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ON THE OPTICAL COUNTERPART OF 1E 1207.4−5209, THE CENTRAL X-RAY SOURCE OF A RING-SHAPED SUPERNOVA REMNANT[1]

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ABSTRACT

The shell-like SNR PKS 1209−52 contains an unresolved X-ray source near its geometrical center. This source, 1E 1207.4−5209, has a flux of $\sim 4 \times 10^{-12}$ ergs cm^{-2} s^{-1} and was observed both by *EXOSAT* and the *Einstein* HRI. An *ESO* NTT observation revealed the presence of only two objects in and near the recently revised error box. Of these, the brightest ($m_v = 17.37$) was already known to be a field K star. Surprisingly, spectroscopy of the fainter object ($m_v = 19.04$) also reveals it to be a normal K star. The X-ray source counterpart remains unseen down to $m_v \leq 24$, in spite of its accurate position in a relatively uncrowded field. Its suggested association with the SNR, and relevant implications, should be reconsidered, in view of its f_x/f_v of >1000.

Subject headings: stars: neutron — supernova remnants — X-rays: general

1. INTRODUCTION

The problem of causally associating a SNR with a compact X-ray source near its center has received much attention, and several interesting cases have been proposed (see, e.g., Helfand & Becker 1984). For SNRs of the non-plerion type, the one in Vela represents so far the best case. PKS 1209−52 is a bona fide radio SNR (Whiteoak & Gardner 1968), located at $b \sim 10°$ at a distance of ~ 2 kpc, with an angular diameter of $\sim 80'$ and an age of $\sim 20{,}000$ yr.

It was well observed and mapped in a series of X-ray observations taken with *HEAO 1*, *Einstein*, and *EXOSAT* (see Matsui, Long, & Tuohy 1988, hereafter MLT, and references therein). These data also show the presence of a pointlike source (1E 1207.4−5209) located near the geometrical center of the remnant. Thus PKS 1209−52 joins the Vela SNR as a ringlike X-ray structure with a central source. The similarities between the two systems are in fact notable, so that it is natural to think of a possible association of 1E 1207.4−5209 with the compact remnant of the SN event, e.g., with a neutron star also born $\sim 20{,}000$ yr ago.

Both MLT and Kellett et al. (1987) show that the X-ray data are compatible with this hypothesis, but that other, more standard, objects could also fit the picture. Exploiting the good (albeit prerevision) HRI position, MLT proceeded to search for an optical counterpart, and showed that an $m_v \sim 17$ star, present in the 3″ radius error circle, has the spectrum of a field K dwarf, and as such cannot be the X-ray emitter. They noted, however, that on the ESO blue plate, the star appears elongated, hinting at the presence of a fainter object, probably the true counterpart.

2. THE OBERVATIONS AND THEIR ANALYSIS

The region of 1E 1207.4−5209 was observed on 1990 January 23, 24 and 25, the first guest astronomer nights offered by ESO on the NTT—the 3.5 m New Technology Telescope on La Silla. The detector was the EFOSC 2 (European Faint Object Spectrograph and Camera) at the telescope Nasmith focus, equipped with a RCA CCD covering a field of 1′.4 × 2′ with a pixel size of 0″.26. A further short *V* exposure was taken at the same telescope a year later, on 1991 January 11, using the red arm of the EMMI (ESO Multi Mode Instrument) equipped with a Thomson CCD with a pixel size of 0″.44 over a field of 7′ × 7′. This image, albeit taken under mediocre seeing conditions, was useful for performing accurate astrometry on the X-ray source error box, especially in view of its recently revised position (Seward 1990).

During the 1990 observing run, the region containing the X-ray source was imaged with subarcsec seeing conditions in *B*, *V*, and *R*. The exposures collected were 5 and 15 minutes in *V*, 15 minutes in *B*, and 5 minutes in *R*. As expected, a fainter object appeared close to the $m_v = 17.37$ star (object A) as shown in Figure 1 (Plate L7), the 15 minute *V* exposure. The *B*, *V*, and *R* magnitudes of the new object (B) are 19.74, 19.04, and 18.7. Thus, the object is not especially blue, as had been suggested by MLT on the basis of the ESO plates; rather, it is probable that the blue plate had a better seeing than the red one. Figure 2 (Plate L8), shows our 5 minute *R* exposure with both the old (MLT) and the revised (Seward 1990) error circles for 1E 1207.4−5209. The positions have been computed using, as a reference frame, several stars from the *Hubble Space Telescope* GSC which are present in the 7′ × 7′ EMMI field. The r.m.s. astrometry error is estimated to be ≤0″.5. It is apparent that the new HRI error box, offset as it is to the northwest, no longer particularly favors object B.

In any case, exploiting the 0″.8 seeing of 1990 January and with careful slit positioning, it was possible to take two spectra of object B through a 1″ slit, thus substantially reducing the possible contamination from star A located $\sim 1''.8$ away. Spectra were taken with a grism, yielding a dispersion of ~ 6 Å per pixel over the wavelength range 3750–7000 Å. The two raw spectra, of 30 and 45 minutes' integration, were carefully cleaned for cosmic-ray contamination and processed using an algorithm designed to optimize the signal-to-noise ratio (Horne 1986). The consistency of the two independent raw spectra gives us confidence in the quality of the data and their

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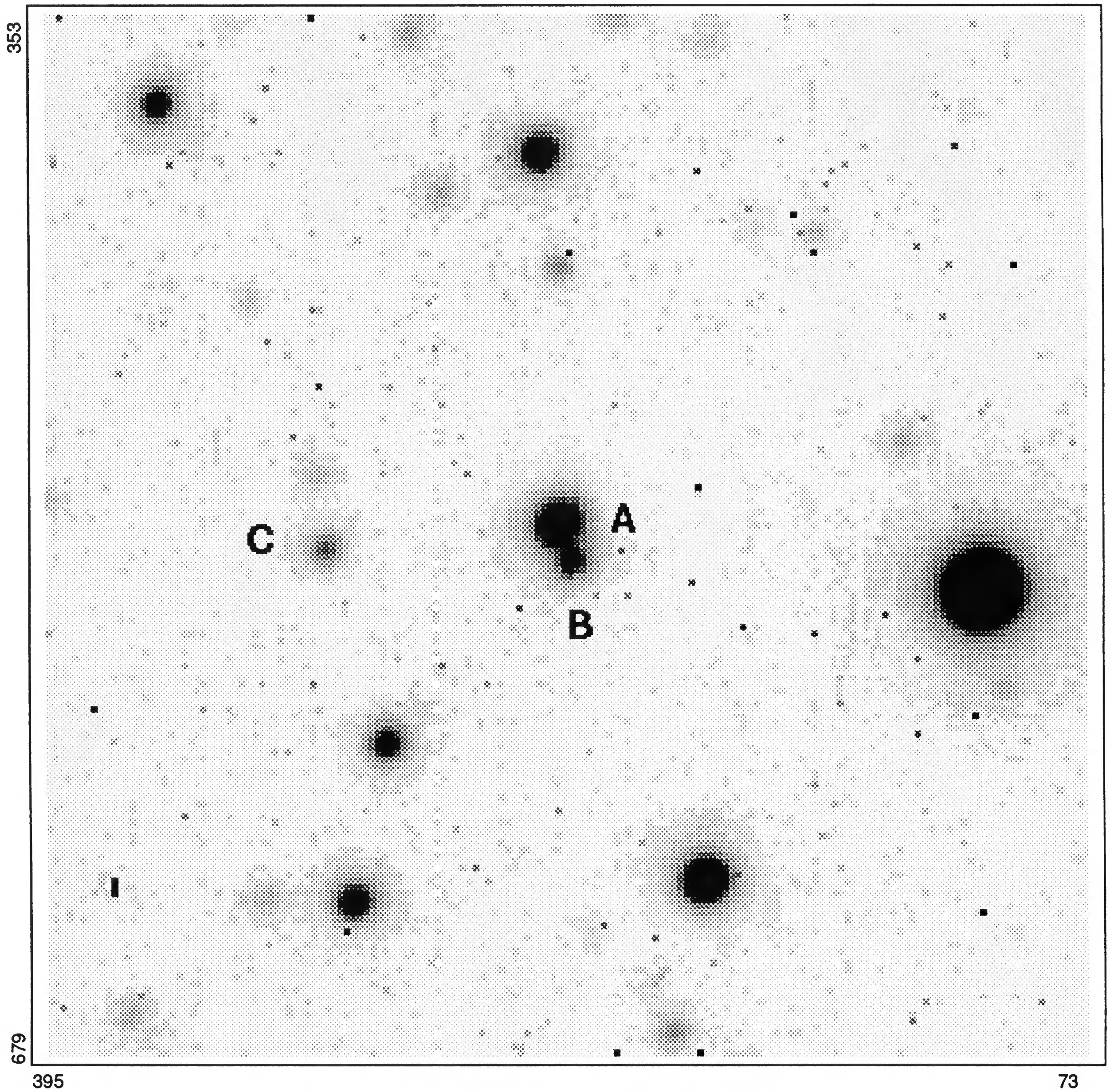

FIG. 1.—A 15 minute V exposure of the field of 1E 1207.4−5209, obtained with ESO's NTT in 1990 January with good seeing (0″.8) conditions. Object A ($m_v = 17.34$) had already been observed by MLT. North is at the top, east is to the left. Each pixel is 0″.26. Objects A and B are separated by about 1″.8.

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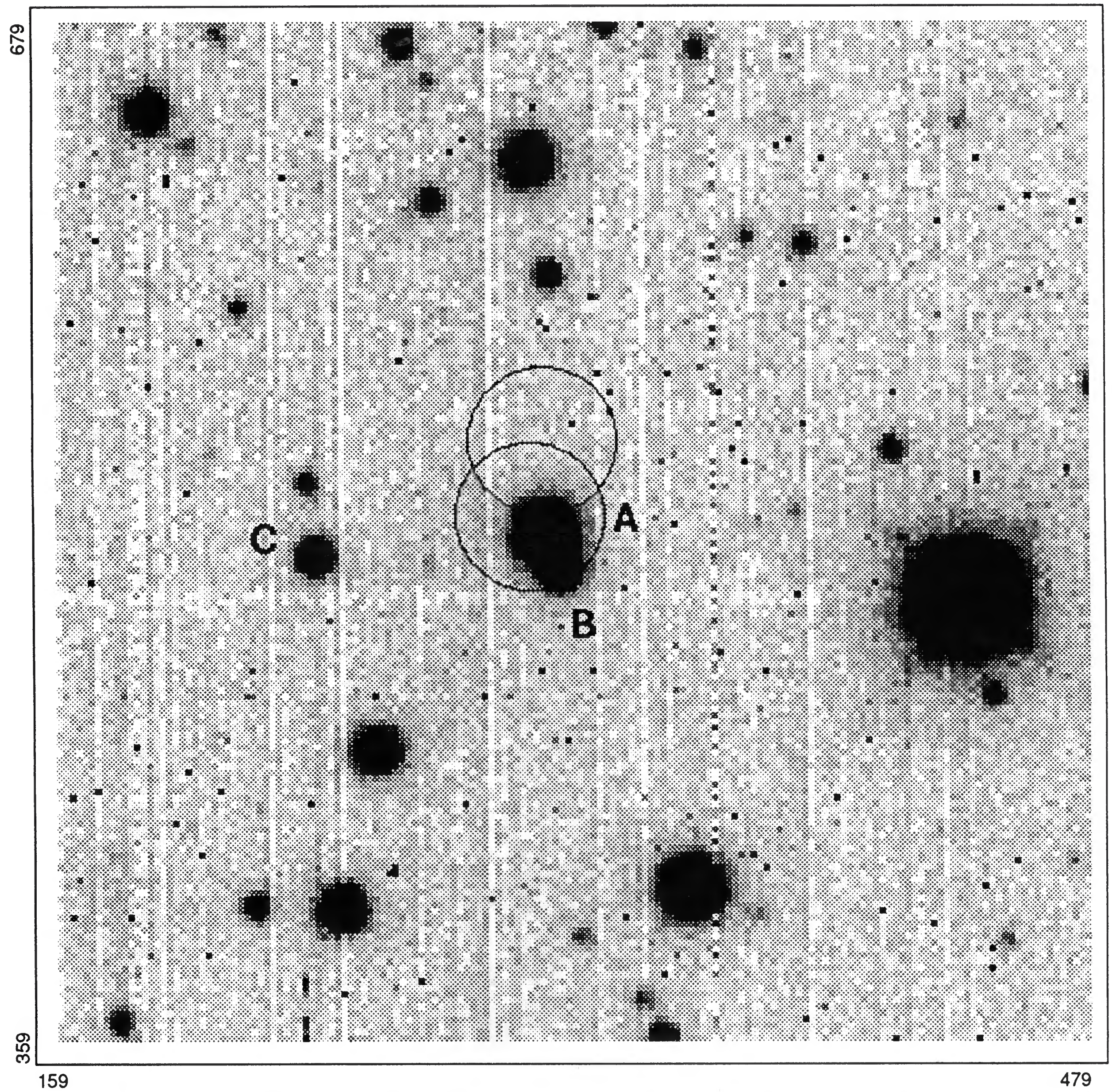

FIG. 2.—A 5 minute *R* exposure of the same field. The "old" (MLT) and "new" (to the northwest, Seward 1990) HRI error boxes are shown with 3″ radius. Object C is the one shown to vary by ~0.4 mag in the 1991 observation.

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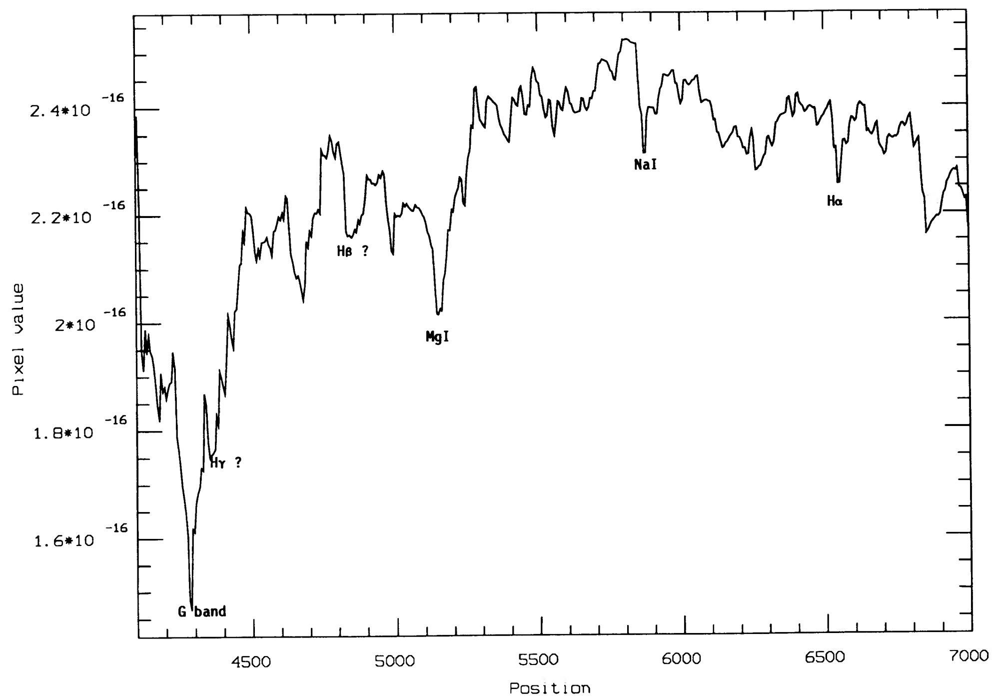

FIG. 3.—Spectrum of object B ($m_v = 19.04$). Shown is the sum of two separate 30 and 45 minute exposures taken in 1990 January with EFOSC 2 at the NTT. The x-axis is in Å, the y-axis in ergs cm^{-2} s^{-1} $Å^{-1}$, and the resolution is 6 Å $pixel^{-1}$. The absorption features, the G-band, the lack of emission, and the overall shape of the continuum support a classification of mid-K spectral type. Slope of continuum blueward of 4500 Å may be affected by uncertainty in the calibration.

good signal-to-noise ratios. Figure 3 shows the sum of the two spectra after flat-fielding and flux calibration. Unfortunately, the choice of the standard star for flux calibration, LTT 4364, introduced uncertainty in the blue part of the spectrum which as a result is shown truncated at $\lambda = 4100$ Å. We have some reservations about the reality of the continuum slope blueward of ~4500 Å for the same reason. However, the overall continuum shape and, above all, the clear spectral features can be regarded with confidence. One can identify with certainty the G-band, the Mg I, the Na I and Hα absorption features, and most probably, also in absorption, Hγ and Hβ, the latter very likely blended with the Fe lines. Interstellar absorptions (as well as telluric O_2) are also present. On the contrary, no emission feature is seen, notably none in the He II λ4686 forbidden line, the signature of many accretion-driven X-ray sources.

From the spectral evidence, and irrespective of the limitations induced by the calibration, one is forced to conclude that object B is also a star of mid-K spectral type, with no obvious features to associate it with the X-ray source.

On the other hand, no other objects are visible in the vicinity of the new (or old) HRI boxes. The limiting magnitudes are 22.5 in R, 23.5 in V, and 23 in B. For the record, one should note that object C, admittedly located several arcsec away from the error box edge, displays a marked time variability: during 1991 January its V image appeared 0.4 mag fainter than in the 1990 January observation.

3. DISCUSSION

As is sometimes the case in the game of field X-ray source identification, with 1E 1207.4−5209 one seems to have met with a surprise. If the HRI position, consistent with the IPC and *EXOSAT* data, is now to be believed (and one sees no reason to the contrary), one is faced with an otherwise empty HRI error box for a source with $f_x \sim 4 \times 10^{-12}$ ergs cm^{-2} s^{-1} which appears to contain, or have in its immediate surroundings, not just one, but two chance field stars, unrelated to it—and this at $b \sim 10°$, in a not especially crowded region. On the other hand, one can find no reason to hold either star A or B responsible for the X-ray emission, which could obviously not be of coronal nature. One could therefore speculate that the true counterpart is a fainter object, lurking somewhere in the error box. The chance of its being eclipsed by object A is quite small for the revised HRI position. The magnitude limits of the images shown above imply an $f_x/f_v >$ (few) × 1000. This is outside the ranges seen for any class of extragalactic sources. While a standard accretion-driven binary could have such a ratio of X-ray to optical output, with an $m_v > 24$ it would have to be well outside the Galaxy, as already noted by MLT. The apparent lack of X-ray or optical flux variability also argues against such a possibility.

It becomes almost compulsory, then, to recall the position of the source inside the SNR and to speculate on its association with a neutron star. The similarity with the Vela SNR and its pulsar again springs to mind, were it not for the absence of a radio signal, pulsed or not, from the central source (MLT). The two SNRs are of comparable age and size when the different distances are taken into account. The two central X-ray sources are constant in time, and probably related to a synchrotron nebula, resolved in the case of the one surrounding PSR 0833−45, but not for 1E 1207.4−5209 which is 4–5 times more distant and also fainter. The X-ray–to–optical ratio of >1000 for PSR 0833−45 would certainly also fit 1E 1207.4−5209, and the $m_b \sim 23.7$ Vela pulsar would be indeed hard to detect at 4 times its distance, approaching $m_b \sim 27$. The X-ray spectral data both of MLT and of Kellett et al. could well fit a Vela-like synchrotron spectrum. Finally, the central position within the SNR must not be neglected: the chance coincidence probability between 1E 1207.4−5209 and the SNR should be calculated not with respect to the whole surface of the remnant, but to its central zone. More precisely, that zone in which a pulsar, born at the SNR center, could be after 20,000 yr of motion at standard pulsar velocities. If this zone, as suggested by Kellett et al. has a radius of 8′, the Helfand & Becker (1984) probability for chance association goes from ~4% to 2×10^{-3}, a more interesting value.

Also, in view of the revised HRI position, it seems to us highly unlikely that either object A or B have anything to do with 1E 1207.4 − 5209. Object C, although interesting owing to its variability, also appears unlikely, because of its distance from the X-ray source position. Future work should (1) address a rechecking of the X-ray position, possibly with *ROSAT*, and (2) concentrate on deeper imaging and multicolor photometry. This is a formidable task, as has already been shown for the case of Geminga, another possibly similar object (Bignami et al. 1987; Halpern & Tytler 1988).

Given this precedent, a *GRO* high-energy γ-ray obervation of the region could also be very helpful, even if the object does not show up prominently in the *SAS* 2/*COS B* data bases. Note that in such data bases, the Vela pulsar, the brightest γ-ray source in the sky, would have been hardly detectable at the supposed distance of PKS 1209 − 52. However, depending on the sky background, such a source flux might now be within the capability of EGRET on *GRO*.

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