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 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.

Astronomy/Planetary Sciences: A Golden Age of Exoplanet Discoveries

SPACS Course: Topics/Dates

1) Mar. 27: Overview of SPACS at George Mason. Planetary Science and Exoplanet Research, Michael E. Summers
4) Apr. 17: The Dusty Universe, Joe Weingartner.
7) May 8: Superfluidity: from a Helium droplet to the interior of neutron. Erhai Zhao.
8) May 15: Cosmic Collisions. Jessica Rosenberg

Orientation: The Planets of our Solar System
The “Old Traditional” Taxonomy of Solar System Planets

From our own solar system:

(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

<table>
<thead>
<tr>
<th>Object</th>
<th>Density (g cm$^{-3}$)</th>
<th>Semi-major axis (AU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>5.4</td>
<td>0.39</td>
</tr>
<tr>
<td>Venus</td>
<td>5.2</td>
<td>0.72</td>
</tr>
<tr>
<td>Earth</td>
<td>5.5</td>
<td>1.0</td>
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<tr>
<td>Moon</td>
<td>3.3</td>
<td>1.0</td>
</tr>
<tr>
<td>Mars</td>
<td>3.9</td>
<td>1.5</td>
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<tr>
<td>Vesta</td>
<td>3.4</td>
<td>2.3</td>
</tr>
<tr>
<td>Ceres</td>
<td>2.1</td>
<td>2.8</td>
</tr>
<tr>
<td>Pallas</td>
<td>2.8</td>
<td>2.8</td>
</tr>
</tbody>
</table>

(2) Giant “Gas” Planets

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

(3) Dwarf Ice Planets

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

(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

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 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
Detecting Earth-like Planets:
Possible spectra implications:
- CO₂ → greenhouse gas
- H₂O → hydrosphere
- O₂ → O₂ production
- CH₄ → biology
What else?

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 H₂ 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)
“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 1285-10, 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.”

“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.”

“Extra-solar planets: Water world larger than Earth

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

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

- 5 x Earth’s Mass
- Tidally Locked to central star: One year ~ 1 Earth day
- Sunside ~2000 C
- Nightside ~200 C


(7) Hot and Superhot Earths

(8) Super Earths

Current Potential Habitable Worlds Compared with Earth and Mars and Ranked in Order of Similarity to Earth

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 (-64°C to 7°C)

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Gliese 581 g is in the middle of the habitable zone for its star!

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.

11) Metallic Planets

The Arros System
Star Type: G
Total Planets: 4
Name: Tarus

Jupiter
Mercury
Jupiter & Mercury
Nearly-so!


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

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).

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

Artists’ Conceptions of Extrasolar Planets
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/