Daylight Photometry of Betelgeuse at conjunction with the sun

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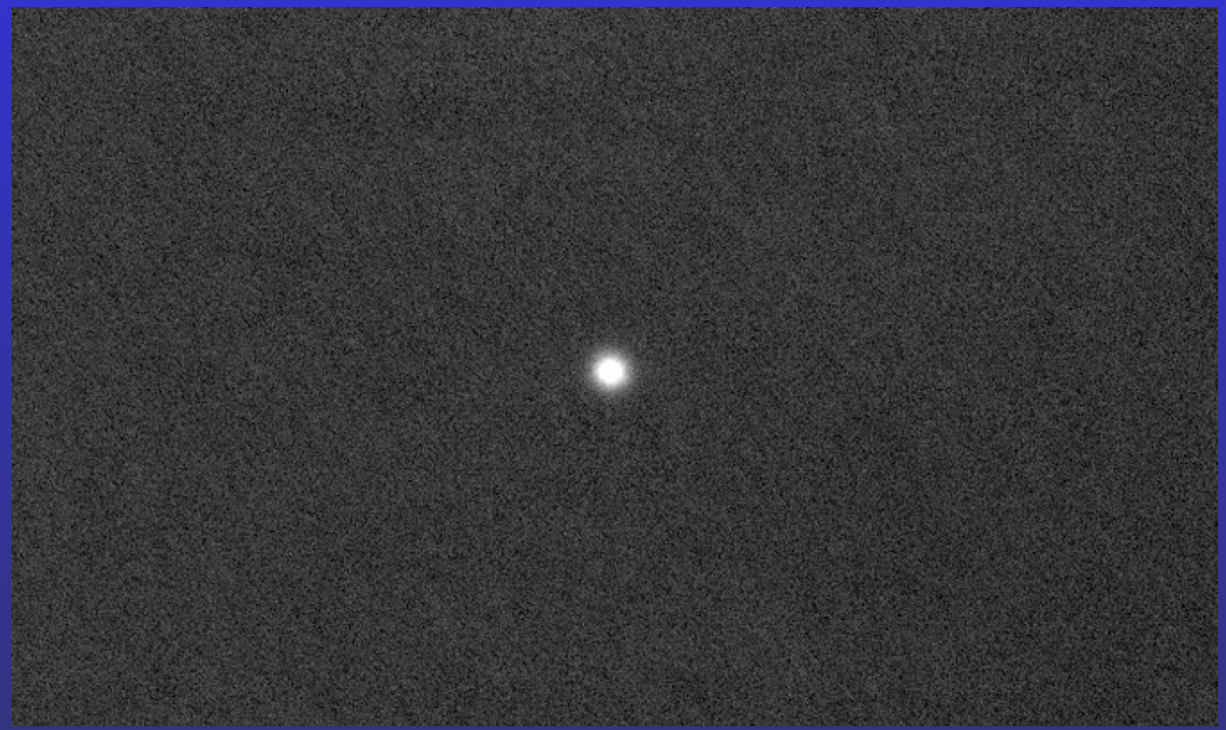
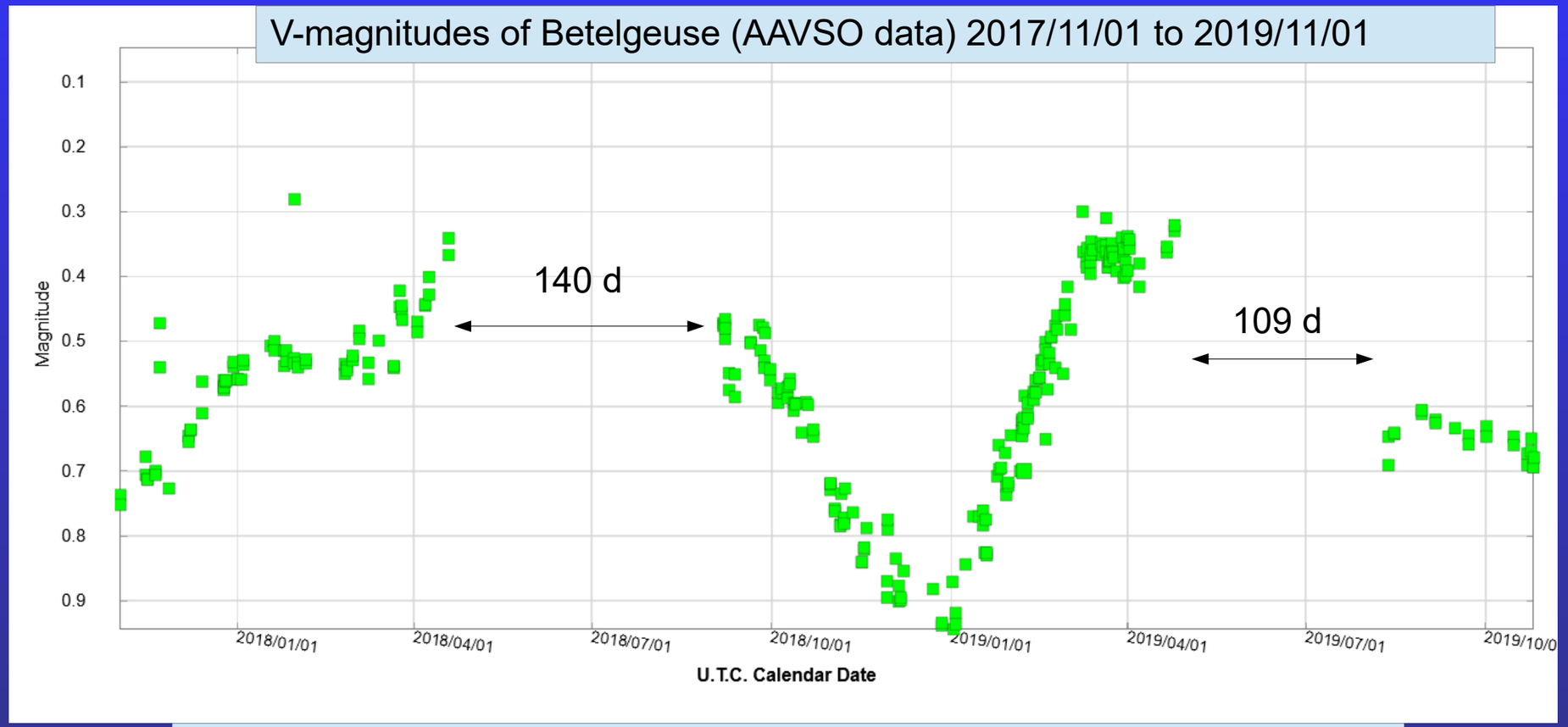


AAVSO 110th Annual Meeting, November 2021

Light curve of Betelgeuse



Reference: Kafka, S., 2021, Observations from the AAVSO International Database, https://www.aavso.org

Ways to fill the gap in the light curve at conjunction

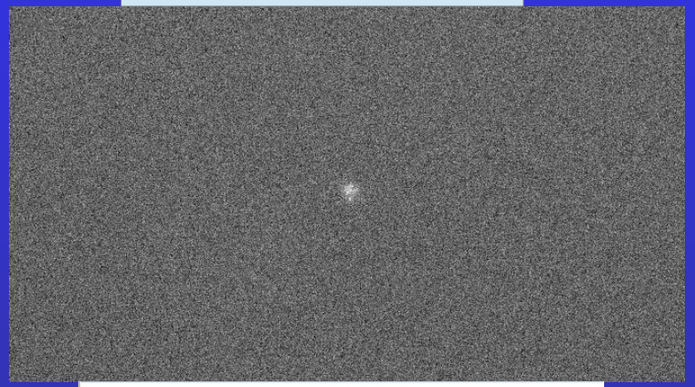
- Observations in twilight close to horizon (preferable in the southern hemisphere)
- Observations with space probes distant from earth (e.g. STEREO-A)
- Observations at daylight

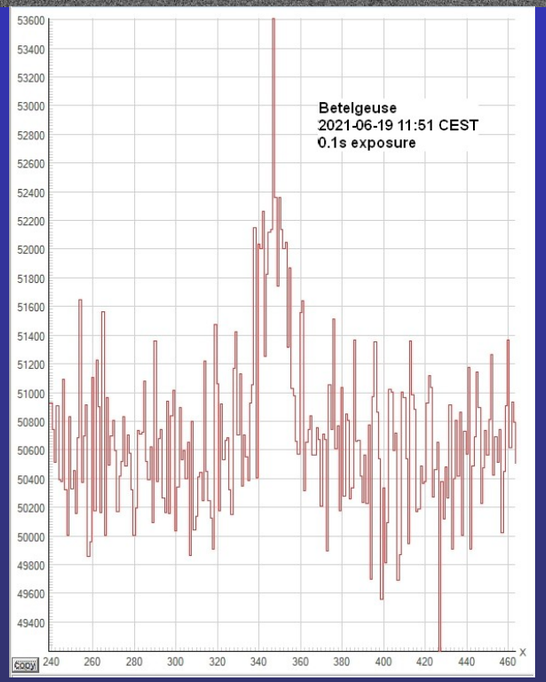
Equipment

- Newton telescope 25cm F/5
- Equatorial mount:
  ASA DDM60 (direct drive, encoders in both axes)
- CCD camera: ATIK 460exm (electronic shutter)
- Filters: Johnson V and ND2 (1% transmission)
- Control software (Windows PC) over ASCOM interface

Images of Betelgeuse close (16°) to sun (June 19)

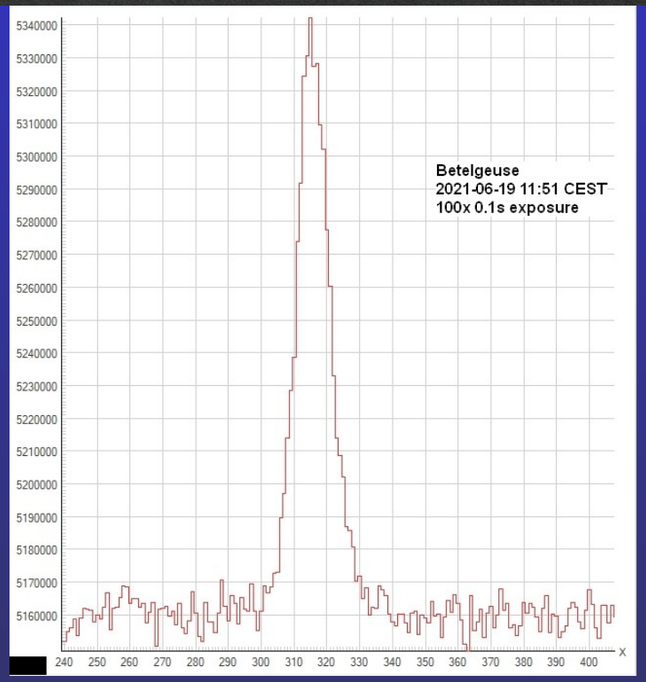
Single image (0.1s)





SNR=15

Stack of 100 images

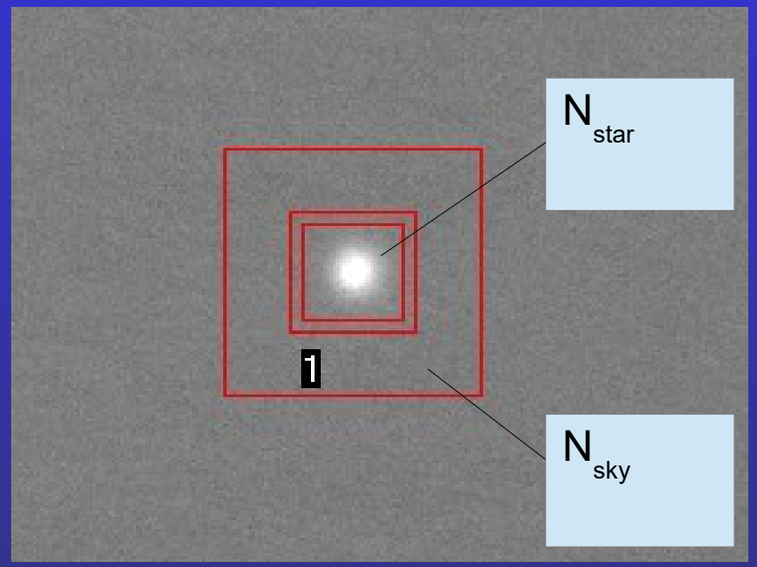


<Star max $0.18 \cdot 10^6$ /pixel = 3.5% of sky photons

SNR=134

<Sky photons $5.16 \cdot 10^6$ /pixel

Sky brightness

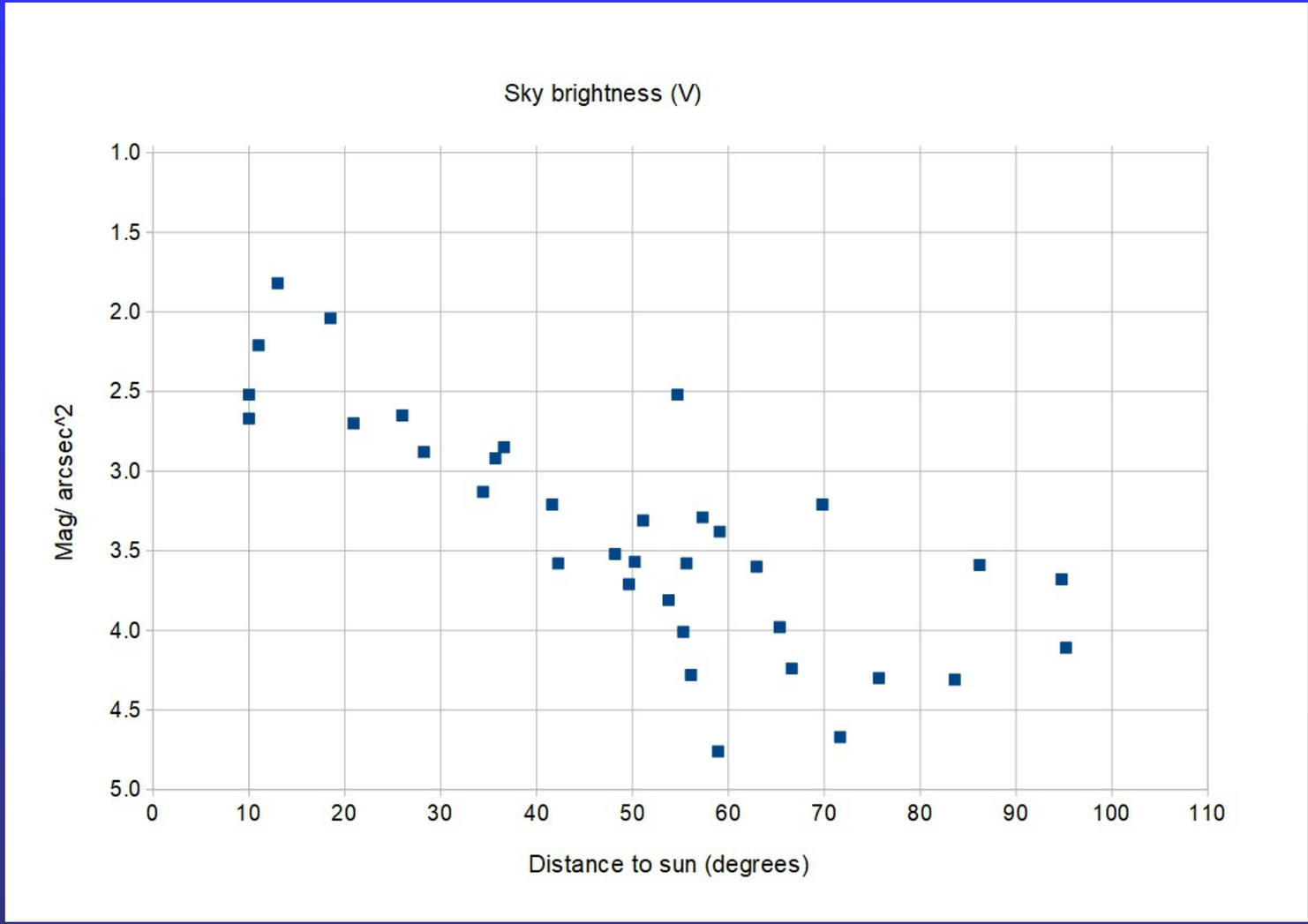


Sky brightness in mag/arcsec^2

$$m_{sky} = -2.5 \log(N_{sky}/(p^2 \sum(N_{star} - N_{sky}))) + m_{star}$$

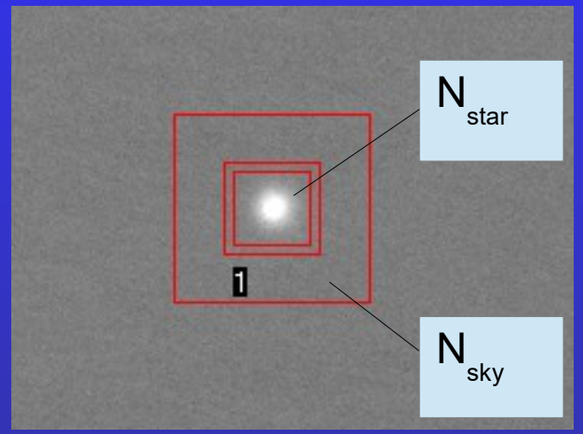
m_{star} = magnitude of star
N_{star} = ADU/pixel in star aperture
N_{sky} = mean ADU/pixel in sky annulus
p = pixel scale in arcsec/pixel

Sky brightness



Brightness of clear sky in Mainz, Germany, 2020-2021

Photometry



Instrumental Magnitude $\mathbf{m_{inst} = -2.5\ log(\ (\sum(N_{star} - N_{sky}))\ /t)}$

N_{star} = ADU/pixel in star aperture
N_{sky} = mean ADU/pixel in sky annulus
t = total exposure time in s

Calculation of standardized magnitudes

Standardized differential magnitude M(var):
Magnitude calibration by one comparison star with known magnitude M(comp)
(neglecting color differences)

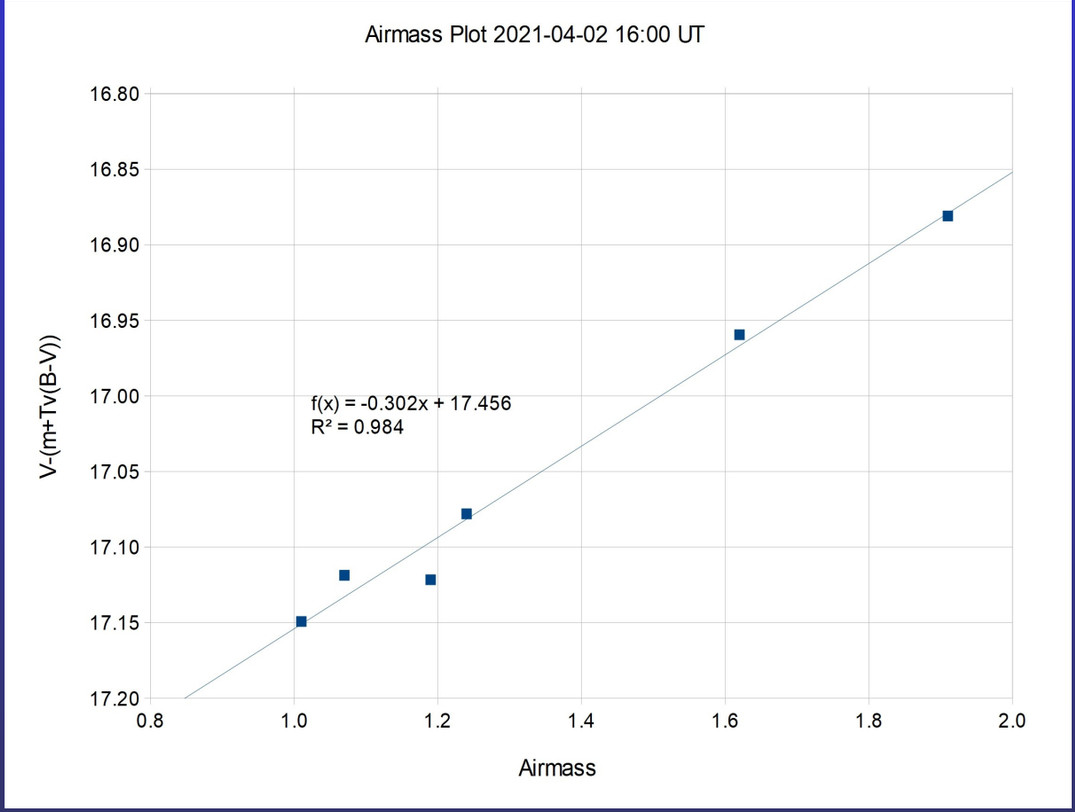
$$\mathbf{M(var) = M(comp) + m_{inst}(var) - m_{inst}(comp) - k\ (X(var)-X(comp))}$$

k = extinction constant X=airmass

Ensemble Photometry

V magnitude $m_v = m_{inst} + T_v(B-V) - k_v X + m0$

m0 = zero point
T_v = color transformation constant, B-V = color index
K_v = extinction constant
X = airmass



Estimation of extinction constant and zero point by linear regression:

$m_v - (m_{inst} + T_v(B-V)) = m0 - k_v X$

Measurement of m_{inst} of an ensemble of stars with known m_v and (B-V) and plot of
$m_v - m_{inst} - T_v(B-V)$ against airmass X

Extinction constant $-k_v$ = slope
Zero point m0 = intercept

Ensemble Photometry

V magnitude of variable

$$m_v = m_{inst} + m0 + T_v(B\text{-}V) - k_v X$$

m0 = zero point
T_v = color transformation constant, B-V = color index
K_v = extinction constant, X= airmass

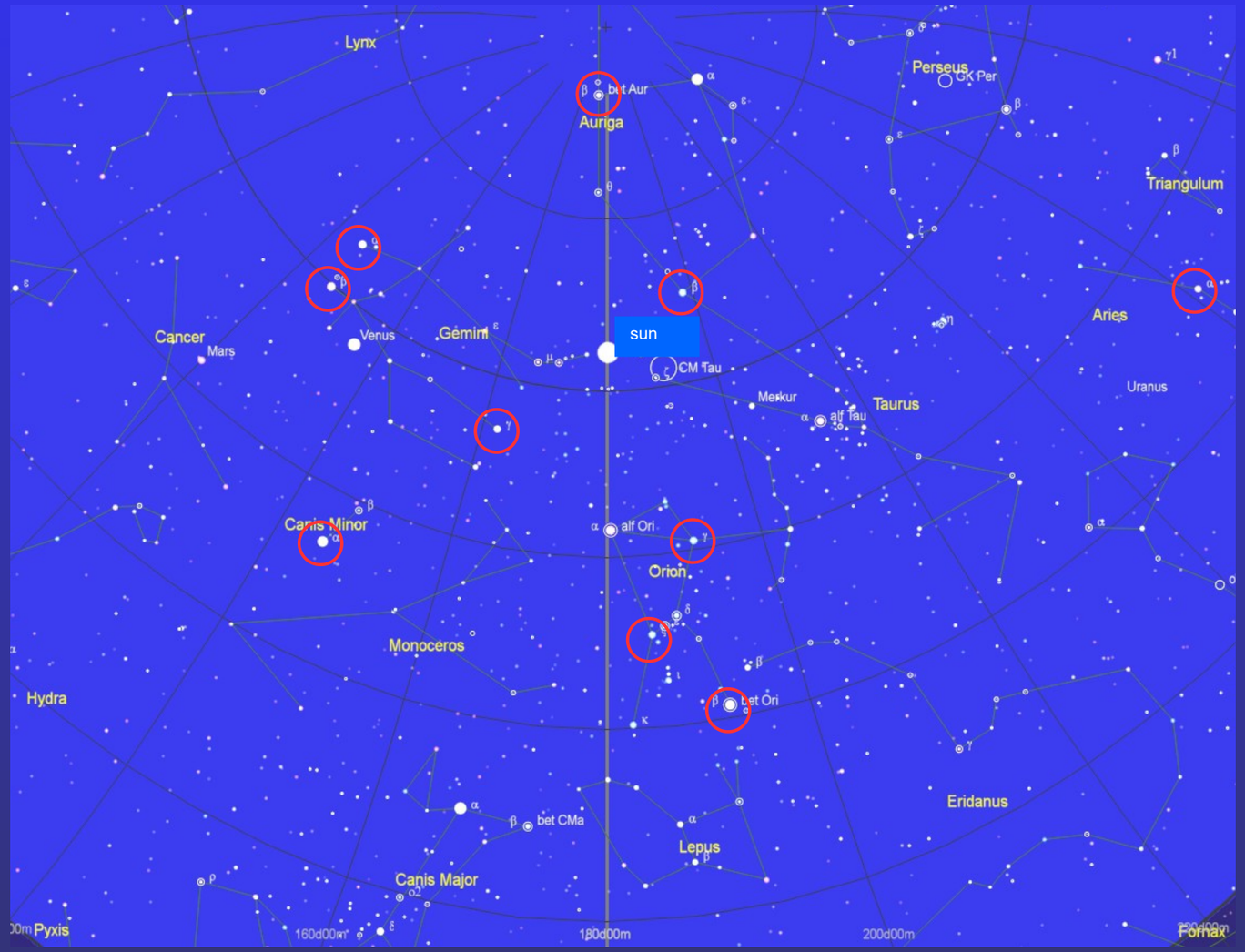
Photometry error

depends on

- Standard error of the linear regression
- SNR of variable (shot noise, scintillation noise)
- Mean error of extinctions

Errors are minimized by long exposure times
Stacks of 100 x 0.1s = 10s

Reference stars



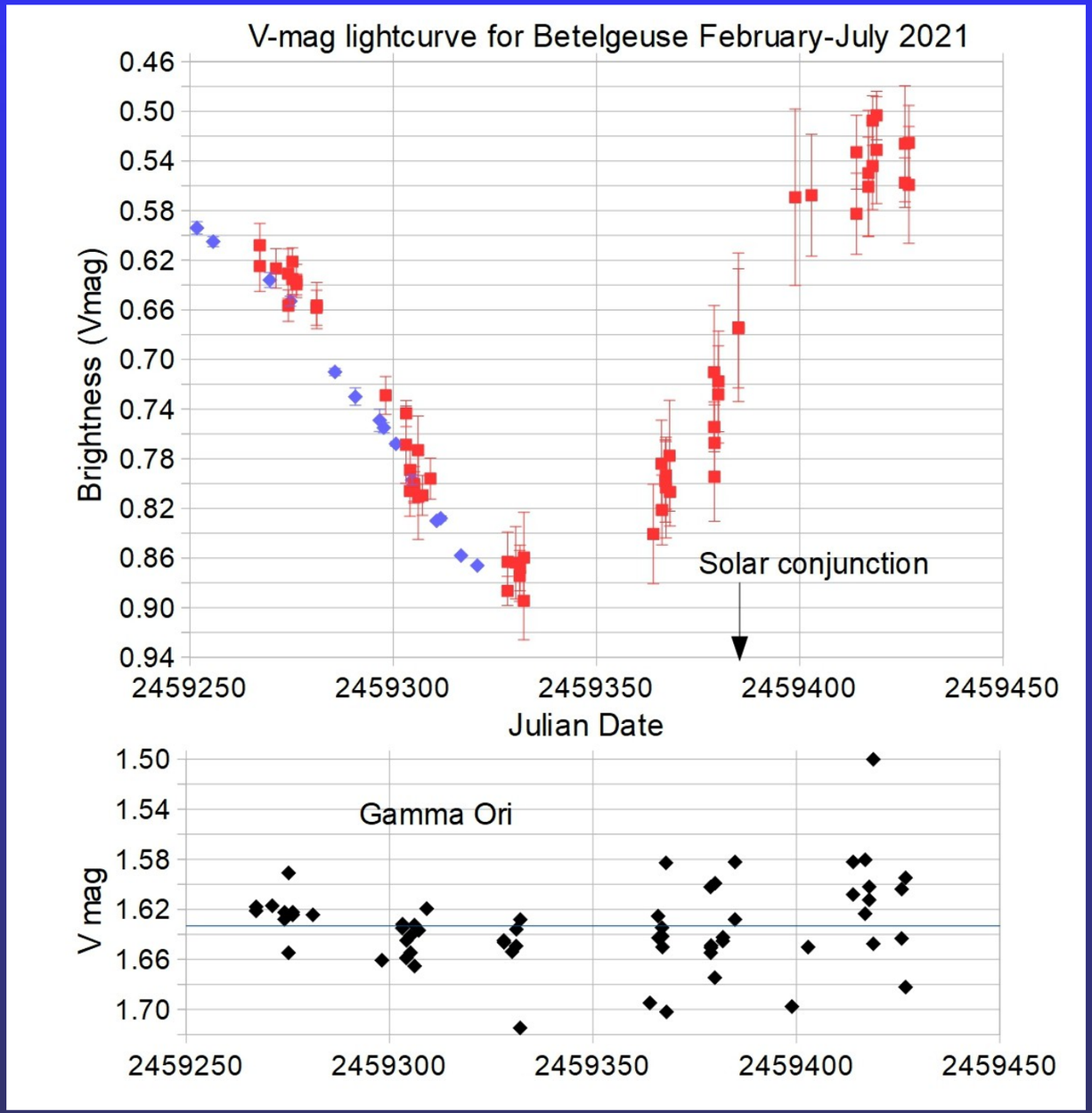
Sky view 2021-06-20 13:29 (solar noon)

Conditions:
m_v <= 2 mag; Variability (m_{min} – m_{max}) <0.1 mag

Star	V-mag (Hipparcos)	B-V	Sun distance 2021-06-20
Beta Ori	0.18	-0.03	33°
Alpha Cmi	0.40	0.43	32°
Beta Gem	1.16	0.99	25°
Alpha Gem	1.58	0.03	24°
Beta Tau	1.65	-0.13	7°
Zeta Ori	1.74	-0.2	25°
Beta Aur	1.9	0.08	21°
Gamma Gem	1.93	0	12°
Alpha Ari	2.01	1.15	51°

Check star:
Bellatrix (Gamma Ori) (m_v=1.64 mag, B-V=-0.22)

Results

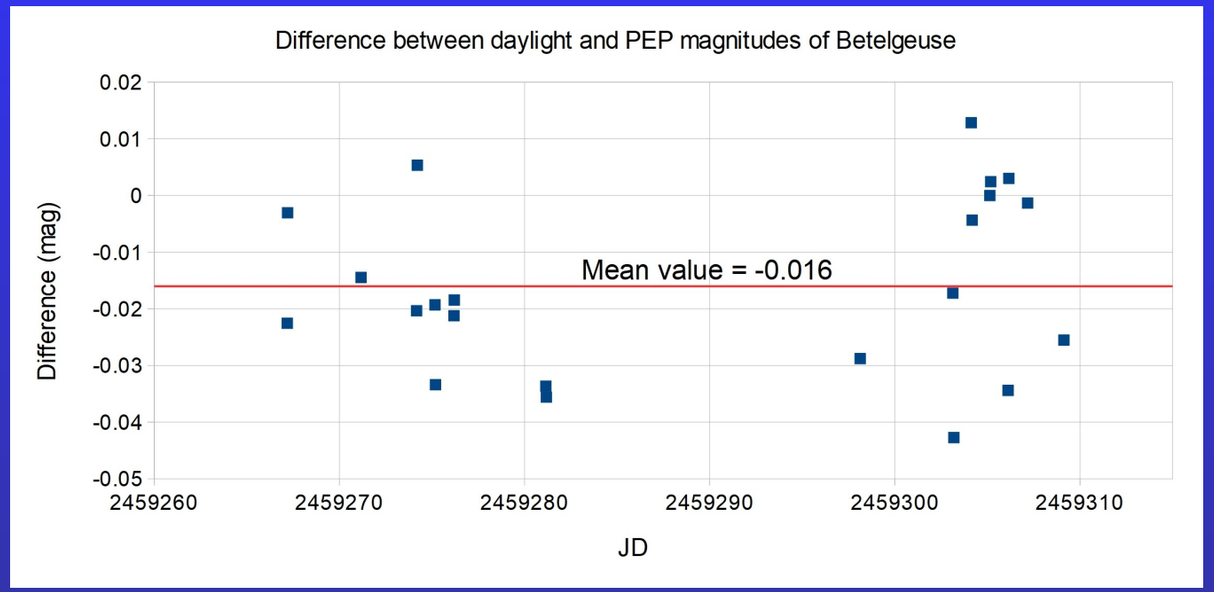


Betelgeuse
Blue: PEP data (Tom Calderwood)
Red: Daylight data

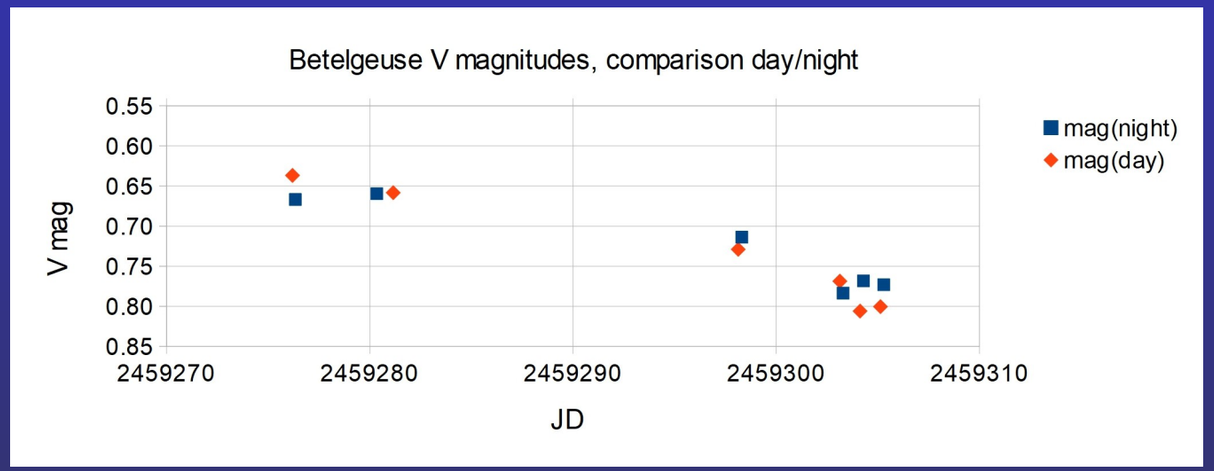
Mean Daylight V-mag errors:
February to April: 0.02 mag
May to July: 0.04 mag

Check star
Bellatrix (Gamma Ori)
Straight line: mean value (1.63 mag)

Results



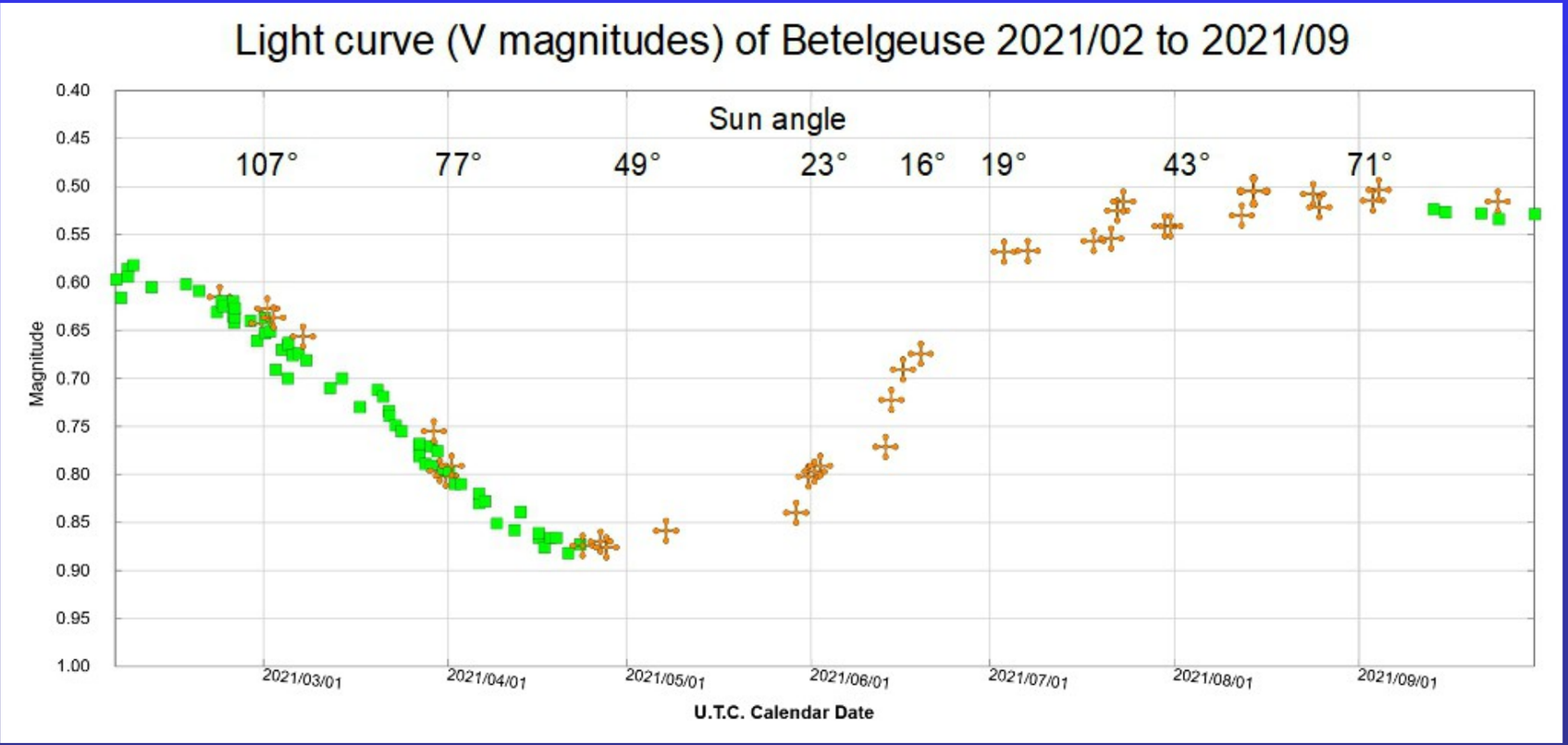
Difference of daylight data to interpolated PEP data (Tom Calderwood)



Comparison of daylight and night data (same method)

Red: daylight
Blue: night

Results



Green: Vmag data (PEP) from AAVSO database
Crosses: daylight Vmag data

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Conclusions

- Measurements of the V magnitude of Betelgeuse is possible with astronomical cameras at daylight, even at closest distance to sun
- The method gives reliable results with errors of 0.02-0.07 mag
- The solar conjunction gap of the light curve can be filled in the future with reliable data, if this (or similar) method is used also by other observers with suitable equipment

Thank you for your attention!