# HiXUV 2022 workshop threads

Hands-on exercise: Warm absorber in Active Galactic Nuclei

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# 1 Introduction: warm absorbers in active galactic nuclei

Active galactic nuclei (AGN) accrete matter onto a central supermassive black hole (SMBH) to produce intense broadband radiation, which can ionize and drive away the surrounding matter in form of outflows, such as warm ionized and cold molecular outflows (Harrison et al., 2018). Many observational proofs have implied that outflows might play an important role in affecting the star formation, evolution, and even the environment of their host galaxies, also known as AGN feedback (King & Pounds, 2003). Therefore, investigating properties of outflows might significantly help us to understand the formation of AGN outflows and their feedback efficiency to the host galaxy. In this project, we focus on the warm ionized outflows.

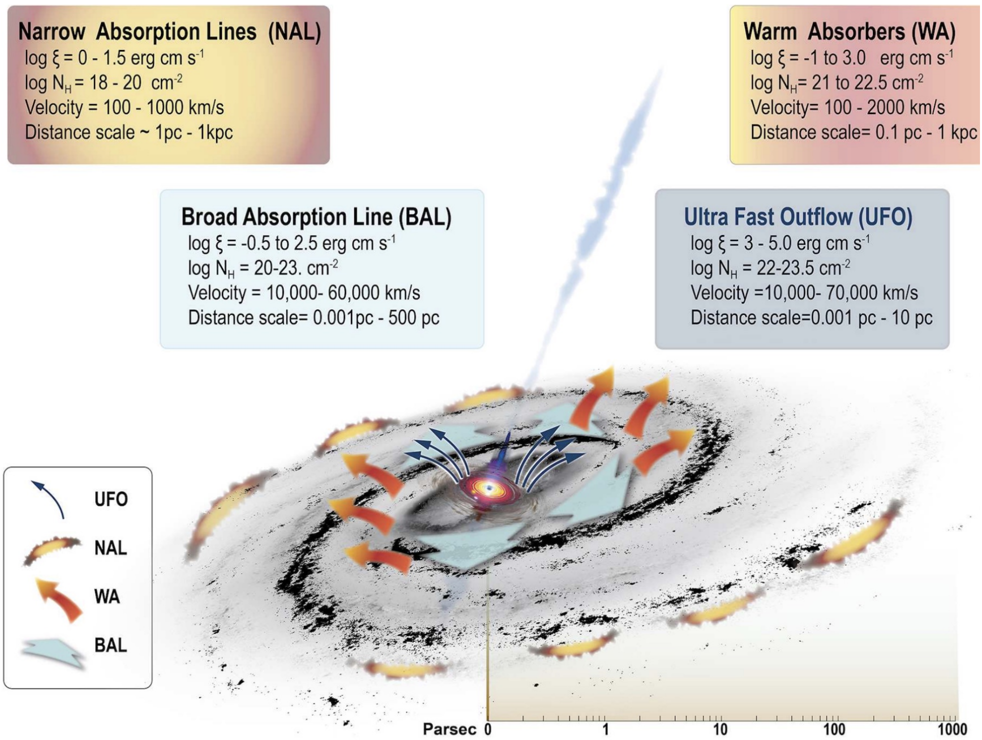


Figure 1: The different ionized outflows detected in AGN and their average physical parameters (Laha et al., 2021).

Warm ionized outflows usually have different types (Laha et al., 2021, and references therein; see Figure 1) such as broad absorption lines (BALs; Weymann et al., 1981), warm absorbers (WAs; Halpern, 1984; Crenshaw et al., 2003), and ultrafast outflows (UFOs; Tombesi et al., 2010), which can be detected via absorption features along the line of sight in the ultraviolet (UV; Kraemer et al., 2002) and X-rays (Mao et al., 2019, or see Figure 2). UFOs might have an origin close to the central engine ($\sim$0.0003–0.03 pc; Tombesi et al., 2012) , with very high velocities ($\sim$0.03–0.3c; Tombesi et al., 2010, 2012). BALs usually reside outside the broad line region (BLR) with high outflow velocities ($v_{\rm out}$) reaching $\sim$30,000 km s$^{-1}$ (Trump et al., 2006; Gibson et al., 2009). Compared with UFOs and BALs, WAs have lower outflow velocities from about one hundred to several thousand km s$^{-1}$ (Kaastra et al., 2000; Ebrero et al., 2013) and they might originate from the accretion disk (Elvis, 2000; Krongold et al., 2007), BLR (Reynolds & Fabian, 1995; Wang et al., 2022b), or dusty torus (Krolik & Kriss, 2001; Blustin et al., 2005). Although different types of outflows have overlaps in their distance scales and outflow parameters, the direct connection between these outflows still remains unclear. In this hand-on exercise, we focus on the properties of the WA outflows.

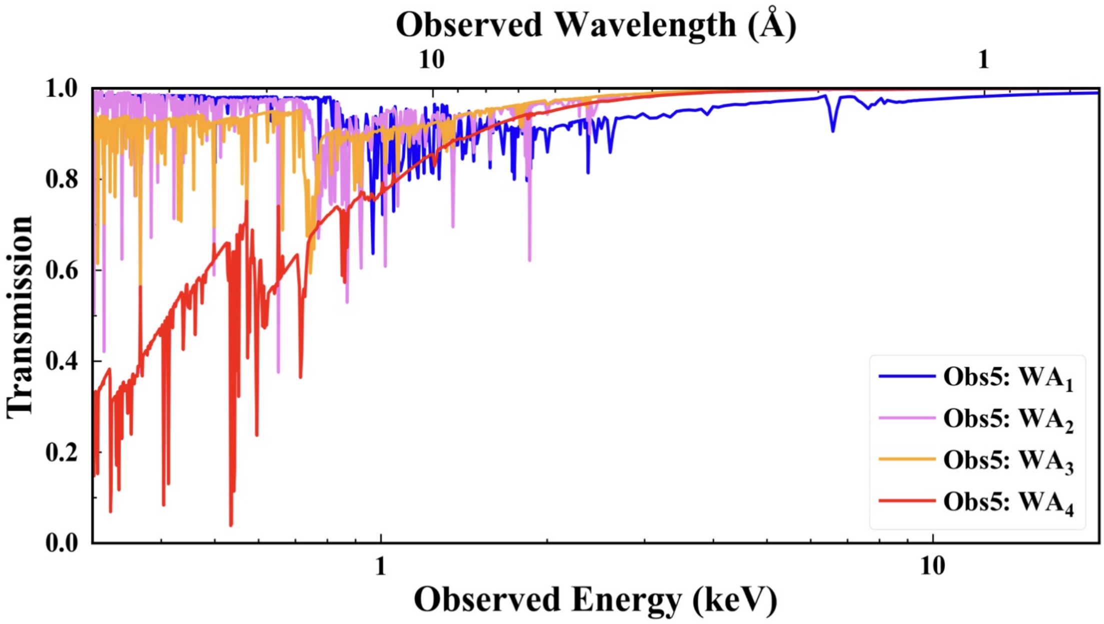


Figure 2: The transmission spectra of warm absorbers: the logarithm of ionization parameters of WA$_1$, WA$_2$, WA$_3$, and WA$_4$ are around 3, 2.5, 2, -1 erg cm s$^{-1}$, respectively (Wang et al., 2022b).

Until now, WAs have been found in about 50% of nearby AGN (Reynolds, 1997; Kaastra et al., 2000; Porquet et al., 2004; Tombesi et al., 2013; Laha et al., 2014). According to Tarter et al. (1969), the ionization parameter can be defined by $\xi = L_{\rm ion}/n_{\rm H}r^2$, where $L_{\rm ion}$ is the ionizing luminosity over 1–1000 Ryd, $n_{\rm H}$ is the hydrogen number density of the absorbing gas, and $r$ is the radial distance of the absorbing gas to the central engine. WAs show a wide range of ionization parameter ($10^{-1} \leq \xi \leq 10^3$ erg cm s$^{-1}$) and hydrogen column density ($10^{20} \leq N_{\rm H} \leq 10^{23}$ cm$^{-2}$) (Laha et al., 2014).

One important question about WAs is how to drive these outflows. Many studies imply that WAs might be driven by radiation pressure (Proga & Kallman, 2004), magnetic forces (Blandford & Payne, 1982; Konigl & Kartje, 1994; Fukumura et al., 2010) or thermal pressure (Begelman et al., 1983; Krolik & Kriss, 1995; Mizumoto et al., 2019). These theories might predict different $v_{\rm out}$-$\xi$ relations. For the $v_{\rm out}$-$\xi$ relation predicted by the radiatively driven outflowing mechanism, readers could refer to Gofford et al. (2015) and Tombesi et al. (2013); while for the predicted relation by the magneto-hydrodynamically (MHD) driven outflowing mechanism, readers could refer to Fukumura et al. (2010) and Behar (2009). In addition, readers could refer to Tombesi et al. (2013), Laha et al. (2014), and Wang et al. (2022a) for the observed $v_{\rm out}$-$\xi$ relation. During this hand-on exercise, you might be interested about the relation between the observed $v_{\rm out}$-$\xi$ results and the theoretical predictions.

## 2 Project Goal

The goals of this project are shown as follows.

- Understand the different types of ionized outflows of AGN, especially WAs.
- Correctly use the `SPEX` package (Kaastra et al., 1996, 2020) to fit the spectrum with the absorption features. The installation and detailed introduction for the `SPEX` are provided in the following links:
  - https://box.nju.edu.cn/d/0a3a4793c06d41cc8375/ (pwd: hixuv; directory: /SPEX)
  - https://box.nju.edu.cn/d/616b8ea401684379aa4a/ (pwd: xuv02; directory: /SPEX)
  - `SPEX` github website
- Analyze (or discuss) the physical properties of WAs, such as hydrogen column density, outflowing velocity, distance, driven mechanism, feedback, interaction with the surrounding medium, ...

## 3 Spectral analysis exercise

### 3.1 Basic information

Now we have a Seyfert 1 galaxy named HiXUV_AGN with the **redshift of 0.24, RA of 155.9 degrees, and DEC of 19.9 degrees**. Its spectrum with a lot of absorption lines is shown in the file **HiXUV_AGN.spo** and the file **HiXUV_AGN.res** is the response file. These two files are provided in the link https://box.nju.edu.cn/d/616b8ea401684379aa4a/ (pwd: xuv02; directory: /exercise).

### 3.2 Hand-on exercise

Through this hand-on exercise, we aim to preliminarily study the suitable models to describe WAs with the `SPEX` and analyze physical properties of WAs.

#### 3.2.1 Confirm the suitable relation between different components

✍ Assignments:

- ❒ Confirm the required components for the intrinsic spectral energy distribution (SED) in the soft X-rays
- ❒ Confirm the possible components that affect the SED along the line of sight
- ❒ Confirm the relation between different components

#### 3.2.2 Obtain the best-fit model of WAs

Next, we will find a suitable model to describe the spectrum and obtain the parameters of the best-fit model.

✍ Basic assignments:

- ❒ Learn the following SPEX commands: data, plot, ignore, bin, com, fit, cal, log, model, par, error, quit
- ❒ Learn the following SPEX models: dbb, pow, hot, reds, xabs
- ❒ Plot the data spectrum with the best-fit model and the fit residuals (the units of X-axis and Y-axis are [Å] and [counts m$^{-2}$ s$^{-1}$ Å$^{-1}$], respectively), similar to Figure 3. Notes:
  - ✧ Check the spectrum and background
  - ✧ Start the spectral fitting with the continuum models
  - ✧ Consider the Galactic X-ray absorption
  - ✧ Add WA components to the model
  - ✧ Fit the spectrum and check the fit residuals
- ❒ Save the data and the best-fit model into files.
- ❒ Show and save the parameters of the best-fit model.

✍ Advanced assignments:

- ❒ Learn the following SPEX models: pion
- ❒ Replace the xabs component with the pion component, and fit the spectrum again
- ❒ Plot the data spectrum with the best-fit model and the fit residuals: the units of X-axis and Y-axis are [Å] and [counts m$^{-2}$ s$^{-1}$ Å$^{-1}$], respectively.
- ❒ Save the data and the best-fit model into files.
- ❒ Show and save the parameters of the best-fit model.
- ❒ Compare the fitting parameters for the pion component with those for the xabs component.

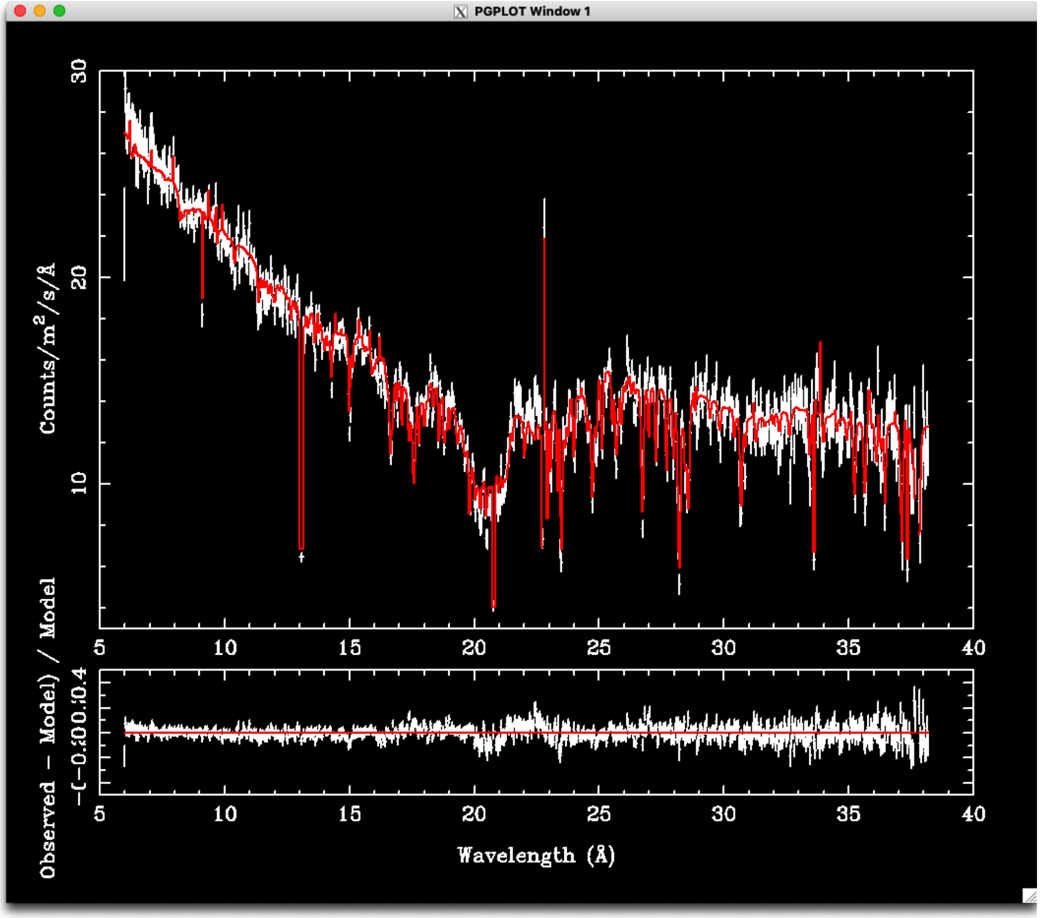


Figure 3: One example for the spectral fitting with `SPEX`: data spectrum (white points) and the best-fit model (red solid curve).

### 3.2.3 Analyze the physical properties of WAs

In this part, we aim to get the physical properties of WAs, such as X-ray luminosity, effects from WAs to the continuum radiation, distance of WAs, et al.

Notes: use the fitting results with the `pion` component.

✍ Basic assignments:

- ❒ Learn the following SPEX commands: `elim`
- ❒ Calculate the 0.3–2 keV, 2–10 keV, and 1–1000 Ryd luminosity from each continuum component
- ❒ Calculate the ionizing luminosity of the second WA component

✍ Advanced assignments:

- ❒ Calculate the 1–1000 Ryd ionizing luminosity absorbed by each WA component
- ❒ Estimate the distance range of each WA component (refer to, e.g., Wang et al., 2022b)

#### 3.2.4 Other interesting questions about WAs (optional)

In this part, you can explore and think about any interesting questions about WAs. You could record them below:

- ❒ ____________________________________________________________
- ❒ ____________________________________________________________
- ❒ ____________________________________________________________

## 4 Summary

Through this project, we have a preliminary understanding for the WA outflows which is one type of ionized outflows in AGN. We also study the basic commands of `SPEX` and finish the exercise using `SPEX` to fit the spectra with the absorption features in the soft X-rays. In addition, we explore the physical properties and interesting questions of WA outflows.

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