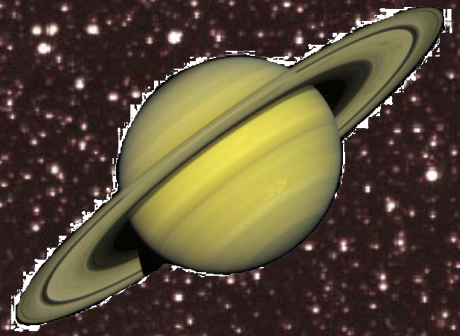
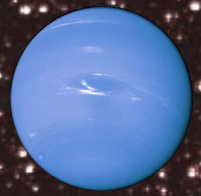
The Kepler Mission:
Are There Any Good Worlds Out There?





Jon Jenkins,
Co-Investigator for Data Analysis

31 December 2010

Ball

LMS

SETI INSTITUTE

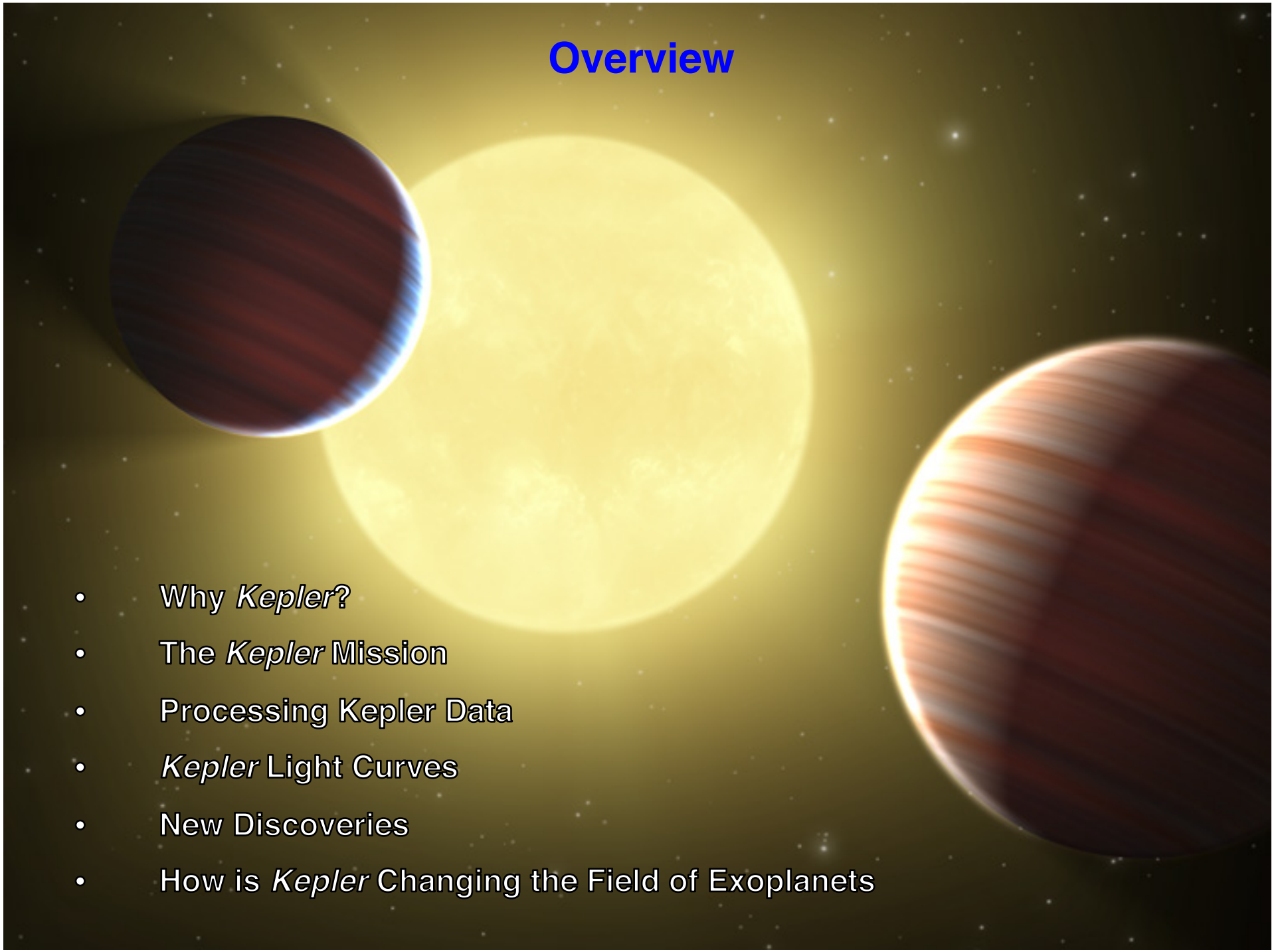
STScI

SAO

JPL

Ames Research Center

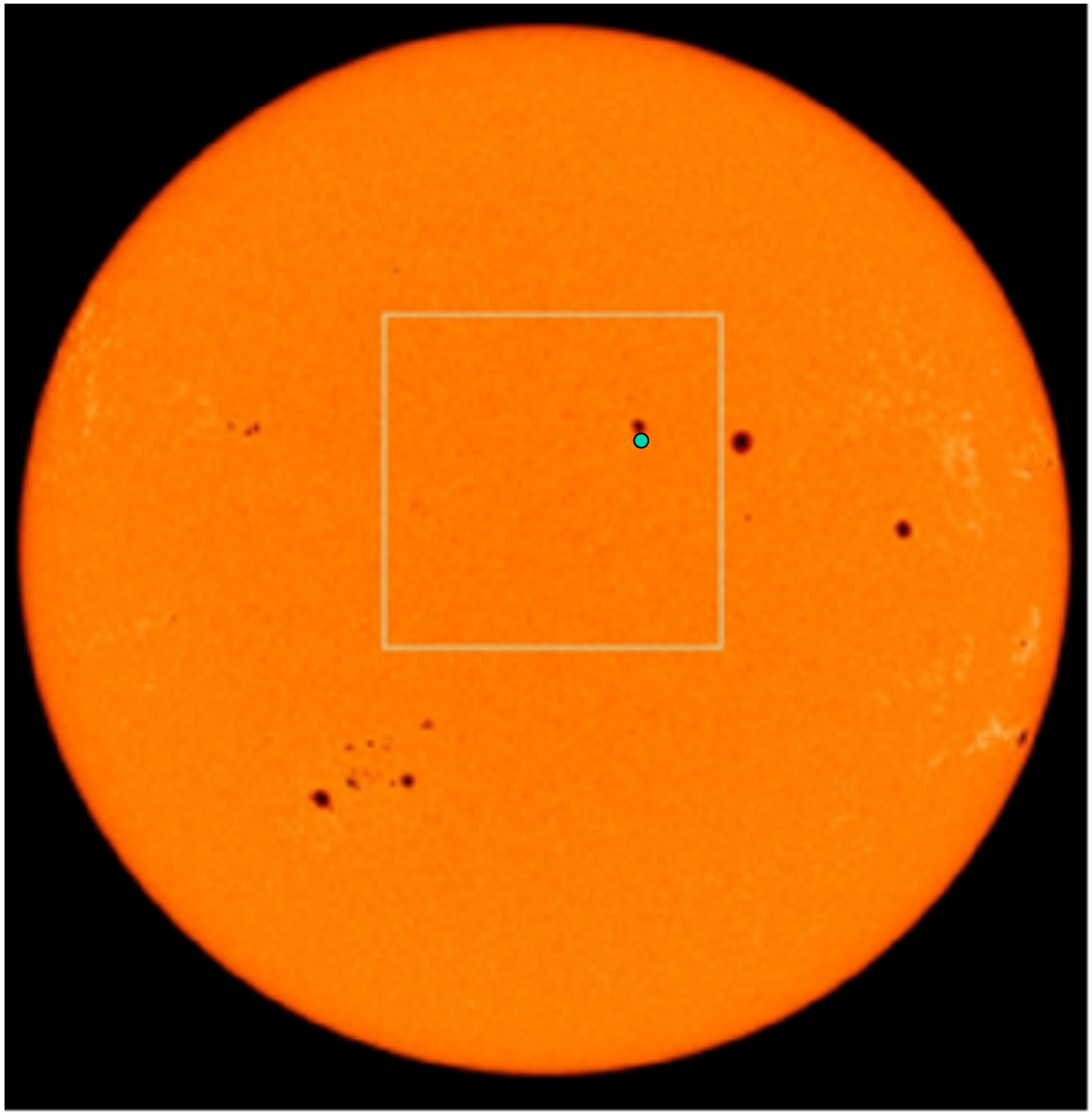
Overview



- Why *Kepler*?
- The *Kepler* Mission
- Processing Kepler Data
- *Kepler* Light Curves
- New Discoveries
- How is *Kepler* Changing the Field of Exoplanets

The Sun In Visible Light

Kepler
A Search for Habitable Planets



Earths are much easier to find when UV light is blocked.

Earth-size planets Are about the size of a star spot.

Rapid motion and uniform repetition is used to distinguish planets from spots.

Instrument

Kepler
A Search for Habitable Planets

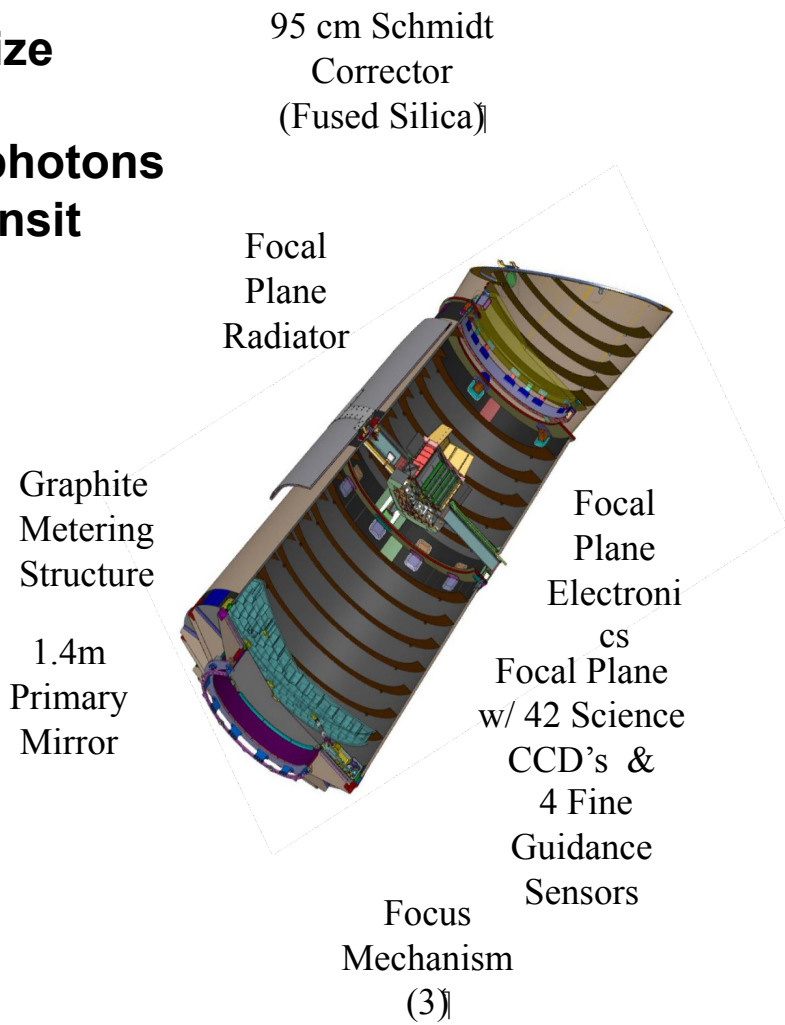
KEPLER: A Wide Field-of-View Photometer that Monitors 100,000 Stars for 3.5 yrs with Enough Precision to Find Earth-size Planets in the Habitable Zone

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**

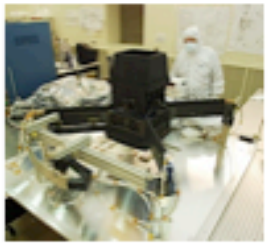
Get statistically valid results by monitoring 100,000 stars

- **Wide Field-of-view telescope**
- **Large array of CCD detectors**

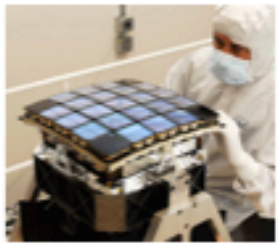


Kepler Spacecraft

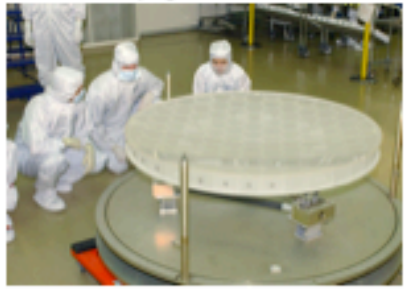
Schmidt Corrector 0.95 m dia.



Spider with Focal Plane
and Local Detector Electronics

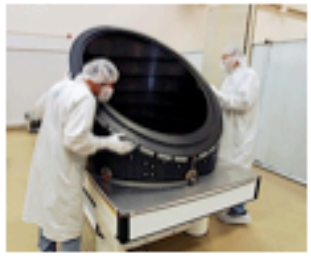


Focal Plane
95 Mega pixels, 42 CCDs



Primary Mirror
1.4 m dia., 85% lt. wt.

Fully assembled Kepler photometer
Mounted on the spacecraft



Sunshade

Upper Telescope Housing

Lower Telescope Housing

Spacecraft bus integration

Earth-Trailing Heliocentric Orbit

A Search for Habitable Planets

View from Ecliptic North Pole

Winter Solstice

W

Windows 4 places

Planned Quarterly Roll Dates

Year	Sp	Su	A	W
2009	-	6/18	9/17	12/17
2010	3/19	6/23	9/23	12/22
2011	3/24	6/27	9/29	12/29
2012	3/29	6/28	10/01	-

Season 3

Season 2

Year 4

Year 1

Launch 3/6/2009

Vernal Equinox

Sp

Earth's orbit

Sun

Autumnal Equinox

A

Kepler's orbit

Ecliptic Reference	Earth	Kepler
Period (days)	365.24	370.84
Semi-major Axis (AU)	1.00	1.01
Eccentricity	0.02	0.04
Inclination (deg)	0.00	0.49
Arg. of Periapse (deg)	102.96	-80.09
Long. of Node (deg)	0.00	155.09

Season 4

Season 1

Su

Summer Solstice

Ecliptic Projection of Photometer Boresight

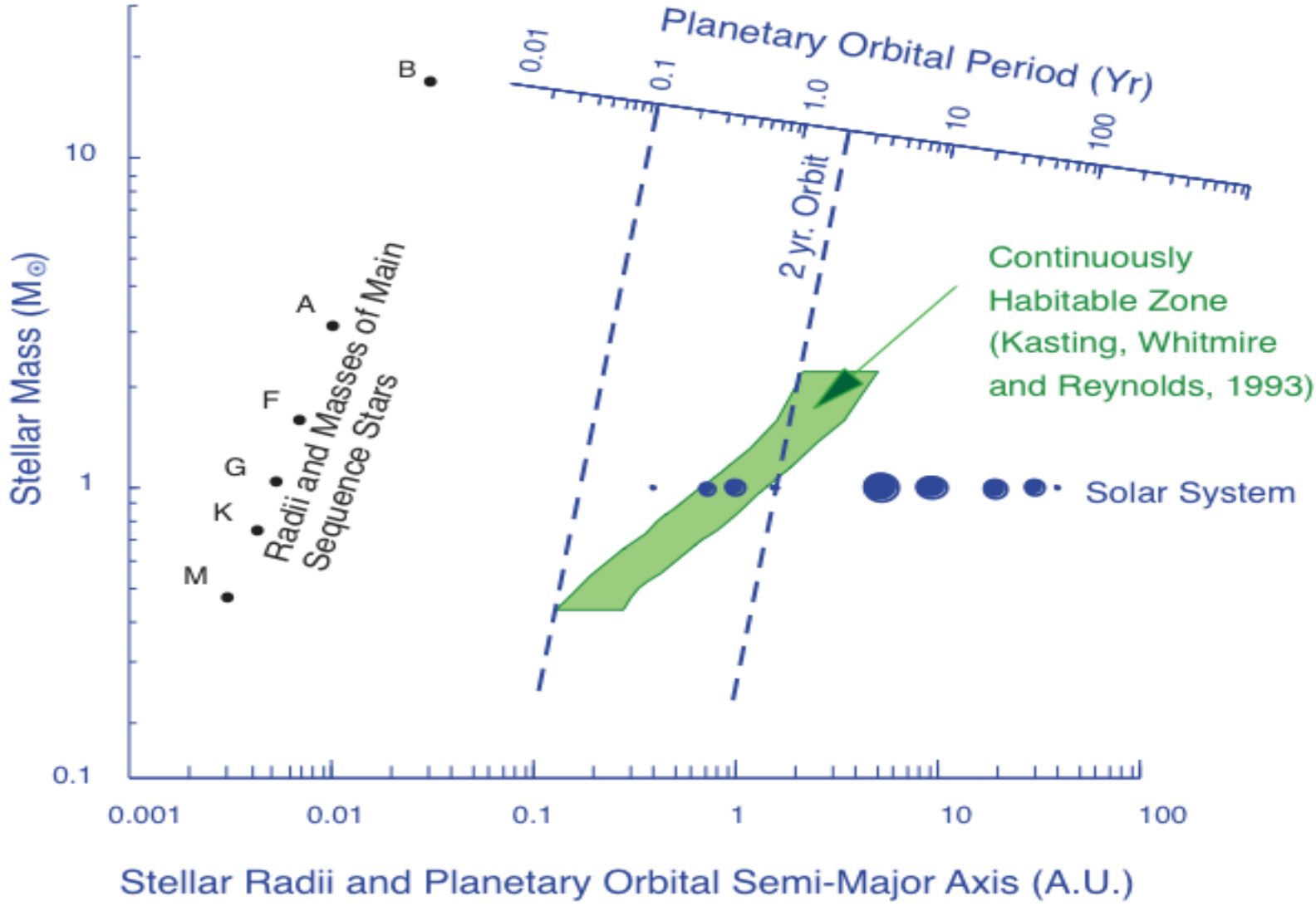
Earth's orbit

Kepler's orbit

Kepler's position

The Habitable Zone for Various Stellar Spectral Types

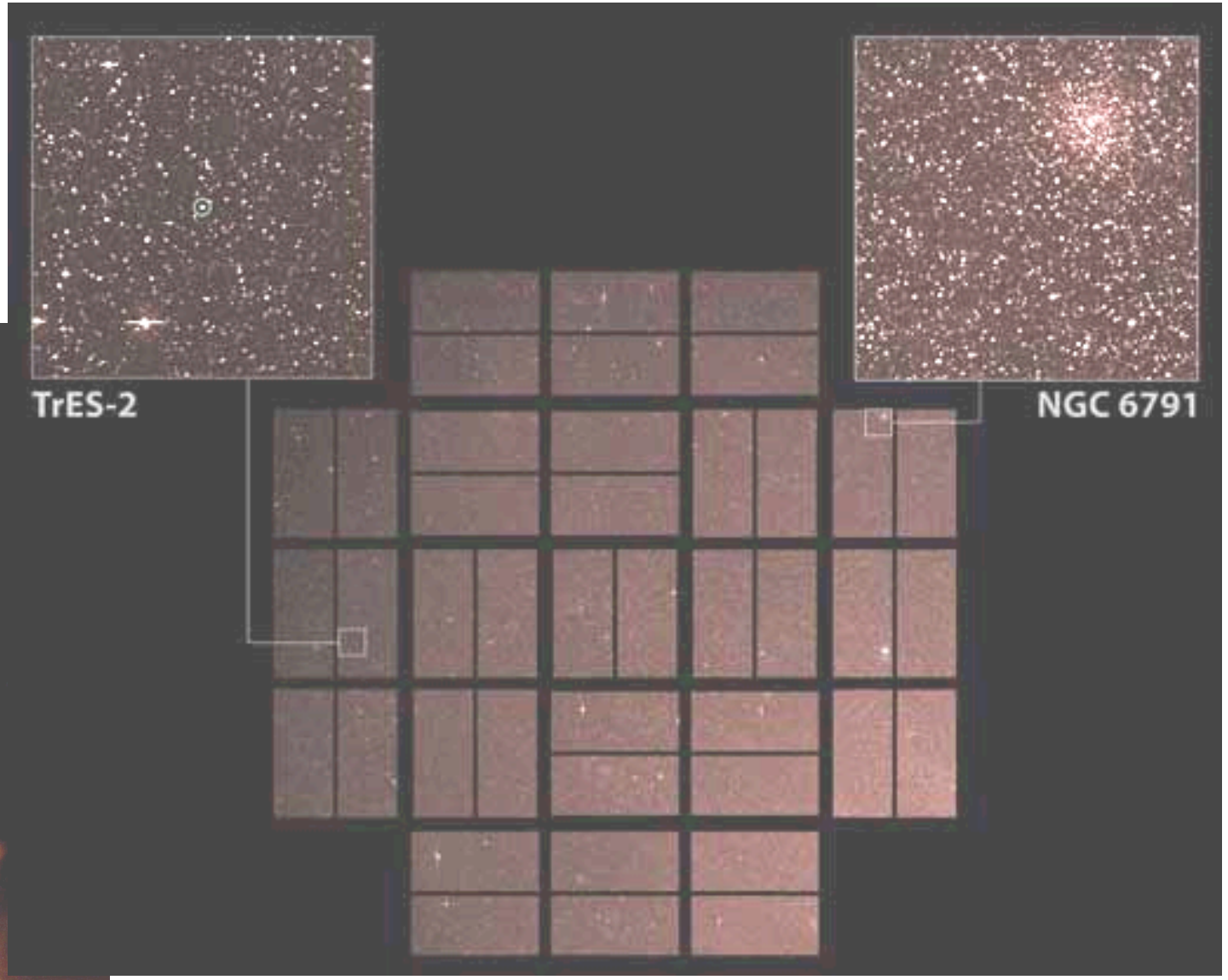
Kepler
A Search for Habitable Planets



First Light Full Field Image

Kepler
A Search for Habitable Planets

Launched
March 6, 2009



First Light April 7, 2009

Kepler Mission Data Flow

A Search for Habitable Planets

Raw Data

Deep Space Network
Canberra/Madrid/Goldstone

Mission Operations Center
LASP
Boulder, CO

Science Operations Center
NASA A.R.C.
Moffett Field, CA

Raw Pixels

Data Management Center
Baltimore, MD

Calibrated Pixels
Calibrated Light Curves

& PLANETS!

The SOC Pipeline: From Pixels To Planets

Kepler
A Search for Habitable Planets

Raw Data

CAL
Pixel Level Calibrations

Cali-brated Pixels

PA
Photometric Analysis

Sums Pixels Together/Measures Star Locations

Raw Light Curves/ Centroids

PDC
Presearch Data Conditioning

Removes Systematic Errors

Corrected Light Curves

TPS
Transiting Planet Search

DV
Data Validation

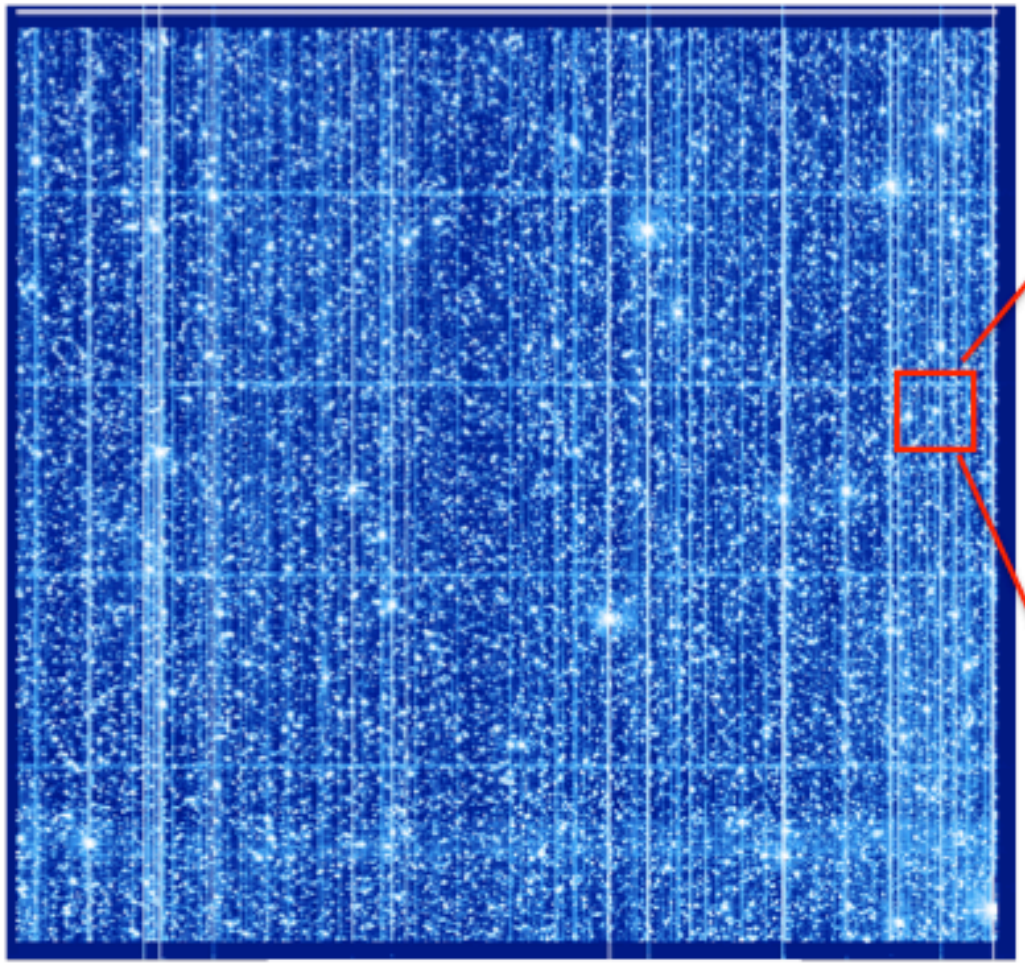
Diagnostic Metrics

TCEs:
Threshold Crossing Events

Pixel Level Data From Kepler

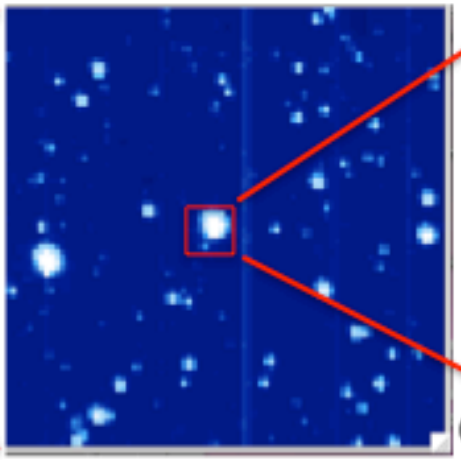
Kepler
A Search for Habitable Planets

Module 17 Output 2



1.13 (h) x1.22 (w) degrees

Zoomed Image
near HAT-P-7b



0.09x0.09 degrees
80x80 pixels
6400 pixels total

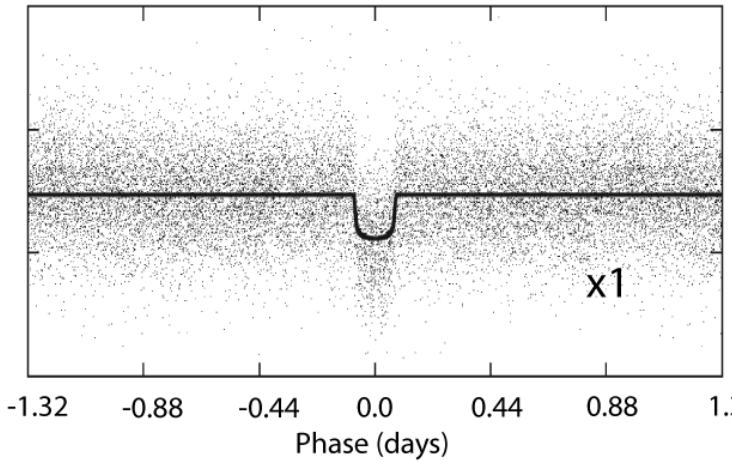
HAT-P-7b LC
pixels

6.6x6.6 millidegrees
28 pixels collected
Black = no data

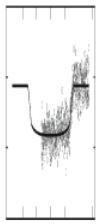
Scaled to show faint detail

HAT-P-7b Ground vs. Space

A Search for Habitable Planets

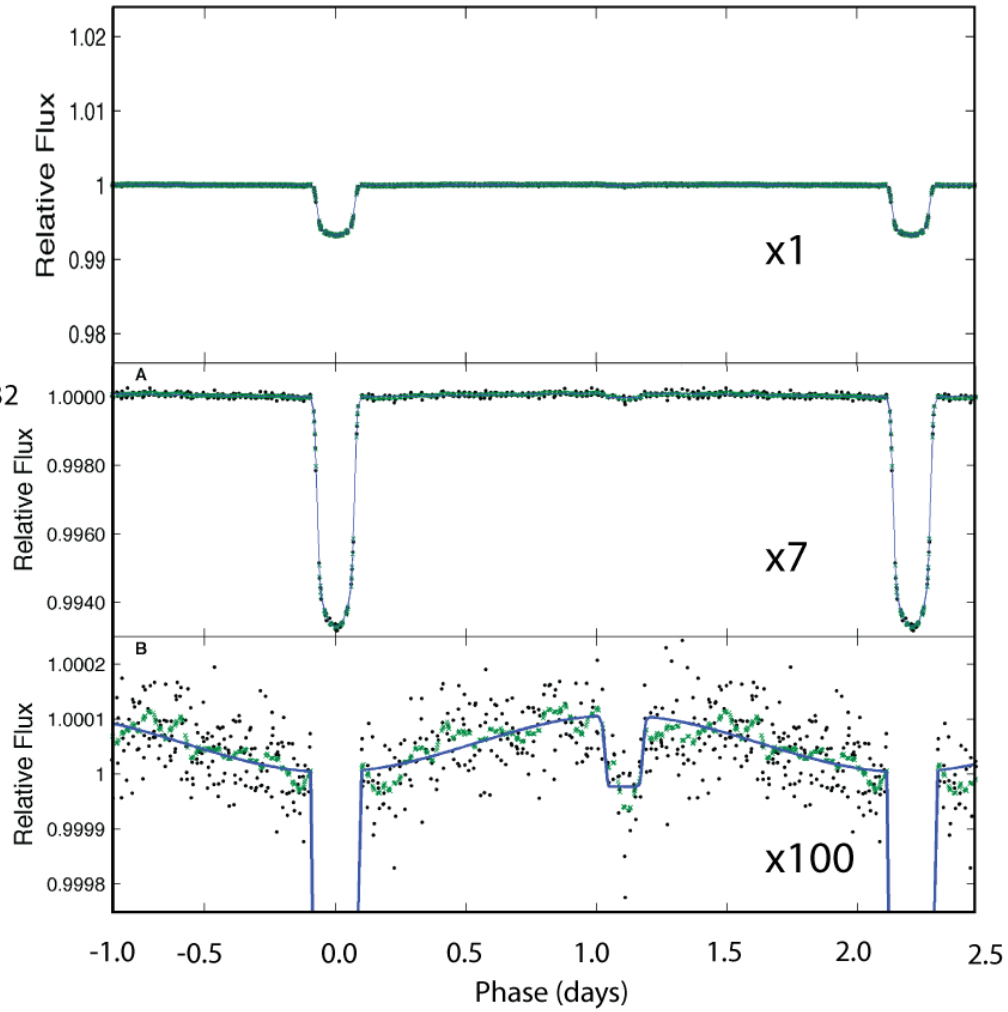


16,620 HATNet data points (57.7 days of data)



x1

Single night at 1.2 m FLWO with Kepler Cam

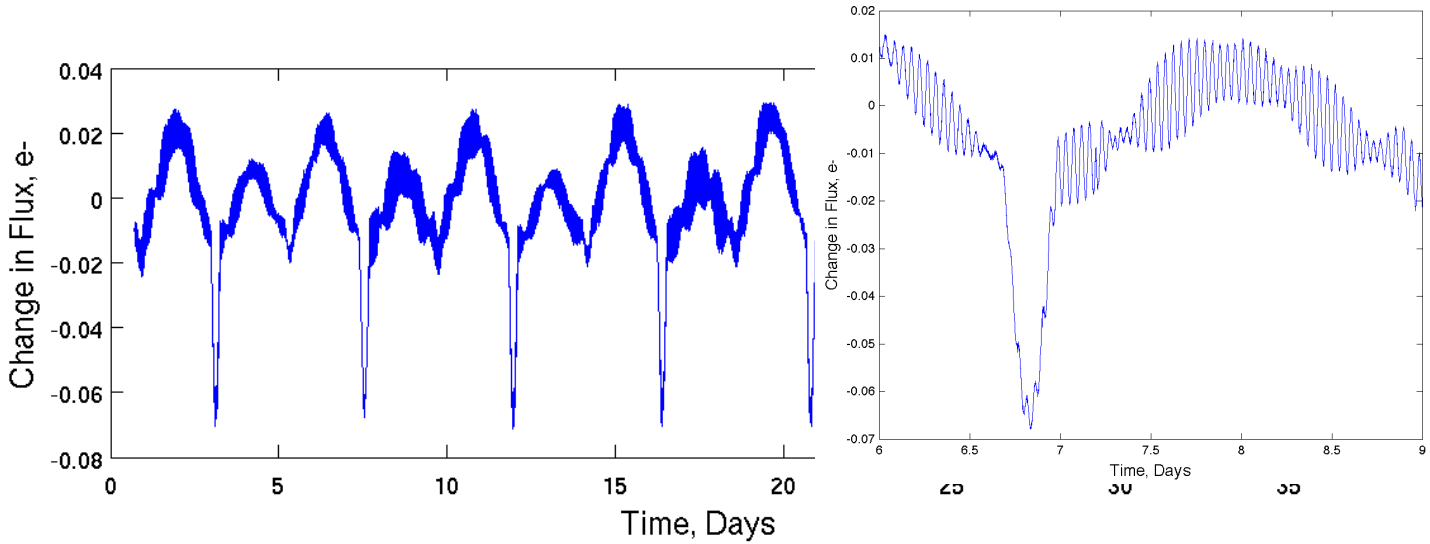


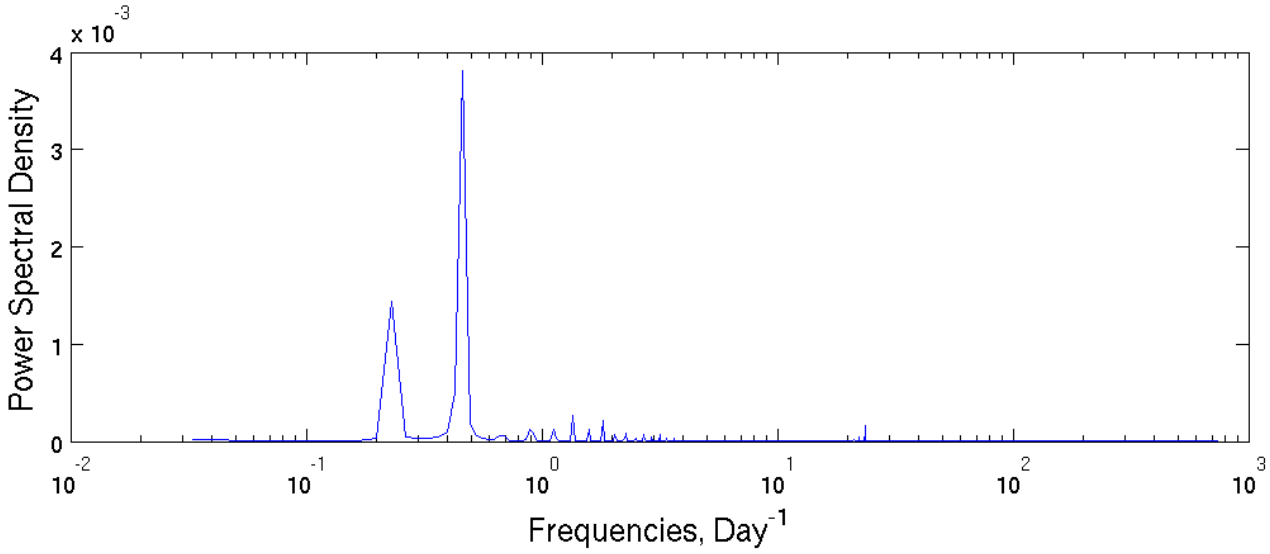
HAT-P-7b data from the ground
A. Pal et al., 2008

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

Music From the Stars (3)

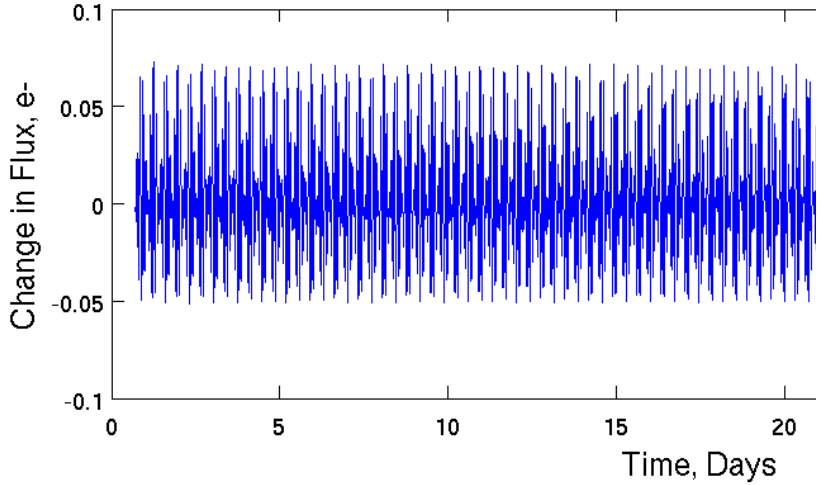
A Search for Habitable Planets

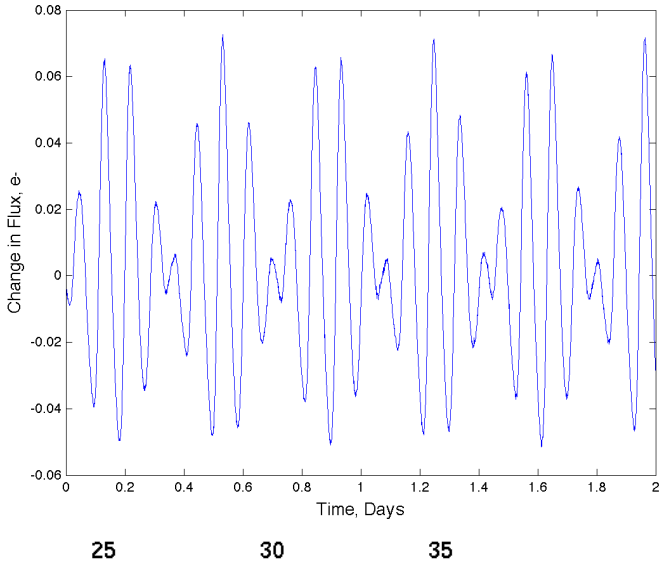


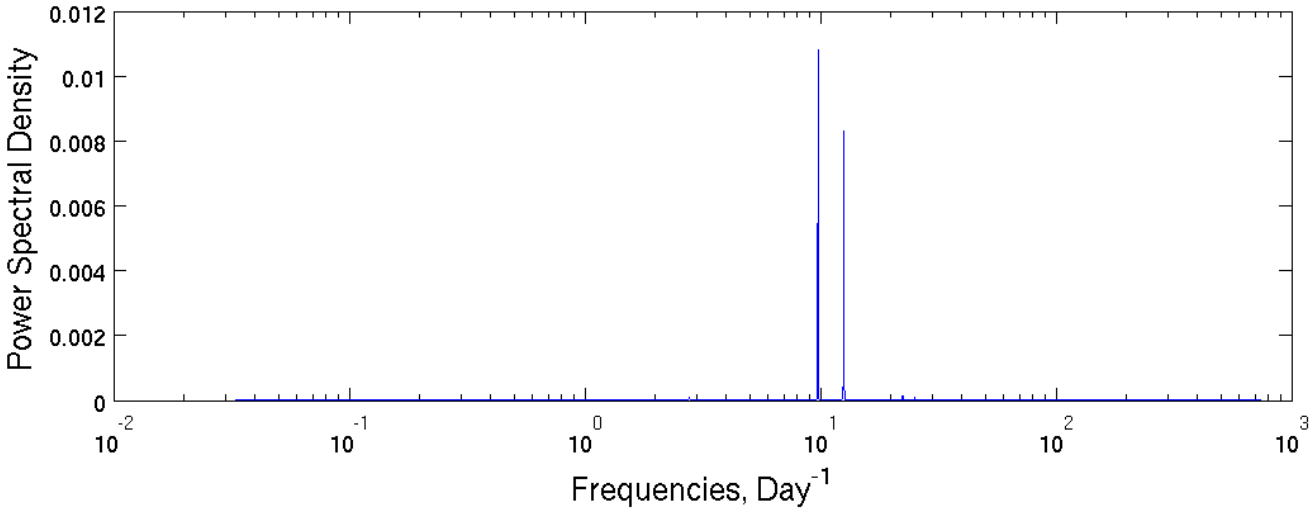


Music From the Stars (4)

Kepler
A Search for Habitable Planets

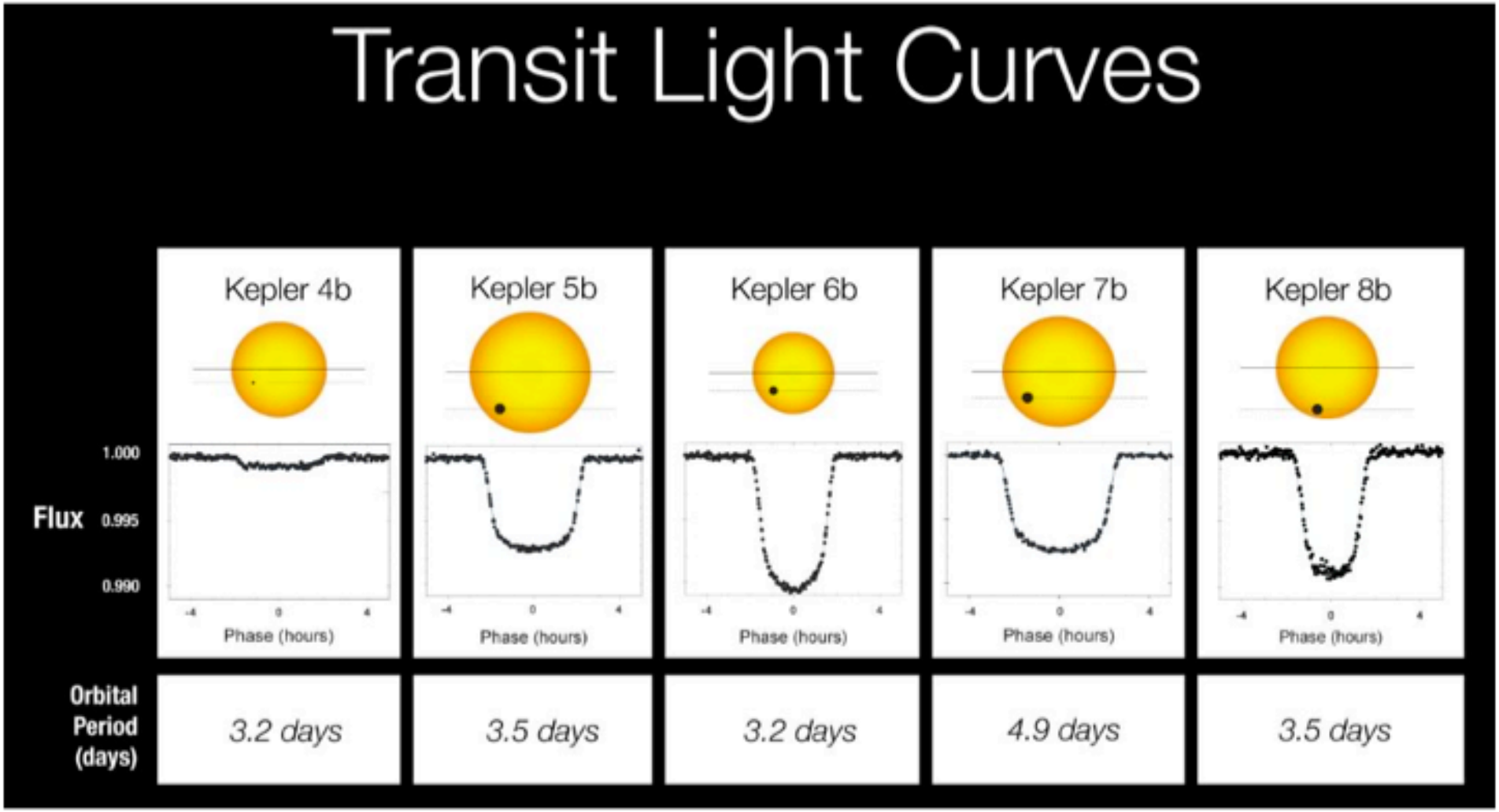






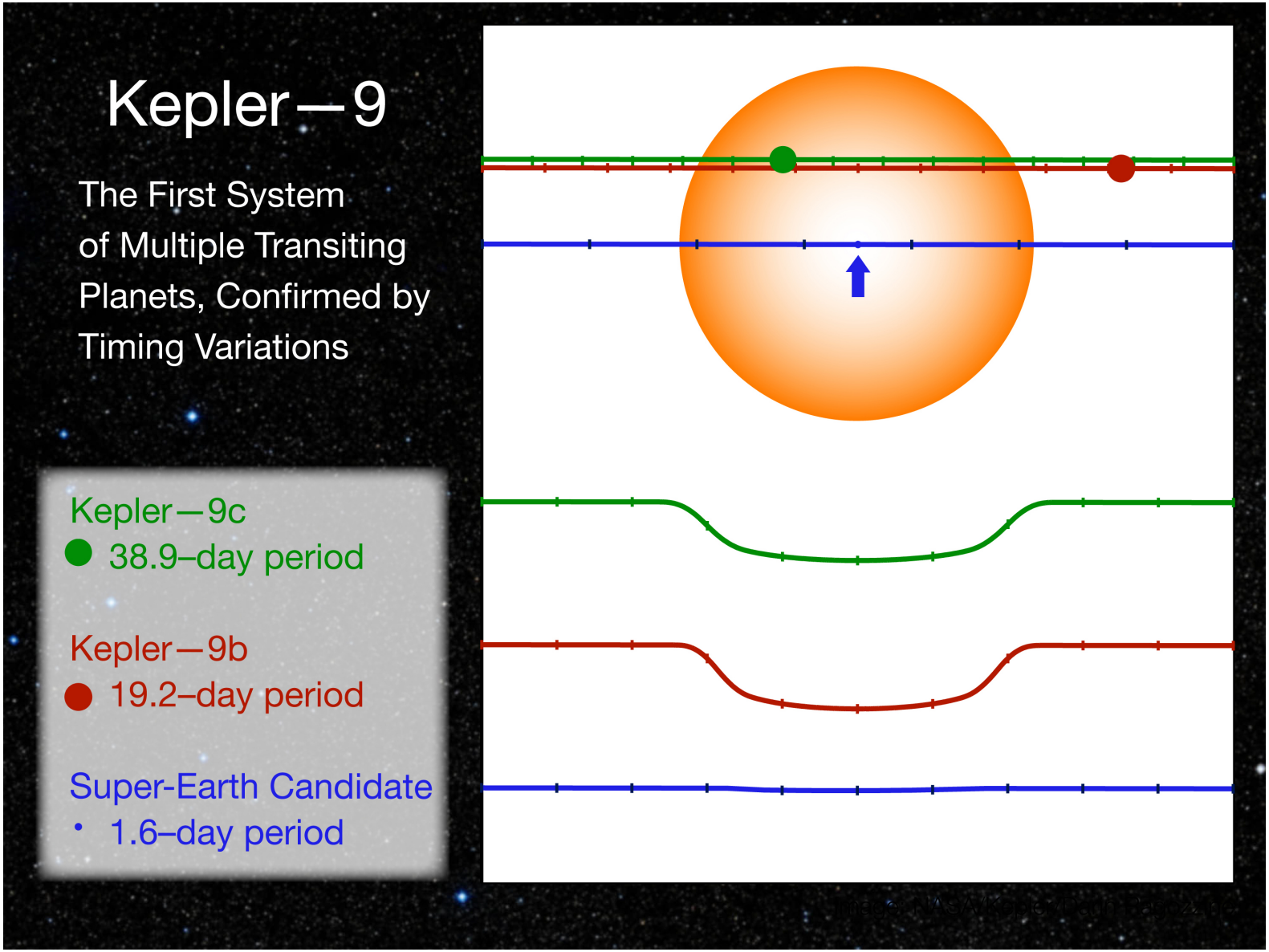
Kepler Discoveries

A Search for Habitable Planets



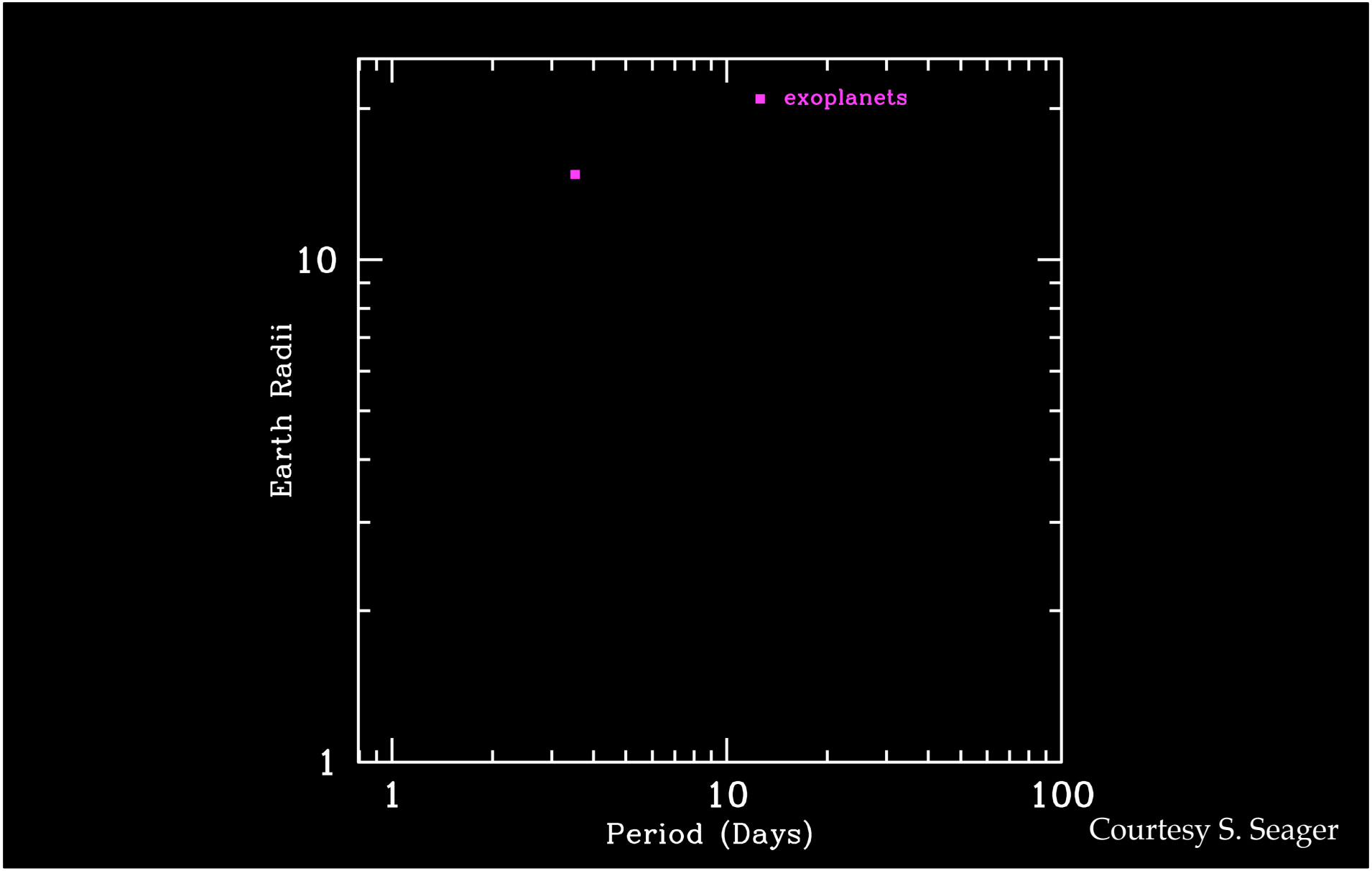
Keple-9b, c and d

Kepler
A Search for Habitable Planets



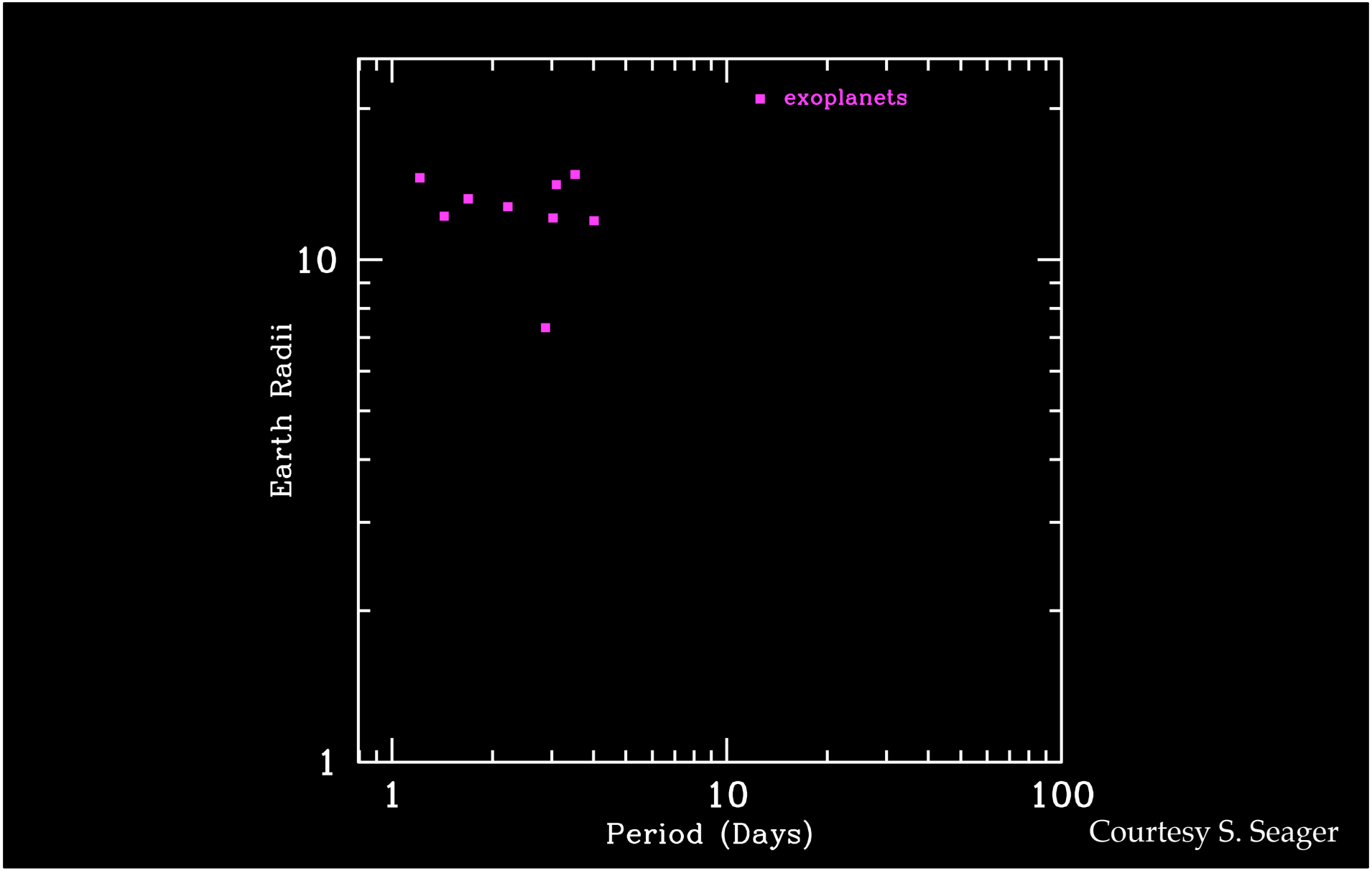
Transiting Planets 2000

Kepler
A Search for Habitable Planets



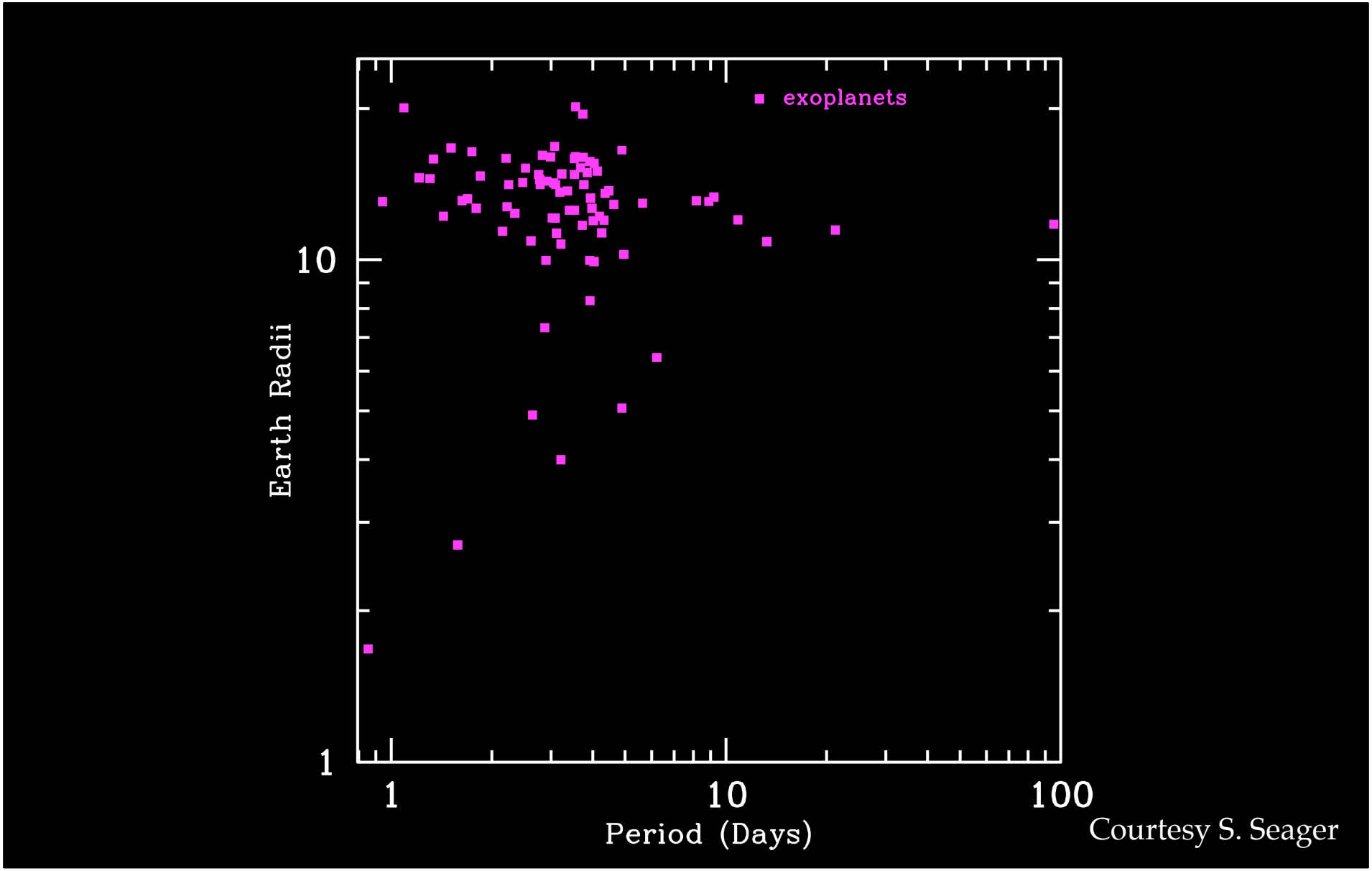
Transiting Planets 2005

Kepler
A Search for Habitable Planets



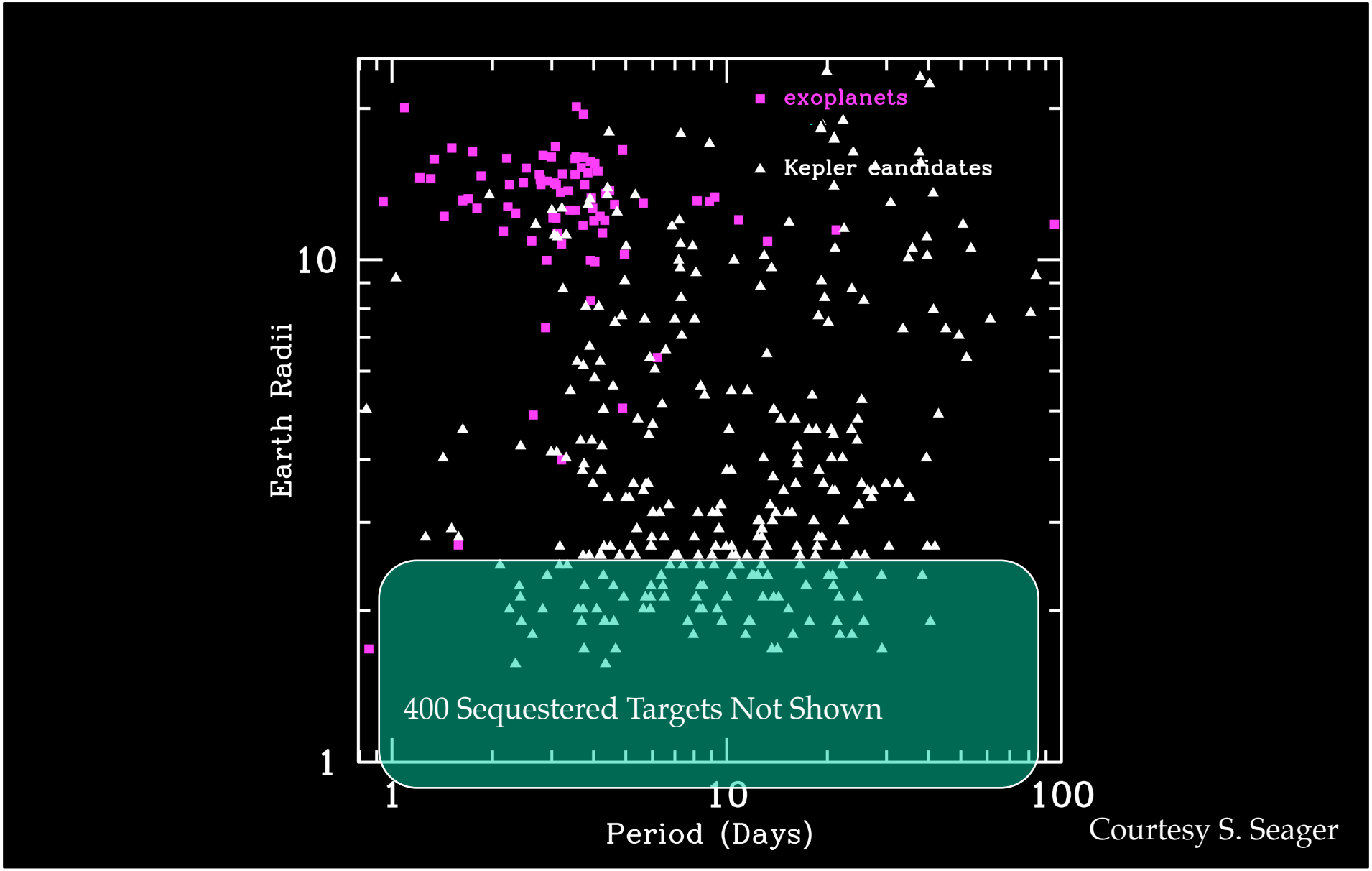
Transiting Planets June 14, 2010

Kepler
A Search for Habitable Planets



Transiting Planets June 15, 2010

Kepler
A Search for Habitable Planets



How is Kepler Changing the Field Of Exoplanets?

Kepler
A Search for Habitable Planets

"Well, this mission answers at least one big question: Are there other planets like ours in the universe?"

Drawing by H. Martin; © 1991
The New Yorker Magazine, Inc.

... the ways by which men arrive at knowledge of the celestial things are hardly less wonderful than the nature of these things themselves.

— Johannes Kepler 1571-1630

Do there exist many worlds or is there but a single one? This is one of the most noble and exalted questions in the study of Nature

— Saint Albertus Magnus 1206-1280
Scholar, Patron Saint of Scientists