Exoplanet Dynamics: What we know from Kepler

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“There are countless suns and countless earths all rotating around their suns in exactly the same way as the seven planets of our system. We see only the suns because they are the largest bodies and are luminous, but their planets remain invisible to us because they are smaller and non-luminous. The countless worlds in the universe are no worse and no less inhabited than our Earth.”

- Giordano Bruno (1584)
Significance of Extrasolar Planets

• New examples of different types of planets.
• Clues for how planets form.
• How special/common is our Earth?
• Start of search for life beyond the solar system.
Finding planets is **hard**
Gravitational interaction

Electromagnetic interaction

- Radial velocity
- Astrometry
- Microlensing
- Timing

\[ G_{\mu\nu} = -8\pi T_{\mu\nu} \]

- Transit
- Secondary eclipse
- Imaging
Growth of exoplanet discoveries

Exoplanet data is from the Open Exoplanet Catalogue,
Transit of Venus
Kepler spacecraft

[Diagram of Kepler spacecraft with labeled parts such as Sun Shade, Photometer, CCD Radiator, Solar Array, Star Trackers, Thruster Modules, and High Gain Antenna.]

[Map of the Kepler FOV with star magnitudes and celestial objects labeled.]
Kepler discoveries

Pre-Kepler Planets in the Field of View

Locations of Kepler Planet Candidates

- Earth-size
- Super-Earth size: 1.25 - 2.0 Earth-size
- Neptune-size: 2.0 - 6.0 Earth-size
- Giant-planet size: 6.0 - 22 Earth-size

(Out of date!)
Planetary architectures

1500 confirmed planets as of March 17, 2015
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Survey of 150,000 stars from 2009-present

Example folded transit light curve:
Measuring mass with transit timing: what are super-Earths/mini-Neptunes made of?

\[ F_i = m_i a_i \]

\[ F_i = \frac{G m_1 m_2}{d^2} \]

\[ a_i = \frac{G m_2}{d^2} \]
Kepler-36c: a quasi-periodic Neptune
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Kepler-36b,c: closest two orbiting planets

Carter, Agol et al. (2012)
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The Future

• More measurements of planet masses & radii from the Kepler data

• Ground-based: Keck, LCOGT, KOINet, Thirty-Meter Telescope (TMT)

• NASA planet missions: K2, Transiting Exoplanet Sky Survey (TESS), James Webb Space Telescope (JWST)

• Discovery/characterization of more ‘Earth-like’ planets