Binary Evolution towards Ultra-luminous X-ray sources with Neutron-star accretors

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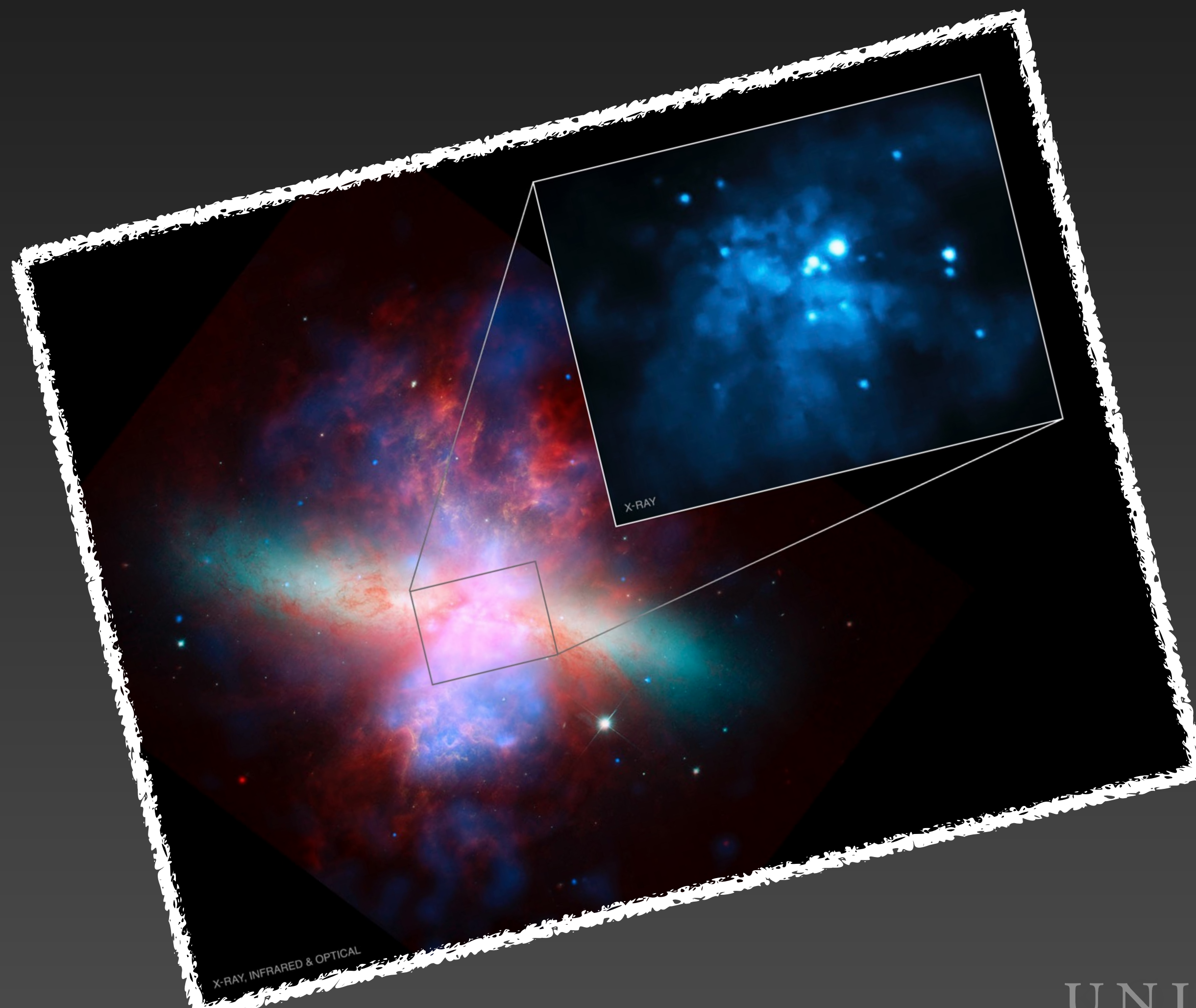
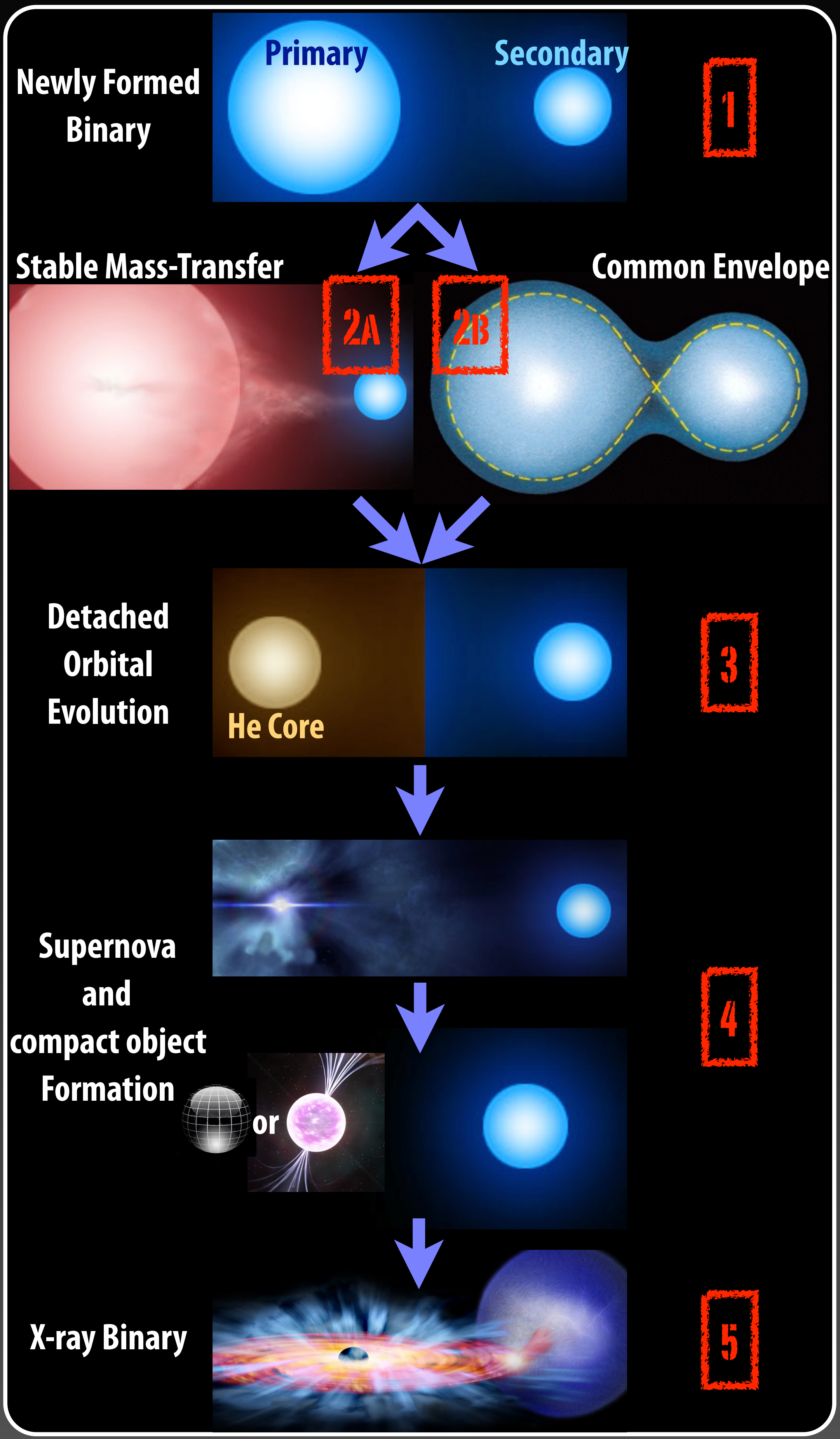


UNIVERSITY OF COPENHAGEN

Ultra-luminous X-ray Pulsars - Madrid, June 7th, 2018

The Formation of an (ultra-luminous) X-ray Binary



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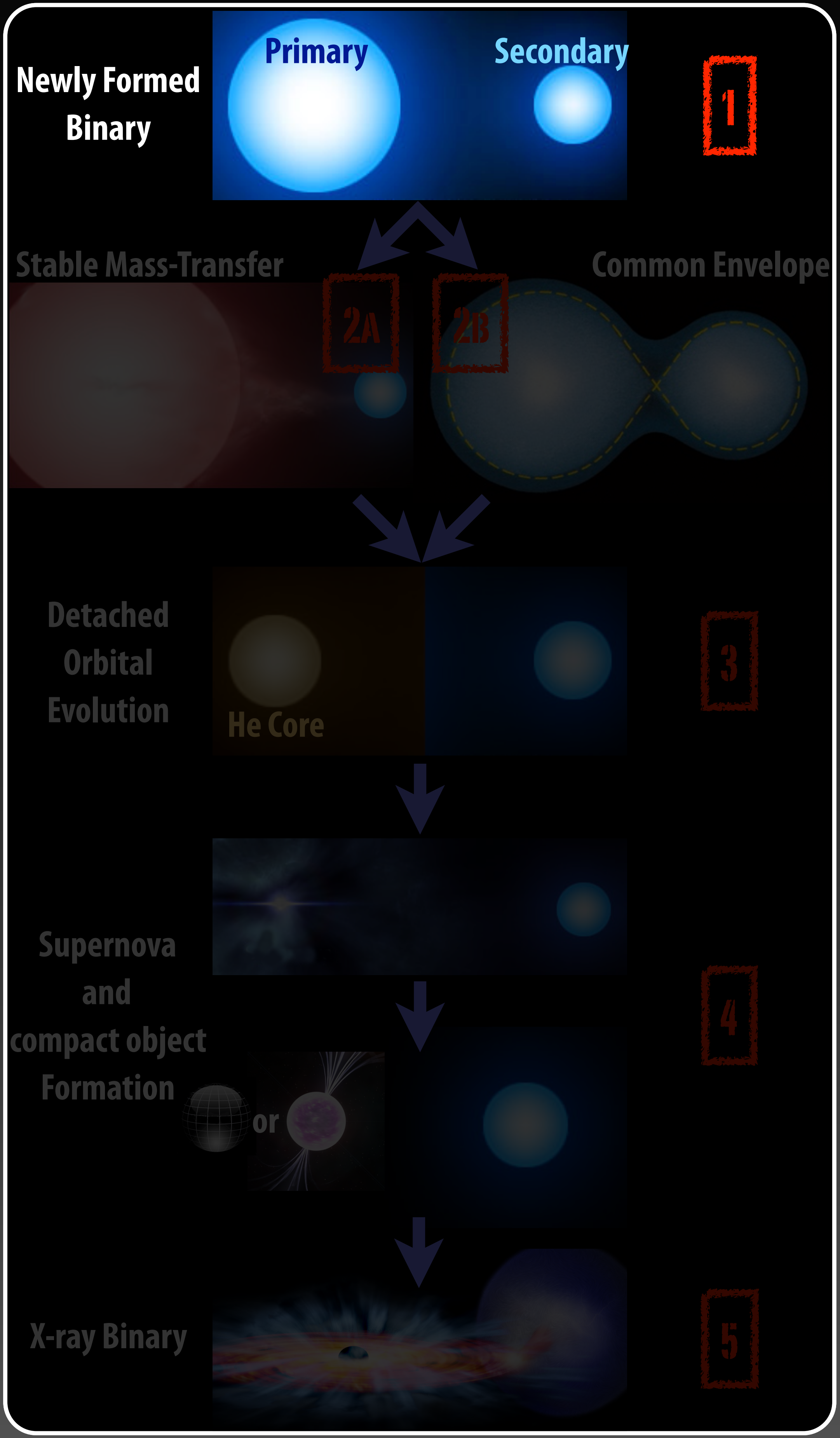

Start from a binary star

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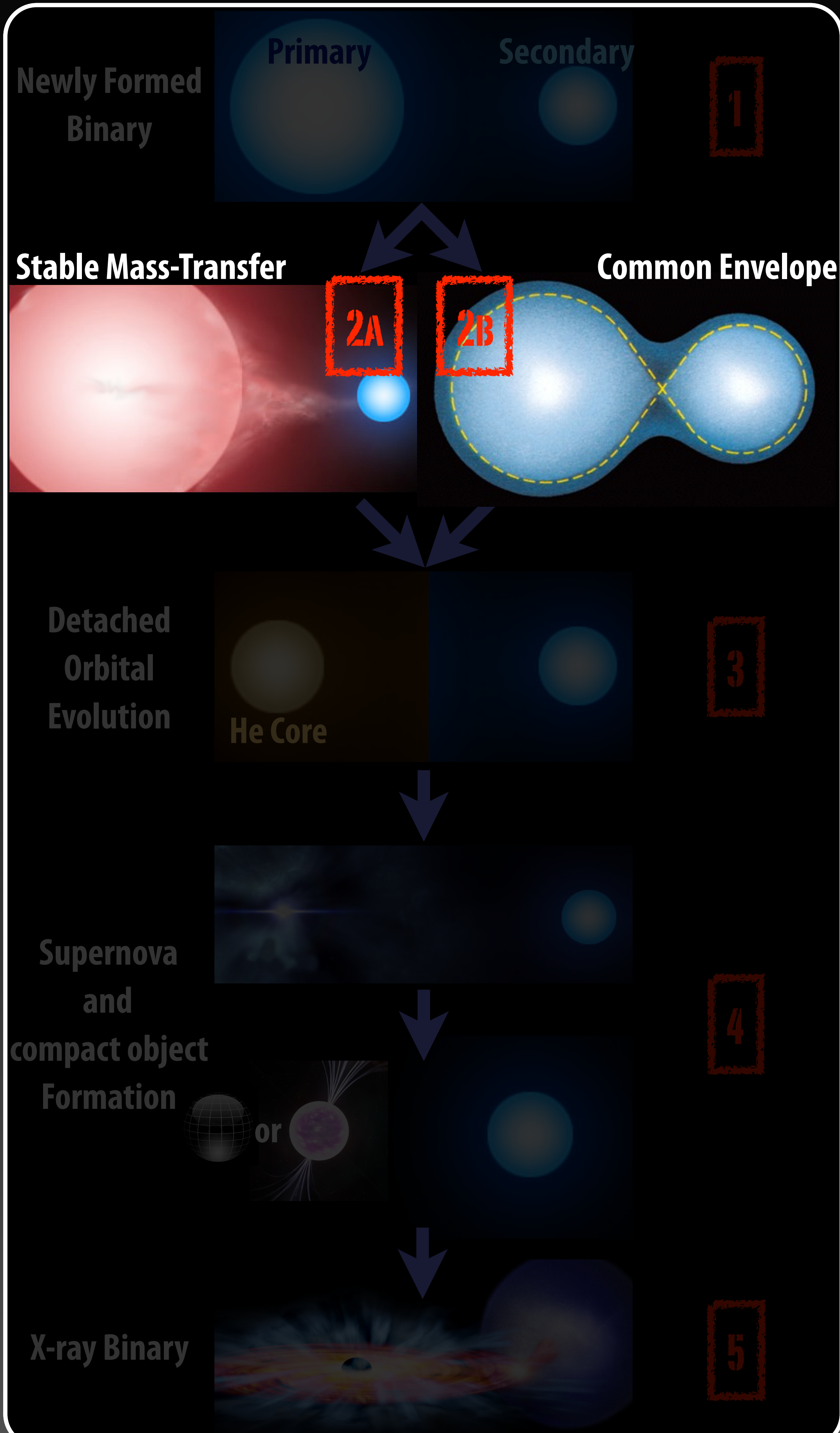

Start from a binary star

Mass-transfer phase

Stable or ***common envelope*** depending on the binary's mass-ratio

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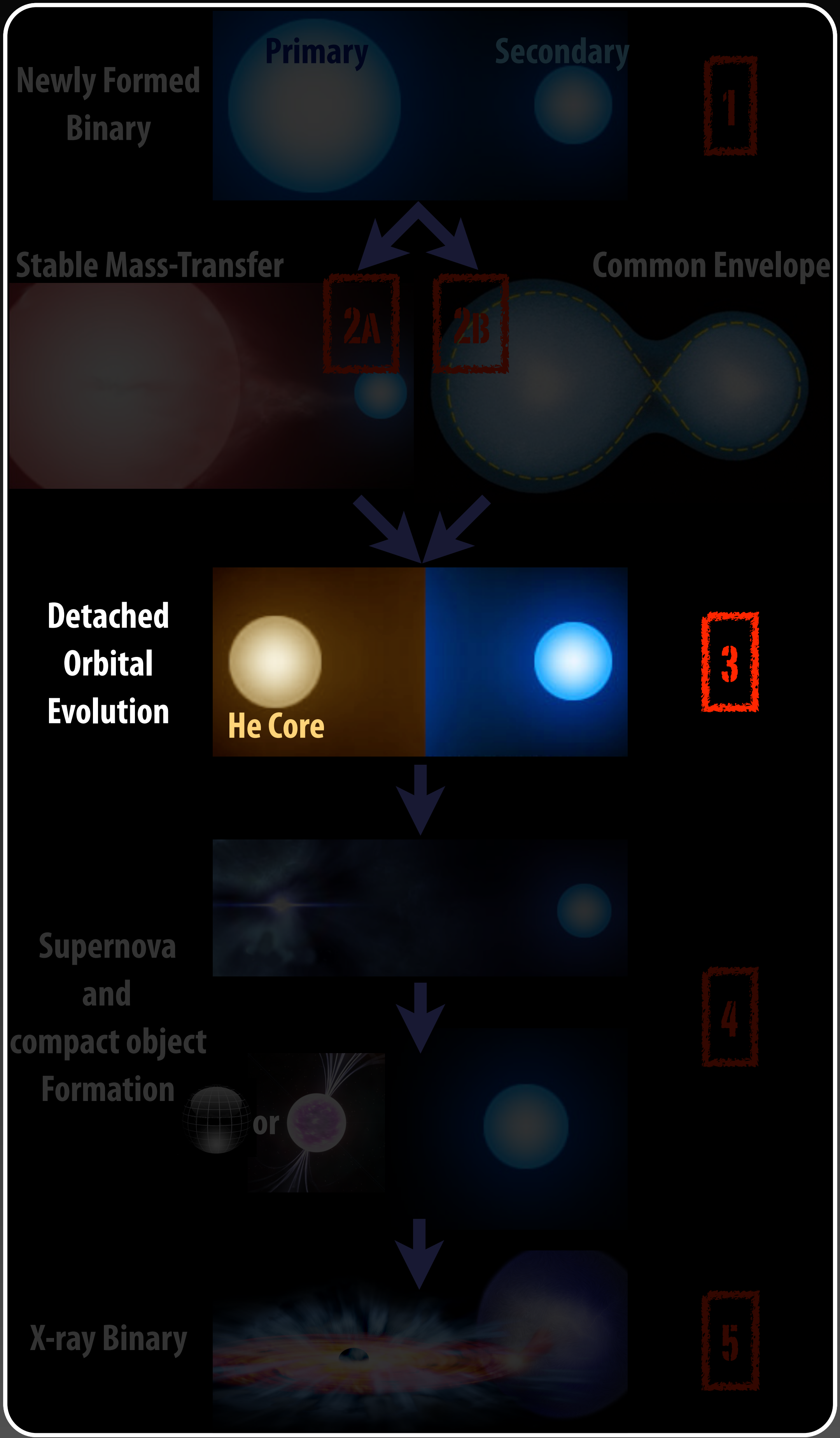

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Detached orbital evolution
Due to tidal interactions

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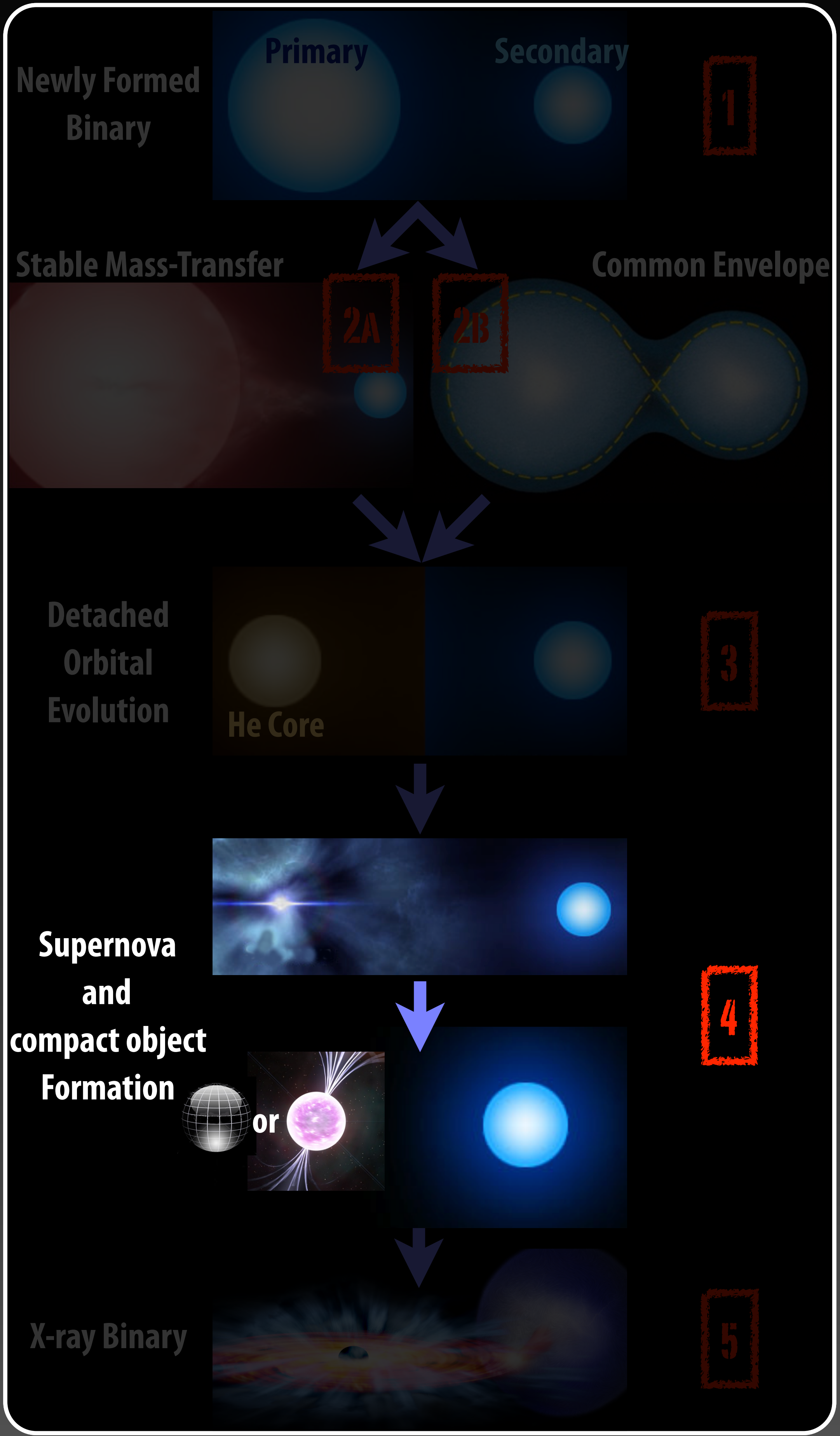

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Supernova and black hole formation.
Asymmetries in the explosion can changes further the orbit

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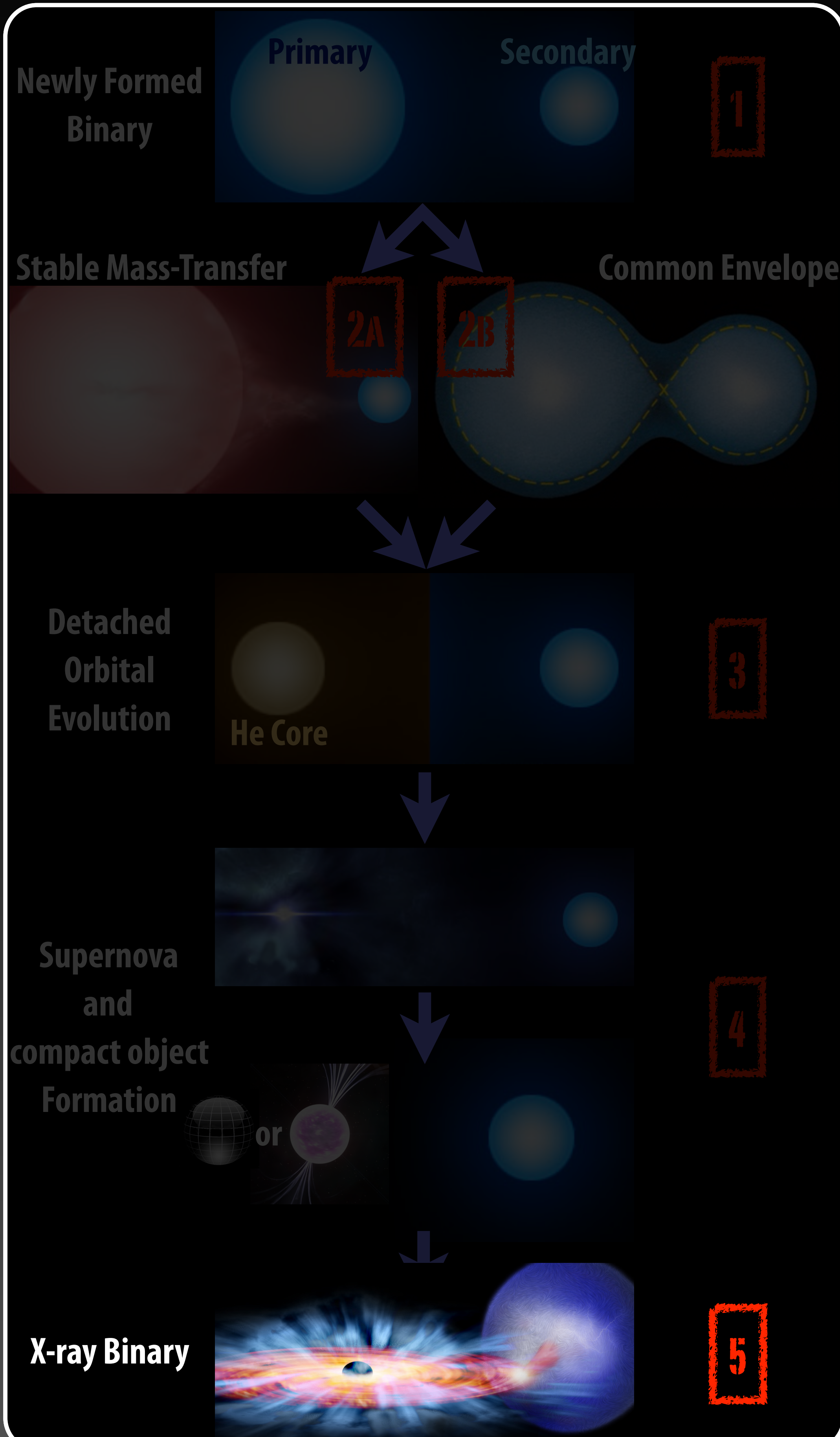

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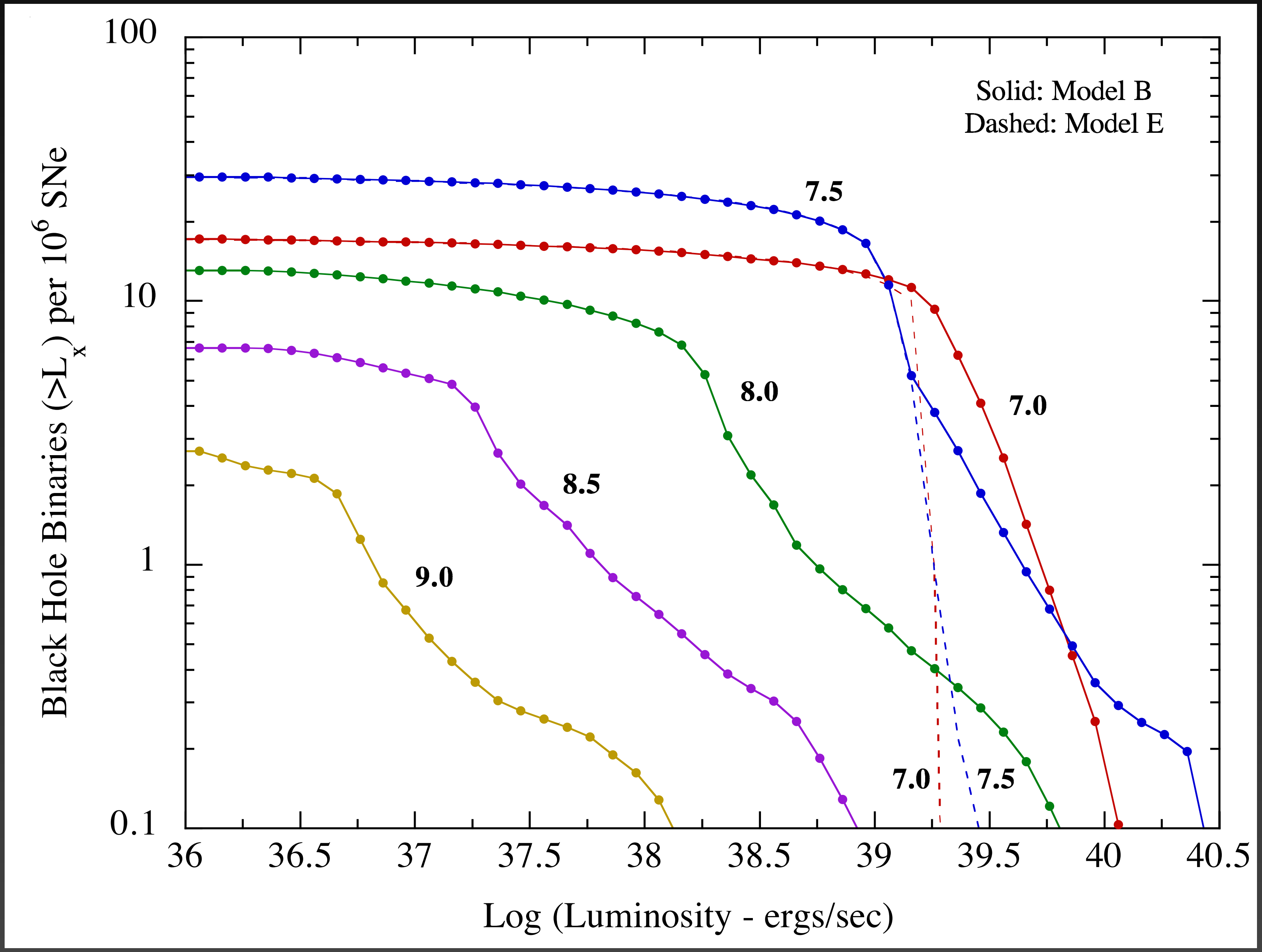
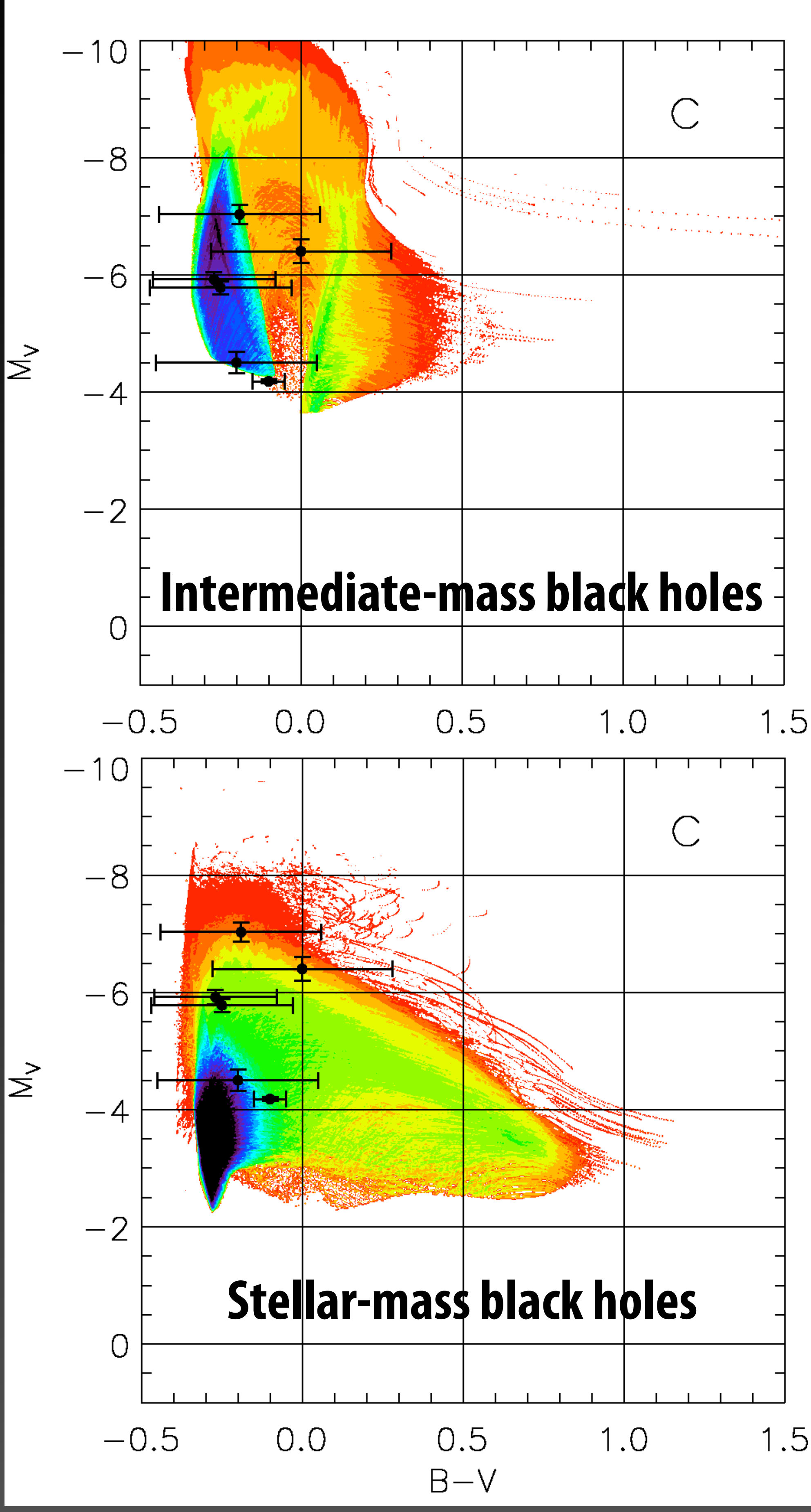
X-ray binary phase
Accretion of matter onto the compact object

Stellar or Intermediate Black holes?

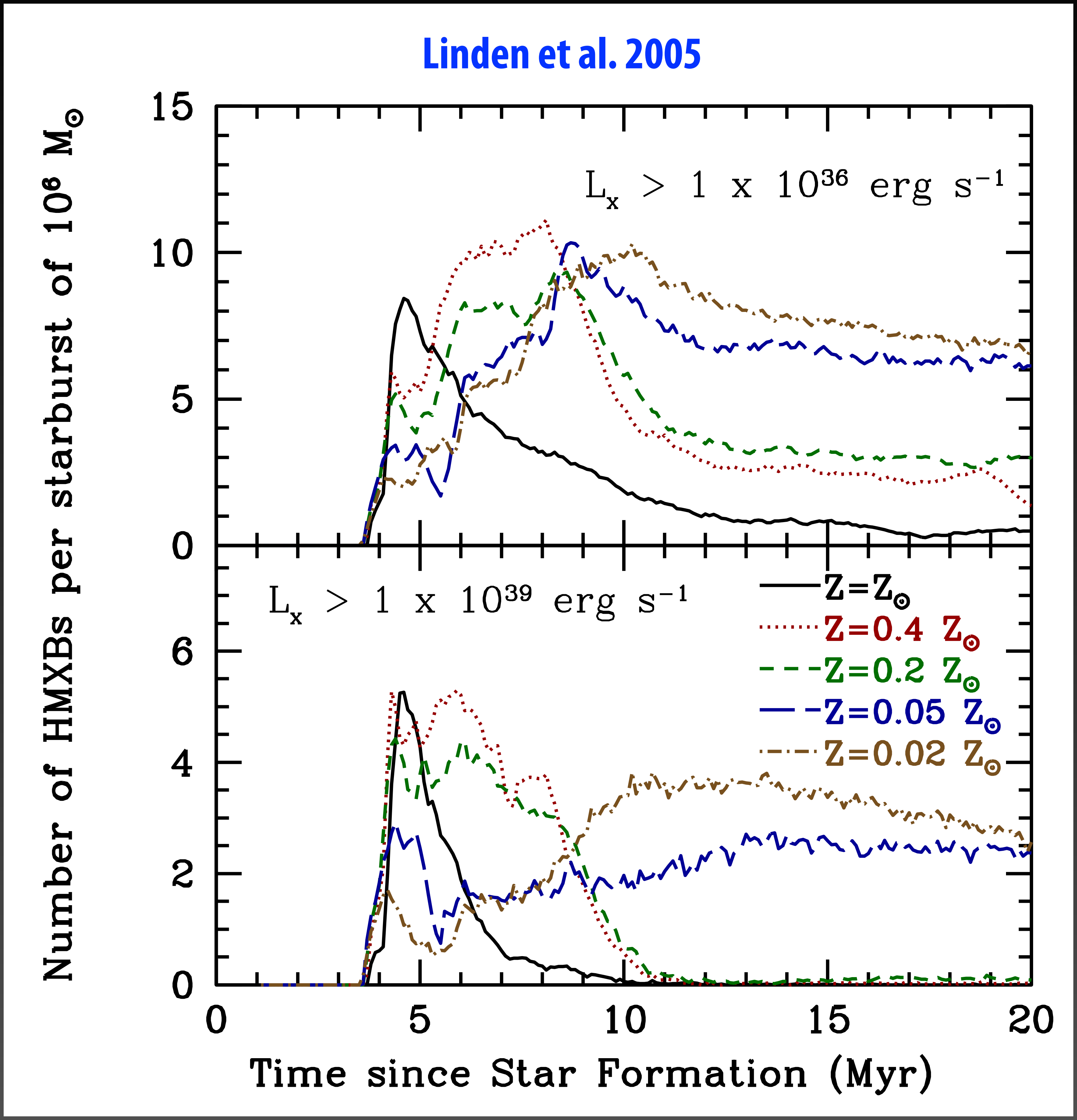
Rappaport et al. 2005



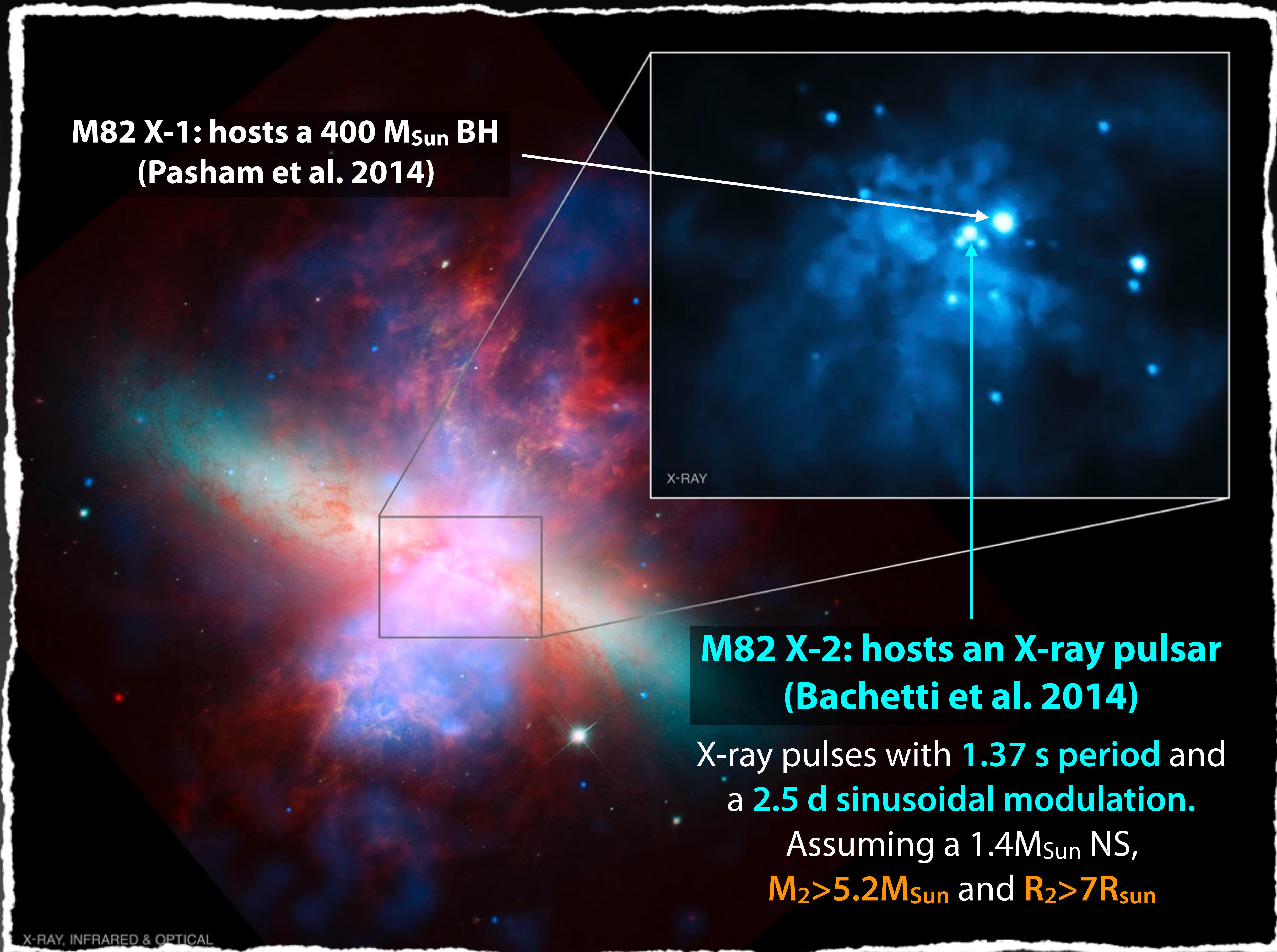
Madhusudhan et al. 2008



Rate depends on metallicity or age?



M82: a factory of the most exotic XRBs???



Challenging our understanding …

- How can a NS emit X-rays at 100 x $L_{Eddington}$?

(e.g. Lyutikov 2014, Christodoulou et al. 2014, Eksi et al. 2015, Kluzniak and Lasota 2015, Dall'Osso et al. 2015, Tong 2015, Mushtukov et al. 2015)

- How can such a system form?

(e.g. Podsiadlowski et al. 2002, Tauris et al. 2011, Fragos et al. 2015, Shao et al. 2015, Wictorowicz et al. 2015)

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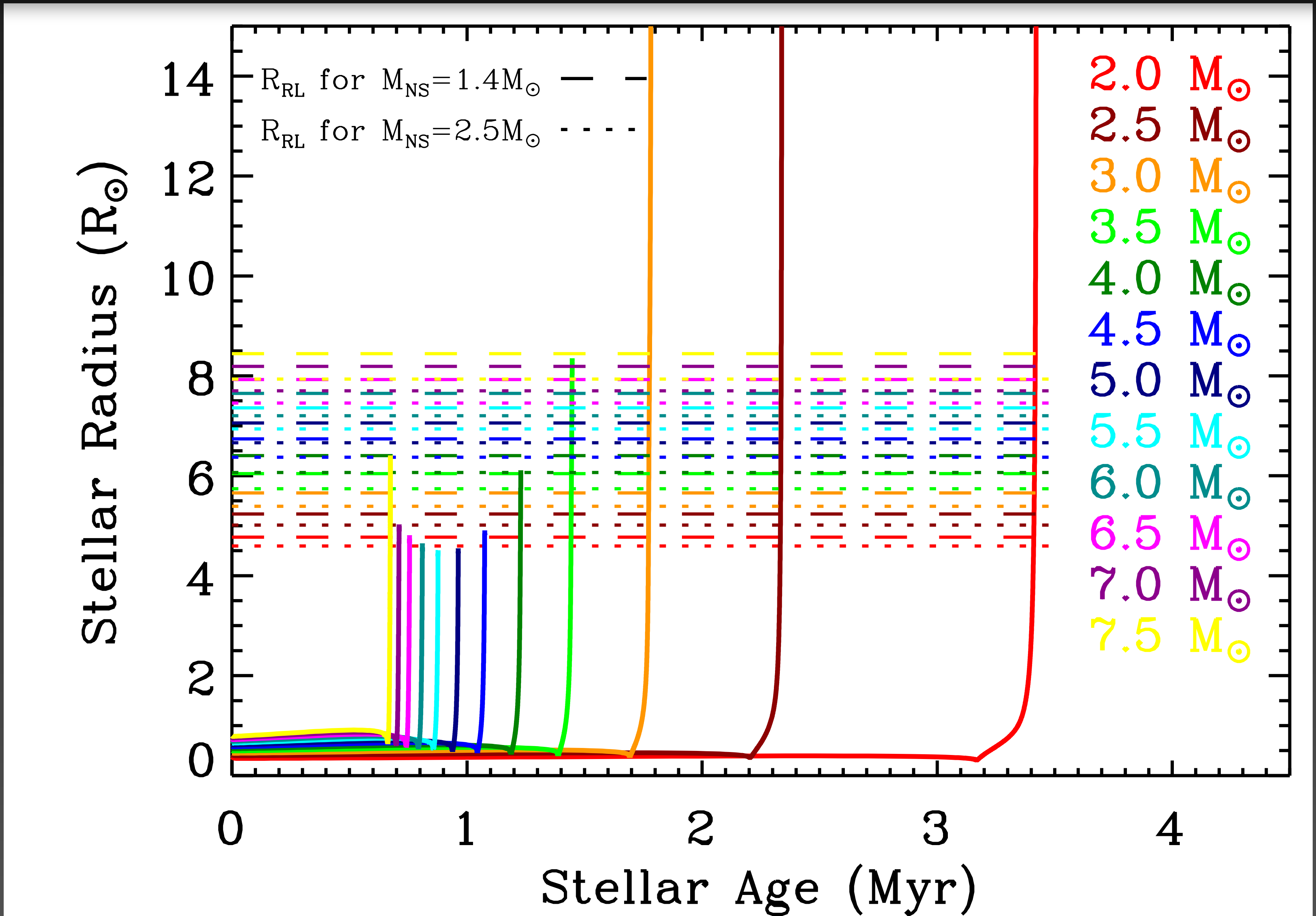
Evolutionary state of the system

- The companion star is filling its Roche Lobe

  Even the brightest wind-fed BH XRBs do not exceed 10^{39} erg/s

- The Companion is a main sequence star

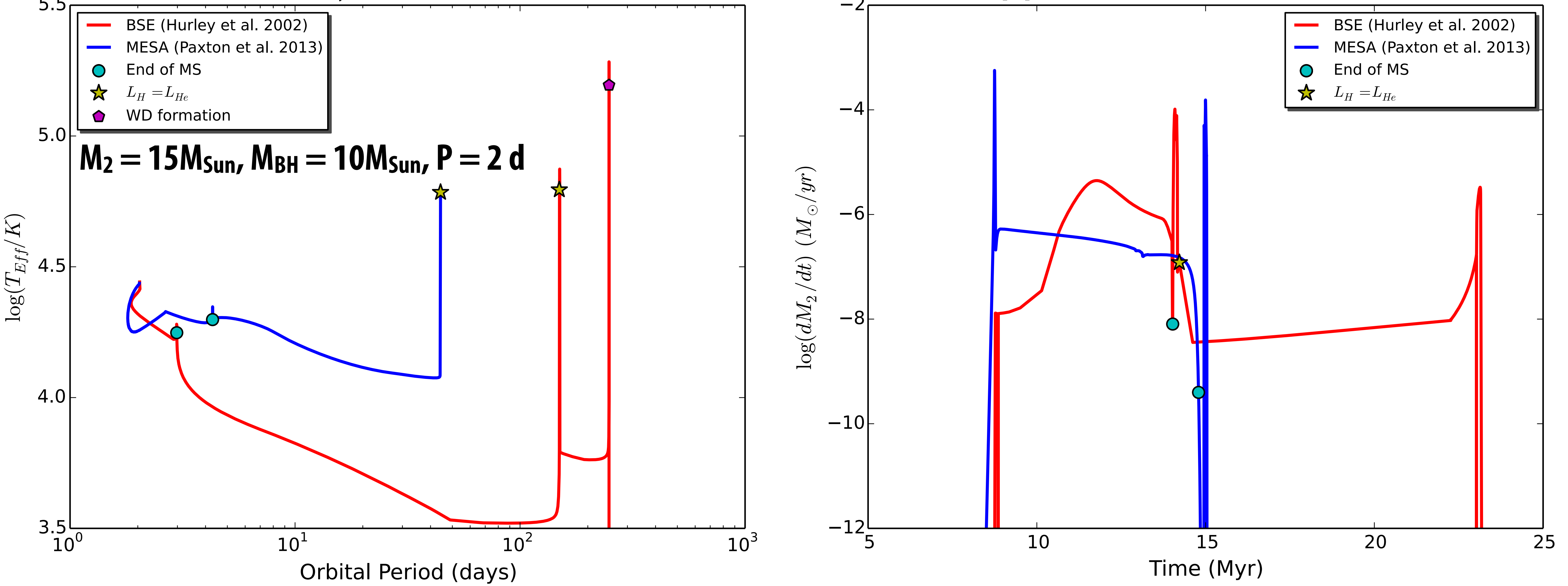
  Helium stars are too compact to fill their Roche Lobe in a 2.5 d orbit



Stability of mass-transfer

- Assuming hydrostatic equilibrium and adiabatic mass-loss, $q=M_2/M_{NS} >$ 2.2 - 3 leads to dynamical instability
  (e.g. Hjellming & Webbink 1987; Ivanova & Taam 2004)
  BUT see more recent: e.g. Passy et al. (2012) and Pavlovskii & Ivanova (2015)
- Accuracy of thermally unstable mass-transfer in parametric binary population synthesis codes

Thermally unstable mass-transfer: Detailed vs Approximate treatment



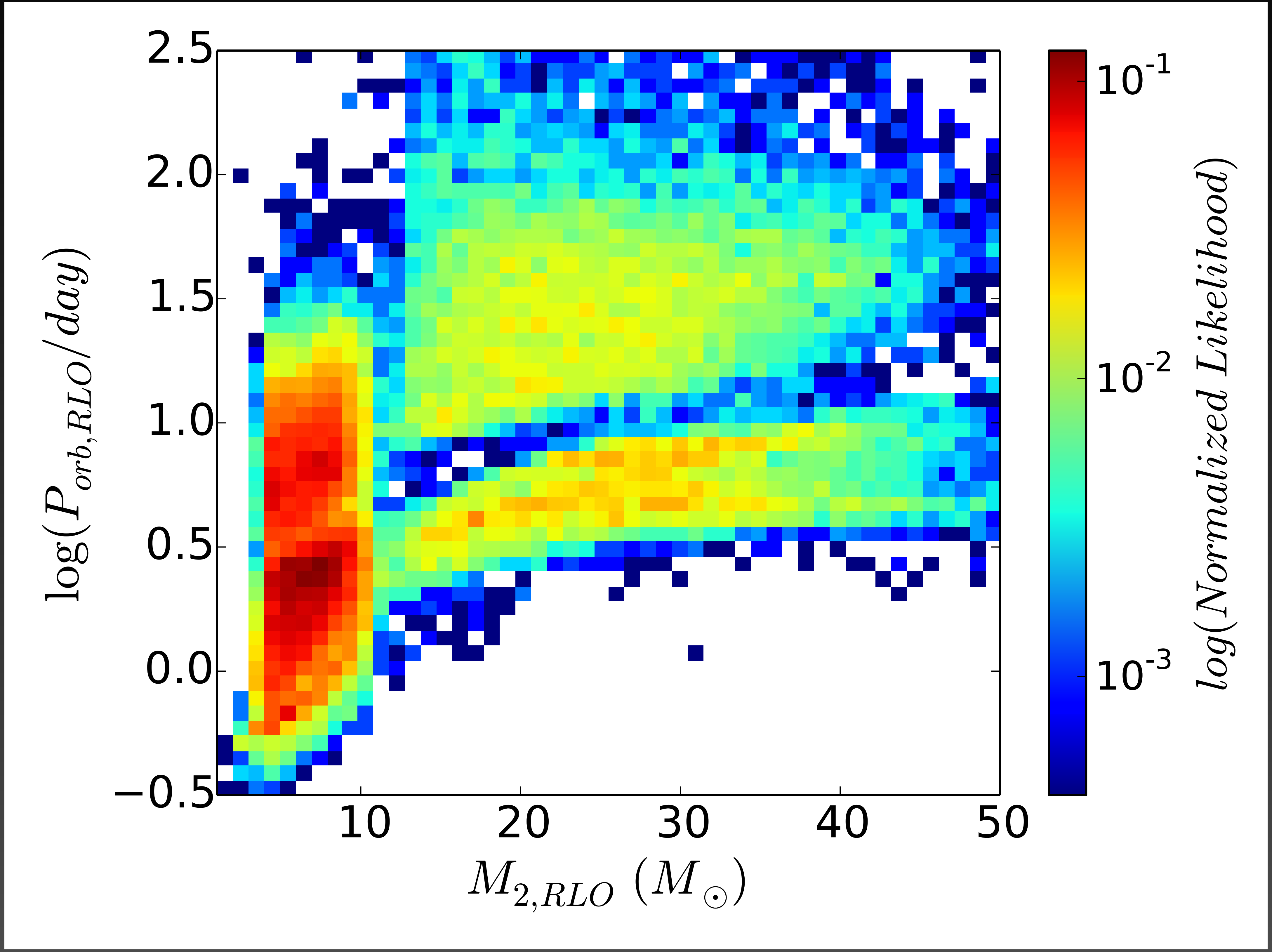
Hybrid Population Synthesis Study

1) Use **BSE (approximate PS code)** to estimate the **distribution of binary properties** of systems with **NSs** that reach **Roche Lobe overflow**.

2) Use **MESA (detailed binary ev. code)** to calculate **mass-transfer stability, duration, and rate.**

Neutron Star Binaries at Roch lobe Overflow

Fragos et al. 2015



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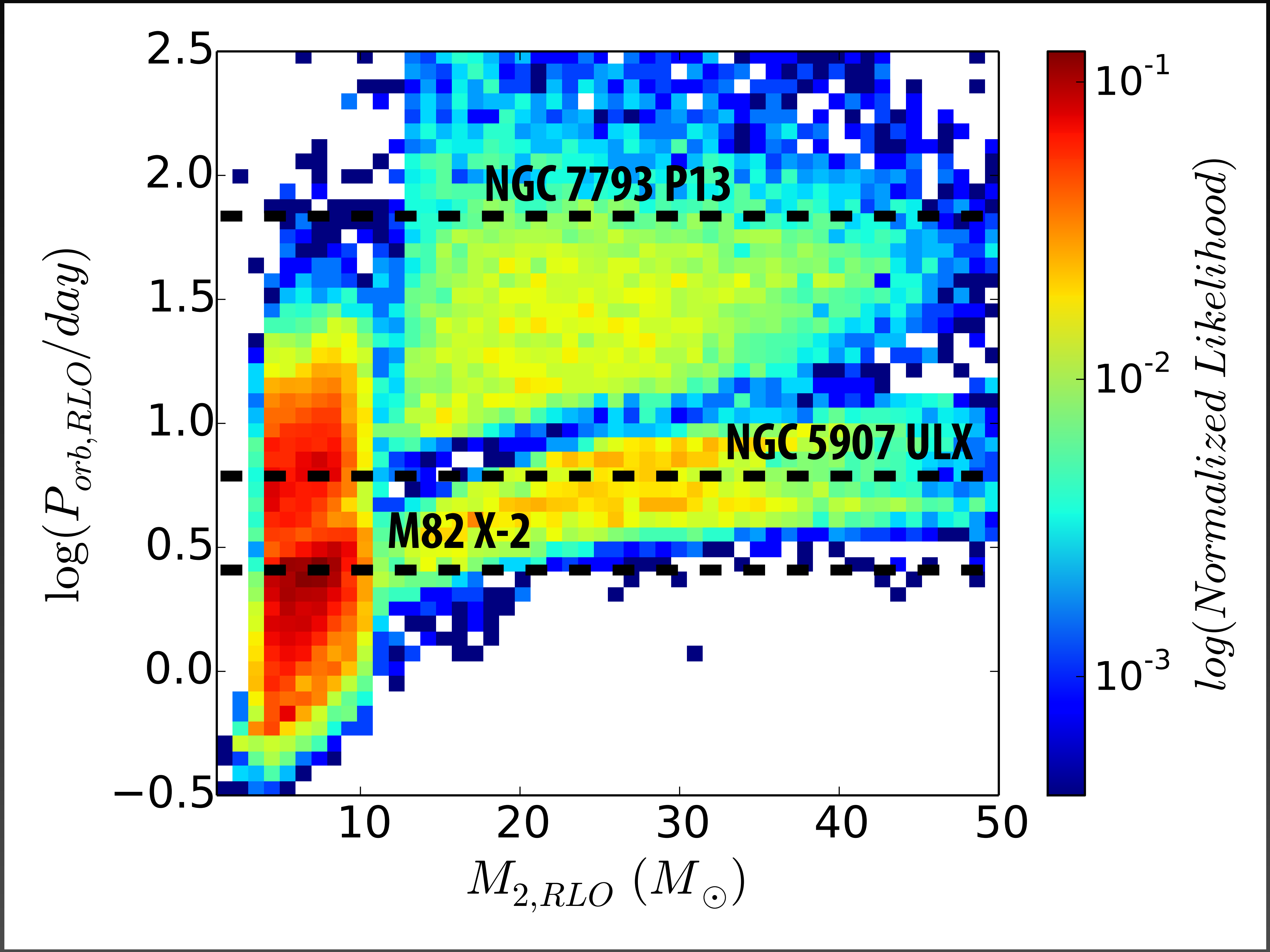
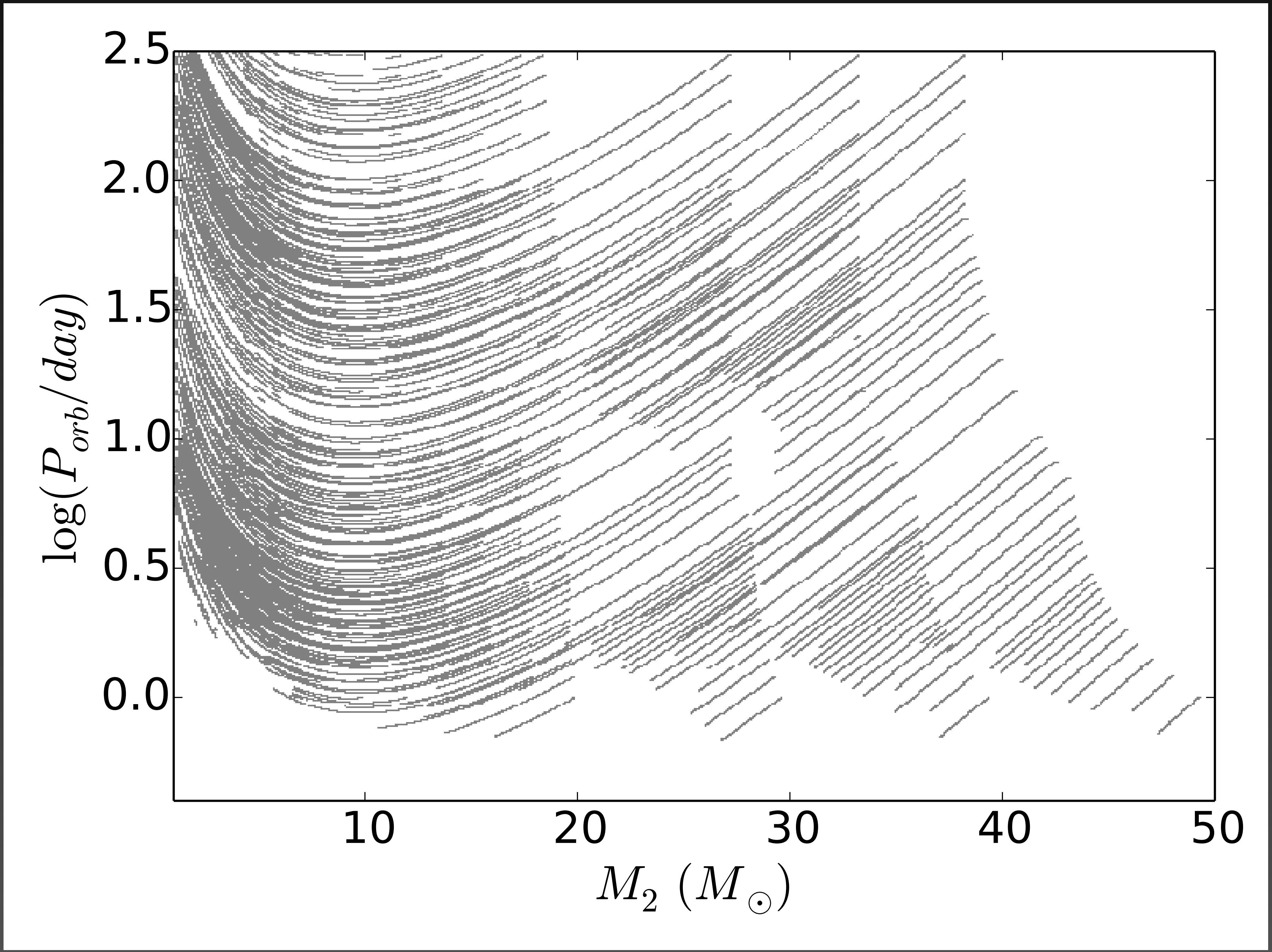


MT Calculations between NS and Massive Stars

$$\frac{\dot{J}_{orb}}{J_{orb}} = \frac{\alpha + \beta q}{1+q}\frac{\dot{M}_2}{M_2}, \quad q = \frac{M_2}{M_{NS}}$$

mass-transfer efficiency
&
angular momentum losses



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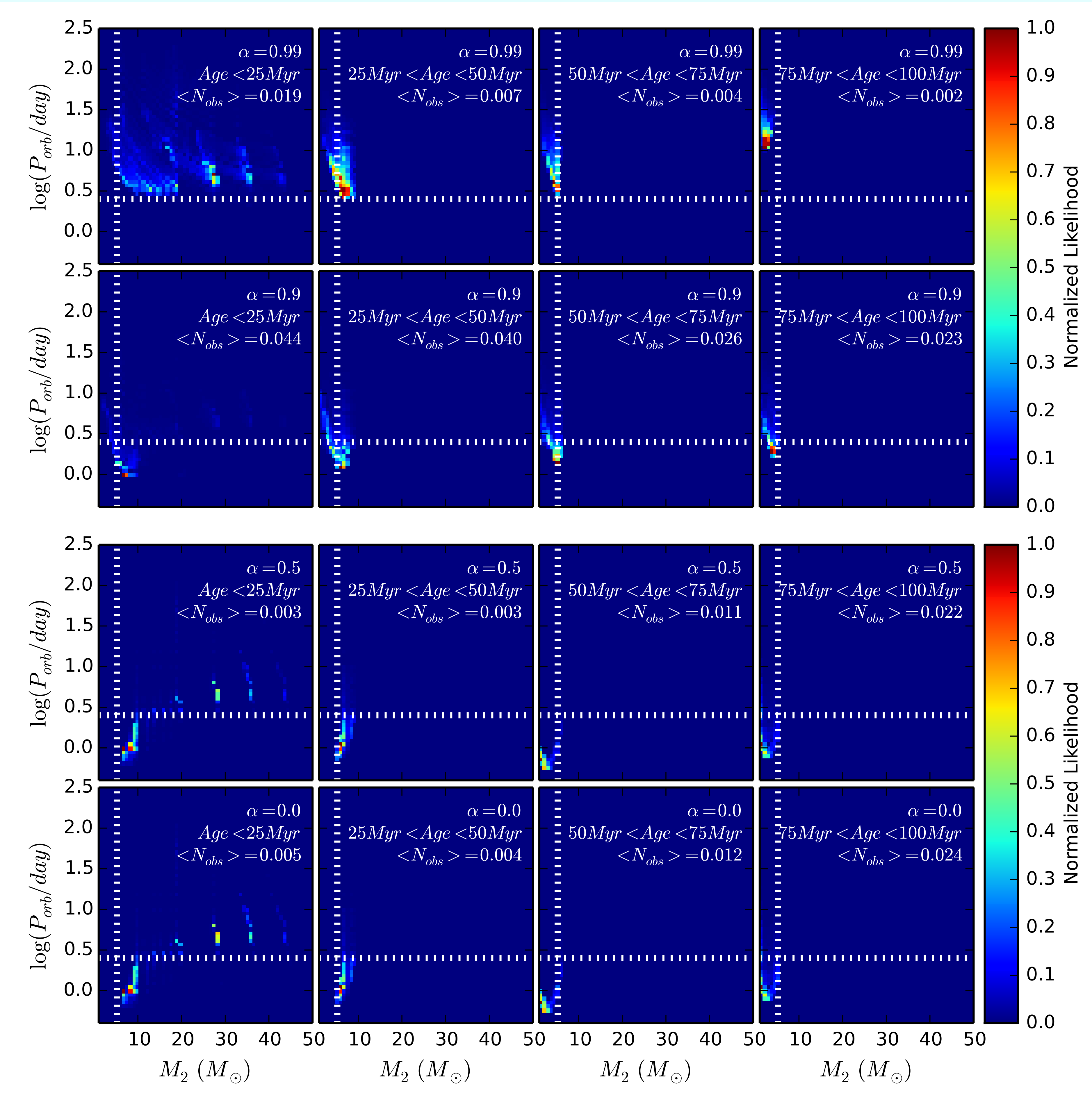
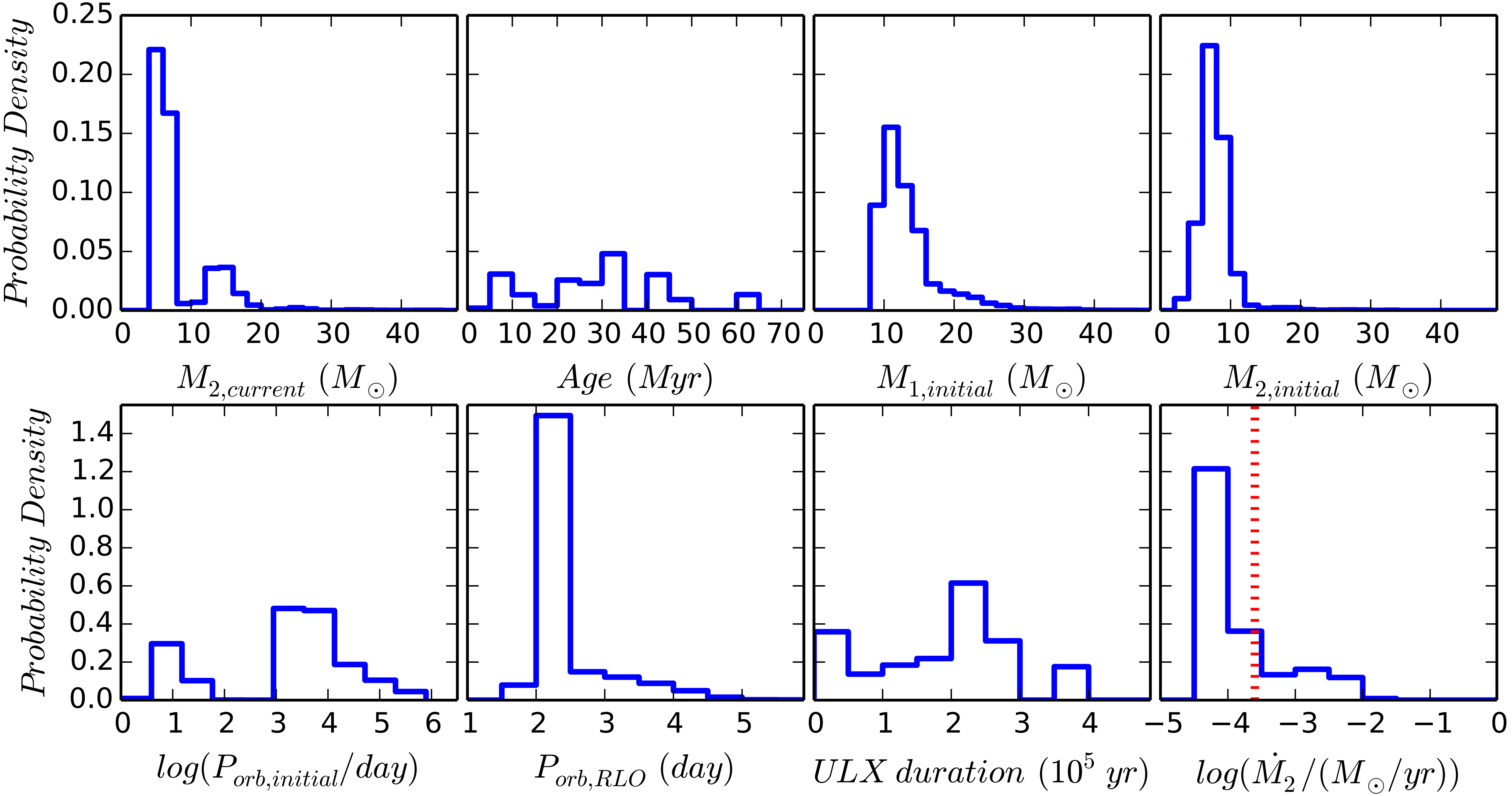
Connecting the dots…



Fragos et al. 2015

The properties of M82 X-2 and its progenitor

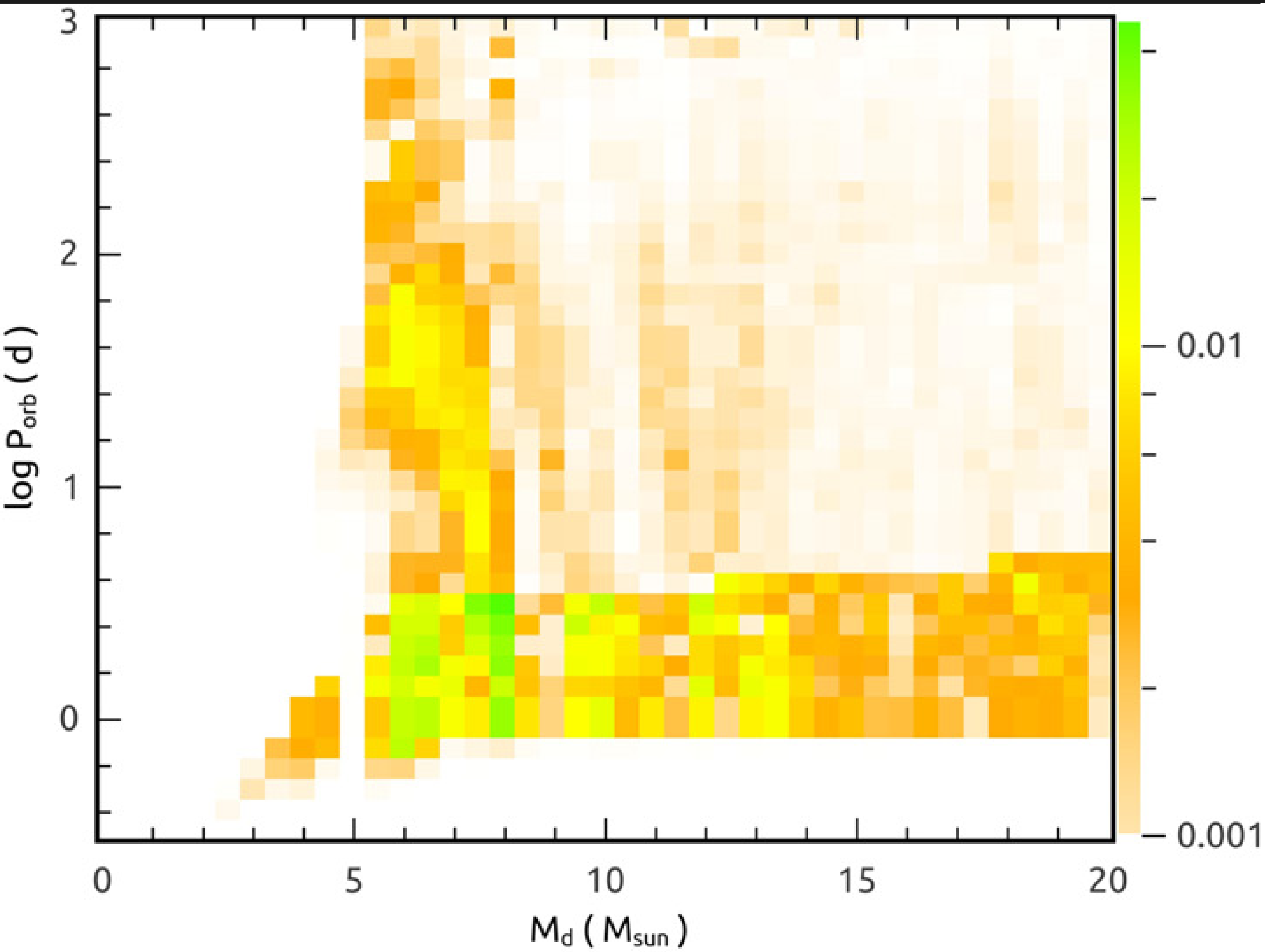
Fragos et al. 2015

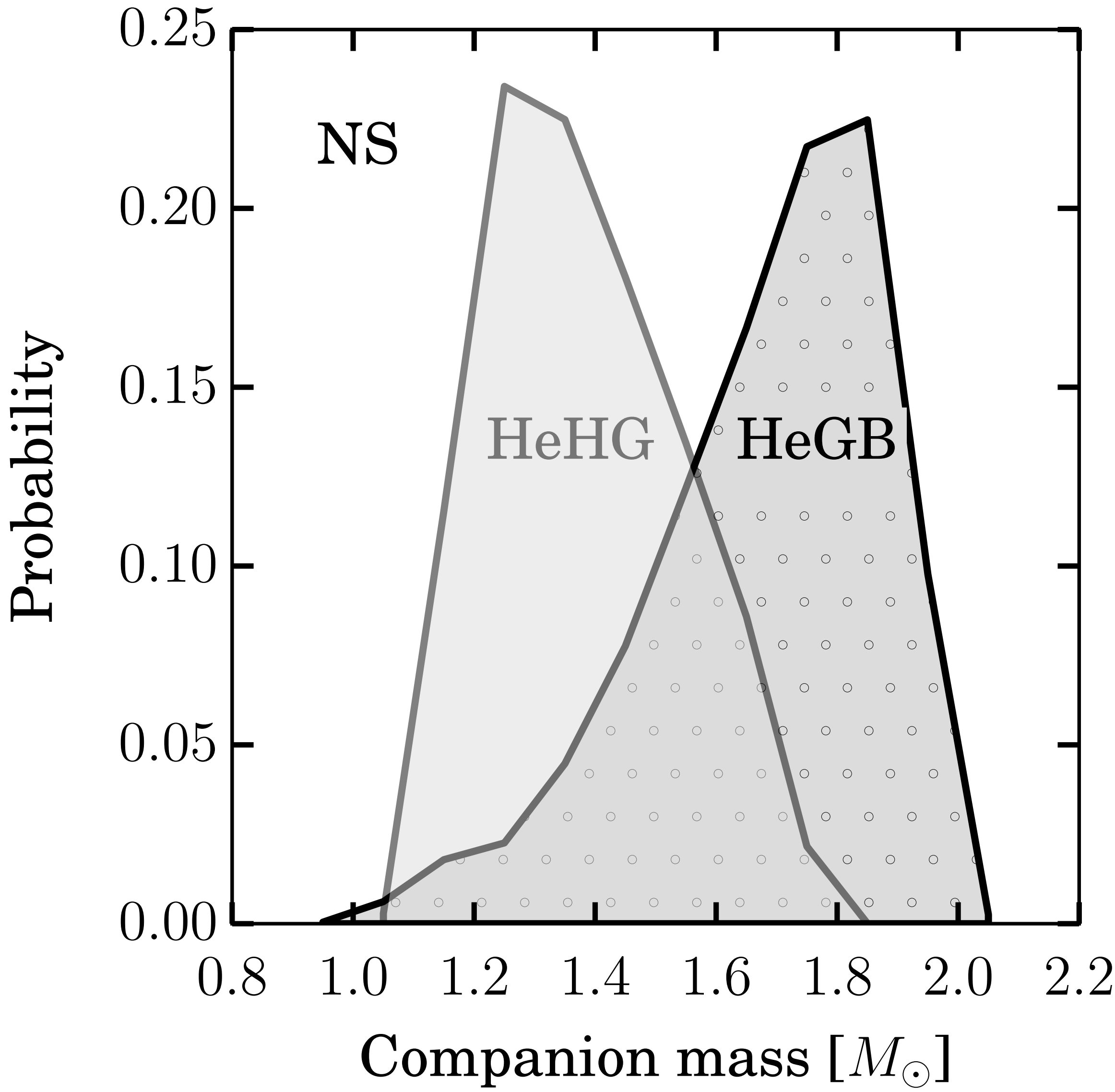


Populations of ultraluminous accreting NSs

NS accretors may dominate the ULX population in Milky way type galaxies
Shao et al. (2015)

ULXs with NS accretors can reach luminosities of up to 10^{42} erg/s
Wiktorowicz et al. (2015,2017)

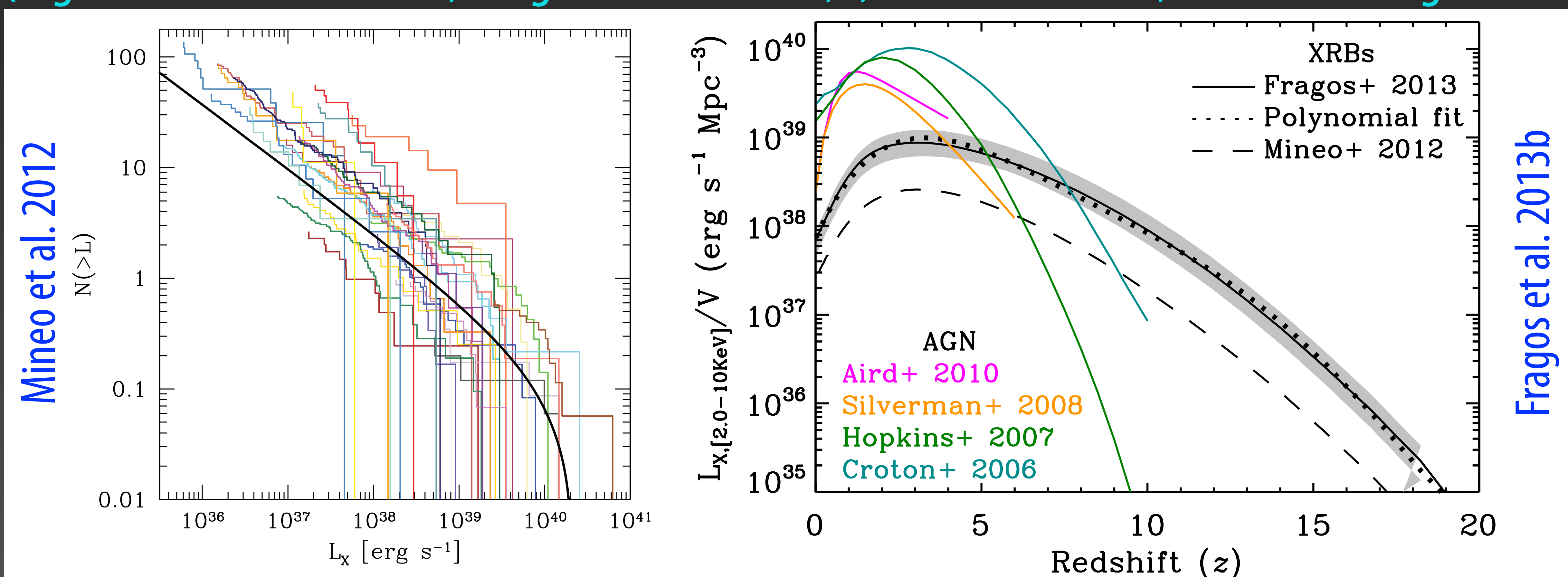




Implications for gravitational wave astrophysics & cosmology

- **ULXs are progenitors of GW sources or bi-products of certain formation channels** (e.g. Marchant et al. 2017, Finke & Razzaque 2017)
  - Selection effects need to appropriately modeled
  - Comprehensive population studies need to be performed

- **Soft X-ray photons from ULXs in the early Universe can heat up the IGM** (e.g. Mirabel et al. 2011, Fragos et al. 2013a,b, Das et al. 2017, Madau & Fragos 2017)

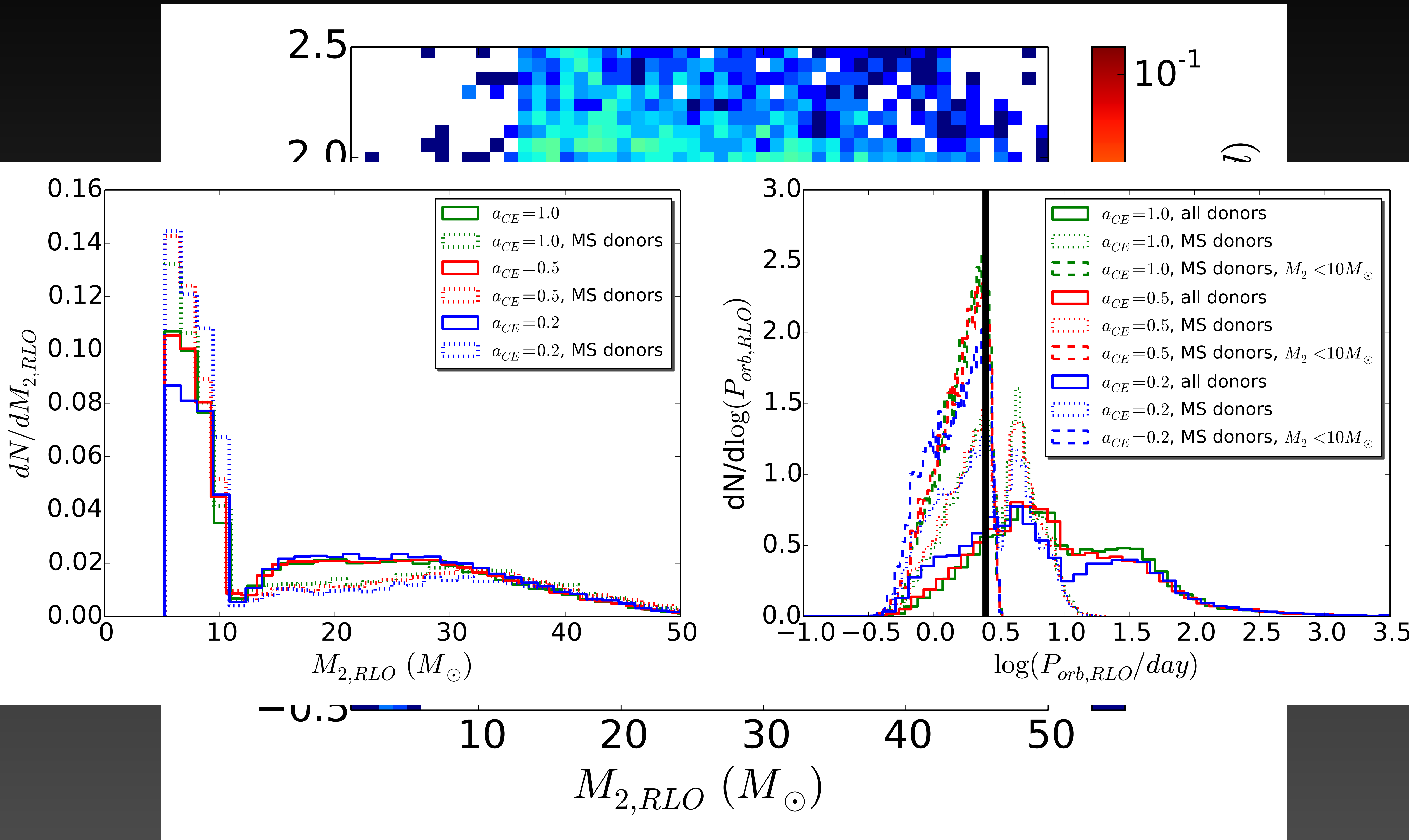


Take-home points

- The orbital period of any ULX with a NS accretor is most likely to be observed with an orbital period between 1-3 days, and a donor mass between 3-8 M_{Sun}.
- The MT is highly non-conservative and happens on the thermal timescale. A reduced specific angular momentum of the ejected material is favored.
- We estimate that the number of observed NS ULXs per unit of star formation is ~0.03 $(M_{Sun}/yr)^{-1}$. This number is an order of magnitude lower than predictions for the formation rate of observed ULXs with BH accretors.
- ULX pulsars are excellent laboratories to study the efficiency of mass-transfer at ULX rates, especially after the orbital period derivative is measured.
- ULXs and ratio of BH vs NS accretors can pose constraints on formation channels of gravitational wave sources
- If ULXPs are dominating the ULX population we need to revisit the role of ULXs as a feedback mechanism in the early Universe

Neutron Star Binaries at Roch lobe Overflow

Fragos et al. 2015



What is an Ultraluminous X-ray Source?

ULXs are off-nuclear X-ray sources whose bolometric luminosity exceeds the Eddington limit of a $20M_\odot$ black hole,

i.e. $L_X > 3 \times 10^{39}$ erg/s

Statistical properties

- ➡ tend to be associated with recent star formation
- ➡ small number have possible optical associations with bright stars
- ➡ some show transitions similar to that seen in galactic black holes
- ➡ the overall X-ray luminosity function of high-mass X-ray binaries does not show a clear feature associated with the ULXs