From Pixels to Planets

Lee Brownston, SGT, Inc.
Jon M. Jenkins, NASA
The Known Planets in 1994
Direct Imaging: Beta Pictoris b
Planetary System Center of Mass
Radial Velocity

Doppler Shift due to Stellar Wobble

Unseen planet
Doppler Measurements

![Graph showing velocity over orbital phase](image)
Earth-size Planets: Detection Method

Kepler Candidate KOI-351

- Rp = 9.7Re
- P = 331.6d

Kepler Planet — Kepler-20e

- Rp = 0.87Re
- P = 19.58d
Gravitational Microlensing
The Habitable Zone

Hotter Stars

Sunlike Stars

Cooler Stars
HAT-P-7b Ground vs. Space

16,620 HATNet data points (57.7 days of data)

Single night at 1.2 m FLWO with Kepler Cam

HAT-P-7b data from the ground
A. Pal et al., 2008

Kepler Commissioning data (10 days)
W. Borucki et al., 2009
Kepler’s Field of View
Sizes of Kepler Planet Candidates

Totals as of January 6, 2015

- Super Earth-size (1.25 - 2 Rₖ) - 1,233
- Earth-size (<1.25 Rₖ) - 808
- Neptune-size (2 - 6 Rₖ) - 1,542
- Jupiter-size (6 - 15 Rₖ) - 260
- Larger (15 - 25 Rₖ) - 49
NASA Kepler’s Hall of Fame:
Small Habitable Zone Planets
As of January 2015

NEW

Kepler-438b
Kepler-442b
Kepler-440b

Kepler-186f
Kepler-62f
Kepler-62e
Kepler-296e
Kepler-296f

Earth

ARTIST’S CONCEPTS
5253 Planet Transits in a Typical Week
• http://i.imgur.com/28LQQo2.gifv
The Focal Plane
Autumnal Equinox

Kepler's orbit

Projection of photometer axis onto the ecliptic

Planned Dates for Quarterly Rolls

<table>
<thead>
<tr>
<th>Year</th>
<th>Sp</th>
<th>Su</th>
<th>Fall</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>4/2</td>
<td>6/28</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Sun

Earth's orbit

Kepler's orbit

Launch

Earth on March 5th

View from the ecliptic North Pole

Kepler 4 years later

Kepler 1 year later

Spring roll

Winter roll

Winter Solstice

Autumnal Equinox

Summer Solstice

Orbital direction
Reaction Wheel
K2 Captures Neptune and Moons
https://youtu.be/Tw-q3uM_5_0
Target and Aperture Definition
CAL: Pixel Level Calibrations

Raw FFI

Calibrated FFI

2011 Jan 11 – AAS Splinter Session – Getting Started with Kepler
Light Curves Also Need ‘Calibration’

Q2 Raw and Corrected Light Curves

- Thermal transient
- Safe mode
- Attitude tweak
- Earth point
- Coarse point
- Attitude tweak

Flux (e-/cadence)

Cadence

Raw flux
Corrected flux
Single Transit Statistics

![Graph showing single transit statistics over time. The x-axis represents time in days, ranging from 0 to 1200. The y-axis represents single event statistics, with values ranging from -6 to 8. The graph includes two lines: one for data with transits and another for data without a planet.](image-url)
Folded Transit Statistics

![Graph showing folded transit statistics with data with transits and data without planet.](image)
Limb Darkening
Centroid Timeseries

Row centroid shows large shifts correlated with flux
Eclipsing Binary
Discrimination Test Example

- Odd depths ≠ even depths
- Unlikely a planet

Flight data, 1 TCE
Flight data, 2 TCEs

- $P_1 = P_2$
- Unlikely a planet
The Detection of Kepler-186f

30-Oct-2012

Kepler-186f

Software Revision: svn+ssh://murzim/repo/soc/tags/release/8.3.1@49247  Date Generated: 30-Oct-2012 16:27:15 Z
SOC Clusters
The Pleiades Supercomputer
For More Information

- http://kepler.nasa.gov
- http://www.nasa.gov/kepler/
- http://exoplanetarchive.ipac.caltech.edu
- https://archive.stsci.edu/kepler/
- http://exoplanets.org