Exoplanet Science:
Detections, Biomarkers, & Prospects

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Outline of Talk

• Exoplanets today

• Signs of Life

• Future research
Planet Discoveries in the Solar System

- <1000 BC: Mercury/Venus/Earth/Mars/Jupiter/Saturn
- 1610: Moons of Jupiter, by Galileo
- 1655-86: Moons of Saturn, by Huygens & Cassini
- 1781: Uranus, by Herschel
- 1846: Neptune, by Galle & LeVerier
- 1930: Pluto, by Tombaugh
- <2011: Over 205 planets, moons, & dwarf planets
Exoplanets Are Discovered!

- 1989: D. Latham et al., HD 114762
- 1992: A. Wolszczan & D. Frail, PSR 1257+12
- 1995: D. Queloz & M. Mayor, 51 Peg
- 1995: G. Marcy & P. Butler, 51 Peg
Astrometry, Imaging, Radial Velocity
Transits
5 Ways to Find & Characterize Exoplanets:

- Radial velocity
- Transits
- Microlensing
- Imaging
- Astrometry
David & Goliath

"Year of discovery" vs "Planet Mass" (528)

- Brown Dwarf
- Jupiter
- Super Earth
- Earth

(exoplanet.eu (14/02/11))
Kepler: 1235 Candidate Exoplanets

- **Earth**: 6%
- **Super-Earths**: 24%
- **Neptunes**: 55%
- **Jupiters**: 14%
- **Super-Jupiters**: 1%

Chart showing the distribution of different types of exoplanets based on their proximity to the central star (R(Earths)).
Signs of Life: Microbes to Mega-cities

• Life needs a surface or ocean (so terrestrial planets only)
• Life needs liquid water (e.g., NH₃ is unlikely)
  - So we search in habitable zones (0 to 100 C)
  - And for H₂O vapor
• Life is carbon-based (e.g., Si is unlikely)
  - And we search for CO₂ (plant food)
• Plant life produces large amounts of O₂ (>>photochemistry)
  - So we search for strong O₂ signatures, also O₃
• Visible & near-infrared spectrum (O₂, O₃, H₂O, CO₂, CH₄) excellent
• Mid-infrared spectrum (O₃, CO₂, CH₄) good
• Earth’s spectrum has been the same for ~300 Myr
Earth Over Geologic Time

Relative Concentration

Time (billions of years ago)

Early Sun: 76% S until 2.3 Gyr

Global ice ages

Oxygen appears in atmosphere

Oxygen-producing bacteria start

Methane

Methanogens start

First life consumes CO₂

High CO₂ compensates for faint Sun

Refs: Kasting, Scientific American; Kaltenegger et al, 2006; Holland 2006
Visible Earthshine Spectrum

- Observed Earthshine, reflected from dark side of moon.

Signs of Life: Intelligent Civilizations

- Radio/TV signal search (SETI) started in 1960
  - Big sky, big spectrum, searching continues

- Laser beam search (optical SETI) started in 1998
- Optical fibers reduce these leaks
- If a beacon is found, it is likely an intentional signal
Future Exoplanet Research

- Transits: Kepler & Corot active; others proposed
- RV: active, 1.0 → 0.1 m/s goal
- Microlensing: active, statistics to snowline
- Exozodi: active (Keck & LBTI)
- SETI, active
- WFIRST: microlensing/DE/surveys, 2010s (Astro2010)
- Imaging: discovery/spectra, 2020s (Astro2010)
- Distant future:
  - infrared imaging
  - pictures with 1000-km telescope array
- Prediction: 5 nearby terrestrial planets by 2030