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ASCA MEASUREMENT OF THE HYDROGEN COLUMN DENSITY TO 1E 1740.7 − 2942

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ABSTRACT

We report an accurate measurement of the hydrogen absorption column density to the microquasar and annihilator Galactic black hole candidate 1E 1740.7−2942 near the Galactic center using data from *ASCA* observations. Two separate *ASCA* observations of this source, in 1993 and 1994 Fall, consistently give a best-fit hydrogen column density $N_{\rm H} \sim 8 \times 10^{22}$ cm^{-2} with small dispersion. This value lies right in the middle of the range estimated by Chen et al. using *ROSAT* data, but significantly below previous estimates based on the *SPARTAN* and *ARTP*-SIGMA observations. It has important implications for the location of the source relative to the dense molecular cloud G−0.86−0.08 and the mass limit on any potential companion.

Subject headings: black hole physics — Galaxy: center — ISM: abundances — ISM: individual (G−0.86−0.08) — stars: individual (1E 1740.7−2942)

1. INTRODUCTION

The Galactic center region hard X-ray source 1E 1740.7−2942 has recently emerged as a very interesting and important black hole candidate. In addition to a hard X-ray spectrum and luminosity almost identical to those of Cygnus X-1 (Sunyaev et al. 1991a; see review by Liang & Nolan 1984; Liang 1993), it is found to be associated with double-radio jets similar to those of a quasar (Mirabel et al. 1992) and possible flares of annihilation-like radiation (Bouchet et al. 1991; Sunyaev et al. 1991b; see, however, Jung et al. 1995; Leventhal 1996). Yet unlike Cygnus X-1, intense optical and IR searches have failed to reveal any companion star (Prince & Skinner 1991; Mereghetti et al. 1992; Djorgovski et al. 1992; Mirabel & Duc 1992). The precise mass limit on its companion, however, depends on its location relative to the dense molecular cloud (DMC) G−0.86−0.08 near the Galactic center (Bally et al. 1987), which can in principle provide as much as 50 mag of optical extinction (Chen et al. 1994). Since the hydrogen column density in that general direction outside the molecular clouds is believed to be in the range 4.6–7.2 × 10^{22} cm^{-2} (Savage & Mathis 1979), a precise measurement of the hydrogen column density to this source will help to determine whether the source is in front of, behind or deeply imbedded in the molecular cloud. In addition to limiting the mass of the companion, this will also affect the estimates of the velocity of the source (from lack of bending of the jets), the expansion velocity and overall energetics of the jets and the annihilation rates of any escaping positron (Ramaty et al. 1992).

Unfortunately, previous estimates of the hydrogen column density $N_{\rm H}$ to this source gave disparate values, ranging from 4×10^{22} cm^{-2} (Skinner et al. 1991) to $\sim 2 \times 10^{23}$ cm^{-2} (Kawai et al. 1988). This is mainly due to the limited spectral range and poor spectral resolution of the detectors in the keV range which is most crucial to the determination of $N_{\rm H}$. This situation was summarized in the article by Chen et al. (1994). Using the *ROSAT* HRI (0.1–2 keV) results and the *ARTP* (3–30 keV) normal state flux scaled down by a factor 5, they also argue that the $N_{\rm H}$ to this source can be limited to the range ∼0.5–1.1 × 10^{23} cm^{-2}, if its spectral slope below 20 keV is constrained to lie between −1 and −2. While reasonable, such scaling arguments are unreliable.

With a spectral range of 0.5–12 keV and good spectral resolution (8% for the GIS detector and 2% for the SIS detector at 5.9 keV), the *ASCA* satellite (see NASA NRA 95-OSS-13 Appendices) is the ideal instrument to measure accurately the $N_{\rm H}$ to this source. Moreover, its high spatial resolution allows us to avoid any source confusion from nearby sources in the Galactic center region. Here we report the results from two separate *ASCA* observations of 1E 1740.7−2942: the first during the Performance Verification (PV) period on 1993 September 26, for about 40 ks and the second during cycle A02 on 1994 September 8–12 for a total of 30 ks. Even though the source intensity varied by ∼20% between the two observations, we find that, to within statistical uncertainties, the measured power law indices and $N_{\rm H}$ for the two epochs are consistent with each other, giving us confidence in the validity of the results.

2. OBSERVATIONAL RESULTS

Figures 1 and 2 give the count spectrum and the deconvolved photon spectrum for the PV and A02 data respectively. The combined spectra from both data sets are given in Figure 3. We fit the spectra with simple power-law (or thermal bremsstrahlung) models together with hydrogen absorption column density. The ISM photoelectric cross section per H-atom used is based on Morrison & McCammon (1983). Spectral fitting is done in count space by varying the power-law index (or bremsstrahlung temperature) and $N_{\rm H}$ to minimize the χ^2. The results for power-law models are summarized in Table 1. For comparison we mention here that the best-fit bremsstrahlung model for the combined data gives $N_{\rm H} \sim 8.7 \times 10^{22}$ cm^{-2} and kT = 200 keV. Since the *ASCA* energy range is too low to effectively constrain such a high temperature, this temperature value is meaningless and the power-law model is much more robust and relevant for *ASCA* energies. Hence, we concentrate on the power-law model results. Also we

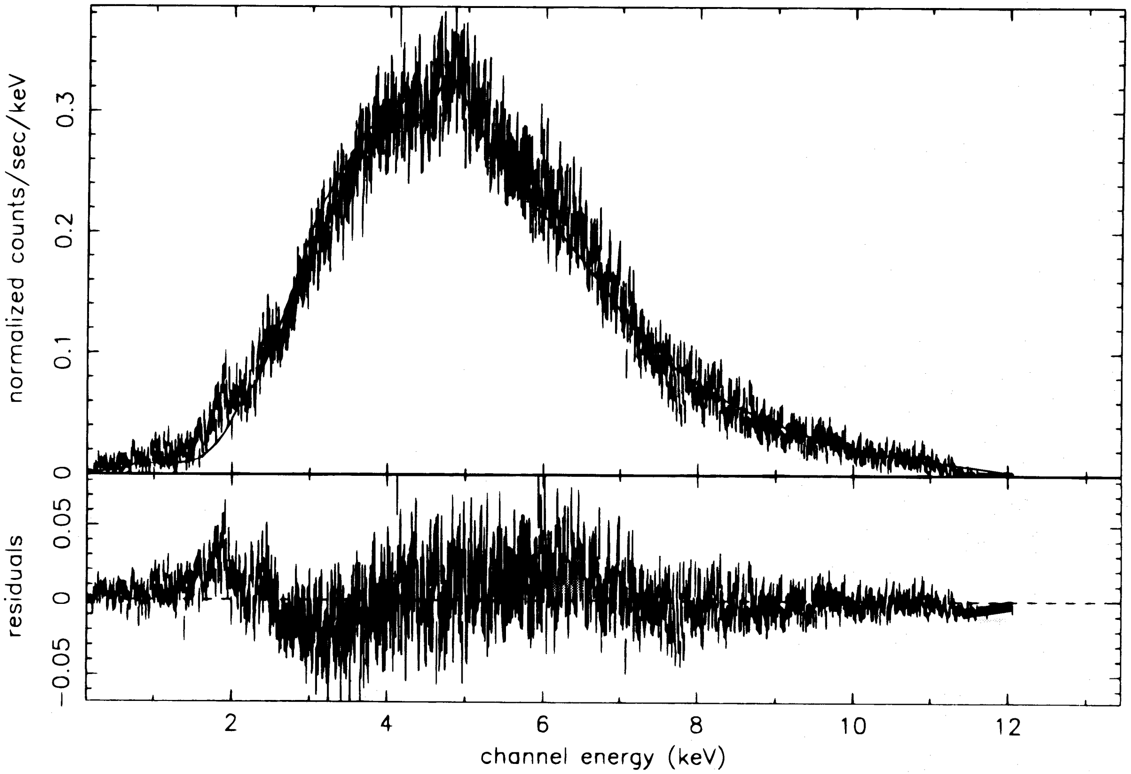

FIG. 1*a*

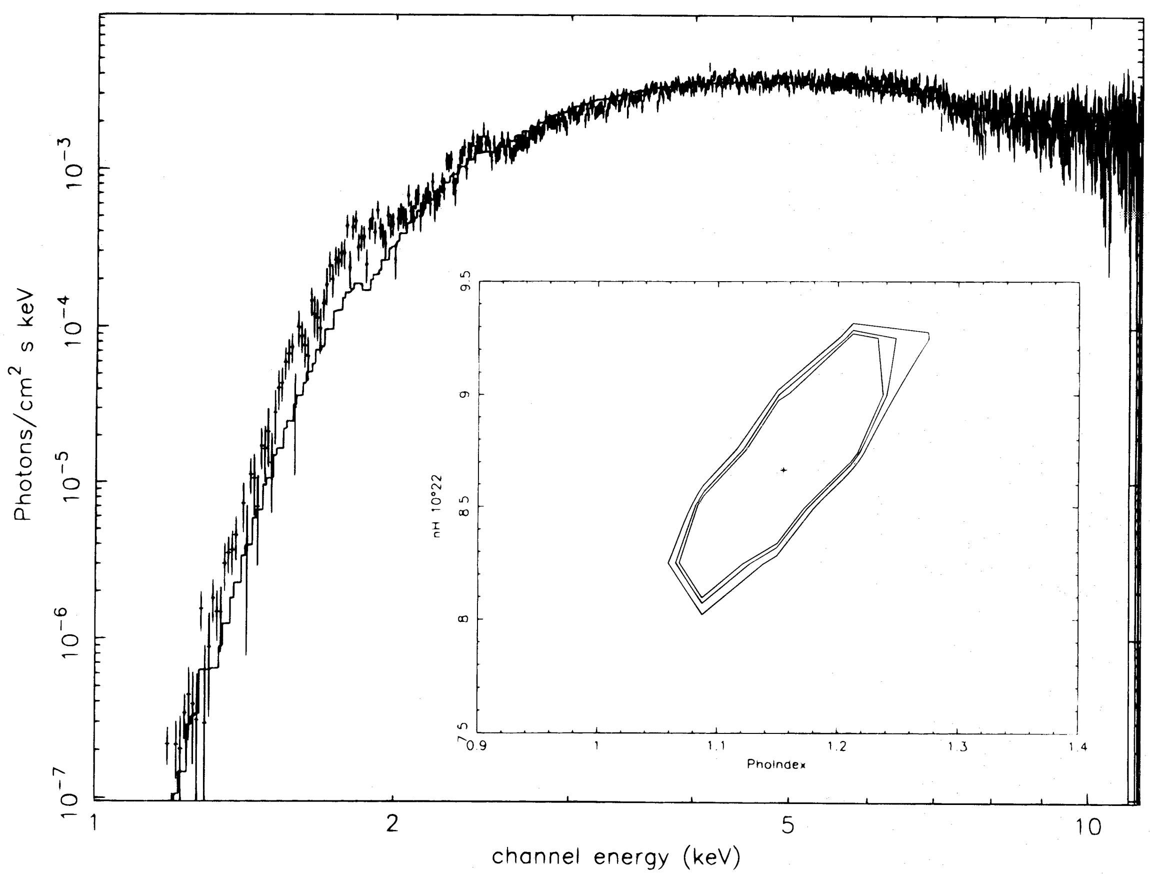

FIG. 1*b*

FIG. 1.—*ASCA* GIS spectrum of the 1993 PV phase observation of 1E 1740.7−2942. Solid line is the best-fit power law model with ISM absorption. (*a*) Top panel is detector count spectrum and bottom panel is plot of residuals. (*b*) Deconvolved photon spectrum; inset gives the error contours corresponding to 1, 2, and 3 σ confidence levels.

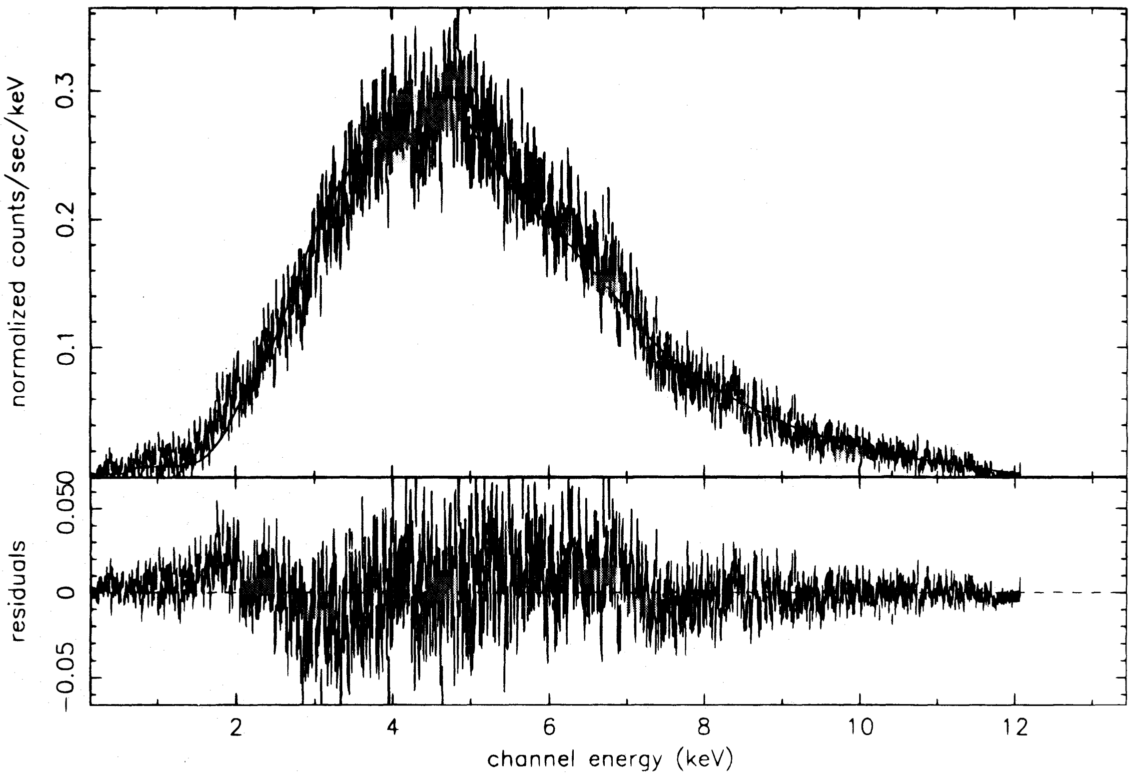

FIG. 2*a*

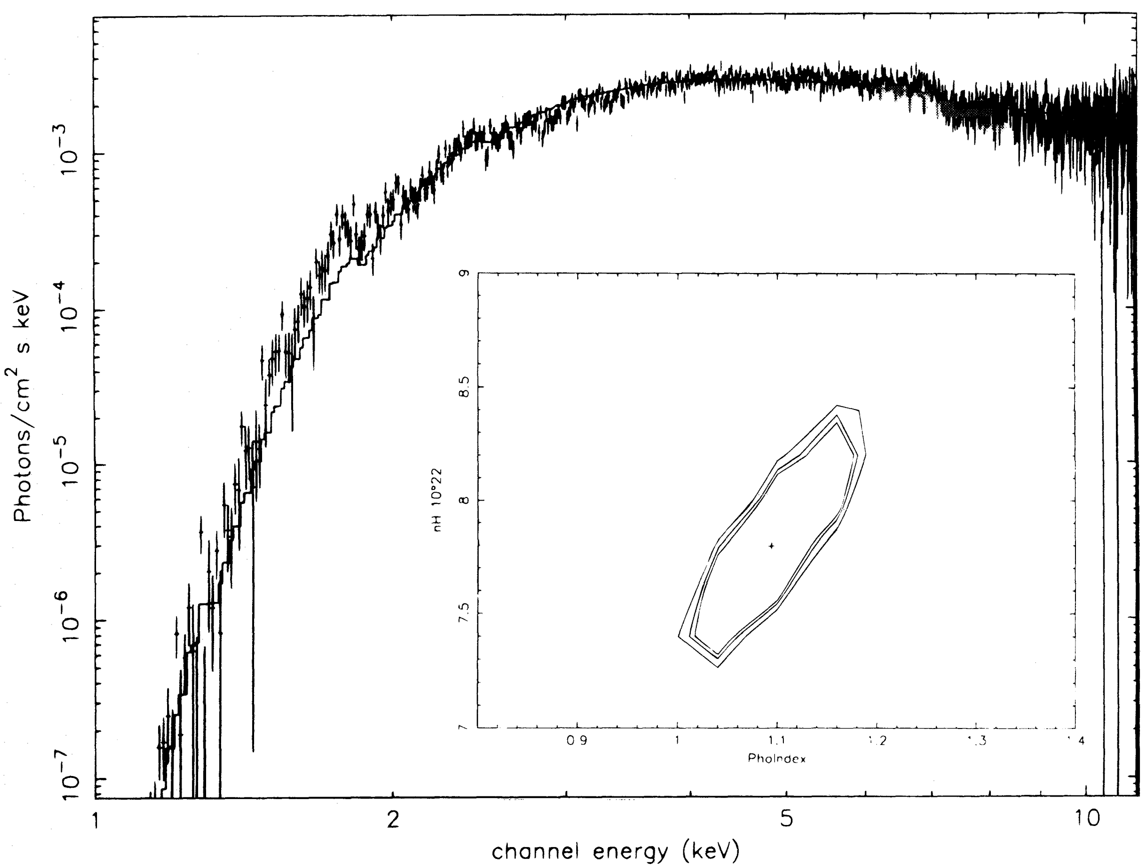

FIG. 2*b*

FIG. 2.—Same as Fig. 1 for the 1994 A02 observation

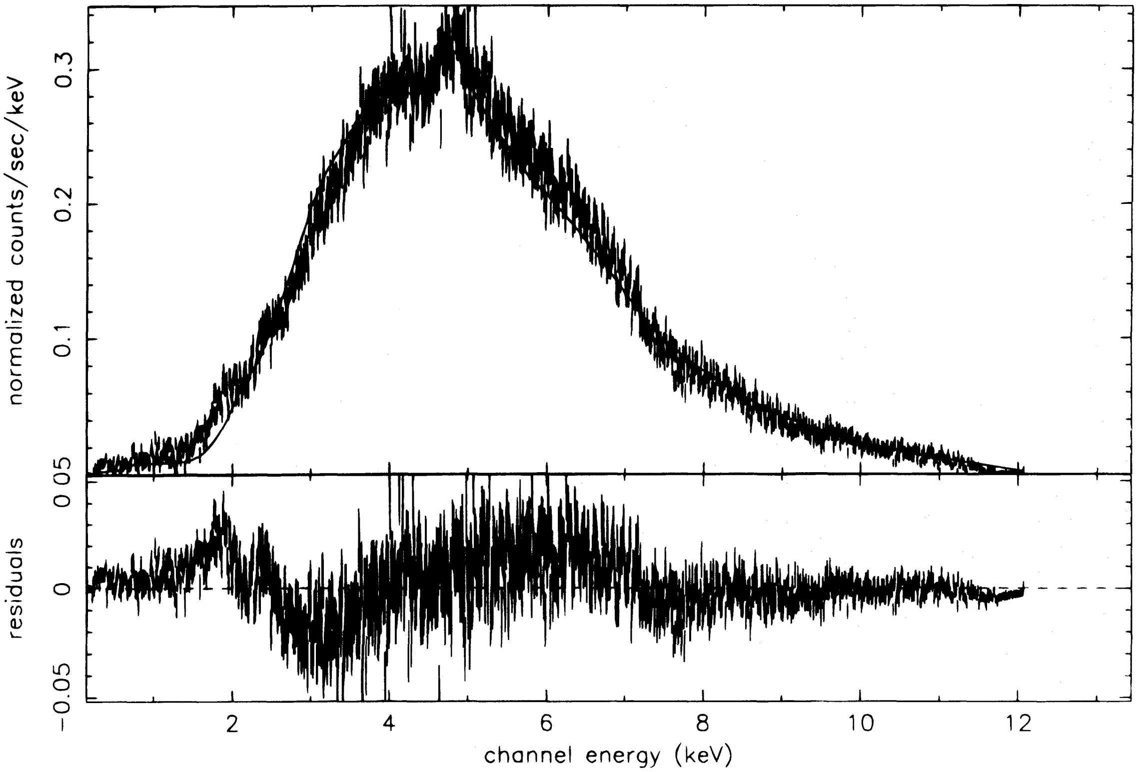

FIG. 3*a*

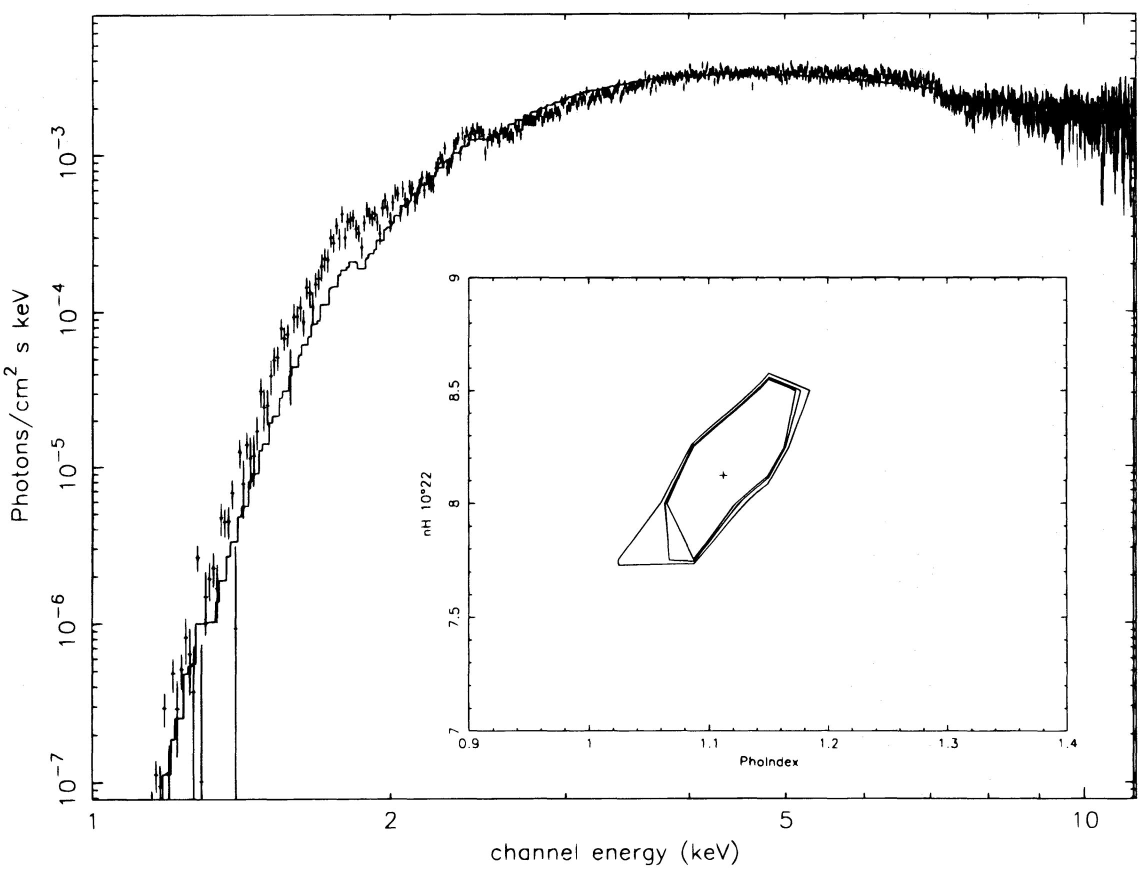

FIG. 3*b*

FIG. 3.—Same as Fig. 1 for the combined PV and A02 data

TABLE 1

POWER-LAW MODEL FITTING OF 1E 1740.7−2942 *ASCA* SPECTRAL DATA[a]

ASCA Data Set	N_H (10^{22} cm^{-2})	Photon Index	Photon Flux (photon cm^{-2} s^{-1})	Energy Flux (ergs cm^{-2} s^{-1})	Reduce χ^2
1993 Sept. 26	8.67 ± 0.117	1.16 ± 0.021	2.519×10^{-2}	2.694×10^{-10}	1.718
1994 Sept. 9–12......	7.80 ± 0.115	1.09 ± 0.021	2.029×10^{-2}	2.162×10^{-10}	1.404
Combined data	8.12 ± 0.079	1.11 ± 0.014	2.280×10^{-2}	2.435×10^{-10}	2.351

[a] Data from GIS 2 & 3 are combined. Reduced χ^2 based on 1021 degrees of freedom. Errors correspond to 1 σ.

report the results only for the GIS data because there seems to be some systematic problems with the SIS data, especially for the A02 observation, that make the SIS results unreliable.

We see from Table 1 that the results from the two separate observations are basically consistent with each other. The combined data give a mean power-law photon index of 1.11 and N_H of 8.1×10^{22} cm^{-2}. This is right in the middle of the range estimated by Chen et al. (1994) using *ROSAT* data but is significantly lower than either the *SPARTAN* (Kawai et al. 1988) or *ARTP*-SIGMA results (Bouchet et al. 1991).

From Figures 1–3 we see that the model fits, though giving good χ^2 overall, fall significantly below the data points around 2 keV. This is likely due to Galactic ridge contamination of the source spectra. From the combined data (Fig. 3) we also see that there is significant evidence for Fe K-edge absorption (above that of the ISM model contribution) but no evidence for Fe Kα or Lα lines. In future work we will try to model these in more detail.

3. ASTROPHYSICAL IMPLICATIONS

The above N_H value to 1E 1740.7, derived using solar abundance for the interstellar medium (ISM), is likely a conservative upper limit since there are known abundance gradients towards the Galactic center (Shaver et al. 1983). This gradient ranges from $2.3 \pm 4.6\%$ kpc^{-1} for Ne-S to $16 \pm 3.5\%$ kpc^{-1} for 0-N (Shaver et al. 1993). For our *ASCA* data fitting the absorption is dominated by Ne-S so that including the effects of such gradients the "true" N_H to 1E 1740.7 could be lowered by a factor of 1.1–1.33, assuming a distance of ~8 kpc, to 6.1–7.4 $\times 10^{22}$ cm^{-2}. Since the N_H value in the general direction of the Galactic center outside of any DMC is already in the range of 4.6–7.2 $\times 10^{22}$ cm^{-2} (Savage & Mathis 1979), and G−0.86−0.08 itself has an estimated N_H of 2.8–4.5 $\times 10^{23}$ cm^{-2} (Bally & Leventhal 1991), the above limit definitely excludes 1E 1740.7−2942 from being behind or deeply imbedded in G−0.86−0.08. It may be completely in front of the cloud. Note that velocity arguments (Bally et al. 1987; Bally & Leventhal 1991) suggest that G−0.86−0.08 cannot be more than ~300 pc from the Galactic center.

Following the argument of Chen et al. (1994) and scaling their mass limit to our N_H value, we can limit the luminosity and mass of any normal companion to 1E 1740.7 as a function of the limiting apparent magnitude in the L and K bands. Using the conservative upper limit of $N_H = 8.1 \times 10^{22}$ cm^{-2} (in which case 1E 1740.7 would be at least slightly imbedded in the DMC), in Figure 4 we plot the upper limits corresponding to an L magnitude of 13 and a range of K magnitudes on the H-R diagram, superposed on the zero-age main sequence (ZAMS) locations and evolution trajectories of stars of sample masses (e.g., Bowers & Deeming 1984). We see that the K-band limits are more stringent than the L band. For the current K-band limit of 17 (e.g., Mereghetti et al. 1992) a star of greater than 9 $M_\odot$ can be ruled out since it must also be later than B2 from radio flux limits (Mirabel et al. 1991). If future observations can lower the limit to $K = 20$, then a star of greater than 4 $M_\odot$ can be ruled out; and if very deep exposure ever reaches $K = 23$, then even a 1 $M_\odot$ star can be ruled out. We therefore strongly urge deep exposure studies of this source.

On the other hand if 1E 1740.7 is totally outside G−0.86−0.08, accretion from the ISM (Bally & Leventhal 1991) is unlikely, and the companion mass limit from Figure 4 for $K = 17$ goes up to ~18 $M_\odot$ since the radio flux limit of Mirabel et al. 1991 no longer applies, but the mass limit for $K > 18$ is the same as for the embedded case. At the same time the constraint on its proper velocity based on the lack of jet bending, and the limit on the jet positron fraction based on upper limits of the 511 keV flux must also be relaxed.

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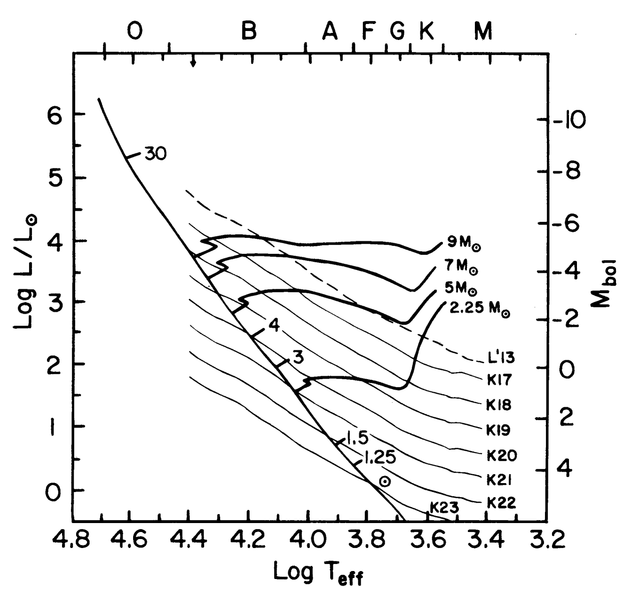

FIG. 4.—H-R diagram with luminosity upper limits corresponding to an extinction of $N_H = 8.1 \times 10^{22}$ cm^{-2}. The dashed curve is for a L magnitude limit of 13 and the light solid curves are for K magnitude limits of 17–23. Sample stellar evolution trajectories and locations on the ZAMS are sketched. Arrow marks the B2 color limit of Mirabel et al. (1991).

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