Pt5m: Monitoring Binary Pulsar systems using a automated pipeline

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Overview

Using our automated pipeline to fit light curves to pt5m data

The creation of this pipeline will allow for

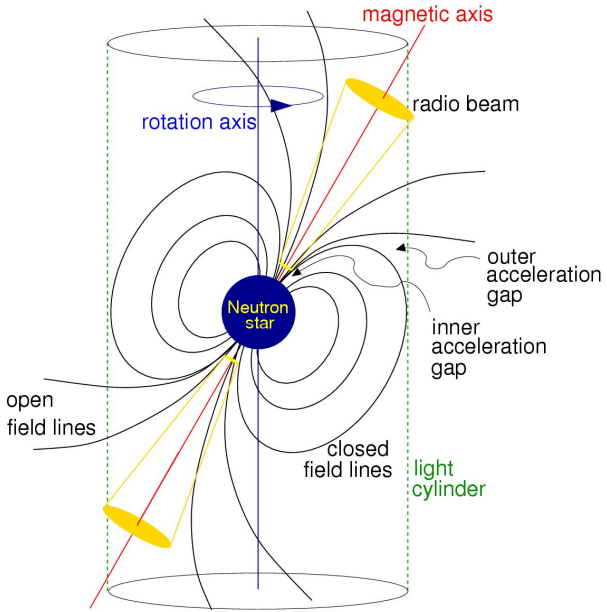
- Determination of parameters in a pulsar system

The final aim

To find changes in a transitional millisecond pulsar system.

What are pulsars?

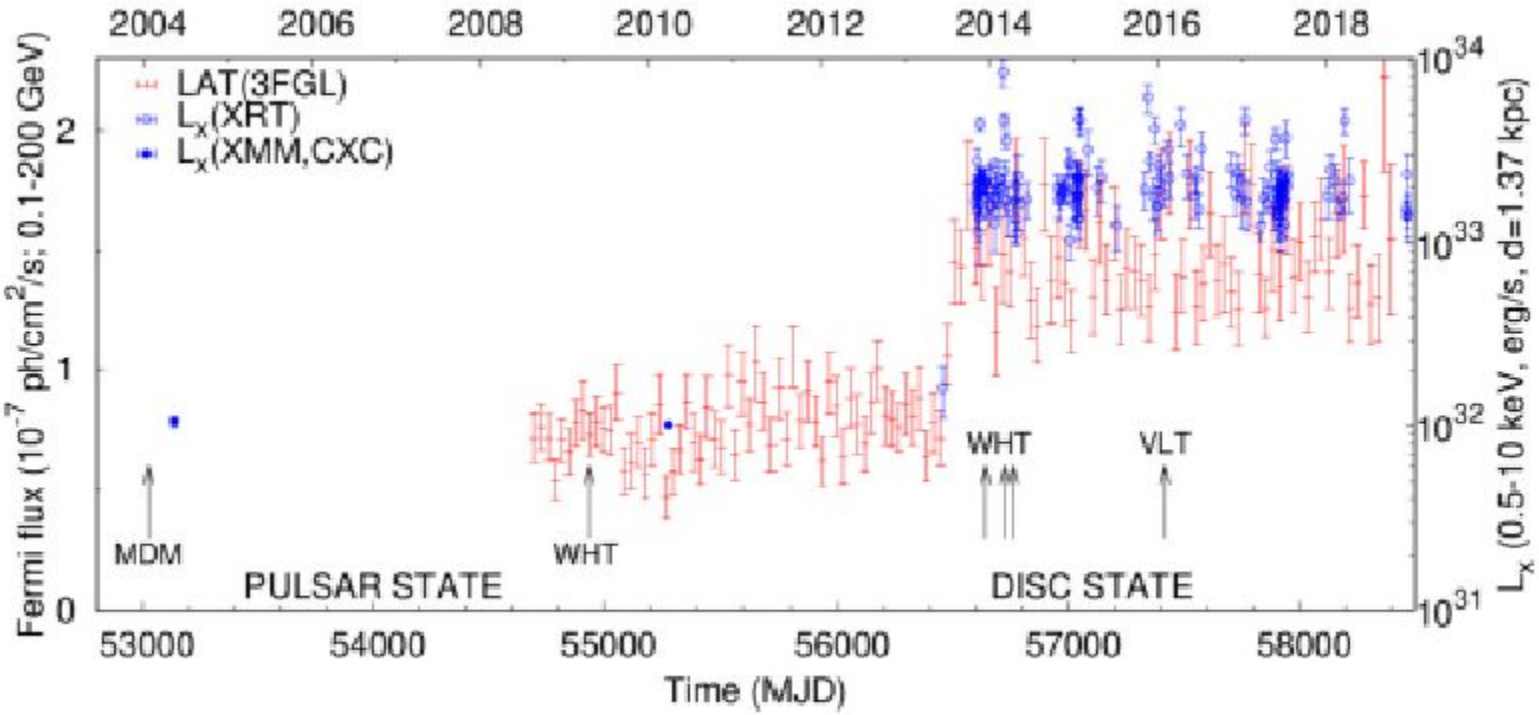
- Pulsars:
  - Rotating neutron stars
  - Supernovae remnants
  - Mass < 1.4 solar masses
  - Pulsing signal
  - Charged particles + rapid rotation = magnetic fields
  - Collimated beam



Type of pulsars

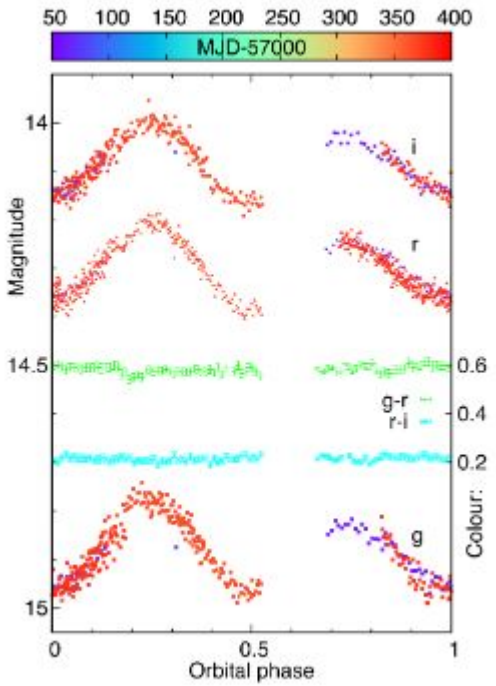
- Millisecond pulsars - typically found in binary
- Spider pulsars: Redback (M > 0.1 Ms) and black widow (M > 0.01 Ms)
- Transitional millisecond pulsars; accreting and high-energy emitting X-ray binary system as well as a radio powered rotation state.
- Human timescales transitions:months/years
- Transient bursts turn on the radio-powered rotation mode
- Magnitude differences in luminosity between states

First transition directly observed



What object are we observing?

Previous research of a candidate

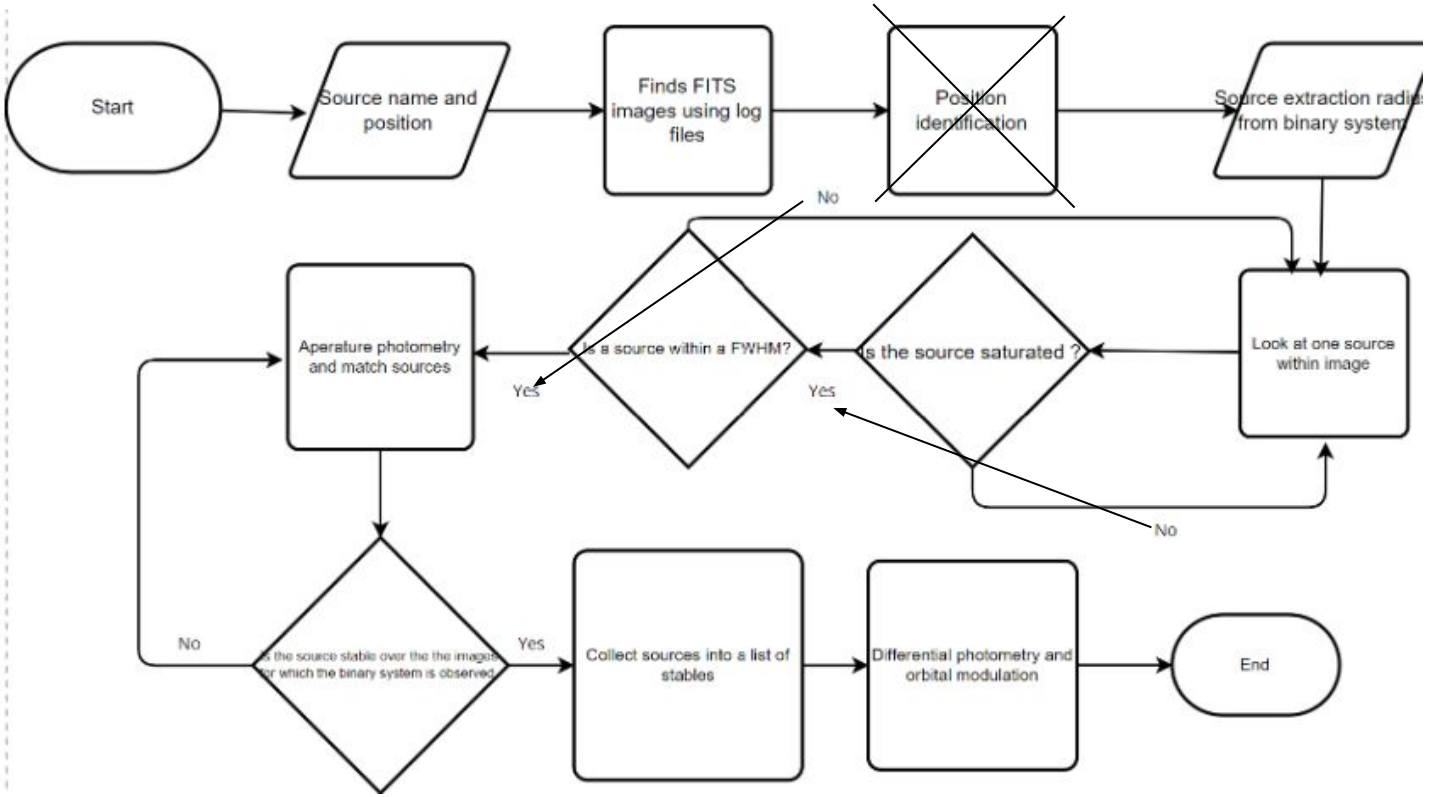


3FGL J0212+5320		
Parameters	Value	Reference
Pulsar mass (M_{NS})	1.3-1.6$M_\odot$	Linares et al. (2017)
Companion mass (M_c)	0.34 0.42$M_\odot$	Linares et al. (2017)
Orbital period (P_{orb})	0.86955 d	Li et al. (2016)
Roche lobe filling factor	0.64>	Li et al. (2016)
Mass ratio (q)	$0.26^{+0.02}_{-0.03}$	Linares et al. (2017)
Inclination angle (i)	90	Linares et al. (2017)

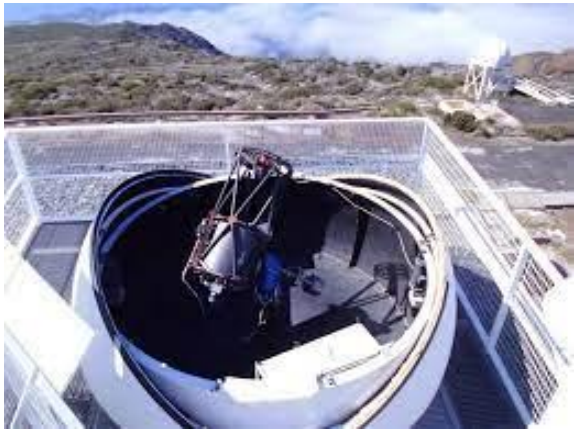
- Average magnitude suggest that the its one of the brightest binary systems
- Young reback
- Companion uniformly irradiated suggest higher temperature than calculated
- No evidence of heating from pulsar
- Mass lighter leading to a higher calculation of luminosity than normal
- System transition to accretion state suggested
- High interaction
- Asymmetric light curve - off-centre heating due to binary shock
- Constant shape across colours

The pipeline
(Example 3FGL J0212+5320)

Pipeline method



Pt5m



- Optical observation taken with science camera QSI 53 and a Cousins R filter
- Images taken of the pulsar fields
- Calibrated fields

FITS info

- Three different time periods: 2018-07-04 to 2019-02-07, 2019-06-26 to 2020-02-07 and 2020-08-19 to 2021-02-23
- R band filter
- FOV = 10.1 x 6.83 arcmins
- Exposure time = 60s
- Pulsar coords = (454,498)

Coordinate transformation

- Reference image is chosen
- Stack images
- Sources taken from darker regions from 1 std clip
- Astrometry.net api is used to calibrate it to wcs to Pan-STARRS
- Astroalign is then used to obtain transformation matrices for all images

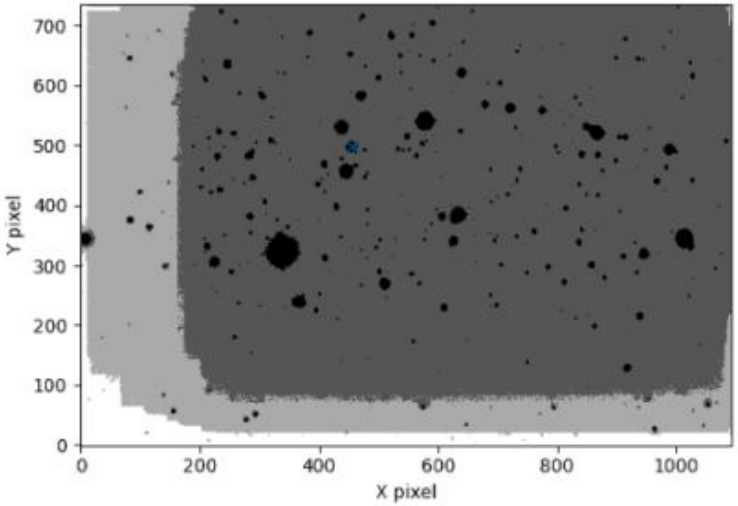
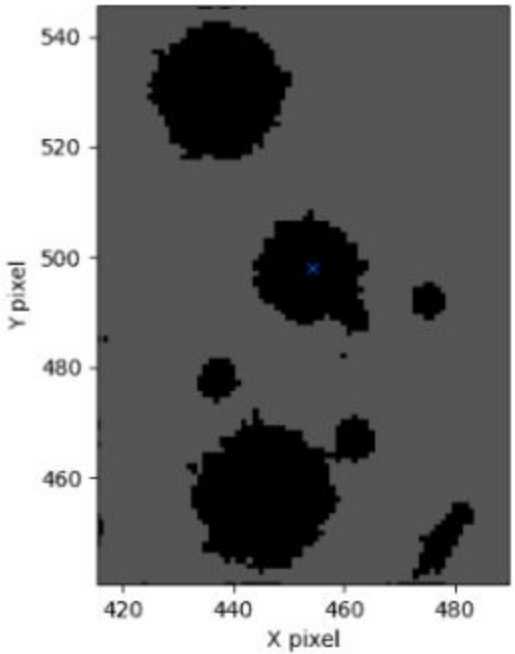
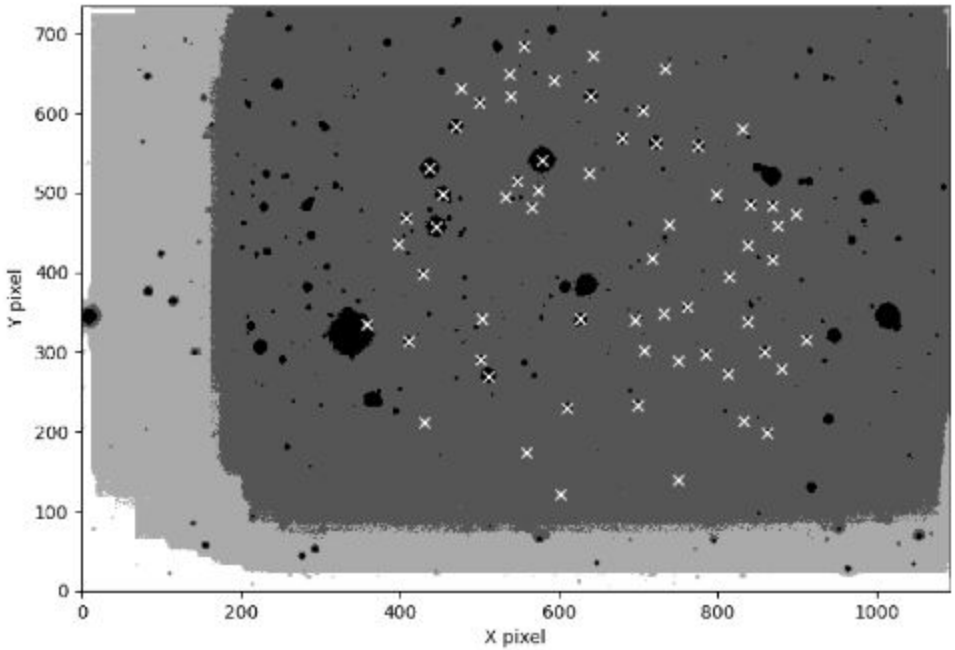


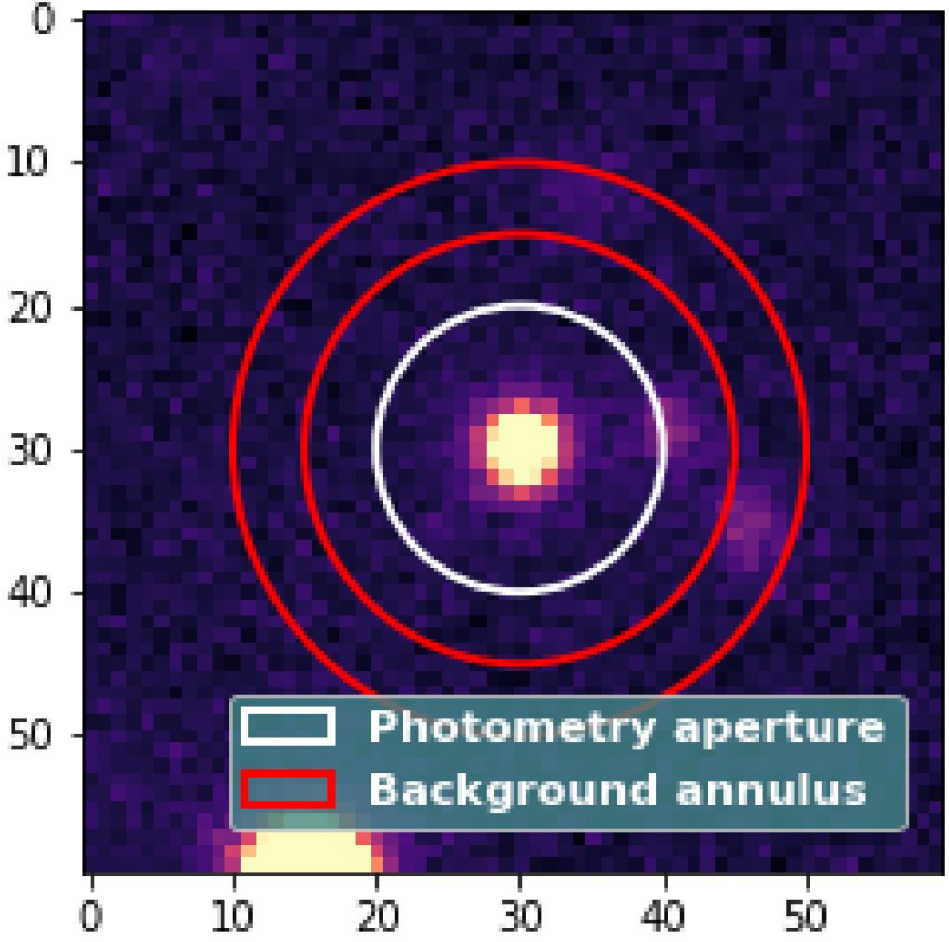
Fig 3: Stacked image of transformed set of images

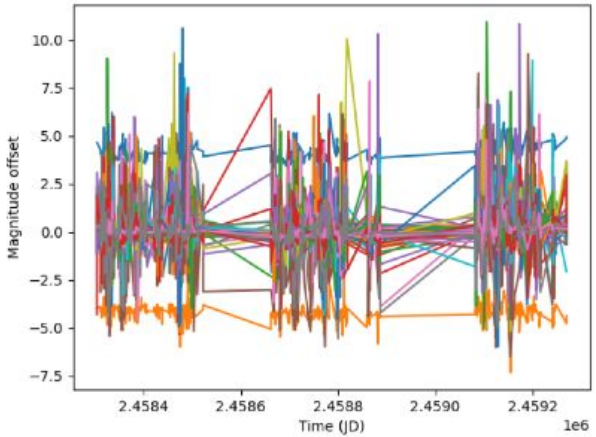

540
520
500
480
460
Y pixel
420
440
460
480
X pixel

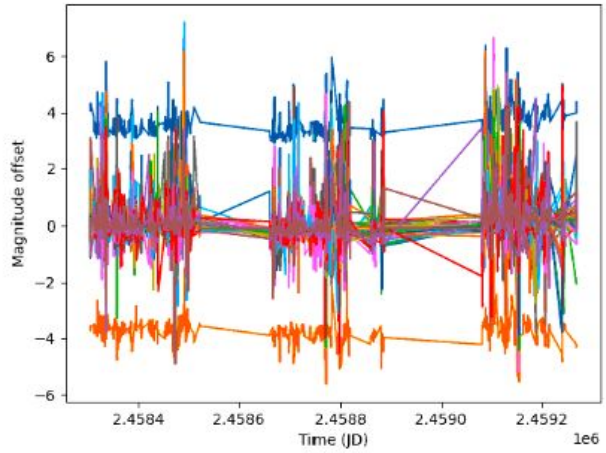

700
600
500
400
300
200
100
0
Y pixel
0
200
400
600
800
1000
X pixel

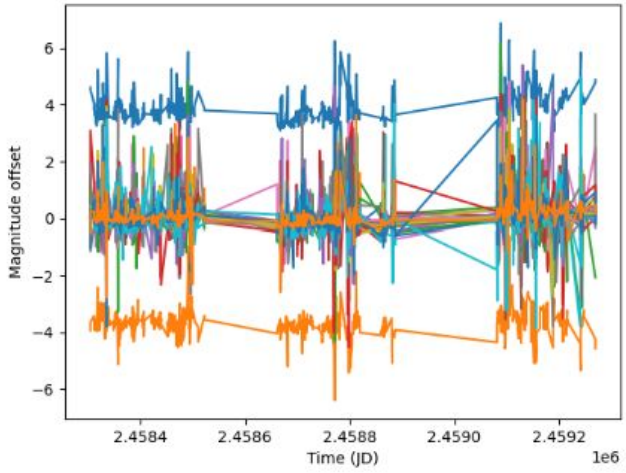
Photometry

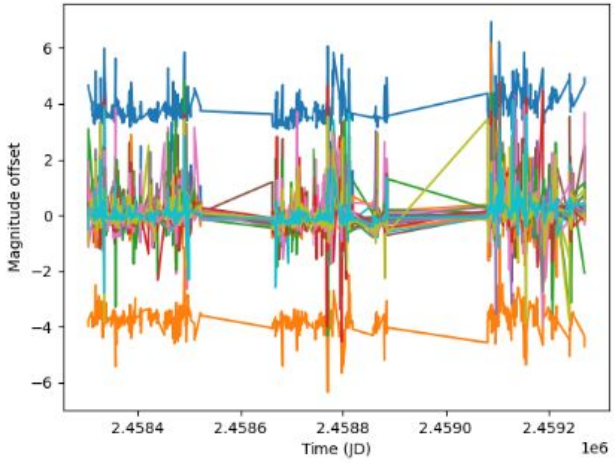
- Photometry extraction of Light from image
- Taken from positions from stack
- Differential photometry : Comparison relatively stable stars against the average of all source residuals. The difference is then used against the actual values of comparison stars to find flux of variable sources
- Top 25% of pixel values removed from sky annulus

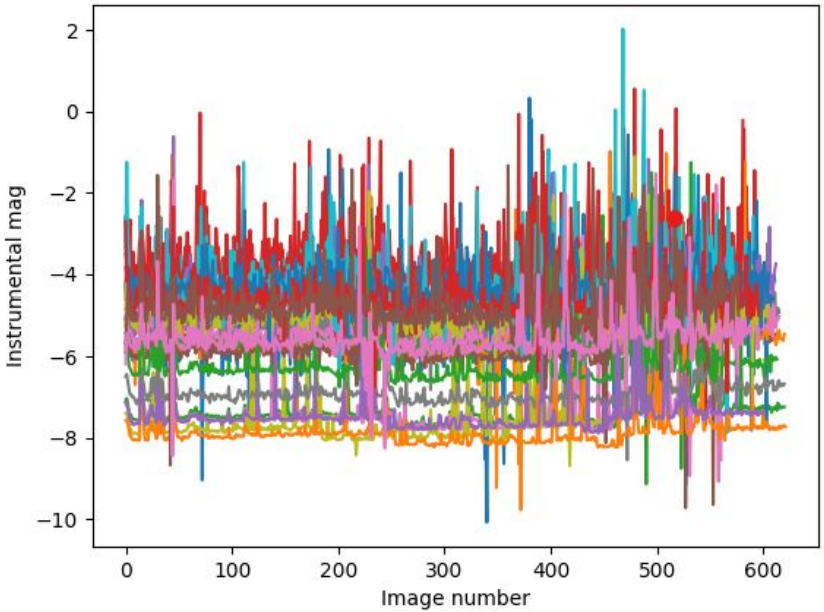

0
10
20
30
40
50
0
10
20
30
40
50
Photometry aperture
Background annulus

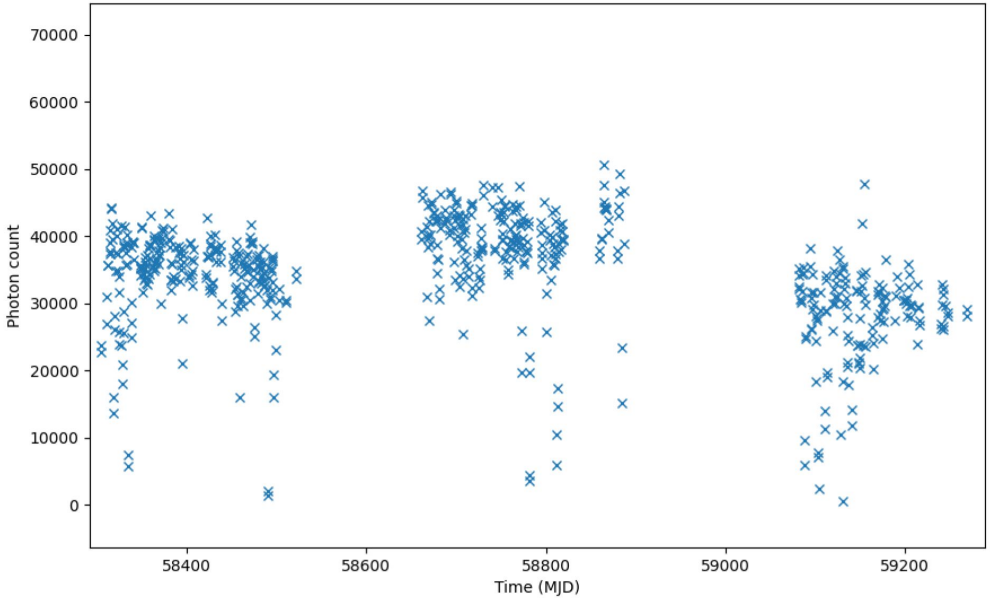

Magnitude offset
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
2.4584
2.4586
2.4588
2.4590
2.4592
Time (JD)
1e6


Magnitude offset
6
4
2
0
−2
−4
−6
2.4584
2.4586
2.4588
2.4590
2.4592
Time (JD)
1e6


Magnitude offset
6
4
2
0
−2
−4
−6
2.4584
2.4586
2.4588
2.4590
2.4592
Time (JD)
1e6


Magnitude offset
6
4
2
0
−2
−4
−6
2.4584
2.4586
2.4588
2.4590
2.4592
Time (JD)
1e6


Instrumental mag
2
0
−2
−4
−6
−8
−10
0
100
200
300
400
500
600
Image number


Photon count
70000
60000
50000
40000
30000
20000
10000
0
58400
58600
58800
59000
59200
Time (MJD)

Ensemble photometry

- Using gaia query function, the centre coordinates determined by wcs function set as center of image with a source detection radius of 0.4 degrees
- Gaia query : real magnitude of sources
- Using instrumental difference, accurate conversion to real finding zero point for each epoch
- M=M_(ins)+M_0
- M_0 should be approx similar for all images at each epoch
- Stable

Parameter fitting

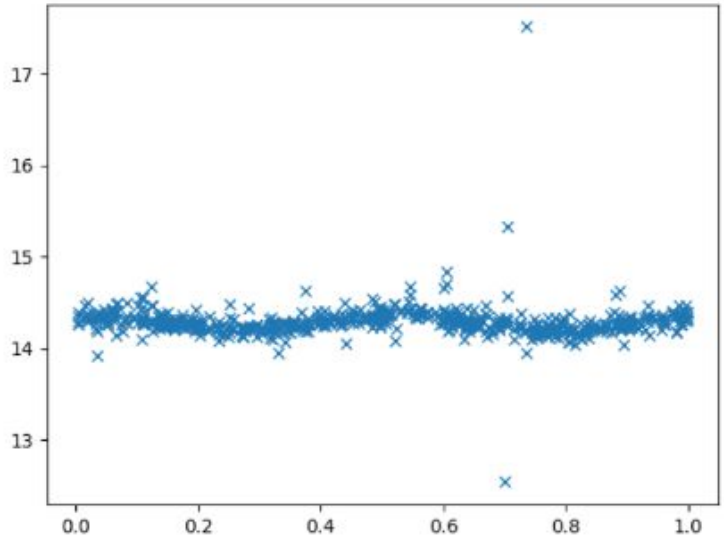
$$F(\phi) = a_0 + \sum_{i}^{4} a_i(\cos 2\pi i\phi + \sin 2\pi i\phi)$$

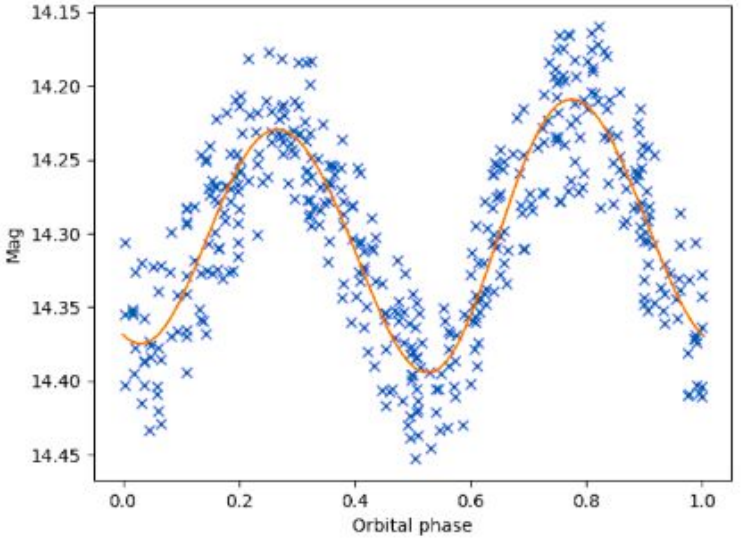
$$A_2 \cos\phi_2 = f_{EV}\frac{M_2}{M_1}\left(\frac{R_1}{a}\right)^3 \sin^2 i,$$

$$r_L = \frac{0.49q^{\frac{2}{3}}}{0.6q^{2/3} + \ln 1 + q^{1/3}}.$$

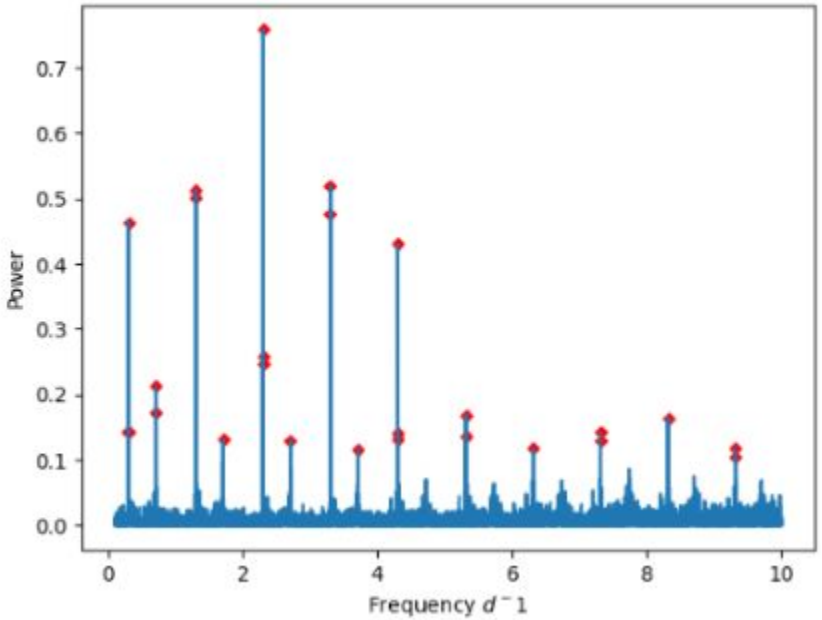
Min to max ratio is ratio of the luminosities which can be used to find the temperature ratio

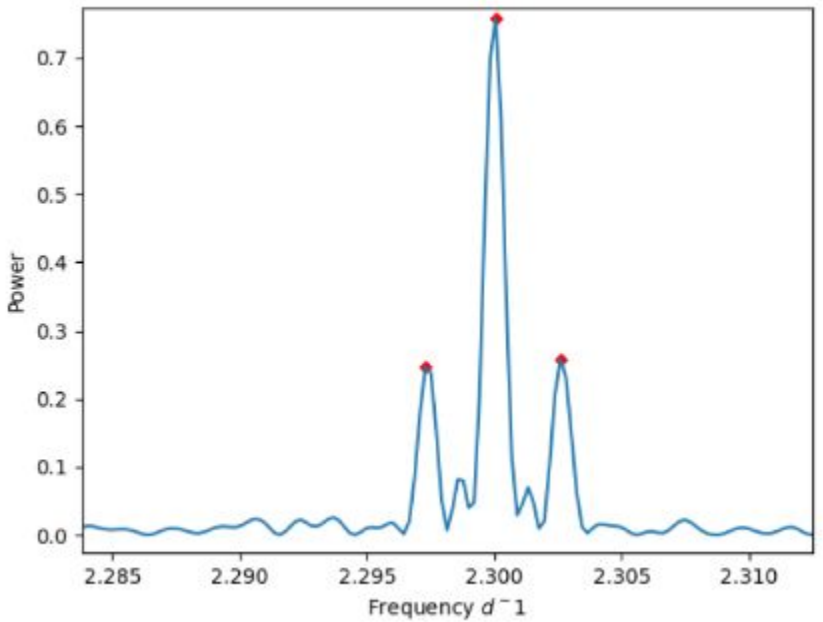
Final light curve





- Folded at points at orbital period and divided by orbital period 0.86955d
- Difference in the peaks is consistent with the theory that asymmetric peaks show minimal deviation
- So the Temperature ratio from T_night/T_day from the flux curve was given as 0.996
- Mass ratio = 0.426



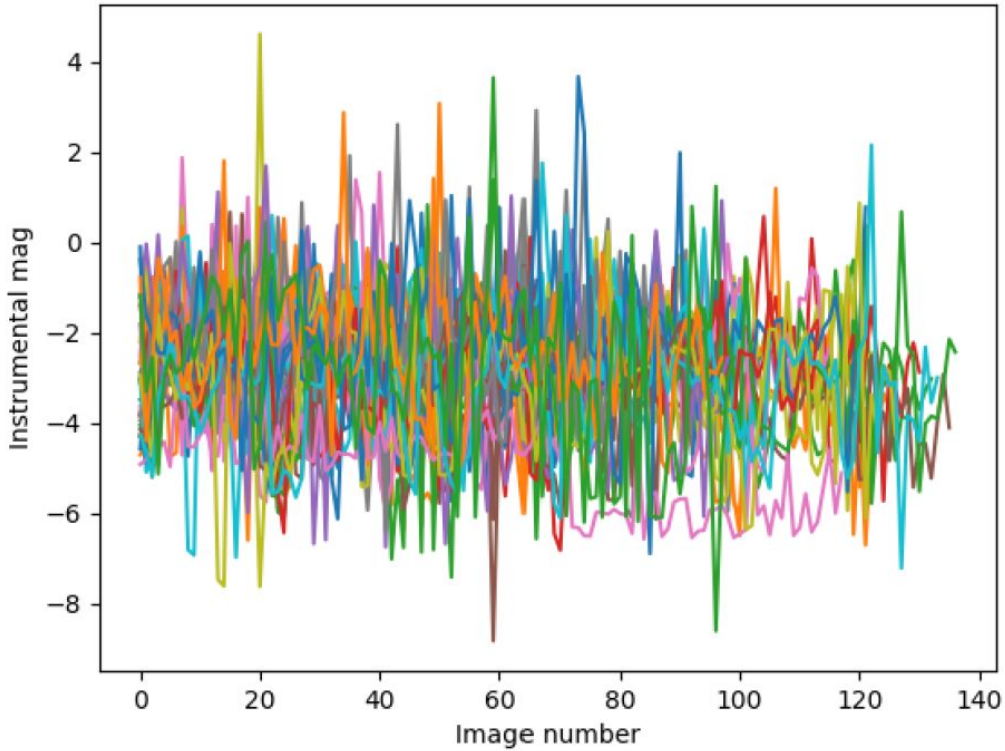


- Largest peak = photometric period = 2.3 (d)^-1
- Orbital period = 1/(2.3/2) = 0.8696 d

Errors

- Light curve plotting error
- Wide spread of points about line of best fit
- May need to remove more outliers
- Could not find night and day side values in literature
- Low ratio agrees with source material
- Pipeline accurately determines orbital period

Errors



- 3 STD limit - 4 sources with minimal correlation for J1023+0038
- 3.5 std limit - 30 sources shown here
- Issues with sensitivity when finding stables
- Make the program more sensitive for sources
- Program may pick up more sources in the poor quality images
- Set up program to a higher minimum source detection per image

Future work

- At the moment, we need to adjust the standard deviation limit
- Automate std limit
- More frequent observations over the shorter epochs
- Short time parameter changes (Might find variation in peaks)
- J2129-0429 suggest shorter term variability
- Change in roche lobe filling factor on shorter time scales
- Change in state may be soon as approach one