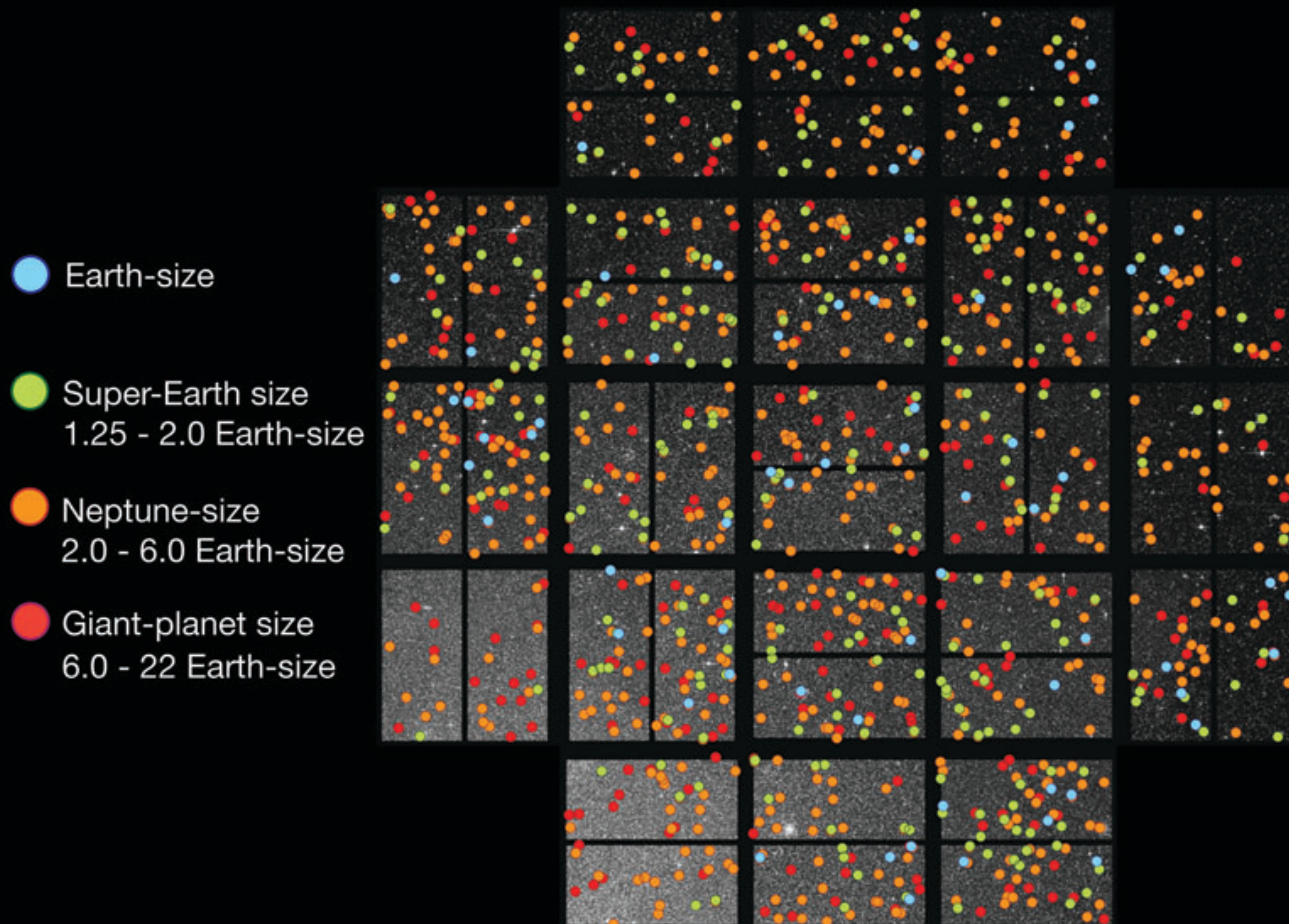
The *Kepler* Mission



John Lurie – ASTR 597B – 2/18/15

Outline

- Mission goals and background
- Spacecraft details
- The data
- Science results
- The next chapter – K2

Kepler Mission Objective
(in one sentence)

What is the abundance of Earth-like planets orbiting Sun-like stars?

Much More than Exoplanets

Kepler was designed to find exoplanets, but in doing so it monitored almost 200,000 stars nearly continuously for 4 years with superb photometric precision, producing an incredibly rich dataset.

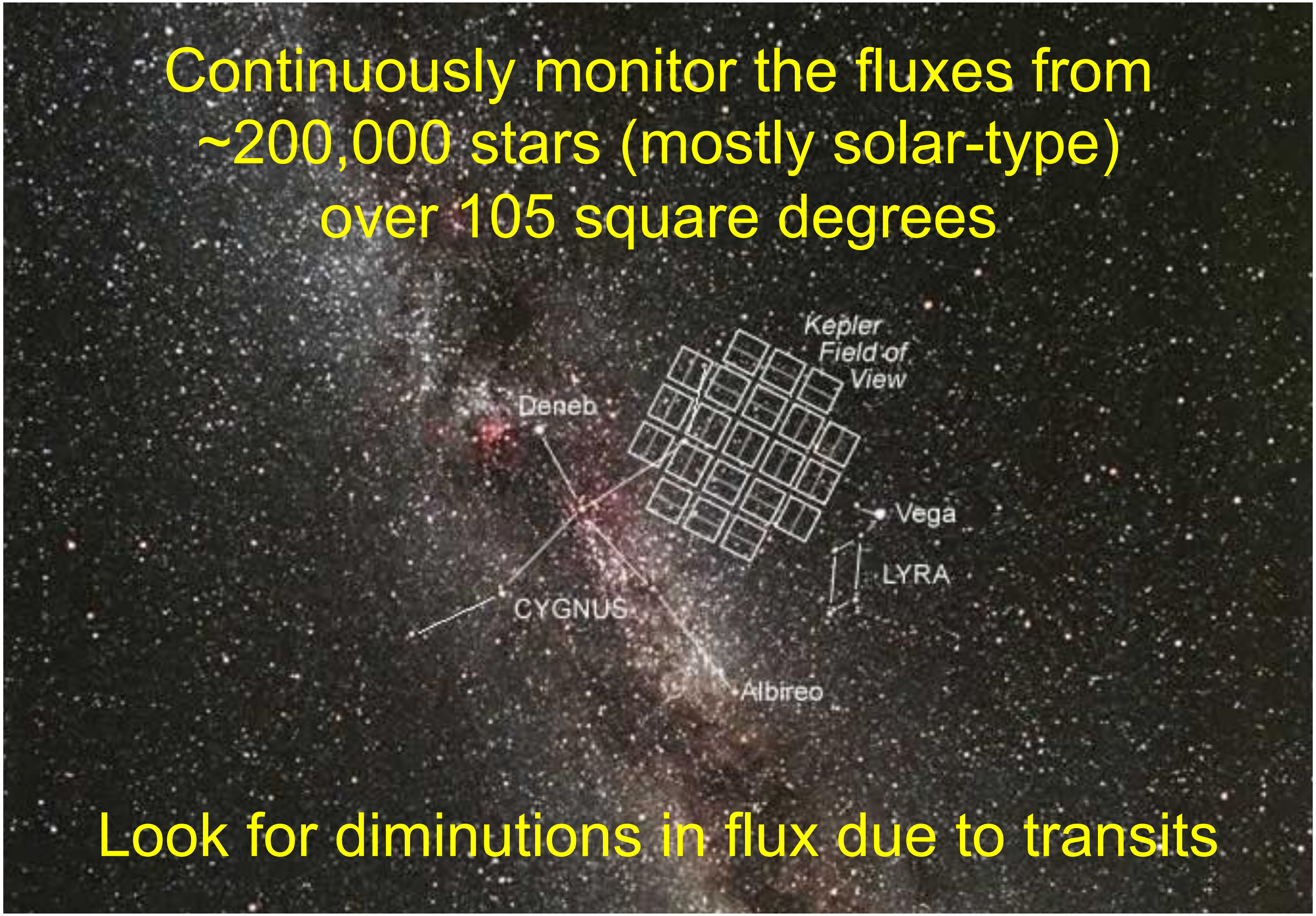
Kepler Mission Objective(s)
(in many sentences)

From the NASA website: “The scientific objective of the Kepler Mission is to explore the structure and diversity of planetary systems. This is achieved by surveying a large sample of stars to”:

1. Determine the **abundance of terrestrial** and larger planets in or near the **habitable zone** of a wide variety of stars
2. Determine the distribution of **sizes and shapes of the orbits** of these planets
3. Estimate **how many planets are in multiple-star systems**
4. Determine the variety of orbit sizes and planet reflectivities, sizes, masses and densities of short-period giant planets
5. Identify additional members of each discovered planetary system using other techniques
6. Determine **the properties of those stars that harbor planetary systems**.

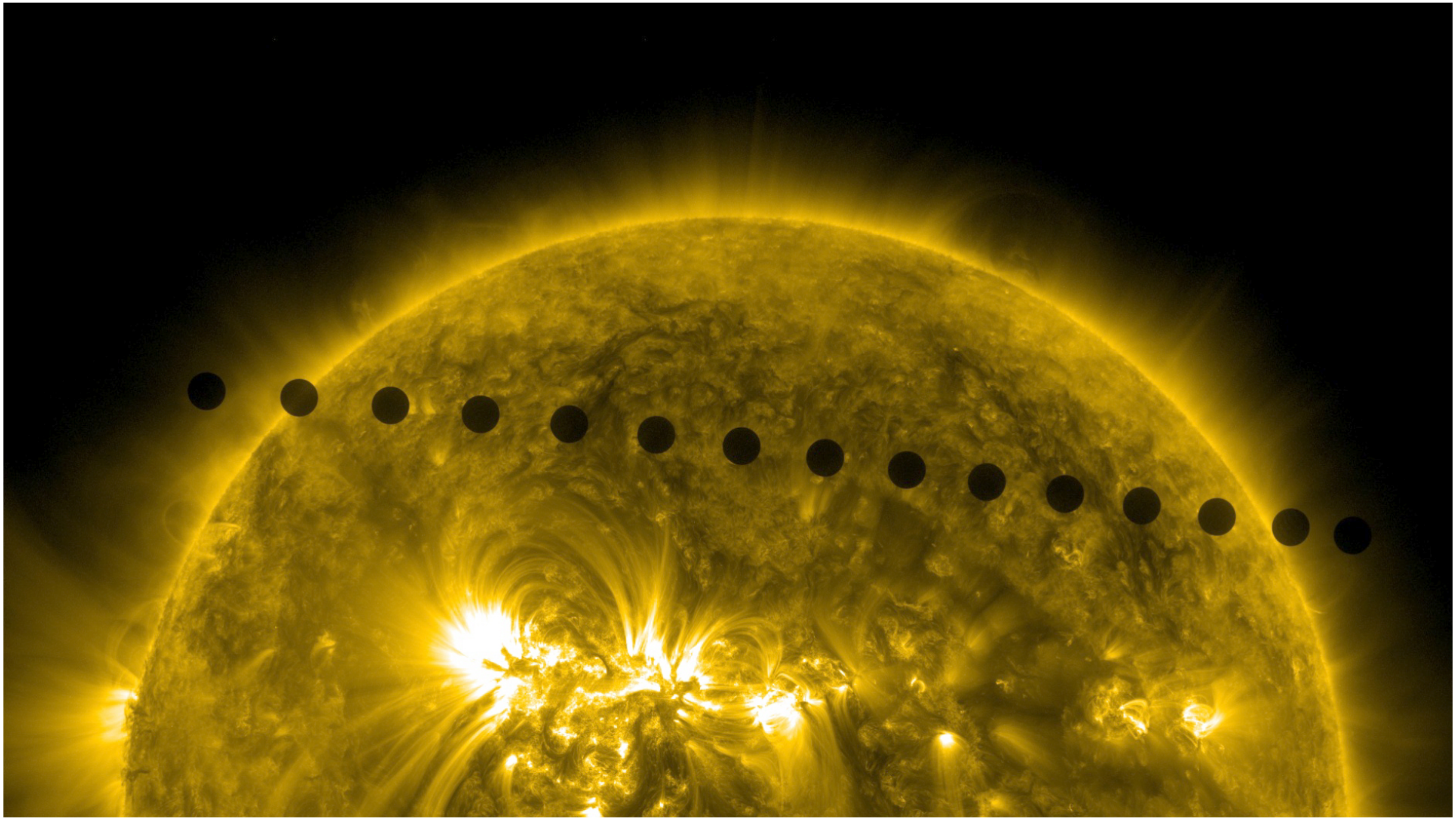
A “Simple” Survey Scheme

Continuously monitor the fluxes from ~200,000 stars (mostly solar-type) over 105 square degrees



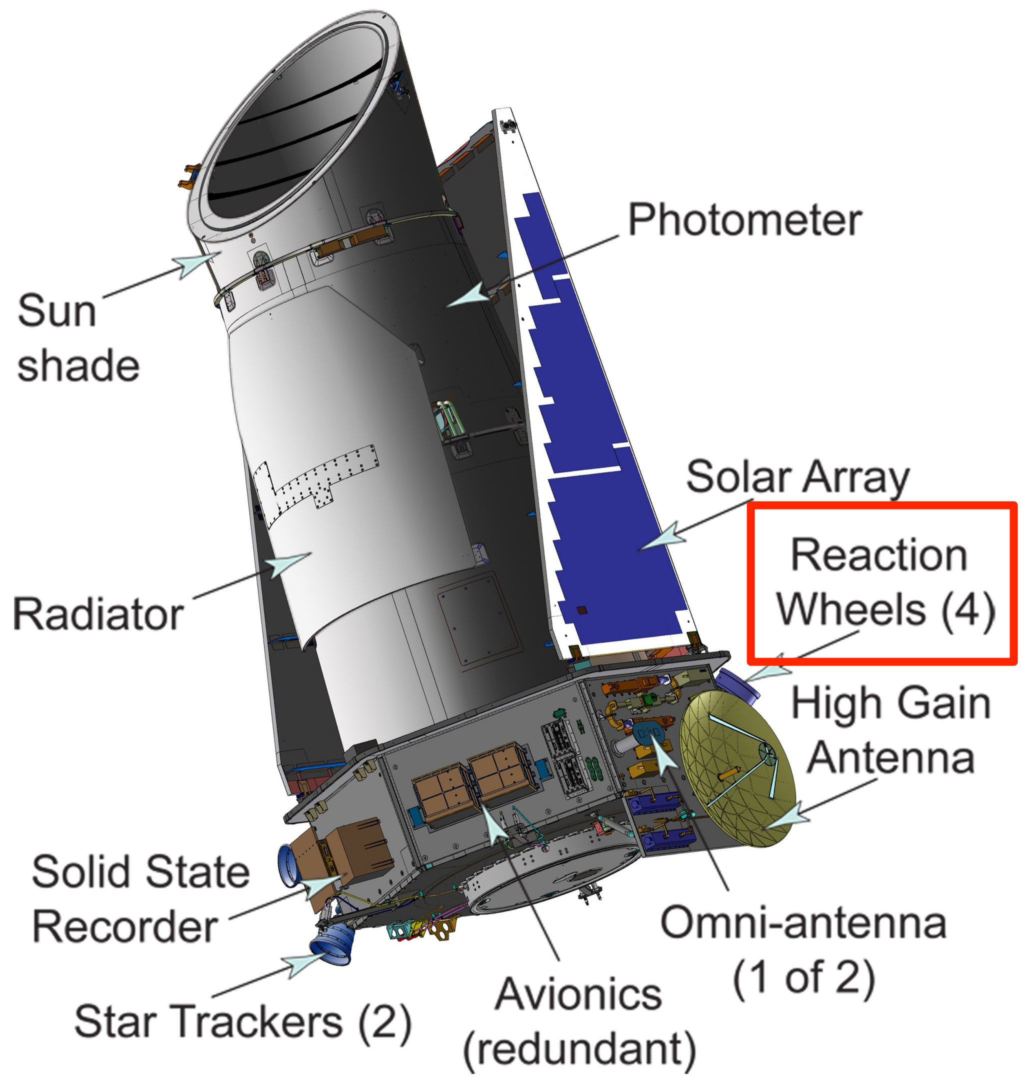
Look for diminutions in flux due to transits

The Transit Technique

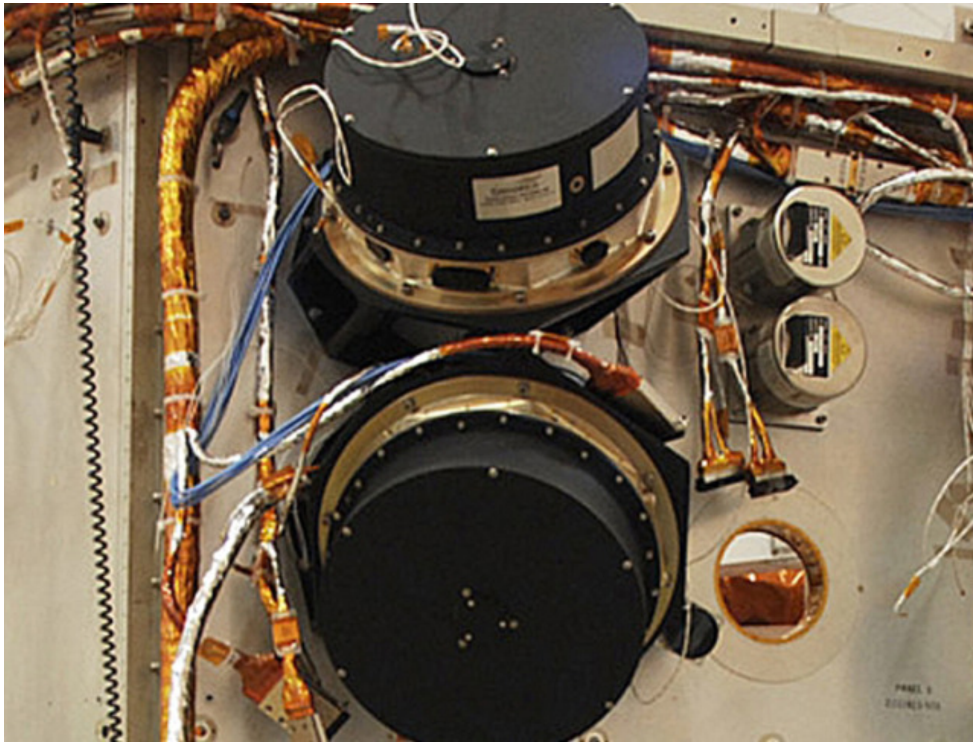


Requires high (ppm) photometric precision and high temporal resolution
Limited by astrophysical “noise”, i.e., stellar activity

The Spacecraft



Reaction Wheels

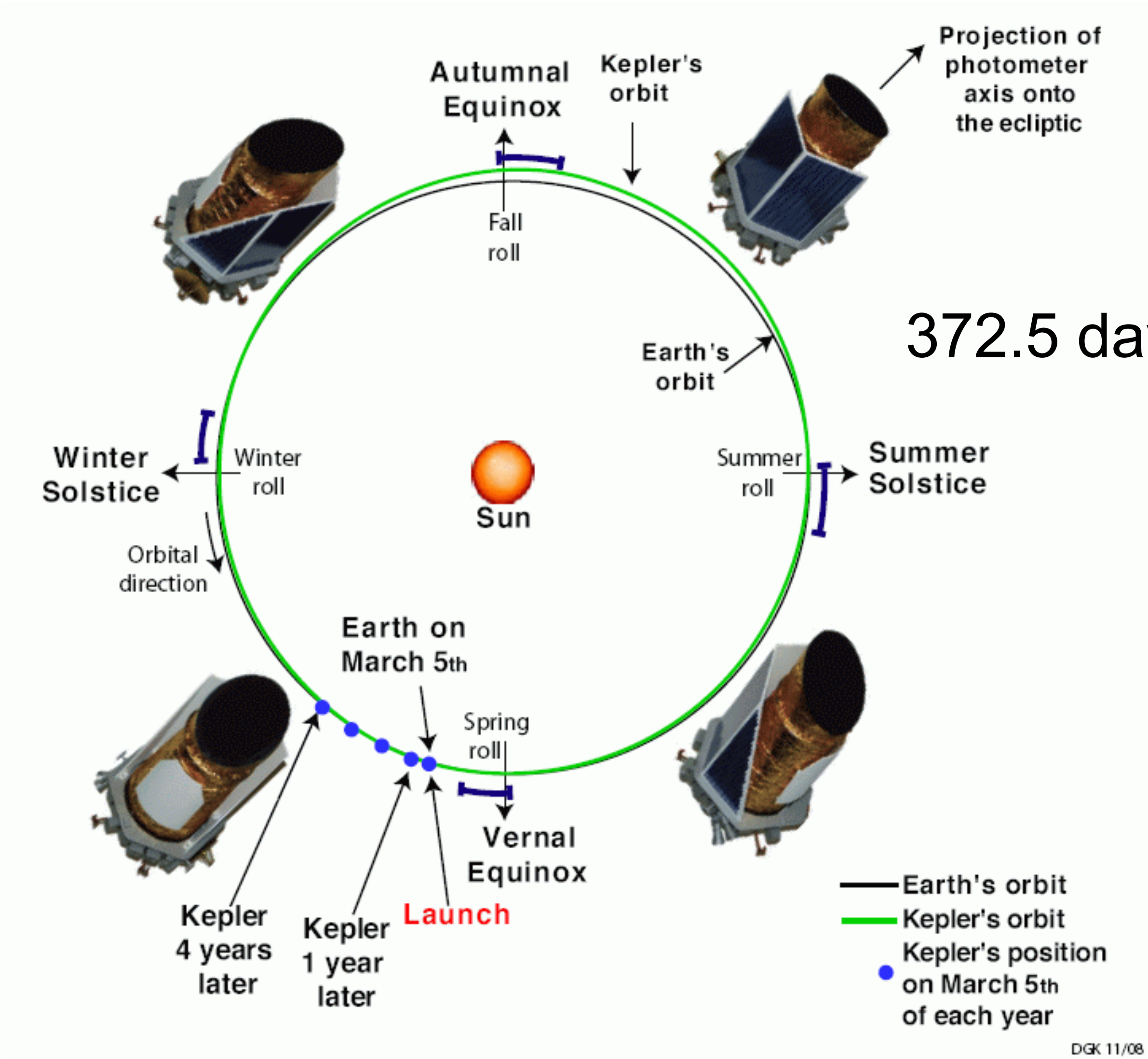


Like a gyroscope; maintains telescope pointing

Preparing for Launch

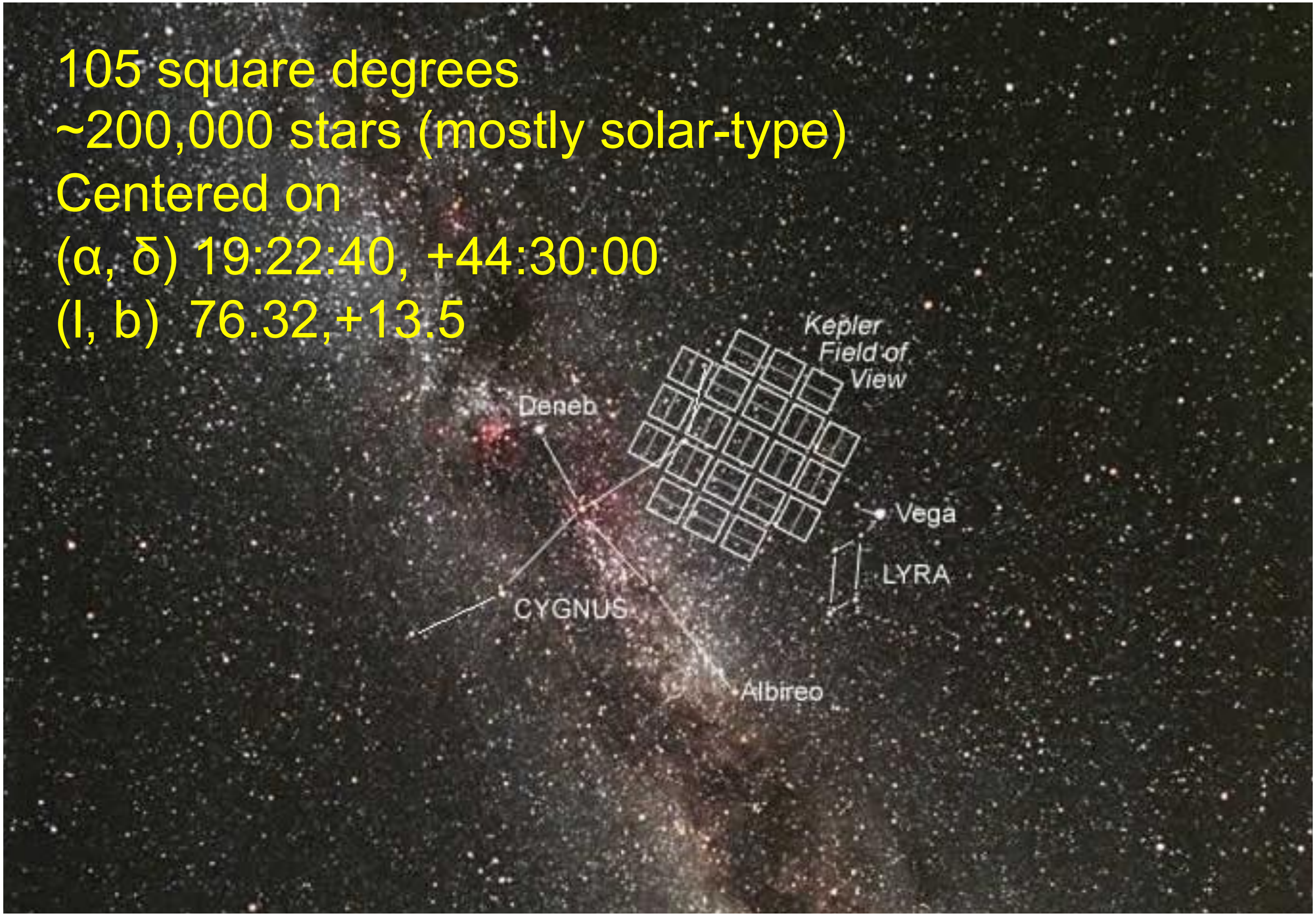
Launch: March 7, 2009

Earth Trailing Orbit

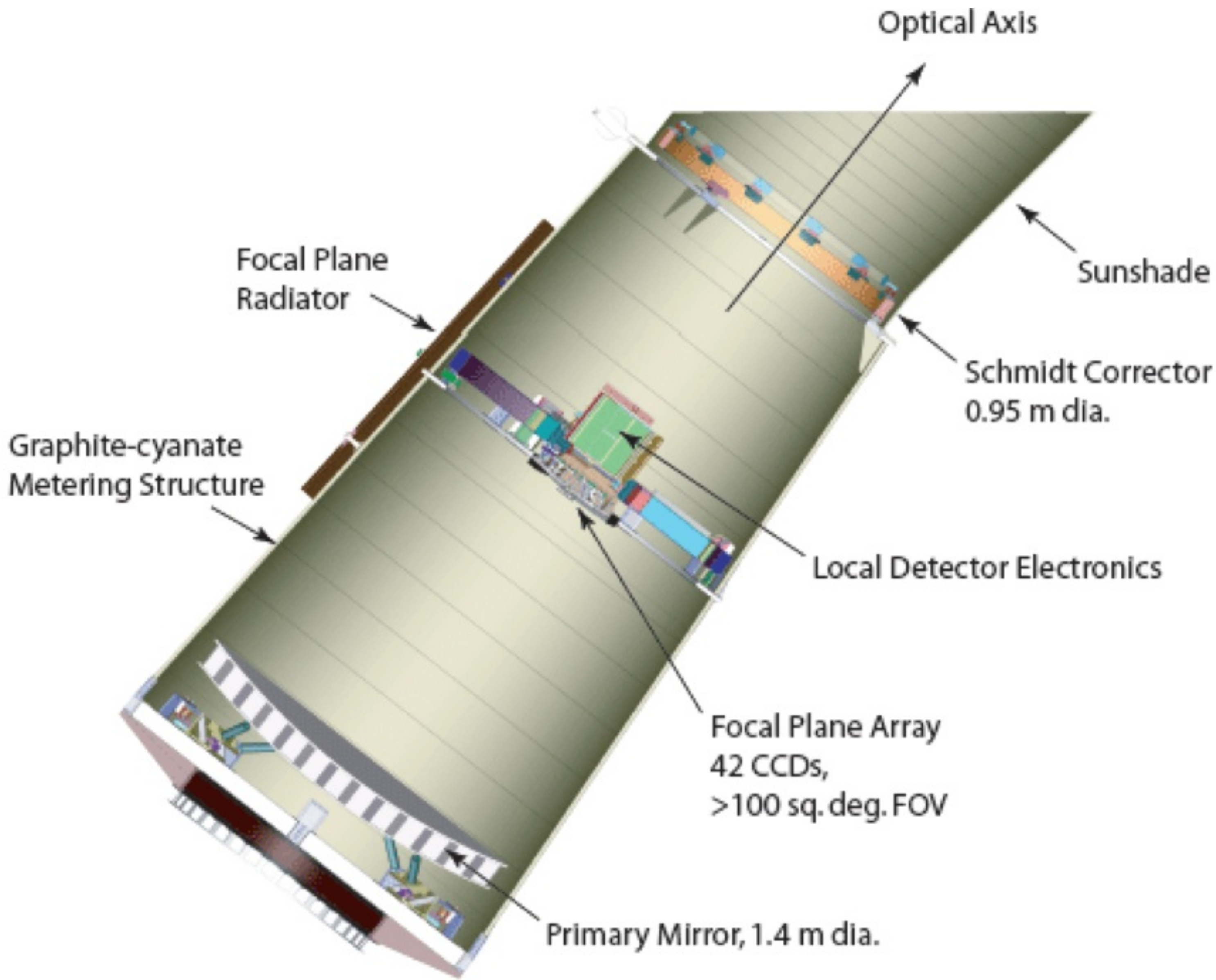


372.5 day orbit

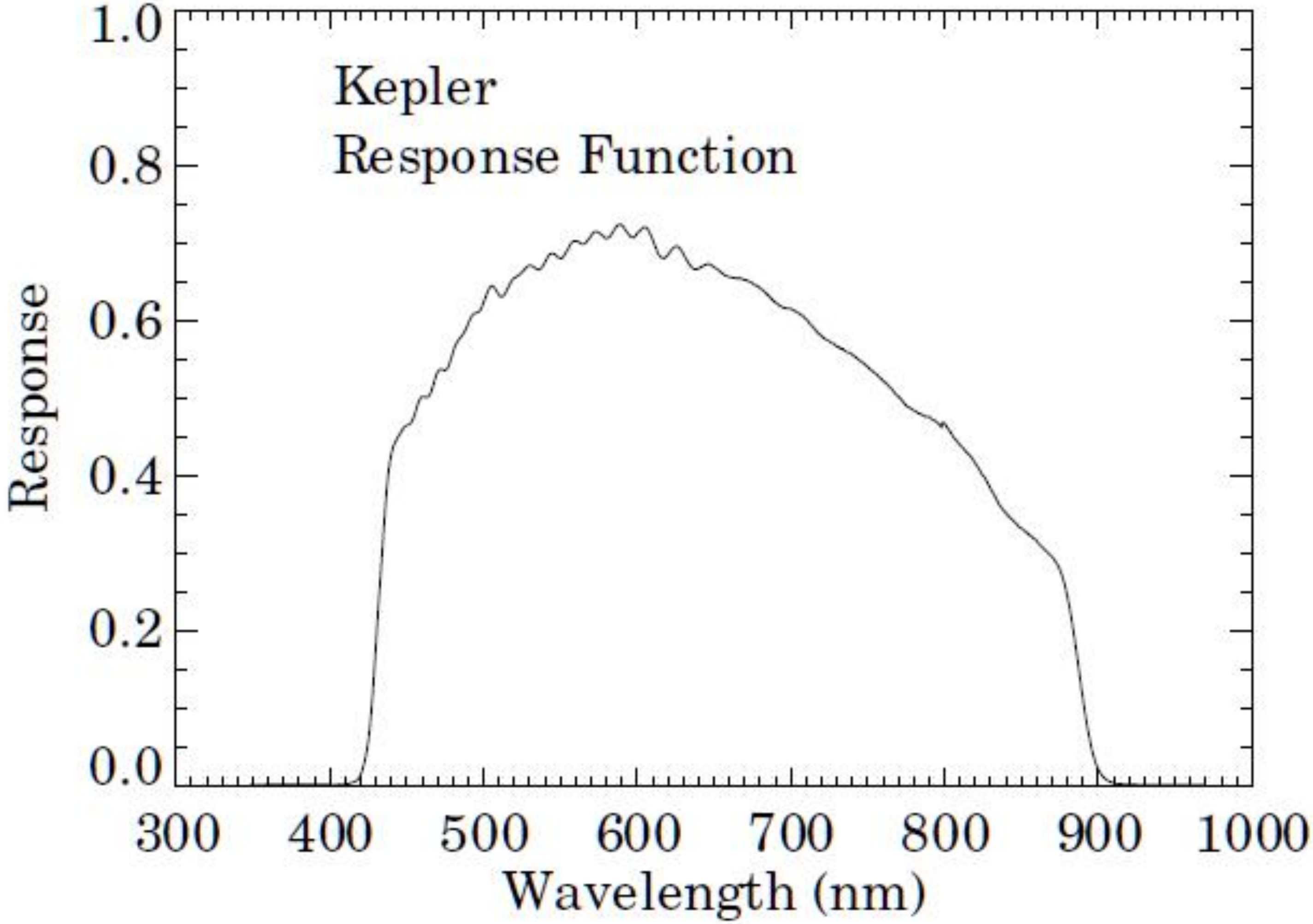
Field of View



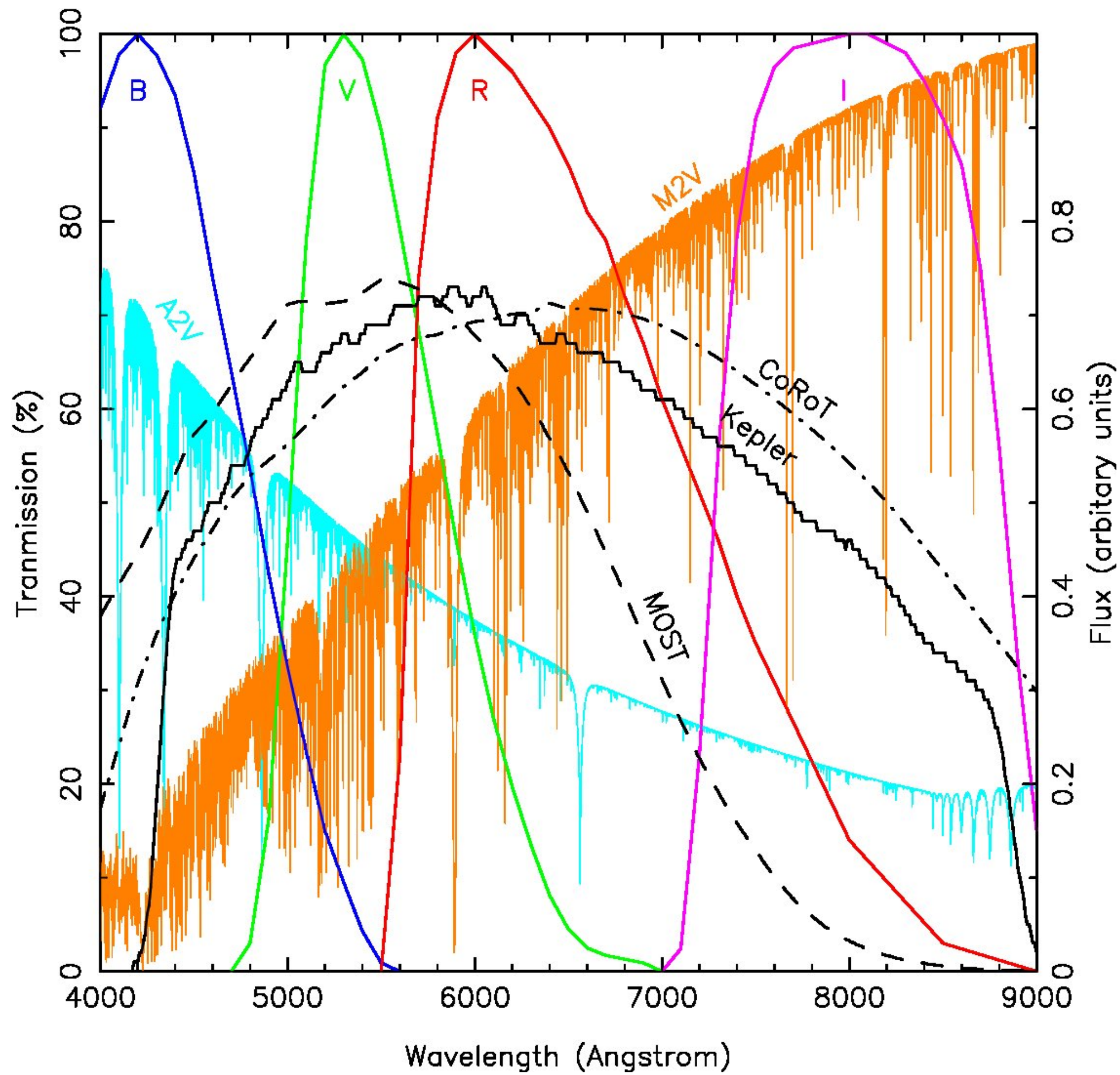
The Optics


Optical Axis
Sunshade
Focal Plane
Radiator
Schmidt Corrector
0.95 m dia.
Graphite-cyanate
Metering Structure
Local Detector Electronics
Focal Plane Array
42 CCDs,
>100 sq. deg. FOV
Primary Mirror, 1.4 m dia.

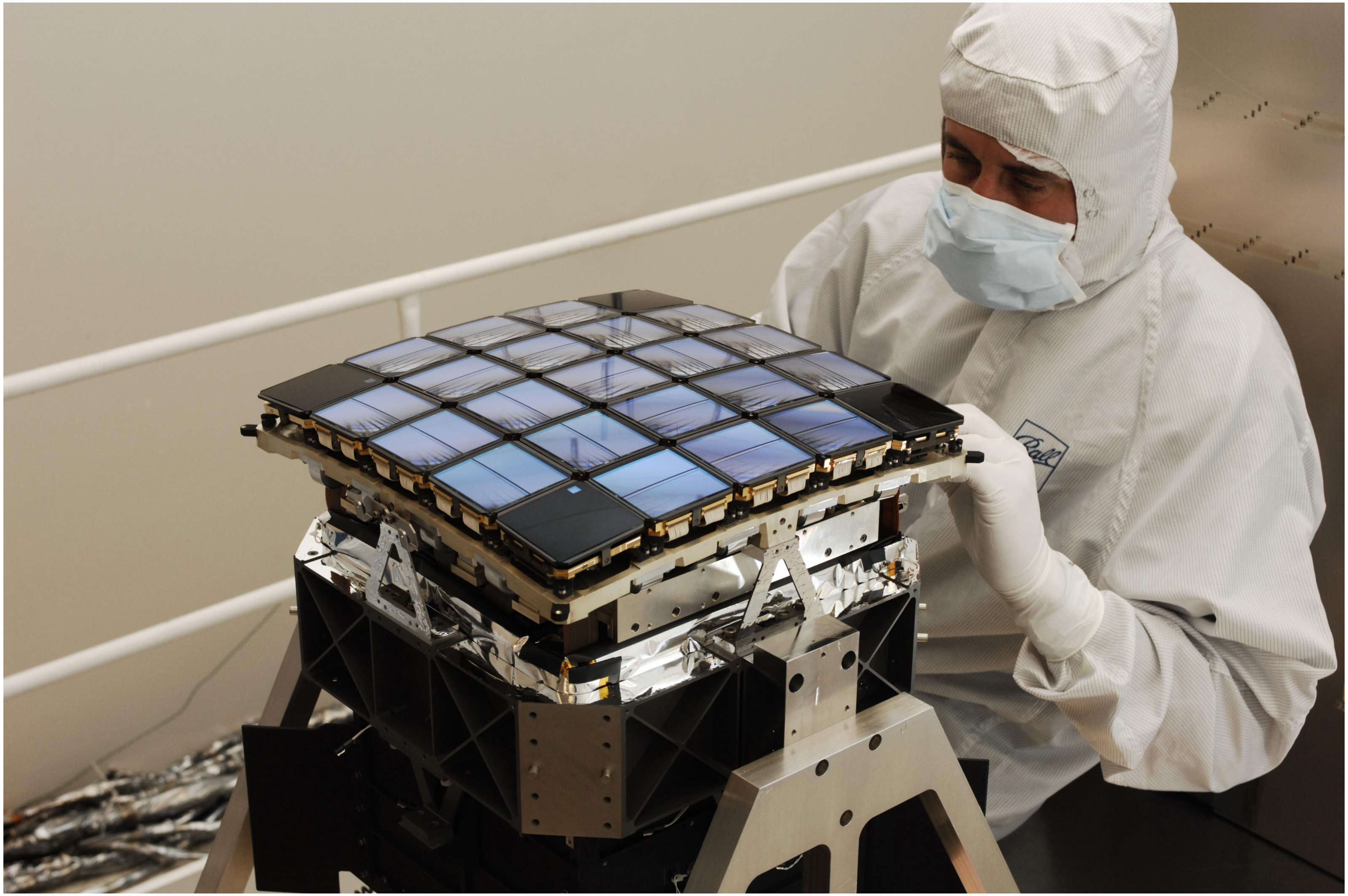
“White Light” Bandpass



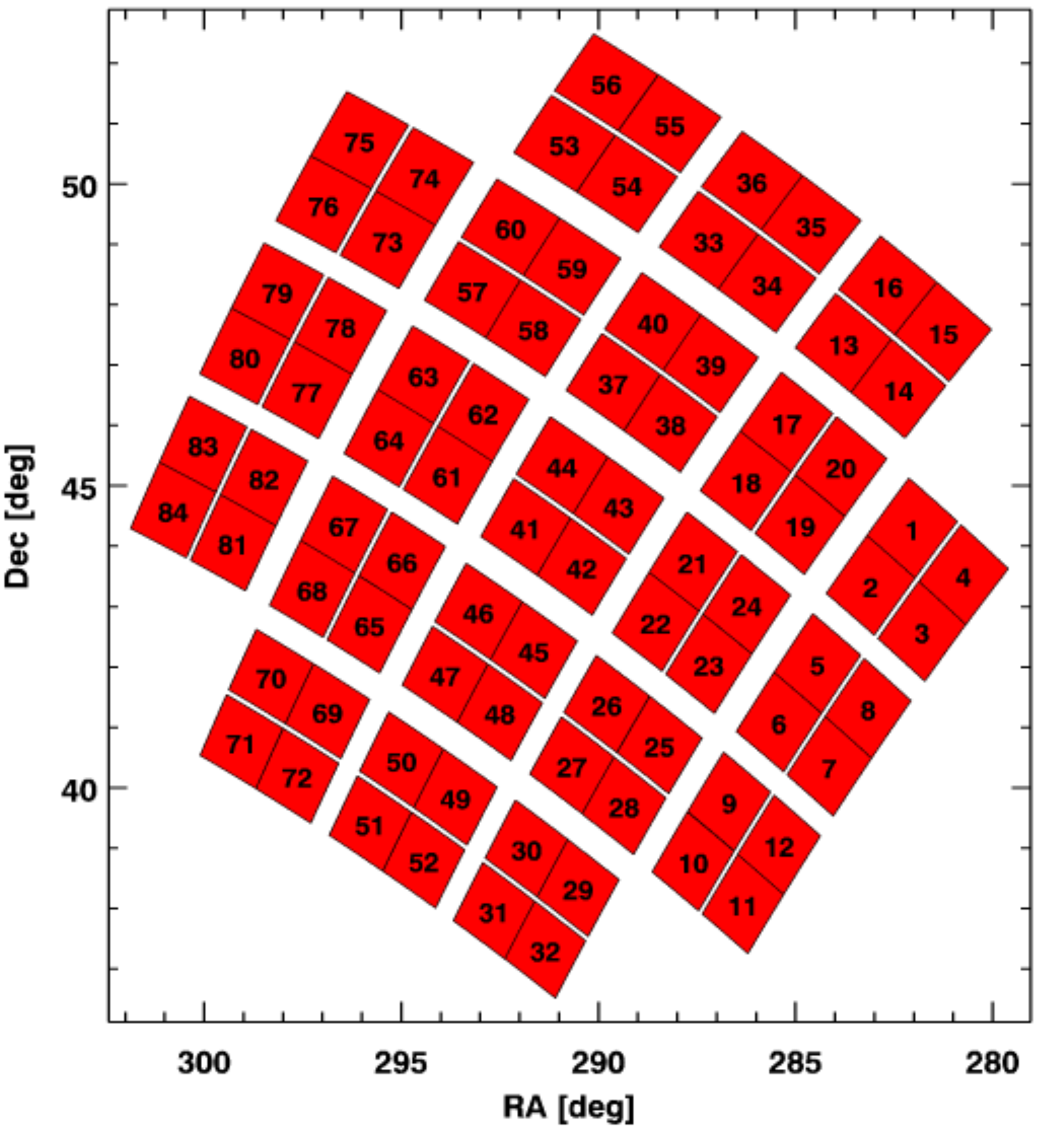
“White Light” Bandpass



The Detector

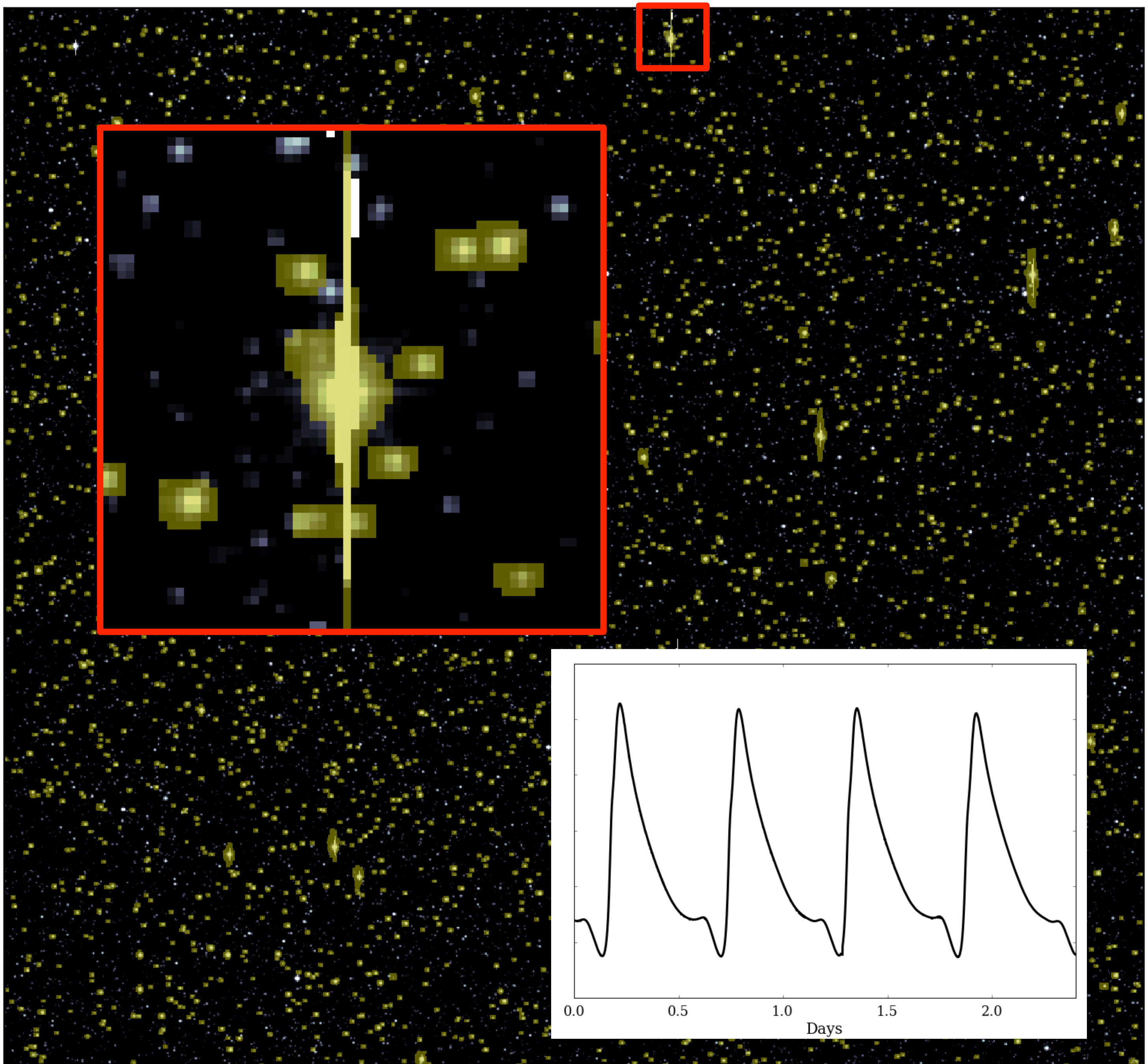


The Detector



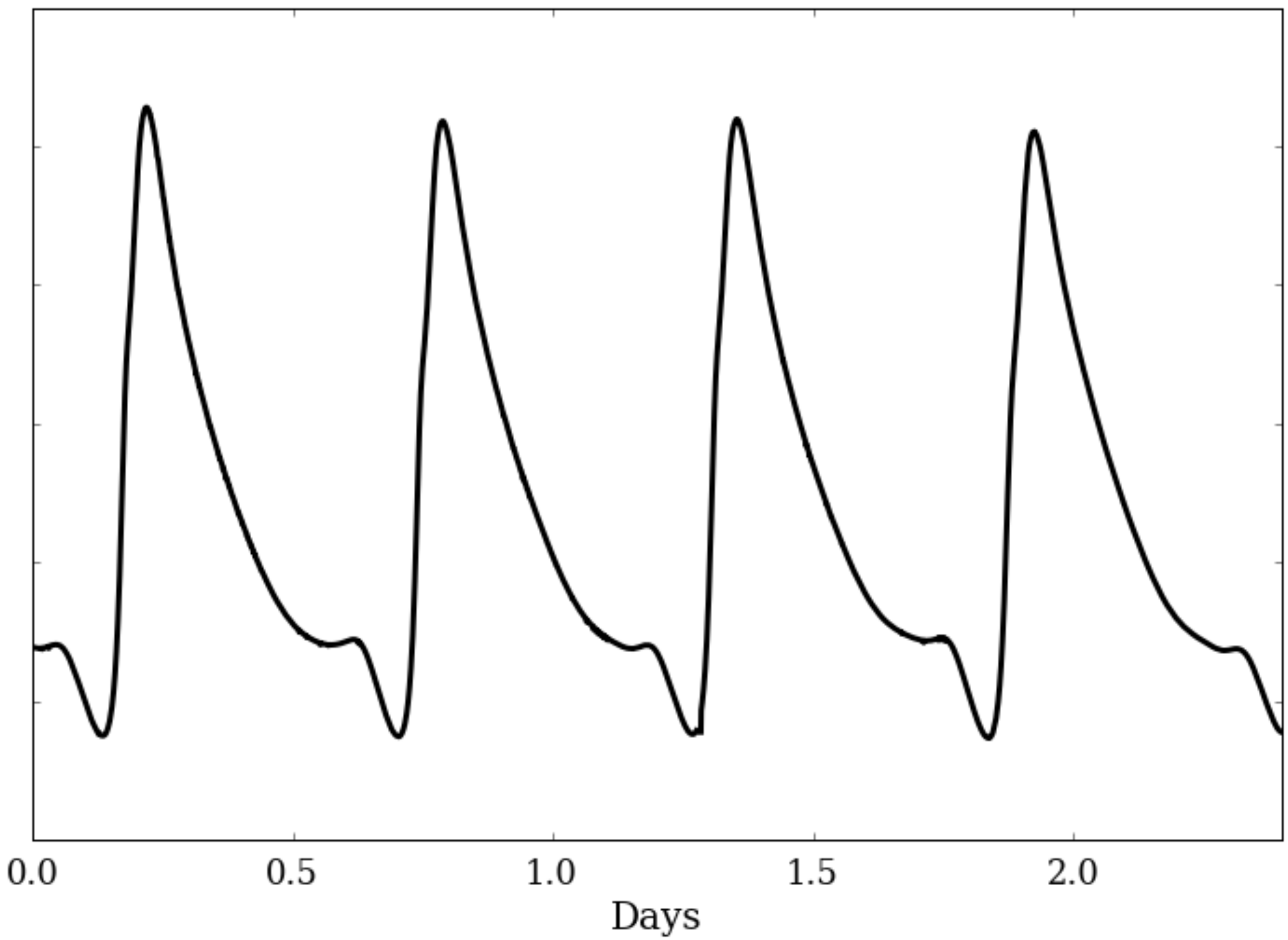
- 42 CCDs
- 2,000 x 1024 pixels each
- 86 Mpixels
- Sub-divded into 84 channels
- 4”/pixel plate scale


Channel 14 - Quarter 14
1 degree



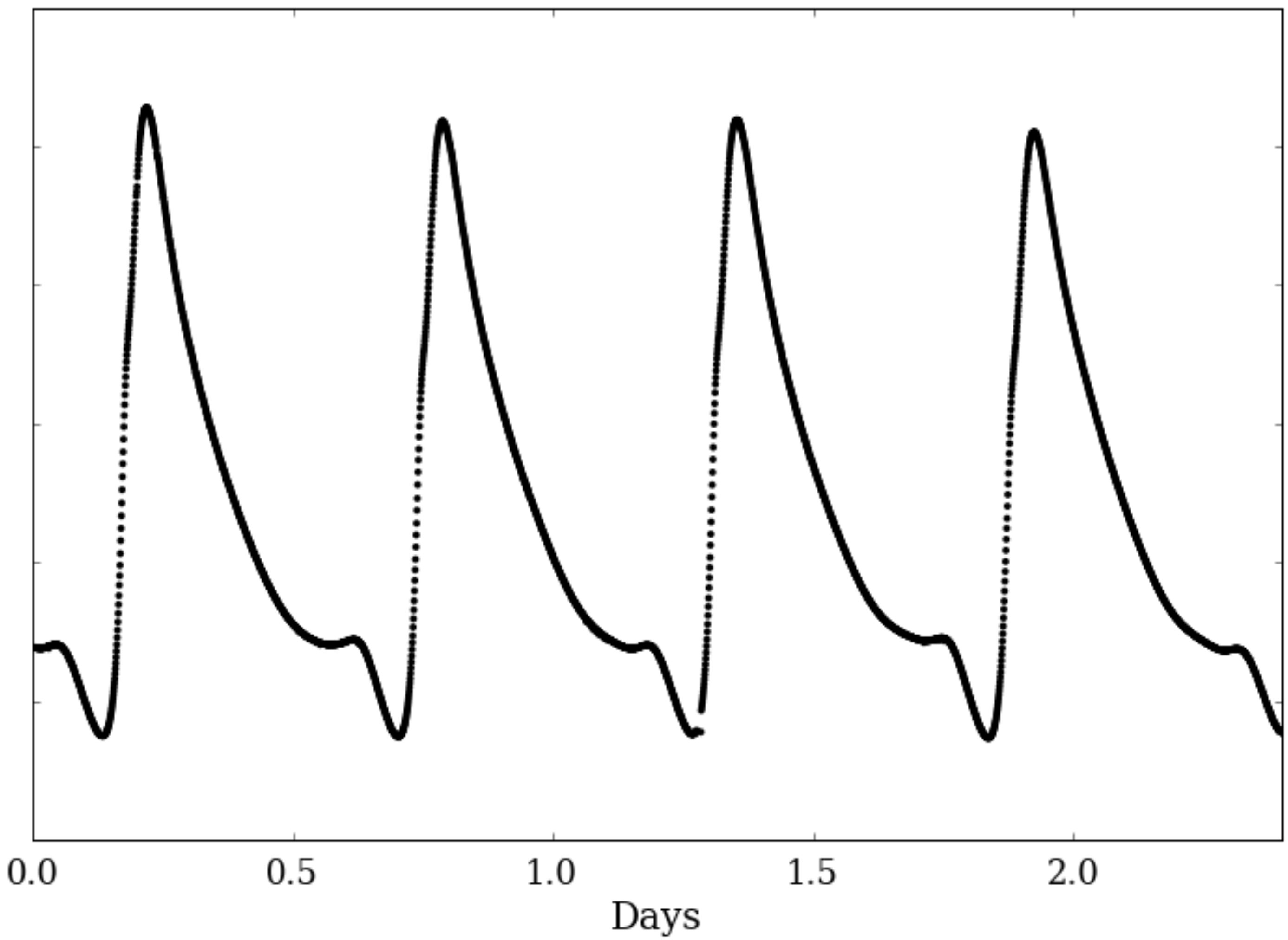
0.0
0.5
1.0
1.5
2.0
Days

RR Lyrae



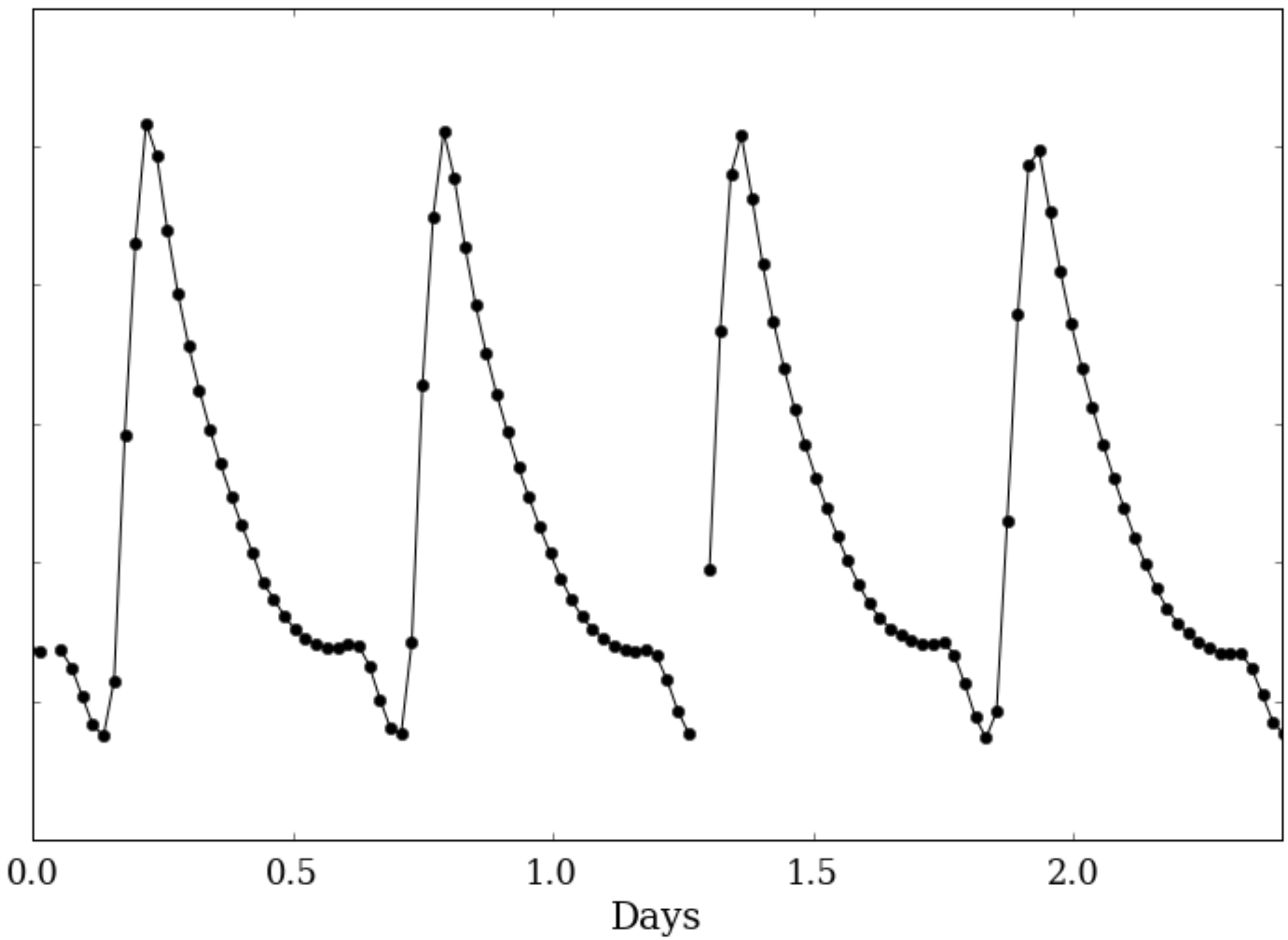
RR Lyrae

1 minute sampling a.k.a. short cadence



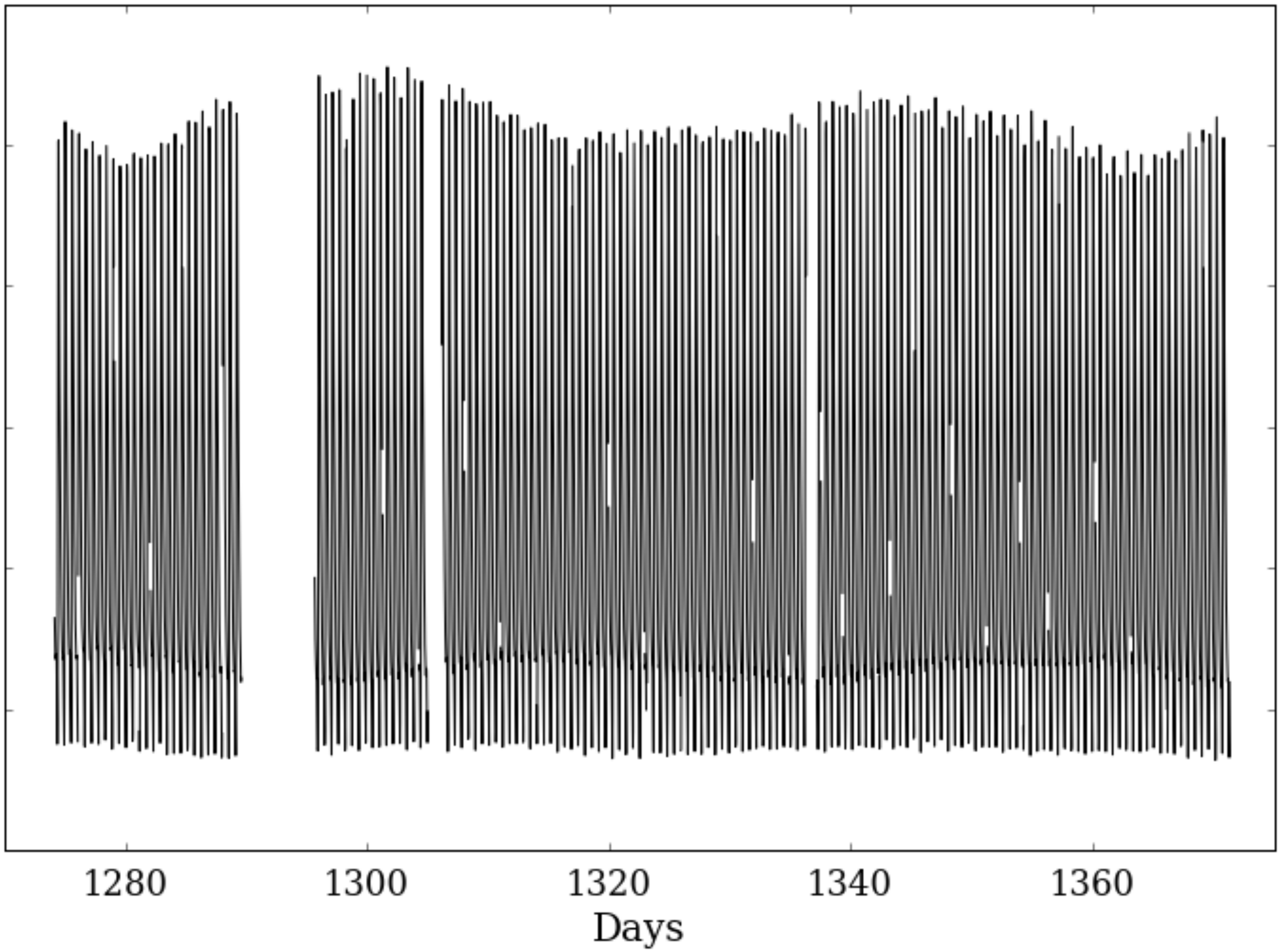
RR Lyrae

30 minute sampling a.k.a. long cadence



RR Lyrae

Long baseline data demonstrates Blazhko effect



Kepler as a Survey

- Unlike SDSS, WISE, etc., each target was imaged 10^3 – 10^6 times
- Kepler Input Catalog (KIC) has basic information on targets in/near FOV
- A separate catalog tells you if (and how much) a target was actually observed
- User then goes and retrieves data for targets

Kepler Input Catalog (KIC)

(Brown et al. 2011, AJ, 142, 112)

- Contains *ugriz, JHK,* and fundamental properties for stars in *Kepler* FOV
- Beware of photometry and parameters! (Pinsonneault et al. 2012, ApJS, 199, 30)
- Each target has a *Kepler* ID (KIC#)
- Planet candidates given additional KOI#
- Not all targets in catalog have data
- Downloadable as an ASCII file
- SQL queryable via CasJobs

Getting the Data

- MAST (archive.stsci.edu) GUI is good for exploring data for a single target
- wget scripts are likely best option for retrieving large amounts of data
- Demo for KIC 8451881

Light Curve Files

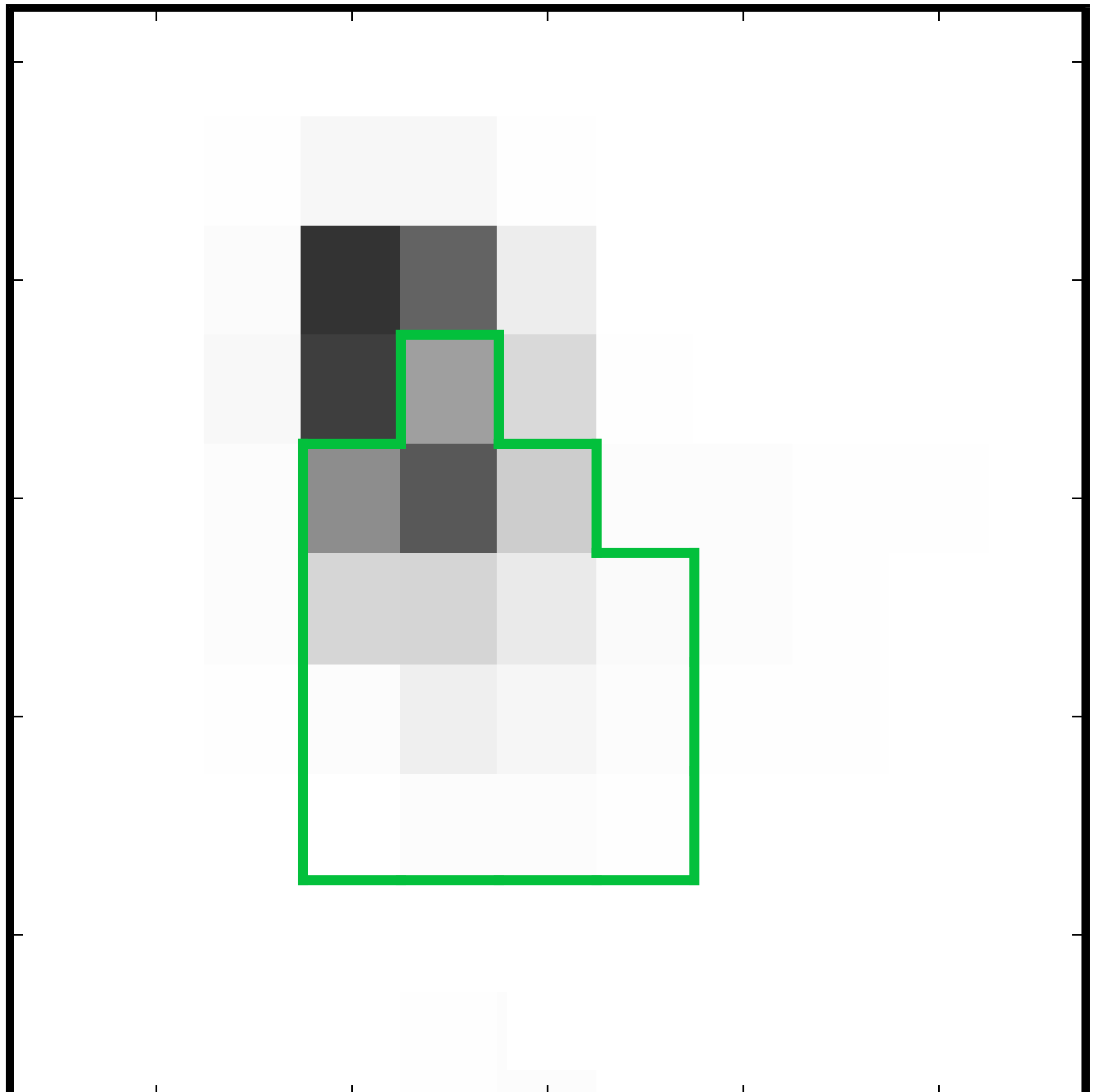
Pros…

- Data already reduced, easy to analyze
- Likely the only data you’ll need for many targets

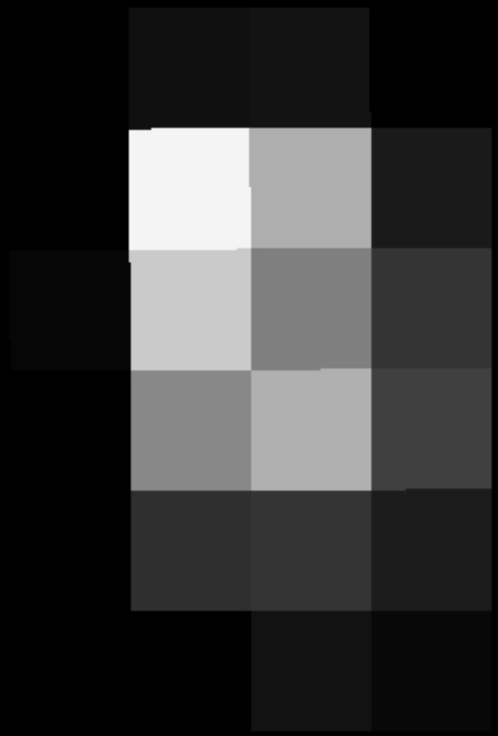
But…

- Beware of systematics
- Look at the target pixel files!

Target Pixel File – KIC 8451881




WIYN 0.9m Image
NOAO Archive - PI: Steve Howell

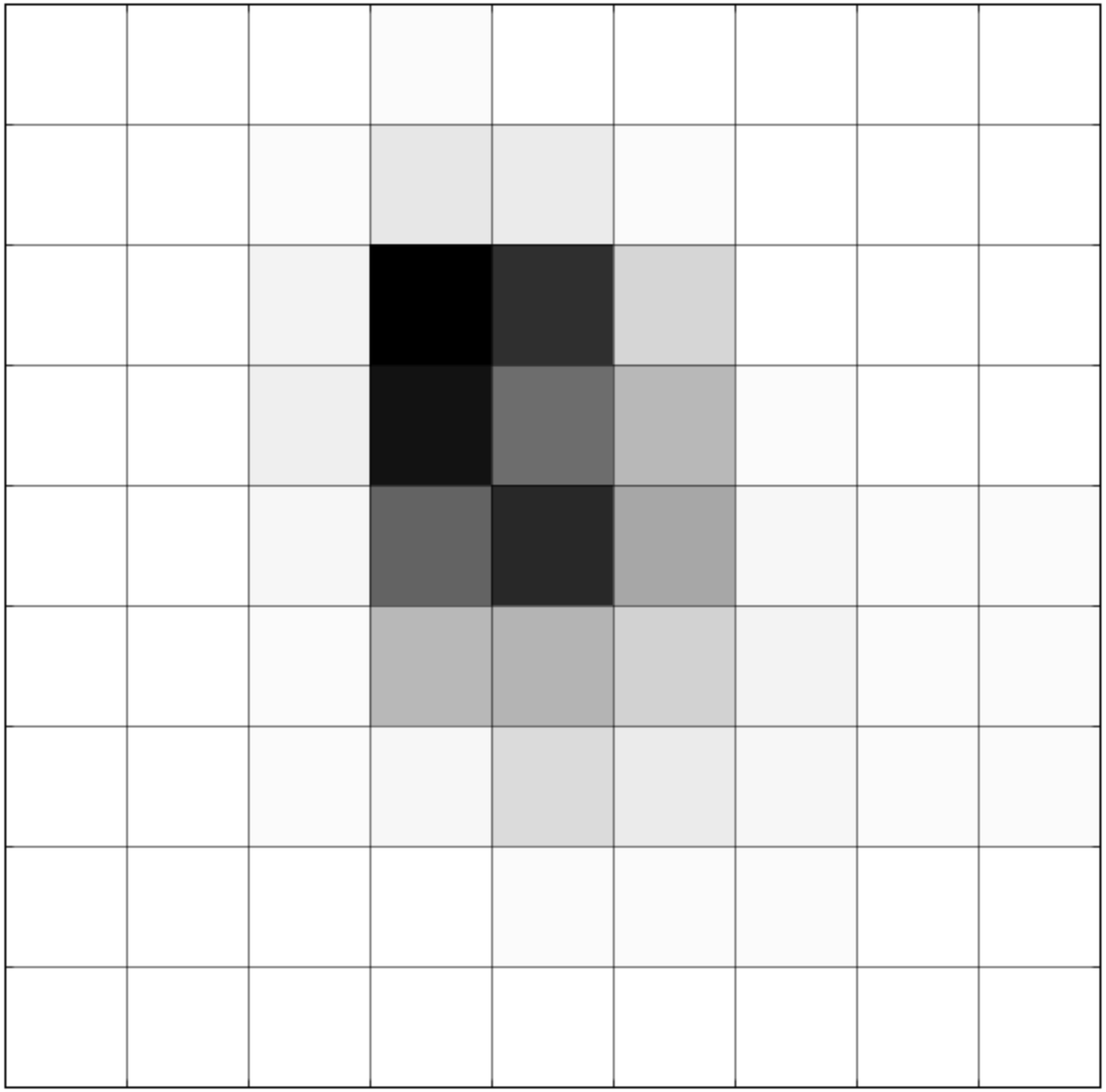


Kepler Image

Pixel Data Reveals Two Signals

A: P_{rot} = 0.26 days

B: P_{rot} = 0.71 days



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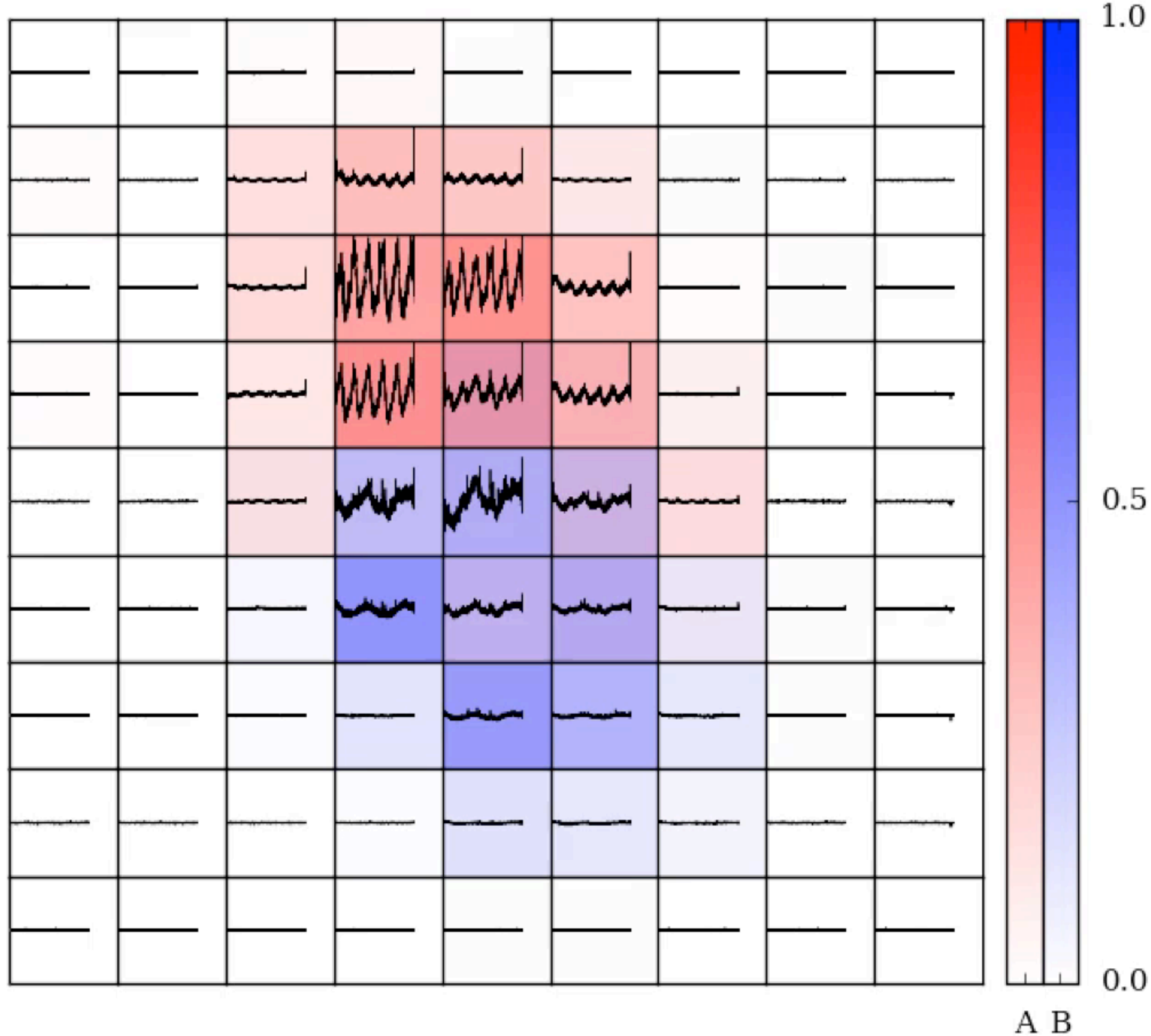

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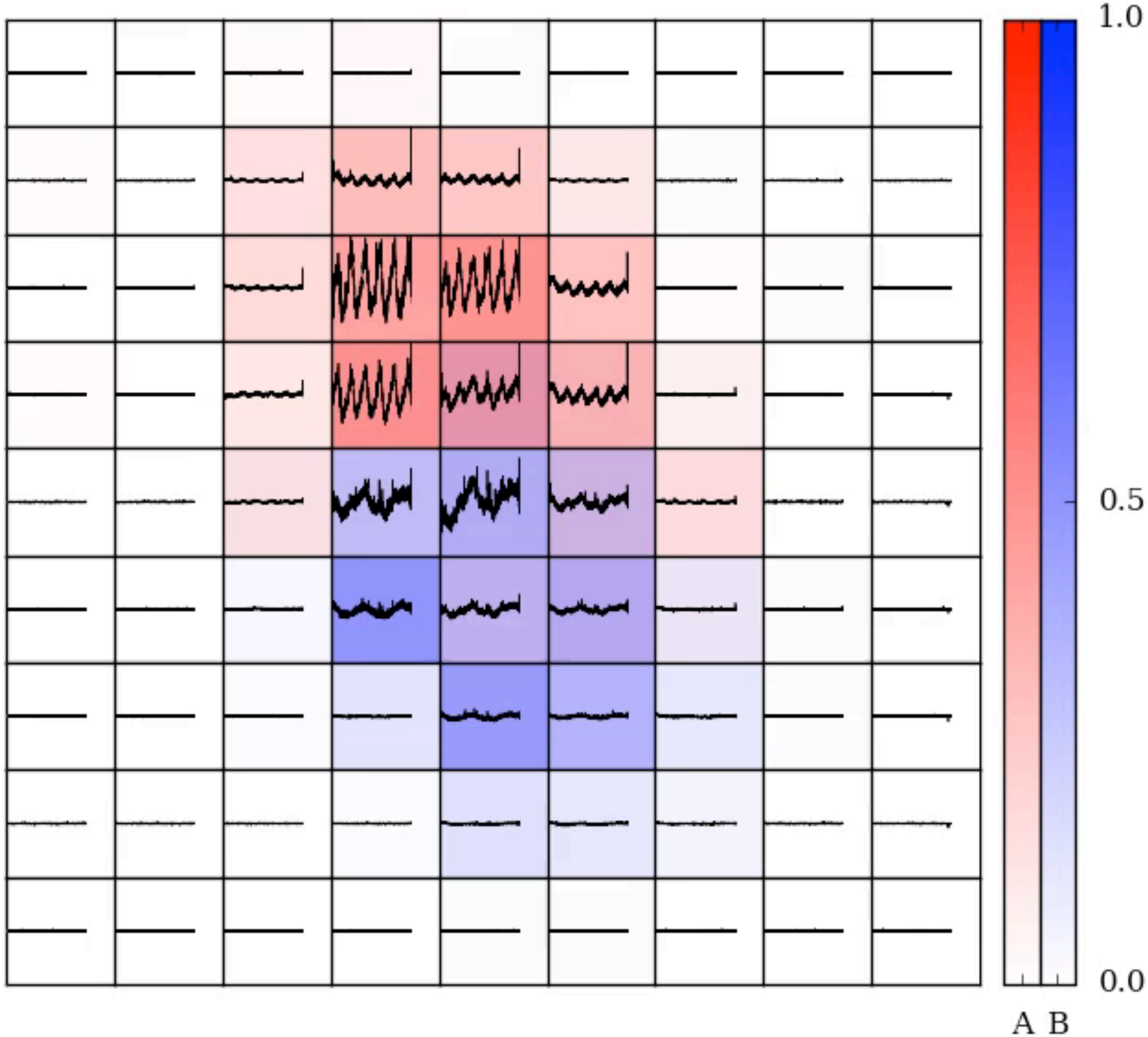
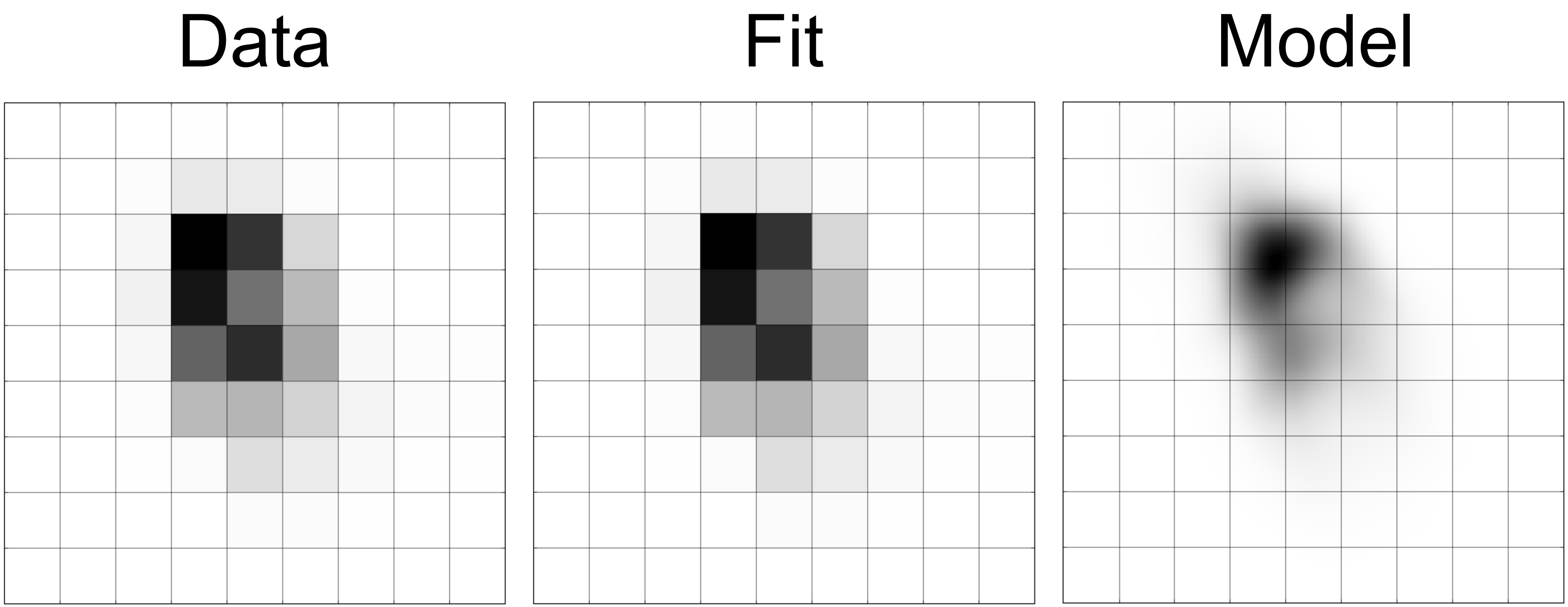
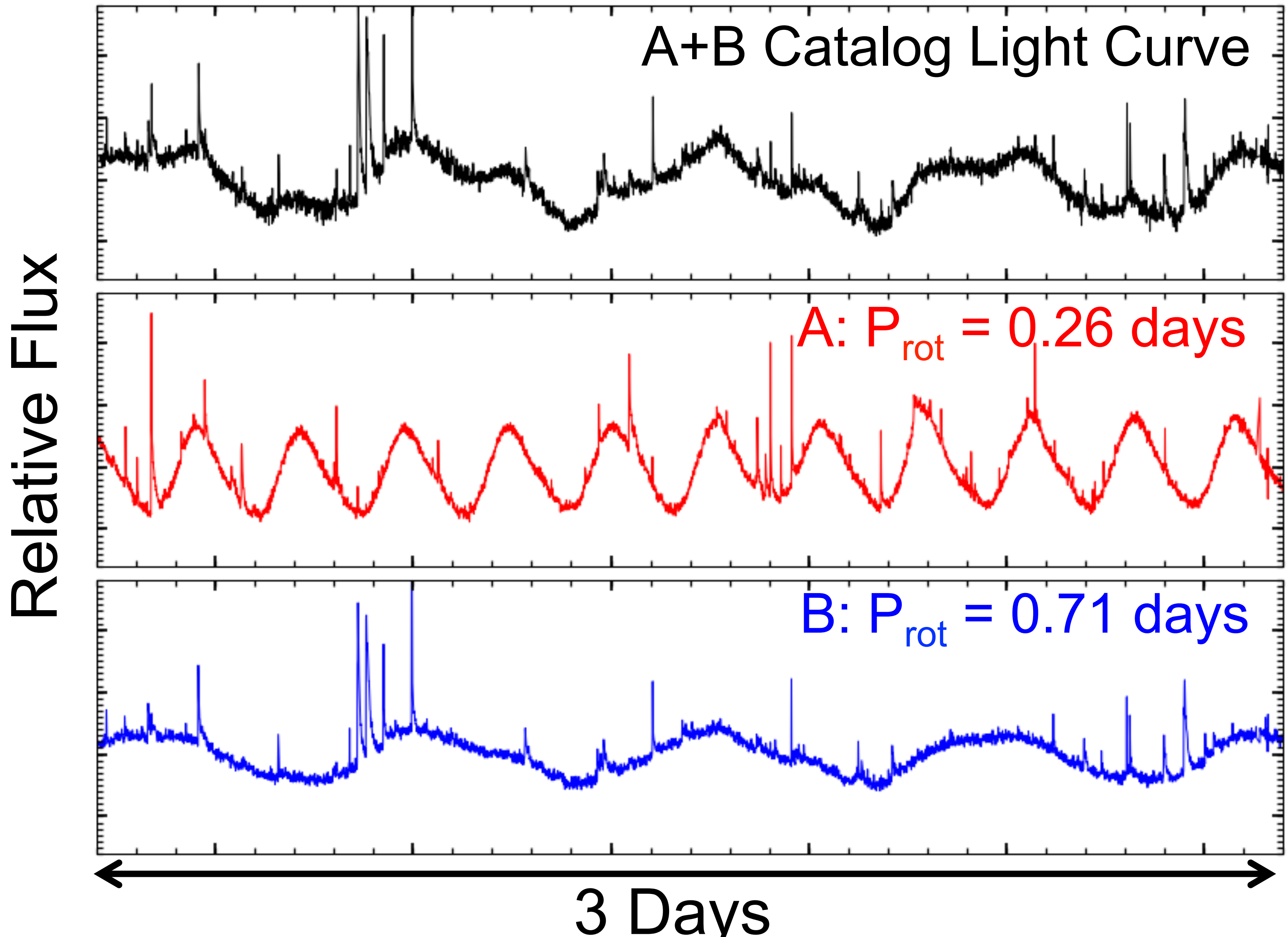


PSF Fit to Pixel Data with PyKE[1]



[1]Still and Barclay (2012)

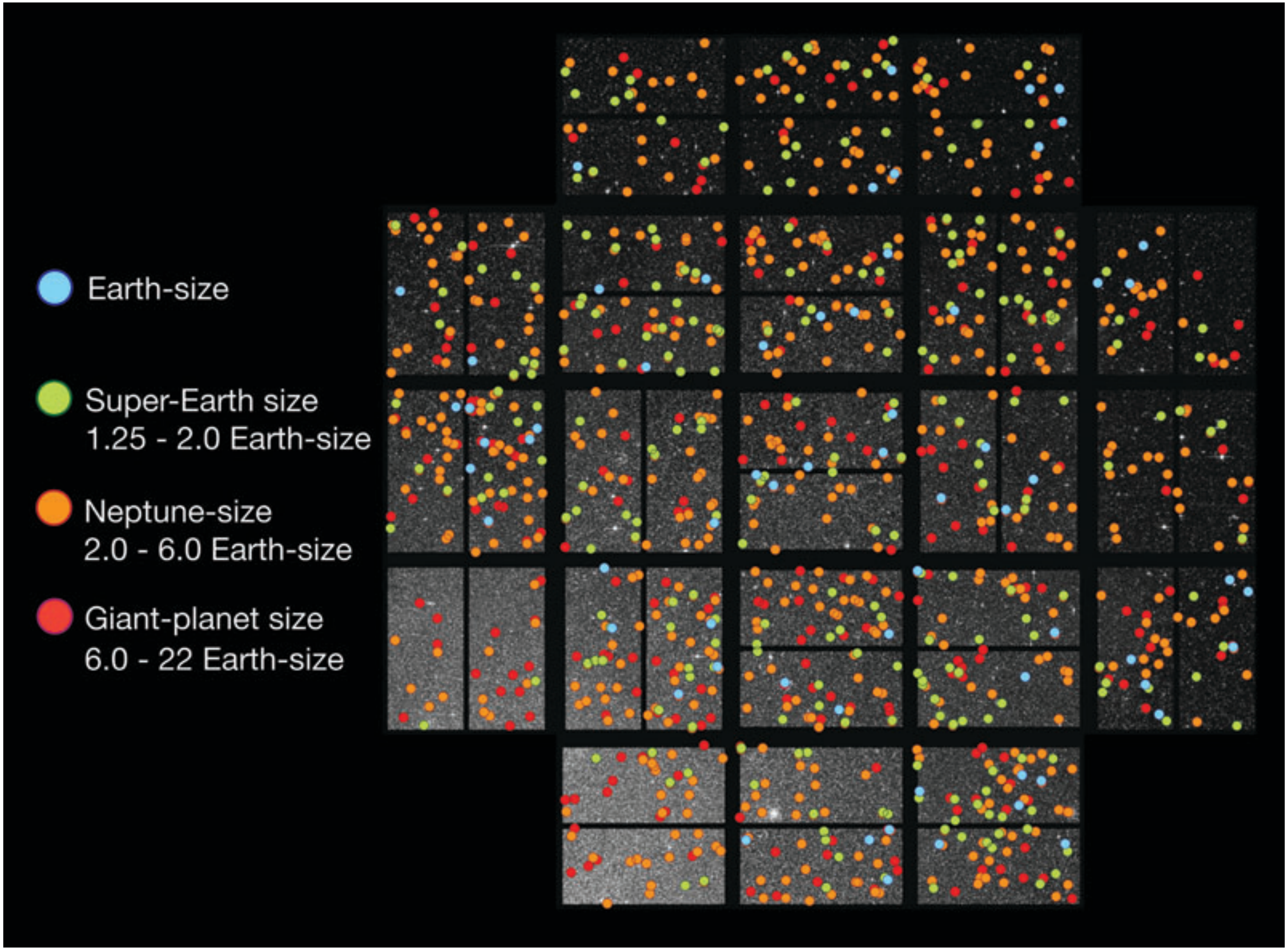
Deconvolved Kepler Light Curves



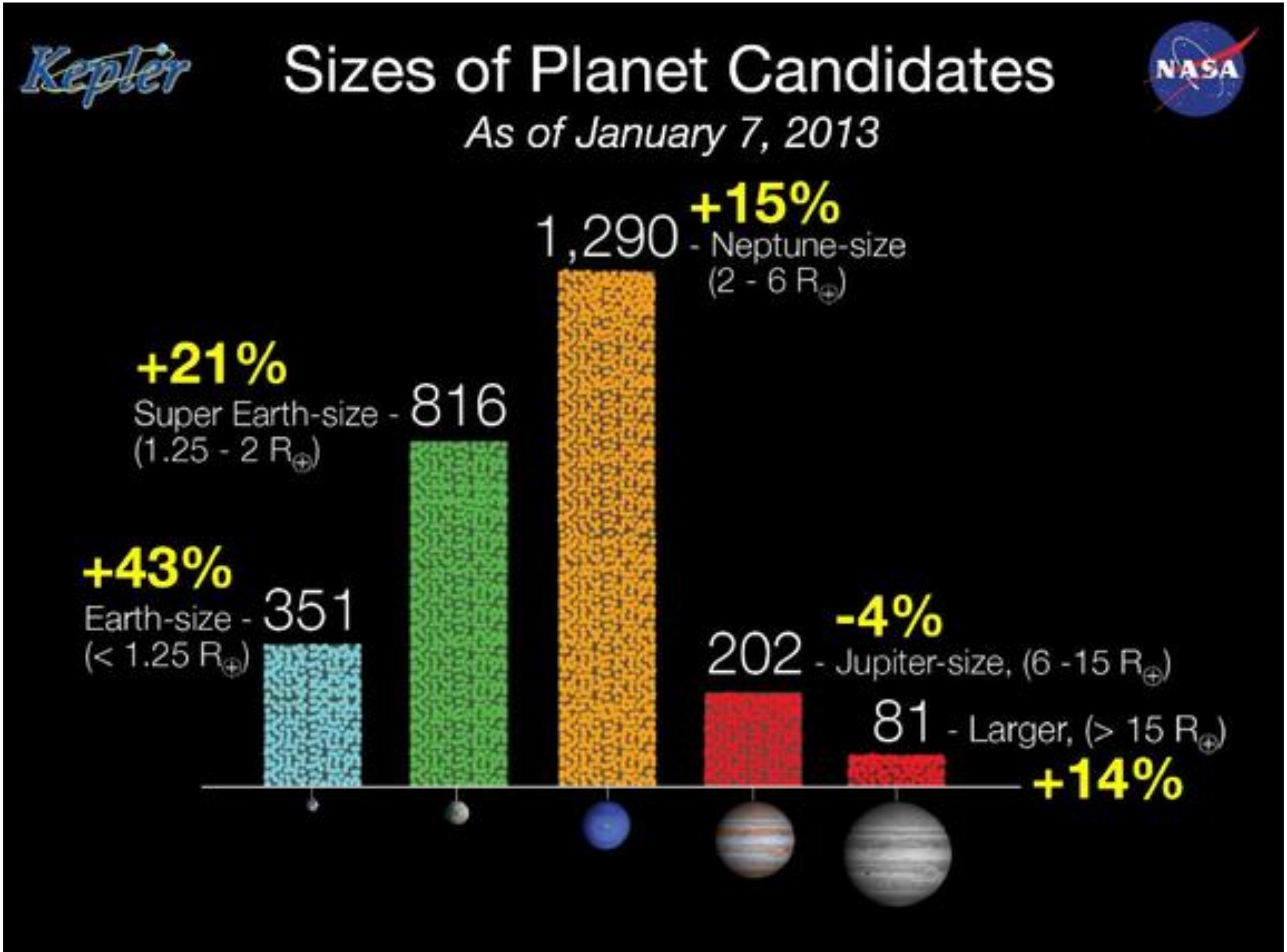
Kepler Science Results

- A boon for exoplanet research
  - occurrence rates, fundamental properties
- Great for stellar astrophysics, too
  - Variables and eclipsing binaries
  - Reinvigorating asteroseismology
  - Magnetic activity
- Extragalactic
  - AGN variability, e.g. Revalski et al. (2014)
- And more…

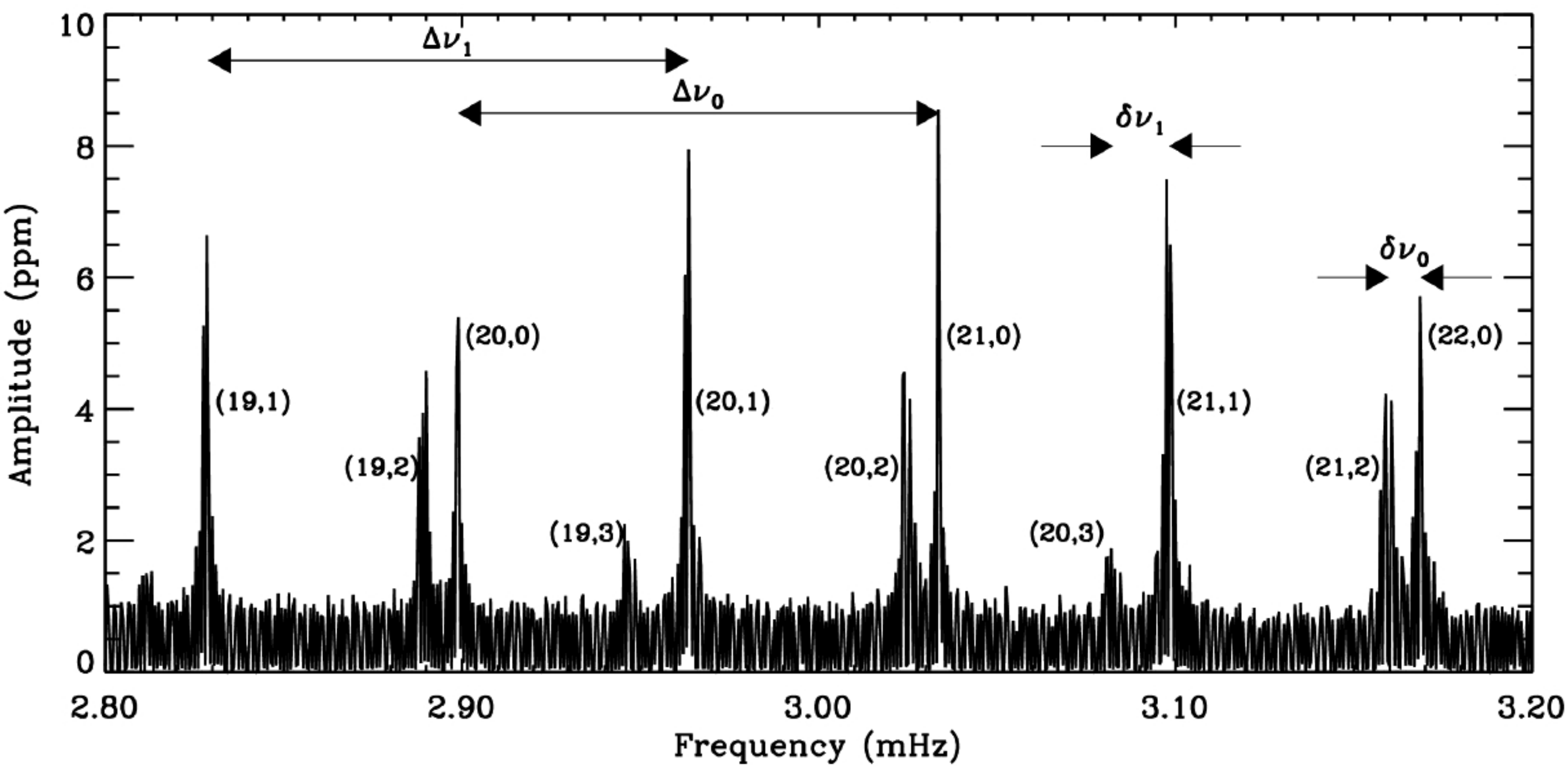
Exoplanets are everywhere!



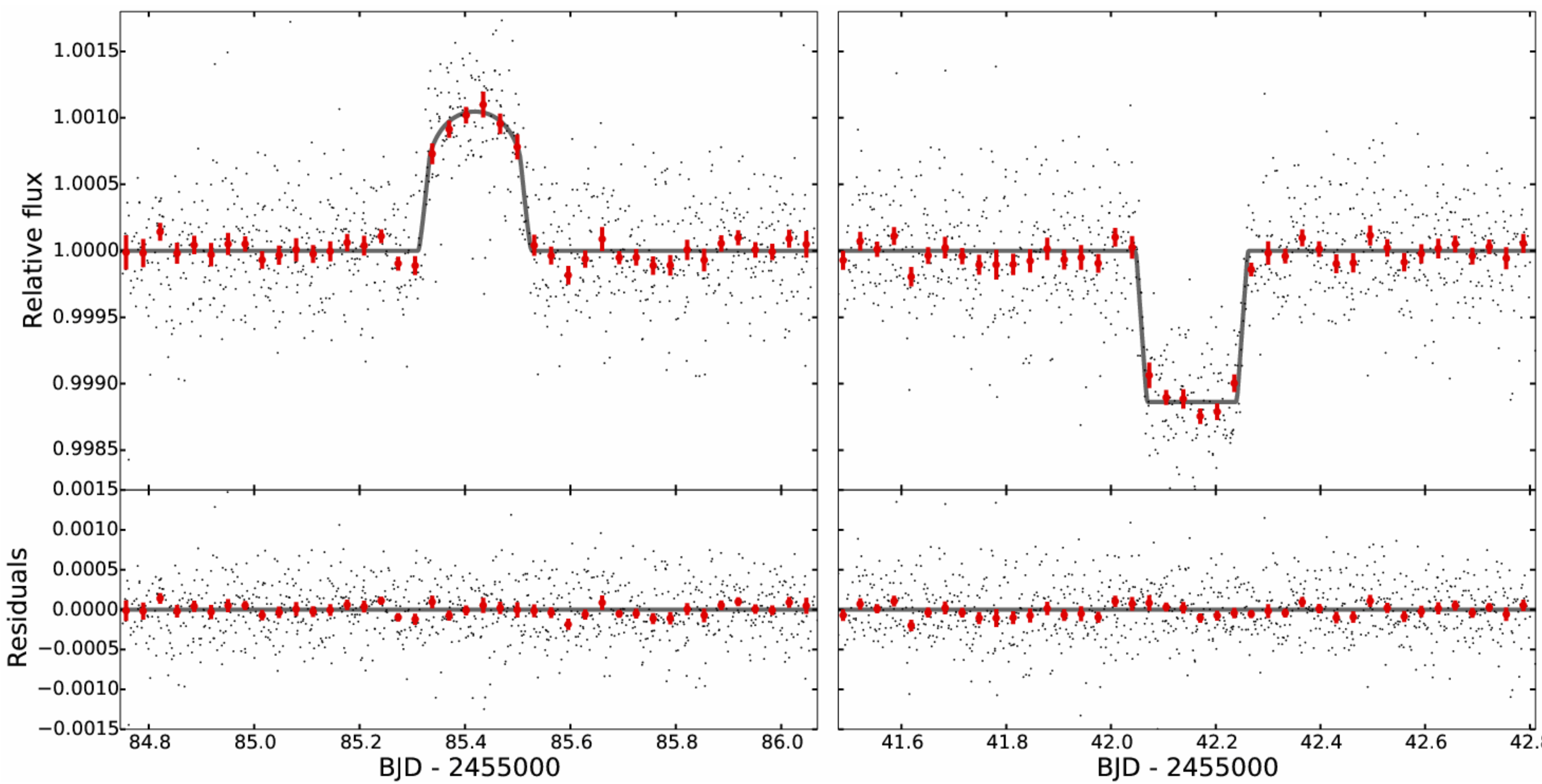
Exoplanets are diverse!



Asteroseismology



Self-lensing Eclipsing Binary



Ethan Kruse and Eric Agol (UW) Science, 344, 275

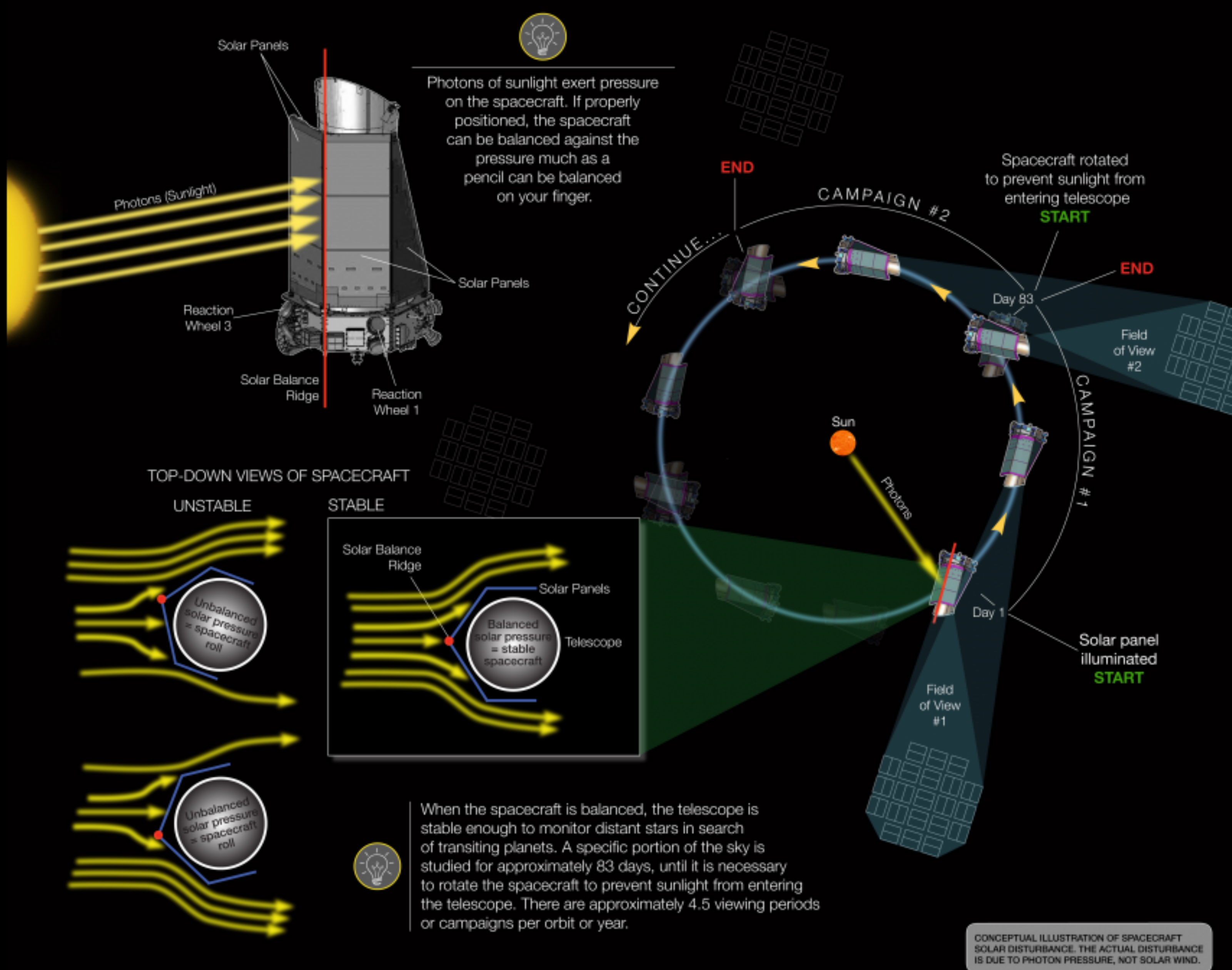
Self-lensing Eclipsing Binary

Ethan Kruse and Eric Agol (UW) Science, 344, 275

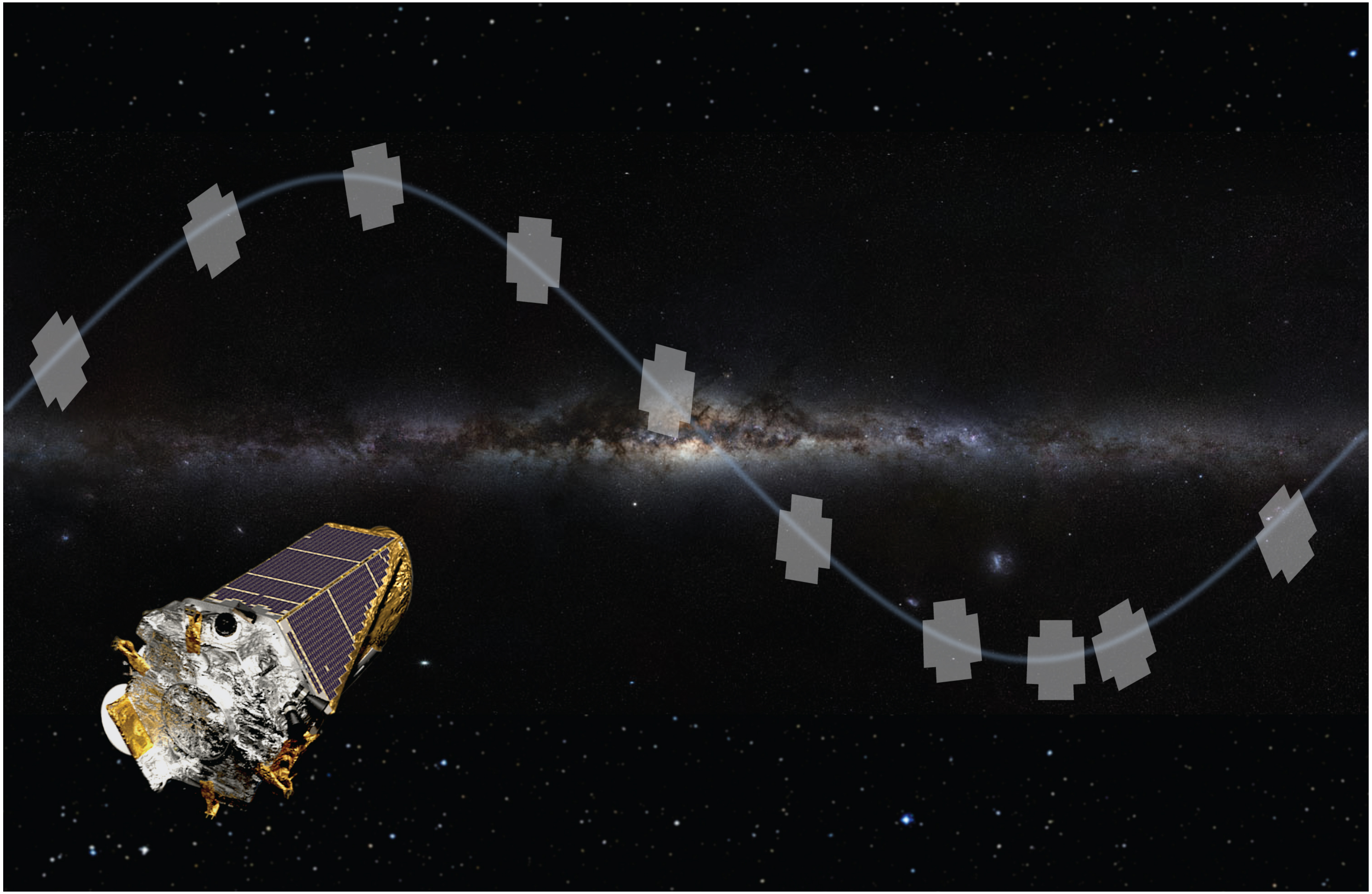
Current Mission Status

- Second of four reactions wheels failed in May 2013
- Telescope could not maintain stable pointing due to solar photon pressure
- Revised mission (K2) looks along the ecliptic
- Opportunities for solar system science
- Fields have a range of galactic latitudes

Kepler's Second Light: How K2 Will Work



K2 Fields



K2 Data and Results

- Reduced photometric precision, but still far better than ground-based
- Campaigns 0 and 1 already available
- Only un-reduced target pixel files
- Many community-based reduction pipelines have been developed
- Several planets already discovered

Summary

- Thanks in major part to *Kepler,* we now believe that most stars have planets, and that planet formation is a ubiquitous part of star formation
- A game-changer for time-domain stellar astrophysics, e.g. asteroseismology
- Caution: Look at the target pixel files!
- New science opportunities with K2