MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E INOVAÇÕES
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

Degeneracy of the white-dwarf mass estimation in magnetic cataclysmic variables

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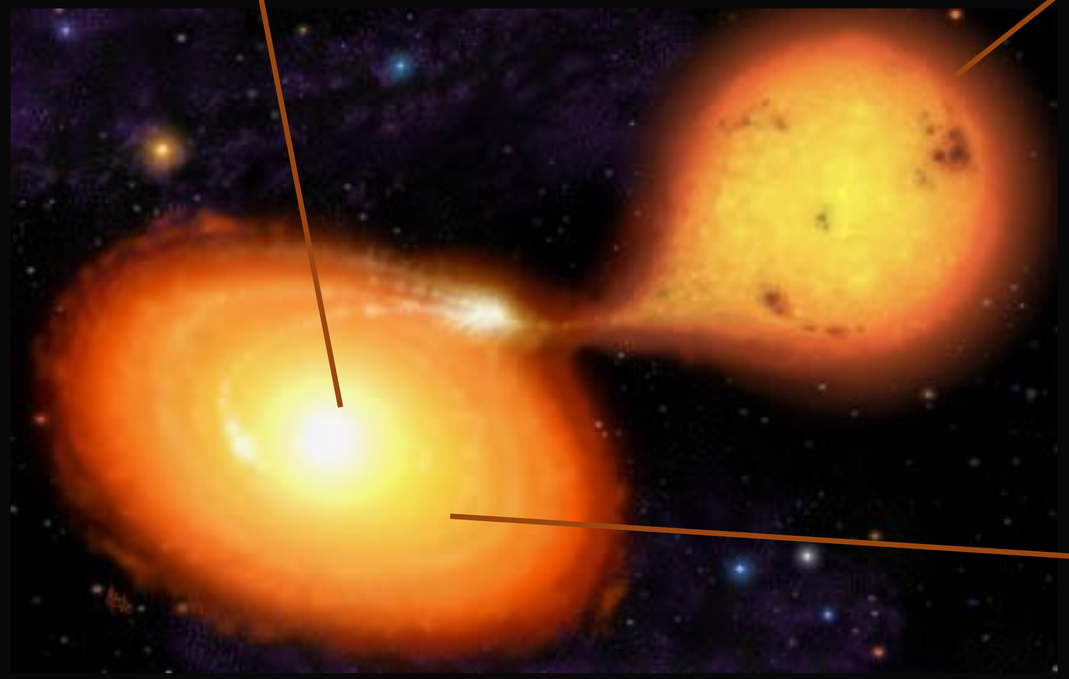
CATACLYSMIC VARIABLES

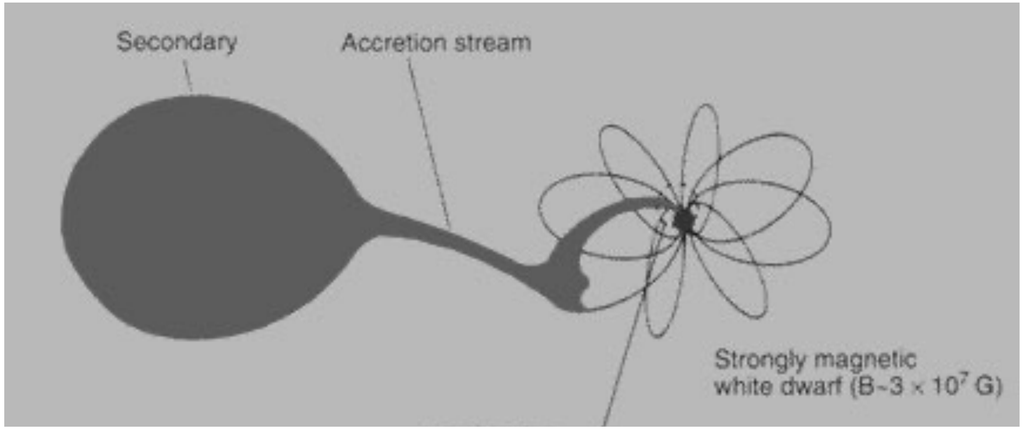
White dwarf (WD)

main sequence or
slightly evolved
low mass star



Mass transfer
to the WD

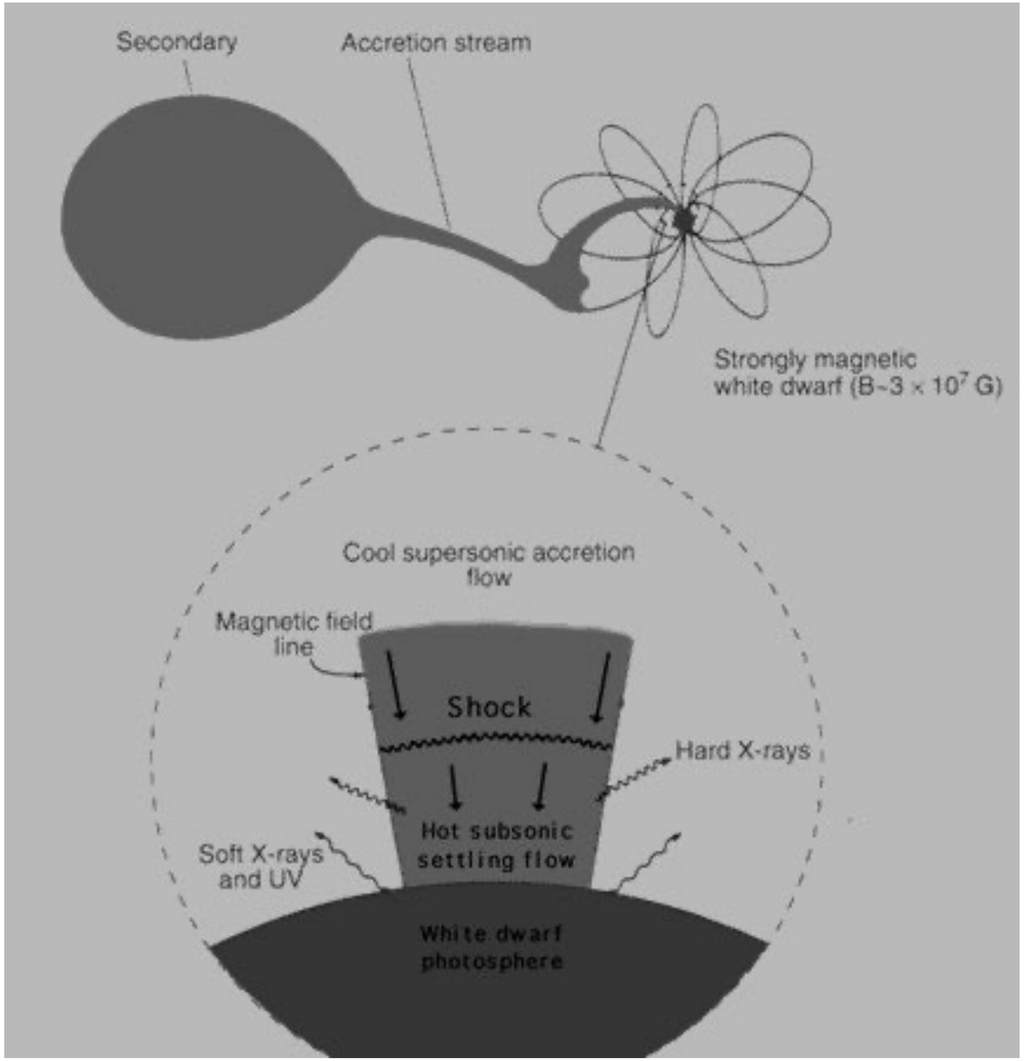
MAGNETIC CATACLYSMIC VARIABLES (MCVS)



- In <u>magnetic</u> cataclysmic variables
  - ❖ the white-dwarf magnetic field plays a role in defining the accretion geometry
  - ❖ the mass flow reaches the white dwarf through a magnetic column

https://heasarc.gsfc.nasa.gov/docs/objects/cvs/cvstext.html

MAGNETIC CATACLYSMIC VARIABLES (MCVS)



https://heasarc.gsfc.nasa.gov/docs/objects/cvs/cvstext.html

- In magnetic cataclysmic variables
  - the white-dwarf magnetic field plays a role in defining the accretion geometry
  - the mass flow reaches the white dwarf through a magnetic column
- post-shock region
  - a density enhancement in the magnetic column near the white-dwarf surface due to a shock
  - Main emission source in X-rays

OBTAINING THE WD MASS IN MCVS

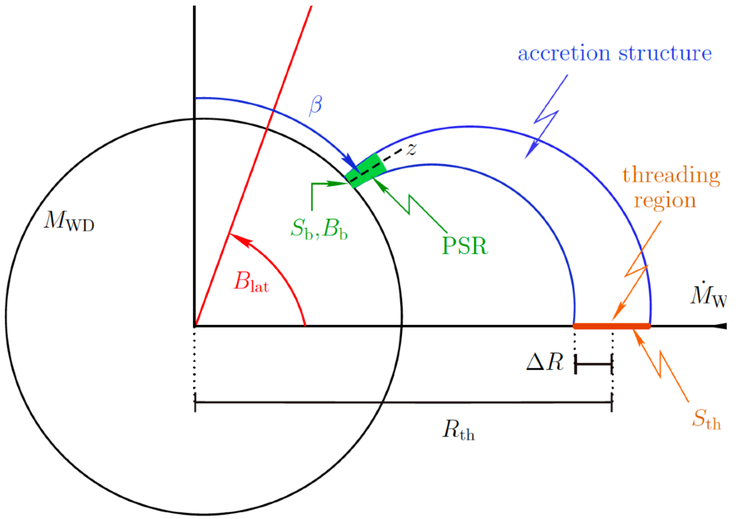
- In a seminal work, Aizu (1973) showed that the gravitational energy of the mass flow is transformed in thermal energy in the post-shock region.

$$GM/R \sim kT$$

- Therefore, the post-shock region temperature depends basically on the WD mass.

$$T_b = (3/8)\,(GMm_H\mu/kR)\,,$$

- As the main emission process in X-rays is bremsstrahlung and it depends mainly on the temperature, the bremsstrahlung temperature is a proxy of the WD mass

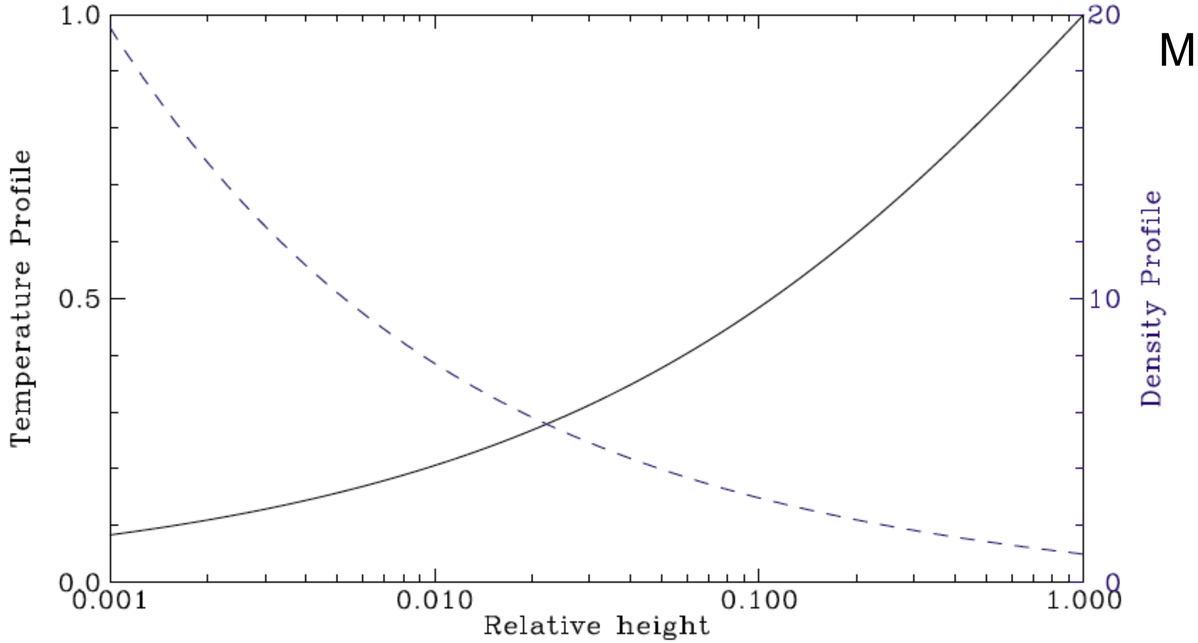


Belloni, CVR+ 2021

The X-ray spectrum can be used to estimate the WD mass in MCVs (e.g. Suleimanov+2019)

REFINING THE PROBLEM

- Temperature and density are not homogeneous in the post-shock region
  - ❖ the observed X-ray spectrum should reflect these profiles



Mukai 2017

Figure 2. Relative temperature (solid black, left axis) and density (dashed blue, right axis) of the post-shock region, in an Aizu-type accretion column, normalized to the respective values at the shock.

Cyclops

Cyclotron Emission of Polars

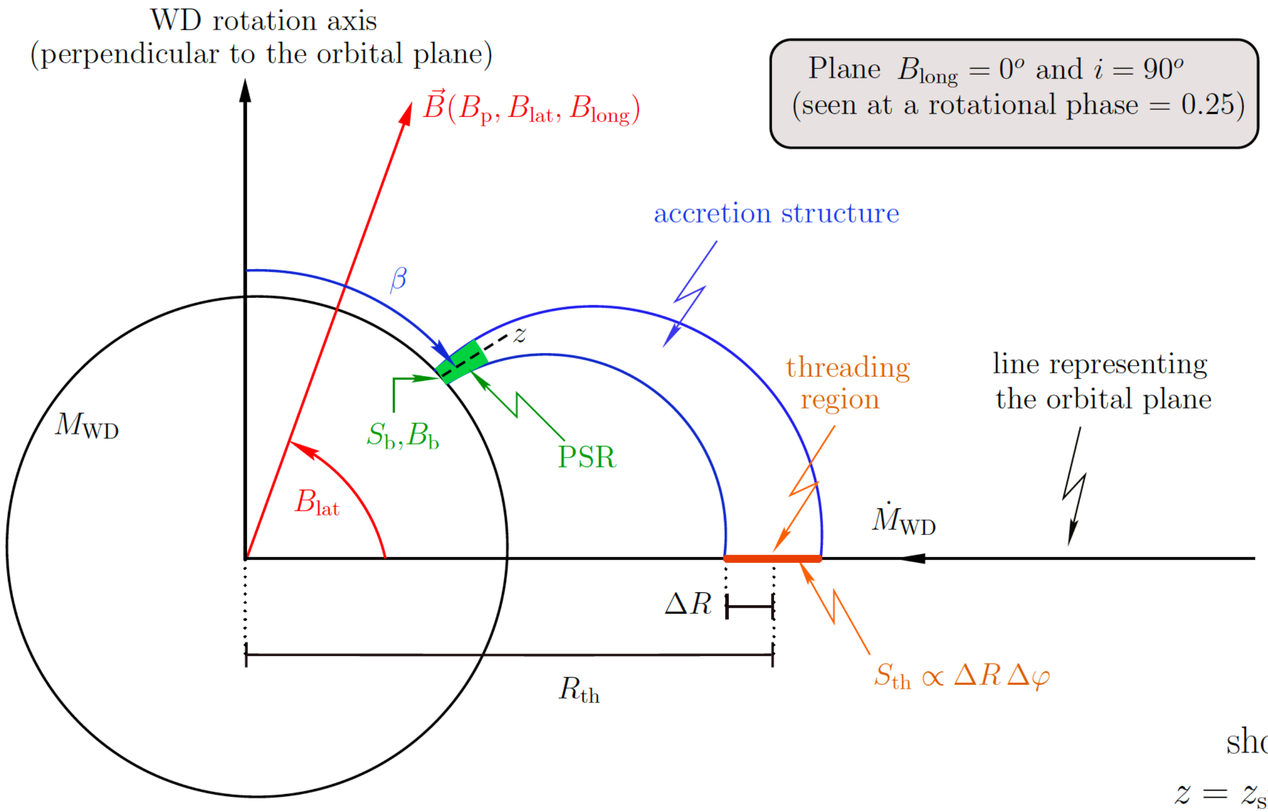
A code to model optical and X-ray emission of polars

- Post-shock region modelling
  - ❖ radiative transfer
    - ✦ 3D region
    - ✦ Emission
      - ‣ cyclotron (optical emission)
      - ‣ bremsstrahlung (X-rays)
    - ✦ Photo-absorption
      - ‣ Internal and interstellar
  - ❖ density and temperatures profiles
    - ✦ based on proper solution of the hydrodynamical equations

Costa & CVR 2009
Silva, CVR + 2013
Belloni, CVR+2021

POST-SHOCK STRUCTURE PROBLEM

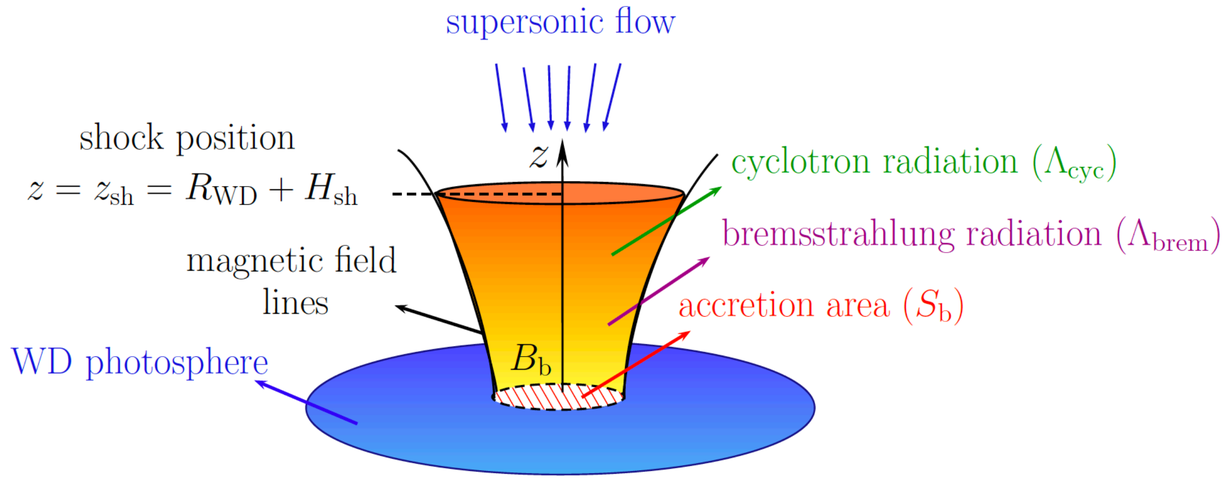
Belloni, CVR+ 2021



$$\frac{\mathrm{d}}{\mathrm{d}z}\left(S\rho v\right) = 0,$$

$$\frac{\mathrm{d}}{\mathrm{d}z}\left(\rho v^2 + P\right) + \frac{\rho v^2}{S}\frac{\mathrm{d}S}{\mathrm{d}z} + \rho\, g_{\rm WD} = 0,$$

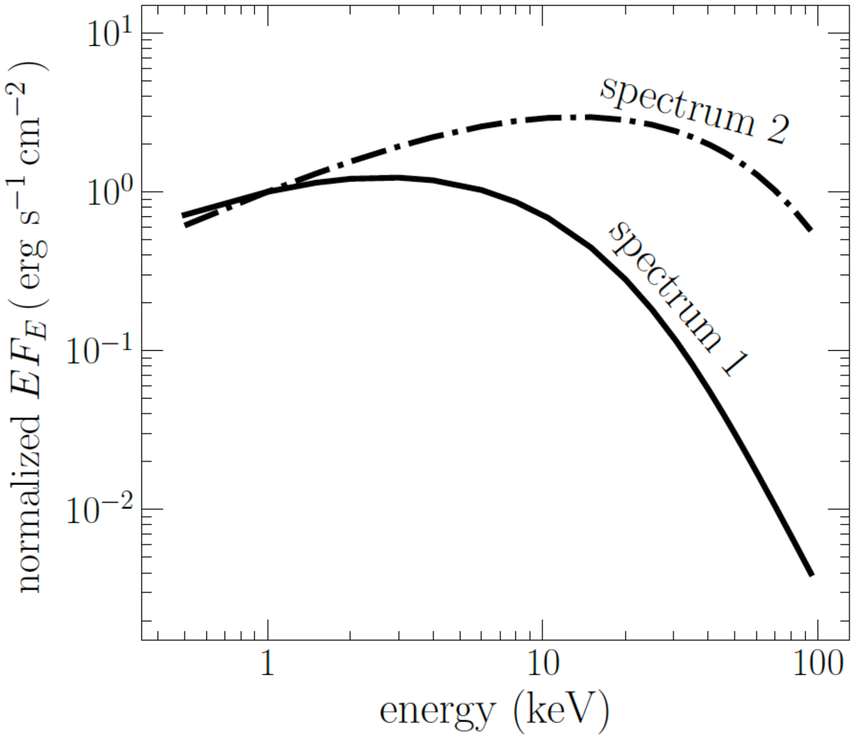
$$v\frac{\mathrm{d}P}{\mathrm{d}z} + \gamma P\frac{\mathrm{d}v}{\mathrm{d}z} + (\gamma - 1)\left(\Lambda - \frac{\rho v^3}{2S}\frac{\mathrm{d}S}{\mathrm{d}z}\right) = 0,$$



X-ray spectrum degeneracy

X-RAY SPECTRUM DEGENERACY

Belloni, CVR+ 2021



Model	$M_{\rm WD}$ ($M_\odot$)	$B_{\rm p}$ (MG)	$\dot{M}_{\rm WD}$ ($10^{-10}\,M_\odot\,{\rm yr}^{-1}$)	$S_{\rm b}$ ($10^{16}\,{\rm cm}^2$)	$\dot{m}_{\rm b}$ (g s^{-1} cm^{-2})	β (^{o})	$R_{\rm th}$ ($R_{\rm WD}$)	$H_{\rm sh}$ ($R_{\rm WD}$)	$T_{\rm sh}$ (keV)	$\rho_{\rm sh}$ (10^{-9} g cm^{-3})	$\langle T\rangle$ (keV)
					Spectrum 1						
1a	1.35	29	0.50	1.58	0.20	48	1.80	0.0146	83	0.92	7.7
1b	1.18	21	0.39	1.66	0.15	45	1.99	0.0217	45	0.93	7.7
1c	1.06	63	15.85	8.74	1.14	50	1.72	0.0057	29	9.25	7.4
1d	0.74	141	15.84	4.05	2.47	27	4.82	0.0019	25	21.46	7.1
					Spectrum 2						
2a	1.29	1	15.85	1.30	7.69	54	1.52	0.0424	43	45.68	28.9
2b	1.03	68	63.10	0.68	58.93	28	4.48	0.0036	49	365.66	28.5
2c	0.94	26	0.63	0.11	35.54	14	18.35	0.0057	48	221.45	29.6
2d	0.87	44	3.98	0.03	95.38	2	1136.27	0.0019	43	633.39	27.4

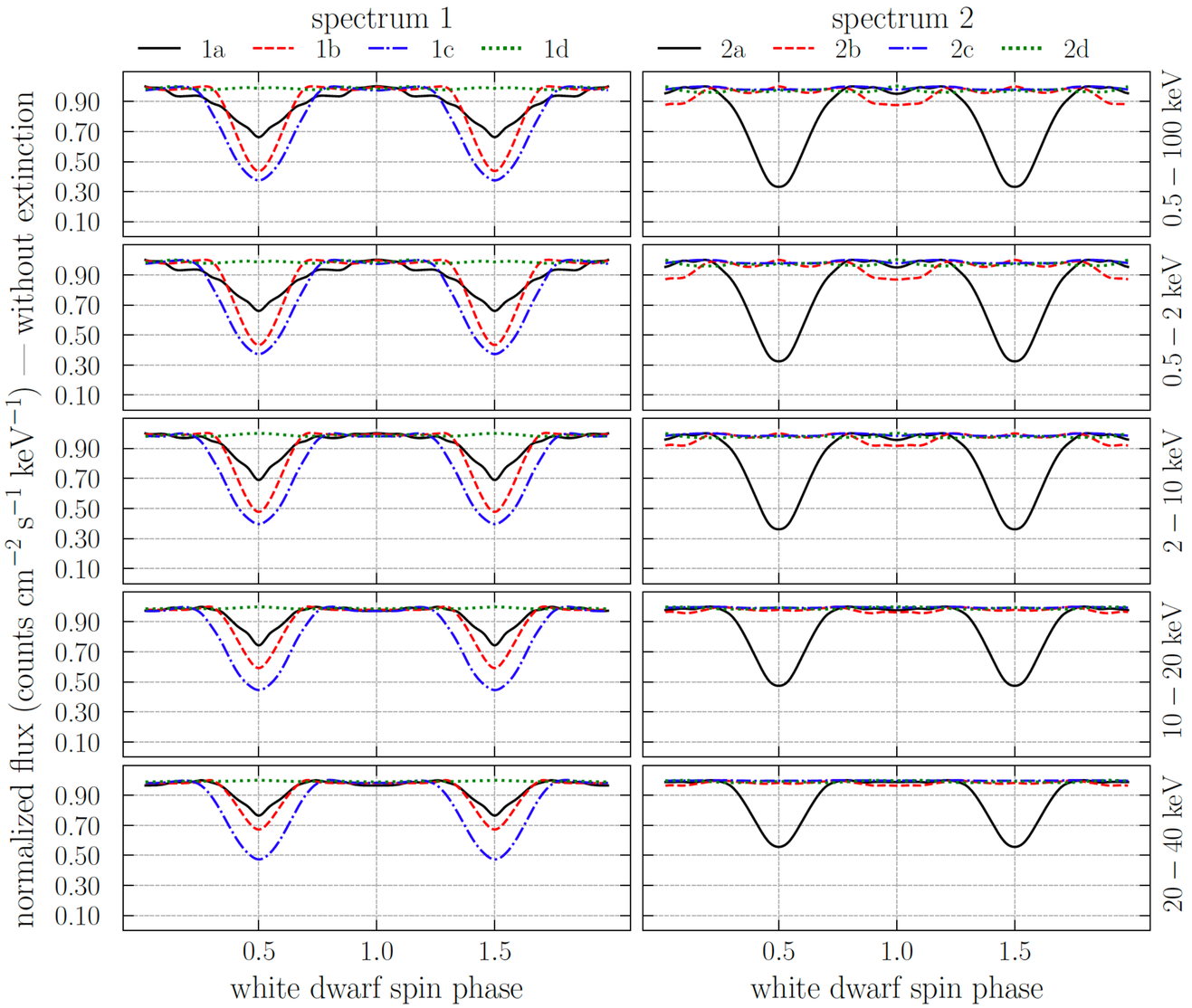
The same X-ray spectrum can be obtained using very different parameters

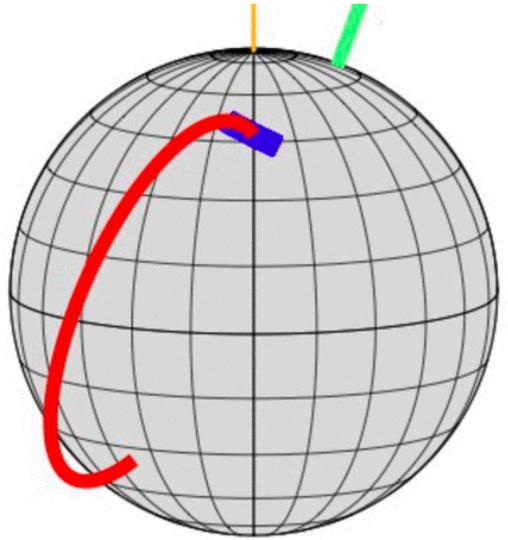
BREAKING THE DEGENERACY

- Fitting absolute counts
- Variation of the emission with WD spin phase
  - X-rays
  - optical flux
  - optical polarization

SELF-ECLIPSE OF THE POST-SHOCK REGION

Belloni, CVR+ 2021





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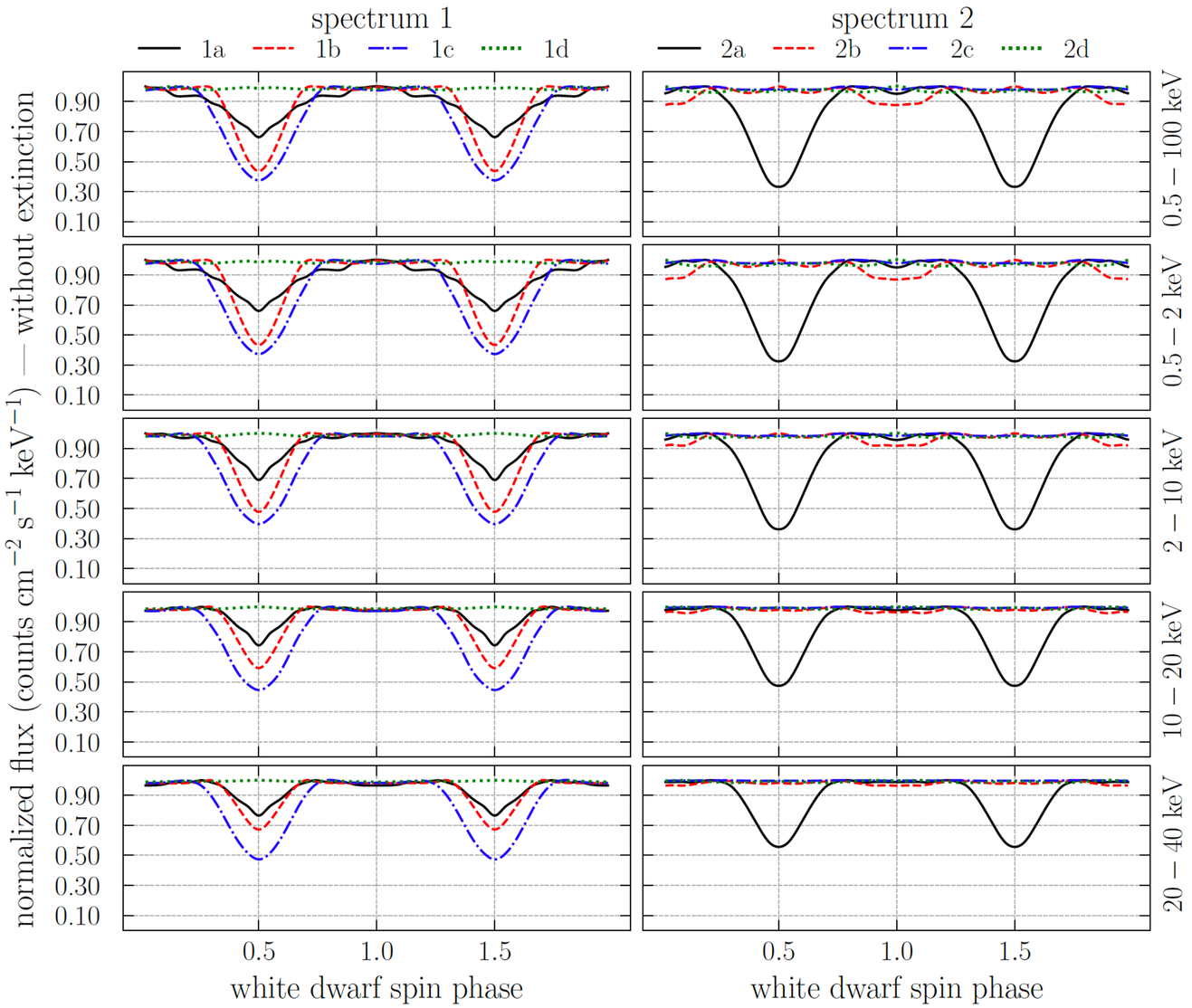
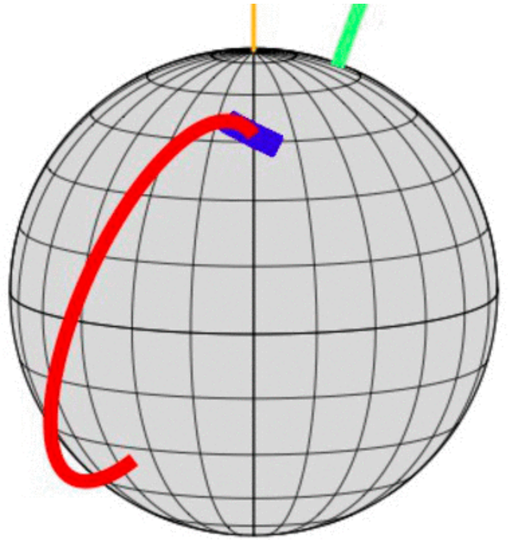
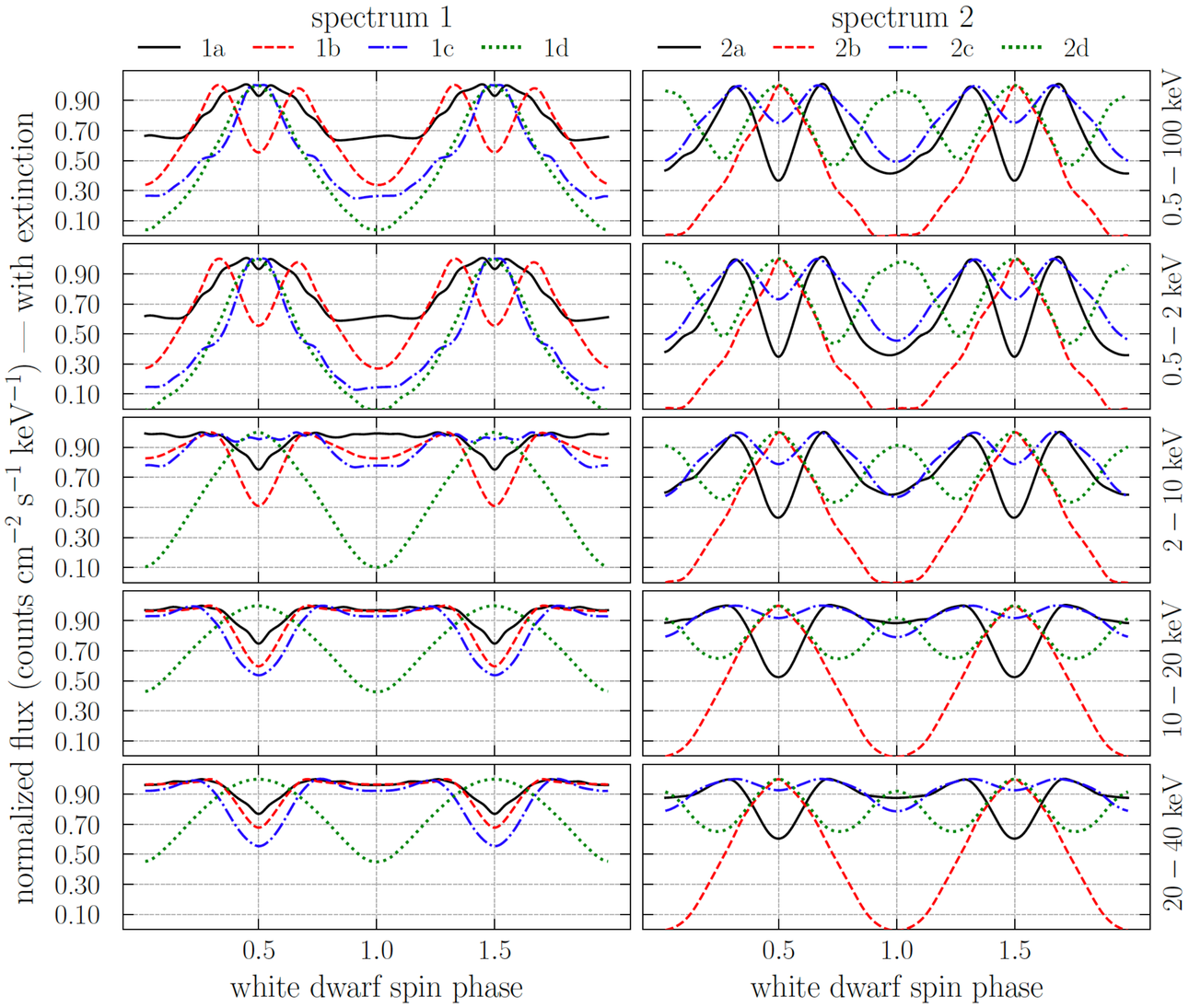
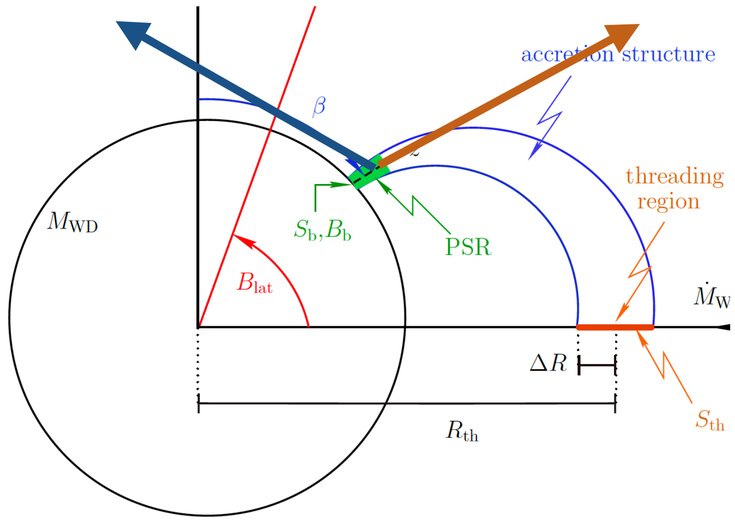
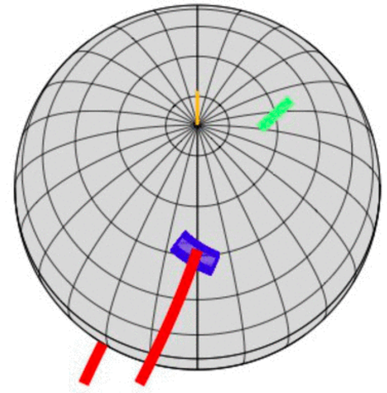




SELF-ECLIPSE + ABSORPTION IN THE PRE-SHOCK REGION







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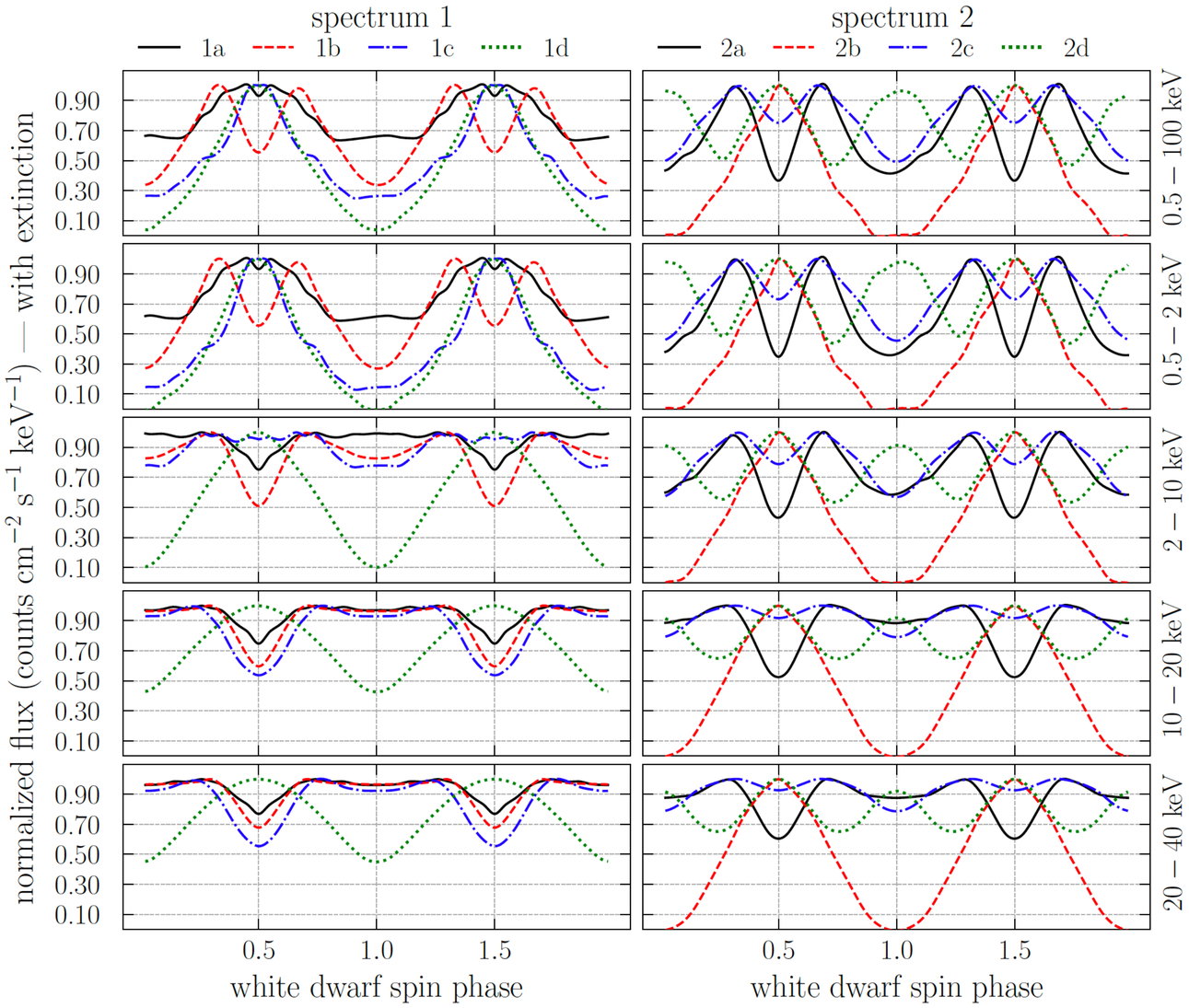

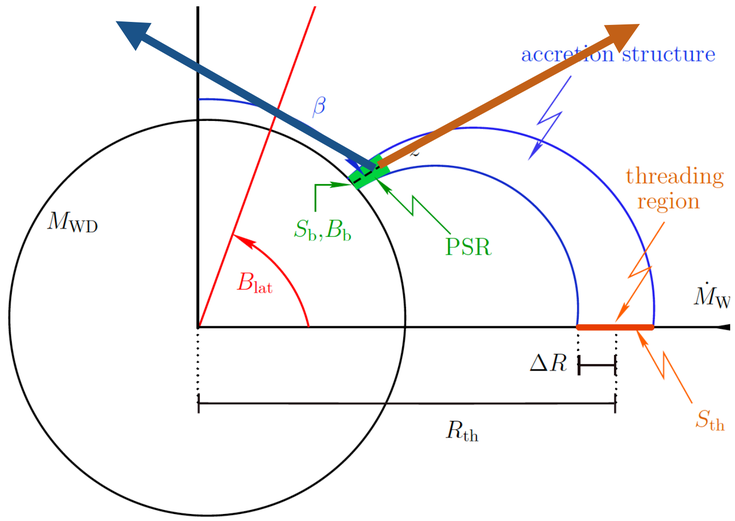

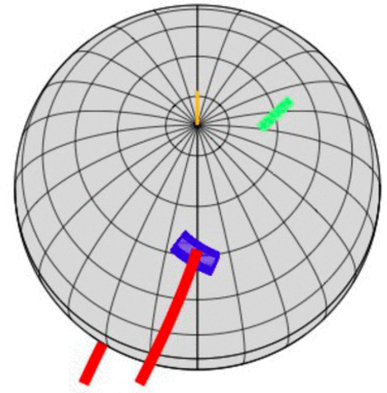

Fitting observations

AM Her - Spectrum shape

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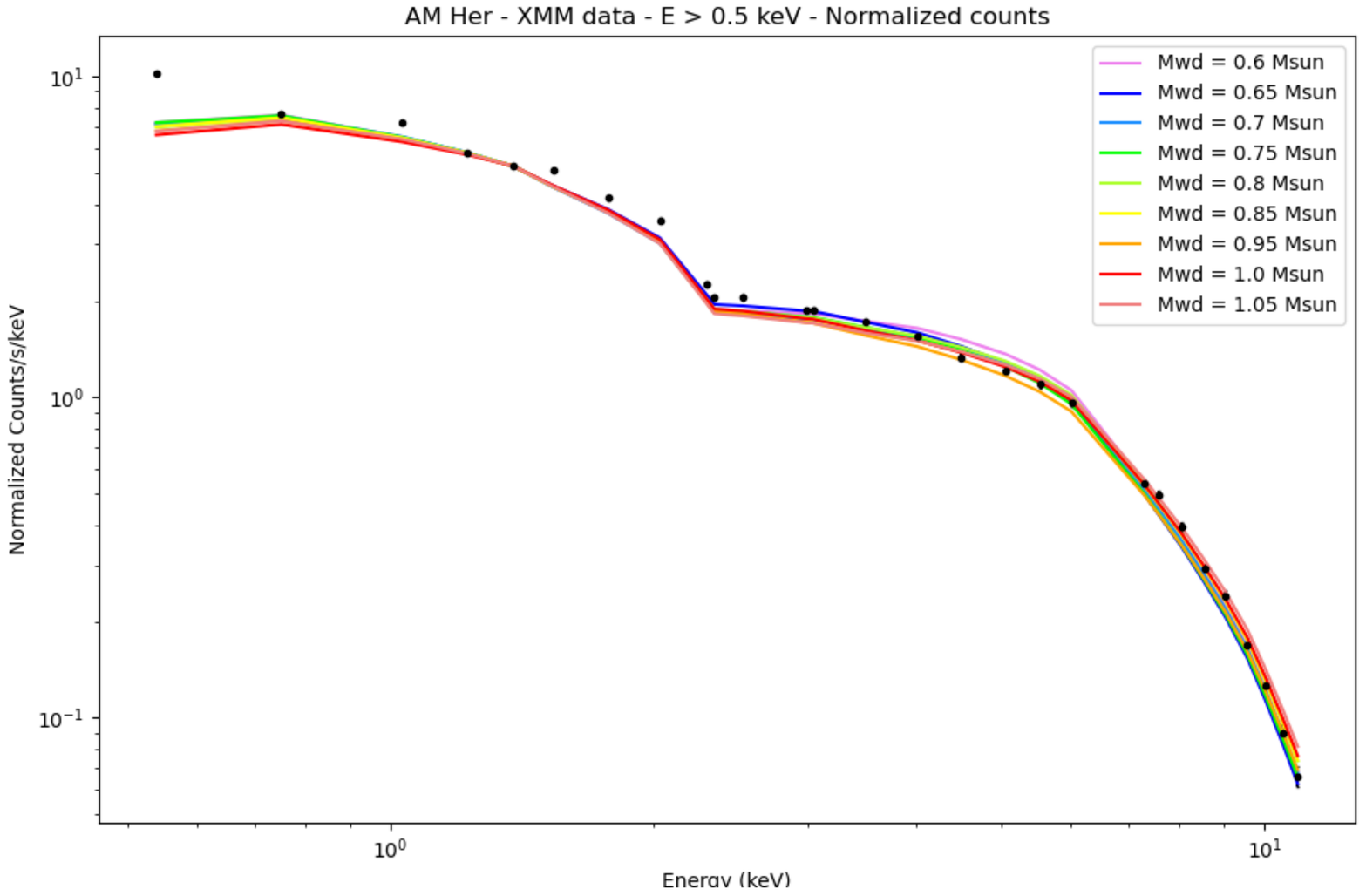
- XMM data
  - ObsId 0744180801
  - 2015 April
  - Schwope+2020

AM HER - SPECTRUM SHAPE

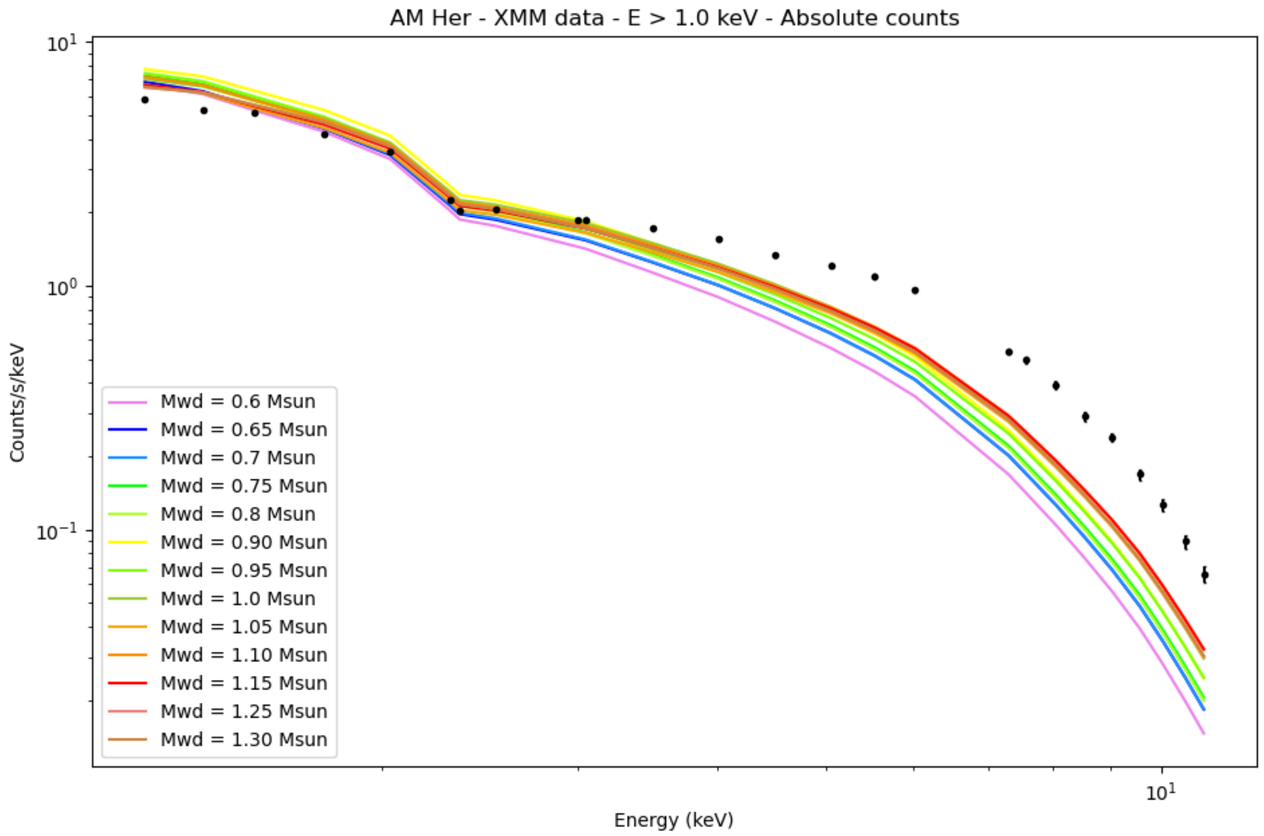


- XMM data
  - ObsId 0744180801
  - 2015 April
  - Schwope+2020

- Fit procedure
  - Mwd is kept fixed
  - other parameters can vary (B, Mdot, ...)

FITTING ALSO THE SPECTRUM COUNTS - AM HER

- Bad fitting...
  - ❖ Free additional parameter in the fitting?
  - ❖ Line emission contribution?
  - ❖ Two post-shock regions?
  - ❖ Additional absorption at soft energies?



- Distance from Gaia DR3
  - ❖ d = 87.9 (Bailer-Jones+2021)

1RXS J174320.1-042953

- Simultaneous modeling of X-ray and optical data

- Observations
  - X-ray spectrum - XMM
  - optical light and polarization curves - OPD

1RXS J174320.1-042953

Martins' PhD thesis 2022

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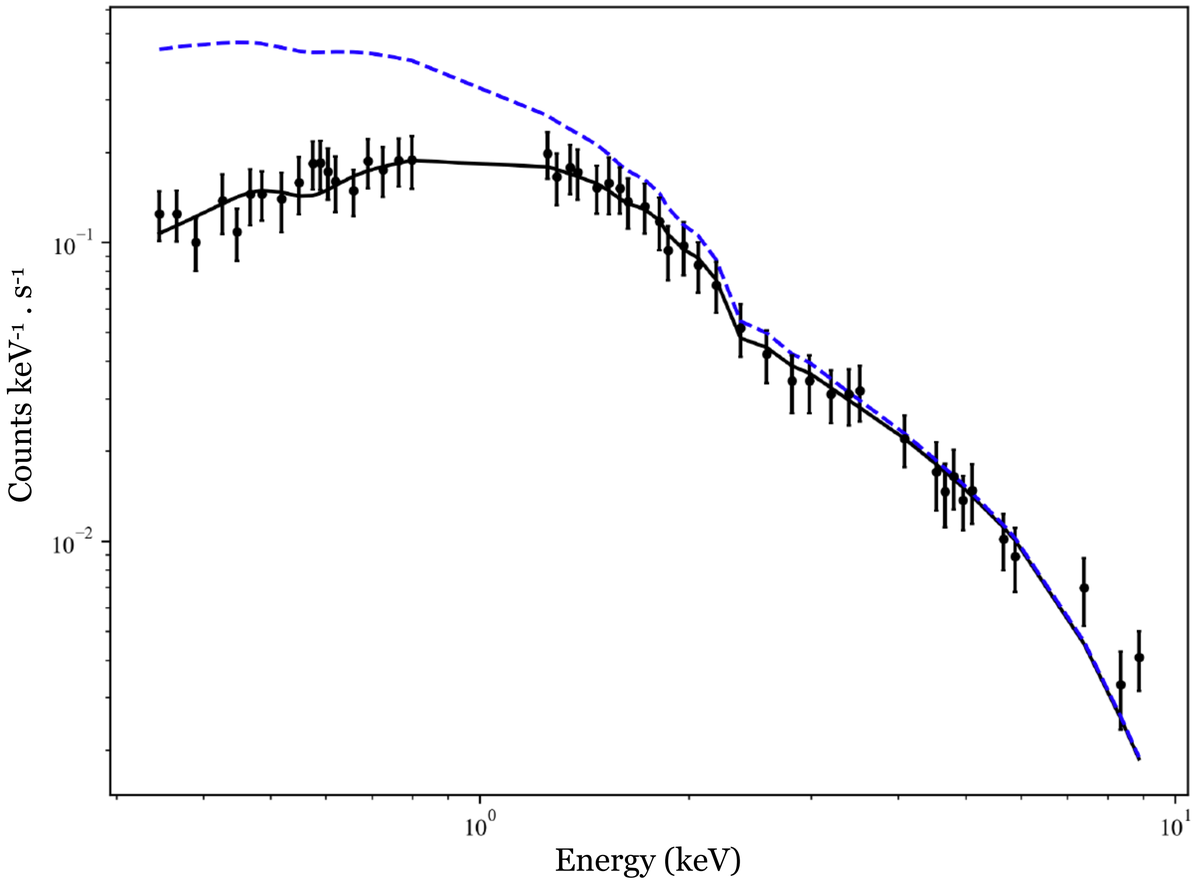
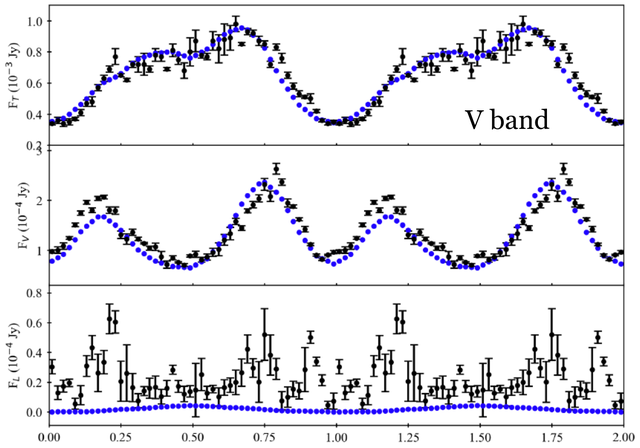
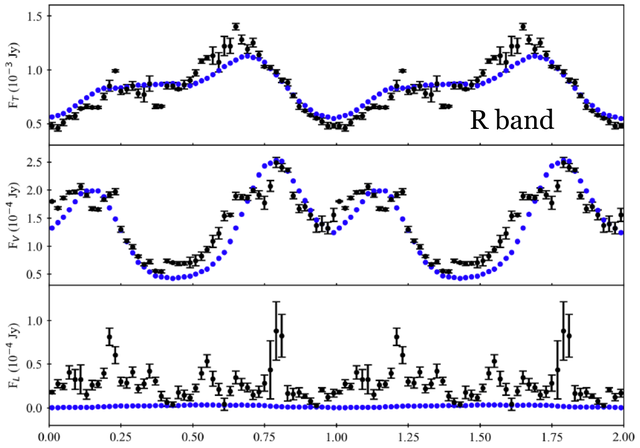
Preliminary results

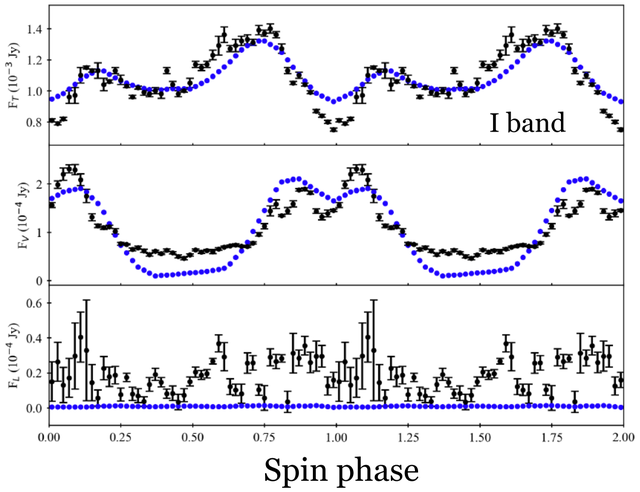


1RXS J174320.1-042953

Martins' PhD thesis 2022







Black: data

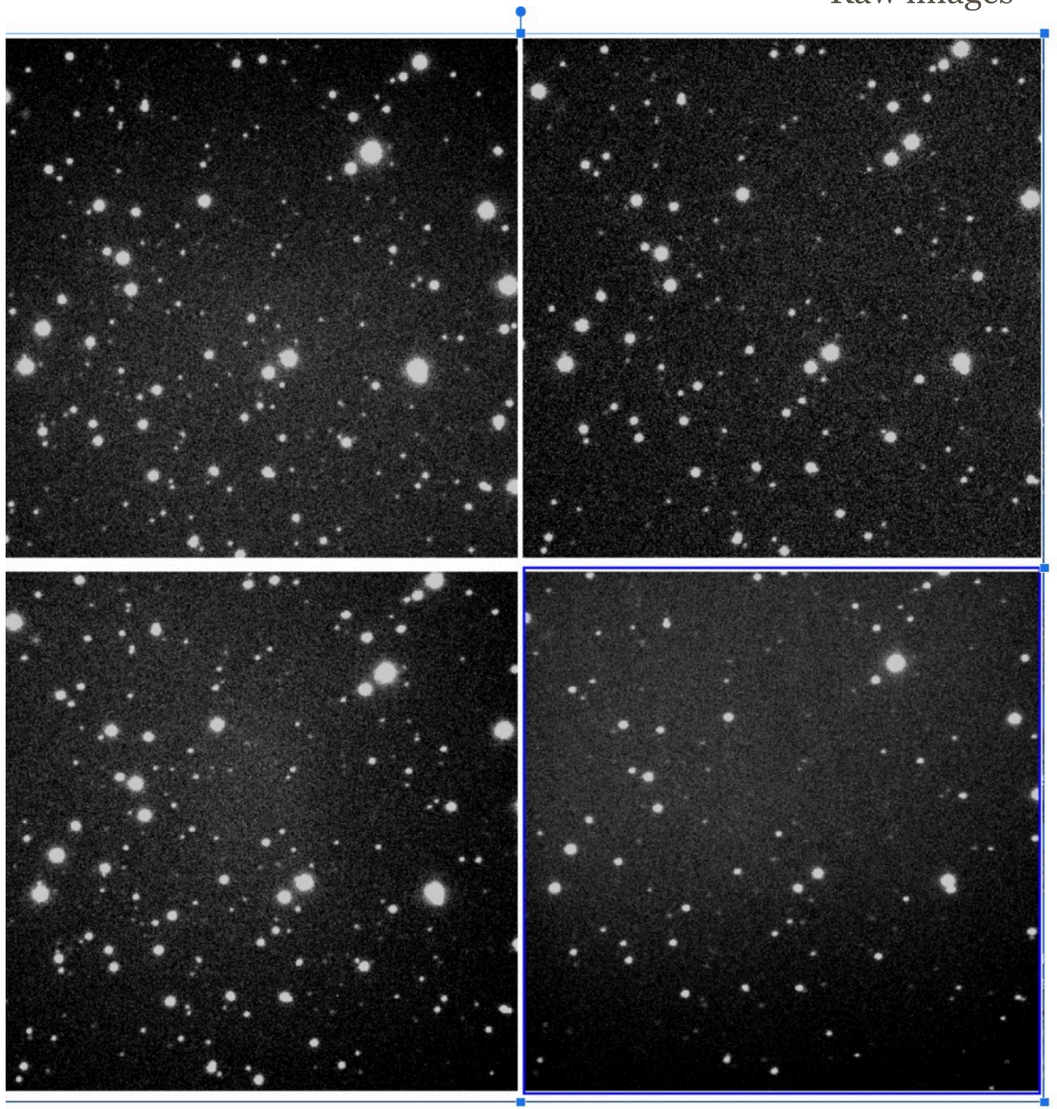
Blue: Model

Preliminary results

SPARC4 - First light

- Simultaneous Polarimeter And Rapid Camera in 4 bands
  - ❖ simultaneous imaging in four bands (griz SDSS)
  - ❖ 5.6 x 5.6 arcsin sq.
  - ❖ polarimetry as an option
  - ❖ sub-second time resolution
- at 1.6-m telescope of Observatório do Pico dos Dias (Brazil)
- First light on 2022 Nov 4th

Raw images



CONCLUSIONS

- The estimation of Mwd using X-ray spectra should be done with care
- It is desirable to use as many observational constraints as possible
- Cyclops is a nice tool to study accretion in magnetic cataclysmic variables

Thanks!

Acknowledgements

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