

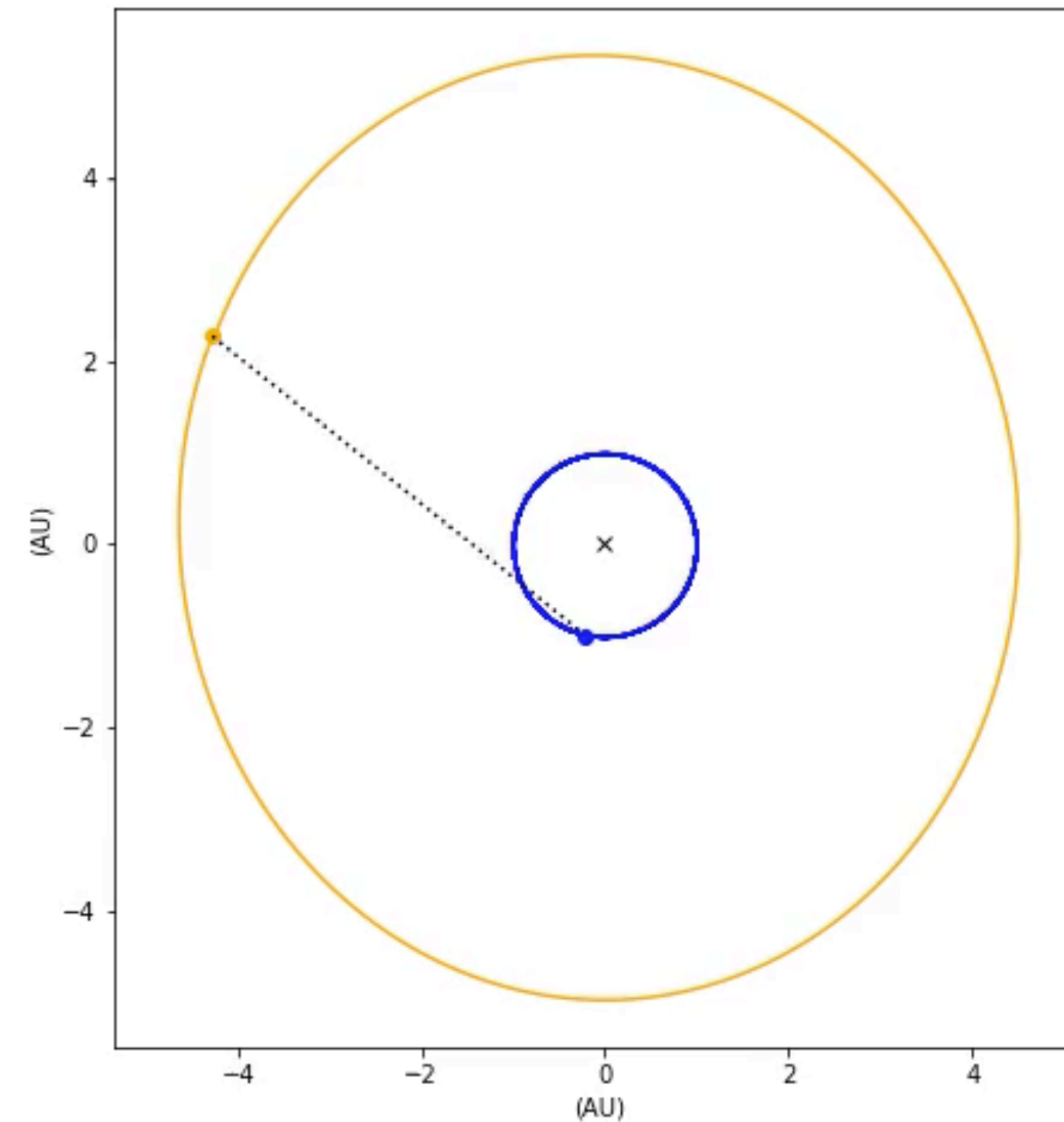
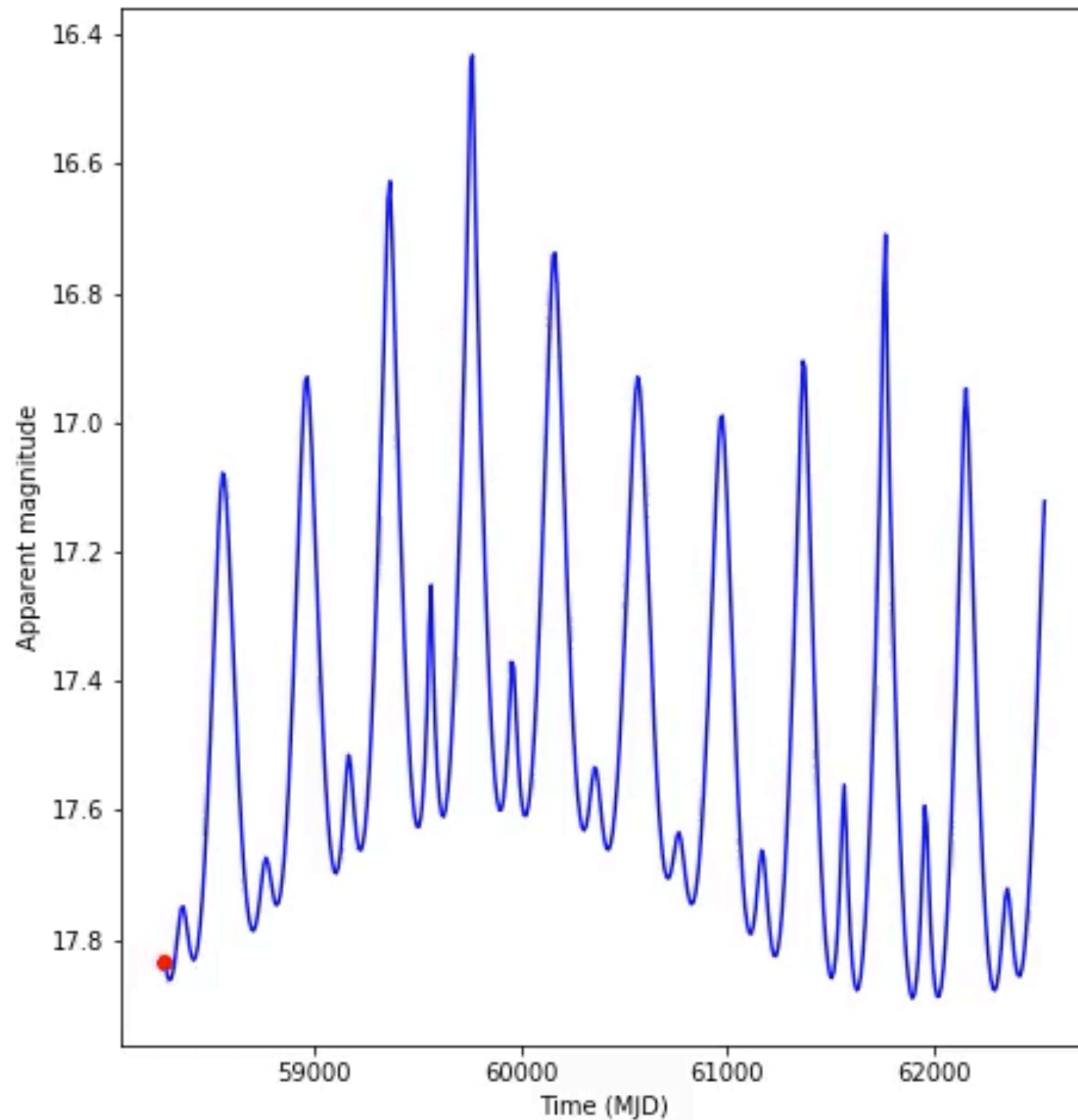
# Asteroid Lightcurves from ZTF Alert Photometry

Lynne Jones, Mercedes Thompson  
ZTF Solar System Working Group

DiRAC Alert Database - Mario Juric, Zack Galkhou, Eric Bellm,  
Maria Patterson, Chris Phillips

# Asteroid apparent magnitudes

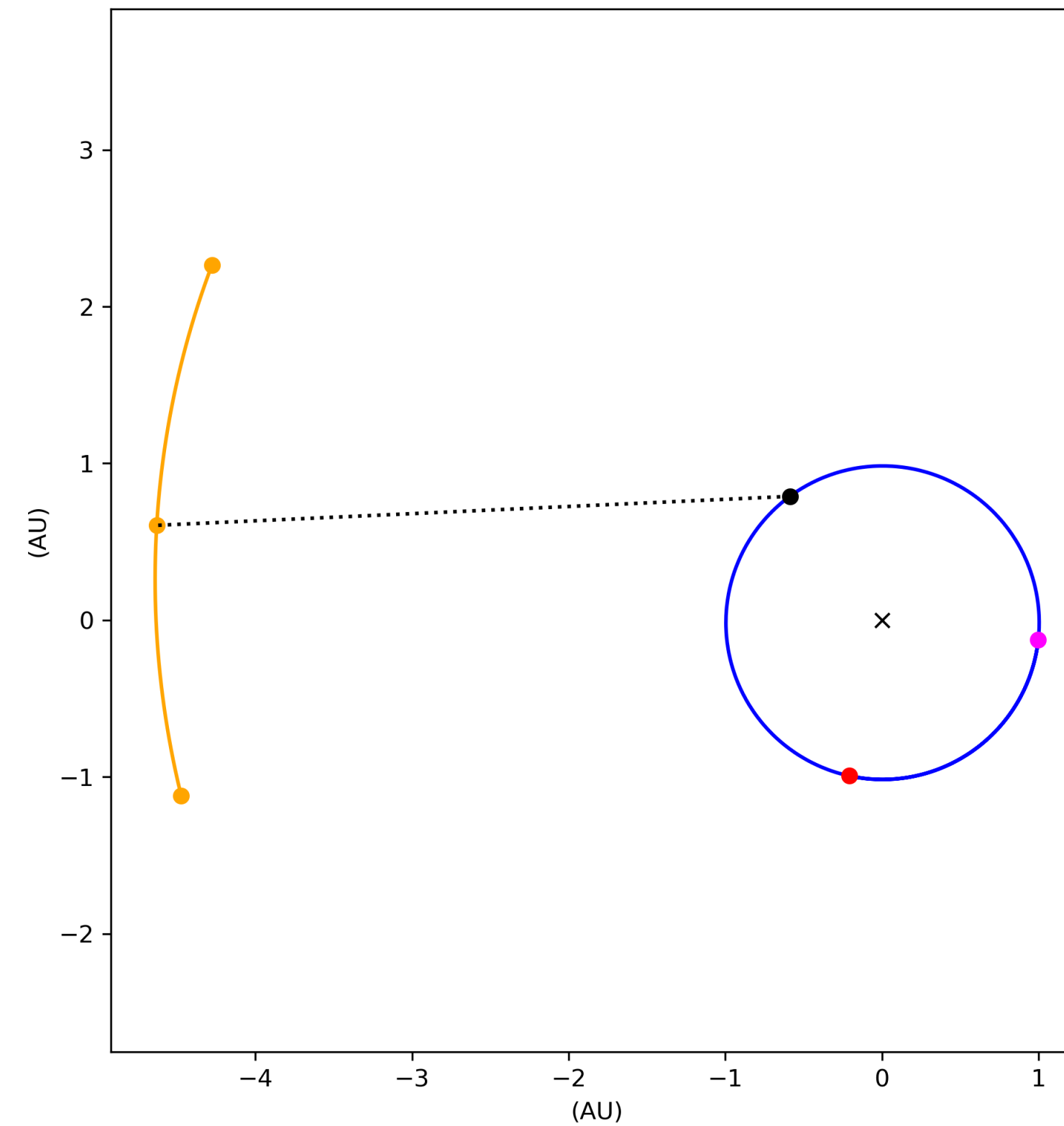
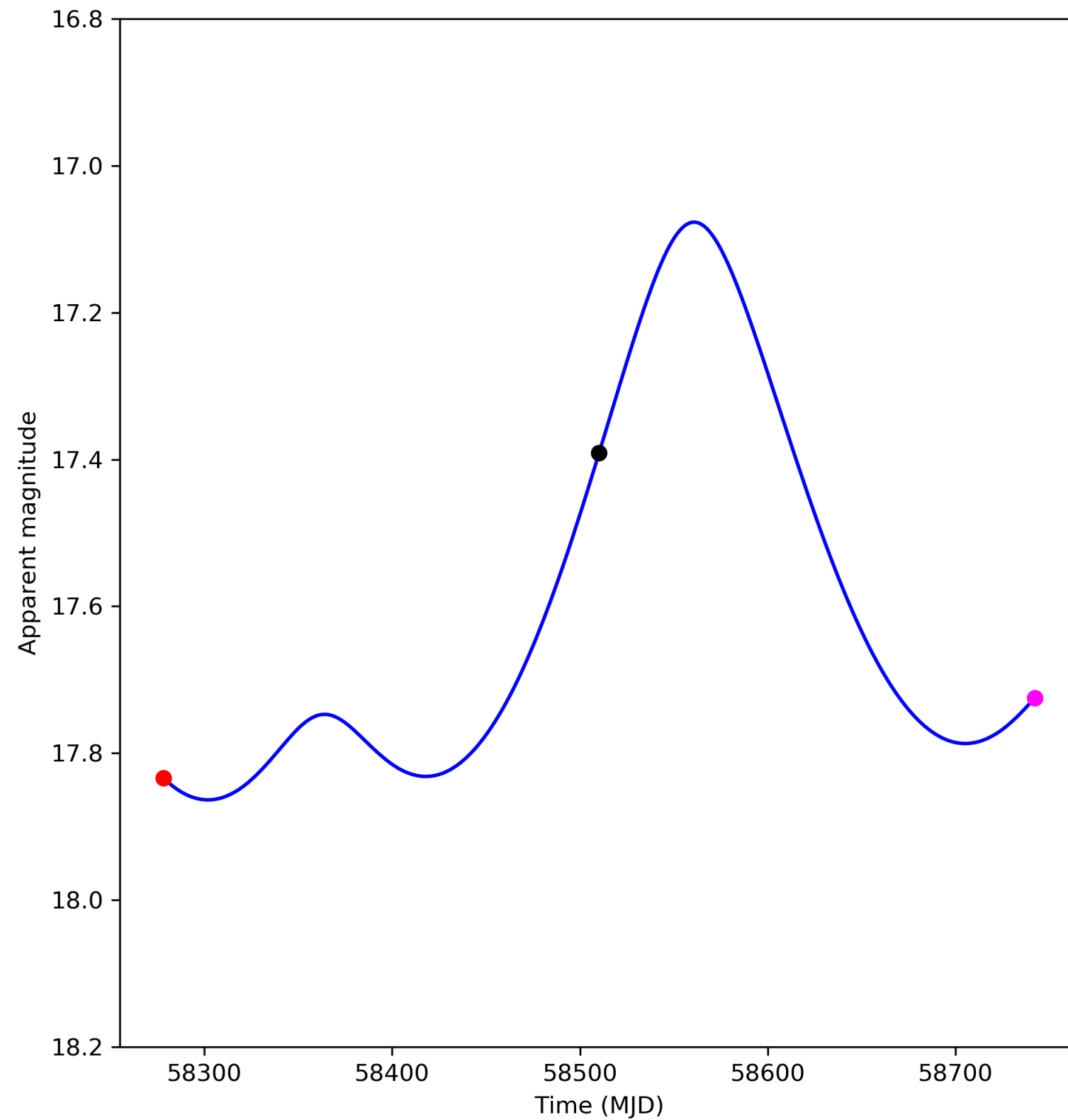
**Jovian Trojan  
34746  
(4,270 days)**



**Apparent magnitude changes due to distance and phase angle**

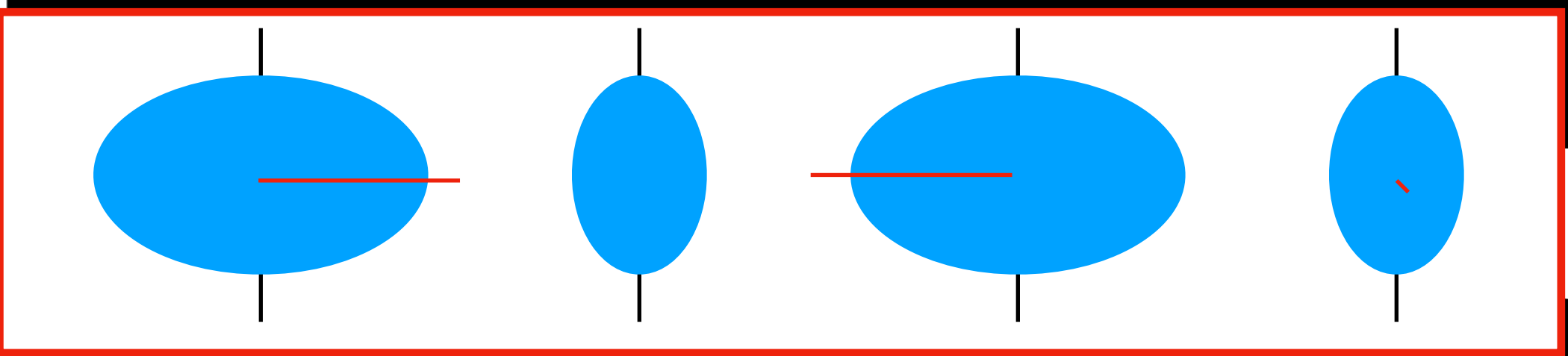
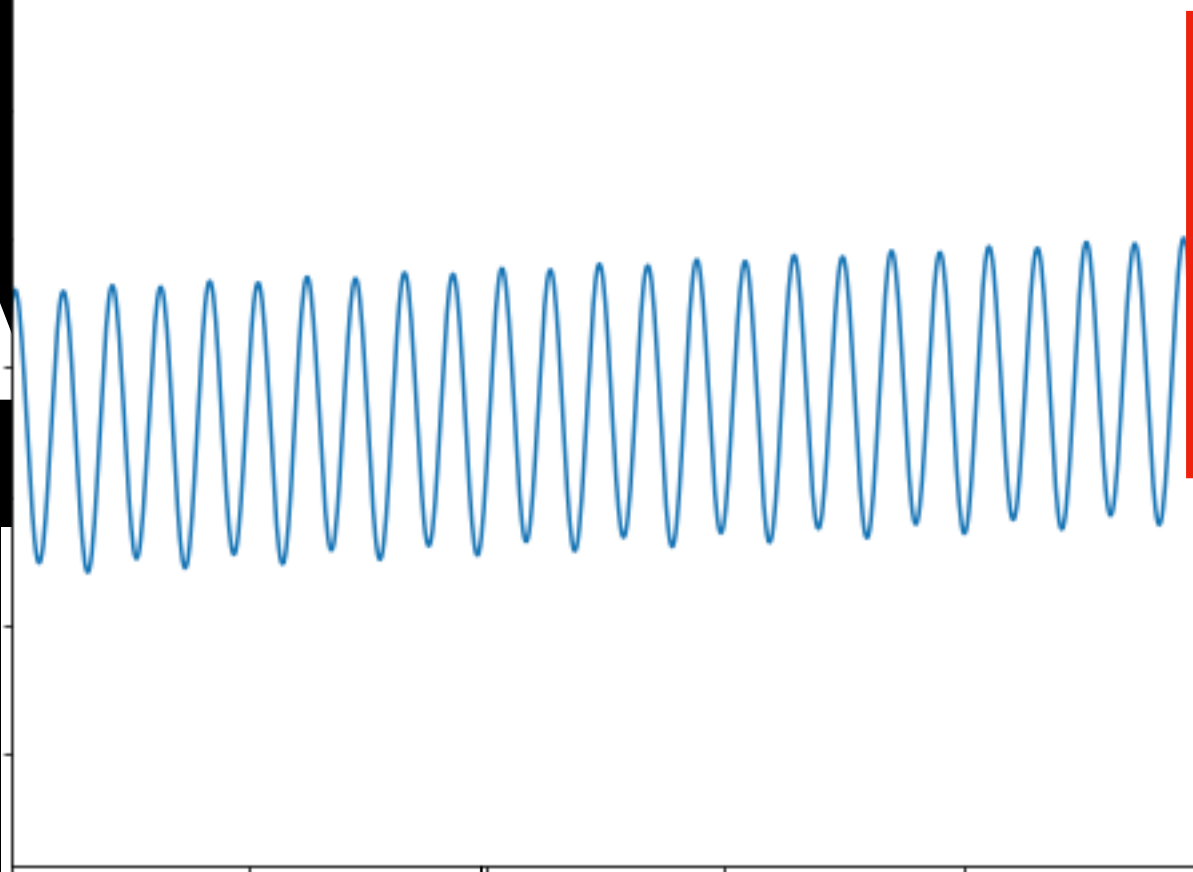
# Asteroid apparent magnitudes

**Jovian Trojan  
34746  
(464 days)**



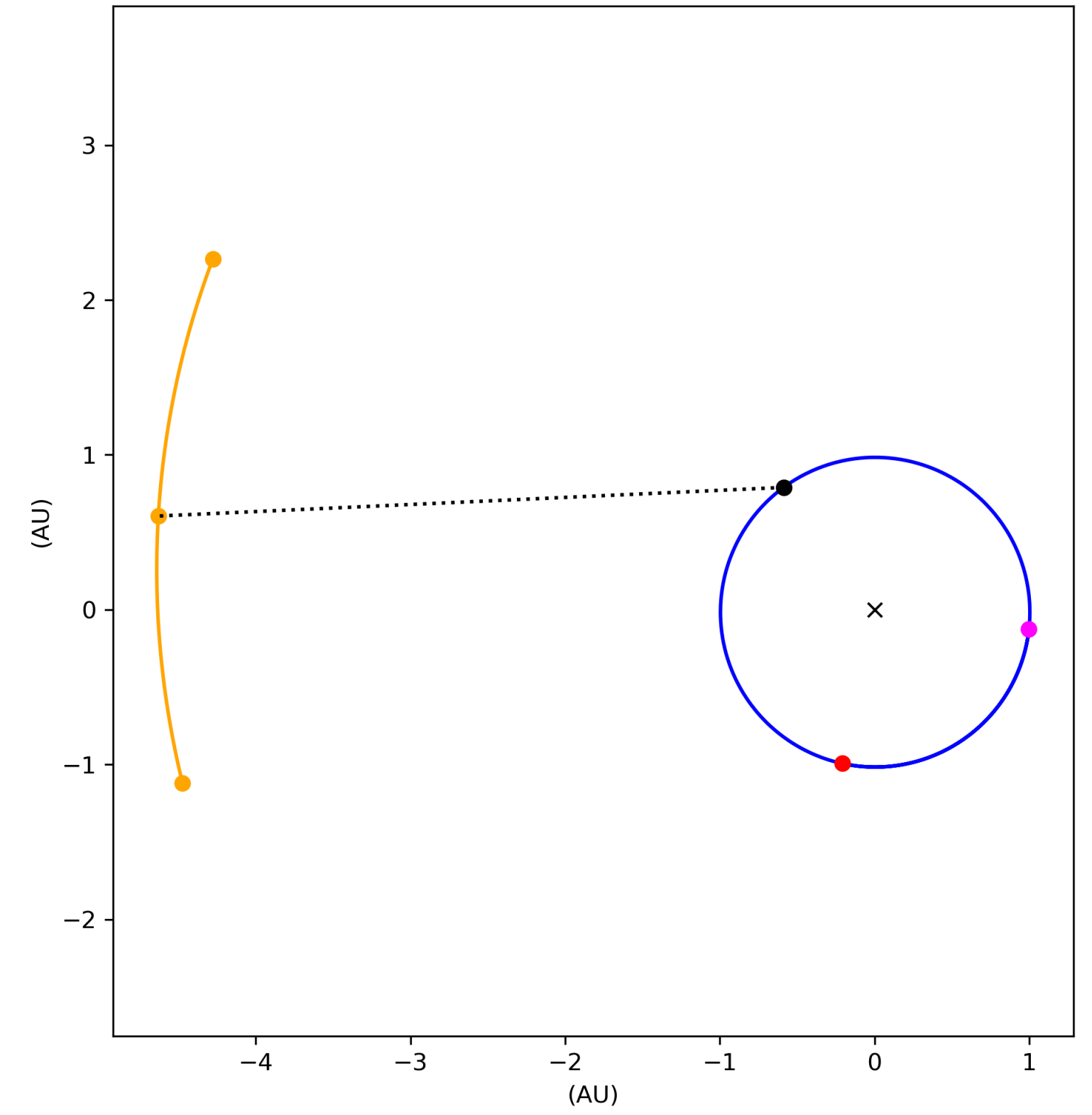
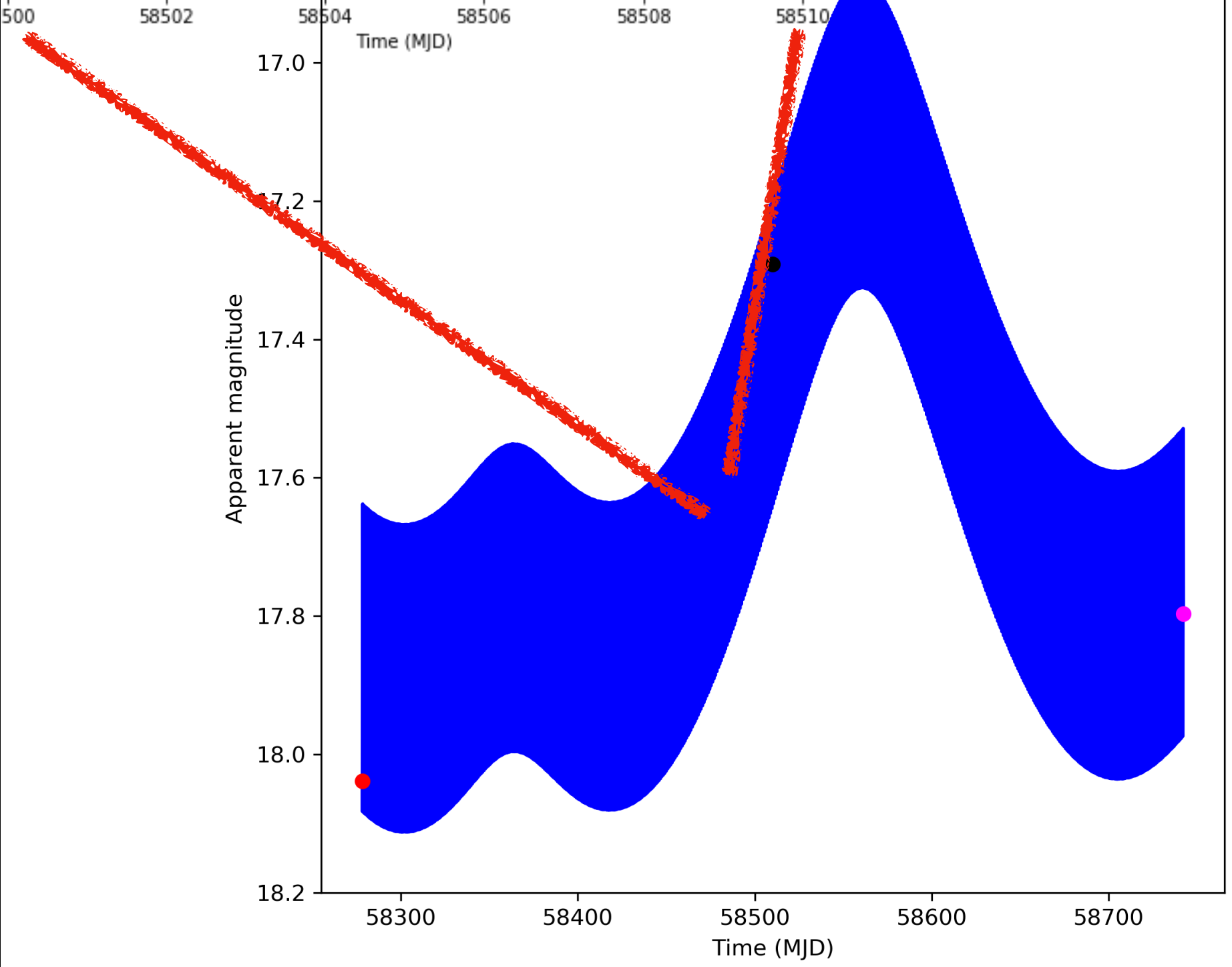
**Apparent magnitude changes due to distance and phase angle**

A



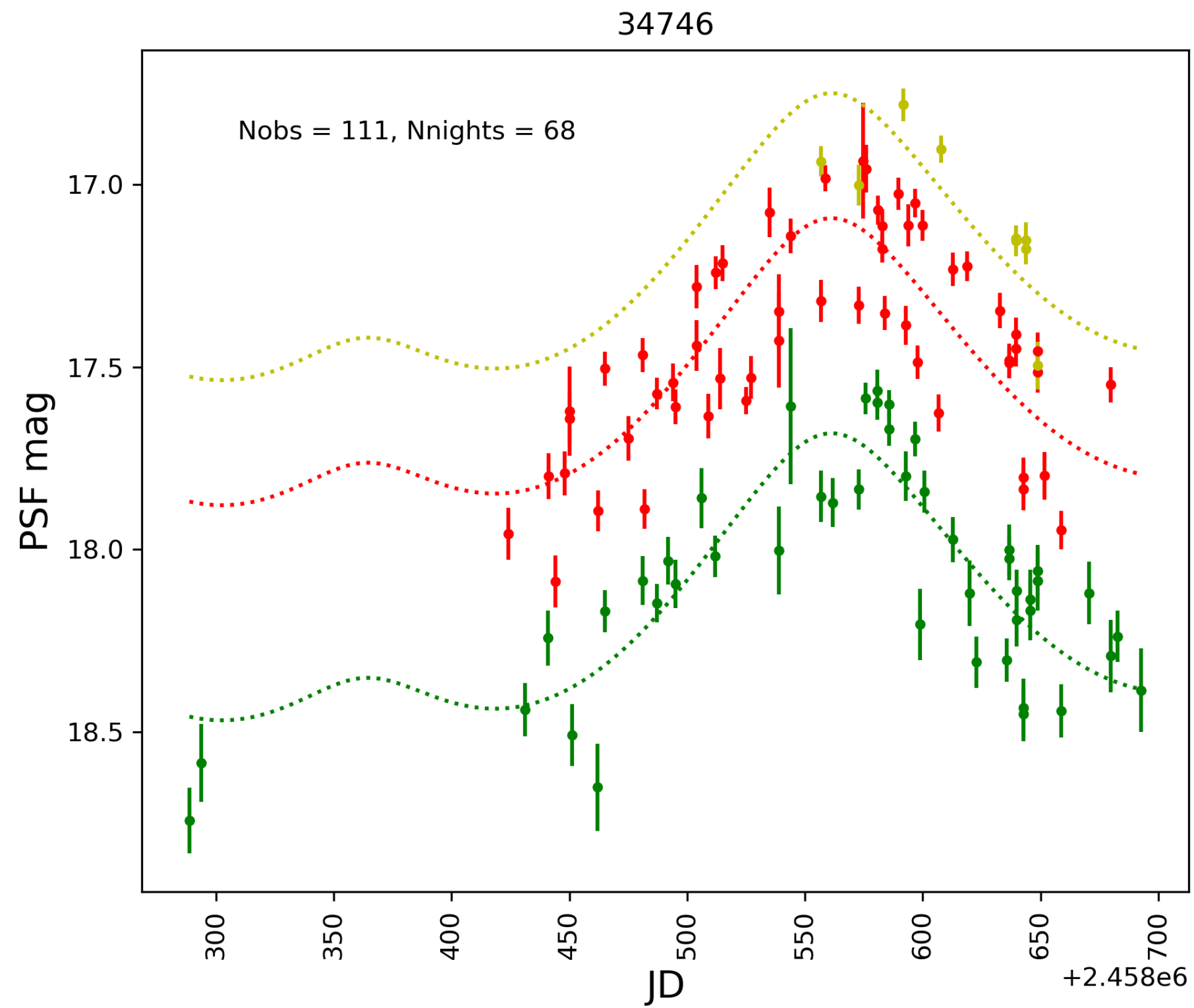
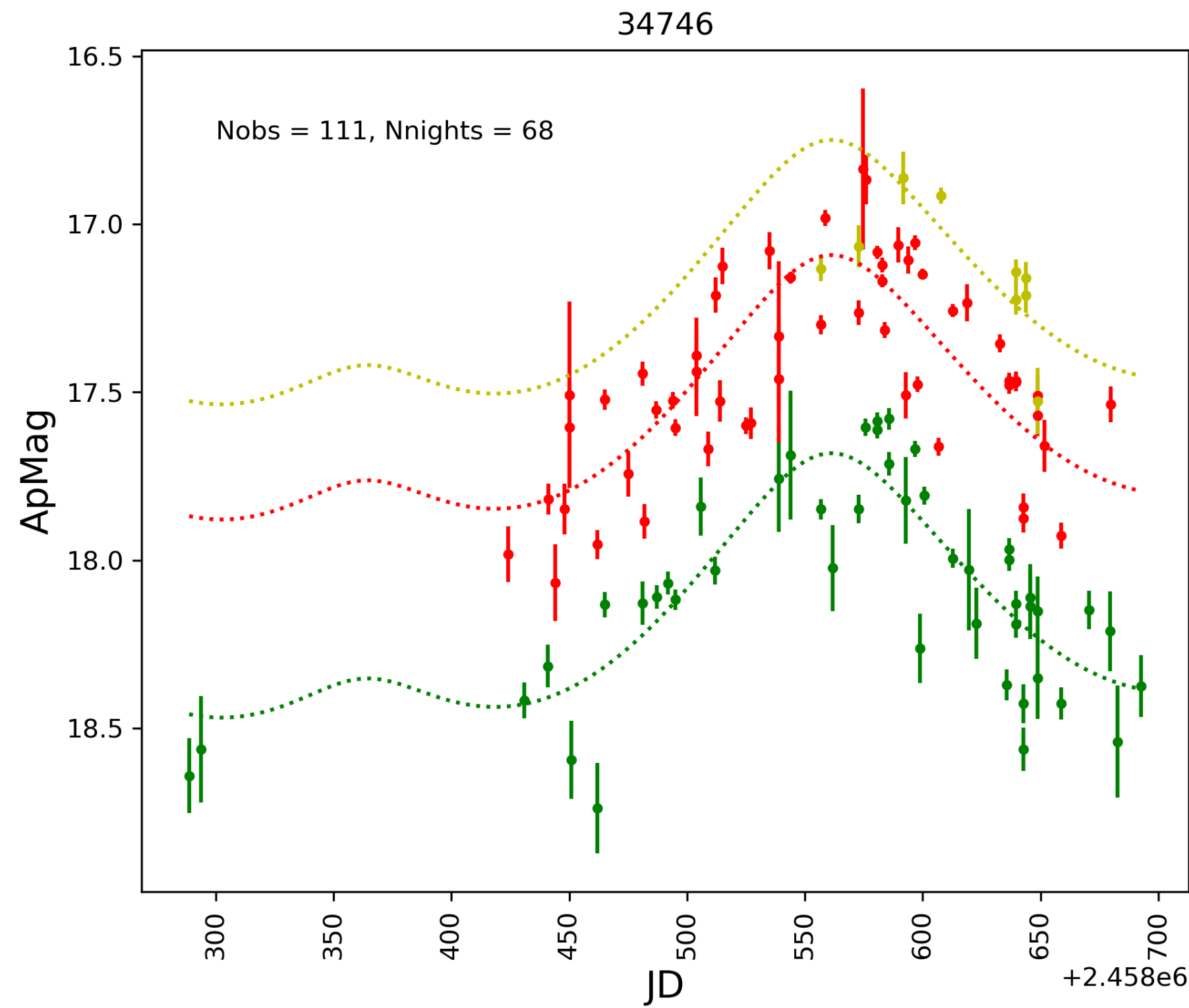
itudes

**Jovian Trojan  
34746  
(464 days)**



**Apparent magnitude changes due to distance and phase angle plus rotation (plus viewing geometry/shape)**

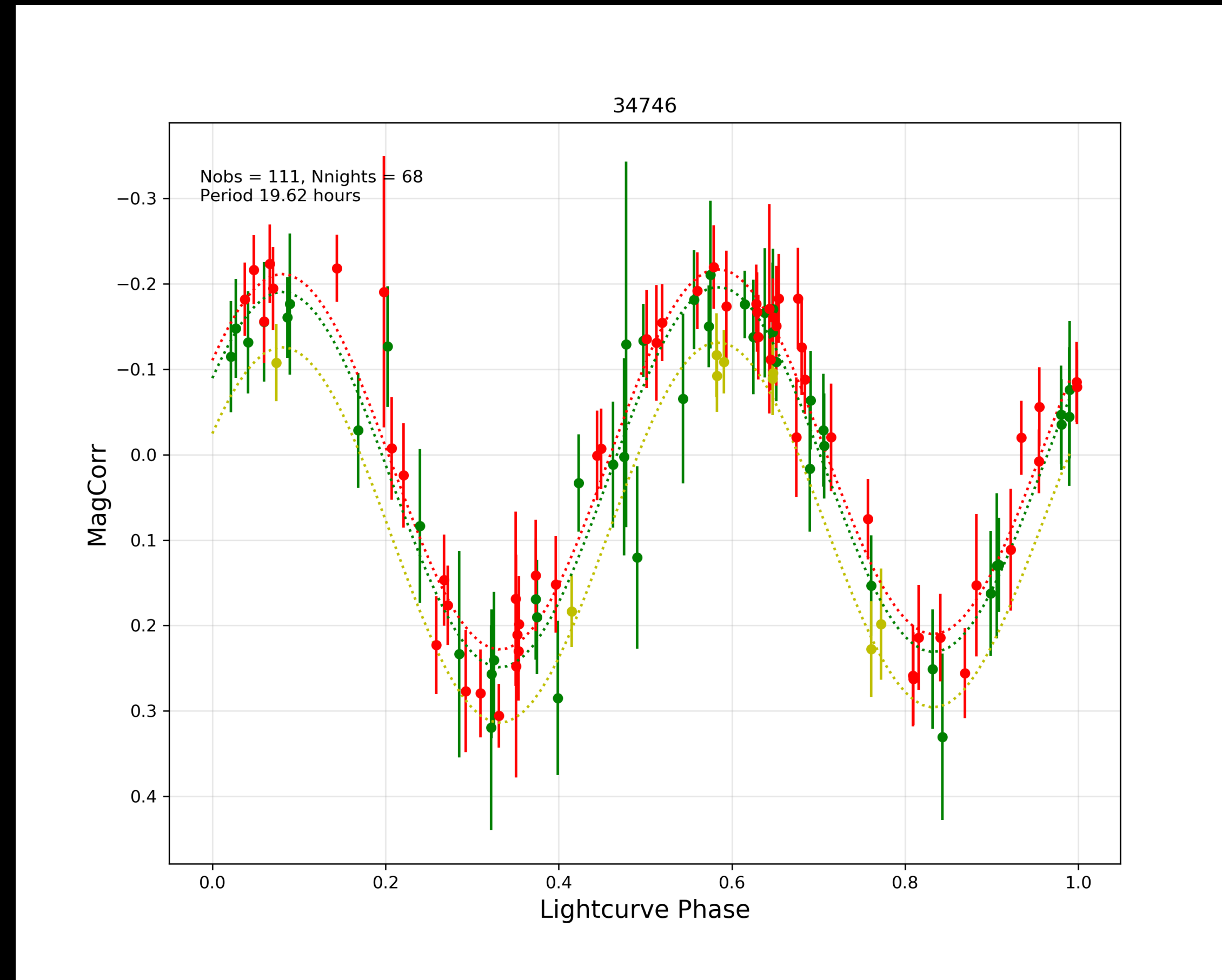
# Asteroid apparent magnitudes



Jovian Trojan  
34746  
(404 days)

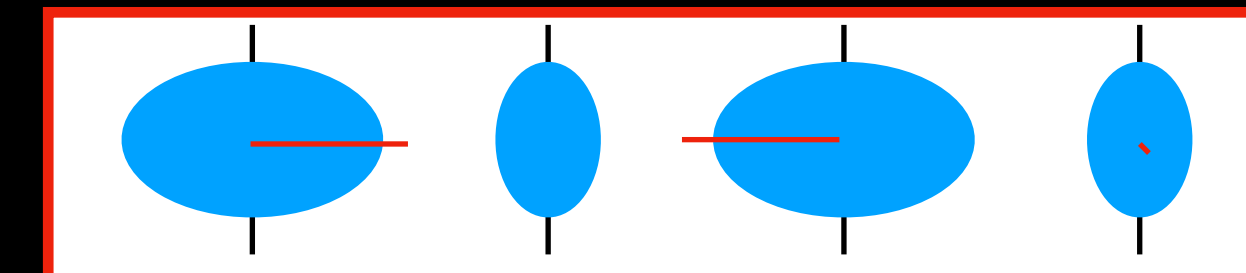
As observed by ZTF  
and published in the Alert Stream

# Asteroid rotational light curves



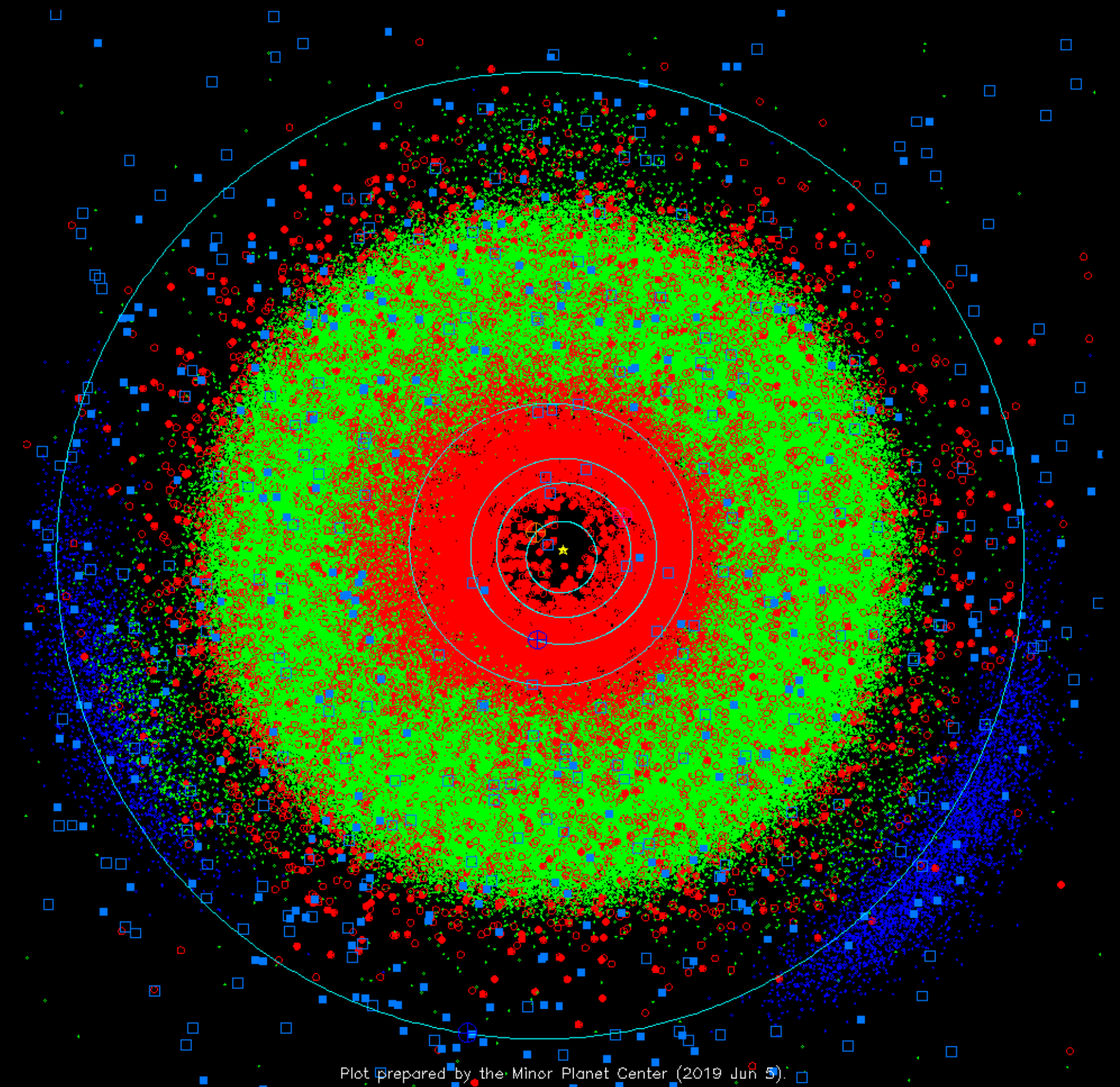
Jovian Trojan  
34746  
(404 days)

Corrected for distance and phase effects  
Fit for rotation period (19.6 hrs)



# Jovian Trojans

- In 1-1 resonance with Jupiter
- 7079 currently known (MPC, Sep 2019)
- Clues to planet formation and evolution
  - When were they captured & where from?
  - How many in each libration island? What are their orbital parameters? What are their physical properties?
    - Rotation periods



**Credit: Minor Planet Center**

# Lightcurves of Jovian Trojans

- Asteroid Lightcurve Photometry Database
  - Brian Warner
    - *Stephens & Warner, 2018 (DPS), Warner, Stephens & Harris, 2011 (MPB), Stephens & Warner, 2010 (DPS), Warner, Harris, & Pravec 2009 (Icarus)*
  - <http://alcdef.org>
- 21724 asteroids including 397 Trojans

**ALCDEF**  
Asteroid Lightcurve Photometry Database

[What is ALCDEF?](#) [About Asteroid Lightcurves](#) [Acknowledgements](#) [Giving Credit](#) [Data and Privacy Policy](#)

**Special Announcements**  
Version 2.2.7 Released 2019 April 25. Please download and review the latest [ALCDEF standards PDF](#).  
The Multi-lightcurve block plotting tool is now available. You'll find a button to access it when displaying the lightcurve blocks for a chosen object.

**Statistics and Search**

Objects	LC Blocks	Observations
14800	193373	3560443

Last update: 2019-09-02 08:13:10

Object Search  
Search Database

**Required "Opt-in" and File Upload**

You must give express permission before your data can be stored and distributed. Without this permission, your data will not be accepted by the ALCDEF site. You must also choose whether or not your data will be automatically made part of a periodic release from the NASA Planetary Data System.

For more information, see the [Data and Privacy Policy](#) statement and the [ALCDEF documentation](#).

Allow sharing  Submit to PDS

File  No file chosen

**ALCDEFVerify**

ALCDEFVerify is a web-based tool that runs the same verification checks used when uploading files to the ALCDEF database. It was developed for those writing third-party programs or scripts to debug and validate their data prior to uploading the files to the ALCDEF database.

Up to three files can be processed during each run. It is *strongly* recommended that each file be < 1 MB.

No file chosen

[Defined Constant Keywords](#)  
(see section 3 of ALCDEF standards documentation)

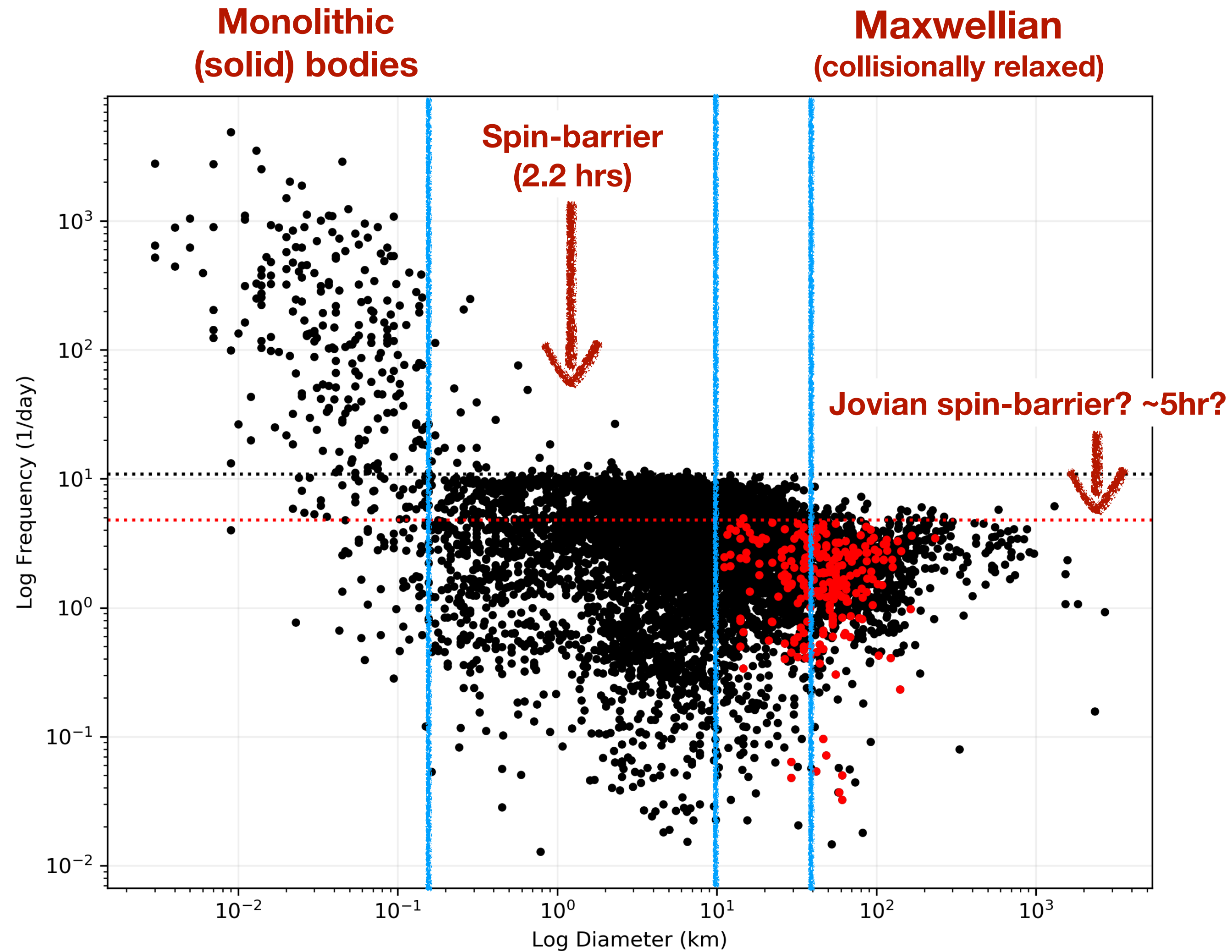
**Simple ALCDEF (S-ALCDEF)**

S-ALCDEF is for those who have basic text data files, e.g., JD, magnitude[, magerror]. Usually with a minimal amount of editing, these files can be uploaded to the ALCDEF database without creating the more detailed and rigorous standard ALCDEF files.

See the [ALCDEF documentation](#) for details  
Click here to go to the S-ALCDEF upload page



# Rotation Periods

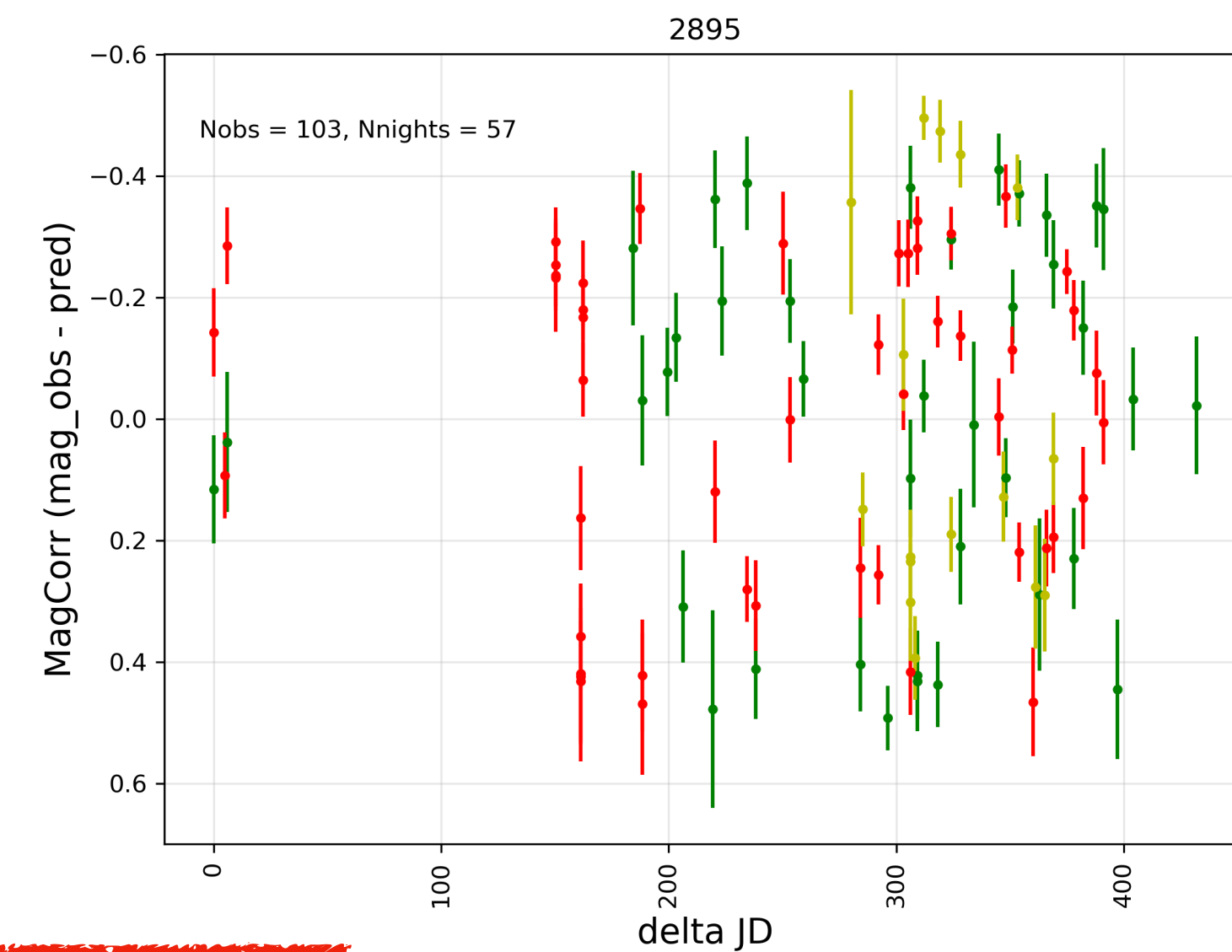
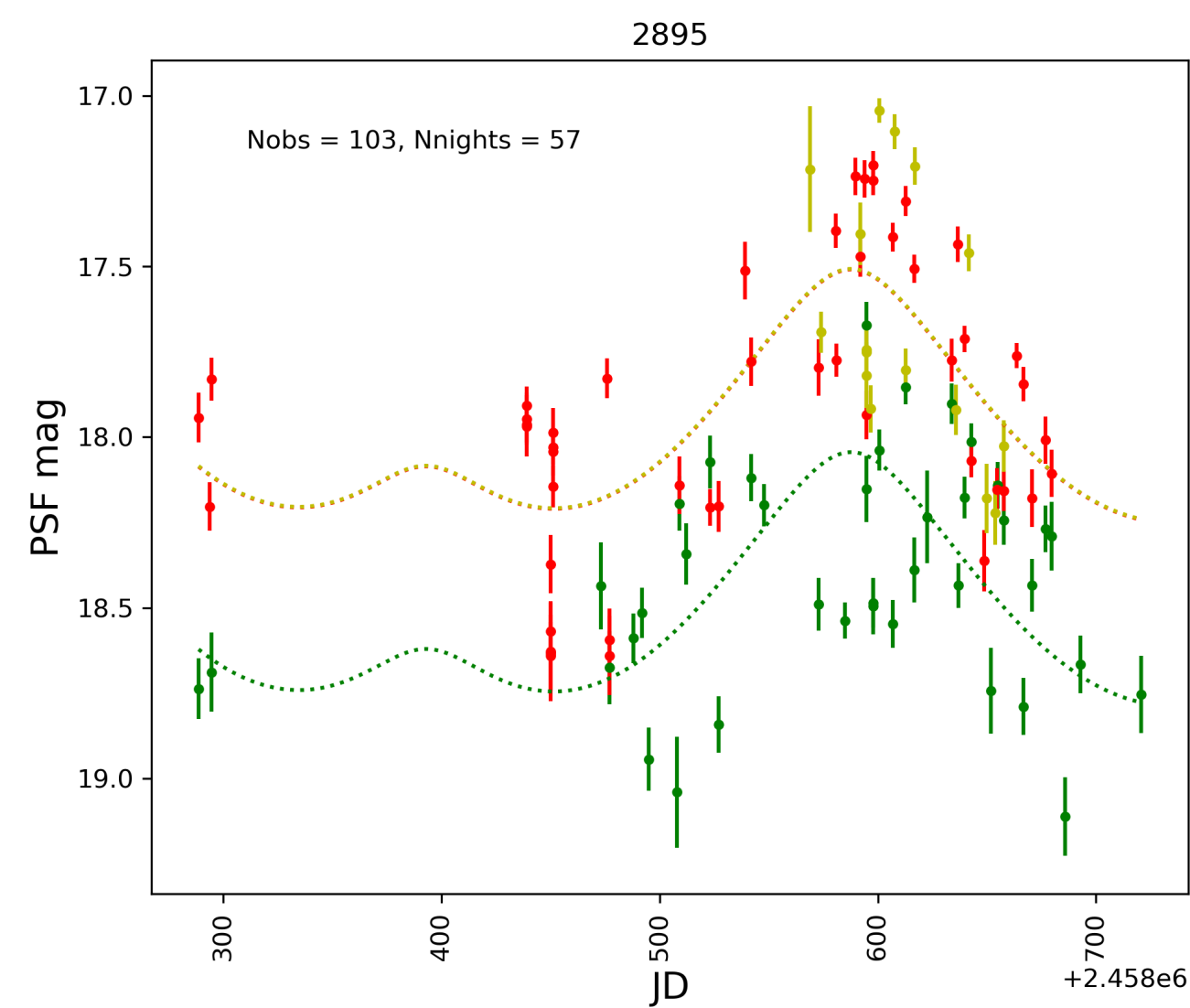
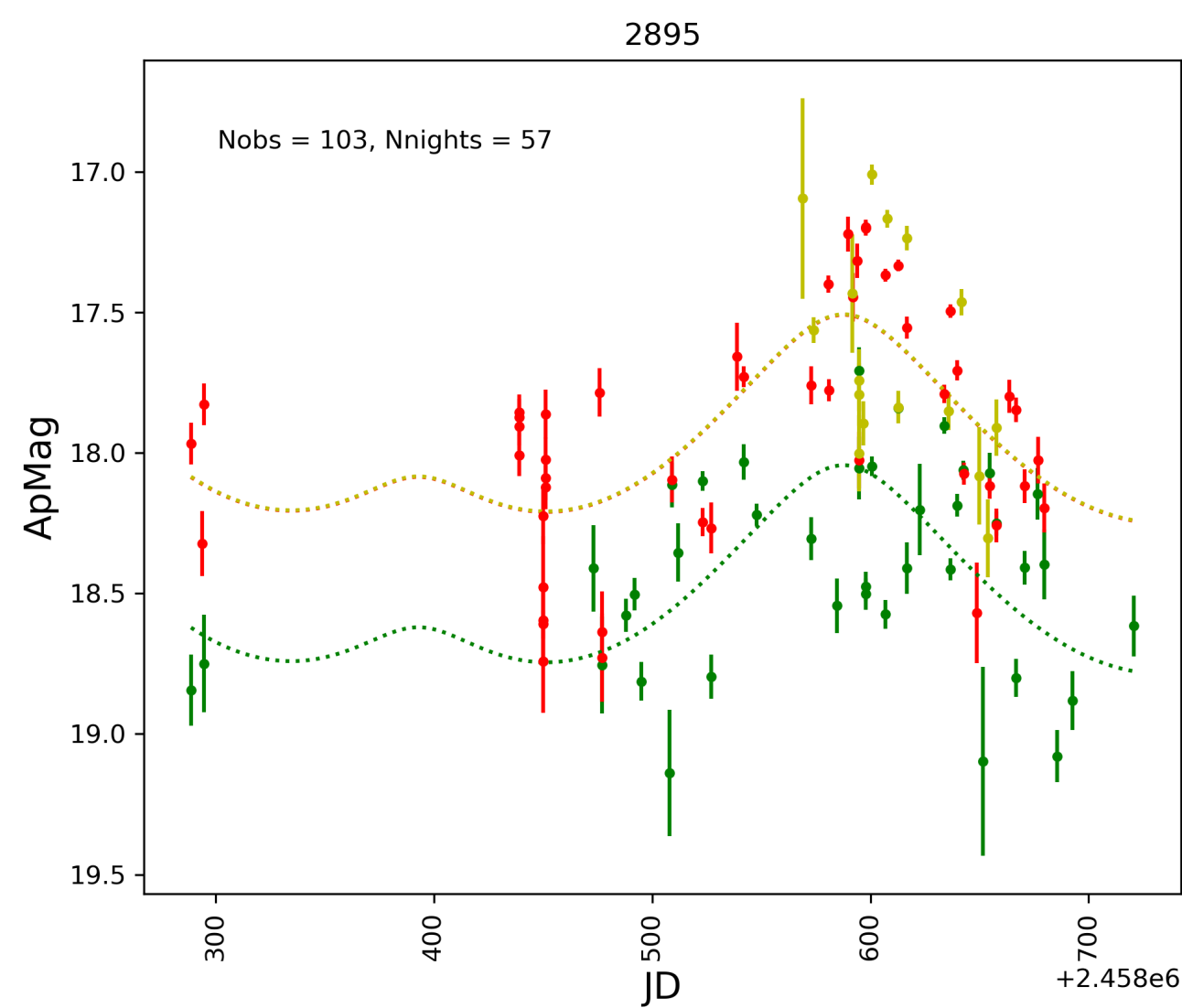


*Waszczhak et al 2014 (AAS)  
French et al 2015 (Icarus),  
French et al 2017 (DPS)  
Szabo et al 2017 (A&A),  
Carbognani 2017 (Icarus),*

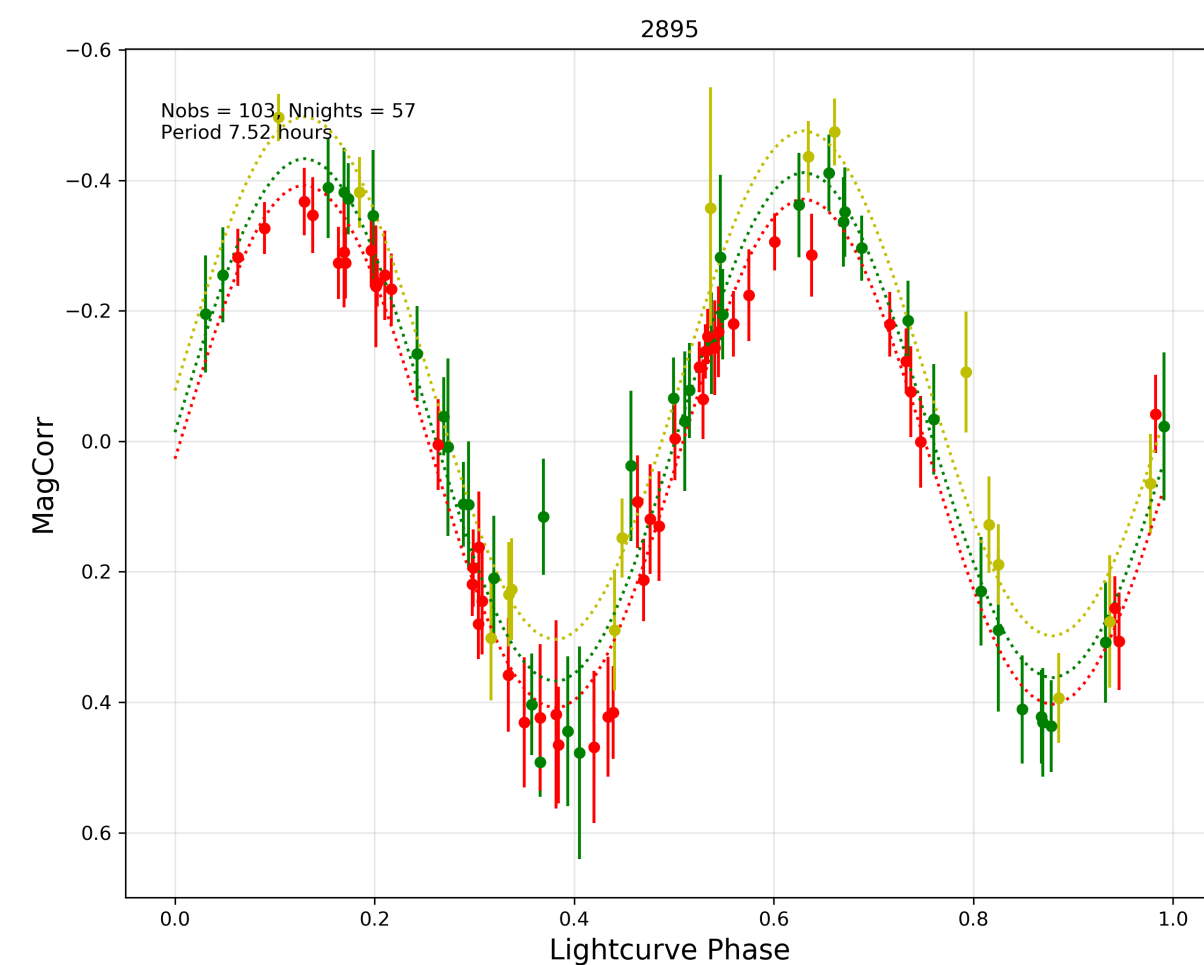
# Measuring Trojan rotation periods with ZTF

- 376 Jovian Trojans observed more than 30 times with ZTF
- Fantastic! Let's look for rotation periods!
  - Using PSFmag from Alert photometry - comes with SSNAMENR (object ID)
  - Get orbits from JPL horizons
  - Predict magnitudes using OpenOrb (= phase curve and distance)
  - Subtract predicted magnitudes (with approximate filter corrections)
  - Fit resulting 'corrected' magnitudes with multi-band 2-term LS (gatspy)

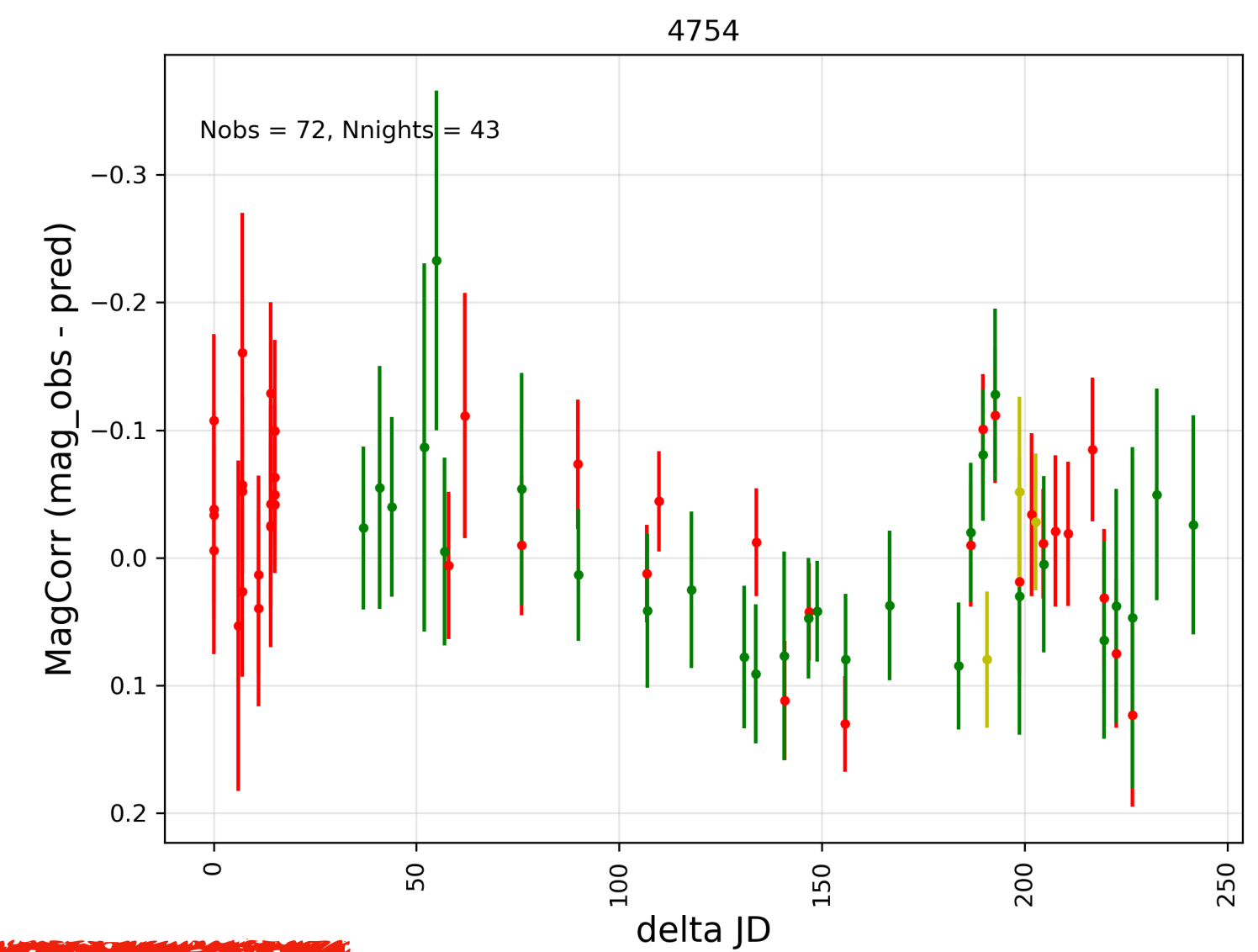
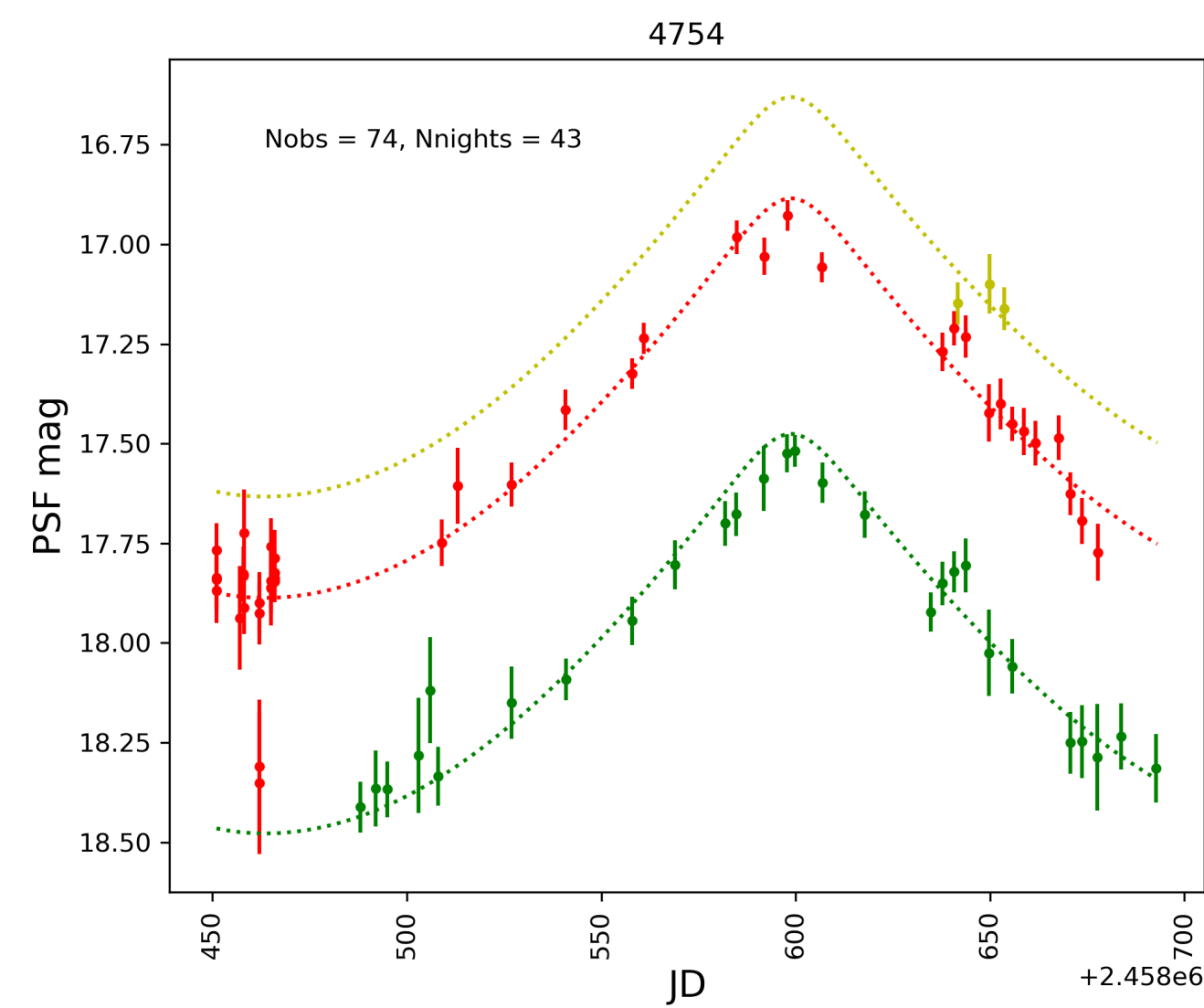
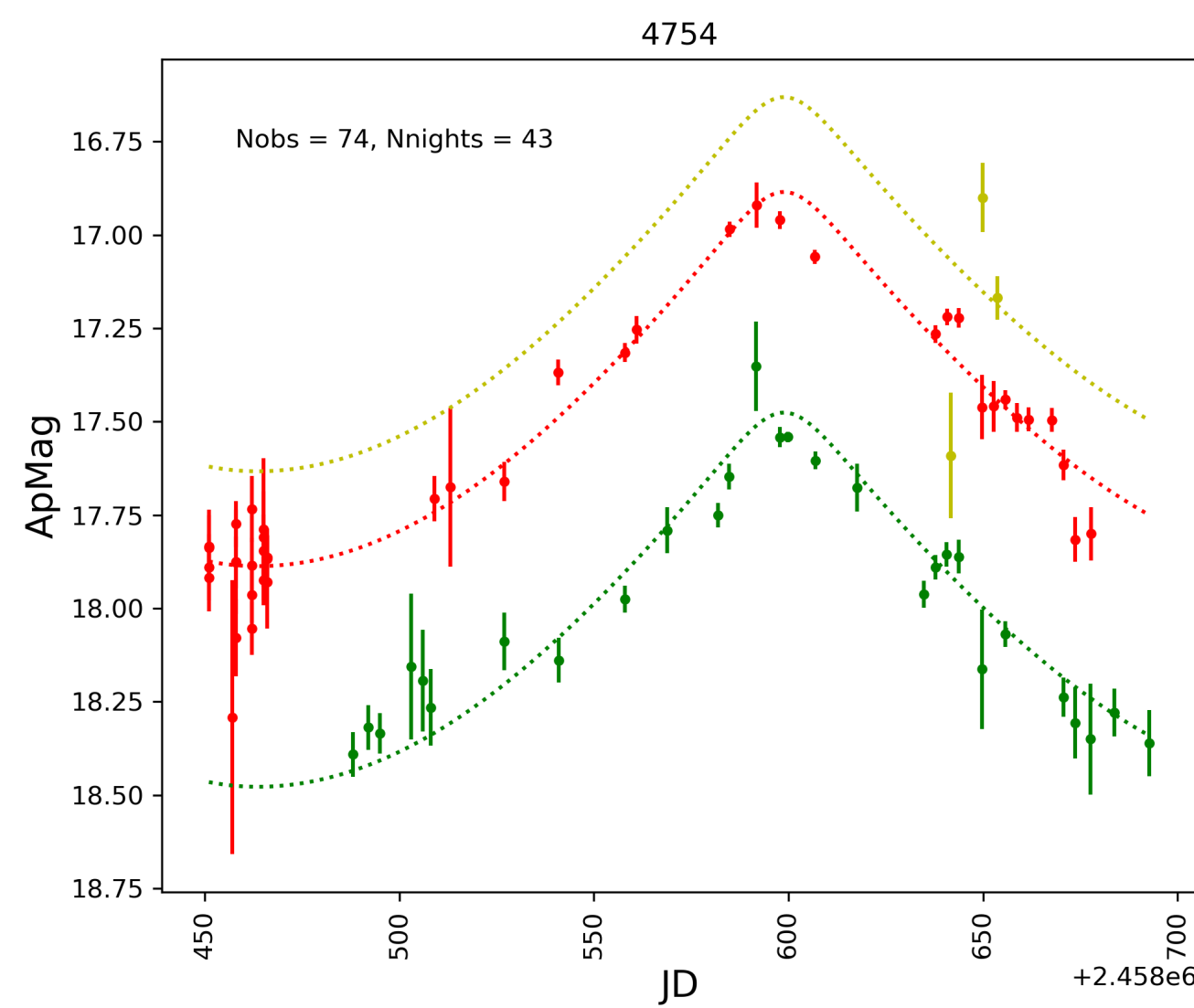
# Nice example



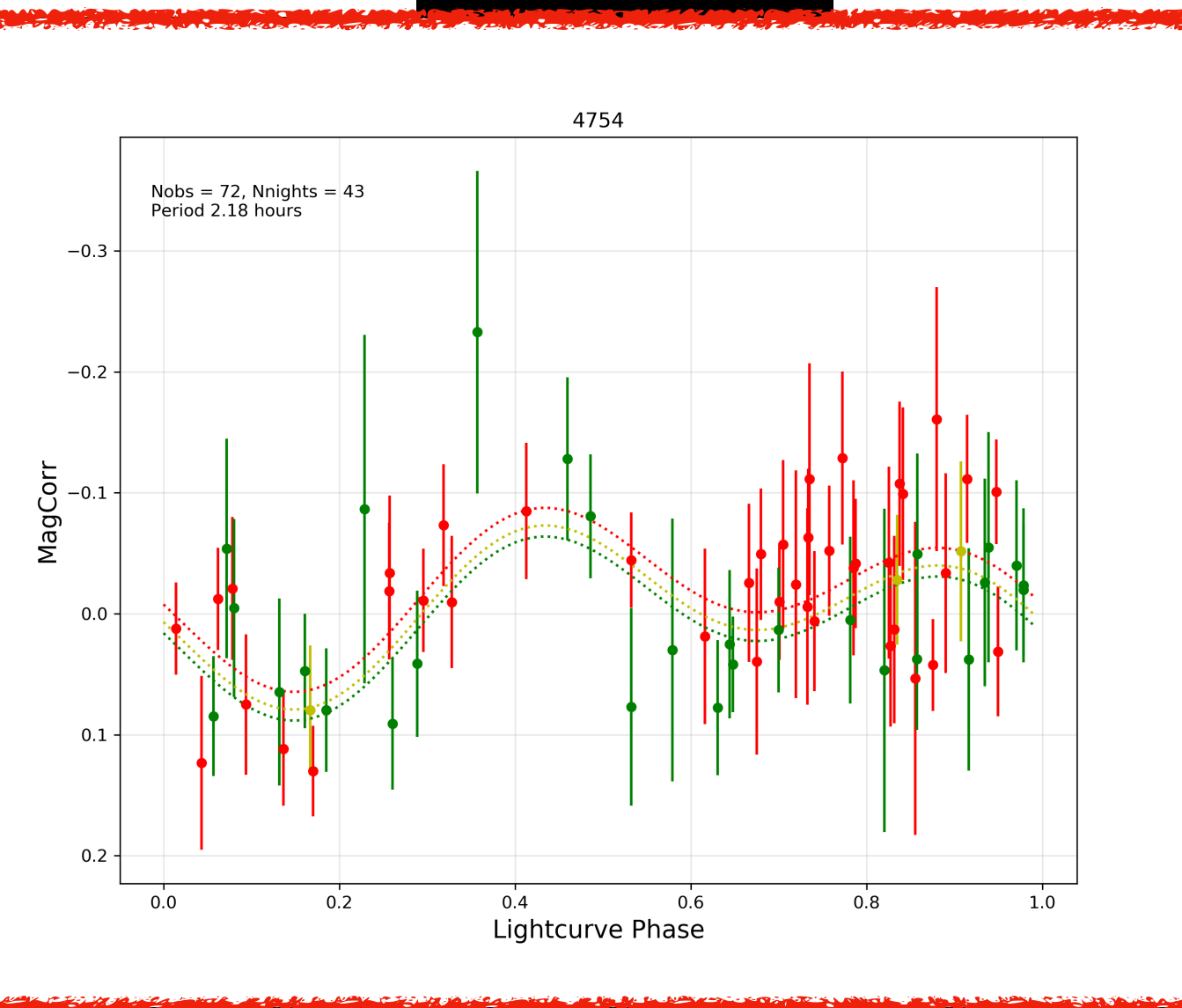
**2895 Memnon**  
**103 observations**  
**7.5hr period**  
**0.8 mag amplitude**  
**(previously known with 7.5hr period)**



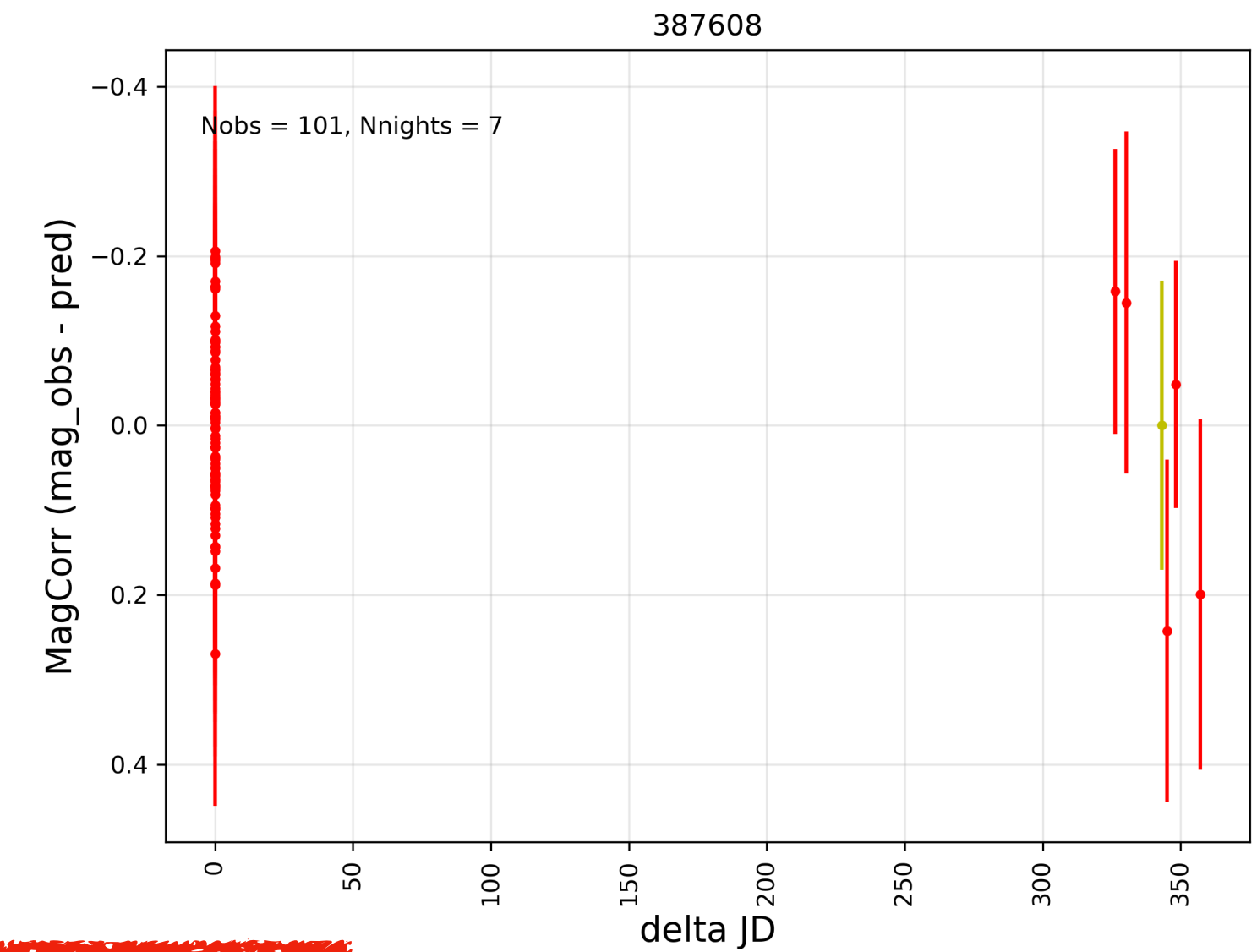
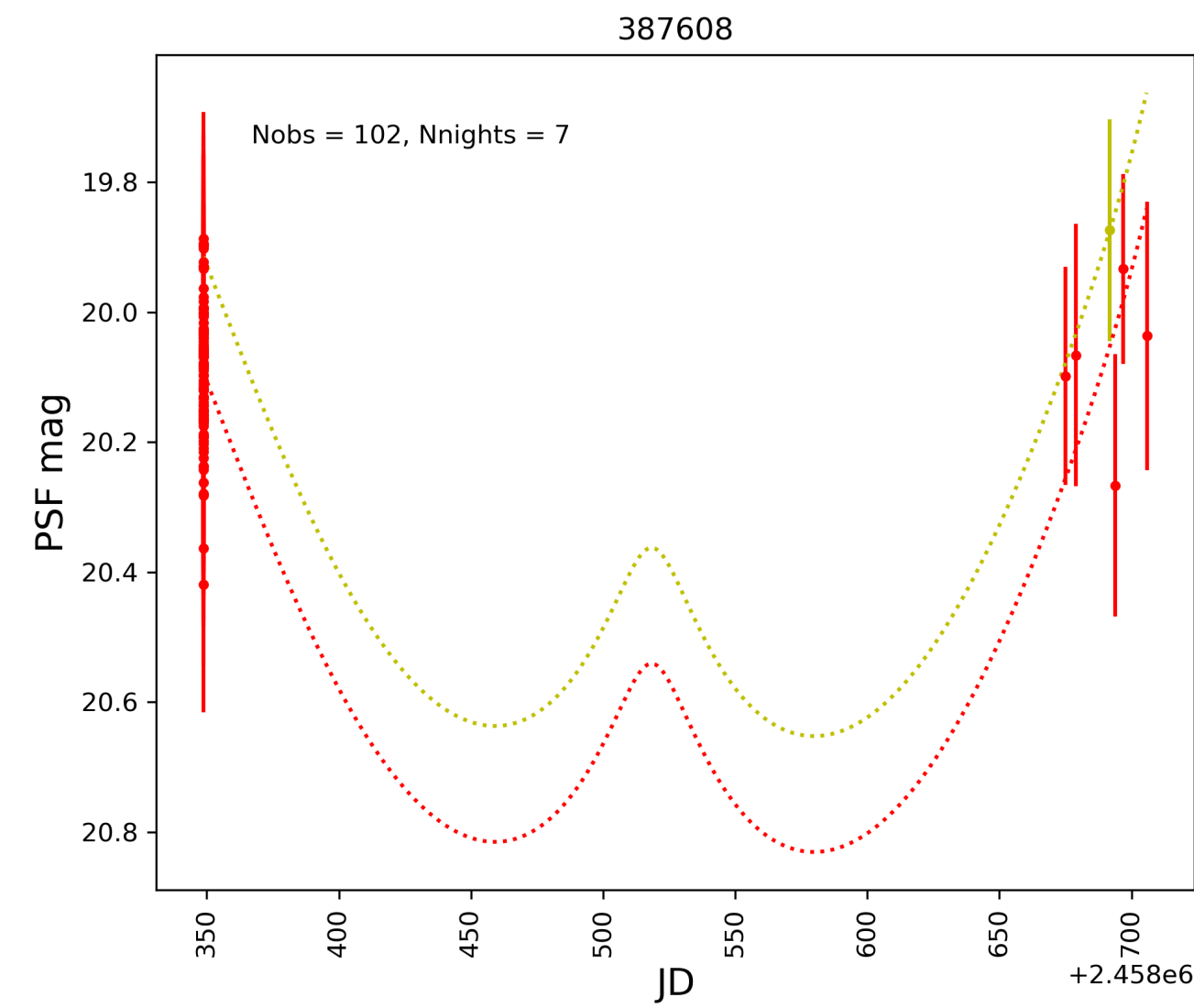
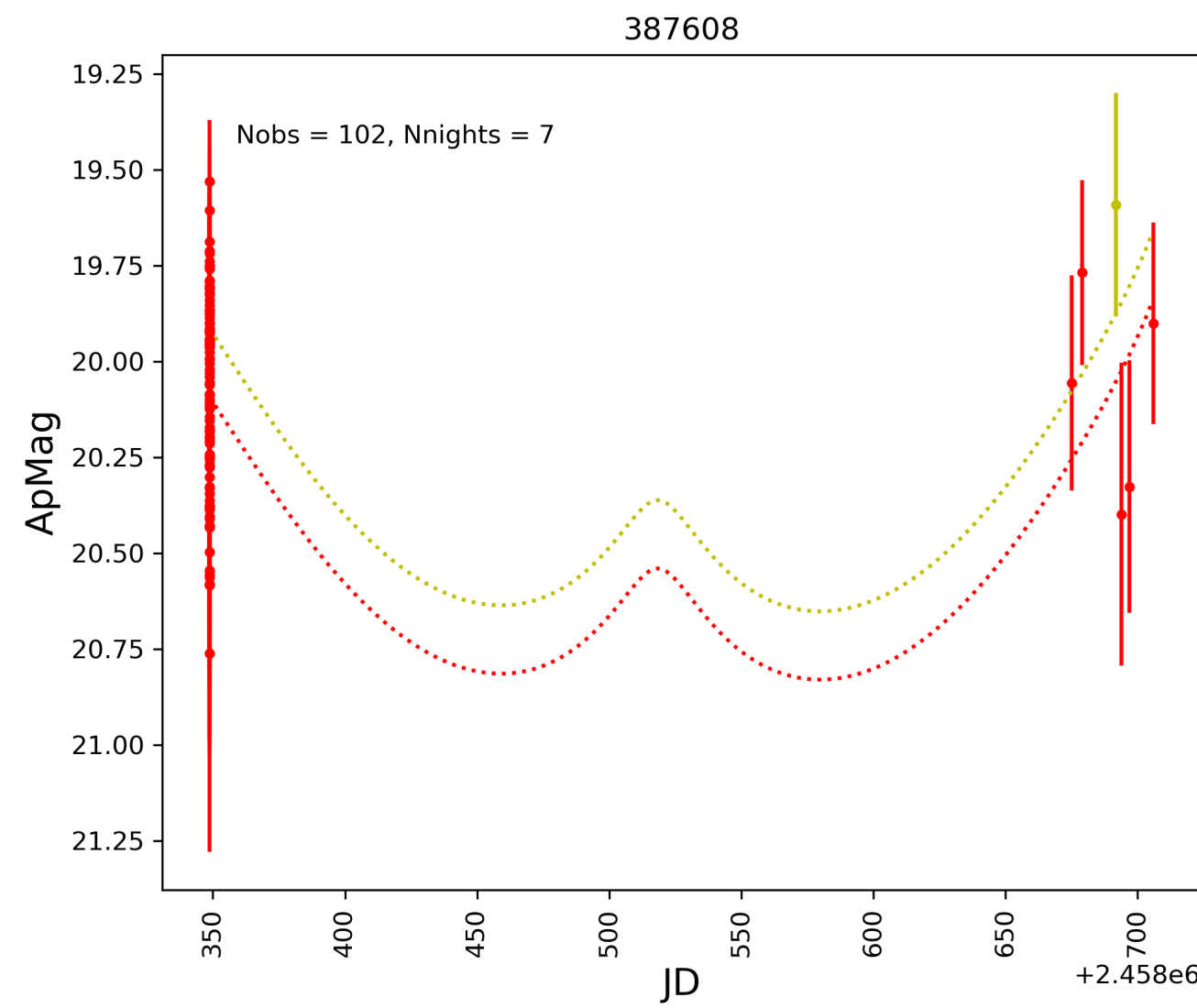
# Noisy example



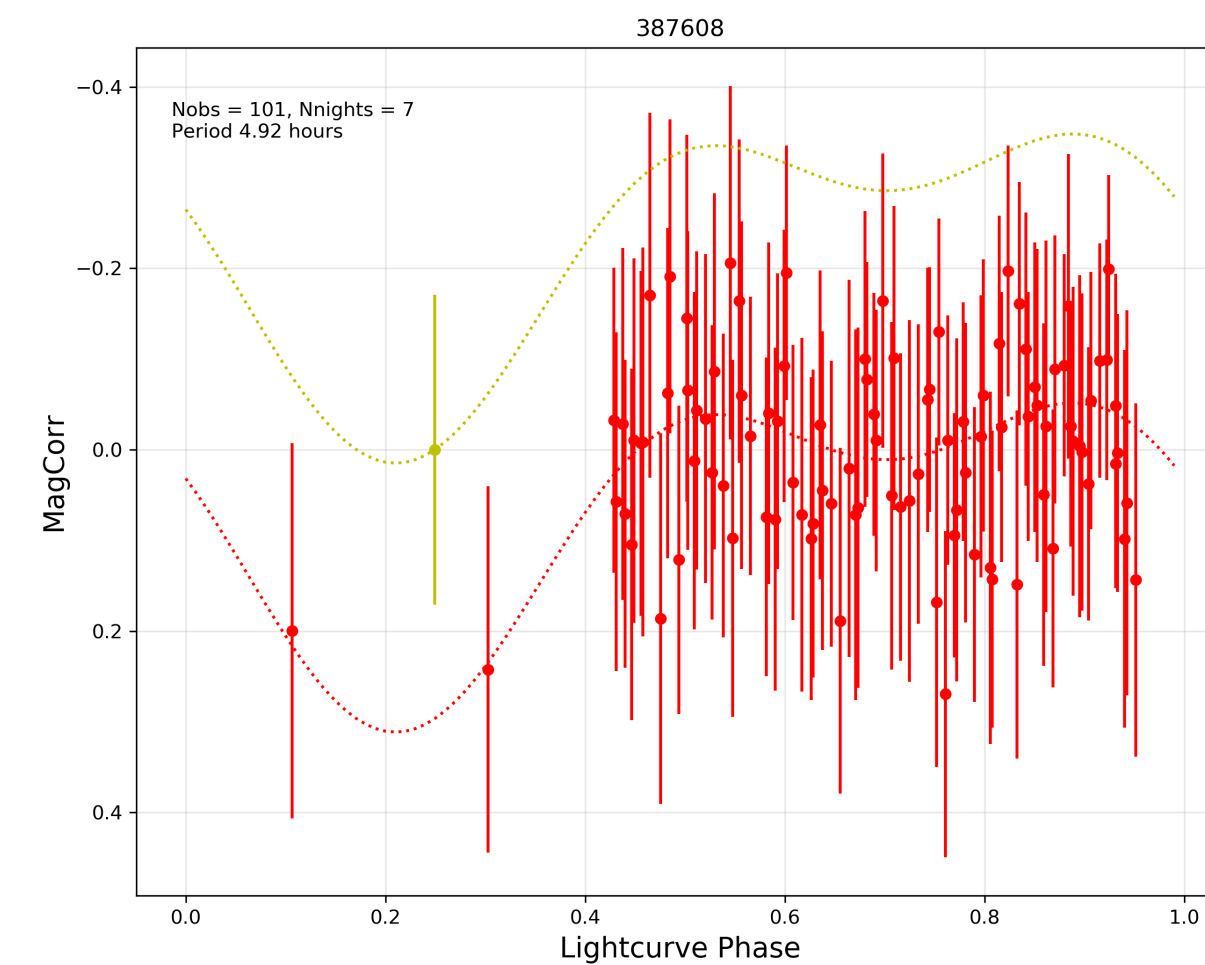
**4754 Panthoos**  
**72 observations**  
**2.2hr period (!)**  
**0.15mag amplitude**  
**(previously known - with 27hr period)**



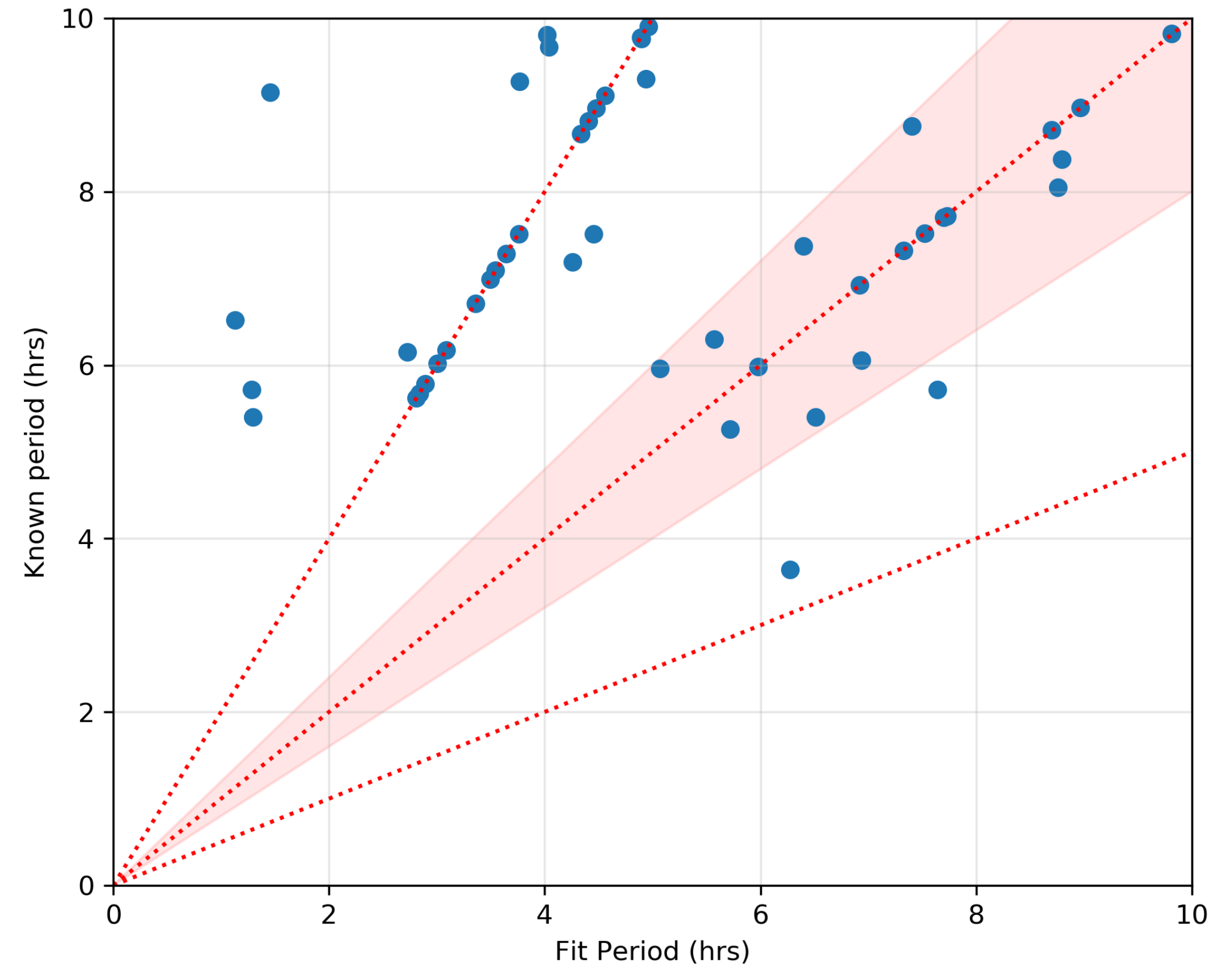
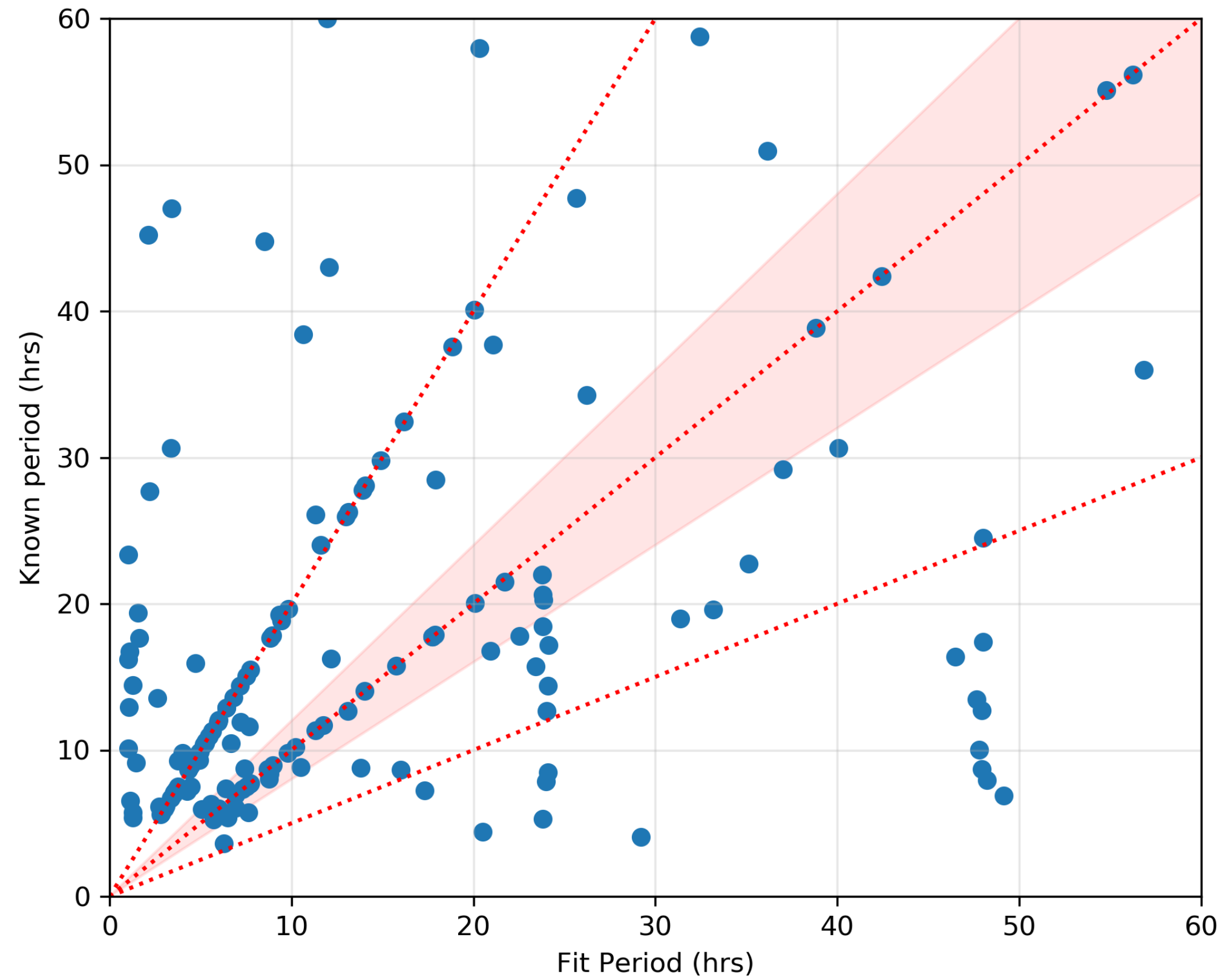
# Terrible example



**387608**  
**101 observations**  
**4.9hr period**  
**0.37mag amplitude**  
**(not previously measured)**

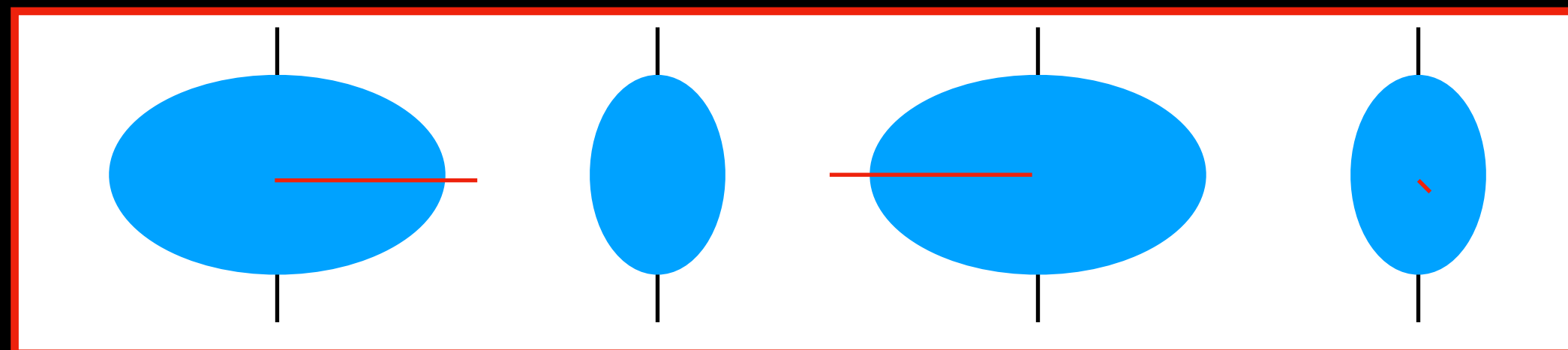
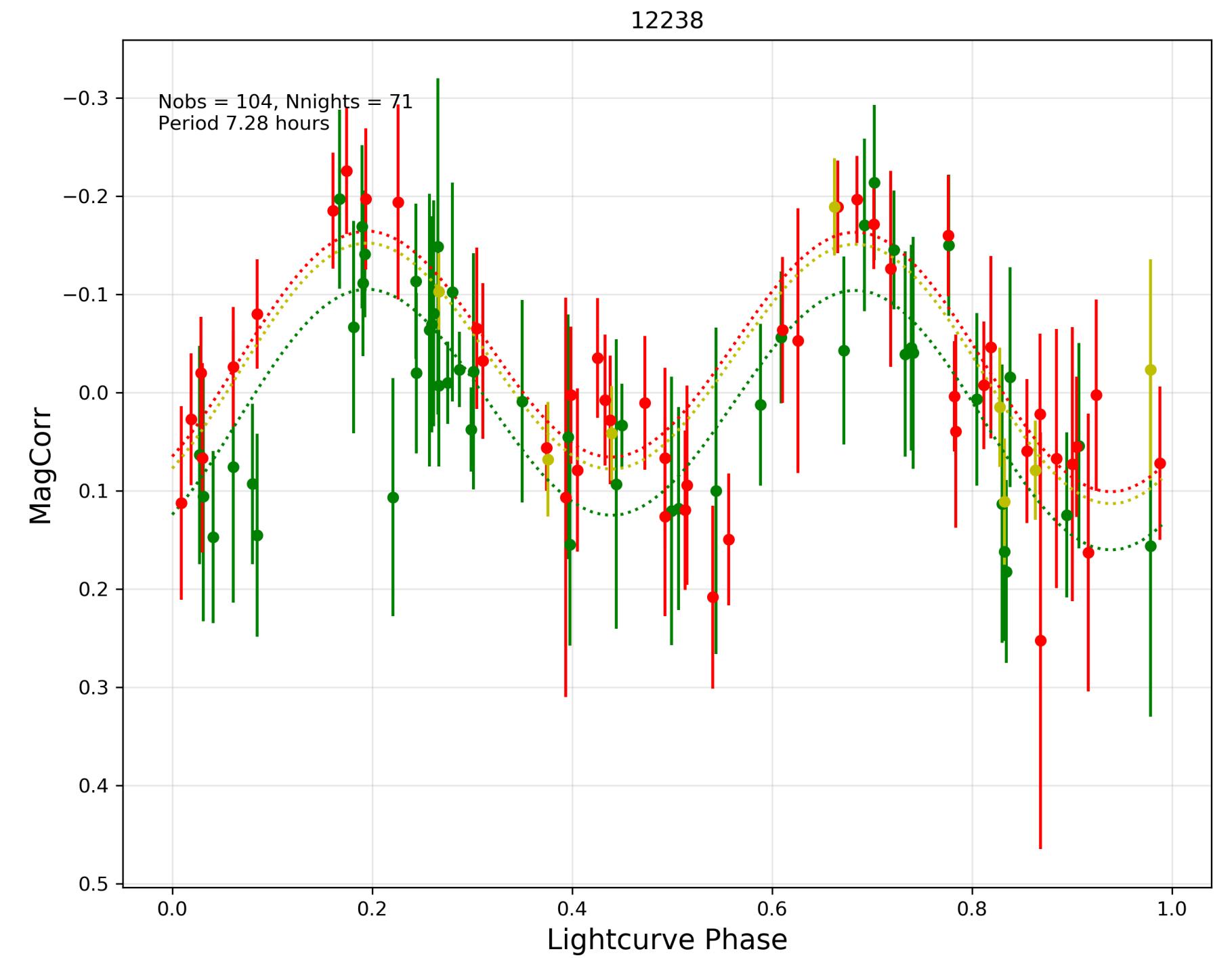
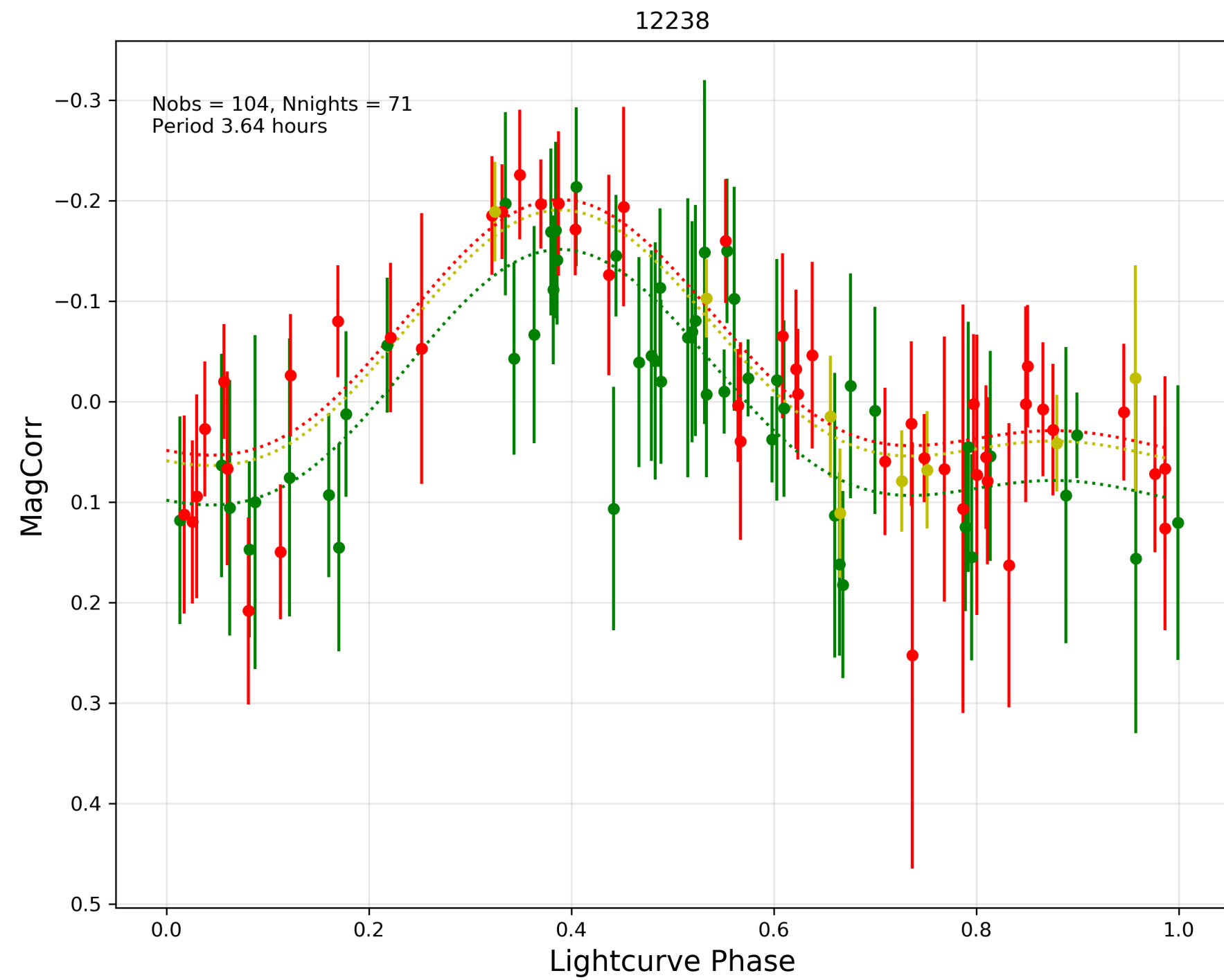


# Compare against ALCDEF



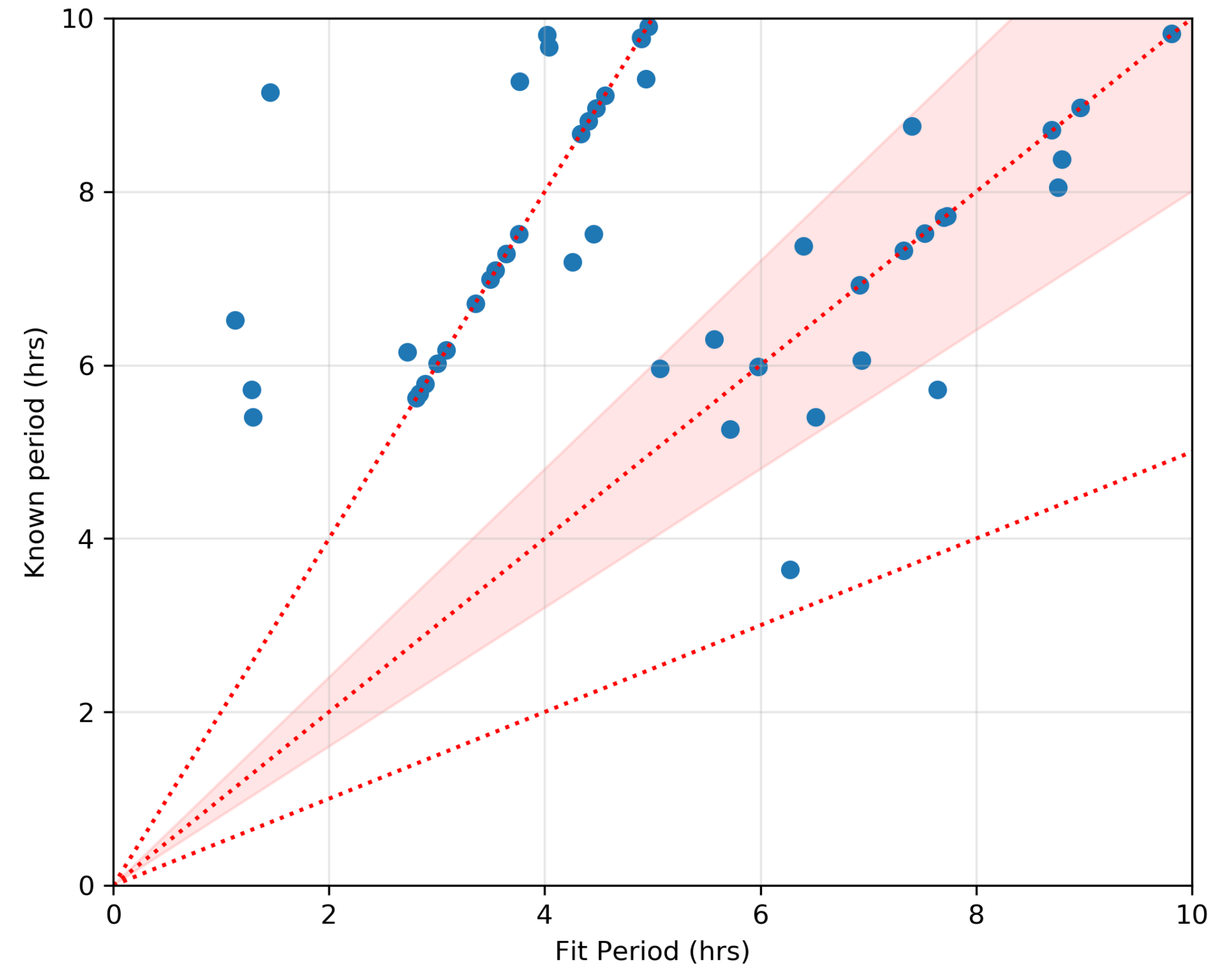
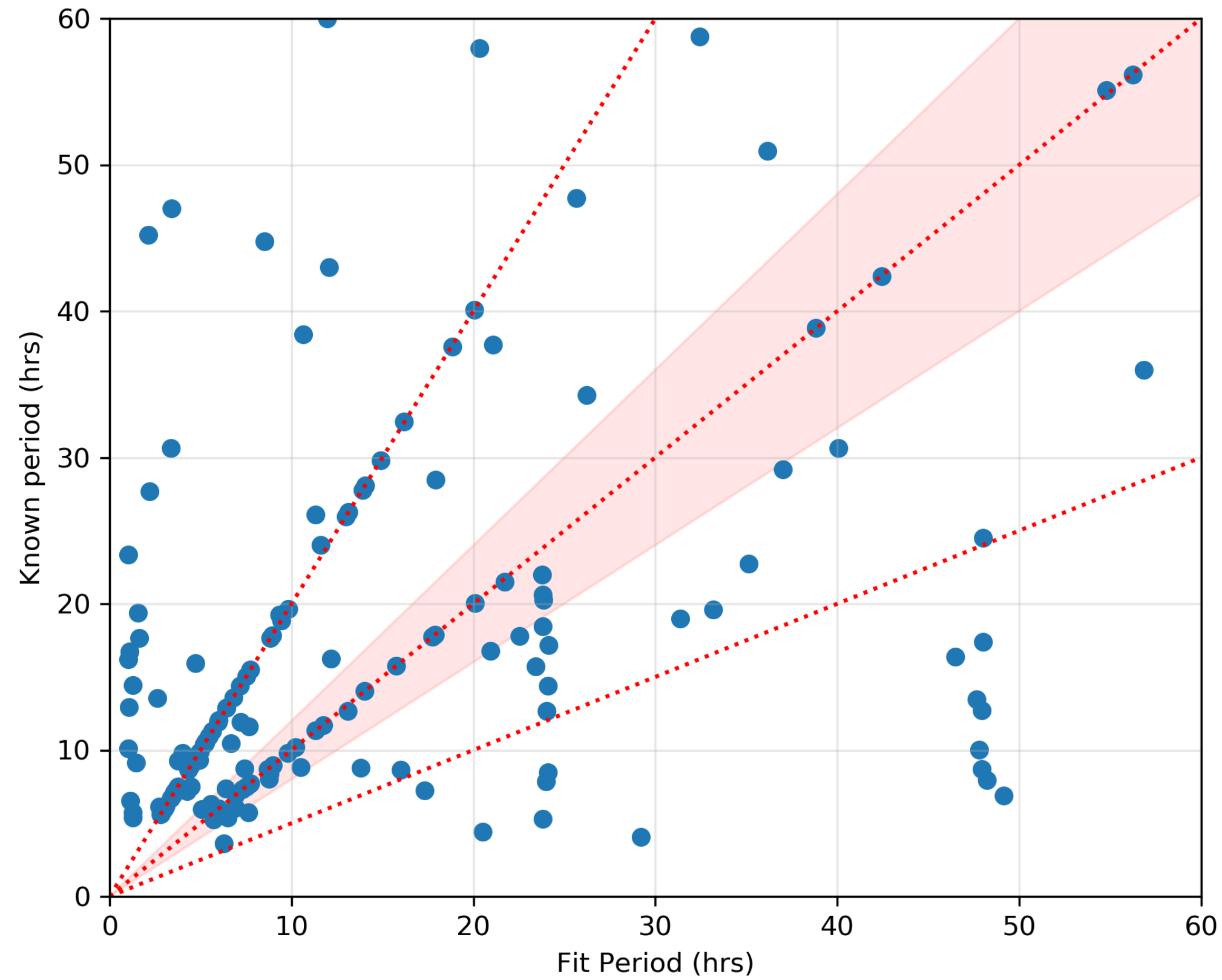
**Lots of points at half of known rotation period**

# Half a rotation period?



**Add a peak-finder and double period if needed  
(`scipy.signal.find_peaks`)**

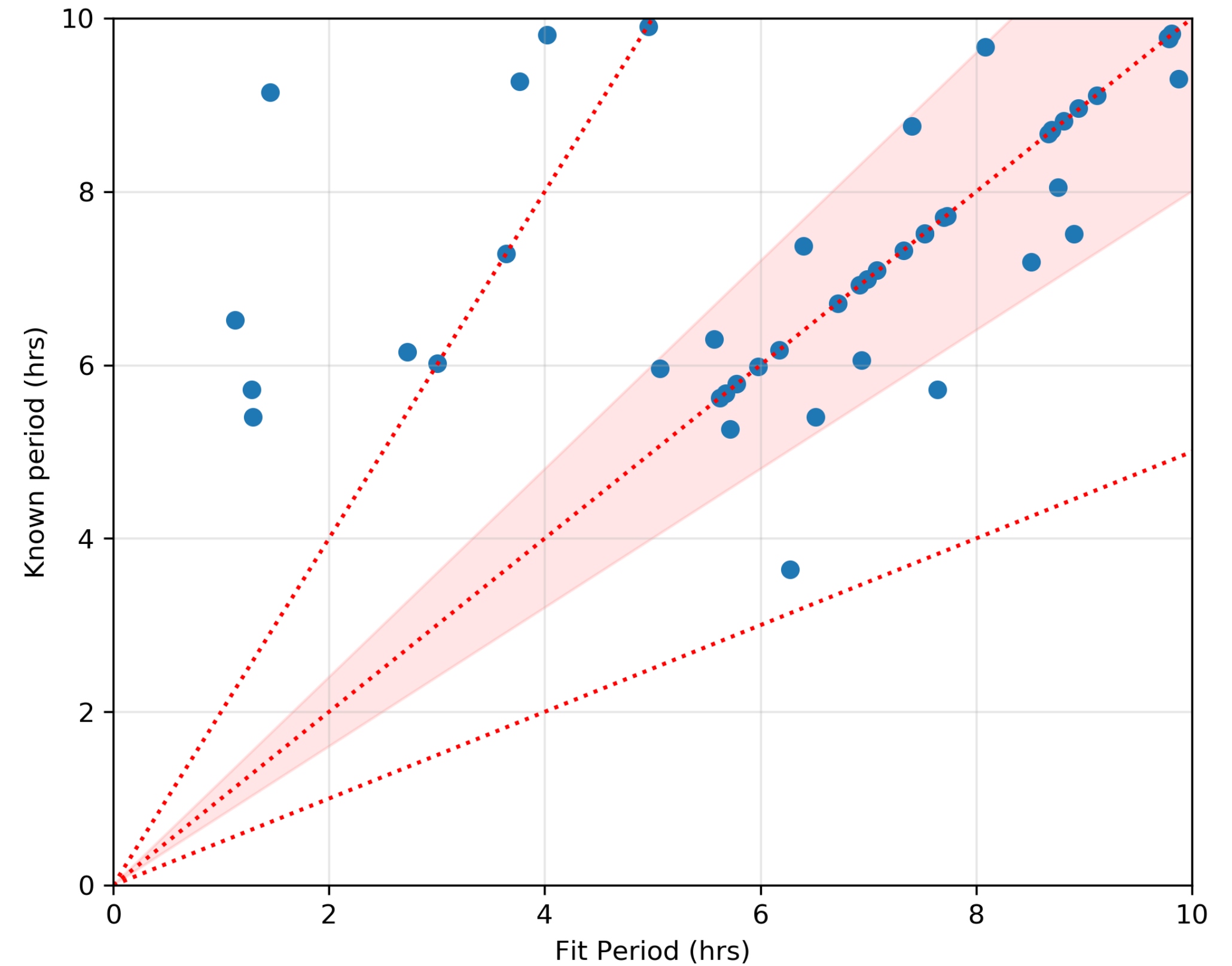
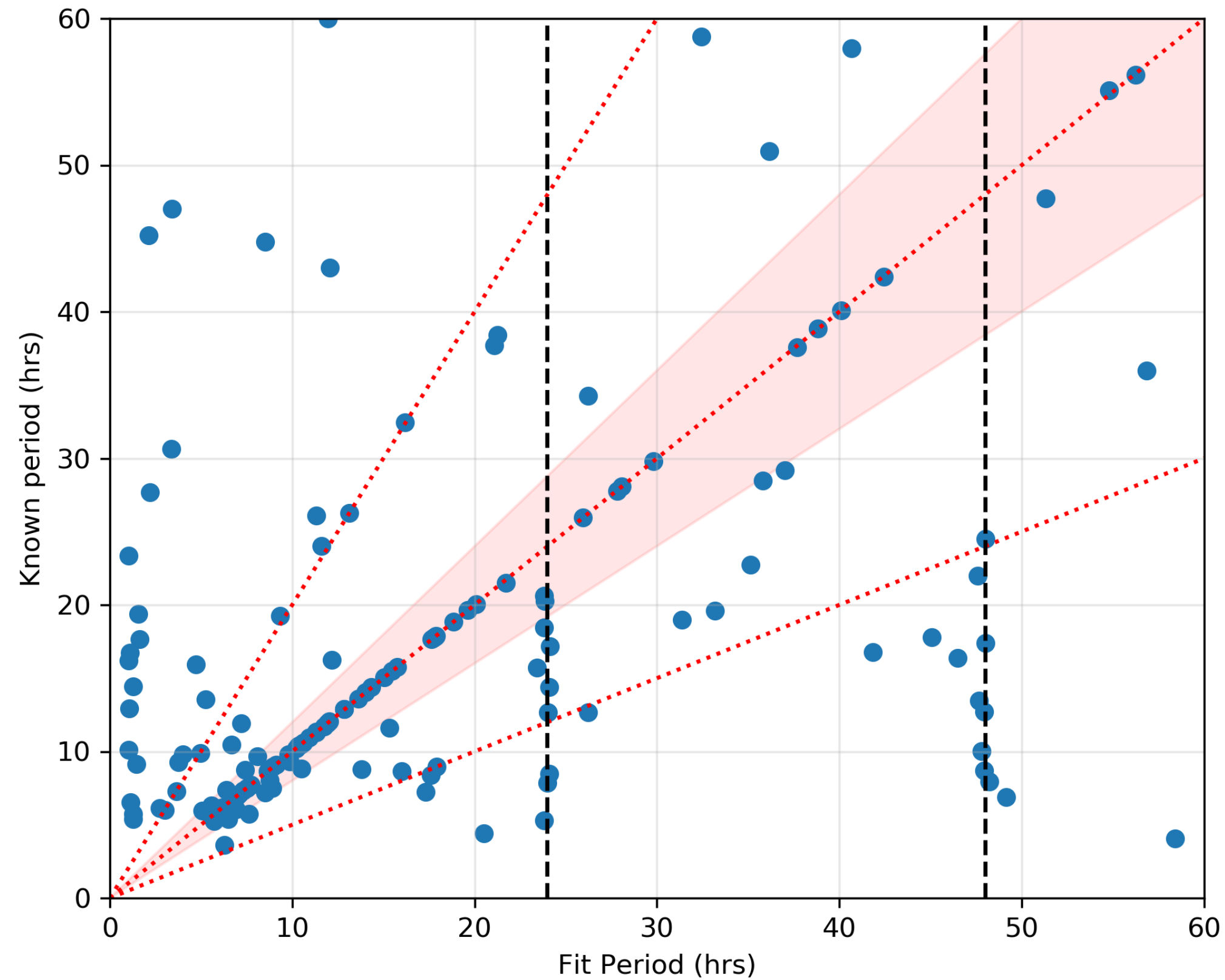
# Compare against ALCDEF



**Lots of points at half of known rotation period**

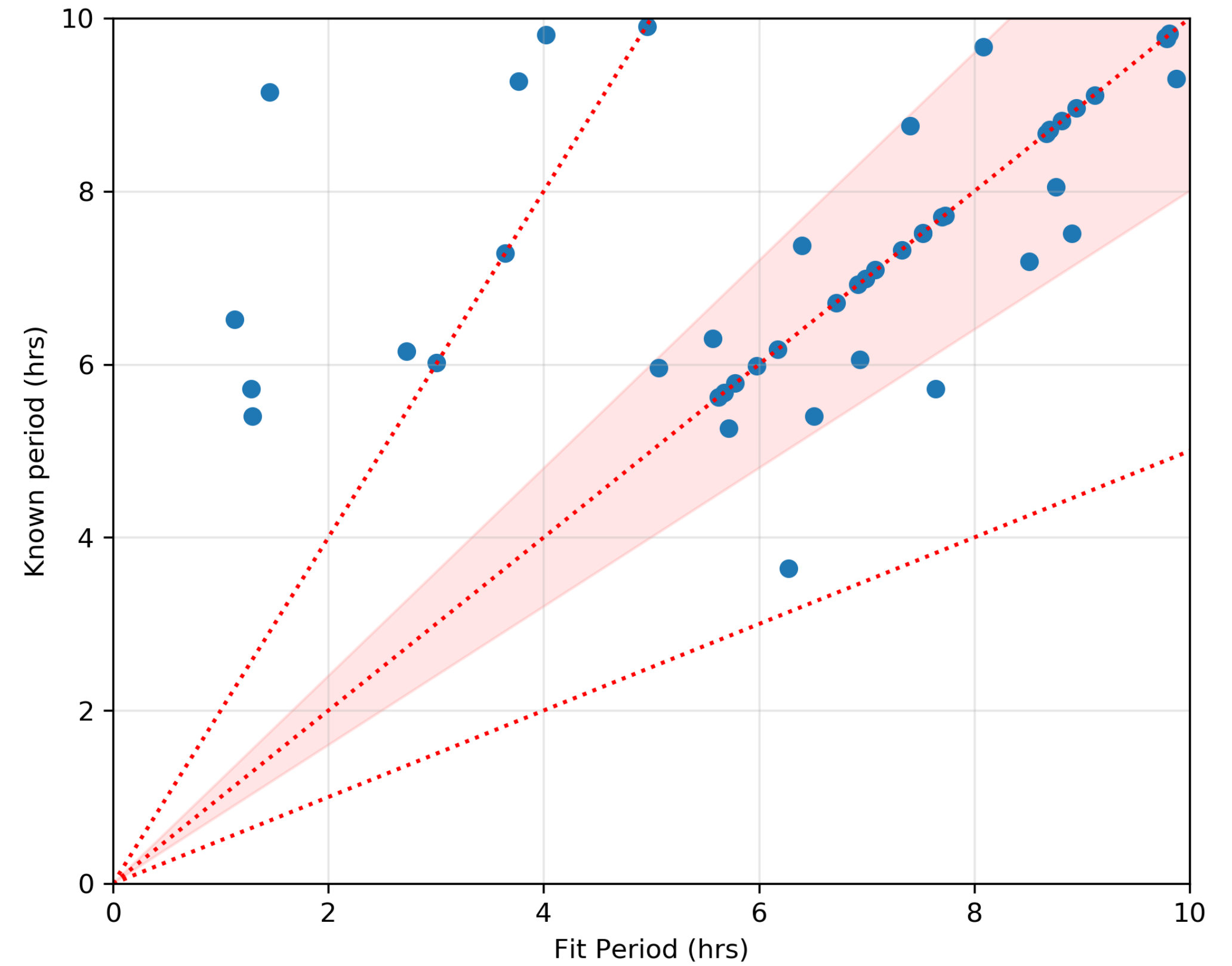
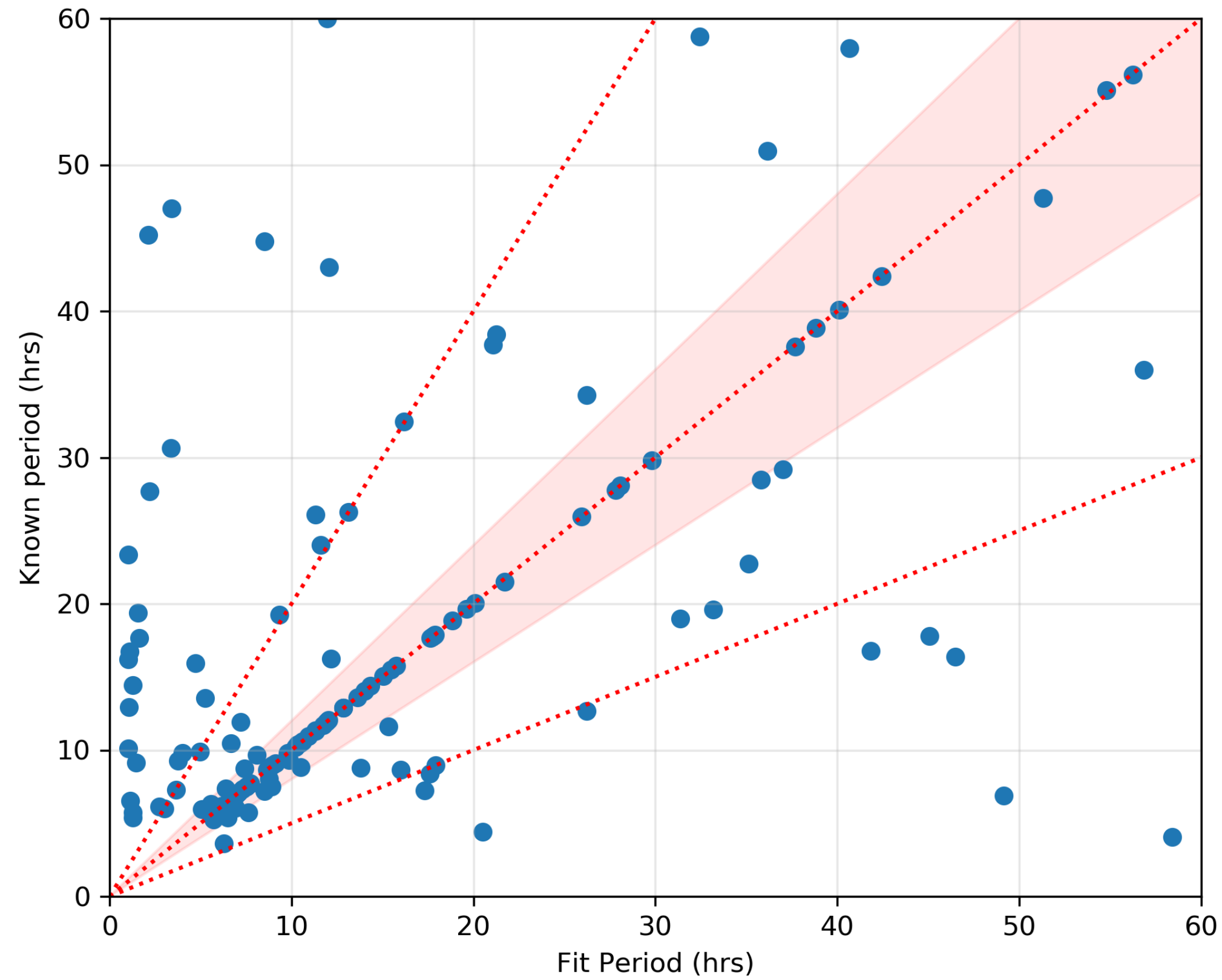


# Compare against ALCDEF



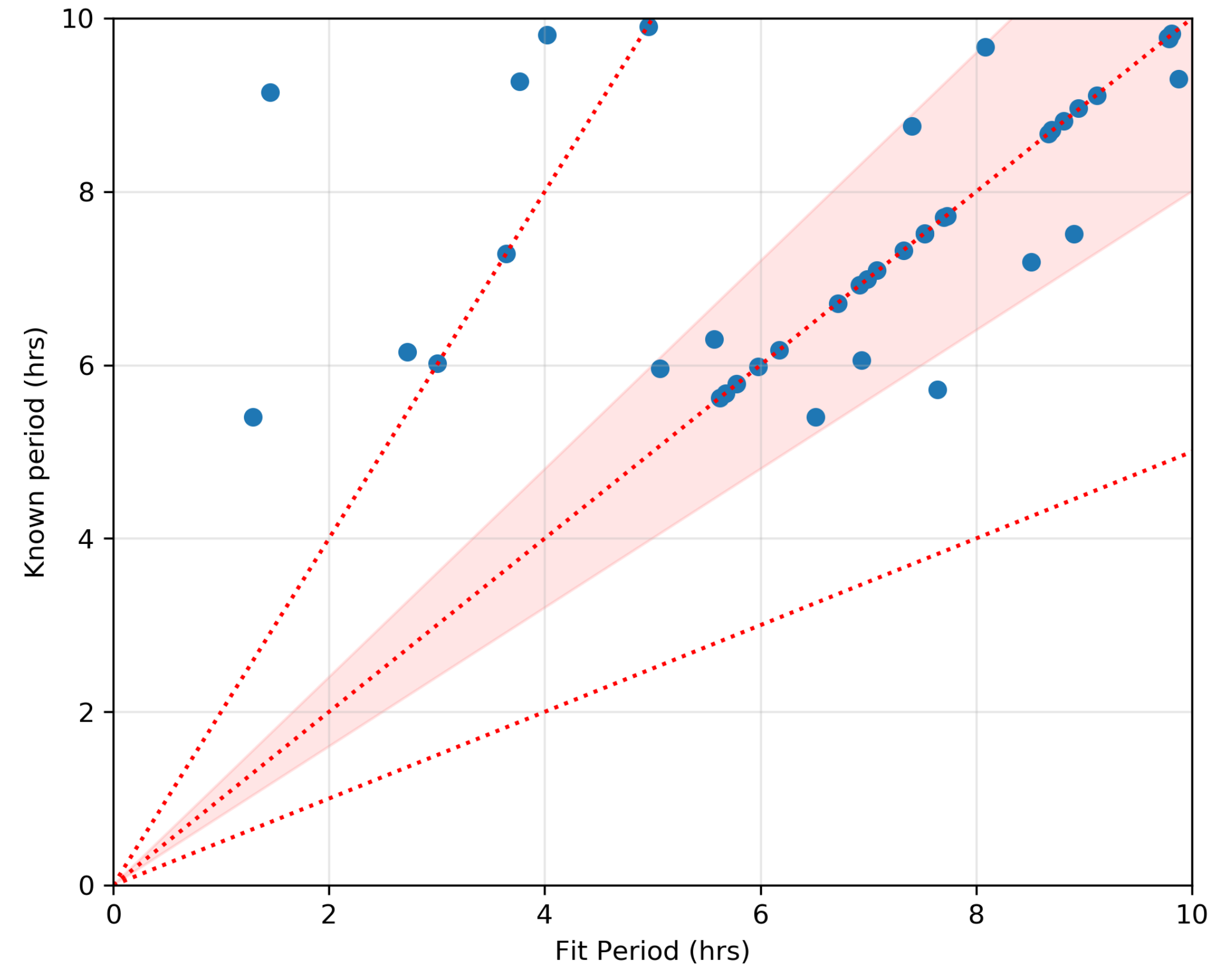
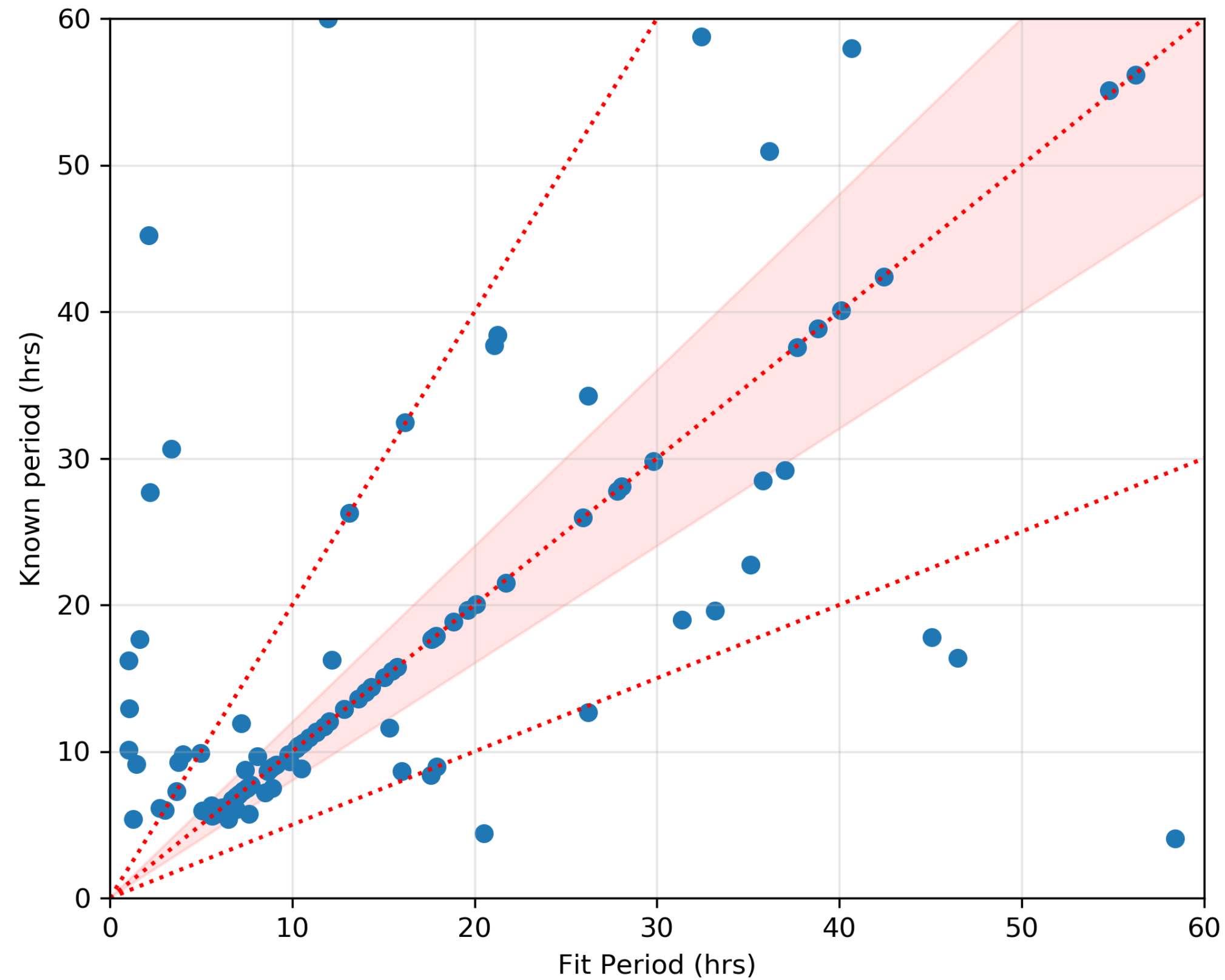
**Many fewer half-rotation periods, but still needs a bit of work.  
Hey - look at that 24 hour aliasing.**

# Compare against ALCDEF



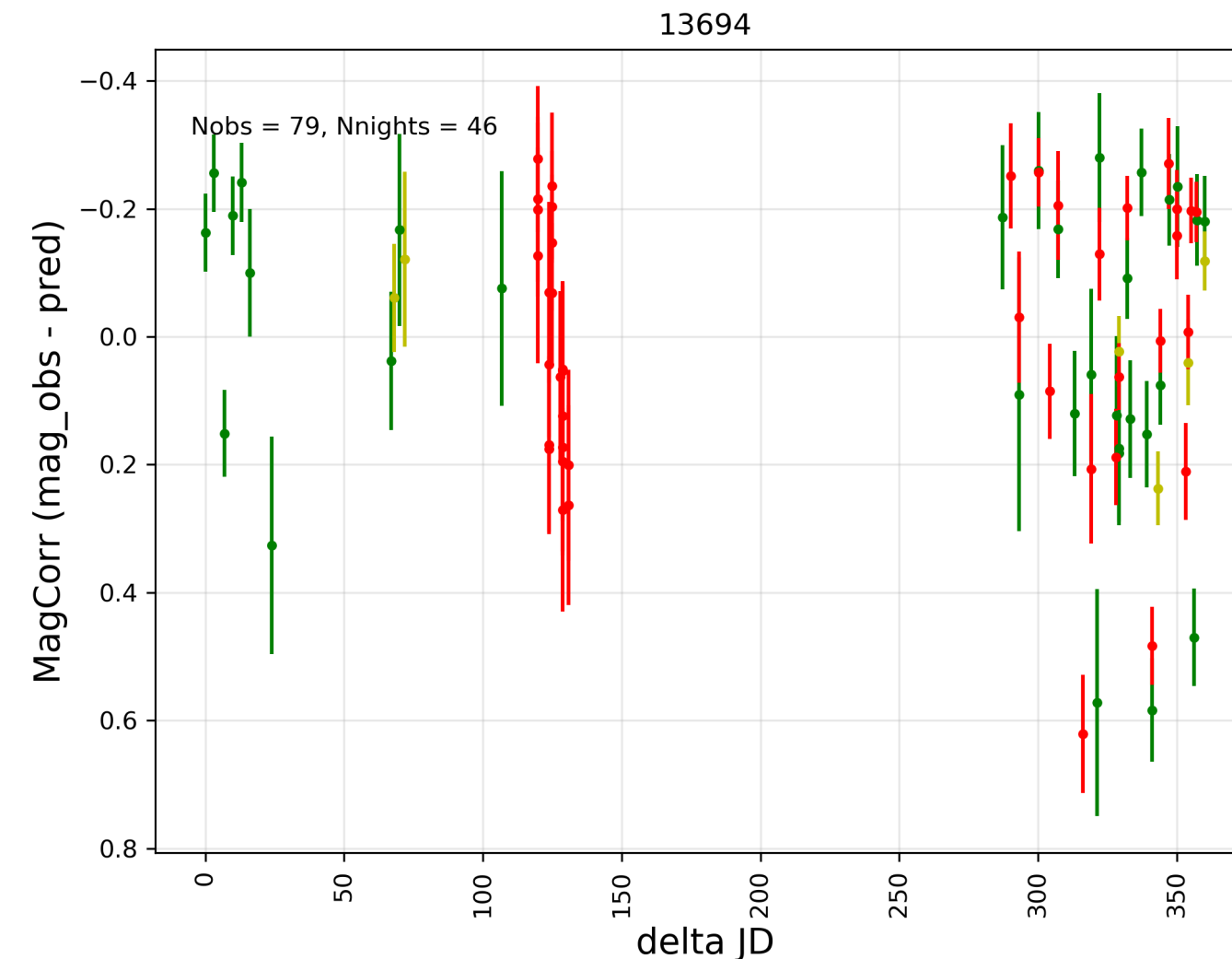
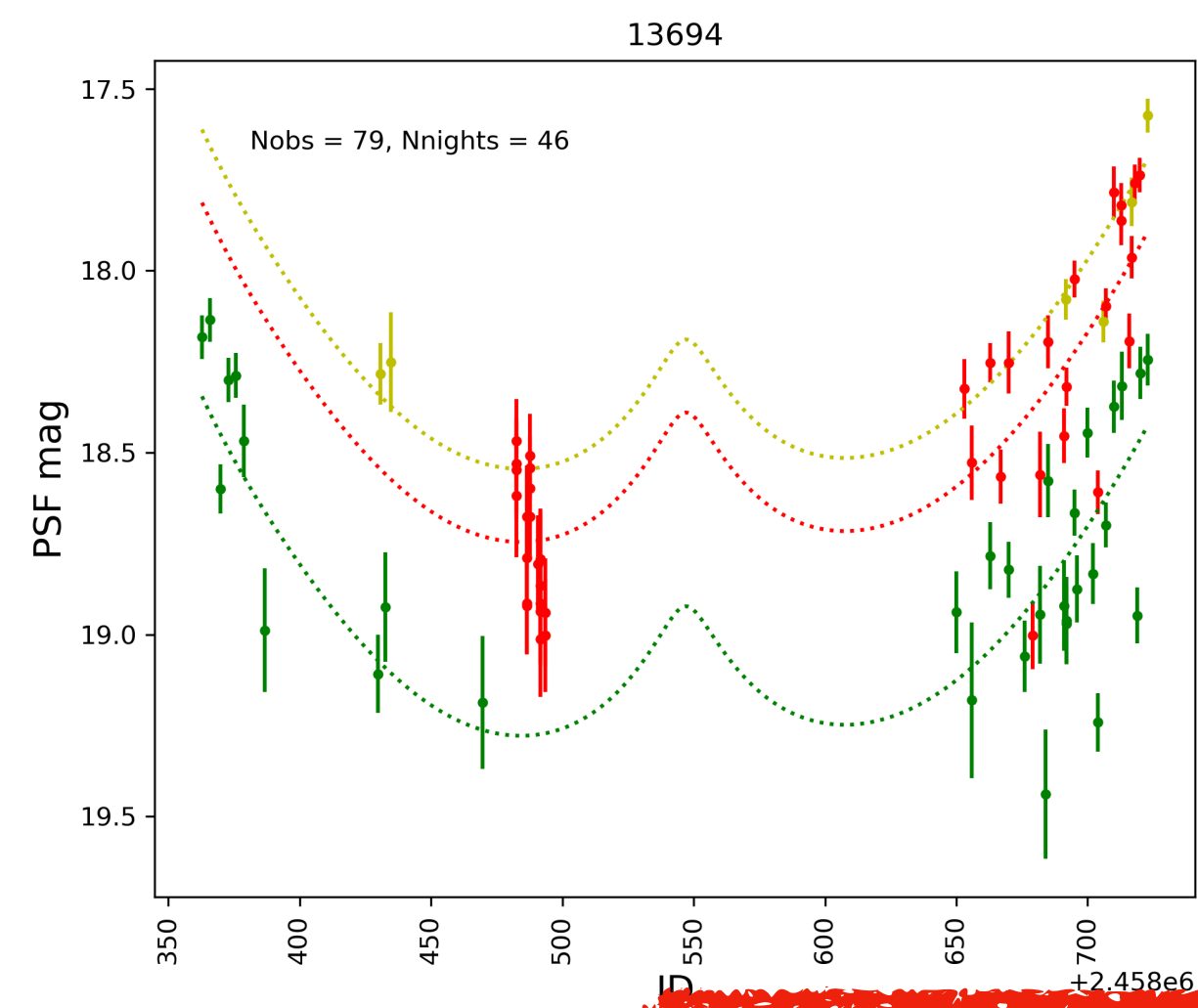
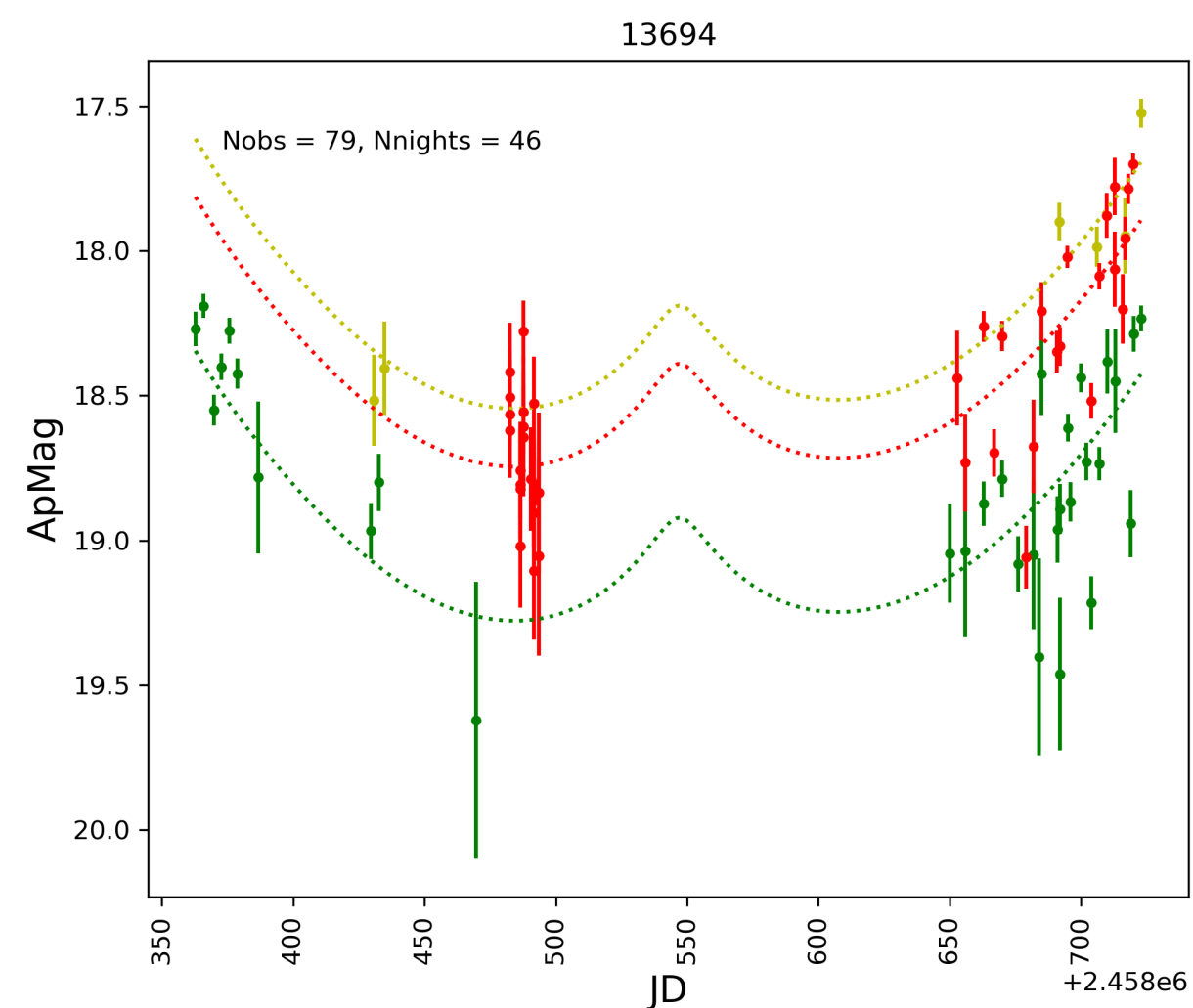
Removed 24/48 hr periods

# Compare against ALCDEF



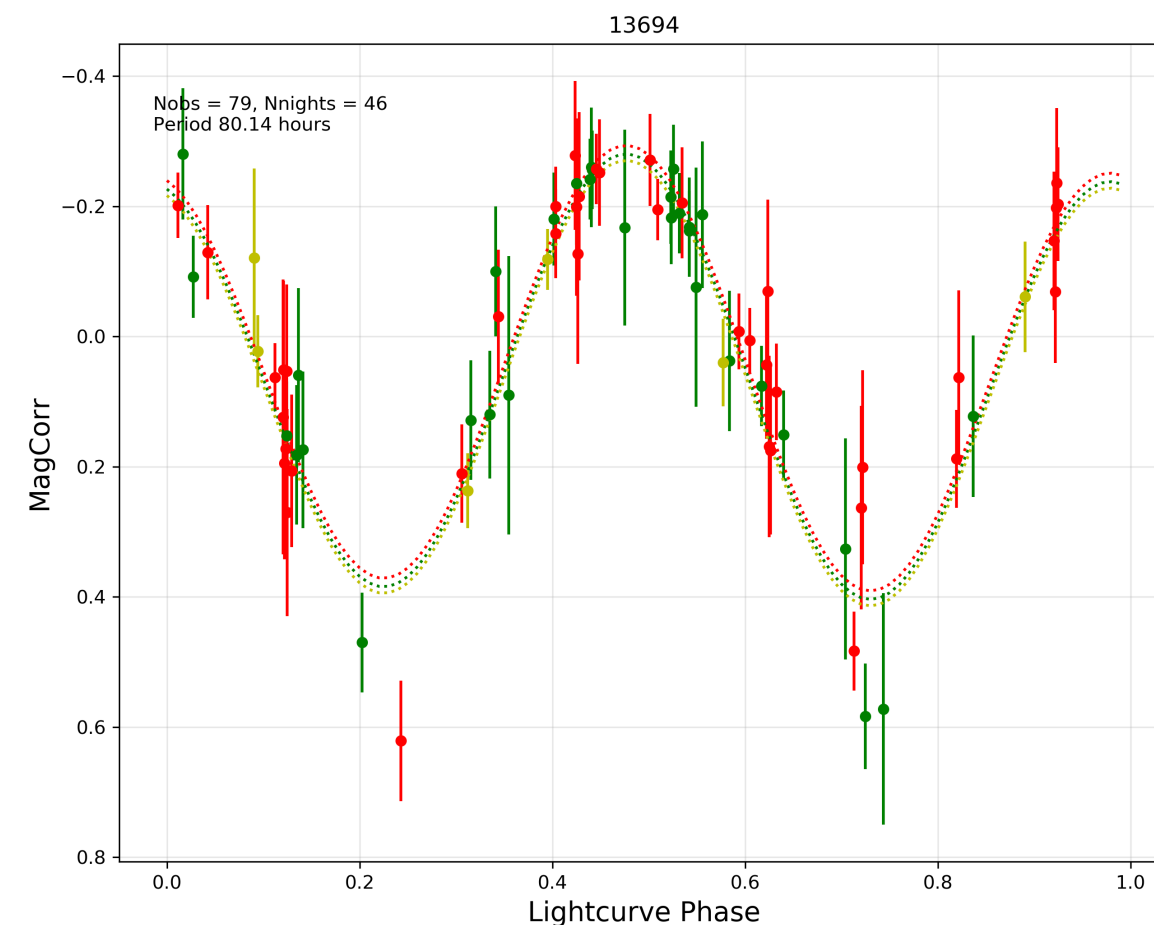
**Also removed low-amplitude fits ( $\text{amp} > 2 * \text{median photo err}$ )**  
**Not entirely terrible. But still needs review.**

# Sometimes the rotation period looks right but still doesn't match the ALCDEF

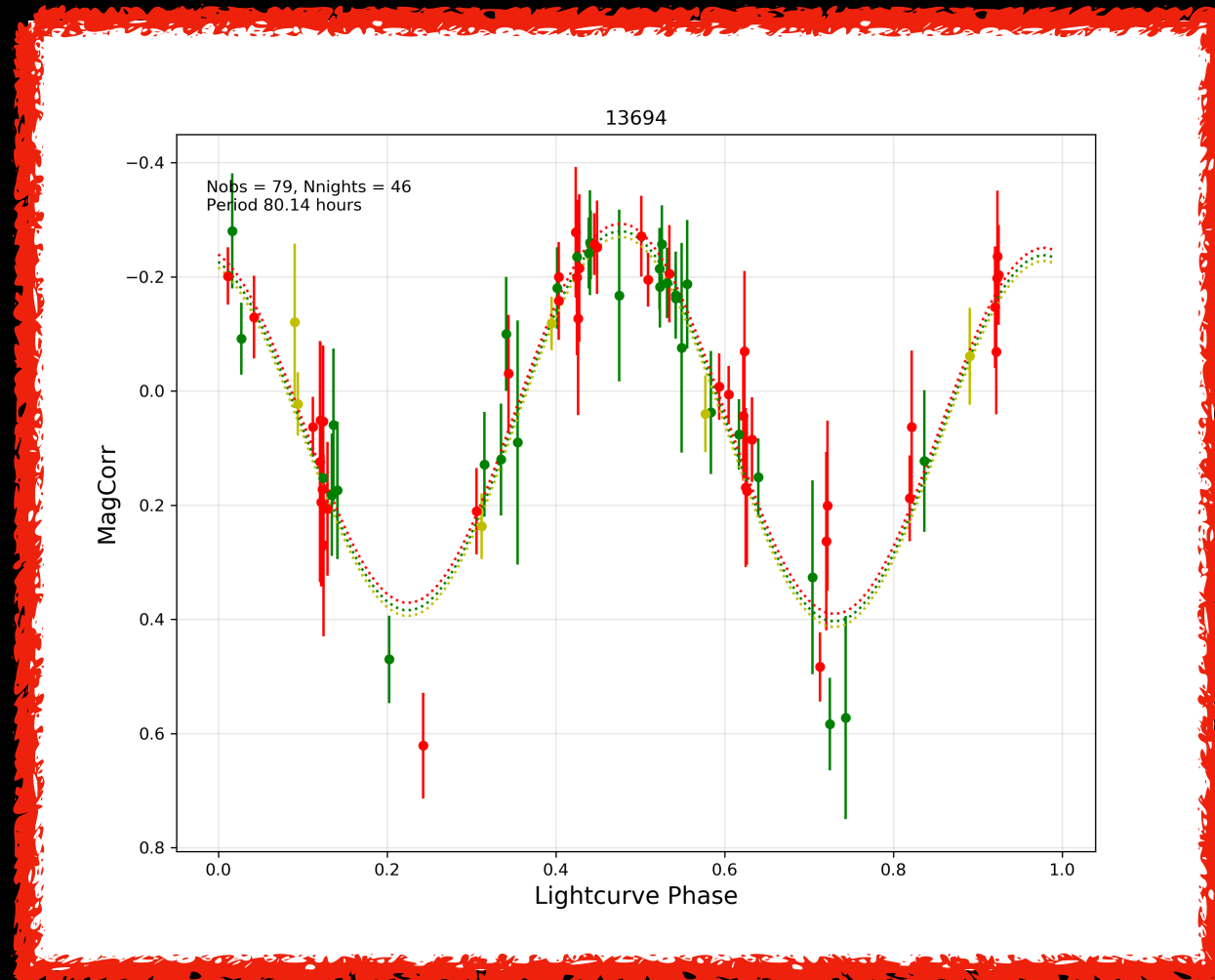


**13694 (1997 WW7)**  
**79 observations**  
**80.1hr period**  
**0.7mag amplitude**

**In ALCDEF: 30.64hr period, 0.4mag amplitude**



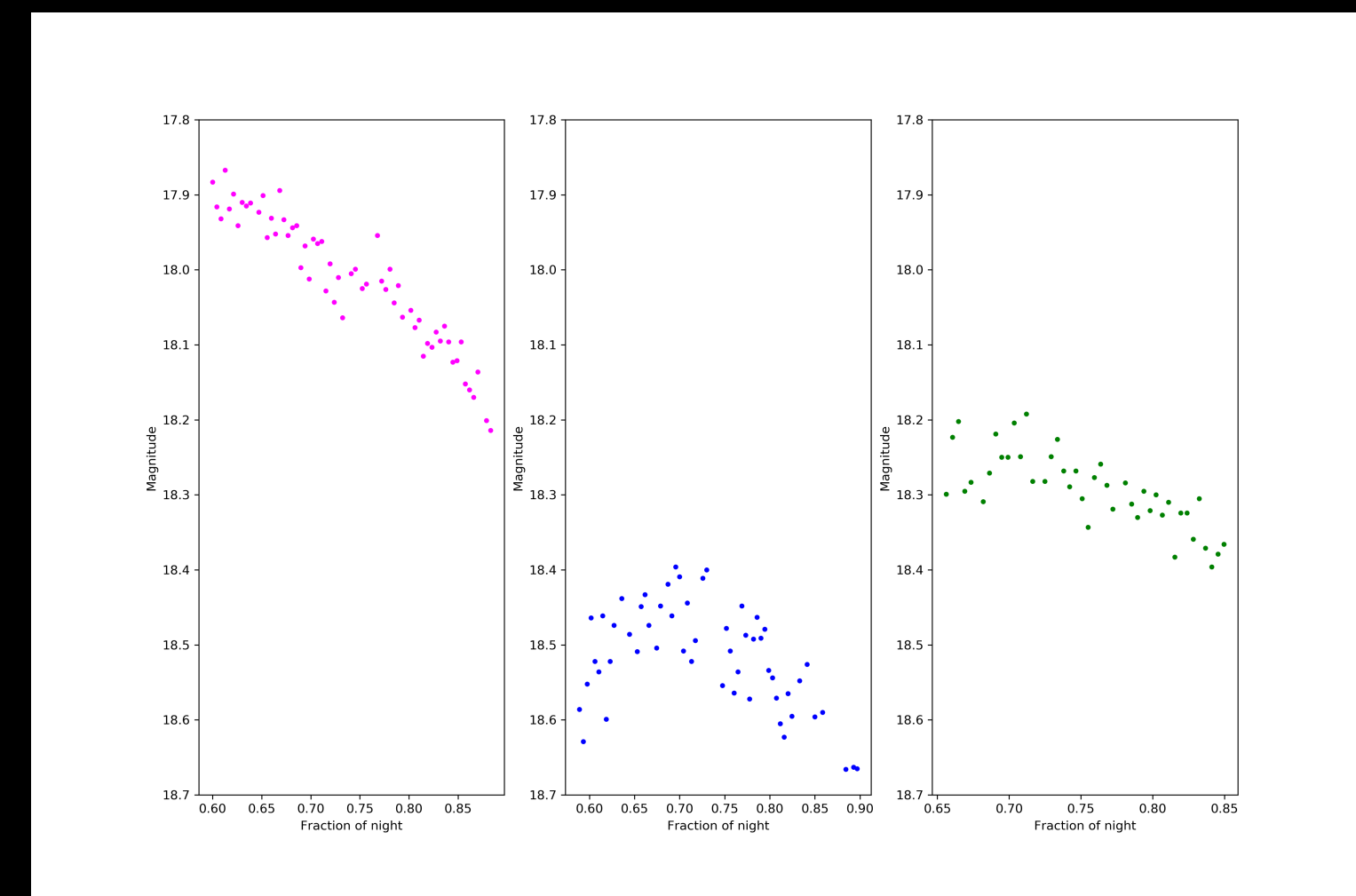
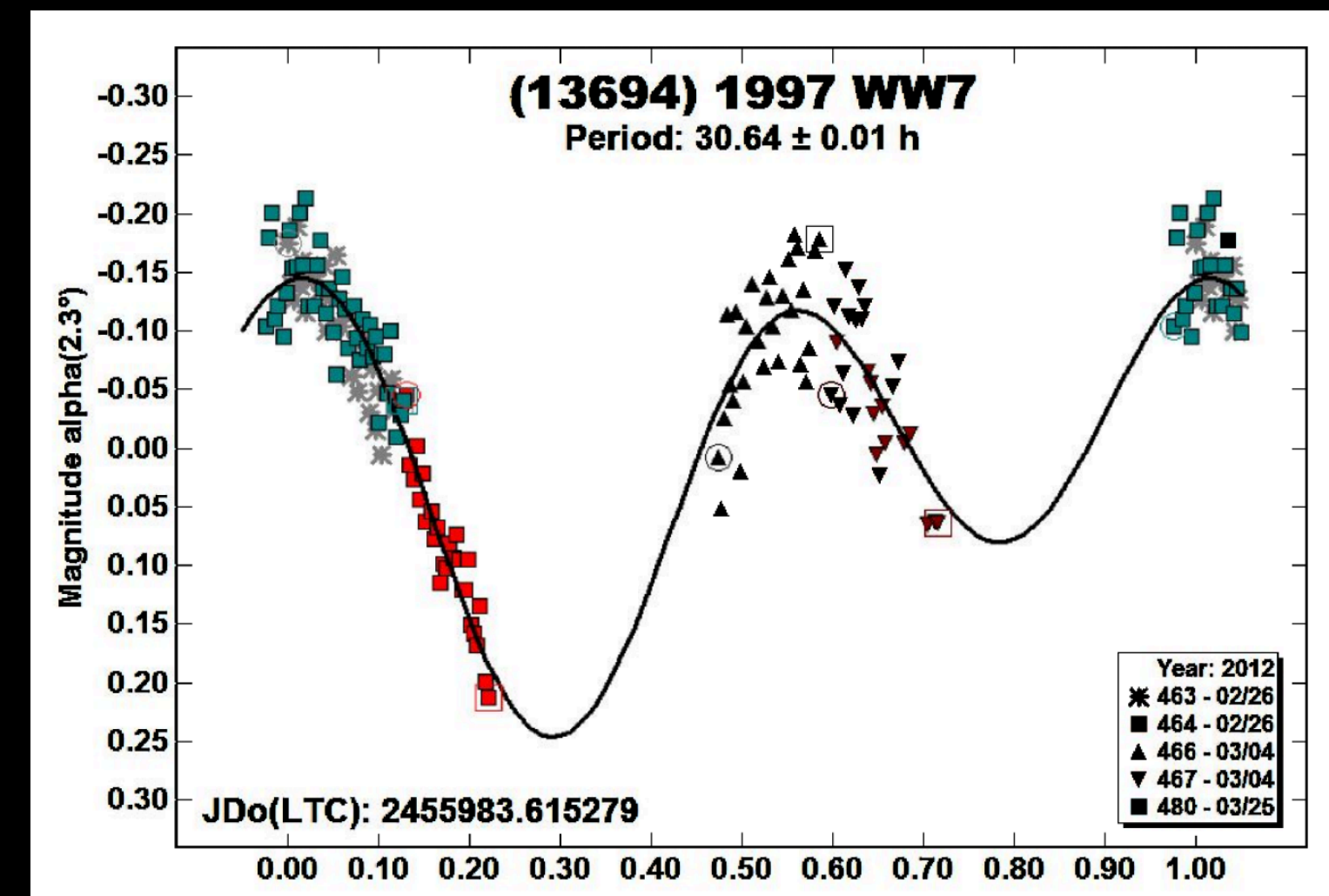
# Sometimes the rotation period looks right but still doesn't match the ALCDEF



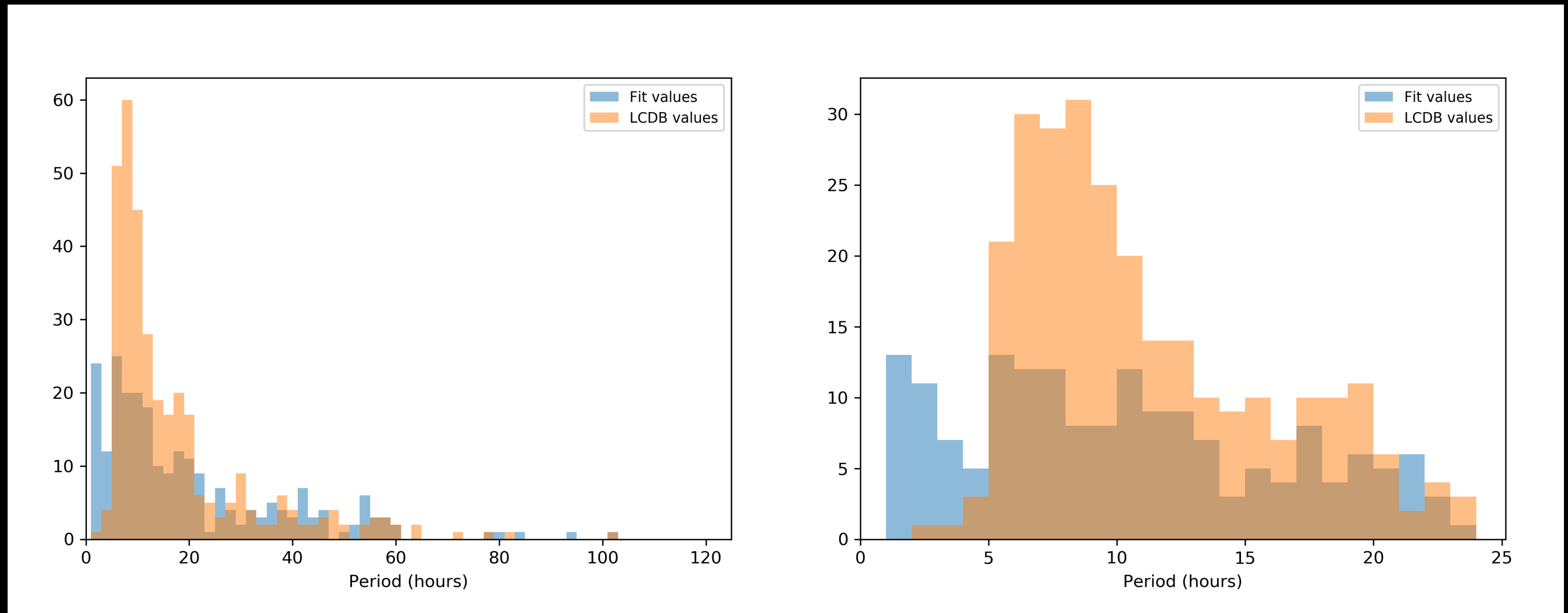
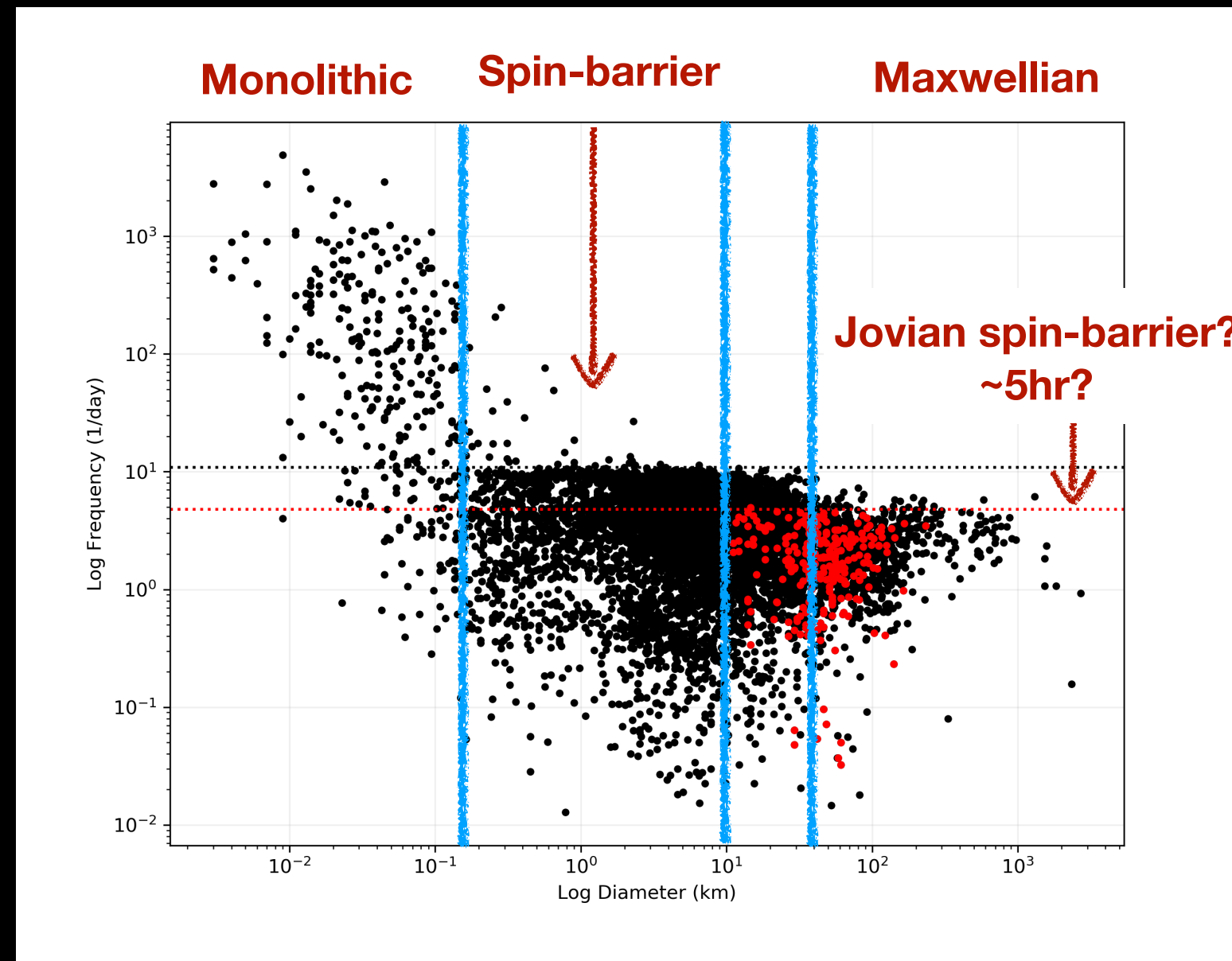
13694 (1997 WW7)  
79 observations  
80.1hr period  
0.7mag amplitude

In ALCDEF: 30.64hr period, 0.4mag amplitude

*French et al 2012, MPB*  
30.64 hr period  
Data available in ALCDEF!



# Rotation Periods

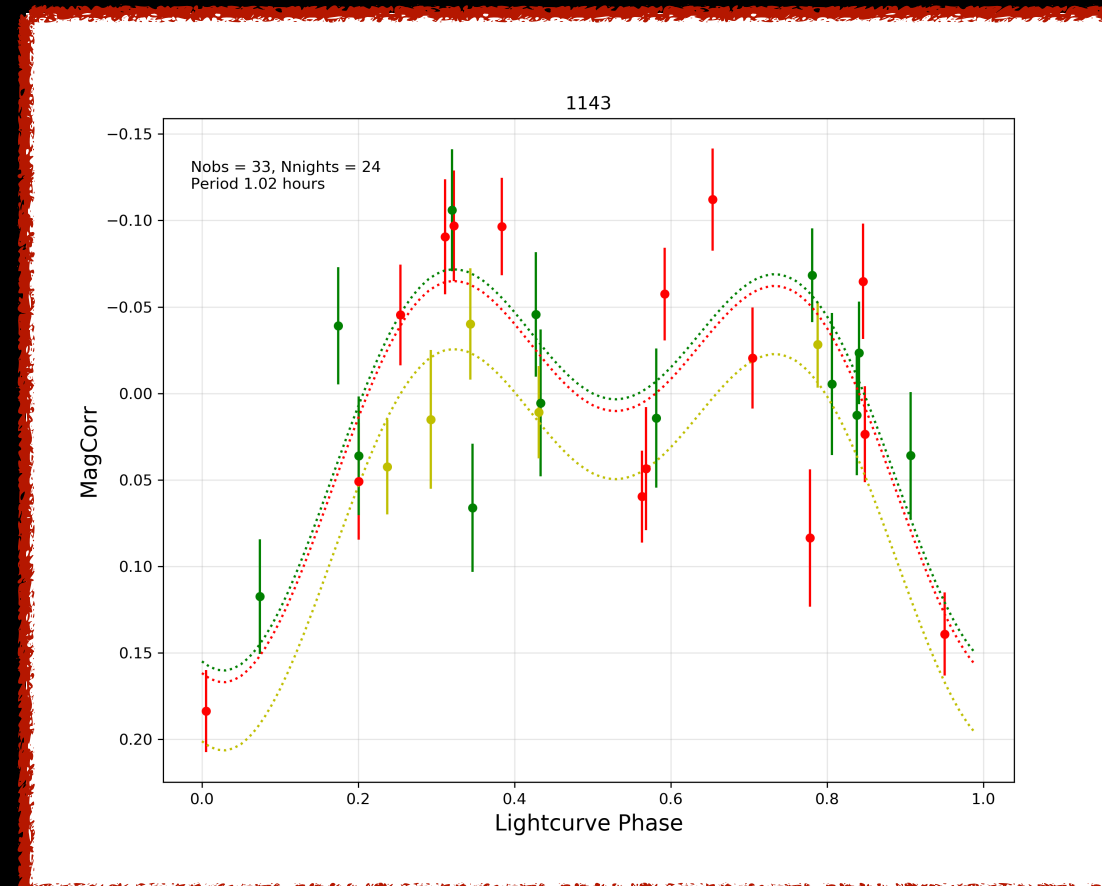
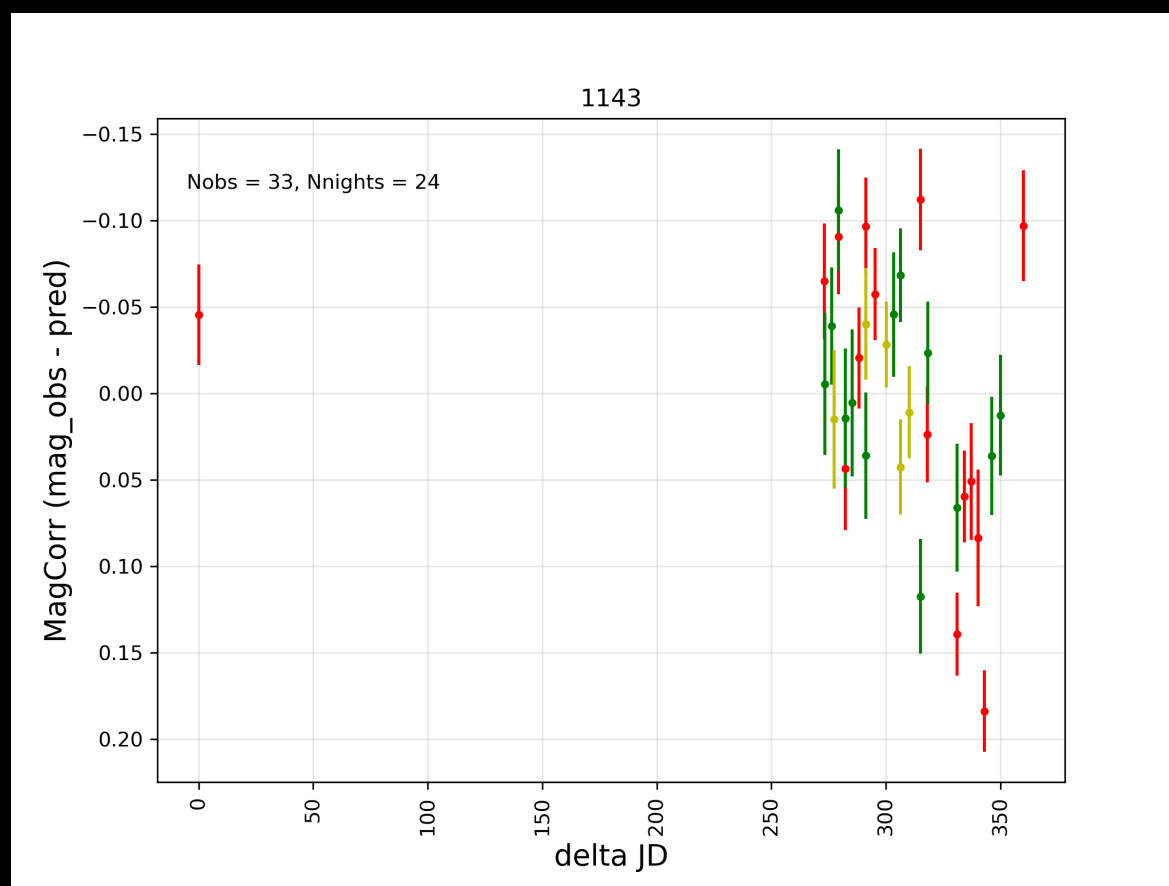
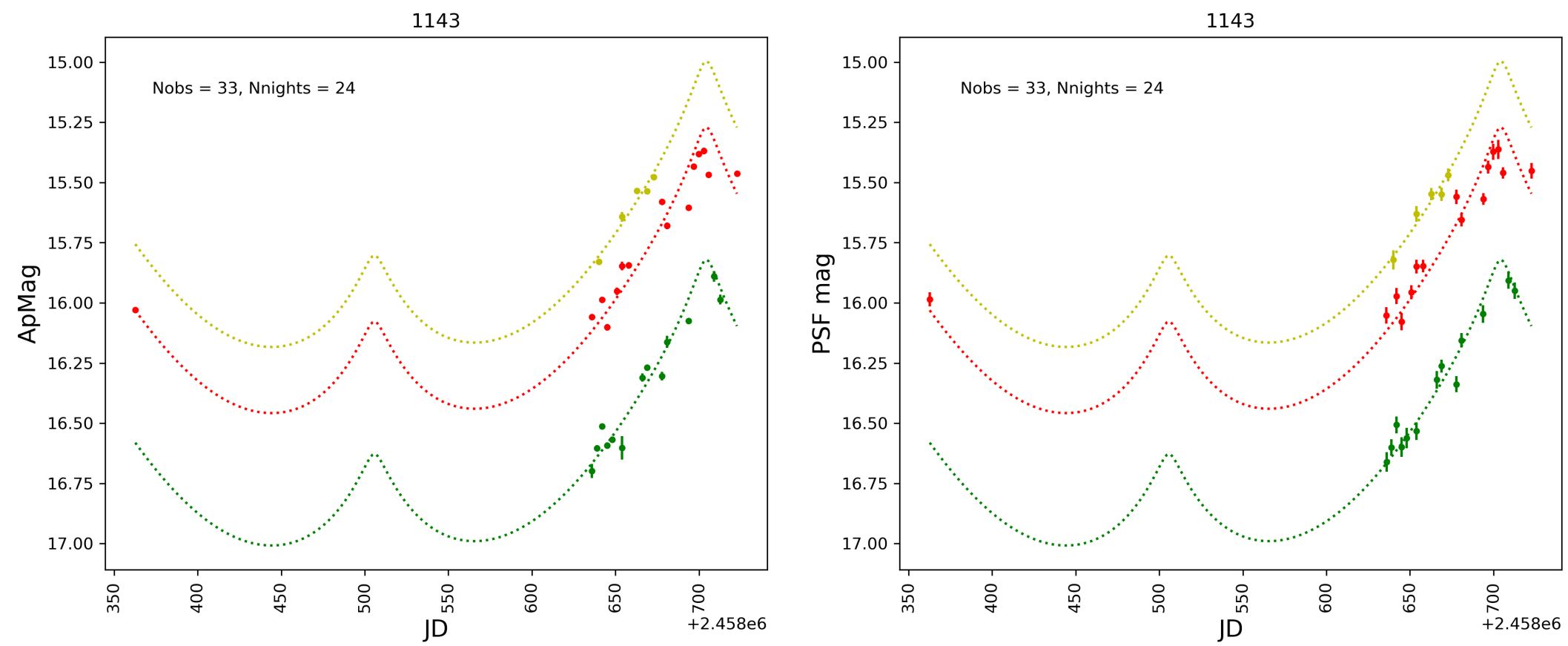


**239 Trojans from ZTF; 397 Trojans from LCDB**  
**36 with fit periods < 5 hours**

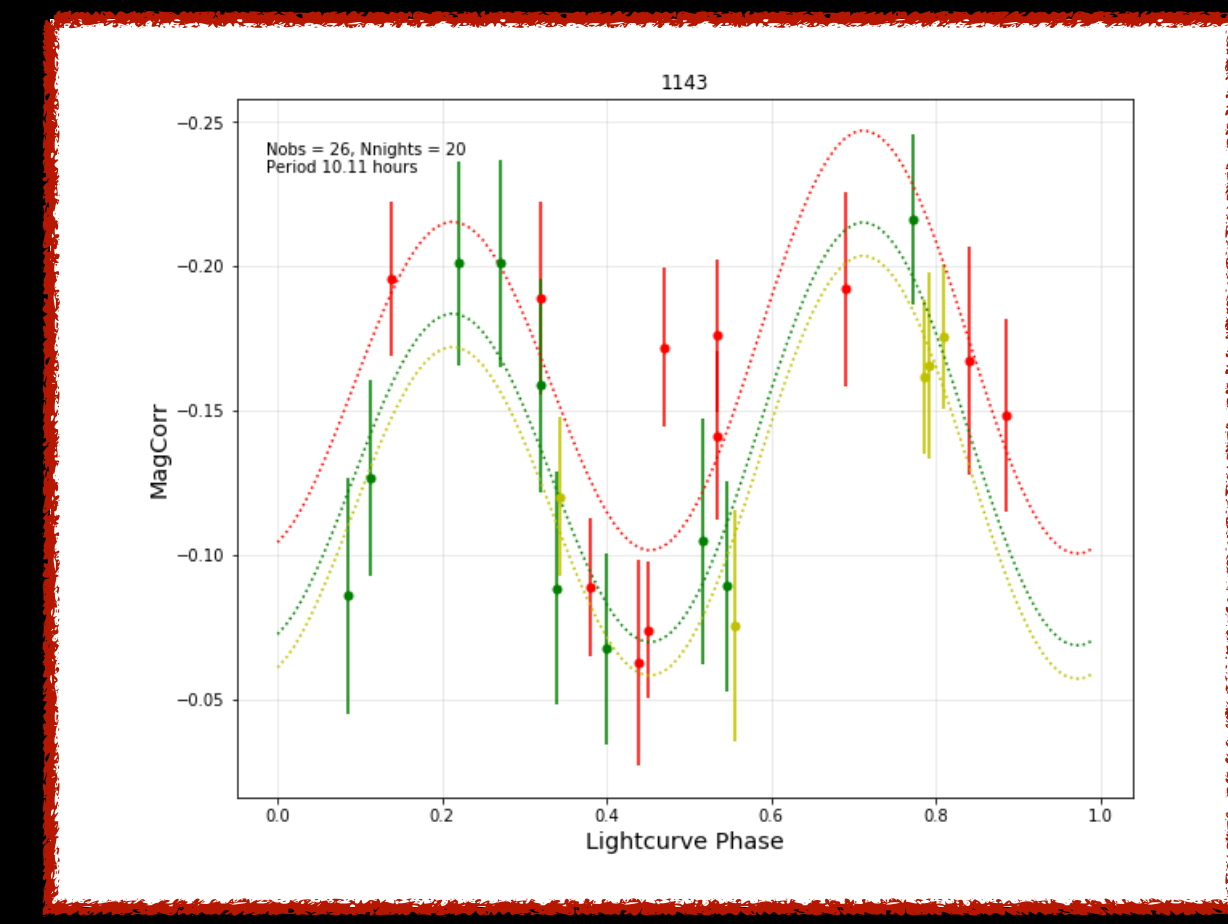
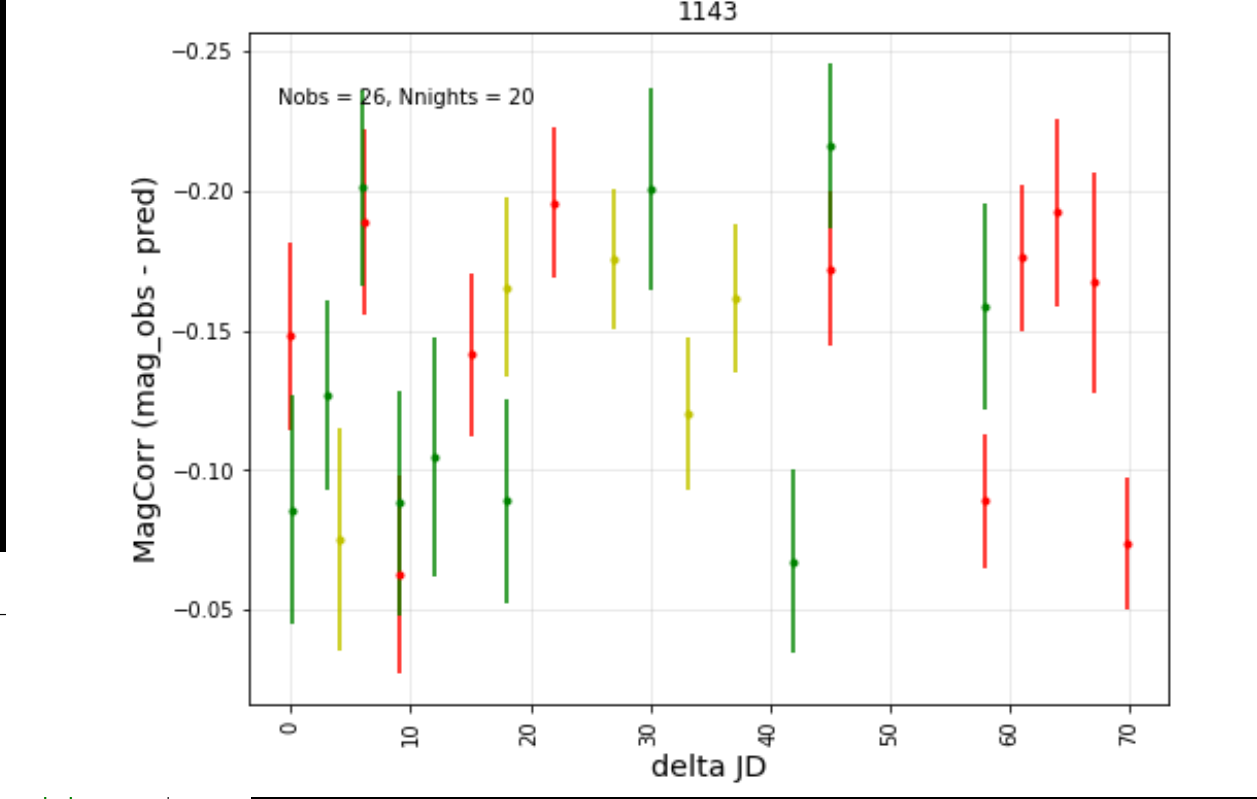
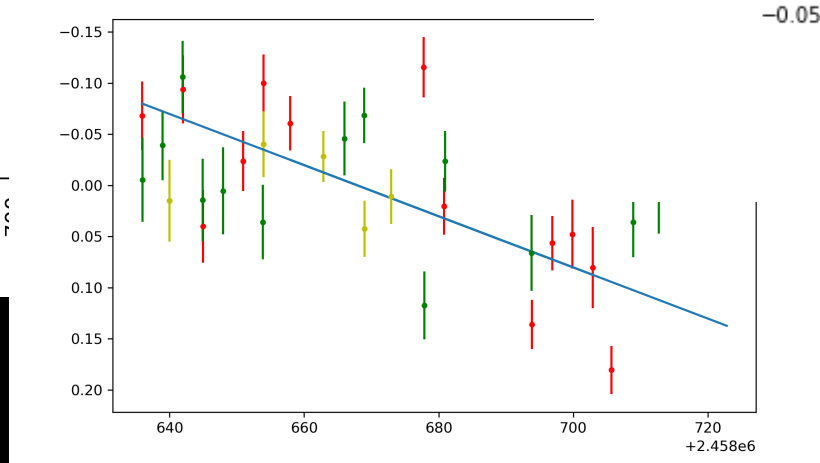
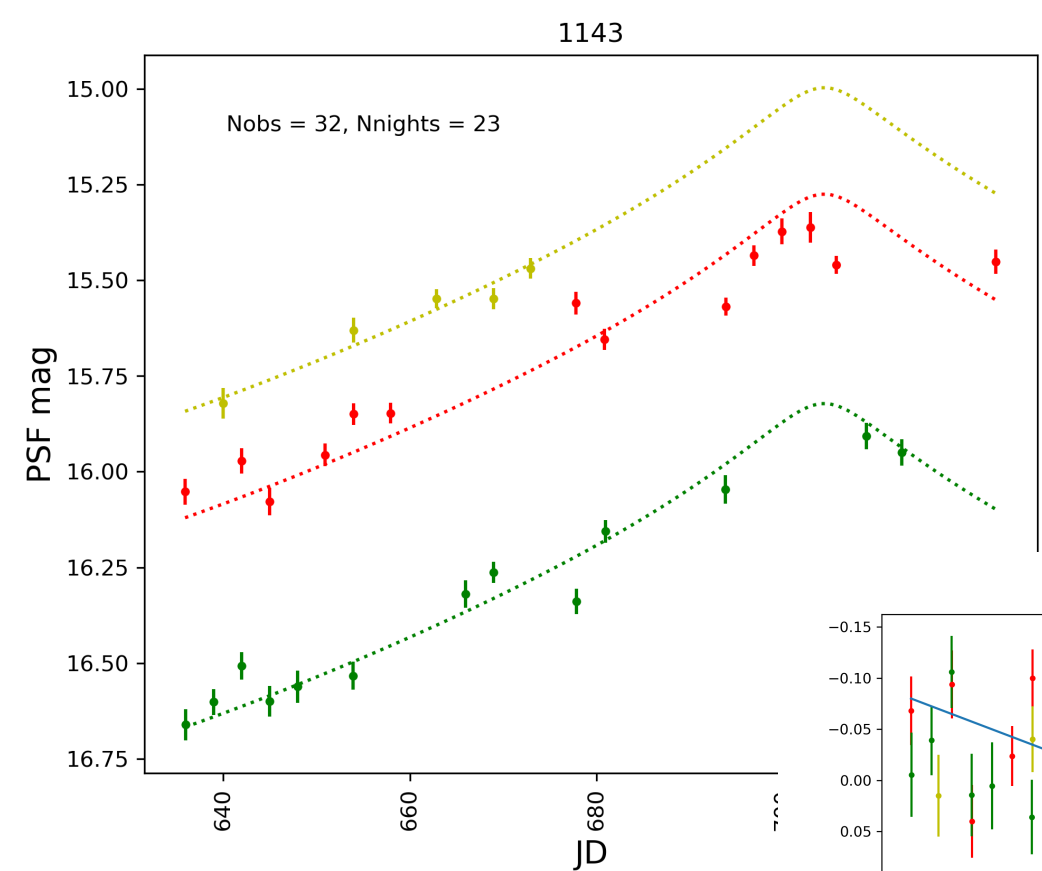
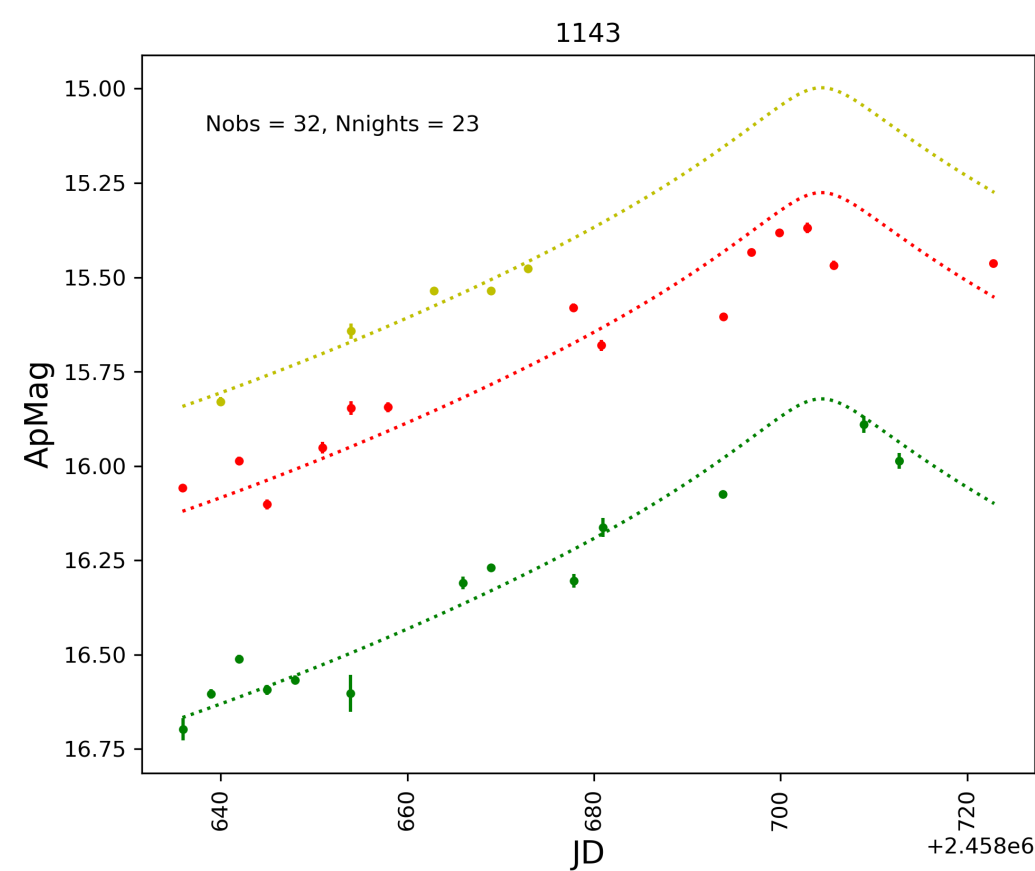
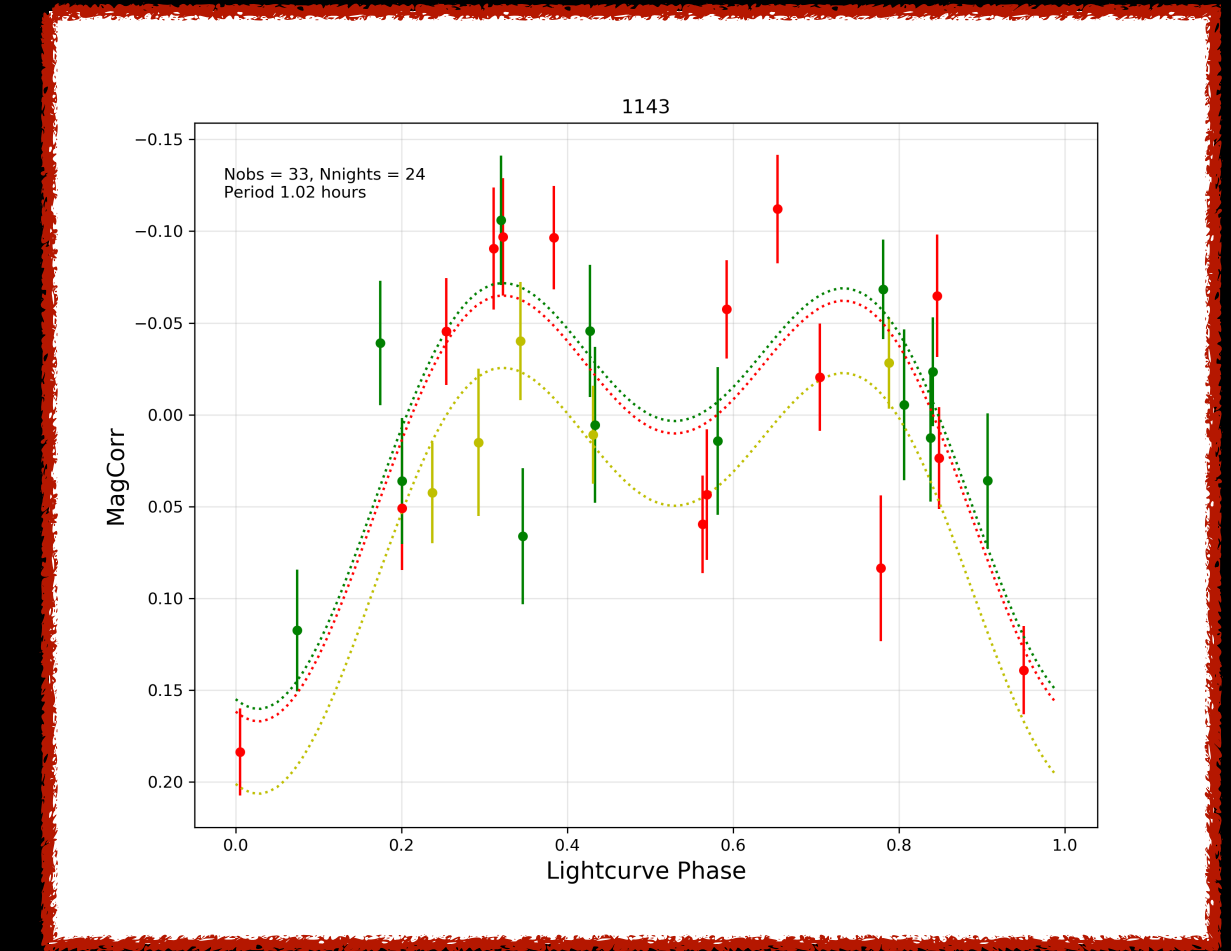
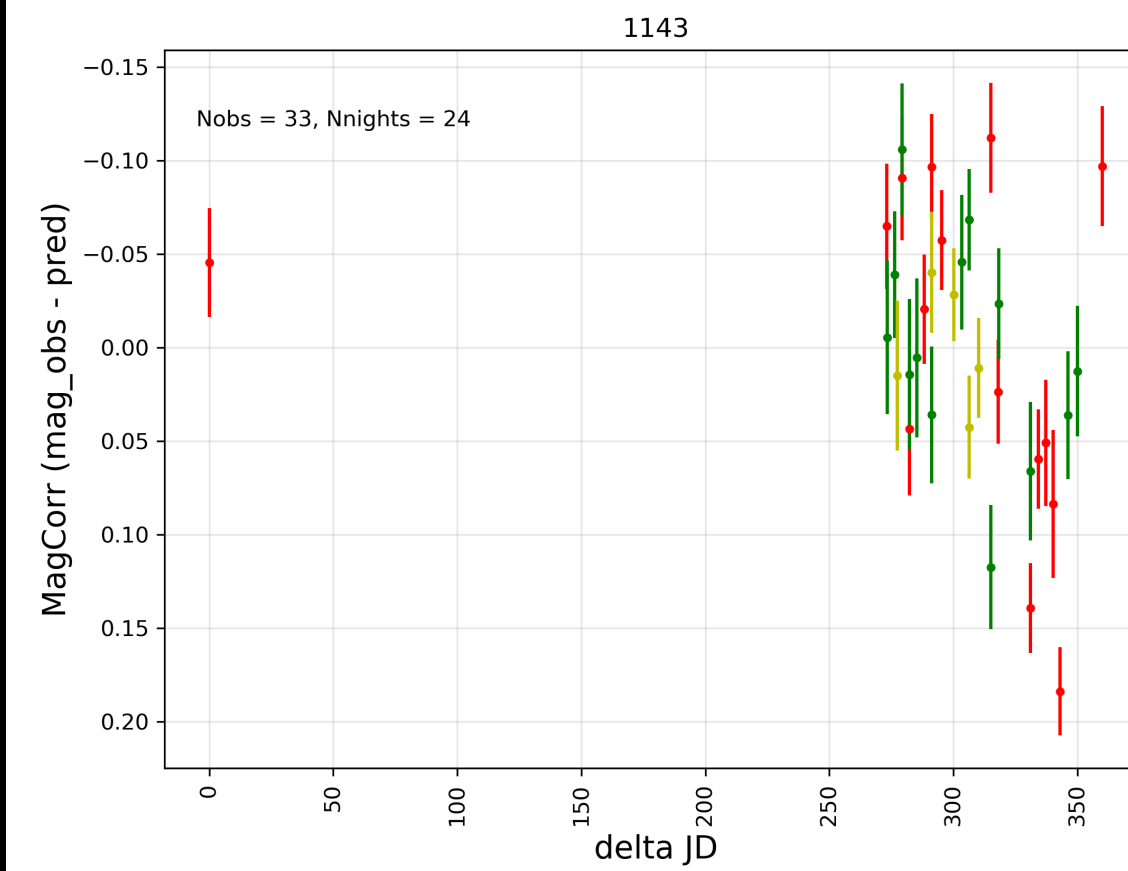
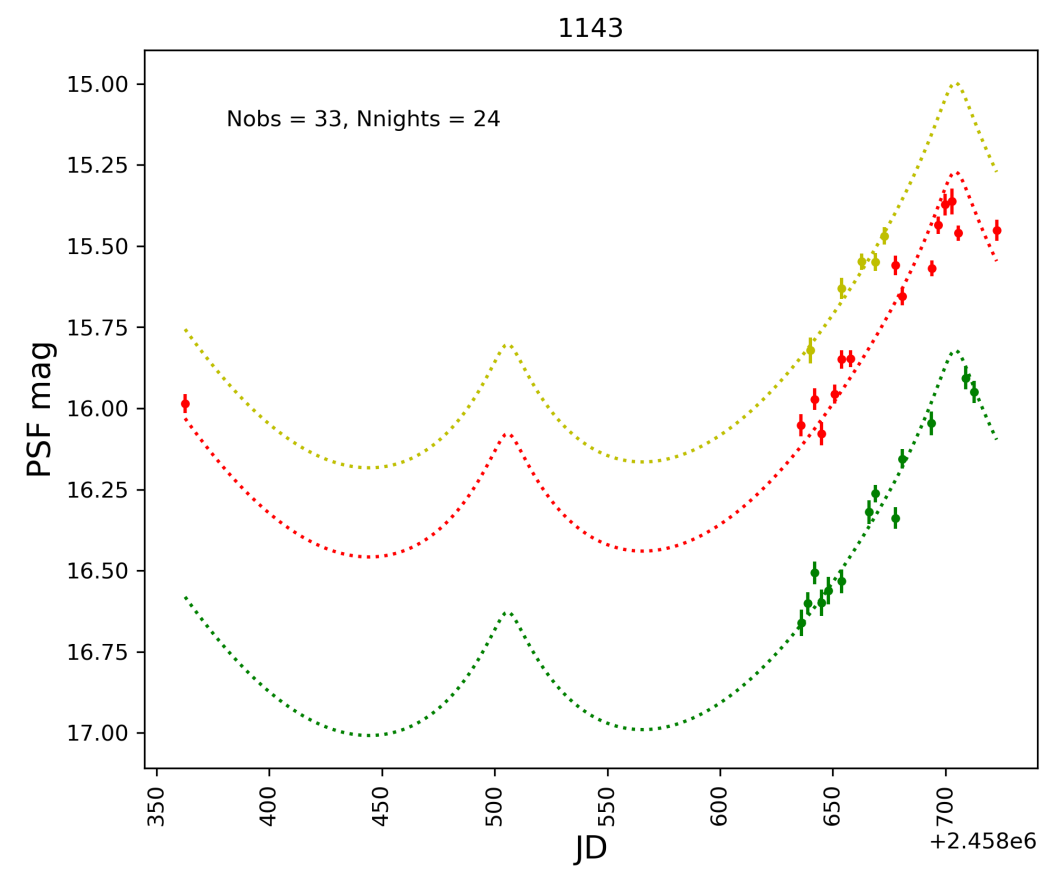
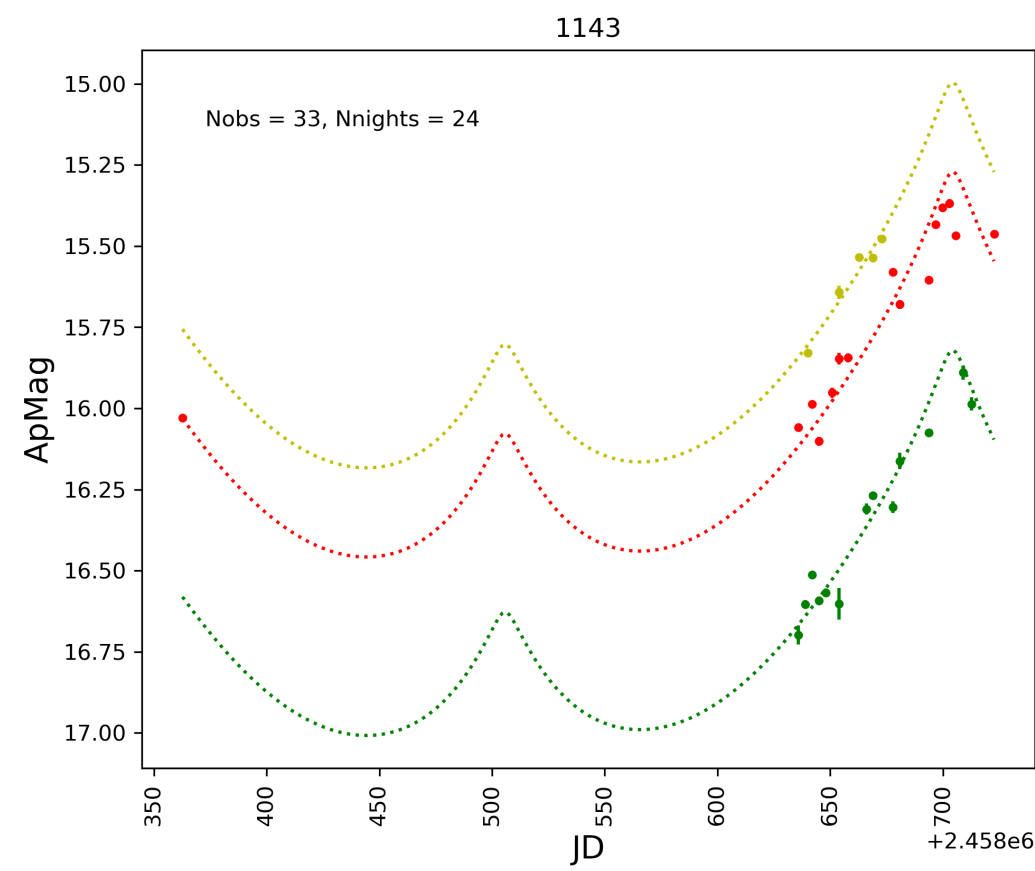
**For the  $P < 5$  hour Trojans:**

- some cases where period should be doubled
- some cases which are just noise
- some cases where phase curve influenced fit
- nothing truly convincing

# Fit the phase curve too

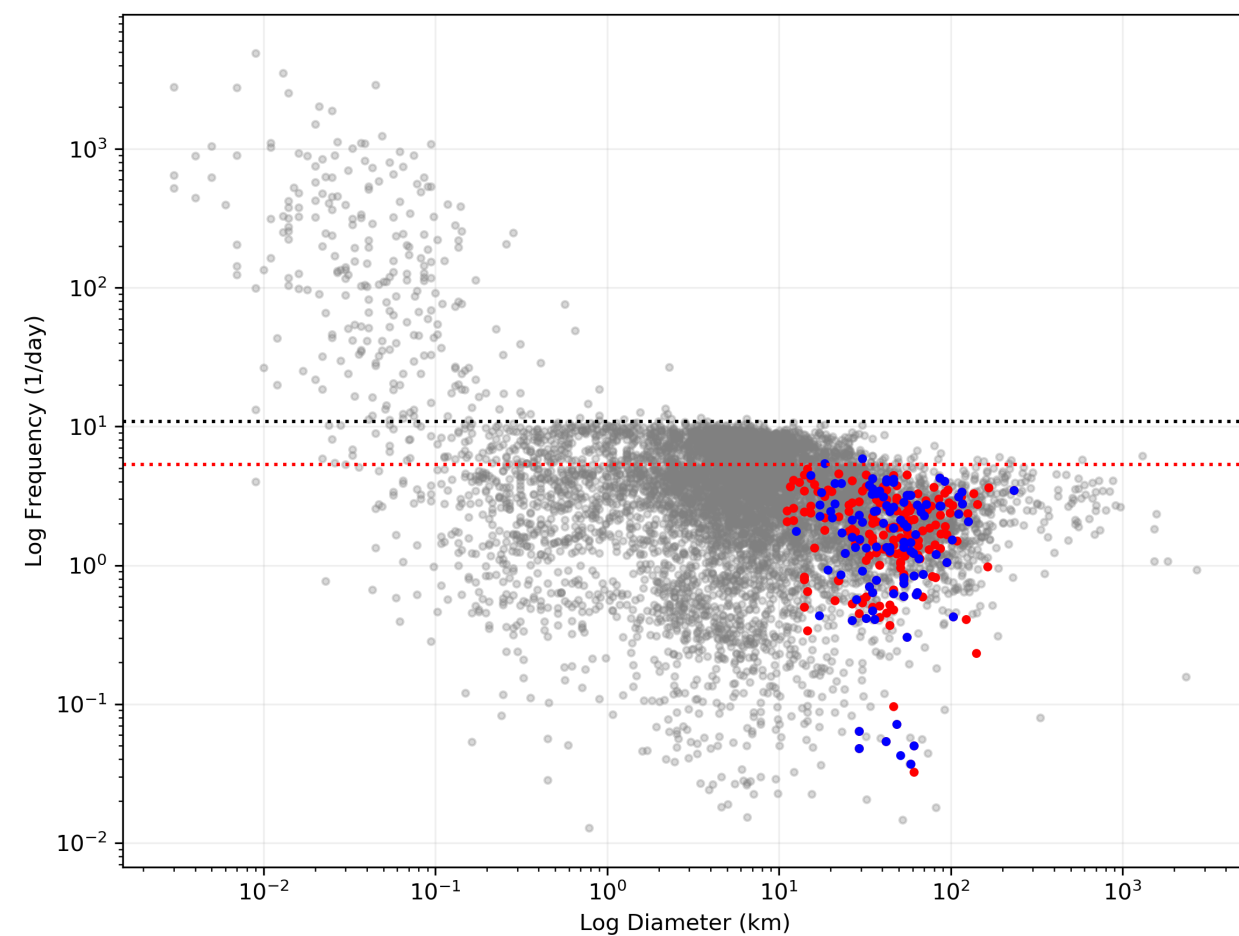
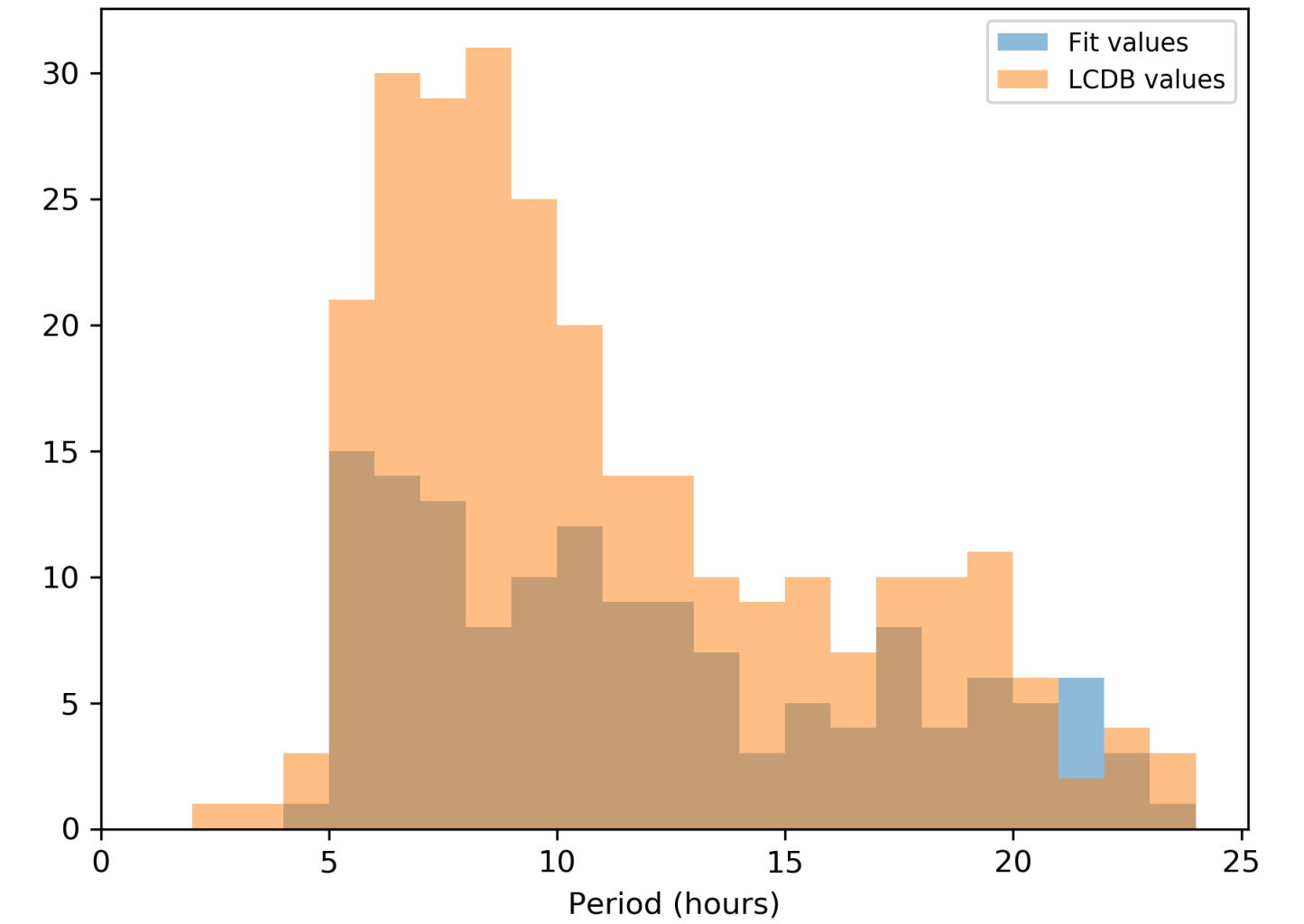
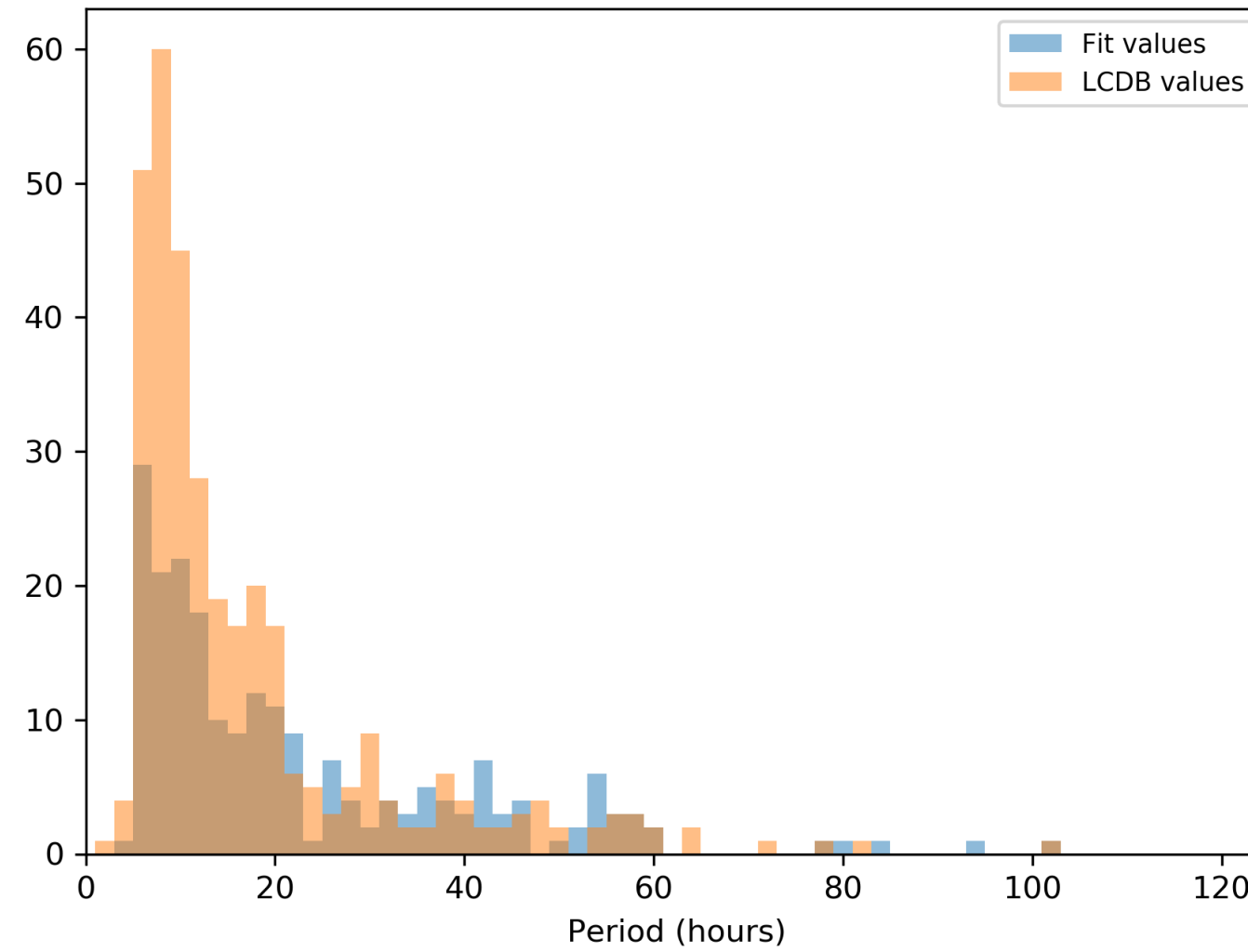
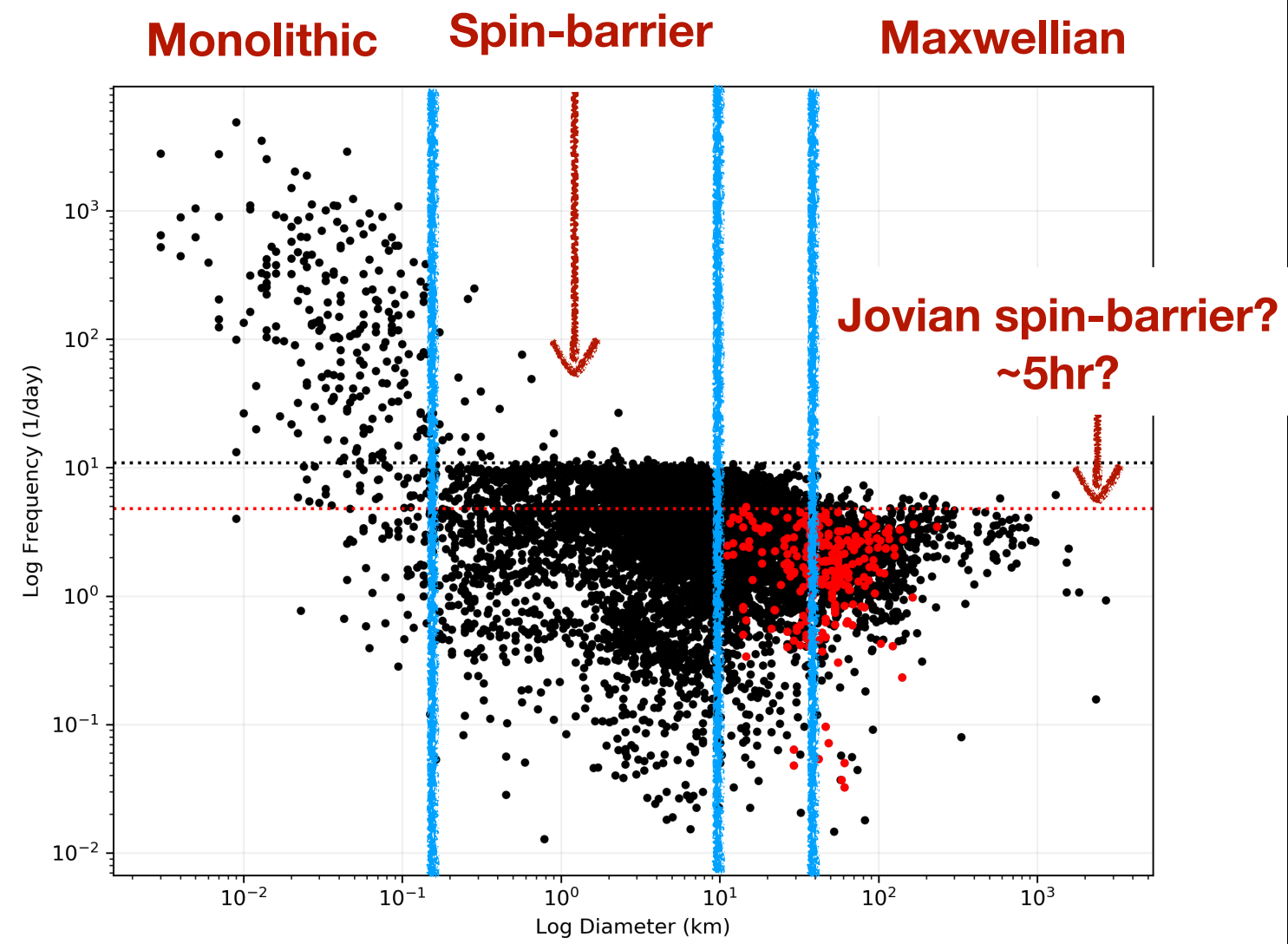


# Fit the phase curve too





# Rotation Periods (take 2)



(after reconsidering  $P < 5\text{hr}$  objects)  
211 Trojans from ZTF; 397 Trojans from LCDB

- ZTF catalogs are an excellent resource for finding rotation curves for asteroids (and Jovians) - close to existing sample size in single survey
  - We can learn a lot about the history of the solar system
- We have learned a lot more about fitting sparse light curves
  - We can fit sparse light curves in multiple bandpasses
  - Fitting phase curves (as well as colors) will improve fits
  - I should learn about ways to link plots in python (faster data analysis)
  - Still no Jovian Trojan rotating faster than 5 hours