Finding Extra-Solar Earths with Kepler

William Cochran
McDonald Observatory

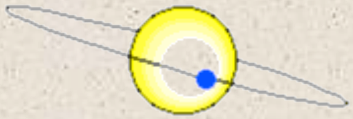
Who is Bill Cochran?

- Senior Research Scientist – McDonald Observatory
- Originally interested in outer planet atmospheres
- Started a radial-velocity search for exoplanets in 1989
- Program has been successful in discovering a large number of expolanets
- Co-Investigator on NASA *Kepler* mission
- Other interests include comets, and solar system formation and evolution

What is ***Kepler***?

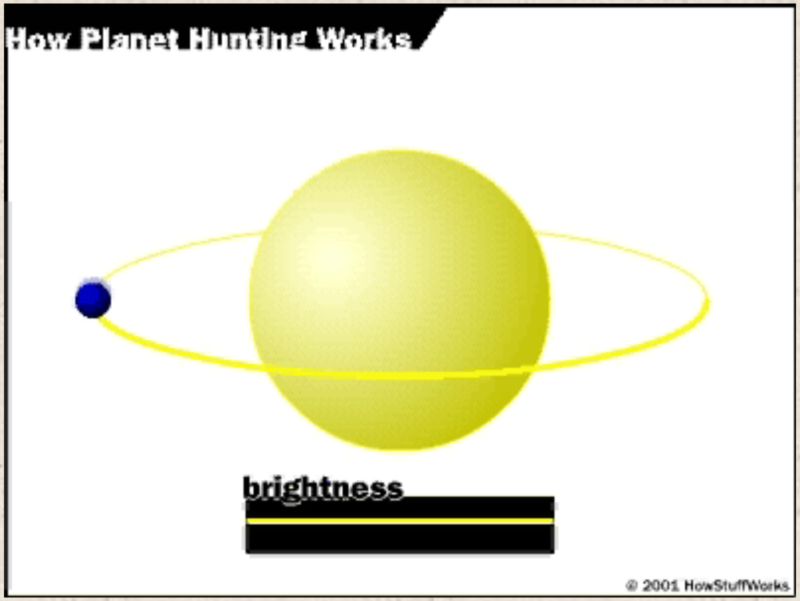
The ***Kepler*** *Mission,* a NASA Discovery mission, is specifically designed to survey our region of the Milky Way galaxy to detect and characterize hundreds of Earth-size and smaller planets in or near the habitable zone.

Kepler searches for transits of planets across the disks of their parent stars.

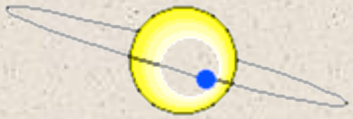


Physics of Planet Transits

If we are viewing a planetary system nearly edge-on, then the planet will pass between us and the star once per orbit, blocking part of the light from the star.



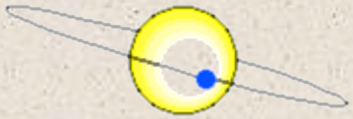
To see a transit, we must be near the planetary orbital plane.



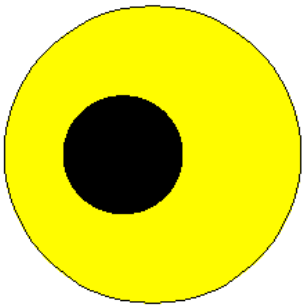
Physics of Planet Transits

Three parameters describe the characteristics of a transit:

- the period of recurrence of the transit;
- the duration of the transit, and
- the fractional change in brightness of the star.

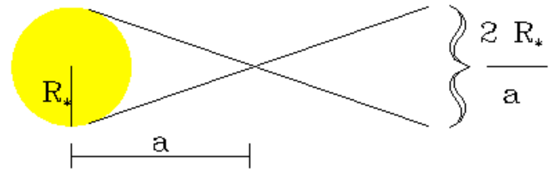


Physics of Planet Transits



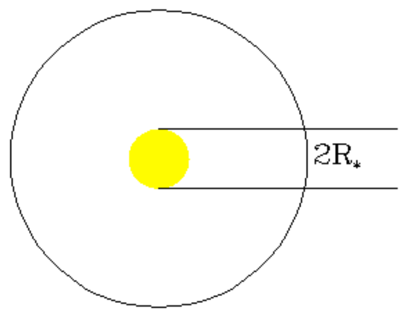
$$\text{Transit Depth} = \frac{\text{Planet Area}}{\text{Star Area}} = \frac{R_p^2}{R_*^2}$$

The transit depth is set simply by the ratio of the planet disk size to the stellar disk size.



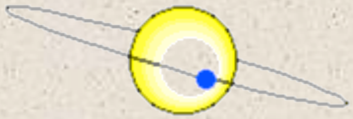
$$\text{transit probability} = \frac{2\pi(2R_*/a)}{4\pi} = \frac{R_*}{a}$$

Transit probability is the ratio of the stellar radius to the orbital radius.



$$\text{Transit Duration} = P\,\frac{2R_*}{2\pi a}$$

The transit duration Is the ratio of the Stellar diameter to the orbital circumference.



Physics of Planet Transits

Planet	Orbital Period (years)	Semi-Major Axis a (A.U.)	Transit Duration (hours)	Transit Depth (%)	Geometric Probability (%)	Inclination Invariant Plane (deg)
Mercury	0.241	0.39	8.1	0.0012	1.19	6.33
Venus	0.615	0.72	11.0	0.0076	0.65	2.16
Earth	1.000	1.00	13.0	0.0084	0.47	1.65
Mars	1.880	1.52	16.0	0.0024	0.31	1.71
Jupiter	11.86	5.20	29.6	1.01	0.089	0.39
Saturn	29.5	9.5	40.1	0.75	0.049	0.87
Uranus	84.0	19.2	57.0	0.135	0.024	1.09
Neptune	164.8	30.1	71.3	0.127	0.015	0.72

Kepler Mission Design

The Challenge: Detect an Earth-transit

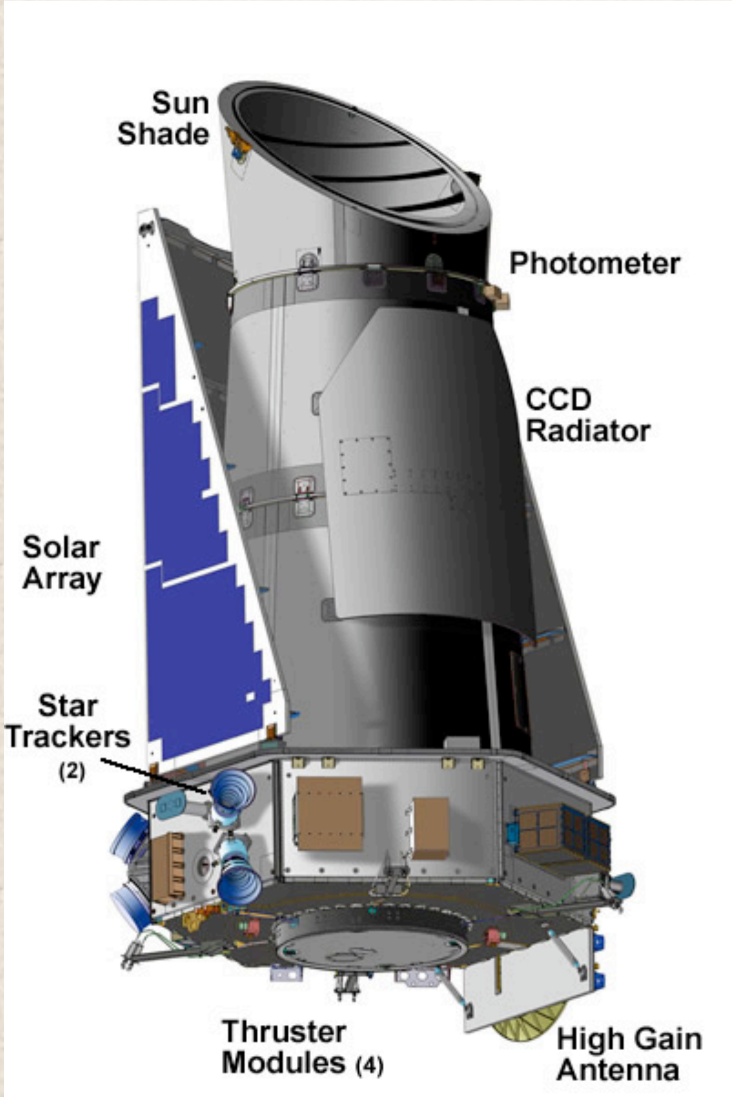
Transit Frequency:	1 year
Transit Duration:	13 hours
Transit Depth:	84 parts per million (ppm)
Geometric Prob.:	0.47%

Test the hypothesis that:

All sun-like stars have an Earth-like planet within 1 AU of the star.

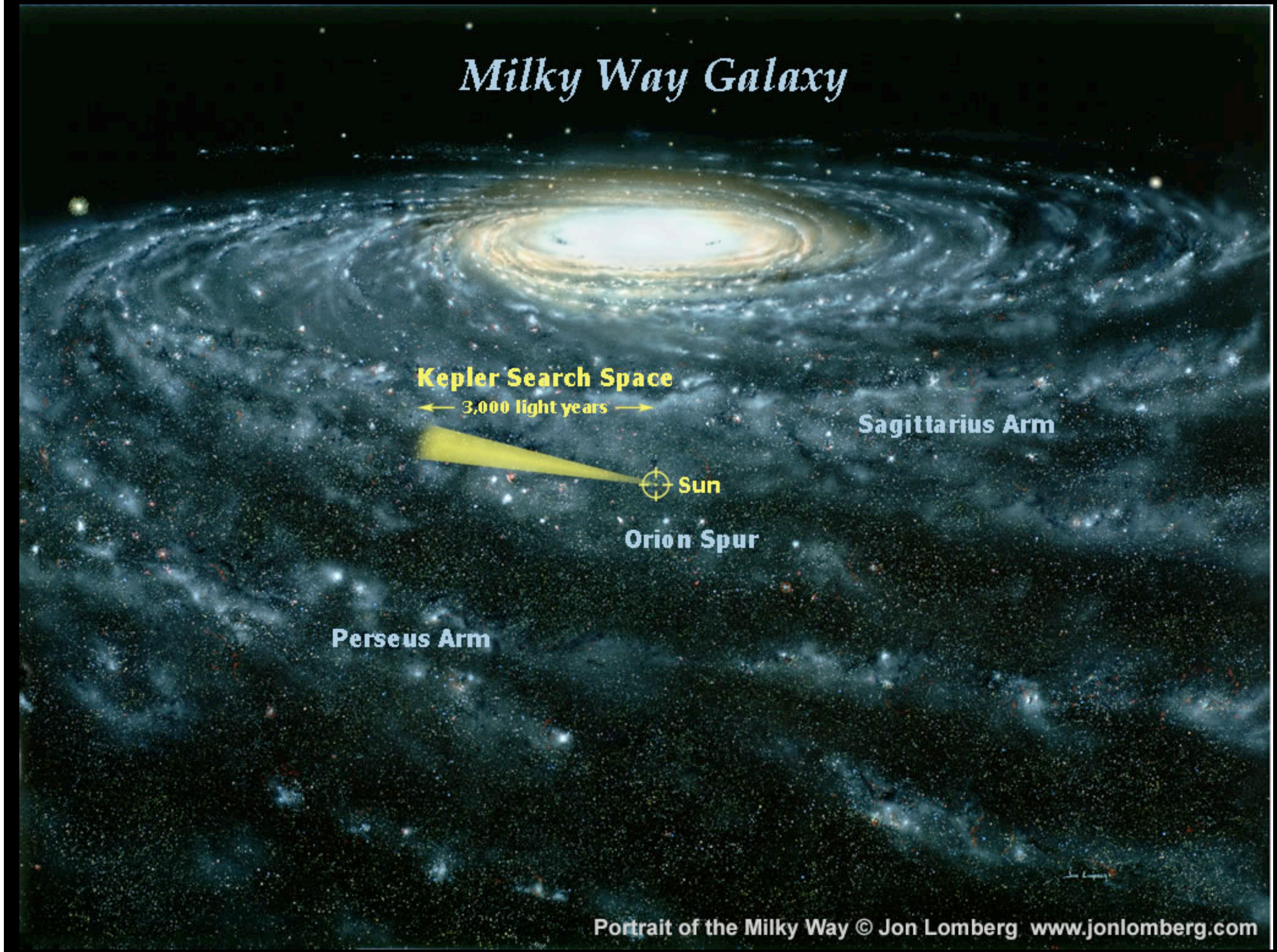
Sample a sufficient number of stars to obtain a statistically significant null result.

Kepler Mission Design



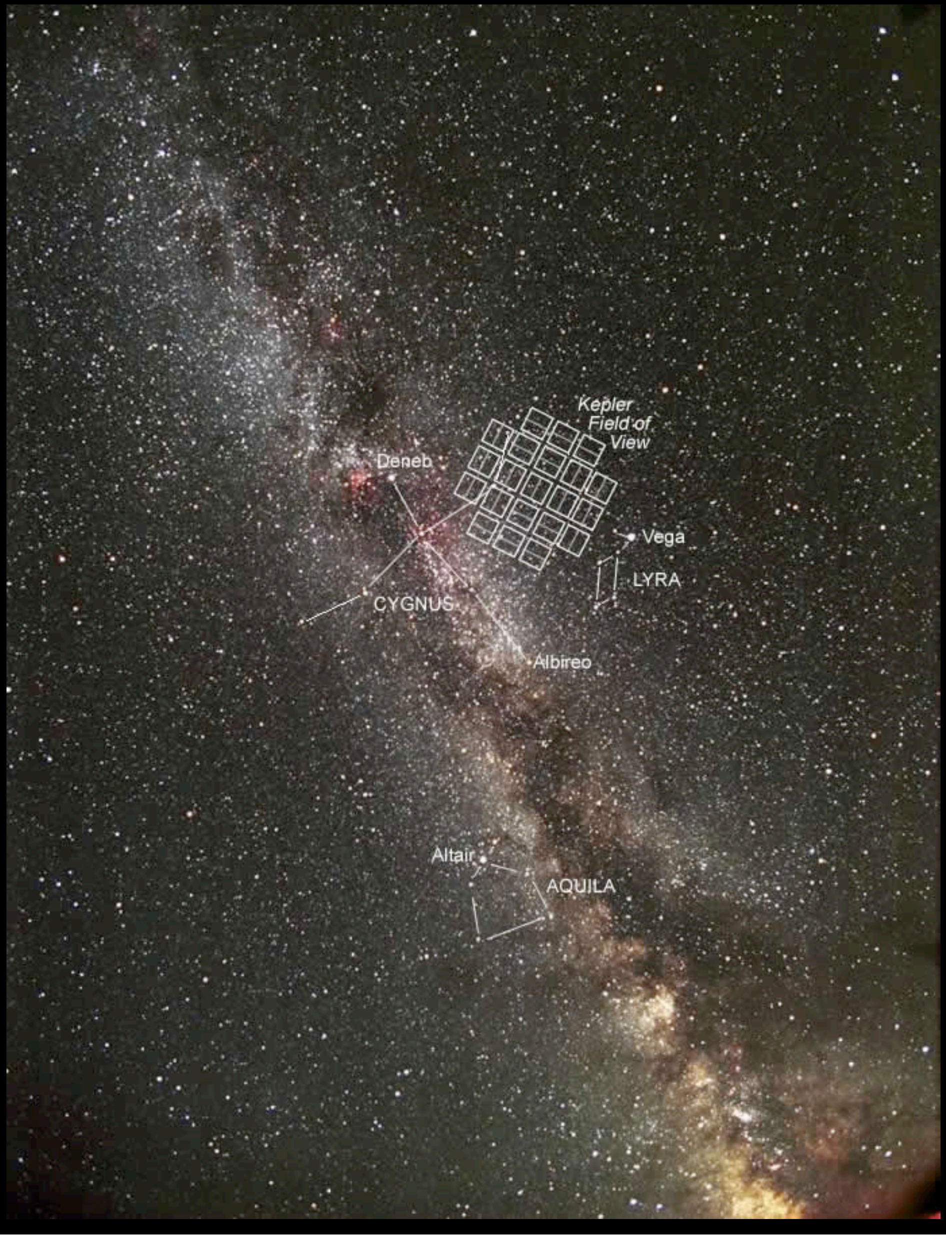
The Photometer mounted on the spacecraft bus.

Kepler Mission



The *Kepler* spacecraft will observe a portion of our Milky Way galaxy in the constellation Cygnus.

Kepler Mission



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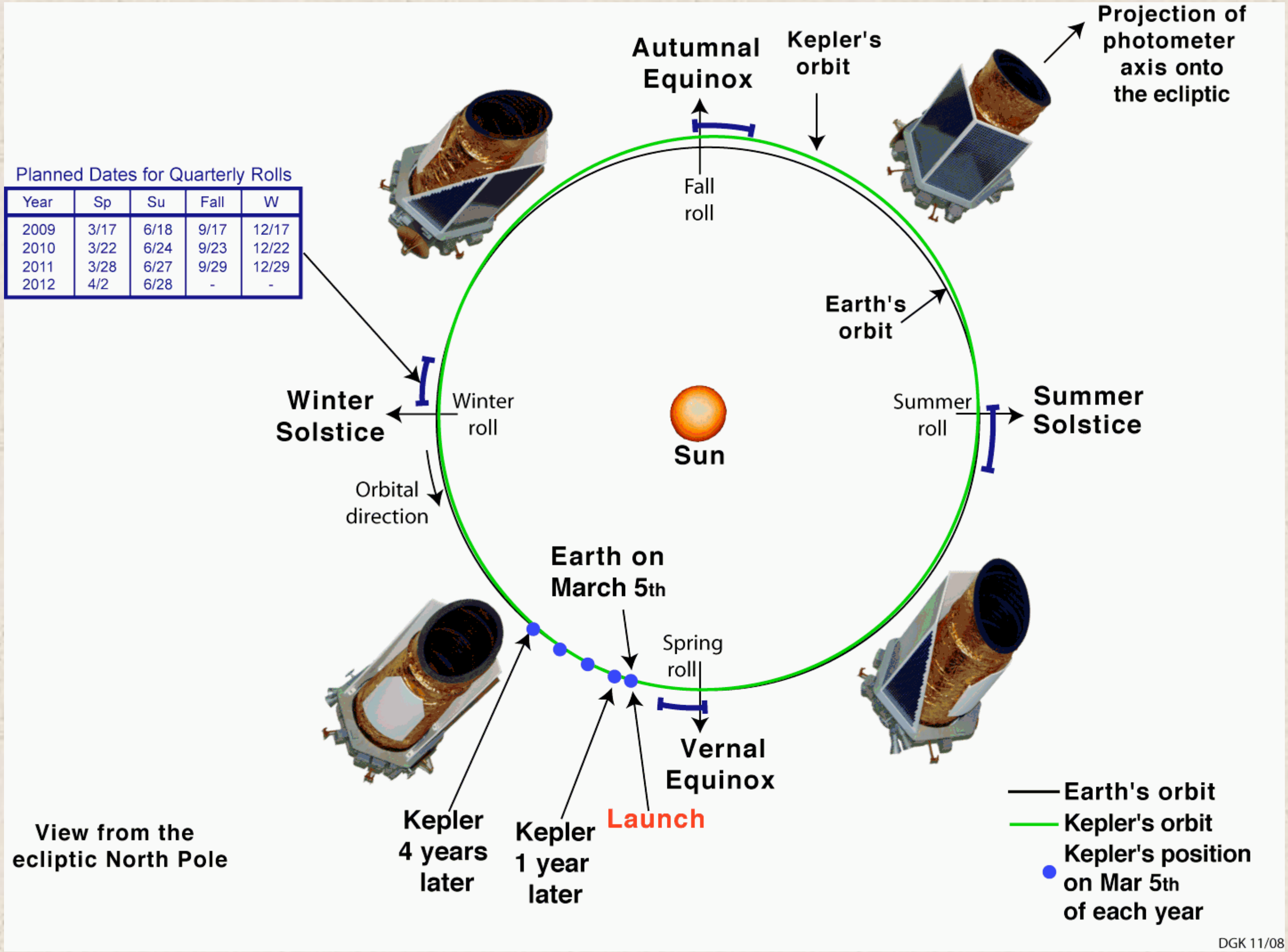
Kepler Mission Design



Year	Sp	Su	Fall	W
2009	3/17	6/18	9/17	12/17
2010	3/22	6/24	9/23	12/22
2011	3/28	6/27	9/29	12/29
2012	4/2	6/28	-	-

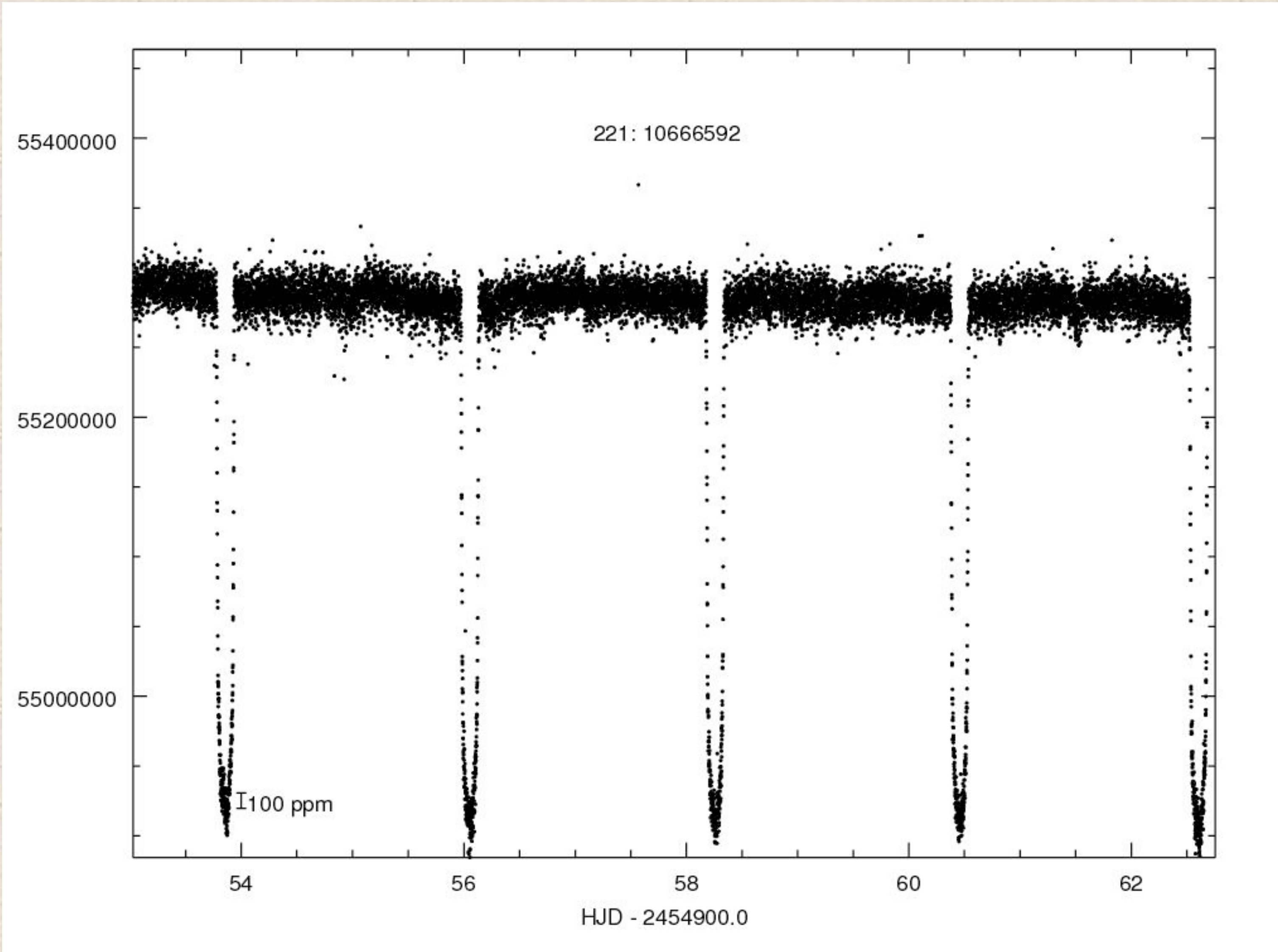
Kepler Launch

6 March 2009
from Cape
Canaveral Fl

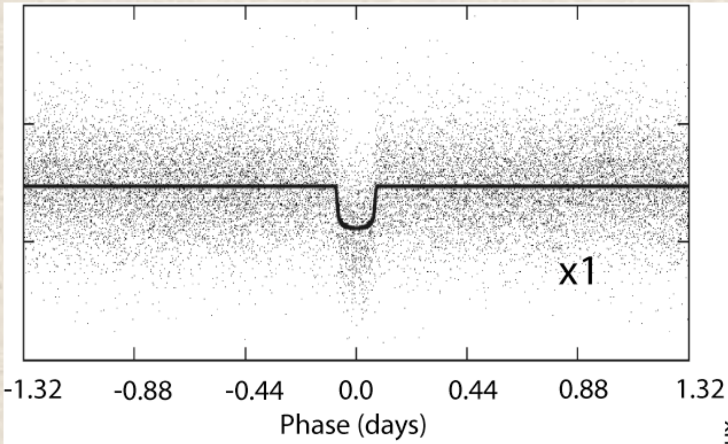
Kepler First Science Results

- There were three previously known transiting planets in the Kepler field
- These stars were included in a sample of 52496 stars observed in the spacecraft commissioning tests of photometric precision
- One of these is HAT-P-7

Kepler First Science Results

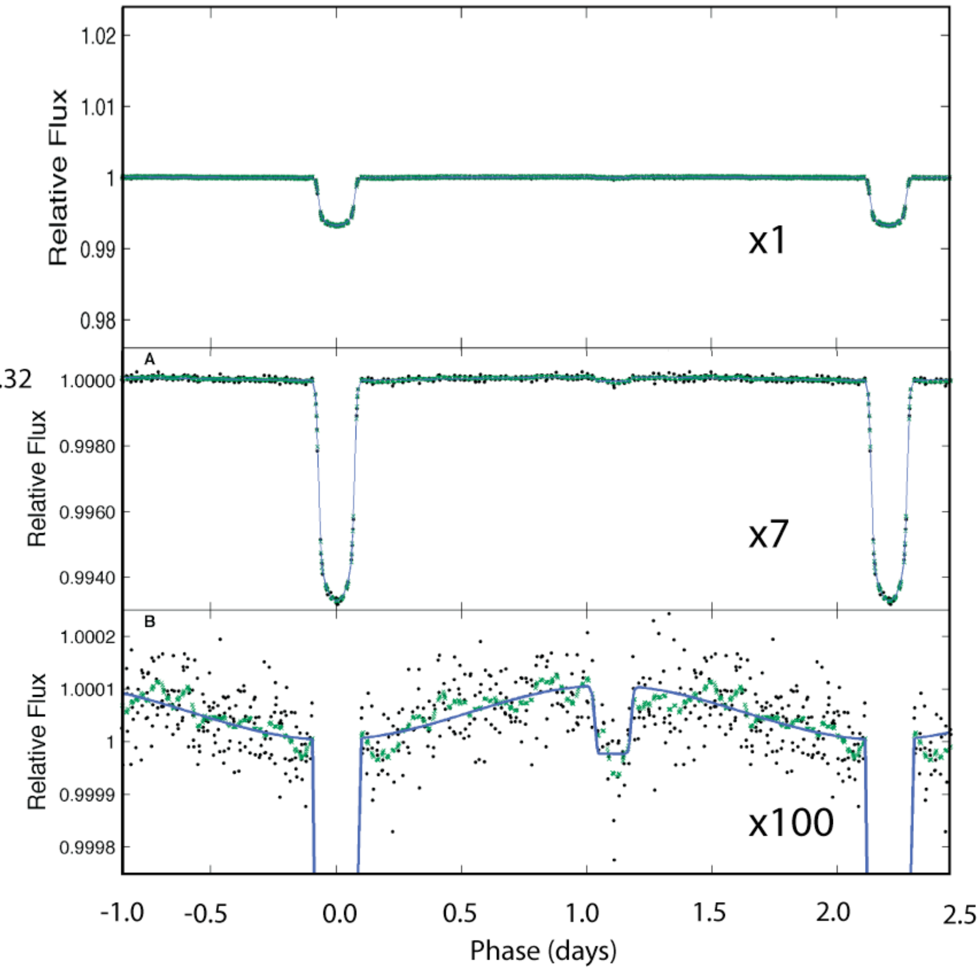


Kepler First Science Results



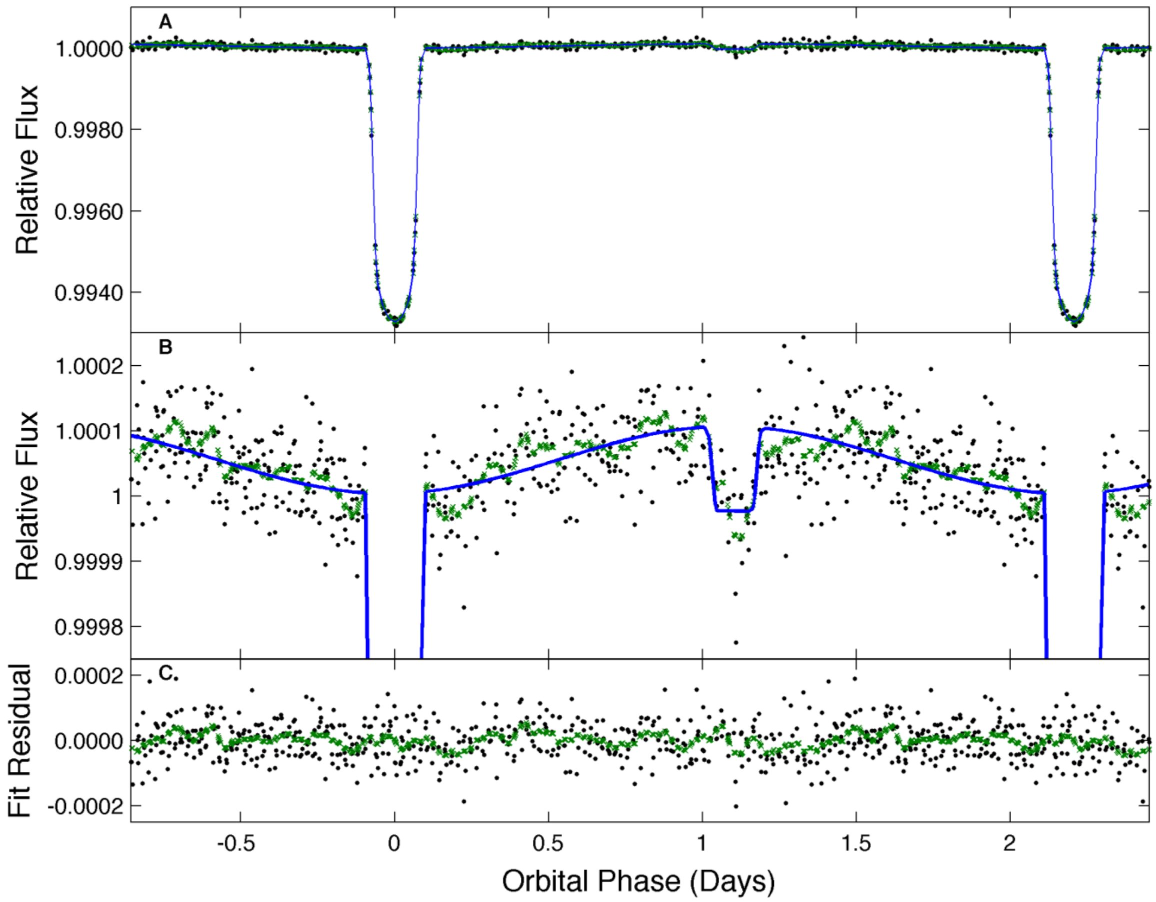
16,620 HATNet data points (57.7 days of data)

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



Kepler Commissioning data (10 days)
W. Borucki et al., 2009

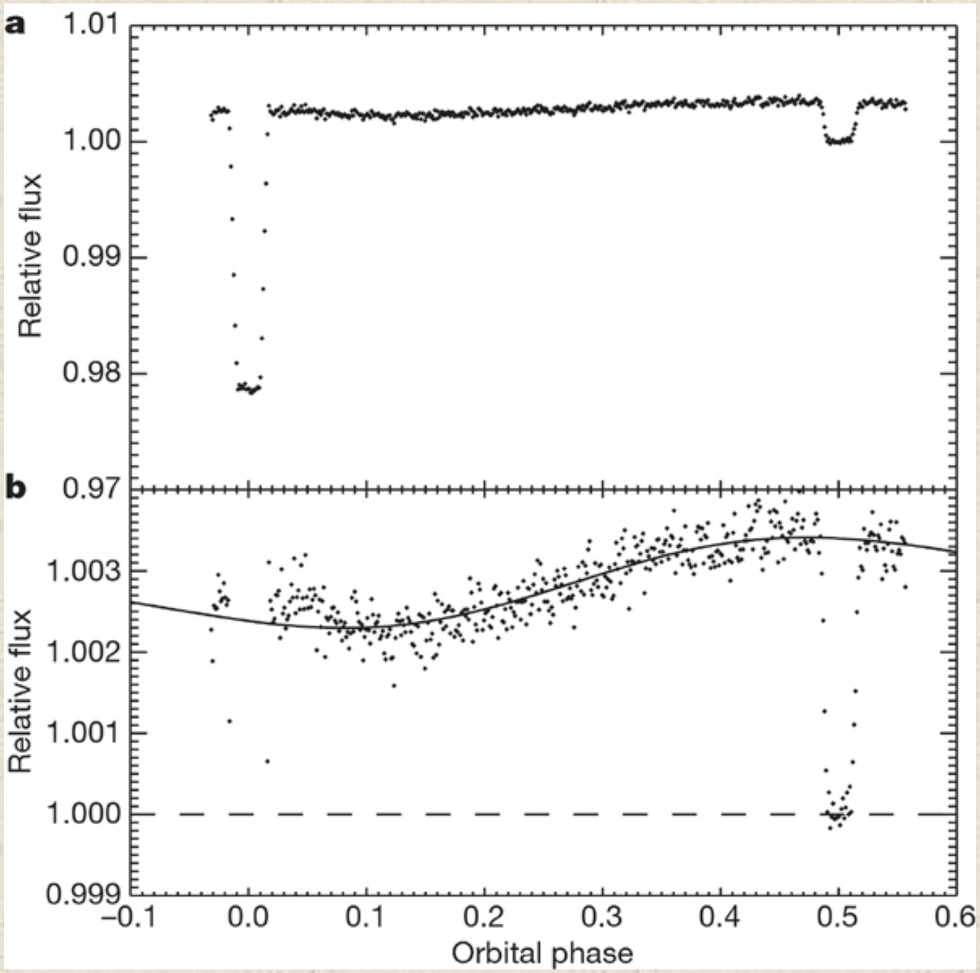
Kepler First Science Results



Kepler First Science Results

- The secondary occultation (planet passing behind the star) is *clearly* visible even in the raw data!
- The secondary occultation depth is 130±11ppm, an 11.3 σ result for the combined set of 4 events.
- The phase variation of the light curve represents the combination of starlight reflected from the planet and thermal emission from the planetary atmosphere at T=2650±100K.
- This result clearly demonstrates that ***Kepler*** operates at the level required to detect Earth-size planets.

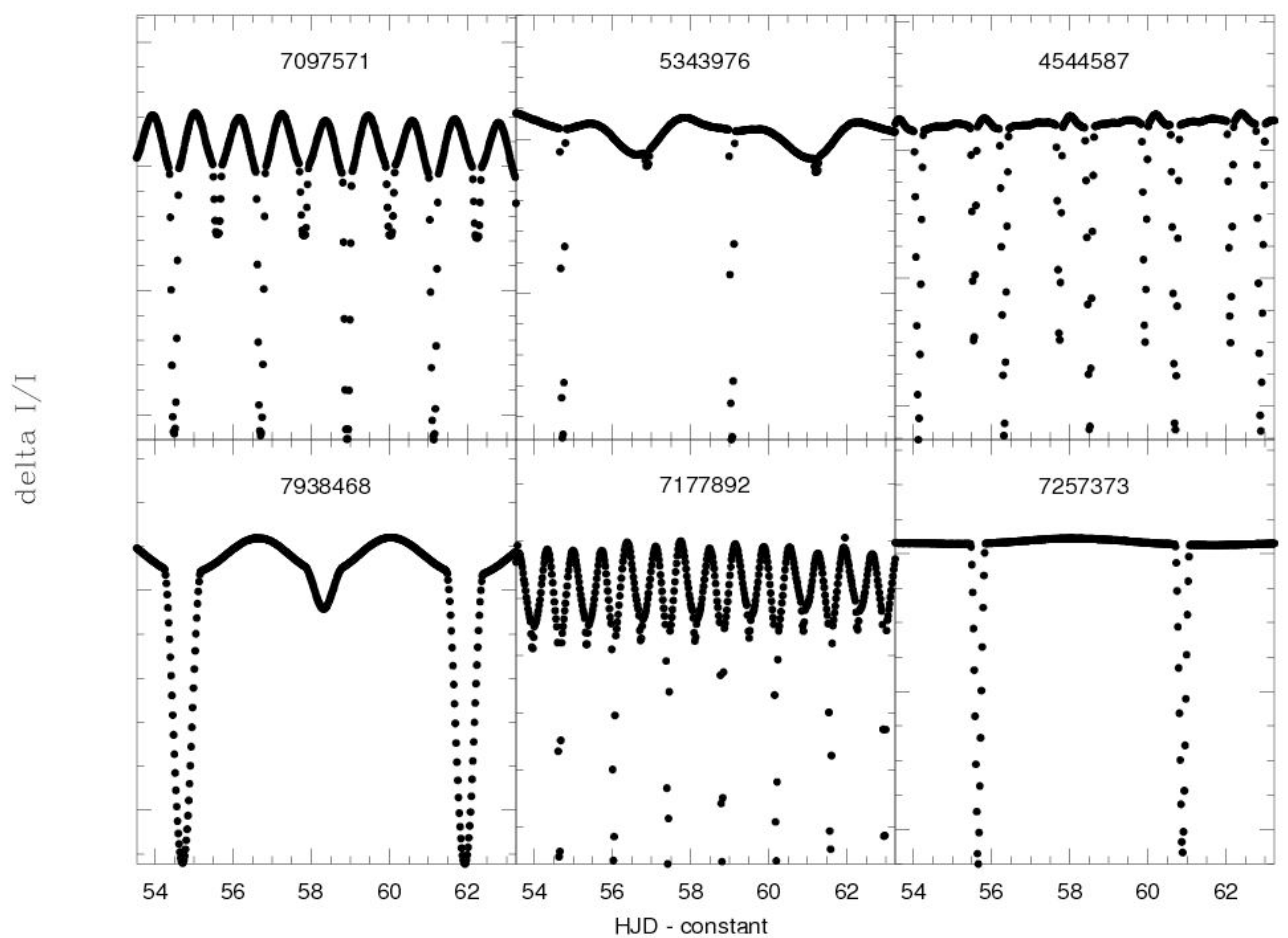
Kepler First Science Results



This effect has previously been seen in the hot-Jupiter around HD189733 using the Spitzer spacecraft by Knutson et al. (Nature, 2007).

The effect is *much* larger in the infrared where Spitzer operated.

Kepler First Science Results



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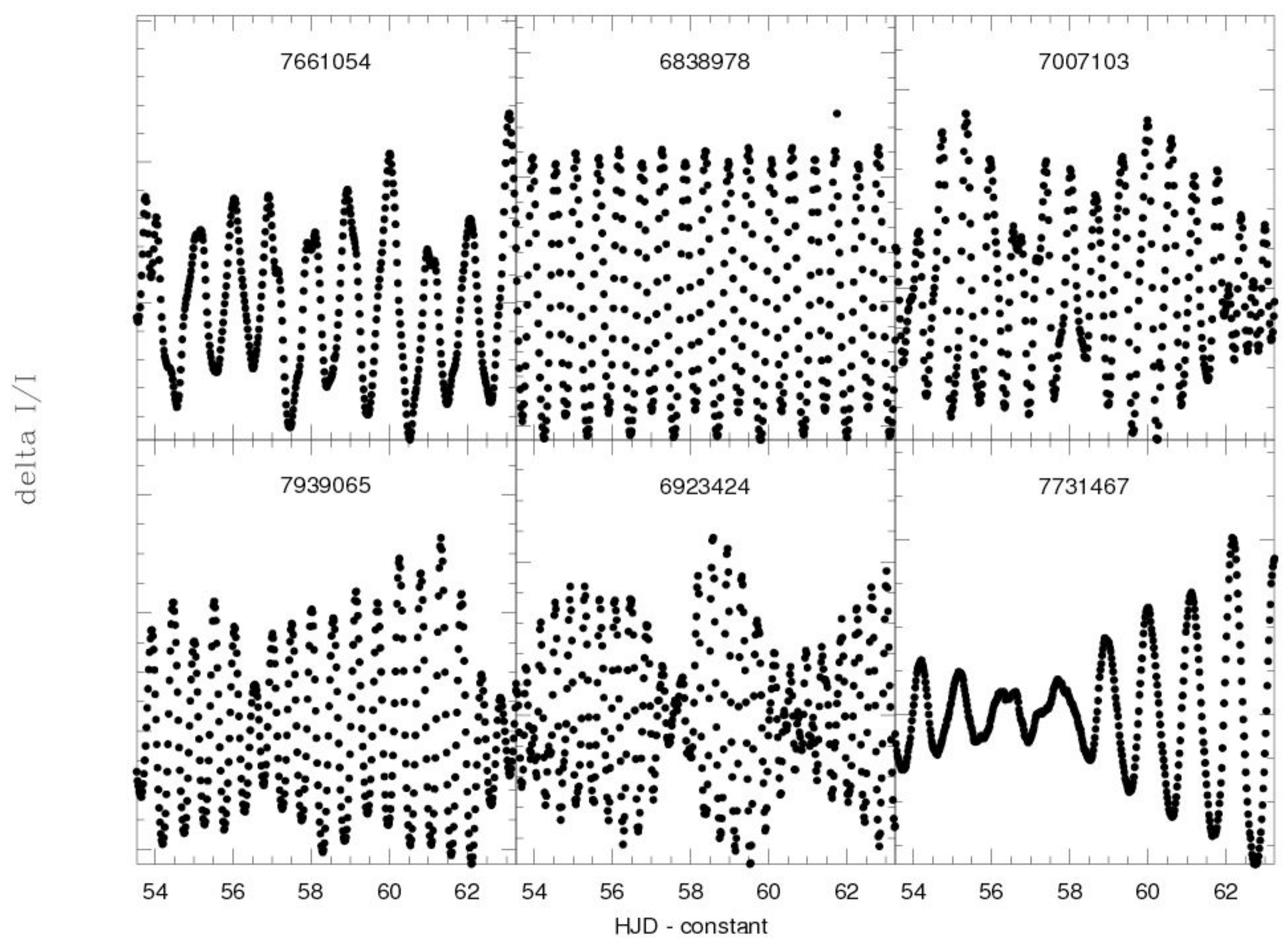
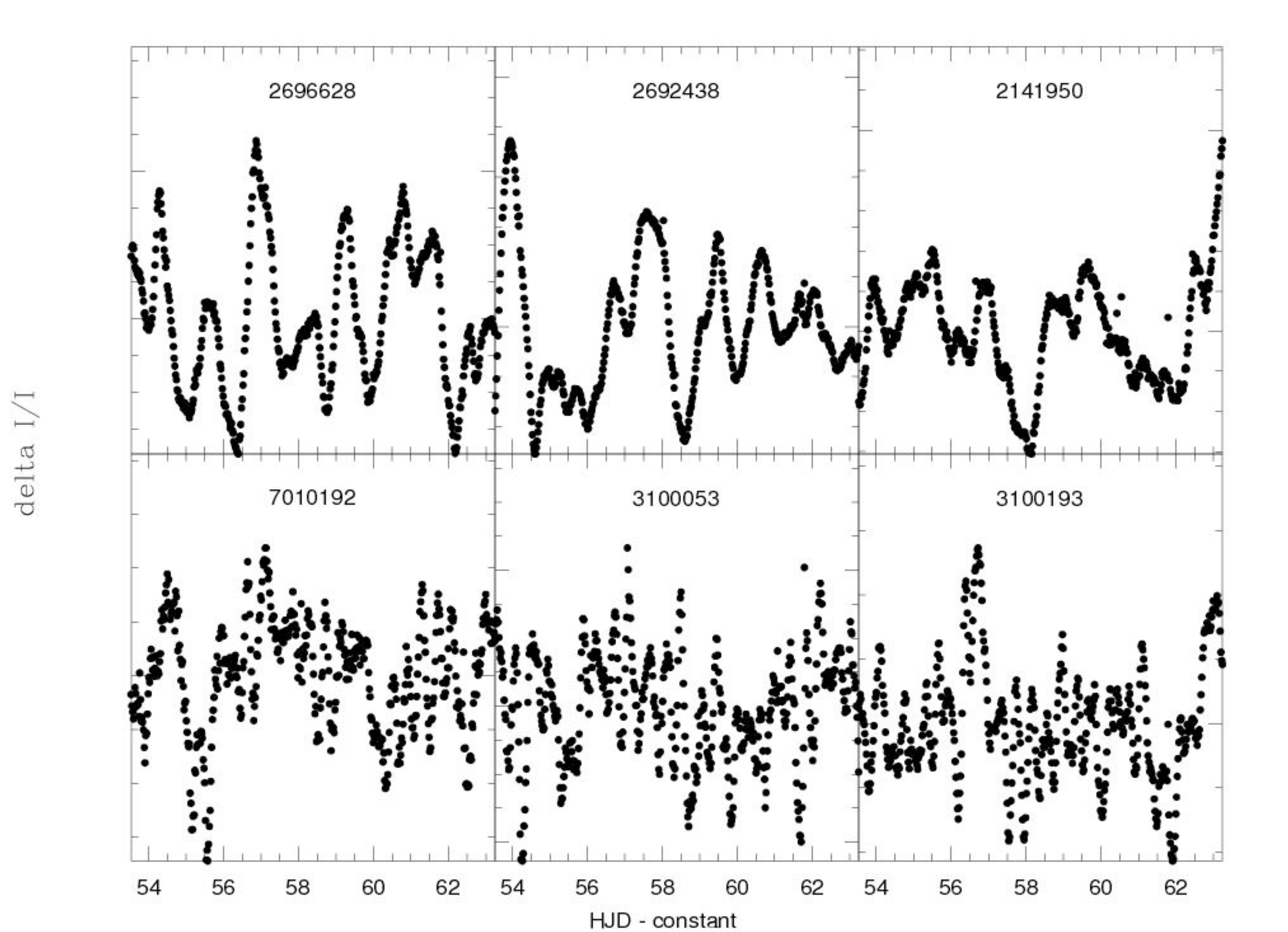


Kepler First Science Results



Follow-Up Observing Program

Just because ***Kepler*** finds a photometric light curve that looks like a planetary transit, you can't assume that it really *is* a planet!

Some possible sources of false-positives:

- grazing stellar transits
- white dwarf or brown dwarf companions
- background eclipsing binary stars

For all candidate transit cases, complementary follow-up observations are made to confirm that the transits are due to planets and to learn more about the characteristics of the parent stars and planetary systems.

U.T. Involvement

We are using the McDonald 2.7m HJS Telescope and the HET, along with Lick 3m, NOT , Keck and HARPS-NEF to obtain spectra of candidate systems found by *Kepler*. The purpose is to:

- Eliminate false positive signals
- Measure the mass of transiting giant planets
- Attempt to measure the mass of short-period transiting Earths
- Search for outer, non-transiting giant planets in systems with an inner transiting planet
- Determine inclination of planetary orbit to stellar equator via Rossiter-McLaughlin effect.
- Use template spectra to determine stellar parameters T_{eff}, [Fe/H] log *g*. Combine these results with astrometry and asteroseismology to determine mass, radius and age of parent star.


Illustration by Melody Lambert
McDonald Observatory