The Search for AM CVn Systems with the Palomar Transient Factory

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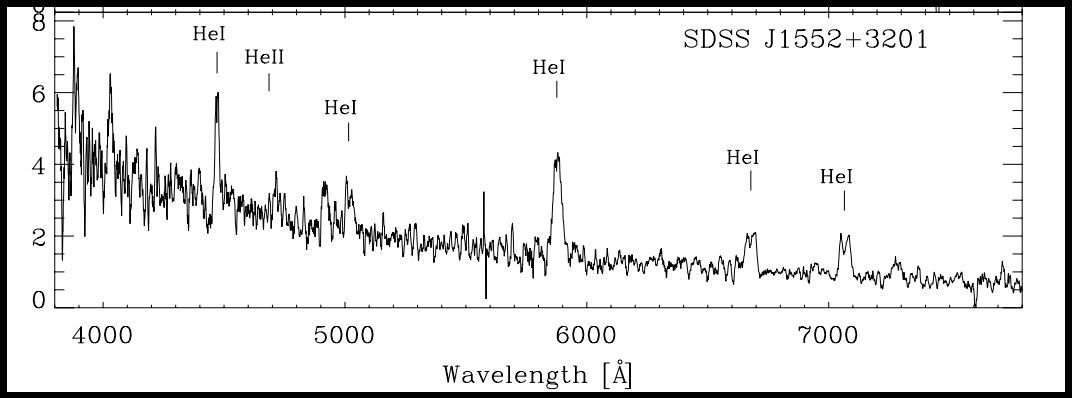
Caltech

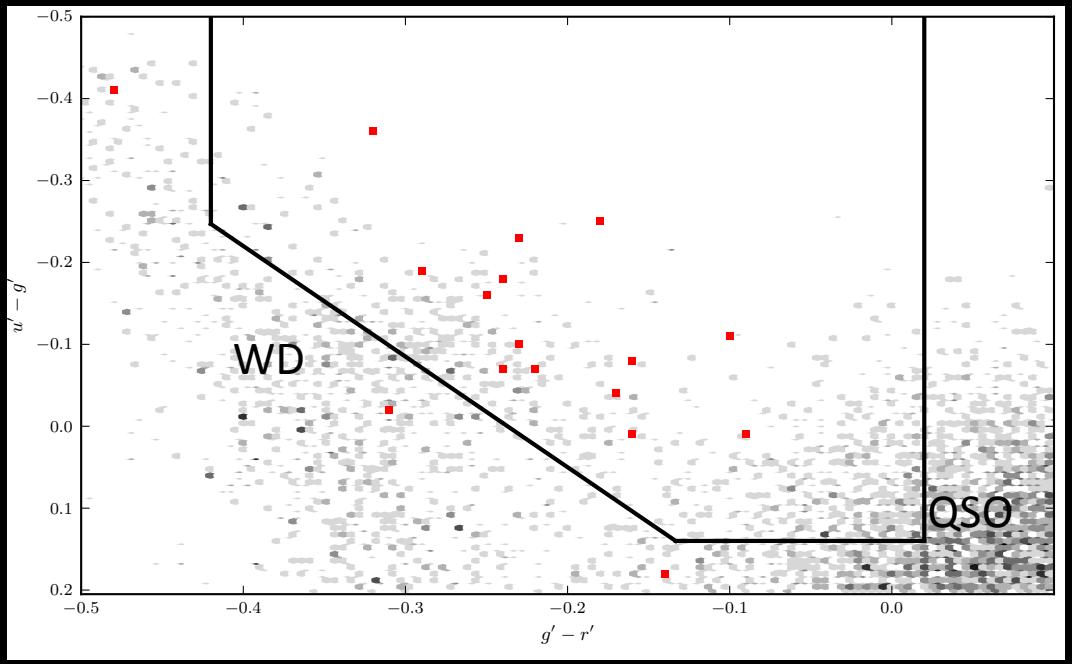
in collaboration with Paul Groot, Thomas Kupfer, Shri Kulkarni, Tom Prince and the PTF Collaboration

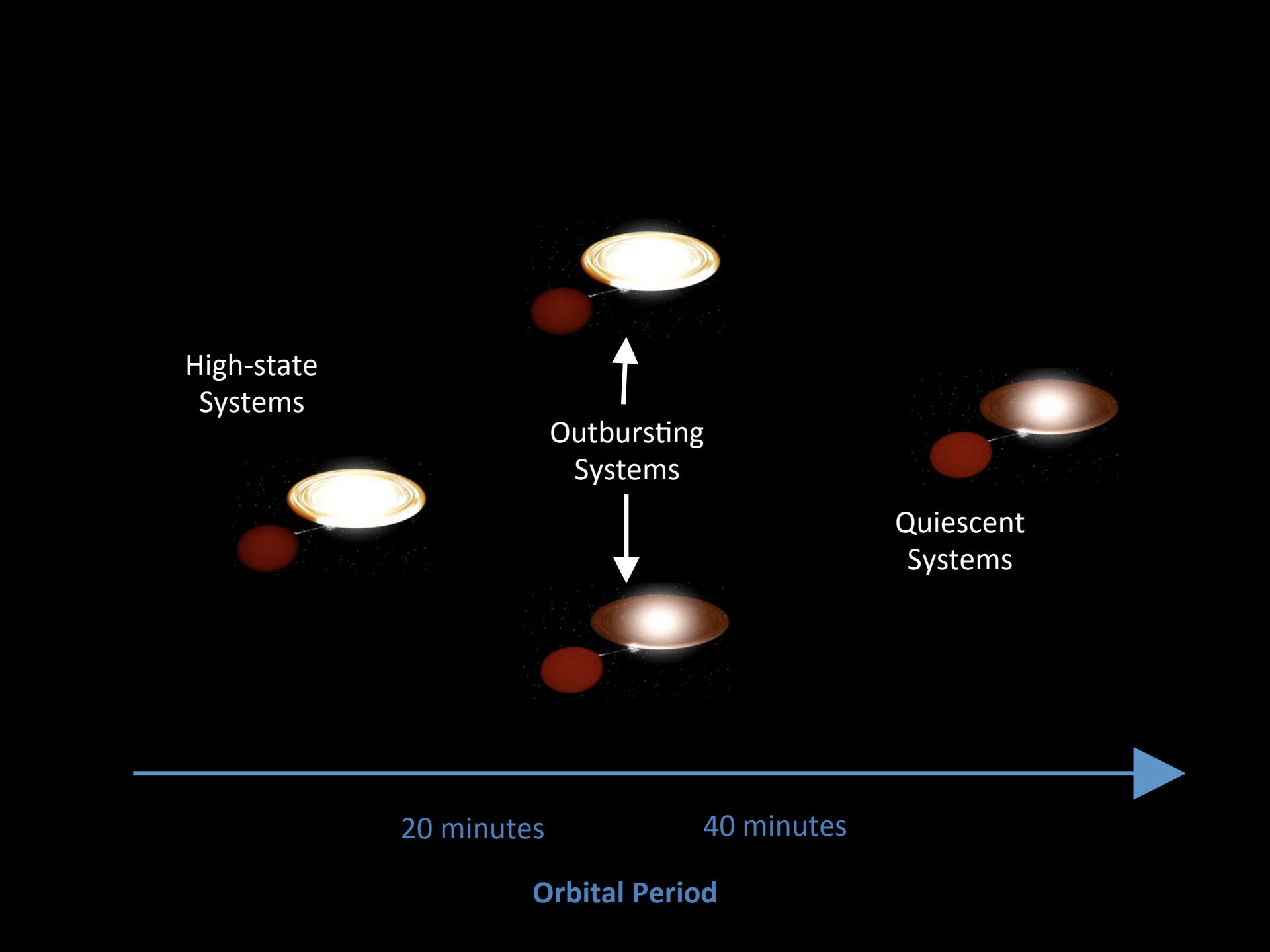
AM CVn Workshop **April 16th, 2012**

The SDSS Survey

Sloan Digital Sky Survey






High-state
Systems
Outbursting
Systems
Quiescent
Systems
20 minutes
40 minutes
Orbital Period

Photometric Variability

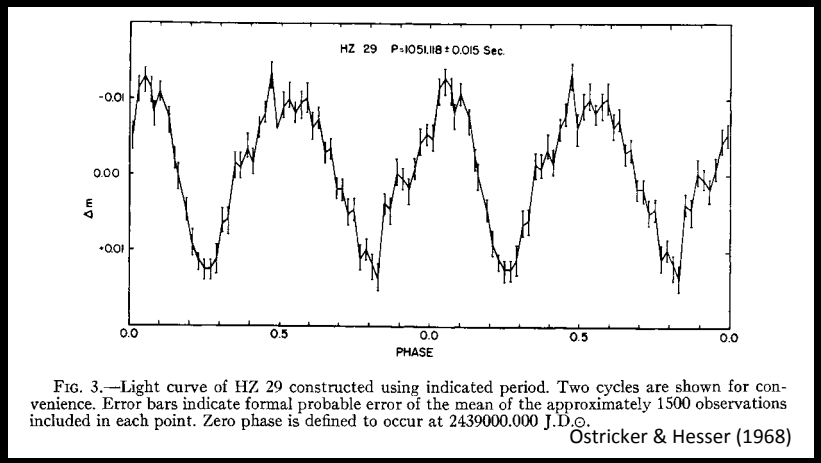
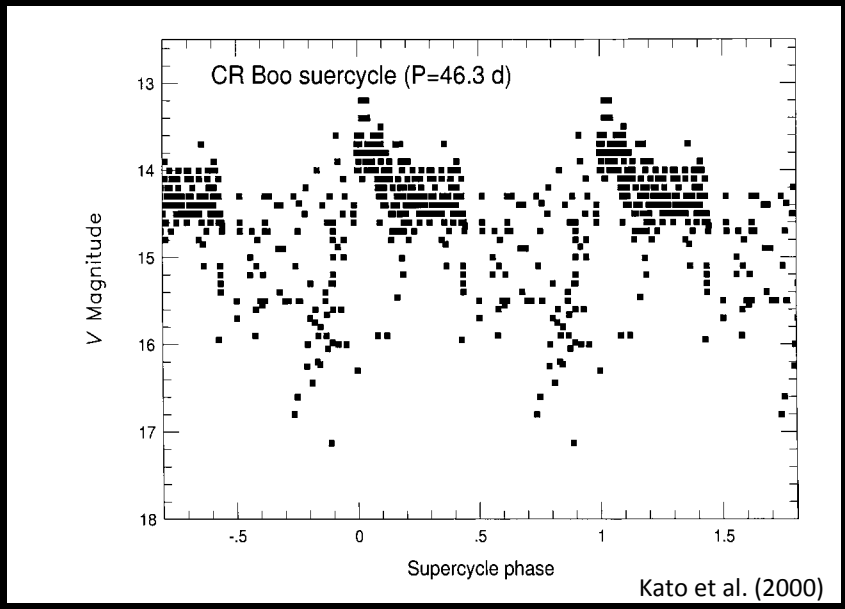


FIG. 3.—Light curve of HZ 29 constructed using indicated period. Two cycles are shown for convenience. Error bars indicate formal probable error of the mean of the approximately 1500 observations included in each point. Zero phase is defined to occur at 2439000.000 J.D.⊙.

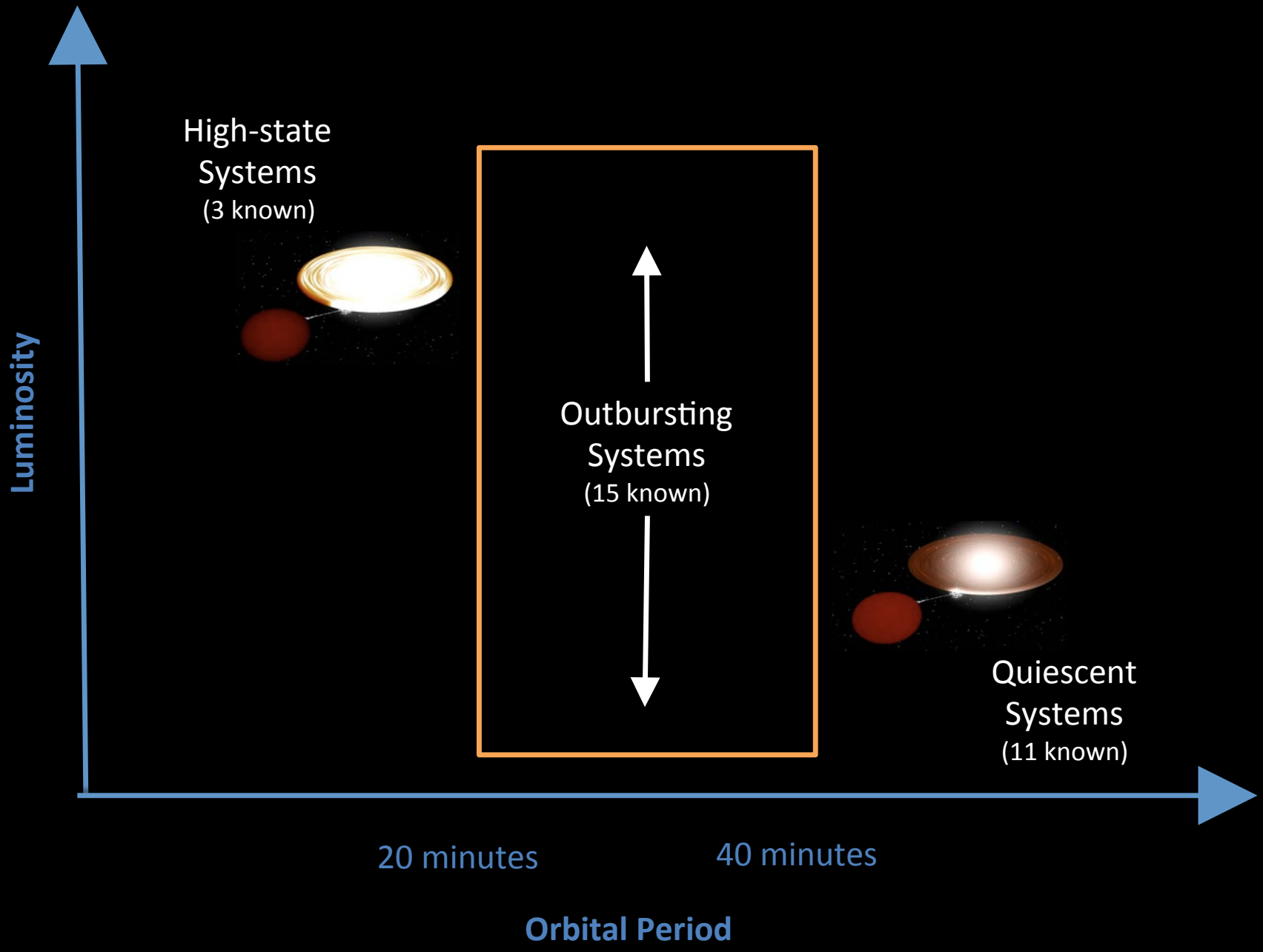
Ostricker & Hesser (1968)

Light Curve of AM CVn



Kato et al. (2000)

Light Curve of CR Boo

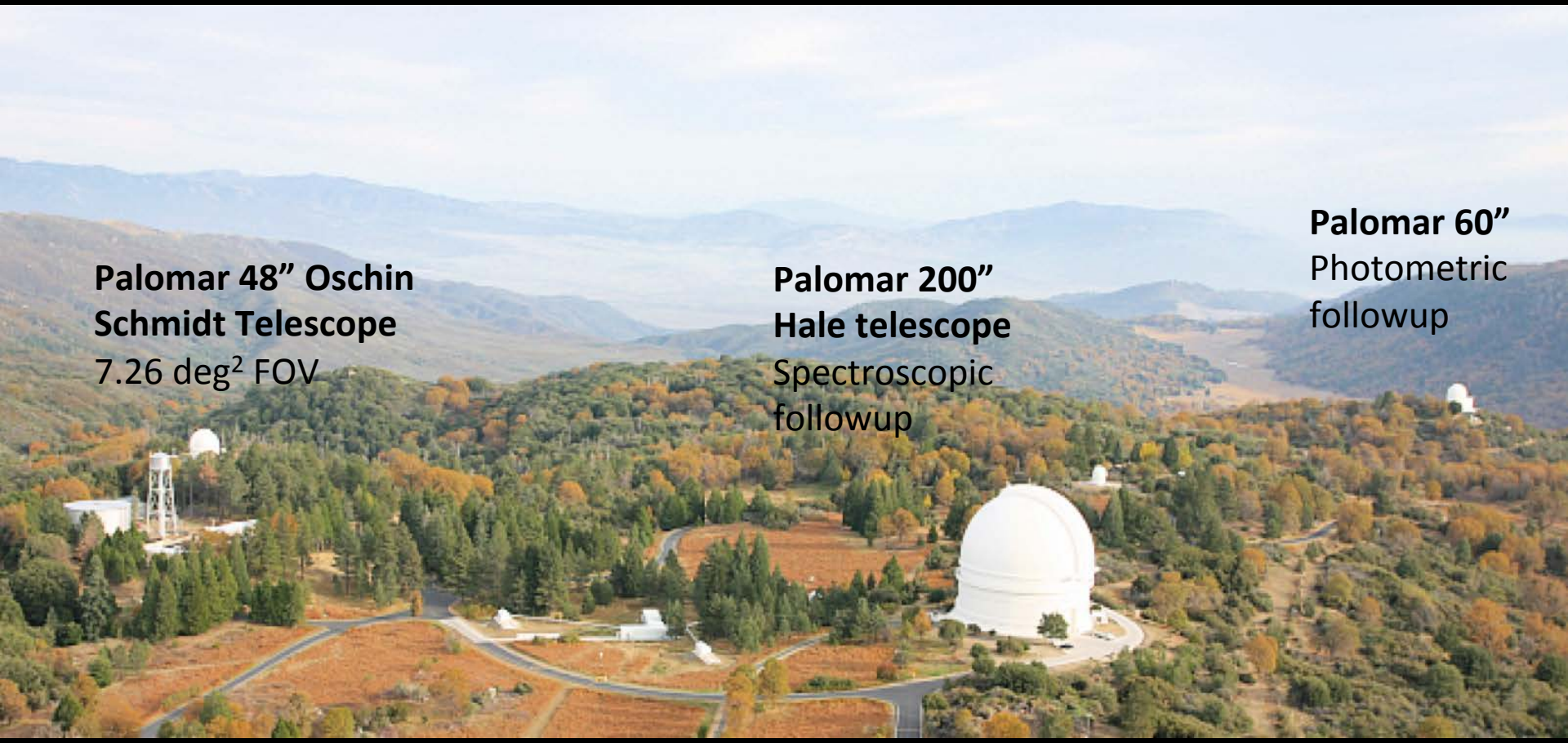

High-state
Systems
(3 known)
Outbursting
Systems
(15 known)
Quiescent
Systems
(11 known)
Luminosity
20 minutes
40 minutes
Orbital Period

Why Outburst Selection?

PALOMAR TRANSIENT FACTORY

- Color-independent
- Surveys a (believed) different part of the AM CVn system population
- Allows us to probe deeper (to 23rd mag!)
- Photometry does not need to be perfect
- A significant fraction of the AM CVn lifetime is believed to be spent in the outbursting phase

Palomar Transient Factory

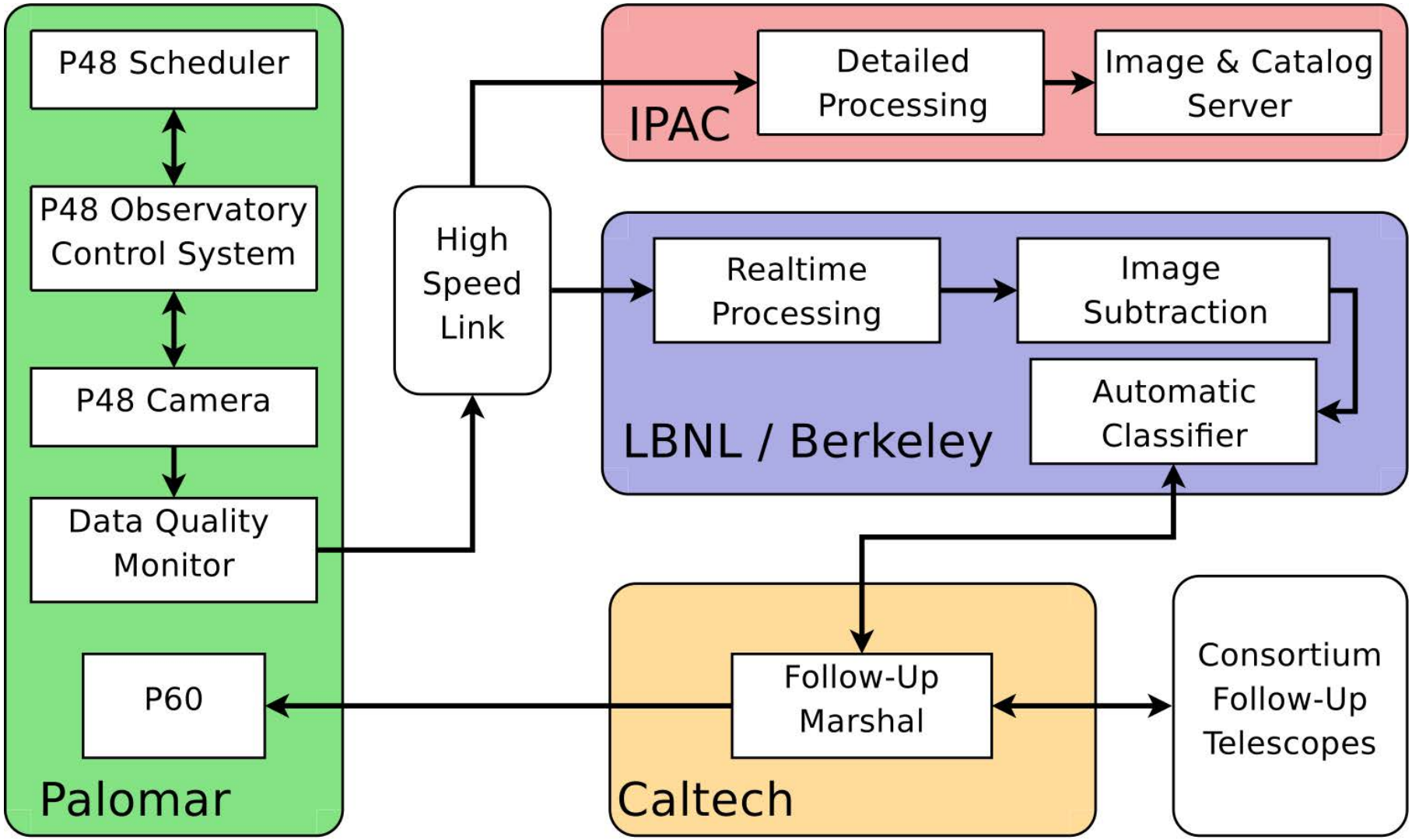


+ Follow-up @ Collaboration Observatories (i.e. Keck, Gemini, etc…)

The PTF Field of View

PALOMAR TRANSIENT FACTORY

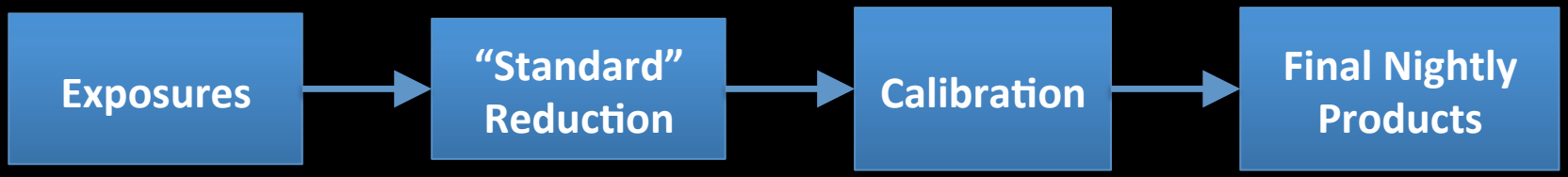
The Transient Data Flow



What happens at IPAC?

PALOMAR TRANSIENT FACTORY

Nightly Image Processing:



Second Level Products:

Depth: 21.7 – 23.2

< 0.1" precision at bright end
1.5" at faint end

Photometric Performance

PALOMAR TRANSIENT FACTORY

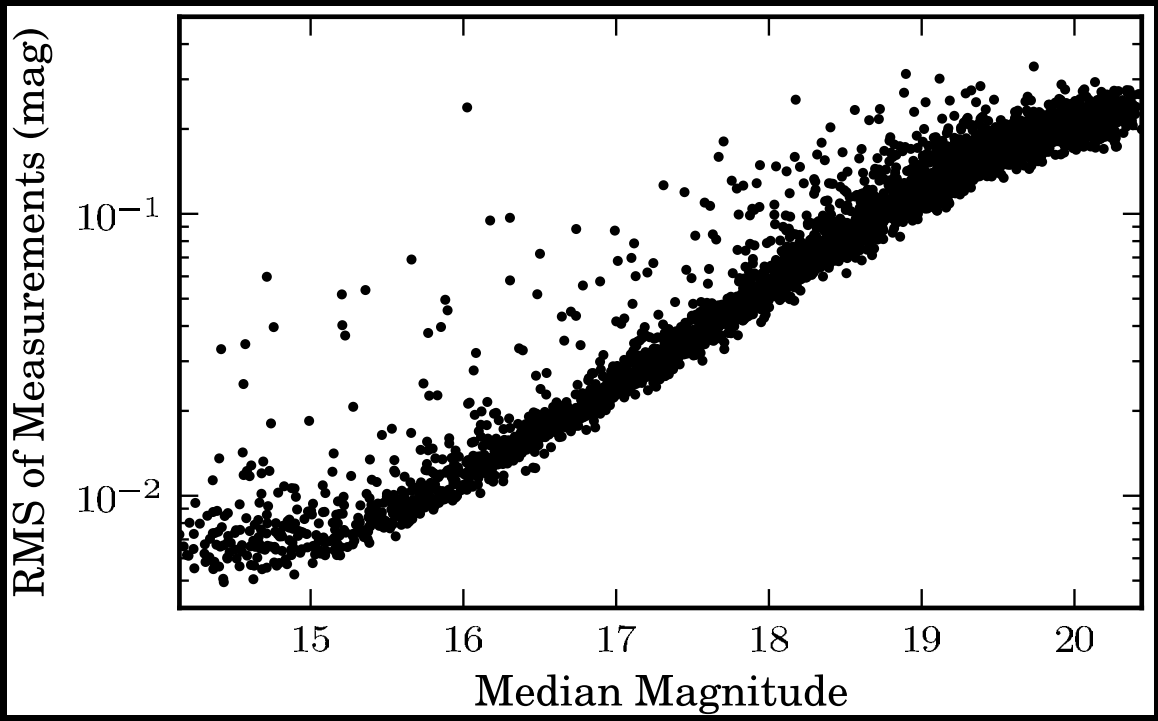
<u>*R*-band Coverage:</u>
~15,000 deg^2 with > ~10 exp
~8,000 deg^2 with ≥ 30 exp

<u>*g'*-band Coverage:</u>
~5,000 deg^2 with > ~10 exp
~1,800 deg^2 with ≥ 30 exp

Many fields are covered daily

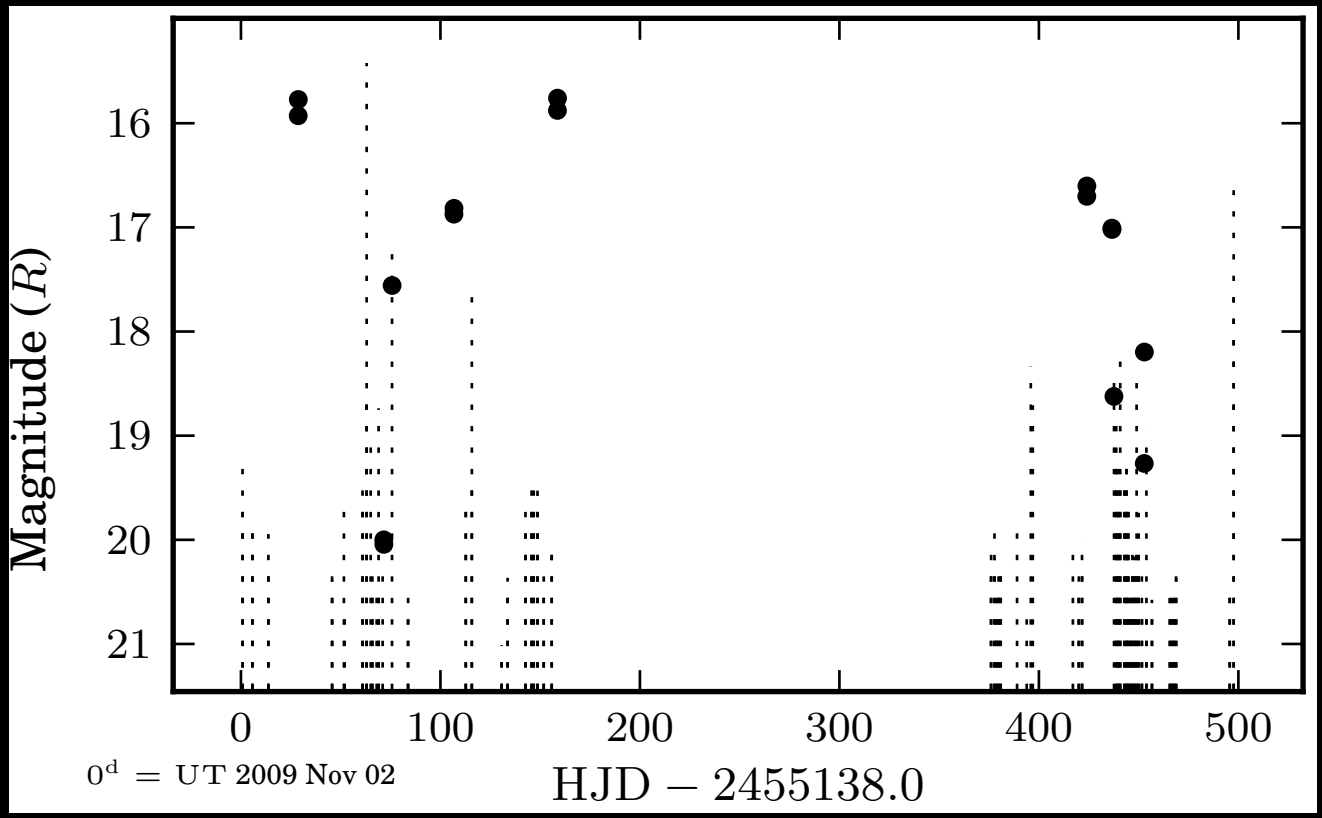
<u>Depth coverage:</u>
14 < *R* < 20.6
14.5 < *g'* < 21

Calibration is both absolute (to SDSS) and relative



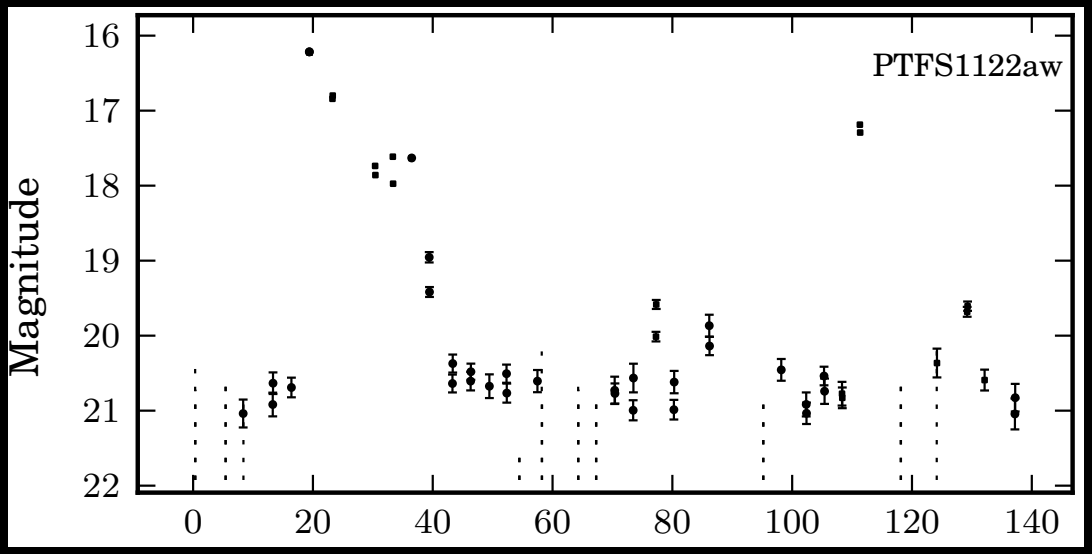
PTF is one of the deepest, best-calibrated synoptic surveys with large sky coverage

Transient Detection

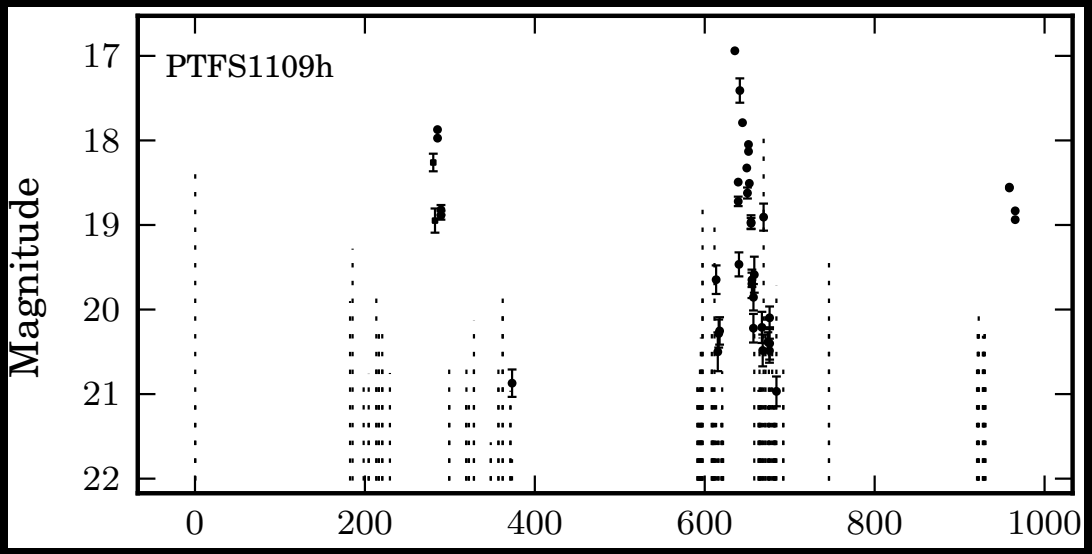


Transient detection is best for faint systems that are seen in outburst only once
But measurements only obtained when there is significant change in brightness

Outburst Detection



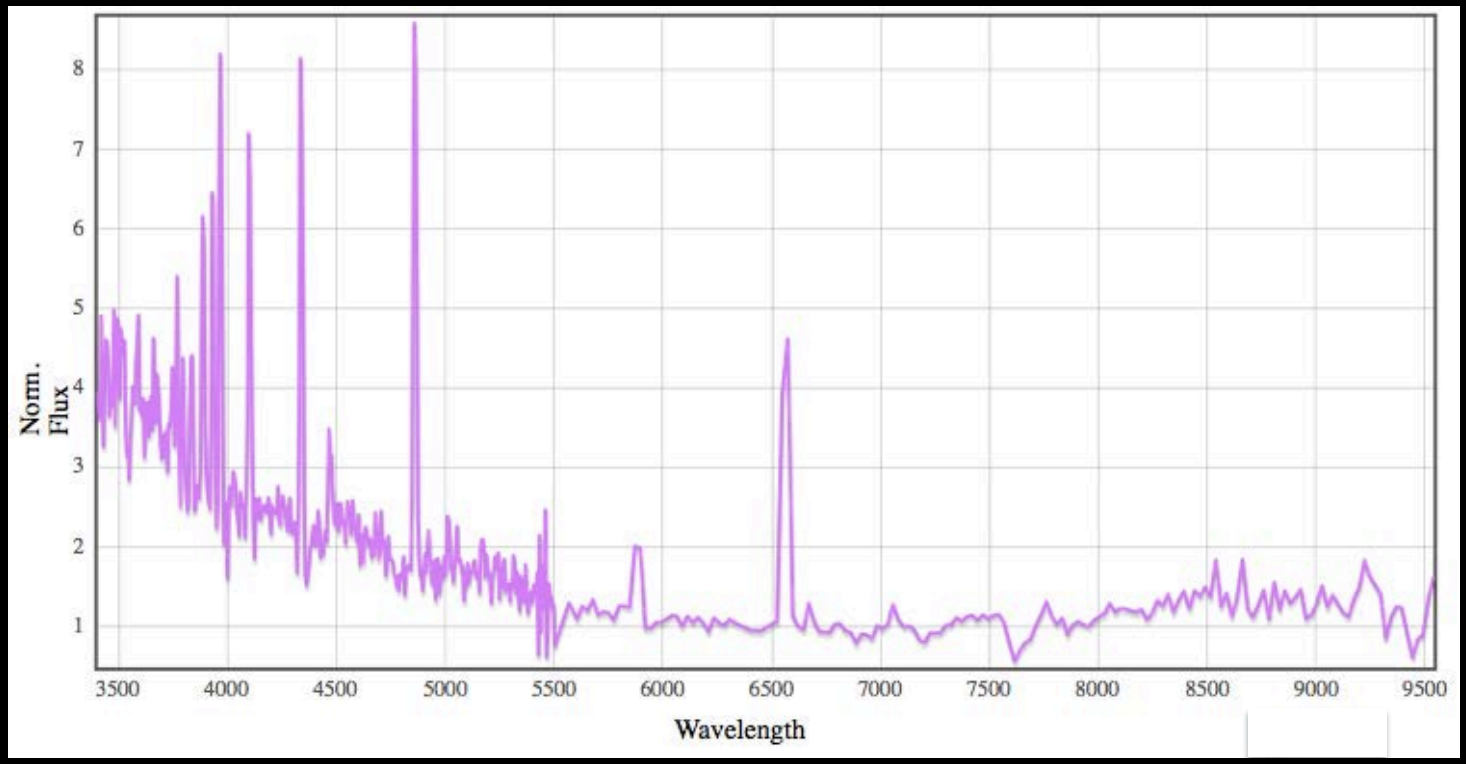
Brighter systems typically have solid detections in quiescence



Fainter systems will only be observed in outburst – thus we need deep "reference" images

Classification Spectra

PALOMAR TRANSIENT FACTORY



Outburst light curve tells us little more than that there is an outbursting system. Classification spectra are necessary to identify the type of system.

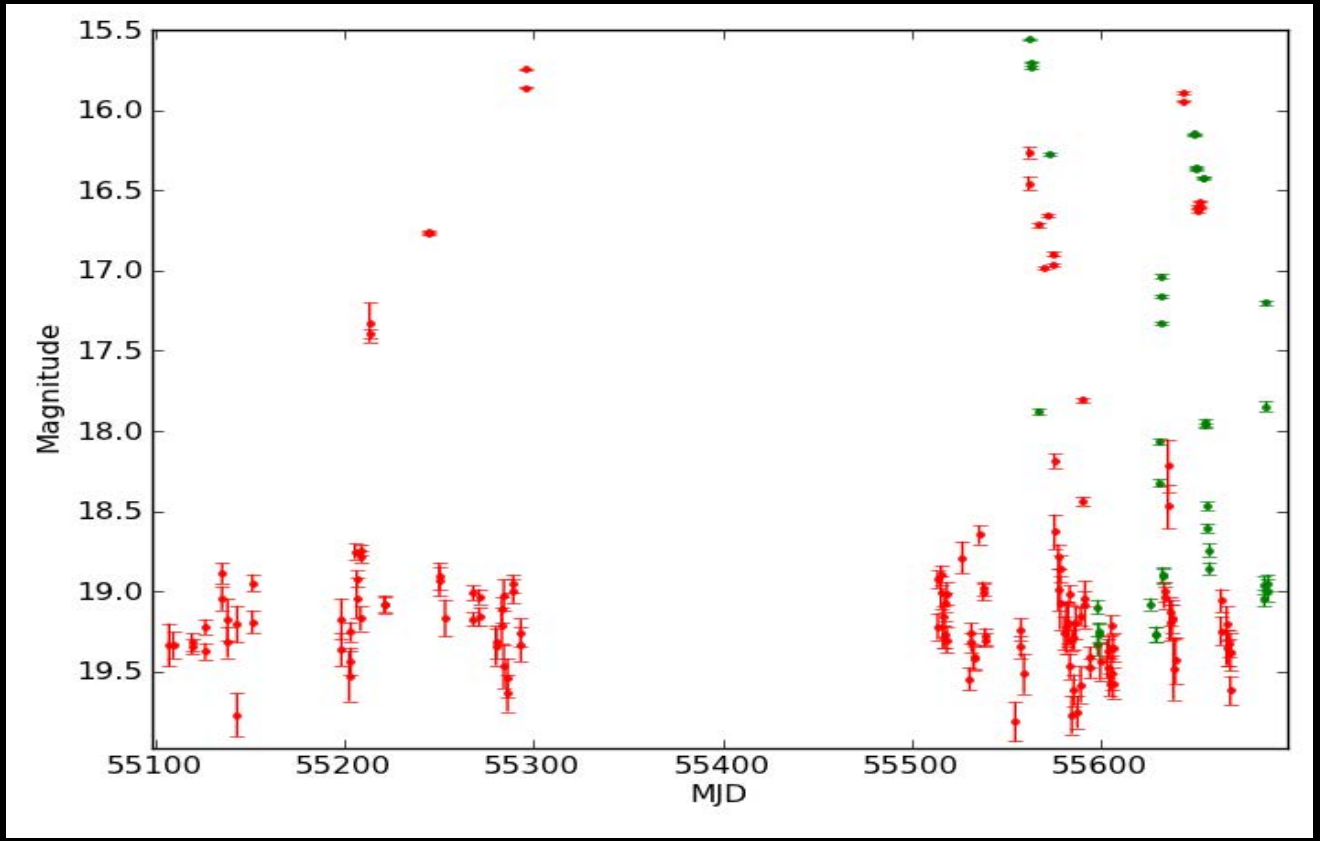
PTF1 J071912.13+485834.0

PALOMAR TRANSIENT FACTORY

Detected as Supernova candidate on 2009 December 01

Classification spectrum obtained as part of SN program

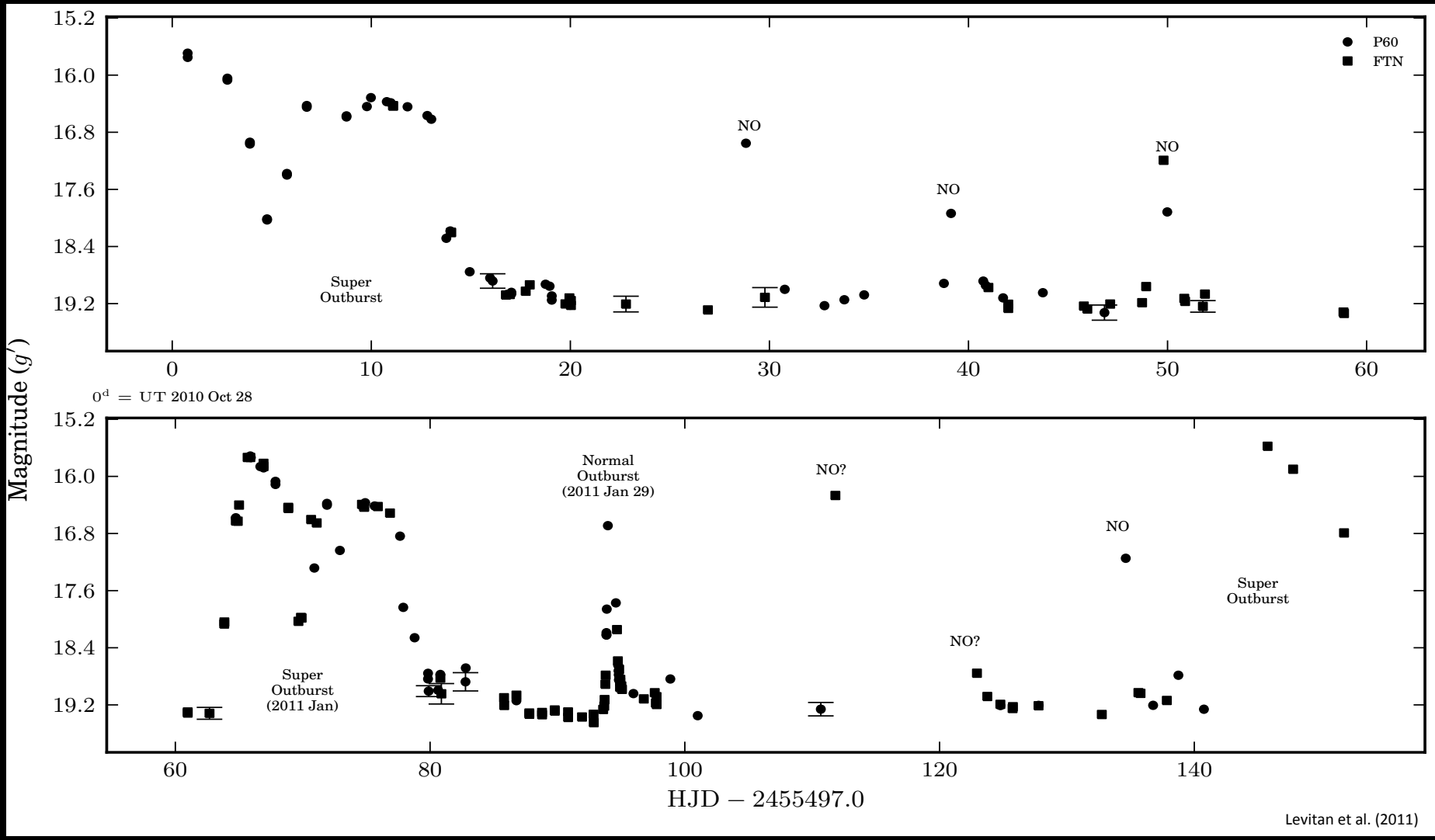
Identified as AM CVn system with additional significant follow-up



P48 Relative Photometry Light Curve of PTF1J0719+4858

PTF1J0719+4858 Light Curve

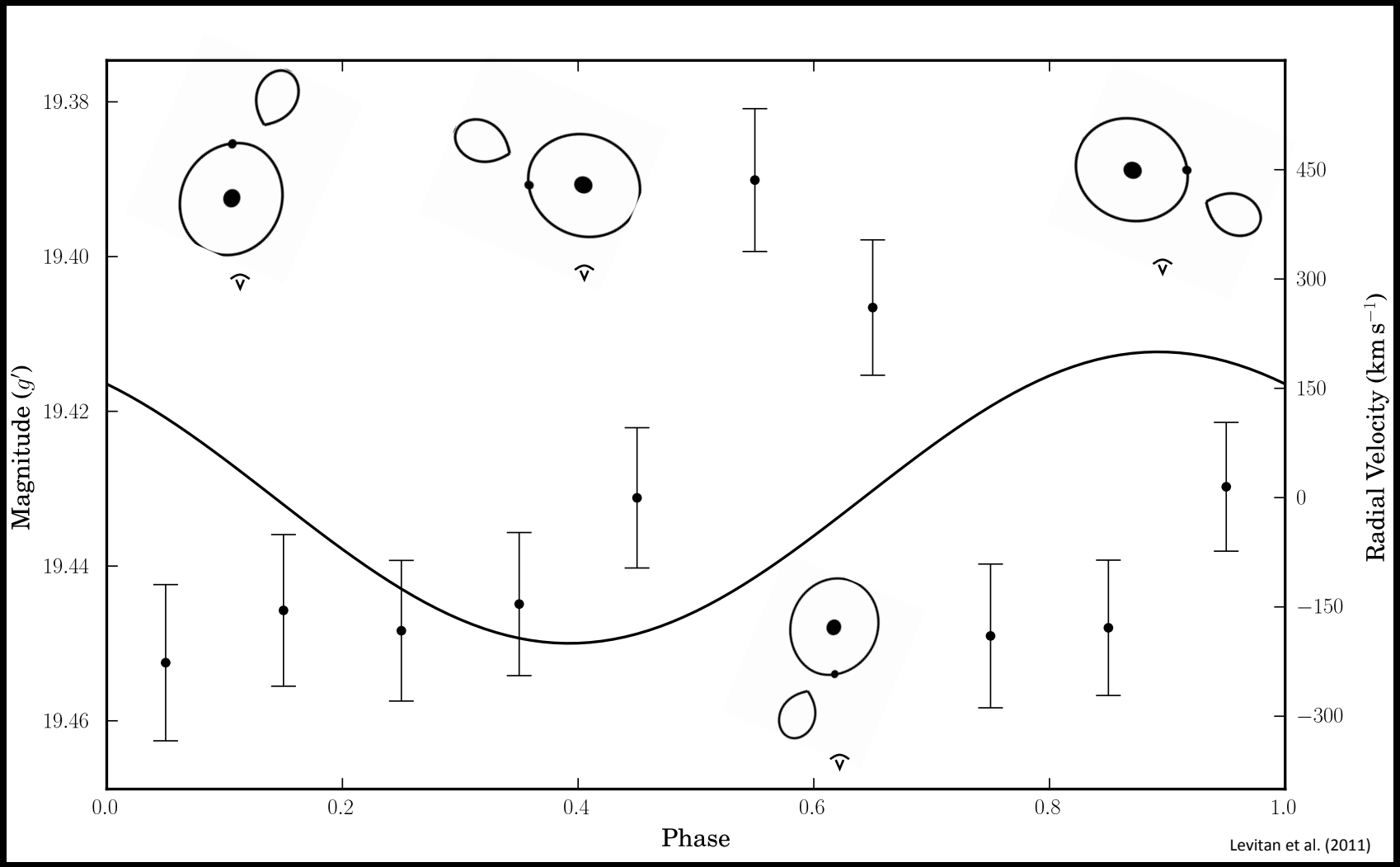
PALOMAR TRANSIENT FACTORY



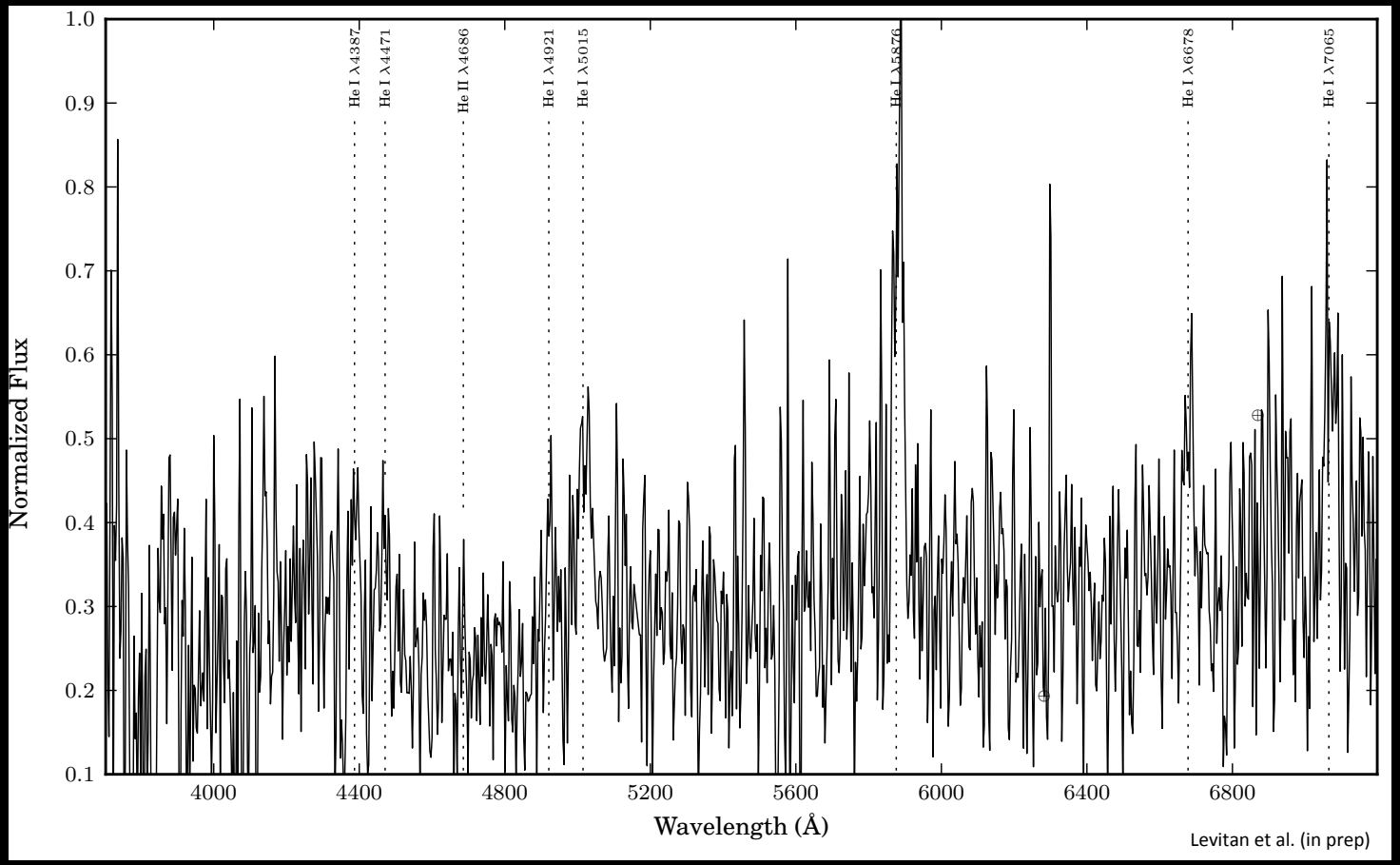
Orbital Period: 26.77 minutes

Super-outburst recurrence time: 65-80 days

Source of AM CVn Photo. Variability

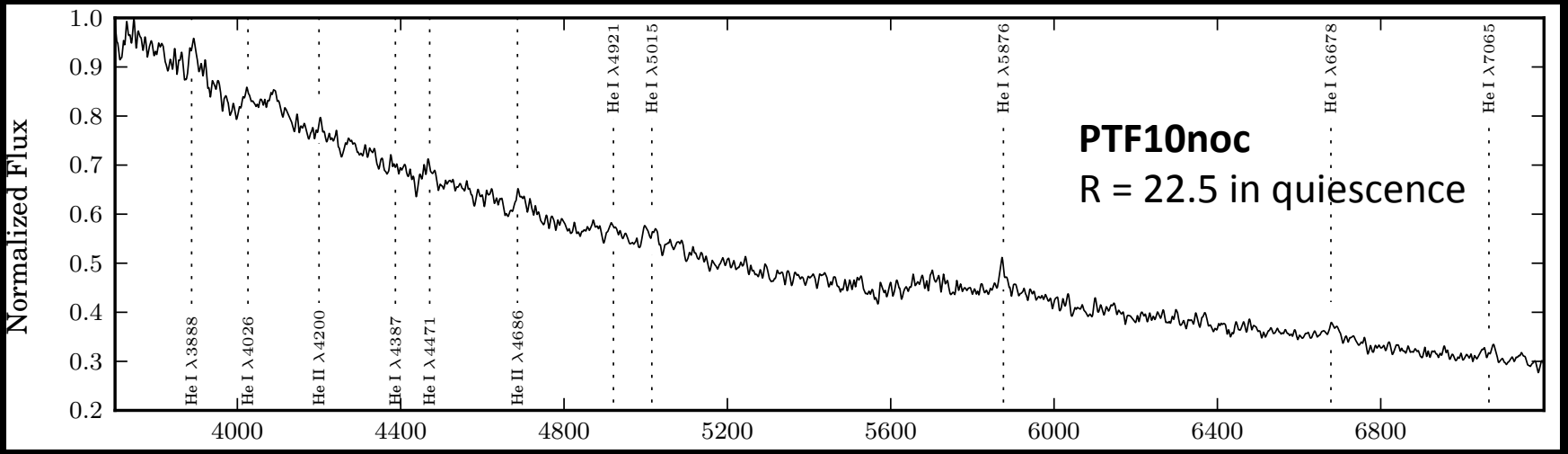


PTF11aab – High Inclination?

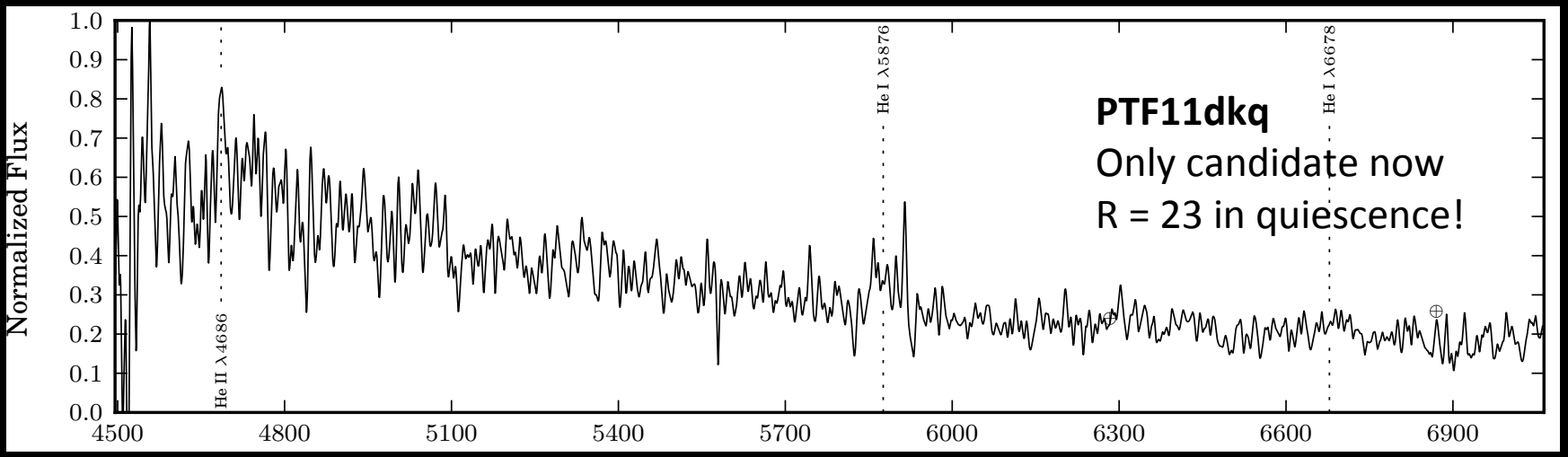


Detected in outburst, spectrum taken, shows emission lines in outburst!
In CVs, this is indicative of high inclination, but we have not seen any eclipses

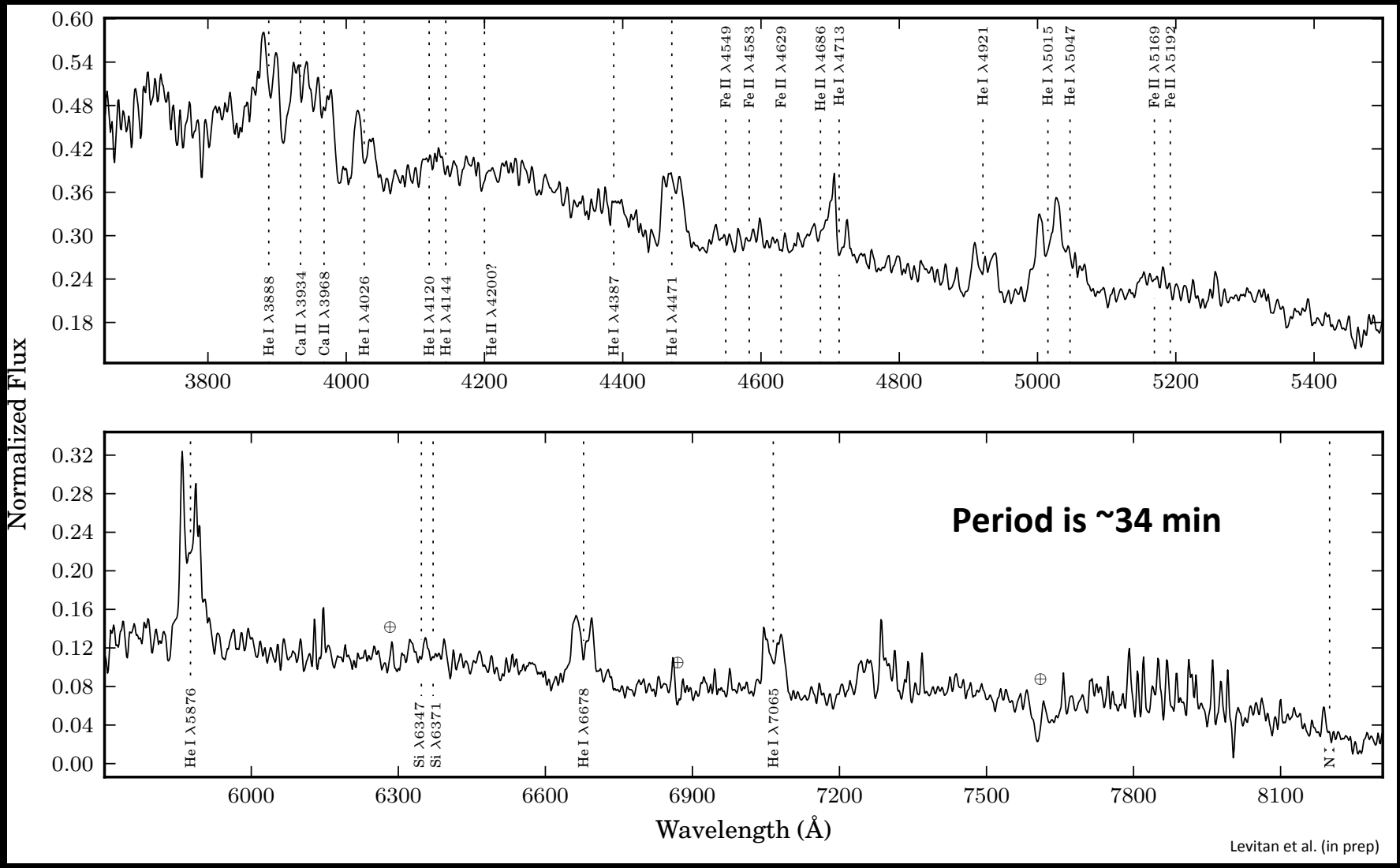
PTF10noc and PTF11dkq



Levitan et al. (in prep)



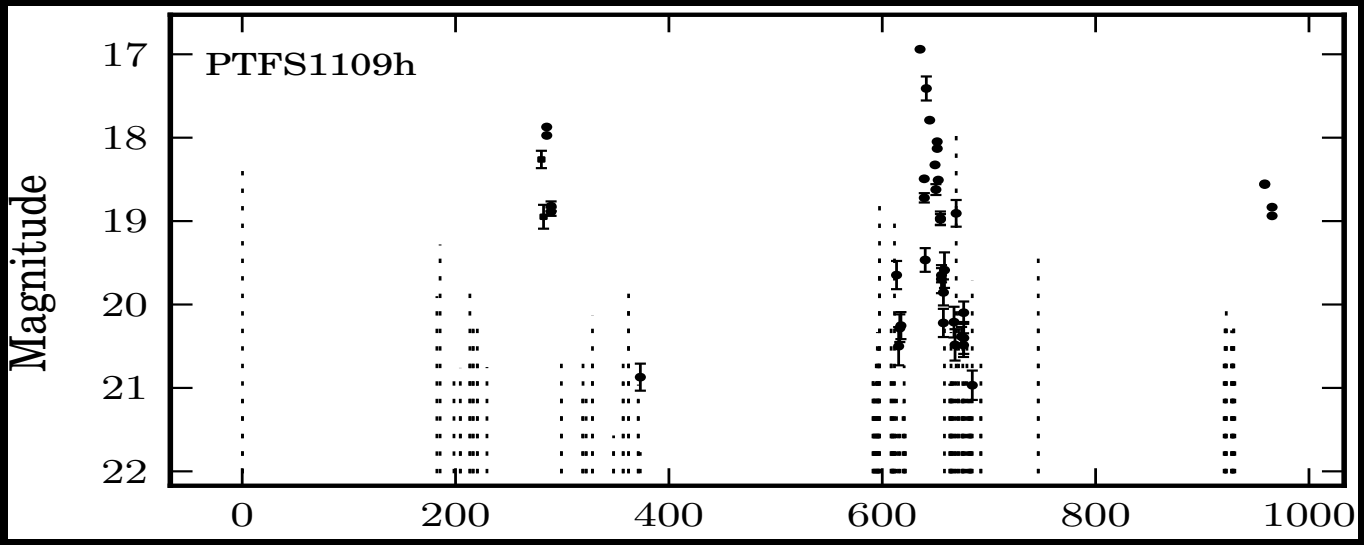
PTF11avm

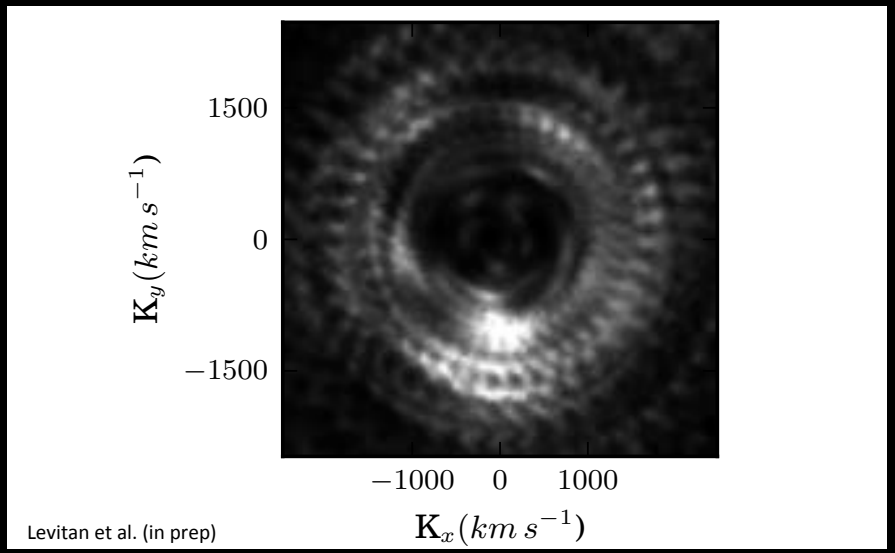


Levitan et al. (in prep)

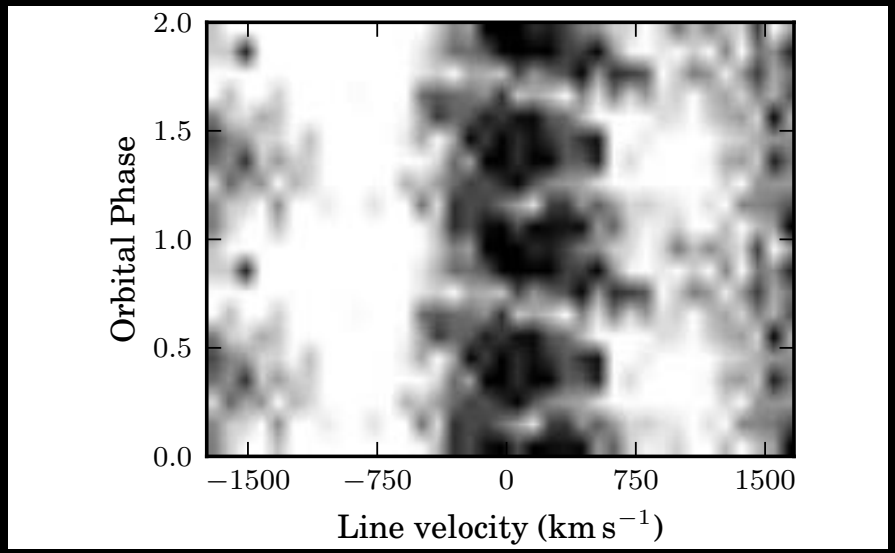
PTFS1109h

Orbital period identified as 30.35 min

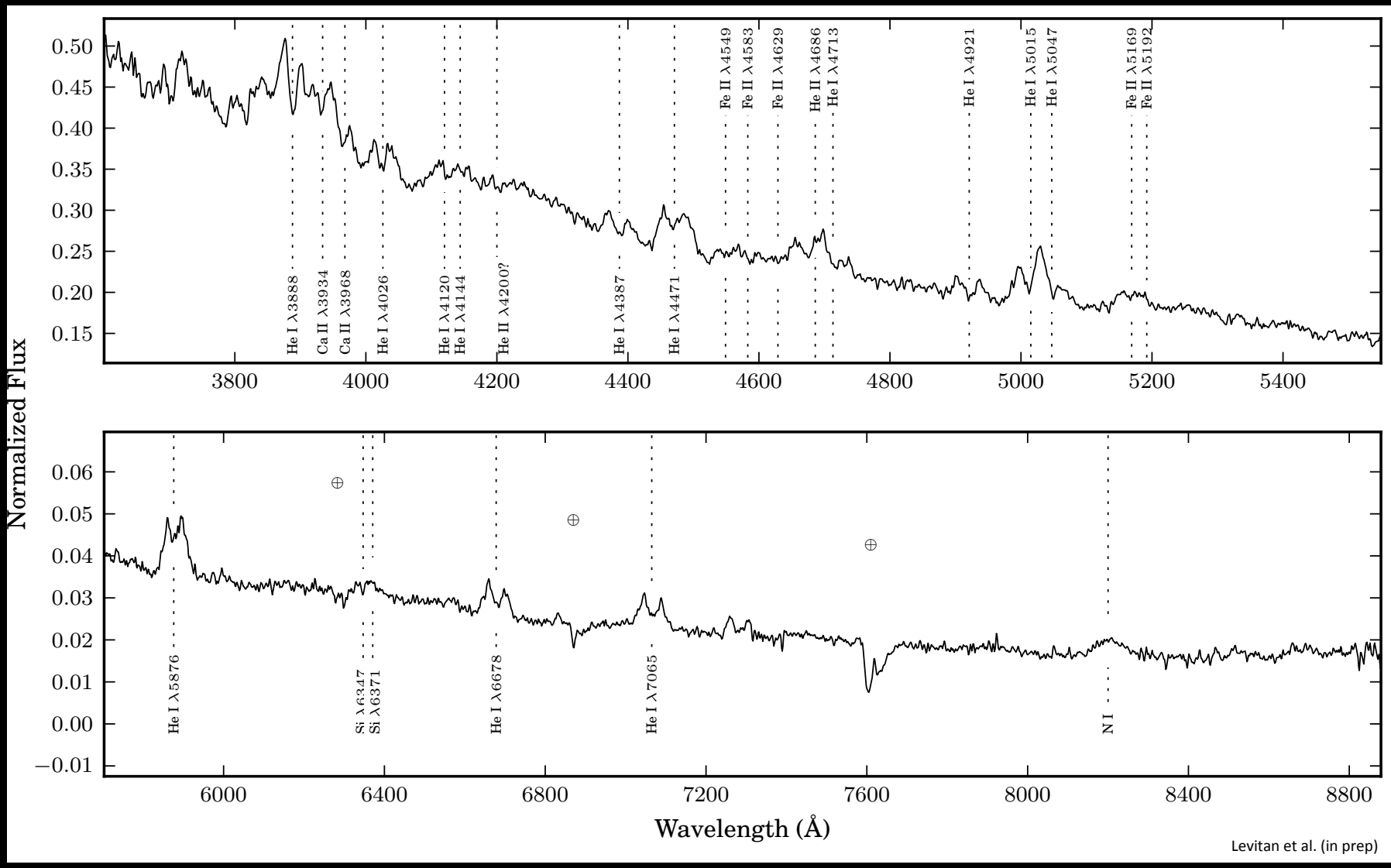




Levitan et al. (in prep)

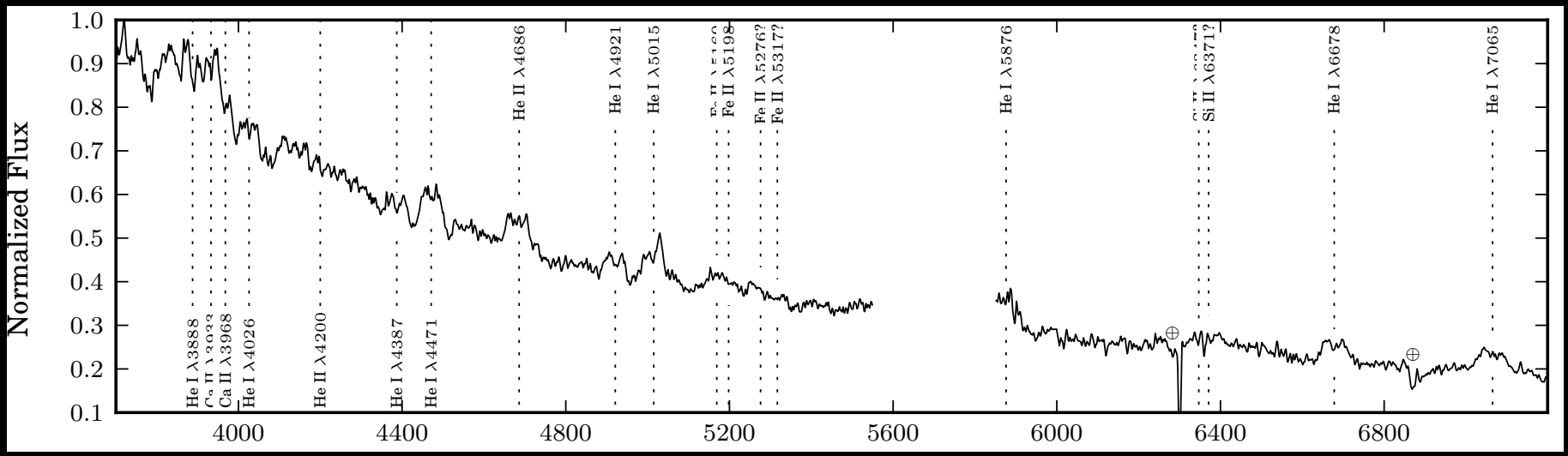


PTFS1109h

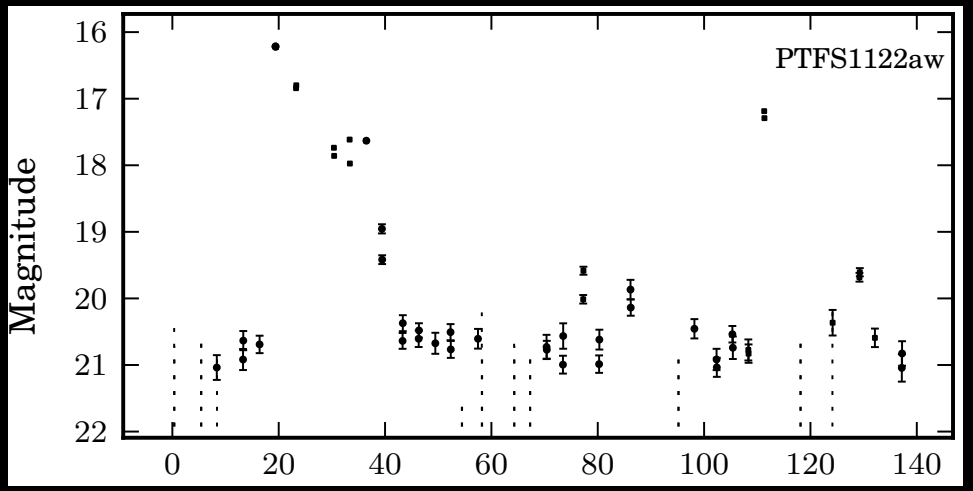


Levitan et al. (in prep)

PTFS1122aw

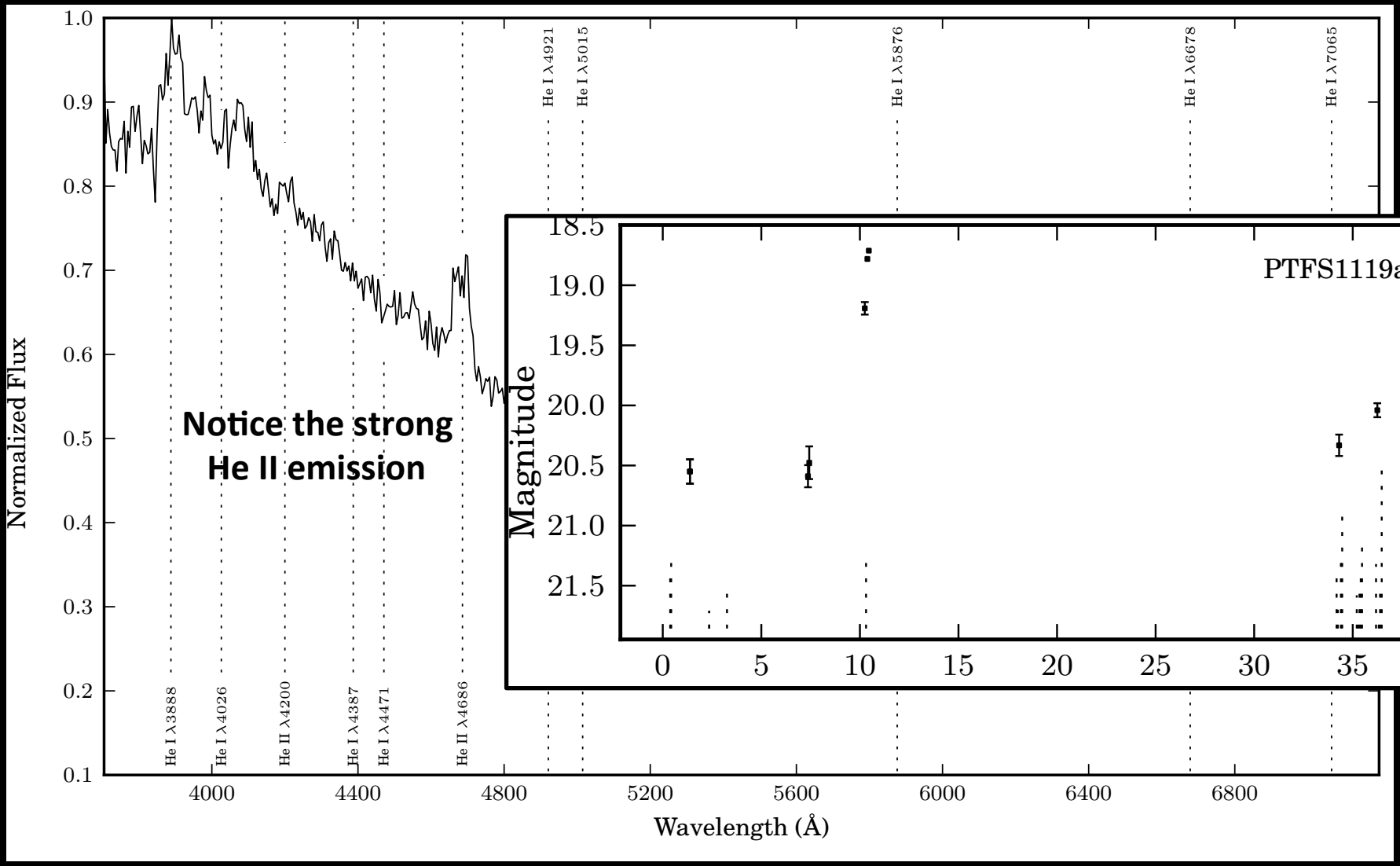


Period as of yet unmeasured
But not significant metal lines



Levitan et al. (in prep)

PTFS1119aq


Normalized Flux
Wavelength (Å)
He I λ3888
He I λ4026
He II λ4200
He I λ4387
He I λ4471
He II λ4686
He I λ4921
He I λ5015
He I λ5876
He I λ6678
He I λ7065
Notice the strong
He II emission
Magnitude
PTFS1119aq

Summary of Results

PALOMAR TRANSIENT FACTORY

- The PTF has discovered 6 new AM CVn systems for sure, plus 1119aq and 11dkq
- This is over 20% of the total AM CVn population
- But these are also the faintest systems
- Simultaneous spectroscopic and photometric observations allow linking periods
- This is a systematic search for AM CVn systems that does not rely on colors
- Additionally, over new 100 CVs have been found as part of this survey

Upcoming Observing Plans

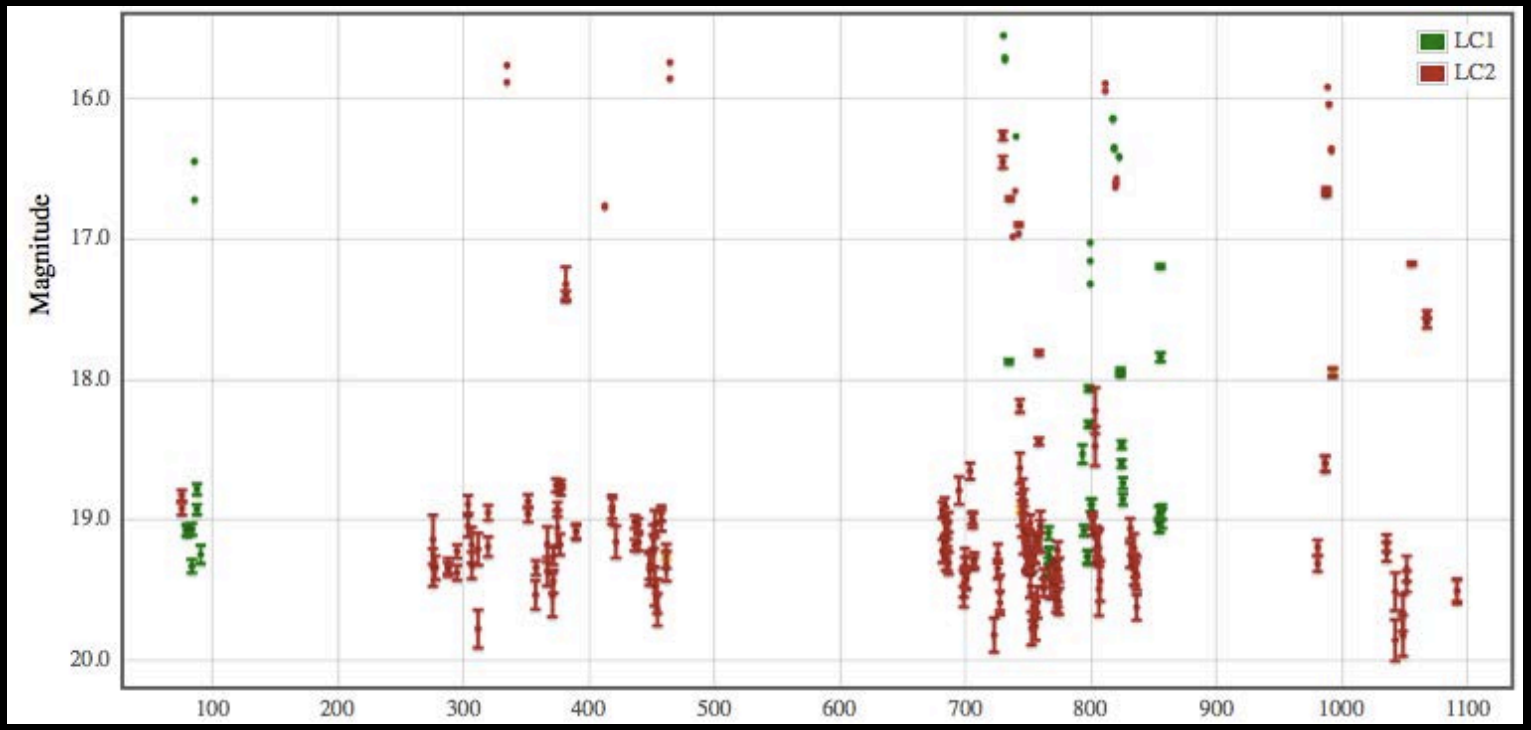
PALOMAR TRANSIENT FACTORY

- Classification spectra of >100 targets
  - Currently have about 70 “bright” targets
  - About 30 additional faint targets below R = 20.5
- Follow-up period determination
  - Phase-resolved spectroscopy of PTF11aab, PTF1122aw, and PTFS1119aq
  - Prove link between photometric period and spectroscopic period by measuring CR Boo
- Planning on looking through Chandra-PTF cross match for short period systems

Outburst Recurrence Rates

PALOMAR TRANSIENT FACTORY

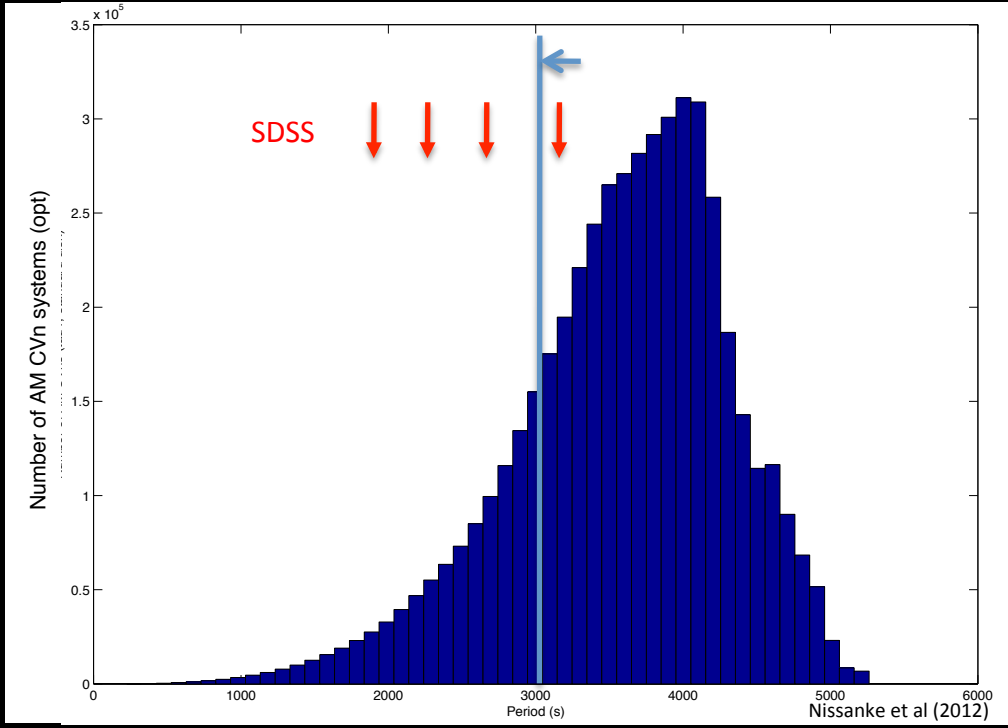
Synoptic surveys provide unprecedented long-term light curves of AM CVn systems. What can we say about their outbursts?



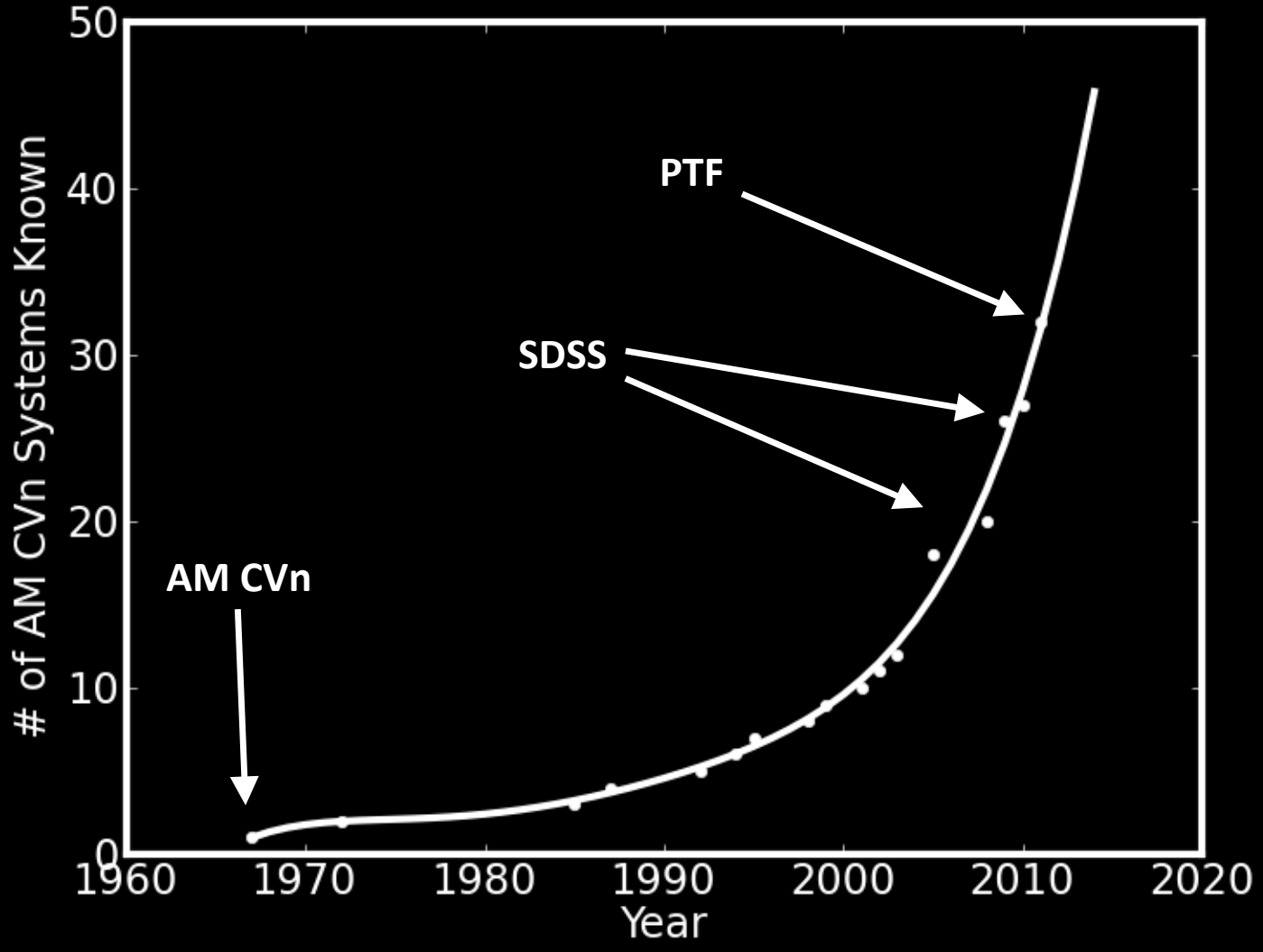
Testing Population Models

Previous population studies have been based on limited systems dominated by SDSS-discovered systems (i.e. quiescent systems).

However, evolutionary models have not been well tested and are currently assumed to be very simple. Is this actually the case?



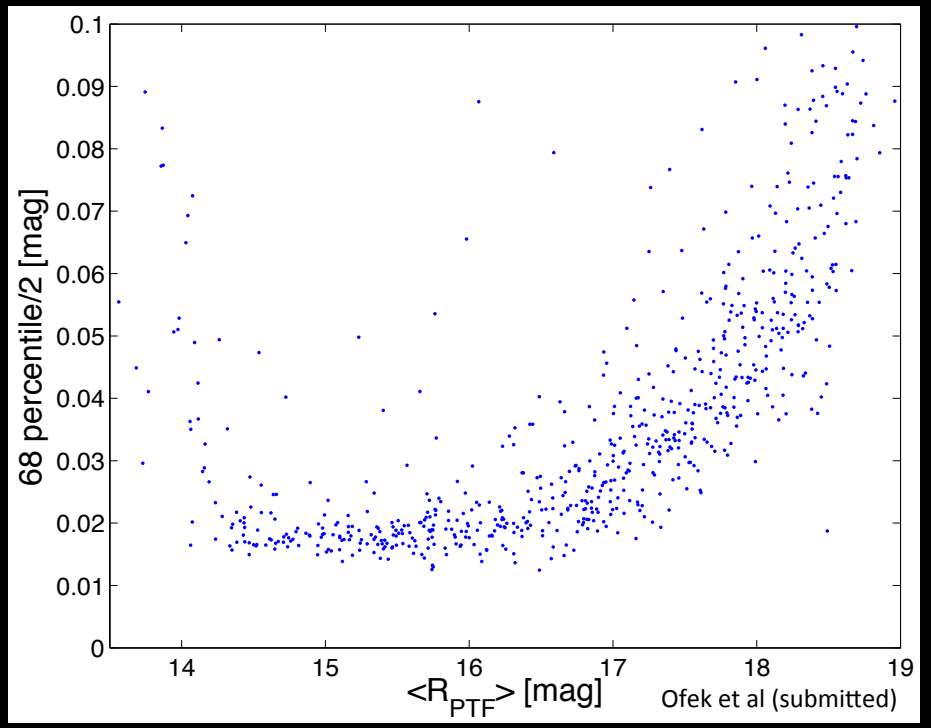
AM CVn System Discoveries



Photometric Calibration to SDSS

PALOMAR TRANSIENT FACTORY

- Obtain photometric zero-points for all exposures (whether in SDSS field or not)
- Find a "Zero-Point Variation Map" to account for changes in the PSF over the chip



$$
\begin{aligned}
r_{\rm SDSS} - R^{\rm inst}_{\rm PTF} &= ZP_R + \alpha_{{\rm c},R}(r_{\rm SDSS} - i_{\rm SDSS}) \\
&+ \alpha_{{\rm a},R} AM + \alpha_{{\rm ac},R} AM (r_{\rm SDSS} - i_{\rm SDSS}) \\
&+ \alpha_{{\rm t},R}(t - t_{\rm m}) + \alpha_{{\rm t2},R}(t - t_{\rm m})^2 \\
&- 2.5 \log_{10}(\delta t),
\end{aligned}
$$

Photometric Calibration to SDSS

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- Obtain photometric zero-points for all exposures (whether in SDSS field or not)
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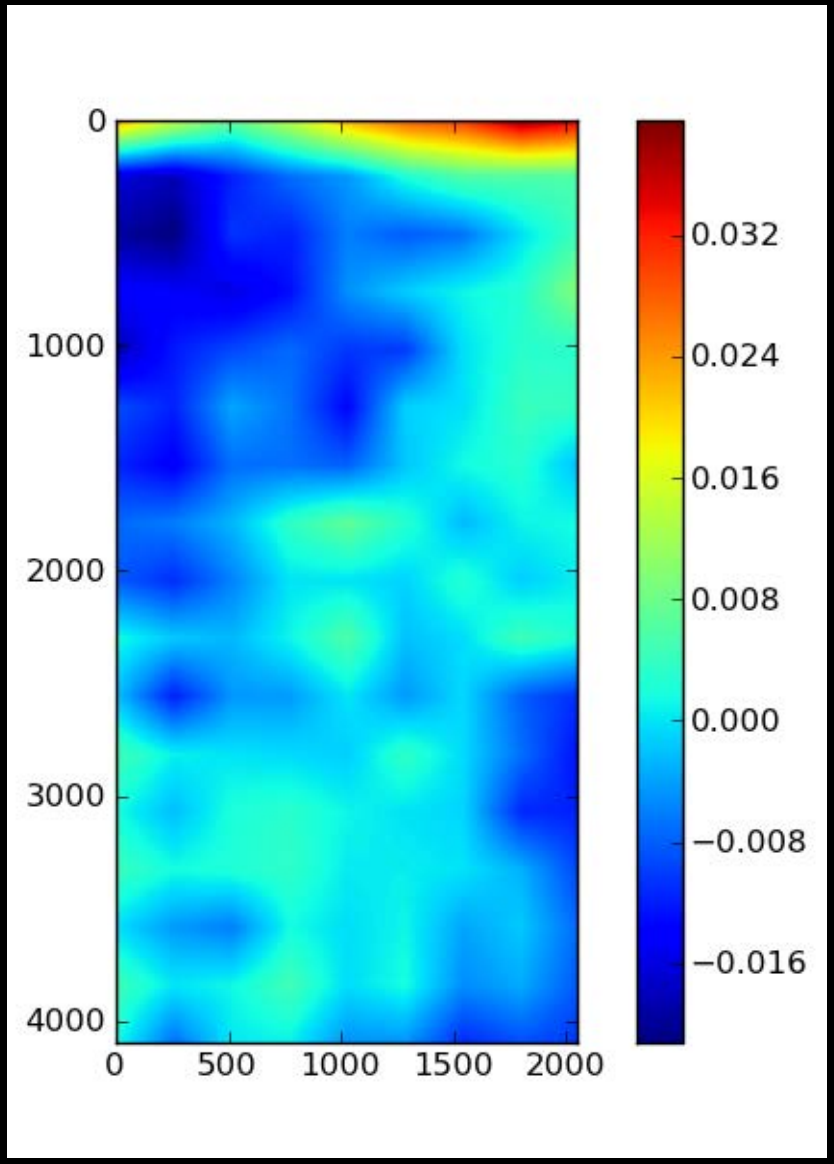
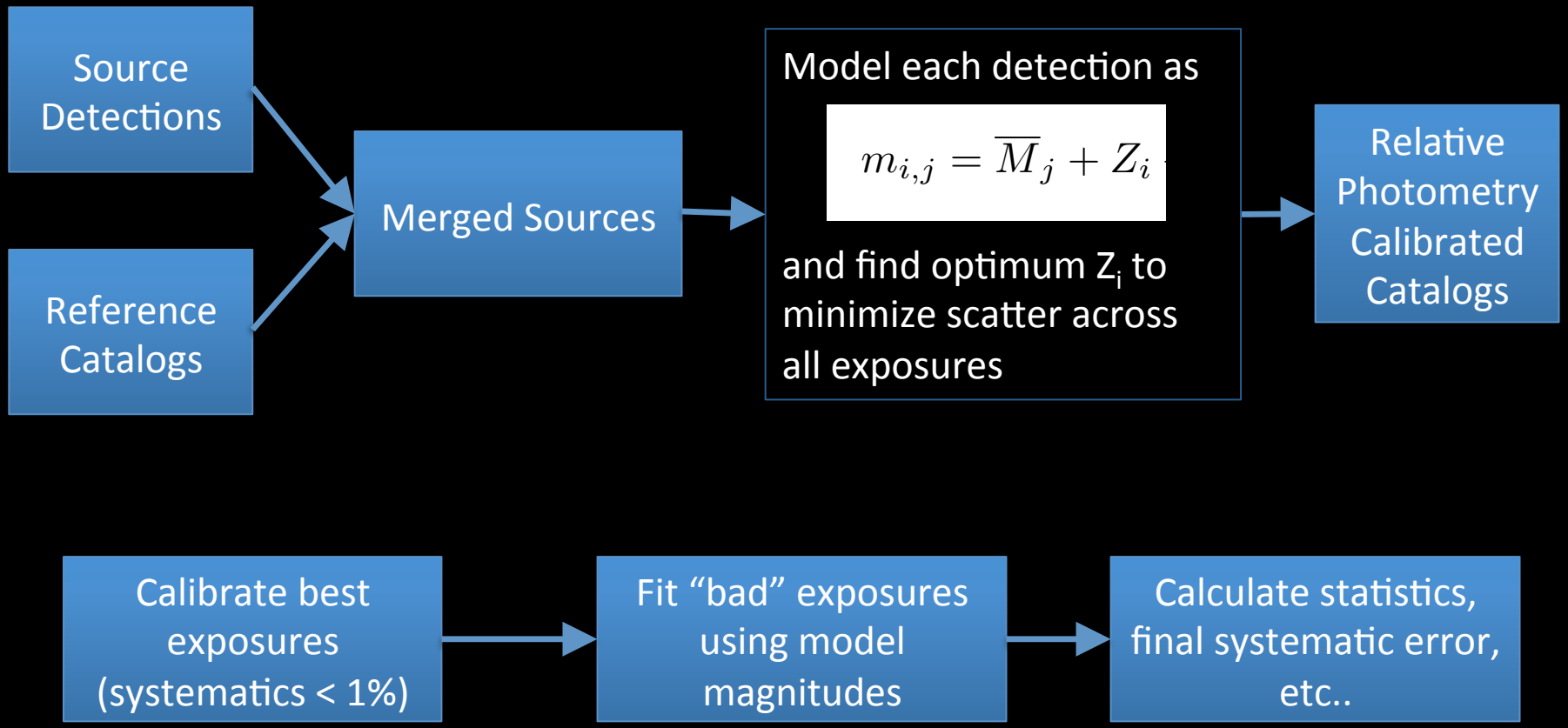
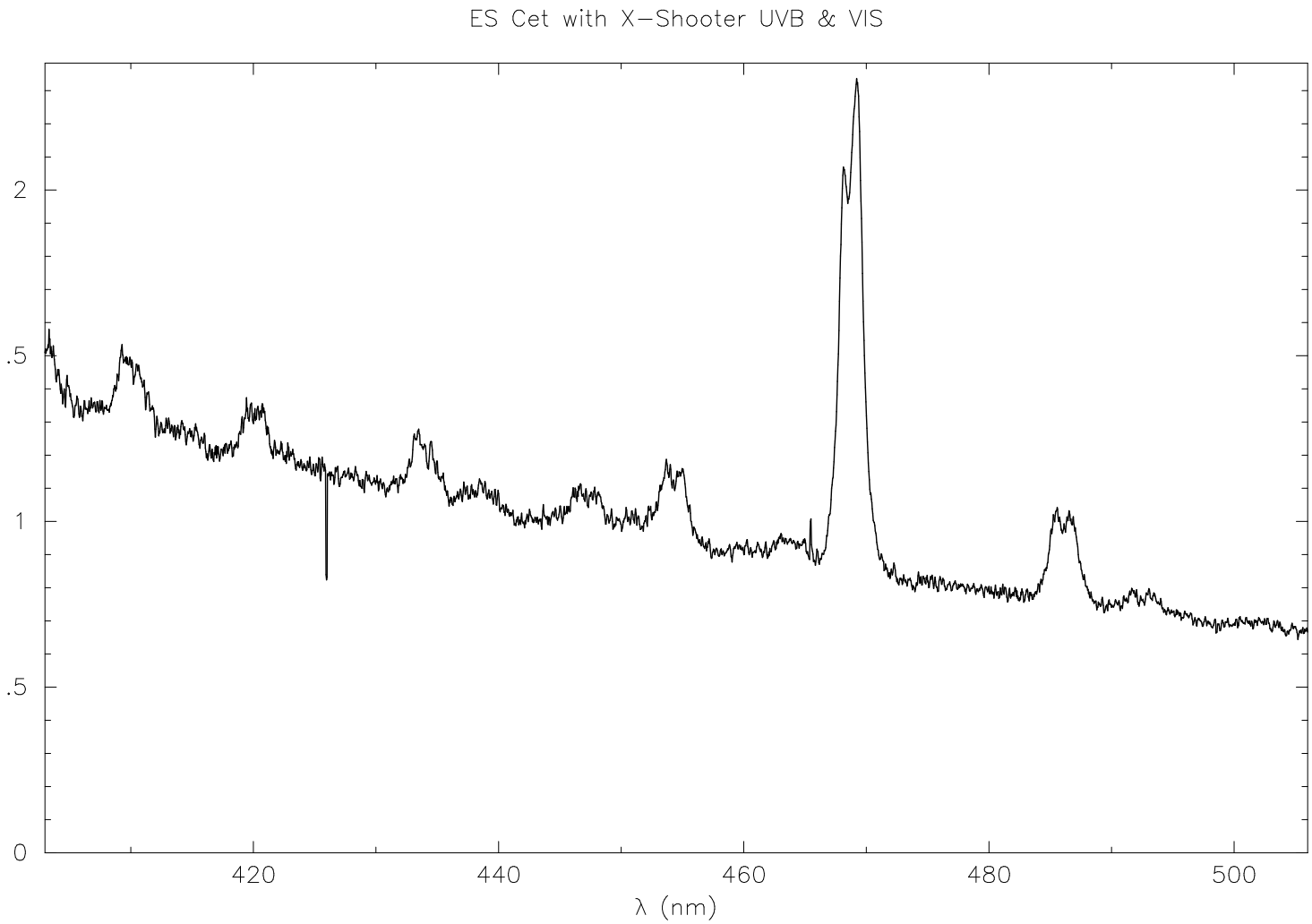


Relative Photometry Pipeline

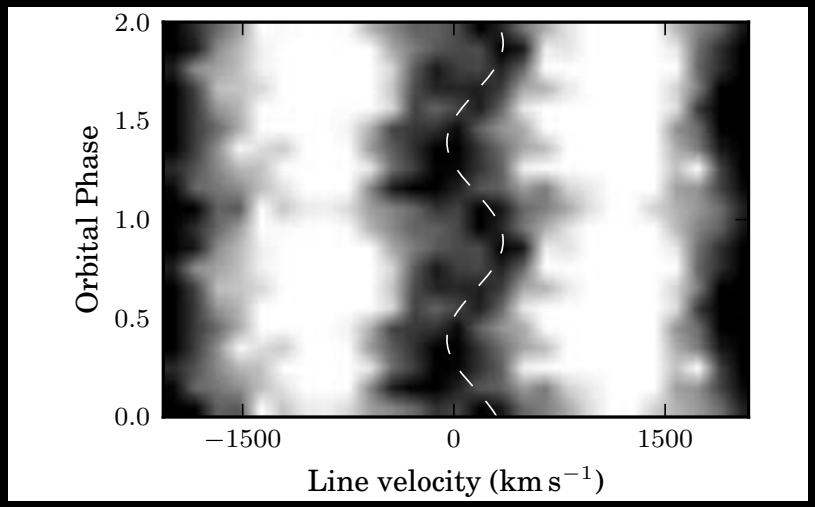


ES Ceti

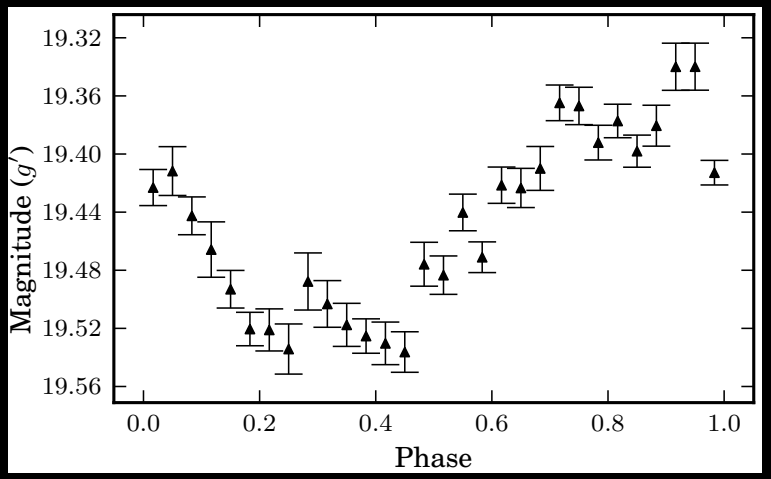
PALOMAR TRANSIENT FACTORY



PTF1J0719+4858 Analysis



PTF1J0719+4858 "S-Wave"

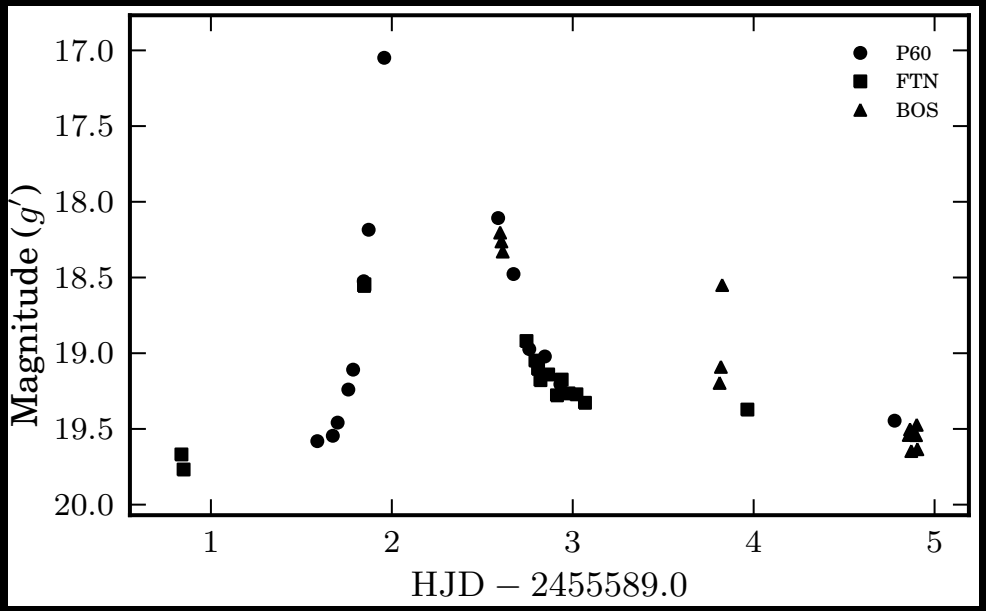


PTF1J0719+4858 Quiescent Variability

PTF1 J0719+4858

Orbital Period: 26.77 minutes

Super-outburst recurrence time: 65-80 days



PTF1J0719+4858 Normal Outburst

Eclipsing Binaries

PALOMAR TRANSIENT FACTORY

Project just starting, but already likely results: