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
Earth-size Planets: Detection Method

- **Jupiter (~1%)**
- **Earth (~0.01%)**

**Kepler Candidate KOI-351**
- $R_p = 9.7R_e$
- $P = 331.6$ days

**Kepler Planet — Kepler-20e**
- $R_p = 0.87R_e$
- $P = 19.58$ days
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
Kepler Observations of Supernova KSN 2011b

Expected range of deviation in the data if a companion star is present

KEGS: Olling et al. 2015
Sizes of Kepler Planet Candidates

Totals as of January 6, 2015

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

Earth

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

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

NEW

ARTIST'S CONCEPTS
5253 Planet Transits in a Typical Week
• http://i.imgur.com/28LQQo2.gifv
The Spacecraft

- Reaction Wheels (4)
- Star Trackers (2)
- Thruster Modules (4)
- High Gain Antenna
- Sun Shade
- Photometer
- CCD Radiator
The Focal Plane
Reaction Wheel
K2 Captures Neptune and Moons
• https://youtu.be/Tw-q3uM_5_0
Target and Aperture Definition
Expose
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

- Raw flux
- Corrected flux

- Thermal transient
- Safe mode
- Attitude tweak
- Earth point
- Coarse point
- Attitude tweak
Single Transit Statistics

![Graph showing single transit statistics over time with data with and without planet transits.](image)
Folded Transit Statistics

![Graph showing maximum folded detection statistic over period in days with data with transits and data without planet depicted.]

Jon Jenkins
Limb Darkening
Centroid Timeseries

Row centroid shows large shifts correlated with flux
Odd depths ≠ even depths

Unlikely a planet

P₁ = P₂

Unlikely a planet
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