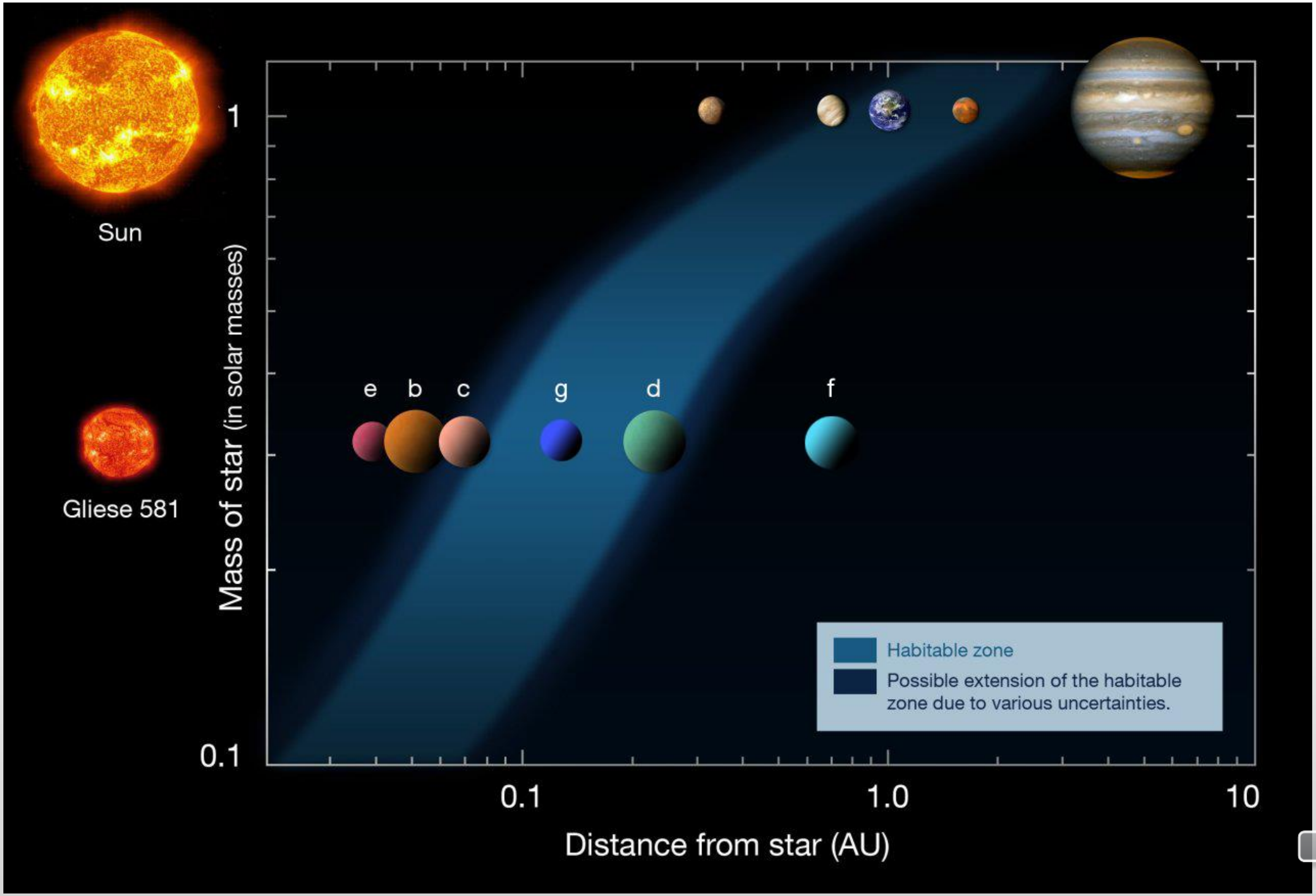
This diagram from a current paper argues that there is…

Distribution of ExoPlanets

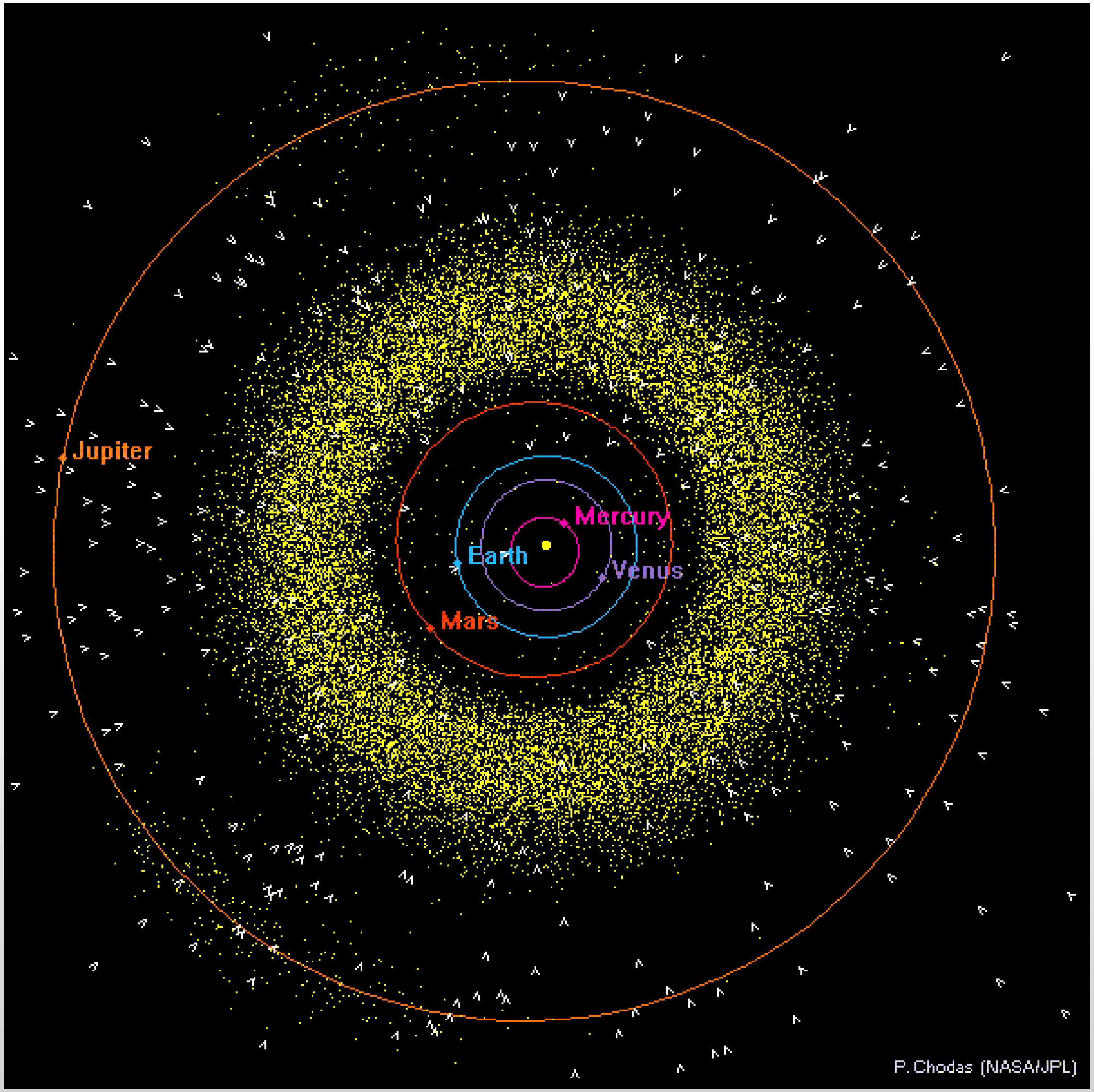


Boivard et al, https://doi.org/10.1093/mnras/stv221

Search for ExoPlanets



Inner Solar System



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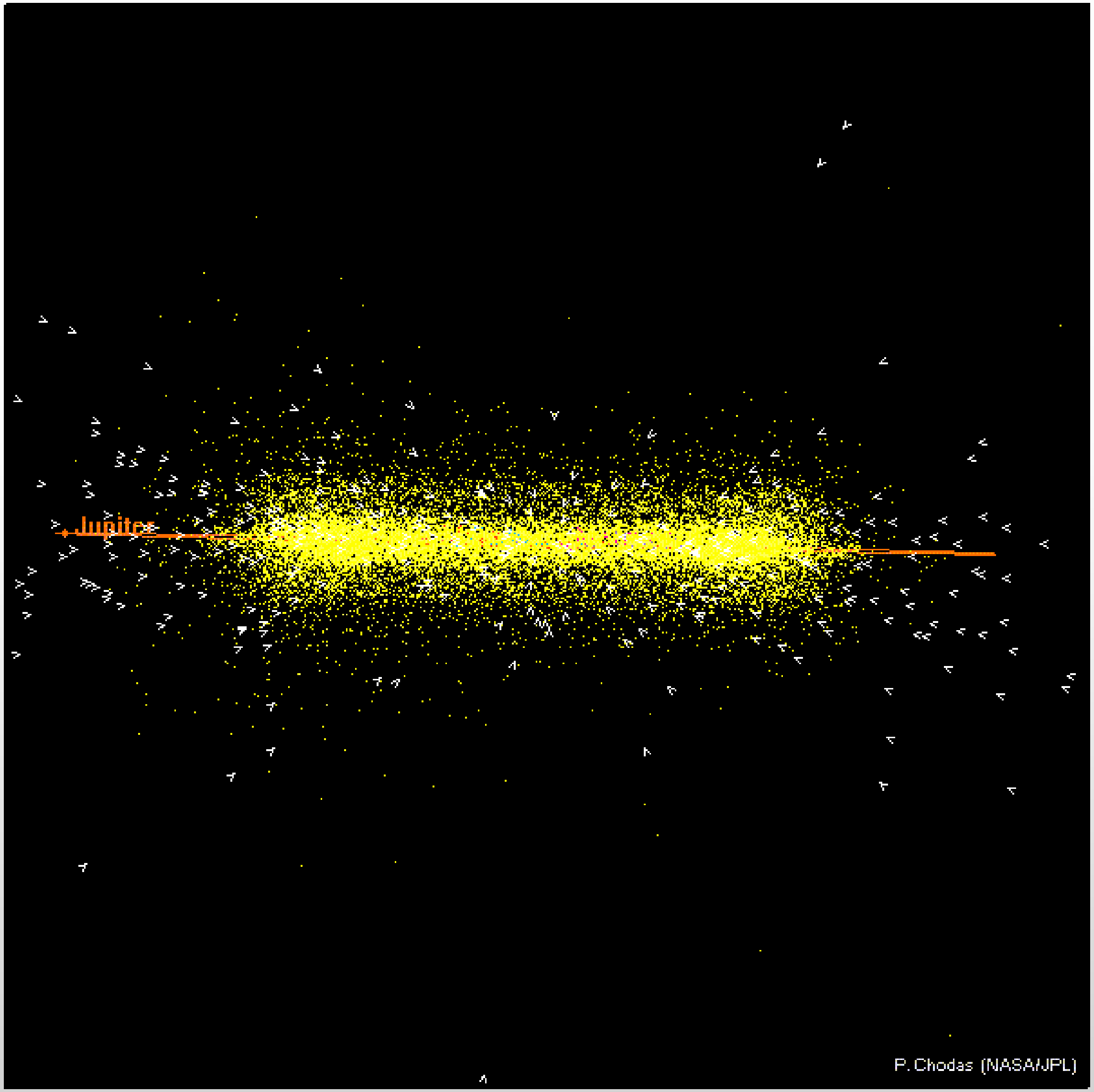
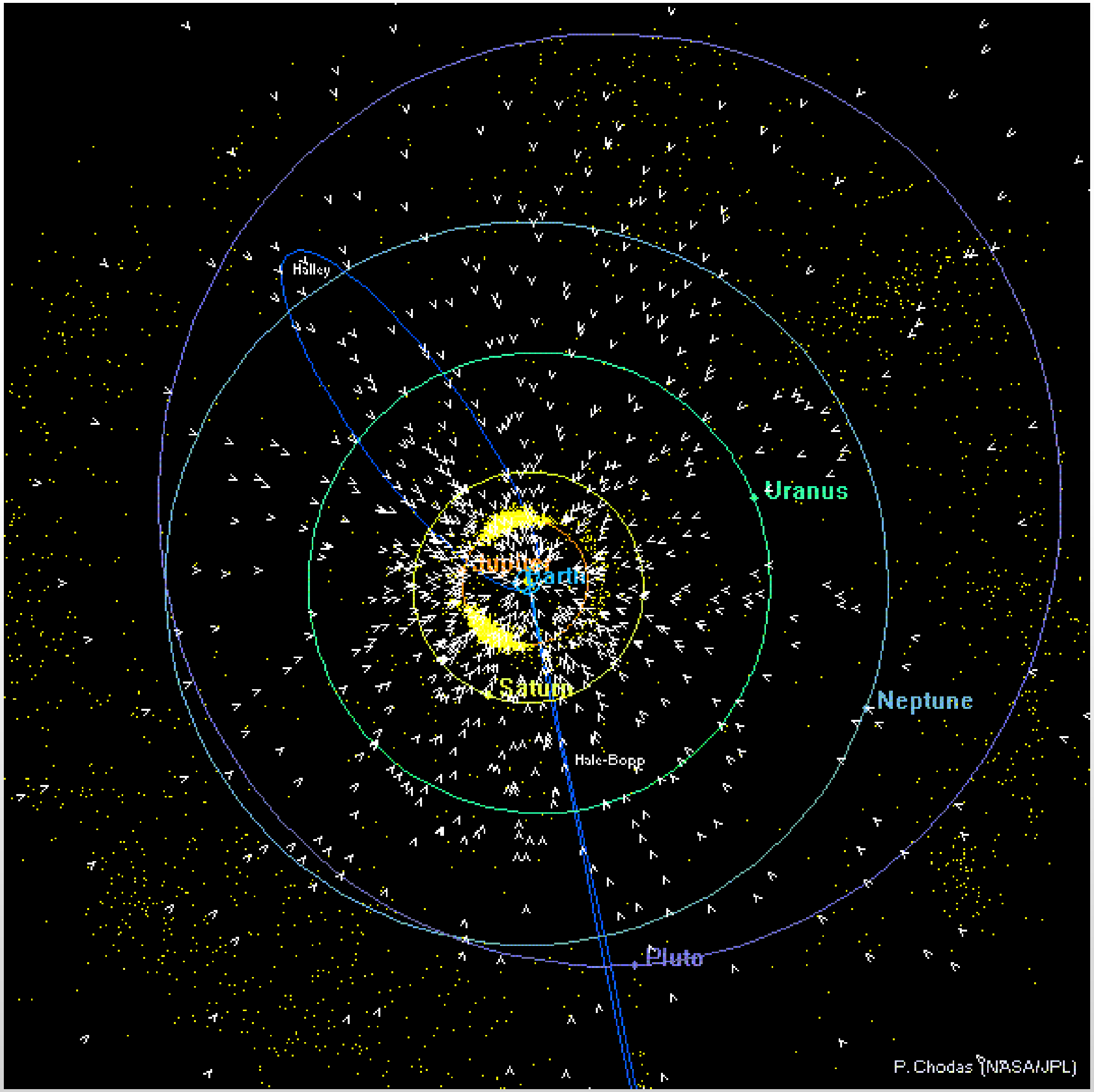


Outer Solar System



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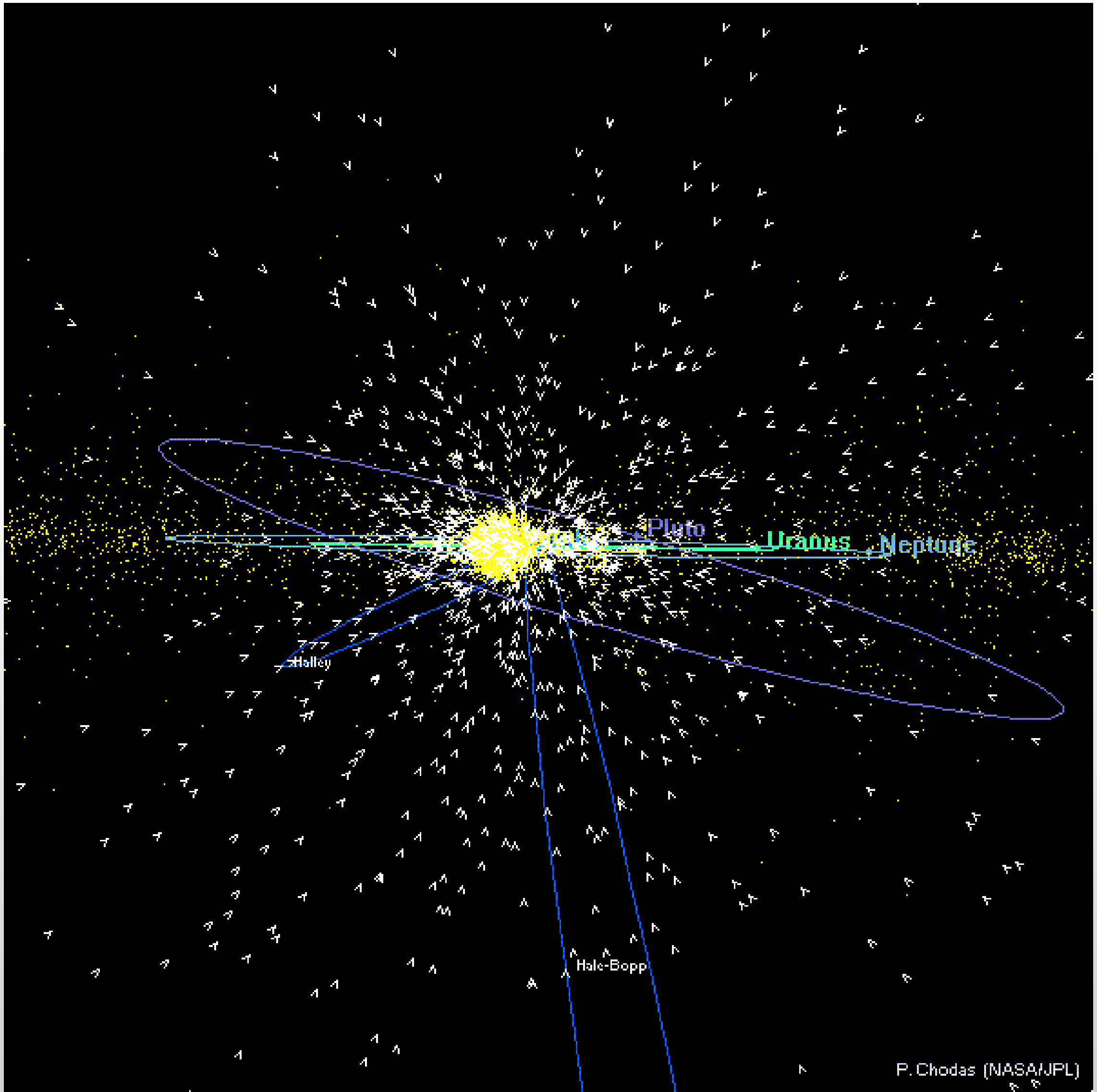
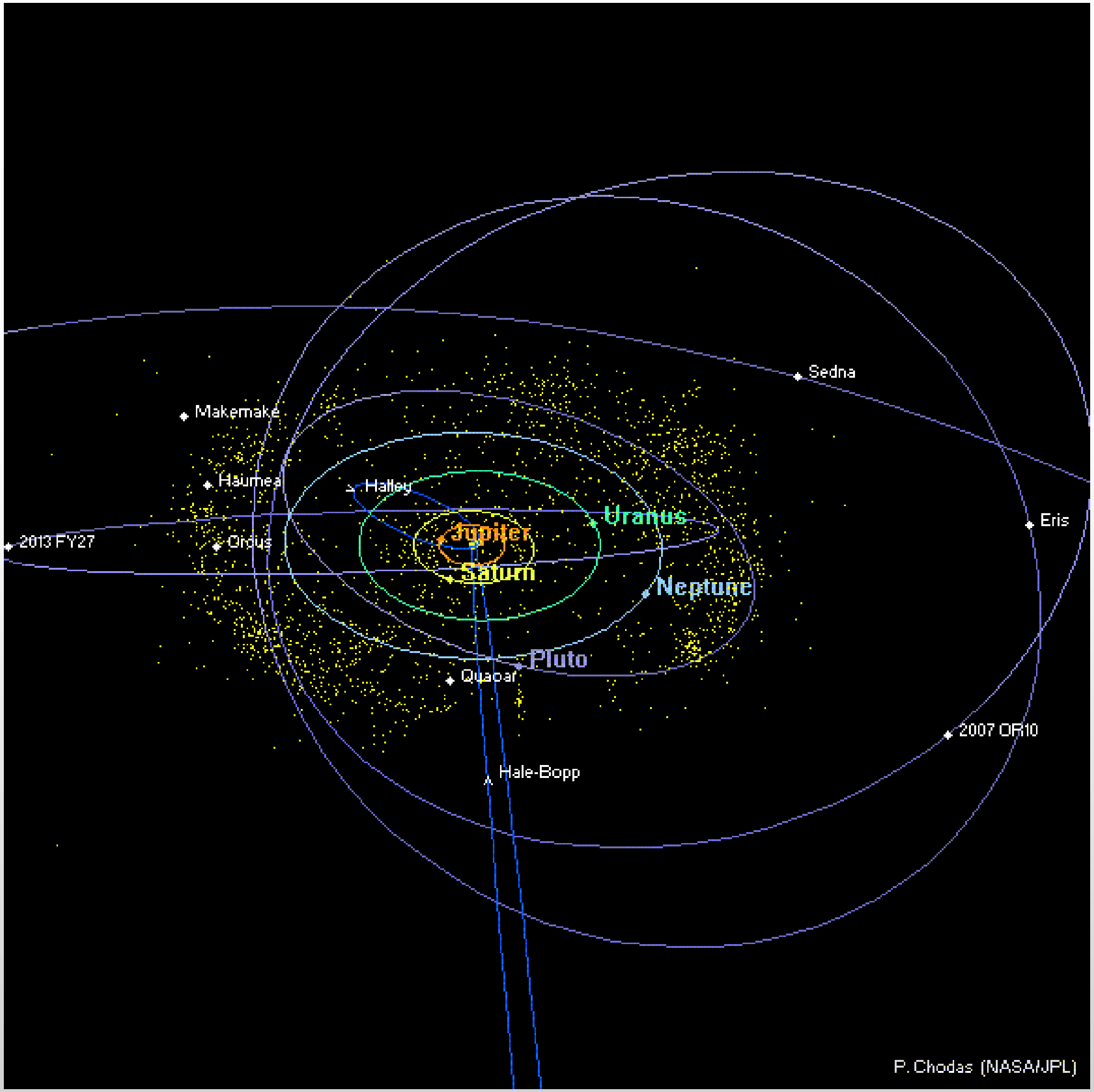
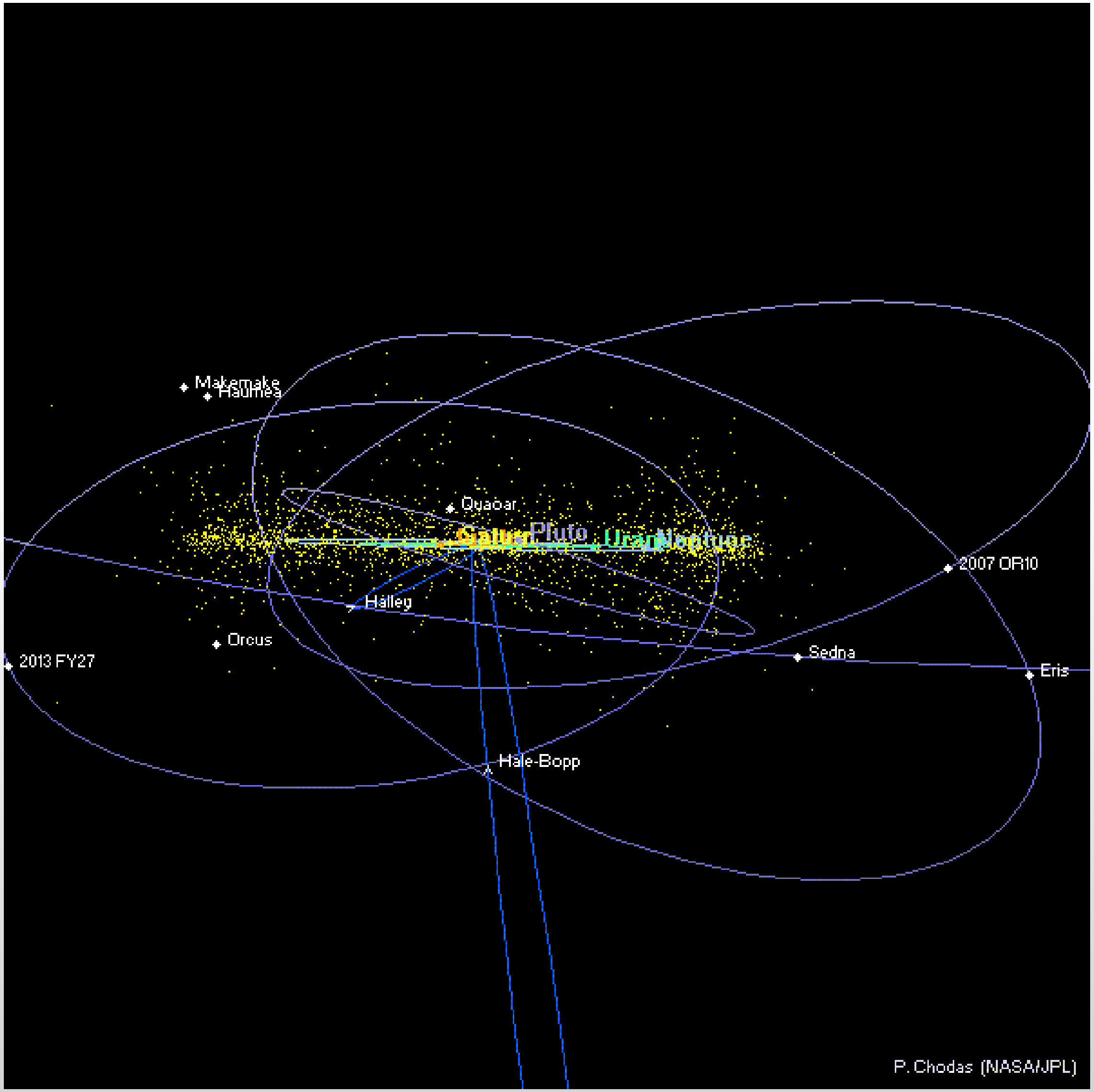


Beyond Neptune



Beyond Neptune



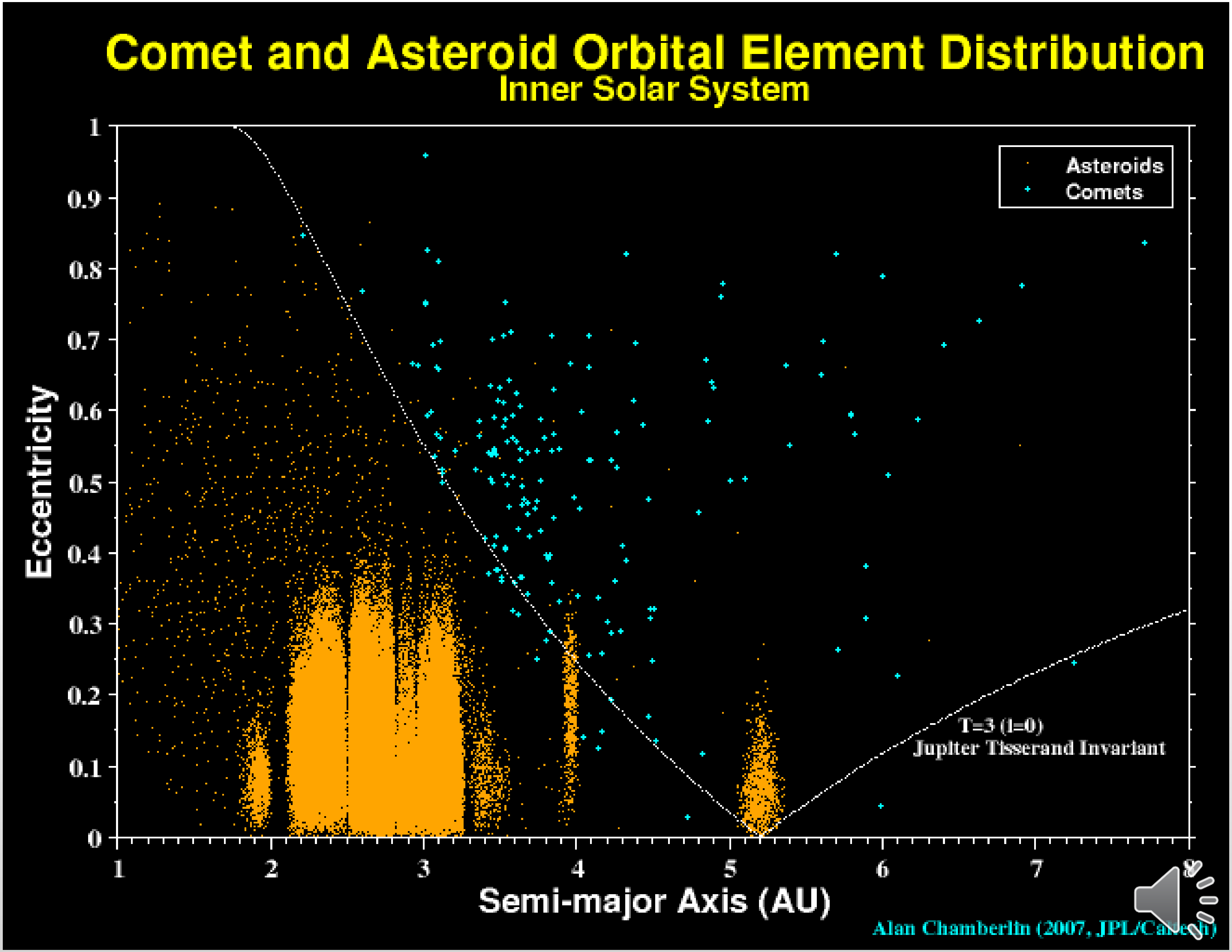
The planetary system: orbital parameters				
Planet	Period (yr)	Distance (AU)	Eccentricity	Inclination °
Mercury	0.2408	0.39	0.206	7.0
Venus	0.6152	0.72	0.007	3.4
Earth	1	1	0.017	0
Mars	1.881	1.52	0.093	1.9
Ceres*	3.63	2.36	0.237	7.1
Jupiter	11.86	5.2	0.049	1.3
Saturn	29.46	9.54	0.056	2.5
Uranus	84.01	19.19	0.047	0.8
Neptune	164.79	30	0.009	1.8
Pluto*	248.5	39.53	0.25	17.2

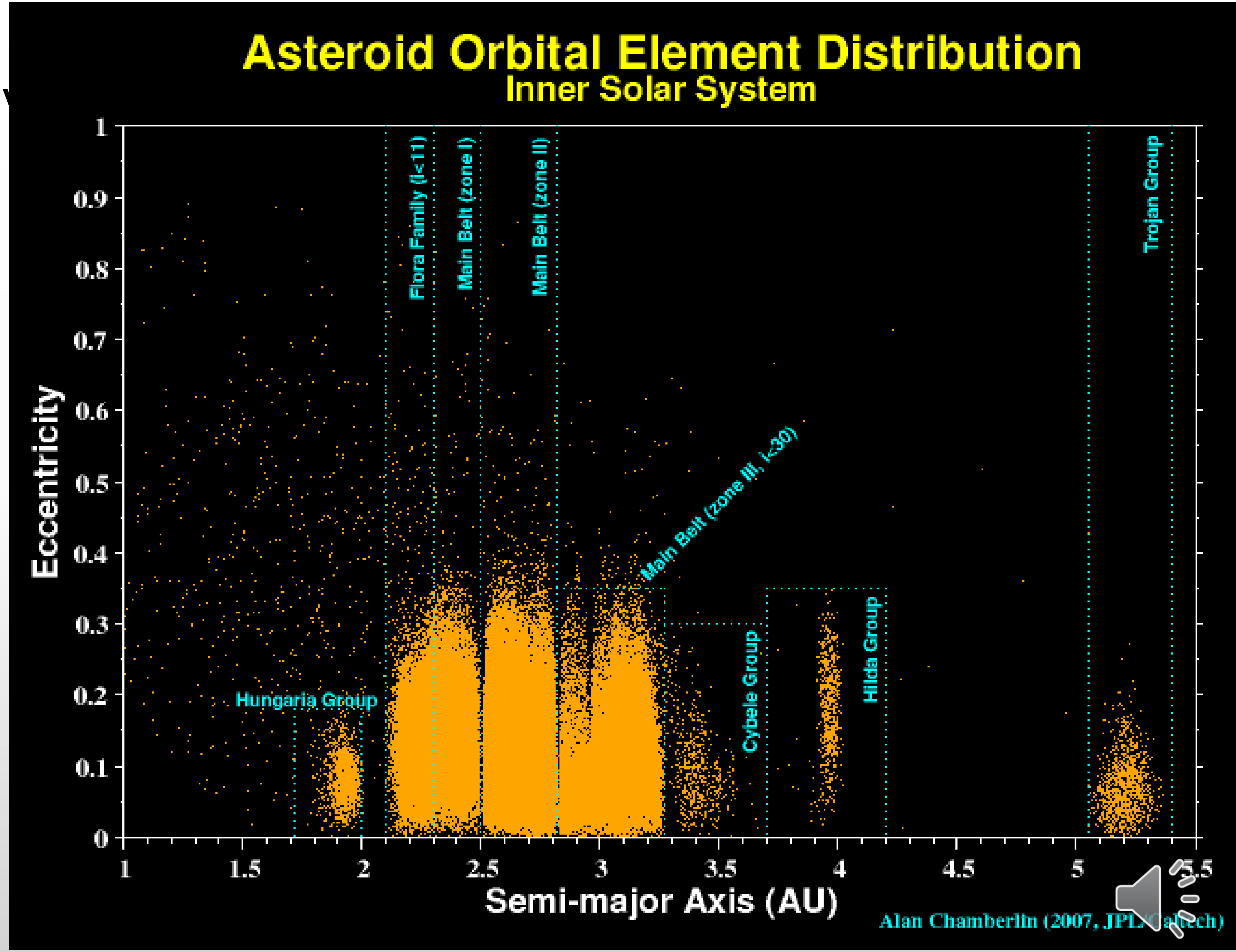
* Dwarf planets

Let us learn something of these planets and their orbits.

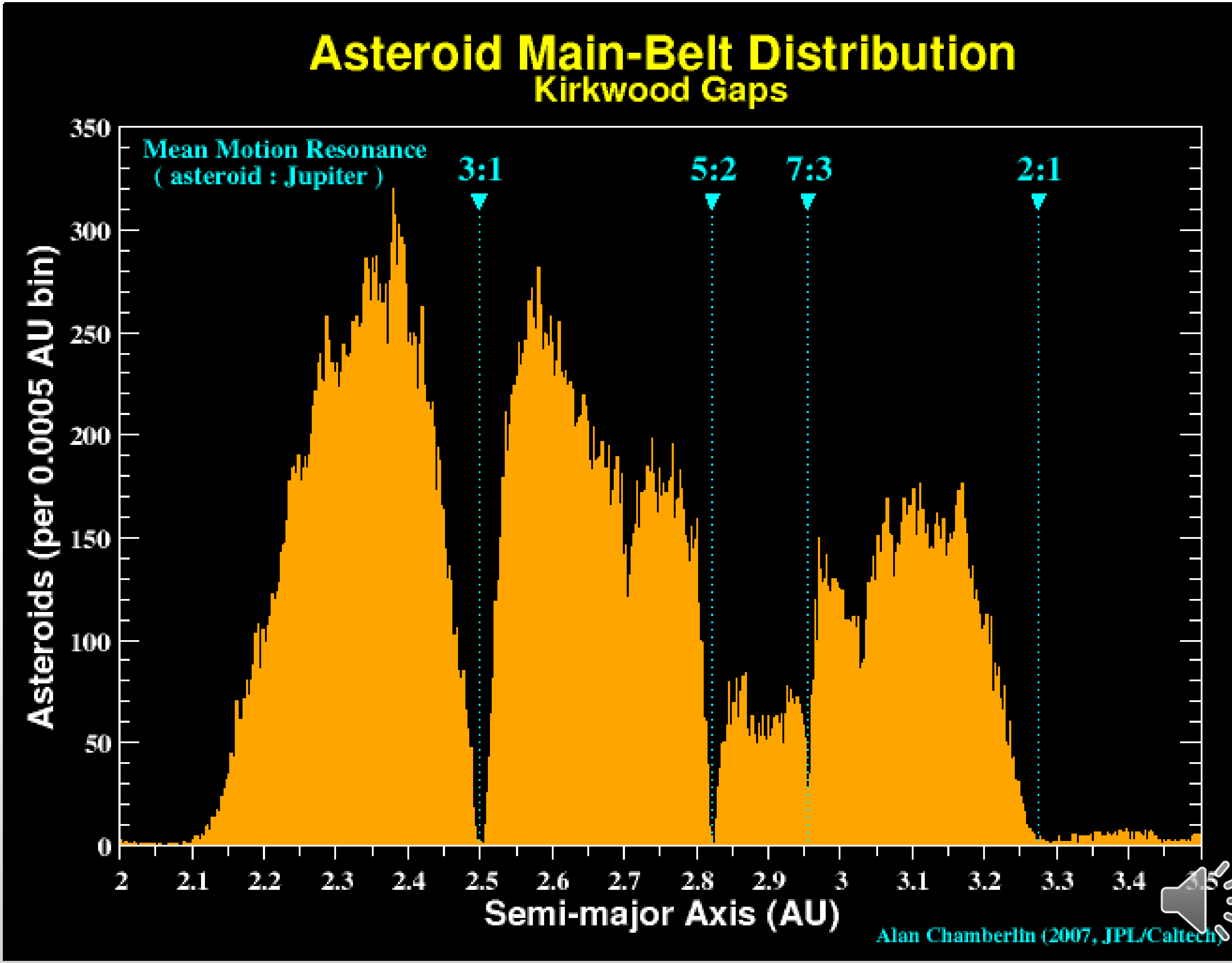
The Major Asteroids			
Name	Size (km)	Mass x 10^{15} kg	Distance (AU)
Ceres	960x932	870000	2.767
Pallas	570x525x482	318000	2.774
Juno	240	20000	2.669
Vesta	530	300000	2.362
Eugenia	226	6100	2.721
Siwa	103	1500	2.734
Kleopatra	217x94		2.79

Orbits in the solar system and other stellar systems:
http://janus.astro.umd.edu/javadir/orbits/ssv.html


Comet and Asteroid Orbital Element Distribution
Inner Solar System
Eccentricity
Semi-major Axis (AU)
Asteroids
Comets
T=3 (i=0)
Jupiter Tisserand Invariant
Alan Chamberlin (2007, JPL/Caltech)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2
3
4
5
6
7
8



Asteroid Orbital Element Distribution
Inner Solar System
Eccentricity
Semi-major Axis (AU)
Flora Family (i<11)
Main Belt (zone I)
Main Belt (zone II)
Main Belt (zone III, i<30)
Trojan Group
Hungaria Group
Cybele Group
Hilda Group
Alan Chamberlin (2007, JPL/Caltech)


Asteroid Main-Belt Distribution
Kirkwood Gaps
Mean Motion Resonance
(asteroid : Jupiter)
3:1
5:2
7:3
2:1
Asteroids (per 0.0005 AU bin)
0
50
100
150
200
250
300
350
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
3.1
3.2
3.3
3.4
3.5
Semi-major Axis (AU)
Alan Chamberlin (2007, JPL/Caltech)