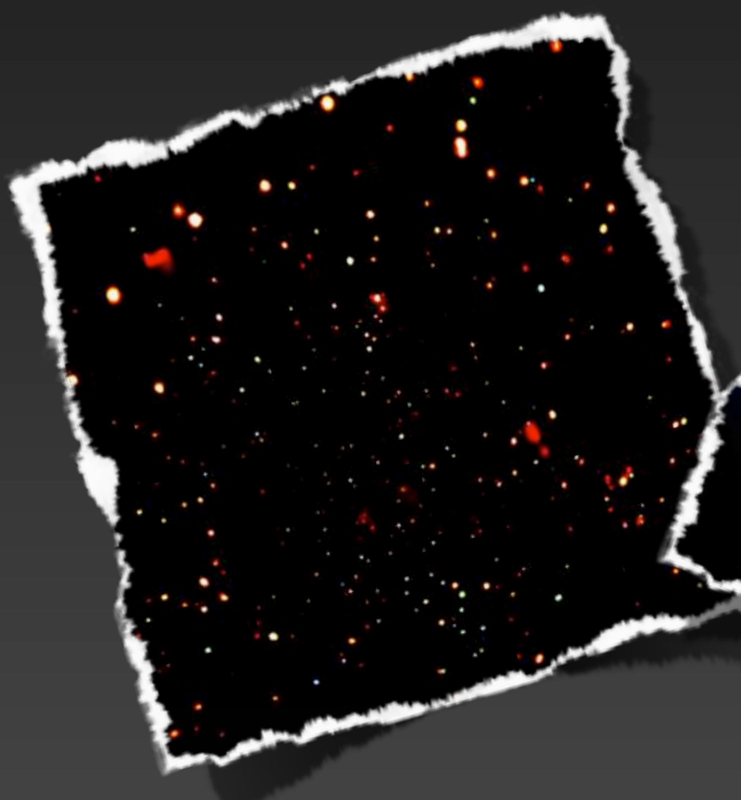
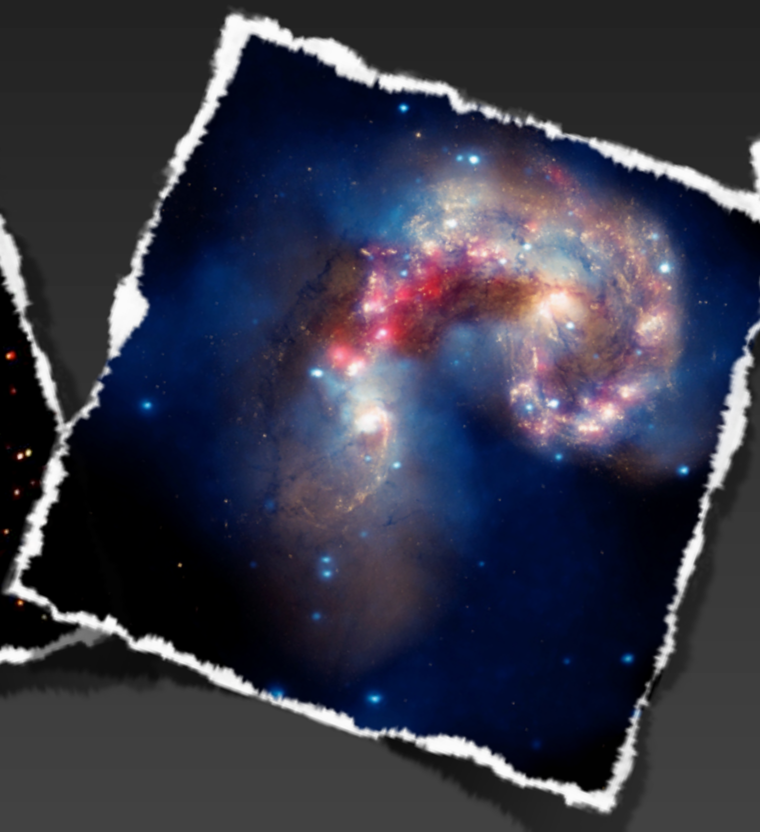
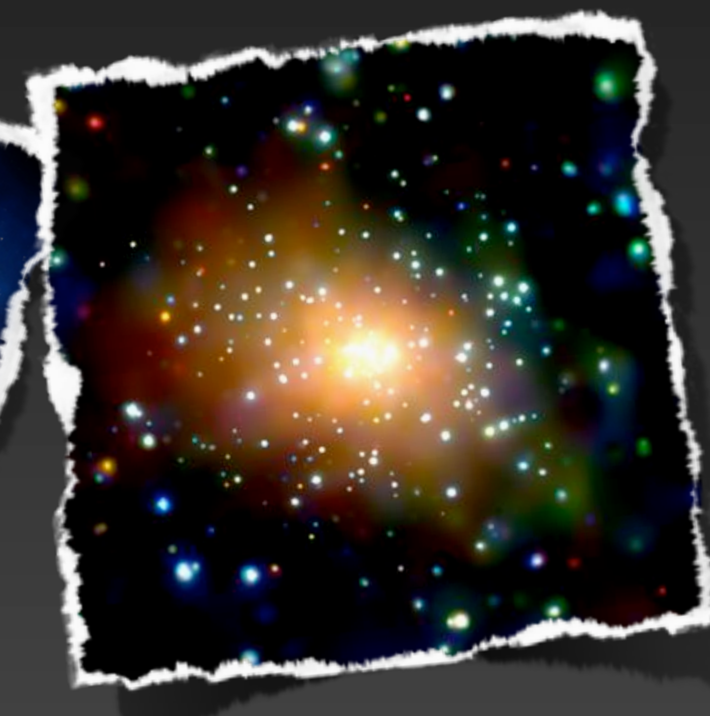
X-ray Binary Formation and Evolution on cosmological timescales

Tassos Fragos







**with M. Tremmel, B. Lehmer, P. Tzanavaris,
A. Hornschemeier, V. Kalogera A. Zezas, K. Belczynski**

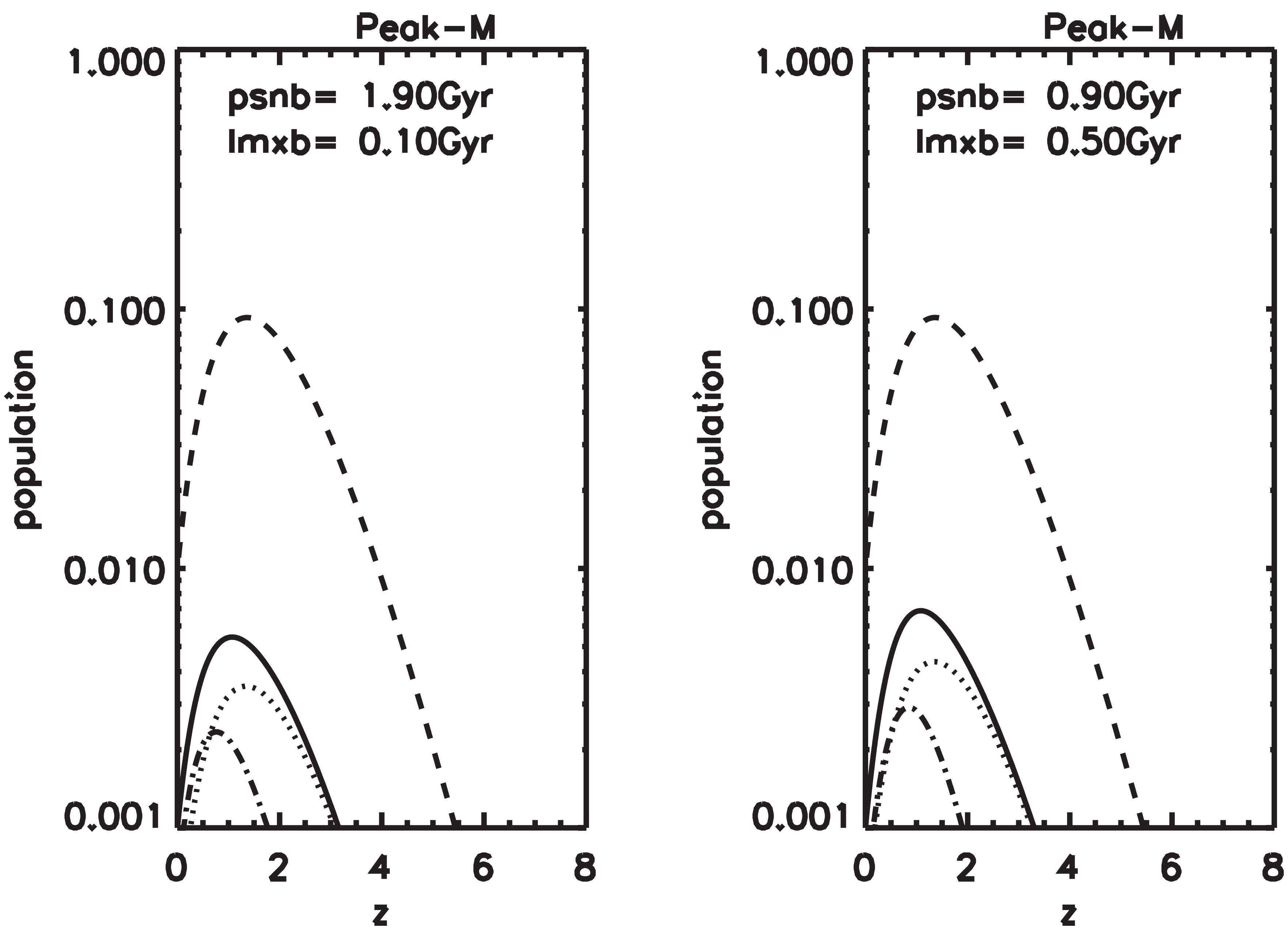
Harvard-Smithsonian CfA *Institute for Theory and Computation*

Outline

- Motivation
- *StarTrack* and *Millennium* simulations
- Constraining the model with observations
- Summary and next steps

Existing Theoretical Models

White & Ghosh 1998
Ghosh & White 2001



Timescale estimates for binary evolution

$$\frac{\partial n_{\rm HMXB}(t)}{\partial t} = \alpha_h {\rm SFR}(t) - \frac{n_{\rm HMXB}(t)}{\tau_{\rm HMXB}},$$

$$\frac{\partial n_{\rm PSNB}(t)}{\partial t} = \alpha_l {\rm SFR}(t) - \frac{n_{\rm PSNB}(t)}{\tau_{\rm PSNB}},$$

$$\frac{\partial n_{\rm LMXB}(t)}{\partial t} = \frac{n_{\rm PSNB}(t)}{\tau_{\rm PSNB}} - \frac{n_{\rm LMXB}(t)}{\tau_{\rm LMXB}},$$

Several Star Formation history models

New observational constraint and **advances in theoretical understanding** allow the development of ***detailed population synthesis models***

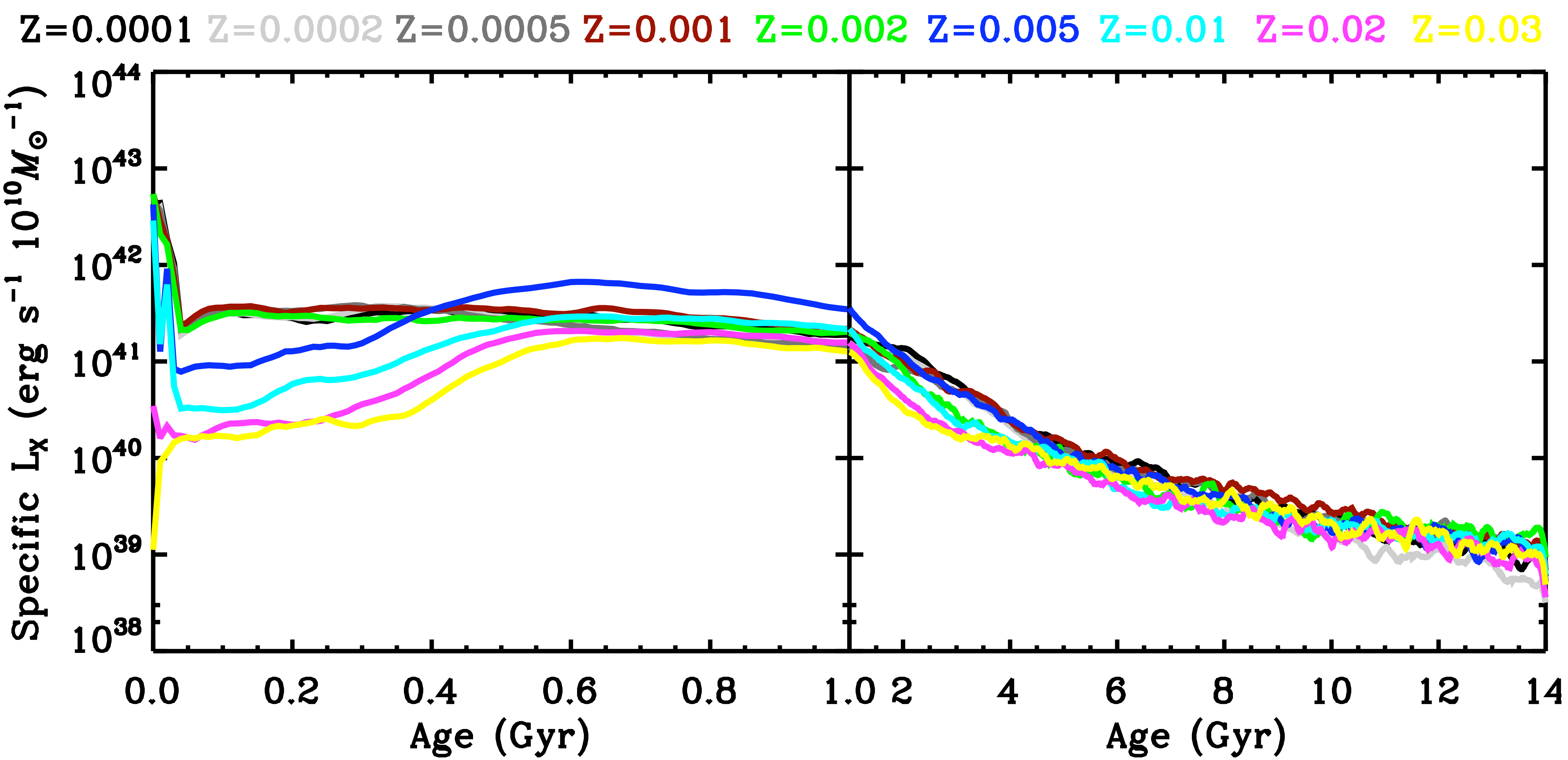
The Largest X-ray Binary Population Synthesis Simulations Ever!

The largest library of X-ray binary PS models

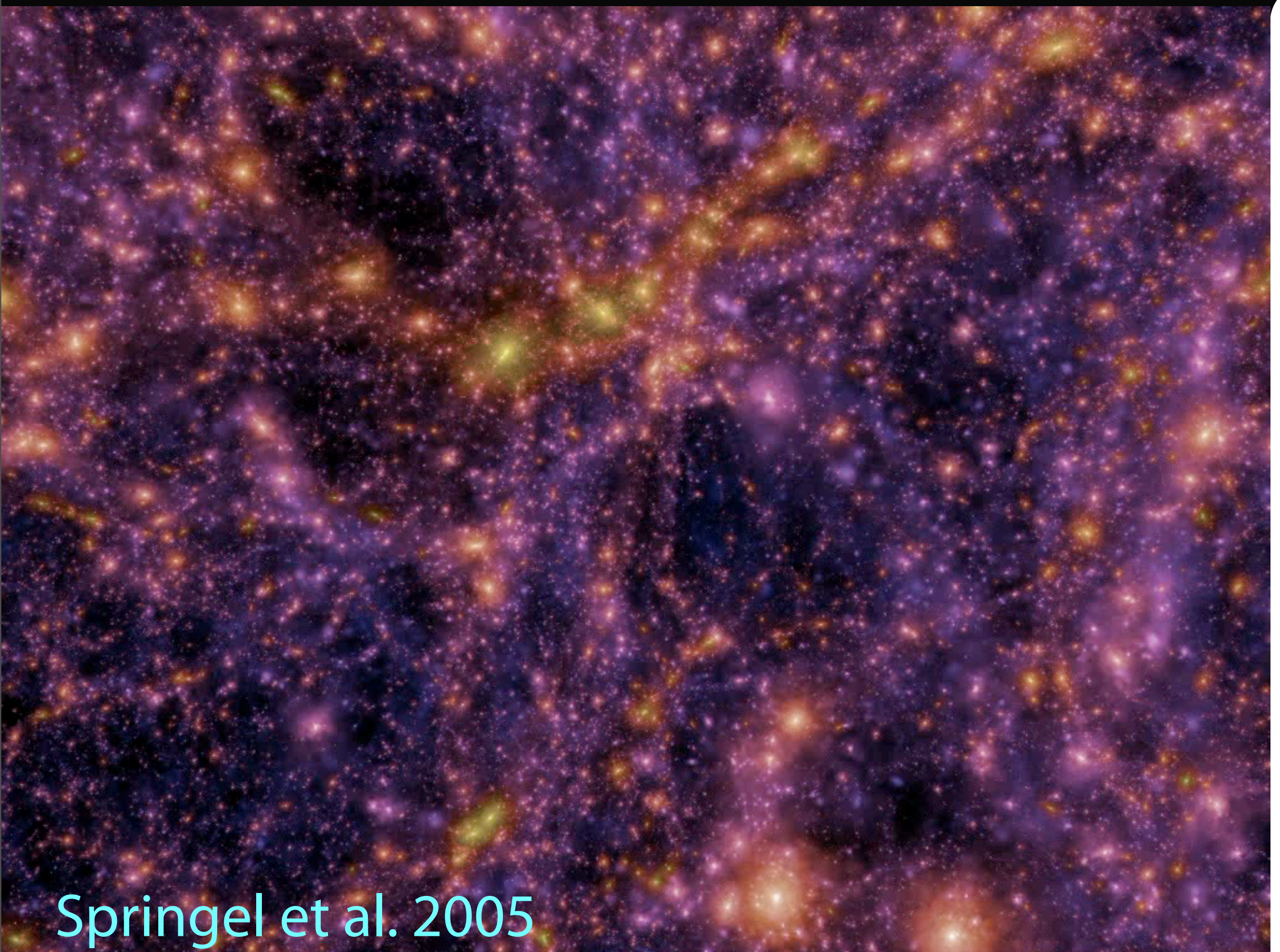
with the StarTrack PS code (Belczynski et al. 2008)

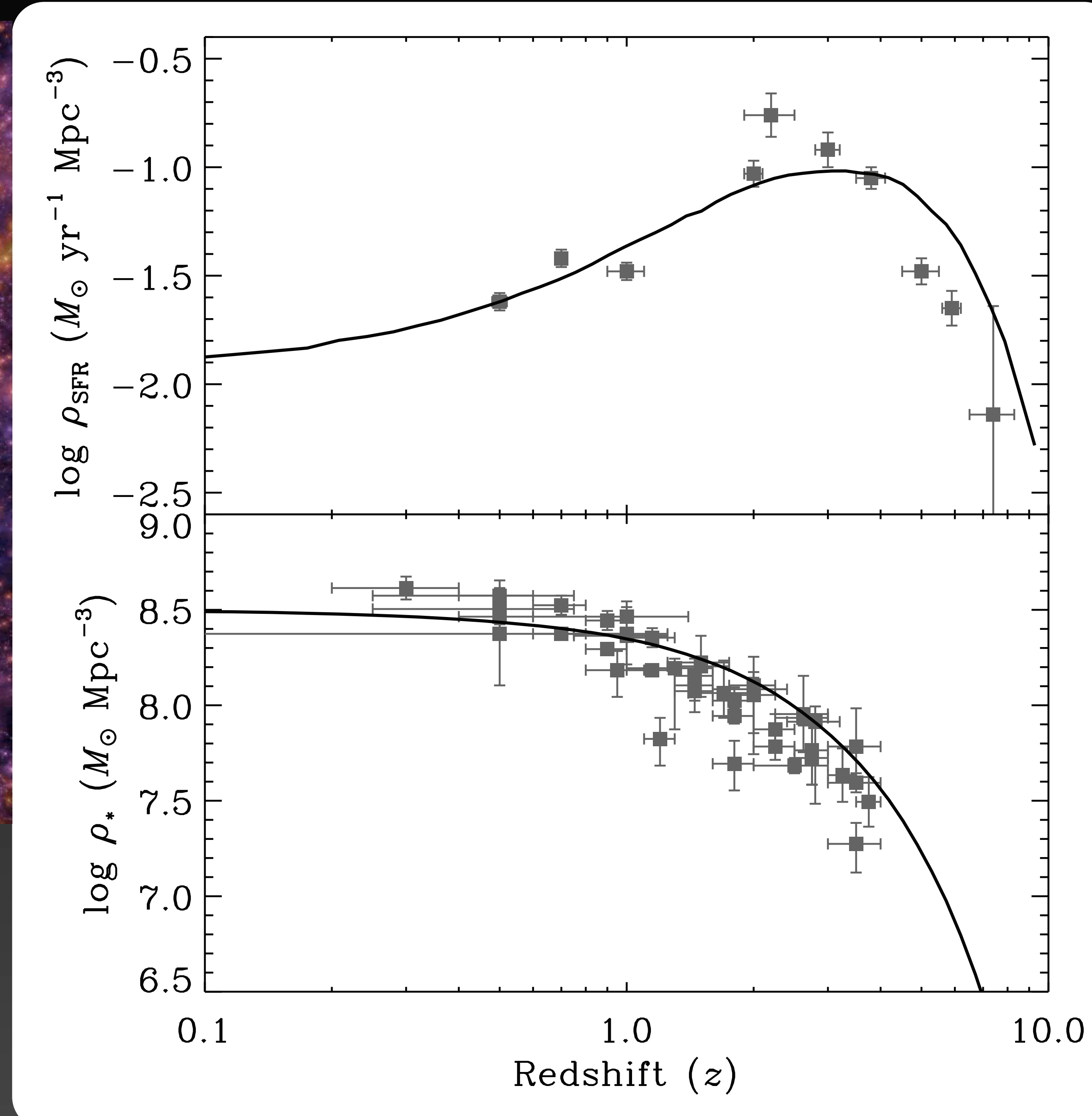
- **Preliminary parameter space study**: 25 PS models for 9 metallicity values and ~20 Million binaries per model
- **Target parameter space study:** 100 PS models for 9 metallicity values and ~100 Million binaries per model
- Available computational resources:
  - 300,000 cpu hours @ Quest HPC cluster (NU)
  - 300,000 cpu hours @ Discover HPC cluster (NCCS)
  - Priority access @ Fugu HPC cluster (astro-NU)
  - **Total of ~1,000,000 cpu hours**

Modeling the X-ray Luminosity from a Single Stellar Population



The Millennium Simulation





Semi-analytical galaxy catalogue by De Lucia et al. 2006

Stellar mass, SFR, gas mass, type, and metallicity as a **function of time** for all galaxies in a 62.5Mpc^3/h volume

Bouwens et al. 2004
Marchesini et al. 2009

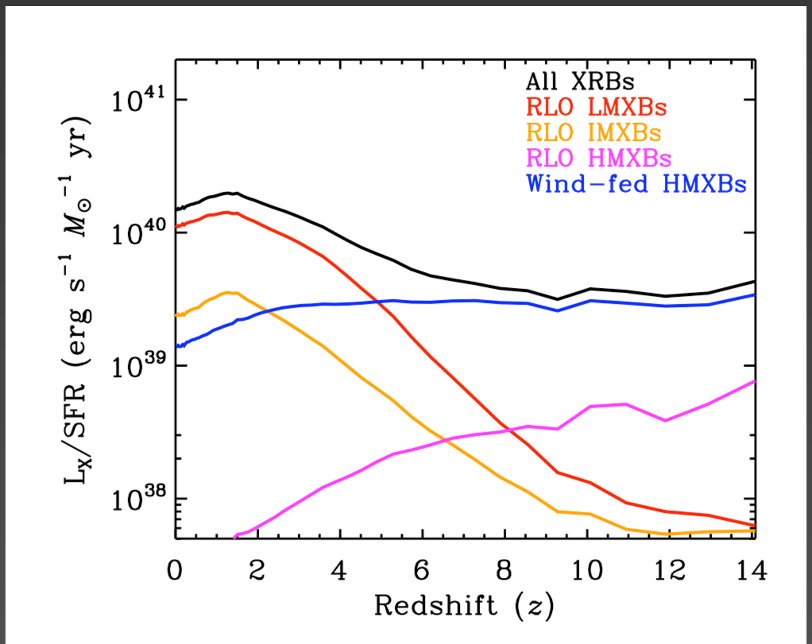
Combining the two simulations

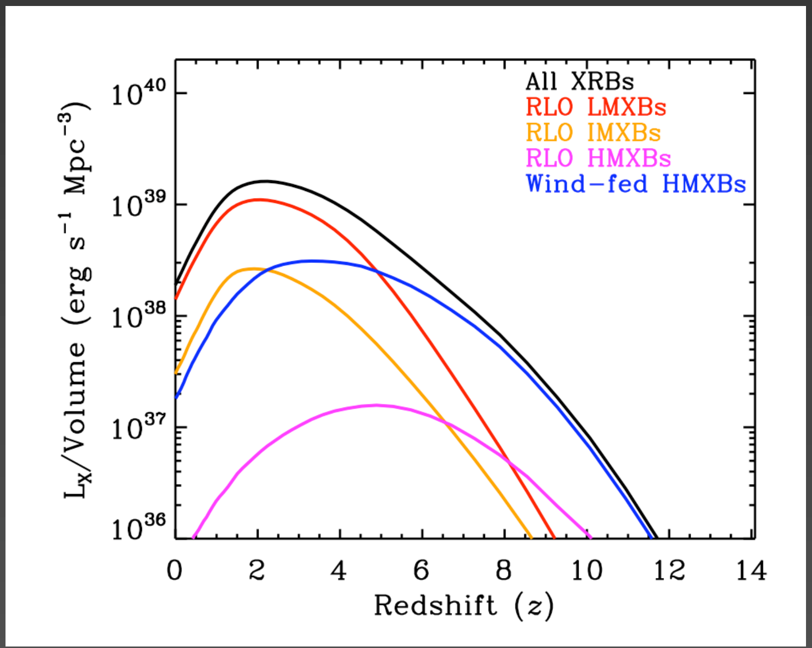
- From the ***Millennium Simulation*** we track the new stellar mass formed at each metallicity bin as a function of time.
- Using the ***StarTrack*** models, we add new stellar population according to the star formation history
- The resulting XRB population is a **mix of populations at different ages and different metallicities**

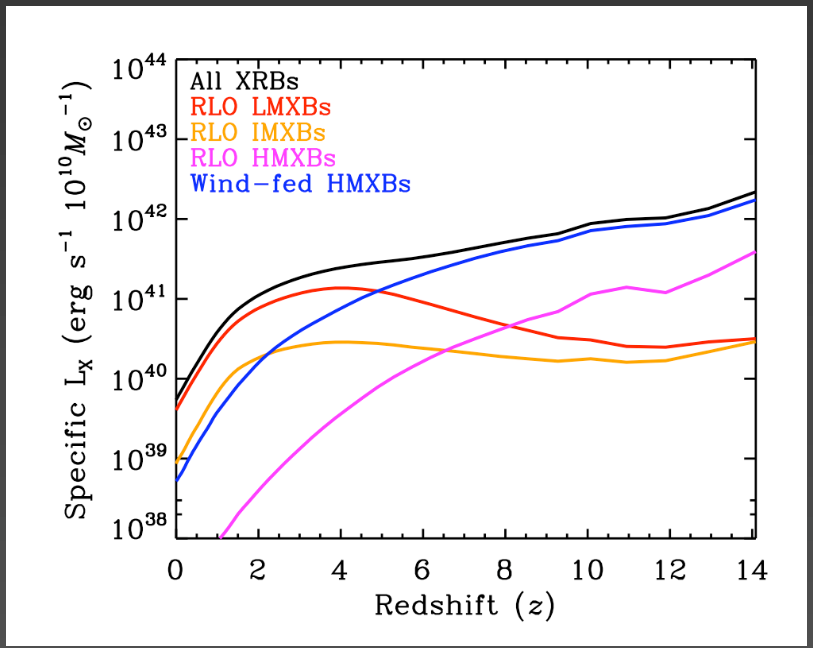
LMXB: $M_{donor} < 2M_\odot$

IMXB: $2M_\odot < M_{donor} < 10M_\odot$

HMXB: $M_{donor} > 10M_\odot$



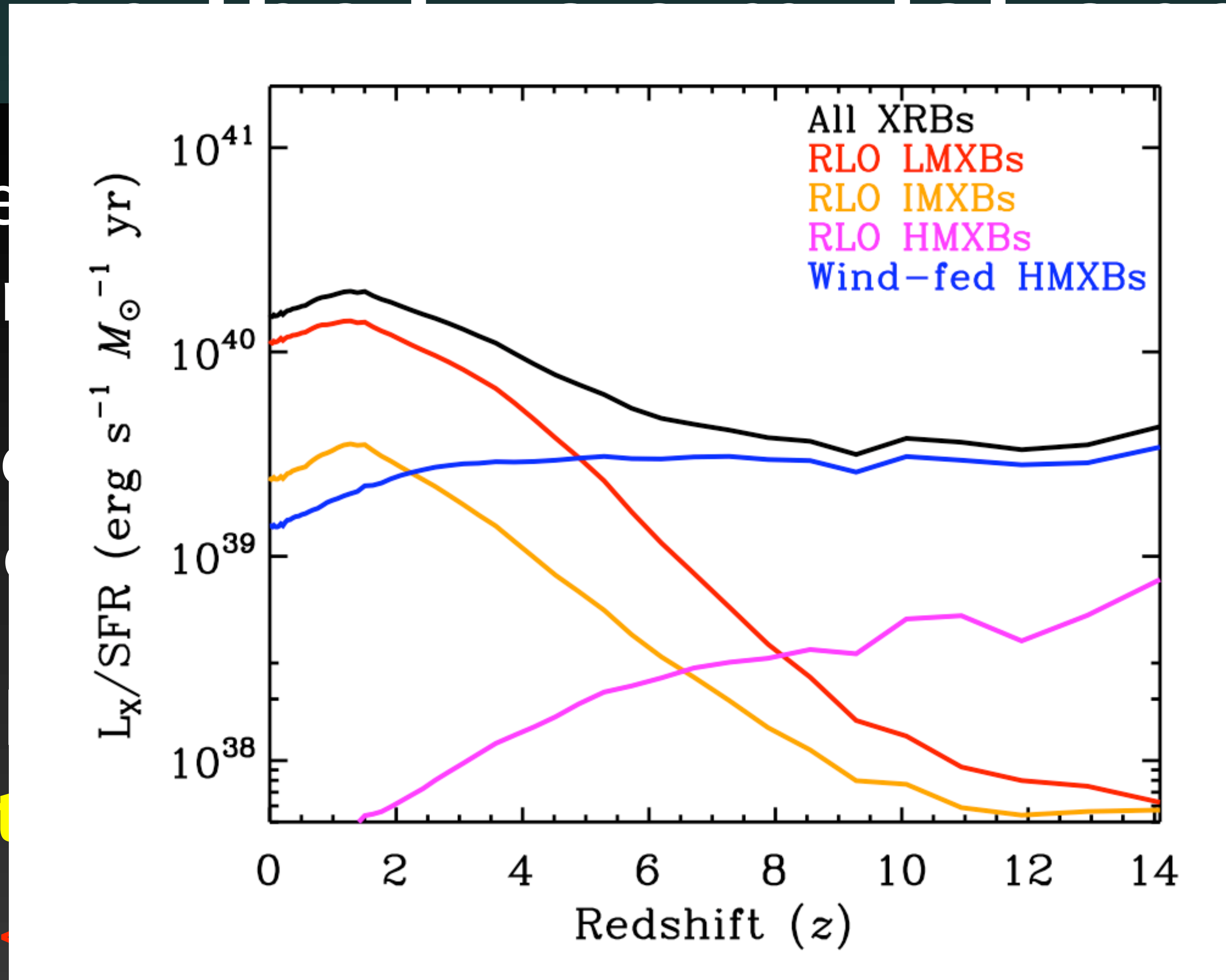


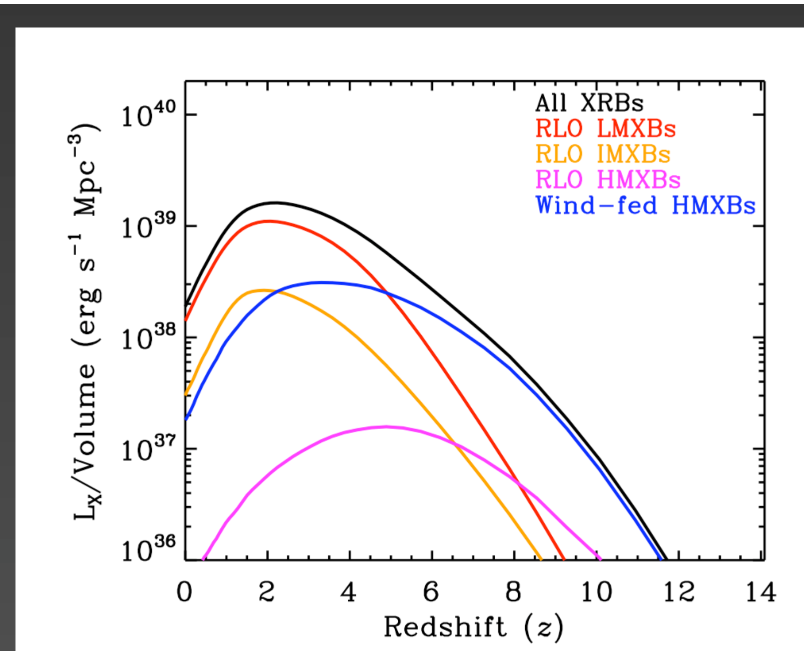


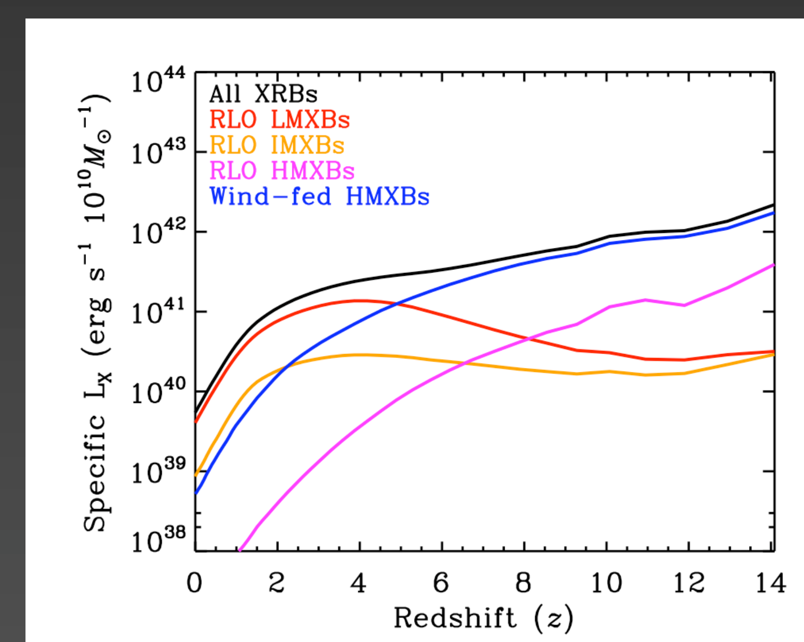
Combini...

- From the ... ew stellar mass for... on of time.
- Using th... r populati... tory
- The resu... **ations at different...**

LMXB: M_{donor}... : $M_{donor}>10M_\odot$



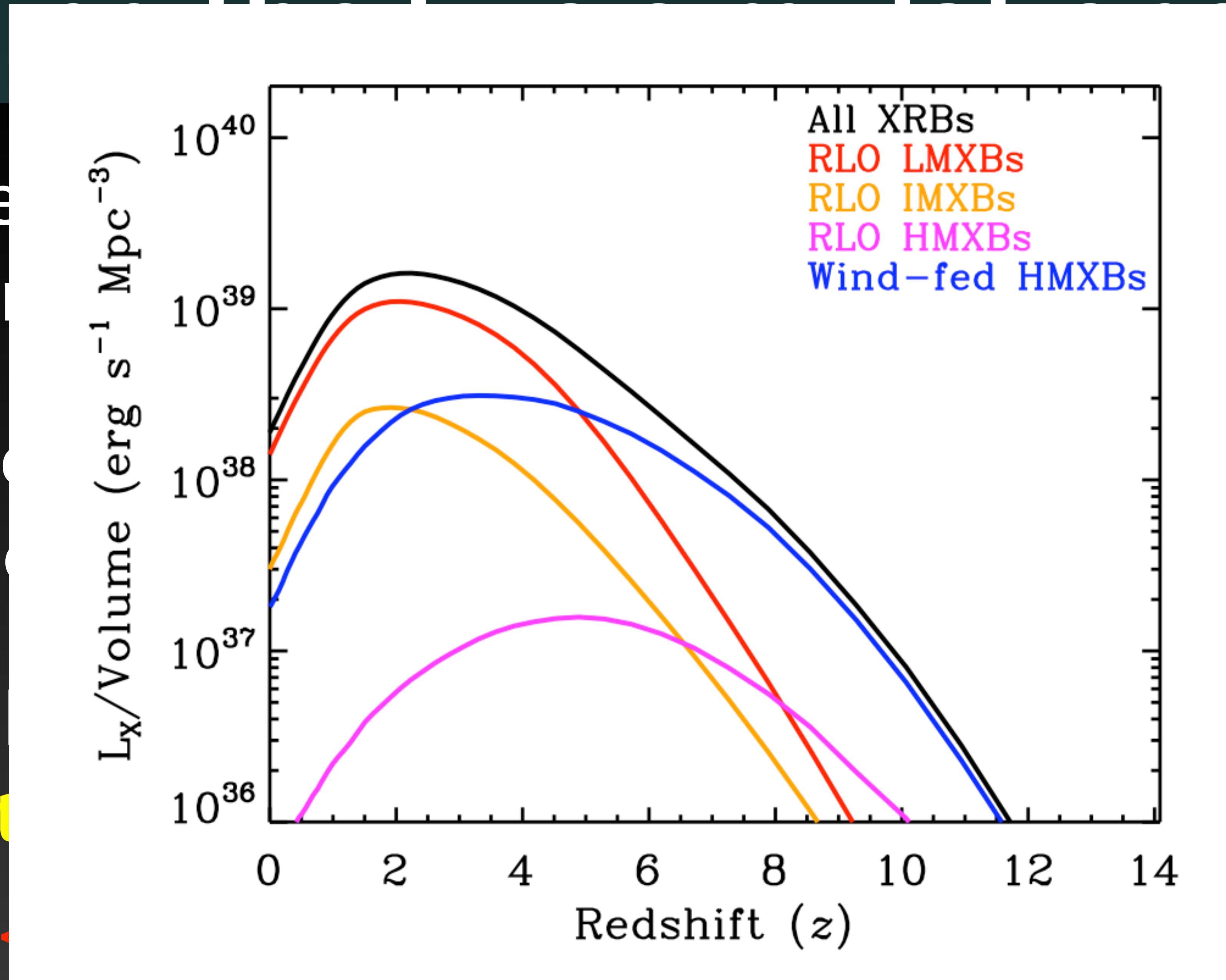


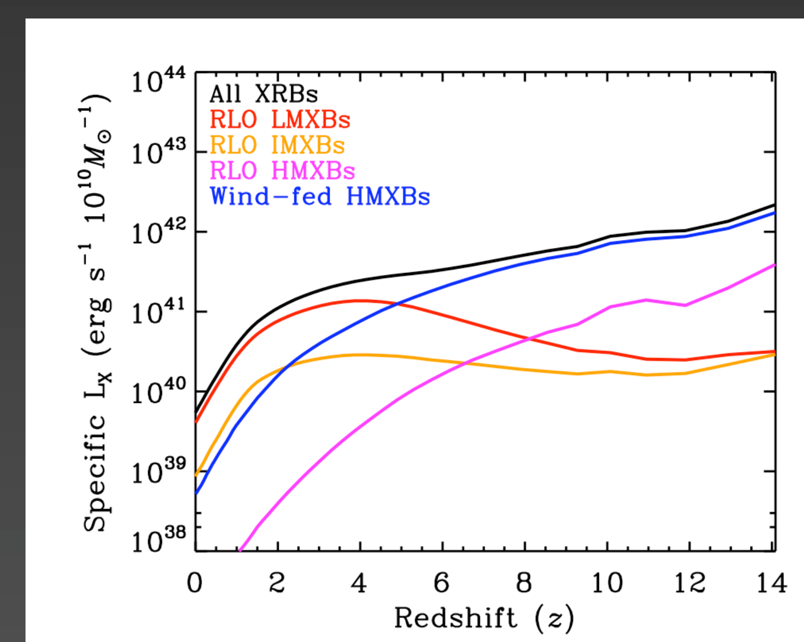


Combini…

- From the … new stellar mass for… on of time.
- Using th… r populati… tory
- The resu… **ations at differen…**

LMXB: M_{donor}< … : M_{donor}>10$M_\odot$





Combini

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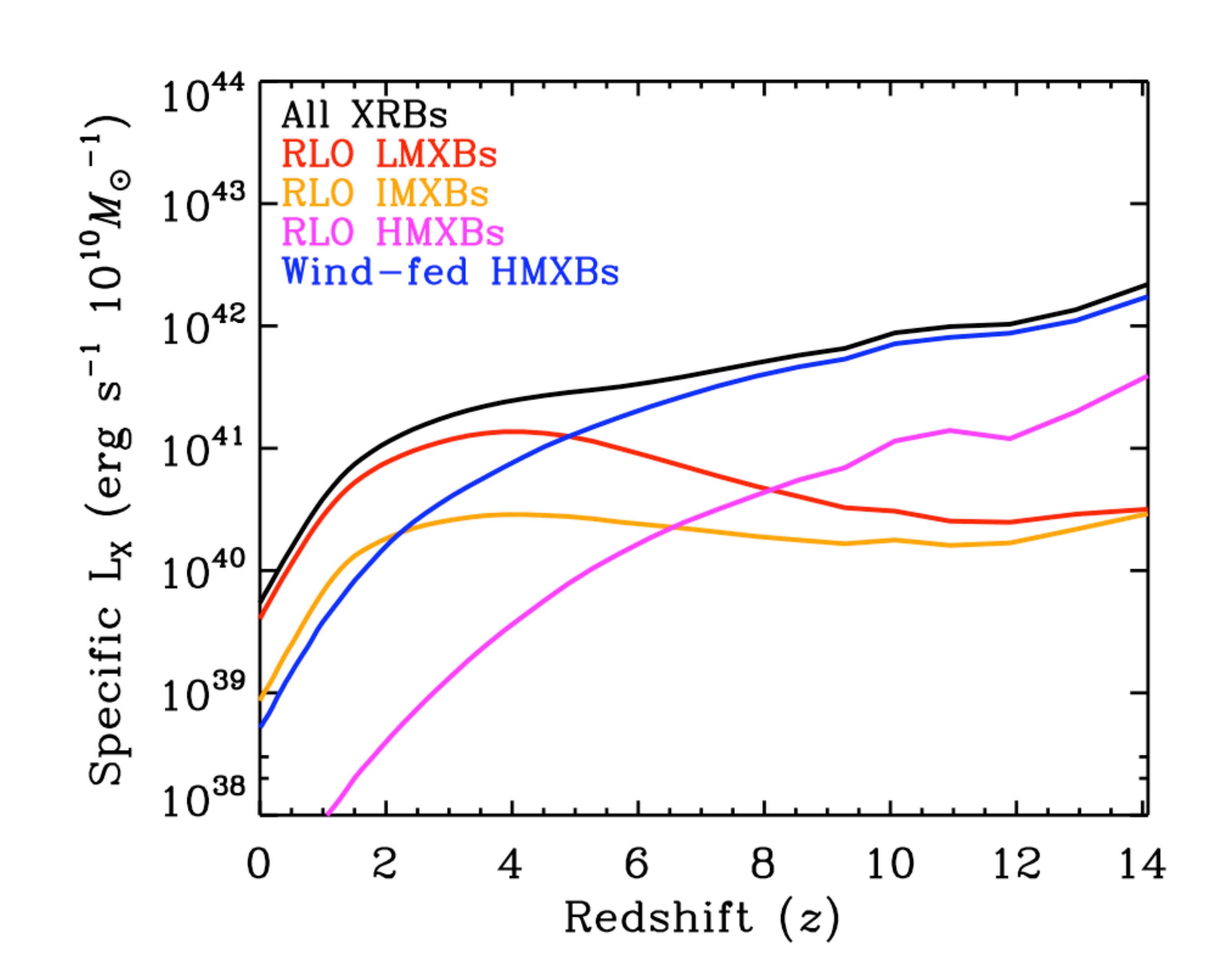
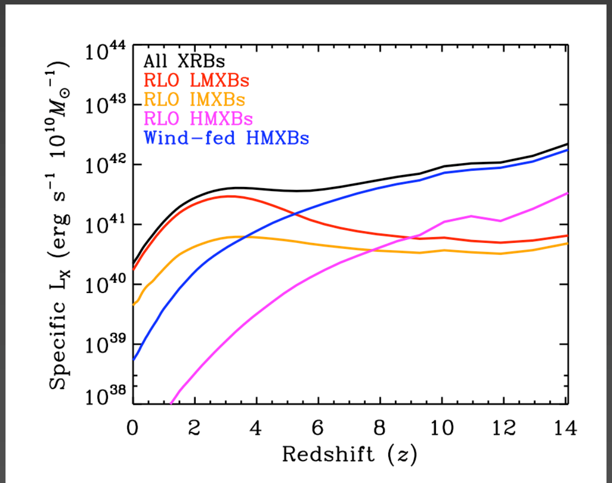


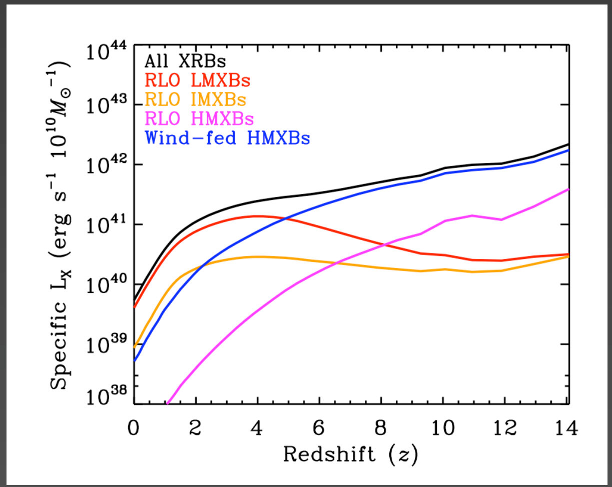
Exploring the Parameter Space

- For the first time we are taking into account **simultaneously multiple observational constraints**
- Tentative parameter study: 25 PS models varying:
  CE efficiency, Stellar winds, SN kicks
  IMF, initial mass ratio and orbital period distribution
- Dominant effects:
  CE efficiency for LMXB and **Stellar winds for HMXBs**

LMXBs

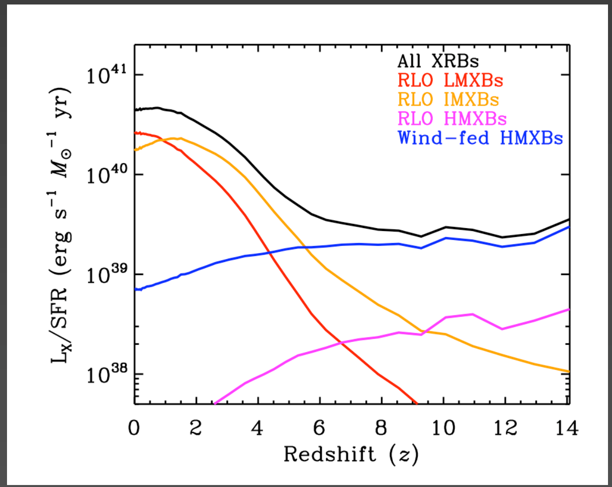
$\alpha_{ce}=0.5$ $\alpha_{ce}=0.1$

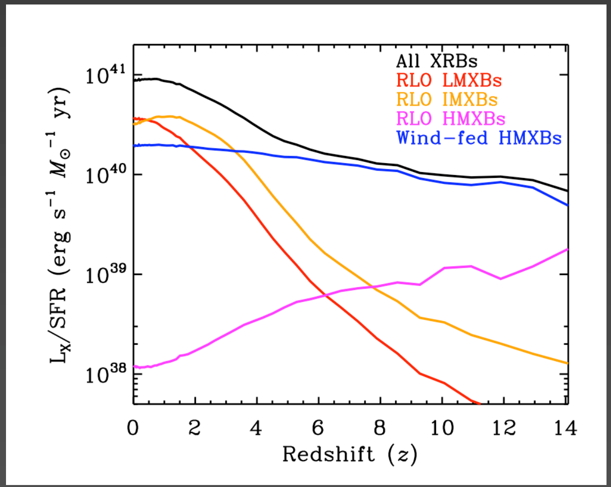




HMXBs

$\eta_{wind}=2.0$ $\eta_{wind}=0.25$





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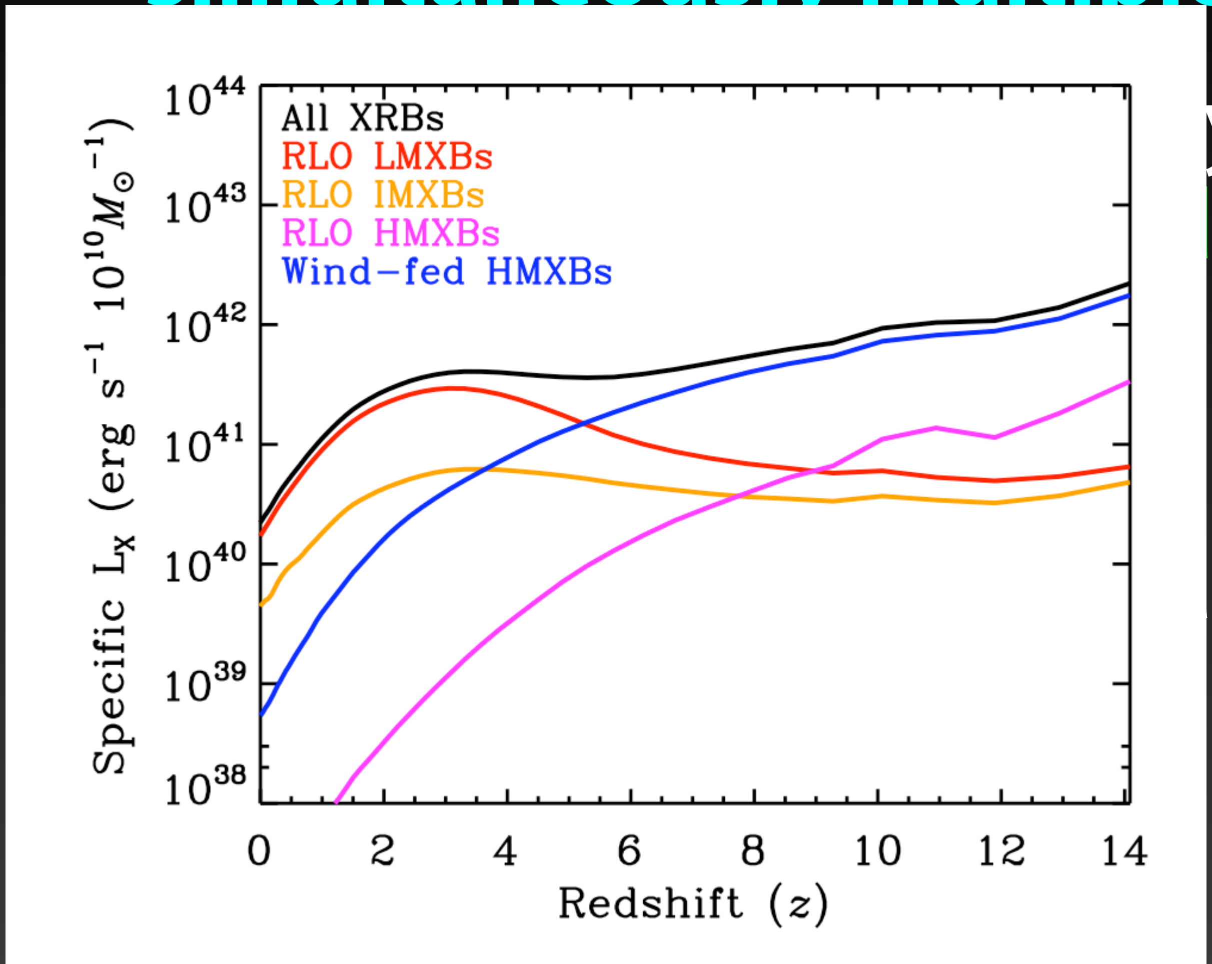
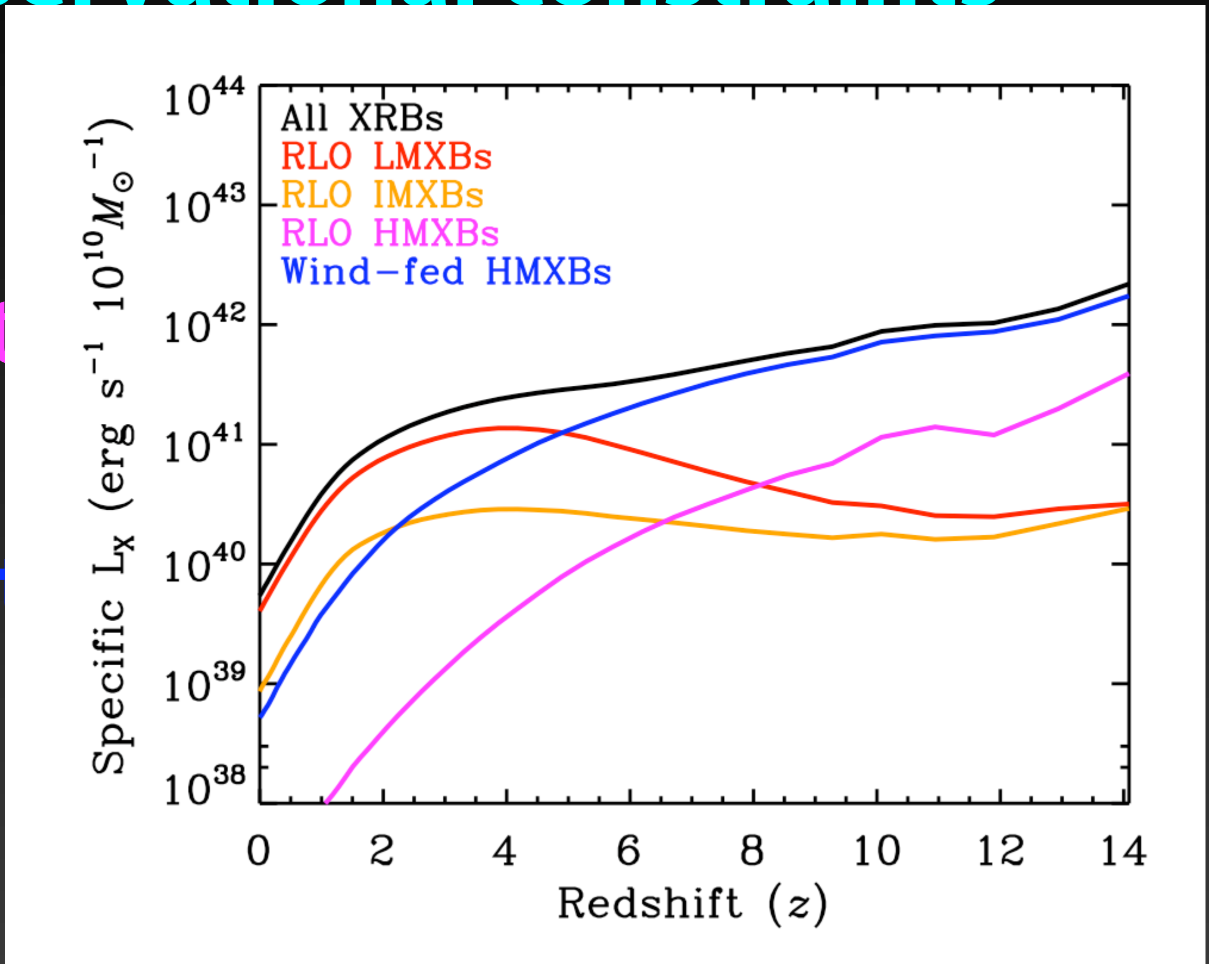


y: 25

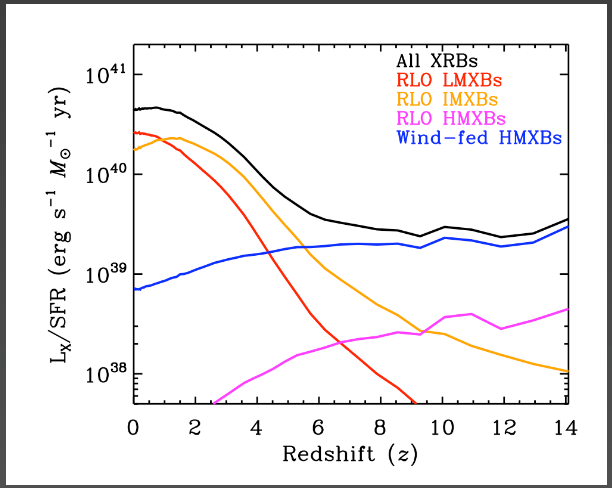
s, SN

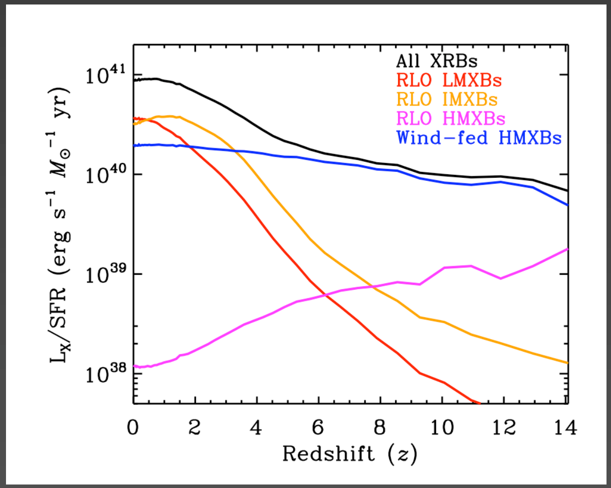
orbit

nd S



$\alpha_{ce}=0.3$ $\alpha_{ce}=0.1$ $\eta_{wind}=2.0$ $\eta_{wind}=0.25$





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y: 25

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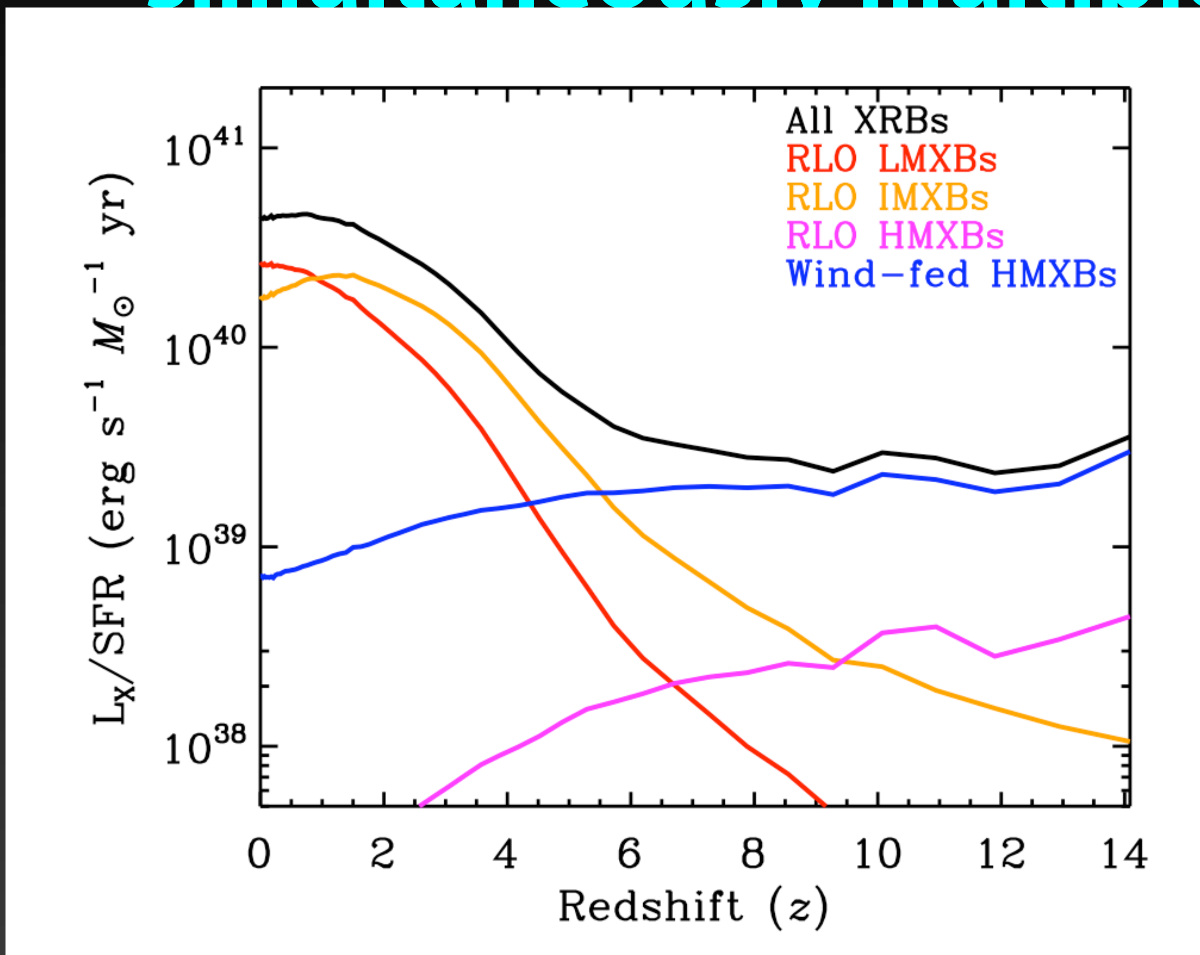
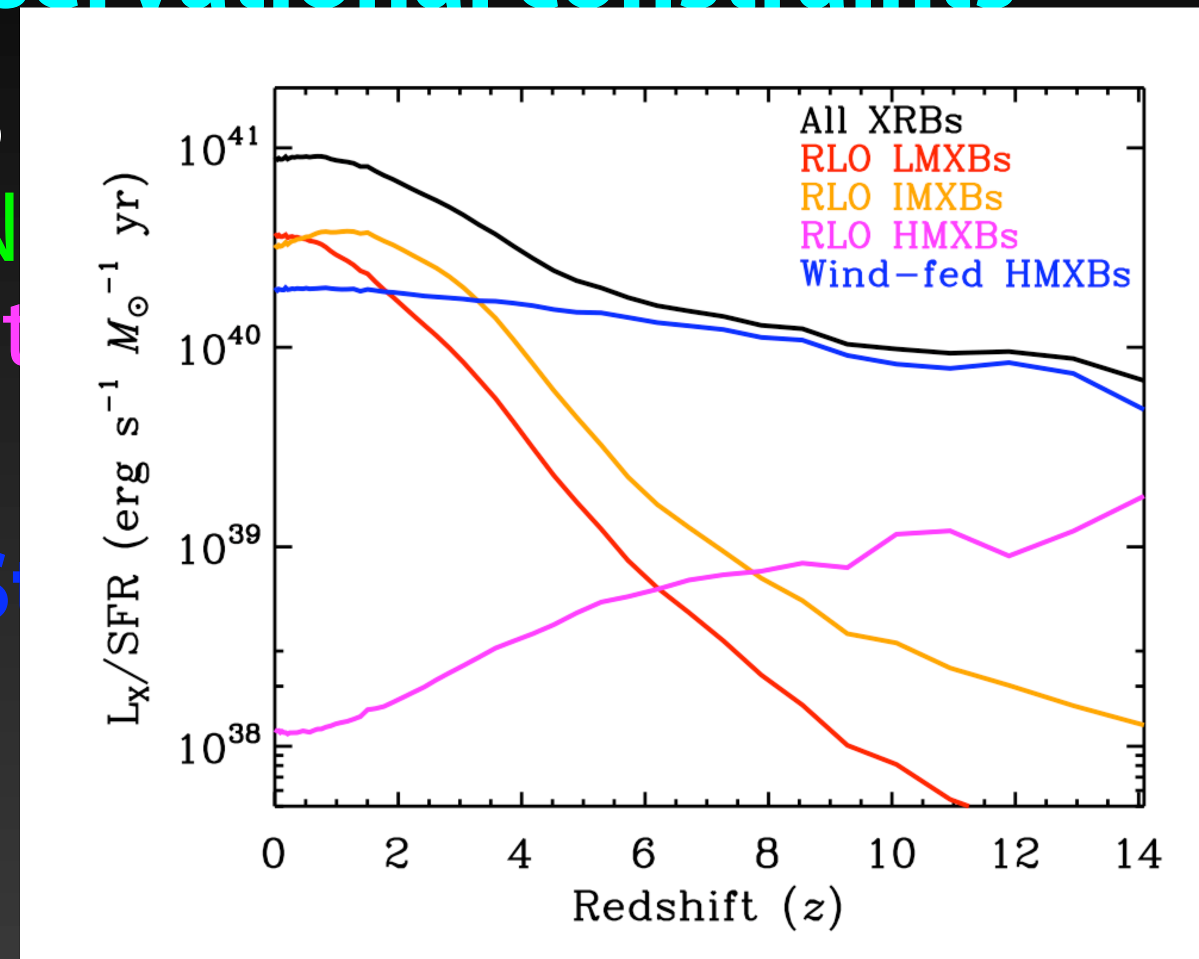
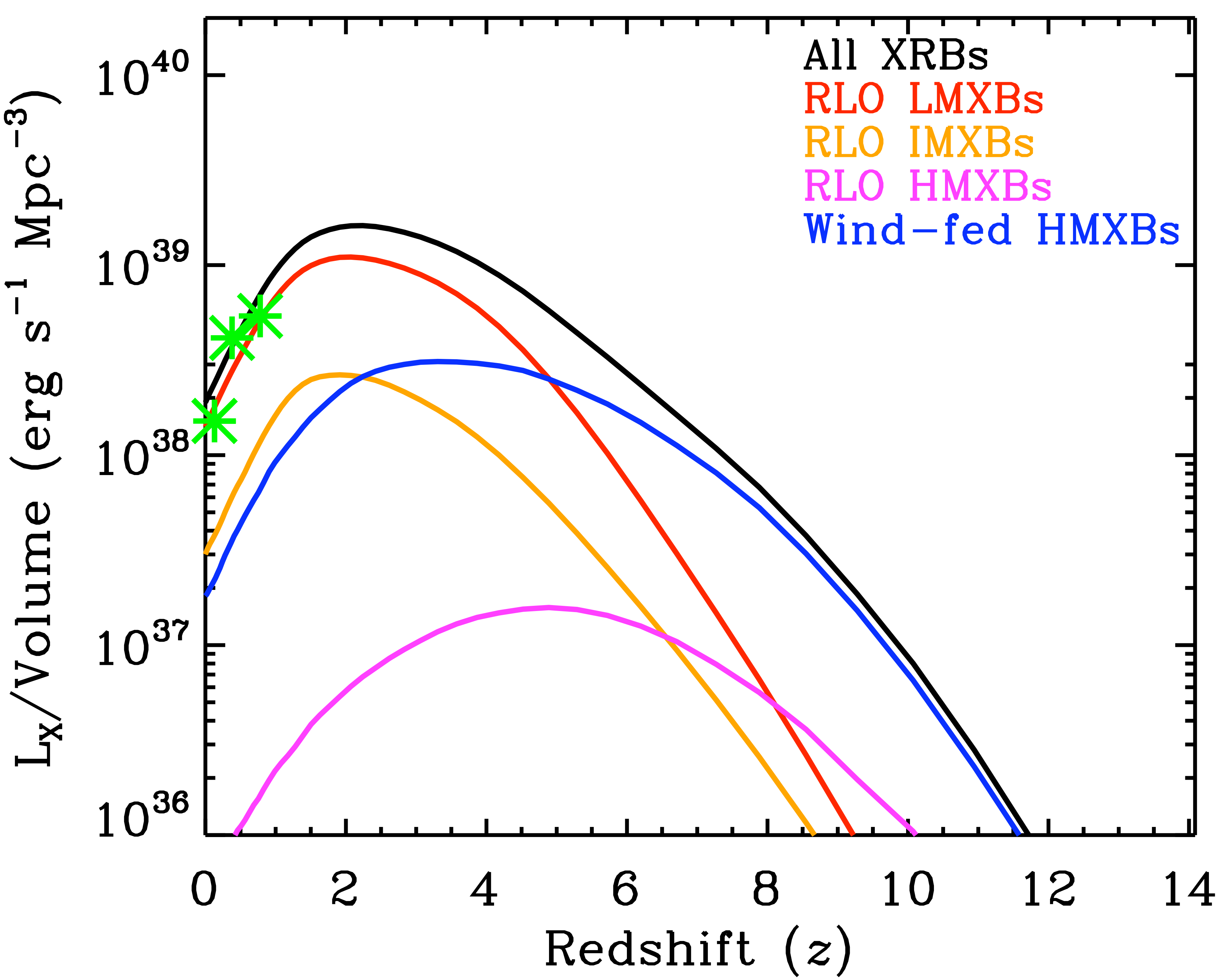
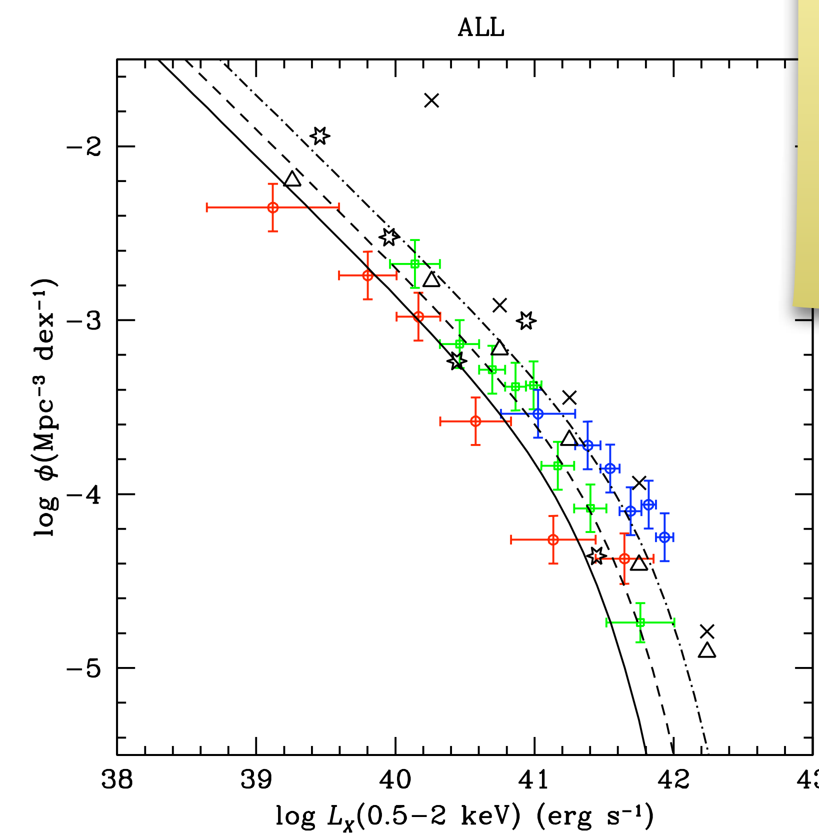




$\alpha_{ce}=0.5$ $\alpha_{ce}=0.1$ $\eta_{wind}=2.0$ $\eta_{wind}=0.25$

Observational Constraints I:
Total X-ray luminosity





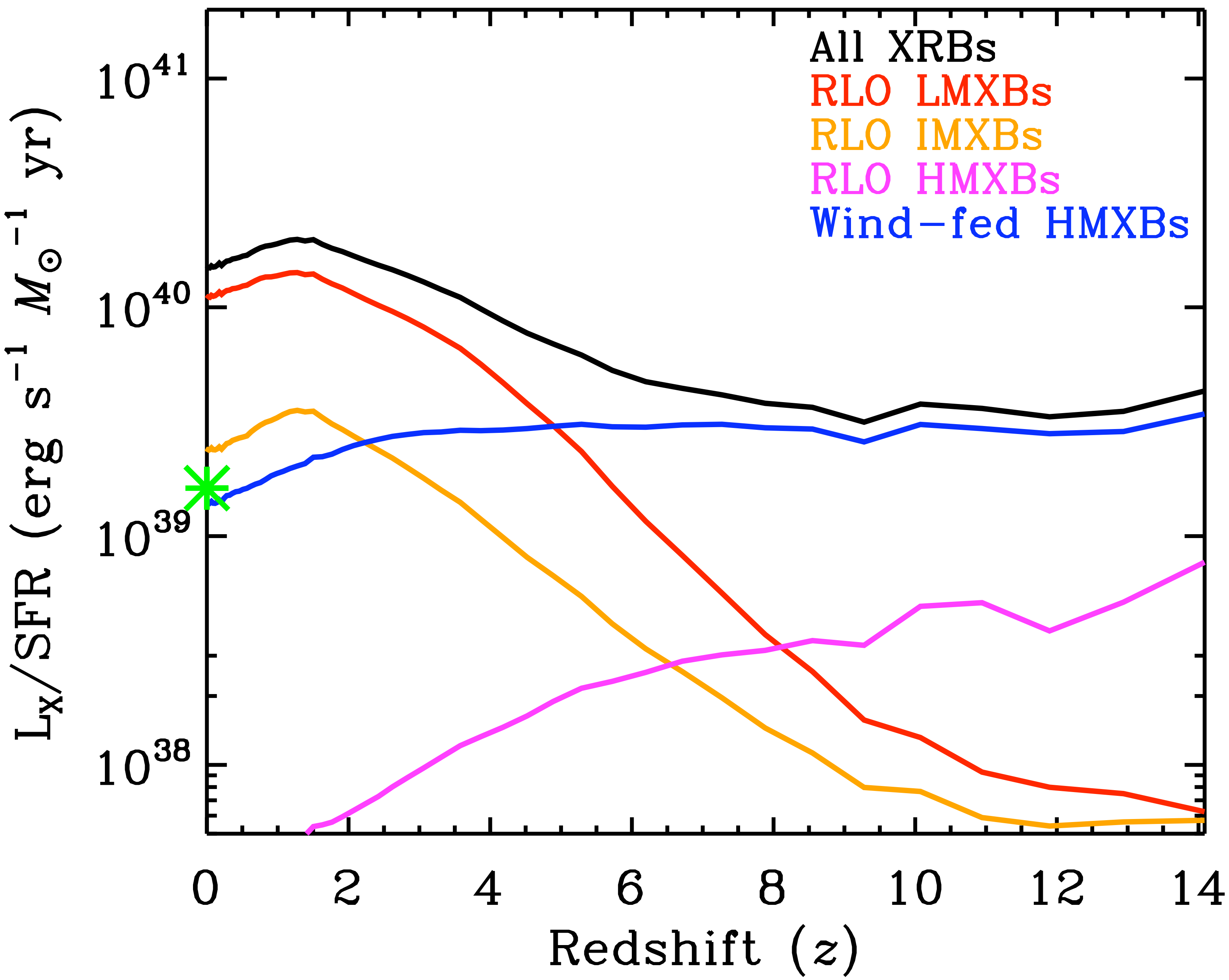
Tzanavaris & Georgantopoulos 2008

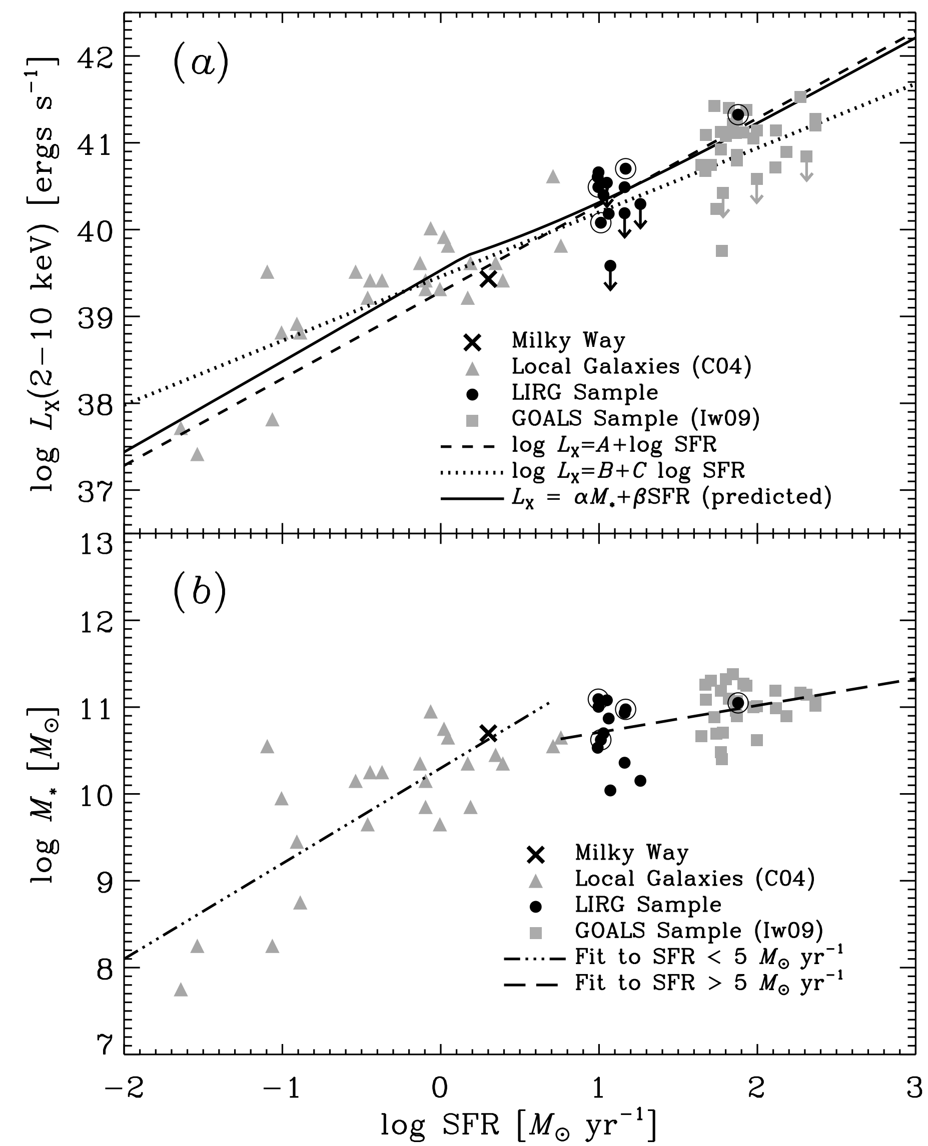
XLF of normal galaxies at 3 redshift bins:

0<z<0.2, 0.2<z<0.6, 0.6<z<1.4

Other
work
of Kim
Norma
shown
triangle

Observational Constraints II: Wind-fed HMXBs





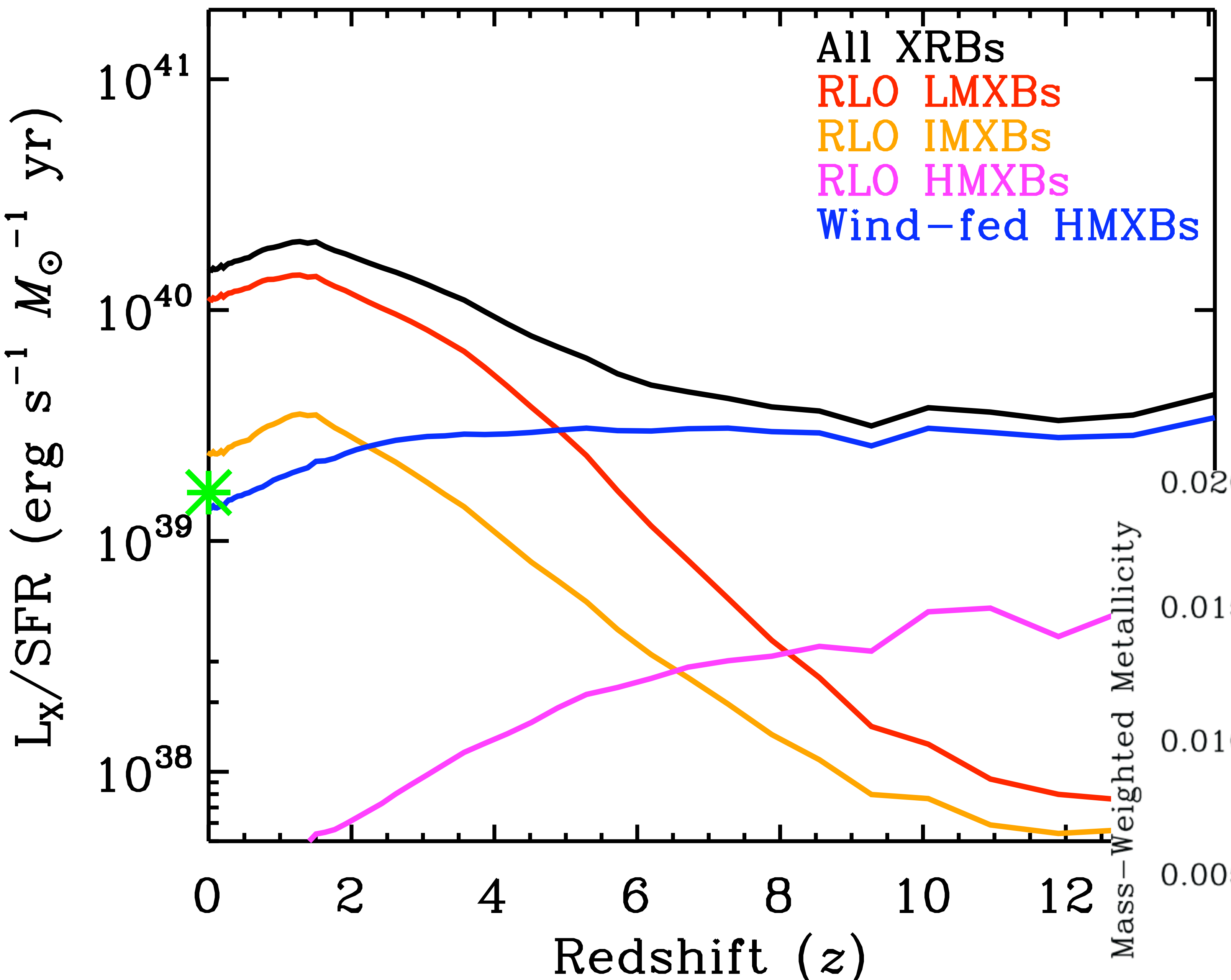
Lehmer et al. 2010

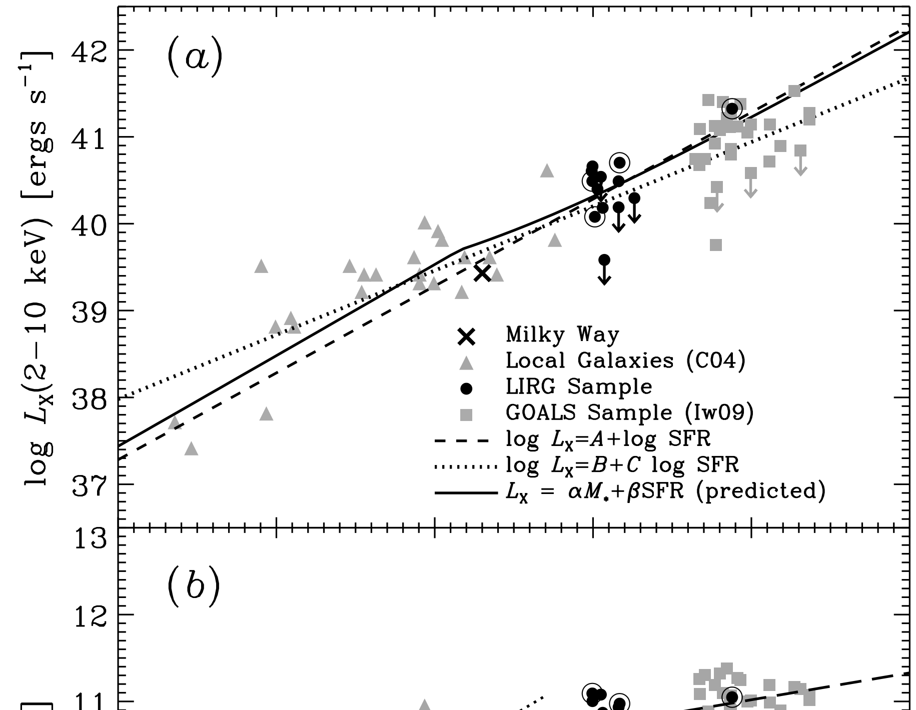
$$L_{\rm HX}^{\rm gal} = L_{\rm HX}^{\rm gal}({\rm LMXB}) + L_{\rm HX}^{\rm gal}({\rm HMXBs}) = \alpha M_\star + \beta {\rm SFR},$$

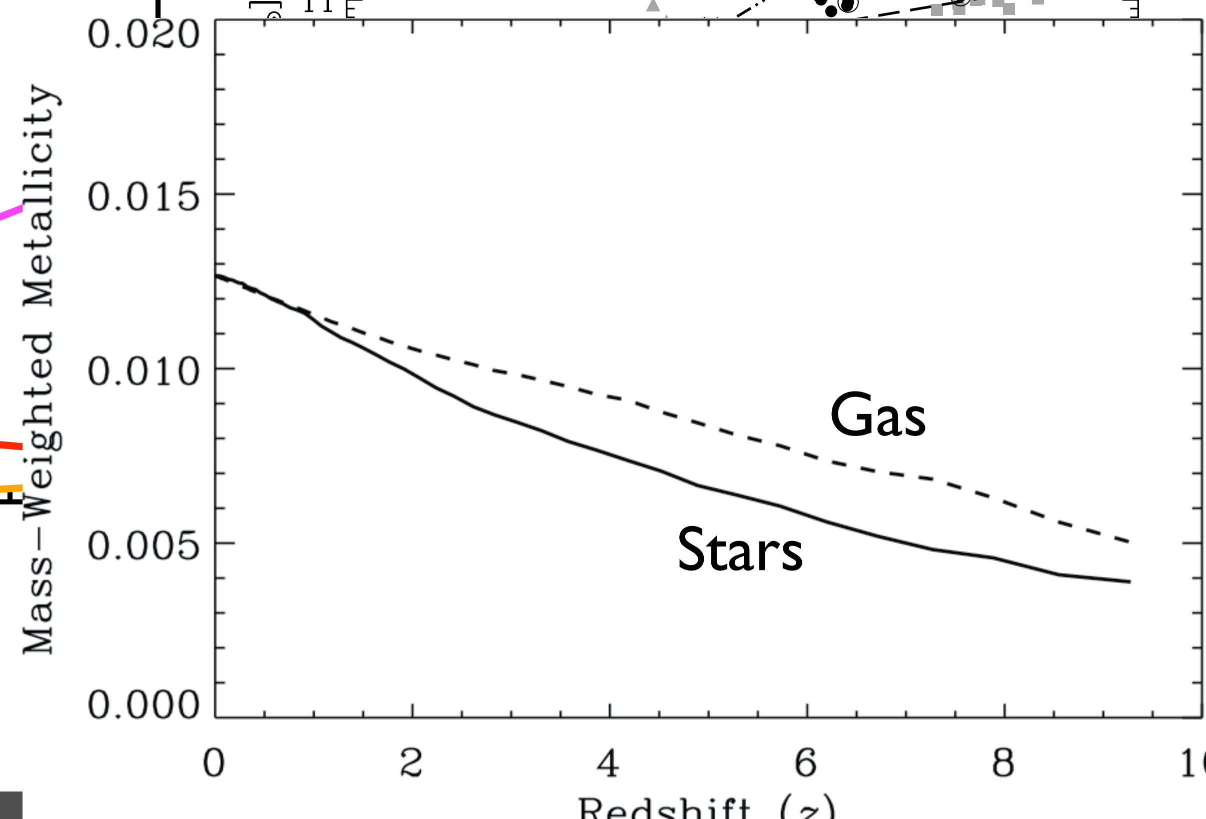
$$\alpha = (9.05 \pm 0.37) \times 10^{28}\ {\rm ergs\ s^{-1}}\ M_\odot^{-1}$$

$$\beta = (1.62 \pm 0.22) \times 10^{39}\ {\rm ergs\ s^{-1}}\ (M_\odot\ {\rm yr^{-1}})^{-1}$$

Observational Constraints II: Wind-fed HMXBs

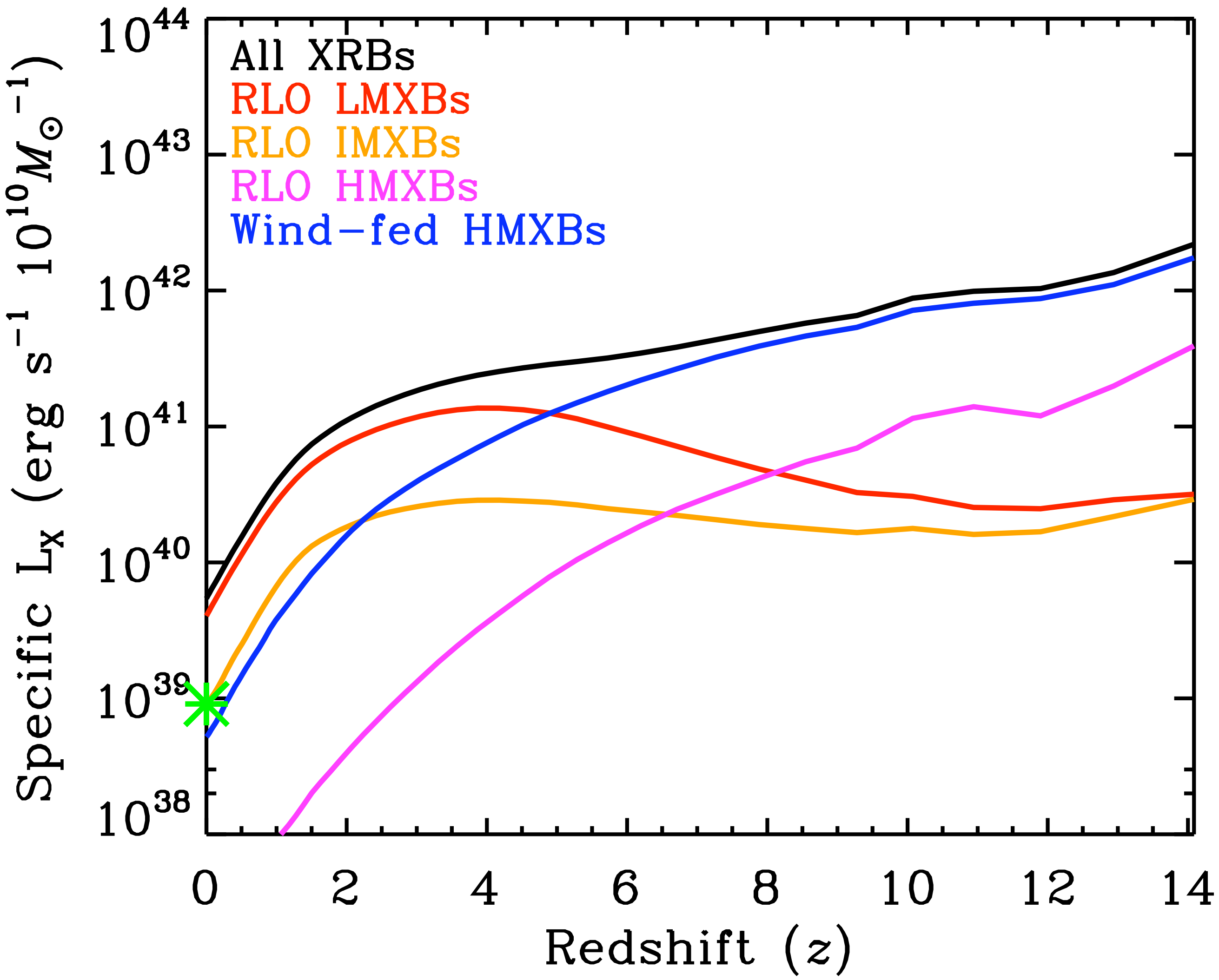


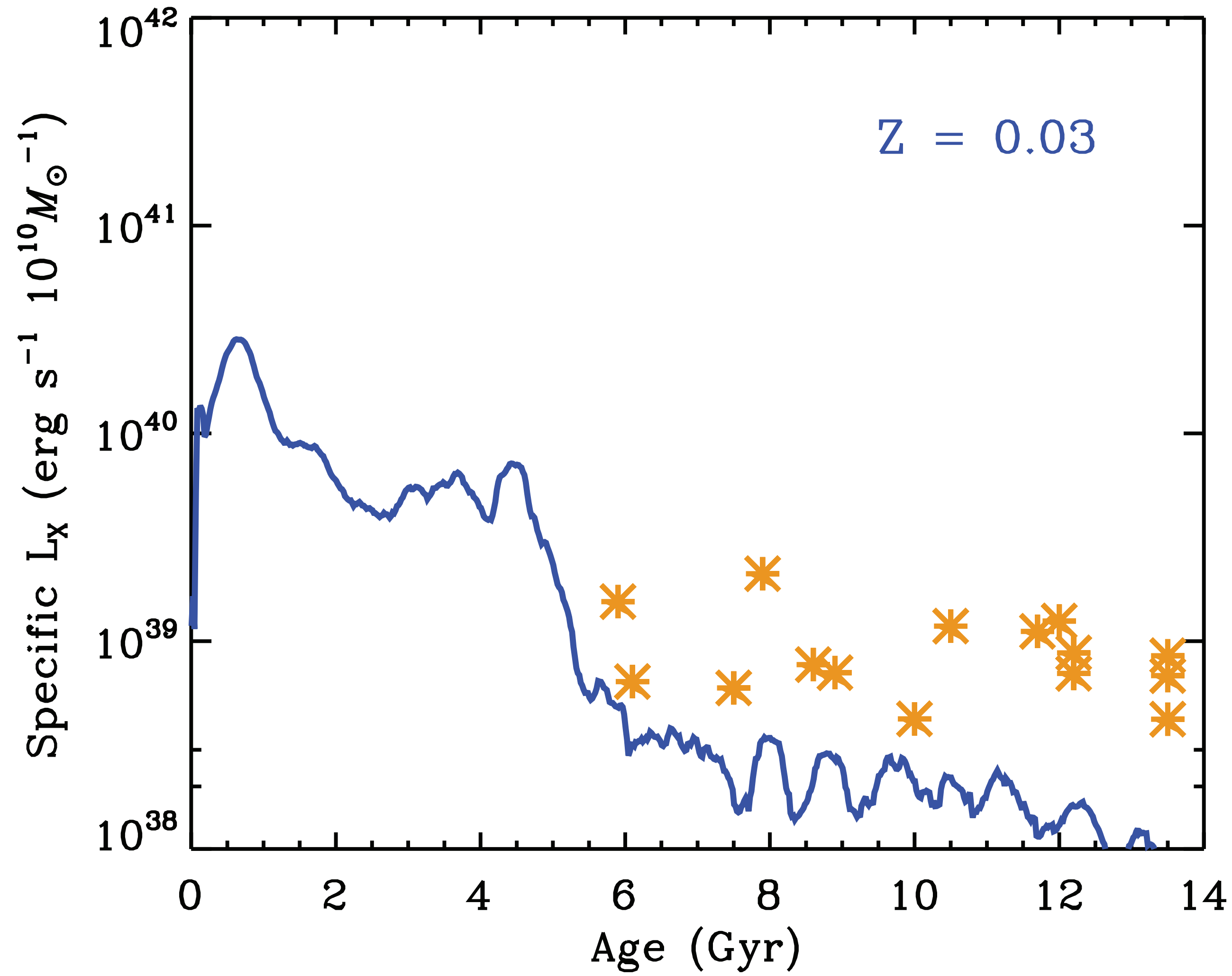




Observational Constraints III: LMXBs

☹





Lehmer et al. (2010)

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Boroson, Kim & Fabbiano (2010, in prep.)

selection of ellipticals with
total Lx, M*, Age, [Fe/H] measurements

Summary

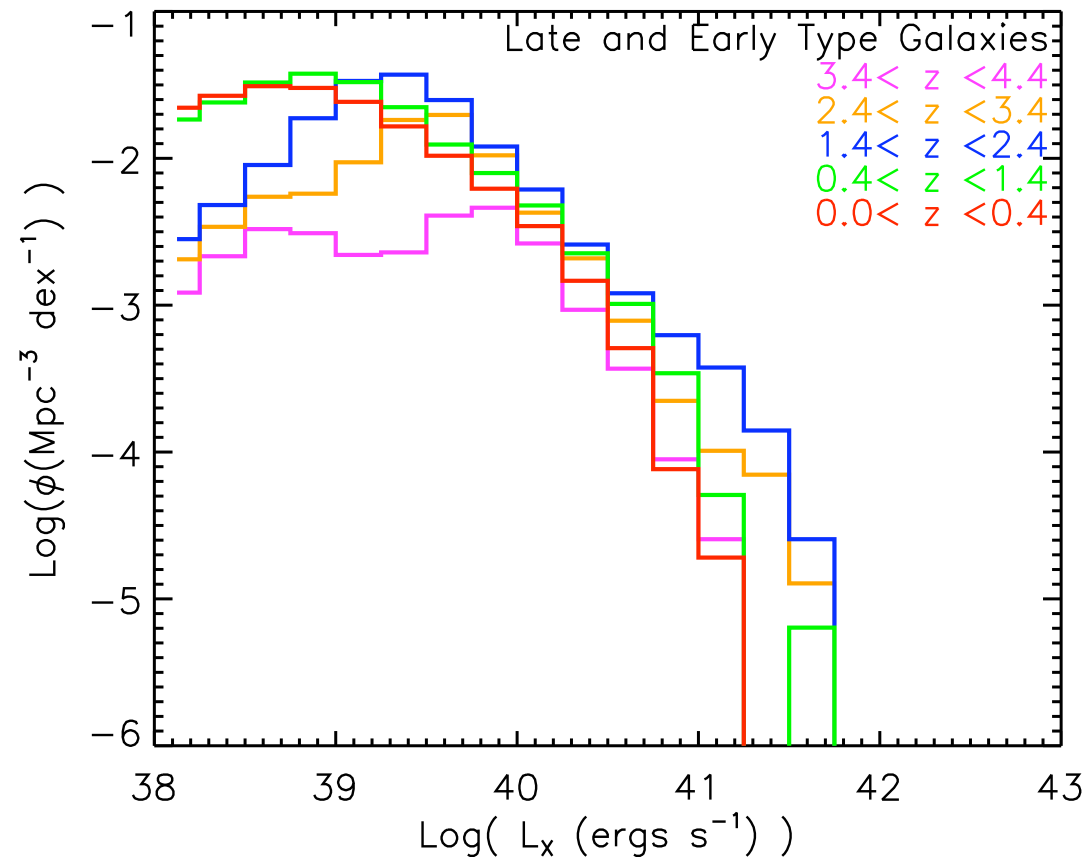
We are building **the largest PS model library** in order to study the **evolution of XRBs at high redshifts**, **using cosmological simulations as input** in our modeling.

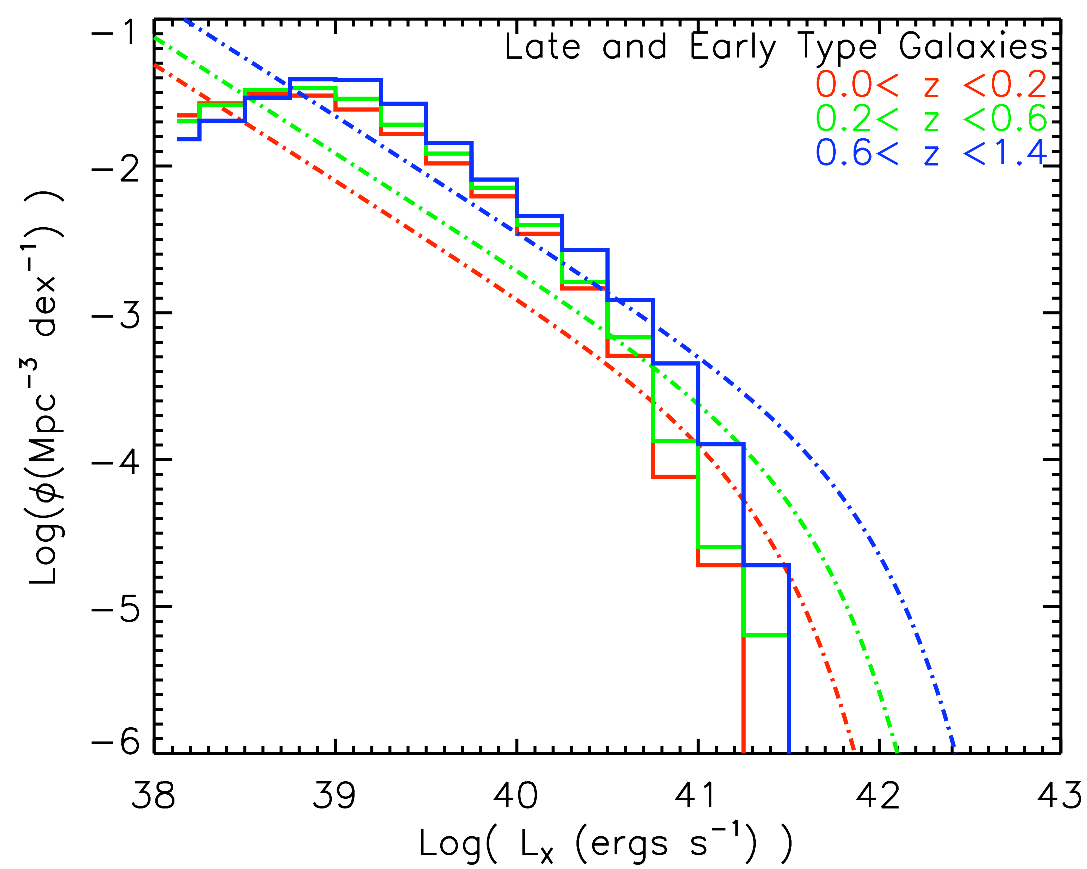
- We predict an inversion in the evolution of galaxy XLFs at a redshift of ~2
- The contribution of wind-fed HMXBs ($L_{X,HMXBs}$/SFR) is increasing with z, as a result of metallicity evolution.
- Average delay between star formation and peak Lx from LMXBs is ~1.2Gyr
- Constraining the LMXB population seems problematic. Are old elliptical galaxies really old?

Work in Progress...

- Completion of PS model library
- Comparison in a galaxy by galaxy basis
- Modeling the spectral states of XRBs to refine bolometric corrections
- Modeling of selection effects in galaxy surveys
- Use as a constraint the XLFs of the most well observed nearby ellipticals, after revisiting their observational age estimates.

- Do LMXBs or HMXBs dominate our universe today?
- What is their relative contribution as a function of redshift?
- What is the contribution of XRBs to the re-ionization at high redshifts?





Modeling the X-ray Luminosity from a Single Stellar Population