How Massive can a Stellar Black Hole be?
Chandra's multi-observatory time domain study of the IC 10 X-1 binary system

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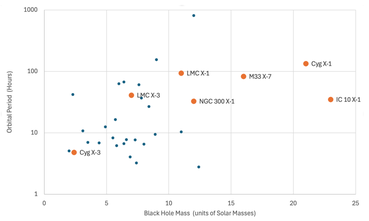
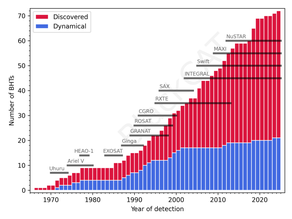
Abstract

Chandra has observed the massive Black Hole + Wolf-Rayet star X-ray binary IC 10 X-1 repeatedly across its 25 year mission. Synergy between Chandra's unparalleled high-resolution X-ray optics and the other great observatories all operating at the same time, has enabling a detailed time domain study of this fascinating system and its host galaxy's X-ray binary population. IC 10 X-1 exhibits an interaction between the radiation field of the black hole, the wind of the accretion disk, and the stellar wind of the WR star. This manifests as an apparently stable phase-offset between the X-ray eclipse and the radial velocity curves traced by different ion species, which can confound traditional BH mass determinations. Contemporaneous pan-wavelength monitoring data from Gemini, HST (UV), Swift, XMM-Newton will hopefully soon be extended to the infrared by JWST, highlighting Chandra's increased value in the JWST era. IC 10 X-1 serves as a laboratory for studying the progenitors of the most massive black holes.

Context: Mass Distributions for Dynamically Confirmed Black Holes



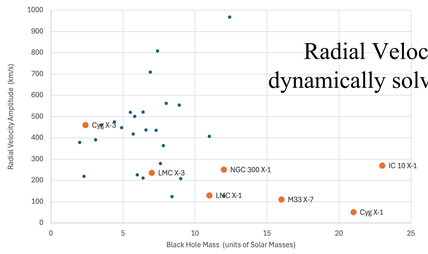
BH-XRB transients and HMXBs



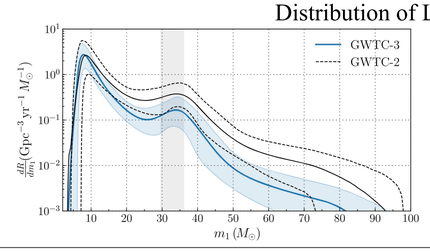
Cumulative histogram of **transient** BH candidates detected since the beginning of the X-ray astronomy era. The horizontal black bars show the X-ray missions that have discovered BH candidates in outburst. (BlackCat)

Analyzing the distances and spatial distribution of the observed systems, Corral-Santana + (2016) estimate a total population of ~1300 Galactic black hole transients. Hence we have discovered < 5% of the total Galactic distribution.

Radial Velocity Amplitudes for dynamically solved BH X-ray Binaries

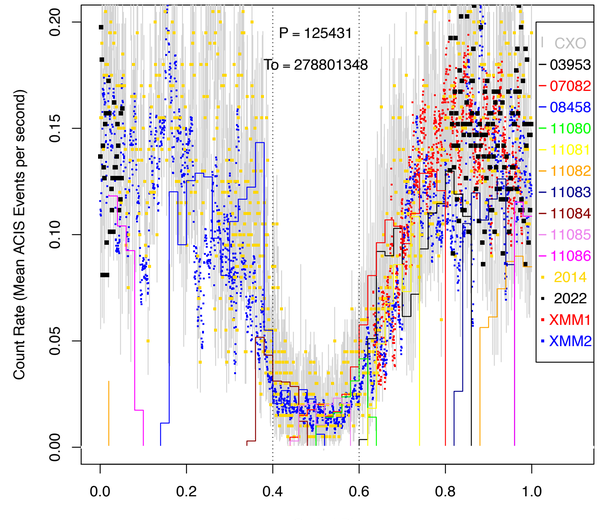


Distribution of LIGO black hole masses

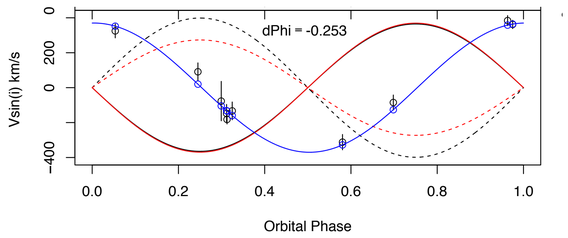


All Chandra Observations Phase-Connected (~20 years)

Shows a stable broad eclipse

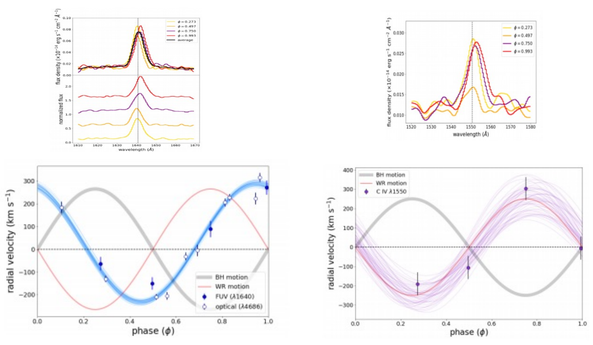


X-ray Eclipse Offset from the He II Radial Velocity curve by ¼ Phase

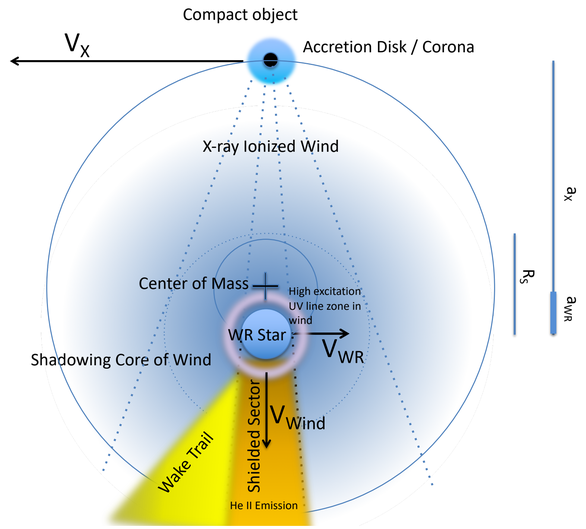


- **Problematic for RV based Mass-Determination**
- Also, Eclipses are too broad to be consistent with the Star alone, but could be due to scattering in the dense core of the WR wind

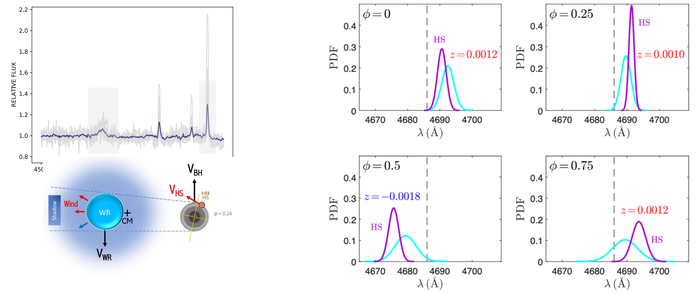
Phase resolved UV spectral lines with HST, show that higher excitation lines appear to track the WR star, in the near-twin NGC 300 X-1



General Picture from X-ray, Optical and UV Observations



Decomposition of a large collection of Gemini Spectra, model a systematic variation in He II line-profile with viewing angle, as a circulating hot-spot.



Conclusions

- The number of LIGO BHs now rivals the number of BHs discovered in X-ray binaries
- High Mass XRBs represent just one of the progenitor channels for BH+BH binaries
- No XRB has a dynamically confirmed BH above 30 Solar Masses, yet LIGO show the distribution extends past 60.
- WR + BH Binaries such as IC 10 X-1 show how **mass signatures** can be affected by the interaction between the two stars
- Lack of any significant lag vs time puts a constraint in Pdot/P $< 5 \times 10^{-7}$ yr $^{-1}$
- New observations and new missions can test improved BH mass diagnostics.

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