A Decade in the Life of the Massive Black-Hole Binary IC10 X-1

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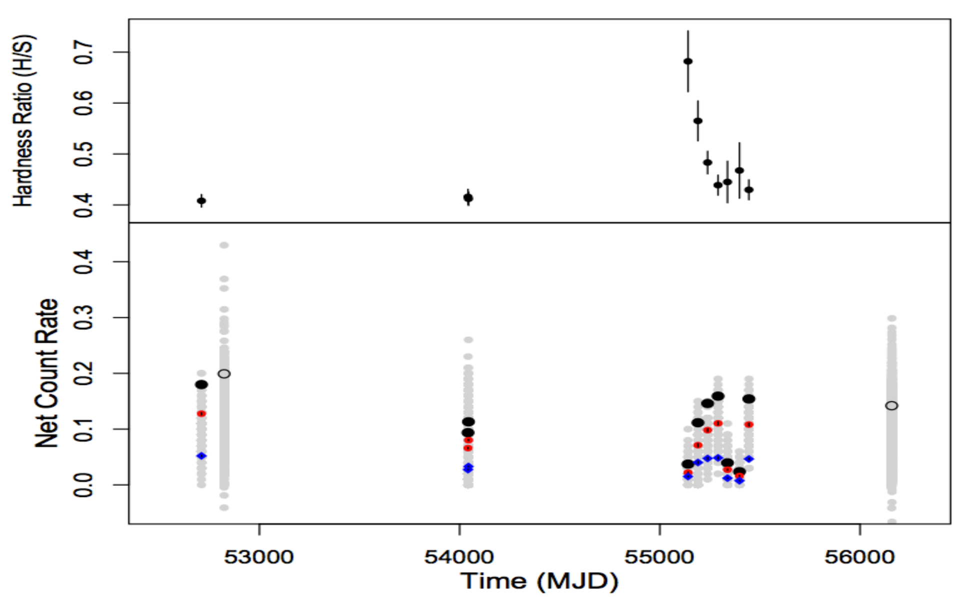
Abstract

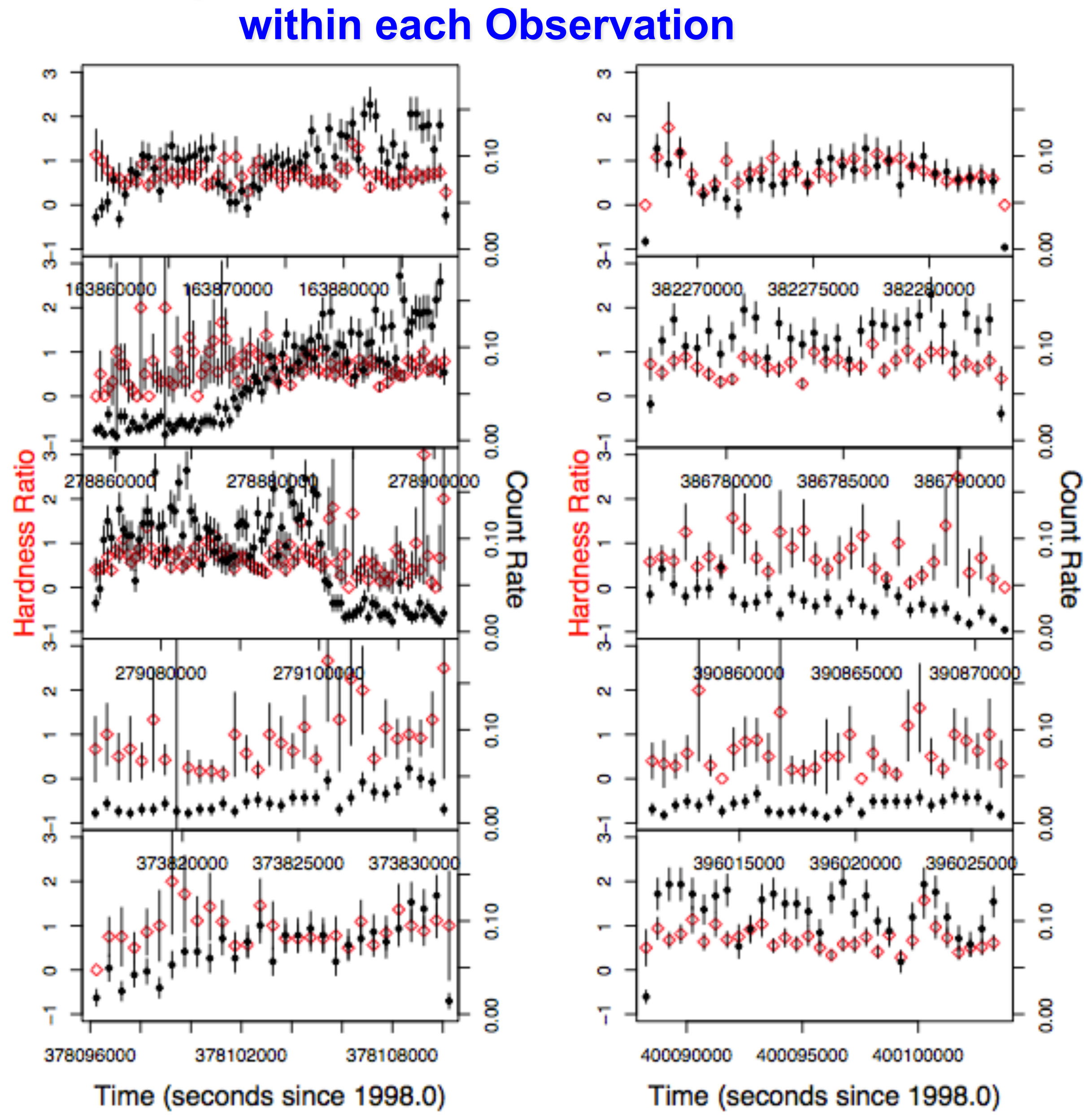
Chandra thanks to its angular resolution, sensitivity and endurance has been able to monitor individual X-ray binaries in the starburst galaxy IC 10. The Wolf Rayet + BH binary known as IC10 X-1 is regarded as one of the most massive stellar black holes; a class of objects representing the pinnacle of the stellar mass function. BH binaries occupy key roles in seeding SMBHs, producing long GRBs at birth, and gravitational waves at death. We report our use of Chandra to refine the orbital ephemeris of X1 and match-up the radial velocity curve of the optical spectral lines with the X-ray eclipse. The resulting phase offset has fascinating implications for our understanding of the interactions between the WR star, its wind, and the radiation field of the compact object. Among other things it appears that the need for a massive BH in the system is evaporating along with the dynamical evidence. The RV curve appears to instead trace a slim sector of stellar wind that escapes ionization in the X-ray shadow of the star.

Long-Term Lightcurve from Chandra and XMM-Newton

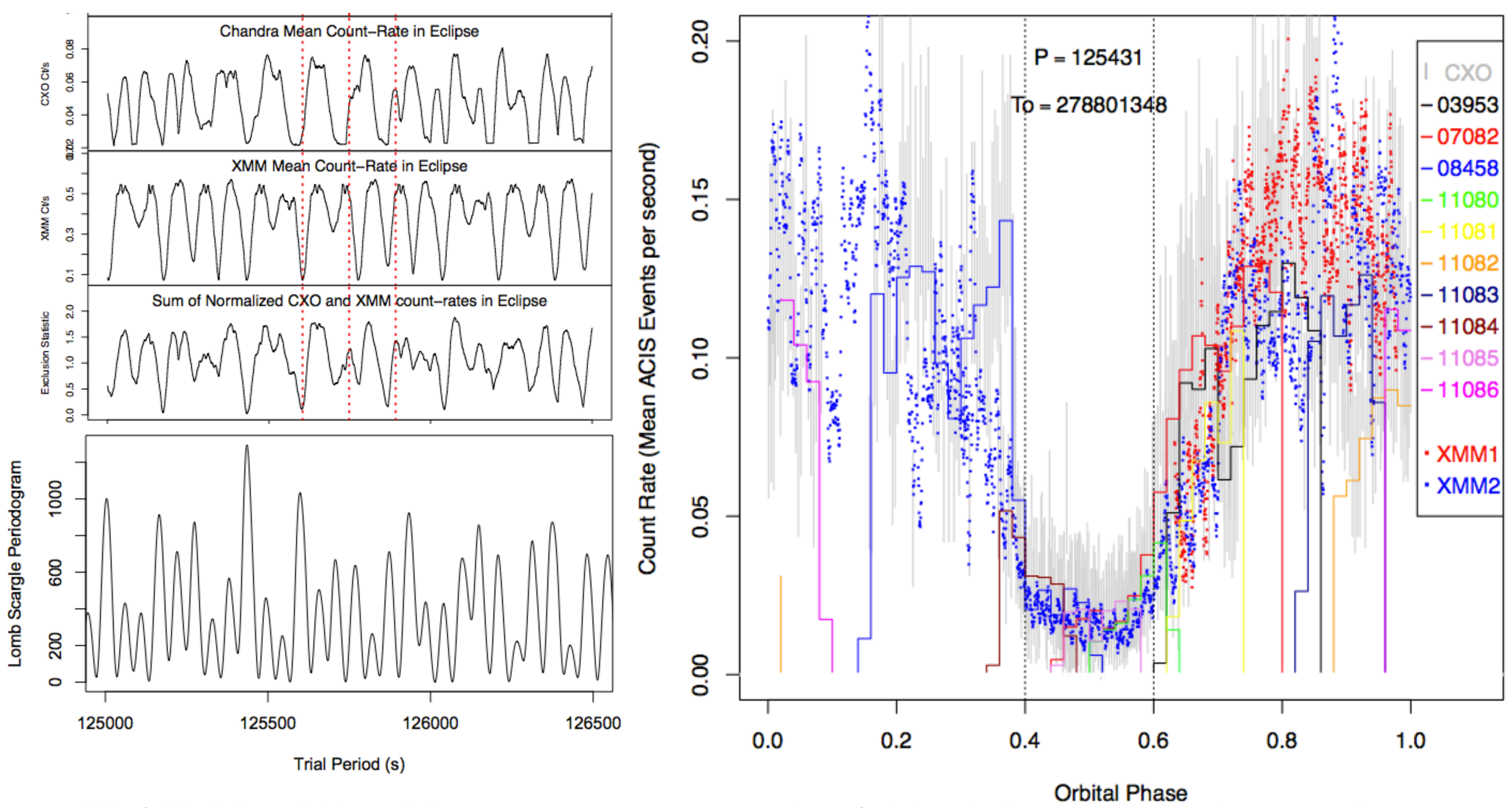


Chandra Broad-band (0.3-8 keV, black), Soft-band (0.3-1.5 keV) and Hard-band (2.5-8 keV). XMM points (open circles) have been scaled using PIMMS to match ACIS. The grey points are the count rates binned at 1000s within each observation. The hardness ratio (H/S) spiked during the 2009 monitoring series.

Lightcurves and Hardness Ratios within each Observation

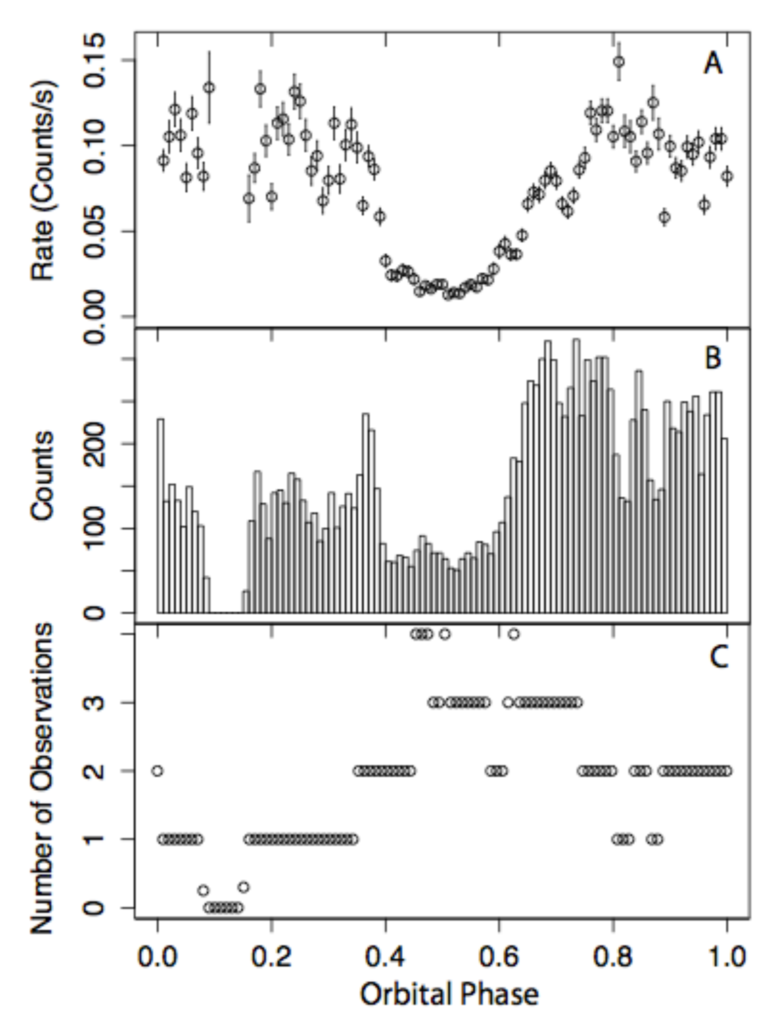


Phase-Connecting the X-ray Lightcurve

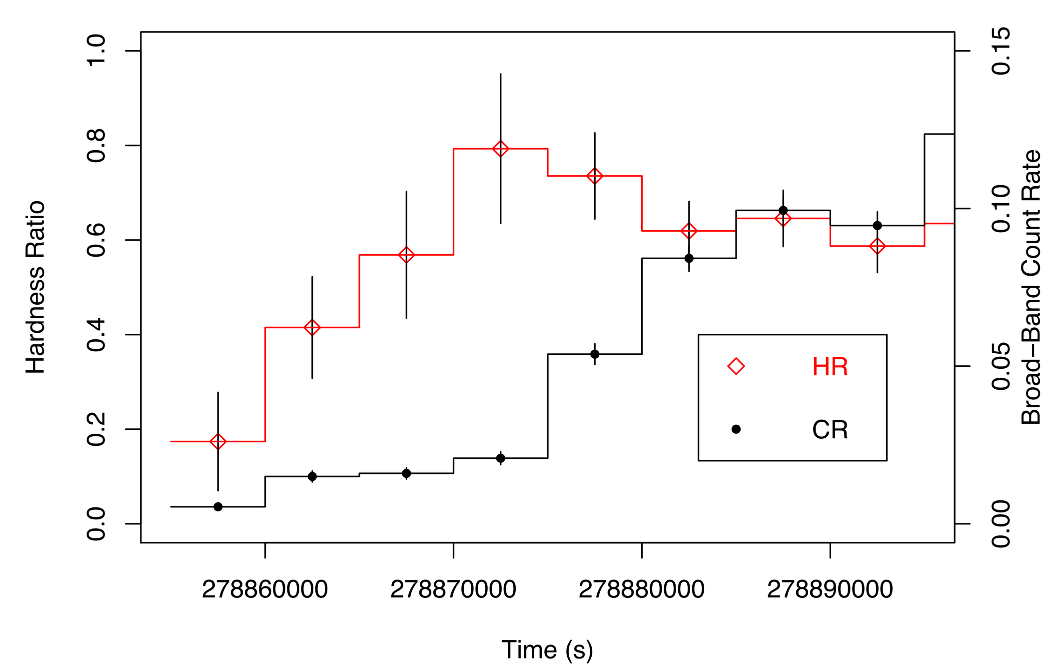


- We folded the 12 X-ray light-curve segments on a series of trial periods spanning the 3σ uncertainty region for the orbital period reported by Silverman & Fillipenko (2008).
- At each trial period we computed the mean count-rate in the phase range 0.4-0.6, which is mid-eclipse.
- Chandra and XMM-Newton data were analyzed separately, yielding two sets of flux-minima, most of which are mutually exclusive.
- The resulting best period, also found by the Lomb-Scargle periodogram, is 125431s (1.45175(1) d)
- Visual inspection confirms no other trial-period can simultaneously place all low-flux points inside eclipse and all high-flux points outside eclipse.

The Eclipse Profile



- Duration of eclipse-minimum is ~ 5 hours, with roughly 1 hr ingress/egress stages.
- The Eclipse feature is much (5x) wider than can be explained by a straightforward eclipse of the companion star.
- The dense core of the WR star's stellar wind appears to be the extended eclipsing body.
- The average profile shown at left seems to show asymmetry:
  - Egress is more gradual than ingress
  - More flaring is seen before eclipse

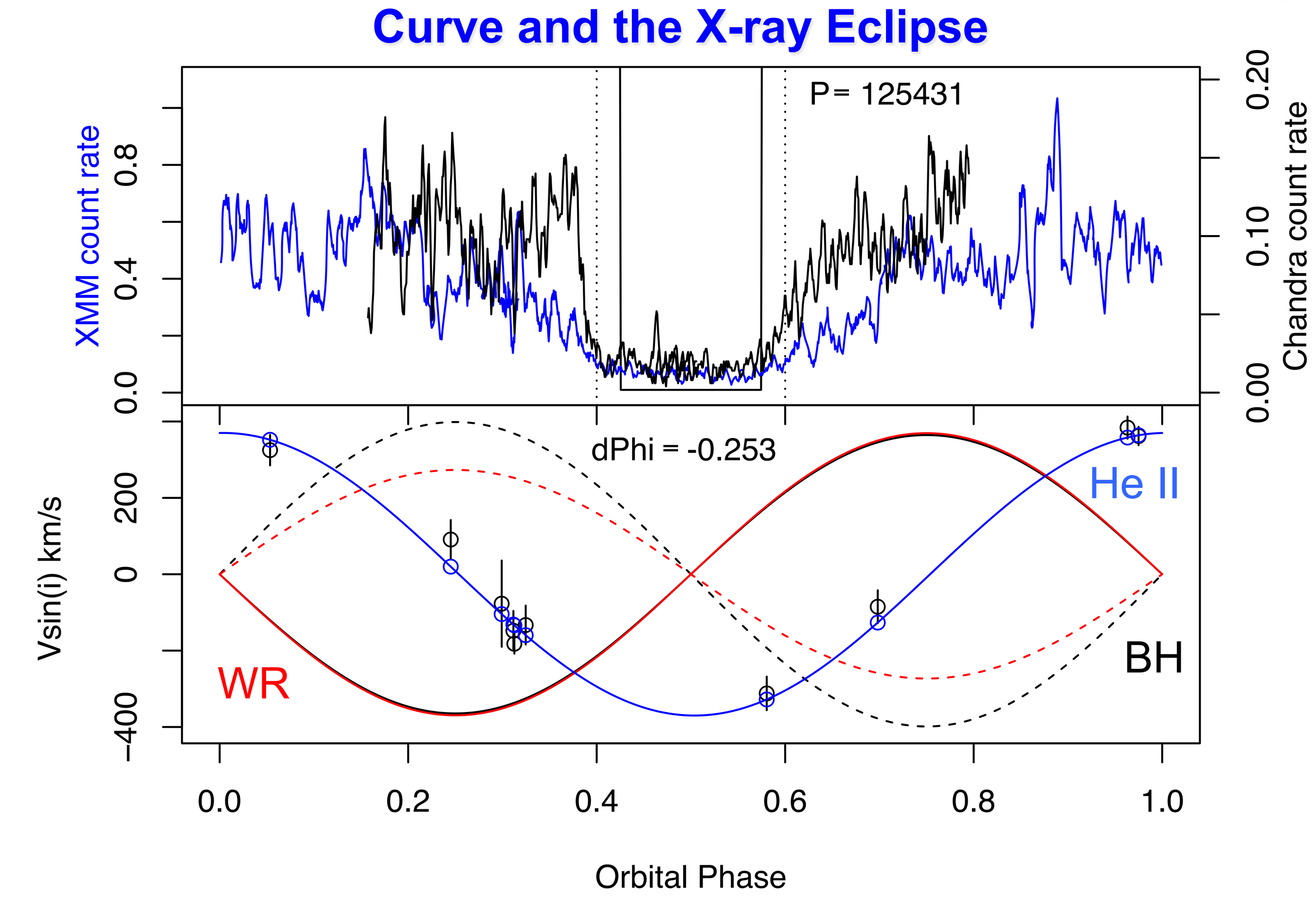


- During egress the hardness ratio climbs, indicating that a harder emitter is coming into view. This feature leads the rise in broad-band flux.
- If we were simply seeing a point source with wind-absorption, the HR would go the other way
- Suggests an extended hard corona.

References:

Laycock, S., Cappallo, R., Moro, M., 2014, *MNRAS*, arXiv: 1410, 3417
Silverman & Fillipenko, 2007, *ApJ*, 678, L17,
van Kerkwijk, M., H., 1993, *A&A*, 276, 9,
Prestwich et al., 2007, *ApJ*, 669 L21,
Barnard, R. et al., 2014, *ApJ*, 792, 131

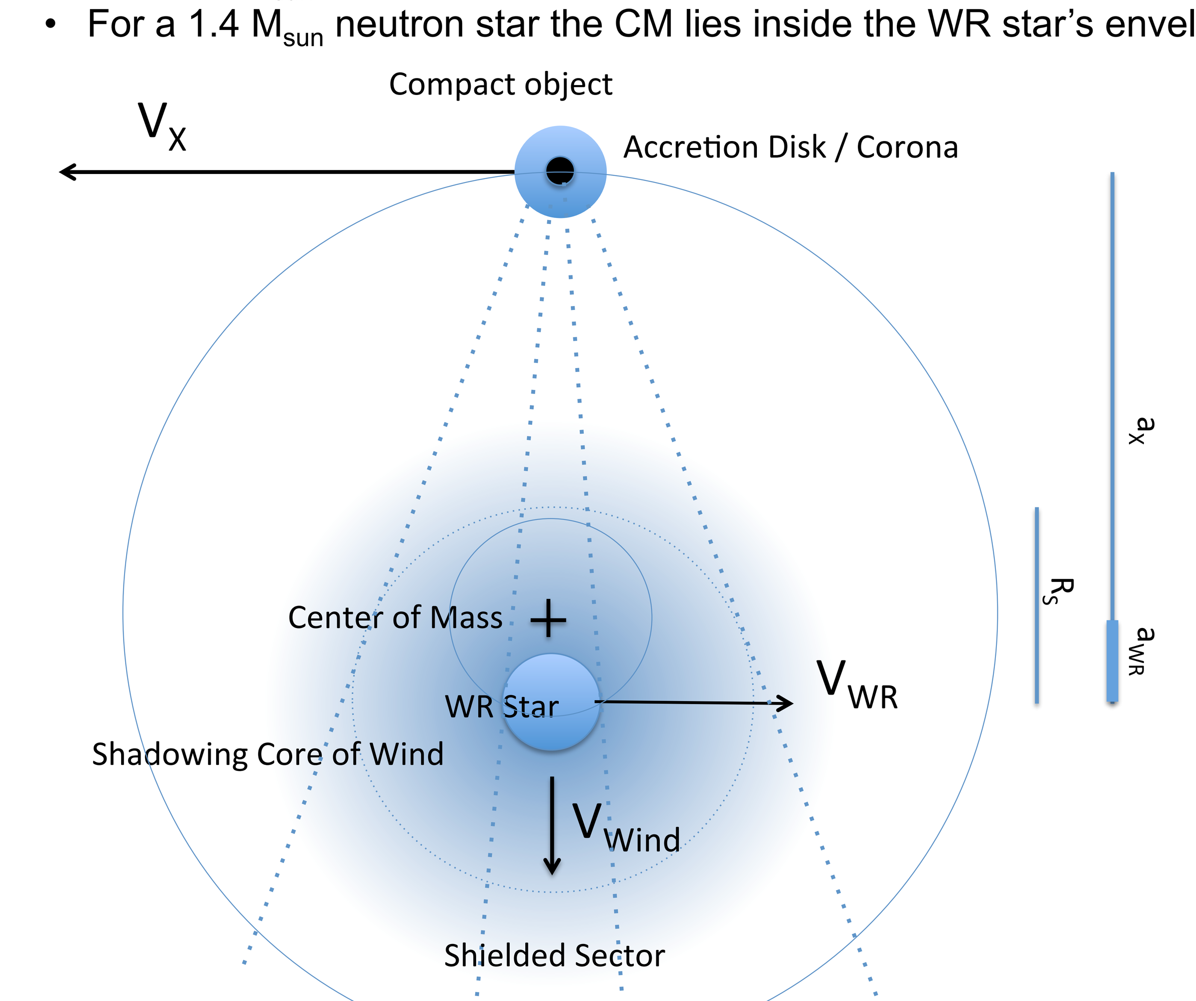
Discovery of a Phase Offset between the Radial Velocity Curve and the X-ray Eclipse



- The optical RV points folded modulo our X-ray ephemeris show an offset of ¼ orbital cycle (90°) relative to the eclipse.
- At mid-eclipse the He II line has its greatest doppler velocity shift towards us.
- The orbital motion of WR star should trace the red line
- RV is likely a projection of the stellar wind, not the orbital motion of the binary.

A New Model for the IC 10 X-1 Binary System

- The wind is fully photo-ionized by X-rays from the compact object
  - Optical spectral lines can only arise in the shielded sector of the wind
  - Free electron scattering will dominate the orbital profile.
- The wind core radius of 8 R_{sun} is inferred from the eclipse profile
- Companion star radius is 2R_{sun} as for a 35 M_{sun} Wolf-Rayet star
- Binary separation is 18 R_{sun} from the binary period and Kepler's law.
- Location of the Center of Mass depends upon the nature of the compact object, which is now unconstrained by any dynamical evidence.
  - For a 24 M_{sun} black hole, the CM lies midway
  - For a 1.4 M_{sun} neutron star the CM lies inside the WR star's envelope



- The table gives computed binary parameters for variants of the massive BH model and a lower mass BH or neutron star model.

M_{WR} $M_\odot$	M_X $M_\odot$	i deg	$a_1 + a_2$ $R_\odot$	v_{WR} km/s	v_X km/s	T_E hr	R(s) $R_\odot$	R_{WR} $R_\odot$	T_{WR} hr
35	32	90	23.27	364.7	398.9	5	9.88	2	1.01
17	23	90	19.59	369.7	273.3	5	8.32	1.5	0.90
35	1.4	90	18.99	23.96	599.10	5	8.06	2	1.24
35	2.5	90	19.18	41.95	587.32	5	8.14	2	1.23
17	1.4	90	15.13	37.76	458.57	5	6.42	1.5	1.17
17	2.5	90	15.42	64.88	441.15	5	6.55	1.5	1.15

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