12th Serbian Conference on Spectral Line Shapes in Astrophysics

Supersoft Be X-ray binaries in the Magellanic Clouds

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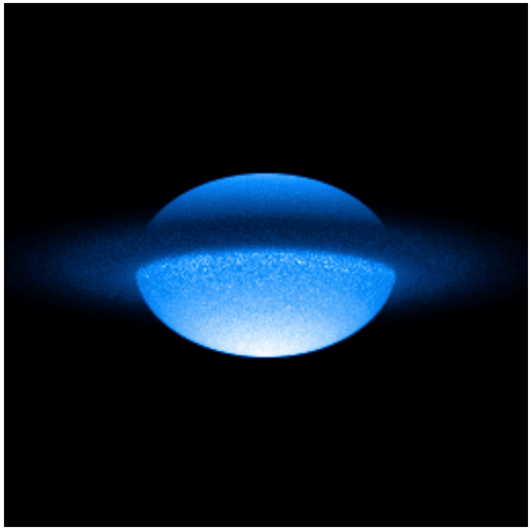
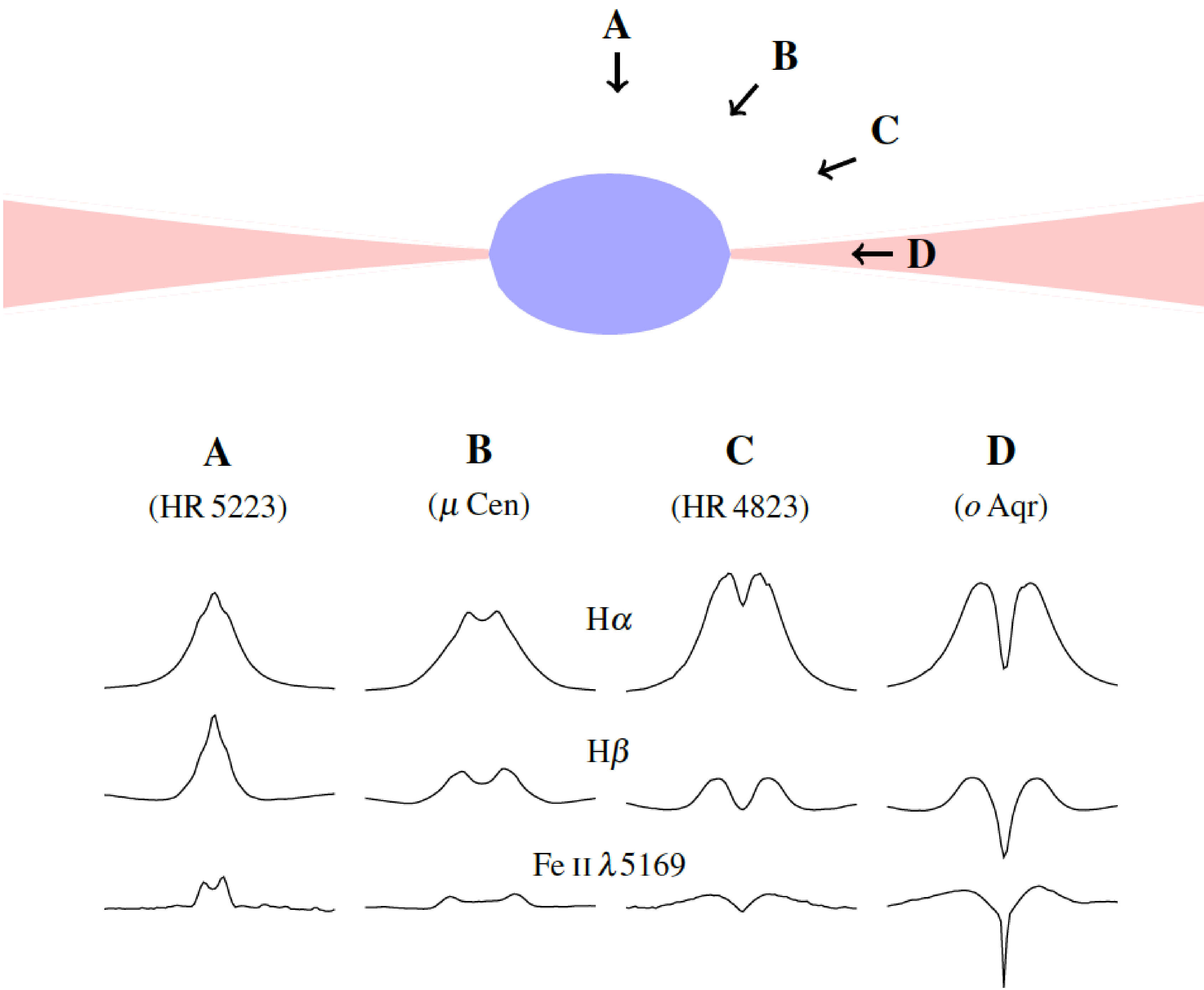
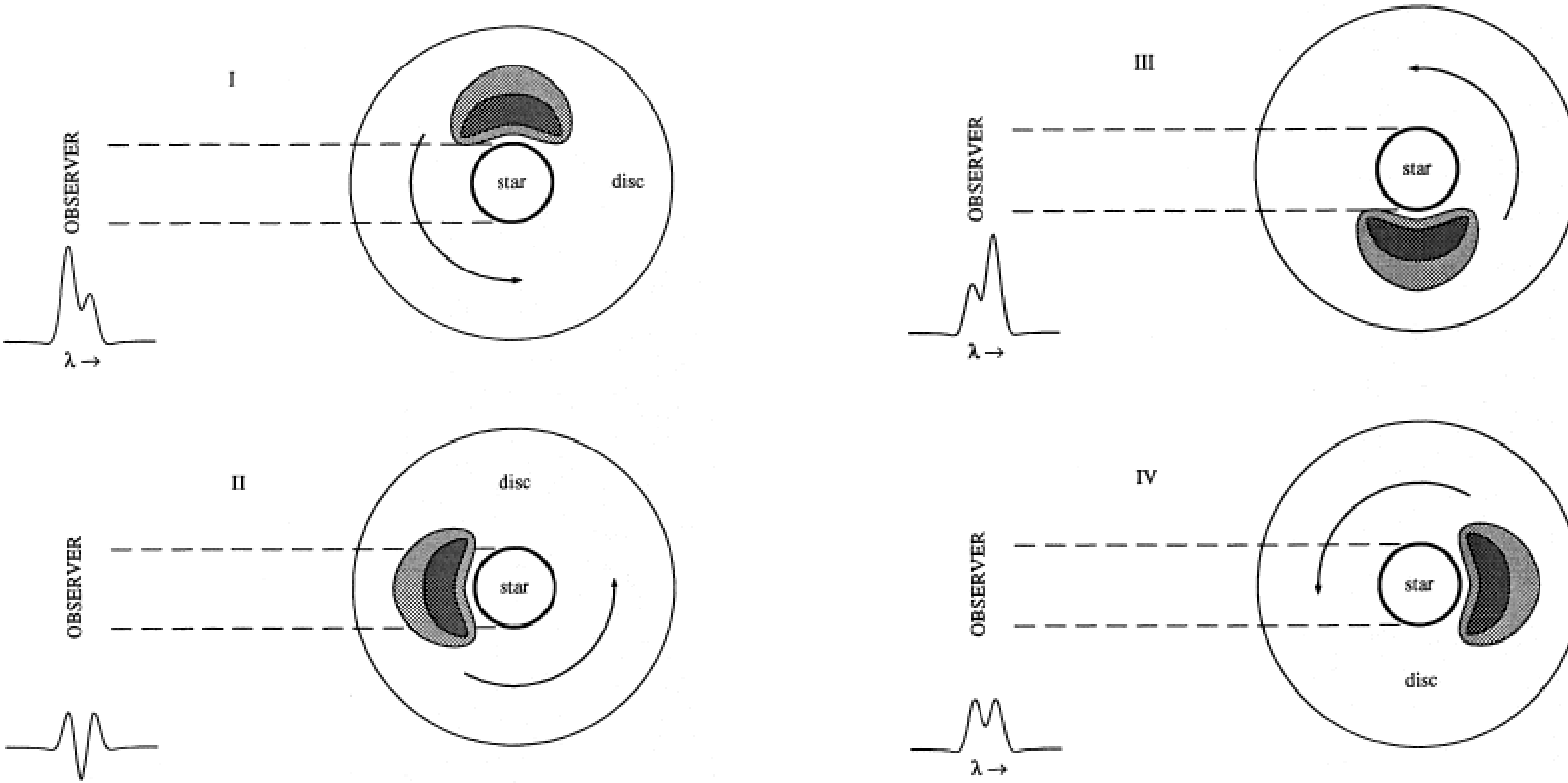
Be stars

- Rapidly rotating B stars forming a decretion (also excretion) Keplerian emission line disk
- Equivalent width of Hα 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





(Rivinius+ 2013)



(Telting+ 1994)

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 $L_{SX} \sim 10^{35} – 10^{38}$ 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 (~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

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

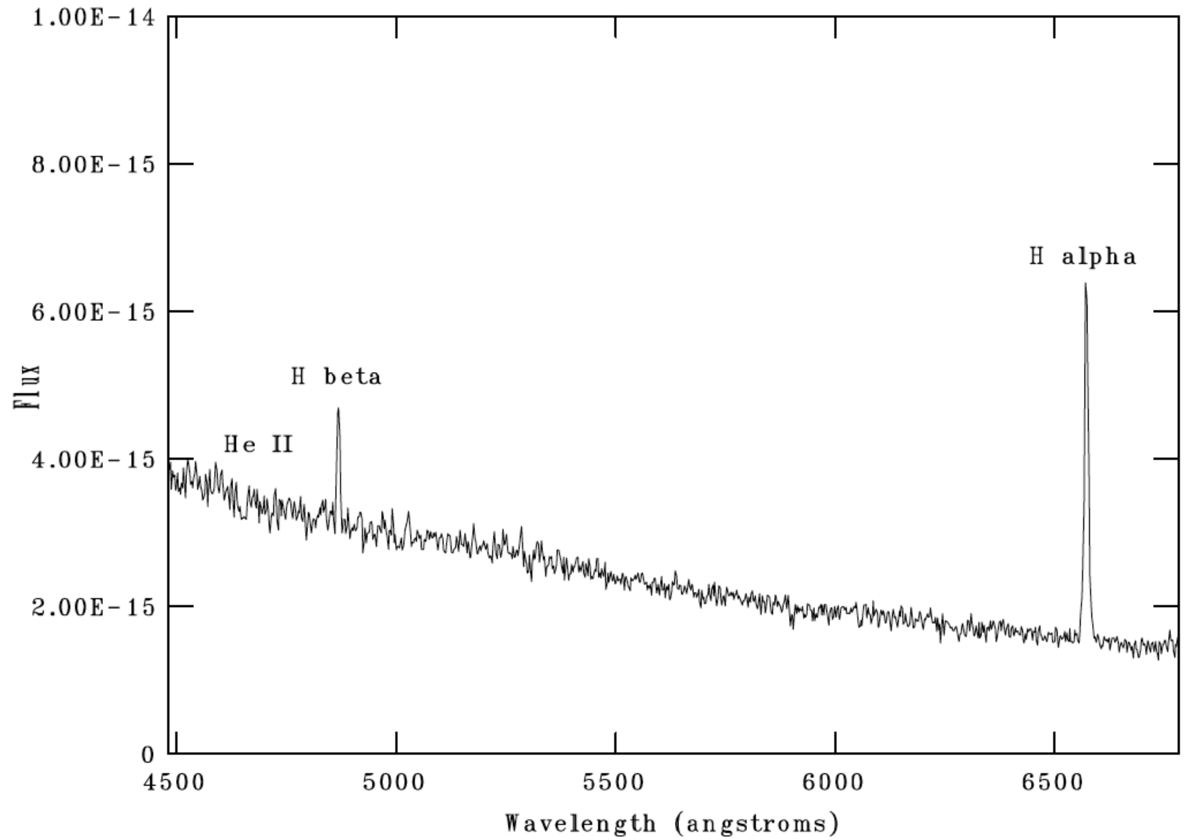
V = 14.80 ± 0.02
B-V = -0.03 ± 0.03

SpType = B0-3e

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

EW(Hα) = 32 - 37 Å
V_{rad}(Hα) = 6 - 430 km s^{-1}

(Kahabka+ 2006)



XMMU-J010147.5-715550

AzV281
Recurrent SSS

L_{SX} = 7.3 × 10^{37} erg s^{-1}

V = 14.47±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_{SX} = 2 ×10^{37} erg s^{-1}

V = 14.64 (Evans+ 2004)

SpType = B0 IV (Evans+ 2004)
O9.3 III/Ve (Lamb+ 2016)

MAXI J0158-744

Transient SSS

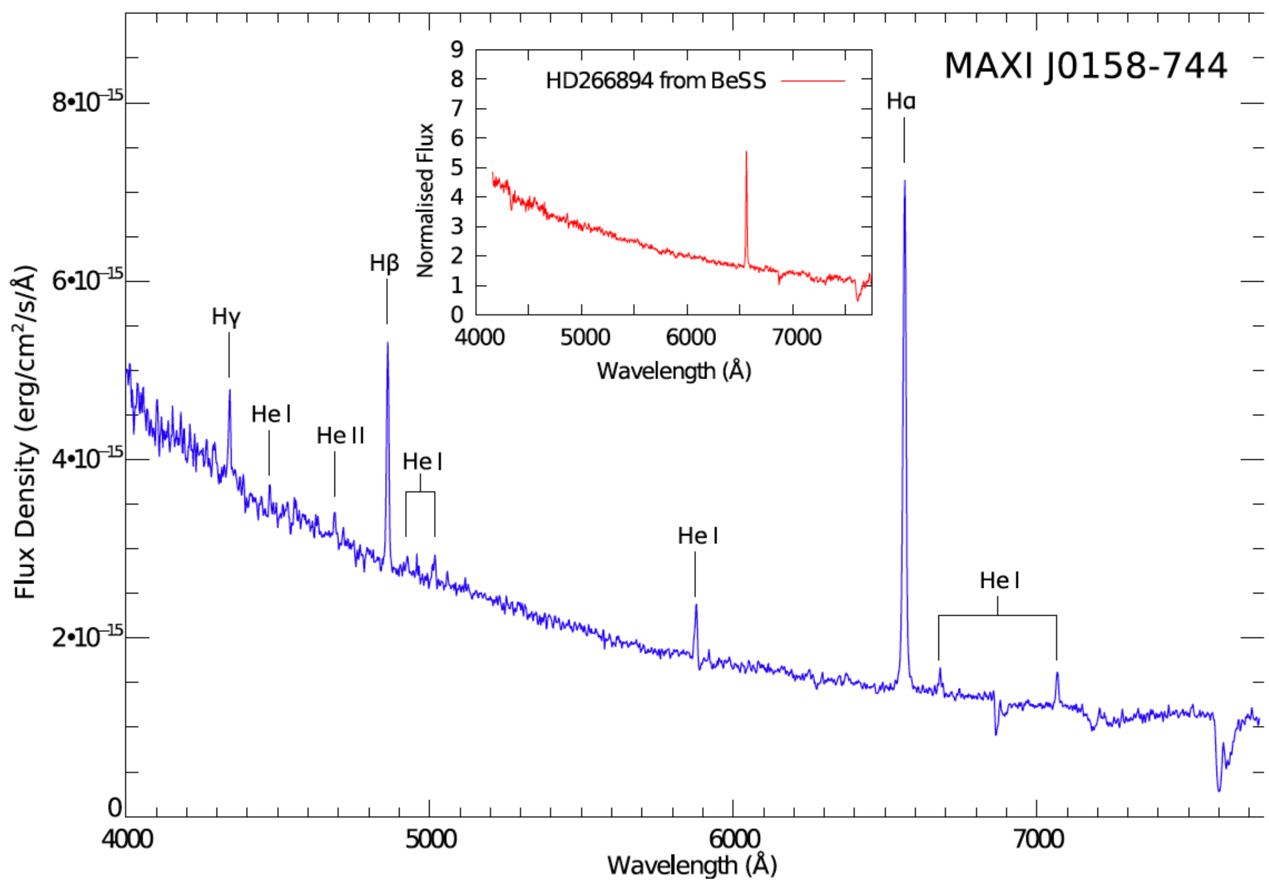
$L_{0.2\text{-}2\ keV} \sim 2 \times 10^{37}$ erg s^{-1}
$L_{2\text{-}4\ keV} \sim 1.6 \times 10^{39}$ erg s^{-1}

I = 14.82

SpType = B1/2 IIIe

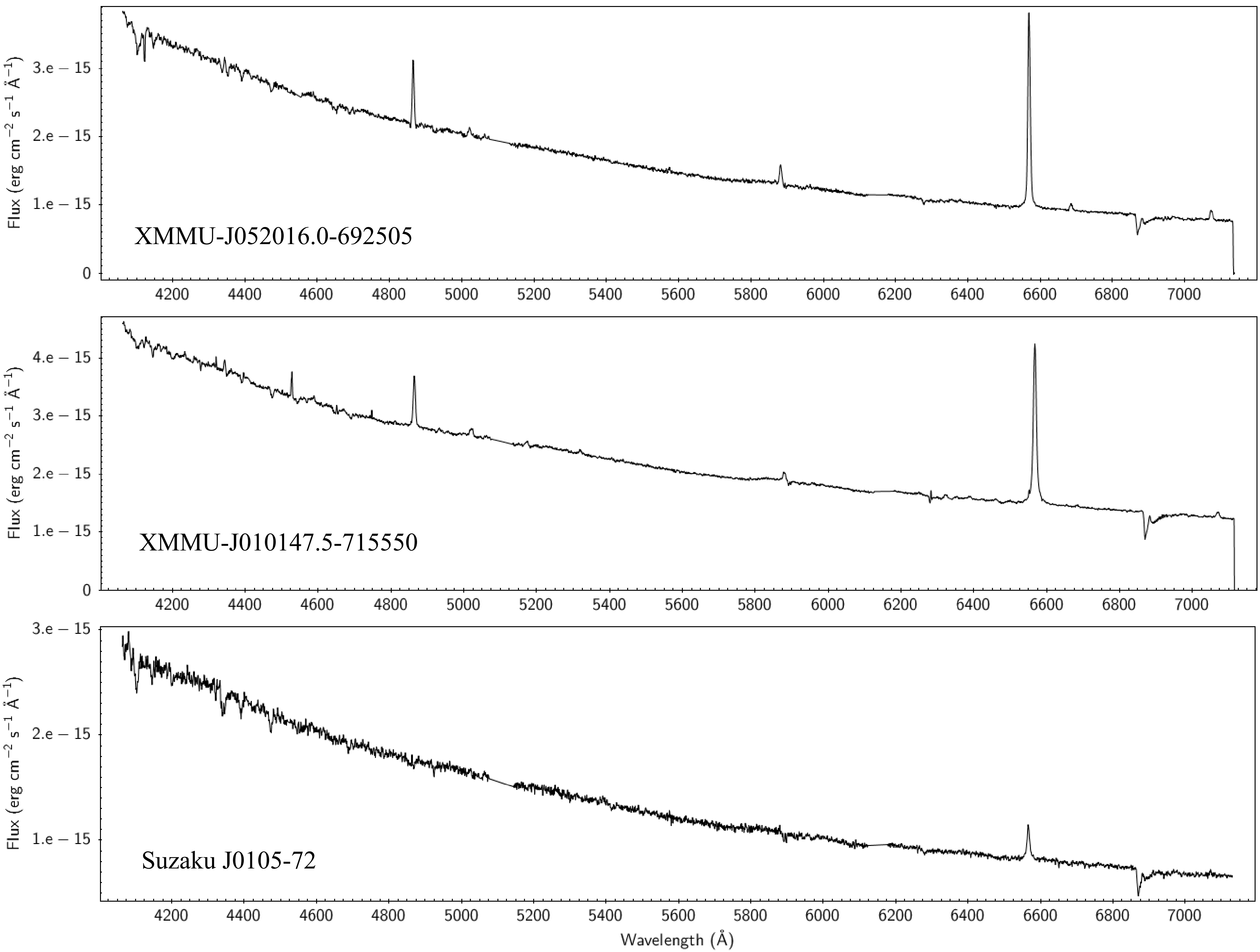
WD Be/X-ray binary
Nova explosion event

(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

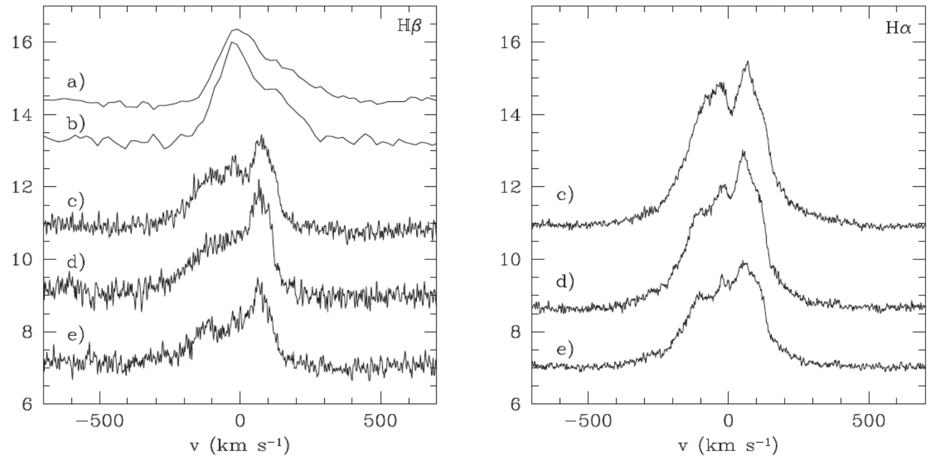


XMMU-J052016.0-692505
XMMU-J010147.5-715550
Suzaku J0105-72
Flux (erg cm^{-2} s^{-1} Å^{-1})
Wavelength (Å)

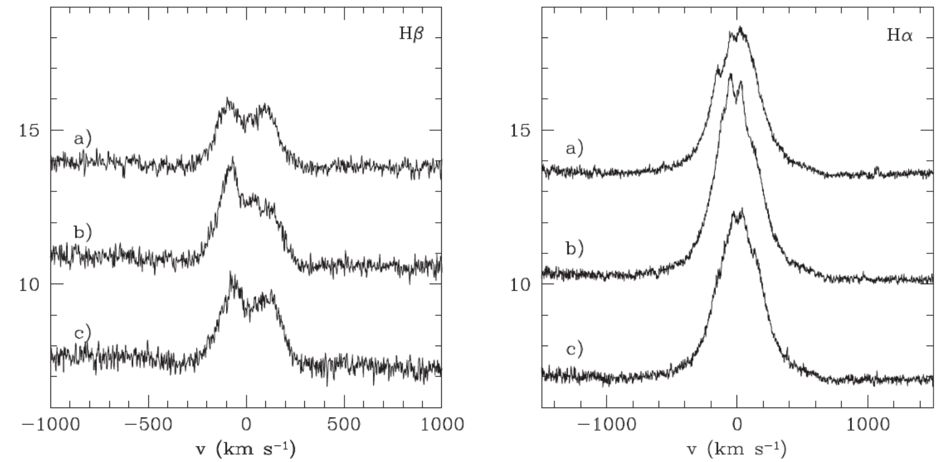
High Resolution Spectrograph (HRS)
Dual-beam fiber-fed echelle
Low Resolution R=15000

XMMU J05	3 epochs	2017
XMMU J01	3 epochs	2017
Suzaku J01	3 epochs	2017
MAXI J0158	3 epochs	2017

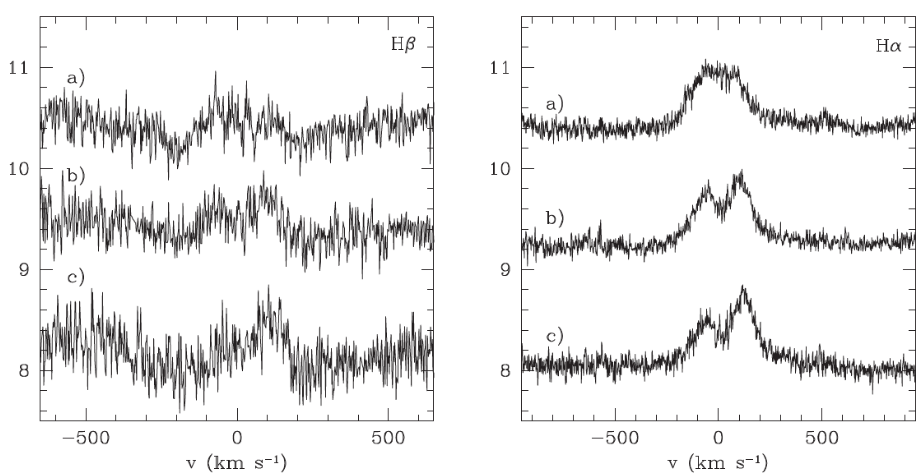
XMMU-J052016.0-692505



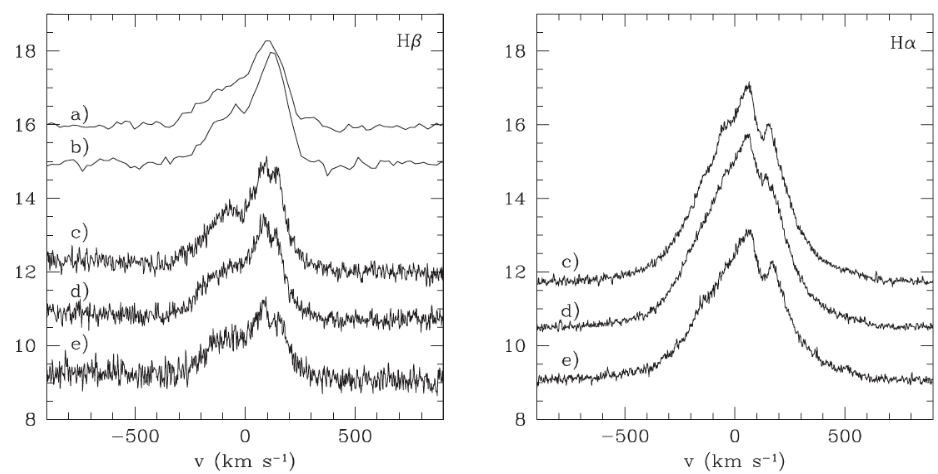
XMMU-J010147.5-715550



Suzaku J0105-72



MAXI J0158-744



(Cracco et al. 2018)

Results

– blue continuum with Hα, Hβ, Hγ, 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 Hβ with V/R changing from 0.5 to 1.5 in few days

– Δv(Hβ) ~ 130 – 220 km s^{-1}

– complex Hα profiles with multiple peaks or wine-bottle shape

– Δv(Hα) ~ 120 – 200 km s^{-1}

– small disk radii (~ 10 $R_\star$ vs. ~ 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

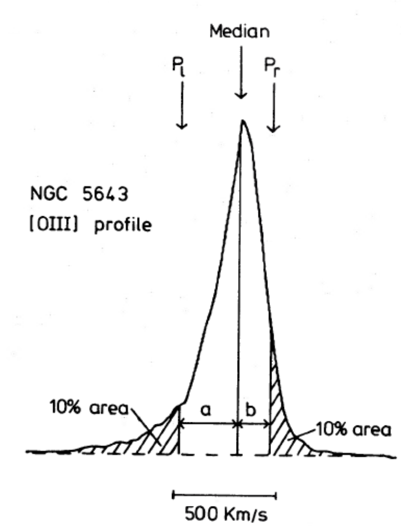
Work in progress

- Equivalent width

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

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

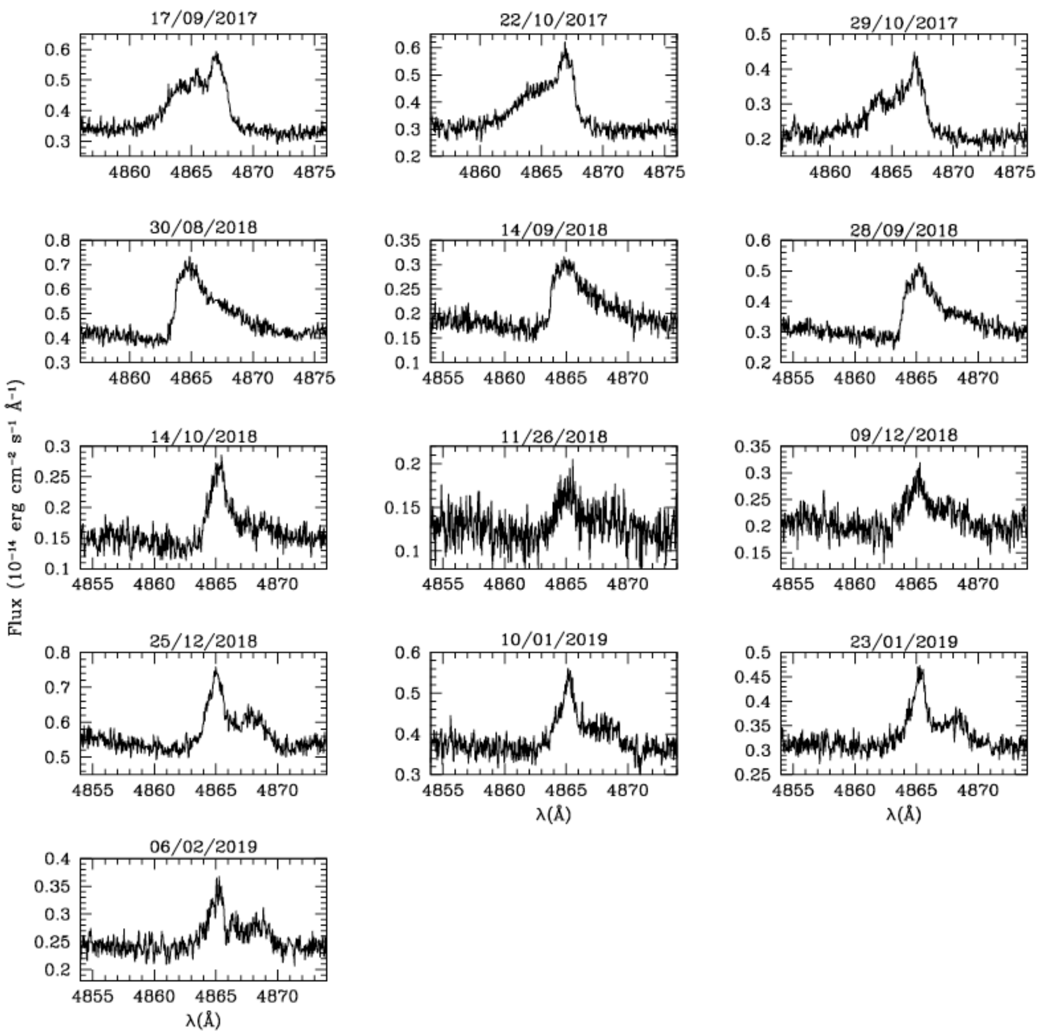
- Asymmetry → $A = \frac{a-b}{a+b}$

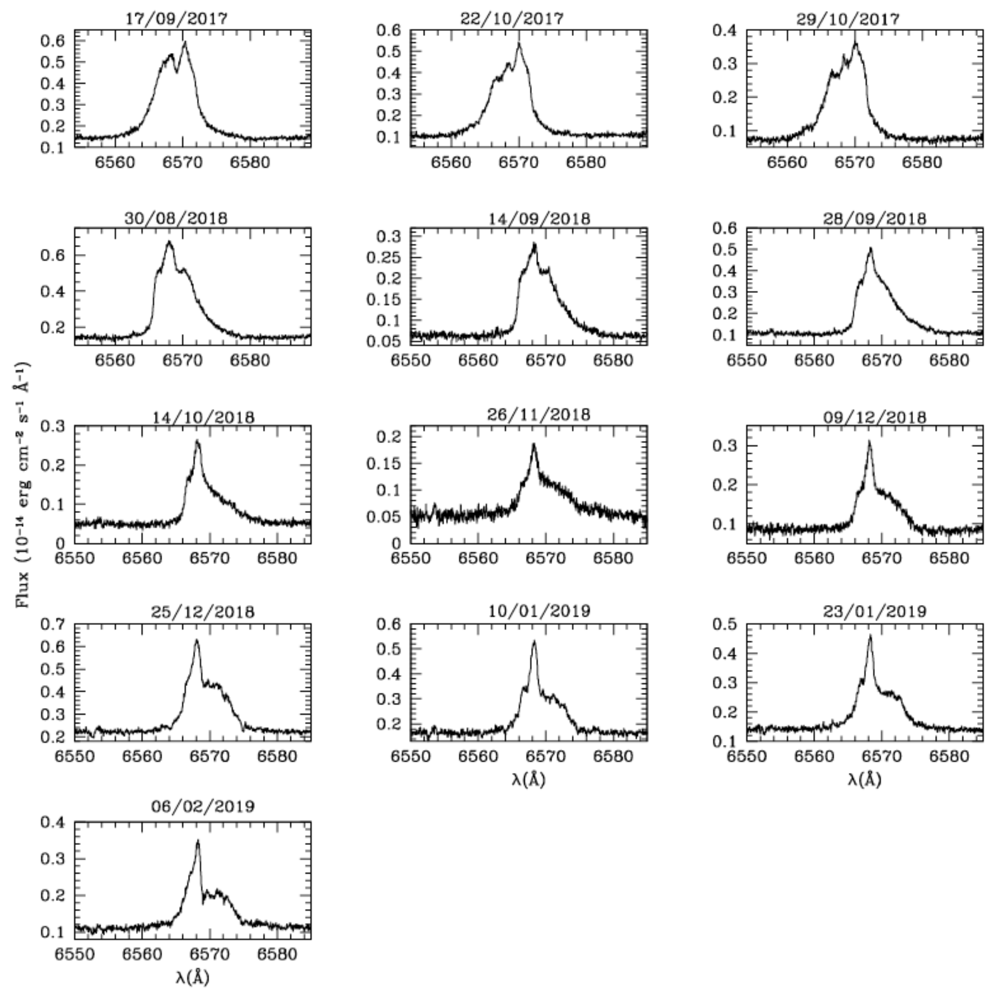


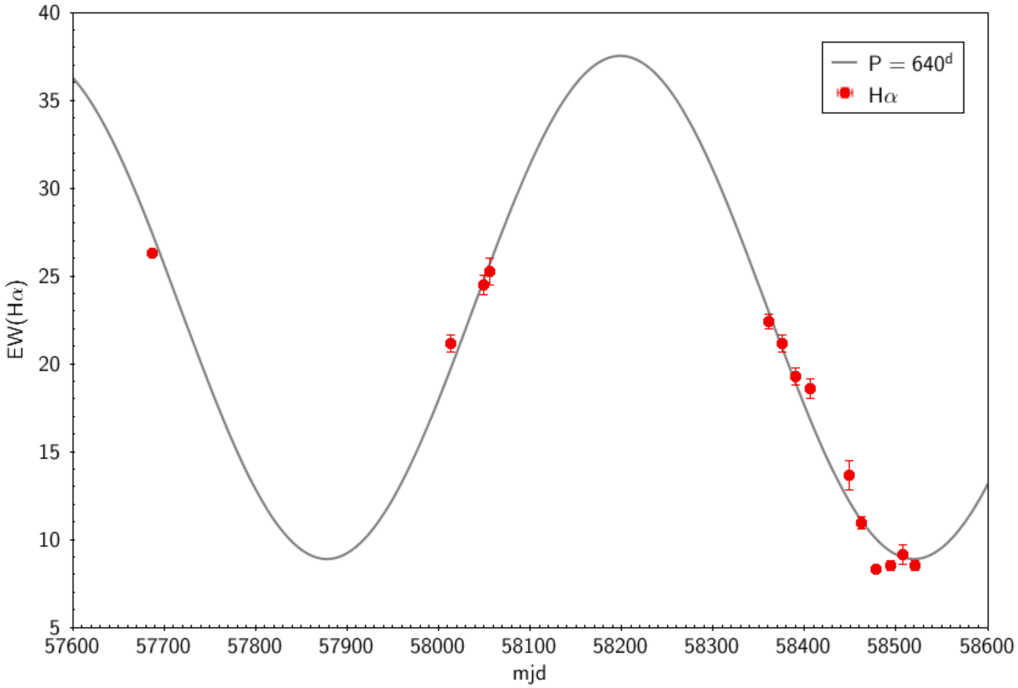
(Whittle 1985)

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

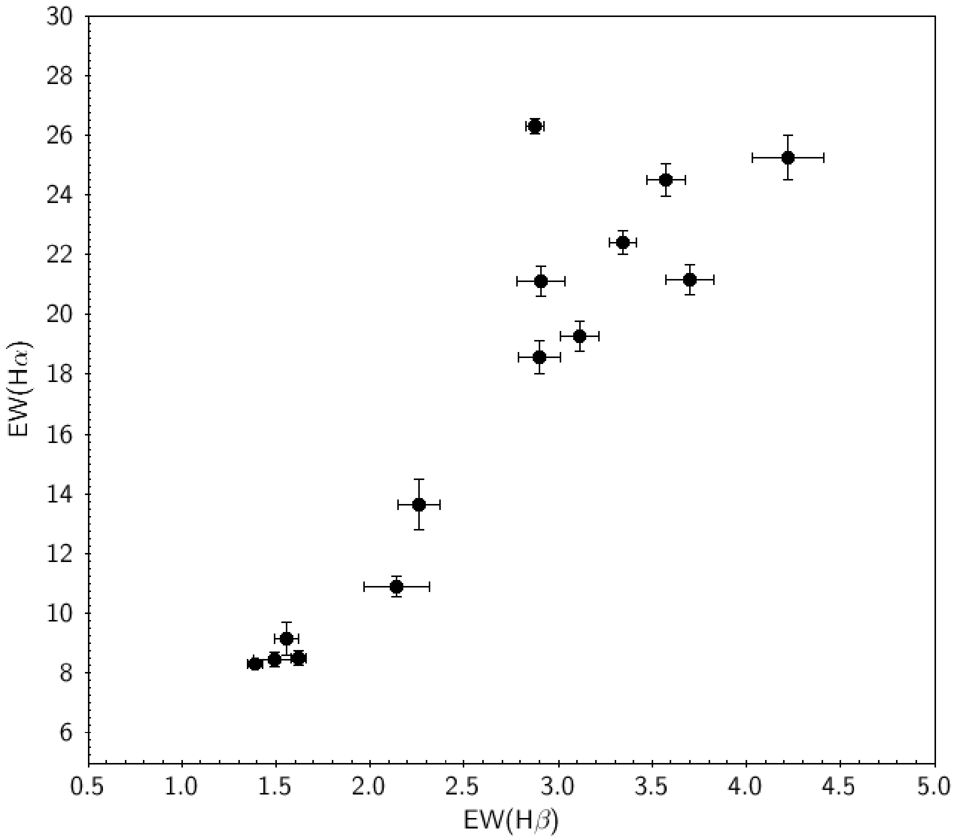
XMMU-J052016.0-692505

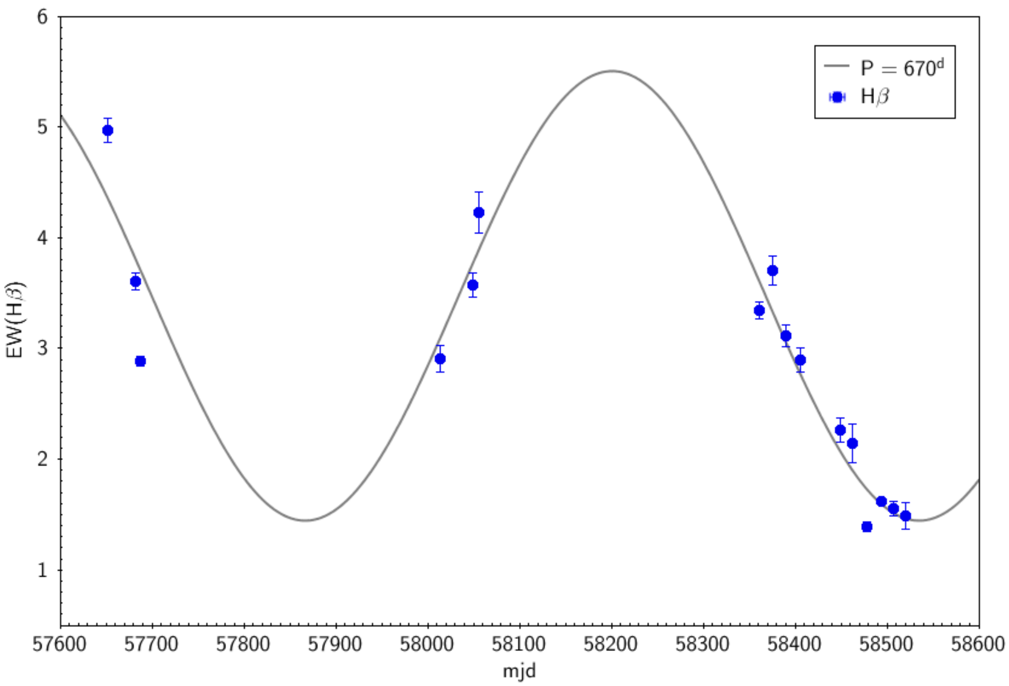






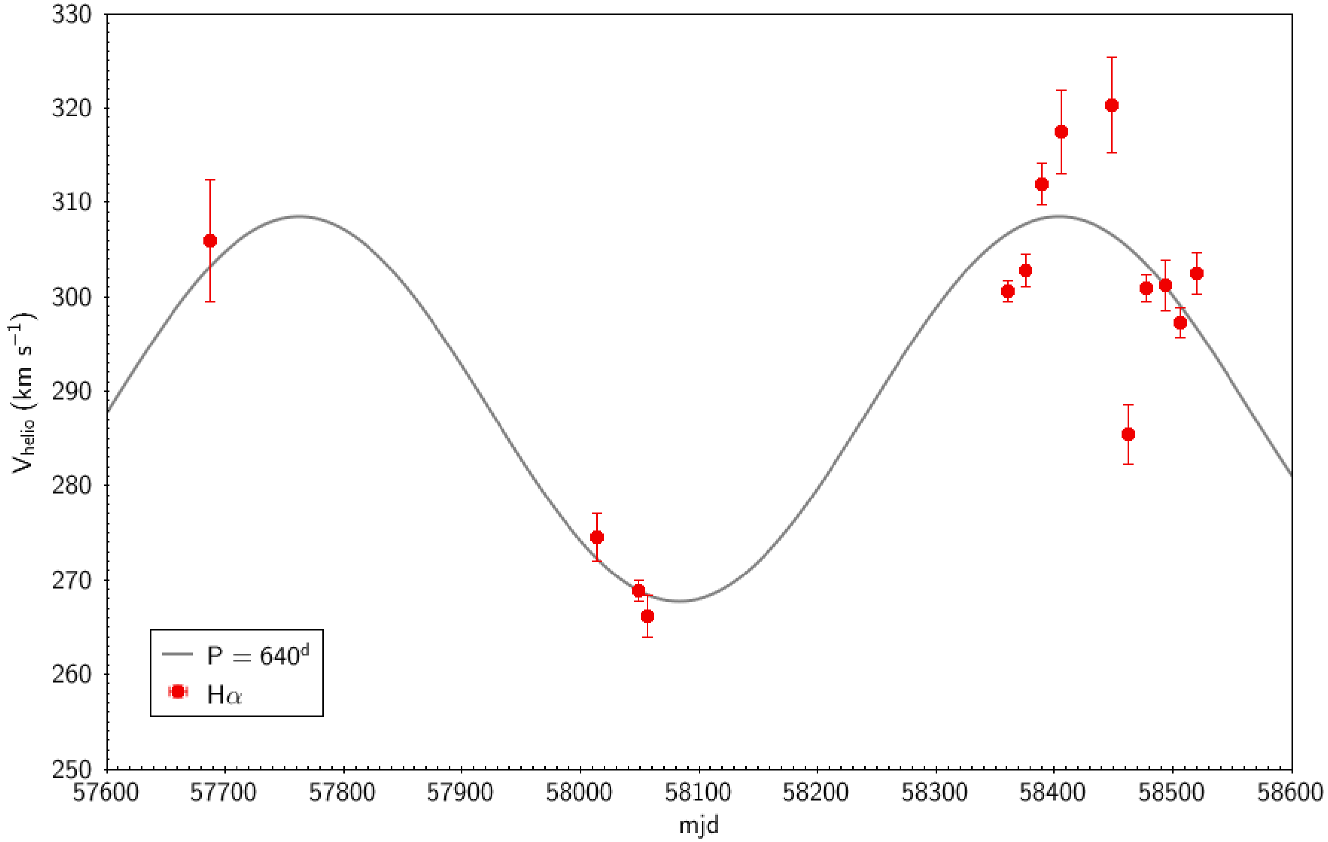
Equivalent Width





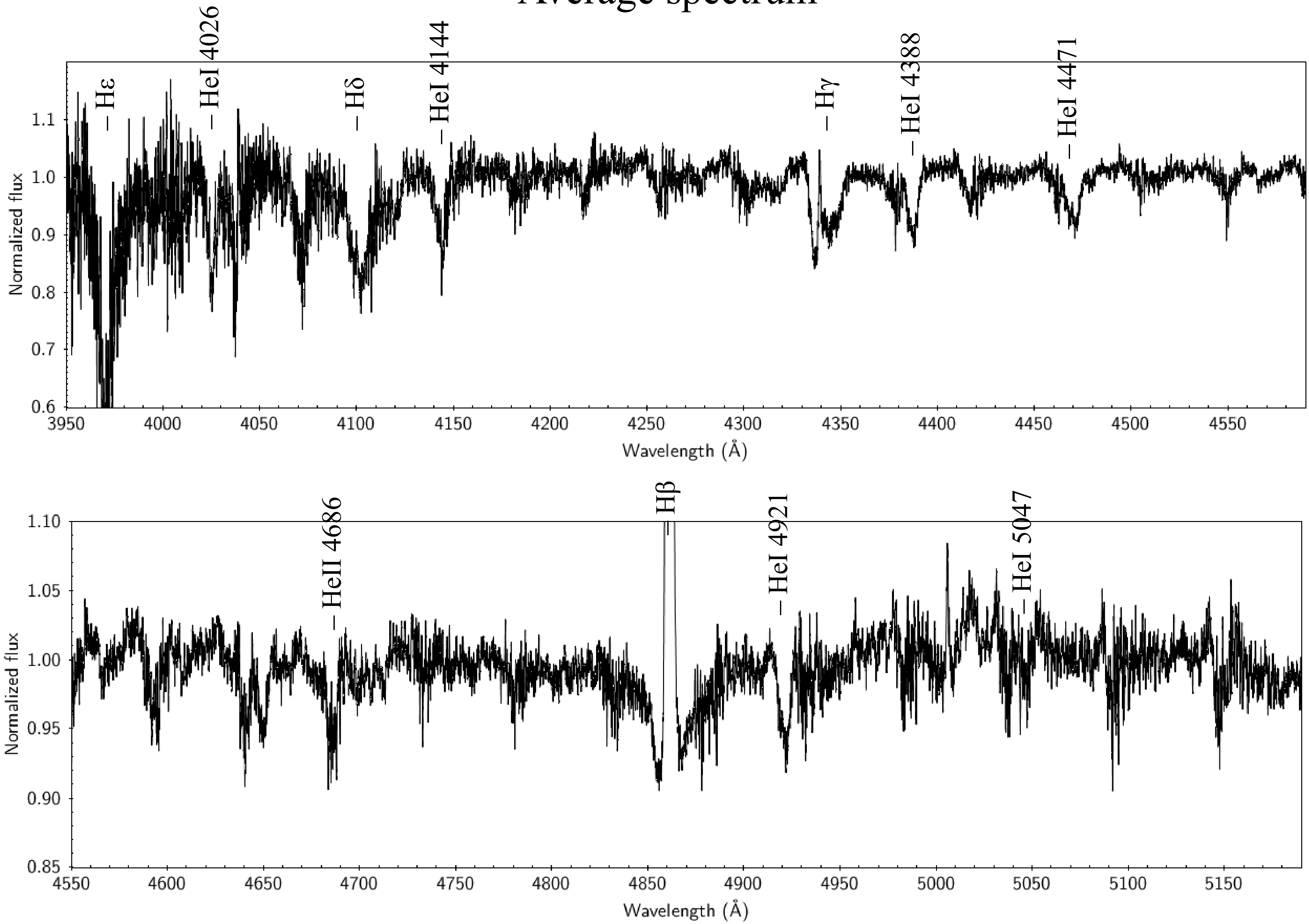
P(Hβ) = 670 days (fap = 0.02%)
P(Hα) = 640 days (fap = 0%)

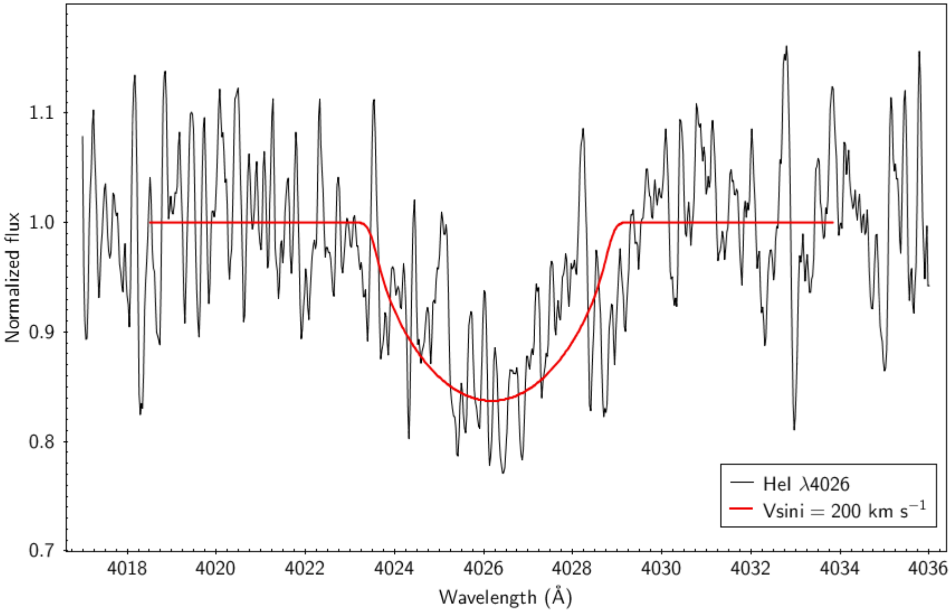
Heliocentric velocity

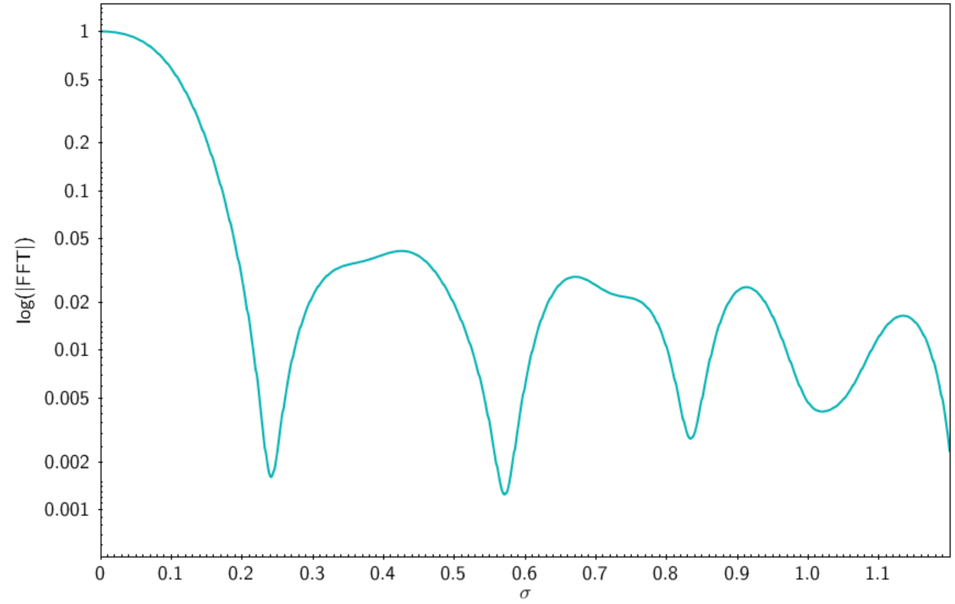


P(Hα) = 640 days (fap = 3%)

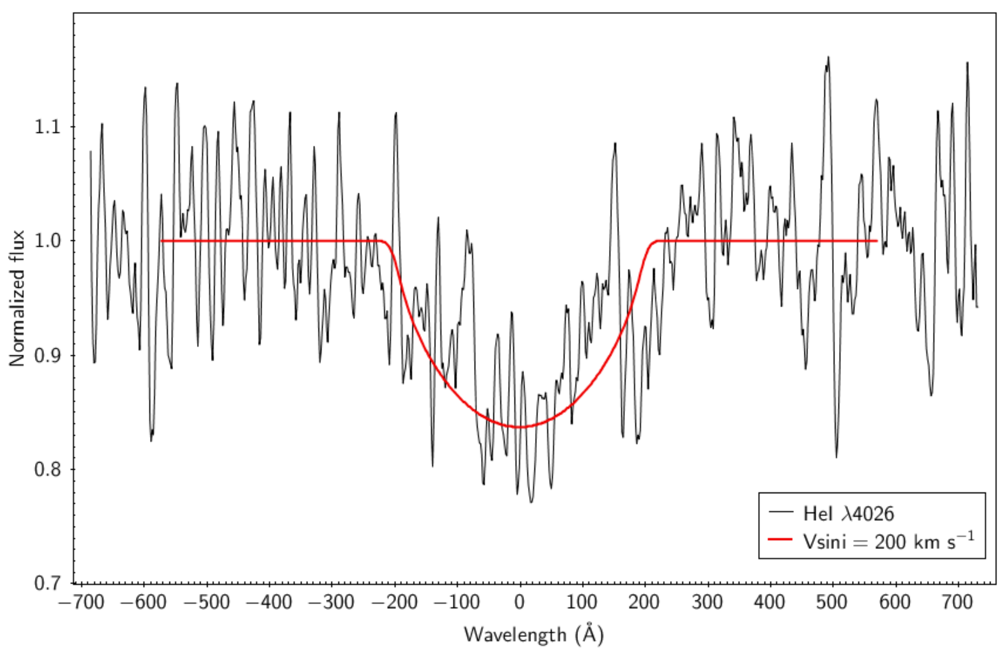
Average spectrum



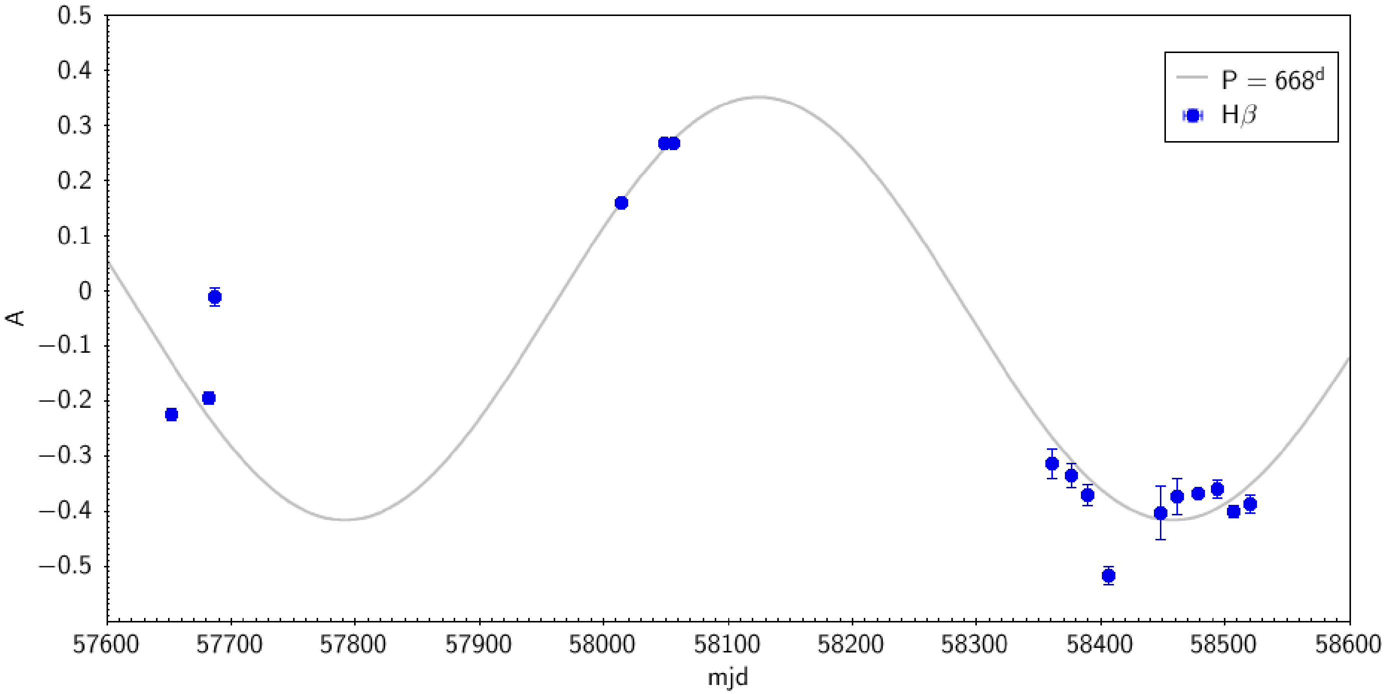




$$V \sin i = \frac{c}{\lambda} \frac{f(\epsilon)}{\sigma} \approx 200 \text{ km s}^{-1}$$



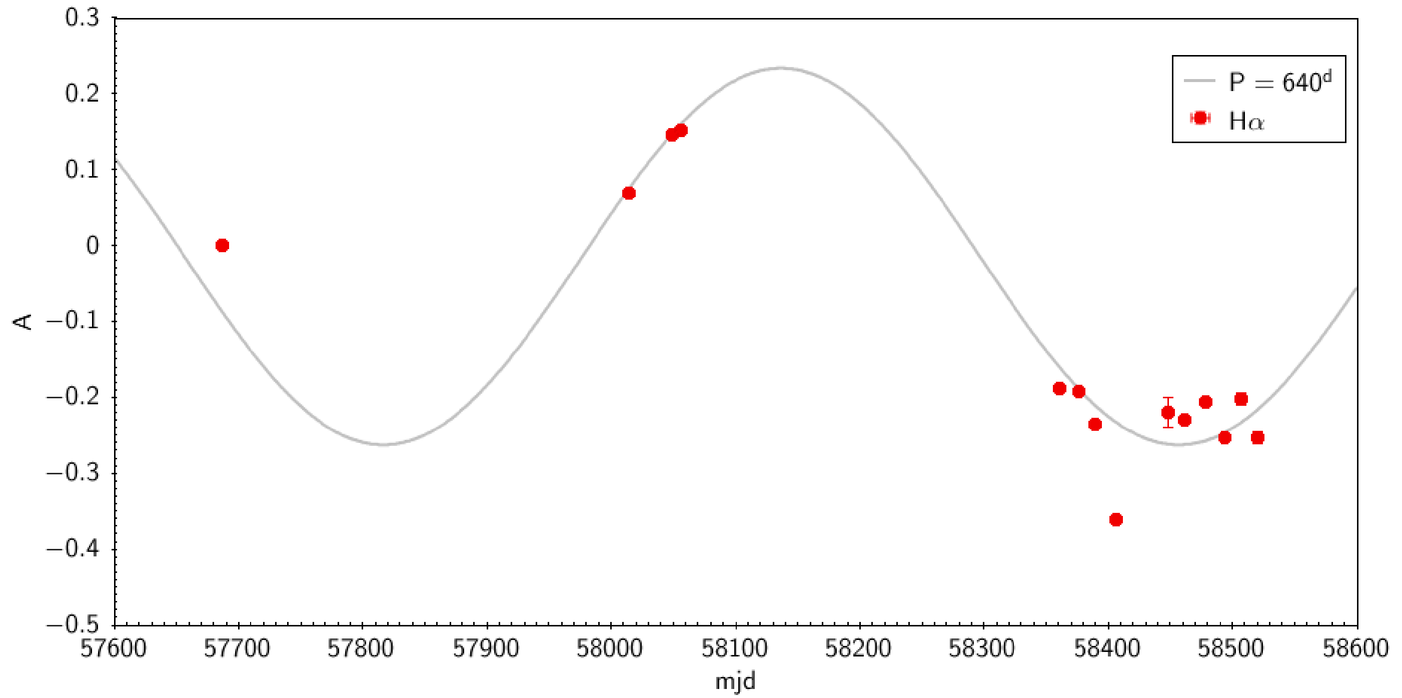
Asymmetry



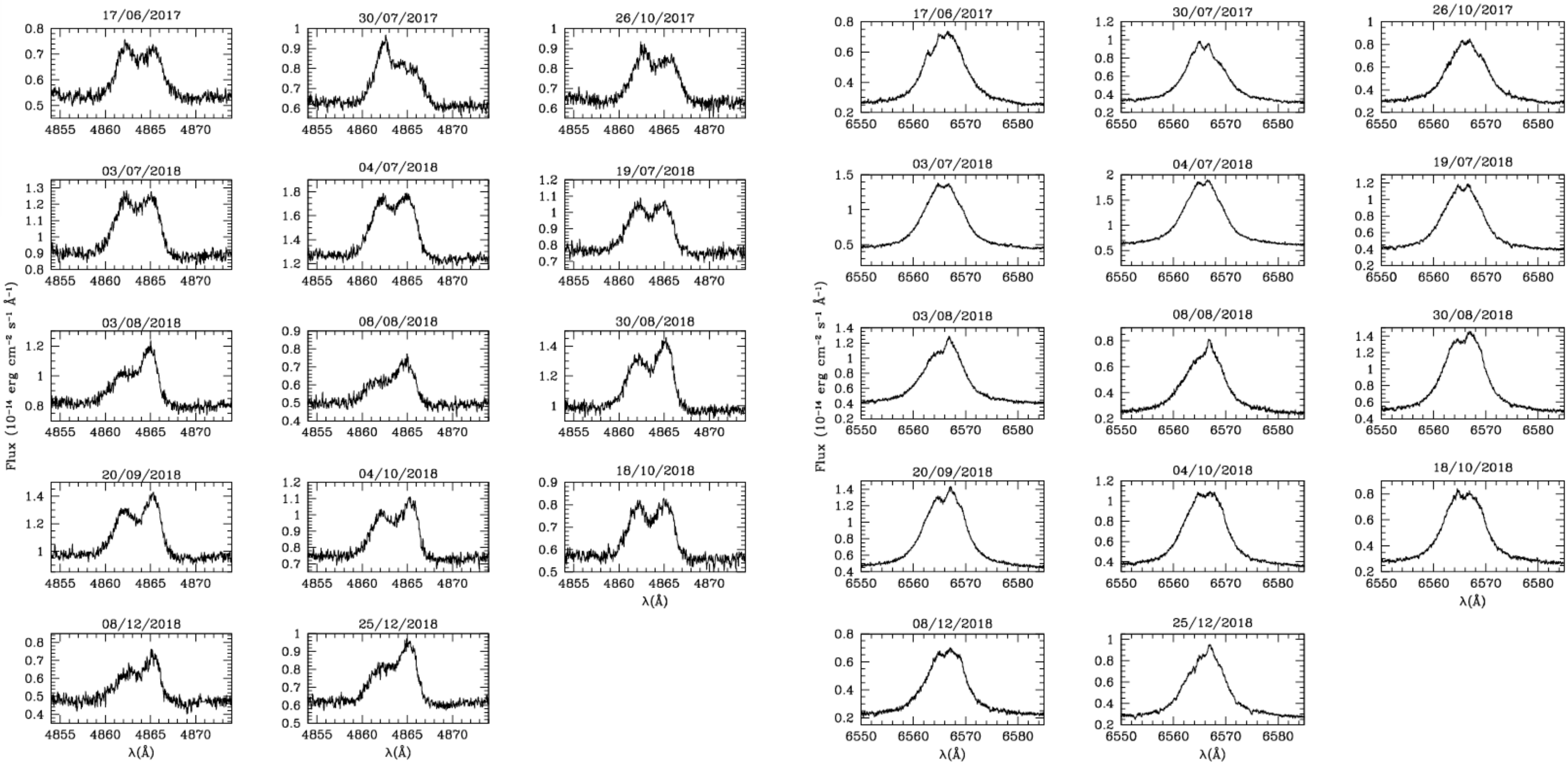
V/R < 1

V/R > 1

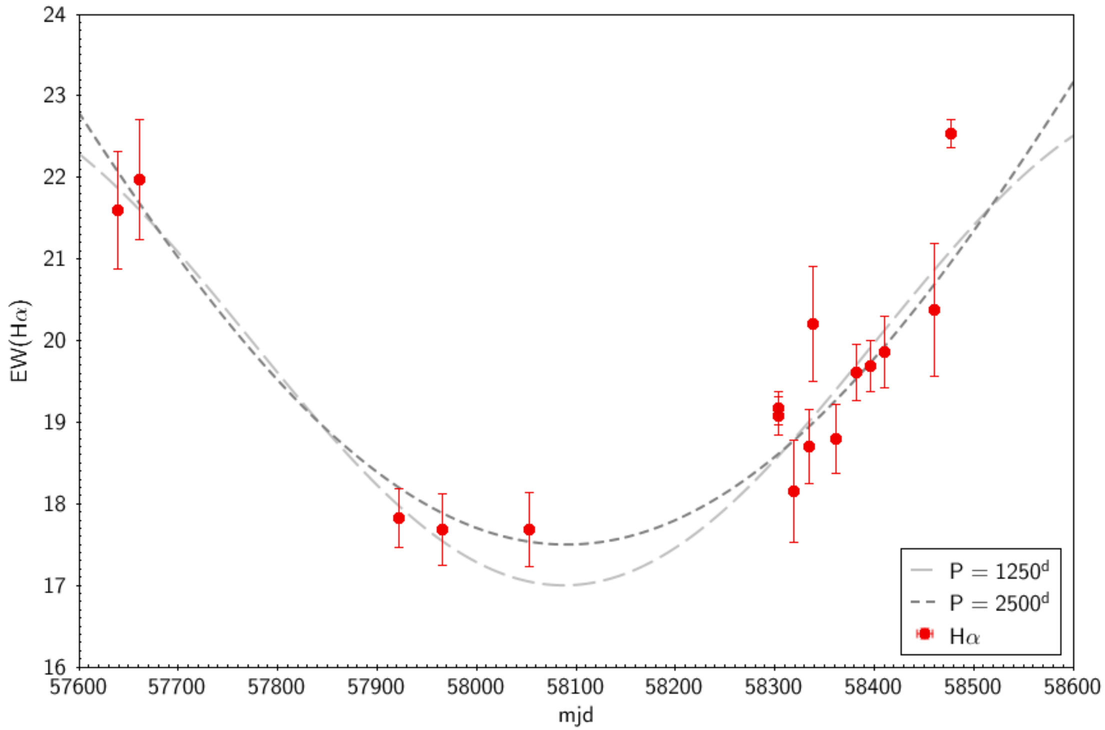
P(Hβ) = 668 days (fap = 0.02%)
P(Hα) = 640 days (fap = 0.13%)

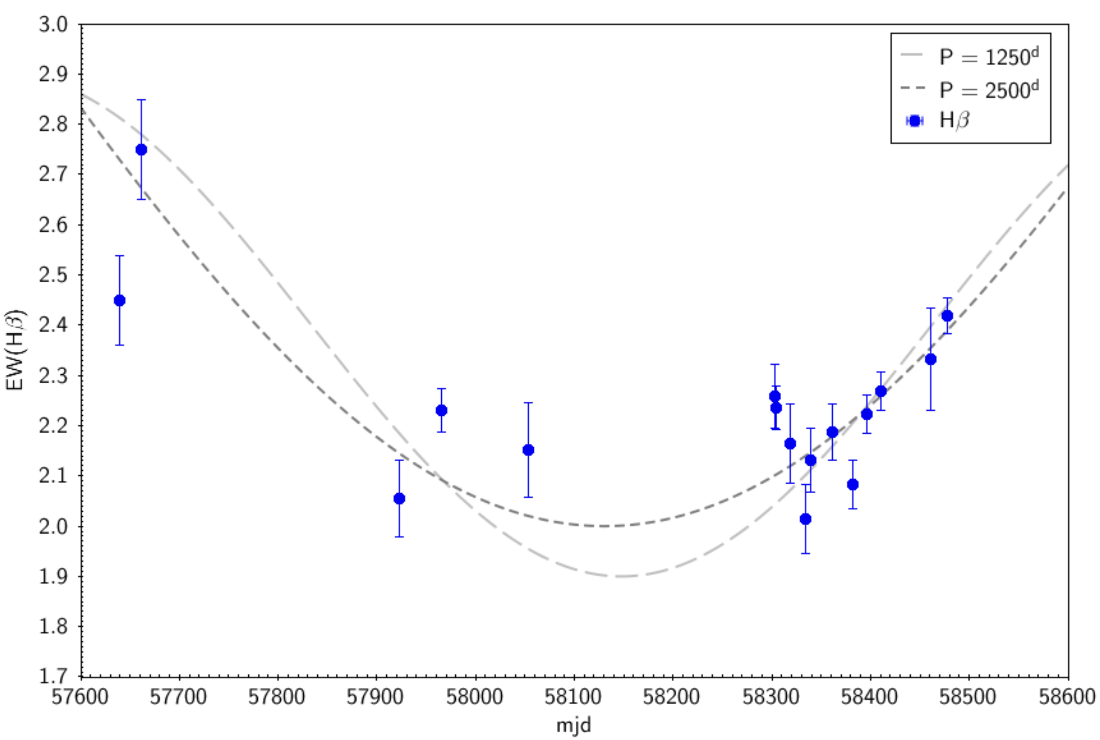


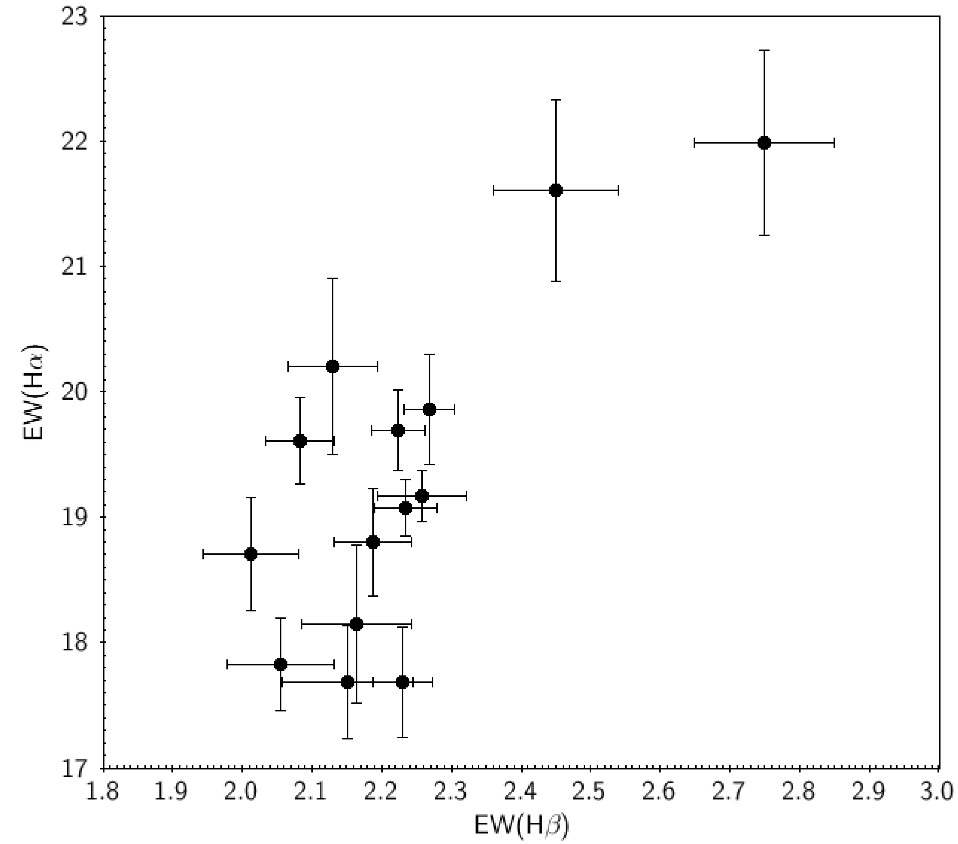
XMMU-J010147.5-715550



Equivalent Width

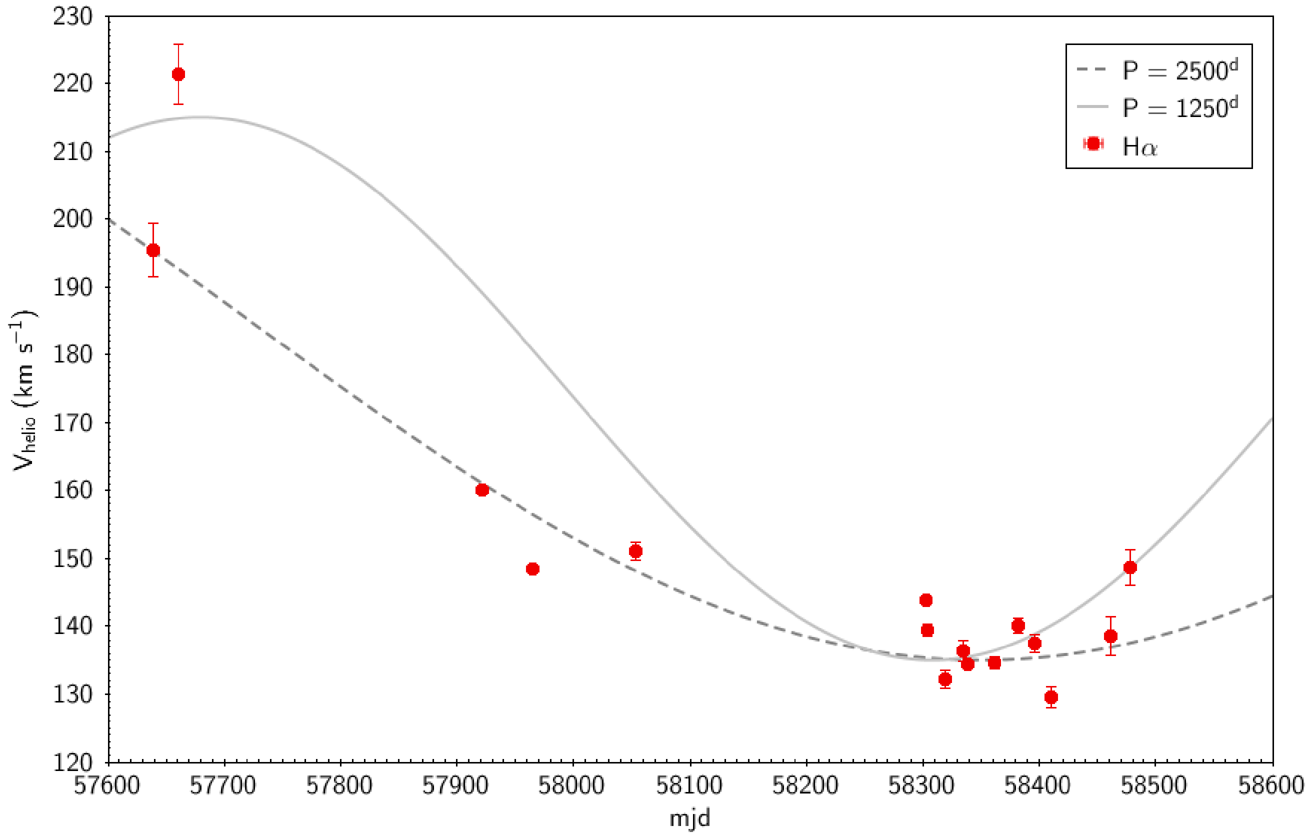




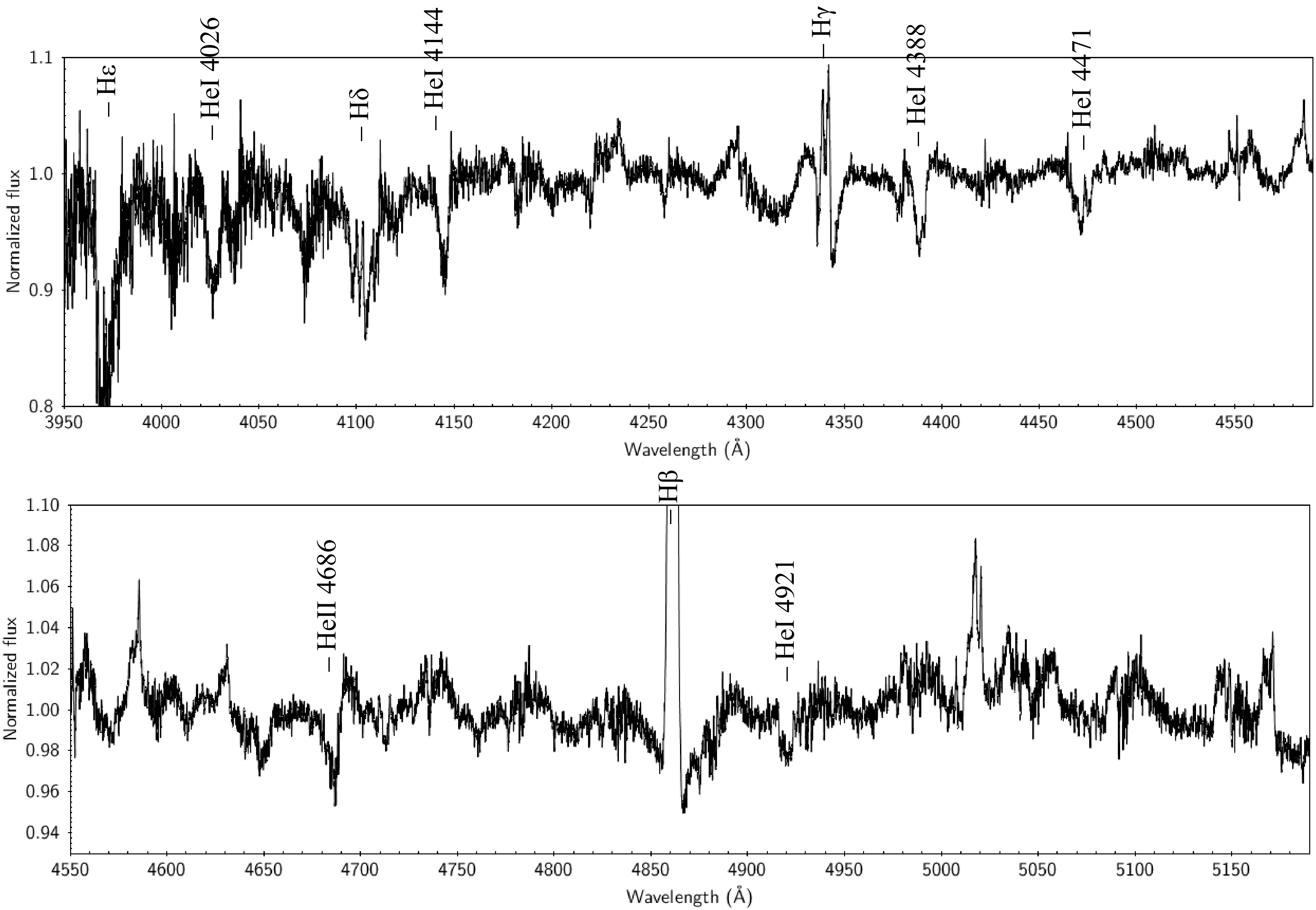


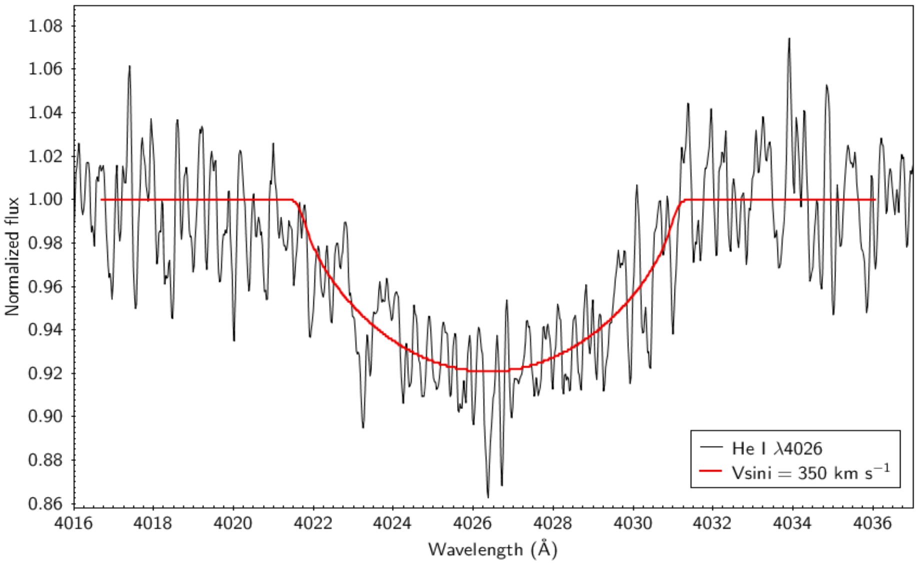
P = 1264 ± 2 days (Sturm+ 2012)

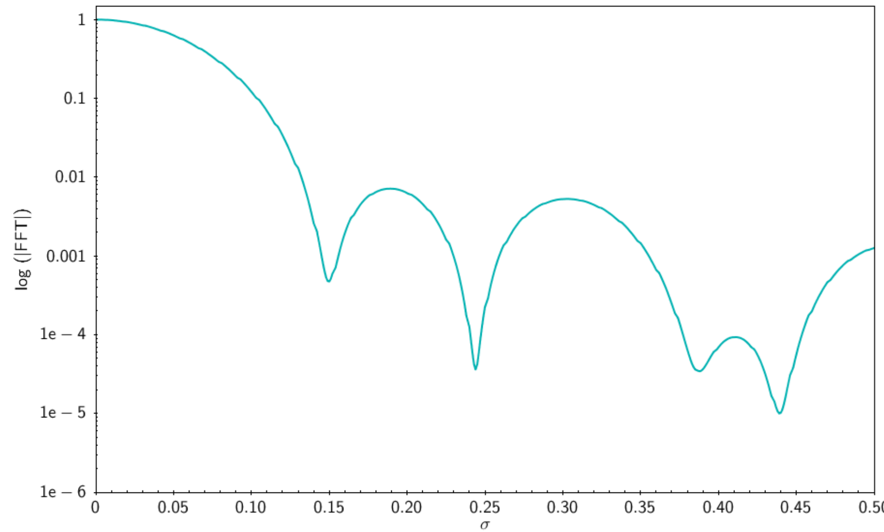
Heliocentric velocity



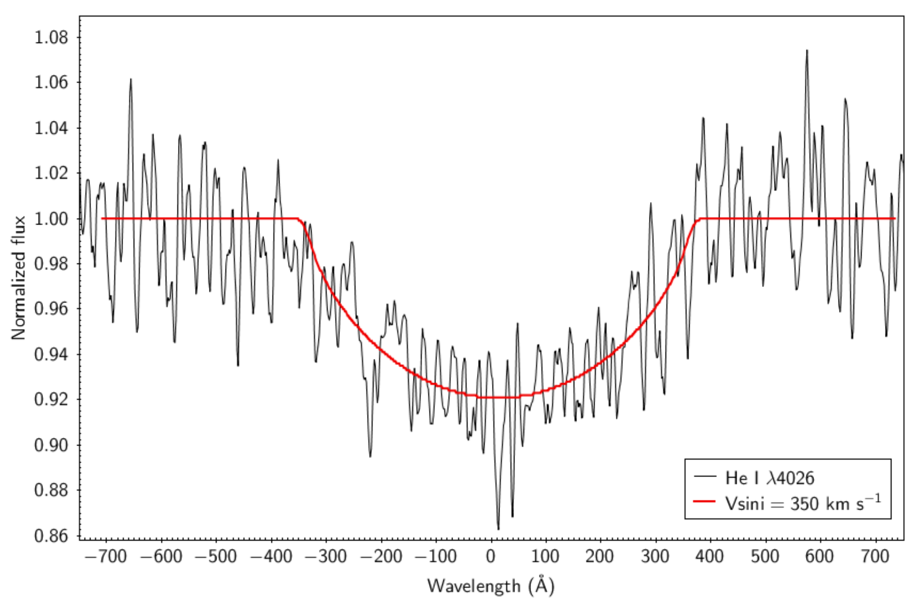
Average spectrum



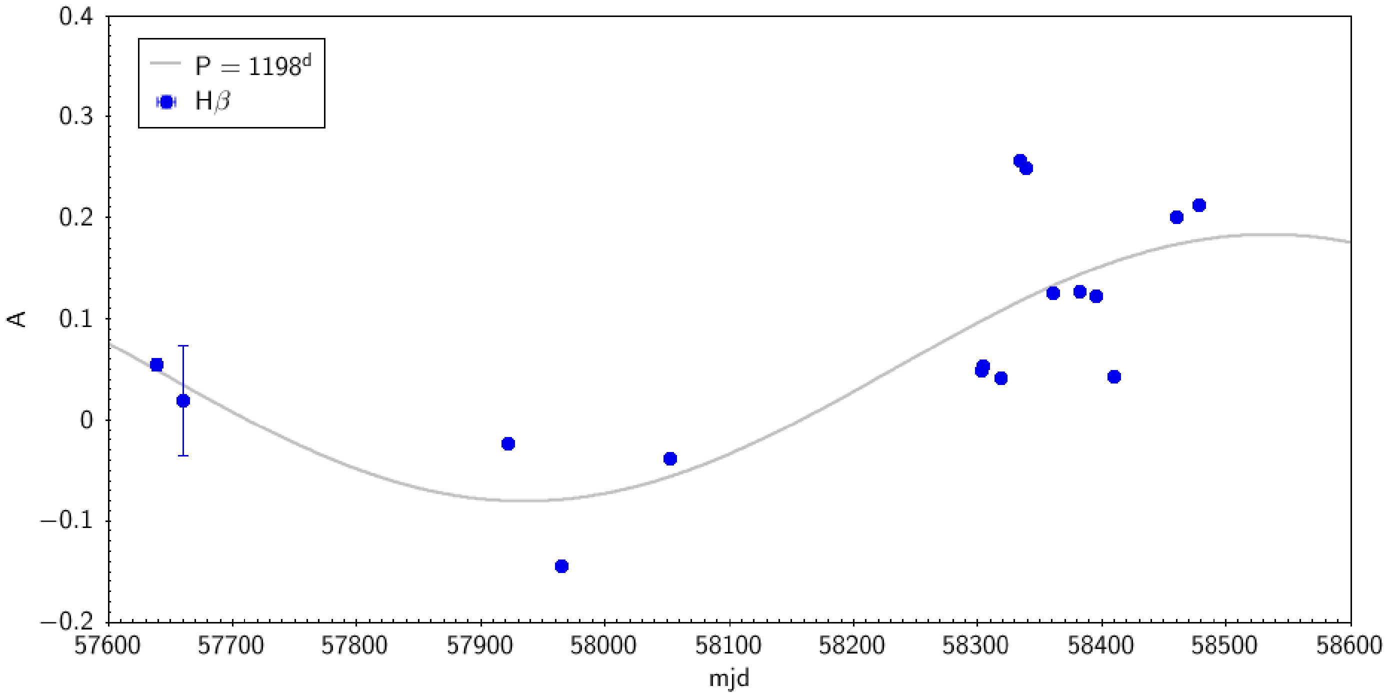




$$V \sin i = \frac{c}{\lambda} \frac{f(\epsilon)}{\sigma} \approx 350 \text{ km s}^{-1}$$



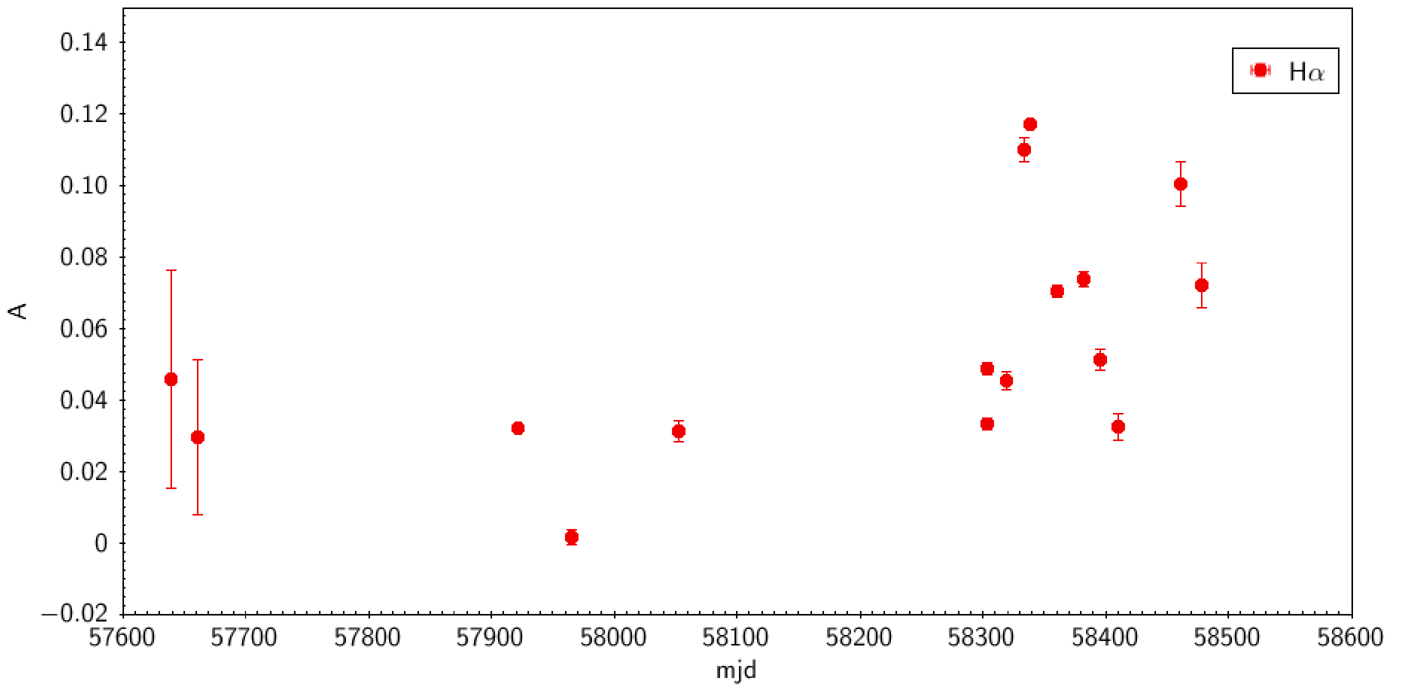
Asymmetry



V/R < 1

V/R > 1

P(Hβ) = 1198 days (fap = 24%)



To be continued….