Low Mass X-ray Binaries: Population at Roche Lobe Overflow

K. X. Van[1], N. Ivanova[1], C. O. Heinke[1]

[1] University of Alberta, Edmonton, AB, T6G 2R3, Canada

Abstract: We present a new method for constraining the mass transfer evolution of low and intermediate-mass X-ray binaries -- a reverse population synthesis technique. This is done using the detailed 1D stellar evolution code MESA (Modules for Experiments in Stellar Astrophysics) and evolving a range of binary systems with different magnetic braking prescriptions. These simulated systems are then compared to the observed properties seen in persistent low mass X-ray binaries allowing us to determine possible progenitors to these binaries. In addition to constraining progenitor of observed systems, this study also allows us to constrain magnetic braking recipes further. For this, we compare the populations formed with different magnetic braking laws and the observed populations, using Bayesian statistics. While an absolute probability of producing an observed system cannot be found, comparisons between prescriptions are possible giving an indication where different magnetic braking schemes encounter problems.

Method

Mass transfer is one of the main ways we can probe binary systems, however the number of persistent, well observed binaries is limited[3,7,13].

Using MESA[9,10,11,12], we run binary simulation models using a variety of initial conditions to test possible donor masses and initial periods that may reproduce observations. The models were done using the default prescription for magnetic braking[14] and for two other modified prescriptions.

The simulated models are combined together to produce a density plot allowing for comparisons between simulations and observed models.

Magnetic Braking Prescriptions

The most commonly used magnetic braking scheme is the "Skumanich" prescription,

$$\dot{J}_{\mathrm{MB,Sk}} = -3.8\times10^{-30} M_{\mathrm{d}} R_{\odot}^{4}\left(\frac{R_{\mathrm{d}}}{R_{\odot}}\right)^{\gamma_{\mathrm{mb}}}\Omega^{3}\mathrm{dyne\ cm}$$

however this default scheme cannot reproduce all observed systems [3,5,8]. We derive additional magnetic braking schemes in addition to this default prescription. A general magnetic braking equation is thus:

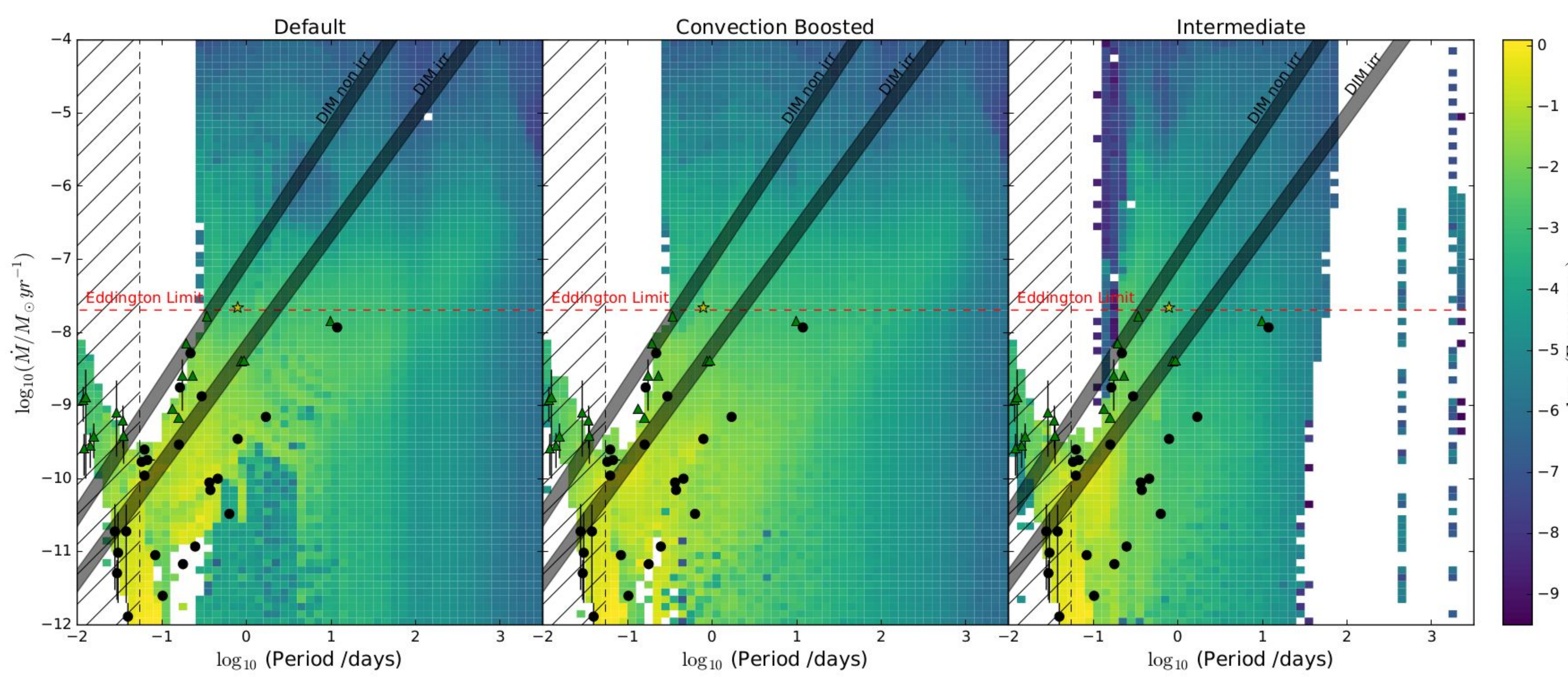
$$\dot{J}_{\mathrm{MB,boost}} = \dot{J}_{\mathrm{MB,Sk}}\left(\frac{\Omega}{\Omega_{\odot}}\right)^{\beta}\left(\frac{\tau_{\mathrm{conv}}}{\tau_{\odot,\mathrm{conv}}}\right)^{\xi}\left(\frac{\dot{M}_{\mathrm{W}}}{\dot{M}_{\odot,W}}\right)^{\alpha}$$

Case	β	ξ	α
1 - Default Skumanich	0	0	0
2 - Convection Boosted	0	2	0
3 - Intermediate	0	2	1
4 - Wind Boosted	2	4	1

The results presented in this work will be on the first three cases shown in the table. Case 3 represents an intermediate case between convection boosted and wind boosted and is for comparison purposes.

Normalized Frequency Plots

Binning the total amount of time spent in each grid square, and normalizing this value to the total evolutionary time of a given model, we can produce a normalized frequency plot.



The hashed area shows the systems considered "ultra compact" with periods shorter than 80 minutes[2].

The two grey lines show two disc instability models that theoretically split persistent systems and transient systems[2,6] which are denoted by green triangles and black circles respectively.

References

[1] Andrews, J.J., Farr, W. M., Kalogera, V. & Willems, B. 2015, ApJ, 801, 32
[2] Coriat M., Fender R. P., Dubus G., 2012, MNRAS, 424, 1991
[3] Heinke C. O., Ivanova N., Engel M. C., Pavlovskii K., Sivakoff G. R., Cartwright T. F., Gladstone J. C., 2013, ApJ, 768, 184
[4] Ivanova N., Taam R. E., 2003, ApJ, 599, 516
[5] Justham, S., Rappaport, S., & Podsiadlowski, P. 2006, MNRAS, 366, 1415
[6] Lasota J.-P., 2001, New Astron. Rev., 45, 449
[7] Liu Q. Z., van Paradijs J., van den Heuvel E. P. J., 2007, A&A, 469, 807
[8] Pavlovskii K., Ivanova N., 2016, MNRAS, 456, 263
[9] Paxton B., Bildsten L., Dotter A., Herwig F., Lesaffre P., Timmes F., 2011, ApJS, 192, 3
[10] Paxton B., et al., 2013, ApJS, 208, 4
[11] Paxton B., et al., 2015, ApJS, 220, 15
[12] Paxton B., et al., 2018, ApJS, 234, 34
[13] Podsiadlowski P., Rappaport S., Pfahl E. D., 2002, ApJ, 565, 1107
[14] Rappaport S., Verbunt F., Joss P. C., 1983, ApJ, 275, 713

Contact

Kvan@ualberta.ca

Statistical Analysis

We use a Bayesian analysis[1] to obtain a numerical value to how likely an observed system is to be produced by our simulations though the following:

$$P(M|D) \propto \Pi_i P(p_i, q_i, \dot{M}_i|M)$$

The probability of a model producing the data is proportional to the product of the probability of each observed system's period, mass ratio and mass transfer rate being reproduced.

Observed System	Period [hours]	Default	Convection Boosted	Intermediate
4U 0513-40	0.283	1.1×10^{-3}	9.2×10^{-4}	6.8×10^{-3}
2S 0918-549	0.290	0.0	0.0	4.4×10^{-6}
4U 1543-624	0.303	1.8×10^{-3}	1.8×10^{-3}	7.3×10^{-3}
4U 1850-087	0.343	0.0	0.0	0.0
M15 X-2	0.377	2.6×10^{-3}	4.8×10^{-3}	0.016
4U 1626-67	0.700	3.6×10^{-3}	3.4×10^{-3}	2.5×10^{-3}
4U 1916-053	0.833	4.6×10^{-3}	9.0×10^{-4}	2.5×10^{-3}
4U 1636-536	3.793	0.23	0.42	0.22
4U 1728-16 (GX 9+9)	4.200	0.21	0.0	0.012
4U 1735-444	4.652	0.0	0.0	0.0
2A 1822-371	5.561	1.2	0.30	0.23
H 1617-155 (Sco X-1)	18.90	0.0	0.014	8.4×10^{-5}
4U 1624-49	20.88	0.0	0.0	0.0
3A 1702-363 (GX 349+2)	22.50	1.8×10^{-3}	9.0×10^{-3}	0.0
4U 2142+38 (Cyg X-2)	236.3	8.4×10^{-4}	6.4×10^{-3}	3.2×10^{-4}

The number in the table gives a relative probability of producing that observed system to other systems using that magnetic braking prescription assuming that all seed binaries are equally likely.

None of the tested magnetic braking prescriptions can reproduce all observed systems with a flat initial probability.