THE WARM ABSORBER IN SEYFERT 1 GALAXIES

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ABSTRACT

Our aim is to explain the spectral features of the Warm Absorber (WA) in Seyfert 1 galaxies. We have shown that the coronal lines strongly constrain its physical parameters, especially the hydrogen density, unlike the absorption edges produced by the WA and observed in the soft X-rays. It implies that the distance of the WA from the incident radiation source is of the order of that of the Broad Line Region (BLR), and then it is a powerful probe of the central region of Active Galactic Nuclei. In addition, we show that the ionization processes of the WA (pure photoionization or not) will be discriminated thanks to the ratios of the X-ray lines which will be detected with the XMM mission (RGS).

1. Observed X-ray features

The WA is generally thought to be an optically thin photoionized medium, located along the line of sight of the X-ray source, but the possibility of an additional ionization process (e.g. collisional heating) has not been rigorously ruled out. Observationally, the WA is mainly characterized in the soft X-ray range by strong absorption edges of O VII and O VIII (0.74 and 0.87 keV respectively) and sometimes by emission lines: O VII, O VIII in NGC 3783 (George et al. 1995), in MCG-6-30-15 (Otani et al. 1996) and in 1E 1615+061 (Piro et al. 1997). Some other features were also observed in a few objects, like edges of Ne IX and/or Ne X (1.20 and 1.36 keV) in NGC 4051 (Mihara et al. 1994; Komossa & Fink 1997) and in MCG-6-30-15 (Orr et al. 1997), and edges of O VI or N VII (0.67 keV) in NGC 3227 (Ptak et al. 1994).

2. Modeling

We use the **PEGAS** and **IRIS** photoionization codes (see Dumont & Porquet 1998 a,b for more information about those codes). We assume optically thin clouds in plane-parallel geometry with constant hydrogen density (n_H), in ionization equilibrium and surrounding a central source of radiation. We use two shapes of incident continua (see Fig. 1): Laor et al. 1997 ("Laor continuum") and Mathews & Ferland 1987 ("AGN continuum") (same as in Cloudy).

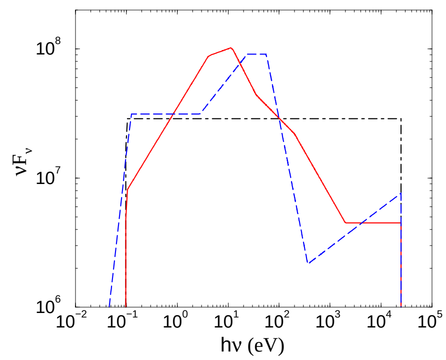

Fig. 1.— Energy distribution of the two incident continua for Radio-Quiet quasars used in this study, as well as a power law continuum ($F_\nu \propto \nu^{-1}$) used for comparison. *Solid line*: Laor et al. (1997) ("Laor continuum"), *dashed line*: Mathews & Ferland (1987) but with a break at 10μm ("AGN continuum") and *dot-dashed line*: simple power law.

Two models are investigated: the first one is a pure photoionization model (i.e in thermal equilibrium) and the second one is an hybrid model: photoionization plus collisional processes (i.e out of thermal equilibrium: T=10^6K). The ionization parameter is defined as $\xi = \frac{L}{n_H\ R^2}$ where L=$\int_{0.1eV}^{10keV} L_\nu d\nu$ is the bolometric luminosity (erg.s^{-1}) and R is the distance from the ionizing radiation source to the illuminated face of the cloud (cm). The element abundances are from Allen (1973) and the covering factor is assumed to be 0.5. The models are dust-free.

2.1. Connection with other spectral ranges

Porquet et al. (1998) show that coronal lines ([Fe X] 6375Å, [Fe XI] 7892Å, [Fe XIV] 5303Å), whether they are emitted or not by the WA, constrain its physical parameters, especially the hydrogen density. Indeed, any model of the WA producing coronal equivalent widths (EWs) larger than observed values must be ruled out.
The grid of parameters investigated is:

1. Hydrogen density: $10^8 \leq n_H \leq 10^{12}$ cm^{-3}

2. Hydrogen column density: $10^{20} \le N_H \le 5 \times 10^{23}$ cm^{-2}

3. Ionization parameter: $2 \le \xi \le 4000$ erg cm s^{-1}

In Fig. 2, illustrations of the confrontation of observational constraints with the WA models are reported. Published **average** values for Seyfert 1 are considered, except for [Fe XIV] 5303Å (rarely detected) and for τ_{OVII}=0.10 (roughly the limit to detect the WA).
A high density, n$_H(WA) \geq 10^{10}$ cm^{-3}, is required, and a two-zone model is favored: an inner region (associated with O VIII) which could be located inside the BLR and an outer region (associated with O VII) at a distance similar to those of the BLR, as found by Otani et al. (1996) and by Reynolds (1997) on the basis of different variation time-scales.

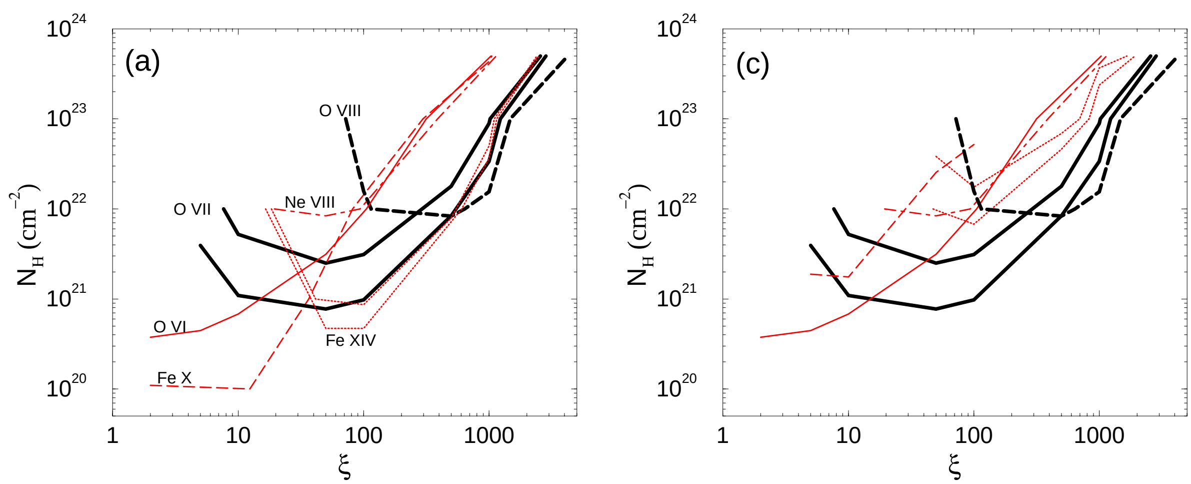

Fig. 2.— Isovalue curves in the plane (ξ,N$_H$) for the **pure photoionized model** with the incident "Laor continuum" for two hydrogen density values. Left: n$_H$=10^8 cm^{-3}, right: n$_H$=10^{10} cm^{-3}. *Thick lower and upper solid lines*: τ_{OVII}=0.10 and 0.33 respectively, *thick long dashed line*: τ_{OVIII}=0.2. *Thin long dashed line*: EW([Fe X] 6375Å)=1.5 Å, *Thin lower and upper dotted lines* EW([Fe XIV] 5303Å)=2 and 3 Å respectively, *dotted-dashed line*: EW(Ne VIII 774Å)=4 Å and *thin solid line*: EW(O VI 1034Å)=7Å. **The regions above each thin curve are forbidden since producing too large EWs**.

2.2. Soft X-ray emission lines as model diagnostics

Below, we present model diagnostics on soft X-ray resonance lines which allow to discriminate between the two models investigated here (pure photoionization or hybrid

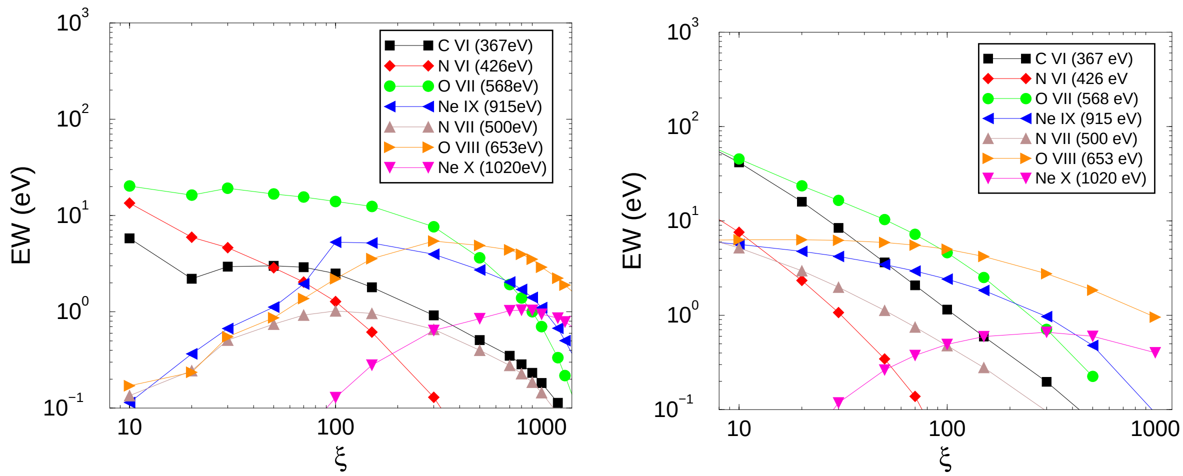

Fig. 3.— EWs of some soft X-ray emission resonance lines for a "Laor continuum" with $n_H=10^8$ cm^{-3}, $N_H=10^{22}$ cm^{-2}. *Left*: pure photoionization model and *right*: hybrid model.

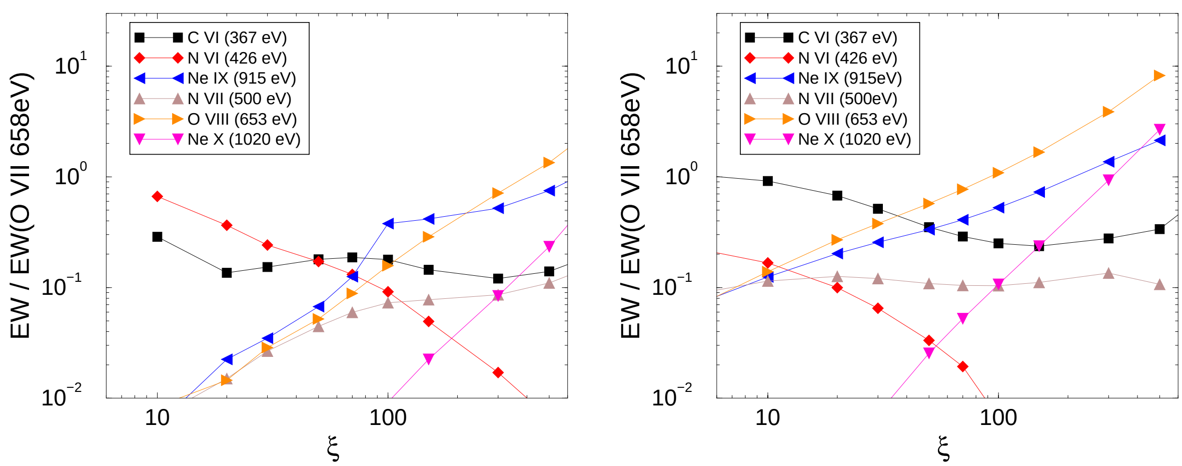

Fig. 4.— Ratio of EW(soft X-ray emission lines)/EW(O VII). Same legend as Fig 3.

models). As displayed in Figures 3 and 4, the equivalent widths (EWs) and the ratio of the soft X-rays lines versus the ionization parameter (ξ) have different behaviors. In case of the pure photoionization model the O VII line is the strongest line over a wide range of ξ (10–400), the N VI being the second strongest line expected from the outer region of the WA. At ξ >400, the O VIII line dominates and Ne IX is the second strongest line expected from the inner region for ξ <1000. For the hybrid model, O VII line dominates for a narrower ionization parameter range (ξ <100) and the C VI line is the second strongest line expected from the outer region of the WA. The O VIII line dominates at ξ >100 and the second strongest line expected from the inner region is the Ne X for ξ >500. It should be noticed that the EWs of these lines are very little sensitive to the density value (n_H). For N_H <10^{22} cm^{-2}, similar ionization states are found for lower ξ values.

3. Future prospects with XMM

The high spectral resolution of the RGS combined with a high sensitivity, will allow an accurate determination of the position of the edges and of the soft X-ray lines, and thus will give an indication on the dynamics of the medium. For example, the blueshift of the edges seen in NGC 4051 (Mihara et al. 1994) could be confirmed. In addition, the lines fluxes of the soft X-ray lines will be measured and, as shown in the last section, they will provide a powerful diagnostic for the ionization processes involved in the WA (pure photoionization model versus hybrid model). The high temporal resolution will permit variability studies and the determination of the physical conditions of the medium (in or out of photoionization equilibrium). For instance, if the recombination time-scale is larger than the variability time-scale of the source, photoionization equilibrium could not be reached.

4. Conclusion

We have briefly presented some results obtained from photoionization codes (PEGAS and IRIS) for optically thin media, with the aim to explain the spectral features of the Warm Absorber (WA) present in Seyfert 1 galaxies. The knowledge of this medium will be a powerful probe of the central region since it could lie inside the Broad Line Region as shown in Porquet et al. (1998). The WA is generally thought to be an optically thin photoionized medium (since its lies along the line of sight of the X-ray source) but the possibility of an additional ionization process (e.g. collisional heating) has not been rigorously ruled out. We have shown that the two models (pure photoionized medium or not) could be discriminated since different shapes of the continuum (edges) and different X-ray line ratios are produced. The XMM mission will bring important tools to determine the ionization processes (pure photoionized medium or not?), the physical conditions (in or out of photoionization equilibrium?) and the dynamics (outflow?) of the WA of the Seyfert 1 galaxies.

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