Lightcurve analysis of HW Vir stars

Workshop on Observational Techniques

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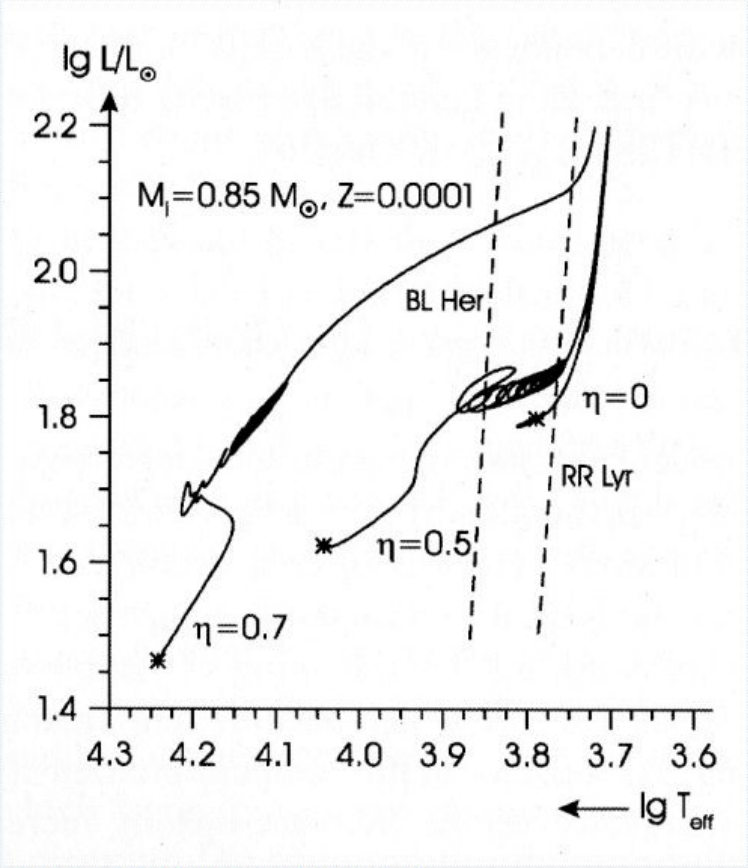
Evolutionary Stages of Low Mass stars

- Hydrogen exhaustion
- Entering red giant phase
- Helium flash.

Horizontal branch stars



Kippenhahn, Weigert & Weiss 2012

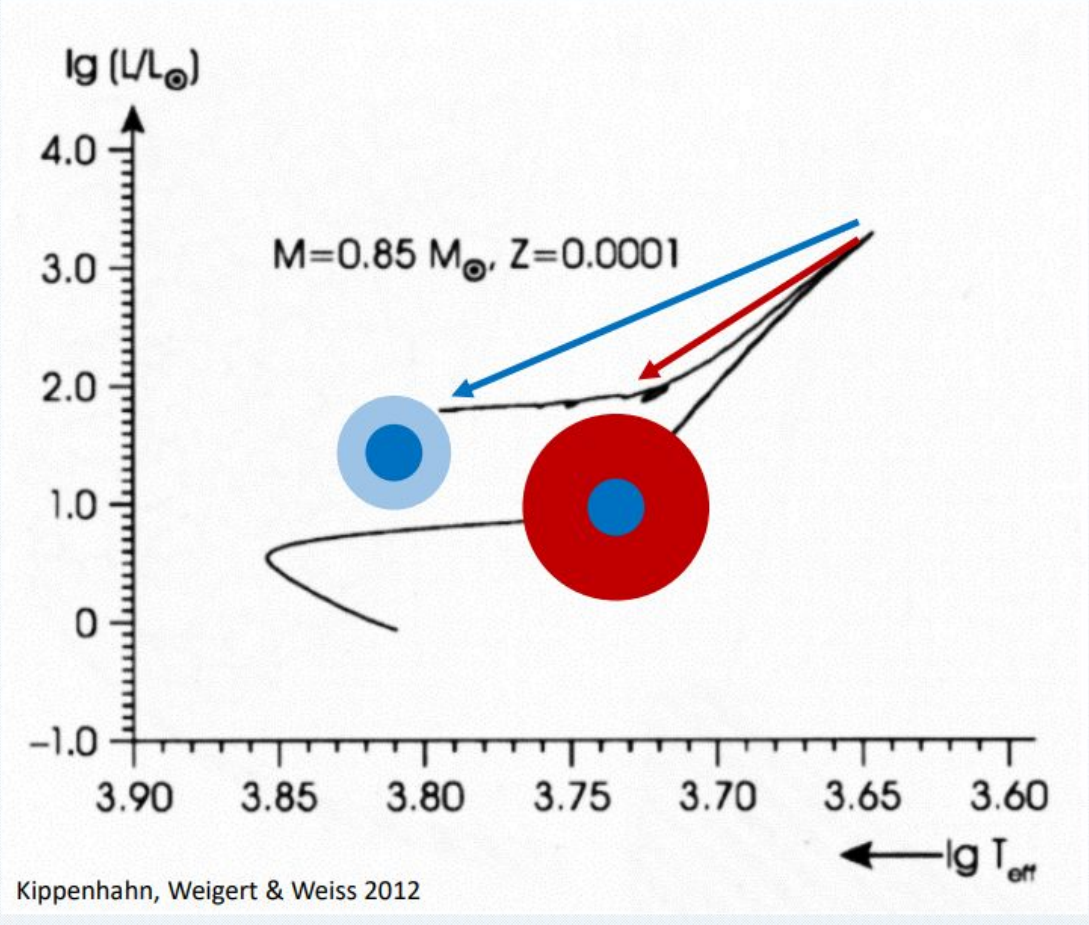
Horizontal Branch stars

→ **Different mass loss η on the RGB leads to different thickness of the hydrogen envelopes**

→ **Mass of the He-core is constant** $(\sim 0.48\ M_\odot)$

→ **Diverse types of HB stars**

Horizontal branch stars



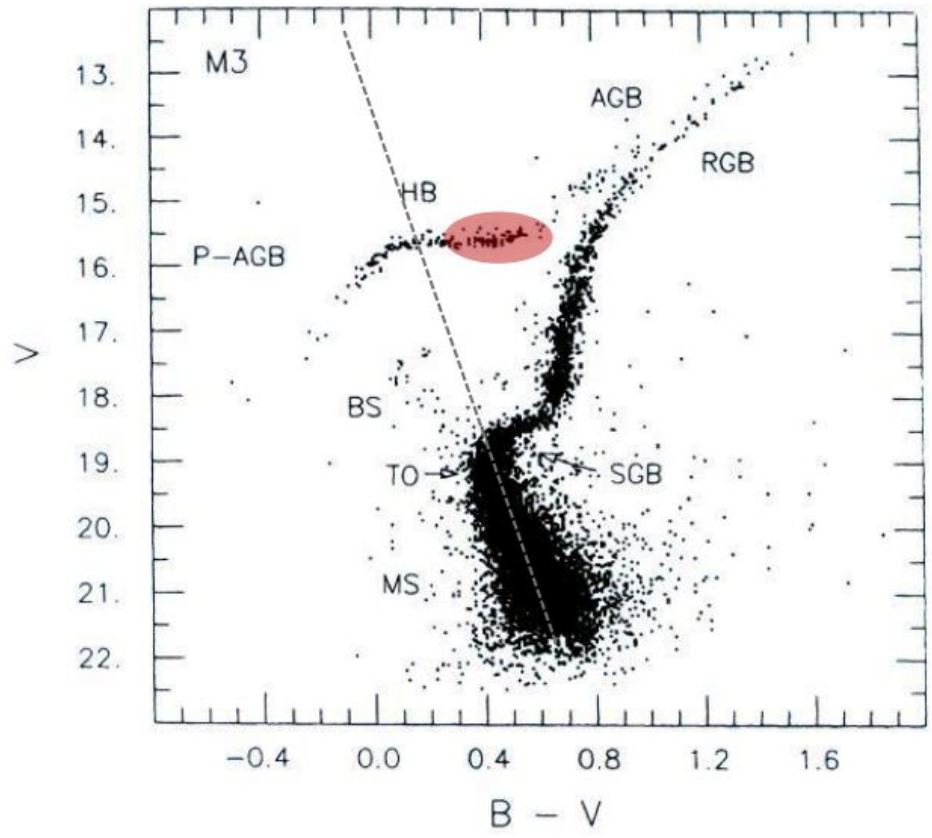
Kippenhahn, Weigert & Weiss 2012

Horizontal Branch stars

→ The thinner the hydrogen envelope, the bluer the HB star

→ Morphology of HB depends on metallicity and age

Horizontal branch stars



Renzini & Fusi Pecci 1988, ARA&A, 26, 199

Red Horizontal Branch (RHB) stars

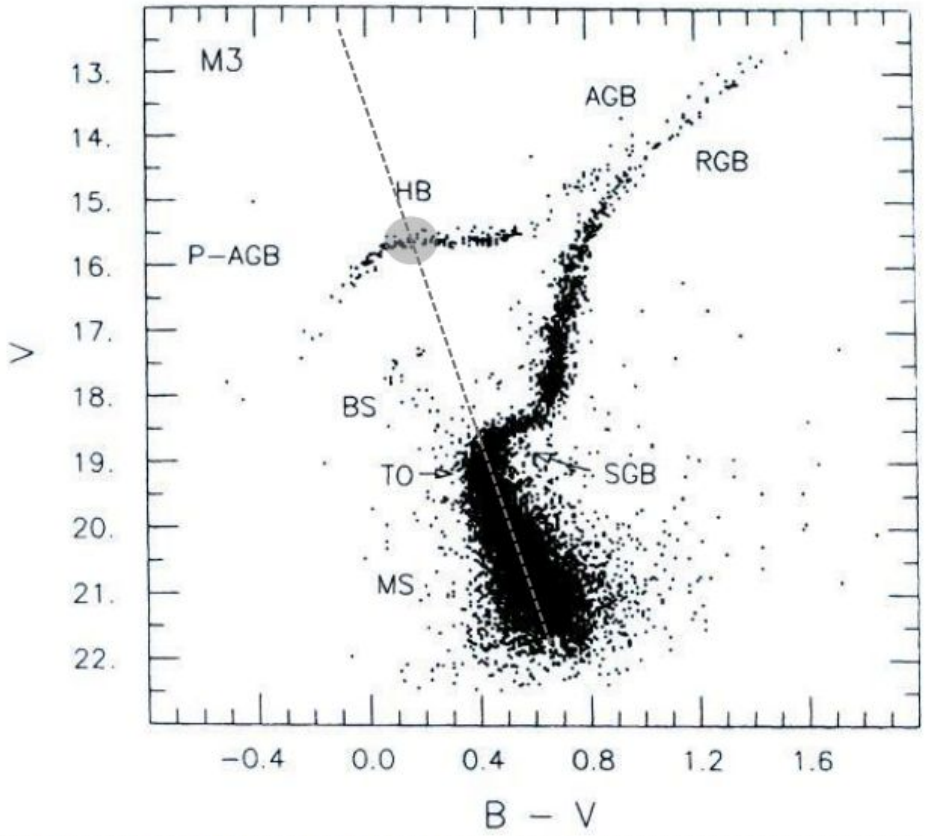
→ Redward of the MS

→ (Sub-)giants

→ Spectral types K, G

→ metal-poor, old population

Horizontal branch stars



RR Lyr stars

→ (Sub-)giants

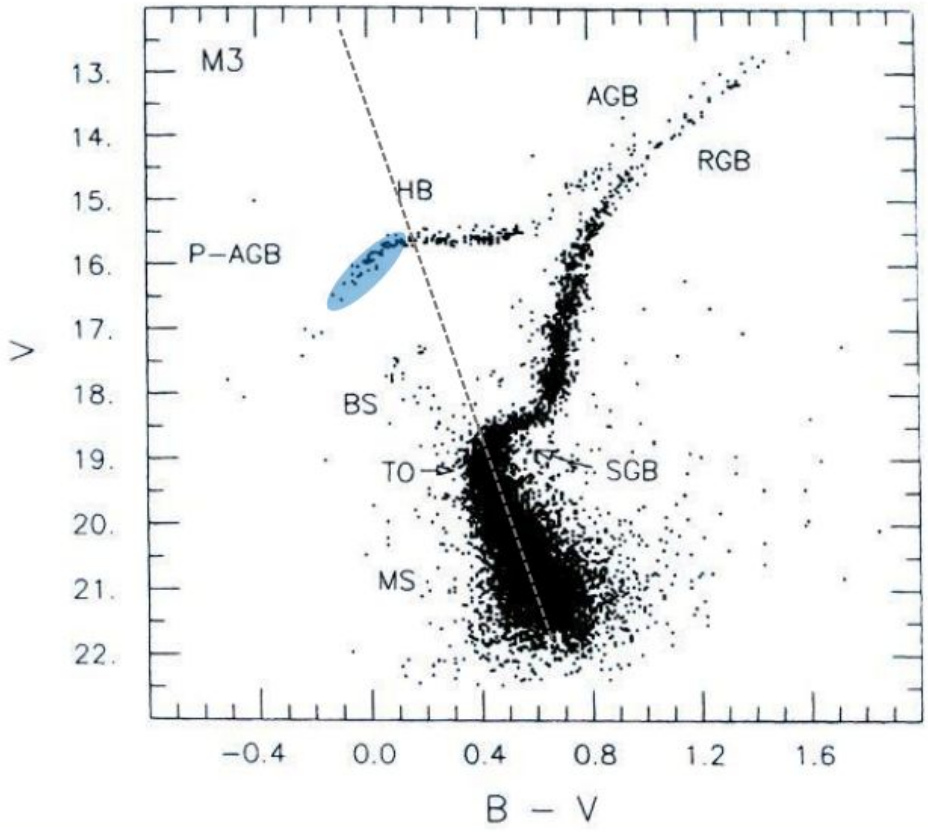
→ Spectral types F

→ metal-poor, old population

→ Pulsators

Renzini & Fusi Pecci 1988, ARA&A, 26, 199

Horizontal branch stars



Renzini & Fusi Pecci 1988, ARA&A, 26, 199

Blue Horizontal Branch (BHB) stars

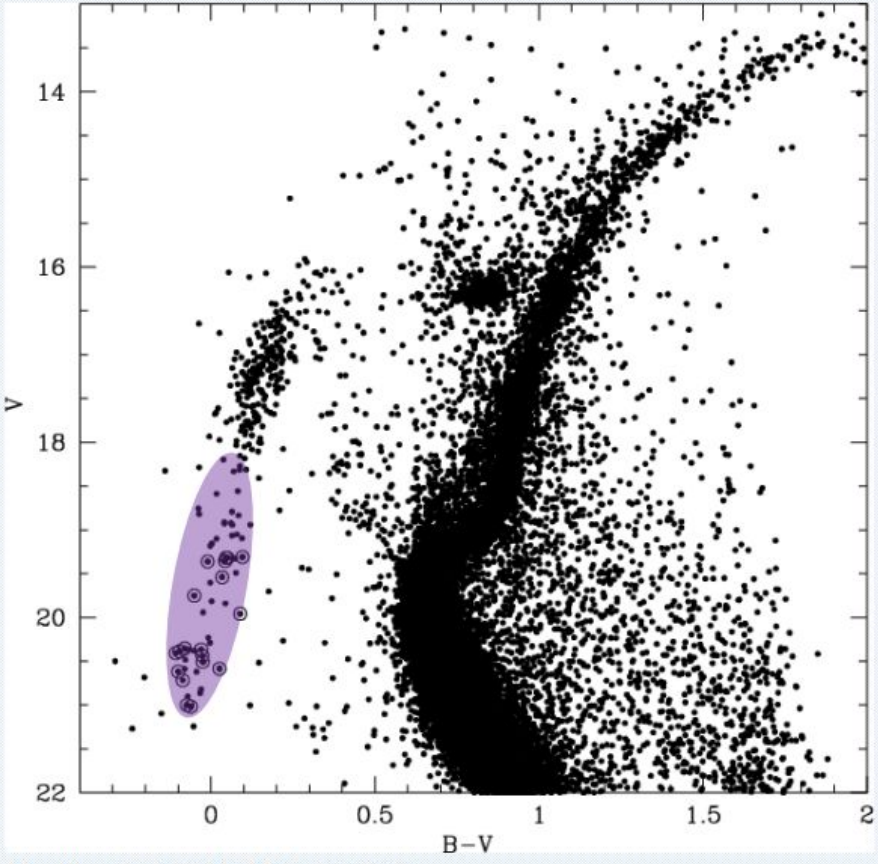
→ Blueward of the MS

→ (Sub-)dwarfs

→ Spectral types A, B (HBA, HBB)

→ chemically peculiar

Horizontal branch stars



Moehler et al. 2004, A&A, 415, 313

Extreme Horizontal Branch (EHB) stars

→ Subdwarfs

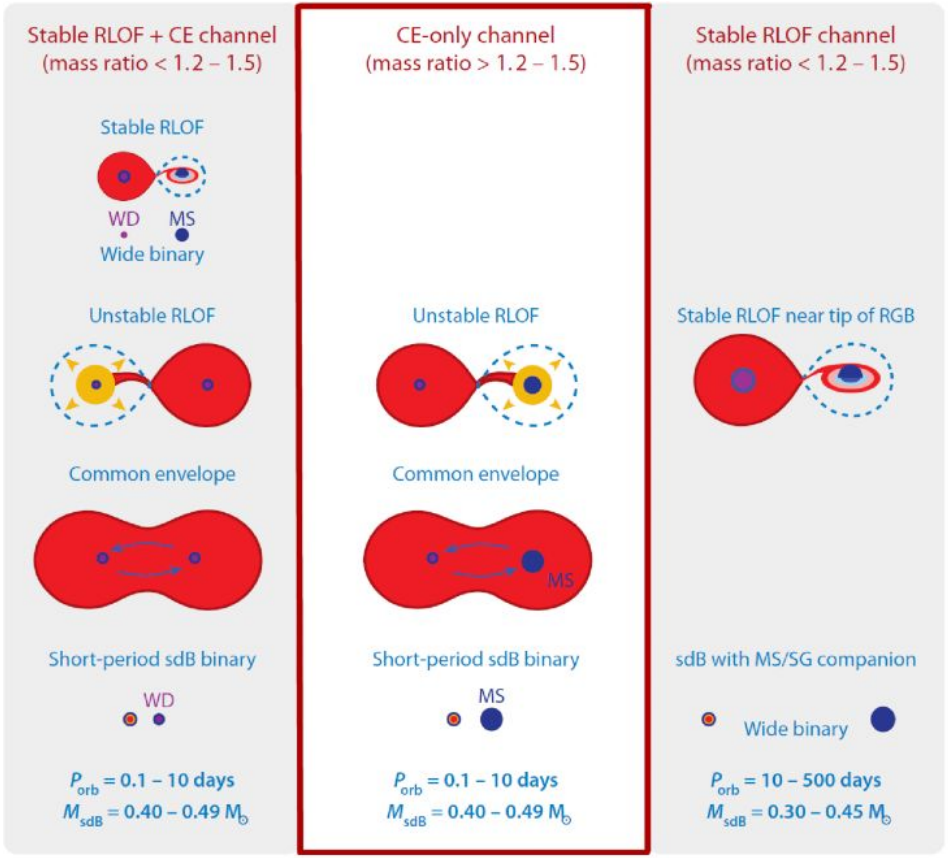
→ Spectral types O, B (sdO, sdB)

→ Extremely thin hydrogen envelopes, **no H-shell burning**

➔ **Fontaine et al. 2012 observed mass distribution of sdBs is 0.47M⊙**

Subdwarf B star and the Formation Channels

- Core helium burning stars with extremely thin hydrogen envelopes (< 0 .02 M⊙).
- Masses around 0 . 5 M⊙ (Heber 1986; Saffer et al. 1994).
- About half of the sdB stars reside in close binaries with periods ranging from ~ 0.1 d to ~ 30 d (Maxted et al. 2001; Napiwotzki et al, 2004a).
- Based on an interpretation of their evolutionary state, sdB stars are also sometimes referred to as extreme horizontal branch stars.
- The common envelope (CE) ejection channel, the stable Roche lobe overflow (RLOF) channel and the double helium white dwarfs (WDs) merger channel.



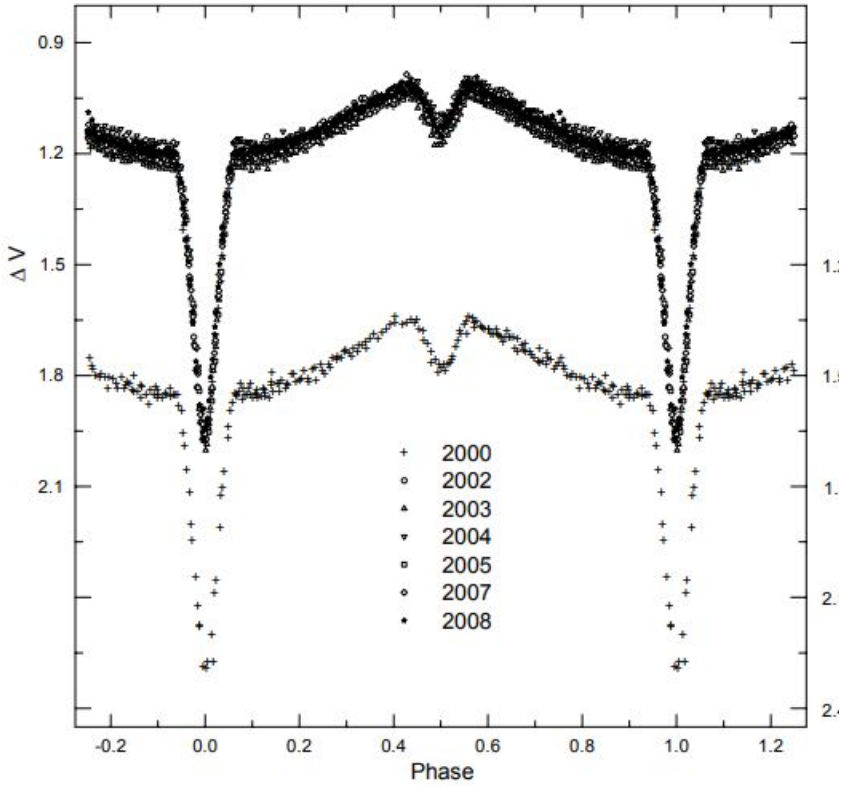
Han et al. (2002,2003)

Why are they important?

- Pulsating sdB stars (Kilkenny et al. 1999) -Standard candle for distance determinations.
- Constrain the ages of the oldest galaxies.
- sdB stars are exotic objects because of their thin hydrogen-rich envelopes.
- Improve our understanding of the theory of stellar and binary evolution.

HW Virginis systems

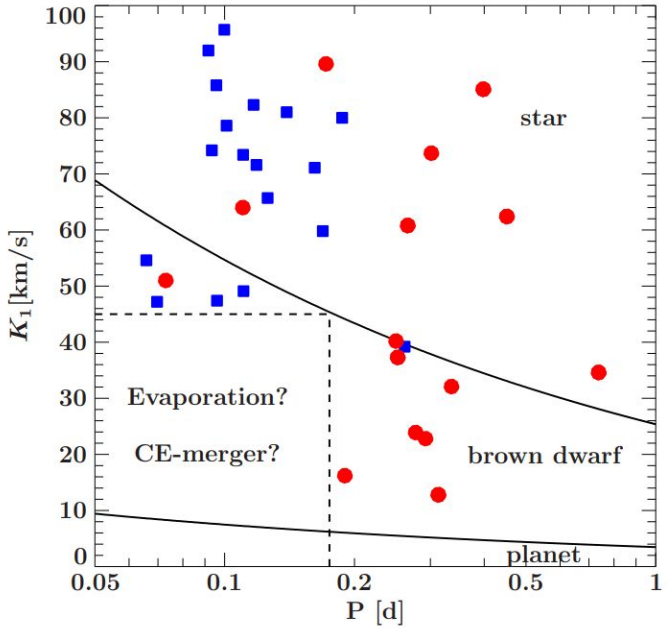
- eclipsing binaries consisting of sdB and cool, low mass stellar or substellar companion
- 20 HW Vir systems published
- very short period ~ 1.5-6 h (separation ~ 1 $R_\odot$)
- post common envelope system
- only sdB visible in spectrum
- huge reflection effect



Lightcurve of HW Virginis
(Lee et al. 2009)

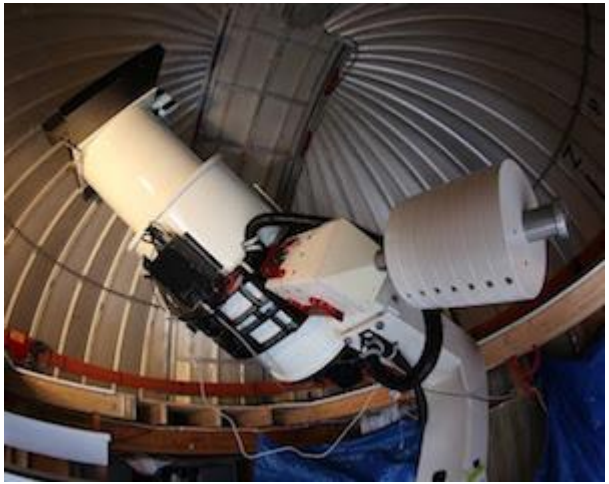
Aim of the project

- Study the lightcurve of the HW Vir systems and determine the parameters of the binary.
- Minimum companion masses of hot subdwarfs v
- better understanding of the CE phase and the re



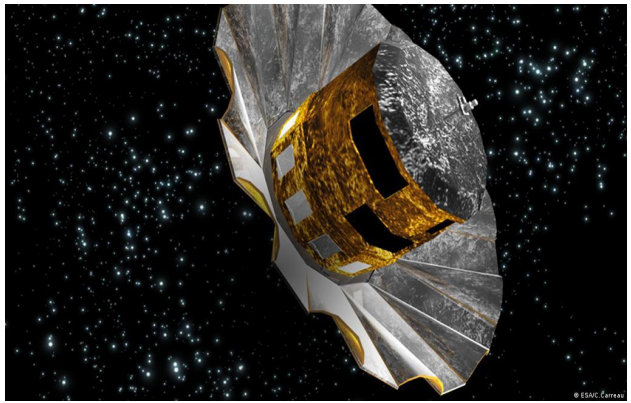
Schaffenroth et al. 2019 in press

Target catalogue



ATLAS(1)

ZTF(2)



GAIA(3)

1.Crossmatching

2. subset with RA & DEC

(31 August -21march)/365 *24h=10h 39 min

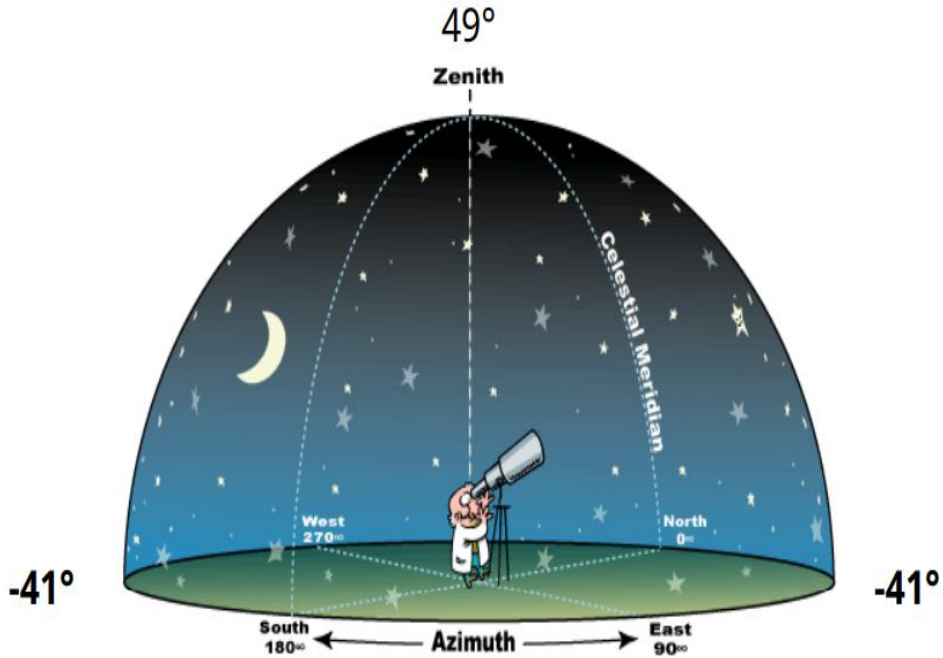
10h 39 min + 12 h = 22h 35 min

And night period is 12h

16h 35 min < a < 28h 35 min

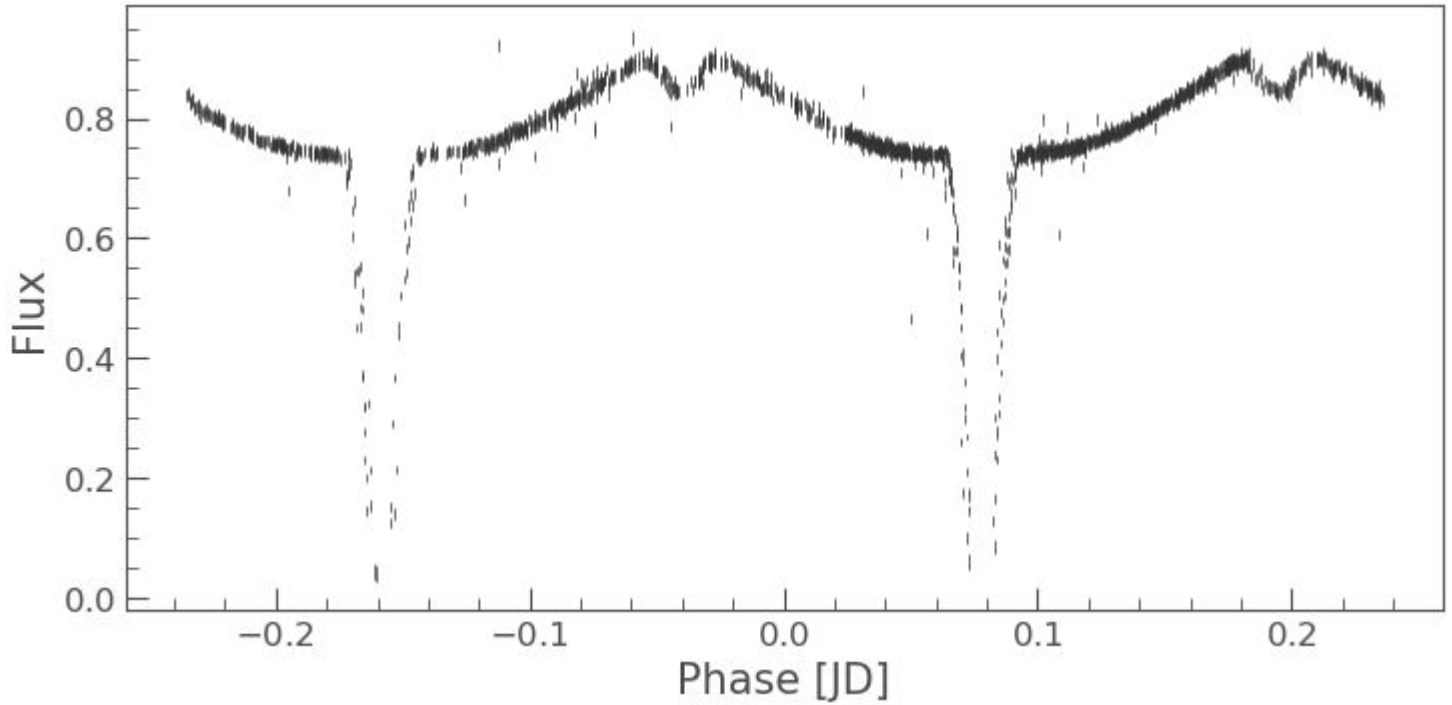
observable -> (ra_1 > 249 || ra_1 < 68)

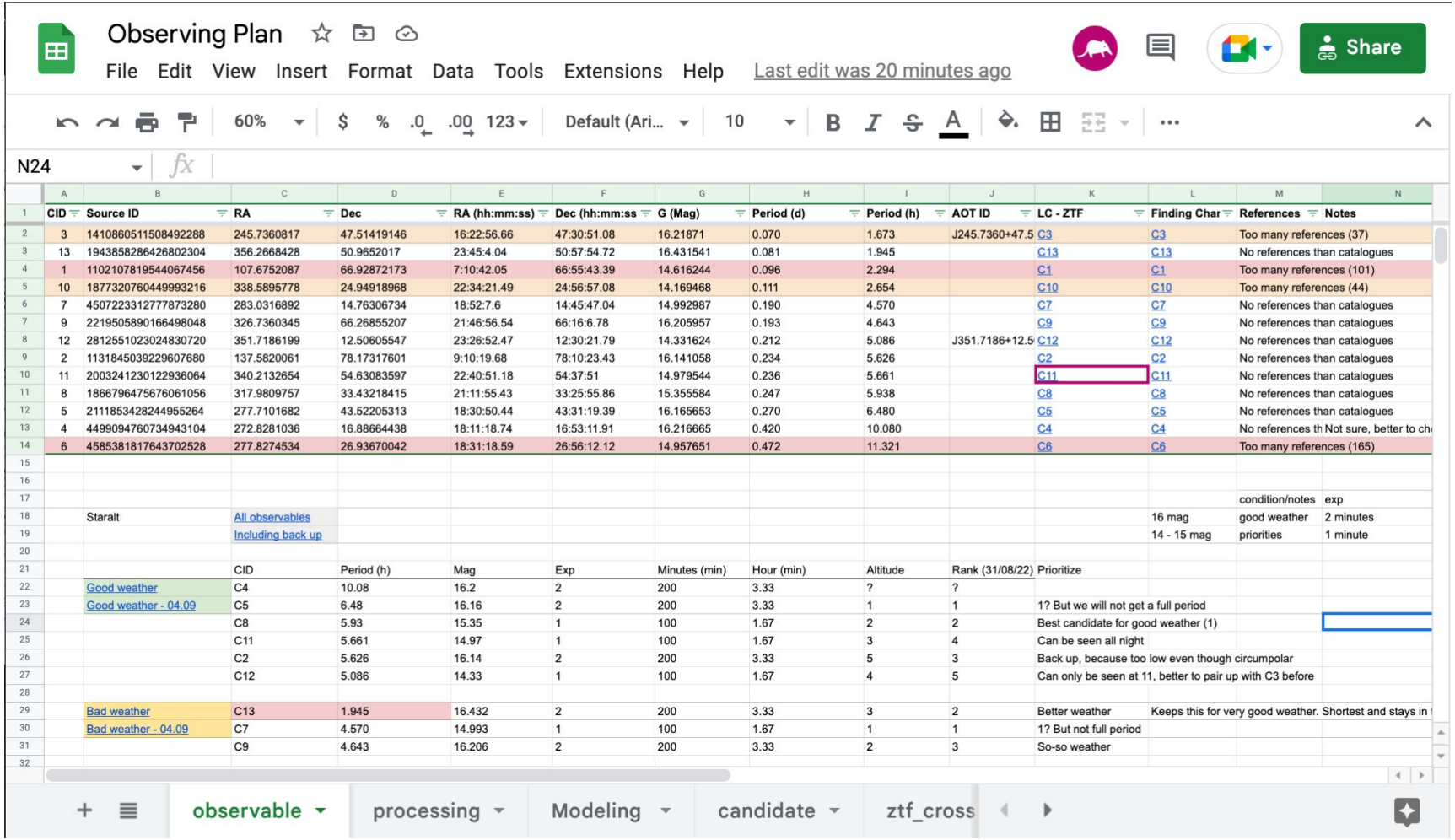
DEC > -11



Max presentation

ZTF lightcurve





Observing Plan

File Edit View Insert Format Data Tools Extensions Help Last edit was 20 minutes ago

Share

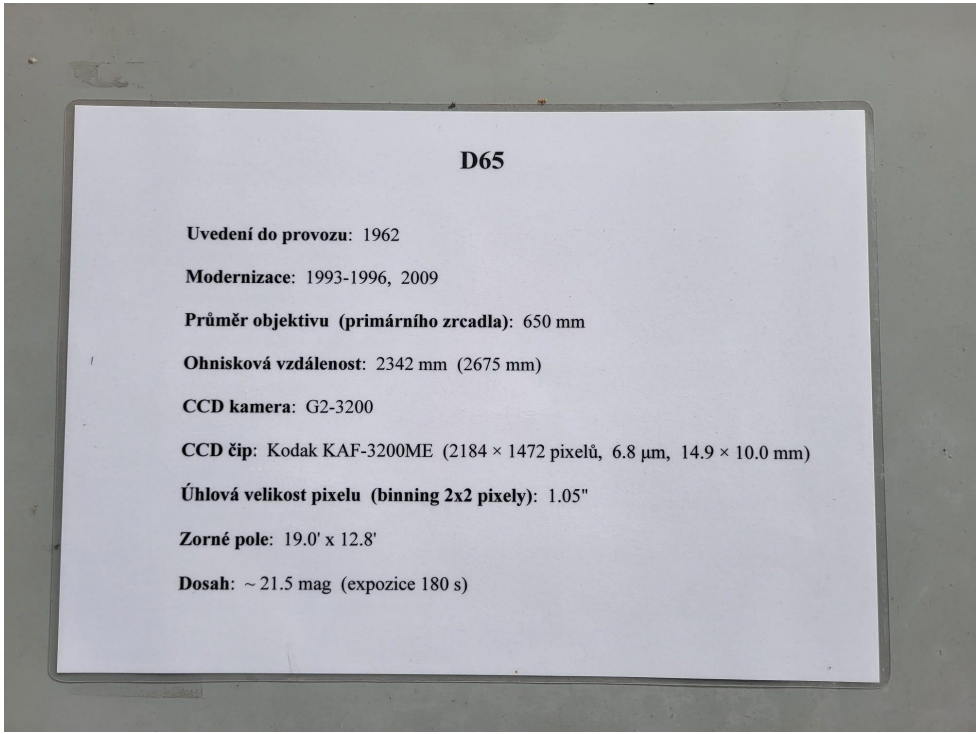
N24

CID	Source ID	RA	Dec	RA (hh:mm:ss)	Dec (hh:mm:ss	G (Mag)	Period (d)	Period (h)	AOT ID	LC - ZTF	Finding Char	References	Notes
3	1410860511508492288	245.7360817	47.51419146	16:22:56.66	47:30:51.08	16.21871	0.070	1.673	J245.7360+47.5	C3	C3	Too many references (37)	
13	1943858286426802304	356.2668428	50.9652017	23:45:4.04	50:57:54.72	16.431541	0.081	1.945		C13	C13	No references than catalogues	
1	1102107819544067456	107.6752087	66.92872173	7:10:42.05	66:55:43.39	14.616244	0.096	2.294		C1	C1	Too many references (101)	
10	1877320760449993216	338.5895778	24.94918968	22:34:21.49	24:56:57.08	14.169468	0.111	2.654		C10	C10	Too many references (44)	
7	4507233312777873280	283.0316892	14.76306734	18:52:7.6	14:45:47.04	14.992987	0.190	4.570		C7	C7	No references than catalogues	
9	2219505890166498048	326.7360345	66.26855207	21:46:56.54	66:16:6.78	16.205957	0.193	4.643		C9	C9	No references than catalogues	
12	2812551023024830720	351.7186199	12.50605547	23:26:52.47	12:30:21.79	14.331624	0.212	5.086	J351.7186+12.5	C12	C12	No references than catalogues	
2	1131845039229607680	137.5820061	78.17317601	9:10:19.68	78:10:23.43	16.141058	0.234	5.626		C2	C2	No references than catalogues	
11	2003241230122936064	340.2132654	54.63083597	22:40:51.18	54:37:51	14.979544	0.236	5.661		C11	C11	No references than catalogues	
8	1866796475676061056	317.9809757	33.43218415	21:11:55.43	33:25:55.86	15.355584	0.247	5.938		C8	C8	No references than catalogues	
5	2111853428244955264	277.7101682	43.52205313	18:30:50.44	43:31:19.39	16.165653	0.270	6.480		C5	C5	No references than catalogues	
4	4499094760734943104	272.8281036	16.88664438	18:11:18.74	16:53:11.91	16.216665	0.420	10.080		C4	C4	No references th	Not sure, better to ch
6	4585381817643702528	277.8274534	26.93670042	18:31:18.59	26:56:12.12	14.957651	0.472	11.321		C6	C6	Too many references (165)	

											condition/notes	exp
Staralt	All observables									16 mag	good weather	2 minutes
	Including back up									14 - 15 mag	priorities	1 minute

	CID	Period (h)	Mag	Exp	Minutes (min)	Hour (min)	Altitude	Rank (31/08/22)	Prioritize		
Good weather	C4	10.08	16.2	2	200	3.33	?	?			
Good weather - 04.09	C5	6.48	16.16	2	200	3.33	1	1	1? But we will not get a full period		
	C8	5.93	15.35	1	100	1.67	2	2	Best candidate for good weather (1)		
	C11	5.661	14.97	1	100	1.67	3	4	Can be seen all night		
	C2	5.626	16.14	2	200	3.33	5	3	Back up, because too low even though circumpolar		
	C12	5.086	14.33	1	100	1.67	4	5	Can only be seen at 11, better to pair up with C3 before		
Bad weather	C13	1.945	16.432	2	200	3.33	3	2	Better weather	Keeps this for very good weather. Shortest and stays in	
Bad weather - 04.09	C7	4.570	14.993	1	100	1.67	1	1	1? But not full period		
	C9	4.643	16.206	2	200	3.33	2	3	So-so weather		

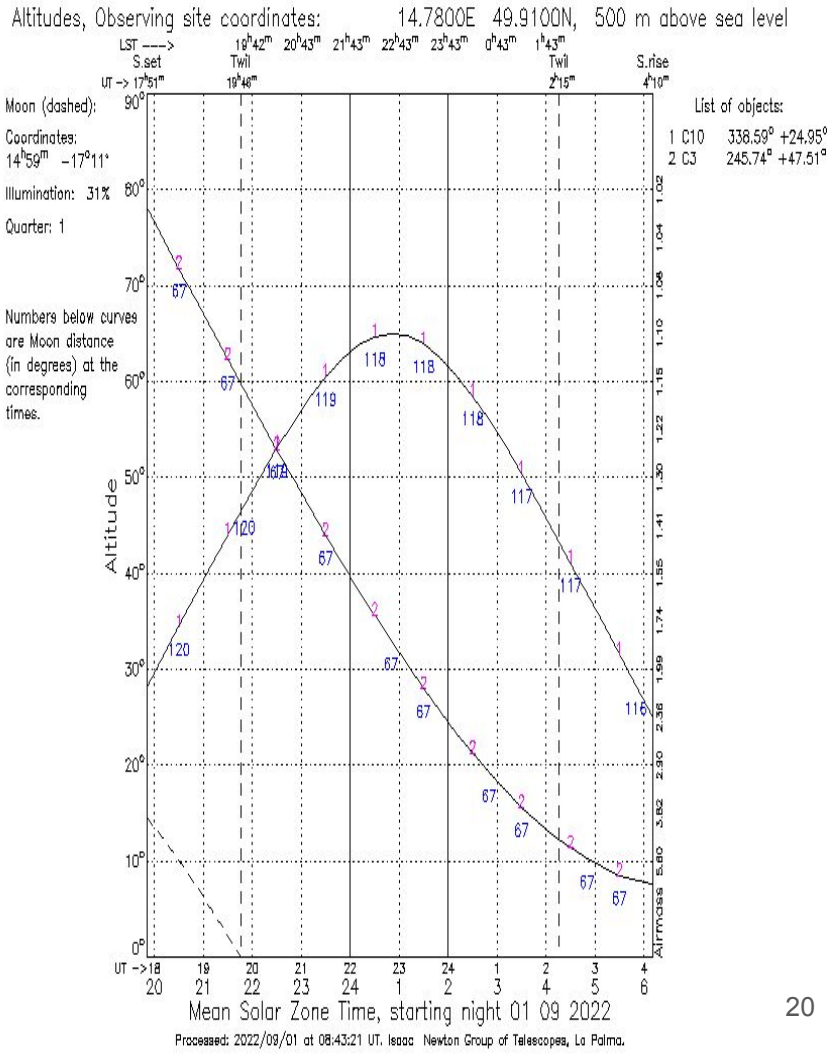
observable processing Modeling candidate ztf_cross

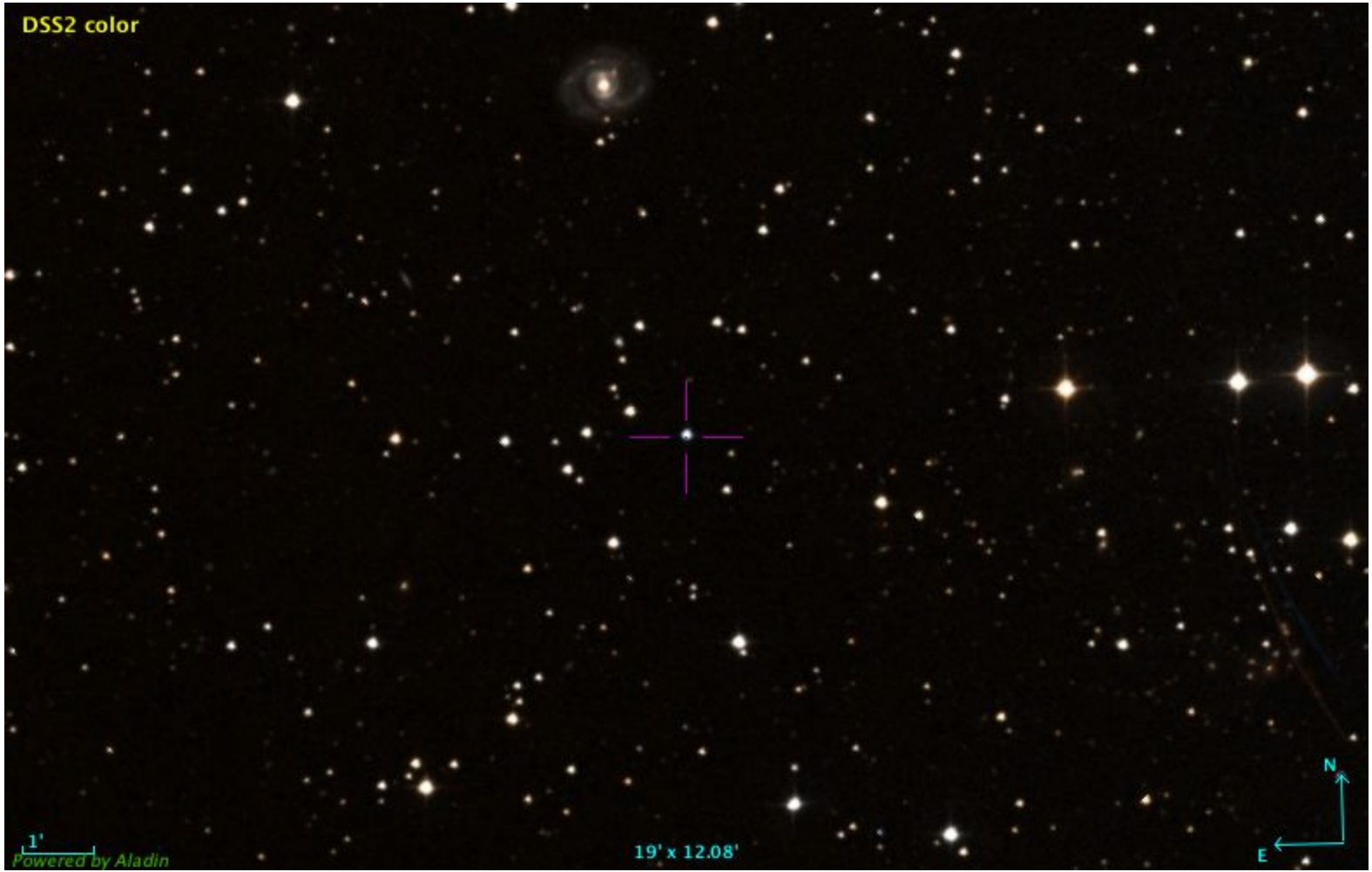

D65
Uvedení do provozu: 1962
Modernizace: 1993-1996, 2009
Průměr objektivu (primárního zrcadla): 650 mm
Ohnisková vzdálenost: 2342 mm (2675 mm)
CCD kamera: G2-3200
CCD čip: Kodak KAF-3200ME (2184 × 1472 pixelů, 6.8 µm, 14.9 × 10.0 mm)
Úhlová velikost pixelu (binning 2x2 pixely): 1.05"
Zorné pole: 19.0' x 12.8'
Dosah: ~ 21.5 mag (expozice 180 s)

Pc: AC

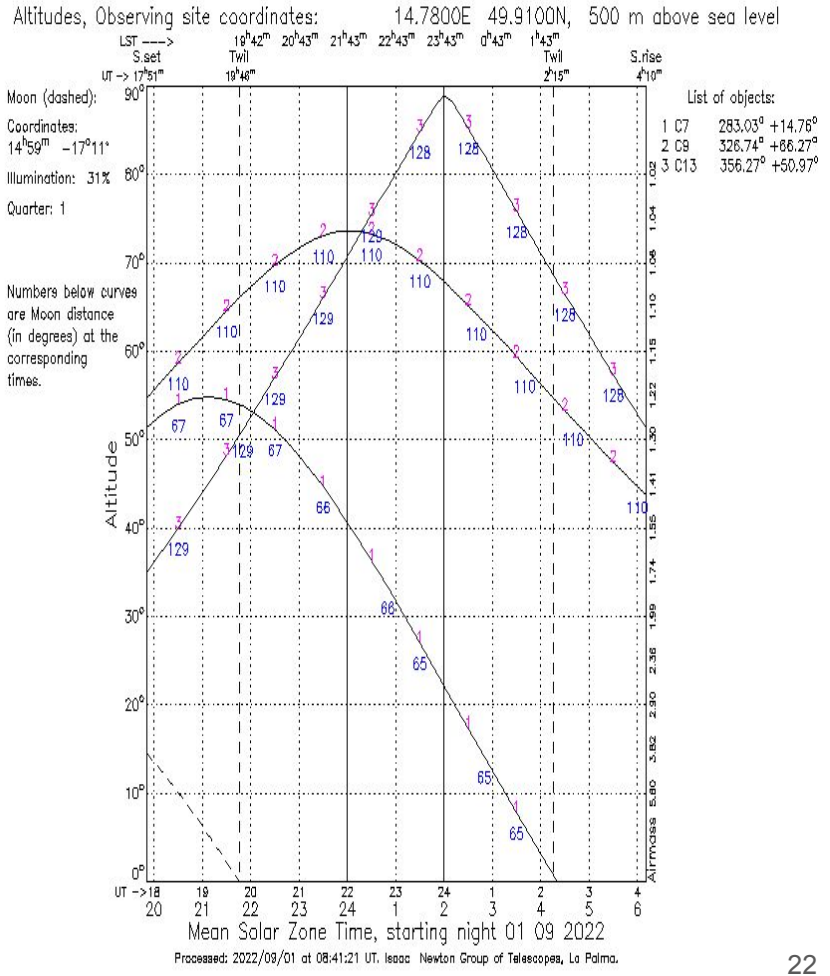
Observation

Gaia DR2 Source ID C10	1877320760449993216
Mag	14.169
Exposure time	1 min
Period (h)	2.654



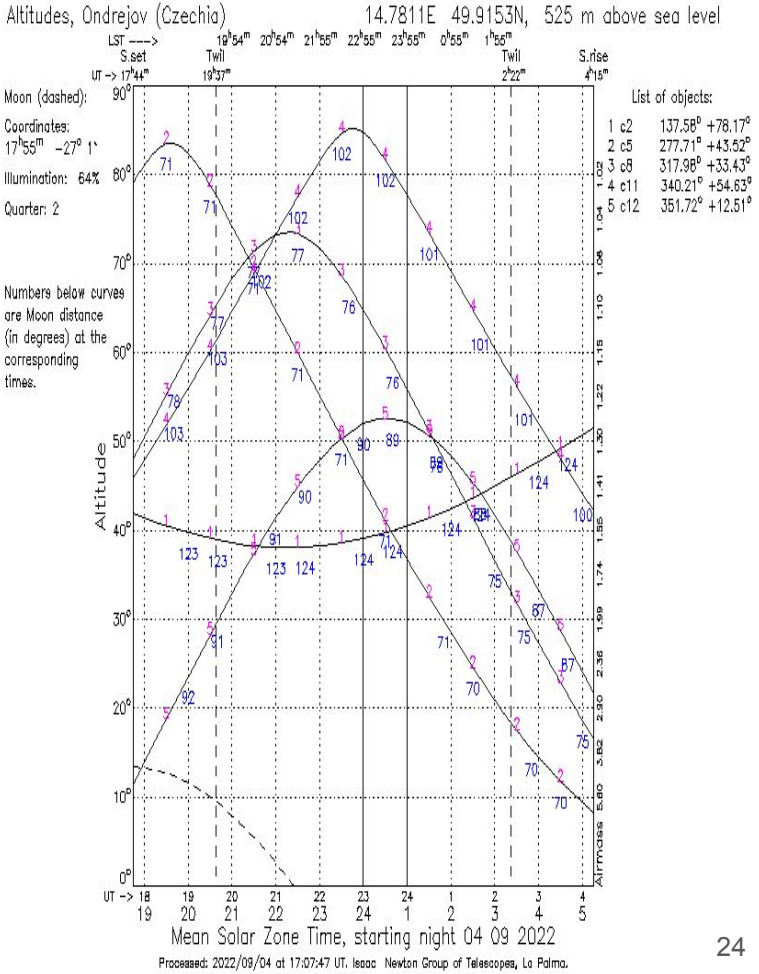

DSS2 color
1'
Powered by Aladin
19' x 12.08'
N
E

Gaia DR 2 Source ID C13	1943858286426802304
Mag	16.432
Exposure time	2min
Period (h)	1.945




DSS2 color
1'
Powered by Aladin
19' x 12.01'
N
E

Gaia DR2 Source ID C11	2003241230122936064
Mag	14.979544
Exposure time	2_1min
Period (h)	5.661




DSS2 color
1'
Powered by Aladin
19' x 12.01'
N
E

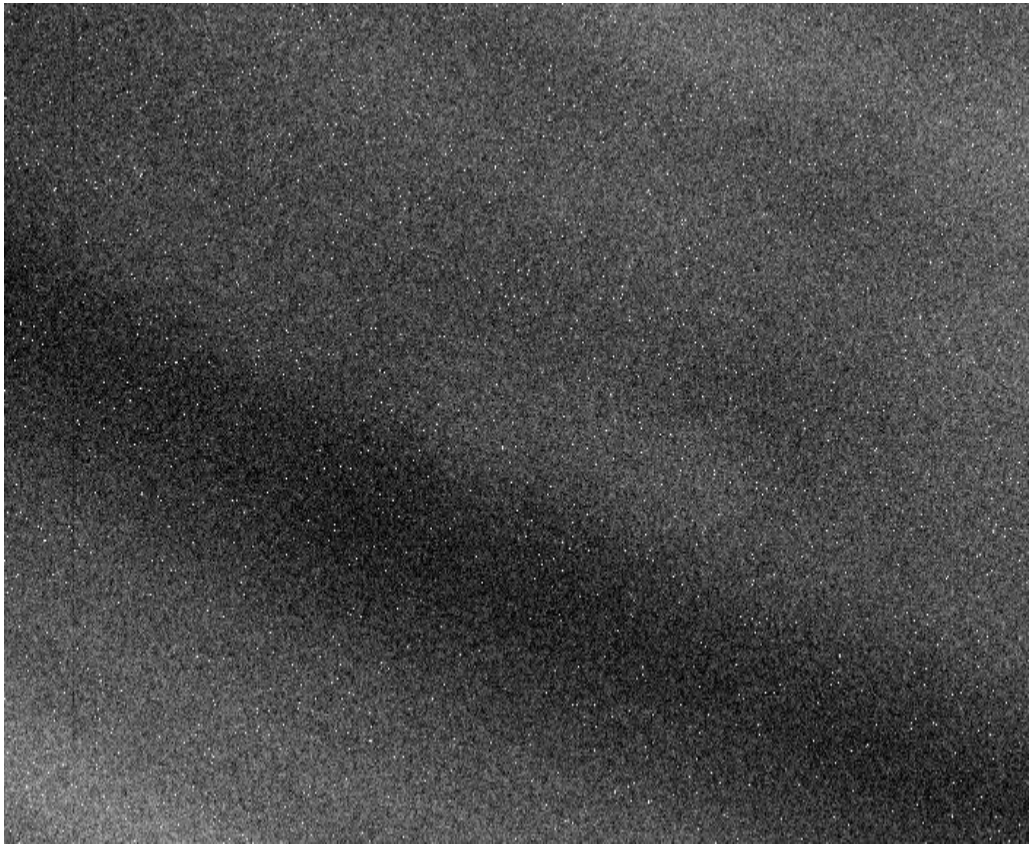
Data Reduction using IRAF

- Dark Frame
- Flat Frame
- Science Frame

- Display all the images in DS9
- Display the fits image header using **imhead** or **hselect** task to check for the exposure time for all the images.

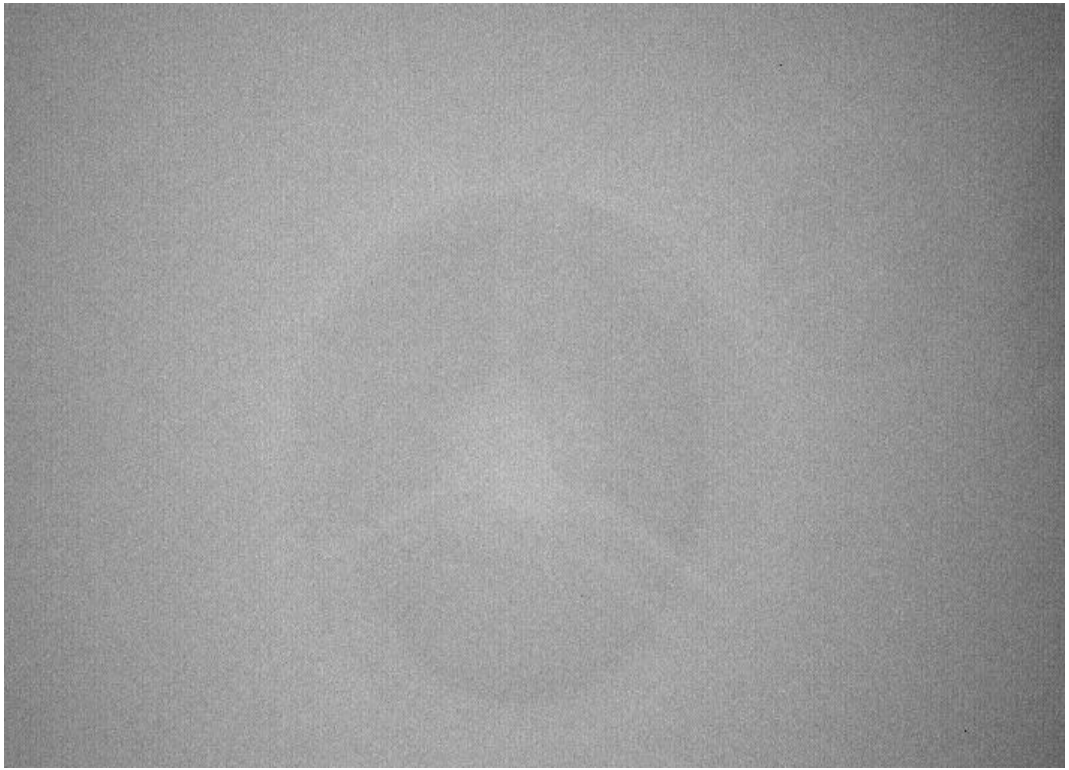
Dark Frame

- Dark currents
- Long exposure images with the CCD shutter closed.
- **Zerocombine** task in ccdred package
- Use median value to combine the frames
- Master dark frame is created

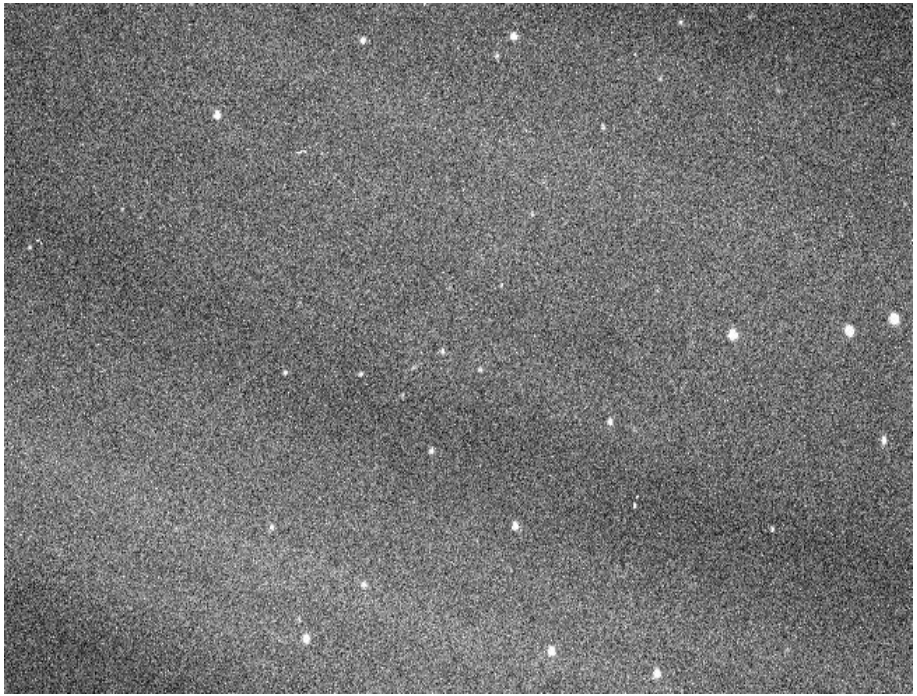


Flat Frame

- Vignetting and variation of pixel response in CCDs
- Uniformly illuminated frame by a flat field panel or the twilight sky using the same filter as the science frame.
- Master flat frame is created similar to the dark frames by combining and normalising the flux



Before correction

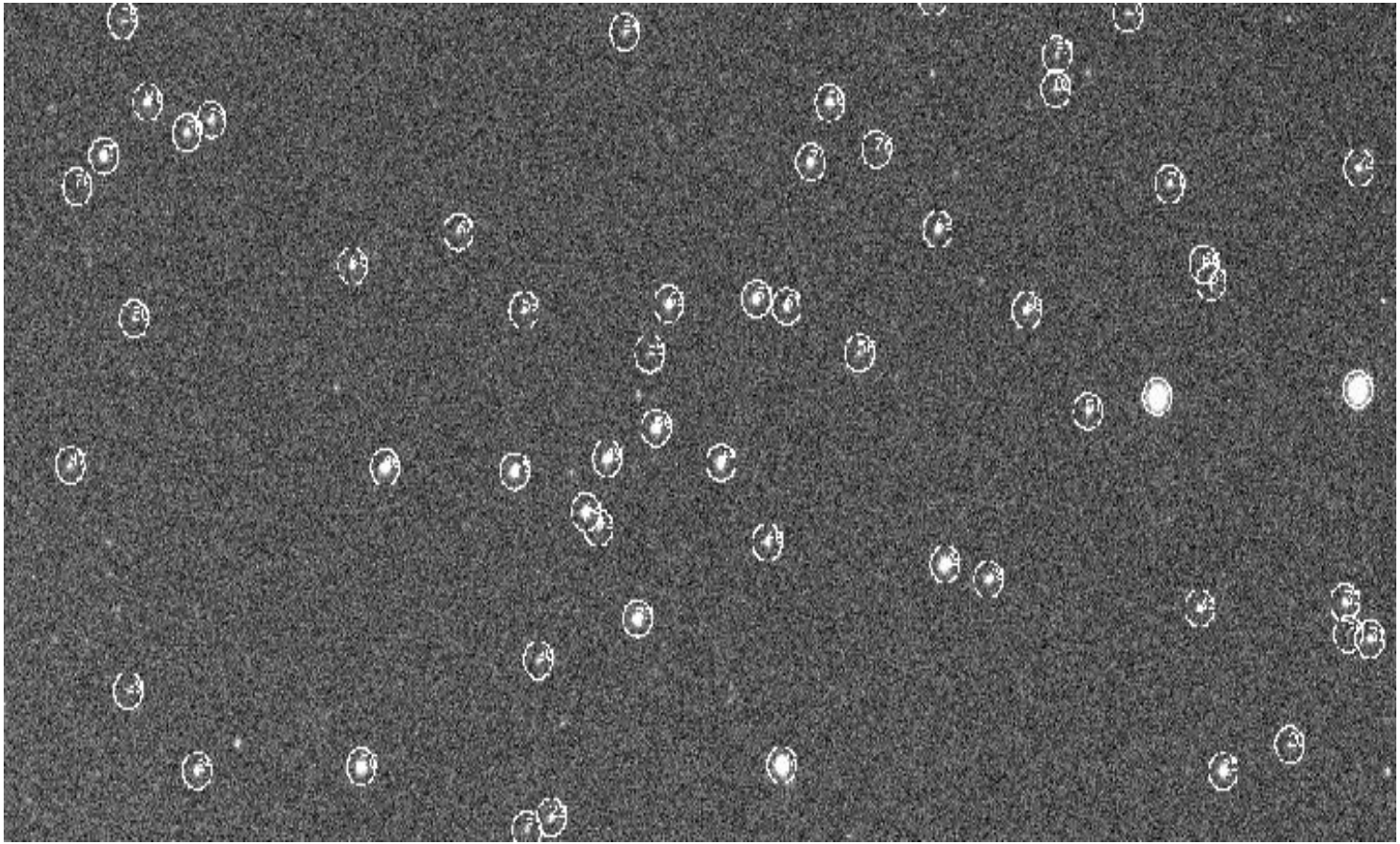


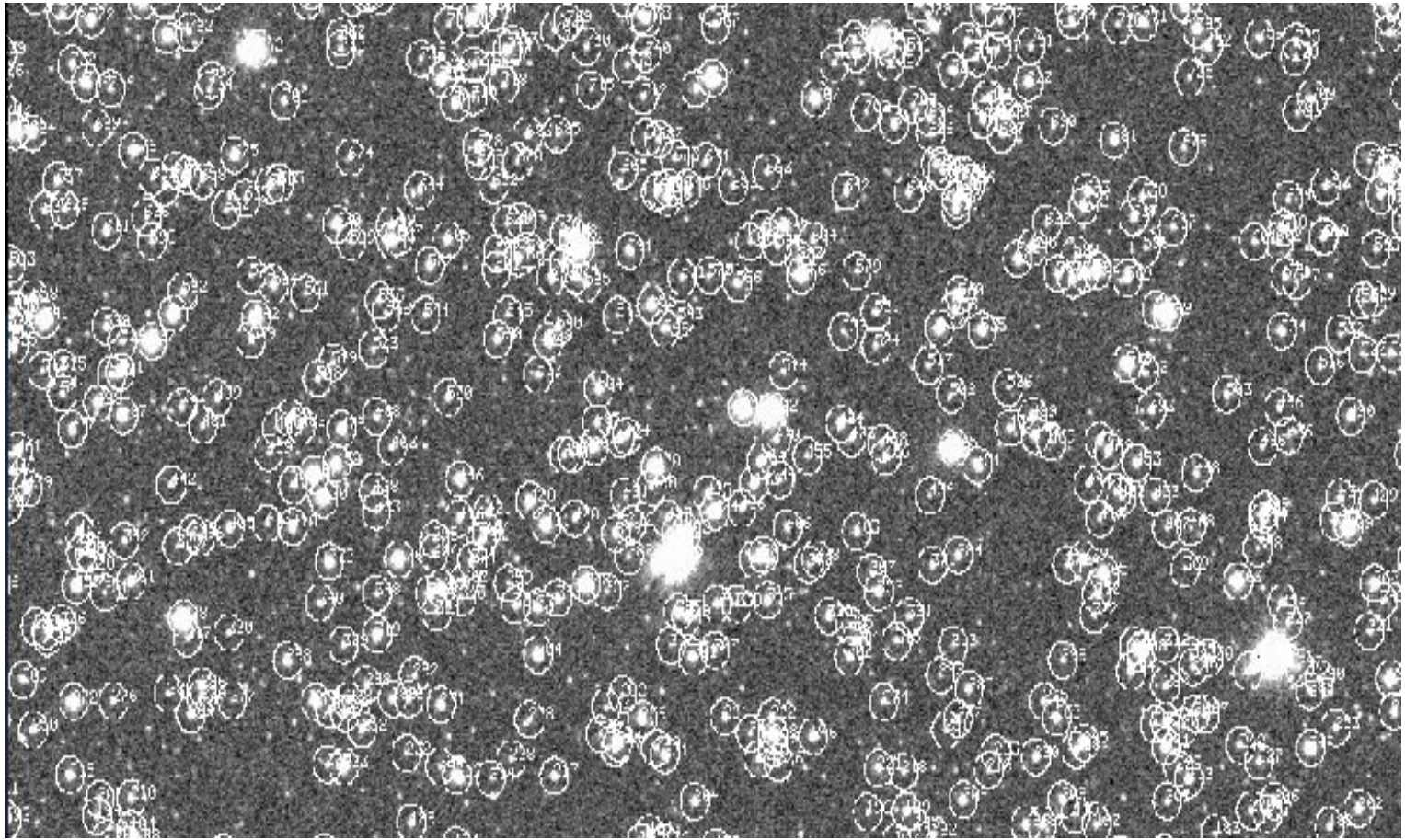
After correction

- The task **CCDPROC** in the CCDRED package in IRAF was used to apply these corrections to the science frames.
- Image alignment using iraf and python script

Locating the stars in the frame

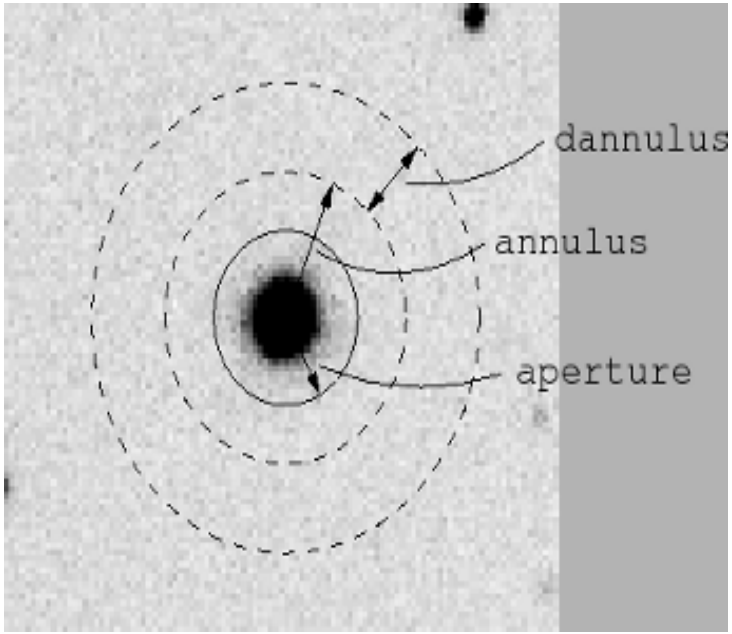
- Parameters for finding the stars
  - **SKY** value - initial guess for the background
  - **FWHM -** Full Width at Half Maximum
- Used **DAOFIND** task
  - DATAPARS - median of FWHM and sqrt(median of sky value) as sigma
  - FINDPARS - Adjust the threshold
  - .coo.1 files were created
- **TVMARK**





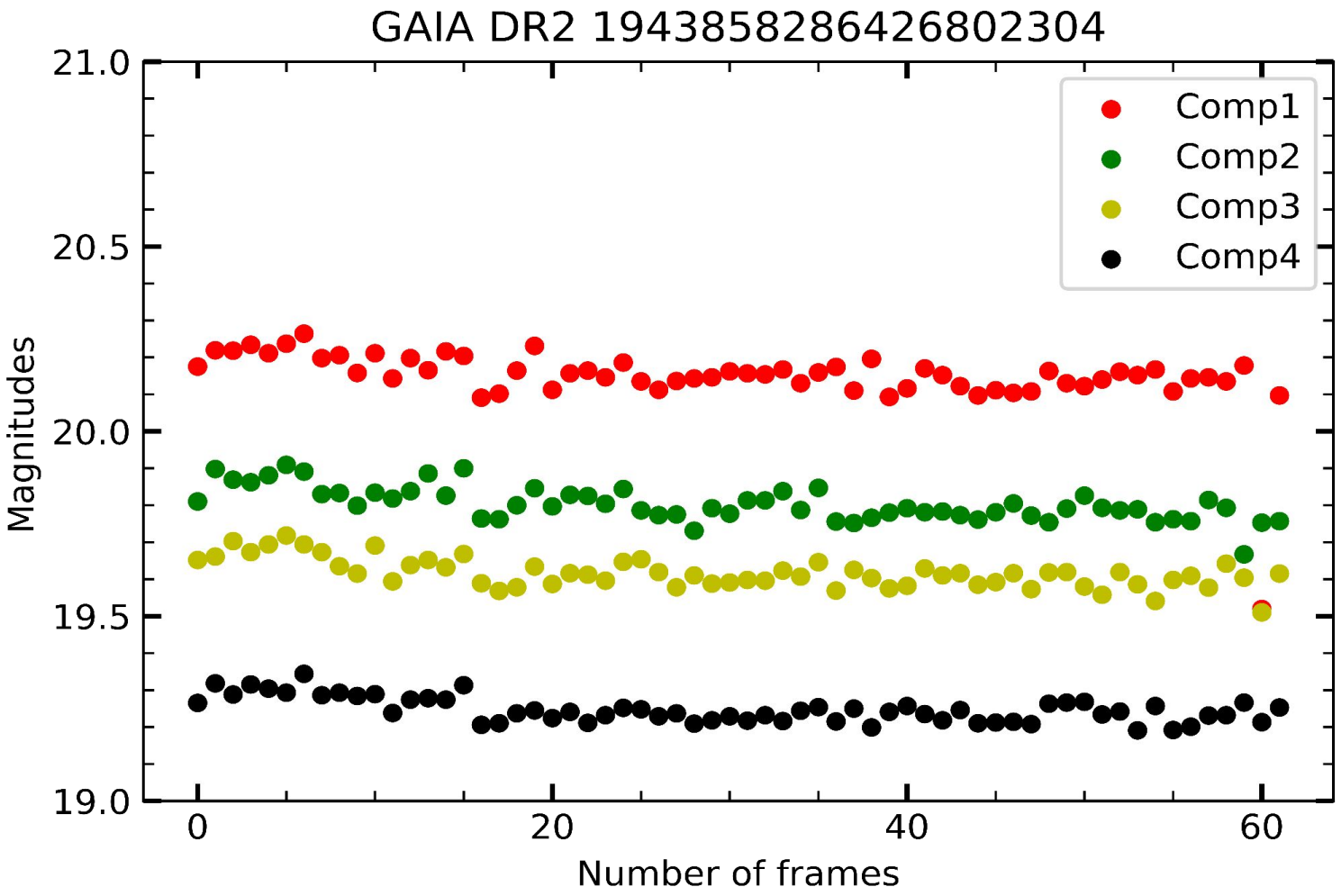
Photometry

- **PHOT** task
  - Coordinate list of the stars
  - CENTERPARS - centroid algorithm
  - FITSKYPARS
    - Annulus, dannulus, sky value
  - PHOTPARS - aperture radius
    - 2.5 * FWHM
  - .mag.1 files are created



Working with the .mag.1 files

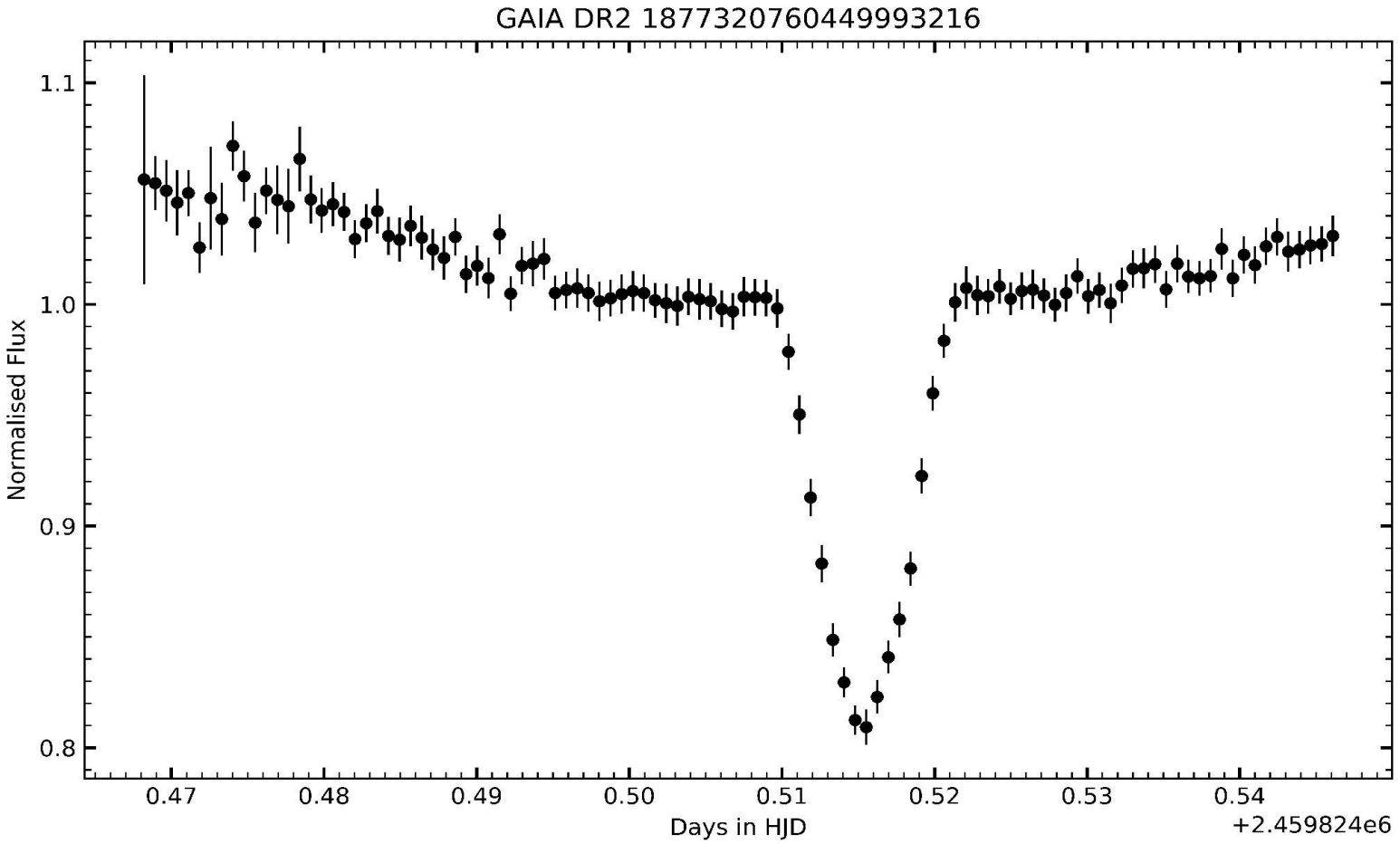
- Text dumped the data from .mag.1 file
  - ID, XCENTER, YCENTER, MAG, MERR, FLUX - mag files
- Identify the target star and companion stars using TVMARK
- **! awk '{if ($1==222) print;}' V_mags > V_star**
- Plot the magnitudes of the comparison stars to see if they are variable or not.
- Calculate the mean magnitude of target star and the companion stars
- Subtracted the mean magnitudes
- Taking the average of the comparison stars
- Subtract the comparison star from the target star


GAIA DR2 1943858286426802304
Comp1
Comp2
Comp3
Comp4
Magnitudes
21.0
20.5
20.0
19.5
19.0
0
20
40
60
Number of frames

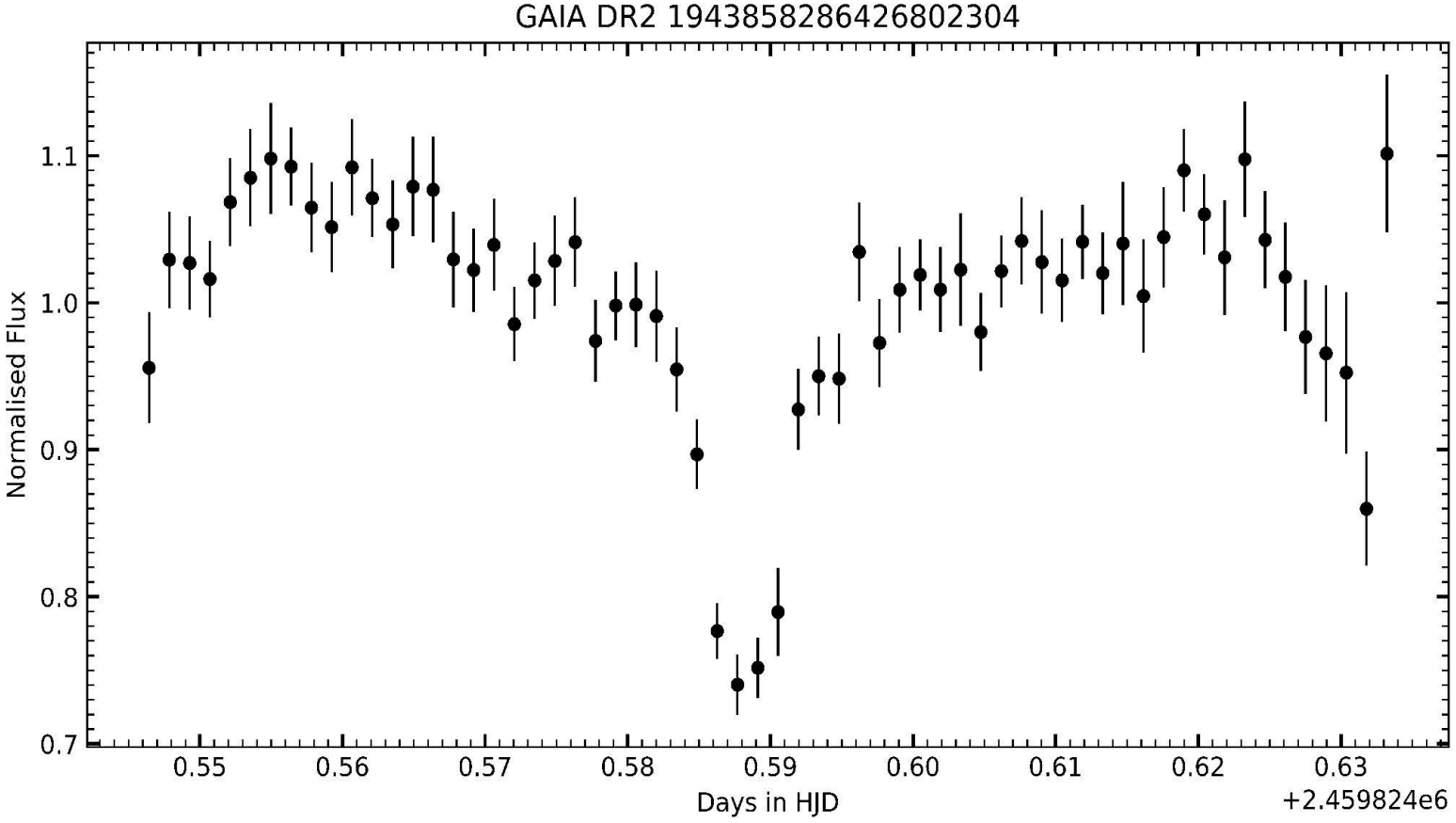
Calculating the time for the light curve

- Update the header of the fits file with EPOCH, RA, DEC using **hedit**
- The **SETJD** task would calculate the time in heliocentric julian dates.
- Final step is to combine the time and the difference magnitude to a file.
- Plot the light curve

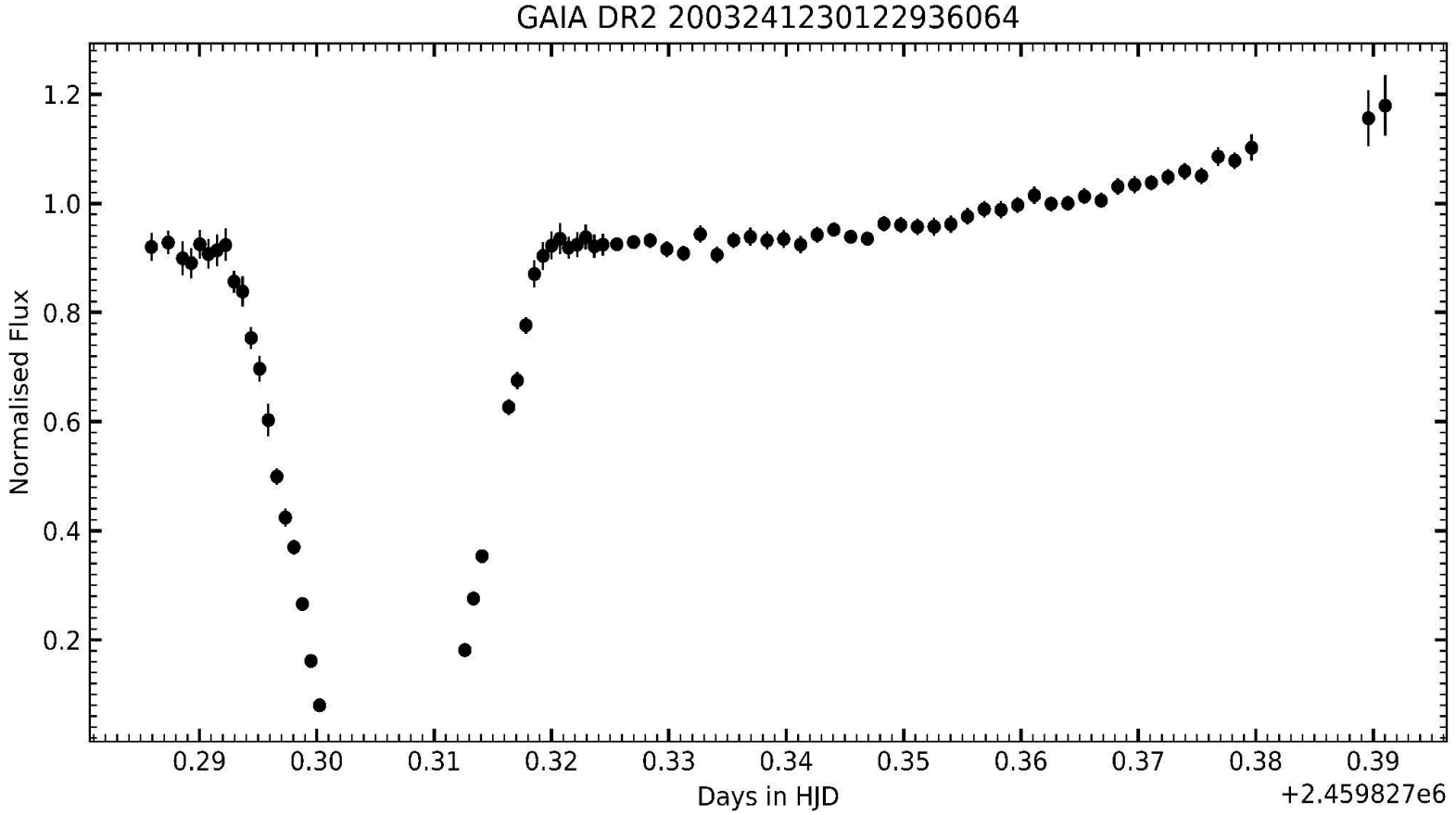
C10


GAIA DR2 1877320760449993216
Normalised Flux
1.1
1.0
0.9
0.8
0.47
0.48
0.49
0.50
0.51
0.52
0.53
0.54
Days in HJD
+2.459824e6

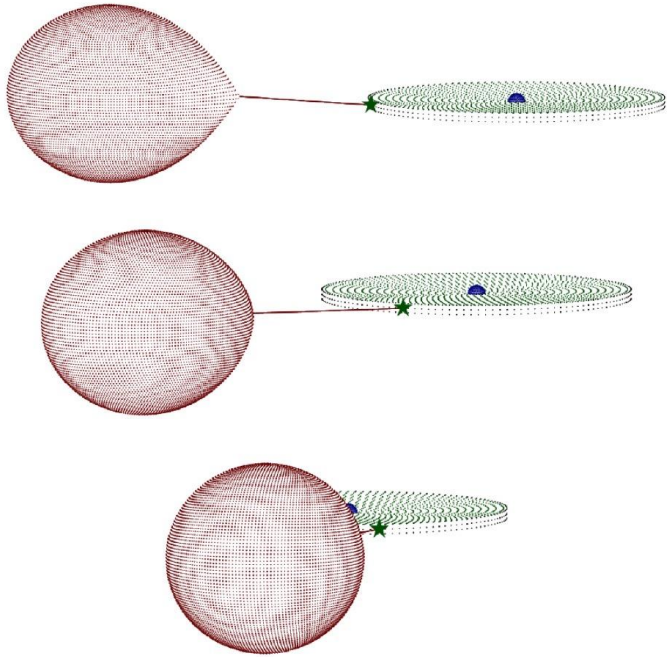
C13


GAIA DR2 1943858286426802304
Normalised Flux
1.1
1.0
0.9
0.8
0.7
0.55
0.56
0.57
0.58
0.59
0.60
0.61
0.62
0.63
Days in HJD
+2.459824e6

C11


GAIA DR2 2003241230122936064
Normalised Flux
1.2
1.0
0.8
0.6
0.4
0.2
0.29
0.30
0.31
0.32
0.33
0.34
0.35
0.36
0.37
0.38
0.39
Days in HJD
+2.459827e6

Lightcurve analysis with lcurve[1]



- To derive the physical parameters from our lightcurve we need to generate a light curve.
- This can be done as follows:
  - Generate grids covering all objects (stars, dics, etc.)
  - Set their surface brightness, including all effects
  - At every phase compute what can and can't be seen

[1] Copperwheat et al. 2012

Lightcurve analysis with lcurve

- **lroche** generates modelled lightcurve of a white dwarf or a subdwarf/main-sequence binary.
  - The modul does this by computing a lightcurve equivalent to a model of a sphere and a Roche-distorted star
  - Find which models are consistent with the data
- Different methods:
  - Levenberg-Marquardt method
  - Simplex method

Fundamental parameters

- Lightcurve
  - Orbital period (P)
  - Mass ratio (q)
  - Inclination (i)
  - Effective temperature (T_2)
  - Relative radius (r_1/a)
  - Relative radius (r_2/a)
  - Limb darkening[2]
- Spectrum
  - Radial velocity curve K_1
  - Effective temperature (T_1)
  - Log g_1
  - Orbital separation (a)
- Our project
  - Radii of both stars (R_1 and R_2)
  - Mass of secondary component (M_2)

[2] Claret and Bloemen 2012

Calculation of fundamental parameters

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

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

Masses $$M_1 = \frac{P}{2\pi G} \frac{K_1^3 (q+1)^2}{(q \sin i)^3} \qquad M_2 = q \cdot M_1$$

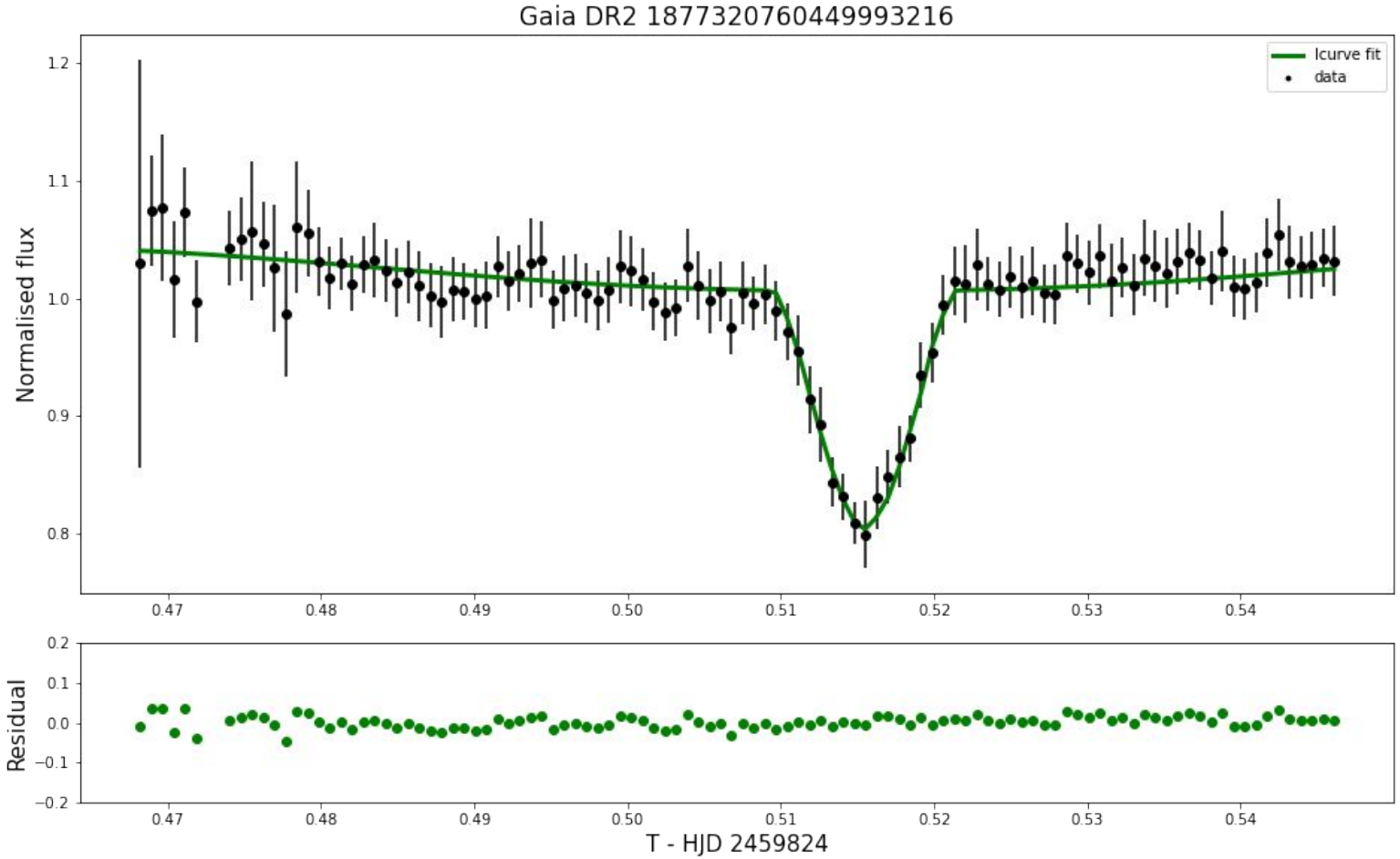
$M_1 = 0.47\ M_\odot$

Parameters in Iroche

- **Orbital period (P)**
- **Mass ratio (q)**
- Inclination (i)
- **Effective temperature (T_1)**
- Effective temperature (T_2)*
- **Wavelength**

- Relative radius (r_1/a)
- Relative radius (r_2/a)
- **Limb darkening**
- Absorb
- **Slope**

C10


Gaia DR2 1877320760449993216
lcurve fit
data
Normalised flux
1.2
1.1
1.0
0.9
0.8
0.47
0.48
0.49
0.50
0.51
0.52
0.53
0.54
Residual
0.2
0.1
0.0
−0.1
−0.2
T - HJD 2459824

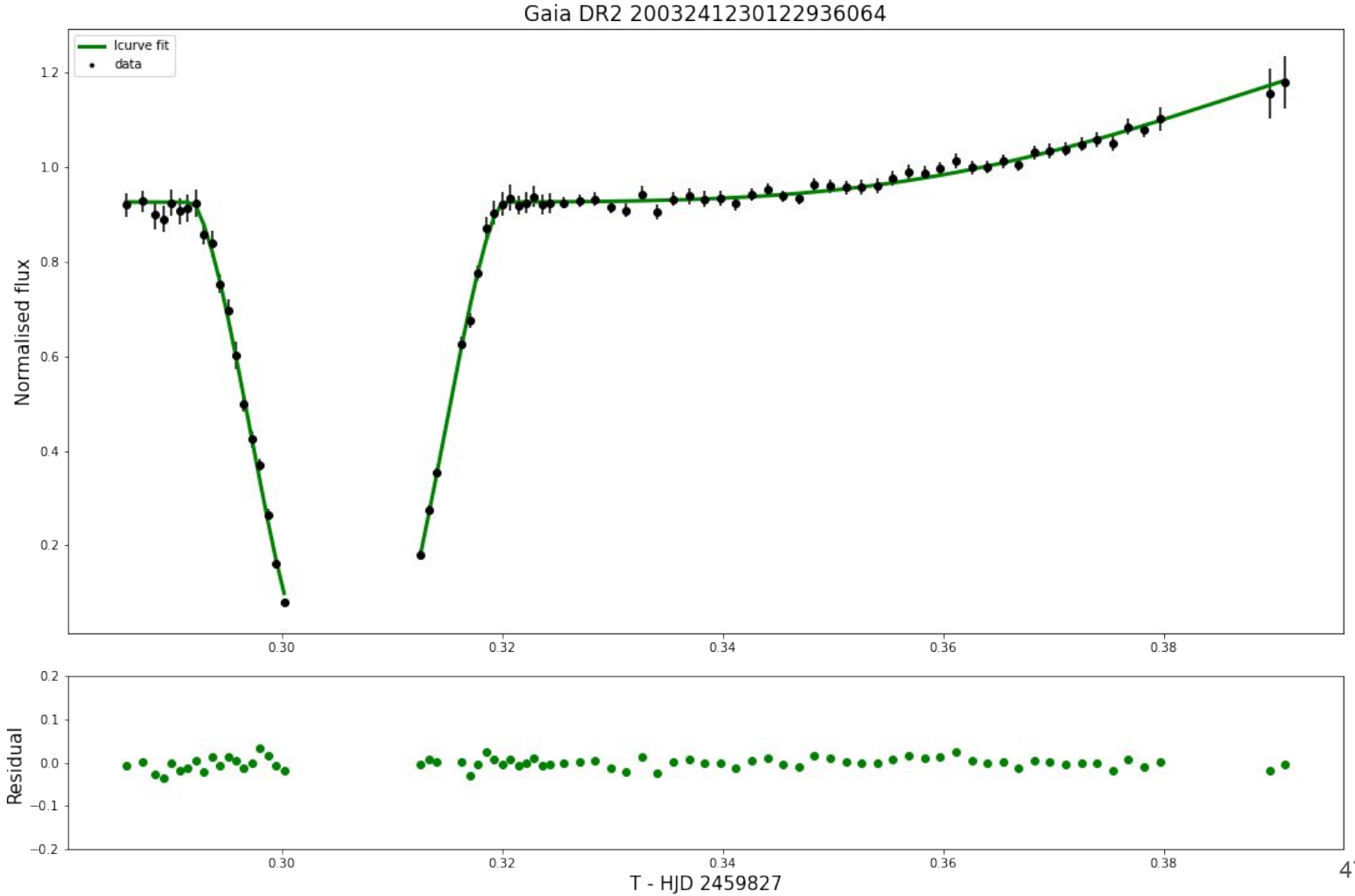
Physical parameters of C10

K_1 (km/s)	49.1 ± 3.1
T_1 (K)	28400 ± 500
Log g	5.39 ± 0.011
P (hours)	2.654

q	0.159 ± 0.012
I (°)	80.780 ± 0.167
R_1 ($R_\odot$)	0.198 ± 0.018
R_2 ($R_\odot$)	0.094 ± 0.008
M_2 ($M_\odot$)	0.074 ± 0.006
T_2 (K)	2391.856 ± 99252
Absorb	0.927 ± 0.267

Gaia DR2 1877320760449993216

C11


Gaia DR2 2003241230122936064
lcurve fit
data
Normalised flux
Residual
T - HJD 2459827

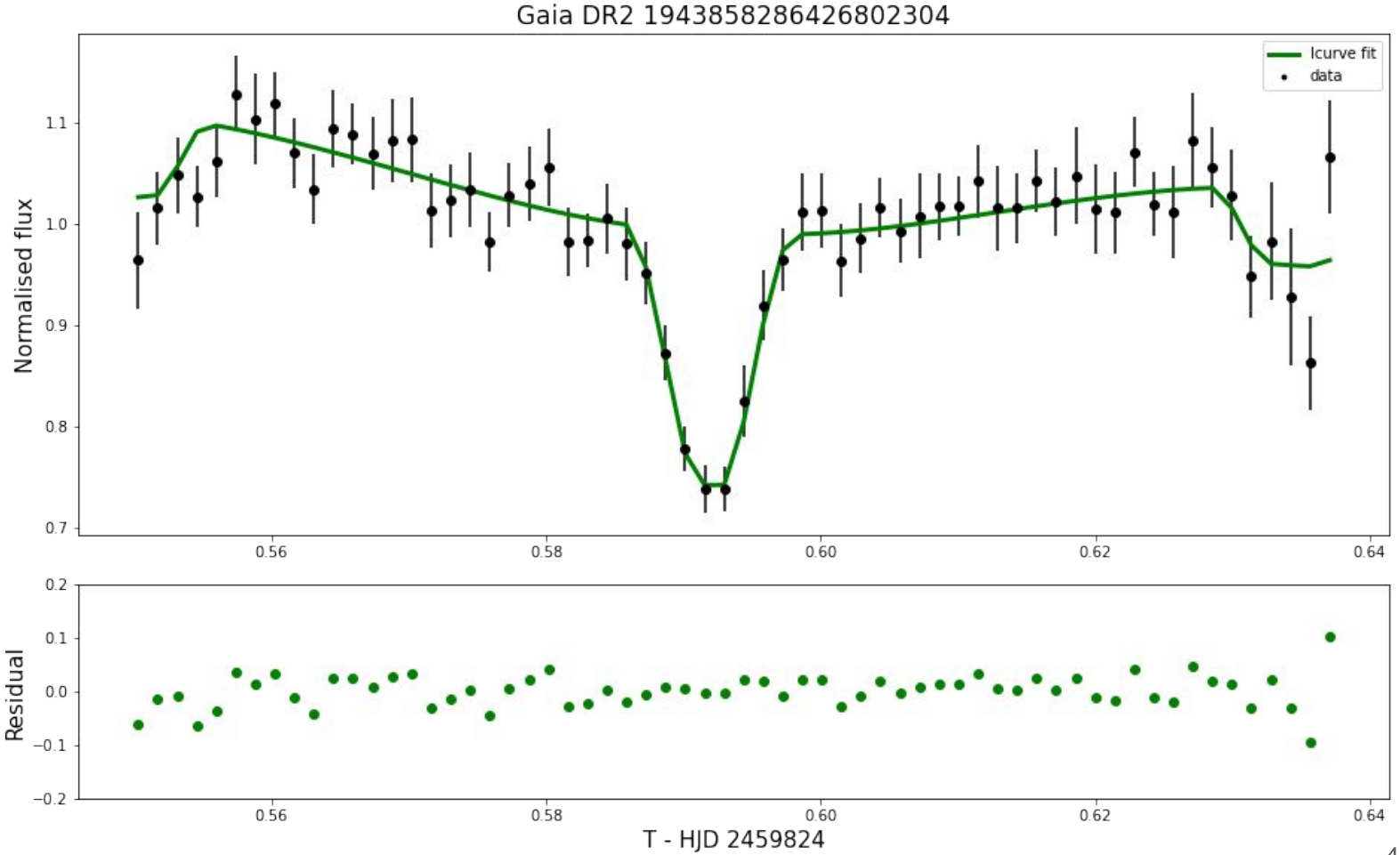
Physical parameters of C11

K_1 (km/s)	182 ± 8
T_1 (K)	37500 ± 500
Log g	5.5 ± 0.05
P (hours)	5.661

q	1.129 ± 0.077
I (°)	83.565 ± 0.274
R_1 ($R_\odot$)	0.18 ± 0.087
R_2 ($R_\odot$)	0.45 ± 0.024
M_2 ($M_\odot$)	0.531 ± 0.036
T_2 (K)	2984.04 ± 9809
Absorb	0.771 ± 0.05

Gaia DR2 1943858286426802304

C13


Gaia DR2 1943858286426802304
lcurve fit
data
Normalised flux
1.1
1.0
0.9
0.8
0.7
0.56
0.58
0.60
0.62
0.64
Residual
0.2
0.1
0.0
−0.1
−0.2
T - HJD 2459824

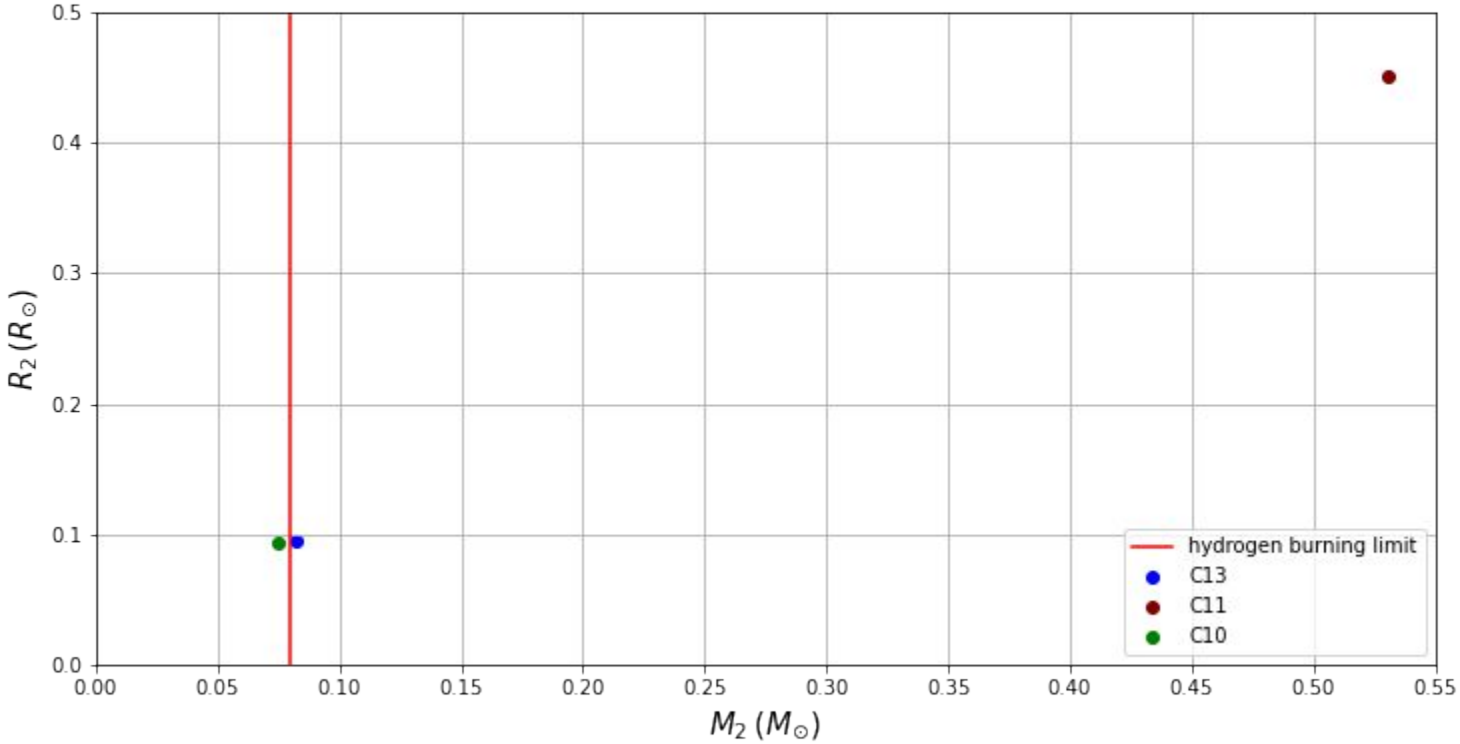
Physical parameters of C13

K_1 (km/s)	60 ± 5
T_1 (K)	30000 ± 500
Log g	5.55 ± 0.05
P (hours)	1.945
Limb darkening	0.259

q	0.176 ± 0.016
I (°)	83.292 ± 0.984
R_1 ($R_\odot$)	0.198 ± 0.022
R_2 ($R_\odot$)	0.094 ± 0.011
M_2 ($M_\odot$)	0.083 ± 0.008
T_2 (K)	2901.67
Absorb	1.885 ± 0.643
Slope	-0.035

Gaia DR2 2003241230122936064

Mass-radius relation of the companion



Discussion: C10

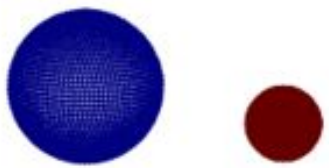
M_1 ($M_\odot$)	0.47
R_1 ($R_\odot$)	0.198 ± 0.018
T_1 (K)	28400 ± 500
M_2 ($M_\odot$)	0.074 ± 0.006
R_2 ($R_\odot$)	0.094 ± 0.008
T_2 (K)	2391.856 ± 99252

Primary: **Hot subdwarf**

Companion: **Brown dwarf**

Gaia DR2 1877320760449993216

Model of the system



Discussion: C11

M_1 ($M_\odot$)	0.47
R_1 ($R_\odot$)	0.18 ± 0.087
T_1 (K)	37500 ± 500
M_2 ($M_\odot$)	0.531 ± 0.024
R_2 ($R_\odot$)	0.45 ± 0.024
T_2 (K)	2984.04 ± 9809

Primary: **Hot subdwarf**

Companion: **M-dwarf**

Gaia DR2 1943858286426802304

Model of the system

Discussion: C13

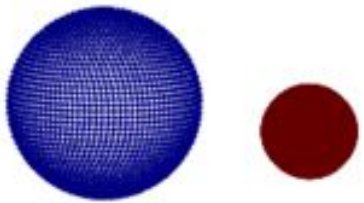
M_1 ($M_\odot$)	0.47
R_1 ($R_\odot$)	0.198 ± 0.022
T_1 (K)	30000 ± 500
M_2 ($M_\odot$)	0.083 ± 0.008
R_2 ($R_\odot$)	0.094 ± 0.011
T_2 (K)	2901.67

Primary: **Hot subdwarf**

Companion: **M-dwarf**

Gaia DR2 2003241230122936064

Model of the system



Conclusion

- Three HW Vir targets were observed for two nights
- We found that our observed targets consisted as follows:
  - Hot subdwarf + Brown dwarf
  - Hot subdwarf + M dwarf
  - Hot subdwarf + M dwarf

Sources

[1] https://www.ztf.caltech.edu/ztf-news.htmlc

[2] https://atlas.fallingstar.com/home.php

[3] https://www.dw.com/en/debut-data-from-europes-gaia-mission-shows-milky-way-bigger-than-we-thought/a-19550212

[4] https://fanart.tv/series/76172/top-cat/

Special Mention

[1] Veronika’s slides

[2] Stephan’s slides

[3] Tina’s slides

[4] Max’s slides

[5] Harry’s slides

[6] Jan’s software (thank you for letting us check our lightcurves!)