Physica Scripta. Vol. T77, 86-87, 1998

Two-phase Spectrum of the Black Hole Candidate 1E1740.7-2942

J. Nevalainen[1,2], O. Vilhu[2,3], J. Poutanen[4,5], M. Gilfanov[6,7] and M. Vargas[8]

[1] Harvard Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 01238, USA
[2] University of Helsinki, Finland
[3] NORDITA Blegdamsvej 17 DK-2100 Copenhagen Denmark
[4] Astronomical Observatory, Box 515, SE-75120 Uppsala, Sweden
[5] Stockholm Observatory, SE-13336 Saltsöbaden, Sweden
[6] MPI für Astrophysik, Karl-Schwarzschild-Strasse 1, 86740 Garching, Germany
[7] Space Research Institute (IKI), Profsouznaya 84/32, 117810 Moscow, Russia
[8] CEA/DSM/DAPNIA/SAp, CEA-Saclay, 91191 Gif-sur-Yvette, France

Received November 7, 1997; Accepted December 22, 1997

PACS Ref: 9760 LF

Abstract

Combined ASCA and SIGMA data of 1E1740.7-2942 during its standard state (September 1993 and 1994) were successfully fitted with a two-phase model ISM (iterative scattering method) [1]. The classical cold accretion disk does not extend up to the innermost stable orbit, but is truncated at $\sim 30\mathrm{GM}/\mathrm{c}^2$. A hot inner disk has electron temperature $T_e \approx 60$ keV and radial Thomson optical depth $\tau \approx 2.4$. The cold disk radiates ≈ 40 % of the total luminosity with $\dot{M} \approx 0.04\dot{M}_{\rm Edd}$ of $10M_{\odot}$.

1. Introduction

1E1740.7-2942 (1E) is the famous jet-source (micro-quasar, Great Annihilator) close to the Galactic Center, observable in the cm/mm and X/Gamma-ray wavelengths [2-9]. During the last few years, new tools for modelling X-ray data of black hole binaries have been developed. In this paper we model 1E data using a two-phase pair plasma sombrero model, ISM [1] (see Figure 1). ISM computes the Comptonization spectrum in a given geometry. Electrons (pairs) can be thermal or non-thermal. Here we consider thermal plasma.

2. The data

We use ASCA GIS and SIS archival data (Sept 1993 and 1994) and SIGMA hard X-ray observations (1990–1995) to explore 1E1740.7-2942 with the help of the ISM model. We noticed that statistics of SIGMA data accumulated during a few days around the dates of the ASCA 1993 and 1994 observations don't allow us to restrict the ISM parameters, therefore we had to accumulate SIGMA data for a longer period. We are aware of the problems introduced with the use of non-simultaneous data. During 1990–1995 1E goes through different spectral states and its hard flux varies by a factor of 10 [10]. However, we noticed that in the 30–300 keV range the SIGMA 1990–1995 data is consistent (within the errors) with the SIGMA data accumulated during a few days around the dates of the ASCA 1993 and 1994 observations.

The ASCA GIS data have been analyzed earlier [6-7], and the 1993 SIS data have been analyzed in [7], using a simple power-law model for the continuum, while our modelling is more physically meaningful. We also analyzed earlier the ASCA data used in this paper [9], but we use here an updated version of the ISM, and a different set of SIGMA data.

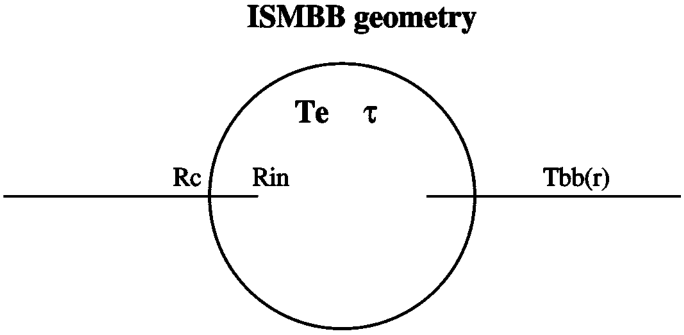

Fig. 1. Schematic view of the geometry of the ISM model.

3. Results and conclusions

We fitted 1993 ASCA GIS, 1994 ASCA GIS, 1994 ASCA SIS and SIGMA 1990–1995 data simultaneously, allowing normalizations to vary between the data sets. The essential parameters in the ISM model are T_e (electron temperature of the hot cloud), τ (Thomson optical depth of the cloud), T_{bb} (inner temperature of the cold disk), and a ratio of the inner radius of the disk to the radius of the corona R_{in}/R_c. Since the ISM model is quite complex and contains correlations between parameters, we decided to fix parameters R_{in}/R_c and inclination, i, keeping the reflection amplitude fixed to a standard value of 1 (corresponding to the amount of reflection expected from an infinite cold plane disk with a hole of size R_{in} in the center and a source of hard photons from a spherical homogeneous cloud of size R_c in the center). We noticed that $R_{in}/R_c = 1$ gives a better fit than smaller R_{in}/R_c and that a decrease in the inclination improves χ^2 without much effect on the best fit values of T_e, τ and T_{bb}. However, the inclination must be non-zero, because radio jets have been observed from 1E [5]. Therefore we give best fit values of the other parameters fixing $R_{in}/R_c = 1$ and $i = 18^{\circ}$ as follows: $T_e = 60$ keV, $\tau = 2.4$, $kT_{bb} = 0.27$ keV, $N_H = 13.1 \times 10^{22}$ cm^{-2} (see Table I). $\chi^2 = 835.7$ with 760 d.o.f., so the data can be fitted very well with the ISM model, see Figure 2.

The 1993 and 1994 data of 1E are both well fitted with a similar set of parameter values, but the total flux in 93 is 40 % higher than in 1994, whereas Sheth *et al.* [6] found a difference of 20 % using a power law model. We are currently working on studying the time variability of ISM parameters that cause the flux variation. Here we use the average 1994 and 1993 ASCA flux, together with the above parameters to derive results. Since electron scattering modifies the spectrum in the upper layers of the

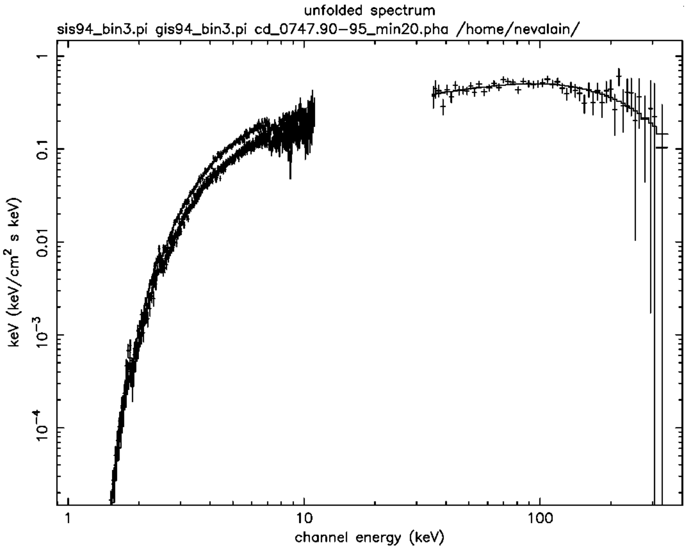

Fig. 2 The best fit ISM model to ASCA and SIGMA data as explained in the text.

Table I. *ISM fit parameters of the standard state of 1E1740.7-2942*

PARAMETERS	
N_H (10^{22} cm^{-2})	13.1
kT_{bb} (keV)	0.27
kT_e (keV)	60
τ_e	2.4
$\cos i$	0.95
reflection (fixed)	1.0
R_{in}/R_c	1.0
χ^2/d.o.f.	1.1
L_{total}(10^{37} erg/s)	4.4
L_{disk}/L_h	0.7
R_{in} (km)	450
R_{in}/R_{Sch}^a	15
$\dot{M}$ (10^{18} g s^{-1})	1
$\dot{M}/\dot{M}_{Edd}$ ^{b}	0.04

[a] in units of Schwarzschild radius, $2GM/c^2$, for a $10M_\odot$ black hole
[b] For $M = 10M_\odot$ and efficiency of 0.057

accretion disk we take the effective inner temperature of the disk to be $T_{eff} = 0.6T_{bb}$ [11]. This gives an inner radius of the disk ≈ 450 km or ≈ 15 Schwarzschild radii of a $10M_\odot$ black hole radiating with $L_{disk} \approx 1.8 \times 10^{37}$ erg/s, corresponding to a mass transfer rate of $\approx 1 \times 10^{18}$ g/s, ($\dot{M} = L_{disk}/c^2$/efficiency, using efficiency = 0.016 at R_{in} [12]). This mass transfer rate $\approx 0.04\ \dot{M}_{Edd}$ ($\dot{M}_{Edd} = L_{Edd}/c^2$/efficiency, where the efficiency, calculated at $r = 3R_{Sch}$, is 0.057 [14]). Inside R_{in}, the spherical hot corona ($T_e \approx 60$ keV) emits Comptonized radiation with $L_h = 2.6 \times 10^{37}$ erg/s.

The inner radius of the disk that we deduce from observations of 1E is very similar to the one obtained for other black hole candidates in their hard states. Poutanen *et al.* [13] and Życki *et al.* [14-15] deduce $R_{in} \approx 10 - 20R_{Sch}$ for the disk in Cyg X-1 and X-ray novae GS 2023+338 (V404 Cyg) and Nova Muscae. The central hot cloud in 1E has temperature $T_e \approx 60$ keV and optical depth $\tau \approx 2.4$. These values are surprisingly close to the electron temperatures and optical depths obtained from the spectral fits to the broad band data of Cyg X-1 ($T_e = 90$ keV, $\tau \approx 1.8$ [16, 17]) and GX 339-4 ($T_e = 60$ keV, $\tau \approx 2.0$ [18]). It seems that an electron temperature of order 60–100 keV and optical depth of the Comptonizing cloud of 1.5–2 are the signatures of accreting black holes.

References

1. Poutanen, J. and Svensson, R., Astrophys. J. **470**, 249 (1996).
2. Sunyaev, R. *et al.*, Astrophys. J. **383**, L49 (1991).
3. Bally, J. and Leventhal, M., Nature **353**, 234 (1991).
4. Mirabel, I. F. *et al.*, Astron. Astrophys. **251**, L43 (1991).
5. Mirabel, I. F. *et al.*, Nature **358**, 215 (1992).
6. Sheth, S., Liang, E., Luo C., and Murakami, T. Astrophys. J. **468**, 755 (1996).
7. Churazov, E., Gilfanov, M. and Sunyaev, R., Astrophys. J. **464**, L71 (1996).
8. Vilhu, O. *et al.*, "The Transparent Universe", Proc. 2nd INTEGRAL workshop, (ESA SP-382, 1997), p.221 (astro-ph/9612194).
9. Vilhu, O. *et al.*, Proc. 4th Compton Symposium, Williamsburg, April 1997, AIP in press (astro-ph/9704094).
10. Kuznetsov, S., *et al.*, Mon. Notes R. Astron. Soc., in press.
11. Shimura, T. and Takahara, F., Astrophys. J. **445**, 780 (1995).
12. Shapiro, S. L. and Teukolsky, S. A., "Black holes, white dwarfs, and neutron stars", (John Wiley, New York 1983), p. 346.
13. Poutanen, J., Krolik, J. H. and Ryde, F. Mon. Notes R. Astron. Soc., in press (astro-ph/970724).
14. Zycki, P. T., Done, C. and Smith, D. A. Astrophys. J., **488**, L113 (1997).
15. Zycki, P. T., Done, C. and Smith, D. A. Astrophys. J., in press.
16. Gierliński, M., *et al.*, Mon. Notes R. Astron. Soc., **288**, 958 (1997)
17. Zdziarski, A. A., Johnson, W. N., Poutanen, J., Magdziarz, P. and ierliński, M., "The Transparent Universe", Proc. 2nd INTEGRAL workshop, (ESA SP-382 1997), p.373 (astro-ph/961210).
18. Zdziarski, A. A. *et al.*, in preparation