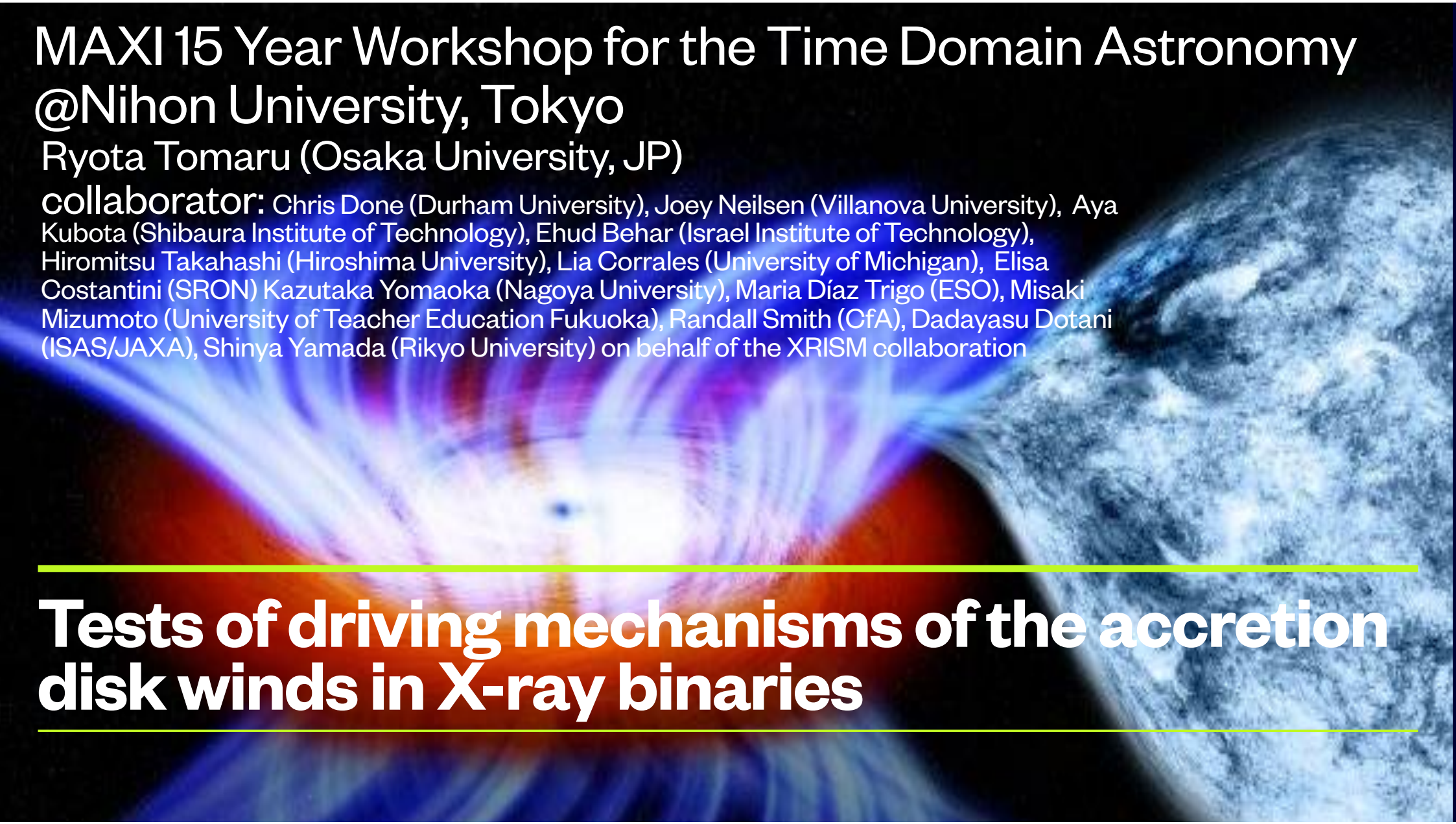


MAXI 15 Year Workshop for the Time Domain Astronomy @Nihon University, Tokyo

Ryota Tomaru (Osaka University, JP)
collaborator: Chris Done (Durham University), Joey Neilsen (Villanova University), Aya Kubota (Shibaura Institute of Technology), Ehud Behar (Israel Institute of Technology), Hiromitsu Takahashi (Hiroshima University), Lia Corrales (University of Michigan), Elisa Costantini (SRON) Kazutaka Yomaoka (Nagoya University), Maria Díaz Trigo (ESO), Misaki Mizumoto (University of Teacher Education Fukuoka), Randall Smith (CfA), Dadayasu Dotani (ISAS/JAXA), Shinya Yamada (Rikyo University) on behalf of the XRISM collaboration

Tests of driving mechanisms of the accretion disk winds in X-ray binaries

Accretion disc winds in LMXBs

Blue-shifted absorption lines in spectroscopic data

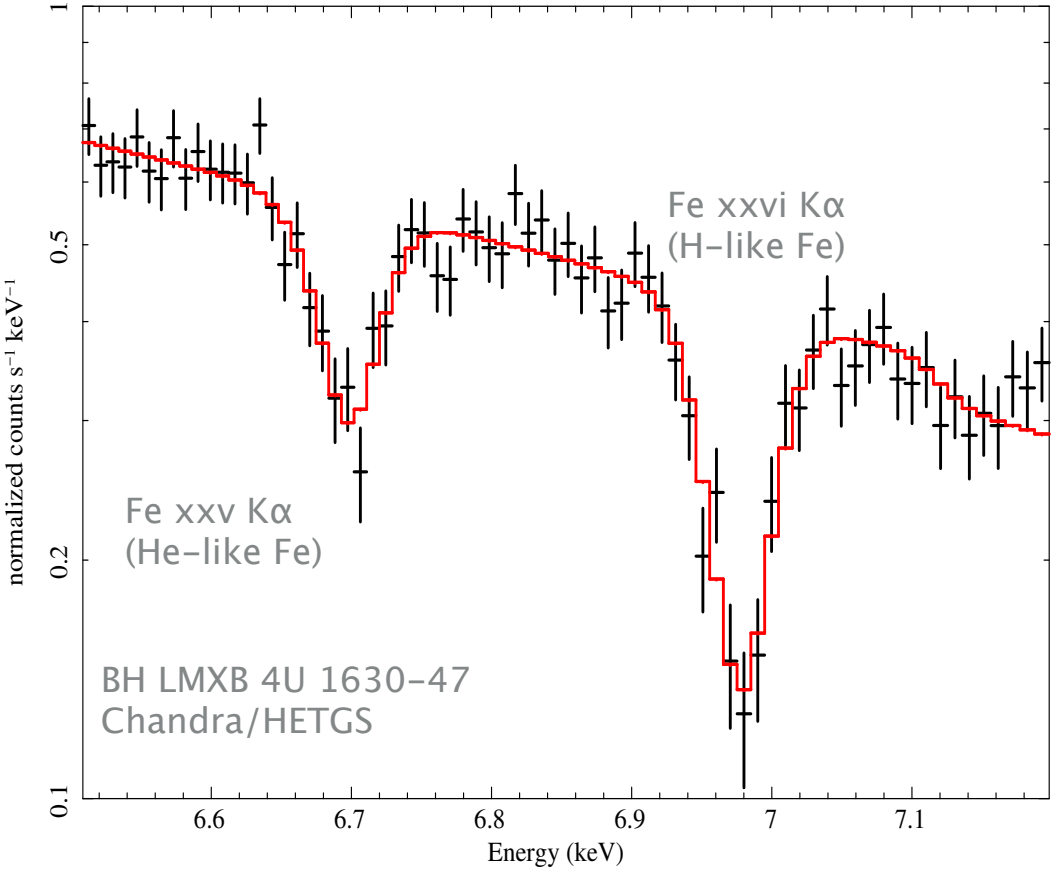
- Observable (e.g. Ueda+04, Lee+02)
  - $N_H \sim 10^{22-24}$ cm^{-2}
  - $v_{\rm out} \sim 100 - 1000$ km s^{-1} ($\sim 10^4 - 10^5\ R_g$)
  - $\xi = L/(nR^2) \sim 10^3 - 10^5$ erg cm s^{-1}

    (H and He-like ions, especially Fe)
  - High inclination close to Edge-on ($i > 60°$)
- Large mass loss rate:

$$\dot{M}_w = 4\pi R^2 m_p n_p v_{\rm our} = 4\pi L/\xi v_{\rm out} m_p \sim \dot{M}_a$$

What powers these winds?

→ Physical models are required.



Accretion disc winds in LMXBs

Blue-shifted absorption lines in spectroscopic data

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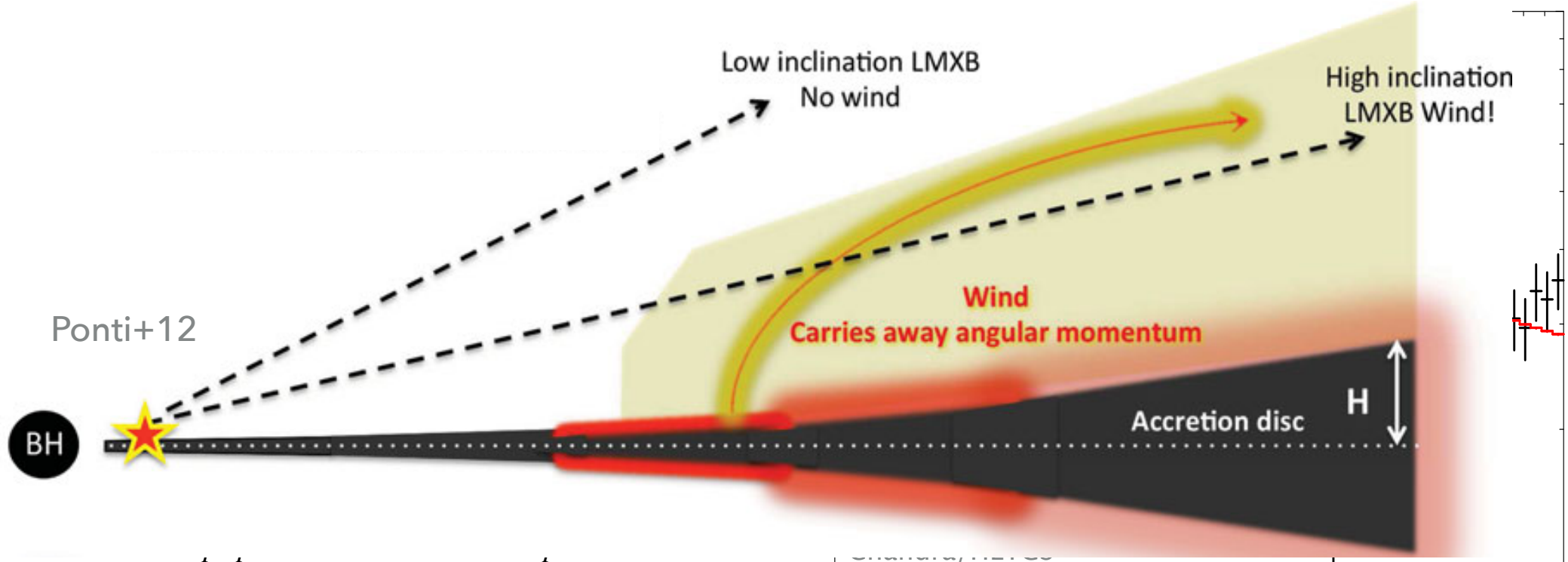


What powers these winds?

→ Physical models are required.

Thermal winds (Compton heated winds)

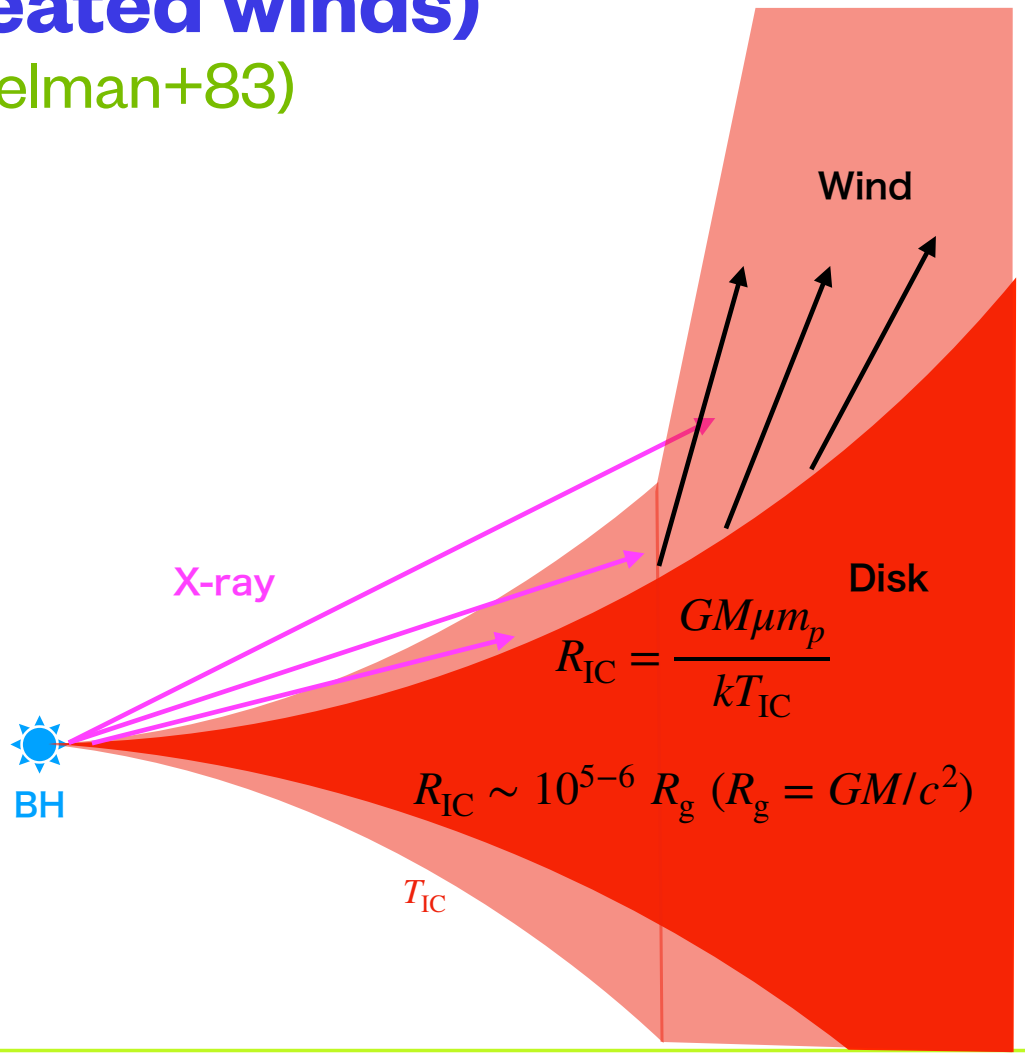
Powered by X-ray radiation heating (Begelman+83)

- The temperature of the disc surface

$$T_{\rm IC} = \frac{\int EF_E(E)dE}{4k\int F_E(E)dE} \sim 10^{7-8}\ {\rm K}$$

- Gas pressure force > The gravity
  →Wind ($R > 0.2\ R_{\rm IC}$)
  Inevitable occurrence (if R is large)
- Radiation force also affects.
  (thermal-radiative winds if $L/L_{\rm Edd}$ is large)
- $v_{\rm esc}(R_{\rm IC}) \sim 100 - 1000\ {\rm km\ s^{-1}}$

Possible to predict the dynamics and line profiles
by X-ray SED, $L/L_{\rm Edd}$, and the outer disc size



The thermal-radiative wind model

We build radiation hydrodynamic (RHD) simulation code.

- The new RHD code for comparison with observation
  - Input parameters
    (SED, $L/L_{\rm Edd}$, Disc size)
  - Radiative heating/cooling
    (Compton and Inverse Compton,
    Lines, photoelectric abs, recombination,
    bremsstrahlung with $Z = Z_{\rm solar}$)
  - Radiative acceleration + attenuation
    (scattering, lines and photoelectric abs)

The thermal-radiative wind model

Radiation hydrodynamic (RHD) simulations

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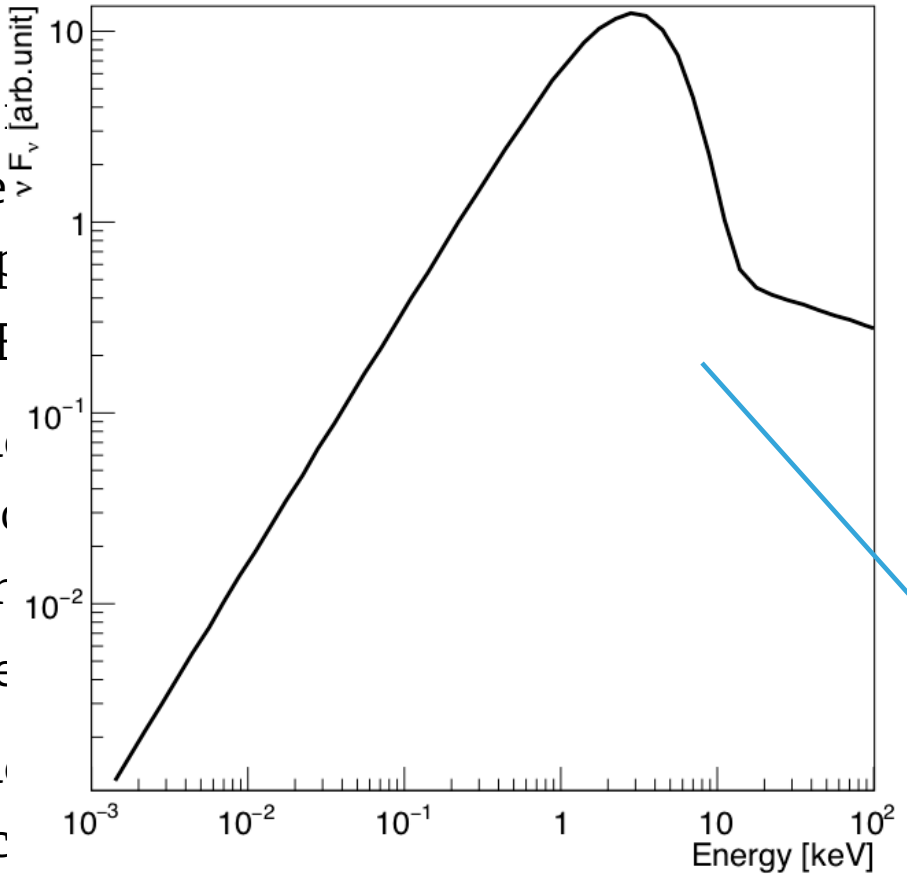
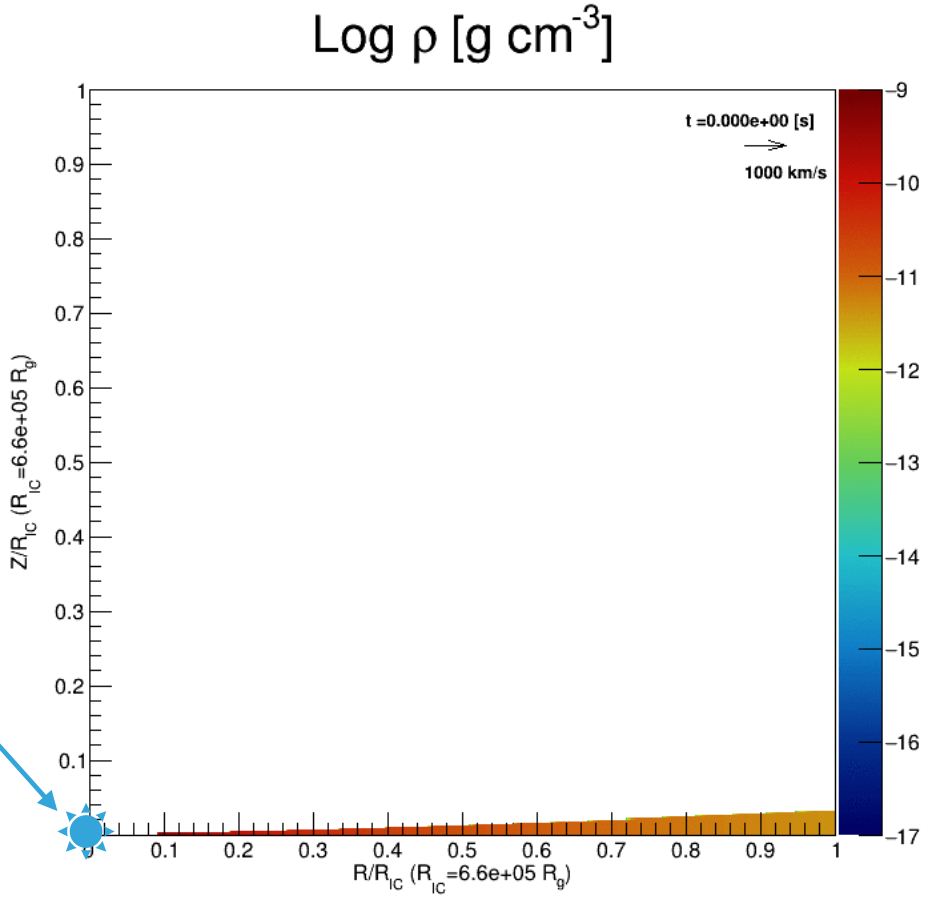
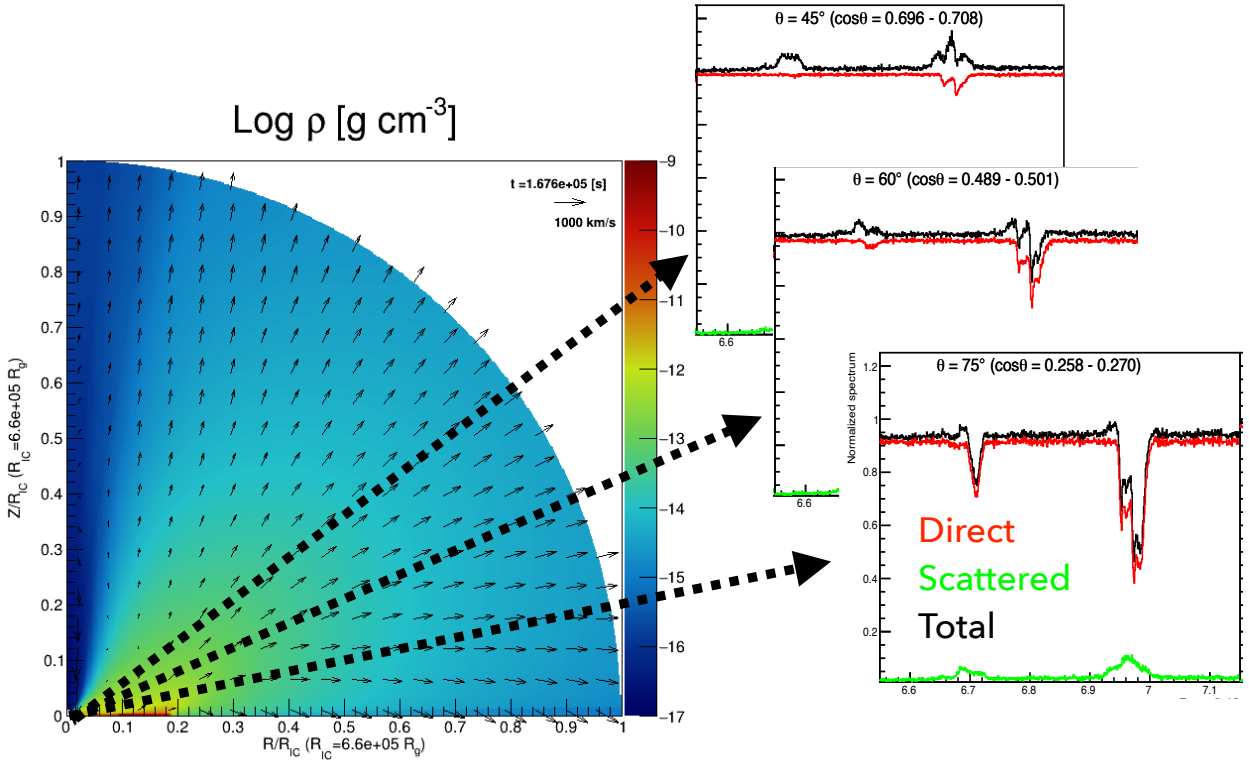
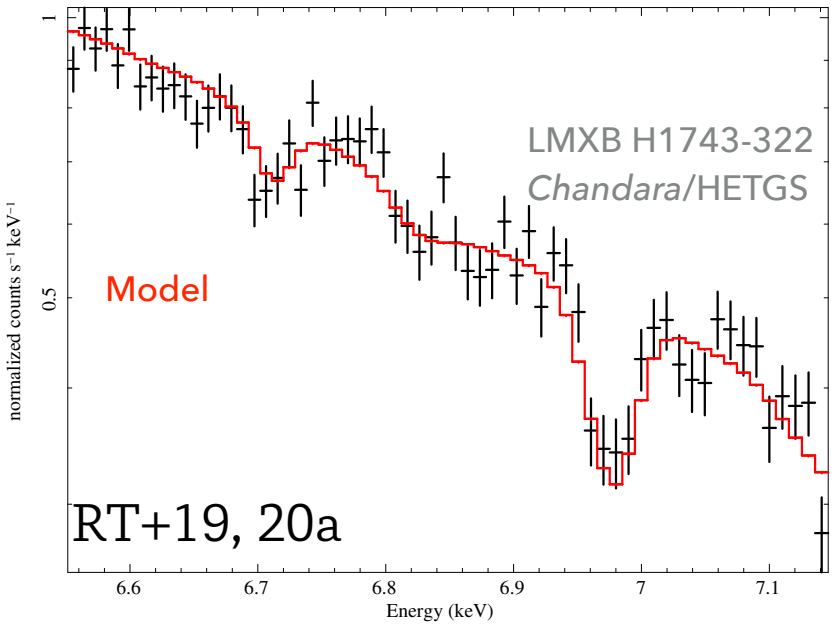




The RHD model

RHD simulation & Monte-Carlo radiation transfer

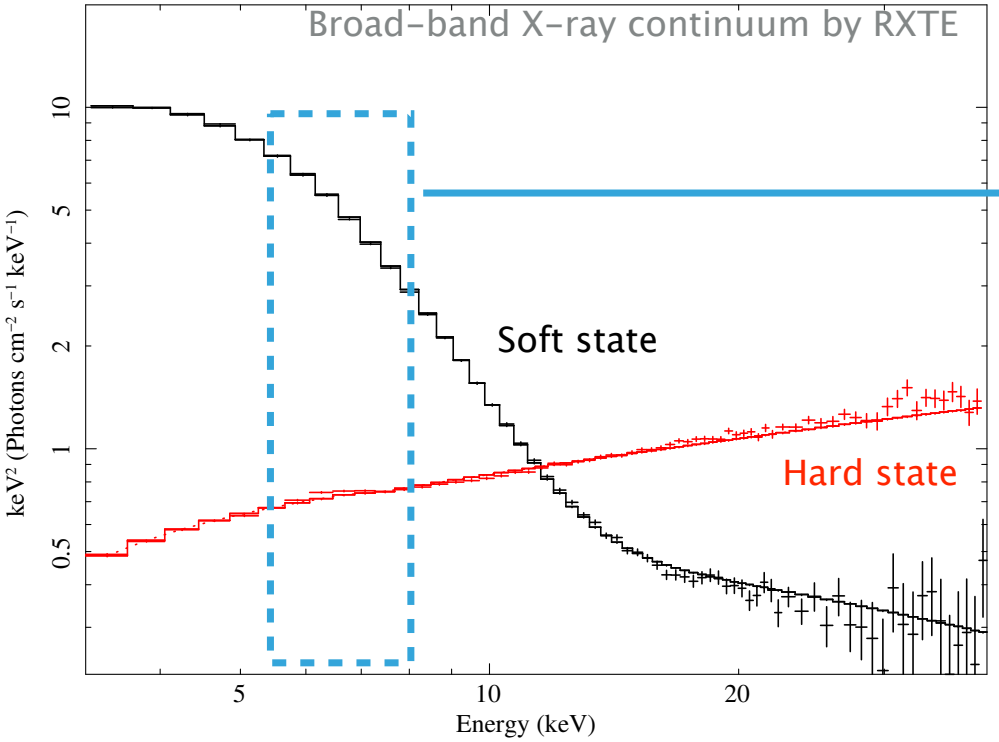


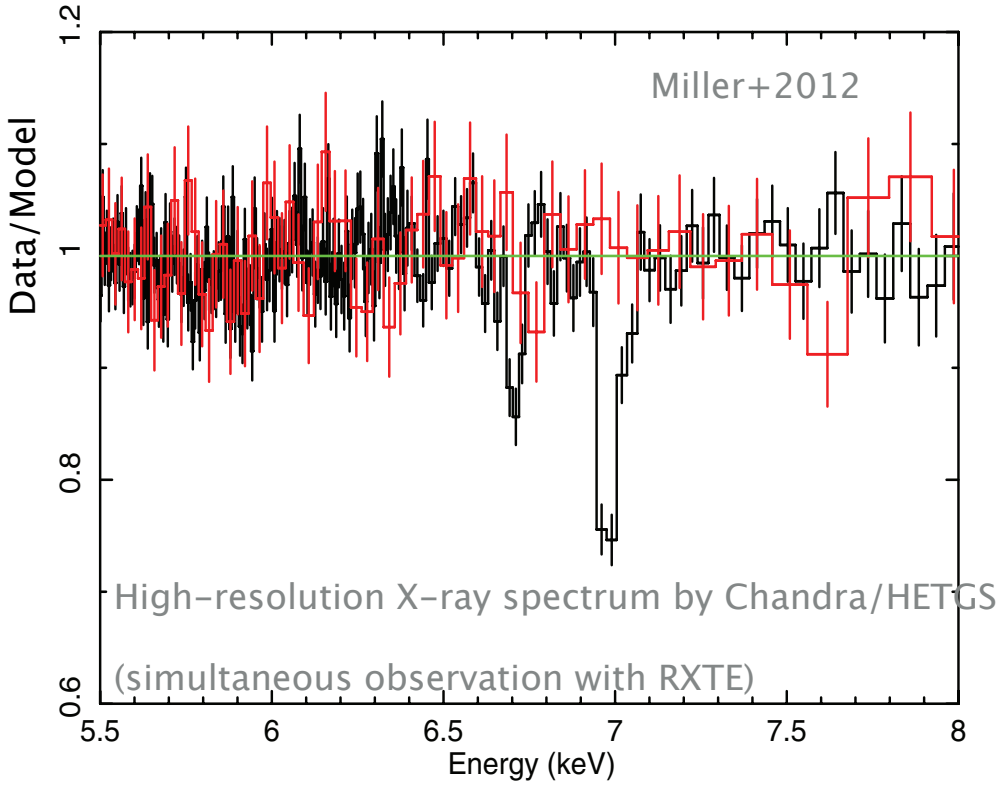


- RHD wind can explain the observed line profiles.

Absorption lines in H1743-322

Disappearance in the hard state

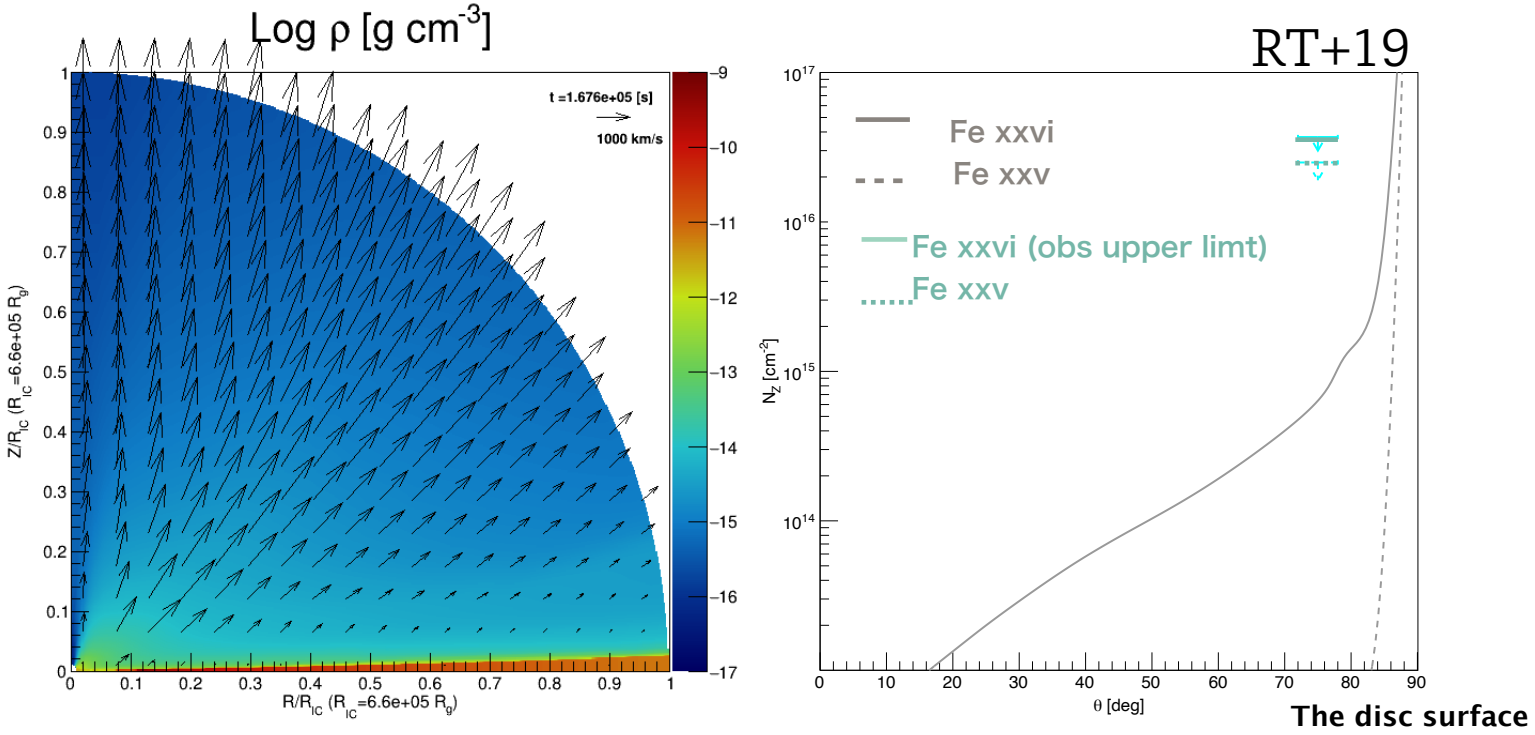




- Can our RHD wind model explain the wind in the hard state?

The comparison with observation

The RHD wind can not observed in the hard state.



- The wind is completely ionized.
- We confirm the RHD wind can explain the absorption appearance due to the different SEDs.

The dynamics of winds by different SED

The thermal equilibrium curve depends on the incident SED.

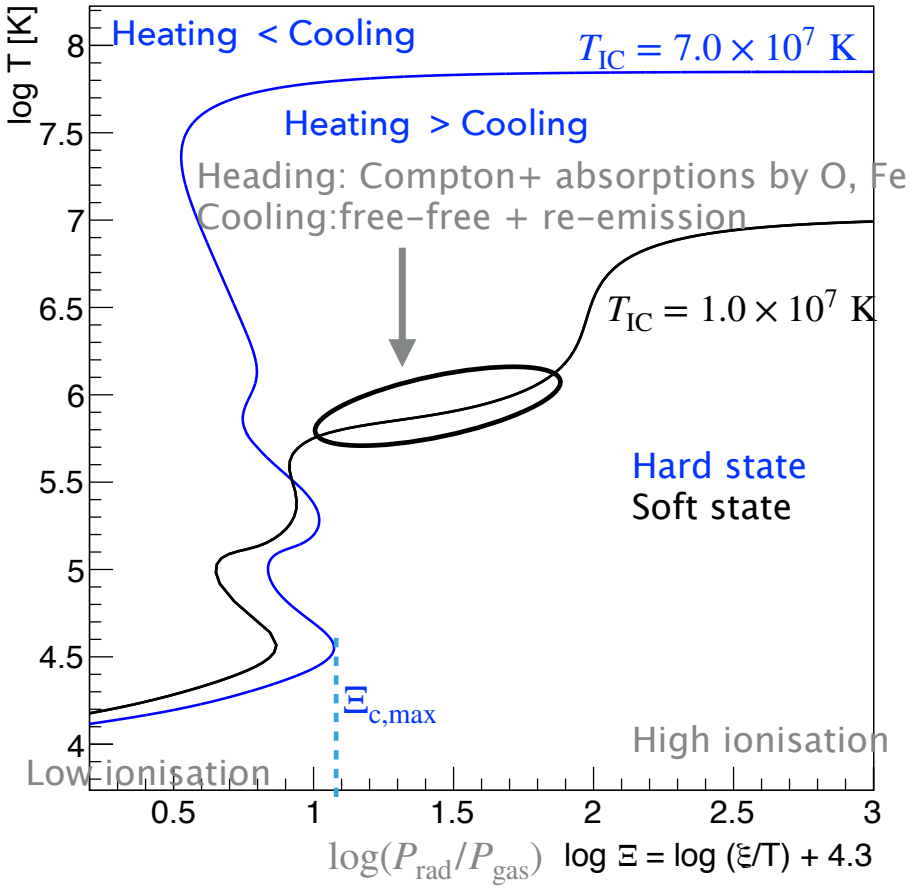
- $dT/d\Xi > 0$: Thermally stable

  With constant $\Xi = P_{\rm rad}/P_{\rm gas}$, T ↑

  →Cooling >Heating

  Thermal instability happens at $\Xi_{\rm c,max}$

  - Hard state: the rapid rise of $T \sim T_{\rm IC}$
    - We confirm the transition in the RHD simulation of the Hard state.
  - Soft state: stable mid-ionised state
    → Absorption lines

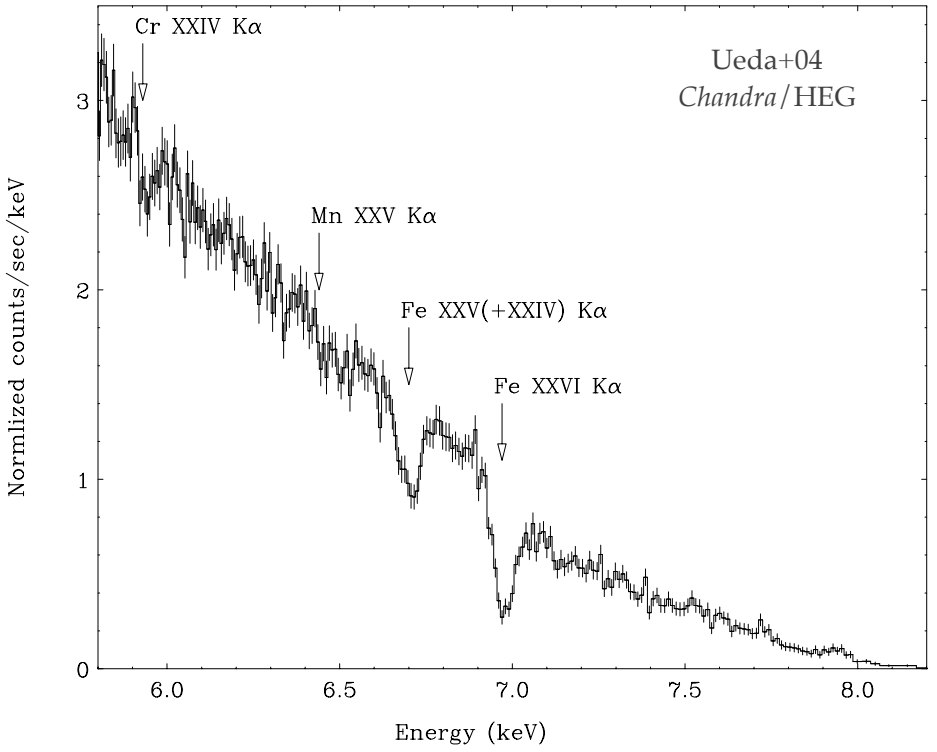


NS LMXB GX 13+1

Absorption lines are constantly observed.

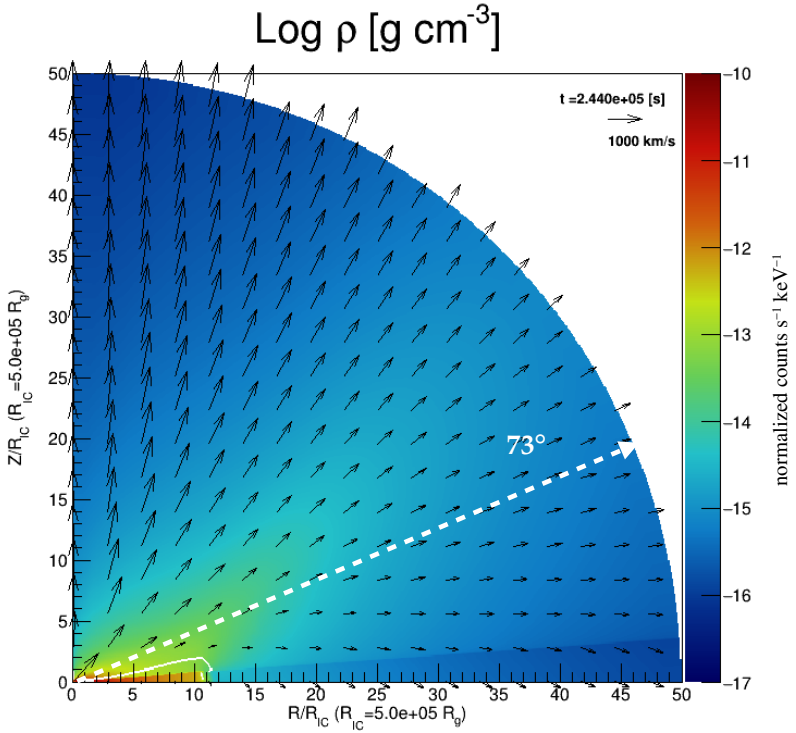
- Persistent bright NS $L = 0.5\ L_{\rm Edd}$
- Largest disc size $R_{\rm disc} = 10^{12}$ cm $(5 \times 10^6\ R_{\rm g})$
  - $P_{\rm orb} = 24$ d
  - $M_{\rm NS} \sim 1.4 M_\odot$
  - $M_{\rm s} = 5 M_\odot$
- →Thermal-radiative winds predict large columns.

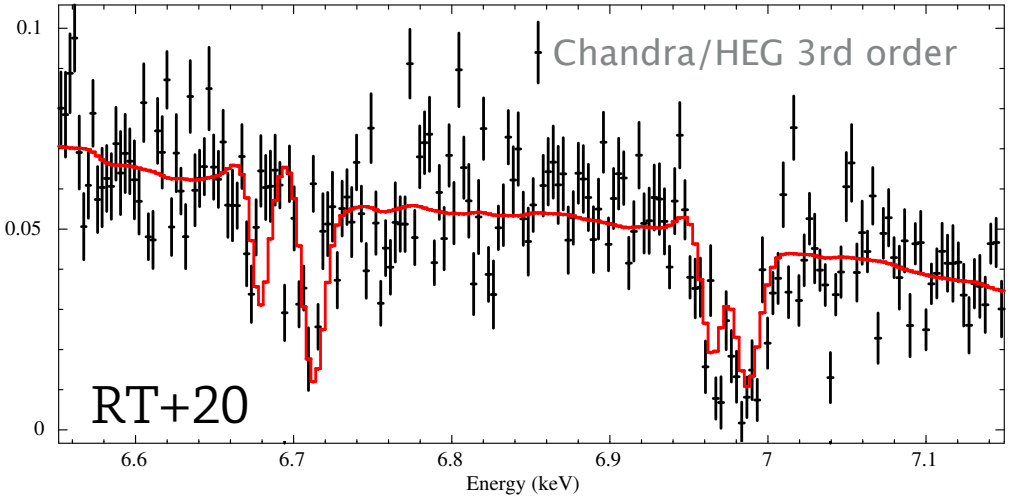
- Can our framework reproduce even large columns?
  SED, L, disc size→RHD→MCRT→ absorption lines
- We also analyzed the HEG 3rd spectrum
  $(\delta E \sim 20$ eV@7 keV$)$



The RHD model for NS LMXB GX 13+1

The RHD wind model works even in the NS system.

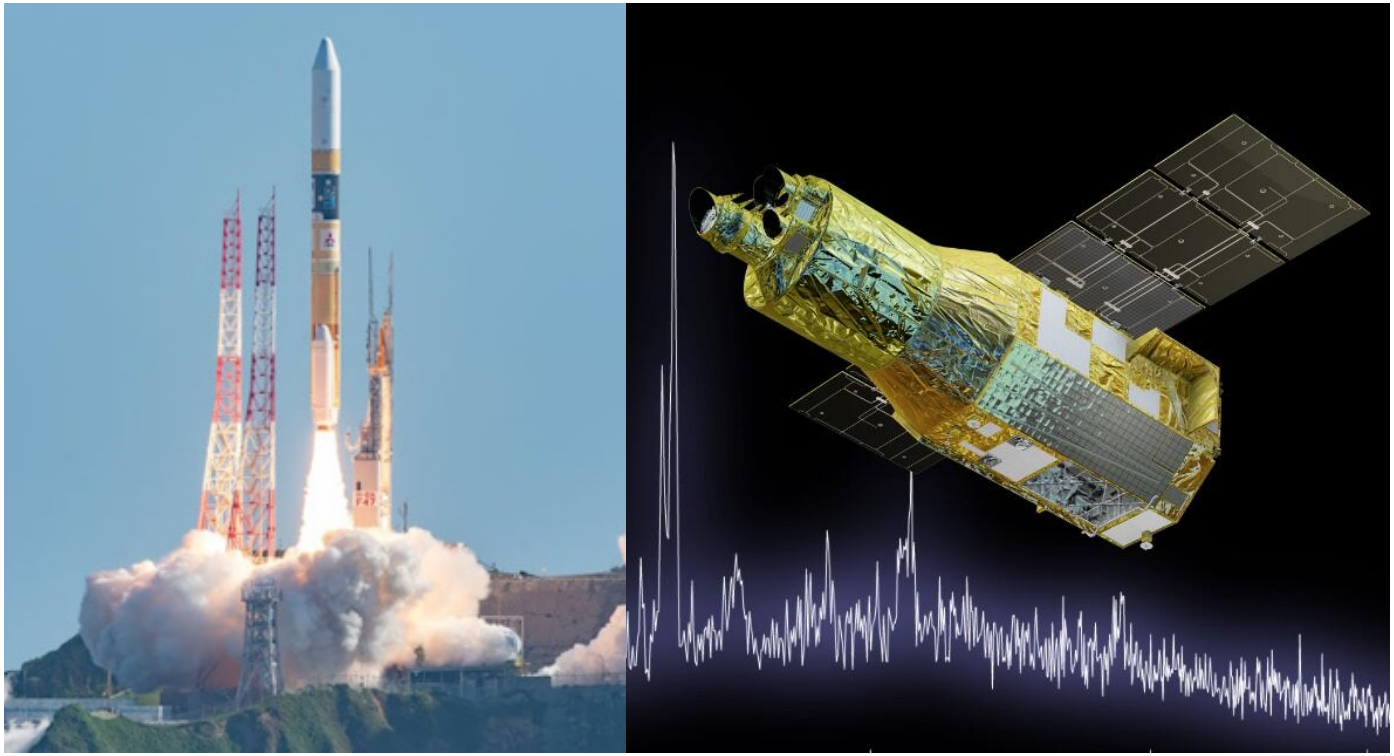




- The RHD model can explain line profiles with only one free parameter (inclination).
- The inclination is also consistent with observation.

XRISM (Launched on 7th September 2023)

I had been waiting since I was a master student!



- XRISM observed GX 13+1 in PV phase at 25 Feb 2024

Summary

- We build models of thermal-radiative (RHD) wind by RHD and RT simulations
- The RHD wind model can explain the observed X-ray spectrum by Chandra
  - Absorption lines in the soft state and disappearance in the hard state of H1743-322
  - Absorption lines of Neutron Star LMXB GX 13+1
- XRISM observation shows a lot of absorption lines in GX 13+1.
  - Supper-Eddington wind?
    - The spectrum requires 2 highly ionised absorbers (seems optically thick)
    - The line profile of our RHD wind model missed the faster component.