

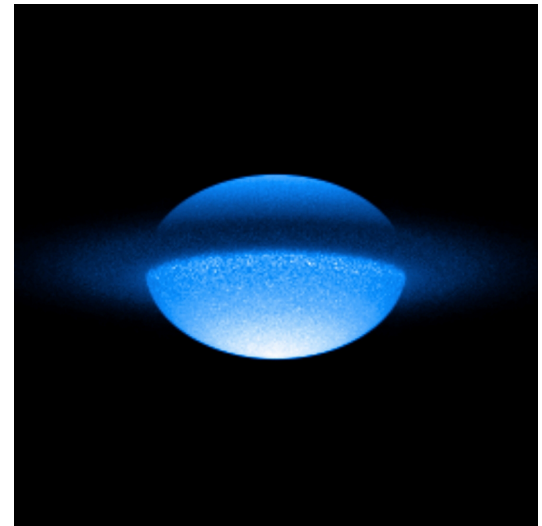
Supersoft Be X-ray binaries in the Magellanic Clouds

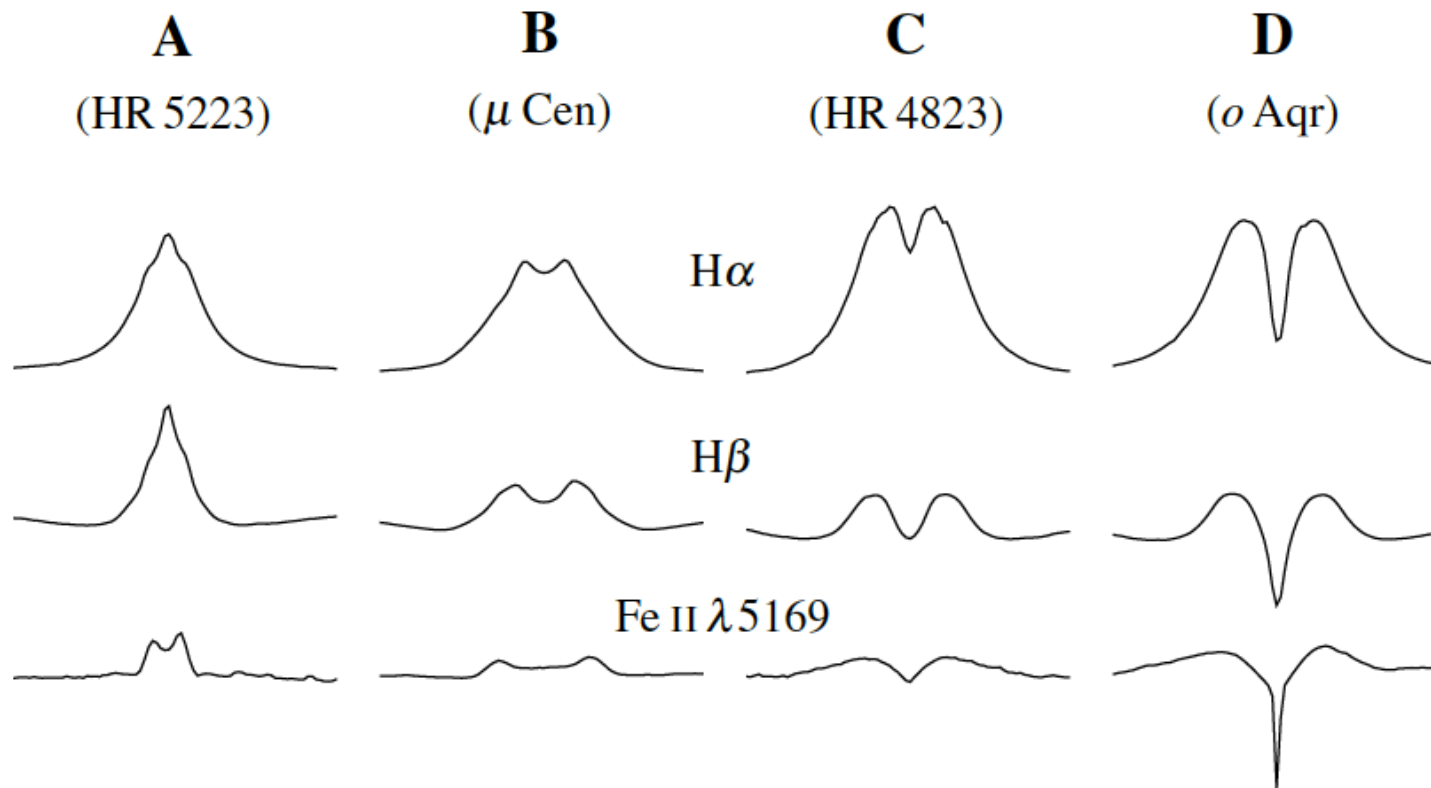
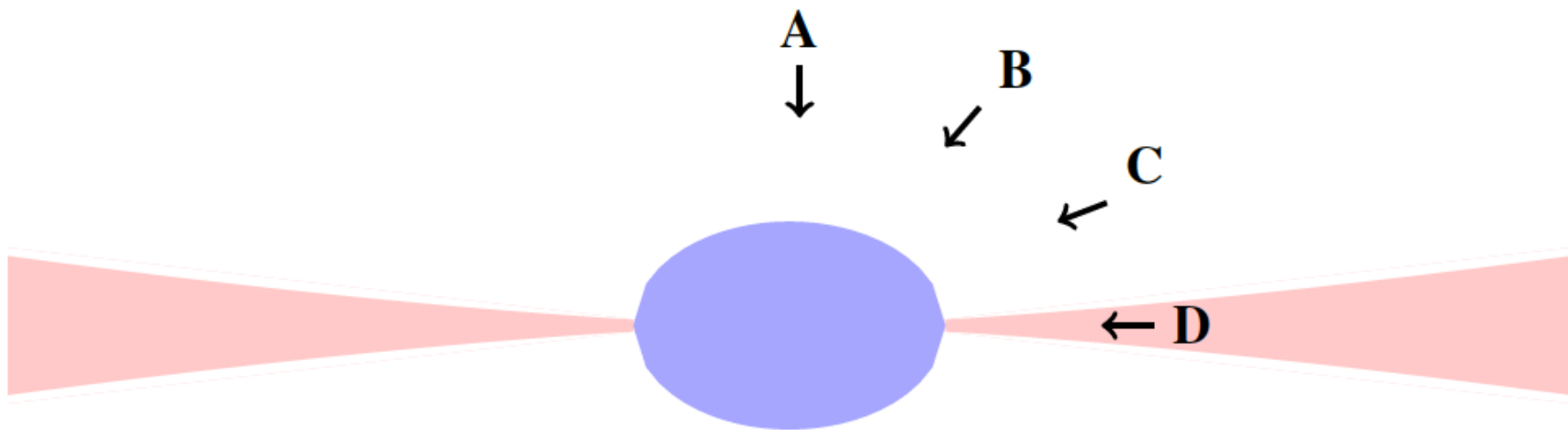
Stefano Cirio
(University of Padova)

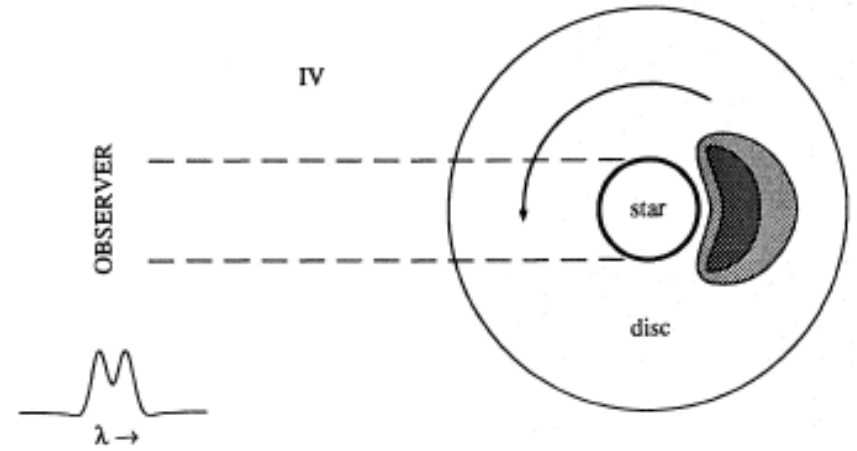
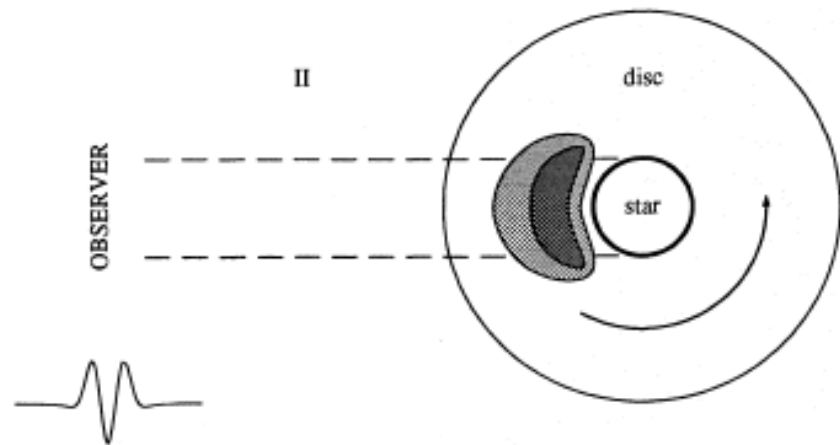
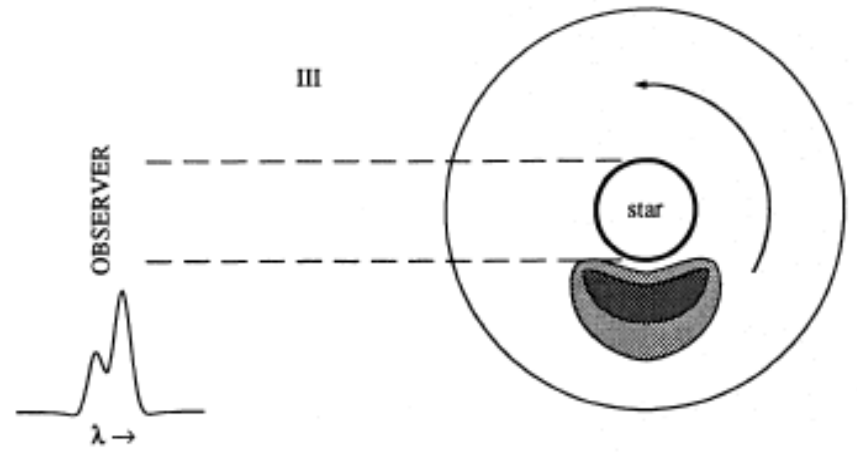
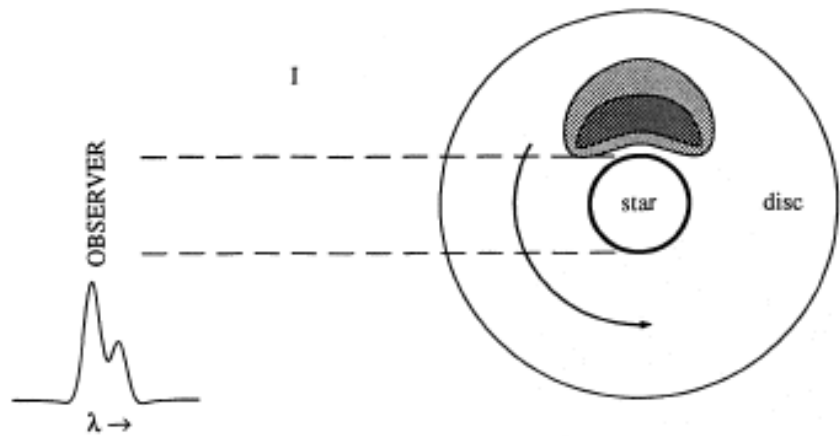
V. Cracco, M. Orio, J. Gallagher, R. Kotulla, E. Romero-Colmenero

Be stars

- Rapidly rotating B stars forming a decretion (also excretion) Keplerian emission line disk
- Equivalent width of H α from some Å to some tens of Å
- Emission line variability on time scale of years
- Emission line profile variability
- Excess of near infrared emission







SuperSoft Be X-ray binaries

- 30% of Be are binary systems (Oudmaijer & Parr, 2010)
- thin viscous **truncated** Keplerian disk of gas in the equatorial plane of the B star
- **higher density** disk than in isolated Be (Reig+ 2016)
- variability of emission lines (H, He, Fe) on **shorter time scales** (1-5 yrs, Reig 2011) than isolated Be (2-11 yrs, Okazaki 1997)
- **double spiral arms** caused by the binarity (Panoglou+ 2016, 2018)

SuperSoft Be X-ray binaries

- very soft X-ray spectrum $L_{\text{SX}} \sim 10^{35} - 10^{38} \text{ erg s}^{-1}$ (and negligible emission above 1 keV)
- SS flare hypothesis: short thermonuclear flash caused by ignition of hydrogen from the Be disk through the CNO cycle onto a WD
- Be/WD binaries in MW are expected to be frequent ($\sim 70\%$, Raguzova 2001),
- Be/X-ray binaries in MCs are mostly Be/NS, very few examples of Be/WD have been discovered
- It is extremely difficult to detect the WD presence
- Be+WD binaries are expected to host a massive WD and, if the WD accretes from the Be excretion disk, they are candidate SNe Ia progenitors through a new channel

XMMU-J052016.0-692505

LMCV 2135
SSS

$$L_{\text{SX}} = 5.5 \times 10^{36} \text{ erg s}^{-1}$$

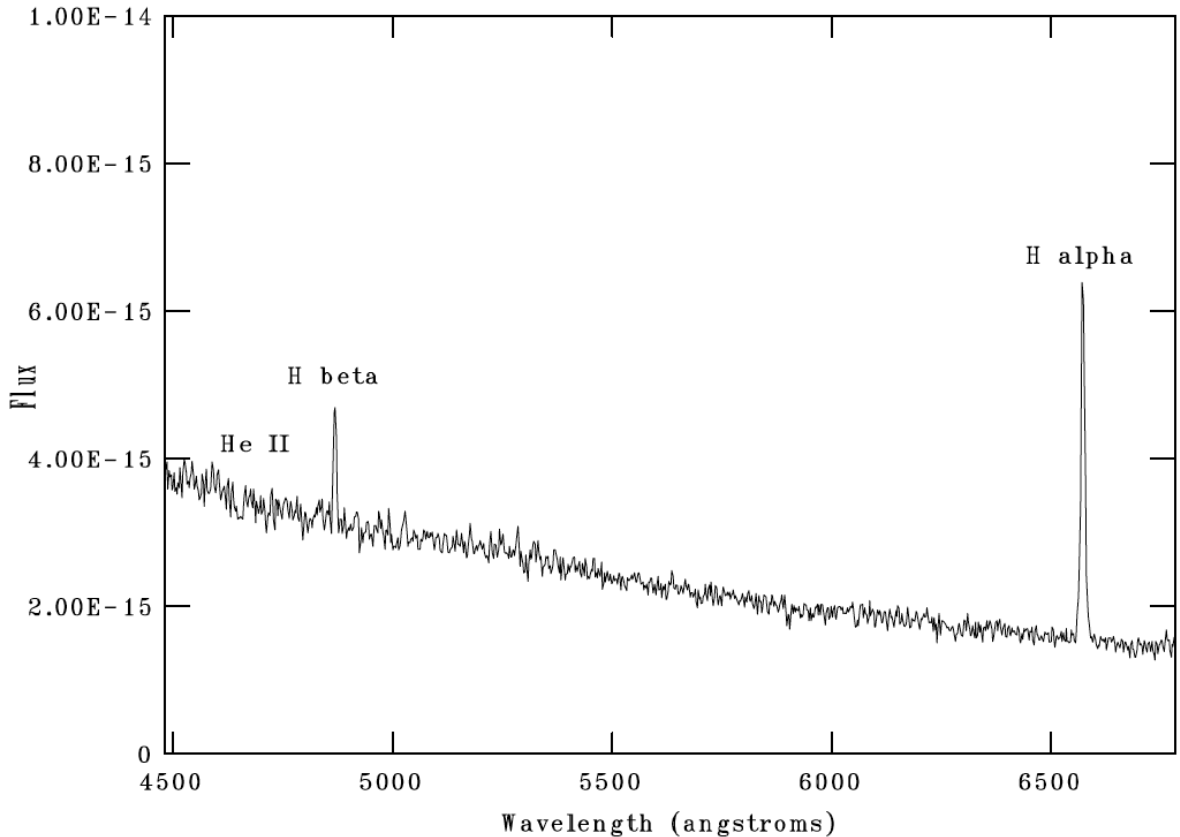
$$V = 14.80 \pm 0.02$$
$$B-V = -0.03 \pm 0.03$$

SpType = B0-3e

WD Be/X-ray binary
 $7-15 M_{\odot} + 0.9-1.0 M_{\odot}$

$$\text{EW}(\text{H}\alpha) = 32 - 37 \text{ \AA}$$
$$V_{\text{rad}}(\text{H}\alpha) = 6 - 430 \text{ km s}^{-1}$$

(Kahabka+ 2006)



XMMU-J010147.5-715550

AzV281

Recurrent SSS

$$L_{\text{SX}} = 7.3 \times 10^{37} \text{ erg s}^{-1}$$

$$V = 14.47 \pm 0.04$$

SpType = O7IIIe – B0Ie

NIR excess and variability

WD Be/X-ray binary

(Sturm+ 2012)

Suzaku J0105-72

1E0102.2-7219 (Takei+ 2008)

2dFS 2064 (Evans+ 2004)

Transient SSS in a SNR

$$L_{\text{SX}} = 2 \times 10^{37} \text{ erg s}^{-1}$$

$$V = 14.64 \text{ (Evans+ 2004)}$$

SpType = B0 IV (Evans+ 2004)

O9.3 III/Ve (Lamb+ 2016)

MAXI J0158-744

Transient SSS

$$L_{0.2-2 \text{ keV}} \sim 2 \times 10^{37} \text{ erg s}^{-1}$$

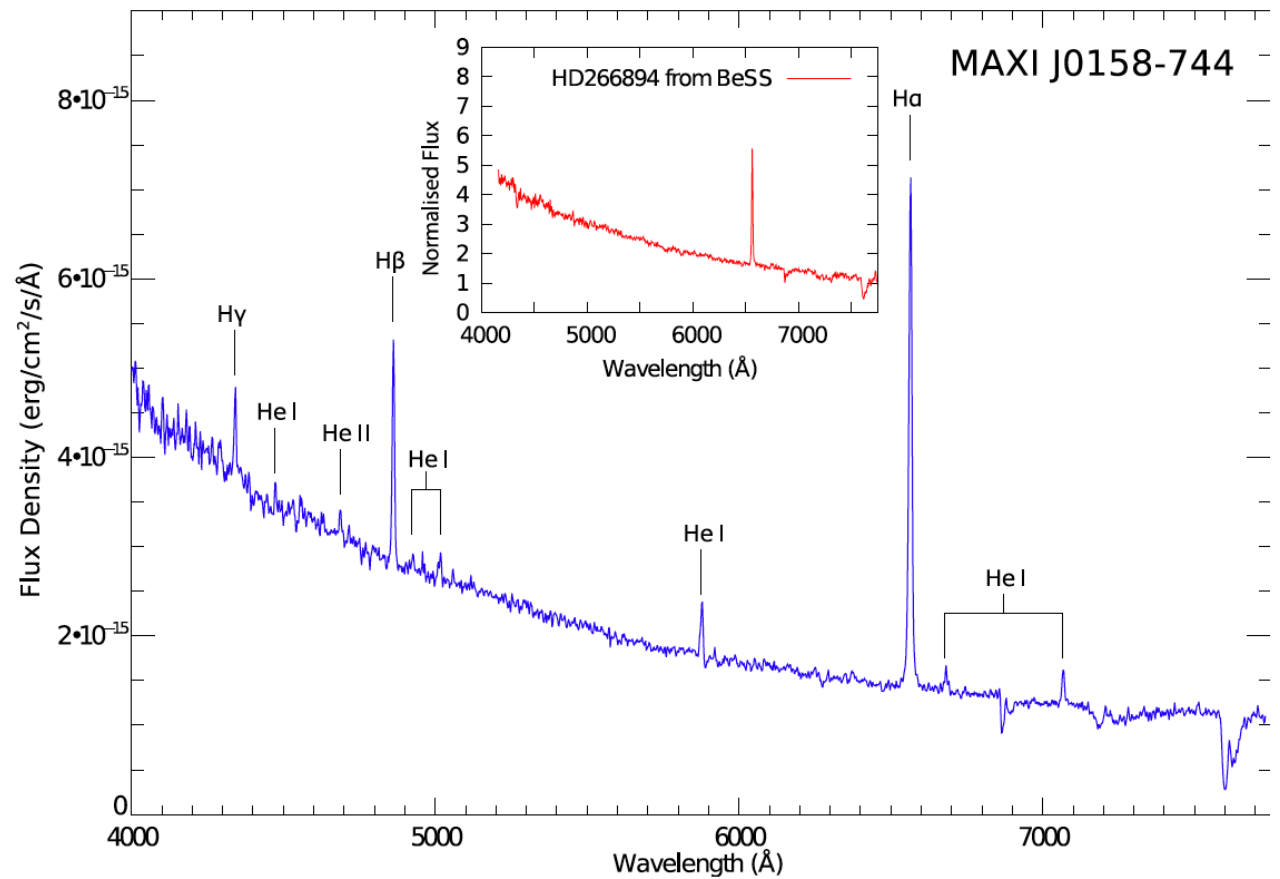
$$L_{2-4 \text{ keV}} \sim 1.6 \times 10^{39} \text{ erg s}^{-1}$$

$I = 14.82$

SpType = B1/2 IIIe

WD Be/X-ray binary
Nova explosion event

(Li+ 2012)





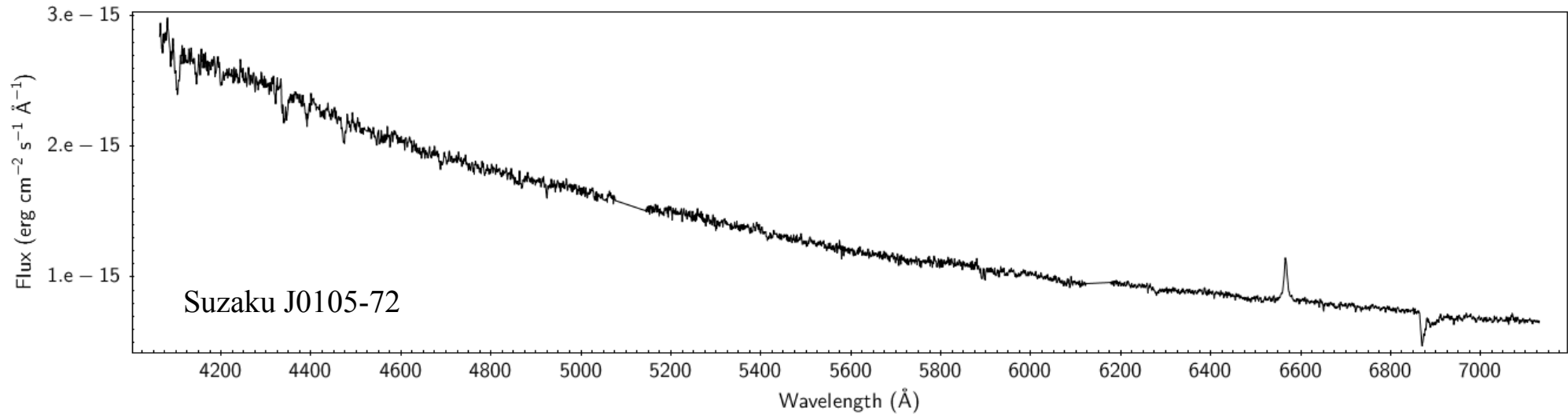
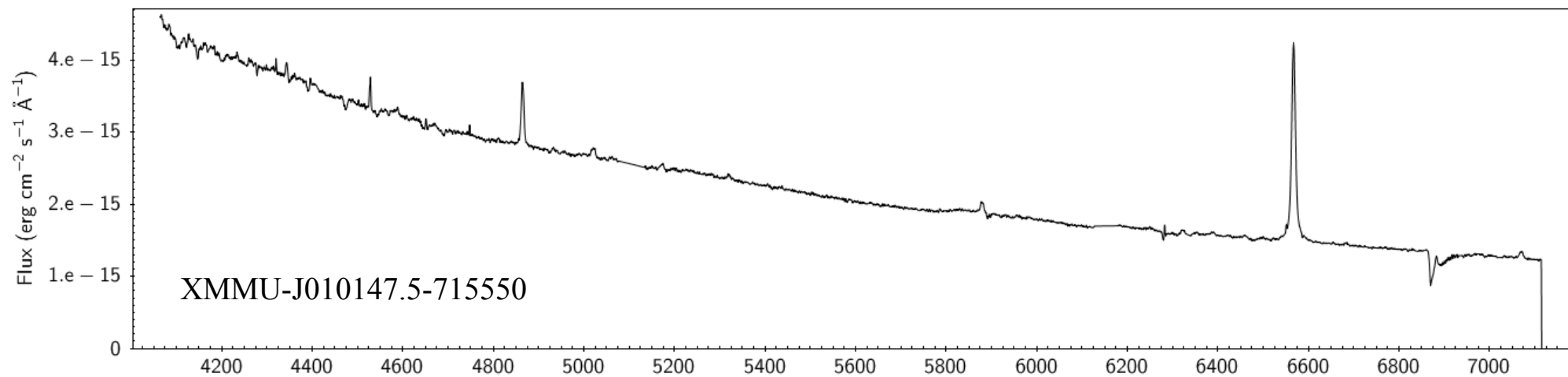
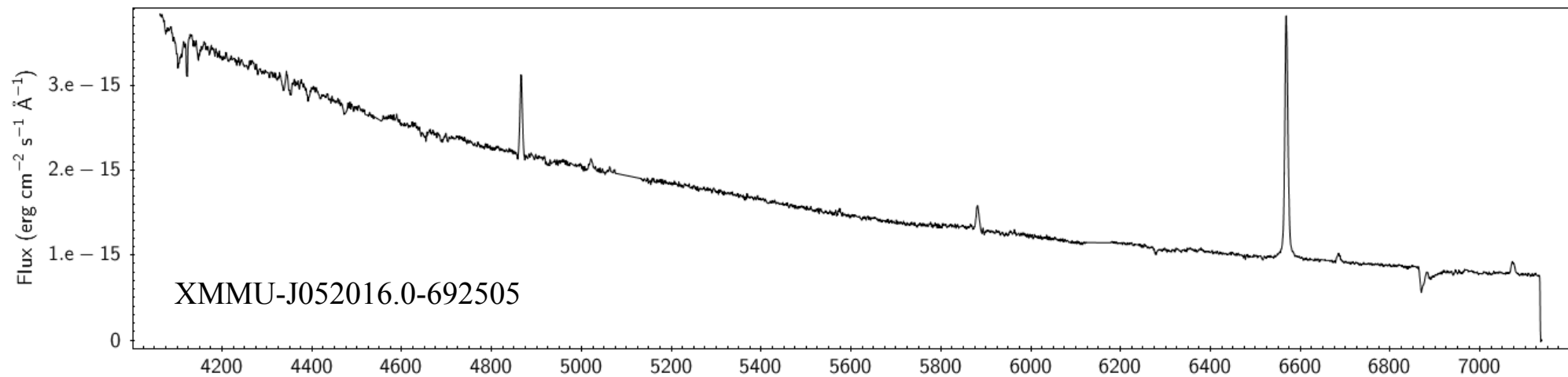
Robert Stobie Spectrograph (RSS)
Long-slit mode
PG900 (R=1100), PG2300 (R=2900)

XMMU J05 3 epochs 2016

XMMU J01 2 epochs 2016

Suzaku J01 2 epochs 2016

MAXI J0158 2 epochs 2016





High Resolution Spectrograph (HRS)

Dual-beam fiber-fed echelle

Low Resolution $R=15000$

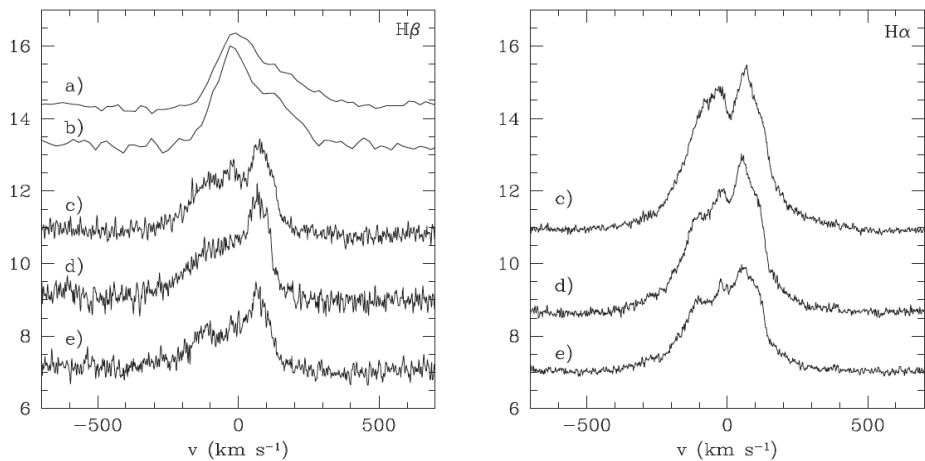
XMMU J05 3 epochs 2017

XMMU J01 3 epochs 2017

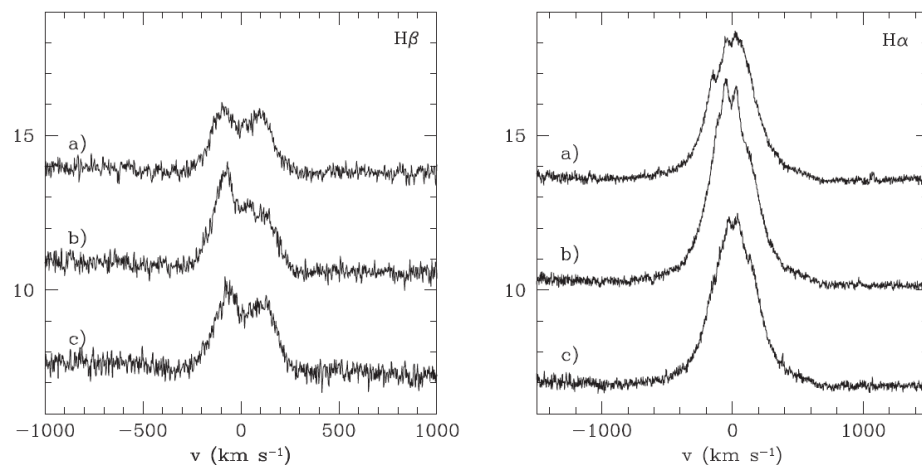
Suzaku J01 3 epochs 2017

MAXI J0158 3 epochs 2017

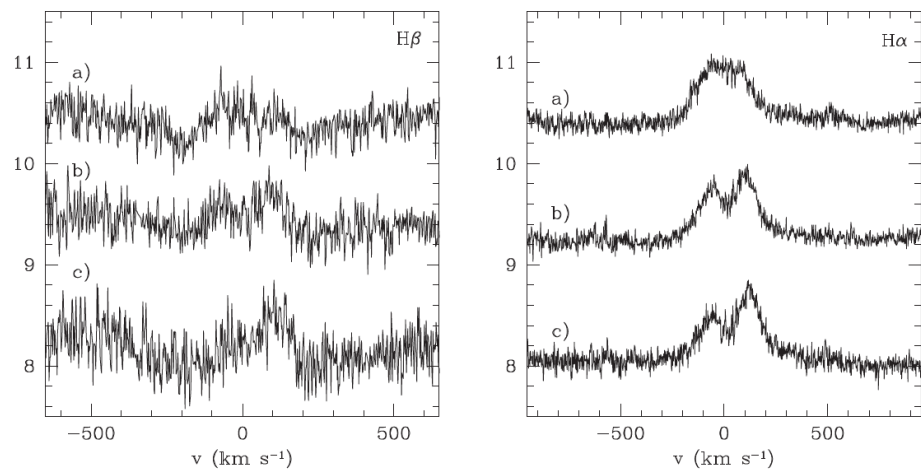
XMMU-J052016.0-692505



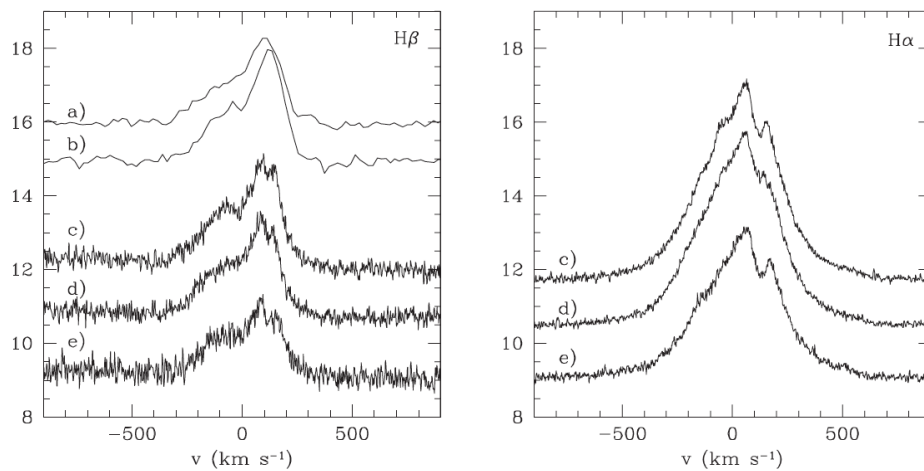
XMMU-J010147.5-715550



Suzaku J0105-72



MAXI J0158-744



Results

- blue continuum with H α , H β , H γ , He I 5876,6678,7065, Fe II 4523,5018,5317
- no He II 4686 (= no accretion disk)
- no one is a shell Be
- double peaked H β with V/R changing from 0.5 to 1.5 in few days
- $\Delta v(\text{H}\beta) \sim 130 - 220 \text{ km s}^{-1}$
- complex H α profiles with multiple peaks or wine-bottle shape
- $\Delta v(\text{H}\alpha) \sim 120 - 200 \text{ km s}^{-1}$
- small disk radii ($\sim 10 R_{\star}$ vs. $\sim 14-22 R_{\star}$, Reig+2016)

Since V/R variations could indicate disk perturbations induced by the binary system, time series of profiles may allow to constrain the physical properties of binaries (Panoglou+2018)



High Resolution Spectrograph (HRS)

Dual-beam fiber-fed echelle

Low Resolution $R=15000$

XMMU J05 10 epochs 2018

XMMU J01 11 epochs 2018

Work in progress

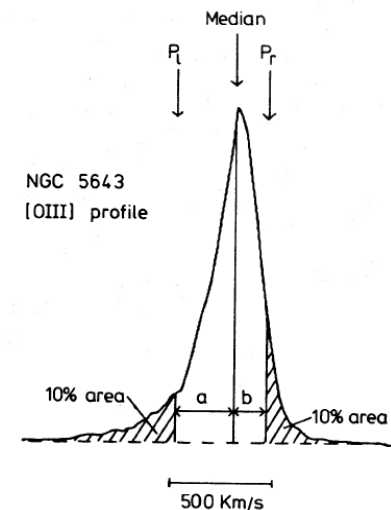
- Equivalent width

- Radial velocity \longrightarrow $\lambda_0 = \frac{\int \lambda f_\lambda d\lambda}{\int f_\lambda d\lambda}$ First Moment (Peterson+ 2004)

- $V \sin i$ \longrightarrow Fast Fourier Transform (Gray 1973, Simon-Diaz+ 2006, Dufton+ 2006, Dufton+ 2011)

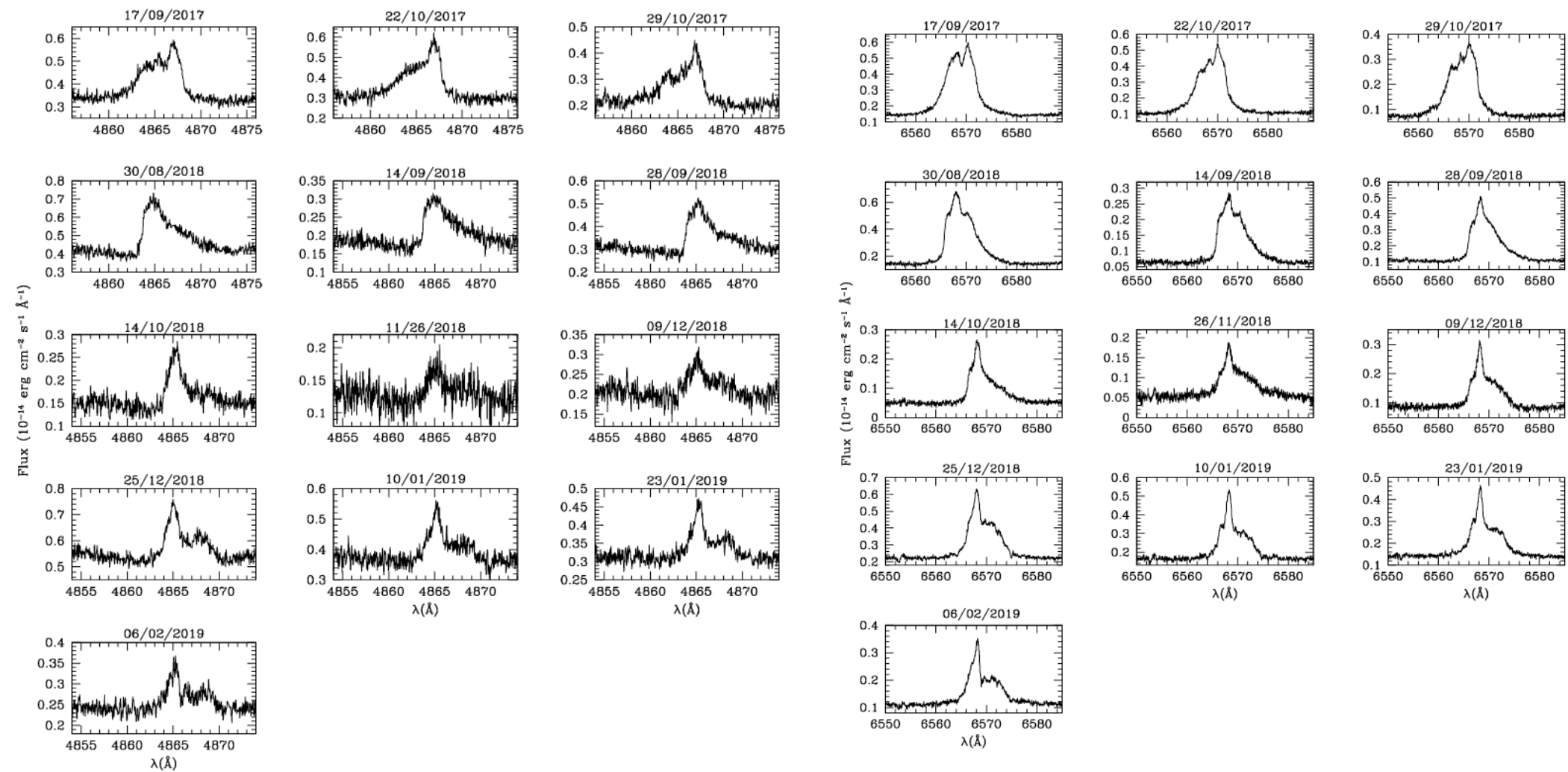
- Asymmetry \longrightarrow $A = \frac{a-b}{a+b}$

- Periodicity \longrightarrow Lomb-Scargle Periodogram (Lomb 1976, Scargle 1982, VanderPlas 2017)

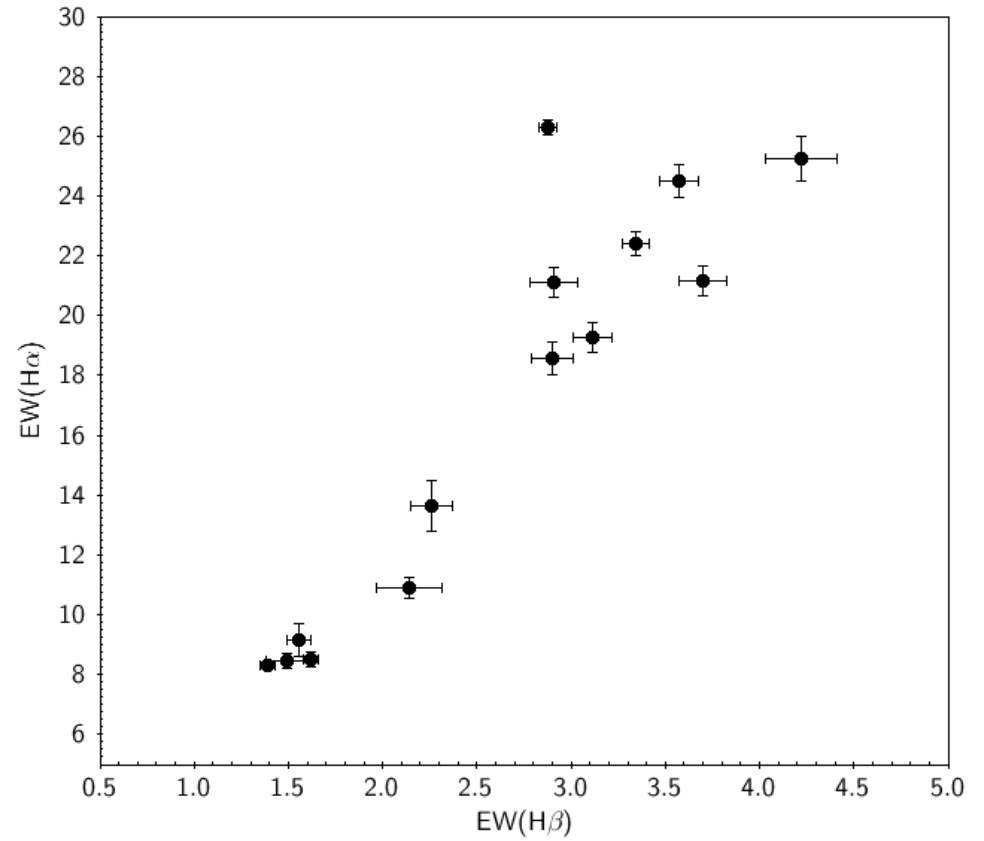
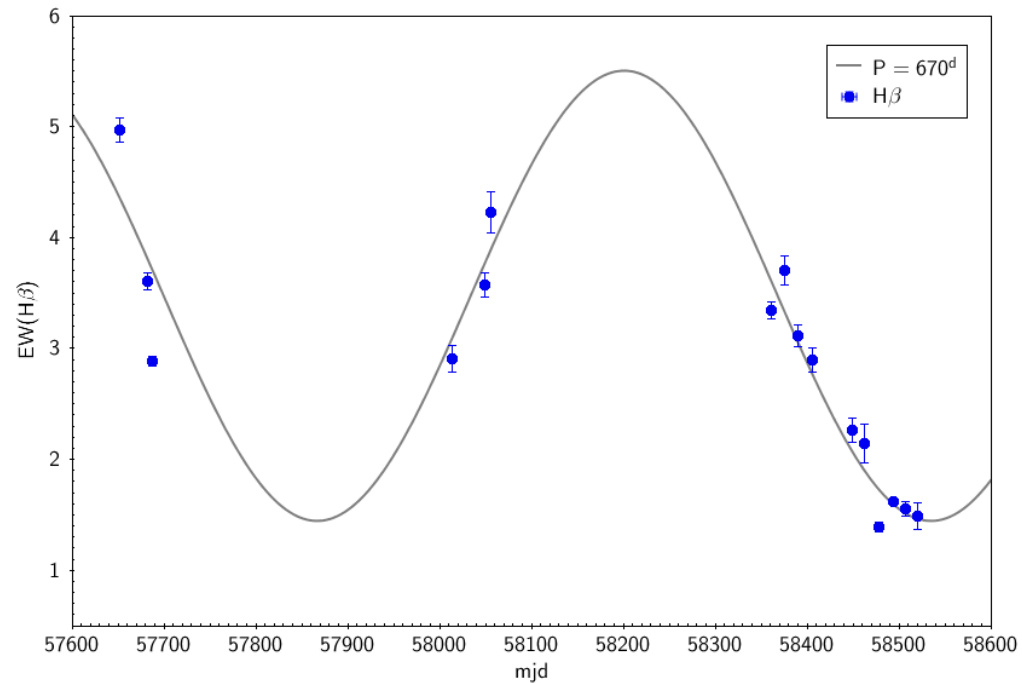
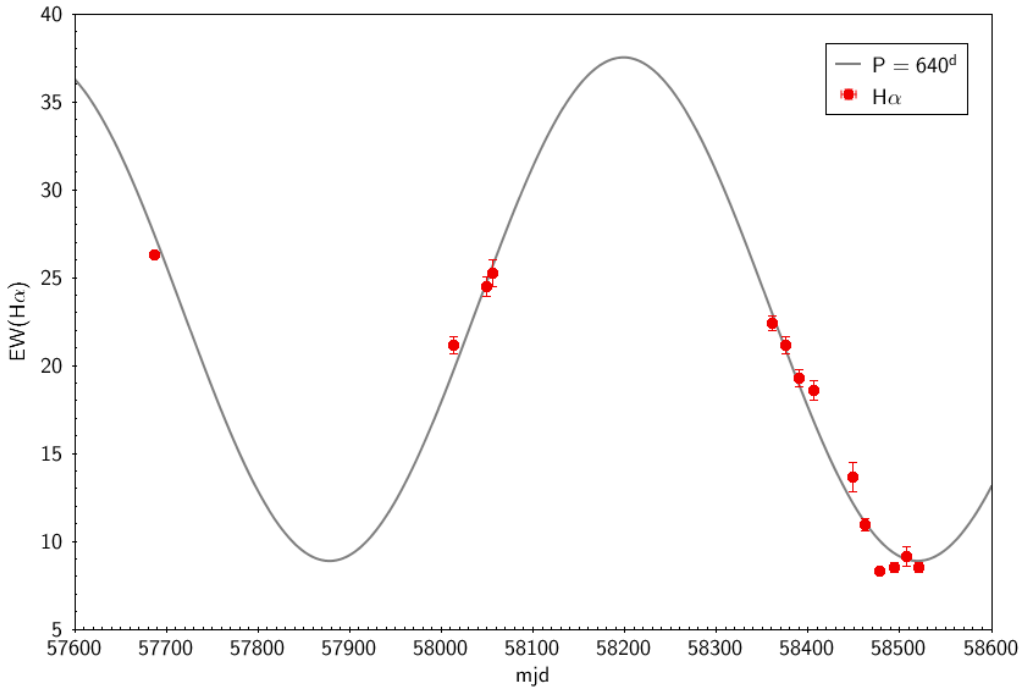


(Whittle 1985)

XMMU-J052016.0-692505

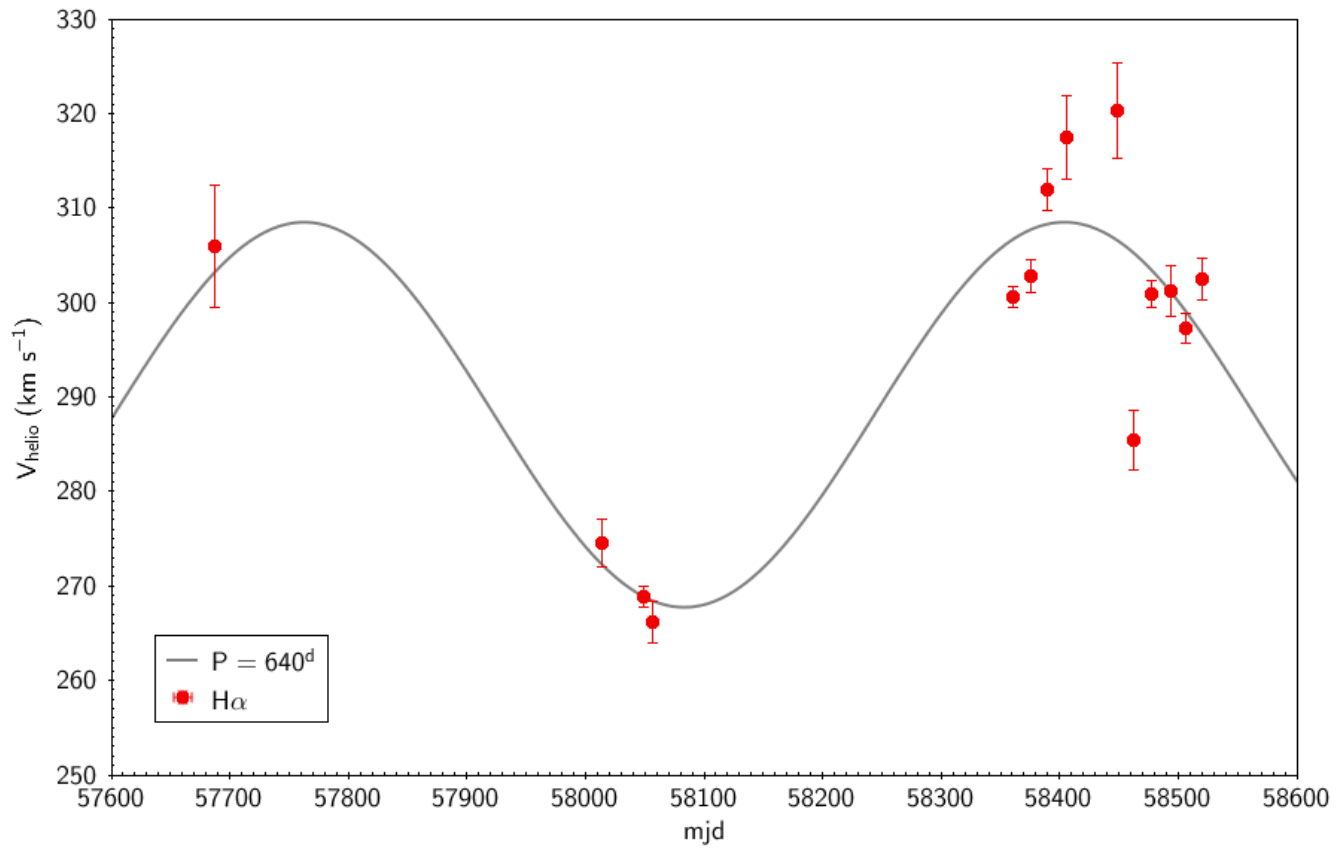


Equivalent Width



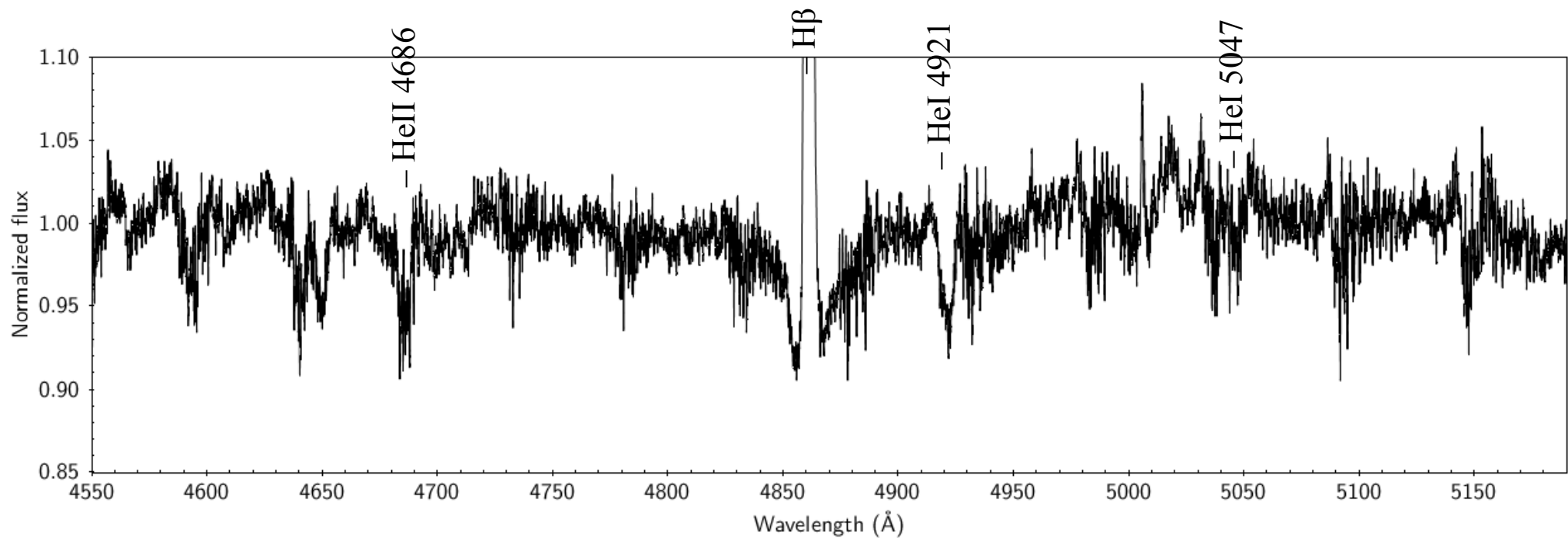
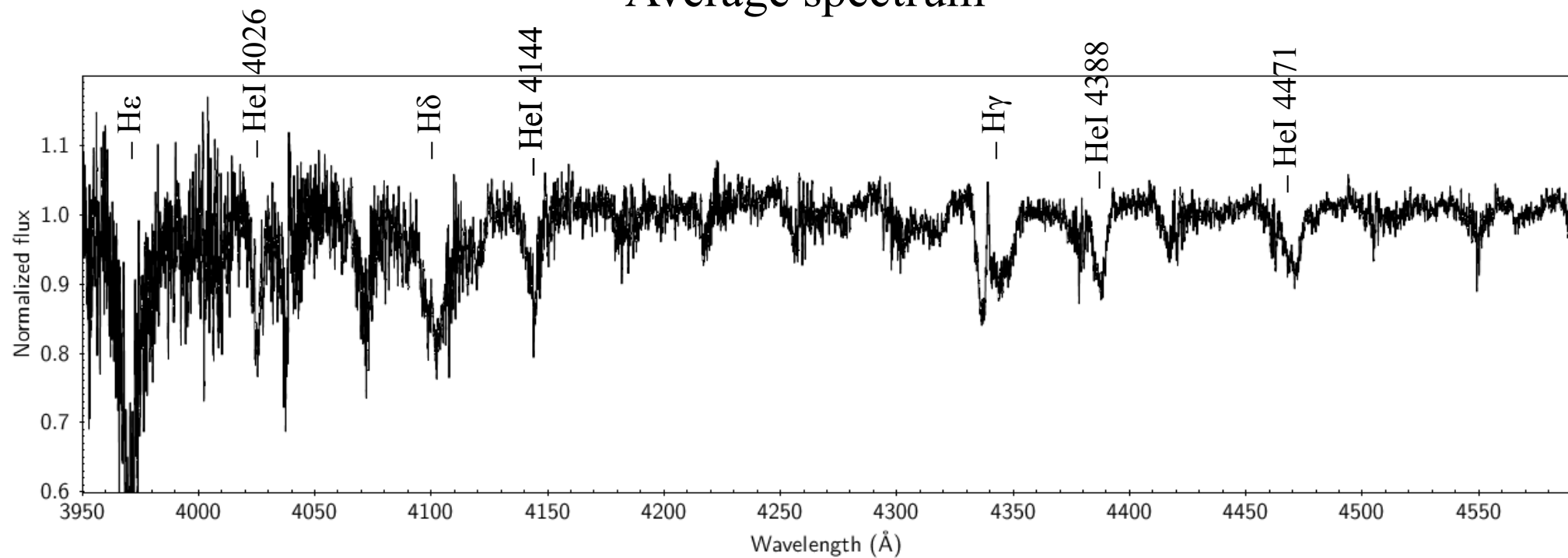
$P(\text{H}\beta) = 670$ days (fap = 0.02%)
 $P(\text{H}\alpha) = 640$ days (fap = 0%)

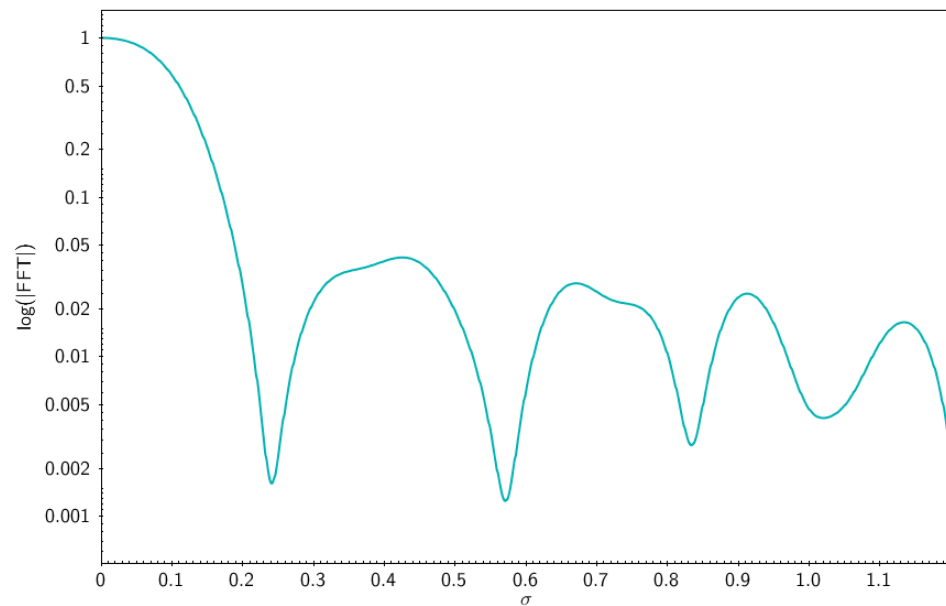
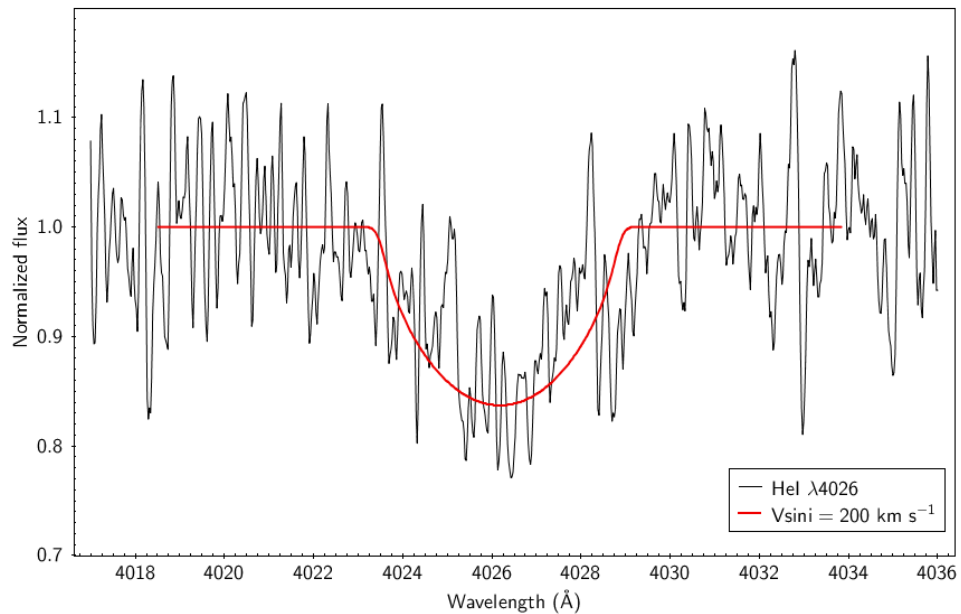
Heliocentric velocity



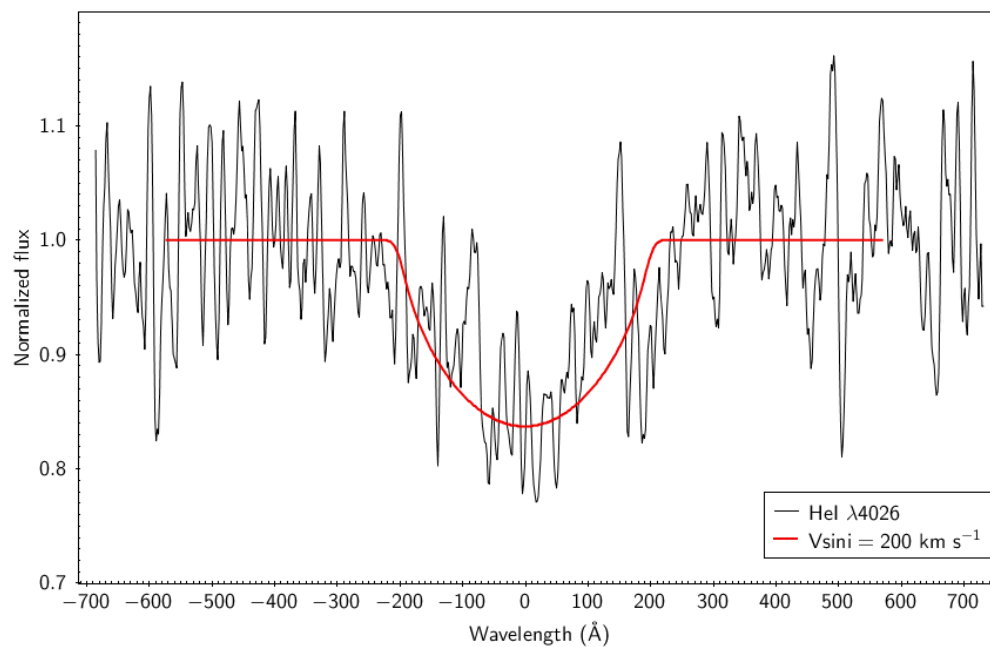
$P(\text{H}\alpha) = 640 \text{ days (fap} = 3\%)$

Average spectrum

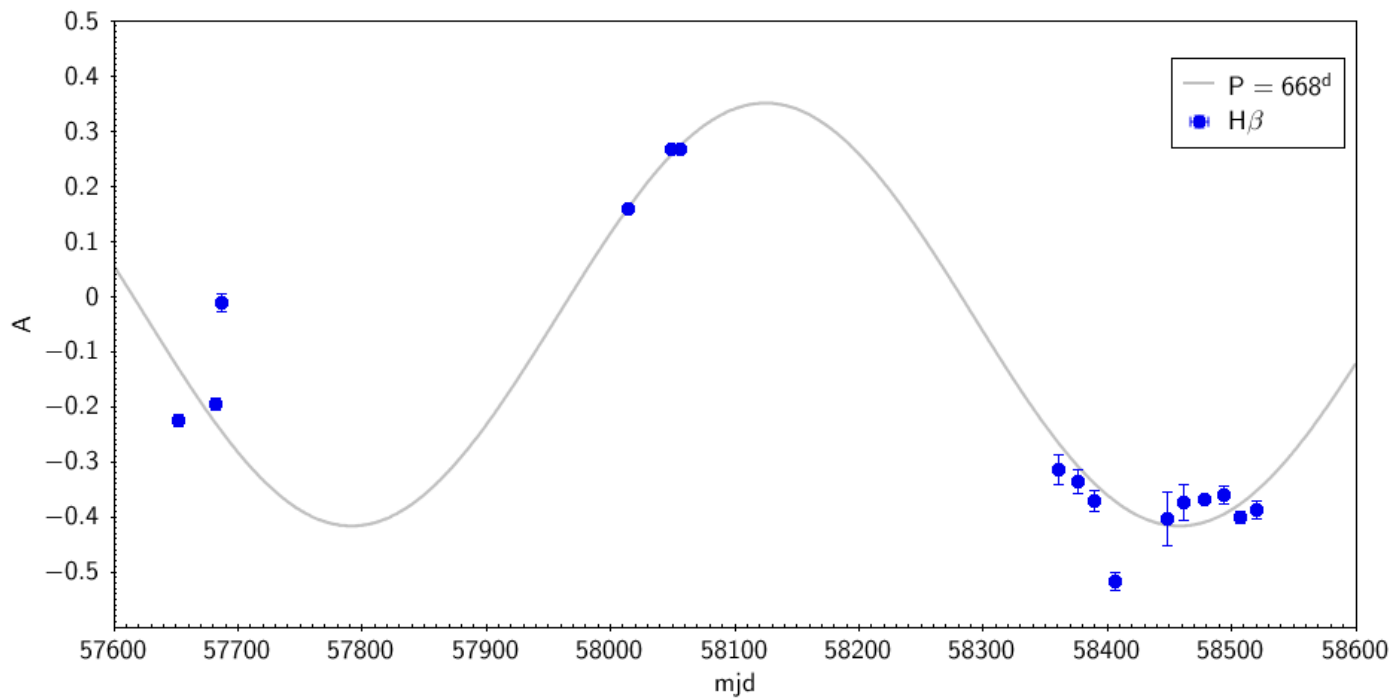




$$V \sin i = \frac{c}{\lambda} \frac{f(\epsilon)}{\sigma} \approx 200 \text{ km s}^{-1}$$



Asymmetry

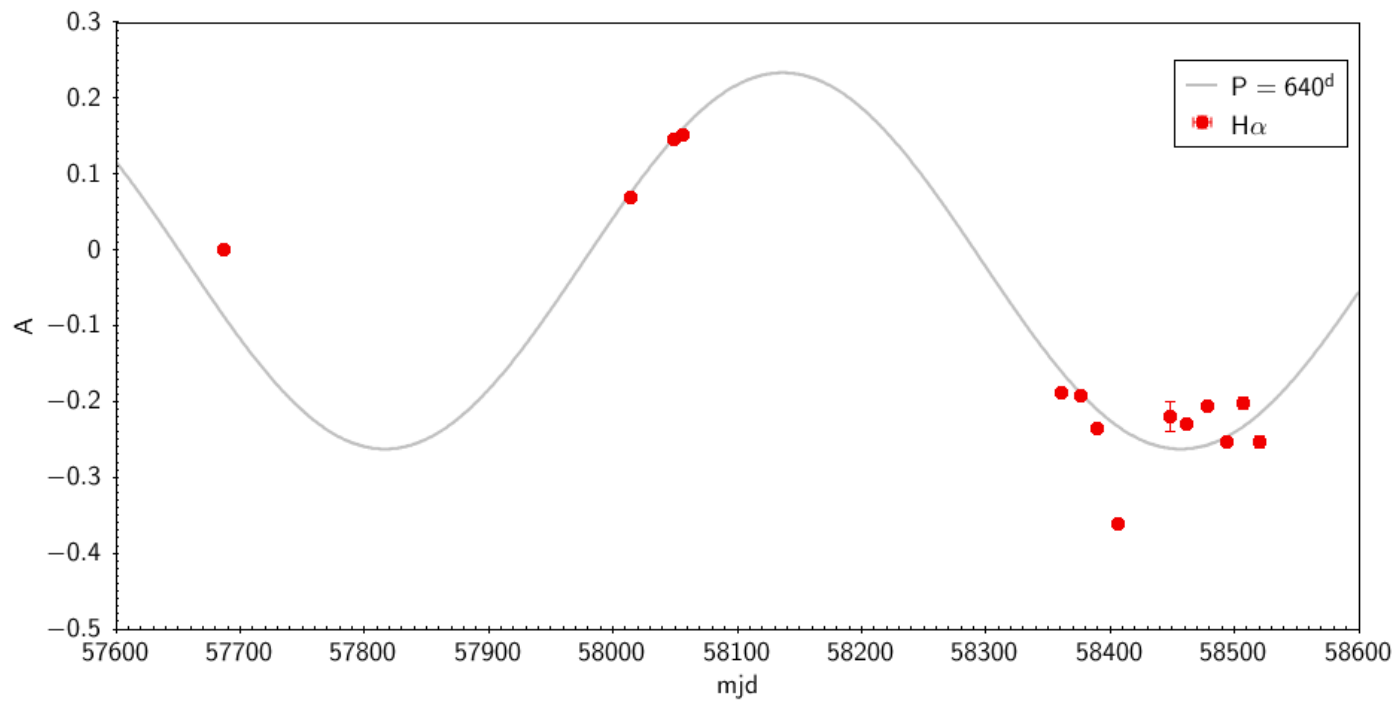


$V/R < 1$

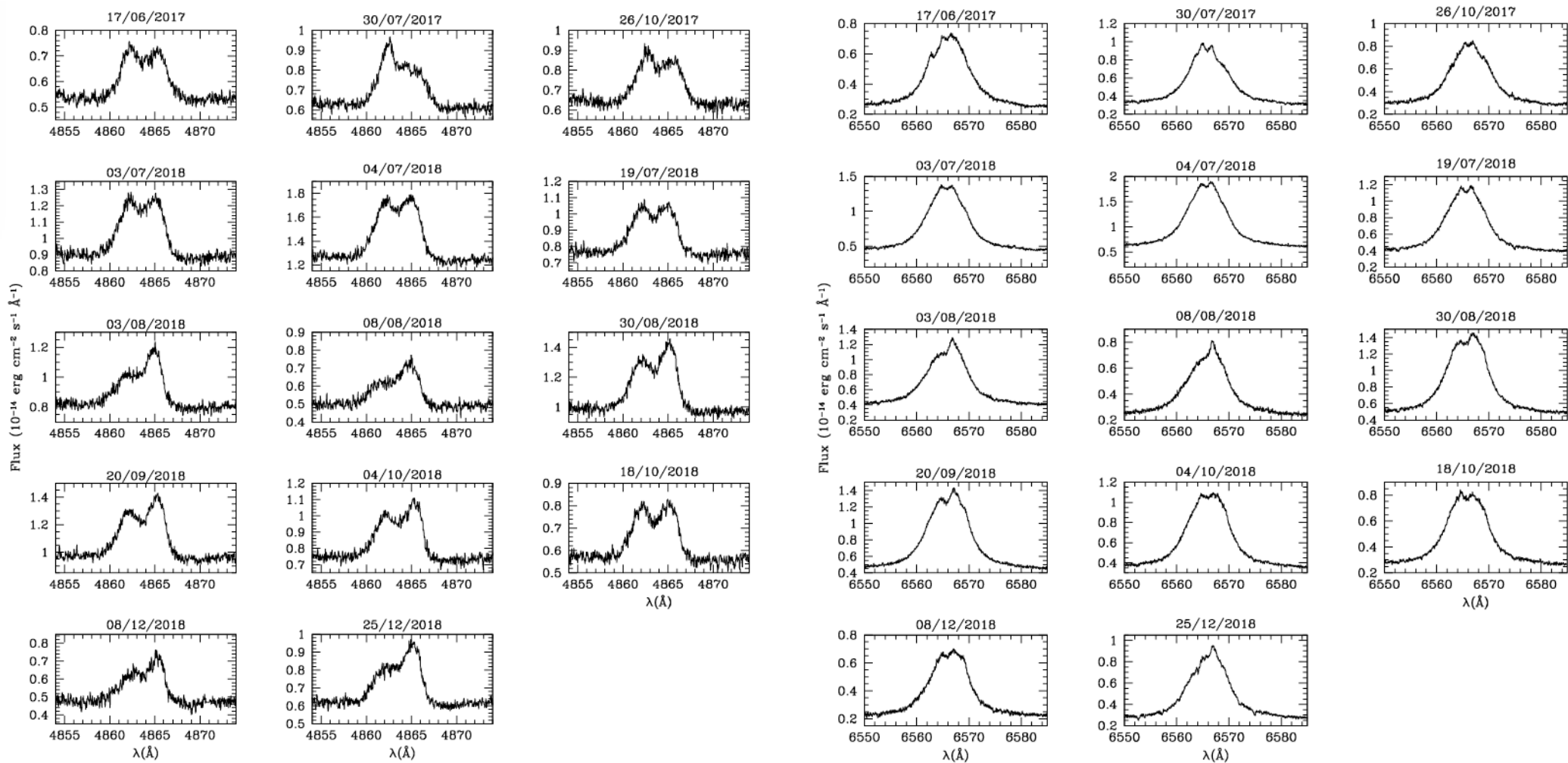
$V/R > 1$

$P(H\beta) = 668$ days (fap = 0.02%)

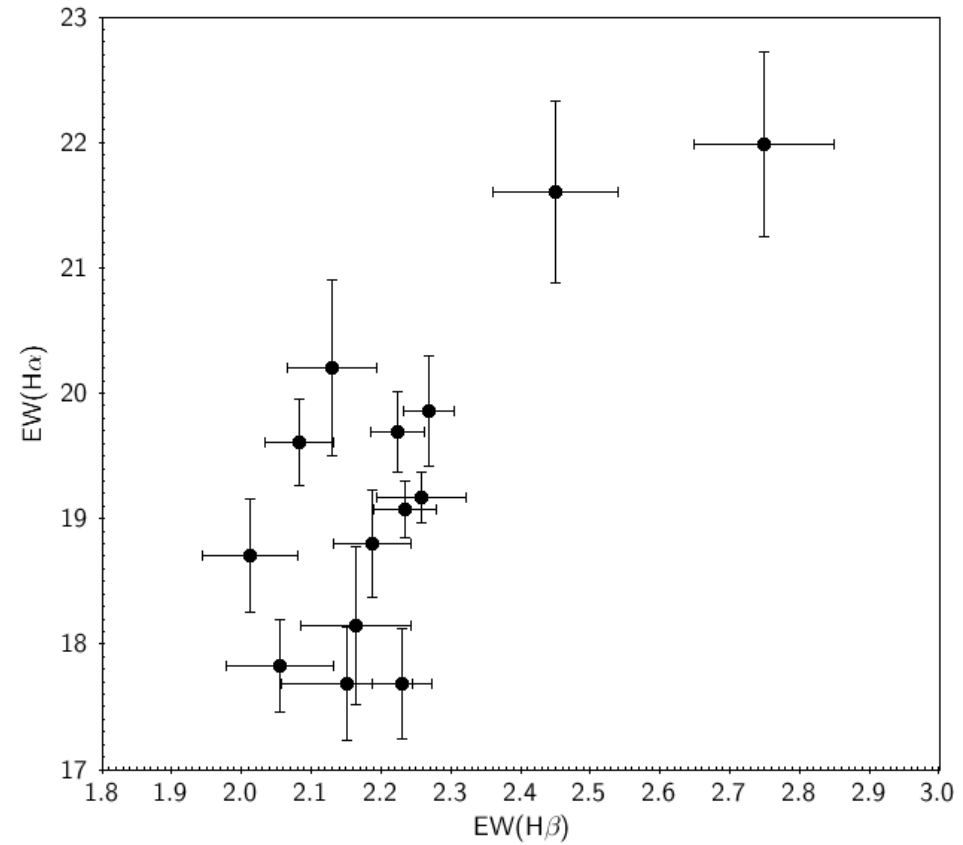
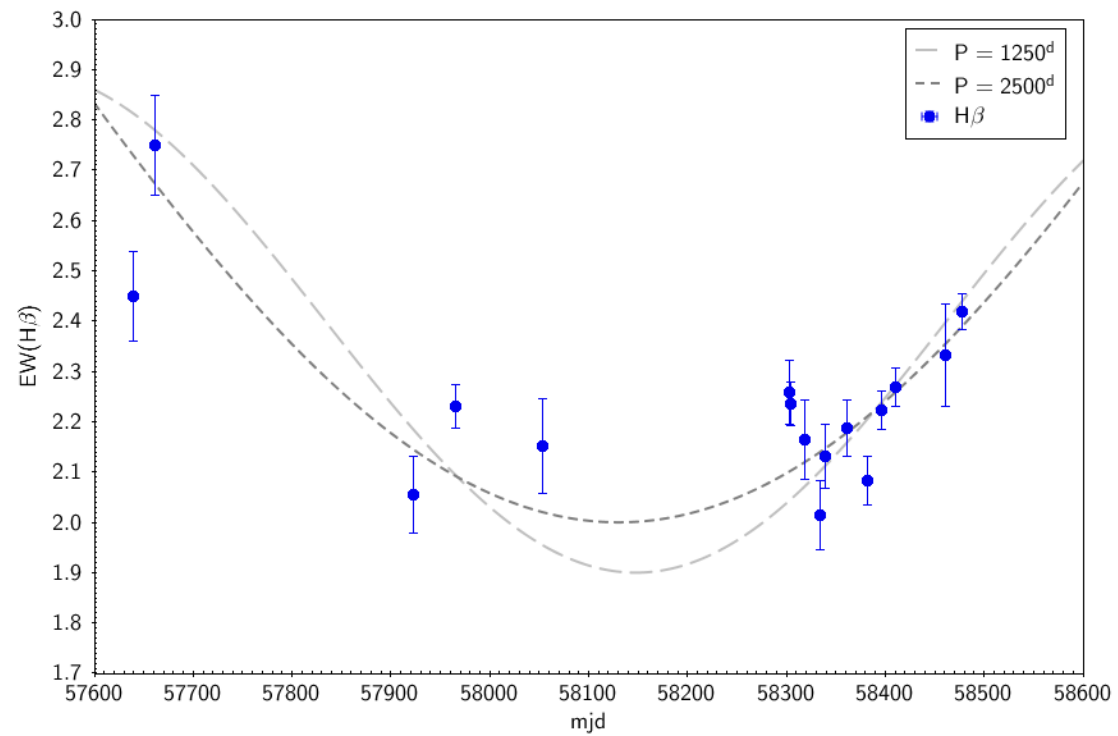
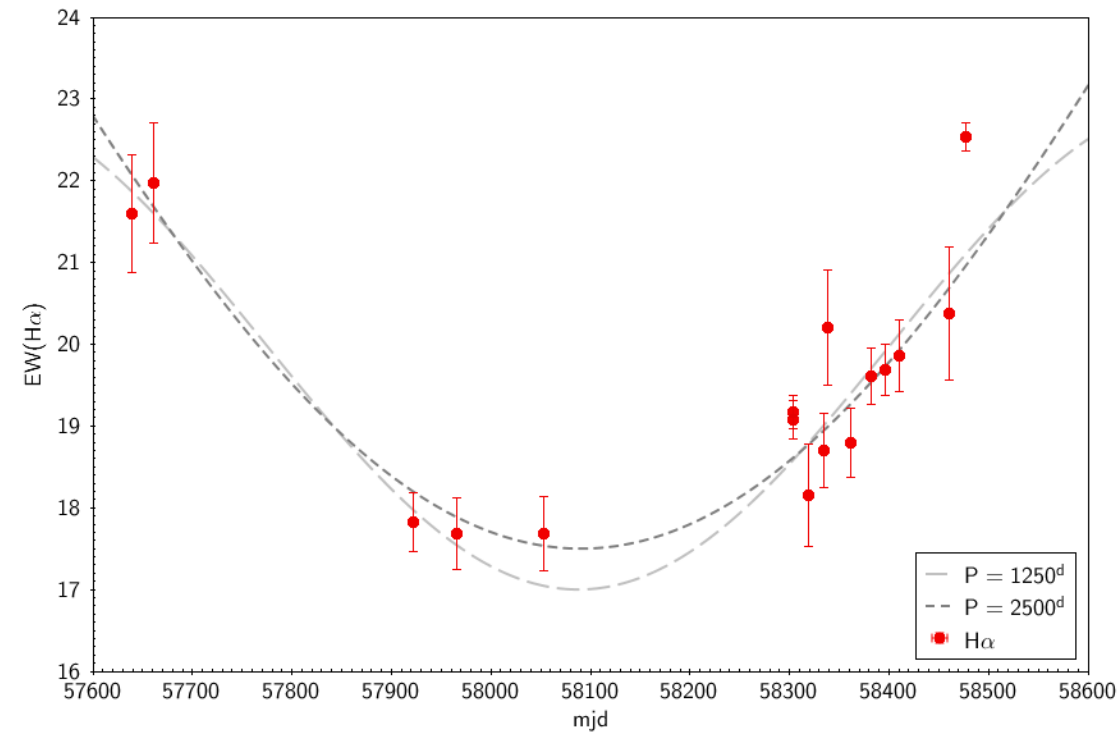
$P(H\alpha) = 640$ days (fap = 0.13%)



XMMU-J010147.5-715550

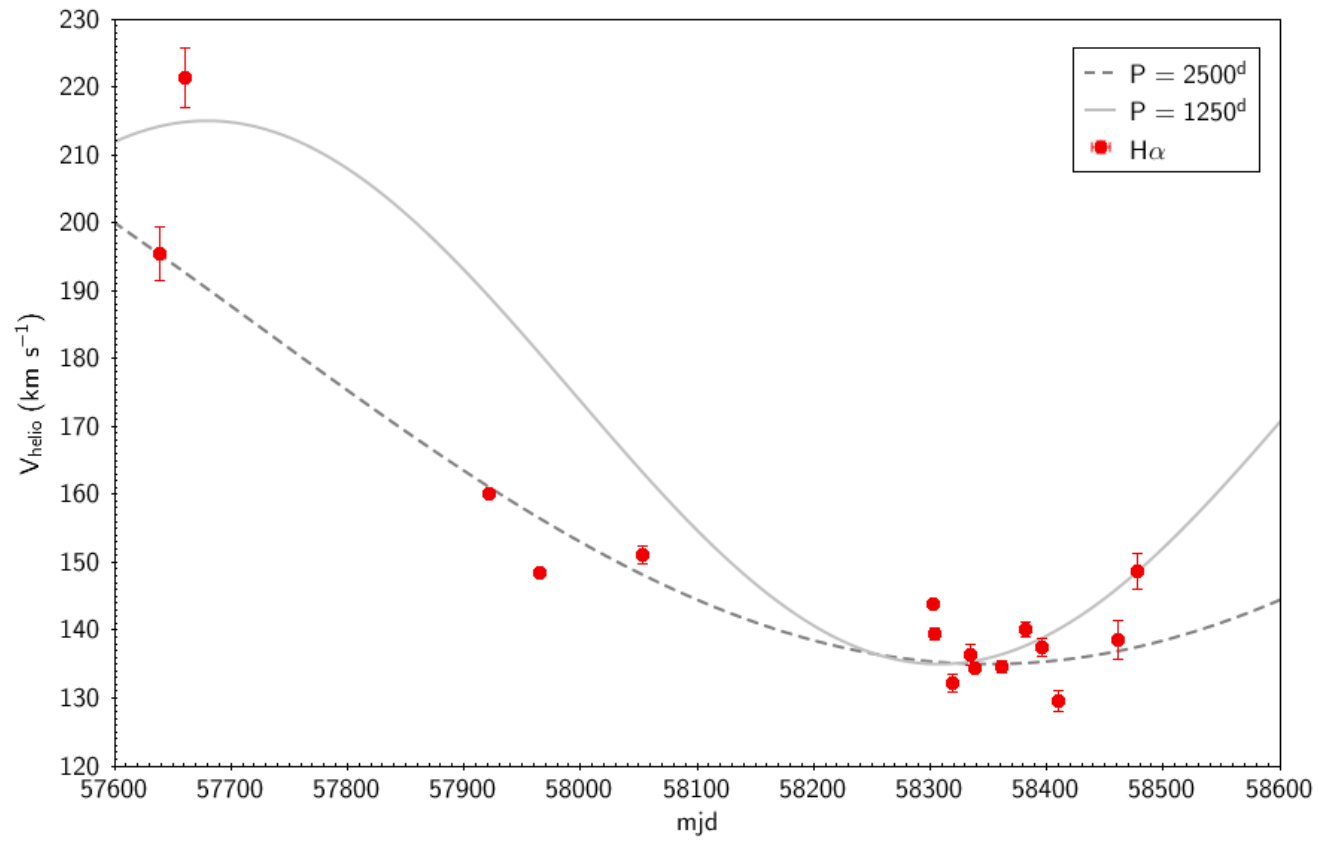


Equivalent Width

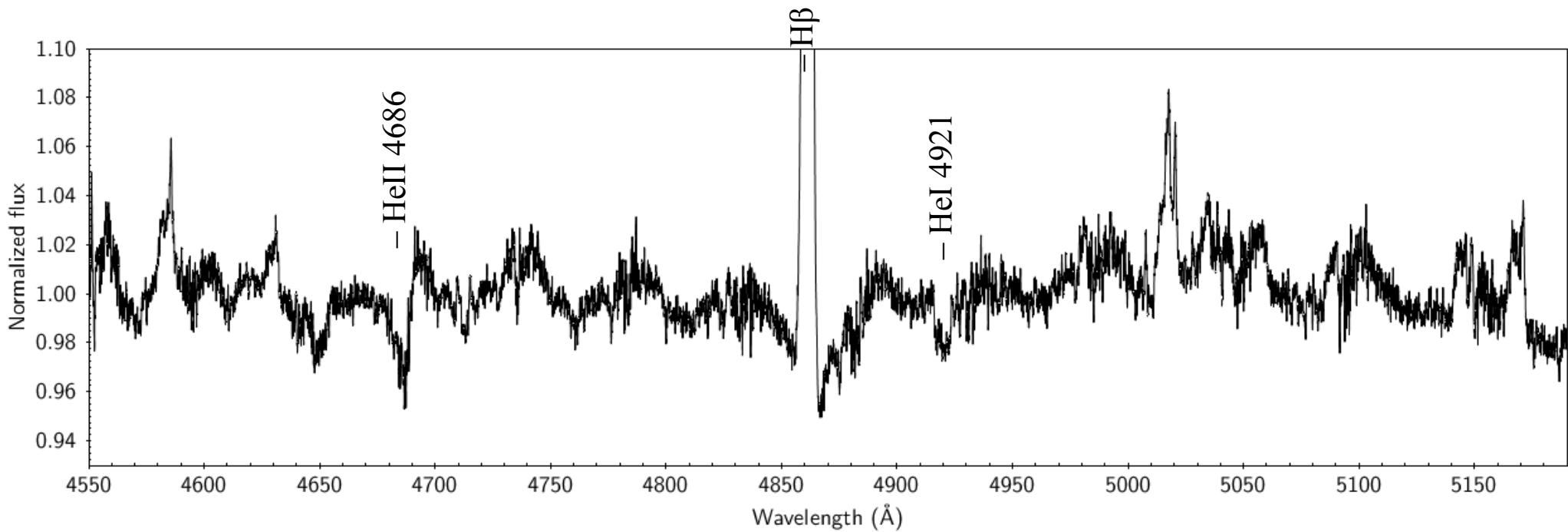
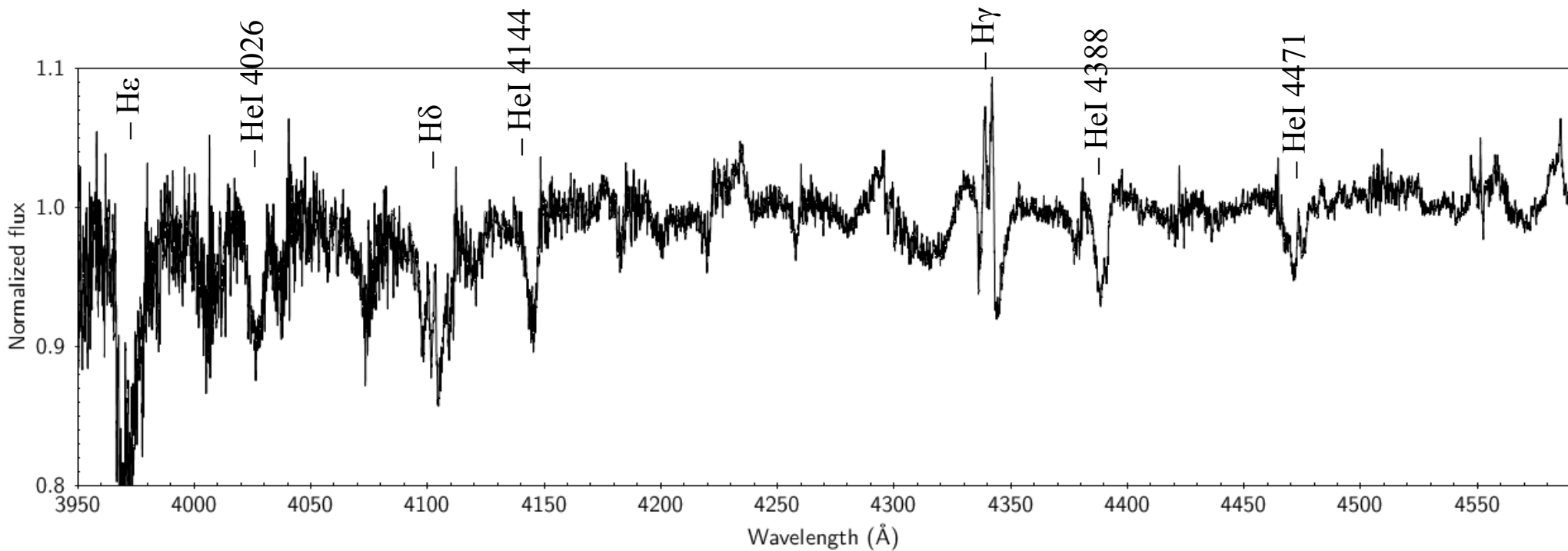


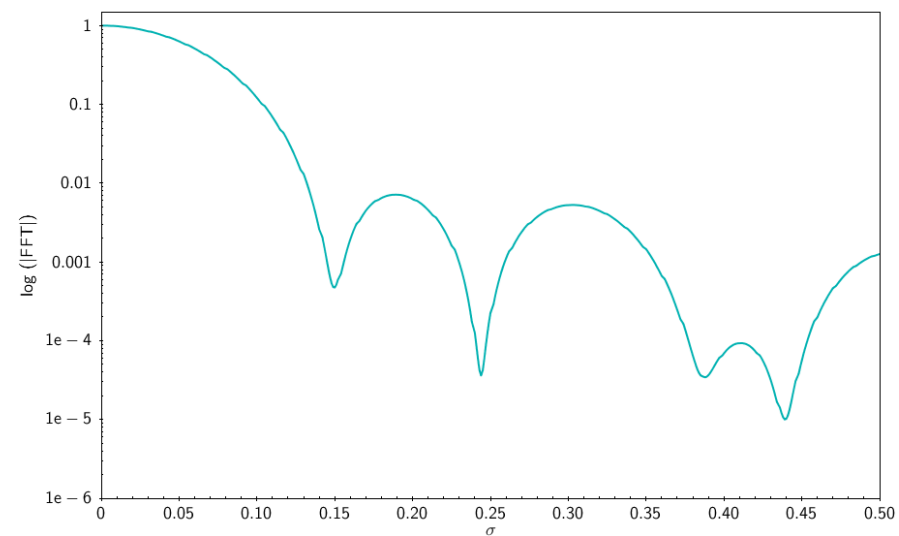
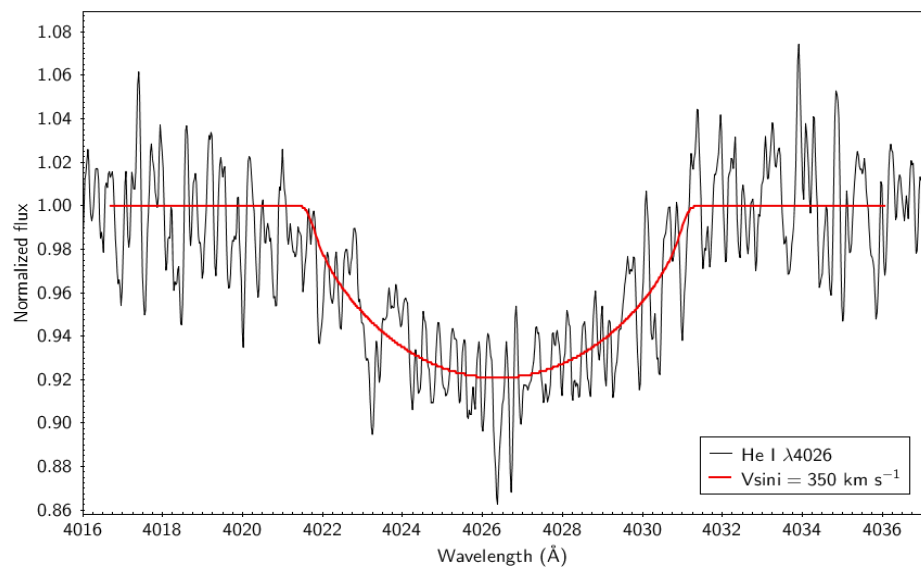
$P = 1264 \pm 2$ days (Sturm+ 2012)

Heliocentric velocity

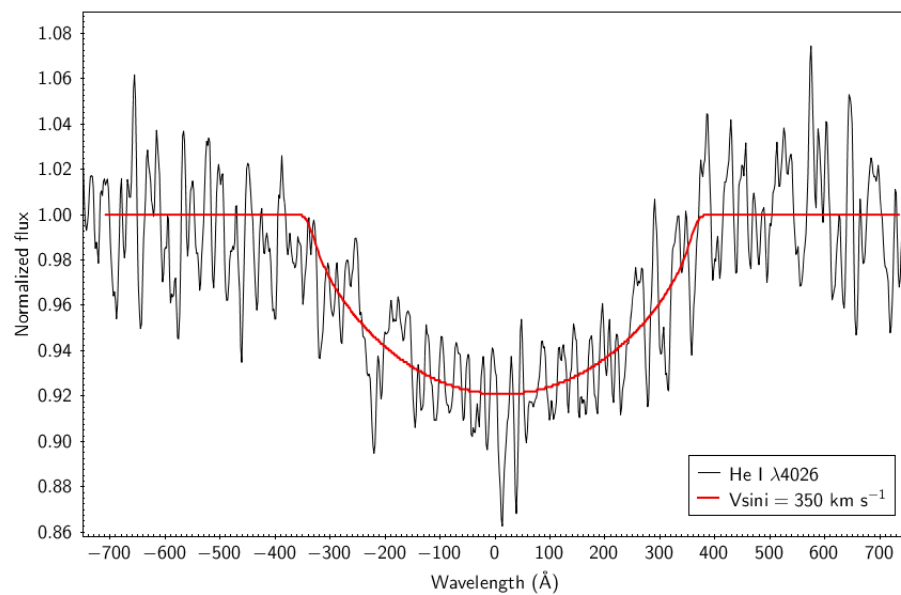


Average spectrum

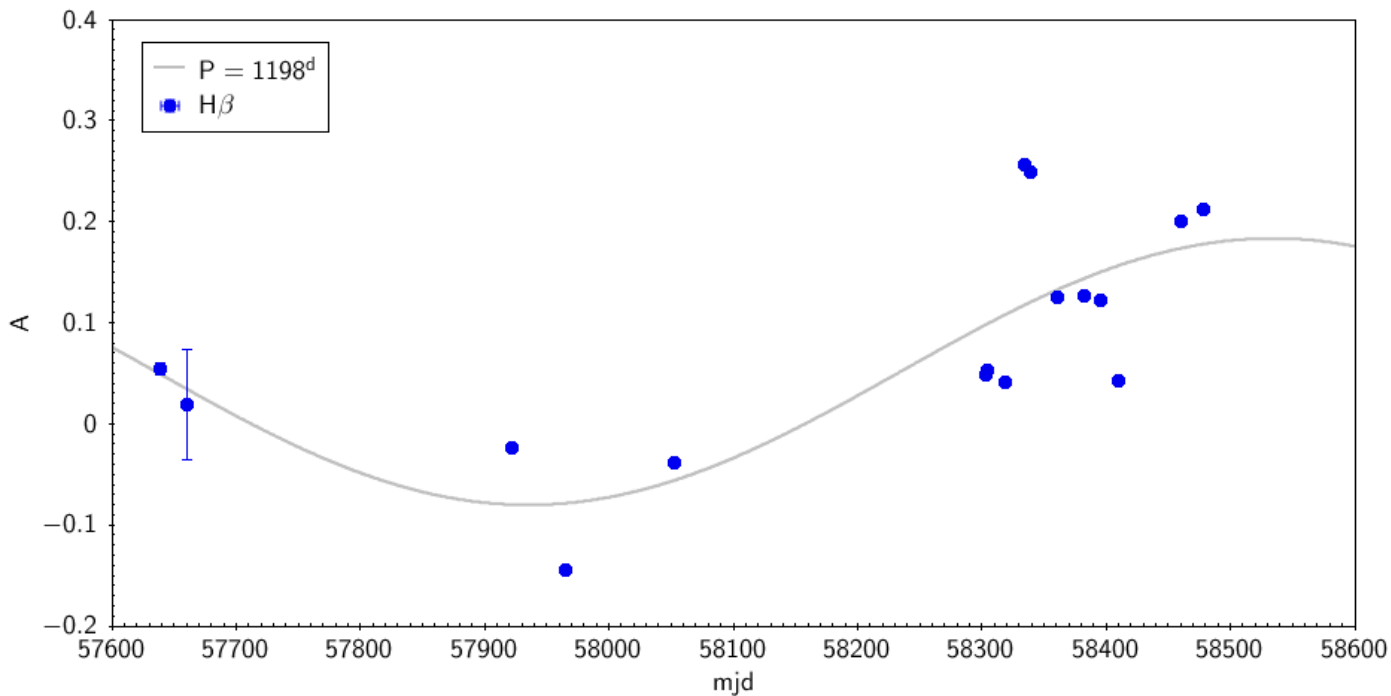




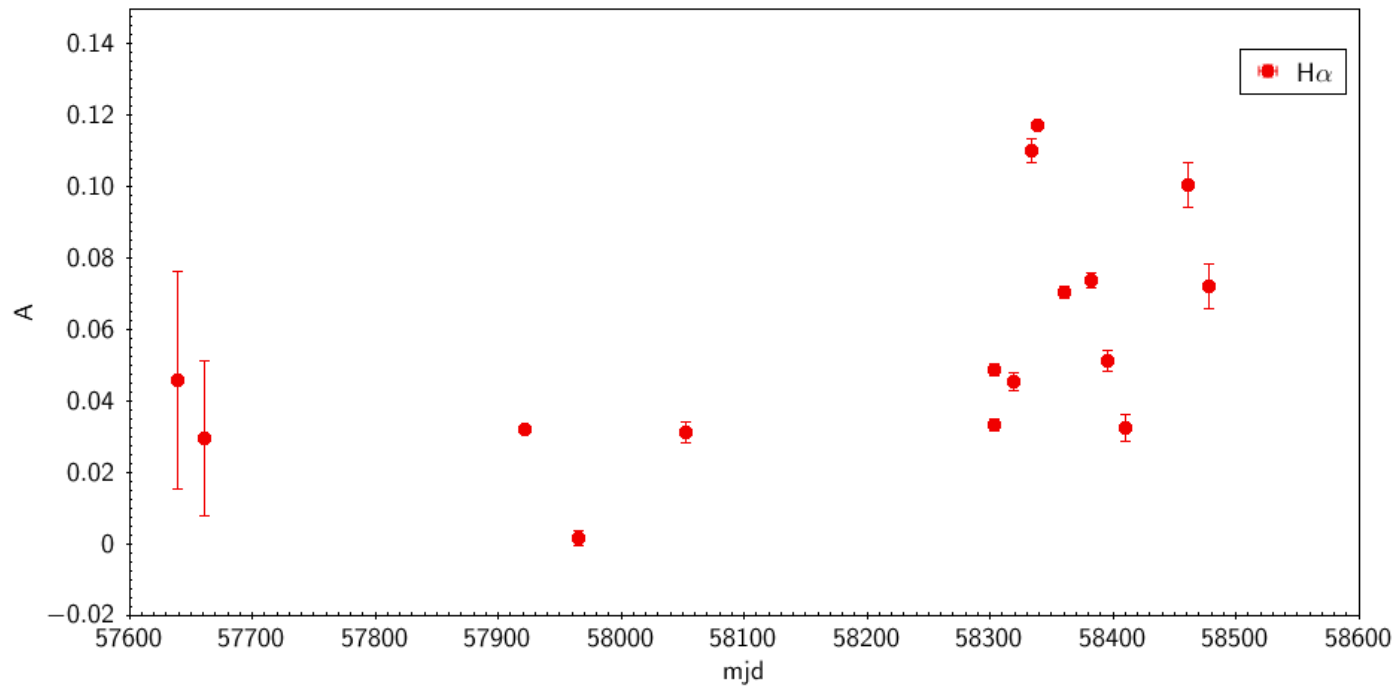
$$V \sin i = \frac{c}{\lambda} \frac{f(\epsilon)}{\sigma} \approx 350 \text{ km s}^{-1}$$



Asymmetry



$P(H\beta) = 1198$ days (fap = 24%)



To be continued...