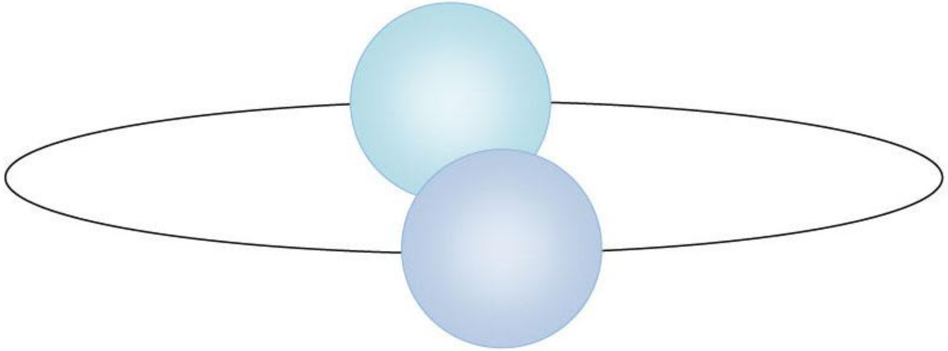
Radial velocity measurement

using the commercial spectrograph Dados by Baader Planetarium

Subject: **Menkalinan - Beta Aurigae,** the spectroscopic eclipsing binary star

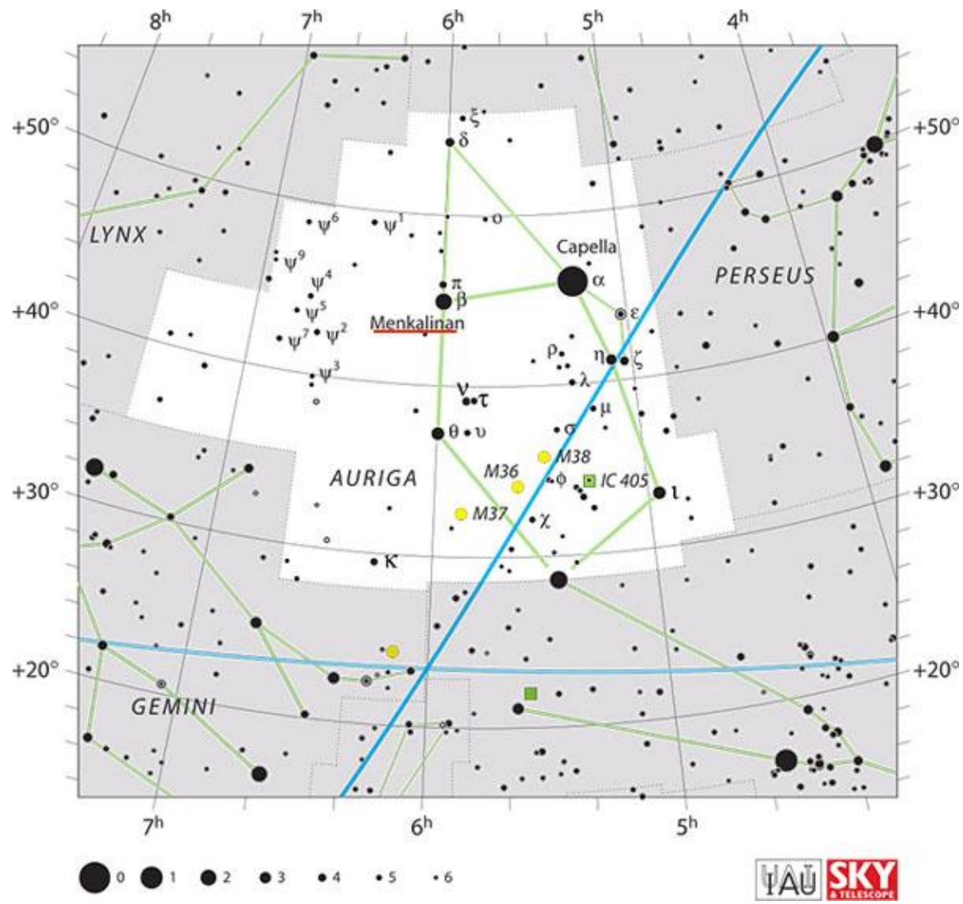


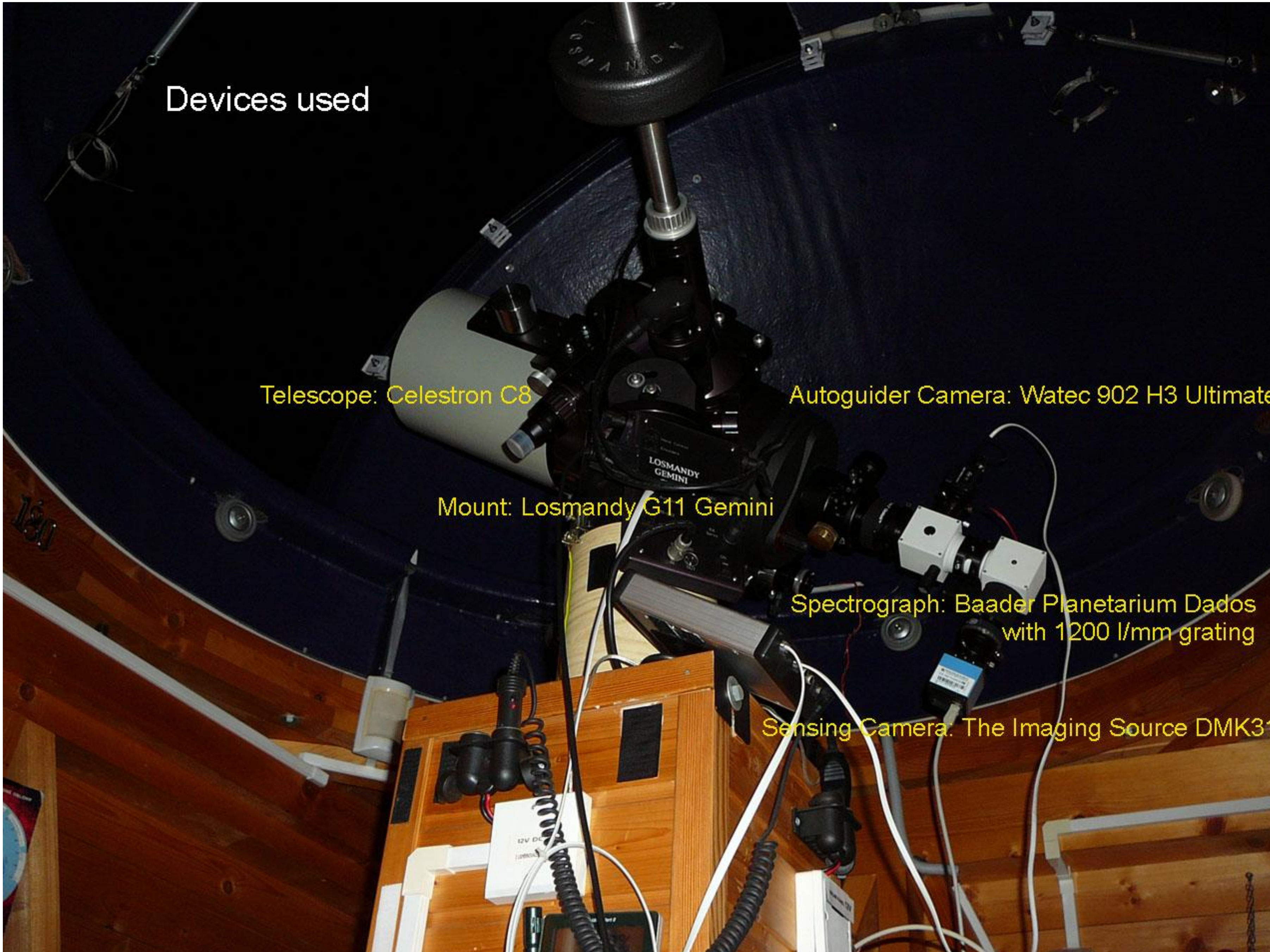
Miroslav Matoušek

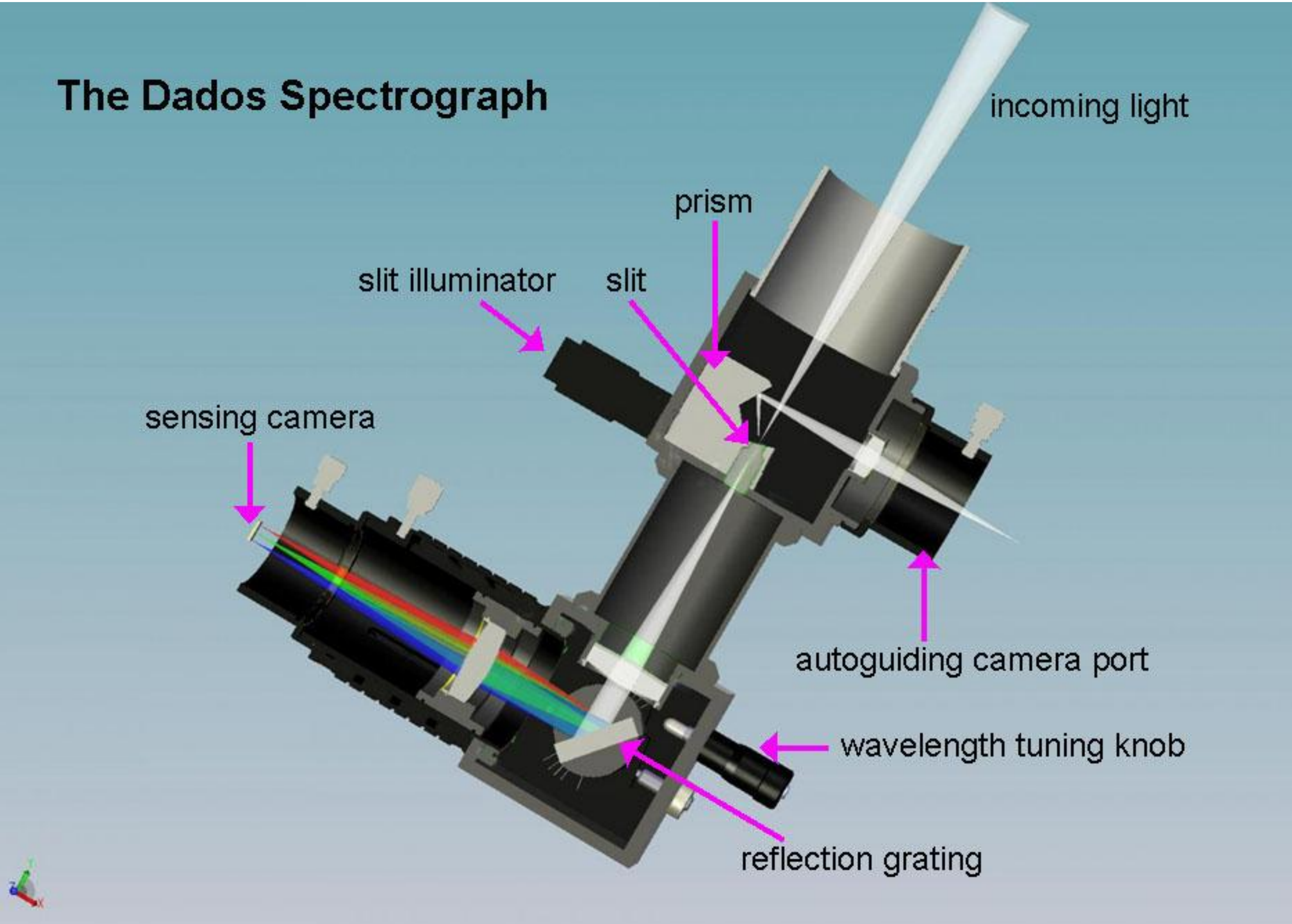
Facts:

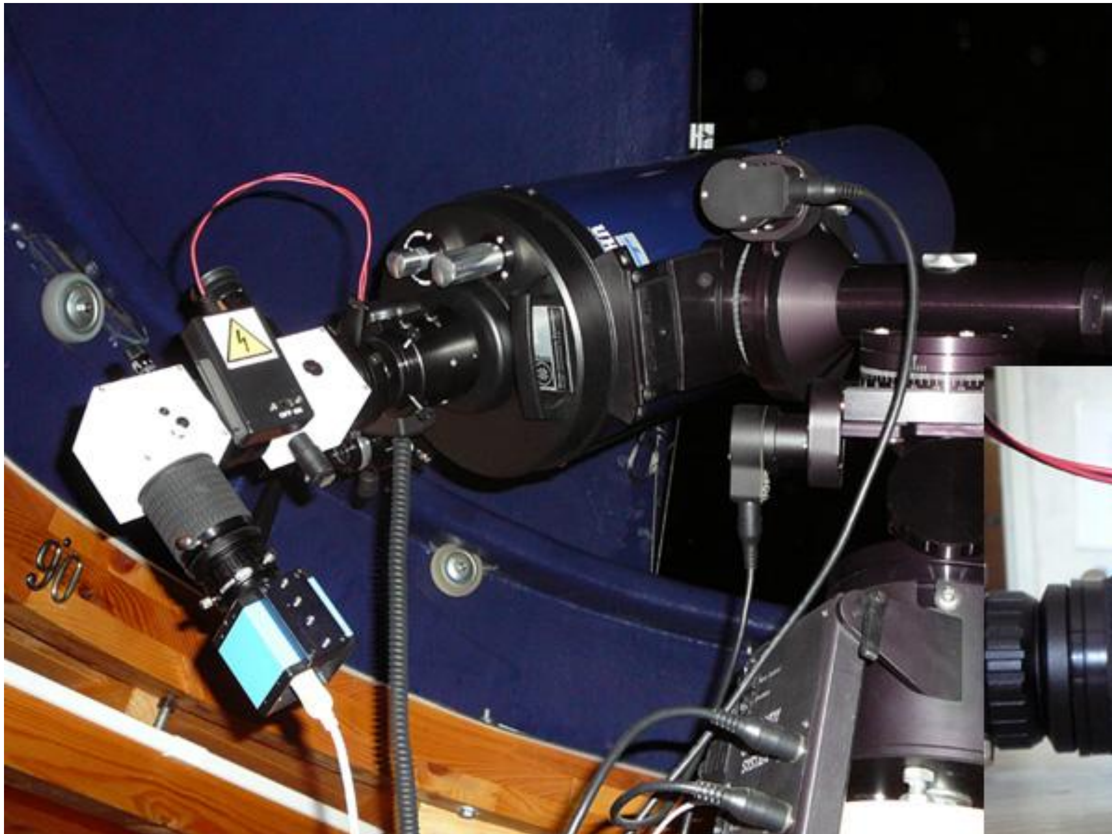
Menkalinan is a spectroscopic eclipsing binary which consists of two almost identical stars. Both stars are of spectral class A and have a surface temperature of about 9000 K. The diameter of each of the two stars is more than 2 times the diameter of the Sun. They orbit a common center of mass in a tight orbit at a distance of about 12 million kilometers. Orbital period is approximately four days. We can see the orbital plane almost edge-on. Every two days one star is partially eclipsed by the other star, but the luminosity drop is only a tenth of a magnitude. The binary is at a distance of 82 ly from the Earth and we cannot distinguish the binary components from our planet visually by a telescope. It is possible to discover them only through a spectrograph or by photometry. The data presented below I obtained using the instruments in my observatory which is situated in the suburbs of Prague.

Constellation of Auriga with Menkalinan:




Devices used
Telescope: Celestron C8
Autoguider Camera: Watec 902 H3 Ultimate
Mount: Losmandy G11 Gemini
Spectrograph: Baader Planetarium Dados
with 1200 l/mm grating
Sensing Camera: The Imaging Source DMK31
LOSMANDY GEMINI

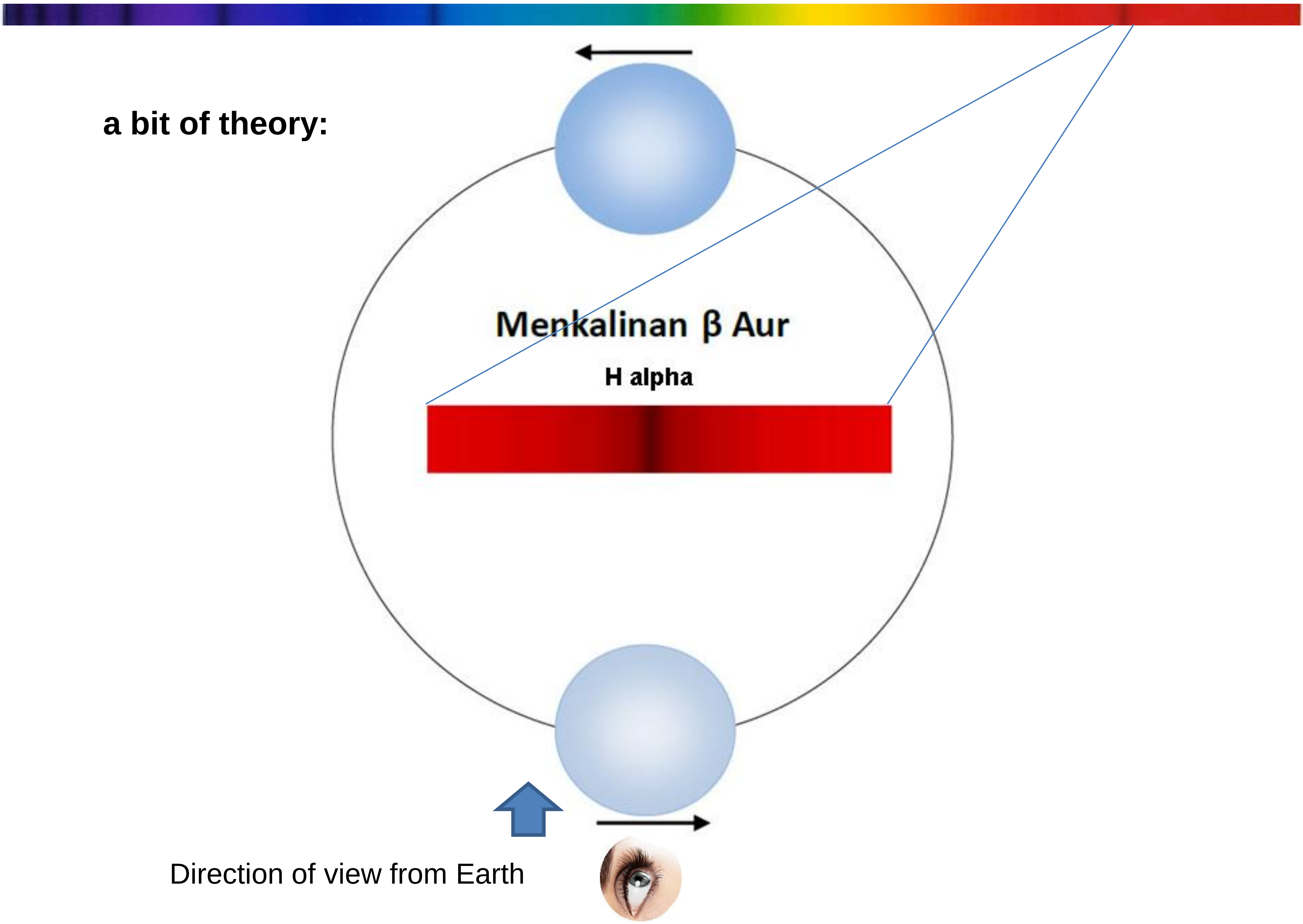

The Dados Spectrograph
incoming light
prism
slit illuminator
slit
sensing camera
autoguiding camera port
wavelength tuning knob
reflection grating



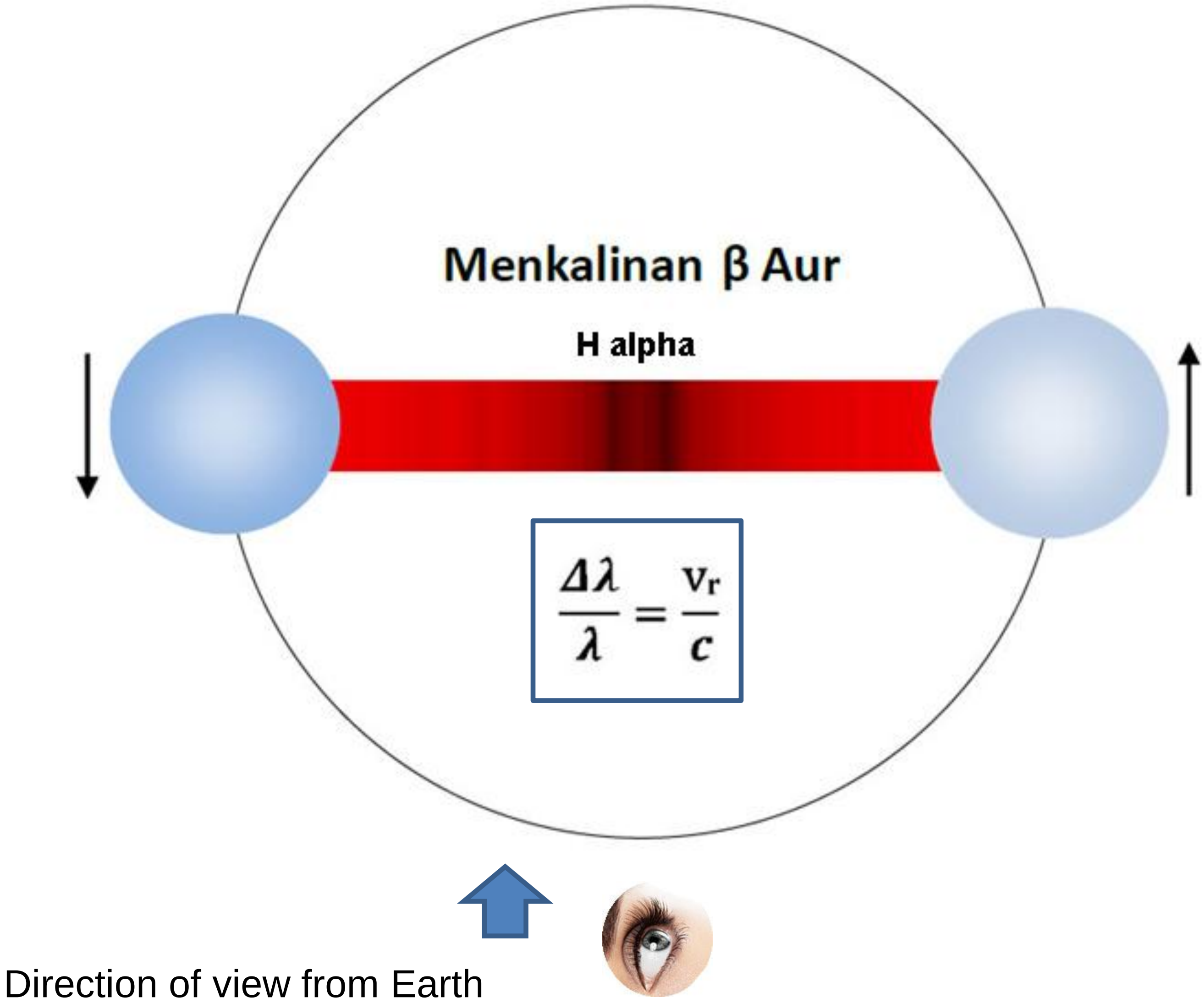
New Neon Calibration Unit

For my spectrograph I made a new push & pull calibration unit. Without any smallest change in configuration of the telescope – spectrograph – camera assembly, the neon glow lamp easily slides into the optical path and retracts again after calibration.

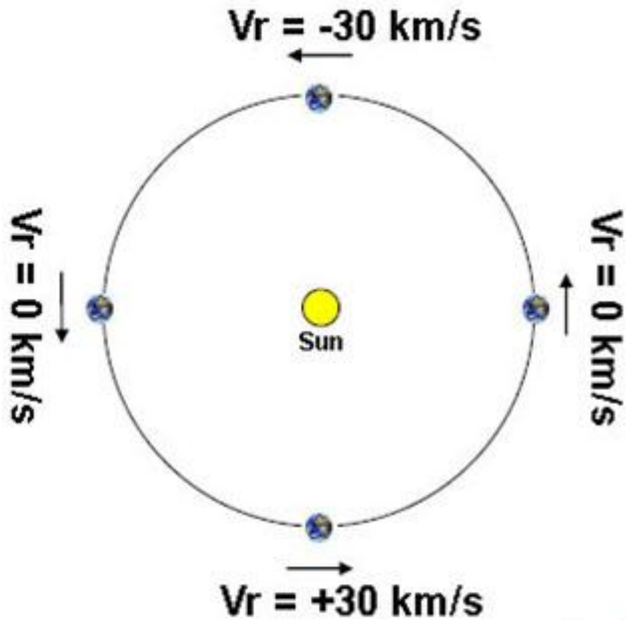
a bit of theory:

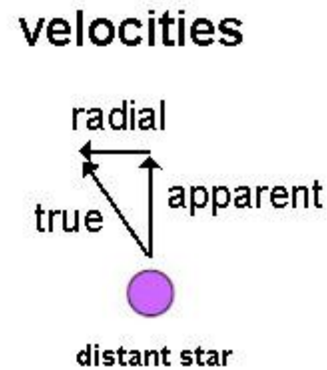


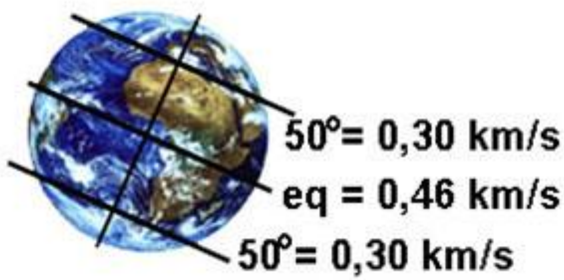
Doppler equation for spectroscopy



The principle of heliocentric correction





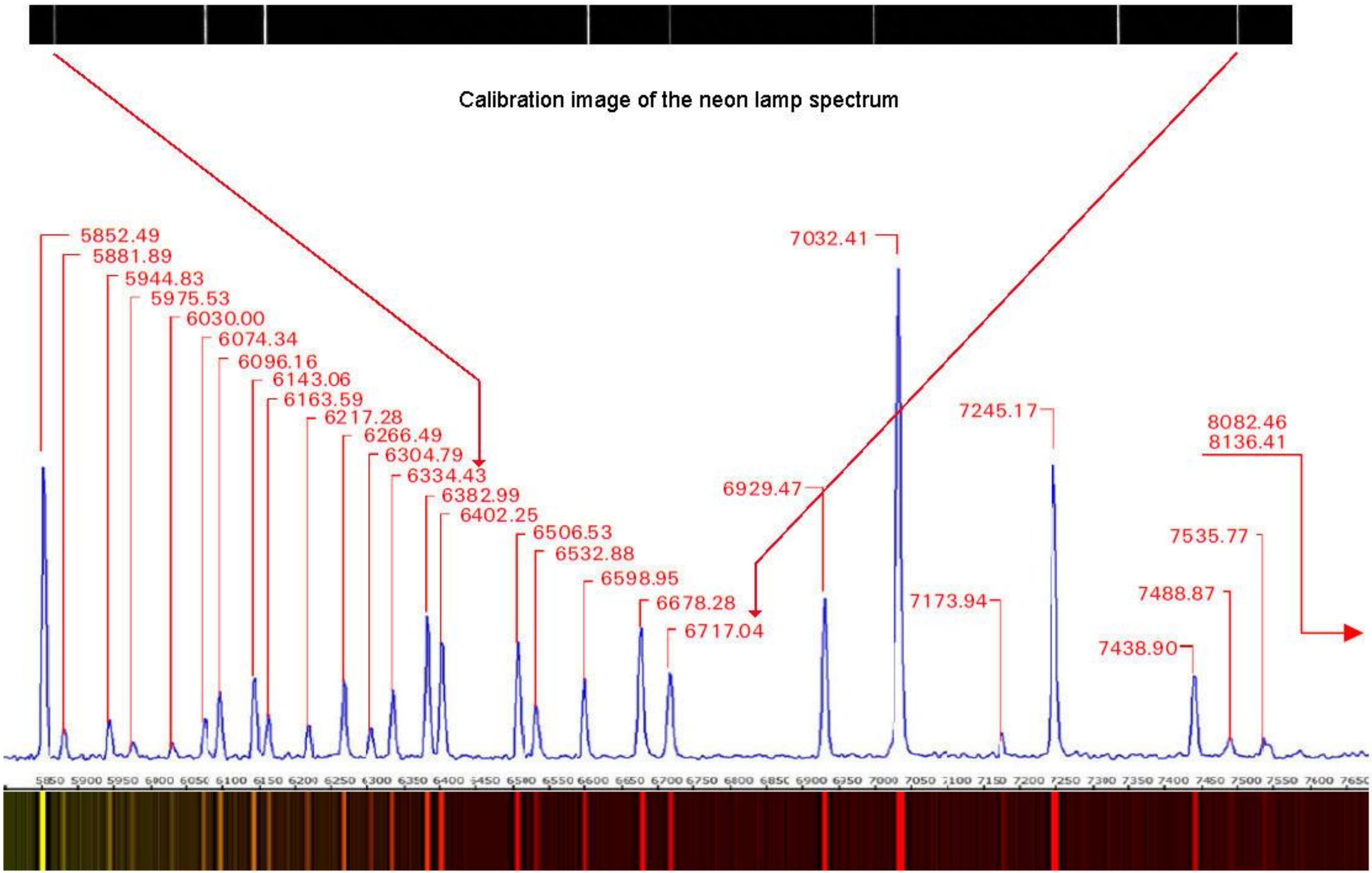


The measured radial velocity of the star must be corrected for the movements of the Earth

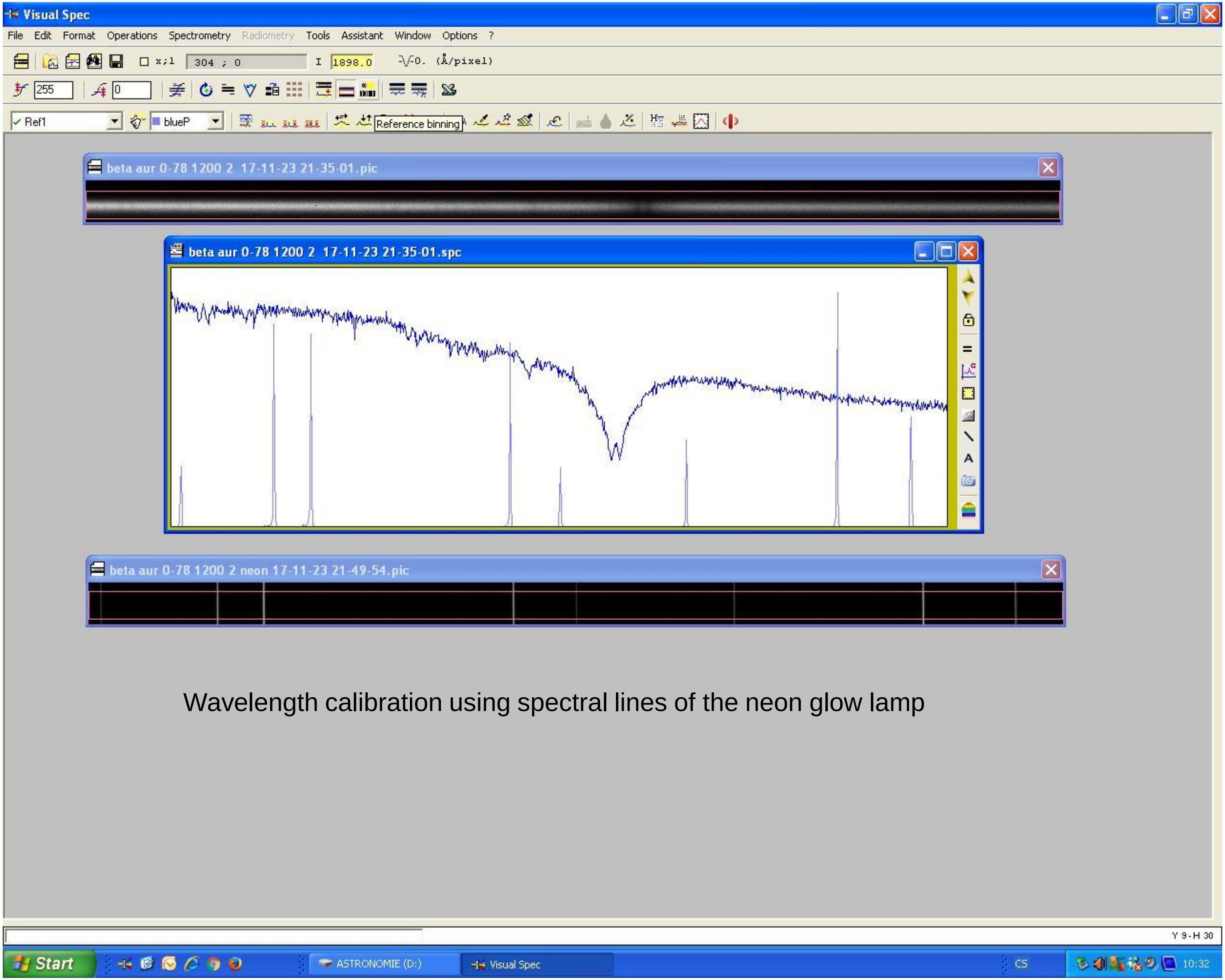
…and now practice:

23.11.2017 20:35 UT
exposure time 157 sec.

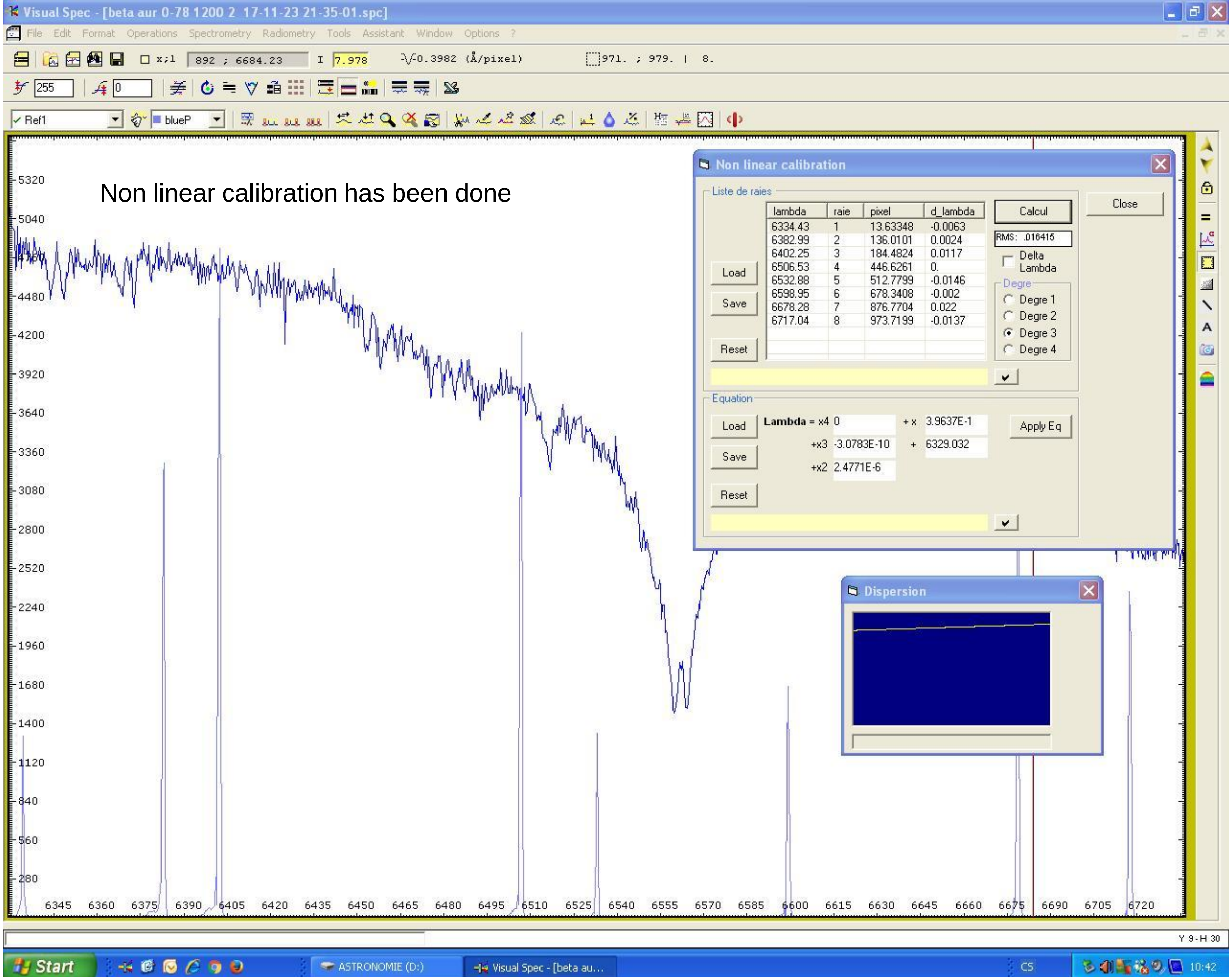
Original image of Beta Aur H-alpha region spectrum before DF calibration

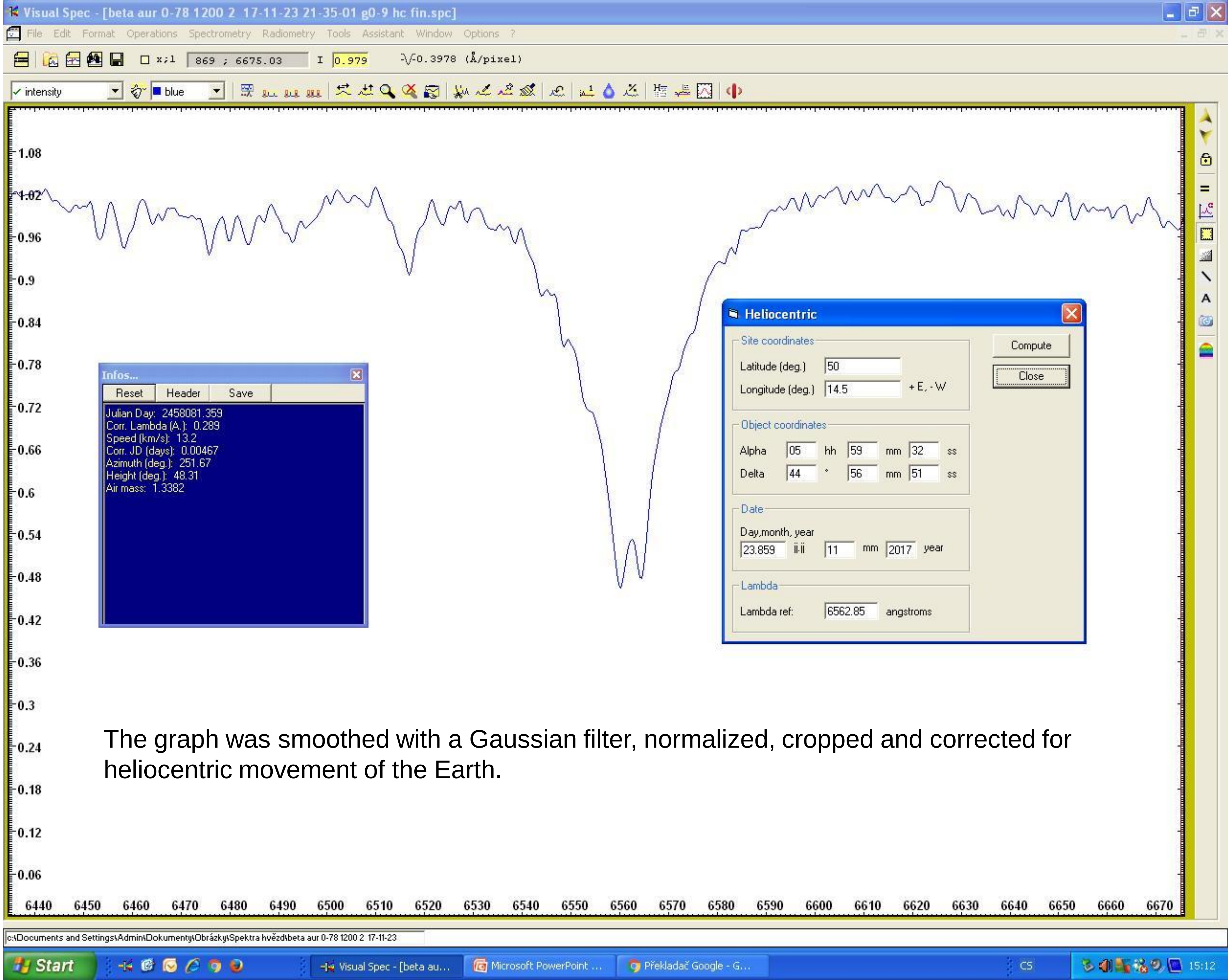


Calibration image of the neon lamp spectrum
5852.49
5881.89
5944.83
5975.53
6030.00
6074.34
6096.16
6143.06
6163.59
6217.28
6266.49
6304.79
6334.43
6382.99
6402.25
6506.53
6532.88
6598.95
6678.28
6717.04
6929.47
7032.41
7173.94
7245.17
7438.90
7488.87
7535.77
8082.46
8136.41

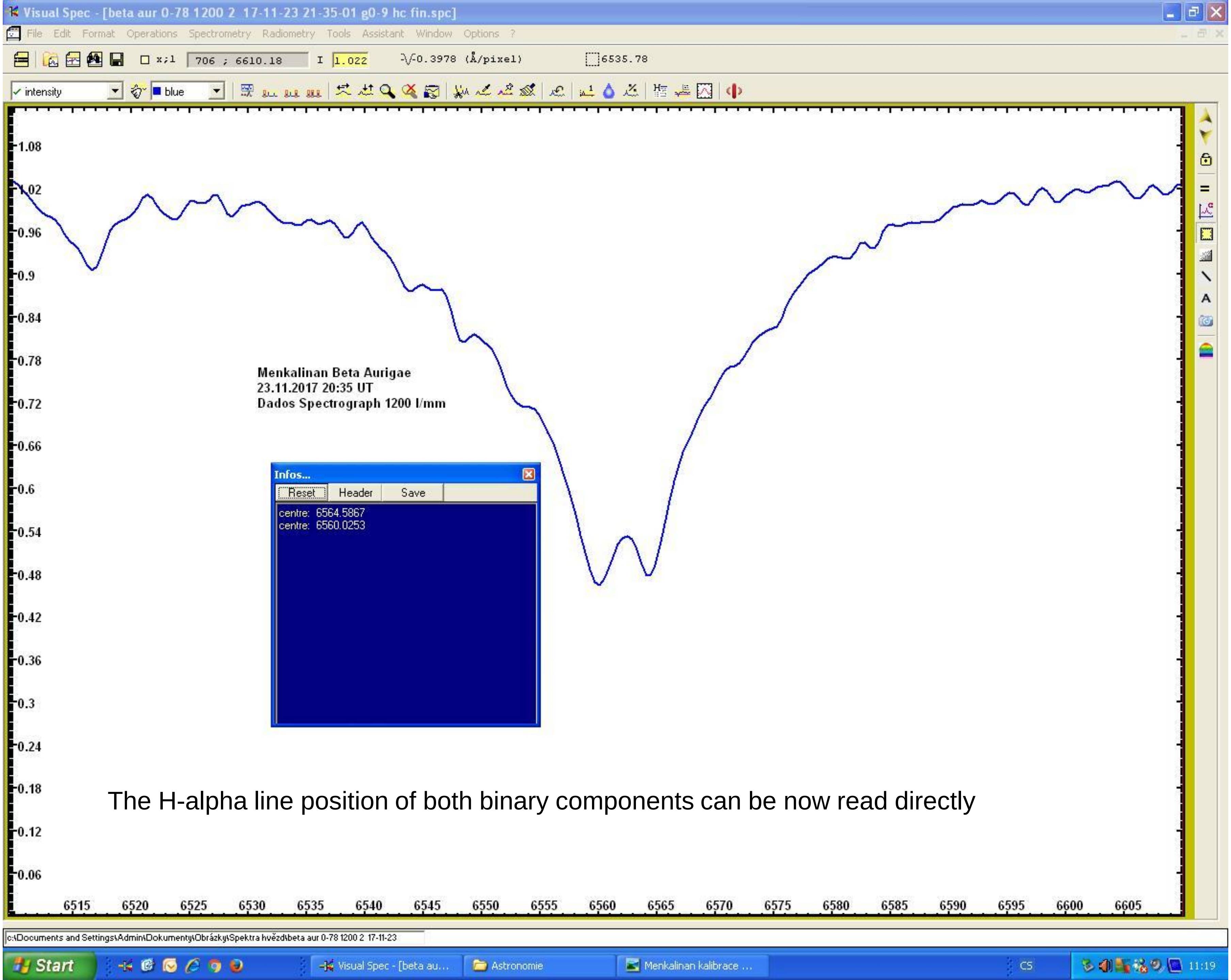


Wavelength calibration using spectral lines of the neon glow lamp


Visual Spec - [beta aur 0-78 1200 2 17-11-23 21-35-01.spc]
File Edit Format Operations Spectrometry Radiometry Tools Assistant Window Options ?
Non linear calibration has been done
Non linear calibration
Liste de raies
lambda raie pixel d_lambda
6334.43 1 13.63348 -0.0063
6382.99 2 136.0101 0.0024
6402.25 3 184.4824 0.0117
6506.53 4 446.6261 0.
6532.88 5 512.7799 -0.0146
6598.95 6 678.3408 -0.002
6678.28 7 876.7704 0.022
6717.04 8 973.7199 -0.0137
Calcul
RMS: .016415
Delta Lambda
Degre
Degre 1
Degre 2
Degre 3
Degre 4
Close
Load
Save
Reset
Equation
Lambda = x4 0 + x 3.9637E-1
+x3 -3.0783E-10 + 6329.032
+x2 2.4771E-6
Apply Eq
Dispersion
Start
ASTRONOMIE (D:)
Visual Spec - [beta au...
10:42



The graph was smoothed with a Gaussian filter, normalized, cropped and corrected for heliocentric movement of the Earth.



The H-alpha line position of both binary components can be now read directly

Menkalinan (β Aur) - Hα 6562.85 Å

Spectroscopic eclipsing binary system

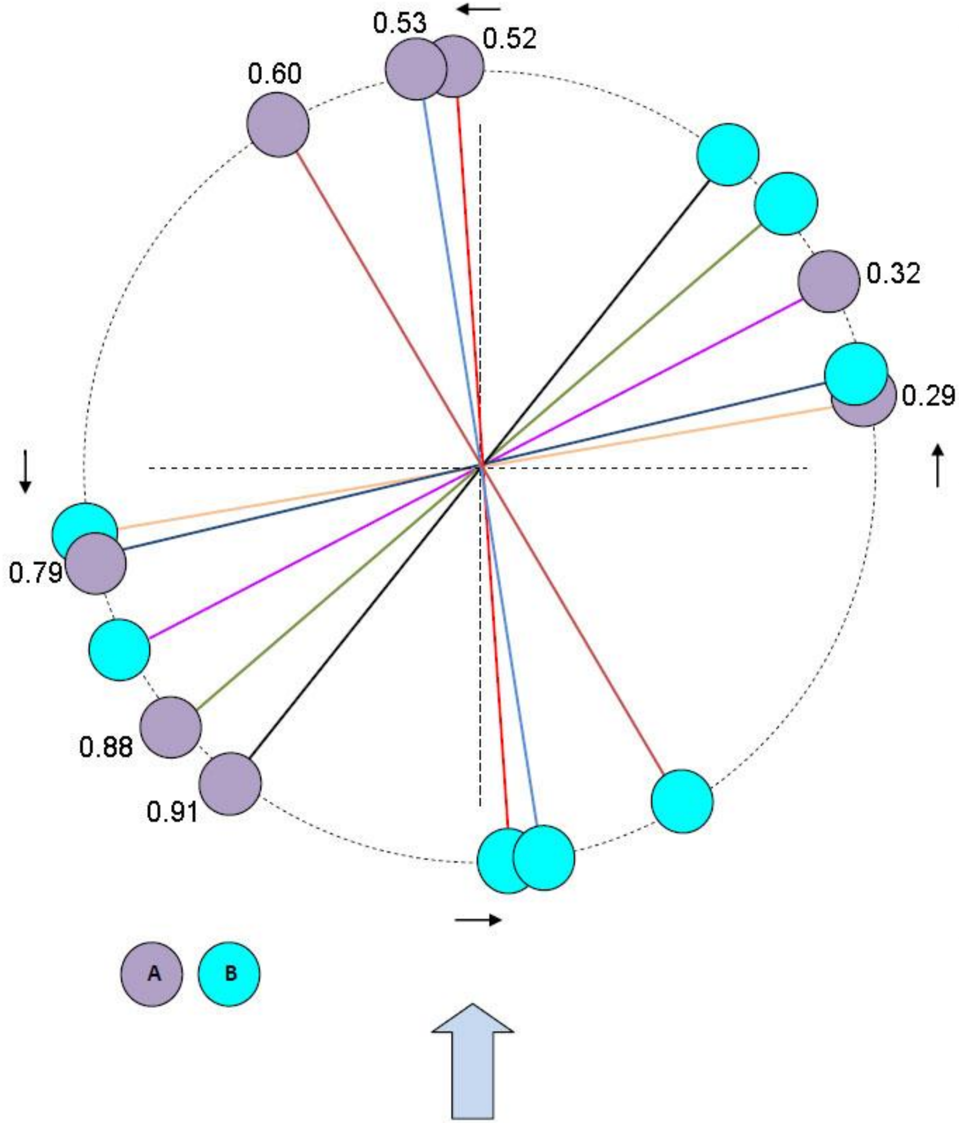
RA = 05 h 59 m 31.7 s Dec = 44° 56´ 50.7 ´´

spectrograph Dados 1200 l/mm   0.39 Å/pixel

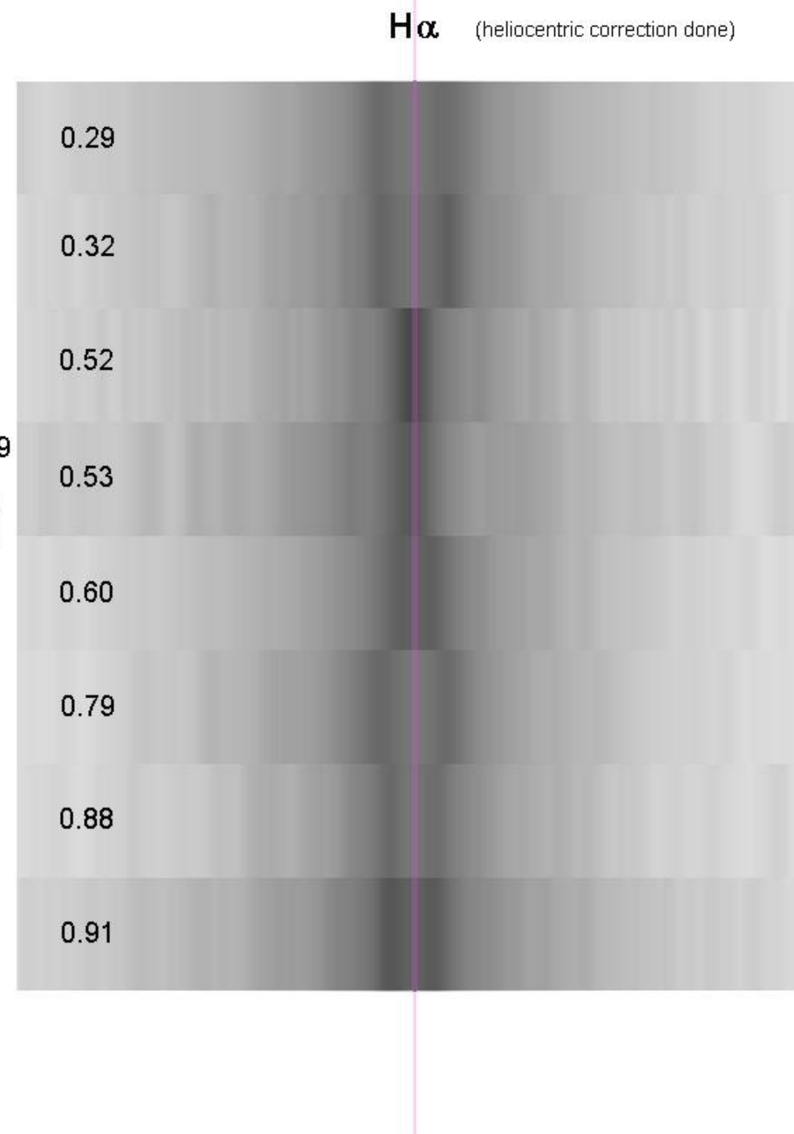
Heliocentric correction done

date (MDY)		UT	JD	λA (Å)	λB (Å)	Δλ|A-B|	$\Delta v_r \cdot \sin i$	$v_r A$	$v_r B$	λMC (Å)	A pos.	phase
11/22/2017		**19:46**	2458080.3237							**6562.42**	***189.70°***	***0.53***
11/23/2017		**20:35**	2458081.3576	**6560.03**	**6564.59**	**4.56**	**208.32**	**-108.27**	**100.05**	**6562.40**	*+94.00°*	***0.79***
12/07/2017		**20:47**	2458095.3660	**6564.48**	**6560.22**	**4.26**	**194.61**	**95.02**	**-99.59**	**6562.40**	*+193.48°*	***0.32***
12/21/2017		**22:26**	2458109.4347	**6561.03**	**6564.06**	**3.02**	**137.96**	**-63.04**	**75.38**	**6562.41**	*+198.96°*	***0.88***
01/26/2018		**17:16**	2458145.2194	**6561.08**	**6563.65**	**2.57**	**116.95**	**-59.85**	**57.56**	**6562.39**	*+13.12°*	***0.91***
02/13/2018		**22:40**	2458163.4417							**6562.41**	*+216.56°*	***0.52***
02/24/2018		**22:30**	2458174.4381	**6564.69**	**6560.15**	**4.54**	**202.83**	**100.04**	**-102.79**	**6562.40**	*+279.66°*	***0.29***
03/21/2018		**22:16**	2458199.4278	**6561.51**	**6563.52**	**2.01**	**91.82**	**-42.48**	**49.34**	**6562.44**	*+111.77°*	***0.60***

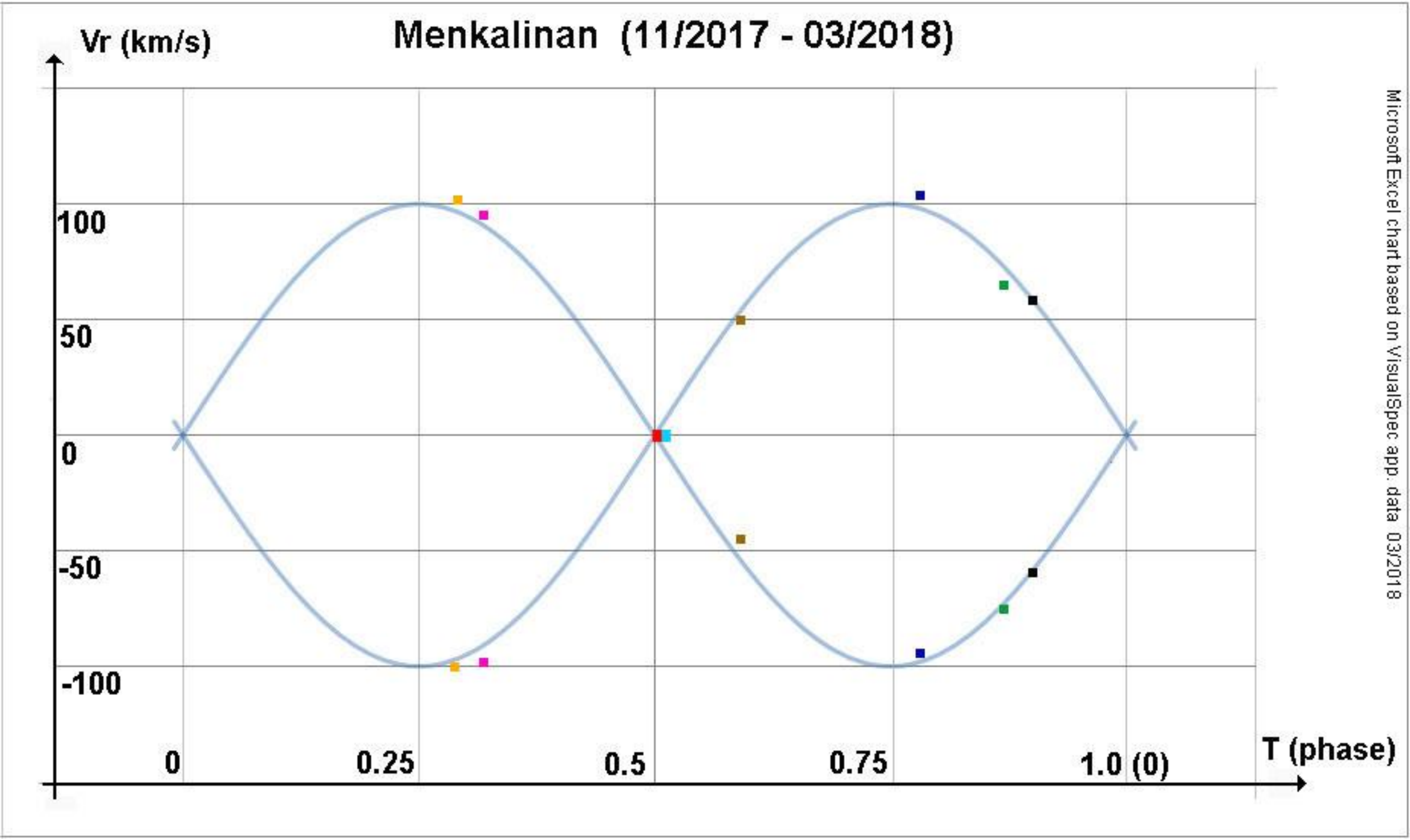
Menkalinan (β Aur)



Direction of view from Earth

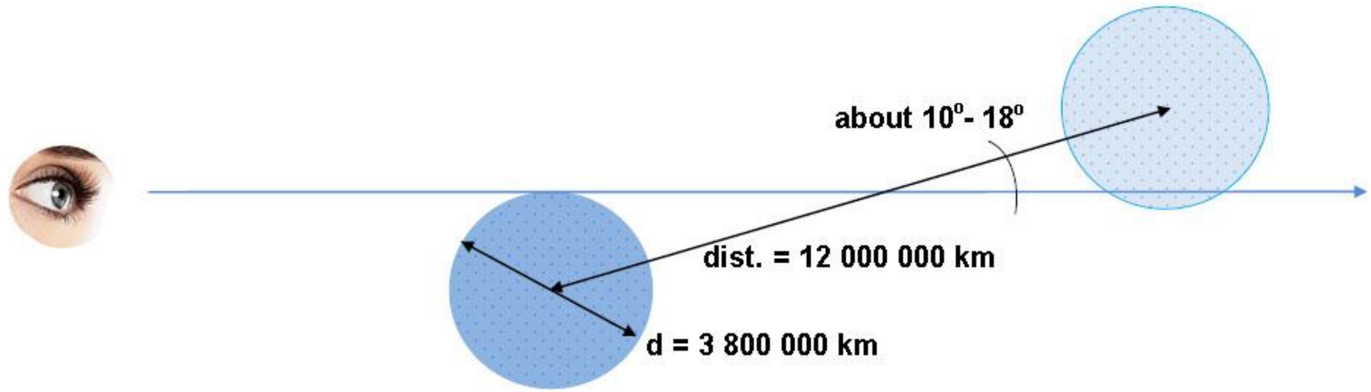


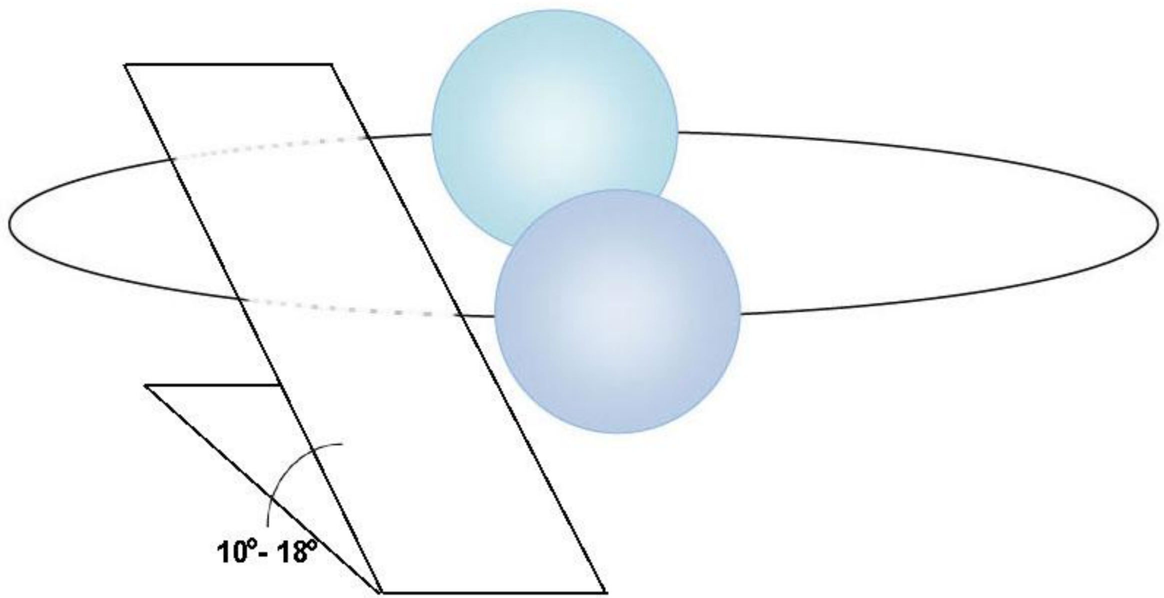
Miroslav Matoušek 03/2018


Menkalinan (11/2017 - 03/2018)
Vr (km/s)
100
50
0
-50
-100
0
0.25
0.5
0.75
1.0 (0)
T (phase)
Microsoft Excel chart based on VisualSpec app. data 03/2018

Menkalinan: orbit inclination

precise inclination is uncertain - photometric data are needed





Menkalinan (β Aur) calculations

Miroslav Matoušek (2018)

Based on the measured radial velocity data and the observed orbital period, the distance between the binary components and their mass can be calculated by using the Kepler's third law.

The two stars in the system do not have a negligible mass, so the equation has the following shape:

$$M_1 + M_2 = \frac{4 \cdot \pi^2 \cdot a^3}{\kappa \cdot T^2}$$

$$a = r_1 + r_2 = \frac{\Delta Rv_{max} \sin i \cdot T}{2 \cdot \pi}$$

κ: $6.674 \cdot 10^{-11}$ Nm^2kg^{-2} (gravitational constant)

a: distance between the binary components

T: 3,96 days = 342114 s

$\Delta Rv_{max} \cdot \sin i$ = 212.5 km/s

$$a = \frac{212.5 \cdot 342144}{6.283} = 11\,571\,796 \text{ km}$$

The orbit of Menkalinan is seen from Earth almost edge-on. The inclination appears to be between 72° and 80° (see the sketch), otherwise the magnitude drop during eclipse would be more distinct.

If we take the middle value i.e. 76°:

$$i = 76° \Rightarrow \sin i = 0{,}97 \Rightarrow \Delta Rv_{max} = 219 \text{ km/s}$$

$$a = \frac{219 \cdot 342144}{6.283} = 11\,925\,757 \text{ km} \sim 12 \cdot 10^9 \text{ m}$$

$$M_1 + M_2 = \frac{39.478 \cdot 1.69 \cdot 10^{30}}{6.674 \cdot 10^{-11} \cdot 1.17 \cdot 10^{11}} = 8.563 \cdot 10^{30} \text{ kg}$$

The stars are running around the common center of mass almost on the circular orbit and both have almost the same mass. For Menkalinan it means $M_1 = M_2 = 4.2815 \cdot 10^{30}$ kg. The mass of the Sun is $1.99 \cdot 10^{30}$ kg =1 $M_{\odot}$. Each star of the binary system thus has a mass slightly larger than two masses of the Sun = 2.15 $M_{\odot}$. Literature says that the masses of the components are 2.35 $M_{\odot}$.

Both stars are early A class subgiants (A1 IV).