Michela Mapelli (INAF, Padova Observatory)

# The impact of three-body encounters on the demographics of X-ray binaries in young star clusters

Collaborators: Elena Gavagnin (Zurich), Alessandro Trani (SISSA), Brunetto Ziosi (Padova University), Luca Zampieri (Padova Observatory), Emanuele Ripamonti (University of Padova), Alessandro Bressan (SISSA), Mario Spera (Padova Observatory)

The dance of stars, Bad Hoennef, Germany, June 5th 2014

# OUTLINE

1. IMPORTANCE of young star clusters (YSCs) for BH demographics and X-ray BH-binaries

2. Simulations of YSCs: method

3. Simulation of YSCs: DEMOGRAPHICS of Roche Lobe Overflow (RLO) BH-binaries

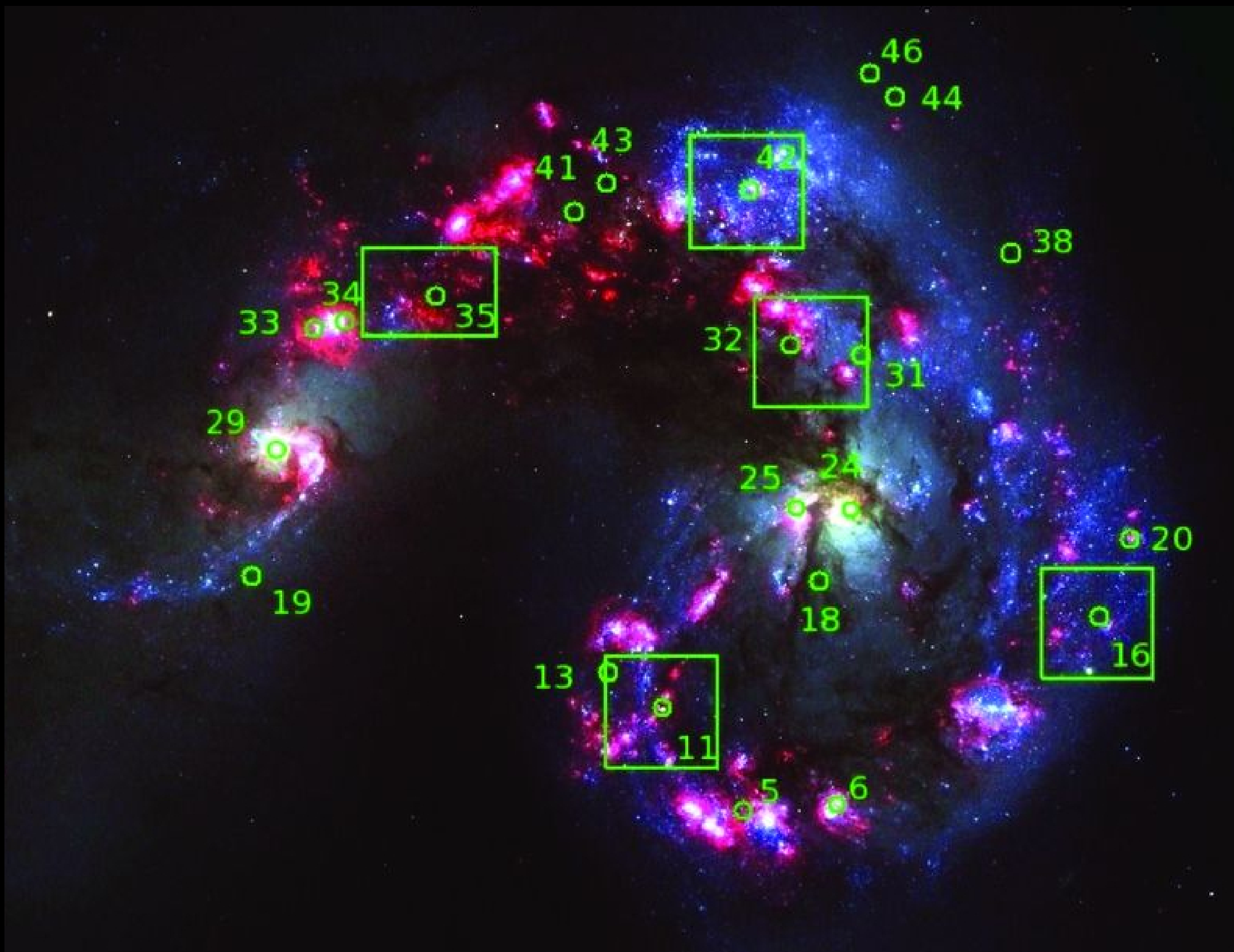
4. Comparison with observed ultraluminous X-ray sources (ULXs)

5. Conclusions

## 1. Importance of YSCs

– Large fraction (~80%) of stars form in young star clusters (YSCs, lada & lada 2003)

– Bright high-mass X-ray binaries are associated to YSCs




e.g. the Antennae

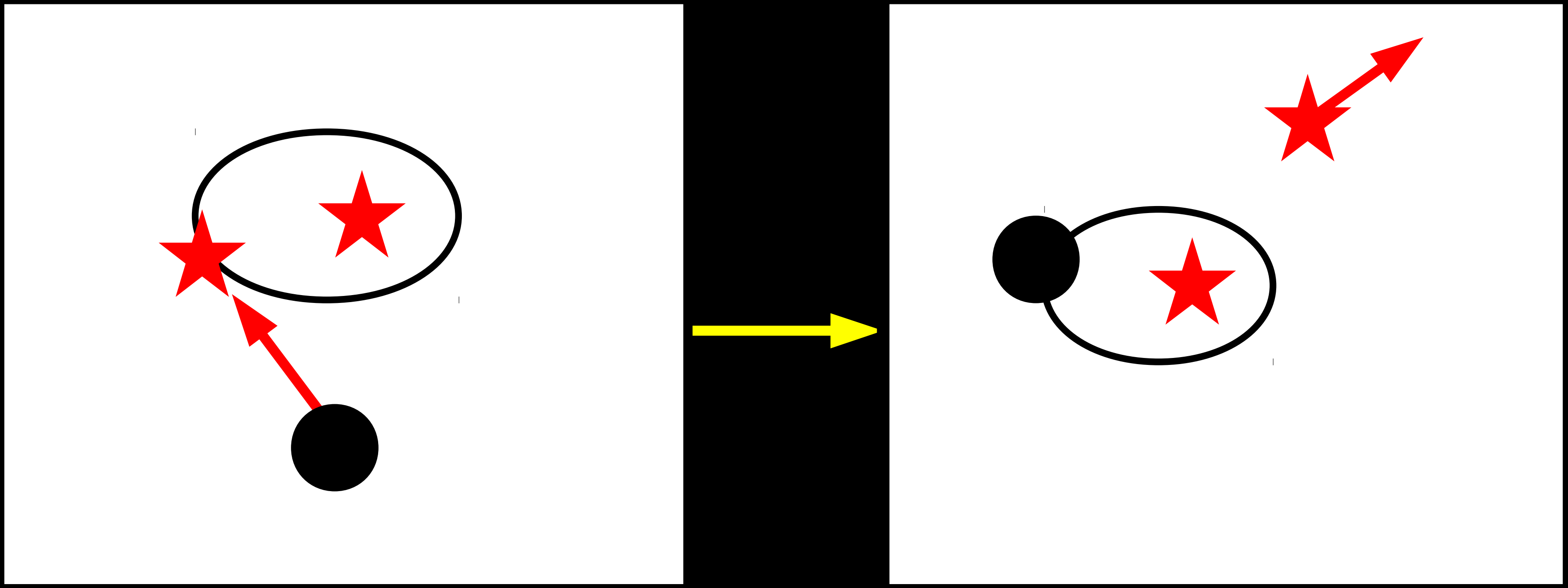
Poutanen et al. 2013
Rangelov et al. 2012

– DENSE YSCs ARE DYNAMICALLY ACTIVE: is this important for X-ray binaries?

*3-body encounters : = close interactions between a star and a binary system*

→ THE BINARY CAN EXCHANGE COMPANION

EXCHANGE PROBABILITY MAXIMUM FOR MASSIVE OBJECTS



→ 3-body encounters (and especially EXCHANGES) ENHANCE THE FORMATION OF BH-BINARIES

## 2. Simulations of YSCs: method

### STARLAB (Portegies Zwart+2001):

- accurate N-Body integration of SC dynamics
- stellar evolution at solar metallicity

### OUR VERSION OF STARLAB (MM+ 2013) INCLUDES

- METALLICITY DEPENDENCE of STELLAR EVOLUTION (Hurley+ 2000)
- METALLICITY DEPENDENT STELLAR WINDS for MS and WR (Vink+ 2001; Vink & de Koter 2005)
- METALLICITY-DEPENDENT RECIPES for SN and BH MASS (Mapelli+ 2009; Belczynski et al. 2010)

## 2. Simulations of YSCs: method

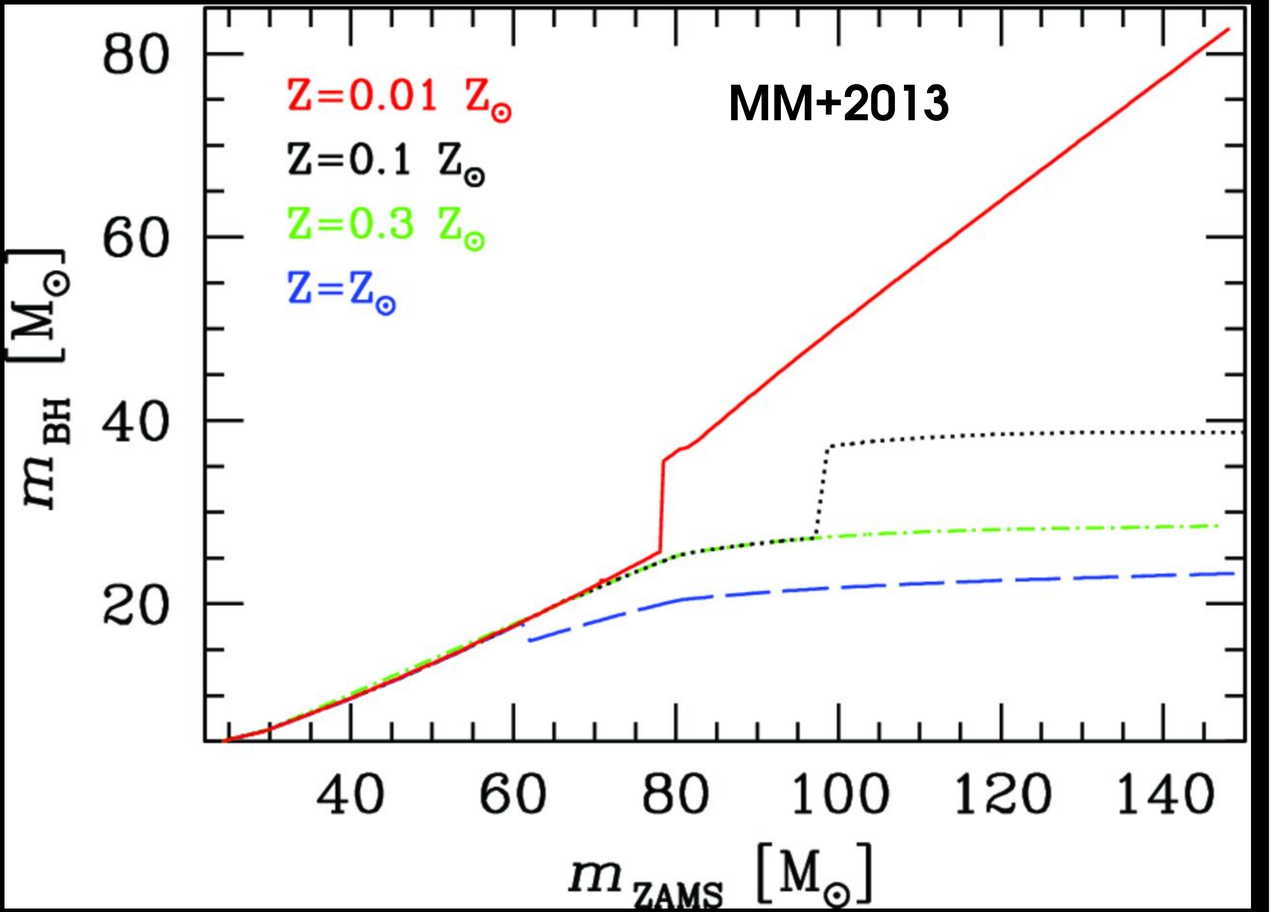
- MASSIVE STARS (>30 M⊙) lose significant mass by stellar winds, and STELLAR WINDS depend on METALLICITY

at low Z, stars lose less mass by stellar winds!

e.g. Kudritzki & Puls 2000, Vink+ 2001

- IF FINAL MASS SUFFICIENTLY HIGH (> 40 $M_{\odot}$), SN EXPLOSION 'FAILS': almost NO EJECTA and direct collapse to BHs (Fryer 1999)

BH mass higher at lower metallicity




Fryer 1999;
Fryer & Kalogera 2001;
MM+ 2009;
Zampieri & Roberts 2009; Belczynski+ 2010;
MM+ 2010, 2011;
Fryer+ 2012;
MM+ 2013

# INITIAL CONDITIONS

## 600 YOUNG SCs with Z=0.01, 0.1 and 1 $Z_{\odot}$

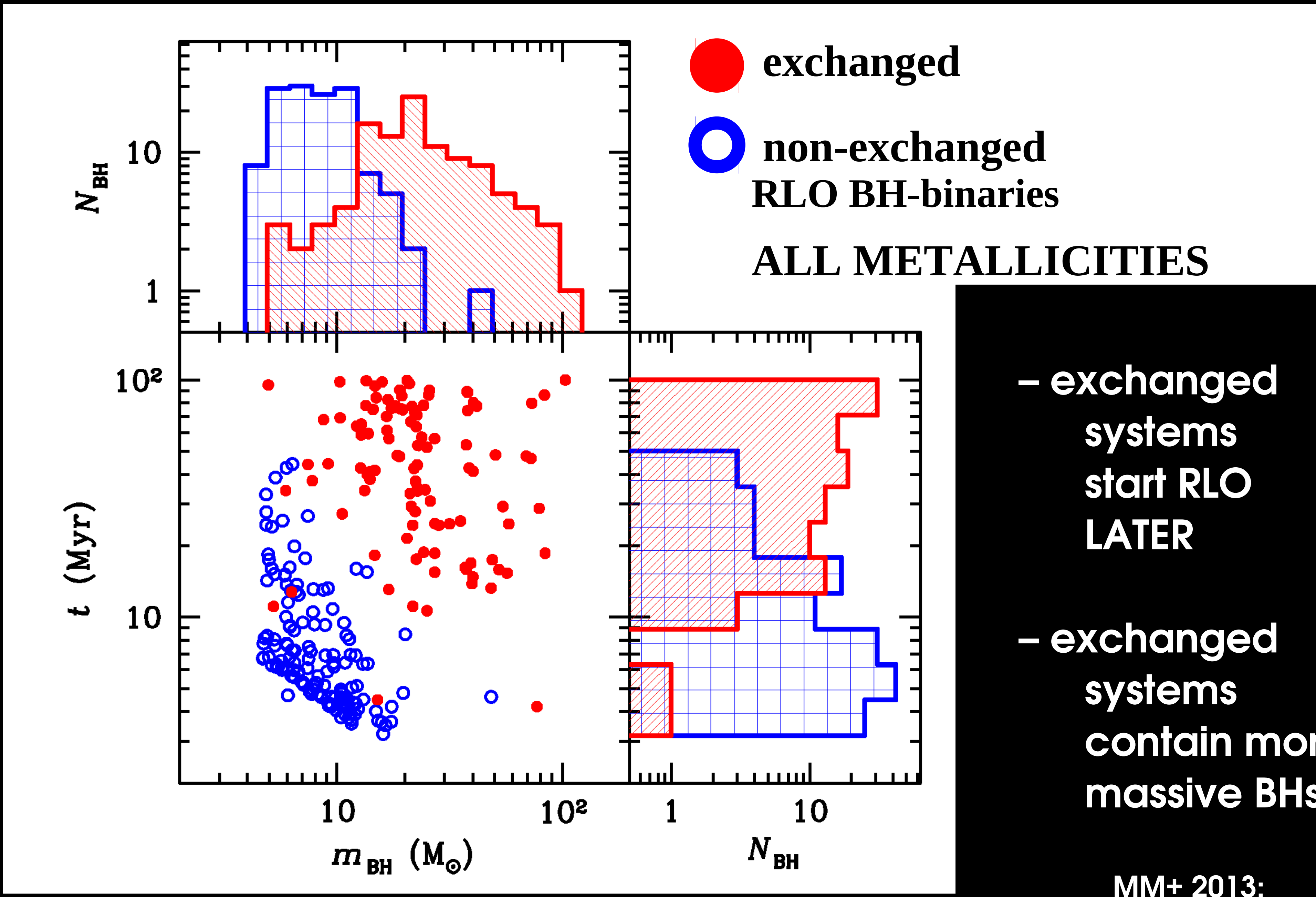
- $r_{virial}$ = 1 pc
- King, $W_0$=5
- total mass ~ 3500 M⊙ per SC
- primordial binaries (~18%)
- Kroupa IMF (Kroupa 2001)
- RUN for 100 Myr

** details in MM+2013 **

– NO tidal fields
(we are about to include them now)

– NO gas evaporation
(work in progress)

## EXCHANGES FAVOUR HIGH-MASS BHs in RLO systems

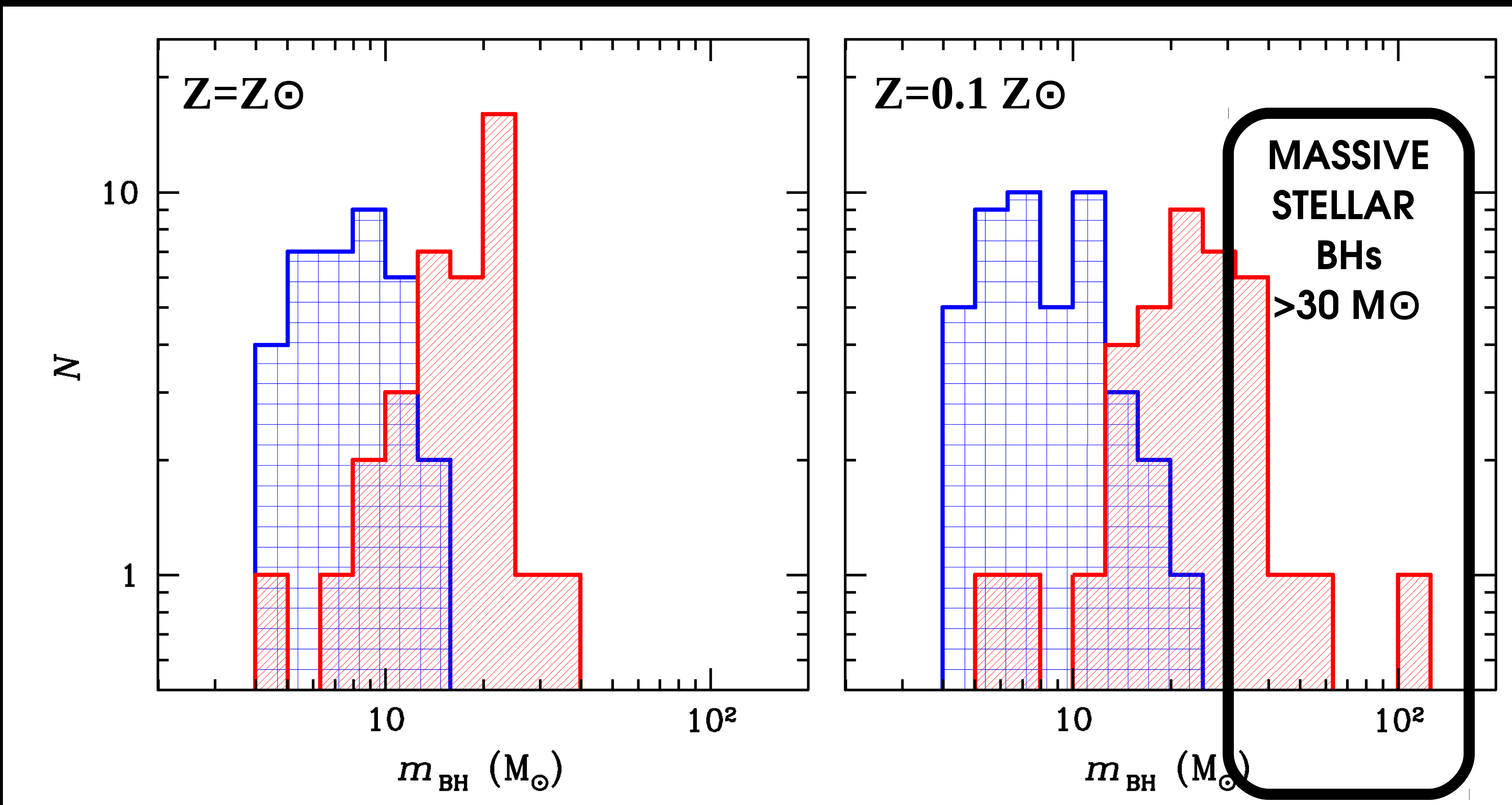



- exchanged systems start RLO LATER
- exchanged systems contain more massive BHs

MM+ 2013;
MM & Zampieri 2014

## RLO systems at LOW/HIGH METALLICITY

## BH mass


MM+ 2013; MM & Zampieri 2014

## RLO systems at LOW/HIGH METALLICITY

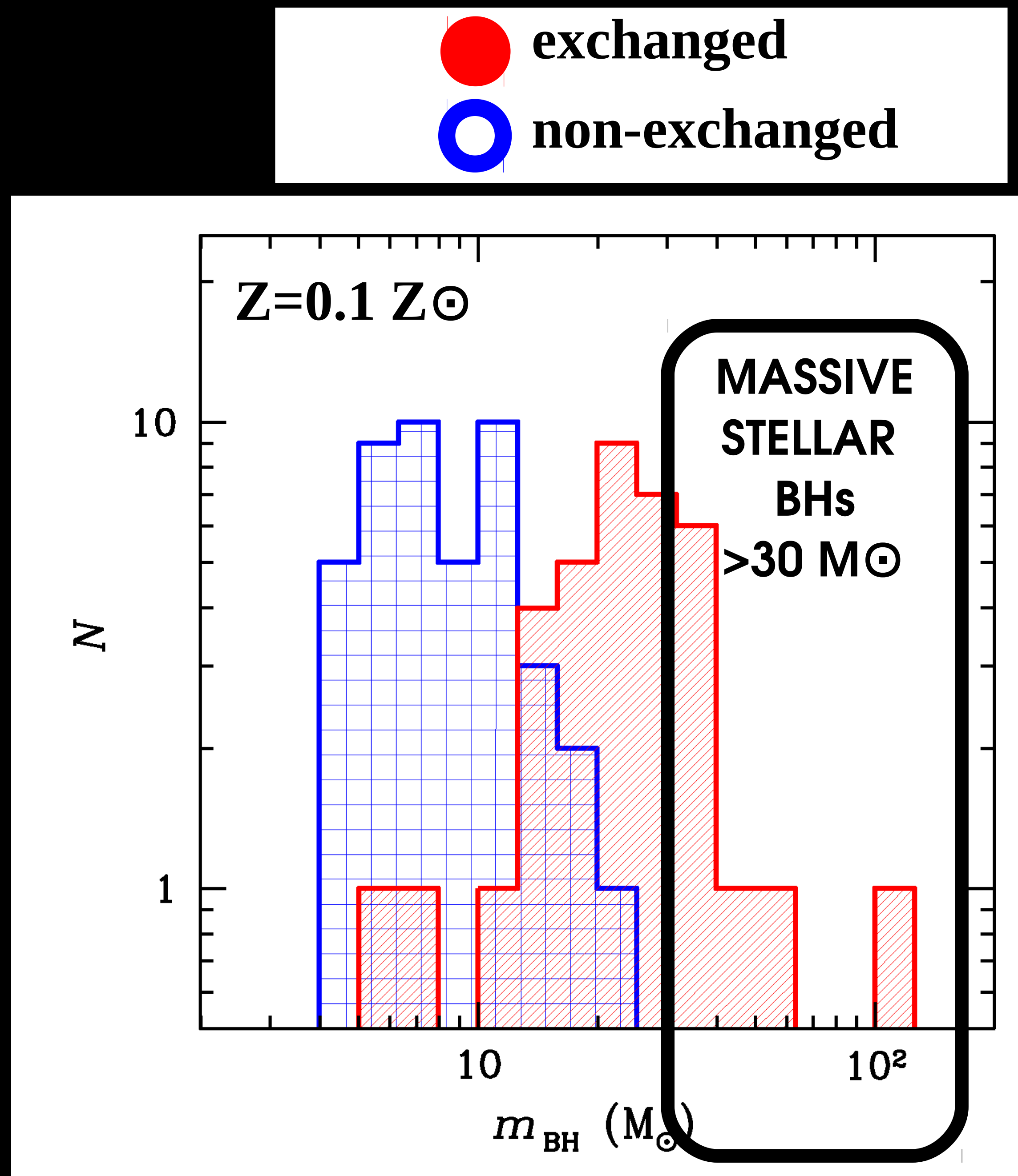
CLUE to EXPLAIN
ULTRALUMINOUS
X-RAY SOURCES (ULXs)

:= off-nuclear sources with luminosity > Eddington luminosity of a 10 M⊙ BH

–> Beamed emission?

–> Super-Eddington emission?

–> BHs with mass >> 10 M⊙?



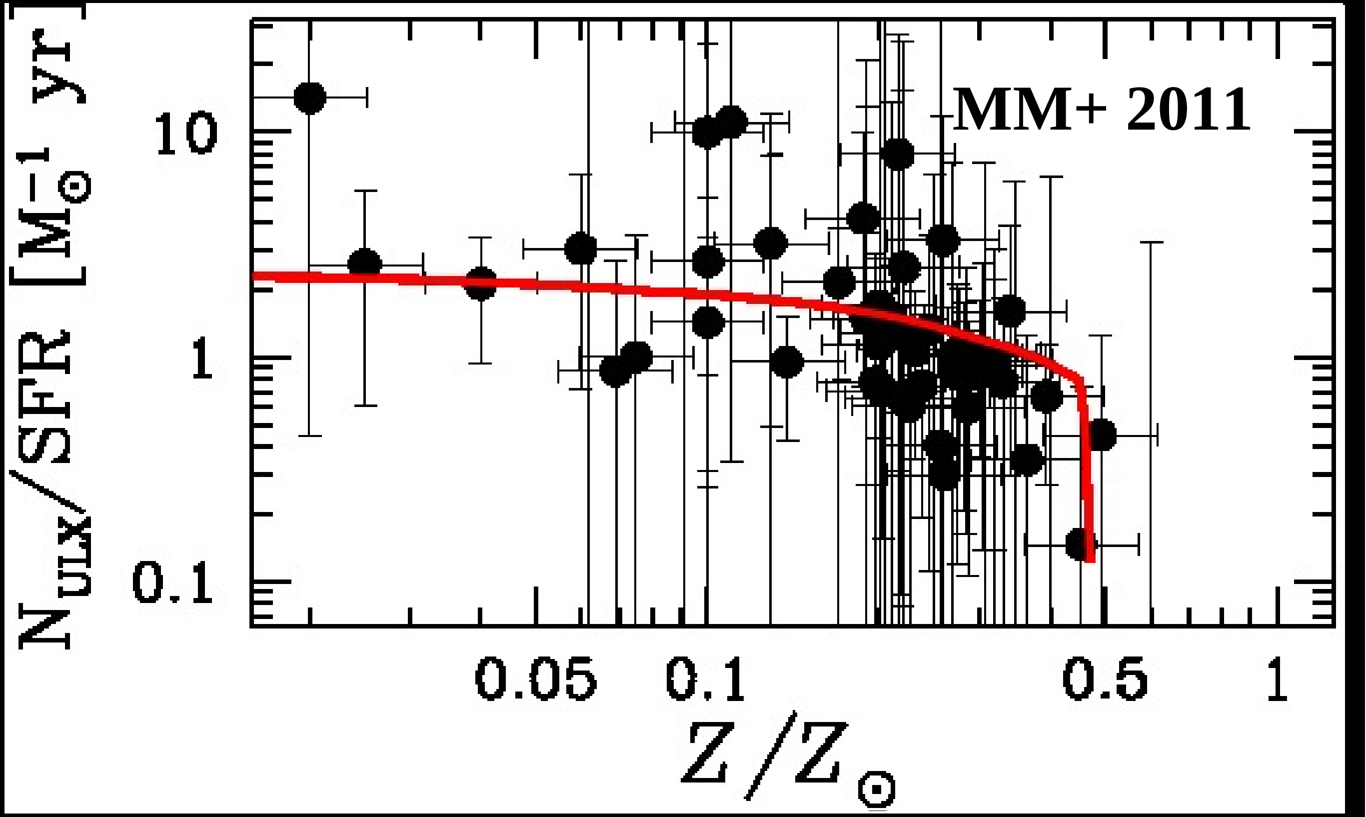

MM, Colpi & Zampieri 2009;
MM+ 2010, 2011

MM+ 2013; MM & Zampieri 2014

## RLO systems at LOW/HIGH METALLICITY

CLUE to EXPLAIN ULXs and their preference for low Z environments

DATA POINTS:
SAMPLE of 66 galaxies with X-ray data
SFR
Metallicity
→ inverse correlation between ULXs and Z

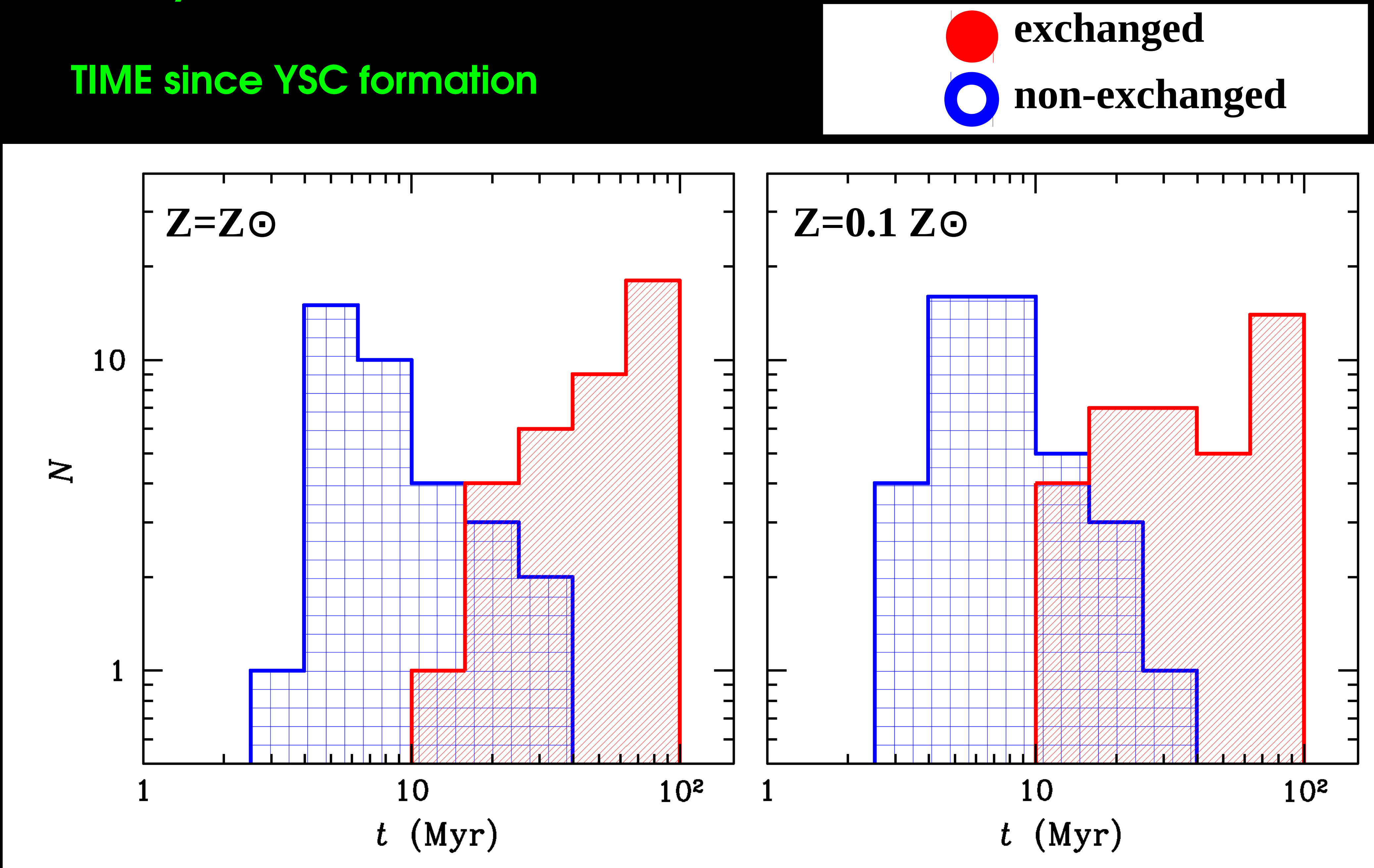



RED LINE:
Model in which ULXs are powered by MSBHs

MM+ 2010, 2011

## RLO systems at LOW/HIGH METALLICITY

## TIME since YSC formation



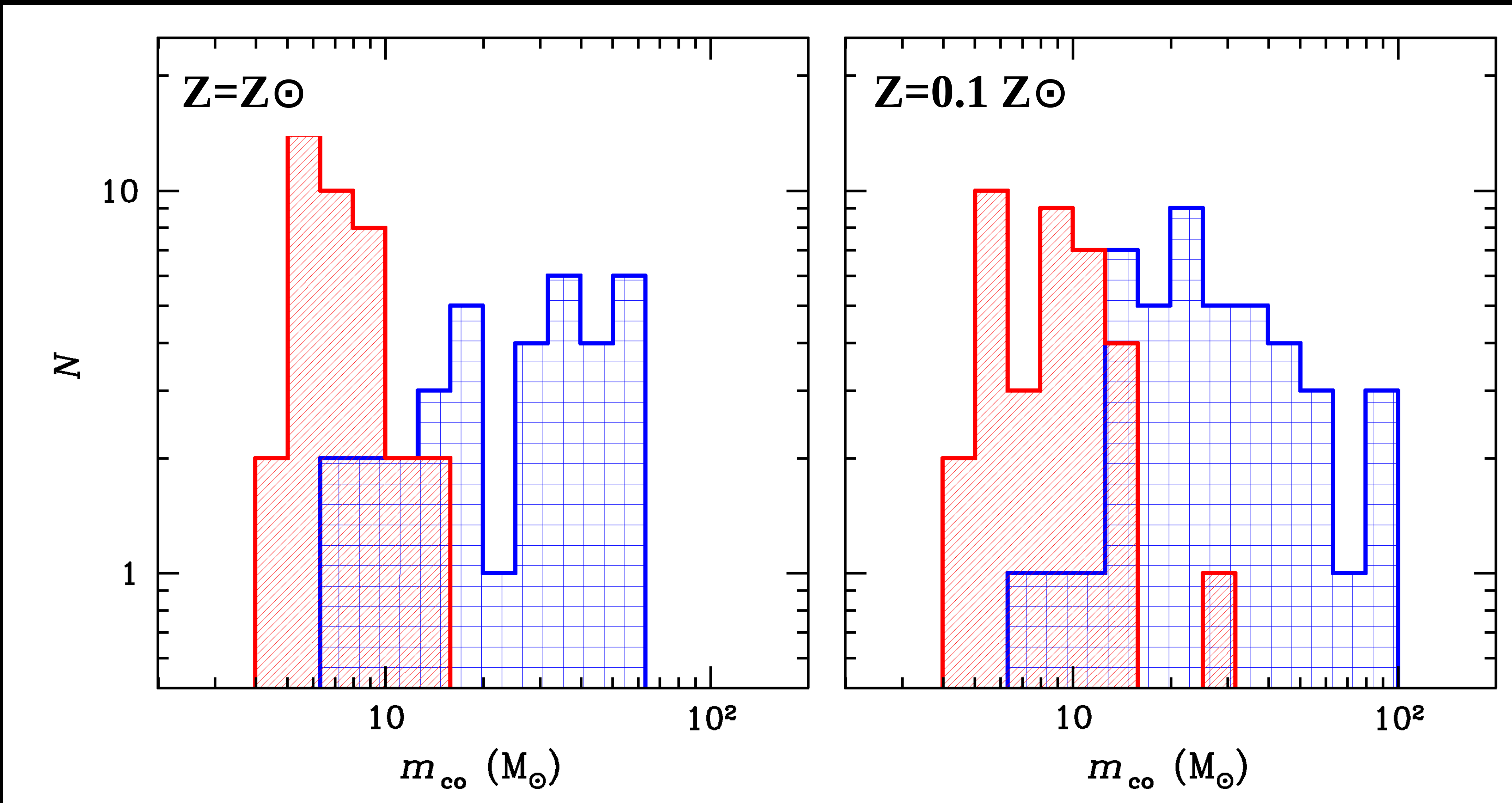

MM+ 2013; MM & Zampieri 2014

## RLO systems at LOW/HIGH METALLICITY

## donor mass

exchanged

non-exchanged

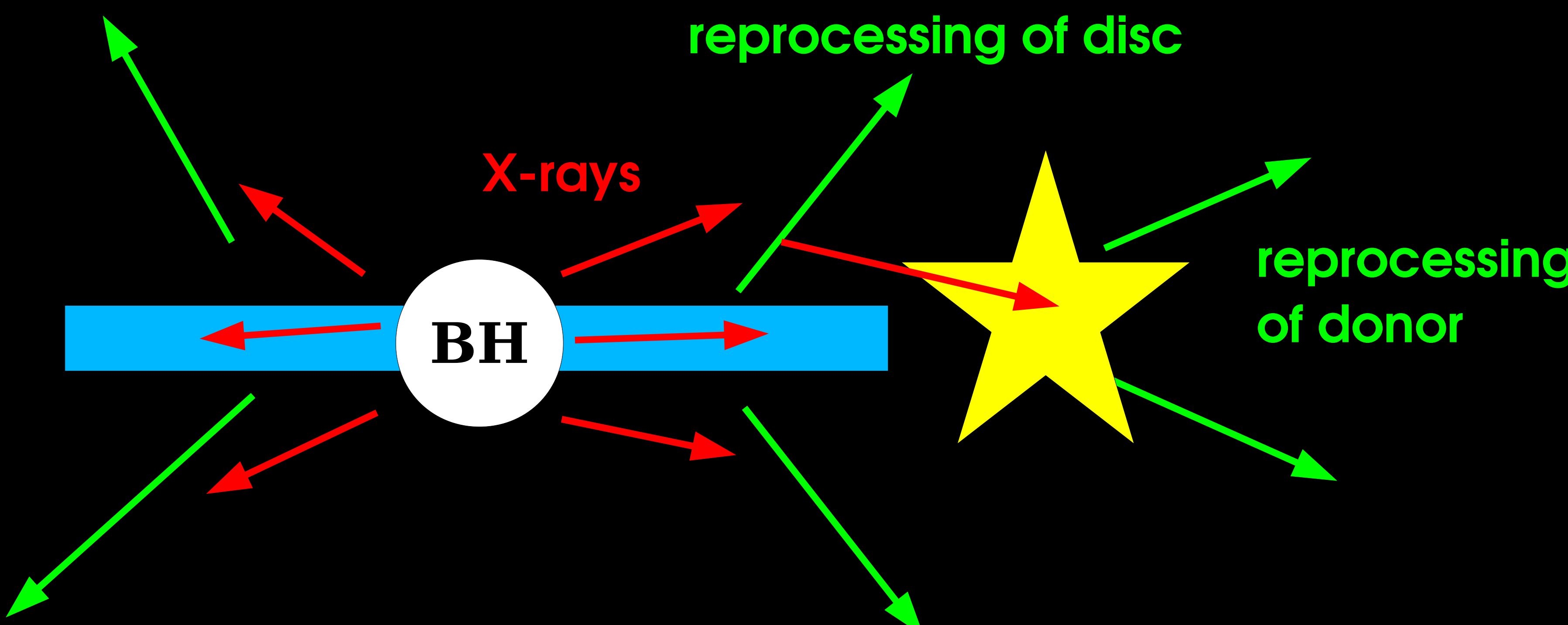



MM+ 2013; MM & Zampieri 2014

## OPTICAL LUMINOSITY and COLOUR of the SIMULATED RLO SYSTEMS:

- BH mass → from N-body simulations
- period → from N-body simulations
- donor star → from N-body simulations

- X-ray reprocessing of disc and donor star
  → from code by Patruno & Zampieri (2008, 2010)



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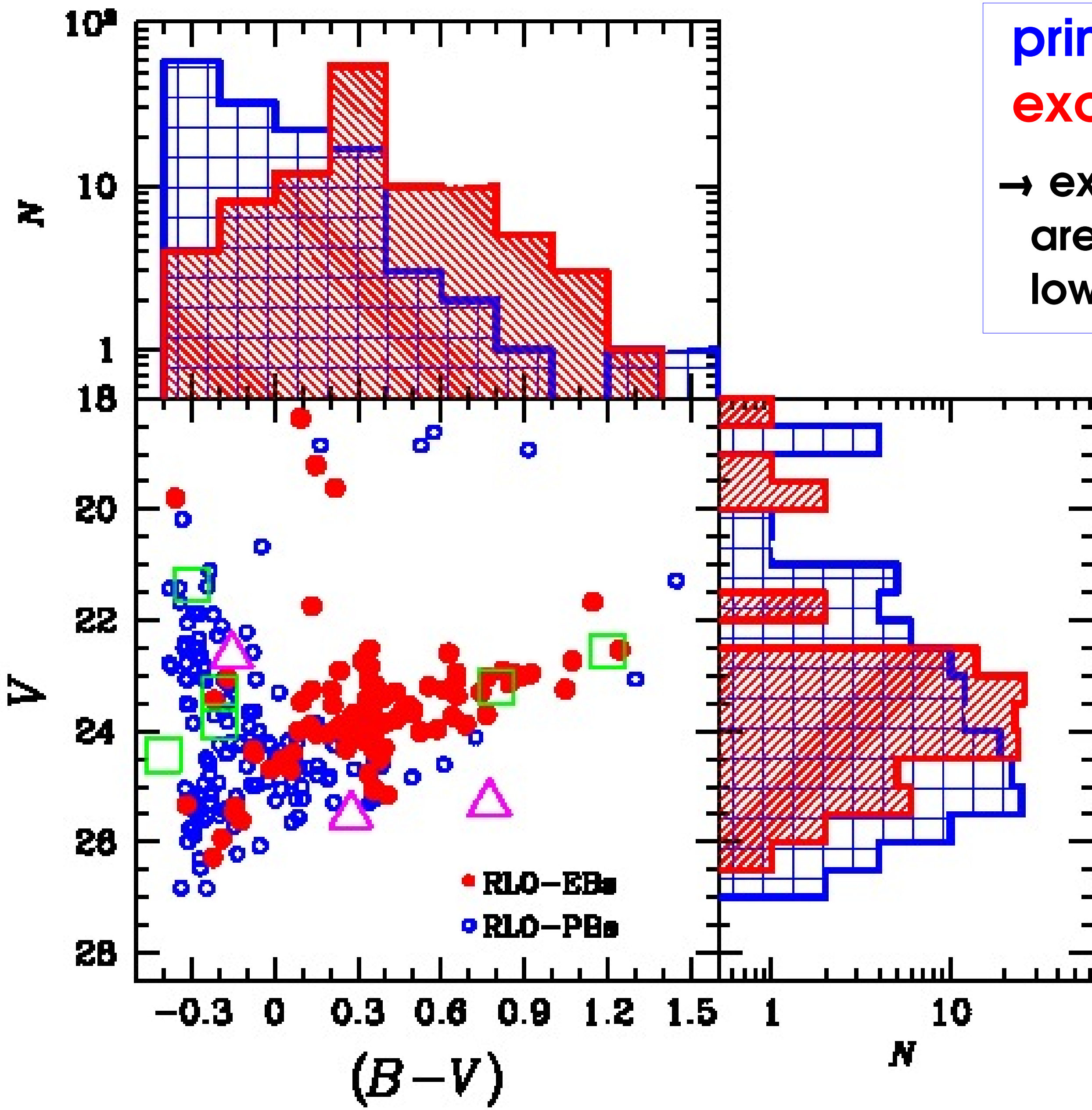
We produce optical luminosity and colours of simulated RLO systems in B, V Johnson filters, Vegamag, as observed at 5 Mpc distance

4. Simulations of YSCs: Comparison with ULX counterparts

## OPTICAL LUMINOSITY and COLOUR of the SIMULATED RLO SYSTEMS:



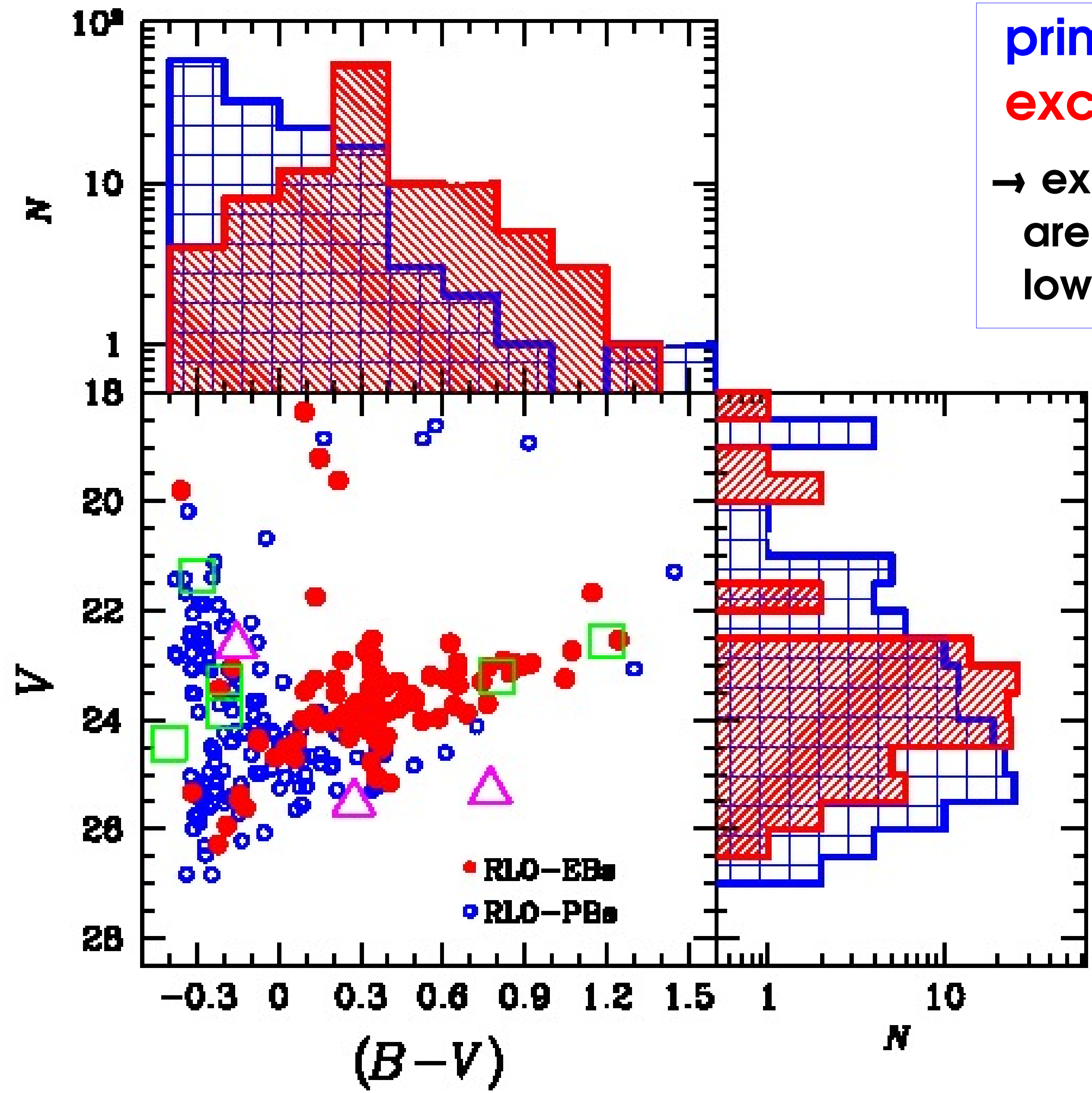

primordial binaries

exchanged binaries

→ exchanged binaries are redder because lower mass donor stars

MM+ 2013;
MM & Zampieri 2014

## OPTICAL LUMINOSITY and COLOUR of the COUNTERPARTS




primordial binaries

exchanged binaries

→ exchanged binaries are redder because lower mass donor stars

HST counterparts from Gladstone + 2013 @ 5Mpc:

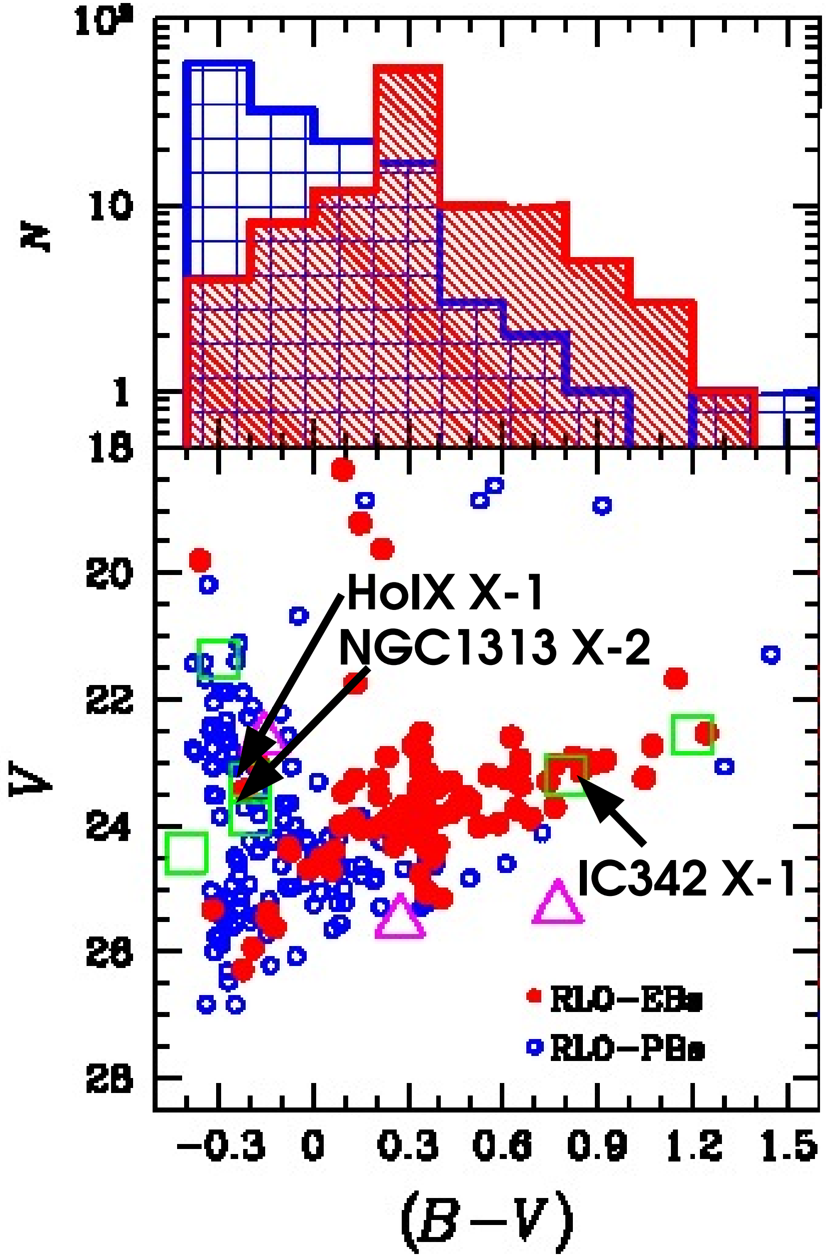
□ := F555W, F435W

△ := F606W, F435W (F606W shifted to match F555W)

MM+ 2013;
MM & Zampieri 2014

4. Simulations of YSCs: Comparison with ULX counterparts

# OPTICAL LUMINOSITY and COLOUR of the COUNTERPARTS



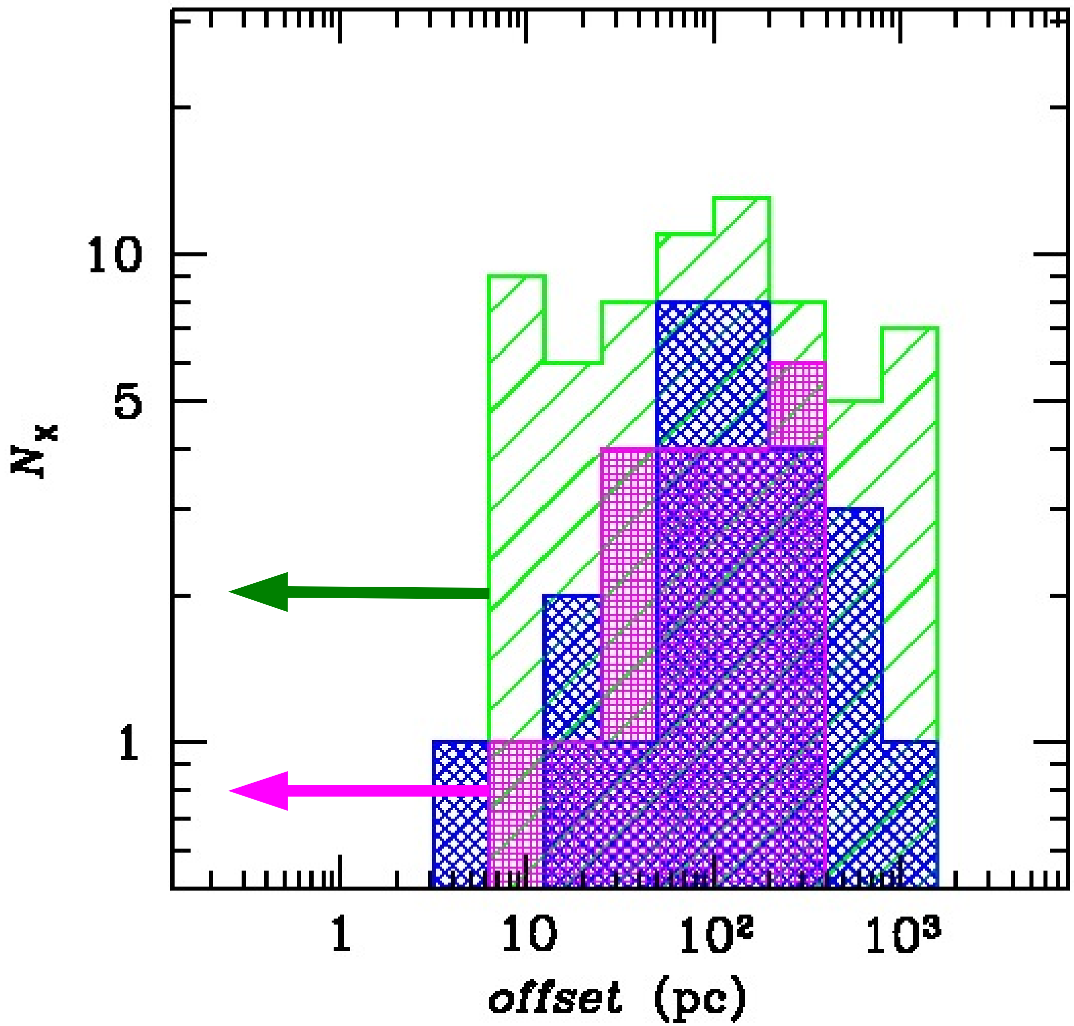

HST counterparts from Gladstone et al. 2013 @ 5Mpc:
M81 X-6, HoIX X-1, NGC1313 X-1, NGC1313 X-2, IC-342 X-1, M83 XMM1, NGC 2403 X-1, NGC 5204 X-1, NGC3034 ULX5

IC-342 X-1 is the strongest MSBH candidate in this model (21-40 M⊙)

HoIX X-1 and NGC1313X-2 are strong candidates

MM+ 2013;
MM & Zampieri 2014

# ULX environment: close to young clusters BUT OFFSET

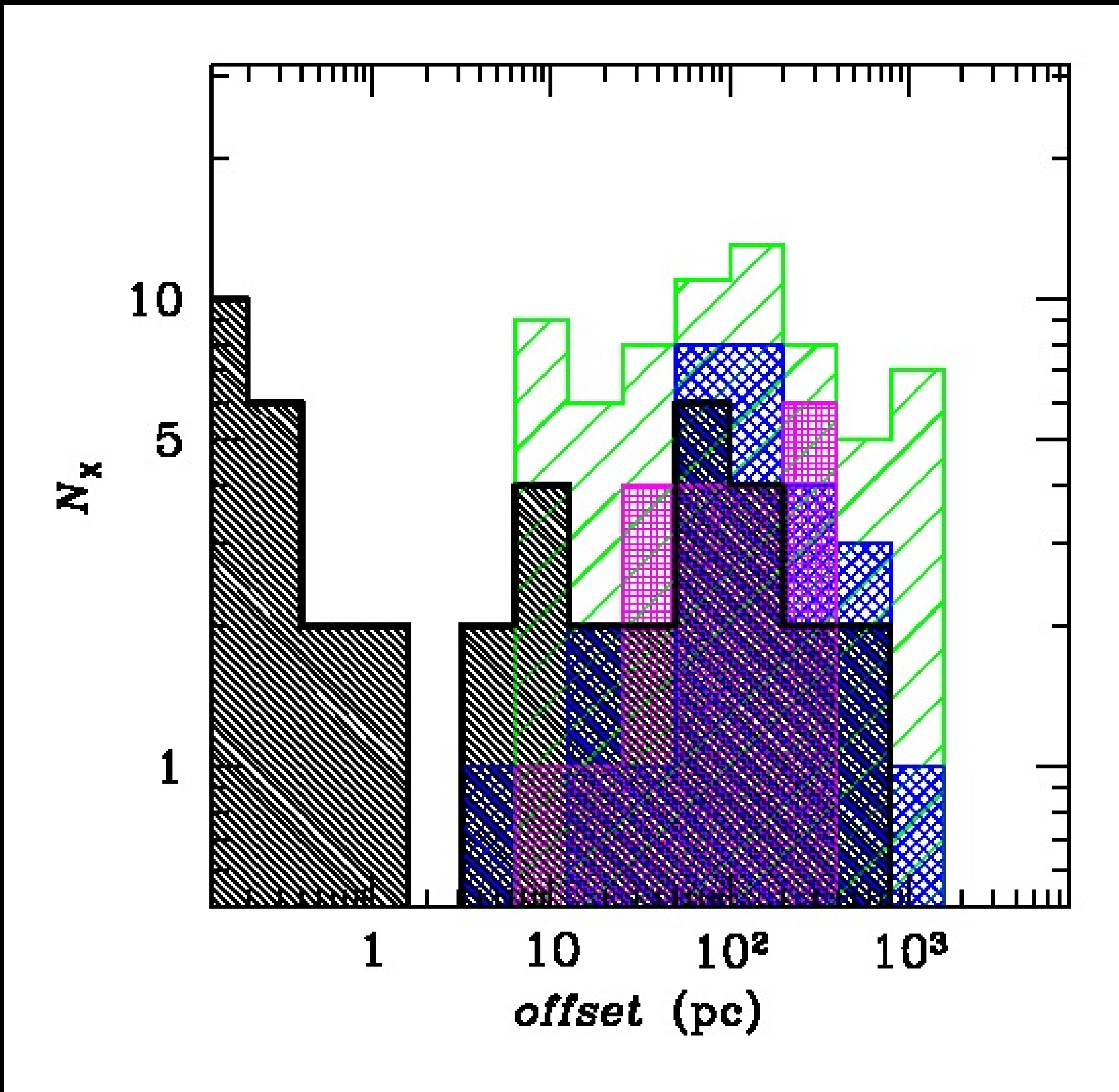



Kaaret et al. 2004 (bright X-ray binaries in M82, NGC1569, NGC5253)

Berghea, PhD Thesis, 2009
Berghea et al. 2013 (ULXs in nearby galaxies)

Poutanen et al. 2013 (bright X-ray binaries in the Antennae, see also Zezas et al. 2002)

# ULX environment: close to young clusters BUT OFFSET

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MM et al. 2011 simulated BH binaries in YSC – NO stellar evolution

# CONCLUSIONS:

* A large fraction of BH-binaries form in YSCs by **dynamical EXCHANGES**

* RLO BH-binaries born from **exchanges start RLO later and host more massive BHs**

* RLO BH-binaries at $Z=0.1\ Z_{\odot}$ host MSBHs with mass 40-100 $M_{\odot}$
  → **clue to explain the connection between ULXs and low metallicity?**
  IC342 X1, Ho IX X1 and NGC1313 X2 are well matched by MSBHs

# SEE ALSO...

* Poster by Brunetto Marco Ziosi about BH-BH binaries

* Poster by Alessandro Alberto Trani
  about
  Core collapse of YSCs

* Poster by Elena Gavagnin about Formation of
  multiple populations in globular clusters


THANKS