The hot and cold phases of the X-ray absorber in NGC 3783

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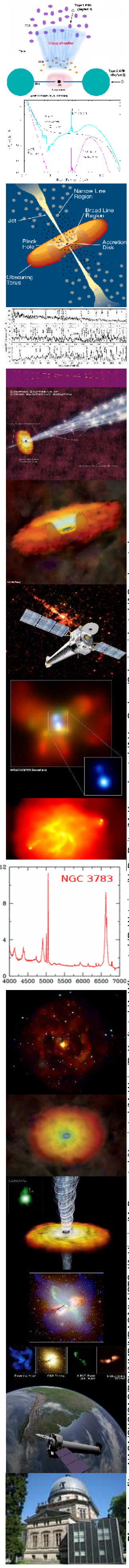

We investigate the presence of thermal instabilities in the X-ray warm absorber (WA) of the well-studied Seyfert galaxy NGC 3783. We assume the absorbing medium to be in total pressure equilibrium (total pressure = gas pressure + radiation pressure). By comparing the observed ionic column densities to a set of theoretical modeling results, we constrain the ionization parameter of the incident radiation and the total column density of the warm absorber. The X-ray data is taken from the 900 ksec Chandra observation of NGC 3783 and the radiative transfer modeling is carried out with the TITAN code. We also obtain theoretical temperature profiles of the medium that are compared to a data analysis based on the absorption measure distribution (AMD). Both, the observational AMD and the theoretical modeling are in agreement with a forbidden temperature zone that may be attributed to the occurrence of thermal instabilities. The absorbing, constant pressure plasma is probably a clumpy, two-phase medium where cold, dense clumps are embedded in a hotter, diffuse gas. We explore the temperature solutions for the net cooling of these two gas phases.

THERMAL INSTABILITIES IN A NUTSHELL

- A photoionized gas in thermal equilibrium can be subject of thermal instability (Krolik et al. 1981, ApJ 249, 422).
- The phenomenon is related to the non-monotonous behaviour of heating and cooling mechanisms as a function of temperature. Hence, the S-shaped plot of plasma temperature versus radiation to gas pressure ratio indicates, at certain pressure ratios, the possible co-existence of several gas temperature phases.
- At a given pressure ratio, the gas can thus be in three (or more) thermal equilibrium states, which depend on the ionizing spectral energy distribution (SED), the abundances and other physical parameters related to the heating and cooling (see Fig. 1).
- Not all of the multiple temperature solutions are stable, there is an even number *n* of stable solutions surrounding *n*-1 thermally unstable solutions. The plasma of course adopts only stable solutions.
- The TITAN code (Dumont et al. 2000, A&A 357, 223; Dumont et al. 2003, A&A 407, 13) allows to choose between the hot and the cold stable solutions; it also provides an intermediate solution which can be understood as a mixture of the WA cold and hot phases (Gonçalves et al. 2007, A&A 465, 9).
- In this work, **we explore the extreme thermal states the WA can adopt by imposing throughout the medium only the hottest or the coldest possible temperature solution.** Note that despite this strong condition our radiative transfer computations remain coherent.

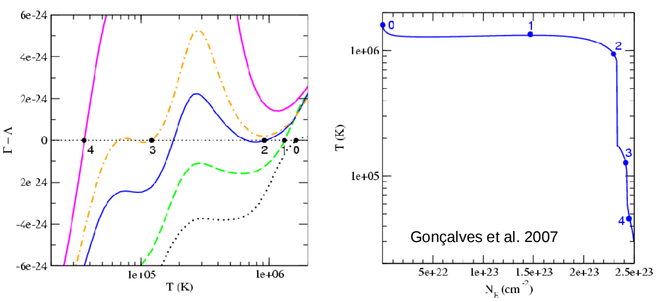

Fig. 1 - Example of the net cooling function computed for different positions in a warm absorber gas (left). Whenever the net cooling function is neutral for more than one temperature, the hot solution was selected (blue and orange curves). A stratified density profile of the medium follows naturally (right).

THE AMD METHOD APPLIED TO AGN X-RAY WINDS

- For a continuous distribution of column density one can define:

$$AMD(\xi) = dN_H/d\log\xi$$

Herein, $\xi = 4\pi F_{ion} / n_H$ is the ionization parameter and F_{ion} the ionizing flux integrated over the SED at a given position in the medium. It then follows for the individual ionic column densities:

$$N_{ion}\ (\text{measured}) = A_z \int AMD(\xi)\, f_{ion}(\xi)\, d\log\xi$$

where A_Z is the elemental abundance and f_{ion} is the ionization fraction.

- The best AMD solution is obtained by a chi-square minimization procedure providing values of N_{ion} that best reproduce the ensemble of the measured values (see Holczer et al. 2007, ApJ 663, 799 for details).
- The **AMD method indicates a forbidden temperature zone** (see Fig. 2) in the X-ray absorbing gas of NGC 3783 (and also other Seyfert galaxies).

Question: Can we **explain this gap as a result of thermal instability** by doing radiative transfer modeling **in total pressure equilibrium**?

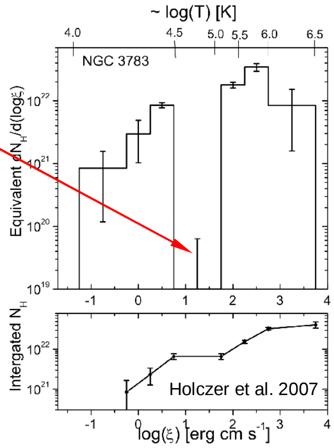

Fig. 2 – The observational AMD profile and the column density as a function of the ionization parameter inside the warm absorber gas.

COMPARING SIMULATIONS AND X-RAY DATA

- We applied the TITAN code and the AMD method to the **900 ksec *Chandra* data of NGC 3783**. In the modelling we assumed the WA to be in total pressure equilibrium.
- The TITAN radiative transfer simulations allow to directly compute the ionic structure of the WA medium and the outward (i.e. the transmitted + reprocessed) spectrum.
- We present modelling results for different values of the incident ionization parameter ξ_{inc} on the irradiated side. In each case, the **total column density N_H of the gas is adjusted so that the observed spectral continuum is correctly reproduced.** We assume the incident SED of Kaspi et al. (2002, ApJ, 574, 643)
- We consider **uniformly hot** and **uniformly cold solutions:** In the multi-phase regime, the code assumes everywhere in the medium only the hottest (or the coldest) temperature solution for the net cooling. These cases thus represent the two extreme, but physically possible thermal states the medium can adopt.

TEMPERATURE PROFILES

- The **discrete structure of the temperature profile is in good agreement** between the modelling and the data (Fig. 3). However, only the normalized column densities allow a match between the observationally derived profile and the modelling results. **While depending on the thermal state assumed** (hot or cold), **the match is in the range of ξ_{inc} = 4000 — 8000 ergs cm/s.**

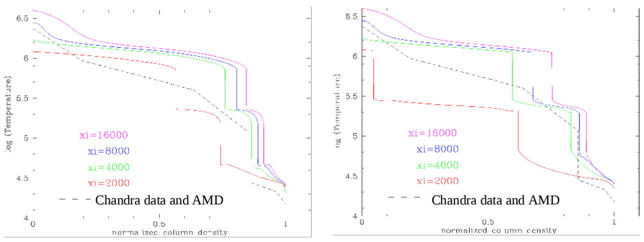

Fig. 3 – Temperature profile as a function of column density in the medium. The black dashed line denotes the observed profile obtained from the AMD analysis. The coloured solid lines represent the uniformly hot (left) and cold (right) models. The horizontal axis is normalized to the total column density of each case.

IONIC COLUMN DENSITIES

- When considering the reproduction of the spectral continuum and the ionic column densities, it turns out that the best agreement between the model and the observation is found for ξ_{inc} = 8000 and N_H ~ 6.8 x 10^{22} cm^{-2}. Both temperature limits describe the observed characteristics rather well (Fig. 4).

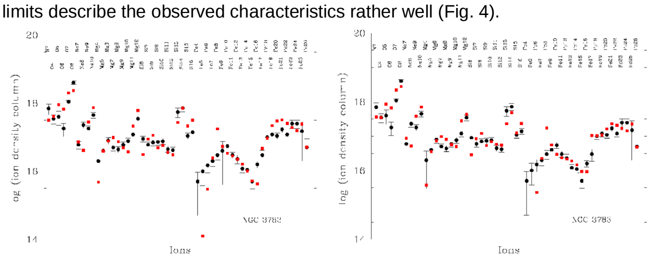

Fig. 4 – Comparison of the observed (black) and modelled (red) ionic column densities for a uniformly hot (left) and uniformly cold (right) solution.

CONCLUSIONS:

A thermal instability in total pressure equilibrium is in good agreement with many observed characteristics of the warm absorber in NGC 3783.

- Distribution of the ionic column densities
- Observationally derived temperature profile
- Spectral continuum shape

For both, **uniformly hot** or **uniformly cold** states, satisfying **solutions are found**. But the **comparison between modeling and observation has limits:**

- The AMD analysis describes only one forbidden temperature zone, but our models show two such zones.
- The observed and modeled temperature profiles resemble but do not compare exactly; they only match in the proportions of the optical depth.

These discrepancies are partly related to the mutually independent techniques applied on the observational and on the modeling side. The differences might imply that **the highly-ionized component on the irradiated side of the WA is difficult to spot directly in the observed spectrum**. Such a medium leaves no sufficient imprint in the absorption spectrum but rather absorbs and scatters continuum radiation out of the line of sight.