SMBH winds under the magnifying glass of WINE

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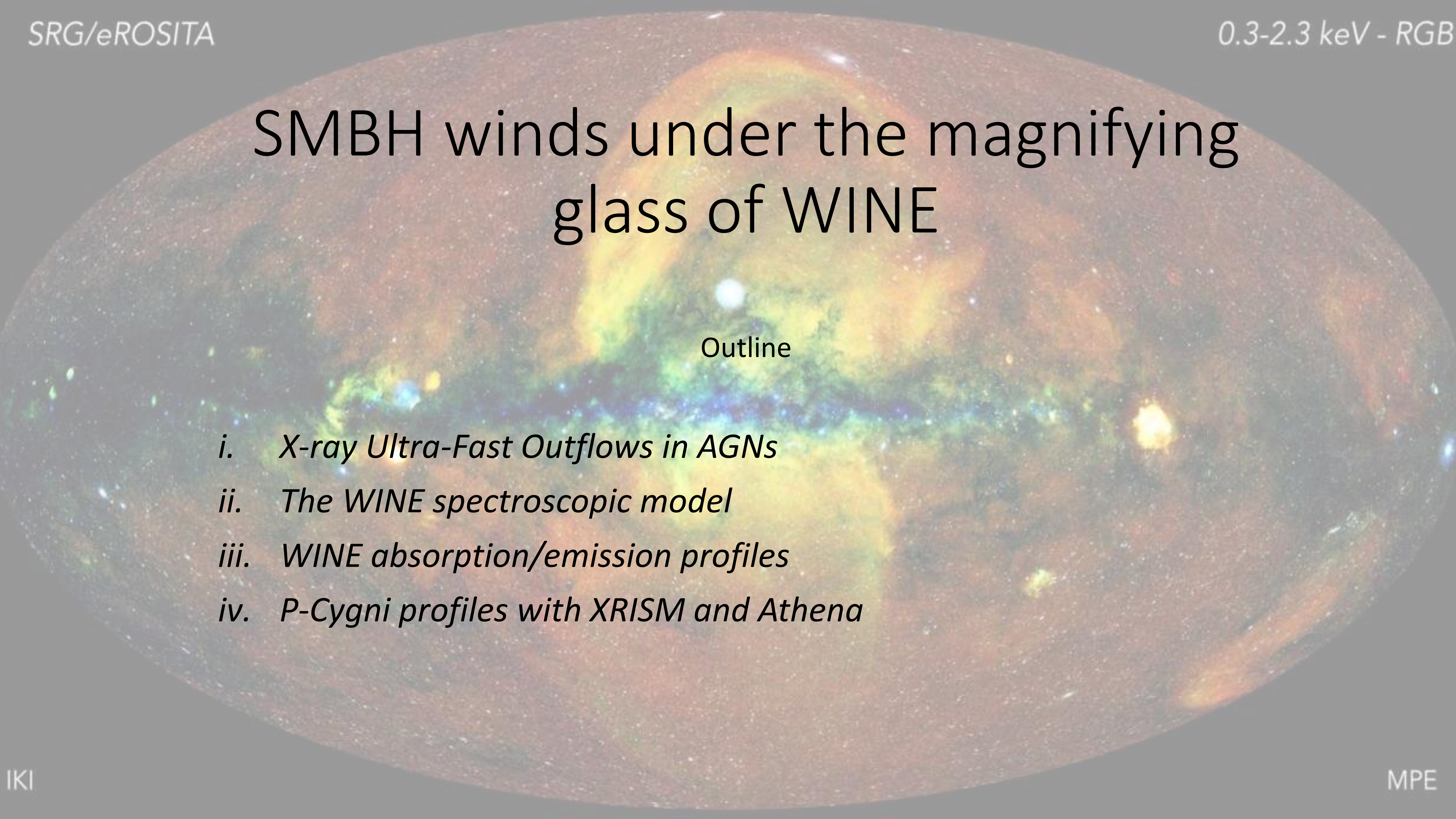
In collaboration with:
E. Piconcelli, F.Nicastro, L. Zappacosta and all the AGN group @ OAR,
F. Tombesi (UNI-ToV)



SMBH winds under the magnifying glass of WINE

Outline

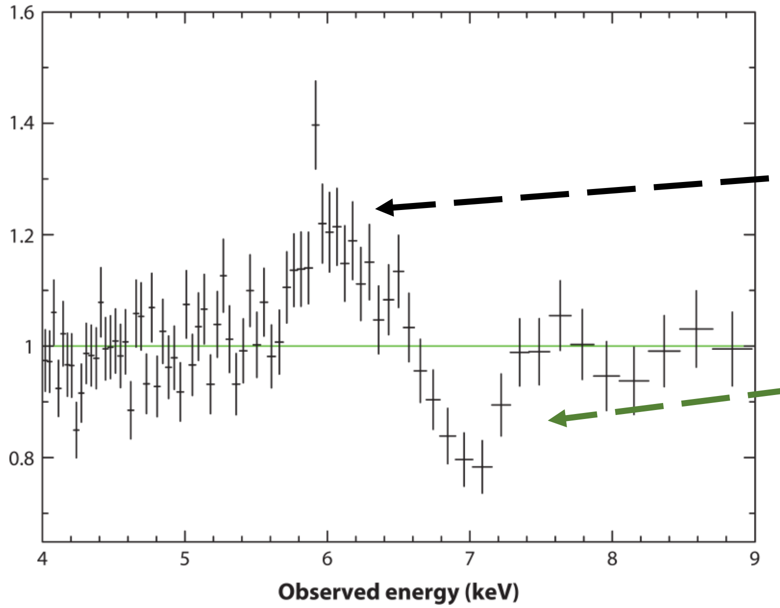
i. *X-ray Ultra-Fast Outflows in AGNs*
ii. *The WINE spectroscopic model*
iii. *WINE absorption/emission profiles*
iv. *P-Cygni profiles with XRISM and Athena*

i. X-ray Ultra –Fast Outflows in AGNs

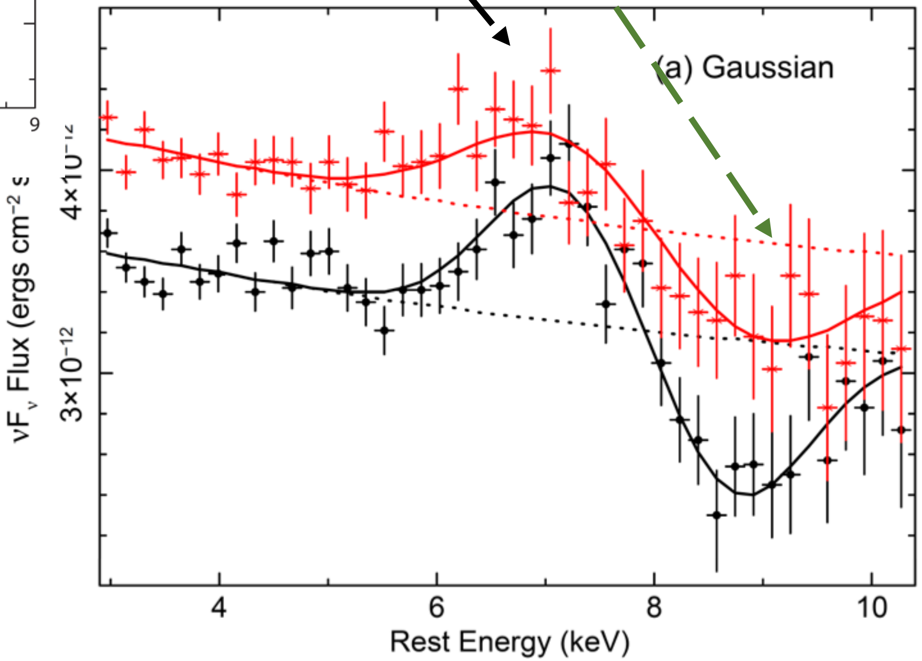
Emission/absorption features imprinted on the $4 - 10\ keV$ spectrum:

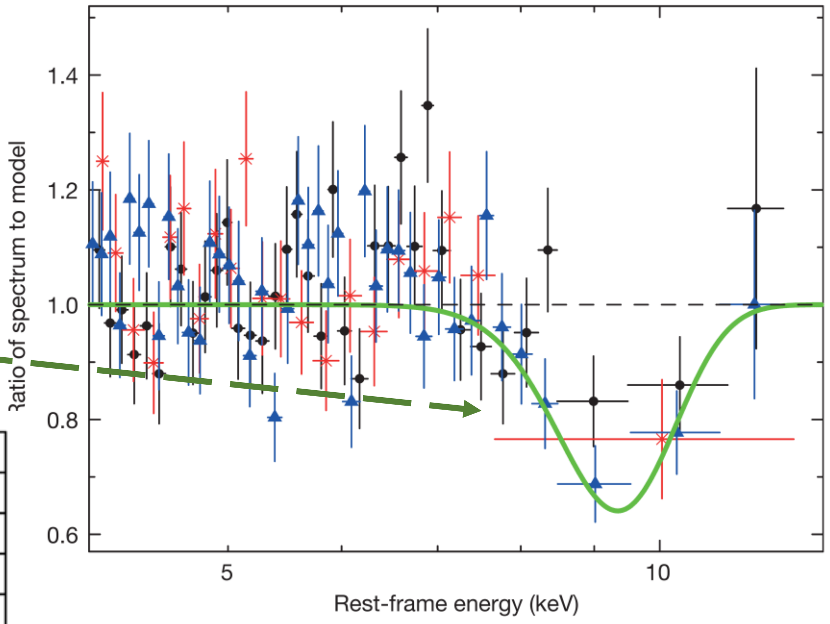
Emission

Absorption



PG 1211+143: $v_{out} = 0.15\ c$
(Pounds+09)





IRAS F11119+3257: $v_{out} = 0.25\ c$
(Tombesi+15)

I Zwicky1: $v_{out} = 0.27\ c$
(Reeves+19)

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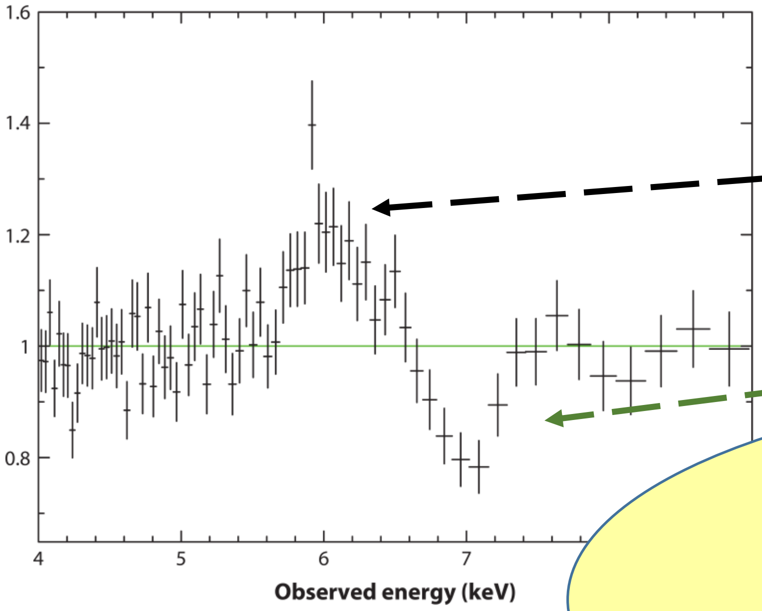

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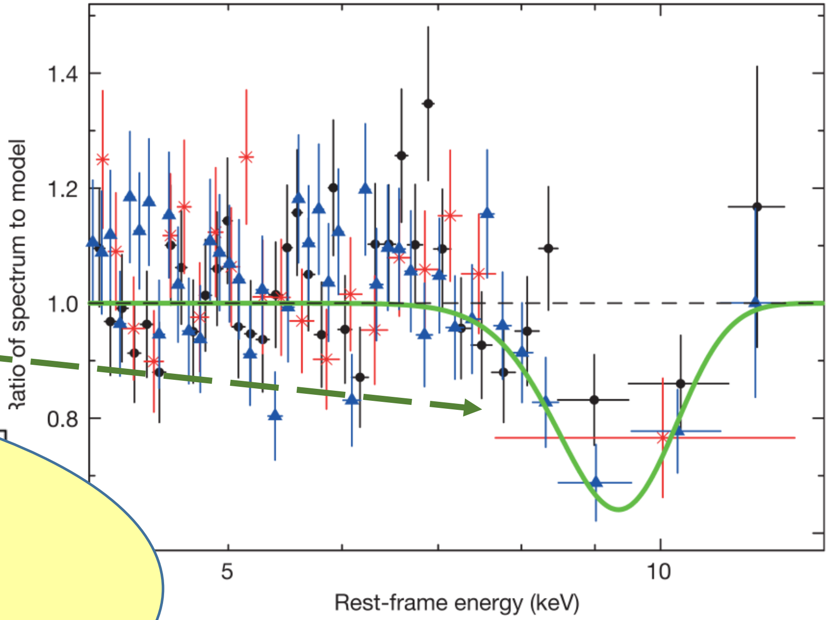

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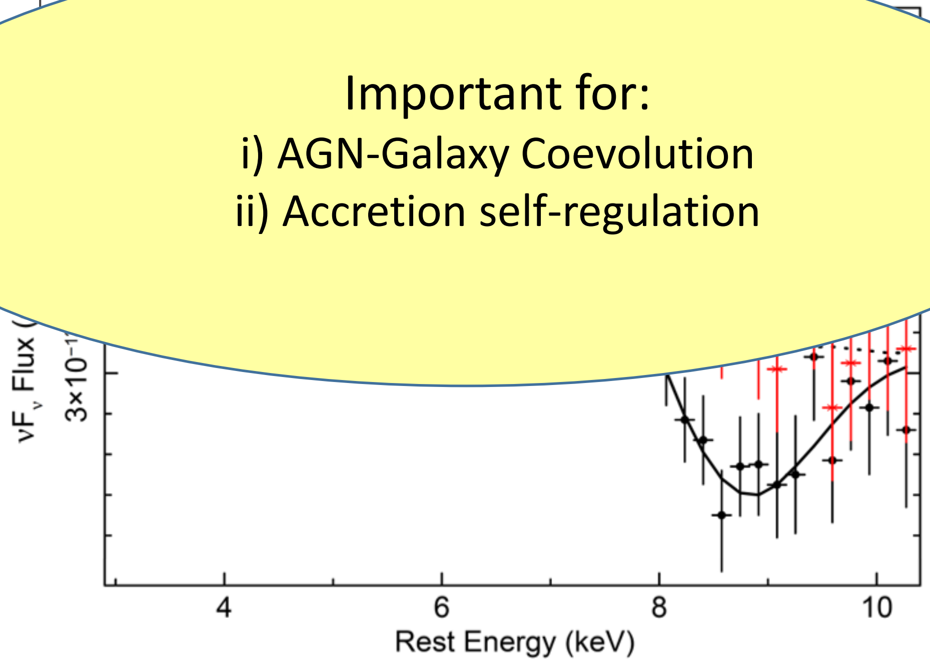

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Important for:
i) AGN-Galaxy Coevolution
ii) Accretion self-regulation

ii. The WINE spectroscopic model

Current approach

i. Spectral analysis is done mainly through simulated absorption/emission spectra, using radiative transfer codes borrowed from **different astrophysical** settings (e.g. *Cloudy, XSTAR*)

ii. Simulated spectra rely on several assumptions on the **geometry** and the **kinematics** of the **wind**

iii. The wind is modeled as a **layer of gas at rest** with turbulent broadened features, which are a posteriori blue-shifted to account for the wind velocity smearing

WINE model

Winds in the Ionised *Nuclear* Environment

i. WINE is a **self-consistent model** for absorption and emission from disk winds. It is highly customizable and can mimic different launching scenarios.

ii. The **physical, kinematical and geometrical parameters** are determined fitting the model to the observed spectra and minimizing the χ^2 statistic

iii. R**elativistic effects** are taken into account in the radiative transfer calculations. Absorption and emission profiles are directly built according to the geometry and velocity profiles.

ii. The WINE spectroscopic model

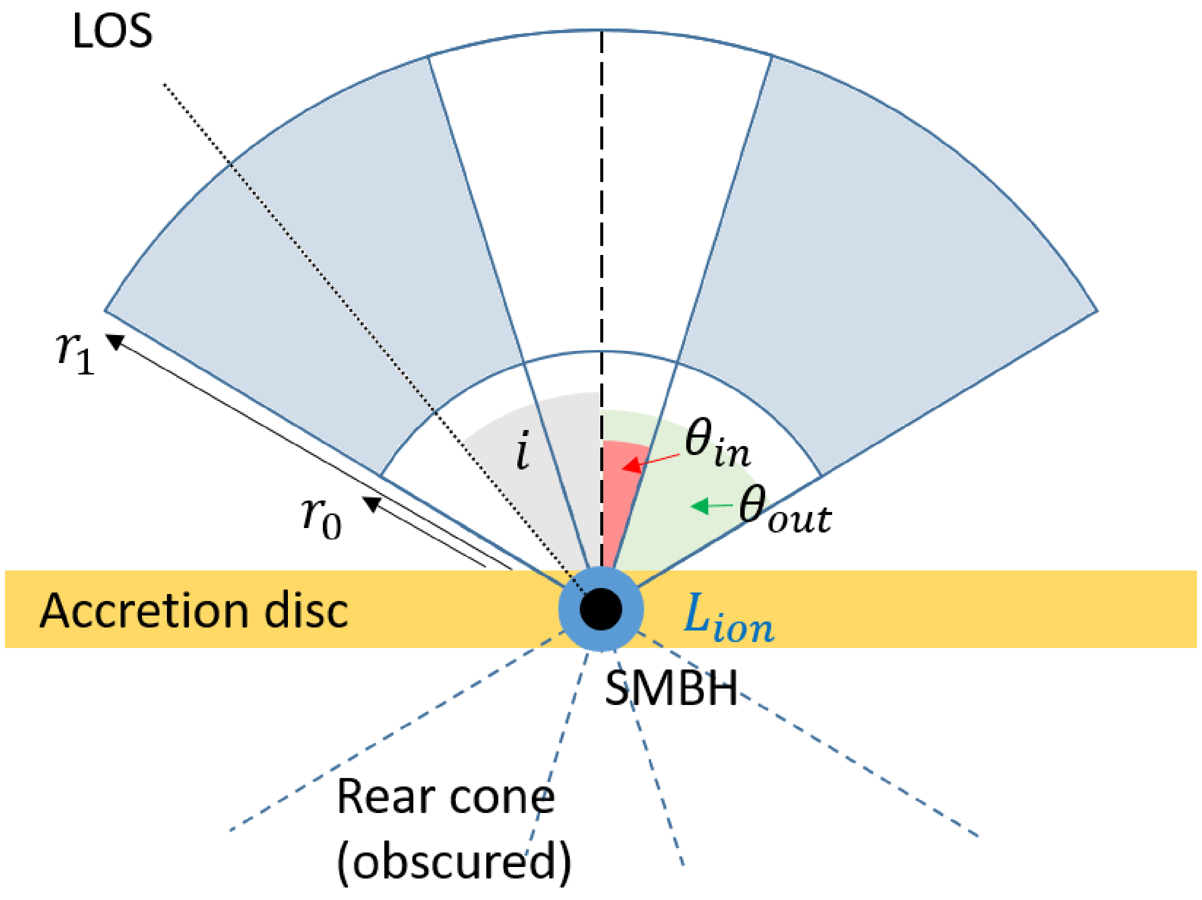
Parameters of the model:

1. Incident spectrum (SED and luminosity)
2. Ionization parameter $\xi(r)$
3. Column density N_H
4. Launching radius r_0
5. Density and velocity profiles:

$$n(r) = n_0 \left(\frac{r_0}{r}\right)^{\alpha}, v(r) = v_0 \left(\frac{r_0}{r}\right)^{\beta}$$

5. Geometry of the source: $\theta_{out}, \ \theta_{in}, i$

Best-fit values are determined comparing the model with the data and minimizing the χ^2 statistic.

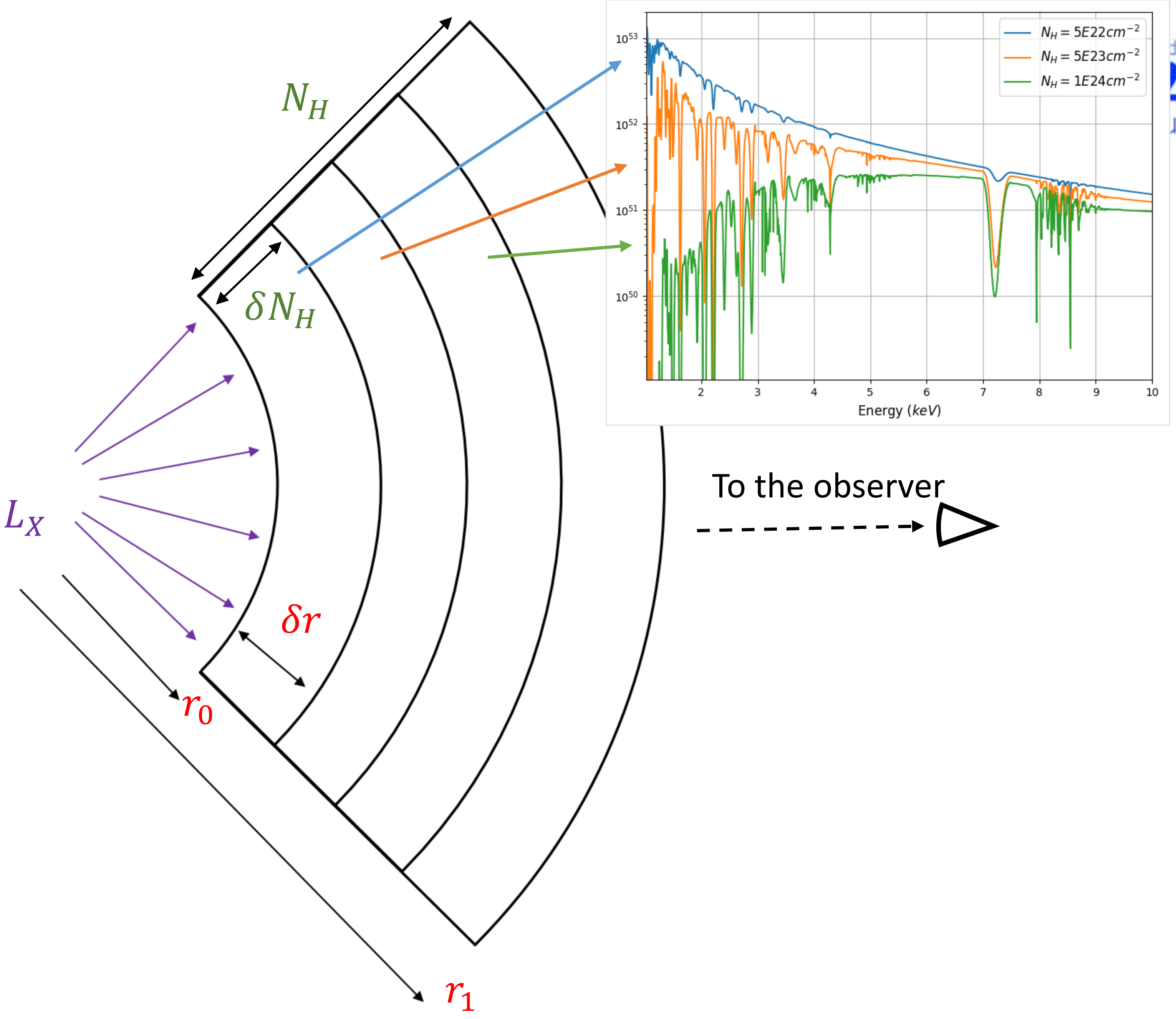


$\rightarrow C_f$, $\dot{M}_{out}$, $\dot{E}_{out}$ are determined self-consistently

ii a. Radiative transfer

<u>ABSORPTION:</u>
Chain of calls with the *XSTAR code*

Simulation is propagated from the innermost to the outermost shell to represent the wind evolution



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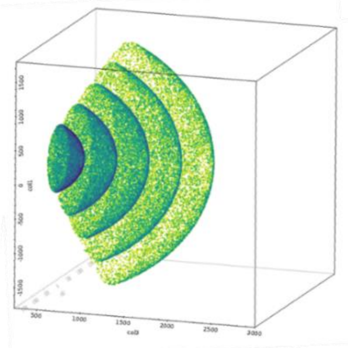
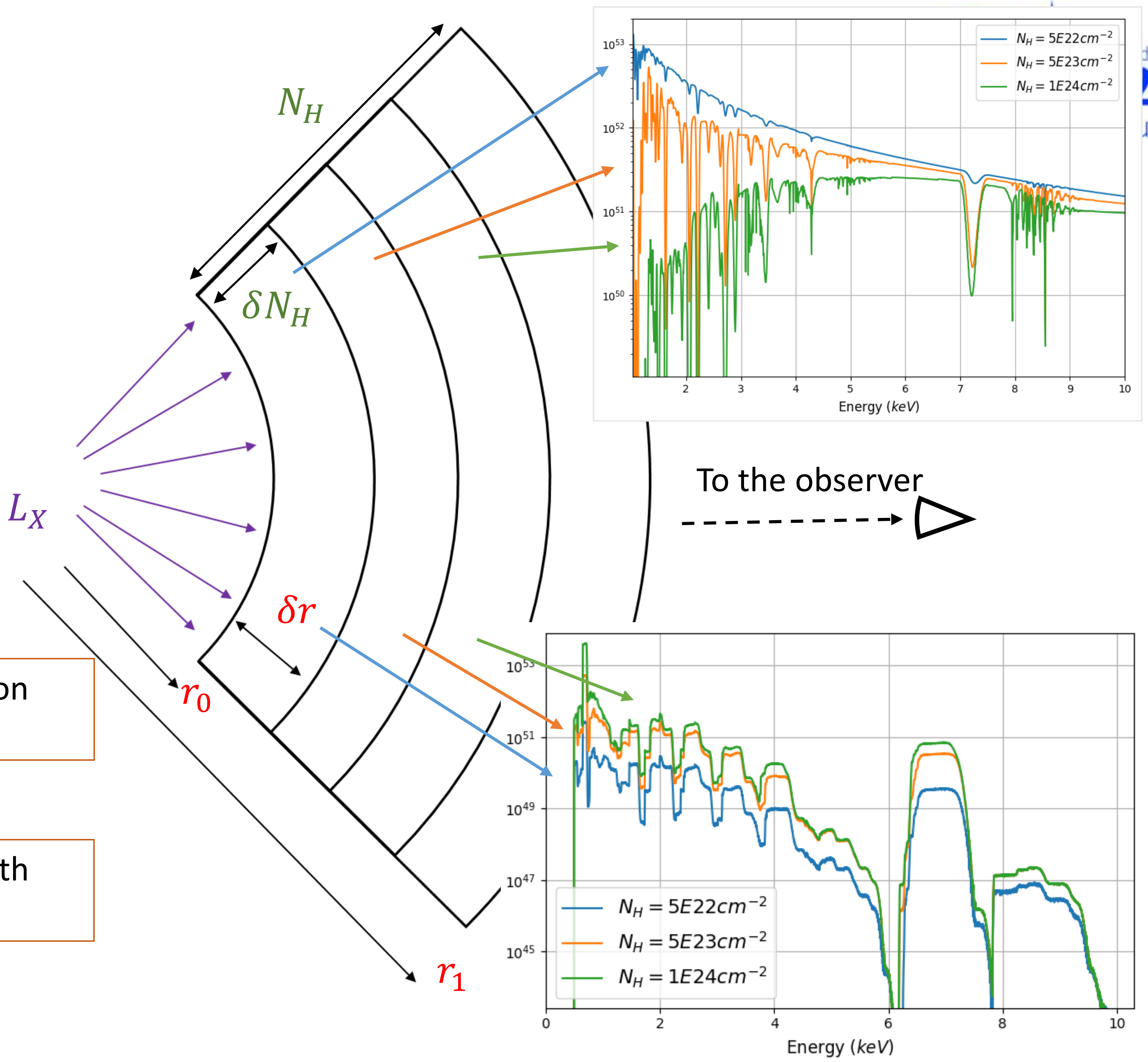


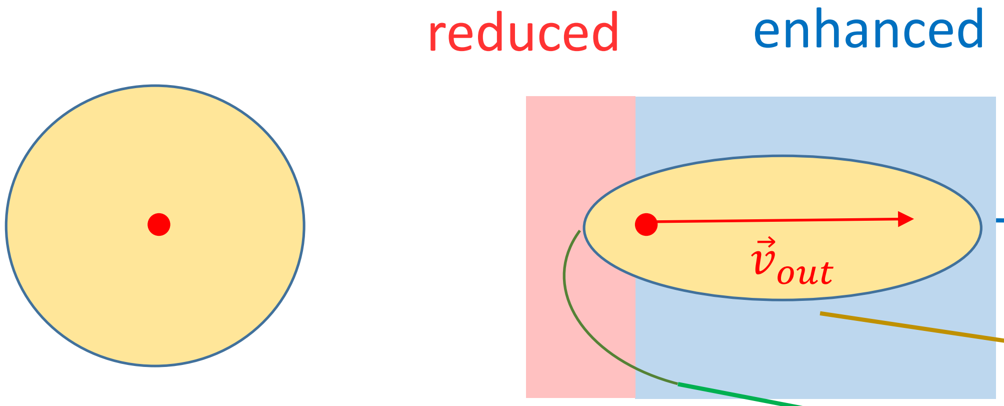
Calculate Monte Carlo emission profiles

Convolve emission profiles with *XSTAR* line emissivities



ii b. Relativistic effects

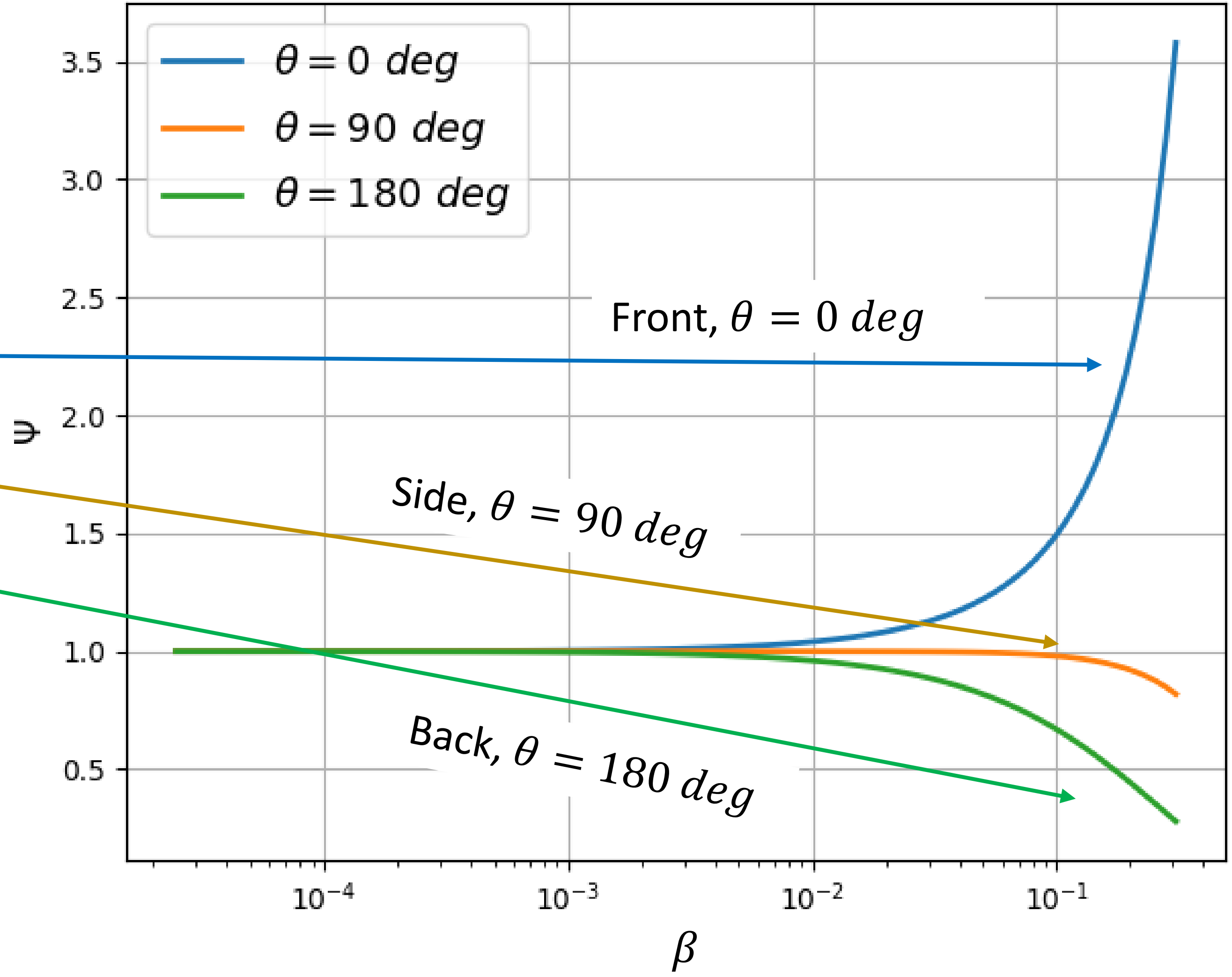
The cross section of a relativistic particle is enhanced frontward ($\theta = 0\ deg$) and reduced backward ($\theta = 180\ deg$):



Isotropic cross section at rest → Relativistic cross section

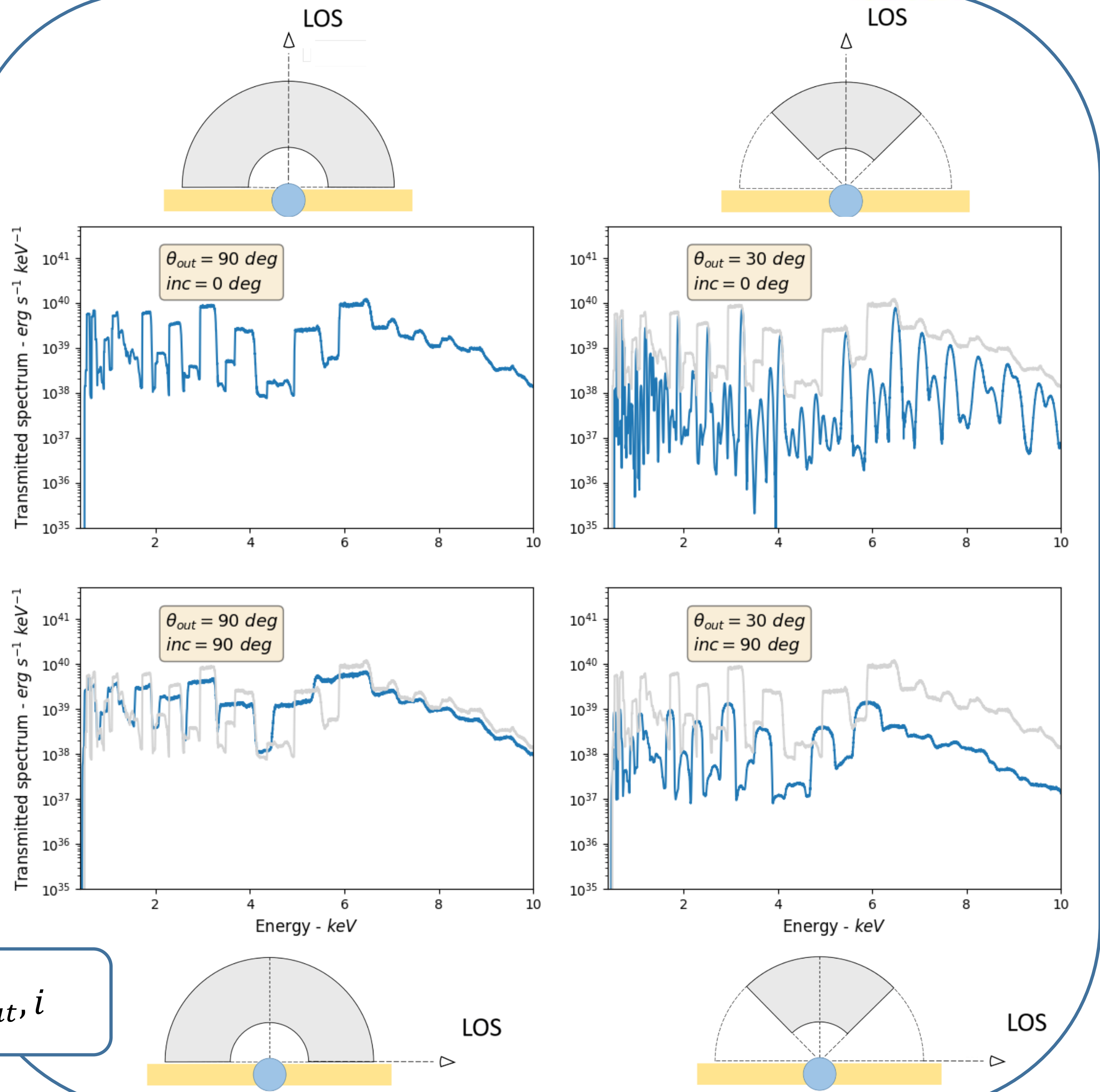
$$\psi^4 \equiv \frac{1}{\gamma^4(1-\beta\cos\theta)^4}$$

Ψ as a function of β for different θ



iii. WINE profiles

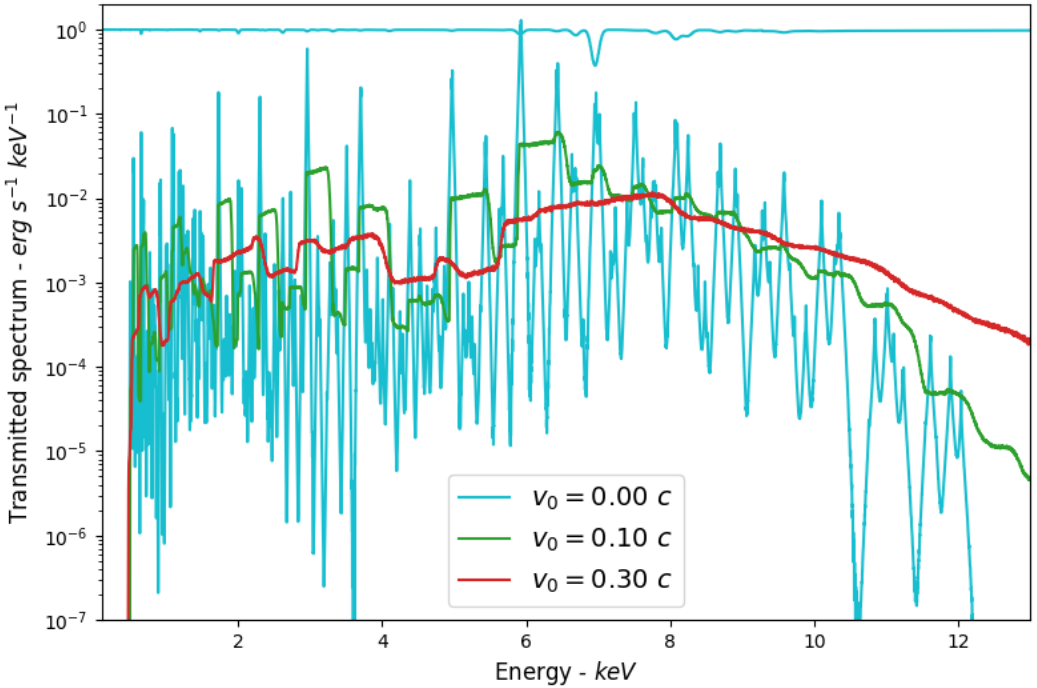
Emission:



Different geometries: θ_{out}, i

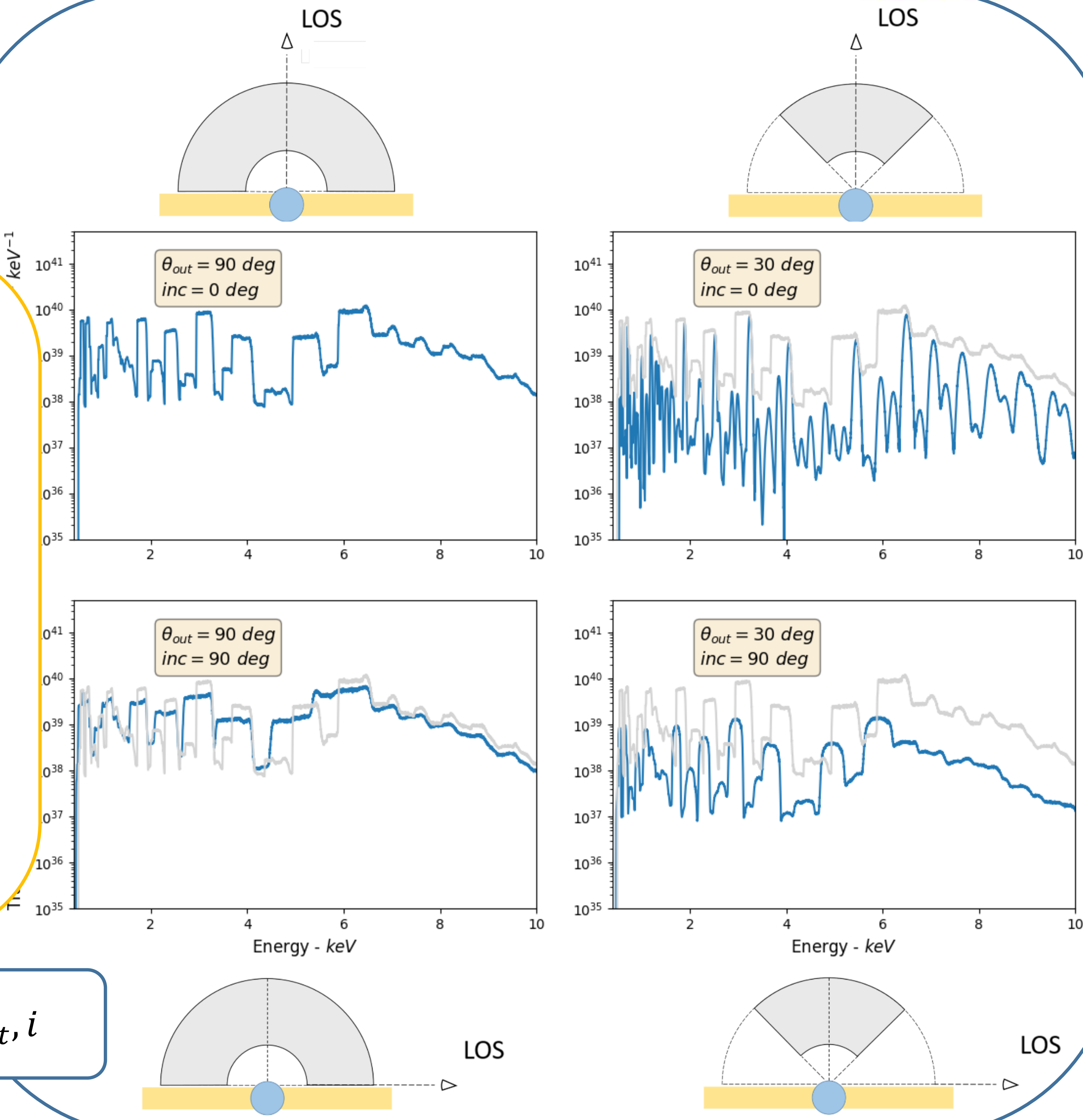
iii. WINE profiles

Emission:



Increasing v_{out}:

Fainter emission



Different geometries: θ_{out}, i

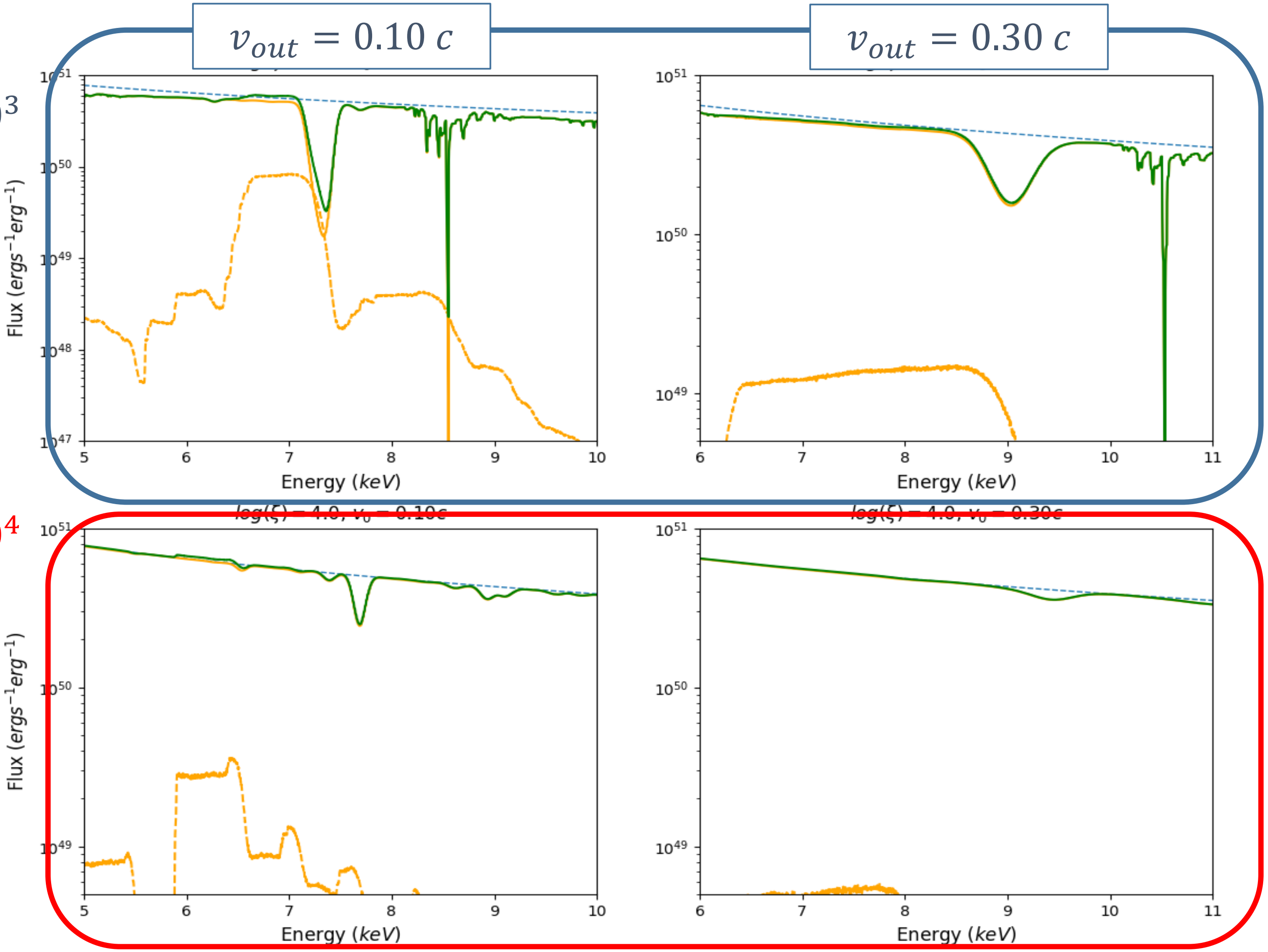
iv. P-Cygni profiles with XRISM and Athena

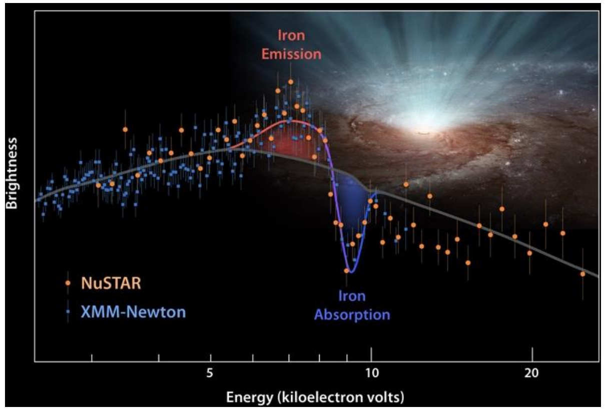
→ *smoking guns* of the global outflow structure
BUT sometimes we observe them, some others not…

P-Cygni profiles with *WINE*

$\xi = 10^3$

$\xi = 10^4$





PDS456 (Nardini+15)

iv. P-Cygni profiles with XRISM and Athena

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BUT sometimes we observe them, some others not…

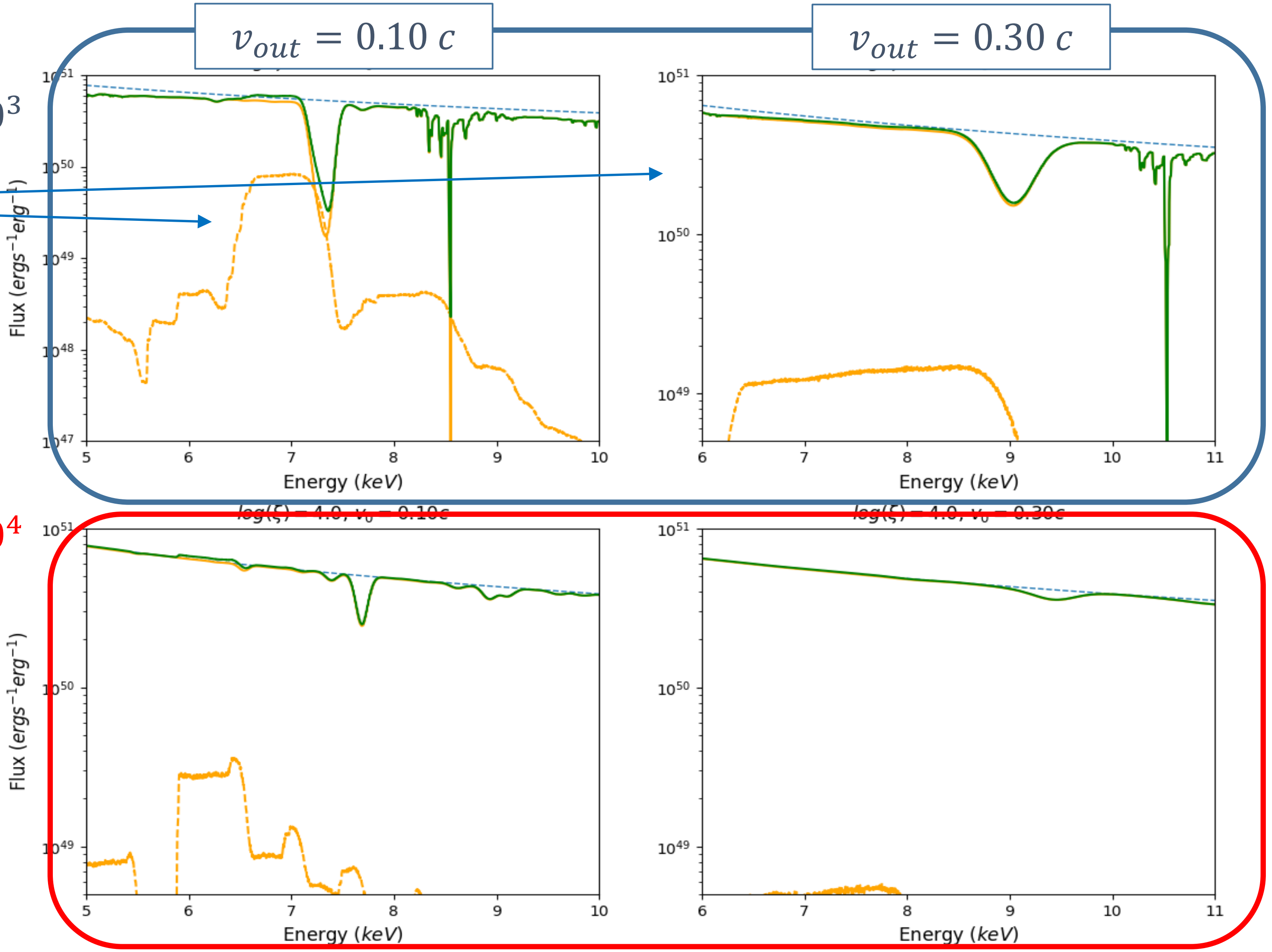
P-Cygni profiles
with *WINE*

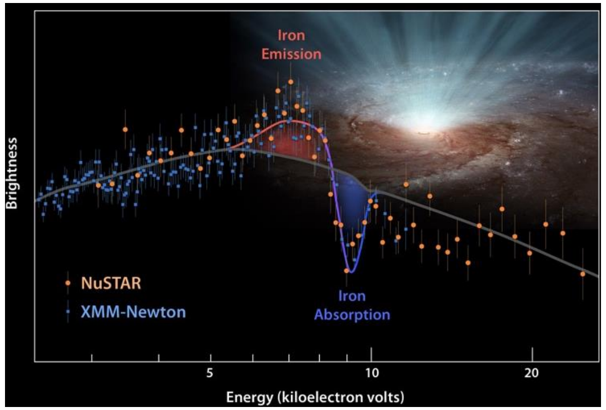
Fainter emission for:

i) Increasing v_{out}
ii) Increasing ξ_0

$\xi = 10^3$

$\xi = 10^4$





PDS456 (Nardini+15)

iv. XRISM and Athena simulations

1000 simulations of the UFO in IZWicky1 with *XRISM* and *Athena*
with $t_{exp} = 10^5 - 10^6\ s.$

Two-step fitting:

Input values:

$\log(\xi_0) = 4.9,\ N_H = 1.3 \cdot 10^{24} cm^{-2},\ v = 0.26\ c$

$\theta_{out} = 60°, i = 30°$

Regulating
emission profiles

1st fit:

absorption only ($\theta_{out} == 0$)

2nd fit:

absorption + emission (free θ_{out}, i)

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<u>*emission profiles*</u>

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absorption only ($\theta_{out} == 0$)

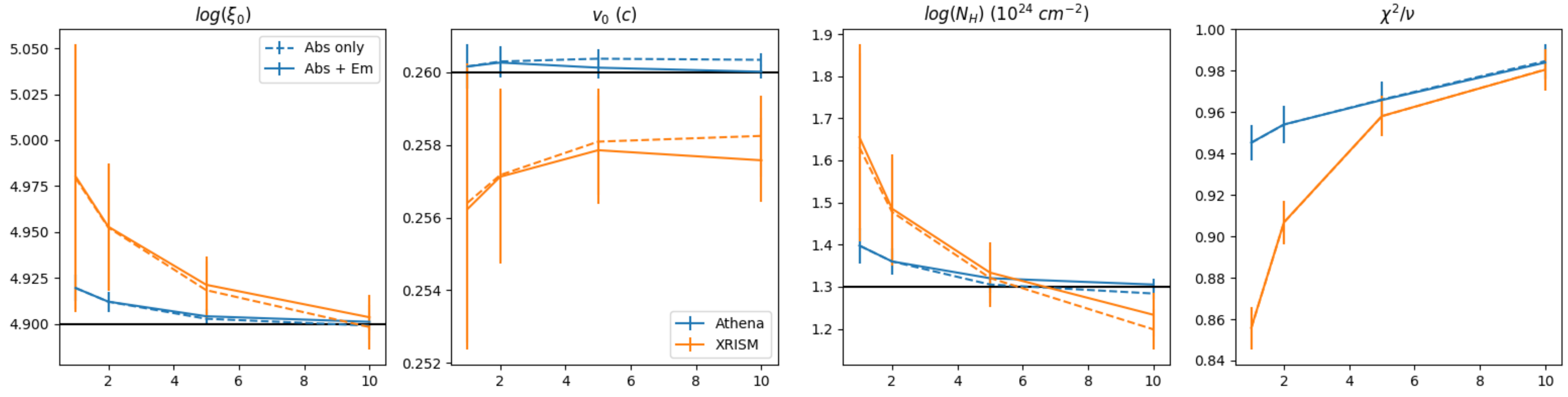
2nd fit:

absorption + emission (free θ_{out}, i)

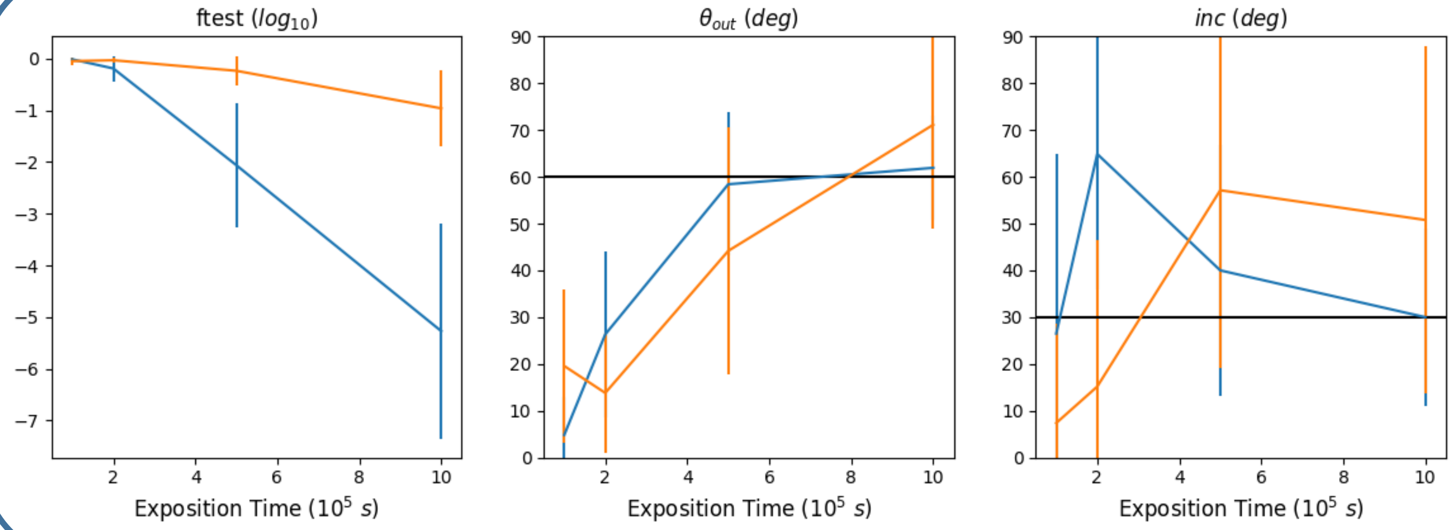
F-test to check significativity of emission

iv. XRISM and Athena simulations

Absorption: well constrained with both XRISM and Athena for $t_{exp} = 2.5 - 5 \cdot 10^5\ s$



Exposure time $(10^5 s)$



Emission:

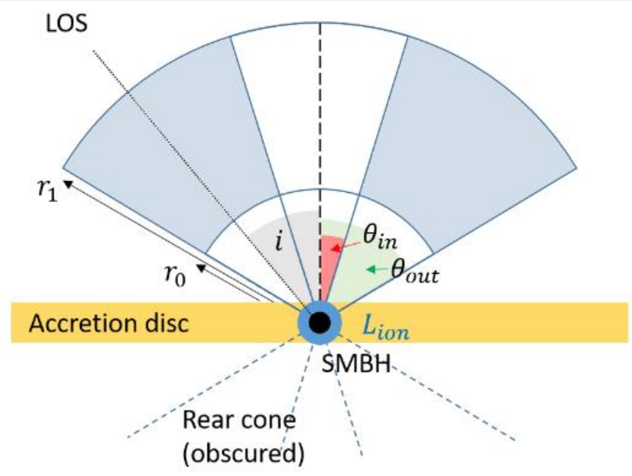
XRISM: ok with $t_{exp} = 10^6\ s$

Athena: ok with $t_{exp} = 5 \cdot 10^5\ s$
(higher resolution and effective area)

Conclusions

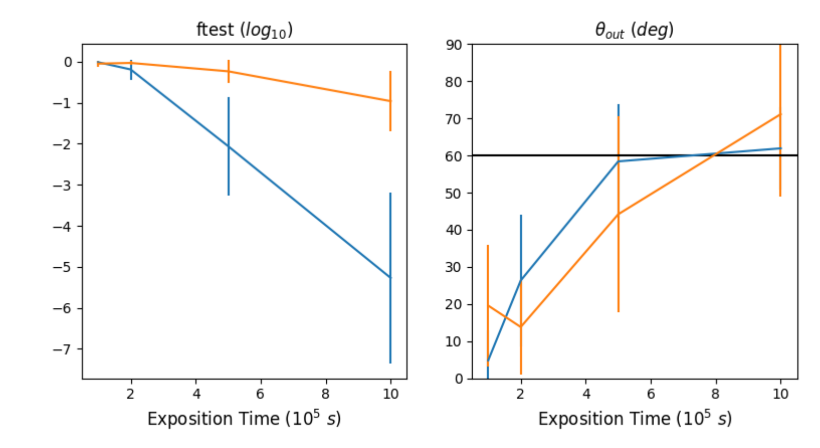
The WINE model

- Constrain **the physics and the geometry** of the wind
- Derive $\dot{M}_{out}, \dot{E}_{out}$ and estimate the impact on the galaxy
- Incorporates **radiative transfer, Monte Carlo** modellisation and **special relativity**



P-Cygni profiles

- Self-consistent, physical modelisation of the wind spectra
- ***XRISM*, *Athena* will be able to constrain the wind emission**



Future prospects

- Can be easily incorporated in spectral fitting programs (eg. Xspec)
- **Public release of the WINE code at the end of 2021 (Luminari+21 *in prep*)**
- *stay tuned!* Comments, questions welcomed – *alfredo.luminari@inaf.it*

References to WINE:

Luminari, Marinucci, *in prep* - Laurenti, Luminari+21 - Luminari+21,+20, +18