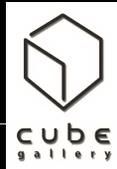


There are More Things in Heaven....

© Steve Gilbert



Peter Watson, Dept. of Physics

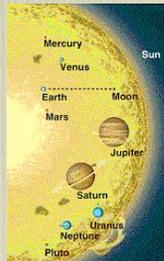
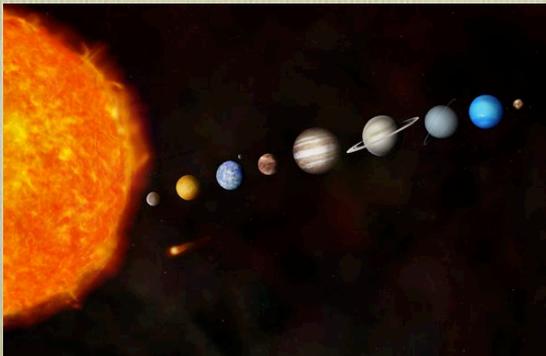


The solar system looks so simple



Cosmogony: Origins of the Solar System

- So where did the solar system come from....?



Peter Watson

Earthrise from Apollo 8



Peter Watson

What we Thought we Knew (~1960)

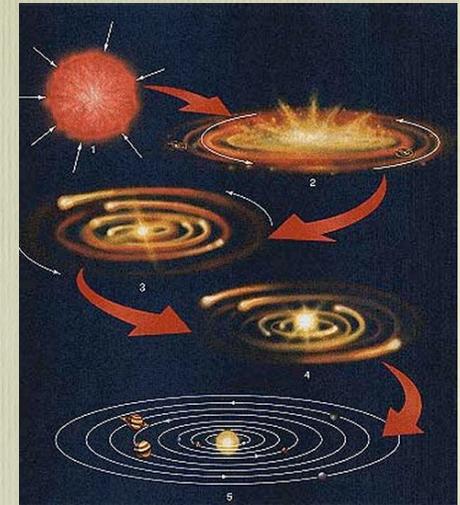
- Age ~4.5 billion years
- All planets orbit in almost the same plane, and directions of rotation are same (except Venus).
- Orbit shapes are nearly circular (little eccentricity)
- Most of mass the of solar system is in the sun.
- Inner planets are small and rocky (terrestrial), outer planets are large cold gas giants (jovian)
- moons are rocky and bare



Peter Watson

Nebular Hypothesis.

- A rotating gas cloud, probably compressed by a nearby supernova shock wave, starts to collapse.
- The central part collapses to the sun.
- Conservation of angular momentum causes the outer part to speed up.



<http://scienceclass.ning.com/>



Peter Watson

- The outer planets condense first.
- Gas and dust particles moving at an angle to ecliptic are more likely to interact and hence collapse into the plane normal to the rotation axis.
- Majority rule : less effective at the limits, hence Mercury & Pluto orbit further out of the plane.

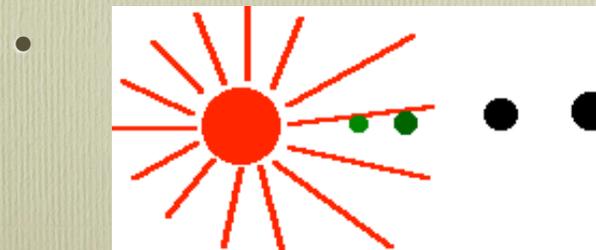


- The orbits are circularized by collisions and tidal effects.



Peter Watson

- Intense solar winds remove hydrogen and helium from the inner part of the solar system.
- Terrestrial planets form from the left over refractory materials.



Peter Watson

Except then we got smart!

- Voyager (1970's) (Jupiter & Saturn)
- Galileo (Jupiter close-up)
- Cassini (Saturn close-up)
- Hubble (everything!)
- Spitzer (infra-red space telescope)
- CoRot, Kepler (planet searchers)
- and LOTS of others



Peter Watson

Moons of Jupiter: Io

- Four large moons, easily visible with binoculars
- Can watch Io rotating
- Pictures by Voyager



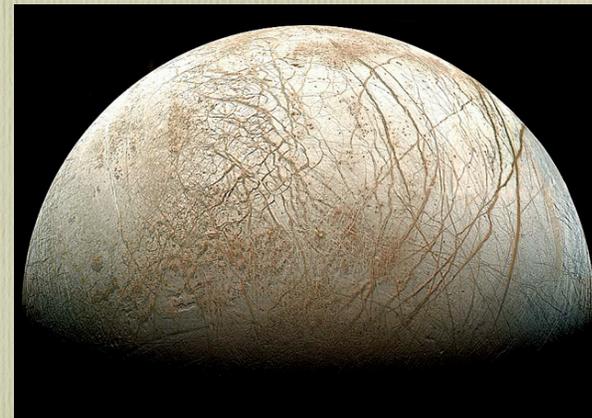
Peter Watson

- Io is in a state of continuous volcanic eruption.
- Volcanic plumes to 250 km
- Vulcanism caused by "tidal pumping" by other moons.



Peter Watson

Moons of Jupiter: Europa



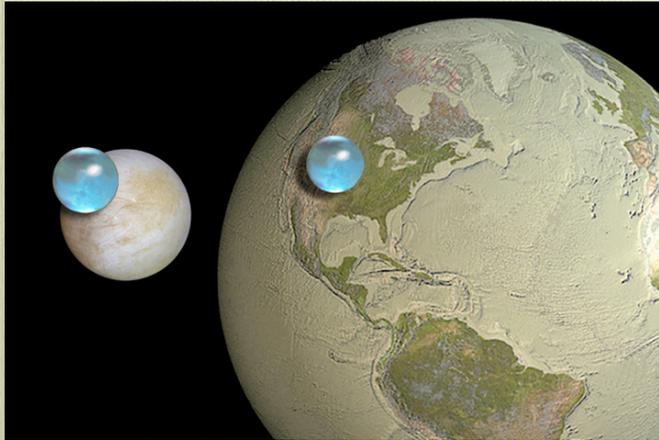
- Rock covered with ice, probably slushy since no impact craters.



Peter Watson

Now thought to have a huge ocean below the ice

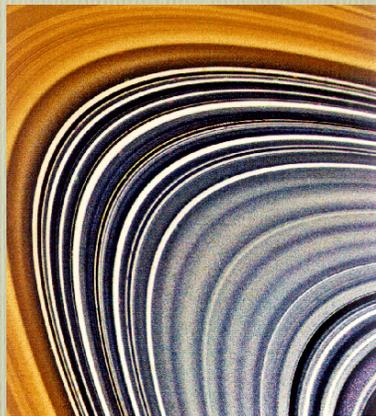
- More water than the earth!



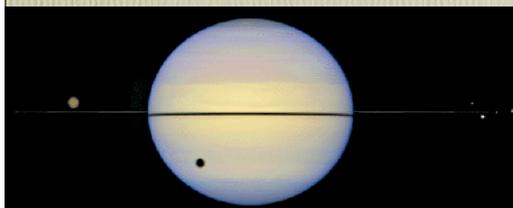
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Cassini fly-through of Saturn:
still pictures assembled by Stephen van Vuuren

Peter Watson



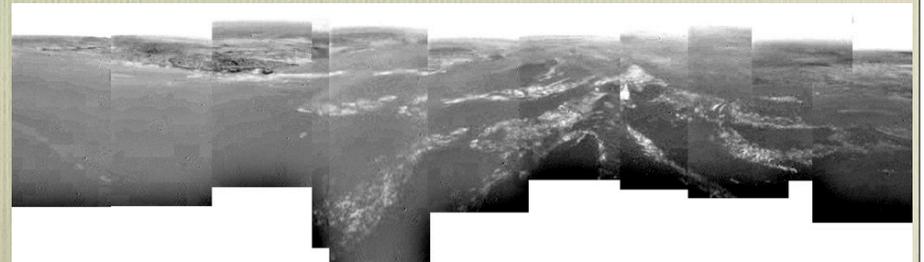
- Galileo described them as "Handles"
- Made of small ice pellets and dust (moonlets)
- many thousands of ringlets, some braided
- rings very thin (< 2 km) held in place by "shepherd" moons



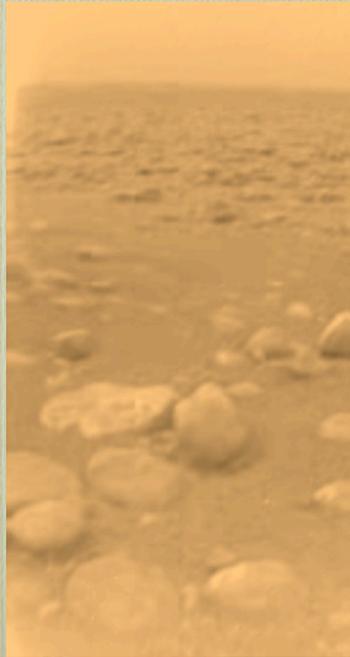
Peter Watson

Titan

- larger than our moon, yellow atmosphere so surface invisible
- Touchdown of probe: 14 January 2005,
- The white streaks are 'fog' of methane or ethane vapour. Wind speed at 6-7 m/s.



Peter Watson

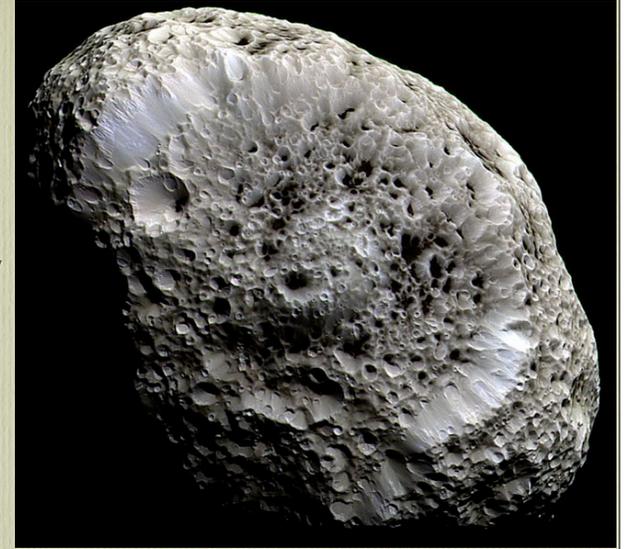


- Touch down at 4.5 m/s
- probe penetrated 15 cm.
- Surface consistency of wet sand or clay.

Peter Watson

Hyperion

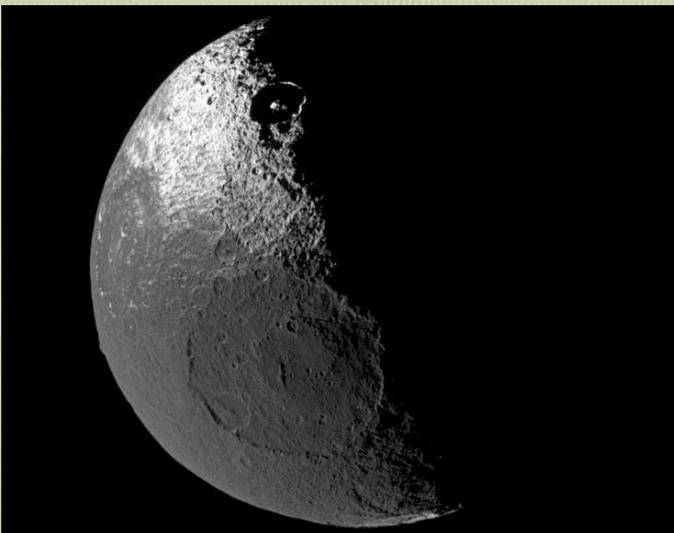
- Density about 1/2 water (!)
- suggests spongy texture!



Peter Watson

Iapetus

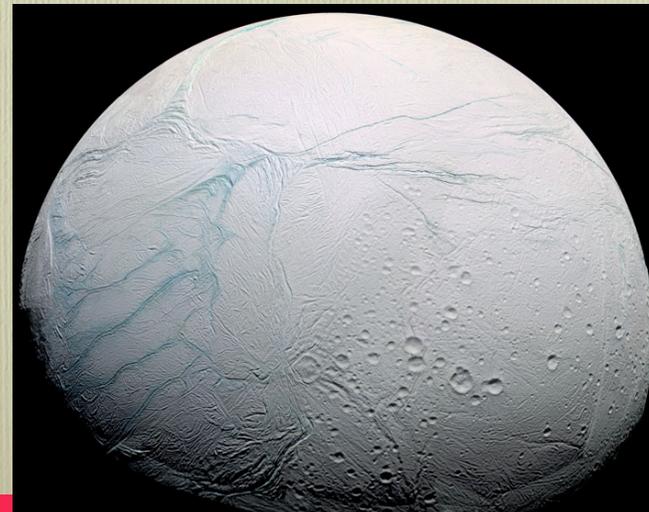
- Half of moon is covered in material as black as coal!



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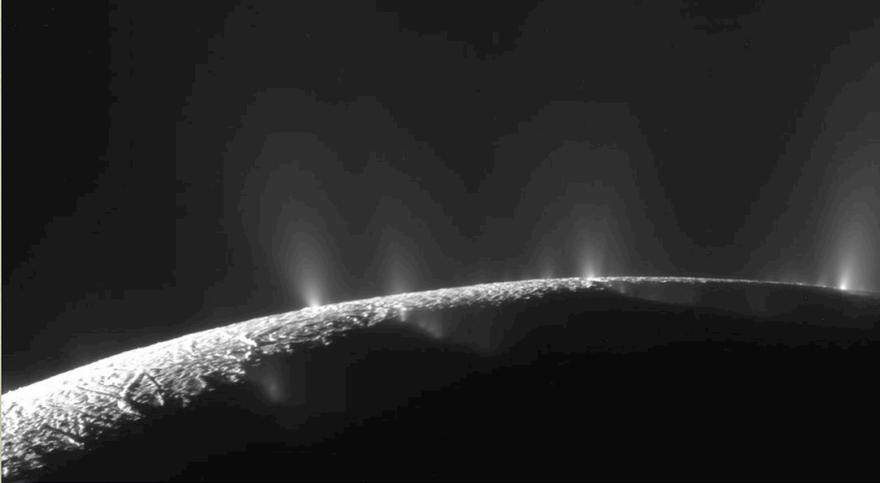
Enceladus

Giant stripey snowball?



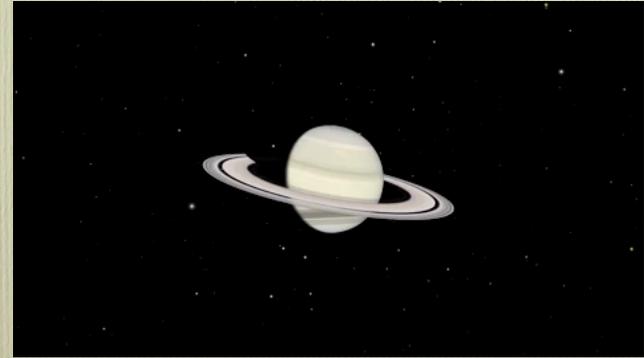
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- With ice volcanoes!



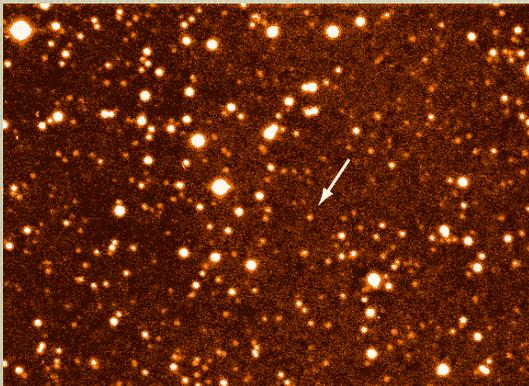
Peter Watson

- and finally (for the time being)
- Spitzer space telescope found a new, very diffuse dark ring round Saturn
- Could be source of the dark face of Iapetus



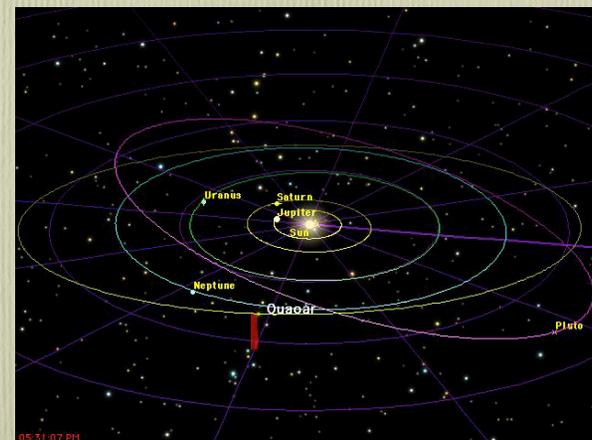
How big is the solar system?

- For a long time Pluto set the bounds, but now Quaoar



Peter Watson

- And it's really far out



Peter Watson

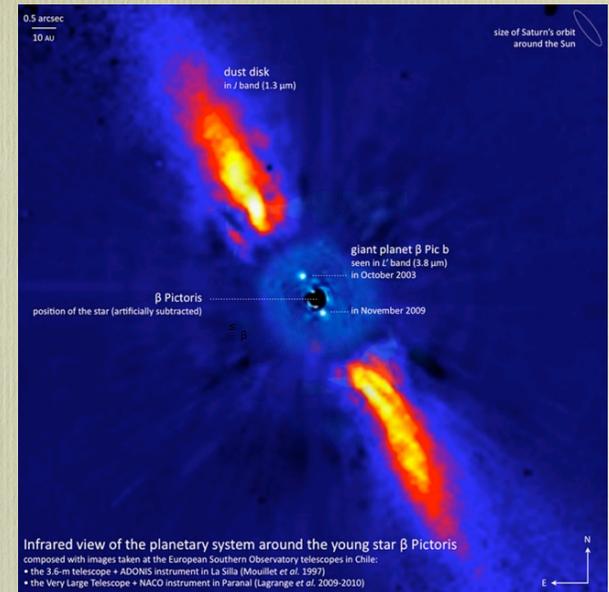
Now we are seeing **lots** of other solar systems

- first found around 51 Pegasi in 1995: 5 times as big as Jupiter
- if we are lucky, we can see them directly



Peter Watson

- e.g β -Pictoris
- Young star
- dust clouds
- giant planet



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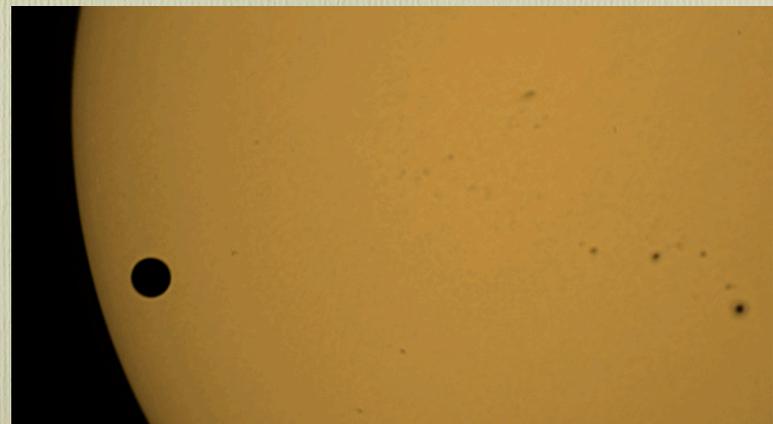
Now we are seeing **lots** of other solar systems

- Many methods & collaborations
- Most look for tiny fluctuations in stellar brightness due to “eclipses”
- Amateurs (AXA)
- Ground-based
- CoRoT & Kepler space telescopes



Peter Watson

Like this! (except this is our sun and Venus, June 5)

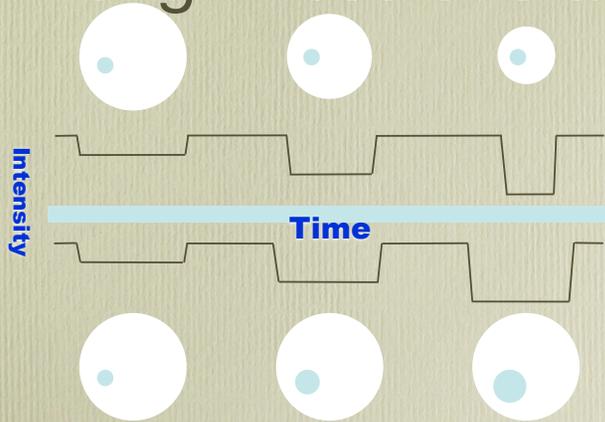


Picture by Etienne Rollin



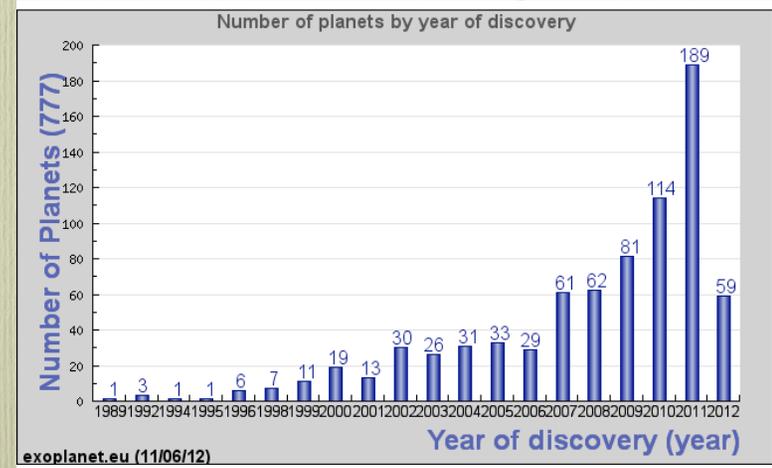
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Regular tiny dips in brightness of star



Peter Watson

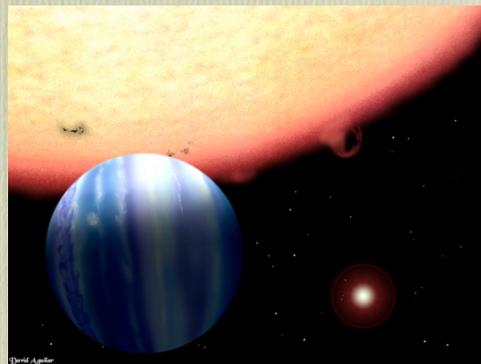
How many?



Note: even this is an underestimate:
Kepler has 2321 candidates, 6174 confirmed

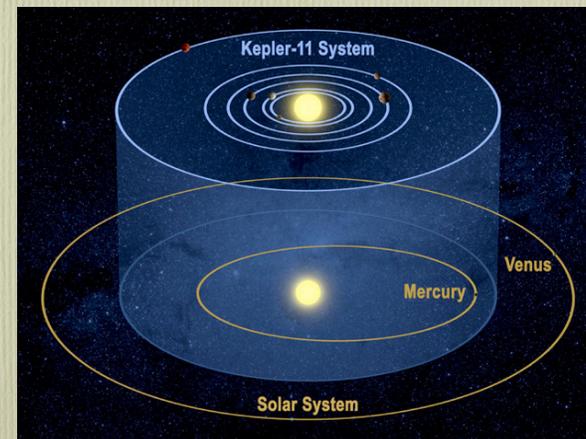
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- Orbit has to be aligned with earth
- Need to see several transits
- Does best with large planets, close to star
- “hot jupiters”



Peter Watson

Kepler 11 has at least 6 planets



Peter Watson

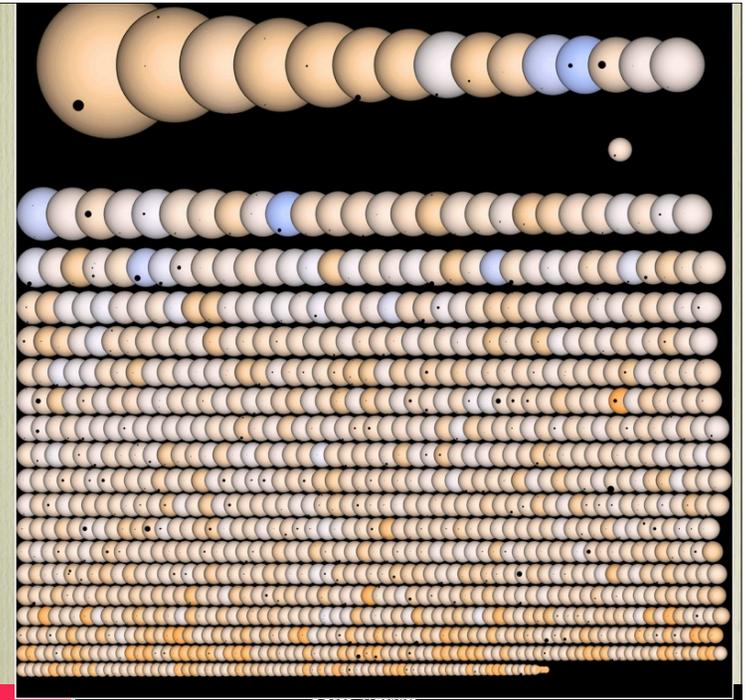


- CoRoT-7b
- mass ~ five Earth, radius~ 1.7 Earth
- year lasts ~20 hours
- FAR too hot (1500°)

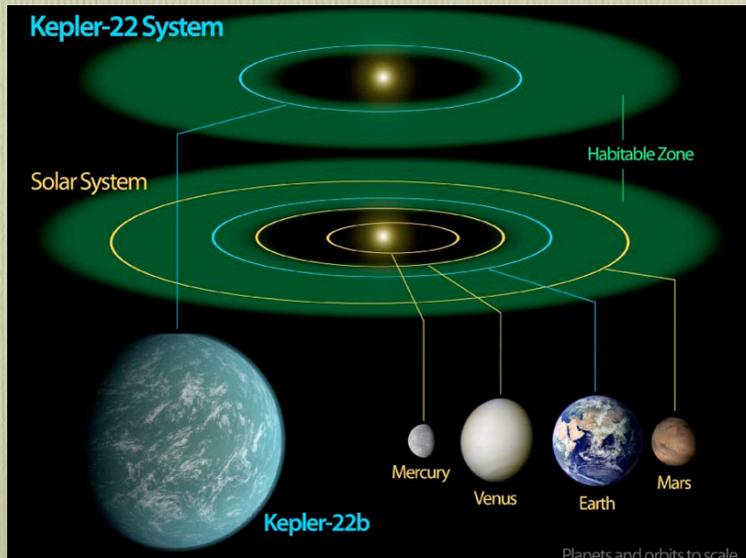
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Kepler has found lots!

nearly 2300 confirmed and candidates



- Kepler 22b: first earth-sized planet in Goldilocks zone (not too hot, not too cold!)



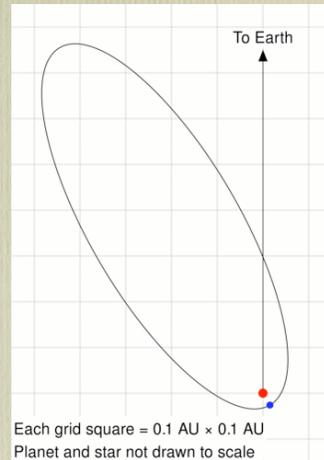
Peter Watson

So planetary systems are common:
do they look like ours?

Peter Watson

Not really

- Lot of stars have hot Jupiters
- Some don't know they should be in circular orbits!
- HD80606b goes from 500°C to 1200°C in 6 hours
- Lots go backwards



Peter Watson

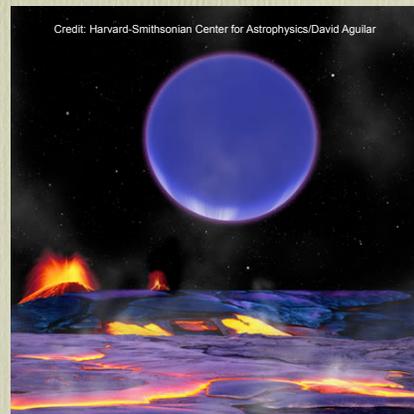
- Planets in orbit round binary (double-star) systems: Kepler 16b



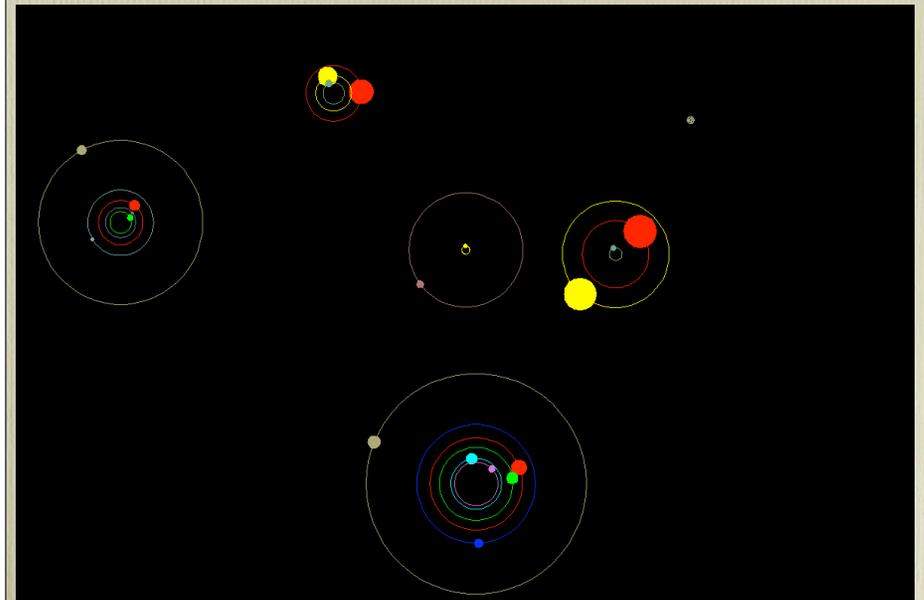
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Kepler 36

- ~Earth sized planet +
~Neptune sized planet
- Every 97 days approach to
~1.5 million km



Peter Watson



Peter Watson

Conclusions

- Based on a very small # of stars and short observing time, it seems likely ALL stars have planets
- We haven't had time to observe orbits of longer than a year or so
- Maybe more than 100 billion planets in the Milky Way



Peter Watson

- There may be many planets that don't orbit stars
- A real αστήρ πλανήτης (*astēr planētēs*), meaning "wandering star"
- Except we have defined planets to be in orbit round stars!



Free Floating Planet - [NASA/JPL-Caltech/R. Hurt]



Peter Watson

- If you want to play games with the data, try <http://exoplanets.org/plot/>
- <http://exoplanet.eu/index.php>
- Acknowledgements:
- Pictures by Steve Gilbert, Steven Van Vuuren, NASA, ESA

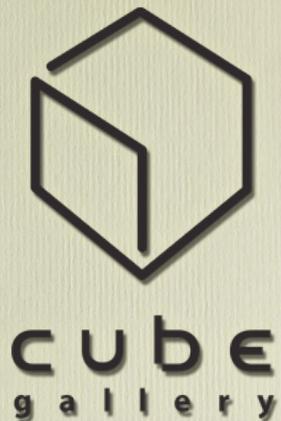


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- Thanks to Don Monet for the invitation



Carleton
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