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MASSIVE STELLAR BHs
from stellar evolution and dynamics

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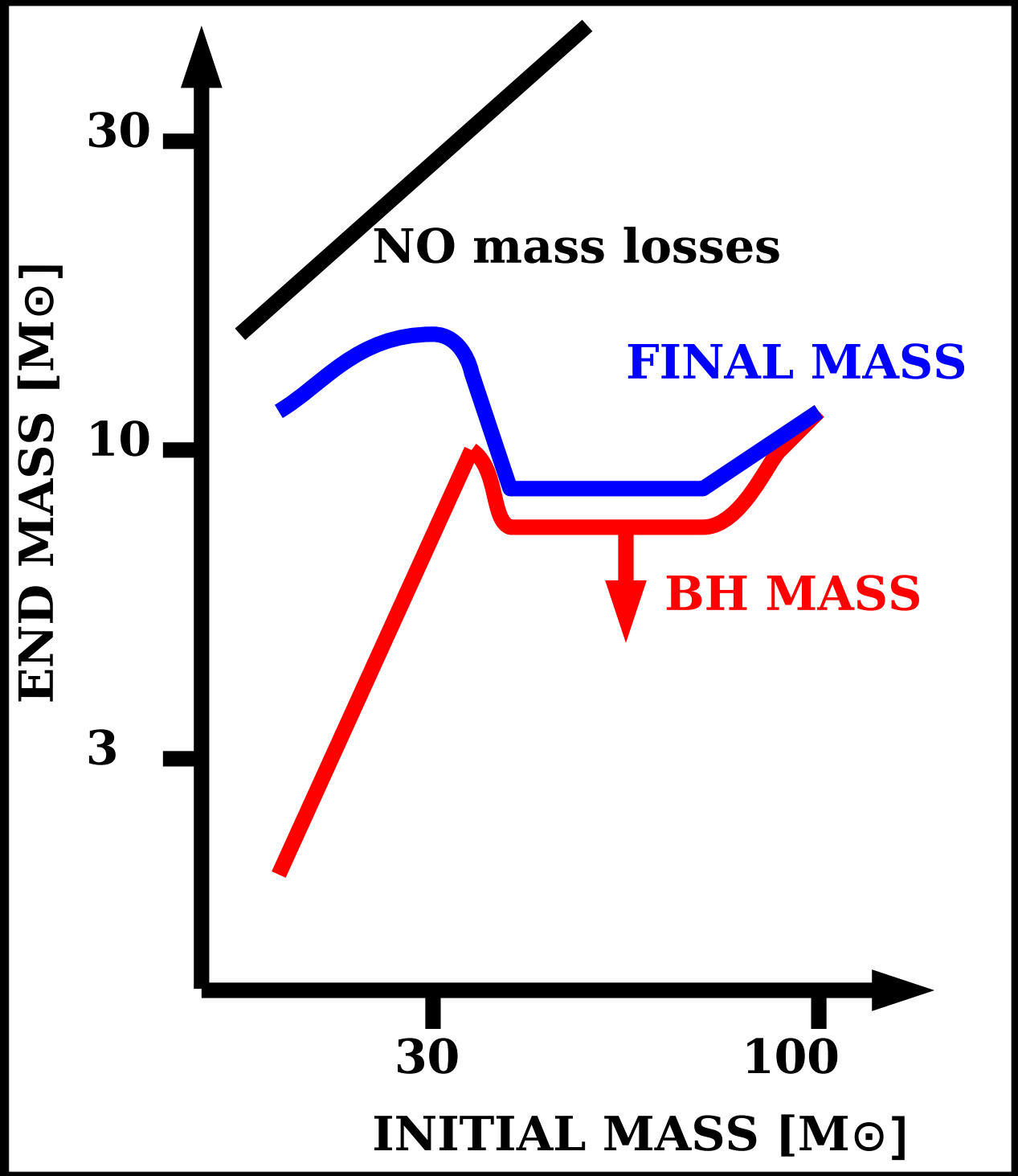
OUTLINE

1- The mass spectrum of stellar BHs

2 – The simulation code: dynamics and stellar evolution

3 – X-ray binaries from MSBHs and BHs



PREDICTED BH MASS Z=Zsun

-difference IM & FM: stellar winds

-difference FM & BH: supernova

Predicted mass of BHs after SN: 3 <mBH/Msun<15

Heger et al. (2002, 2003)

Role of metallicity:

- STELLAR WINDS depend on METALLICITY

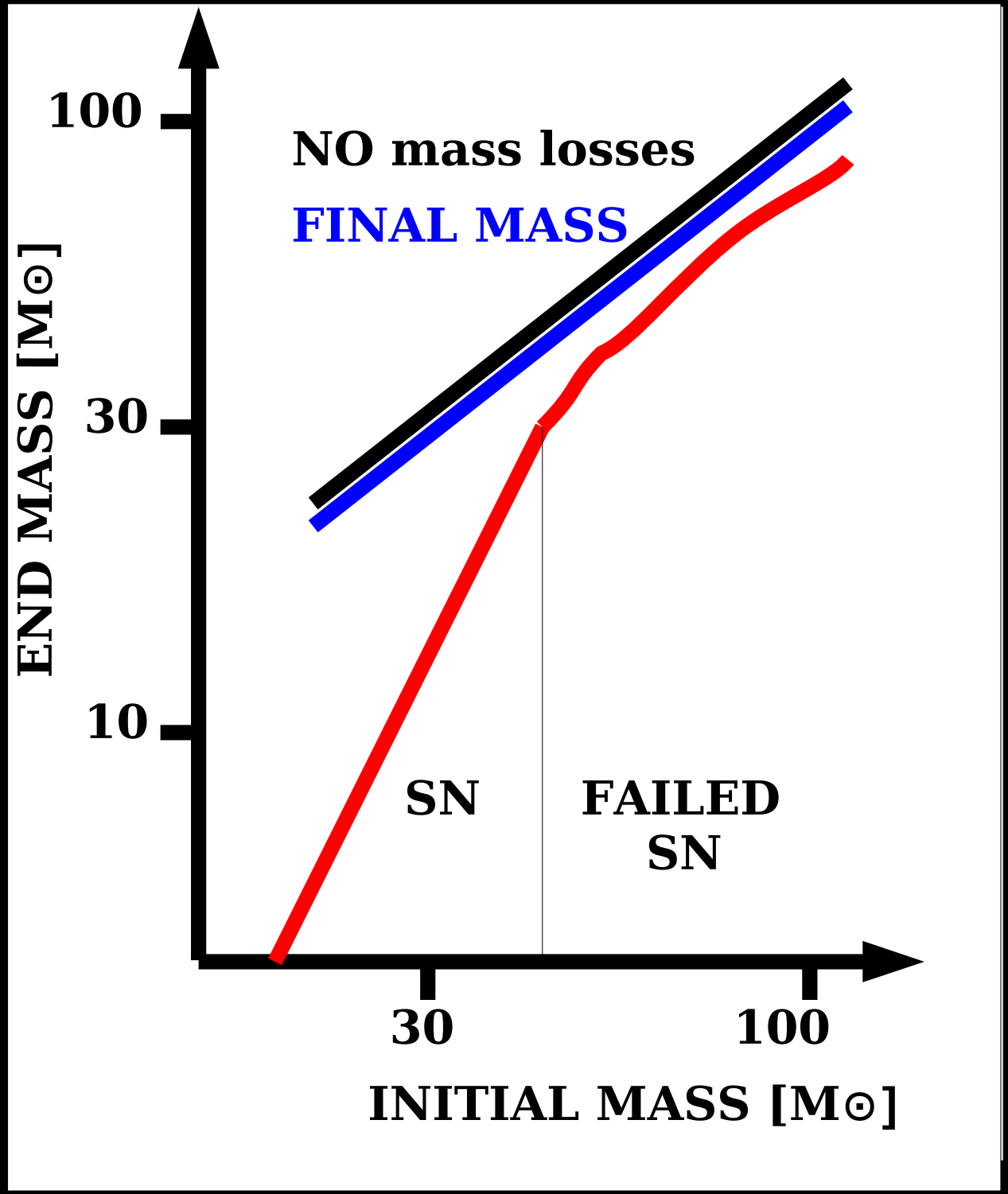
$$\dot{M}(Z) \propto \left(\frac{Z}{Z_\odot}\right)^{\alpha}$$

$$\alpha = 0.5 - 0.9$$

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

Vink+ (2001)

- IF FINAL MASS SUFFICIENTLY HIGH (> 40 Msun),
SN EXPLOSION CANNOT SUCCEED:
almost NO EJECTA and direct collapse to BHs
(FAILED SUPERNOVAE, Fryer 1999)



PREDICTED BH MASS Z=0

- ~no stellar winds: IM ~ FM

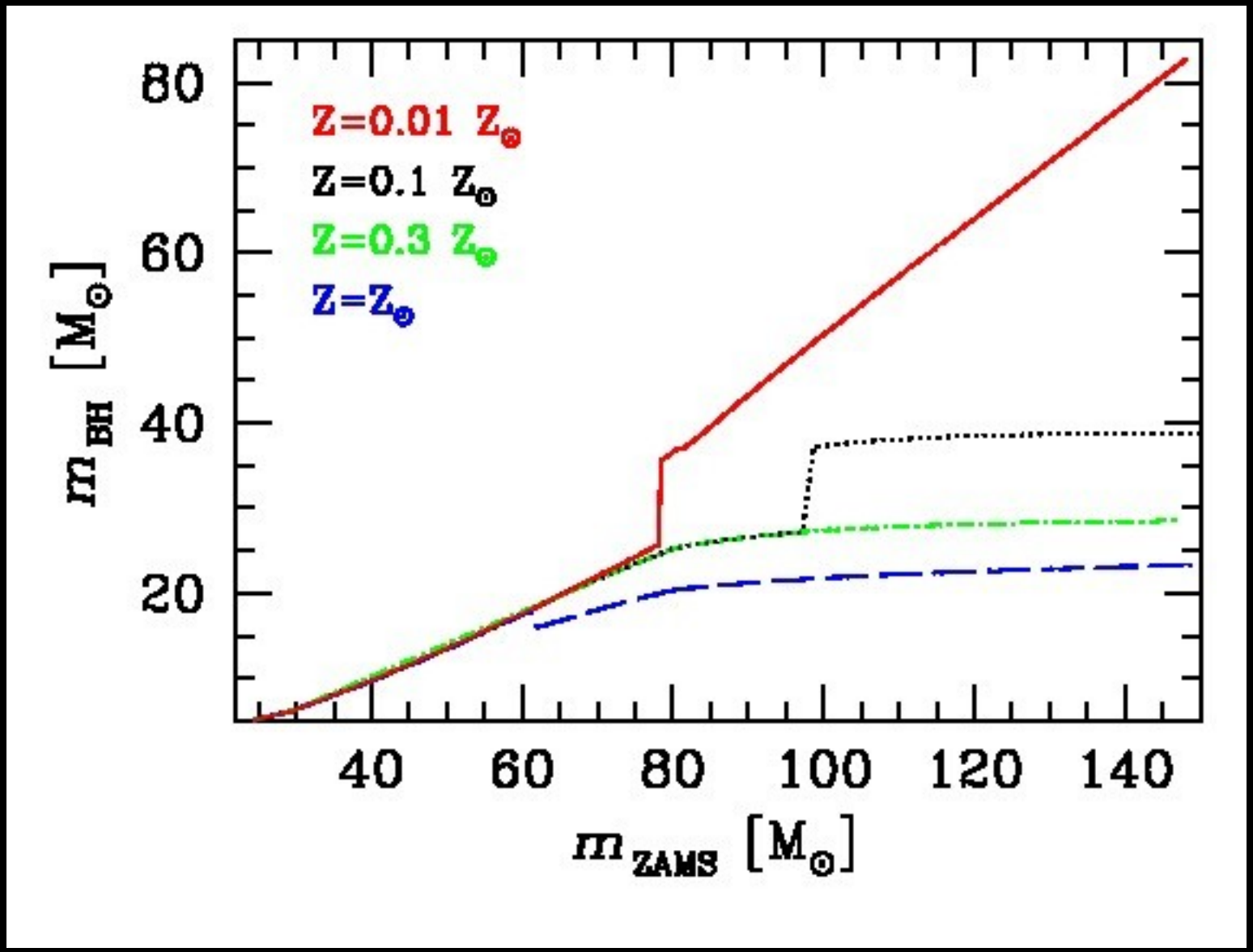
-difference FM & BH: Supernova

-FAILED SN

Predicted mass of BHs after SN:
3 <mBH/Msun<80

Heger et al. (2002, 2003)

MASS SPECTRUM of BHs accounting for METALLICITY and FAILED Sne:



MM+2012

OPEN QUESTIONs:

* HOW DOES METALLICITY AFFECT X-RAY BINARIES?

* Can massive stellar BHs (MSBHs, ie BHs with mass >25 Msun) explain a fraction of ultraluminous X-ray sources (ULXs)?

NUMERICAL TOOL:

STARLAB (Portegies Zwart+2001):

-integration of SC dynamics with TREE code (KIRA) with 4th order Hermite scheme
leaves are 'true' stars=0 softening (resolves 3-body encounters)

-optimized for GRAPE and multiple GPU computation (through SAPPORO, Gaburov+2009)

NUMERICAL TOOL:

to study BH formation, binary evolution
& mass transfer we need
METAL DEPENDENT STELLAR EVOLUTION

UPGRADE OF STARLAB INCLUDING:

- metal dependence of T, L and R (Hurley+2000)

- Vink's winds (2001) for MS

- WR stars (with metal dependence, Belczynski+2010)

- LBV stars (Humphreys & Davidson 1994, Belczynski+2010)

- direct collapse (Fryer 1999, Fryer & Kalogera 2001)

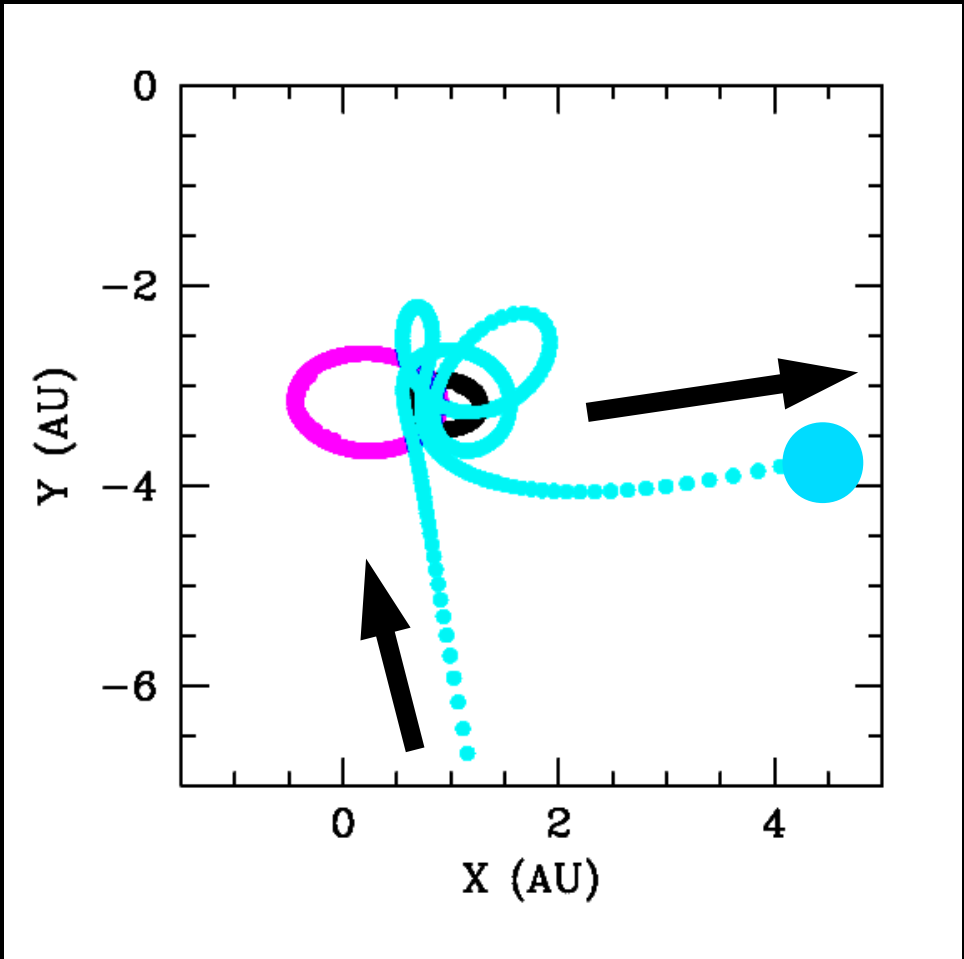
NUMERICAL TOOL:

WHY DYNAMICS?

* MSBHs are expected to form mainly in STAR CLUSTERS (SCs)

* SCs are dynamically active sites where

  3BODY ENCOUNTERS HAVE IMPORTANT ROLE FOR X-RAY BINARIES

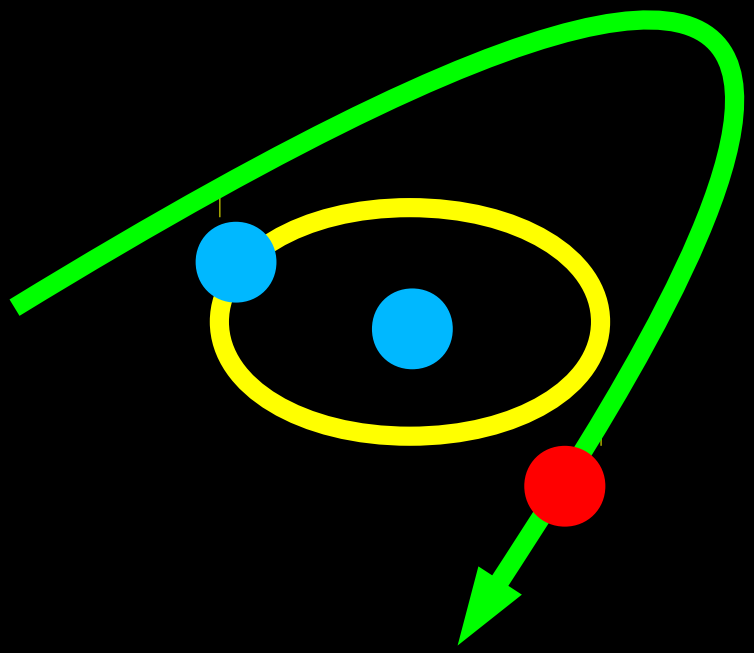


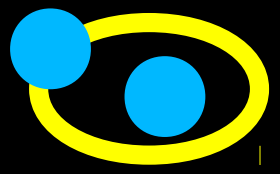
3-body encounters:

- **BINARY has ENERGY RESERVOIR:**
  internal energy

$$E = \tfrac{1}{2}\,\mu\, v^2 - G\, m_1\, m_2/a$$

- **If star extracts internal energy from binary, binary binding energy increases (binary shrinks)**

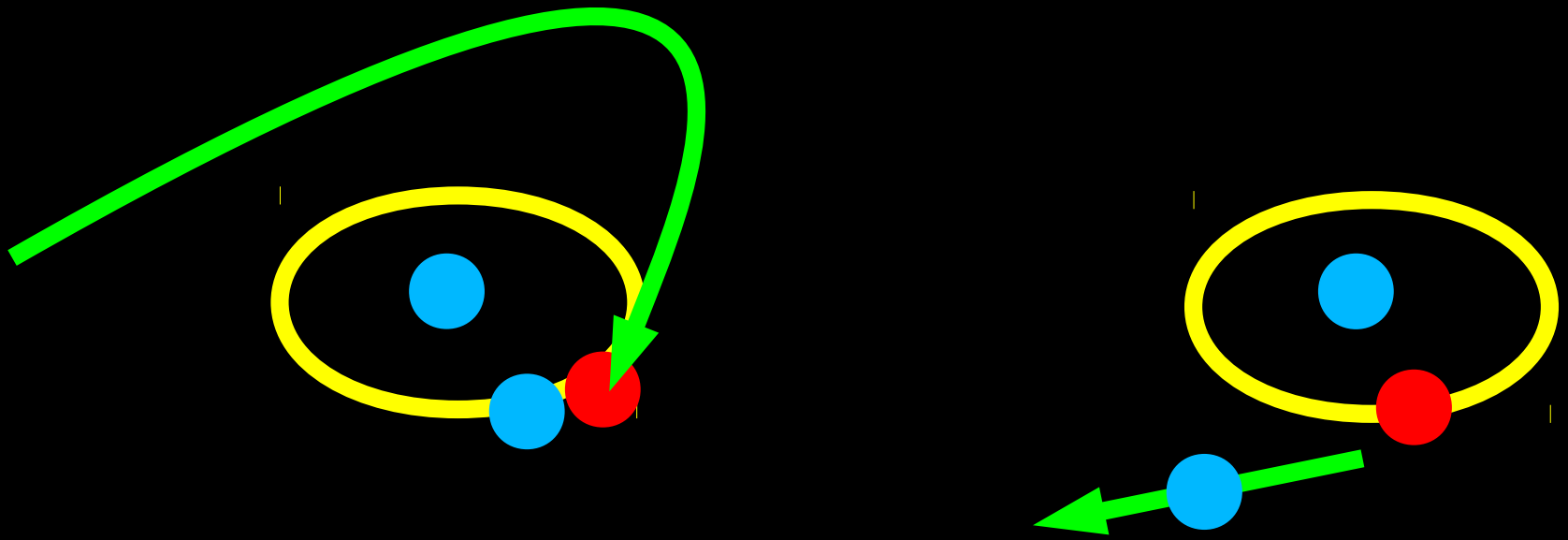




CAN TRIGGER MASS TRANSFER!!!

3-body encounters:

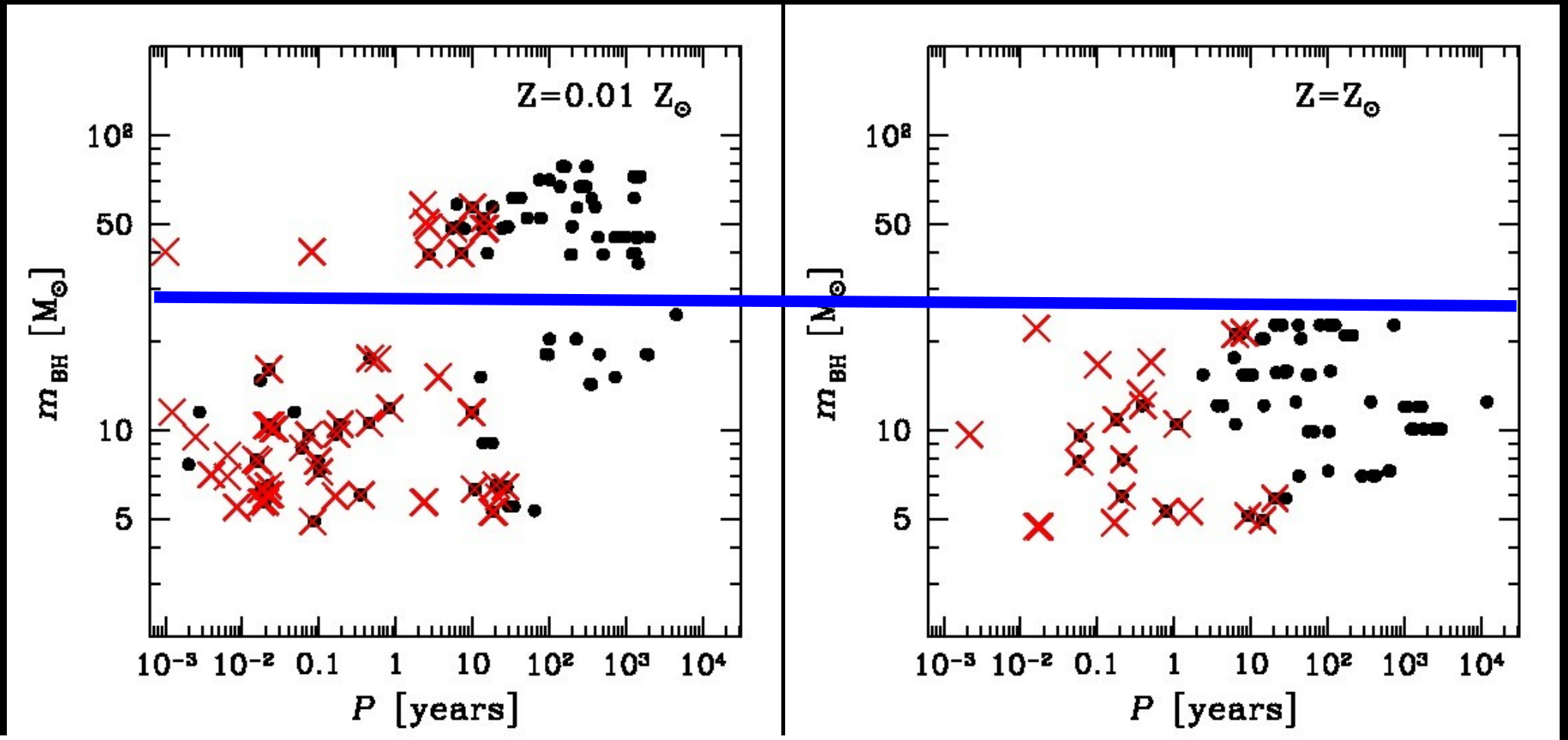
- the binary can exchange companion



BHs can ENTER BINARIES via DYNAMICAL EXCHANGE!!!

SIMULATIONS:

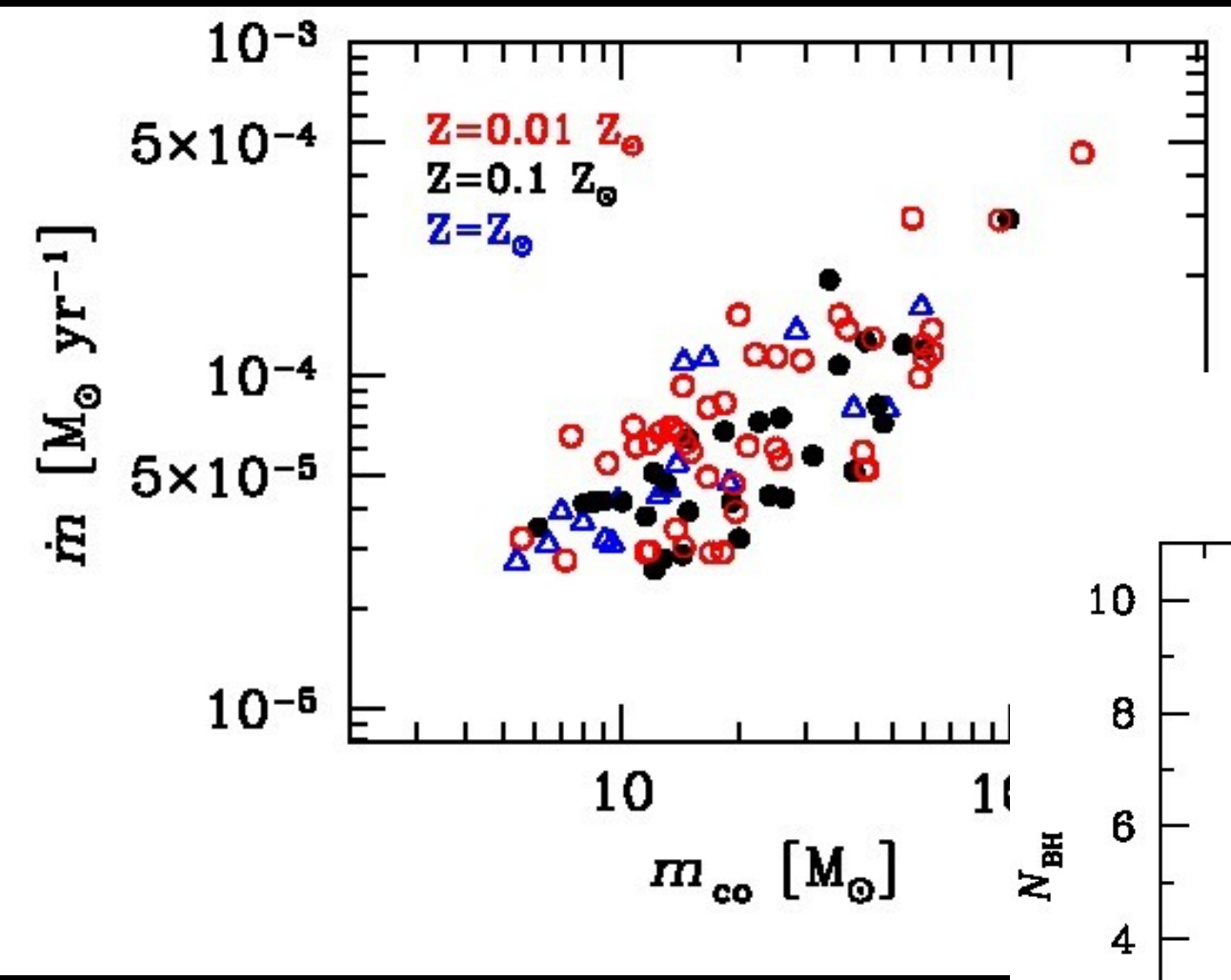
300 YOUNG SCs with Z=0.01, 0.1 and 1 Zsun

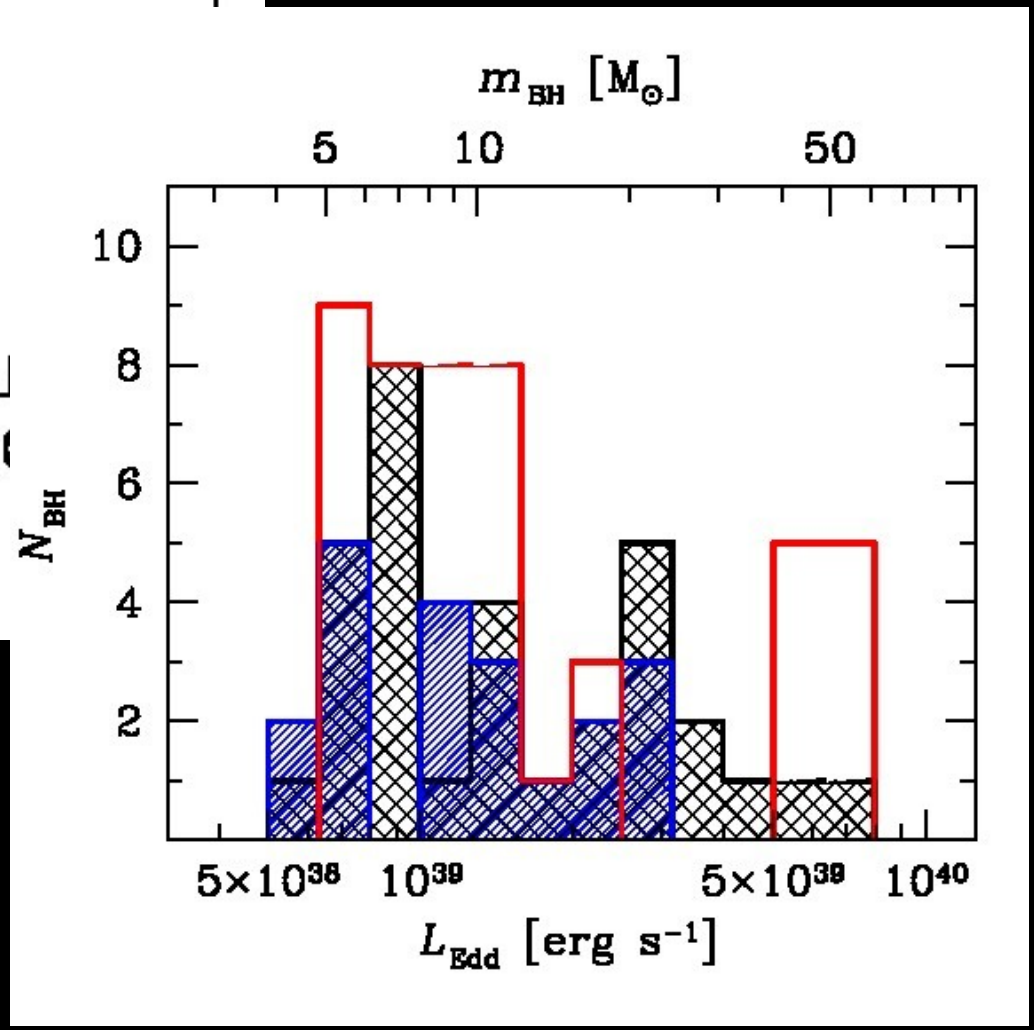


X = RLO systems

● = wind-accreting systems

SIMULATIONS: properties of RLO systems





CONCLUSIONS:

* **FORMATION of MSBHs with mass**
  $25 < m_{BH}/Msun < 80$ for $Z < 0.3$ Zsun

* **MSBHs are as efficient as low-mass BHs in powering wind-accreting and RLO systems**

* **the large majority of MSBHs in wind-accreting and RLO systems became member of the binary after DYNAMICAL EXCHANGE**

  → DYNAMICS IS IMPORTANT for X-RAY BINARIES

* **MSBHs in RLO systems explain ULXs with no or mild super-Eddington factor**


THANKS