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BOWEN FLUORESCENCE FROM COMPANION STARS IN X-RAY BINARIES

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RESUMEN

Este artículo examina una nueva técnica para detectar estrellas compañeras en los LMXB y las transitorias de rayos X durante la transferencia de masa utilizando las líneas NIII fluorescentes de Bowen en 4634-4640. Estas líneas se reprocesan muy eficientemente en las atmósferas de las estrellas compañeras proporcionando estimaciones de las velocidades K2 y funciones de masas. Este método se aplicó a Sco X-1, X 822-371 y GB339-4 el cual, en este último caso, proporciona una evidencia dinámica de la presencia de un agujero negro acreciente. También se presentan resultados preliminares de una campaña VLT sobre V801 Ara, V926 Sco y XTE J1814-338.

ABSTRACT

This paper will review a new technique of detecting companion stars in LMXBs and X-ray transients in outburst using the Bowen fluorescence NIII lines at 4634-4640. These lines are very efficiently reprocessed in the atmospheres of the companion stars and, thereby, provide estimates of the K_2 velocities and mass functions. The method has been applied to Sco X-1, X1822-371 and GX339-4 which, in the latter case, provides dynamical evidence for the presence of an accreting black hole. Preliminary results from a VLT campaign on V801 Ara, V926 Sco and XTE J1814-338 are also presented.

Key Words: **ACCRETION, ACCRETION DISCS — X-RAYS: BINARIES — X-RAYS: STARS**

1. INTRODUCTION

The Galaxy is populated with just over 100 known *persistent* Low Mass X-ray Binaries (LMXBs hereafter) whose optical emission is triggered by X-ray reprocessing into the gas surrounding the compact object, mainly the accretion disc. The companion star is $\sim 10^6$ times fainter than the optical disc and hence completely undetected. This has hampered dynamical studies of LMXBs which have been restricted so far to radial velocity studies of X-ray transients in *quiescence*. In several cases, the quiescent companion spectrum is just too faint for current instrumentation (e.g. GX339-4, N. Oph 93) or the target is contaminated by a bright line-of-sight star (e.g. Aql X-1, 4U 2129+47). Dynamical studies and mass determination of compact stars in LMXBS has paramount implications in astrophysics since it may yield new black hole discoveries and the first massive neutron stars. The latter would rule out soft equations of state and will prove LMXBs are indeed the progenitors of millisecond pulsars, spun up by accretion.

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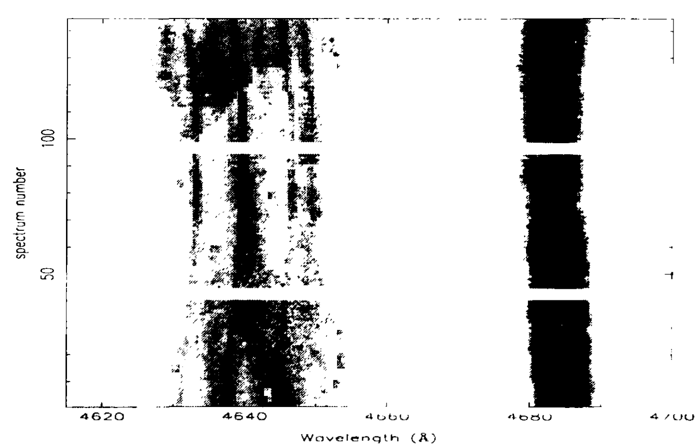

Fig. 1. Trailed spectrogram of the Bowen blend and He II λ4686 line showing the Doppler shift of the narrow C III and N III components. From Steeghs & Casares (2002).

2. DETECTION OF DONOR IN SCO X-1

A new avenue for mass determination in LMXBs has been opened thanks to the discovery of narrow high-excitation emission components arising from the irradiated companion in Sco X-1 (Steeghs & Casares 2002), the most prominent being C III 4647-50 and N III 4634-40 (see Fig. 1).

The N III lines are produced by Bowen fluorescence through cascade recombination, which requires seed photons of He II Lyα, and must arise from the irradiated companion because (1) they are extremely

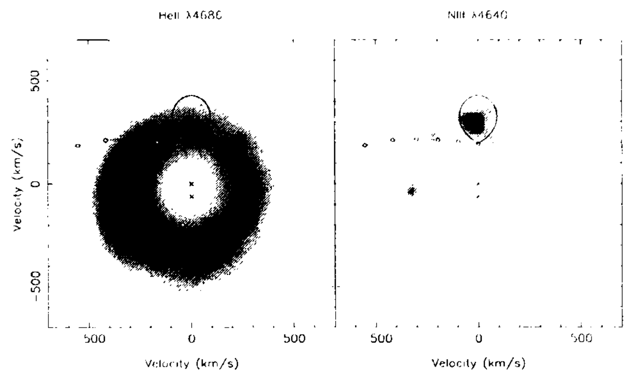

Fig. 2. Doppler maps of He II λ4686 and N III λ4640 in the pulsar LMXB X1822-371. The Roche lobe of the companion and gas stream trajectory are overplotted for a 1.4 $M_{\odot}$ neutron star. From Casares et al. (2003).

narrow (i.e. $FWHM = 50$ km s^{-1}, the instrumental resolution), and (2) move in anti-phase with the wings of the He II λ4686 line (which trace the motion of the compact star). Furthermore, the radial velocity curve is very sinusoidal indicating a fixed structure in the binary frame. This work represents the first detection of the companion star in Sco X-1 and opens a new window to extract dynamical information in a population of $\simeq$ 20 LMXBs with optical counterparts.

3. GX339-4 AND X1822-371

The Bowen fluorescence diagnostic is a powerful technique also for transient sources as we have clearly demonstrated in Hynes et al. (2003). GX339-4 has been a black hole candidate for decades based on its X-ray properties but no dynamical proof could be provided. In summer 2002 we used the opportunity of a new outburst episode to obtain AAT, NTT and VLT spectroscopy which revealed (1) He II velocities modulated with an orbital period of 1.76 d, and (2) narrow N III Bowen components from the companion star with a velocity semi-amplitude of 317 ± 10 km s^{-1}. The implied mass function is 5.8 ± 0.5 $M_{\odot}$ and hence a robust evidence for an accreting black hole.

The next obvious target is X1822-371 because, at B=16 it is one of the brightest LMXBs. It is also a key system because (1) is eclipsing hence the inclination is well constrained (2) is an X-ray pulsar and therefore the orbit of the neutron star is known to great accuracy. In summer 2002 we obtained AAT spectroscopy but the moderate S/N prevented identification of the narrow fluorescence components in individual spectra (see Casares et al. 2003). However, we exploited the Doppler Tomography technique which uses all the information contained in the phase-resolved emission profiles at once to reconstruct the emissivity distribution in velocity space.

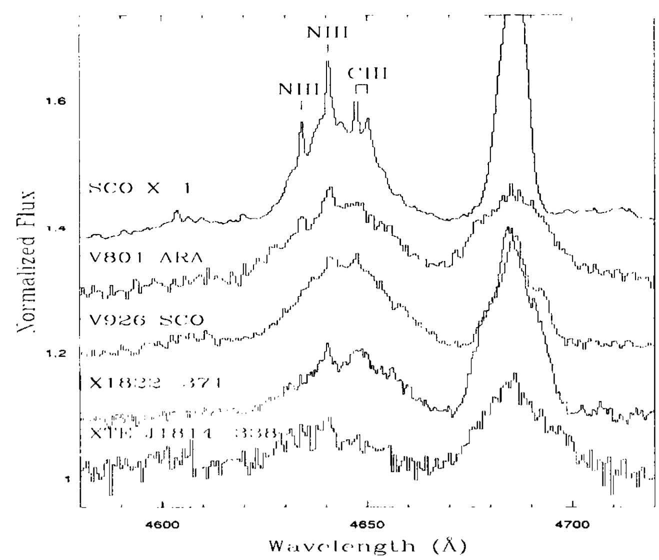

Fig. 3. Doppler-corrected sums, in the rest frame of the companion, of systems studied by our group.

Fig. 2 presents the Doppler maps of He II λ4686 and N III λ4640. The former displays a classic accretion disc distribution whereas the latter shows a very compact spot consistent with the velocity and phasing of the companion star. The spot velocity, 300 km s^{-1}, is a lower limit to the true velocity of the donor star because it is formed on the inner irradiated face. This, combined with the knowledge of the inclination and neutron star's orbit, leads to solid lower limits to the masses of the neutron star and companion of 1.14 ± 0.06 $M_{\odot}$ and 0.36 ± 0.02 $M_{\odot}$, respectively. Tighter constraints require modelling the *K-correction* (Wade & Horne 1988) to determine the displacement of the irradiated region from the center of mass of the donor star.

4. VLT SURVEY

We have started a VLT survey of LMXBs to target new candidates with strong Bowen emission for future studies. These are MM Ser, X1957+115, LU TrA, V926 Sco, GX9+9, GR Mus, V801 Ara and X0614+091. In summer 2003 we observed V926 Sco, V801 Ara and the newly discovered transient millisecond pulsar XTE J1814-338 using VLT+FORS2. Our Doppler tomograms enables us to detect the companion star in N III λ4640 and derive lower limits to their K-velocities of 223, 282 and 345 km s^{-1} respectively (Casares et al. 2004a,b in preparation).

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