Blue Horizontal Branch Stars

Stars are 7, but BHBs are at least ~~a~~ 5 :)

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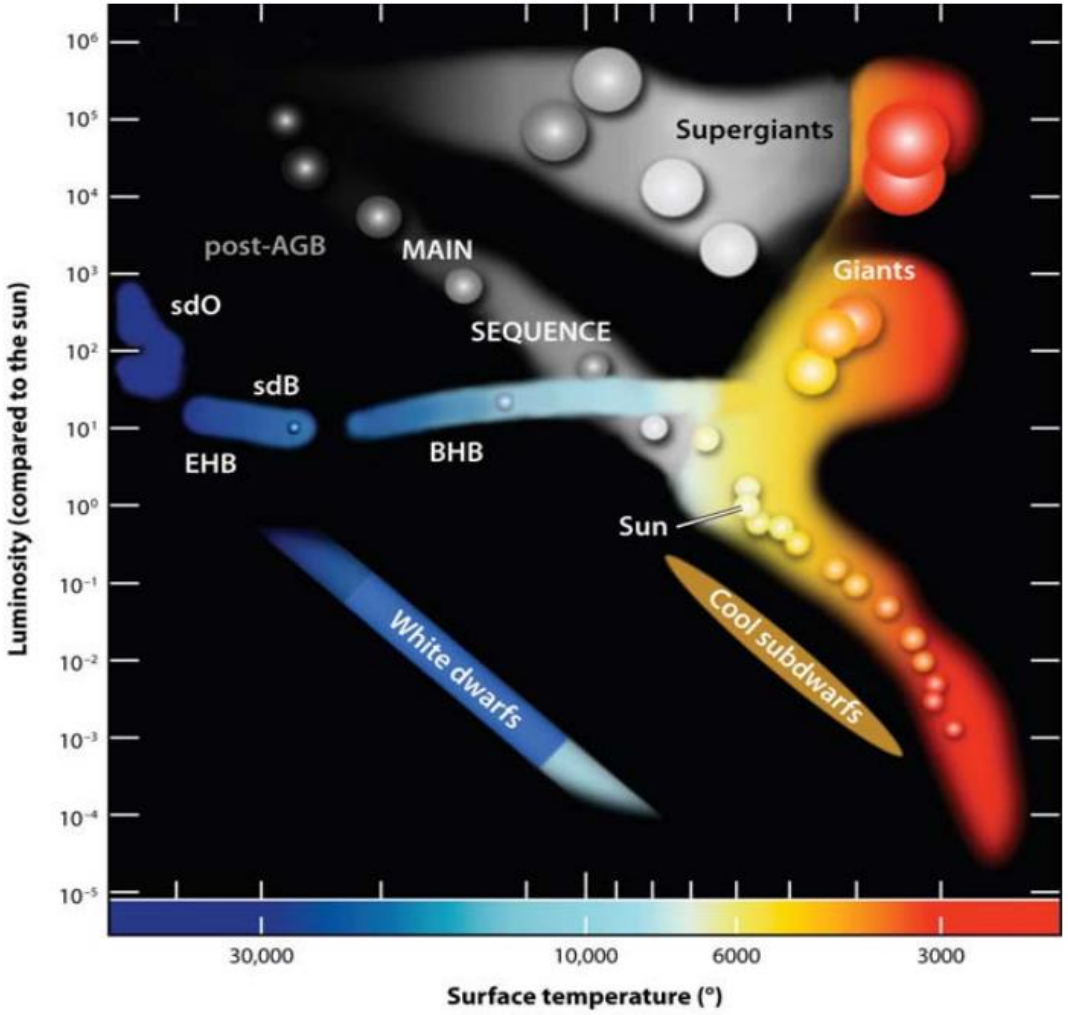
What are Blue horizontal branch stars?

- Evolve from low-mass main sequence stars
- Population II stars
- (Sub-)dwarfs
- Spectral types A, B

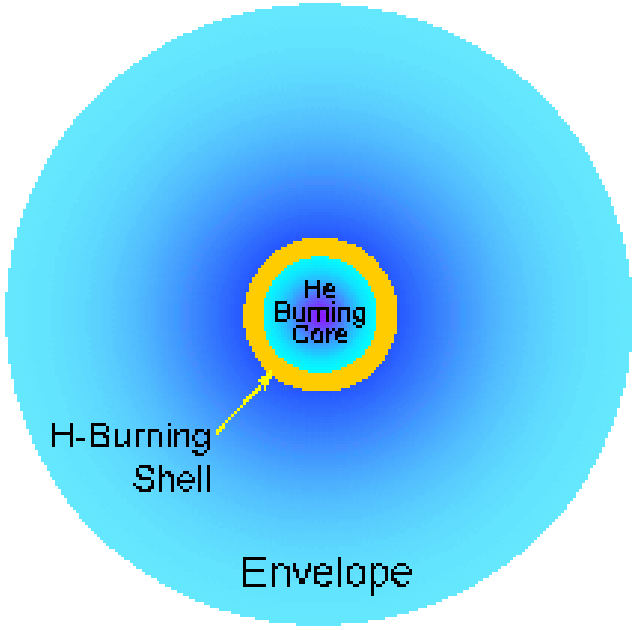


Evolution of Horizontal Branch Stars

- In low mass stars the core is radiative
- Hydrogen gets exhausted in the core
- Leaves the main sequence once core hydrogen burning ceases
- H-shell burning starts → Core contracts, envelope expands
- Star evolves onto the Red Giant Branch
- Large amount of the outer envelope is lost by the strong solar wind
- Critical temperature for helium burning ~108 K is reached for a core mass of about 0.48 $M_{\odot}$ Due to energy losses via neutrinos in the center, helium is ignited in a shell

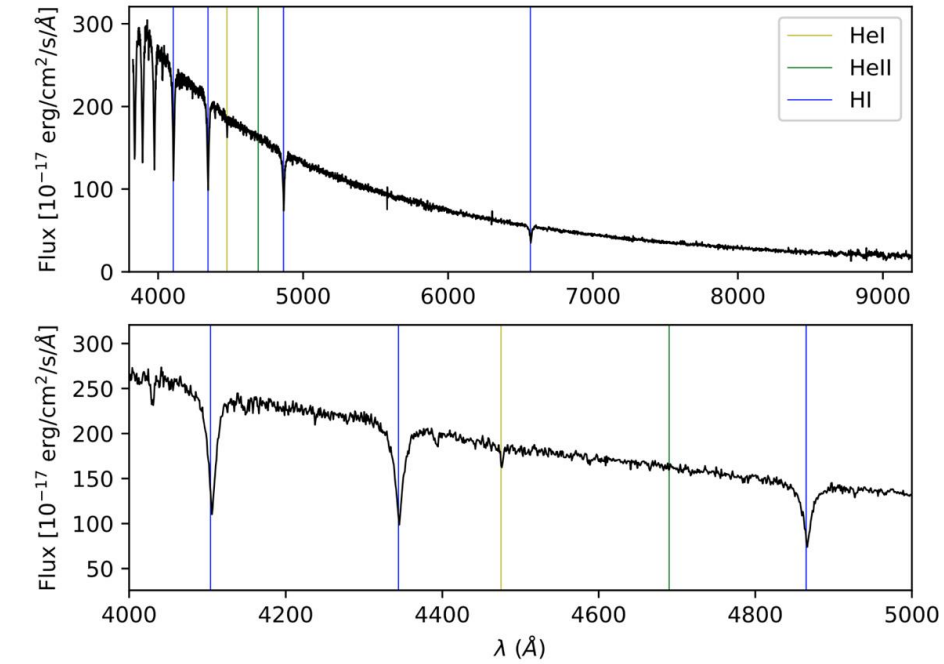
More Evolution

- Due to high temperature dependency of the 3α reaction $\langle \sigma v \rangle \sim$
- ρT^{40}.
- HE flash→ Degeneracy is lifted → Core expands, density drops → Stable He-core burning.
- Different mass loss η on the RGB leads to different thickness of the hydrogen envelopes.
- The thinner the hydrogen envelope, the bluer the HB star



BHB Characteristics:

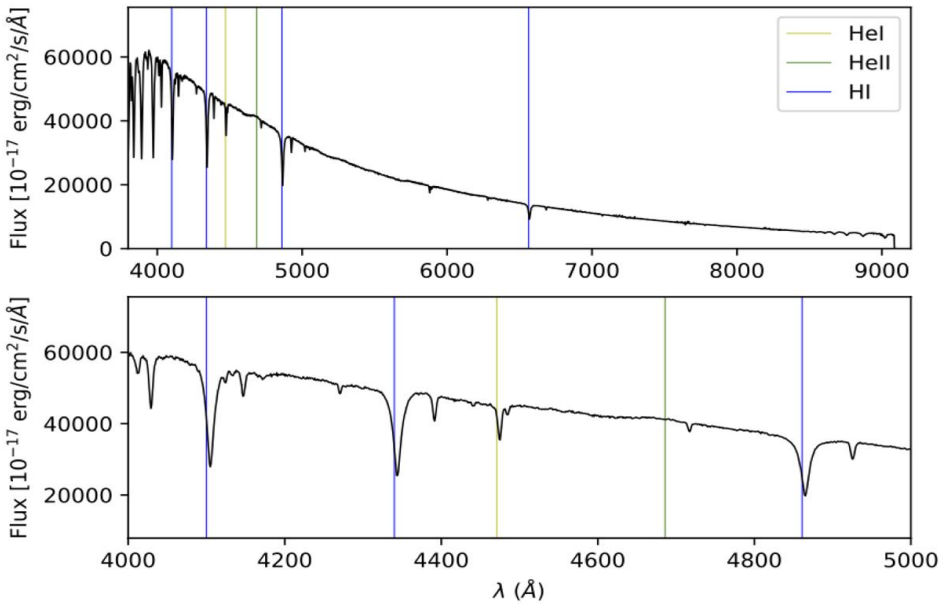
Old, metal-poor, Core He burning, H burning envelope
Sharper absorption lines



Geier et al. (2015)

MS Characteristics:

- Younger, higher metallicity
- Deeper He lines
- Rounded absorption lines due to high rotation



Culpan et al. (2021)

How are spectrums important for us?

- Temperature
- Surface gravity
- Chemical composition
- Stellar winds
- Magnetic fields
- Projected rotation
- Radial velocity

Luminosity, Radius, and Radial velocity

$$L = 4\pi\sigma R^2 T_{eff}^4$$

$$R = \frac{\theta}{2\omega}$$

$$\frac{\Delta\lambda}{\lambda} = \frac{v_{rad}}{c}$$

Motivation

Prove that BHB stars evolve from main-sequence stars without the need for stellar interactions with other external factors

Acquire spectra for BHB candidates over several epochs to identify radial velocity variations caused by orbiting binary companions;

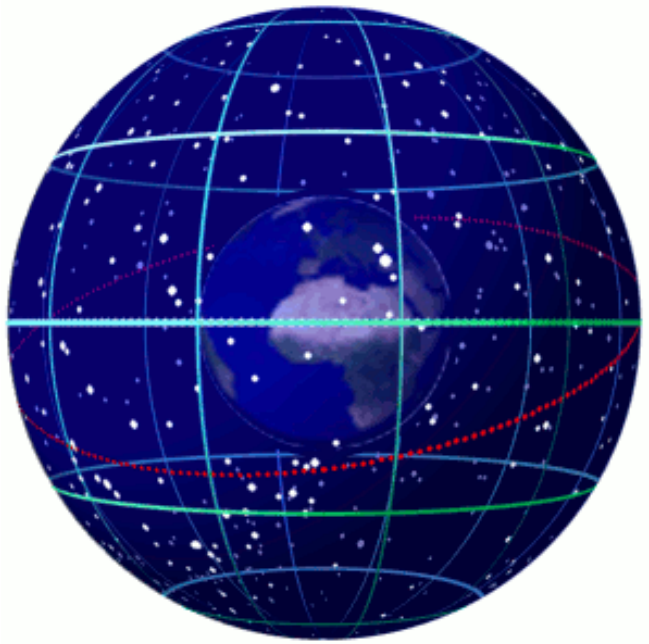
Compare the number of BHB binary systems to the population seen in main-sequence objects

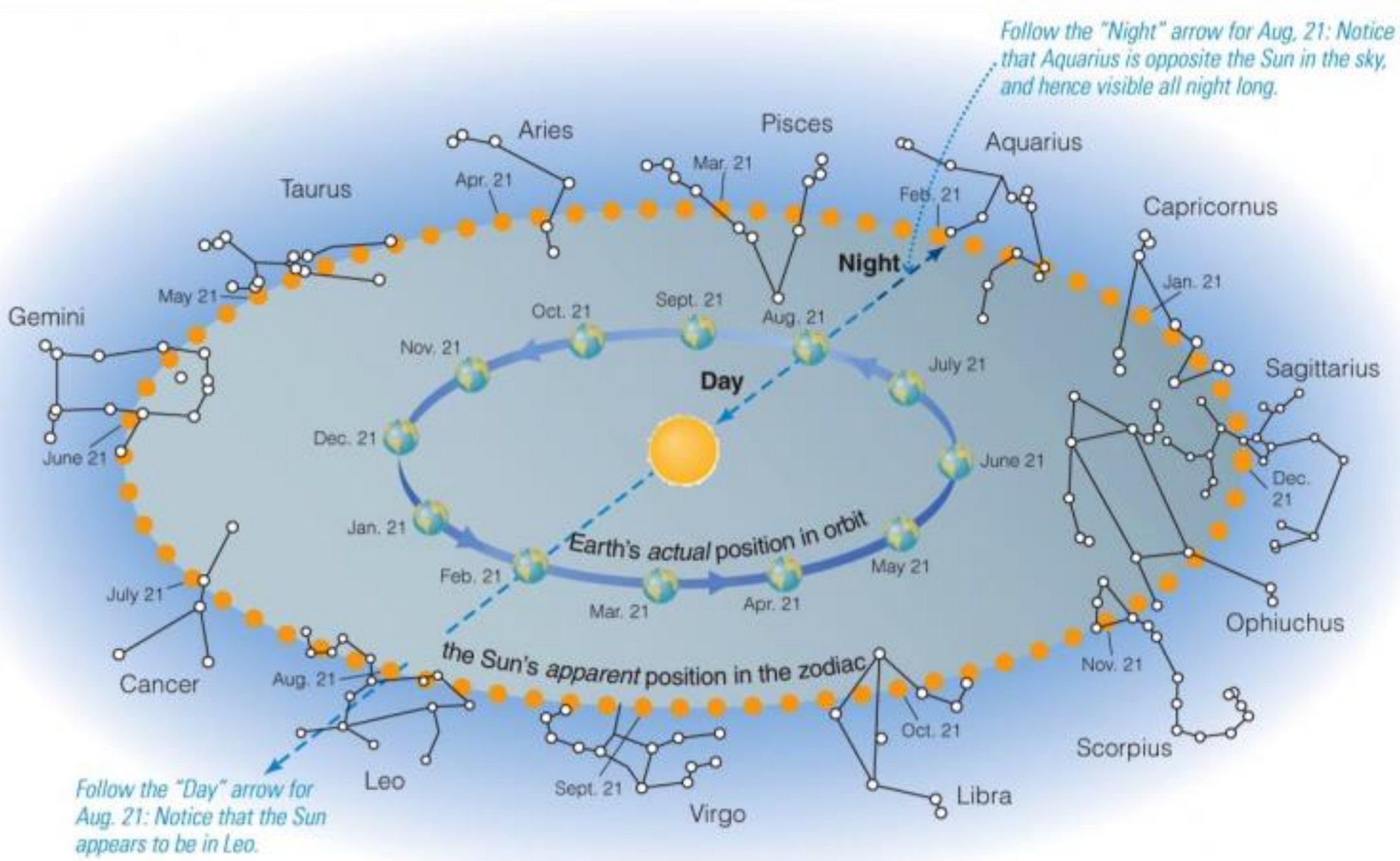
Preparing the Target list

What are the constraints???

Visibility

The Star has to be visible at night.
Everyone can not see every thing. Why?
Earth is a huge sphere
Rotation of Earth on its axis
Earth is orbiting Sun



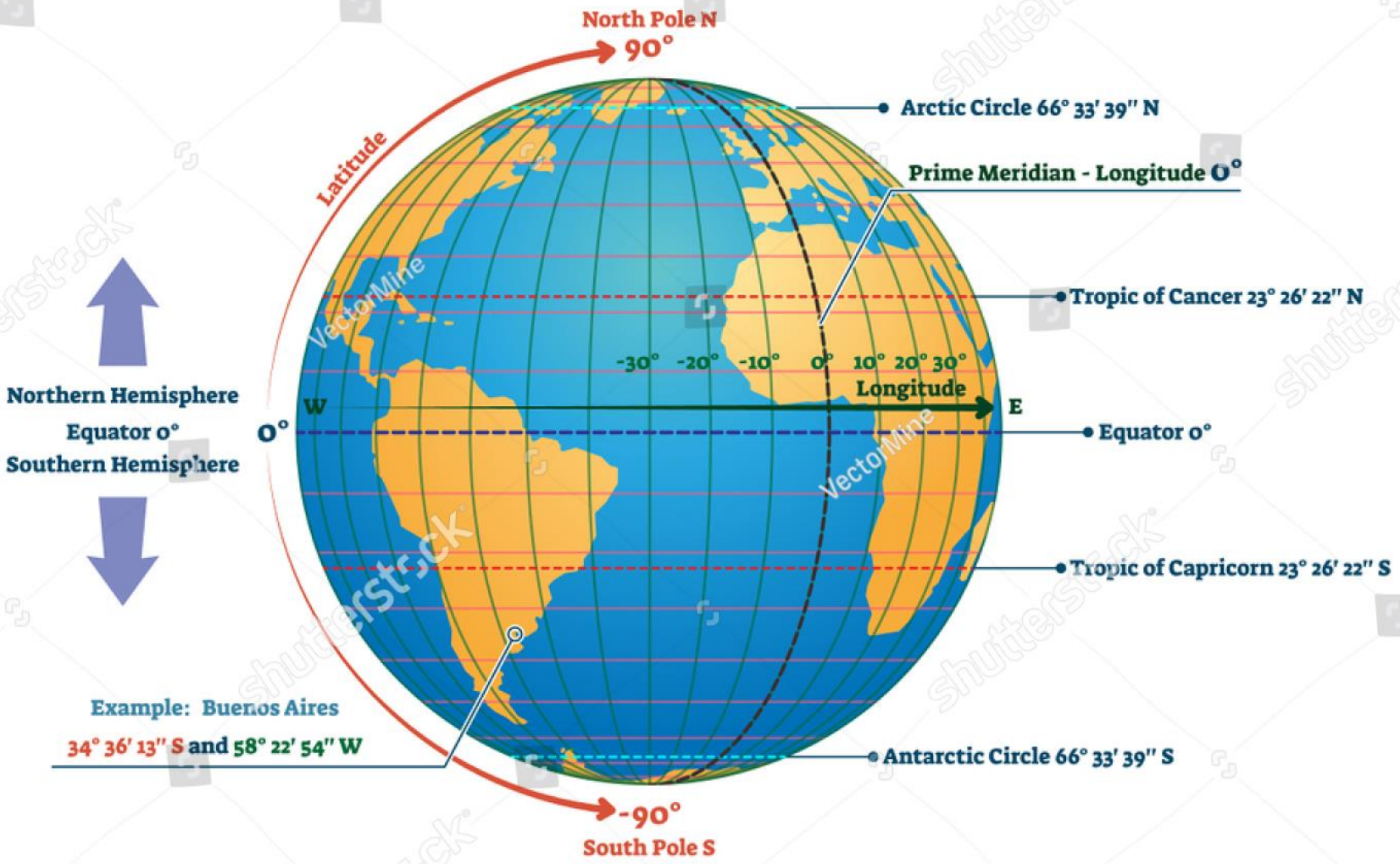


Using Celestial Coordinates

Latitude and Longitude

To label locations on Earth

EQUATOR
LATITUDE AND LONGITUDE



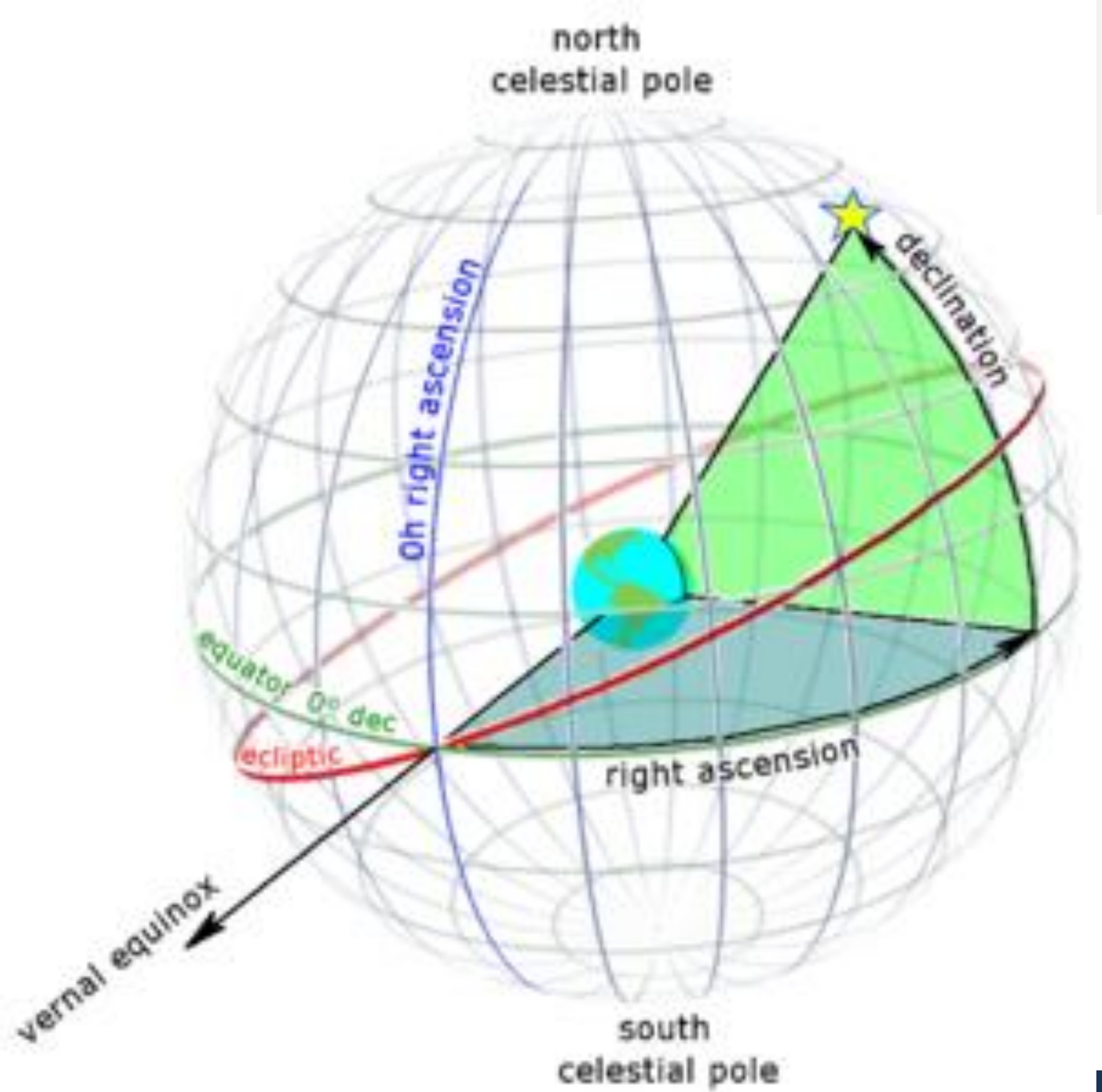
Using Celestial Coordinates

Latitude and Longitude

- To label locations on Earth

Right Ascension (RA) and Declination (dec)

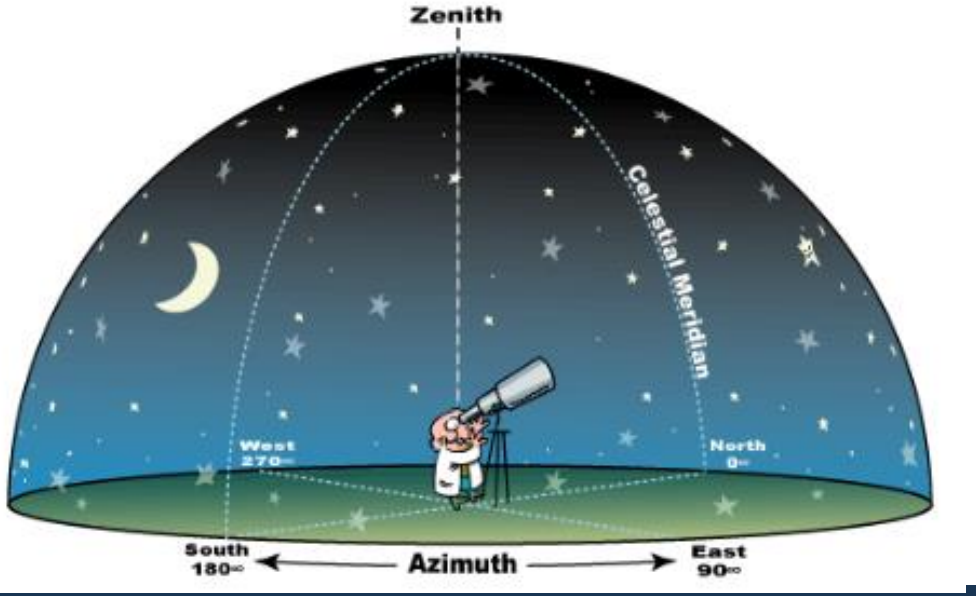
- For Astronomical Objects


north
celestial pole
declination
0h right ascension
equator 0° dec
ecliptic
right ascension
vernal equinox
south
celestial pole

Where are We???

Ondrejov 2m: 49°54'54.6"N 14°46'51.6"E

Zenith: 49° approx



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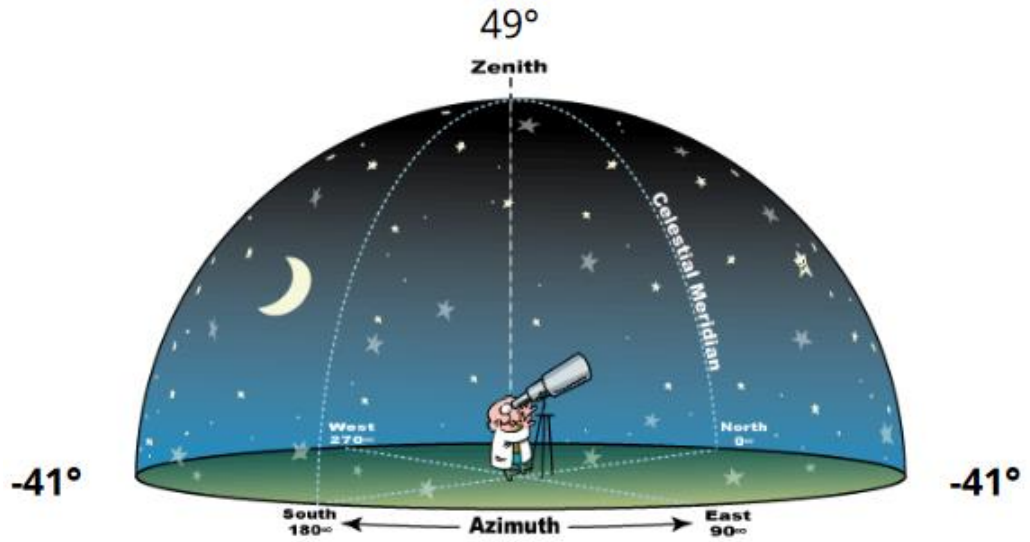
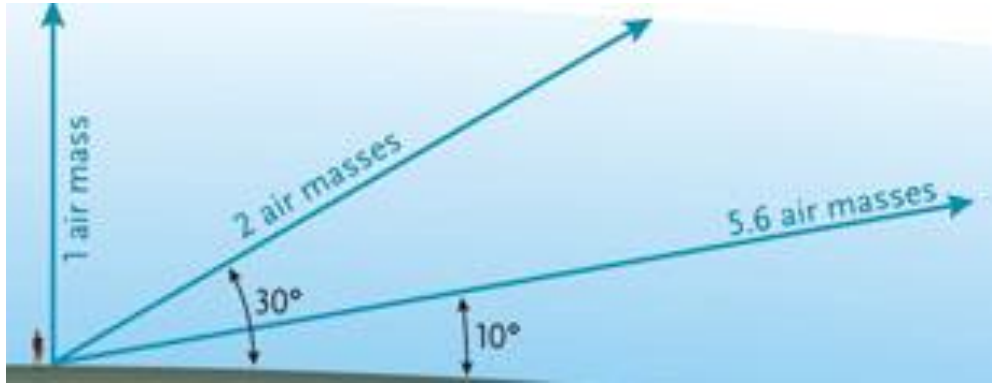


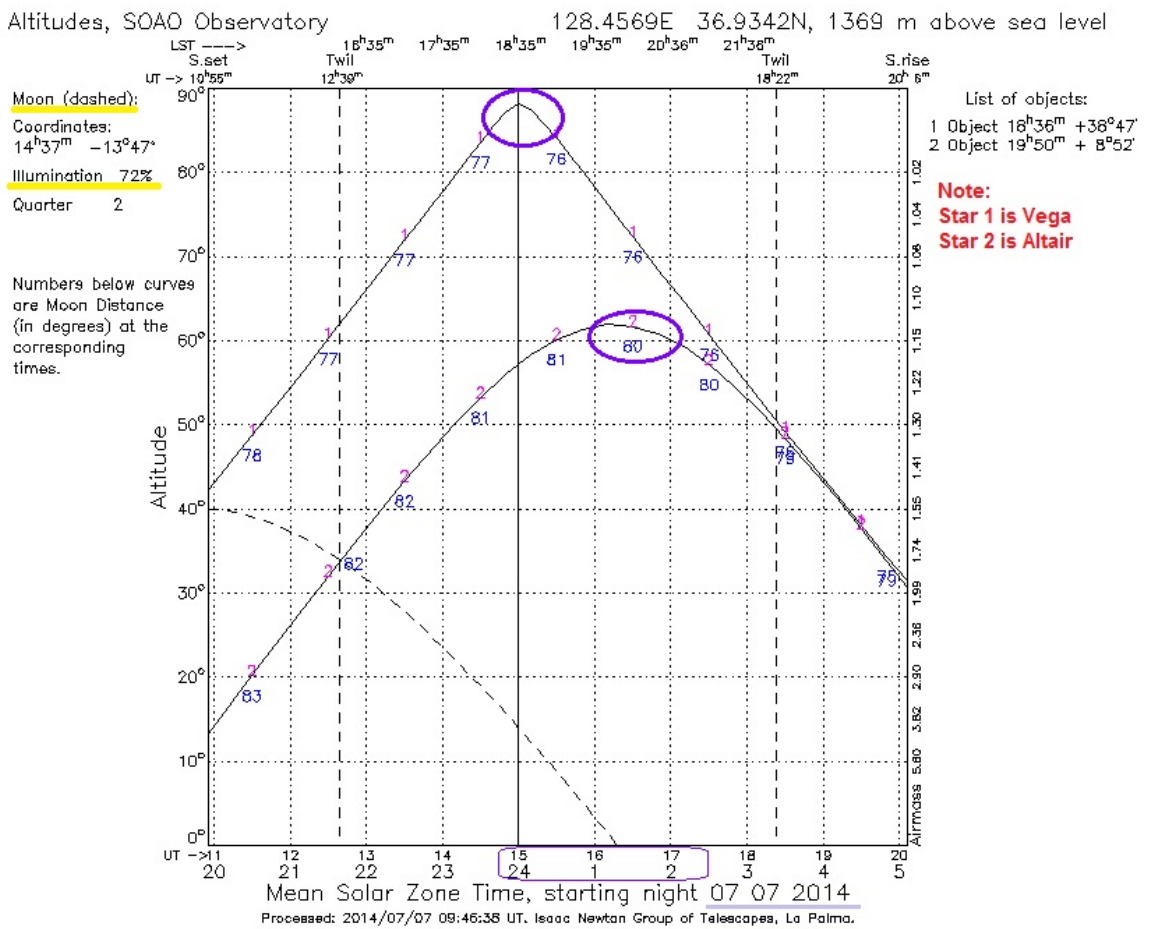
Visibility Window

- Amount of Air Mass between Eyes and Star is greater near the Horizon
- Air is not a pure optical medium
- Light is absorbed mostly by the air
- Light Pollution is significantly higher near the horizon
- Best to observe the stars at least 30° above the horizon
- In our case declination will become 11°



Observing Strategy

Efficient Observing Sequence
Brightness of targets
Bad Weather → Bright Stars
Clear Night → Faint Stars



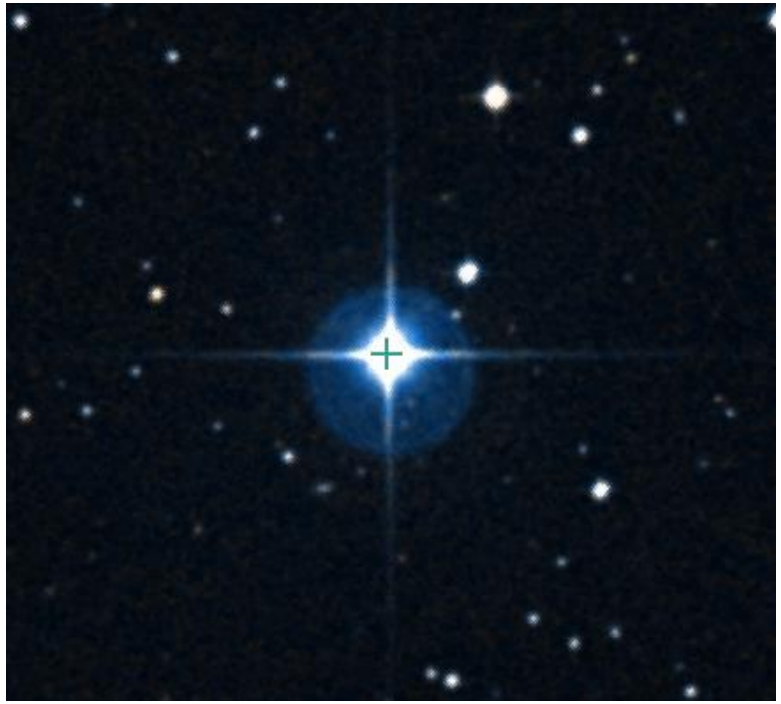
Finding Charts

Identify Star on the Charts.

Visual Tools

→ Simbad

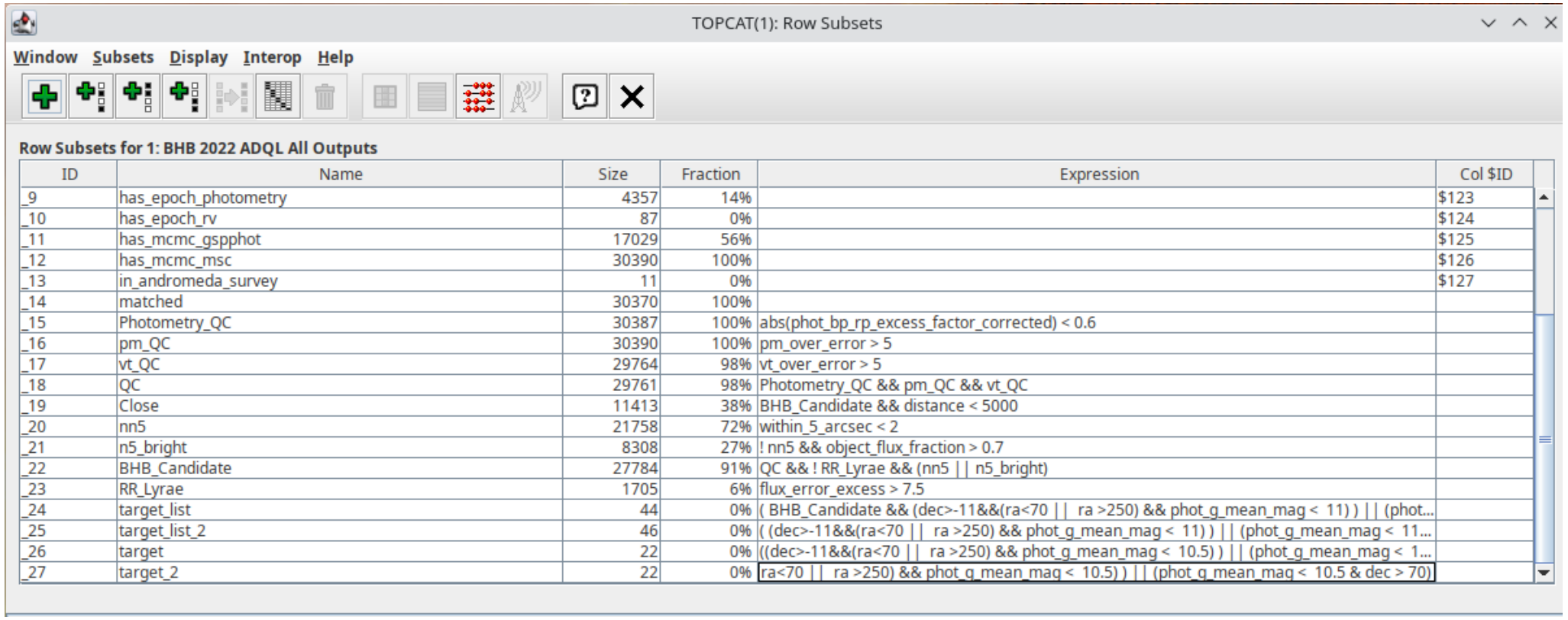
→ Stellarium



Creating our Target List for spectroscopy

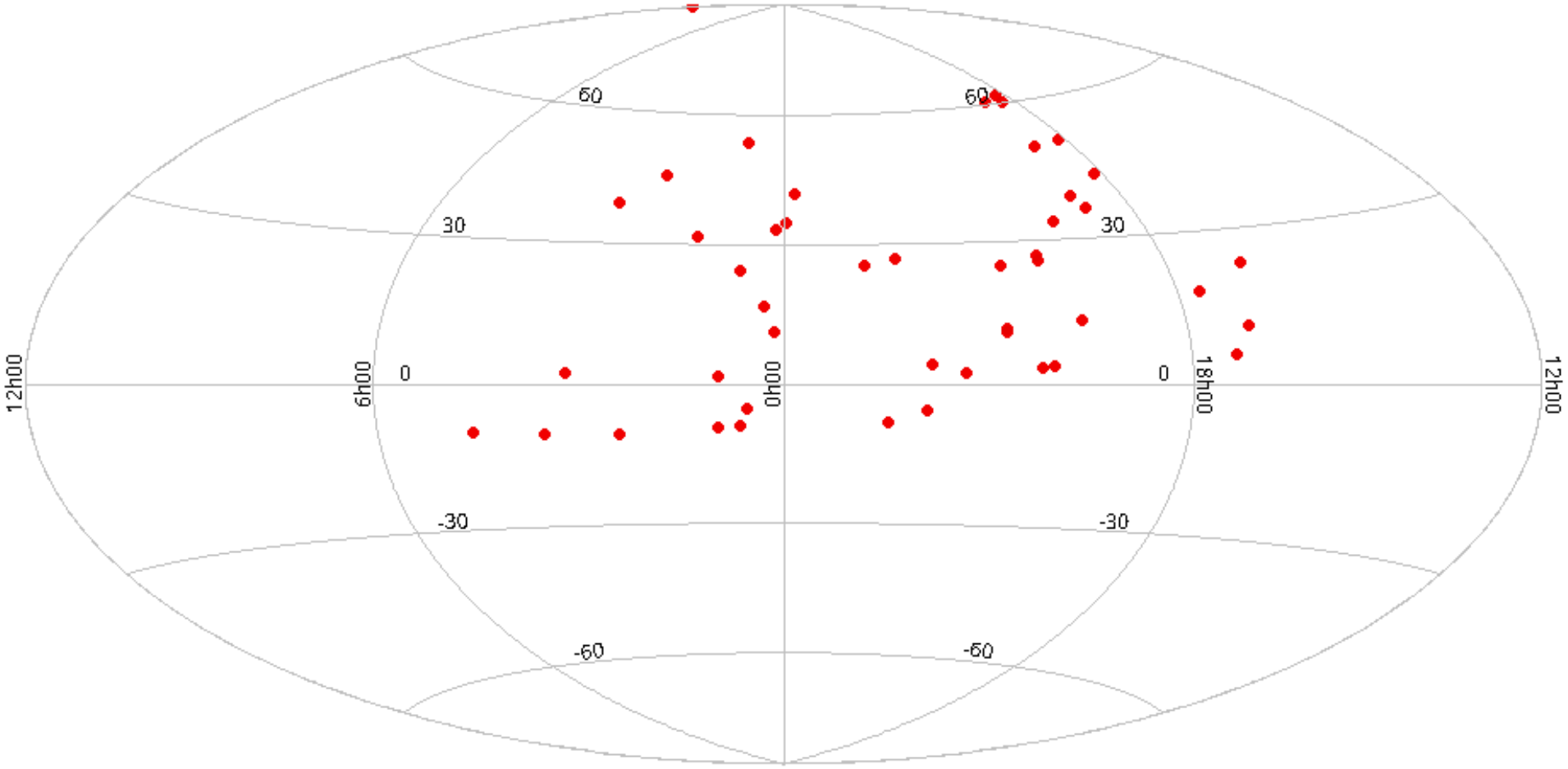
Perek 2 meter telescope
Target Declination
Target Right Ascension
Brightness Constraints: < ~11 Gmag

TOPCAT

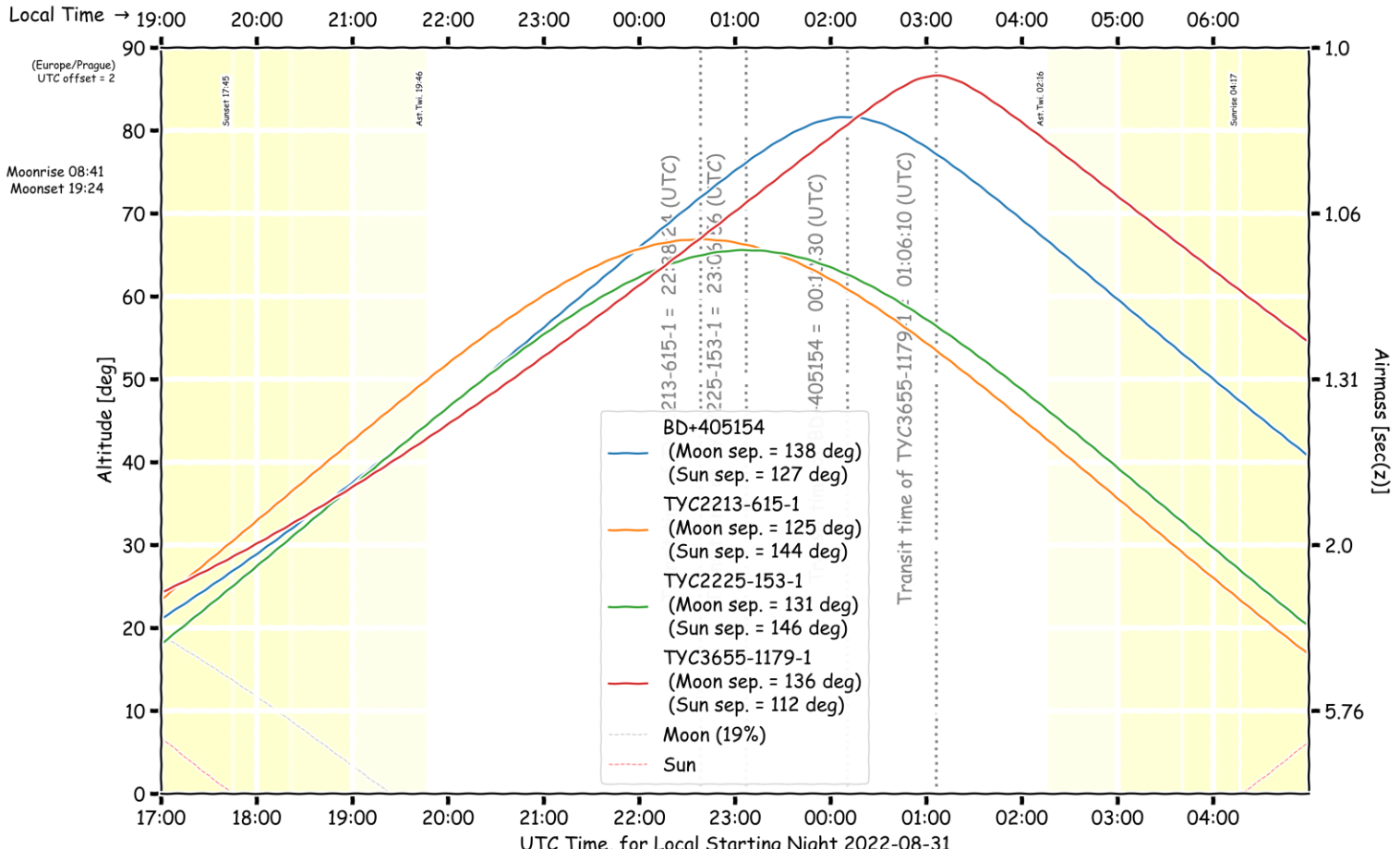


ID	Name	Size	Fraction	Expression	Col $ID
_9	has_epoch_photometry	4357	14%		$123
_10	has_epoch_rv	87	0%		$124
_11	has_mcmc_gspphot	17029	56%		$125
_12	has_mcmc_msc	30390	100%		$126
_13	in_andromeda_survey	11	0%		$127
_14	matched	30370	100%		
_15	Photometry_QC	30387	100%	abs(phot_bp_rp_excess_factor_corrected) < 0.6	
_16	pm_QC	30390	100%	pm_over_error > 5	
_17	vt_QC	29764	98%	vt_over_error > 5	
_18	QC	29761	98%	Photometry_QC && pm_QC && vt_QC	
_19	Close	11413	38%	BHB_Candidate && distance < 5000	
_20	nn5	21758	72%	within_5_arcsec < 2	
_21	n5_bright	8308	27%	! nn5 && object_flux_fraction > 0.7	
_22	BHB_Candidate	27784	91%	QC && ! RR_Lyrae && (nn5 || n5_bright)	
_23	RR_Lyrae	1705	6%	flux_error_excess > 7.5	
_24	target_list	44	0%	(BHB_Candidate && (dec>-11&&(ra<70 || ra >250) && phot_g_mean_mag < 11)) || (phot...	
_25	target_list_2	46	0%	((dec>-11&&(ra<70 || ra >250) && phot_g_mean_mag < 11)) || (phot_g_mean_mag < 11...	
_26	target	22	0%	((dec>-11&&(ra<70 || ra >250) && phot_g_mean_mag < 10.5)) || (phot_g_mean_mag < 1...	
_27	target_2	22	0%	ra<70 || ra >250) && phot_g_mean_mag < 10.5)) || (phot_g_mean_mag < 10.5 & dec > 70)	

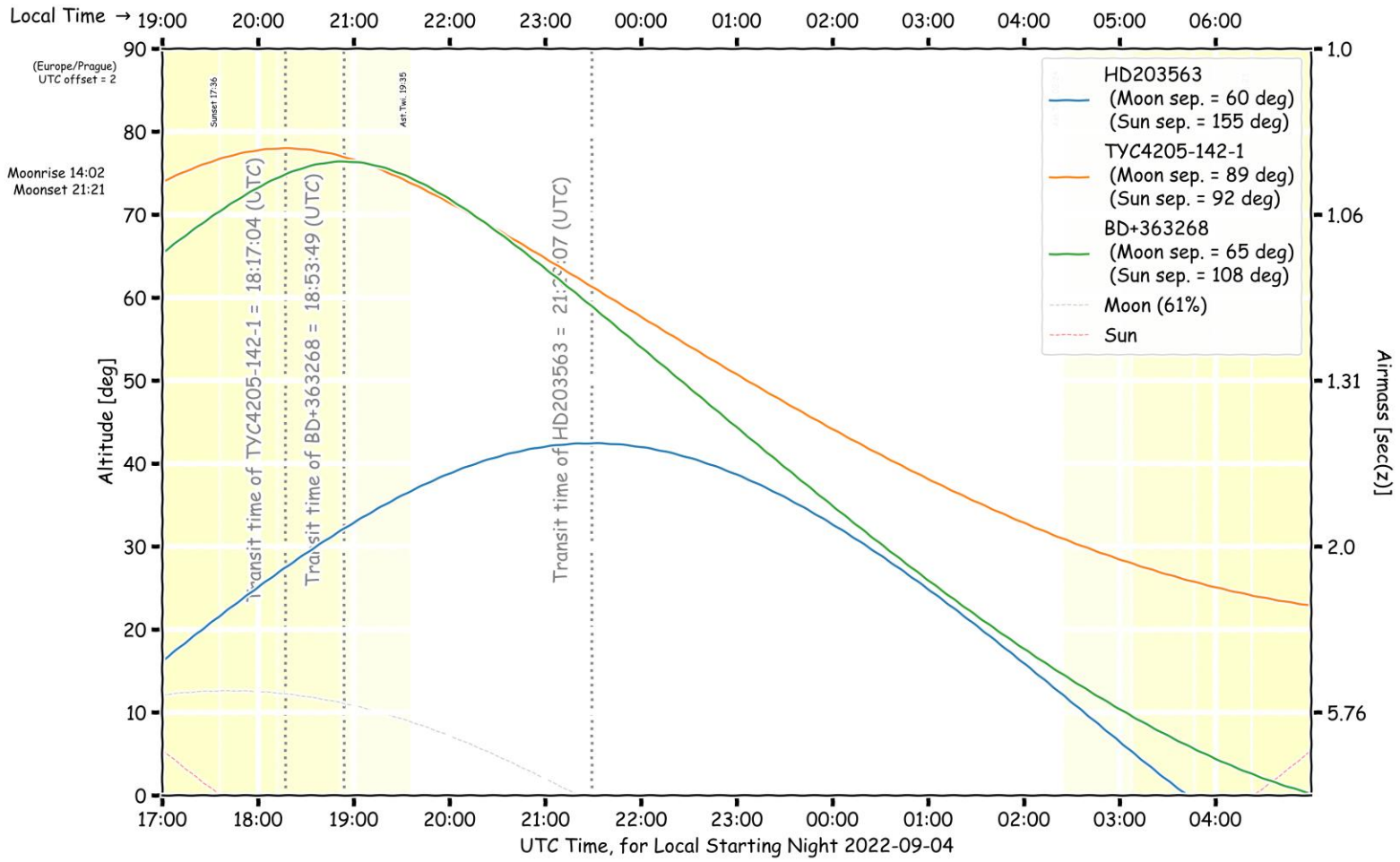
Selected BHB Candidates



First Observation Night

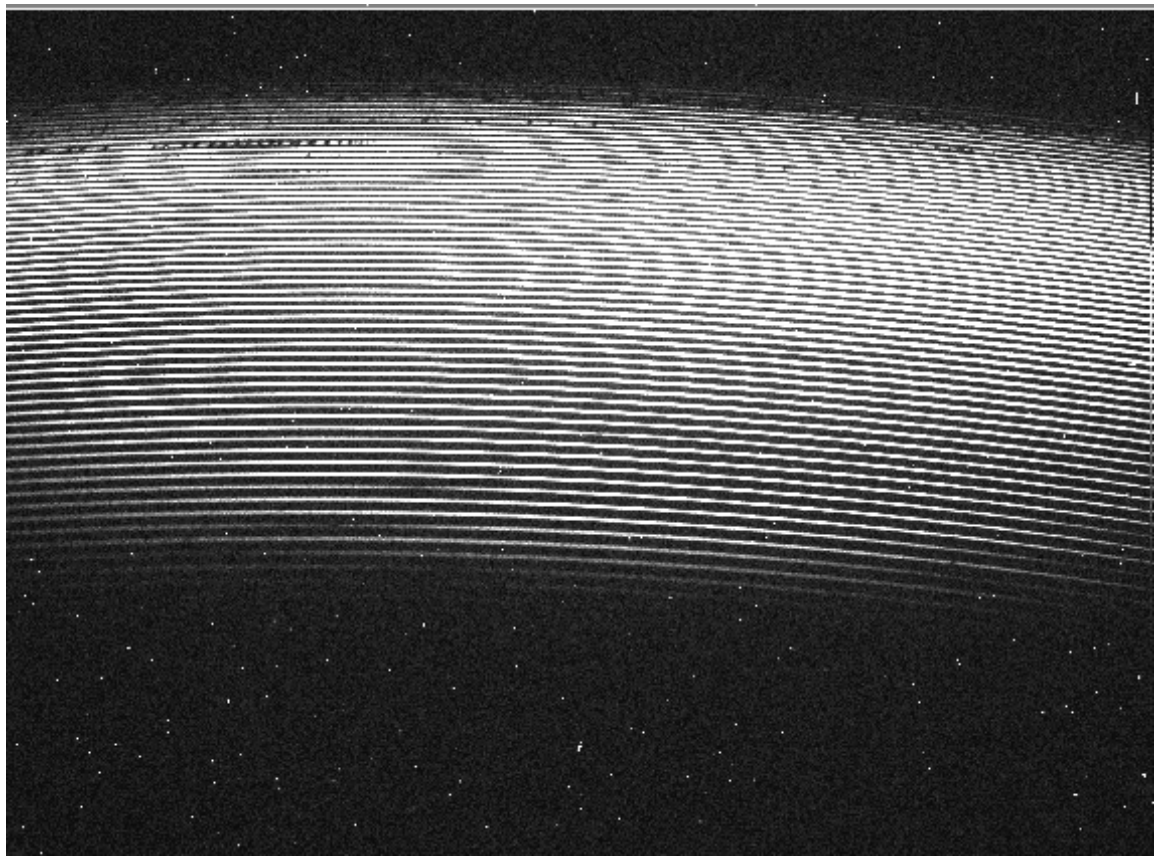


Second Observation Night



Data Reduction

Why?



BD+36 3268

Data Reduction

Science frame

Bias frame

Dark frame

Flat-field frame

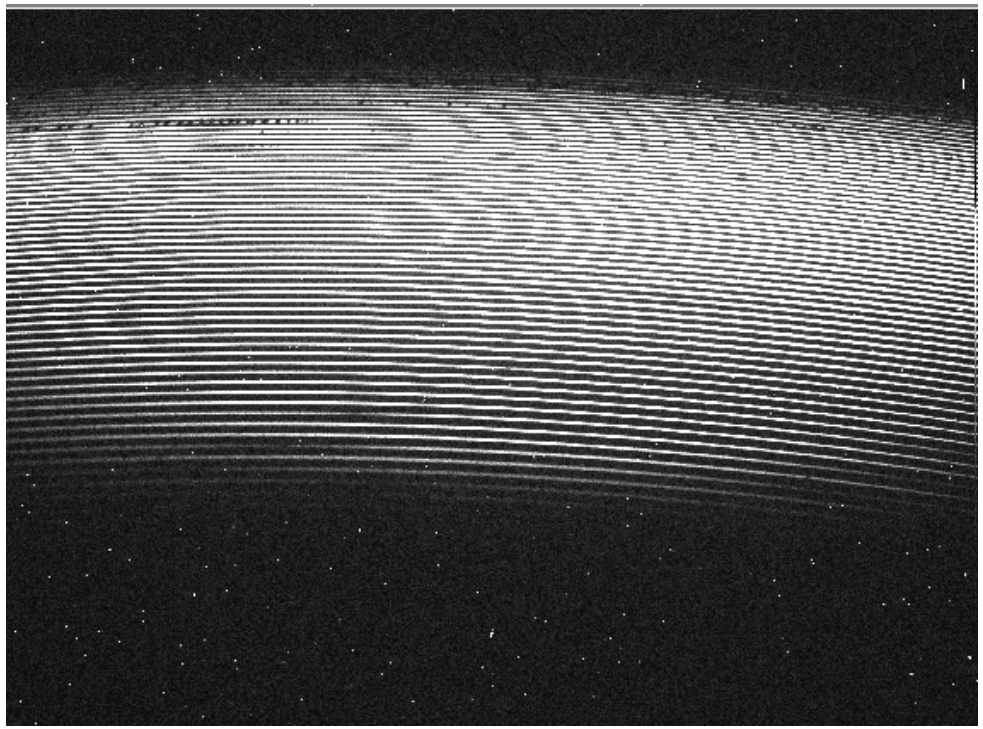
Calibration (comp) frame

$$\text{stars} = \frac{\text{raw image} - \text{bias} - \text{dark current}}{\text{flat}}$$

Science Frame

Two-dimensional array of values

To analysis and do science



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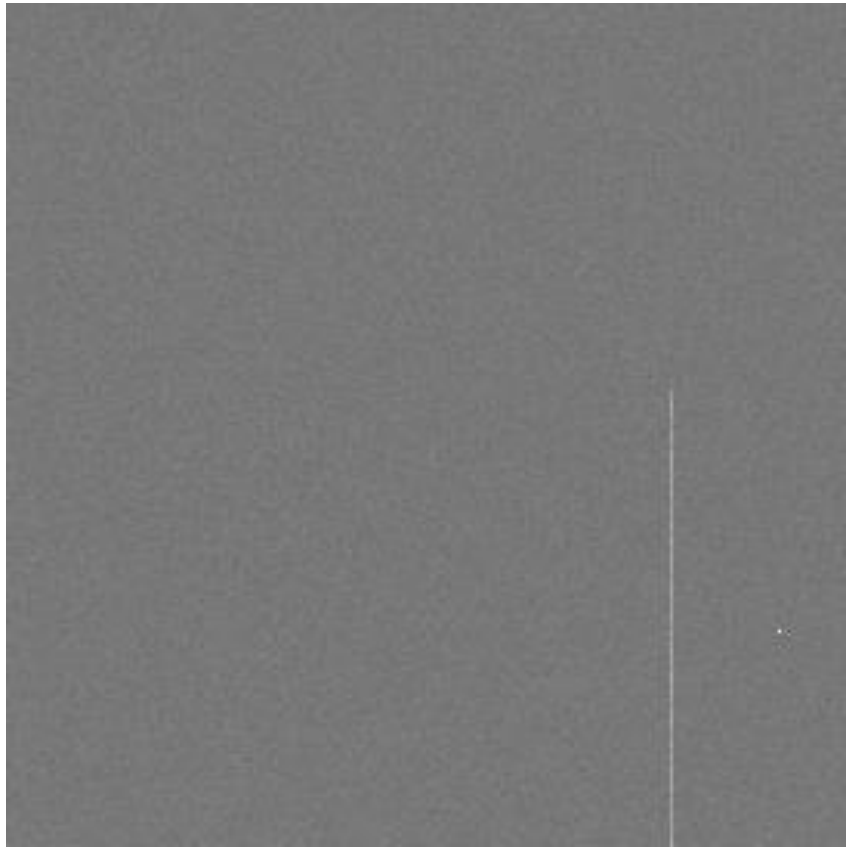
Bias Frame

To remove the CDD readout signals

Exposure time: Shortest

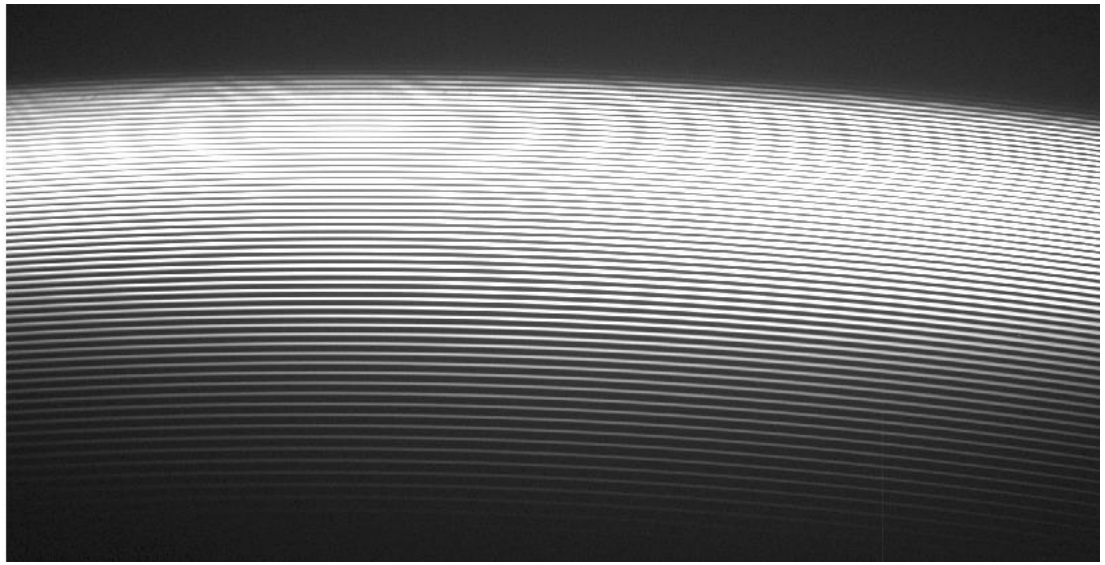
Remove from science



Bias frame

Flat-Field Frame

To compensate for any non-uniformity
Variations in the sensitivity of pixels
Vignetting effect, or
Anything else in the optical path
Need to be corrected



Flat frame from 1st observation

Dark Frame

Background noise: Thermal effect

Exposure time: Same as science frame

No dark frames were taken!

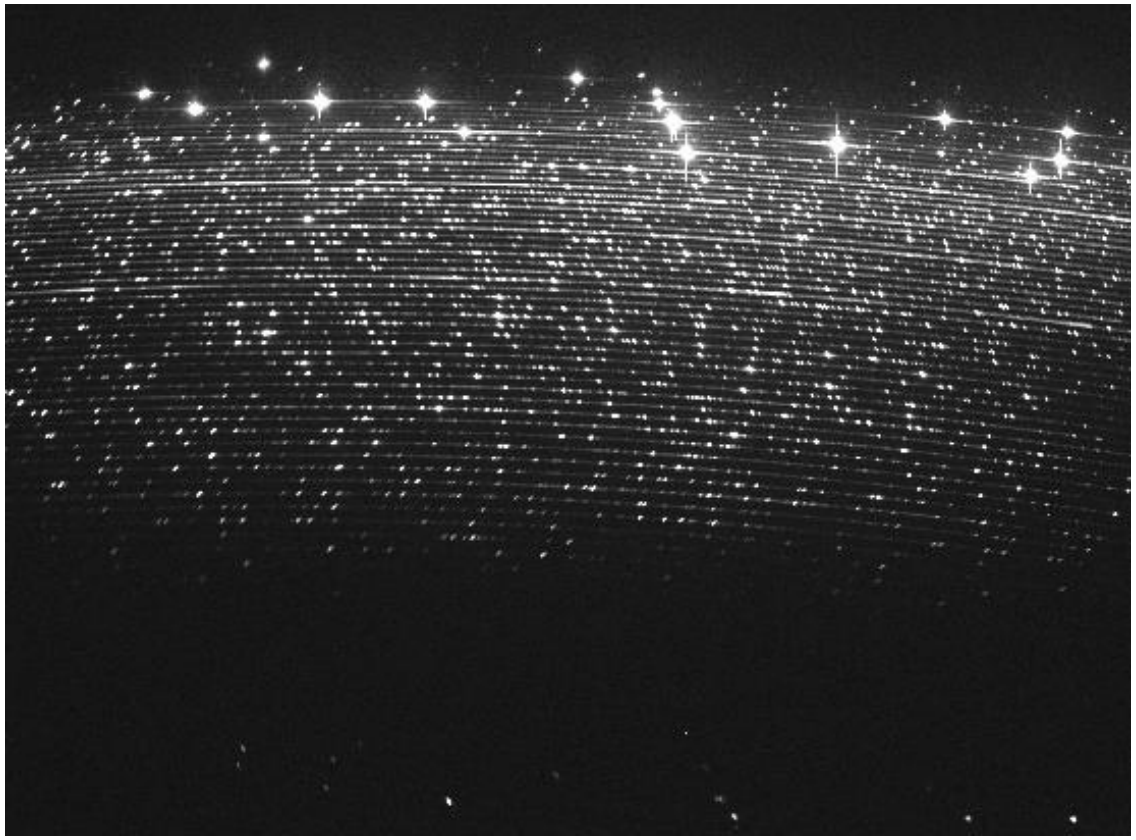
CCD cooled with Liquid Nitrogen

Calibration (comp) Frame

ThAr lamp used

ThAr has strong emission lines

Need for wavelength calibration



ThaAr spectra from 1st observation

Data Reduction Process

Pipeline – created by Mauricio Cabezas

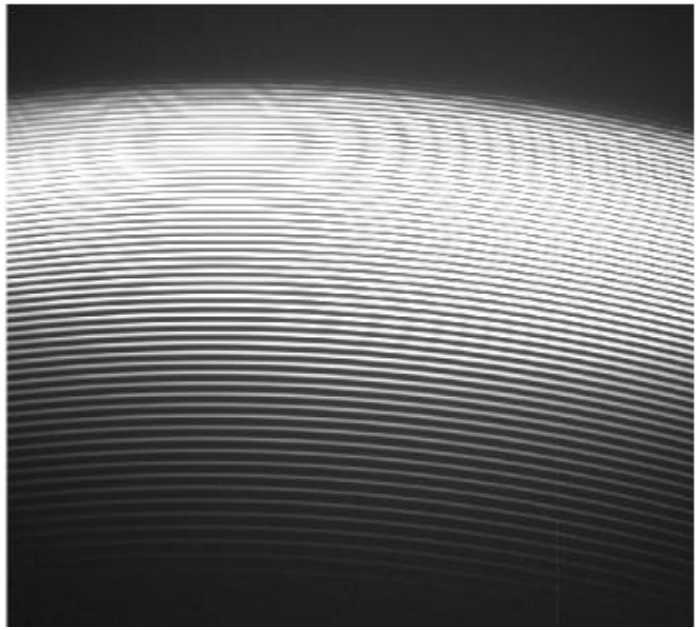
```
                                IRAF
                Image Reduction and Analysis Facility
PACKAGE = clpackage
   TASK = oesred

input   =  e202102040008.fit  Spectrum target to reduce(.fit)
(output =              hd54482) Output filename
(idtarge=            HD 54482) Target name on header
(napertu=                  49) Number of apertures to be found
(id     =                0008) Observation id number

                          # CALIBRATION PARAMETERS

(orgfile=                  no) do you want organize files?
(zerocom=                  no) Combine zero level images?
(trimcal=                  no) Trim flat and comp?
(iftrimc=                  no) Use trim flat & comp?
(zerocor=                  no) Apply zero level correction to flat & comp?
(compcom=                  no) Combine comparison lamp images?
(flatcom=                  no) Combine flat field images?
(flatapa=                  no) Extract flat apertures?
(compapa=                  no) Extract comparison apertures?
(iddatab=                  no) Use database folder for identification?
(idfolde=              idcomp) folder name with identification database
(idencom=                  no) Identify features in spectrum for dispersion sol
```

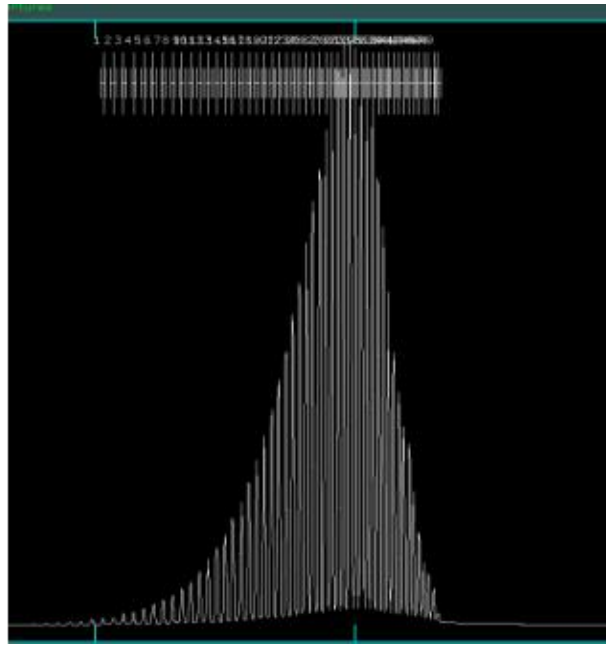
```
                          # OBJECT PARAMETERS

(trimob =                  no) Trim object?
(iftrimo=                  no) Use trim object?
(zerocor=                  no) Apply zero level correction to object?
(crays  =                  no) Remove cosmic rays?
(ifcrays=                  no) Use object with cosmic rays extraction?
(objecta=                  no) Extract object apertures?
(flatcor=                  no) Apply flat correction to object?
(helioco=                  no) calculate JD + heliocentric correction?
(idref  =                  no) refer database identification to images?
(norm   =                  no) normalize spectra?
(ncombin=                  no) combine normalized spcectra?
(mode   =                  ql)

                                                        ESC-? for HELP
```

Model Aperture

The lines: Aperture

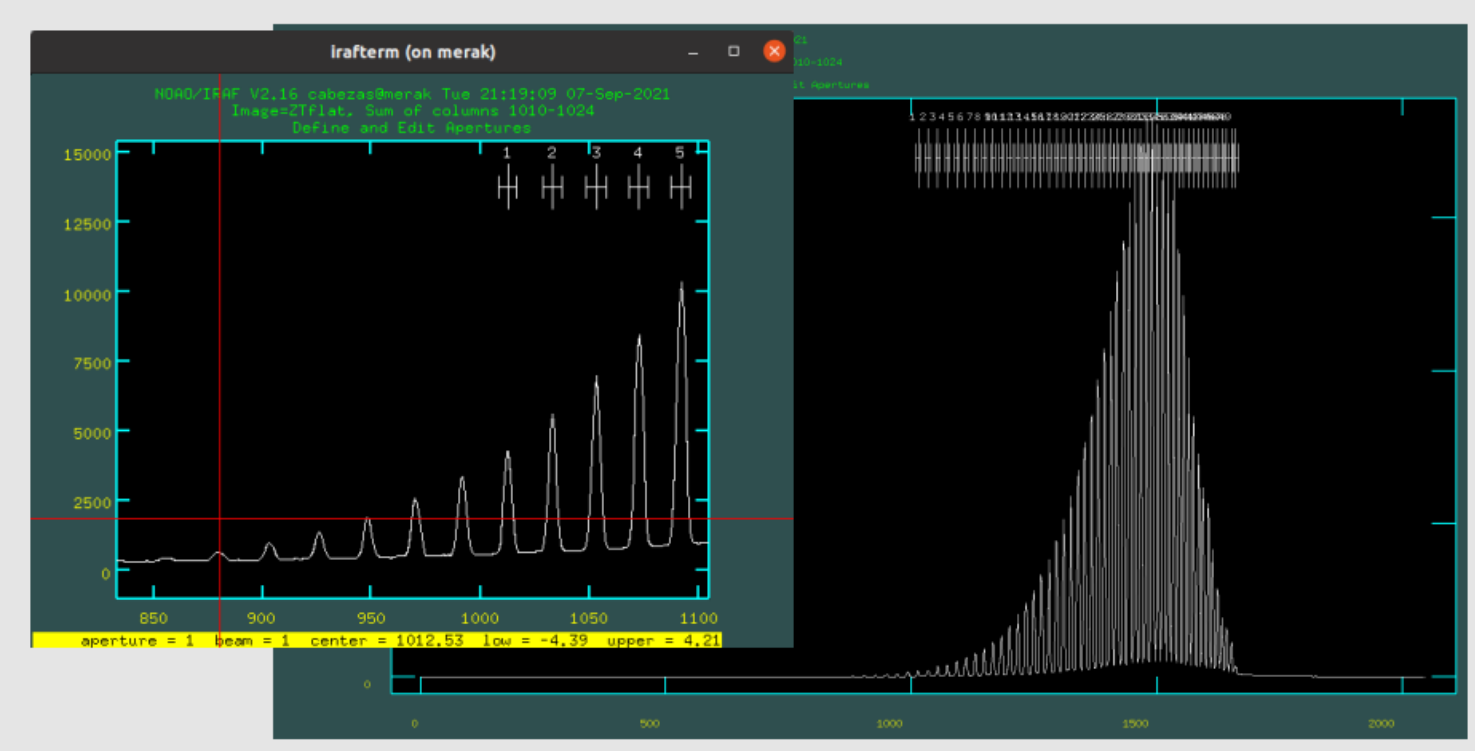
49 aperture





Source: Mauricio Cabezas

Model Aperture

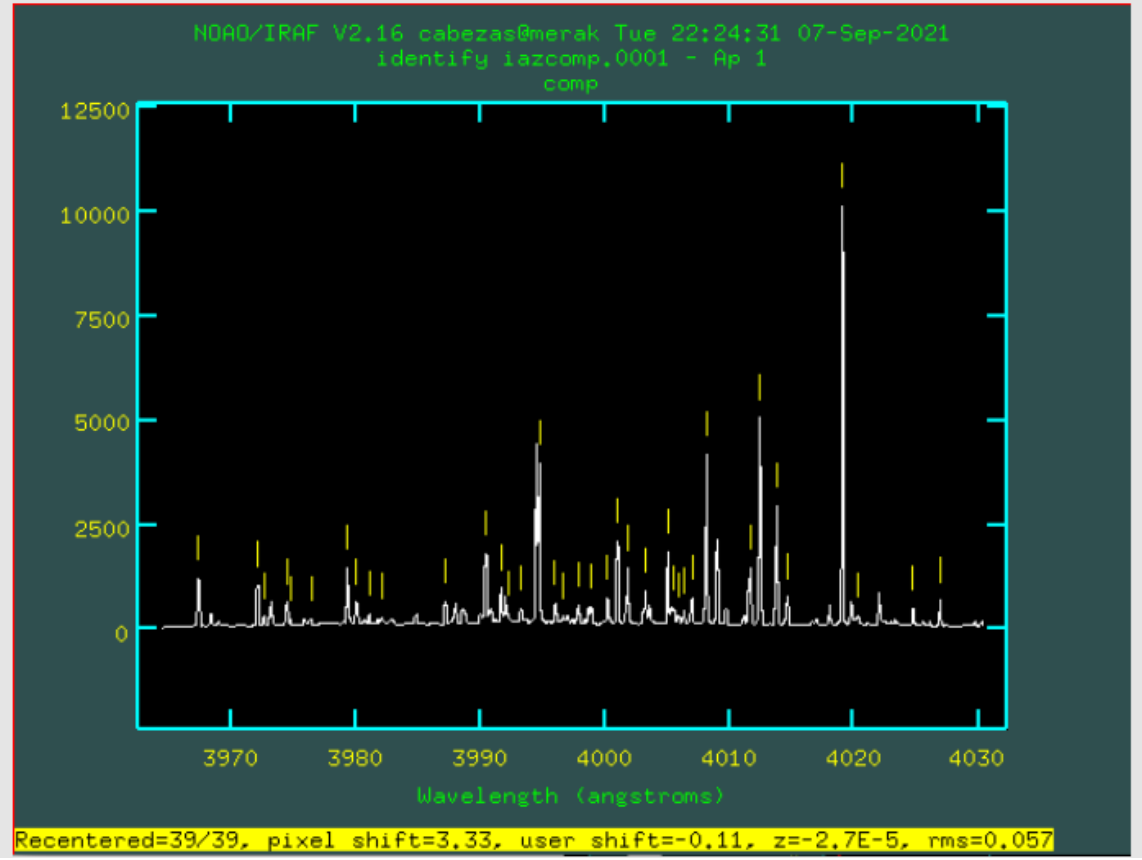


Source: Mauricio Cabezas

Wavelength Calibration

Thorium-Argon spectra

Database of emission lines



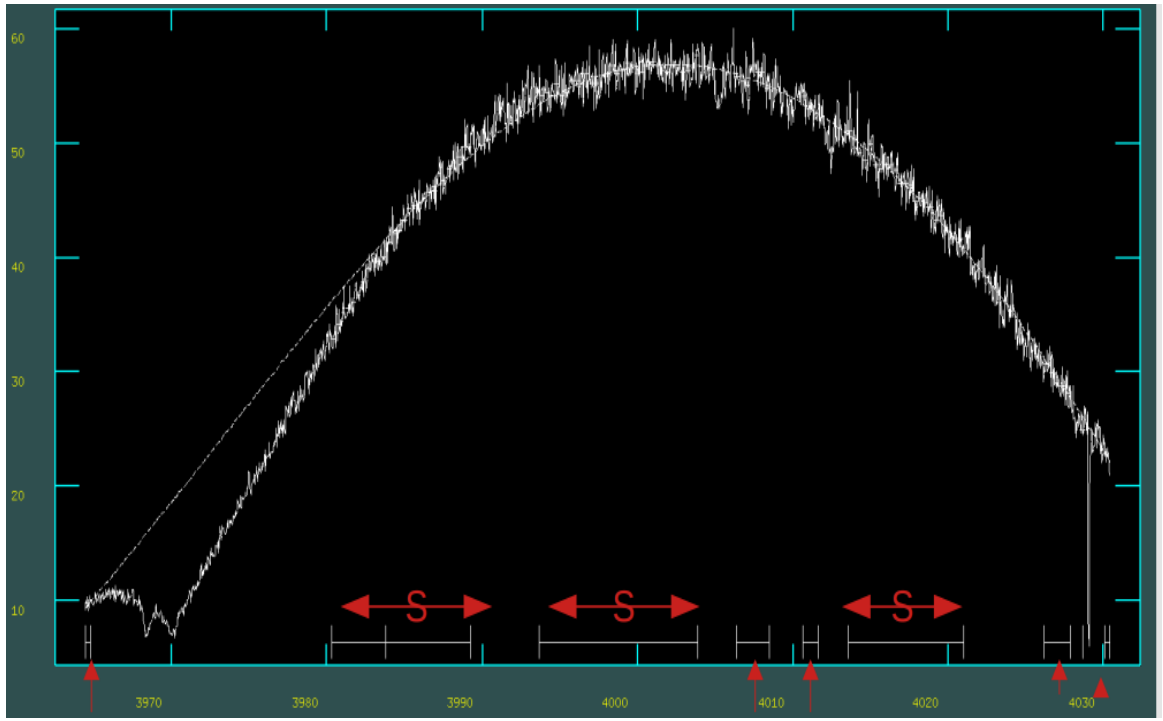
Source: Mauricio Cabezas

Normalization

Normalisation or blaze correction

Useful:

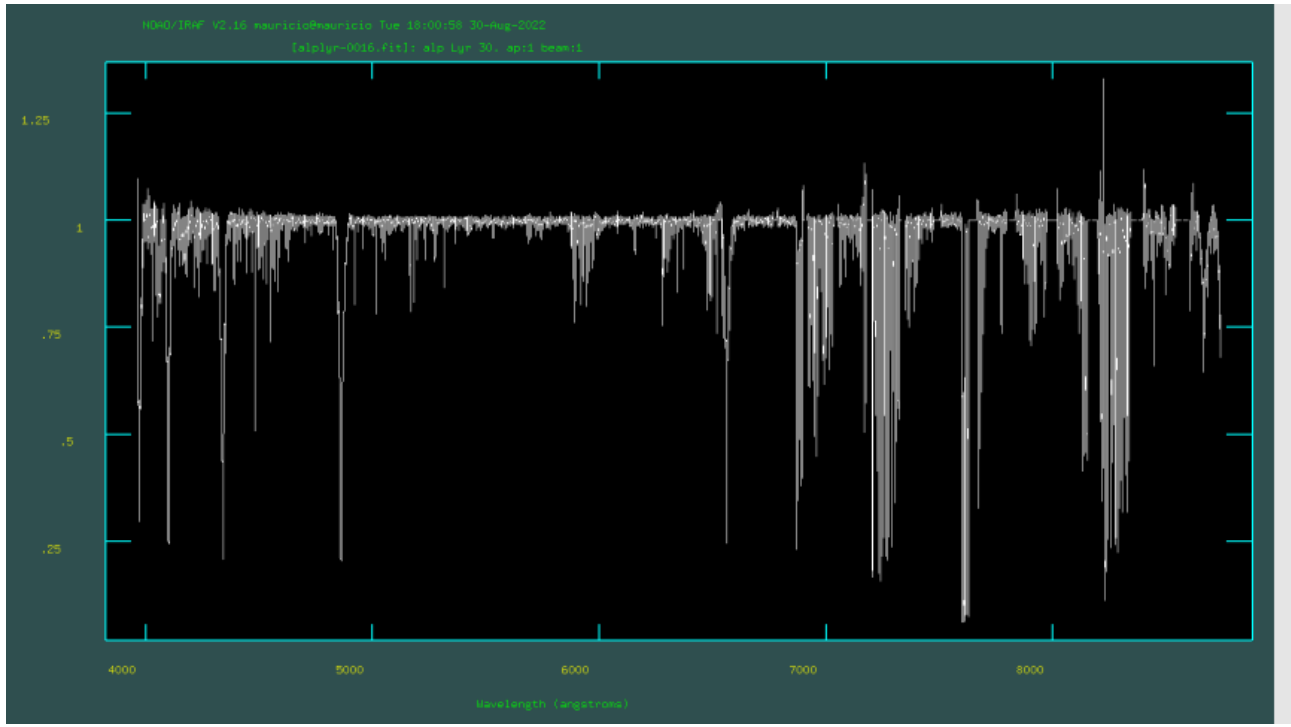
- Absorption line profiles
- Model their shapes, or
- Determine their widths



Source: Mauricio Cabezas

Merging

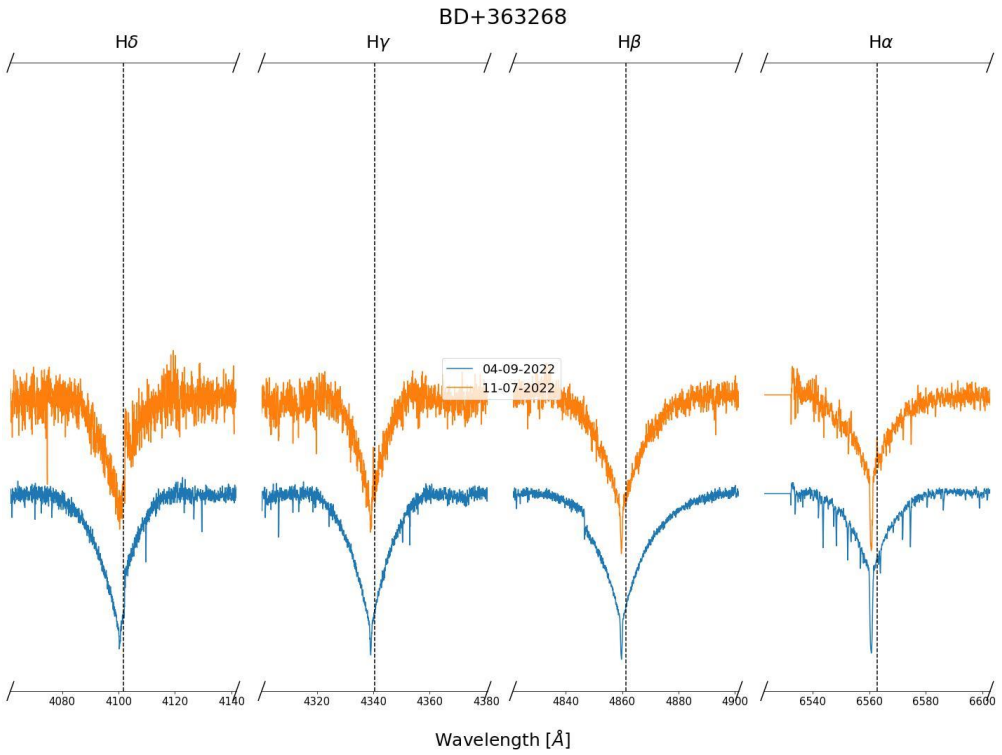
Merging all aperture
Spectra is ready

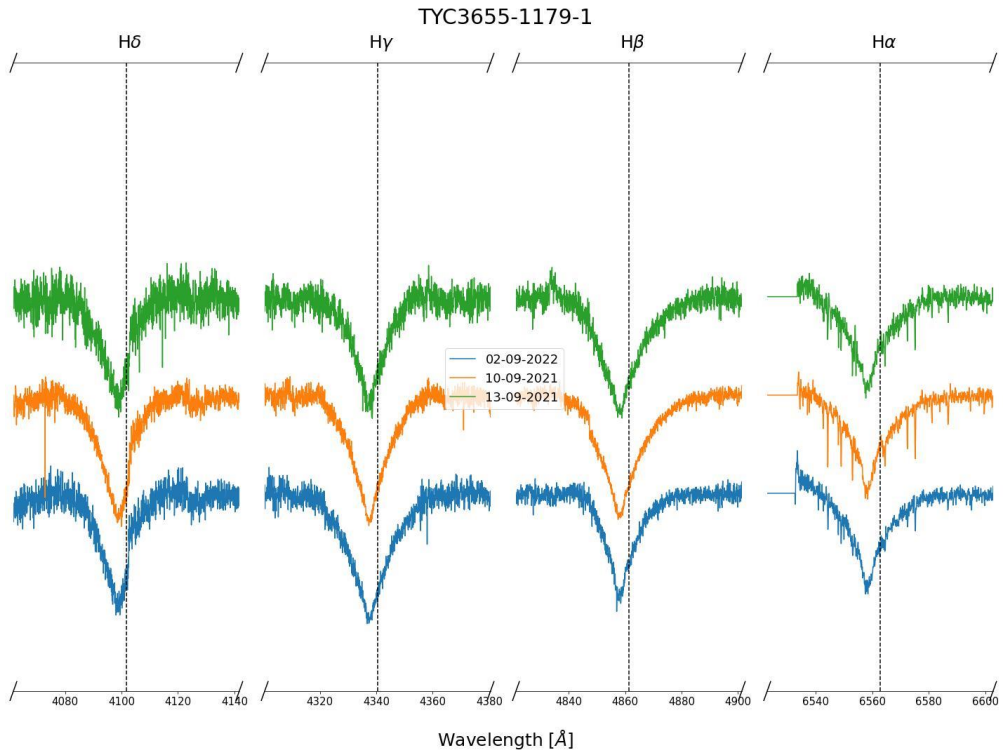


Source: Mauricio Cabezas

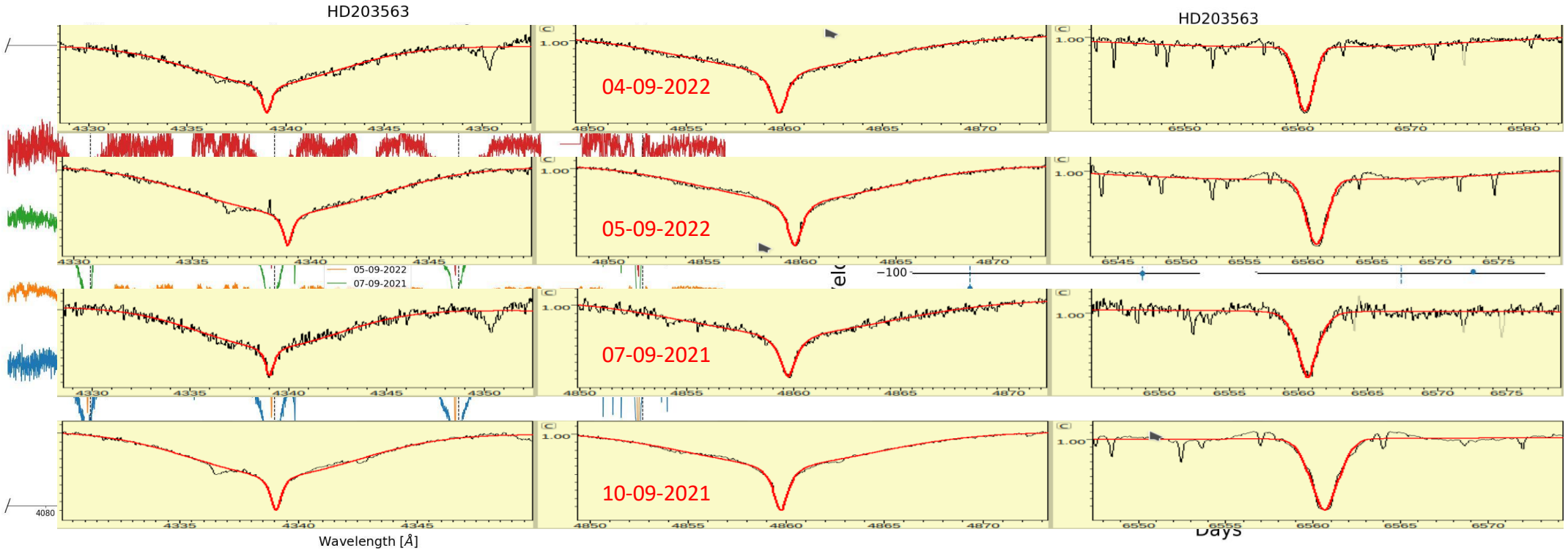
Analysis methods

Preliminary checks on line broadening

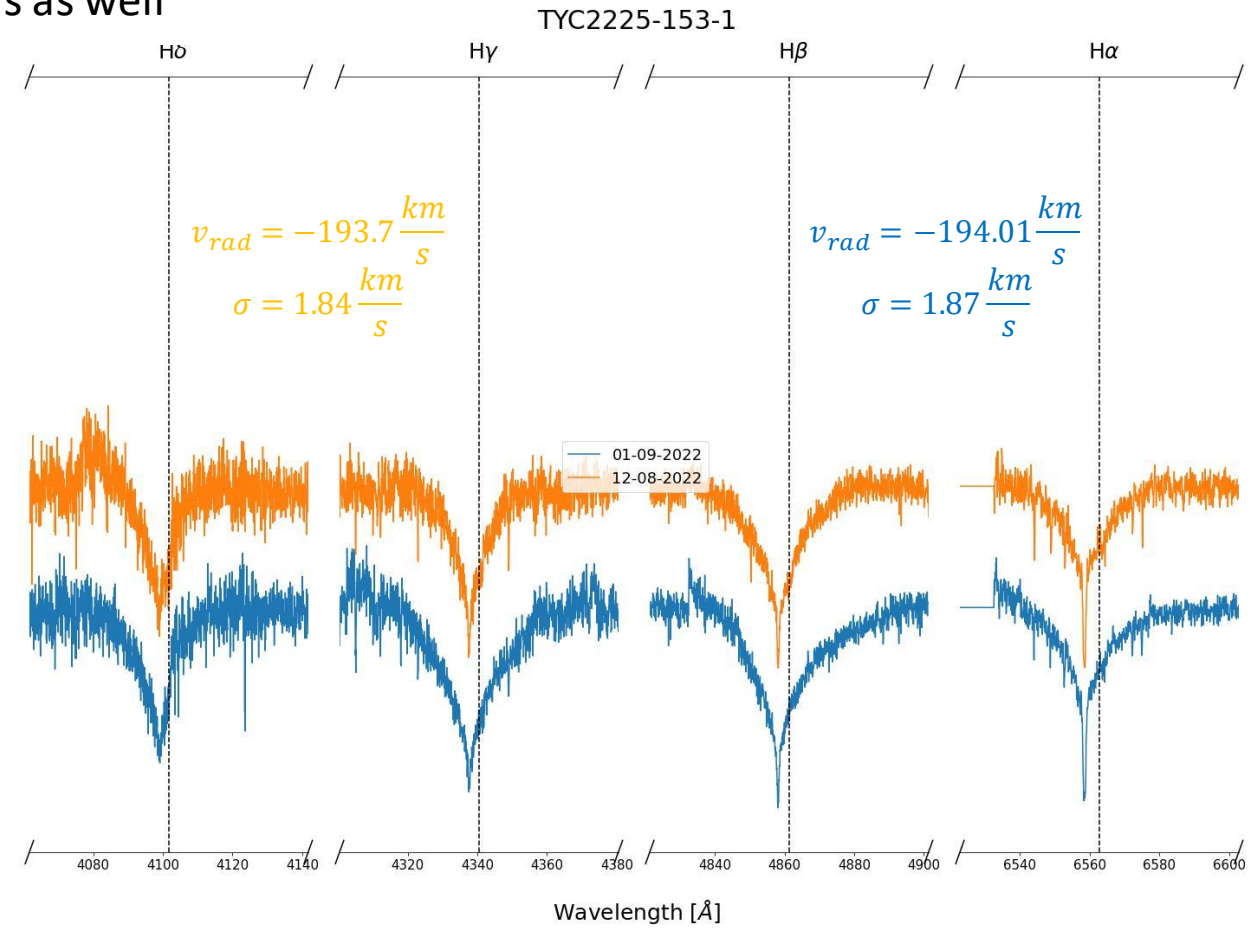




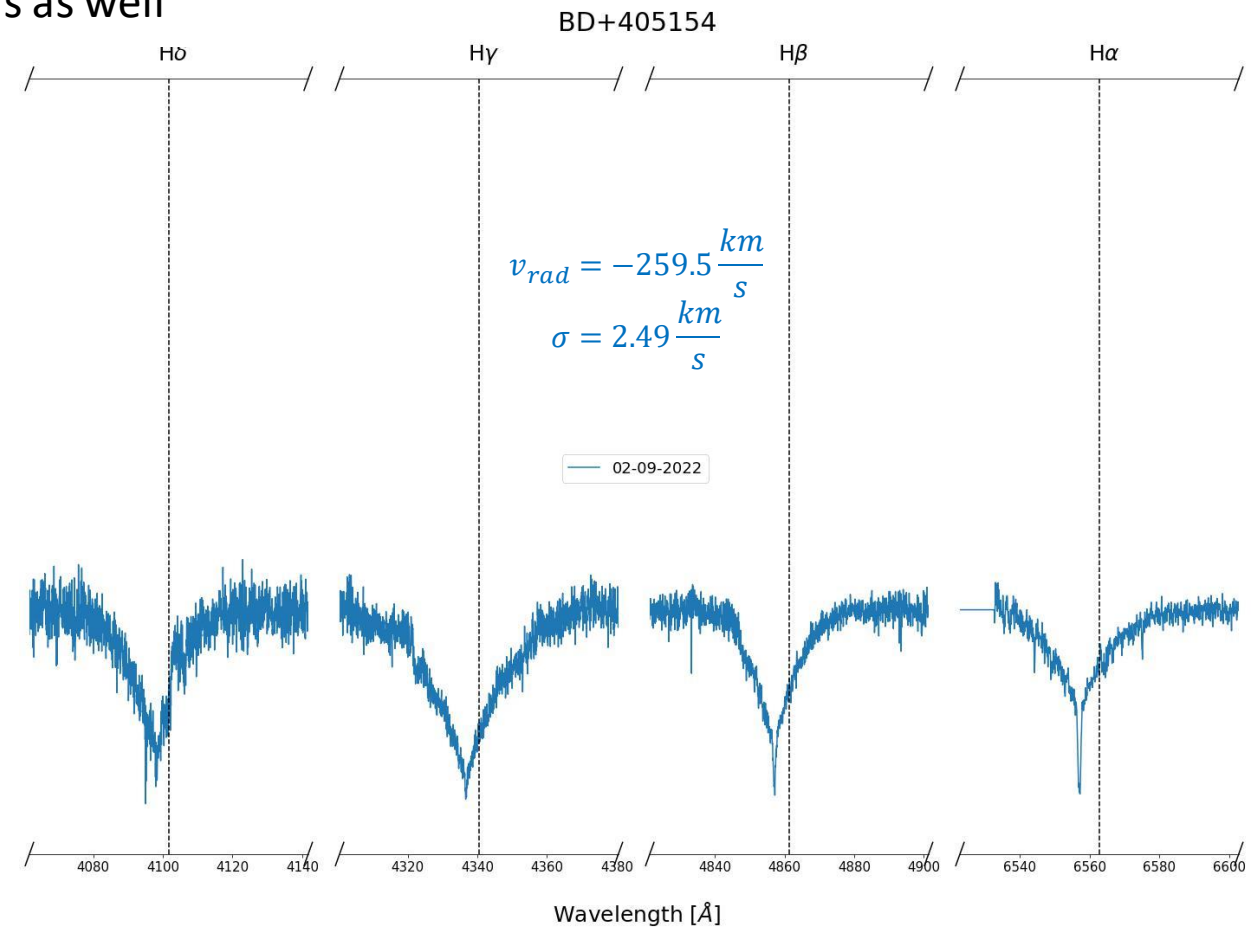
Radial Velocity determination



A brief look at other stars as well



A brief look at other stars as well



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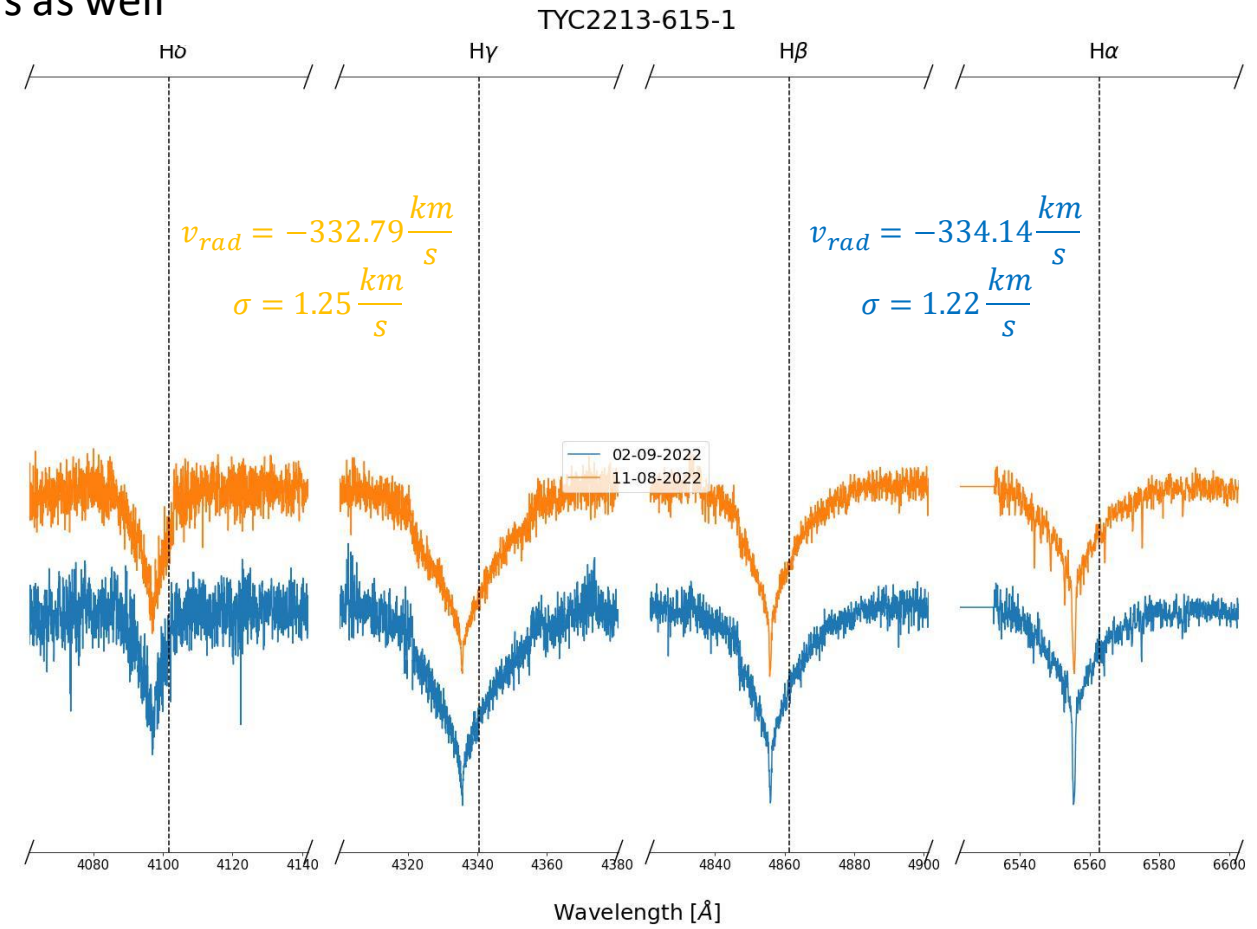
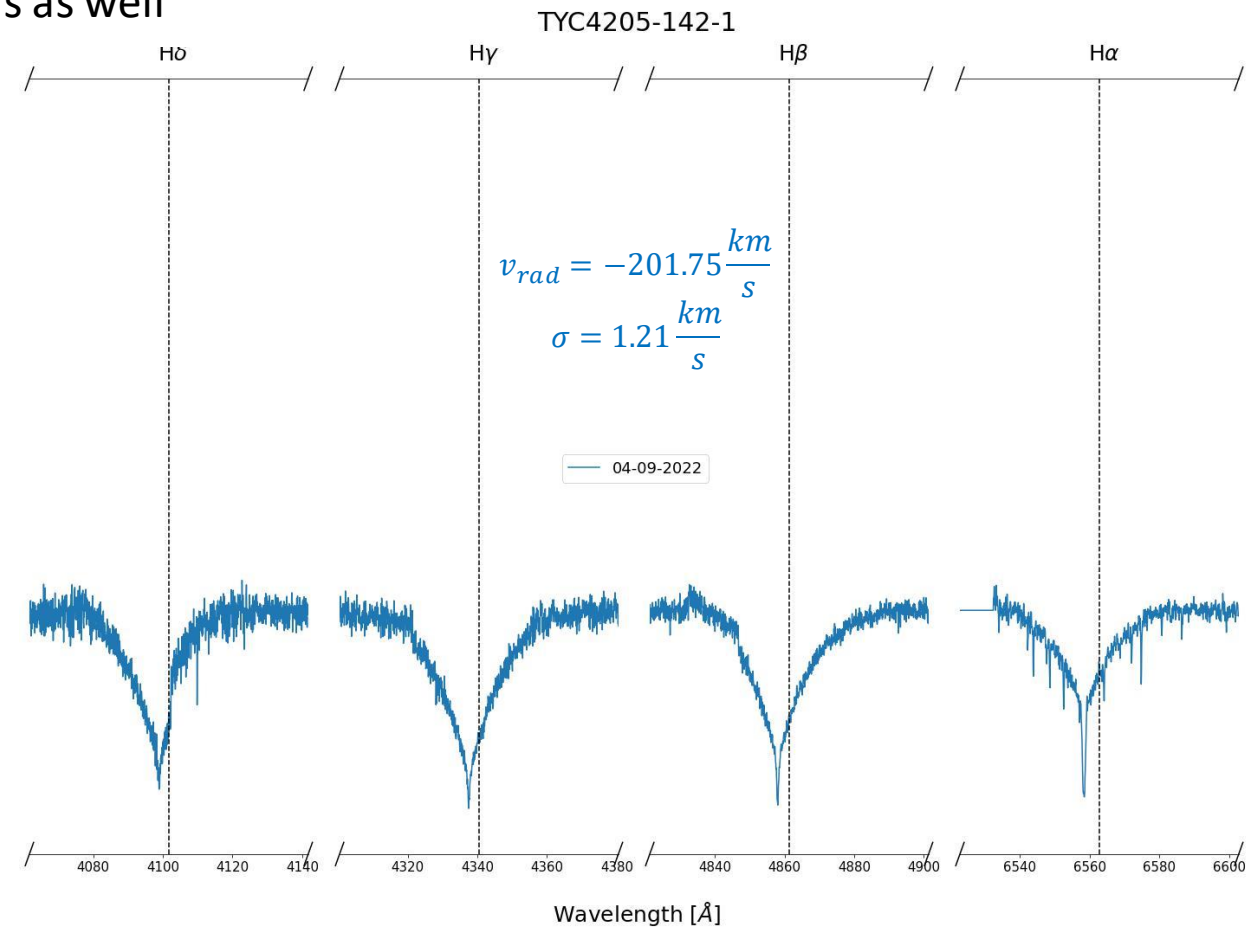
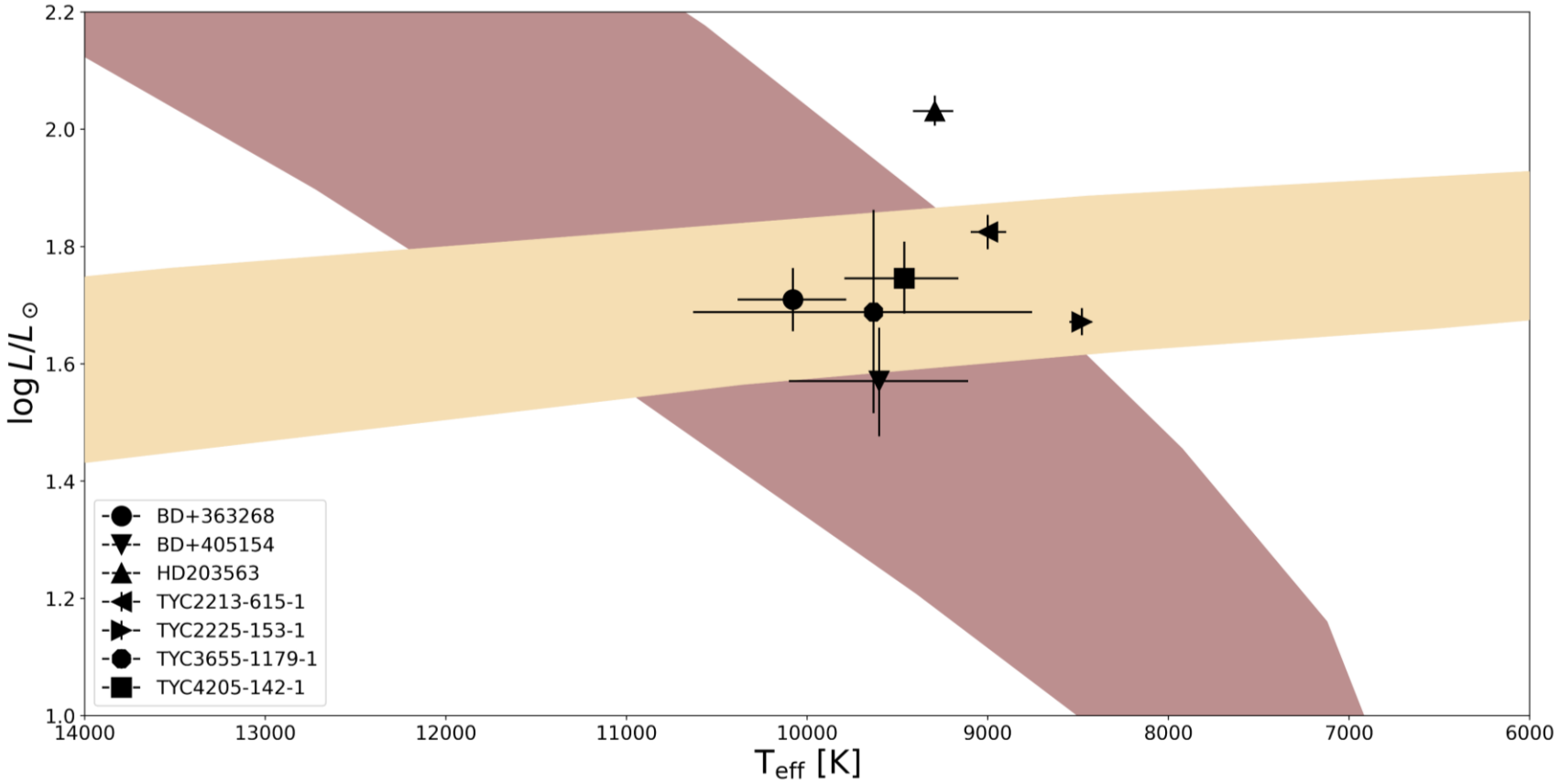


A brief look at other stars as well



SED Fit


2.2
2.0
1.8
1.6
1.4
1.2
1.0
log $L/L_\odot$
14000
13000
12000
11000
10000
9000
8000
7000
6000
T_{eff} [K]
BD+363268
BD+405154
HD203563
TYC2213-615-1
TYC2225-153-1
TYC3655-1179-1
TYC4205-142-1

Conclusion