# PTF and Kepler Projects: An Overview
# PTF 與克卜勒計畫

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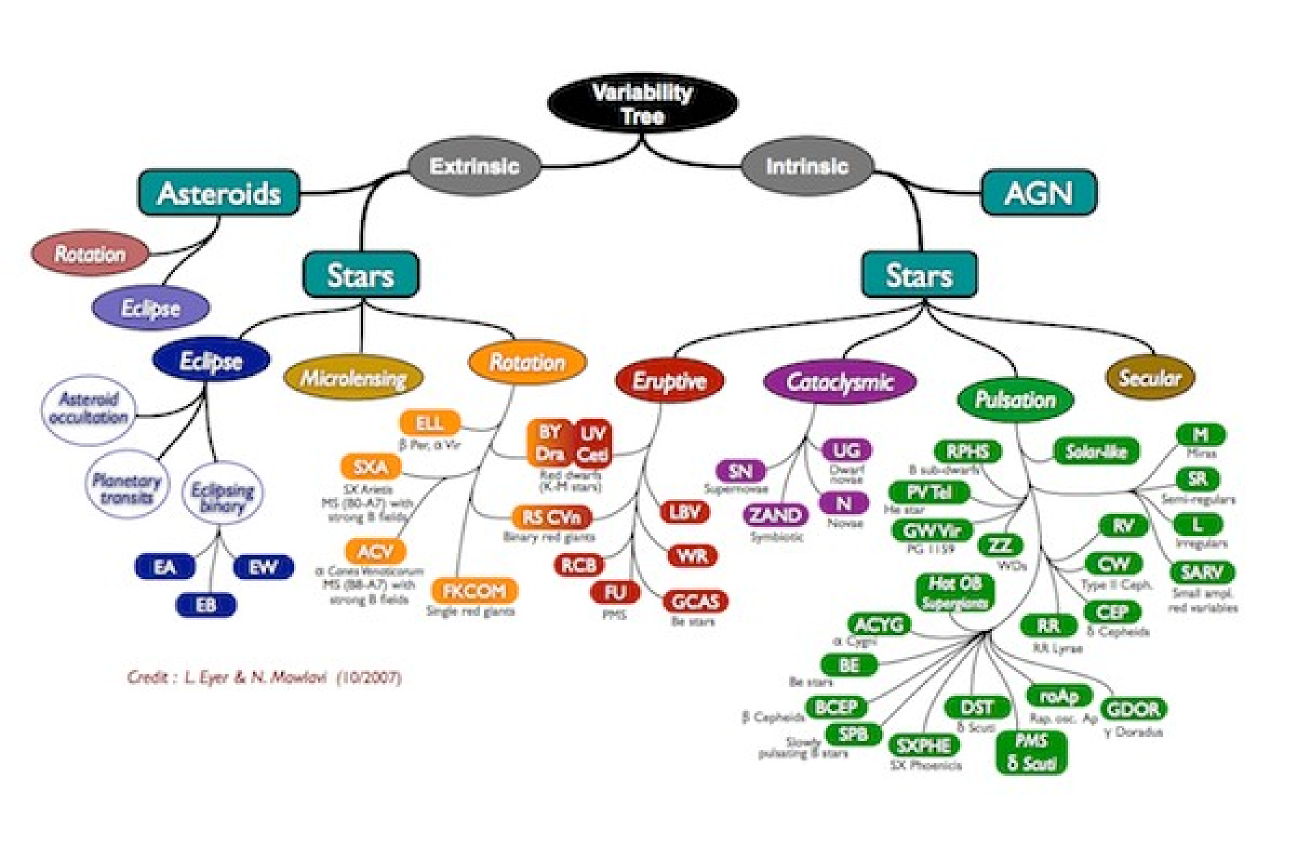
# Before We Start …

- Photometry = measurement of brightness (or flux)
- Astrometry = measurement of positions
- Variable stars = changes brightness with various time-scale
- Transients = objects suddenly appear, or become "bright"
- Magnitude = logarithmic scale of flux
    - $\Delta m = 2.5 \rightarrow$ can see 10x's fainter; $\Delta m = 5 \rightarrow$ 100x's fainter
- Angular units
    - 1 arcminute = (1/60) degree.
    - 1 arcsecond = (1/3600) degree. Typical limit due to "seeing".

# Science with Time-Domain Astronomy

- Asteroids motions and rotations
- Many types of variable stars and their activities
- Explosive events such as novae and supernovae
- Micro-lensing
- Extra-Solar planets transit

Magnitude/flux/position varies with time



# Time Domain Astronomy

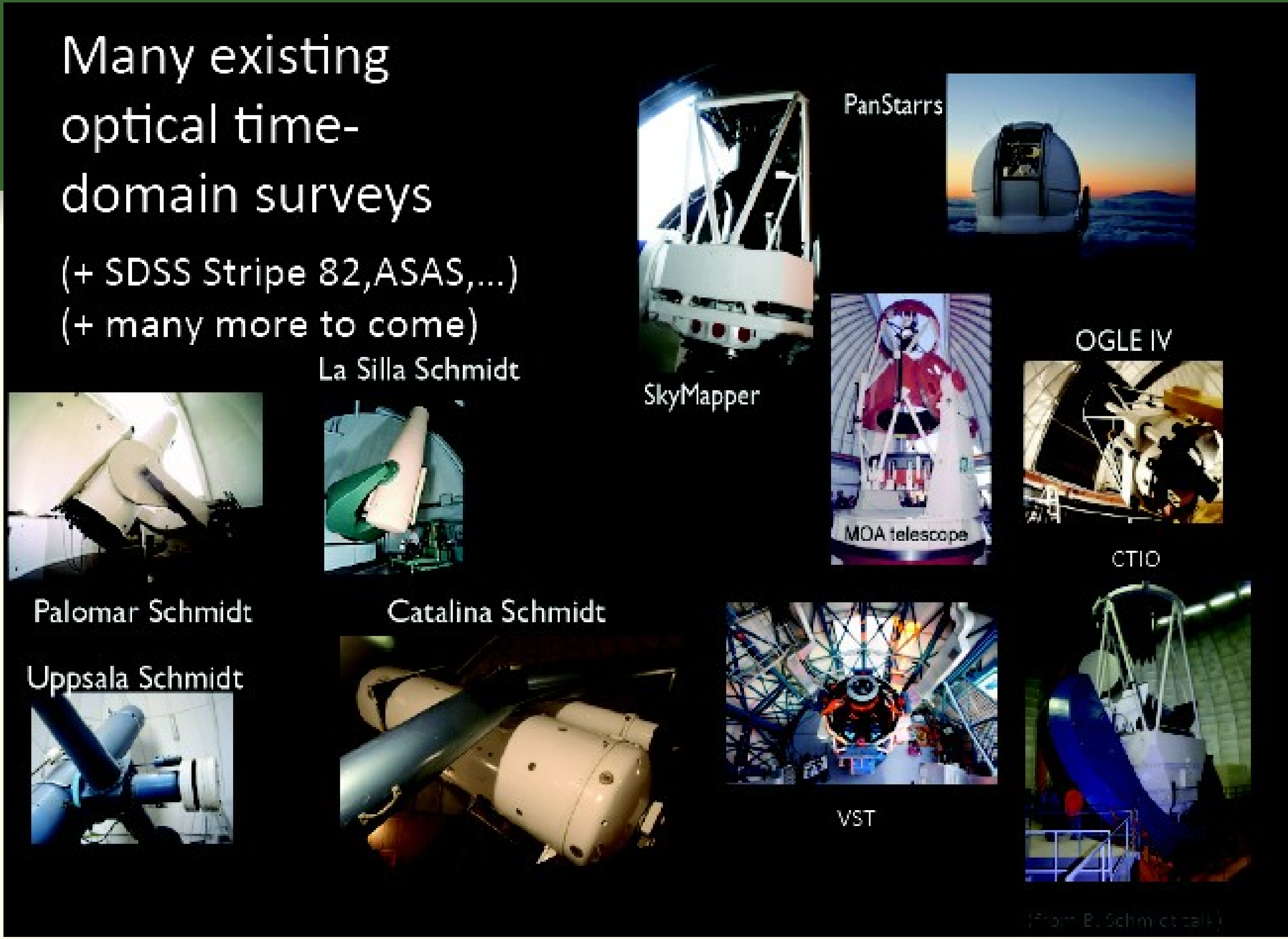
The data-centric problem statement:

– Databases: Given ~1 petabyte of image data, extract sources and create a database of ~1 billion objects.

– Machine learning: In near real time, analyze ~Gbytes/minute of image data to identify which of millions of “candidates per night” are true astronomical transients. Similarly, identify fast-moving near earth asteroids.

– Time-frequency algorithms: Using efficient queries on the database, determine which of the ~10’s of millions of variable sources are “interesting sources”

Requires highly automated data exploration
Reduce false positives to manageable level

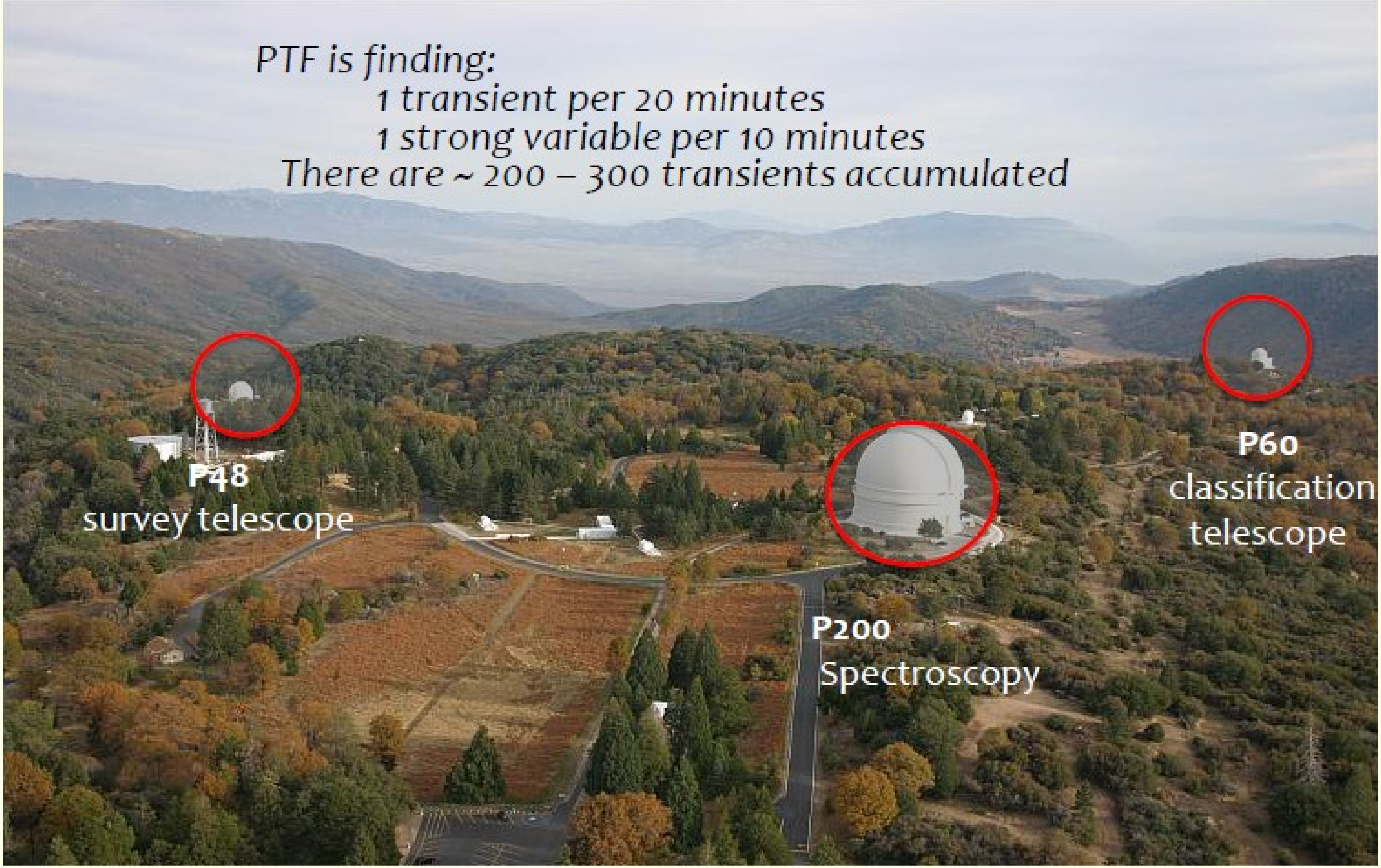



Focus on PTF and Kepler here

# The Palomar Transient Factory (PTF)

- Dedicated time-domain survey for transients discoveries
- Main survey telescope: 48-inch Schmidt Telescope or P48
    - Wide-field mosaic CCD
    - Single band observation, mainly in R-band (also in g or H-alpha bands)
    - Fixed exposure time of 60 second (occasion with shorter exposure time)
    - Variable cadence from few minutes to few days
- Follow up with P60 and P200, and other telescopes
- P48, P60 and P200 → located at the Palomar Observatory

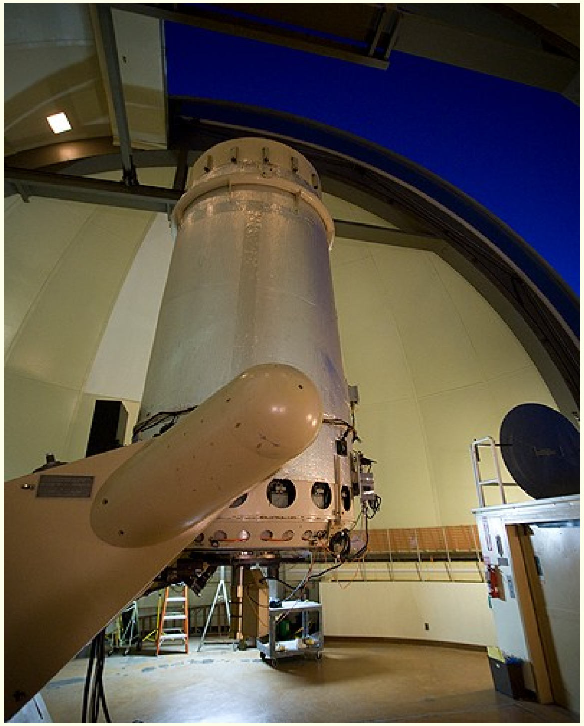
# PTF @ The Palomar Observatory



# PTF, iPTF and ZTF

- PTF = Palomar Transient Factory (2009 – 2012)
- iPTF = Intermediate PTF (2013 – 2016)
- ZTF = Zwicky Transient Facility (2017 - ~2020)

P48: Survey Telescope

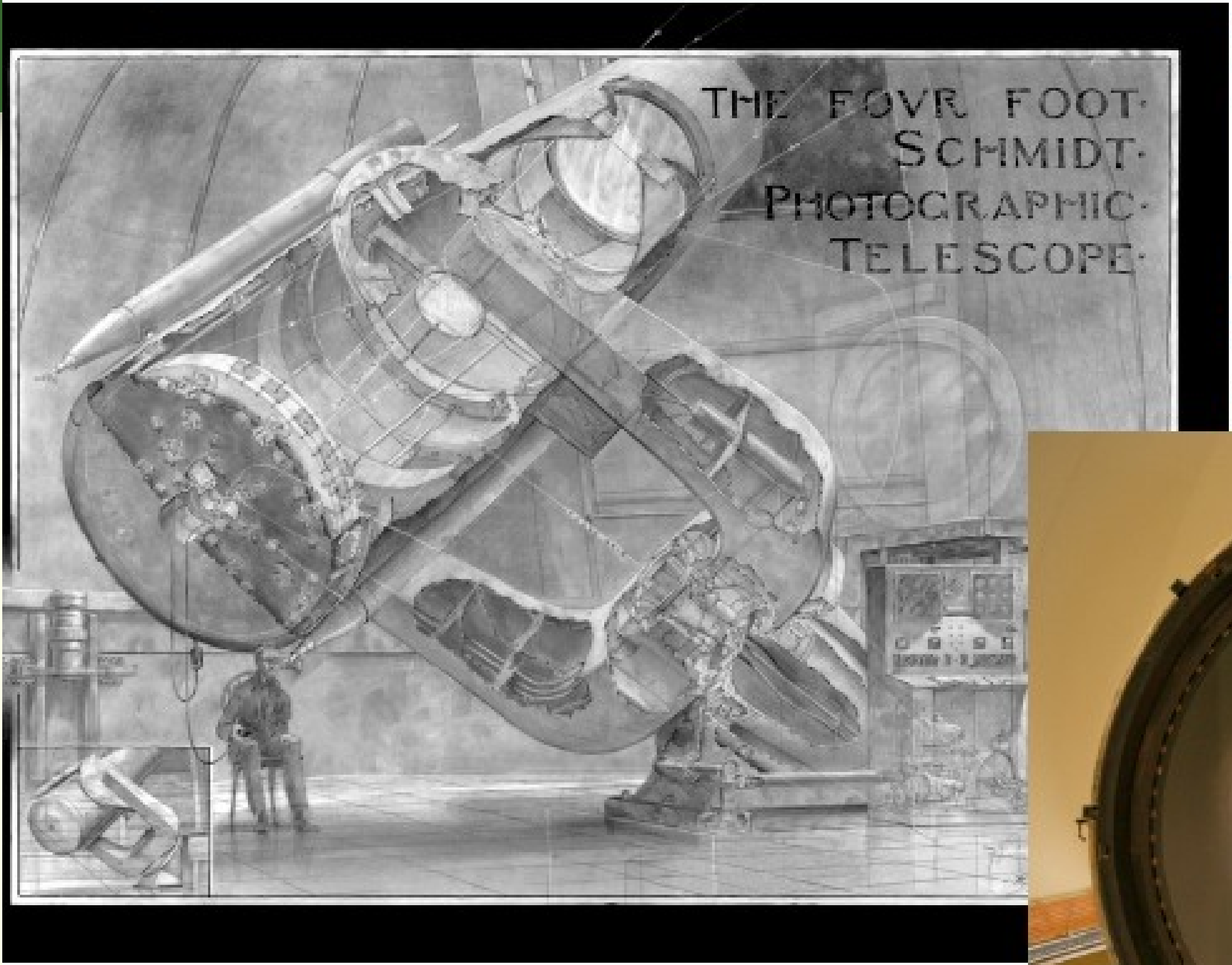


P60: Follow-Up Telescope

# In Honor of Fritz Zwicky


- Dark Matter & gravitational lens
- Separate out supernova and nova (with W. Baade)
- Systematic search of SN with wide-field telescopes

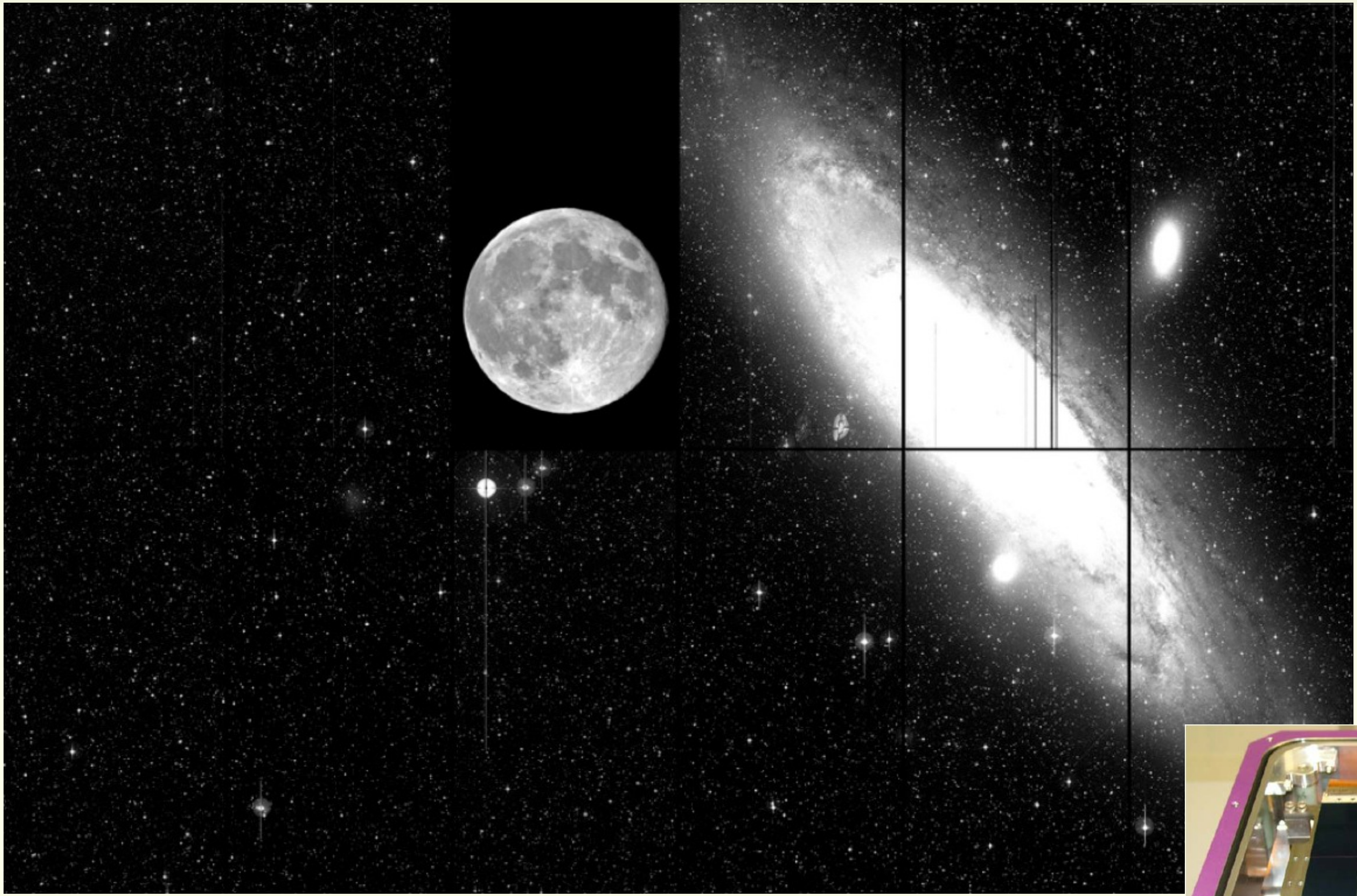
# The P48 is a larger survey telescope with a distinguished history.

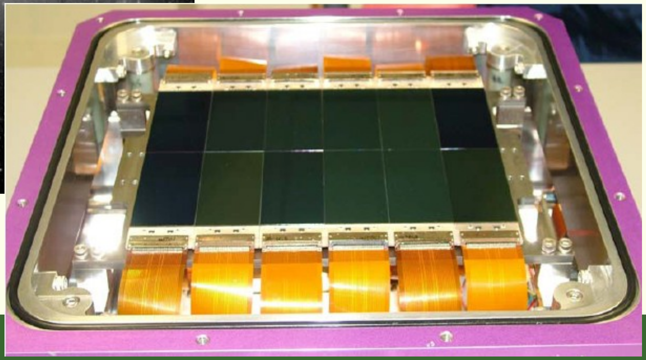



POSS I & II
NEAT, QUEST, PTF

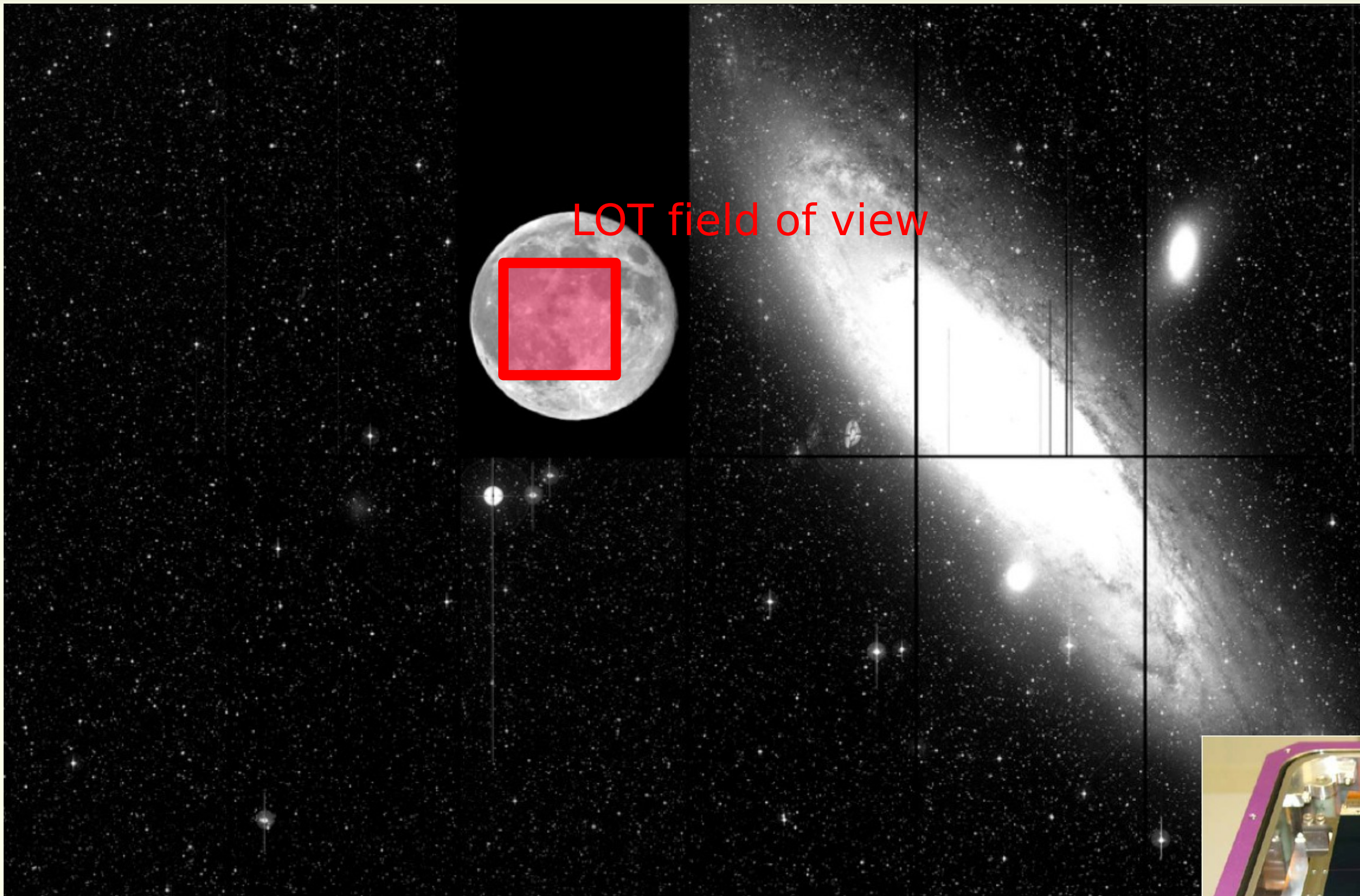
large sky surveys
supernovae
asteroids and KBOs

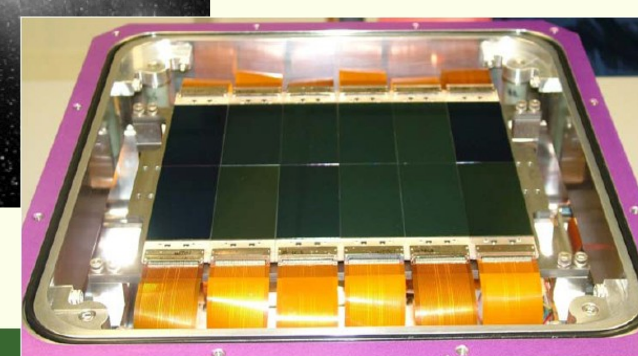
# Wide-Field Mosaic CCD at P48



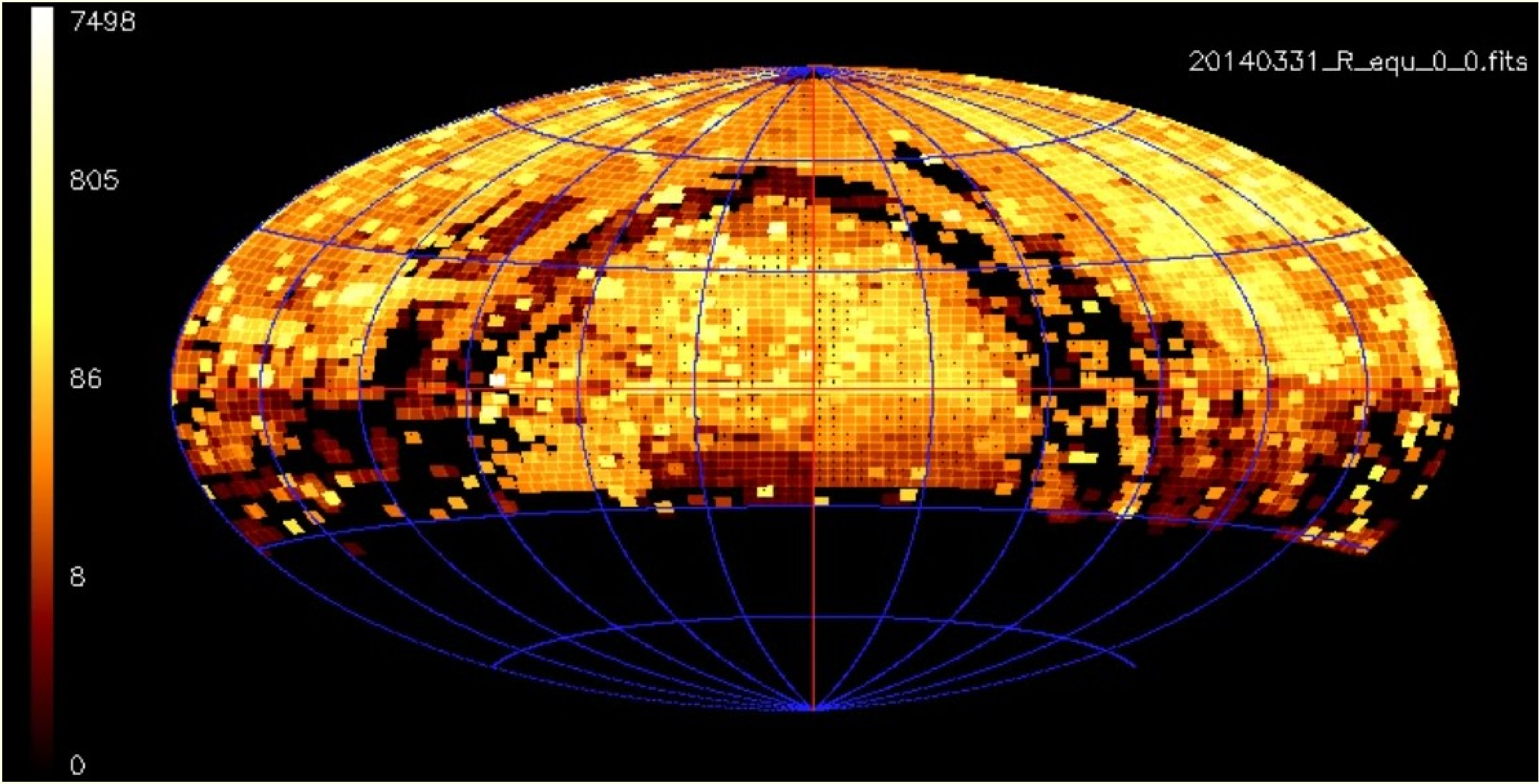


# Wide-Field Mosaic CCD at P48

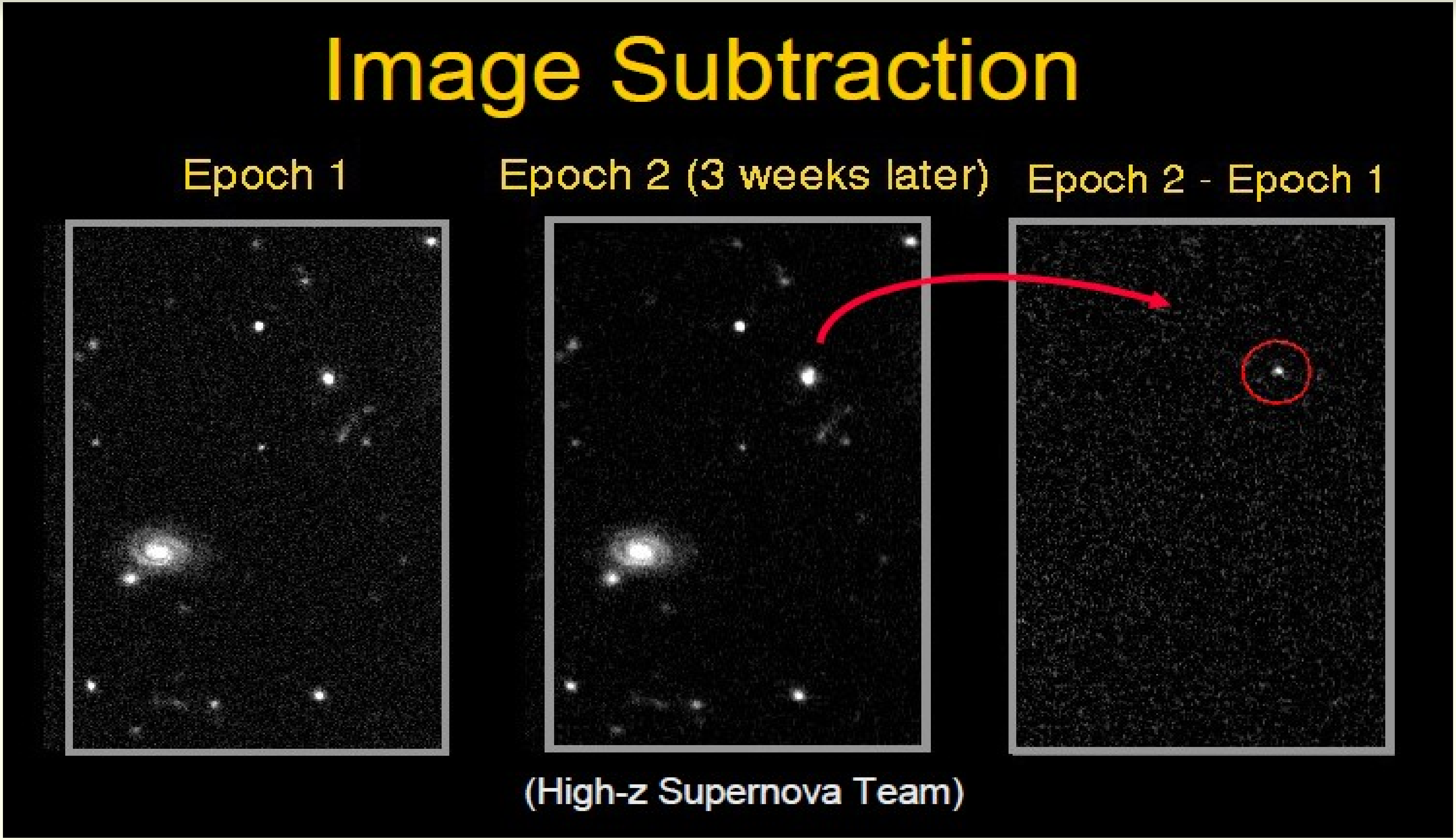


# Accumulated Sky Coverage in R-Band



# Finding Transients with Image Subtraction



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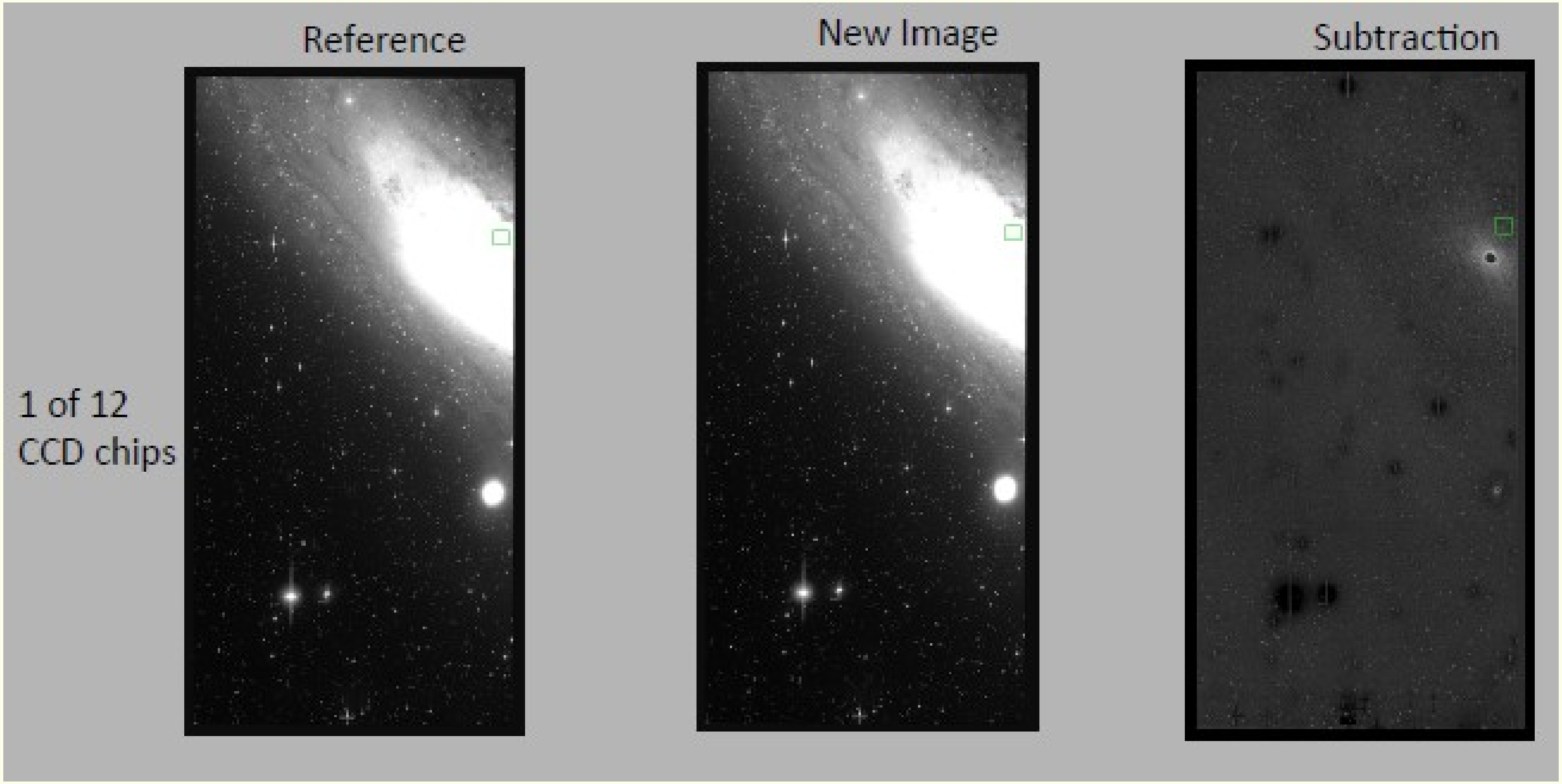
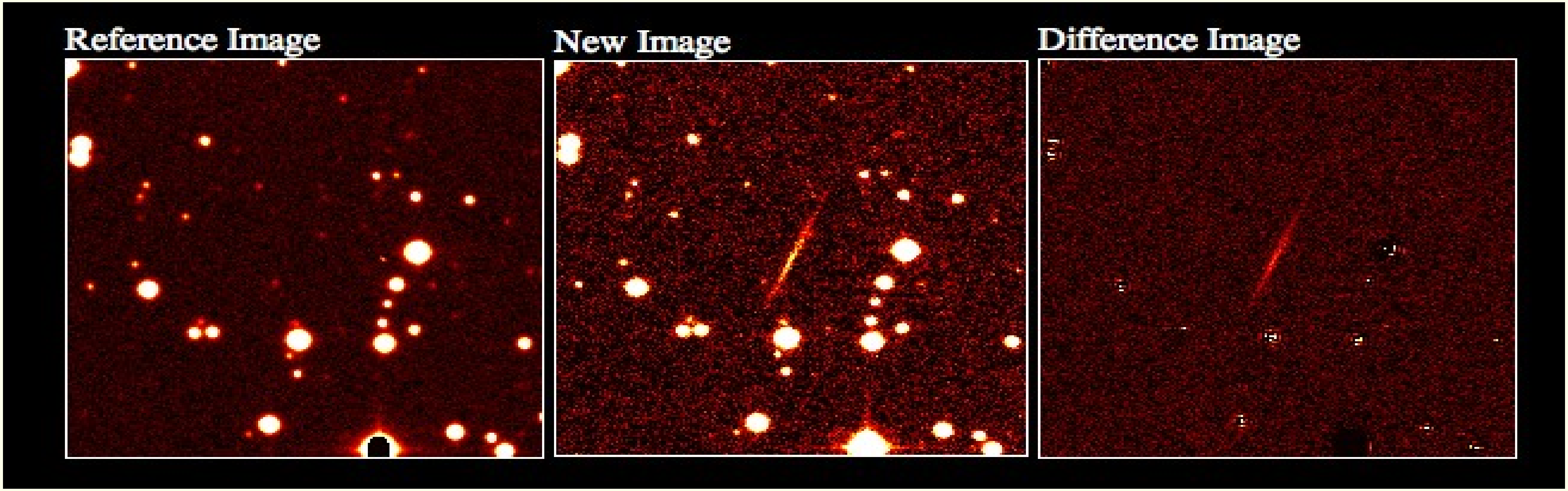
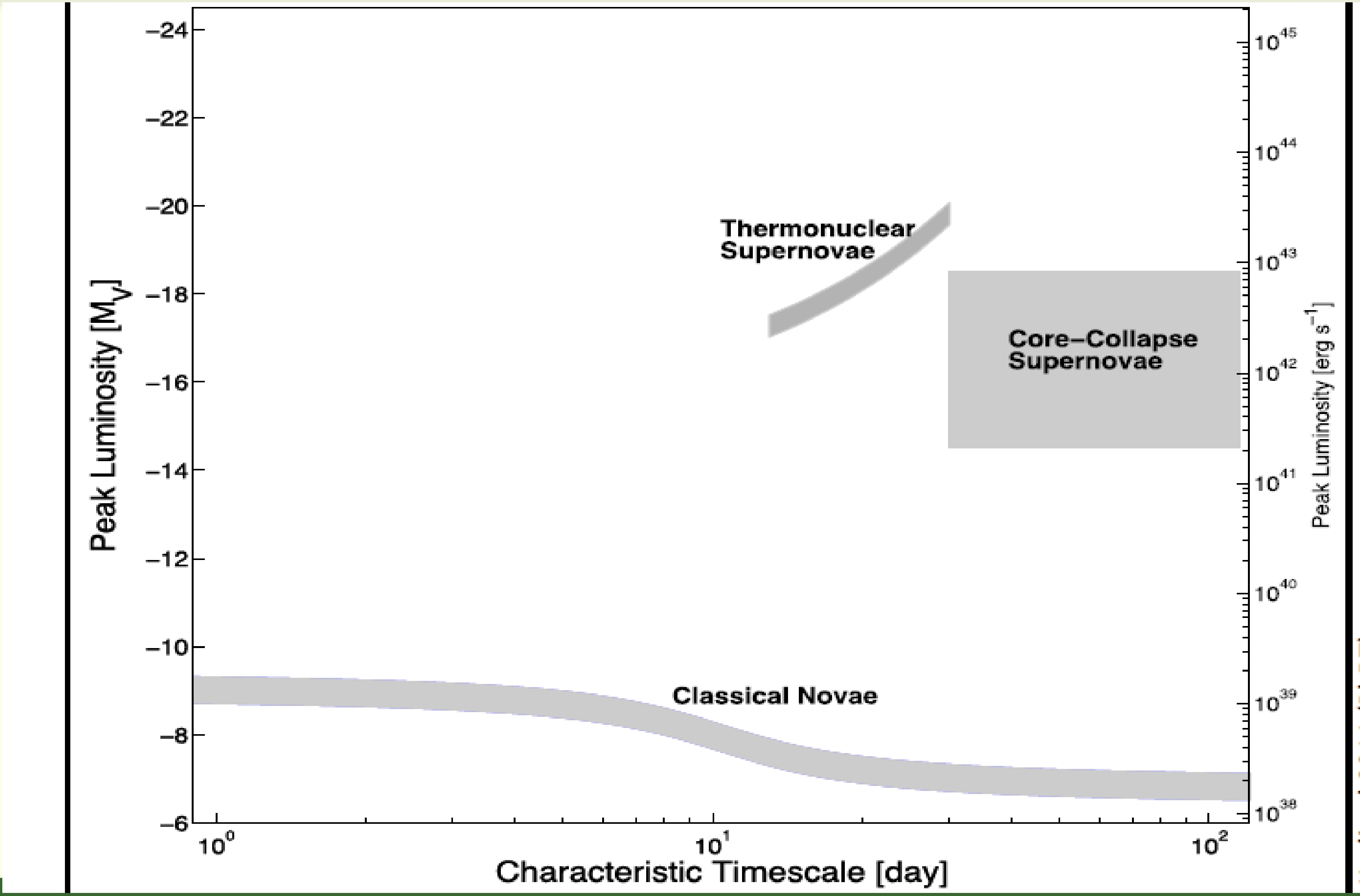


# Finding Fast Moving Asteroids with Image Subtraction



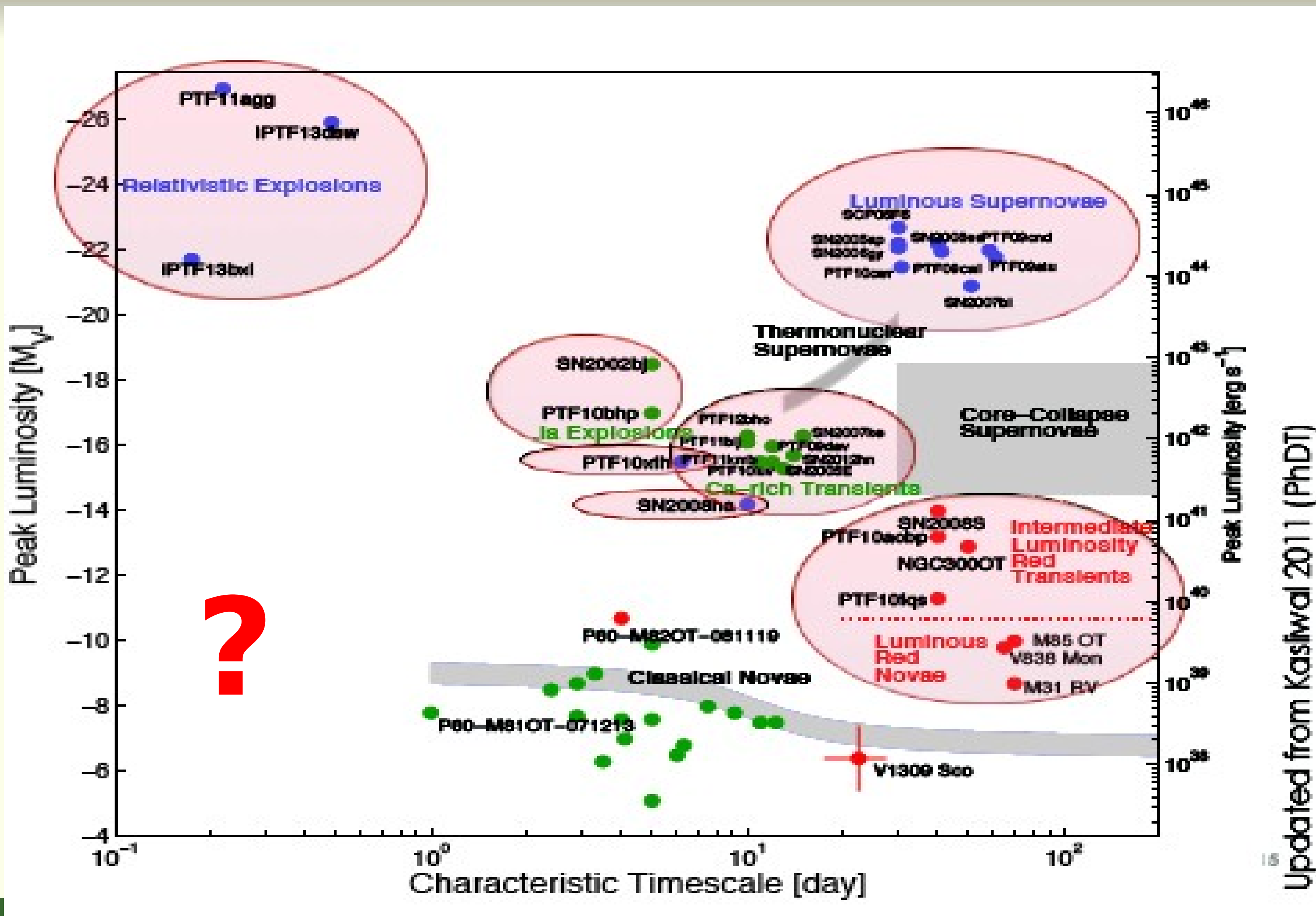

Fast moving asteroids leave “streaks” on images

# PTF Discoveries on Transients (Before)

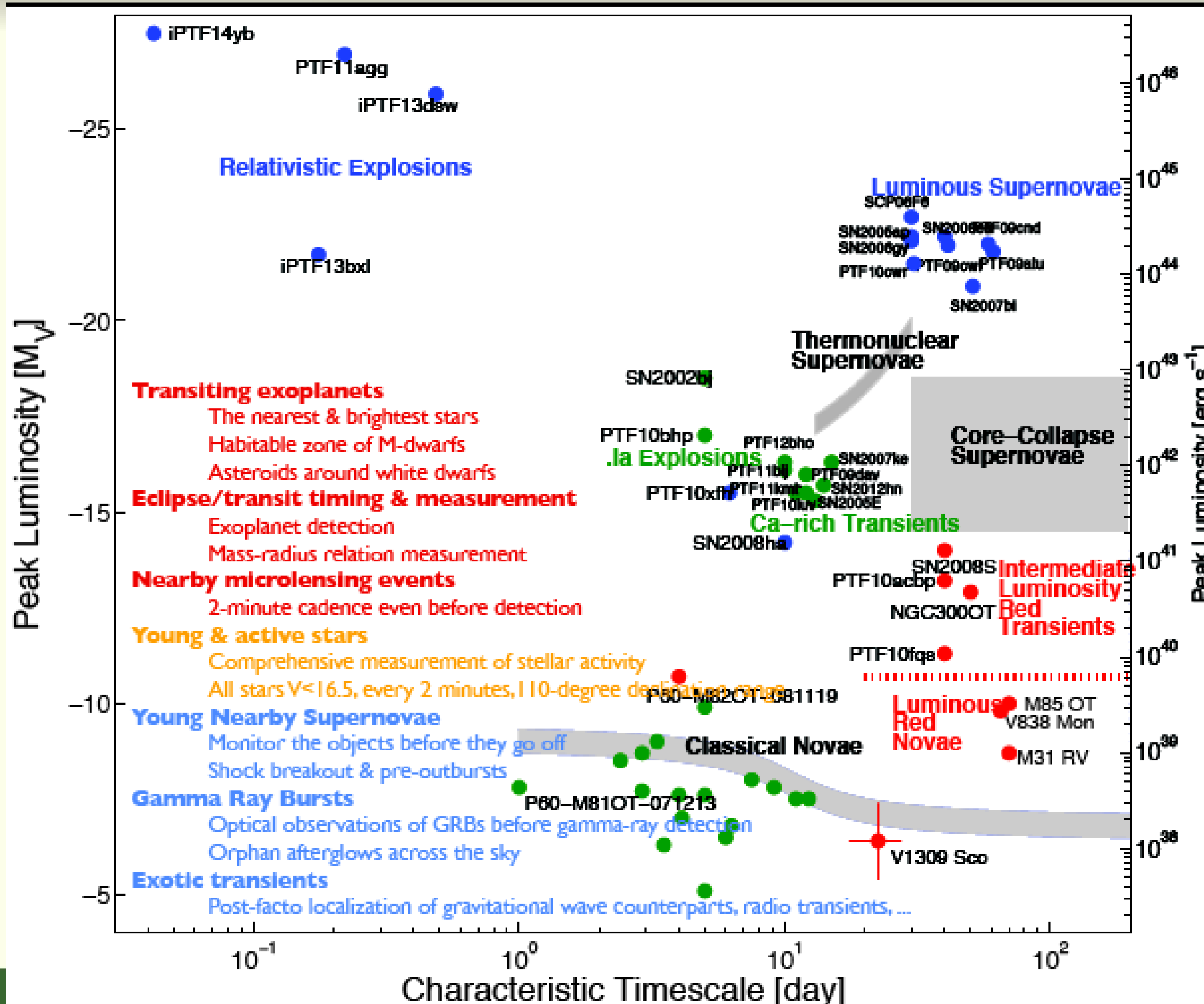



Kasliwal 2011 (PhDT)

# PTF Discoveries on Transients (After)



# PTF Discoveries on Transients (Future)



# Example: PTF Discovered SN in M101

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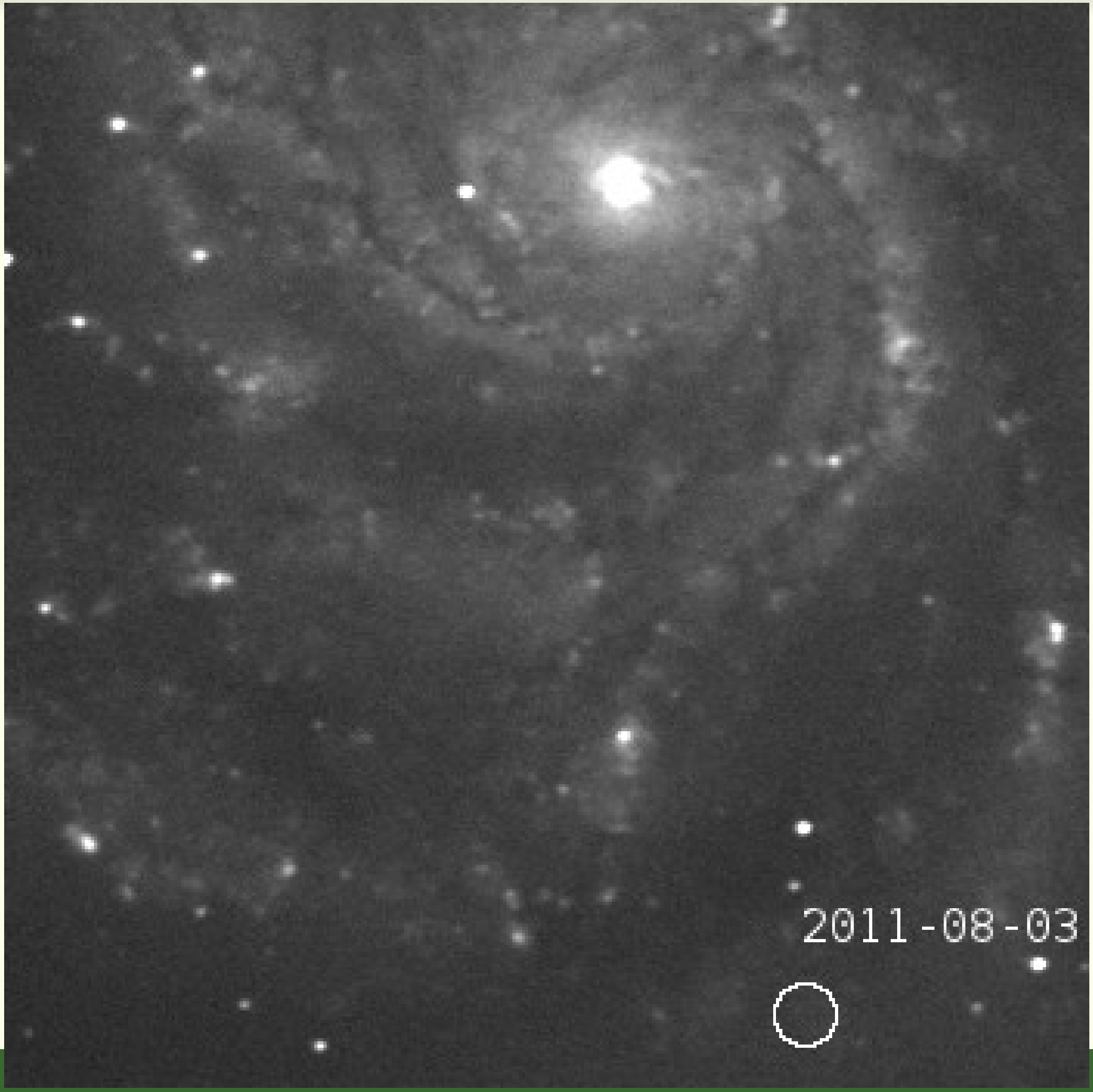
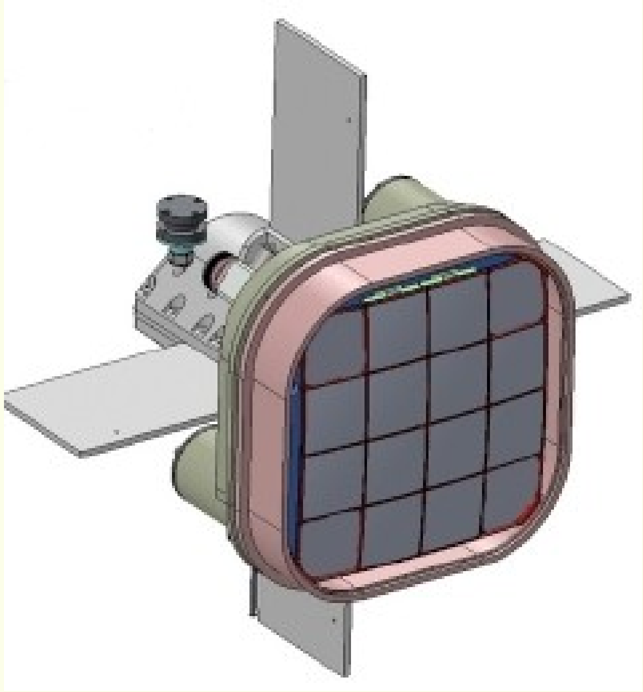


# P48 Survey Telescope

PTF & iPTF → ZTF



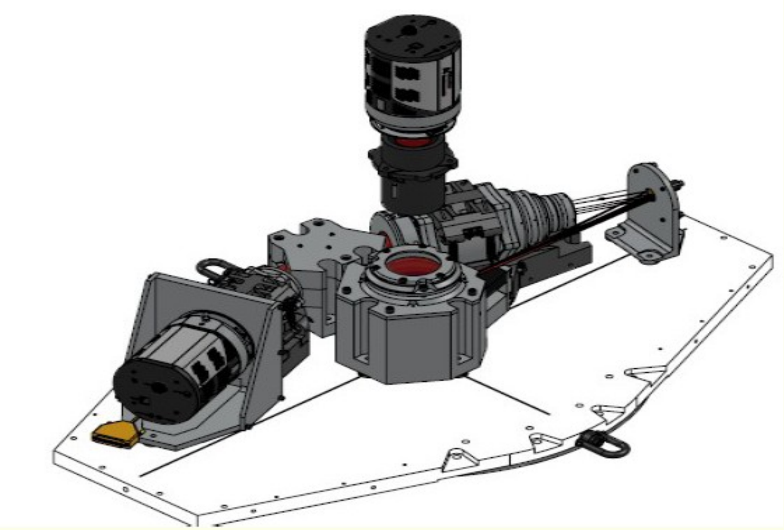
- 11 2k x 4k mosaic CCD (CFH12K)
- 1.01 "/pix → ~7.26 deg$^2$ FOV
- Mould R (main), g' & Hα filters

- 16 6k x 6k e2V CCD
- 1 "/pix → ~47 deg$^2$ FOV
- Mould R & g'

# P60 Follow-Up Telescope

PTF → iPTF → ZTF

| Property | Amplifier 1 | Amplifier 2 | Full Chip |
|---|---|---|---|
| Array Size | $2048 \times 1024$ | $2048 \times 1024$ | $2048 \times 2048$ |
| Pixel Size ($\mu$m) | ... | ... | 24 |
| Plate Scale (arcsec pixel$^{-1}$) | ... | ... | 0.378 |
| Field of View (arcmin) | $12.9 \times 6.5$ | $12.9 \times 6.5$ | $12.9 \times 12.9$ |
| Gain ($e^-$ ADU$^{-1}$) | 2.2 | 2.8 | ... |
| Read Noise ($e^-$) | 5.3 | 7.8 | ... |
| Dark Current ($e^-$ s$^{-1}$) | $10^{-3}$ | $10^{-3}$ | ... |
| Charge Transfer Efficiency | > 99.999% | 99.999% | ... |
| Full Well Capacity ($e^-$) | 130,000 | 140,000 | ... |
| Bias Level (ADU) | 610 | 445 | ... |
| Saturation Limit (ADU) | 50,000 | 45,000 | ... |



- Fully robotic
- Standard broadband filters (UBVRI + griz)

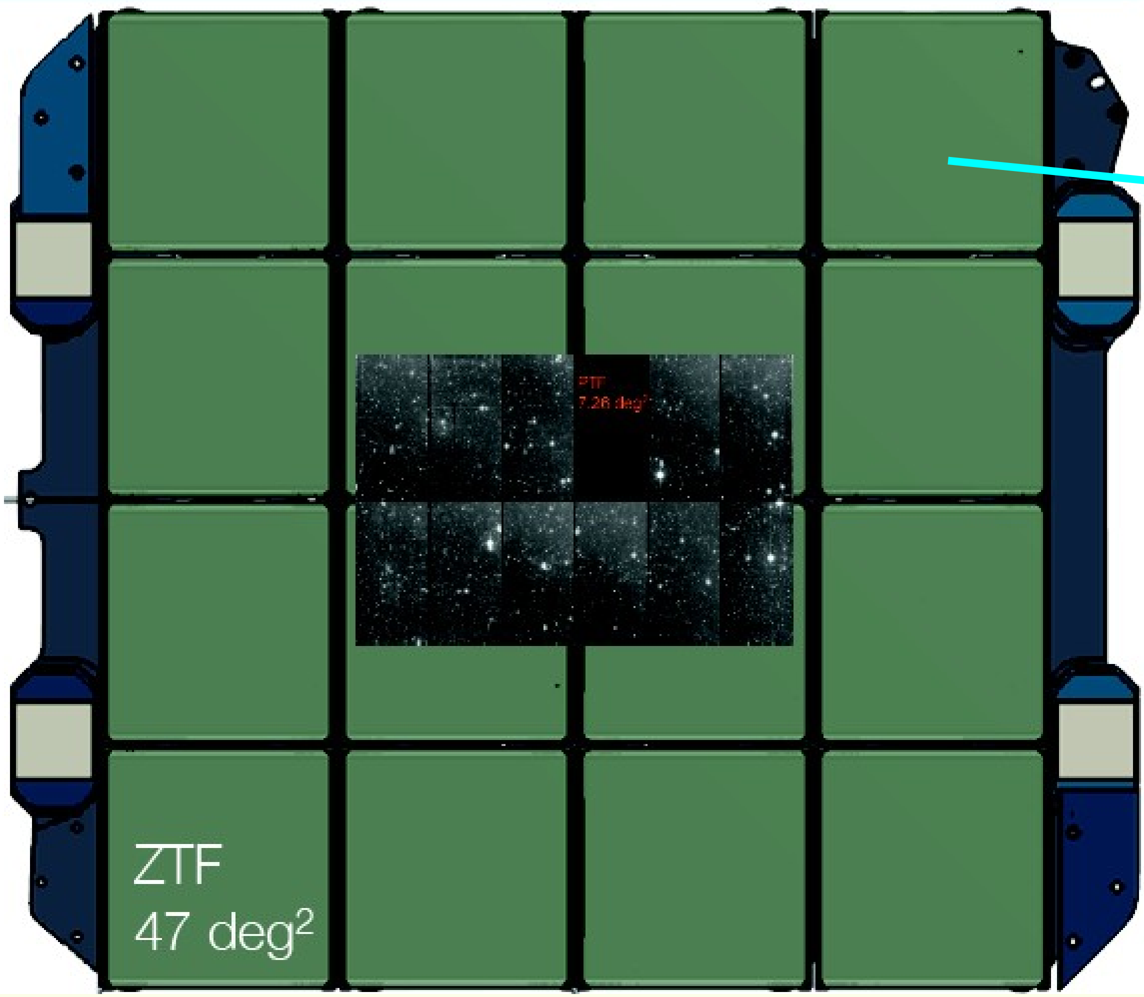
- Low resolution (R~100) IFU using lenslet array
- Simultaneous 4-band imager for flux calibration
- Fast classification of SNe

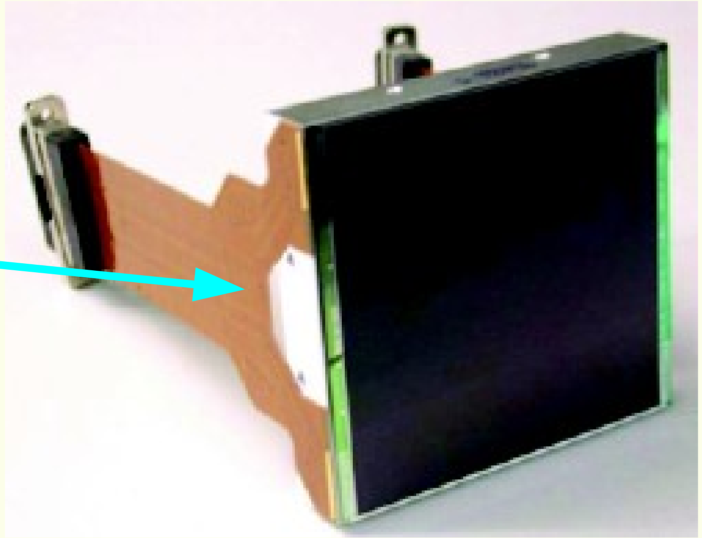
"GRB"Cam

SED Machine

# Next Step: ZTF and Its Camera

A new camera will fill the P48 focal plane.



| e2v | |
|---|---|
| dimension | 9.2 x 9.2 cm |
| pixels | 6.1k x 6.1k |
| pixel size | 15 micron |
| pixel scale | 1"/pixel |
| outputs | 4 |

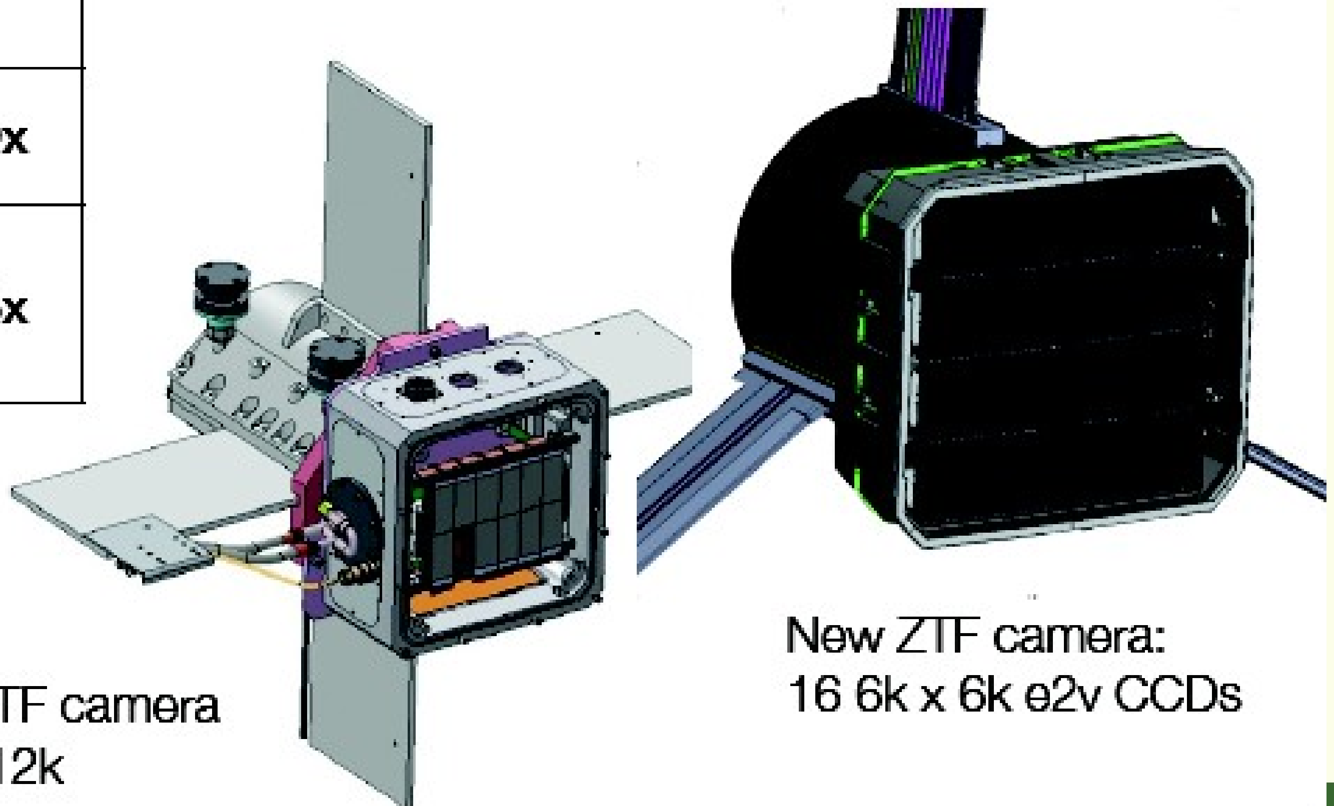
# ZTF will survey an order of magnitude faster than PTF.

| | PTF | ZTF |
|---|---|---|
| Active Area | 7.26 $deg^2$ | 47 $deg^2$ |
| Overhead Time | 46 sec | <15 sec |
| Optimal Exposure Time | 60 sec | 30 sec |
| Relative Areal Survey Rate | 1x | **15.0x** |
| Relative Volumetric Survey Rate | 1x | **12.3x** |

**3750 $deg^2$/hour**

⇒ 3π survey in 8 hours

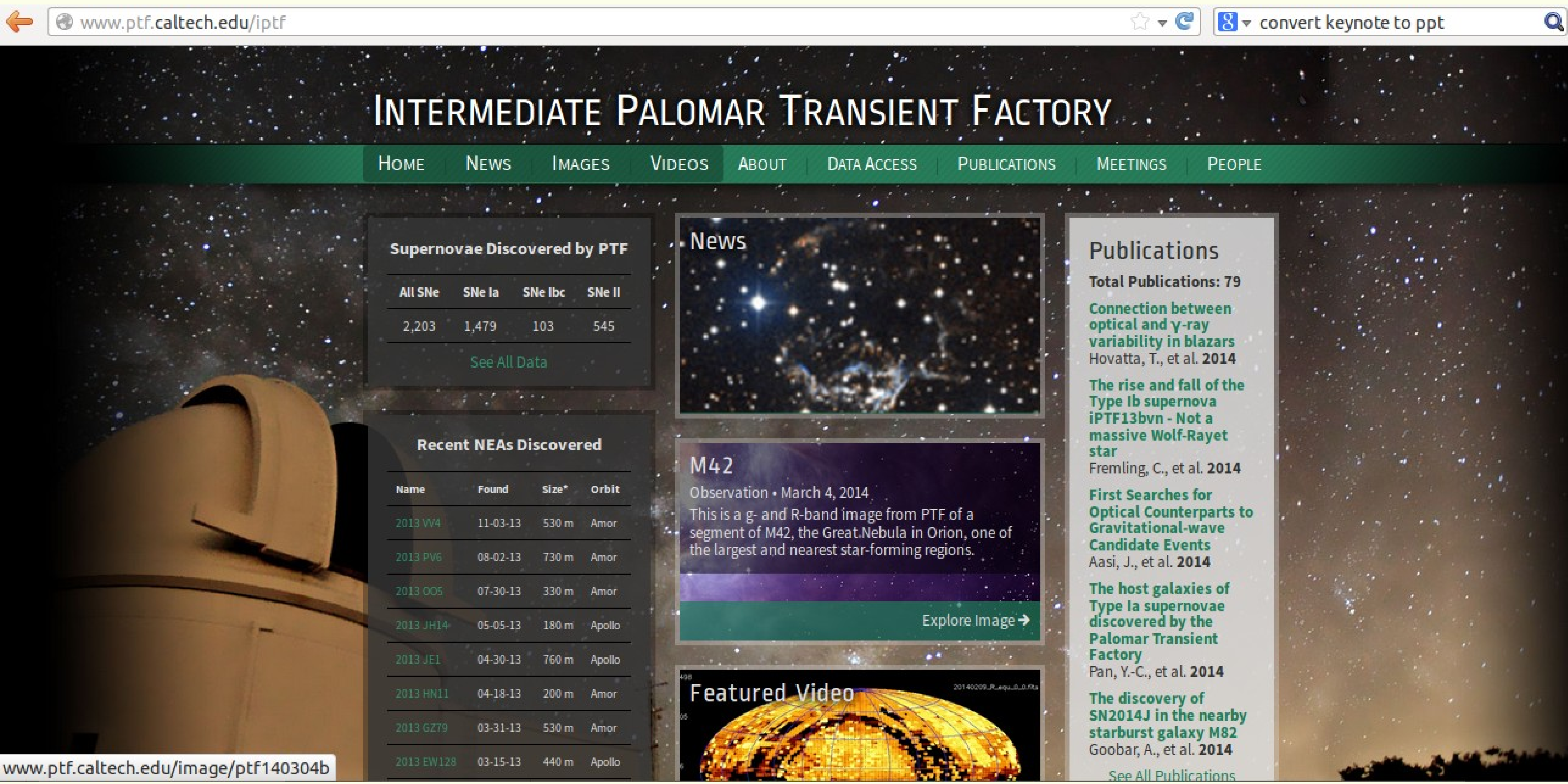
**>250 observations/field/year** for uniform survey



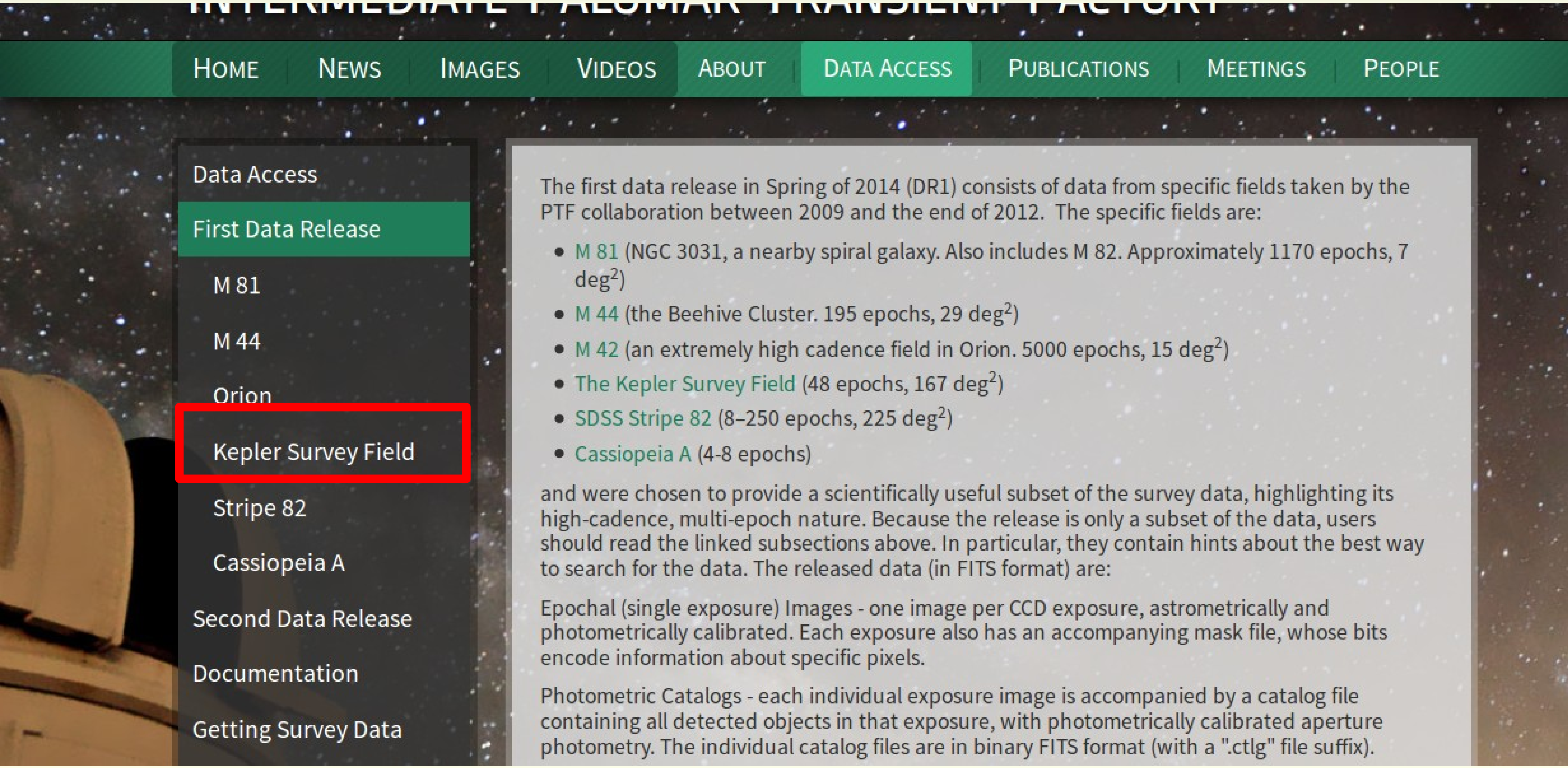
Existing PTF camera MOSAIC 12k

New ZTF camera: 16 6k x 6k e2v CCDs

# http://www.ptf.caltech.edu/



# PTF Public Released Data: DR1



HOME | NEWS | IMAGES | VIDEOS | ABOUT | DATA ACCESS | PUBLICATIONS | MEETINGS | PEOPLE

- Data Access
- First Data Release
  - M 81
  - M 44
  - Orion
  - Kepler Survey Field
  - Stripe 82
  - Cassiopeia A
- Second Data Release
- Documentation
- Getting Survey Data

The first data release in Spring of 2014 (DR1) consists of data from specific fields taken by the PTF collaboration between 2009 and the end of 2012. The specific fields are:

- M 81 (NGC 3031, a nearby spiral galaxy. Also includes M 82. Approximately 1170 epochs, 7 $deg^2$)
- M 44 (the Beehive Cluster. 195 epochs, 29 $deg^2$)
- M 42 (an extremely high cadence field in Orion. 5000 epochs, 15 $deg^2$)
- The Kepler Survey Field (48 epochs, 167 $deg^2$)
- SDSS Stripe 82 (8–250 epochs, 225 $deg^2$)
- Cassiopeia A (4-8 epochs)

and were chosen to provide a scientifically useful subset of the survey data, highlighting its high-cadence, multi-epoch nature. Because the release is only a subset of the data, users should read the linked subsections above. In particular, they contain hints about the best way to search for the data. The released data (in FITS format) are:

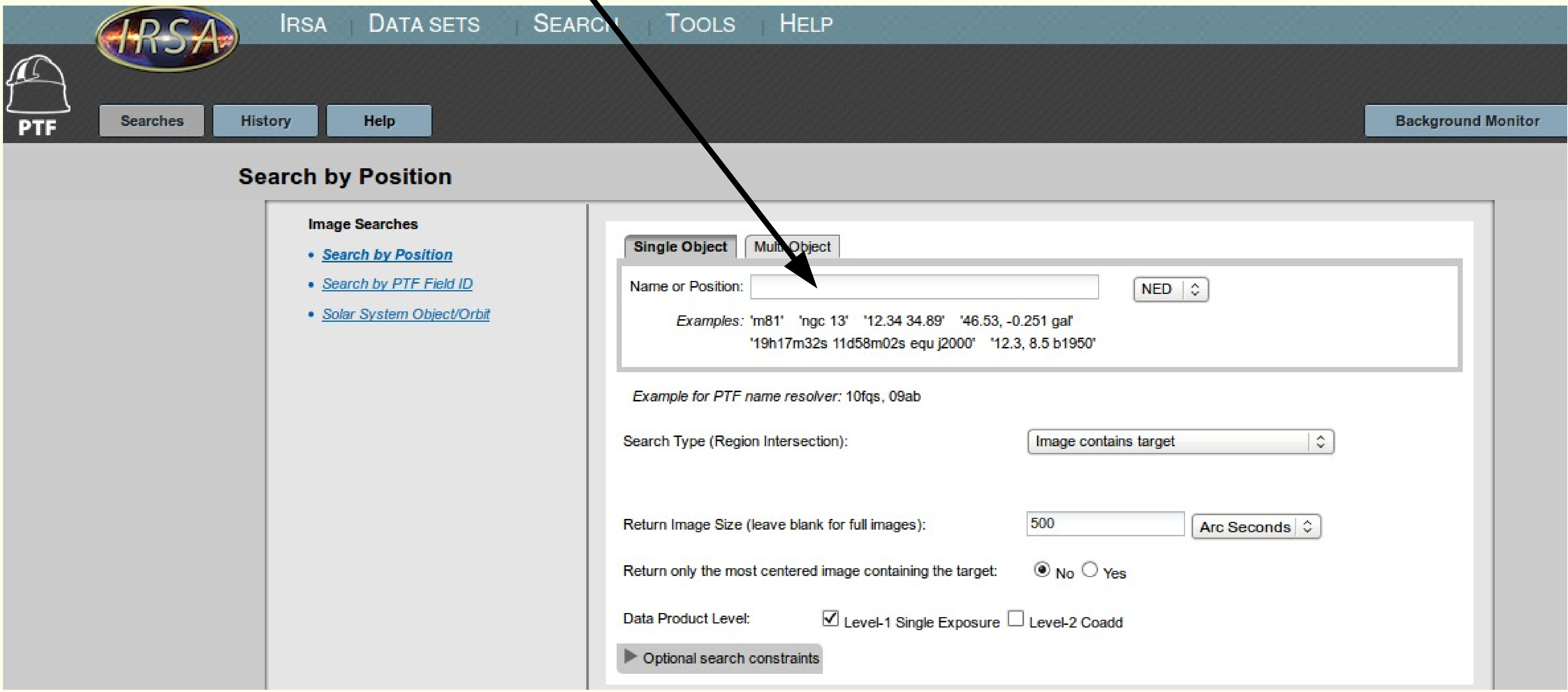
Epochal (single exposure) Images - one image per CCD exposure, astrometrically and photometrically calibrated. Each exposure also has an accompanying mask file, whose bits encode information about specific pixels.

Photometric Catalogs - each individual exposure image is accompanied by a catalog file containing all detected objects in that exposure, with photometrically calibrated aperture photometry. The individual catalog files are in binary FITS format (with a ".ctlg" file suffix).

# Getting the PTF Public Data

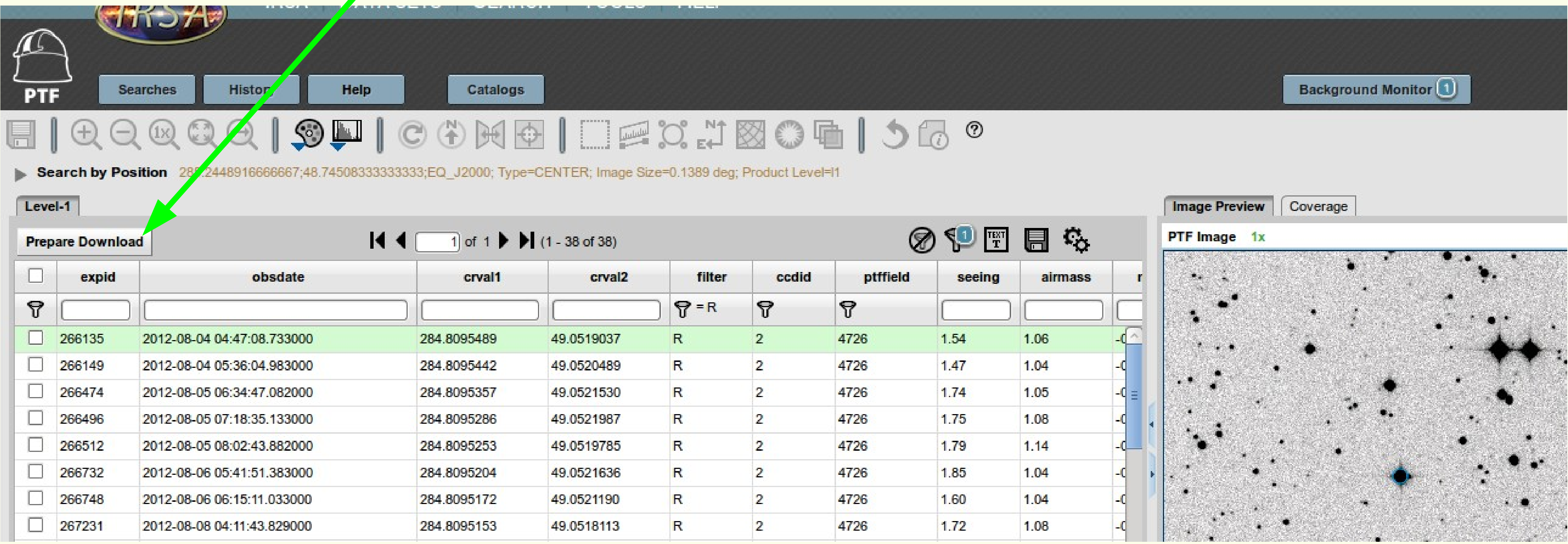
# Getting the PTF Public Data

Input target's coordinate (RA/DEC) here

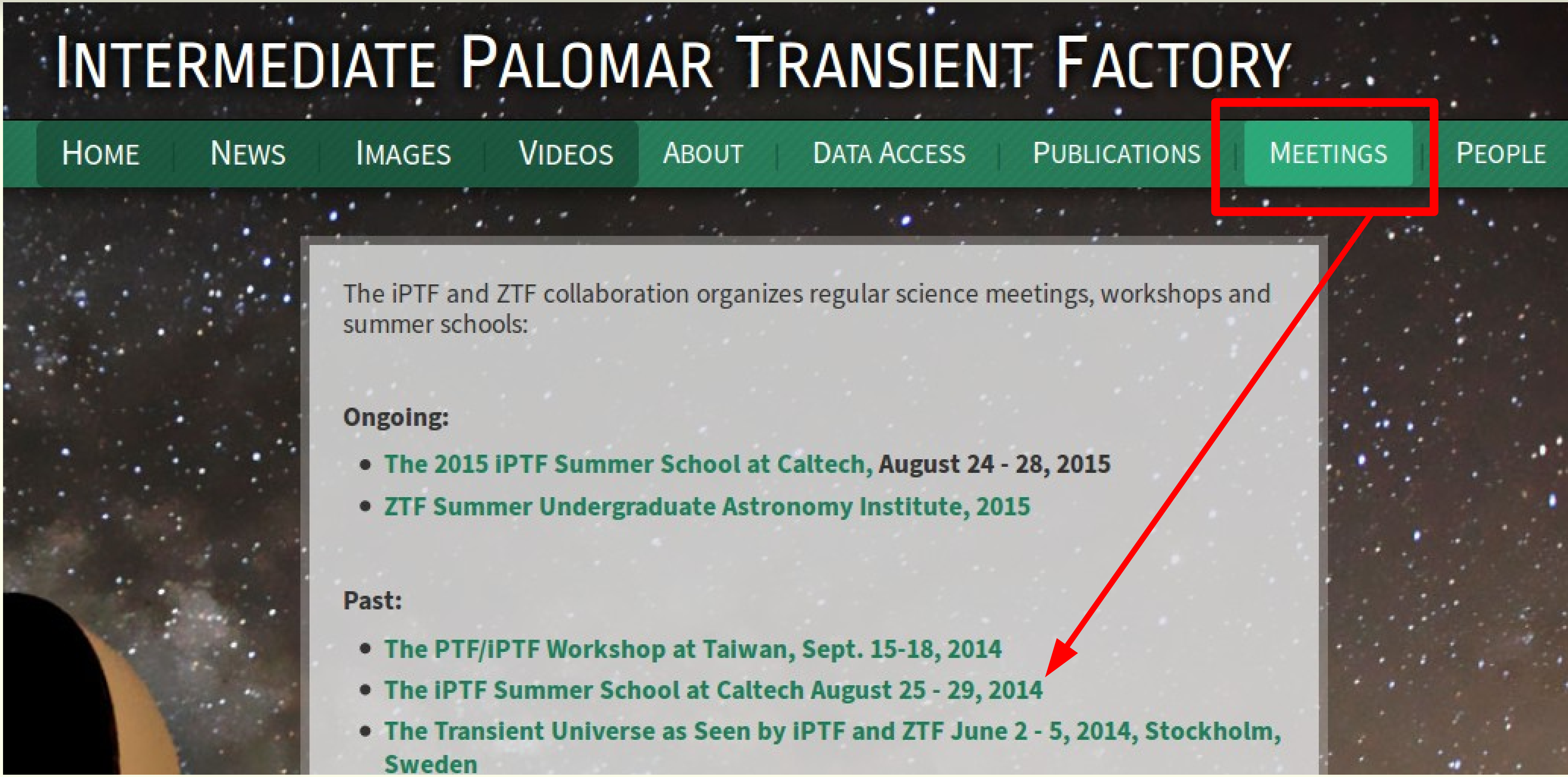


# Getting the PTF Public Data

Select data and download



# Accessing PTF FITS Catalogs



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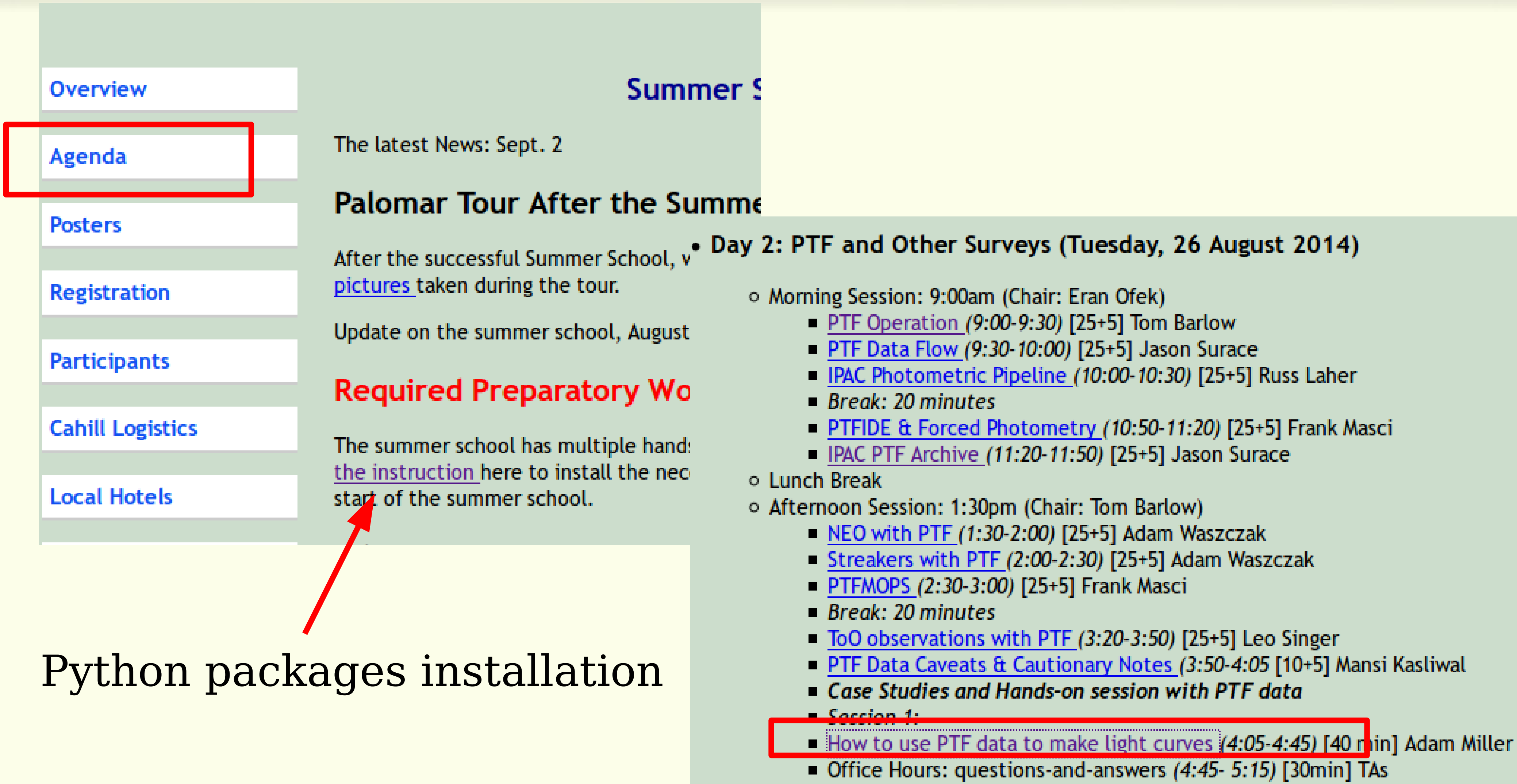


Overview

Agenda

Posters

Registration

Participants

Cahill Logistics

Local Hotels

Summer S

The latest News: Sept. 2

**Palomar Tour After the Summe**

After the successful Summer School, v
pictures taken during the tour.

Update on the summer school, August

**Required Preparatory Wo**

The summer school has multiple hand
the instruction here to install the nec
start of the summer school.

- **Day 2: PTF and Other Surveys (Tuesday, 26 August 2014)**
  - Morning Session: 9:00am (Chair: Eran Ofek)
    - PTF Operation *(9:00-9:30)* [25+5] Tom Barlow
    - PTF Data Flow *(9:30-10:00)* [25+5] Jason Surace
    - IPAC Photometric Pipeline *(10:00-10:30)* [25+5] Russ Laher
    - *Break: 20 minutes*
    - PTFIDE & Forced Photometry *(10:50-11:20)* [25+5] Frank Masci
    - IPAC PTF Archive *(11:20-11:50)* [25+5] Jason Surace
  - Lunch Break
  - Afternoon Session: 1:30pm (Chair: Tom Barlow)
    - NEO with PTF *(1:30-2:00)* [25+5] Adam Waszczak
    - Streakers with PTF *(2:00-2:30)* [25+5] Adam Waszczak
    - PTFMOPS *(2:30-3:00)* [25+5] Frank Masci
    - *Break: 20 minutes*
    - ToO observations with PTF *(3:20-3:50)* [25+5] Leo Singer
    - PTF Data Caveats & Cautionary Notes *(3:50-4:05* [10+5] Mansi Kasliwal
    - ***Case Studies and Hands-on session with PTF data***
    - *Session 1:*
    - How to use PTF data to make light curves *(4:05-4:45)* [40 min] Adam Miller
    - Office Hours: questions-and-answers *(4:45- 5:15)* [30min] TAs

Python packages installation

# Accessing PTF FITS Catalogs

## Collecting Catalog Files

PTF SExtractor catalogs can be obtained from the IRSA PTF image archive. Images and source catalogs can be searched for via position or PTF field ID, more details are available on the PTF Data Access website. The example below uses source catalogs from images of the open cluster M44.

We begin with the assumption that the images have been downloaded and unzipped in the present working directory.

## Making a Light Curve: I. The Basic Solution

For PTF a nightly photometric solution is determined for each image (for further details see Ofek et al. 2012), thus, the easiest way to create a light curve for a given star is to grab its measured brightness on each of the PTF images. This is simple to implement in python using a for loop.

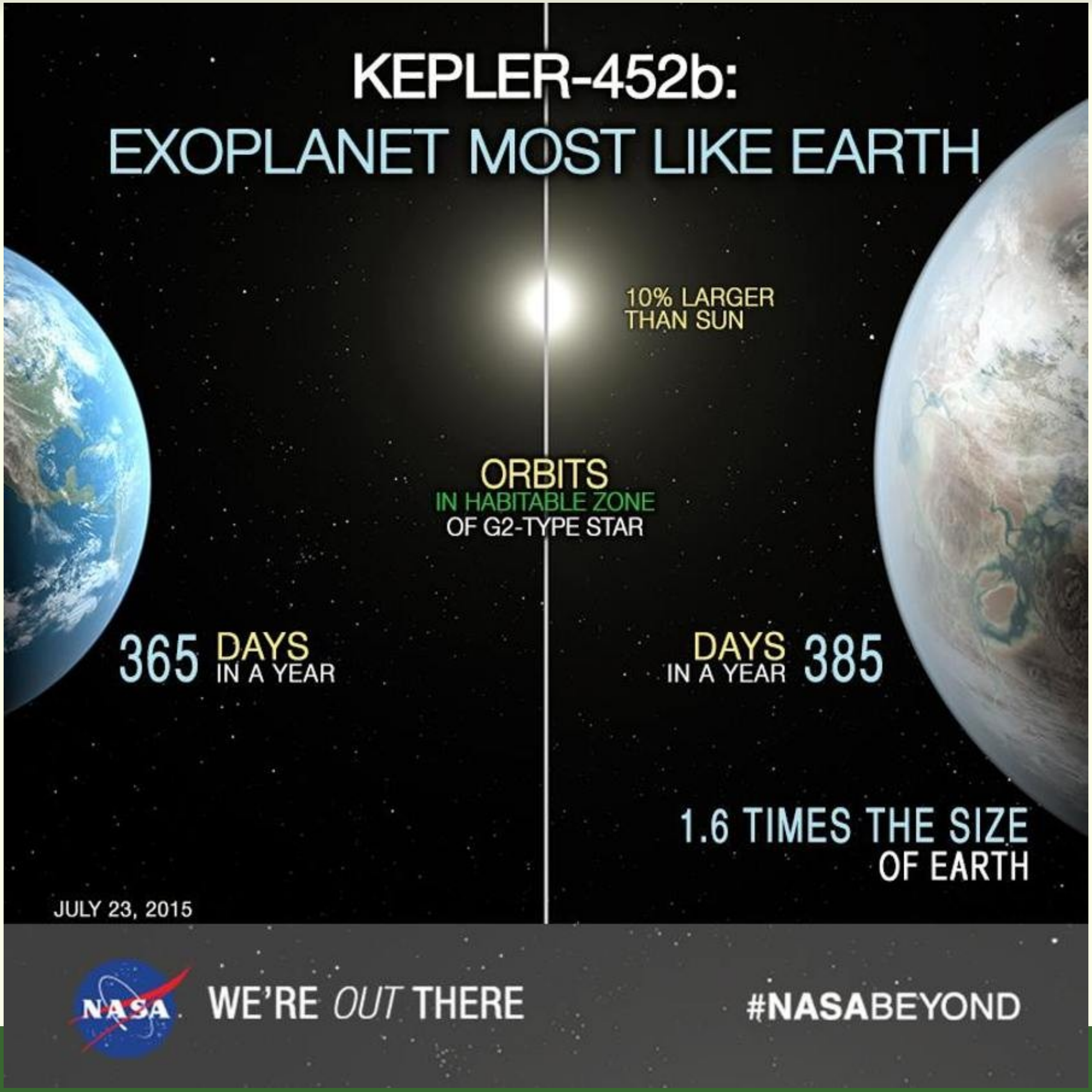
```
import numpy as np                      # array manipulation
import astropy.io.fits as fits            # fits file manipulation
import glob                            # to grab source files

files = glob.glob("PTF*ctlg")          # list of all source files
targ_ra = 128.86346                    # right ascension of target
targ_dec = 19.75875                    # declination of target
match_r = 2.0                          # source matching radius in arcesc
```

Python!!

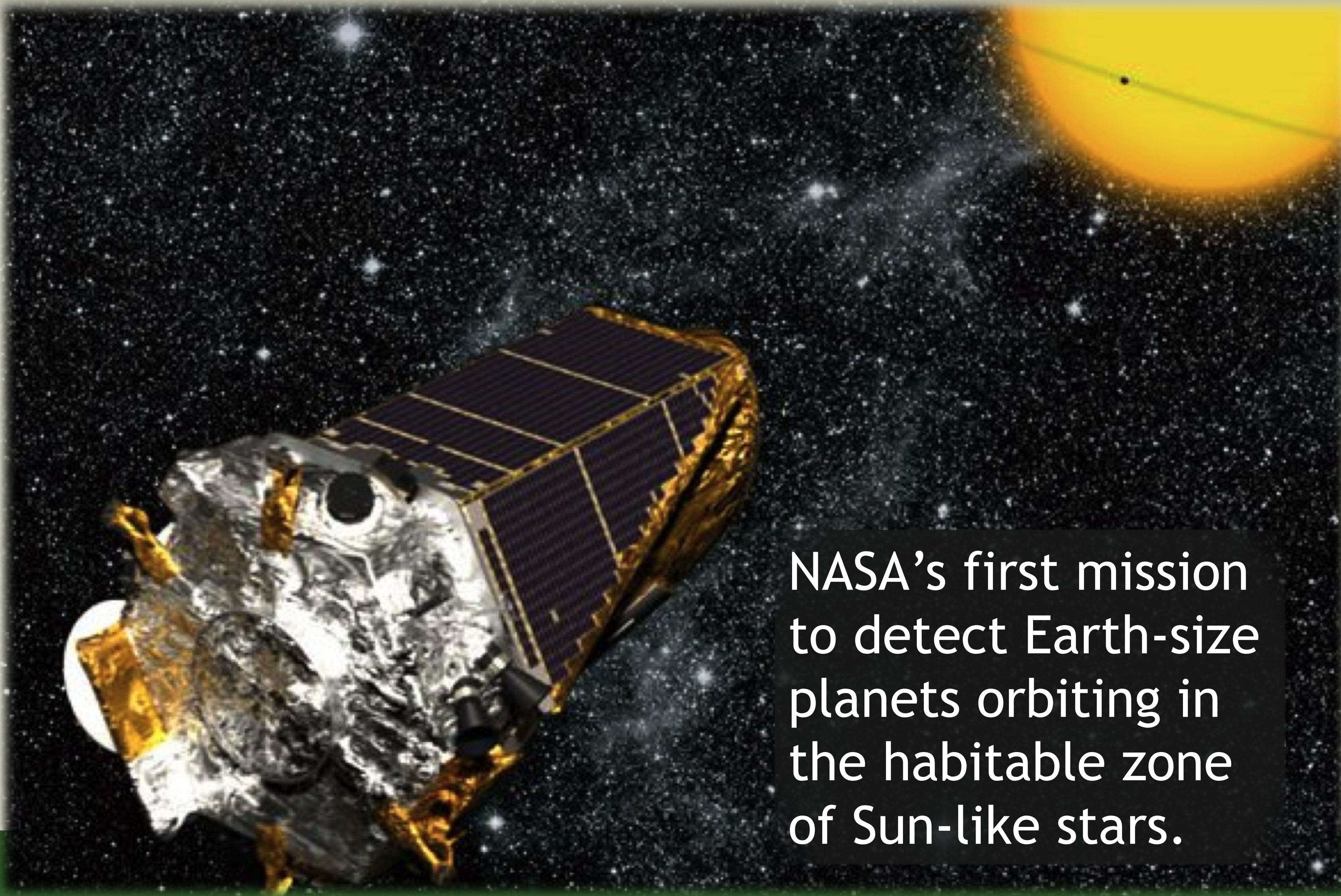
# PTF/iPTF/ZTF and NCU

- Our institution (IANCU) joined PTF in 2012 (last year of PTF) and fully participate in iPTF under the TANGO Project (PI: W.-H. Ip)
    - Science interest: asteroids and variable stars
- We plan to join the ZTF under TANGO-II Project
    - Year 1 funded, Year 2 and beyond pending on funding
- Participation to PTF/iPTF/ZTF under UST ( 台聯大 , both NCU and NTHU)

# Latest News on Kepler's Discovery

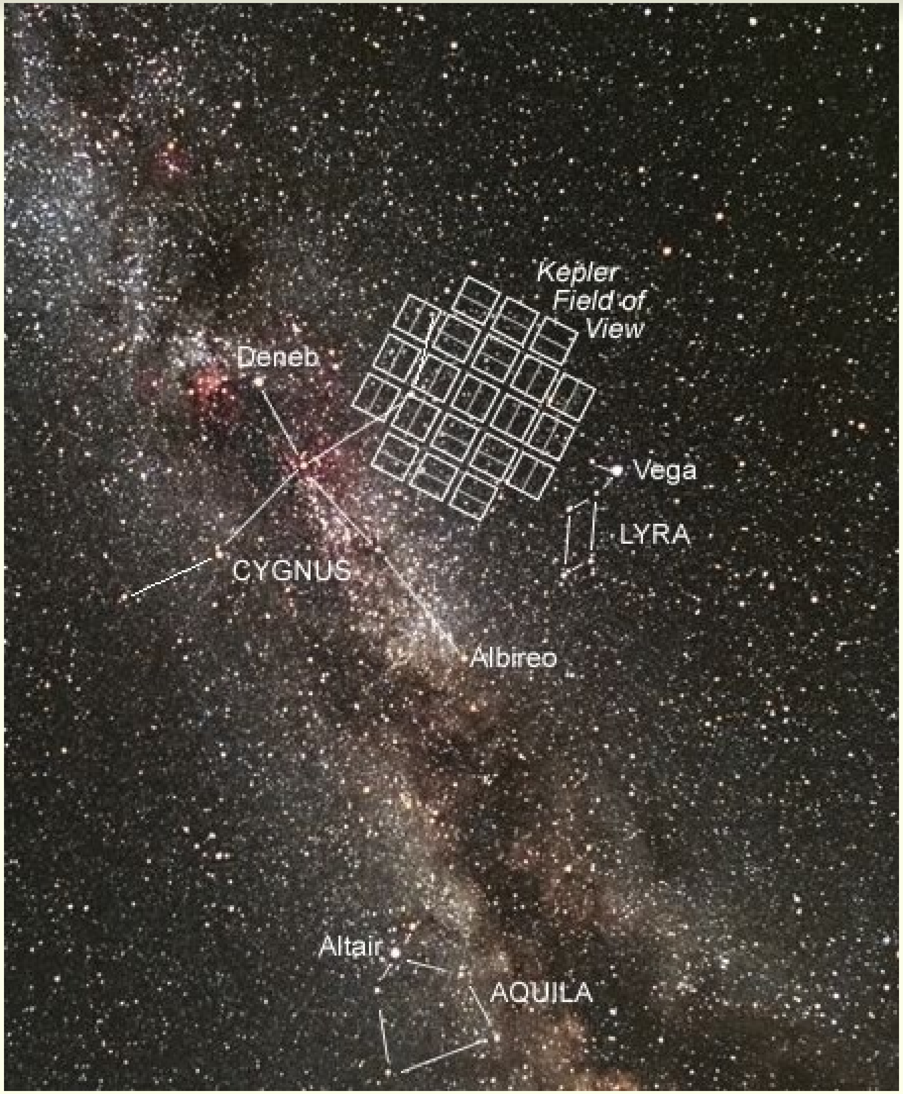


# NASA's Kepler Space Telescope



NASA's first mission to detect Earth-size planets orbiting in the habitable zone of Sun-like stars.

# Kepler's Mission: An Overview

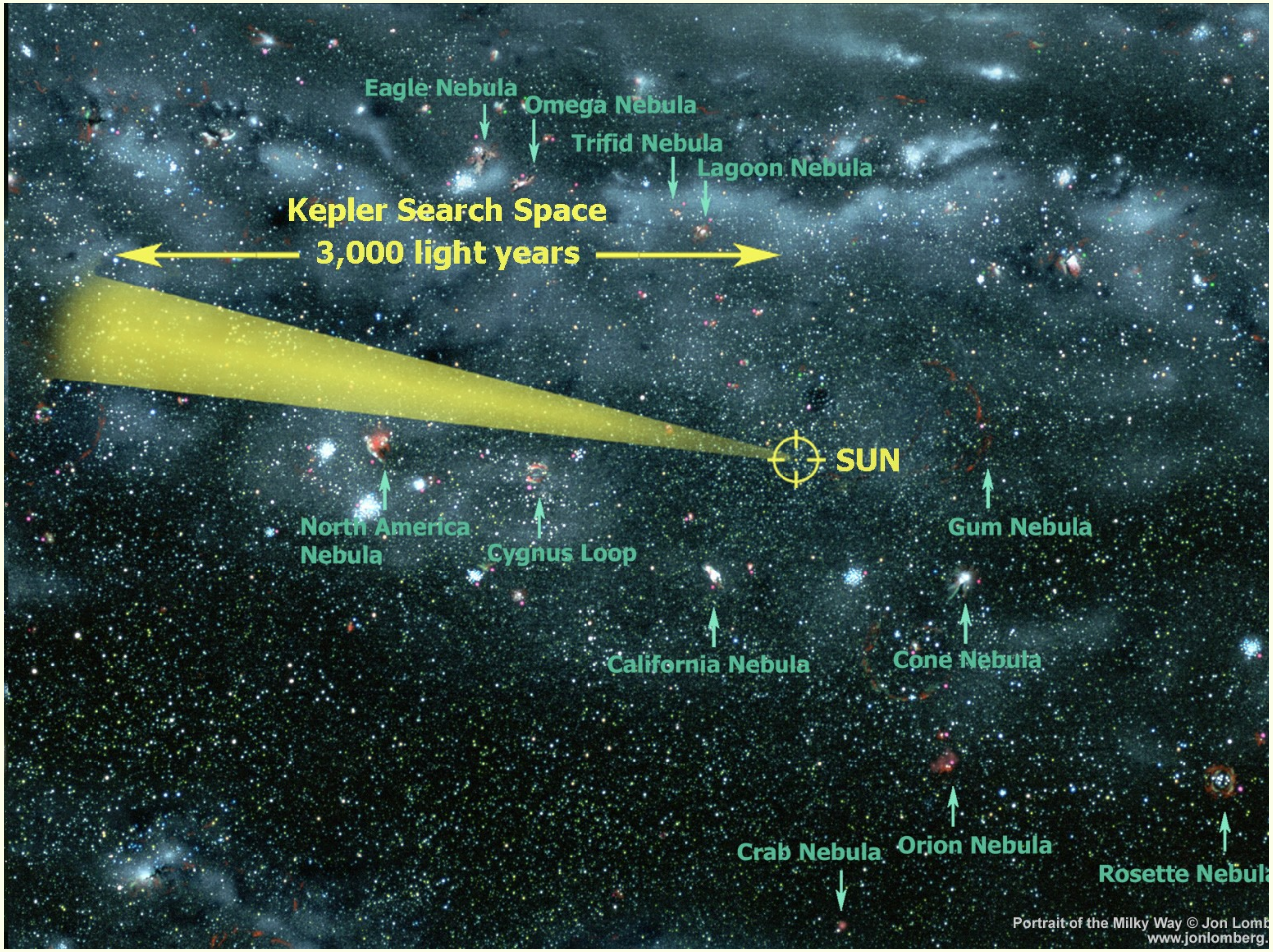



- NASA mission launched in 06 March 2009
- 105 square degrees (10° x 10°) just above galactic plane in the constellation Cygnus (and Lyrae)
- Single field for ~4 years, 150,000 stars 30 minute sampling, 512 at 1 minute

  → BIG DATA!

Continuously and simultaneously monitoring same area of sky!

# Kepler's Observations

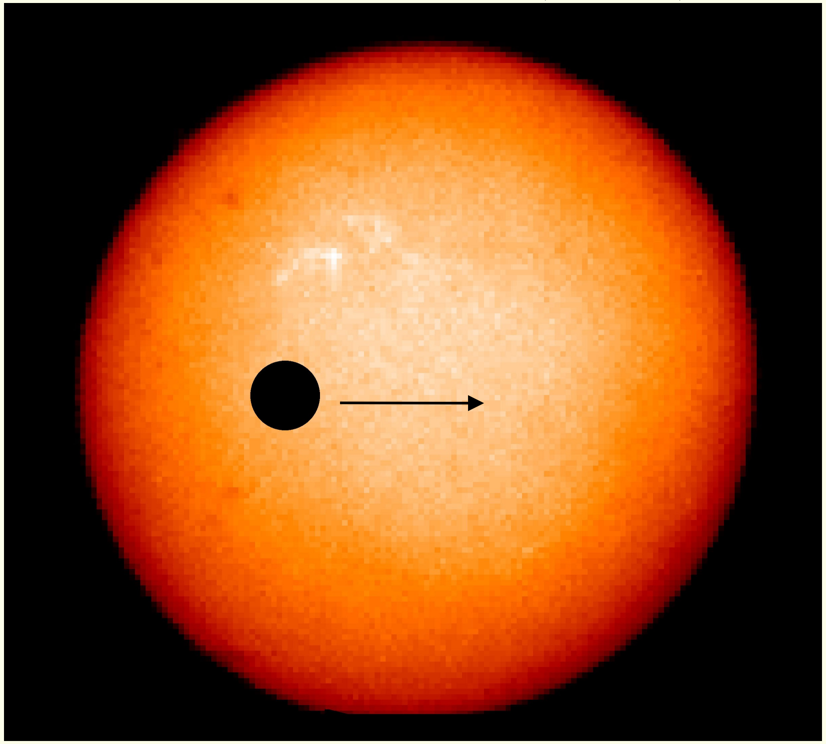



To detect two or more orbits of each planet orbiting in the habitable zone of sun-like stars.

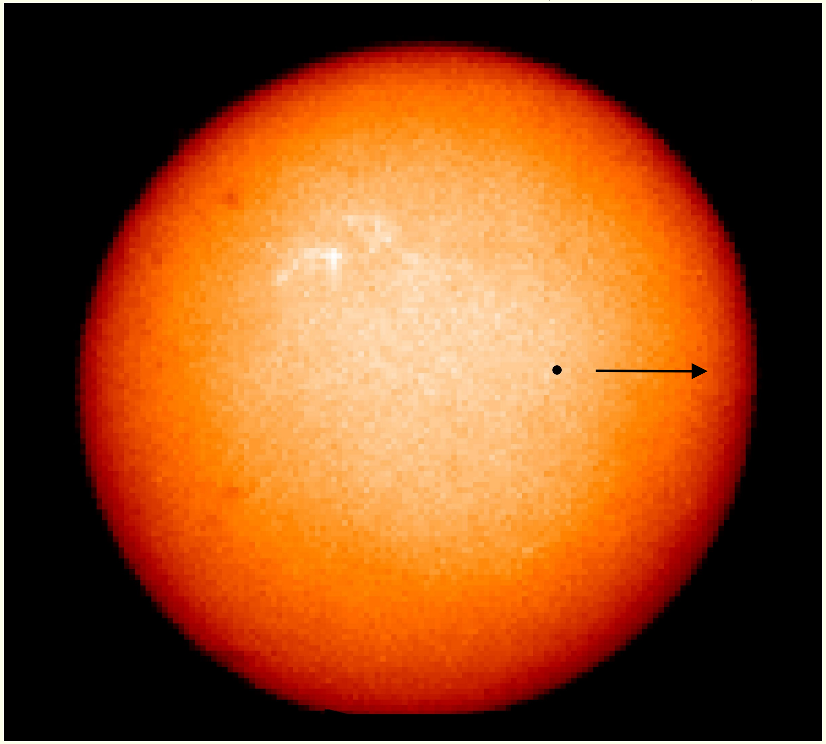
The probability that a planet in the habitable zone is aligned properly to transit the star is about 0.5%.

# Kepler's ST Main Goal: Detecting Exo-Planets Transits

Size of Jupiter:
1% area of the Sun (1/100)

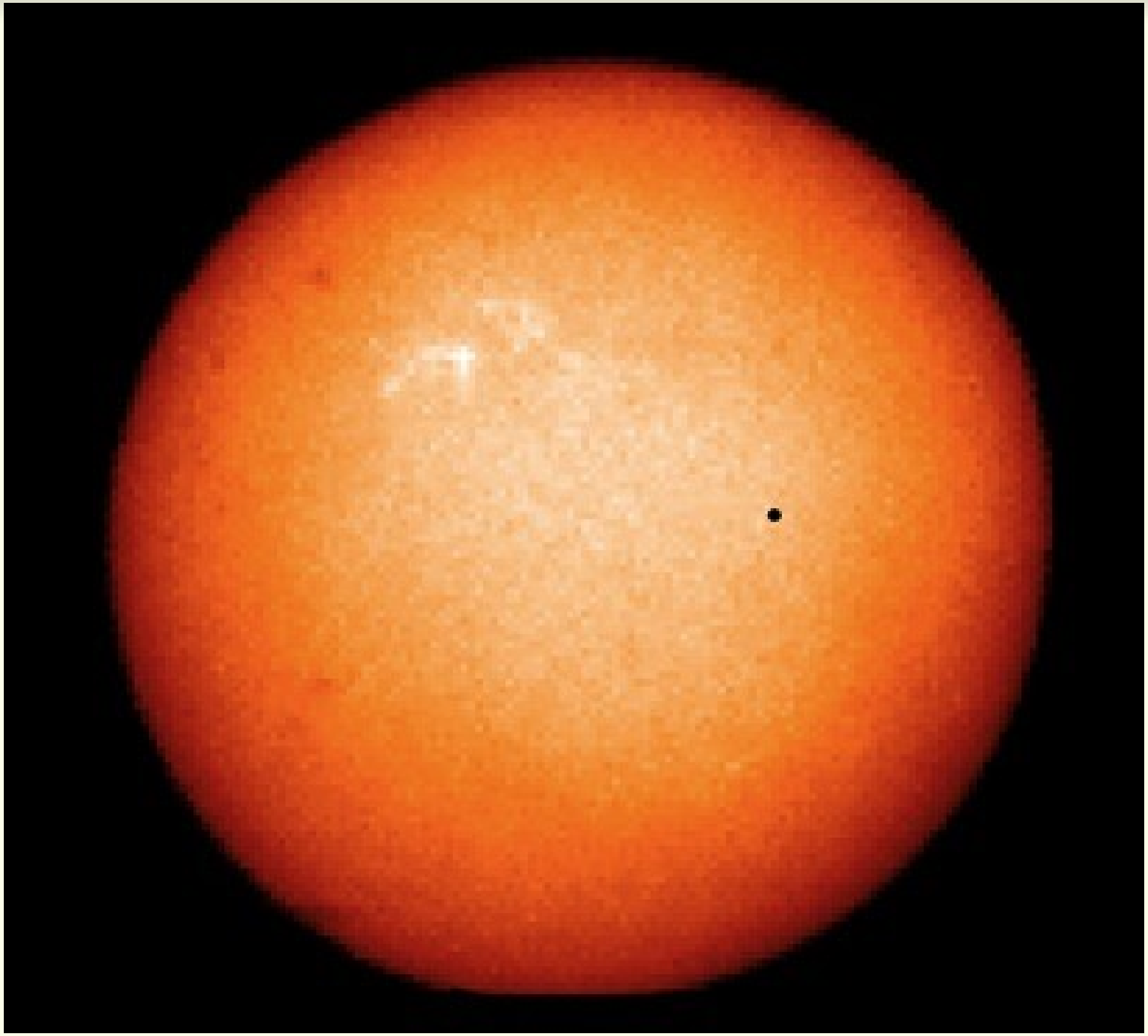


Size of Earth or Venus:
0.01% area of the Sun (1/10,000)



A transit occurs when a planet crosses the line of sight between an observer and a star and blocks a small amount of light from the star, causing the light from the star to dim slightly for a few hours.

# Stars Are Very Far Away …



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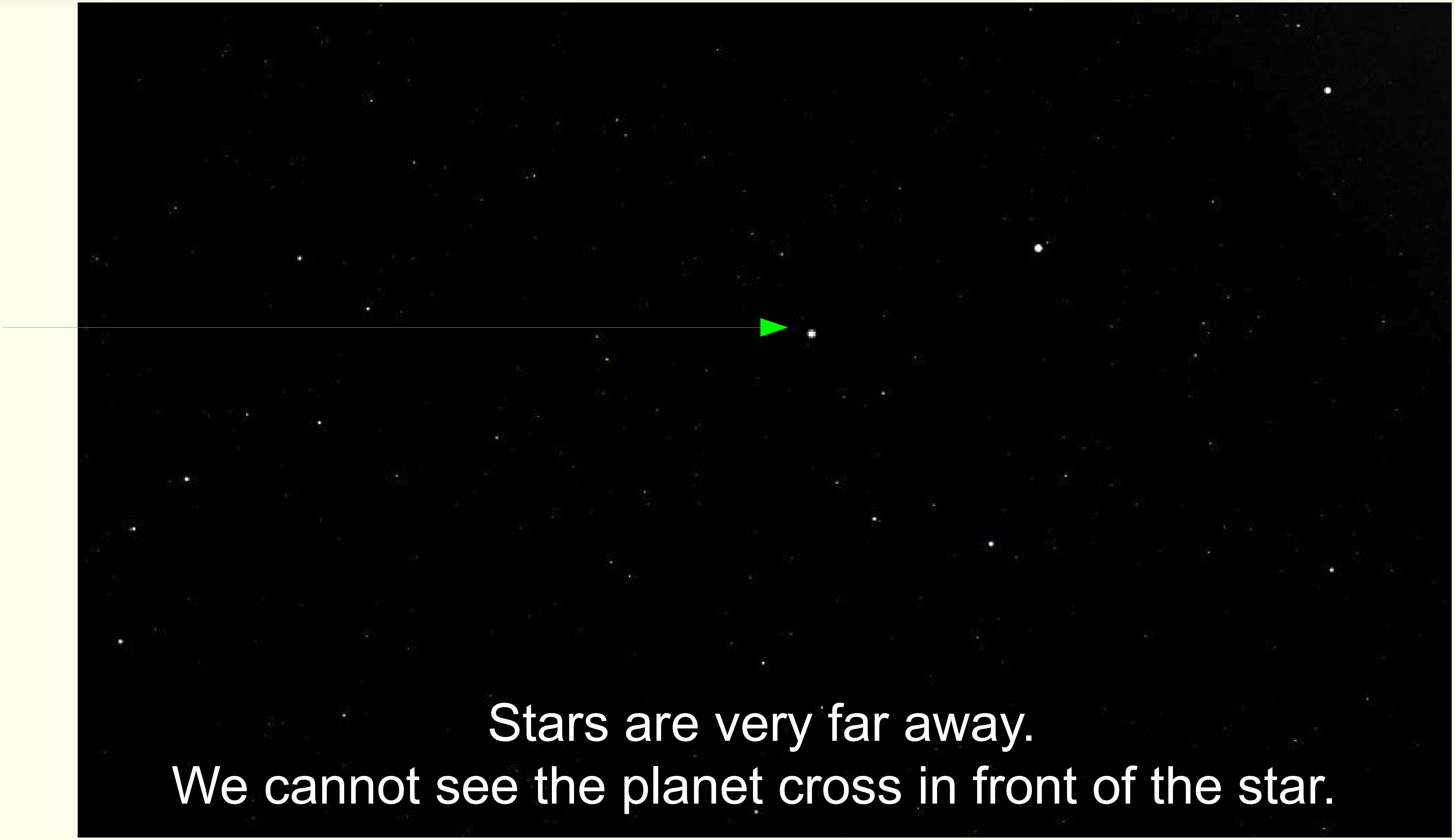
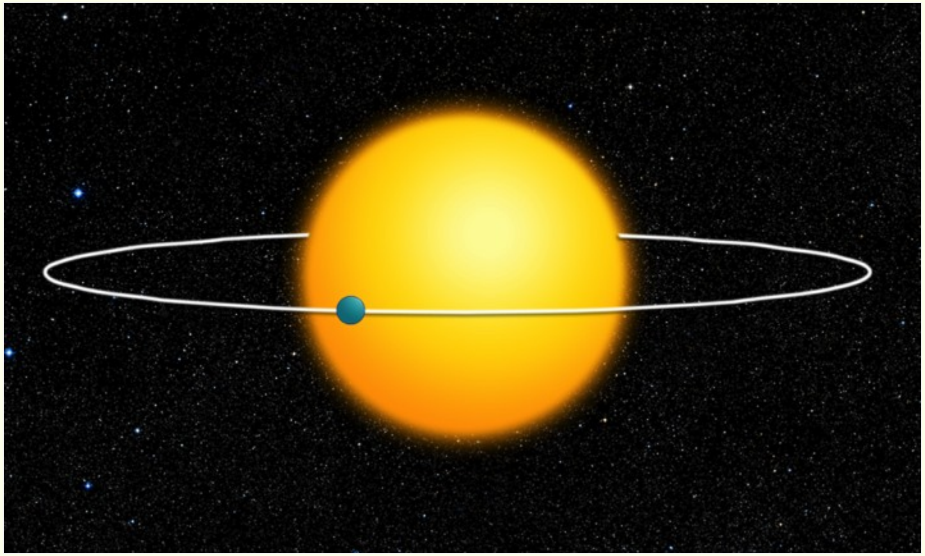
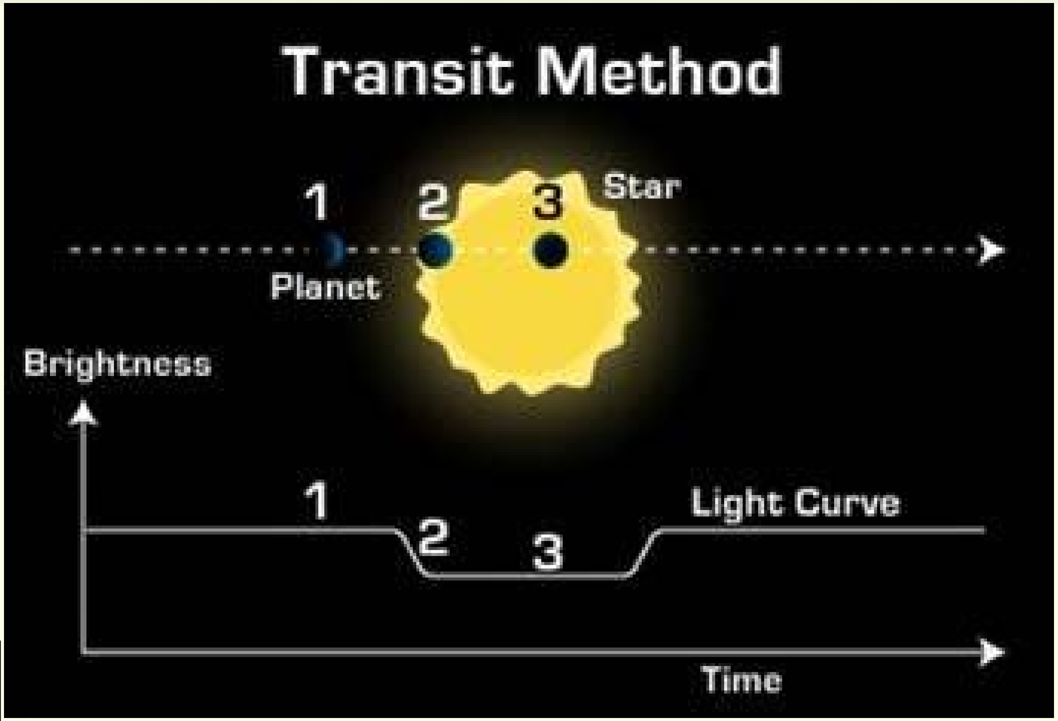
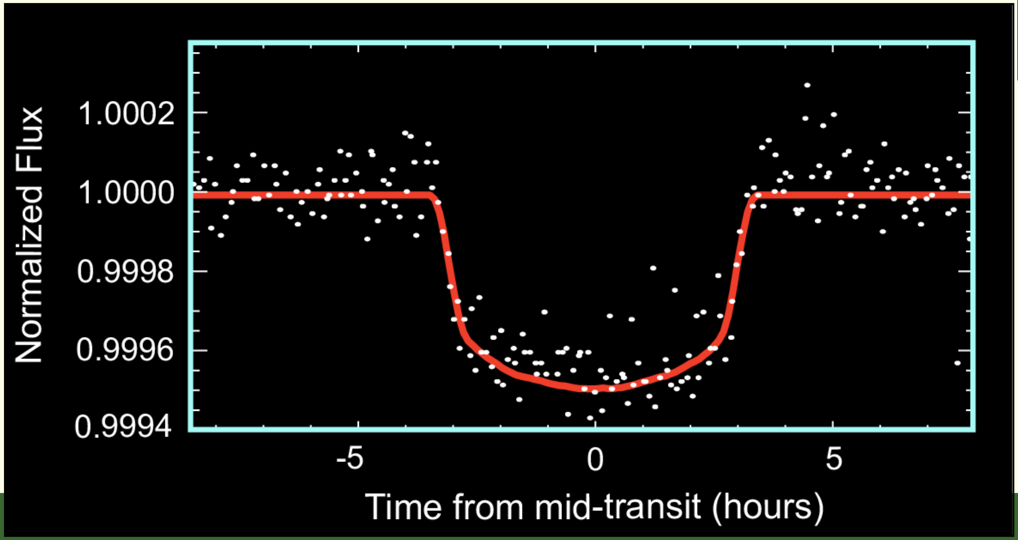


# The Transit Technique

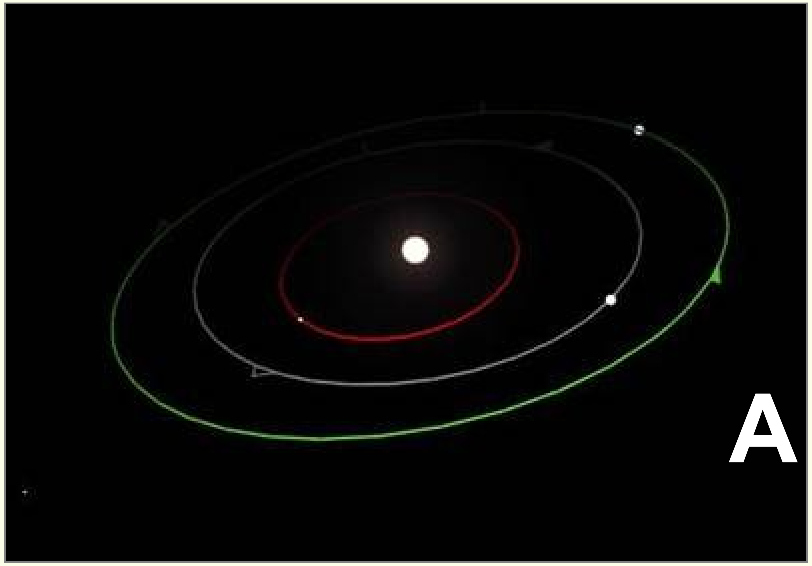


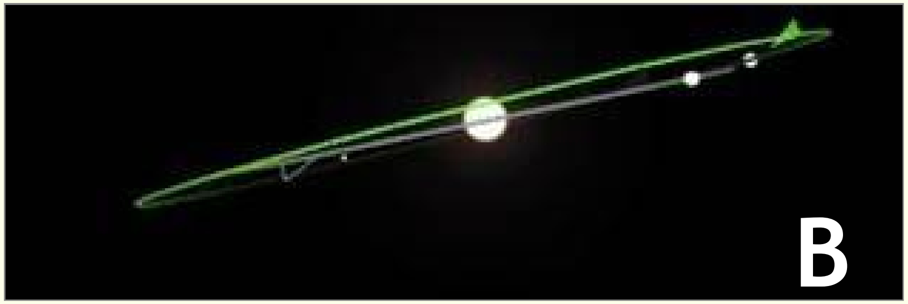


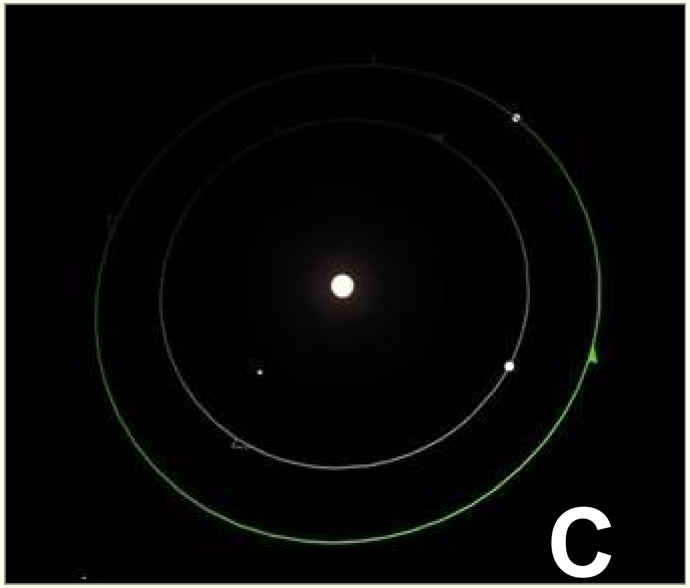




# Orientation of the Planetary Systems

For which of these systems would Kepler be able to detect transiting planets?



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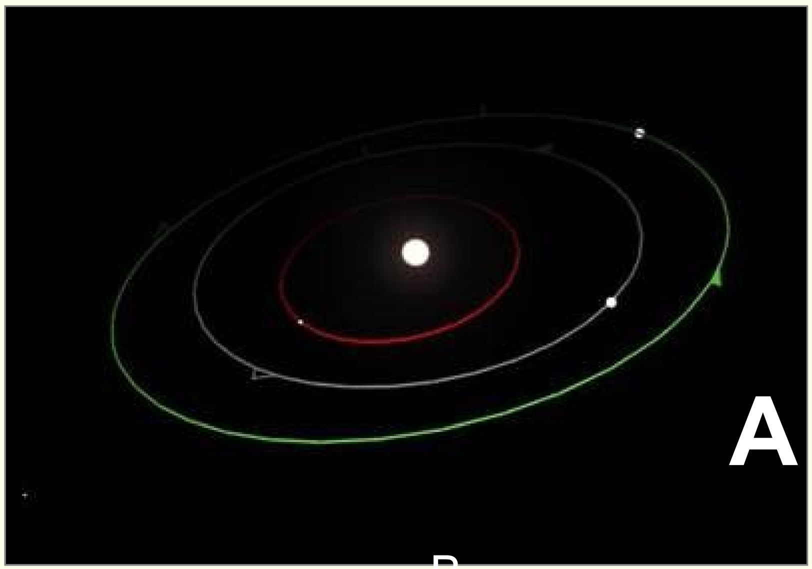
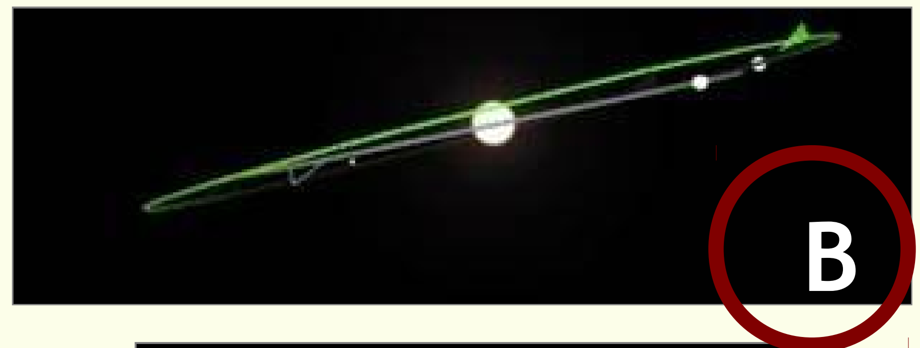
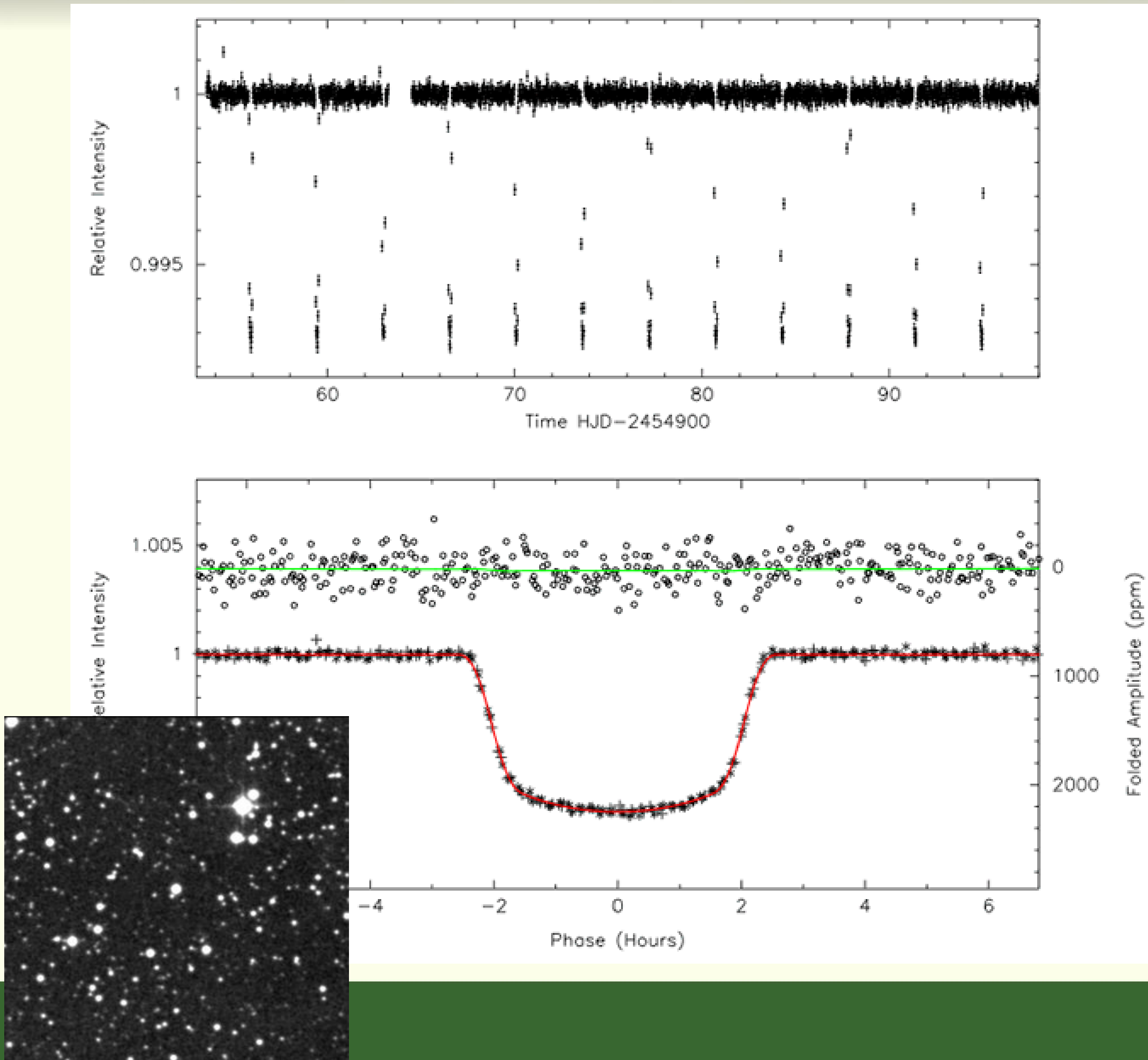


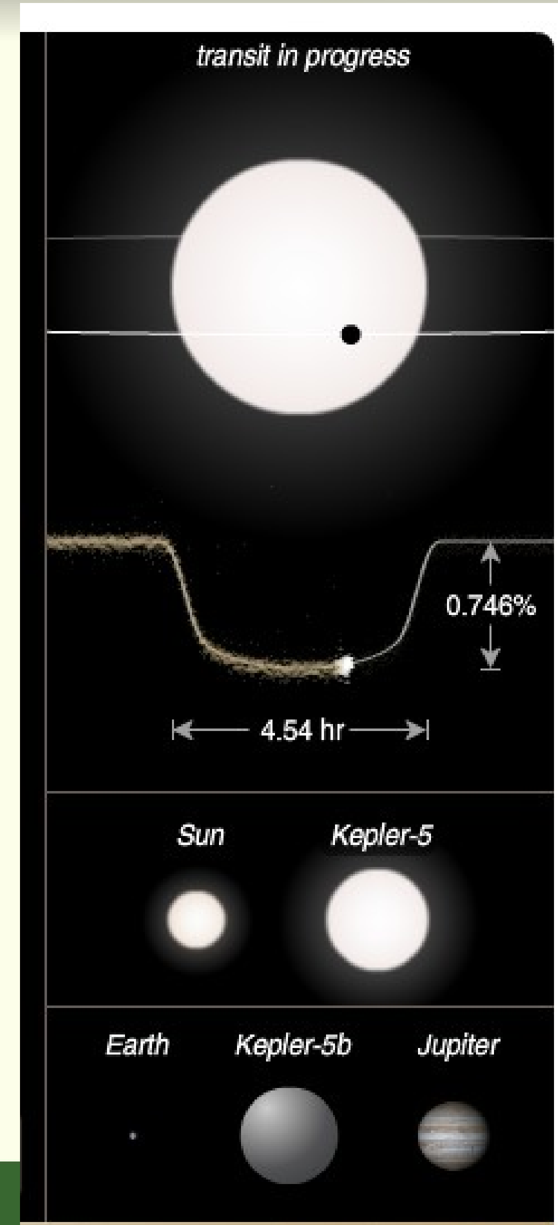





The star's planets must orbit the star edge-on from our viewpoint! Not all planetary orbits are aligned this way . So we must watch thousands of stars to find several that are correctly oriented.

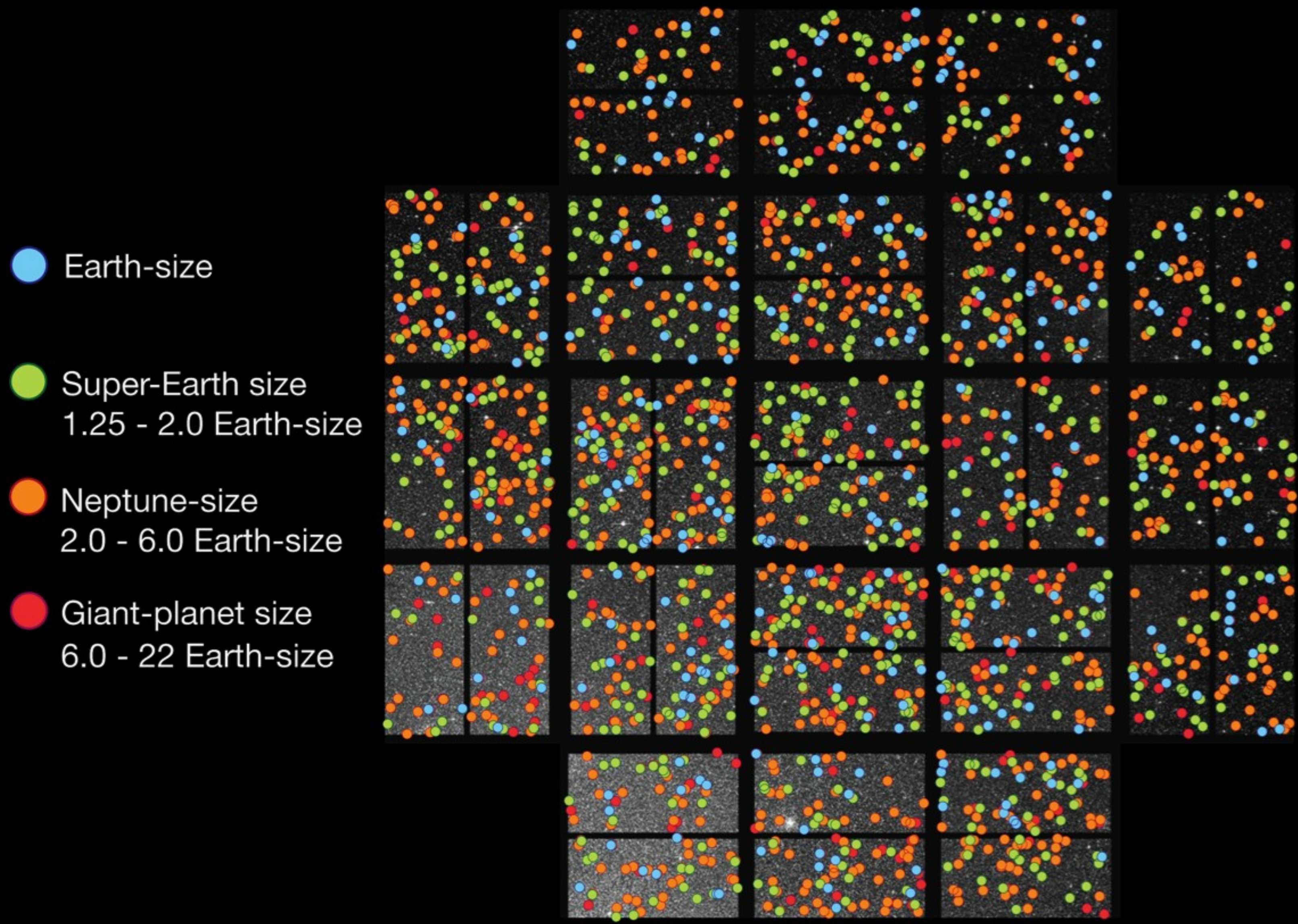
# Example: Kepler 5-b Light Curve



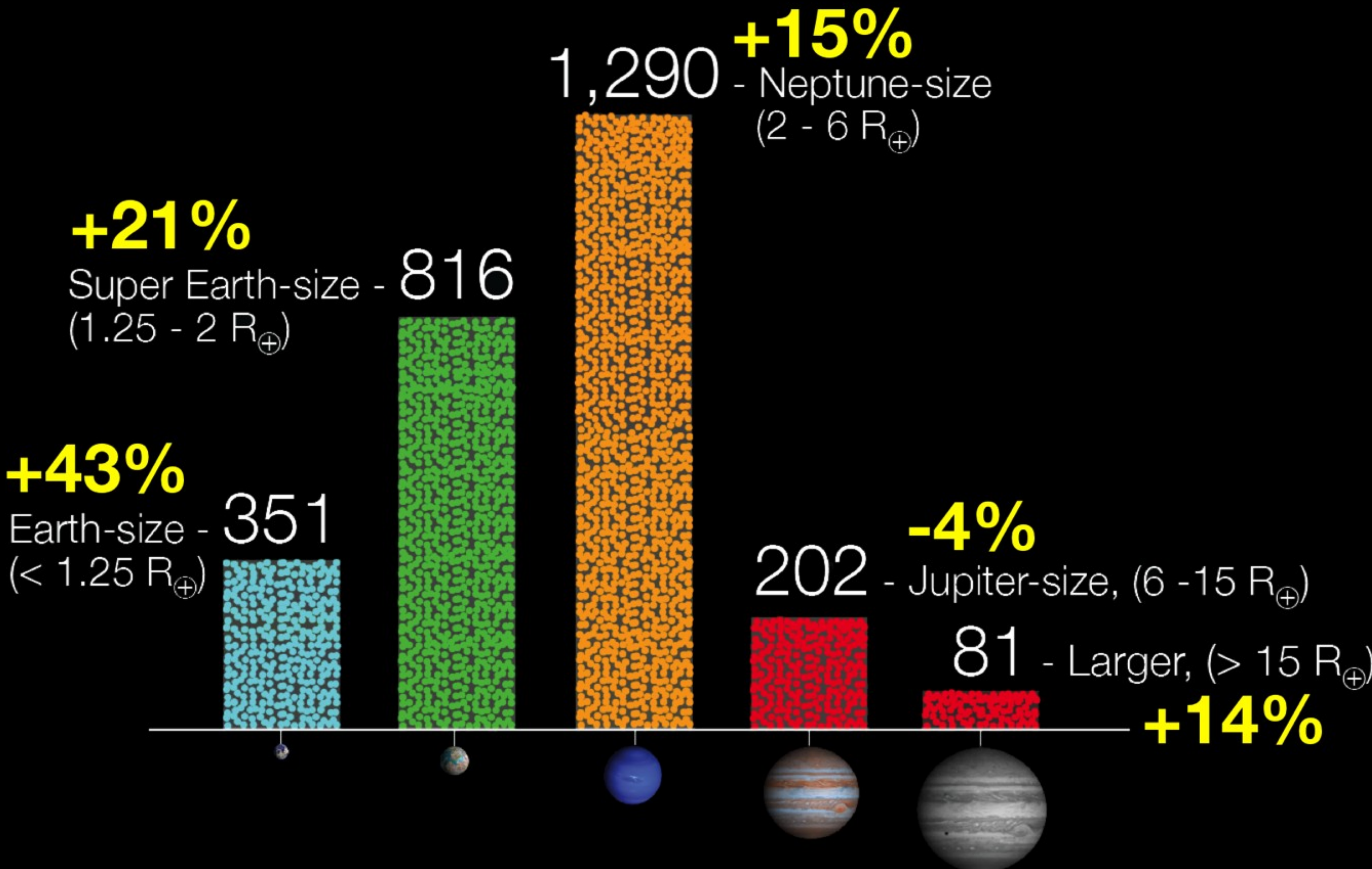
# Locations of Kepler Planet Candidates

*As of January 7, 2013*



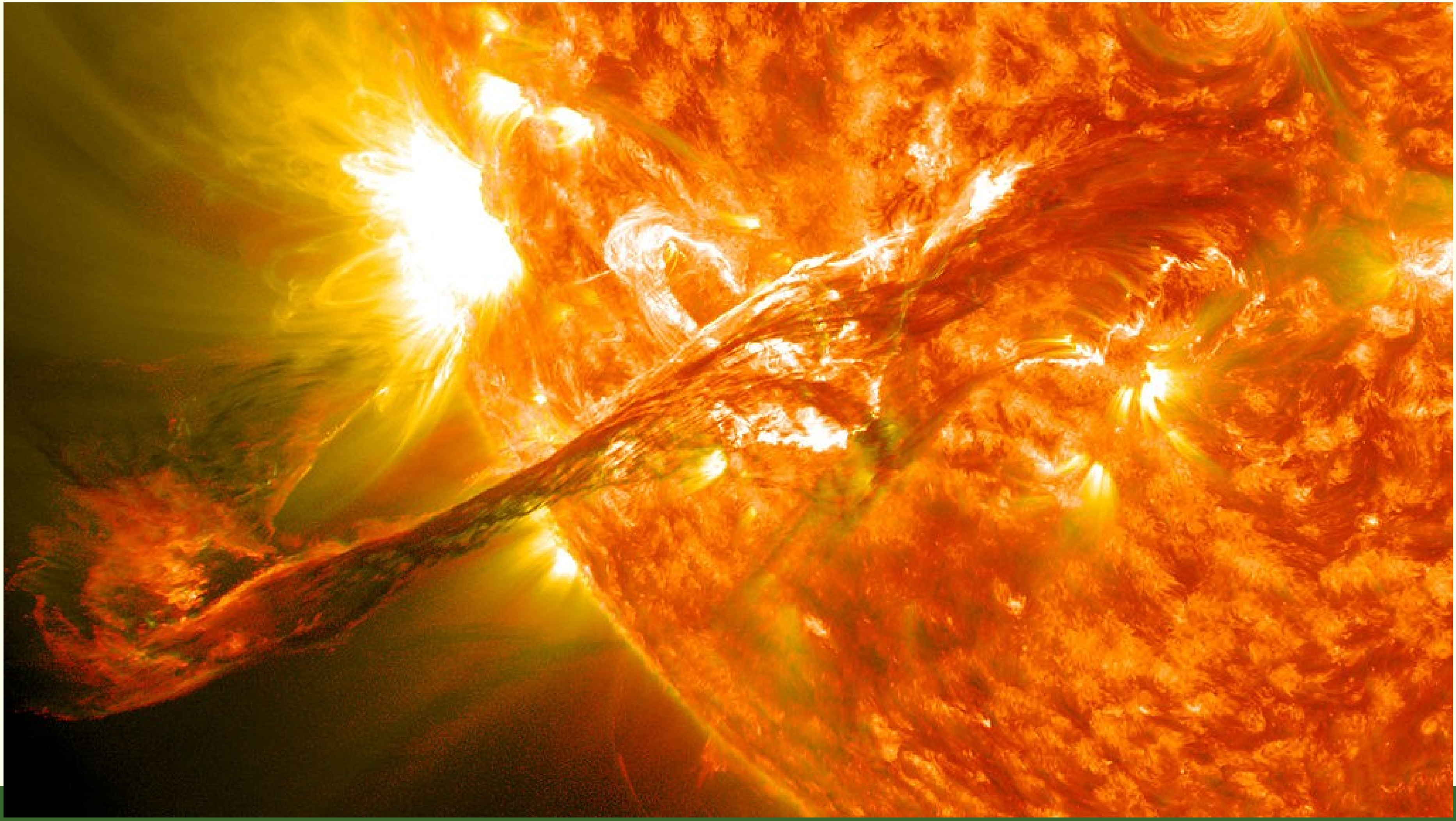
# Sizes of Planet Candidates

*As of January 7, 2013*

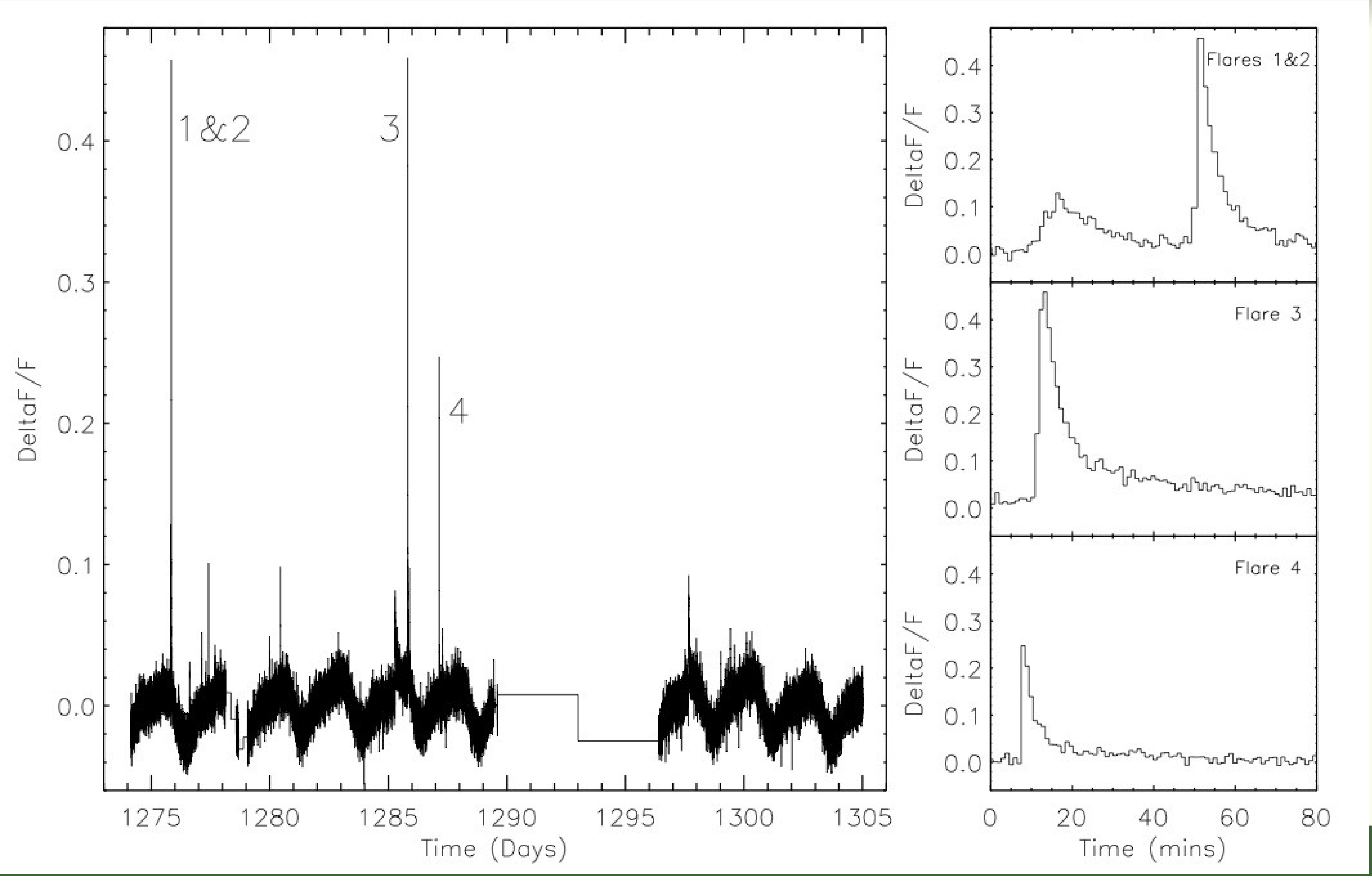


# Not Just Transit: Kepler's Flare Stars

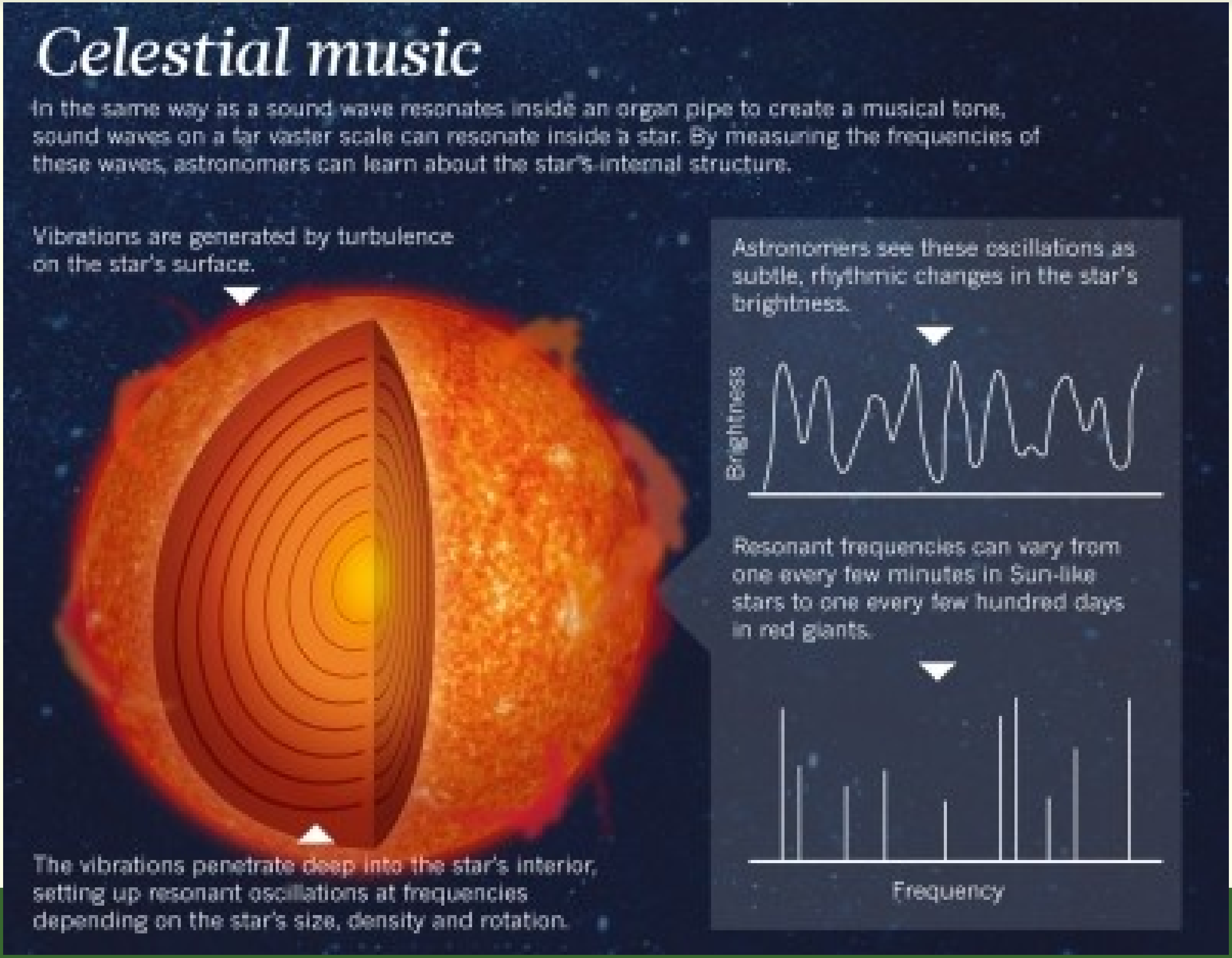
- Stellar flares: unpredicted eruption of corona's flares



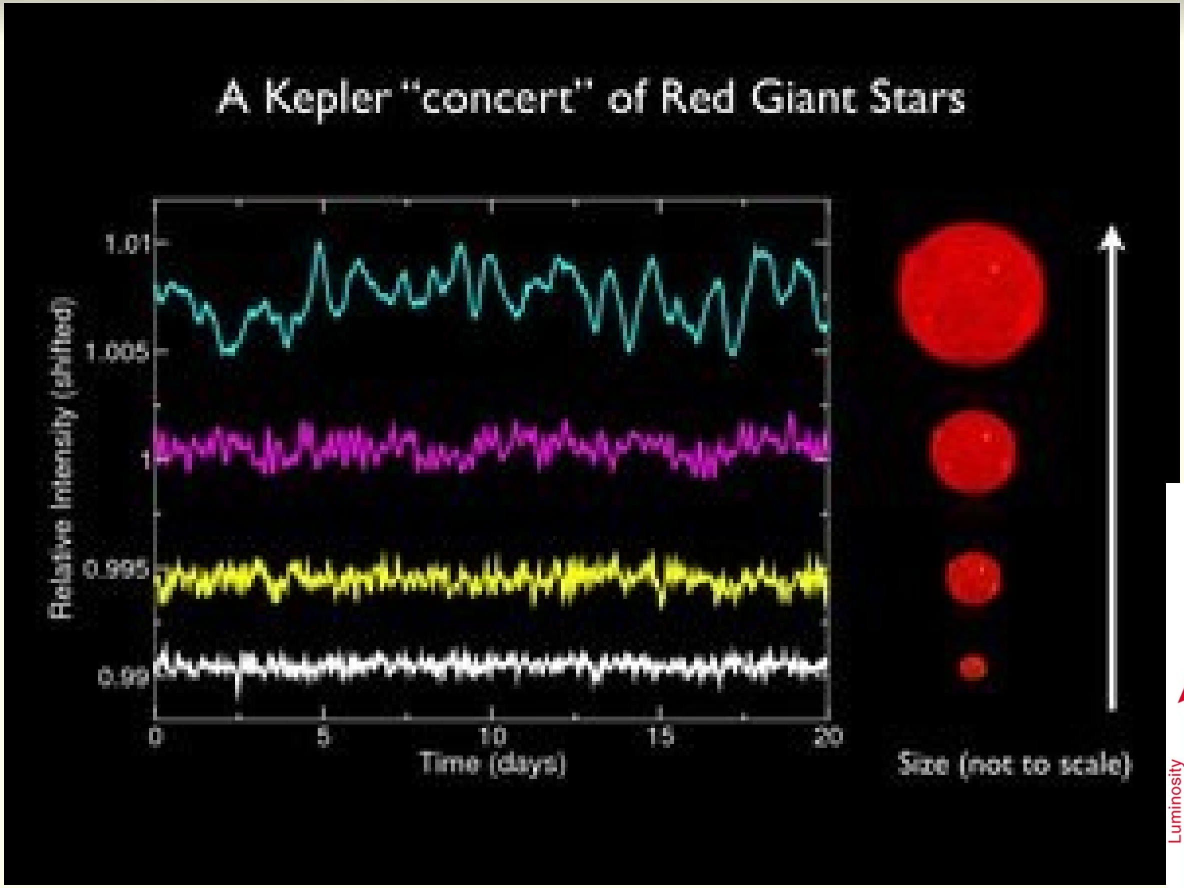
# Not Just Transit: Kepler's Flare Stars



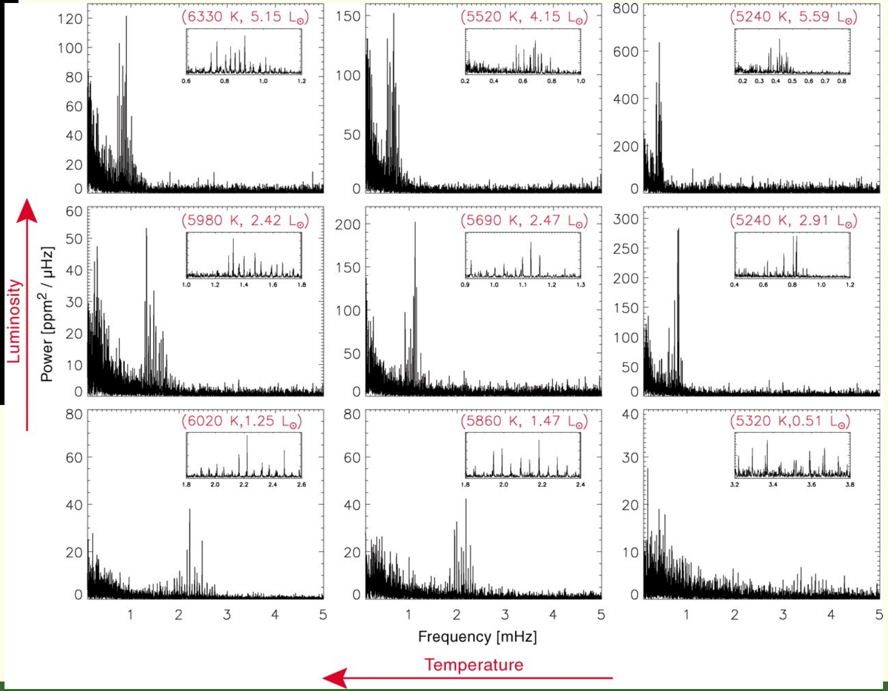
# Not Just Transit: Asteroseismology



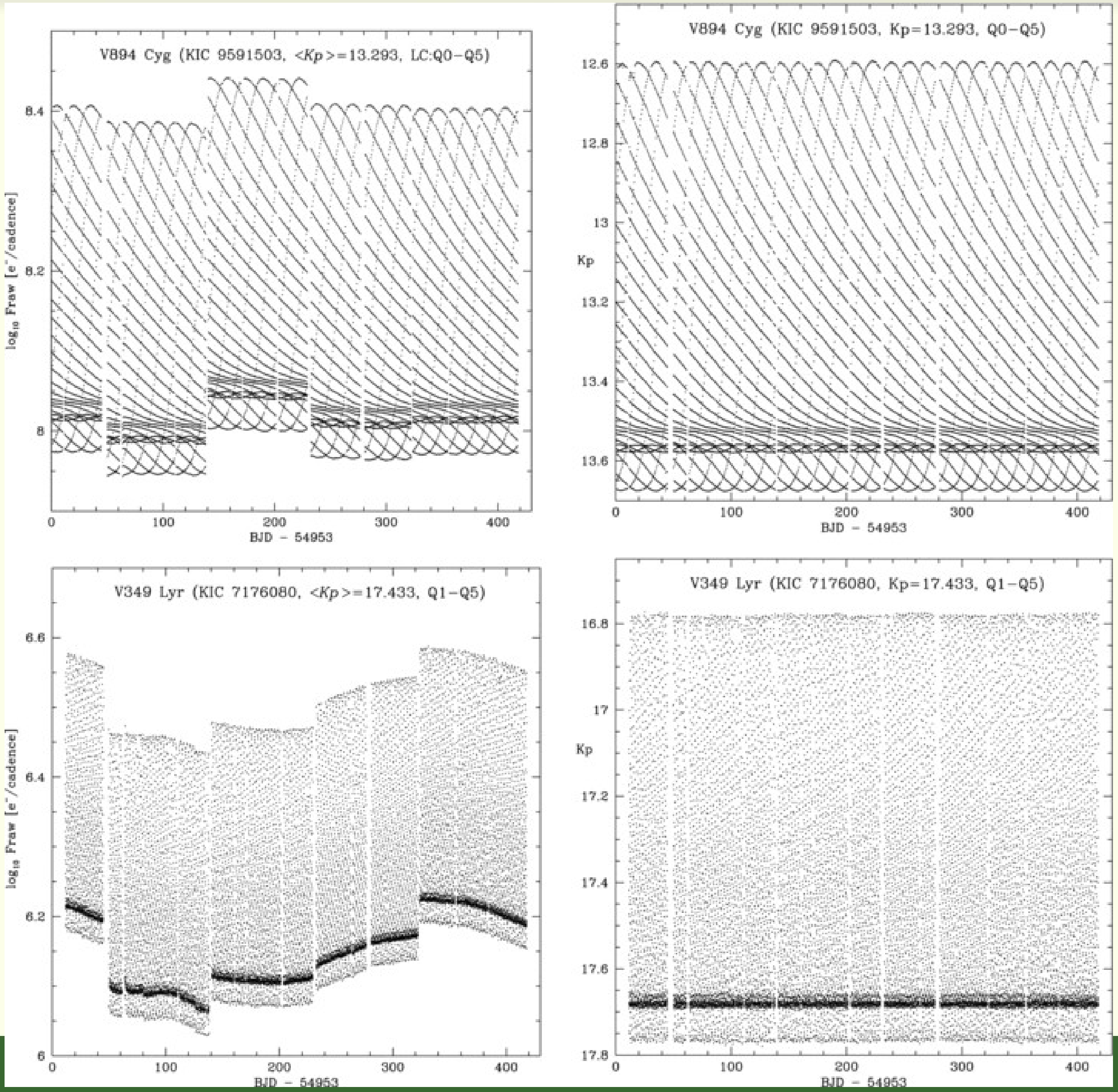
# Not Just Transit: Asteroseismology



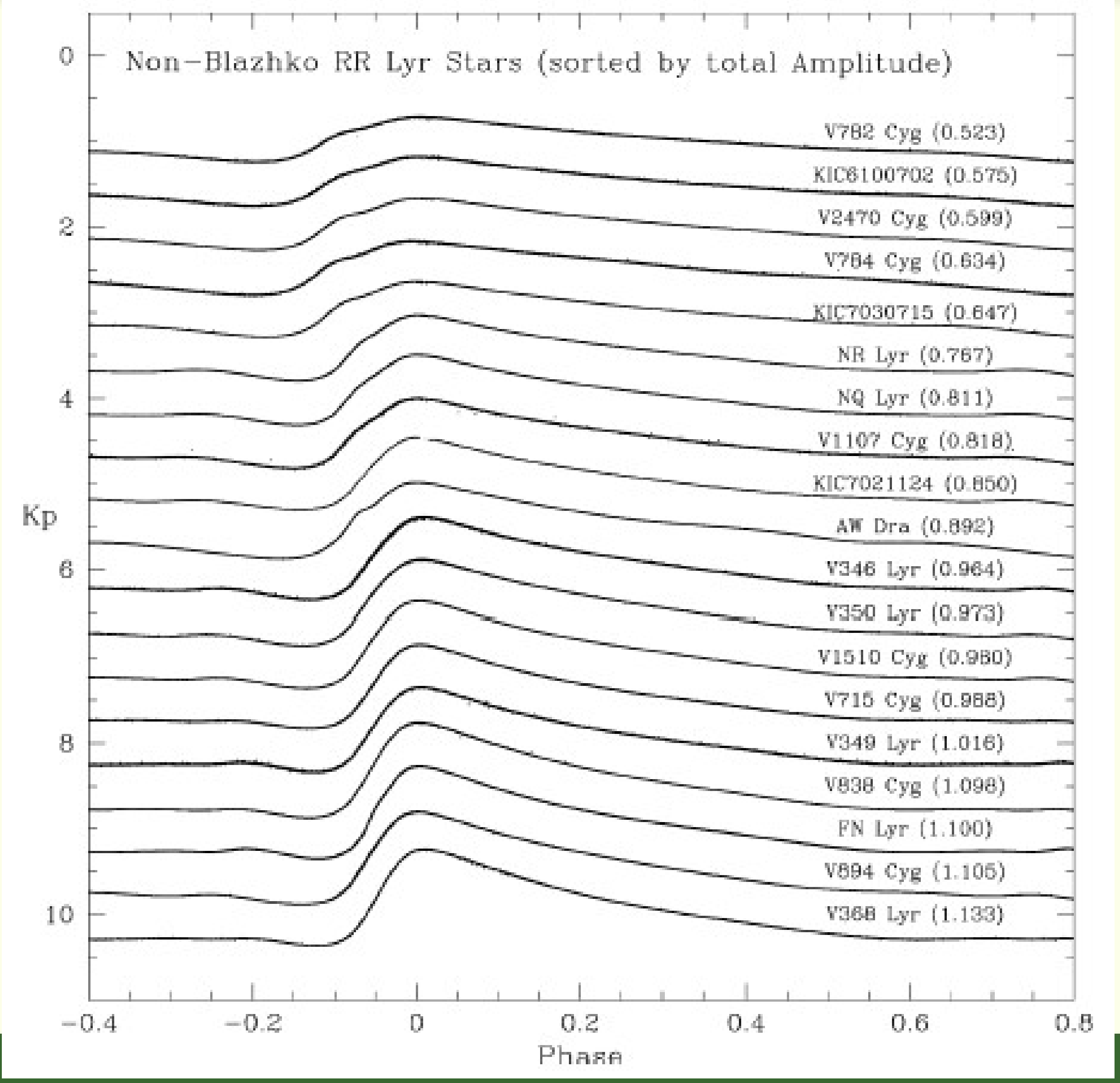

"continuous" light curves data is key success



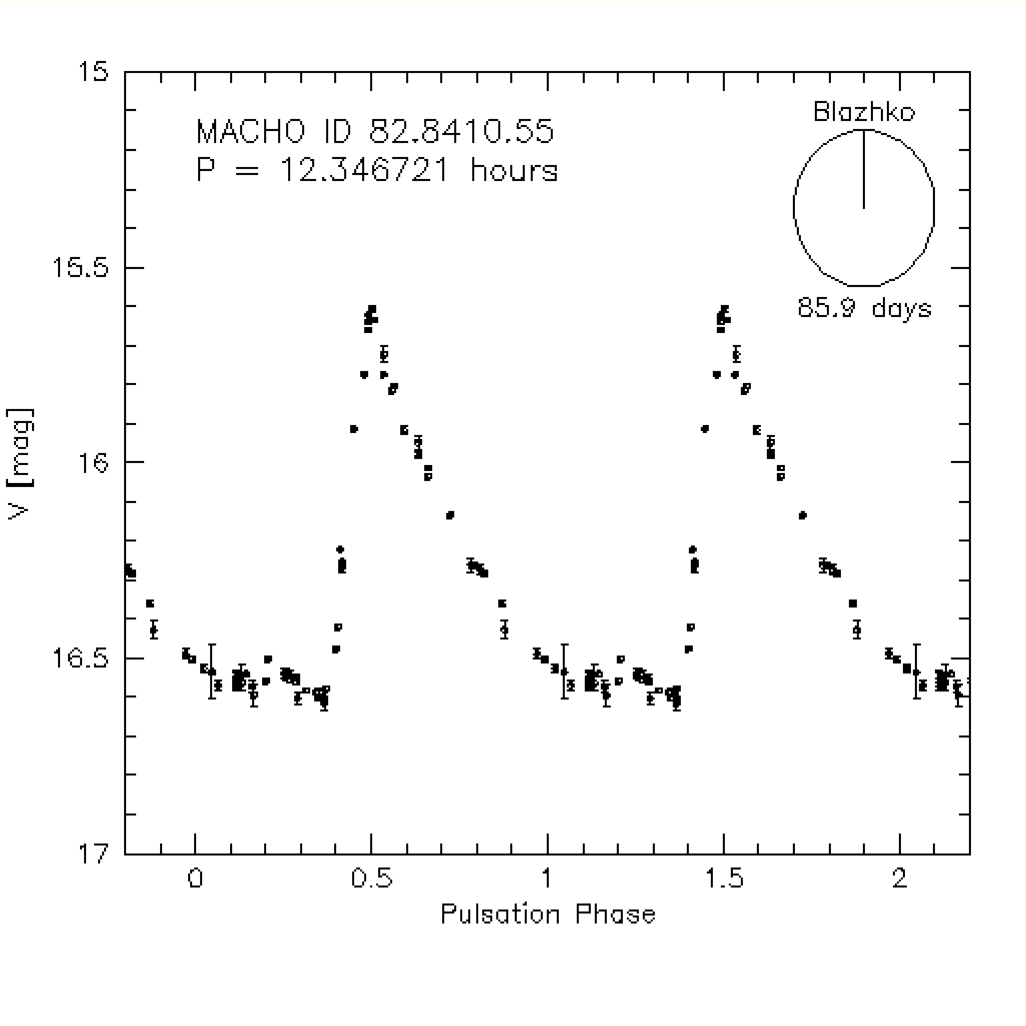
# Not Just Transit: RR Lyrae



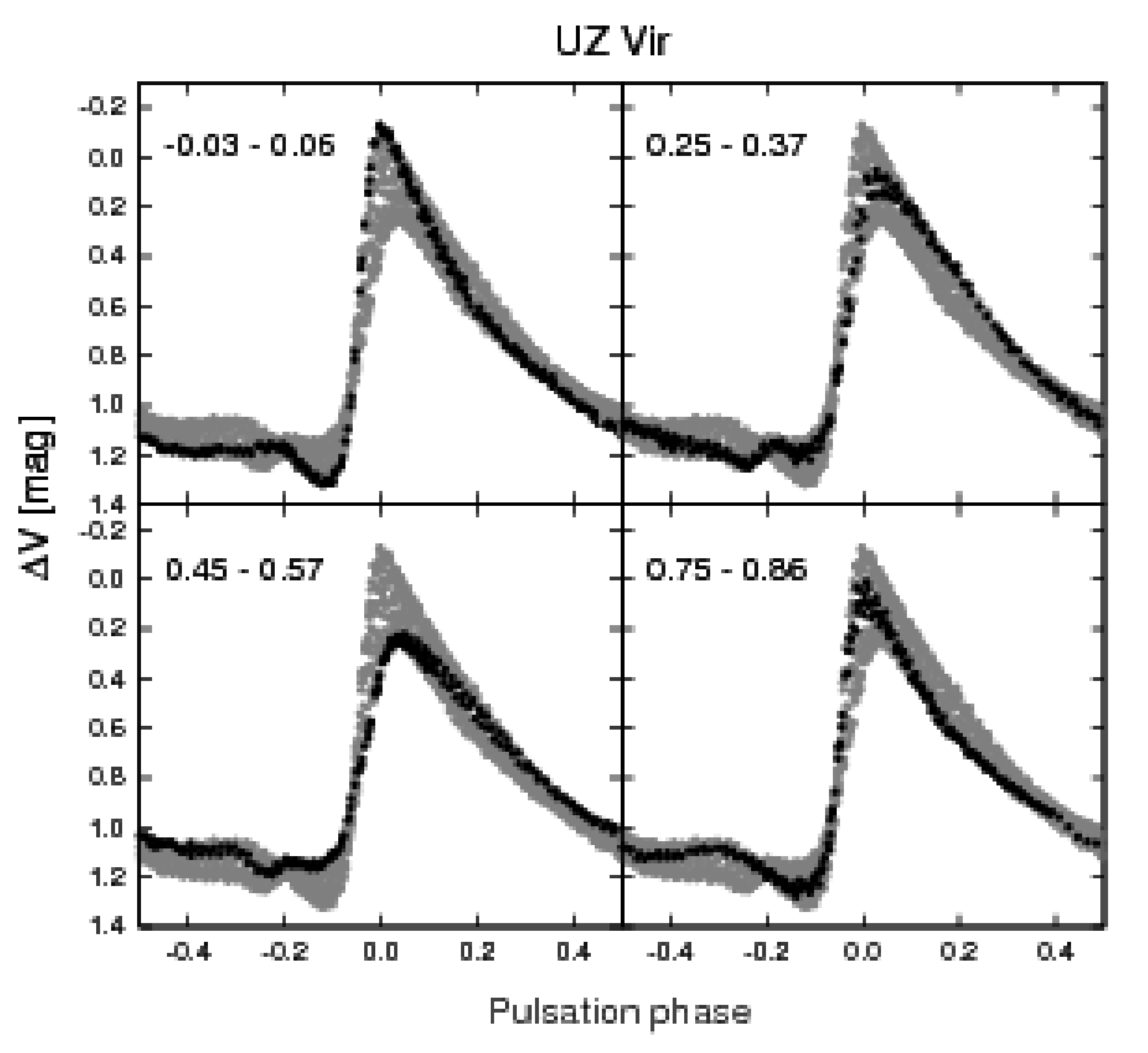
# Not Just Transit: RR Lyrae



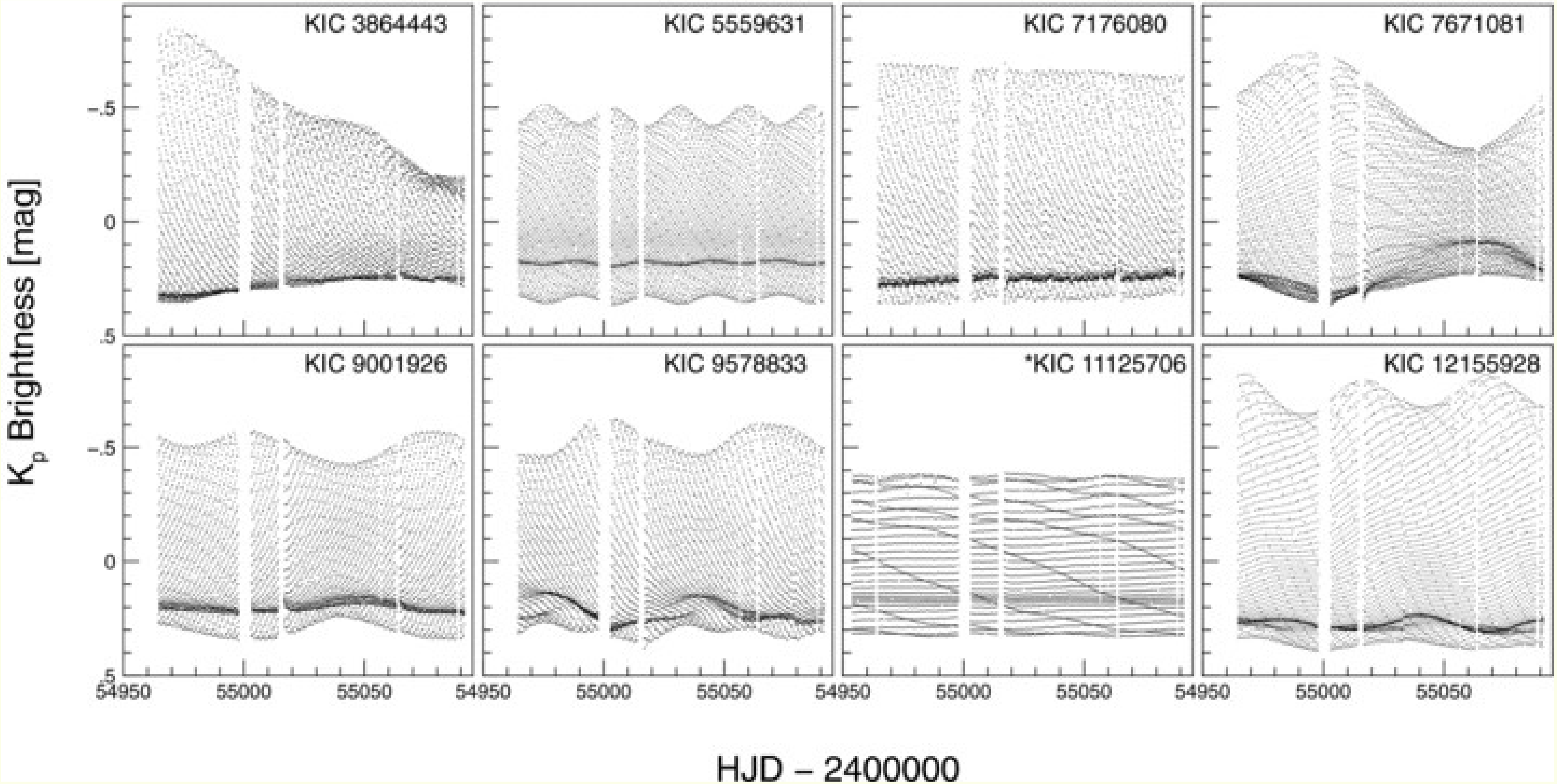
# The Blazhko RR Lyrae



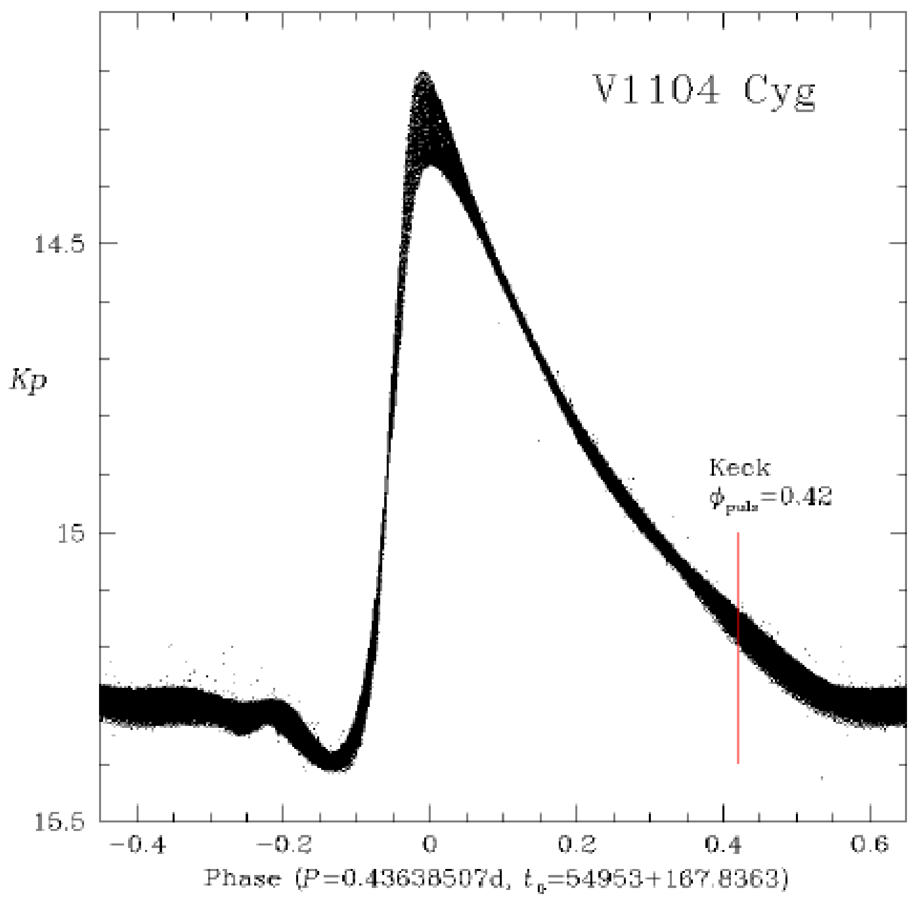
# The Blazhko RR Lyrae

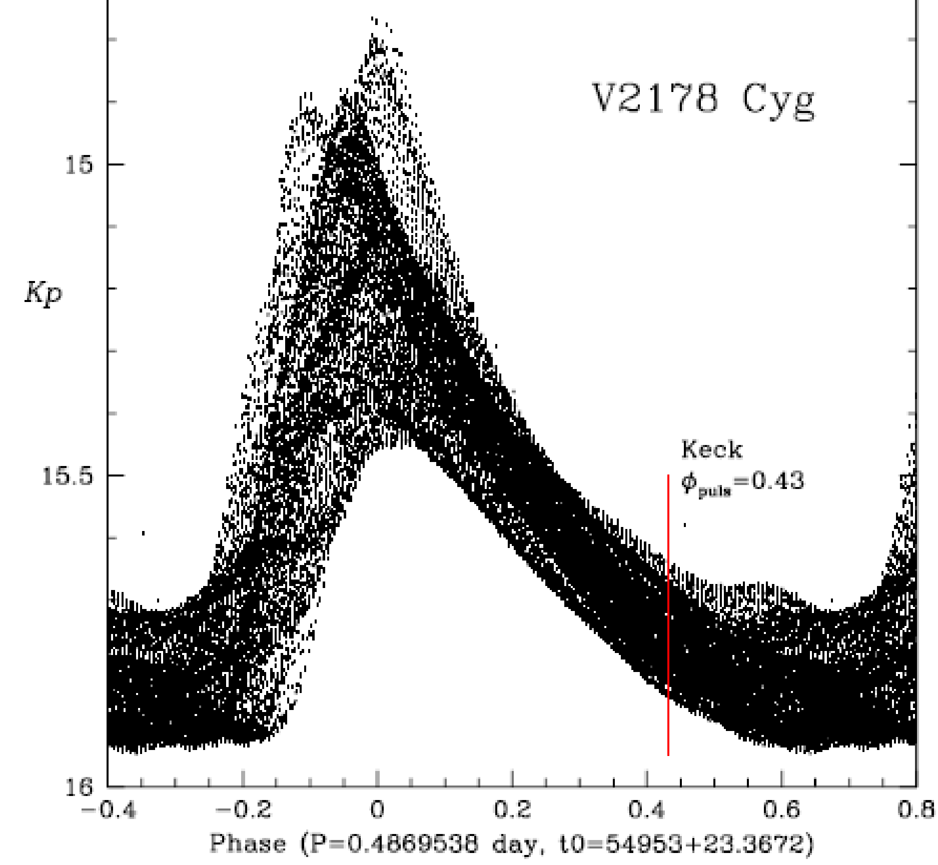


# Not Just Transit:
# RR Lyrae with Blazhko Effect



# Not Just Transit: RR Lyrae with Blazhko Effect



# RR Lyrae's [Fe/H]-Light Curve Relation

- RR Lyrae: Old population II periodic (P~0.3 to ~0.8 days) pulsating variables located in horizontal branch (HR diagram)
    - Constant absolute V-band magnitude → standard candle
- $M_V = a[Fe/H] + b$
- Measuring metallicity [Fe/H]:
    - Spectroscopy: expensive
    - Photometric: from LC shape

Astron. Astrophys. 312, 111–120 (1996)

ASTRONOMY AND ASTROPHYSICS

**Determination of [Fe/H] from the light curves of RR Lyrae stars***

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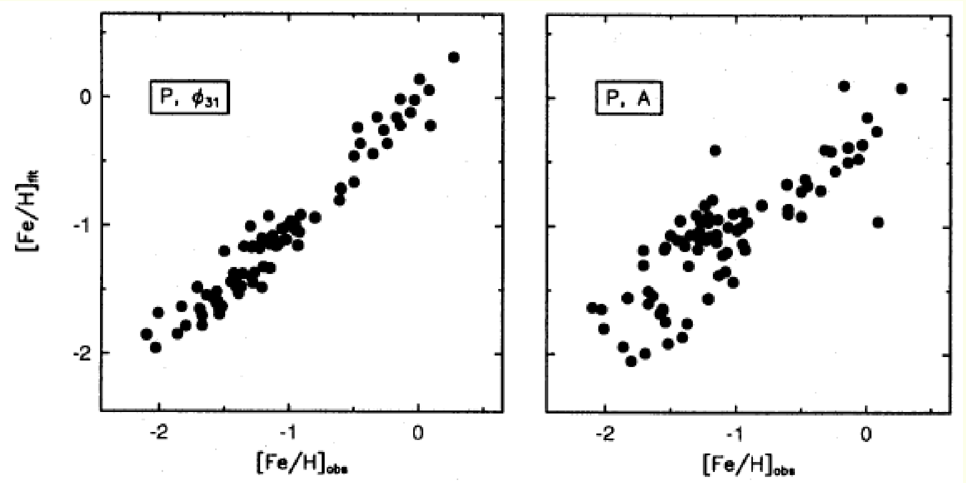
Received 19 July 1995 / Accepted 4 January 1996




$$[Fe/H] = -5.038 - 5.394P + 1.345\varphi_{31} \quad .$$

# Science Case with PTF Public Data: [Fe/H]-LC Relation for RR Lyrae in Kepler Field

- JC relation only valid in V-band, yet PTF observed in R-band
- RR Lyrae in Kepler fields have both spectroscopic [Fe/H] and PTF light curves data from public release of DR1

**Table 7**
Spectroscopic Iron-to-Hydrogen Abundances (VWA) for the *Kepler*-field RR Lyrae Stars

| Star | Obs. | $\phi_{\rm puls}$ | S/N | FWHM | $T_{\rm eff}$ / log $g$ / $\xi_t$ | [Fe/H]$_{\rm spec}$ Fe I Lines | [Fe/H]$_{\rm spec}$ Fe II Lines | [Fe/H]$_{\rm spec}$ Adopted |
|---|---|---|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| (a) 17 Non-Blazhko RRab-type stars | | | | | | | | |
| NR Lyr | CFHT | 0.29 | 37 | 0.163 (02) | 6500/2.6/2.5 | $-2.54 \pm 0.13$ (6) | $-2.53 \pm 0.17$ (5) | $-2.54 \pm 0.11$ |
| FN Lyr | CFHT | 0.28 | 32 | 0.209 (19) | 6300/2.44/2.5 | $-2.00 \pm 0.13$ (10) | $-1.97 \pm 0.12$ (12) | $-1.98 \pm 0.09$ |
| NQ Lyr | CFHT | 0.32 | 30 | 0.197 (15) | 6000/1.80/2.5 | $-1.88 \pm 0.19$ (11) | $-1.90 \pm 0.10$ (3) | $-1.89 \pm 0.10$ |
| V350 Lyr | Keck | 0.53 | 34 | 0.293 (11) | 6180/2.9/2.6 | $-1.84 \pm 0.15$ (12) | $-1.81 \pm 0.14$ (10) | $-1.83 \pm 0.12$ |
| V894 Cyg | CFHT | 0.39 | 28 | 0.193 (08) | 6200/2.46/2.0 | $-1.65 \pm 0.18$ (11) | $-1.66 \pm 0.16$ (9) | $-1.66 \pm 0.12$ |
| AW Dra | CFHT | 0.30 | 38 | 0.202 (05) | 6540/2.40/2.5 | $-1.33 \pm 0.13$ (9) | $-1.33 \pm 0.12$ (6) | $-1.33 \pm 0.09$ |
| KIC 7030715 | CFHT | 0.26 | 19 | 0.26 (04) | 6500/2.64/2.5 | $-1.32 \pm 0.07$ (6) | $-1.34 \pm 0.15$ (3) | $-1.33 \pm 0.08$ |
| V1107 Cyg | Keck | 0.48 | 21 | 0.220 (17) | 6300/2.8/3.0 | $-1.23 \pm 0.42$ (33) | $-1.31 \pm 0.18$ (11) | $-1.29 \pm 0.23$ |
| V368 Lyr | Keck | 0.43 | 20 | 0.183 (02) | 6300/2.8/3.0 | $-1.33 \pm 0.31$ (22) | $-1.25 \pm 0.24$ (10) | $-1.28 \pm 0.20$ |
| KIC 9658012 | Keck | 0.84 | 37 | 0.413 (16) | 6500/2.8/3.0 | $-1.22 \pm 0.26$ (26) | $-1.31 \pm 0.12$ (11) | $-1.28 \pm 0.14$ |
| KIC 9717032 | Keck | 0.23 | 19 | 0.262 (06) | 6620/2.8/3.5 | $-1.27 \pm 0.17$ (14) | $-1.26 \pm 0.17$ (13) | $-1.27 \pm 0.15$ |
| V715 Cyg | Keck | 0.51 | 21 | 0.241 (13) | 6400/3.0/3.0 | $-1.13 \pm 0.12$ (25) | $-1.14 \pm 0.14$ (12) | $-1.13 \pm 0.09$ |

Nemec et al (2013)

# Science Case with PTF Public Data: [Fe/H]-LC Relation for RR Lyrae in Kepler Field

- Using 16 non-blazhko ab-type RR Lyrae stars in Kepler fields
- PTF's DR1 light curves data fitted with Fourier expansion

$$m(t) = m_0 + \sum_{i=1}^{n} A_i \sin\left(\frac{2i\pi t}{P} + \phi_i\right)$$

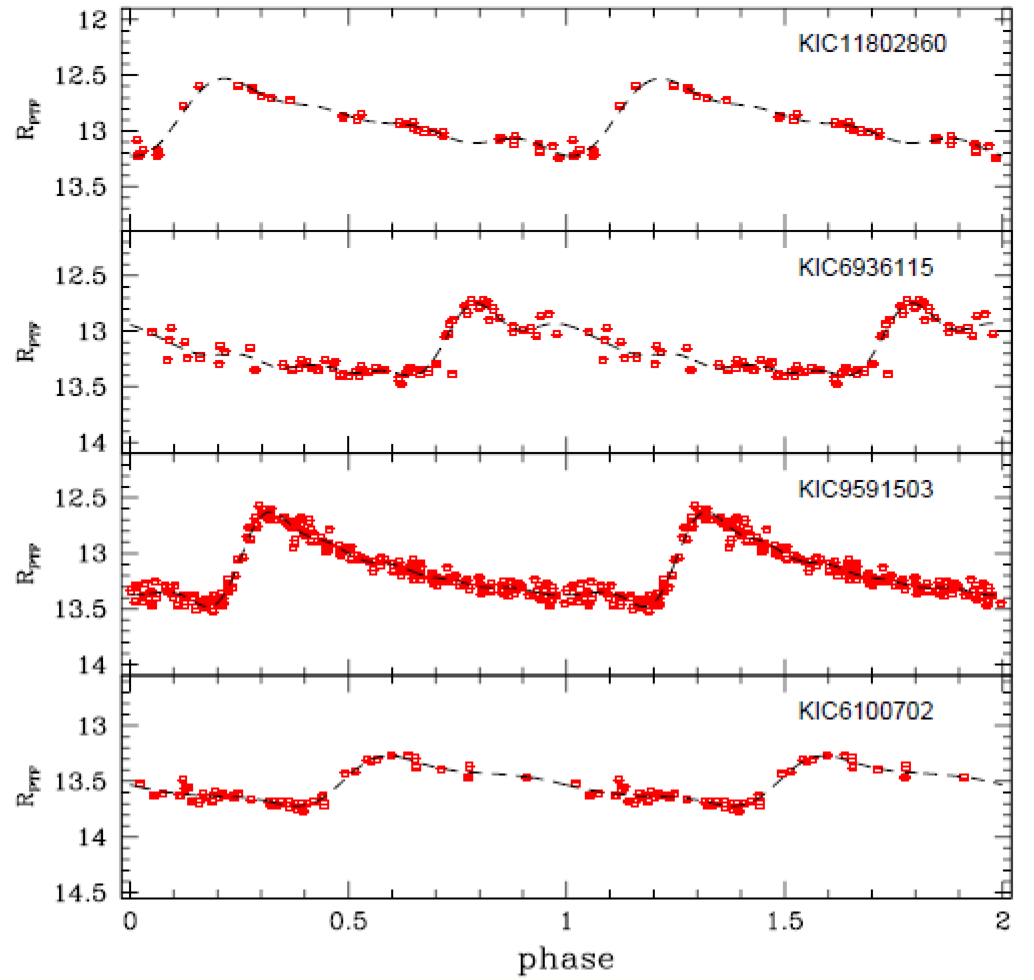
$$R_{ij} = \frac{A_i}{A_j}; \quad \phi_{ij} = \phi_i - i\phi_j.$$

- Found that need to split to two groups:
  - Group A: 8 RR-ab brighter than ~14 mag
  - Group B: 8 RR-ab fainter than ~14 mag

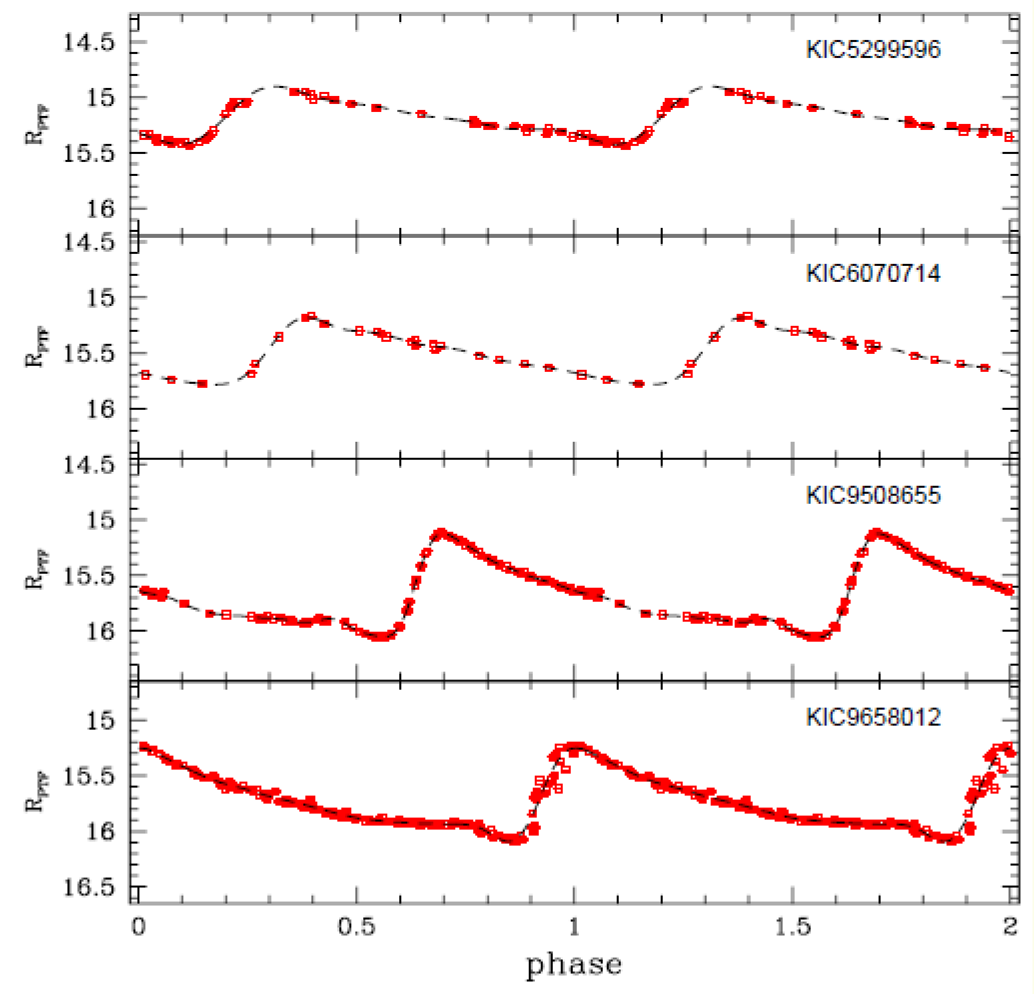
where ~14 mag is the saturation limit in PTF data

# Science Case with PTF Public Data: [Fe/H]-LC Relation for RR Lyrae in Kepler Field

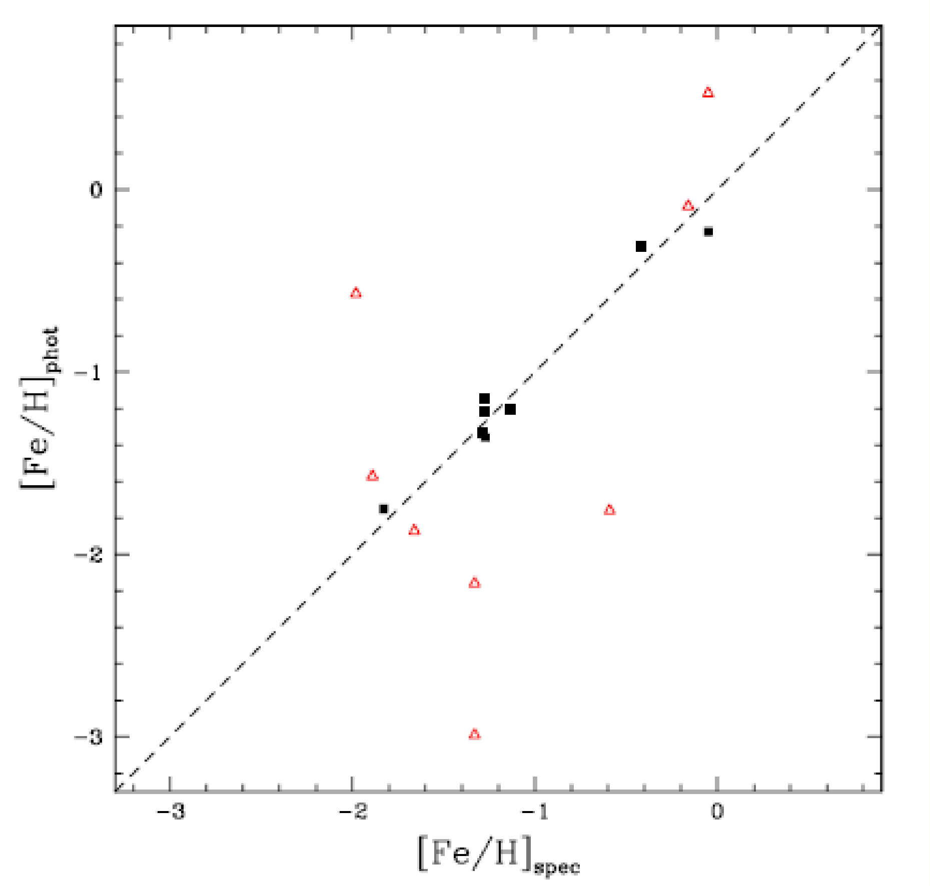
## Group A example LCs




## Group B example LCs



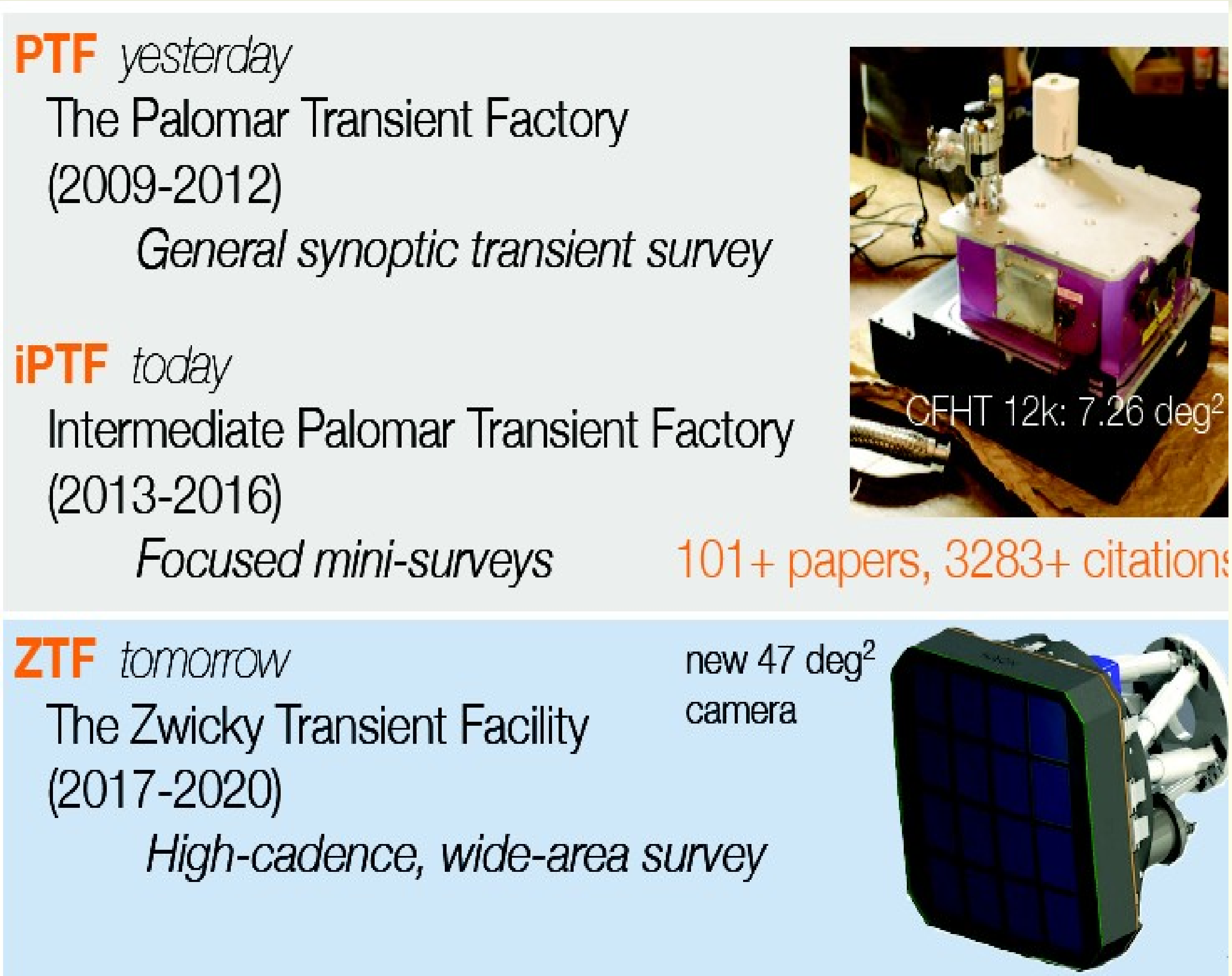
# Science Case with PTF Public Data: [Fe/H]-LC Relation for RR Lyrae in Kepler Field




- Using RR-ab in Group B (and one RR-ab in Group A with acceptable LC), the [Fe/H]-LC relation in PTF R-band is found to be:

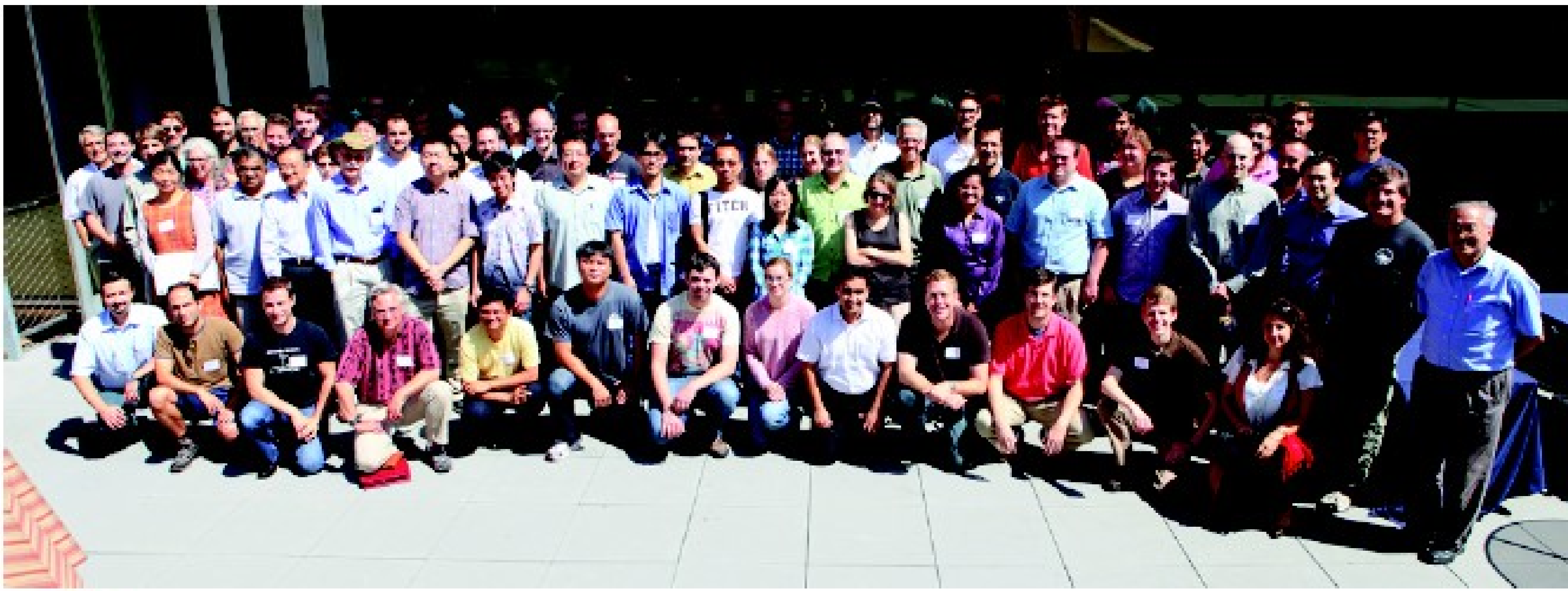
$$[Fe/H] \quad = \quad -3.261 - 8.274P + 1.219\phi_{31}.$$

# Conclusion




- Kepler main goal: exo-planet using transit method
- Continuous light curves good for variable stars

# ~ THANK YOU ~



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