



Kepler

A Search for Earth-size Planets

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CRITICAL QUESTIONS

- **What is the frequency of Earth-size planets in or near the Habitable Zone (HZ) of solar-like stars?**
 - **Are terrestrial planets common or rare?**
- **What are the distributions of sizes & semi-major axes?**
- **What are the frequency & orbital distributions of planets in multiple star systems?**
- **What are the distributions of semi-major axes, albedo, size, mass, and density of short-period giant planets?**
- **How are these properties associated with stellar characteristics?**



INSTRUMENT

Kepler

A Search for Earth-size Planets

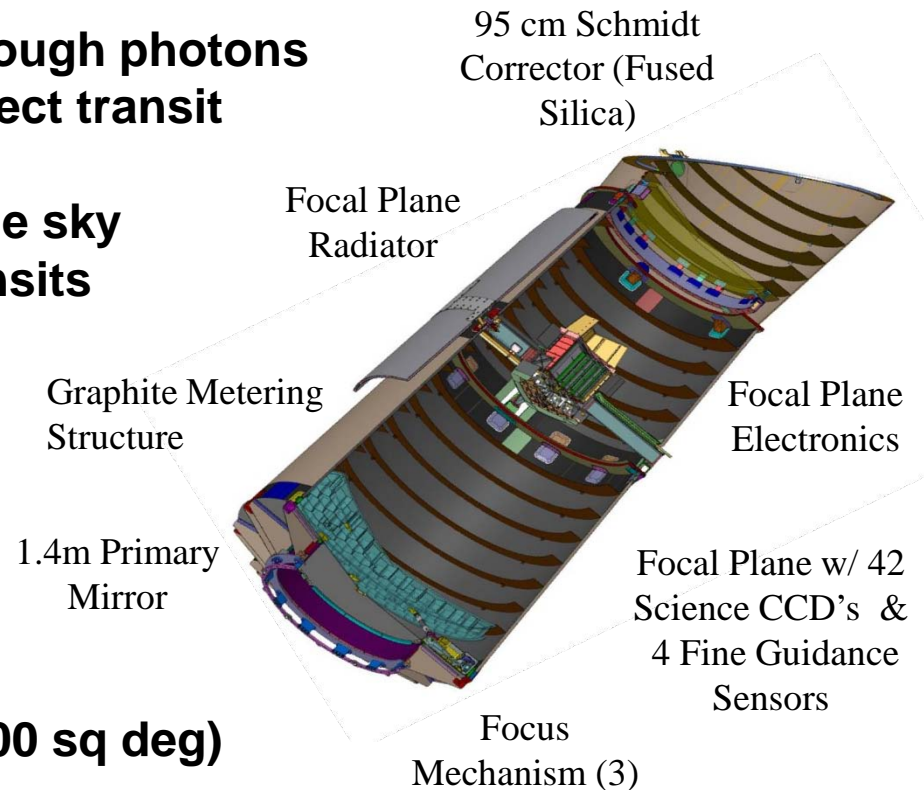
KEPLER: A Wide Field-of-View Photometer that Monitors 100,000 Stars for 3.5 yrs with Enough Precision to Find Earth-size Planets in the Habitable Zone

Use transit photometry to detect Earth-size planets

- **0.95 meter aperture provides enough photons**
- **Observe for several years to detect transit patterns**
- **Monitor a single large area on the sky continuously to avoid missing transits**
- **Use heliocentric orbit**
- **Up to 170,000 targets at 30 min cadence & 512 at 1 min**

Get statistically valid results by monitoring; 100,000 stars

- **Wide Field-of-view telescope (100 sq deg)**
- **Large array of CCD detectors**





PREPARED FOR LAUNCH

Kepler

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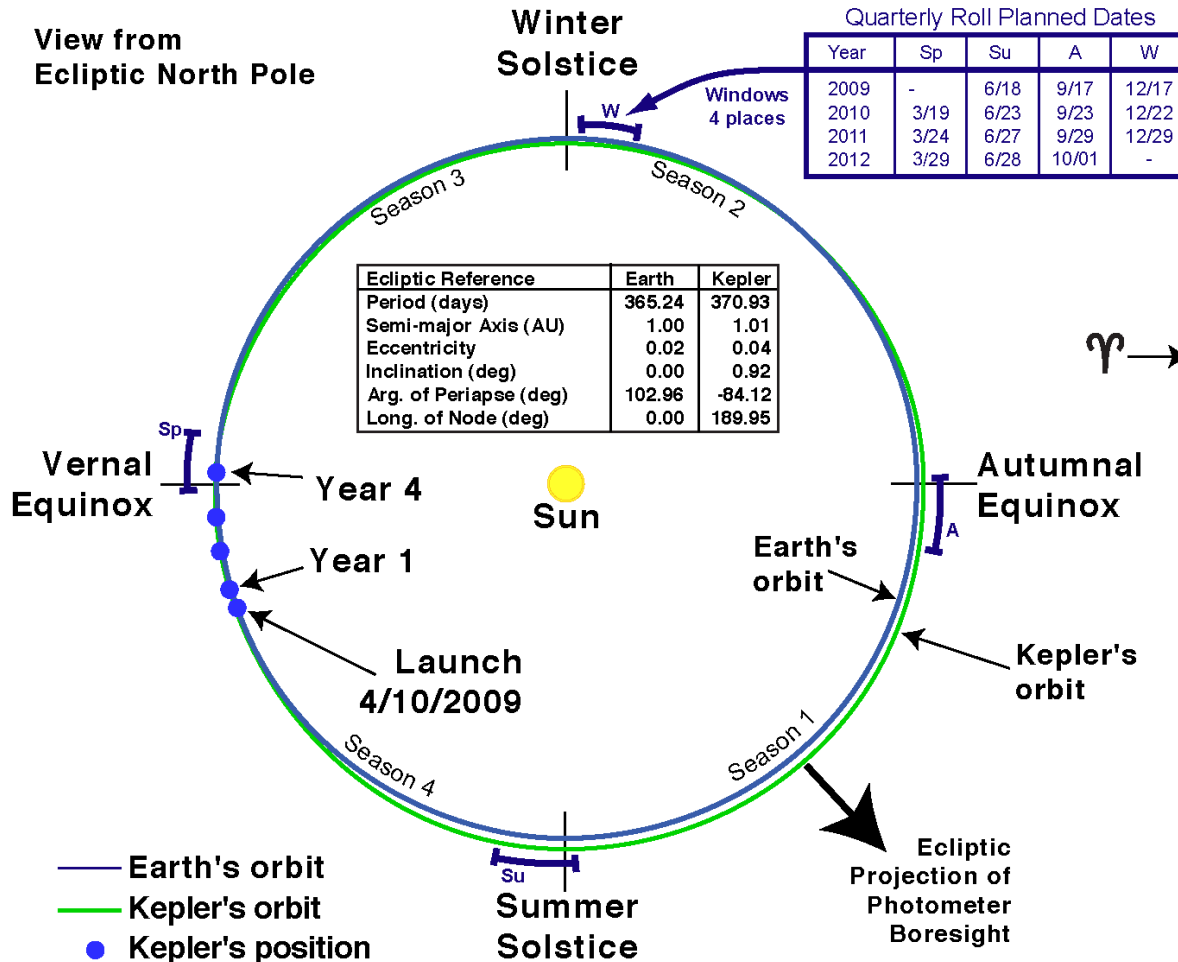




ORBITS OF EARTH & KEPLER



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OBSERVATIONS



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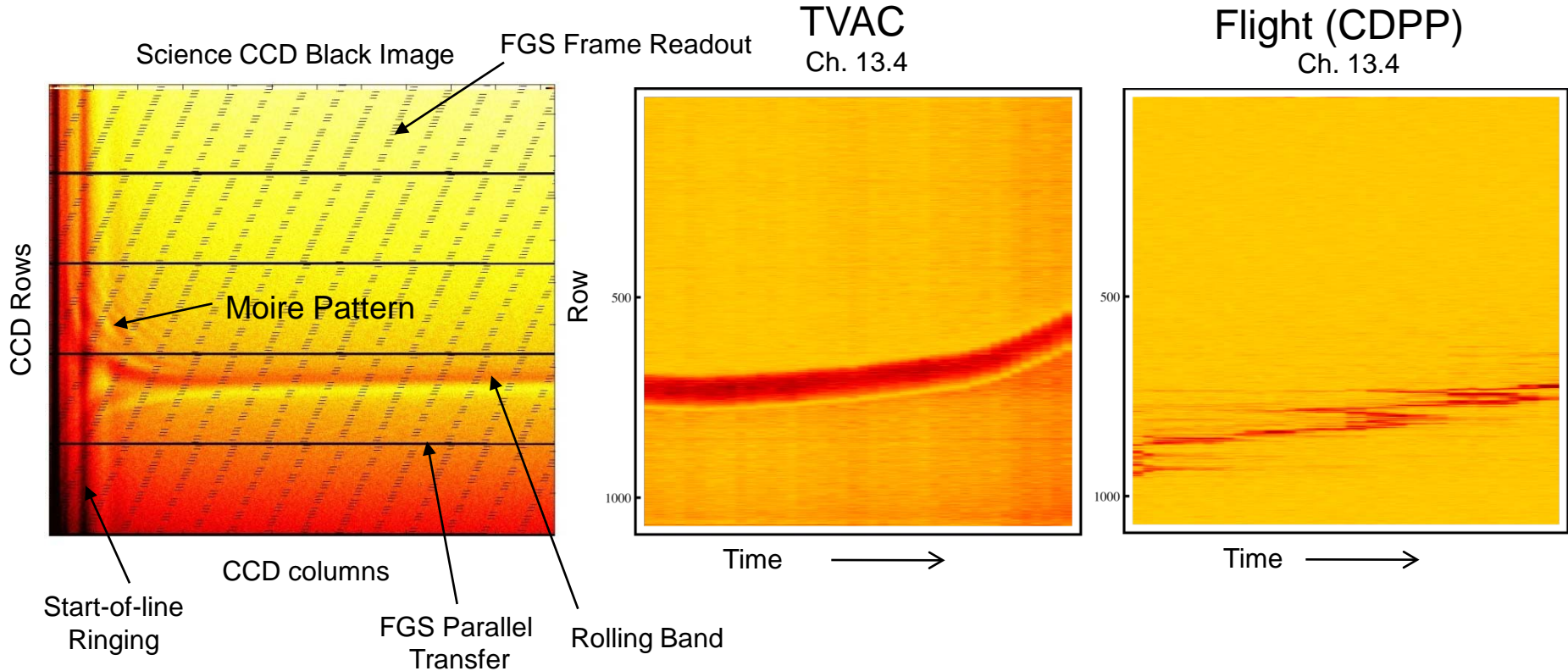
- 9.7 days of calibration observations of 53,000 bright stars of all types were received on 12 May 2009
- Several hundred eclipsing binaries and thousands of variable stars are visible in these data.
- Several low-amplitude transit-like signatures have been detected.
Most are expected to be false positives.
Observations to identify FP & exoplanets are about complete for 2009.
- Science operations began on 12 May with observations of 145,000 mostly dwarf stars.
 - 1000 red giants for astrometry/parallax measurements
 - 1700, mostly variable, bright stars for asteroseismology at 30 min cadence
 - 450, mostly variable, bright stars for asteroseismology at 1 min cadence
- Data presented here is based on the first 47 days of observations



IMAGE ARTIFACTS ARE SLOWING DATA ANALYSIS AND AVAILABILITY



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- Image artifacts and image motion are a greater concern than expected.
- Mitigation work is underway to correct or flag problem areas & will be complete in 2011
- Until that time, it will very difficult to find Earth-size planets in the HZ of stars like the Sun
- There should be little effect on planets in short period orbits.

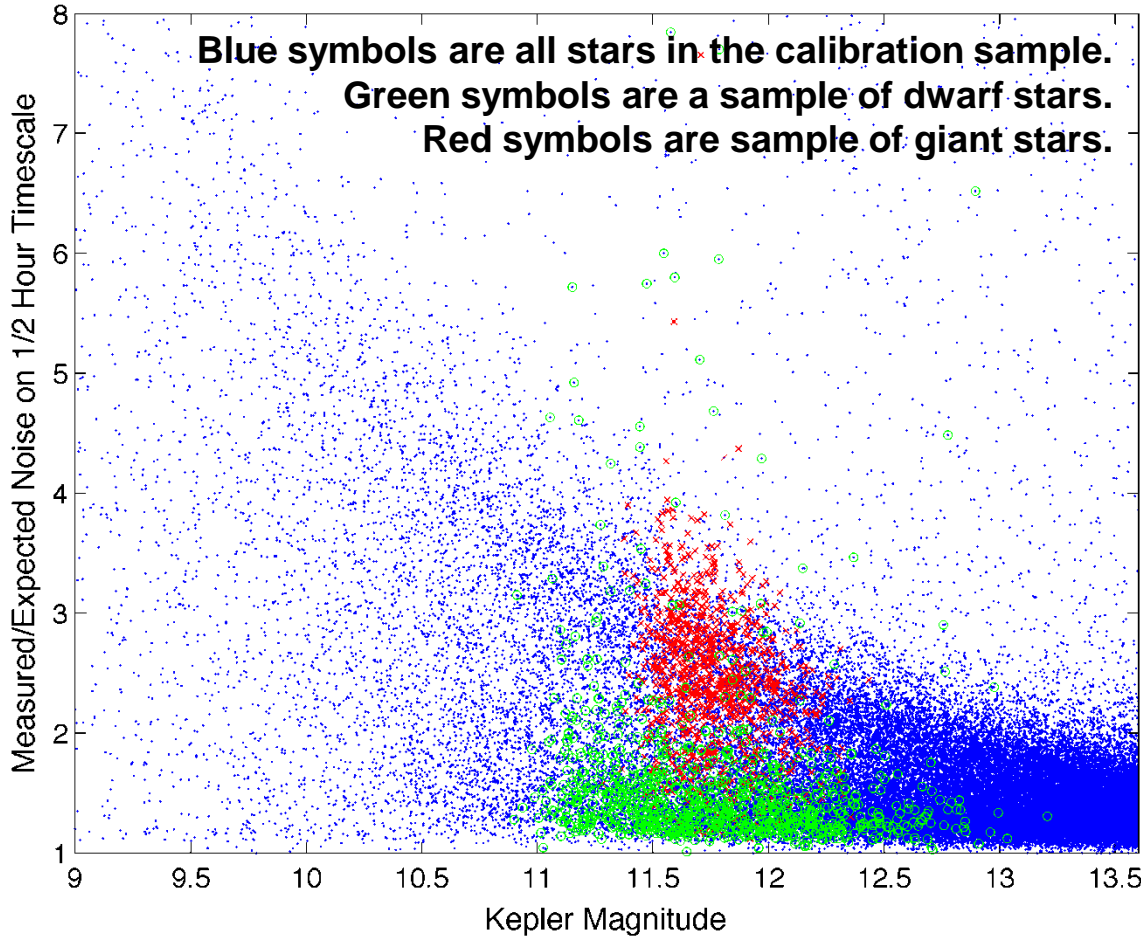


STELLAR + INSTRUMENT NOISE LOW ENOUGH TO DETECT EARTH-SIZE PLANETS



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MEASURED VARIABILITY COMPARED TO RANDOM NOISE .



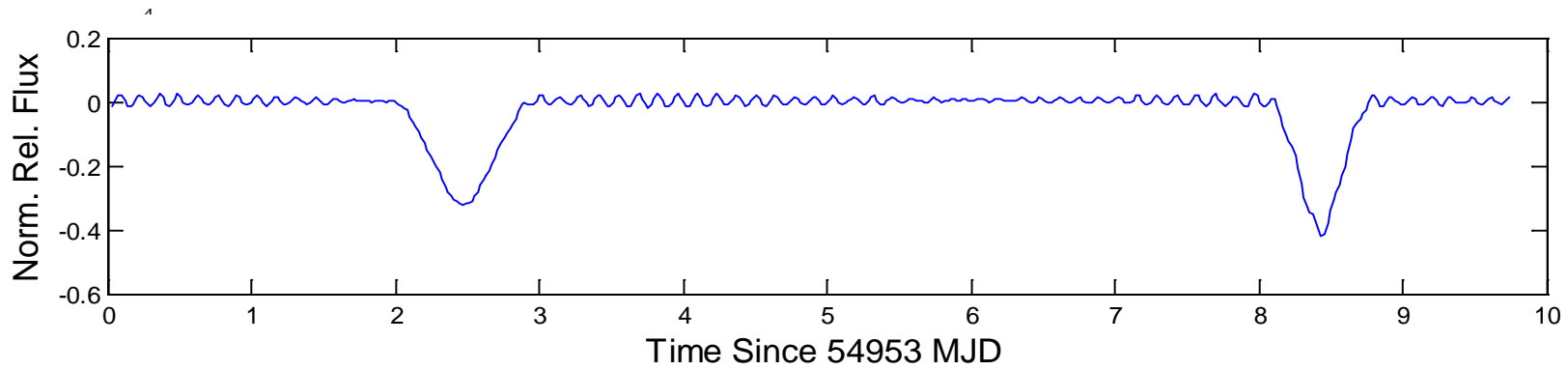
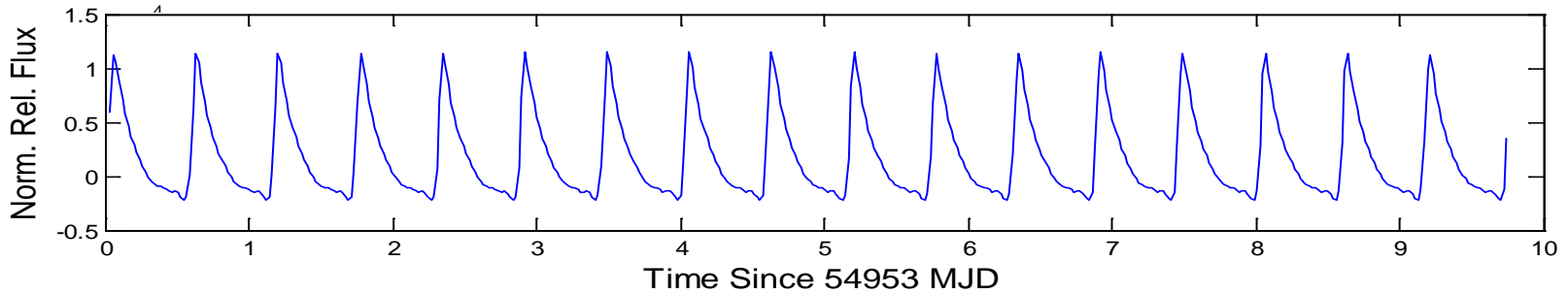
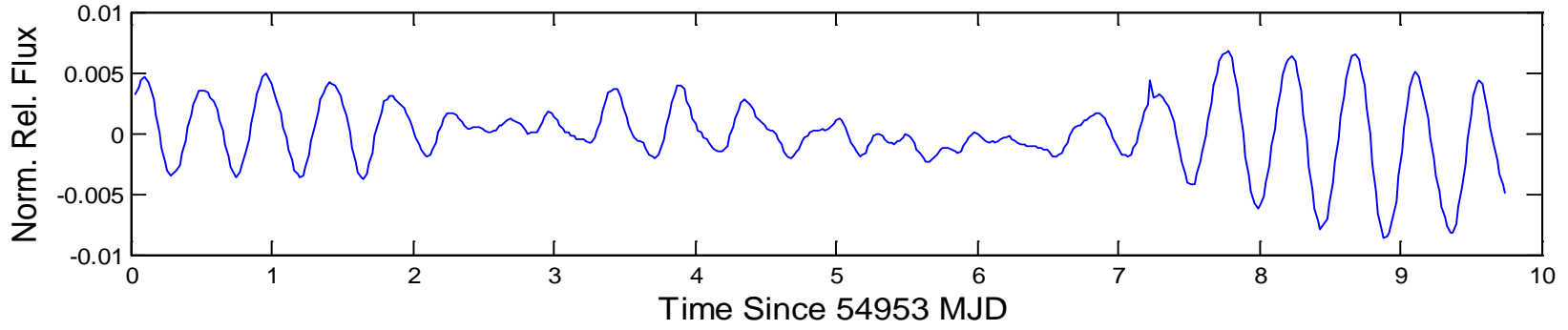
**EVEN WITHOUT SYSTEMATIC
NOISE REMOVAL, THE
PHOTOMETRIC PRECISION IS
WITHIN 50% OF DESIGN**



SAMPLE OF LIGHT CURVES



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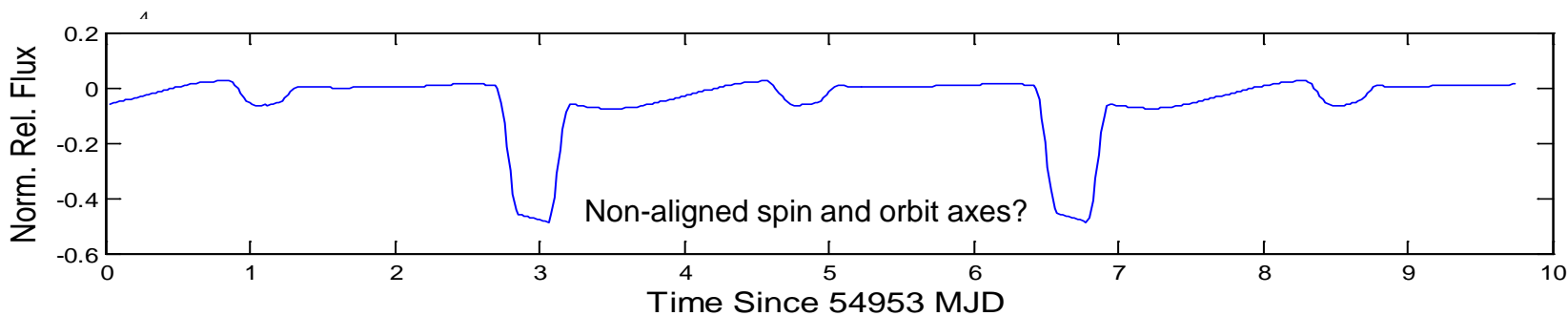
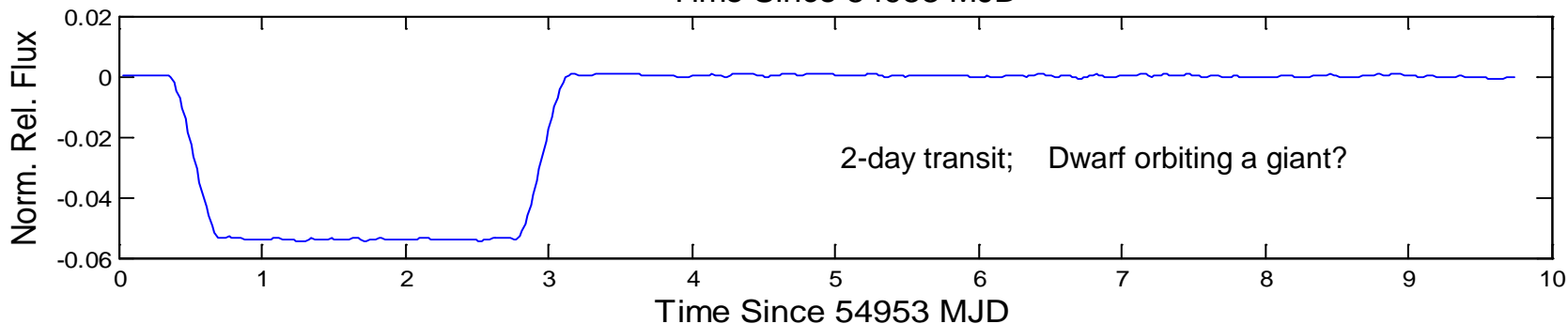
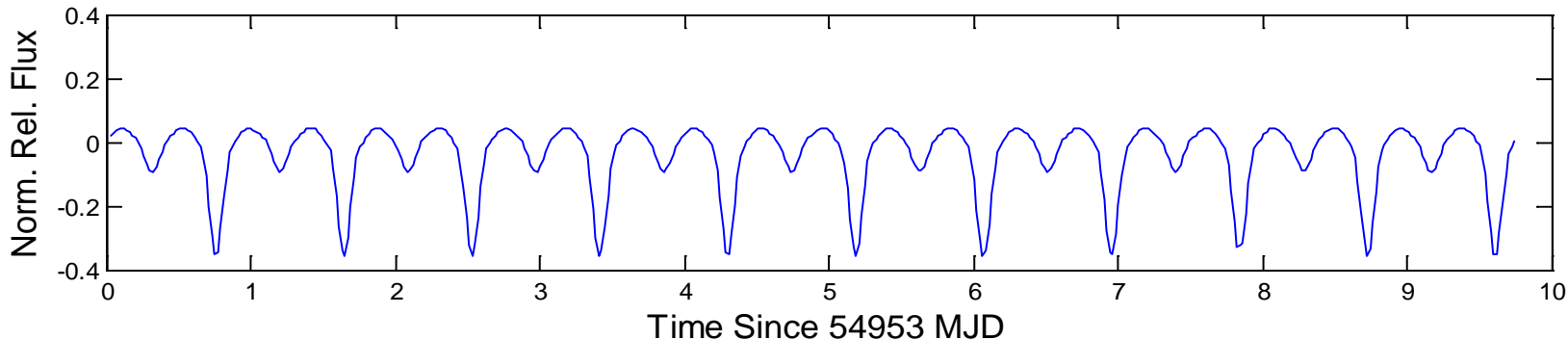




SAMPLE LIGHT CURVES



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KEPLER ASTEROSEISMIC SCIENCE CONSORTIUM

Kepler

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Group of over 300 investigators analyzing the light curves

Asteroseismology observations will provide characterization of planet-hosting stars, including size and age.

$$\frac{\delta R}{R} \approx 2\% - 3\%$$

$$\frac{\delta(\text{age})}{\text{age}_{MS}} \approx 5\% - 10\%$$

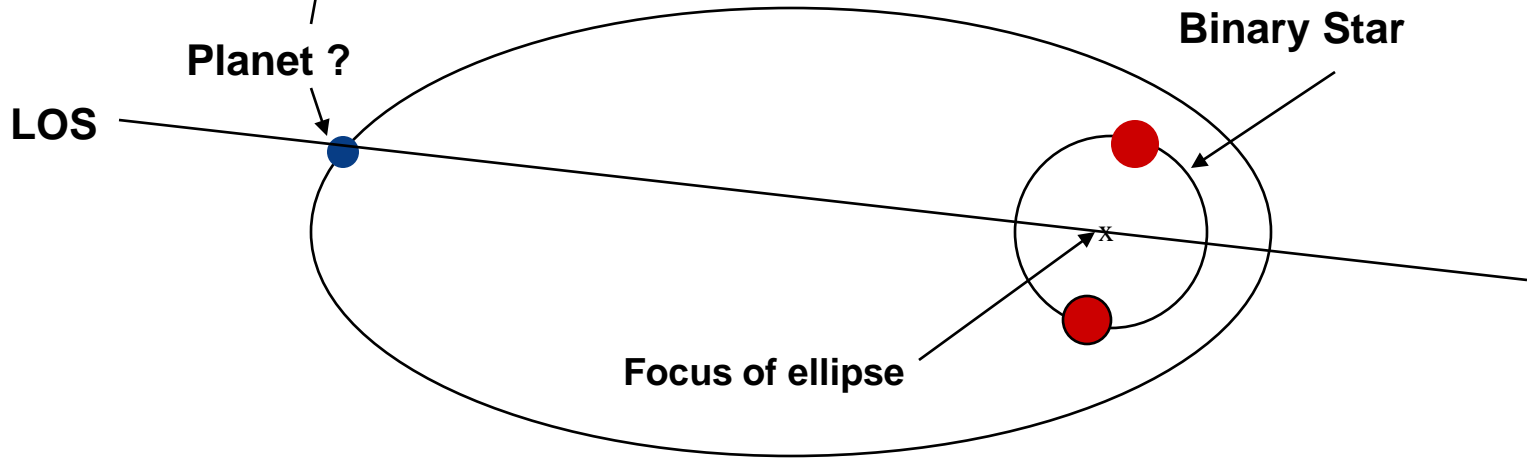
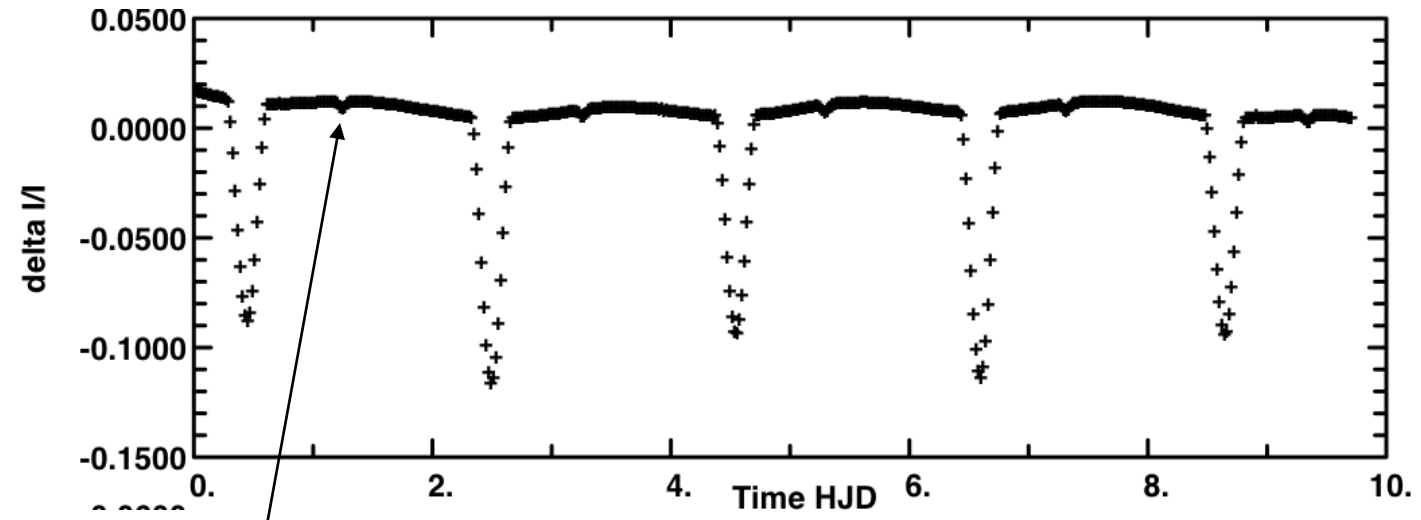
$$\delta(i_{ROT}) \approx 5^\circ$$



BINARY WITH CIRCUMBINARY PLANET?



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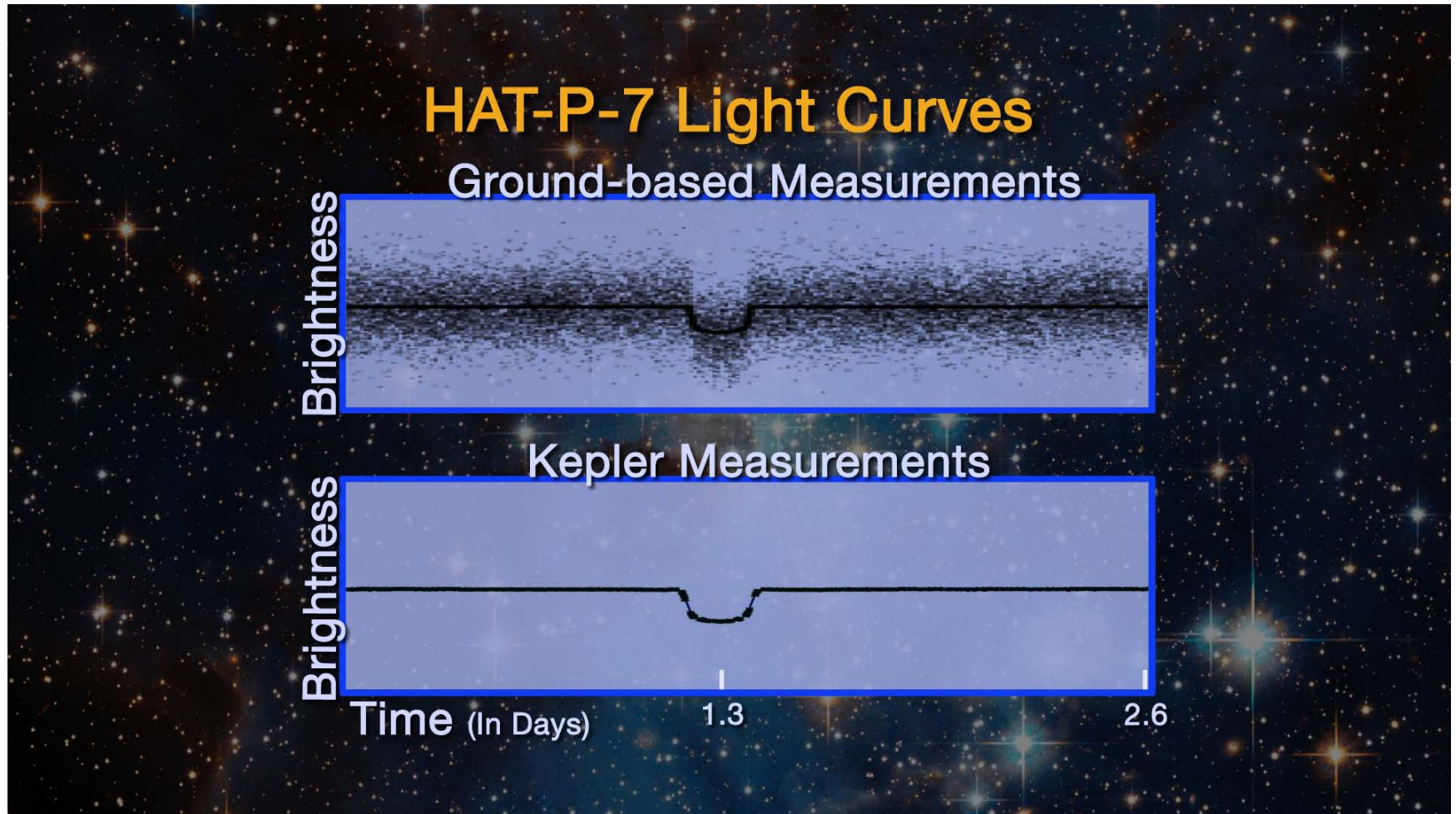




VALIDATION OF DISCOVERIES

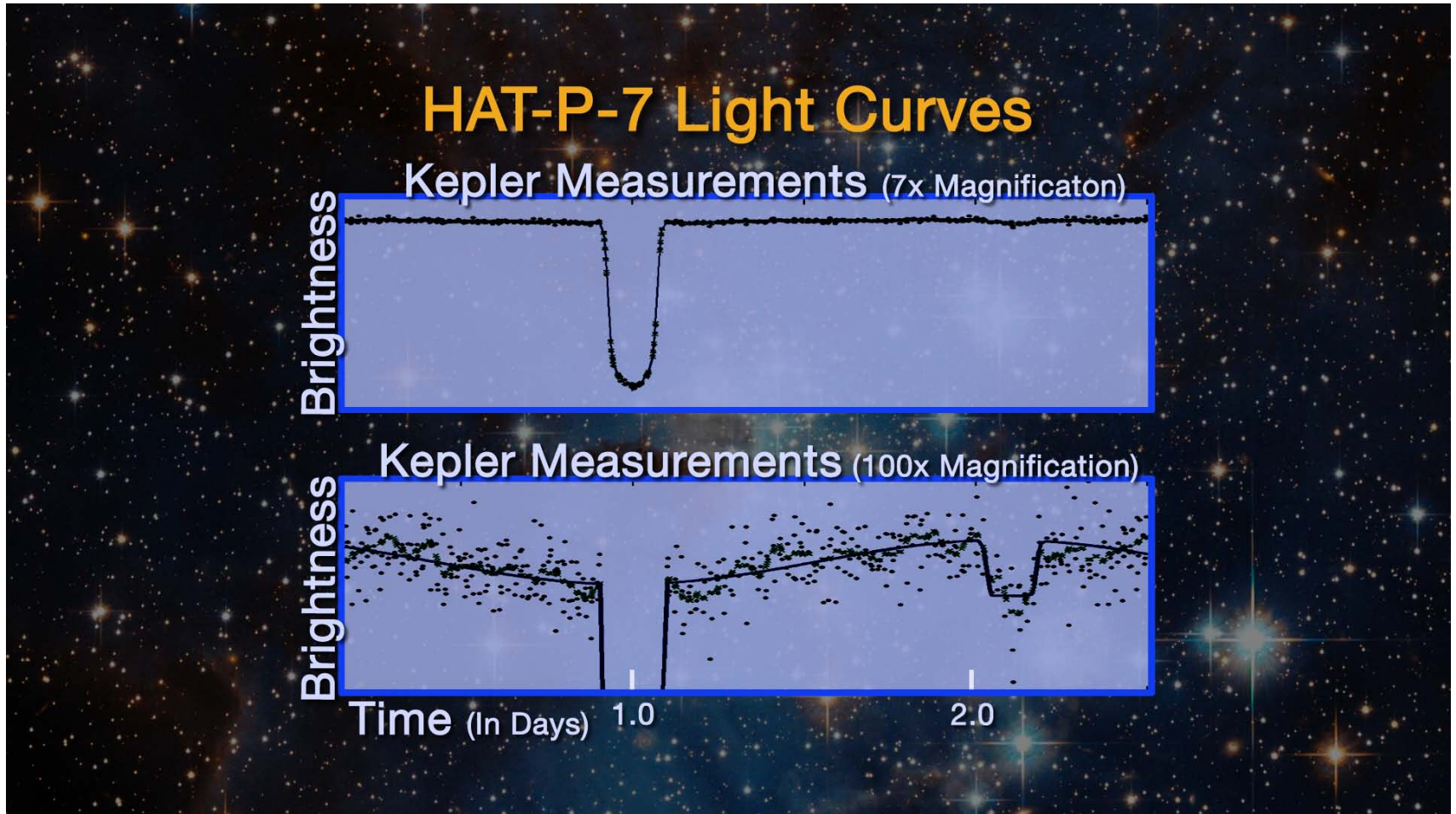


- **SNR > 7 to rule out statistical fluctuations**
- **Three or more transits to confirm orbital periodicity**
- **Light curve depth, shape, and duration**
- **Image subtraction to identify signals from background stars**
- **Radial velocity**
 - **Medium precision to rule out stellar companions**
 - **High precision to measure mass of super-Earths and giant planets**
 - **R-M effect to confirm orbiting planet**
- **High spatial resolution to identify extremely close bkgd stars. Then observe transits of background stars.**
- **Check for color change during transit**
- **Measure number of background binaries & compute reliability**



Scatter in the *Kepler* measurements is within the thickness of the line.

OCCULTATION WITH AMPLITUDE SIMILAR TO THAT OF AN EARTH-SIZE TRANSIT



Detection of the occultation proves that *Kepler* has the precision to find Earth-size planets.



ORAL PRESENTATIONS FOR THE AAS MEETING IN WASHINGTON



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- Batalha; Characteristics of the Kepler Target Stars
- Borucki; Kepler Planet Detection Mission: Introduction and First Results (plenary)
- Caldwell; Instrument Characterization & Performance in Kepler's First Months
- Gautier; The Kepler Follow-Up Observation Program
- Gilliland. The Kepler Short Cadence Data and Applications for Asteroseismology and Transit Light Curves
- Jenkins Preliminary Characteristics of Kepler Long Cadence Data For Detection of Transiting Planets
- Koch; The Design and On-Orbit Performance of the Kepler Mission
- Kolenberg; First Results from Kepler for RR Lyrae Stars
- Latham; Spectroscopic Follow Up of Kepler Planet Candidates
- Marcy; Doppler Follow-up of Kepler Planets
- Monet; Kepler Astrometry
- Rowe; Kepler Observations of Transiting Hot Compact Objects
- Sasselov; Kepler Results for Previously Known Planets: the HAT-P-11 Planet System
- Welsh; The Kepler Light Curve of HAT-P-7



POSTER PAPERS



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- Bryson Characterization and Application of the Kepler Pixel Response Function
- Dotson; The Kepler Full Frame Images
- Fanelli; The Kepler Guest Observer Program
- Fraquelli; Using MAST to Access the Kepler Data Archive
- Haas; The Kepler Dropped Target Program
- Holman; A Search for Additional Planets in the TrES-2, HAT-7b, and HAT-P-11b Systems Via Transit Timing Variations
- Howell Kepler Observations of Three Pre-Launch Exo-Planet Candidates
- Mighell; A Calibration Study of Variable Stars in the Kepler Field
- Meibom; The Kepler Open Cluster Study
- Still; Cataclysmic variables within the Kepler Field
- Teske; Variability Trends in Kepler Data: A WWZ Transform Analysis
- Van Cleve; The Knowledge of Celestial Things: Using the Kepler Instrument and Data Analysis Handbooks to Plan Observations and Believe the Results
- Verner; HST Imagery of the Kepler Field-of-view Acquired with WFPC2 and ACS
- 28 papers scheduled for 2 Kepler sessions at January AAS Meeting
- Similar number of papers for special issues of Science & ApJL



SUMMARY



A Search for Earth-size Planets

***KEPLER IS WORKING WELL, PRODUCING
DISCOVERIES, AND SHOULD MEET ALL
SCIENCE GOALS AFTER MITIGATION
WORK IS COMPLETED.***