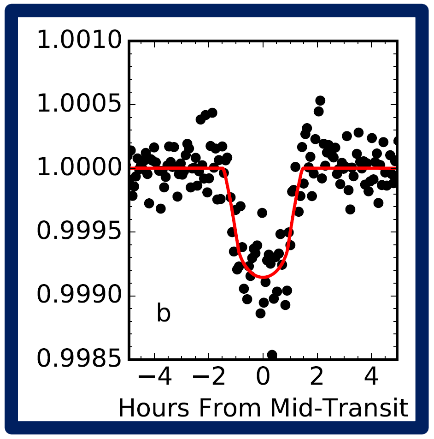
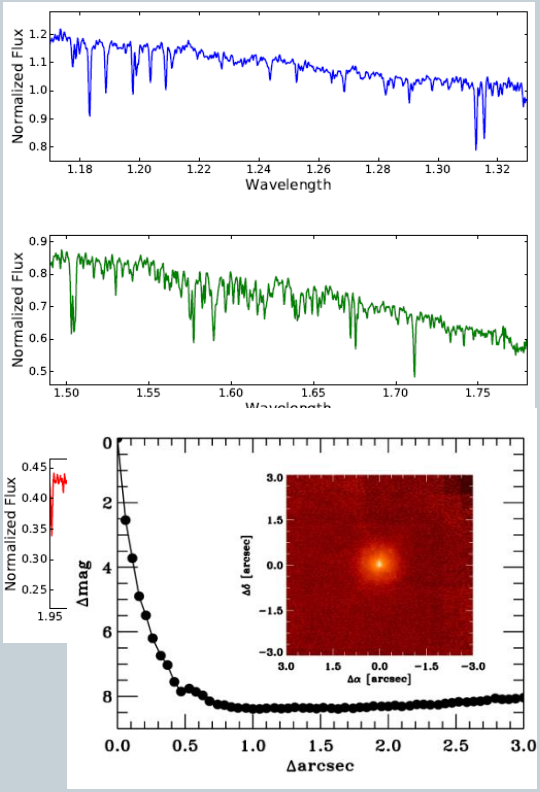
The Kepler Legacy Continues: A Catalog of K2 Planets

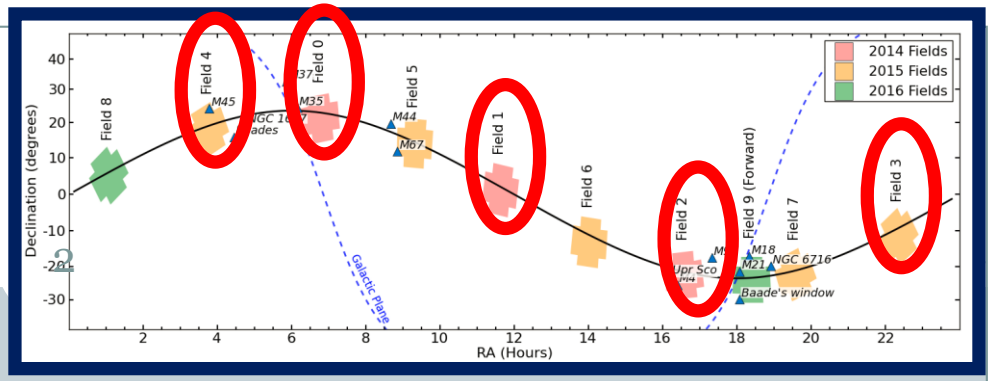
David R. Ciardi
NExScI/Caltech



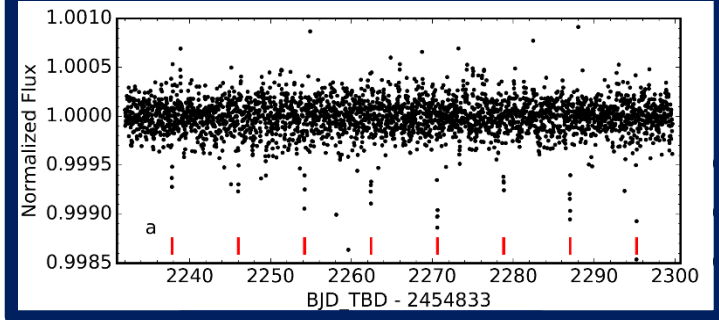
IAN J. M. CROSSFIELD, ERIK A. PETIGURA, EVAN SINUKOFF, **JOSHUA E. SCHLIEDER**, ANDREW W. HOWARD, **CHARLES A. BEICHMAN**, HOWARD ISAACSON, COURTNEY DRESSING, **JESSIE L. CHRISTIANSEN**, BENJAMIN J. FULTON, SEBASTIEN LEPINE, LAUREN WEISS, LEA HIRSCH, JOHN LIVINGSTON, CHRISTOPH BARANEC, NICHOLAS M. LAW, REED RIDDLE, CARL ZIEGLER, STEVE B. HOWELL, ELLIOTT HORCH, MARK EVERETT, JOHANNA TESKE, ARTURO O. MARTINEZ, CHRISTIAN OBERMEIER, NIC SCOTT, KIMBERLY M. ALLER, BRAD M. S. HANSEN, LUIGI MANCINI, SIMONA CICERI, RAFAEL BRAHM, ANDRES JORDAN, BJORN BENNEKE, HEATHER A. KNUTSON, THOMAS HENNING, MICHAEL BONNEFOY, MICHAEL C. LIU, JUSTIN R. CREPP, JOSHUA LOTHRINGER, PHIL HINZ, VANESSA BAILEY, ANDREW SKEMER, DENIS DEFRERE

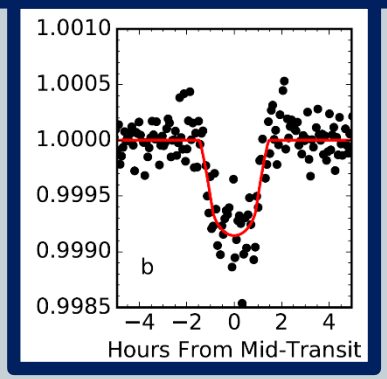


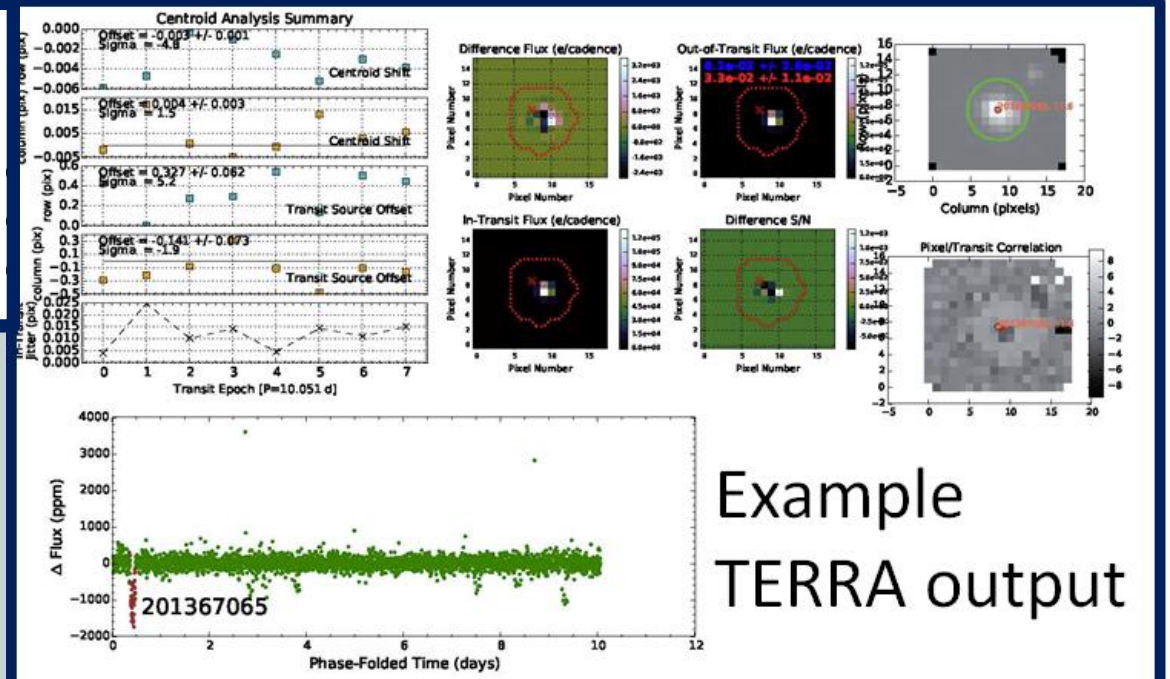
Campaigns 0 – 4:



- Adaptation of TERRA pipeline
- 196 Candidate Planets → 104 Confirmed Planets
- 46 Planets in multi-planet systems
- 68 Candidates; 24 False Positives

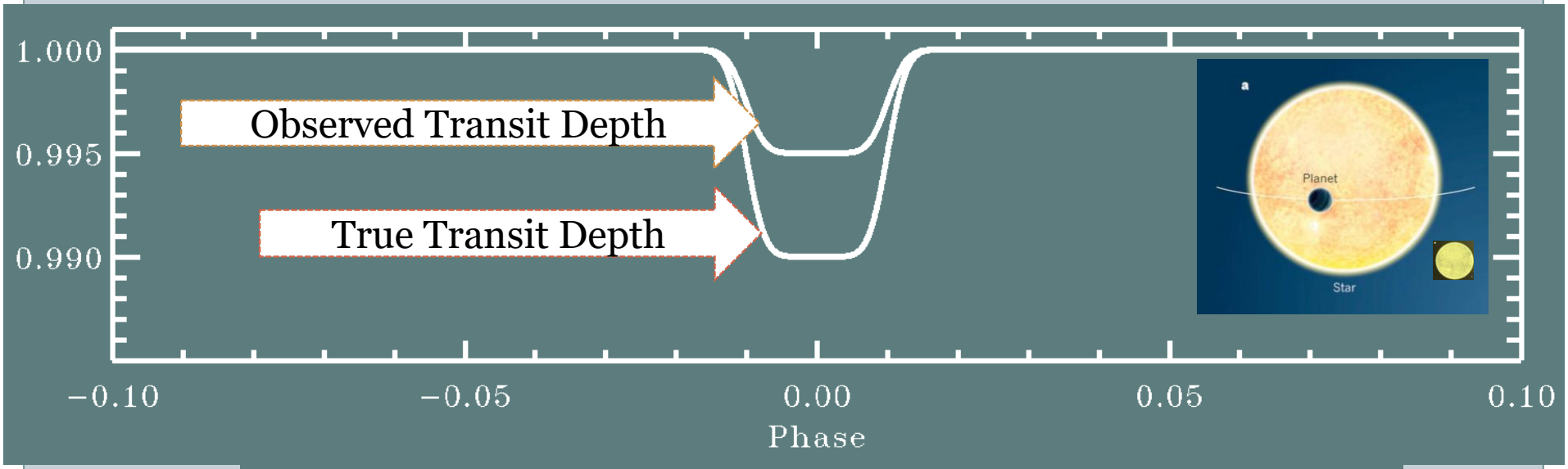






Example TERRA output

Good Planet Radii Require Good Stellar Radii and a Good Understanding of the Photometric Blending



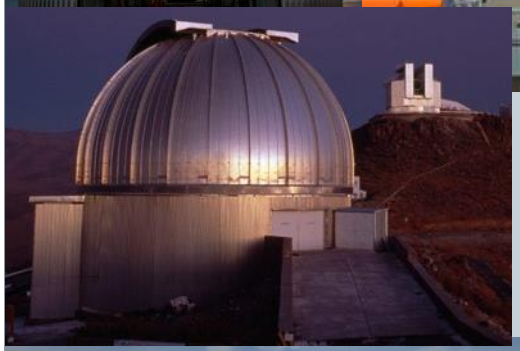
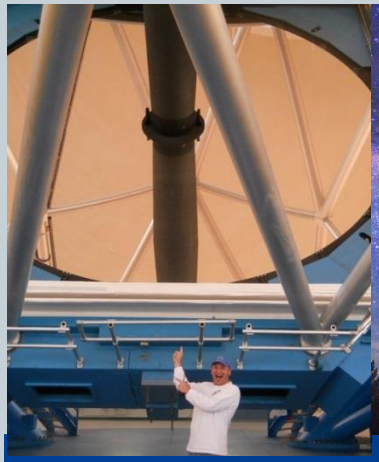
$$\delta_o = \left(\frac{F_t}{F_{total}}\right)\left(\frac{R_p}{R_{t\star}}\right)^2$$

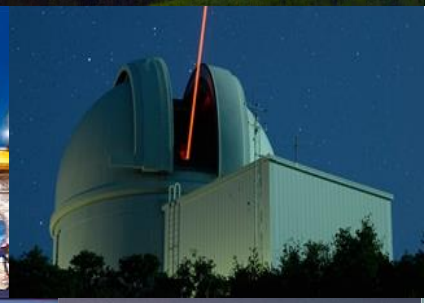
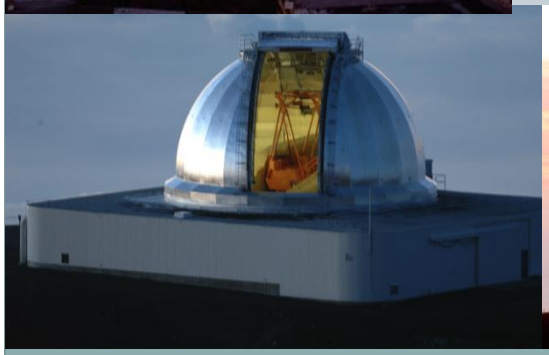
Establishing A Follow-Up Program

- All K2 Candidates need additional support observations to validate the candidacy of the planets
- Spectroscopy
  - Determine stellar parameters
    - Teff, log(g), [Fe/H] → Stellar Radius (R_*) → Planet Radius (R_p)
  - Determine if host stars are binaries (double-lines and RV variation)
  - Establish good candidates for radial velocity follow-up
- Imaging
  - Determine if there any stars within the K2 photometric aperture – correct the measured transit depths
  - Determine if the stars are binaries
- Radial Velocity for select set of candidates for masses

A Large Number of Telescopes

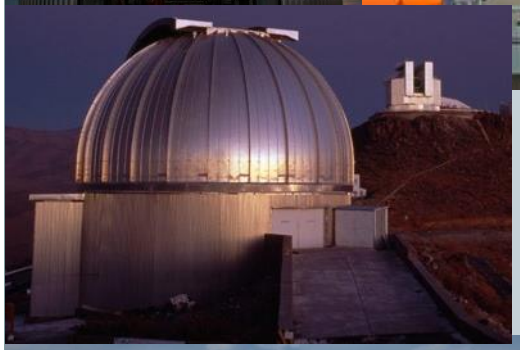


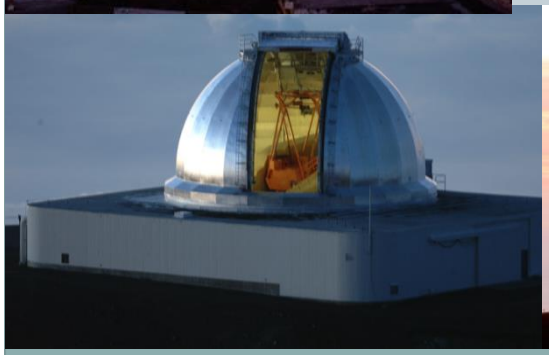




Imaging →
← Spectroscopy

A Large Number of Telescopes – Spectra





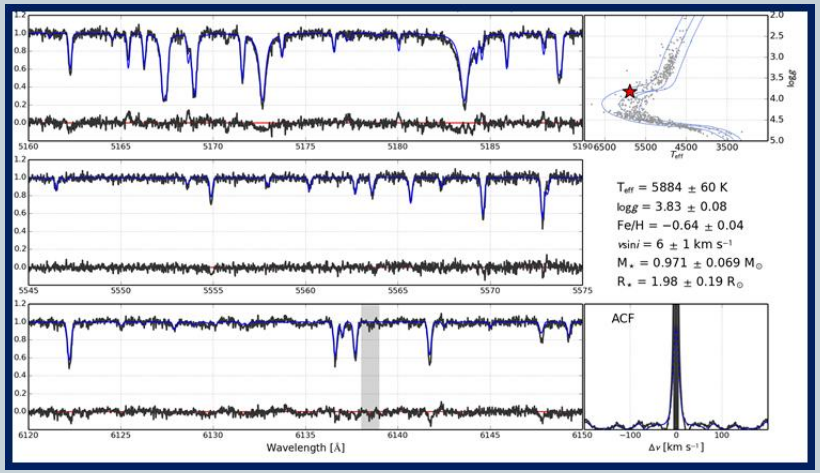
Imaging →

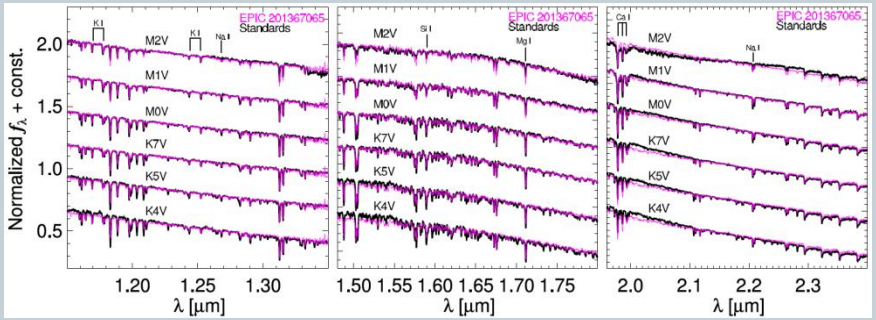
← Spectroscopy

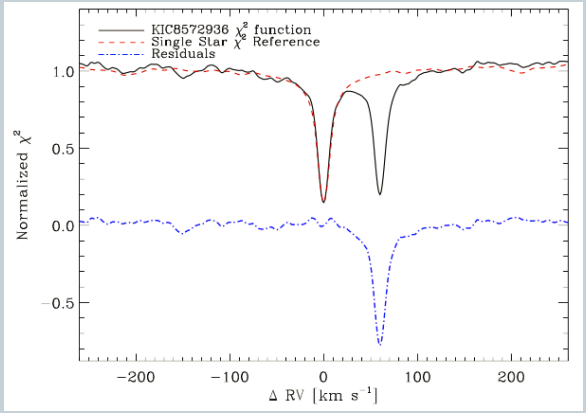
- Keck HIRES
- APF
- IRTF SPEX
- NTT SOFI
- ESO 2.2m FEROS
- Palomar Triplespec
- Palomar Doublespec

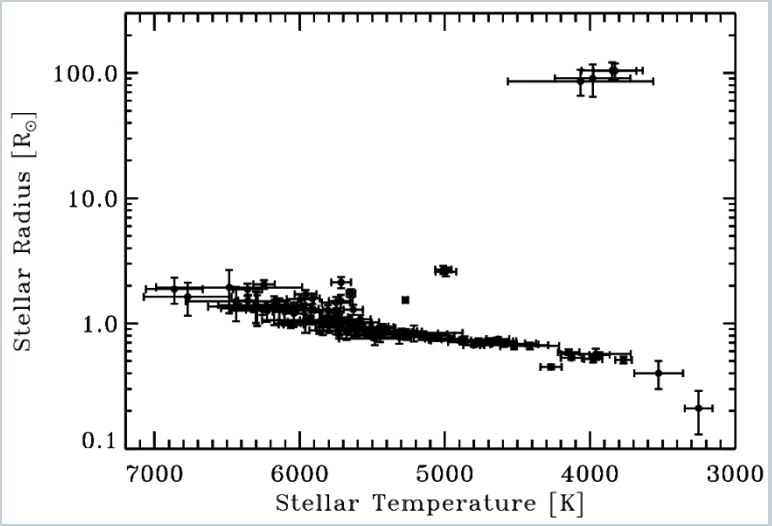
A Large Number of Telescopes – Spectra

- Spectra are fit to templates and isochrones to derive stellar parameters
- Search spectra for lines secondary lines





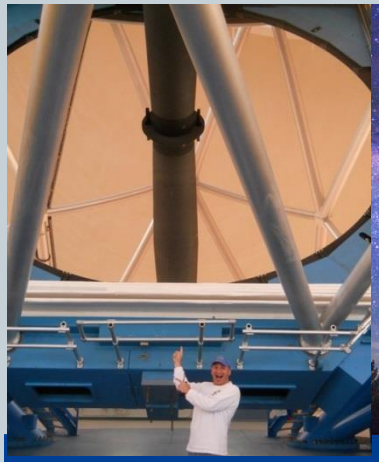


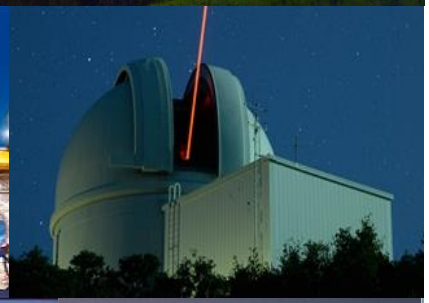


A Large Number of Telescopes – Imaging

- Keck NIRC2
- Palomar 200” PHARO
- LBT LMIRCam
- Gemini-N NIRI
- Gemini-N/S Speckle
- Gemini-S GNIRS Imaging →
- Robo-AO

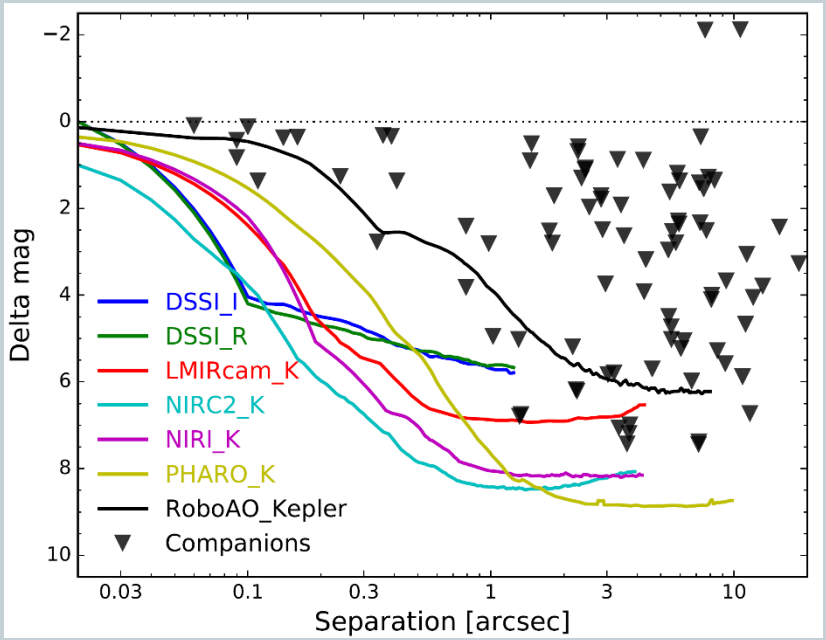
← Spectroscopy

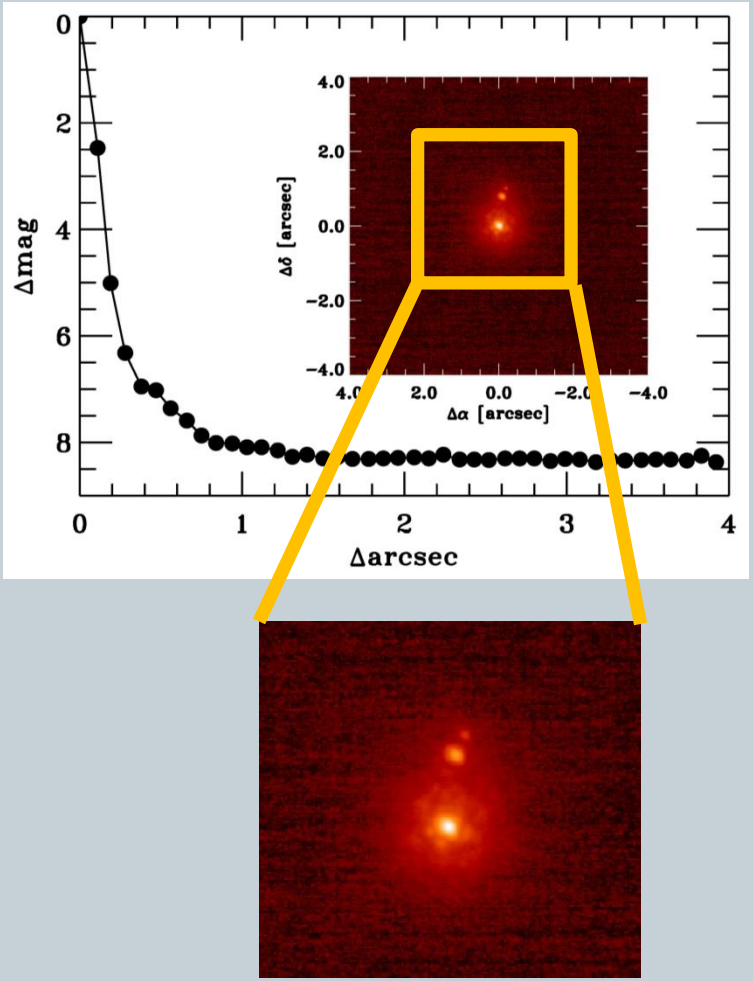



A Large Number of Telescopes – Imaging

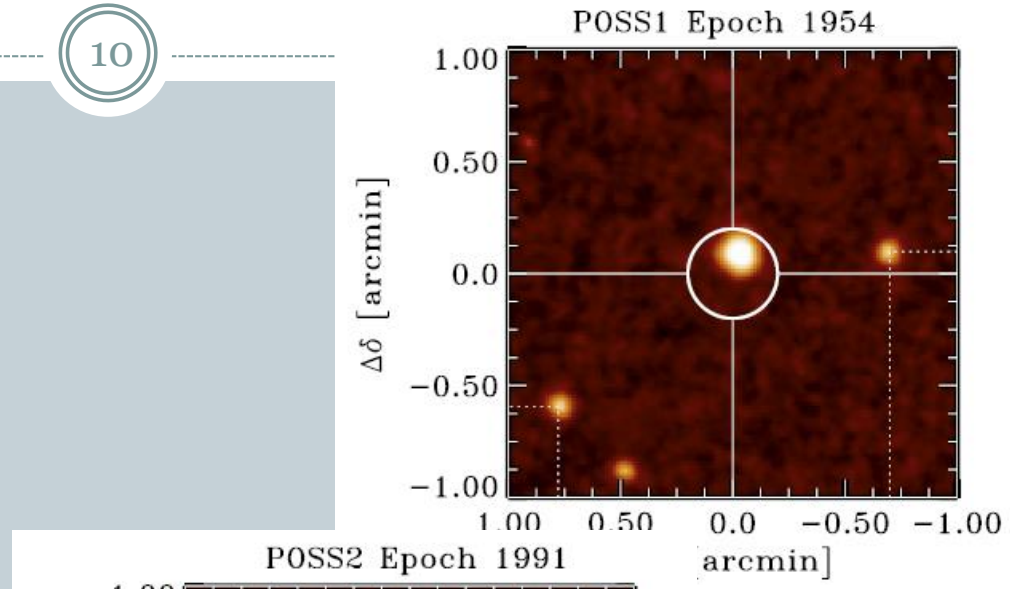
- Resolution: 0.05” – 0.2”
- Sensitivity: Δm = 5 – 10 mag
- ~25% of K2-candidates show companion with in 10”

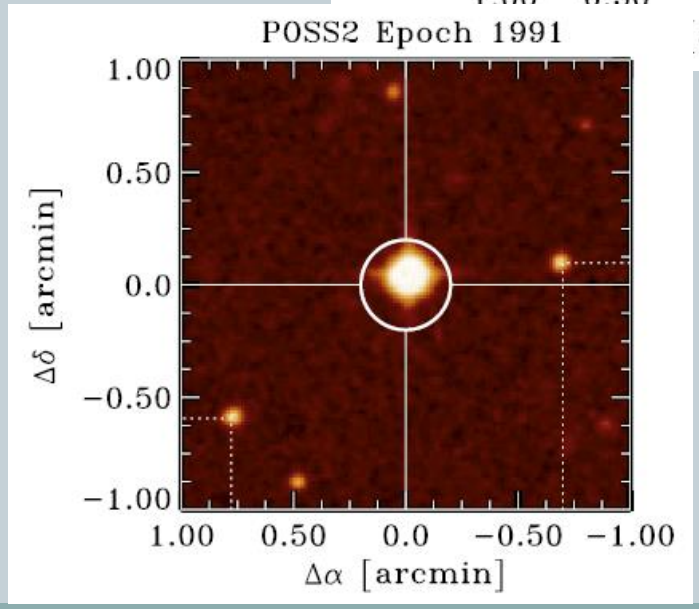




Proper Motion Finds 'Hidden' Background Stars

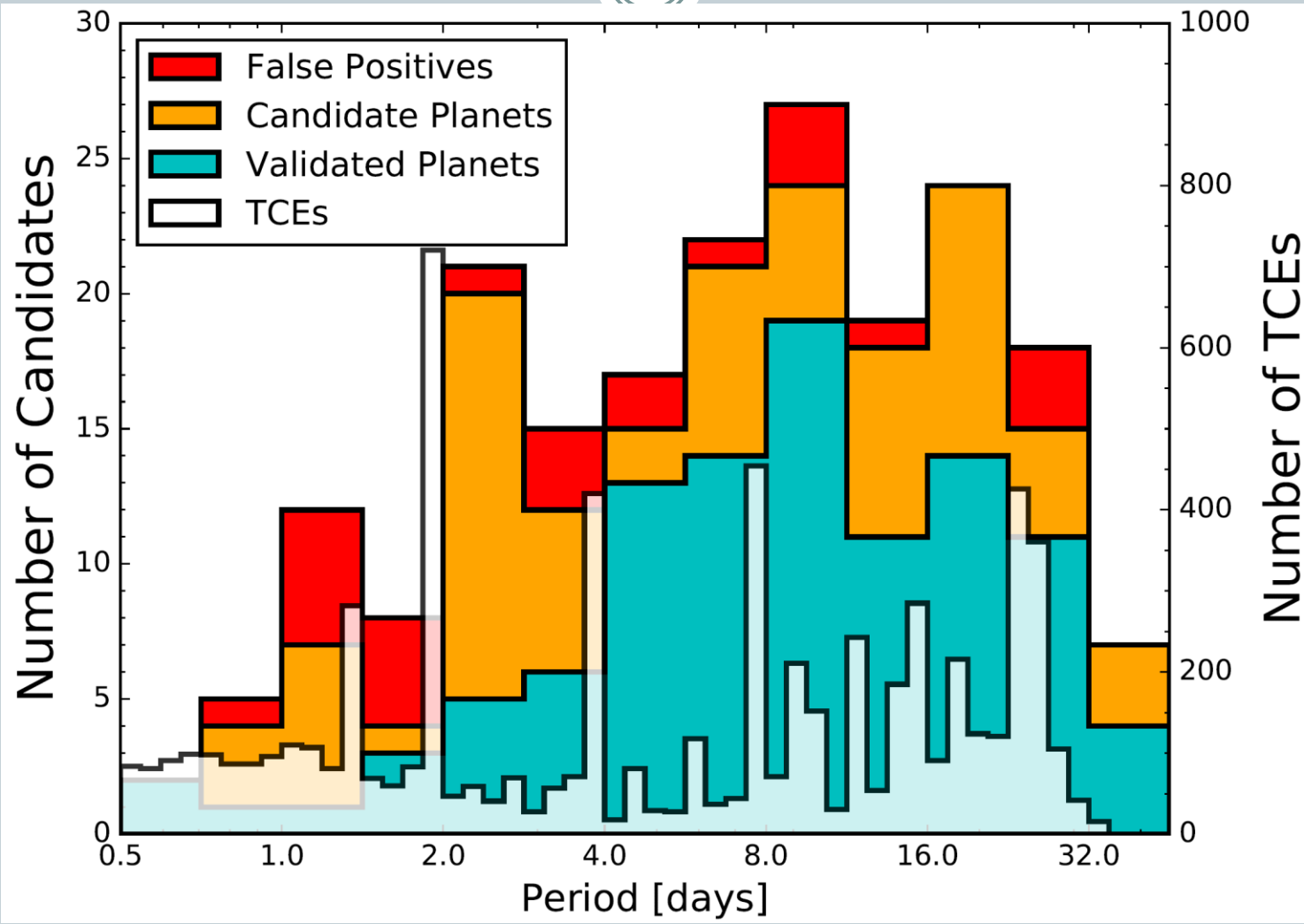
- K2 targets are often close with large proper motions
- Archival image data can be searched for background stars hidden today (even with high resolution)





K2-21
3" motion
in 37 years

Candidate Rates Similar to Kepler

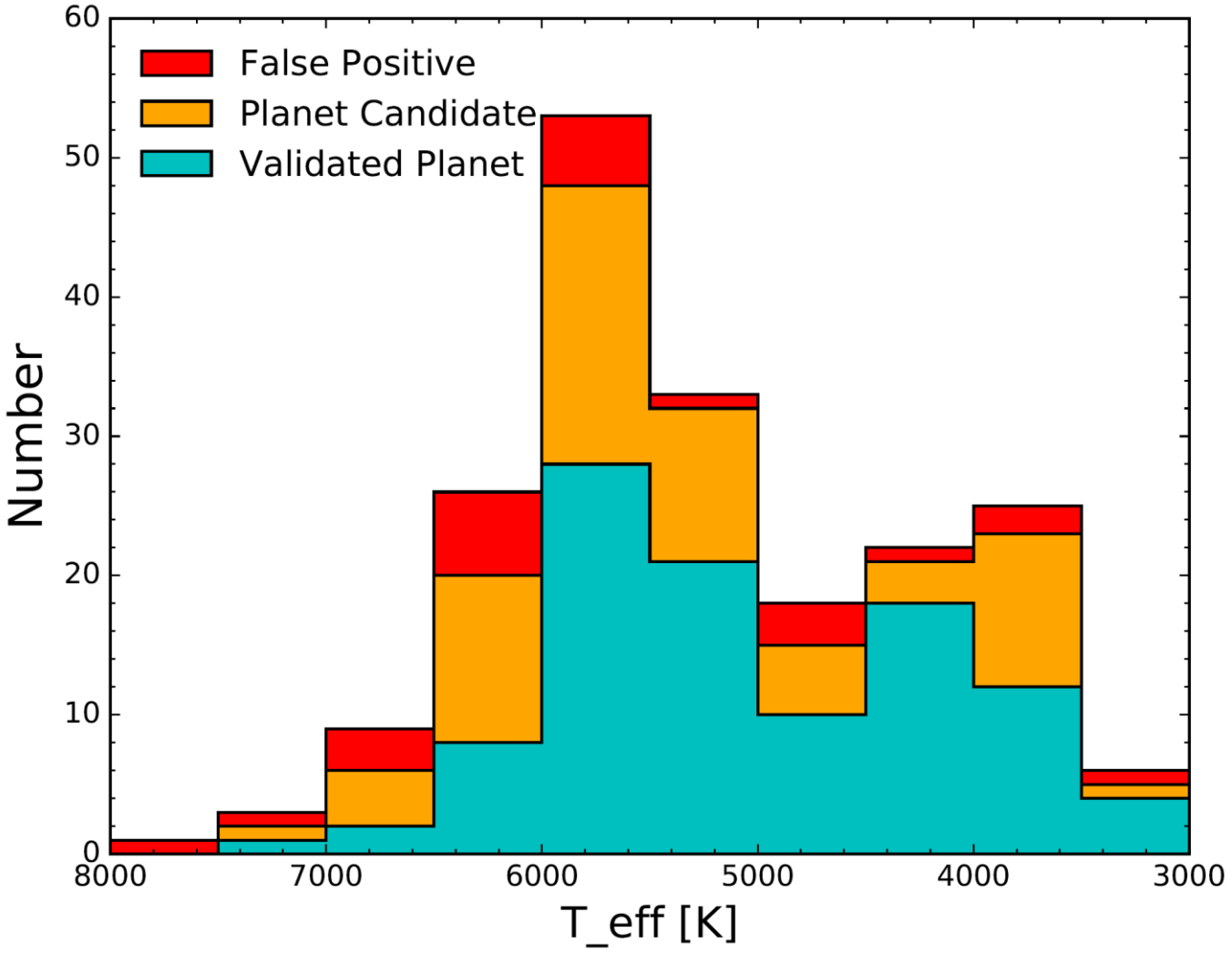


False – Positive Rates Similar to Kepler

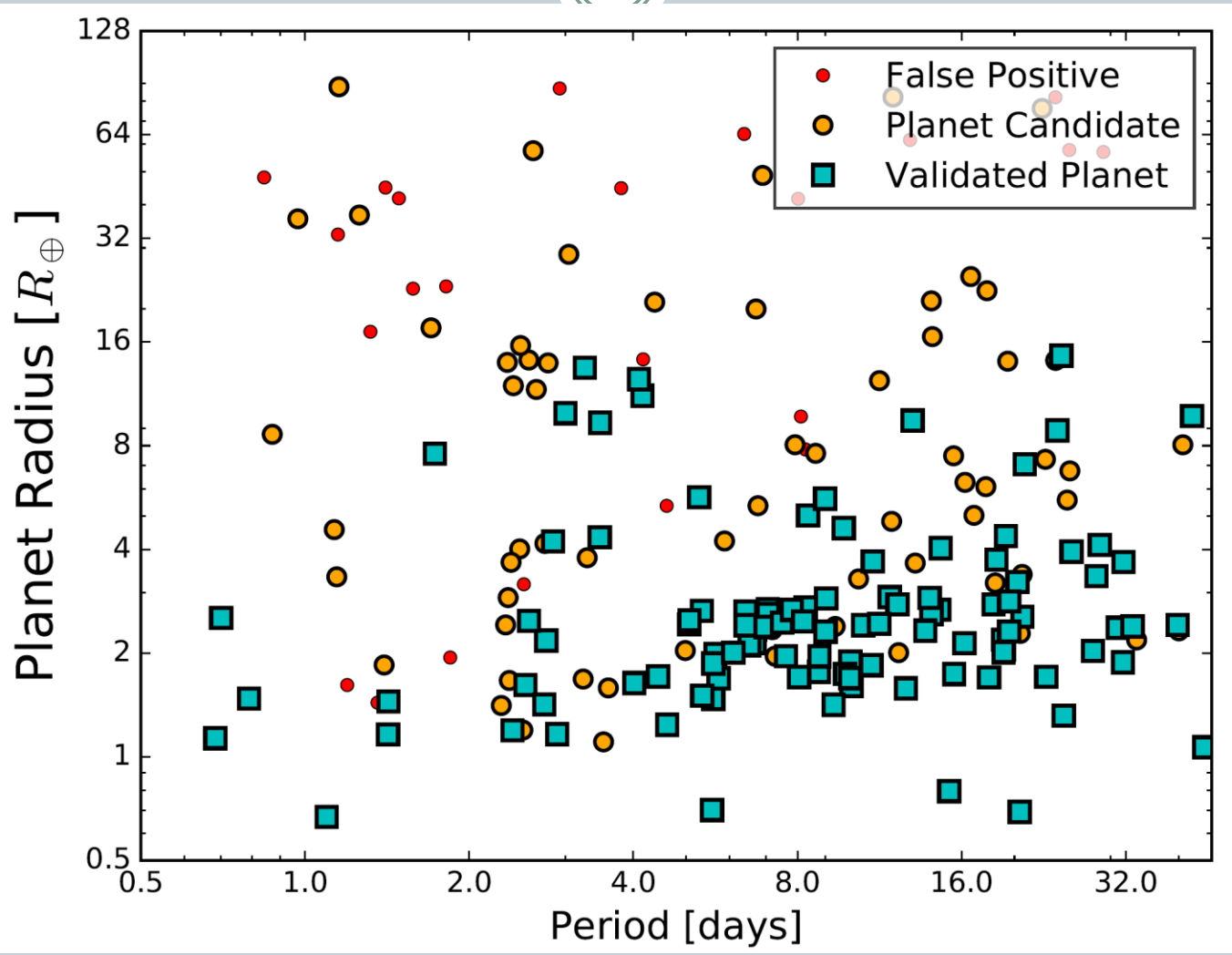
- Largest and Shortest Period candidates
  - Eclipsing Binary blends
- FP rate mostly independent of
  - Star brightness
  - Stellar properties
  - Candidate size (after the largest planet category)

Category	FP Rate
$R_P \leq 2R_\oplus$	0.07
$2 \leq R_P/R_\oplus \leq 8$	0.09
$R_P \geq 8R_\oplus$	0.50
$P \leq 3\,\mathrm{d}$	0.31
$3 \leq P \leq 15$	0.12
$P \geq 15\,\mathrm{d}$	0.16
Entire Sample	0.18

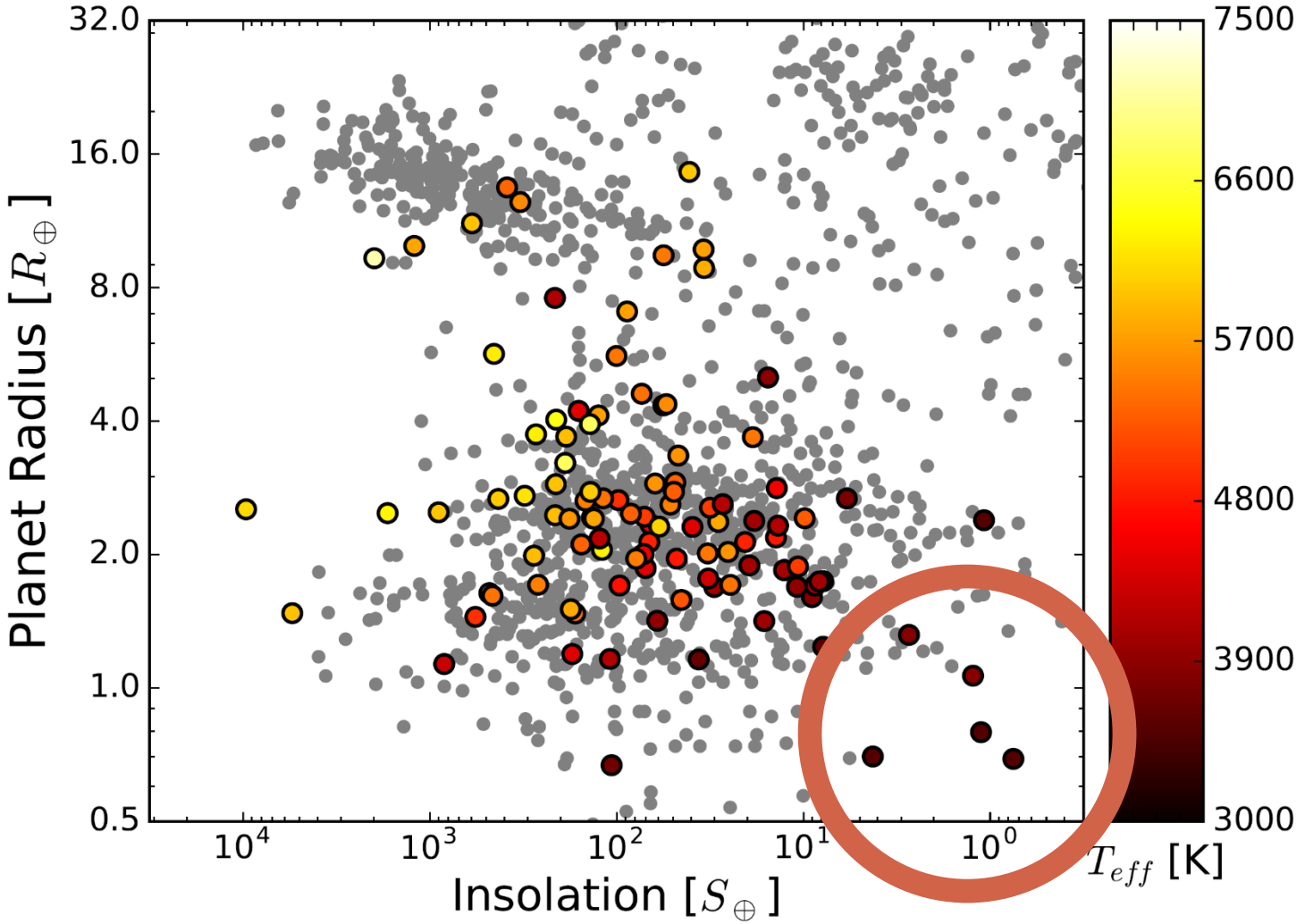
G & K Stars with an Emphasis to M Stars



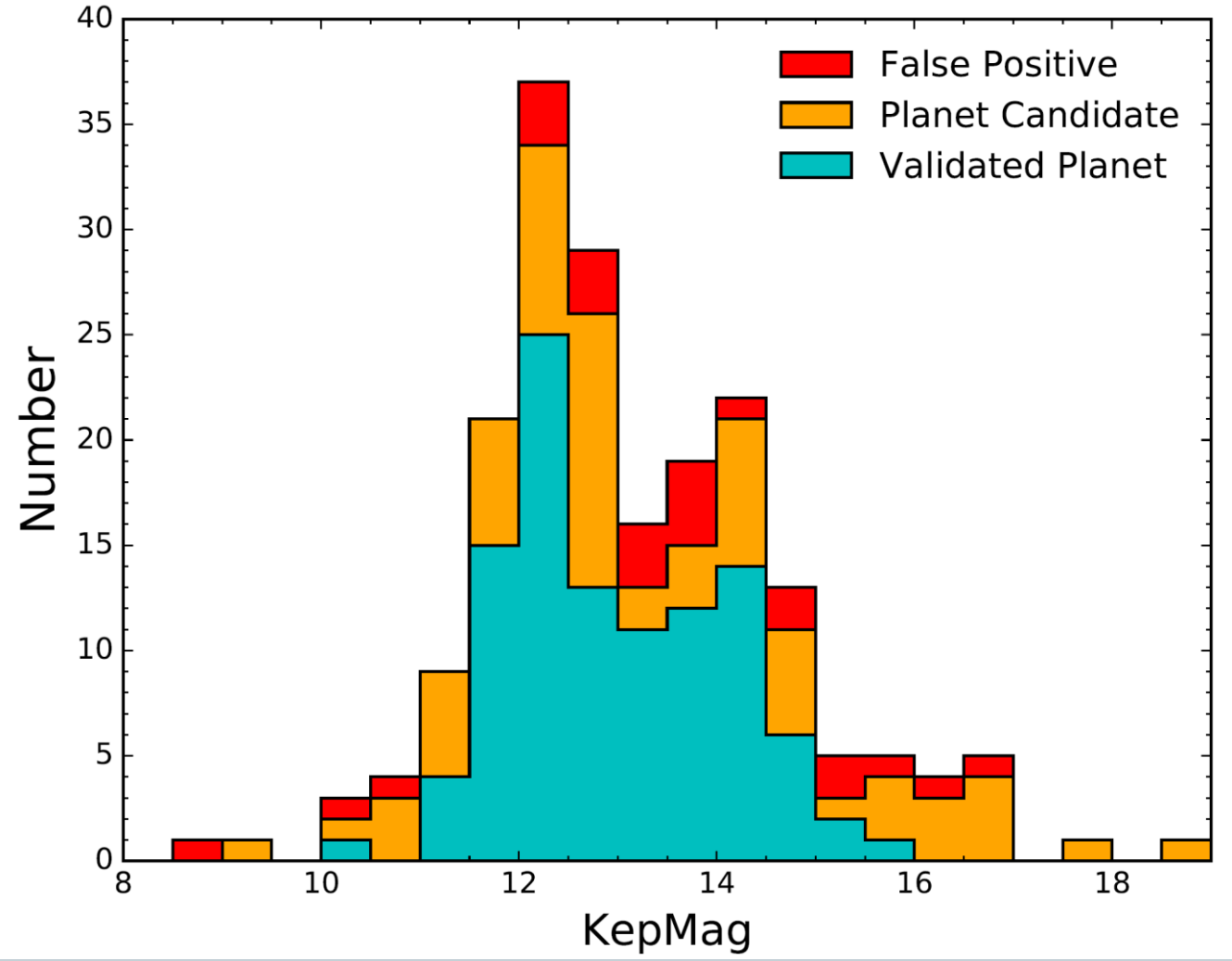
Radius – Period Distribution



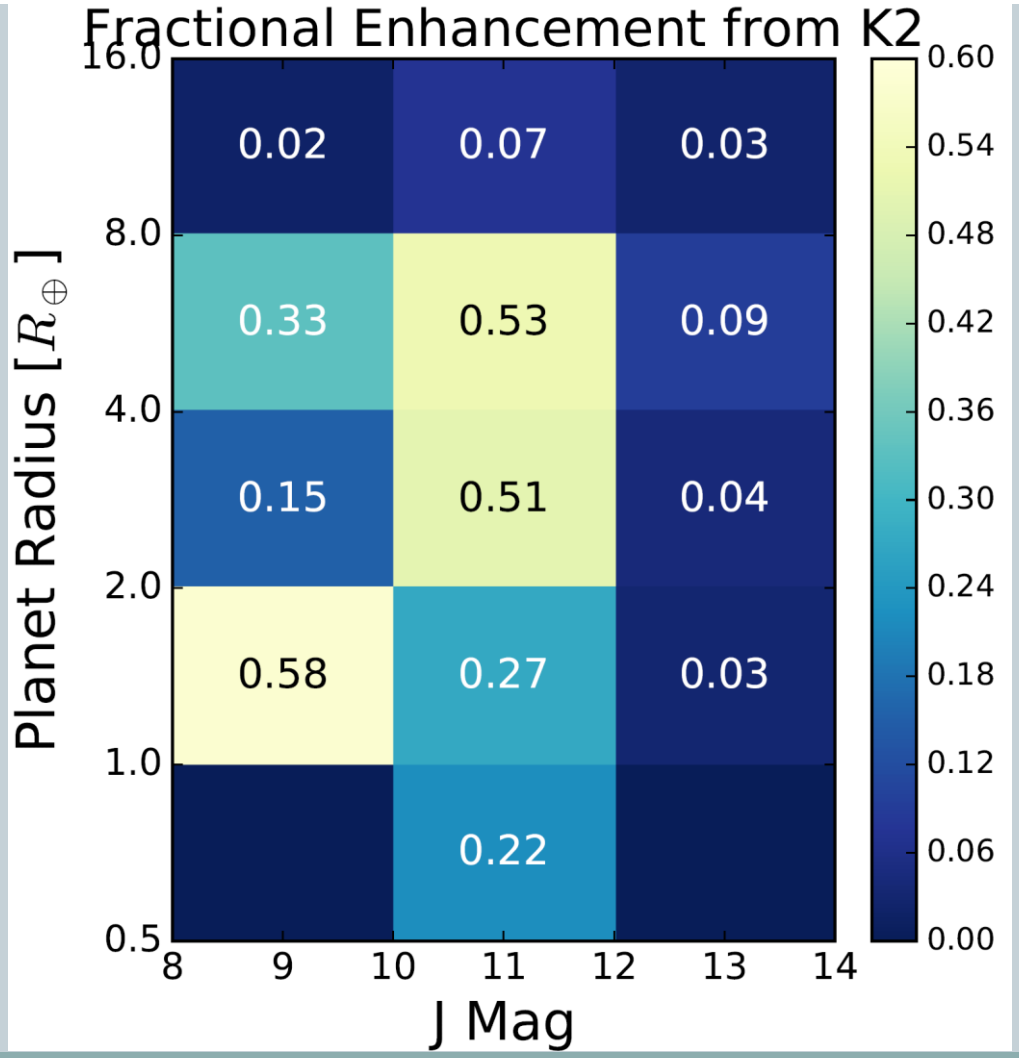
Small 'HZ'-like Planets



More Planets Around Brighter Stars



More Planets Around Brighter Stars



Continuing the Legacy of Kepler

- Confirmed 104 K2 planets in Campaigns 0 – 4
- Finding planets around brighter stars → Enables more detailed follow-up
  - More precise planet parameters
  - Atmospheres
  - Masses from RVs
- Exploring planet population around the Galaxy → How universal are the Kepler results
- Program Continues
  - Following up candidates from Fields 5 – 8
- Key Projects:
  - Keck
  - Palomar
  - Spitzer