

Changing look: from Compton-thick to Compton-thin, or the rebirth of fossil active galactic nuclei

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ABSTRACT

We discuss the properties of a small sample of type 2 Seyfert galaxies whose X-ray spectra changed appearance on time-scales of years, becoming reflection-dominated from Compton-thin, or vice versa. A reflection-dominated spectrum is usually taken as evidence of Compton-thick absorption, but we instead argue that such a spectrum is due to a temporary switching-off of the nuclear radiation. The observations discussed here may help to explain mismatches between optical and X-ray classifications, and provide new strong and direct evidence for the presence of more than one cold circumnuclear region in type 2 Seyfert galaxies.

Key words: galaxies: active – galaxies: Seyfert – X-rays: galaxies.

1 INTRODUCTION

It is well known (for a review, see e.g. Matt 2002, and references therein) that most active galactic nuclei (AGN) are ‘obscured’ in X-rays. Their observed spectrum depends on the (hydrogen equivalent) column density, N_{H} , of the absorber. If the column density exceeds the value $\sigma_{\text{T}}^{-1} = 1.5 \times 10^{-24} \text{ cm}^{-2}$, for which the Compton scattering optical depth becomes equal to unity, the sources are called ‘Compton-thick’. If the column density is smaller than σ_{T}^{-1} but still in excess of the Galactic one, the source is called ‘Compton-thin’. Assuming the simple geometry depicted in Fig. 1 [in which the absorbing matter is assumed to form a geometrically thick torus, according to the popular unification models (see Antonucci 1993)], the expected spectrum is shown in Fig. 2. In the Compton-thin case, the nuclear spectrum (assumed for simplicity to be a power law with photon spectral index 2) can be directly observed above a few keV, and a fluorescent iron line (with equivalent width $\text{EW} \sim 10 \text{ eV}$ for $N_{\text{H}} = 10^{22} \text{ cm}^{-2}$ and $\text{EW} \sim 100 \text{ eV}$ for $N_{\text{H}} = 10^{23} \text{ cm}^{-2}$, see Fig. 3) is produced. In the moderately Compton-thick case ($N_{\text{H}} = 4 \times 10^{24} \text{ cm}^{-2}$), the spectrum below 10 keV is dominated by the reflection continuum [plus a prominent iron line with $\text{EW} \sim 1 \text{ keV}$ (Ghisellini, Haardt & Matt 1994; Krolik, Madau & Zicky 1994; Matt, Brandt & Fabian 1996)] produced by the visible part of the inner wall of the torus itself (see Fig. 1), while the nuclear radiation can be directly visible in transmission at higher energies. This is, for instance, the case for two out of the three closest AGN, the Circinus galaxy (Matt et al. 1999) and NGC 4945 (Iwasawa et al. 1993; Guainazzi et al. 2000). For column densities exceeding $N_{\text{H}} = 10^{25} \text{ cm}^{-2}$, no nuclear radiation is transmitted, and only the reflec-

tion component is visible (see for instance NGC 1068; Matt et al. 1997). It is worth noting that reflection from highly ionized matter can also be present (cf. Matt et al. 2000), and that the ionization state of the ‘cold’ reflector may include also mildly ionized components (Bianchi, Matt & Iwasawa 2001). However, for simplicity we will discuss cold reflectors only.

Also the spectrum reflected by the torus depends on its column density. The iron line EW (calculated with respect to both the reflection continuum and the total one) is shown in Fig. 3 for a torus seen face-on as a function of N_{H} in the equatorial plane. In Fig. 4 the reflection spectrum is shown. For Compton-thick material, the spectrum is well known (e.g. George & Fabian 1991; Matt, Perola & Piro 1991); while for Compton-thin matter, it is very different in shape and, overall, less prominent. [Both figures are based on Monte Carlo simulations; see Ghisellini et al. (1994) for details on the simulation code.]

A reflection-dominated spectrum is usually assumed as evidence of Compton-thick absorption, especially when using instruments working up to $\sim 10 \text{ keV}$, and therefore unable to detect the primary emission through moderately thick absorbers. However, such a spectrum may occur not only when the nucleus is absorbed, but also when its emission decreases down to invisibility (in this case we will speak of a ‘switched-off’ source), provided of course that the reflecting material is distant enough from the nucleus to act as an ‘echo’ for a while. The classical example of a switched-off source is NGC 4051, observed by *BeppoSAX* during a prolonged low state (Uttley et al. 1999) and found to be reflection-dominated (Guainazzi et al. 1998), i.e. with a very prominent iron line and the hard (and curved) continuum spectrum typical of a Compton-thick reflection component. NGC 4051 is a well-known type 1 Seyfert galaxy but, based on the *BeppoSAX* spectrum alone, it would have been classified as a Compton-thick absorbed source. The explanation

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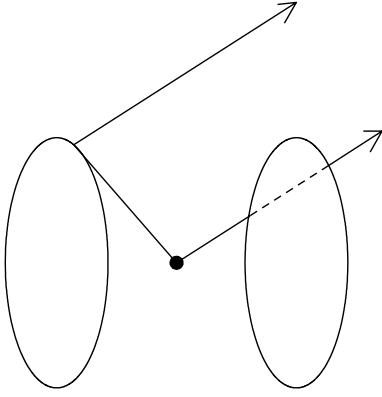


Figure 1. Sketch of the geometry adopted for the calculations presented in Figs. 2–4. The opening angle of the torus is 30° .

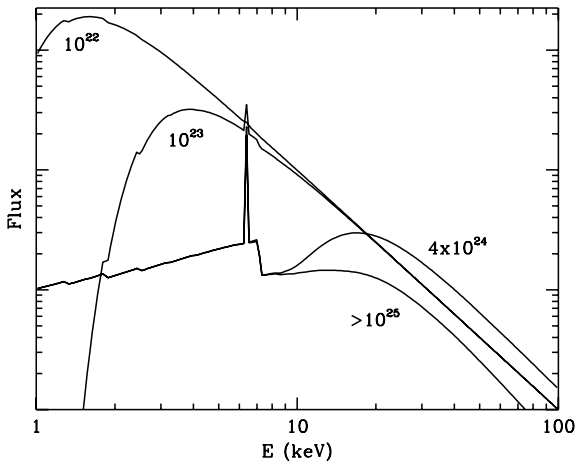


Figure 2. The X-ray spectrum of an obscured AGN is shown, for different column densities of the absorber. The absorbing matter is assumed to form a geometrically thick torus, according to unification models.

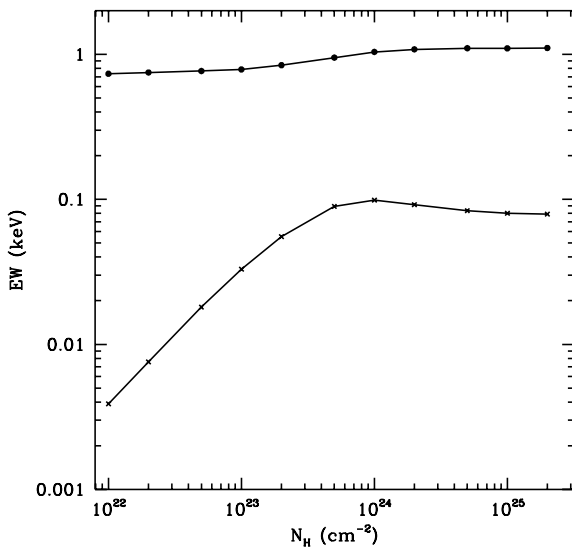


Figure 3. For the same geometry and illuminating spectrum as in Fig. 4, the EW of the iron line against the pure reflection component (upper data) and against the total continuum (lower data). The torus is assumed to be face-on.

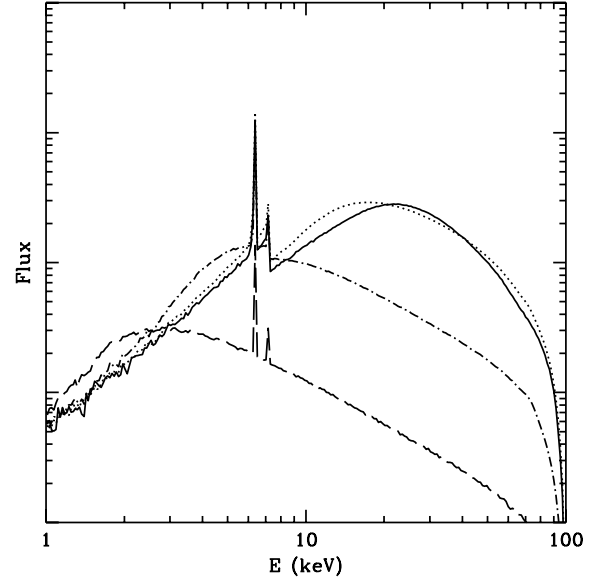


Figure 4. The reflection spectrum from the torus for different column densities: $2 \times 10^{22} \text{ cm}^{-2}$ (dashed line), $2 \times 10^{23} \text{ cm}^{-2}$ (dot-dashed line), $2 \times 10^{24} \text{ cm}^{-2}$ (dotted line) and $2 \times 10^{25} \text{ cm}^{-2}$ (solid line). The illuminating spectrum is a power law with photon index 2 and exponential cut-off at 100 keV. The torus is assumed to be face-on.

in terms of a decrease of the nuclear flux instead of a temporary Compton-thick absorption is further confirmed by recent *Chandra* observations (Fruscione, Uttley & McHardy 2002), which showed a residual short-term and low-amplitude variability during another low state of the source; clearly, in this case the nuclear flux was much fainter than usual, but not completely disappeared as during the *BeppoSAX* observation. We note, incidentally, that a temporary switching-off of the nucleus may explain at least some of the type 1 sources with a large hardness ratio discovered in X-ray surveys (see e.g. Fiore et al. 2001; Della Ceca et al. 2001).

Recently, the same kind of variability was discovered in a few type 2 Seyfert galaxies, which changed from reflection-dominated (and therefore candidate Compton-thick absorbed sources) to Compton-thin, or vice versa. The clearest cases so far are UGC 4203 (Guainazzi et al. 2002), NGC 6300 (Guainazzi 2002), NGC 1365 (Risaliti, Maiolino & Bassani 2000) and NGC 2992 (Gilli et al. 2000). For at least some of these sources, a change in the column density of the absorber, rather than a switching-off of the source, cannot be completely ruled out, and indeed Risaliti, Elvis & Nicastro (2002) claimed that variations in the absorbing column density are common in type 2 Seyfert galaxies. However, the changing absorbers in the Risaliti et al. (2002) sample are all Compton-thin, and in most cases the variations are too small to rule out the possibility that they are an artefact due to comparing spectra obtained with different instruments. Moreover, this solution is clearly untenable for NGC 2992 (Gilli et al. 2000, see Section 2.4), which has been well monitored over the years, showing a gradual change of the nuclear flux and a constant absorber. We find it difficult to imagine a situation in which a Compton-thick absorber on the parsec scale (as suggested by the lack of variability of the reflection components) and with a large covering factor (to allow for the rather large reflection components) can vary so dramatically on time-scales of years. Therefore, in the following we will assume that the observed variations are due to the switching-off of the nucleus. After reviewing the current observation status of this field (Section 2), we will discuss some possible implications (Section 3).

2 TYPE 2 SEYFERT GALAXIES THAT CHANGED LOOK

2.1 UGC 4203

UGC 4203 (Mrk 1210) has recently been observed by *XMM-Newton* (Guainazzi et al. 2002), unveiling an X-ray bright nucleus, absorbed by $N_{\text{H}} \simeq 2 \times 10^{23} \text{ cm}^{-2}$. However, in an *ASCA* observation performed about five and half years earlier (Awaki et al. 2000), the prominent iron line ($\text{EW} \simeq 1 \text{ keV}$) and the factor of 5 lower 2–10 keV flux indicated a reflection-dominated spectrum (Fig. 4), with the nuclear emission too faint to be visible.

The limited bandpass of *ASCA*, along with the low flux of the source, does not permit one to distinguish between different column densities of the reflecting matter, provided that it exceeds about 10^{23} cm^{-2} (see Fig. 4). It is therefore possible that in this case the absorbing and reflecting materials are one and the same.

2.2 NGC 6300

NGC 6300, discovered serendipitously by *Ginga* (Awaki 1991), was observed in a Compton-thick reflection-dominated state by *RXTE* in 1997 February (Leighly et al. 1999). Two and half years later a remarkably strong Seyfert nucleus (2–10 keV flux $\sim 1.3 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$) seen through a column density with $N_{\text{H}} \simeq 2 \times 10^{23} \text{ cm}^{-2}$ (Fig. 4) was discovered in a *BeppoSAX* observation. An *XMM-Newton* observation performed early in 2001 caught the source still in the high-flux, Compton-thin state (Maddox et al. 2002).

As the *RXTE* bandpass extends up to 20 keV, for this source it is possible to distinguish between Compton-thin and Compton-thick reflection (Fig. 4). The detection in the PCA highest energy band is too strong to be explained as pure reflection by matter with $N_{\text{H}} \simeq 2 \times 10^{23} \text{ cm}^{-2}$. In this case, therefore, the (thick) reflector must be different from the (thin) absorber.

2.3 NGC 1365

A *BeppoSAX* observation in 1997 August detected in this source a bright Seyfert nucleus, seen through a Compton-thin ($N_{\text{H}} \simeq 4 \times 10^{23} \text{ cm}^{-2}$; Risaliti et al. 2000) absorber. In contrast, an *ASCA* observation, performed three years earlier, detected a very flat X-ray continuum ($\Gamma \simeq 0.8$) and a 2.1-keV $K\alpha$ iron line, both indicating a reflection-dominated state (Fig. 4). Owing to the limited bandwidth of *ASCA*, and similarly to UGC 4203, the possibility that the reflector is simply the inner wall of the absorber cannot be ruled out.

2.4 NGC 2992

The brightest and best-studied source in our small sample is NGC 2992, a type 1.9 Seyfert galaxy with an X-ray absorbing column density $N_{\text{H}} \sim 9 \times 10^{21} \text{ cm}^{-2}$. The X-ray flux of NGC 2992 steadily declined from 1978, when it was observed by *HEAO-1* (Mushotzky 1982) at an (unabsorbed) flux level of about $8 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$, until 1994, when it was observed by *ASCA* (Weaver et al. 1996) at a flux level more than one order of magnitude fainter. Then the source underwent a rapid recovery: in 1997 it was observed by *BeppoSAX* at a flux level somewhat higher than in 1994, while in 1998 it had fully recovered its 1978 brightness (Gilli et al. 2000, see Fig. 4).

In this case the comparison between the Compton-thin and the *ASCA* almost reflection-dominated states clearly rules out the possibility that the reflector is the inner wall of the absorber. The 4–10 keV

to 2–4 keV flux ratio during the *ASCA* observation is 0.35 ± 0.02 (corresponding to $\Gamma \simeq 1.15$), which is largely inconsistent with the theoretical value expected from a reflection-dominated spectrum by a column density $\sim 10^{22} \text{ cm}^{-2}$ (0.53). It is worth noting that in both *BeppoSAX* observations the power-law spectral index was typical for AGN ($\Gamma \simeq 1.7$), again indicating that the flux recovery is likely to be associated with the re-emergence of the AGN nuclear emission. In summary, for this source there is no doubt that the absorbing and reflecting regions do not have the same column density and probably belong to different gaseous structures.

3 DISCUSSION

We have presented evidence for the switching-off of the nucleus in a few type 2 Seyfert galaxies based on their changed looks (from Compton-thin to reflection-dominated or vice versa) when observed a few years apart. The evidence cannot be considered conclusive yet, and further investigations, both on the same objects and in the search for new objects with a similar behaviour, are needed. In the meantime, let us briefly discuss a few interesting consequences of the proposed scenario.

3.1 How many reflection-dominated sources are not genuine Compton-thick absorbed?

This is a question that involves, of course, both type 1 and type 2 Seyfert galaxies. It is basically impossible to estimate the fraction of these transitions in obscured AGN, as a result of the lack of a complete and unbiased sample of homogeneously defined type 2 Seyfert galaxies with sufficient X-ray temporal and spectroscopic coverage. An *XMM-Newton* programme is ongoing to address this question on the complete sample of Compton-thick AGN defined in Risaliti, Maiolino & Salvati (1999).

3.1.1 Implications for the optical/X-ray classification mismatch

The existence of a population of type 1 Seyfert galaxies with significant X-ray absorption (Maiolino et al. 2001; Fiore et al. 2001; Della Ceca et al. 2001) has been recently recognized. For most of these sources, evidence for absorption comes from the flatness of the X-ray spectrum as derived from a hardness ratio analysis, rather than from a direct measurement of the column density, because they are often too faint to allow for a proper spectral analysis. As the X-ray and optical observations are usually not simultaneous, it is possible that this mismatch is, at least for a fraction of these sources, due to a temporary switching-off of the nuclear radiation. Other explanations are still possible (e.g. ionization of the X-ray absorbing medium, low gas-to-dust ratio in the AGN nuclear environment, dust sublimation). However, if the explanation is indeed in terms of variability, with the sources caught in different states by the X-ray and optical observations, one would expect to find also sources that were switched-off when observed in the optical and switched-on when observed in X-rays, namely X-ray unobscured AGN with a type 2 optical spectrum. Objects of this kind have indeed been recently discovered in sparse samples of nearby Seyfert galaxies, as reported by Pappa et al. (2001) and Panessa & Bassani (2002).

3.1.2 Implications for the cosmic X-ray background

Another possible implication concerns the modelling of the X-ray background (XRB). Popular synthesis models of the XRB (e.g.

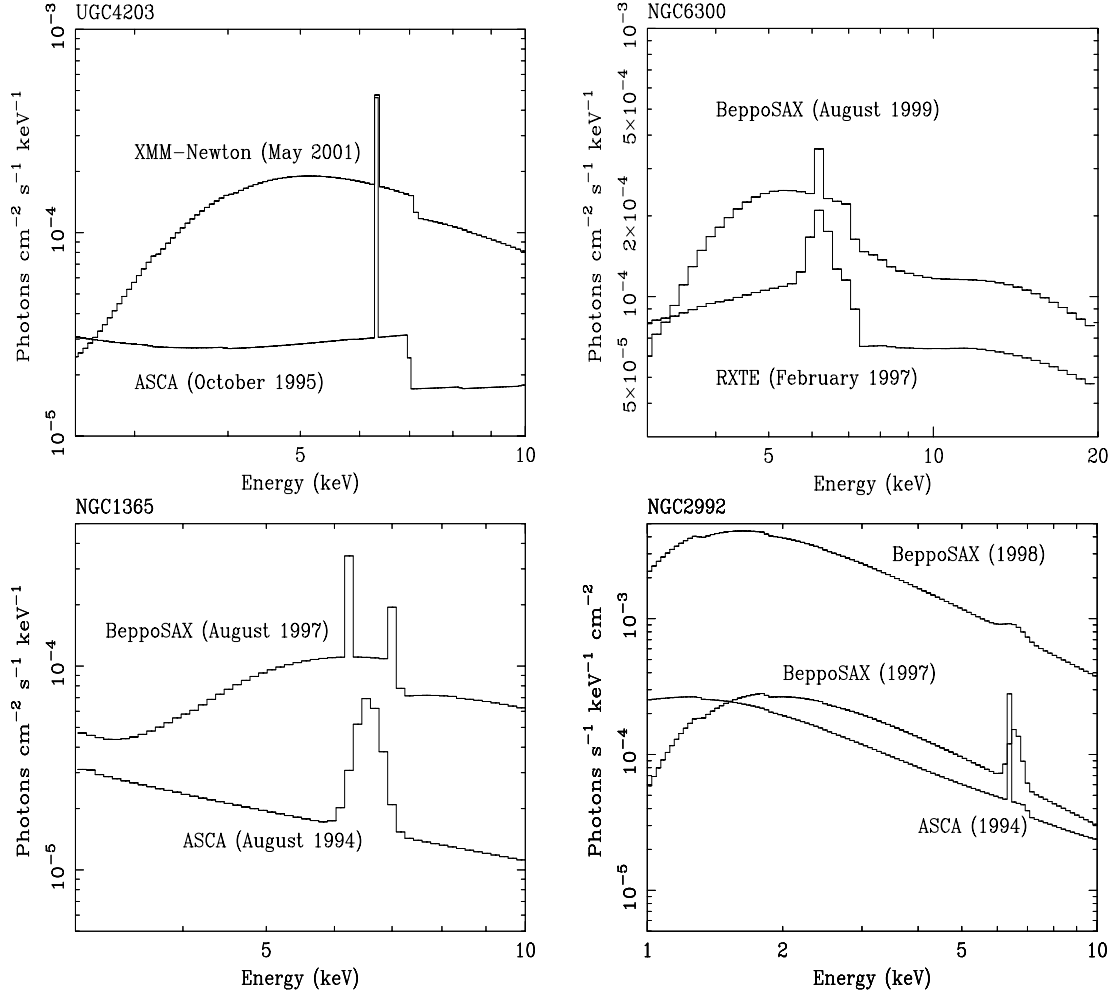


Figure 5. Upper-left panel: The *ASCA* and *XMM-Newton* best-fitting models for UGC 4203 (Guainazzi et al. 2002). Upper-right panel: The *BeppoSAX* and *RXTE* best-fitting models for NGC 6300 (after Leighly et al. 1999, Guainazzi 2002). Lower-left panel: *ASCA* and *BeppoSAX* best-fitting models for NGC 1365 (after Iyomoto et al. 1997, Risaliti et al. 2000, respectively). Note that, in agreement with these papers, the line feature is represented as a single broad Gaussian profile at $E = 6.57$ keV (*ASCA*) or as the blending of two narrow features (*BeppoSAX*) at energies $E = 6.257 \pm 0.09$ keV and 6.95 keV, respectively. Lower-right panel: *ASCA* (1994) and *BeppoSAX* (1997, 1998) best-fitting models of NGC 2992 (after Weaver et al. 1996, Gilli et al. 2000). See text for mode details on each source.

Comastri et al. 1995) require a significant fraction of moderately Compton-thick sources, in which the nuclear radiation can be directly observed at energies of tens of keV. If many of the reflection-dominated sources are in future proven to be simply switched-off AGN, there may in principle be the need for a revision of the XRB synthesis models. However, as the covering factor of the reflecting matter is by all evidence rather large (e.g. Matt et al. 2000), it is unlikely that the possible lack of intermediate Compton-thick sources will turn out to be a serious problem.

3.2 How many cold circumnuclear regions?

A question that instead directly follows from the observations of type 2 Seyfert galaxies which change look, is that of the presence of more than one cold circumnuclear region.

For at least two out of four sources in our sample, at least two (one thin, the other thick) circumnuclear regions are definitely required. (Whether they actually correspond to two physically and geometrically distinct regions or simply to inhomogeneities in one and the same absorber, it is difficult to say with certainty. However, there

is evidence that the Compton-thin absorbers are usually located at much larger distances than the Compton-thick ones; see below.) For the other two, this is possible as well, but the limited bandwidth of the observations when the sources were reflection-dominated does not permit one to rule out Compton-thin reflection. It is worth noting that in another Compton-thin AGN, NGC 5506, the presence of a Compton-thick reflector can be derived from direct spectral analysis (Matt et al. 2001). Moreover, other Compton-thick AGN in which the soft X-ray spectrum is further absorbed by Compton-thin matter with $N_{\text{H}} \sim 10^{21-22} \text{ cm}^{-2}$, are known. The Compton-thin absorber may be associated with the host galaxy disc (e.g. Tololo 0109-389; Matt et al. 2003) or with dusty regions of enhanced stellar formation (e.g. the infrared ultraluminous galaxy NGC 6240; Iwasawa & Comastri 1998; Vignati et al. 1999).

Several authors have already suggested the presence of more than one cold circumnuclear region in AGN. Maiolino & Rieke (1995), Matt (2000) and Weaver (2001) all proposed the presence of both a Compton-thick and a Compton-thin absorber. While all these authors agree that the Compton-thick absorber should be compact (i.e. the ‘real’ torus) on the basis of direct and indirect evidence in

nearby sources [i.e. direct imaging in the Circinus galaxy (Sambruna et al. 2001), photoionization models of the reflection spectrum in Circinus and NGC 1068 (Bianchi et al. 2001), and dynamical mass considerations in the same two sources (Risaliti et al. 1999)], there are several possibilities for the Compton-thin absorber: the Galactic disc (Maiolino & Rieke 1995), dust lanes (Malkan, Gorijn & Tam 1998; Matt 2000), and starburst clouds (Weaver 2001). It is very possible that different Compton-thin absorbers are present in different sources, or even that more than one are simultaneously present in the same source.

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