Photometry Project

Ondrejov Workshop 2024

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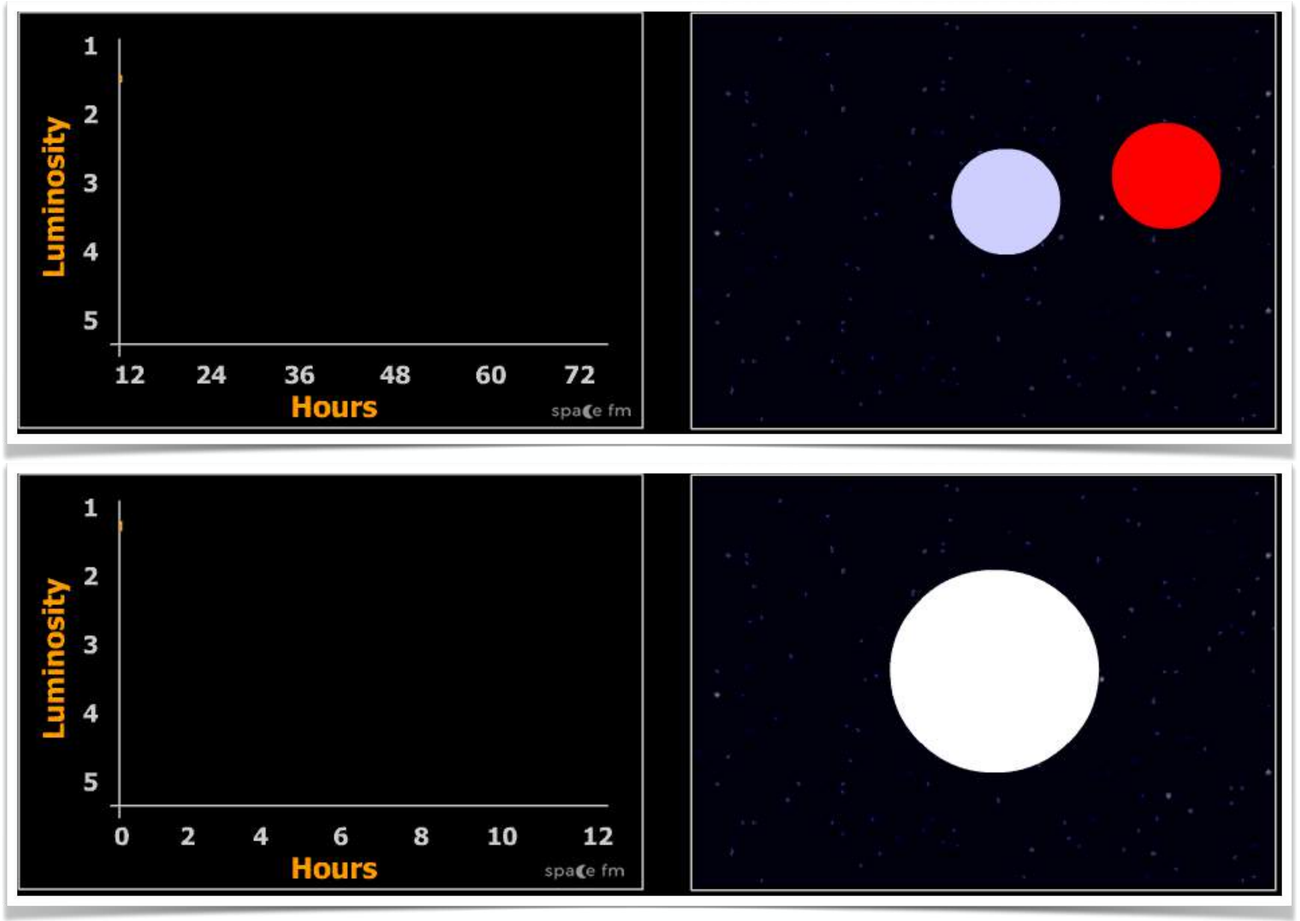
Introduction

Variable Stars

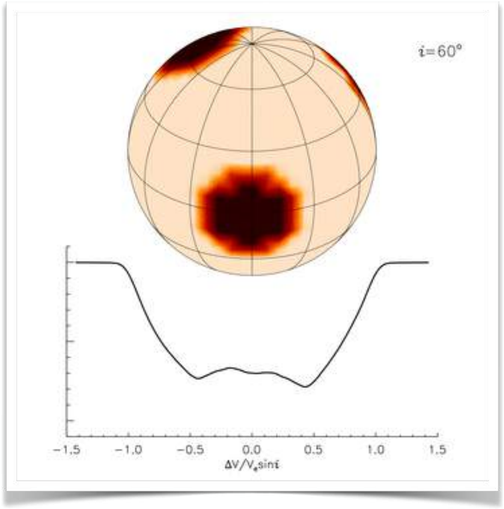
- Stars that change their apparent magnitude in time
- Two main types of variable stars:

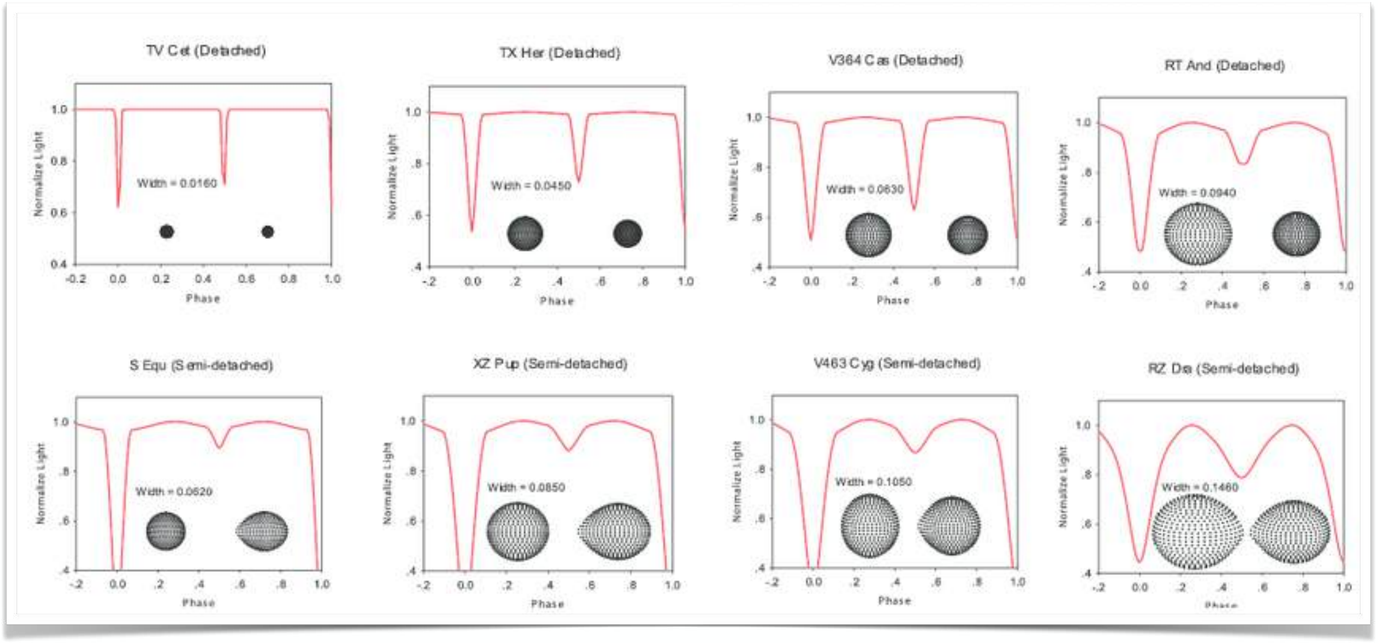
1. Intrinsic variables
2. Extrinsic variables



Extrinsic variables

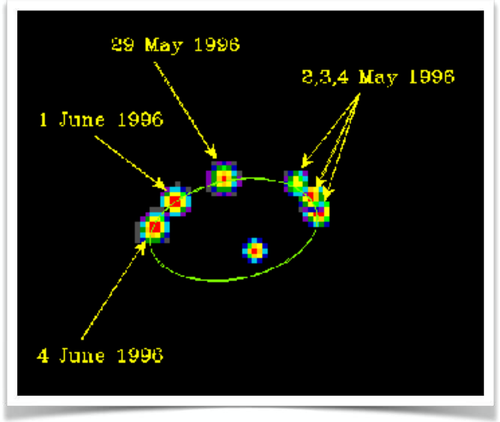
- Two main types of extrinsic variables:
  1. Rotating variables
  2. Eclipsing binaries

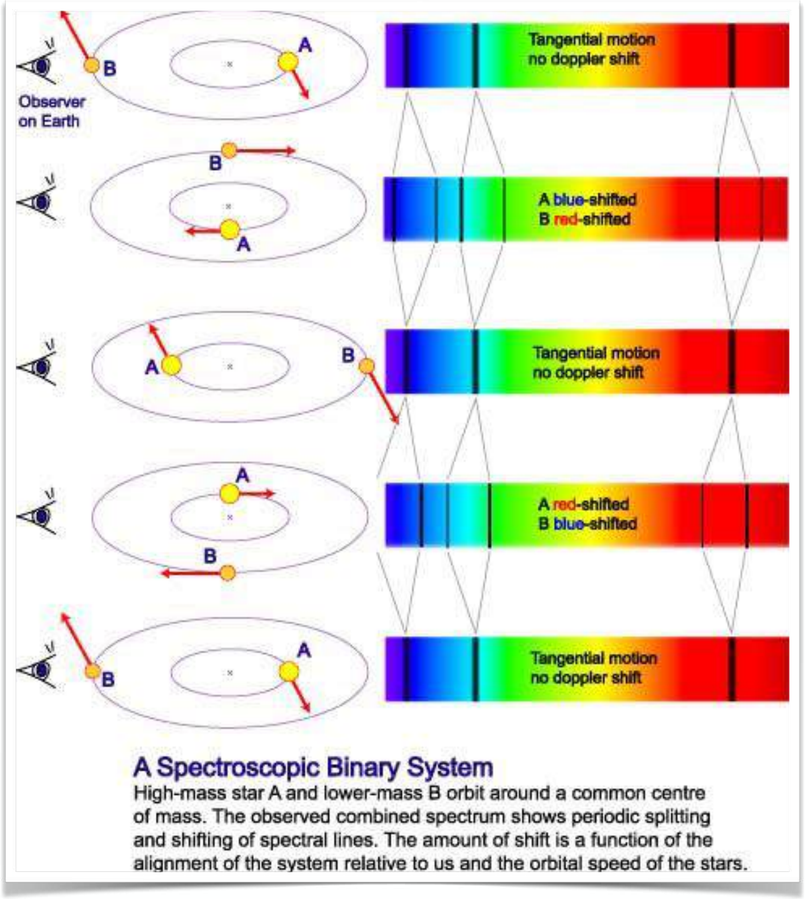


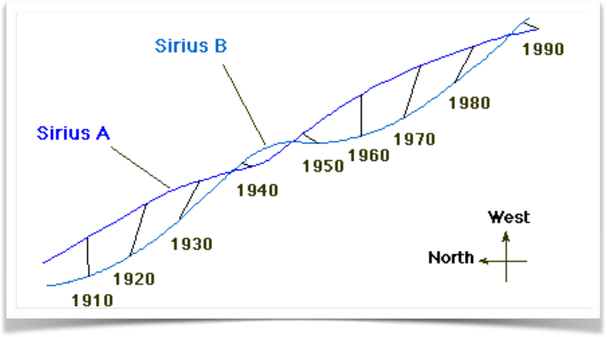


Binaries

- Classification:
  1. Apparent binaries
  2. Visual binaries
  3. Astrometric binaries
  4. Spectroscopic binaries
  5. Eclipsing binaries
- Up to 85 % of stars in binaries or systems with three or more stars
- Important for understanding stellar evolution







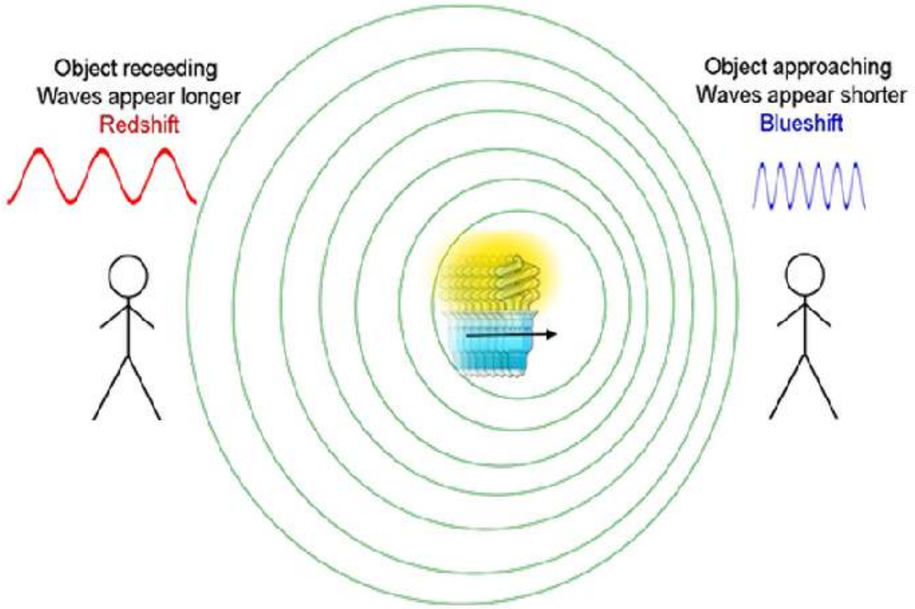
The goal

1. Find and observe suitable binaries
2. Reduce obtained data and acquire lightcurves
3. Fit our lightcurves
4. Determine main parameters of our targets

Theoretical Background

Theoretical Background

Spectroscopic Binaries

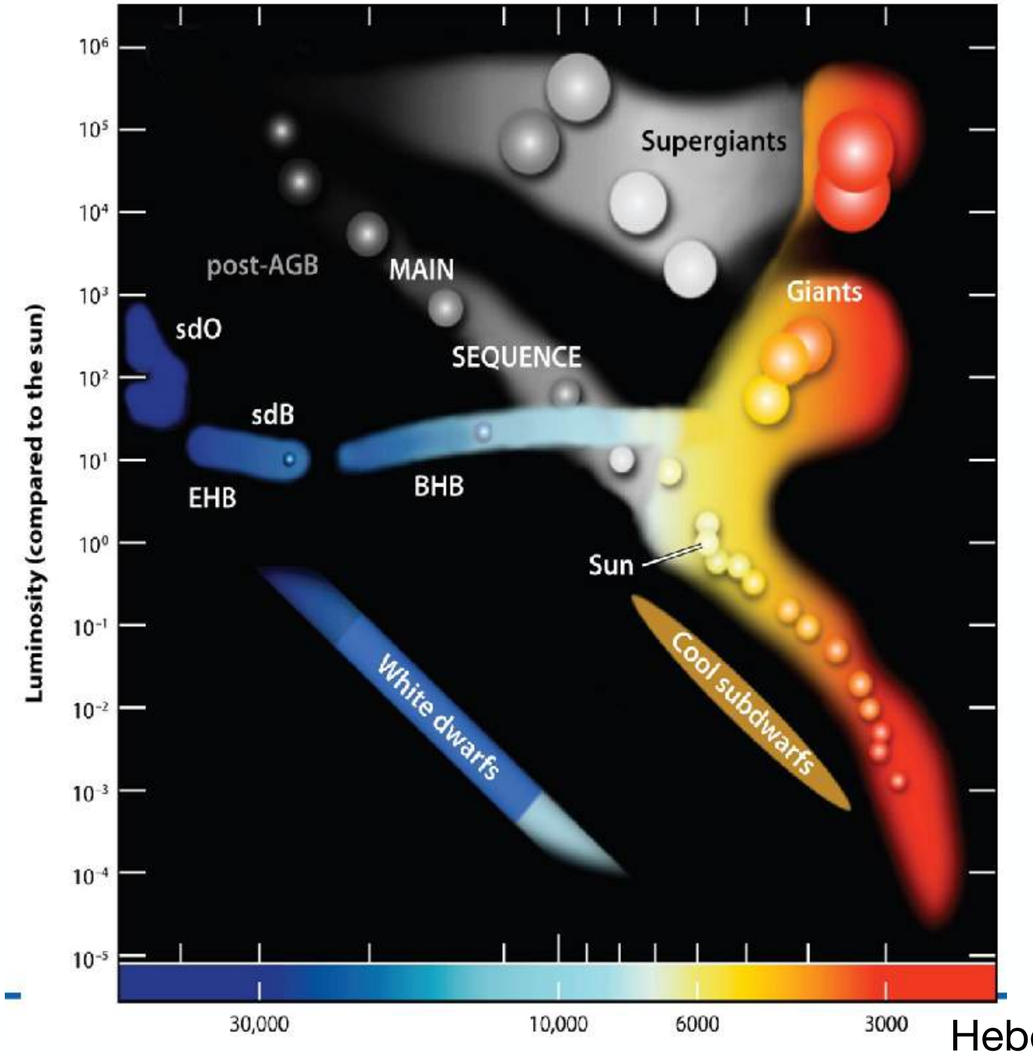


- Components close together
- Periodic Doppler Shift in spectral lines
- SB1: Only one spectrum visible
- SB2: Both spectra are visible
- SB2 system usually: i=90 degrees: masses can be determined for both the components

$$f(m) = \frac{M_2^3 \sin^3 i}{(M_1 + M_2)^2} = \frac{K_1^3 P}{2\pi G}$$

Hot Subdwarfs

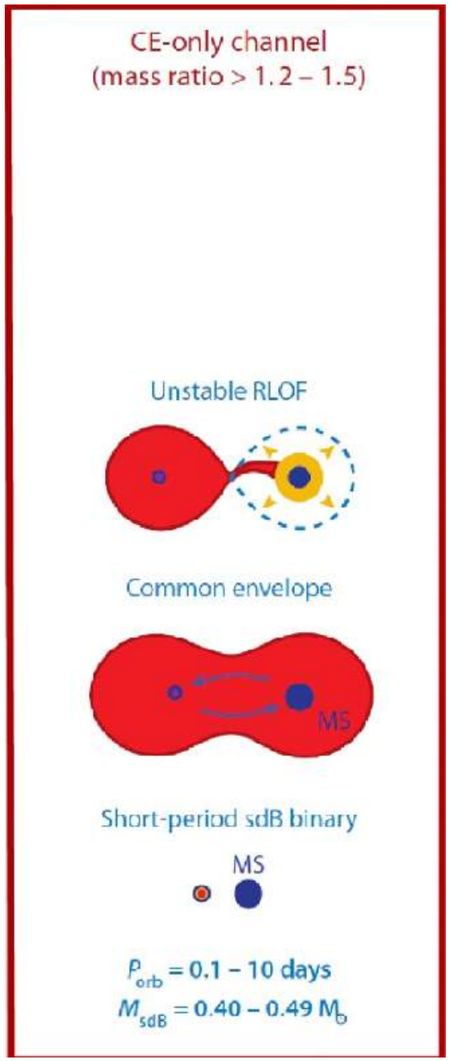
sdO/Bs



Heber et al. (2009)

Mass ~0.47 $M_{\odot}$
Radius ~0.1 - 0.3 $R_{\odot}$
Effective temperature ~ 20 – 100 kK

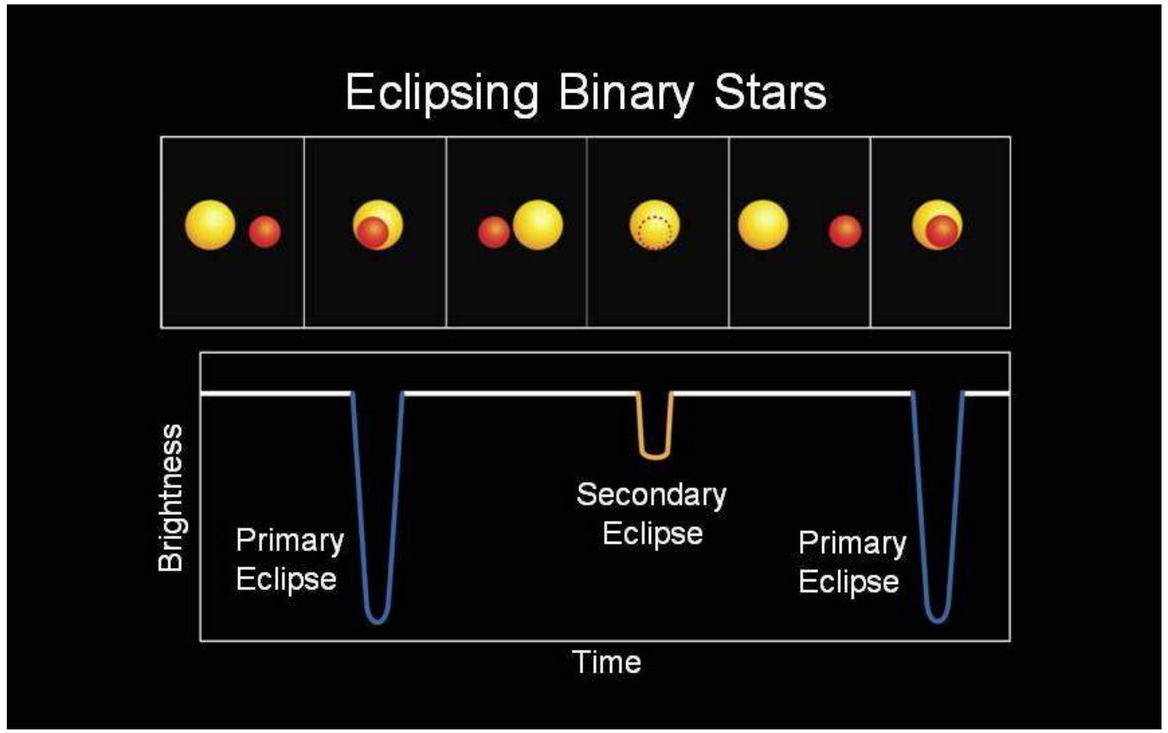
- Only consider sdBs in Binaries
- Companions: MS /Brown Dwarf



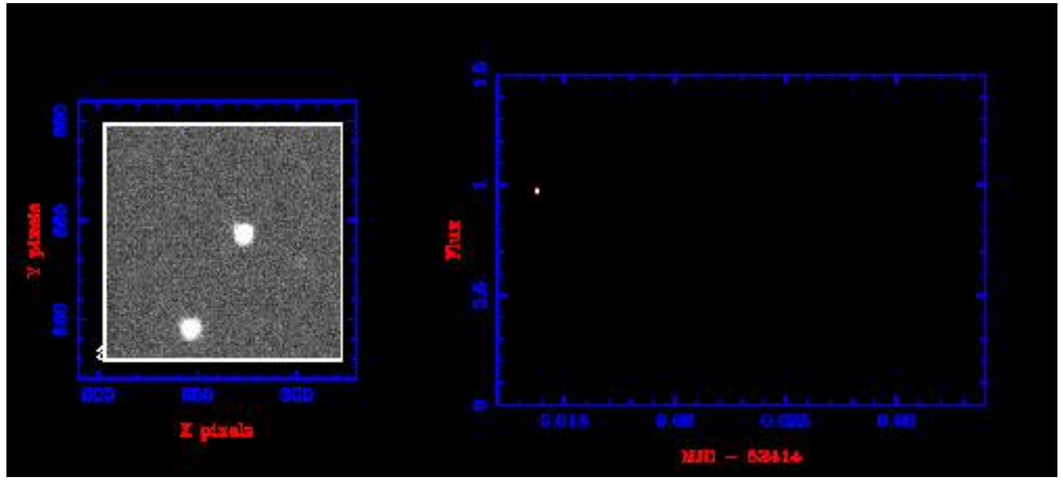
Han et al. (2002,2003)

Hot Subdwarfs

Photometry Lightcurves sdO/Bs



kepler.nasa.gov

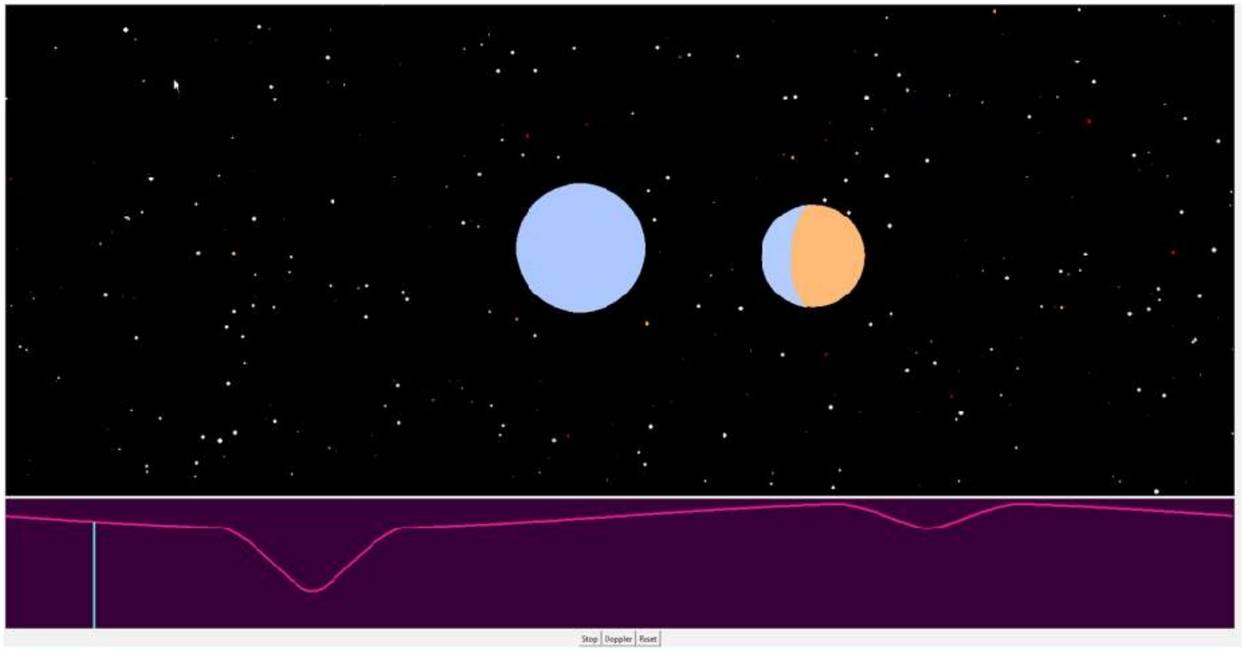


Vik Dhillon/Tom Marsh

- Photometry Filters: I, g, r, b

Hot Subdwarfs: sdB Binaries

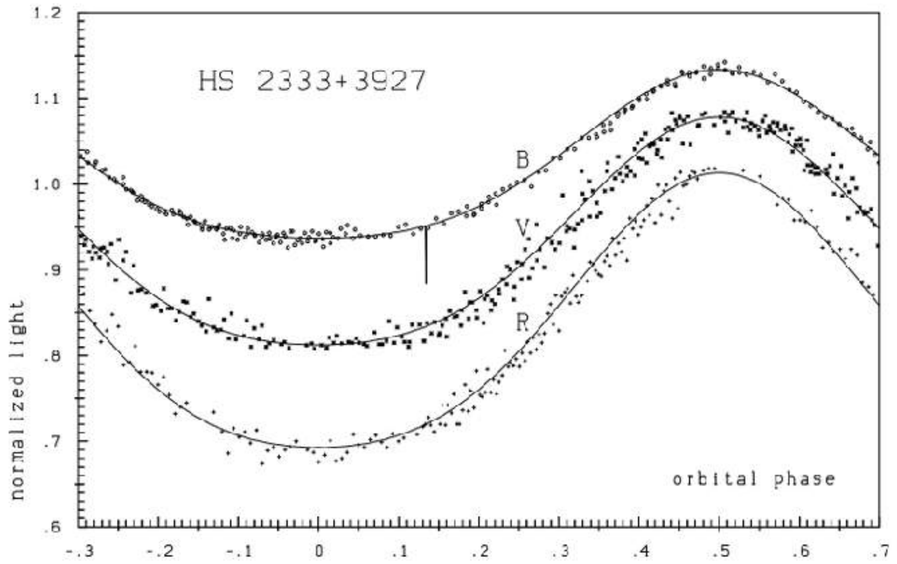
Factors affecting the lightcurves



- **Reflection effect**
- Variation in lightcurve due to irradiated hemisphere of the companion
- Companion: Moon or Venus like phases

Hot Subdwarfs: sdB Binaries

Factors affecting the lightcurves

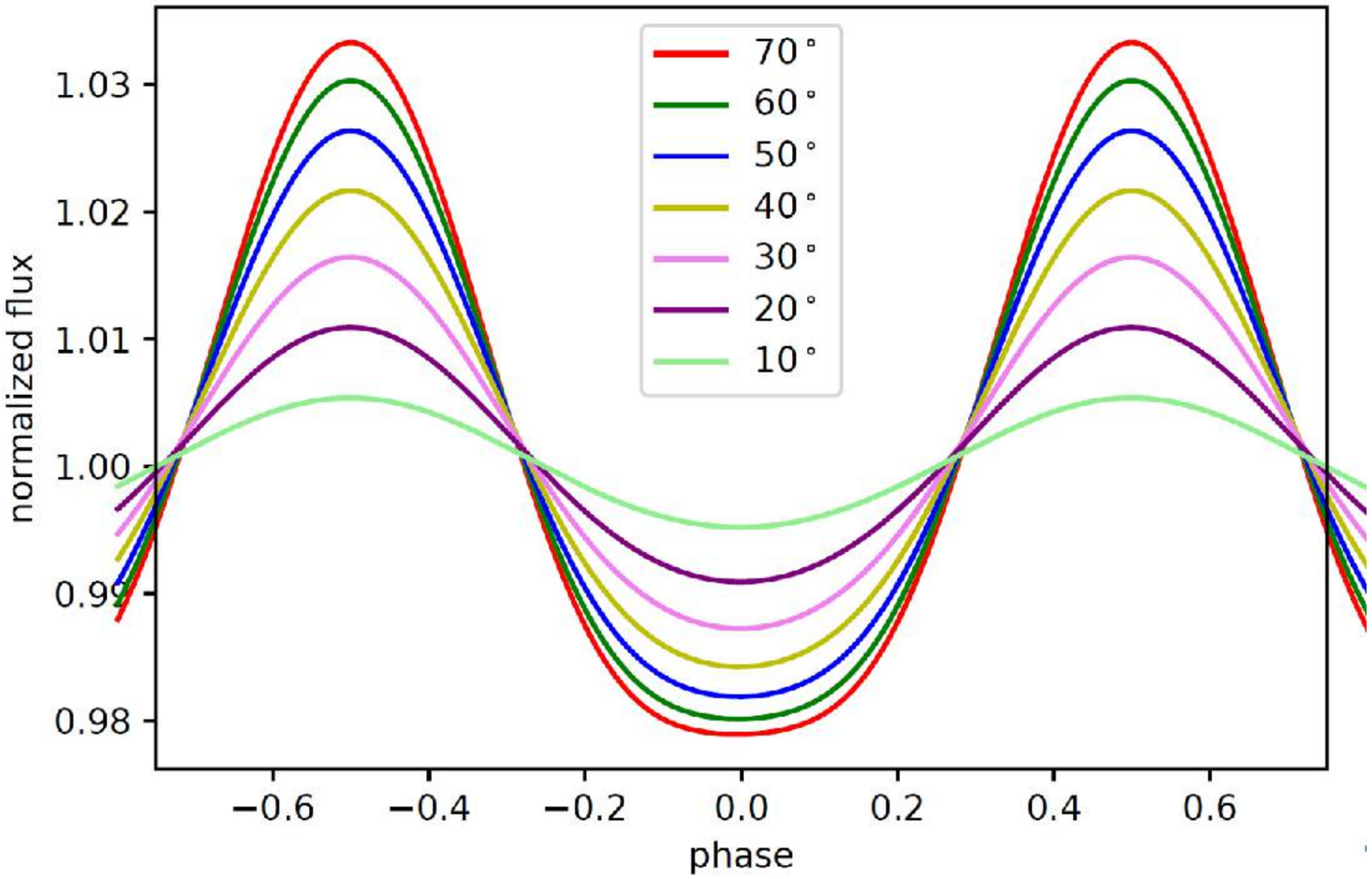


Different amplitudes in different bands

- **Reflection effect**
- Variation in lightcurve due to irradiated hemisphere of the companion
- Companion: Moon or Venus like phases
- Filters and Inclination affects the reflection effect

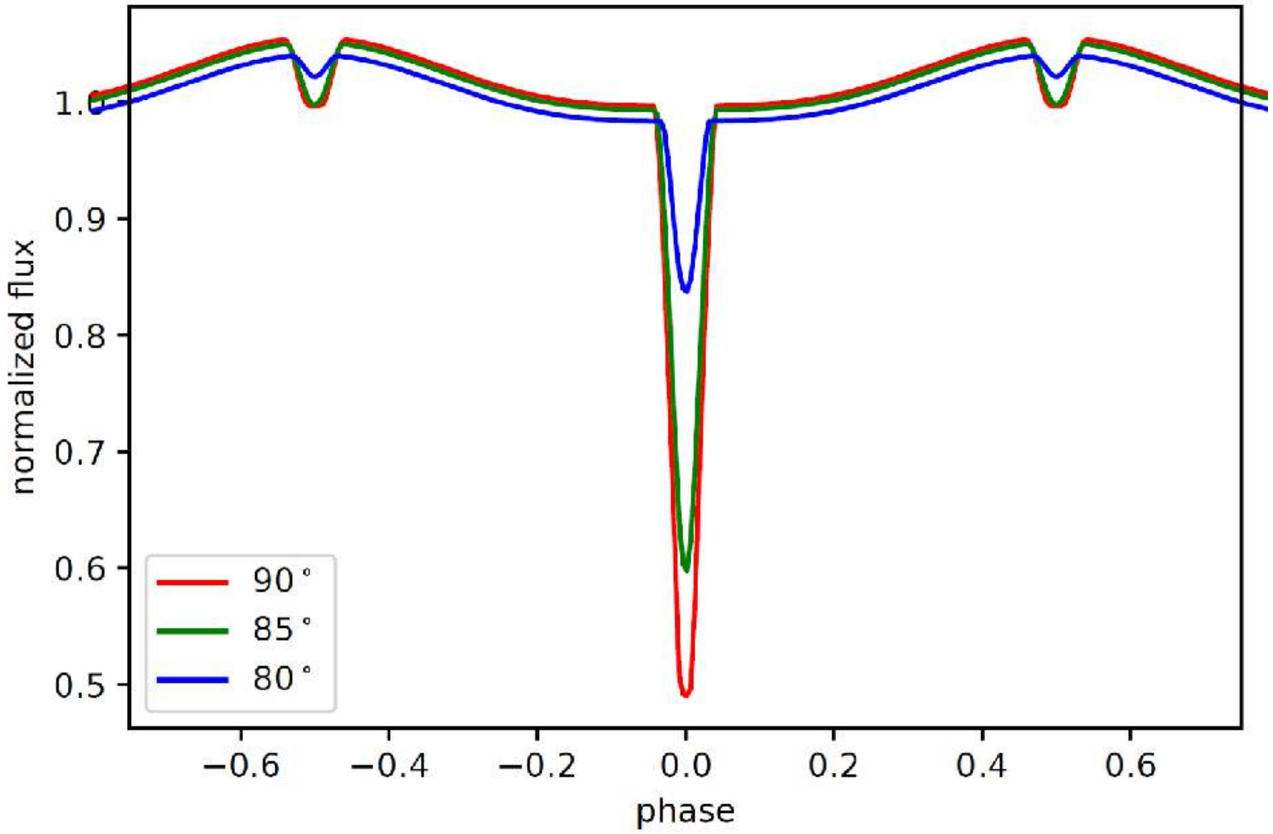
Hot Subdwarfs: sdB Binaries

Factors affecting the lightcurves: Reflection effect



Hot Subdwarfs: sdB Binaries

HW Vir Systems



- Inclination more than 70 degrees
- Average Period roughly 5 hours
- 200 known
- Eclipse duration > 15-20 minutes

Target Selection

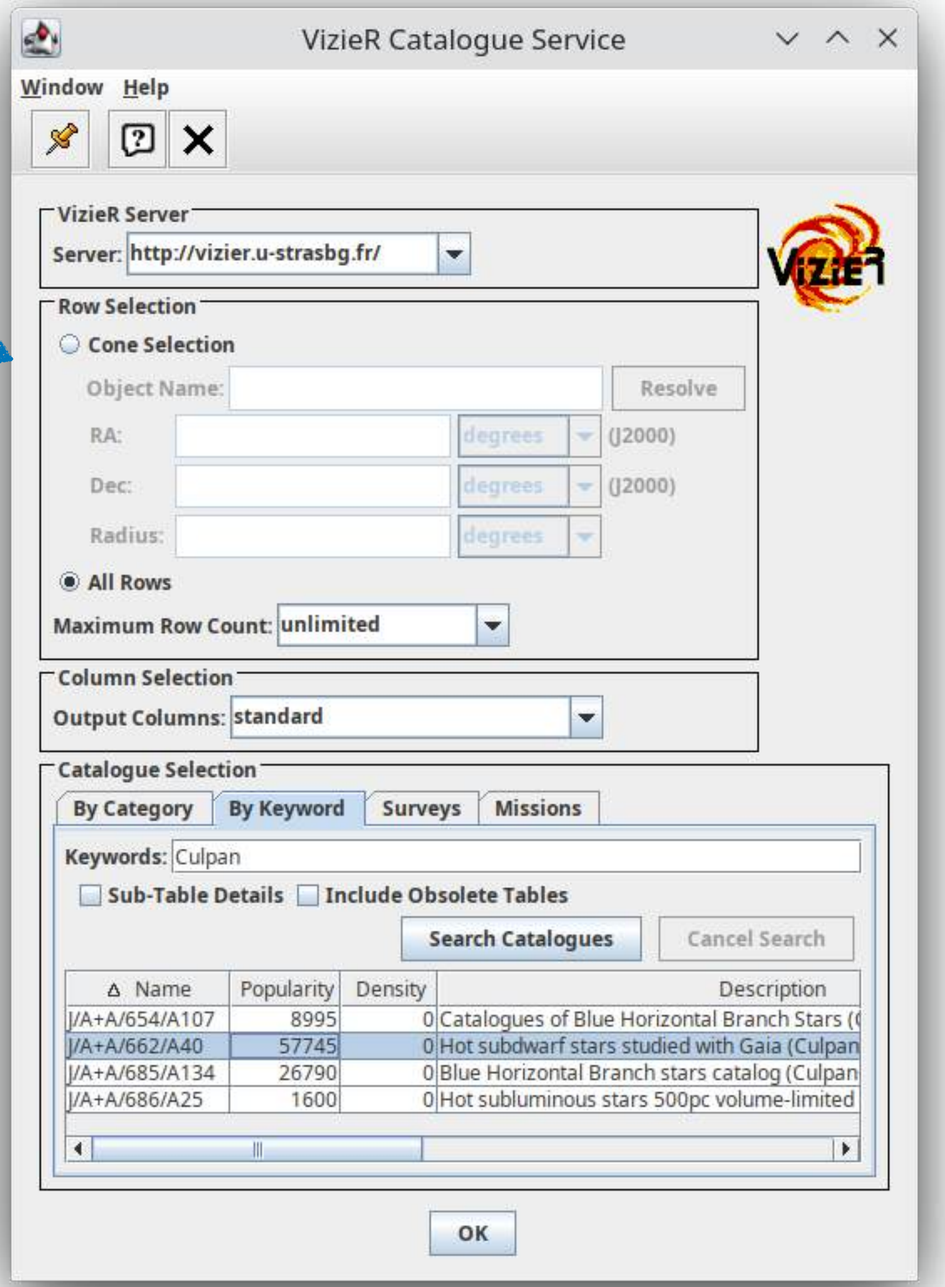
Target Selection

Crossmatch

1. Crossmatch **hot subdwarf** candidate catalog of *Culpan et al. 2022* (J_A+A_662_A40_hotsd - **61.585 targets**) with the catalog of the *Asteroid Terrestrial-Impact Last Alert System (ATLAS)* with **4.734.215 targets**

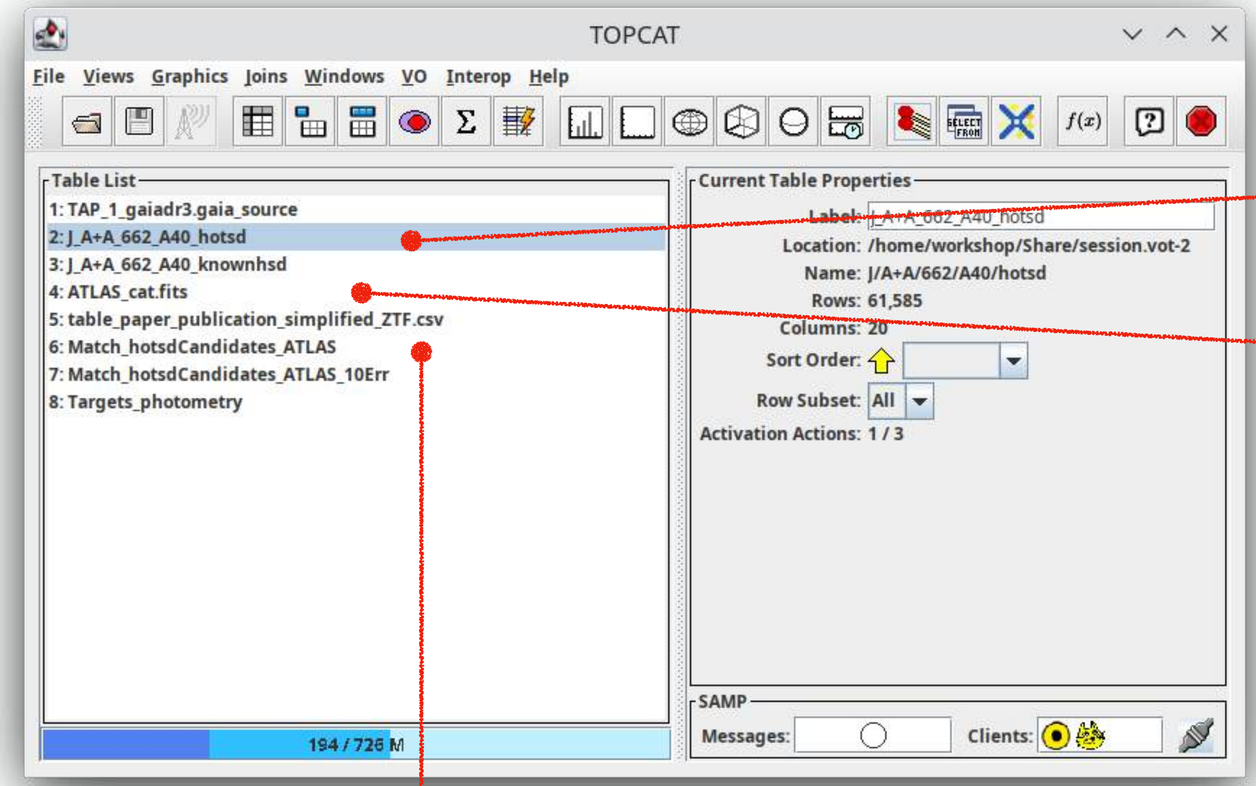
Measured Variables Stars

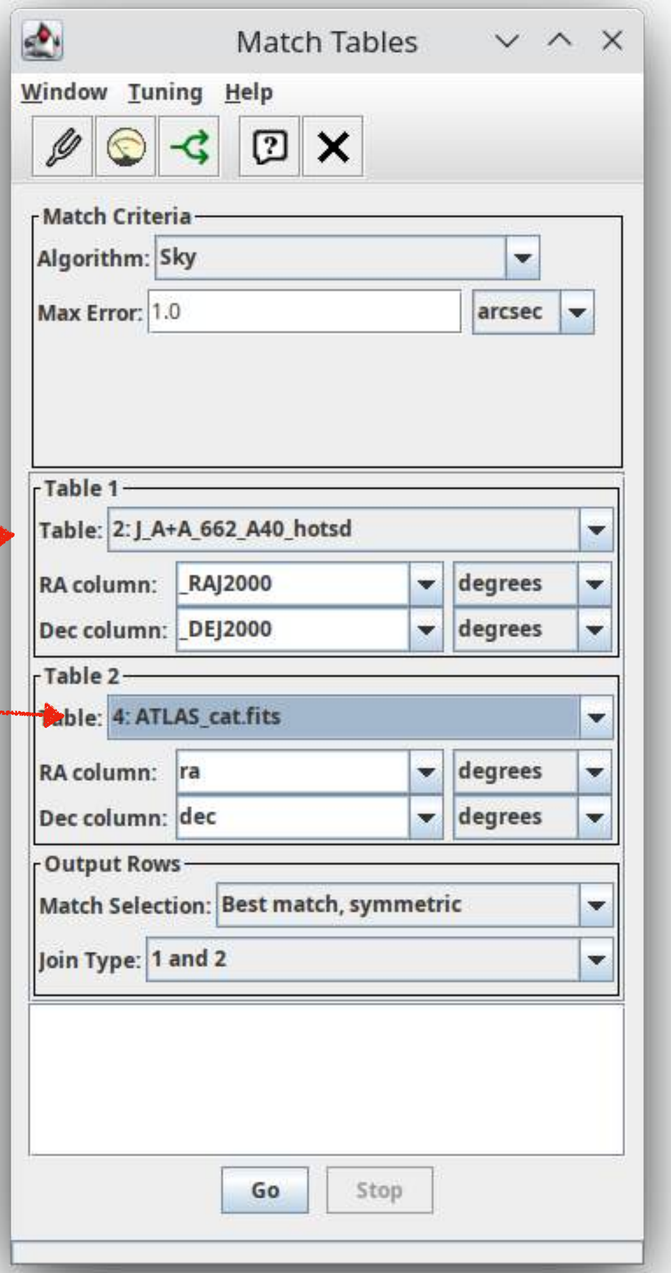
From Photometry Folder in the Virtual machine



Target Selection

Crossmatch

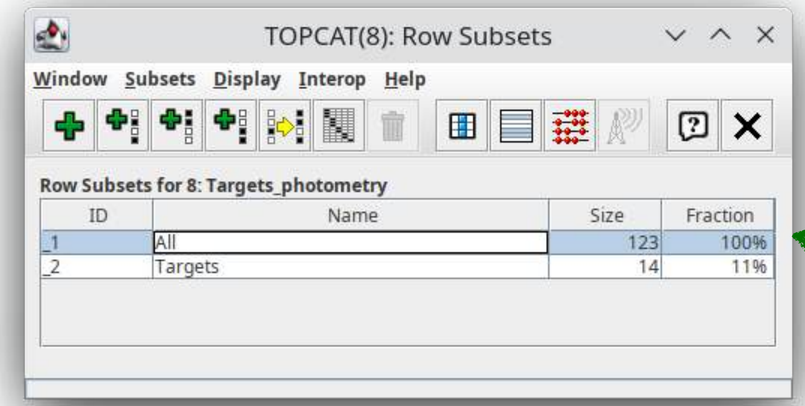




Gives 1241 Targets!

Target Selection

Selection criteria in TOPCAT

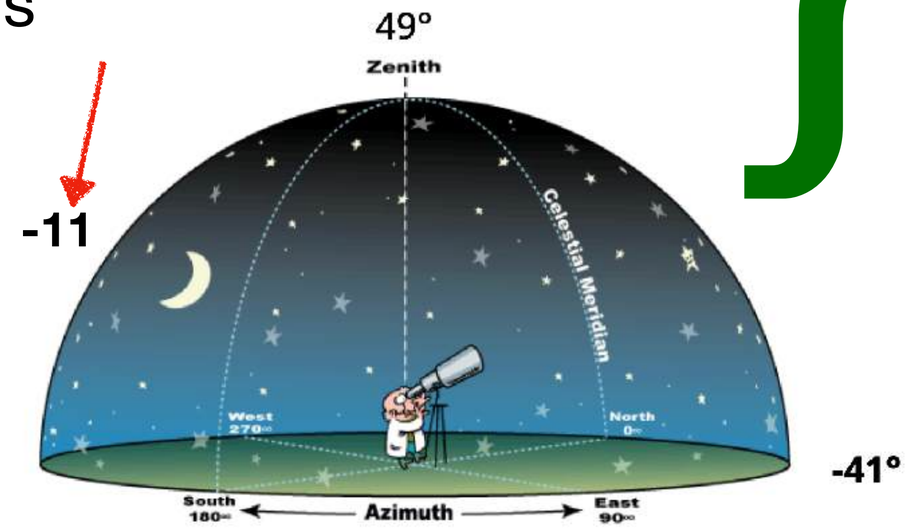


2. Select a series of cutting criteria:

- **apparent magnitude < 18.5 mag** (Perek minimum brightness)

- **RA > 240 and DEC > -11** (Sun is at ~150 deg RA at the moment -> center of the night is at 330 deg -> +/- 90 deg to both sides of the interval) OR **DEC > 60** for circumpolar stars

- **Period** from ATLAS greater than zero



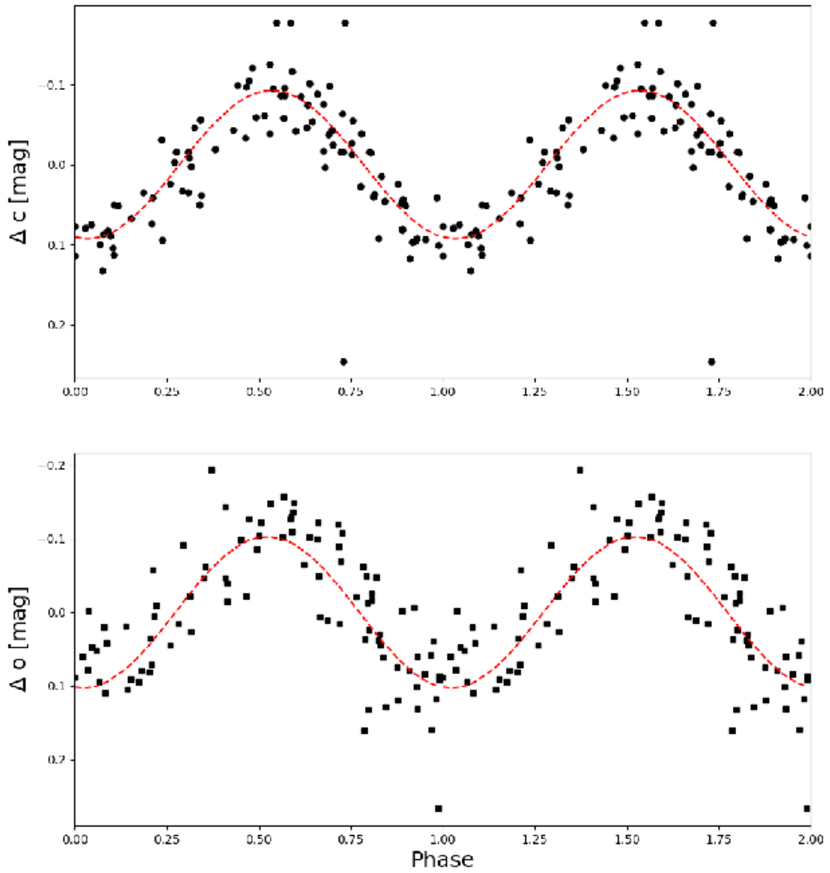
Leaves 123 Targets!

https://atlas.fallingstar.com/videolist.php

Target Selection

ATLAS Lightcurves

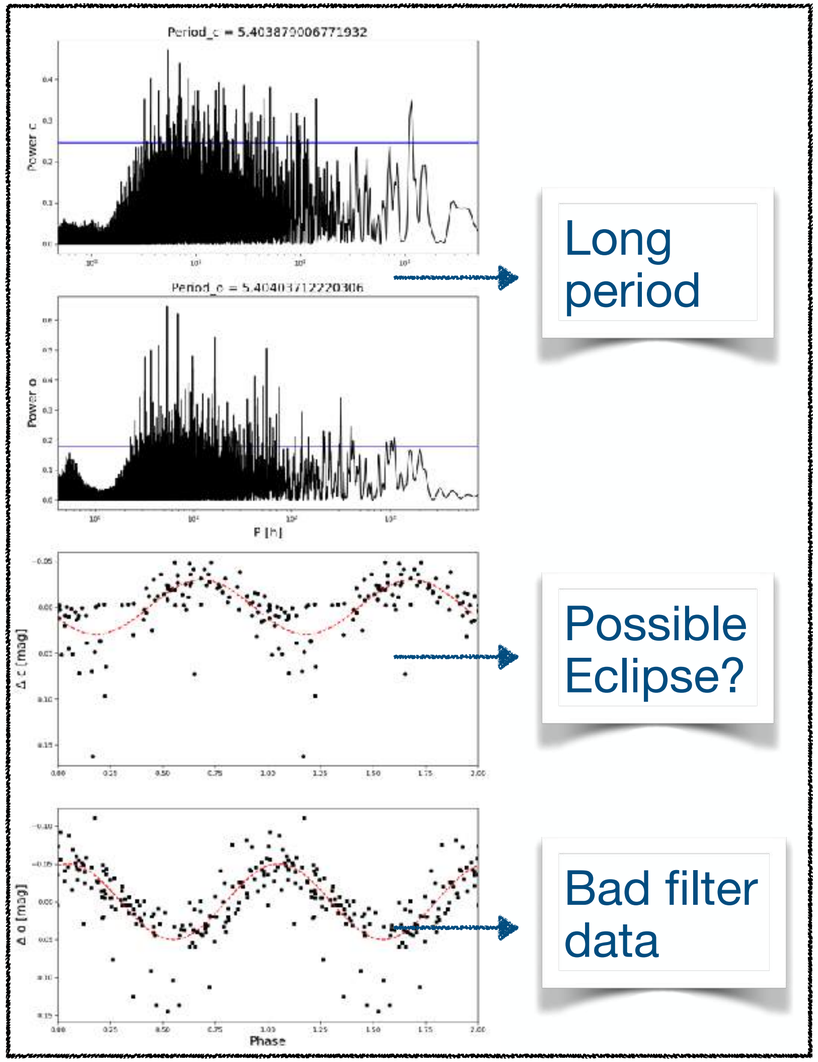
- Look at ATLAS lightcurves to search for short period targets that show reflection effect and eclipse
- Also take targets into account that have missing data
- Delete Garbage data altogether where no conclusion about HW nature can be drawn



→ **Leaves 14 Targets!**

Target Selection

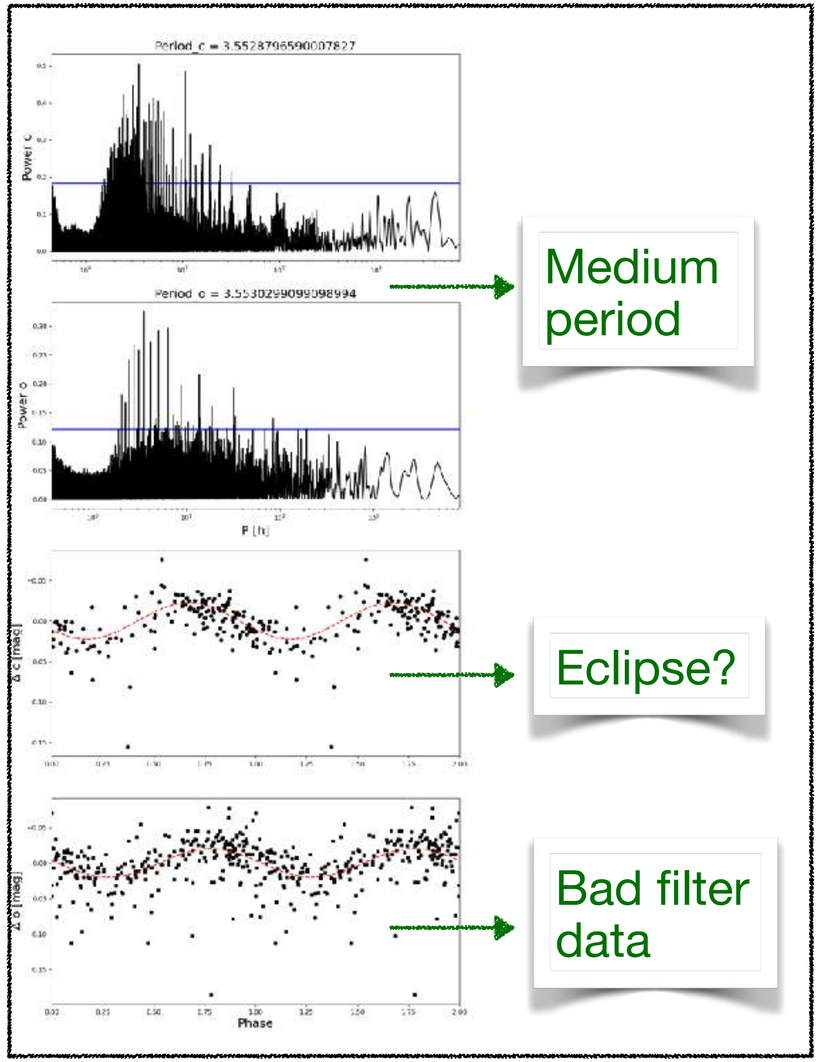
ATLAS Lightcurves



Long period

Possible Eclipse?

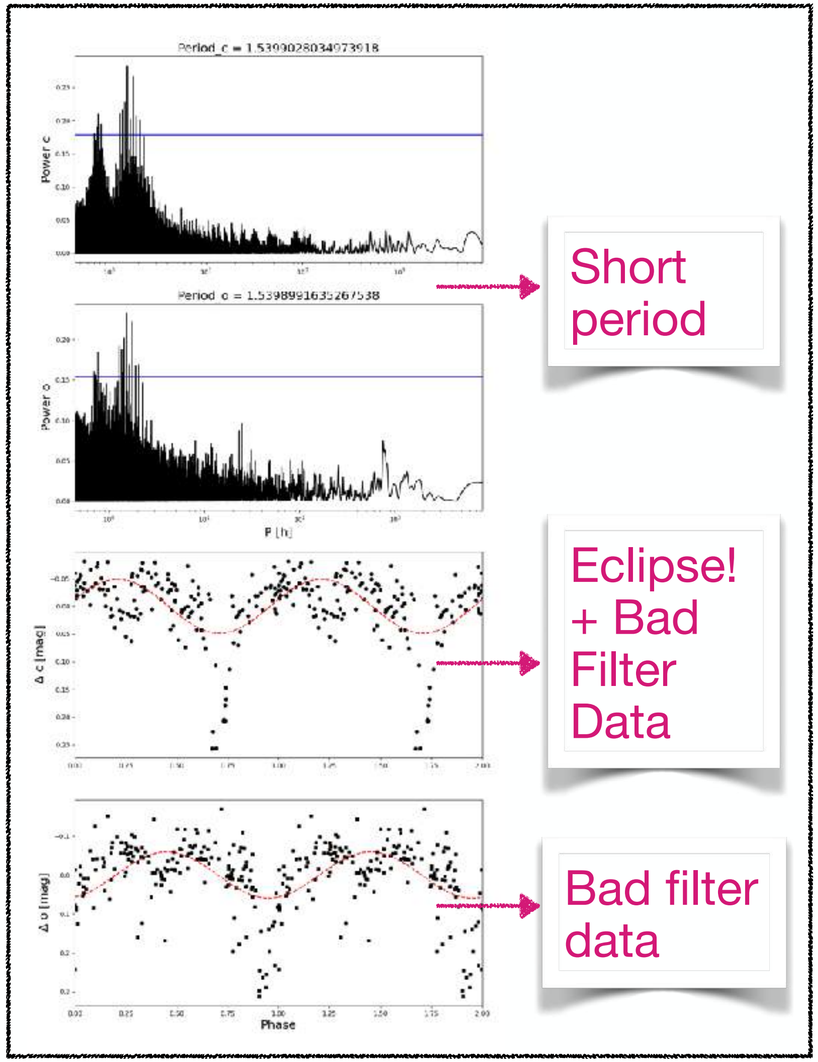
Bad filter data



Medium period

Eclipse?

Bad filter data



Short period

Eclipse! + Bad Filter Data

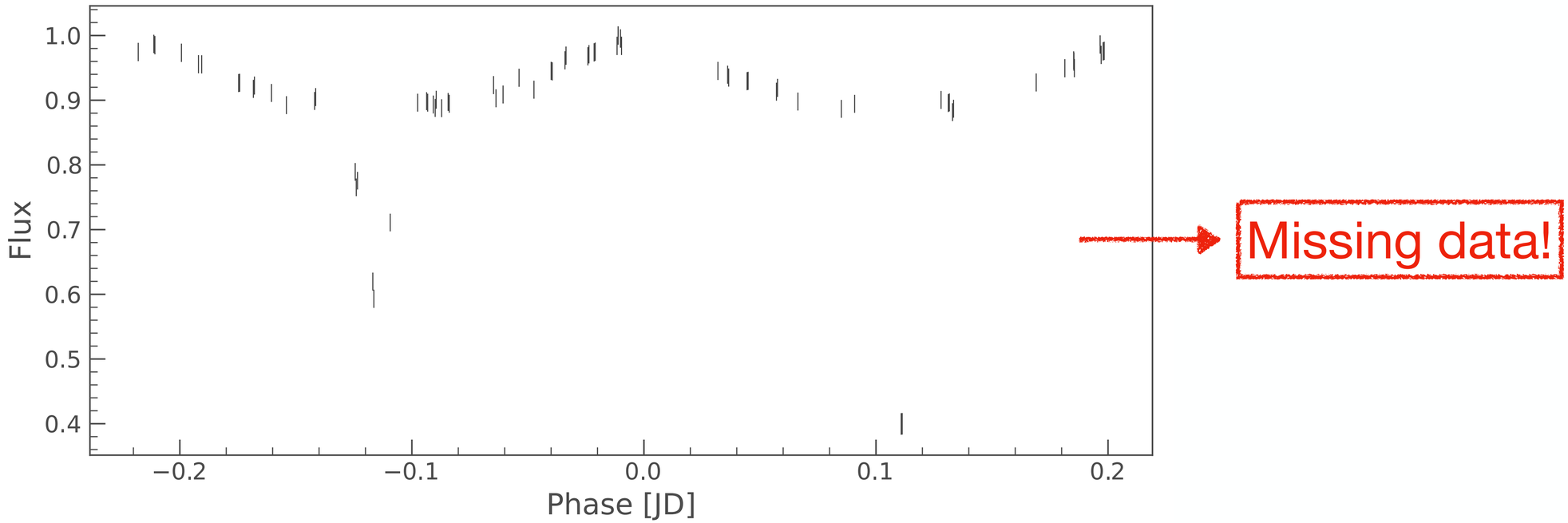
Bad filter data

https://www.redbubble.com/i/poster/The-Zwicky-Transient-Facility-Logo-by-Spacestuffplus/36307341.LVTDI

Target Selection

ZTF spectra

- For the left targets search the **high resolution ZTF spectra** (ZTF_interactive.ipynb file)
- The ones with big error bars or bad data coverage are particularly interesting



Target Selection

Final targets

	g-Mag.	ATLAS Period (days)
J296.1785+54.8285	15.75085	0.0701
J331.6658+32.7267	16.92184	0.22041
J018.4128+22.9608	16.61009	0.09337

1. **J296.1785+54.8285:** shows eclipse and no good data coverage especially in i and r filter
2. **J331.6658+32.7267:** shows eclipse in g filter but not in i filter
3. **J018.4128+22.9608:** faint target with bad i filter data coverage and short period

Other targets were: J283.0316+14.7630, J344.3341+49.6592, J294.7689+11.1822, J343.8249-03.1778

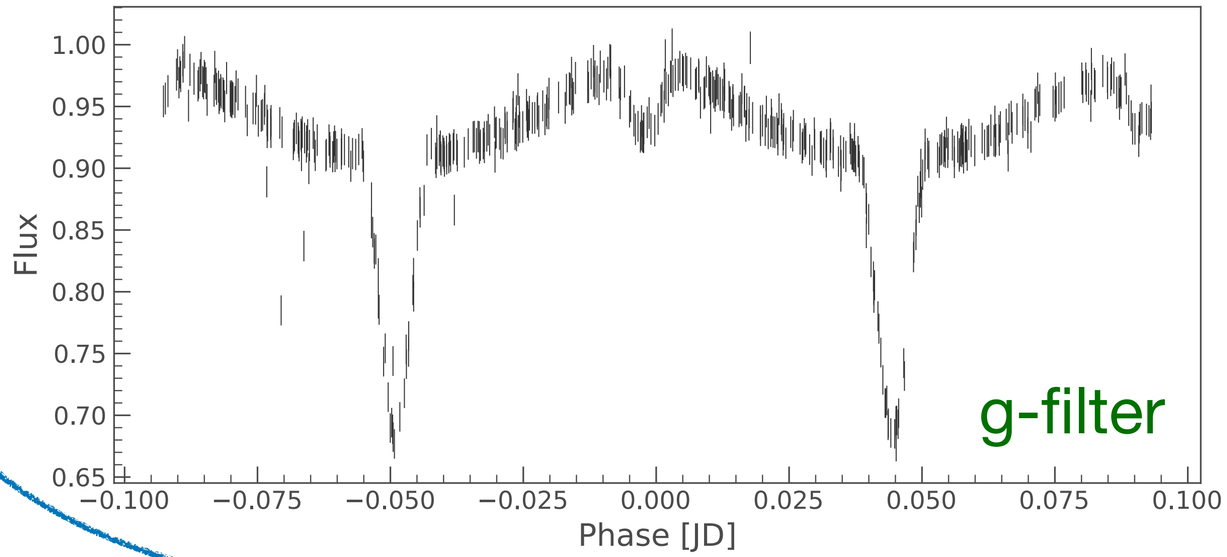
→ Not observed because of visibility, long period, magnitude or weak indication on eclipse

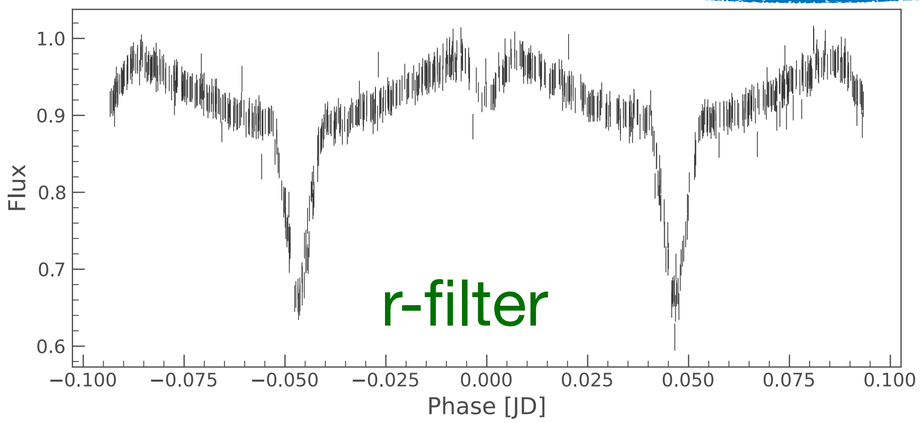
J018.4128+22.9608

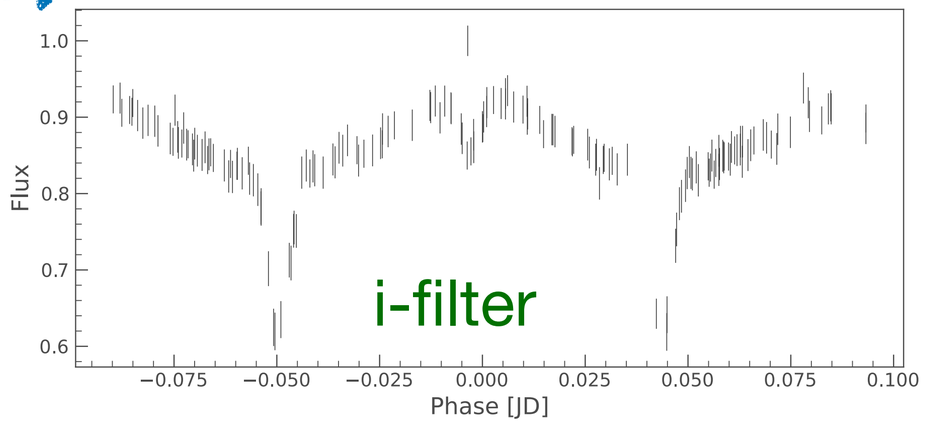
J018.4128+22.9608

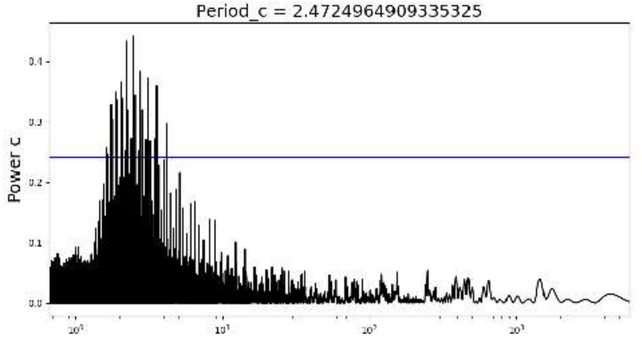
ZTF and ATLAS spectra

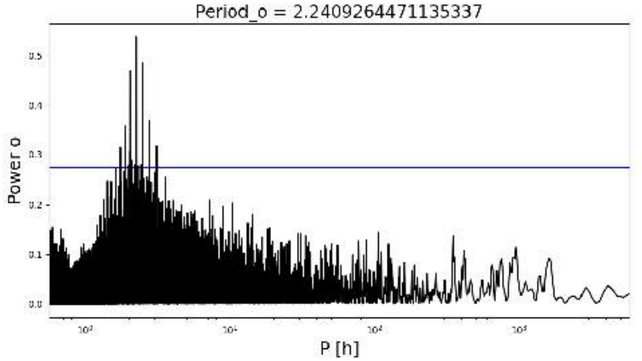
Filter	Wavelength (nm)
i’ (SDSS)	762.5
r’ (SDSS)	623.1
g’ (SDSS)	477.0

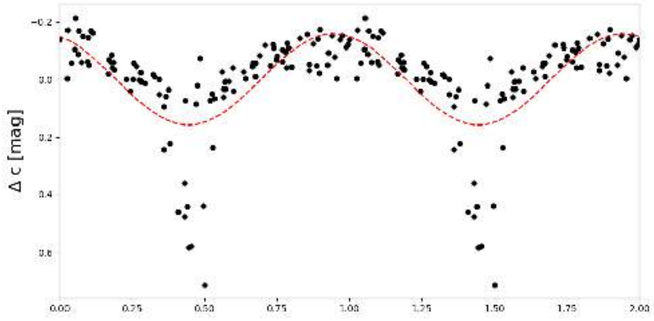


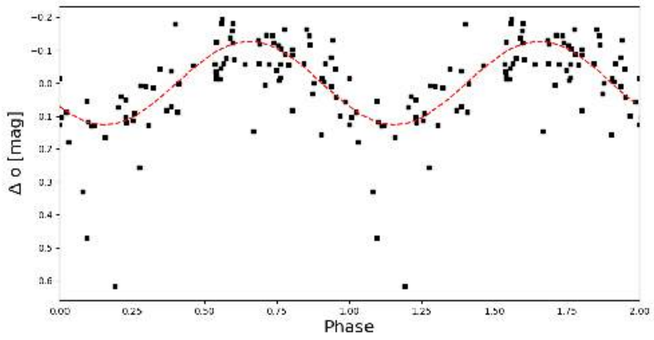






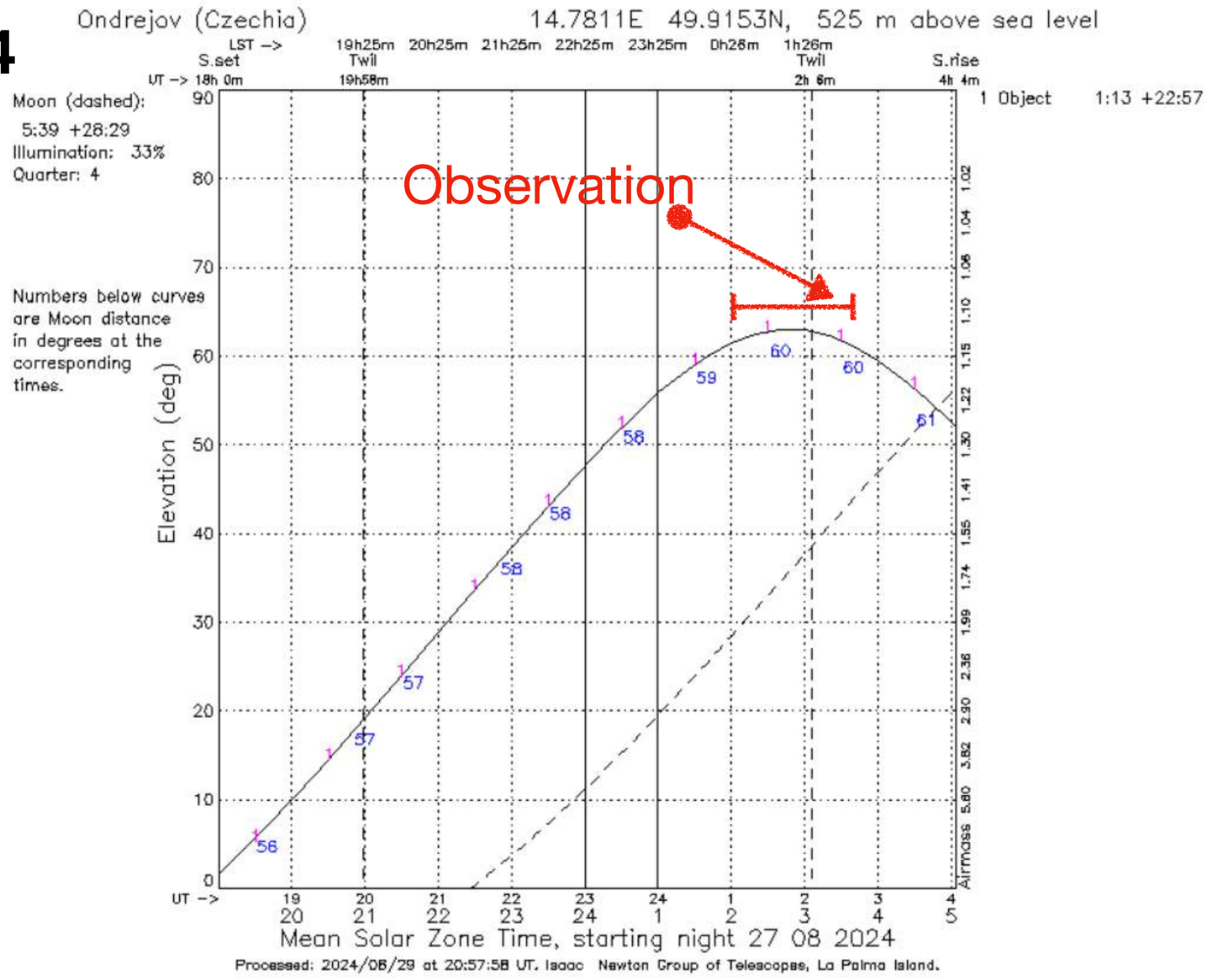






J018.4128+22.9608

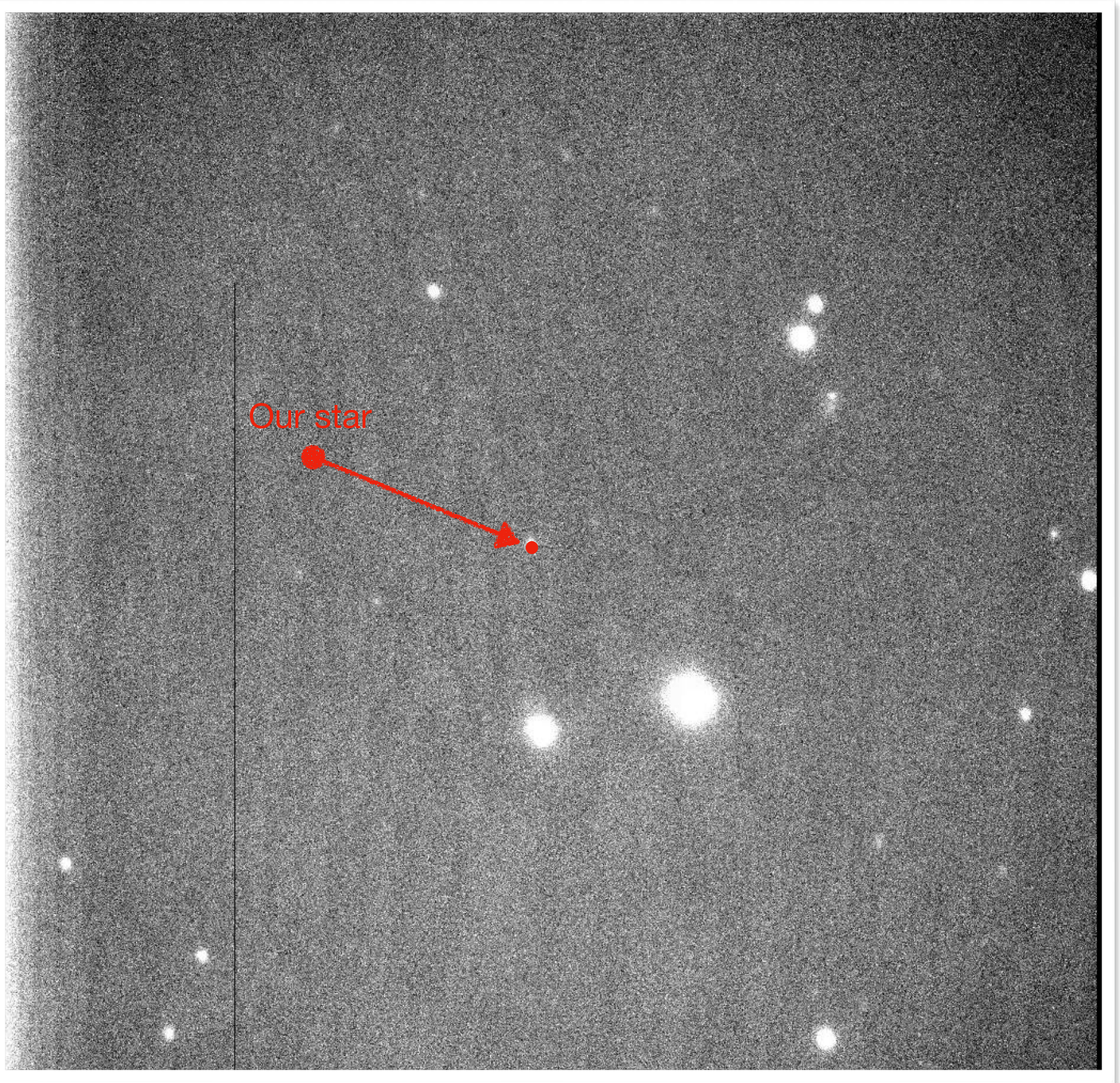
Visibility on night 27.08.2024



J018.4128+22.9608

Observation

- 23:51 UT to 2:51 UT
- **60s** exposures
- At the end of the observing night - Sunrise made some images brighter



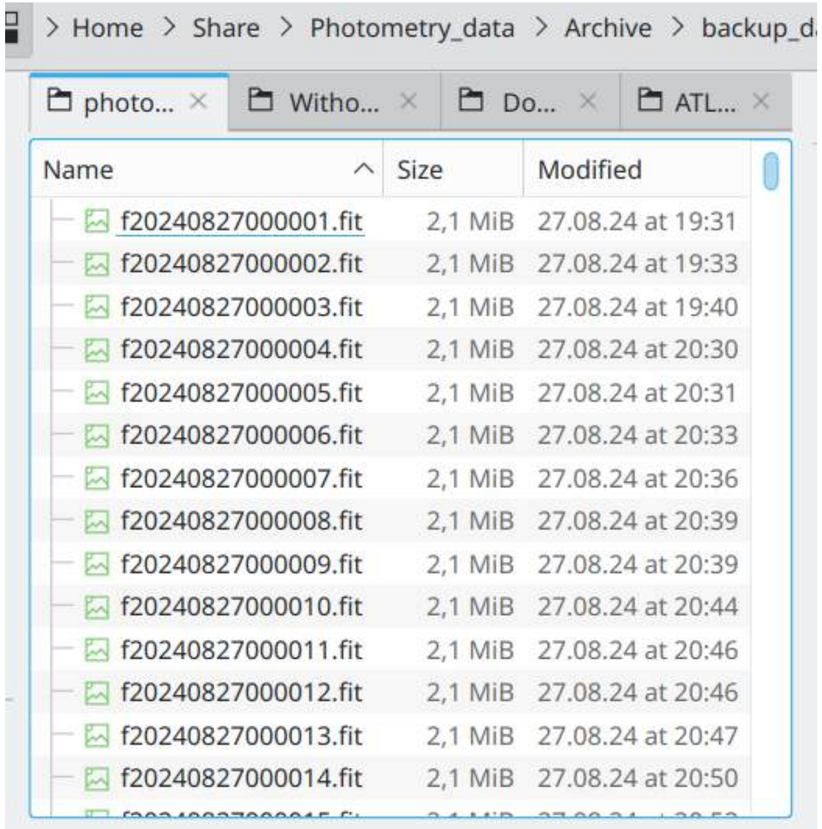
Reduction: J018.4128+22.9608

IRAF: Image Reduction and Analysis Facility

- **Packages:**
  - noao
  - daophot
  - imred
  - ccdred
  - digiphot

Reduction: J018.4128+22.9608

Step 1: Organising the files



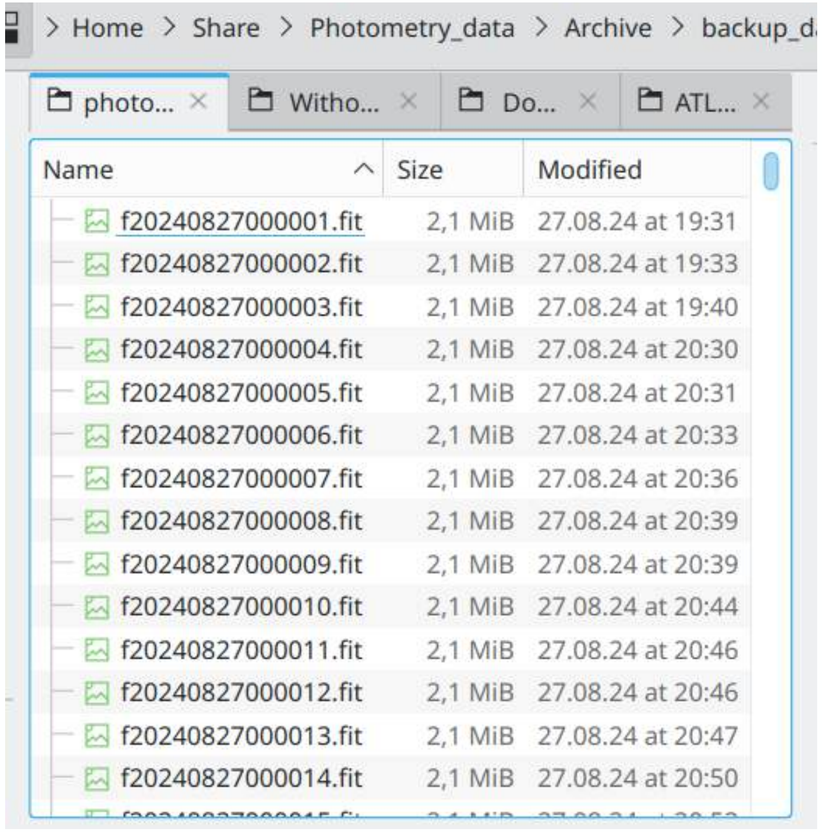
Perek 2-m data files

- **IRAF RECOMMENDED:**
  - *dark_frames_science*
  - *dark_frames_flats*
  - *flats*
  - *science_frames*

Make a copy of your data!

Reduction: J018.4128+22.9608

Step 1: Organising the files

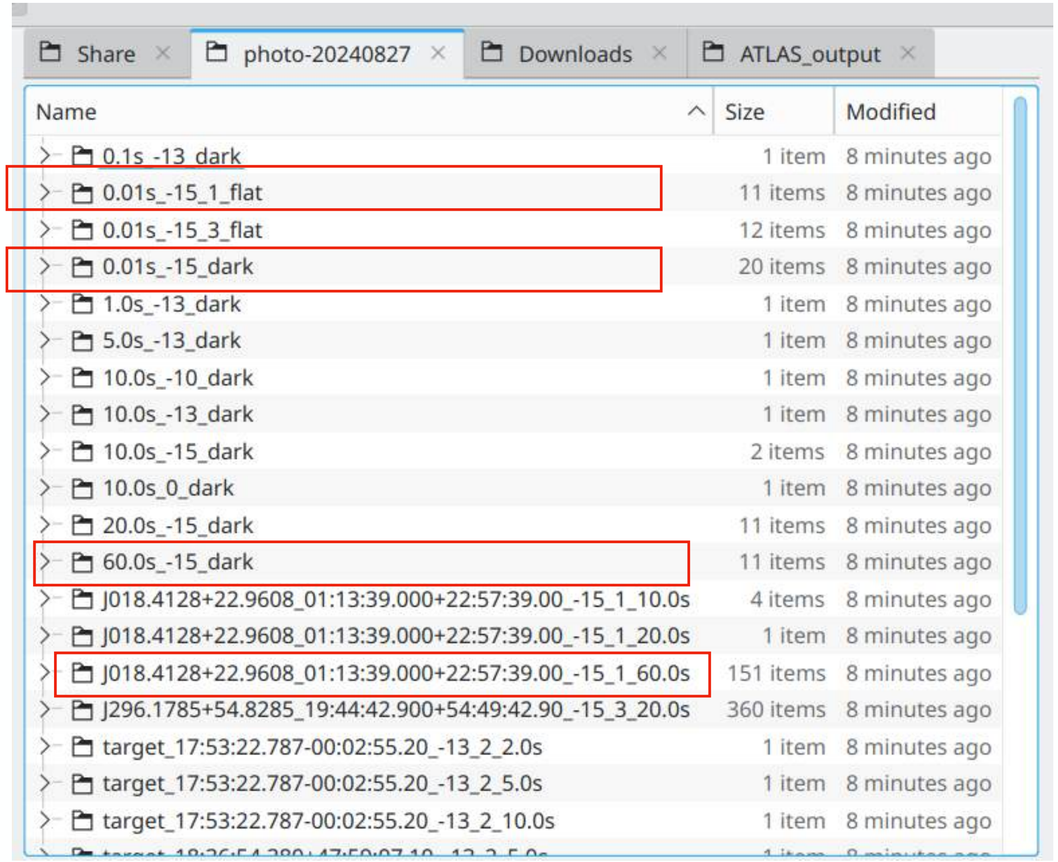


Perek 2-m data files

- **Challenges with the archive:**
  - Filenames: only date & frame no.
  - Test exposures: can be dark/flat/target
  - Different ccd temperatures
  - Science darks + Flat darks
  - May have more targets

Reduction: J018.4128+22.9608

Step 2: Organising the files



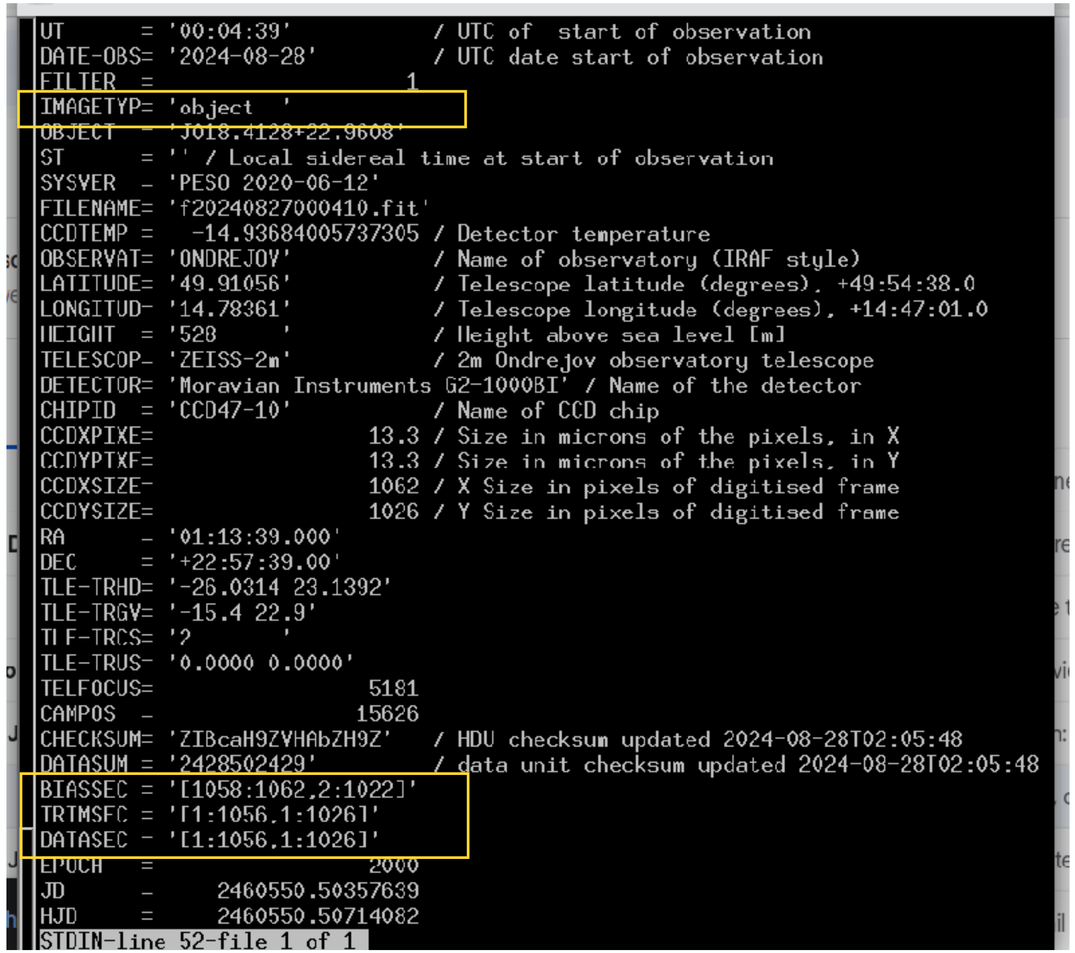
Sorted Perek 2-m data files

- **Workaround:**
  - *data_sorting_perek.py*

```
files = os.listdir()
files = [item for item in files if isinstance(item, str) and item.endswith('.fit')]

files.sort()

# Main Loop to sort out file and darks
for file in files:
    hdul = fits.open(file)
    head = hdul[0].header
    object_name = head['OBJECT']
    if head['IMAGETYP'].strip().lower() == 'dark':
        if dark_avail != 0:
            if not os.path.isdir(f'{head["EXPTIME"]}s_{round(head["CCDTEMP"])}_dark'):
                os.mkdir(f'{head["EXPTIME"]}s_{round(head["CCDTEMP"])}_dark')
            shutil.move(file,os.path.join(os.getcwd(),f'{head["EXPTIME"]}s_{round(head["CCDTEMP"])}_dark'))
    if head['IMAGETYP'].strip().lower() == 'flat':
        if flat_avail != 0:
            if not os.path.isdir(f'{head["EXPTIME"]}s_{round(head["CCDTEMP"])}_{head["FILTER"]}_flat'):
                os.mkdir(f'{head["EXPTIME"]}s_{round(head["CCDTEMP"])}_{head["FILTER"]}_flat')


            shutil.move(file,os.path.join(os.getcwd(),f'{head["EXPTIME"]}s_{round(head["CCDTEMP"])}_{head["FILTER"]}_flat'))

    else:
        if head['IMAGETYP'].strip().lower() == 'target':
            if object_name != '':
                if not os.path.isdir(f'{object_name}_{head["RA"]}{head["DEC"]}_{round(head["CCDTEMP"])}_{head["FILTER"]}_{head["EXPTIME"]}s'):
                    print(object_name)
                    os.mkdir(f'{object_name}_{head["RA"]}{head["DEC"]}_{round(head["CCDTEMP"])}_{head["FILTER"]}_{head["EXPTIME"]}s')
                shutil.move(file,os.path.join(os.getcwd(),f'{object_name}_{head["RA"]}{head["DEC"]}_{round(head["CCDTEMP"])}_{head["FILTER"]}_{head["EXPTIME"]}s'))
            else:
                if not os.path.isdir(f'{head["IMAGETYP"]}_{head["RA"]}{head["DEC"]}_{round(head["CCDTEMP"])}_{head["FILTER"]}_{head["EXPTIME"]}s'):
                    print(head["RA"],head["DEC"])
                    os.mkdir(f'{head["IMAGETYP"]}_{head["RA"]}{head["DEC"]}_{round(head["CCDTEMP"])}_{head["FILTER"]}_{head["EXPTIME"]}s')
                shutil.move(file,os.path.join(os.getcwd(),f'{head["IMAGETYP"]}_{head["RA"]}{head["DEC"]}_{round(head["CCDTEMP"])}_{head["FILTER"]}_{head["EXPTIME"]}s
```

Reduction: J018.4128+22.9608

Step 2: Check your data with ds9 and Fixing Header



Fixing headers

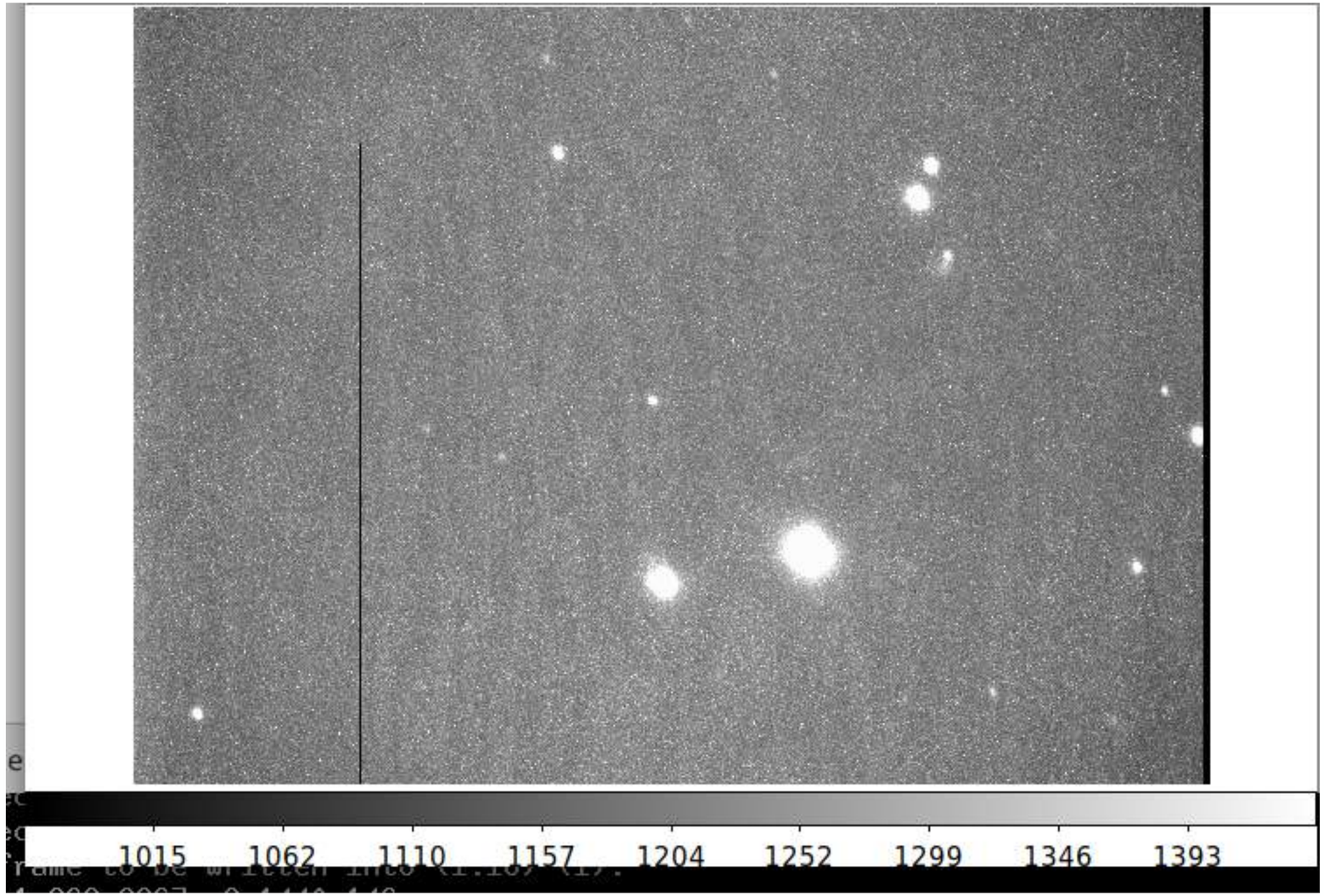
- **Science frames:**
  - Throw frames: Noisy
  - Make a list

    ls *.fit > list_science

- **Fix headers:**
  - Flats, Darks, Science frames
  - Science frames: ’IMAGETYPE’:’target’ -> ’object’

Reduction: J018.4128+22.9608

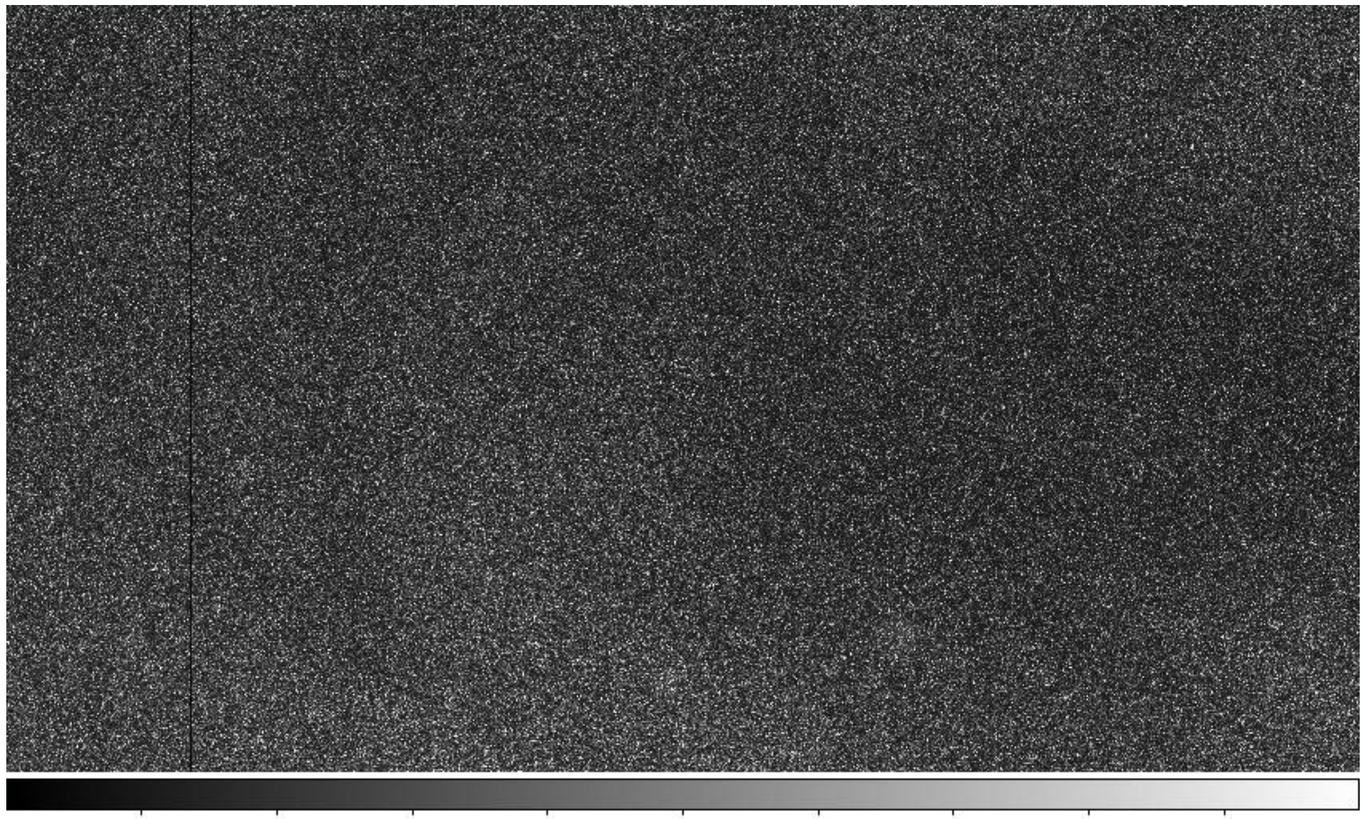
Step 2: Check your data with ds9 and Fixing Header



Reduction: J018.4128+22.9608

Step 3: Creating Master Dark and Master Flat: *epar imcombine*

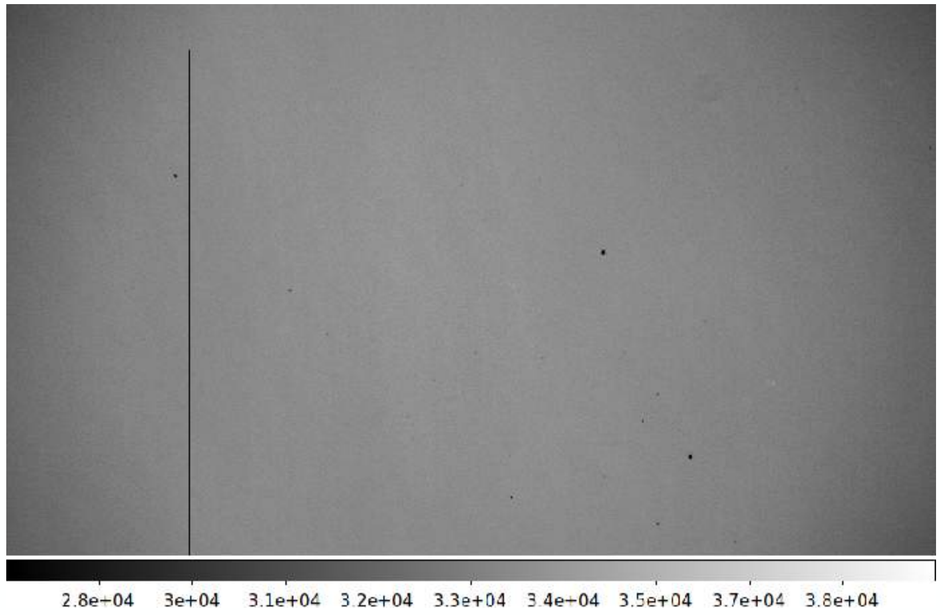
- Make a list and pass it to ***imcombine:*** frames



Reduction: J018.4128+22.9608

Step 3: Creating Master Dark and Master Flat: *epar imcombine*

- **Master Flat:** frames
- Make a list and pass it to ***imcombine :*** Combined Flat (CF)
  - Subtract **DF** from **CF** using ***epar ccdproc*** -> Master Flat (MF)

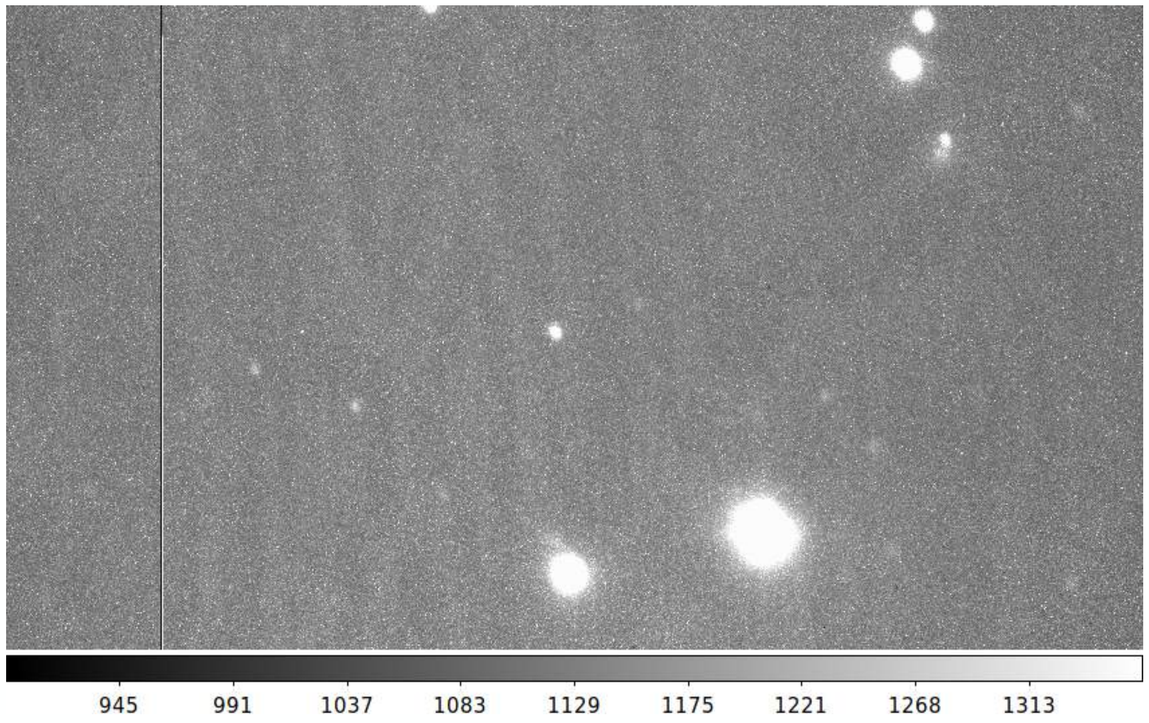


MF

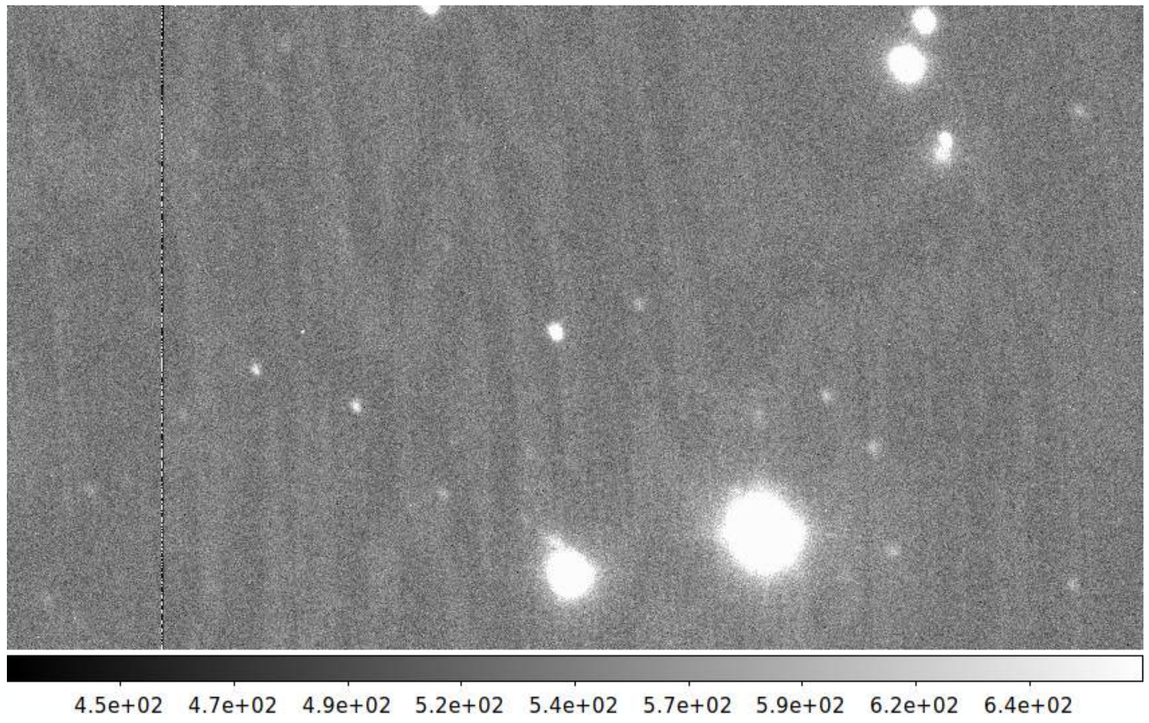
Reduction: J018.4128+22.9608

Step 4: Correct Science Frames: *epar ccdproc*

- Using DS and MF -> Keep the Dark & Flat corrections to **‘yes’**



Uncorrected



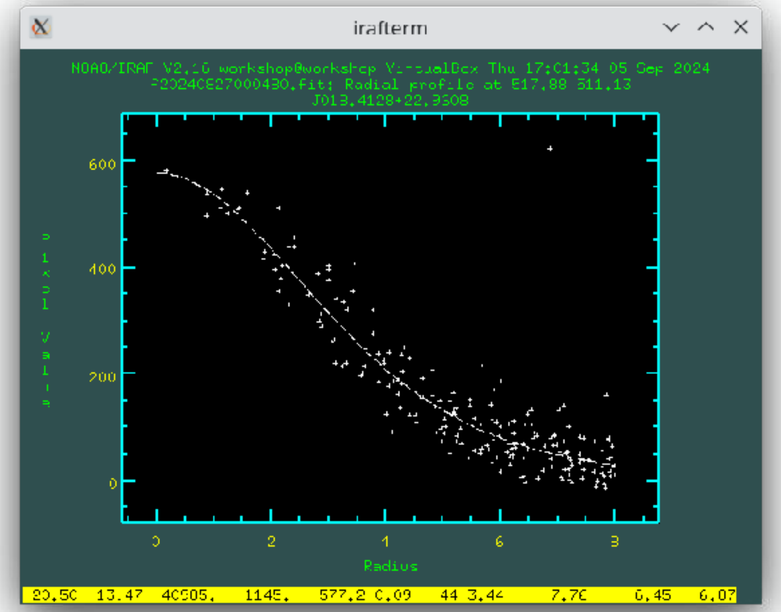
Corrected

Save the list of corrected frames!

Photometry: J018.4128+22.9608

Step 1: Find the stars co-ordinates: *epar daofind*

- Choose a middle frame: ***imexamine*** : Note **FWHM** & **SKY**
  - Pass **FWHM** to ***daofind:*** Output***:*** ***.fit.coo.1**



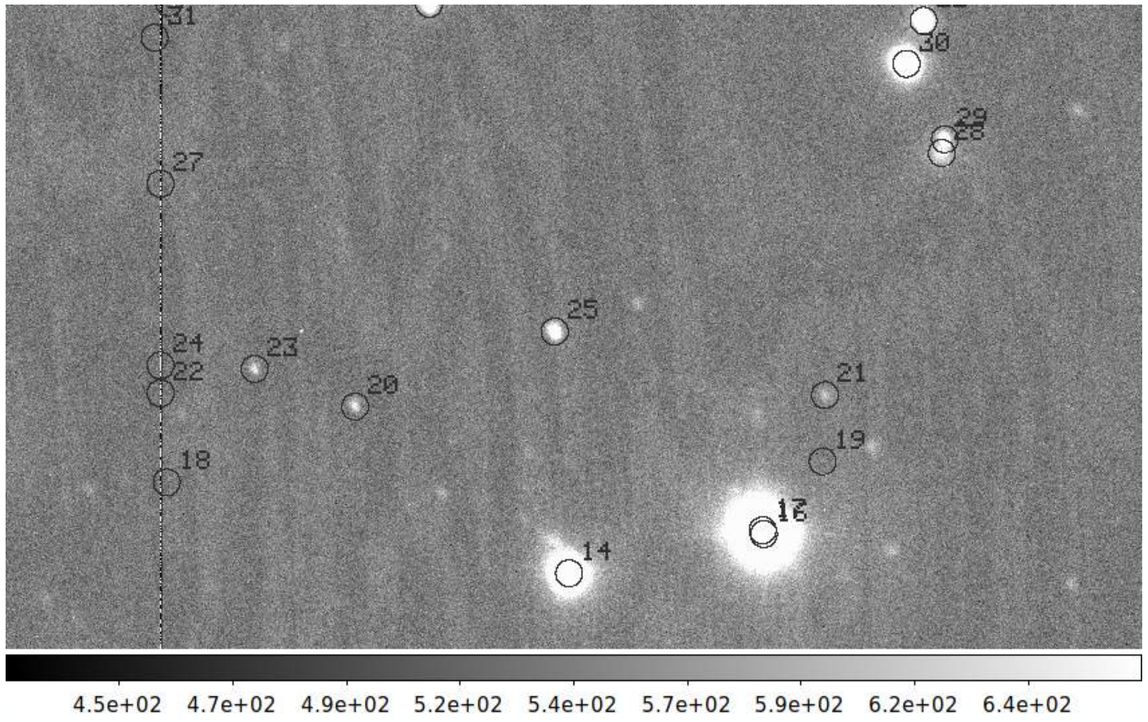
FWHM & Sky

Save the columns into **coordsI** file

Photometry: J018.4128+22.9608

Step 2: Display the stars : *epar tvmark*

- Open the same file used for ***daofind***: Pass **coordsl** & **Radii** to ***tvmark***



Star-coordinates

Note down the star number

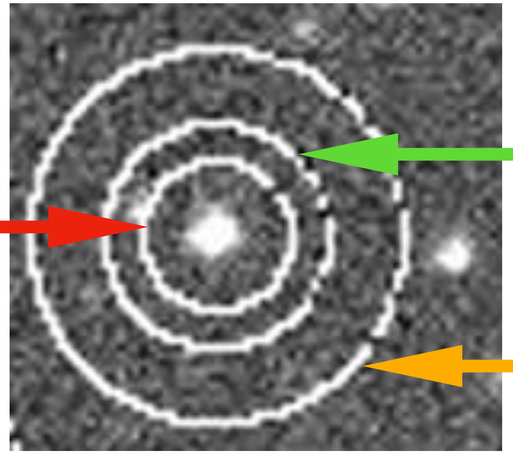
Photometry: J018.4128+22.9608

Step 3: Extracting Relative Magnitudes : *epar phot*

- Use Annulus,Dannulus, SkyValue within ***phot***: Output: **.mag.1** files

Aperture:

Flux of the star measured



Annulus:

Where the Backgorund counts start

Dannulus:

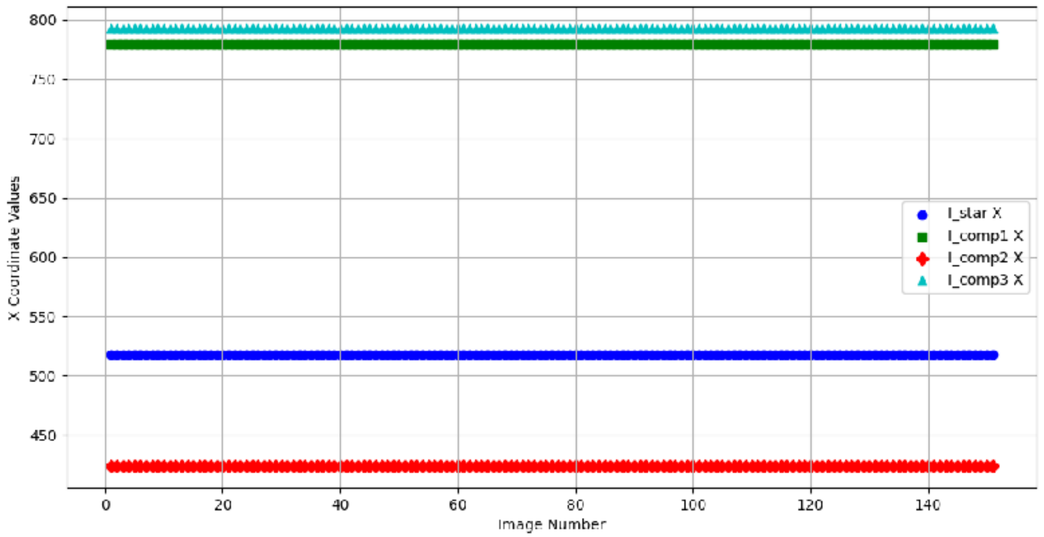
Width of the ring to count background

txdump @Imag_files fields=ID,XCENTER,YCENTER,FLUX,MAG,MERR > I_mags

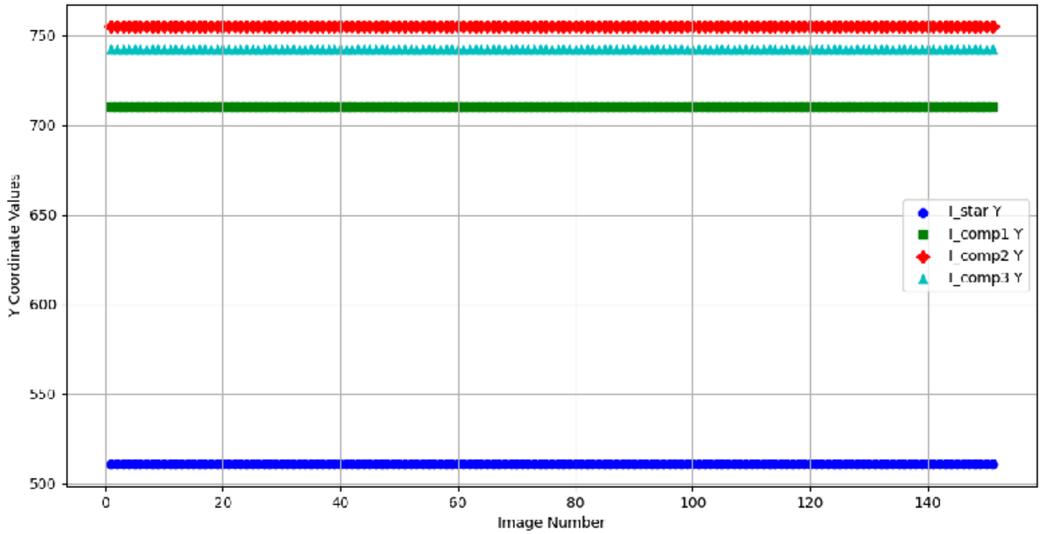
Photometry: J018.4128+22.9608

Step 4: Photometry into separate file :

- *! awk '{if ($1==25) print;}' I_mags > I_star*
- *! awk '{if ($1==30) print;}' I_mags > I_comp1*



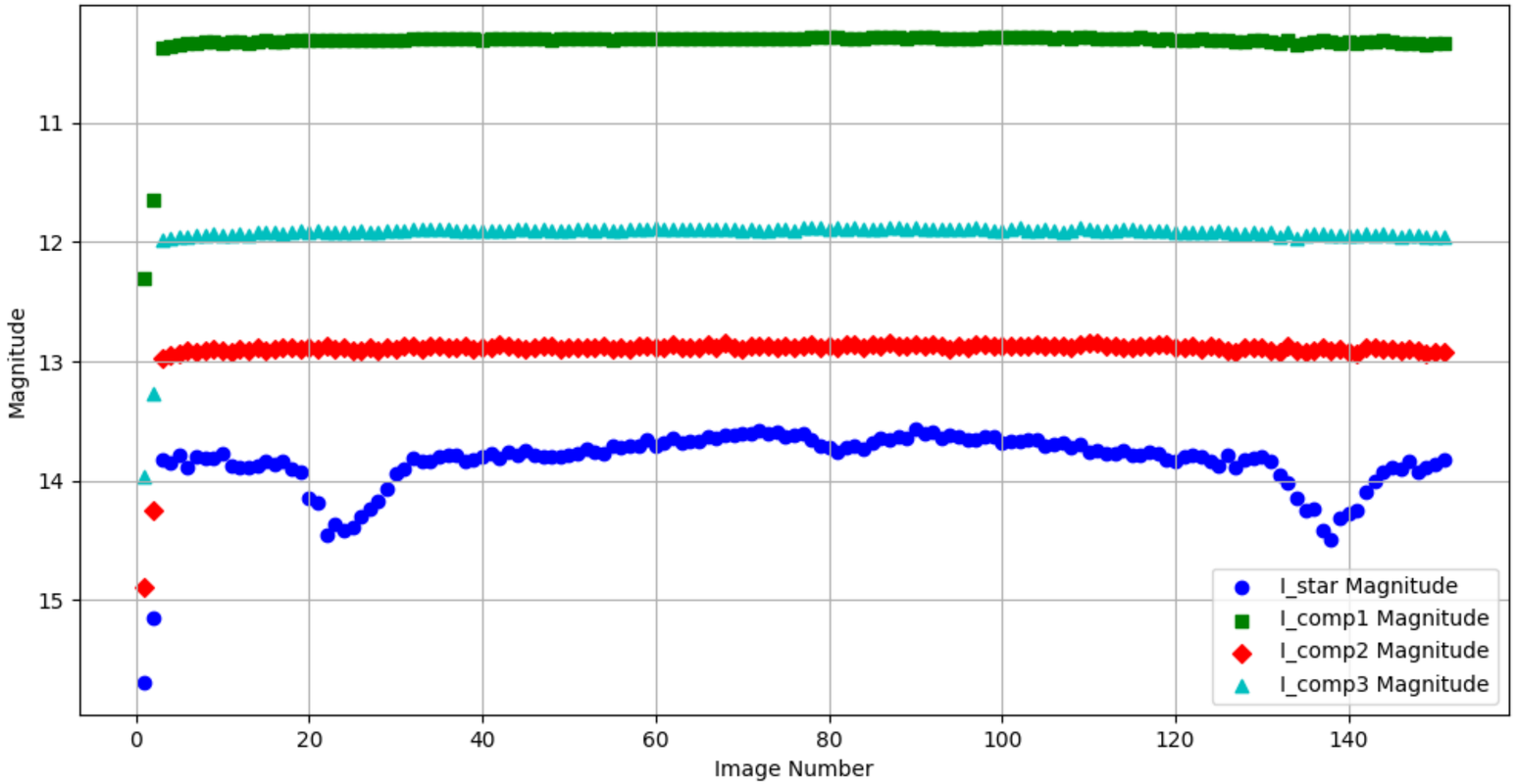
X-Tracking



Y-Tracking

Photometry: J018.4128+22.9608

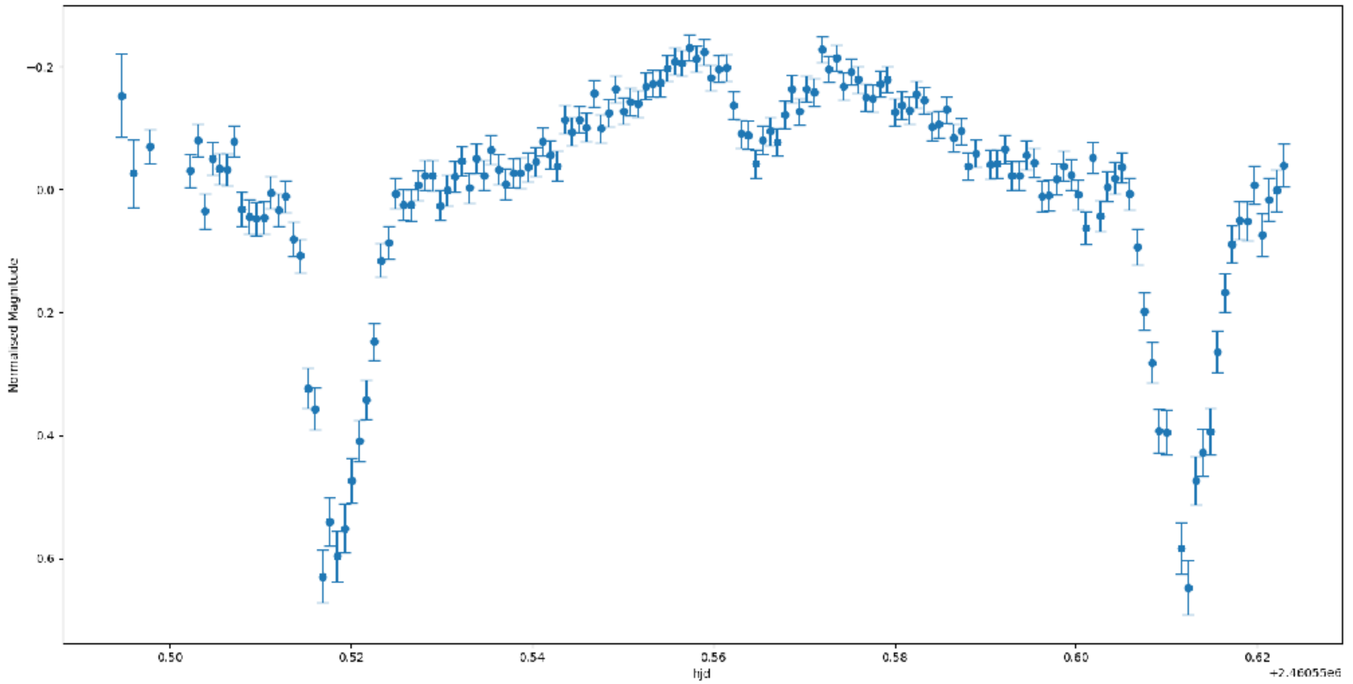
Step 5: Photometry - Magnitudes :



Mean magnitude of each star on the terminal

Photometry: J018.4128+22.9608

Step 5: setjd & Generate the lightcurve:

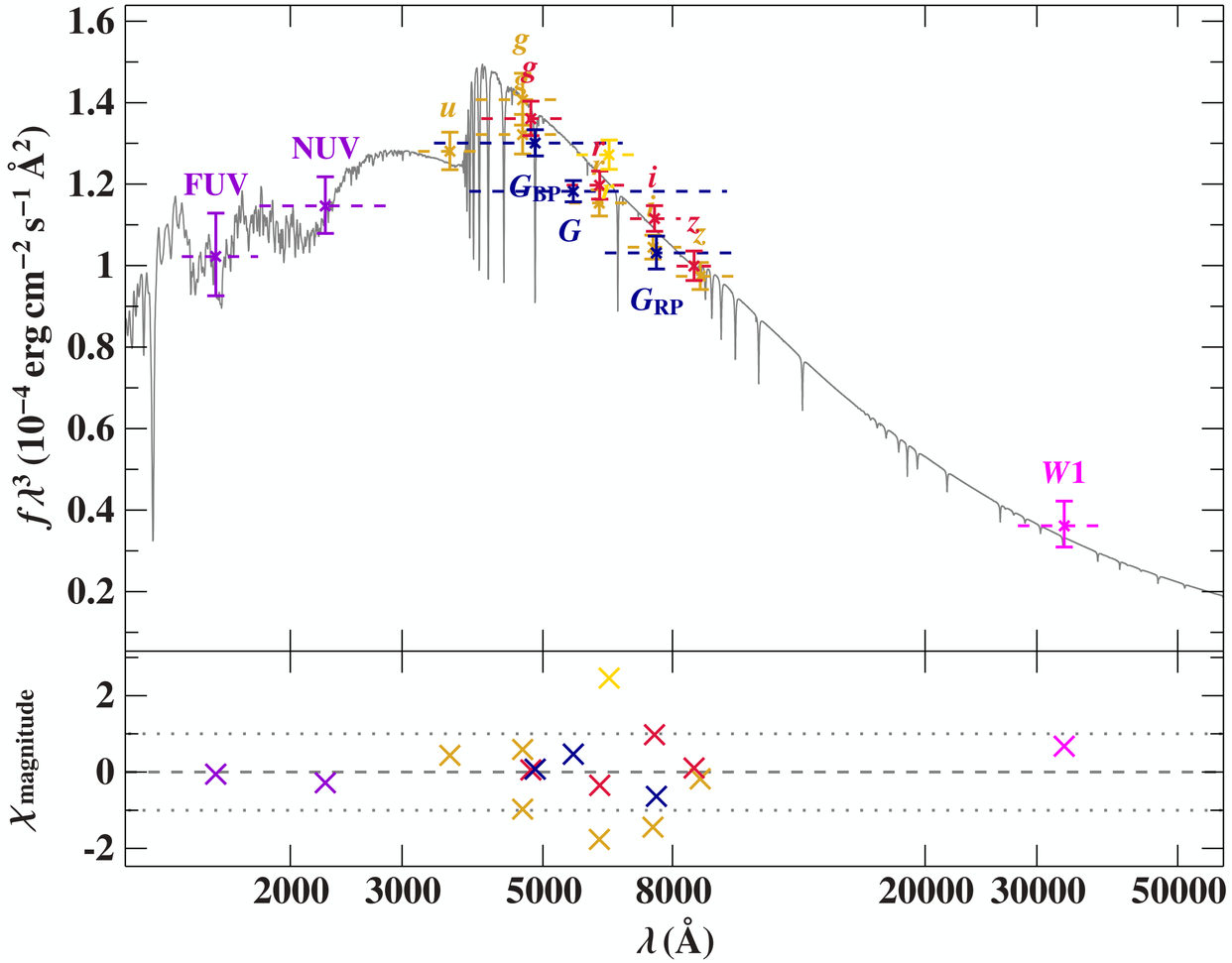


Use those mean magnitudes to generate the lightcurves

J018.4128+22.9608 lightcurve fitting

J018.4128+22.9608

SED fitting - single fit (no RV-curve but spectra, use for fit)

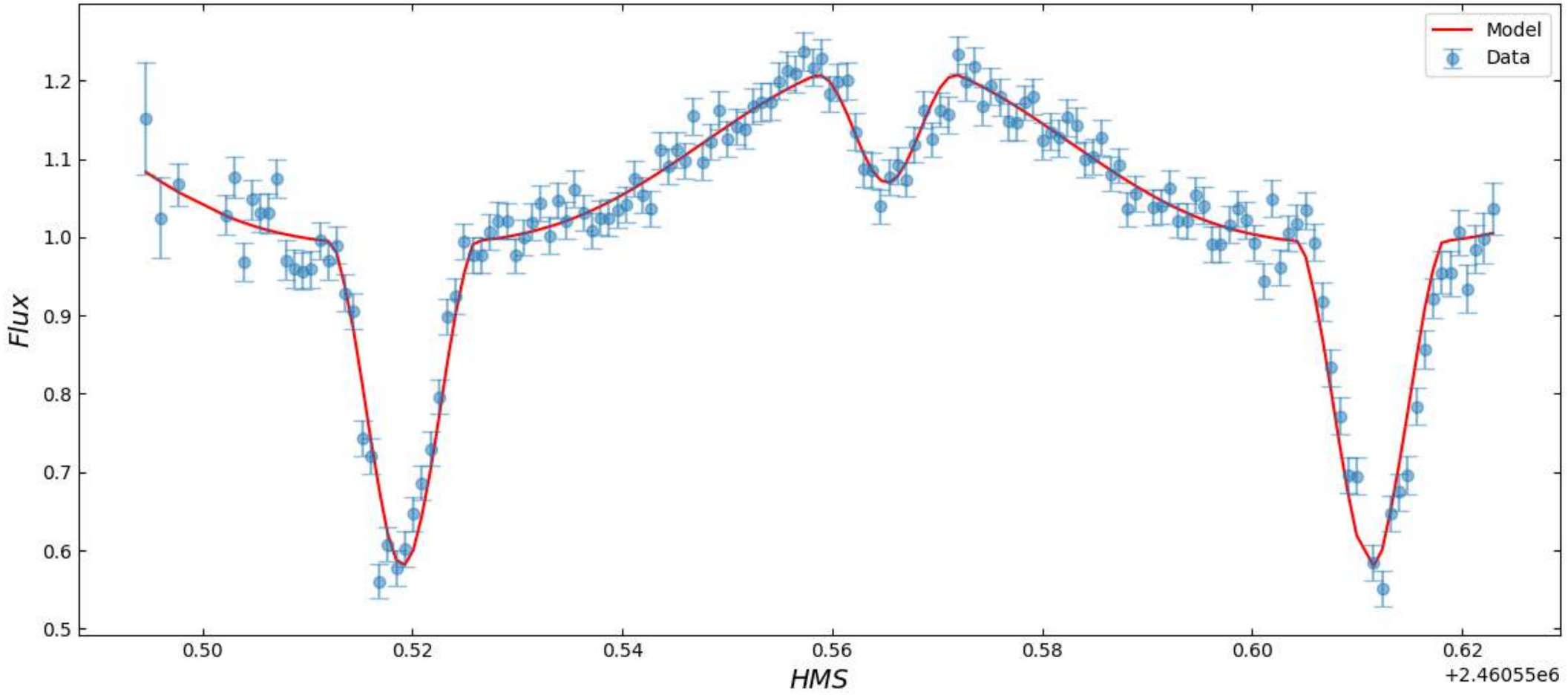


Object: Gaia DR3 2791084432881749760	68% confidence interval
Color excess $E(B-V)$ from SFD (1998)	0.0386 ± 0.0012 mag
Color excess $E(B-V)$ from S&F (2011)	0.0332 ± 0.0010 mag
Color excess $E(B-V)$ from Stilism (Capitanio+ 2017)	0.048 ± 0.016 mag
Distance from Stilism and $E(44-55)$	465 ± 0 pc
Color excess $E(44-55)$	0.058 ± 0.008 mag
Extinction parameter $R(55)$ (fixed)	3.02
Angular diameter $\log(\Theta\,(\mathrm{rad}))$	$-11.518^{+0.009}_{-0.006}$
Parallax ϖ (*Gaia*, RUWE = 1.00, ZPO = −0.0014 mas)	0.42 ± 0.08 mas
Distance d (*Gaia*, mode)	$\left(2.2^{+0.5}_{-0.4}\right) \times 10^3$ pc
Distance d (*Gaia*, median)	$\left(2.4^{+0.5}_{-0.4}\right) \times 10^3$ pc
Effective temperature $T_{\rm eff}$ (prescribed)	28700^{+300}_{-700} K
Surface gravity $\log(g\,(\mathrm{cm\,s^{-2}}))$ (prescribed)	$5.62^{+0.08}_{-0.12}$
Microturbulence ξ (fixed)	0 km s^{-1}
Metallicity z (fixed)	0 dex
Helium abundance $\log(n(\mathrm{He}))$ (prescribed)	$-2.6^{+0.6}_{-0.5}$
Radius $R = \Theta/(2\varpi)$ (mode)	$0.152^{+0.030}_{-0.023}\,R_\odot$
(median)	$0.159^{+0.033}_{-0.024}\,R_\odot$
Mass $M = gR^2/G$ (mode)	$0.31^{+0.18}_{-0.11}\,M_\odot$
(median)	$0.38^{+0.20}_{-0.13}\,M_\odot$
Luminosity $L = (R/R_\odot)^2 (T_{\rm eff}/T_{\rm eff,\odot})^4$ (mode)	$13^{+7}_{-4}\,L_\odot$
(median)	15^{+7}_{-5}
Gravitational redshift $v_{\rm grav} = GM/(Rc)$	1.5 ± 0.5 km s^{-1}
Escape velocity $v_{\rm esc} = \sqrt{2gR}$	950^{+130}_{-150} km s^{-1}
Generic excess noise $\delta_{\rm excess}$	0.023 mag
Reduced χ^2 at the best fit	1.00

From spectra

J018.4128+22.9608

Lightcurve fitting



J018.4128+22.9608

Lightcurve Fitting Parameter Results

$$a = \frac{P}{2\pi} \frac{K_1}{\sin i} \left(\frac{1}{q} + 1 \right)$$

$$R_{1,2} = \frac{r_{1,2}}{a} \cdot a$$

$$M_2 = q \cdot M_1$$

Filter	Period (days)	K-amplitude (km/s)	Orbital separation (AU)	Mass ratio	Mass sdB (solar mass)	Radius sdB (solar radii)	Mass companion (solar masses)	Radius companion (solar radii)	Inclination	Temperature sdB (K)	Temperature companion (K)
i-filter	0.0921 +/- 0.0001	-	0.0029 +/- 0.0004	0.4941 +/- 0.002	0.38 +0.2/-0.13	0.16 +0.033/ -0.024	0.1877 +/- 0.1178	0.1657 +/- 0.0277	77.340 +/- 1	28700 +300/ -700	3000 (fixed)

Lightcurve SED

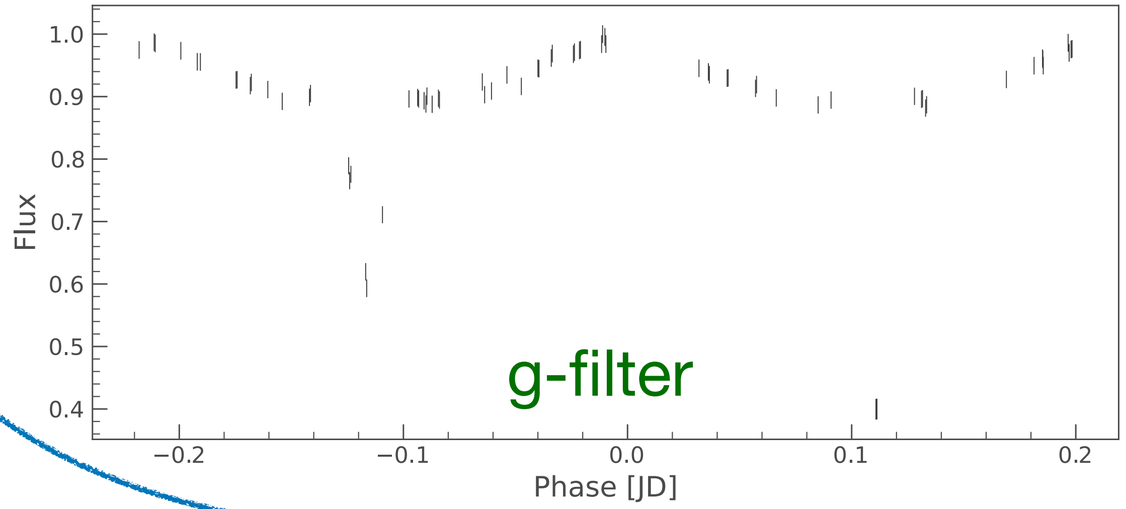
Highly fit-dependent!

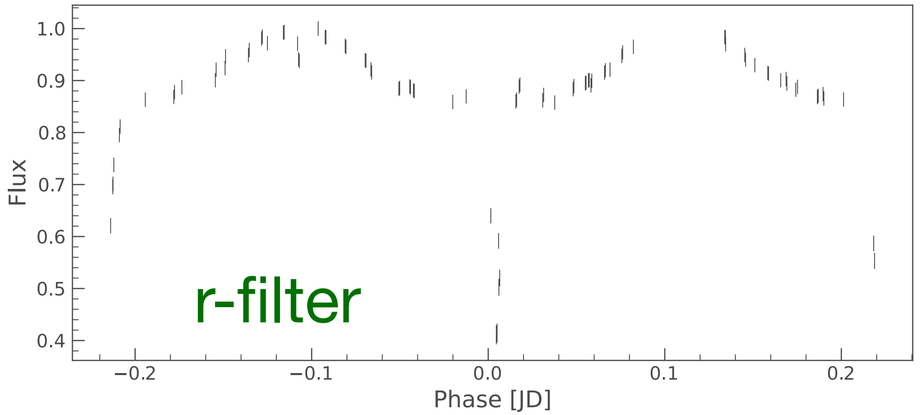
Really uncertain!

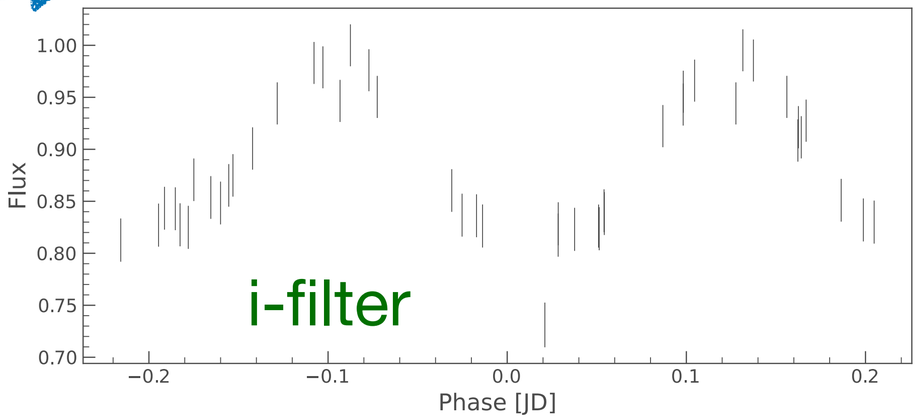
J331.6658+32.7267

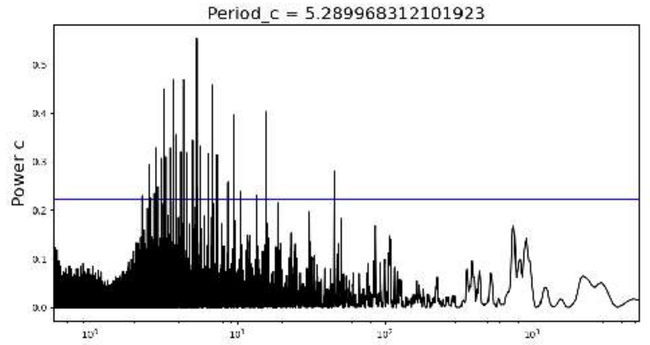
J331.6658+32.7267

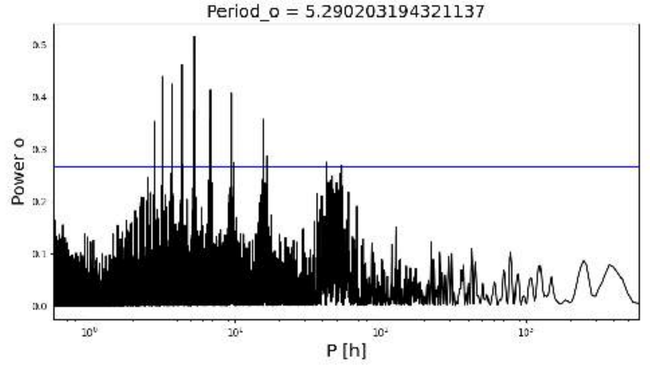
Atlas and ZTF spectra

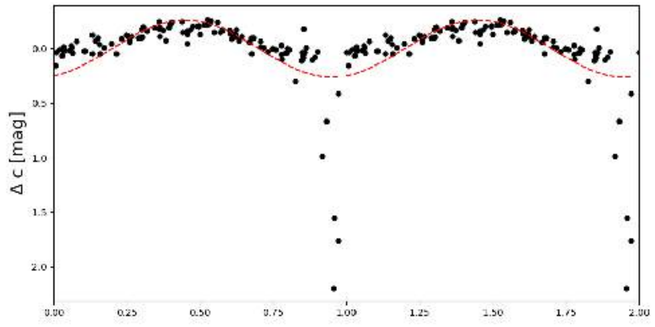


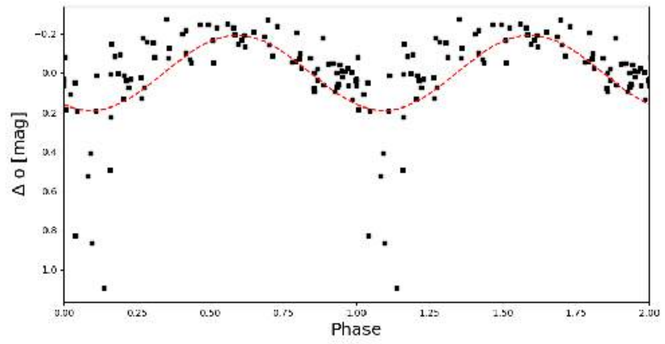








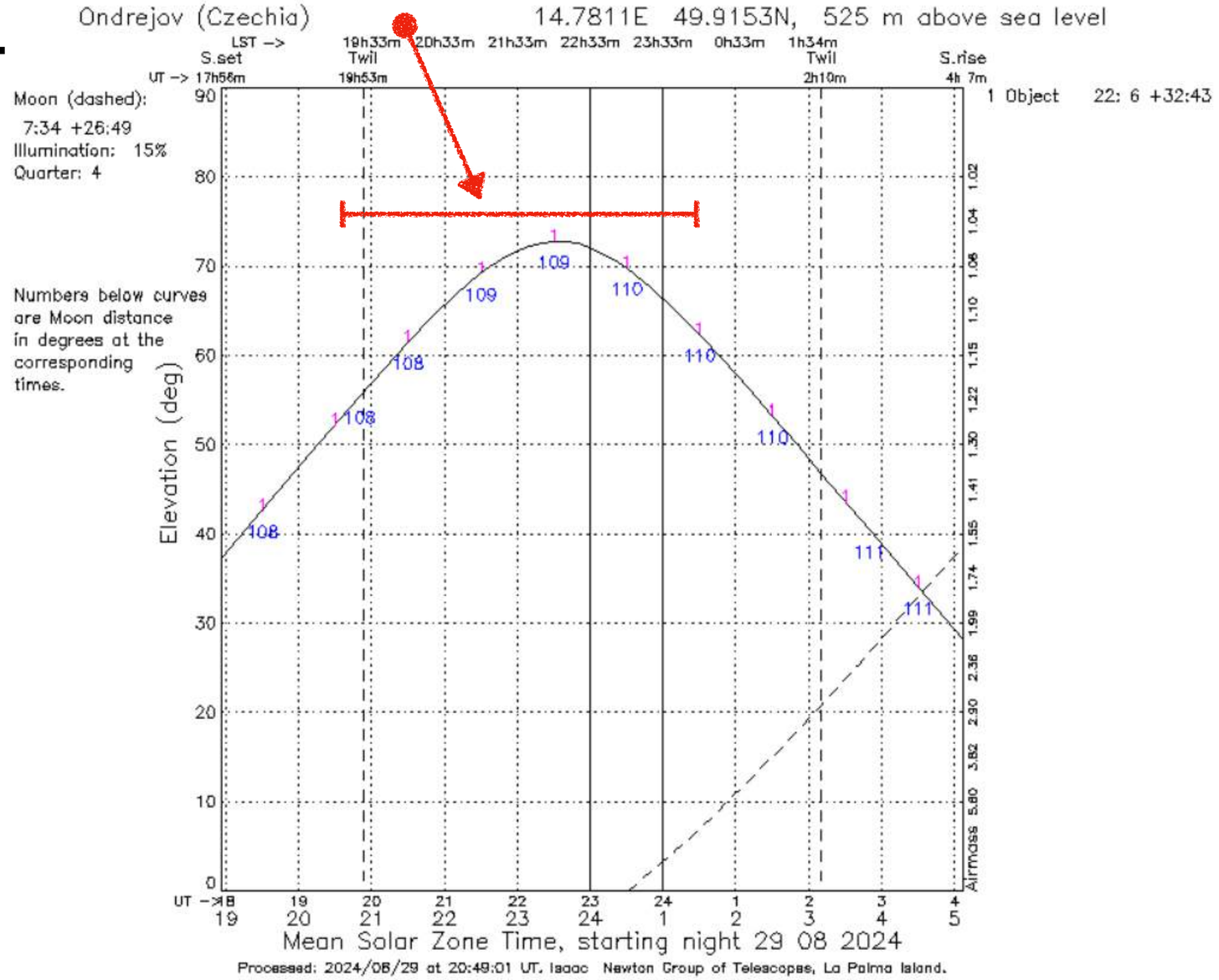




J331.6658+32.7267

Visibility on night 29.08.2024

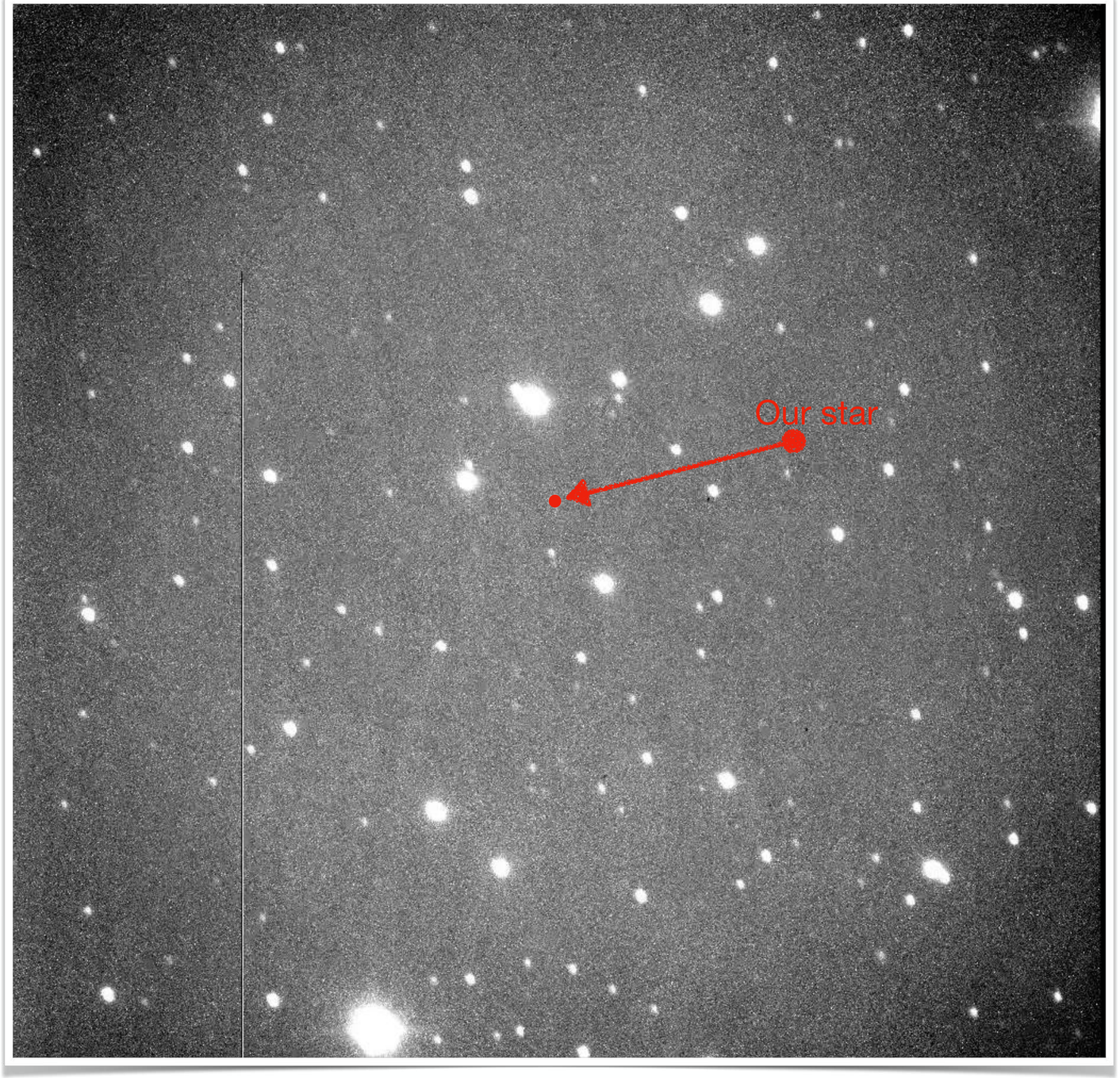
Observation



J331.6658+32.7267

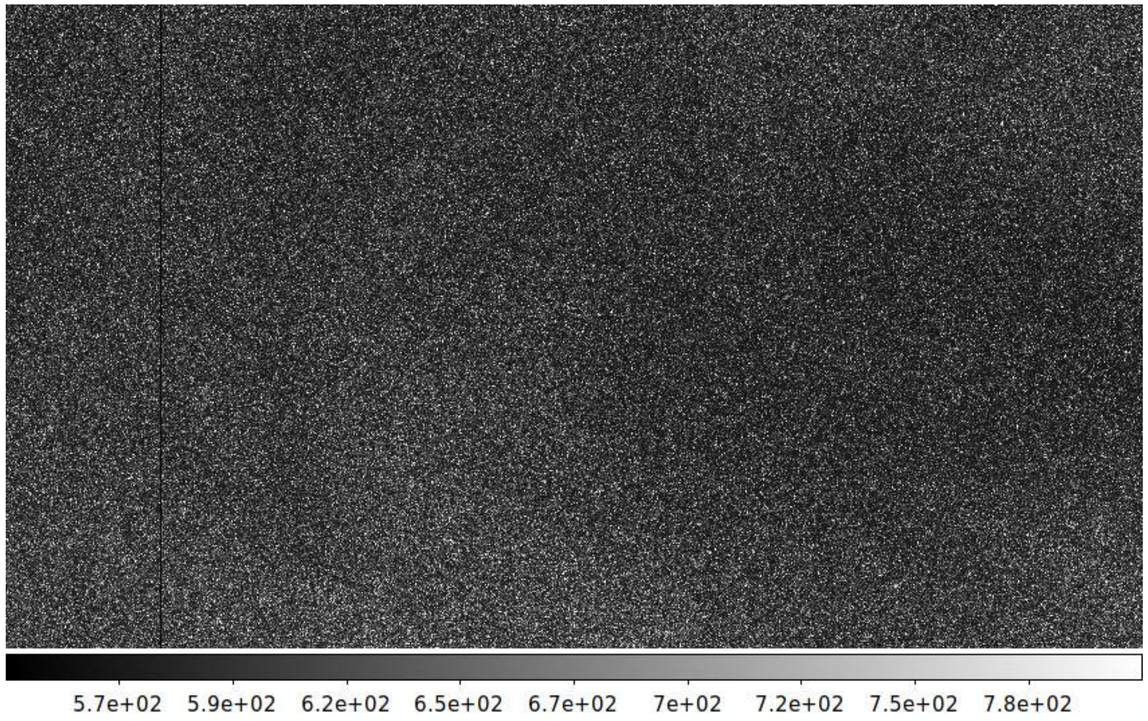
Observation

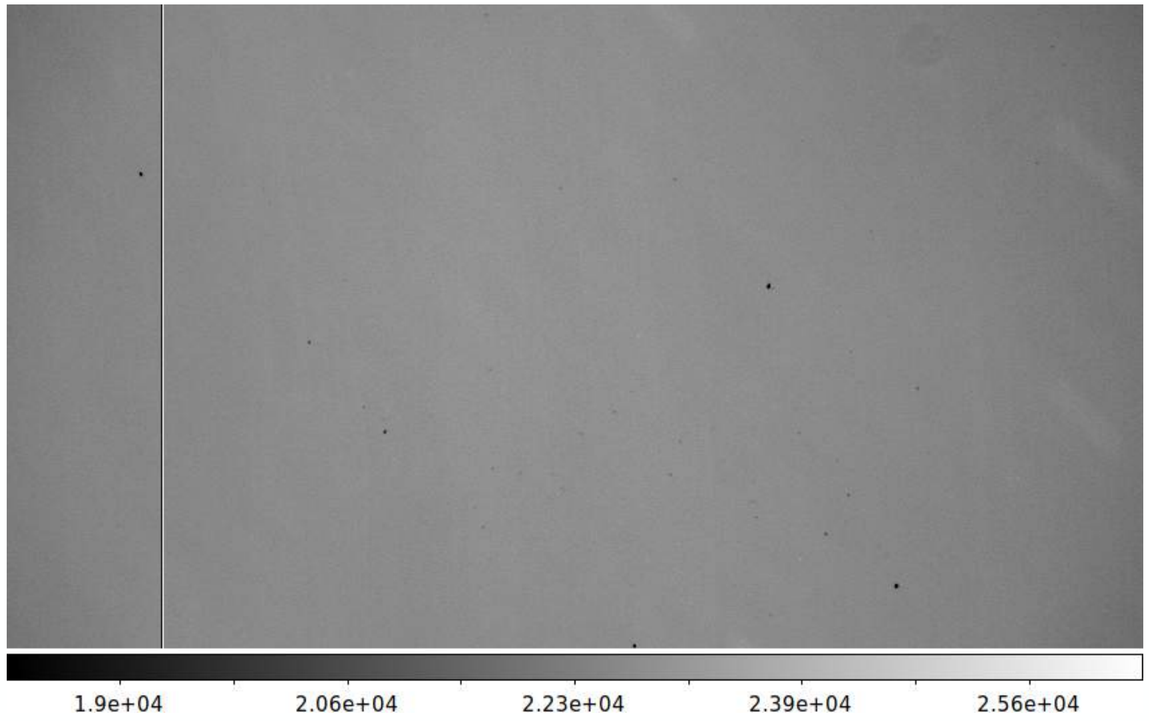
- 18:58 UT to 1:10 UT
- **60s** exposures - faint target
- Clouds were coming in during the observation - removed some images



J331.6658+32.7267

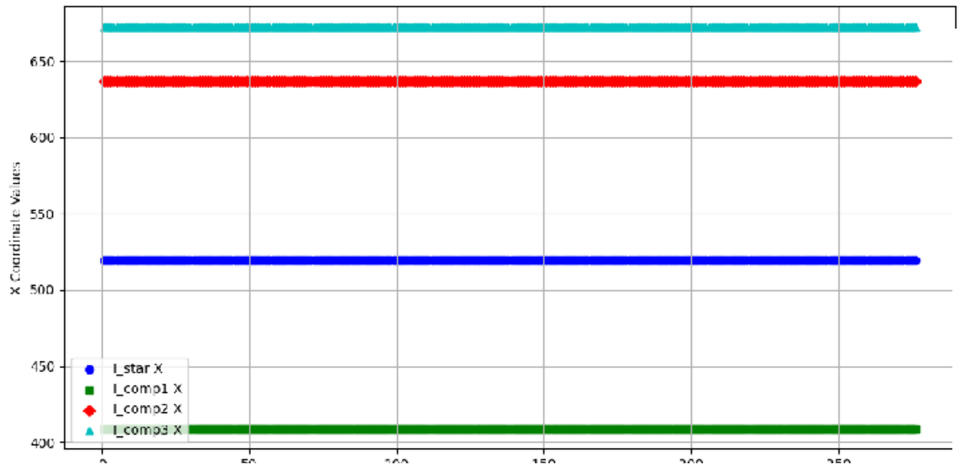
Data Reduction i filter - Master Dark and Flat

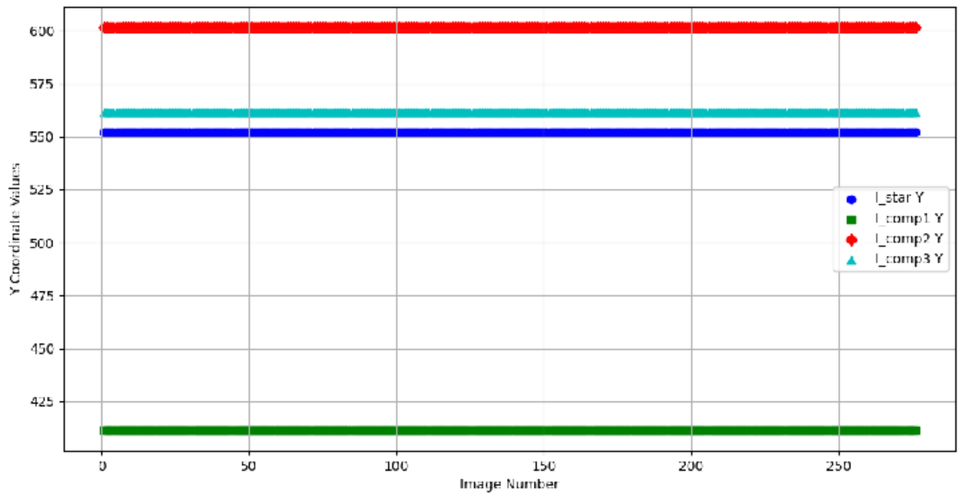


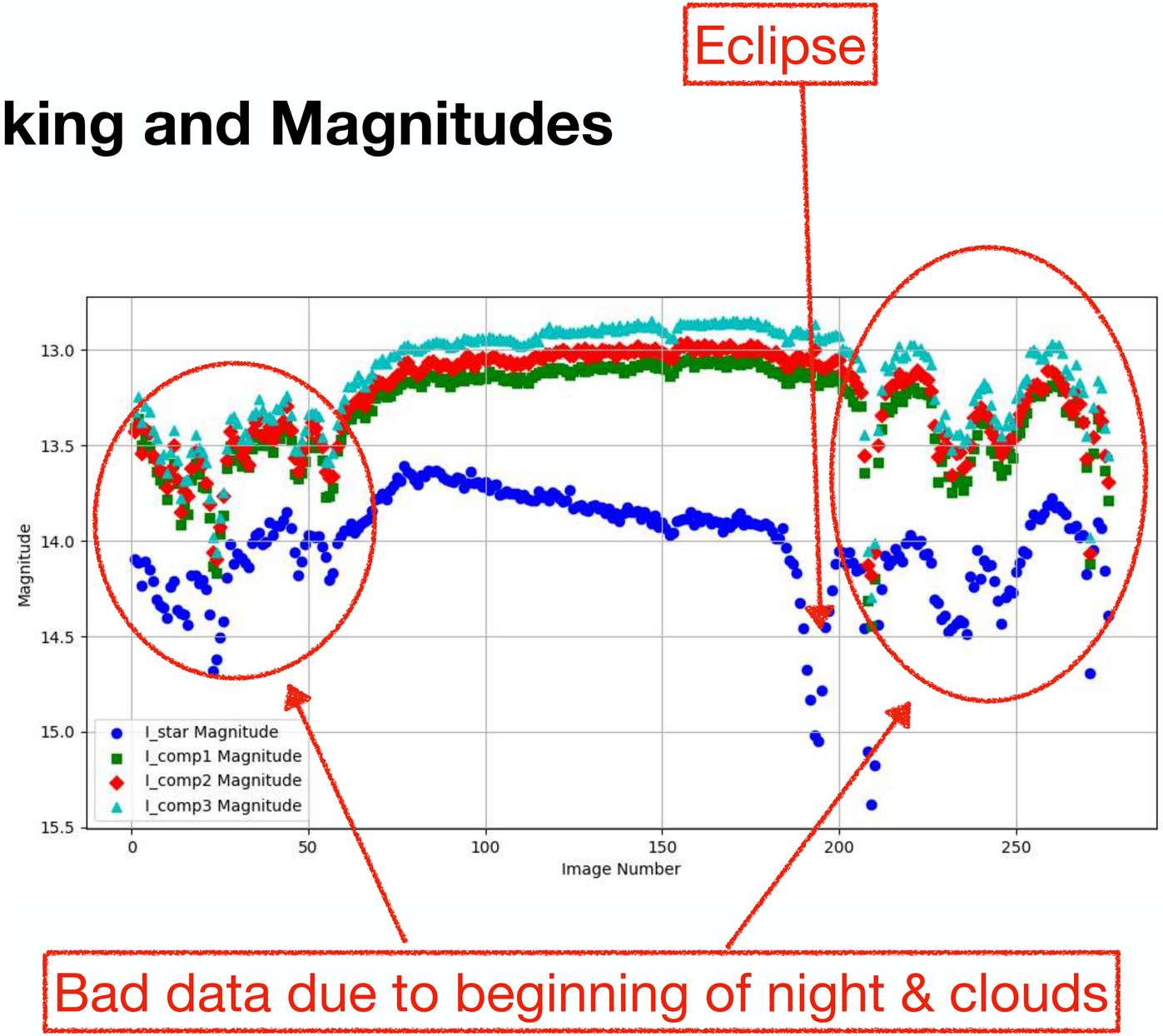


J331.6658+32.7267

Data Reduction i filter - Tracking and Magnitudes

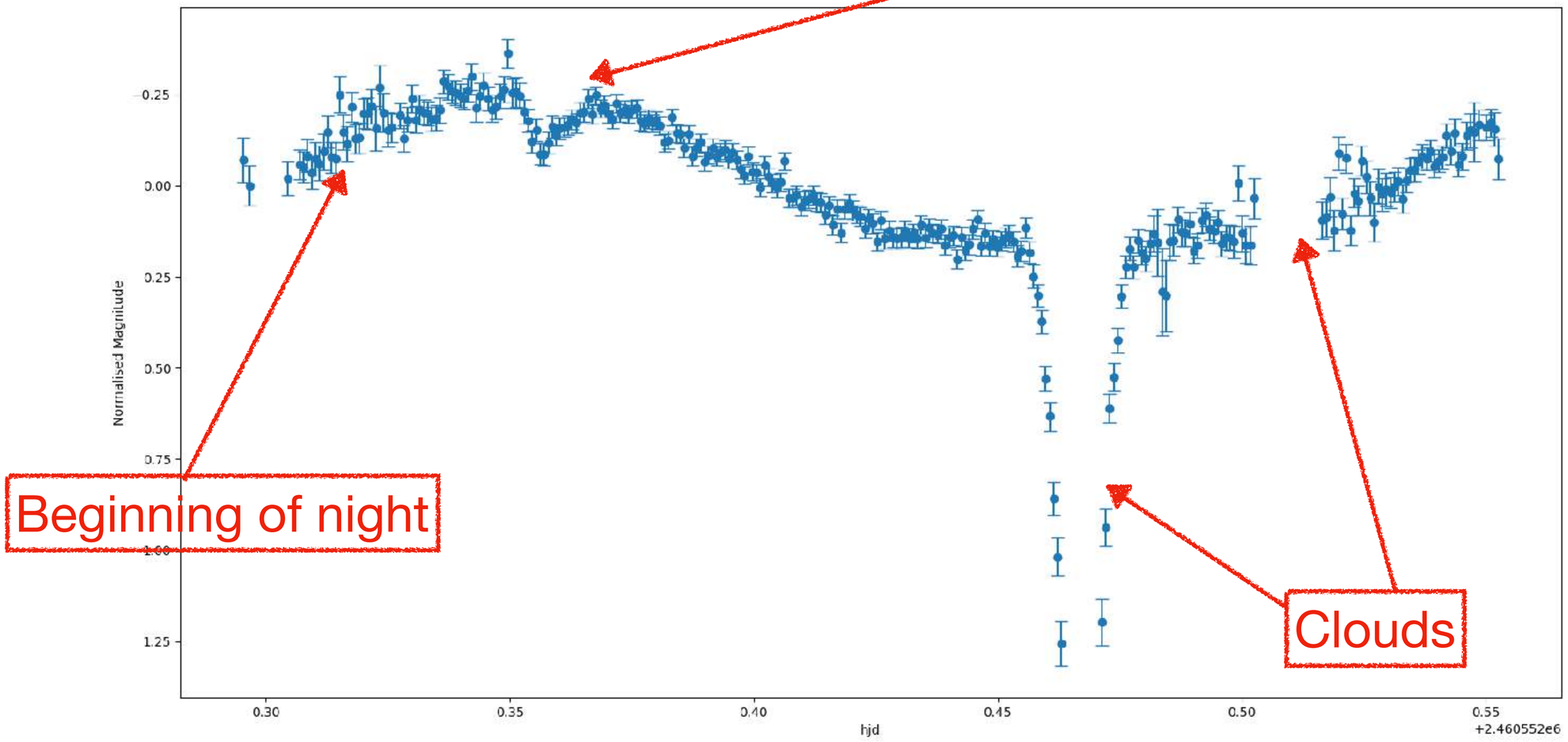






J331.6658+32.7267

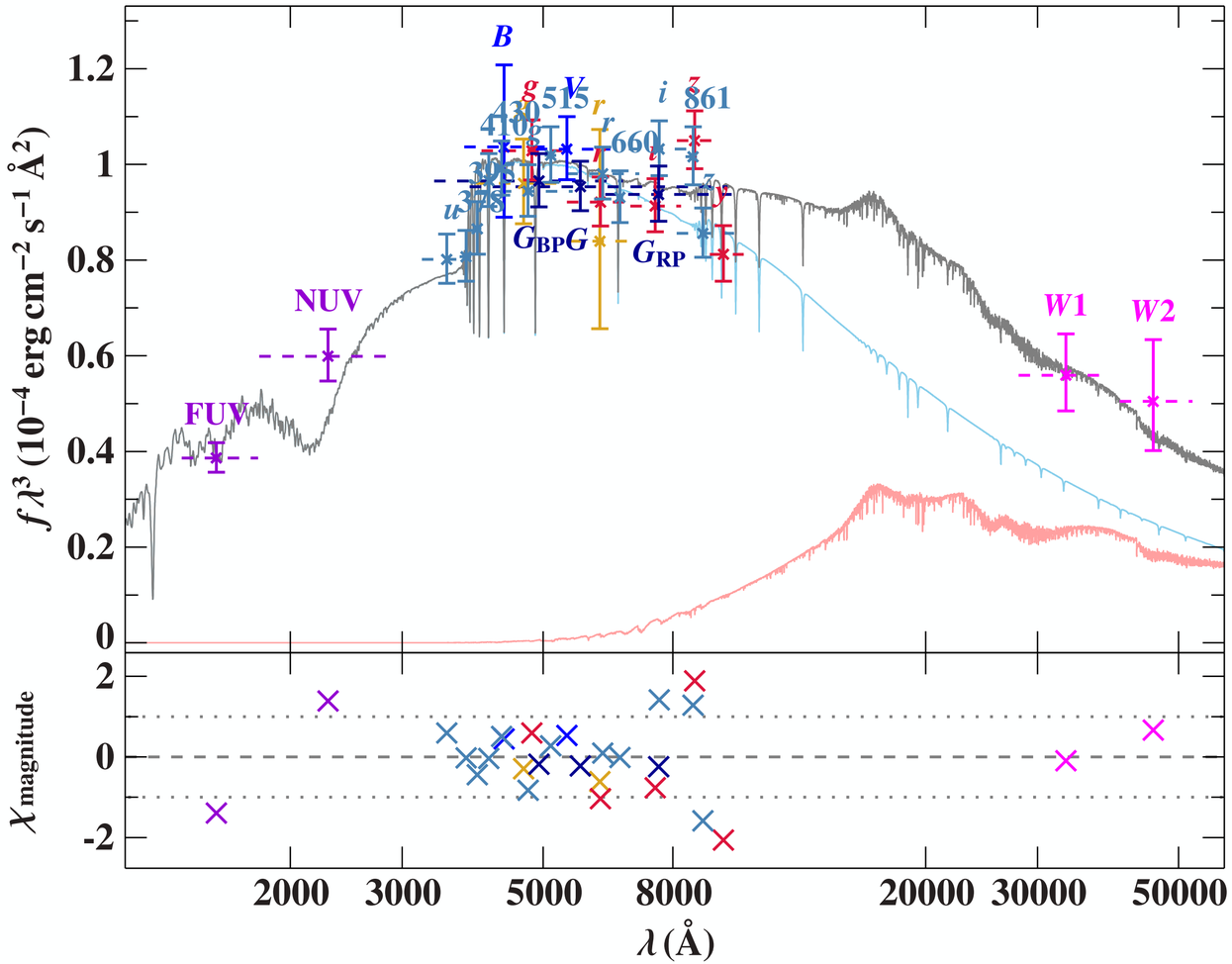
Data Reduction i filter - Lightcurve



J331.6658+32.7267 lightcurve fitting

J331.6658+32.7267

SED fitting - binary fit (no RV or spectra, let the program fit the values)

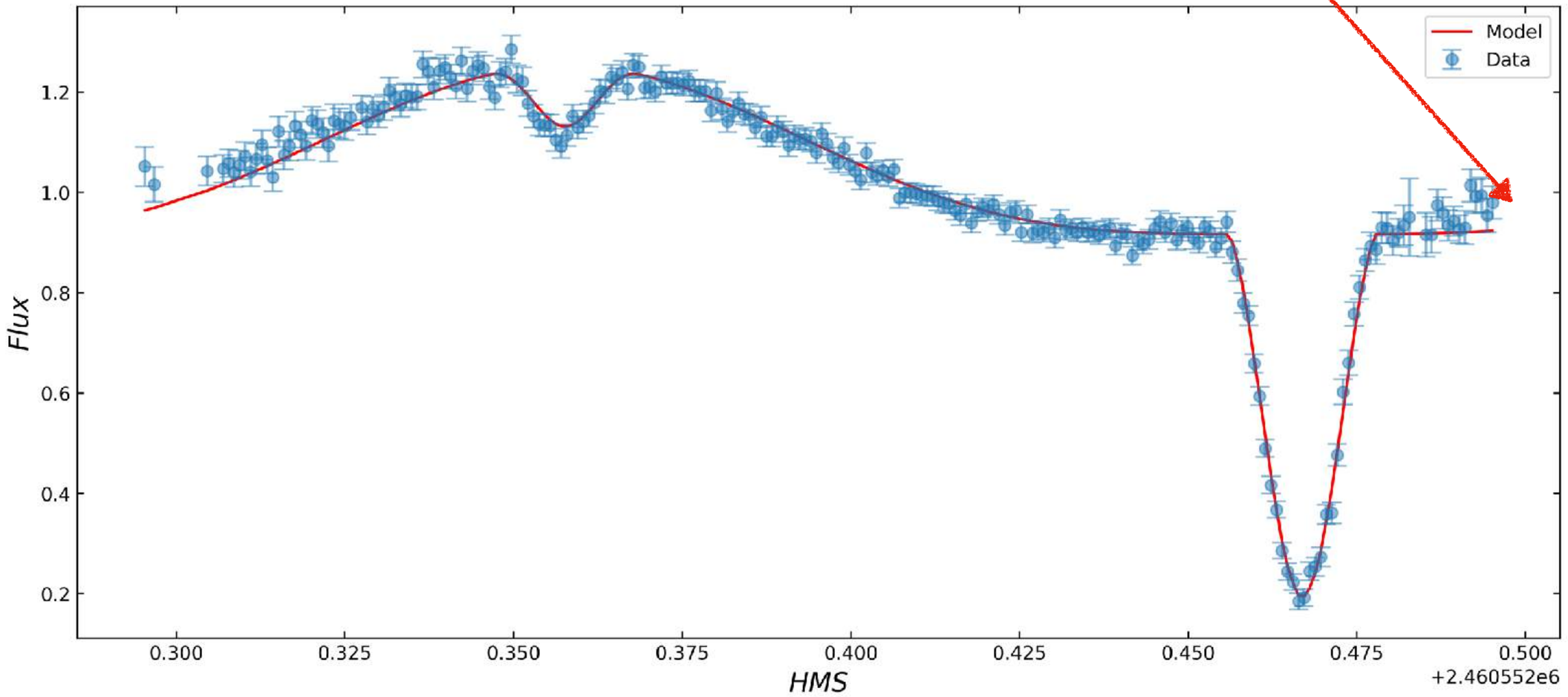


Object: Gaia DR3 1899579411285853952	68% confidence interval
Color excess $E(B-V)$ from SFD (1998)	0.121 ± 0.004 mag
Color excess $E(B-V)$ from S&F (2011)	0.1038 ± 0.0027 mag
Color excess $E(B-V)$ from Stilism (Capitanio+ 2017)	0.09 ± 0.04 mag
Color excess $E(B-V)$ from Bayestar15 (Green+ 2015)	0.097 ± 0.006 mag
Distance from Stilism and $E(44-55)$	935 ± 0 pc
Color excess $E(44-55)$	$0.150^{+0.028}_{-0.036}$ mag
Extinction parameter $R(55)$ (fixed)	3.02
Angular diameter $\log(\Theta\,(\mathrm{rad}))$	$-11.490^{+0.024}_{-0.022}$
Parallax ϖ (*Gaia*, RUWE = 1.01, ZPO = −0.0053 mas)	0.31 ± 0.07 mas
Distance d (*Gaia*, mode)	$\left(3.0^{+0.8}_{-0.6}\right)\times10^3$ pc
Distance d (*Gaia*, median)	$\left(3.2^{+0.9}_{-0.6}\right)\times10^3$ pc
Component 1:	
Effective temperature $T_{\rm eff}$	26600^{+2200}_{-2500} K
Surface gravity $\log(g\,(\mathrm{cm\,s^{-2}}))$ (prescribed)	$5.45^{+0.26}_{-0.35}$
Microturbulence ξ (fixed)	0 km s^{-1}
Metallicity z (fixed)	0 dex
Helium abundance $\log(n(\mathrm{He}))$ (prescribed)	$-2.8^{+0.8}_{-1.2}$
Radius $R=\Theta/(2\varpi)$ (mode)	$0.22^{+0.06}_{-0.04}\,R_\odot$
(median)	$0.23^{+0.07}_{-0.05}\,R_\odot$
Mass $M=gR^2/G$ (mode)	$0.26^{+0.33}_{-0.18}\,M_\odot$
(median)	$0.5^{+0.7}_{-0.4}\,M_\odot$
Luminosity $L=(R/R_\odot)^2(T_{\rm eff}/T_{\rm eff,\odot})^4$ (mode)	$(-nan\pm-nan)\times10^{2147483647}\,L_\odot$
(median)	24^{+19}_{-11}
Gravitational redshift $v_{\rm grav}=GM/(Rc)$	$0.8^{+1.4}_{-0.5}$ km s^{-1}
Escape velocity $v_{\rm esc}=\sqrt{2gR}$	950^{+270}_{-390} km s^{-1}
Component 2:	
Effective temperature $T_{\rm eff}$	3800^{+767}_{-0} K
Surface gravity $\log(g\,(\mathrm{cm\,s^{-2}}))$ (fixed)	4.4
Microturbulence ξ (fixed)	0 km s^{-1}
Metallicity z (fixed)	0 dex
Helium abundance $\log(n(\mathrm{He}))$ (fixed)	−1
Surface ratio $A_{\rm eff}/A_{\rm eff,1}$	$5.6^{+1.9}_{-2.1}$
Radius $R=(A_{\rm eff}/A_{\rm eff,1})^{1/2}\Theta/(2\varpi)$ (mode)	$0.51^{+0.17}_{-0.14}\,R_\odot$
(median)	$0.55^{+0.18}_{-0.14}\,R_\odot$
Mass $M=gR^2/G$ (mode)	$(-nan\pm-nan)\times10^{2147483647}\,M_\odot$
(median)	$0.27^{+0.21}_{-0.12}\,M_\odot$
Luminosity $L=(R/R_\odot)^2(T_{\rm eff}/T_{\rm eff,\odot})^4$ (mode)	$(-nan\pm-nan)\times10^{2147483647}\,L_\odot$
(median)	$0.07^{+0.08}_{-0.04}$
Gravitational redshift $v_{\rm grav}=GM/(Rc)$	$0.30^{+0.10}_{-0.08}$ km s^{-1}
Escape velocity $v_{\rm esc}=\sqrt{2gR}$	430^{+70}_{-60} km s^{-1}
Generic excess noise $\delta_{\rm excess}$	0.058 mag
Reduced χ^2 at the best fit	1.00

J331.6658+32.7267

Lightcurve fitting I filter

Discarded more data for the fitting due to bad data



J331.6658+32.7267

Lightcurve Fitting Parameter Results

$$a = \frac{P}{2\pi} \frac{K_1}{\sin i} \left(\frac{1}{q} + 1 \right)$$

$$R_{1,2} = \frac{r_{1,2}}{a} \cdot a$$

$$M_2 = q \cdot M_1$$

Filter	Period (days)	K-amplitude (km/s)	Orbital separation (AU)	Mass ratio	Mass sdB (solar mass)	Radius sdB (solar radii)	Mass companion (solar masses)	Radius companion (solar radii)	Inclination	Temperature sdB (K)	Temperature companion (K)
i-filter	0.2186 +/- 0.0001	-	0.0084 +/- 0.0048	0.5831 +/- 0.002	0.47 +0.02/ -0.02	0.23 +0.07/ -0.05	0.2915 +/- 0.0165	0.3898 +/- 0.2642	82.183 +/- 1	26600 +2200/ -2500	3000 (fixed)

Lightcurve SED

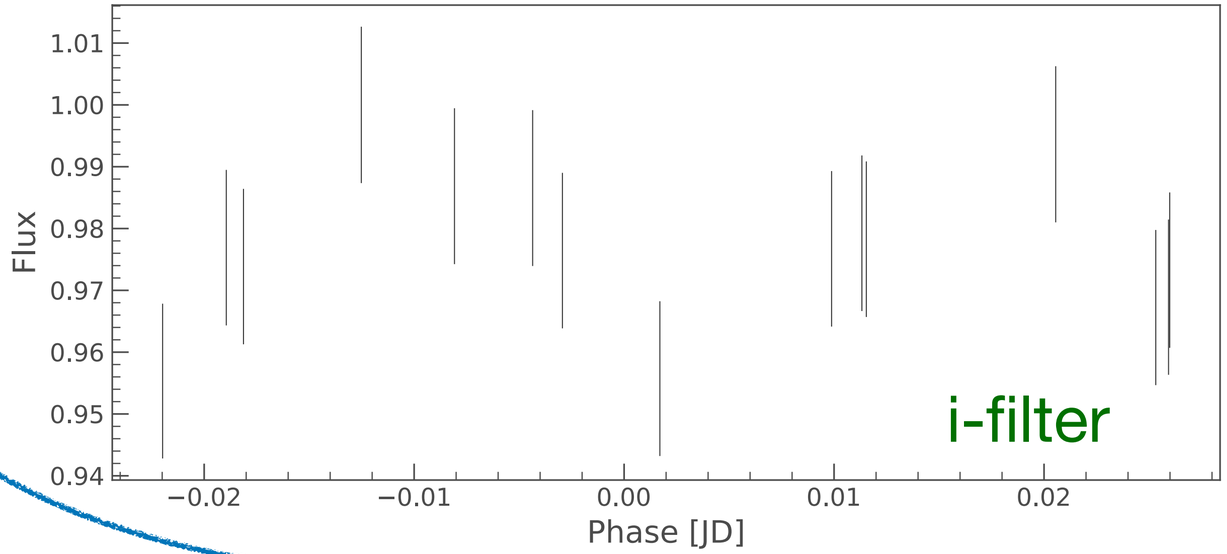
Highly fit-dependent!

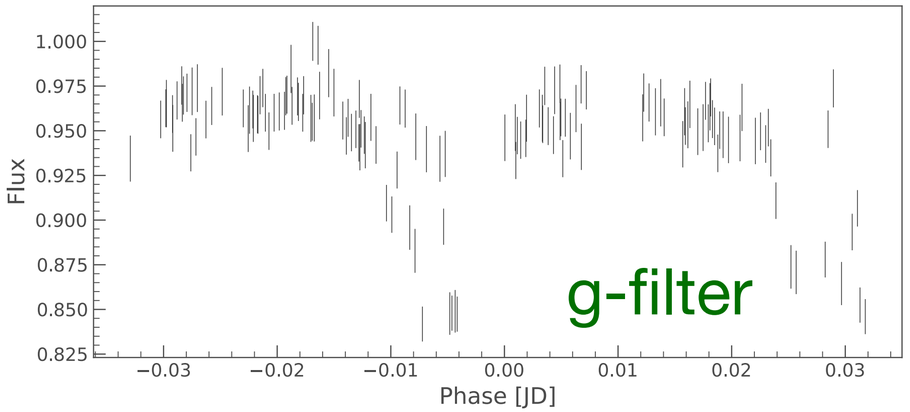
Fixed because SED values and errors are incorrect and large

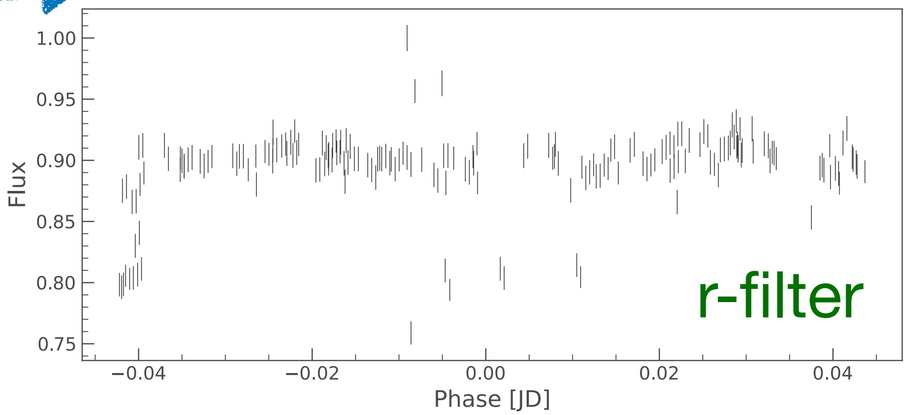
J296.1785+54.8285

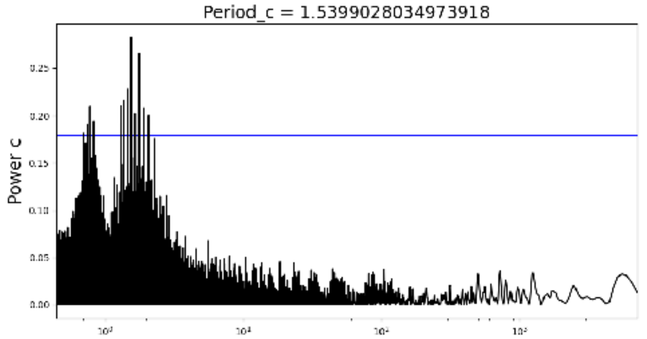
J296.1785+54.8285

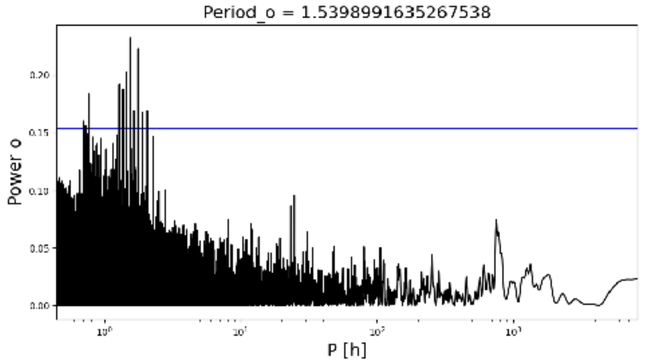
ZTF and ATLAS spectra

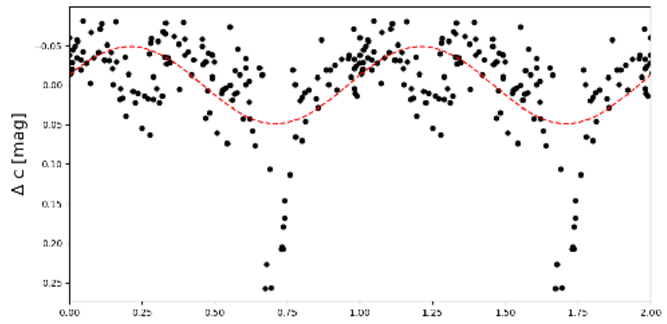


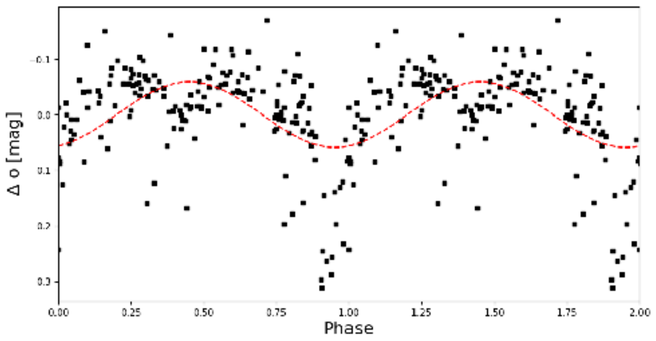








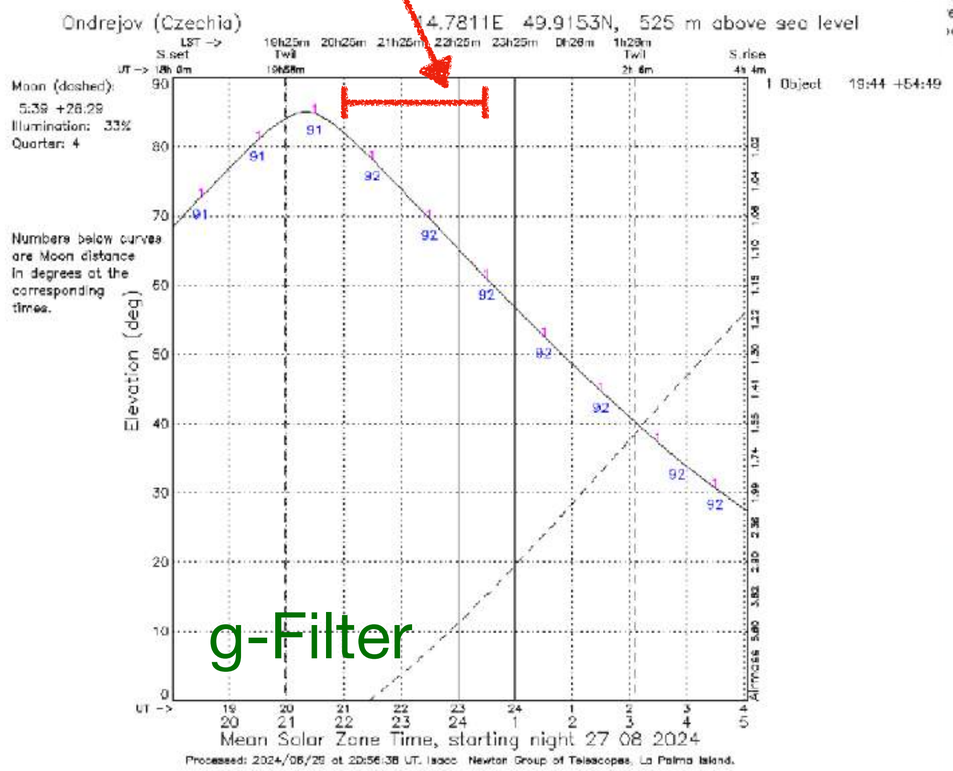


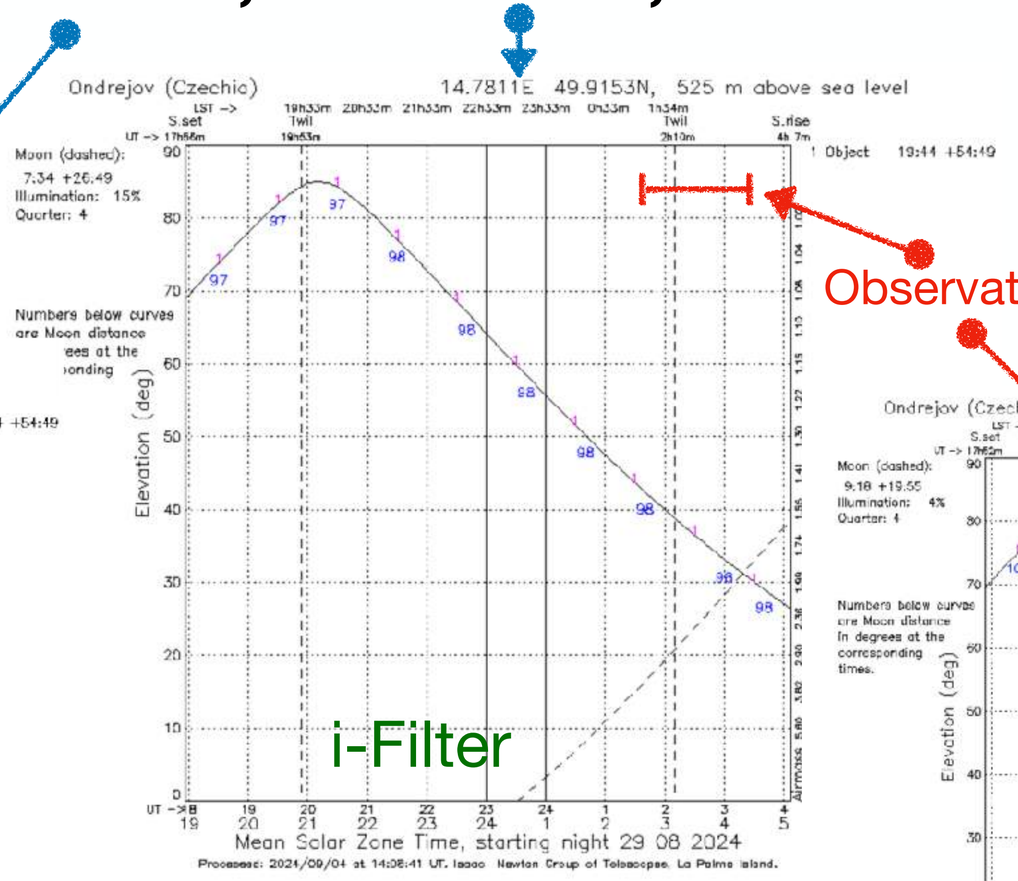


J296.1785+54.8285

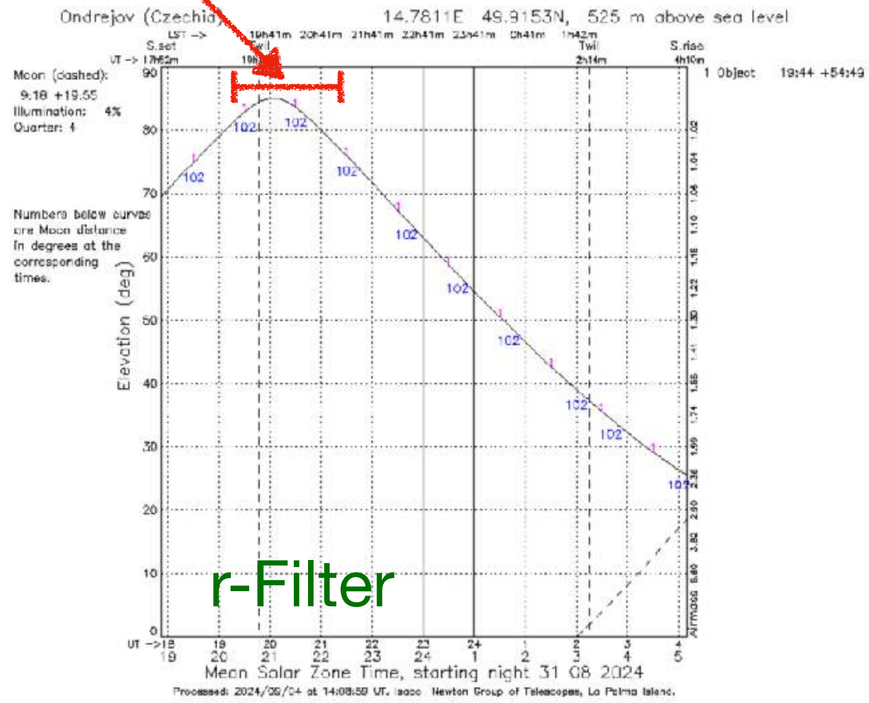
Visibility on night 27.08.2024, 29.08.2024, 31.08.2024

Observation





Observation

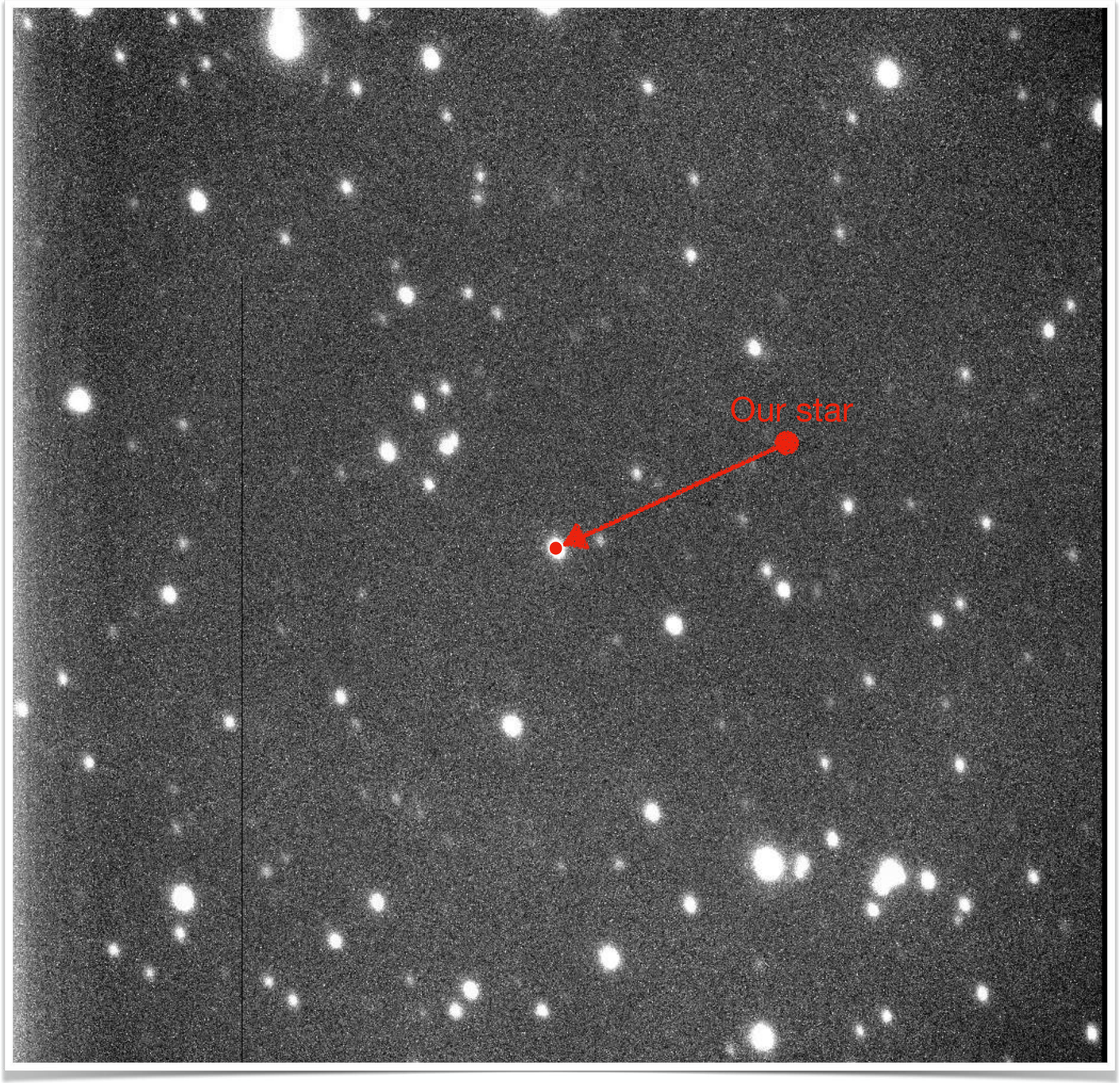


J296.1785+54.8285 g-filter

J296.1785+54.8285

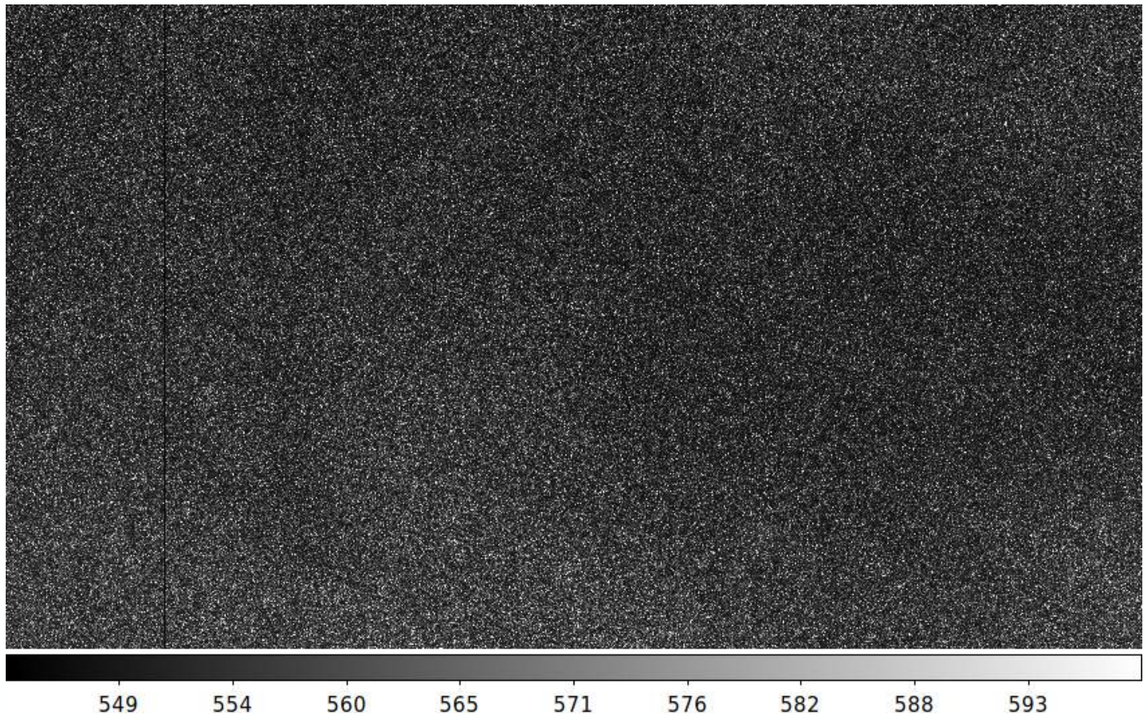
Observation g filter

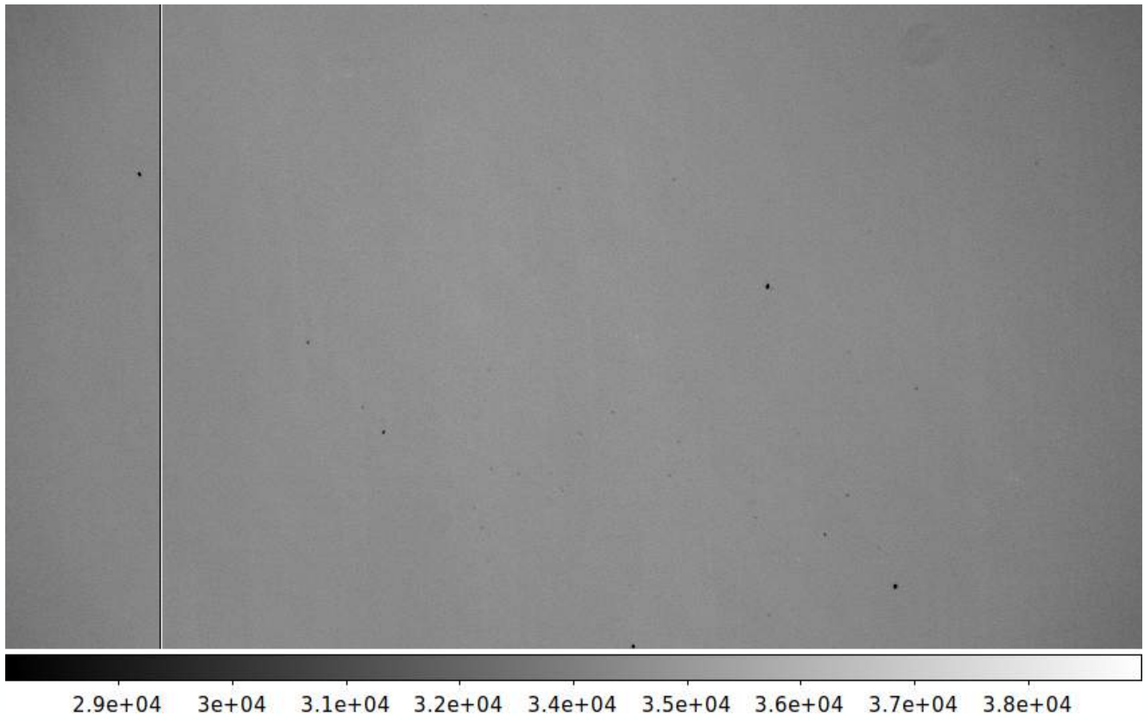
- 20:18 UT to 23:17 UT
- **20s** exposures
- Observation was scheduled to start earlier but the shutter failed



J296.1785+54.8285

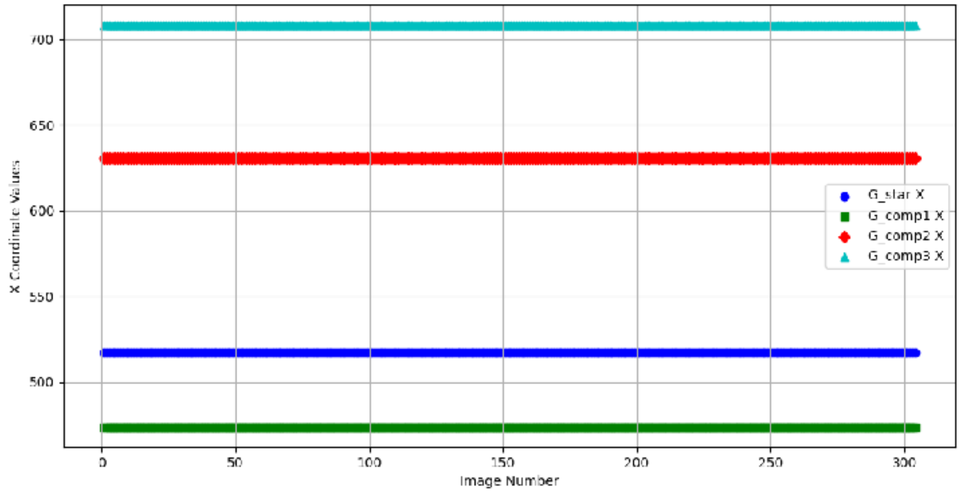
Data Reduction g filter - Master Dark and Flat

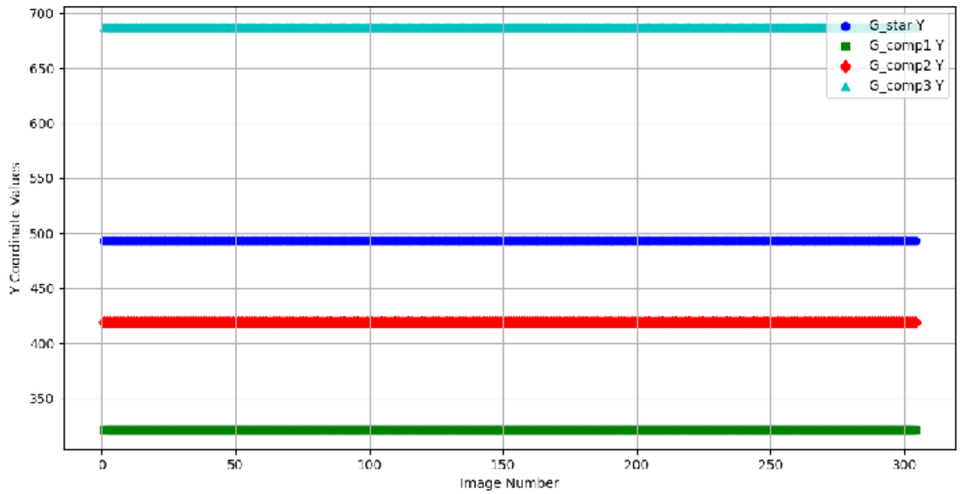


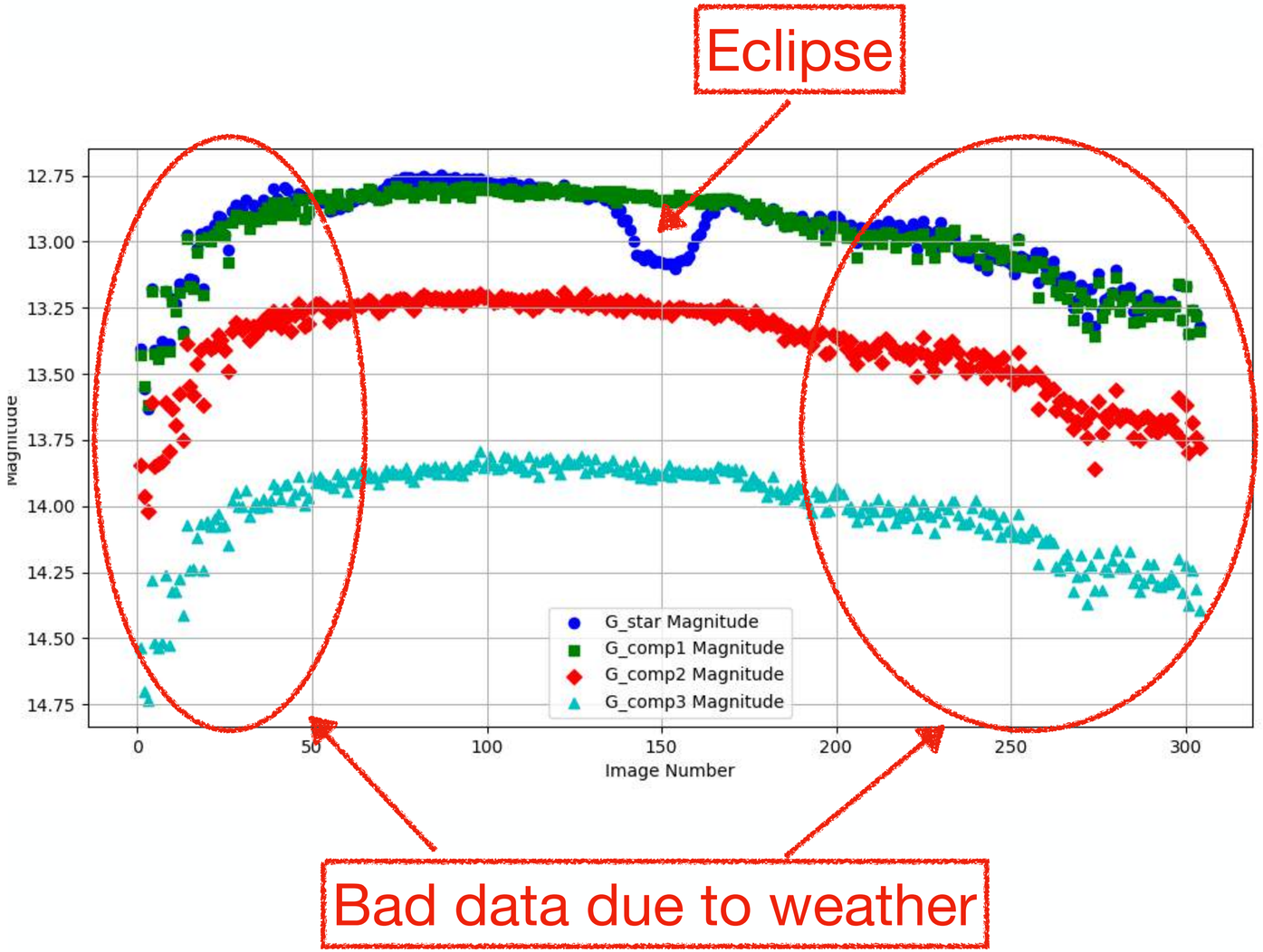


J296.1785+54.8285

Data Reduction g filter - Tracking and Magnitudes

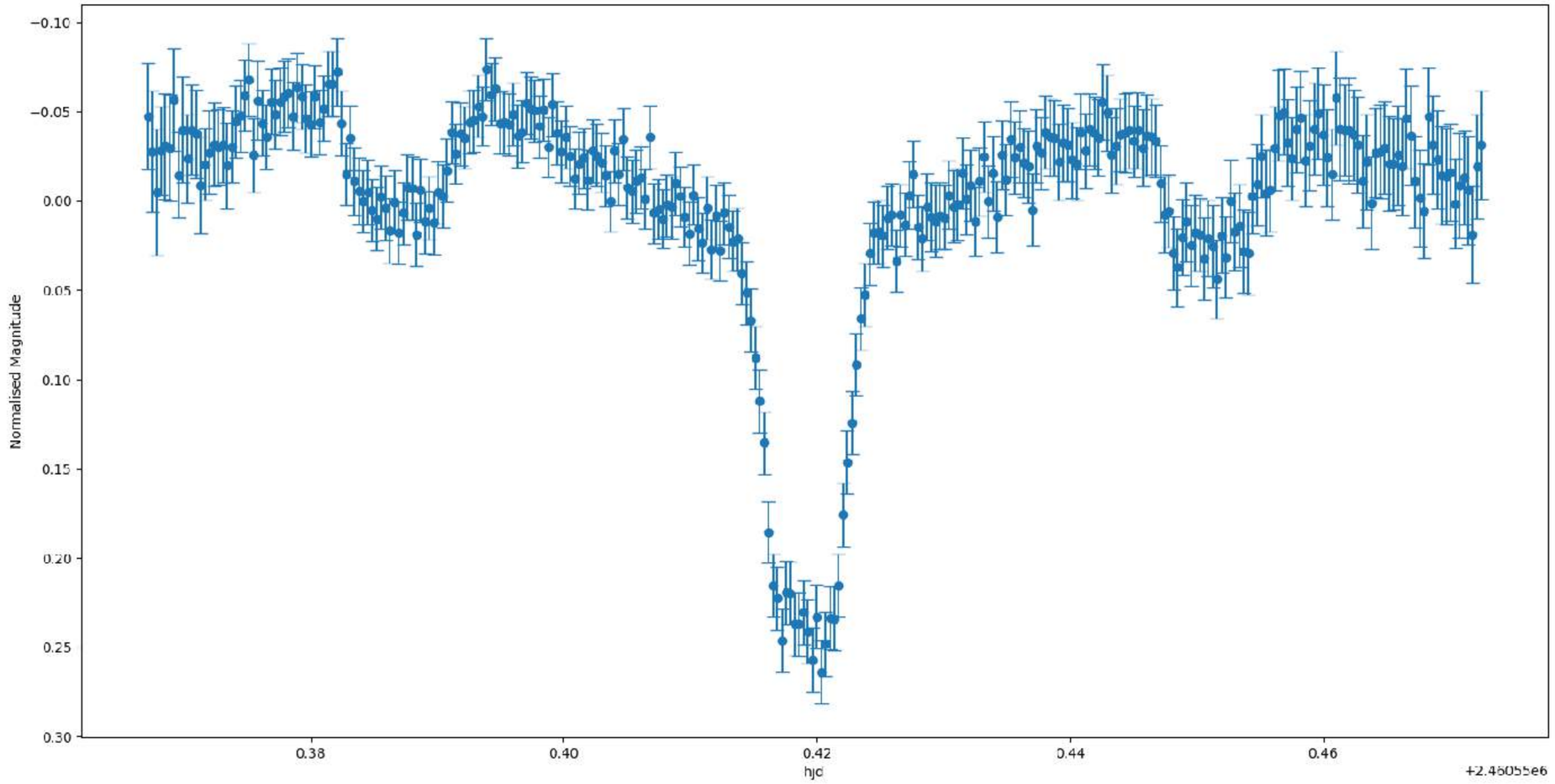






J296.1785+54.8285

Data Reduction g filter - Lightcurve

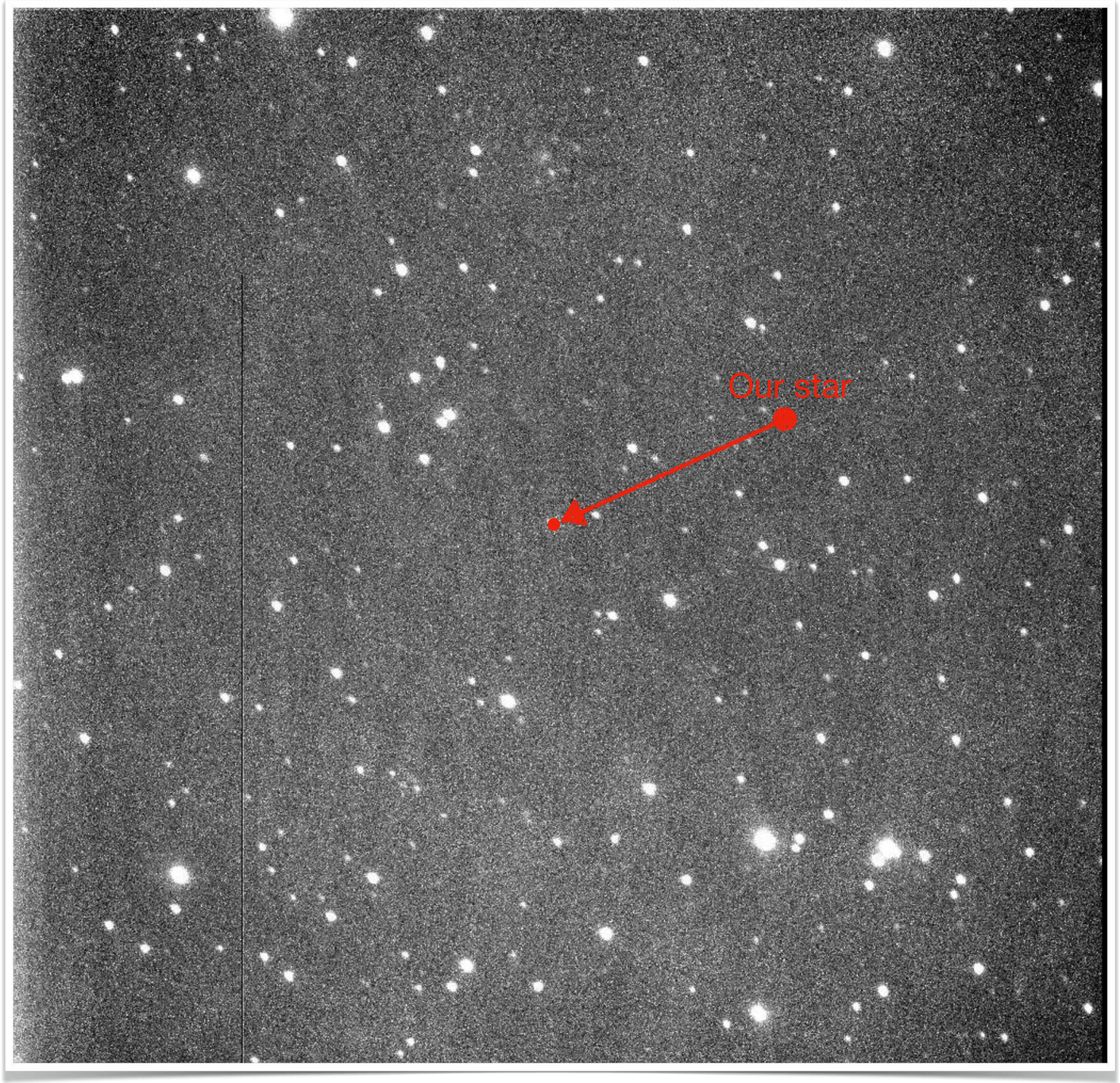


J296.1785+54.8285 i-filter

J296.1785+54.8285

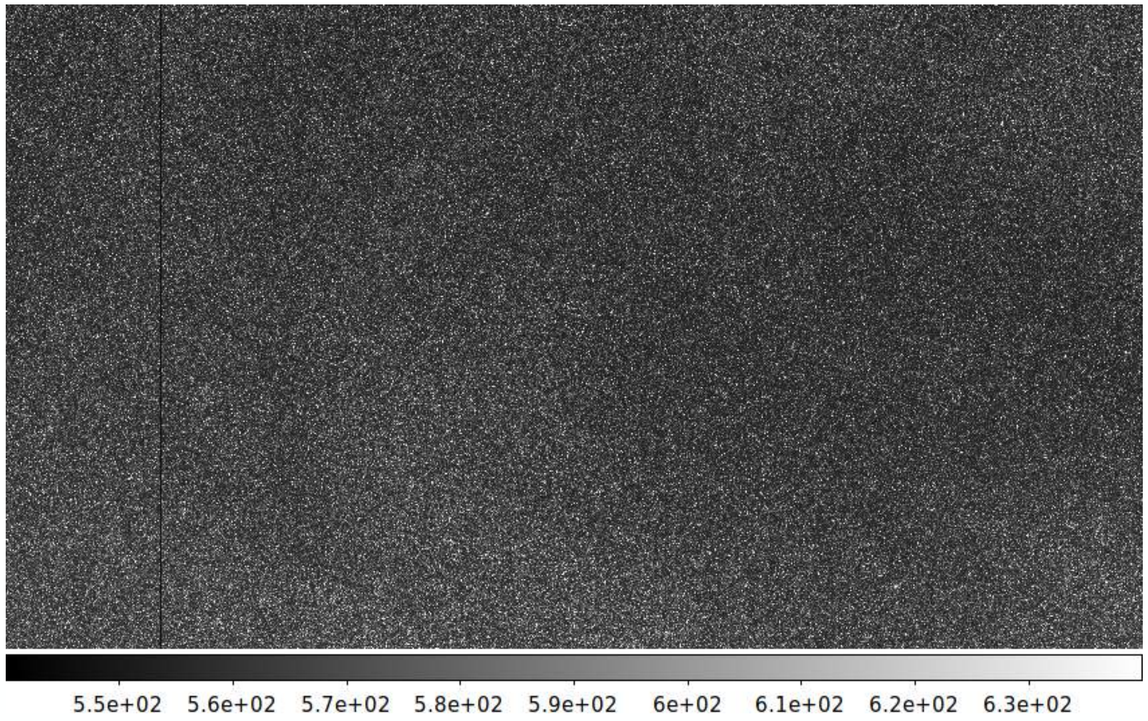
Observation I filter

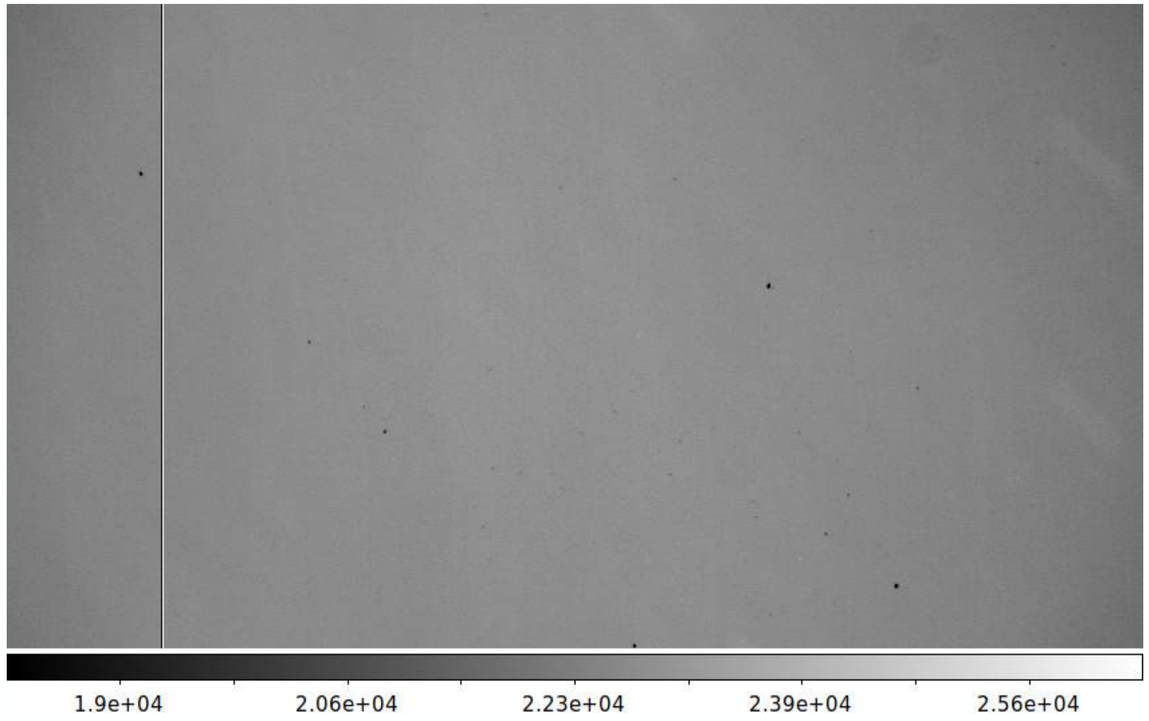
- 1:14 UT to 2:51 UT
- **20s** exposures
- Observation was towards end of the night and some clouds were obscuring the view
- Lots of satellites had to be removed



J296.1785+54.8285

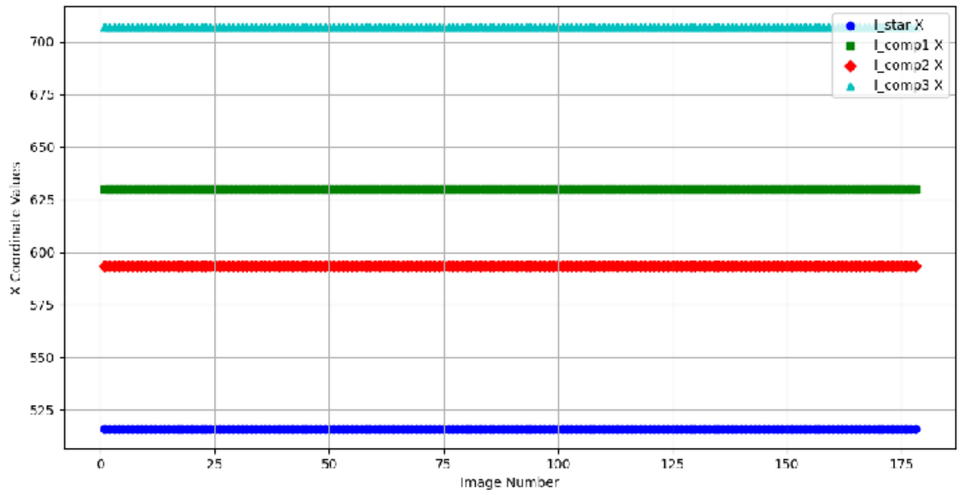
Data Reduction I filter - Master Dark and Flat

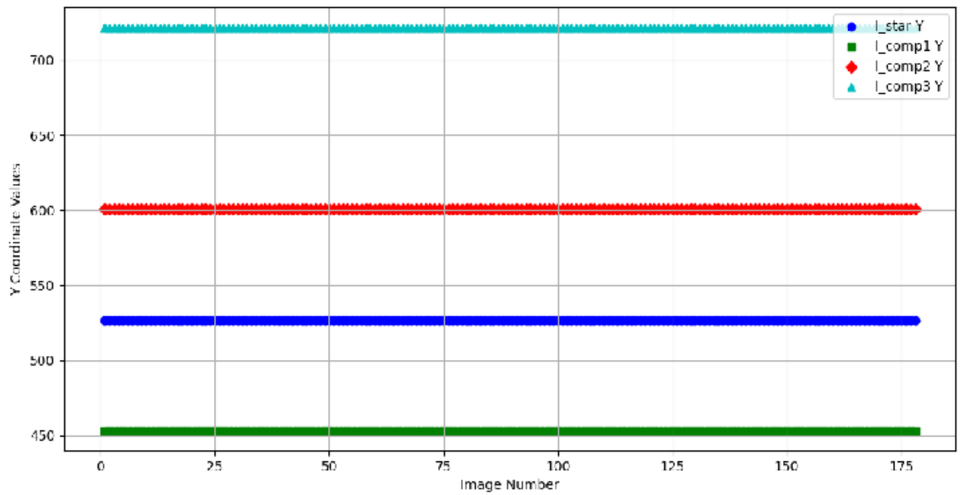


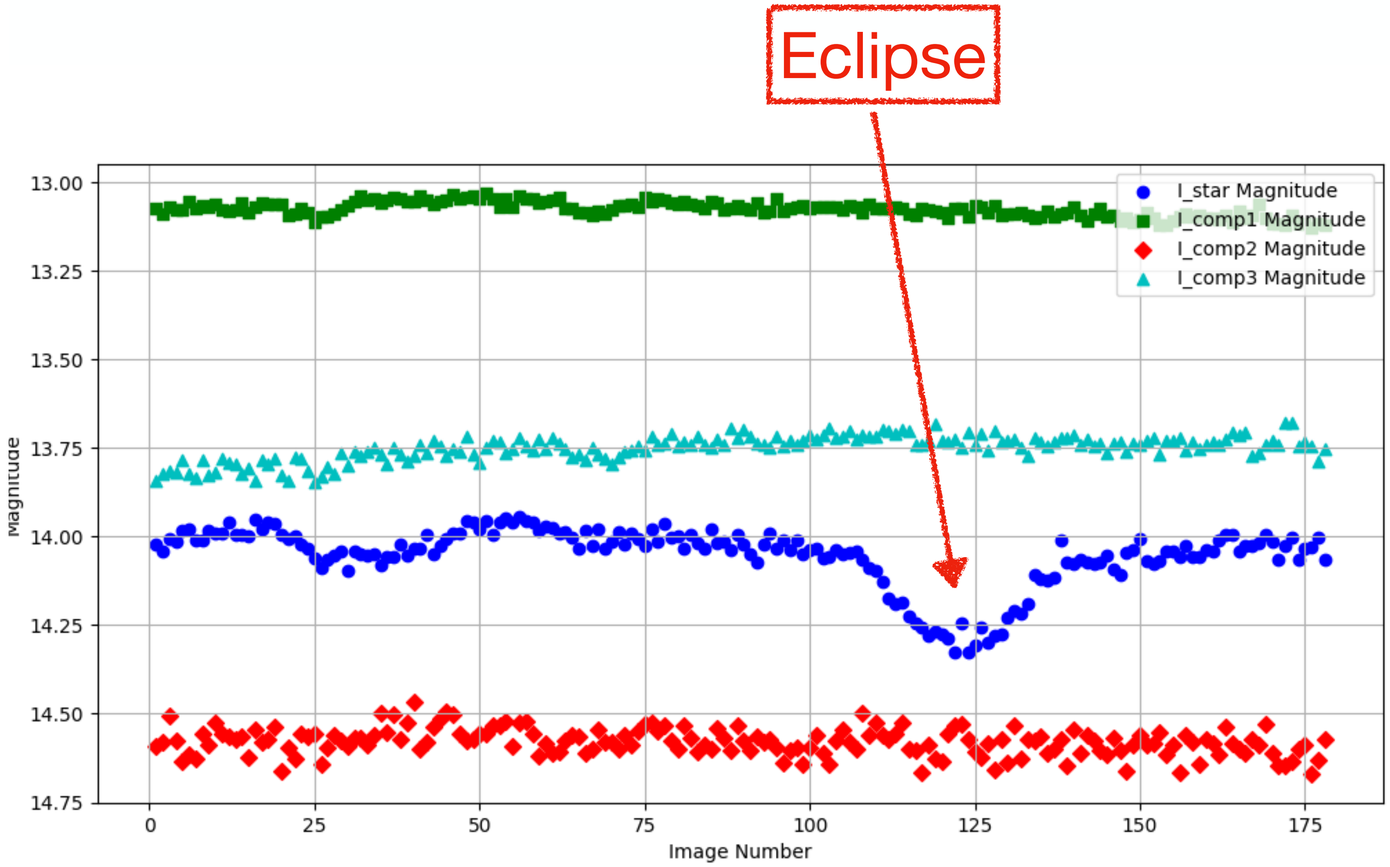


J296.1785+54.8285

Data Reduction I filter - Tracking and Magnitudes



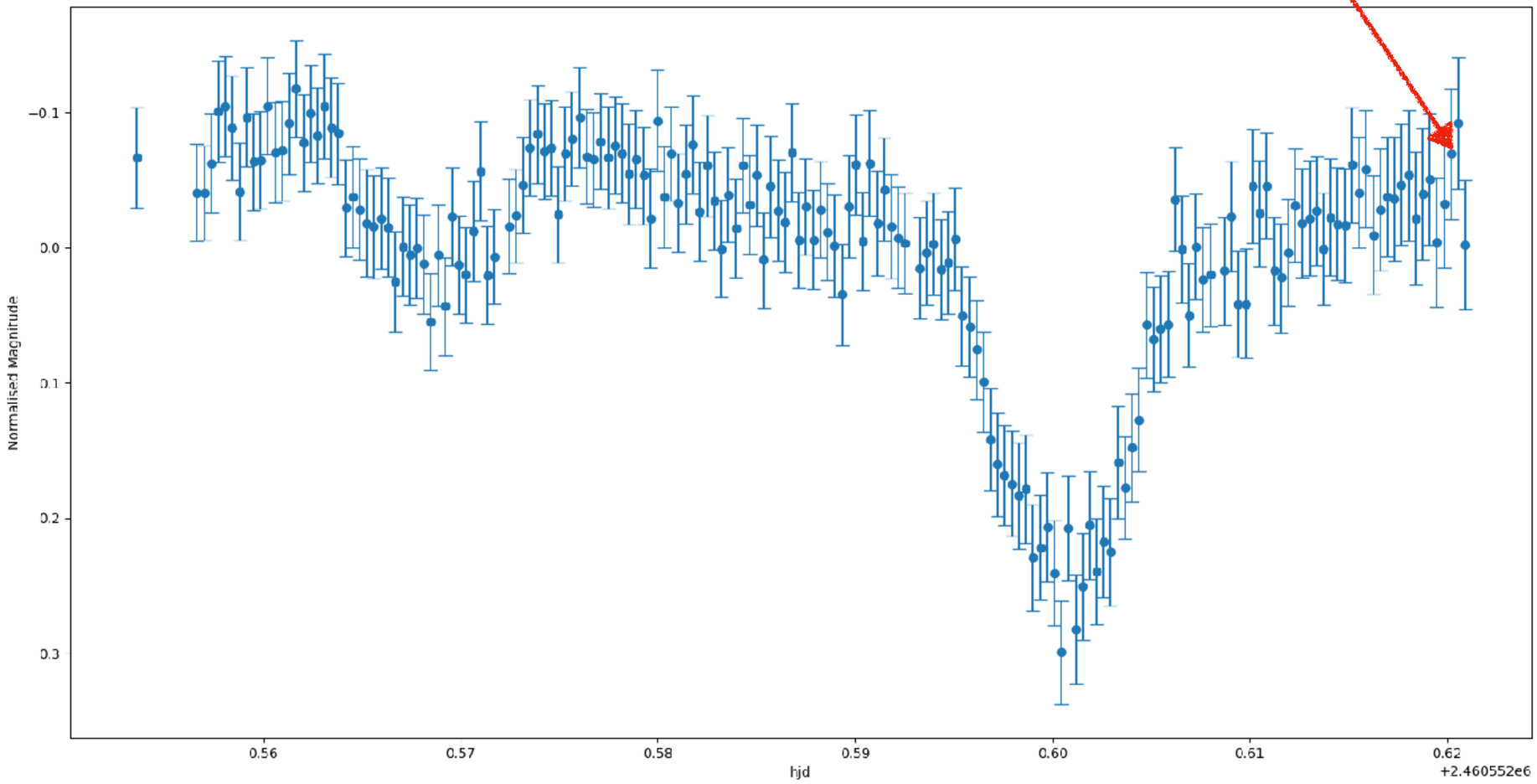




J296.1785+54.8285

Data Reduction I filter - Lightcurve

Missing secondary eclipse due to end of the night and bad data

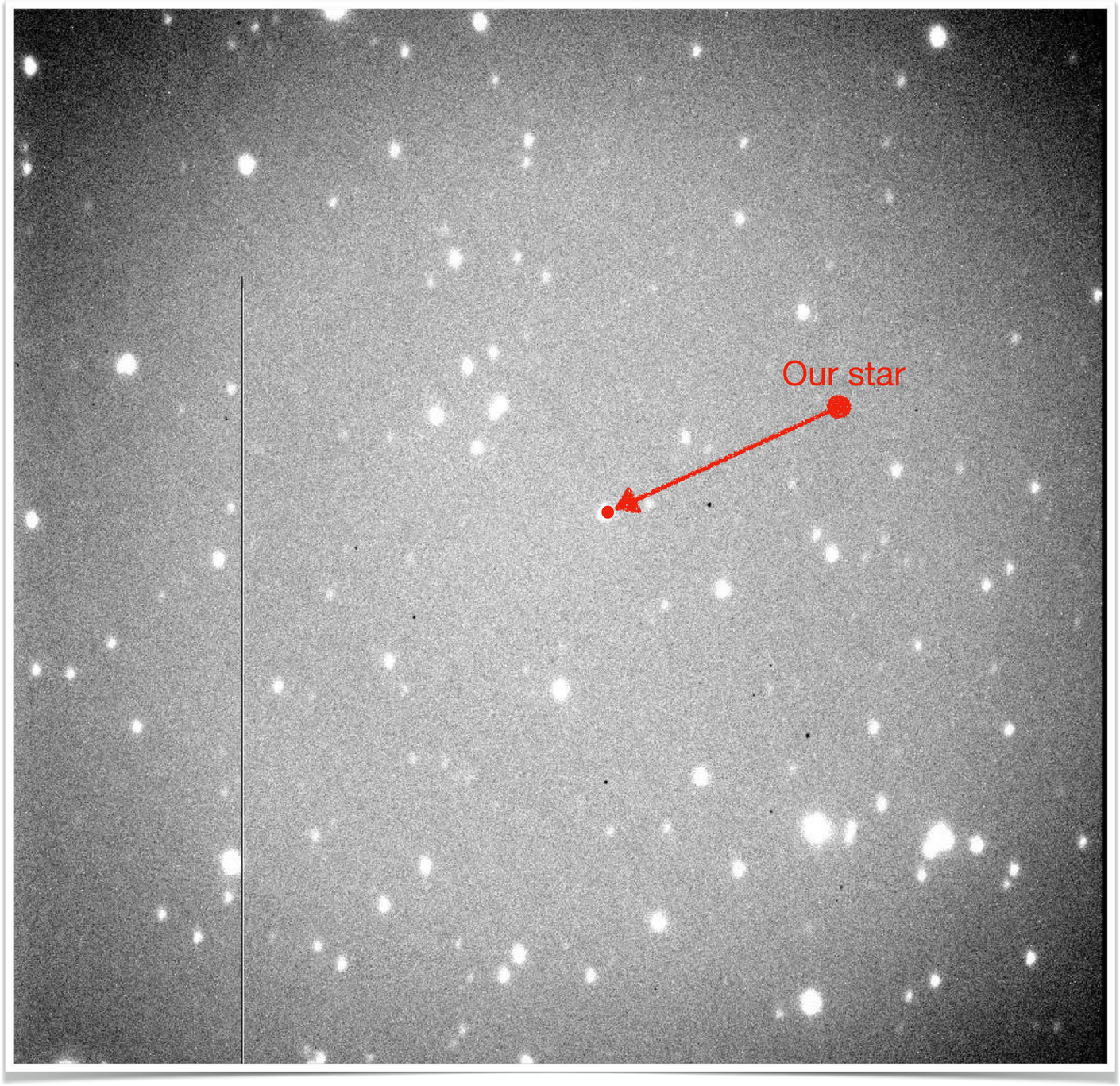


J296.1785+54.8285 r-filter

J296.1785+54.8285

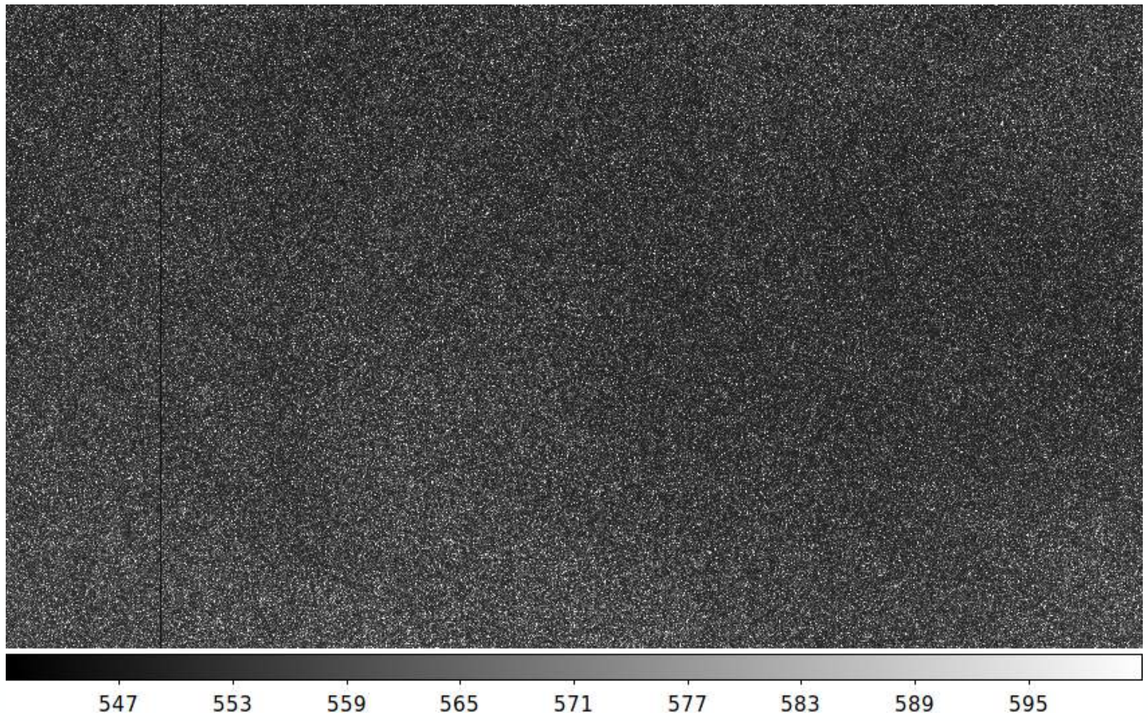
Observation r filter

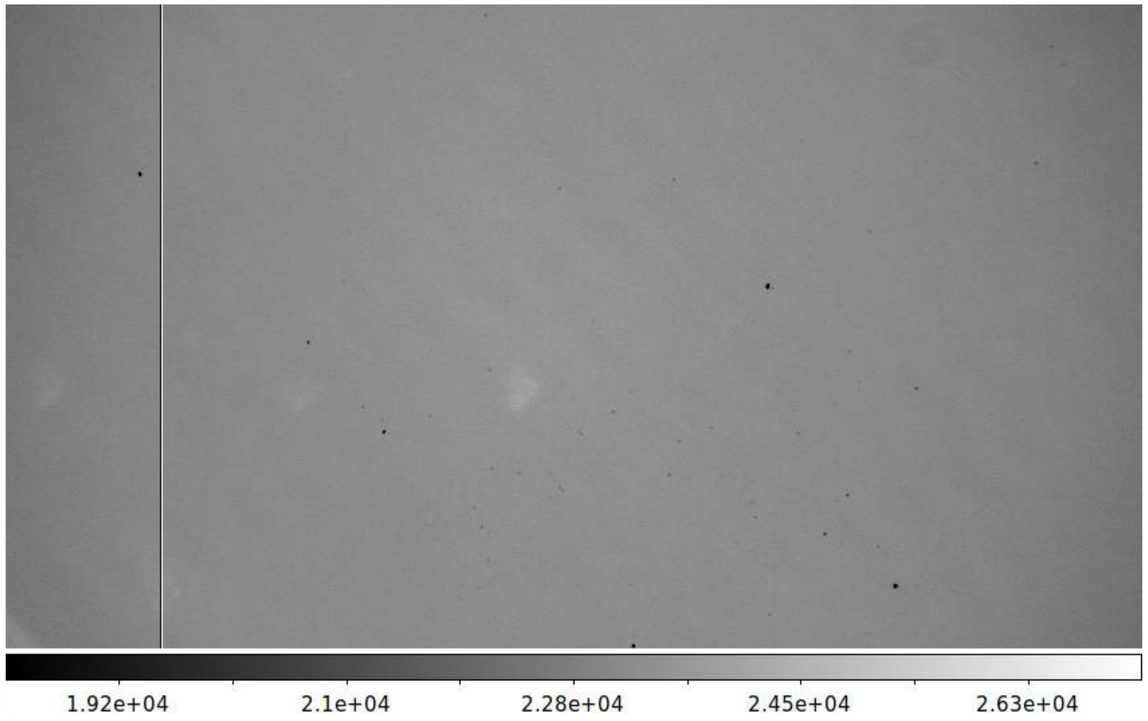
- 18:46 UT to 21:33 UT
- **20s** exposures
- Only 3/4 of the frames could be observed because the dome had to be closed due to high humidity



J296.1785+54.8285

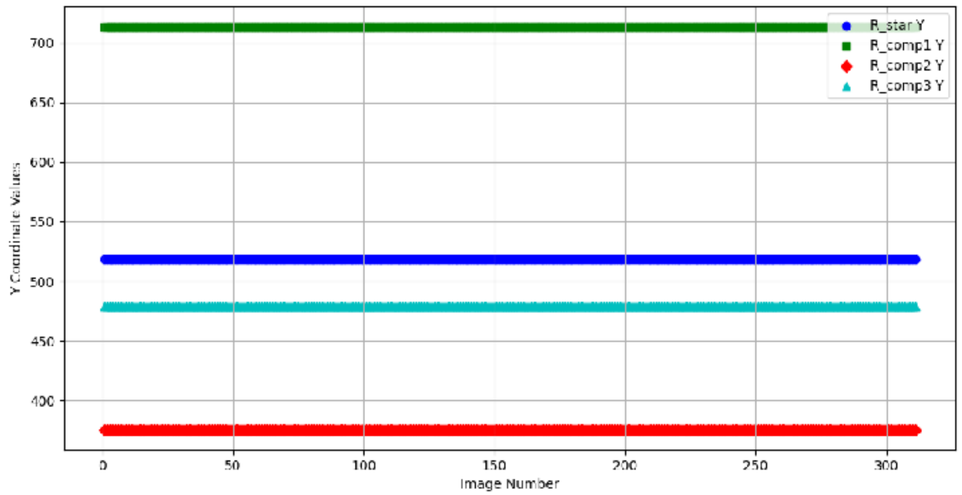
Data Reduction r filter - Master Dark and Flat

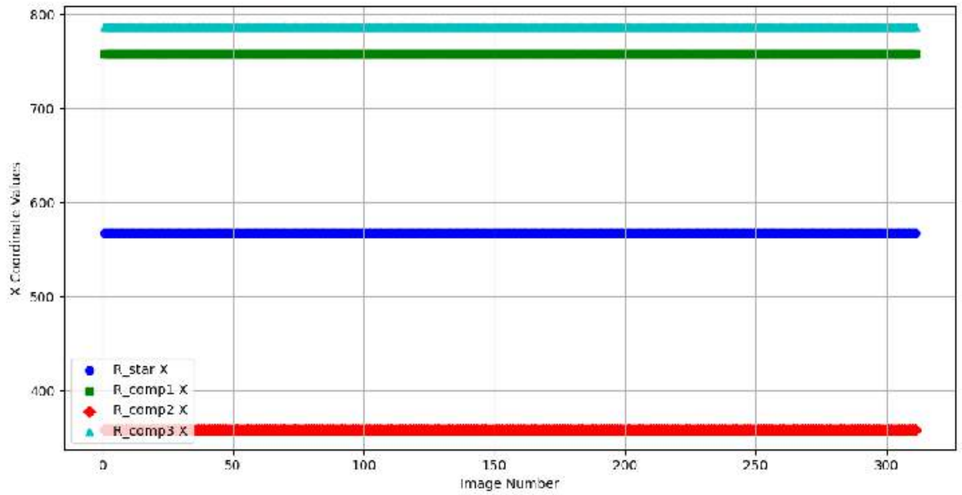


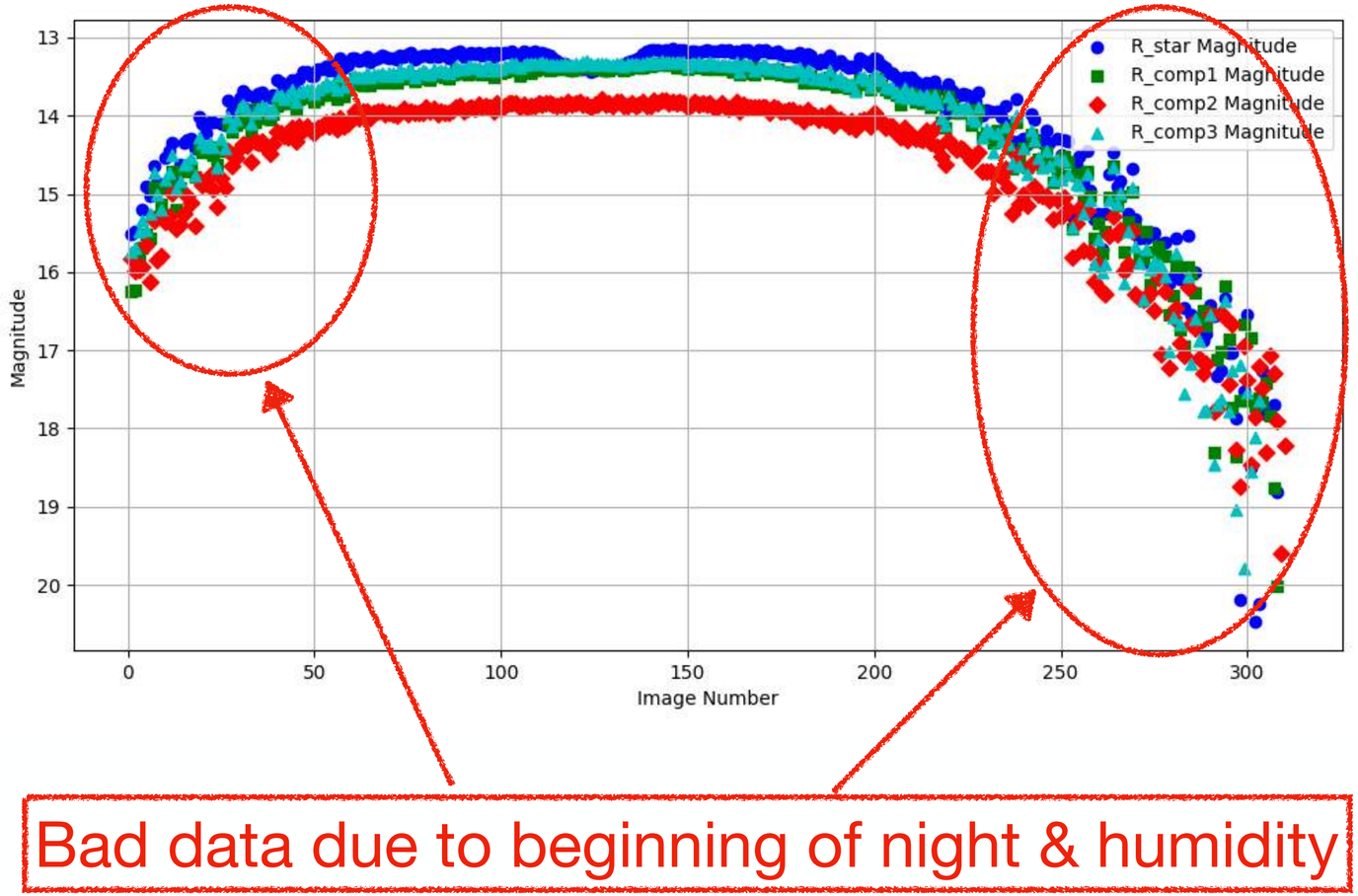


J296.1785+54.8285

Data Reduction r filter - Tracking and Magnitudes

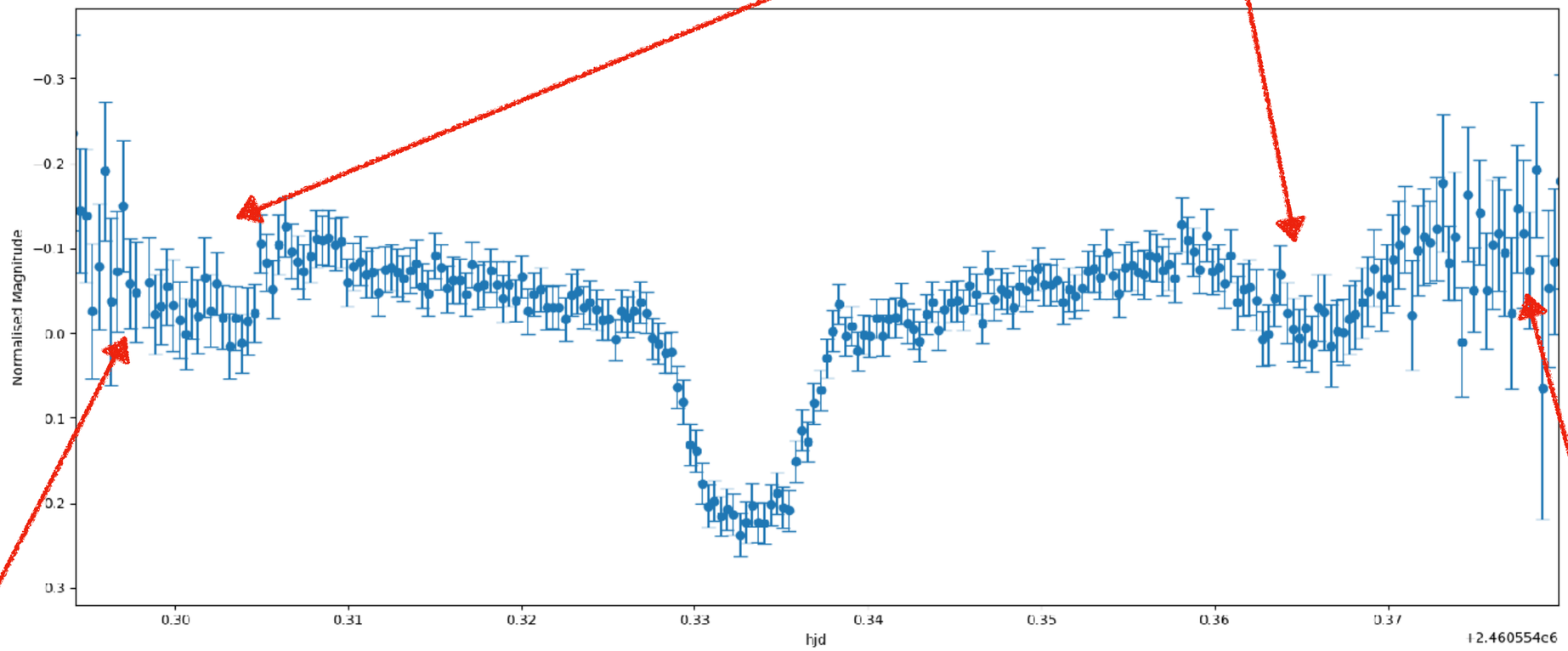






J296.1785+54.8285

Data Reduction r filter - Lightcurve



Secondary Eclipse

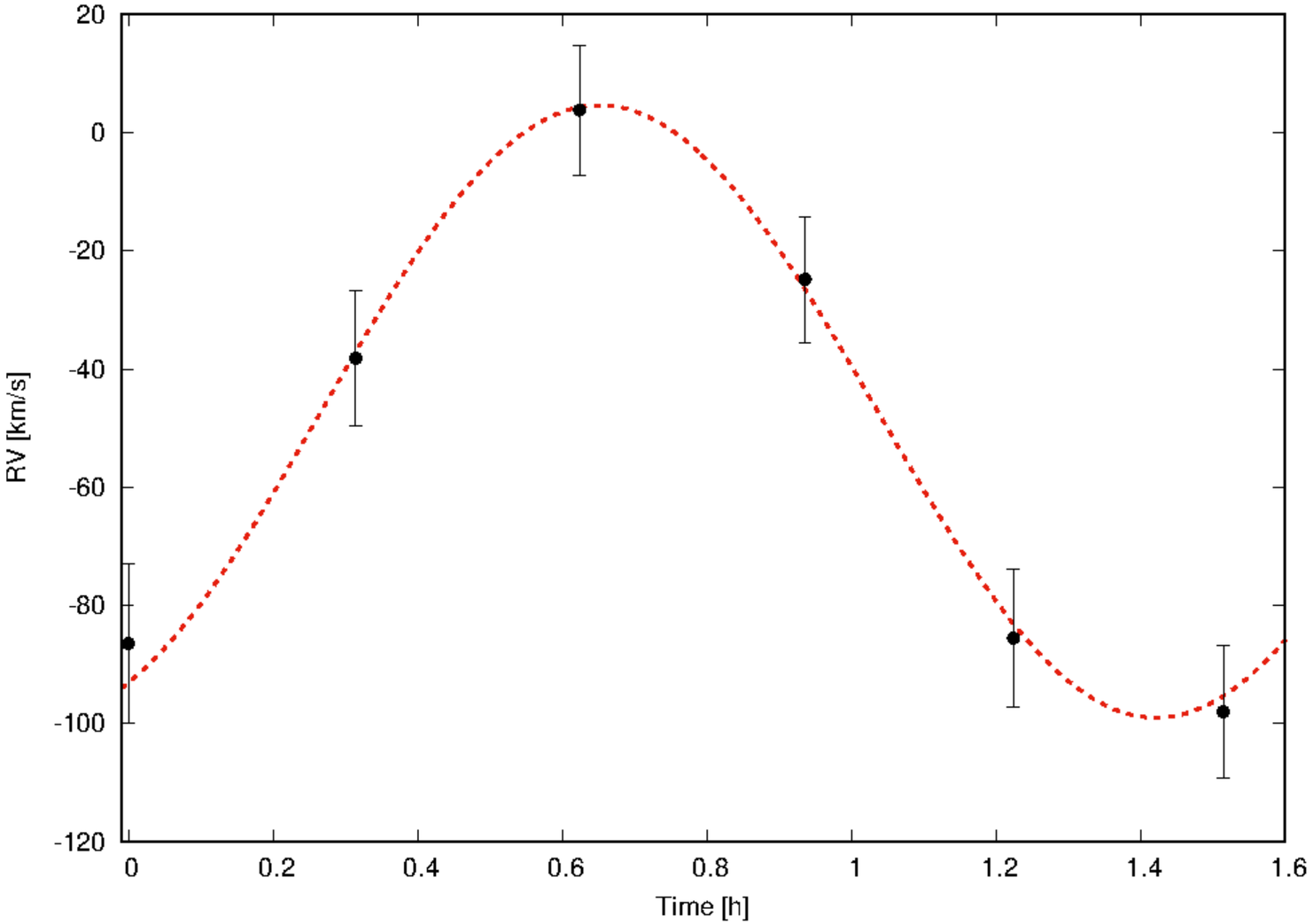
Beginning of night

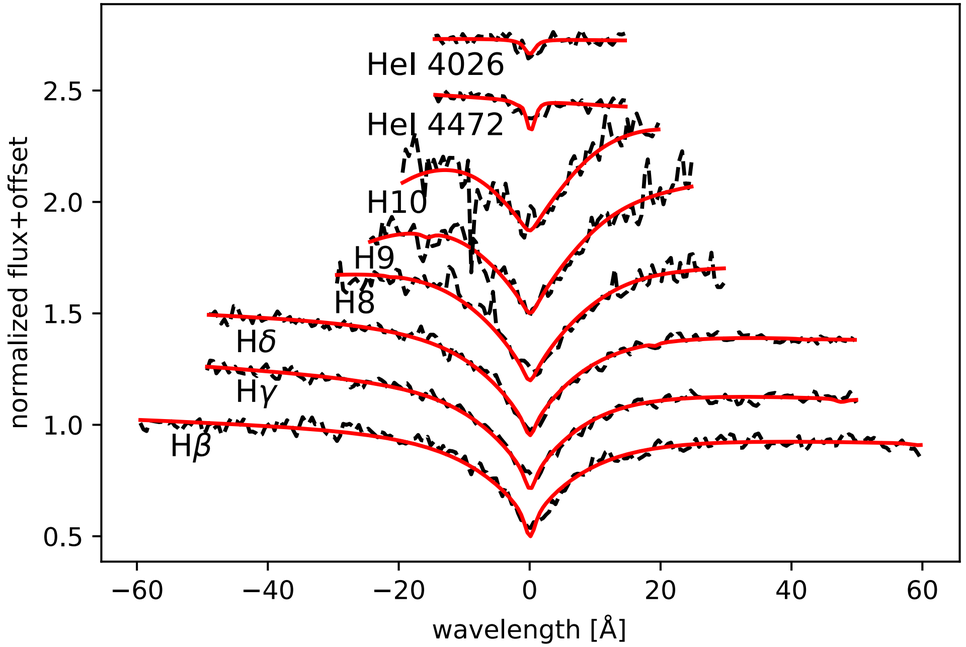
Humidity Spike

J296.1785+54.8285 lightcurve fitting

J296.1785+54.8285

RV-curve

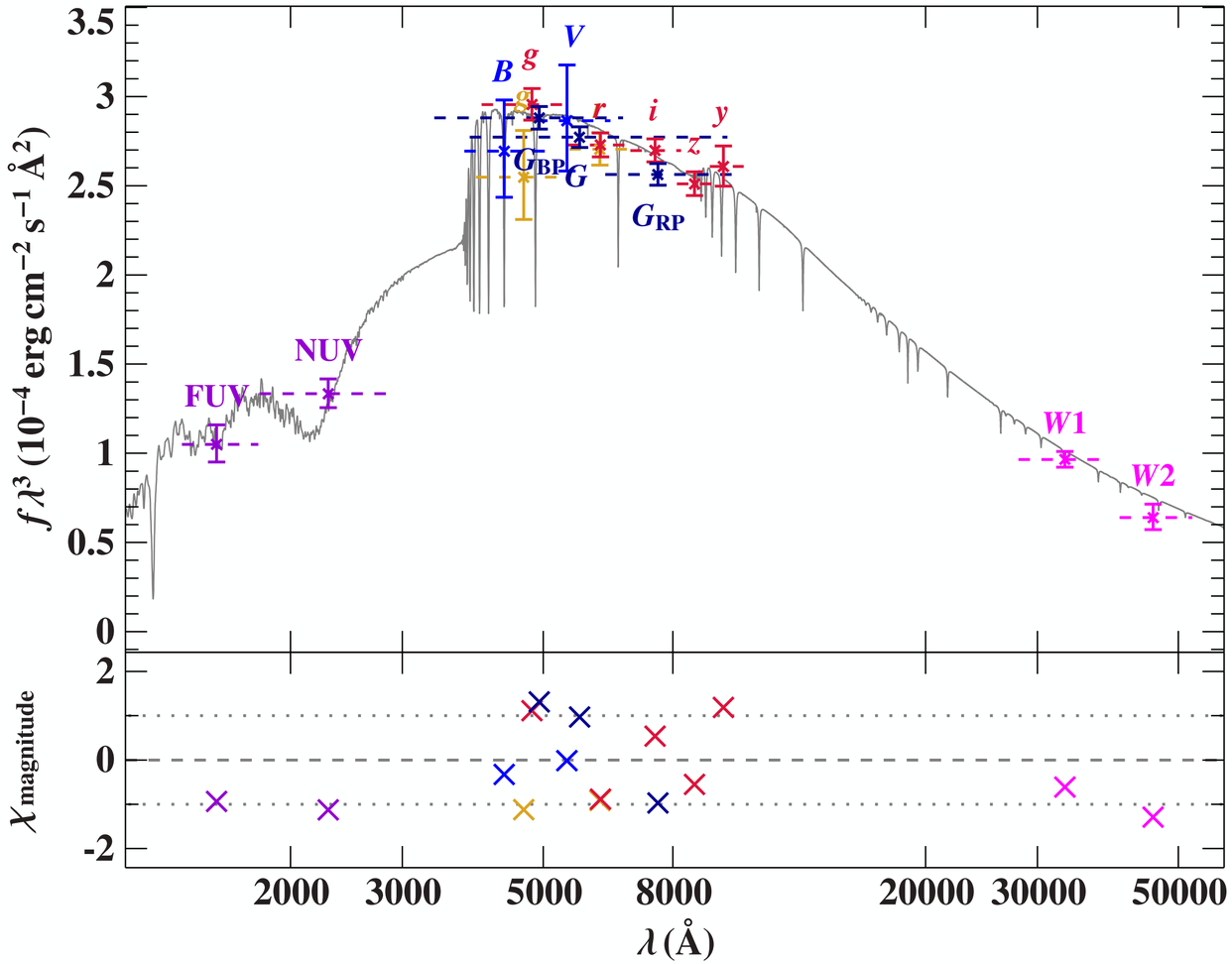




Parameter	Value	Error +/-
Teff (K)	25096	615
logg	5.446	8.7E-02
helium	-2.830	-
K-amplitude (km/s)	52	2

J296.1785+54.8285

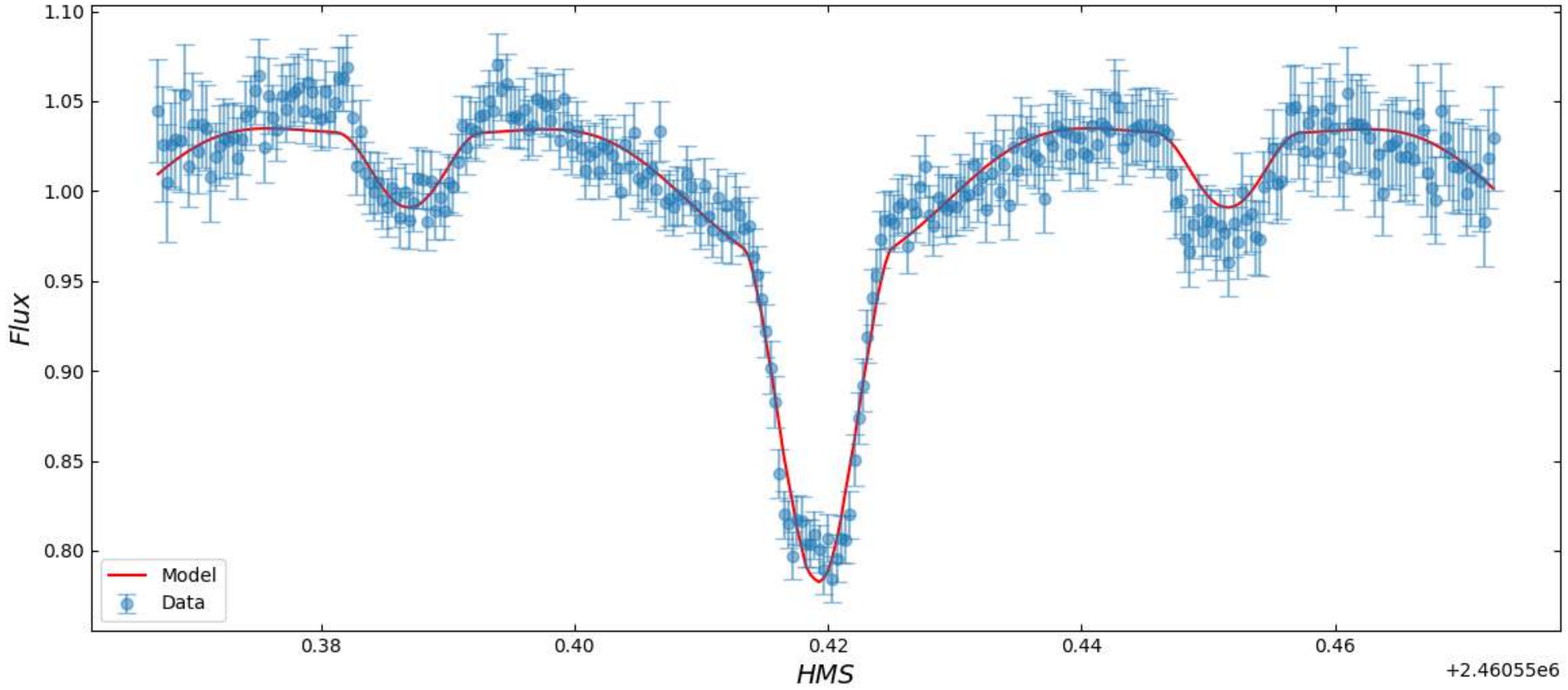
SED Fitting - single fit (use values from RV curve for fit)



Object: Gaia DR3 2138663782338254464	68% confidence interval
Color excess $E(B-V)$ from SFD (1998)	0.160 ± 0.008 mag
Color excess $E(B-V)$ from S&F (2011)	0.138 ± 0.007 mag
Color excess $E(B-V)$ from Stilism (Capitanio+ 2017)	0.071 ± 0.012 mag
Color excess $E(B-V)$ from Bayestar15 (Green+ 2015)	0.065 ± 0.006 mag
Distance from Stilism and $E(44-55)$	$(1.165 \pm 0.000) \times 10^3$ pc
Color excess $E(44-55)$	0.146 ± 0.008 mag
Extinction parameter $R(55)$ (fixed)	3.02
Angular diameter $\log(\Theta\,(\mathrm{rad}))$	-11.236 ± 0.008
Parallax ϖ (*Gaia*, RUWE = 1.11, ZPO = −0.005 mas)	0.65 ± 0.04 mas
Distance d (*Gaia*, mode)	$\left(1.53^{+0.10}_{-0.09}\right) \times 10^3$ pc
Distance d (*Gaia*, median)	$\left(1.54^{+0.10}_{-0.09}\right) \times 10^3$ pc
Effective temperature $T_{\rm eff}$ (prescribed)	25100^{+700}_{-600} K
Surface gravity $\log(g\,(\mathrm{cm\,s^{-2}}))$ (prescribed)	5.45 ± 0.10
Microturbulence ξ (fixed)	0 km s^{-1}
Metallicity z (fixed)	0 dex
Helium abundance $\log(n(\mathrm{He}))$ (prescribed)	-2.80 ± 0.10
Radius $R = \Theta/(2\varpi)$ (mode)	$0.197^{+0.013}_{-0.012}\,R_\odot$
(median)	$0.198^{+0.013}_{-0.012}\,R_\odot$
Mass $M = gR^2/G$ (mode)	$0.37^{+0.12}_{-0.09}\,M_\odot$
(median)	$0.40^{+0.12}_{-0.10}\,M_\odot$
Luminosity $L = (R/R_\odot)^2(T_{\rm eff}/T_{\rm eff,\odot})^4$ (mode)	$13.7^{+2.4}_{-2.0}\,L_\odot$
(median)	$14.0^{+2.4}_{-2.0}$
Gravitational redshift $v_{\rm grav} = GM/(Rc)$	$1.22^{+0.34}_{-0.27}$ km s^{-1}
Escape velocity $v_{\rm esc} = \sqrt{2gR}$	870^{+110}_{-100} km s^{-1}
Generic excess noise $\delta_{\rm excess}$	0.022 mag
Reduced χ^2 at the best fit	1.00

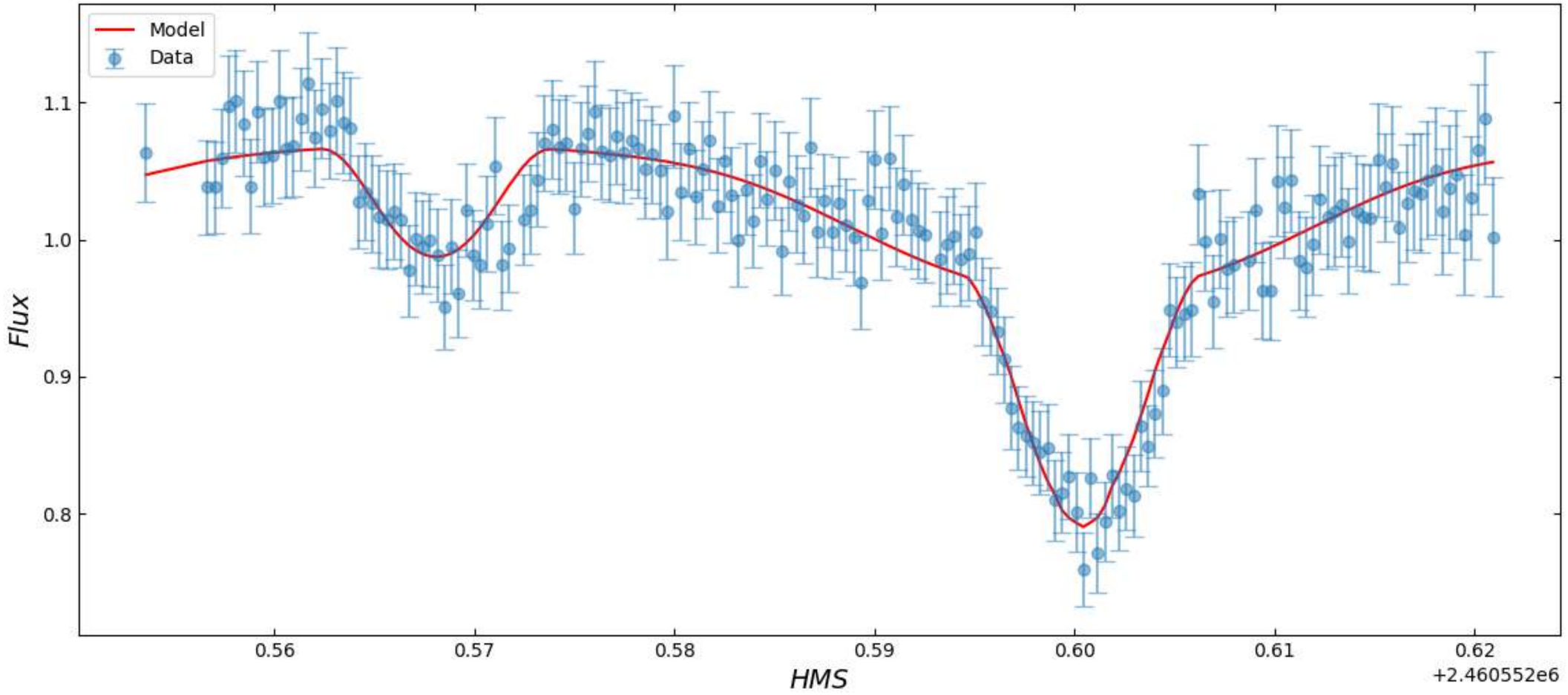
J296.1785+54.8285

Lightcurve Fitting g Filter



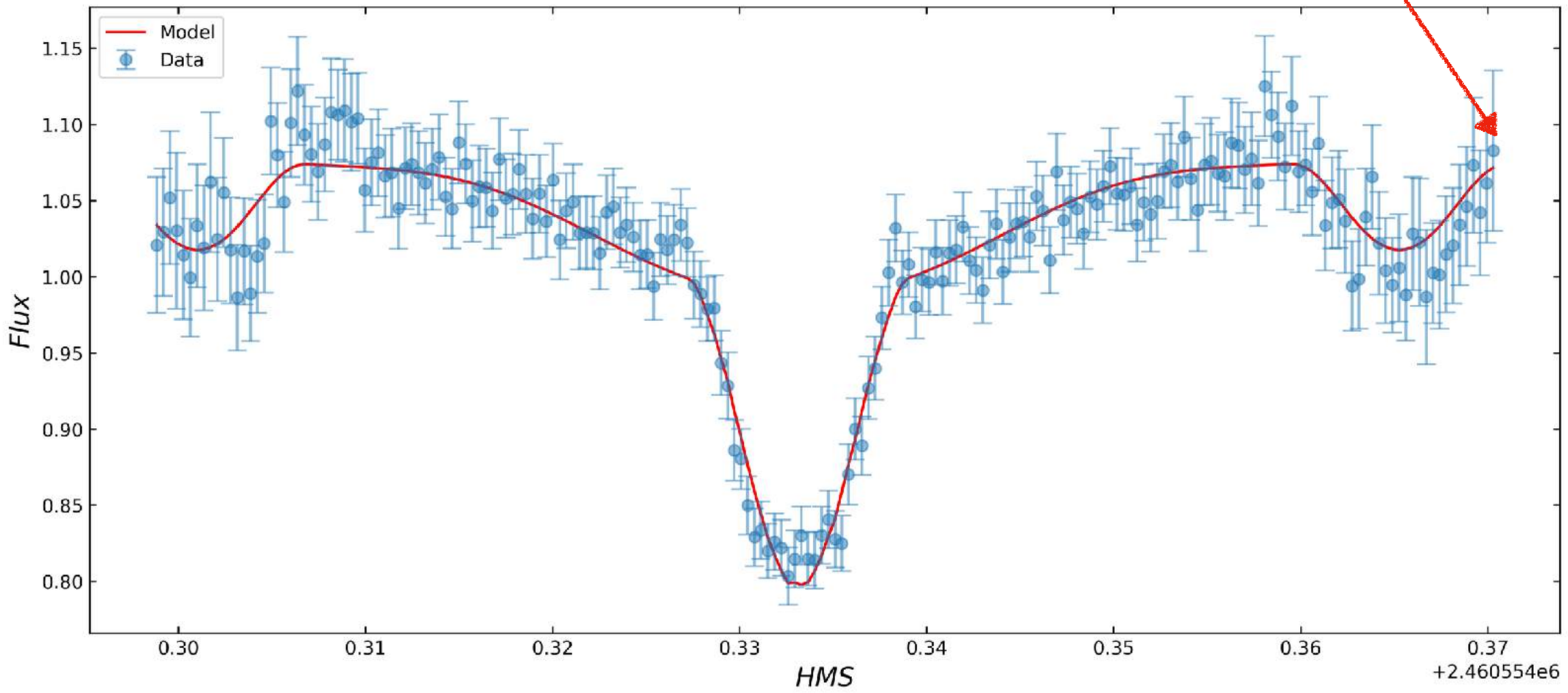
J296.1785+54.8285

Lightcurve Fitting I Filter



J296.1785+54.8285

Lightcurve Fitting r Filter



J296.1785+54.8285

Lightcurve Fitting Parameter Results

$$a = \frac{P}{2\pi} \frac{K_1}{\sin i} \left(\frac{1}{q} + 1 \right)$$

$$R_{1,2} = \frac{r_{1,2}}{a} \cdot a$$

$$M_2 = q \cdot M_1$$

Filter	Period (days)	K-amplitude (km/s)	Orbital separation (AU)	Mass ratio	Mass sdB (solar mass)	Radius sdB (solar radii)	Mass companion (solar masses)	Radius companion (solar radii)	Inclination	Temperature sdB (K)	Temperature companion (K)
i-filter	0.0646 +/- 0.0001	52+/-2	0.0022 +/- 0.00009	0.3123 +/- 0.002	0.40 +0.12/ -0.10	0.1980 +0.013/ -0.012	0.1249 +/- 0.0487	0.1063 +/- 0.0067	71.642 +/- 1	25100 +700/ -600	3000 (fixed)
r-filter	0.0642 +/- 0.0001	52+/-2	0.0023 +/- 0.0001	0.3622 +/- 0.002	0.40 +0.12/ -0.10	0.1980 +0.013/ -0.012	0.1448 +/- 0.0565	0.1256 +/- 0.0076	70.652 +/- 1	25100 +700/ -600	3000 (fixed)
g-filter	0.0646 +/- 0.0001	52+/-2	0.0024 +/- 0.0001	0.4685 +/- 0.002	0.40 +0.12/ -0.10	0.1980 +0.013/ -0.012	0.1874 +/- 0.0731	0.1381 +/- 0.0080	68.649 +/- 1	25100 +700/ -600	3000 (fixed)

Highly fit-dependent!

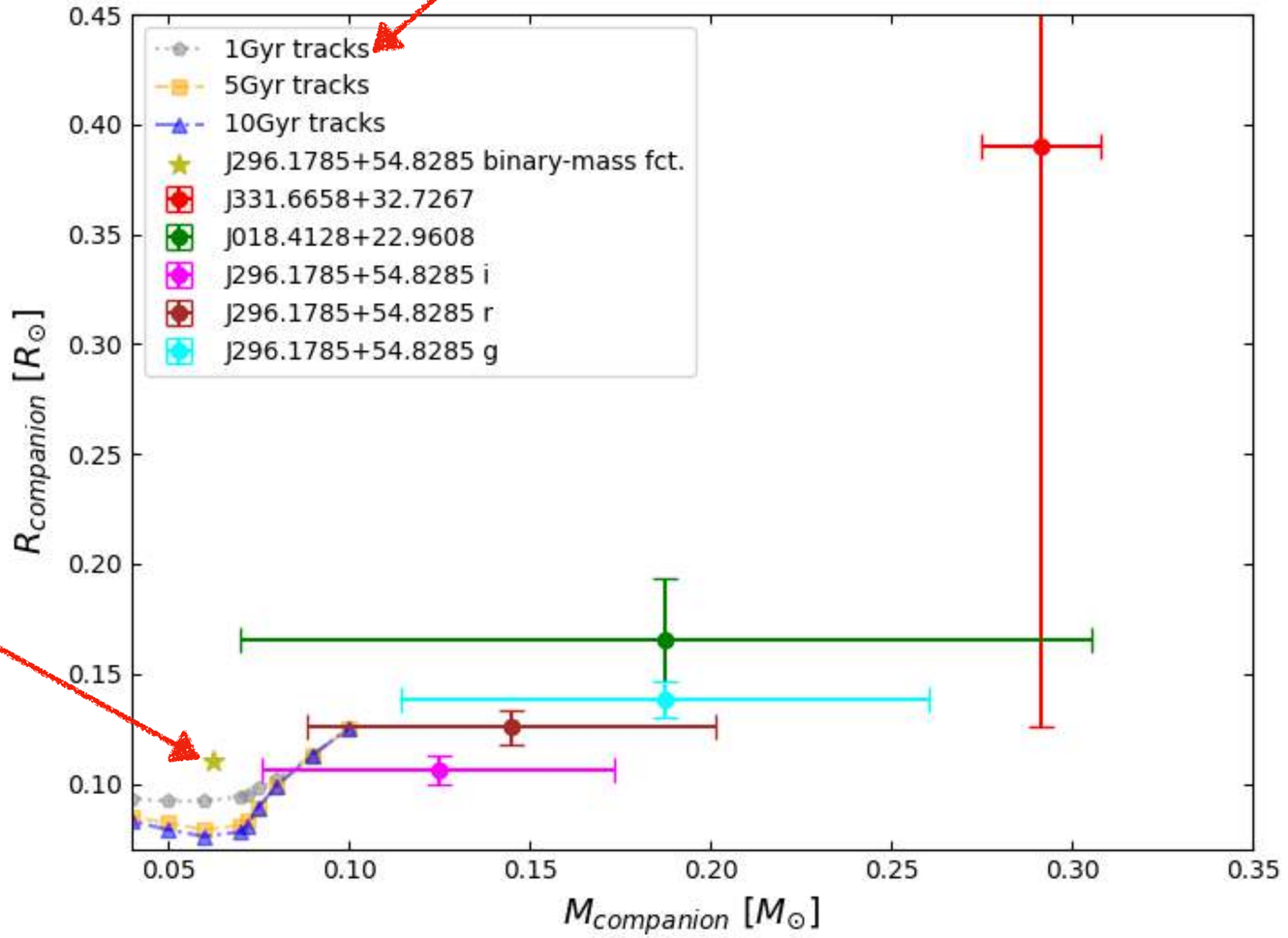
Lightcurve SED

Mass-Radius Relation

Companion

Cool brown dwarf evolutionary tracks (Baraffe et al. 2003)

J296 with Binary-mass fit. solution!



Thank you for your attention!