A&A 508, 1275–1278 (2009)
DOI: 10.1051/0004-6361/200810811

Astronomy & Astrophysics

Suzaku observation of IGR J16318−4848

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Received 15 August 2008 / Accepted 19 October 2009

ABSTRACT

We report on the first *Suzaku* observation of IGR J16318−4848, the most extreme example of a new group of highly absorbed X-ray binaries that have recently been discovered by the International Gamma-Ray Astrophysics Laboratory (*INTEGRAL*). The *Suzaku* observation was carried out between 2006 August 14 and 17, with a net exposure time of 97 ks.
The average X-ray spectrum of the source can be well described ($\chi^2_{\rm red} = 0.99$) with a continuum model typical for neutron stars i.e., a strongly absorbed power law continuum with a photon index of 0.676(42) and an exponential cutoff at 20.5(6) keV. The absorbing column is $N_{\rm H} = 1.95(3) \times 10^{24}\,{\rm cm}^{-2}$. Consistent with earlier work, strong fluorescent emission lines of Fe Kα, Fe Kβ, and Ni Kα are observed. Despite the large $N_{\rm H}$, no Compton shoulder is seen in the lines, arguing for a non-spherical and inhomogeneous absorber. Seen at an average 5–60 keV absorbed flux of $3.4\times10^{-10}\,{\rm erg\,cm^{-2}\,s^{-1}}$, the source exhibits significant variability on timescales of hours.

Key words. stars: individual IGR J16318−4848 – binaries: general – X-rays: binaries

1. Introduction

IGR J16318−4848 was detected on 2003 Jan. 29 during a scan of the Galactic plane by the IBIS/ISGRI soft gamma-ray detector onboard the International Gamma Ray Laboratory (*INTEGRAL*, Courvoisier et al. 2003; Walter et al. 2003). The source was the first and most extreme example of a number of highly absorbed Galactic X-ray binaries discovered with *INTEGRAL*. Due to the strong absorption, which can exceed an equivalent hydrogen column of $10^{24}\,{\rm cm}^{-2}$, these sources are extremely faint in the soft X-rays and had not been detected by earlier missions (Rodriguez et al. 2003; Patel et al. 2004; Kuulkers 2005).

Right after its discovery, a re-analysis of archival *ASCA* data by Murakami et al. (2003) revealed a highly photoabsorbed source ($N_{\rm H} = 4 \times 10^{23}\,{\rm cm}^{-2}$) coincident with the position given by *INTEGRAL*. The data also suggested an iron emission line at 6.4 keV. These results were confirmed by various subsequent studies (e.g. Schartel et al. 2003; de Plaa et al. 2003; Revnivtsev et al. 2003; Walter et al. 2003). Matt & Guainazzi (2003) detected intense Fe Kα, Fe Kβ, and Ni Kα emission lines in the spectrum. Based on the interstellar absorption toward the system, which is two orders of magnitude lower than the measured $N_{\rm H}$, Revnivtsev (2003), Filliatre & Chaty (2004), and Lutovinov et al. (2005) also suggested that much of the X-ray absorption is intrinsic to the compact object.

In an optical study of the system, Filliatre & Chaty (2004) proposed that IGR J16318−4848 is a High Mass X-ray Binary (HMXB) with an sgB[e] star as the mass donor surrounded by a dense and absorbing circumstellar material (see also Revnivtsev 2003; Moon et al. 2007). This dense stellar wind results in significant photoabsorption within the binary system. Based on the optical data, Filliatre & Chaty (2004) suggest a distance between 0.9 and 6.2 kpc for the system. A likely location for the source is in the Norma-Cygnus arm (Revnivtsev 2003; Walter et al. 2004), which would place it at a distance of 4.8 kpc (Filliatre & Chaty 2004).

In this Paper, we describe the results of follow-up observations of IGR J16318−4848 obtained with the *Suzaku* satellite, the instruments on which are uniquely suited to study Compton-thick absorption. In Sect. 2 we describe the data reduction. Section 3 is devoted to a presentation of the results of the spectral and temporal analysis. We discuss our results in Sect. 4.

2. Data analysis

We observed IGR J16318−4848 with *Suzaku* from 2006 August 14 until 2006 August 17 for a total net exposure of 97 ks (*Suzaku* sequence number 401094010). We used the standard procedures to reduce the data from the X-Ray Imaging Spectrometer (XIS, Koyama et al. 2007) and the Hard X-Ray Detector (HXD, Takahashi et al. 2007). For the XIS in particular we barycentered the data with *aebarycen* (version 2008-03-03) and then extracted source events, images, spectra, and lightcurves with XSELECT v2.4. A circular source extraction region of 3.′23 radius was applied. The background spectrum was extracted from a circular region having the same area as the source extraction region. This process was done for every XIS. Response matrices and ancillary response files were generated using XISRMFGEN (version 2009-02-28) and XISSIMARFGEN (version 2009-02-28), taking into account the hydrocarbon contamination on the optical blocking filter (Ishisaki et al. 2007). As recommended by the *Suzaku* team, the spectra of the three front illuminated CCDs (XIS0, XIS2, and XIS3) were then combined with *addascaspec* (version 1.30). Although the XIS1 was operational when the observation was

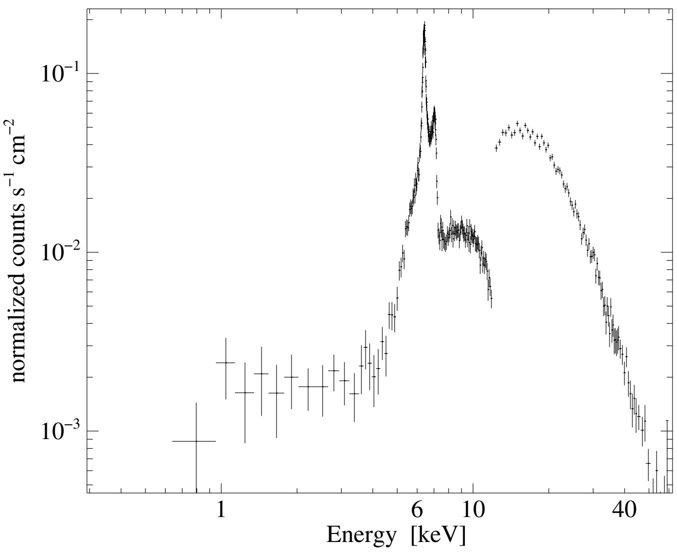

Fig. 1. Spectrum of IGR J16318−4848 in the range 0.3–60 keV.

made, it is not used in the present study due to cross calibration issues.

To extract the HXD PIN spectrum, we again followed the standard procedure of barycentric correction, gti-filtered spectrum extraction with XSELECT and dead-time correction with HXDDTCOR (version 1.50). The cosmic background was created with a model provided by the *Suzaku* team using a flat response (ae_hxd_pinflate2_20080129.rsp) and then combined with the internal background model provided by the *Suzaku* team (ae401094010_hxd_pinbgd.evt). The resulting combination is used for the background subtraction. The response matrix used for the analysis is the one proposed by the *Suzaku* team for the time of our observation, ae_hxd_pinxinome2_20080129.rsp. The count rates of IGR J16318−4848 are 0.1437 ± 0.001 cts s^{-1} for the combined XISs and 0.6108 ± 0.004 cts s^{-1} for the HXD PIN diodes.

For the analysis with XSPEC (v.11.3.2ag; Arnaud 1996) we rebinned the spectrum to a minimum of 250 and 200 counts per bin for the XIS and the PIN, respectively. The uncertainties for all fits are quoted at the 90% level for a single parameter of interest. In order to account for flux cross calibration issues among the instruments, in all spectral fits a multiplicative constant was introduced.

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3.1. Spectral analysis

Although we detected a soft excess in the spectrum below 5 keV (Fig. 1), we did not include it in the modeling because it is most probably due to a serendipitous source at a distance ≃30″ from IGR J16318−4848 (Ibarra et al. 2007; Matt & Guainazzi 2003). The presence of this source could not be confirmed here because of the lower angular resolution of the XISs compared to *XMM-Newton*, even when using an optimal attitude solution for *Suzaku* by measuring the attitude directly through following the location of IGR J16318−4848 on the XIS chips.

In order to describe the 5–60 keV broad-band spectrum of the source we fit the spectral continuum with an absorbed cut-off powerlaw, taking also into account non-relativistic Compton scattering. Photoabsorption was modeled with a revised version of the TBabs model (Wilms et al. 2000, 2006), using the interstellar medium abundances summarized by Wilms et al. (2000). This model describes the continuum extremely well (Fig. 3). In addition to the continuum, strong fluorescent emission lines from iron (Fe Kα and Kβ) and nickel (Ni Kα) are introduced in the model (within the absorber) to obtain a satisfactory description of the data (Fig. 4). We model these lines with Gaussians fixed to a width of $\sigma = 0.1$ eV (i.e., we use lines narrow compared to the resolution of the XIS). The Fe Kα line is modeled as the superposition of the Fe Kα_1 and Fe Kα_2 lines, with the relative line normalizations held at the 2:1-ratio of the flourescence yields of these lines and the Fe Kα_2 line constrained to be 13.2 eV below the Fe Kα_1 line. We also modeled the Fe Kβ line as the combination of the Fe Kβ_1 and Fe Kβ_3 lines (the Fe Kβ_3 energy being fixed to 16 eV below Fe Kβ_1, and its intensity to half the one of Fe Kβ_1). This physically correct approach is to be preferred to modeling the Fe Kα and Fe Kβ lines with a single Gaussian. We introduced a multiplicative constant c to normalize the HXD flux with respect to the XIS one.

The resulting model (Table 1) provides a good description of the data (χ^2/d.o.f. = 242.6/245). With $N_\mathrm{H} = 1.95^{+0.02}_{-0.03} \times 10^{24}$ cm^{-2} the column density is very high, as is to be expected for this kind of source, and is in agreement with the previous observations (e.g., Lutovinov et al. 2005; Walter et al. 2006; Ibarra et al. 2007). In contrast, the photon index, $\Gamma = 0.676^{+0.009}_{-0.042}$, is considerably harder than in several earlier analyses (e.g., Walter et al. 2004: $\Gamma = 2.6$ or Ibarra et al. 2007: $\Gamma = 1.35$–1.46). As shown by the contour plots in Fig. 2, our broad-band data allow us to determine Γ to a high precision. The photon index is not correlated with N_H, and there is only a slight dependency between Γ and E_fold, which is much smaller than the difference between the photon index found here and that found in earlier observations.

Despite the large N_H, which corresponds to a moderately high Thomson optical depth of $\tau_\mathrm{es} = 1.3$, no Compton shoulder is apparent in the spectrum and all lines are well modeled with narrow Gaussians (Fig. 4). In order to determine an upper limit for the flux in a putative Compton shoulder, following Matt & Guainazzi (2003) we model this feature by adding a moderately broad ($\sigma = 50$ eV) Gaussian at 6.3 keV to the model. The 90% upper limit for the flux in the Compton shoulder is 1.8×10^{-5} ph cm^{-2} s^{-1}, corresponding to a 90% upper limit of 34.6 eV for the equivalent width.

Data from the three XIS and the HXD-PIN were used to obtain lightcurves in the 5–12 keV and in the 12–60 keV band. To study the evolution of the spectral hardness of the source, count rates were determined at the resolution of the good time intervals of the XIS0 detector, which cover approximately one *Suzaku*-orbit each (∼90 min). Figure 5 shows the significant variability of IGR J16318−4848 on this resolution. Throughout the observation, for XIS count rates above 0.1 counts s^{-1} the source shows no clear dependence of the hardness ratio from the source count rate, indicating that only slight changes in the spectral shape occur. At even lower count rates, the X-ray spectrum softens, but the signal to noise in the X-ray spectrum is too low to allow us to quantify these changes further.

4. Summary and conclusions

We have presented first results from the analysis of a long *Suzaku* observation of IGR J16318−4848, the most extreme of the strongly absorbed "*INTEGRAL*-sources". As found in previous studies, the average spectrum of the source is consistent with a strongly absorbed exponentially cutoff power-law and strong flourescent line emission. In contrast to earlier studies,

Table 1. Best fit parameters obtained from modeling the joint XIS and HXD data in the 5–60 keV band.

$A_{\rm cutoffpl} = 3.79^{+0.05}_{-0.03} \times 10^{-2}$	$F_{\rm Fe\ K\alpha_1} = 3.7 \pm 0.1 \times 10^{-3}$	$F_{\rm Fe\ K\alpha_2} = 1.85 \pm 0.05 \times 10^{-3}$	
	$F_{\rm Fe\ K\beta_1} = 3.2^{+0.3}_{-0.4} \times 10^{-4}$	$F_{\rm Fe\ K\beta_3} = 1.57^{+0.15}_{-0.20} \times 10^{-4}$	$F_{\rm Ni\ K\alpha} = 7.4^{+2.2}_{-2.7} \times 10^{-4}$
$c = 1.00 \pm 0.01$	$\Gamma = 0.676^{+0.009}_{-0.042}$	$E_{\rm Fold} = 20.5^{+0.6}_{-0.3}$ keV	
$N_{\rm H} = 1.95^{+0.02}_{-0.03} \times 10^{24}$ cm^{-2}	$A_{\rm Fe} = 1.14^{+0.03}_{-0.02}$		
$E_{\rm Fe\ K\alpha_1} = 6404^{+3}_{-2}$ eV	$EW_{\rm Fe\ K\alpha_1} = 467^{+13}_{-54}$ eV	$E_{\rm Fe\ K\alpha_2} = 6391^{+3}_{-2}$ eV	$EW_{\rm Fe\ K\alpha_2} = 233^{+7}_{-27}$ eV
$E_{\rm Fe\ K\beta_1} = 7093^{+13}_{-14}$ eV	$EW_{\rm Fe\ K\beta_1} = 44.1^{+1.4}_{-5.2}$ eV	$E_{\rm Fe\ K\beta_3} = 7092^{+13}_{-14}$ eV	$EW_{\rm Fe\ K\beta_3} = 22.1^{+0.6}_{-2.7}$ eV
$E_{\rm Ni\ K\alpha} = 7446^{+46}_{-51}$ eV	$EW_{\rm Ni\ K\alpha} = 108^{+4}_{-12.7}$ eV		
$F^{\rm absorbed}_{5.0-60\,{\rm keV}} = 3.4^{+0.7}_{-0.1}\ 10^{-10}$ erg cm^{-2} s^{-1}	$F^{\rm unabsorbed}_{5.0-60\,{\rm keV}} = 2.43^{+0.44}_{-0.09}\ 10^{-9}$ erg cm^{-2} s^{-1}	χ^2/d.o.f. = 242.6/245	$\chi^2_{\rm red} = 0.99$

We list the photon index (Γ), folding energy ($E_{\rm Fold}$), hydrogen equivalent column ($N_{\rm H}$), Fe abundance ($A_{\rm Fe}$), the total absorbed and unabsorbed fluxes, and the energy (E) and equivalent width (EW) of the fluorescence lines. The norm of the absorbed cutoff powerlaw ($A_{\rm cutoffpl}$) is defined as the photon flux at 1 keV; for the absorbed Gaussian lines the norm (F) equals the total line flux.

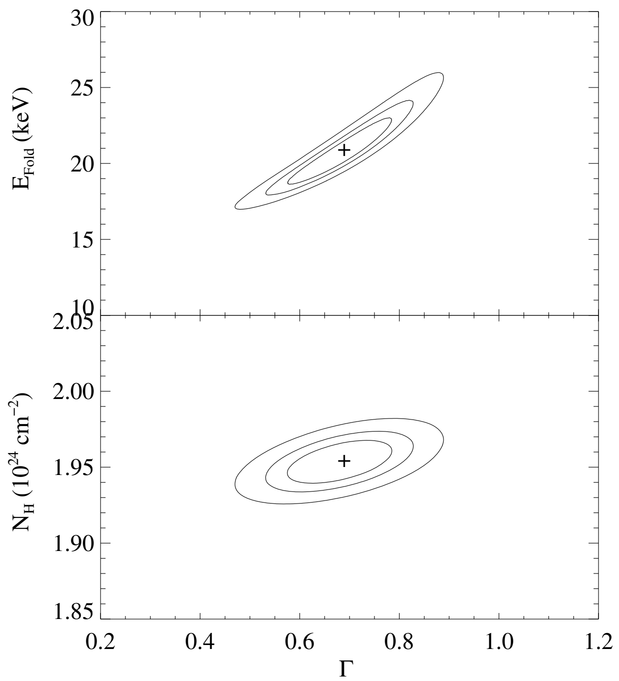

Fig. 2. Confidence contours (68, 90, and 99 percent) of the column density and the folding energy as a function of the photon index. The cross mark indicates the best fit value.

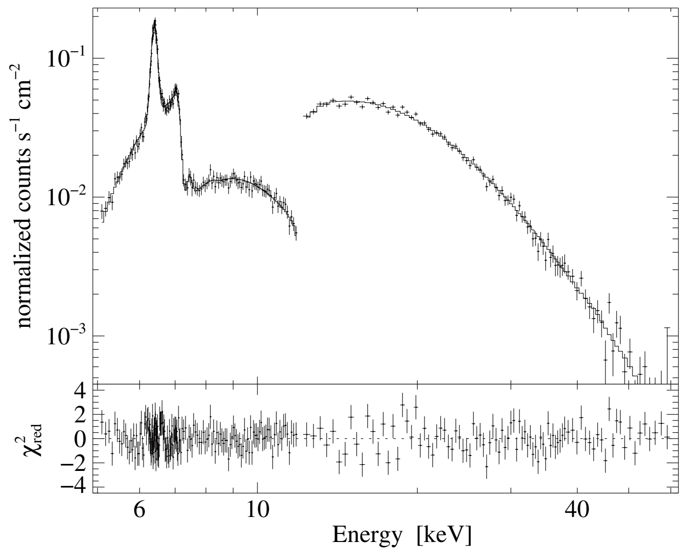

Fig. 3. Broad band spectrum of IGR J16318−4848 together with the best fit model and its residuals.

the power-law photon index was found to be considerably harder than before ($\Delta\Gamma$ from 0.67 up to 1.93). This result can be due to the significantly better signal to noise ratio in the energy band above 10 keV compared to the earlier studies, which allows for a better determination of the high energy cutoff, the continuum parameters, and $N_{\rm H}$ than the earlier soft X-ray measurements, although an instrinsic change in the source is not ruled out.

The soft excess below 2 keV is probably due to a serendipitous source near IGR J16318−4848 (Ibarra et al. 2007). The considerable variability of the source can be explained as being due to variations in $N_{\rm H}$.

As pointed out by Walter et al. (2004), the general spectral characteristics derived from the fit are typical for accreting neutron stars (e.g., Naik & Paul 2004; Hill et al. 2008). Note that this result does not mean that the neutron star nature of the compact object in IGR J16318−4848 is confirmed, which would require e.g. the detection of pulsations. A search for pulsations in the range between 1 s and 10 ks was negative, while shorter period pulsations are probably not detectable due to the smearing of pulsations by Compton scattering (Kuster et al. 2005).

Turning to the emission lines, we note that our fit requires a slight overabundance of iron with respect to the ISM values of Wilms et al. (2000), as one would expect for an evolved star. Furthermore, the flux ratio of Fe and Ni also points towards a Ni overabundance by a factor of ∼2.5 with respect to Fe.

The ratio of the Fe Kα and Fe Kβ line fluxes is given by $\eta = (F({\rm Fe\,K}\beta_1) + F({\rm Fe\,K}\beta_3))/(F({\rm Fe\,K}\alpha_1) + F({\rm Fe\,K}\alpha_2)) = 0.086 \pm 0.008$. This flux ratio is formally slightly smaller than that found in theoretical calculations for neutral gas phase Fe atoms of Jacobs & Rozsnyai (1986, $\eta = 0.121$), Kaastra & Mewe (1993, $\eta = 0.125$), or Jankowski & Polasik (1989, $\eta = 0.132(2)$), and it is also smaller than the value of η found in experimental measurements performed in solid Fe (e.g., $\eta = 0.1307(7)$ found by Raj et al. 1998 and Pawłowski et al. 2002). The difference between the different theoretical calculations is due to certain approximations made in solving the structure of the excited Fe ion after the K-shell photoabsorption, while for the latter measurements η is affected by internal absorption in the Fe crystal used to make the measurements as well as by the dependence of the emission probability of the photoelectron on orientation. The systematic uncertainty of η in theory and measurements is

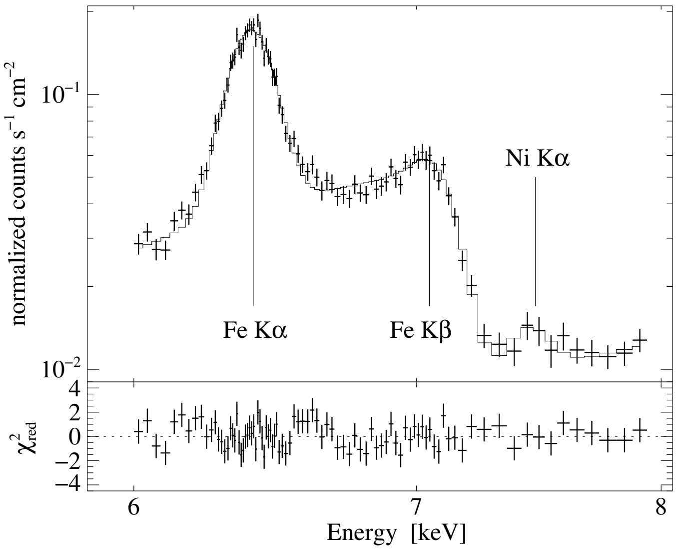

Fig. 4. Close-up of the Fe Kα band.

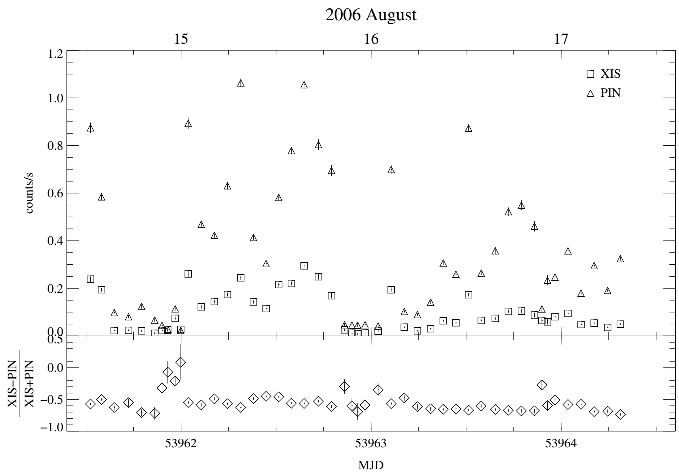

Fig. 5. *Top*: lightcurve for the XIS (5–12 keV, squares) and the HXD PIN (12–60 keV, triangles). *Bottom*: hardness ratio as a function of time.

therefore probably as large as 0.02, which would make our measurement consistent with neutral Fe. We note that our value for η is significantly smaller than the $\eta = 0.20^{+0.02}_{-0.03}$ found in the *XMM-Newton* EPIC-pn analysis of Matt & Guainazzi (2003, but see Walter et al. 2003). These authors speculated that this higher η could be due to the absorbing wind being moderately ionized. Given that the line ratio (and also the line energy) found in the higher resolution *Suzaku* data are consistent with neutral Fe, we might be seeing a change in the ionization structure of the wind between the *XMM-Newton* and the *Suzaku* observations. Alternatively, the larger value for η may be due to systematic effects in the *XMM-Newton* analysis: with *Suzaku*, the Fe Kβ line and the Fe K edge are easier to separate and the spectral continuum is better constrained in the present analysis than with *XMM-Newton*, since spectral information is available above 9 keV.

Finally, despite the large column of the source, no significant evidence for the presence of a Compton shoulder is found in the *Suzaku* spectrum, which is consistent with previous results. This result is in contrast to the expectation for absorption in an homogeneous medium: as shown by Matt (2002), with this assumption the equivalent width of the Fe Kα line at the $N_{\rm H}$ of IGR J16318−484 should be much less than that observed here, and a strong Compton shoulder should be present, in line e.g. with the Compton shoulder observed by Watanabe et al. (2003) in GX 301−2. As pointed out by e.g. Walter et al. (2003, 2006) and Ibarra et al. (2007), the non-existence of the Compton shoulder could be due to a strongly inhomogeneous absorbing medium. Since the strength of the shoulder is strongly dependent on the assumed accretion geometry, further work using self-consistent modeling of the absorption, fluorescent line formation and Compton shoulder formation is required. We will present such self-consistent analyses, as well as a more detailed study of the variability of the source, in a future publication.

Acknowledgements. We want acknowledge the anonymous referee for his/her comments that allowed us to improve this paper. This work was partially funded by the Bundesministerium für Wirtschaft und Technologie through the Deutsches Zentrum für Luft- und Raumfahrt contract 50 OR 0701 and by National Aeronautics and Space Administration grants NNX07AE65G and NNX06AI43G. This research has made use of data obtained from the Suzaku satellite, a collaborative mission between the space agencies of Japan (JAXA) and the USA (NASA).

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