ОПТИЧЕСКИ-ТОНКИЕ АККРЕЦИОННЫЕ ДИСКИ В КАТАКЛИЗМИЧЕСКИХ ПЕРЕМЕННЫХ С ОЧЕНЬ НИЗКИМ ТЕМПОМ ПЕРЕНОСА ВЕЩЕСТВА

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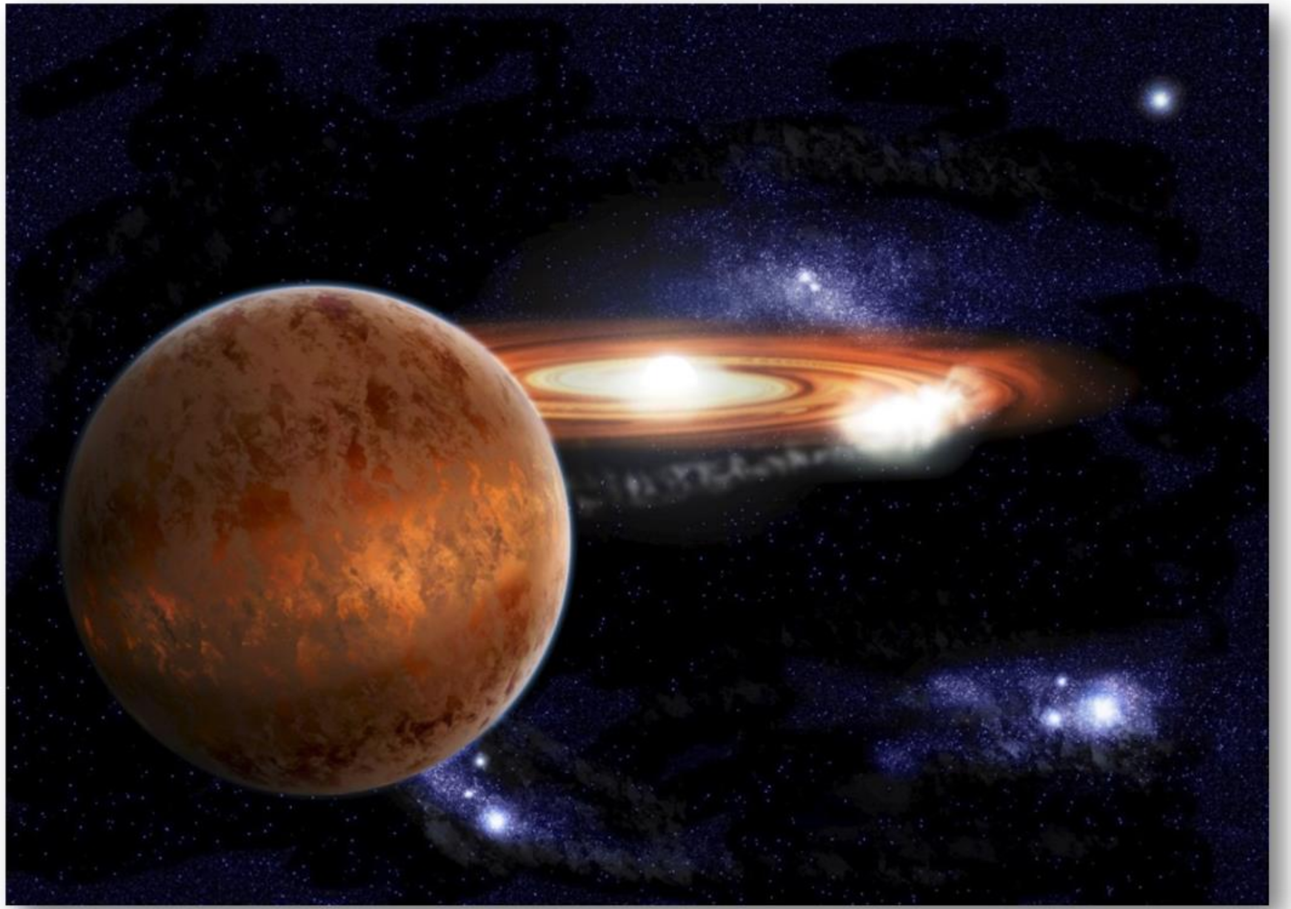
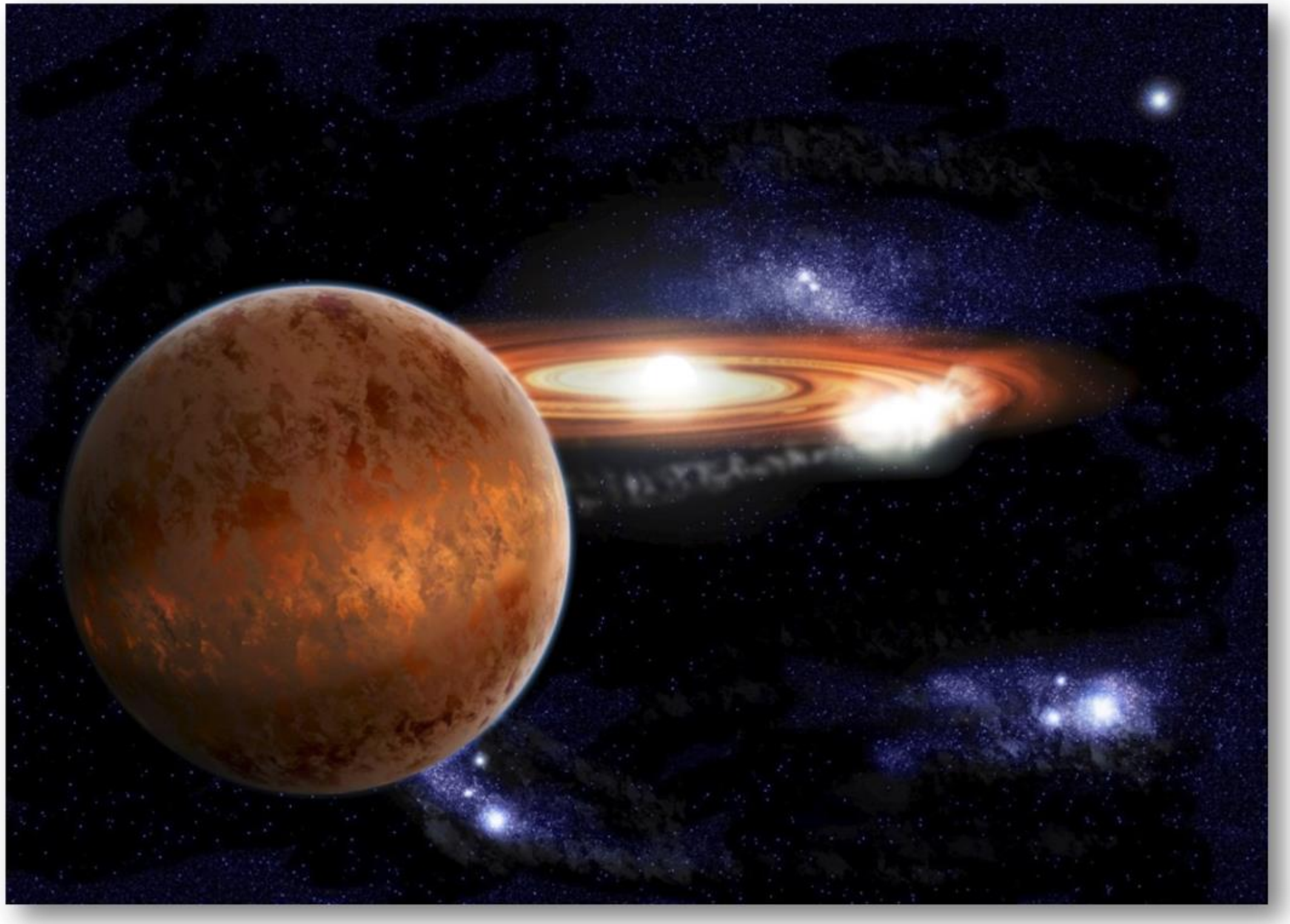
Accreting White Dwarfs

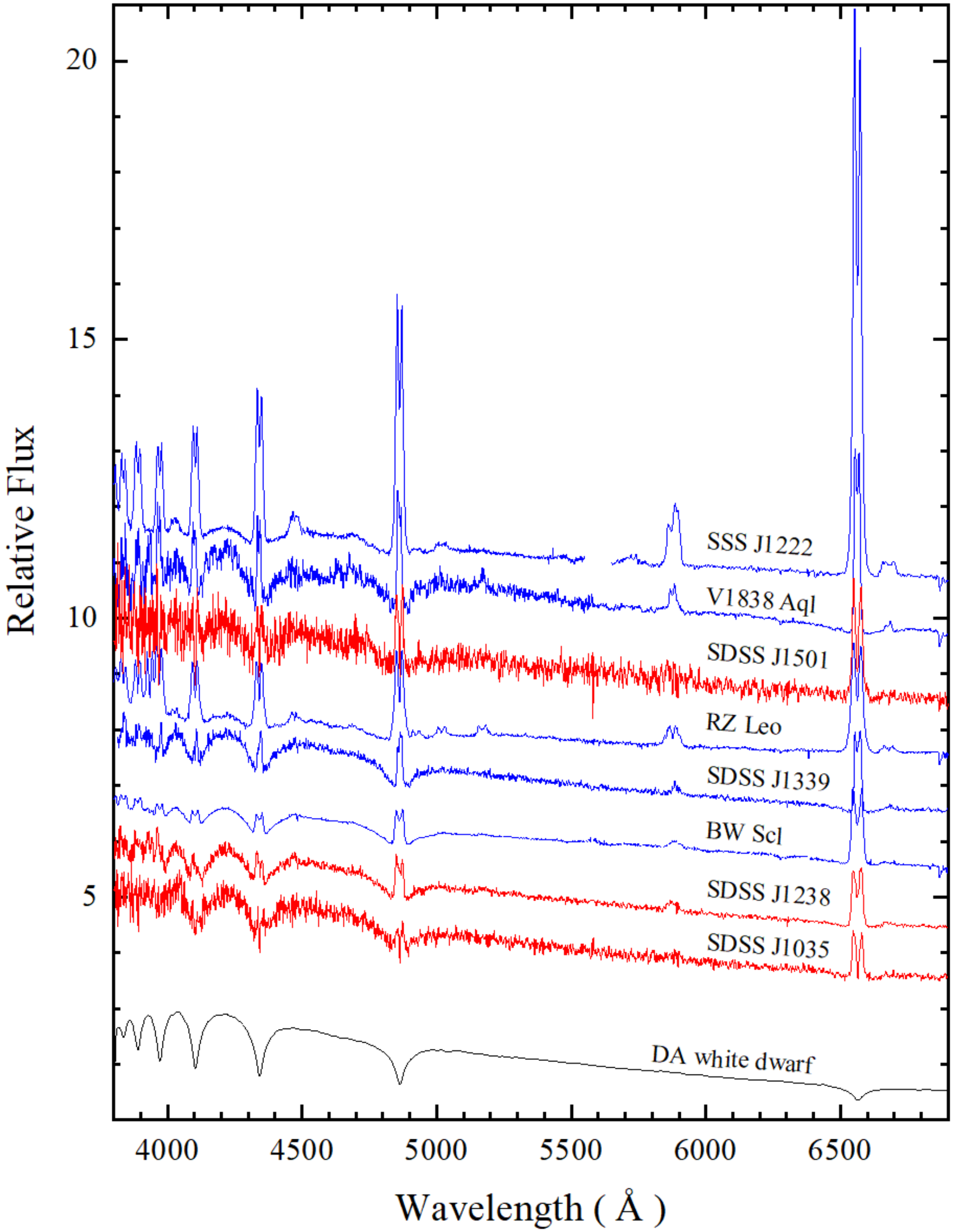


also known as
Cataclysmic variables (CVs).

Spectra of accreting WDs with a relatively low mass-transfer rate often exhibit the clear presence of broad Balmer absorption lines.

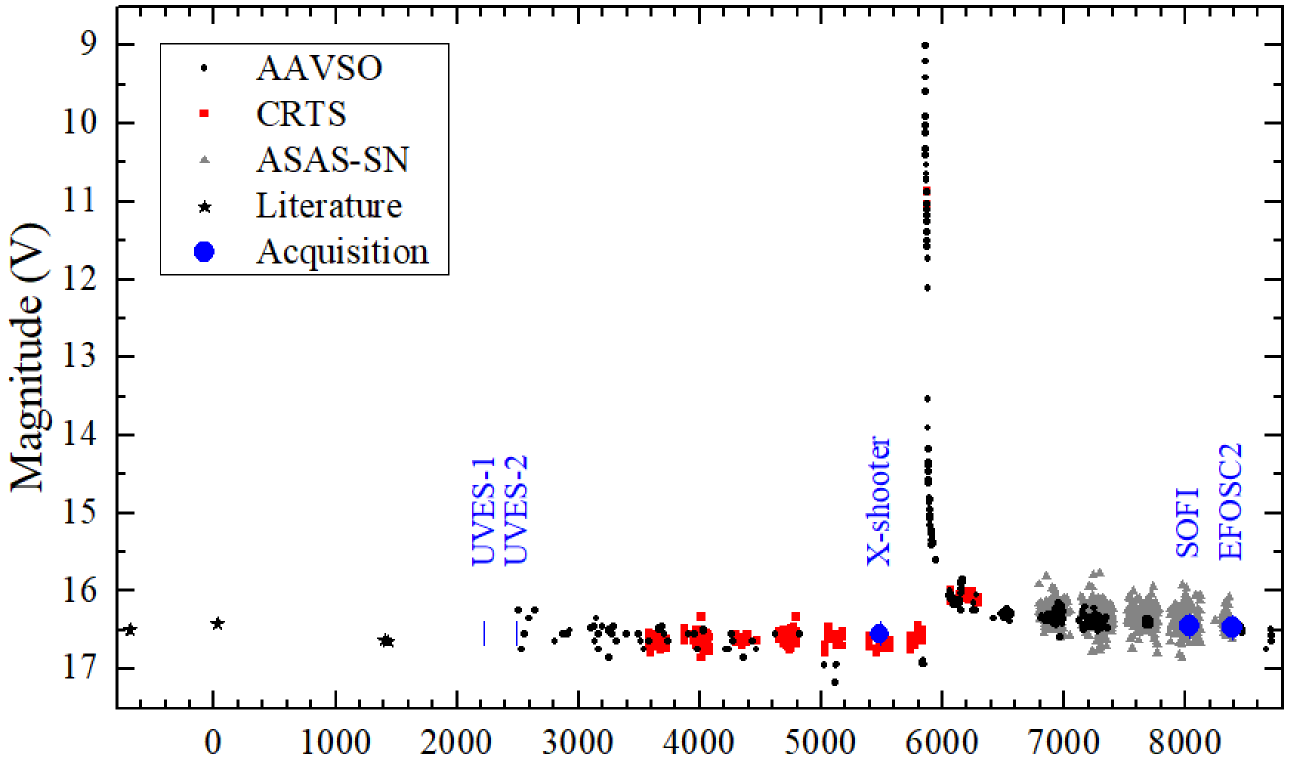
Accreting White Dwarfs

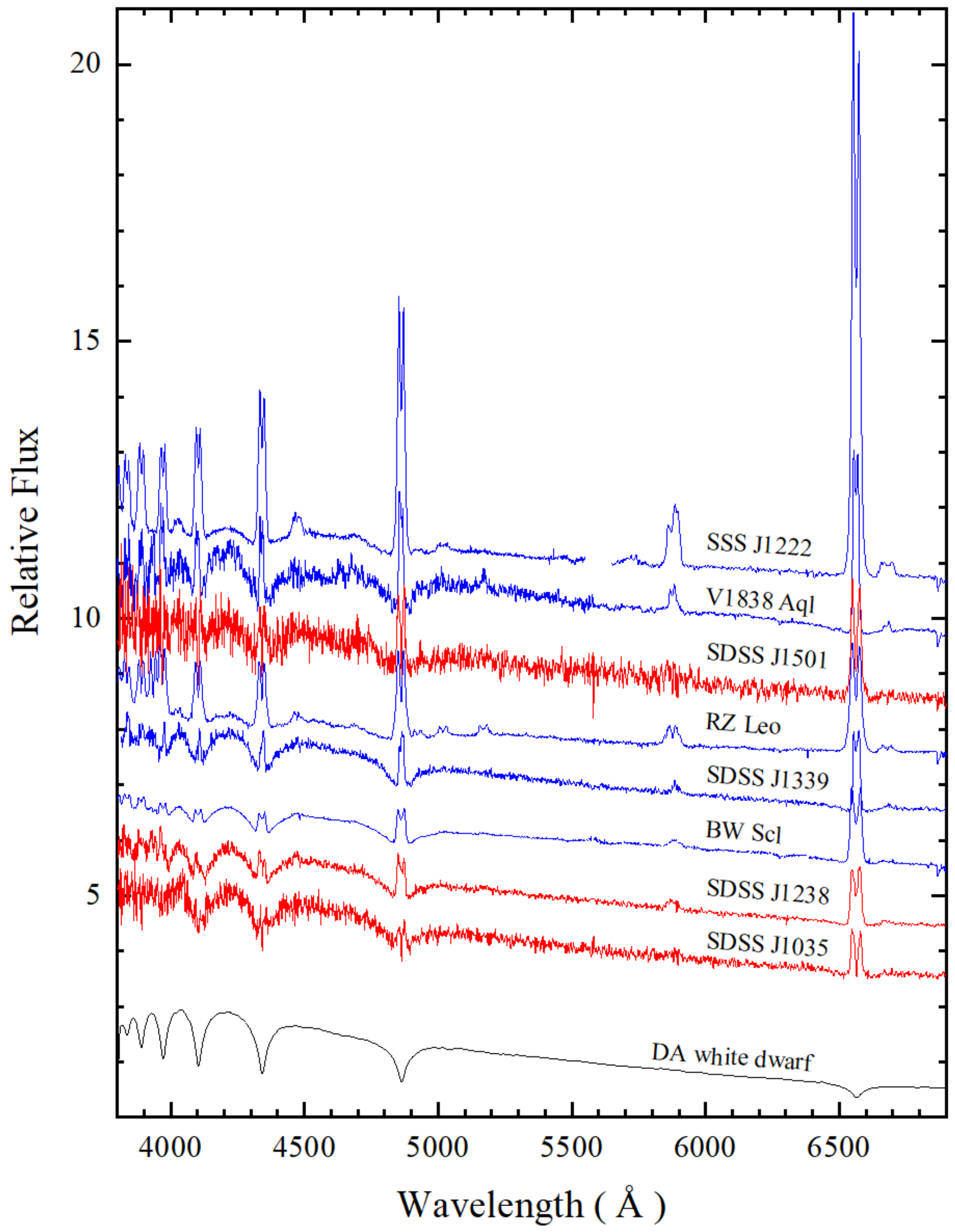




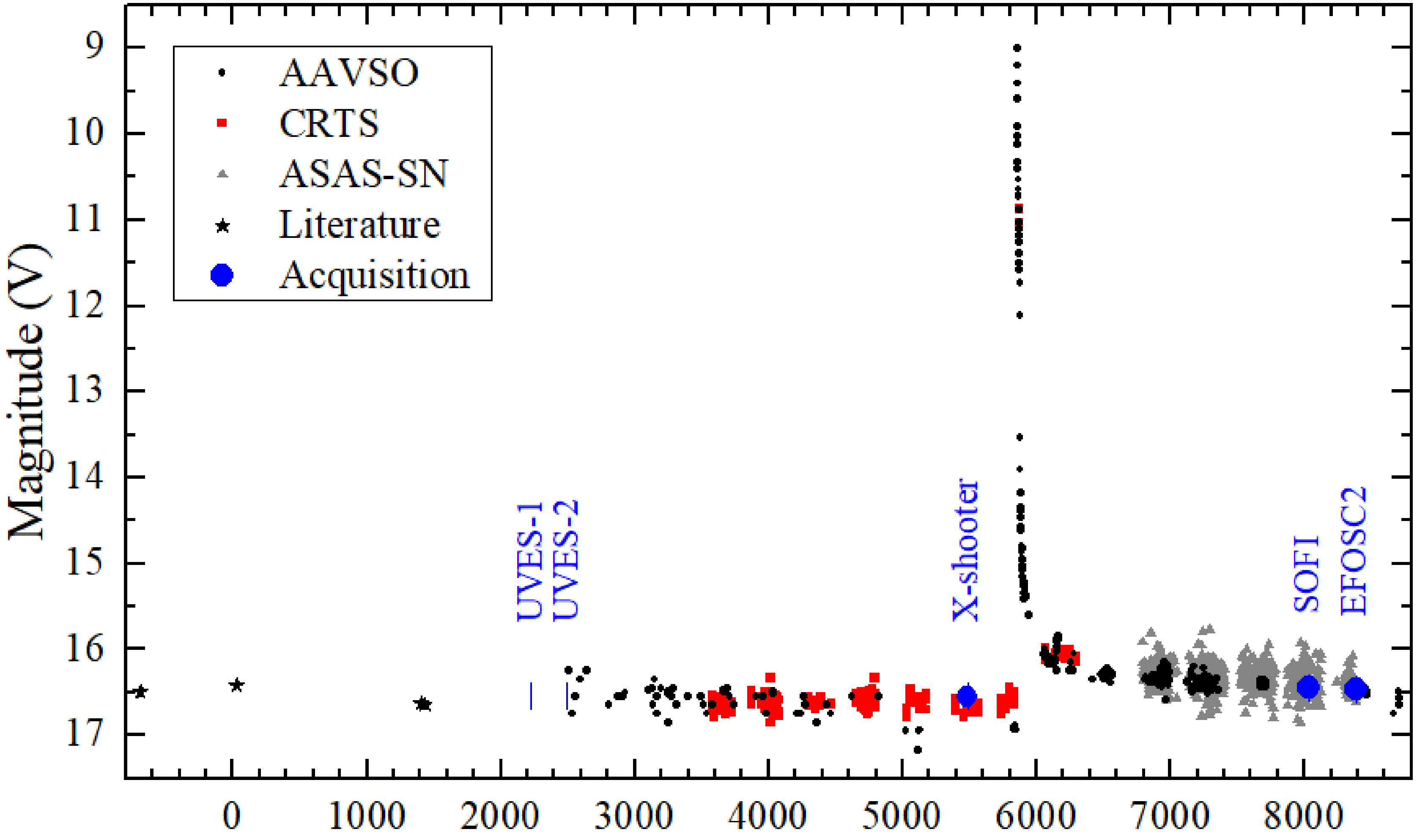
Accreting White Dwarfs

eventually, sooner or later, experience a (super)outburst and become a CV.





Accreting White Dwarfs



Most AWDs are
very stable photometrically
until their outbursts

Результаты, которые я сегодня представлю, являются важным побочным продуктом (by-product) более общих проектов:

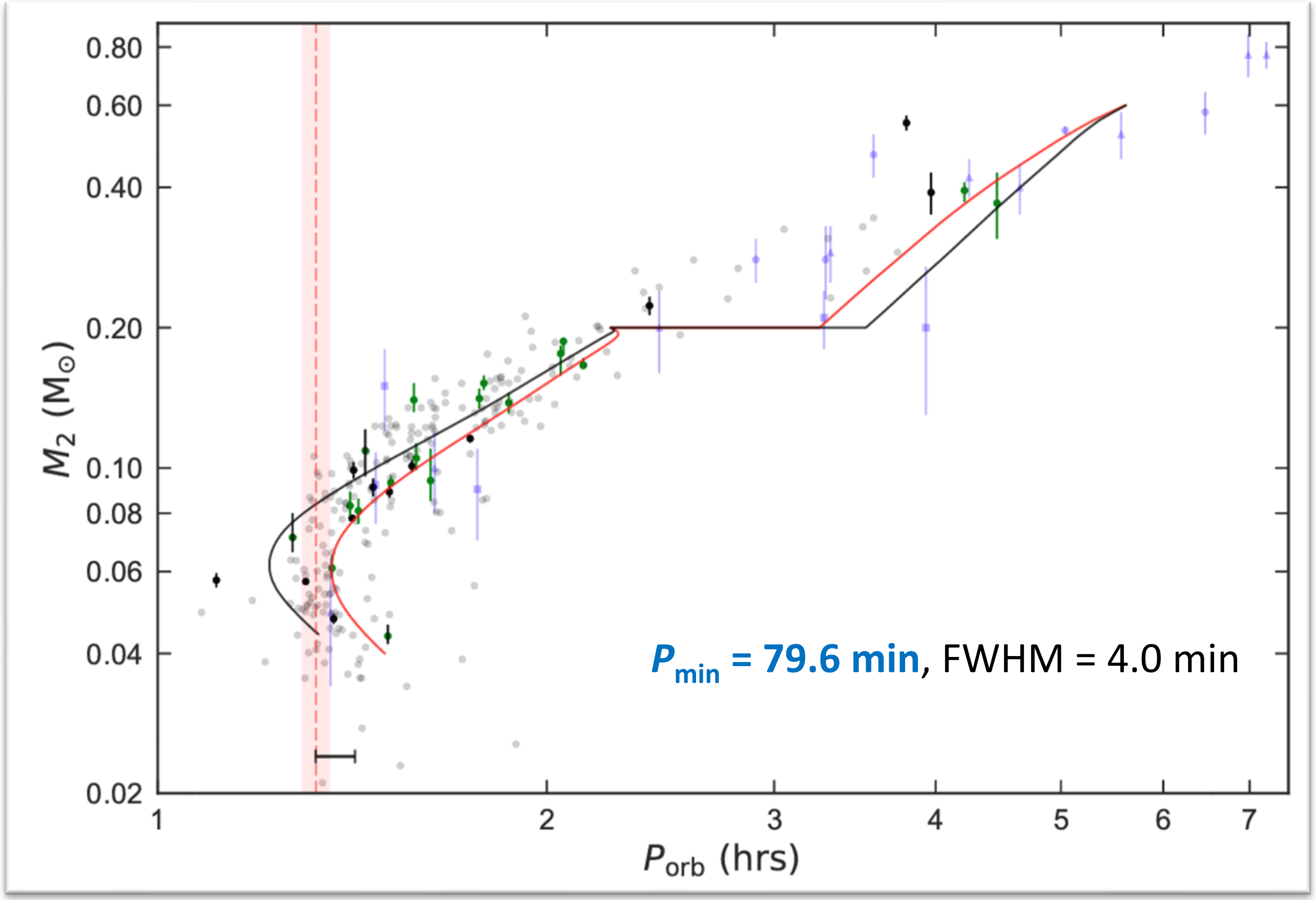
- A systematic search for **period bouncers** among the WZ Sge-stars;
- Digging in the graveyard of cataclysmic variables: the search for direct evidence for brown-dwarf secondaries.

Оба проекта посвящены изучению **Period Bouncers**, катаклизмических переменных, находящихся на заключительном этапе их эволюции (прошедших минимум орбитального периода).

Period Bouncers are cataclysmic variables at the very late stage of their evolution.

Зачем их исследовать?

- Expected to be a lot of such objects but known a few:
  - a major challenge to our understanding of CV evolution;
- Donor stars evolved to a kind of brown-dwarf-like objects:
  - these donors were born as normal stars and became substellar during secular evolution, it is not obvious that these objects behave like ordinary brown-dwarfs;
- Low mass transfer rate:
  - the properties of accretion discs in binaries with a low mass-ratio and a low accretion-rate are poorly understood.



Measured CV donor masses as a function of orbital period (from McAllister et al. 2019). The black and red lines represent the “standard” and “revised” evolutionary tracks from Knigge et al. (2011), respectively.

Наблюдения

Многоцветная фотометрия от UV до NIR:

- (Swift-UVOT)
- UVBRIz+JHK

Спектроскопия относительно ярких объектов (<19-20V):

- VLT/X-Shooter
- VLT/FORS2
- NTT/EFOSC+SOFI
- NOT/ALFOSC

X-rays:

- Swift-XRT
- (XMM-Newton)

Позволяют построить SED, спектральное распределение энергии, в очень широком диапазоне длин волн.

BW Sculptoris

Our observations:

- NTT/EFOSC2 + SOFI (2017+2018)
- *Swift*-XRT & UVOT (all bands)

Archival data:

- UVES (2001+2002)
- X-shooter (2010)

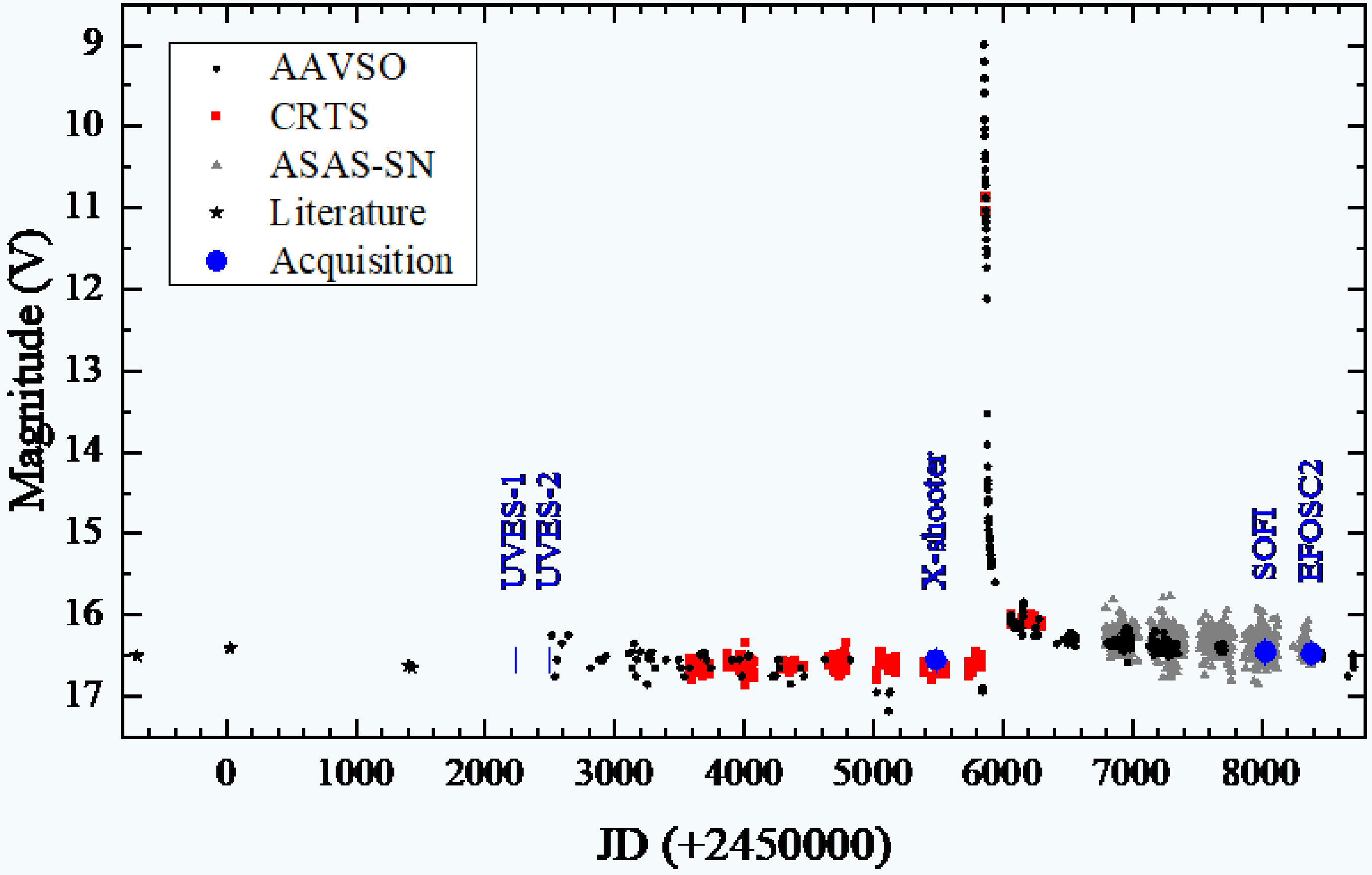
- *TESS* (2020)

✓ Solid period-bounce candidate (q=0.067 – Kato+ 2013)

✓ P_{orb} = 78.2 min

✓ Superoutburst in 2011

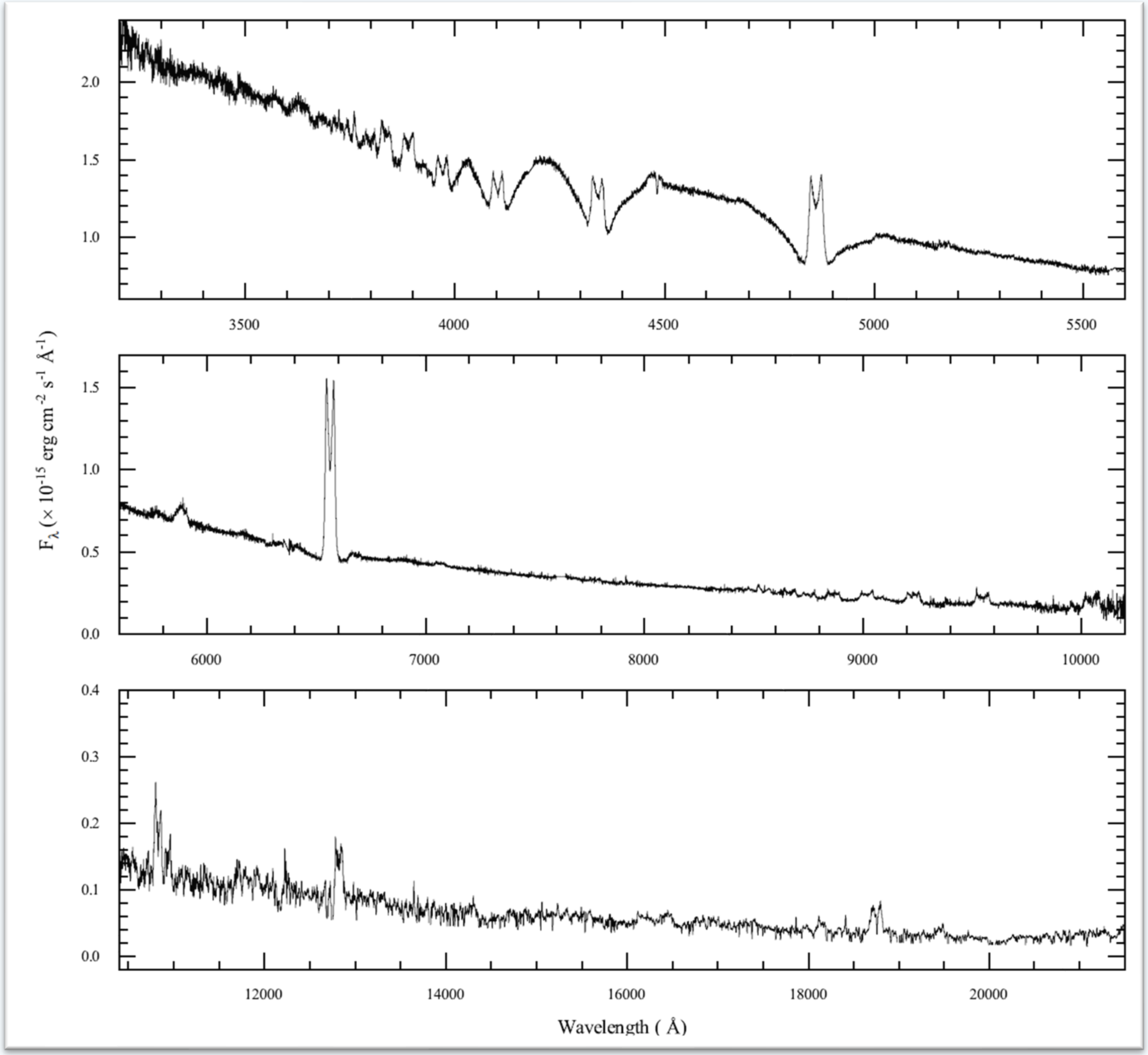
✓ V≈16.5 mag — one of the brightest period-bounce candidates



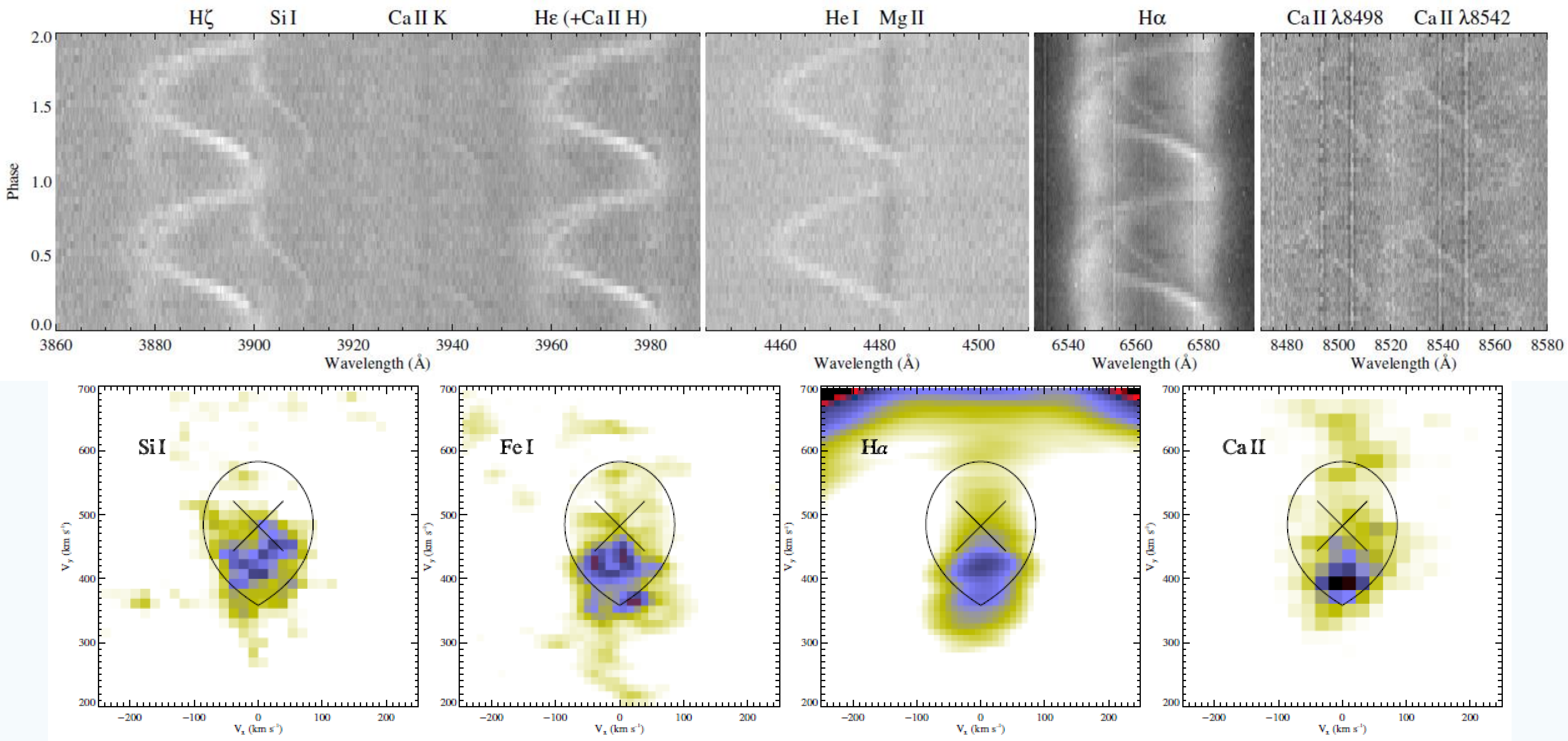
X-shooter spectroscopy

- Exposure times: 1 minute
- 239 spectra
- 5.54 hours (4.25 P_{orb})
- S/N ratio of the average spectrum: up to a few hundreds

Unfortunately, the NIR spectra are very noisy



Trailed spectra

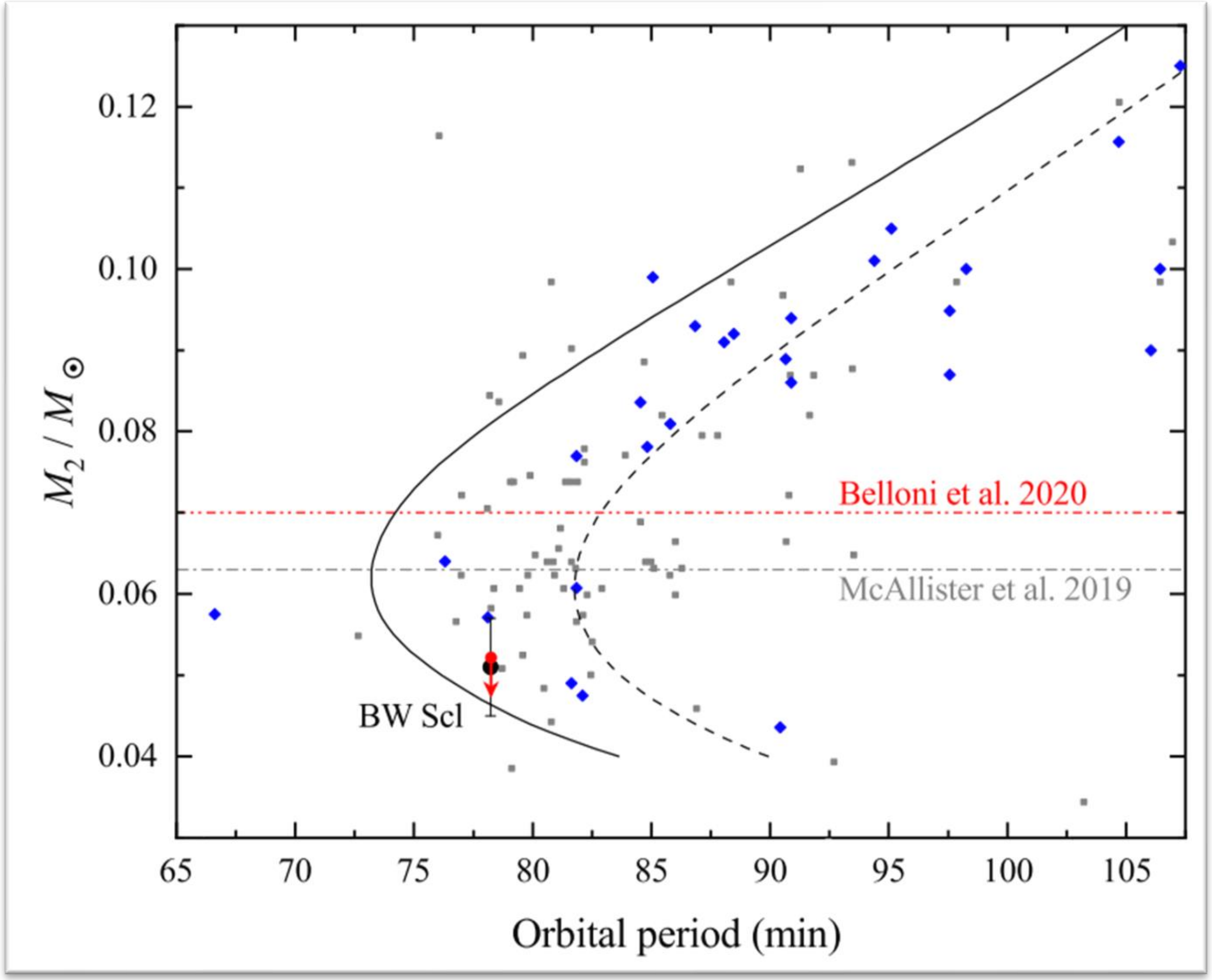


Conclusion

- BW Scl is a period bouncer
  - ✓Confirmed
  - ➢ M_2=0.051 ± 0.006 $M_\odot$

- White dwarf is quite massive:
  - ➢ M_{WD} =0.85 ± 0.04 $M_\odot$
  - ➢ T_{eff} =14250 K

- Accretion disc is optically thin
- Hot spot is optically thick



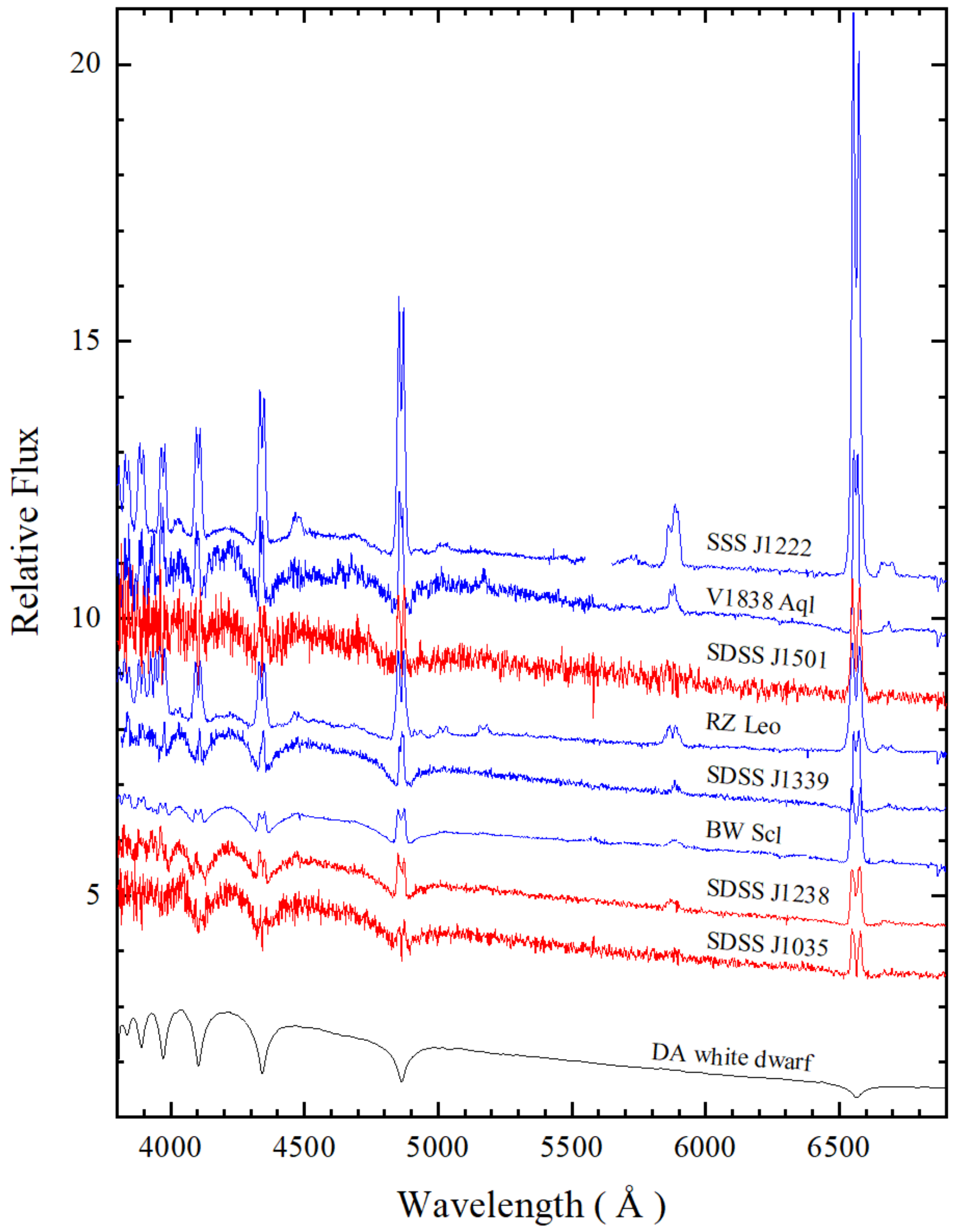
Neustroev & Mäntynen 2023, MNRAS, 523, 6114

Accreting White Dwarfs

What are the physical properties of their accretion discs?

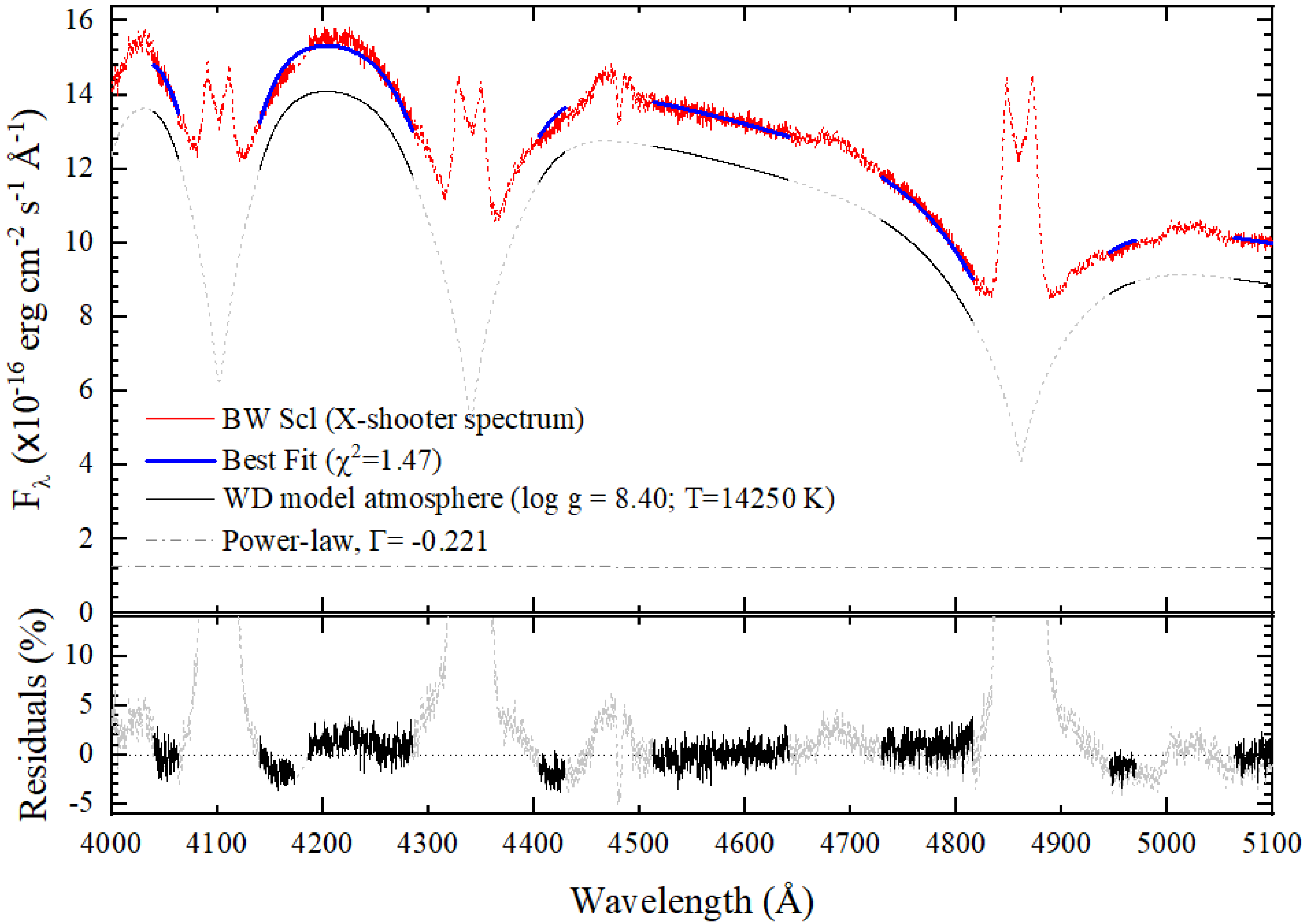
Their parameters are difficult to assess because even the spectra (**continuum**) of such discs are not well known: the optical spectrum is difficult to extract as the system spectrum dominates by a white dwarf.

But it is possible…



BW Scl

Derive the WD parameters (log g & T_{eff}) by fitting the object spectrum to a grid of synthetic spectra of DA WDs, to which the power-law or BB flux was added.

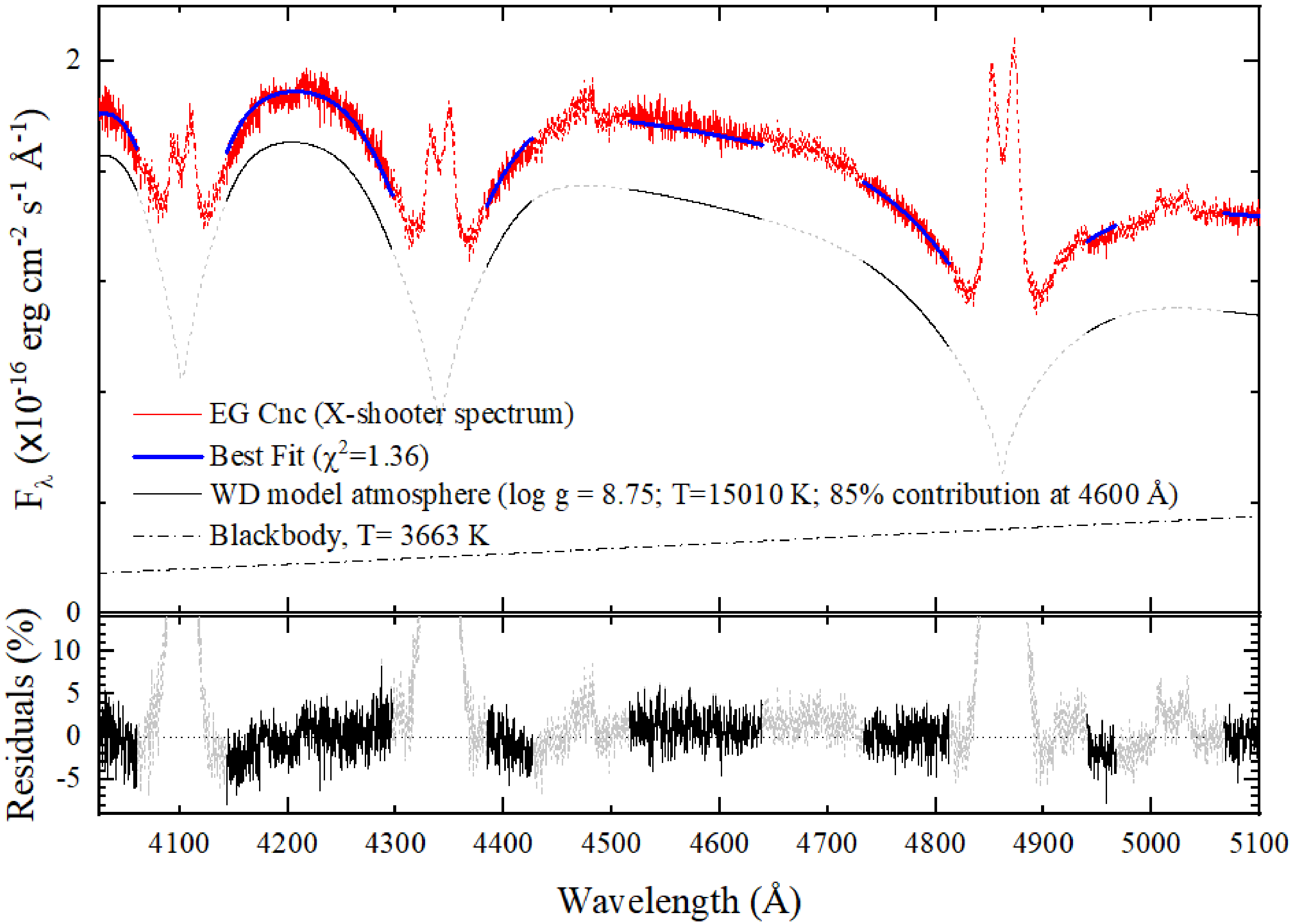


Neustroev & Mäntynen 2023

EG Cnc

6 months after the 2018 superoutburst

Derive the WD parameters (log g & T_{eff}) by fitting the object spectrum to a grid of synthetic spectra of DA WDs, to which the power-law or BB flux was added.

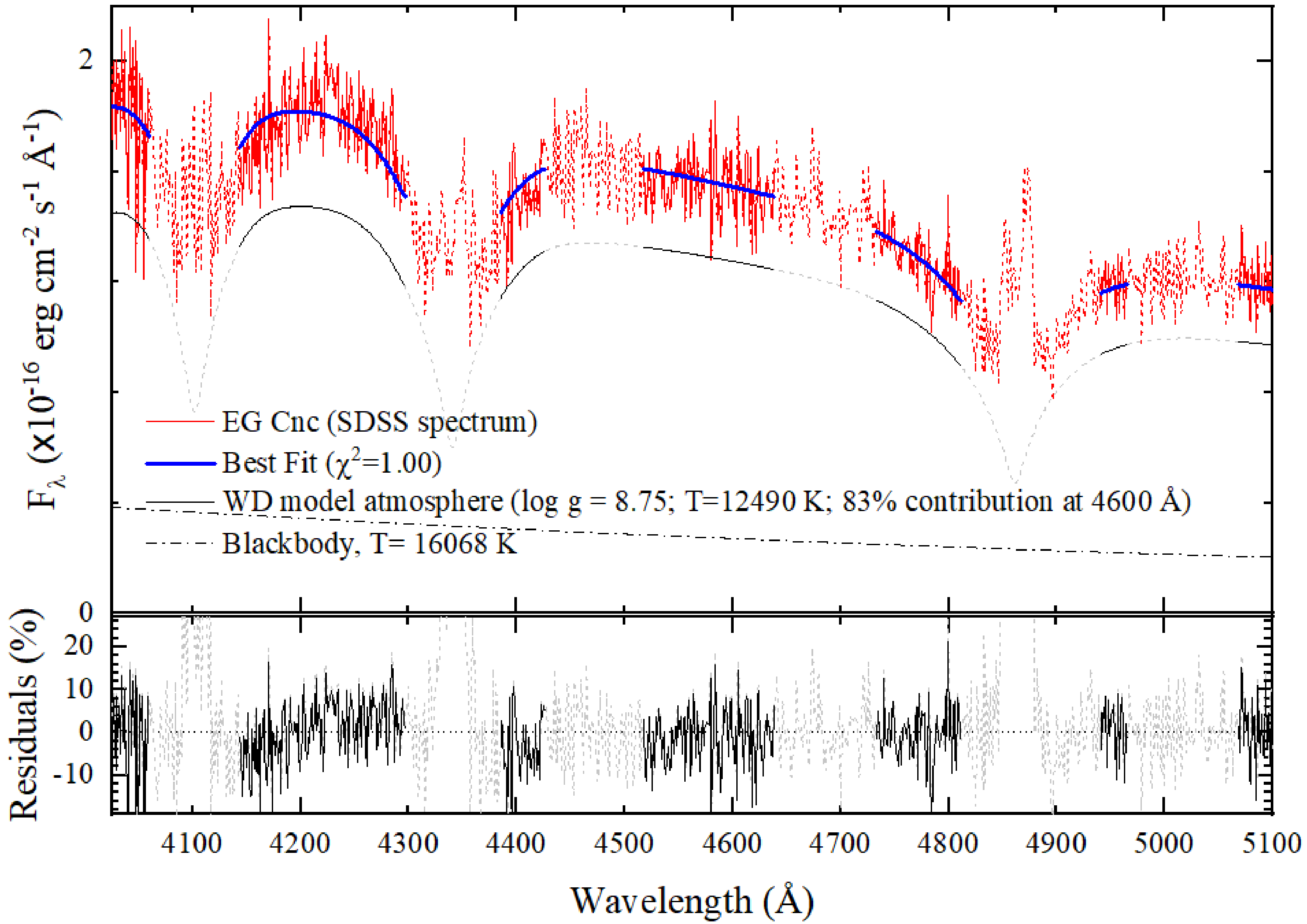


Neustroev & Siitonen, *in prep.*

EG Cnc

15 years before the 2018 superoutburst

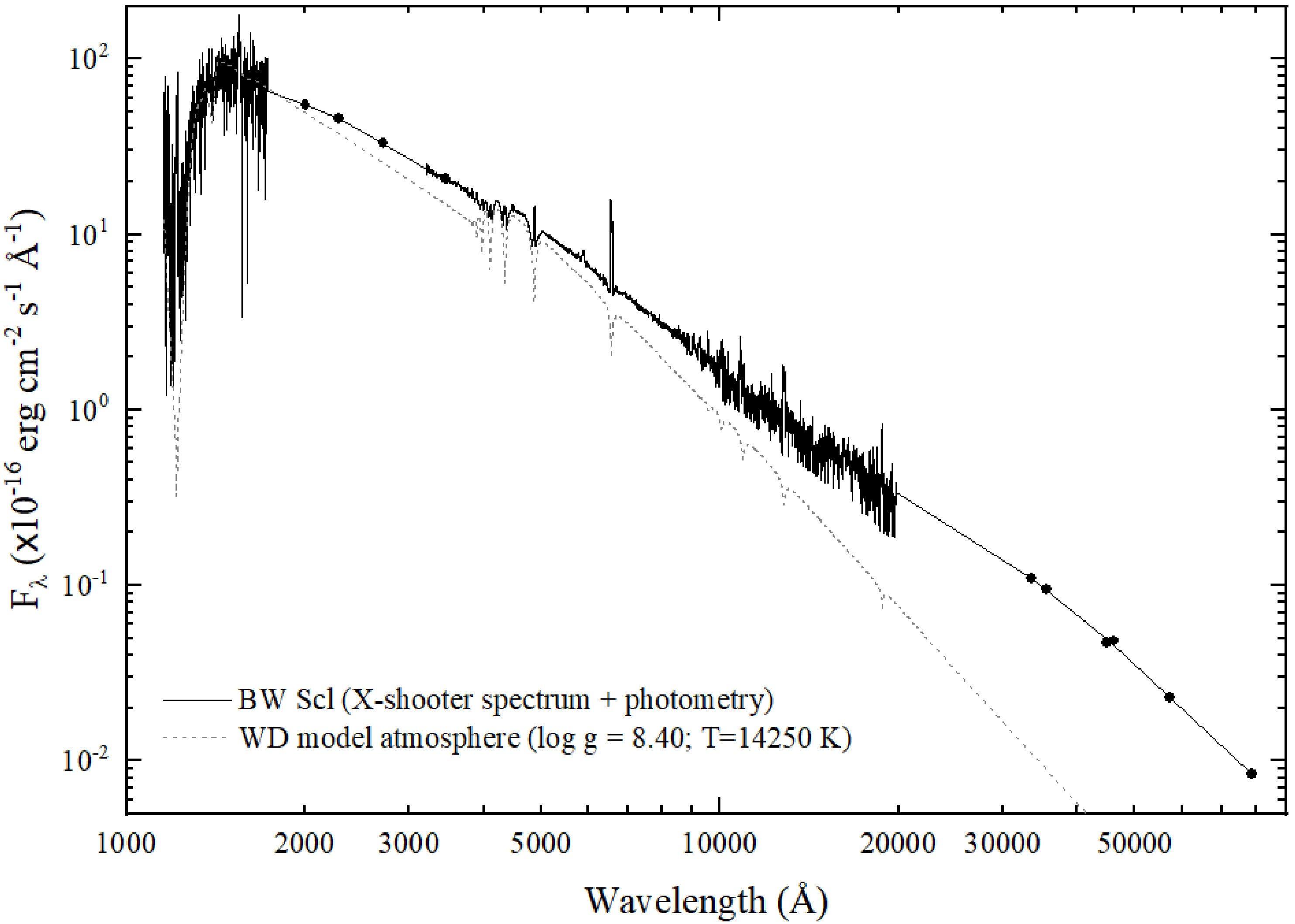
Derive the WD parameters (log g & T_{eff}) by fitting the object spectrum to a grid of synthetic spectra of DA WDs, to which the power-law or BB flux was added.



Neustroev & Siitonen, *in prep.*

BW Scl

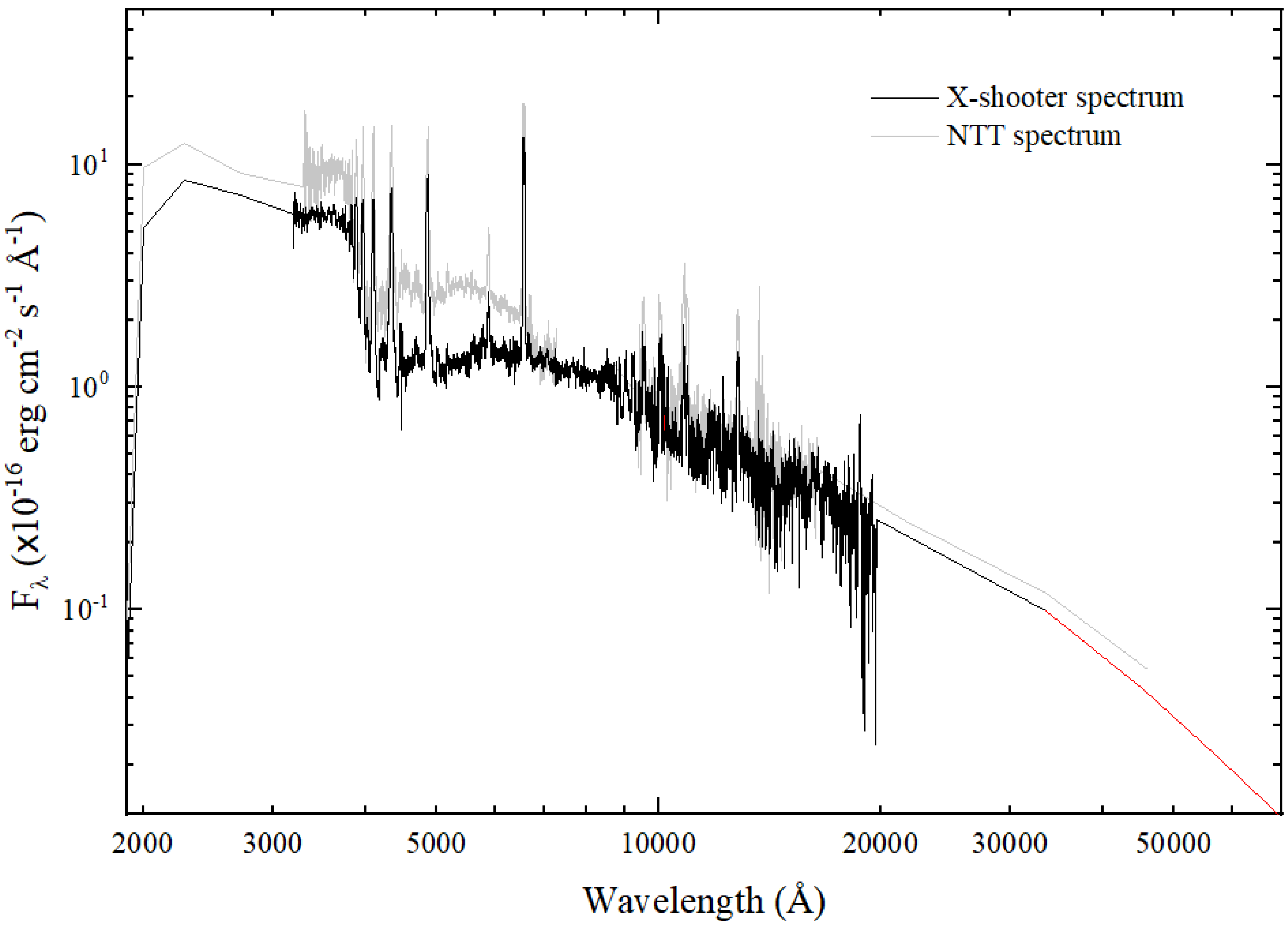
Then subtract the found underlying WD spectrum from the object's SED.



Neustroev & Mäntynen 2023

BW Scl

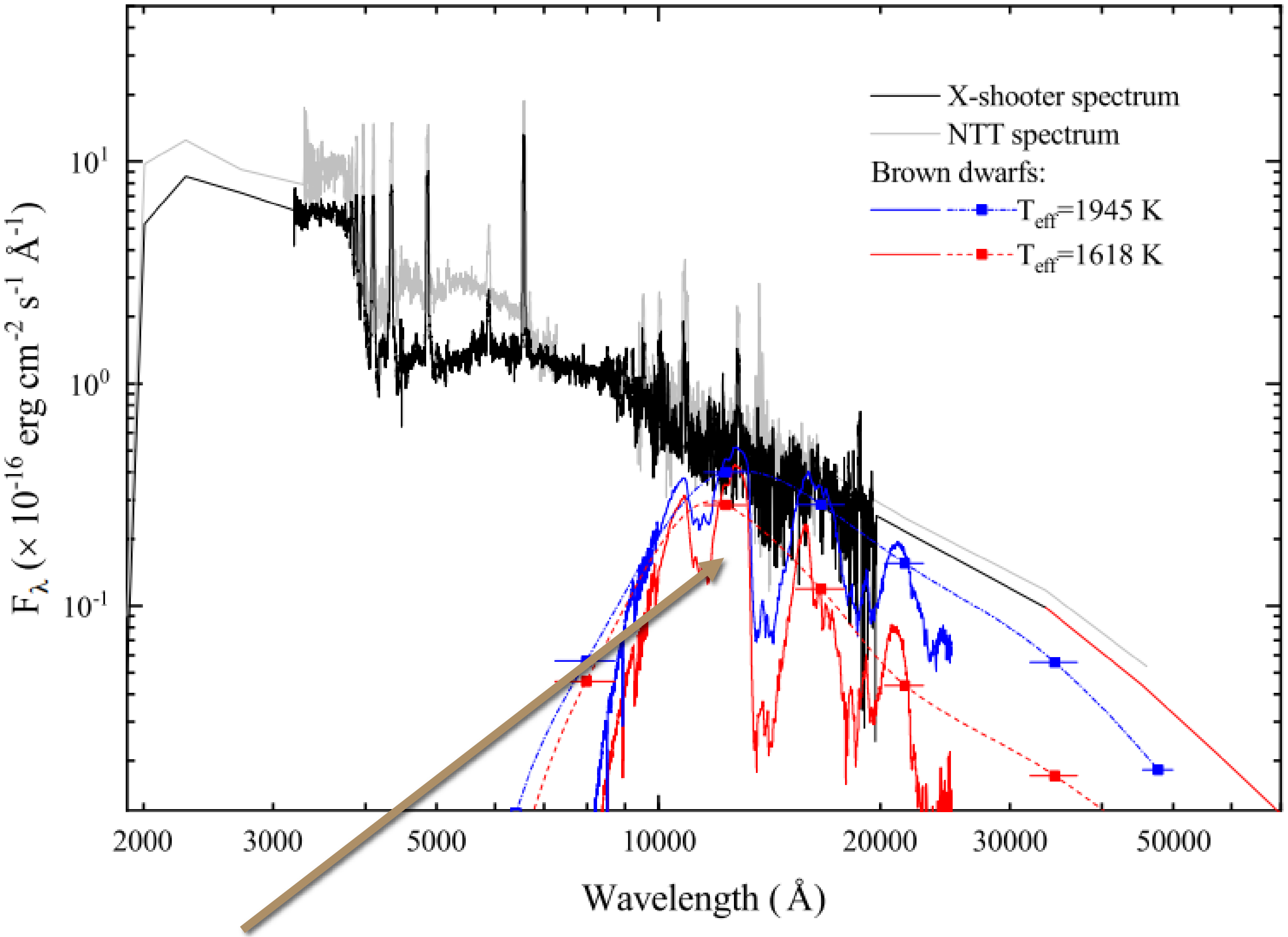
The resulting spectra can
be considered
the accretion disc spectra.



Neustroev & Mäntynen 2023

BW Scl

The resulting spectra can be considered the accretion disc spectra.



No sign of the donor! $T_{eff} < 1600$ **K**

Bolometric Luminosity and Mass-Accretion Rate

By integrating the disc SEDs over all wavelengths, we can put a conservative upper limit on the bolometric luminosity of the disc and on the mass-accretion rate:

- BW Scl (2010): $L_d \lesssim 3.2 \times 10^{30}$ erg s^{-1} $\dot{M} \lesssim 3.7 \times 10^{13}$ g s^{-1} $= 5.9 \times 10^{-13}$ M$_\odot$ yr^{-1}

  BW Scl (2017): $L_d \lesssim 4.0 \times 10^{30}$ erg s^{-1} $\dot{M} \lesssim 4.6 \times 10^{13}$ g s^{-1} $= 7.4 \times 10^{-13}$ M$_\odot$ yr^{-1}

  $L_x \approx 8.6 \times 10^{29}$ erg s^{-1}
- EG Cnc (2003): $L_d \lesssim 1.3 \times 10^{30}$ erg s^{-1} $\dot{M} \lesssim 2.0 \times 10^{13}$ g s^{-1} $= 3.2 \times 10^{-13}$ M$_\odot$ yr^{-1}

  EG Cnc (2019): $L_d \lesssim 2.2 \times 10^{30}$ erg s^{-1} $\dot{M} \lesssim 3.4 \times 10^{13}$ g s^{-1} $= 5.4 \times 10^{-13}$ M$_\odot$ yr^{-1}
- EZ Lyn: $L_d \sim 1.5 \times 10^{30}$ erg s^{-1} $\dot{M} \sim 5 \times 10^{13}$ g s^{-1} $\sim 8 \times 10^{-13}$ M$_\odot$ yr^{-1}

  $L_x \approx 1.4 \times 10^{29}$ erg s^{-1}

$$\dot{M}_{acc} = \frac{2 L_d R_{wd}}{G M_{wd}}$$

Physical properties of the accretion discs?

Theory: Accretion discs in CVs with low mass accretion rates have outer regions optically thin in continuum (Williams 1980).
At $\dot{M} \sim 5 \times 10^{13}$ g s^{-1} the entire disc becomes optically thin in continuum (Tylenda 1981).

The observed $\dot{M}$ in the studied objects are **lower** than this limit implying that most of their accretion discs, possibly **the entire discs are optically thin**.

As a simple exercise, we can estimate the mean effective (blackbody) temperature of the disc using the definition of the luminosity as the integral of the total flux over the disc surface:

$$L_{\rm d} = 2\pi r_{\rm d}^2 \sigma T_{\rm eff}^4 \rightarrow$$

~1500 – 2000 K

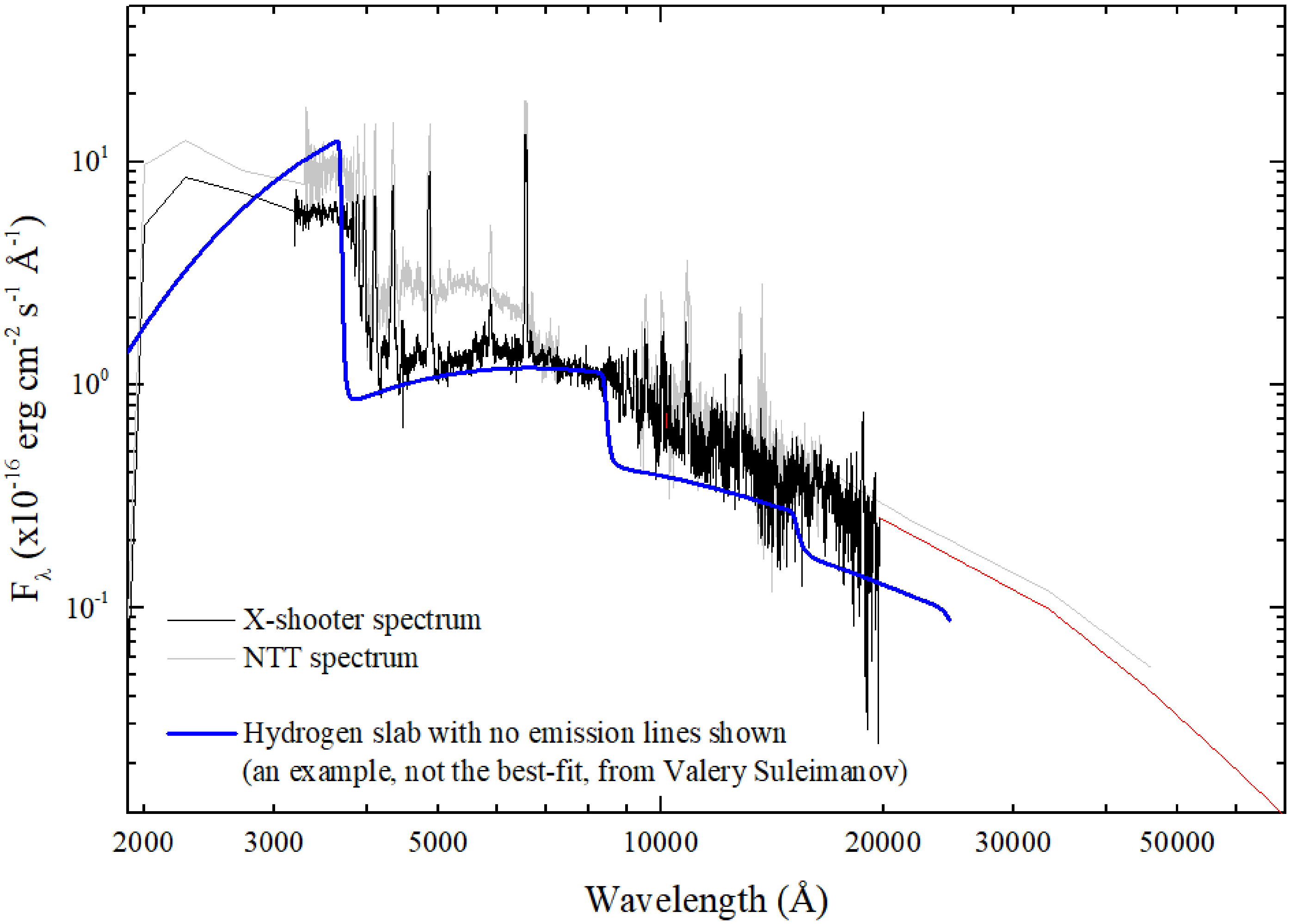
It is **unlikely** that so low $T_{\rm eff}$ represents the true, kinetic temperature of the disc material as the latter should be heated up by e.g. viscosity →

additional support for the optically thin conditions in the disc

Physical properties of the accretion discs?

Can possibly be assessed by the hydrogen-slab fitting to the disc spectrum.

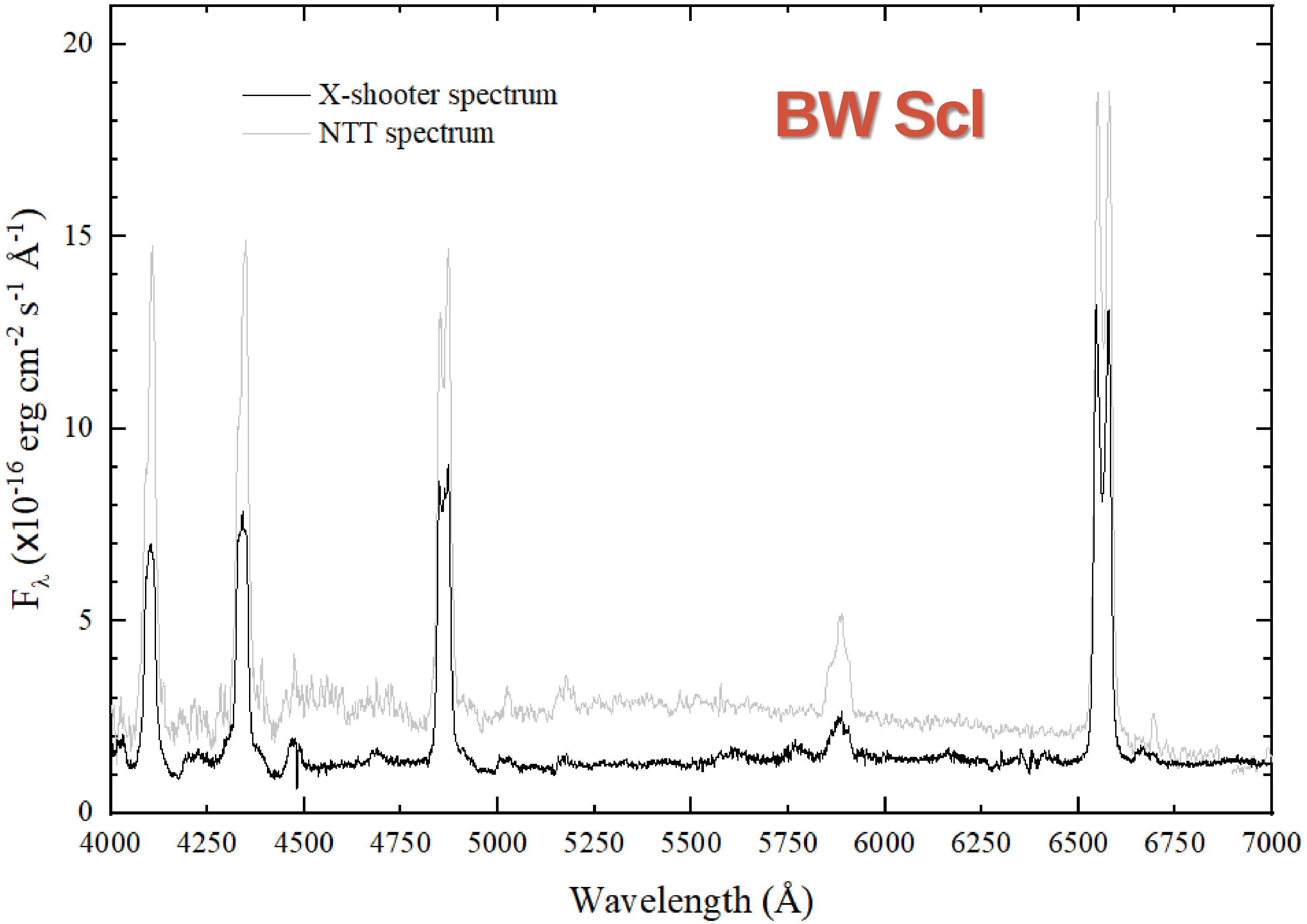
Can also be evaluated from emission lines.



The above fitting procedure allows recovering not only a non-WD continuum but also higher-order Balmer emission lines which were sitting inside the WD absorption troughs.

Hmm, the Balmer decrement is pretty flat…

BW Scl:	1.71 : 1.00 : 0.86 : 0.71
	1.60 : 1.00 : 0.89 : 0.82
EG Cnc:	2.40 : 1.00 : 0.65 : 0.56
EZ Lyn:	1.61 : 1.00 : 0.76 : 0.59

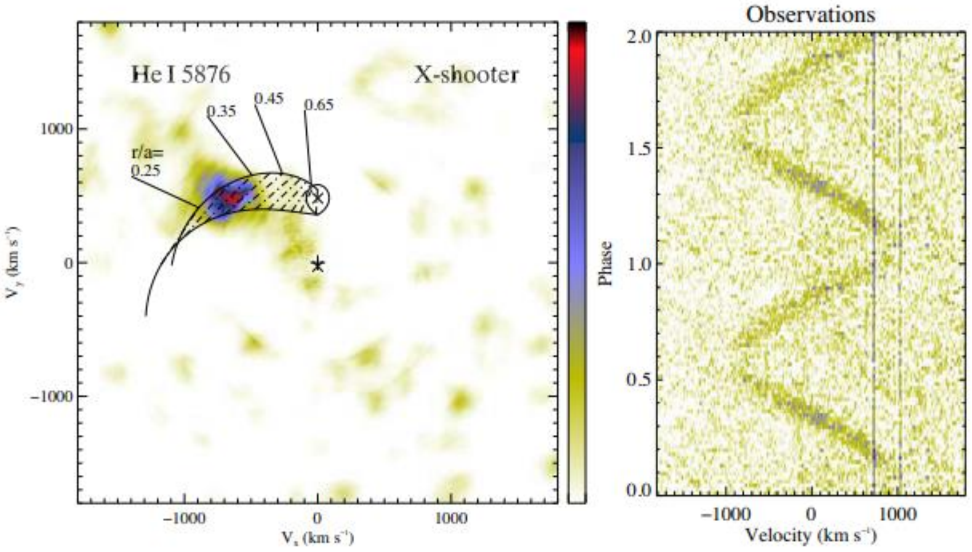


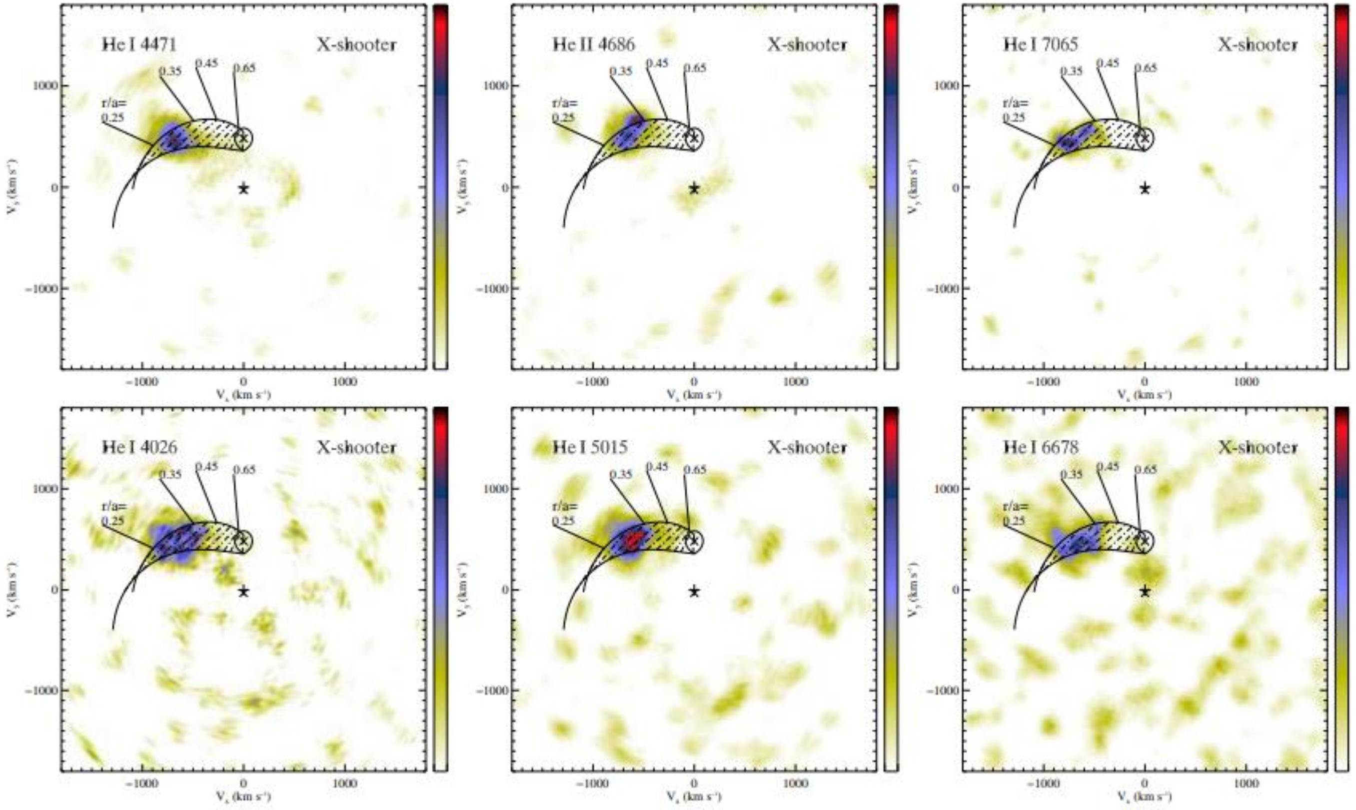
but roughly consistent with the disc temperature of 10000–15000 K and the hydrogen density at the midplane of log N_0≈12 (Williams 1991). However, Williams' radiative transfer models predict much lower EWs than we observe (Hα in BW Scl and EG Cnc ~340 Å), pointing to an even **lower** density.

More detail are revealed from time-resolved spectra:

From the trailed spectra & Doppler maps:

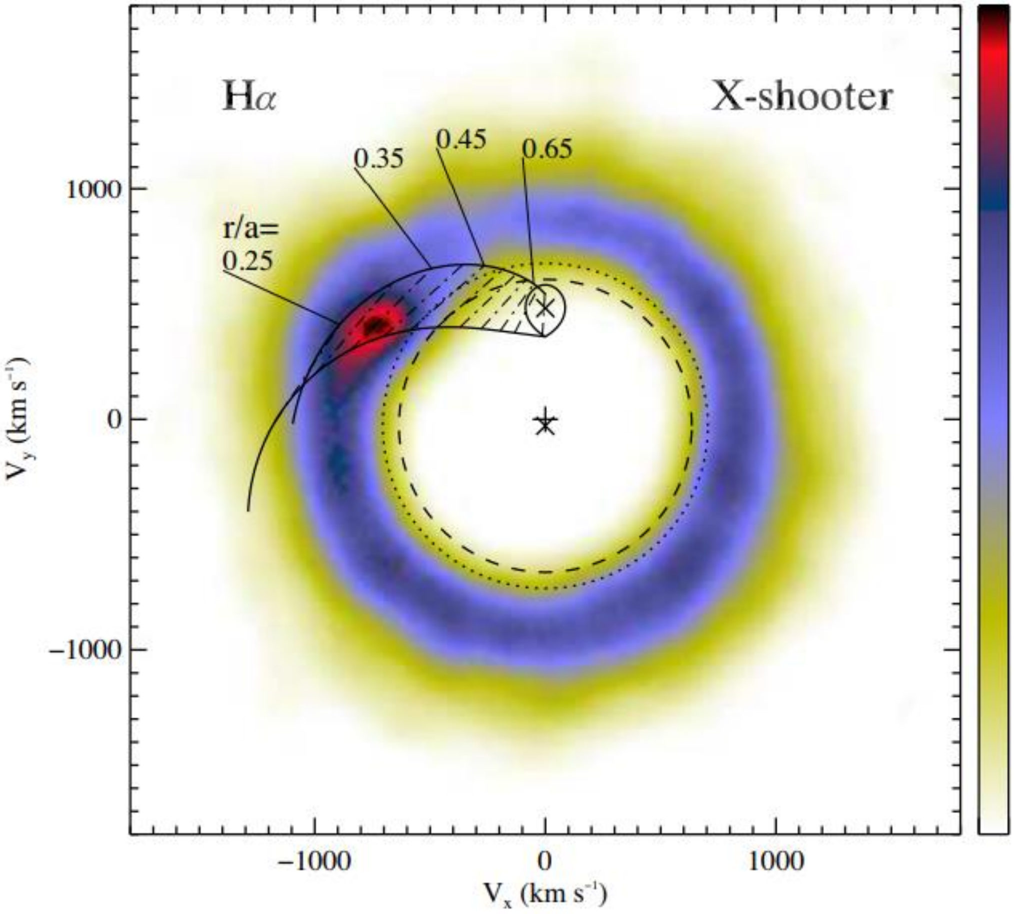
No He lines are seen from the accretion disc!

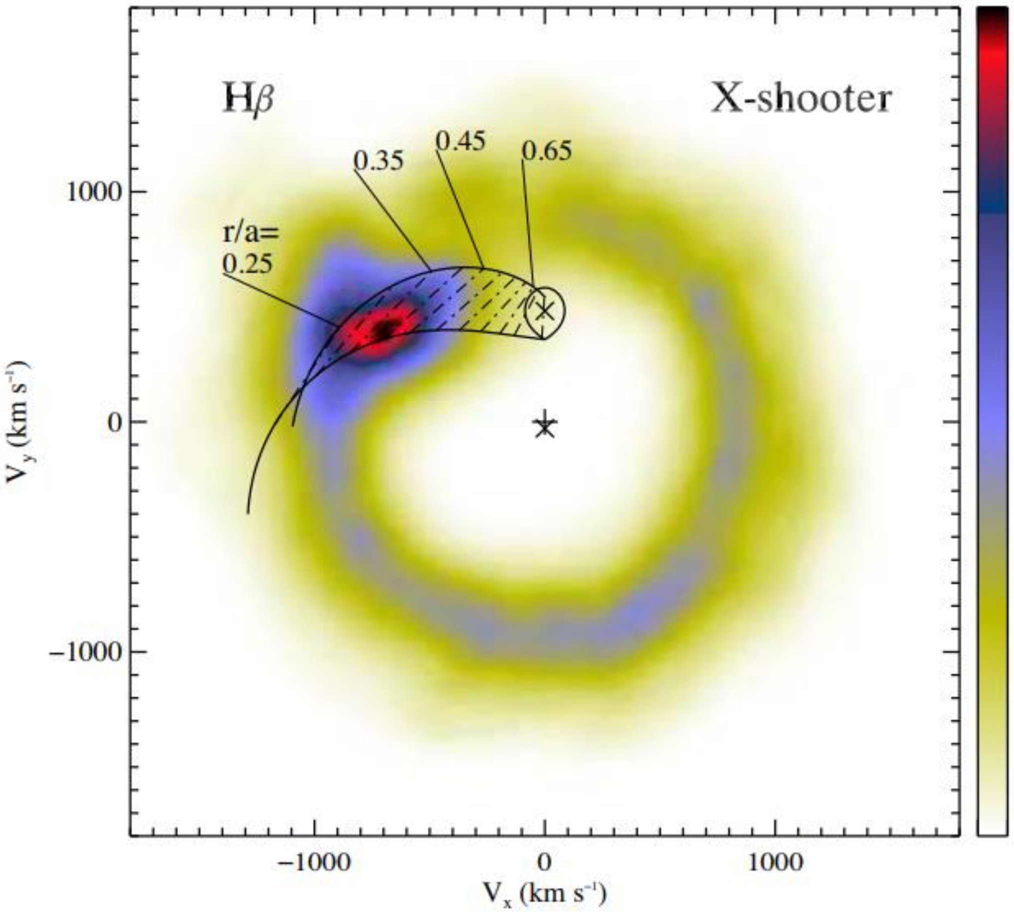




Thus, the disc is NOT hot enough to excite the <u>Helium</u> (and higher-order <u>Balmer</u>) lines.

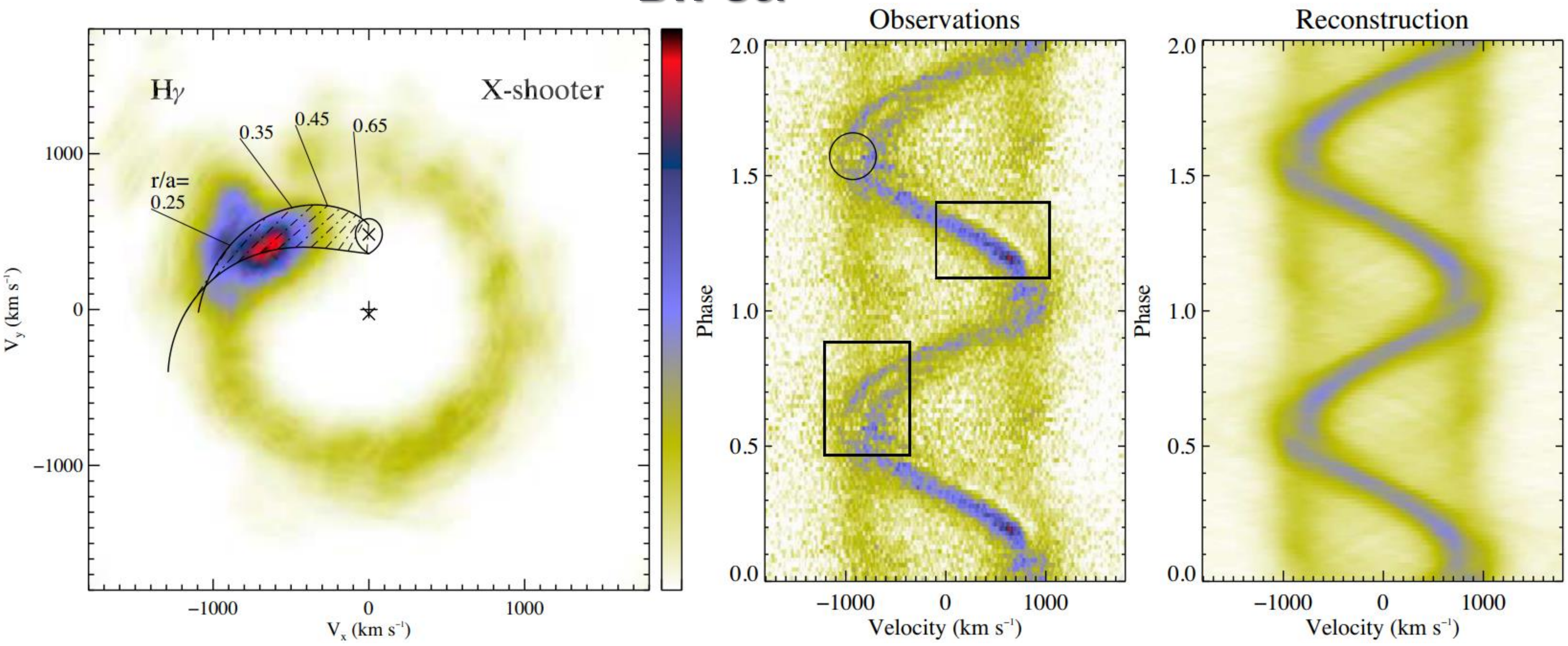
Doppler maps of BW Scl



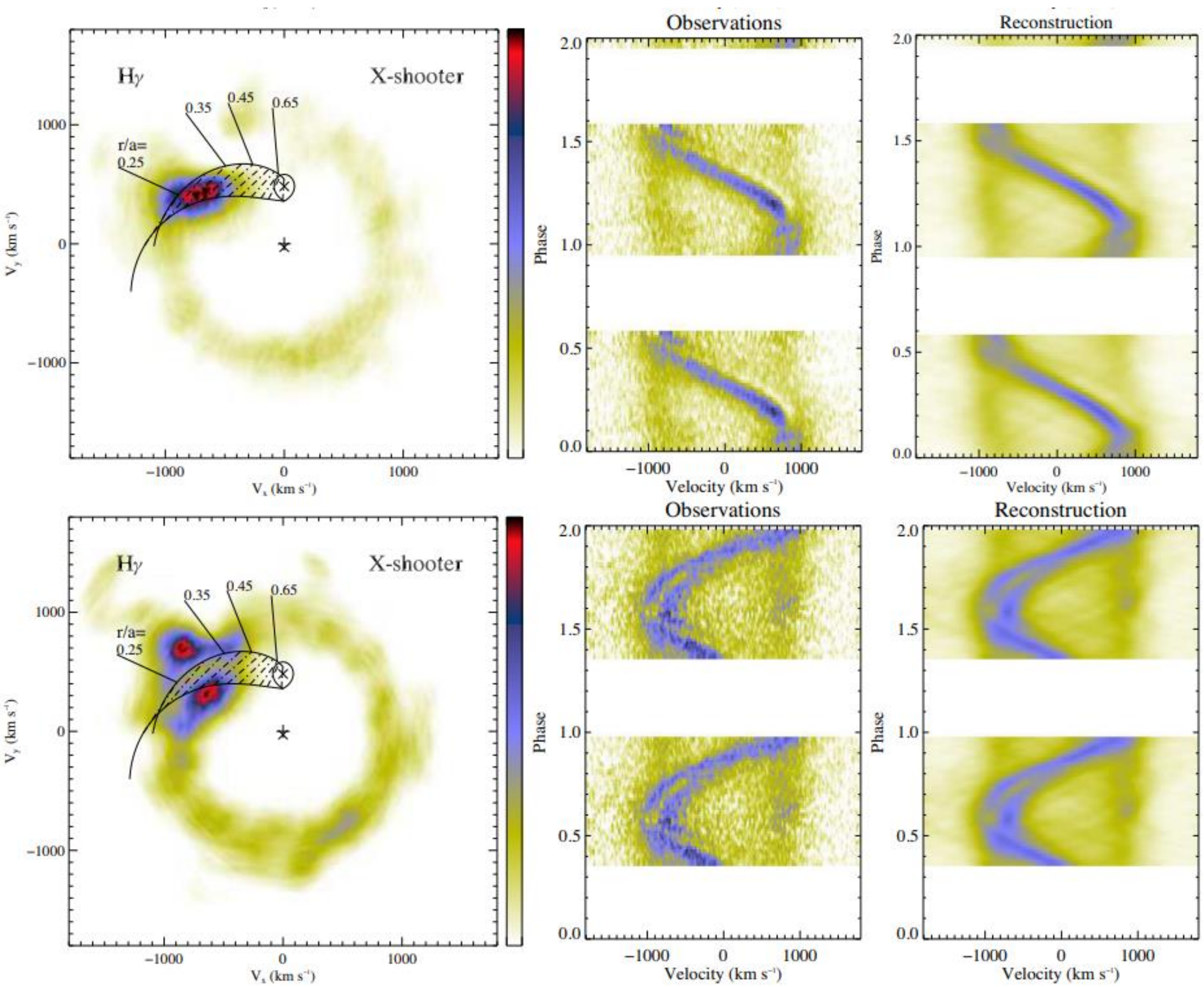


Hotspot is very bright and complex

BW Scl

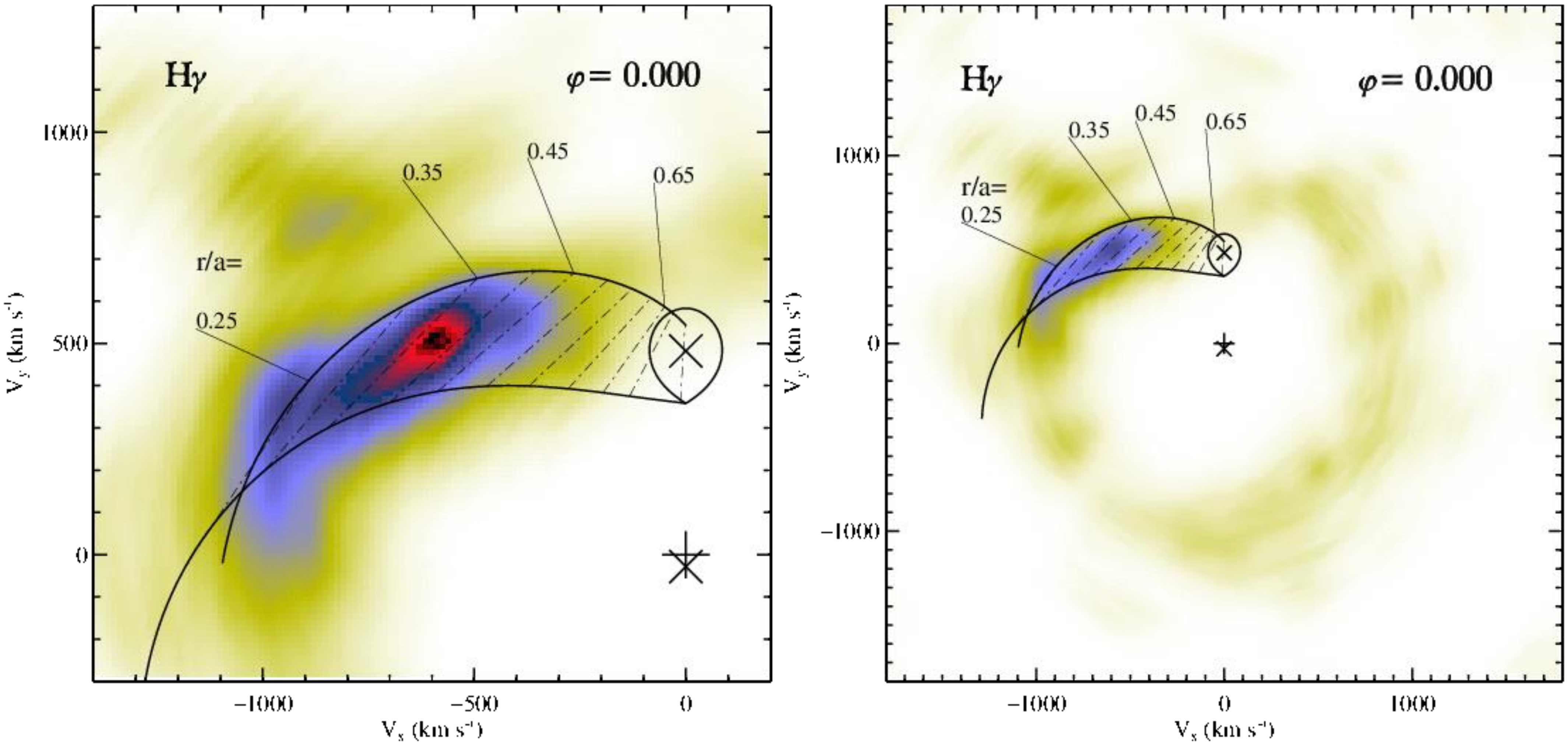


Hotspot is very bright, has a complex structure, and is anisotropic.



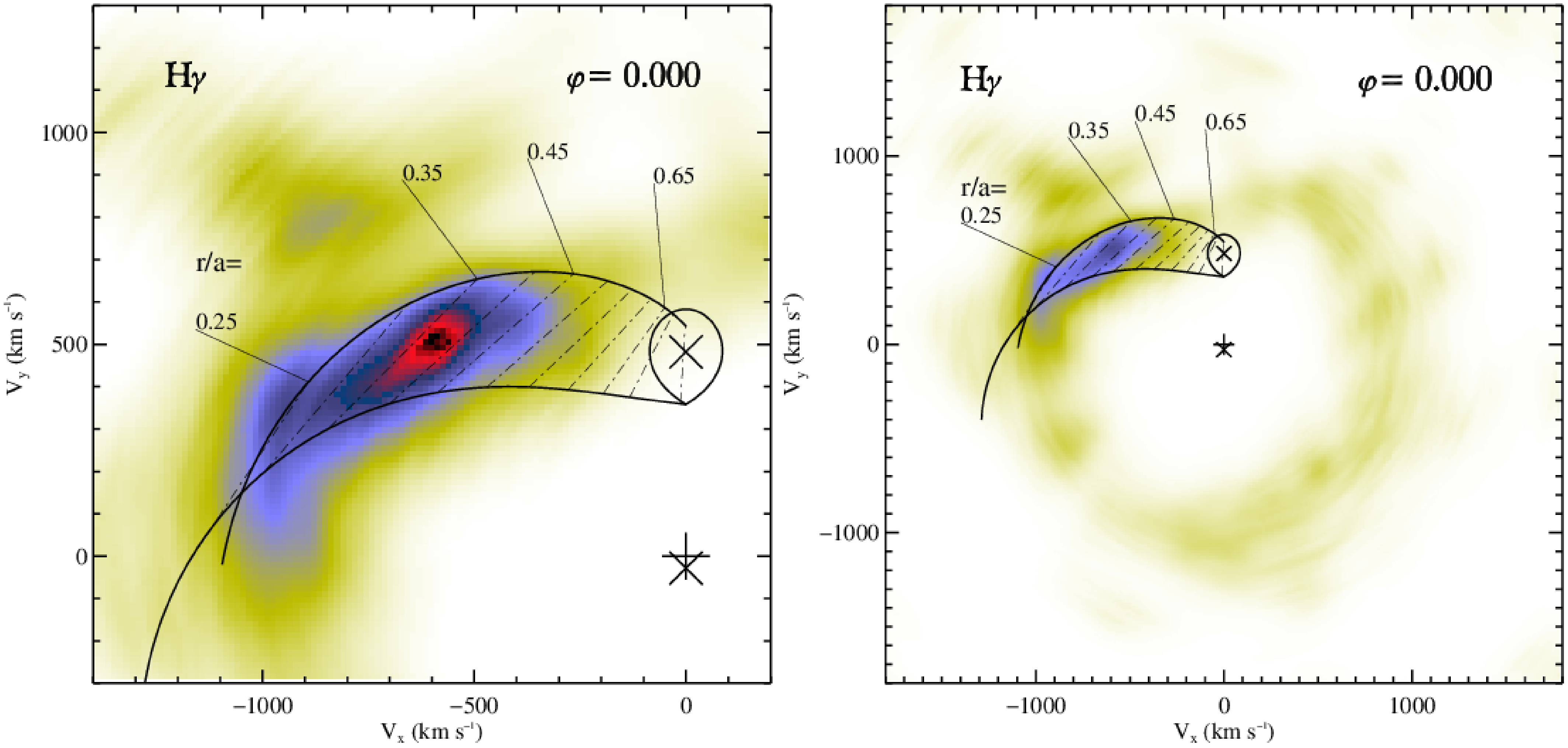
BW Scl

These dynamical Doppler maps are available at https://vitaly.neustroev.net/researchfiles/bwscl/



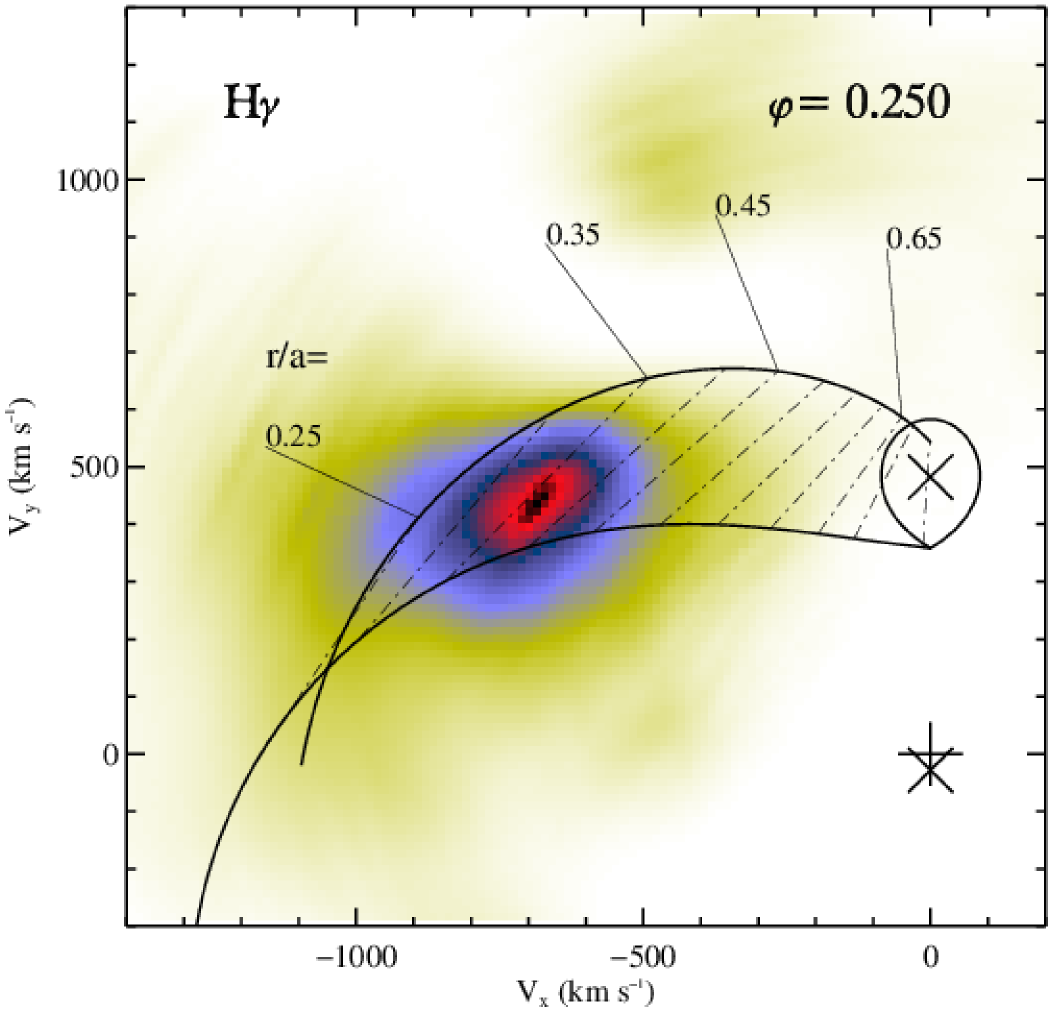
BW Scl

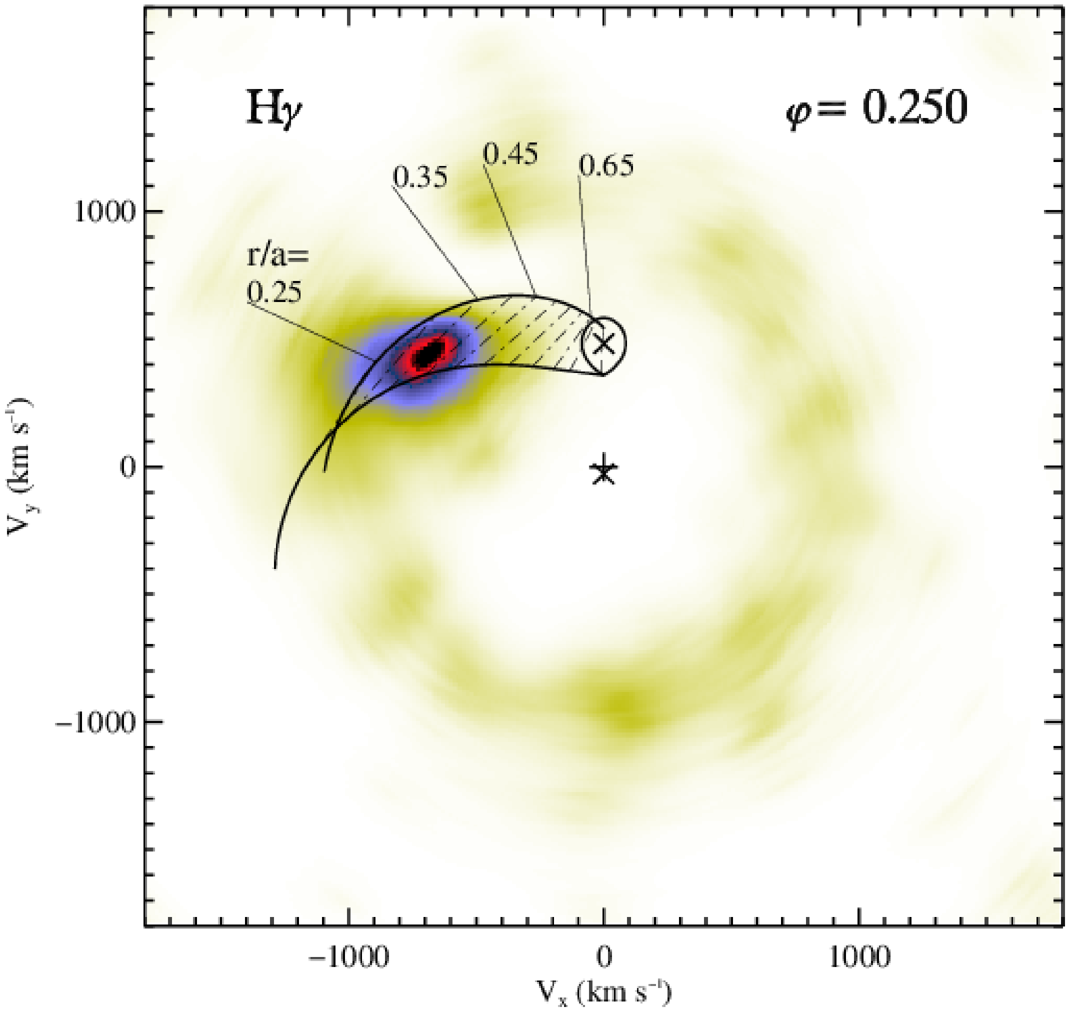
The outer parts of the disc have a low density allowing the stream to **flow down to the inner disc regions**.



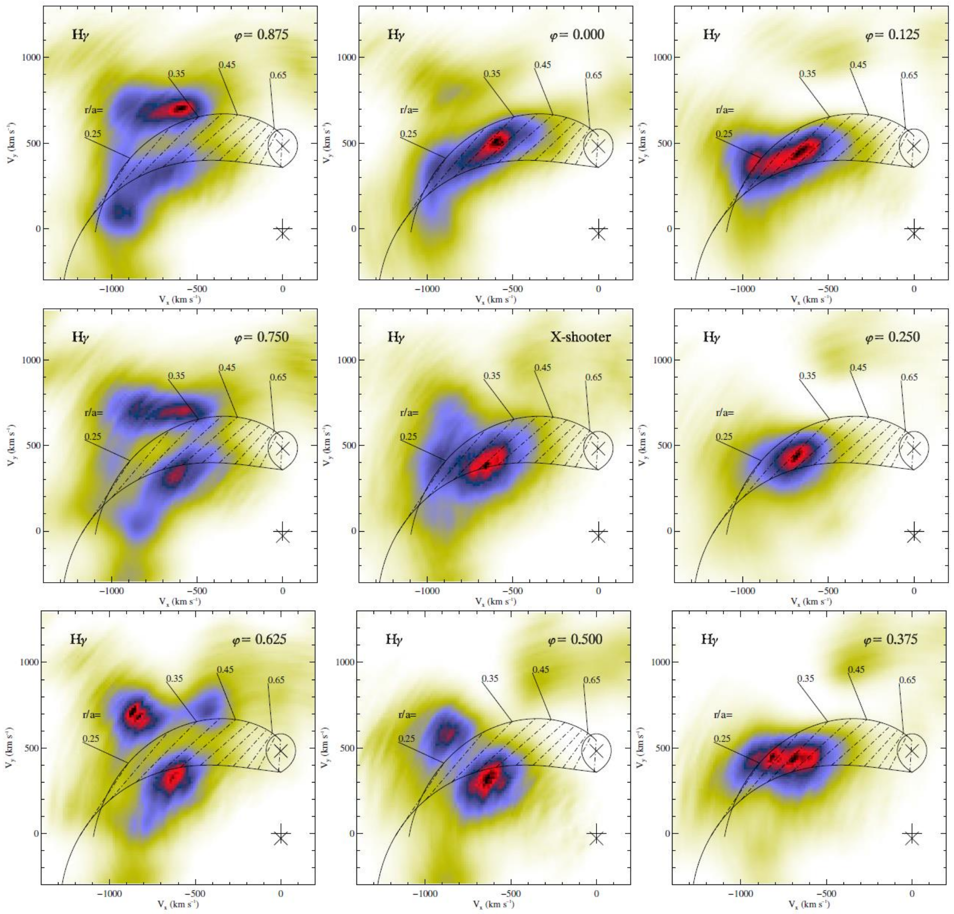
BW Scl

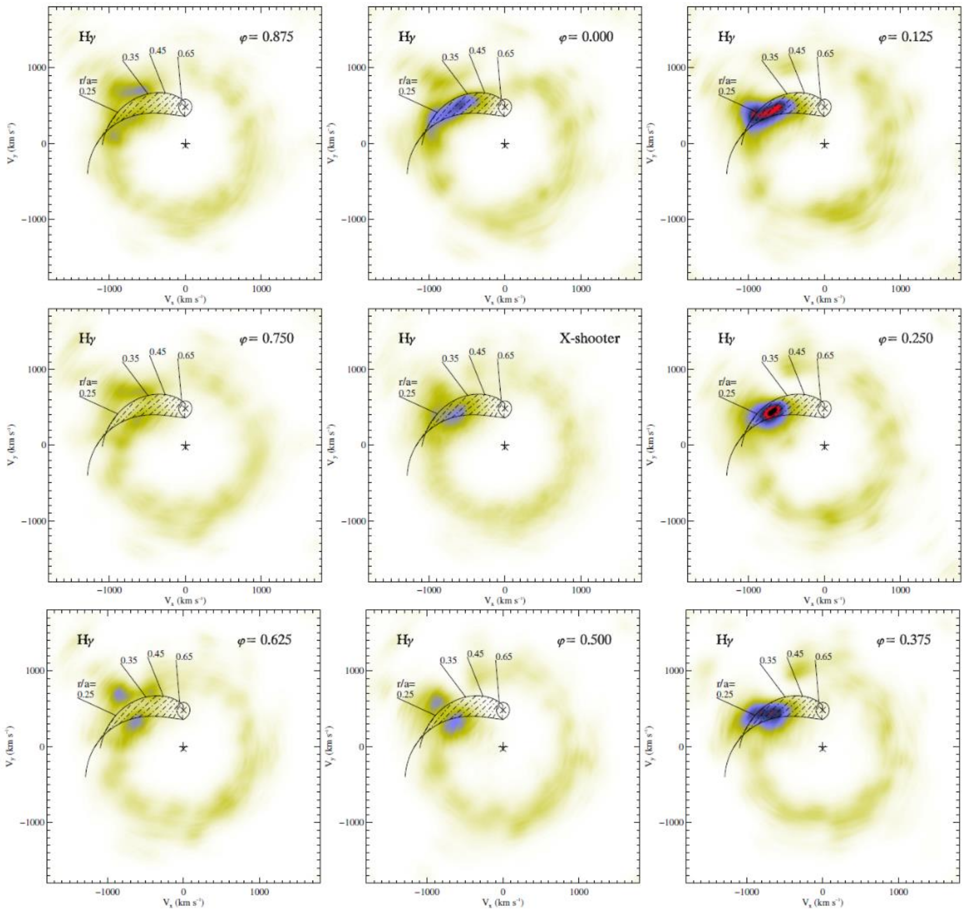
The brightest part of the hotspot is located close to **the circularization radius of the disc.**



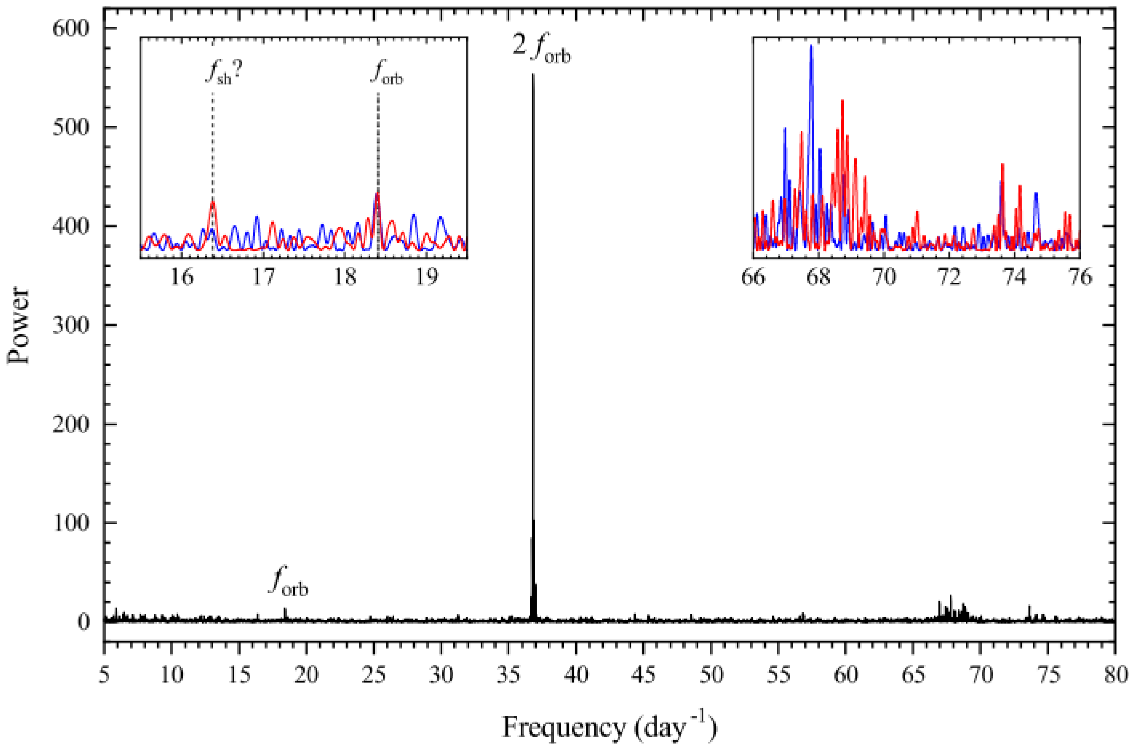


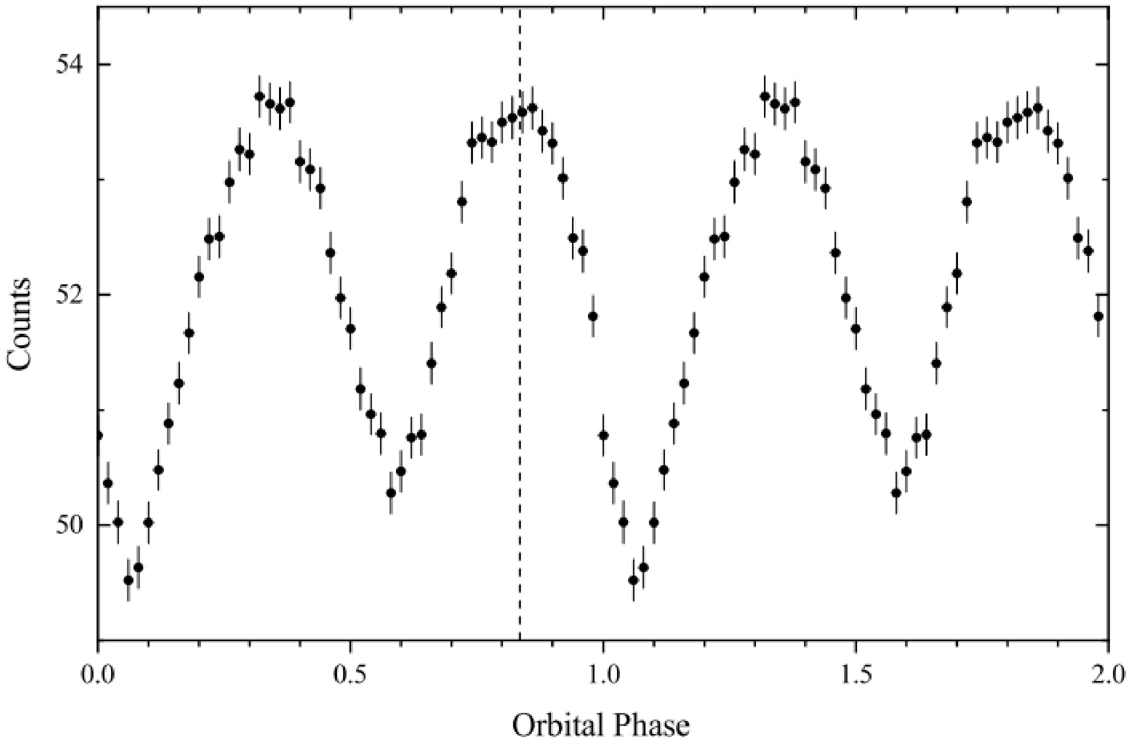
Optically thick hot spot



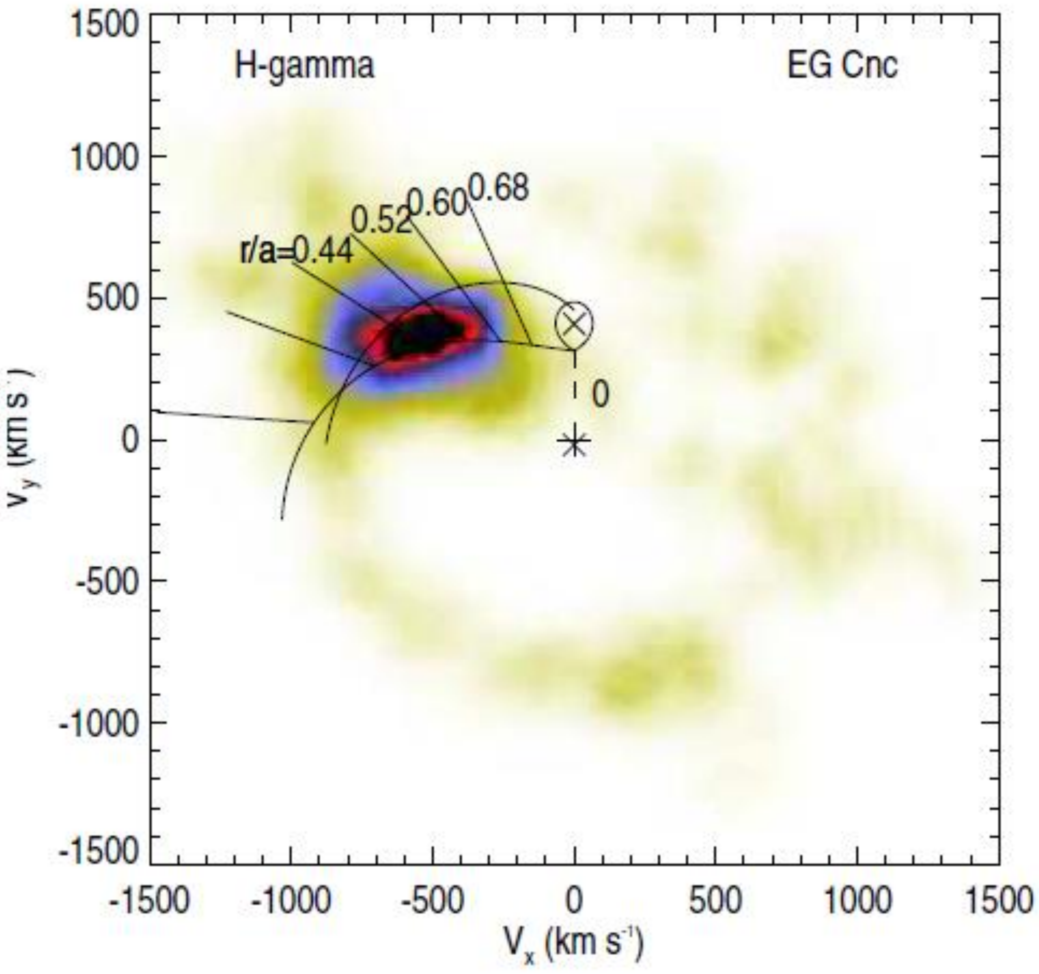


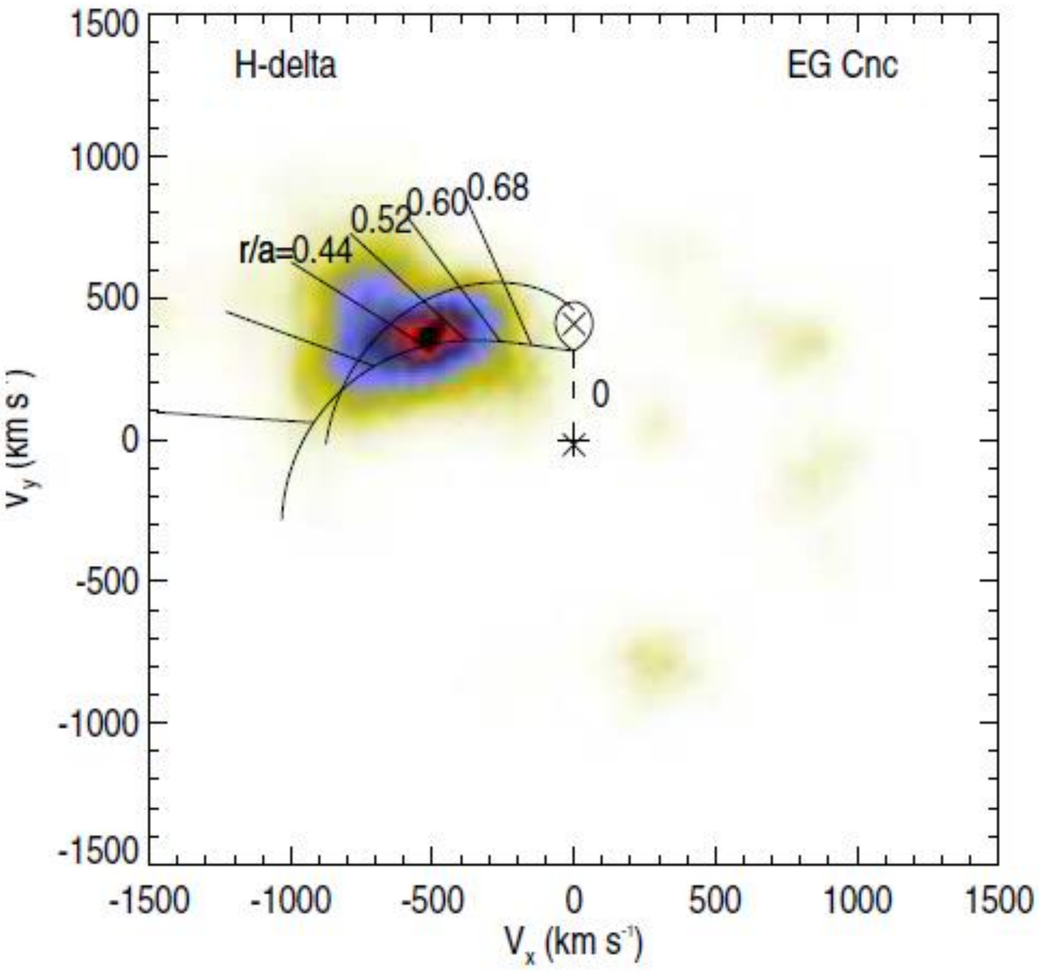
TESS photometry of BW Scl





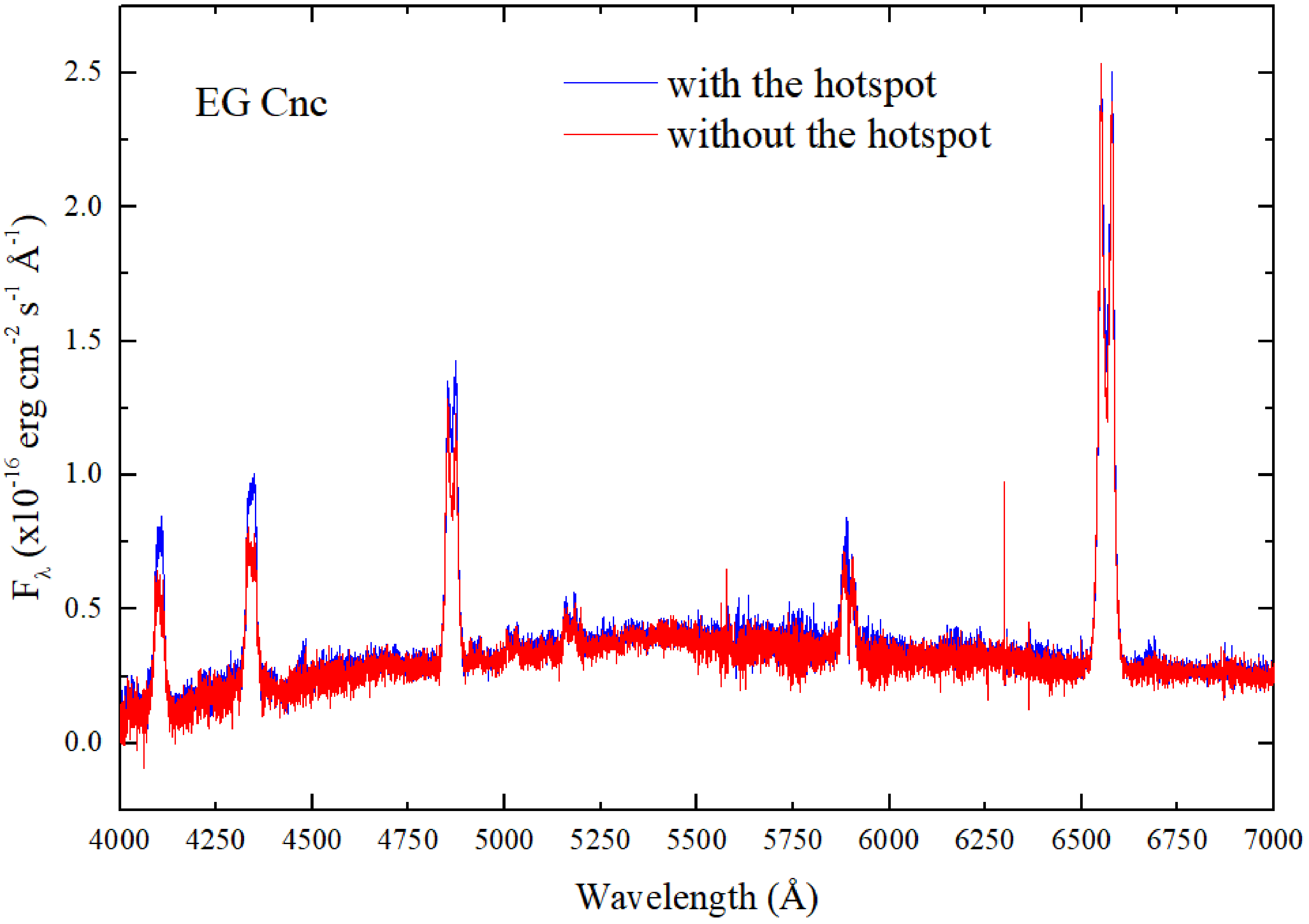
Similar hotspot pattern is seen in other AWDs (e.g. EG Cnc, WZ Sge, …)





Removing the hotspot contribution to the emission lines (you can ask me later how we did it), the Balmer decrement in the resultant disc spectrum appears now **much steeper**:

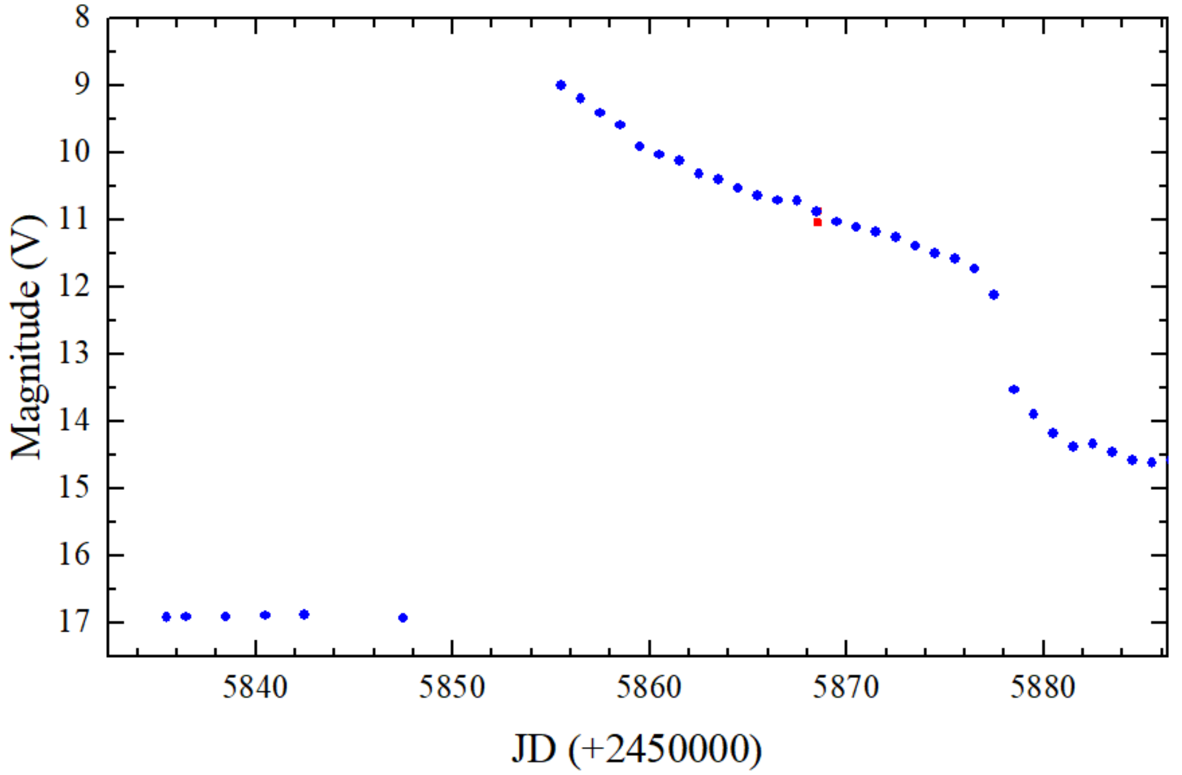
EG Cnc:
With the HS: 2.40 : 1.00 : 0.65 : 0.56
W/o the HS: 2.90 : 1.00 : 0.59 : 0.52



Very low hydrogen density.

Conclusion and open questions

- The entire accretion discs in short-period CVs are optically thin.
- They have a very low bolometric luminosity (a few) × 10^{30} erg s^{-1} which corresponds to a very low-mass accretion rate of (a few) × 10^{-13} $M_{\odot}$ yr^{-1}.
- Observationally, such discs do not change until an outburst.

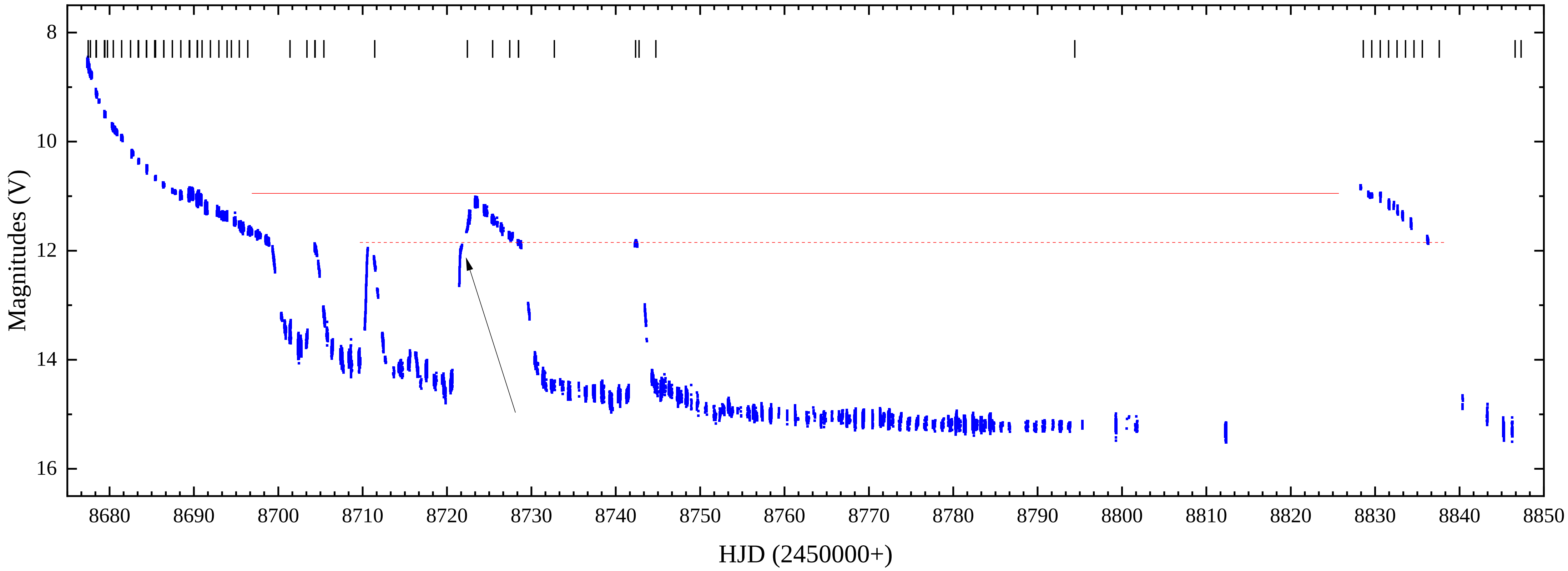


Then, how do they outburst?

The quiescent disc just before the outburst must be filled up to the critical surface density (Lasota 2001).

The latter discs are optically thick in continuum (see normal dwarf novae).

V3101 Cyg


Magnitudes (V)
HJD (2450000+)
8
10
12
14
16
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8690
8700
8710
8720
8730
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8750
8760
8770
8780
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8800
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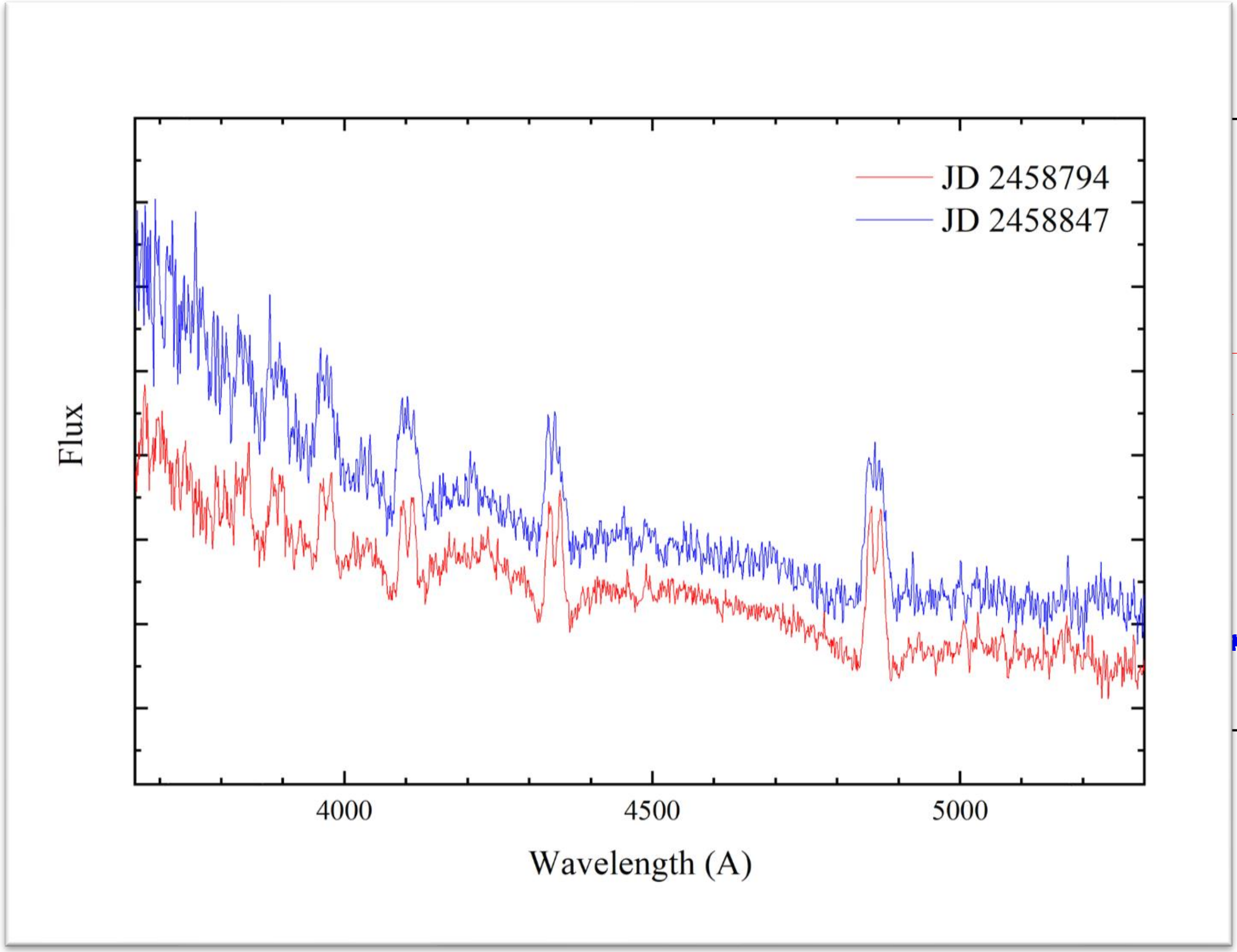
V3101 Cyg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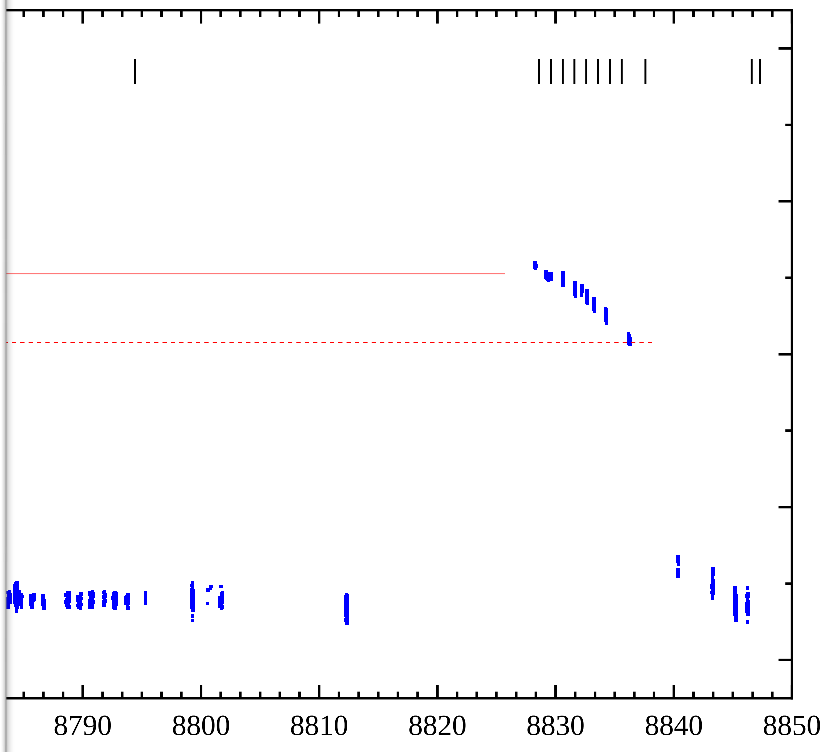
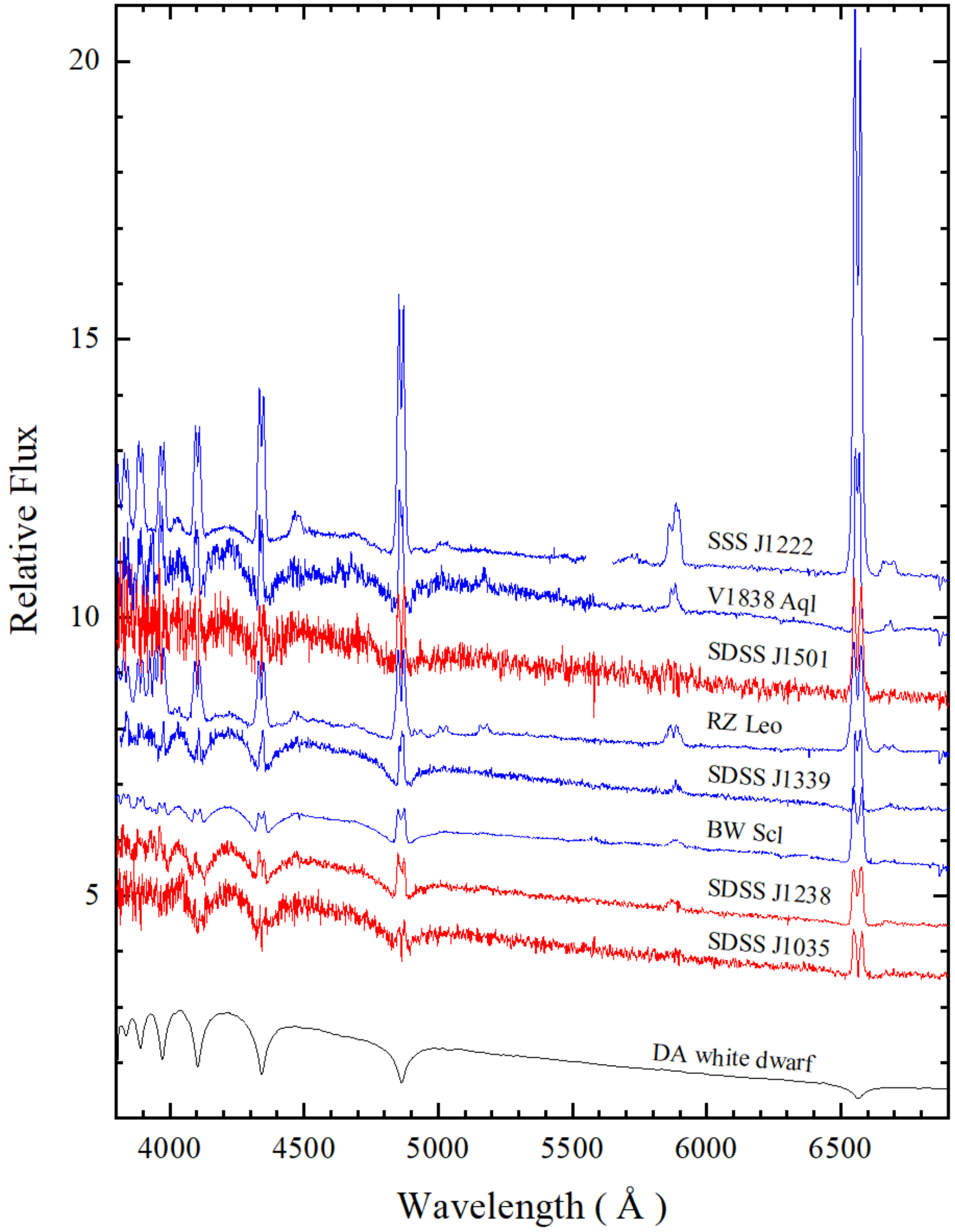
JD 2458847
Flux
4000
4500
5000
Wavelength (A)


8790
8800
8810
8820
8830
8840
8850

Open questions

Some objects show extremely strong emission lines (EW>1000Å) in observed spectra.

- How are they excited?
  The WD is not hot enough for it.



Thanks for listening!