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DISCOVERY OF X-RAYS FROM THE 40 ERIDANI SYSTEM

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ABSTRACT

We report the detection of a new point source of soft X-rays (H0405−08) consistent with the position of the nearby triple star system 40 Eridani. The source, which has a temperature near 10^7 K, has a flux of 3×10^{-11} ergs cm^{-2} s^{-1} at Earth, implying a luminosity of $9 (\pm 3) \times 10^{28}$ ergs s^{-1} at the distance of 40 Eridani. We discuss whether the likely source of the bulk of the X-rays is the K1 dwarf, the DA white dwarf, the dwarf M4 flare star, or accretion onto the white dwarf.

Subject headings: stars: coronae — stars: individual — X-rays: sources

I. INTRODUCTION

The search for direct X-ray evidence of stellar coronae has recently achieved some success through the detection of stars which have RS Canum Venaticorum characteristics and hence are associated with evolved binary systems (Walter, Charles, and Bowyer 1978*a*). Only a handful of the very nearby systems which do not show RS Canum Venaticorum characteristics have yet been detected as steady X-ray sources: α Cen (Nugent and Garmire 1978), Sirius (Mewe *et al.* 1975; Lampton *et al.* 1979), and Vega (Topka *et al.* 1979). Extending our observations of nearby normal stars is of particular value, as we can make sensitive measurements of very common varieties of stars. In this *Letter*, we report the discovery of X-ray emission from the nearby, well-known star system 40 Eridani, which consists of a K1 V (= o^2 Eri = 40 Eri A) plus a DA (= 40 Eri B = EG 033) plus an M4 V (= DM −7.781B = 40 Eri C).

II. OBSERVATIONS

The X-ray flux from 40 Eri was observed with the low-energy detectors of the A-2 X-ray experiment on the *HEAO 1* satellite.[1] These detectors, which are described in more detail by Rothschild *et al.* (1979), consist of two propane-filled proportional counters sensitive in the 0.1–3.0 keV range. Counter 1, which has a geometrical collecting area of 380 cm^2, is behind two coaligned collimators of FWHM response 1°.55 × 2°.95 and 2°.80 × 2°.55. Only the narrow field of view half of counter 1 was used for this observation, for maximum sensitivity to point sources.

The system 40 Eri was observed during the period 1977 August 21–23 as part of the soft X-ray survey of the whole sky. Individual scans can be summed to bring out weak sources, and sums of the 3 days for the 0.5–2.0 keV and 0.1–0.5 keV bands are presented in Figure 1. The figure shows the stretch of sky across the Eridanus diffuse background feature in half-degree bins. The solid curves are the best fit to the data of a second-order polynomial background plus triangle of the appropriate width for a point source located at the position of 40 Eri. In the 0.5–2.0 keV band the polynomial plus triangle model for the count rate had a χ^2 of 13.5 for 15 degrees of freedom. The polynomial without a triangle had a best fit χ^2 of 56.6 for 16 degrees of freedom, implying the presence of a point source near 40 Eridani with a confidence level of about 6.3 σ. The source has an intensity of 2.0 ± 0.34 counts s^{-1} in the 0.1–2.0 keV band. The X-ray flux of 3×10^{-11} ergs cm^{-2} s^{-1} implies a source luminosity of $9(\pm 3) \times 10^{28}$ ergs s^{-1} at an assumed distance of 4.87 pc.

The signal-to-noise ratio of this source is, unfortunately, sufficiently poor to preclude any possibility of pulse-height spectral analysis. By comparing the observed count rates in the broad-band spectral channels with the relative rates predicted by folding isothermal, solar composition plasma spectra (Raymond and Smith 1977) through the detector responses, we have been able to determine that the object is very hot for a corona. By assuming that interstellar absorption over 5 pc can be ignored, we found that the temperature indicated by the data was not less than 8×10^6 K, but we were unable to derive an upper limit on temperature.

The H0405−08 source was identified previously by Ayres *et al.* (1979) in the *HEAO 1* data, but they were unable to determine a likely candidate for the source

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[1] The *HEAO 1* A-2 experiment is a collaborative effort led by E. Boldt (GSFC) and G. Garmire (CIT) with collaborators at CIT, GSFC, UCB, and JPL.

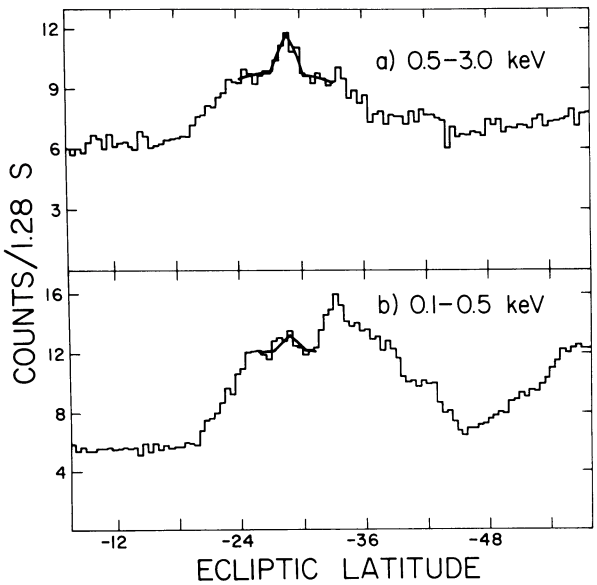

FIG. 1.—*HEAO 1* scan data for the days 1977 August 21–23 summed in half-degree bins. (*a*) count rates from the 0.5–3.0 keV spectral band; (*b*) count rates from the 0.1–0.5 keV spectral band. The solid curves are the best fits to the data of a second-order polynominal plus a triangle of appropriate width for a point source located at the position of 40 Eridani.

of emission. We have derived a formal error box for the position of the source using only the data in the 0.5–2.0 keV band. The corners of the box are: (1950) $4^h15^m26^s$, $-8°19'42''$; $4^h01^m49^s$, $-8°34'51''$; $4^h15^m15^s$, $-7°23'18''$; $4^h15^m39^s$, $-7°50'25''$. The most prominent astronomical object in the box is the 40 Eri system. We have searched the error box for members of other classes which have been shown to include soft X-ray sources. We looked for hard X-ray sources, RS Canum Venaticorum stars, hot white dwarfs, dwarf novae, Seyfert galaxies, quasi-stellar objects, BL Lacertae objects, dMe flare stars, nearby stars, and variable stars. The only alternative candidate found was the cluster of galaxies Abell 484, which, at magnitude 16.9, distance class 5, and richness class 1, is sufficiently ordinary to have little chance of being an unusually strong X-ray source.

H0405−08 falls well within the interesting region of enhanced soft X-ray background in Eridanus. Despite the fact that there is some spatial structure in the Eridanus background enhancement, we feel certain for several reasons that H0405−08 is not just some feature associated with the enhancement. First, its size is less than half a degree, which is far smaller than the overall scale of the enhancement. Second, H0405−08 is much hotter than the overall enhancement, which has a temperature of only 2×10^6 K (Long *et al.* 1977). Third, the H0405−08 feature is unique within the enhanced region, as is clearly visible in Figure 1.

III. DISCUSSION

The 40 Eri system has been very well studied optically because it contains a white dwarf plus one of the nearest K stars, and it is easily observed from the northern hemisphere. The components of the system are well resolved visually, which has led to a complete orbital analysis. The primary, 40 Eri A (also known as o^2 Eridani) is a K1 V which is separated by 82″ from the BC pair. The B component is a DA white dwarf, separated by 7″ from the C component, which is a dwarf M flare star also known as DM −7.781B (Kunkel 1975). X-ray fluxes have in the past been associated with members of each of these three classes and hence we must consider each component separately as the possible source of the bulk of the X-rays.

It is conceivable that DM −7.781B is the source, as it is well established that dMe flare stars are sources of soft X-rays (Heise *et al.* 1975; Haisch *et al.* 1977; Ayres *et al.* 1979). However, H0405−08 emitted an average of 9×10^{28} ergs s^{-1} during observation, which means that the star would have been emitting fully 1% of its luminous output in the X-rays for 3 full days. While Heise *et al.* detected a similar level of emission from UV Ceti and YZ CMi, the duration of emission was less than 1 minute, and a further study of YZ CMi (Karpen *et al.* 1977) produced no events at all in a 3 day observation. In light of the energetics, and the difference in X-ray characteristics from the other observed X-ray flares, it seems unlikely that DM −7.781B is truly the source.

An intriguing possibility is that the DA white dwarf, 40 Eri B, is the source. Although it is a fairly hot white dwarf (17,000 K; Shipman 1972) there would be no possibility of photospheric emission above 0.5 keV, so if the X-ray emission originated in the star, it would imply the presence of a hydrogen corona. Such a white-dwarf corona has been proposed by Mewe *et al.* (1975) and Hearn and Mewe (1976) to explain the X-ray flux from the Sirius system. But while the 40 Eri X-ray source is of a luminosity similar to the Sirius system, its temperature is far higher. Lampton *et al.* (1979) have found that the characteristic X-ray temperature of Sirius is below 5×10^5 K, while that of 40 Eri is above 10^7 K. Lampton and Mewe (1979) have recently argued theoretically that DA white dwarfs are marginally capable of producing coronae of the observed intensity, but they conclude, on the basis of minimum flux corona analysis, that a corona of temperature 10^7 K would imply an intensity two orders of magnitude above that observed in H0405−08. If 40 Eri B is eventually shown to be the component responsible for the X-rays, some theoretical reevaluation of white-dwarf coronae will be necessary.

We next consider the primary component of the system, 40 Eri A, as a candidate for the X-ray emitter. This falls in the region of the H-R diagram shown by Linsky and Haisch (1979) to consist of stars with chromospheres, transition regions, and, by analogy, solar-like coronae. Also, Wilson (1978) has shown that the K line in 40 Eri A exhibits periodic intensity variations with a 10 year time scale, consistent with a solar-like magnetic dynamo. The primary thus should have a corona, but if the detected X-ray emission is produced by its corona, then this corona is unusually hot and intense. It is at least 50 times more intense and

5 times hotter than the Sun, and it is 20 times more intense and 20 times hotter than has been reported for α Cen (Nugent and Garmire 1978). However, the temperature of H0405−08 is similar to that which has been found in Capella (Cash *et al.* 1978) and UX Arietis (Walter, Charles, and Bowyer 1978*b*), and, although its X-ray luminosity is 50 and 250 times fainter, respectively, its X-ray flux per unit area is not too dissimilar.

It is important to compare 40 Eri A (K1 V) with other early K dwarfs. The stars α Cen B (K1 V), 70 Oph A (K0 V), and ϵ Eri (K2 V) have been examined as possible X-ray sources. Since the α Cen AB system is known to be a source comparable in intensity to, and cooler than, the Sun, α Cen B cannot have neither the intensity nor the 10^7 K temperature measured for H0405−08. Alpha Cen B is nearly identical to 40 Eri A in spectral type and chromospheric activity as measured by the Wilson-Bappu Ca II K intensity. On the other hand, 70 Oph A and ϵ Eri are more active chromosphere stars with Wilson-Bappu K line intensities of 3 and 4, compared with 2 for 40 Eri A, and 40 Eri A has a smaller chromospheric radiative loss rate than 70 Oph A or ϵ Eri (Linsky *et al.* 1979). However, Ayres *et al.* (1979) found no source near these two stars in the *HEAO 1* data, even though they lie at comparable or closer distances than 40 Eri.

Walter, Charles, and Bowyer (1978*a*) have reported the detection of X-rays from the wide binary ξ Boo (G8 V + K4 V). With 2×10^{29} ergs s^{-1} of emission at about 10^7 K, the source in the ξ Boo system is quite similar to that in the 40 Eri system. The ξ Boo stars do, unlike 40 Eri, show strong Ca II K line emission. In the Sun strong Ca II K line emission is well correlated with X-ray emission, but active regions never reach temperatures of 10^7 K. Thus if 40 Eri A is the source of the observed X-ray emission, this star does not fit into the usual picture of solar-stellar activity and it must be a unique object or, together with ξ Boo, a progenitor of a new class of stellar corona X-ray sources.

In view of the problems raised by the identification of 40 Eri A as the H0405−08 source, we wish to consider a fourth possibility. Large solar flares are known to produce blast waves in the interplanetary medium, which transport up to 10^{16} g of material from the Sun at typical speeds of 500 km s^{-1} and which produce auroral displays lasting hours when these waves arrive in the vicinity of the Earth and more distant planets. Kunkel (1970) has shown that the total energy of flares in UV Ceti–type flare stars, of which 40 Eri C is an example, can be 100 times that of the largest solar flares. Thus the transient mass loss of flares from 40 Eri C could be 10^{18} g per large flare. If such flares occur once per day, then the time-averaged mass loss is $2 \times 10^{-13}\, M_\odot$ yr^{-1}, which has no effect on the evolution of these stars.

Hard X-ray sources are commonly binary systems with one component a collapsed object. In such systems the accretion of material from the normal star onto a white dwarf either via a steady wind or Roche lobe overflow produces the hard X-rays with a conversion efficiency of typically $10^{-3}\, c^2$ (Fabian, Pringle, and Rees 1976). The difference between 40 Eri BC and such well-studied sources as Cyg X-1 and AM Her is that the mass transfer is transient and the collapsed object (40 Eri B) lies 34 AU from the other star in the system. We have investigated this effect, using estimated values for the parameters of the system: the qualitative outcome is not affected by the exact values of the chosen parameters. The accretion radius R for a nonmagnetic star is

$$R_a = \frac{2GM}{v_w^2}\,, \tag{1}$$

where M is the stellar mass and v_w is the wind speed. For $M = 0.44\, M_\odot$ (Allen 1973) and $v_w = 500$ km s^{-1}, $R_a = 2 \times 10^{10}$ cm. The capture efficiency

$$f = \frac{\pi R_a^2}{4\pi d^2} \tag{2}$$

is then 10^{-9}, assuming an isotropic wind and $d =$ 34 AU.

If accretion onto the white dwarf is the source of the observed X-ray emission, then the observed X-ray luminosity L_x can be simply related to the time-averaged mass loss from the flare star $\dot{M}$ and the capture efficiency f by

$$L_x = 10^{-3} c^2 \dot{M} f^{-1}\,. \tag{3}$$

For $L_x = 6 \times 10^{28}$ ergs s^{-1} and $f = 10^{-9}$, $\dot{M} = 2 \times 10^{-6}\, M_\odot$ yr^{-1}. This rough calculation says that accretion onto 40 Eri B cannot explain the observed X-ray flux unless f can be increased to 10^{-2}–10^{-3}, which requires rather efficient beaming of the flare blast wave from C to B. While this is not out of the question, say perhaps due to magnetic coupling of the two stars, we consider our hypothesis of accretion onto 40 Eri B as unlikely at this time.

In summary, we consider the 40 Eri system as the likely candidate for the X-ray source H0405−08. Each of four possible sources in the 40 Eri system are investigated, but each poses difficulties in terms of what we know about other members of the classes of X-ray sources or in terms of the estimated efficiency factor. Of these four possibilities, we consider a corona about 40 Eri A to be the most likely candidate, and if our identification is correct, then 40 Eri A is the progenitor of a new class of stellar corona X-ray sources.

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