Unveiling the physics and the geometry of X-ray outflows with the WINE model

Alfredo Luminari[1,2,*], F. Tombesi[1,2,3,4], E. Piconcelli[2], K. Fukumura[5], D. Kazanas[4], F. Nicastro[2], L. Zappacosta[2]

[1] *Univ. of Rome Tor Vergata, Italy;* [2] *INAF- Astronomical Observatory of Rome;*
[3] *Univ. of Mariland;* [4] *NASA-GSFC;* [5] *J. Madison Univ., USA;*
* *alfredo.luminari@roma2.infn.it*

Abstract Ultra-fast outflows (UFOs) are often observed in X-ray spectra of Active Galactic Nuclei (AGN) and represent a powerful tool to probe the innermost regions surrounding the SMBH. However, up to now very little is known about the physics and the launching mechanisms driving them.

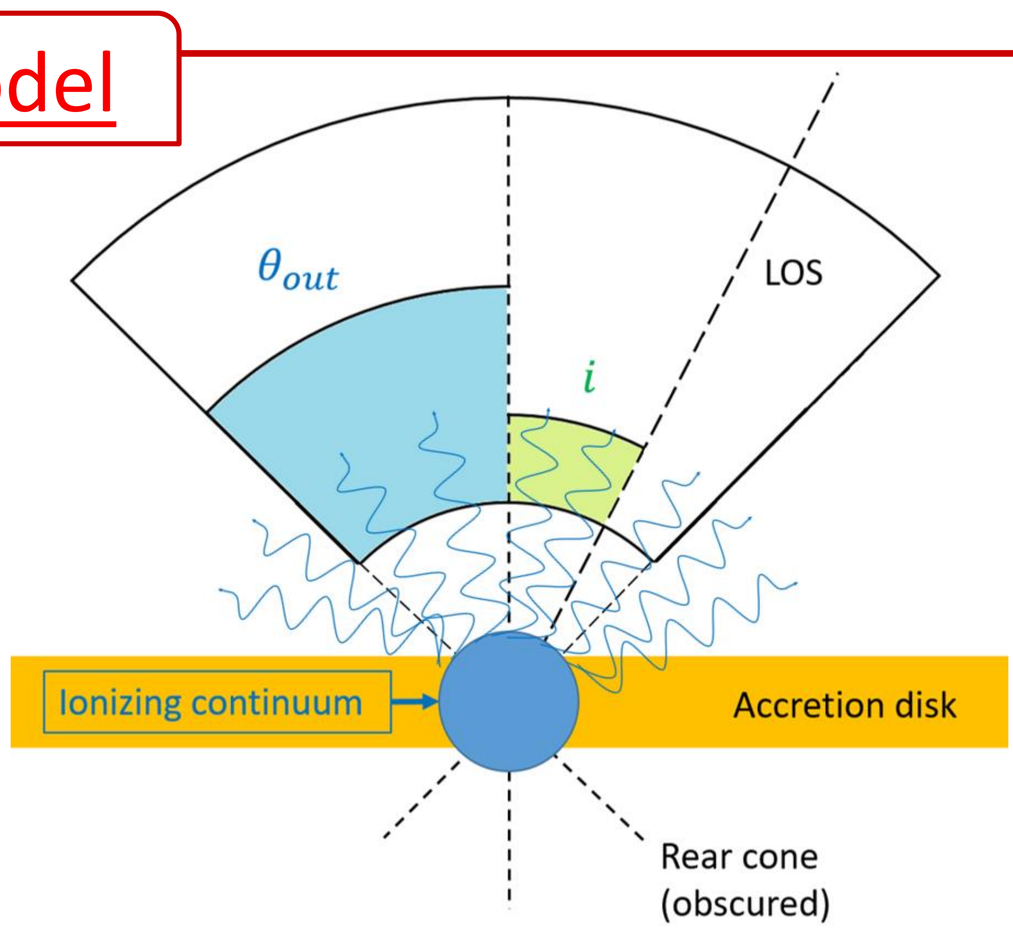
To gain new insights from the data, **we developed a new spectral model** for disk winds, that includes both absorption and emission. Particular attention is devoted to the wind kinematics and geometry and to the photoionization equilibrium. The spectral diagnostics of the model will allow to fully exploit the energy resolution of the upcoming XRISM and ATHENA.

The WINE model

Current status of the field

Spectral analysis of X-ray winds is done mainly through simulated absorption/emission spectra, with assumptions on the **geometry** and the **kinematics** of the wind.

Moreover, P-Cygni profiles are modeled *ad hoc* combining emission and absorption spectra.



WINE is a self-consistent model for absorption and emission from disk winds. It is easy to use, highly customizable and can mimic different wind launching scenarios.

Main parameters of the model:

i. Ionization parameter $\xi(r)$
ii. Column density N_H
iii. Density and velocity profiles as functions of the radius:

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

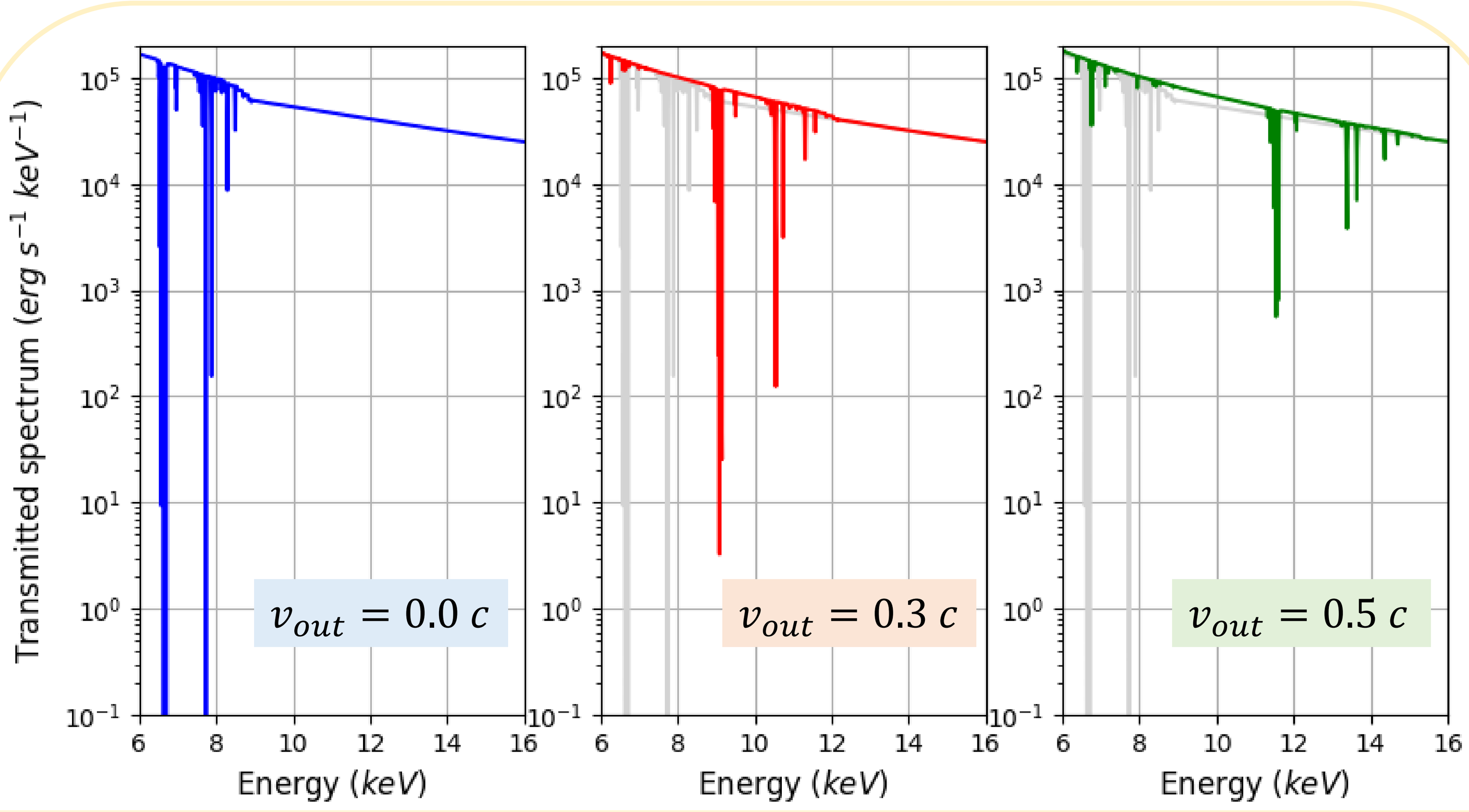
iv. Geometry of the source: θ_{out}, i

Special relativity effects on the wind features

When approaching relativistic velocities, the reference frame of the wind is transformed. This has a double effect:

Wind emission is relativistically beamed, as commonly observed in relativistic systems such as AGN jets, Blazars, GRB, where the outflow points toward the observer.

Wind absorption is reduced for increasing wind velocity:



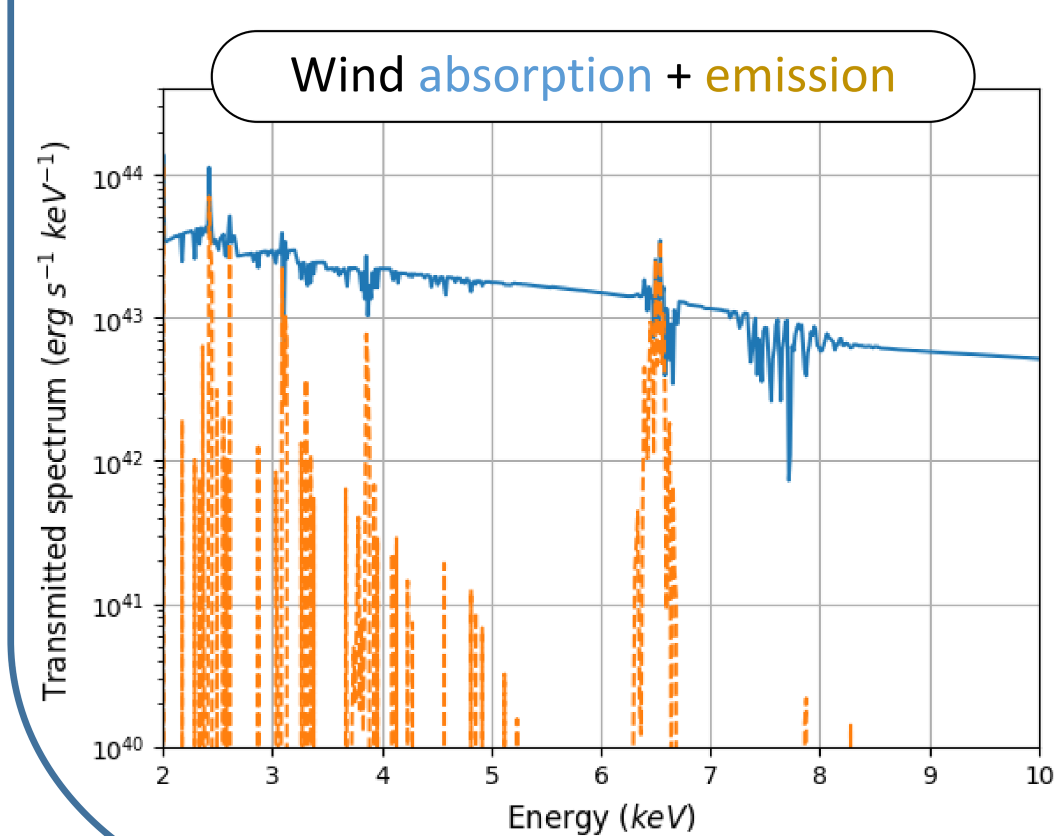
Absorption spectra with increasing v_{out} and fixed $N_H = 6 \times 10^{23} cm^{-2}$ and $\xi = 10^{4.5} erg\ s^{-1} cm^{-2}$.

The observed optical depth of the wind depends on the wind velocity.
Neglecting this effect leads to a systematic underestimate of N_H, that linearly propagates in the derived $\dot{M}_{out}$ and $\dot{E}_{out}$.

Moreover, the radiative pressure exerted on the wind decreases for increasing velocity. **This reduces the ability of the radiation to accelerate the wind outwards.**

Wind absorption

i. The wind is divided in thin shells to sample the gradient of $\xi(r), v(r), n(r)$
ii. Calculation is started from the innermost shell with *XSTAR*, using incident spectrum and ξ_0, v_0 and including relativistic effect
iii. Simulation is propagated to the 2nd shell using data from the transmitted spectrum and computing $\xi(r), v(r)$
iv. Iterate until the total column density N_H is reached



Wind emission

i. Sample each shell with n random points
ii. Compute emission from each point, using XSTAR line emissivities and calculating the relativistic beaming toward the observer
iii. Compute emission from each shell
iv. Total emission is the composition of all the shells

Summary

The WINE model allows to:

- derive **energy and mass flux** of the wind, with particular attention to geometry, kinematics and relativistic effect
- mimic **different wind launching scenarios** and compare them with the data
- constrain the **density and ionization structures** of the wind
- test the geometry of **P-Cygni profiles**

Bibliography

i. *Constraining the geometry of the nuclear wind in PDS 456 using a novel emission model* (Luminari, A. *et al.*, 2018 A&A 619 A149)
ii. *Special relativity effects in modeling black hole winds* (Luminari, A. *et al.*, 2019, submitted)