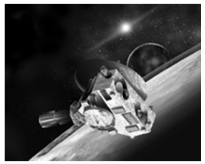
Recent Physics and Astronomy Research in the School of Physics, Astronomy and Computational Sciences (SPACS) at George Mason University

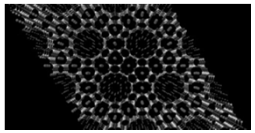
Osher Lifelong Learning Institute

March 27, 2014

Michael E. Summers, Professor of Planetary Science and Astronomy

March 27, 2014





School of Physics, Astronomy and Computational Sciences (SPACS)

spacs.gmu.edu

The School of Physics, Astronomy and Computational Sciences (SPACS)

The School of Physics, Astronomy and Computational Sciences (SPACS) was formed in 2011 by merging two prior departments: The Dept. of Physics and Astronomy, and the Dept. of Computational and Data Sciences.

The primary intent in forming SPACS was to bring together all four pillars of modern science methodology (theory, experiment, modeling, and data sciences) into one unit with two central goals.

The School of Physics, Astronomy and Computational Sciences (SPACS)

- The first goal is to enhance traditional science training thereby giving students a more accurate picture of how most large modern scientific collaborations actually work.
- The second goal is to better prepare students and to better equip them to tackle the vast and complex interdisciplinary problems facing society.
- All modern science is based upon fundamental physical principles expressed in the language of mathematics.

Emphasis on Big Data and Modeling and Simulation/Visualization

But the approach to large and complex problems, such as climate change, understanding the brain and consciousness, understanding the origin of life, all require collaborative work among scientists from a variety of disciplines.

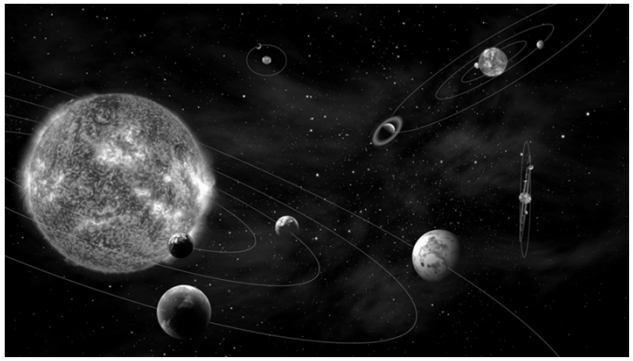
A scientist working alone in a private lab is now a rare exception. Education in the sciences must be modified to reflect how modern science is done, such as using input from multiple disciplines that involve vast quantities of data.

The databases themselves have become, effectively, alternative universes that must be explored using appropriately developed tools in data science.

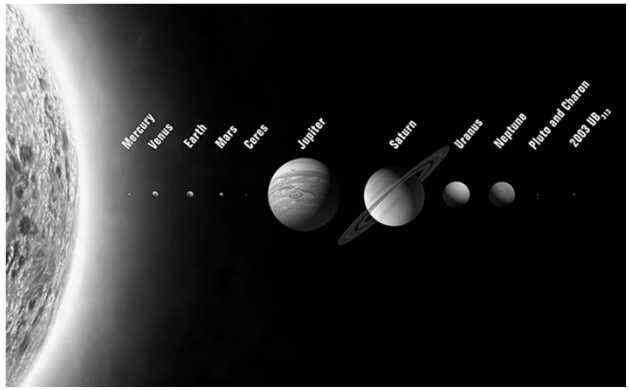
SPACS Course: Topics/Dates

1) **Mar. 27:** *Overview of SPACS at George Mason. Planetary Science and Exoplanet Research,* **Michael E. Summers**
2) **Apr. 3:** *Intricately Searching for Simplicity: An Introduction to Experimental Particle Physics.* **Phil Rubin**.
3) **Apr. 10:** *Black holes: a journey through modern astronomy.* **Mario Gliozzi.**
4) **Apr. 17**: *The Dusty Universe*, **Joe Weingartner.**
5) **Apr. 24**: *The Large Synoptic Survey Telescope and the Ever-Changing Dynamic Universe*. **Kirk Borne.**
6) **May 1**: *Some Exotic Phenomena in the Quantum World*. **Indu Satija.**
7) **May 8:** *Superfluidity: from a Helium droplet to the interior of neutron.* **Erhai Zhao.**
8) **May 15:** *Cosmic Collisions.* **Jessica Rosenberg**

Astronomy/Planetary Sciences: A Golden Age of Exoplanet Discoveries

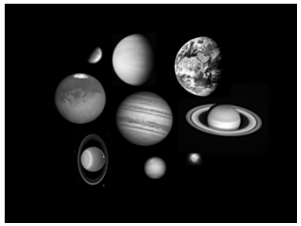


Orientation: The Planets of our Solar System



Terrestrial Rocky Planets | **Gas Giant Planets** | **Dwarf Ice Planets**

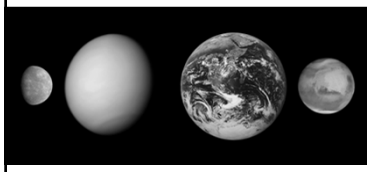
The "Old Traditional" Taxonomy of Solar System Planets



<u>From our own solar system:</u>

(1)Terrestrial Rocky Worlds
(Mercury, Venus, Earth, Mars)
(2) Giant Gaseous Planets
(Jupiter, Saturn, Uranus, Neptune)
(3)(Recently defined) Dwarf Ice Planets
Pluto, KBOs, UB313, Sedna (?)

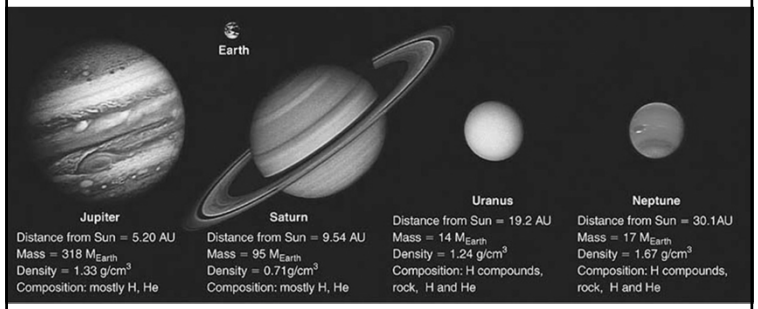
(1) Terrestrial "Rocky" Worlds



Densities and semi-major axis length of terrestrial planets

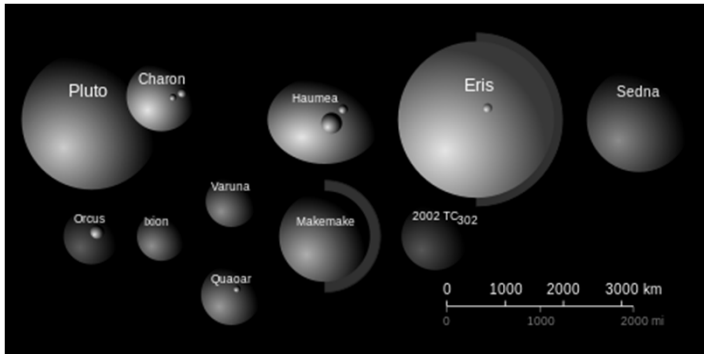
Object	Density (g cm^{-3}) Mean	Density (g cm^{-3}) Uncompressed	Semi-major axis (AU)
Mercury	5.4	5.3	0.39
Venus	5.2	4.4	0.72
Earth	5.5	4.4	1.0
Moon	3.3	3.3	1.0
Mars	3.9	3.8	1.5
Vesta	3.4	3.4	2.3
Ceres	2.1	2.1	2.8
Pallas	2.8	2.8	2.8

(2) Giant "Gas" Planets



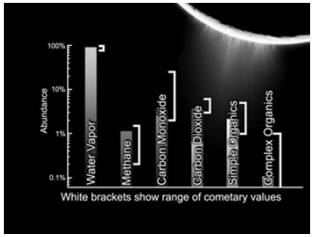
http://lasp.colorado.edu/education/outerplanets/images_giants/big/jovian_planets.jpg

(3) Dwarf Ice Planets

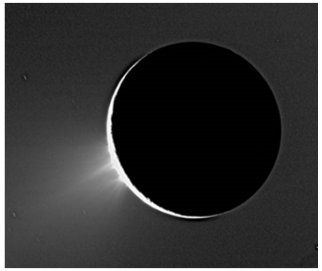


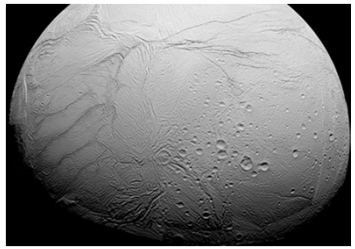
http://en.wikipedia.org/wiki/File:TheTransneptunians_Size_Albedo_Color.svg

Even Dwarf Ice Planets/Moons are far from “Dead”!!!!

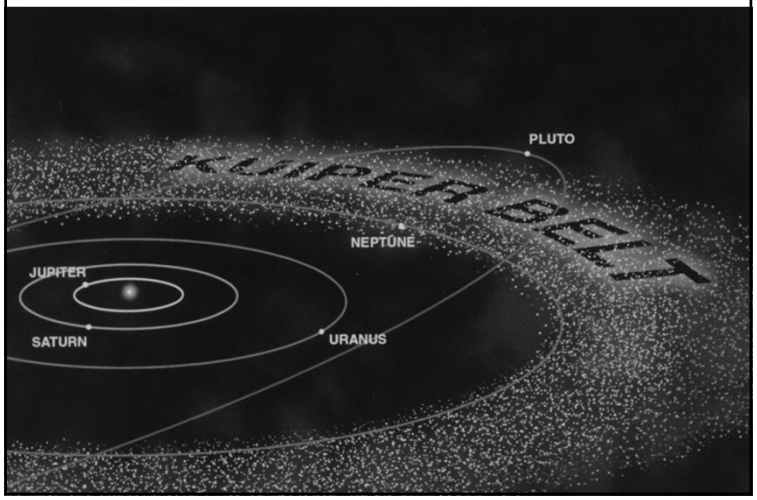


Enceladus

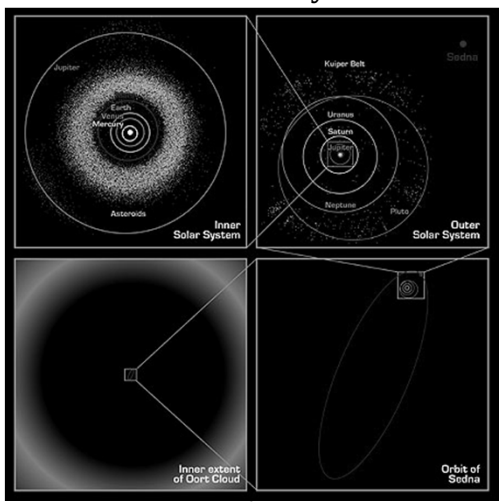




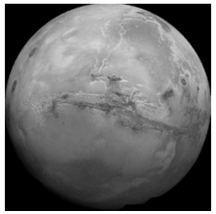
(3) Dwarf Ice Planets (Pluto, KBOs)



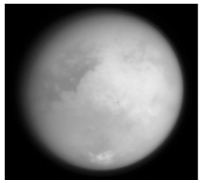
(3) The Far Outer Solar System and Sedna



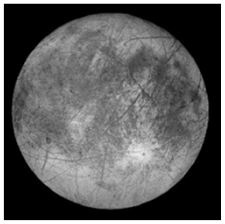
Habitability may encompass many planets where surface water is not stable.



Mars: an underground biosphere?

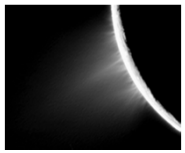


Titan: Natural organic laboratory

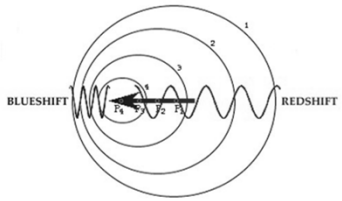


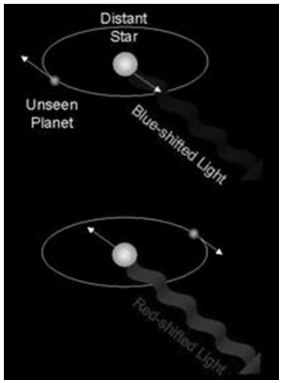
Europa: largest liquid water ocean in the solar system

Enceladus: Geysers of Water and complex organics



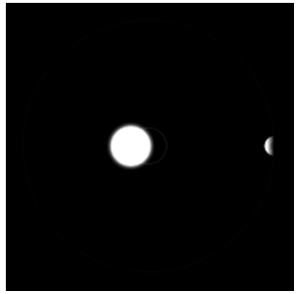
Radial Velocity Technique: Discovering Exo-planets using Doppler Spectroscopy

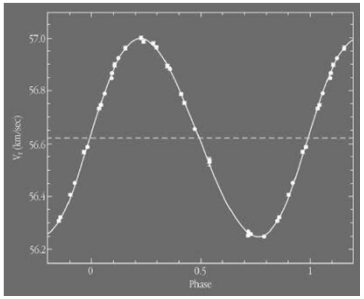




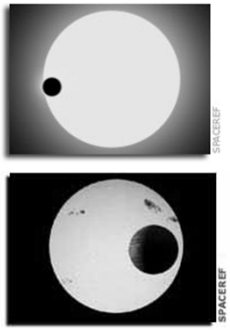
http://astronomy.nmsu.edu/msussman/ExtrasolarPlanets/09.html

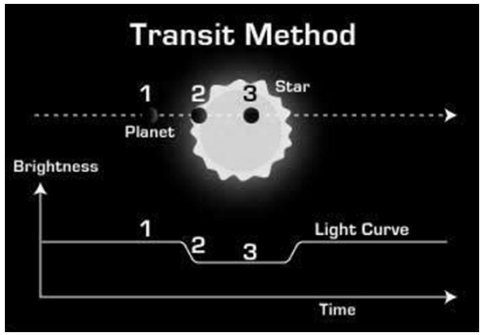
Extrasolar Planets from Radial Velocity Measurements



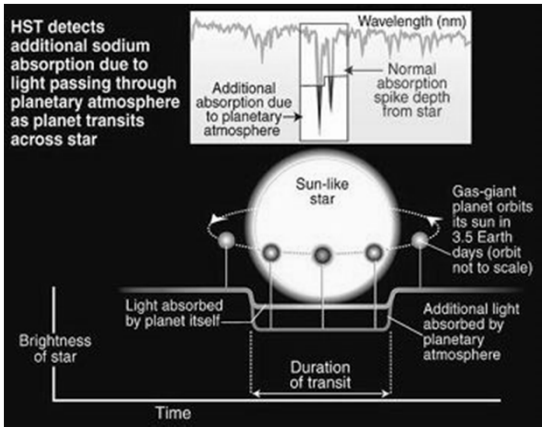


The Transit Technique



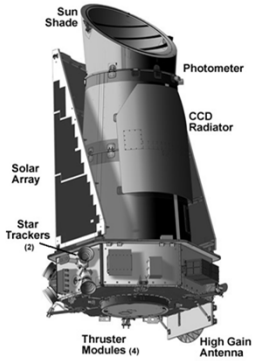


The Transit Technique



The Kepler Mission (Transit Method)

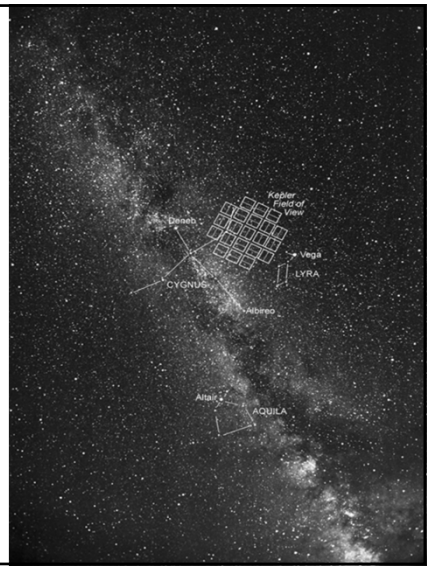
- **Continuously point at a single star field in Cygnus-Lyra region except during Ka-band downlink.**
- **Monitor 100,000 main-sequence stars for planets.**
- **Mission lifetime of 3.5 years extendible to at least 6 years.**



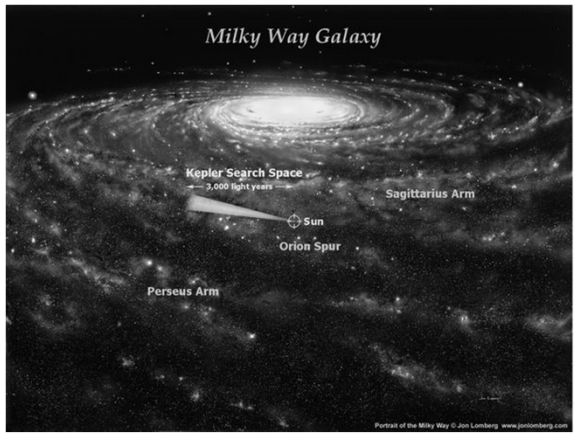
http://kepler.nasa.gov/about/

Kepler field of view in the night sky.

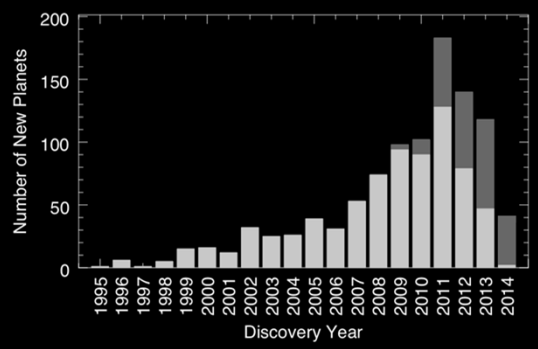
http://seds.org/Maps/Stars_en/Fig/cygnus.html

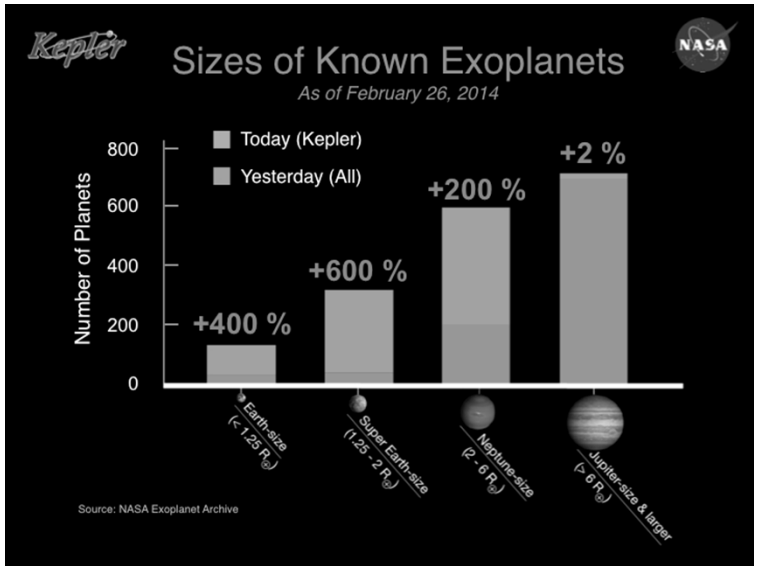


Kepler Search and Milky Way

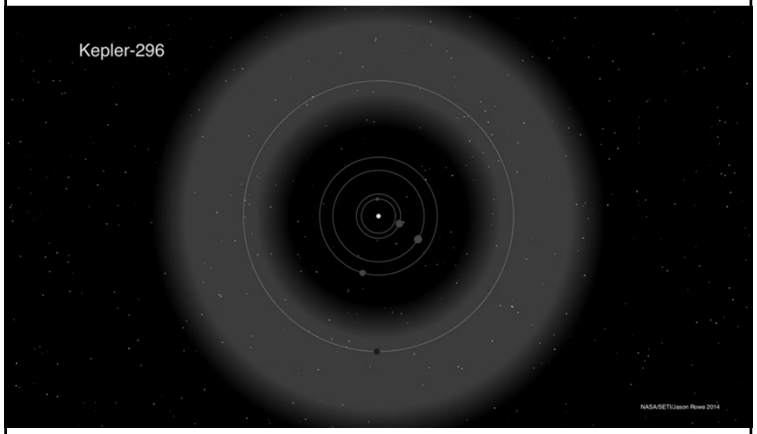


Kepler Contribution of Exoplanet Discoveries

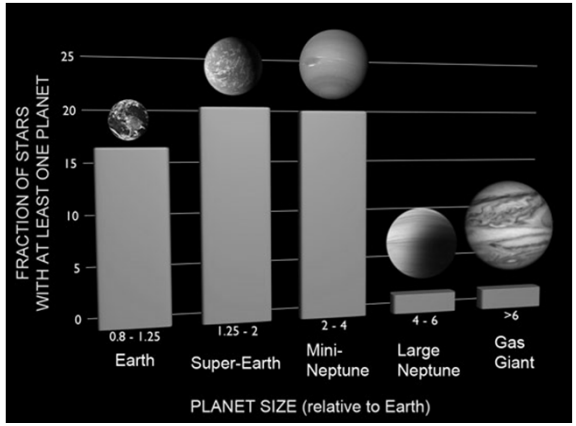




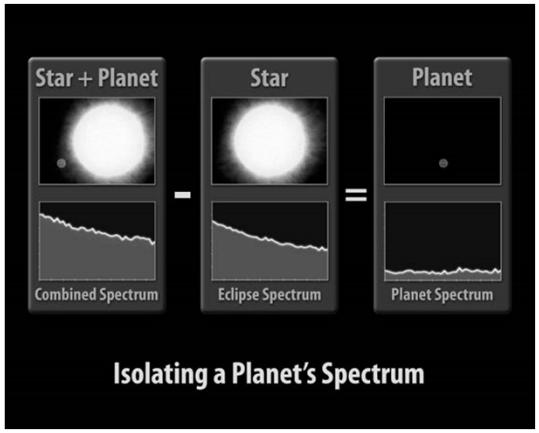
Habitable Zones



One in Six Stars has an Earth-Like Planet



Isolating an Exo-planet's Spectrum



http://www.nasa.gov/centers/goddard/images/content/170716main_extrasolar_planet_spectrum_lgweb.jpg

Detecting Earth-like Planets:

Possible spectra implications:

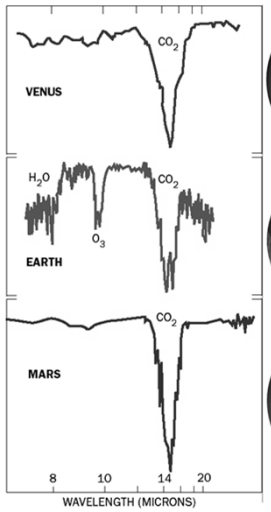
CO_2 → greenhouse gas

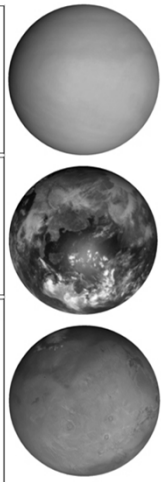
H_2O → hydrosphere

O_3 → O_2 production

CH_4 → biology

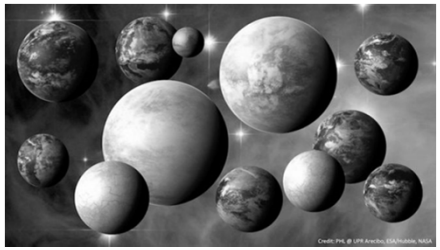
What else?



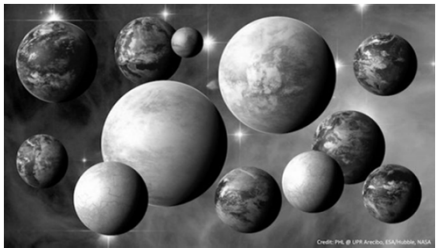


http://www.markelowitz.com/exobiology.htm

Planetary Taxonomy with New Types of Exoplanets



Planetary Taxonomy with New Types of Exoplanets



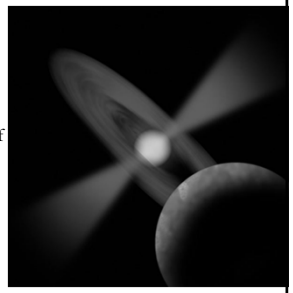
Exoplanets – Newly Discovered Categories

(4) Pulsar planets (survived novae and/or supernovae)
(5) Hot Jupiters, rapidly losing mass to central star
(6) Water Worlds, maybe H_2 or He envelopes
(7) Super hot Earth-types (silicate vapor atmospheres)
(8) Super Earths – appear to dominate statistics so far
(9) Carbon/Diamond planets
(10) Multiple star planets (bound to more than one star, in one case 4 stars)
(11) Metallic planets (>90% metals, Mercury & Jupiter might fit this)
(12) Styrofoam worlds – extremely low density
(13) Rogue worlds
(14) Brown Dwarfs (sub critical for stellar fusion)
(15) Super-speed planets (some relativistic!)

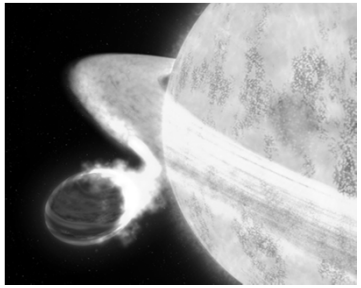
(4) Pulsar Planets

"In 1970, David Richards noticed an anomaly in the periodicity of a signal from the Crab pulsar, discovered one year before. He proposed three explanations : A precession effect, A vibration of the pulsar or a perturbation due to the presence of a planet with a period of 11 days. The vibration hypothesis was considered to be the correct one. On the other hand, in 1991, Andrew Lyne published the discovery of a planet around PSR 1829-10, from observations with the radiotelescope of Jodrell Bank.

In January 1992, the same day Lyne retracted his discovery (he didn't take into account the eccentricity of the orbit of the Earth), Alexander Wolszczan announced the discovery of two planets (with a period of 67 days and a mass of 3,4 M_J for the first one, and a period of 90 days and a mass of 2,8 M_J for the second one) around PSR 1257+12 !
This time, the observations of Wolszczan at Arecibo were confirmed by Dale Frail in VLA. Moreover, the study of the system enabled us to highlight a 3:2 gravitational resonance between the two planets.
The existence of these strange planets seemed to be truly real, since in 1994 a second pulsar, PSR B1620-26, was found to have a planet of mass 2,5 M_J."

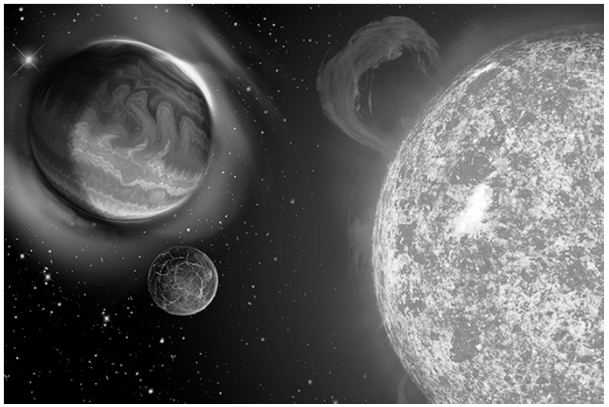


(5) Hot Jupiters



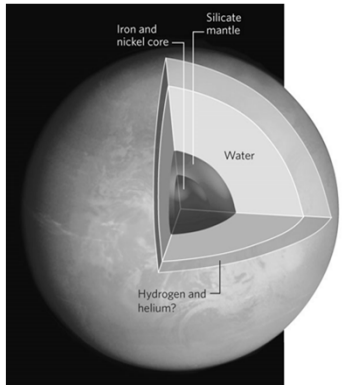
"Osiris is another extra-solar planet classified as a hot Jupiter, because of its position around its host star and its size. Osiris is also strange for some different reasons but it is special that it's also dying. It is leaking carbon-oxygen from its atmosphere, and its leaking out at such a immense rate that it also falls under a new class of extra-solar planets called chthonian planets, or dead cores of completely evaporated gas giants."

Artist's conception of an Hot Jupiter (credit: T. Riecken)
Planet in orbit near its primary star.



http://www.sdss3.org/exoplanets.php

(6) Water Worlds



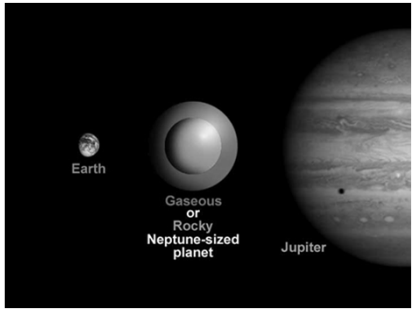
Nature **462**, 853-854 (17 December 2009) | doi:10.1038/462853a; Published online 16 December 2009

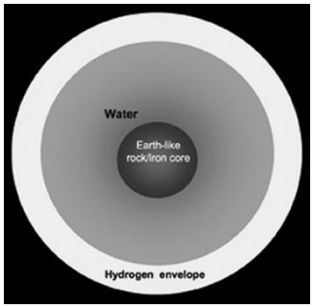
Extrasolar planets: Water world larger than Earth

Geoffrey Marcy

Abstract
The hunt for Earth-like worlds has taken a major step forward with the discovery of a planet only 2.7 times larger than Earth. Its mass and size are just as theorists would expect for a water-rich super-Earth.

Size of Water Worlds



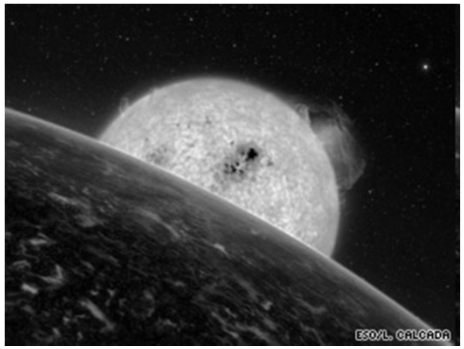


First Rocky Planet Discovered Outside Solar System: CoRot-7b

(7) Hot and Superhot Earths

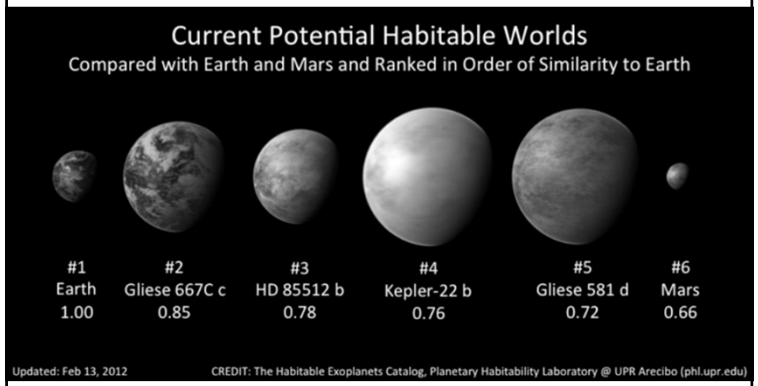
→5 x Earth's Mass
→Tidally Locked to central star: One year ~ 1 Earth day

→Sunside ~2000 C
→Nightside ~200 C



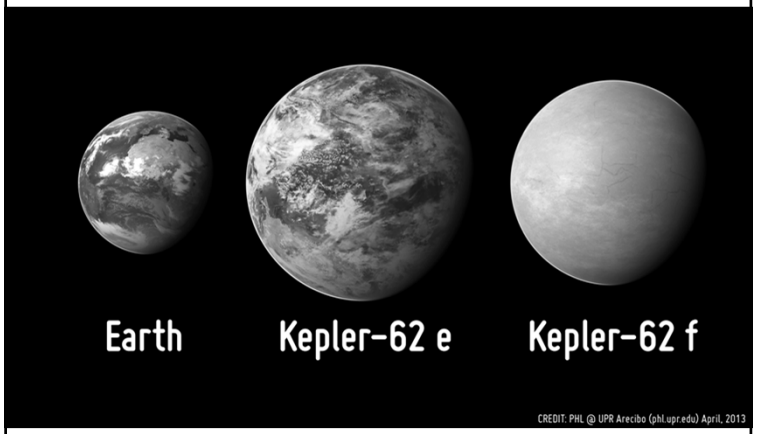
http://www.cnn.com/2009/TECH/space/09/16/new.rocky.planet/index.html

(8) Super Earths

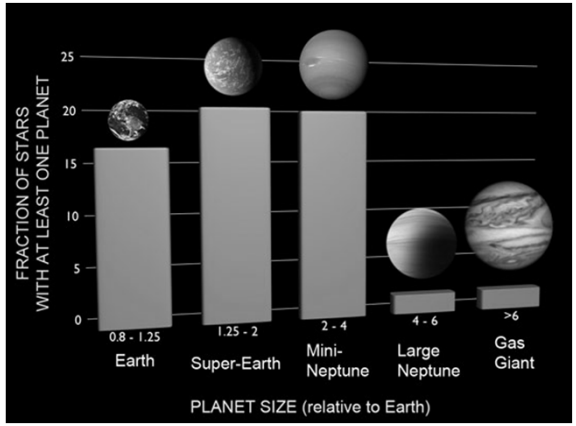


http://annesastronomynews.com/photo-gallery-ii/miscellaneous/current-potential-habitable-worlds/

Kepler "Nearest Earth Types"

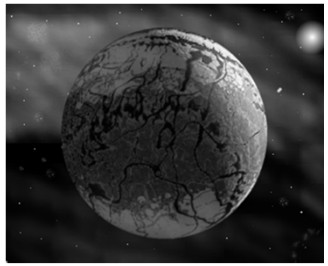


Kepler Statistical Analysis

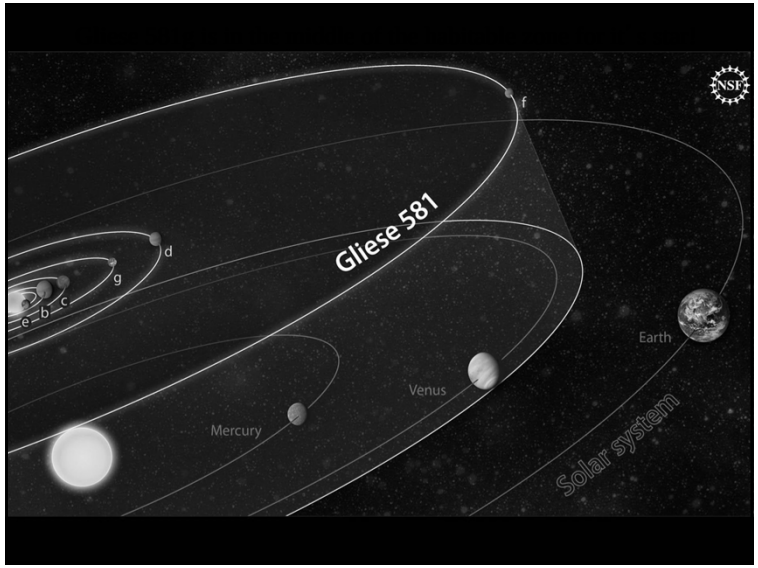


Gliese 581 g

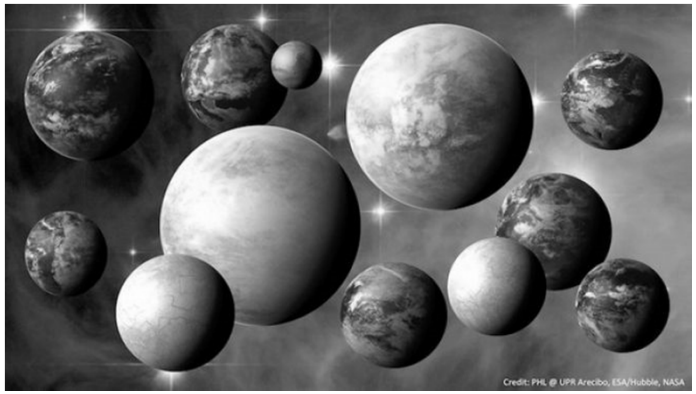
Mass = 3.1-4.3 Earth Masses
Radius = 1.3-1.5 Earth Radii
Year = 37 Earth Days
Surface Temperature = 209-280K
(-64ºC to 7ºC)

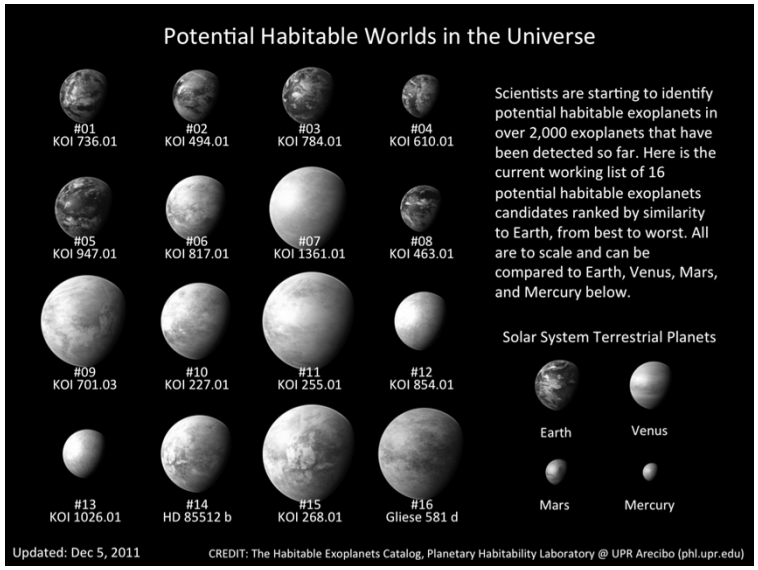


Temperature Comparisons	Venus	Earth	Gliese 581 g	Mars
Global Equilibrium Temperature	307 K (34 ° C)	255 K (−18 ° C)	209 K (−64 ° C) to 228 K (−45 ° C)	206 K (−67 ° C)
+ Venus' GHG eff ect	737 K (464 ° C)			
+ Earth's GHG effect		288 K (15 ° C)	236 K (−37 ° C) to 261 K (−12 ° C)	
+ Mars' GHG effect				210 K (−63 ° C)
Tidally locked	Almost	No	Probably	No
Refs.				



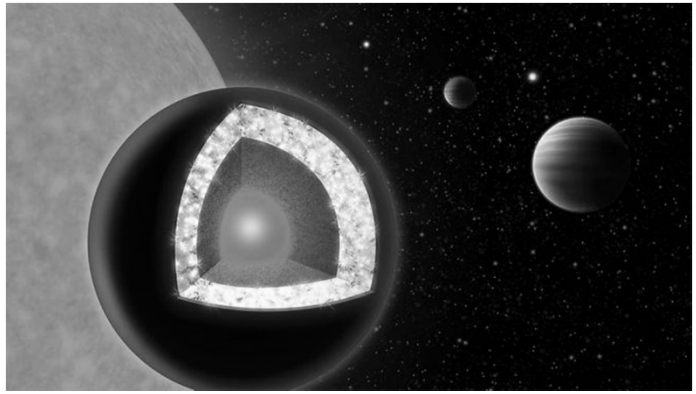
Plethora of Earth-like Planets





(9) Diamond/Carbon Planets

An illustration of 55 Cancri e shows a surface of mostly graphite surrounding a thick layer of diamond.



http://news.nationalgeographic.com/news/2012/10/121011-diamond-planet-space-solar-system-astronomy-science/

(10) Planets with Multiple Primary Stars

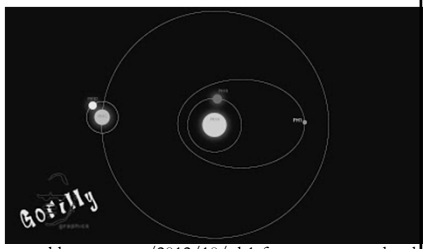
"Tatooine Planet" a la Star Wars movie

Triple Star System

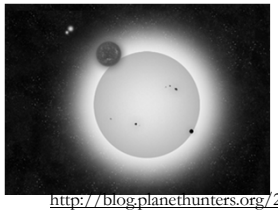
Artist's impression of the view from a (hypothetical) moon of planet **HD 188753 Ab** (upper left), which orbits in a **triple star system**. The brightest component star (A) has just set. The binary pair HD 188753 BC lingers in the sky.

http://en.wikipedia.org/wiki/File:Triple-star_sunset.jpg

Planet in a Four Stars System



http://inhalehornets.blogspot.com/2012/10/ph1-four-star-system.html



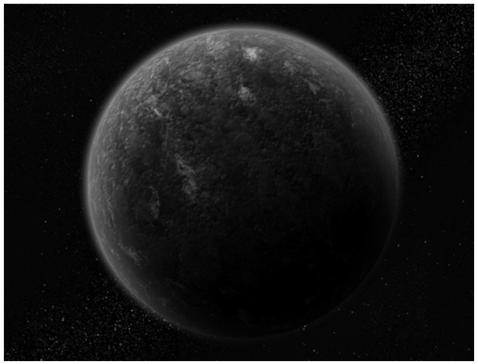
It is a circumbinary planet – one which orbits a double star – and our follow-up observations indicate that there is a second pair of stars approximately 90 billion miles (1000 Astronomical Units) away which are gravitationally bound to the system.

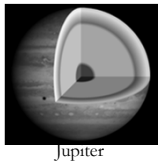
Image credit: Haven Giguere/Yale

http://blog.planethunters.org/2012/10/15/ph1-a-planet-in-a-four-star-system/

(11) Metallic Planets

The Arros **System** (Star Type: G, Total Planets: 4)
Name: **Tartarus**





Jupiter

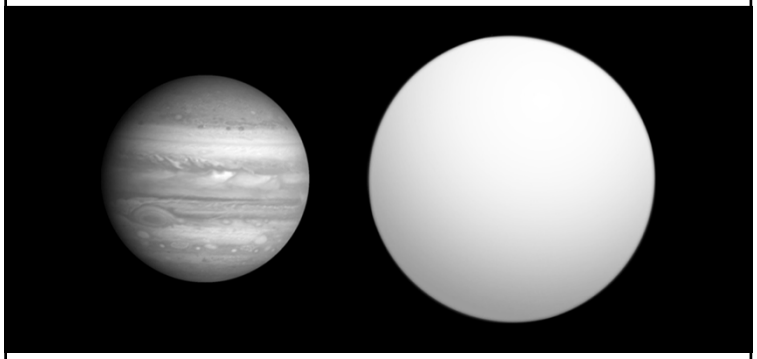
Mercury

Jupiter & Mercury
Nearly-so!

http://forum.astroempires.com/viewtopic.php?f=18&t=39558&view=next

(12) "Styrofoam" Worlds

Low density. HD 209458 is roughly 0.5 Jupiter masses but with 1.14 times its radius.



http://www.geol.umd.edu/~jmerck/geol212/lectures/30.html

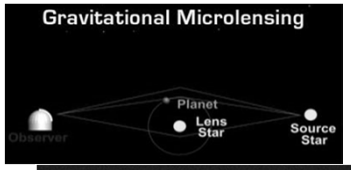
(13) Rogue Planets

Detected by Gravitation Lensing

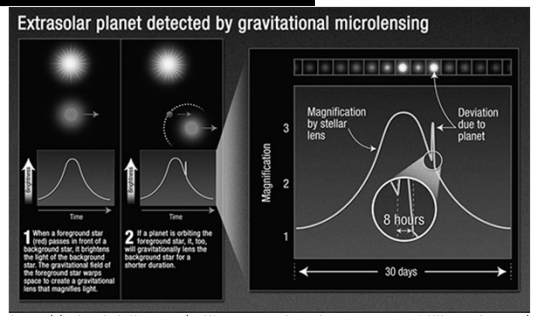
Speculations on ejected (rogue) planets:

- Cooling Jupiters (billions of years to cool!)
- Cooling rocky worlds (subsurface biospheres that propagate inward as planet cools).
- Cooling metallic planets
- Maybe superconducting planets
- "Pin-ball" worlds in globular clusters or the galactic core, eventually ejected from such locales.
- "Never-night" worlds in globular clusters or the galactic core.

Detecting Rogue Planets

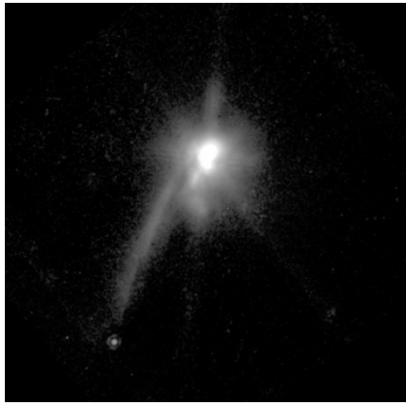


http://www.geol.umd.edu/~jmerck/geol212/lectures/30.html



http://scitechdaily.com/milky-way-galaxy-has-over-100-billion-planets/

Escaped Planets – Hubble Photo of Planet escaping from its primary star.



(14) Brown Dwarfs

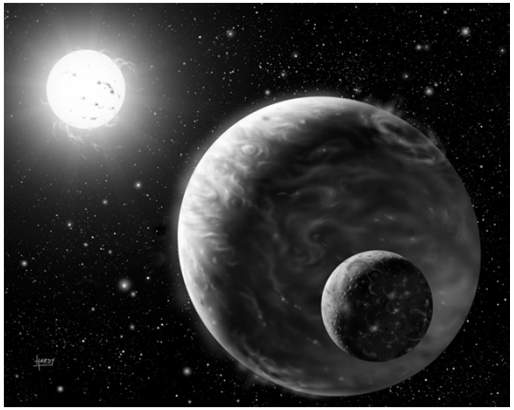
Luhman 16B

http://www.sci-news.com/astronomy/science-cloud-map-brown-dwarf-luhman16b-01730.html

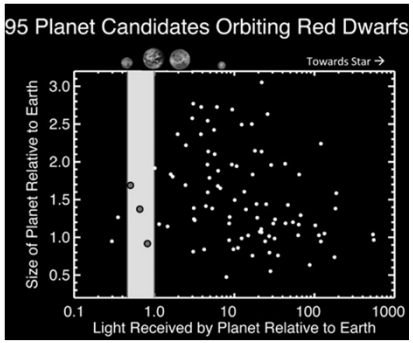
More Speculative Categories

- Large moons (larger than Mercury) around exoplanets (wide range)
- Early Earth analogs (maybe Titan)
- Ancient Earth's where evolution has run its limit, Runaway climates like Venus
- Ancient planets (>10 BY old around low metalicity stars)
- Black hole bound planets
- Super-speed planets (ejected from system collisions, and/or supernovae) --- Just discovered! Relativistic planets!
- CHON – carbonaceous worlds
- Radioactive planets

Exoplanets Planets are Diverse!



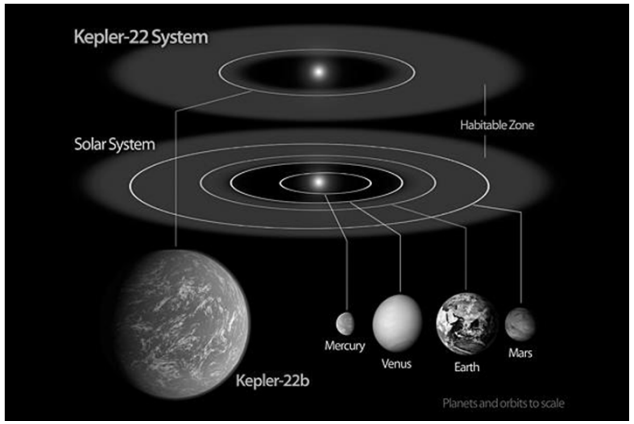
Planets around Red Dwarf Stars (75% of all Stars)



By analyzing publicly available Kepler data, CfA astronomers identified 95 planetary candidates circling red dwarf stars. Of those, three orbit within the habitable zone (marked in green) – the distance at which they should be warm enough to host liquid water on the surface. Those three planetary candidates (marked with blue dots) are 0.9, 1.4, and 1.7 times the size of Earth. In this graph, light received by the planet increases from left to right, and therefore distance to the star decreases from left to right. Planet size increases from bottom to top. Credit: C. Dressing (CfA).

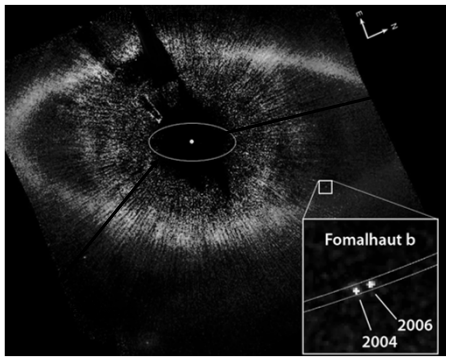
http://scitechdaily.com/earth-like-planets-may-have-older-and-more-evolved-life/

Habitability



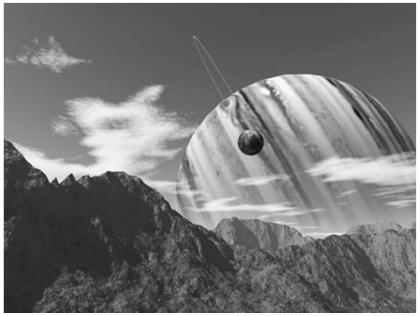
The First Images of Exoplanets

- New images show planets orbiting bright young nearby stars
- Although more than 490 planets are known to orbit other stars, none could be imaged until now



Hubble Space Telescope visible image of the star Fomalhaut (whose light was blocked), with a dust belt similar to the Kuiper belt. Inset*: Images taken ~2 years apart show a planet moving around the star.*

Artists' Conceptions of Extrasolar Planets



http://alas.matf.bg.ac.yu/~af02107/home.jpg

http://www.mondolithic.com/wp-content/uploads/2009/03/alien-abodes-of-life.jpg

Useful Websites:

NASA: Updates on all US space missions:
www.nasa.gov

NASA Astrobiology Institute (NAI):
http://nai.arc.nasa.gov/

The Astrobiology Web: www.astrobiology.com

The Kepler Telescope: http://kepler.nasa.gov/

The exoplanet encyclopaedia: http://exoplanet.eu/