Analysing the orbital solutions of the gamma-ray binary HESS J0632+057 with new radial velocity measurements from SALT

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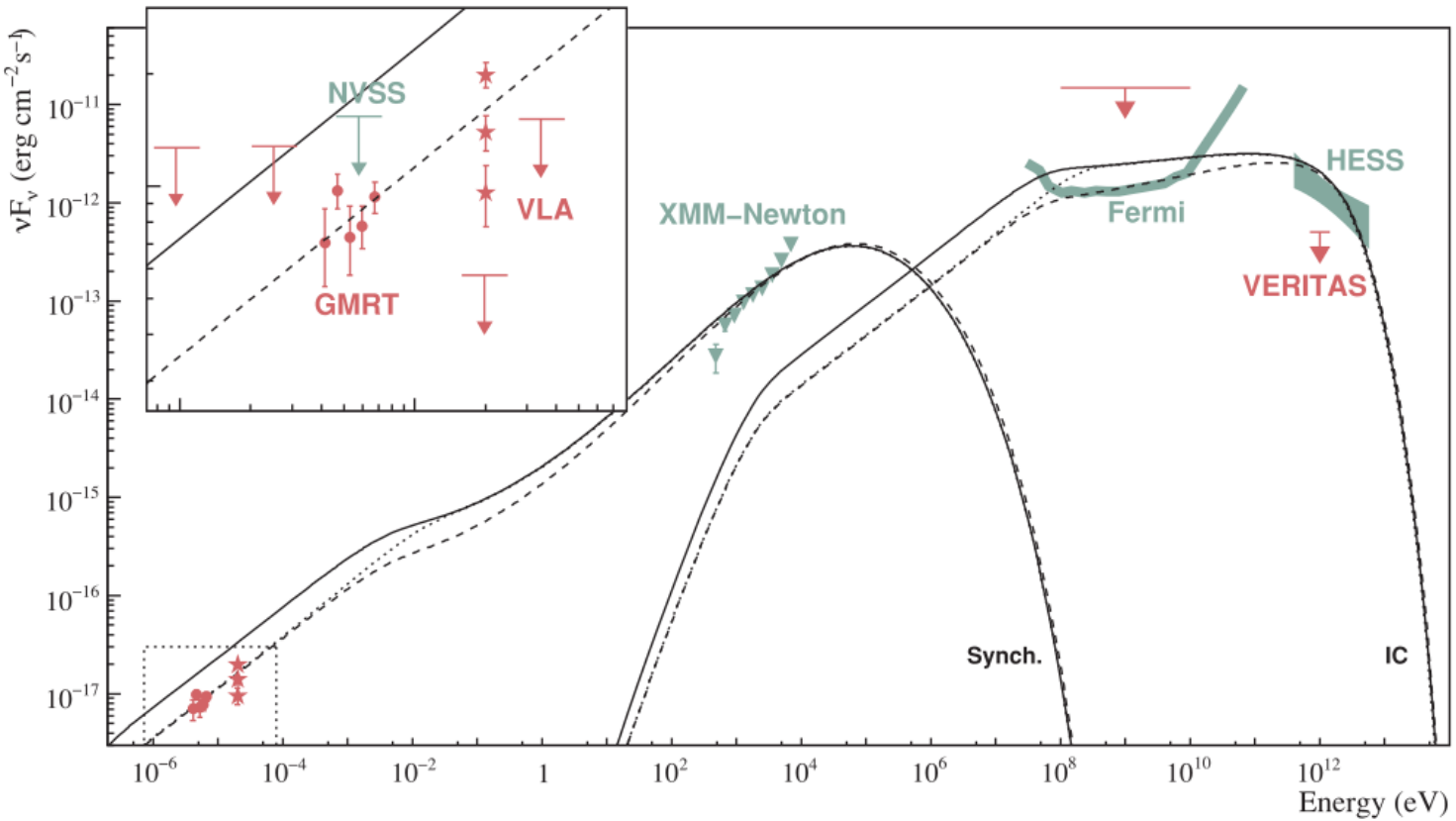
UFS
NATURAL AND
AGRICULTURAL SCIENCES

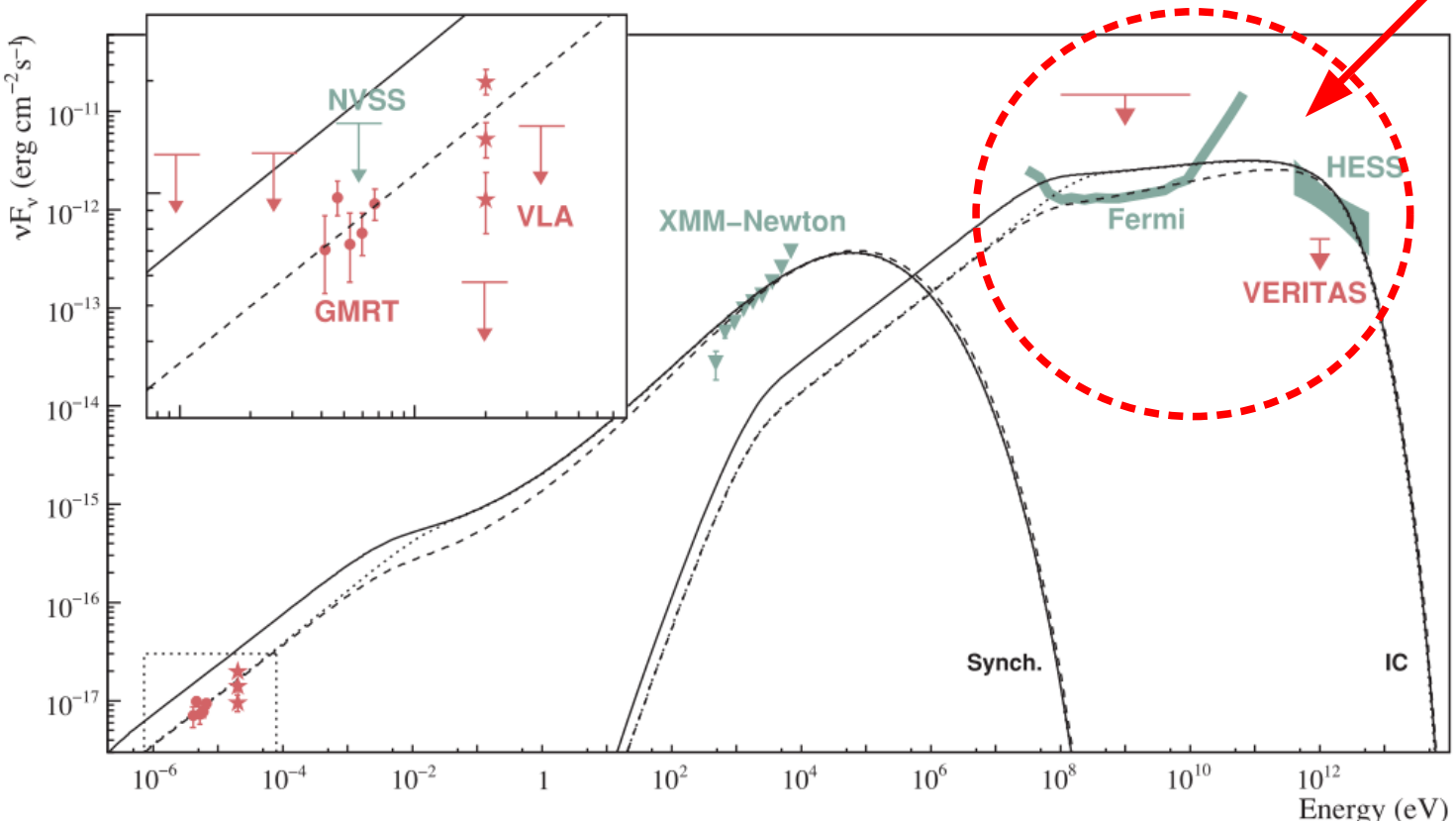
Gamma–ray binaries



[Skilton et al. (2009), *The radio counterpart of the likely TeV binary HESS J0632+ 057*]

Gamma-ray binaries

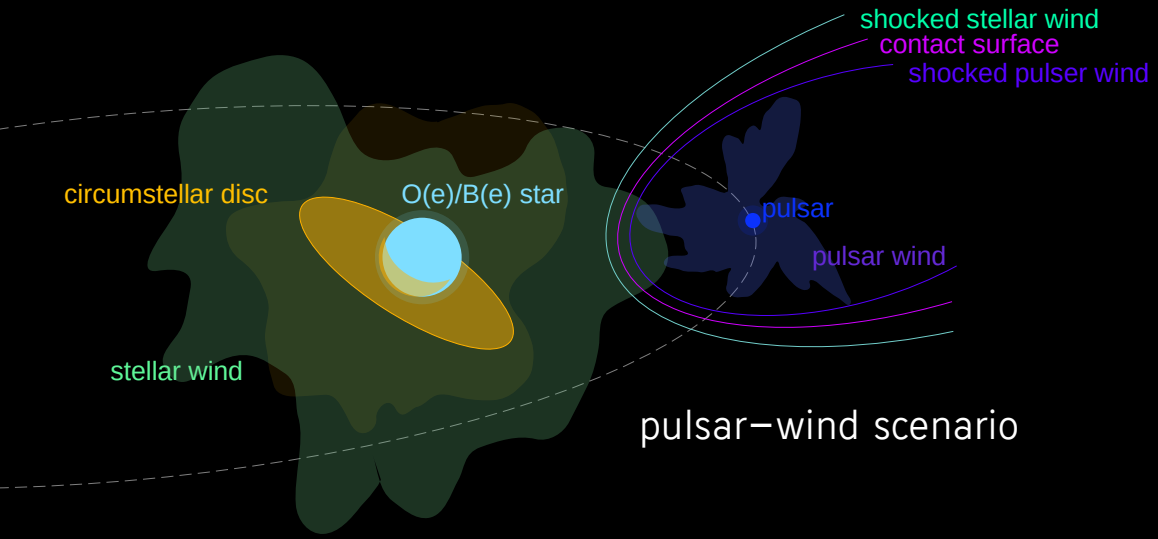
Emission peaks at HE/VHE energies



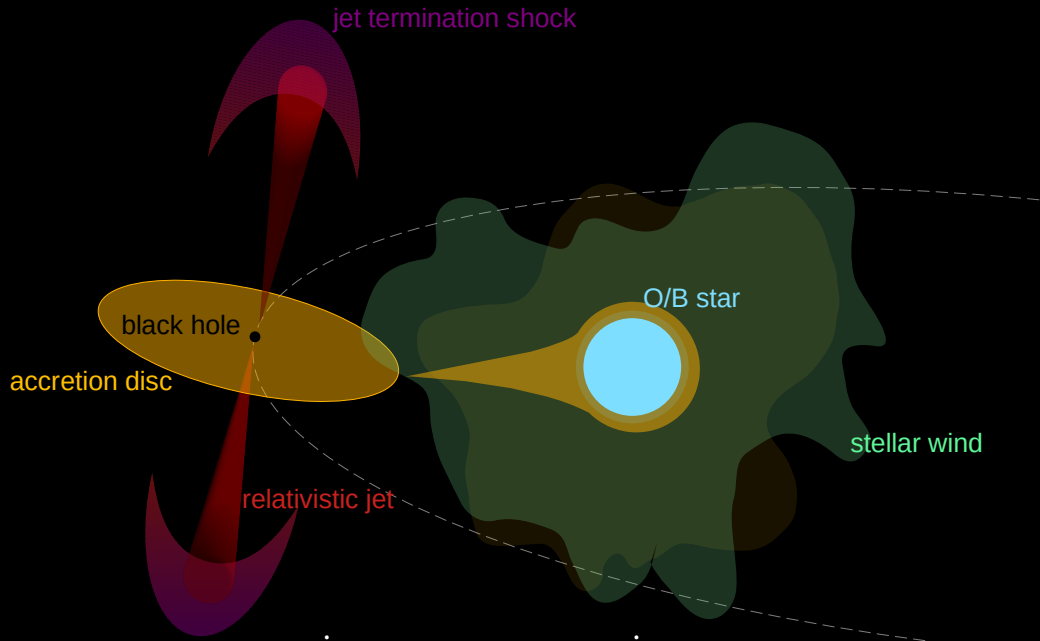
[SED of HESS J0632+057]

[Skilton et al. (2009), *The radio counterpart of the likely TeV binary HESS J0632+ 057*]

Gamma−ray binaries

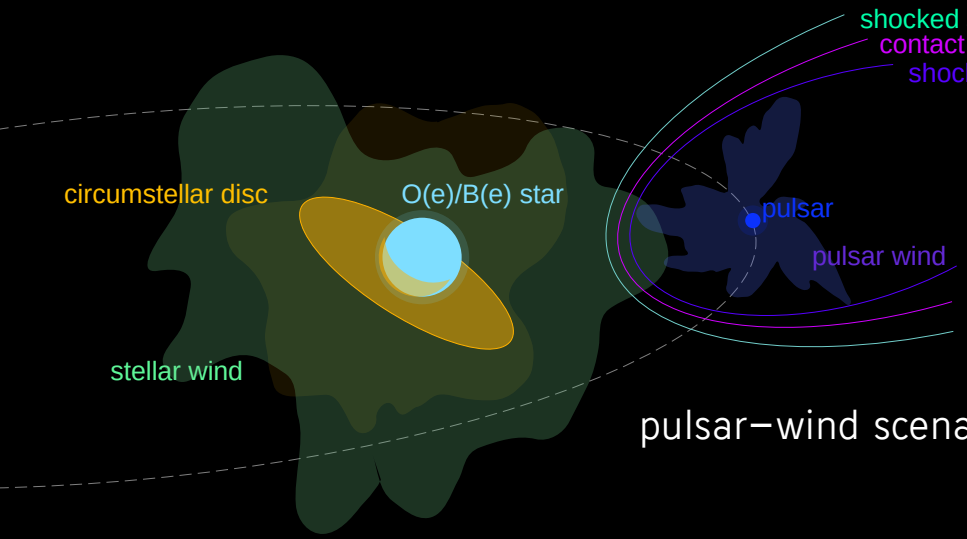


pulsar−wind scenario



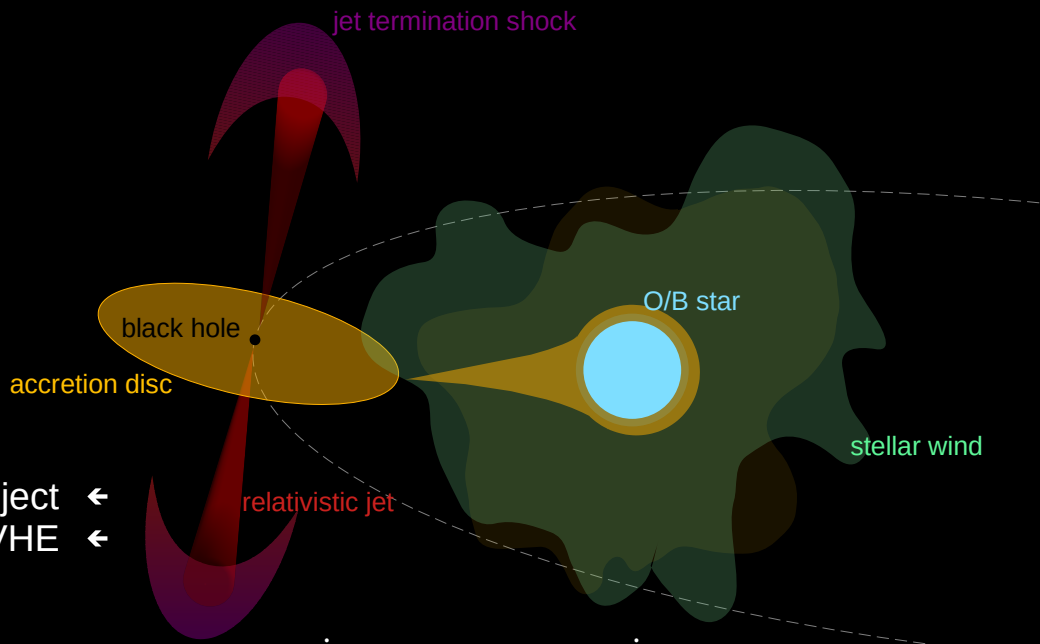
microquasar scenario

Gamma−ray binaries



pulsar−wind scenario

- termination shock forms between the stellar and pulsar wind
- particles accelerated across shock to VHE



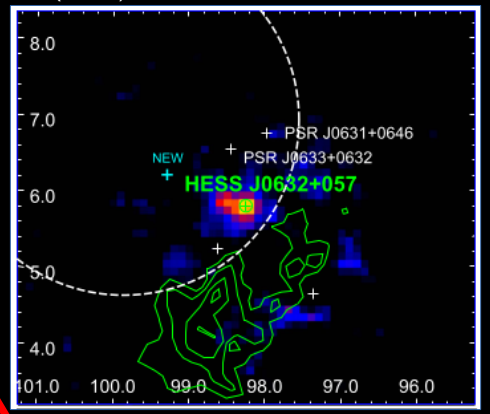
microquasar scenario

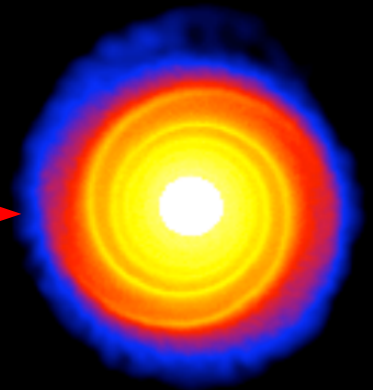
relativistic jet forms from accretion onto the compact object ←
particles accelerated in relativistic jet to VHE ←

HESS J0632+ 057

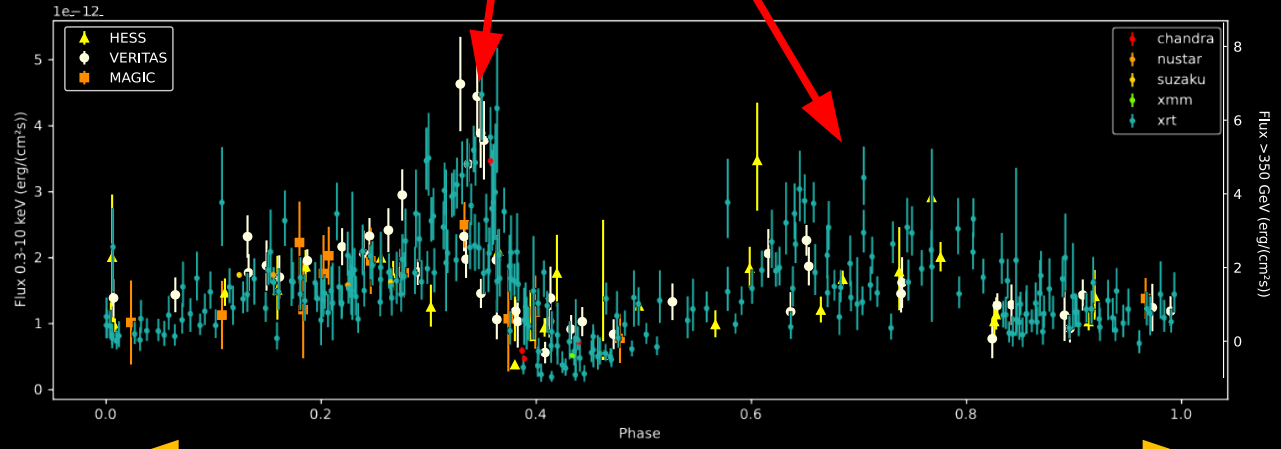
- Be companion star & undetectable compact object
- Modulated X−ray and TeV emisision displays two maxima
- Orbital period ~ 317.3 days
- NEEDS A CLEAR ORBITAL PARAMETER SOLUTION
  - different orbital solutions suggesested by Casares et al. (2012), Moritani et al. (2018), *[Malyshev et al. (2019), Tokayer et al. (2021), Chen et al. (2021), Kim et al. (2022)]*

[Li et al. (2017), *GeV Detection of HESS J0632+ 057*]





[Okazaki, A. (2006), *Origins of X−ray outbursts in Be/X−ray binaries*]



period = 317.3 days

Be stars rotate near break up velocity ∴ material gets ejected to form a circumstellar disc around the star

HESS J0632+ 057

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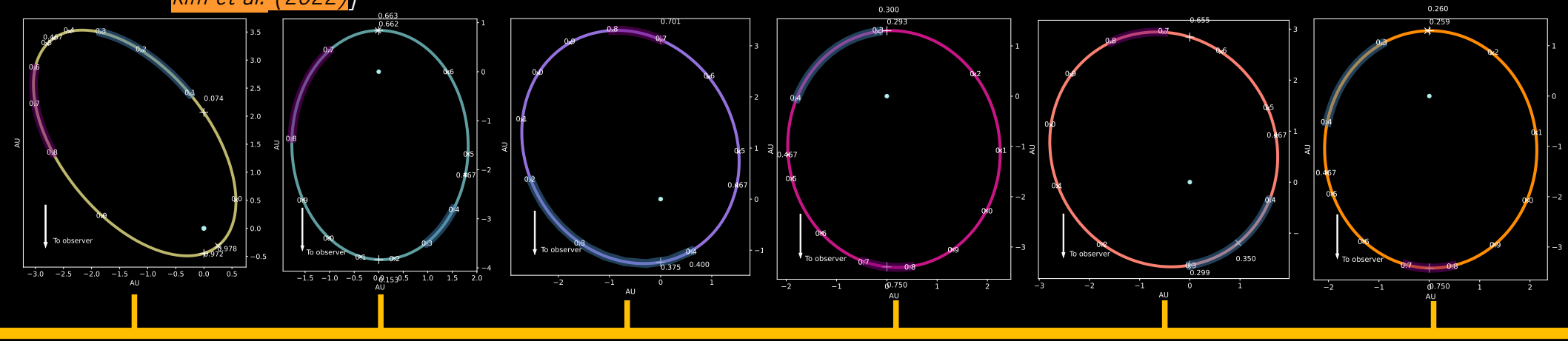

Casares et al. | Moritani et al. | Malyshev et al. | Tokayer et al. | Chen et al. | Kim et al.

optical radial velocity data

numerical emission modelling

HESS J0632+ 057

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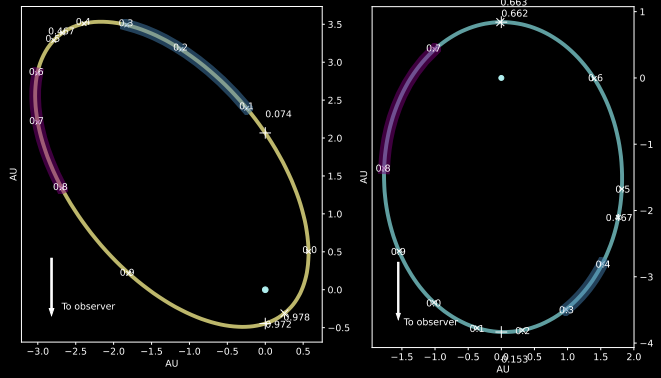
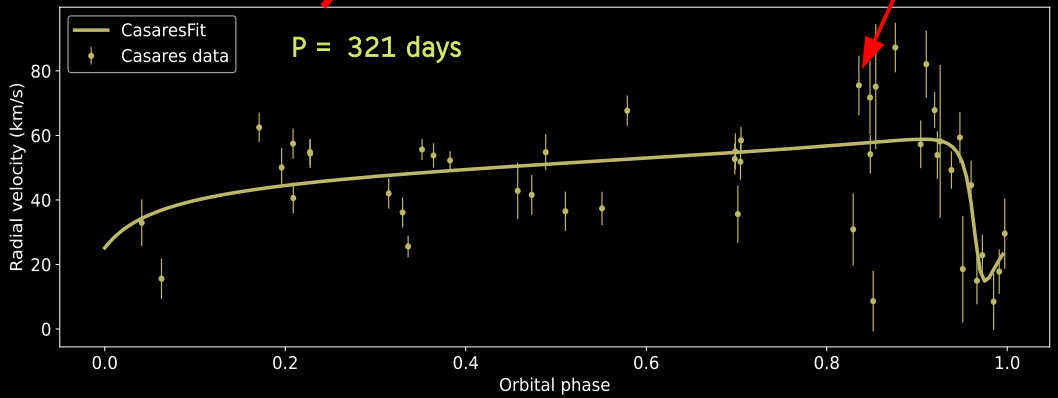
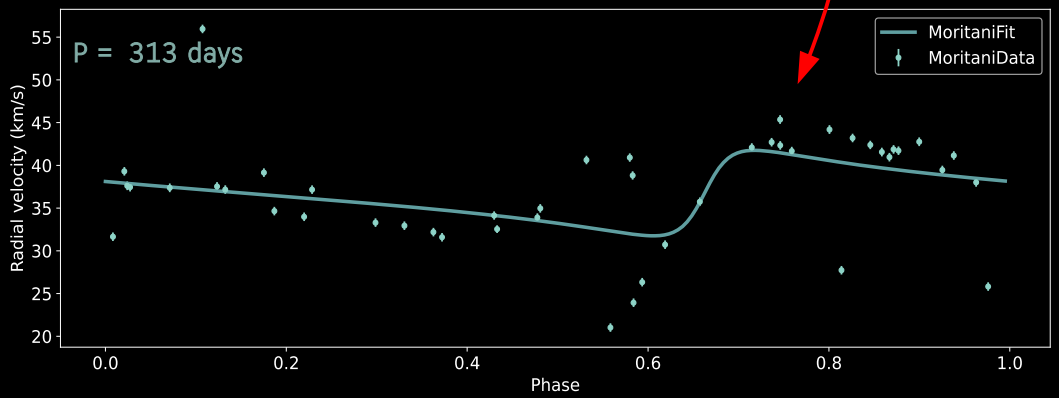


solution fit to radial velocities measured from the **Hα emission line**

solution fit to radial velocities measured from the **absorption lines**

Casares et al. ≠ Moritani et al.





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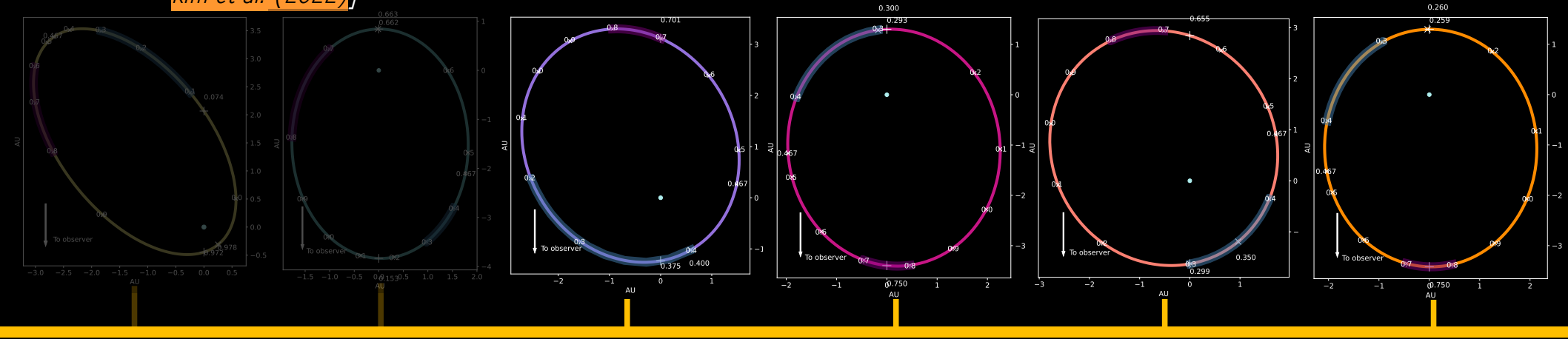

assumed orbital parameters from a 'qualitative analysis' of the X-ray light-curve

numerical emission modelling

HESS J0632+ 057

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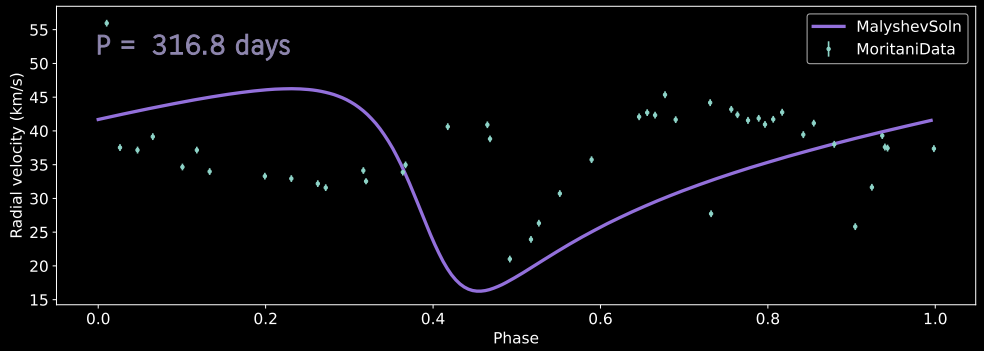
Casares et al. | Moritani et al. | Malyshev et al. | Tokayer et al. | Chen et al. | Kim et al.



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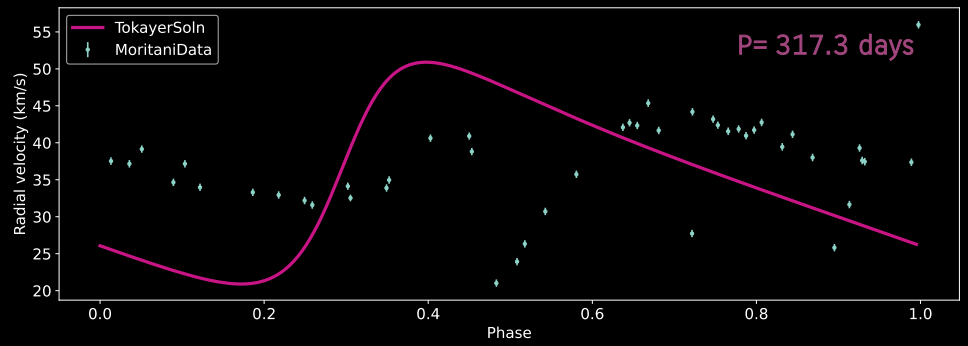

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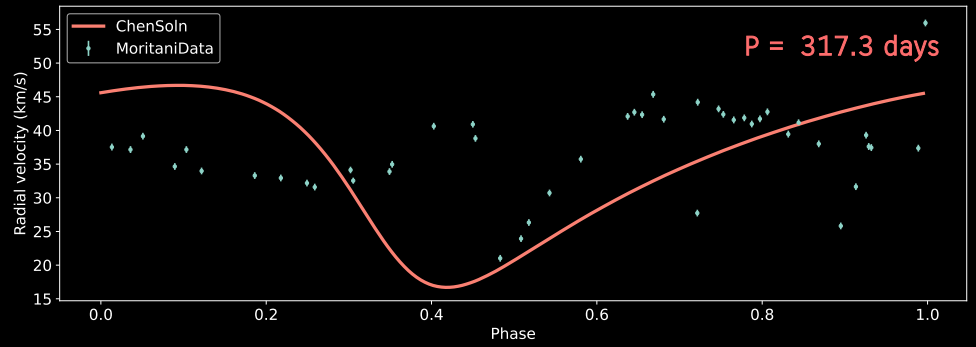

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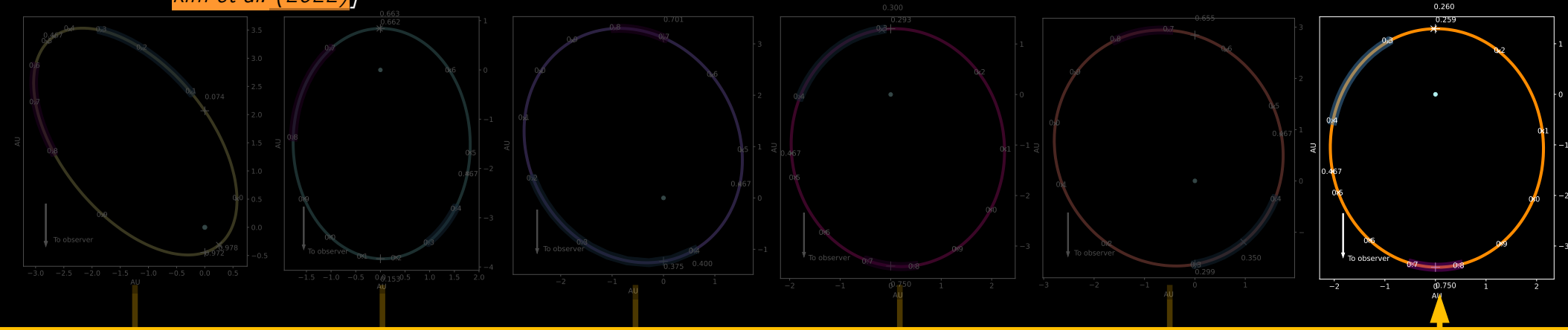

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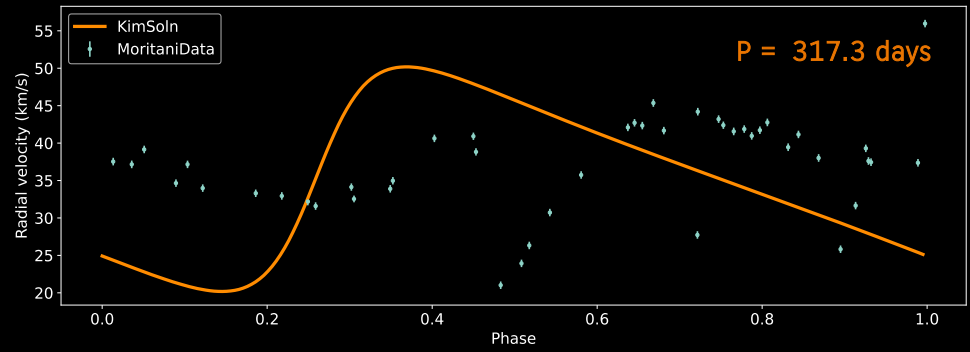
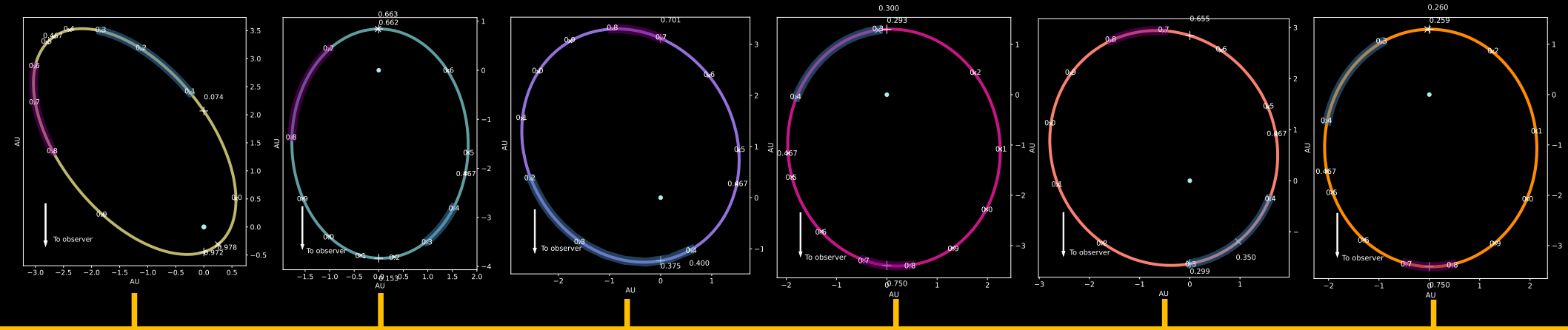
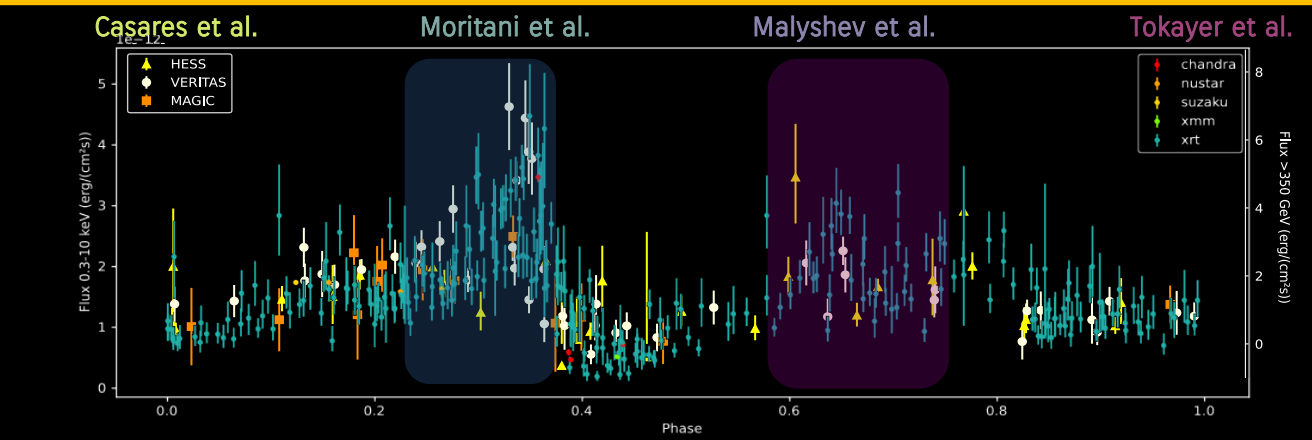
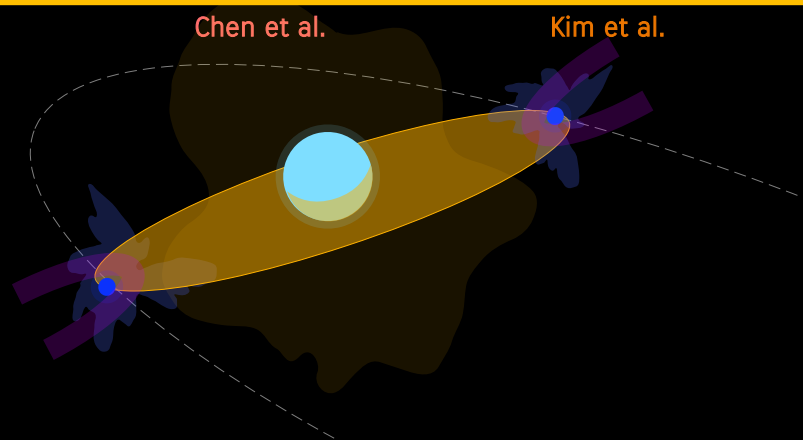


- Malyshev/Tokayer/Chen/Kim et al. solution's disagree with existing radial velocity data
- Casares et al. solution (P = 321d) incompatible with the Moritani et al. solution (P = 313d)
  - Casares used absorption lines :D But have a larger scatter :(
  - Moritani used Hα emission lines :/ But have a smaller scatter :)
- Interpretation of the X−ray/TeV emission discordant with the *geometry of the system*

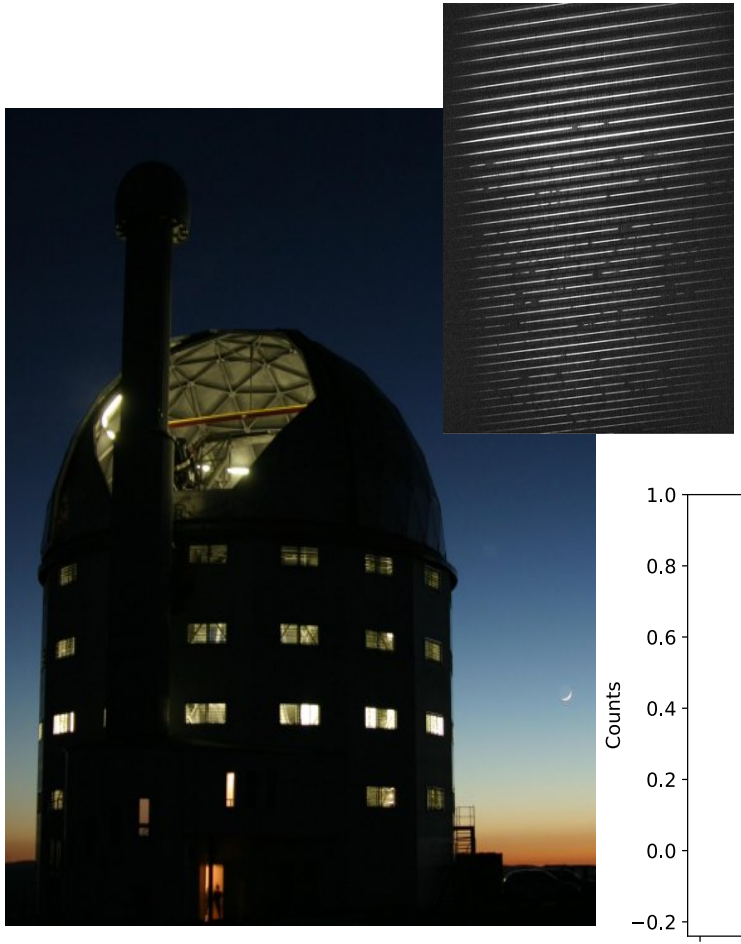




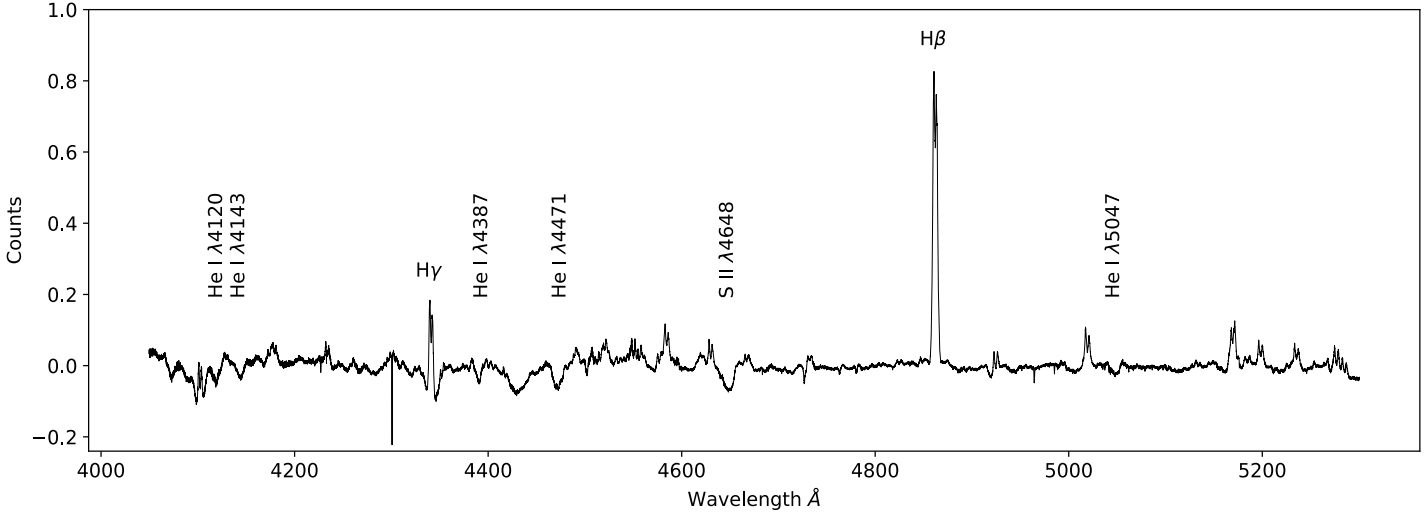


independent radial velocity measurements (emission + absorption features!)

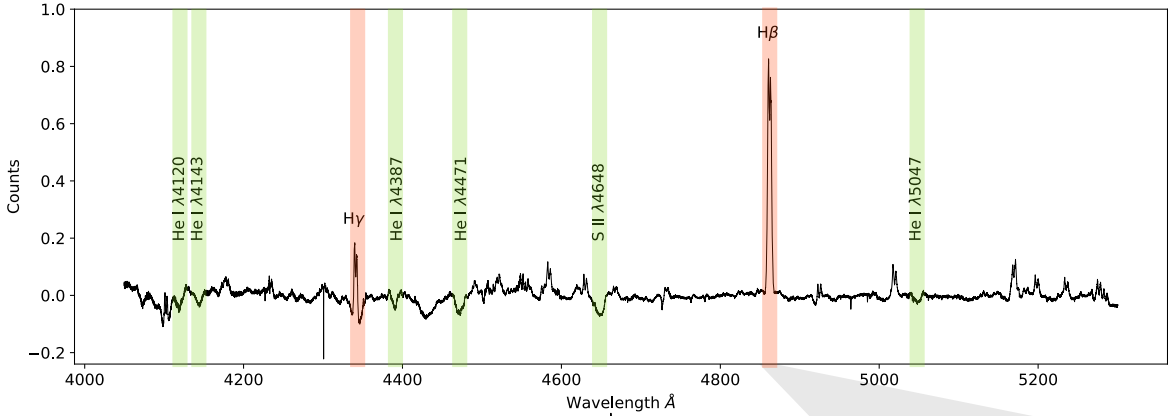
Long−term monitoring with the HRS on SALT



- Obtained (ongoing) 8 high resolution echelle spectra between Dec 2020—Feb 2022 with SALT, HRS in HR mode
- Spectra preprocessed:
  - Reduced through HRS pipeline
  - Orders remerged, sky subtracted, continuum corrected & normalized
  - Corrected to the heliocenter

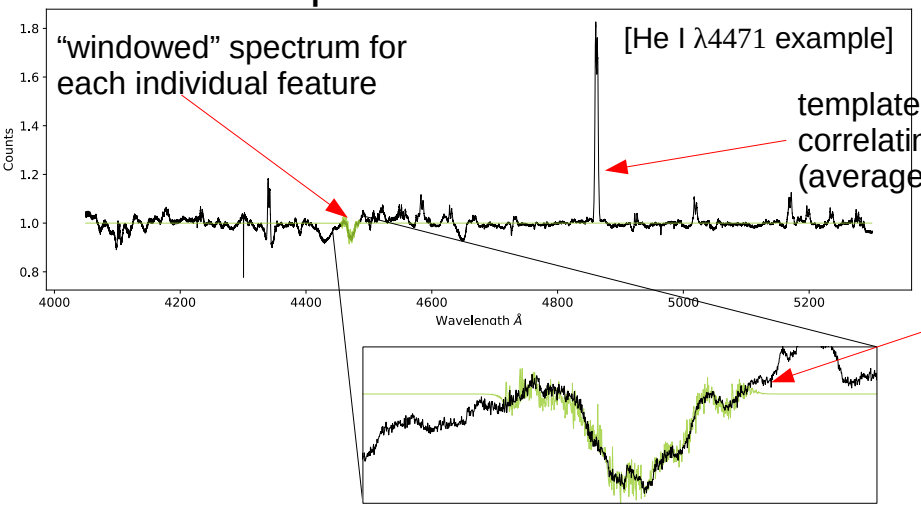


Radial velocity measurements



[+ Hα emission line (red arm spectrum)]

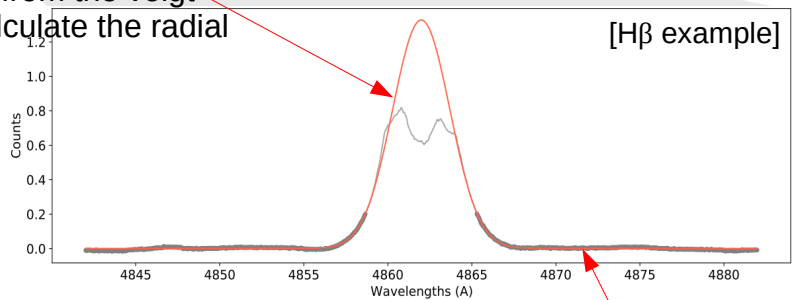
Absorption Lines



“windowed” feature cross-correlated against template using iraf xcsao to obtain radial velocity

Emission Lines

measured the shifted wavelength from the voigt profile to calculate the radial velocity

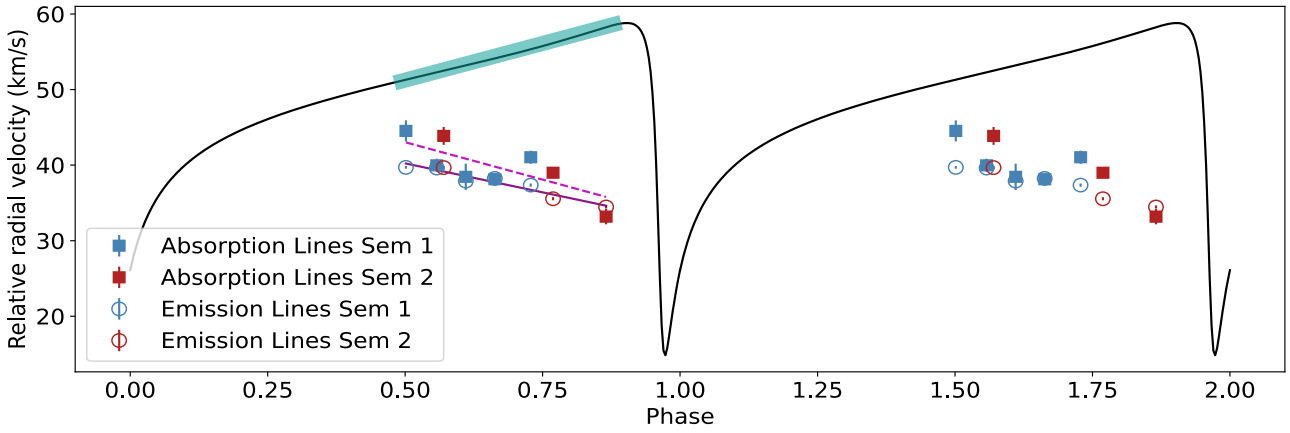


isolated the wings of emission lines & fitted a voigt profile

*[RV measured for absorption lines are relative to the template – systematic velocity for the template was measured from the shift of the Hβ and Hγ emission lines on the template]

Radial velocity measurements

[Casares et al.]



$\chi^2/\nu_{abs} = 26.8149$

$\chi^2/\nu_{em} = 7982.4277$

Slope of trend line of model vs. data:

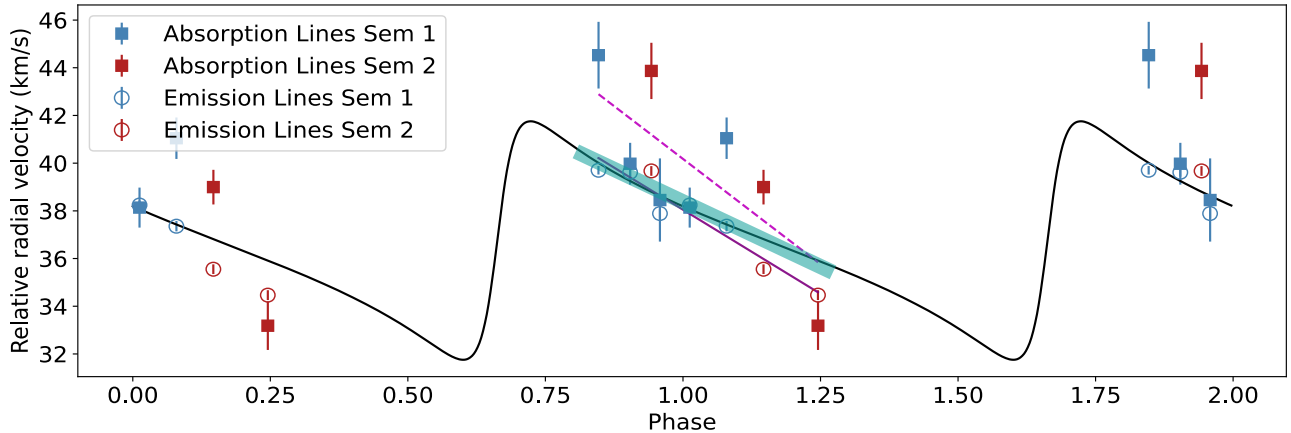
$m_{Casares} = 18.8165 \pm 0.0890$

$m_{abs} = -19.7832 \pm 2.2177$

$m_{em} = -15.3405 \pm 0.3995$

} opp. trend

[Moritani et al.]



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$m_{Moritani} = -9.9648 \pm 0.0560$

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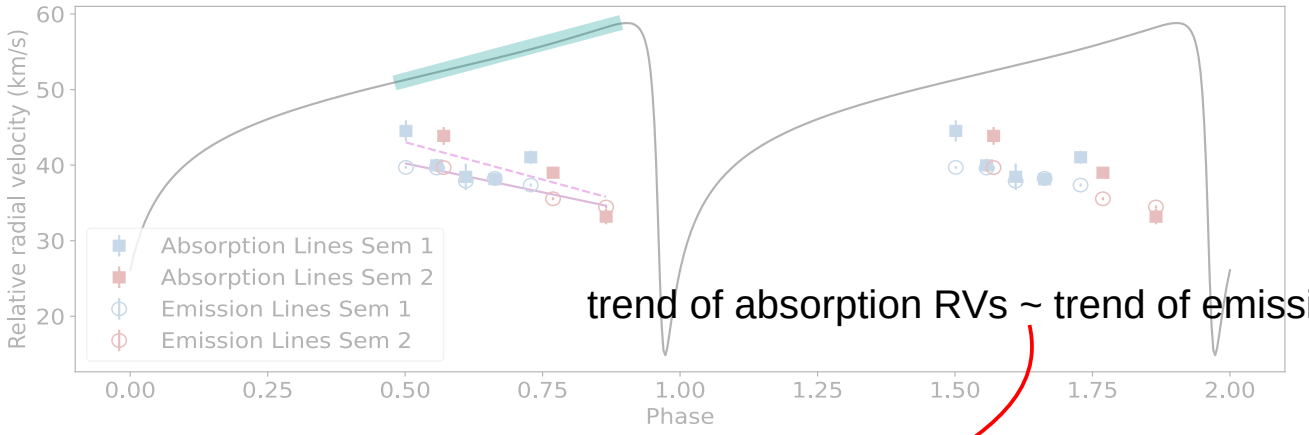
} similar trend

[we only display the **average** of the emission (open circles) and absorption lines (squares) for simplicity]

Radial velocity measurements

[Casares et al.]



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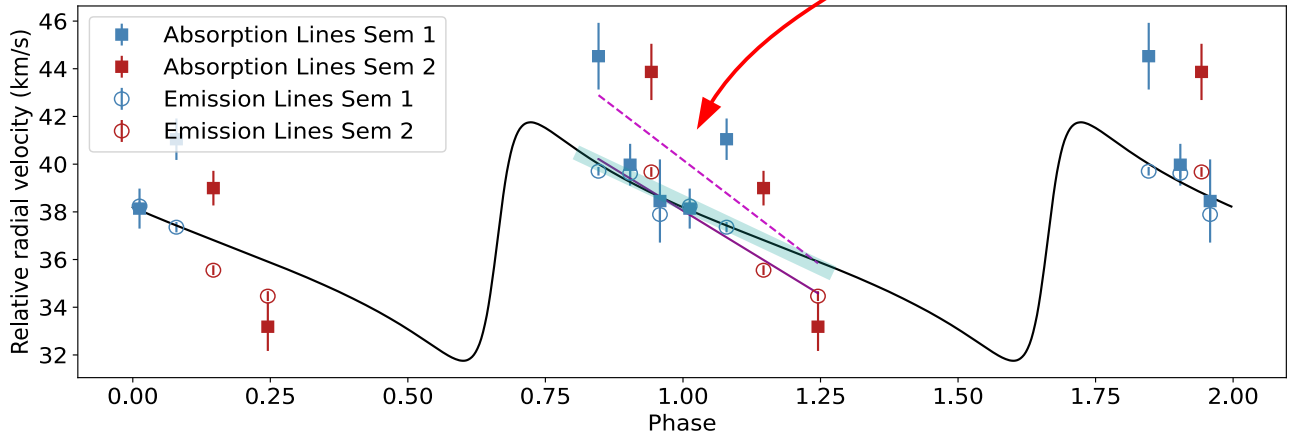
trend of absorption RVs ~ trend of emission RVs

[Moritani et al.]



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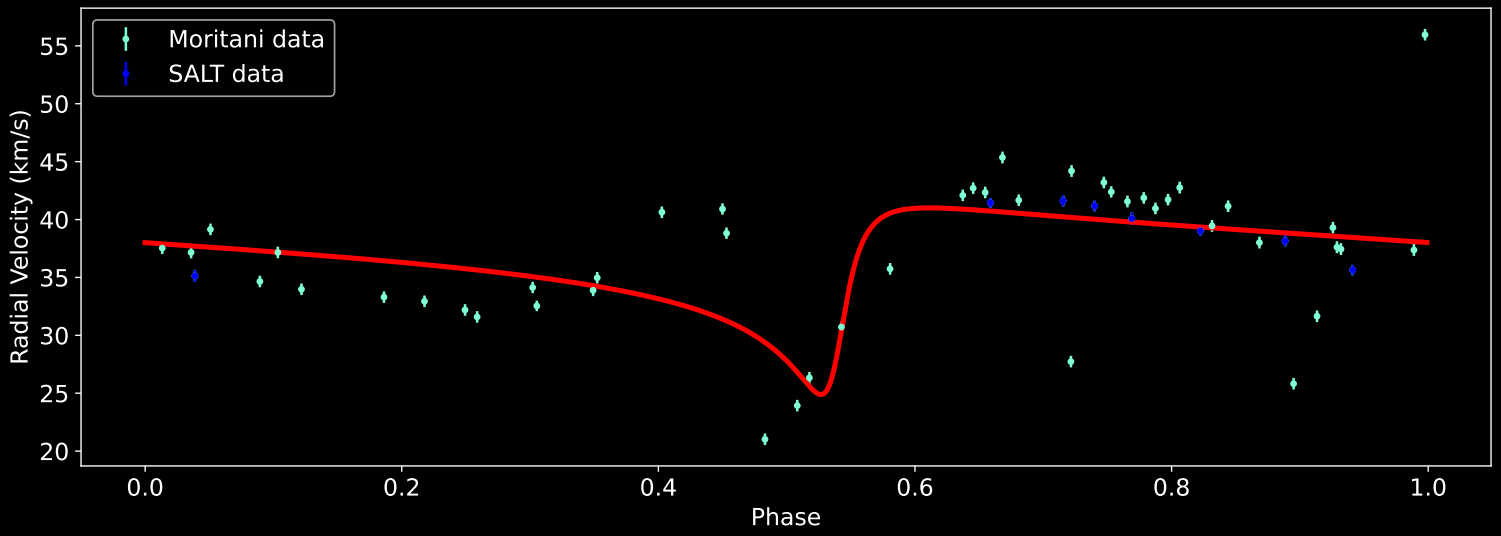
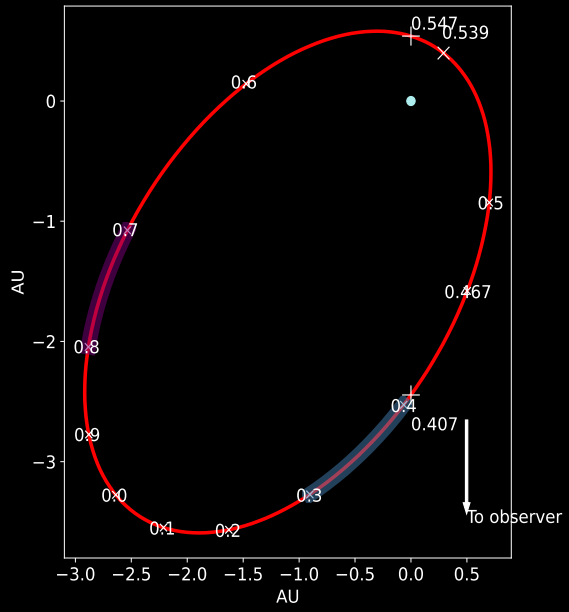
Updated radial velocity solution (Hα lines, P= 317.3 days)*





[*we have made use of publically available radial velocitiy measurements of the Hα emission lines reported by Moritani et al. 2018]

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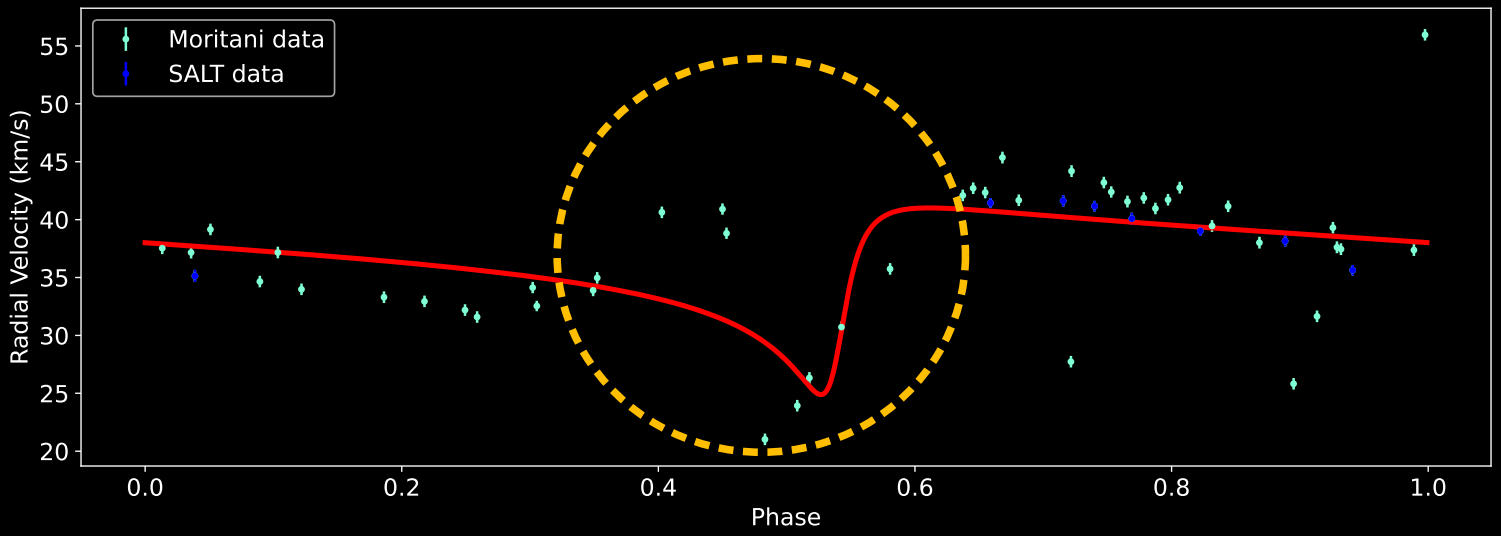

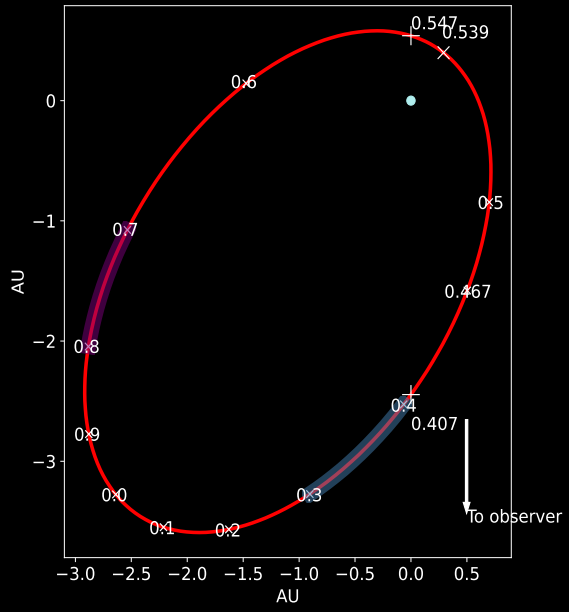

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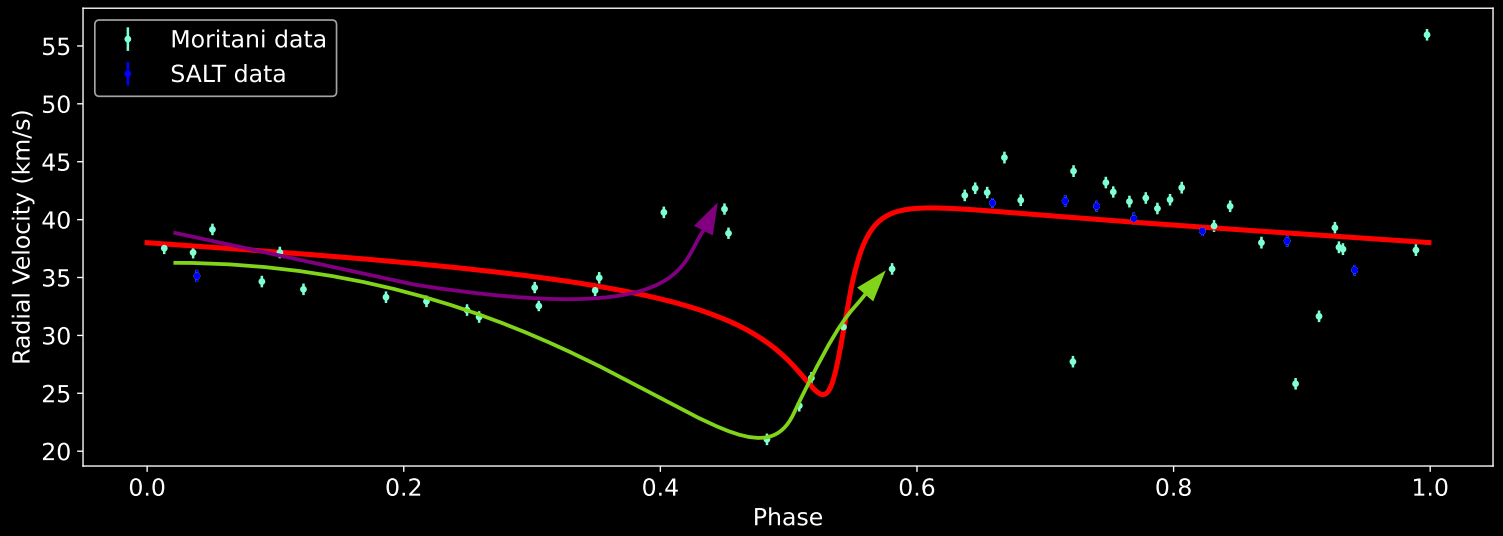

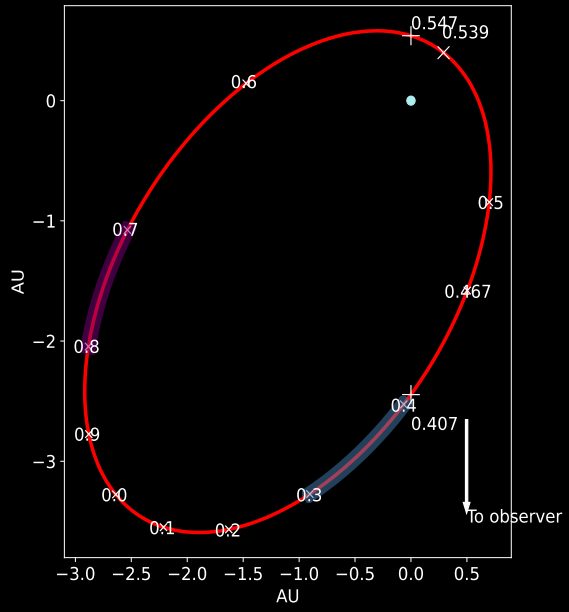

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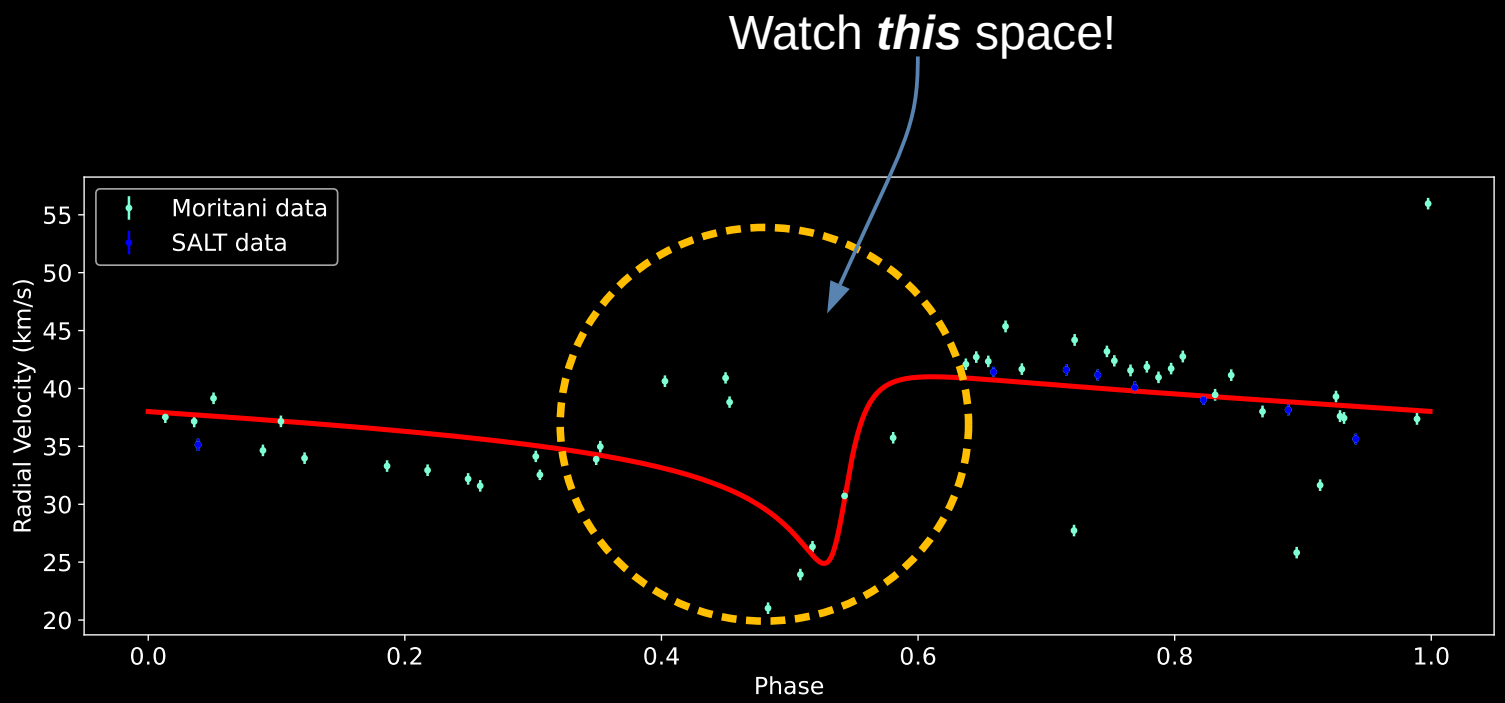
Concluding remarks

- Obtaining an orbital solution - through optical observations! - is very important to understand the physics within this system
  - Continued monitoring of the optical companion will provide further phase coverage – with an emphasis around periastron
    -> Increased data around periastron will help to provide an improved/updated orbital solution

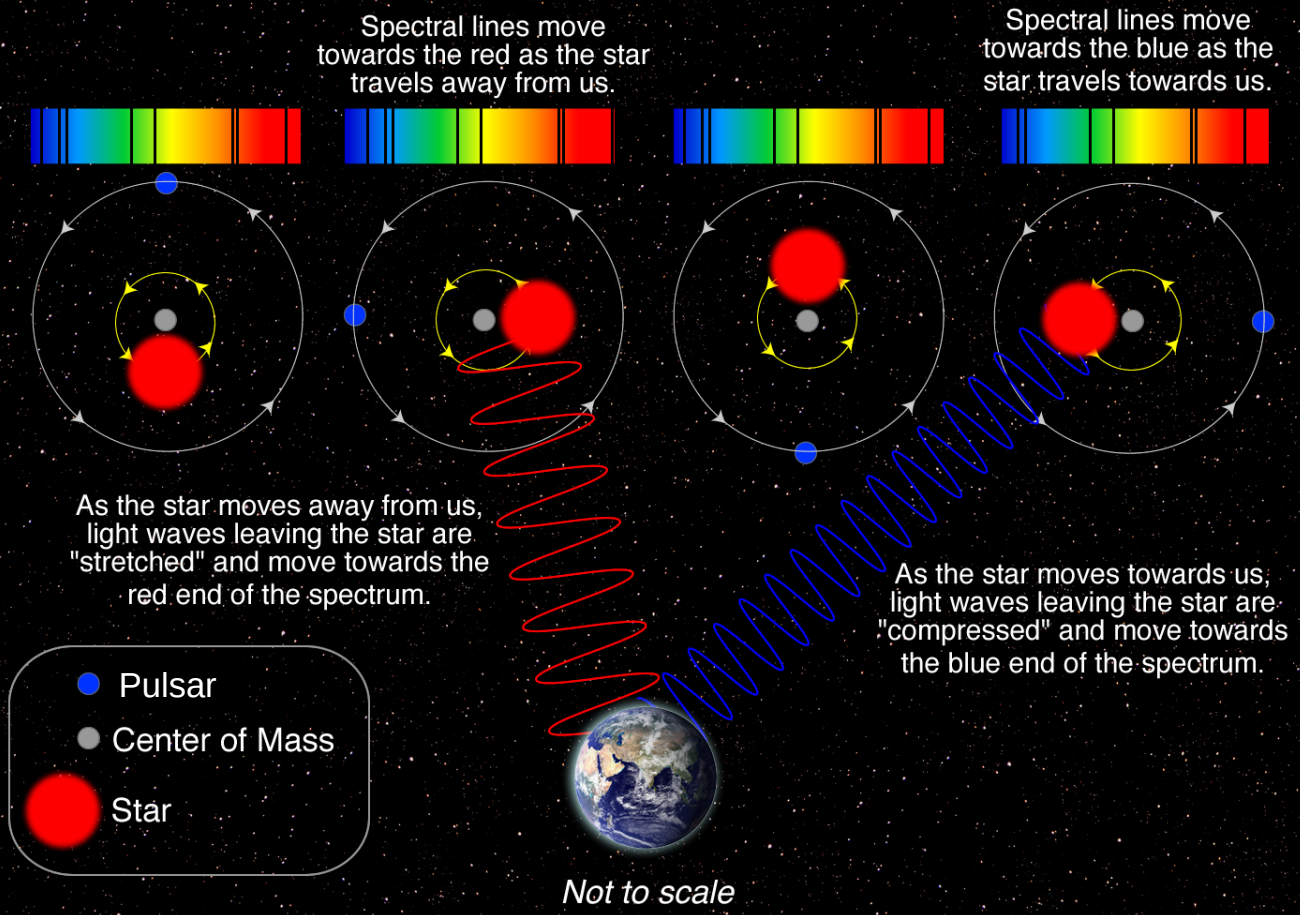


Thank you!

Backup slides

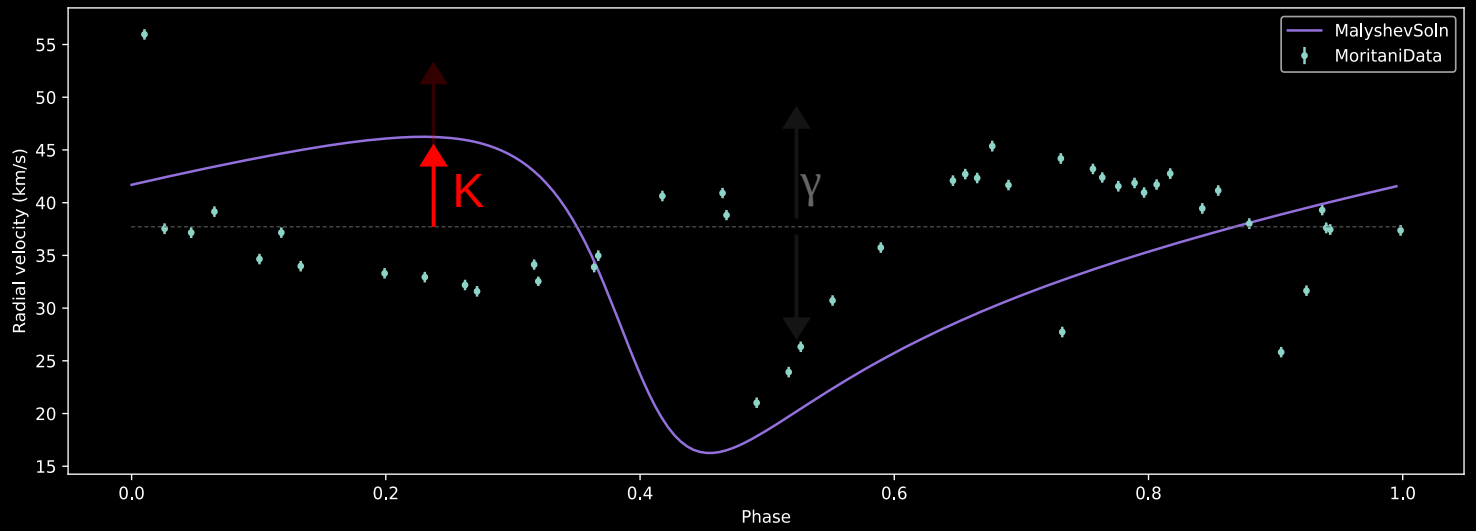
Radial Velocity Method

The star and planet orbit their common center of mass.



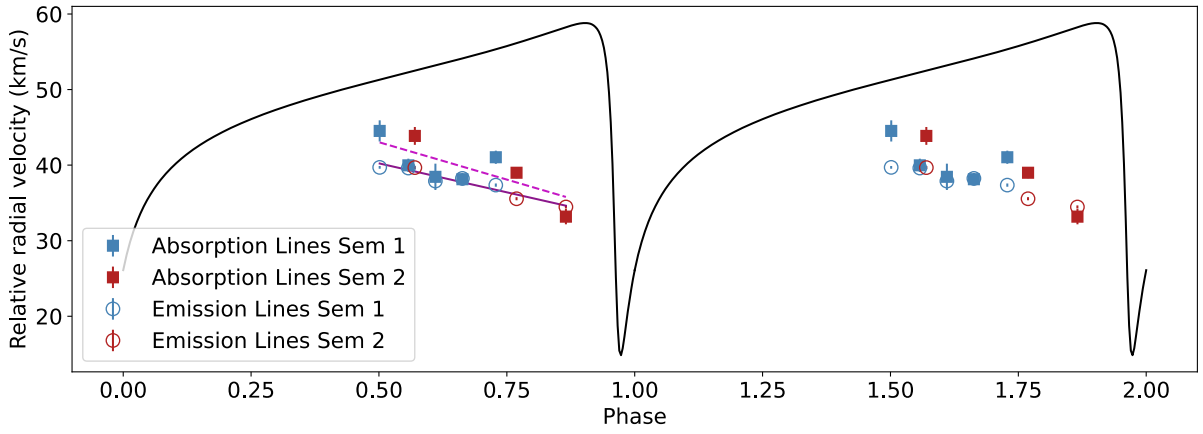
$$v_{rad} = c \frac{\left(\left(\frac{\lambda_{obs} - \lambda_{rest}}{\lambda_{rest}} + 1\right)^2 - 1\right)}{\left(\left(\frac{\lambda_{obs} - \lambda_{rest}}{\lambda_{rest}} + 1\right)^2 + 1\right)}$$

Radial velocity fitting

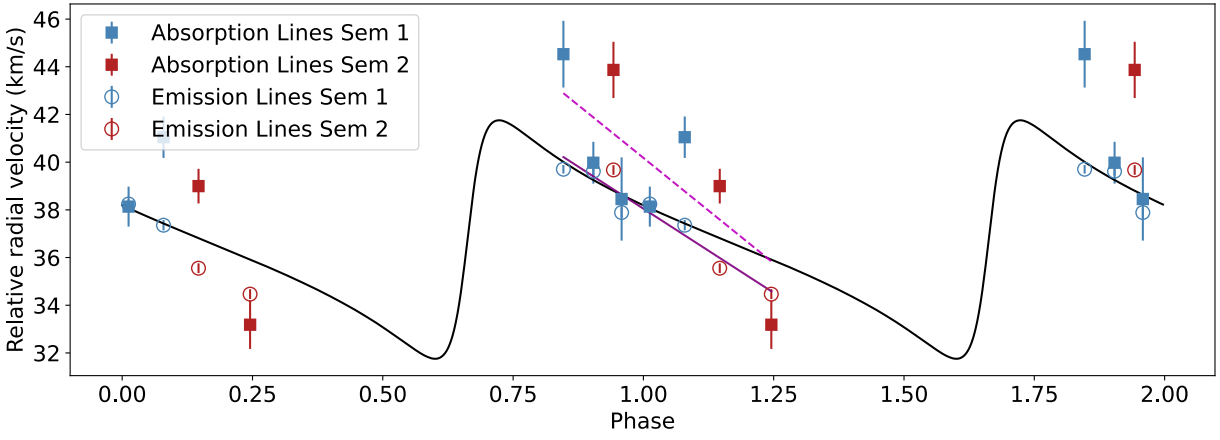


Radial velocity measurements

[Casares et al.]



[Moritani et al.]



Feature	Red_Chi2_Mor	Red_Chi2_Cas
Hα	12.1539	1239.7196
Hβ	23.3824	6514.0046
Hγ	12.2111	258.2389
AVE_emission	18.2120	7982.4277
He I λ4118	23.4953	34.7106
He I λ4142	61.1020	48.0098
He I λ4389	43.3374	181.0489
S II λ4647	183.0354	329.1531
He I λ5047	76.4246	116.1346
AVE_absorption	6.0894	26.8149

[we only display the **average** of the emission (open circles) and absorption lines (squares) for simplicity]