Planetary Systems – What’dya Know?

- Can we reasonably compare our solar system with other planetary systems?
  - What are 5 key properties of our solar system?
  - What are 5 key properties you might use to characterize other planetary systems?
  - Is there overlap in this list?
    - Do the key (i.e. "salient") properties of the solar system provide any insight into the properties of other planetary systems?
    - Do the key (i.e. "salient") properties of other planetary systems provide any insight into our understanding of our own solar system?
Planetary Systems – what next?

- What are three major questions/unknowns remaining about our understanding of planetary systems?

Future Exploration

- ALMA, SKA, TMT, Kepler … so what’s next?

**Exoplanet Prioritized Questions:**
- What are the physical characteristics of planets in the habitable zones around bright, nearby stars?
- What is the architecture of planetary systems?
- When, how, and in what environments are planets formed?

**Exoplanet Science Goals:**
- Measurement of the frequency of low-mass exoplanets, i.e. the mass distribution function (Kepler, CoRoT)
- Searches for all types of exoplanets around nearby stars
- Measurement of exozodiacal disk brightnesses to levels approaching that of the solar system.
- Characterization and search for signs of life on nearby exoplanets, especially Earth-twins.
Overview of Future Exoplanet Science

- Micro-arcsecond astrometry to detect Earth-twins around 100 nearby stars → requires a space mission
- Near-UV to near-IR coronographic capable optical imaging/spectroscopy to observing spectrum of Earth-like planets around other stars
- mid-IR spectroscopy to detect biosignatures of Earth-like planets
- Direct imaging of structure of dust disks
- Microlensing surveys of distant (1-2 kpc) stars to detect planets
- Continue RV surveys, with higher spectral resolution
- Transit surveys (e.g. Kepler)
Life in the Universe

- Life in extreme environments (ocean vents, Antarctica, deep in the crust, etc)
- Astrobiology
  - Life in solar system objects
  - Life elsewhere in the Galaxy — "...together we can rule the Galaxy..."
- SETI
SETI

- Based on two ideas
  - If we needed to communicate across interstellar distances it would be in the radio part of the spectrum
  - We're already emitting lots of radio waves

- 1st broadcast – 1932 Olympics
  - 75 light years ~ 25 pc
  - 3.5 billion years after life began on Earth
  - 250 million years after “animal intelligence”
  - 3 million years after humans showed up

Life in the Solar System

- Earth
  - How did life start on Earth???

- Mars
  - Past surface water
  - Whatever worked for Earth probably worked for Mars….
  - No evidence yet, but….

- Europa
  - Liquid, subsurface ocean → where there is water…

- Titan
  - Nice thick atmosphere, sufficient surface temperatures and pressures…
Life in the Galaxy

- Star
- Mass/size of planet
- Distance from star
- Stable orbit
- Effect of other planets
- Plate tectonics(?)
- Moon(?)

Drake Equation (1950s)

\[ N = N_{\text{stars}} \times f_s \times f_p \times n_{\text{hab}} \times f_{\text{lifetimes}} \times f_{\text{interstellar}} \times f_{\text{intel}} \times f_{\text{comm}} \]
Timescales for Life on Earth
(Ward & Brownlee)

<table>
<thead>
<tr>
<th>Event</th>
<th>When</th>
<th>How Long?</th>
<th>Min. Time?</th>
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<tr>
<td>Origin of Life</td>
<td>3.8-3.5 Gyr</td>
<td>&lt; 0.5 Gyr</td>
<td>0.1 Gyr</td>
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<td>Organic Photosynth.</td>
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<td>&lt; 0.5 Gyr</td>
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<tr>
<td>Oxygen environments</td>
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<td>Animals ecosystems</td>
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<td>5 Myr</td>
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<tr>
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<td>0.400 Gyr</td>
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<tr>
<td>Animal intelligence</td>
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<tr>
<td>Human intelligence</td>
<td>3 Myr</td>
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<tr>
<td>Radio astronomers</td>
<td>80 years</td>
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</table>

Rare Earth (Ward & Brownlee)

- Number of stars in MWG
- Fraction of stars with planets
- Fraction of stars that are metal rich
- Number of planets in star’s HZ
- Number of stars in the Galactic HZ
- Fraction of planets on which life arises
- Percentage of planet's life that it hosts complex life
- Fraction of planets with a large moon
- Fraction of planets with a “nearby” Jupiter
- Fraction of planets with low number of mass extinctions
- Fraction of planets on which life arises that complex life arises as well