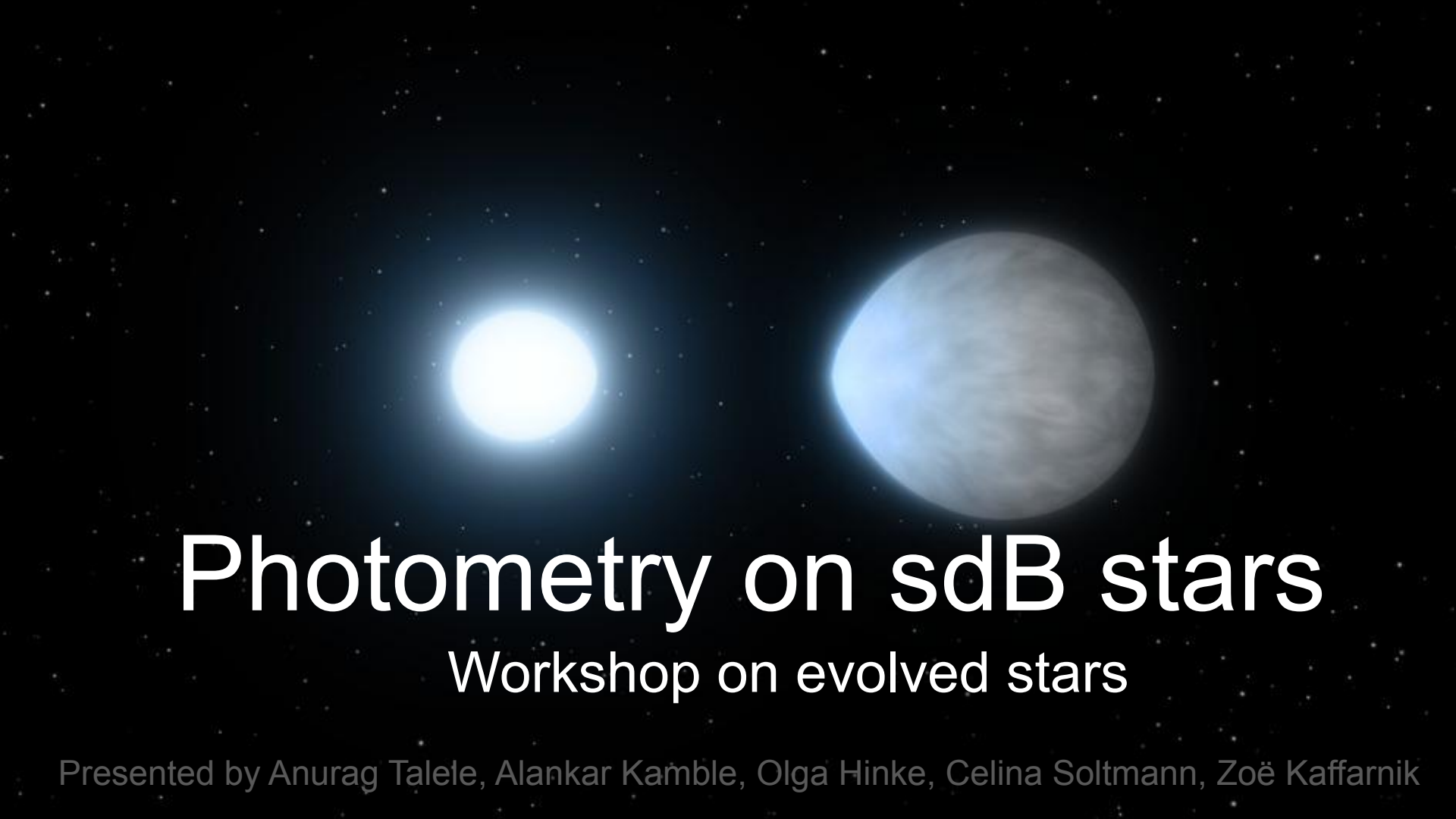


Photometry on sdB stars

Workshop on evolved stars

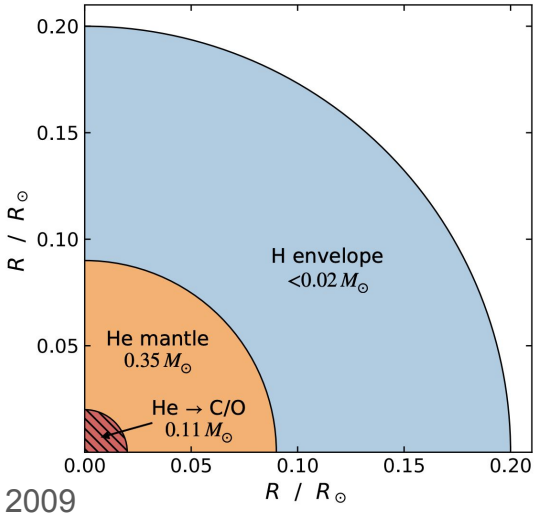
Presented by Anurag Talele, Alankar Kamble, Olga Hinke, Celina Soltmann, Zoë Kaffarnik

Targets: sdB type stars

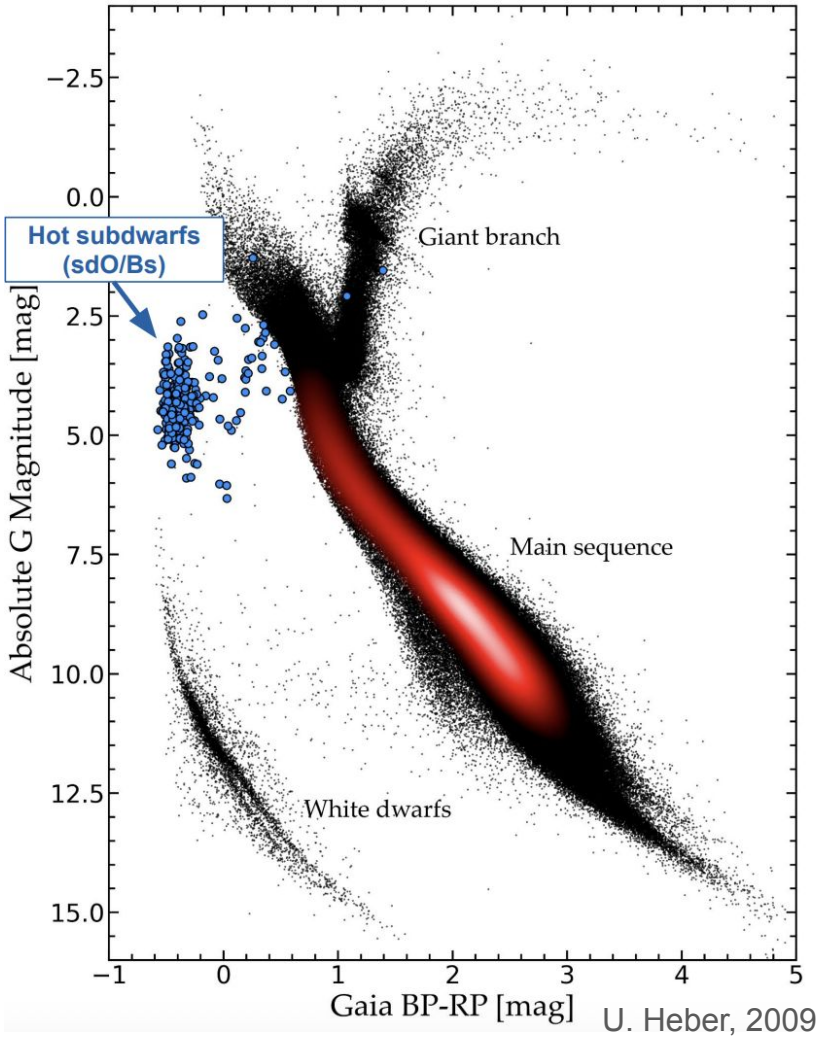
Mass ~ 0.47 $M_\odot$

Radius ~ 0.1 - 0.3 $R_\odot$

Effective temperature ~ 20 – 100 kK



U. Heber, 2009



U. Heber, 2009

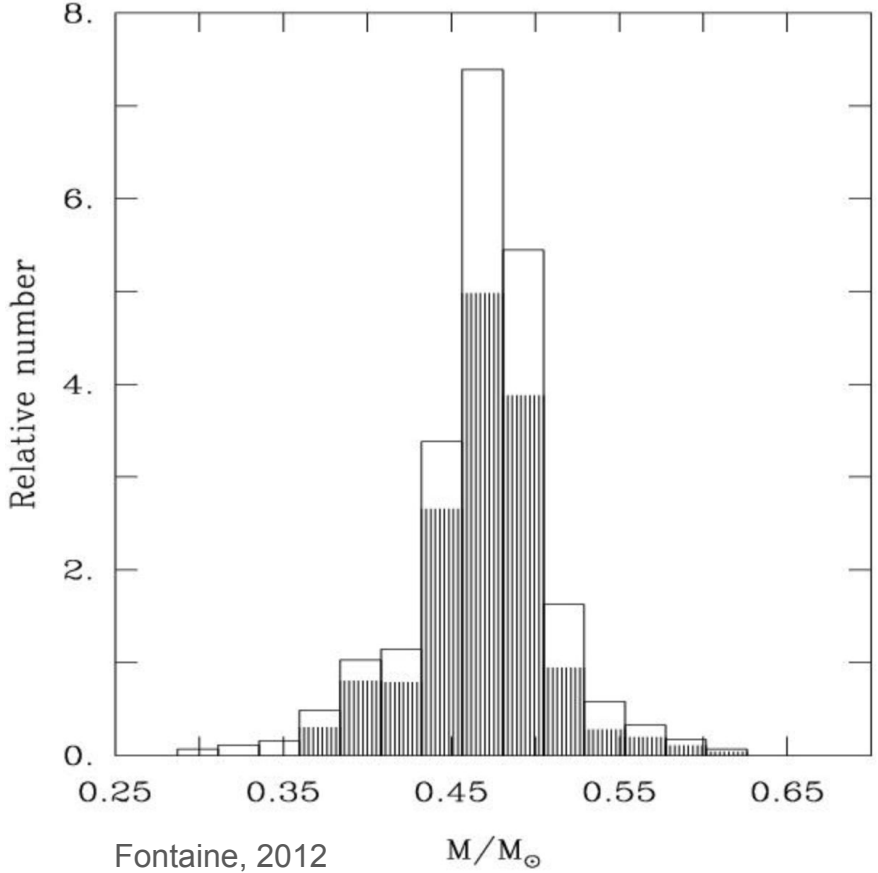
Targets: sdB type stars

Helium burning without helium flash

Mass ~ 0.47 $M_\odot$

Radius ~ 0.1 - 0.3 $R_\odot$

Effective temperature ~ 20 – 100 kK



Fontaine, 2012

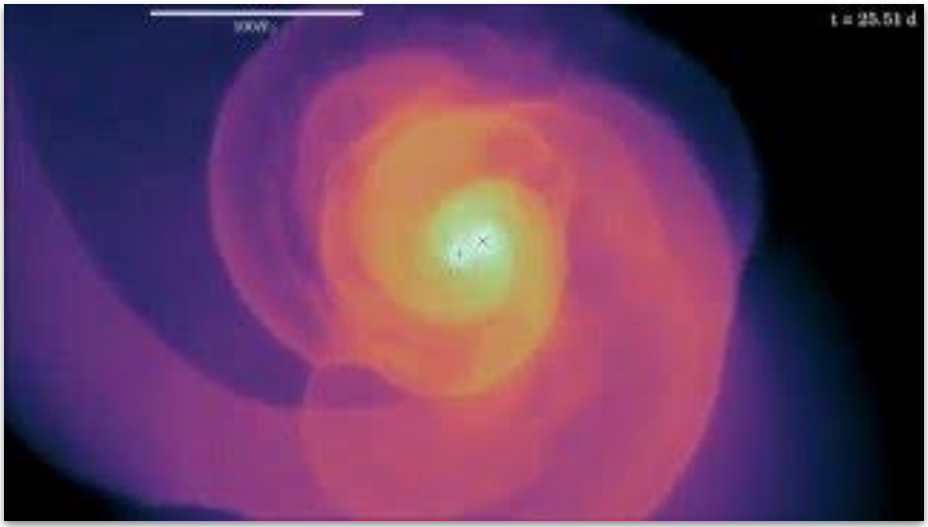
RLOF = Roche lobe overflow

CE = Common envelope

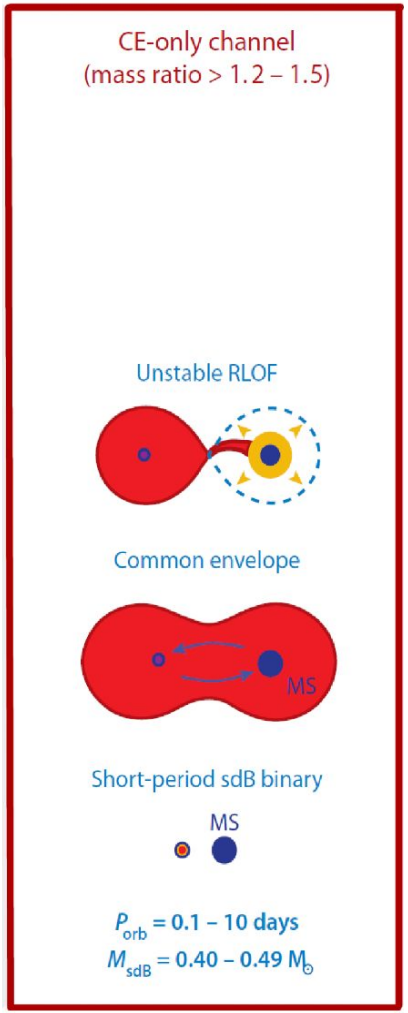
Formation of sdB binaries

- Determined by mass ratio

$$q = M_{don}/M_{acc}$$



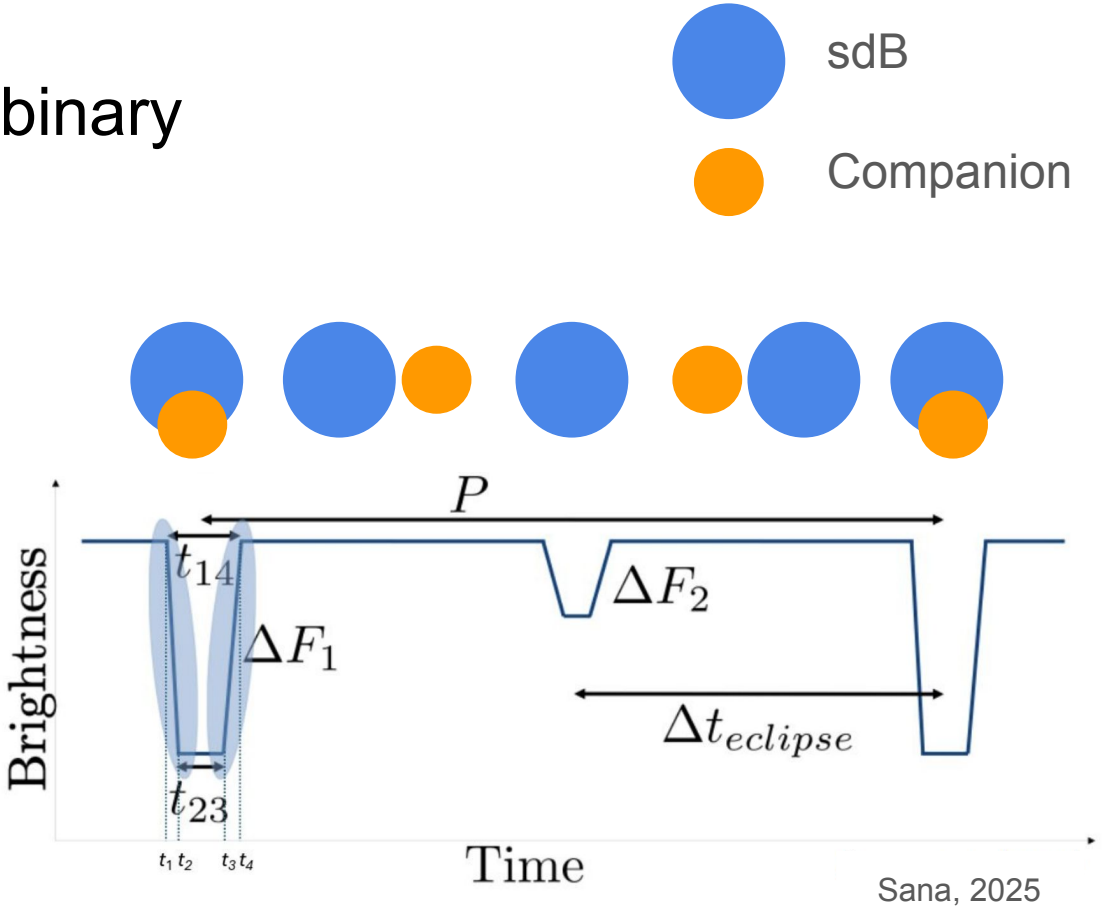
S. Ohlmann, 2016



Podsiadlowski, 2008

Lightcurve of eclipsing binary

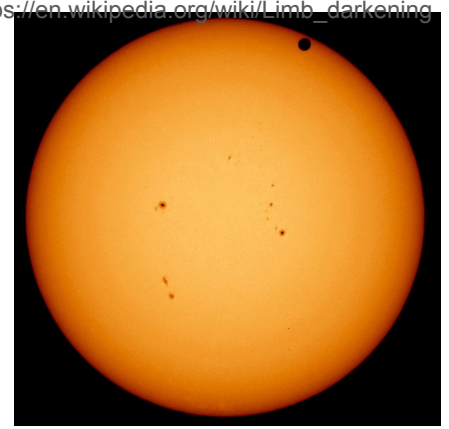
- Primary eclipse: Strong decrease in brightness of sdB due to companion
- Secondary eclipse: sdB moves behind the companion, weaker than primary eclipse



Sana, 2025

https://en.wikipedia.org/wiki/Limb_darkening

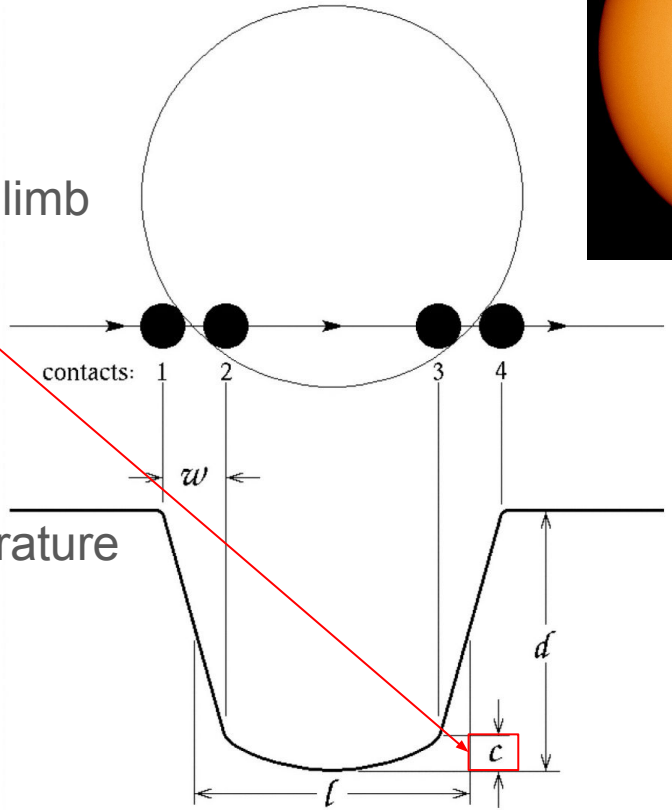
Limb darkening



- Luminosity of the stellar disk decreases from the centre to the limb
- Transit depth is not constant
- Linear law

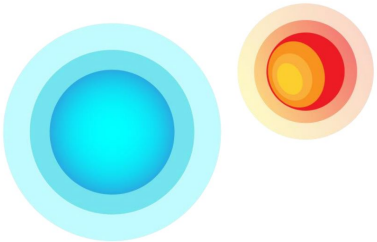
$$I = I_0(1 - \epsilon + \epsilon \cos \gamma$$

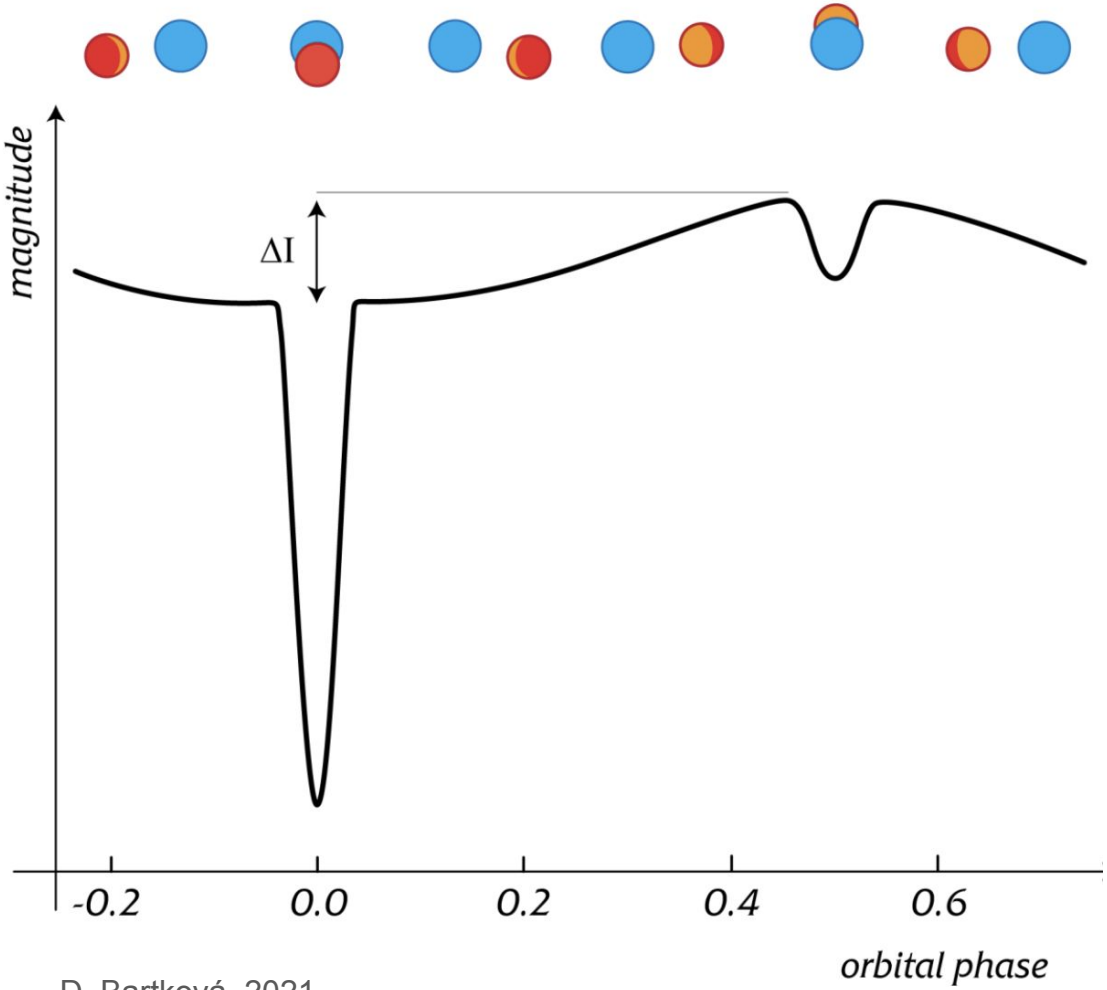
- Limb darkening factor e is temperature dependent => other model used



Brown, 2001

Reflection effect



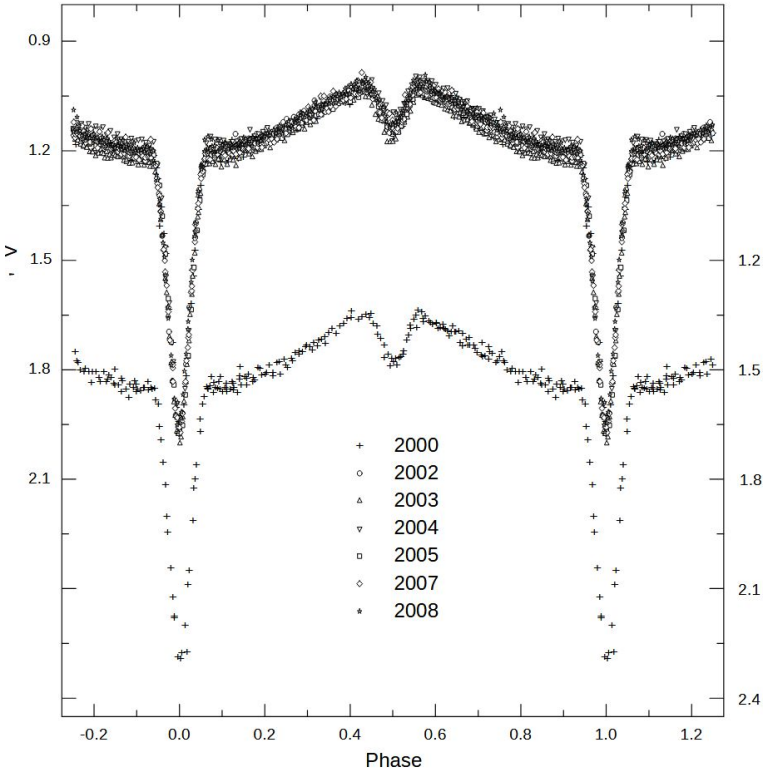


D. Bartková, 2021

Eclipsing binary with reflection effect - HW Vir

- Determine inclination and radii from lightcurve
- Estimate companion mass by assuming main sequence star:

$$M \propto R^{\frac{10}{7}}$$

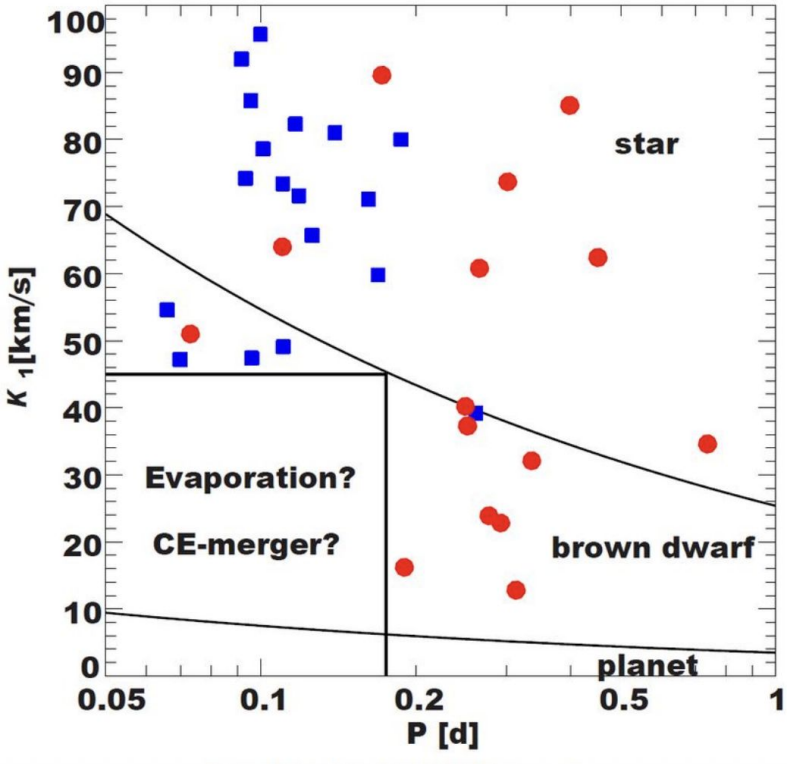


Lee, 2009

Minimal Companion Mass

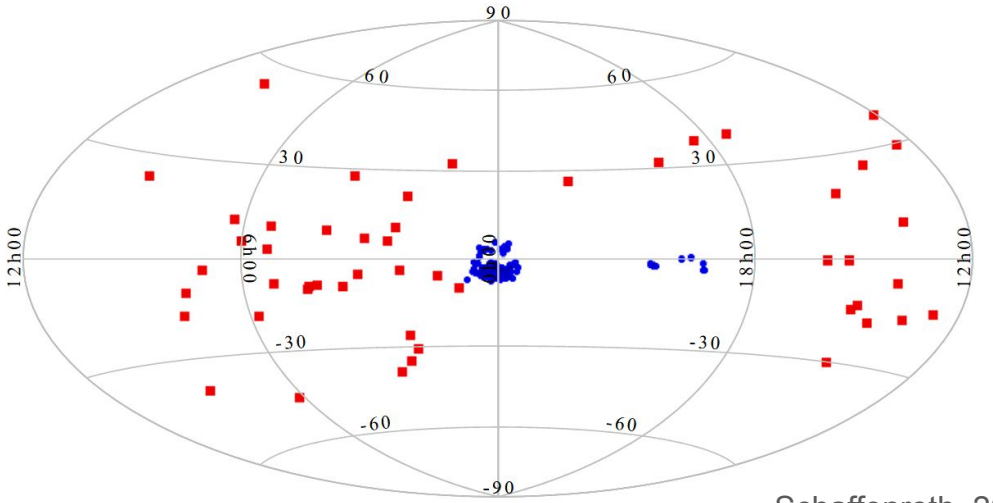
- Determine K from mass function:

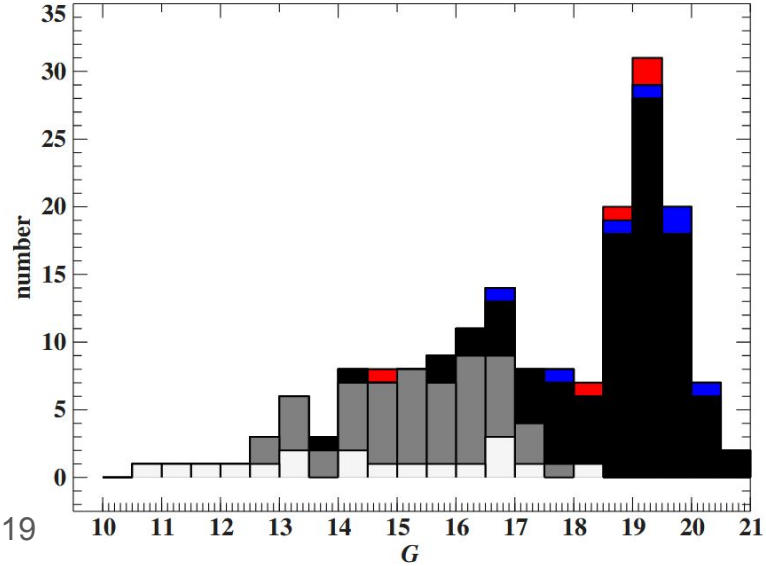
$$f(x) = \frac{M_2^3 sin(i)^3}{(M_1 + M_2)^2} = \frac{PK^3}{2\pi G}$$



Schaffenroth, 2019

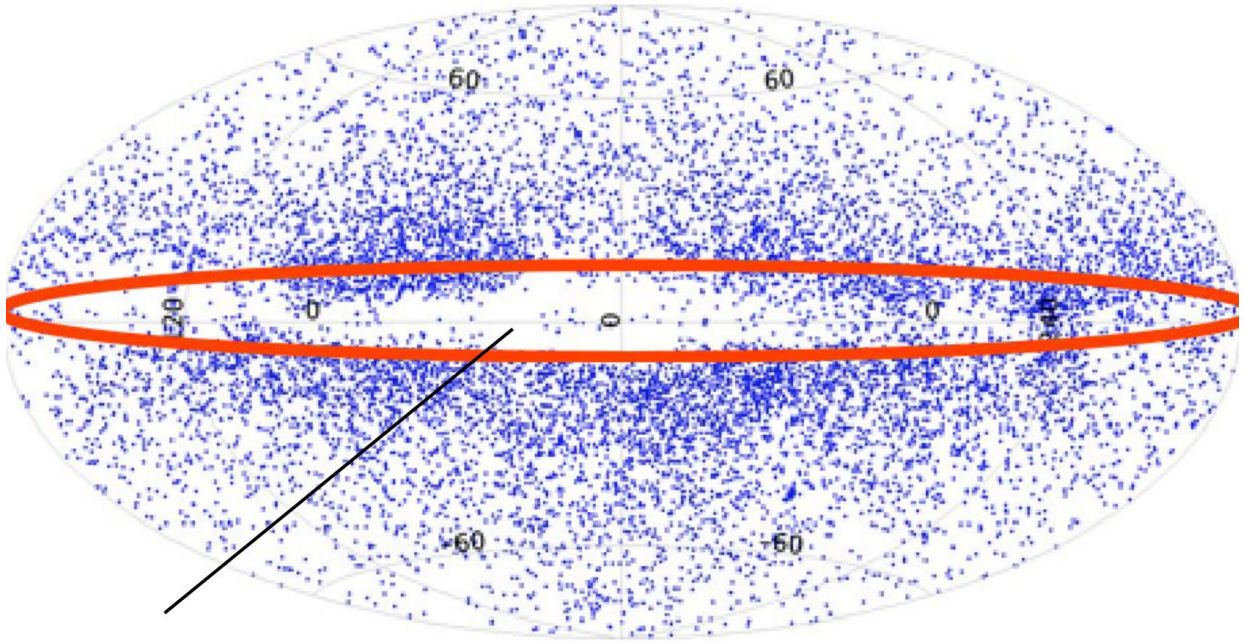
Known HW Vir systems





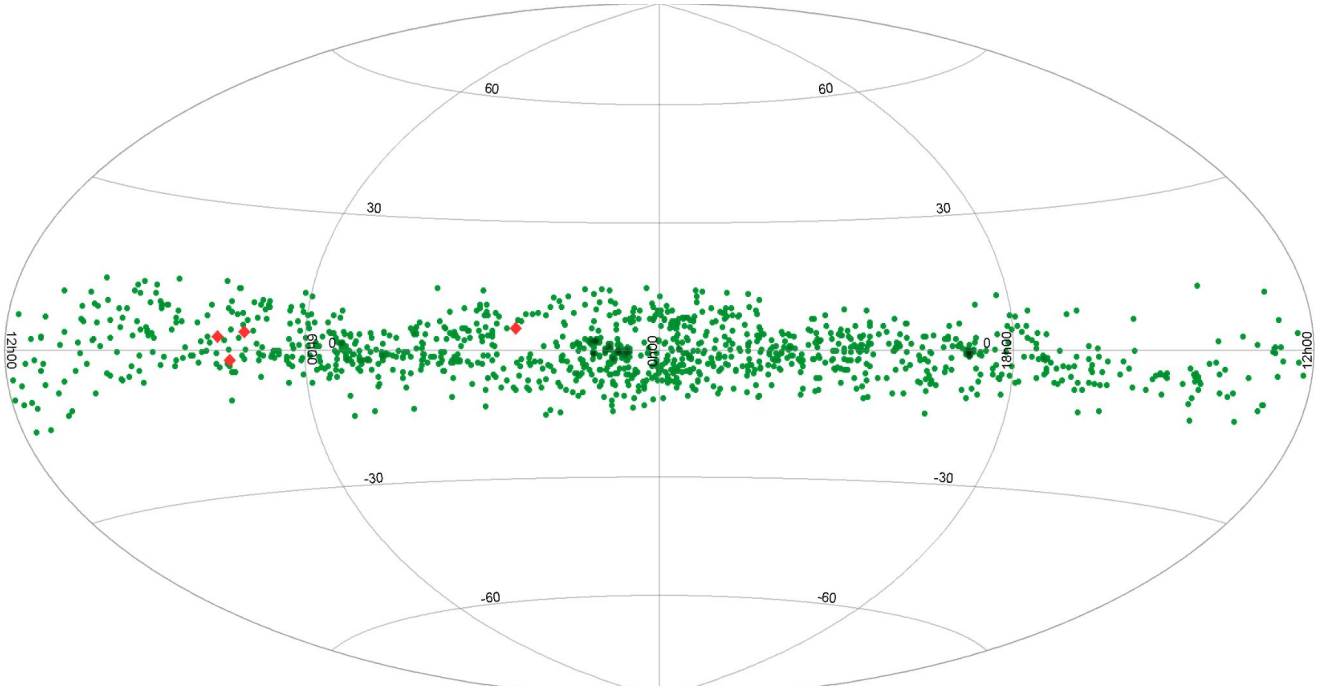
Schaffenroth, 2019

Target selection



Very few candidates inside Galactic disk despite very high stellar density

Target selection



Target selection

Constraints:

- Brighter than 18.5 mag
- Visible: dec > -11°,

  ra >255° or <75°

- Variability index V_G over 0.03

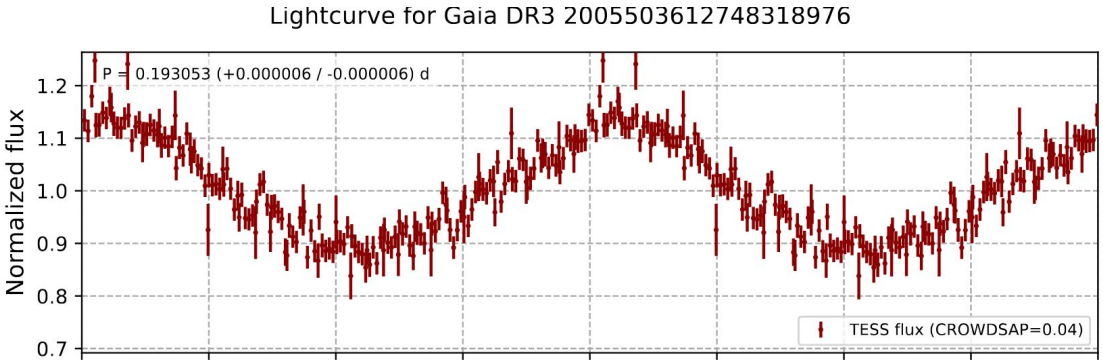
$$V_G = \frac{\sigma_G}{< G >} \cdot \sqrt{n_{obs,G}}$$

2m telescope

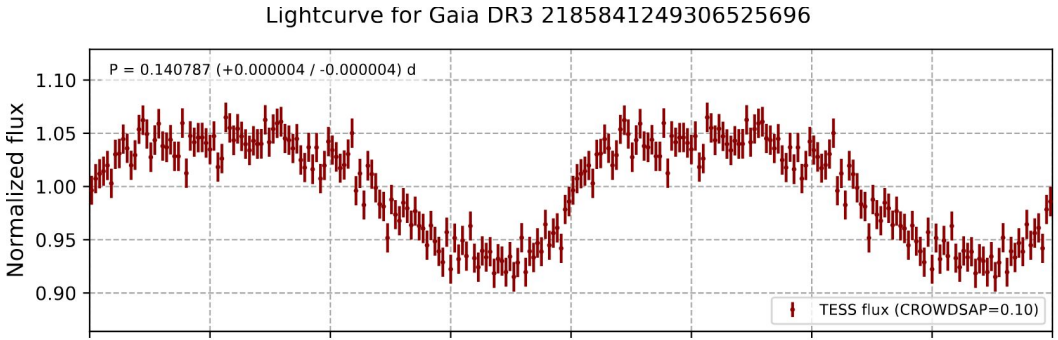
D50
M. Nekola+, 2014

Target selection - No HW Vir

Lightcurve with reflection effect, without eclipses:

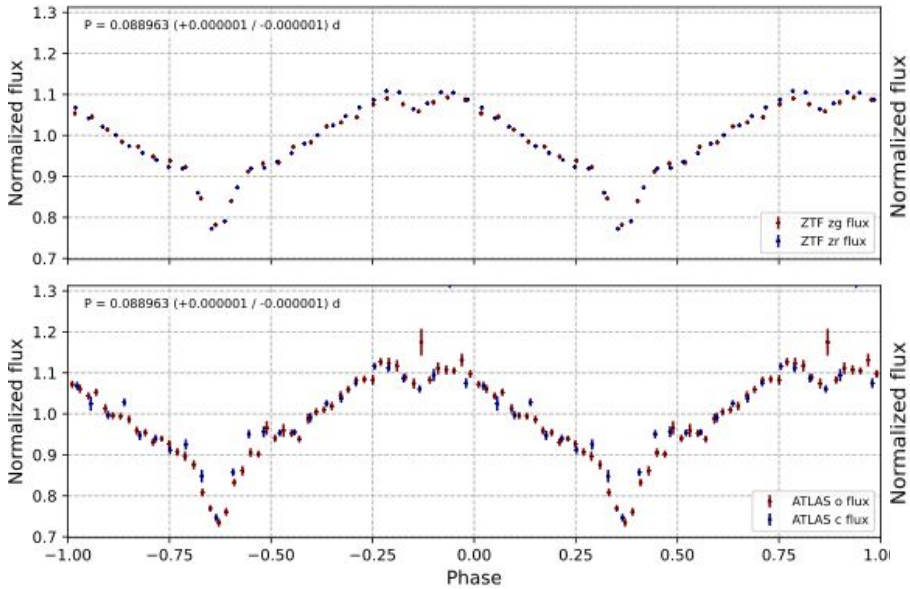


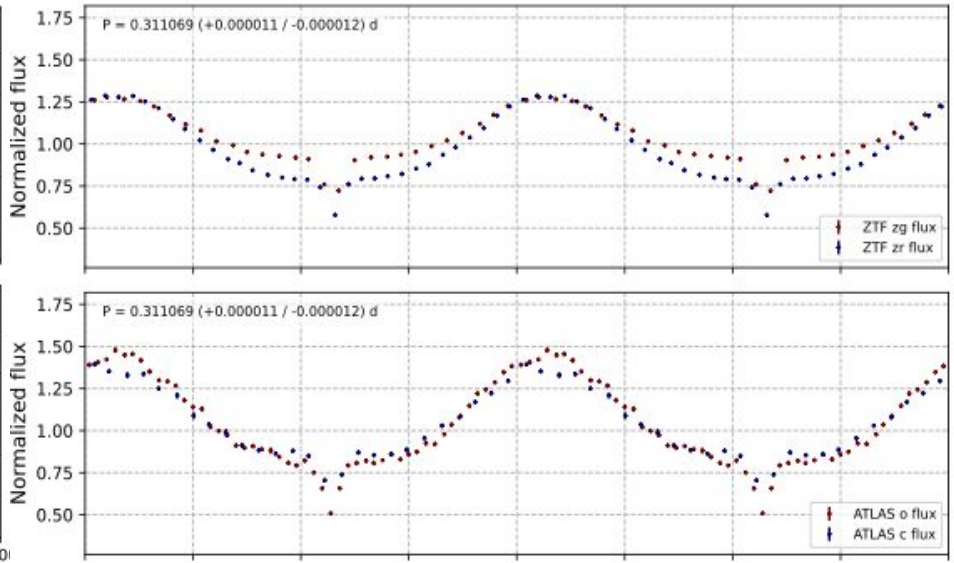
Lightcurve of cataclysmic variable:



Target selection - HW Vir

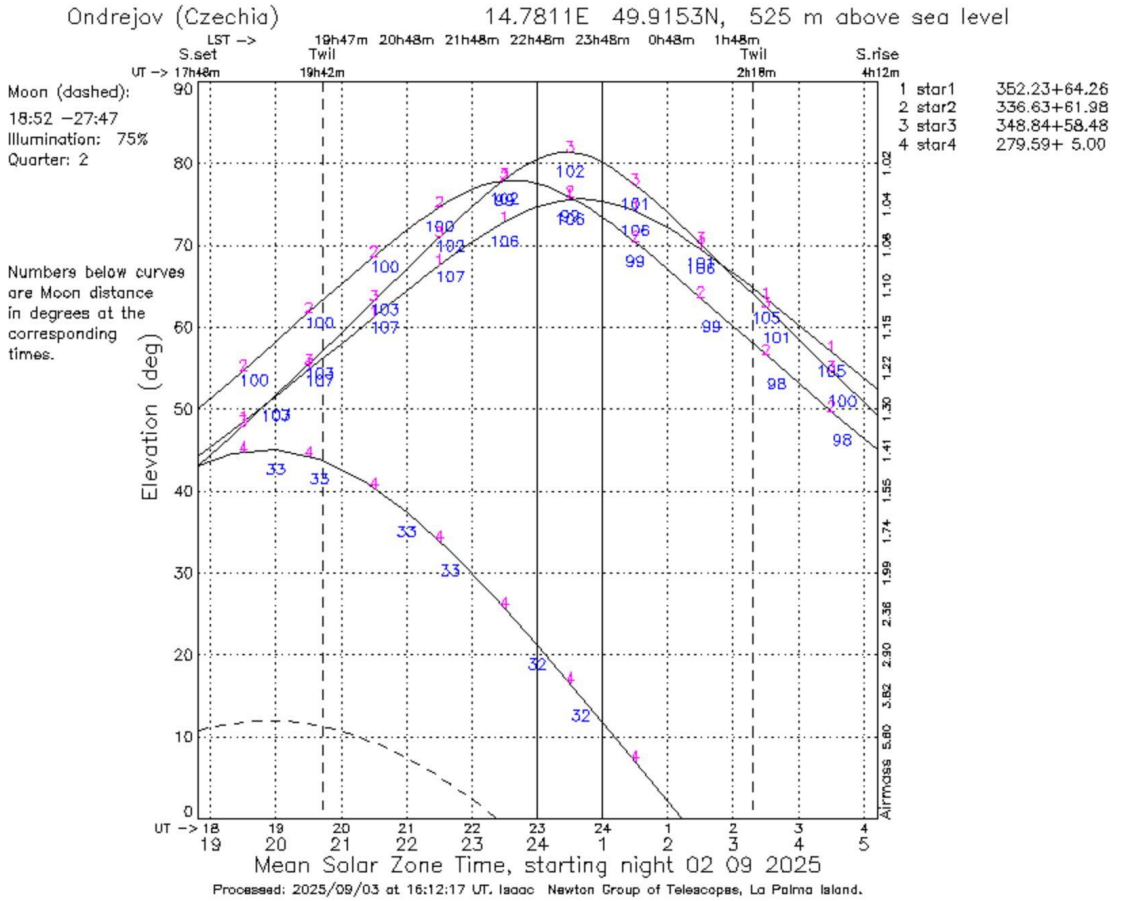
Eclipsing reflection effect systems:





Final Targets

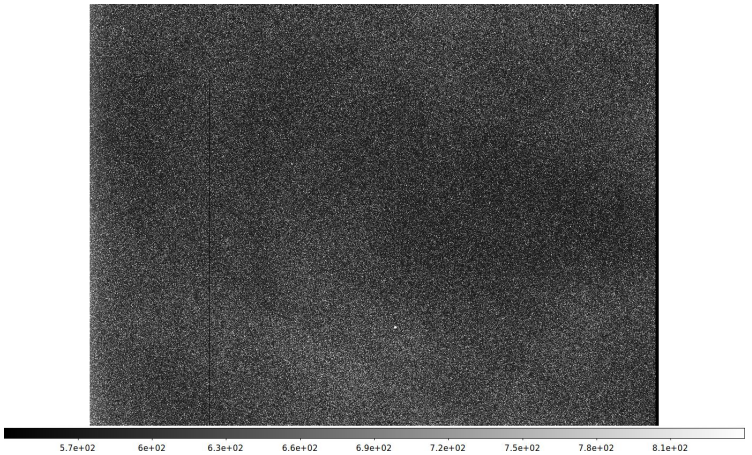
Target	Magnitude	Period in hours
1	17.37	2.14
2	17.05	7.47
3	17.61	3.81
4	17.42	5.04



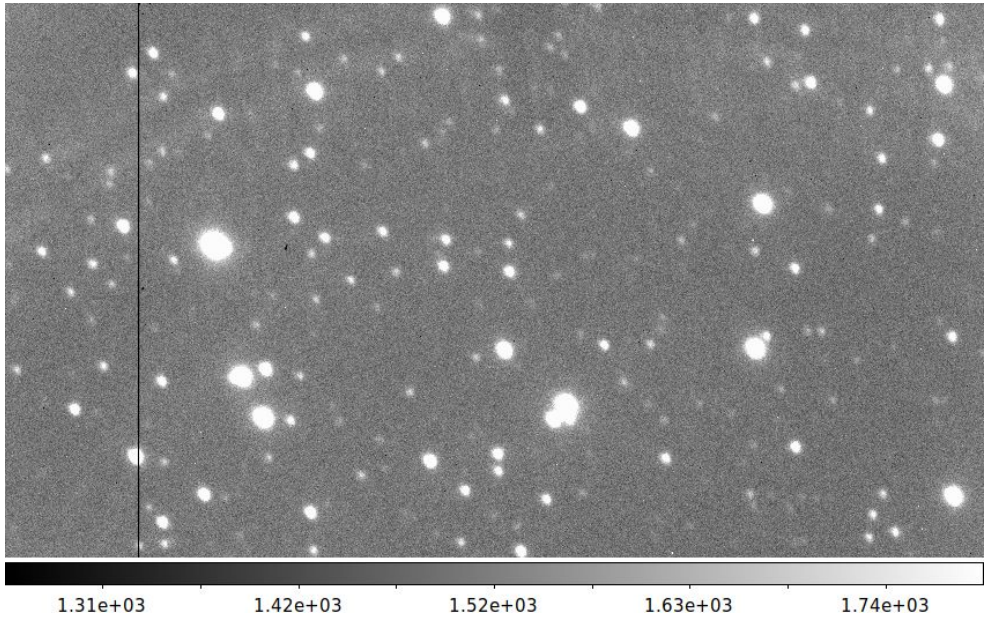
Data reduction - Flats and Darks

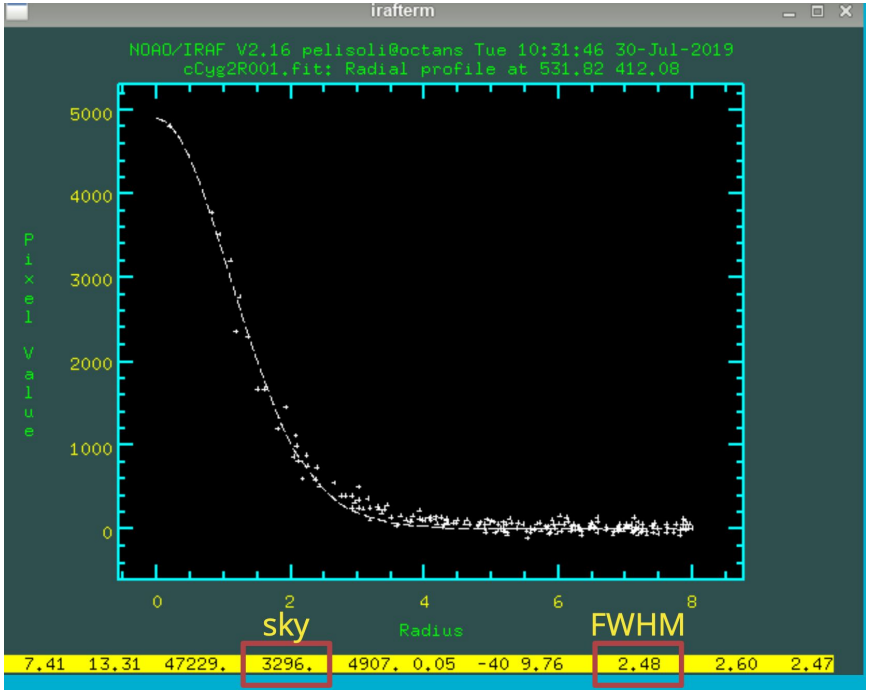
Each exposure time needs its own master dark, here 120s

Each filter needs its own master flat, here R filter



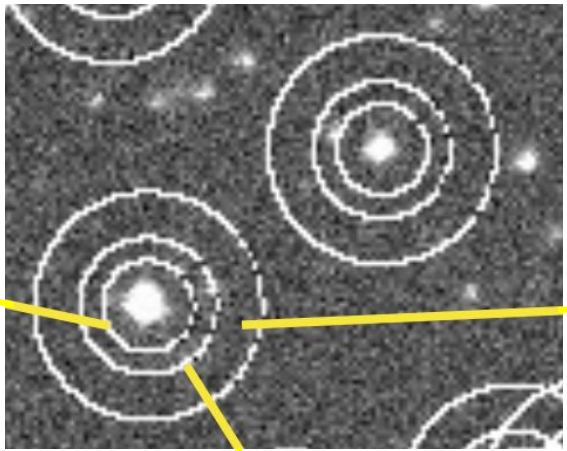
Data reduction - Photometry





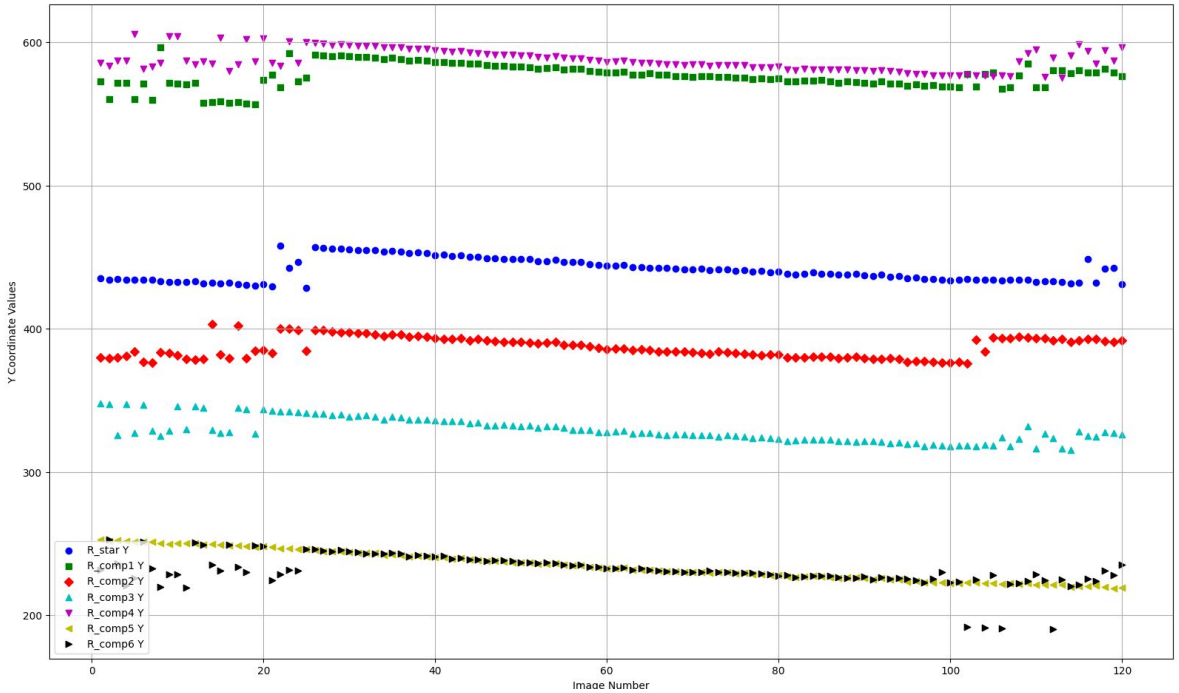
Data reduction - Aperture, Annulus & Dannulus

- Aperture: where flux of star will be measured
- Annulus: distance at which to start counting bg
- Dannulus: width of ring to count bg

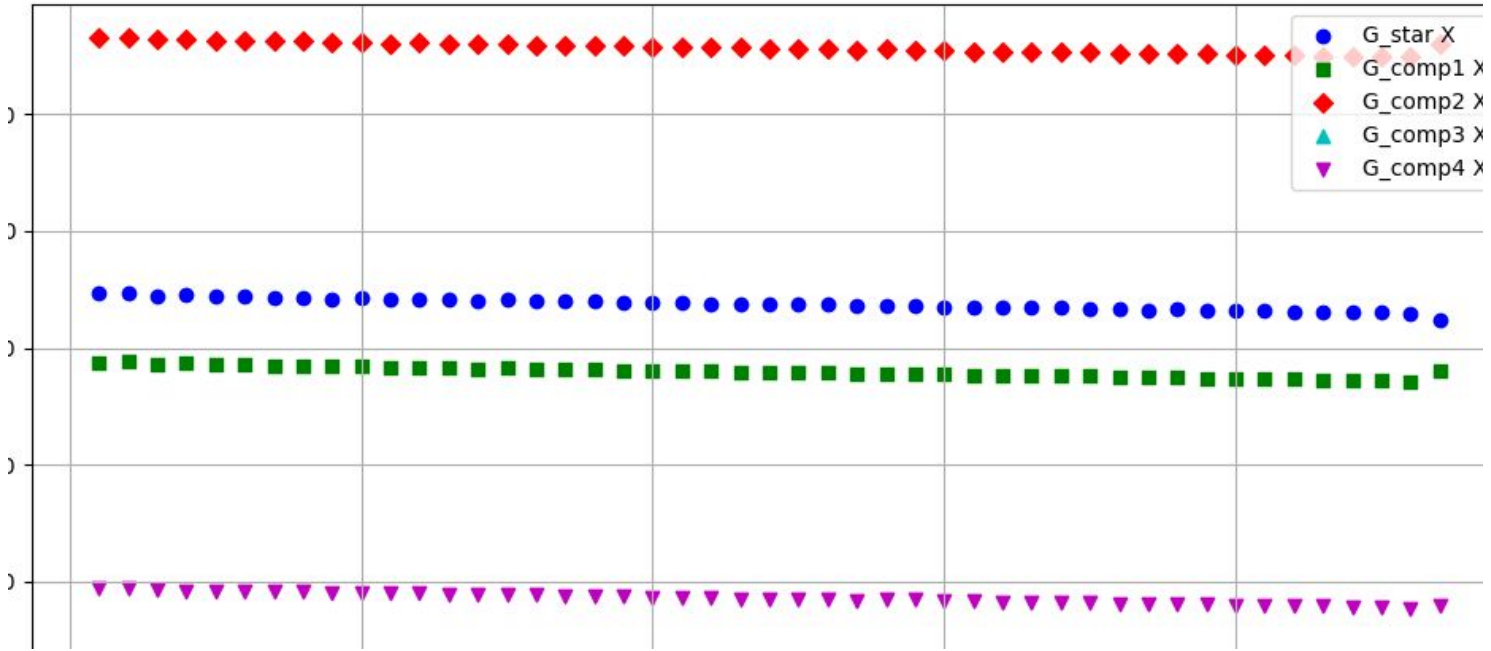


→ insert in list of photometry files

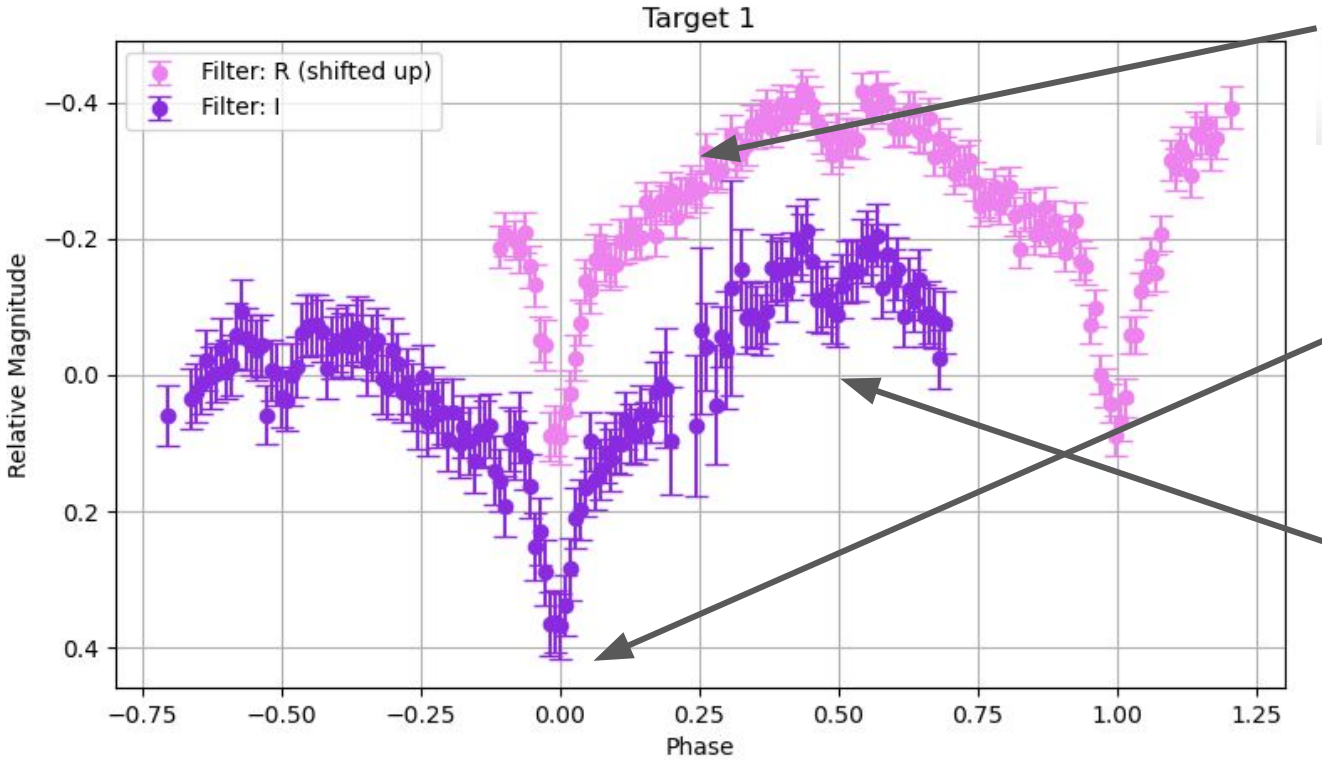
Data reduction - Comparison stars

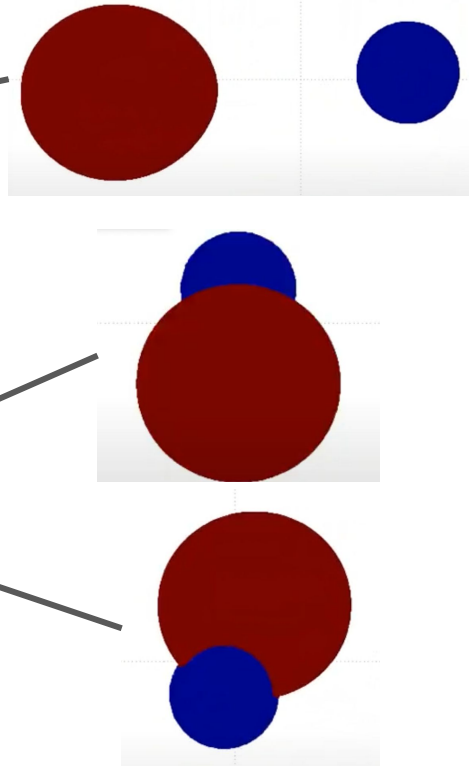


Data reduction - Comparison stars



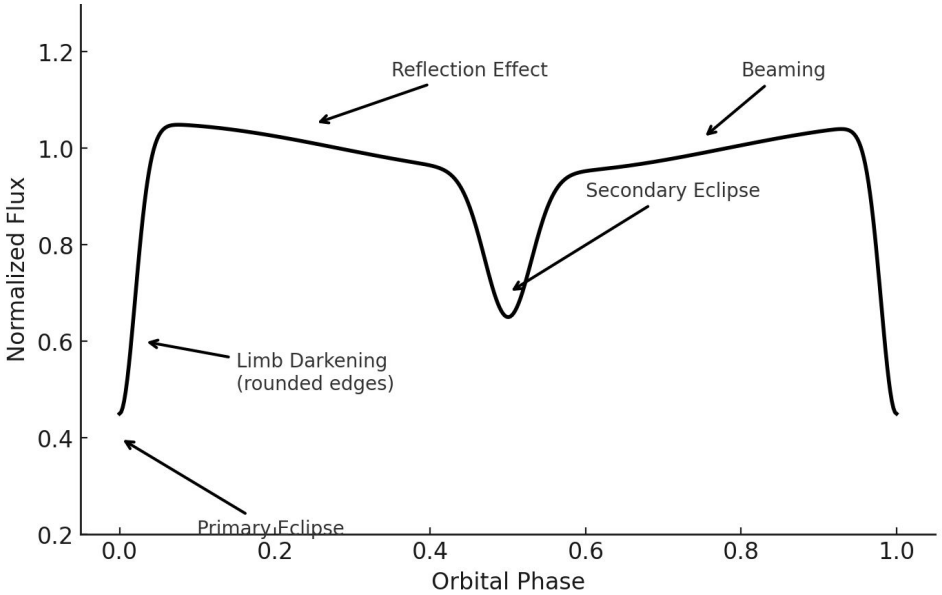
Data reduction - Building a light curve

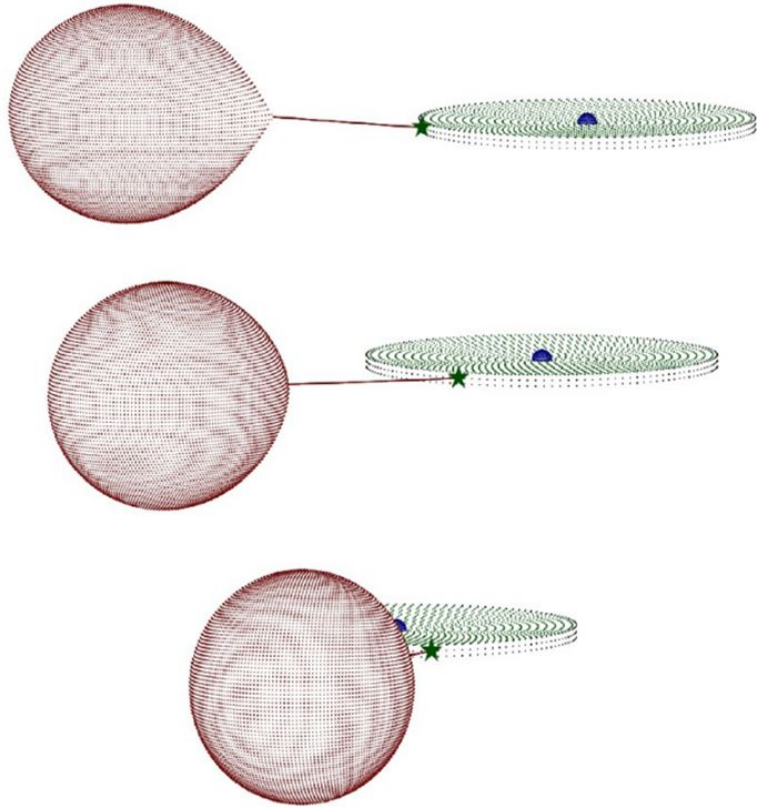




LCurve

Simulates effects: limb darkening, reflection, beaming, geometry.





Fitting- Starting the Fit

HJD	Mag	Mag_error
2460925.33485	-0.2633	0.0619
2460925.33637	-0.2080	0.0527
2460925.33788	-0.2260	0.0559
2460925.33939	-0.1870	0.0623

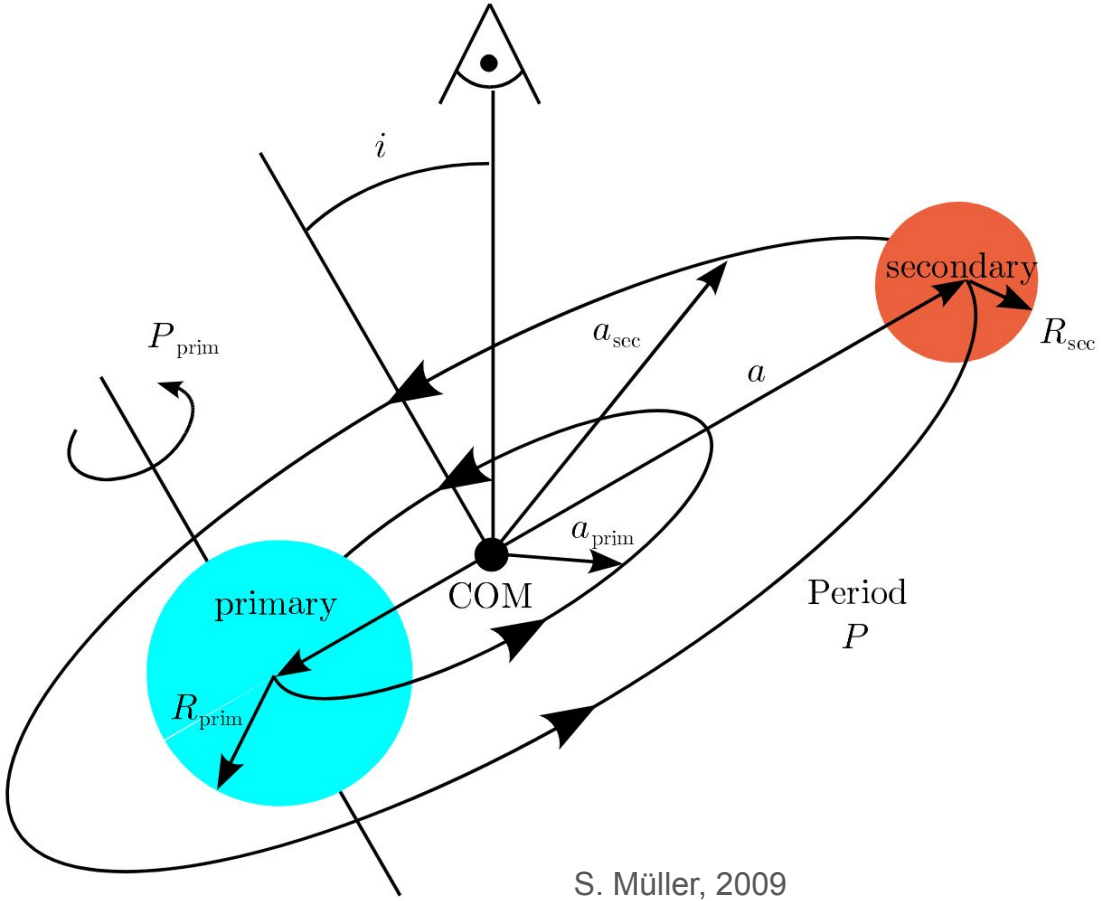
hjd	delta_phase	flux	flux_error	weight	factor
2460925.33485	0.00024609253348500005	1.2744417785504178	0.07265848347559231	1	1
2460925.33637	0.00024609253363700004	1.2111557629827332	0.05878767644430633	1	1
2460925.33788	0.000246092533788	1.2314024122062166	0.06339974161372101	1	1
2460925.33939	0.000246092533939	1.1879550279416518	0.06816535905906546	1	1

$$F = F_0 \cdot 10^{-0.4m}$$

$$F \propto 10^{-0.4m}$$

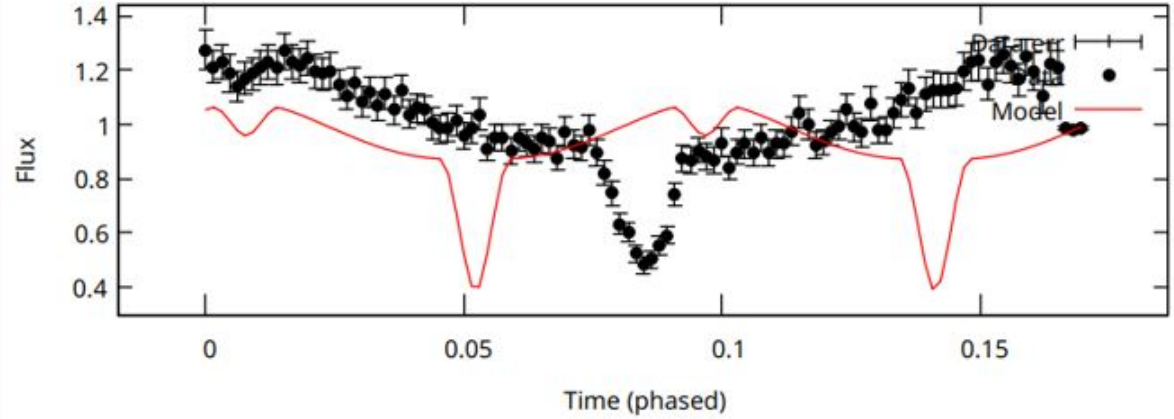
Flux-Magnitude Relation

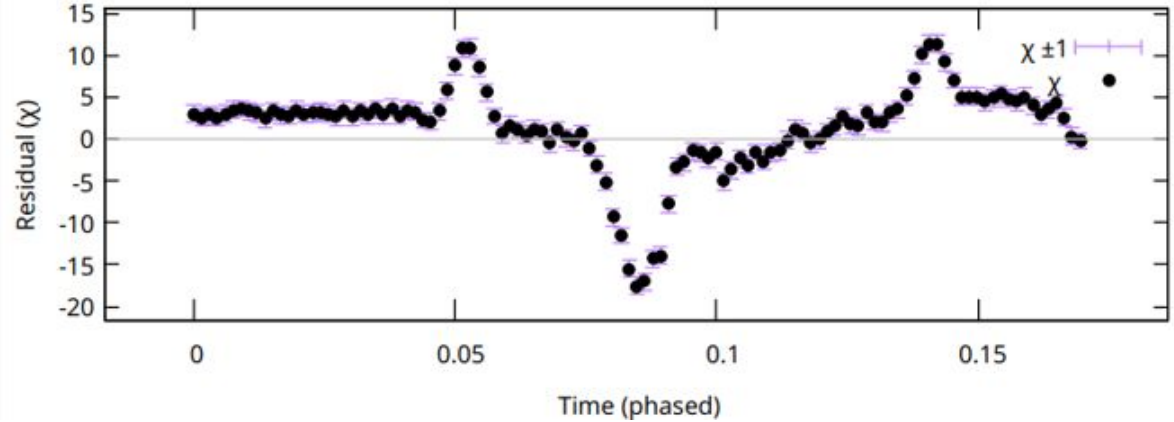
Model Setup



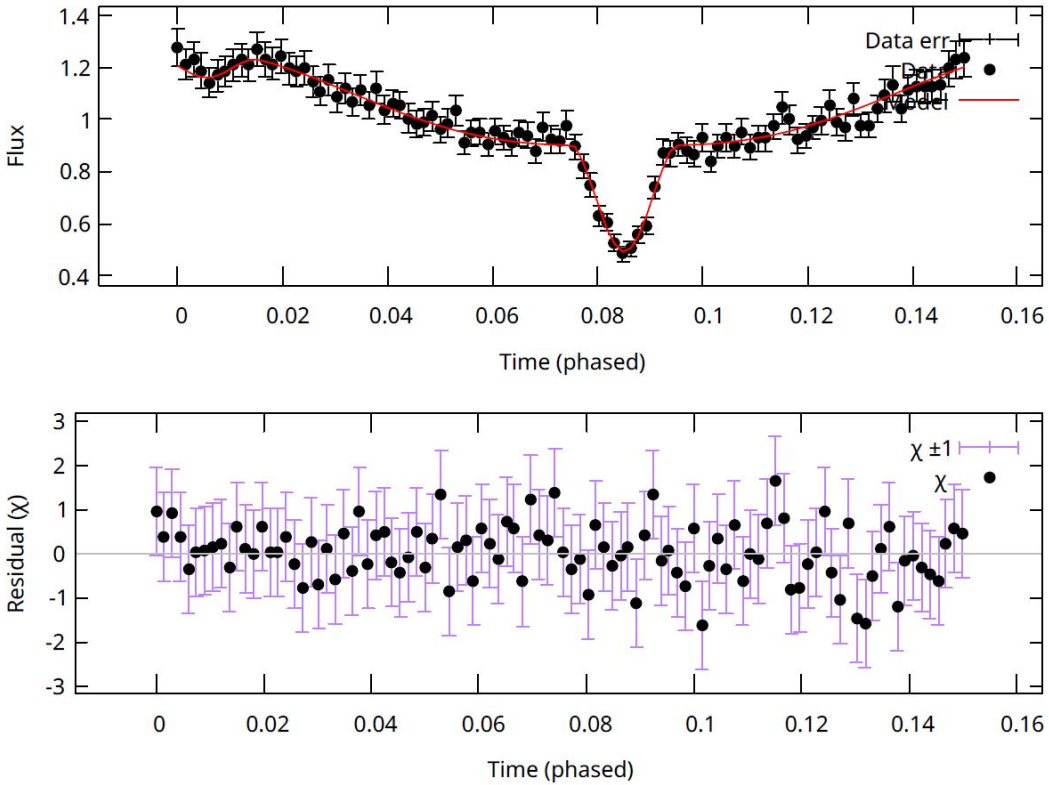
S. Müller, 2009

Running Fits- Initial Fit

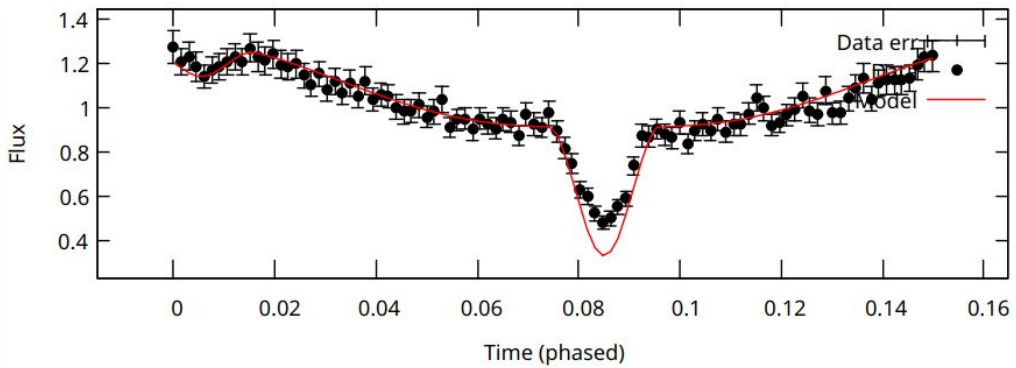


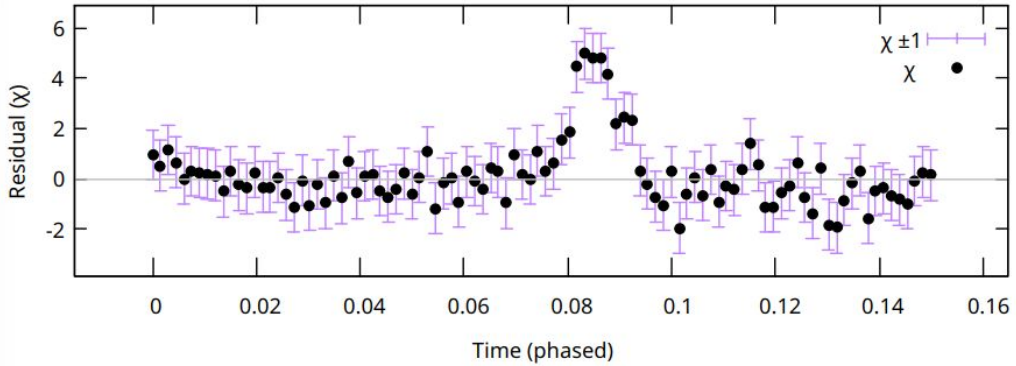


Running Fits- After Simplex

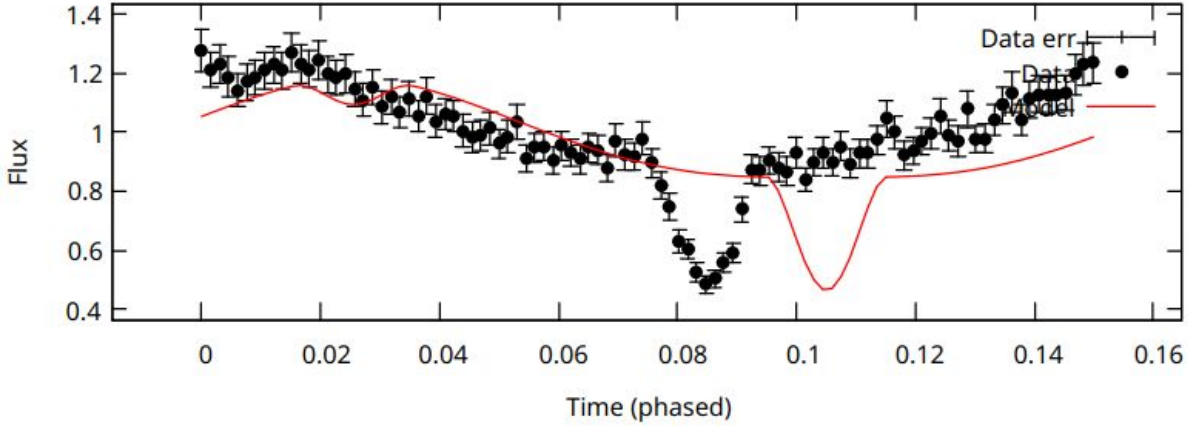


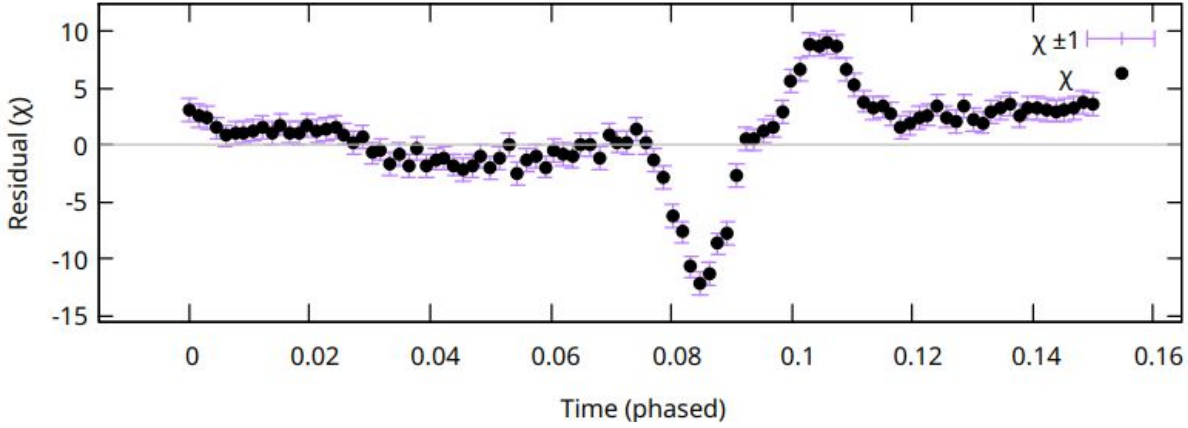
Slight Change in inclination



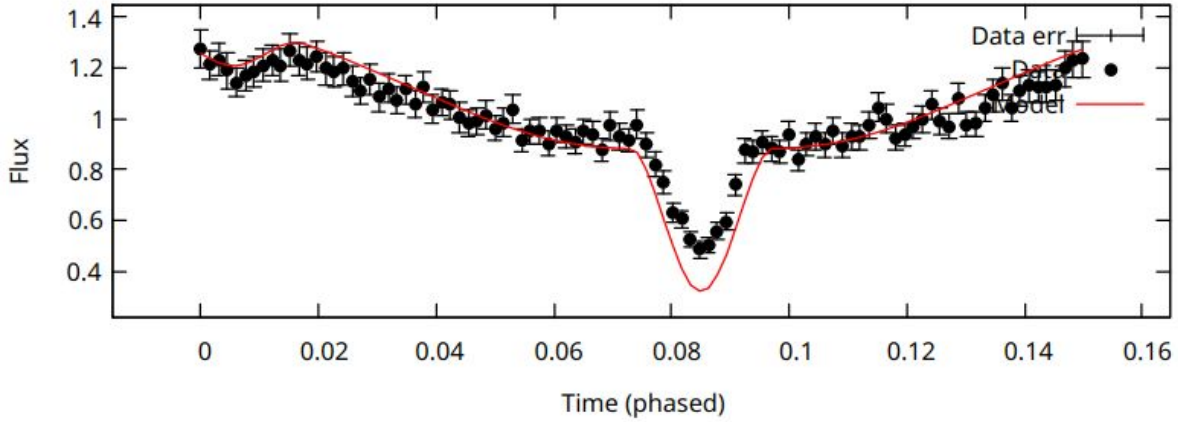


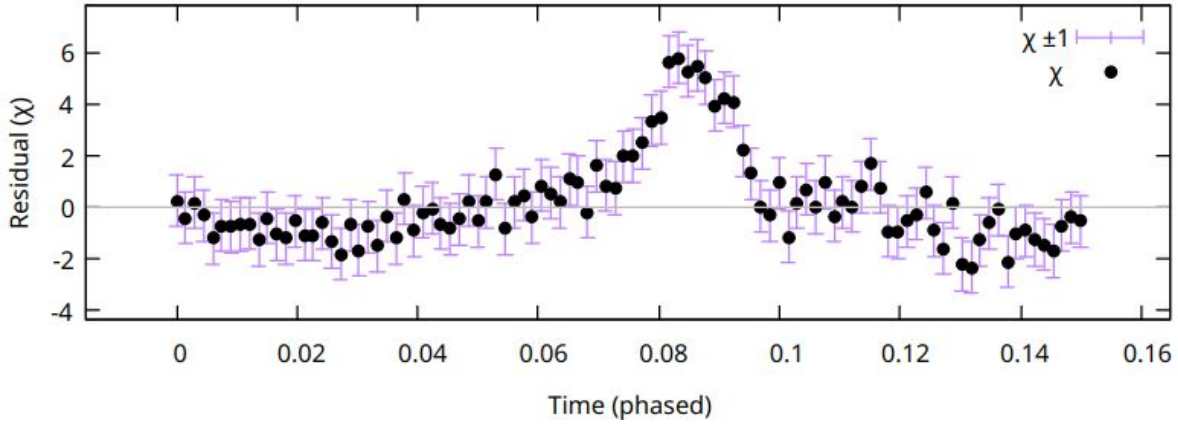
Slight change in t0



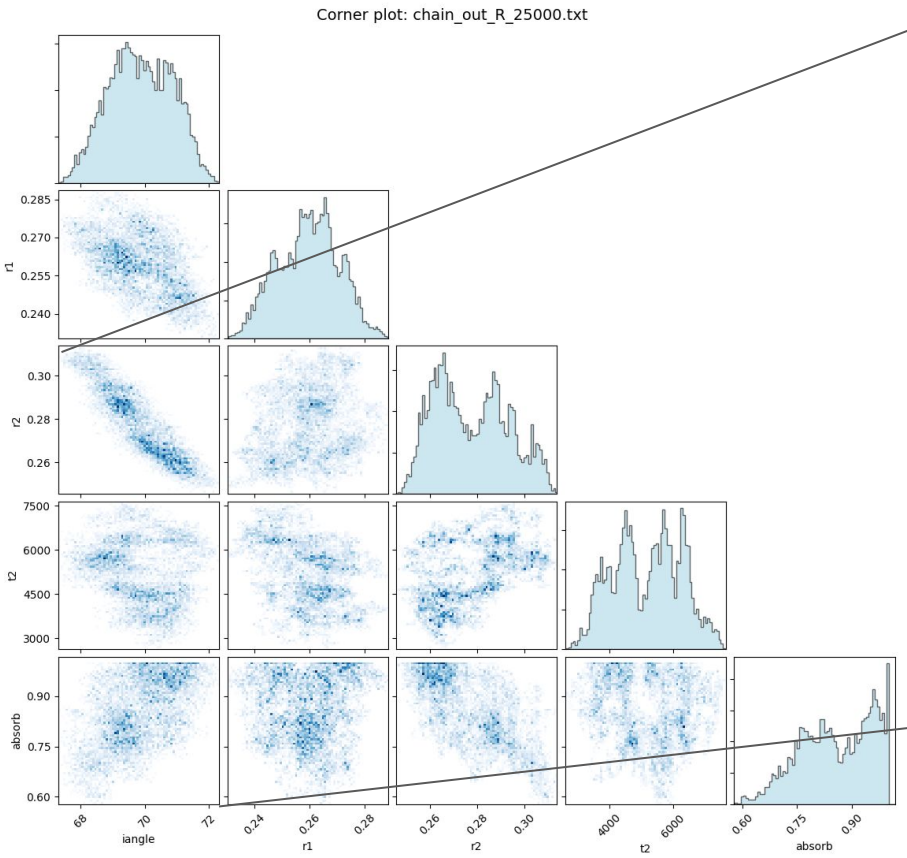


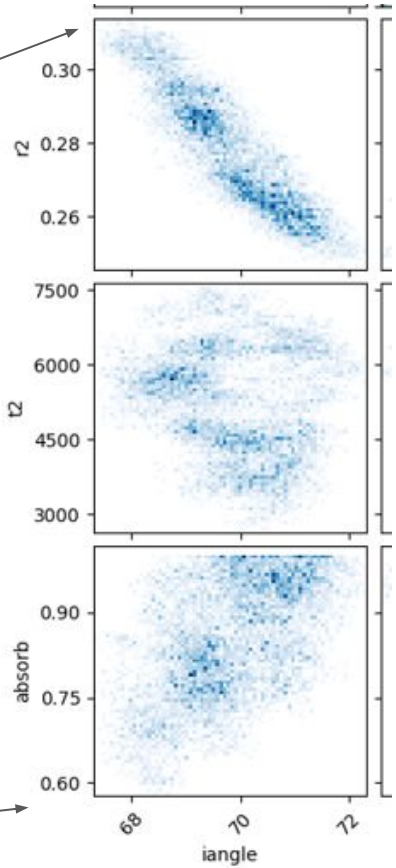
Slight change in r2





Corner Plots and Degeneracies



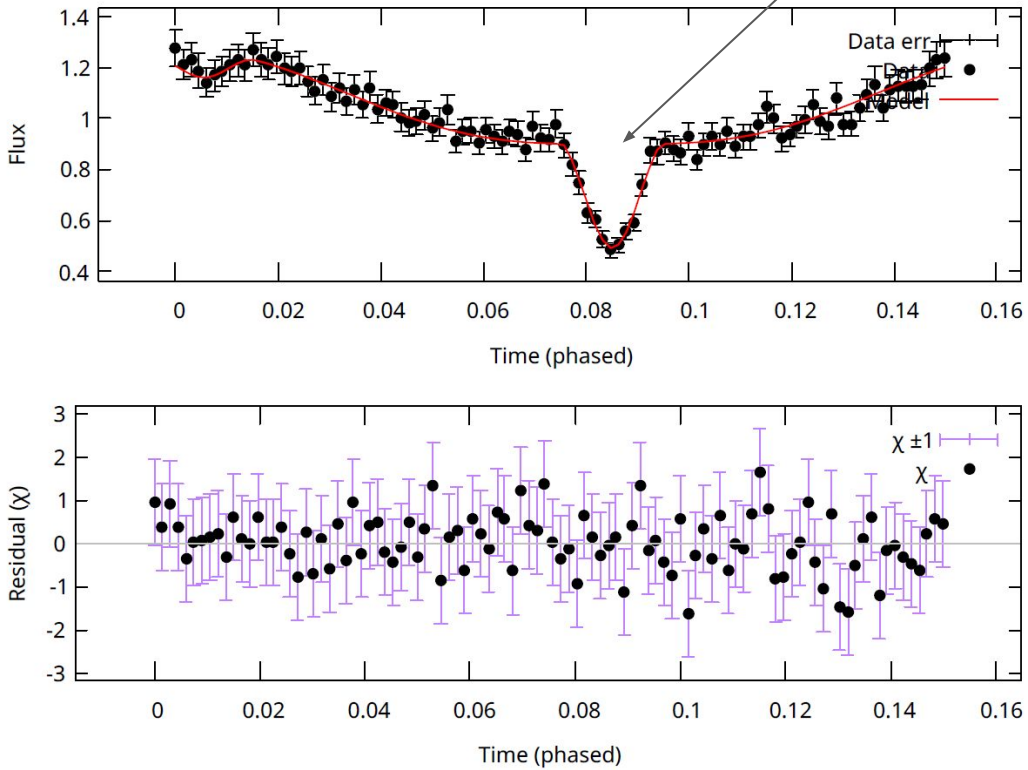


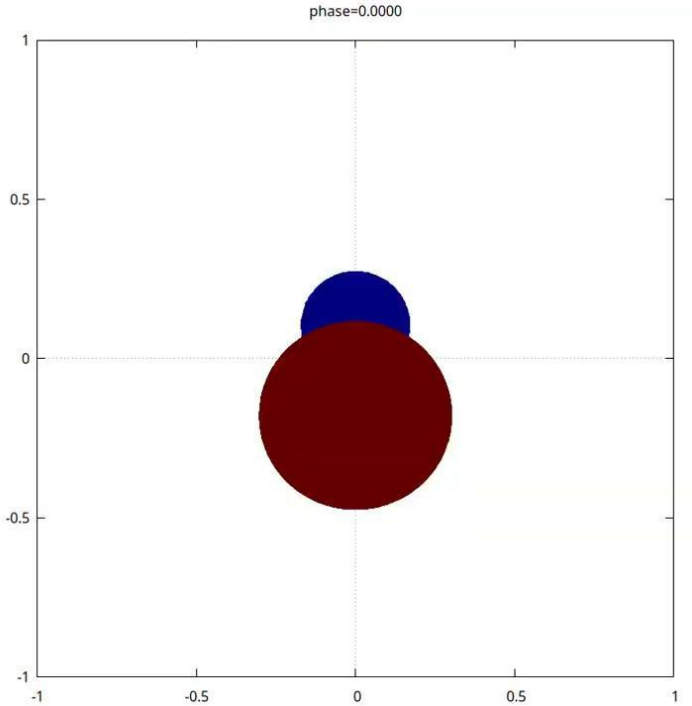
Results

Primary Eclipse

Target 3 - Gaia DR3 2010408220561381632

R - Filter





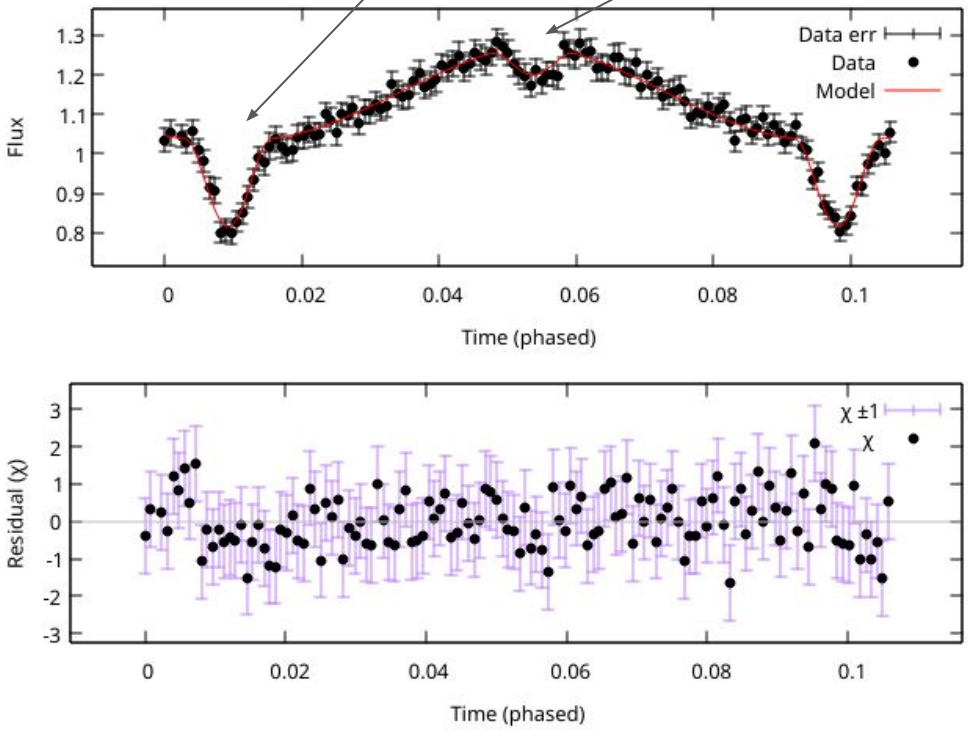
Mag - 17.61
Period - 0.159 d
Inclination - 75.3°
Companion Mass - 0.18 $M_\odot$
Companion Radius - 0.3 $R_\odot$
K value - 76.8 km/s

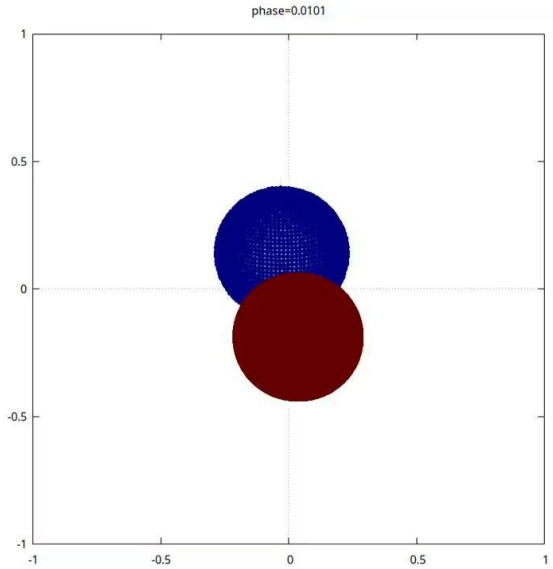
Results

Primary Eclipse

Secondary Eclipse

Target 1- Gaia DR3 2209063896962507520 ***R - Filter***



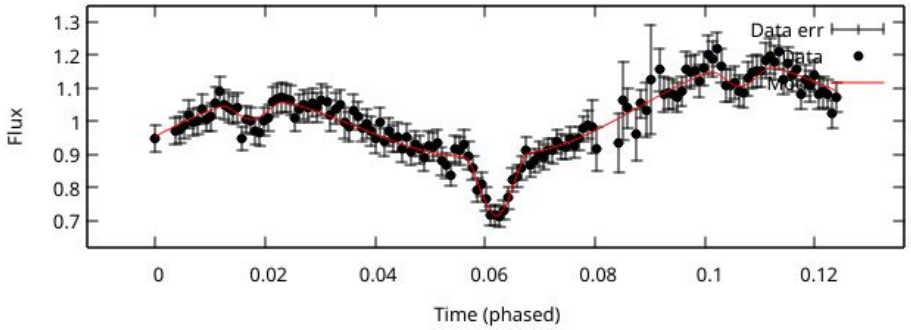


Mag - 17.37
Period - 0.089 d
Inclination - 70.4°
Companion Mass - 0.08 $M_{\odot}$
Companion Radius - 0.17 $R_{\odot}$
K value - 53.32 km/s

Results

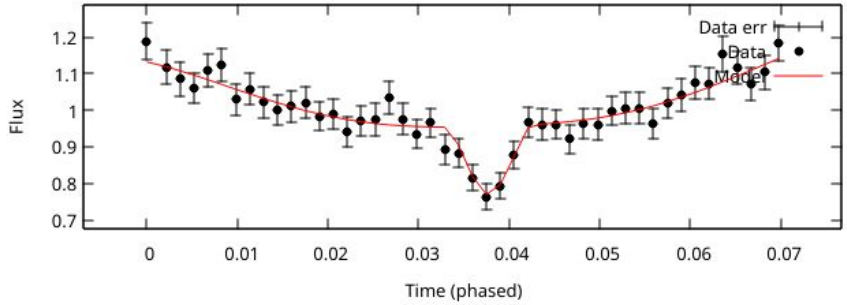
Target 1

I - Filter



- Change in Phase
- long phase range
- K value - 52.5 km/s

G -Filter

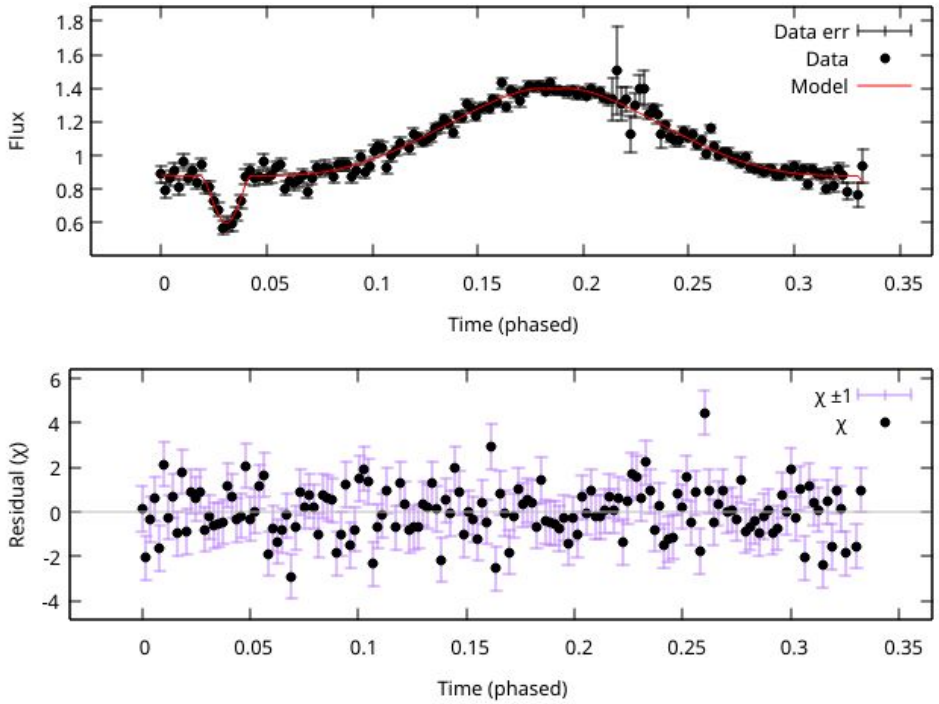


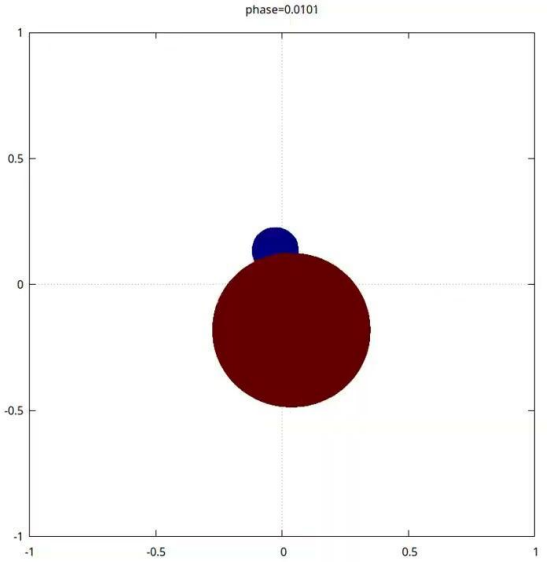
- Short phase range
- less data points
- K value - 49.07 km/s

Results

R - Filter

Target 2 - Gaia DR3 2202073408192045056





Mag -17.05
Period - 0.31 d
Inclination - 76.7°
Companion Mass - 0.32 $M_{\odot}$
K value - 113.3 km/s

Mass-Radius relation

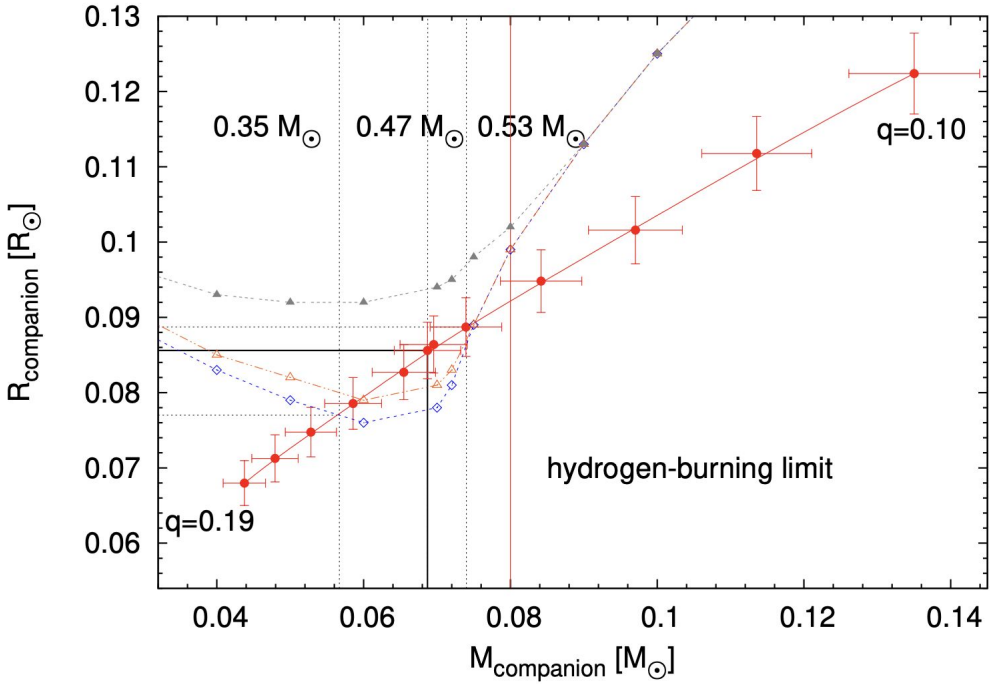
Assumptions for subdwarf:

Mass - 0.47 $M_\odot$
Radius - 0.167 $M_\odot$
Temp - 33,000K

Formula: $M \propto R^{\frac{10}{7}}$

$$f(x) = \frac{M_2^3 sin(i)^3}{(M_1 + M_2)^2} = \frac{PK^3}{2\pi G}$$

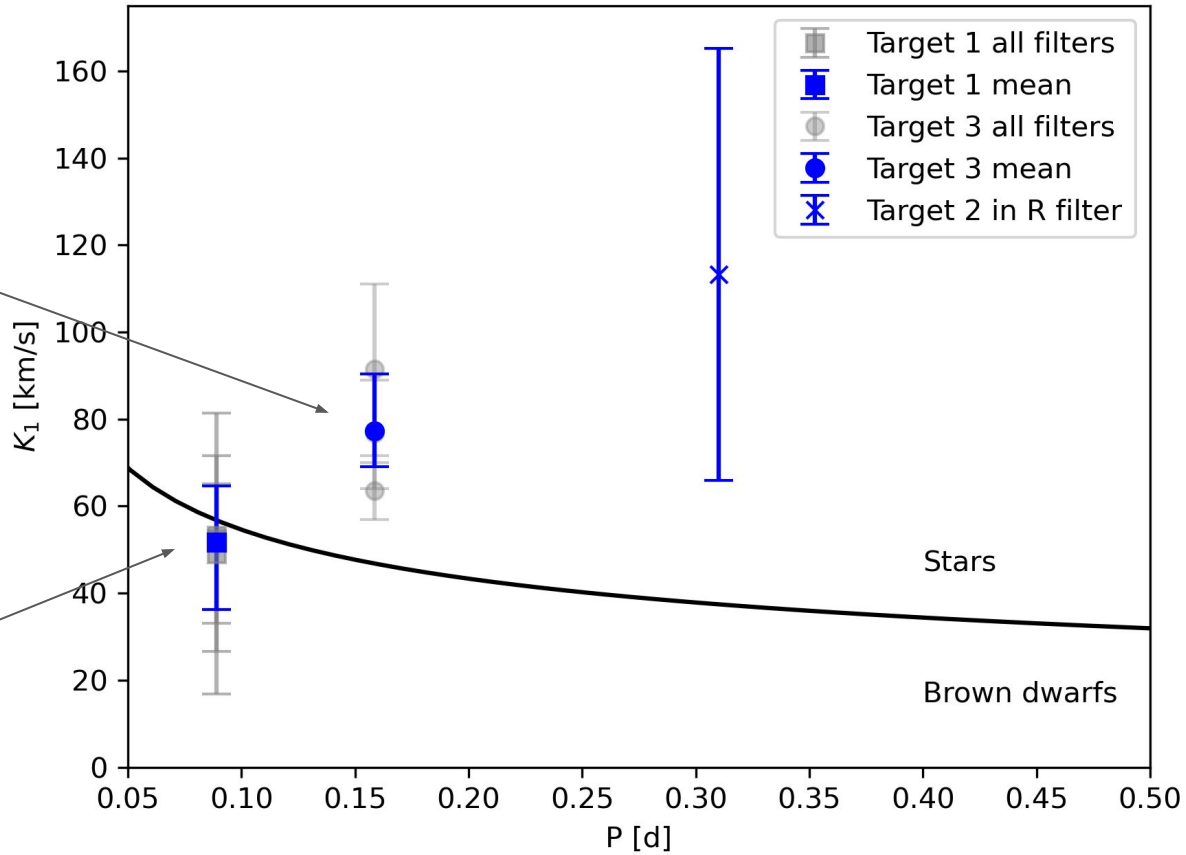
obtained ‘K’ value



Results

High K value -
main sequence star

Low K value -
brown dwarf

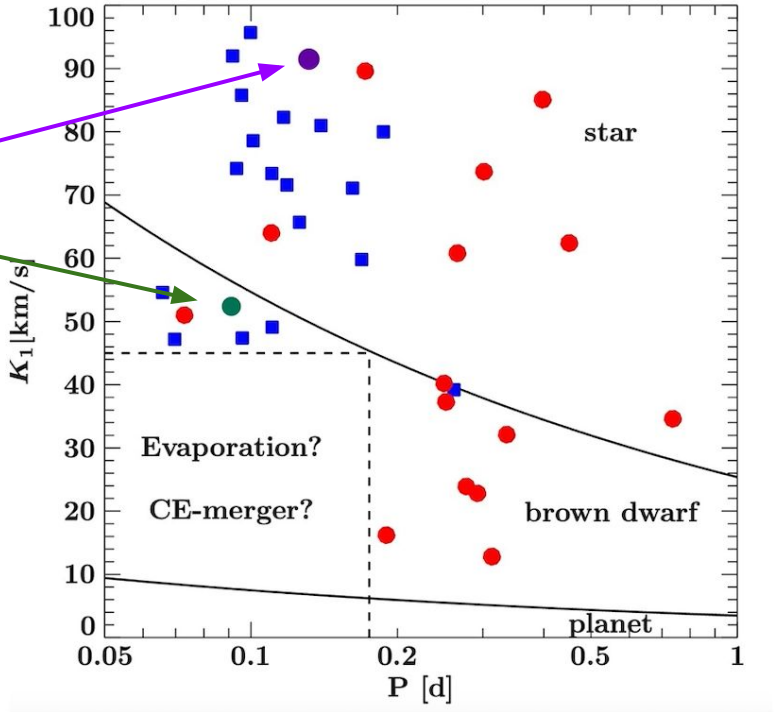


Results

Target 2

Target 3

Target 1



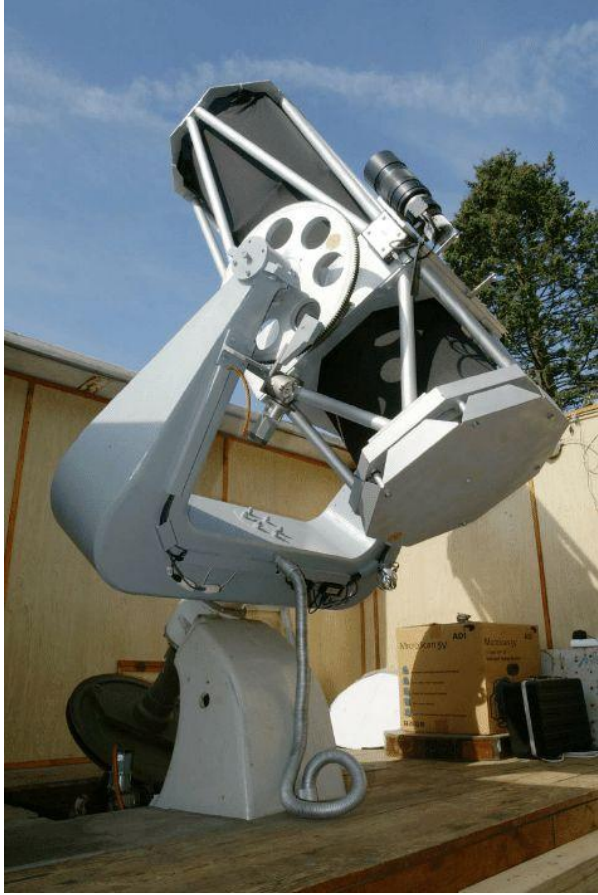
Conclusion

- Target 1 - Close Binary System

  Strong Reflection Effect.

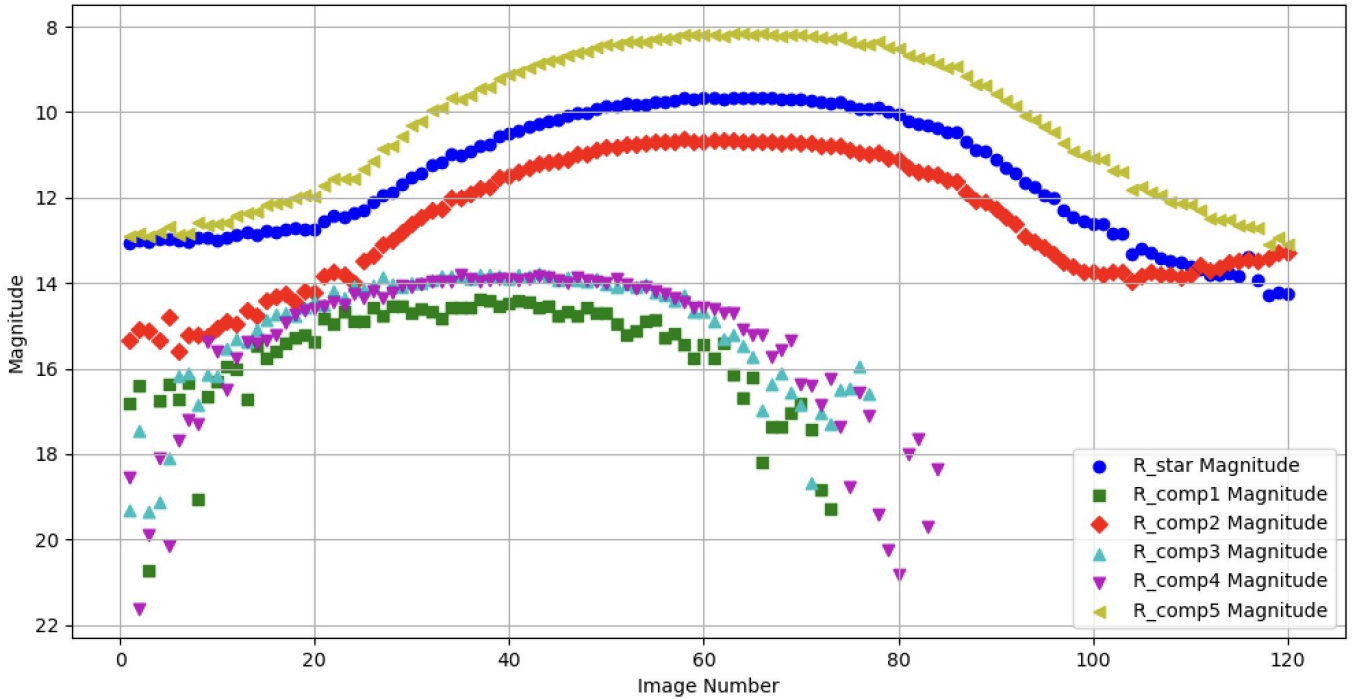
- Target 2 & 3 showed clear primary eclipse.
- Target 2 has a high mass companion.
- Stellar companion and

  Brown dwarf companion was found.

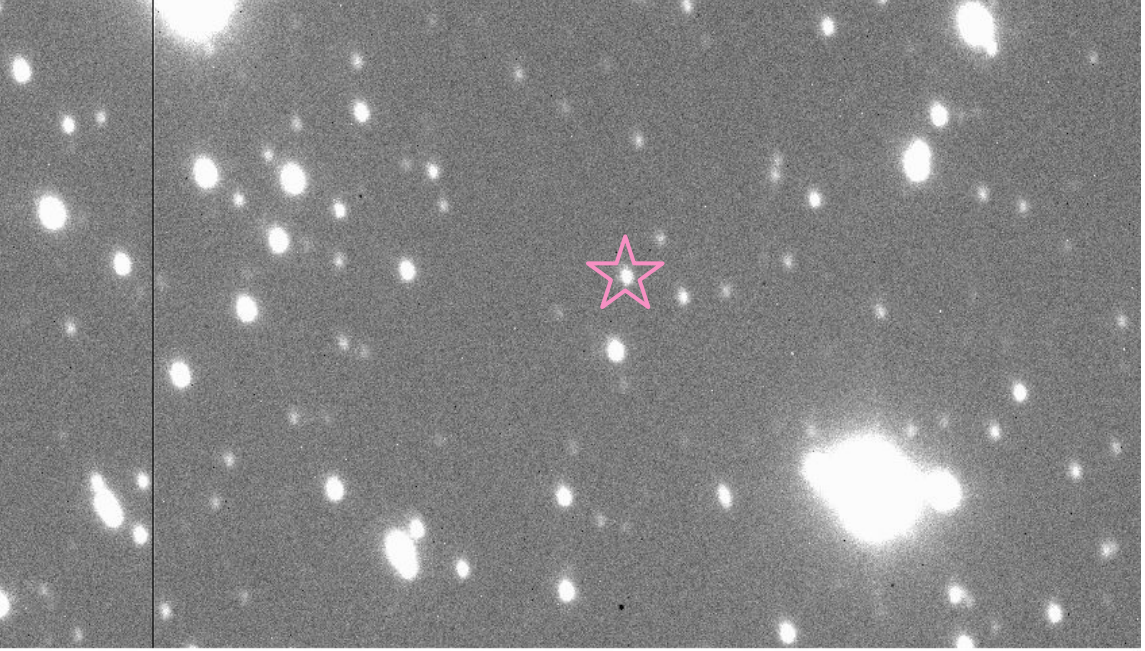


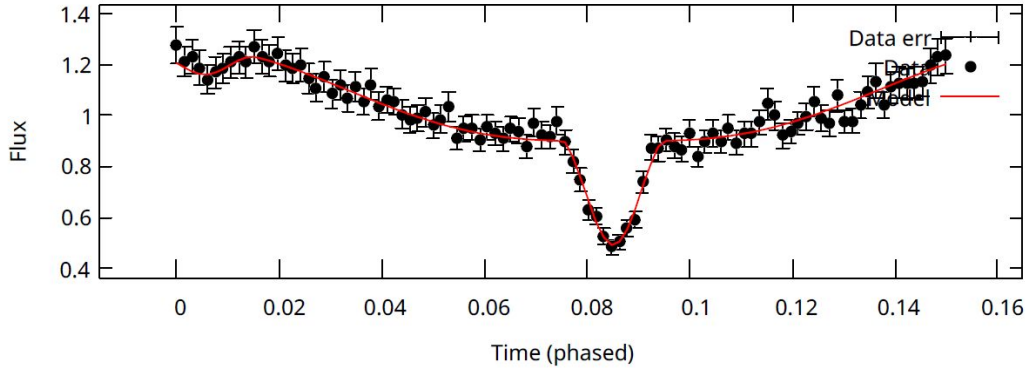
D50 telescope

Outtakes :)

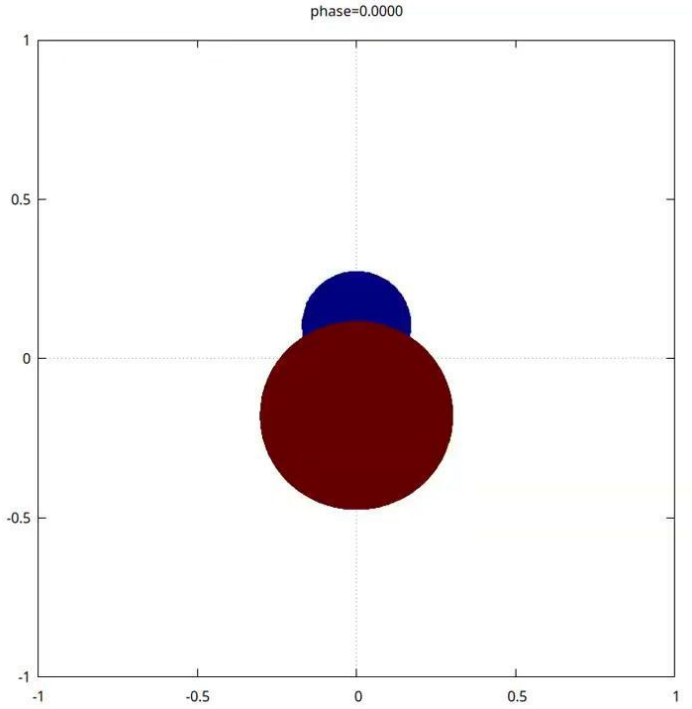


Looks like the flat (and dark possibly) correction did not work





Thank you for your attention!



Citations

[1]:https://www.astro.sk/iau100/bezovec/wp-content/uploads/2021/09/13-Bartkova-The-reflection-effect-in-binary-systems.pdf

[2]:https://stel.asu.cas.cz/en/wp-content/uploads/2021/09/variable_binaries.pdf

[3]:https://stel.asu.cas.cz/public/files/Presentations/Photometric%20variability%20of%20binaries.pdf

[4]: Heber, U. (2009). Hot Subdwarf stars. *Annual Review of Astronomy and Astrophysics*, *47*(1), 211–251. https://doi.org/10.1146/annurev-astro-082708-101836