An absorbed view of a new class of INTEGRAL sources

E. Kuulkers

ISOC, ESA/ESAC, Urb. Villafranca del Castillo, P.O. Box 50727, 28080 Madrid, Spain

Abstract. The European γ-ray observatory INTEGRAL has found a group of hard X-ray sources which are highly absorbed, i.e., with column densities higher than about 10^{23} cm^{-2}. Here I give an overview of this class of INTEGRAL sources. The X-ray, as well as the optical/IR, properties of these sources and their location in the sky suggest that they belong to the class of high-mass X-ray binaries, some of them possibly long-period X-ray pulsars. The donors in these binaries are most probably giant or supergiant stars. I suggest that the soft X-ray spectrum below ∼5 keV of IGR J16318−4848, as well as in several other X-ray binaries (e.g., XTE J0421+56), can be described by emission from a compact object which is strongly absorbed by a partially ionised dense envelope.

INTRODUCTION

Hard X-rays (typically ≥20 keV) and γ-rays are not easily absorbed by matter and thus are highly penetrating. Such radiation is, therefore, ideal to probe high-energy emitting sources in dense regions. Since its launch in October 2002 INTEGRAL (International Gamma-Ray Laboratory; Winkler et al. 2003) is revealing hard X-ray/soft γ-ray sources which were not easily spotted in earlier soft X-ray (typically <10 keV) observations. This invited review deals with this apparent new class of X-ray sources which show intrinsically high absorption along the line of sight, i.e., orders of magnitude higher than the usual interstellar absorption. I will describe their properties, and discuss their nature.

INTEGRAL carries on-board four instruments1: SPI, a hard X-ray/γ-ray spectrometer; IBIS, two coded mask hard X-ray/γ-ray imagers, ISGRI and PICsIT; Jem-X, two identical coded mask X-ray imagers; OMC, an optical monitor. The sources described in this paper are mainly found by IBIS/ISGRI (Ubertini et al. 2003, Lebrun et al. 2003). It has a 8.3°x8° fully-coded field-of-view, while it is partially coded out to 29°x29°; the angular resolution is 12′. This makes it ideal for observations in crowded regions.

The large field-of-view of IBIS makes it ideal to map the hard X-ray/γ-ray sky. During the first year of Galactic Plane observations about 120 point sources were detected down to ∼1 mCrab (30–100 keV; Bird et al. 2004). Among them are previously unknown sources, such as the well-known example IGR J16318−4848 (see below). About 86% of the Galactic hard X-ray emission up to ∼100 keV can be attributed to these high-energy point sources (Lebrun et al. 2004).

1 For a full description of the instruments, as well as an account of the first results, I refer to the special A&A Letters INTEGRAL issue 411 (2003).
NEW, HIGHLY ABSORBED, INTEGRAL SOURCES

As an illustration of the usefulness of the combination of a large field-of-view and high sensitivity at hard X-ray/soft $\gamma$-rays, INTEGRAL discovered its first source, IGRJ16318$-$4848, soon after nominal operation started, on January 29, 2003 during a routine Galactic Plane Scan (Courvoisier et al. 2003). Re-analysis of archival ASCA data revealed that its position coincides with a highly absorbed ($N_H \sim 10^{24} \text{ cm}^{-2}$) source with some hint of an Fe emission line (Murukami et al. 2003, Revnitsky et al. 2003). Two weeks after the INTEGRAL detection, an XMM-Newton TOO observation indeed unveiled a variable and heavily absorbed source ($2 \times 10^{24} \text{ cm}^{-2}$), which emitted strong emission lines (Schartel et al. 2003). The emission complex could be resolved into three components, with centroid energies of 6.4 keV, 7.1 keV and 7.5 keV. They are most naturally interpreted as low ionised emission from Fe K$\alpha$, K$\beta$ and Ni K$\alpha$ (de Plaa et al. 2003, Walter et al. 2003, Matt & Guainazzi 2003).

After IGR J16318$-$4848, INTEGRAL found many more new sources (hereafter called IGR sources). Up to April 2005 more than 50 of these IGR sources have been reported. Some were identified with already known sources (e.g., IGRJ17464$-$3213 = H1743$-$322), but most of them are new ones. About one third of the IGR sources can be classified. Most of them are either persistent or transient low-mass X-ray binaries (LMXBs) or high-mass X-ray binaries (HMXBs). Some of them have been classified as either being cataclysmic variables (e.g., IGR J17303$-$0601), accreting millisecond X-ray pulsar (IGR J00291+5934), AGN (e.g., IGR J18027$-$1455), or the central source of our Galaxy, Sgr A$^*$ (IGRJ17456$-$2901). Still, about two third of them are unclassified, and some work lies ahead of us. The distribution of these sources is shown in Fig. 1. It seems that they are all distributed along the galactic plane, with concentrations in the direction of the Galactic Center and Galactic arms (see, e.g., Lutovinov et al. 2005b). One must note, however, that a lot of the INTEGRAL observations are concentrated on regions around the Galactic plane and the detection of new (especially transient) sources may, therefore, be biased towards these regions.

Of the (up to now well-studied) IGR sources, ten of them show very strong absorption ($N_H \gtrsim 10^{23} \text{ cm}^{-2}$), i.e., one to two orders of magnitude higher than the Galactic value of around $10^{22} \text{ cm}^{-2}$. It is this class of sources which I concentrate on for the rest of this paper, and I will refer to them as highly absorbed IGR sources. They are listed in Table 1; one thing which immediately catches the eye is that all but one (IGRJ19140+0951) are in the direction of the Norma-arm tangent region. I will come back to this later.

Some of the highly absorbed IGR sources seem to be more or less persistent (such as IGR J16318$-$4848; see, e.g., Matt et al. 2005); some of them are clearly transient (e.g., IGR J16358$-$4726: Patel et al. 2004; IGR J16465$-$4507: Lutovinov et al. 2005b). The highly absorbed IGR sources vary in brightness on time scales of minutes to hours, as well as from observation to observation, both at soft and hard X-ray energies (e.g., IGR J16318$-$4848: Walter et al. 2003, Matt & Guainazzi 2003, Matt et al. 2005; see http://isdc.unige.ch/~rodrigue/html/igrsources.html for an up-to-date list and further information.

2 Note, however, that many of the new sources do have catalogueued ROSAT, ASCA, and/or BeppoSAX soft-energy counterparts.
FIGURE 1. Galactic distribution of IGR sources. The size of the symbol • indicates the maximum observed X-ray intensity in units of mCrab in the 20-40 keV or 20-60 keV band. Flux values were mostly taken from those reported in the Astronomer’s Telegrams and IAU Circulars.

IGR J16320–4751: Rodriguez et al. 2003, Foschini et al. 2004). In IGR J16318–4848 the line emission also varies on time scales of ∼15 min and longer (Matt & Guainazzi 2003). Up to now, four of the (well-studied) highly absorbed IGR sources have been seen to also vary on a regular time scale (between ≃4 to ≃100 min, see Table 1). IGR J16358–4726, for example, displayed a strong period flux modulation with a peak-to-peak pulse fraction of ∼70%. These have been interpreted as neutron star pulse periods. The absorption column is also seen to vary, from observation to observation (e.g., IGR J16318–4848: Revnivtsev 2003; IGR J16320–4751: Rodriguez et al. 2003; IGR J19140+0951: Rodriguez et al. 2005a).

In Table 1, I give the parameters for the (cut-off) power-law model, which is usually used to fit the soft X-ray (ASCA, XMM-Newton, Chandra) spectral data, most of the time, in combination with INTEGRAL spectral data. The spectra are hard (Γ ≲ 2), and

The cut-off power-law model is given by $e^{-N_H \sigma(E) A_{pl} E \Gamma / E_{cut}}$, where $N_H$ is the absorption column density, $\sigma(E)$ the absorption cross-section, $A_{pl}$ the power-law normalization, $\Gamma$ the power-law index, and $E_{cut}$ the cut-off energy.
show evidence for high-energy cut-off values. However, one must note here that the soft-energy spectra were not taken simultaneously with the hard X-ray spectra. Since the sources are (highly) variable, both at soft and hard X-ray energies, one must be cautious with the spectral fitting results (see, e.g., Walter et al. 2003). Of the highly absorbed IGR sources, only IGR J16138−4848 shows very strong emission lines (see above). The others only show weak (or undetectable) line emission.

**X-ray and optical/IR emission**

As shown in the previous Section, the highly absorbed IGR sources have similar X-ray properties: hard X-ray (cut-off; \( E_{\text{cut}} \gtrsim 10 \text{ keV} \)) power-law (\( \Gamma \lesssim 2 \)) emission and some, or most of the time, strong (\( N_H \gtrsim 10^{23} \text{ cm}^{-2} \)) and variable absorption. Four of them have been found to show (long-period; \( \gtrsim 4 \text{ min} \)) ‘pulse’ periods. These properties are rather typical for accreting X-ray pulsars in HMXBs (see, e.g., White et al. 1983), suggesting that the highly absorbed IGR sources are HMXBs. The highly absorbed IGR sources are located in the direction of the Norma spiral-arm tangent, except for IGR J19140+0951. The latter is located in the direction of the Sagittarius spiral-arm tangent; various HMXB X-ray pulsars are located in that direction, as well as other IGR sources (see, e.g., Molkov et al. 2004). These regions have an enhanced concentration of young massive stars (e.g., Grimm et al. 2002), and supports the HMXB hypothesis for the highly absorbed IGR sources. If they lie indeed in the above-mentioned spiral arms, their unabsorbed \( \sim 2–100 \text{ keV} \) X-ray luminosity would be around \( 10^{35} \) to a few times \( 10^{36} \text{ erg s}^{-1} \), also very typical for HMXBs. Note that various other of the less absorbed IGR sources are classified as bonafide HMXB/Be-X-ray transients (see, e.g., Negueruela 2005).

---

**TABLE 1.** Properties of highly absorbed (\( N_H \gtrsim 10^{23} \text{ cm}^{-2} \)) INTEGRAL sources

| IGR source     | \( N_H \) (\( 10^{23} \text{ cm}^{-2} \)) | \( \Gamma \) | \( E_{\text{cut}} \) (keV) | \( P_{\text{pulse}} \) (min) | references\(^a\) |
|----------------|---------------------------------|-------------|-----------------|---------------------|-----------------|
| IGR J16195−4945 | \( \approx 1 \)                  | \( \sim 0.6 \) | \( 1.7–2.1 \)    | \( \approx 15 \)     | [1]             |
| IGR J16318−4848 | \( \approx 20 \)                 | \( \sim 0.7 \) | \( 0.5–1.1 \)    | \( \approx 12 \)     | [2],[3]         |
| IGR J16320−4751 | \( \approx 2 \)                 | \( \sim 1.3 \) | \( \approx 22 \)  | \( \approx 150 \)      | [4],[5],[6]   |
| IGR J16358−4726 | \( \approx 4 \)                 | \( \sim 0.7 \) | \( \approx 16 \)  | \( \approx 100 \)      | [7],[8]         |
| IGR J16393−4643 | \( \approx 6 \)                 | \( \sim 1.3 \) | \( \approx 11 \)  | \( \approx 15 \)      | [8],[9],[10]    |
| IGR J16418−4532 | \( \gtrsim 1 \)                  |             | \( \approx 1 \)  | \( \approx 32 \)      | [11]            |
| IGR J16493−4348 | \( \approx 1 \)                 | \( \sim 1.4 \) | \( \approx 4 \)   | \( \approx 1 \)      | [12]            |
| IGR J16465−4507 | \( \approx 7 \)                 | \( \sim 1 \) | \( \sim 2 \)     | \( \approx 1 \)      | [8]            |
| IGR J16479−4514 | \( \approx 1 \)                 | \( \sim 1.4 \) | \( \approx 1 \)  | \( \approx 1 \)      | [8]            |
| IGR J19140+0951 | \( \approx 1^{b} \)             | \( \pm 1.6 \) | \( \pm 1 \)       | \( \pm 1 \)          | [13]            |

\(^a\) References: [1] Sidoli et al. (2005), [2] Walter et al. (2003), [3] Matt & Guainazzi (2003), [4] Rodriguez et al. (2003), [5] Foschini et al. (2004), [6] Lutovinov et al. (2005a), [7] Patel et al. (2004), [8] Lutovinov et al. (2005b), [9] Combi et al. (2004), [10] Walter (2005), [11] Walter et al. (2004), [12] Markwardt et al. (2005), [13] Rodriguez et al. (2005a).

\(^b\) This is an observed maximum value which is only reached occasionnally.
There are a few well-known HMXBs which show strong ($N_H \gtrsim 10^{23}$ cm$^{-2}$) and variable absorption, as well as strong Fe Kα emission and X-ray pulsations: GX 301–2 (Swank et al. 1976, Endo et al. 2002), Vela X-1 (Haberl & White 1990), XTE J0421+56 (CI Cam; Boirin et al. 2002). The latter is an atypical Be/X-ray binary (see below). Note that GX 1+4, not an HMXB but a rare type of symbiotic LMXB (see below), showed also similar spectra during an extended low state (Naik et al. 2005). Other known HMXBs exist which show similarly hard and strongly absorbed X-ray spectra (e.g., EXO 1722–363: Tawara et al. 1989, Takeuchi et al. 1990, see also Walter 2005; 4U 1909+07: Levine et al. 2004). The fact that the absorption is seen to vary in the HMXBs and the highly absorbed IGR sources, suggests it is intrinsic. For example, in GX 302–1 the absorption varies between $3 \times 10^{23}$ and $2 \times 10^{24}$ cm$^{-2}$, and is indeed connected to its 41 day orbit (e.g., White & Swank 1984, Endo et al. 2002).

Long X-ray ‘pulse’ periods have been found previously in HMXBs (but in those which show only moderate X-ray absorption), such as SAX J2239.3+6116 (21 min: in ’t Zand et al. 2001), 4U 2206+54 (≃60 min; Masetti et al. 2004) and 4U 0114+650 (2.7 hr: Finley et al. 1992). 4U 2206+54 and 4U 0114+650 shows noticeable similar pulsation profiles as those seen in the highly absorbed IGR sources. Most of the X-ray pulsar HMXBs with pulse period longer than typically a few minutes are considered to be pulsars fed by a stellar wind (e.g., Nagase 1989). In the classical Corbet (1986) diagram the highly absorbed IGR sources either fall in the group of supergiant systems or the long orbital period (≥30 days) Be/X-ray transients. So far, only IGR J19140+0951 has a reported orbital period ($P_{\text{orb}} \simeq 13.55$ days, Corbet et al. 2004). If the highly absorbed IGR sources indeed contain (slow) pulsars, their compact object is evidently a neutron star. However, if this interpretation is not correct, a black hole can not be excluded either (this is especially true for those IGR sources with no identified pulsations).

The presence of strong absorption in the X-ray domain shows that the compact object must be embedded in a dense circumstellar envelope, originating from a dense stellar wind from the donor. This (relatively cold) envelope also serves as the source of the fluorescent emission, especially in IGR J16318–4848 (e.g., Walter et al. 2003; Matt & Guainazzi 2003; Revnivtsev et al. 2003).

About 70% of the mass donors in HMXB are classical Be stars, the rest are blue supergiants. A big fraction of the accretion powered X-ray pulsars in the Be-systems are transients. Be stars show rich emission line spectra. There is, however, a subclass of objects which also show forbidden lines, as well as a near-IR excess. These are the B[e] stars; they include many objects of different types and evolutionary status (e.g., Lamers et al. 1998). The typical mass-loss rates in these stars are $\dot{M} \gtrsim 10^{-6}$ $M_\odot$ yr$^{-1}$.

---

5 Of course, it is assumed here that the highly absorbed IGR sources are binaries; this, however, remains to be verified. In this respect it is interesting to note that no convincing orbital period has been reported for XTE J0421+56 either (see, e.g., Hynes et al. 2002, for a discussion). Note also, that the HMXB interpretation was questioned by Patel et al. (2004), when discussing the periodic X-ray variations in IGR J16358–4726. They argued that even extremely small amounts of accretion can spin up the star to shorter periods than those observed. The only way out might be a pulsar in a Be/X-ray binary, which is able to spin down due to the propellor effect during the long quiescence period in between outbursts. Interestingly, the pulsations seen in 4U 0114+650 have been interpreted as pulsations from its early B star donor (Finley et al. 1992).
A few of the highly absorbed IGR sources have been identified in the optical and/or IR. The IR spectra of IGR J16318−4848 are rich in emission lines, i.e., various order H-lines, He I and II, low excitation permitted lines, as well as forbidden iron lines; some lines show P-Cygni profiles (Filliatre & Chaty 2004). Many of these IR spectral lines can be identified in XTE J0421+56 too (see Clark et al. 1999). For both XTE J0421+56 (e.g., Clark et al. 1999, Hynes et al. 2002) and IGR J16318−4848 (Filliatre & Chaty 2004) it has been suggested that they have a supergiant B[e] donor present in a dense and absorbing circumstellar environment. Comparable IR spectra are also seen in GX 1+4. Its donor is, however, a cool giant star, and the IR spectra show in addition late-type features, such as CO-bands (Clark et al. 1999). These features are not seen in either XTE J0421+56 or IGR J16318−4848. The donor in IGR J16465−4507 has also been suggested to be an (early) supergiant (Smith 2004), whereas in IGR J16320−4751 it is either a cool giant or supergiant (Rodriguez et al. 2003). Early-type stars are also found in the error circles for some of the other highly IR absorbed sources.

The near-IR excess in B[e] stars points to the presence of hot circumstellar dust. Both in IGR J16320−4751 (Rodriguez et al. 2003) and IGR J16465−4507 (Smith 2004) there is evidence for such a near-IR excess. The IR spectra of IGR J16318−4848 suggest a similar configuration (Filliatre & Chaty 2004).

The column density derived from the optical extinction is found to be one to two orders of magnitude less than that derived from the X-ray measurements (IGR J16318−4848: Walter et al. 2003, Filliatre & Chaty 2004; IGR J16320−4751: Rodriguez et al. 2003; IGR J16465−4507: Smith 2004). This suggests that the dense circumstellar envelope must be rather compact and concentrated towards the compact object (e.g., Revnivtsev et al. 2003).

**Soft X-ray excess**

Soft X-ray excess emission between 0.3 and 5 keV has been reported for IGR J16318−4848 (when fitting the observed X-ray spectrum with a power-law spectrum to standard absorption column, see footnote on page 4). It seems to be consisting of two parts, one above and one below ~2 keV. Partial covering could account for the excess between ~2–5 keV. If the covering fraction is less than 1, part of the X-ray illuminated surface should be directly visible, producing a Compton reflection component (Matt & Guainazzi 2003, Matt et al. 2005, and references therein). It is not clear whether such a component is present or not (Walter et al. 2003, Matt & Guainazzi 2003). The excess between 0.3–2 keV could not be easily explained (Matt & Guainazzi 2003). Hints of a soft X-ray excess are seen as well in IGR J16320−4751 (Rodriguez et al. 2005b).

There is evidence for an (independent) soft component in the X-ray spectrum of XTE J0421+56 in outburst, subsequent decay, and quiescence, below a few keV (Boirin et al. 2002, Ishida et al. 2004, and references therein). A similar feature is seen in the soft X-ray spectrum of CH Cyg, a symbiotic star containing a white dwarf (CH Cyg; Ezuka et al. 1998). Modeling the parts below and above ~2 keV as separate emission components (Ezuka et al. 1998; Ishida et al. 2004), or modeling the emission with a
partial covering absorption model (e.g., Boirin et al. 2002) seemed to work fine. Because of the similarity with CH Cyg, it was proposed that XTE J0421+56 contains a white dwarf (Ishida et al. 2004); this, however, hard to reconcile with the observed X-ray properties of XTE J0421+56 (e.g., Hynes et al. 2002, and references therein) and IGR J16318–4848. It is interesting to note that soft X-ray spectra during X-ray dips in the light curves of LMXBs and HMXBs also show an excess in emission below typically 4 keV (see, e.g., Kuulkers et al. 1998, and references therein). Such dips are thought to be due to strong absorption (up to a few $10^{23}$ cm$^{-2}$) of emission from the inner parts of the accretion disk and compact object by the cooler outer parts of the accretion disk.

Wheatley (2001) showed that the soft X-ray spectrum of CH Cyg can be solely described by emission from the white dwarf which is strongly absorbed by a partitionly ionised wind from the red giant. Recently, a partitionly ionised absorber has been proposed as well to explain the soft X-ray spectra during the dips in LMXBs (Boirin et al. 2005). Since the soft spectral properties of XTE J0421+56 and IGR 16318–4848 are very similar to CH Cyg, it is logical to suggest such a model for these sources as well. The strong emission from the compact object is able to ionize the immediate environment. Such a ionised region can be responsible for, e.g., the observed IR He II emission in XTE J0421+56 and IGR 16318–4848. If this works, than there may not be a need for a Compton reflection component and one can conclude that the whole X-ray emitting region is covered by the circumstellar material.

SUMMARY

The above described X-ray and optical/IR properties suggests that the highly absorbed IGR sources are HMXBs containing either a neutron star or black hole in orbit around a (super)giant donor. The stellar wind accreting onto the compact object could form a dense envelope in which absorption, fluorescence and ionization takes place. This circumstellar envelope does not seem to cover much of the (super)giant donor. Because of the wavelength window INTEGRAL is able to observe, we are now starting to find more of this previously poorly known class of sources. Indeed, thanks to INTEGRAL “we can see clearly now ...” (White 2004).

ACKNOWLEDGMENTS

I am indebted to the conference organizers and editors, who allowed me to review these intriguing class of sources driven by results from INTEGRAL. I thank Deepto Chakrabarty for drawing my attention to the IR observations of GX 1+4, and Jérôme Rodriguez for discussions on an earlier draft of this paper.

REFERENCES

1. A.J. Bird, et al., ApJ, 607, L33 (2004).
2. L. Boirin, et al., A&A, 394, 205 (2002).
3. L. Boirin, et al., A&A, in press [astro-ph/0410385] (2005).
4. J.S. Clark, et al., A&A, 348, 888 (1999).
5. J.A. Combi, et al., A&A, 422, 1031 (2004).
6. R.H.D. Corbet, MNRAS, 220, 1047 (1986).
7. R.H.D. Corbet, et al., ATel, 269 (2004).
8. T.-J. Courvoisier, et al., IAUC, 8063 (2003).
9. J. de Plaa, et al., IAUC, 8076 (2003).
10. T. Endo, et al., ApJ, 574, 897 (2002).
11. H. Ezuka, et al., ApJ, 499, 388 (1998).
12. F. Filliatre, and S. Chaty, ApJ, 616, 469 (2004).
13. J.P. Finley, et al., A&A, 262, L25 (1992).
14. L. Foschini, et al., in The INTEGRAL Universe, ESA SP-552, 247 (2004).
15. H.-J. Grimm, et al., A&A, 391, 923 (2002).
16. F. Haberl, and N.E. White, ApJ, 361, 225 (1990).
17. R.I. Hynes, et al., A&A, 392, 991 (2002).
18. J.J.M. in 't Zand, et al., A&A, 380, L26 (2001).
19. M. Ishida, et al., ApJ, 601, 1088 (2004).
20. E. Kuulkers, et al., ATel, 465 (2005).
21. N. Masetti, et al., A&A, 423, 311 (2004).
22. G. Matt, and M. Guainazzi, MNRAS, 341, L13 (2003).
23. G. Matt, et al., these Proceedings (2005).
24. H. Murukami, et al., IAUC, 8070 (2003).
25. I. Negueruela, in The Many Scales of the Universe - JENAM 2004 Astrophysics Reviews, KAP, in press [astro-ph/0411759] (2004).
26. F. Nagase, PASJ, 41, 1 (1989).
27. S. Naik, et al., ApJ, 618, 866 (2005).
28. S.K. Patel, et al., ApJ, 602, L45 (2004).
29. M. Revnivtsev, AstL, 29, 719 [astro-ph/0304353] (2003).
30. M.G. Revnivtsev, et al., AstL, 29, 587 [astro-ph/0303274] (2003).
31. J. Rodriguez, et al., A&A, 407, L41 (2003).
32. J. Rodriguez, et al., A&A, 432, 235 (2005a).
33. J. Rodriguez, et al., in preparation (2005b).
34. N. Schartel, et al., IAUC, 8072 (2003).
35. L. Sidoli, et al., A&A, 429, L47 (2005).
36. D.M. Smith, ATel, 338 (2004).
37. J. Swank, et al., ApJ, 209, L57 (1976).
38. Y. Takeuchi, et al., PASJ, 42, 287 (1990).
39. Y. Tawara, et al., PASJ, 41, 473 (1989).
40. P. Ubertini, et al., A&A, 411, L131 (2003).
41. R. Walter, talk presented at the Internal INTEGRAL Science Workshop, ESA/ESTEC, Noordwijk, The Netherlands [see http://www.rssd.esa.int/INTEGRAL/workshops/Jan2005/] (2005).
42. R. Walter, et al., A&A, 411, L427 (2003).
43. R. Walter, et al., in The INTEGRAL Universe, ESA SP-552, 417 (2004).
44. P.J. Wheatley, AIP Conf. Ser., 599, 1007 (2001).
45. N. White, Nat, News & Views, 428, 264 (2004).
46. N.E. White, and J. Swank, ApJ, 287, 856 (1984).
47. N.E. White, et al., ApJ, 270, 711 (1983).
48. C. Winkler, et al., A&A, 411, L1 (2003).