
X-ray Observations of Symbiotic Miras

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Summary. Ionized nebulae associated with symbiotic Mira systems often closely resemble those of "classical" bipolar planetary nebulae (PNe), and therefore offer tests of models of collimated outflows in PNe. It is widely assumed that jets and disks in such systems are inextricably linked; this assumption is exceedingly difficult to challenge given the extreme difficulty of observationally distinguishing jet and disk. Therefore we must employ methods to optimize spatial resolution, where possible. To this end, we are reprocessing all available Chandra X-ray Observatory X-ray images of symbiotic systems using subpixel event repositioning (SER), which allows us to push the unprecedented spatial resolution of the Chandra X-ray Observatory to the ($\sim 0''.3$) limits of its exquisite mirror system. We present preliminary results from these efforts to disentangle the jet/disk phenomenon in symbiotic systems R Aqr, CH Cyg, Menzel 3, Hen 2-104, and M 2-9.

Key words: Planetary Nebulae, X-rays, Jets, Symbiotic Miras

1 Introduction

A symbiotic Mira system is comprised of a pulsating Mira variable (i.e. an asymptotic giant branch star) that transfers material to a compact, hot star (Kenyon 1986). Symbiotic Mira systems often feature ionized nebulae with large bipolar lobes (Corradi et al. 1995, 1999, Bode 2004). These nebulae—which resemble bipolar planetary nebulae—are believed to form from the interaction of fast and slow winds, where the slow wind emanates from the AGB star, while the fast wind most likely originates with the compact companion (Balick & Frank 1997). These systems also seem to exhibit efficient jet launching and collimation whose effects are detectable over a range of spatial scales in optical, radio, and/or X-ray imaging. Stute et al. (2005, 2007) and Stute (2006) have produced models of pulsed jets that have raised important questions about the role cooling plays in symbiotic jet systems, we believe, as do they, that multi-epoch, high-resolution Chandra X-ray imaging spectroscopy may be able to provide the answers.

2 Analysis

The objects and Chandra X-ray Observations considered in this contribution are listed in Table 1. Data preparation follows the recommended steps for ACIS data found in CIAO 3.4 using CALDB 3.3.0.1. Subpixel event repositioning (SER) is performed according to Li et al. (2003). SER improves the accuracy of the spatial and spectral information collected with the CXO HRMA by using detailed models of charge cloud distributions produced by events falling at key, off-center, locations within a single pixel. With these models, the energy and position of an observed event can be refined. The pixels of an SER image are rebinned to $0''.24$ by $0''.24$. These images are then regridded without interpolation and convolved with a two dimensional gaussian with a FWHM of $0''.24$.

Table 1. Archived Chandra Observations of Symbiotic Systems

Object	ObsID	Date	t_{exp} (ks)
R Aqr	651	2000-09-10	24.6
R Aqr	4546	2003-12-31	37.0
R Aqr	5438	2005-10-09	70.2
CH Cyg	1904	2001-03-27	47.7
Mz 3	2546	2002-10-23	41.4
Hen 2-104	2577	2002-04-08	20.0
M 2-9	2578	2003-01-24	19.9

3 Results and Discussion

R Aqr: R Aqr was first observed by Chandra in 2000 (Kellogg et al. 2001). Follow-up observations show rapid jet evolution and accretion-related behavior in the central source (Nichols et al. 2007, Kellogg et al. 2007). The northern jet, central source, and southern jet at each epoch are depicted in Figure 1. The X-ray emission in both extended jets is soft, less than 2 keV, indicative of collisionally-heated plasma. The apparent increase in brightness of this soft X-ray emission in the northern jet is a result of the increasing exposure time (see Table 1). In fact, the total X-ray count rate for the northern jet has decreased by more than half in the past five years. The count rate in the southern jet has also decreased. New jets can be seen emerging from the central source over the interval from 2000 to 2005. Since 2000, the hard X-ray (2 to 10 keV) count rate of the central source has more than doubled. The spectra from the three observations show an iron line at 6.4 keV, indicative of an accretion disk. Iron emission is also present in the ACIS spectrum of CH Cyg.

CH Cyg: Originally reported in Galloway & Sokoloski (2004), the CXO observation of CH Cyg shows evidence for collisionally-heated plasma near the central source extending along the axis of a southern jet detected with HST. Karovska et al. (2007) performed a detailed analysis similar to ours and found evidence of a northern jet. Our analysis confirms the evidence of extended emission in the northern

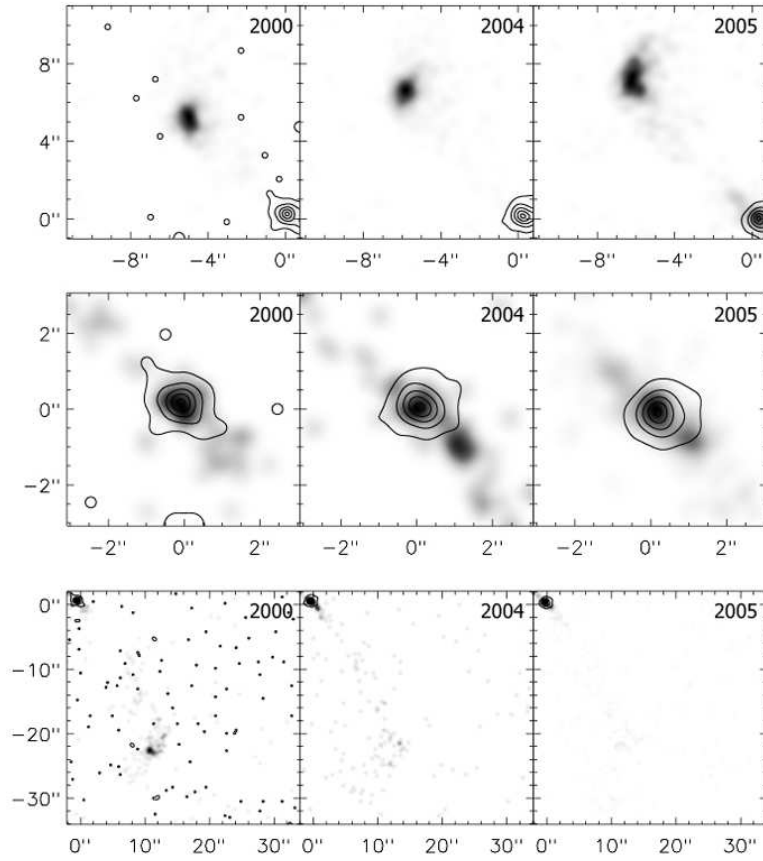


Fig. 1. R Aqr (top to bottom: NE jet, central source, SW jet); hard X-ray emission contours overlaid on soft X-ray emission.

region. The low number of counts (~ 5 counts in each “head” of the northern jet, compared to 100+ counts within the soft central source) warrants some caution, as does the apparent separation observed between the hard and soft X-ray emission.

Figure 2 depicts this hard vs. soft spatial separation “conundrum”. The contours of the hard X-ray emission (2.0 keV to 10.0 keV) are overlaid onto the soft X-ray emission (0.3 to 2.0 keV). The contour levels are at 5%, 25%, 50%, 75%, and 95% of the peak hard emission. The contours and the soft emission suggest the presence of two spatially offset, yet poorly resolved, point-like surface brightness distributions (even without the smoothing, the point-like surface brightness distribution appearance holds). By fitting the count distributions (soft and hard) with two-dimensional gaussian the separation is determined to be $\sim 0''.3$. Such a separation cannot be explained by known aberrations of the Chandra HRMA for HETG (grating spectrometer) observing mode. A MARX simulated image using the observed spectrum shows an expected separation on the order of $0''.01$.

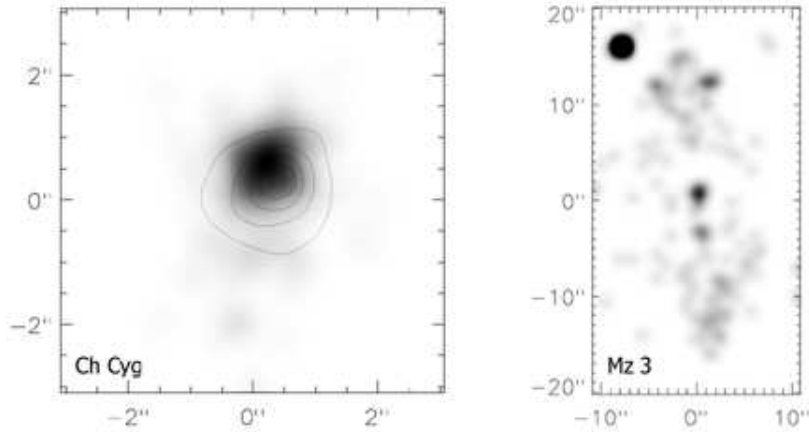


Fig. 2. Left panel: CH Cyg with hard X-ray emission contours overlaid on soft X-ray emission. The apparent offset of hard and soft X-ray emission is discussed in text. Jet-like features extend SSE and, possibly, NNW. Right panel: Menzel 3 soft X-ray emission at central source and along the bipolar cavities.

The X-ray spectrum CH Cyg has spurred various physical interpretations (Wheatley & Kallman 2006, Mukai et al. 2007). Mukai et al. (2007) suggest that the decline in the hard X-ray emission since the 1994 ASCA observation is due to obscuration of the source by the thick accretion disk. They propose we are observing hard X-rays scattered in our direction. The observed hard vs. soft spatial separation might support this claim and would give us the location of the scattering region. At a distance of 245 pc (Galloway & Soloski 2004, references therein), the observed separation corresponds to a distance ~ 70 AU. Future, deeper, X-ray imaging may resolve this matter and provide better sampling of the suspected northern jet.

Menzel 3: Menzel 3 is believed to be a symbiotic Mira system (Kastner et al. 2003, references therein). The low counts observed in the X-ray observation (see Figure 2) prevents decisive spectral fitting of the central source, but the apparent lack of hard X-rays (> 2 keV) suggests no active accretion—contrary to R Aqr and CH Cyg. The fact that the X-ray jet emission is enclosed in the lobes of the ionized bipolar nebula might indicate that the shocked gas is cooling slowly; whereas the jets of R Aqr appear to cool quickly in the ambient medium, where they are free to expand. Hence it appears that the rate of cooling, as governed by the lobe or jet pressure balance with the surrounding ISM, determines the likelihood of X-ray detection of symbiotic star jets.

Hen 2-104: Hen 2-104 is a striking bipolar symbiotic Mira (Schwarz et al. 1989). The X-ray emission from Hen 2-104 was misidentified—due to astrometry problems—as a newly emerging X-ray jet in a poster contribution by R. Montez et al. to the 209th Meeting of the AAS. A new calibration and reprojection of the X-ray image improves the count distribution and indicates a simple, central point source. The emission is restricted to energies less than 2 keV and is perhaps best modeled as a hot, thermal plasma ($T_X \sim 15$ MK). The apparent absence of hard X-ray emission also suggests no active accretion, while the open bipolar lobes could

explain the lack of any X-ray jets, since the shocked gas could have expanded and quickly cooled.

M 2-9: M 2-9 has been classed as a symbiotic Mira system (Schmeja & Kimeswenger 2001). The Chandra observation shows no detectable X-ray emission along the bipolar axis or at the central source. Assuming a distance of 0.9 kpc, the upper limit on the X-ray luminosity (0.3 to 10.0 keV) is determined from the $3\text{-}\sigma$ background count rate to be 5×10^{29} (1×10^{32}) ergs/s for a 10^7 (10^6) K collisionally-heated plasma. The lack of X-ray emission within such an energetic system may again be due to its “open-lobed” structure.

References

1. Balick, B. & Frank, A., Proceedings of the 180th Symposium of the International Astronomical Union (IAU), 180, 190
2. Bode, M. F., 2004, APN III Conference Proceedings, 313, 504
3. Corradi, R. M. & Schwarz, H. E., 1995, A&A, 293, 871
4. Corradi, R. M., Brandi, E., Ferrer, O. E., & Schwarz, H. E., 1999, A&A, 343, 841
5. Galloway, D. K. & Sokoloski, J. L., 2004, ApJ, 613, L61
6. Karovska, M., Carilli, C. L., Raymond, J. C., Mattei, J. A., 2007, ApJ, 661, 1048
7. Kastner, J. H., Balick, B., Blackman, E. G., et al., 2003, ApJ, 591, L37
8. Kellogg, E., Pedelty, J. A., & Lyon, R. G., 2001, ApJ, 563, L151
9. Kellogg, E., Anderson, C., Korreck, K., et al., 2007, ApJ, 664, 1079
10. Kenyon, S. J., 1986, *The Symbiotic Stars*. Cambridge Univ. Press, Cambridge, p. 295
11. Li, J., Kastner, J.H., Prigozhin, G.Y., & Schulz, N. S. 2003, ApJ, 590, 586
12. Mukai, K., Ishida, M., Kilbourne, C., et al., 2007, PASJ, 59, 177
13. Nichols, J. S., DePasquale, J., Kellogg, E., et al., 2007, ApJ, 660, 651
14. Schmeja, S. & Kimeswenger, S., 2001, A&A, 377, L18
15. Schwarz, H. E., Aspin, C., Lutz, J. H., 1989, ApJ, 344, L29
16. Stute, M., Camenzind, M., Schmid, H. M., 2005, A&A, 429, 209
17. Stute, M., 2006, A&A, 450, 645
18. Stute, M. & Sahai, R., 2007, ApJ, 665, 698
19. Wheatley, P. J., Kallman, T. R., 2006, MNRAS, 372, 1602