Blue Supergiant X-ray Binaries in The Starburst Galaxy IC 10

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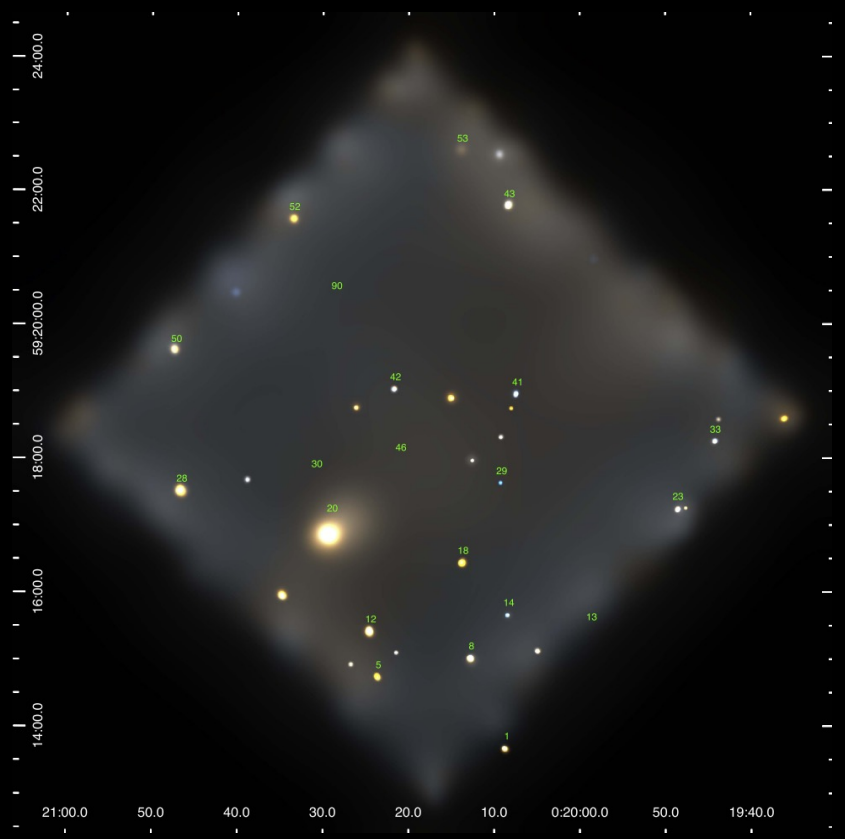
Contents

- Prologue & Characteristics of IC 10
- X-ray Binary Zoo
- Blue Supergiant & Luminous Blue variables
- Special Mentions IC 10 X-1 & IC 10 X-2
- Summary & Future Plans
- Acknowledgements

Characteristics Of IC 10

- Dwarf-irregular galaxy in Cassiopeia.
- IC 10 presents one of the most recent active starburst.
- Located at a distance of 660 Kpc. (~ 2.2 million lightyears)
- IC 10 hosts a young stellar population and highest known density of wolf-rayet (WR) stars. (Massey+ 2007, Crowther+2003)



Laycock+2017, Bhattacharya+2022, ApJ

- IC 10 has a star formation rate (SFR) of 0.5 $M_{\odot}$
- IC 10's SFR is one of the highest in the local group
- Striking similarity between SMC and IC 10 exists (both gas rich dwarf irregulars)
- Differences : Timescale of star formation and metallicity. This makes IC 10 an interesting laboratory to study the physics of stellar evolution, effect of metallicity, X-ray binary population etc.

Image: Sky & Telescope
September 2020

Black Hole Binaries

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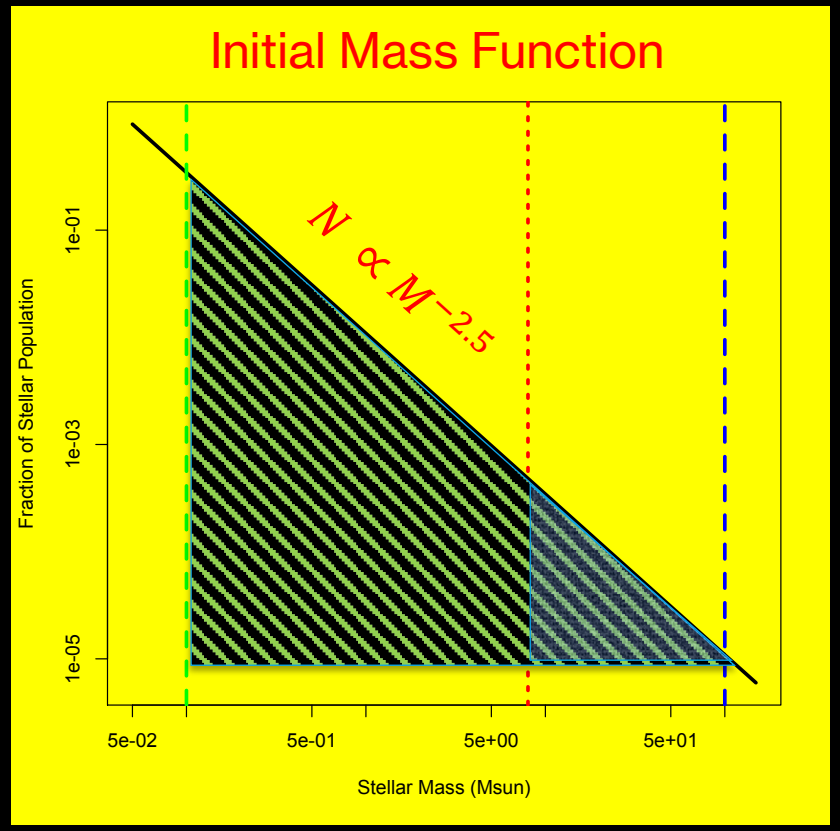
How rare are black holes and neutron stars?



$$f(compact) = \frac{\int_8^{100} M^{-2.5}\, dM}{\int_{0.1}^{100} M^{-2.5}\, dM}$$

$$= \frac{[M^{-1.5}]_8^{100}}{[M^{-1.5}]_{0.1}^{100}}$$

$$= \frac{100^{-1.5} - 8^{-1.5}}{100^{-1.5} - 0.1^{-1.5}}$$

$$= \frac{0.001 - 0.044}{0.001 - 31.62}$$

$$= 0.014$$

Then given 10^{11} stars in the galaxy:

$$N(compact) = 0.014 \times 10^{11}$$

$$= 1.4 \times 10^{8}$$

- Adjusting the limits over the allowed range provides perhaps an order of magnitude variation.
- **Inescapable conclusion is that BHs are "everywhere"**
- **Then why don't we see them?**

The X-ray Binary Zoo

Two stars – but many choices!

Black Hole

Neutron Star

White Dwarf

Compact object

+

Companion

Supergiant

Red giant

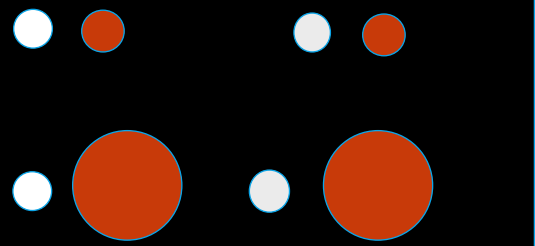
Main Sequence

Red Dwarf

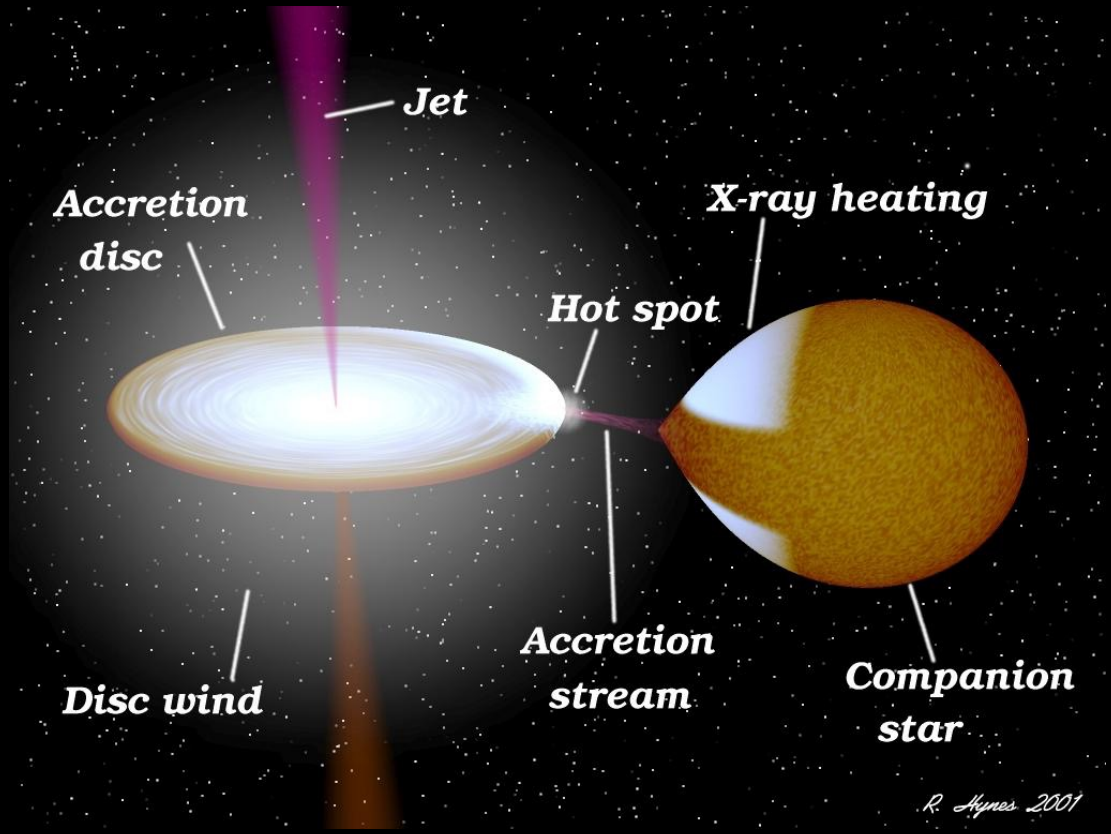
Be star

WR, LBV

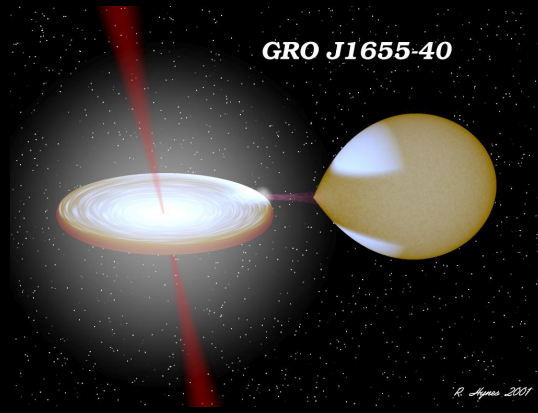
Low Mass X-ray Binary

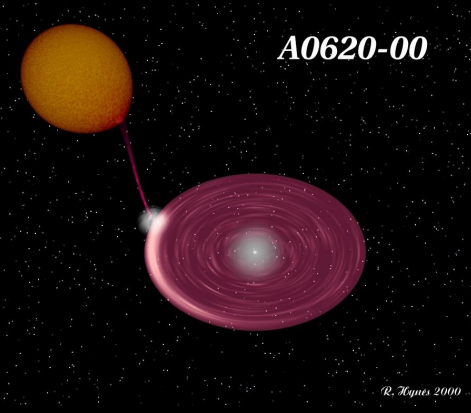


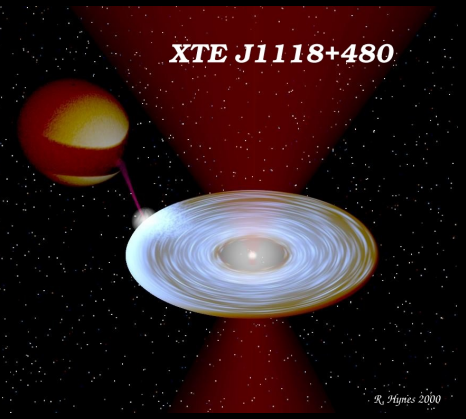
Low Mass X-ray Binaries (LMXB)



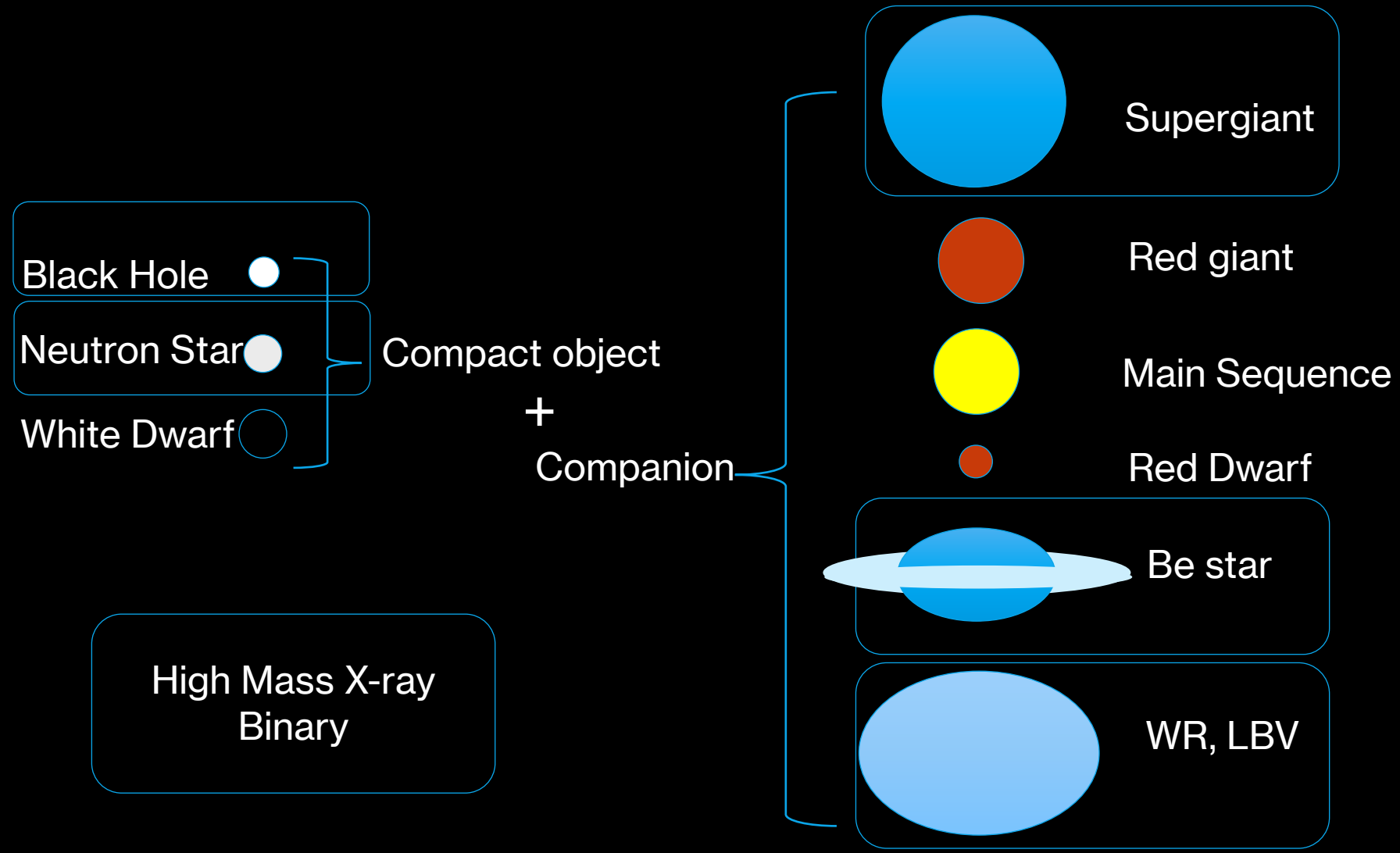
- Most of the light comes from the Accretion Disk
- BH-LMXBs and NS-LMXBs can be quite similar
- Short orbital periods (hours)
- Bewildering array of behaviors!



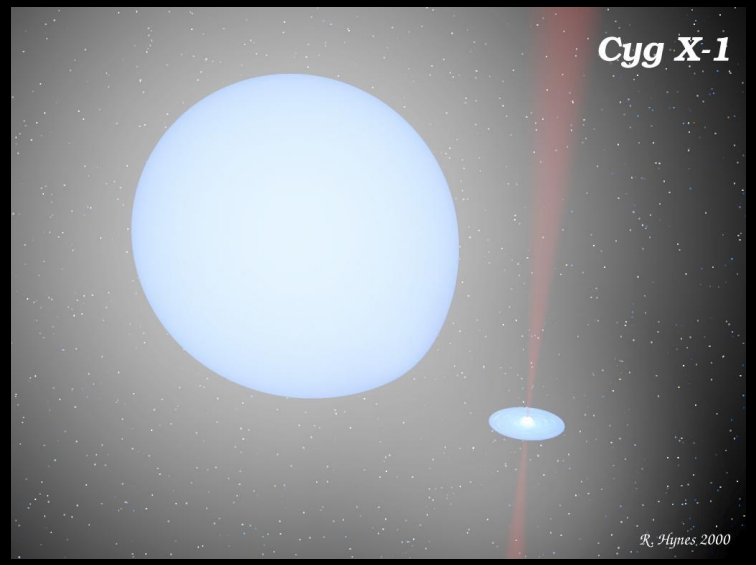




The X-ray Binary Zoo

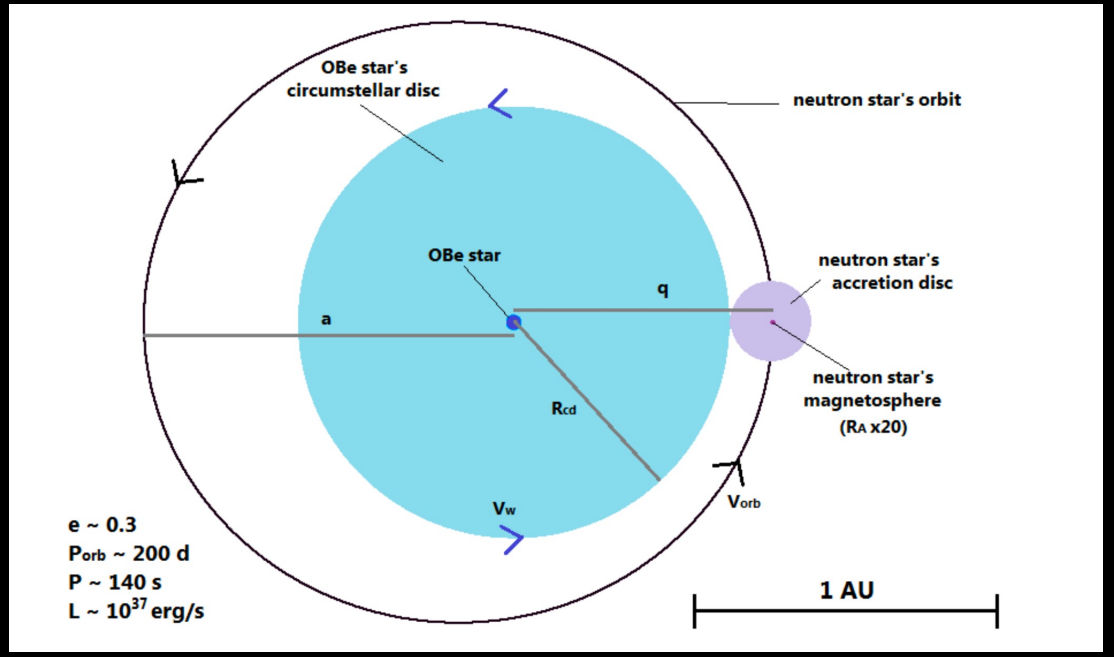


High Mass X-ray Binaries (HMXB)



Supergiant

Be star



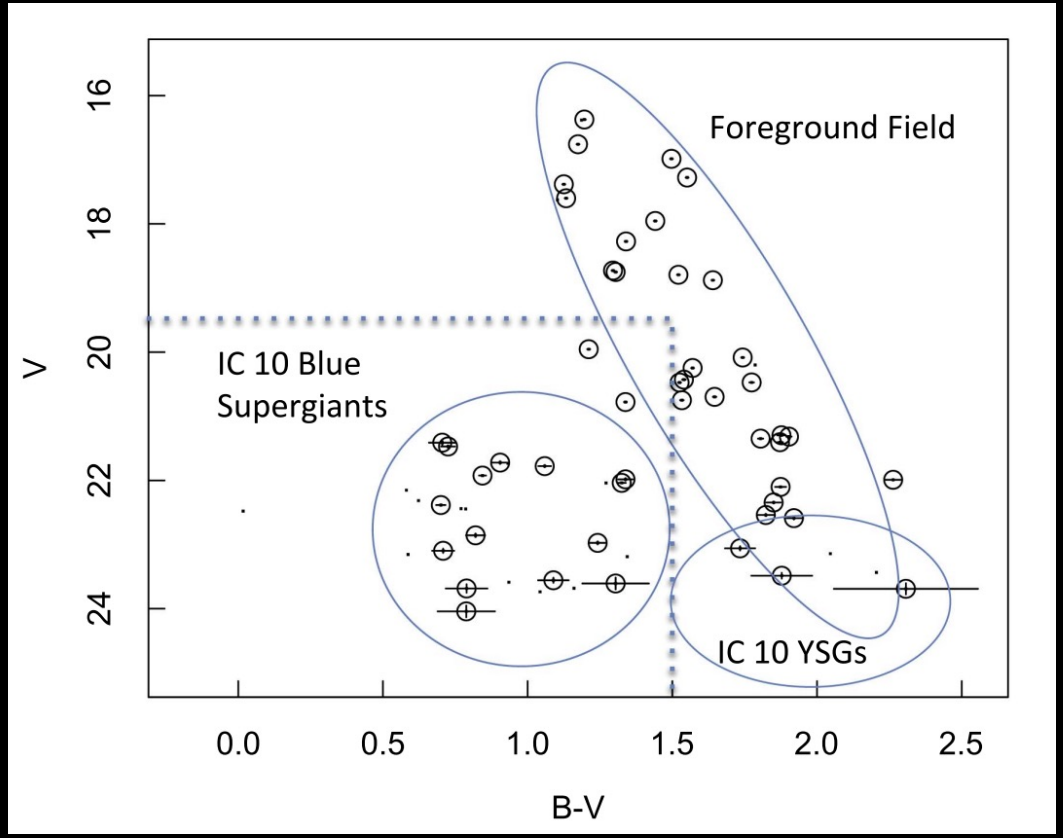
IC 10 X-ray Population survey:

- 10 *Chandra* observations -> 7 snapshot monitoring (15 ks each)

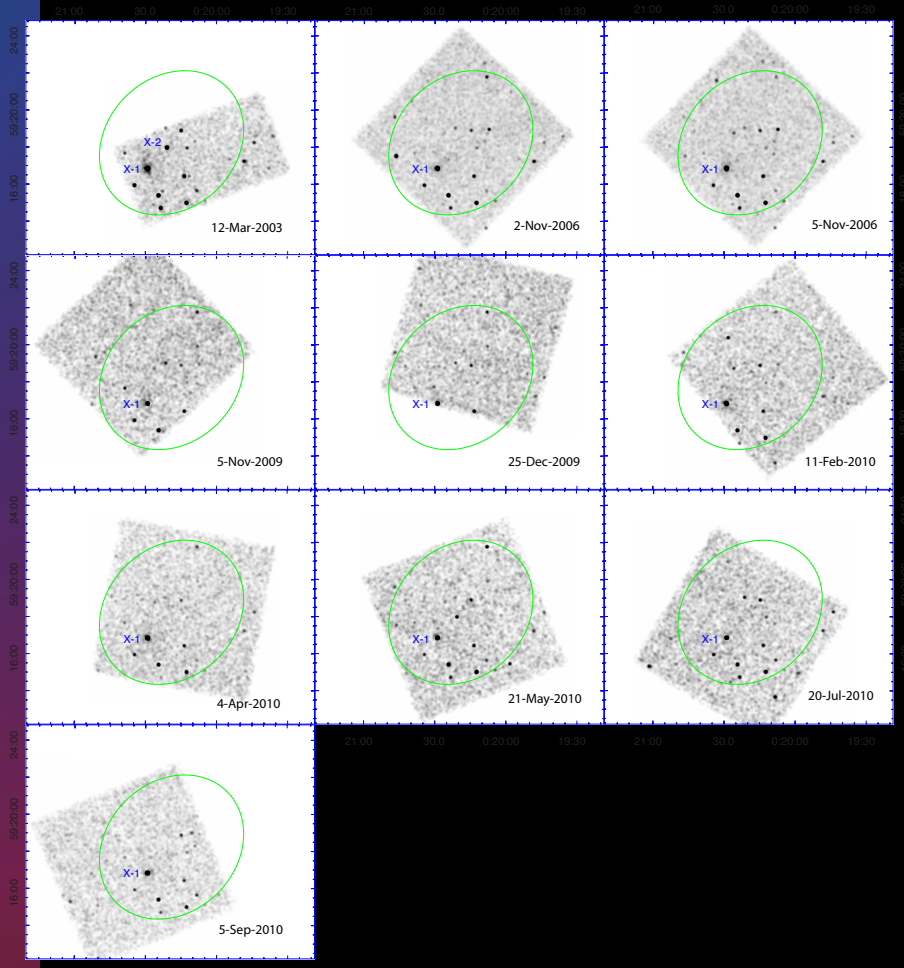
  + 2 deep archival observation (45 ks)
- *Ciao wavedetect* on three energy bands (soft, broad, hard)
- Created an X-ray source catalog with 110 point sources.
- This x-ray catalog was matched with the Massey+(2007a) optical catalog. (limiting Magnitude V ~ 24)
- A total of 42 X-ray sources have optical counterparts. (95% confidence)

Blue Supergiants

- Color – magnitude diagram for a subset of Massey 2007 catalog. (The ones having an x-ray counterpart)
- This helped in isolating the blue supergiant population.
- 16 BSG-XRBs are spotted.
- The optical catalog only serves to identify 50% of the population, V ~ 26 limiting magnitude is needed to probe the entirety.



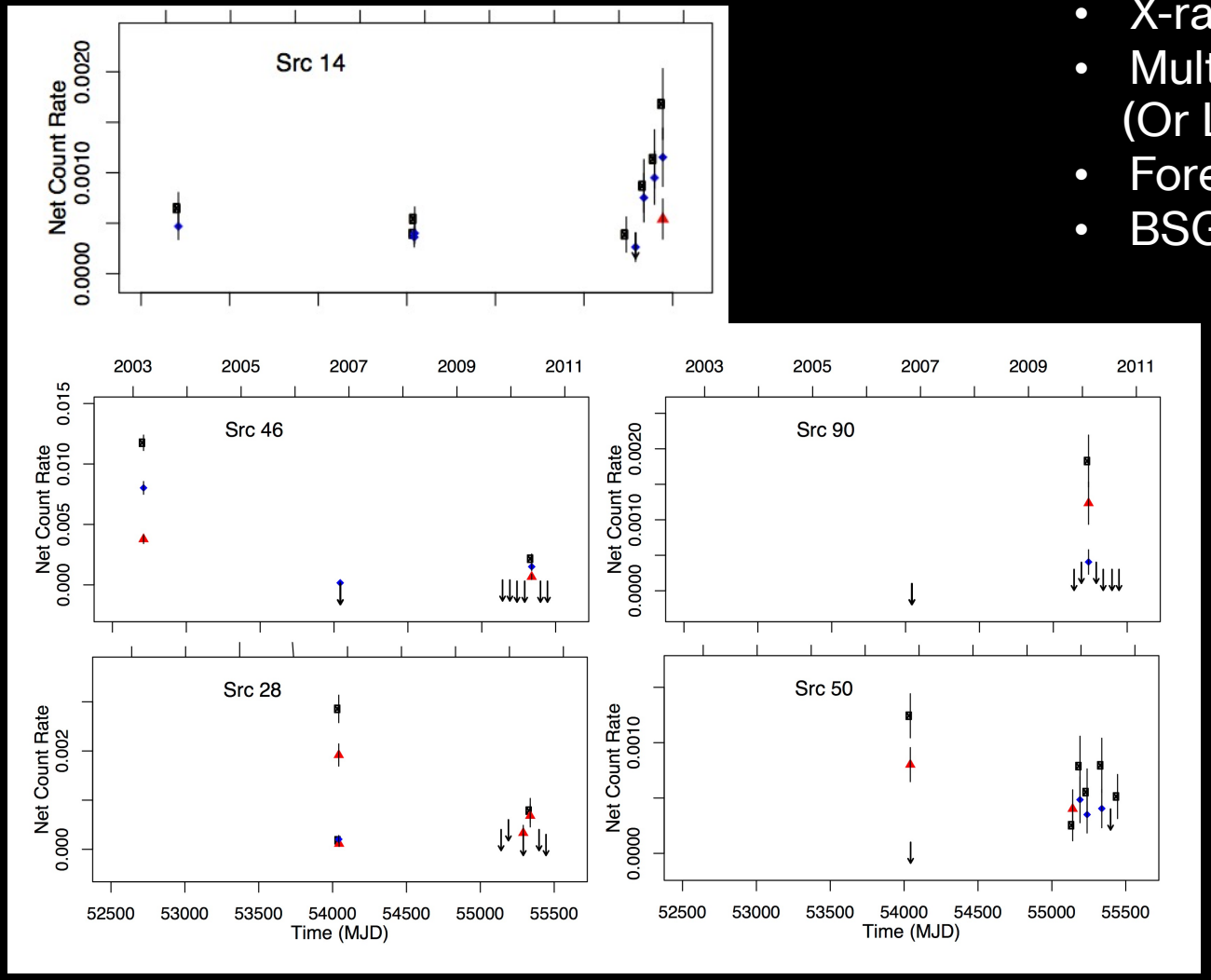
Variability Survey



MJD	Date	ObsID	Exposure ksec	R.A. hh:mm:ss	Dec. dd:mm:ss	Roll Angle degrees	N_{Src}
52710.7	12 Mar 2003	03953(a)	28.9	00:20:25	59:16:55	339.27	31
54041.8	2 Nov 2006	07082	40.1	00:20:04	59:16:45	223.70	48
54044.2	5 Nov 2006	08458	40.5	00:20:04	59:16:45	223.70	41
55140.7	5 Nov 2009	11080	14.6	00:20:17	59:17:56	226.53	19
55190.2	25 Dec 2009	11081	8.1	00:20:19	59:18:02	286.15	24
55238.5	11 Feb 2010	11082	14.7	00:20:23	59:17:10	320.56	24
55290.6	4 Apr 2010	11083	14.7	00:20:34	59:19:01	10.32	25
55337.8	21 May 2010	11084	14.2	00:20:25	59:20:16	67.89	27
55397.5	20 Jul 2010	11085	14.5	00:20:11	59:19:13	121.25	22
55444.6	5 Sep 2010	11086	14.7	00:20:15	59:18:11	157.71	27
(b)	2-5 Nov 2009	57082	80.6	-	-	-	63

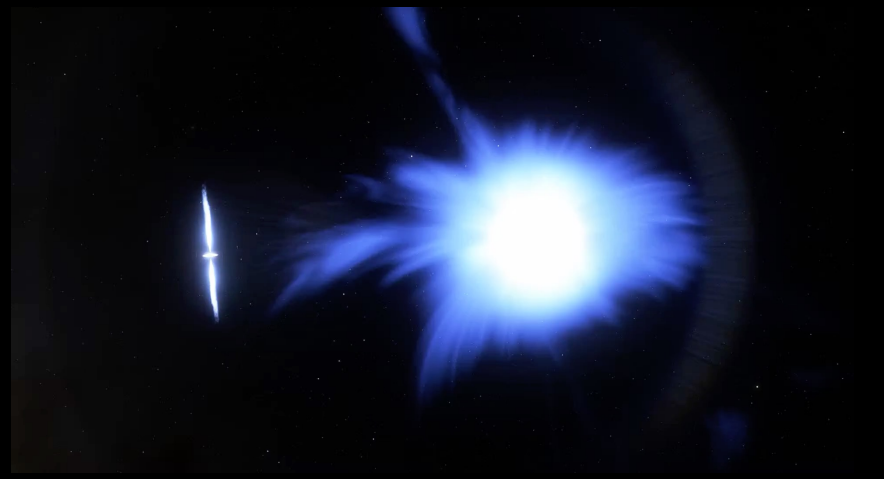
Laycock+2017

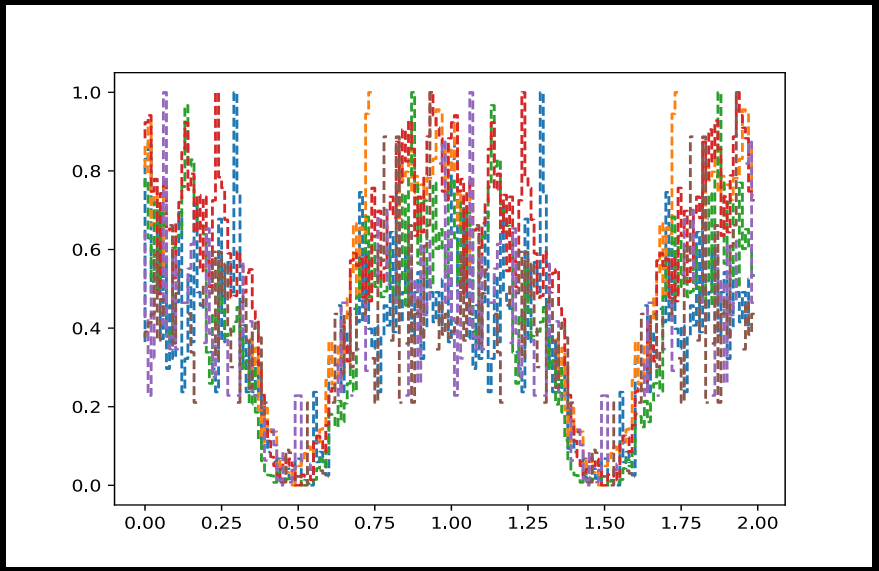
Sample of variable X-ray lightcurves



- X-ray Hardness
- Multi-wavelength counterparts (Or Lack of counterparts to V~24)
- Foreground stars
- BSG-HMXB

Special Mention I : IC 10 X-1

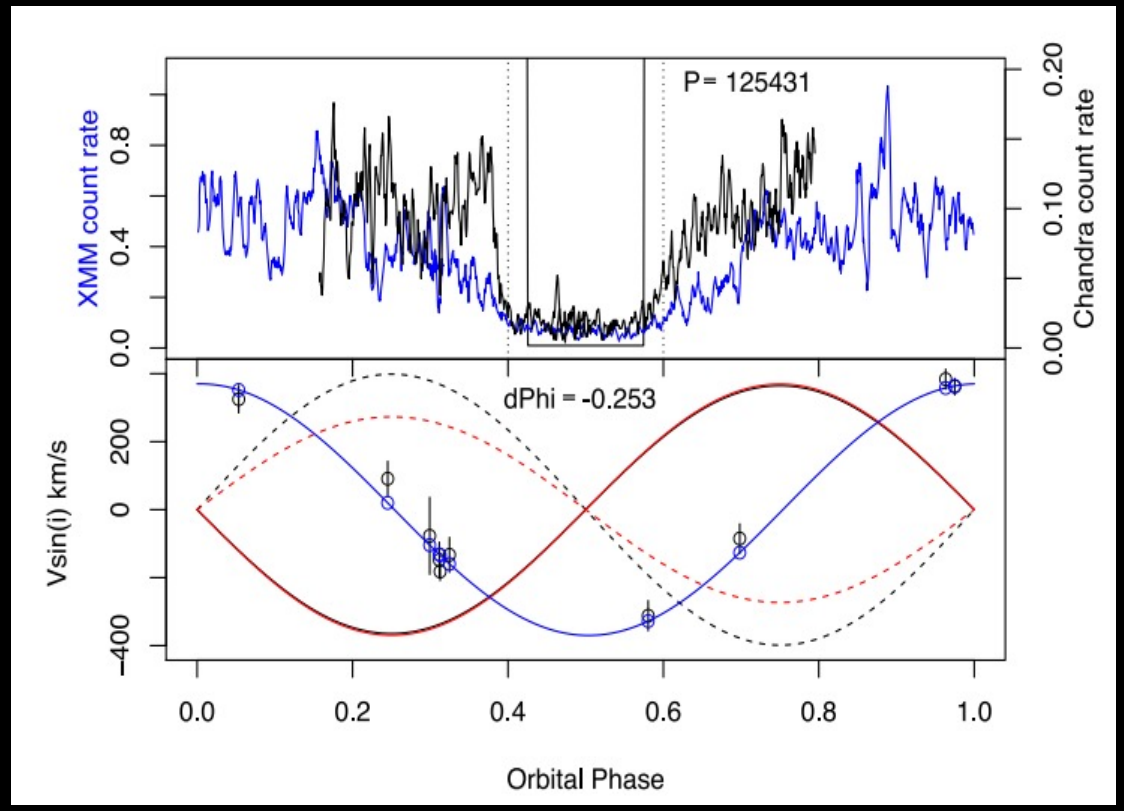




- IC 10 X-1: Eclipsing High Mass X-ray Binary consisting a Wolf-Rayet star and a compact object (Black hole ?). P_{orb} = 34.9 hrs.
- Mass of the compact object has been determined (Silverman et al 2008) using radial velocity(RV) curve created from He II λ4686 emission line. Mass = 23.1 ± 2.1 $M_{\odot}$ ---- suggests one of the most massive stellar mass black hole.
- Later studies (Laycock et. al. 2015) found a quarter phase offset between x-ray eclipse light curve and the RV curve. This puts the previous mass determination in question.

Surprisingly: The X-ray Eclipse and Optical RV doesn't line up !!

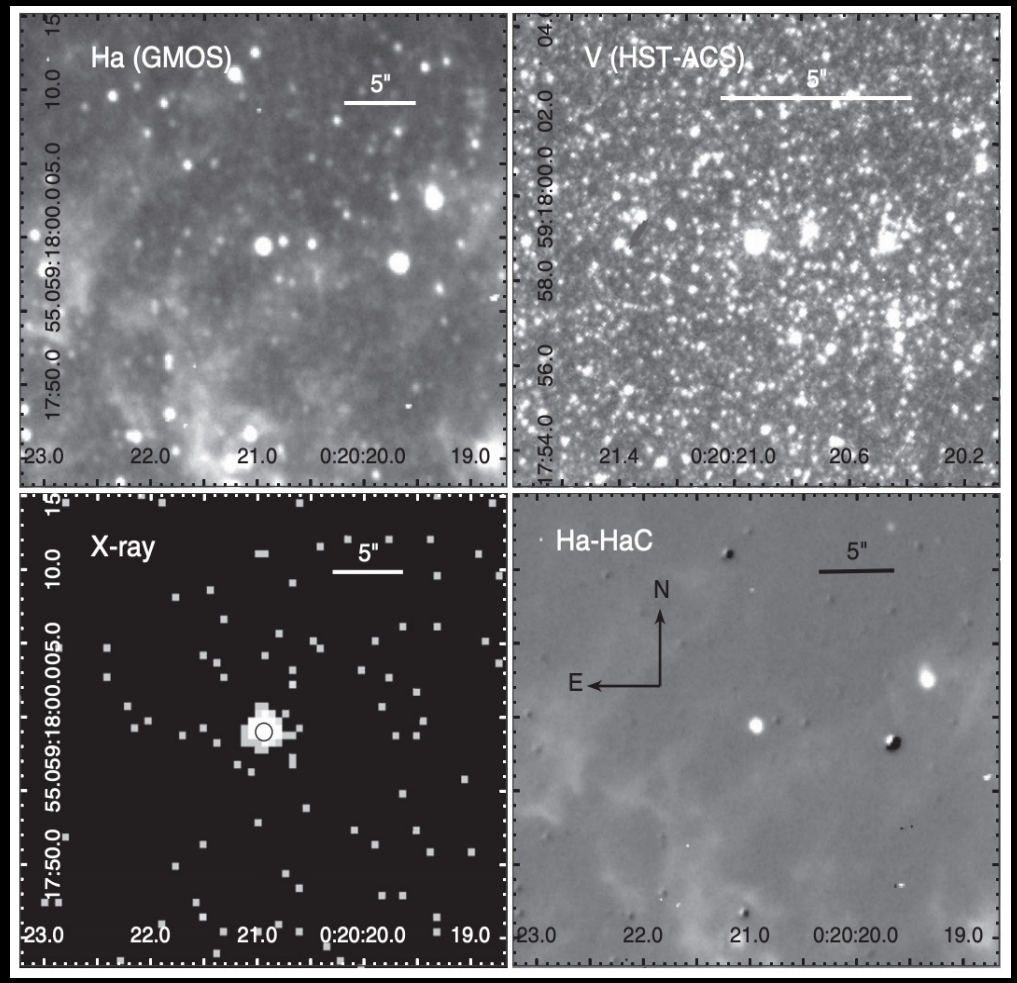
Similar behavior noticed in Cyg X-3 and NGC 300 X-1 ….

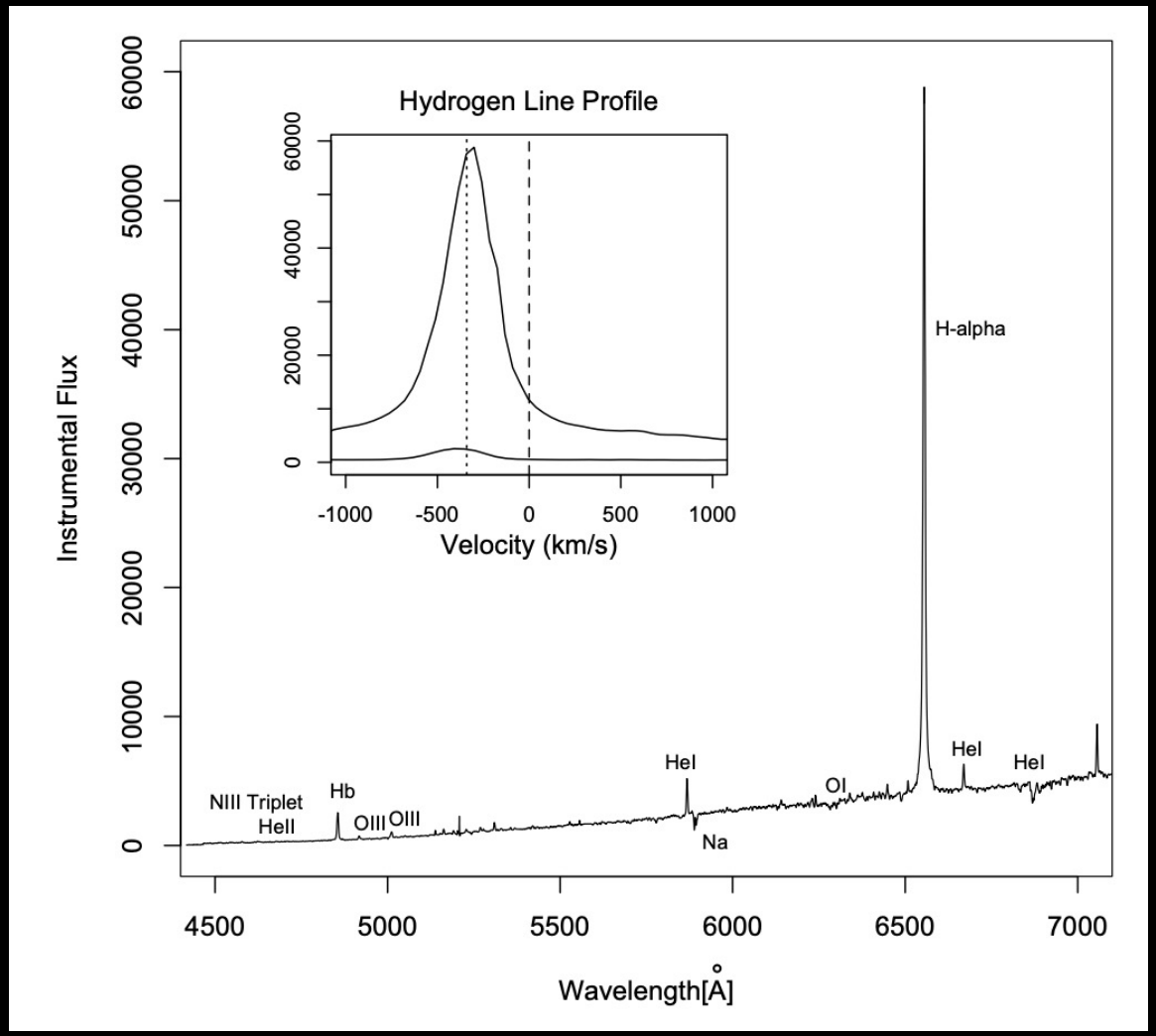


- The premise of using He II line for constructing RV curve can be false with major consequences on the BH mass.
- Possibly the wind is eclipsing the compact object rather than the star.
- The lines originating from the WR stars wind might fail to reveal its true radial velocity.
- Radial velocities from more and more emission lines need to be constructed originating deeper in the wind (e.g., CIV, NIV/V line)

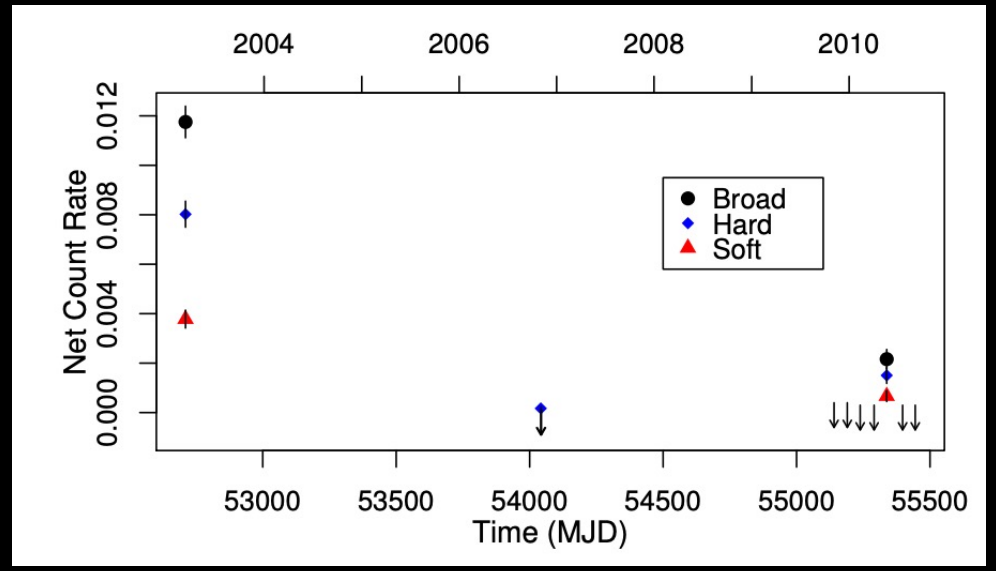
Special Mention II : IC 10 X-2

- X – ray transient with large amplitude of variability (factor of ~ 100).
- Only detected twice in these monitoring campaign.
- Highest observed luminosity 1.8 x 10^{37} erg/s
- Positional optical counterpart found. Shows prominent Hydrogen – balmer emission lines
- Belongs to a rare class (12 confirmed – Romano+2014) of Super fast x-ray transients (SFXTs).





GEMINI/GMOS Spectrum



Lightcurve

Laycock+2014, Romano+2014, Kwan+2018, Urpin 1998

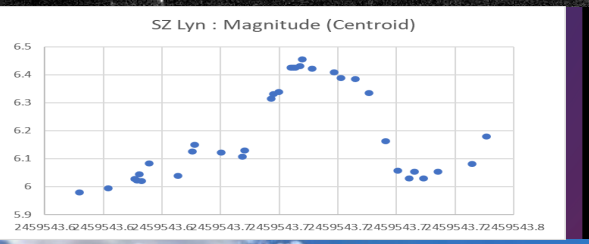
Summary

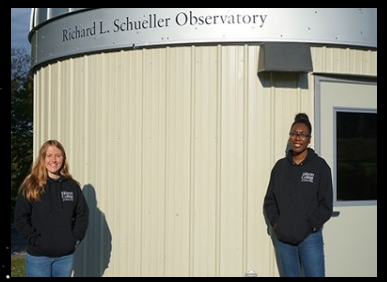
- The *Chandra* monitoring study has found a heterogenous population of HMXBs in IC 10.
- We are witnessing a starburst at an early stage – these systems will play important role in understanding age/metallicity dependence of massive binaries.
- Blue supergiant XRBs are a major class of progenitors of double degenerate sources. Their population is an important factor in modelling the rate of gravitational wave sources.

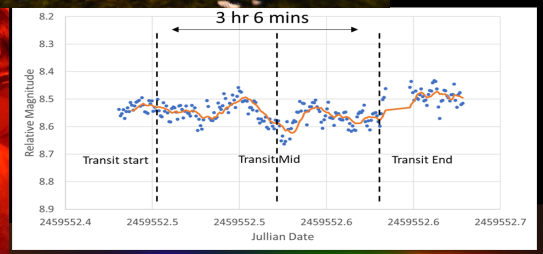
Future Plan

- Detailed/precise spectroscopic classification of each source is necessary (although a time consuming and painful task)
- Use deeper optical observations to find more optical counterparts.
- Continuous monitoring of the IC 10 galaxy in order to get more detections of transient sources like IC 10 X-2.
- IC 10 X-1: Radiative transfer + MHD modelling of such systems in order to decipher the underlying physics.

Astronomy at Schueller Observatory







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