

# Photometry Project

Ondrejov Workshop 2024

Supervisor: Harry Dawson and Max Pritzkeleit

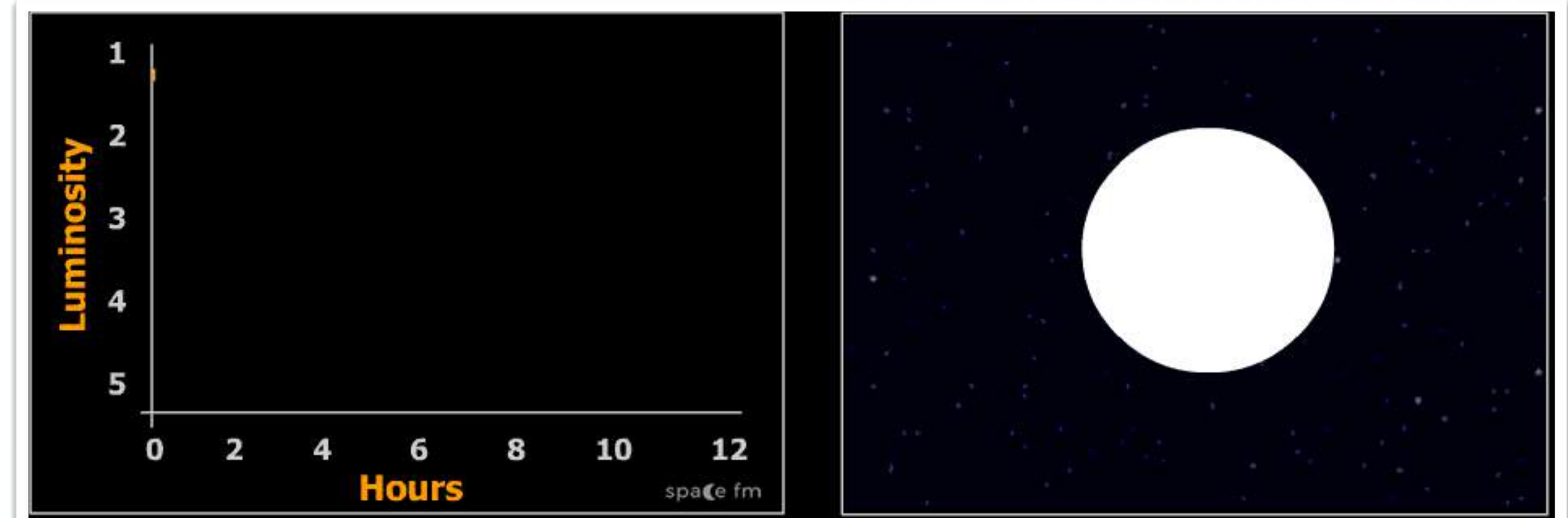
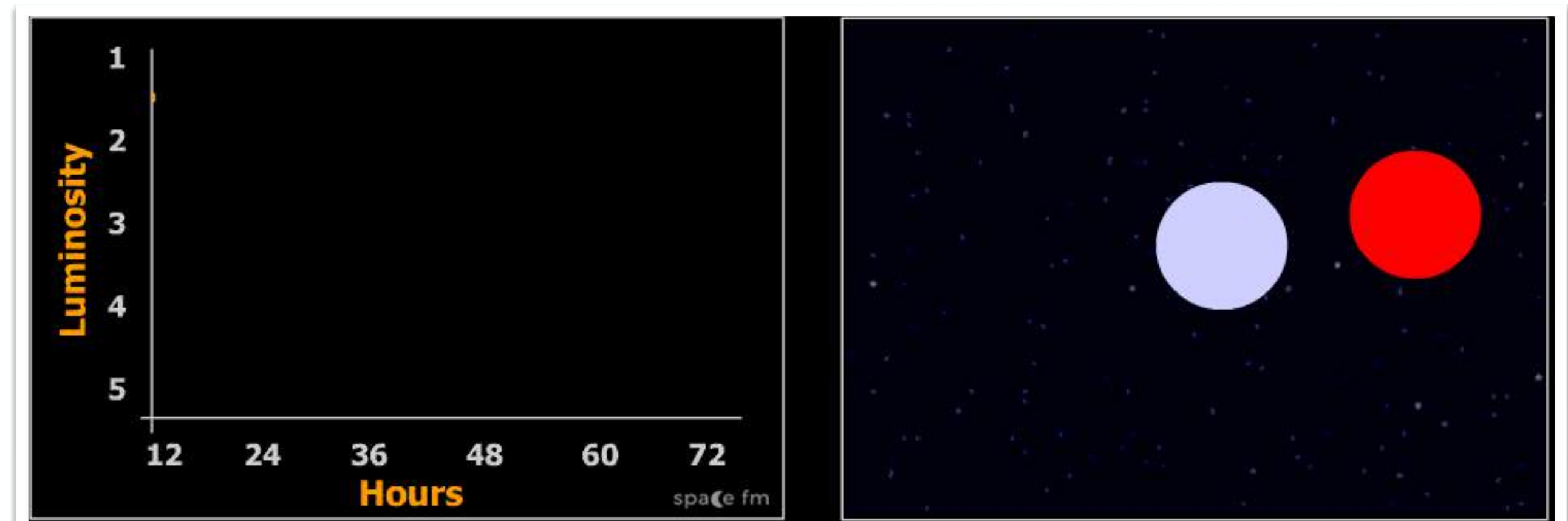
Sarvesh S. Bhogaokar, Adéla Čuchnová, Oliver Steppohn 06.09.2024



# Introduction

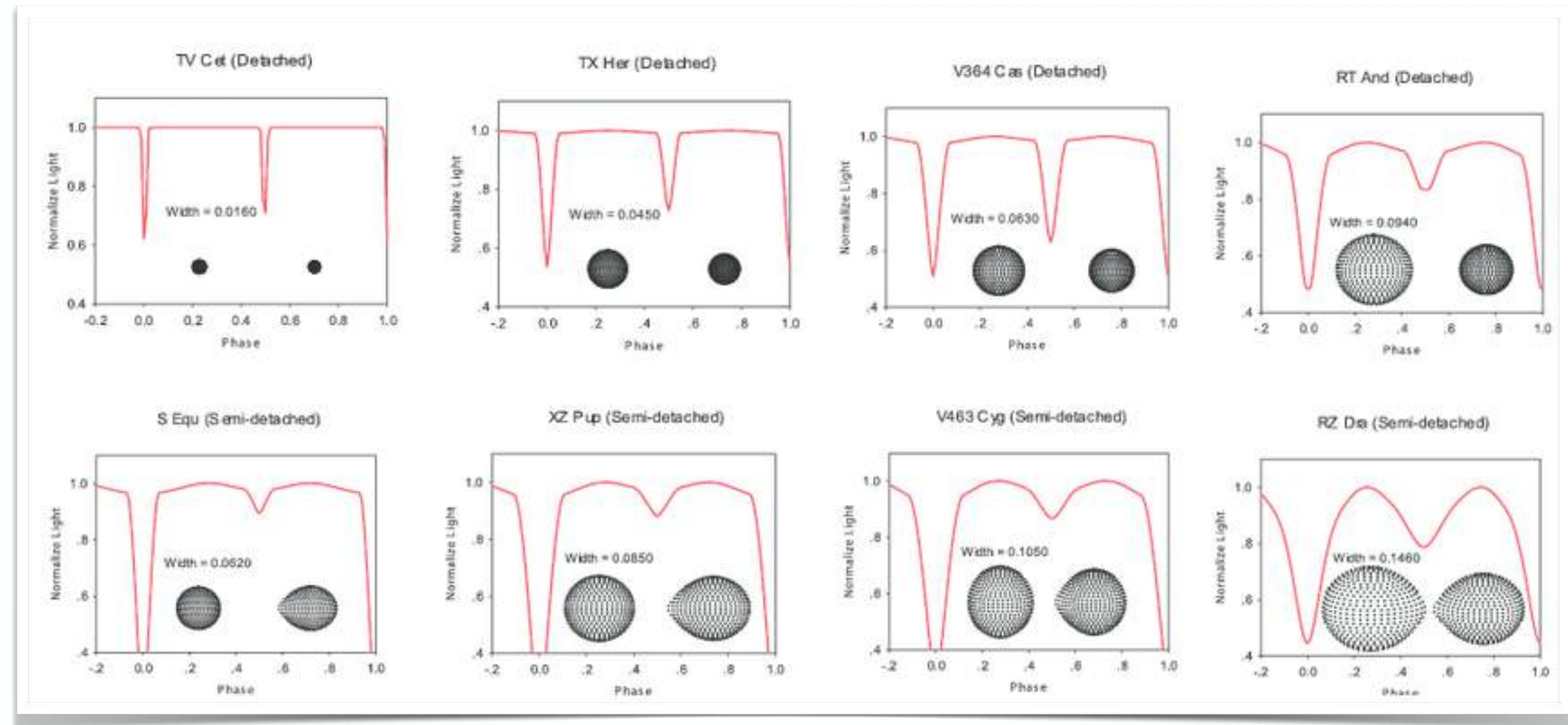
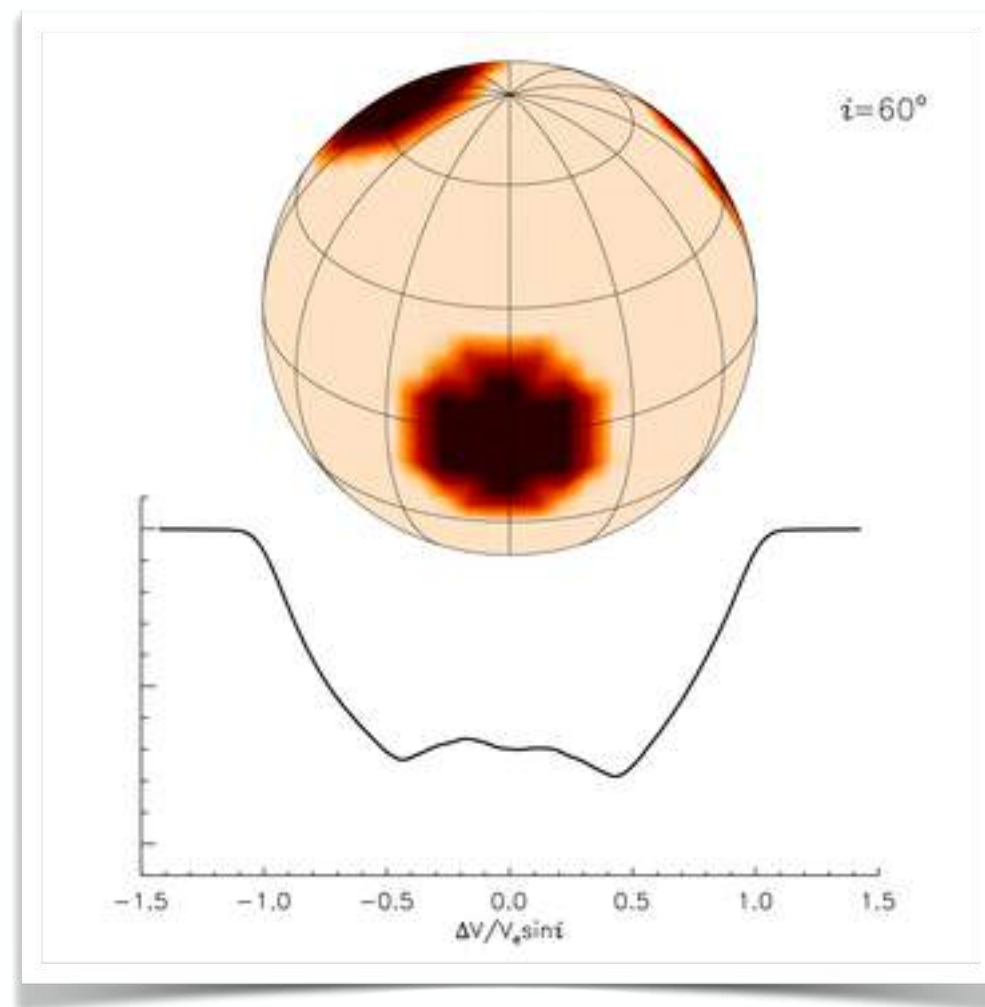
# Variable Stars

- Stars that change their apparent magnitude in time
- Two main types of variable stars:
  1. Intrinsic variables
  2. Extrinsic variables



# Extrinsic variables

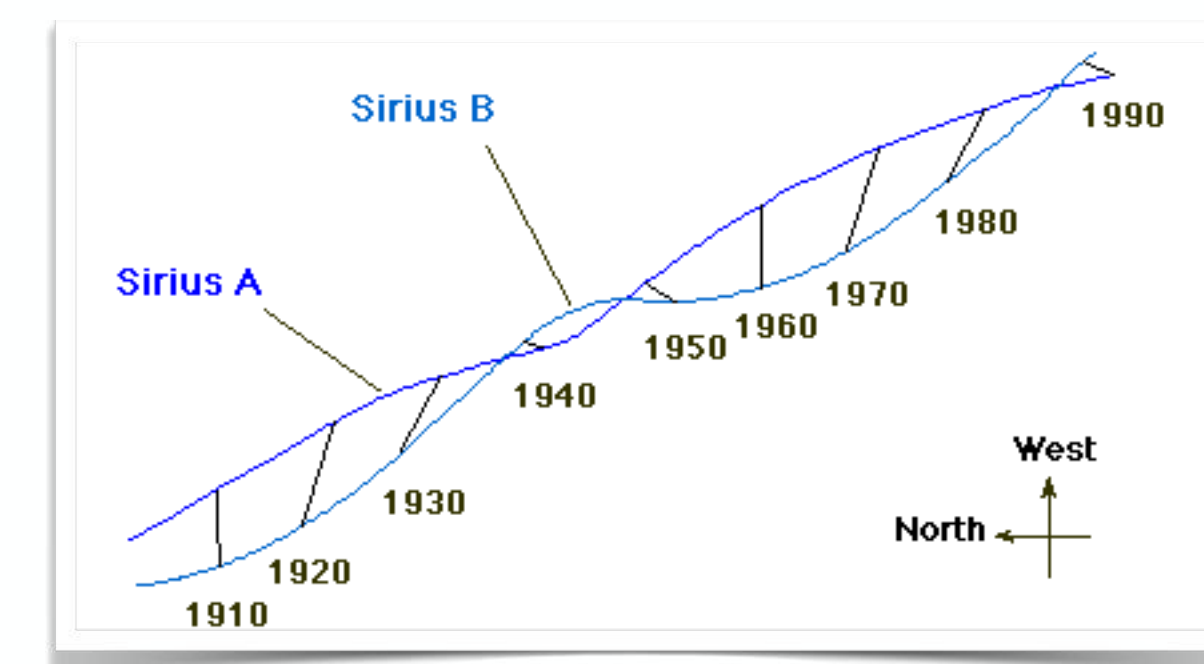
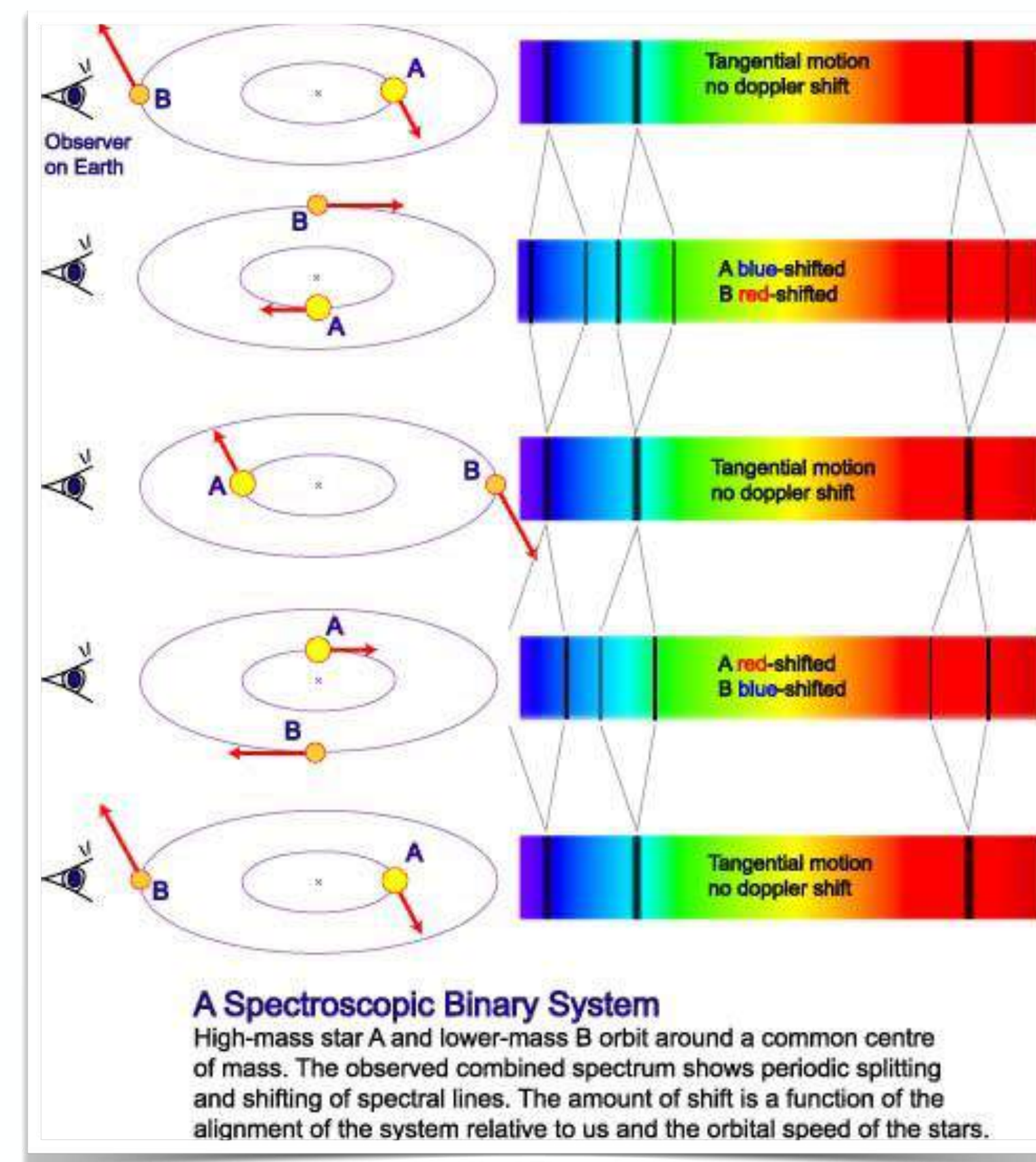
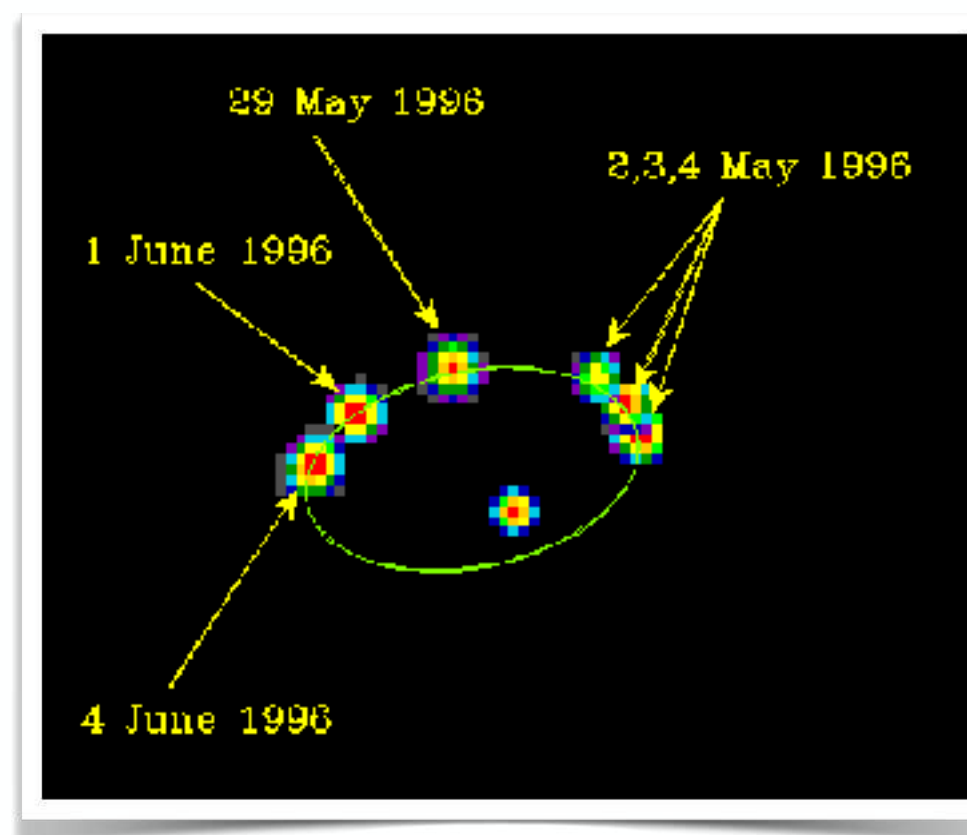
- Two main types of extrinsic variables:
  1. Rotating variables
  2. Eclipsing binaries





# 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

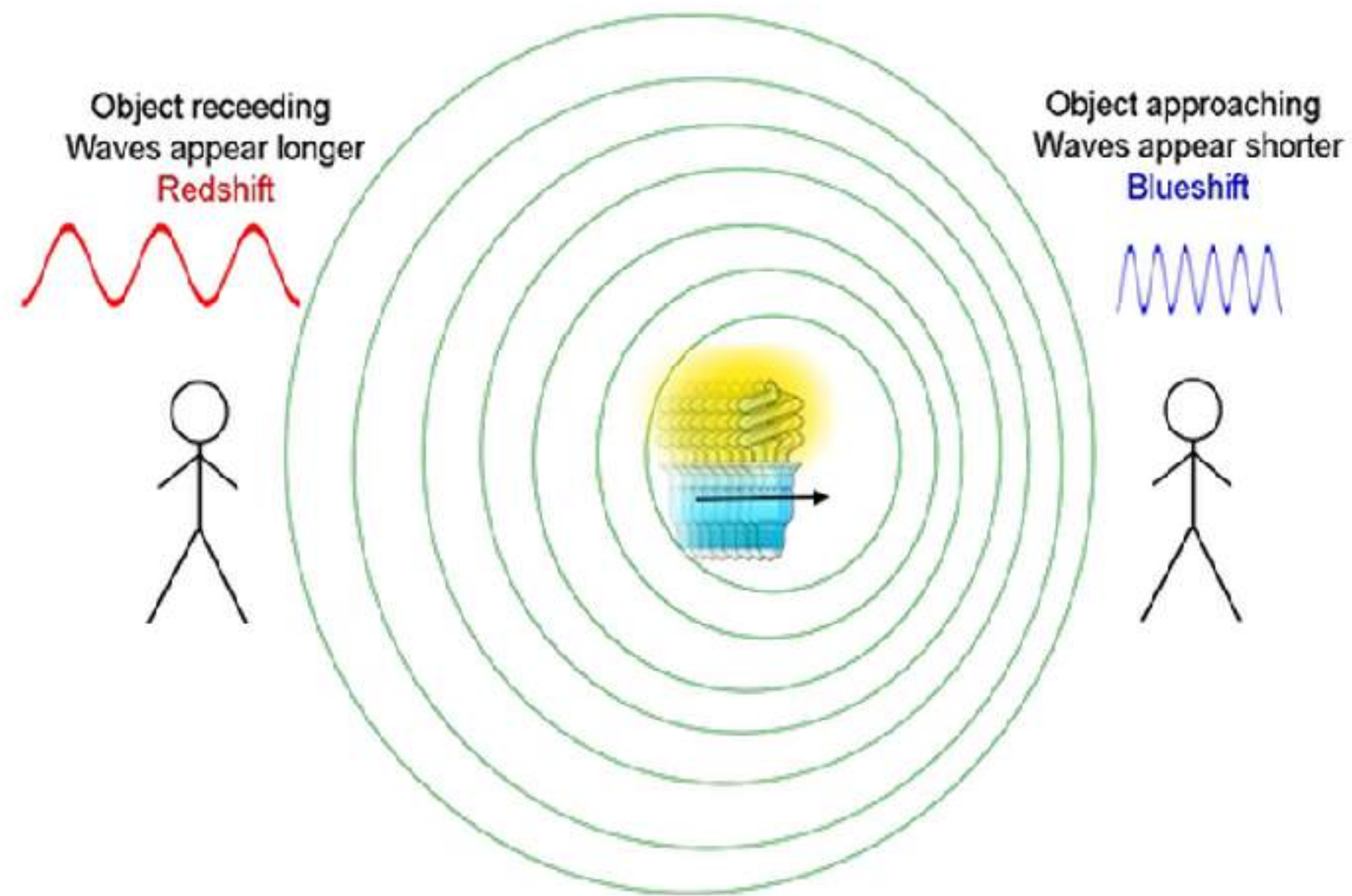


# Theoretical Background



# Theoretical Background

## Spectroscopic Binaries



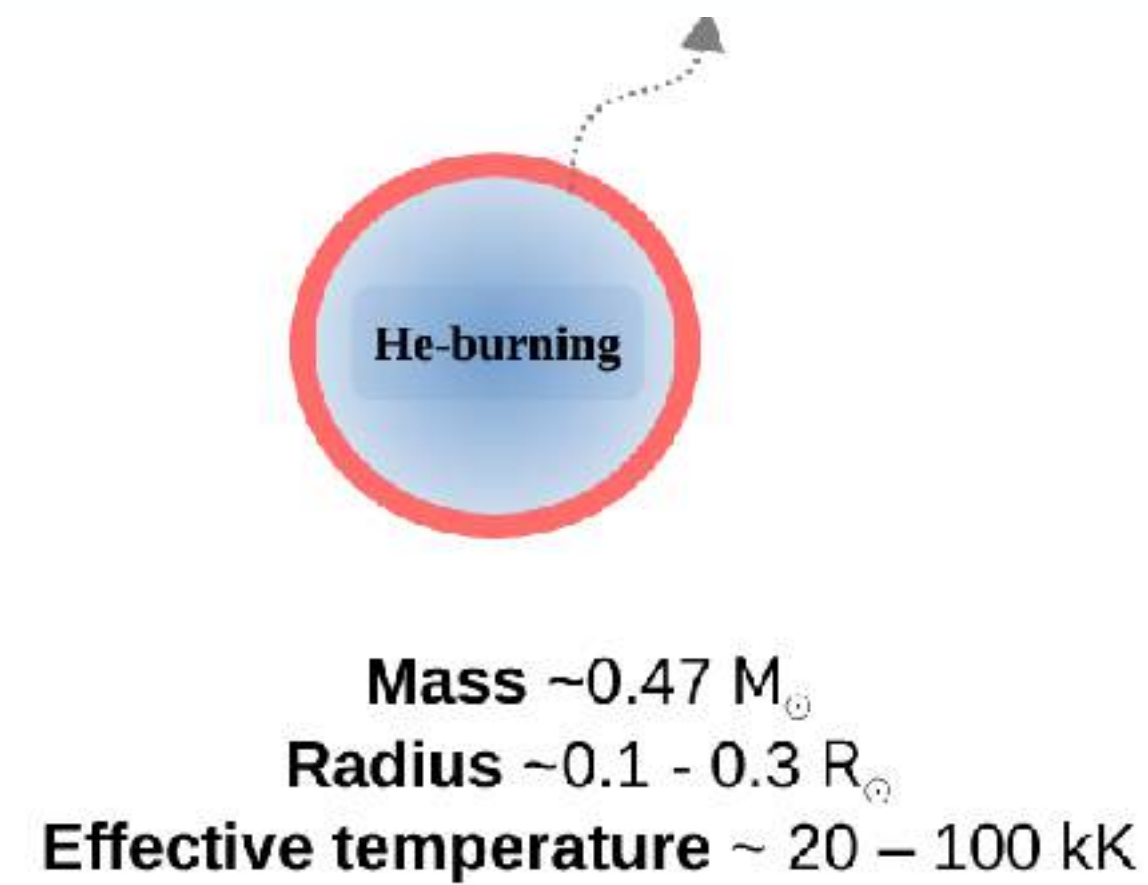
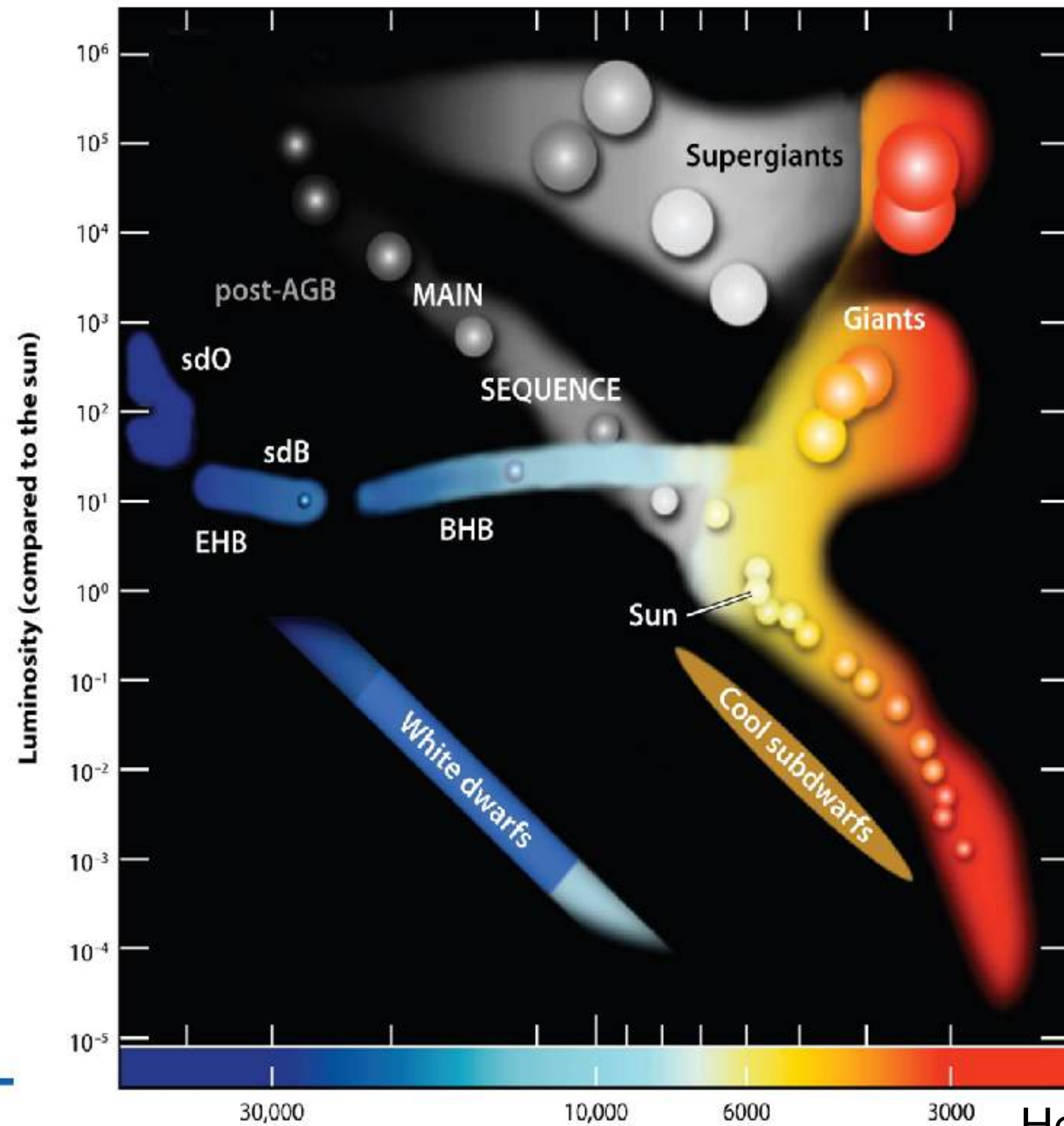
- Components close together
- Periodic Doppler Shift in spectral lines
- SB1: Only one spectrum visible
- SB2: Both spectra are visible
- SB2 system usually:  $i=90$  degrees: masses can be determined for both the components

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

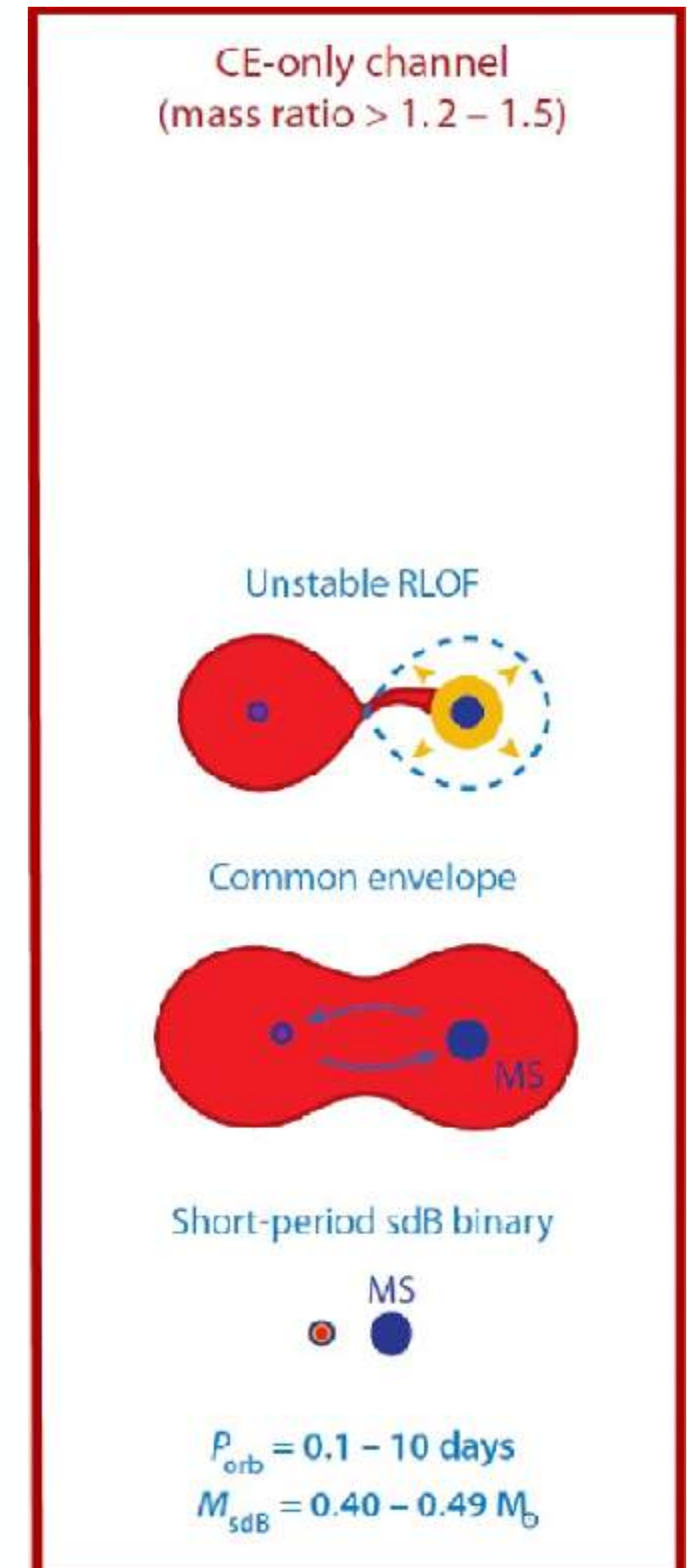


# Hot Subdwarfs

## sdO/Bs



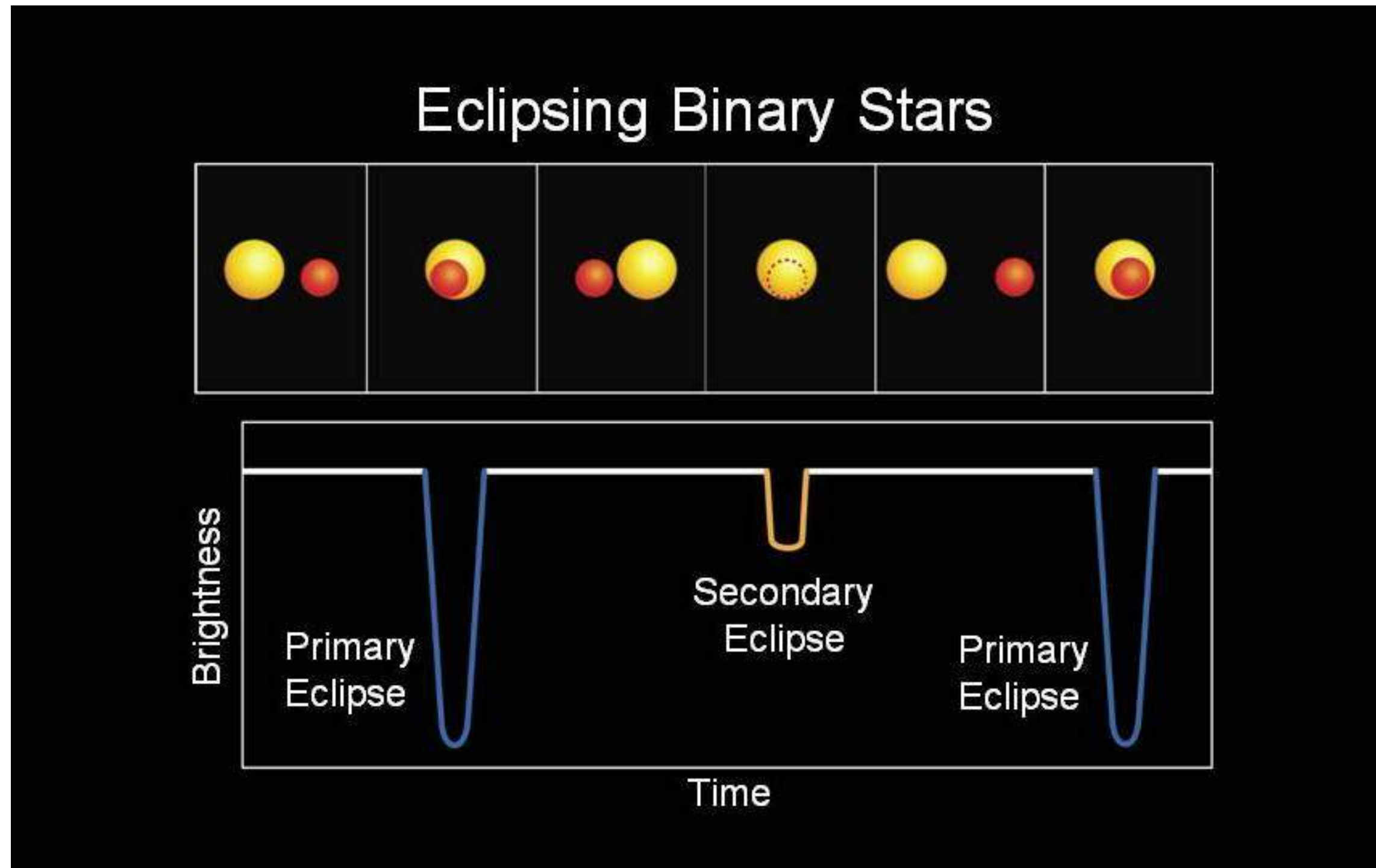
- Only consider sdBs in Binaries
- Companions: MS /Brown Dwarf



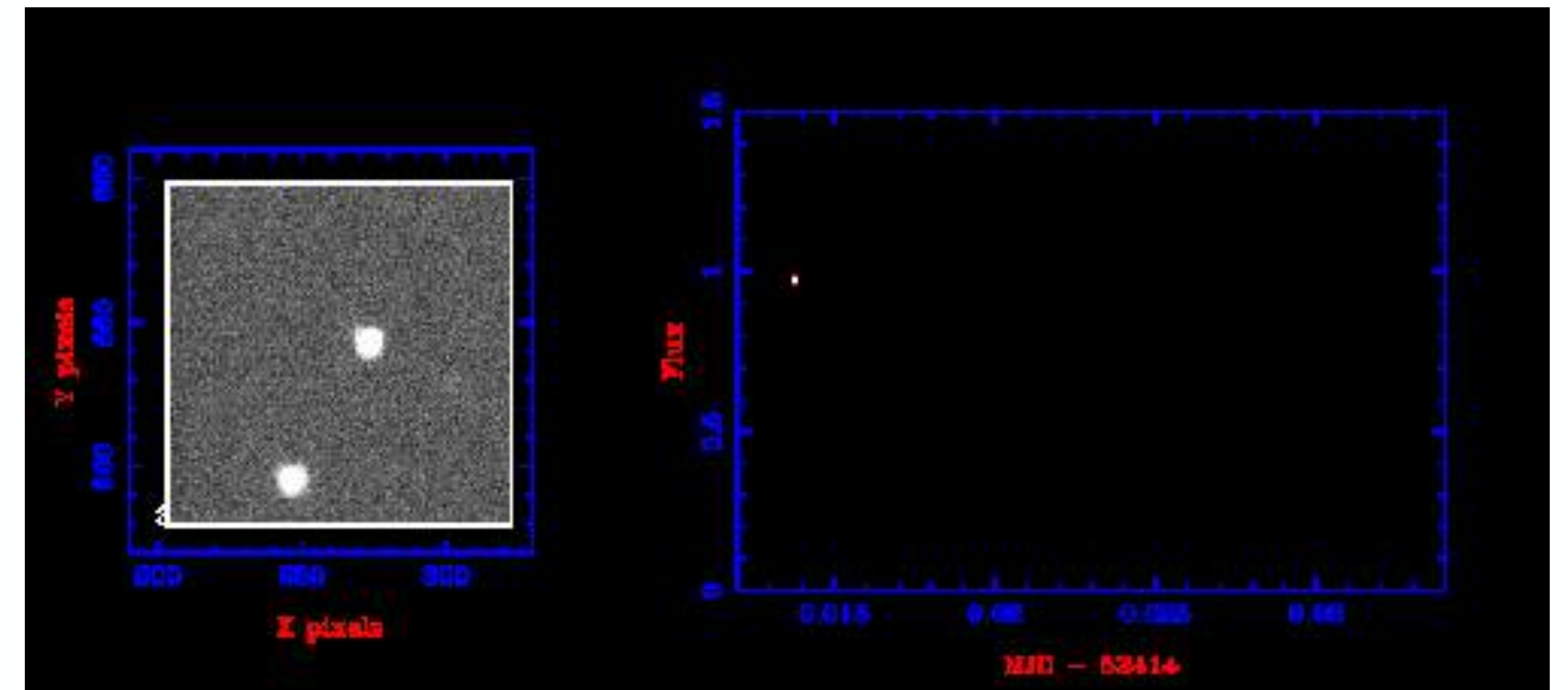
Han et al. (2002,2003)

# Hot Subdwarfs

## Photometry Lightcurves sdO/Bs



[kepler.nasa.gov](http://kepler.nasa.gov)



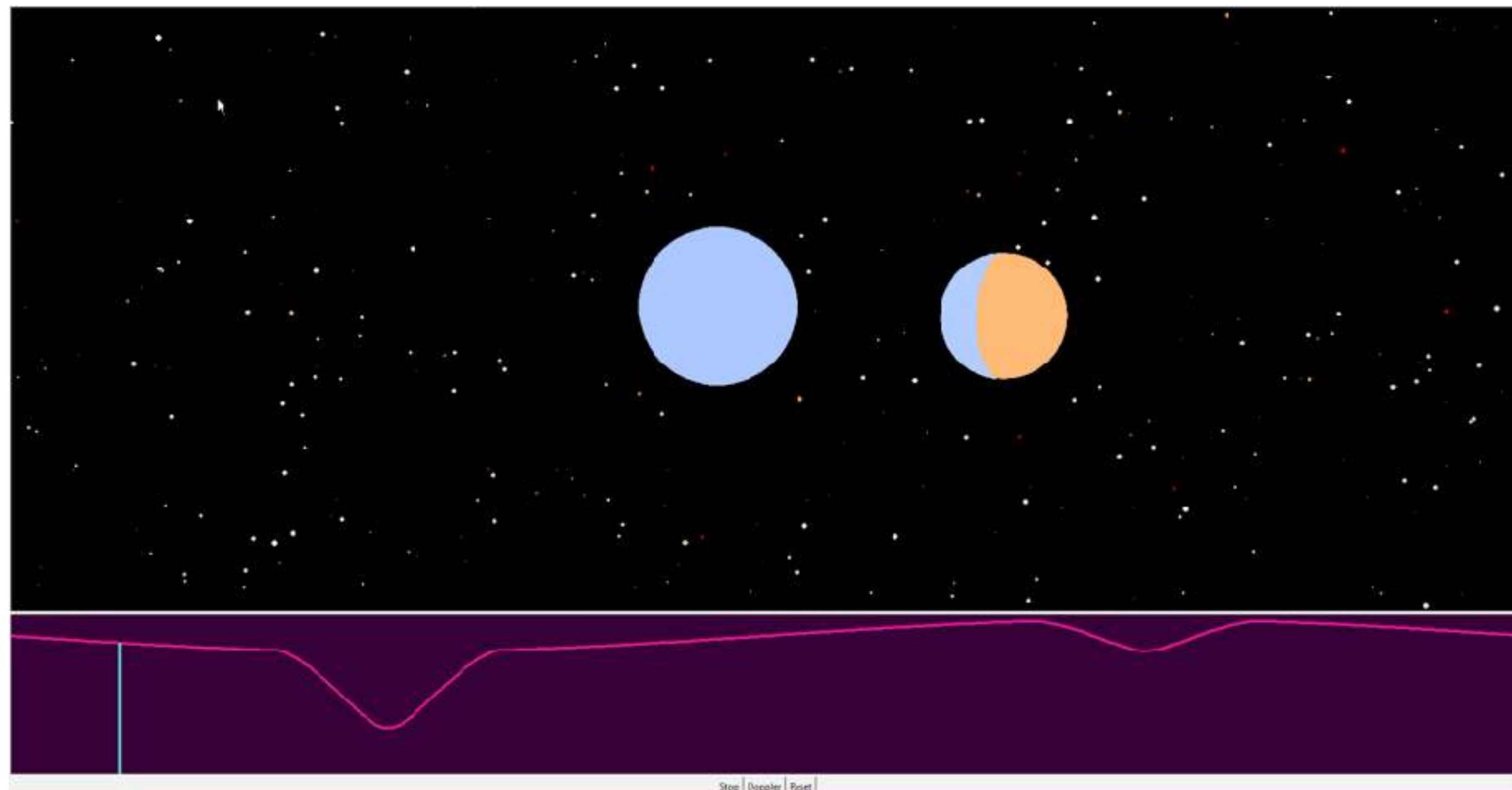
Vik Dhillon/Tom Marsh

- Photometry Filters: I, g, r, b



# Hot Subdwarfs: sdB Binaries

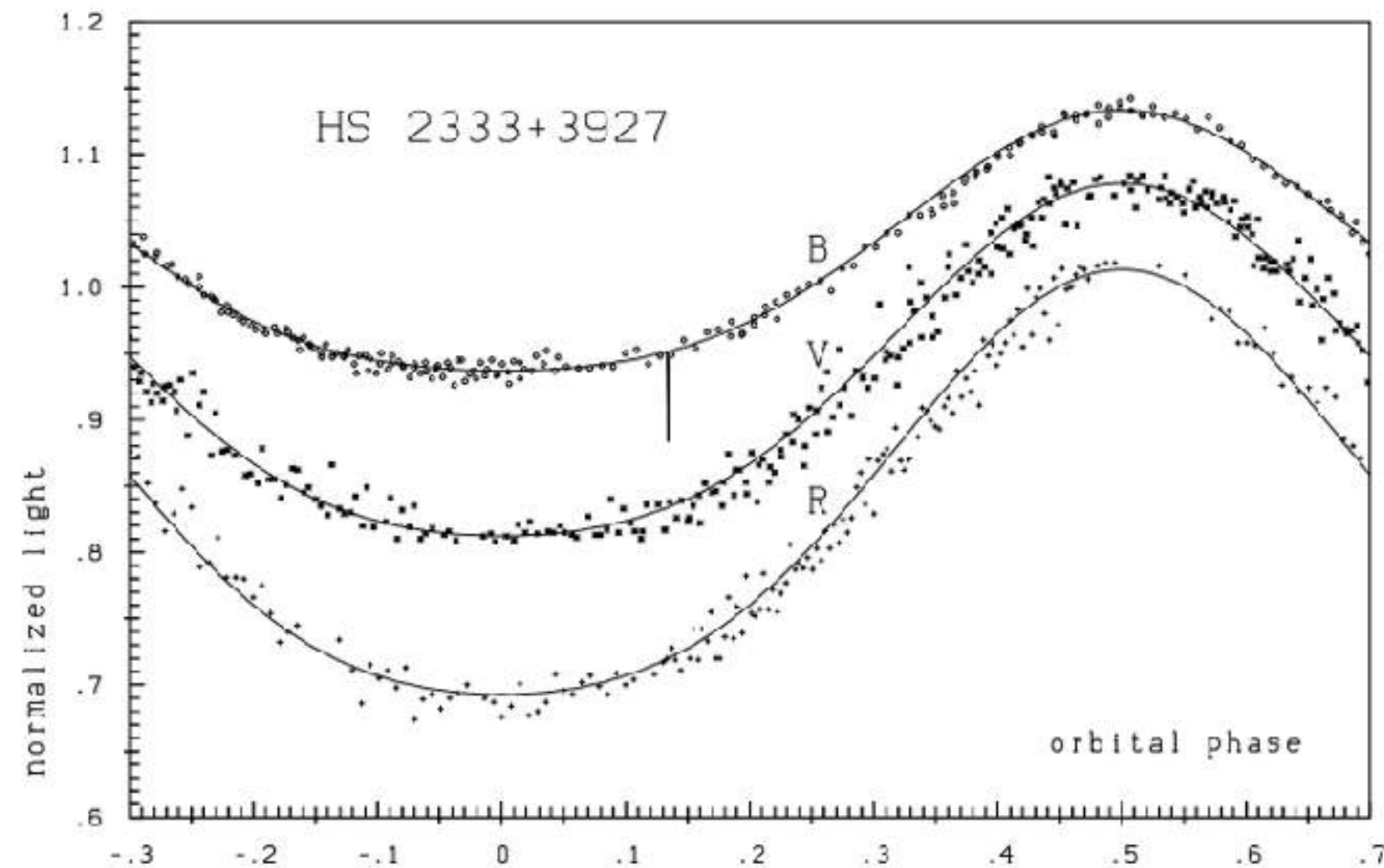
## Factors affecting the lightcurves



- **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



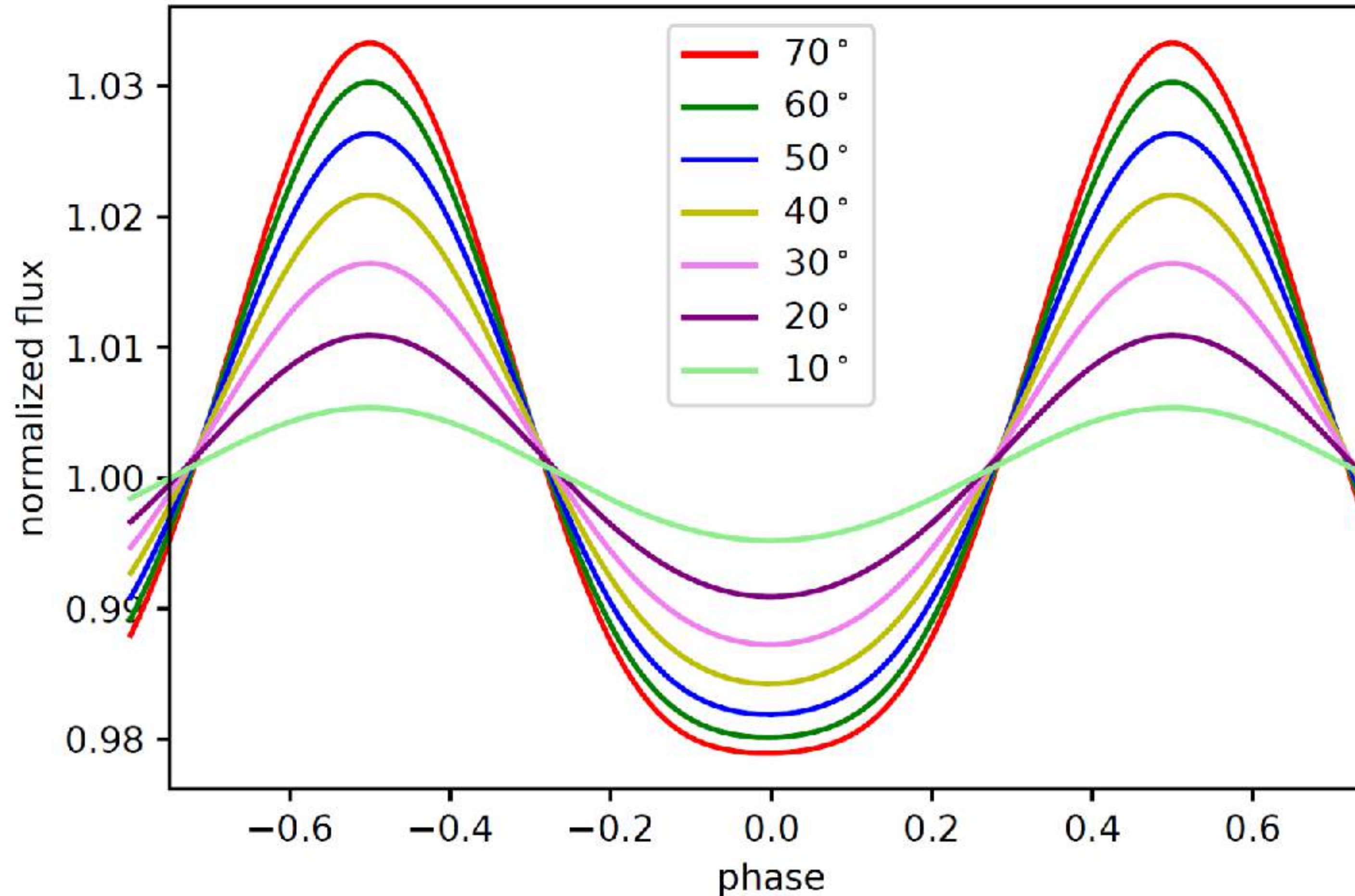
Different amplitudes in different bands

- **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



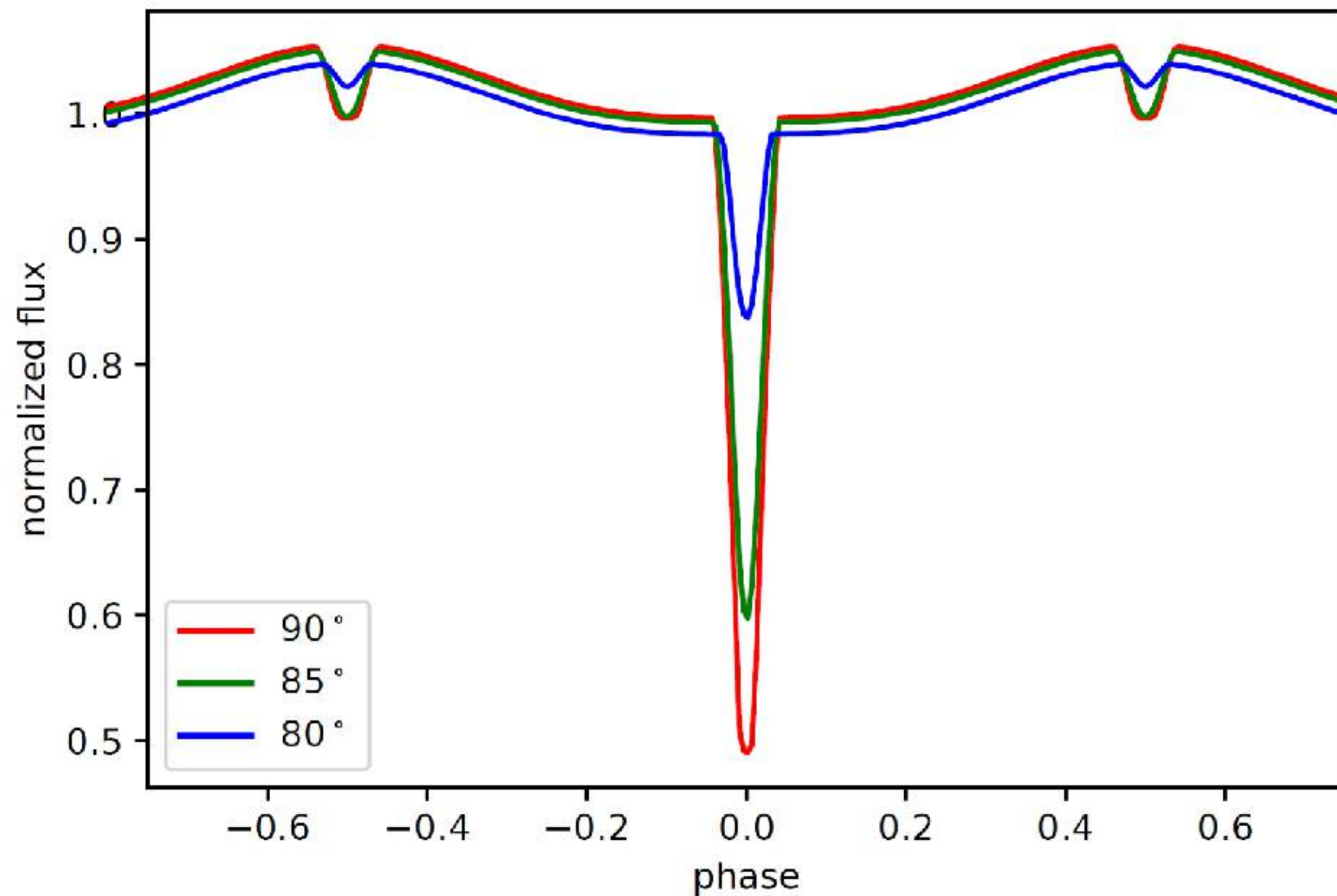
# Hot Subdwarfs: sdB Binaries

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

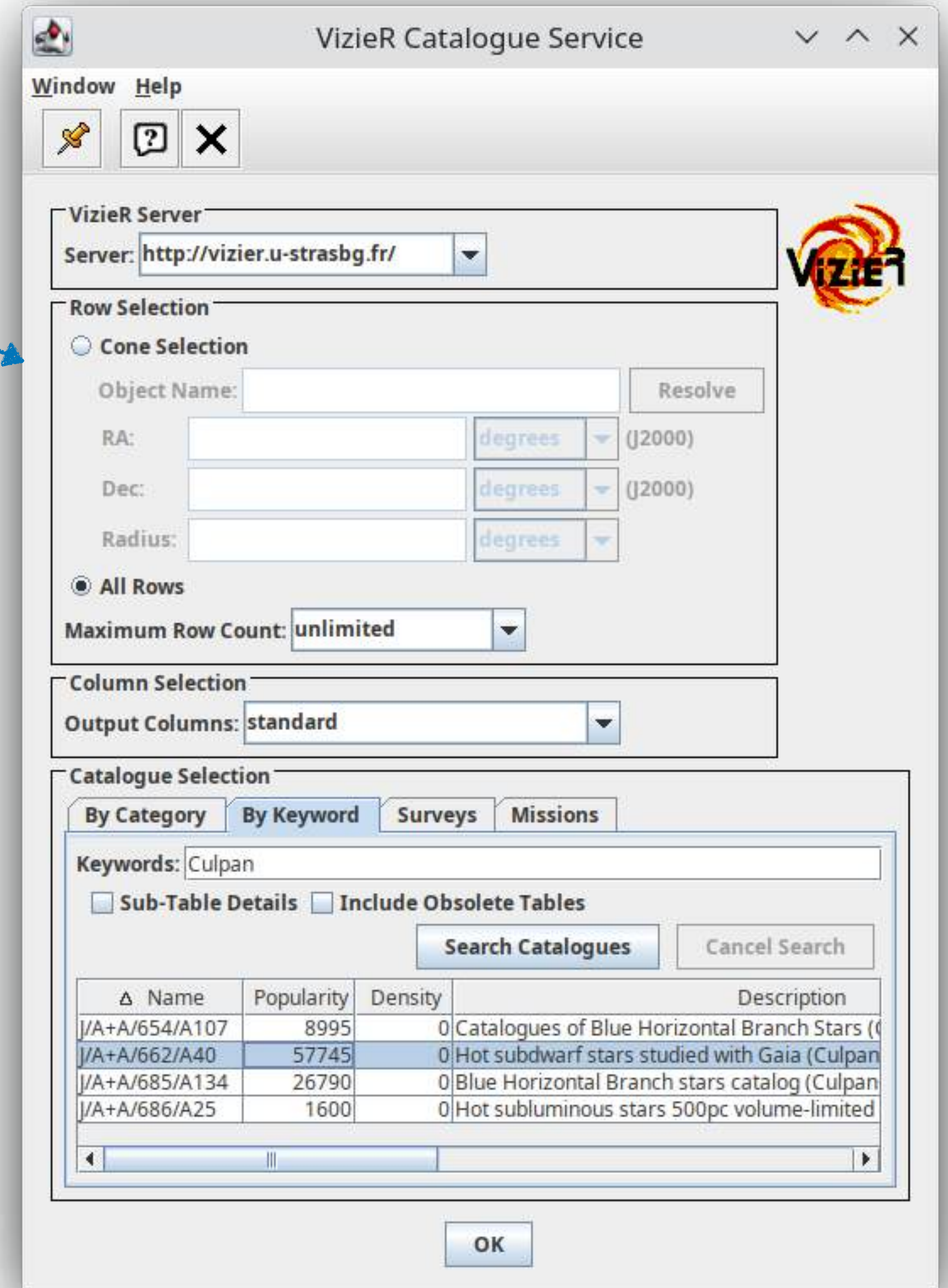
# Target Selection

## 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



VizieR Catalogue Service

Window Help

VizieR Server  
Server:

Row Selection

Cone Selection

Object Name:  Resolve

RA:  degrees (J2000)

Dec:  degrees (J2000)

Radius:  degrees

All Rows

Maximum Row Count:

Column Selection

Output Columns:

Catalogue Selection

By Category By Keyword Surveys Missions

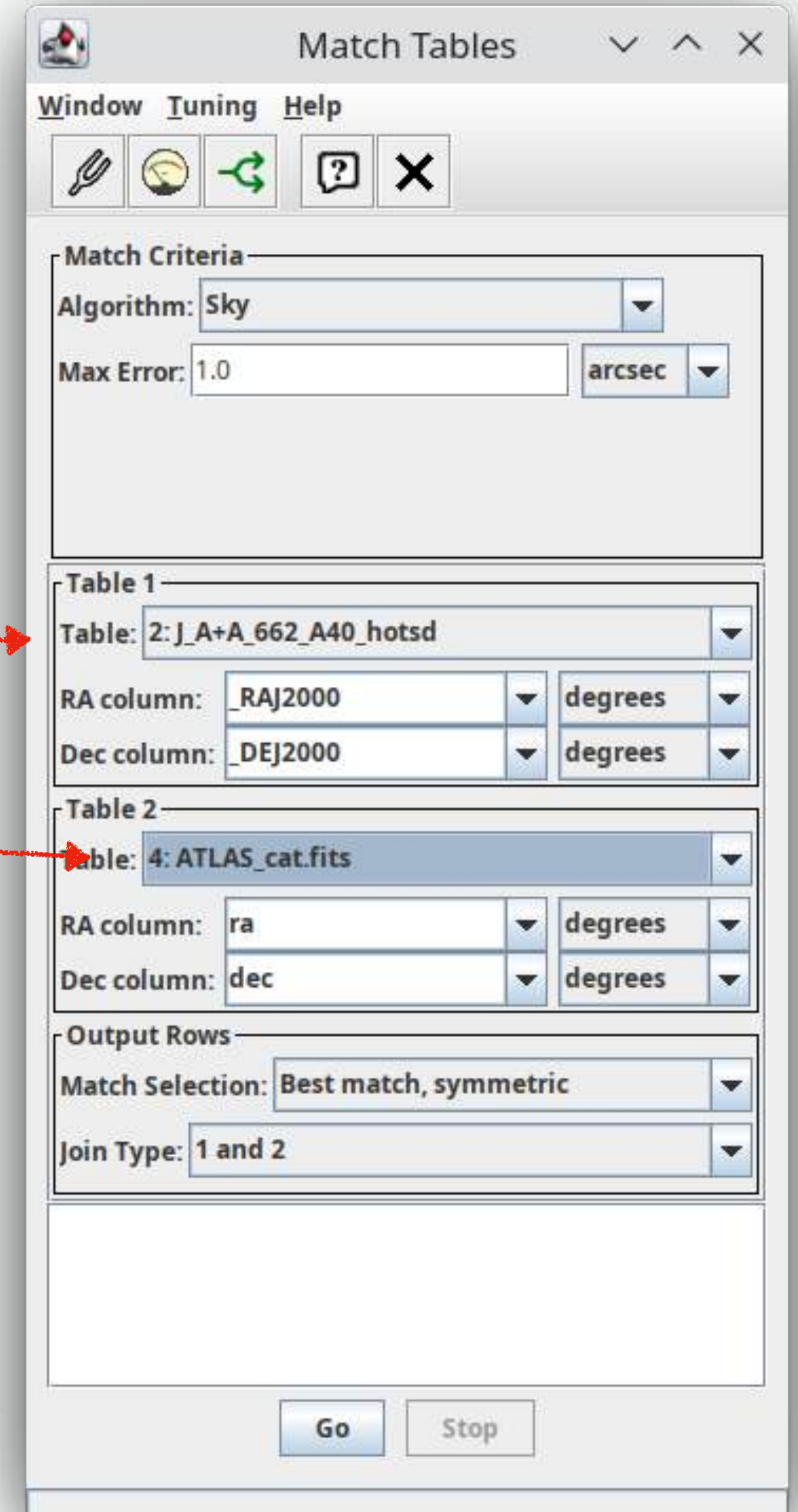
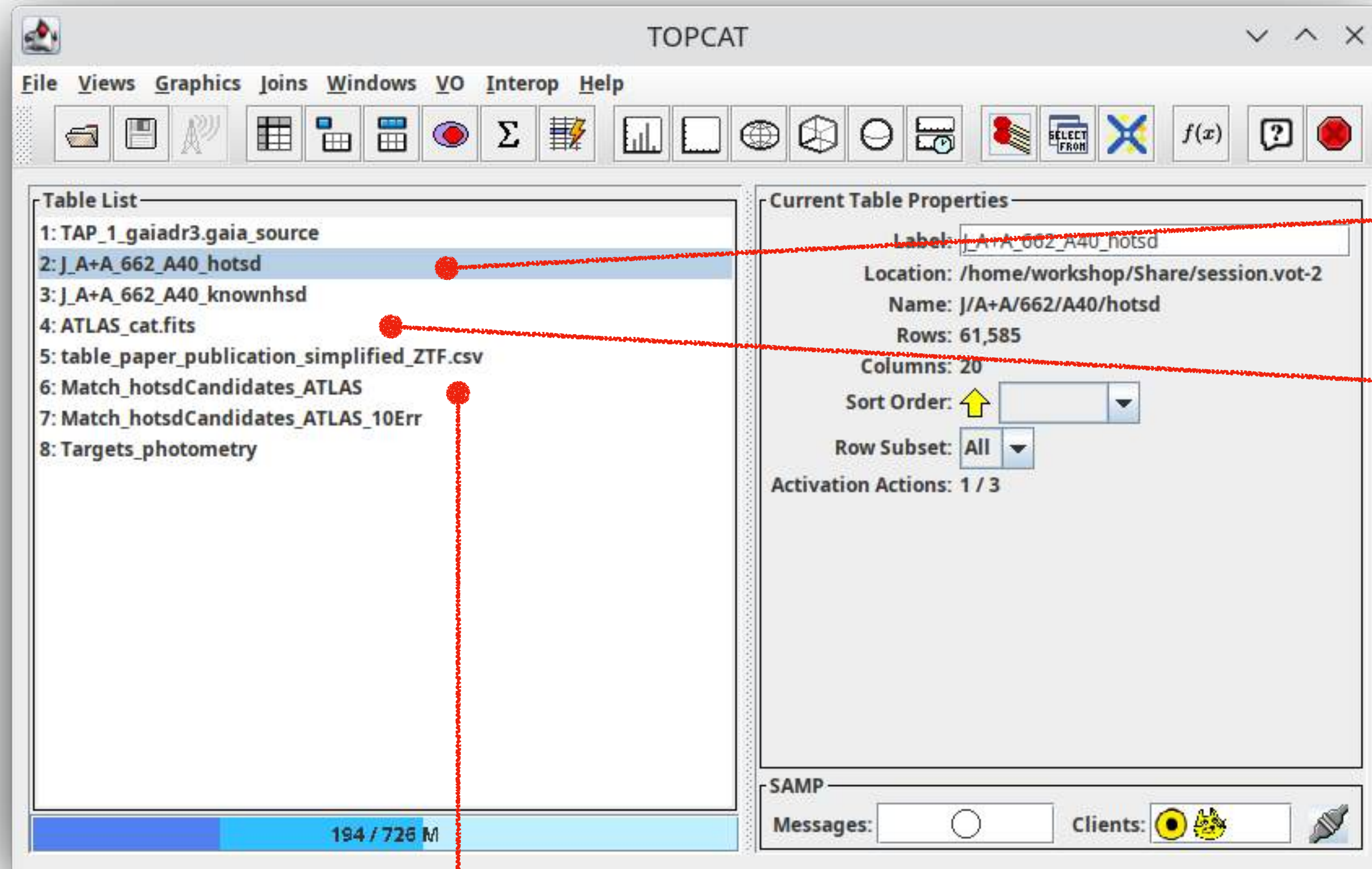
Keywords:

Sub-Table Details  Include Obsolete Tables

Δ Name	Popularity	Density	Description
J/A+A/654/A107	8995	0	Catalogues of Blue Horizontal Branch Stars (Culpan et al. 2022)
J/A+A/662/A40	57745	0	Hot subdwarf stars studied with Gaia (Culpan et al. 2022)
J/A+A/685/A134	26790	0	Blue Horizontal Branch stars catalog (Culpan et al. 2022)
J/A+A/686/A25	1600	0	Hot subluminoous stars 500pc volume-limited (Culpan et al. 2022)



# Target Selection Crossmatch



**Gives 1241 Targets!**

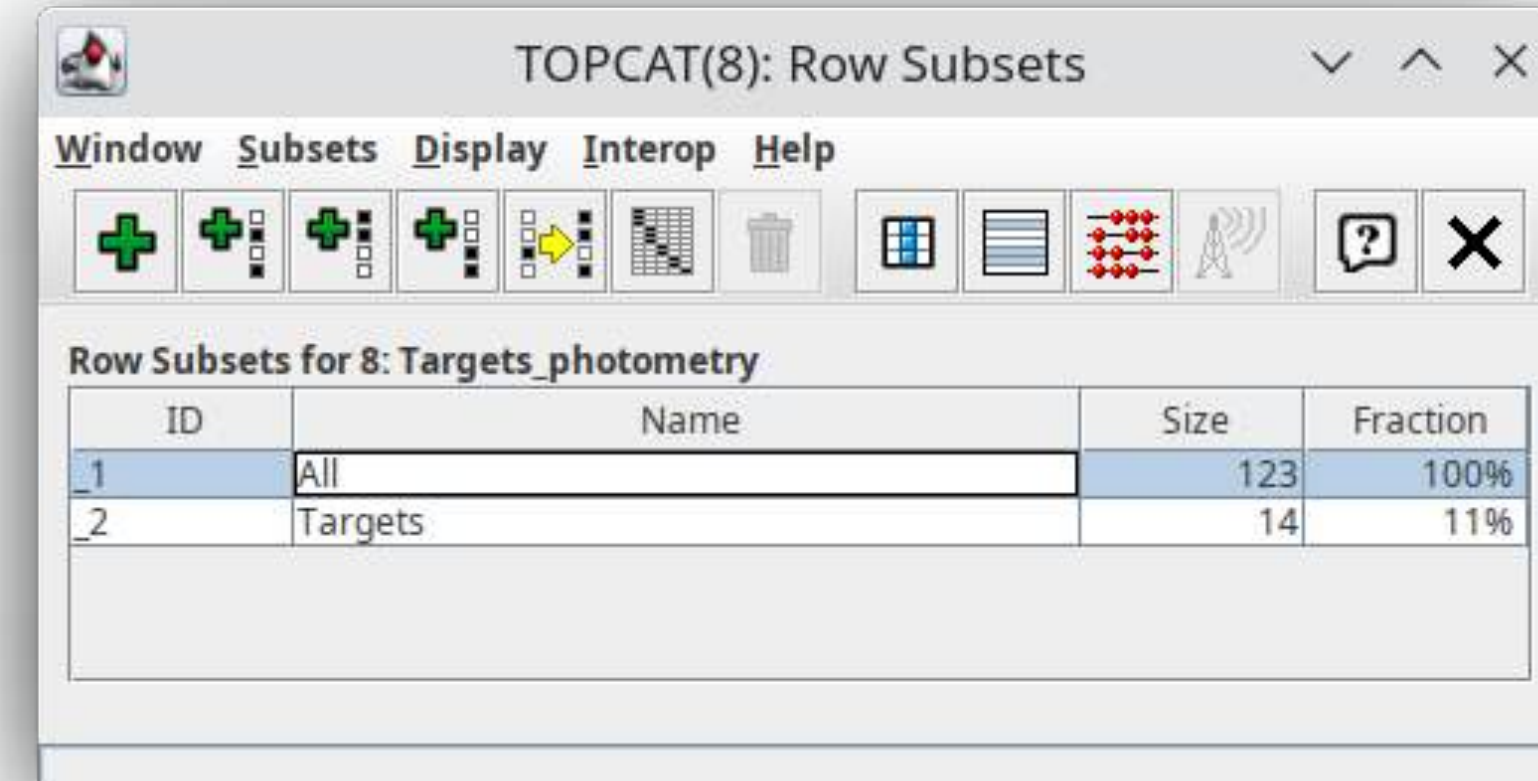


# Target Selection

## Selection criteria in TOPCAT

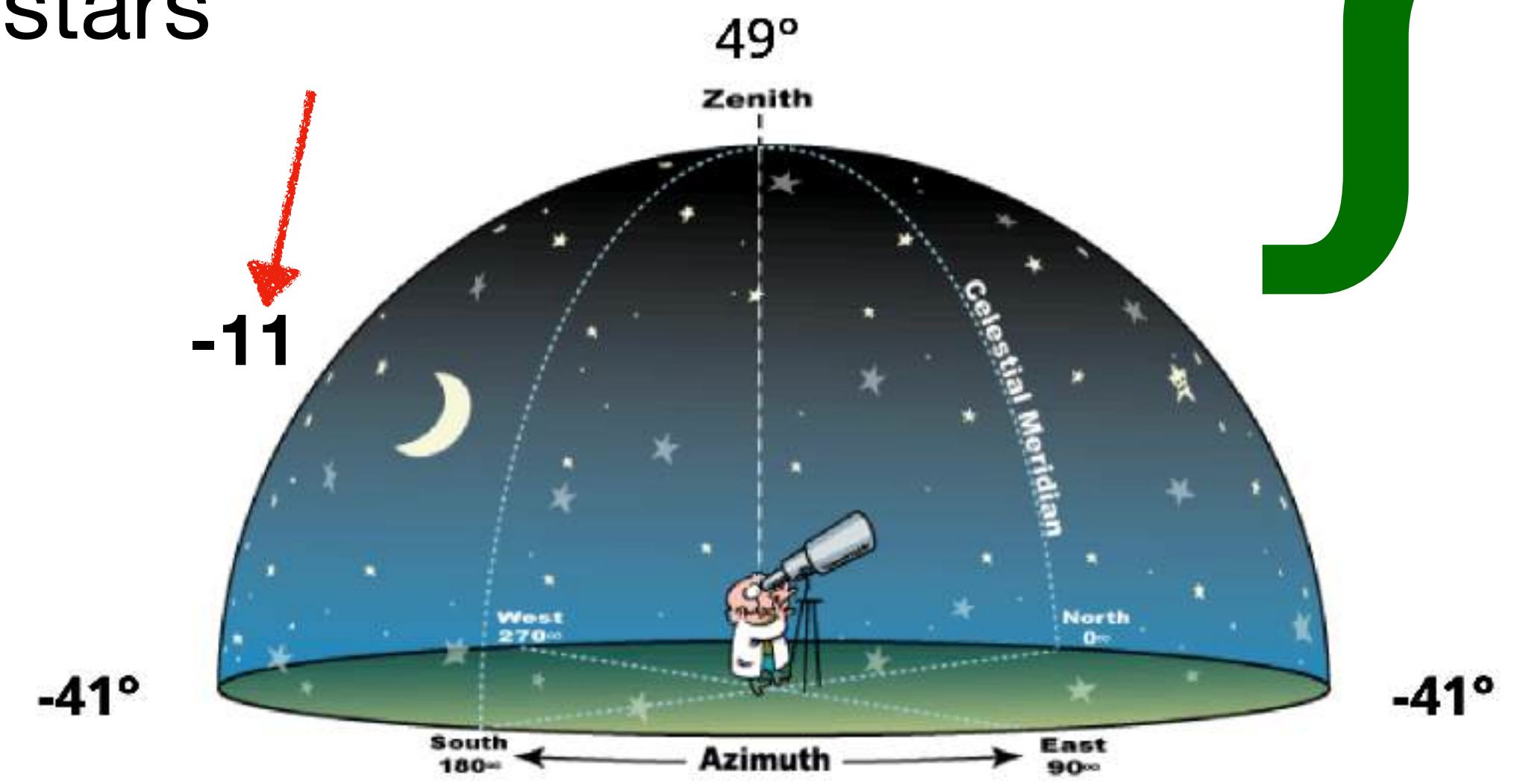
2. Select a series of cutting criteria:

- **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



ID	Name	Size	Fraction
1	All	123	100%
2	Targets	14	11%

→ **Leaves 123 Targets!**

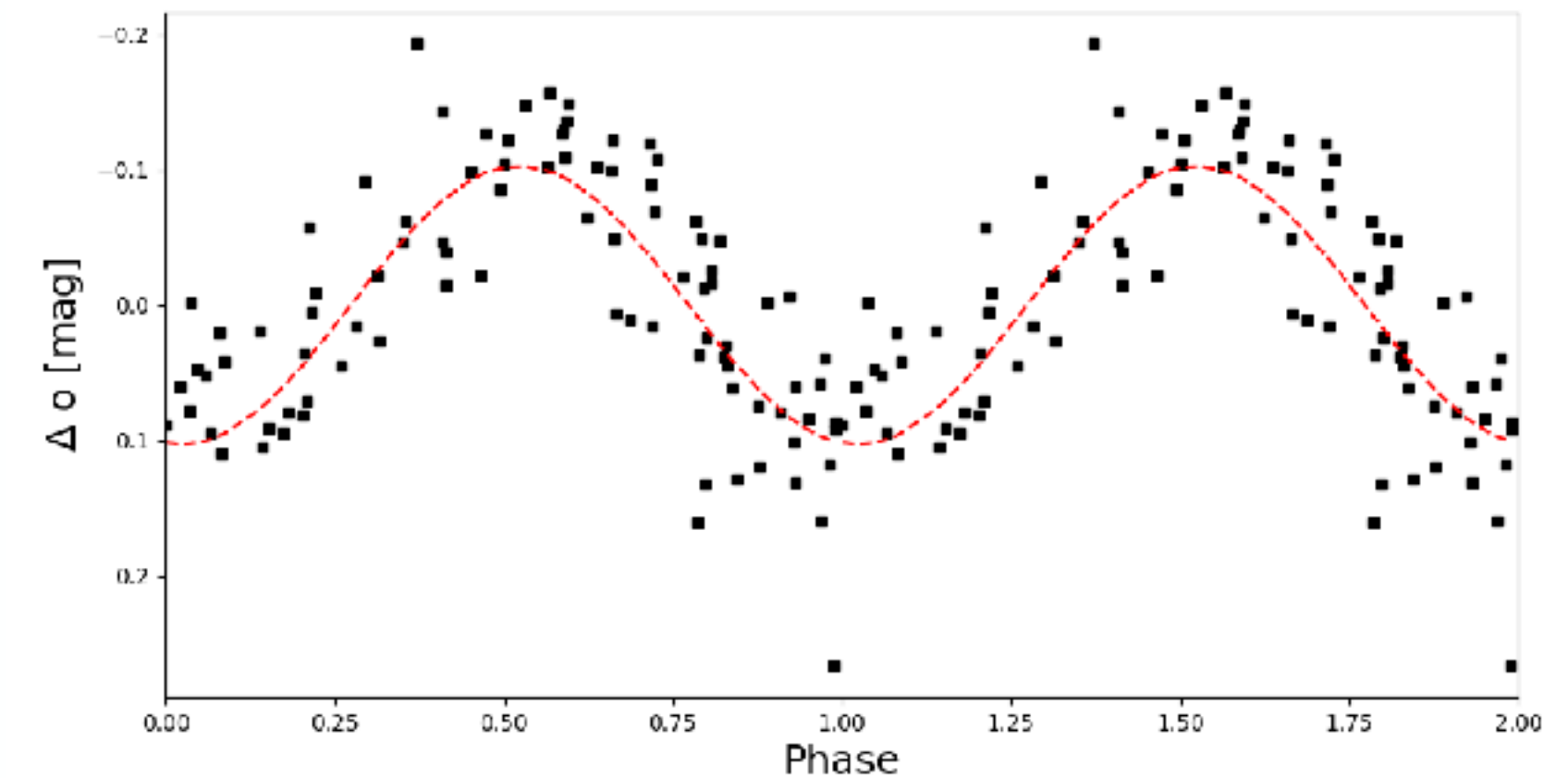
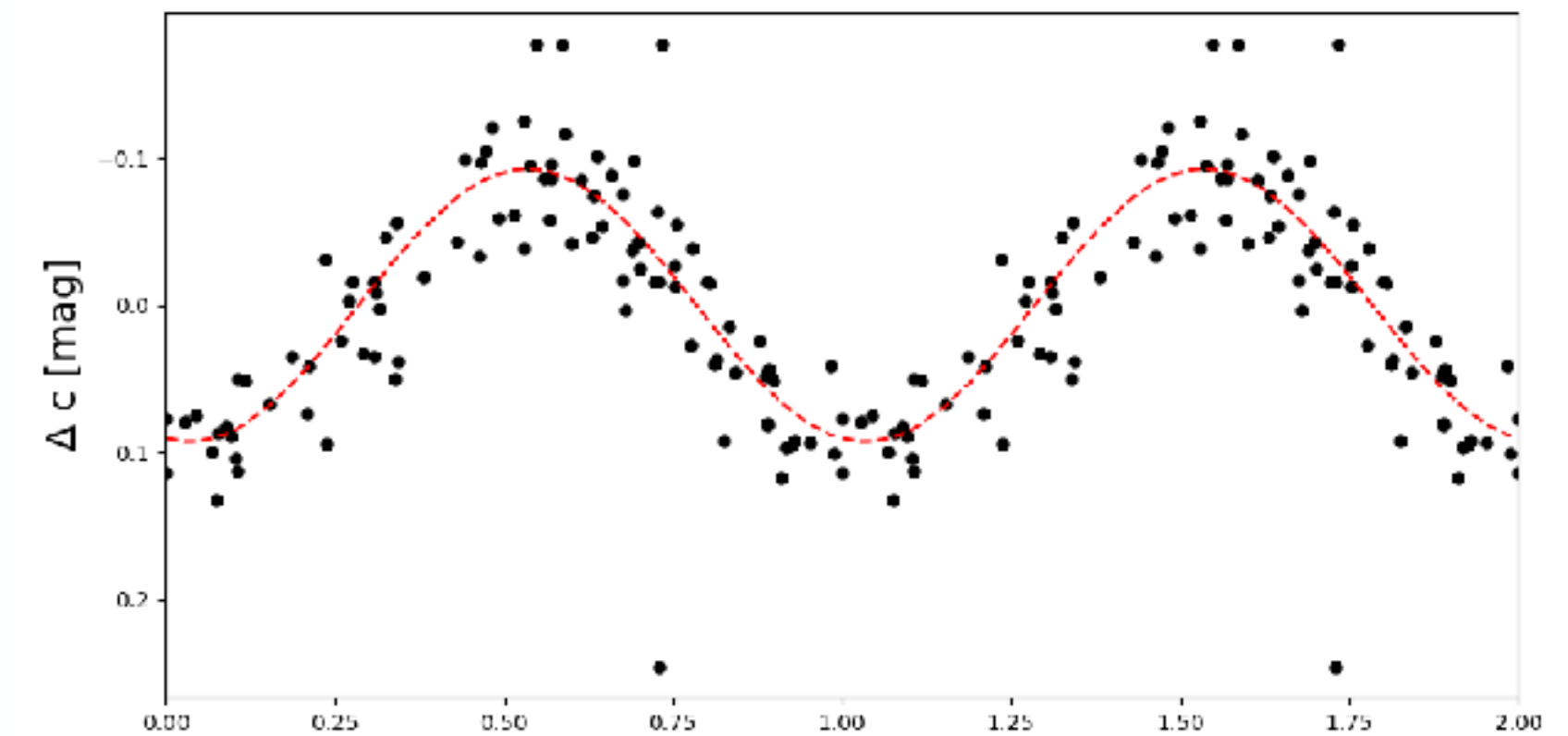




# Target Selection

## 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

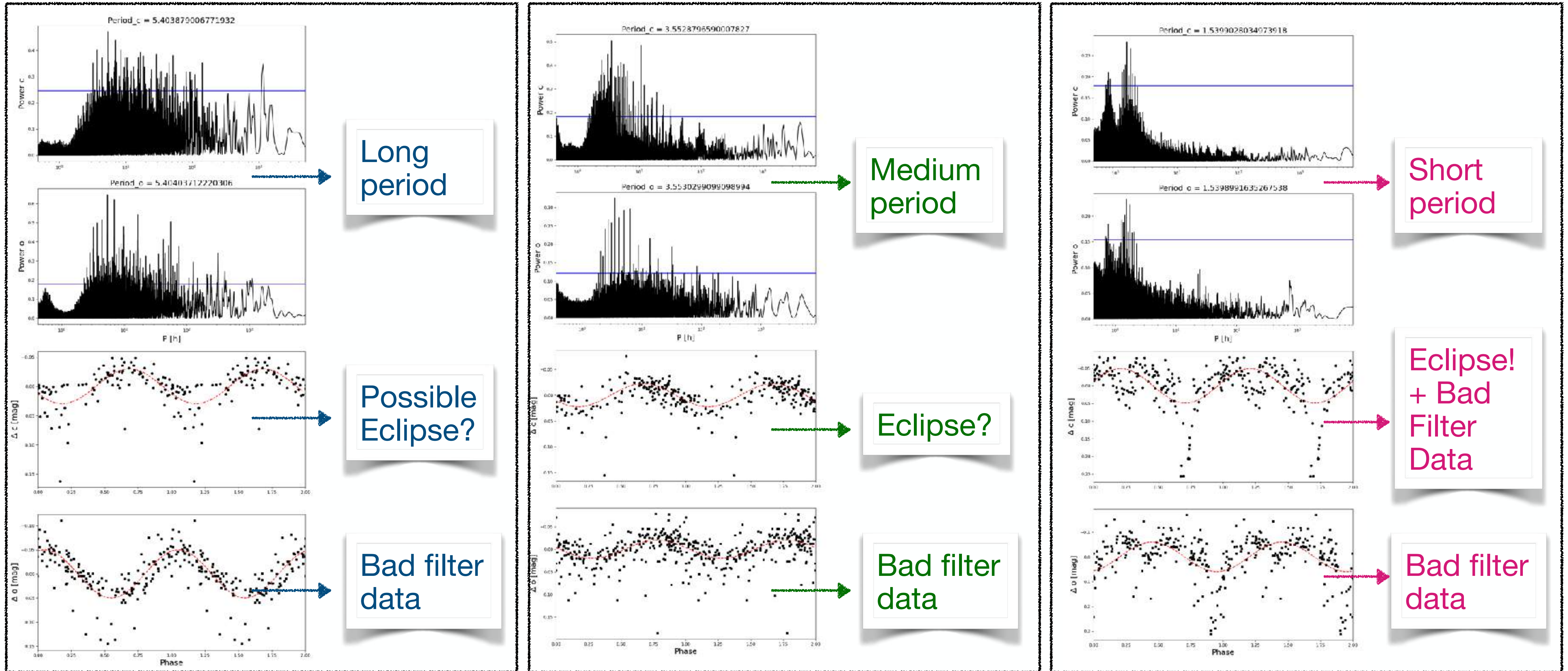


→ **Leaves 14 Targets!**



# Target Selection

## ATLAS Lightcurves



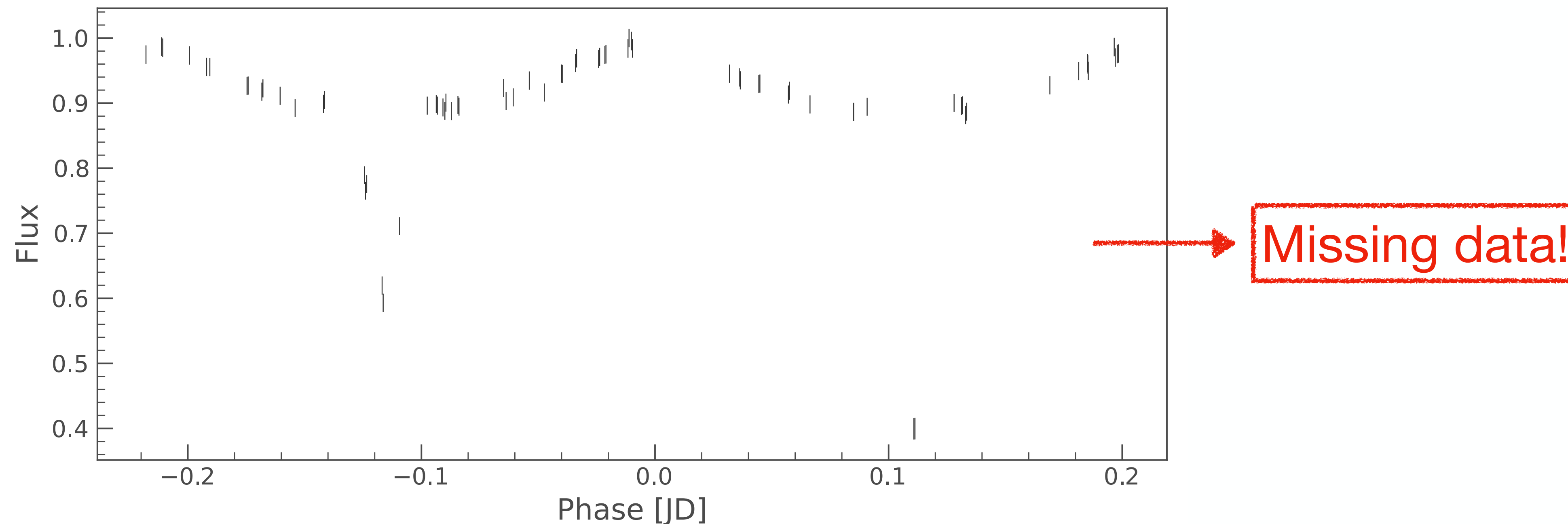




# Target Selection

## 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)
<b>J296.1785+54.8285</b>	15.75085	0.0701
<b>J331.6658+32.7267</b>	16.92184	0.22041
<b>J018.4128+22.9608</b>	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

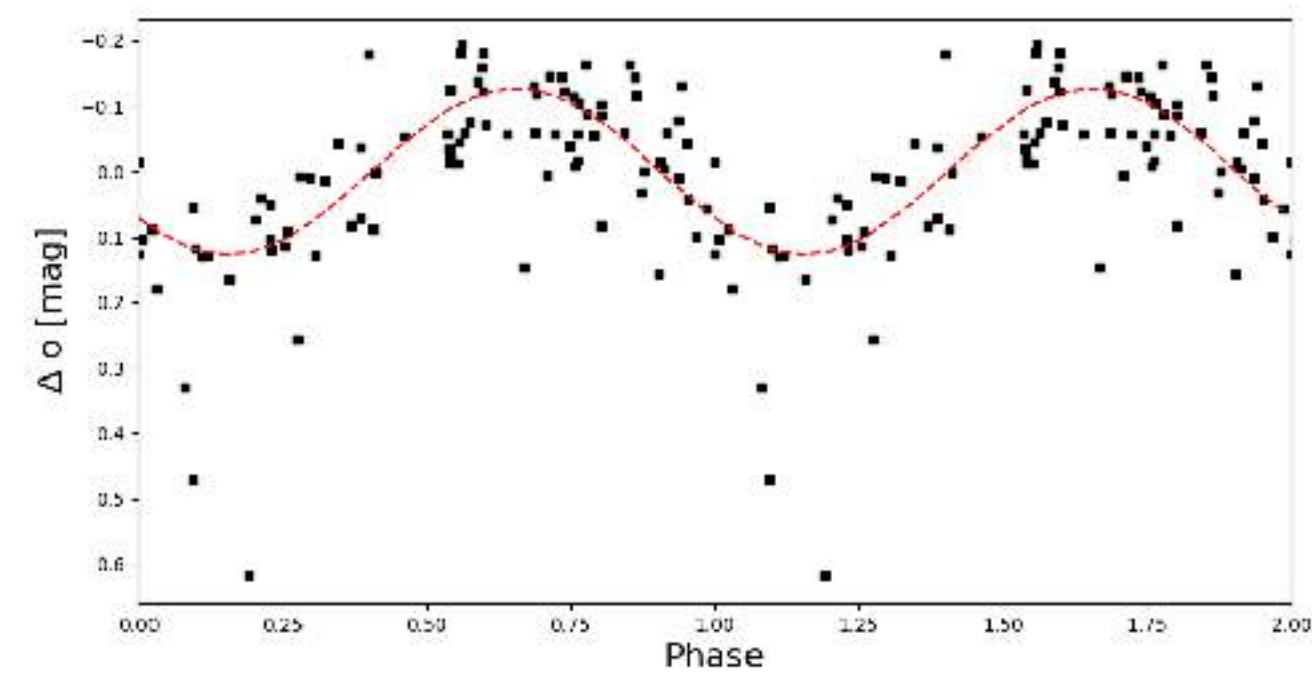
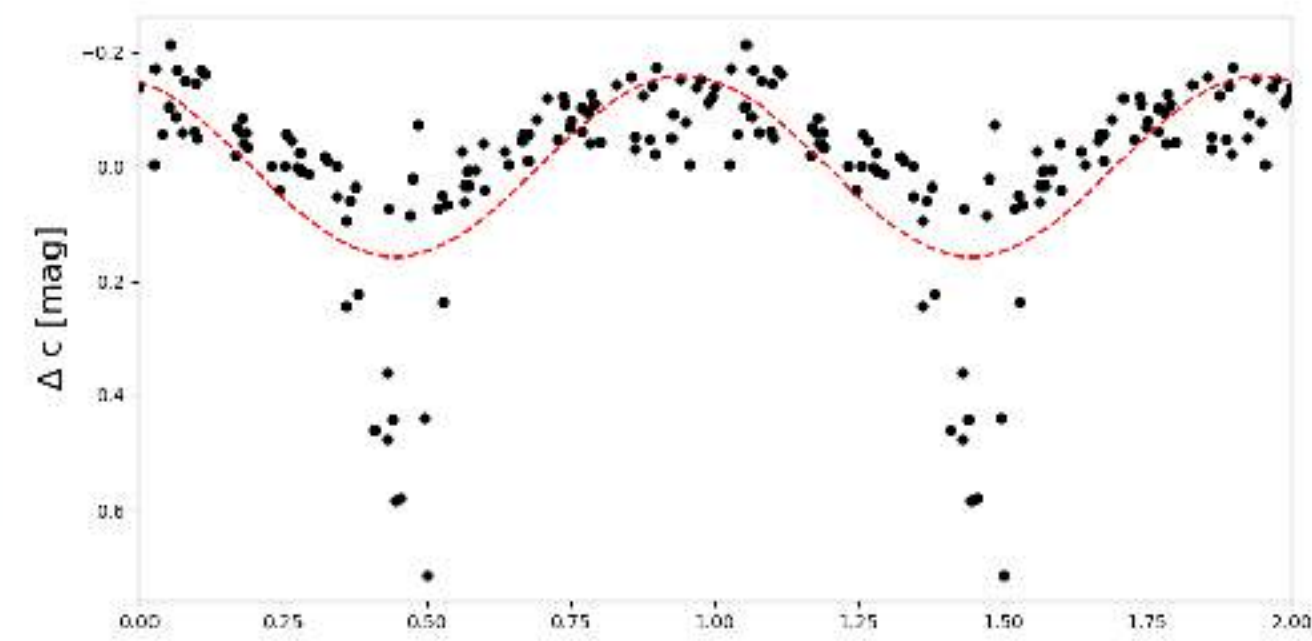
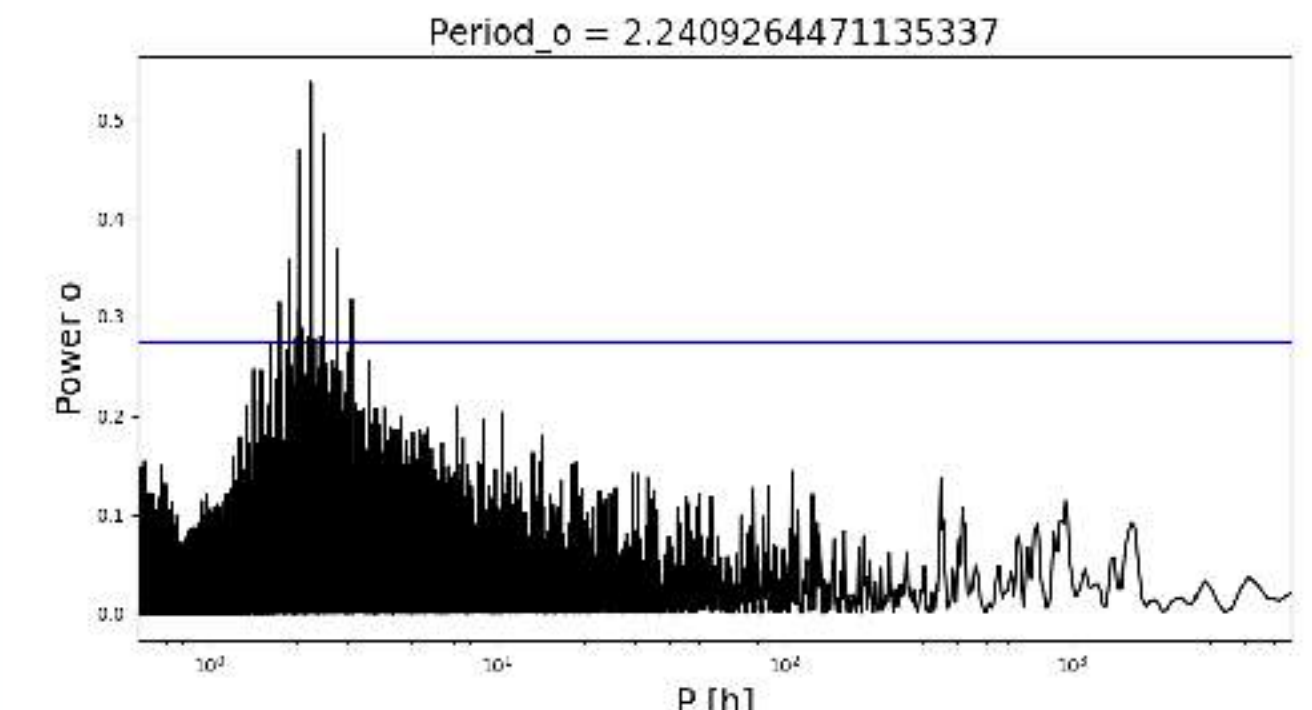
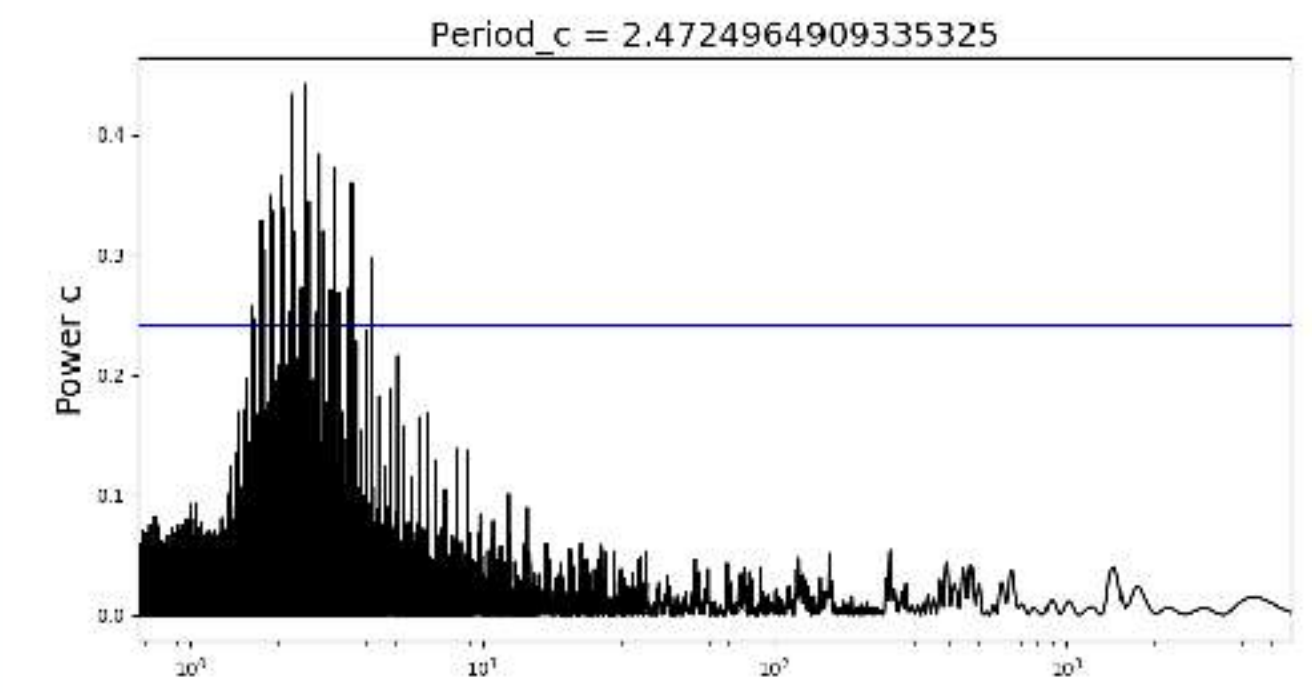
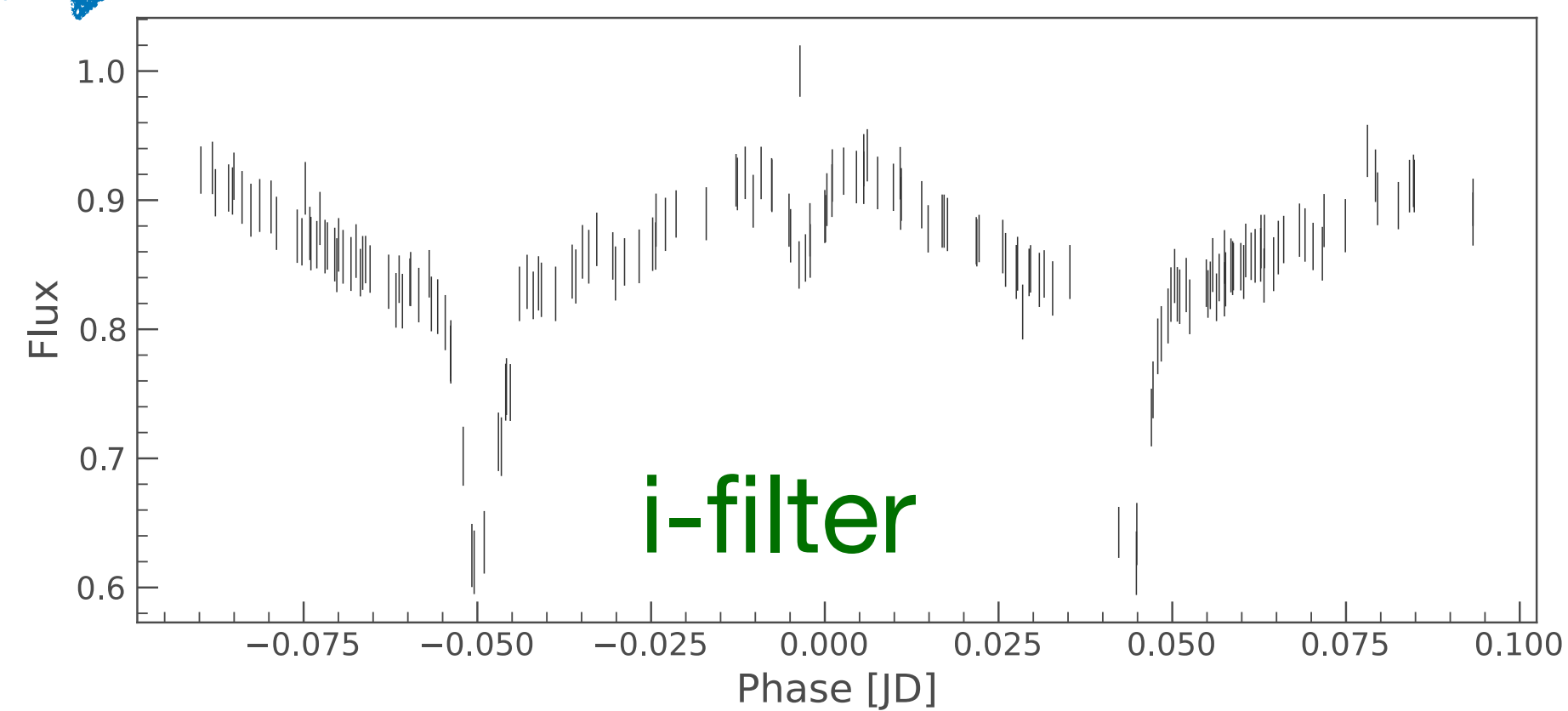
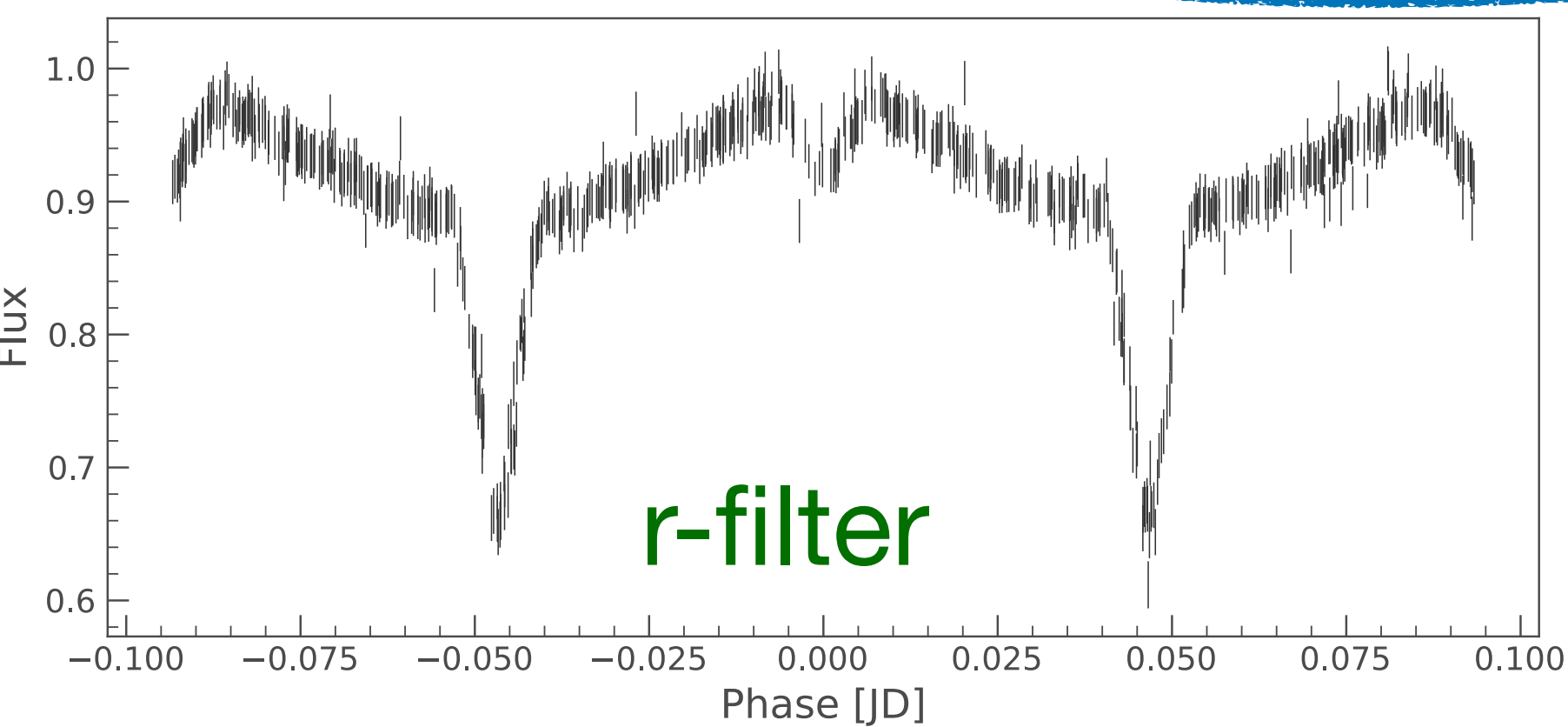
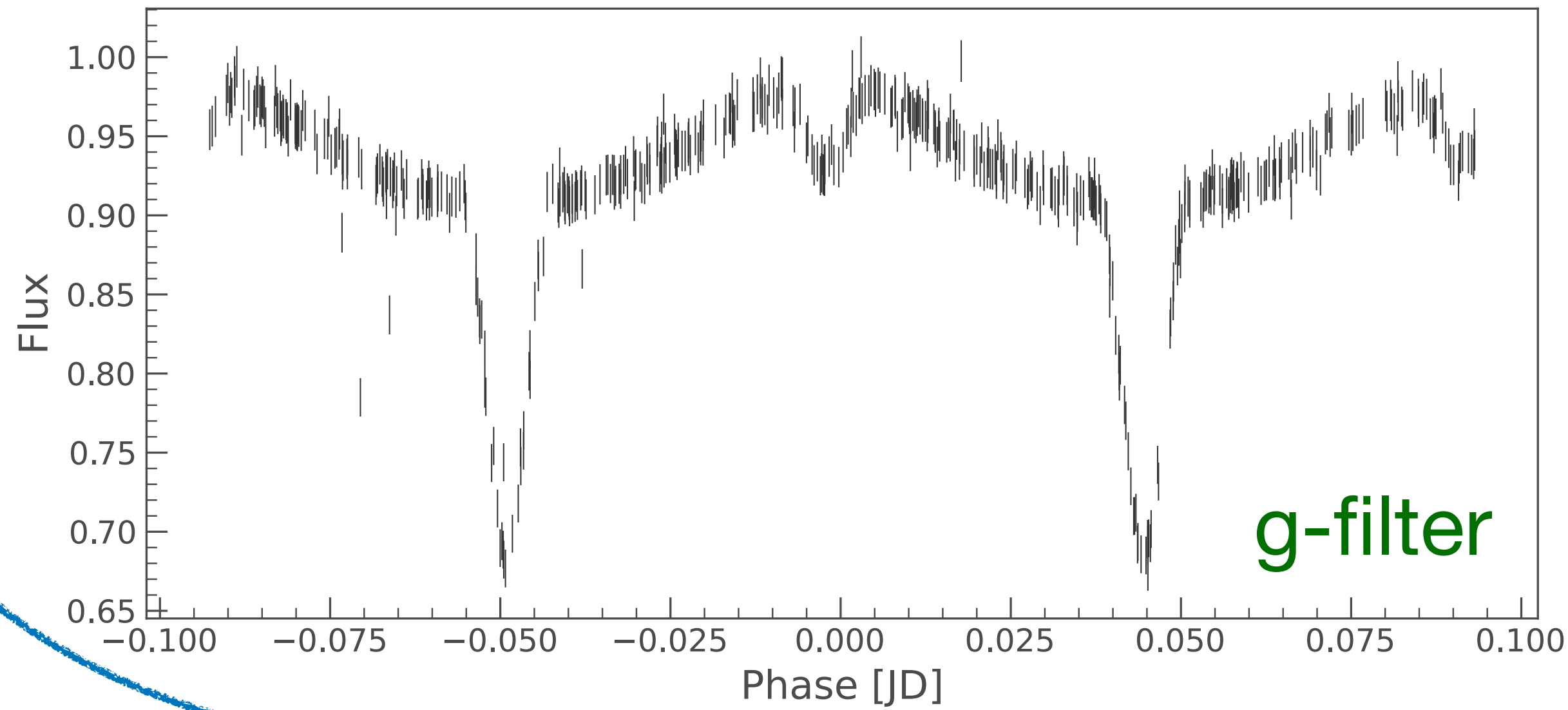


**J018.4128+22.9608**

# J018.4128+22.9608

## ZTF and ATLAS spectra

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



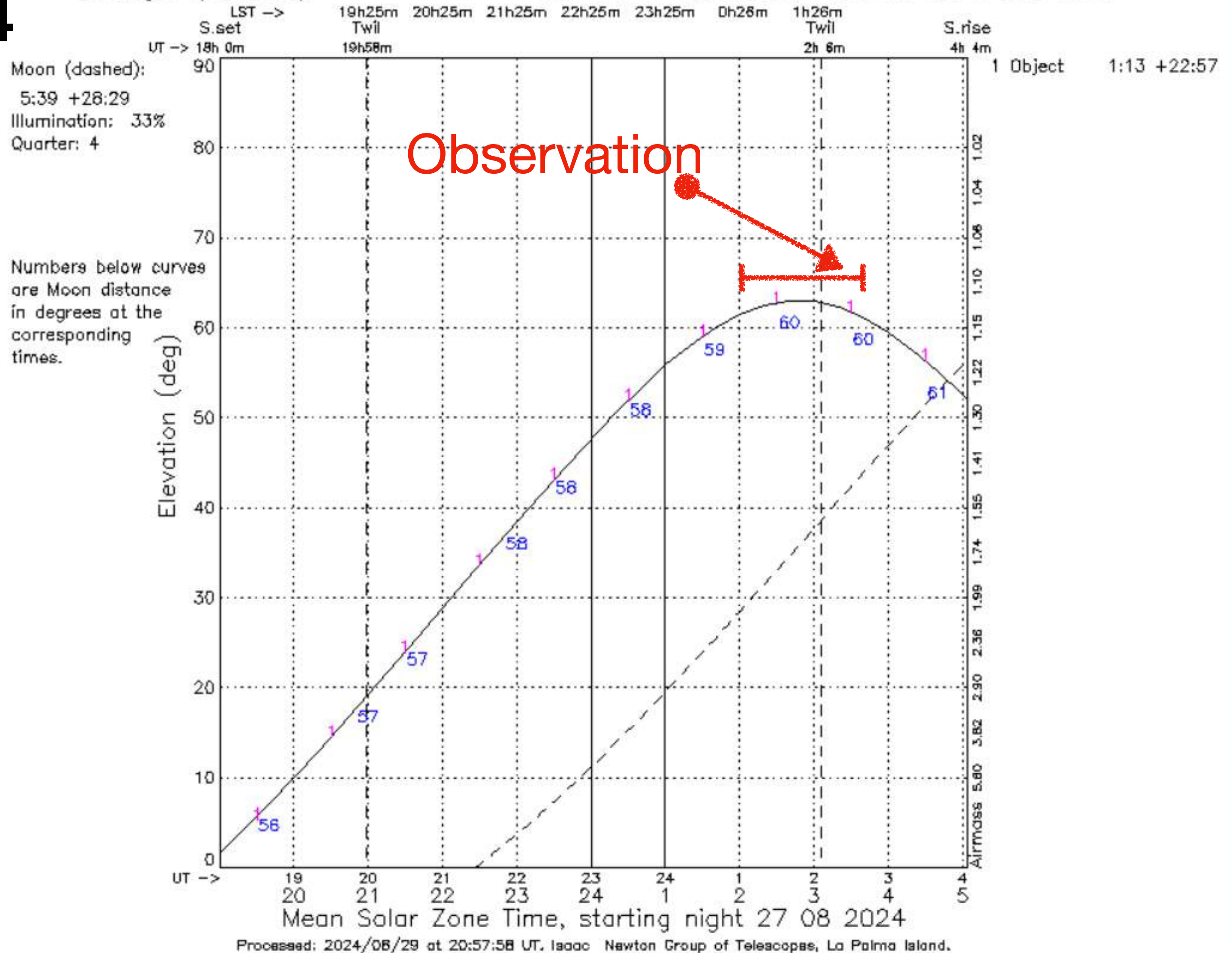


# J018.4128+22.9608

## Visibility on night 27.08.2024

Ondrejov (Czechia)

14.7811E 49.9153N, 525 m above sea level

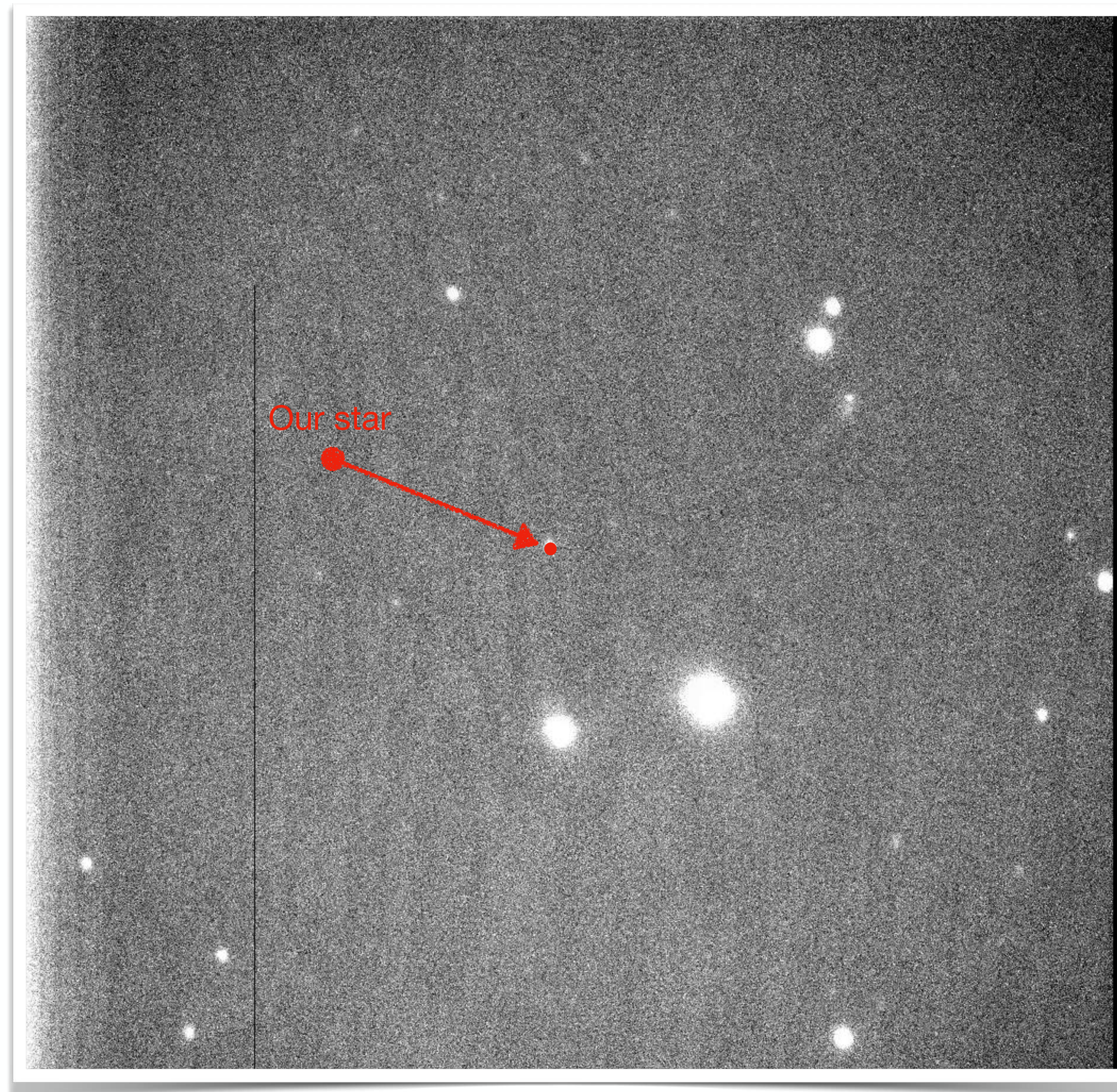




# J018.4128+22.9608

## 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

```
pelisoli@octans:...2/envs/iraf27/iraf
This is the EXPORT version of IRAF V2.16 supporting PC systems.

Welcome to IRAF. To list the available commands, type ? or ??. To get
detailed information about a command, type 'help <command>'. To run a
command or load a package, type its name. Type 'bye' to exit a
package, or 'logout' to get out of the CL. Type 'news' to find out
what is new in the version of the system you are using.

Visit http://iraf.net if you have questions or to report problems.

The following commands or packages are currently defined:

(Updated on 2013-12-13)

adccdrom.  deitab.   images.   mtools.   softtools.  upsquid.
cfh12k.    esowfi.   kepler.   nfextern.  squid.      utilities.
cirred.    finder.   language. noao.      stecf.      vo.
ctio.      fitsutil. lists.     obsolete.  stsdas.     xdimsum.
cutoutpkg. gemini.   mem0.     plot.      system.     xray.
dataio.    gmisc.   mscdb.    proto.     tables.
dbms.      guiapps. mscred.   rvsao.    ucscriss.

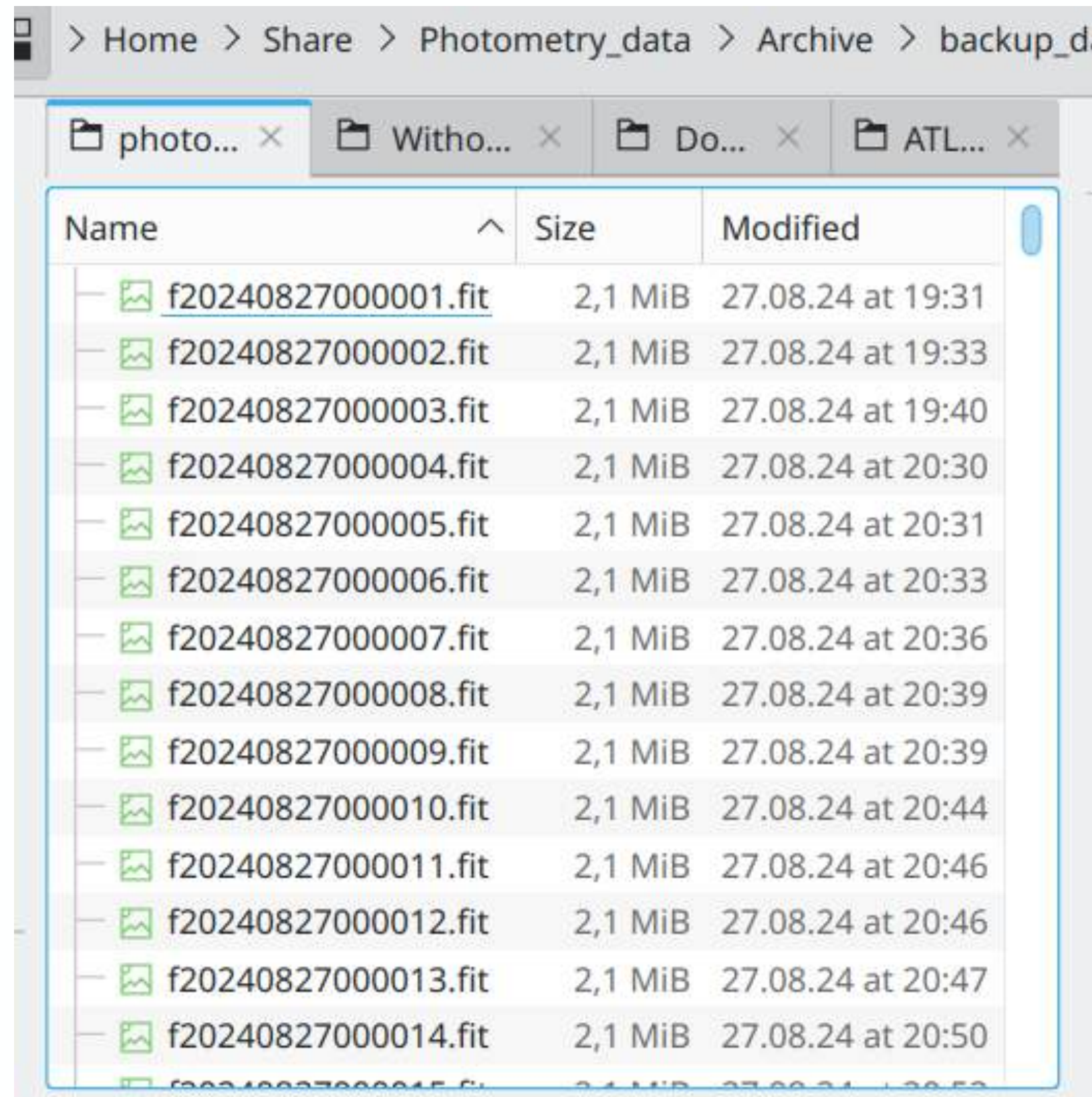
ecl> 
```

- **Packages:**

- noao
- daophot
- imred
- ccdred
- digiphot

# Reduction: J018.4128+22.9608

## Step 1: Organising the files



Name	Size	Modified
f20240827000001.fit	2,1 MiB	27.08.24 at 19:31
f20240827000002.fit	2,1 MiB	27.08.24 at 19:33
f20240827000003.fit	2,1 MiB	27.08.24 at 19:40
f20240827000004.fit	2,1 MiB	27.08.24 at 20:30
f20240827000005.fit	2,1 MiB	27.08.24 at 20:31
f20240827000006.fit	2,1 MiB	27.08.24 at 20:33
f20240827000007.fit	2,1 MiB	27.08.24 at 20:36
f20240827000008.fit	2,1 MiB	27.08.24 at 20:39
f20240827000009.fit	2,1 MiB	27.08.24 at 20:39
f20240827000010.fit	2,1 MiB	27.08.24 at 20:44
f20240827000011.fit	2,1 MiB	27.08.24 at 20:46
f20240827000012.fit	2,1 MiB	27.08.24 at 20:46
f20240827000013.fit	2,1 MiB	27.08.24 at 20:47
f20240827000014.fit	2,1 MiB	27.08.24 at 20:50

Perek 2-m data files

- **IRAF RECOMMENDED:**

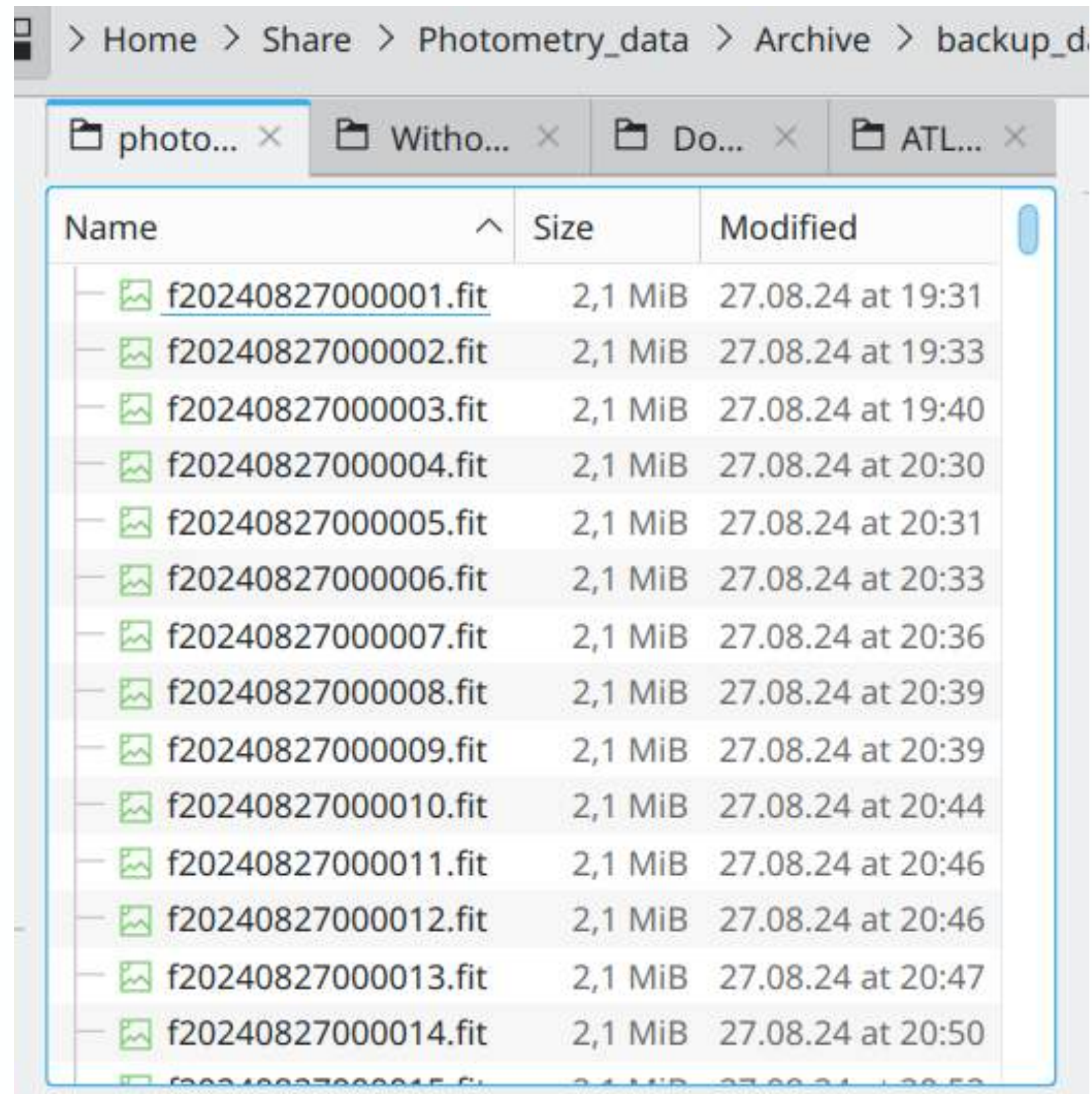
- *dark\_frames\_science*
- *dark\_frames\_flats*
- *flats*
- *science\_frames*

**Make a copy of your data!**



# Reduction: J018.4128+22.9608

## Step 1: Organising the files



Name	Size	Modified
f20240827000001.fit	2,1 MiB	27.08.24 at 19:31
f20240827000002.fit	2,1 MiB	27.08.24 at 19:33
f20240827000003.fit	2,1 MiB	27.08.24 at 19:40
f20240827000004.fit	2,1 MiB	27.08.24 at 20:30
f20240827000005.fit	2,1 MiB	27.08.24 at 20:31
f20240827000006.fit	2,1 MiB	27.08.24 at 20:33
f20240827000007.fit	2,1 MiB	27.08.24 at 20:36
f20240827000008.fit	2,1 MiB	27.08.24 at 20:39
f20240827000009.fit	2,1 MiB	27.08.24 at 20:39
f20240827000010.fit	2,1 MiB	27.08.24 at 20:44
f20240827000011.fit	2,1 MiB	27.08.24 at 20:46
f20240827000012.fit	2,1 MiB	27.08.24 at 20:46
f20240827000013.fit	2,1 MiB	27.08.24 at 20:47
f20240827000014.fit	2,1 MiB	27.08.24 at 20:50

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



• Workaround:

• *data\_sorting\_perek.py*

Name	Size	Modified
> 0.1s_-13_dark	1 item	8 minutes ago
> 0.01s_-15_1_flat	11 items	8 minutes ago
> 0.01s_-15_3_flat	12 items	8 minutes ago
> 0.01s_-15_dark	20 items	8 minutes ago
> 1.0s_-13_dark	1 item	8 minutes ago
> 5.0s_-13_dark	1 item	8 minutes ago
> 10.0s_-10_dark	1 item	8 minutes ago
> 10.0s_-13_dark	1 item	8 minutes ago
> 10.0s_-15_dark	2 items	8 minutes ago
> 10.0s_0_dark	1 item	8 minutes ago
> 20.0s_-15_dark	11 items	8 minutes ago
> 60.0s_-15_dark	11 items	8 minutes ago
> J018.4128+22.9608_01:13:39.000+22:57:39.00_-15_1_10.0s	4 items	8 minutes ago
> J018.4128+22.9608_01:13:39.000+22:57:39.00_-15_1_20.0s	1 item	8 minutes ago
> J018.4128+22.9608_01:13:39.000+22:57:39.00_-15_1_60.0s	151 items	8 minutes ago
> J296.1785+54.8285_19:44:42.900+54:49:42.90_-15_3_20.0s	360 items	8 minutes ago
> target_17:53:22.787-00:02:55.20_-13_2_2.0s	1 item	8 minutes ago
> target_17:53:22.787-00:02:55.20_-13_2_5.0s	1 item	8 minutes ago
> target_17:53:22.787-00:02:55.20_-13_2_10.0s	1 item	8 minutes ago

```
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'))
```

Sorted Perek 2-m data files



# Reduction: J018.4128+22.9608

## Step 2: Check your data with ds9 and Fixing Header

```
UT      = '00:04:39'      / UTC of start of observation
DATE-OBS= '2024-08-28'    / UTC date start of observation
FILTER  = 1
IMAGETYP= 'object'
OBJECT  = 'J018.4128+22.9608'
ST      = '' / Local sidereal time at start of observation
SYSVER  = 'PESO 2020-06-12'
FILENAME= 'f20240827000410.fit'
CCDTEMP = -14.93684005737305 / Detector temperature
OBSERVAT= 'ONDREJOV' / Name of observatory (IRAF style)
LATITUDE= '49.91056' / Telescope latitude (degrees), +49:54:38.0
LONGITUD= '14.78361' / Telescope longitude (degrees), +14:47:01.0
HEIGHT  = '528' / Height above sea level [m]
TELESCOP= 'ZEISS-2m' / 2m Ondrejov observatory telescope
DETECTOR= 'Moravian Instruments G2-1000BI' / Name of the detector
CHIPID  = 'CCD47-10' / Name of CCD chip
CCDXPIXE= 13.3 / Size in microns of the pixels, in X
CCDYPTXF= 13.3 / Size in microns of the pixels, in Y
CCDXSIZE= 1062 / X Size in pixels of digitised frame
CCDYSIZE= 1026 / Y Size in pixels of digitised frame
RA      = '01:13:39.000'
DEC     = '+22:57:39.00'
TLE-TRHD= '-26.0314 23.1392'
TLE-TRGV= '-15.4 22.9'
TIF-TRCS= '?'
TLE-TRUS= '0.0000 0.0000'
TELFOCUS= 5181
CAMPOS  = 15626
CHECKSUM= 'ZIBcaH9ZYHAbZH9Z' / HDU checksum updated 2024-08-28T02:05:48
DATASUM = '2428502429' / data unit checksum updated 2024-08-28T02:05:48
BIASSEC = '[1:1058:1062,2:1022]'
TRTMSFC = '[1:1056,1:1026]'
DATASEC = '[1:1056,1:1026]'
EPOCH   = 2000
JD      = 2460550.50357639
HJD     = 2460550.50714082
STDIN-line 52-file 1 of 1
```

- **Science frames:**

- Throw frames: Noisy

- Make a list

*ls \*.fit > list\_science*

- **Fix headers:**

- Flats, Darks, Science frames

- Science frames:

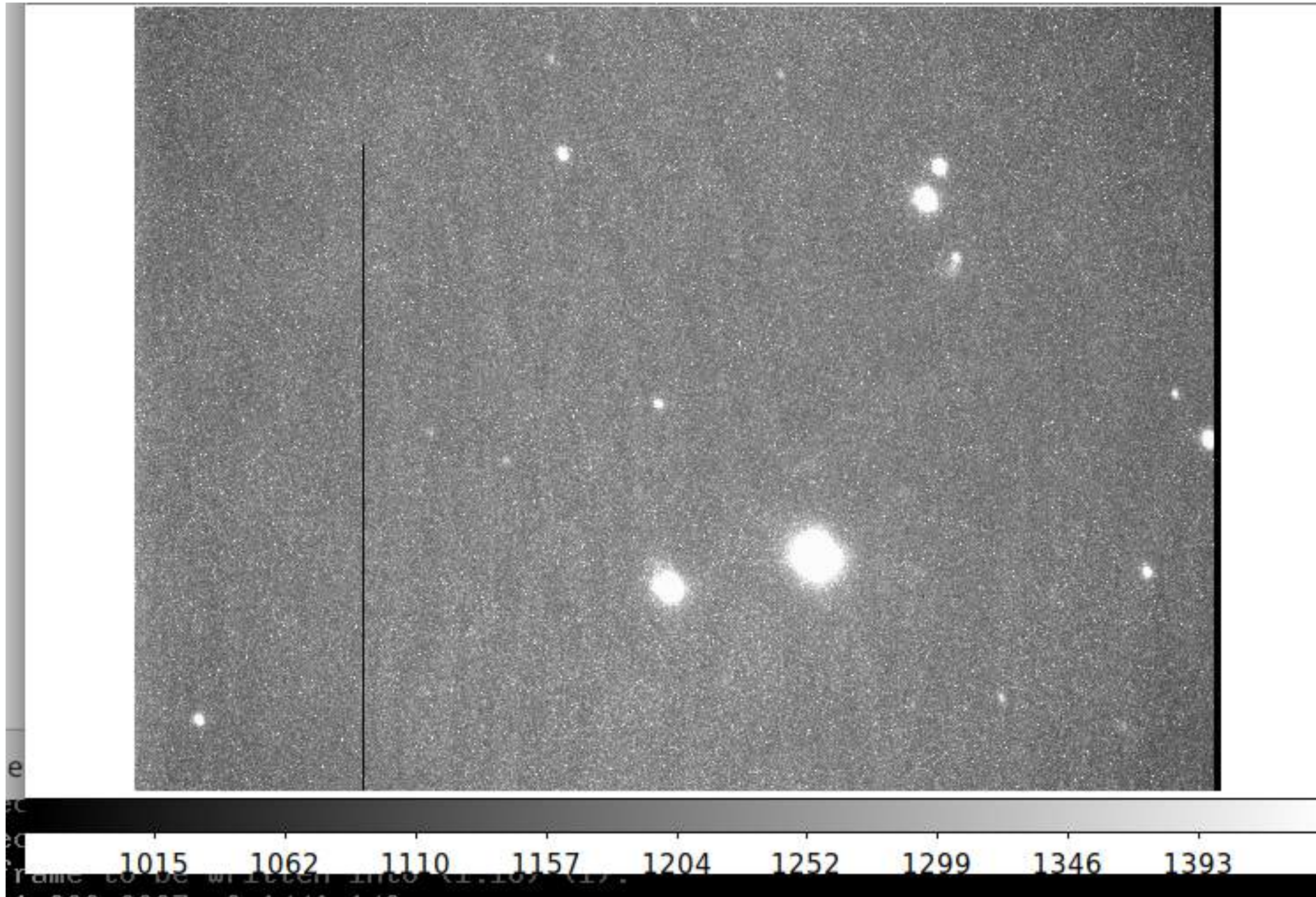
'IMAGETYPE':'target' -> 'object'

Fixing headers



# Reduction: J018.4128+22.9608

Step 2: Check your data with ds9 and Fixing Header

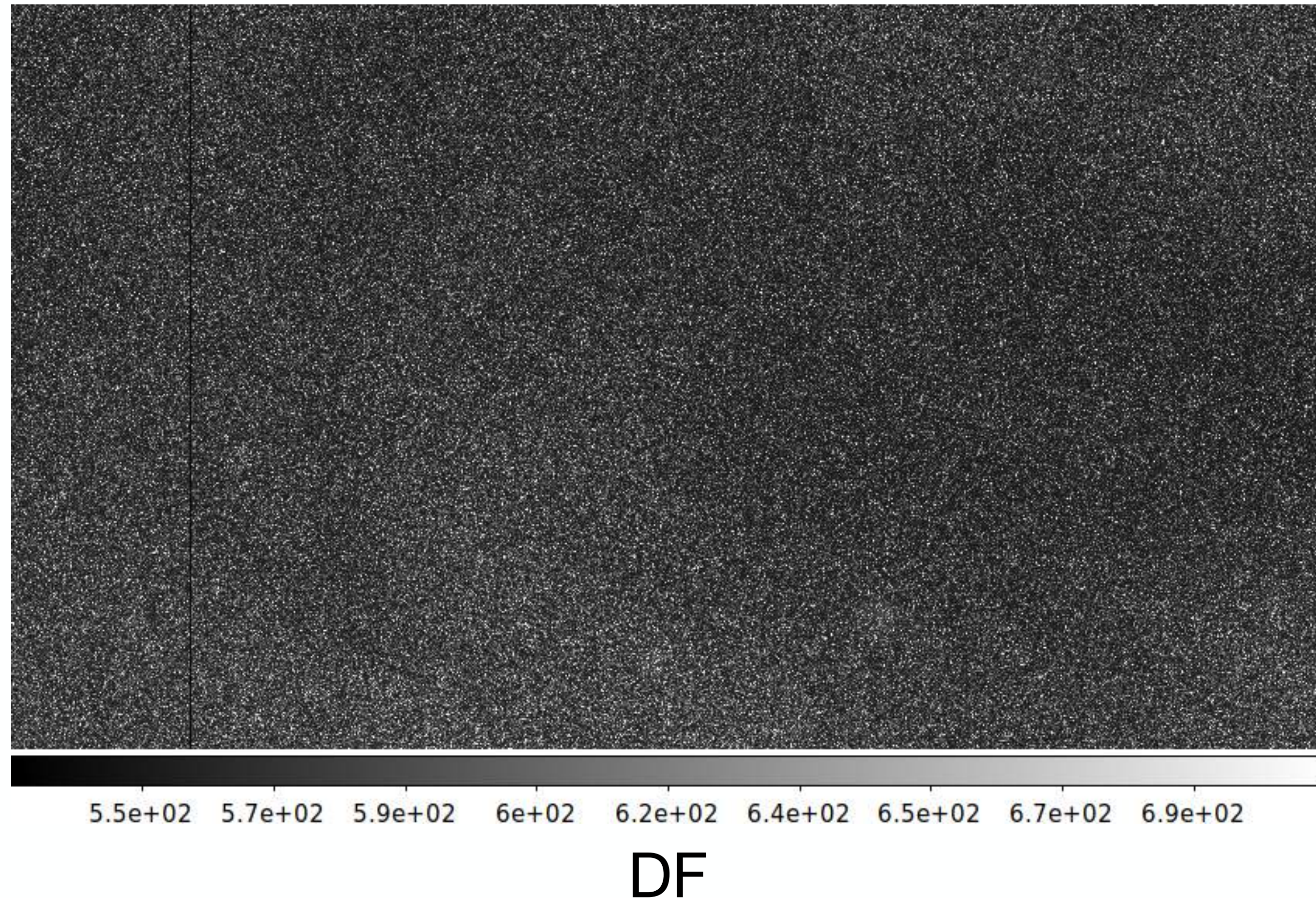




# Reduction: J018.4128+22.9608

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

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

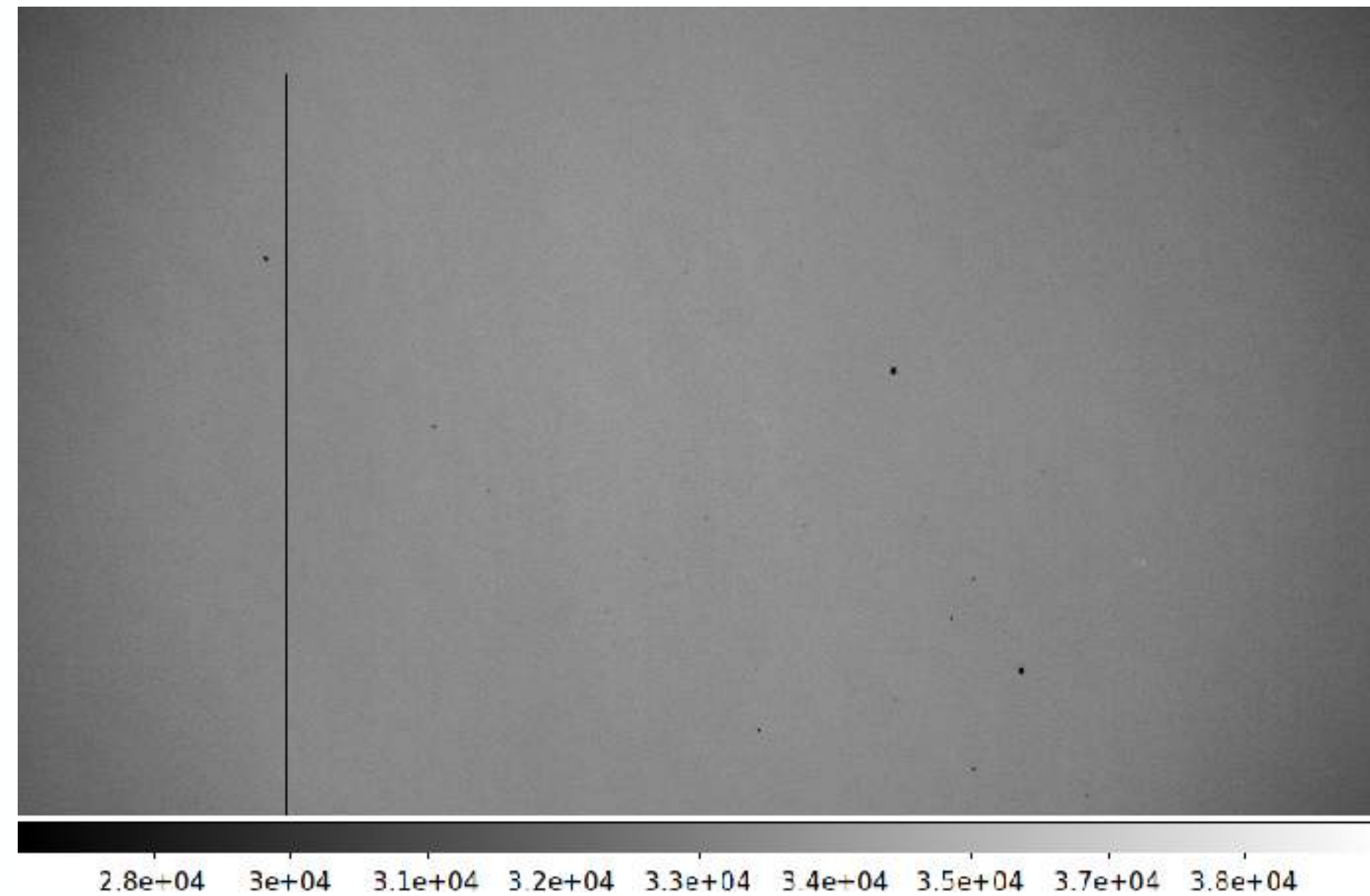




# Reduction: J018.4128+22.9608

## 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)



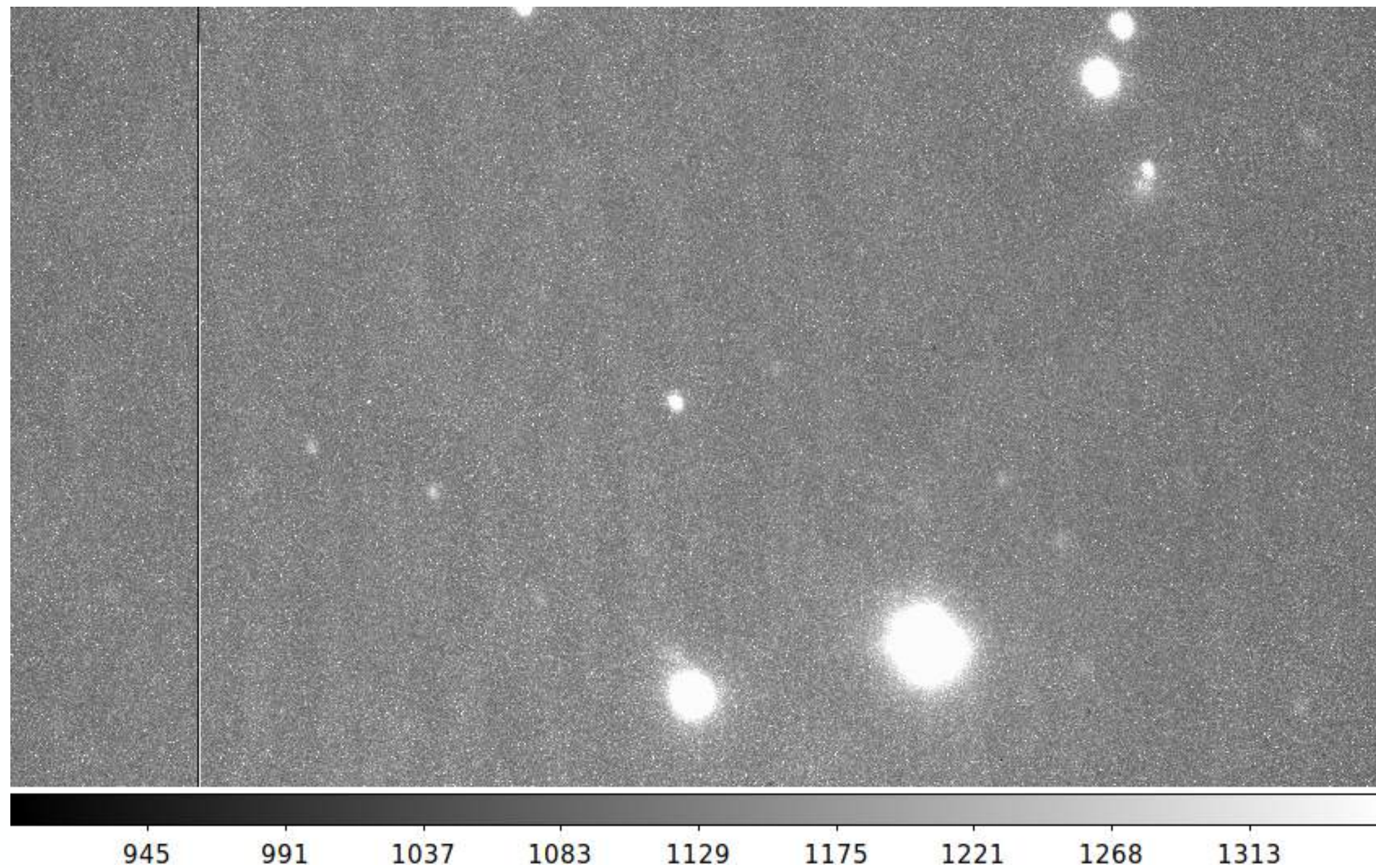
MF



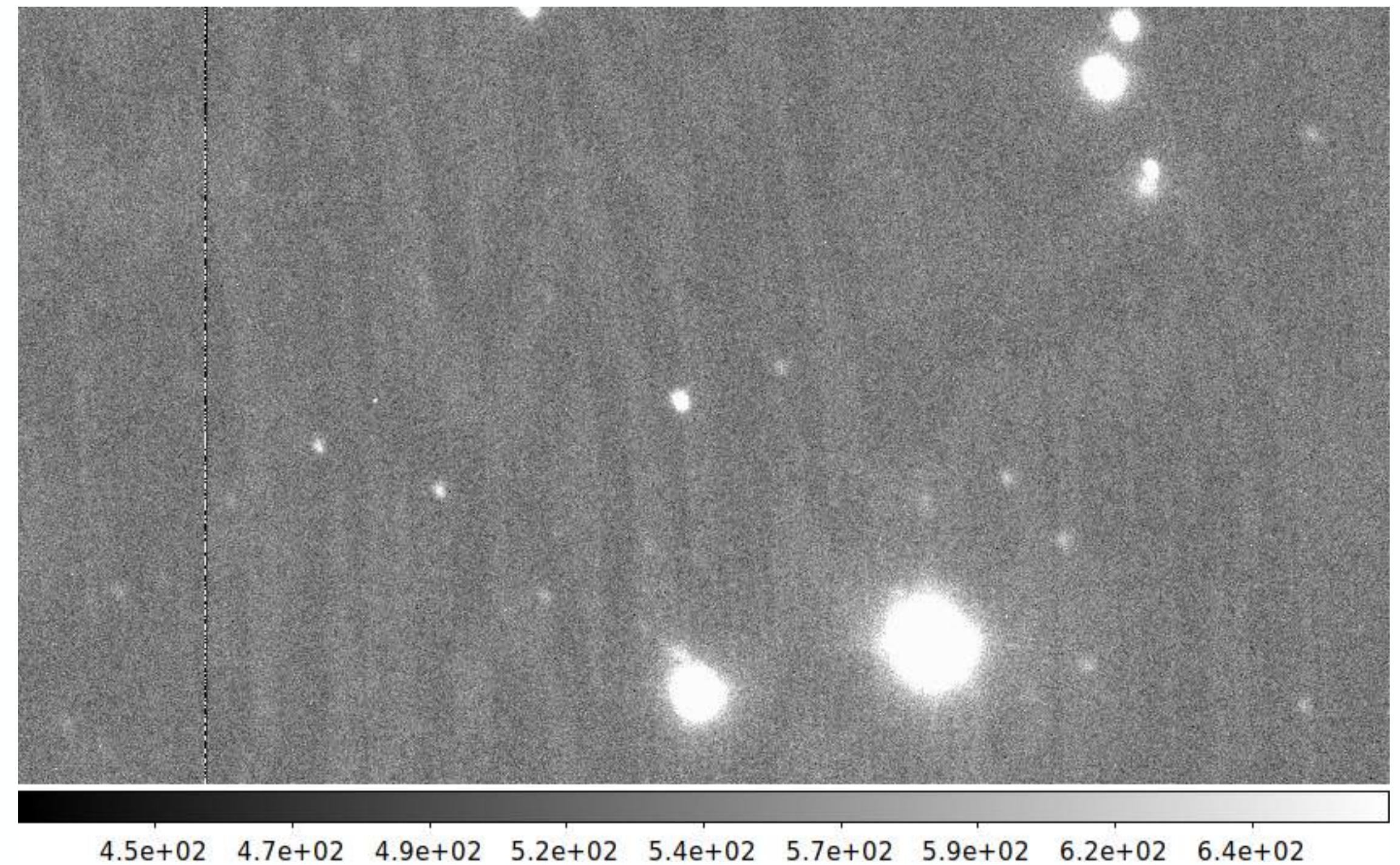
# Reduction: J018.4128+22.9608

## Step 4: Correct Science Frames: *epar ccdproc*

- Using DS and MF -> Keep the Dark & Flat corrections to 'yes'



Uncorrected



Corrected

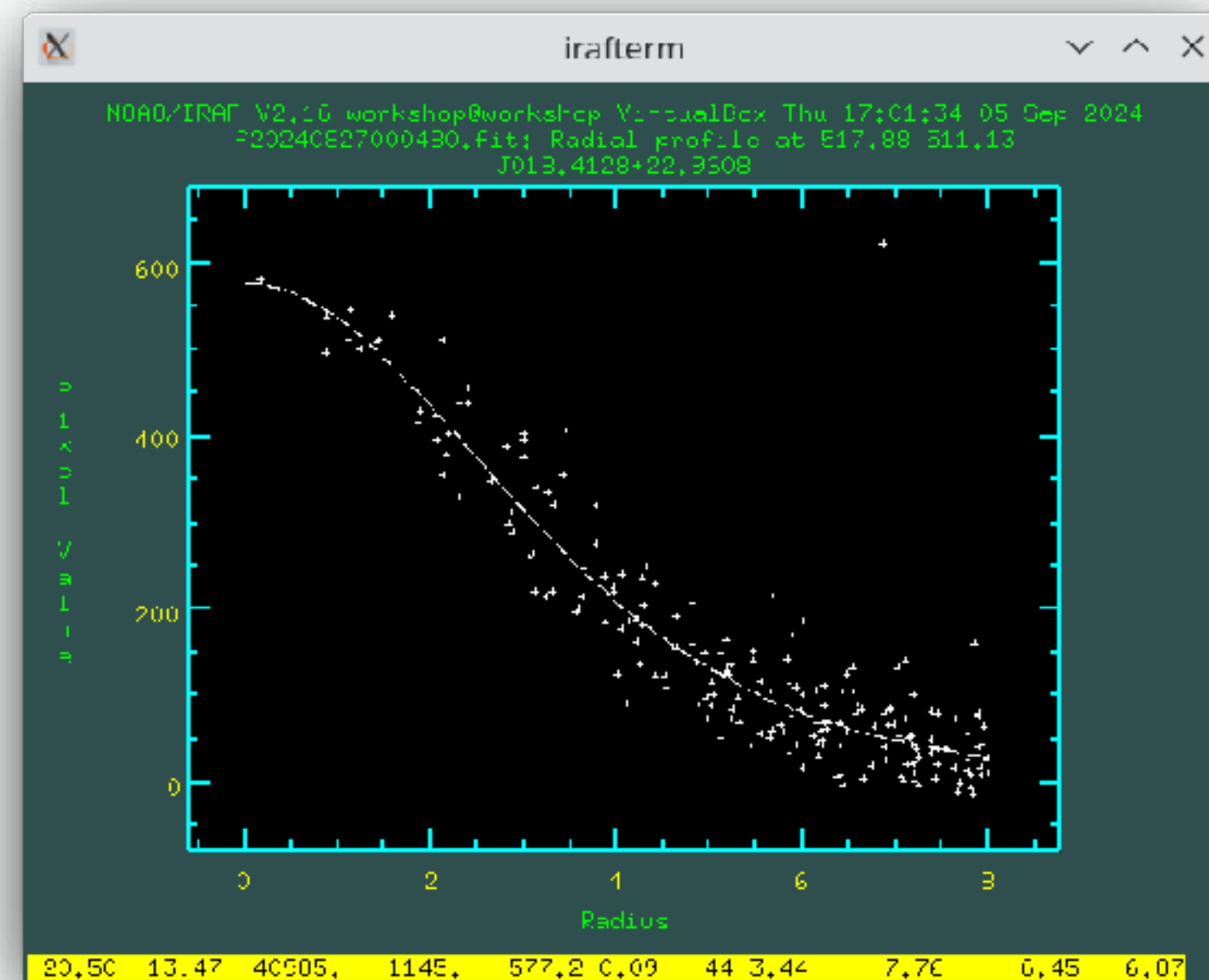
Save the list of corrected frames!



# 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

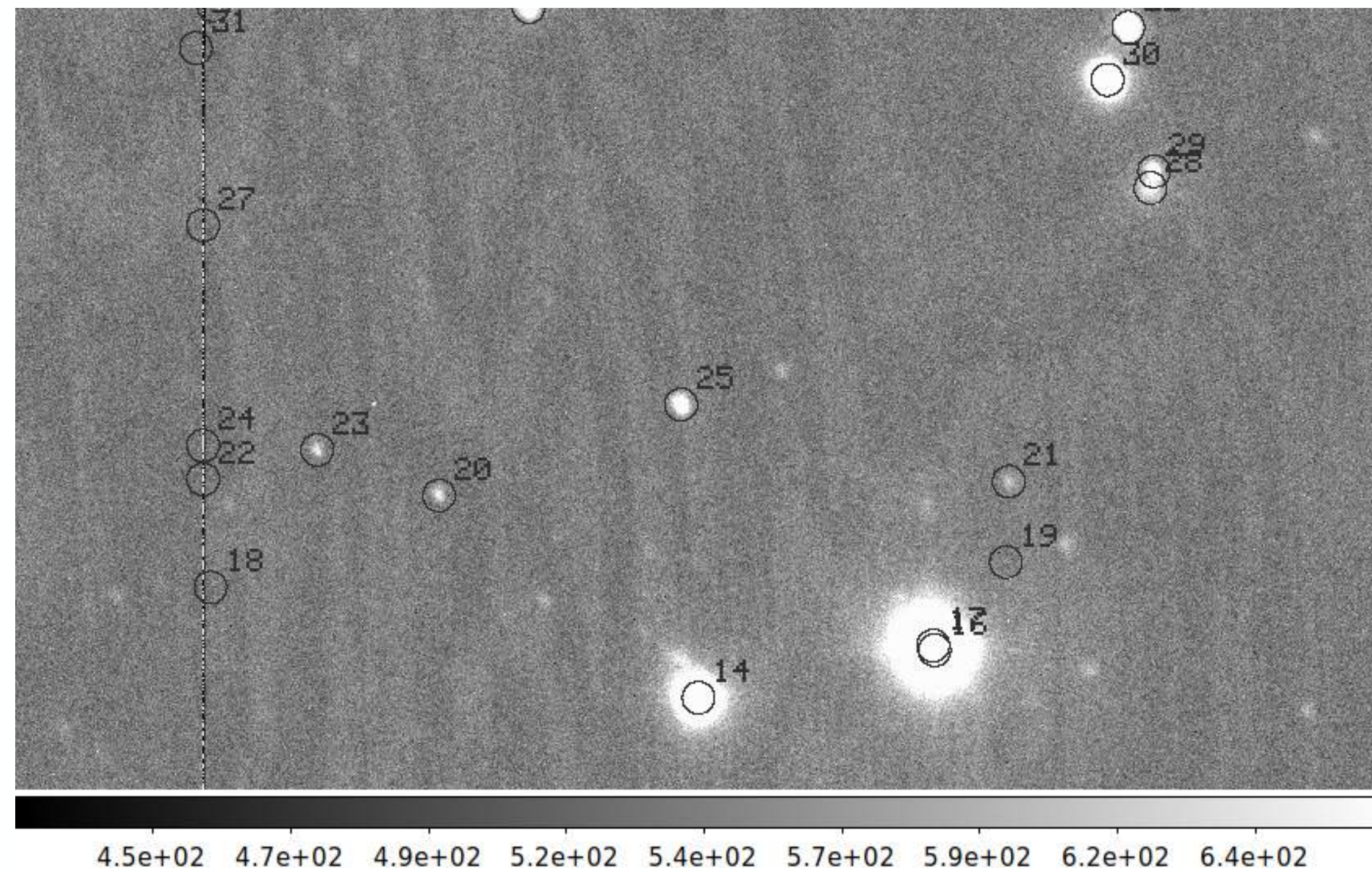
Save the columns into **coords1** file



# Photometry: J018.4128+22.9608

## Step 2: Display the stars : *epar tvmark*

- Open the same file used for *daofind*: Pass **coords1** & **Radii** to *tvmark*



Star-coordinates

Note down the star number



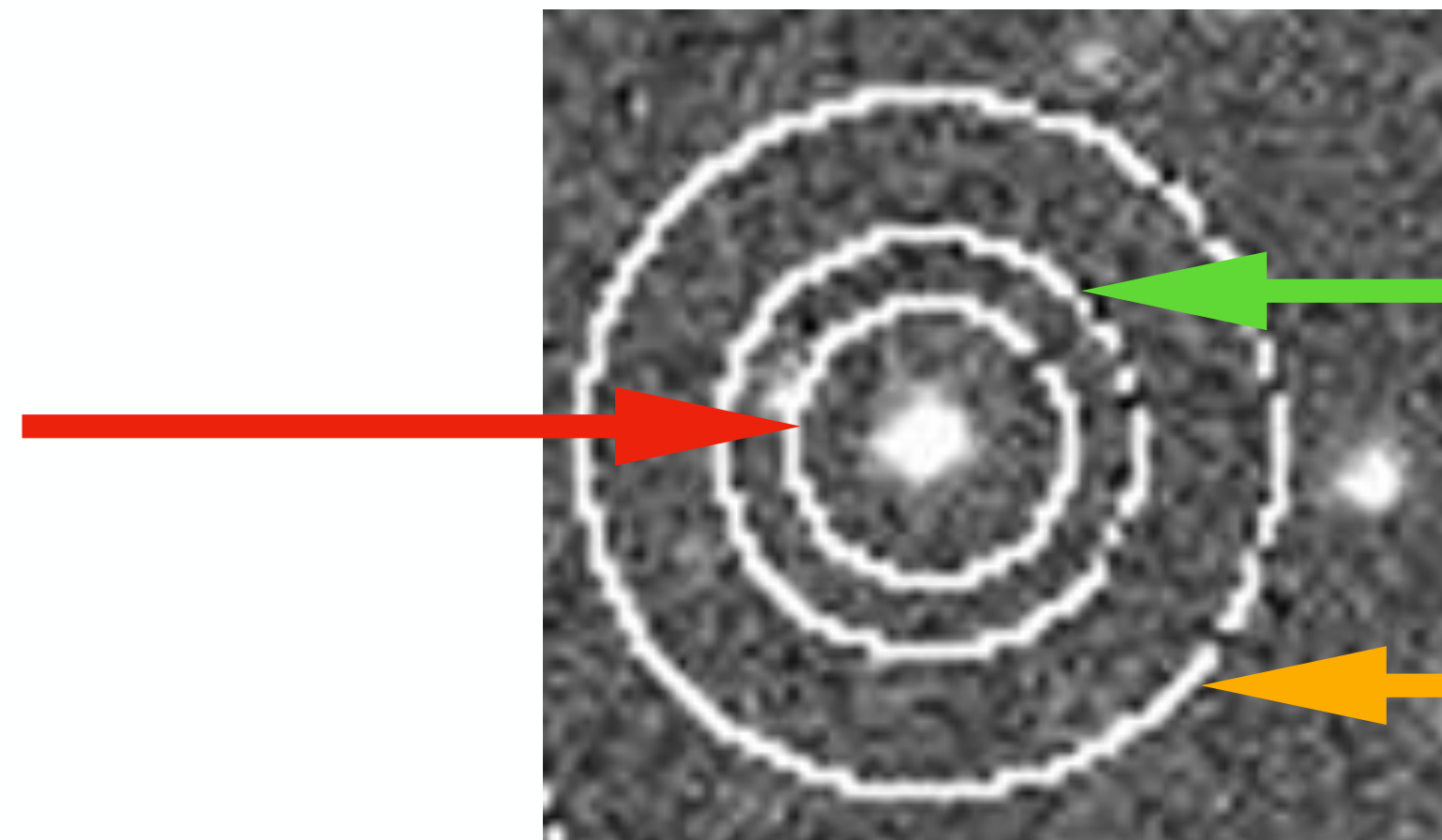
# Photometry: J018.4128+22.9608

## 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 Background  
counts start

### Dannulus:

Width of the ring to  
count background

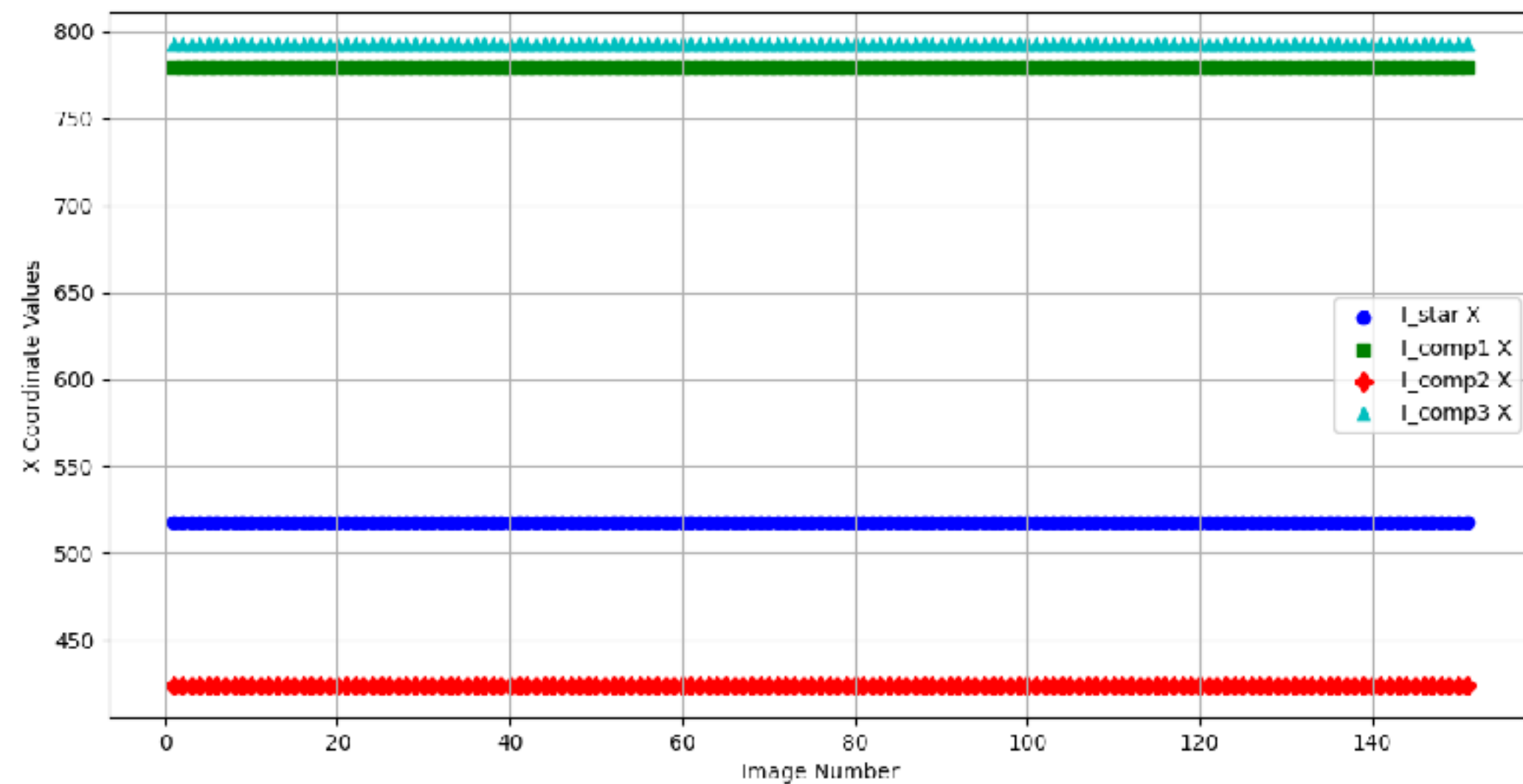
```
txdump @Imag_files fields=ID,XCENTER,YCENTER,FLUX,MAG,MERR > I_mags
```



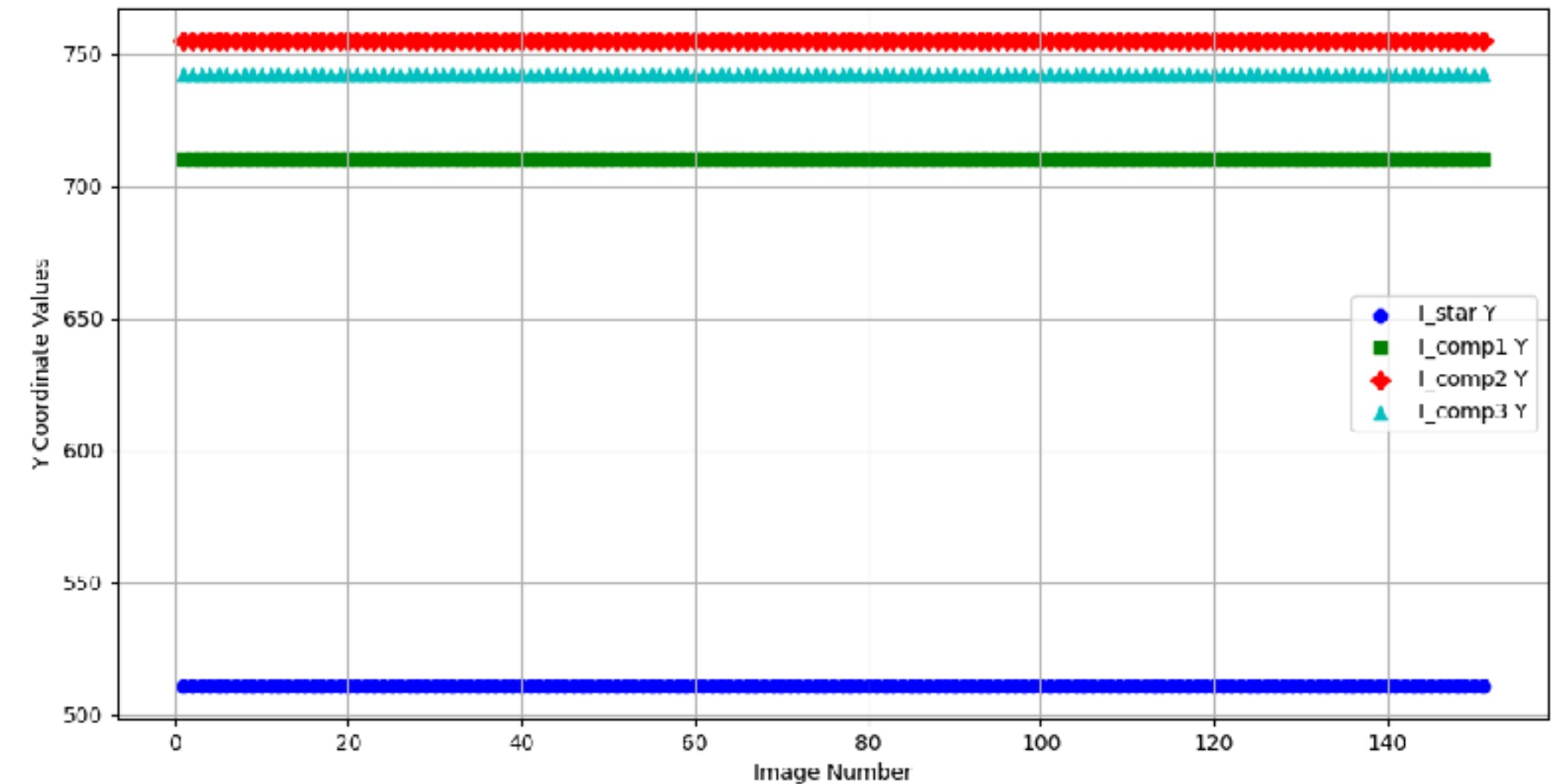
# Photometry: J018.4128+22.9608

## 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

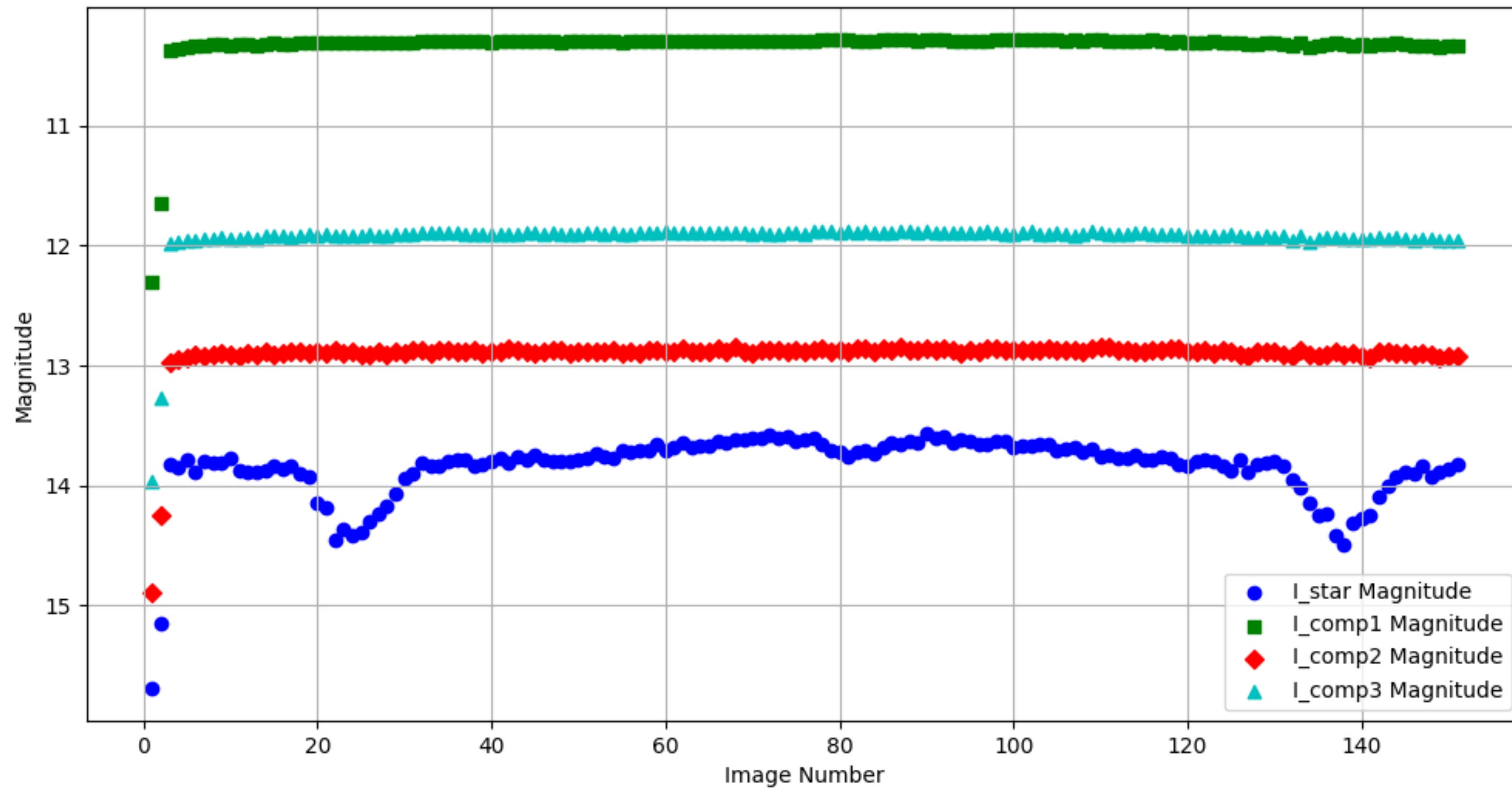


Y-Tracking



# Photometry: J018.4128+22.9608

## Step 5: Photometry - Magnitudes :

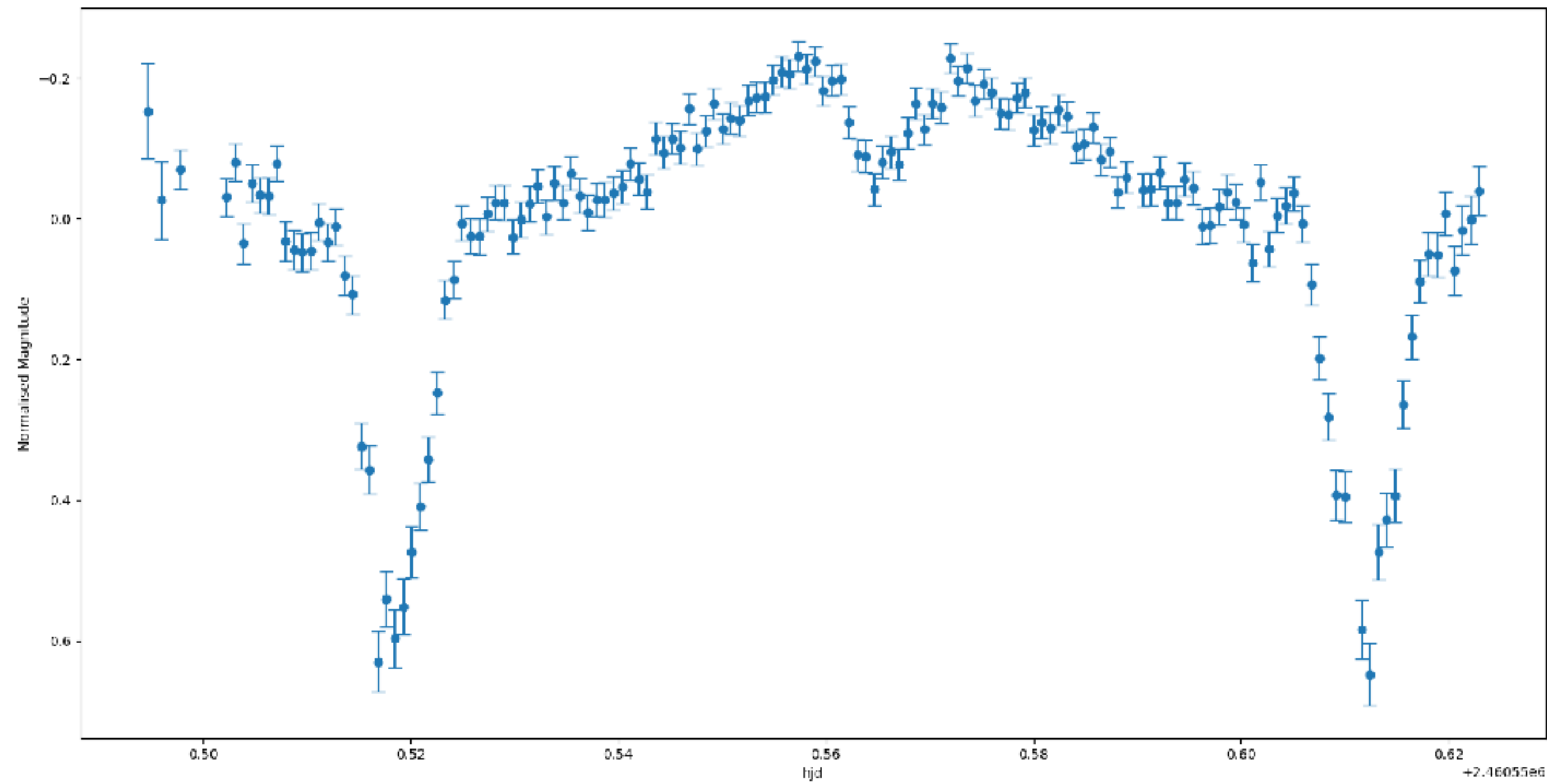


Mean magnitude of each star on the terminal



# Photometry: J018.4128+22.9608

Step 5: setjd & Generate the lightcurve:



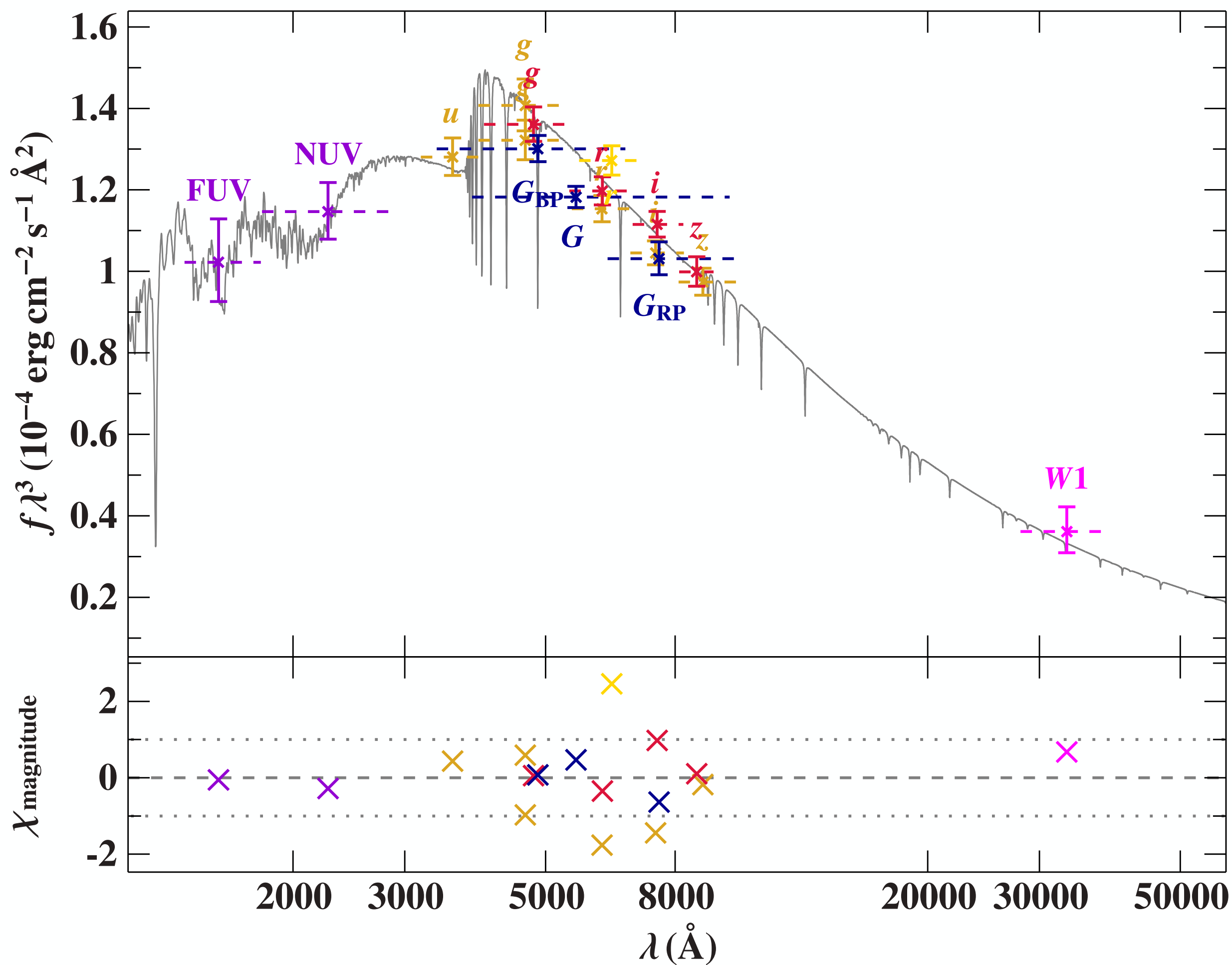
Use those mean magnitudes to generate the lightcurves



**J018.4128+22.9608 lightcurve fitting**

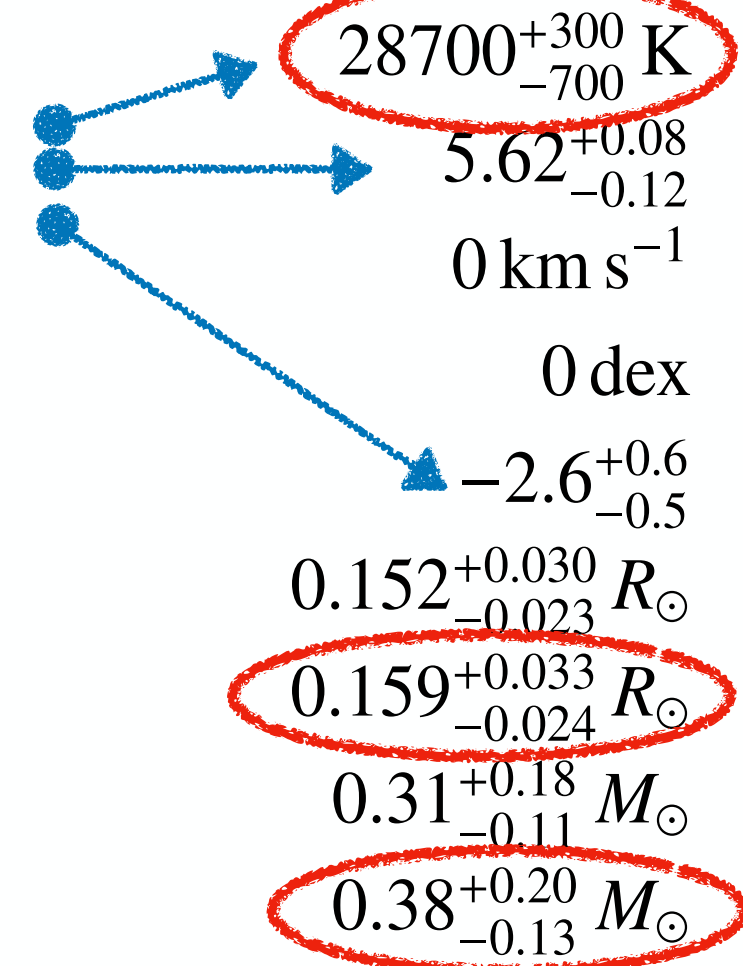
# J018.4128+22.9608

## 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)	$0.0386 \pm 0.0012$ mag
Color excess $E(B - V)$ from S&F (2011)	$0.0332 \pm 0.0010$ mag
Color excess $E(B - V)$ from Stilism (Capitanio+ 2017)	$0.048 \pm 0.016$ mag
Distance from Stilism and $E(44 - 55)$	$465 \pm 0$ pc
Color excess $E(44 - 55)$	$0.058 \pm 0.008$ mag
Extinction parameter $R(55)$ (fixed)	3.02
Angular diameter $\log(\Theta)$ (rad)	$-11.518^{+0.009}_{-0.006}$
Parallax $\varpi$ ( <i>Gaia</i> , RUWE = 1.00, ZPO = $-0.0014$ mas)	$0.42 \pm 0.08$ mas
Distance $d$ ( <i>Gaia</i> , mode)	$(2.2^{+0.5}_{-0.4}) \times 10^3$ pc
Distance $d$ ( <i>Gaia</i> , median)	$(2.4^{+0.5}_{-0.4}) \times 10^3$ pc
Effective temperature $T_{\text{eff}}$ (prescribed)	$28700^{+300}_{-700}$ K
Surface gravity $\log(g)$ ( $\text{cm s}^{-2}$ ) (prescribed)	$5.62^{+0.08}_{-0.12}$
Microturbulence $\xi$ (fixed)	$0 \text{ km s}^{-1}$
Metallicity $z$ (fixed)	$0 \text{ dex}$
Helium abundance $\log(n(\text{He}))$ (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 $L = (R/R_{\odot})^2(T_{\text{eff}}/T_{\text{eff},\odot})^4$ (mode)	$13^{+7}_{-4} L_{\odot}$
(median)	$15^{+7}_{-5} L_{\odot}$
Gravitational redshift $v_{\text{grav}} = GM/(Rc)$	$1.5 \pm 0.5 \text{ km s}^{-1}$
Escape velocity $v_{\text{esc}} = \sqrt{2gR}$	$950^{+130}_{-150} \text{ km s}^{-1}$
Generic excess noise $\delta_{\text{excess}}$	$0.023$ mag
Reduced $\chi^2$ at the best fit	1.00

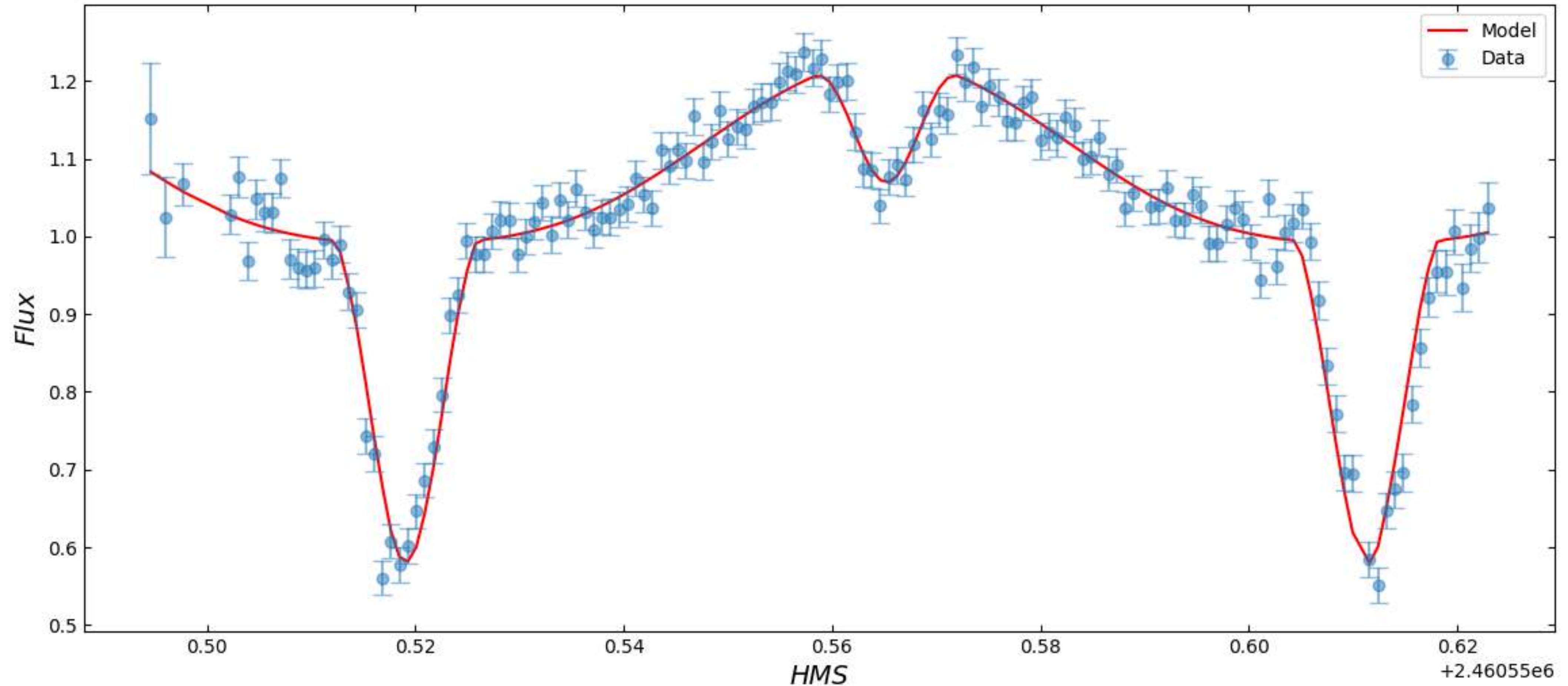
From spectra





# J018.4128+22.9608

## Lightcurve fitting



# J018.4128+22.9608

## Lightcurve Fitting Parameter Results

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

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

$$M_2 = q \cdot M_1$$

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!

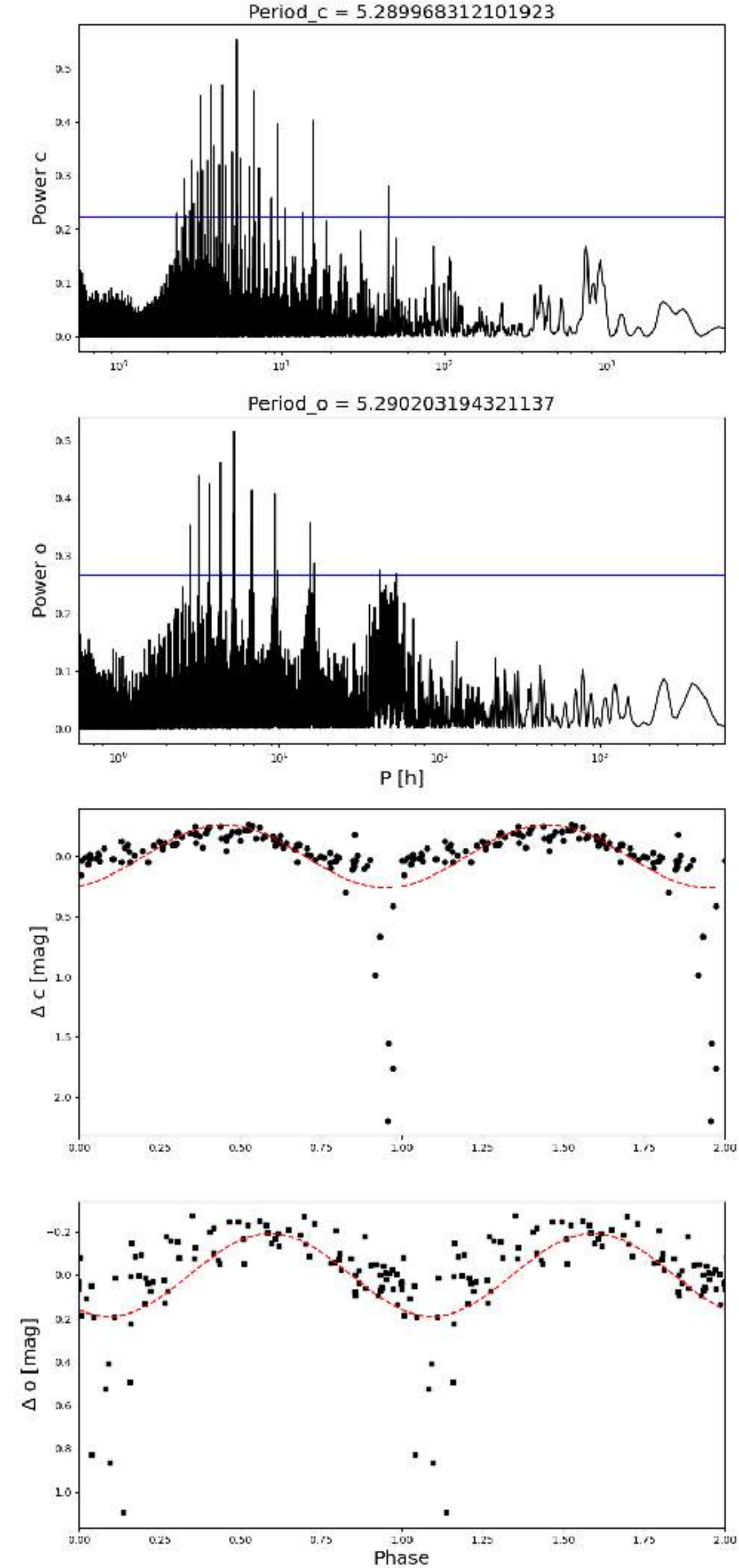
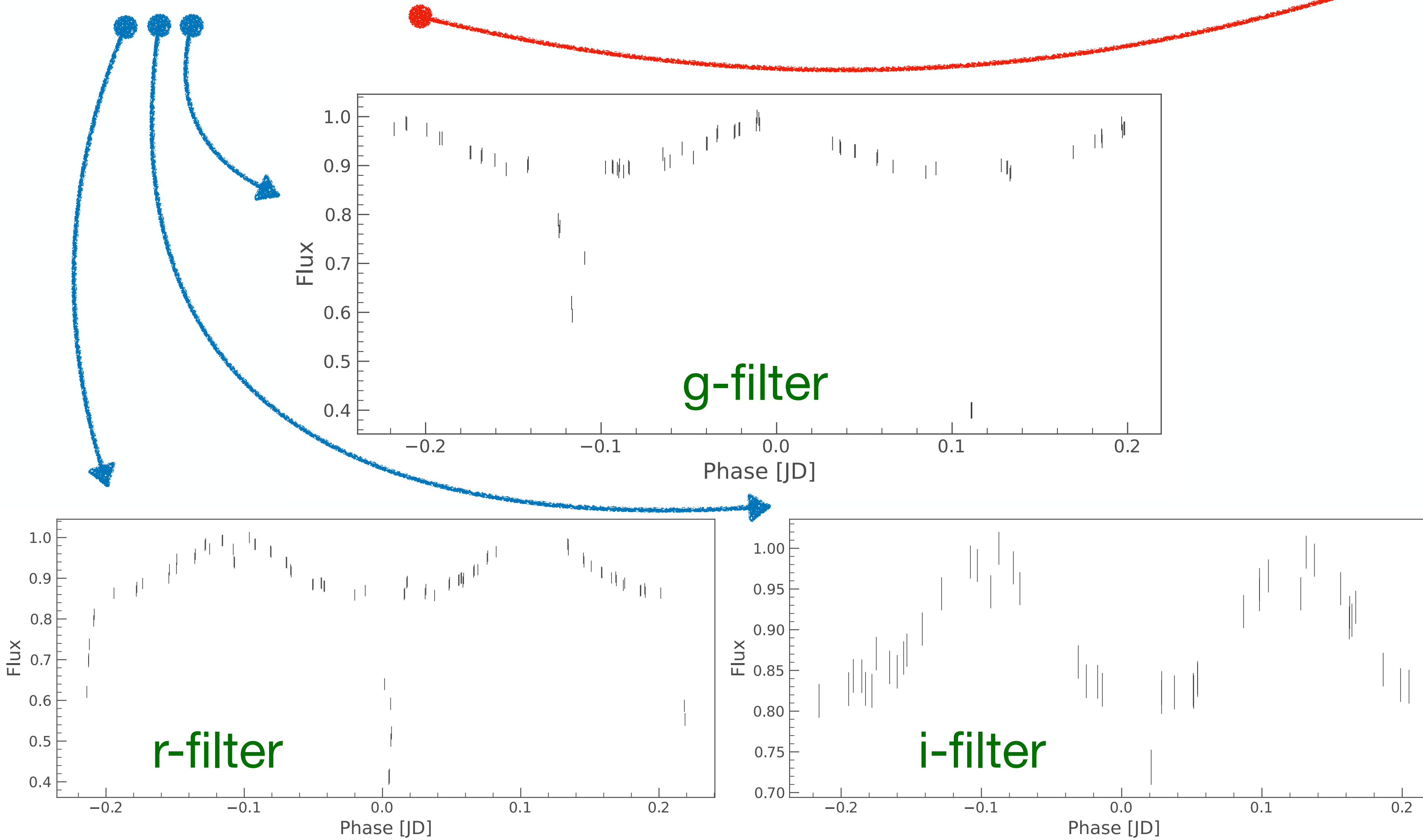
Really uncertain!



**J331.6658+32.7267**

# J331.6658+32.7267

## Atlas and ZTF spectra





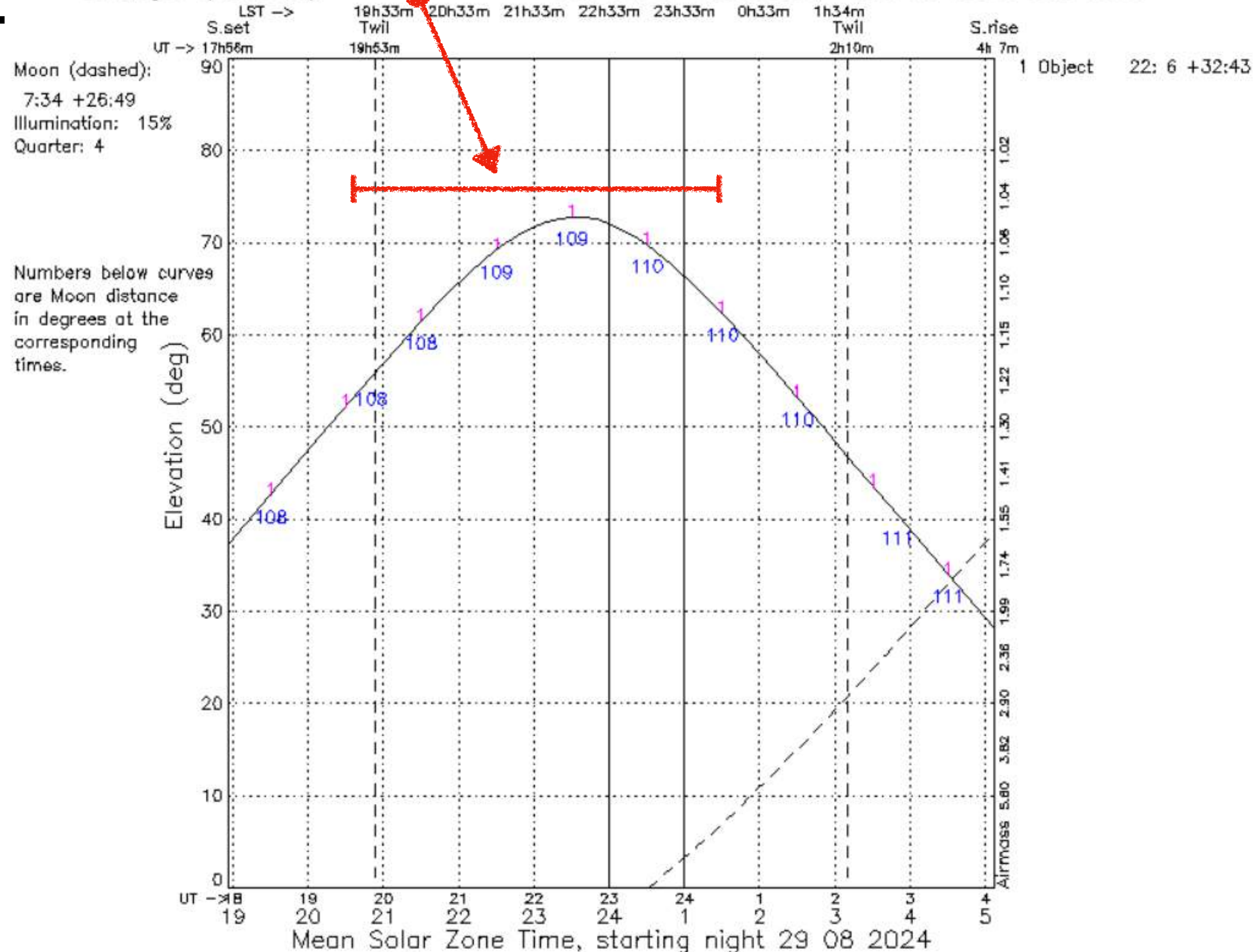
# J331.6658+32.7267

## Visibility on night 29.08.2024

### Observation

Ondrejov (Czechia)

14.7811E 49.9153N, 525 m above sea level

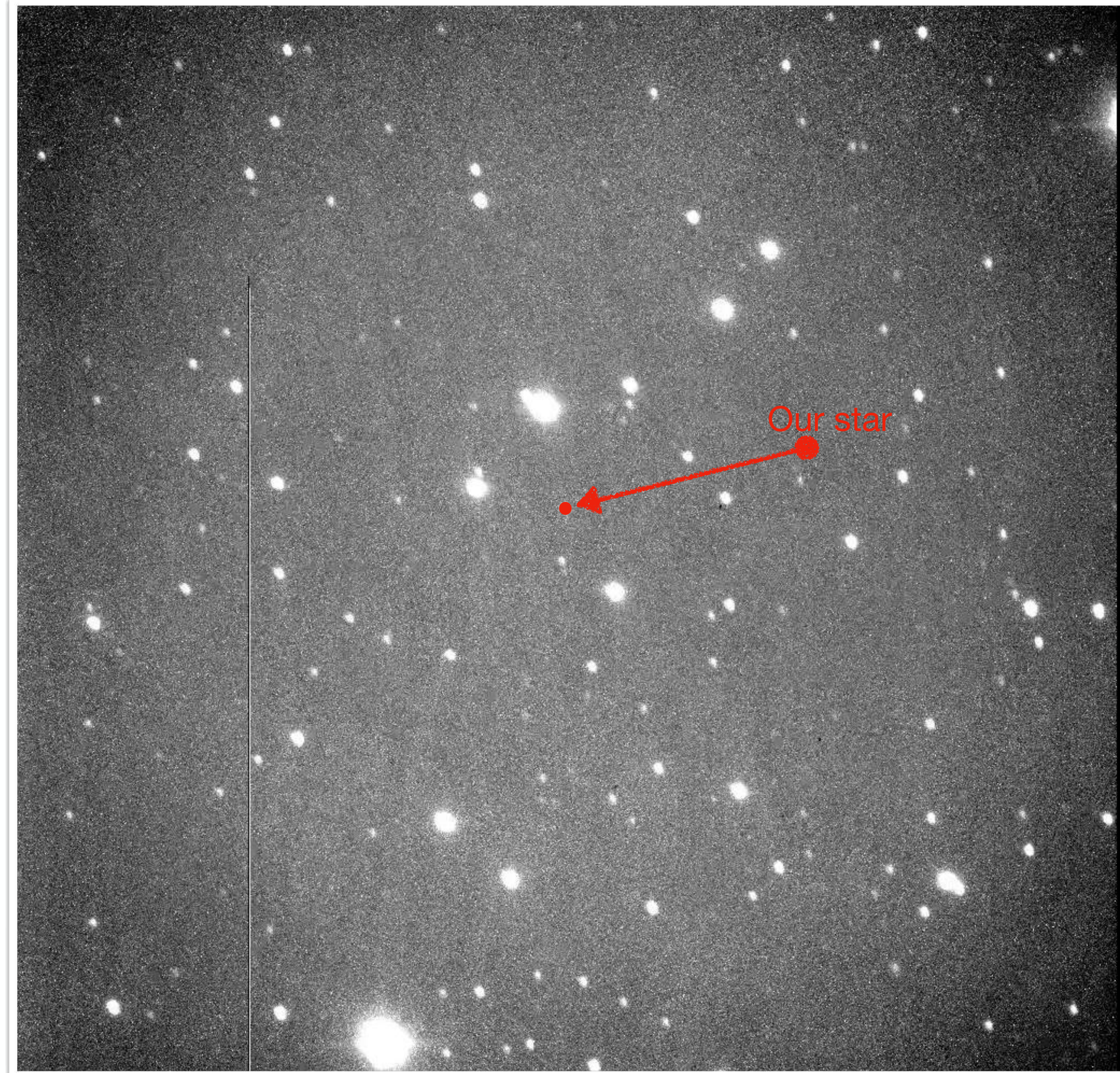




# J331.6658+32.7267

## Observation

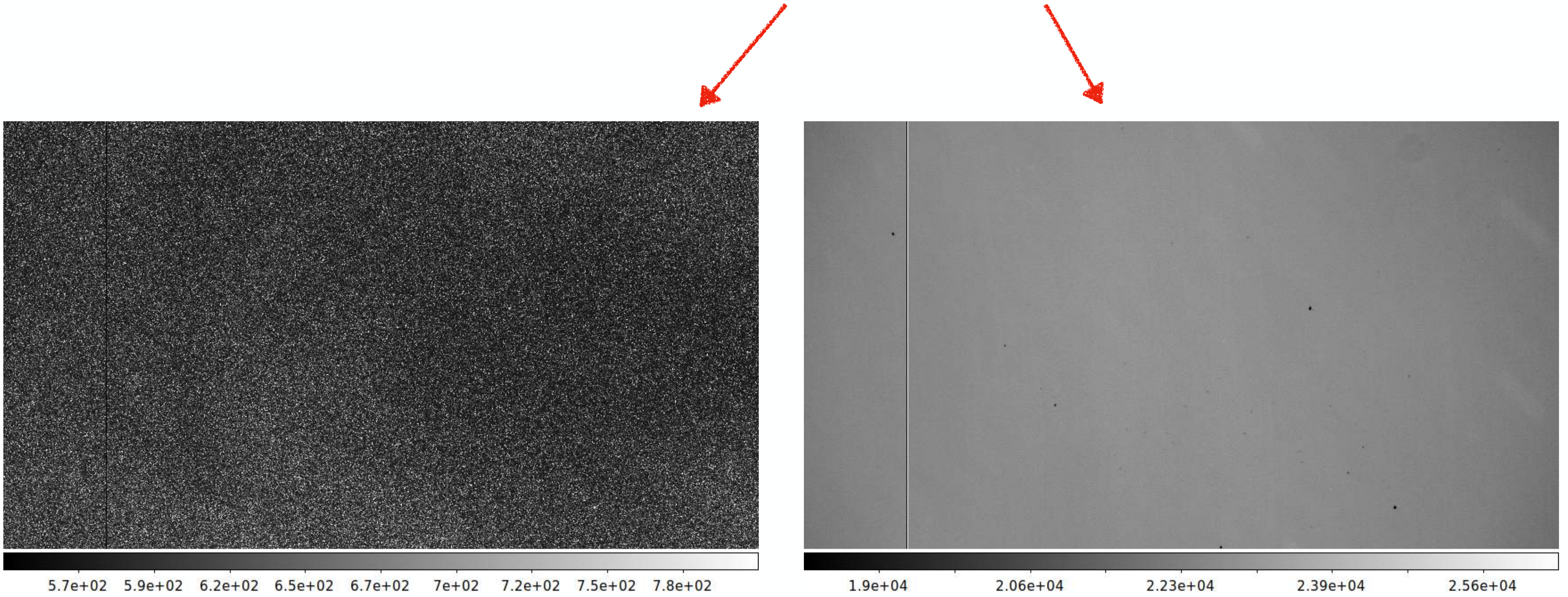
- 18:58 UT to 1:10 UT
- **60s** exposures - faint target
- Clouds were coming in during the observation - removed some images





# J331.6658+32.7267

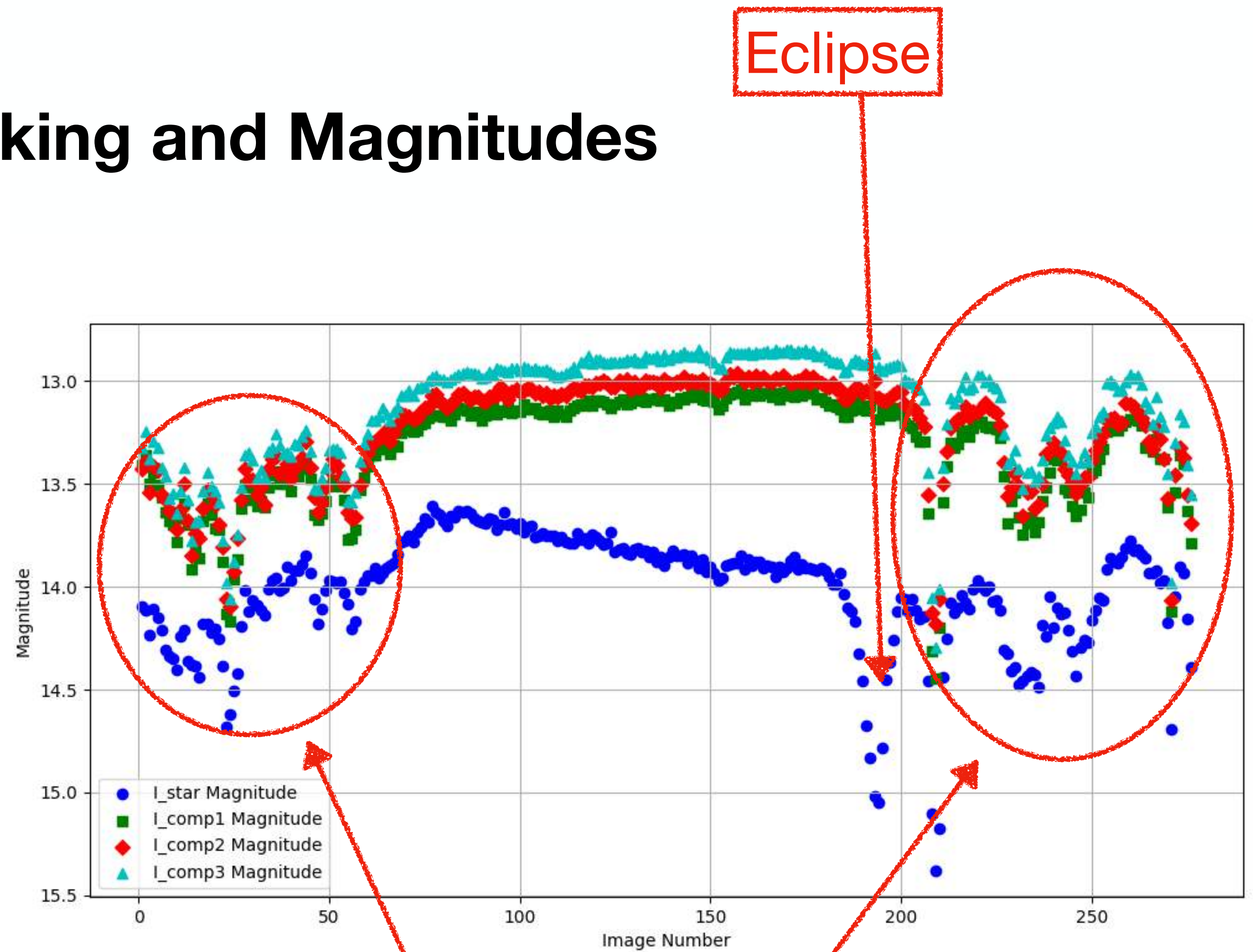
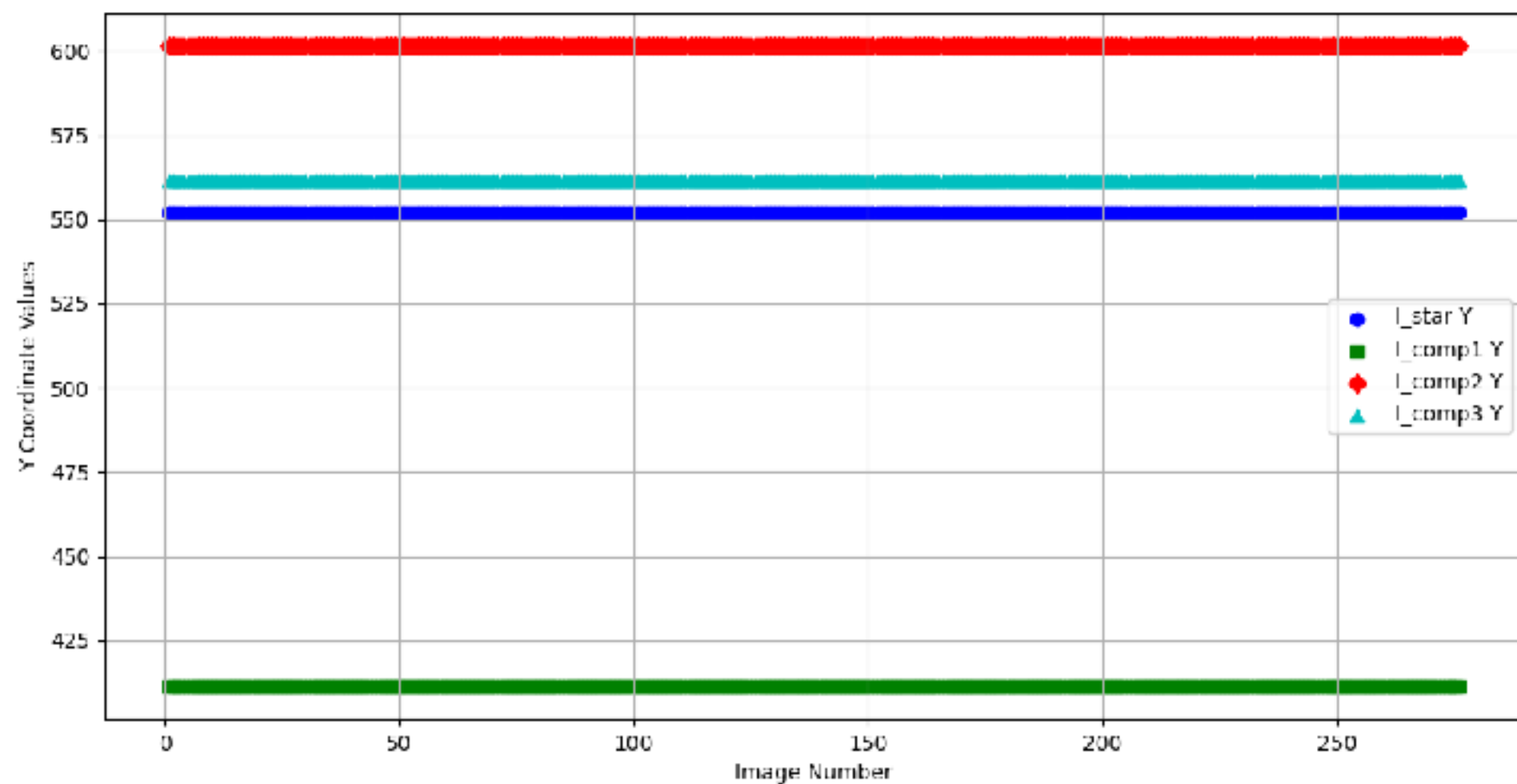
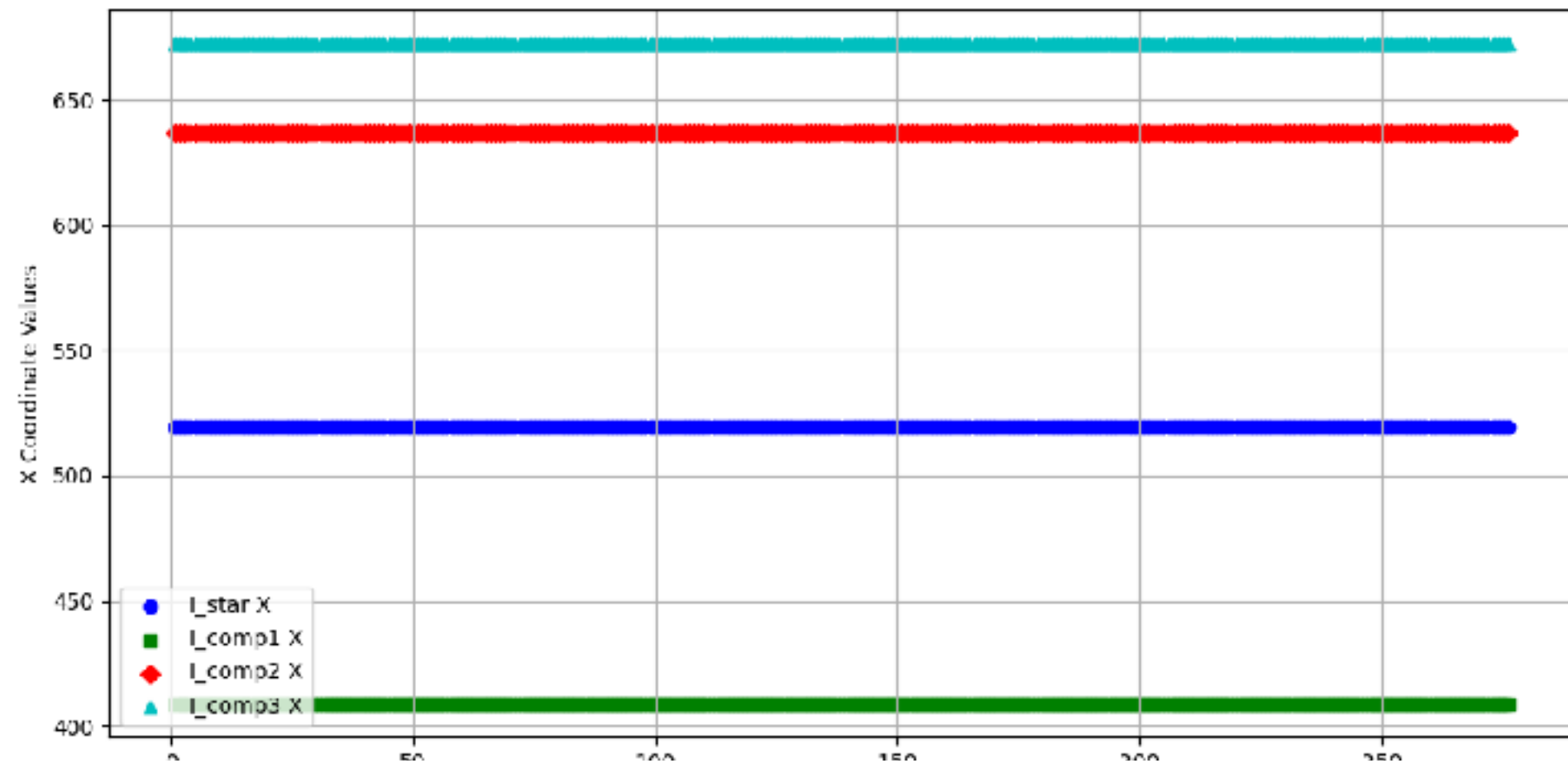
## Data Reduction i filter - Master Dark and Flat





# J331.6658+32.7267

## Data Reduction i filter - Tracking and Magnitudes



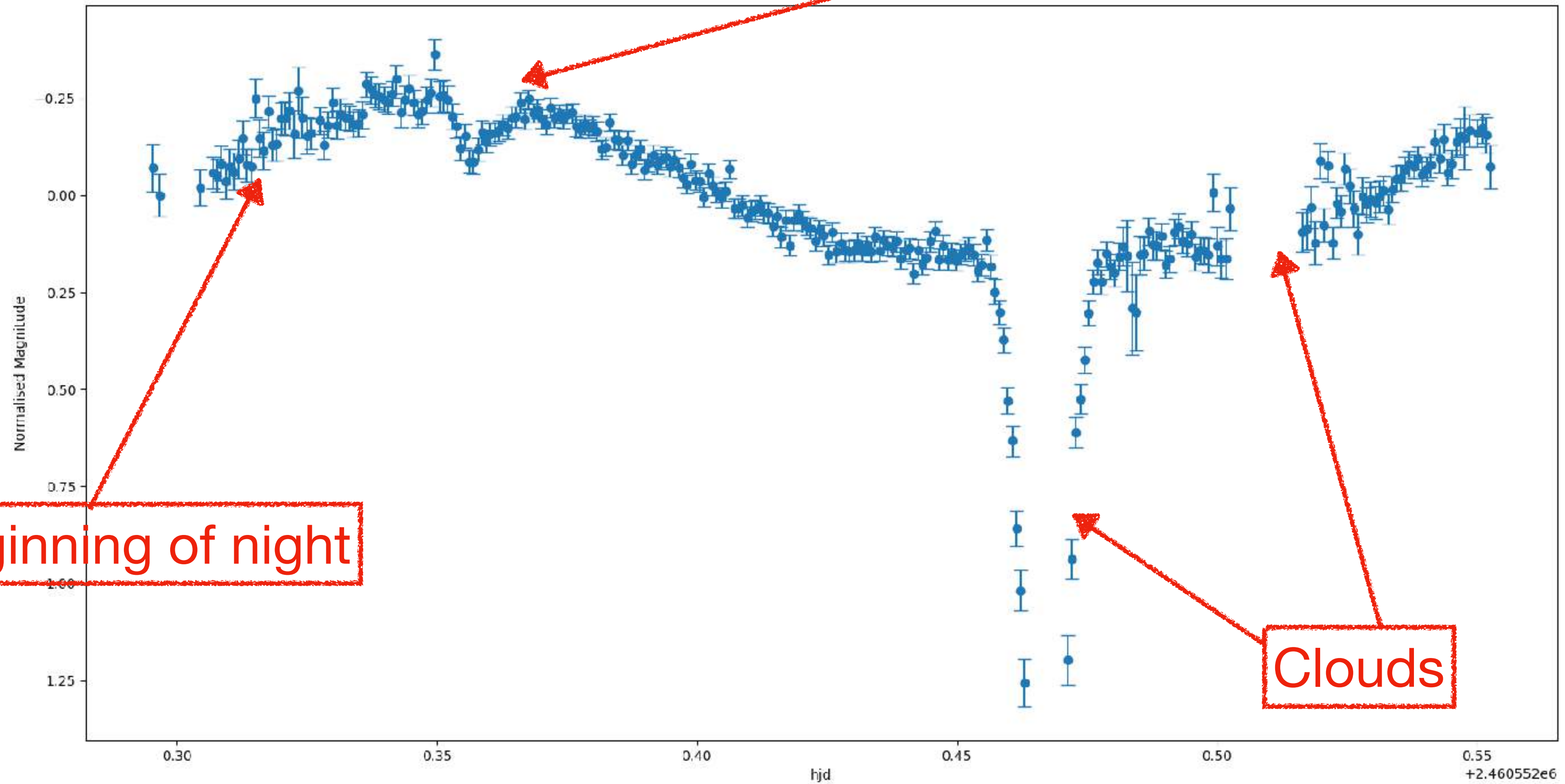
Bad data due to beginning of night & clouds



# J331.6658+32.7267

## Data Reduction i filter - Lightcurve

Secondary Eclipse



Beginning of night

Clouds

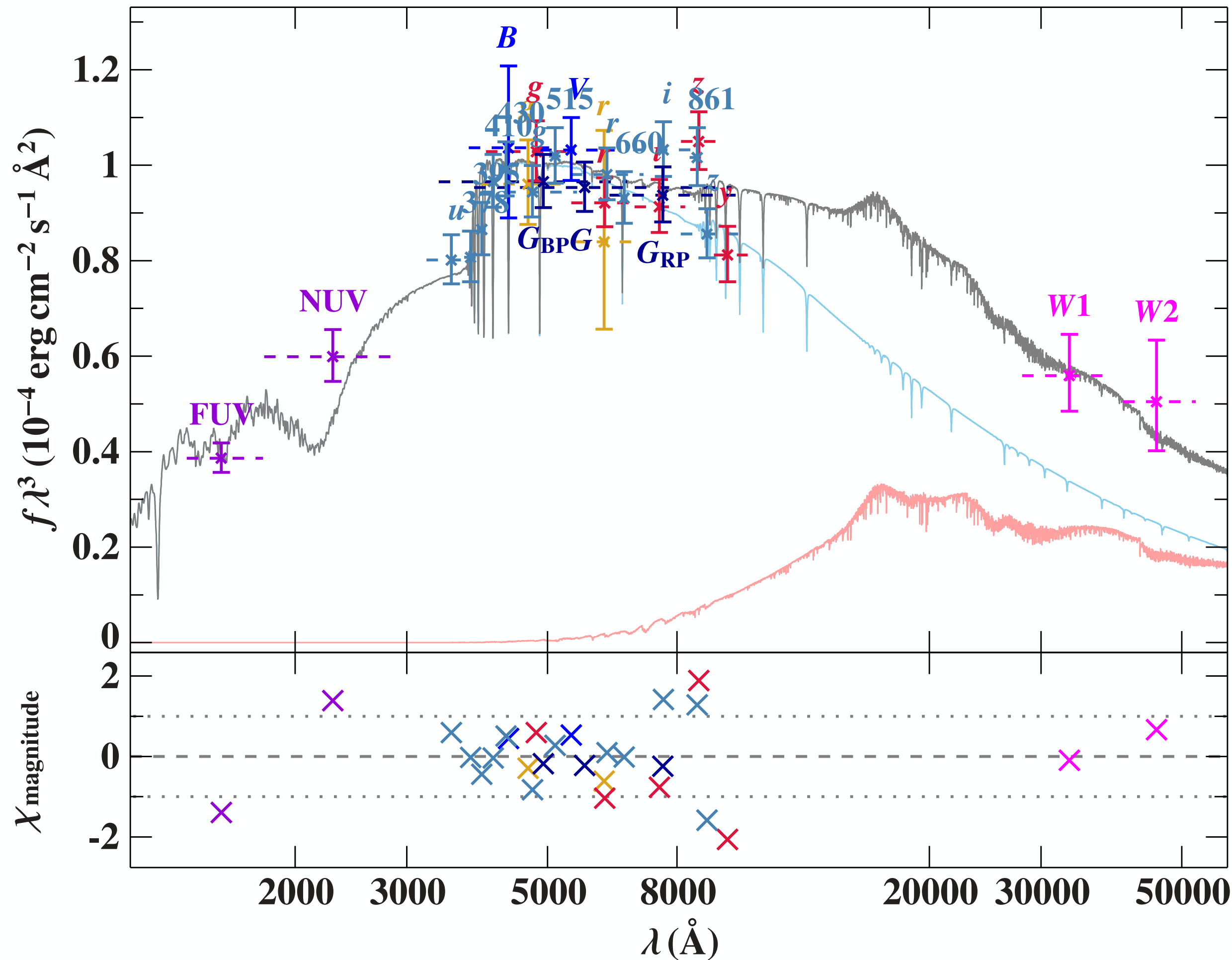


**J331.6658+32.7267 lightcurve fitting**



# J331.6658+32.7267

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

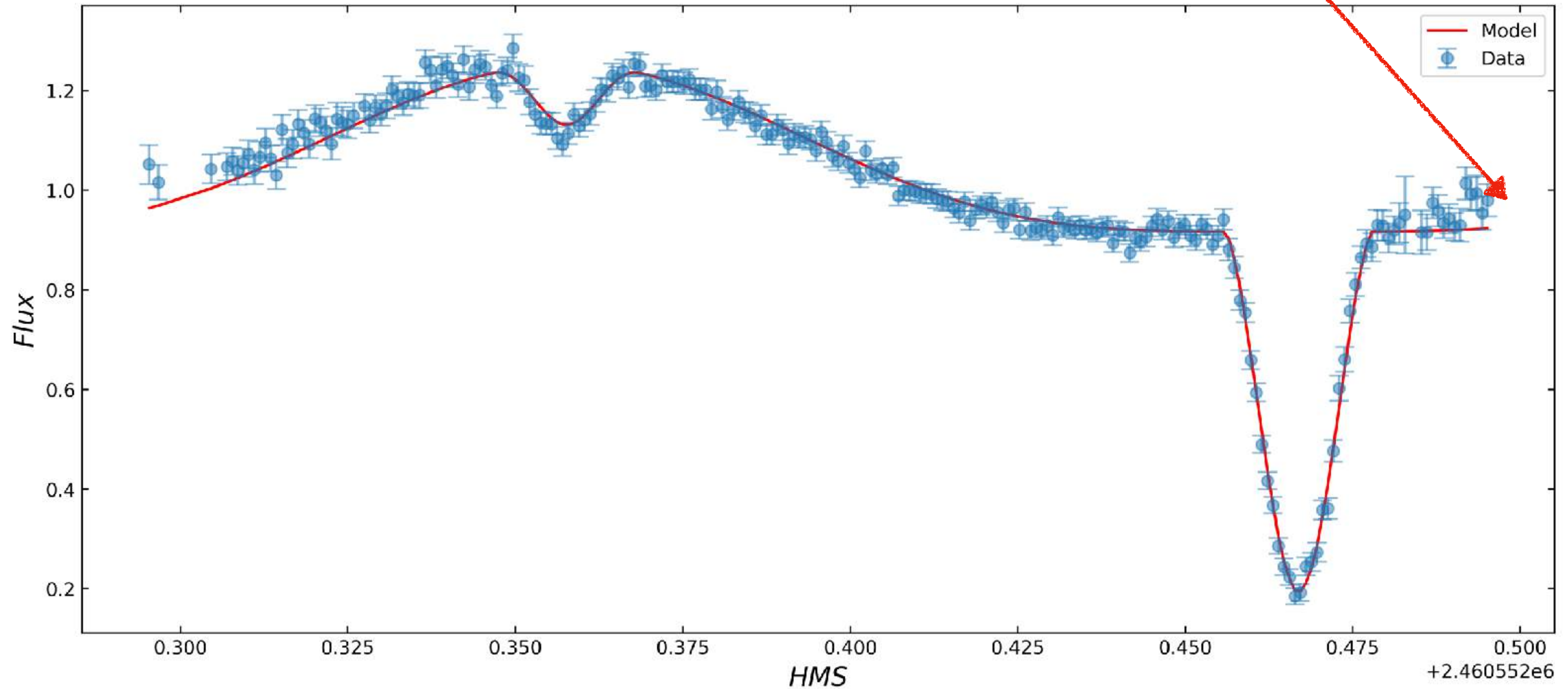


Object: Gaia DR3 1899579411285853952	68% confidence interval
Color excess $E(B - V)$ from SFD (1998)	$0.121 \pm 0.004 \text{ mag}$
Color excess $E(B - V)$ from S&F (2011)	$0.1038 \pm 0.0027 \text{ mag}$
Color excess $E(B - V)$ from Stilism (Capitanio+ 2017)	$0.09 \pm 0.04 \text{ mag}$
Color excess $E(B - V)$ from Bayestar15 (Green+ 2015)	$0.097 \pm 0.006 \text{ mag}$
Distance from Stilism and $E(44 - 55)$	$935 \pm 0 \text{ pc}$
Color excess $E(44 - 55)$	$0.150^{+0.028}_{-0.036} \text{ mag}$
Extinction parameter $R(55)$ (fixed)	3.02
Angular diameter $\log(\Theta \text{ (rad)})$	$-11.490^{+0.024}_{-0.022}$
Parallax $\varpi$ (Gaia, RUWE = 1.01, ZPO = -0.0053 mas)	$0.31 \pm 0.07 \text{ mas}$
Distance $d$ (Gaia, mode)	$(3.0^{+0.8}_{-0.6}) \times 10^3 \text{ pc}$
Distance $d$ (Gaia, median)	$(3.2^{+0.9}_{-0.6}) \times 10^3 \text{ pc}$
Component 1:	
Effective temperature $T_{\text{eff}}$	$26600^{+2200}_{-2500} \text{ K}$
Surface gravity $\log(g \text{ (cm s}^{-2}\text{)})$ (prescribed)	$5.45^{+0.26}_{-0.35}$
Microturbulence $\xi$ (fixed)	$0 \text{ km s}^{-1}$
Metallicity $z$ (fixed)	0 dex
Helium abundance $\log(n(\text{He}))$ (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)	$0.26^{+0.55}_{-0.18} M_{\odot}$
(median)	$0.5^{+0.7}_{-0.4} M_{\odot}$
Luminosity $L = (R/R_{\odot})^2(T_{\text{eff}}/T_{\text{eff},\odot})^4$ (mode)	$(-nan \pm -nan) \times 10^{2147483647} L_{\odot}$
(median)	$24^{+19}_{-11} L_{\odot}$
Gravitational redshift $v_{\text{grav}} = GM/(Rc)$	$0.8^{+1.4}_{-0.5} \text{ km s}^{-1}$
Escape velocity $v_{\text{esc}} = \sqrt{2gR}$	$950^{+270}_{-390} \text{ km s}^{-1}$
Component 2:	
Effective temperature $T_{\text{eff}}$	$3800^{+767}_{-0} \text{ K}$
Surface gravity $\log(g \text{ (cm s}^{-2}\text{)})$ (fixed)	4.4
Microturbulence $\xi$ (fixed)	$0 \text{ km s}^{-1}$
Metallicity $z$ (fixed)	0 dex
Helium abundance $\log(n(\text{He}))$ (fixed)	-1
Surface ratio $A_{\text{eff}}/A_{\text{eff},1}$	$5.6^{+1.9}_{-2.1}$
Radius $R = (A_{\text{eff}}/A_{\text{eff},1})^{1/2}\Theta/(2\varpi)$ (mode)	$0.51^{+0.17}_{-0.14} R_{\odot}$
(median)	$0.55^{+0.18}_{-0.14} R_{\odot}$
Mass $M = gR^2/G$ (mode)	$(-nan \pm -nan) \times 10^{2147483647} M_{\odot}$
(median)	$0.27^{+0.21}_{-0.12} M_{\odot}$
Luminosity $L = (R/R_{\odot})^2(T_{\text{eff}}/T_{\text{eff},\odot})^4$ (mode)	$(-nan \pm -nan) \times 10^{2147483647} L_{\odot}$
(median)	$0.07^{+0.08}_{-0.04} L_{\odot}$
Gravitational redshift $v_{\text{grav}} = GM/(Rc)$	$0.30^{+0.10}_{-0.08} \text{ km s}^{-1}$
Escape velocity $v_{\text{esc}} = \sqrt{2gR}$	$430^{+70}_{-60} \text{ km s}^{-1}$
Generic excess noise $\delta_{\text{excess}}$	0.058 mag
Reduced $\chi^2$ at the best fit	1.00



# J331.6658+32.7267

## Lightcurve fitting I filter



# 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!

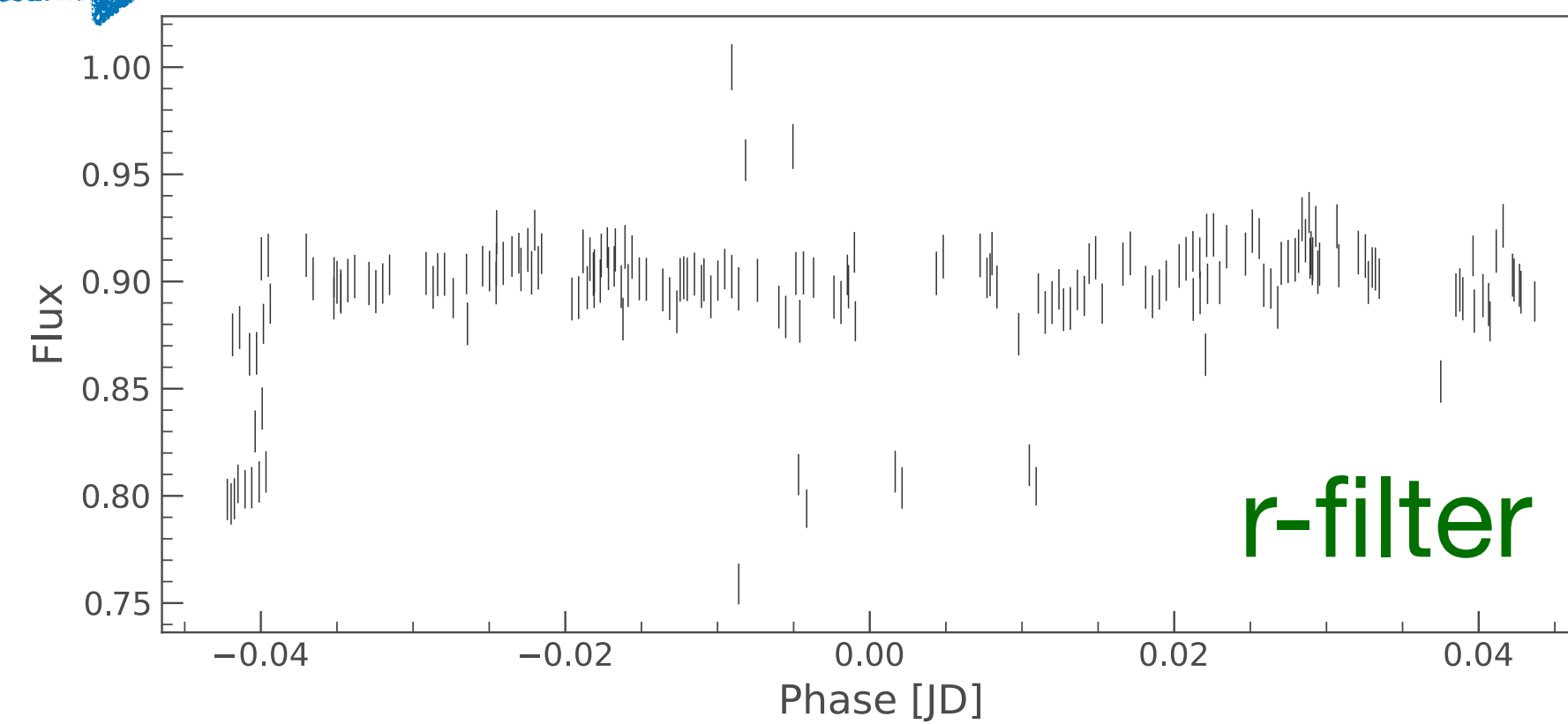
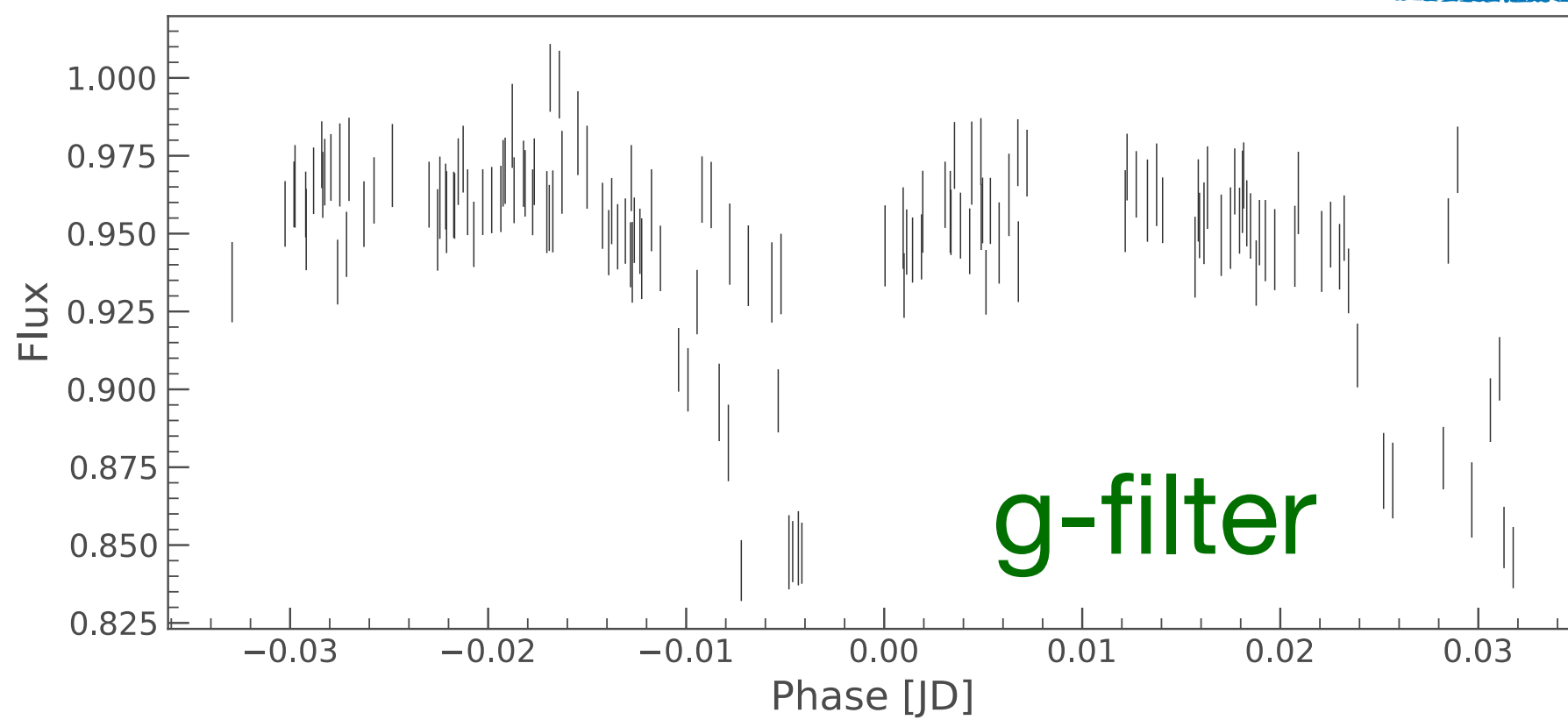
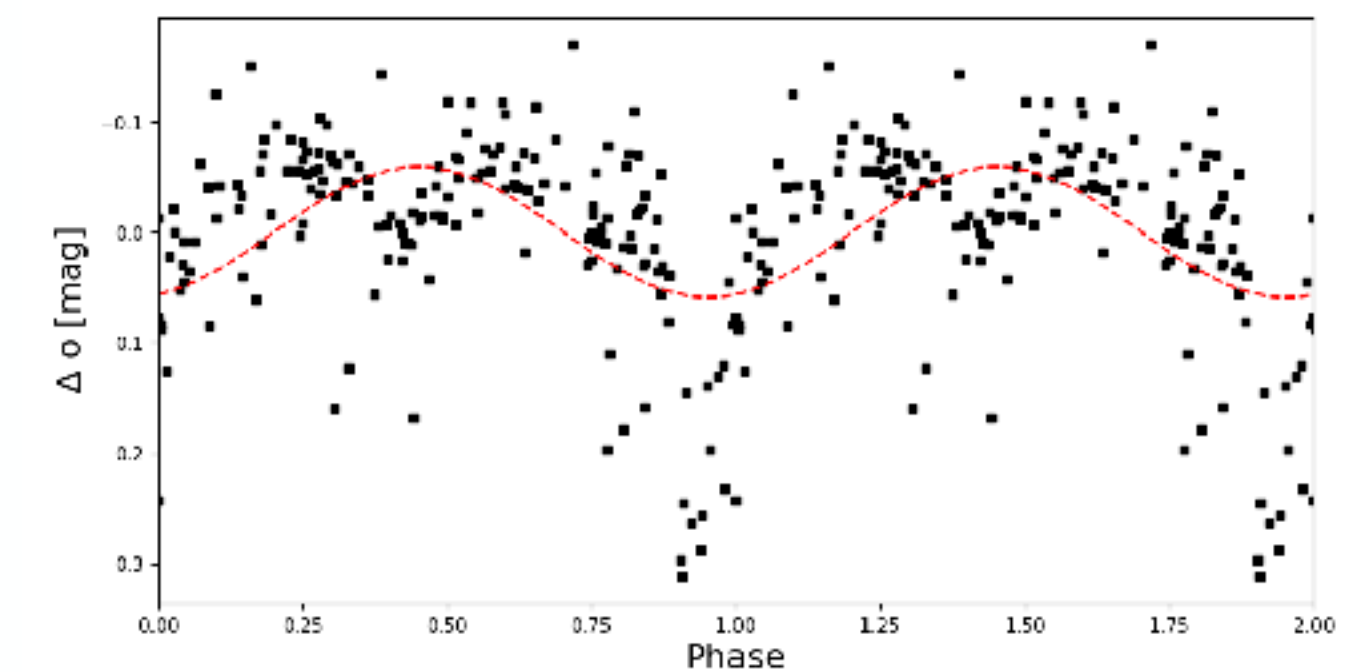
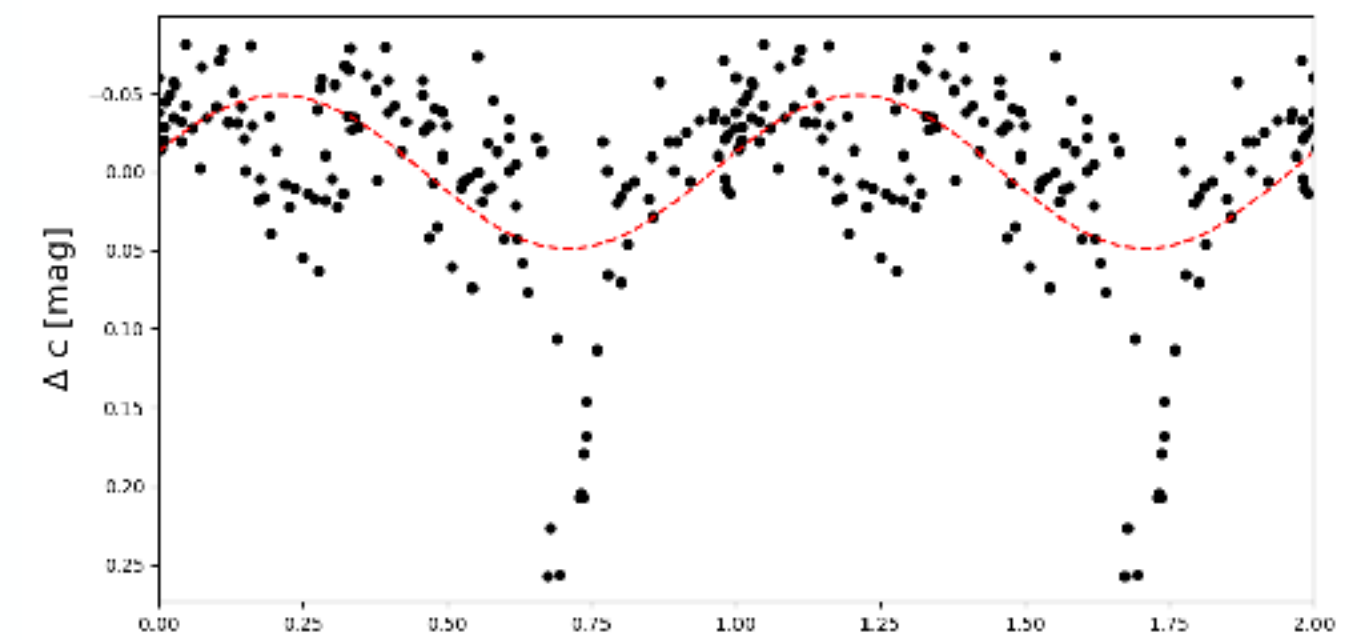
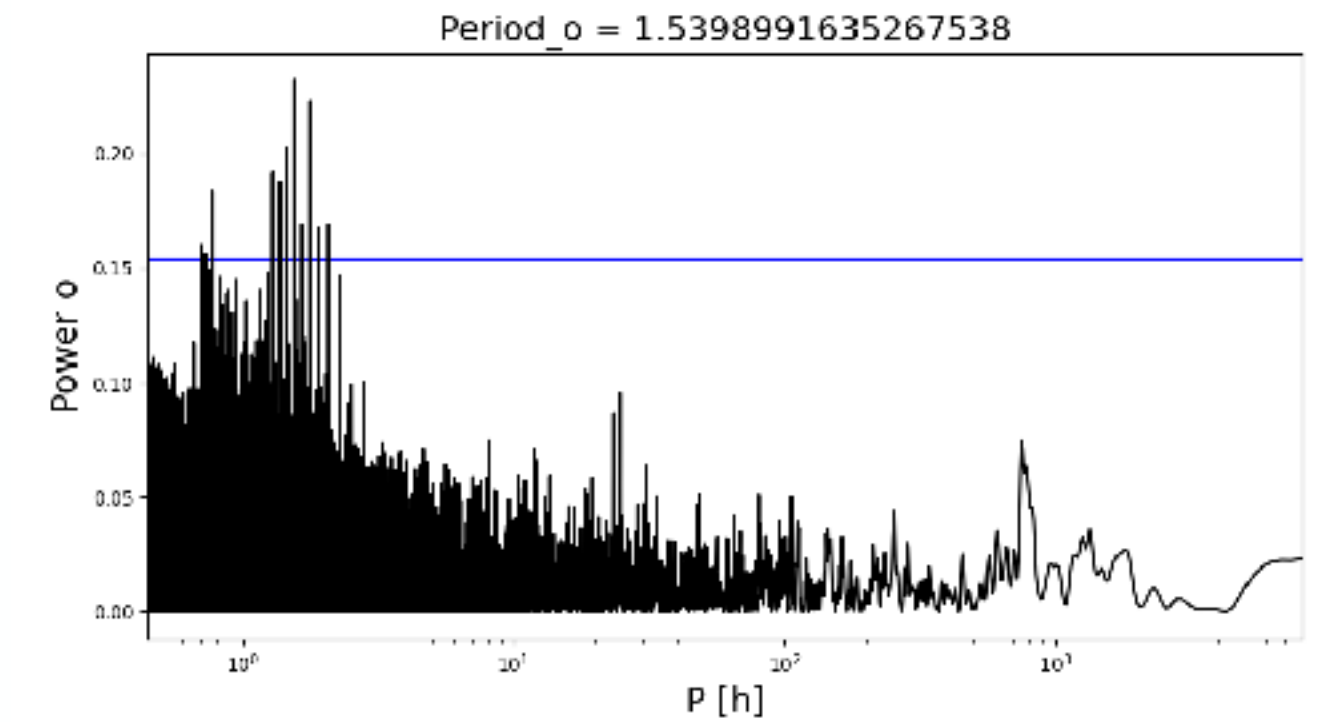
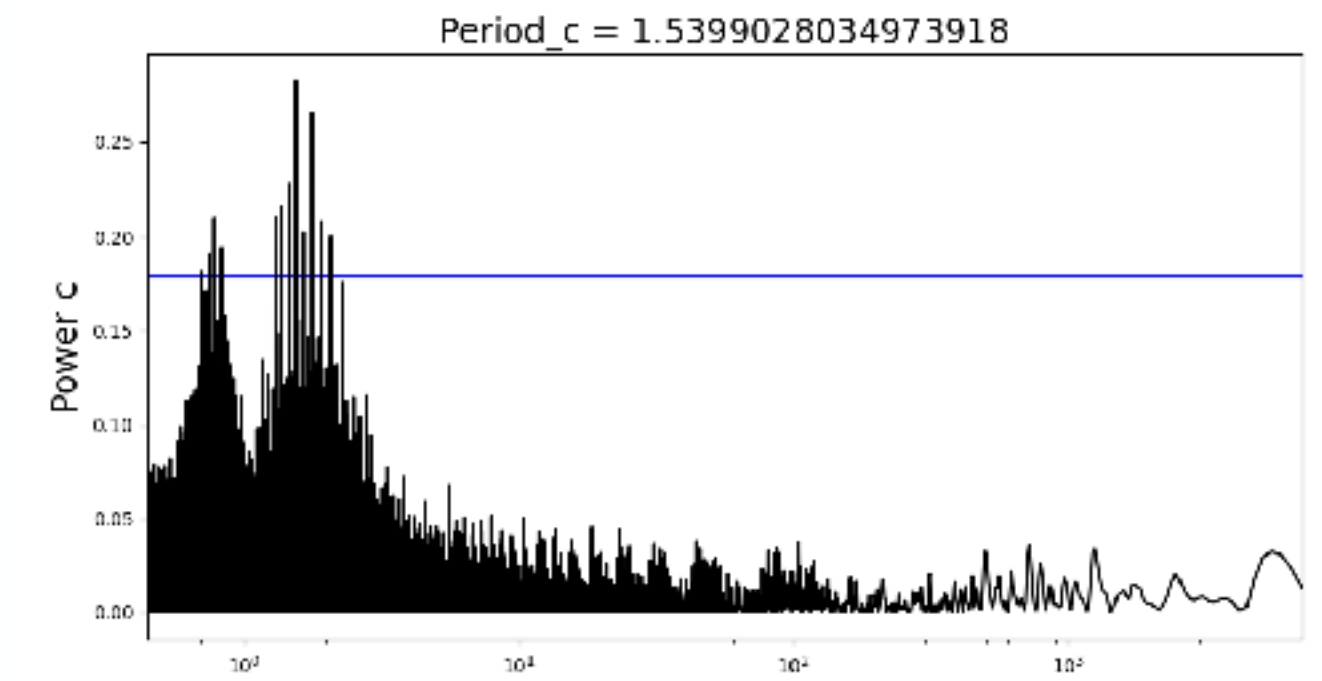
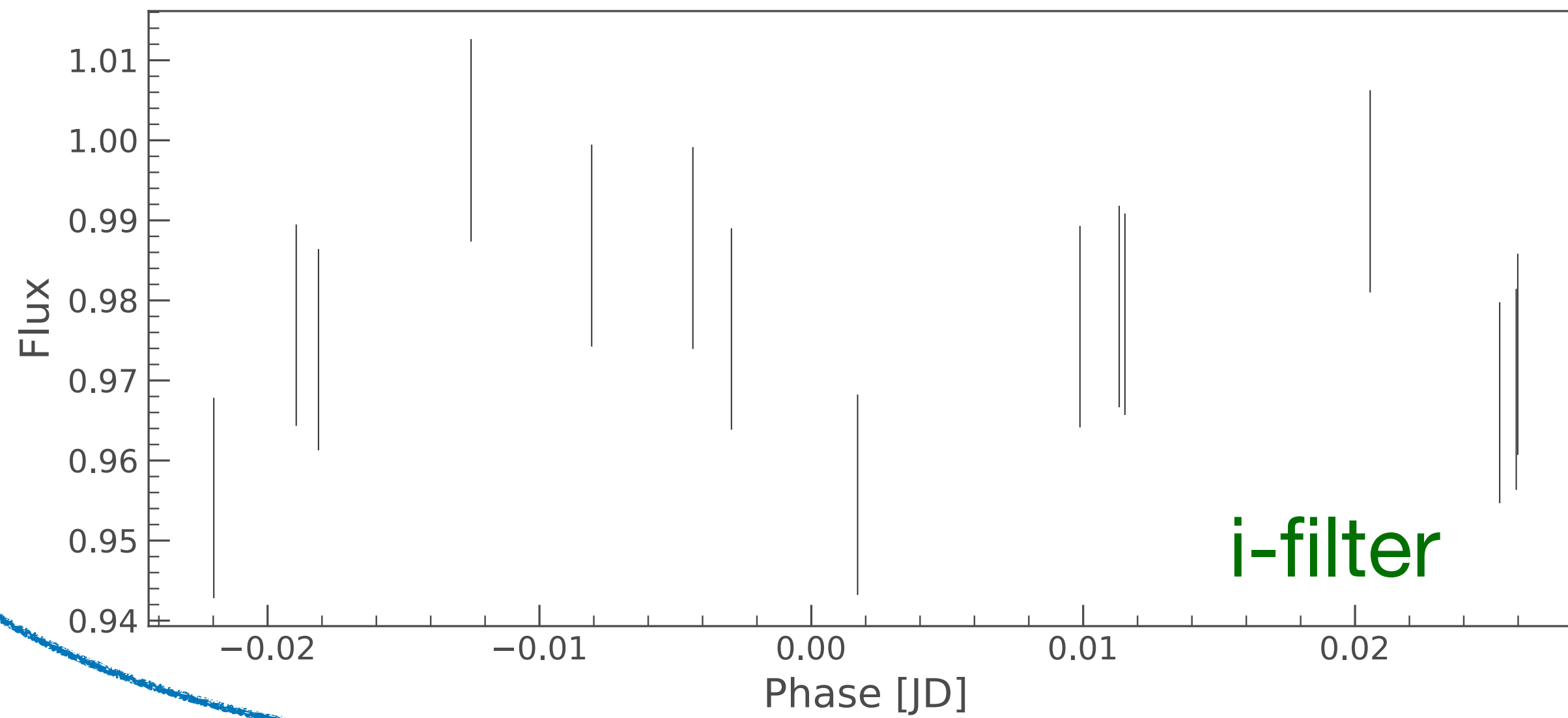
Fixed because SED values and errors are incorrect and large



**J296.1785+54.8285**

# J296.1785+54.8285

## ZTF and ATLAS spectra

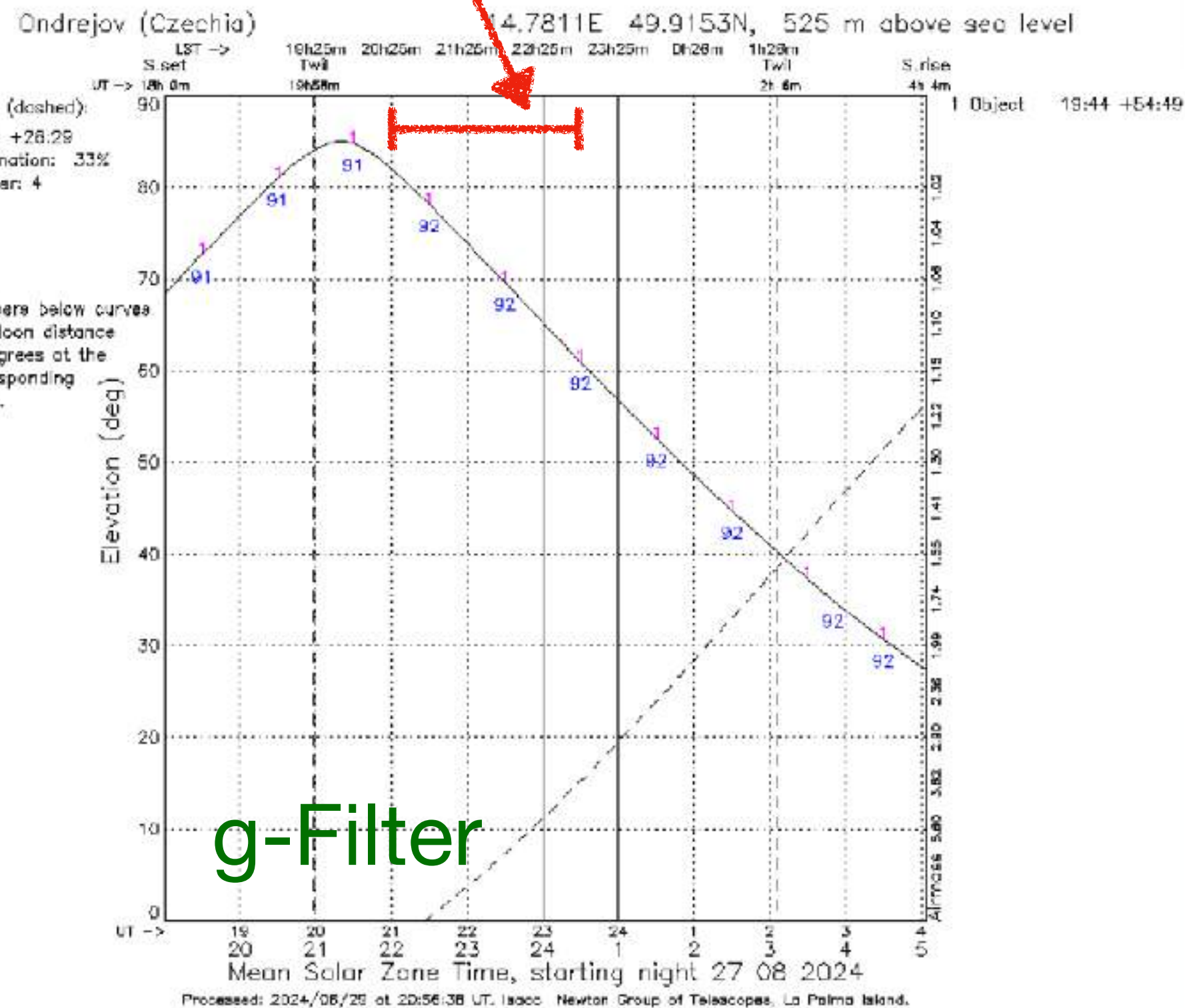




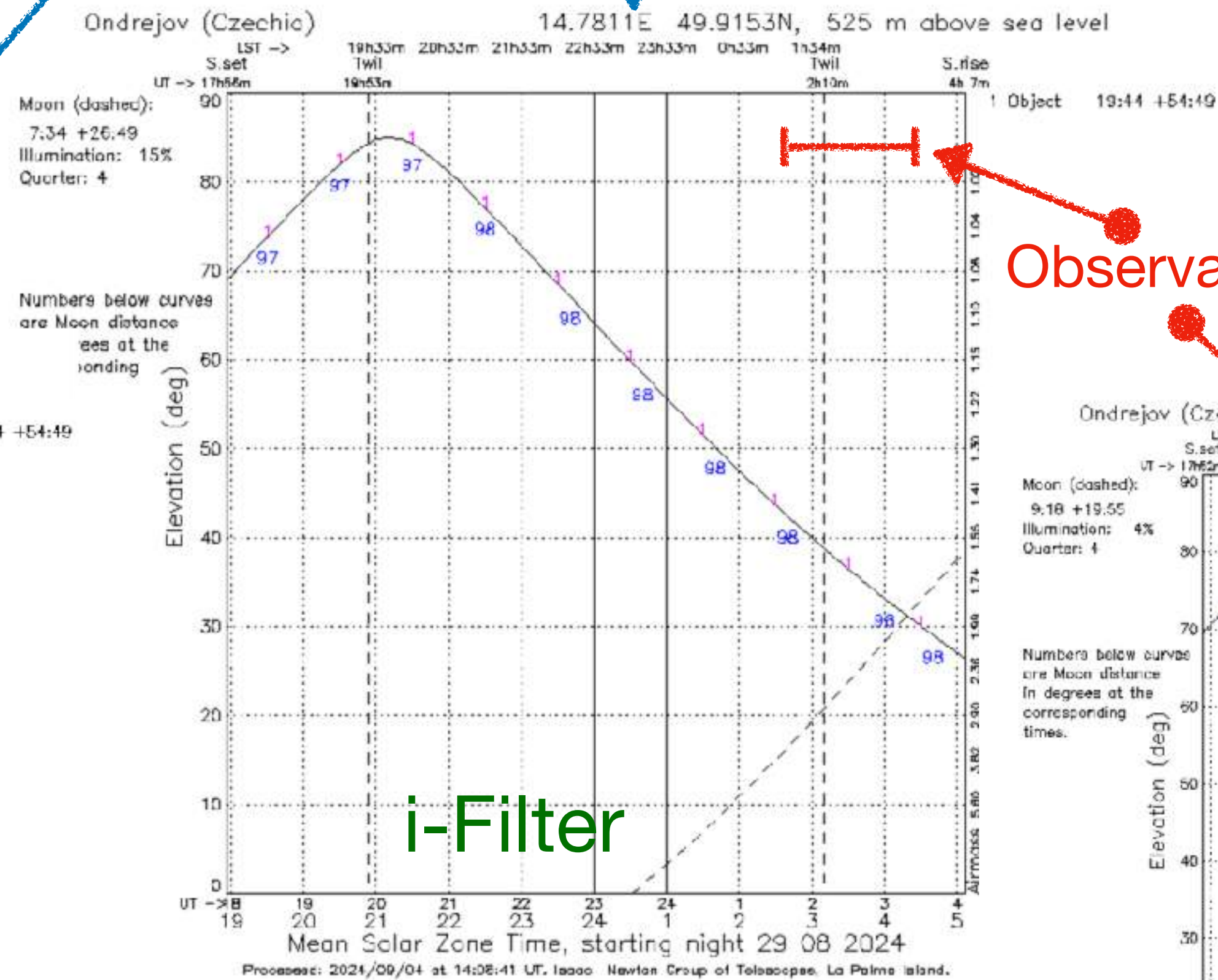
# J296.1785+54.8285

## Visibility on night 27.08.2024, 29.08.2024, 31.08.2024

Observation

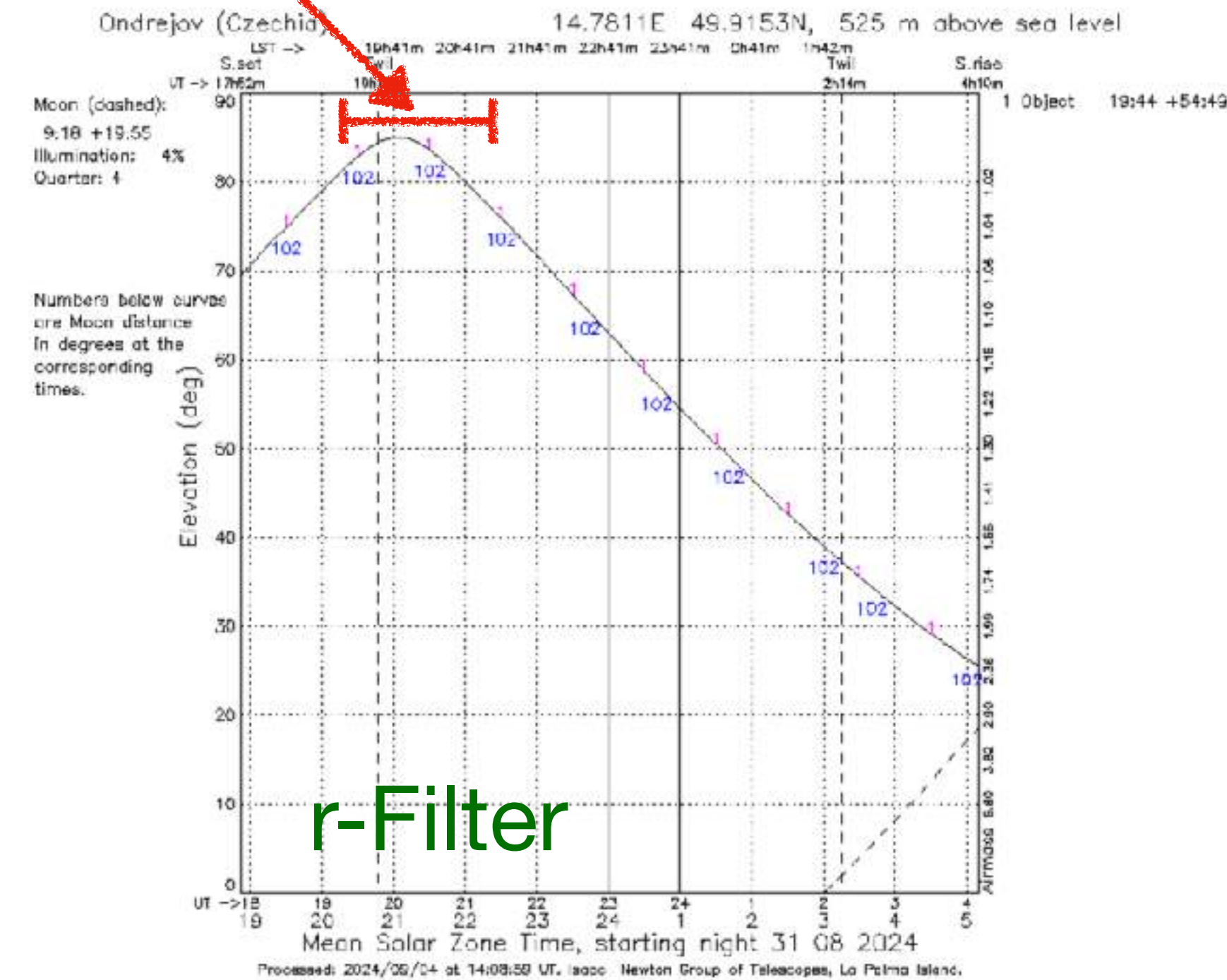


g-Filter



i-Filter

Observation



r-Filter

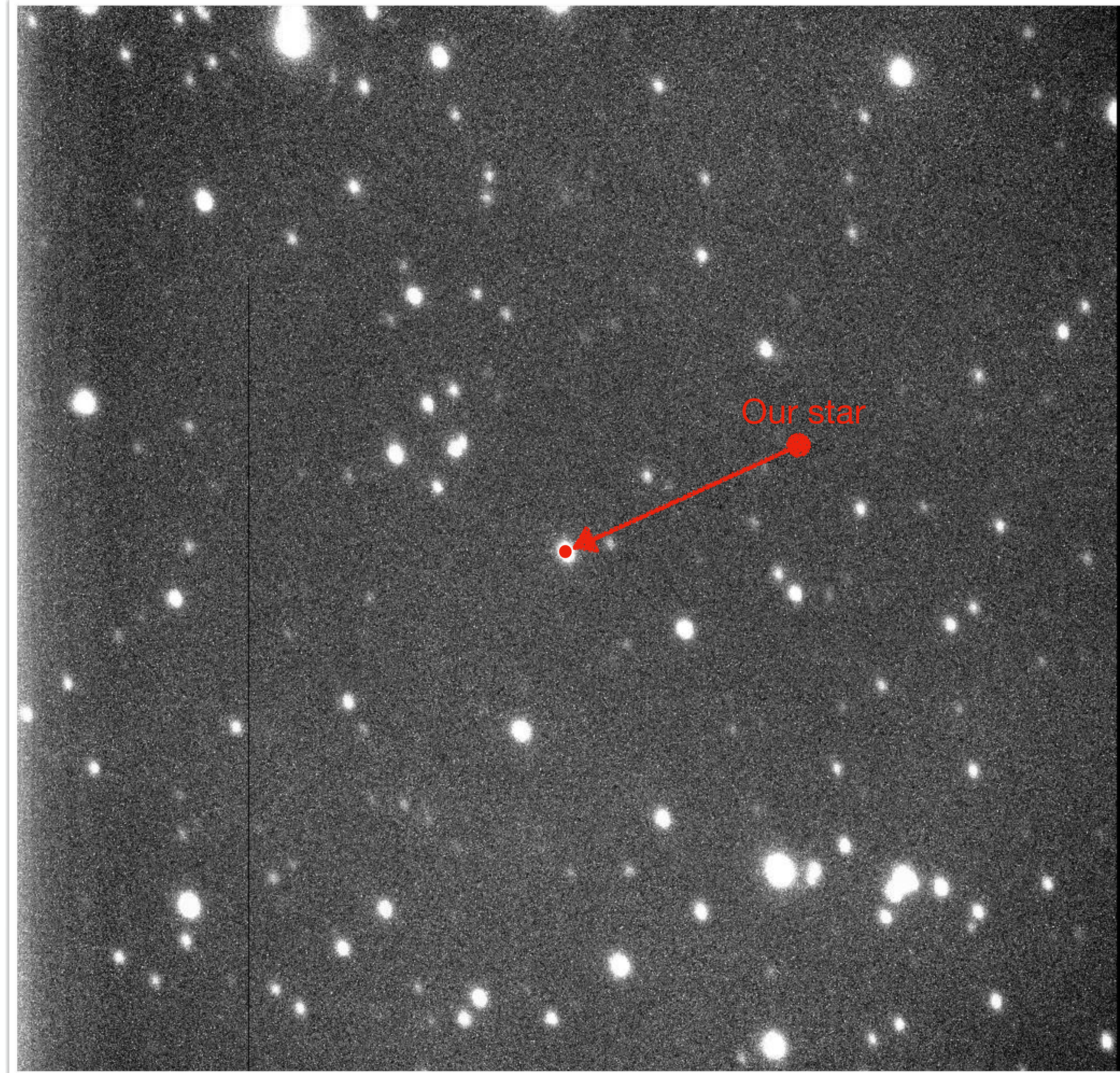
**J296.1785+54.8285 g-filter**



# J296.1785+54.8285

## Observation g filter

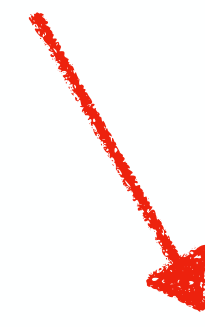
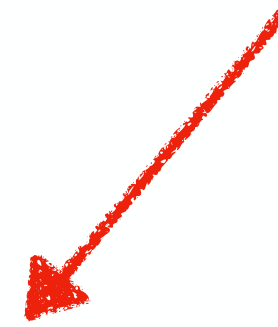
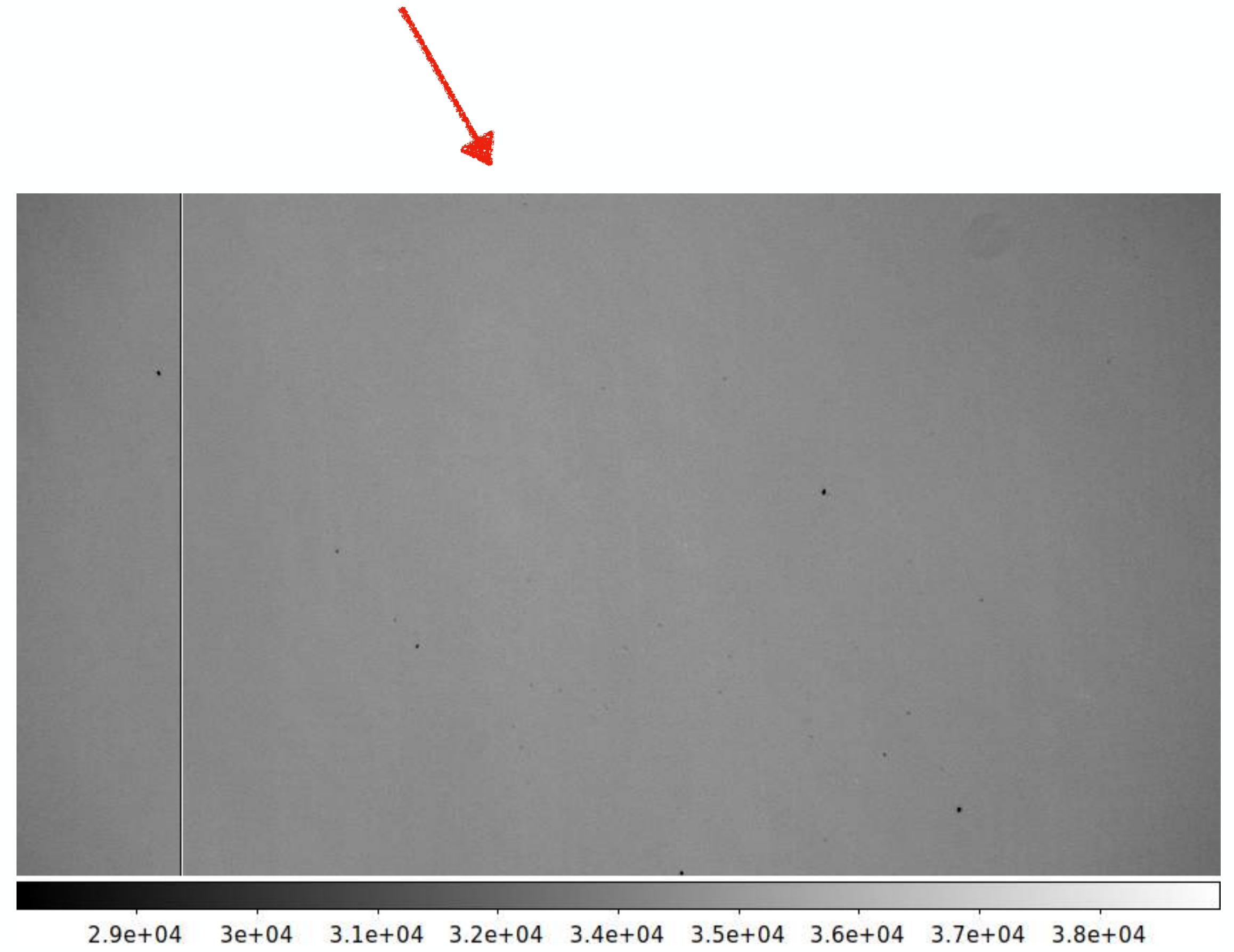
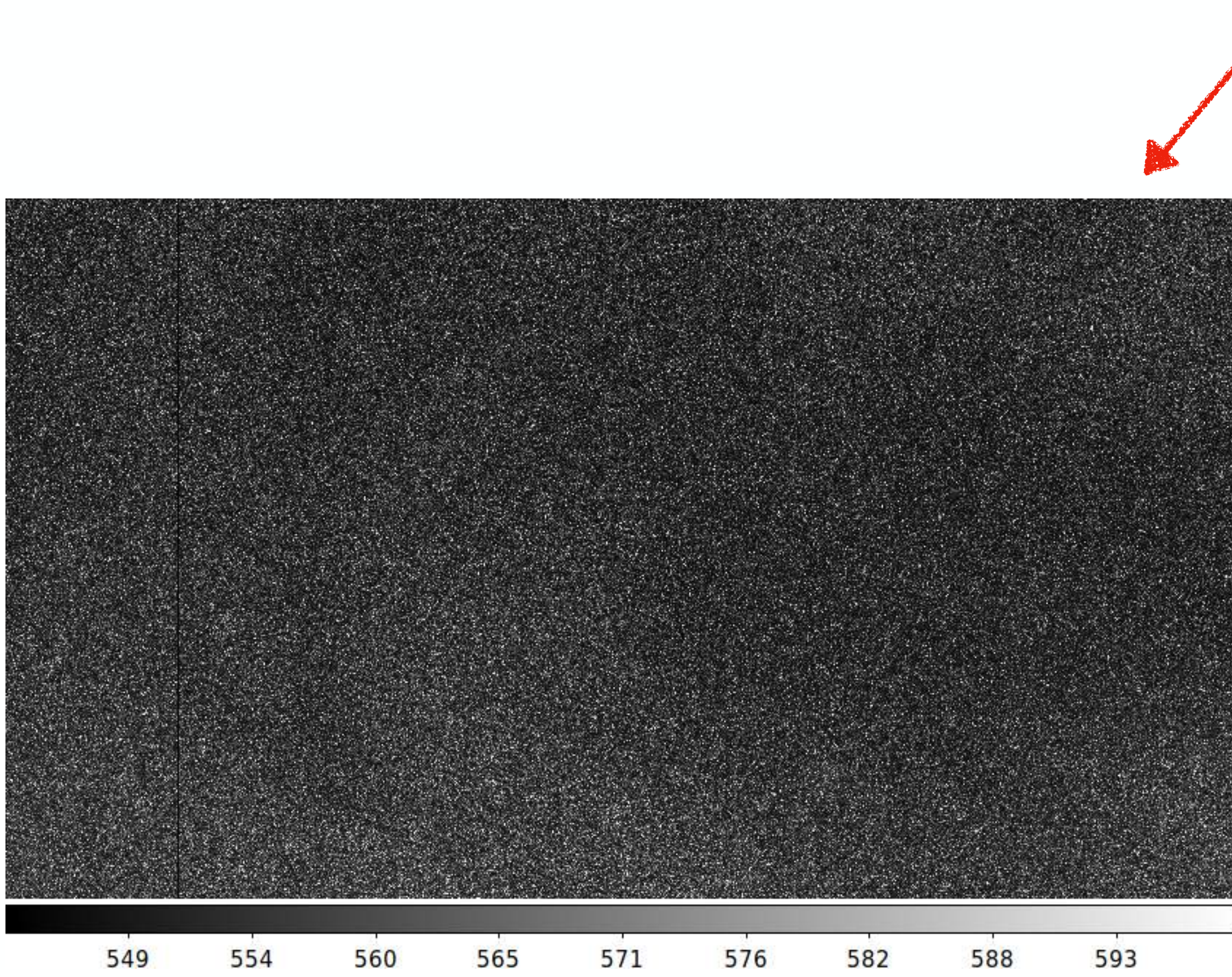
- 20:18 UT to 23:17 UT
- **20s** exposures
- Observation was scheduled to start earlier but the shutter failed





# J296.1785+54.8285

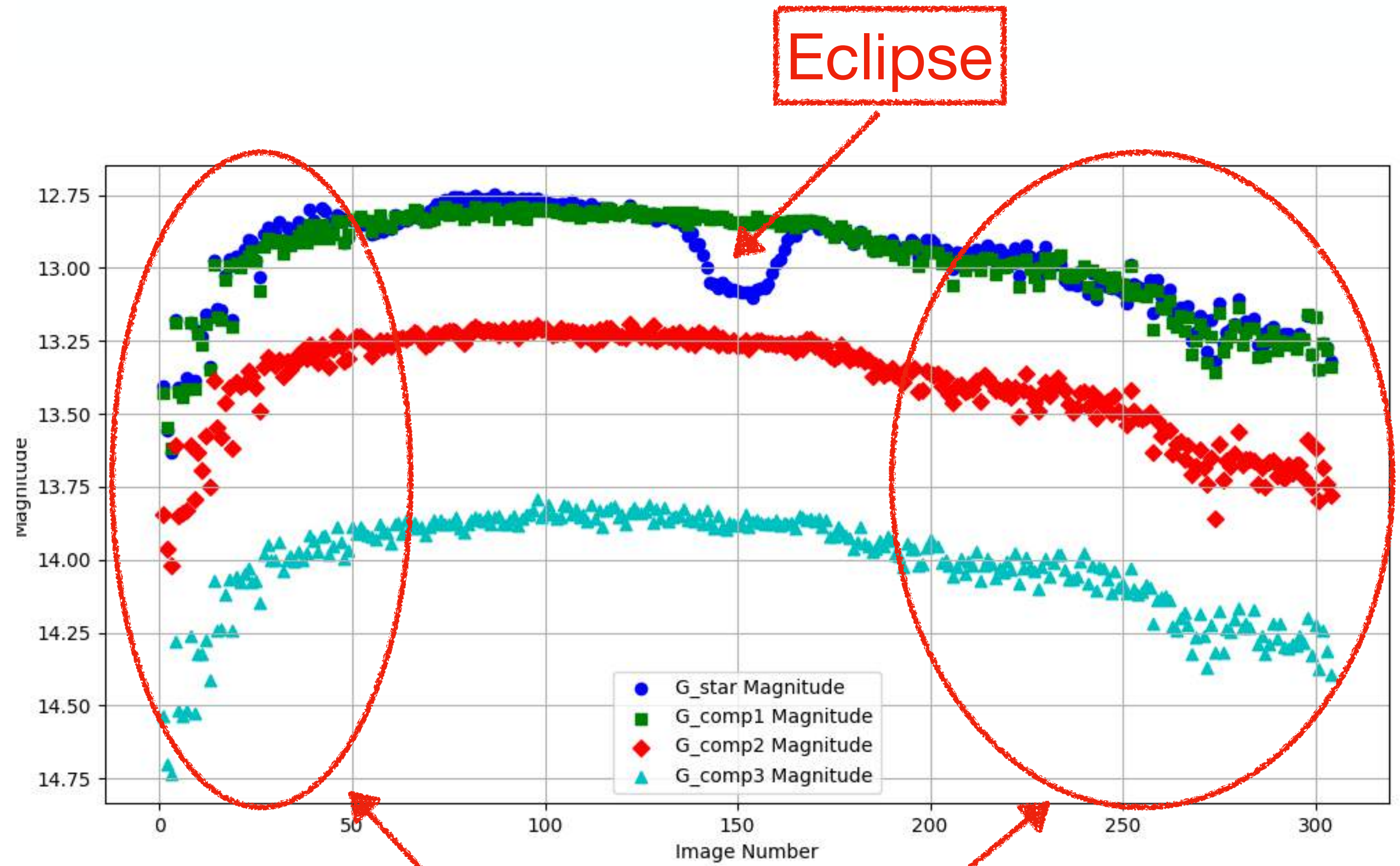
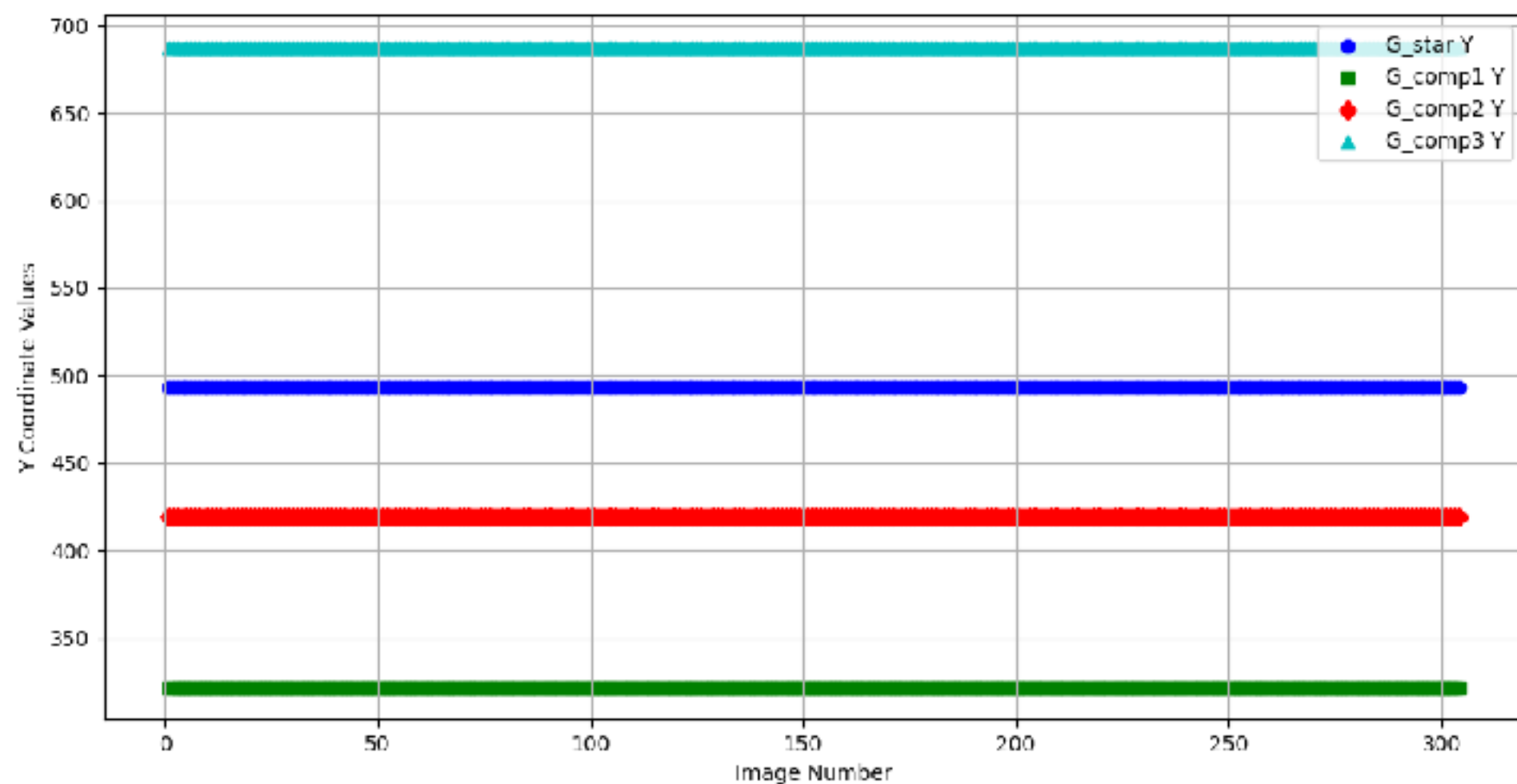
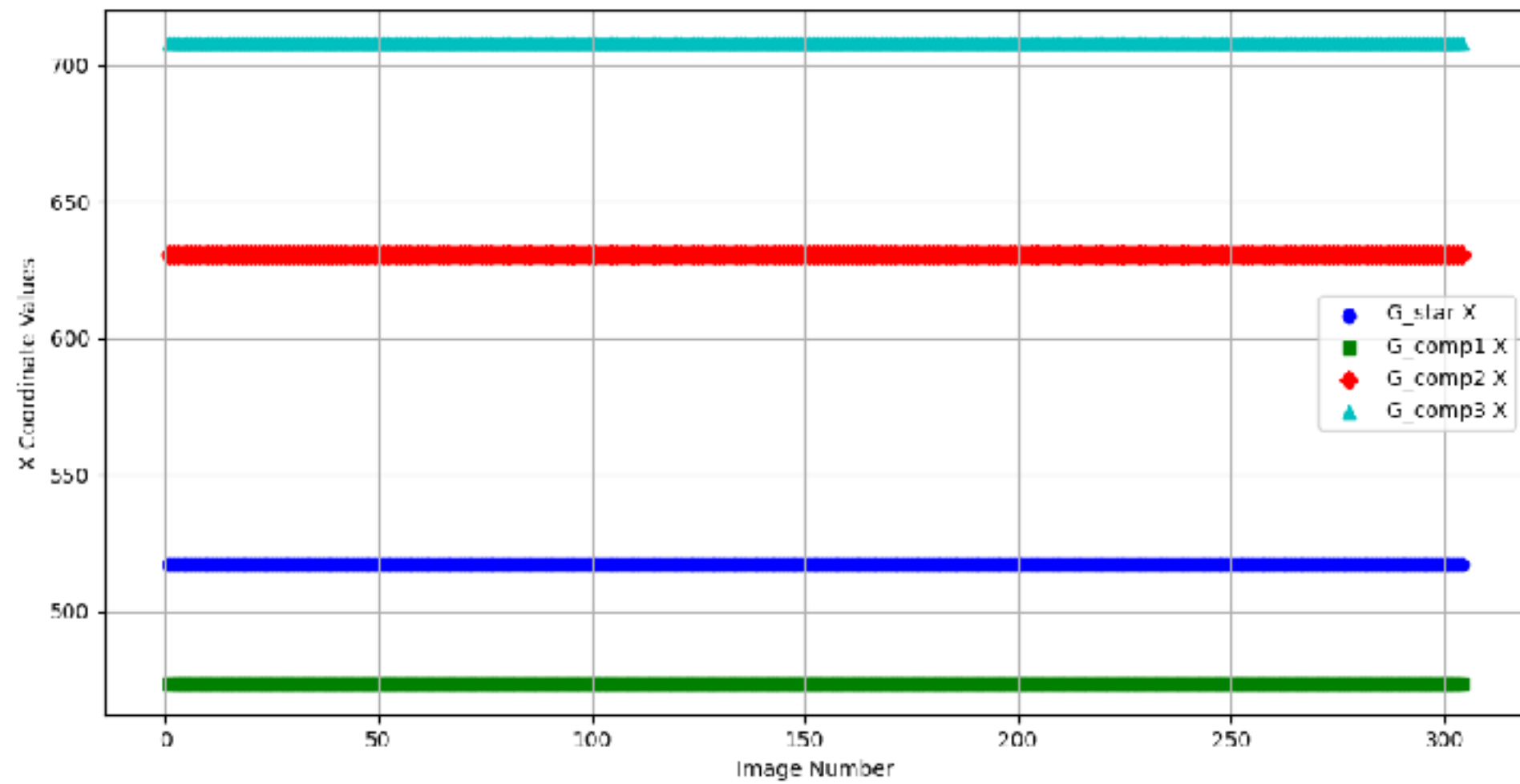
## Data Reduction g filter - Master Dark and Flat





# J296.1785+54.8285

## Data Reduction g filter - Tracking and Magnitudes



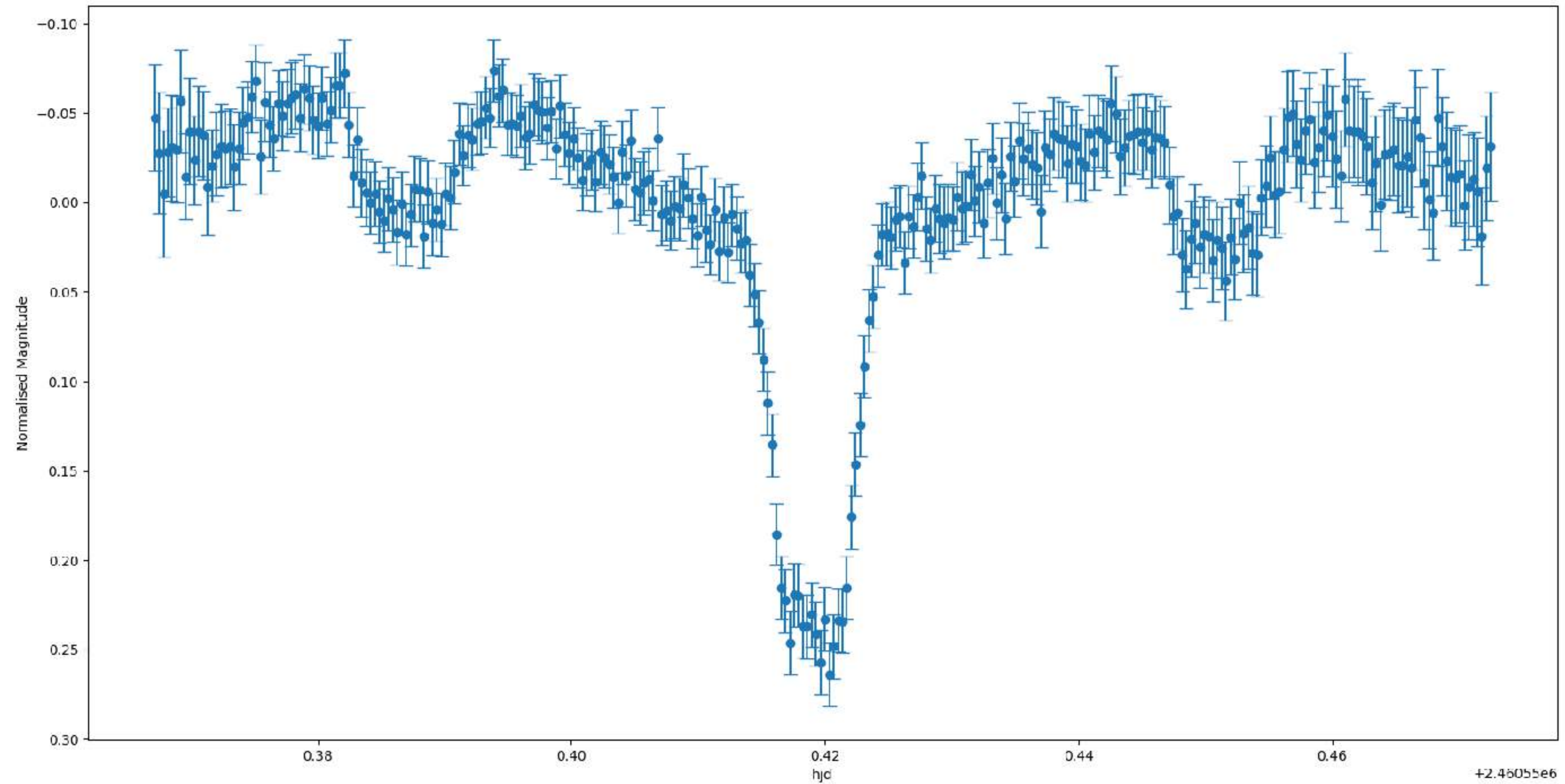
Eclipse

Bad data due to weather



# J296.1785+54.8285

## Data Reduction g filter - Lightcurve





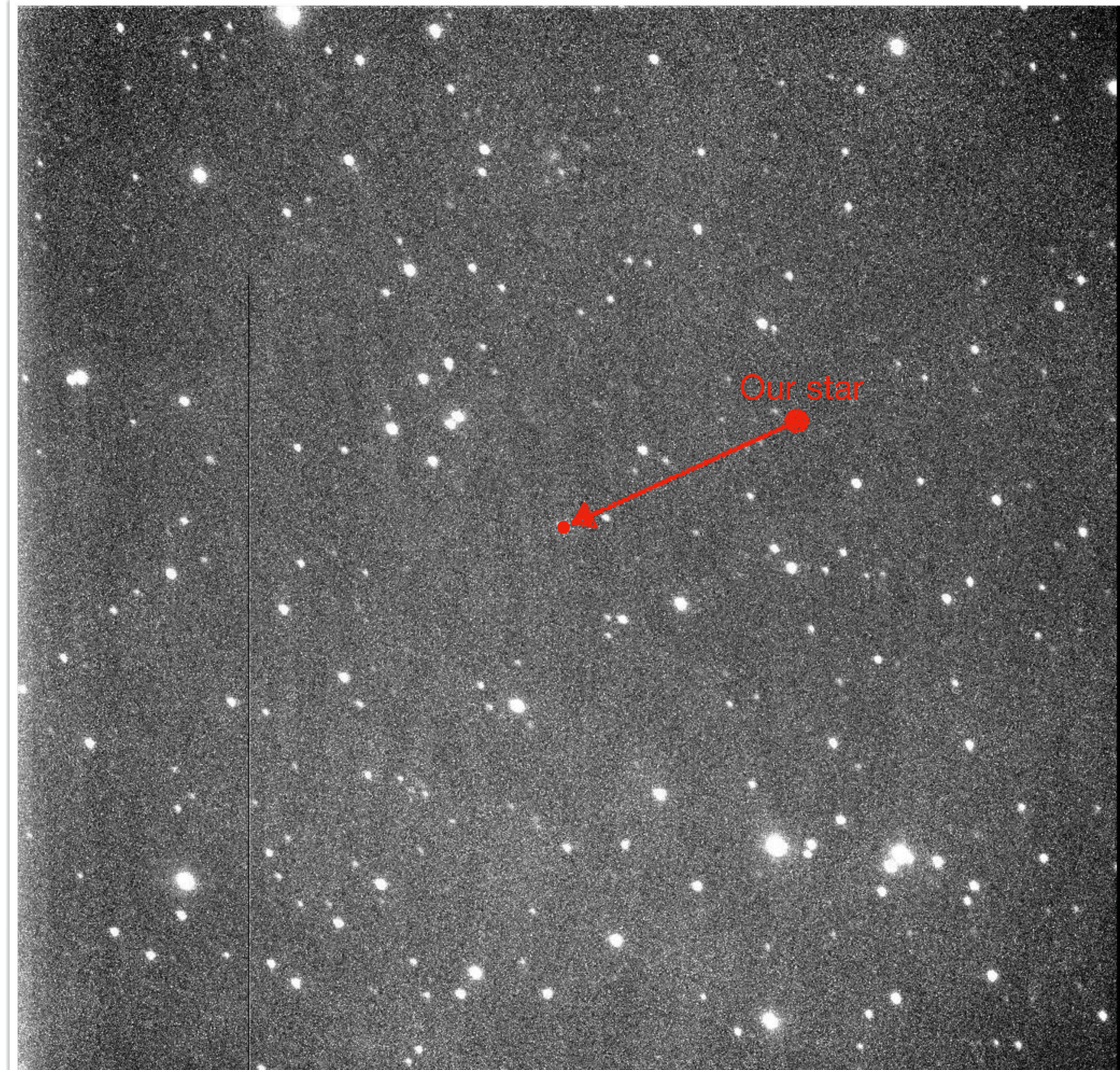
**J296.1785+54.8285 i-filter**



# J296.1785+54.8285

## Observation I filter

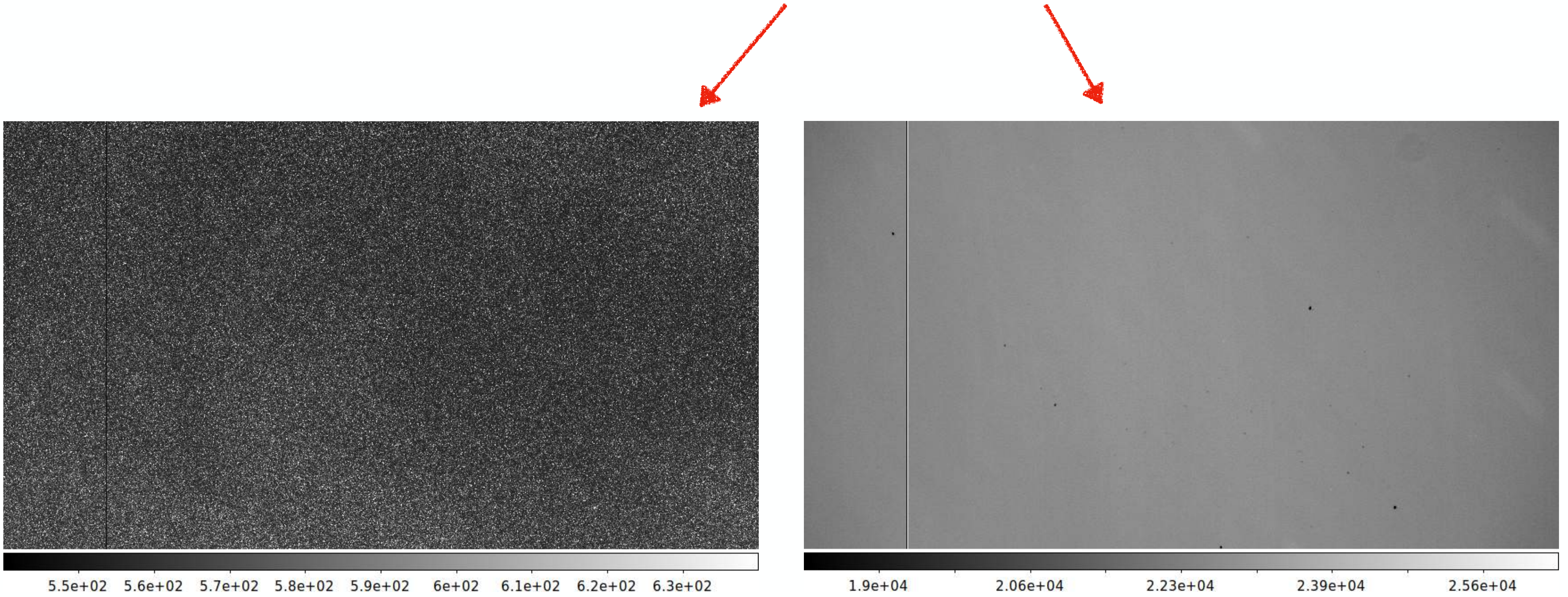
- 1:14 UT to 2:51 UT
- **20s** exposures
- Observation was towards end of the night and some clouds were obscuring the view
- Lots of satellites had to be removed





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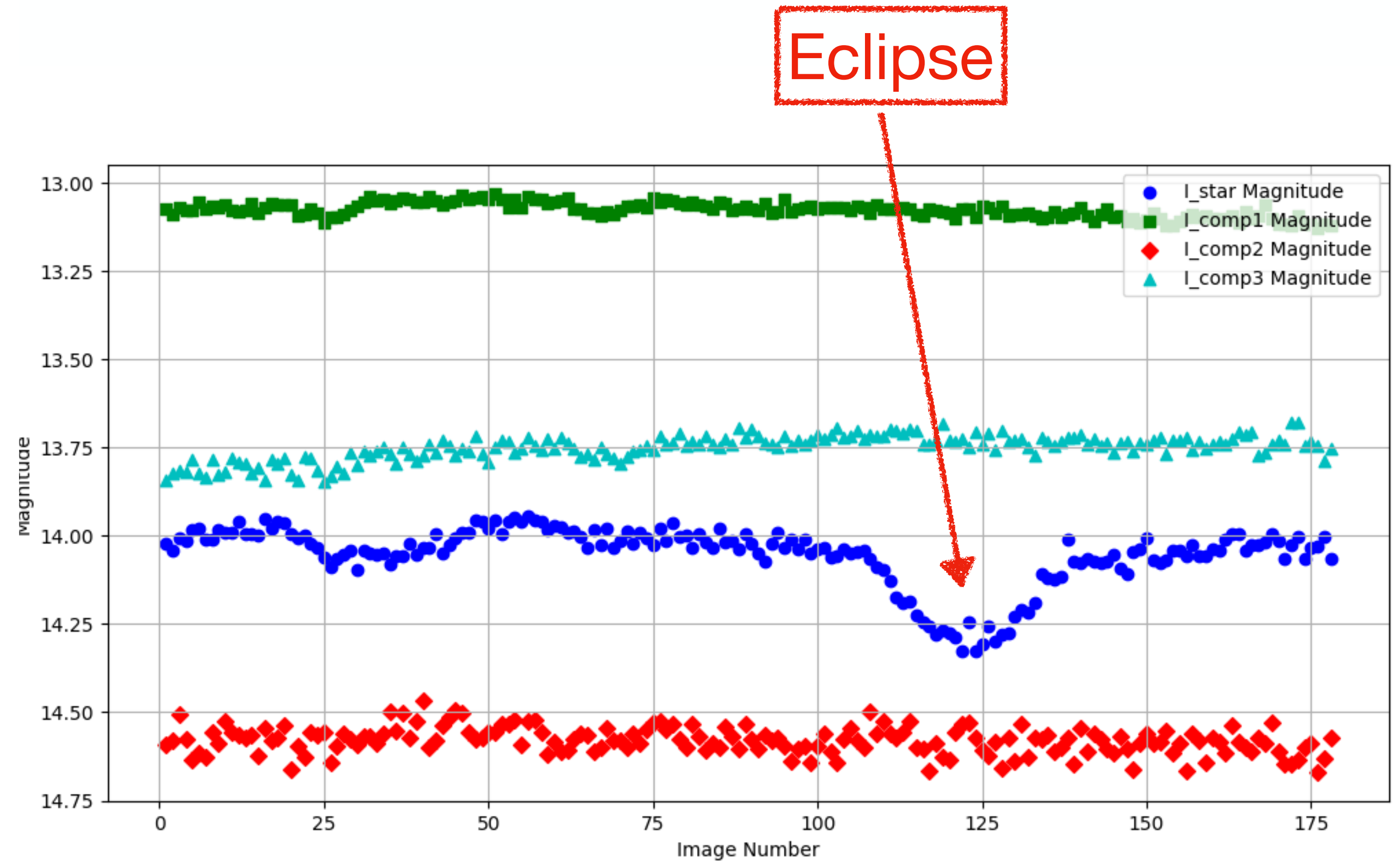
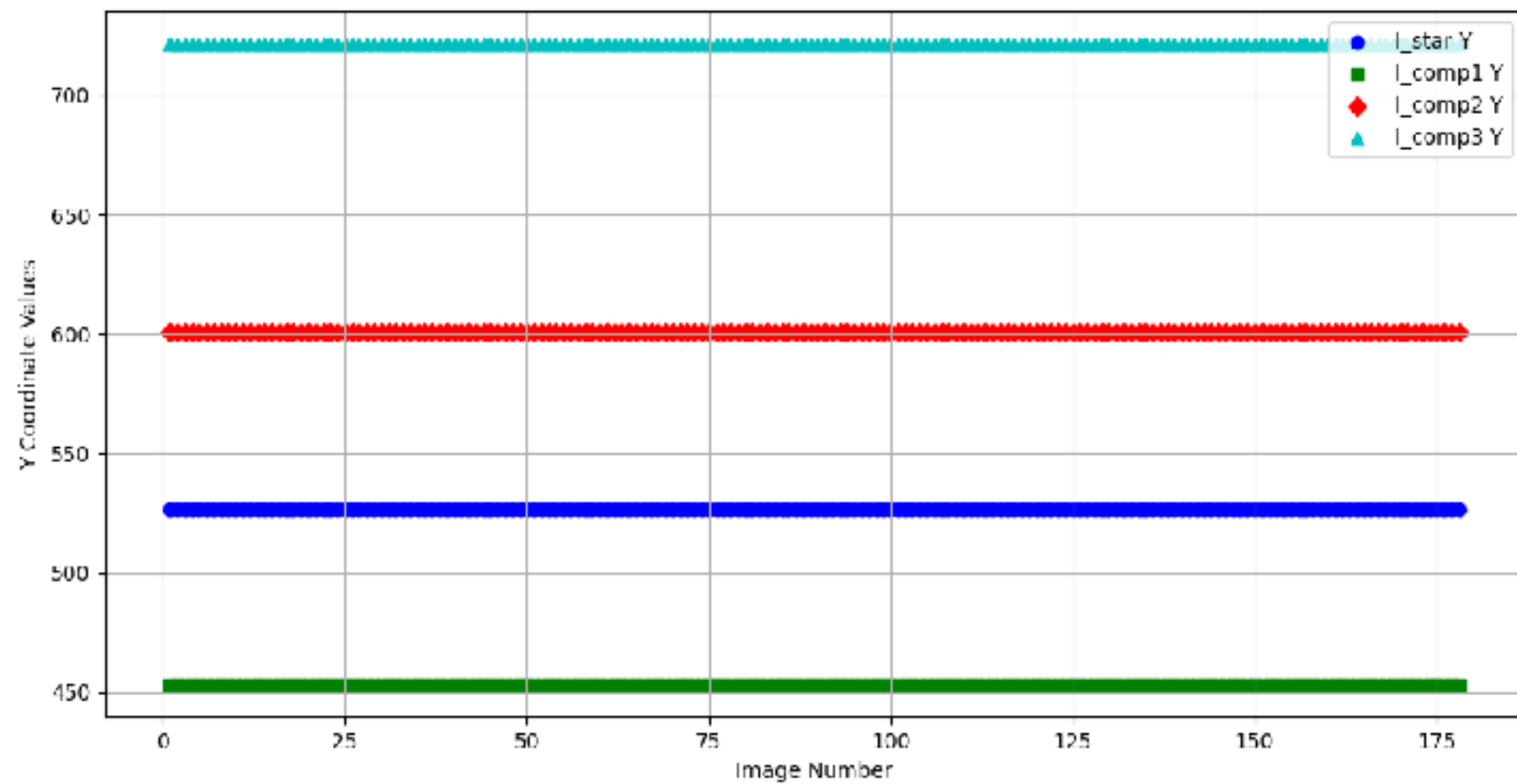
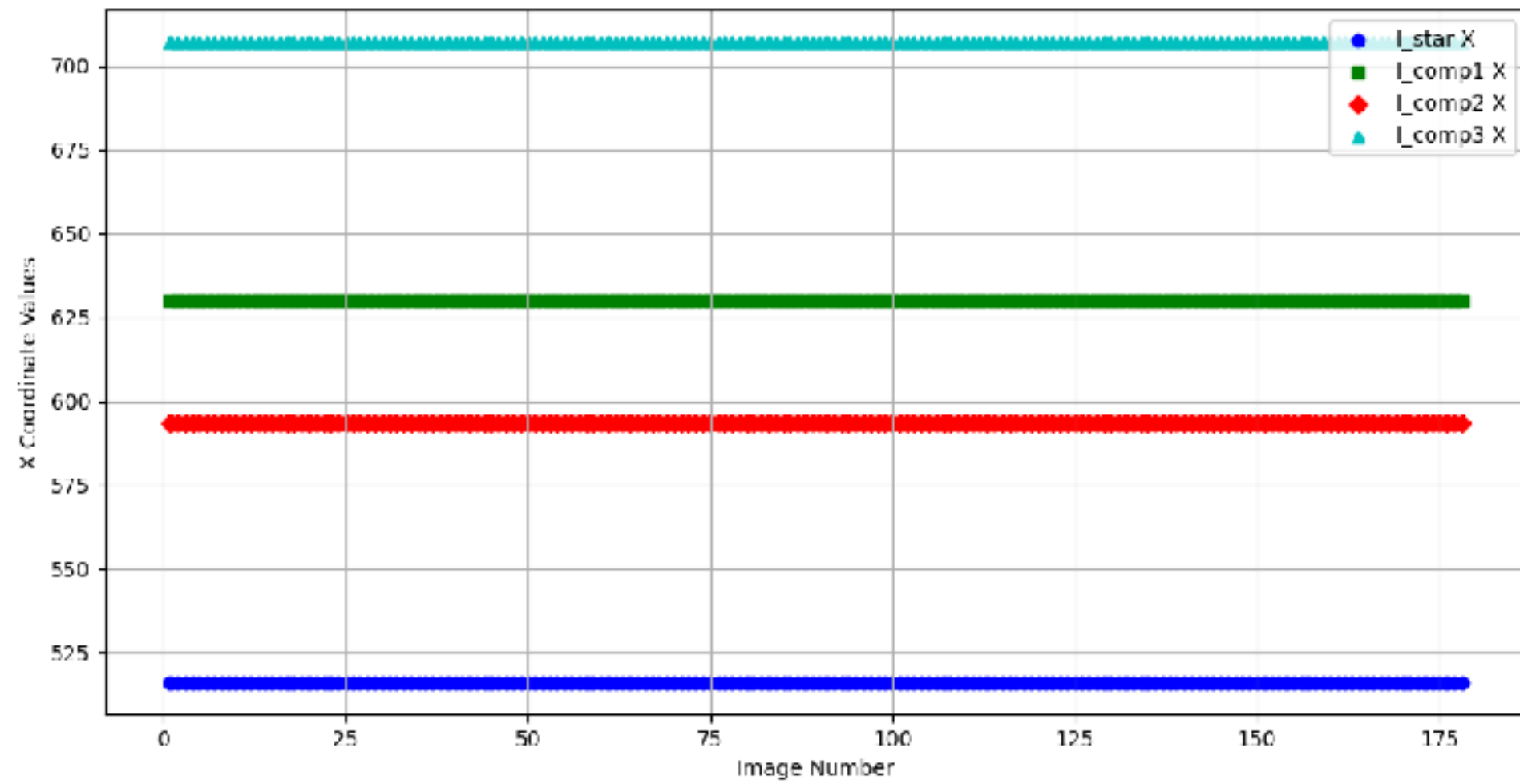
## Data Reduction I filter - Master Dark and Flat





# J296.1785+54.8285

## Data Reduction I filter - Tracking and Magnitudes

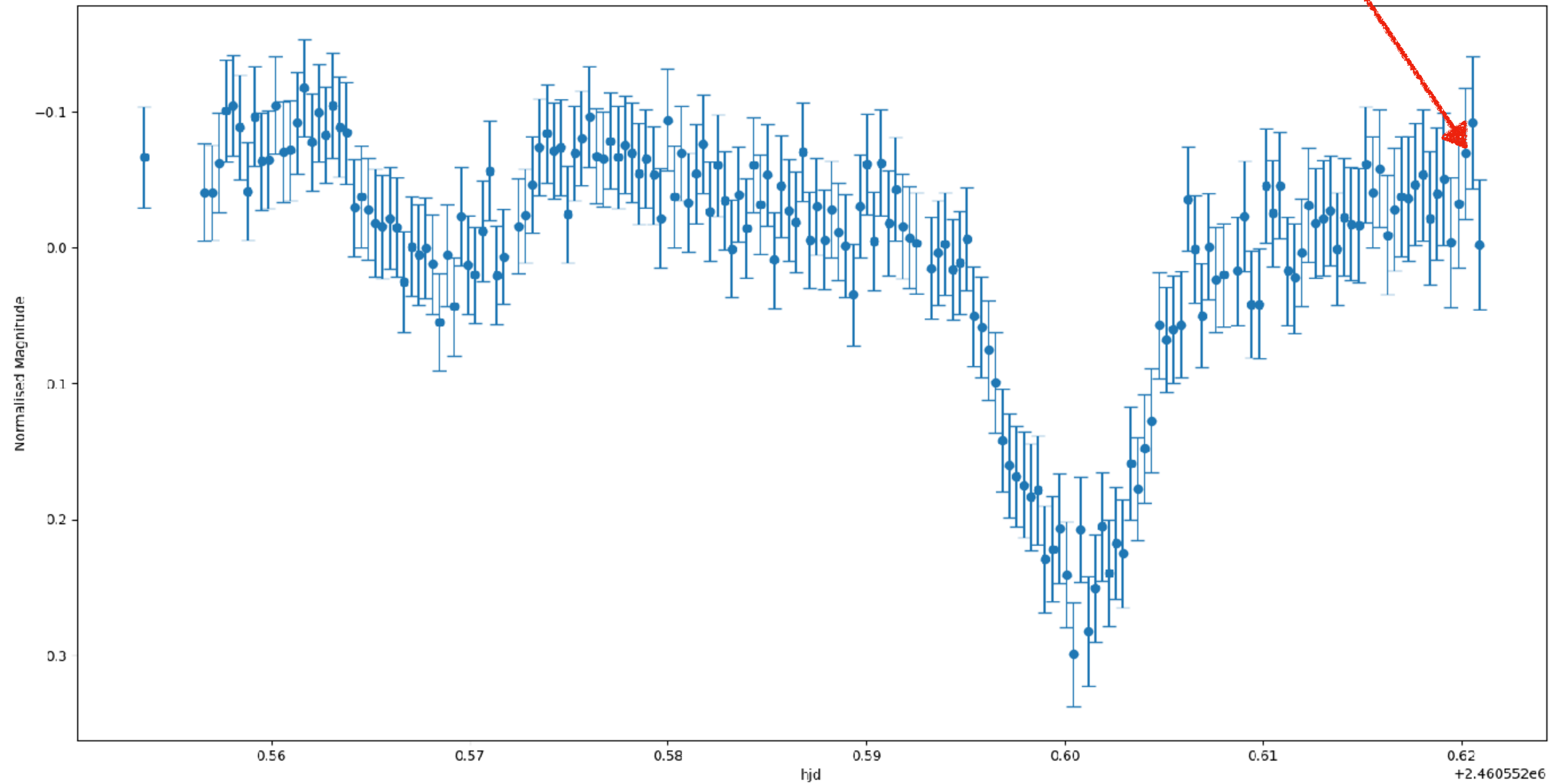




# J296.1785+54.8285

## Data Reduction I filter - Lightcurve

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





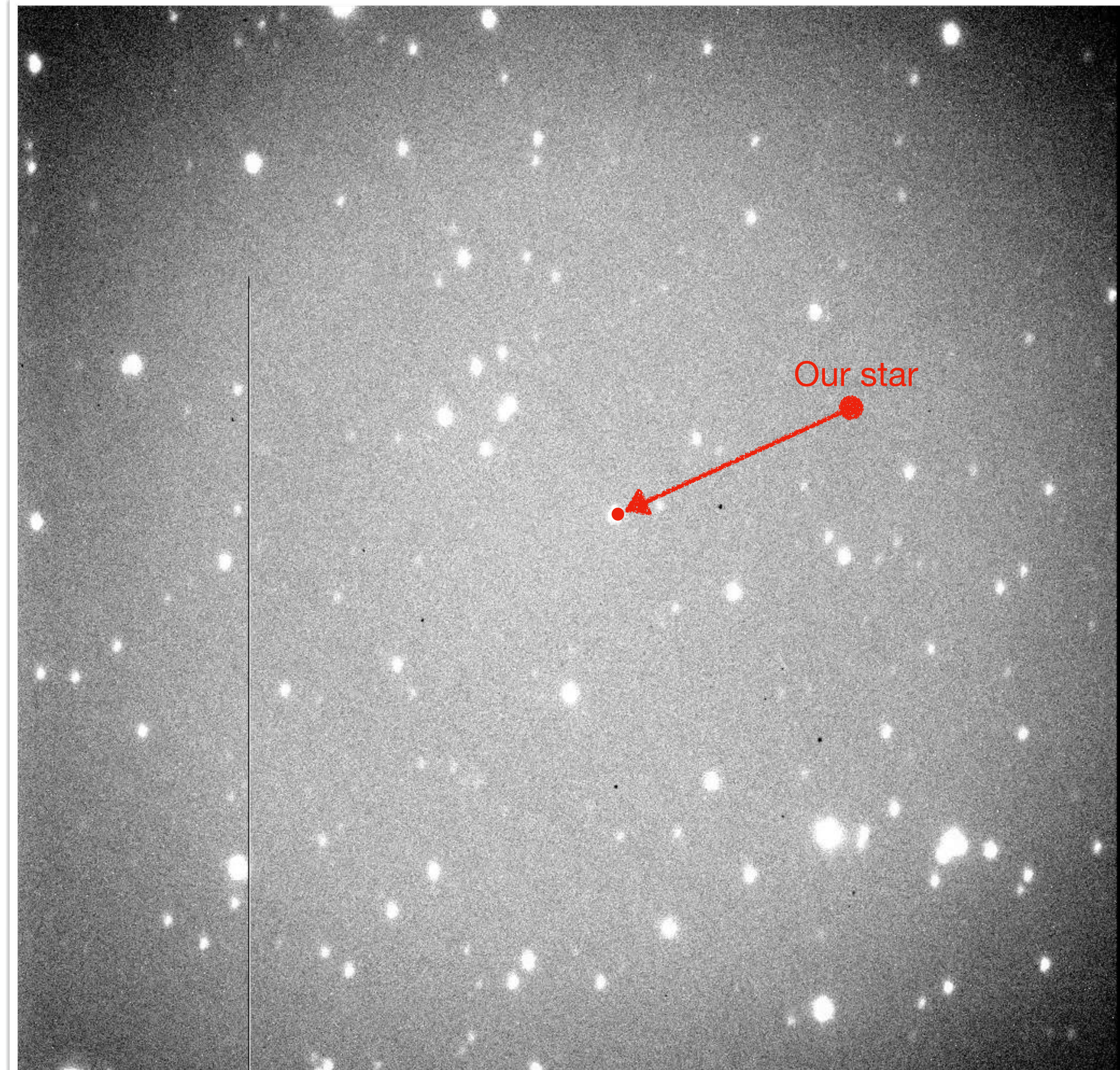
**J296.1785+54.8285 r-filter**



# J296.1785+54.8285

## Observation r filter

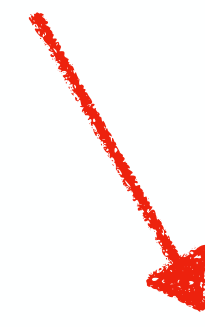
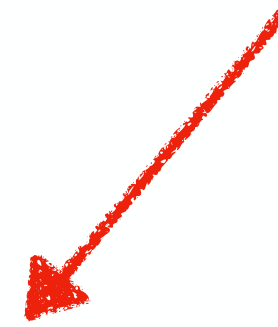
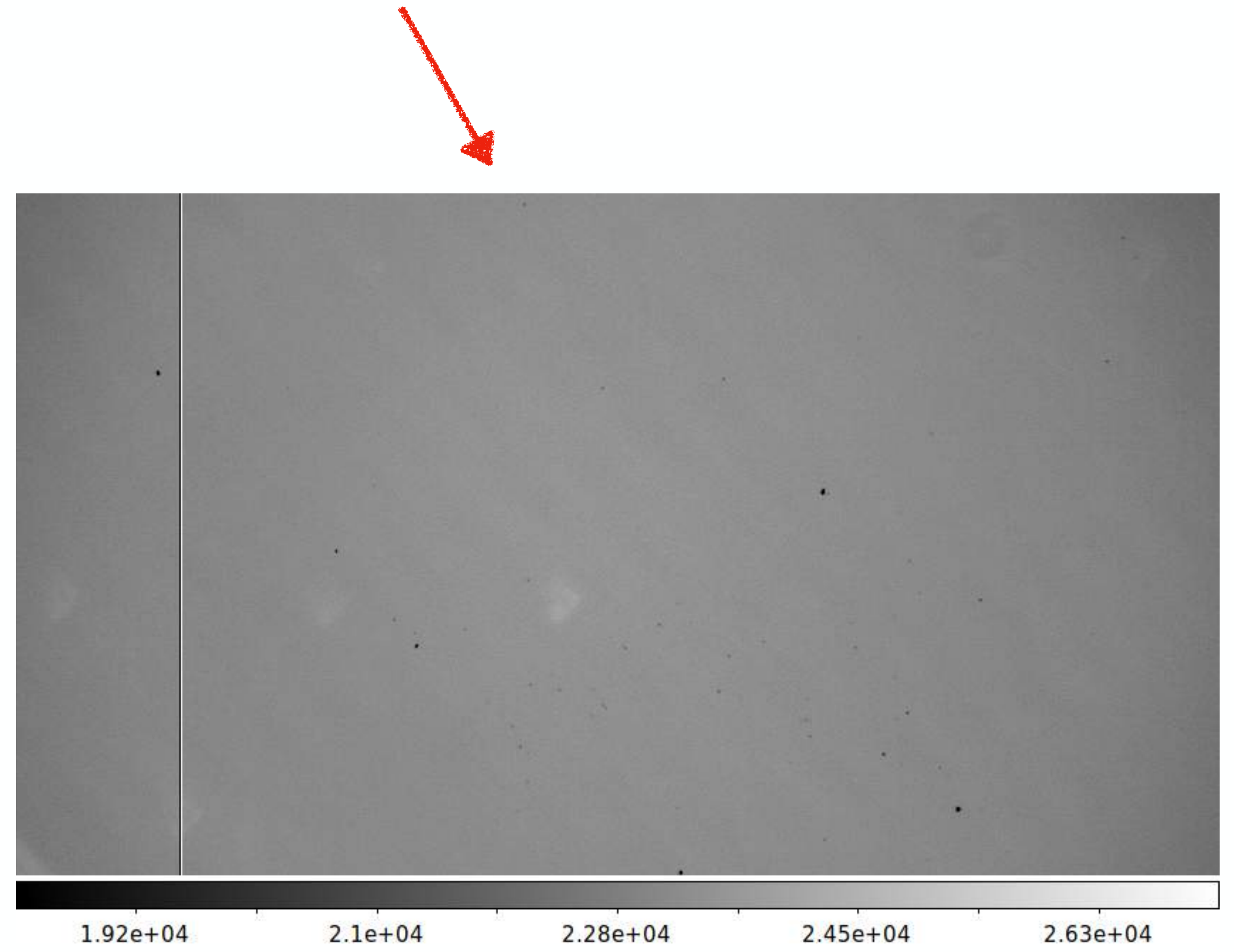
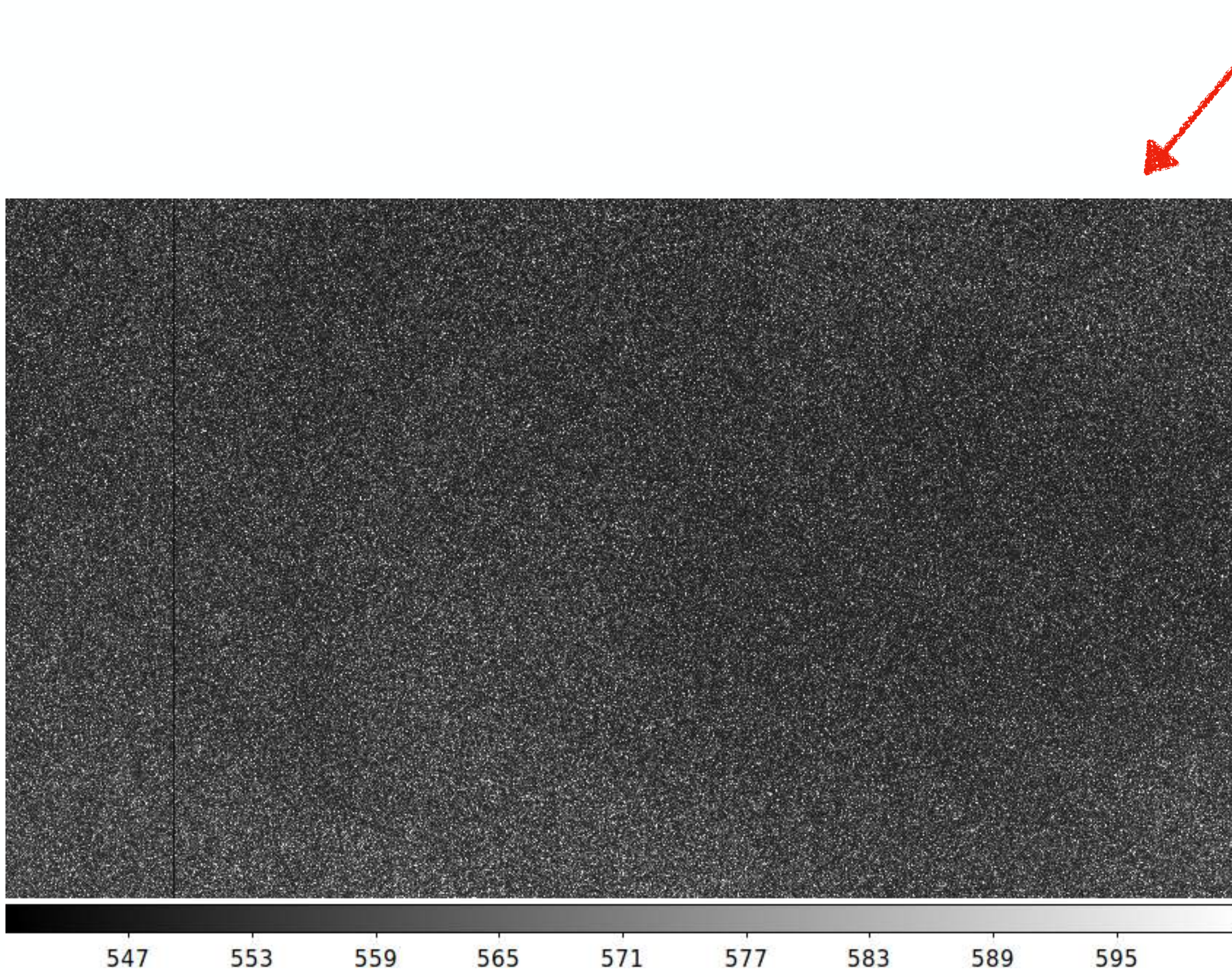
- 18:46 UT to 21:33 UT
- **20s** exposures
- Only 3/4 of the frames could be observed because the dome had to be closed due to high humidity





# J296.1785+54.8285

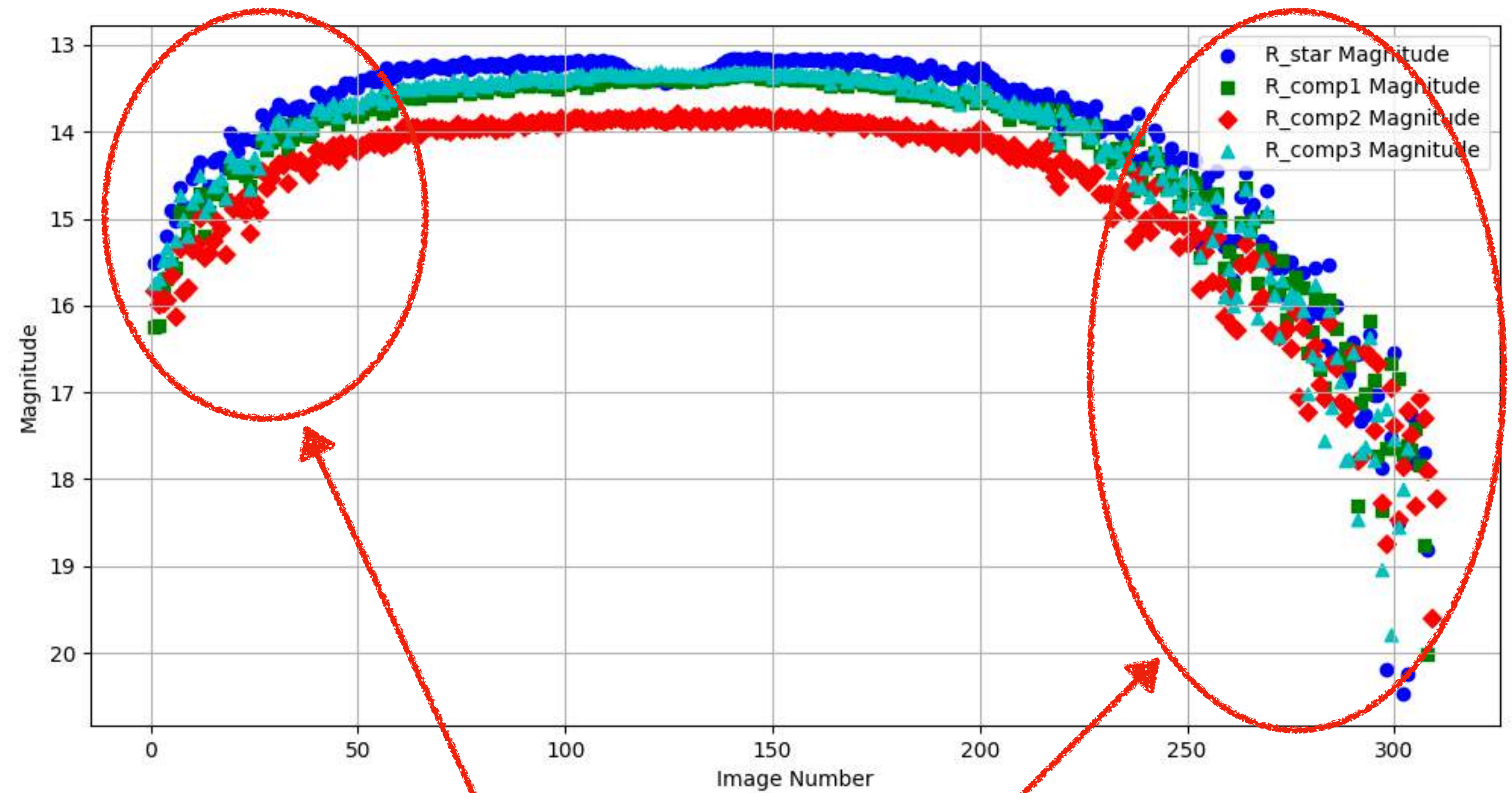
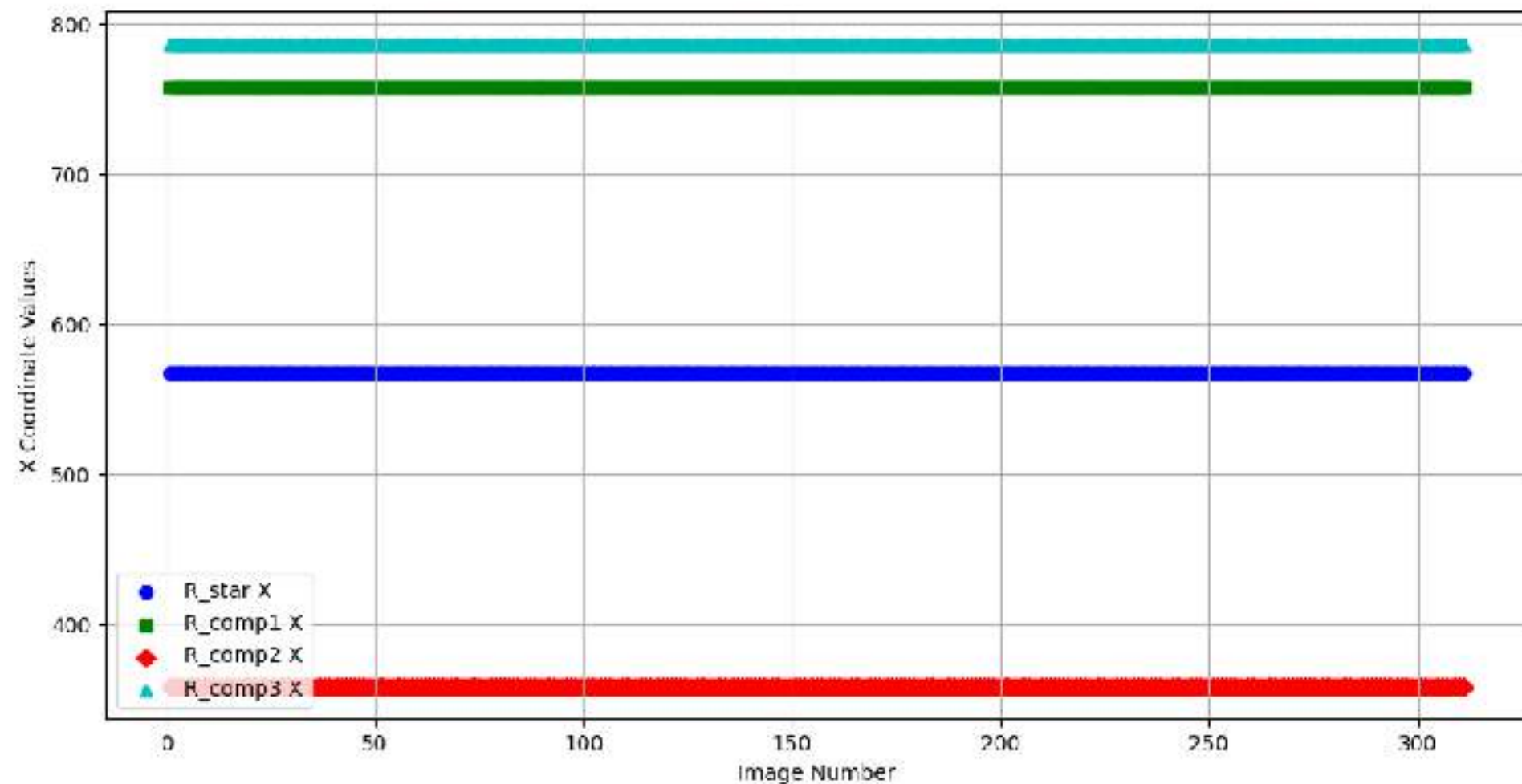
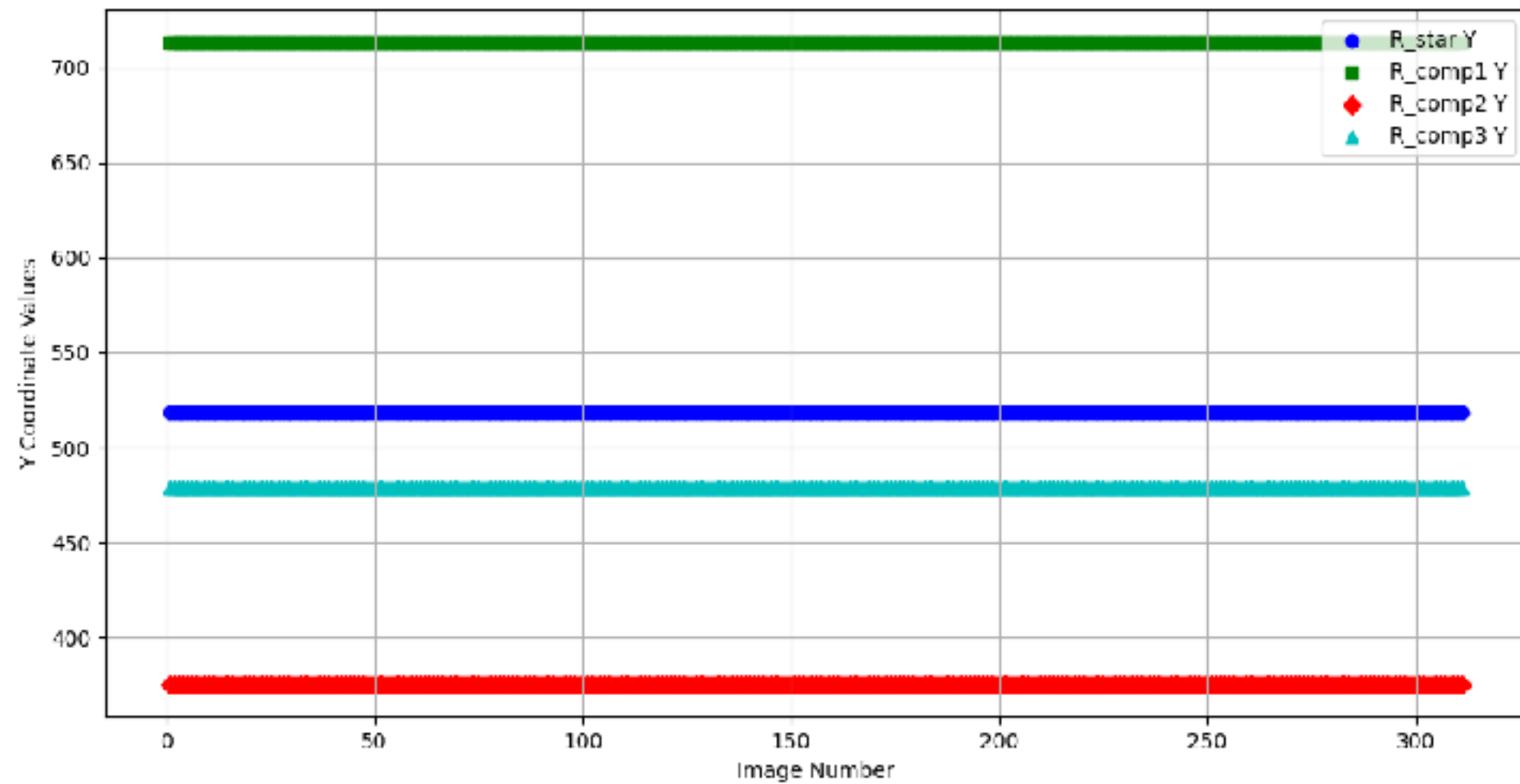
## Data Reduction r filter - Master Dark and Flat





# J296.1785+54.8285

## Data Reduction r filter - Tracking and Magnitudes

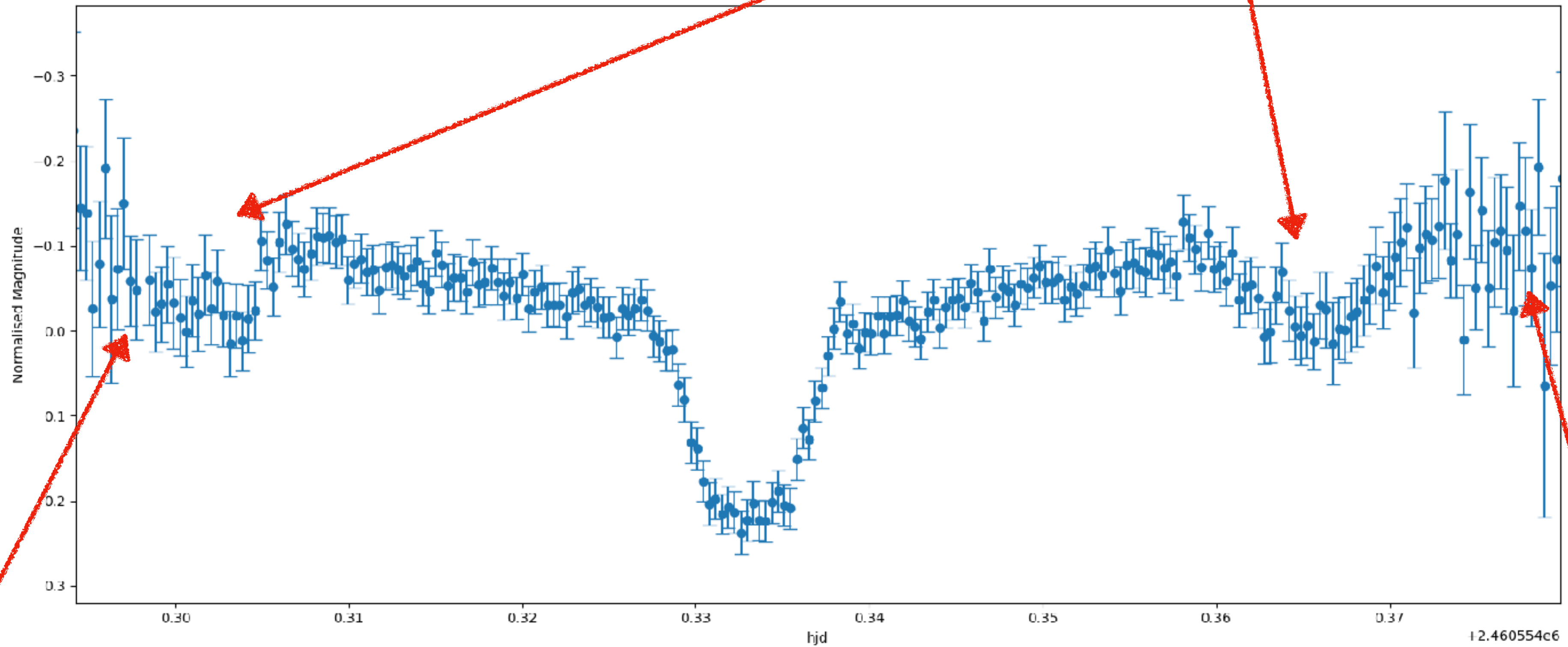


Bad data due to beginning of night & humidity



# J296.1785+54.8285

## Data Reduction r filter - Lightcurve



Beginning of night

Secondary Eclipse

Humidity Spike

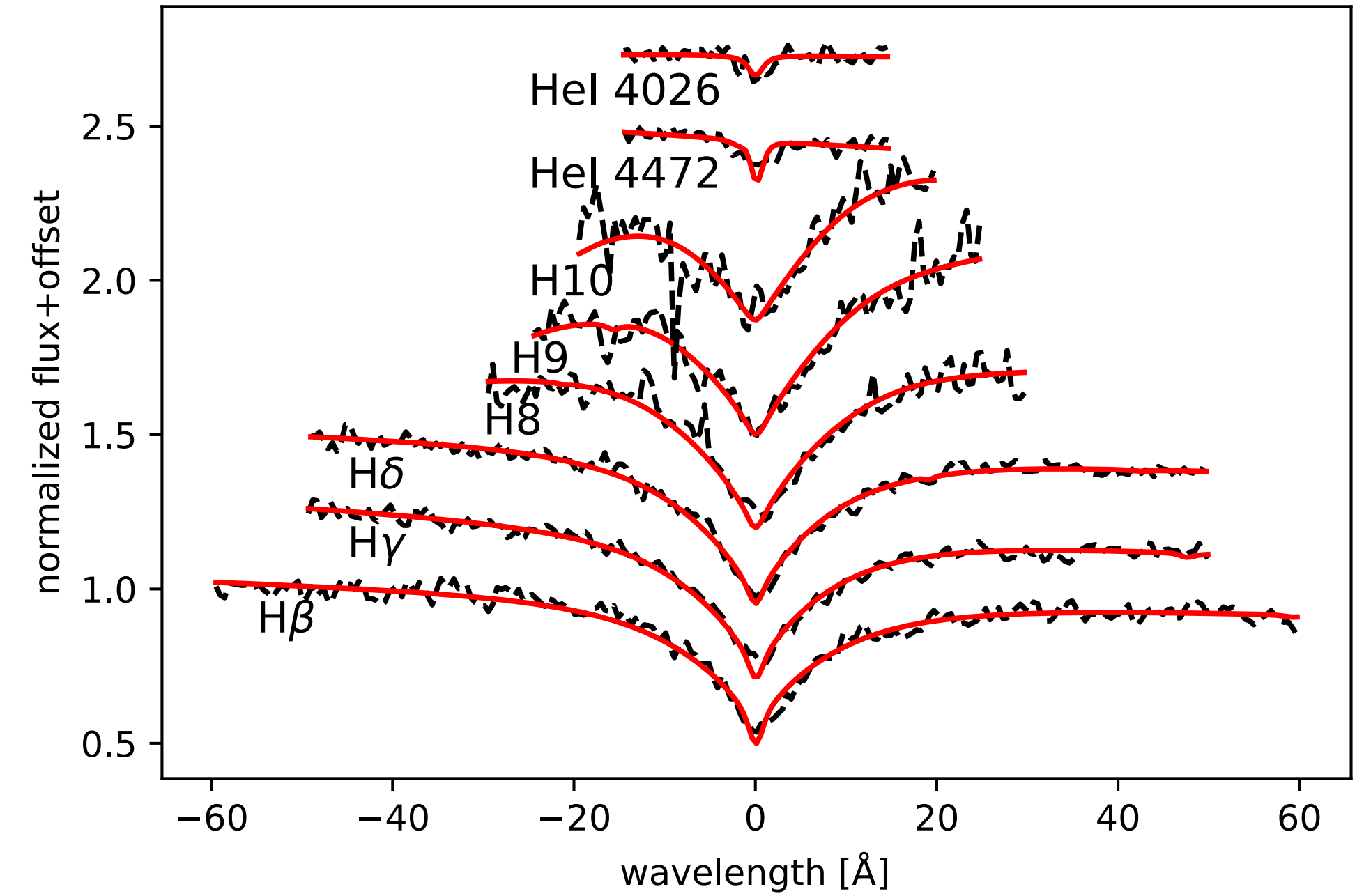
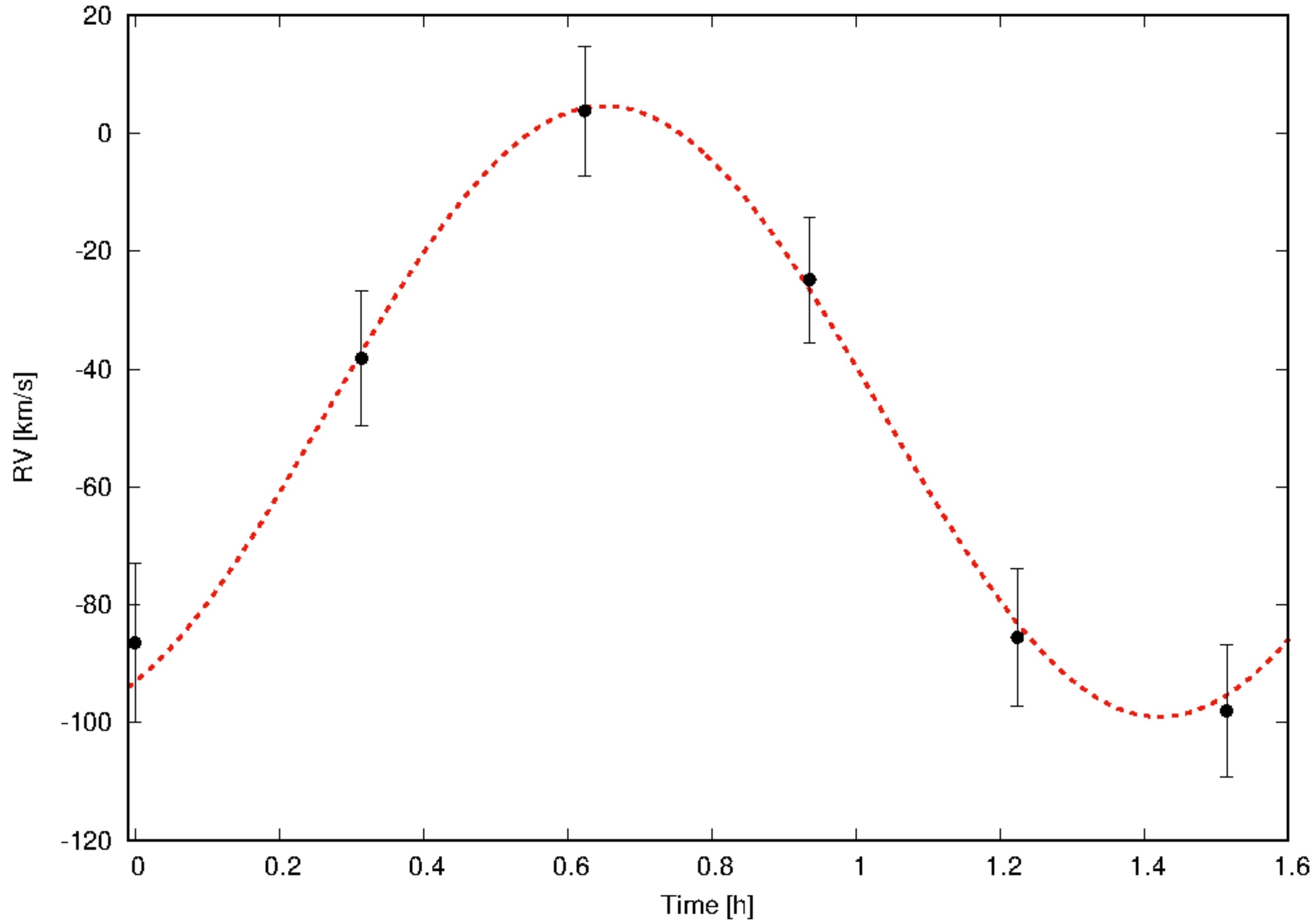


# **J296.1785+54.8285 lightcurve fitting**



# J296.1785+54.8285

## RV-curve

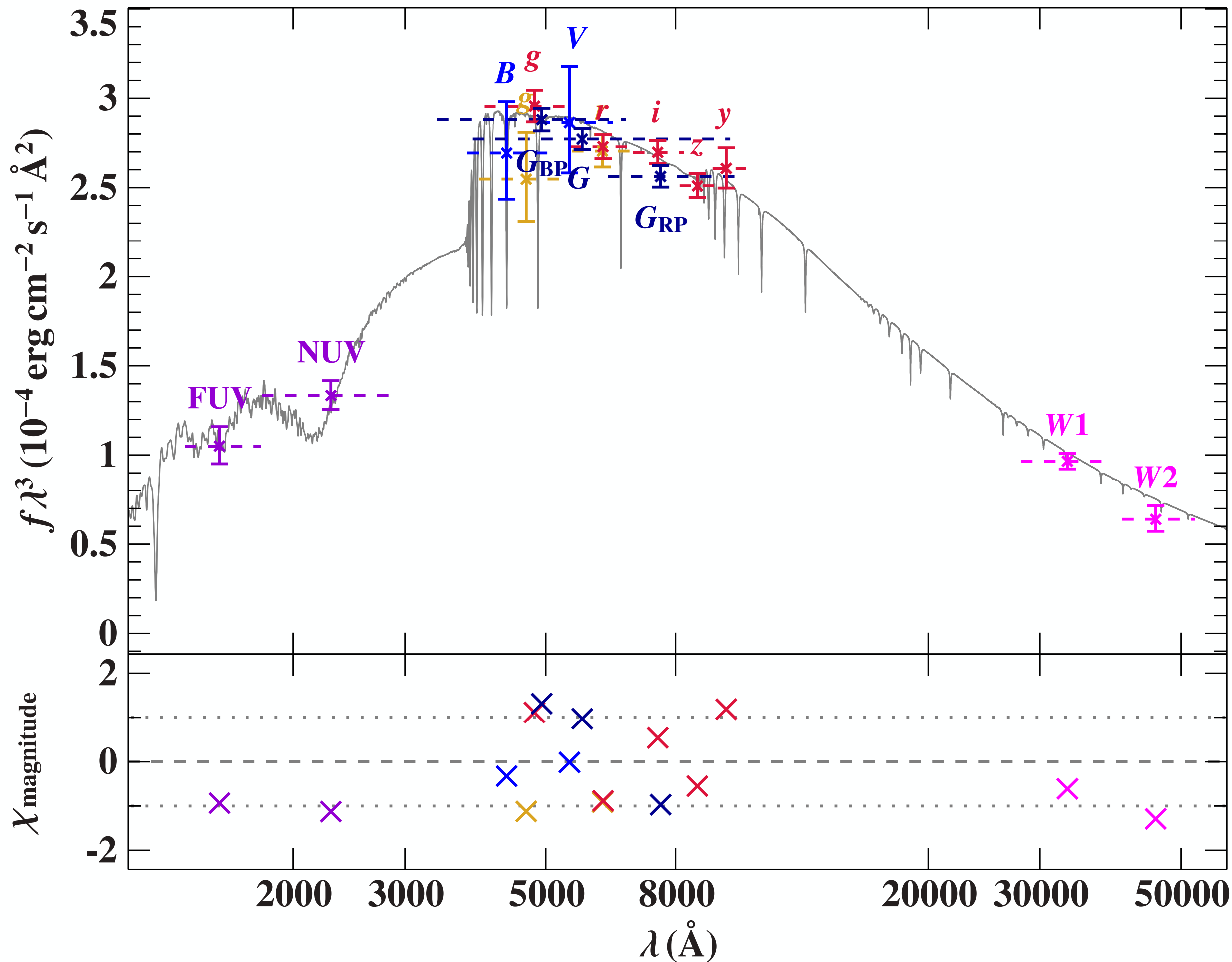


Parameter	Value	Error +/-
<b>Teff (K)</b>	25096	615
<b>logg</b>	5.446	8.7E-02
<b>helium</b>	-2.830	-
<b>K-amplitude (km/s)</b>	52	2



# J296.1785+54.8285

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

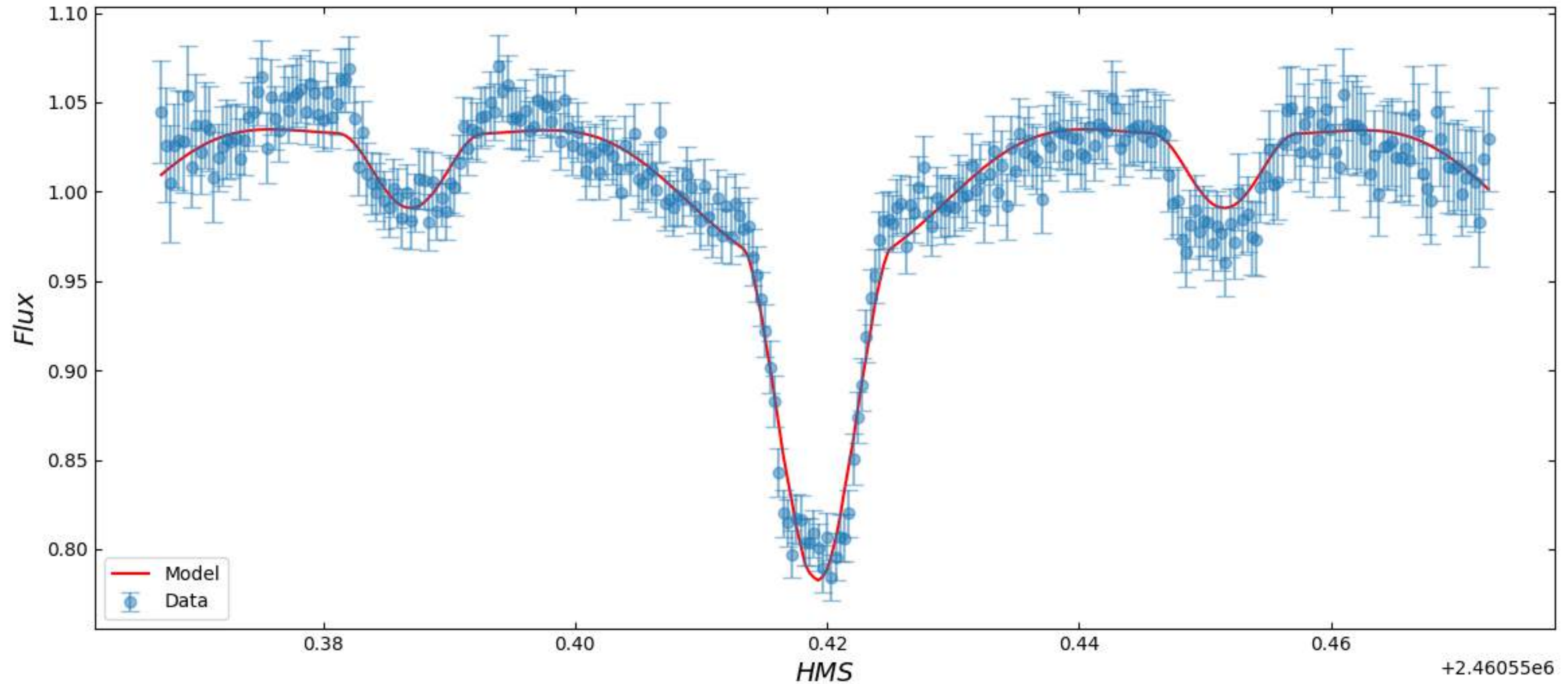


Object: Gaia DR3 2138663782338254464	68% confidence interval
Color excess $E(B - V)$ from SFD (1998)	$0.160 \pm 0.008$ mag
Color excess $E(B - V)$ from S&F (2011)	$0.138 \pm 0.007$ mag
Color excess $E(B - V)$ from Stilism (Capitanio+ 2017)	$0.071 \pm 0.012$ mag
Color excess $E(B - V)$ from Bayestar15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



# J296.1785+54.8285

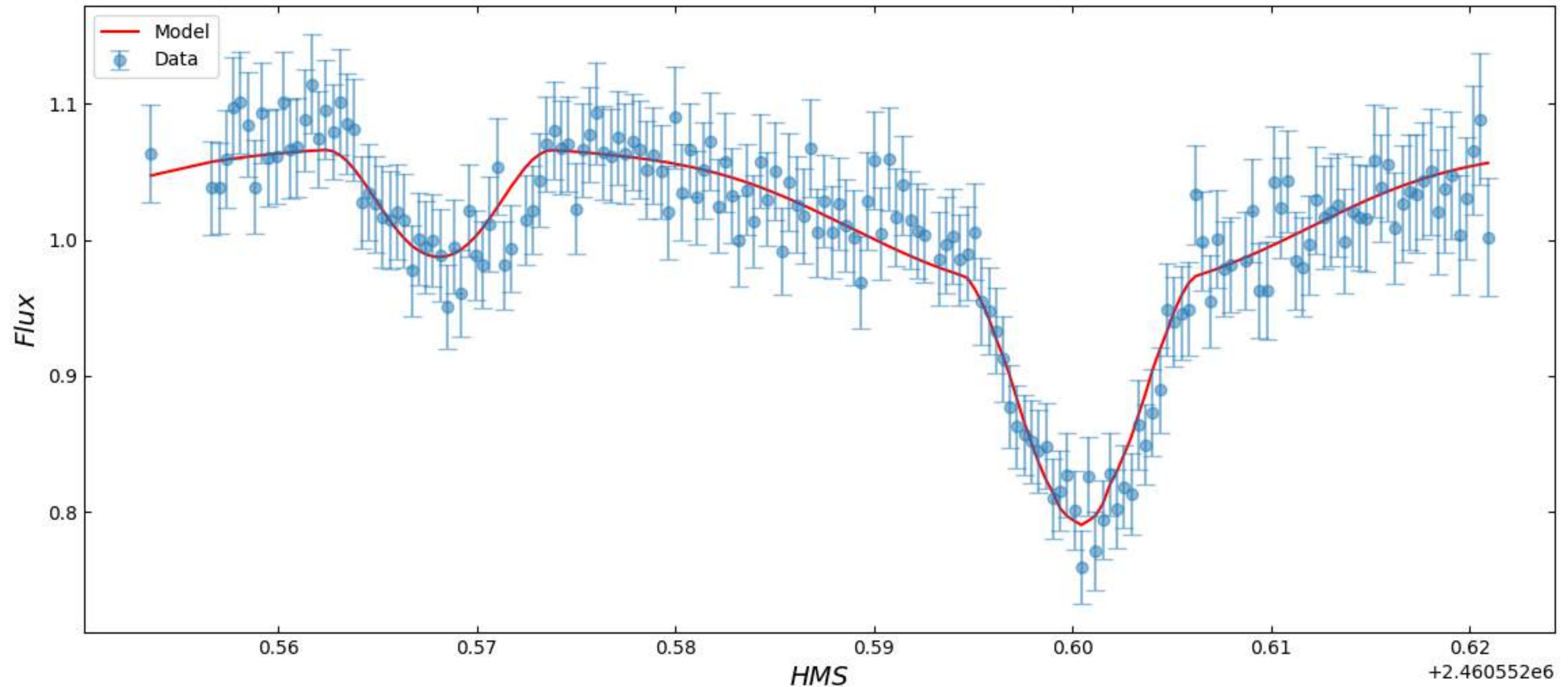
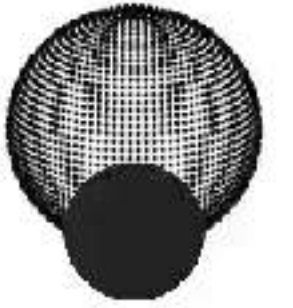
## Lightcurve Fitting g Filter





# J296.1785+54.8285

## Lightcurve Fitting I Filter



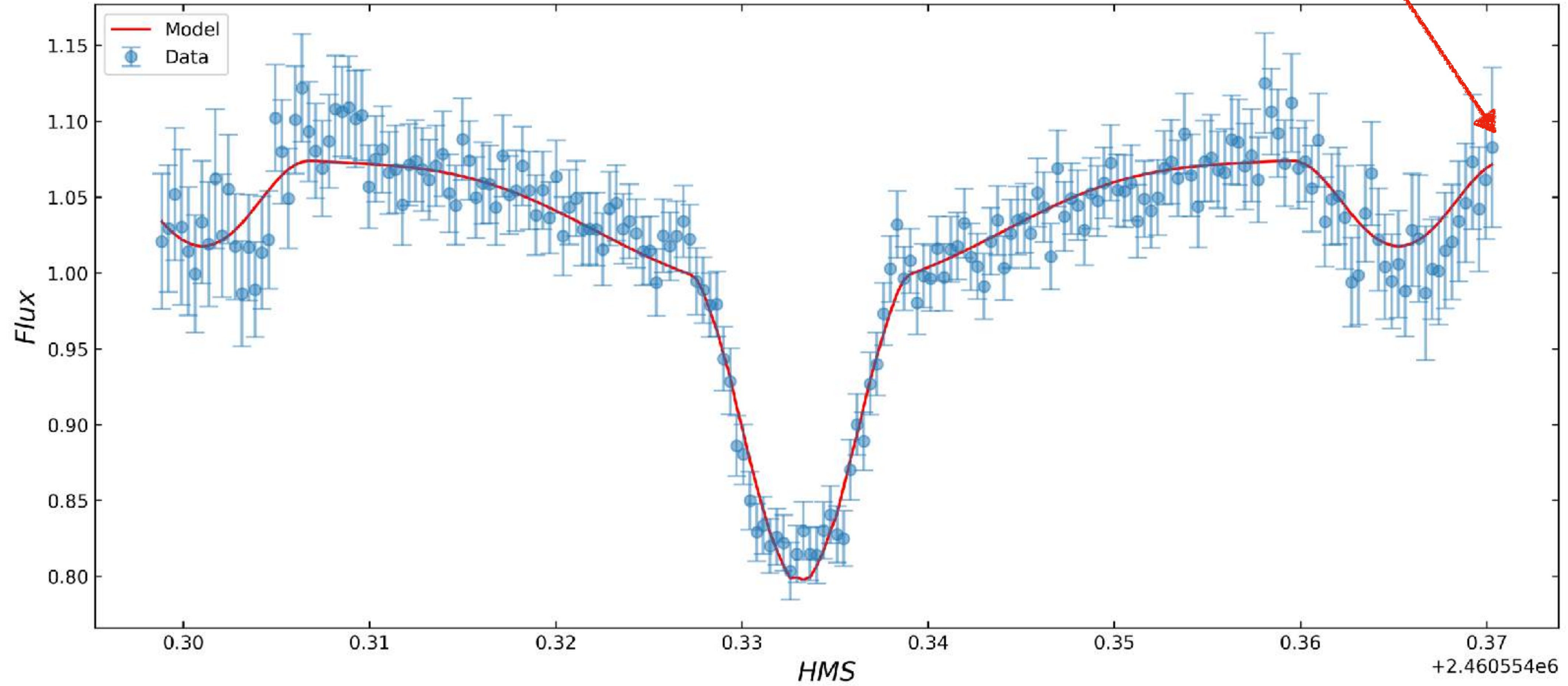


# J296.1785+54.8285

## Lightcurve Fitting r Filter



Discarded more data for the fitting due to bad data





# 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!

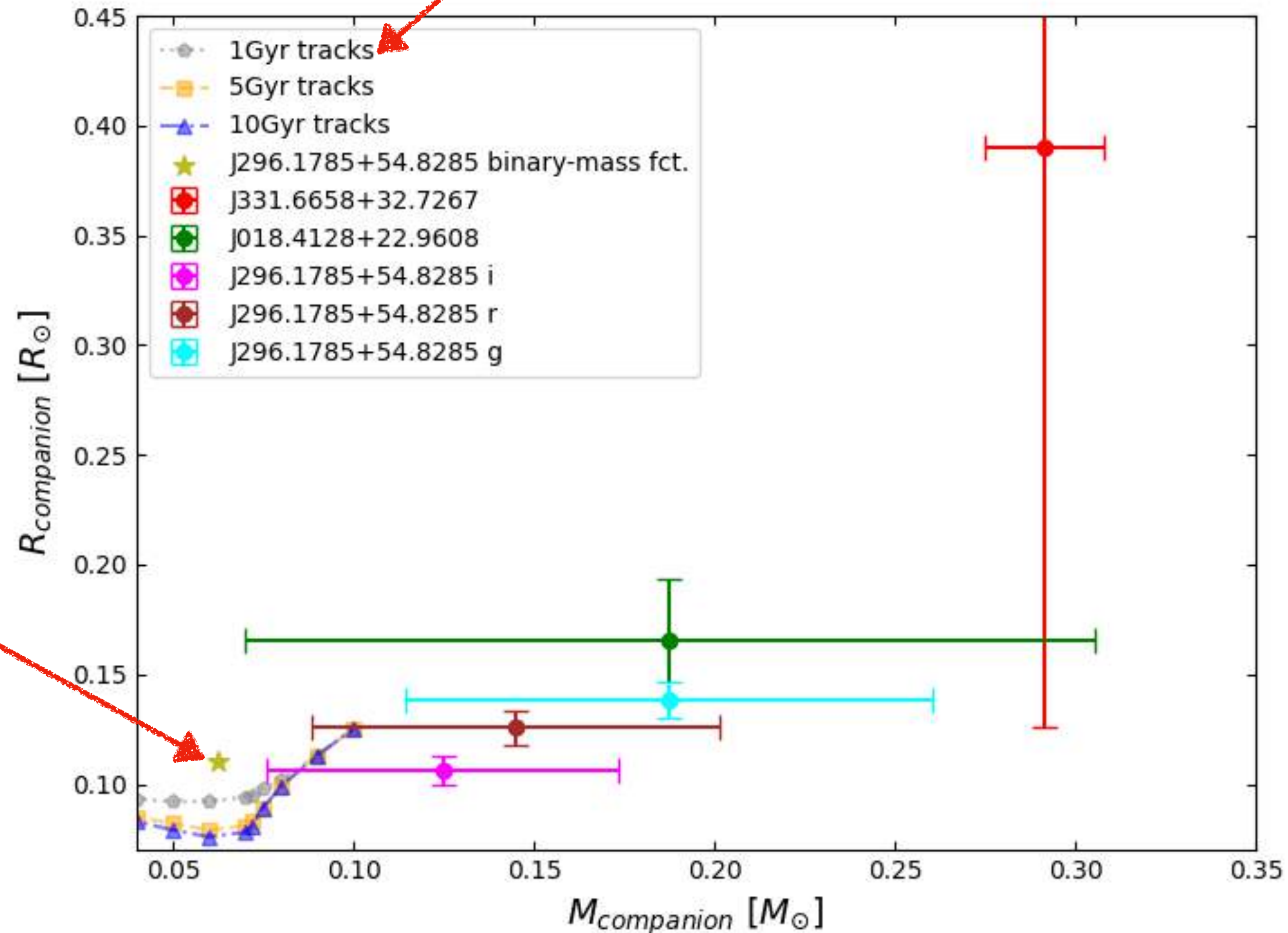
Lightcurve SED



# Mass-Radius Relation

## Companion

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



J296 with Binary-mass fit. solution!



**Thank you for your attention!**