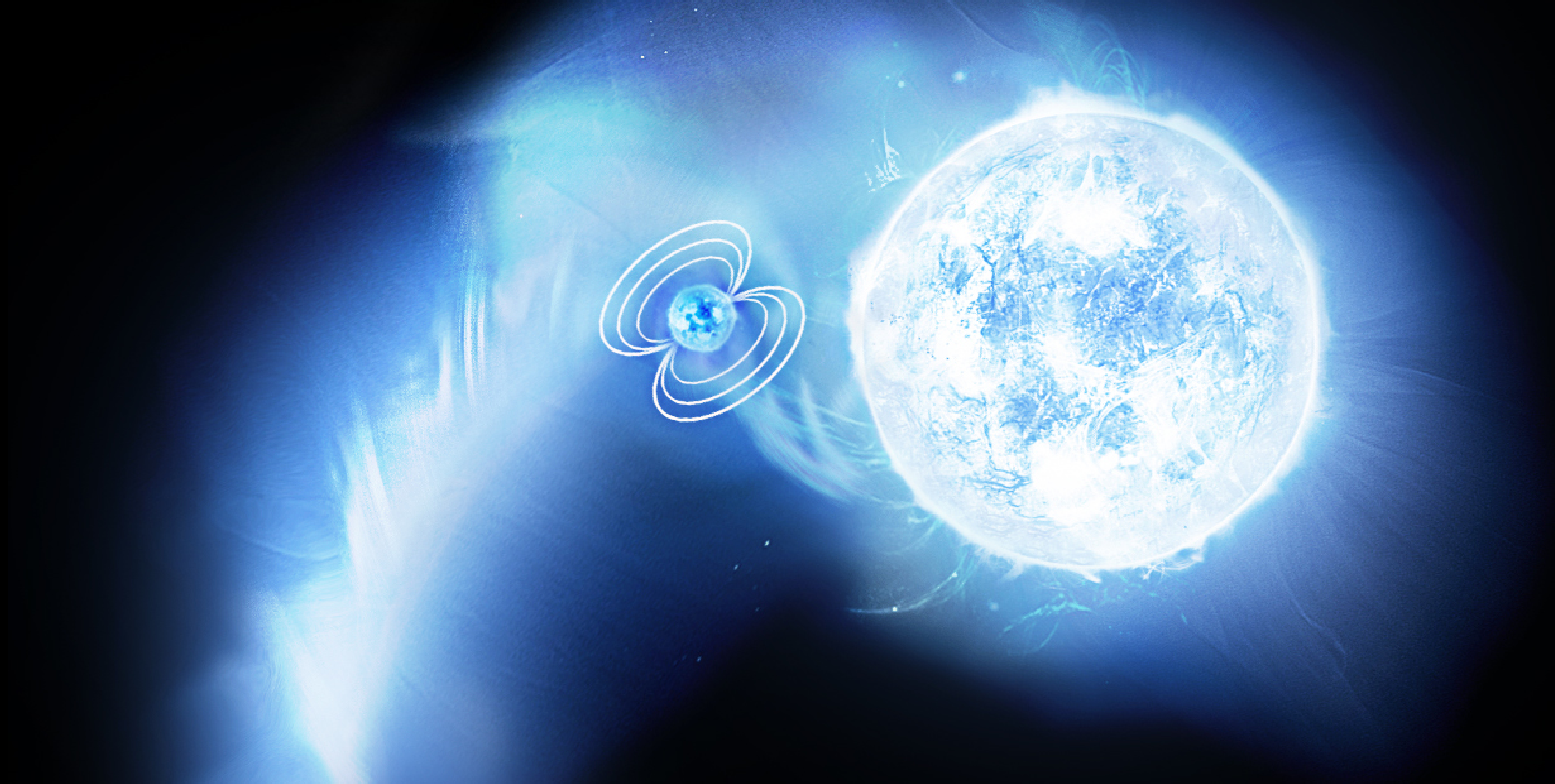
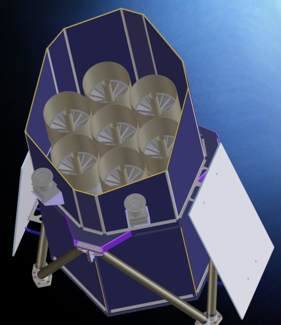
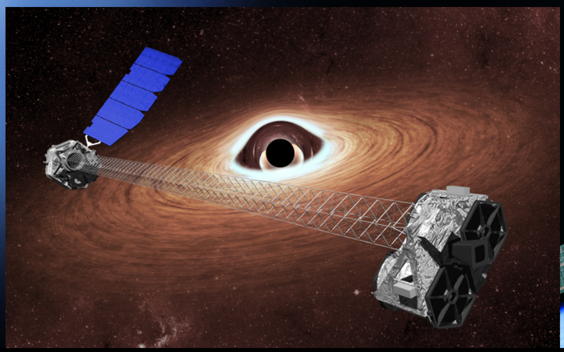
High Mass X-ray Binaries with INTEGRAL (and other missions)

Jörn Wilms (ECAP, FAU Erlangen-Nürnberg)







HMXB Science Case

HMXB science:

1. What is the population of compact objects?

   black holes and neutron stars as tracers of stellar evolution; relationship to gravitational wave sources

2. What is the nature of compact objects?

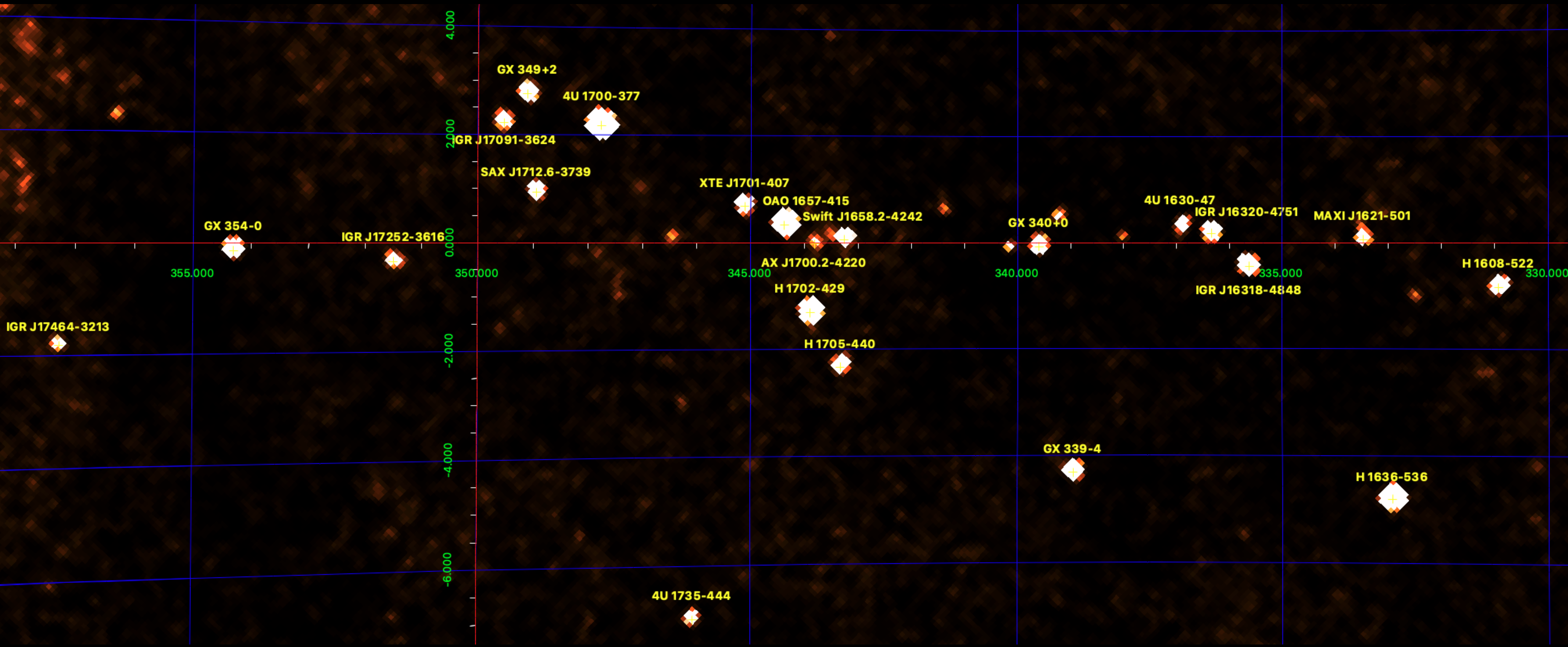
   black hole spins and their origin, structure of neutron stars,...

3. What is the physics of stellar winds?

   Using X-rays to x-ray the circumstellar environment

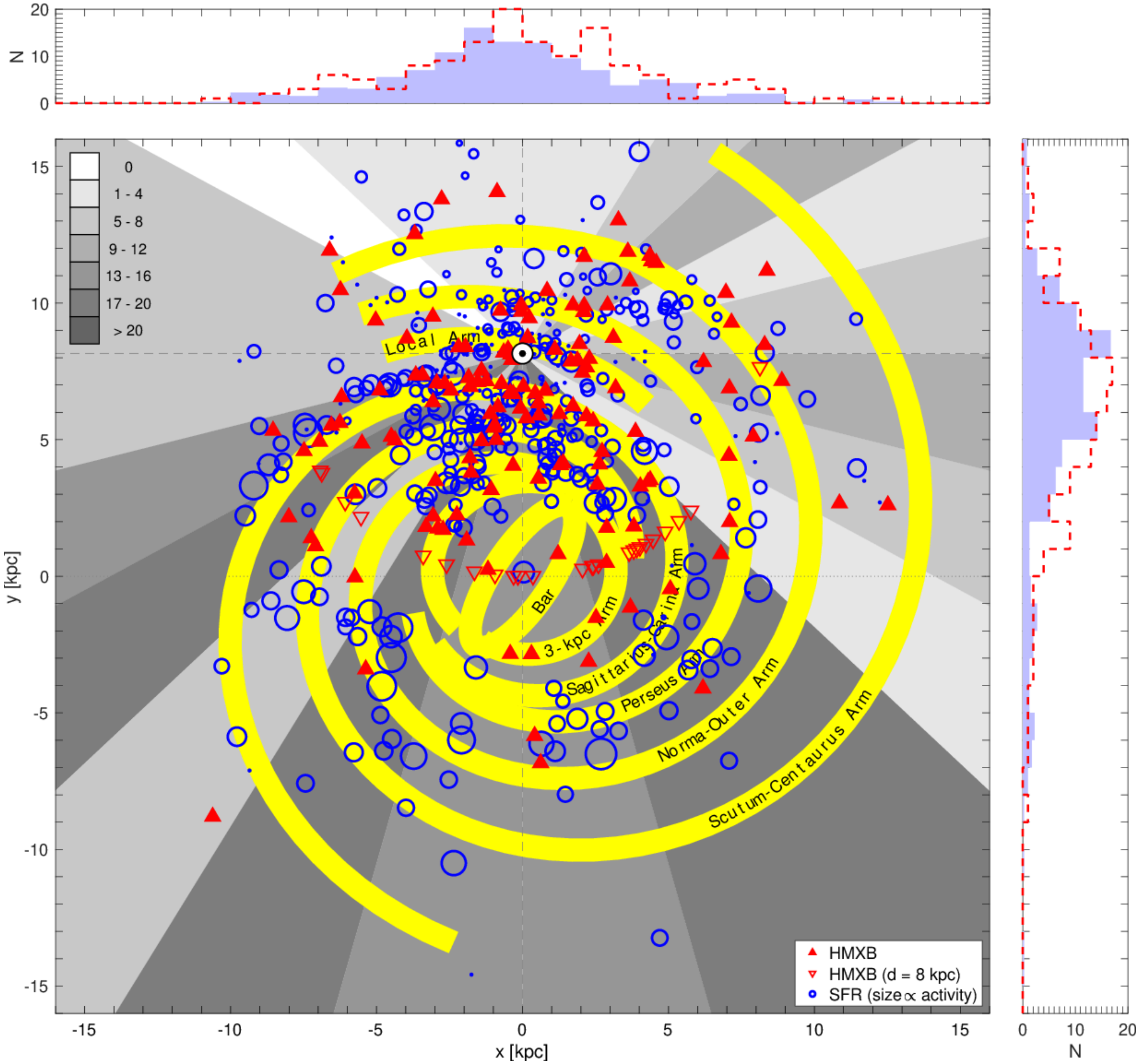
4. What is the physics of the accretion flow?

   physics of accretion disks, jets, strongly magnetic sources,...



(Kretschmar et al., 2019)

Populations: “INTEGRAL sources”

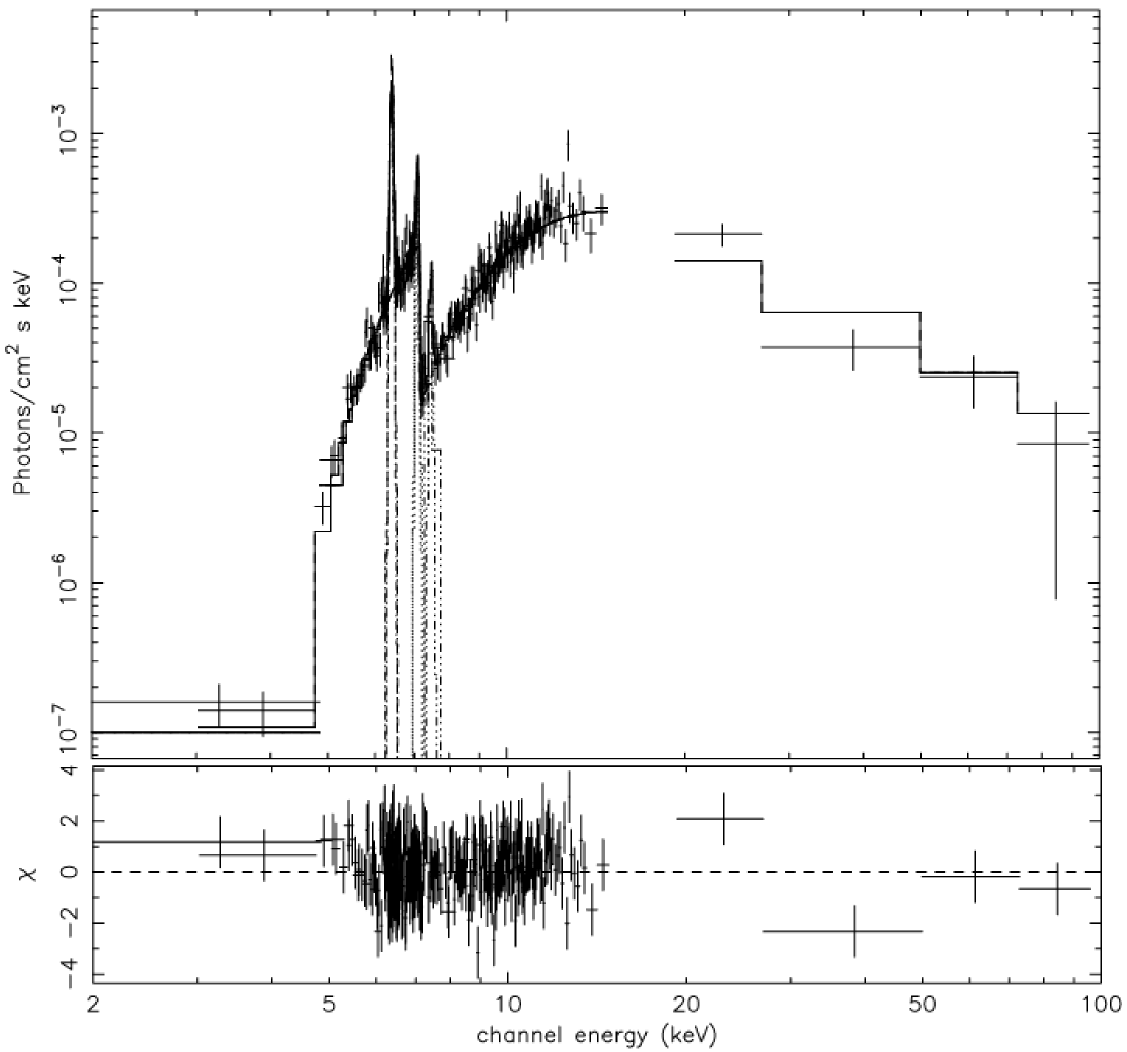


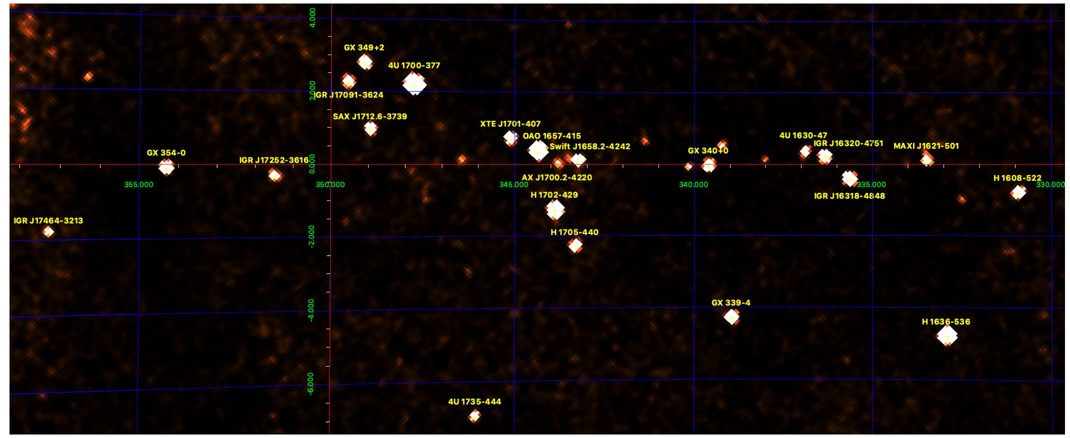
Distribution of HMXB in the Galaxy

Large fraction discovered with INTEGRAL.

Bodaghee et al. (2012), updated mid 2023

Populations: “INTEGRAL sources”



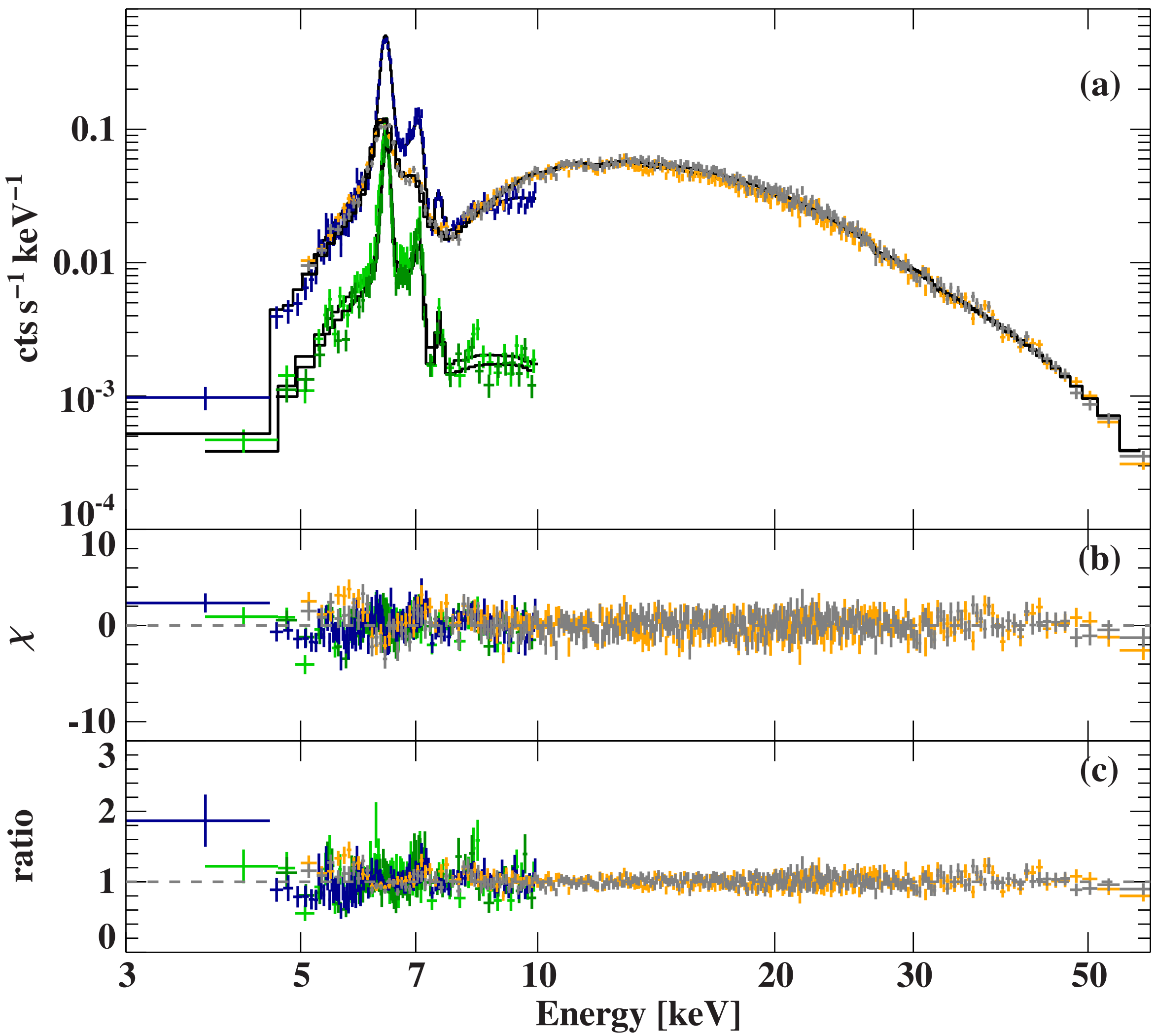


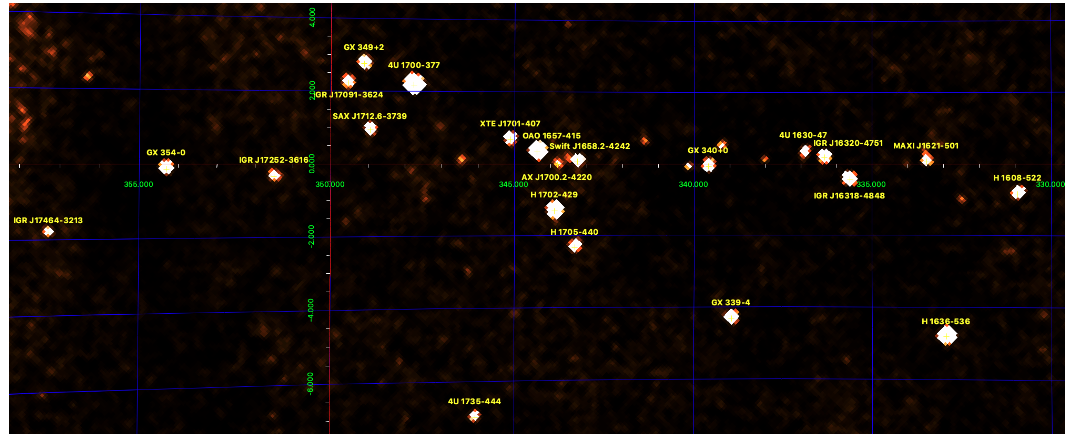
Norma arm with IBIS (Kretschmar et al., 2019)

One of the main discoveries of INTEGRAL: “INTEGRAL sources”:

∃ population of compact objects embedded in very dense, cold stellar winds (Walter et al., 2003).

Populations: “INTEGRAL sources”





Norma arm with IBIS (Kretschmar et al., 2019)

IGR J16318−4848

XMM/NuSTAR (Ballhausen et al., 2020):

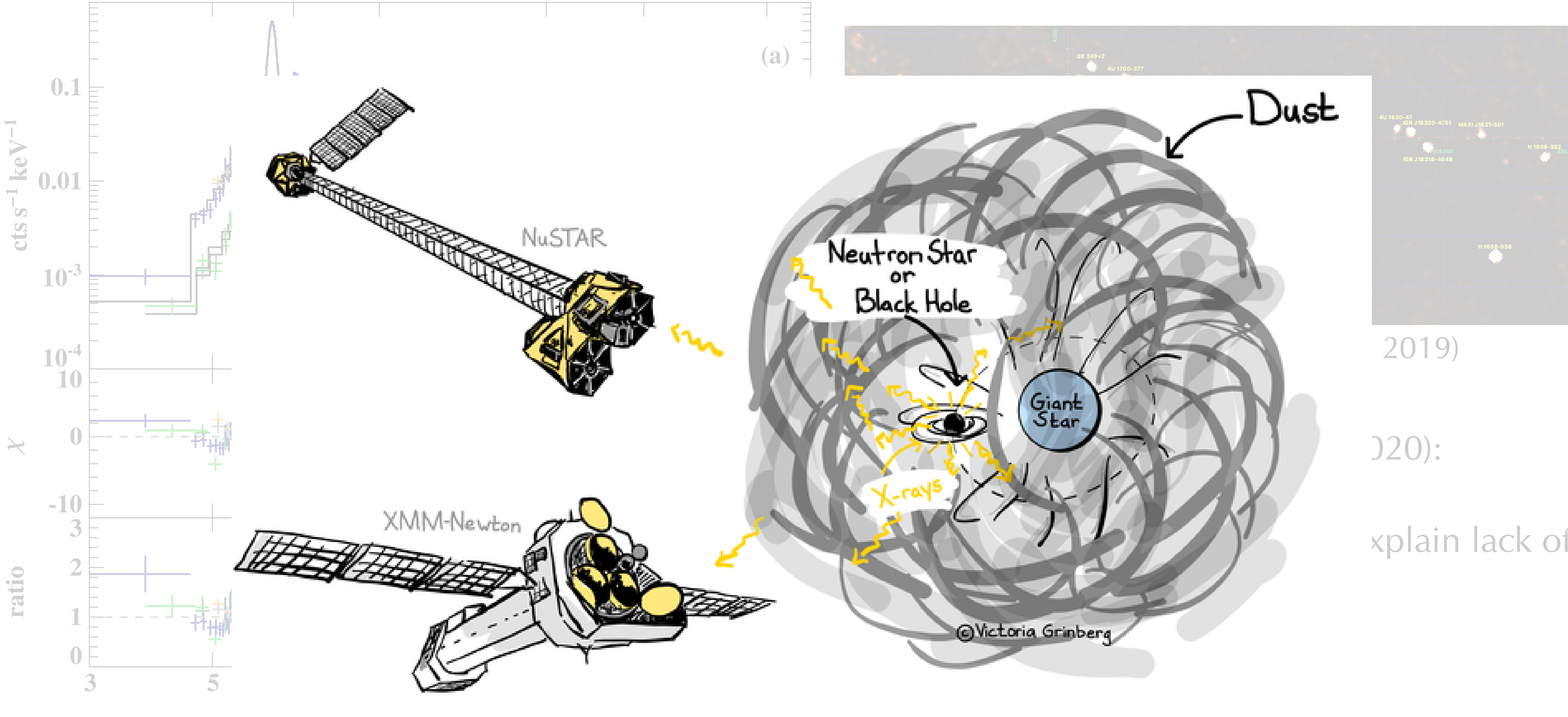
$N_H = 1.8 \times 10^{22}\,\mathrm{cm}^{-2}$,

strong dust absorption needed to explain lack of Compton shoulder.

Hitomi (Collaboration et al., 2018):

Fe Kα is Fe i–iv

Populations: “INTEGRAL sources”

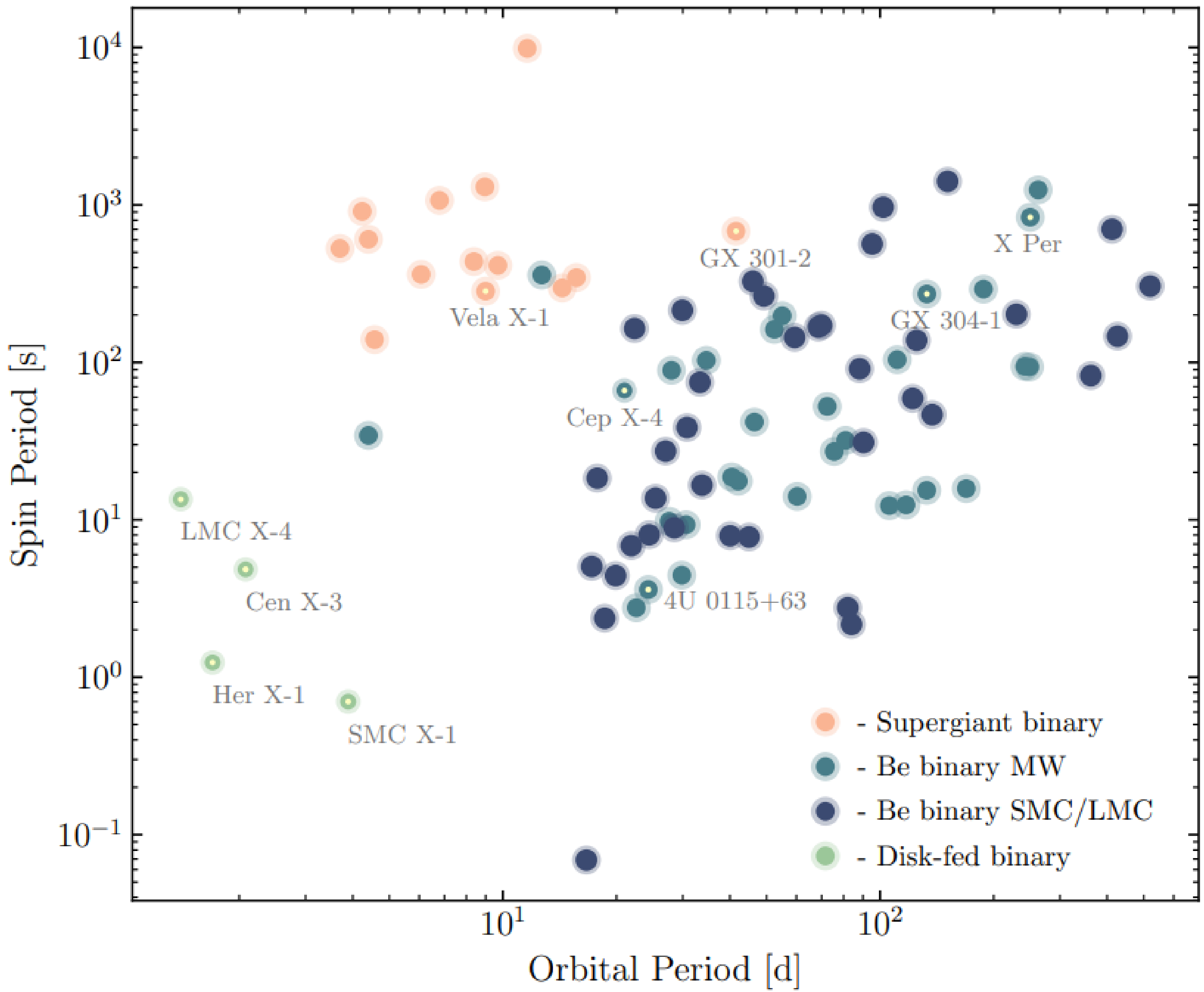


2019)

)20):

xplain lack of

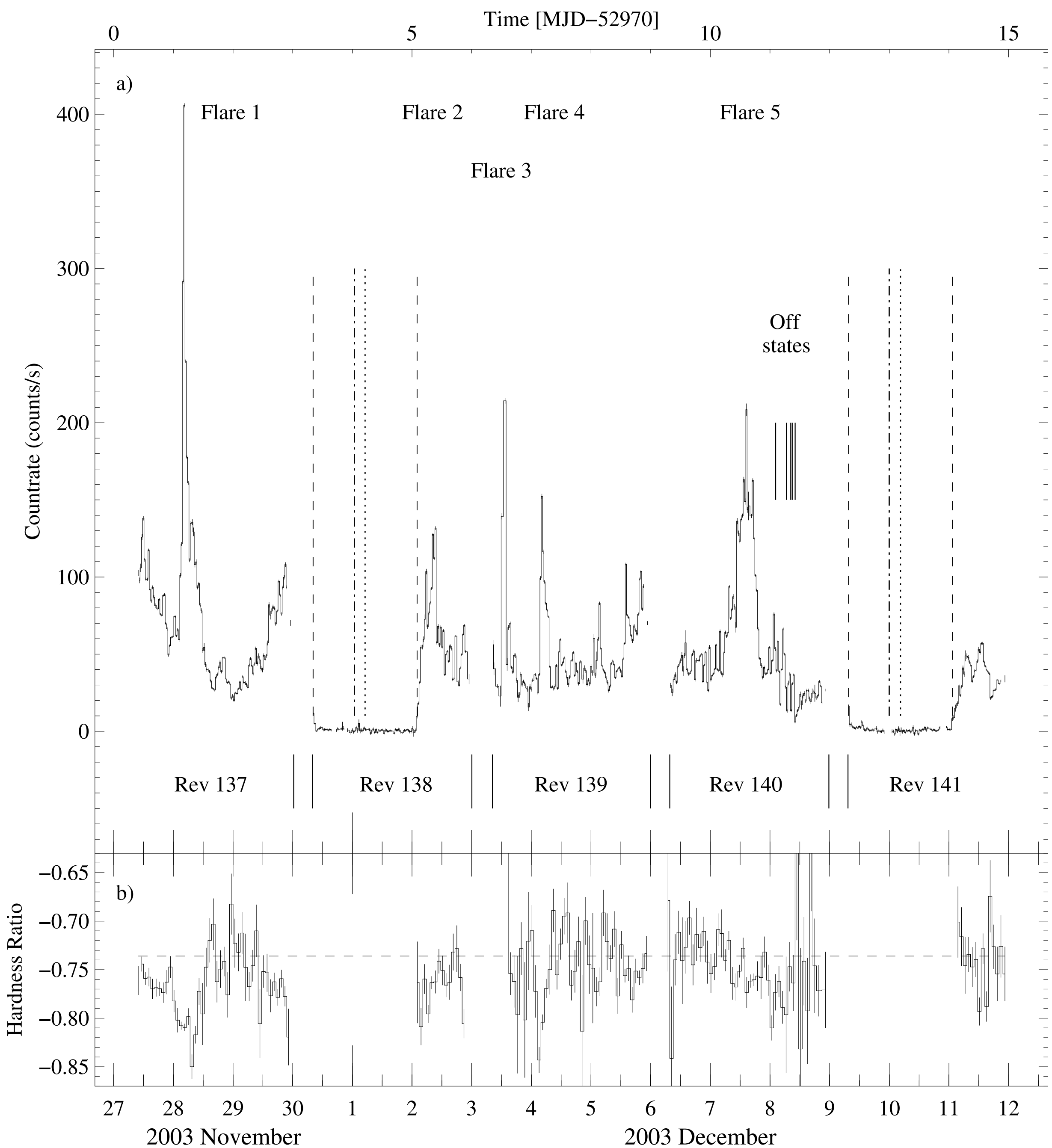
Accretion Environment

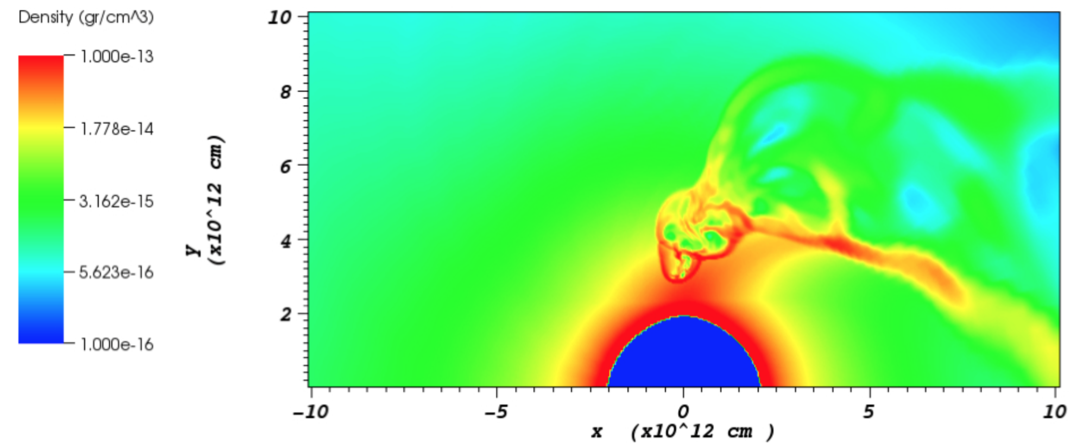


Corbet-Diagram

(E. Sokolova-Lapa, based on Neumann et al., 2023, catalogue)

Accretion Environment





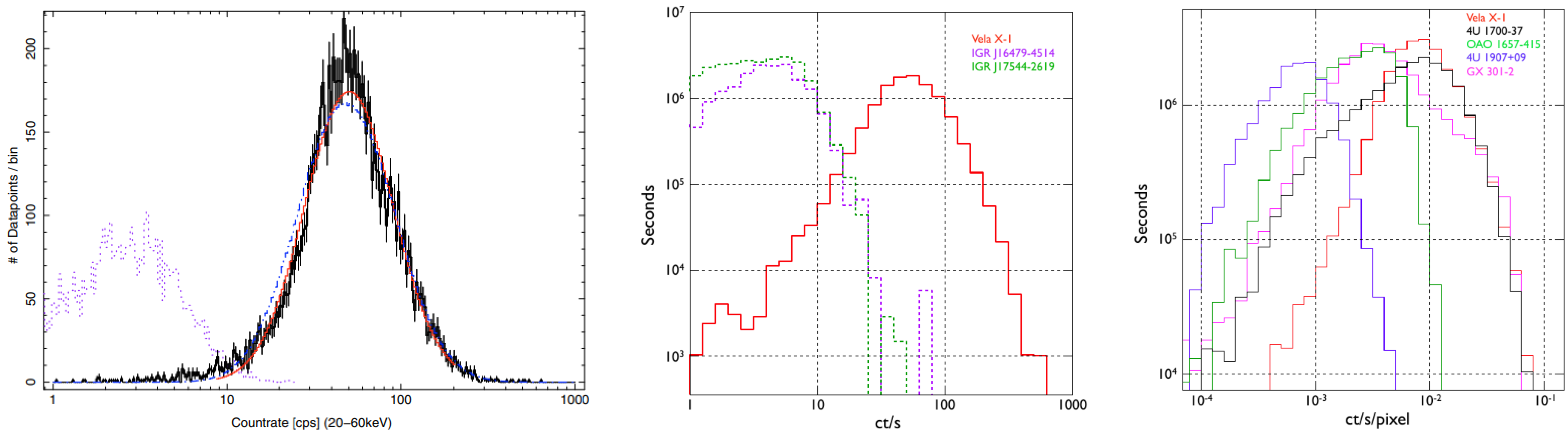
Manousakis (PhD, 2011), Manousakis et al. (2013)

HMXB Variability: direct probe of

- structure of wind
  or the part that can be accreted
- physics of coupling of wind to magnetic field

flares and off-states in Vela X-1 (Kreykenbohm et al., 2008)

Accretion Environment

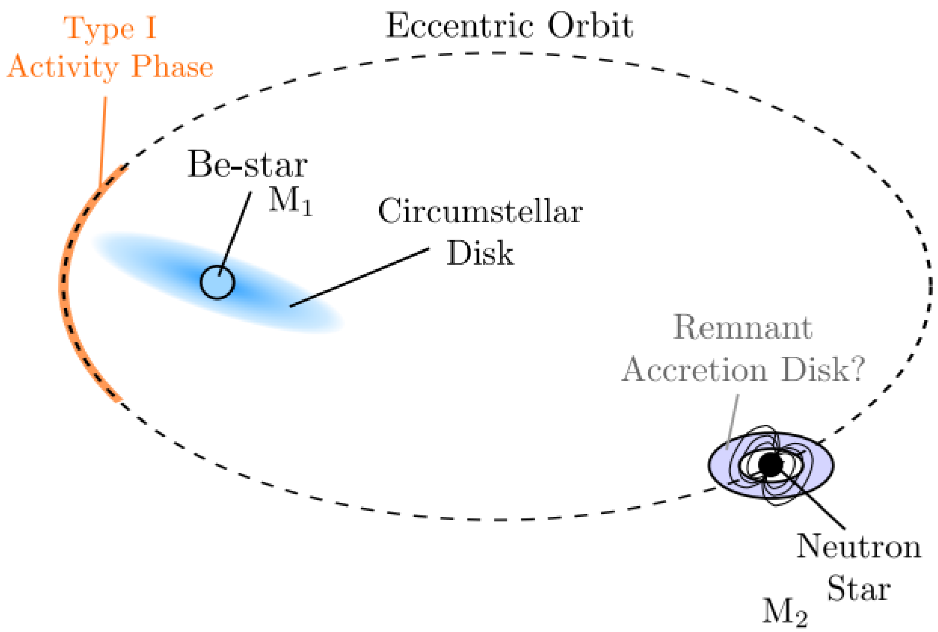


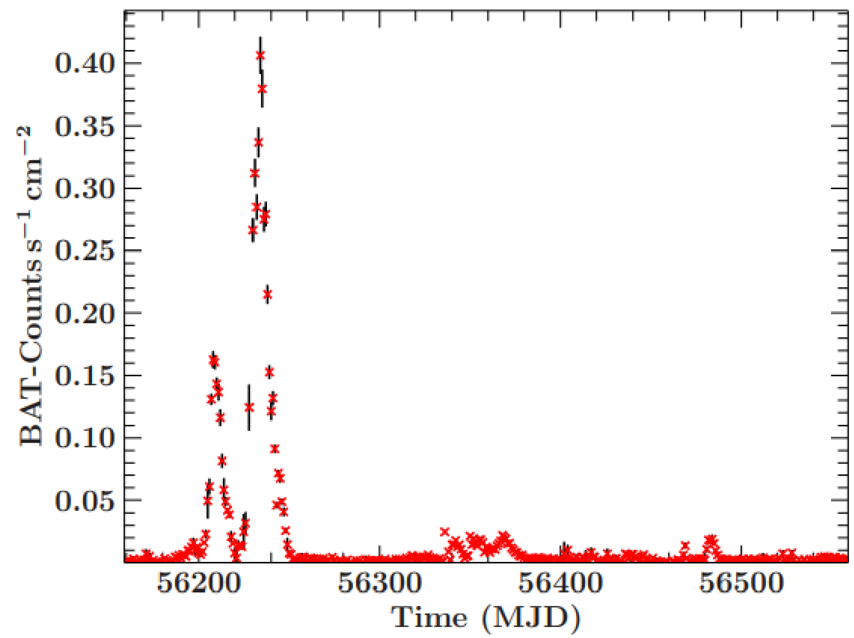
(Fürst et al., 2010; Walter et al., 2015)

While luminosity variability looks erratic, it can be well described by lognormal distributions

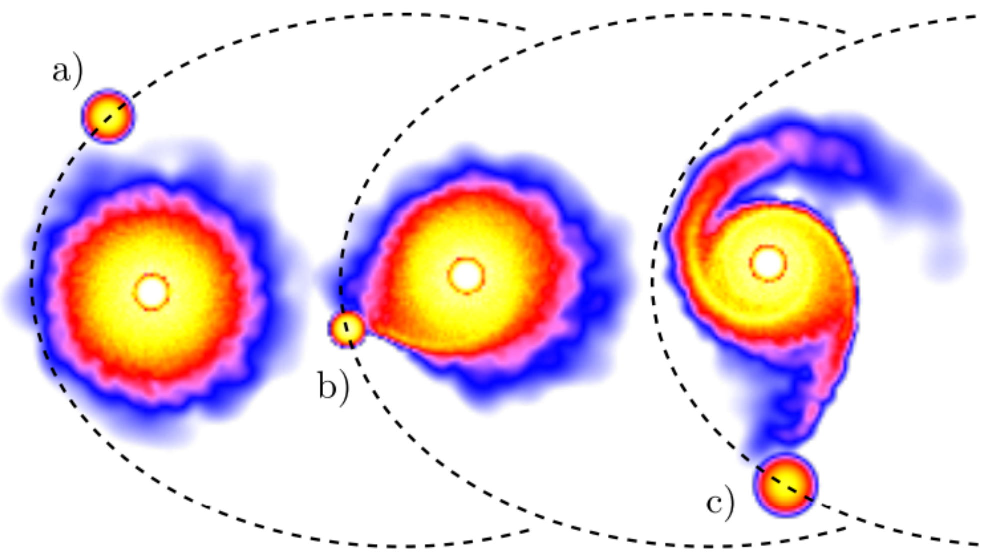
- structure of wind
  or the part that can be accreted
- physics of coupling of wind to magnetic field

Accretion Environment





(Bissinger, 2016, Fig. 1.16)

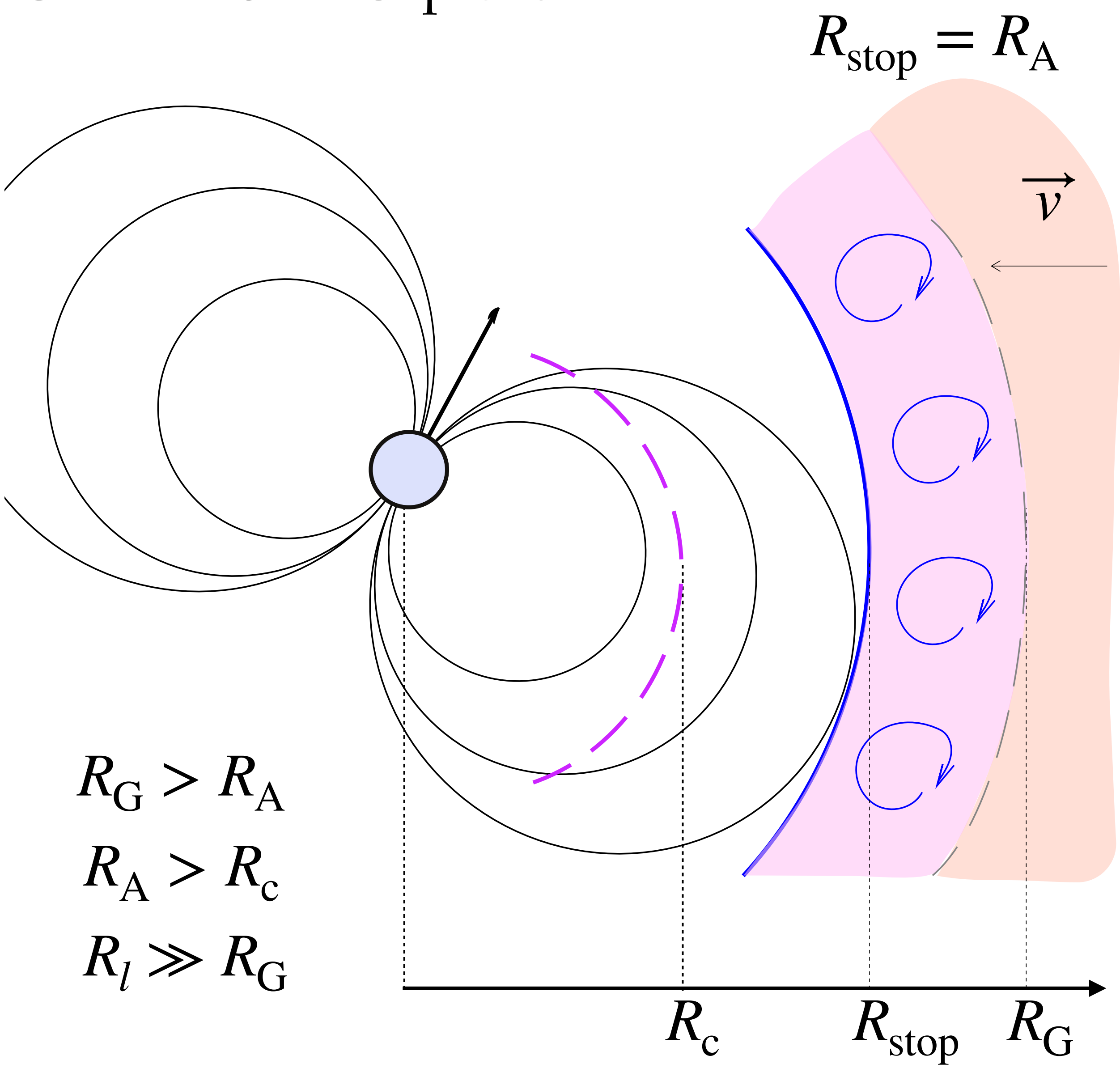


Second HMXB accretion mechanism: accre-tion from Be-star excretion disk

Less short-term variability, mass flow from temporary accretion disk gained from excretion disk during periastron passage of neutron star

(Bissinger, 2016, Fig. 1.17, after Okazaki)

Centrifugal Inhibition
Gravitational Capture



$R_G > R_A$

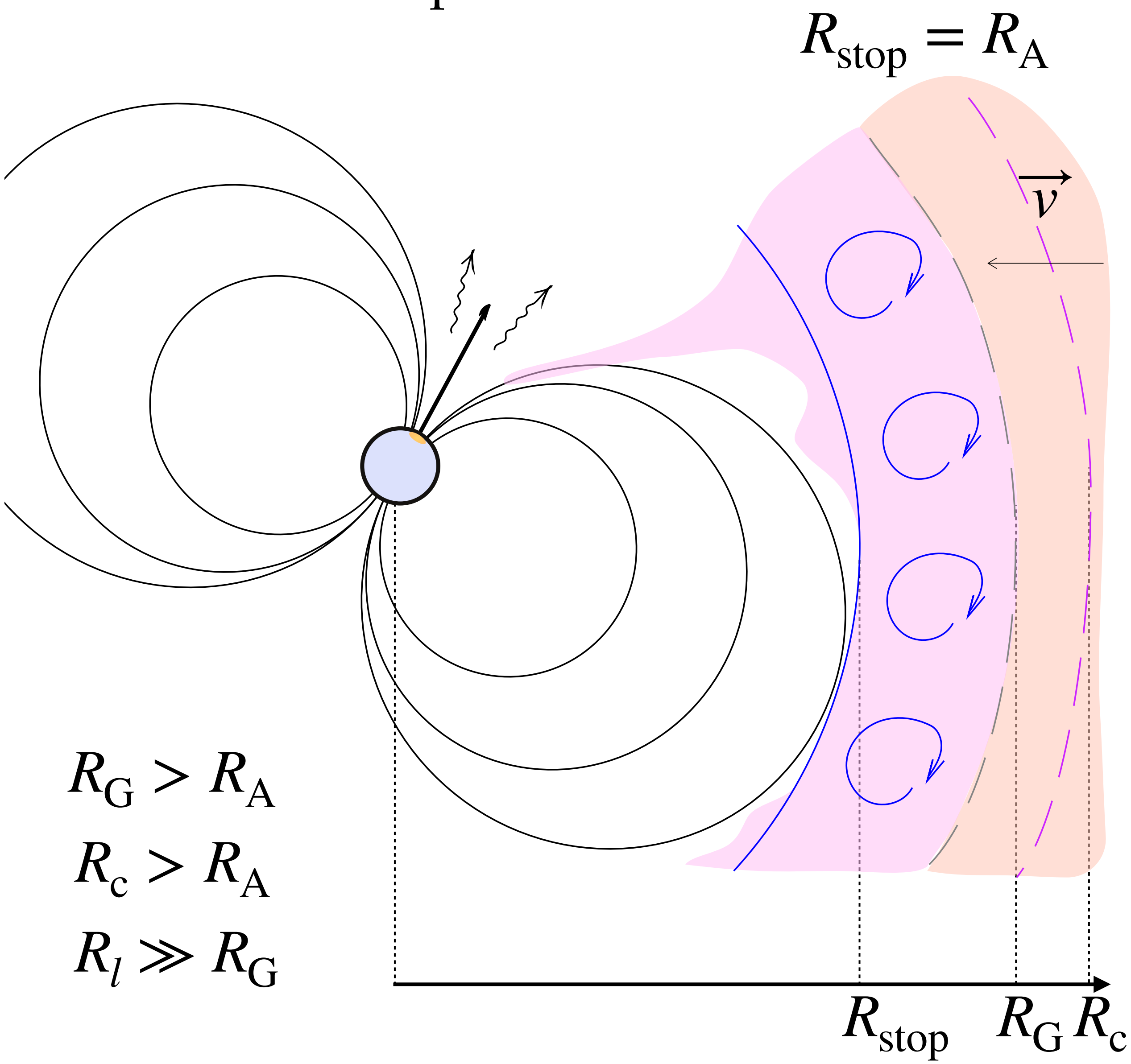
$R_A > R_c$

$R_l \gg R_G$

E. Sokolova-Lapa (PhD, 2023)

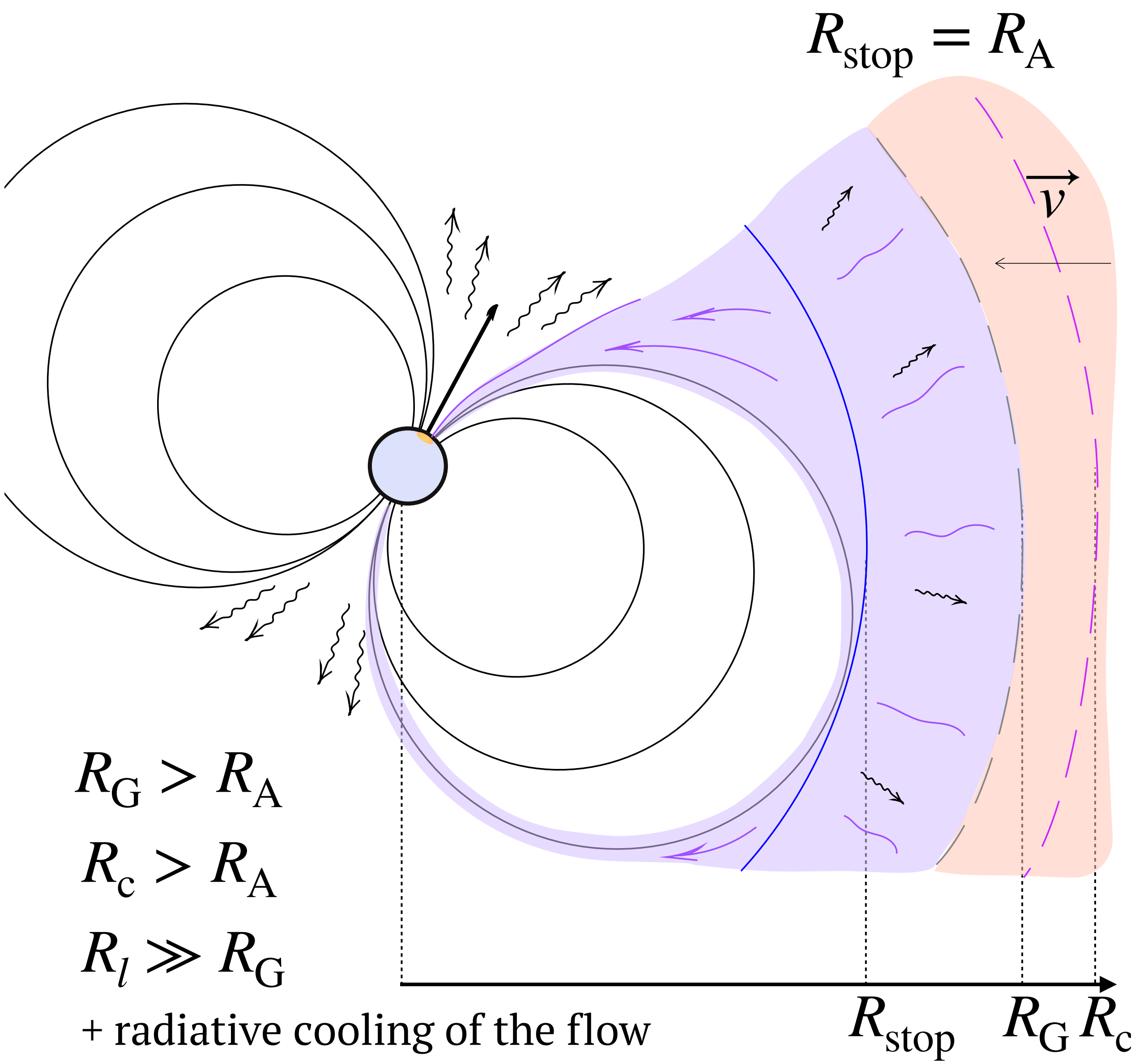
Accretion columns

Magnetic Inhibition
Gravitational Capture



E. Sokolova-Lapa (PhD, 2023)

Accretor



$R_G > R_A$

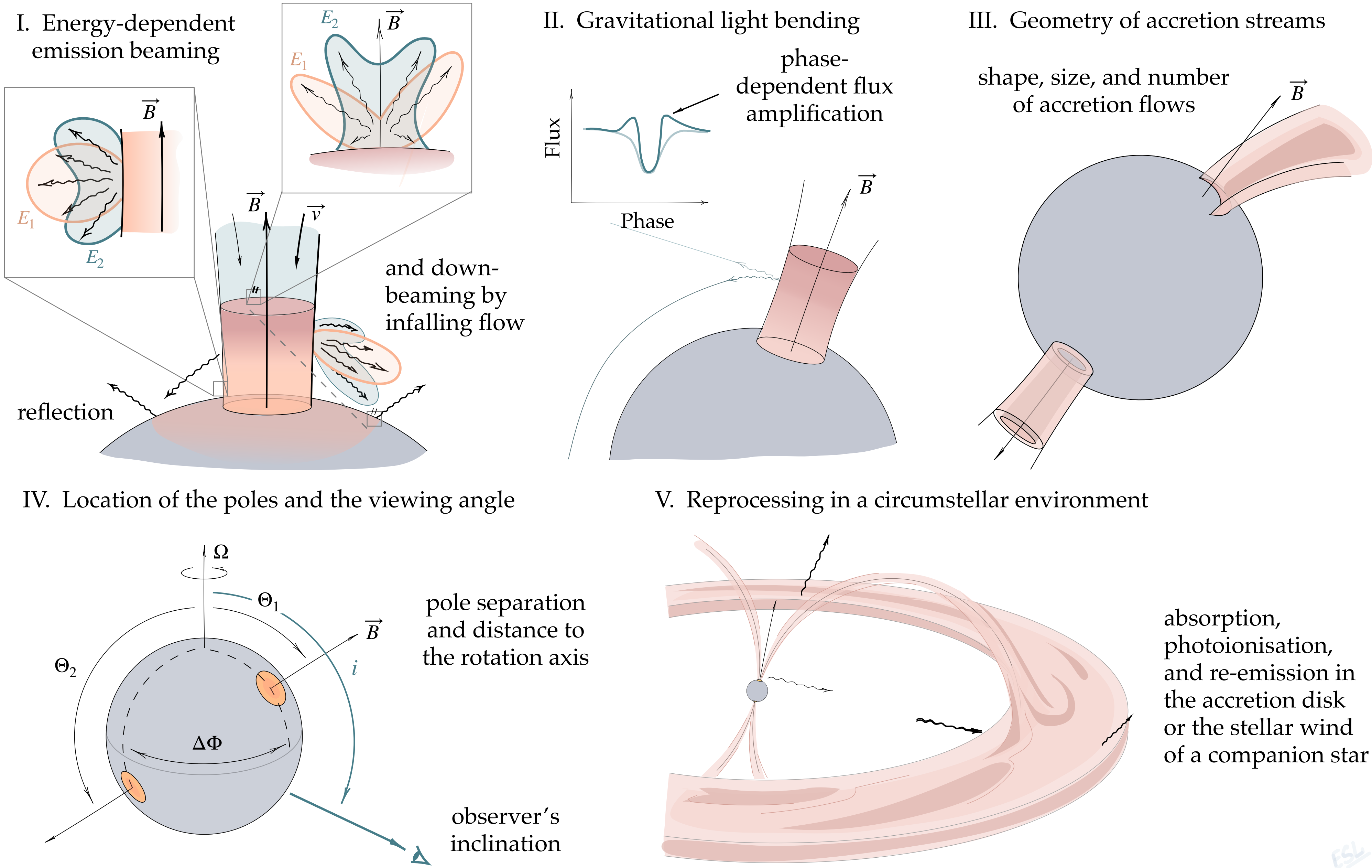
$R_c > R_A$

$R_l \gg R_G$

+ radiative cooling of the flow

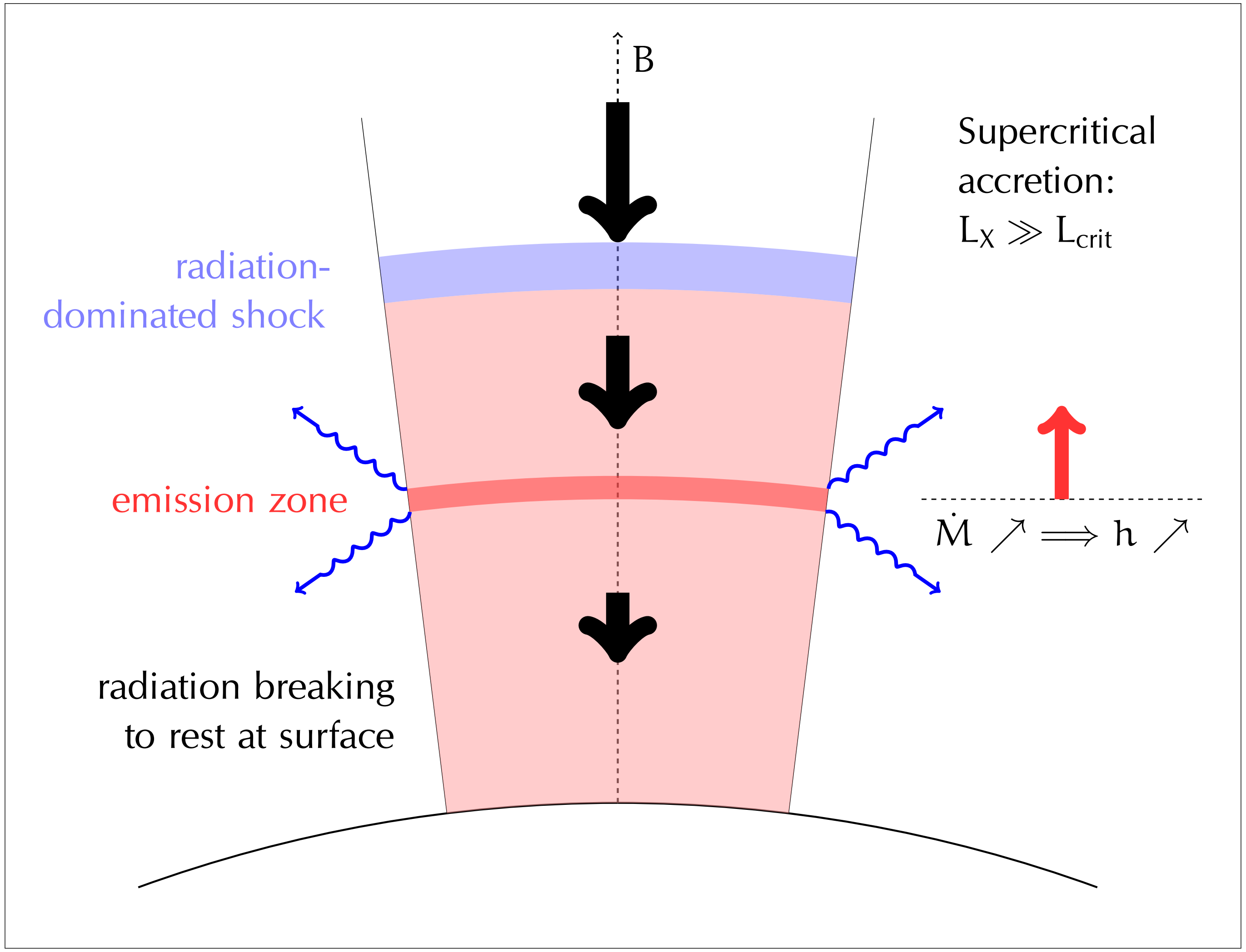
E. Sokolova-Lapa (PhD, 2023)

Accretion columns



XMAG Collab, in prep. (graphics by E. Sokolova-Lapa)

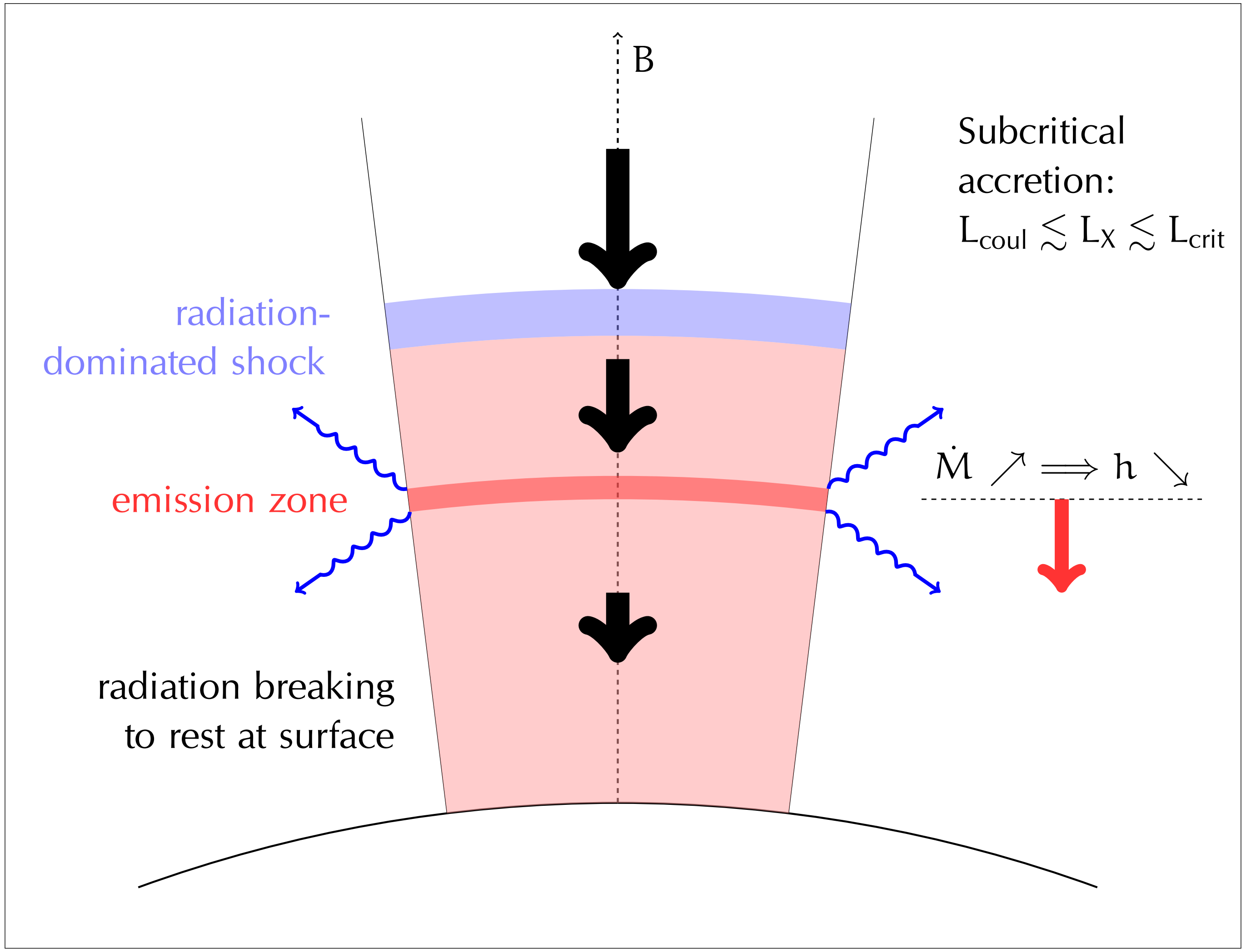
Accretion columns



after P. Becker

Brightest sources: accretion column locally super-Eddington, radiation balances accreted matter

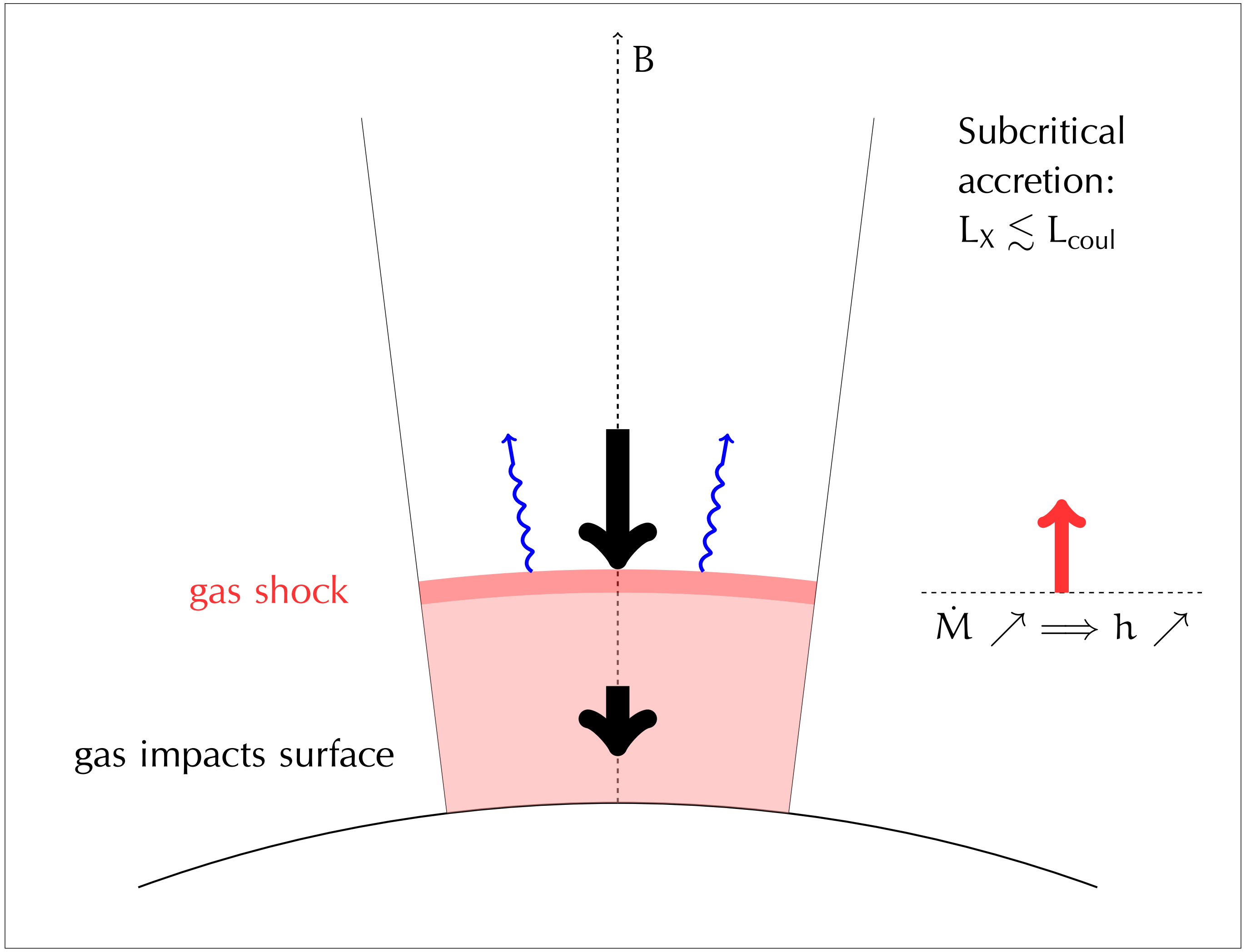
Accretion columns



after P. Becker

Brightish sources: Coulomb braking important, still some radiative pressure

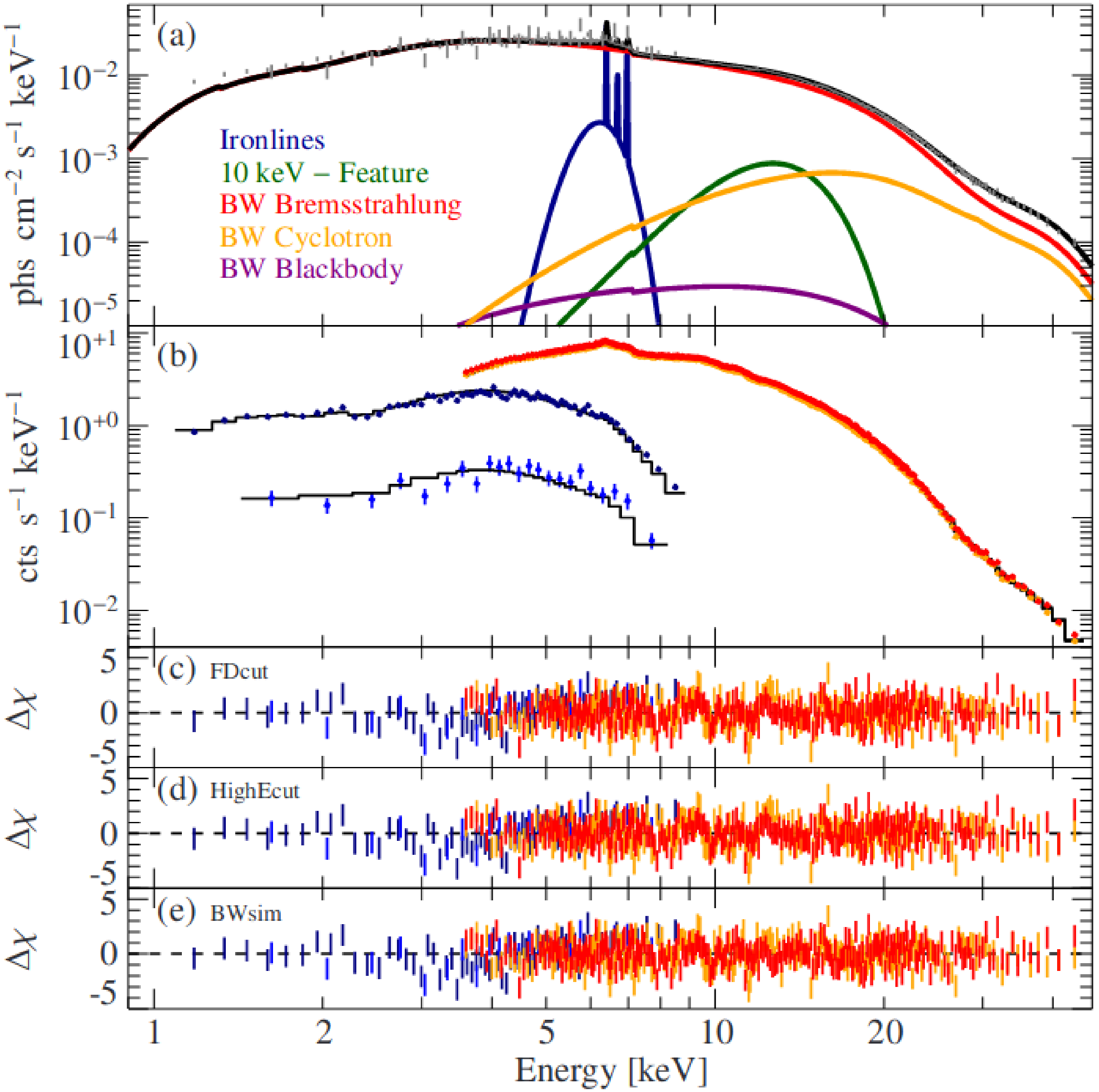
Accretion columns



after P. Becker

Faint sources: Coulomb not sufficient, gas mediated shock somewhere above the surface…

Accretion columns



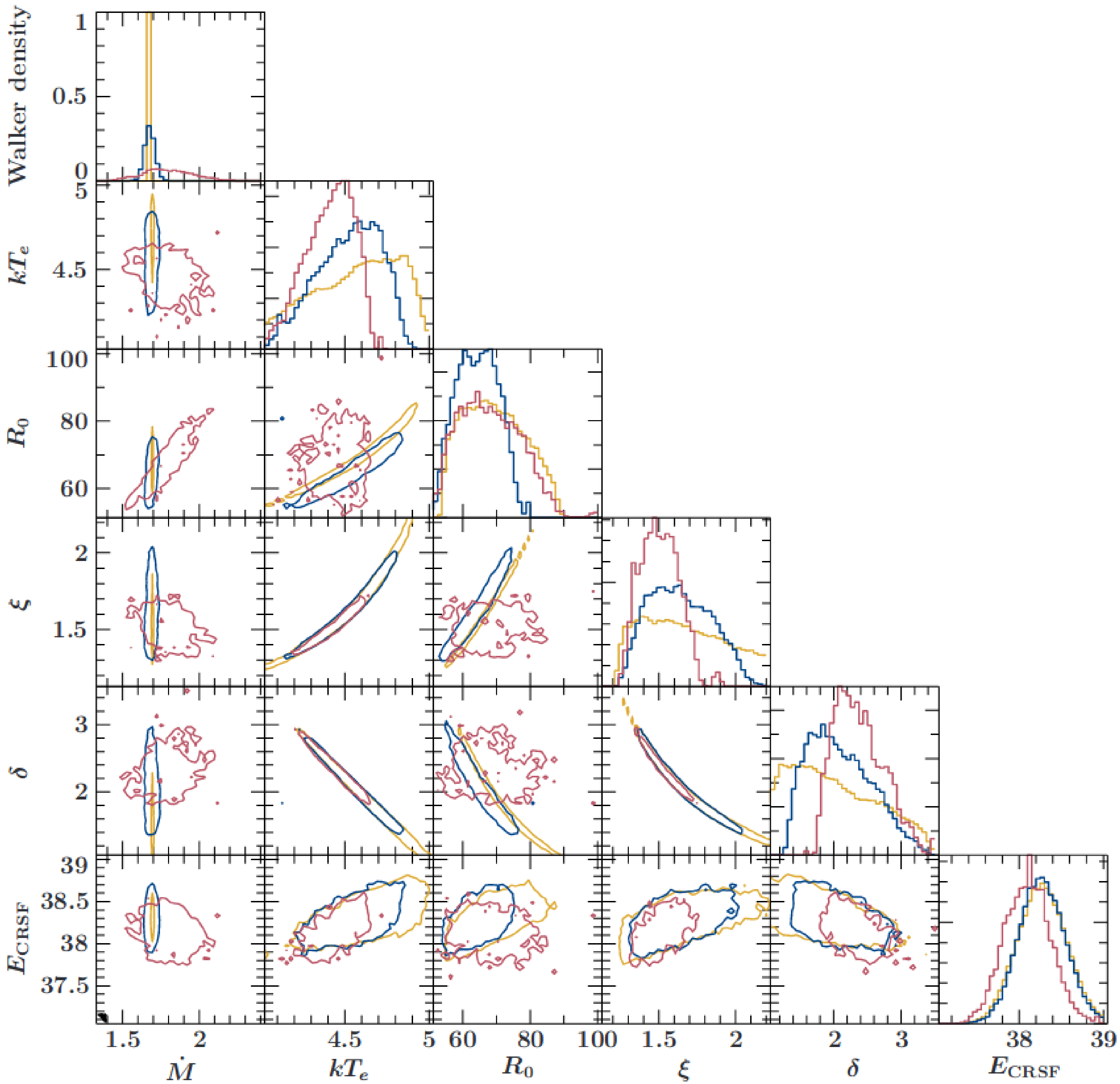
Model fits with physically motivated accretion column models are now possible.

Yield reasonable column parameters

Example: Cen X-3 Thalhammer et al. (2021):

- $\dot{M} = 1.776 \times 10^{17}\,\mathrm{g\,s^{-1}}$,
- $kT_e \sim 4.77^{+0.08}_{-0.09}\,\mathrm{keV}$,
- $r_0 = 77^{+5}_{-4}\,\mathrm{m}$,
- $B = 3.32 \times 10^{12}\,\mathrm{G}$

But large systematic uncertainties due to simplified column models.



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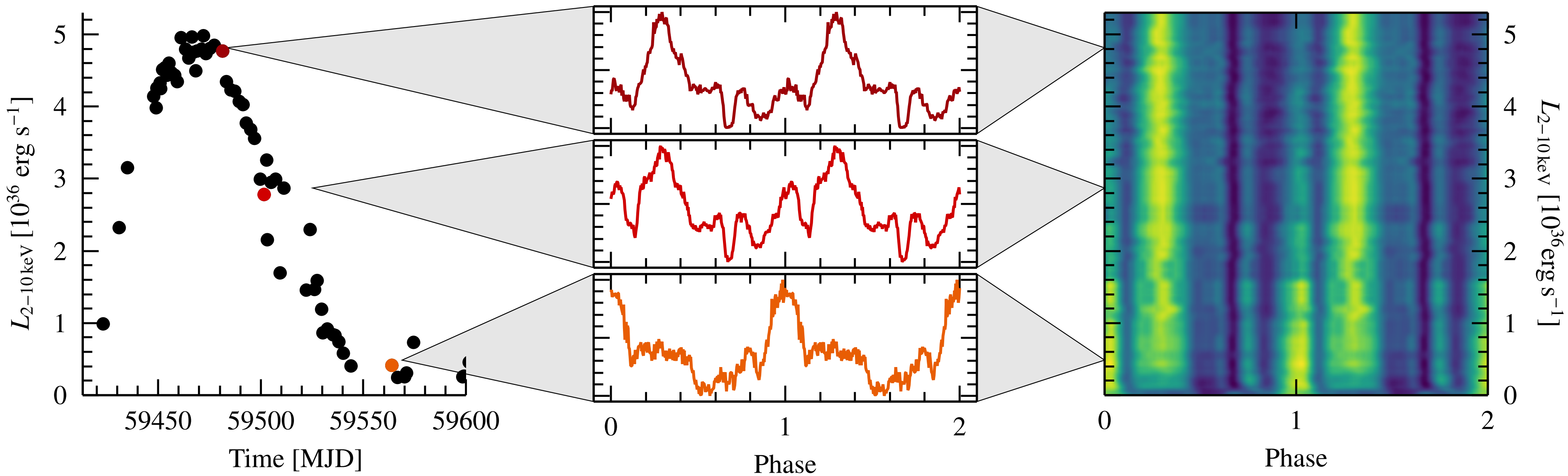
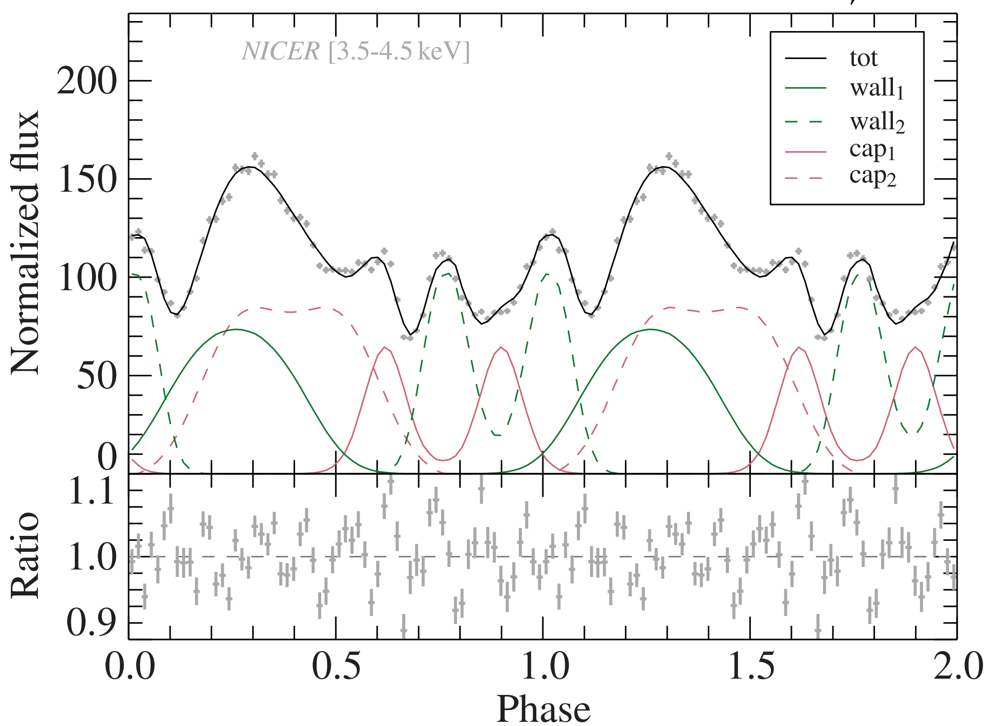
nn models.

Accretion columns



EXO 2030 + 275, XMAG collab., in prep., Thalhammer et al. (2024)

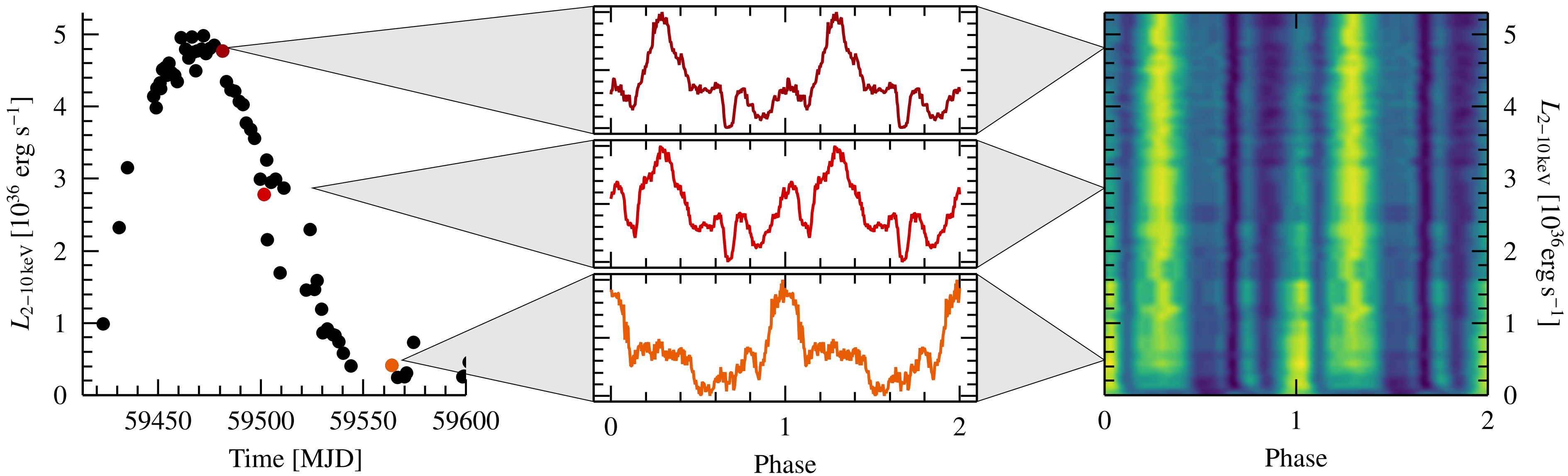


In some sources: systematic change in pulse profile shape with L_X (i.e., $\dot{M}$).

Profile modeling with Gaussian emission characteristic (include light bending)

(Thalhammer et al., 2024)

Accretion columns



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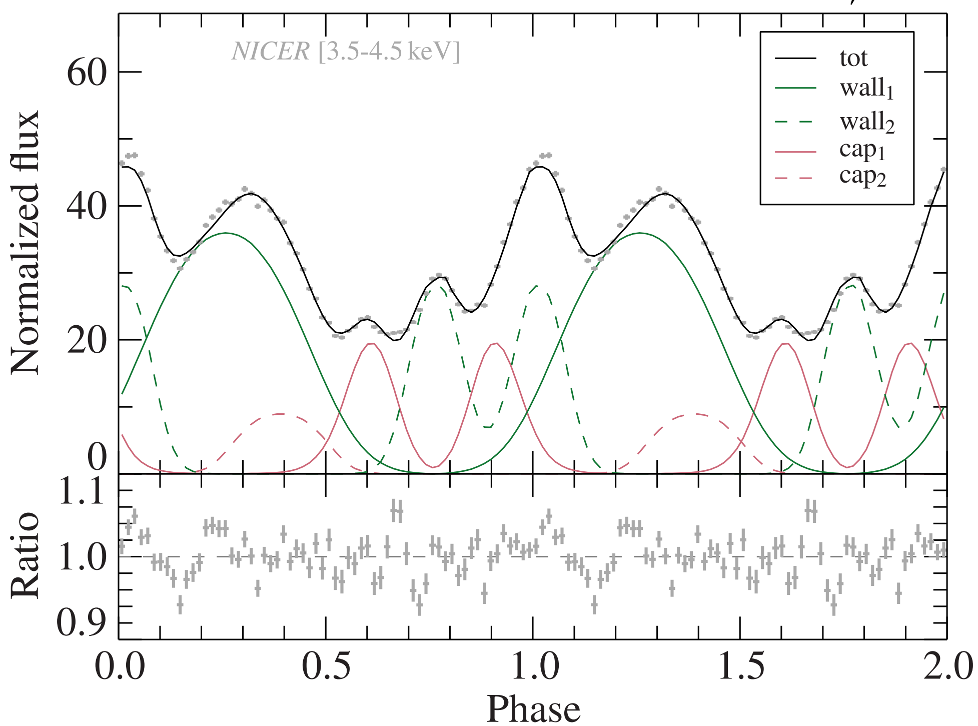

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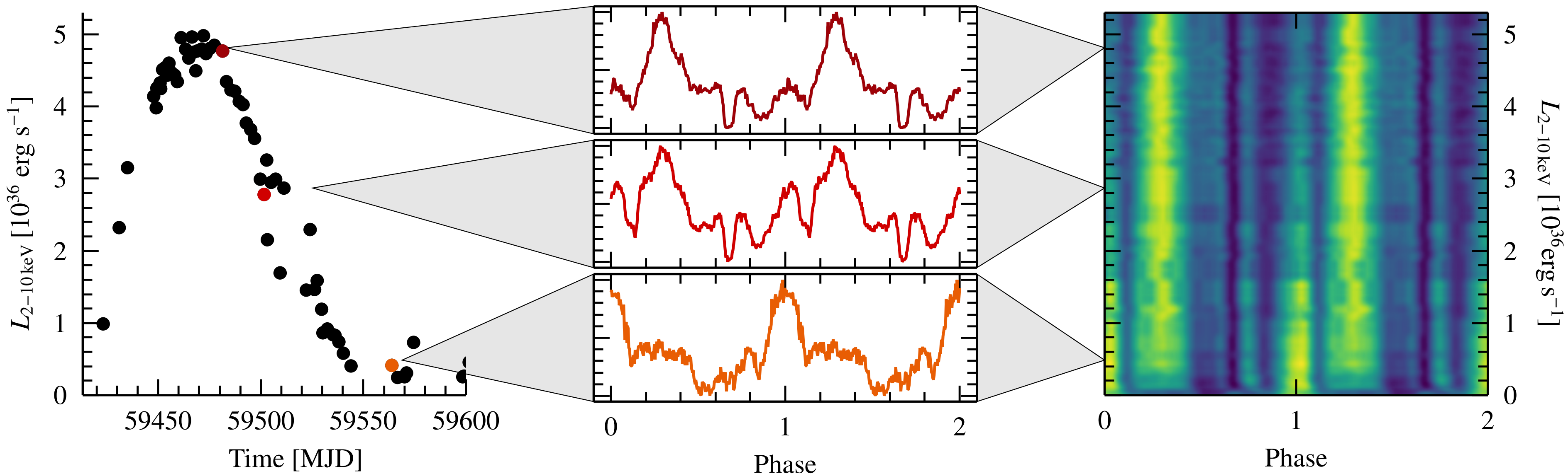

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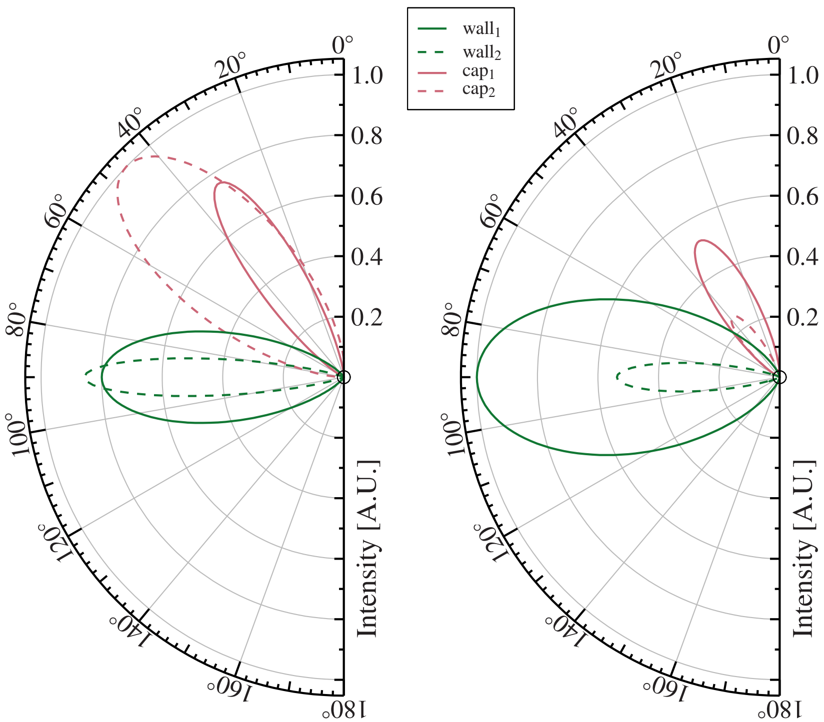

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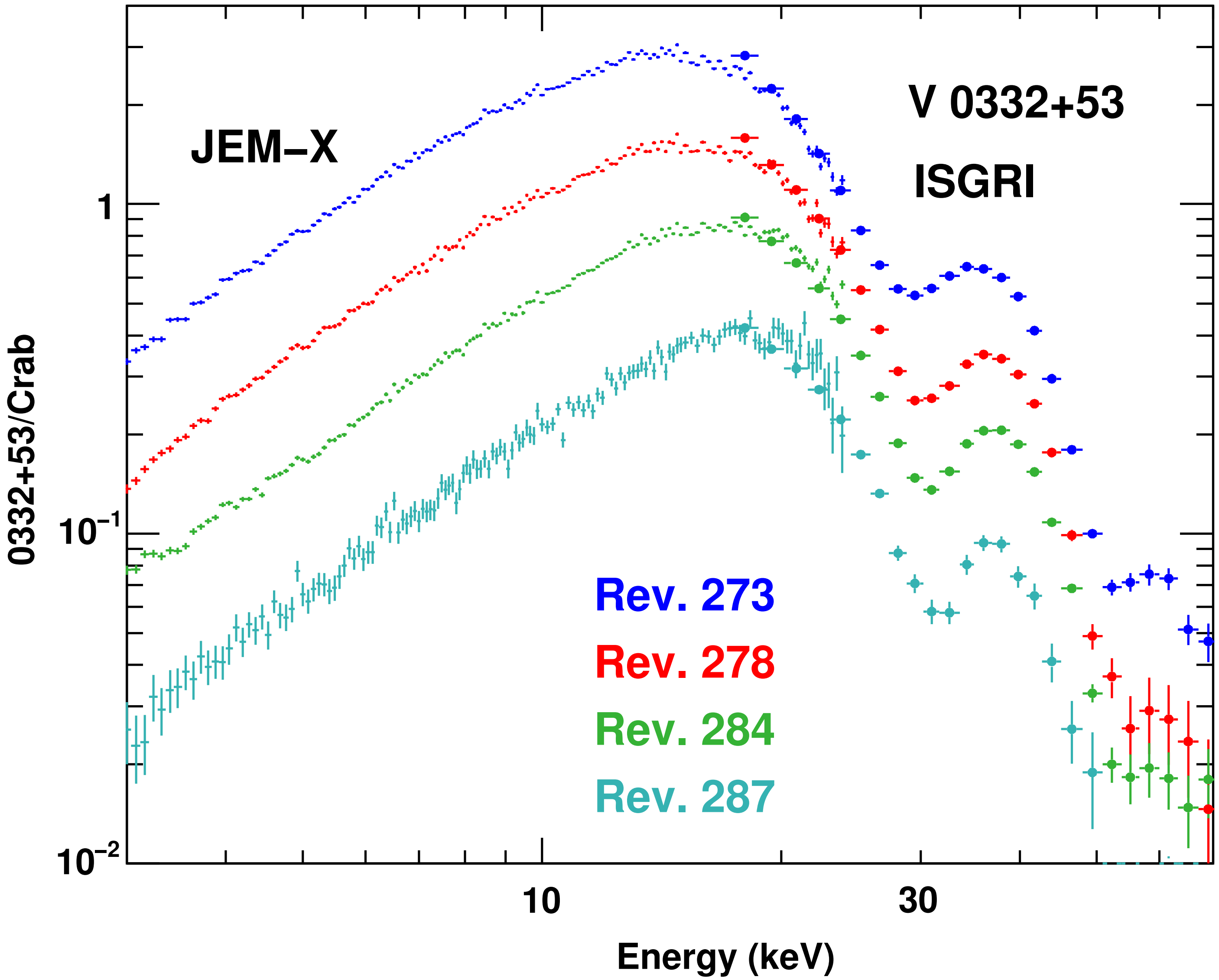


Cyclotron lines: inelastic scattering of photons off electrons in quantized orbits in strong B-field on magnetic poles of neutron stars.

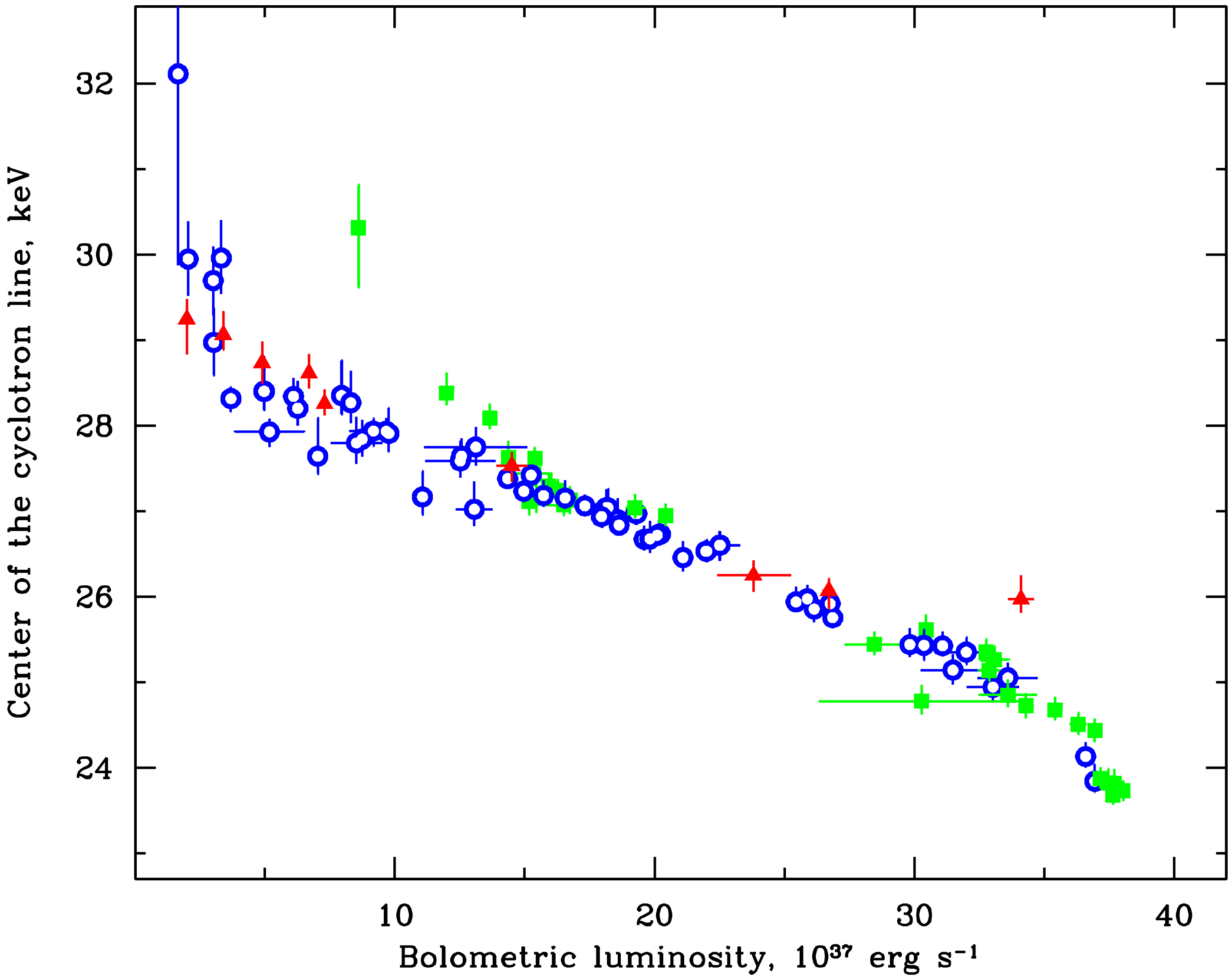
$\Longrightarrow$ can measure neutron star B-field

$\Longrightarrow$ can probe accretion column evolution

See talk by R. Staubert

(V0322 + 53; Mowlavi et al., 2006)

Accretion columns



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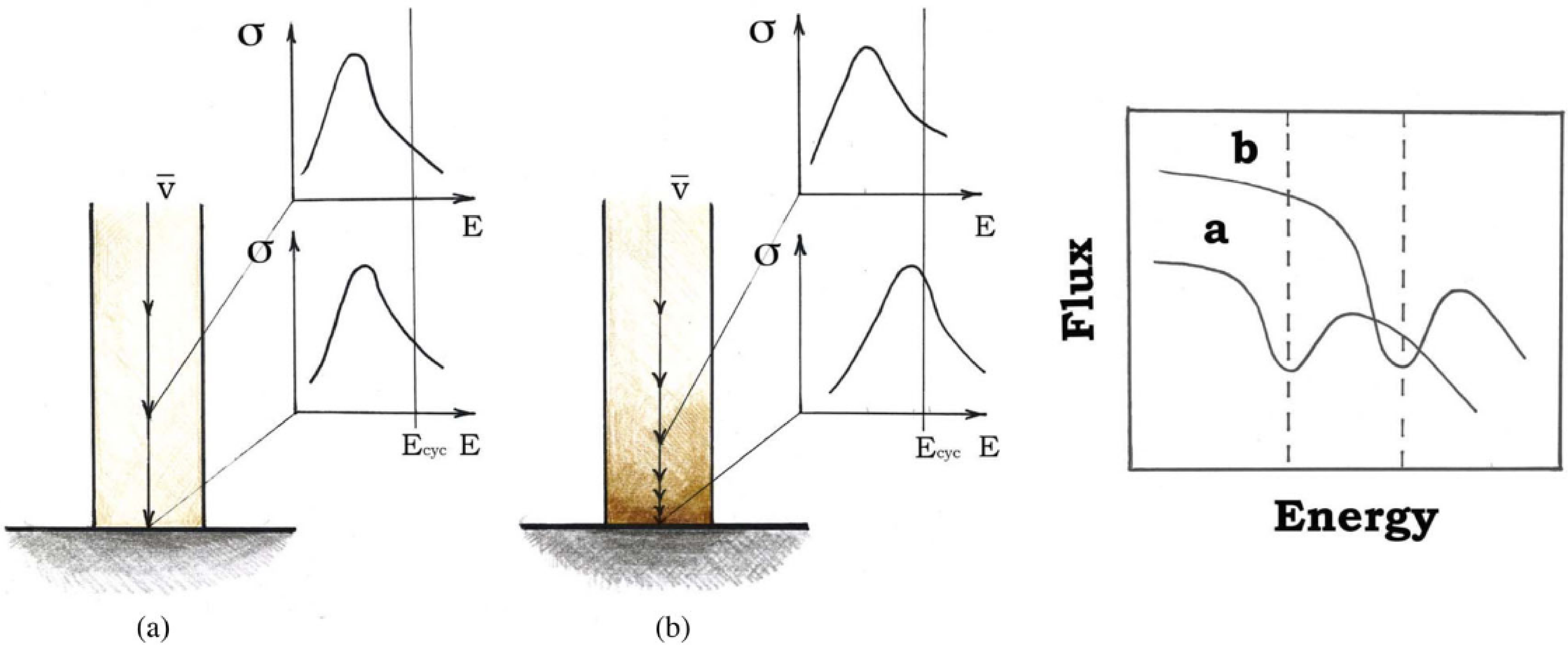
See talk by R. Staubert

(V0332+53; Tsygankov et al., 2010)

Accretion columns

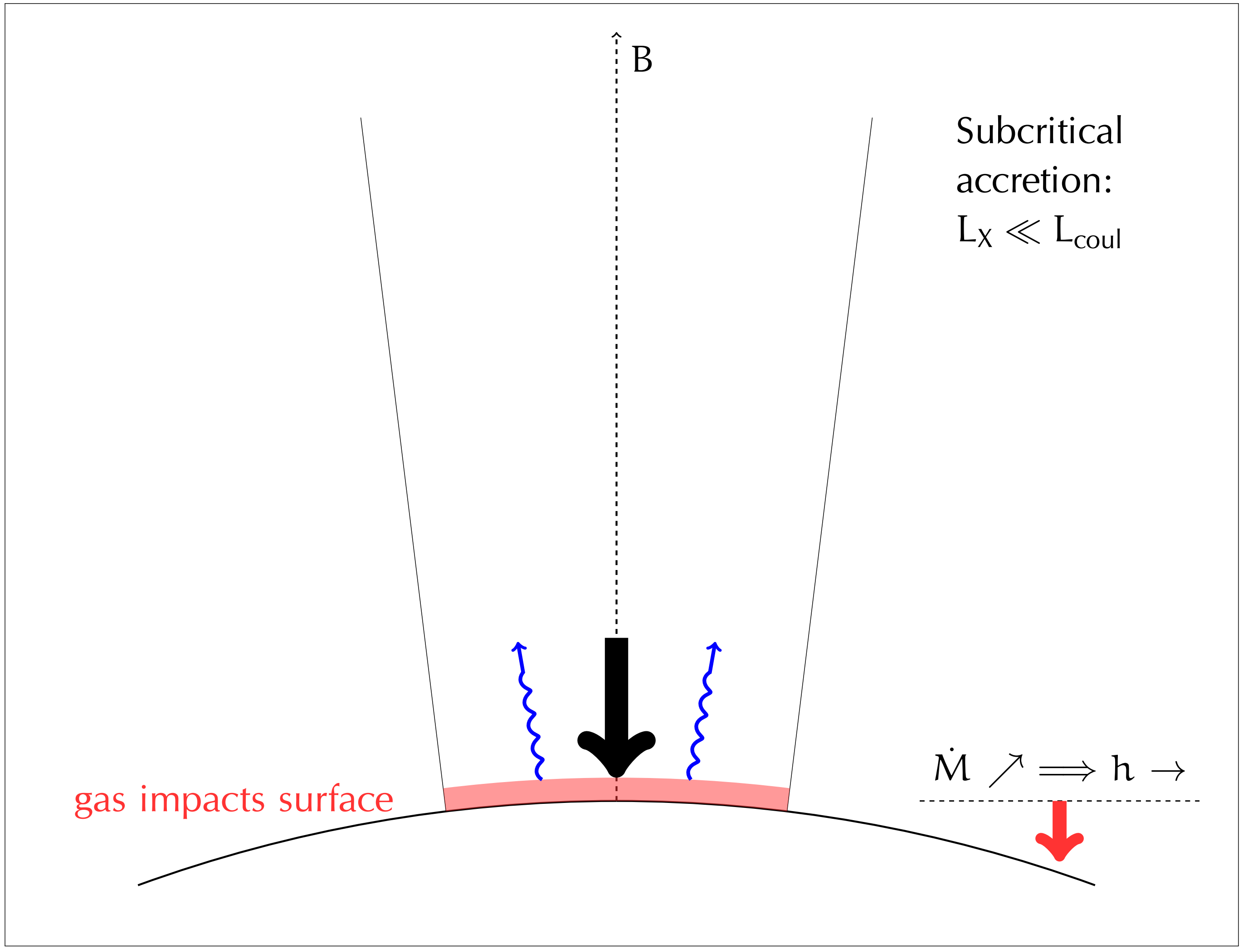


(Mushtukov et al., 2015, Fig. 1)

Explanation for change in CRSF:

- change in height of shock with $\dot{M}$?
- change in velocity profile due to changing $\dot{M}$?

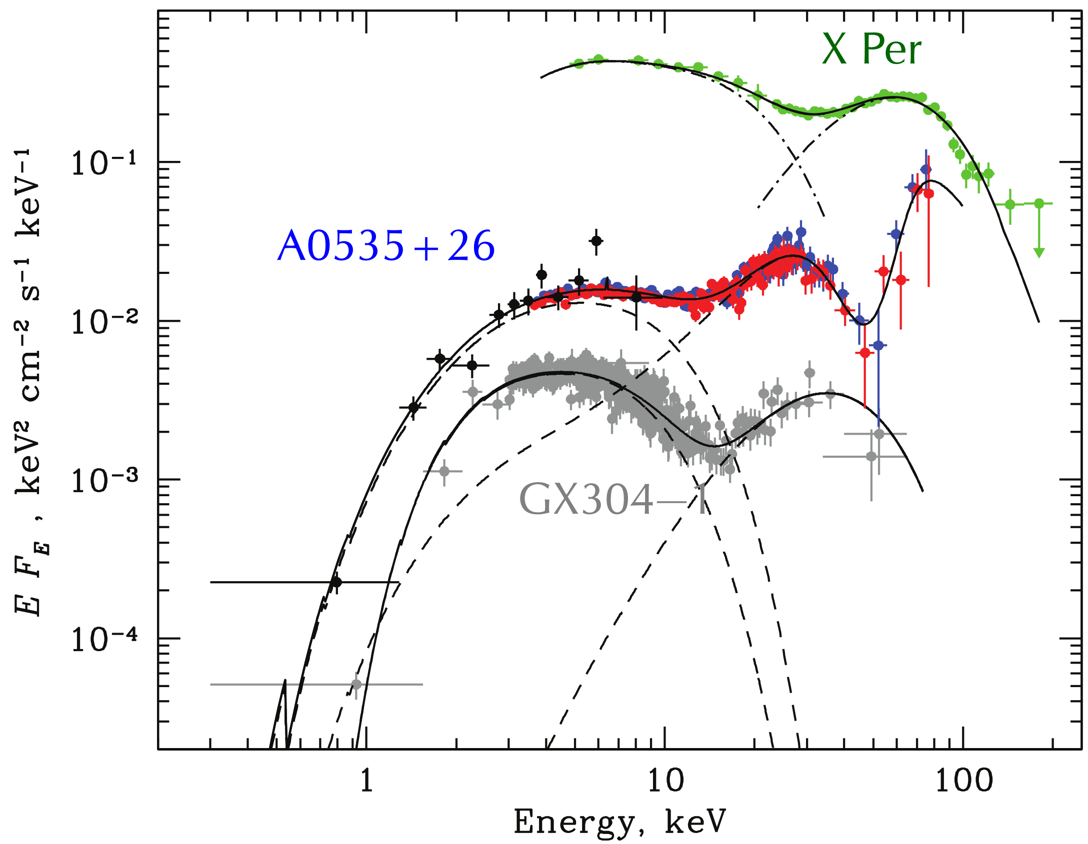
Accretion columns



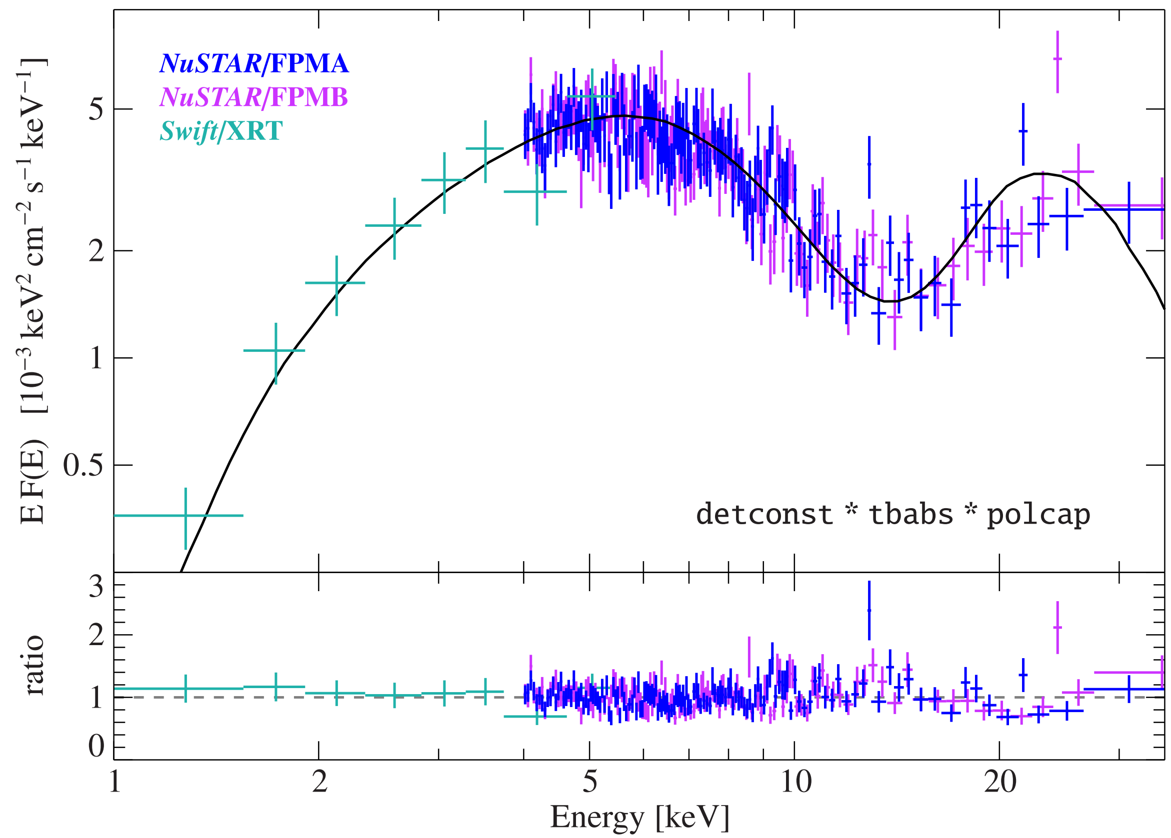
after P. Becker

really faint sources: accreted material smashes into the crust

Accretion columns



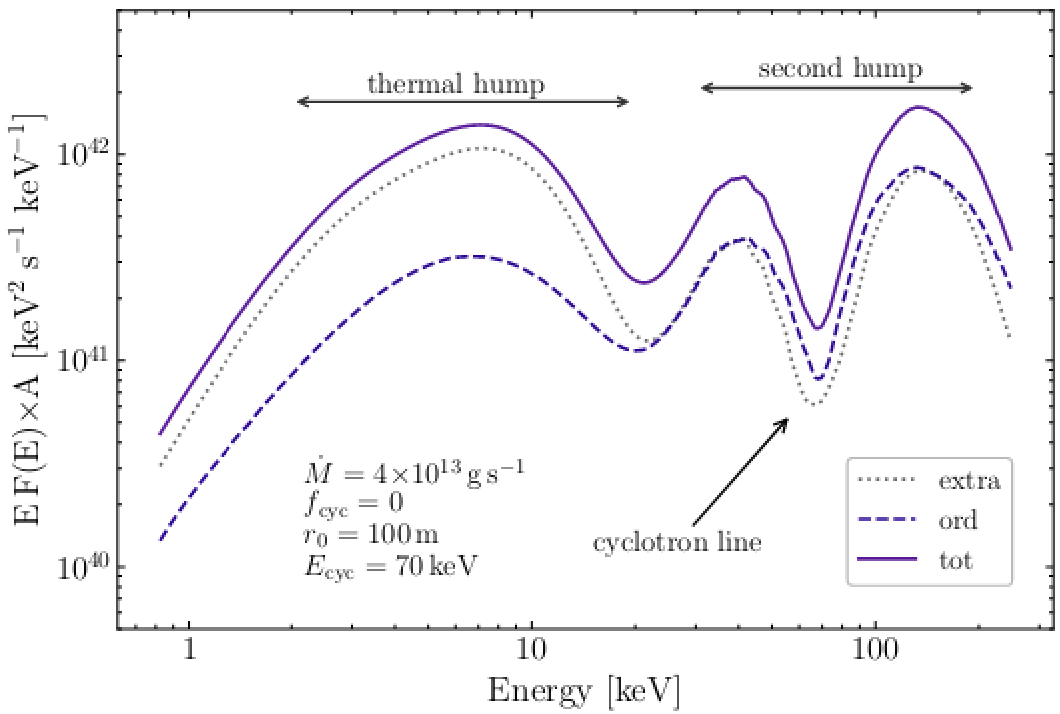
(Tsygankov et al., 2019)

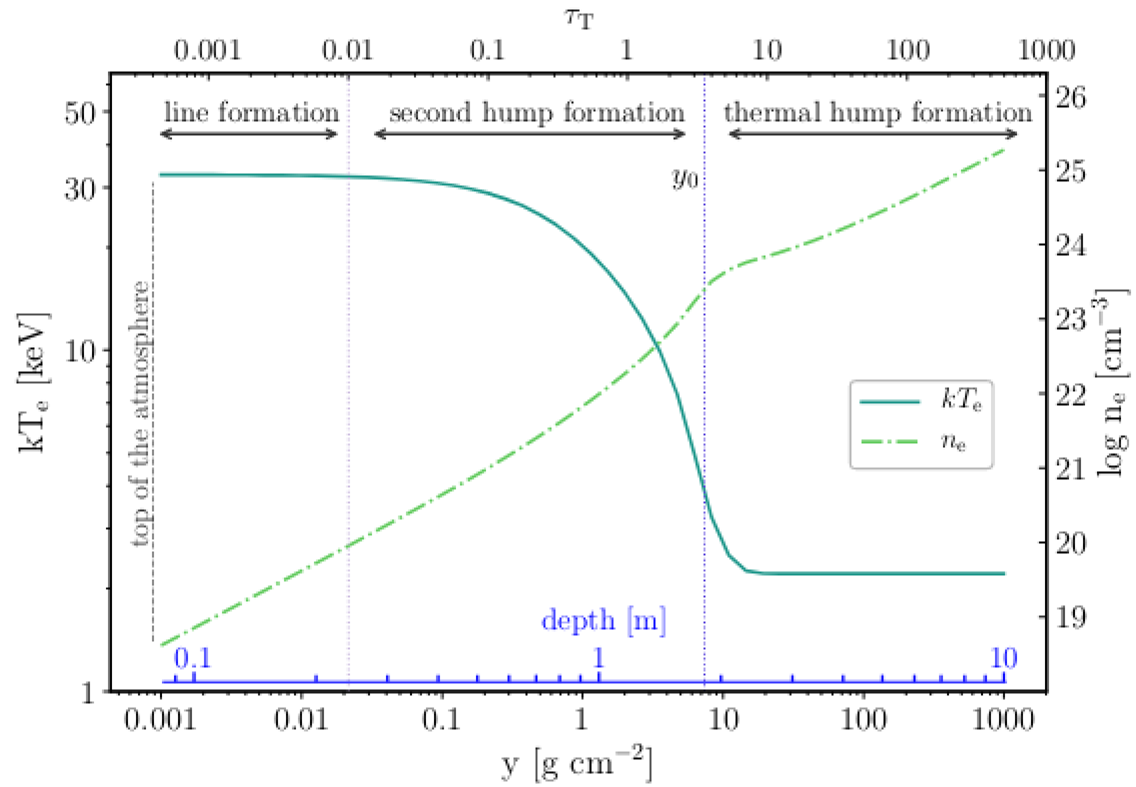


(GX 304−1; Sokolova-Lapa et al., 2021a)

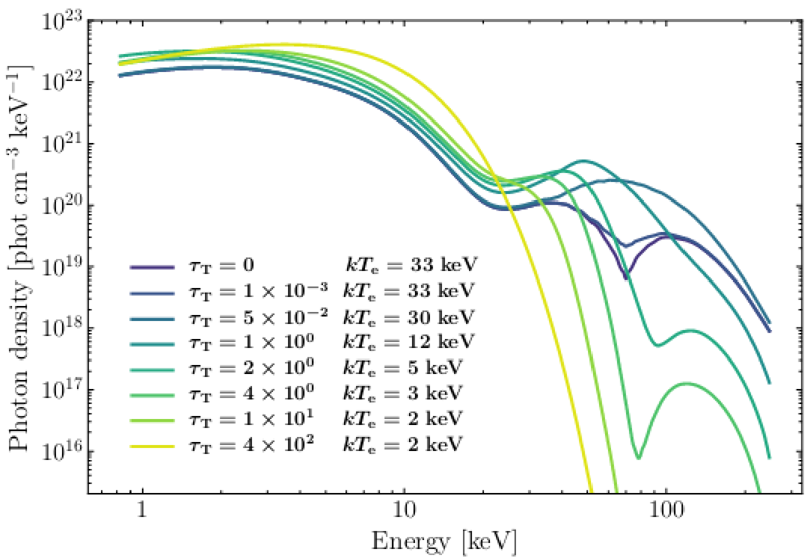
Lowest $\dot{M}$: Fundamental change in structure of spectrum. Important for studying fundamental physics of matter in very strong B fields

Accretion columns





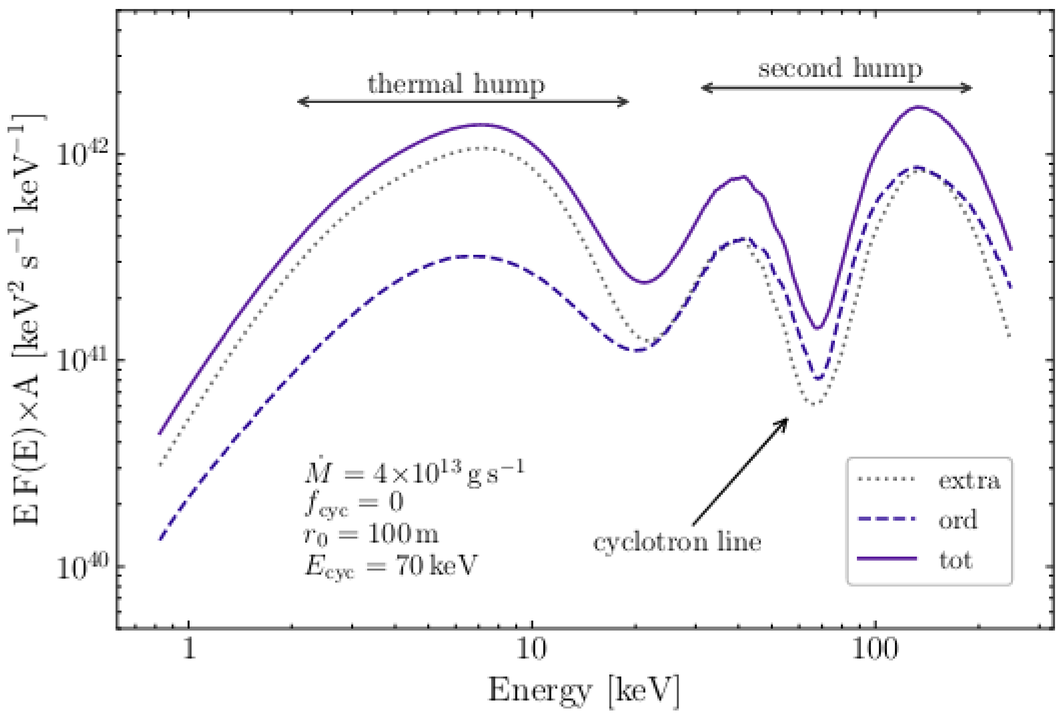
(Sokolova-Lapa et al., 2021b, Fig. 4)

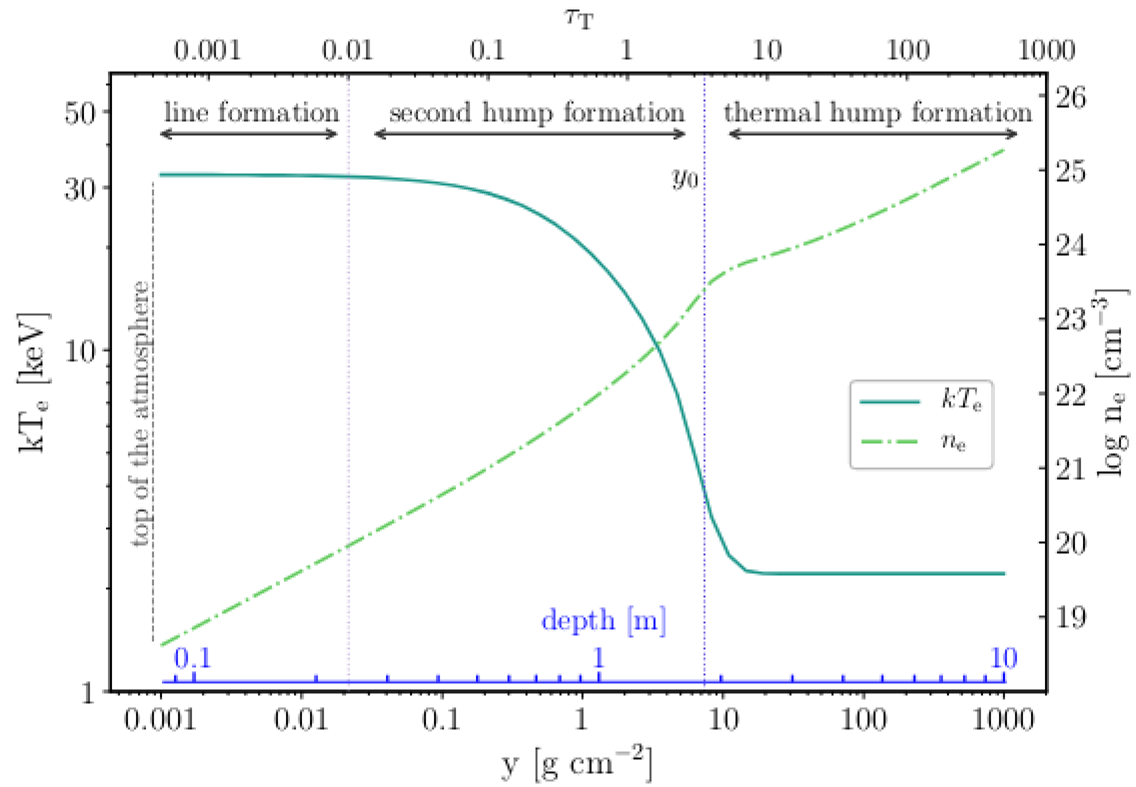


Modeling of structure at low L: start having good physical understanding

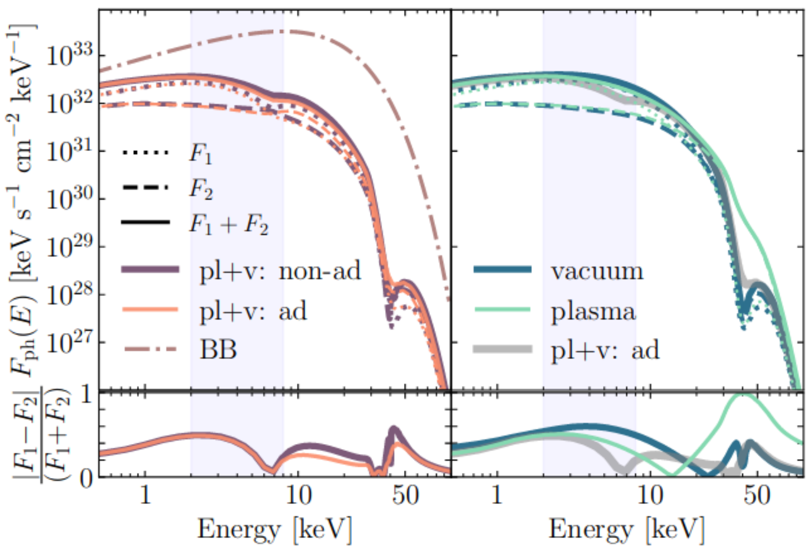
(Sokolova-Lapa et al., 2021b, Fig. 5)

Accretion columns





(Sokolova-Lapa et al., 2021b, Fig. 4)



Modeling of structure at low L: start having good physical understanding

(Sokolova-Lapa et al., 2023, Fig. 5)

Summary

Recent years have seen significant progress in the area of High Mass X-ray Binaries, both theoretical and observational:

- modeling of wind accretion,
- characterization of wind accretion,
  XRISM will be absolutely phenomenal
- (computers are now fast enough to do proper radiative transfer in accretion columns),
- low-L accretion: new tool for understanding accretion columns,
- polarization as new, powerful tool to constrain geometry.

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