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The Isolated Neutron Star RX J185635-3754

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Abstract. We use optical and X-ray data to investigate the atmosphere of the isolated neutron star RX J185635-3754. The space motion suggests an origin about 2 million years ago in the Upper Cen-Lup OB association.

The surfaces of most of the known neutron stars are difficult to study because their surface emissions are obscured either by accretion (X-ray binaries) or by magnetospheric emissions (pulsars). Isolated, nonpulsing neutron stars permit a clear view of their surfaces and their intrinsic properties, e.g., RX J185635-3754 (Walter, Wolk, & Neuhäuser 1996; Walter & Matthews 1997).

Here, we present a brief update on this object. Spectra from ASCA and the EUVE, and photometry between 1780 and 6000Å from the HST, allow us to refine the spectral energy distribution. Optical images at two epochs reveal the space motion and possible age and origin of this neutron star.

1. The Spectrum and the Space Motion

We detect this object from ~1 keV through 6000Å. We have looked for it, but not detected it, in hard (>1 keV) X-rays or γ-rays, in the near-IR (J,H,K), and in the radio (<40 μJy at 6 cm). The blackbody fit to the X-ray data (kT=57 eV, $n_{\rm H}$=1.4×10^{20} cm^{-2}) underestimates the optical flux by factors of 2 at U and 3.7 at V. The Greenstein & Hartke (1983) model, with the temperature varying sinusoidally in magnetic latitude, fits the optical data better. None of the Pavlov et al. (1996) atmospheric models agree with the optical data.

Using the Los Alamos opacity tables, we generated nonmagnetic model atmospheres. The pure H model predicts optical fluxes substantially larger than observed, in agreement with Pavlov et al. (1996). We get good fits with Fe or Si-ash atmospheres (our Fe models are similar to those of Rajagopal & Romani 1996). The parameters for Si-ash or Fe atmospheres are $kT_\infty \approx$48 eV, $g \approx 2\times10^{14}$ cm s^{-2}, and $R \sim 30(D/100\,{\rm pc})$ km. If $1.3 < M/M_\odot < 1.8$, it follows that $10 < R_\infty({\rm km}) < 15.6$ ($5.7 < R({\rm km}) < 11.4$) and $30 < D({\rm pc}) < 50$.

We measured the position on HST/WFPC2 images obtained in October 1996 and March 1999. The observed motion, the sum of 2.5 years of proper motion plus annual parallax, is $0.86 \pm 0.03''$ at a position angle of 99.9°. At 50 pc, this corresponds to a transverse velocity of 70 km/s. This velocity excludes accretion from ISM as a major heating source.

The proper motion heads away from the Sco-Cen OB association, as does the well-known runaway O star ζ Oph (Blaauw 1993). Van Rensbergen, Vanbeveren, & de Loore (1996) argue that the luminosity and He abundance of

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ζ Oph are more consistent with an origin in the Upper Cen-Lupus association. In their model, ζ Oph was part of an OB binary star system which gained about $5\,M_\odot$ before the mass-losing primary exploded about 2–3 Myr ago. Sufficient mass was lost in the explosion (or the remnant acquired sufficient kick velocity) to unbind the system. Is RX J185635-3754 the remnant of that supernova?

Both the distance to the neutron star and its radial velocity are presently unknown. For a grid in current distances and radial velocities of the neutron star, we computed the distance and time of closest approach. Within the uncertainties, the neutron star, ζ Oph, and the Upper Cen-Lup association were all in the same place about 2.2 Myr ago (if the present distance and radial velocity of the neutron star are about 30 pc and -45 km/s). This suggests that RX J185635-3754 could be the former primary of the ζ Oph system. If so, the kinematics of the ζ Oph/neutron star pair can be used to investigate the kick velocity. The two are separating at nearly right angles, suggesting that the kick velocity may have been directed perpendicular to the orbital plane.

3. Discussion and Conclusions

The spectral energy distribution is that of the photosphere of a cooling neutron star, with Fe or Si-ash composition. The data exclude simple blackbodies, as well as pure H atmospheres.

The space motion is consistent with an origin in Upper Cen-Lup about 2.2 Myr ago, as the binary companion to ζ Oph. If confirmed, we will know the progenitor, age, and kick velocity of this object. The implied distance ($\sim$30 pc) suggests a fairly small star (and a soft equation of state), as well as a fairly high density in the ISM along this line of sight ($1.5\,\mathrm{H/cm^3}$).

We will refine these estimates in the near future. A third HST observation should let us separate the parallax and proper motion. The parallax will fix the radius and the transverse velocity, and more tightly constrain the possible origin of the star. X-ray spectra will be the definitive test of the surface composition because Fe and Si-ash atmospheres have identifiable spectral features. These features will also yield a gravitational redshift ($z \propto M/R$). Together with the radius measurement, this will give a direct measurement of the mass of this isolated neutron star.

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