Population Modeling for X-Ray Binaries

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NORTHWESTERN
UNIVERSITY

XRBs @Crete - 2010

CIERA

In this talk ...

- Population modeling ingredients
- Caveats and disclaimers ...

- Results: HMXB sampler
- Results: LMXB sampler

- Where does the future lie ?

Population Modeling

- **Current status: observationally-driven**

  Current observations provide an excellent challenge and opportunity for progress in the study of global XRB population properties.

- **Population Synthesis Calculations: necessary**

  Basic Concept of Statistical Description:

  evolution of an ensemble of binary and single stars with focus on XRB formation and their evolution through the X-ray phase.

X-ray Binary Formation involves long binary evolution sequences of stages

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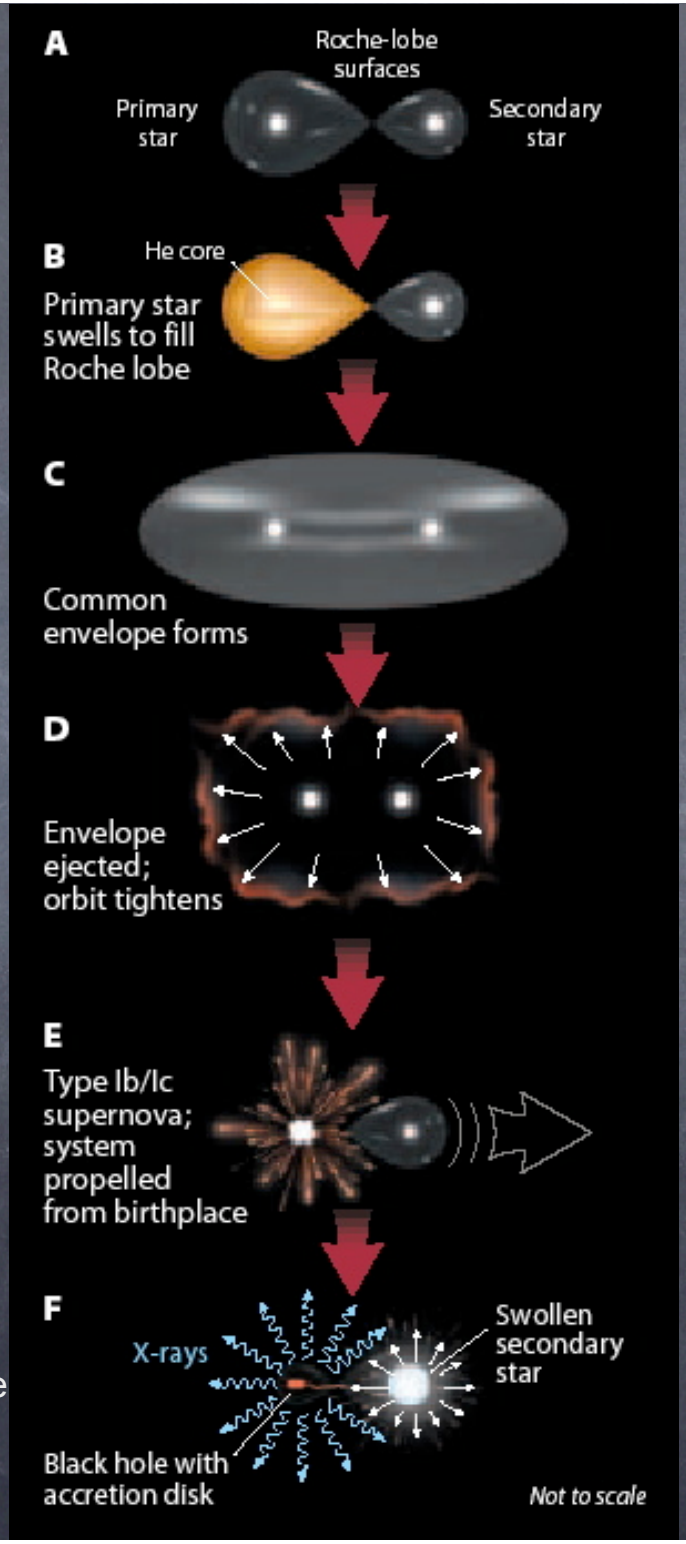
example:



courtesy
Sky & Telescope
Feb 2003 issue

primordial binary

Common Envelope: orbital contraction and mass loss

NS or BH formation

X-ray binary at Roche-lobe overflow

Population Synthesis Elements

Star formation conditions:

- SFR as a function of time: continuous vs starburst
- metallicity
- Initial Mass Function
- binary properties (mass ratios, orbital separations)

Population Synthesis Elements

Star formation conditions:

- SFR vs time, metallicity, IMF, binary properties

Modeling of single and binary evolution

- mass, radius, core mass, wind mass loss
- orbital evolution: e.g., tidal synchronization and circularization, mass loss, mass transfer
- mass transfer modeling:
  stable driven by nuclear evolution or angular momentum loss
  thermally unstable or dynamically unstable
- compact object formation: masses and supernova kicks
- X-ray phase: evolution of mass-transfer rate and X-ray luminosity - transients!

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Population Synthesis Codes

- Scenario Machine (Tutukov, Prokhorov, Postnov, Popov)
- SeBa (Portegies Zwart, Yungel'son, Nelemans)
- StarTrack (Belczynski, Kalogera, Bulik, Taam, Rasio)
- BSE (Hurley, Kiel, Bailes)

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Population synthesis:

"so many parameters ..."

- YES, there's many! and they come in two main flavors
- extended simulation grids: necessary
- simulation results depend only on SOME of them
  - LMXBs: common envelope, NS kicks, mass ratios
  - HMXBs: stellar winds, mass ratios, BH kicks
  - absolute normalizations are the roughest

Population Models: what do we compare to?

- numbers of XRBs (different types, SF conditions)
  - relative comparisons more meaningful
  - absolute comparisons need huge parameter studies
- XLF shapes
  - mass-transfer-rate calculation
  - X-ray band corrections & sensitivity
  - Eddington limit
  - treatment of transients & Be phenomenon and bursts
  - state transitions and "small" Lx variations
- XRB binary properties
  - orbital periods, donors, MT driver, spins, spatial dist.

Selection Biases!

Extragalactic X-Ray Binary Populations

» Starbursts: dominated by recent/ongoing burst of star formation, and young HMXBs

» Spirals: mix of ages and metallicities
mix of LMXBs and HMXBs

» Ellipticals: clean samples of old LMXBs (??)

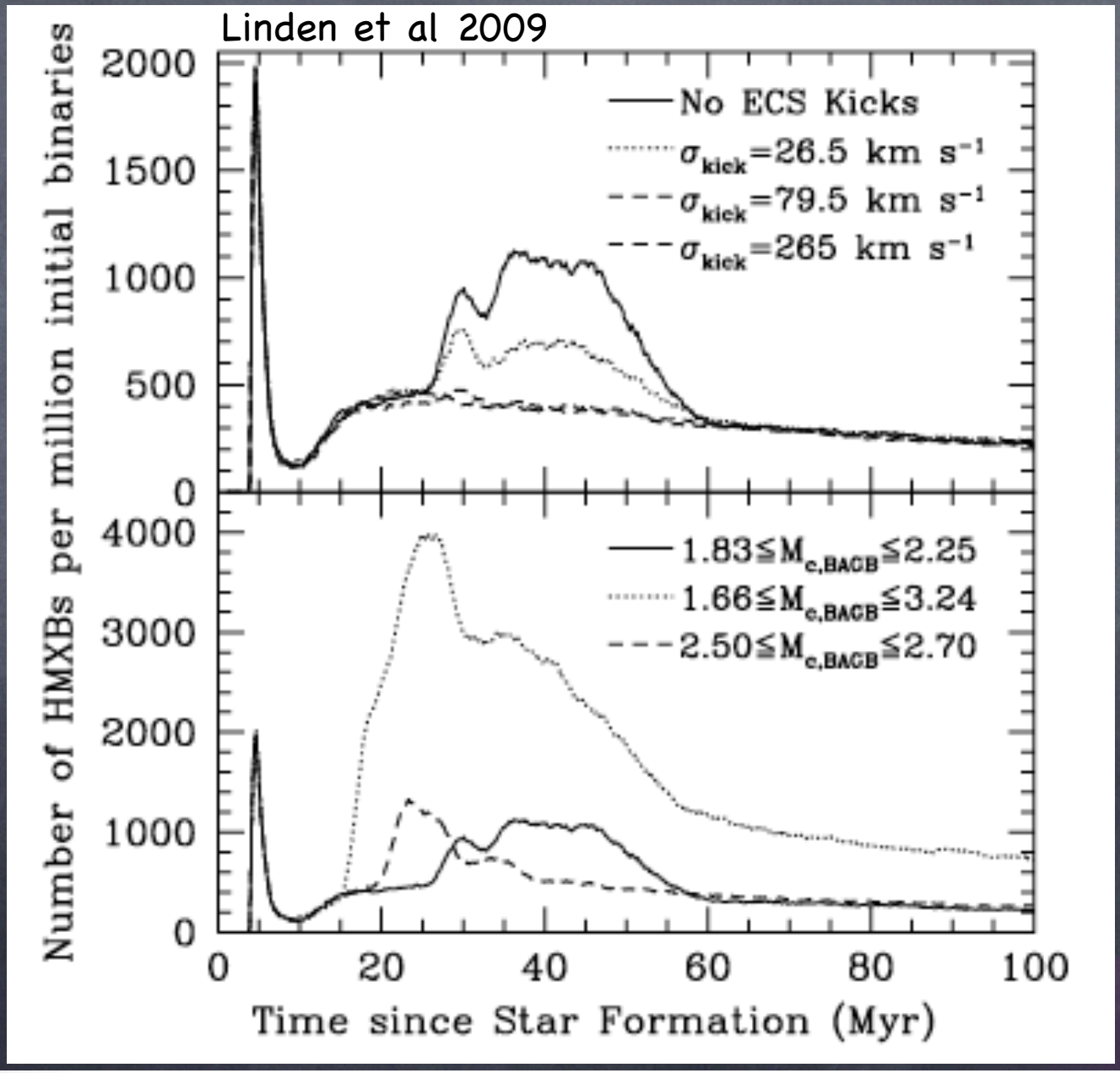
and there's globular clusters ...

HMXBs in Starbursts

Be-HMXBs and electron-capture SN (ECS) ?

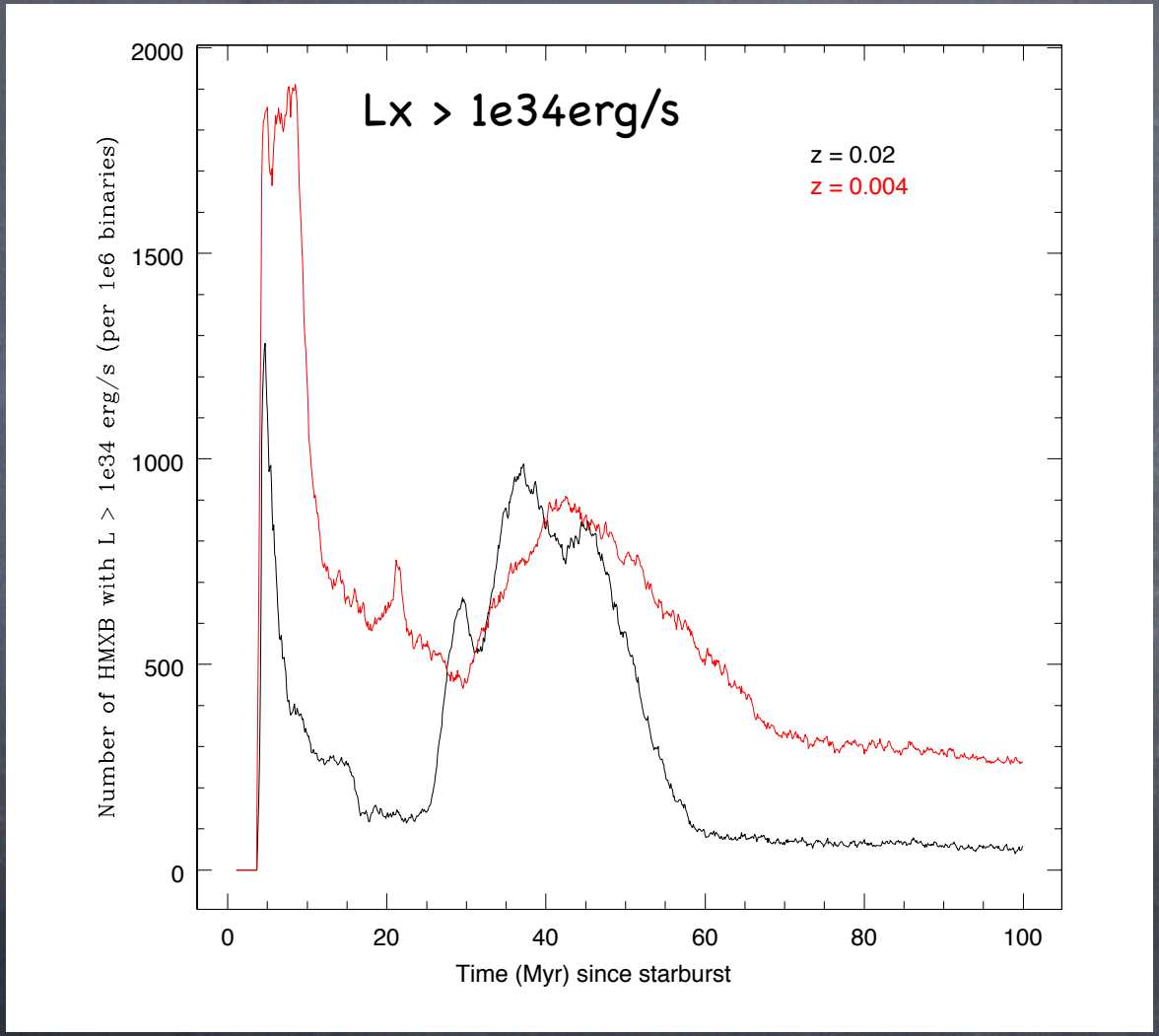
solar metallicity

Lx > 1e32erg/s



HMXBs in Starbursts

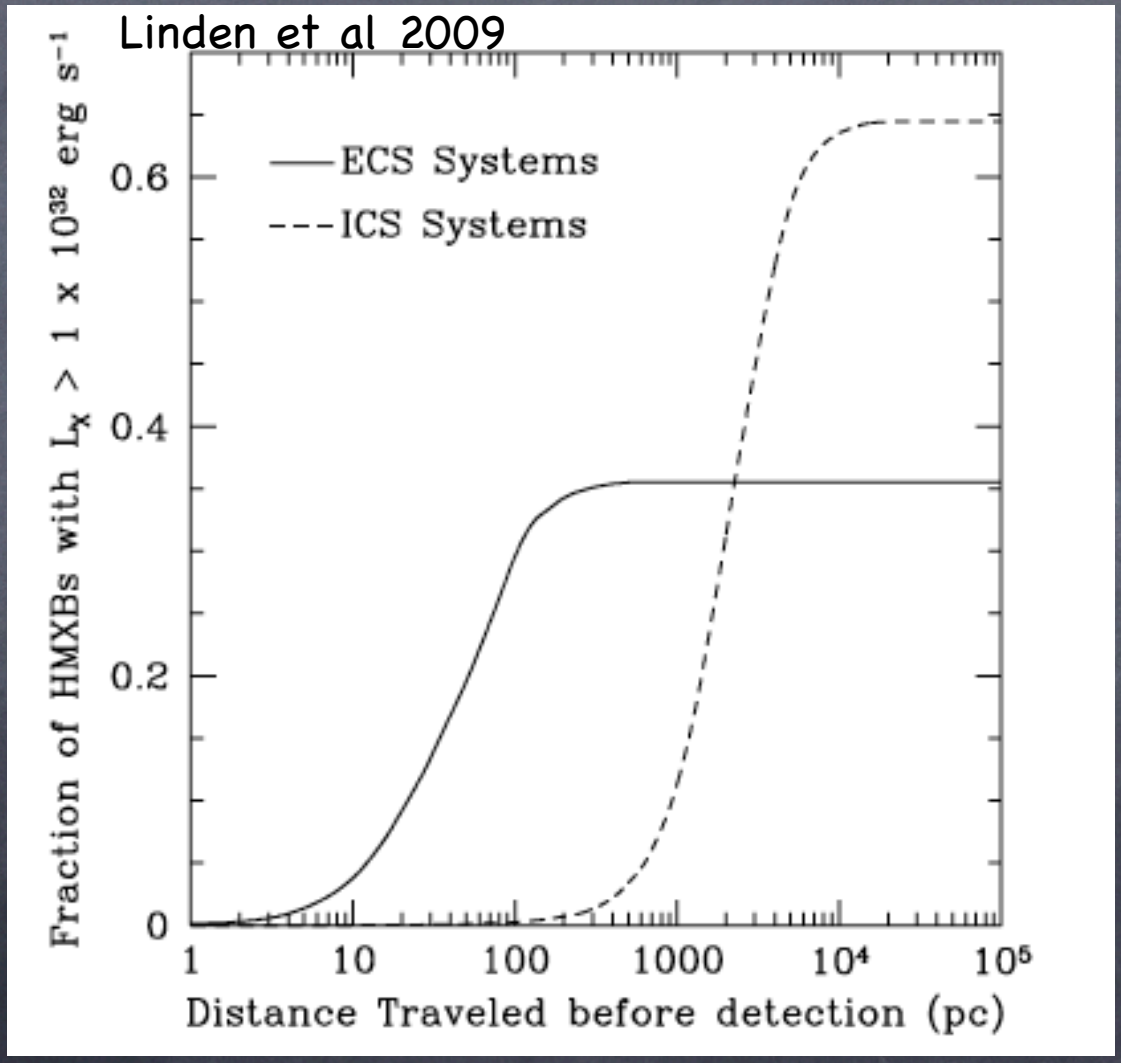
Be-HMXBs and electron-capture SN (ECS) in the SMC ?



Be-phenomenon modeling is needed ...

HMXBs in Starbursts

Be-HMXBs and electron-capture SN (ECS) in the SMC ?
ECS kicks are expected to be low



- note from M.Coe's talk

Challenges with SMC modeling

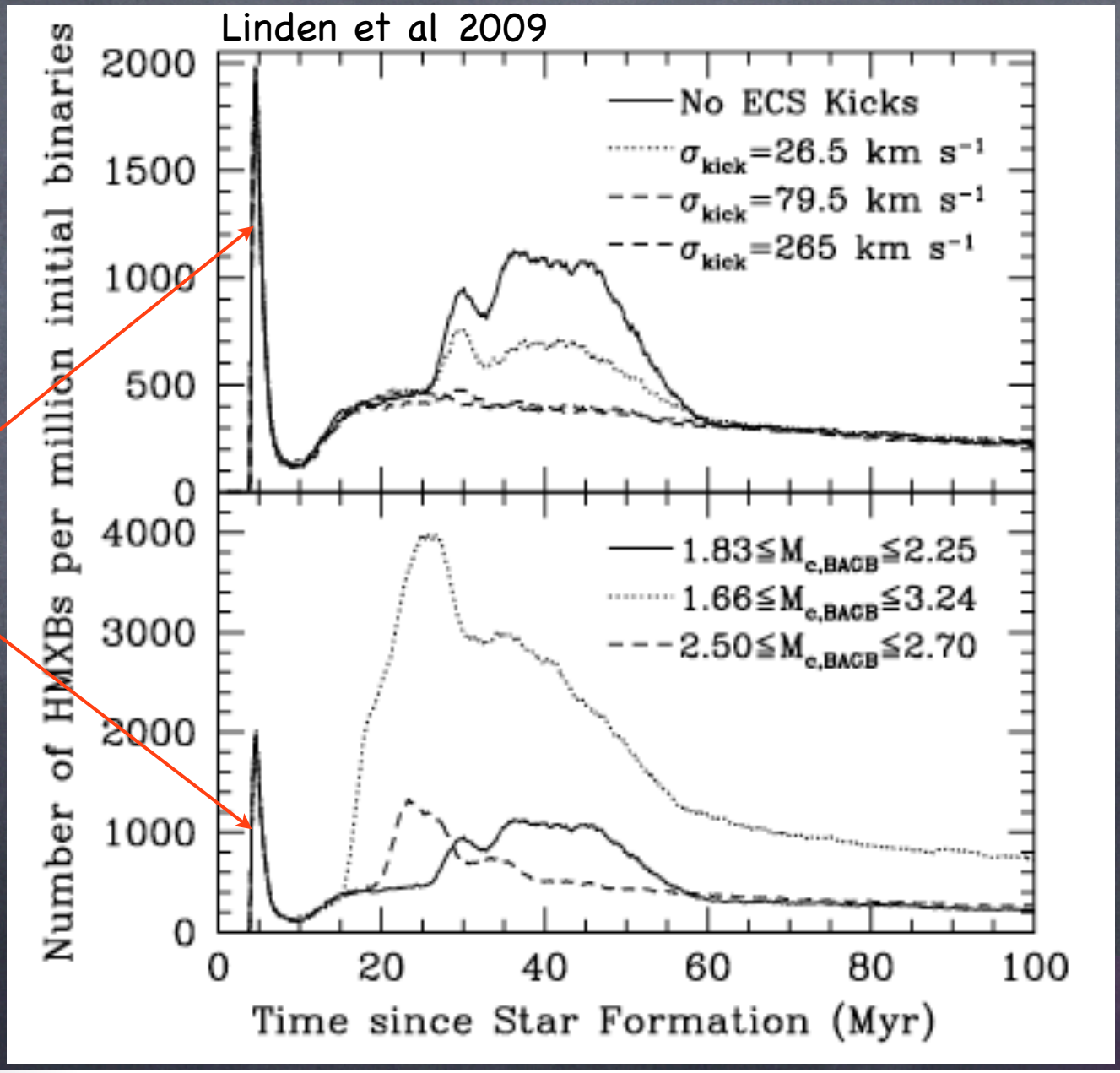
- Be phenomenon:
  - careful modeling is needed for reliable Be identification and their Lx
- in the bar:
  - Be XRB orbital periods are too long
    - resolution: realistic stellar evolution models & HG radii
- in the bar:
  - at least 20% of HMXBs are wind-fed SG-HMXBs
    - resolution: weaker winds ?
- outside the bar:
  - too many wind-fed SG-HMXBs
    - resolution: weaker winds ?

HMXBs in Starbursts

solar metallicity

Lx > 1e32erg/s

BH wind-fed HMXBs, some eccentric with O,B donors

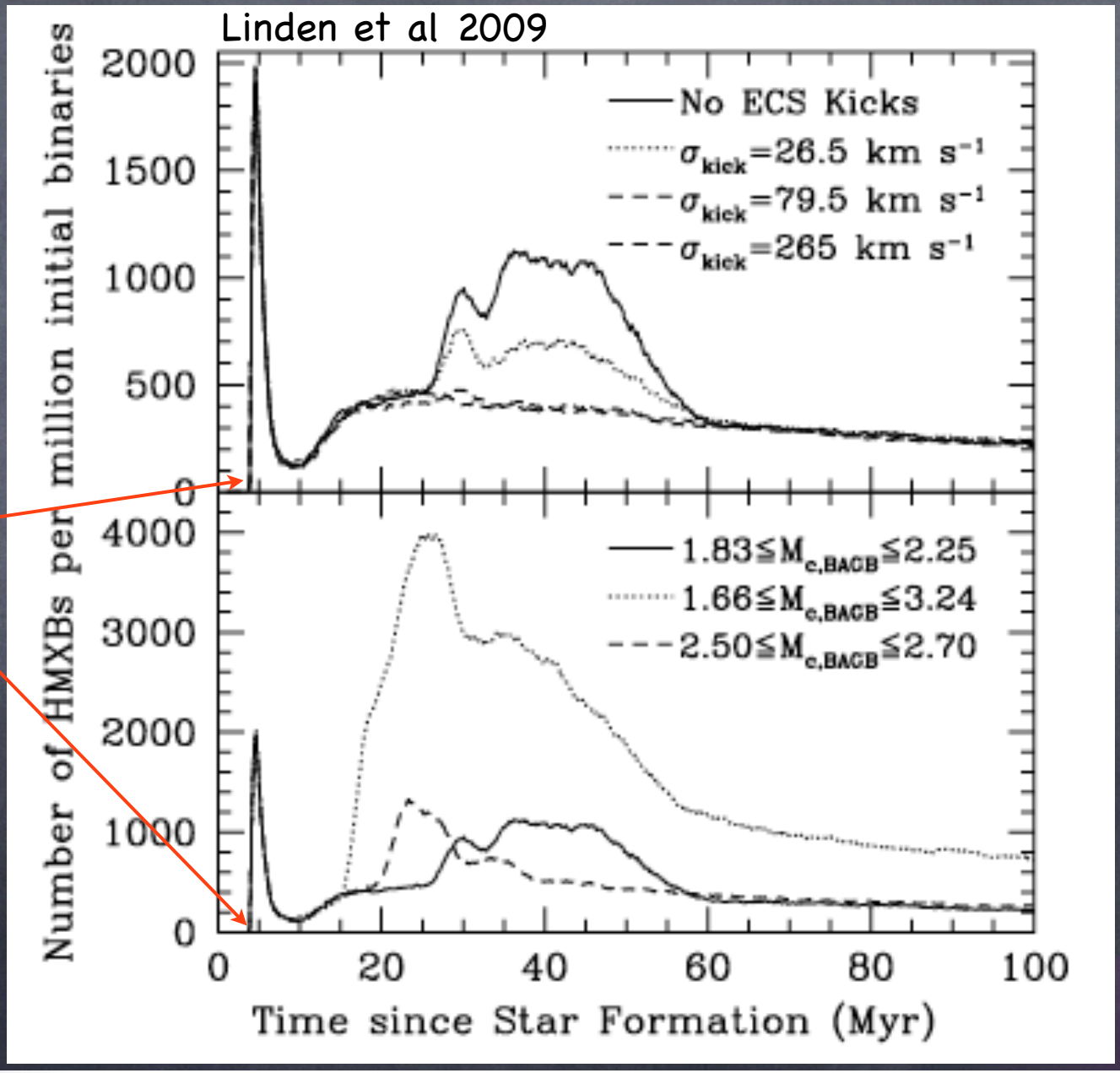


HMXBs in Starbursts

solar metallicity

Lx > 1e32erg/s

No XRBs prior to 3.5-4Myr



HMXBs in Young Starbursts

Age and Metallicity effects

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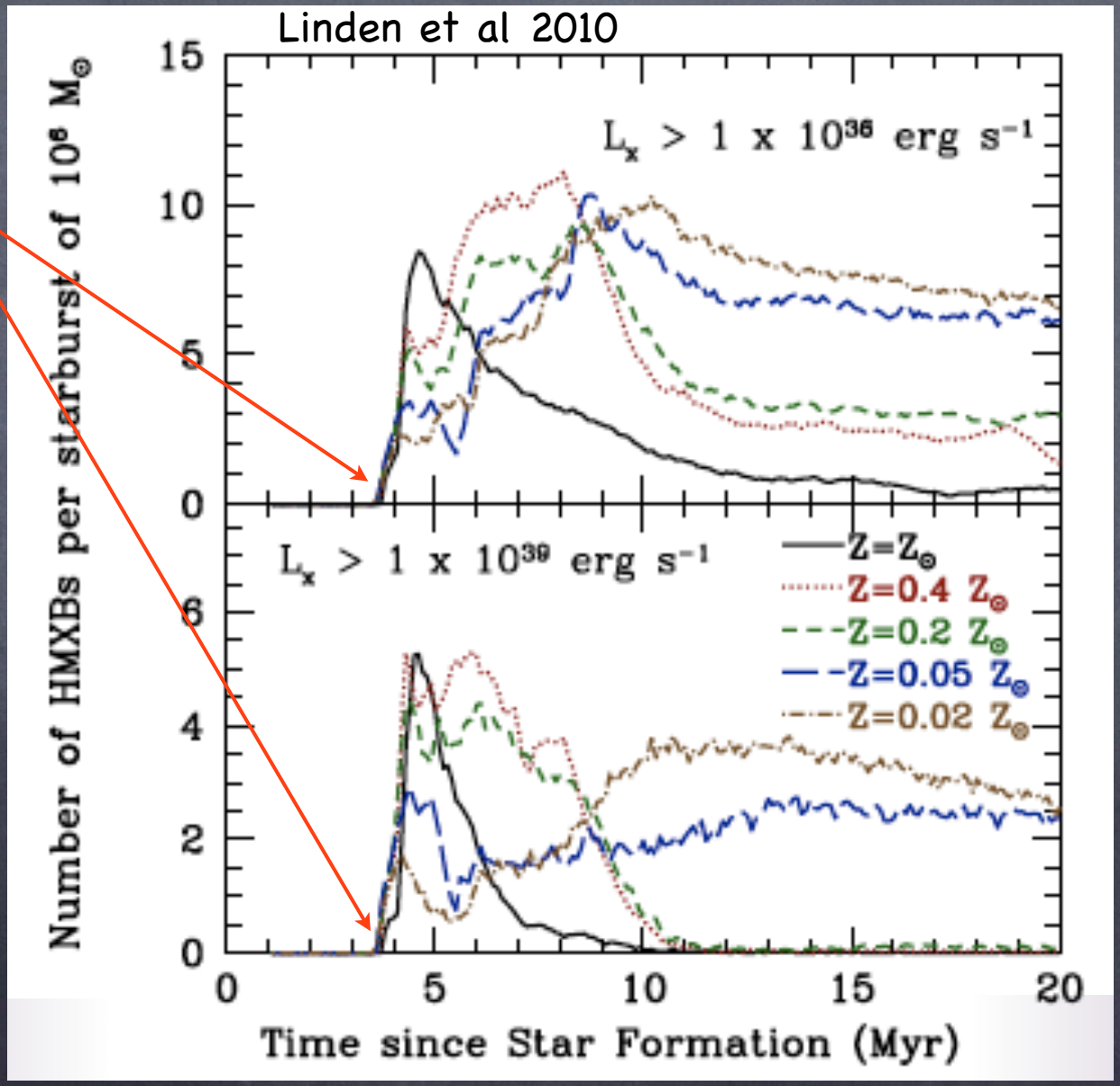
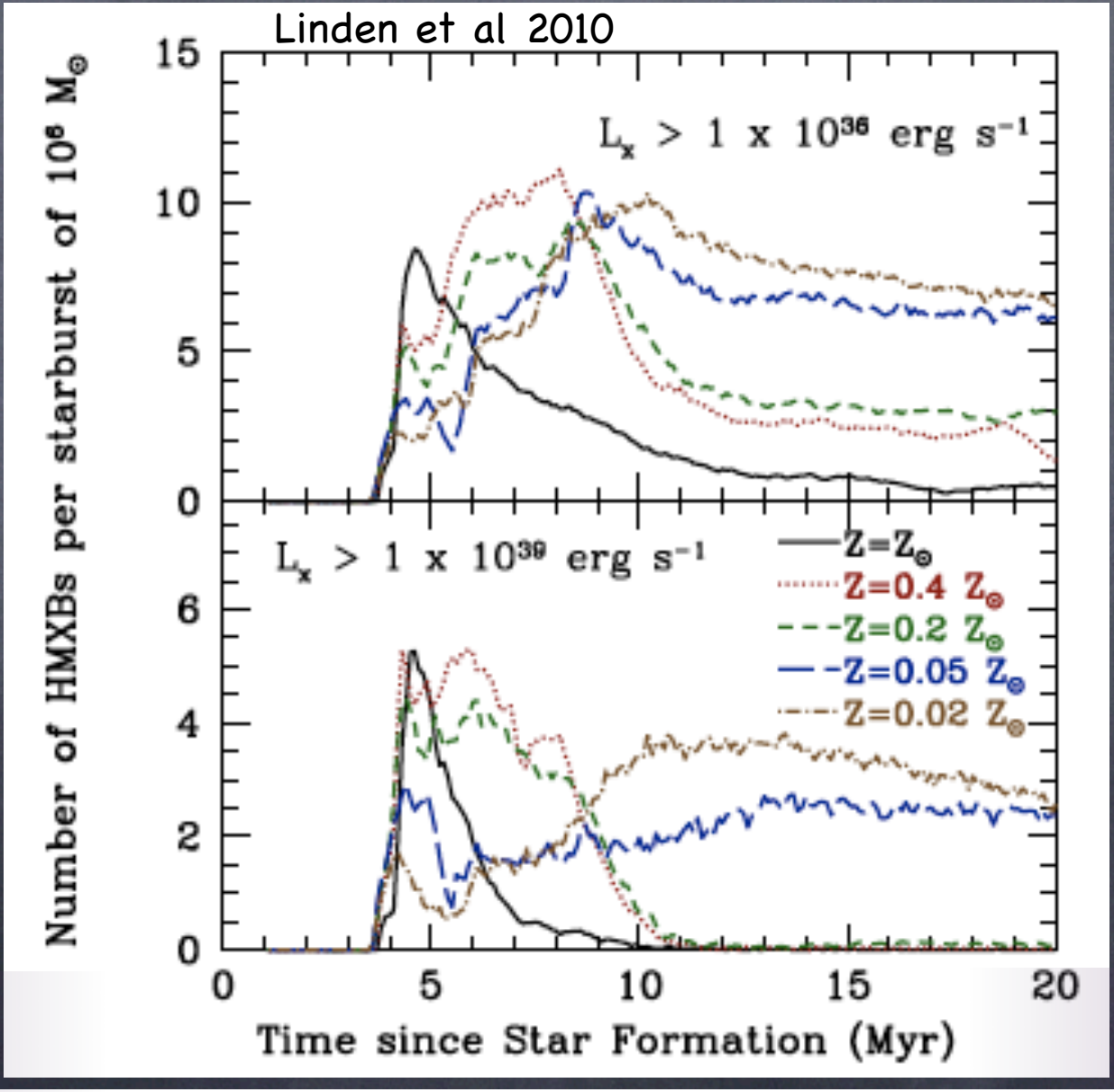


HMXBs in Young Starbursts

Age and Metallicity effects on HMXB relative numbers in young starbursts



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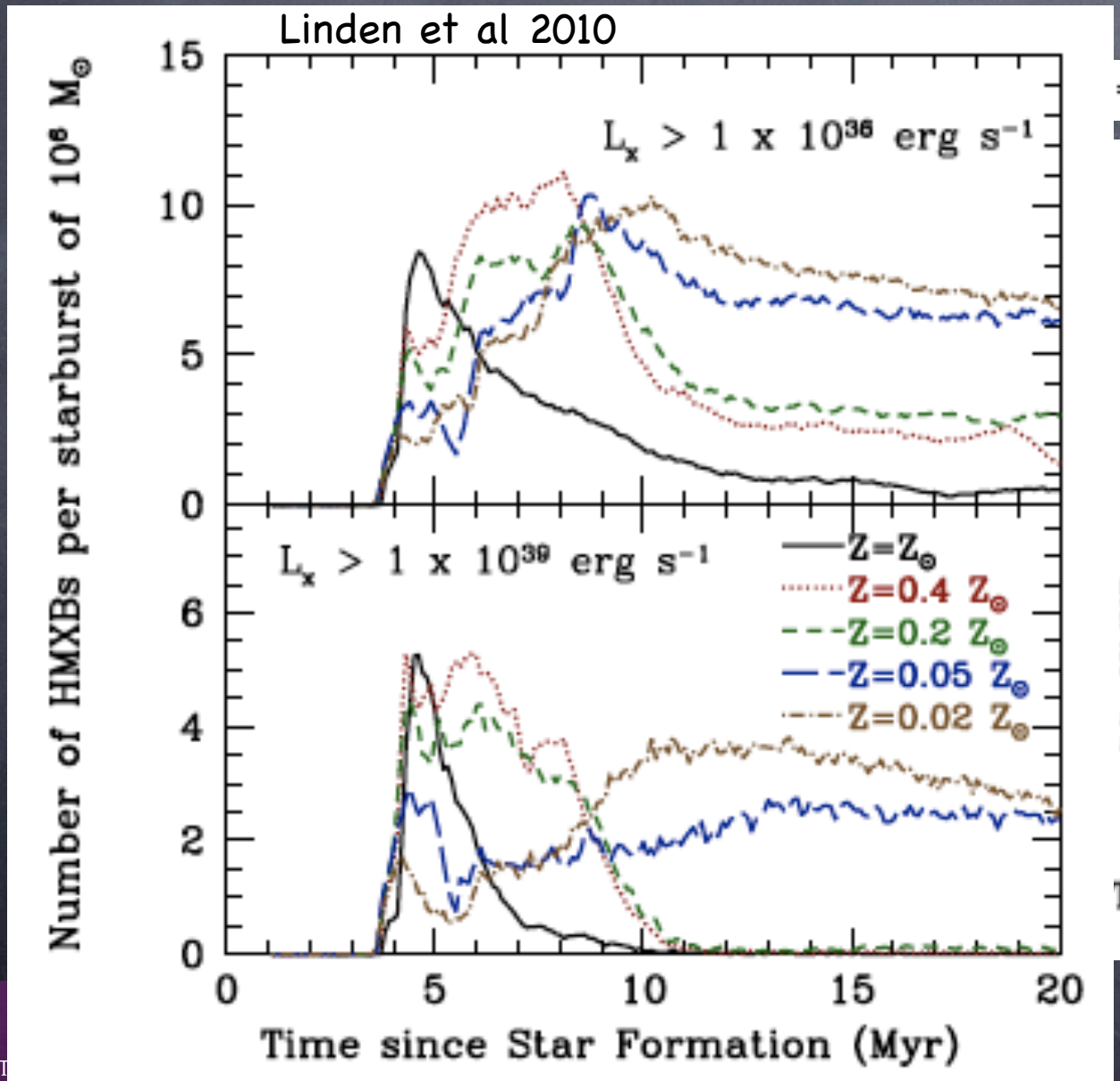
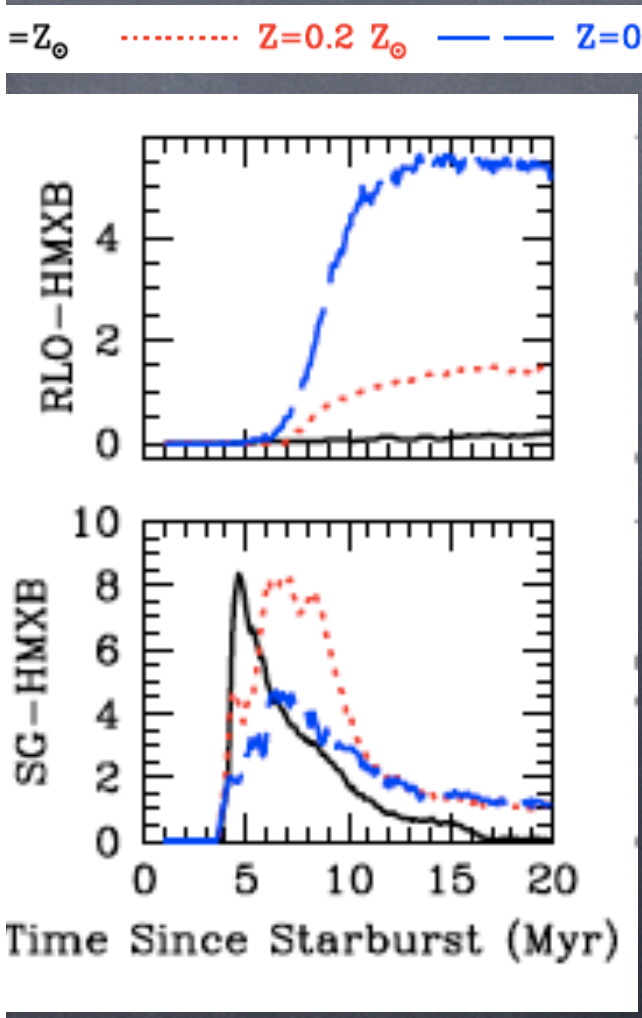
Linden et al 2010



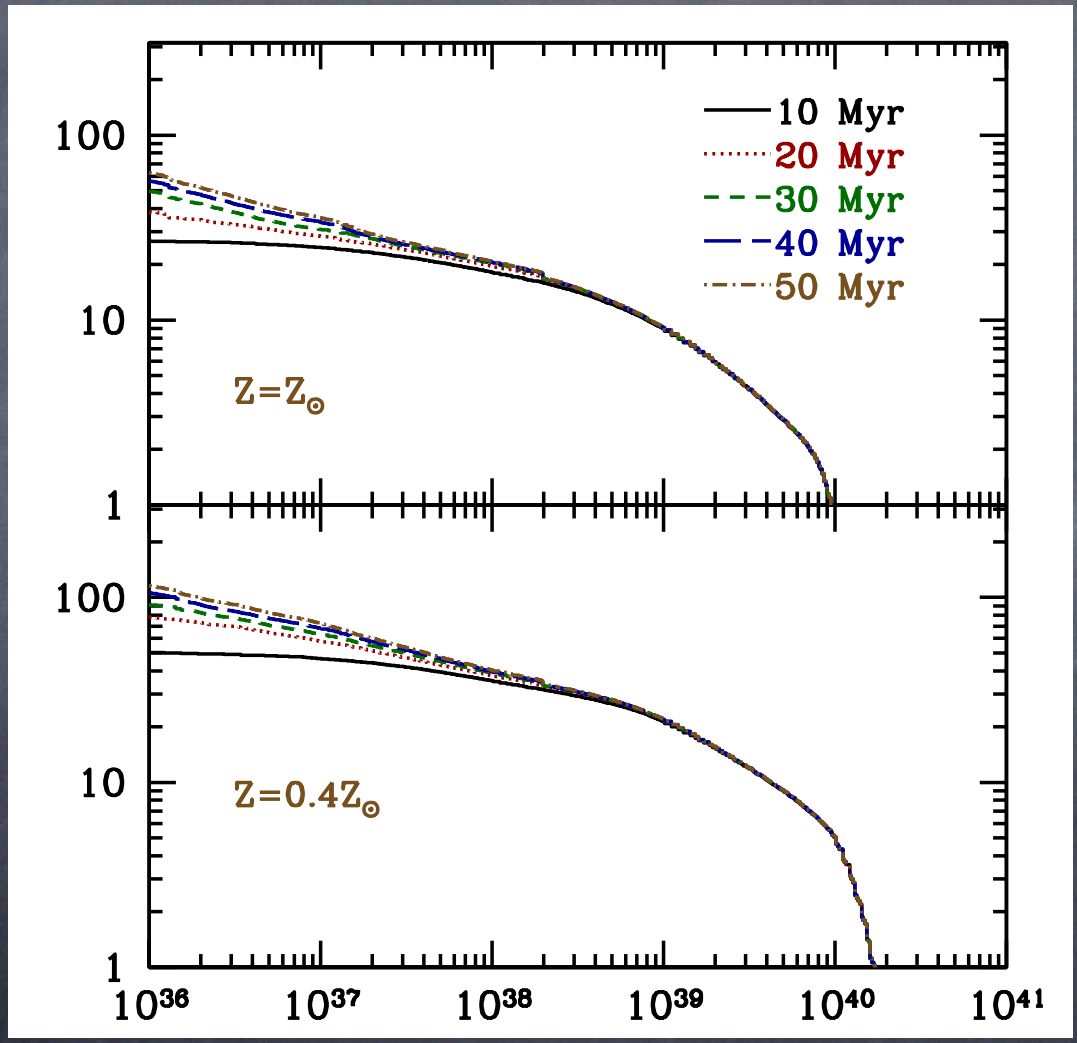


HMXBs in Starbursts

Age and Metallicity effects on HMXB XLF shapes in young starbursts

Cumulative Number / SFR

Linden et al 2010



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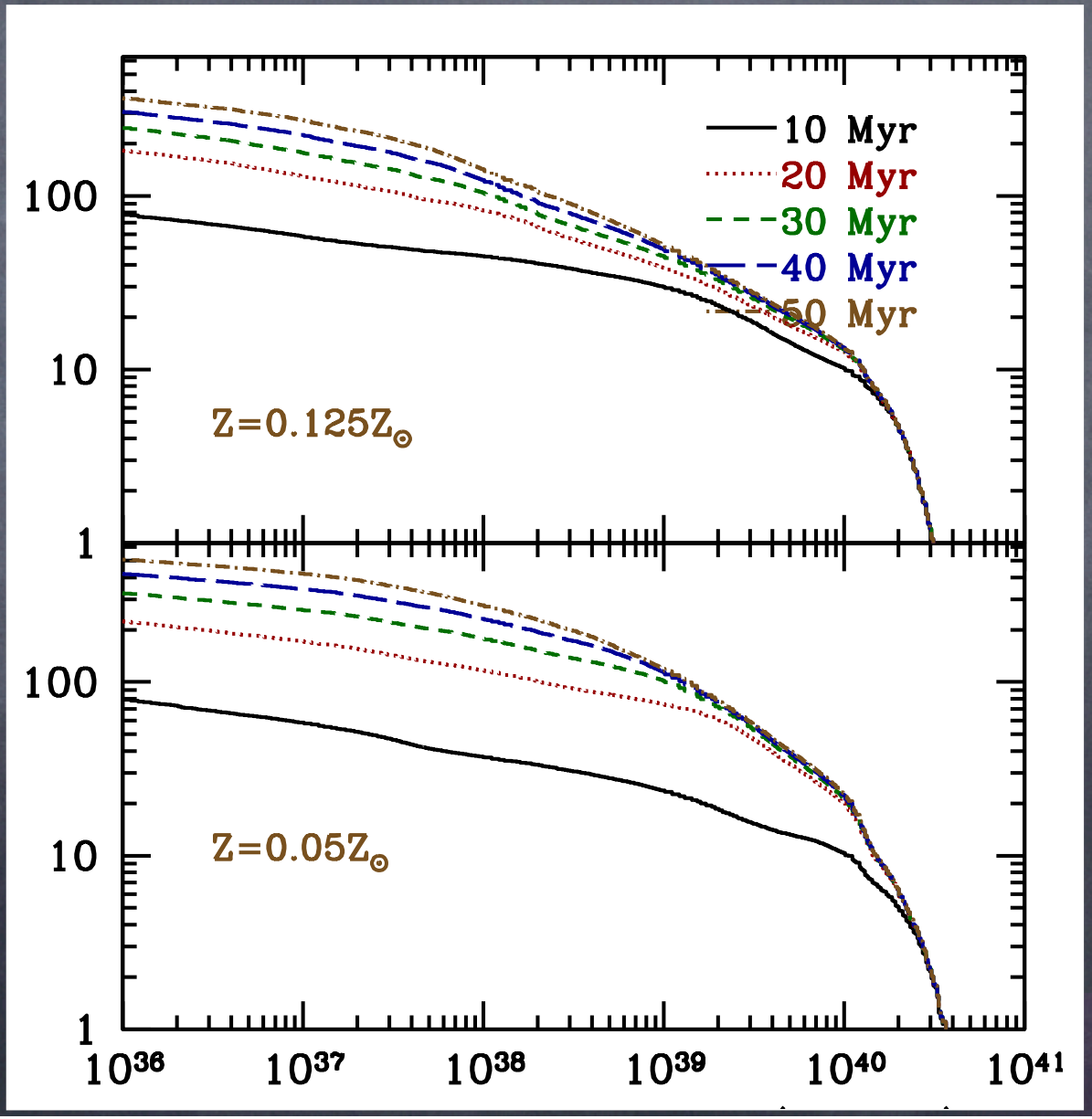

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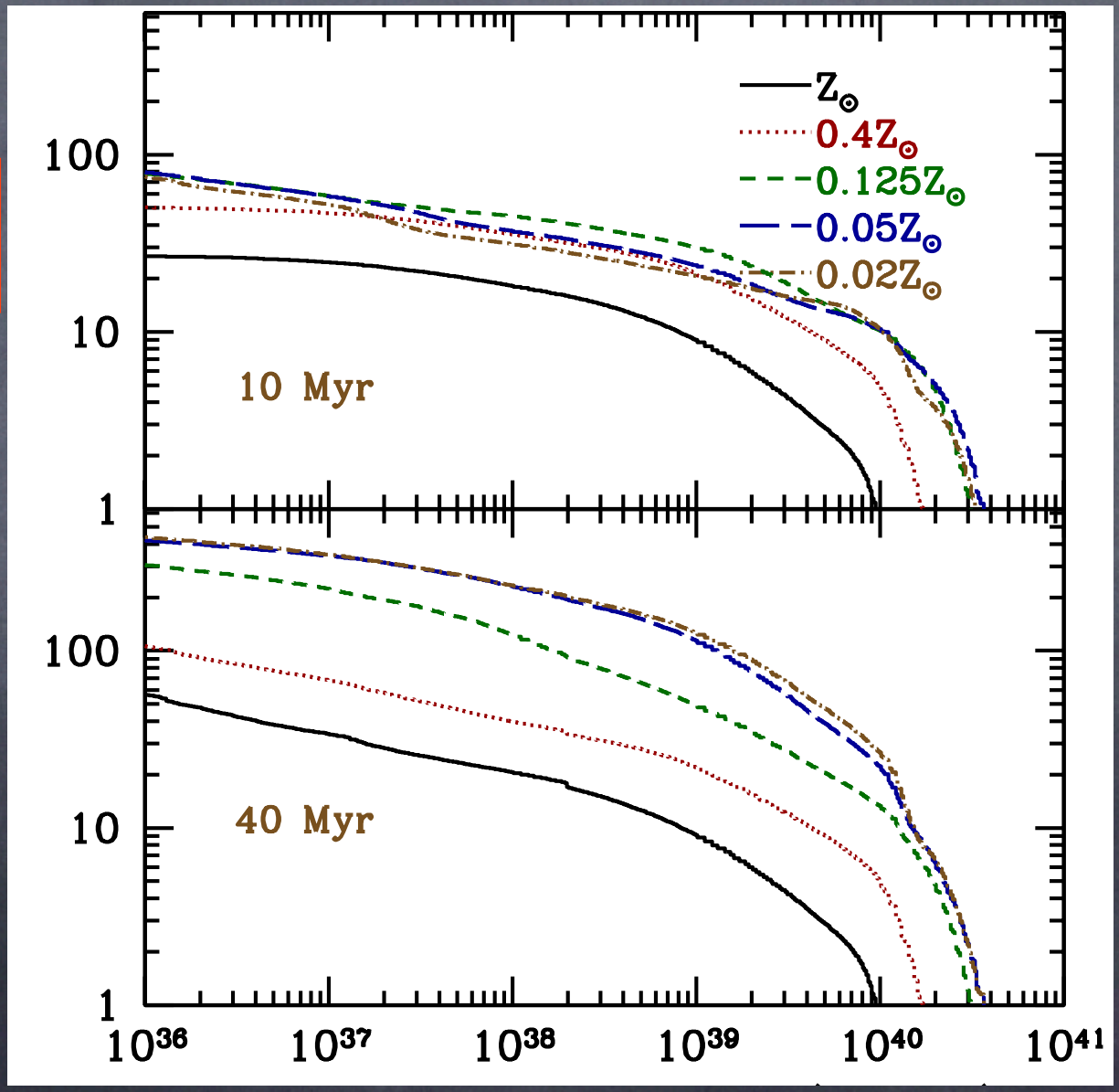
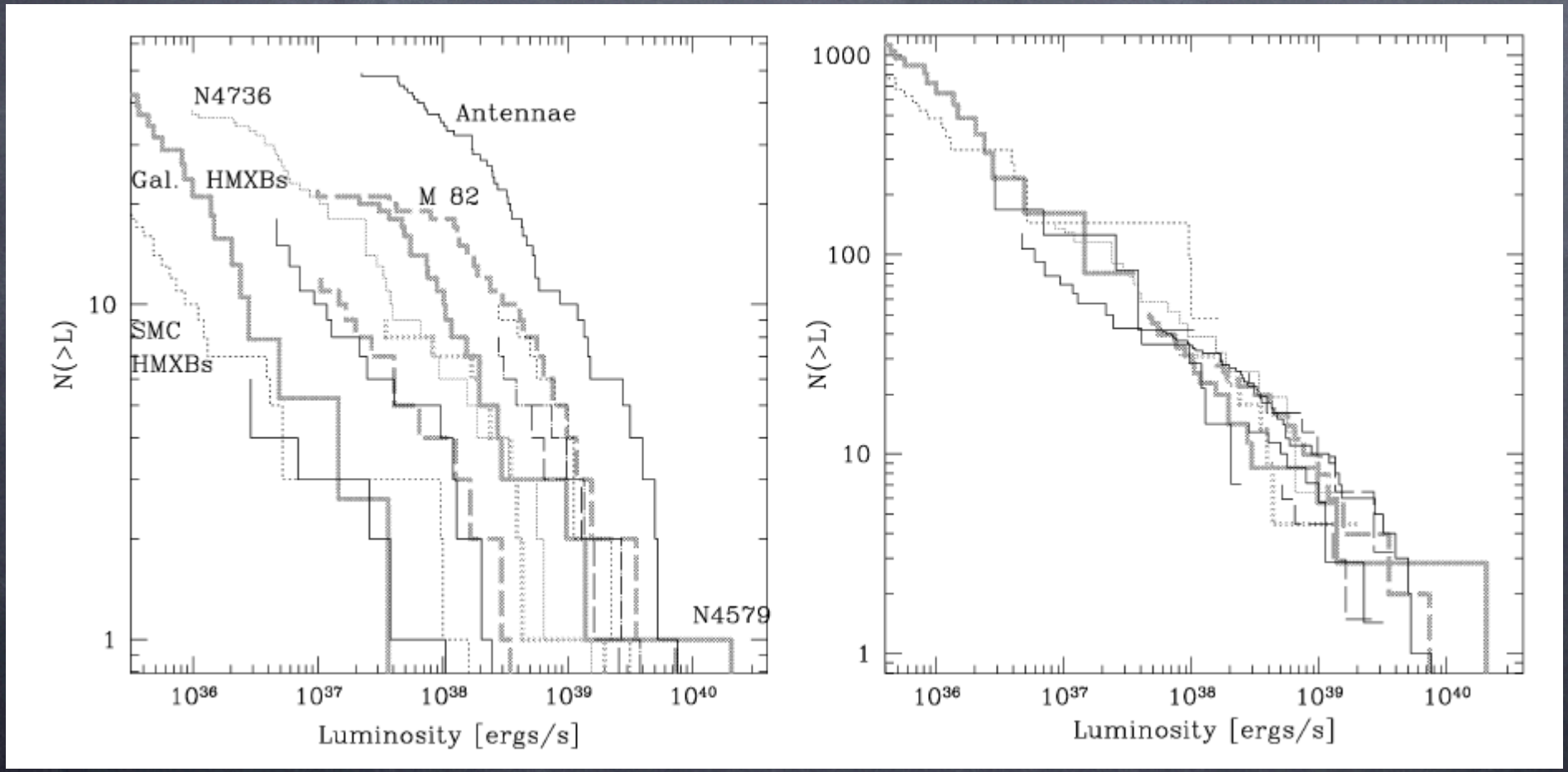


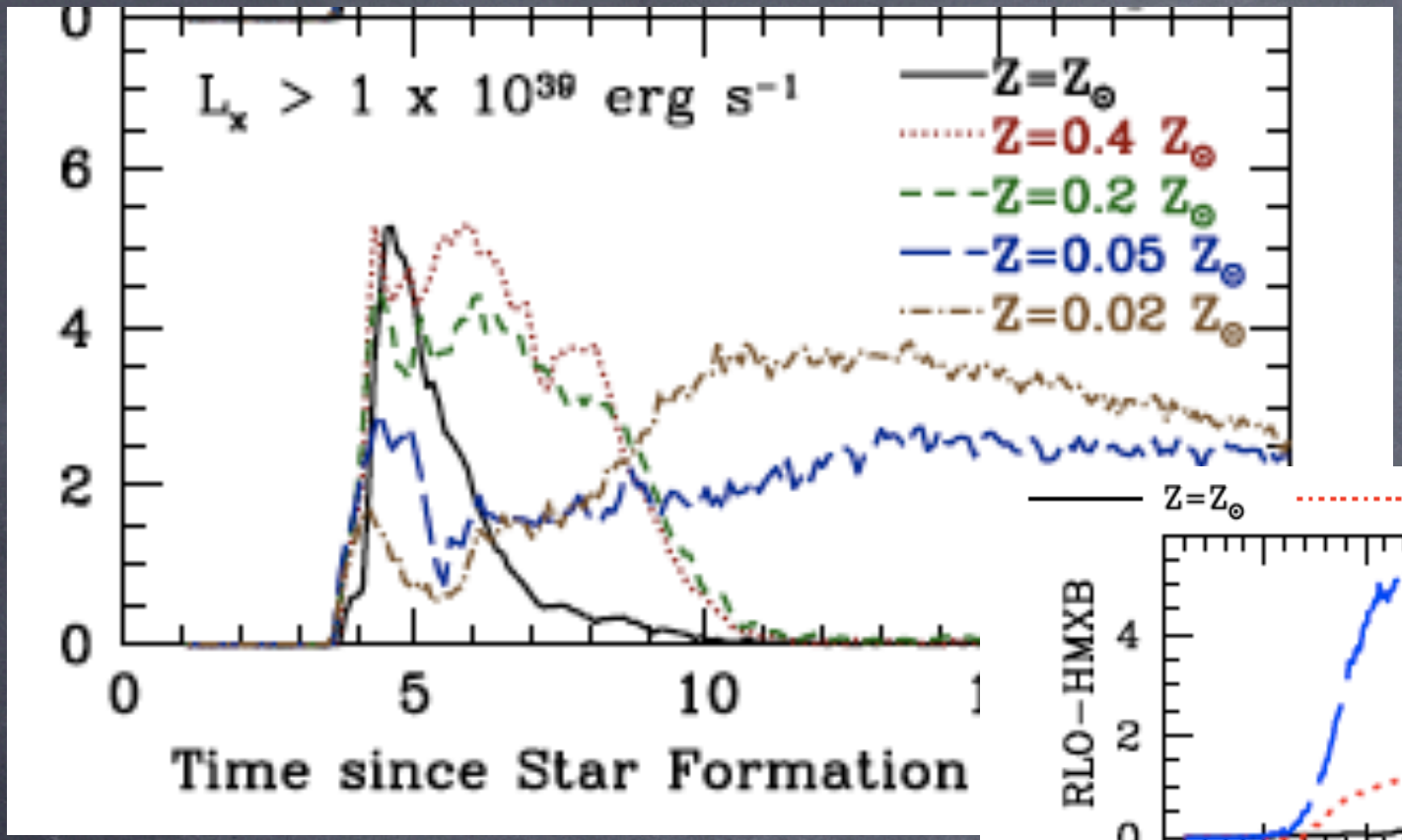
Grimm et al 2003: Universal XLF normalized to SFR

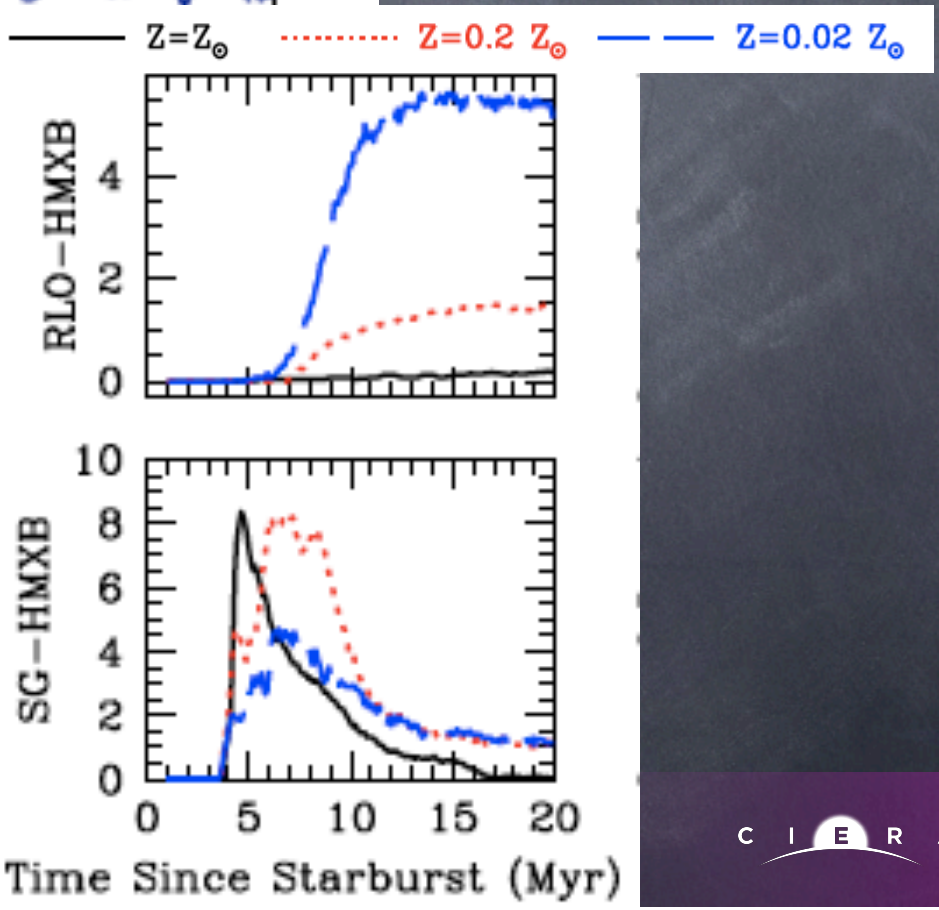
Sample restricted in age & metallicity ??



ULXs & Metallicity

Linden et al 2010





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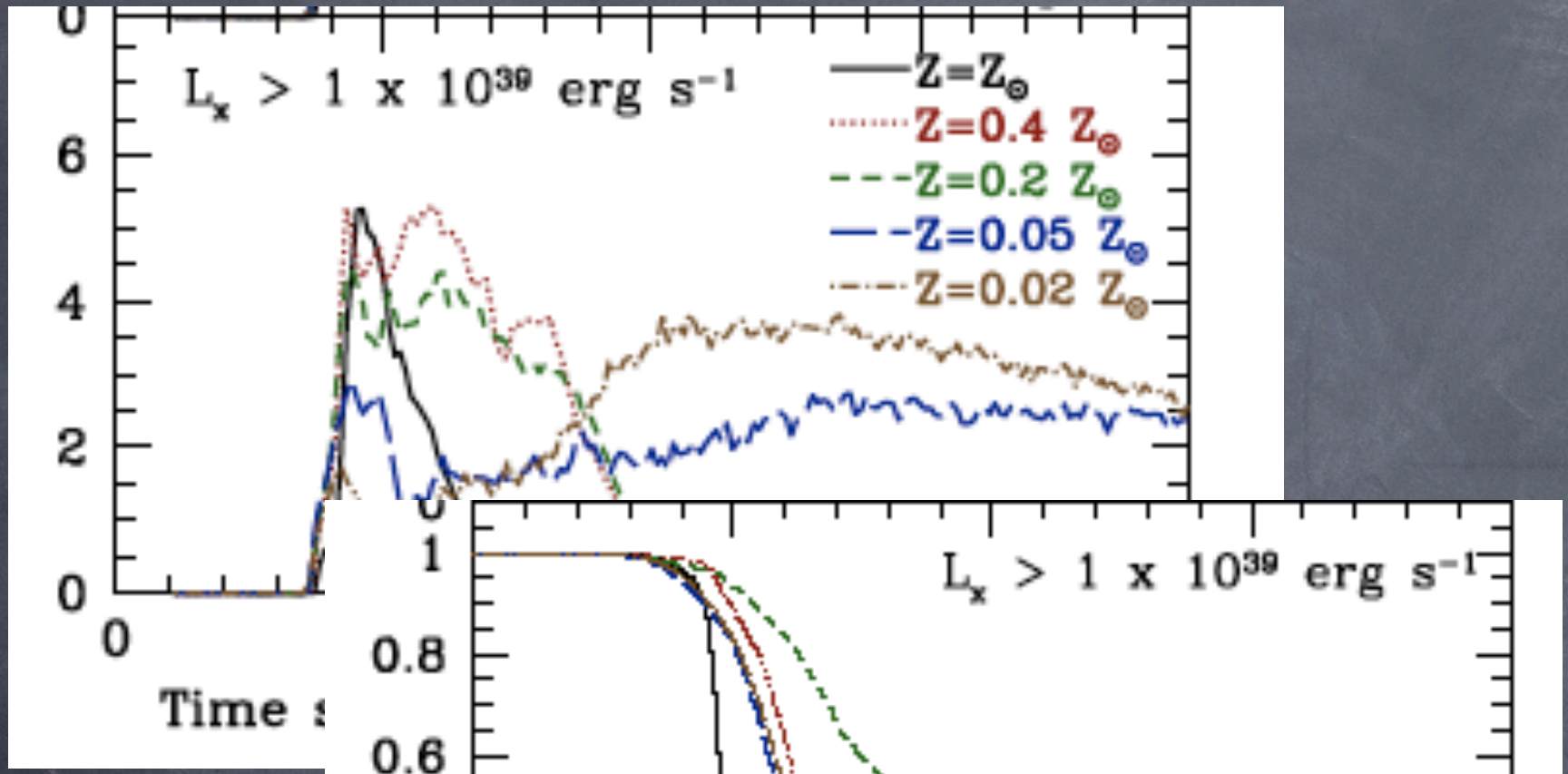

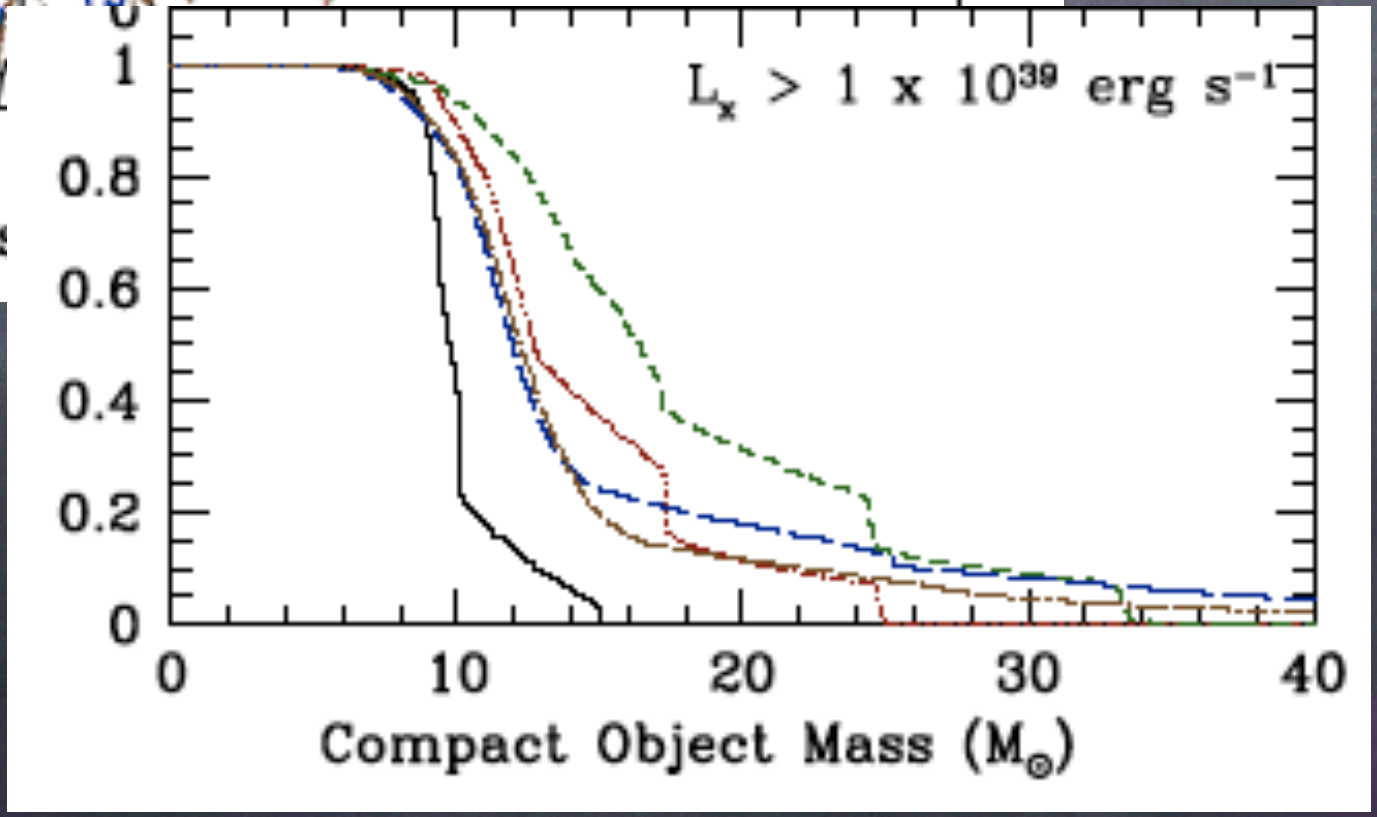

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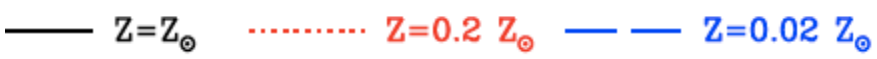
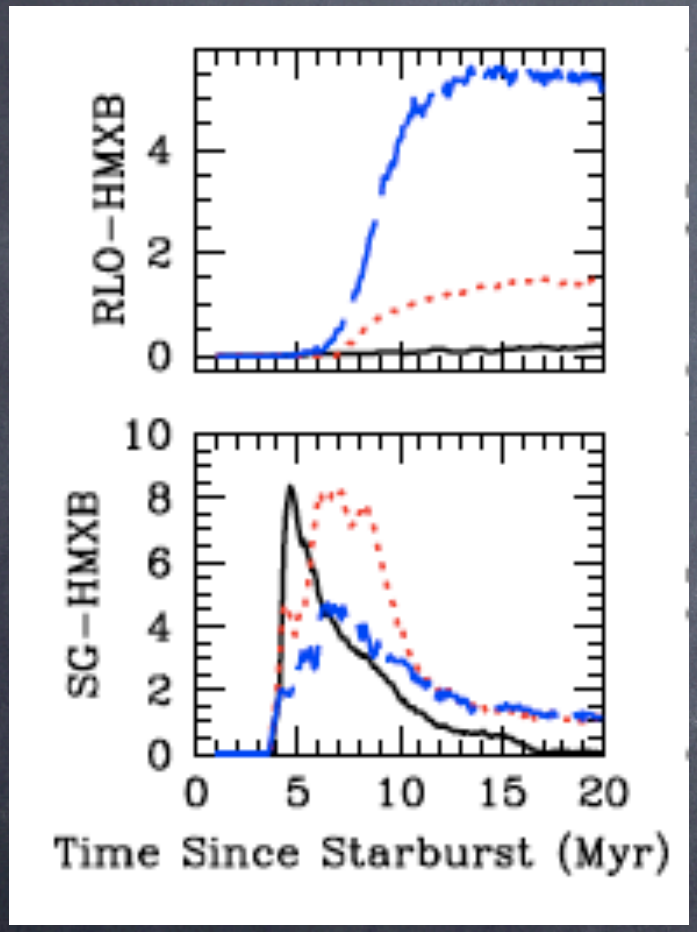
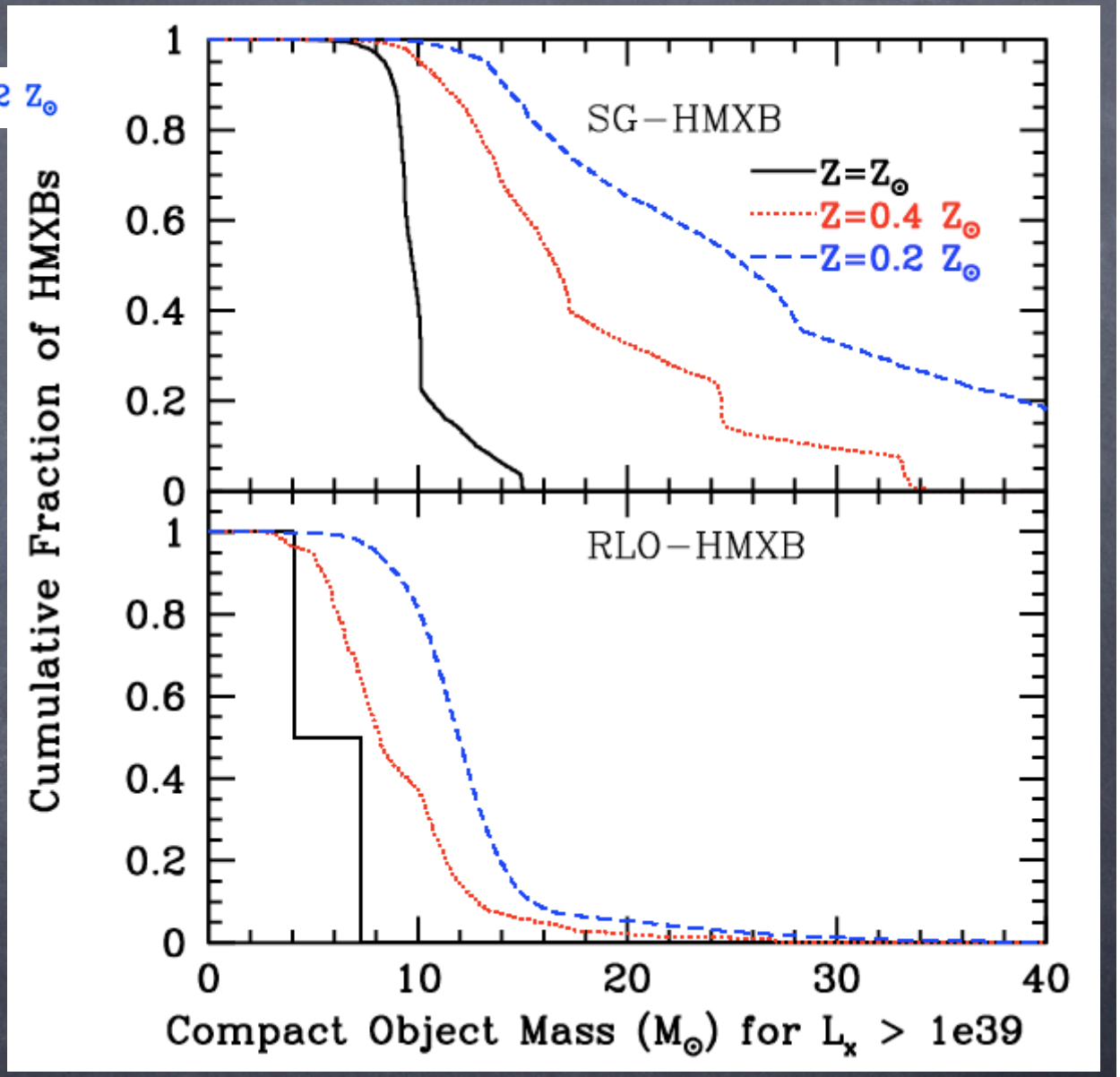


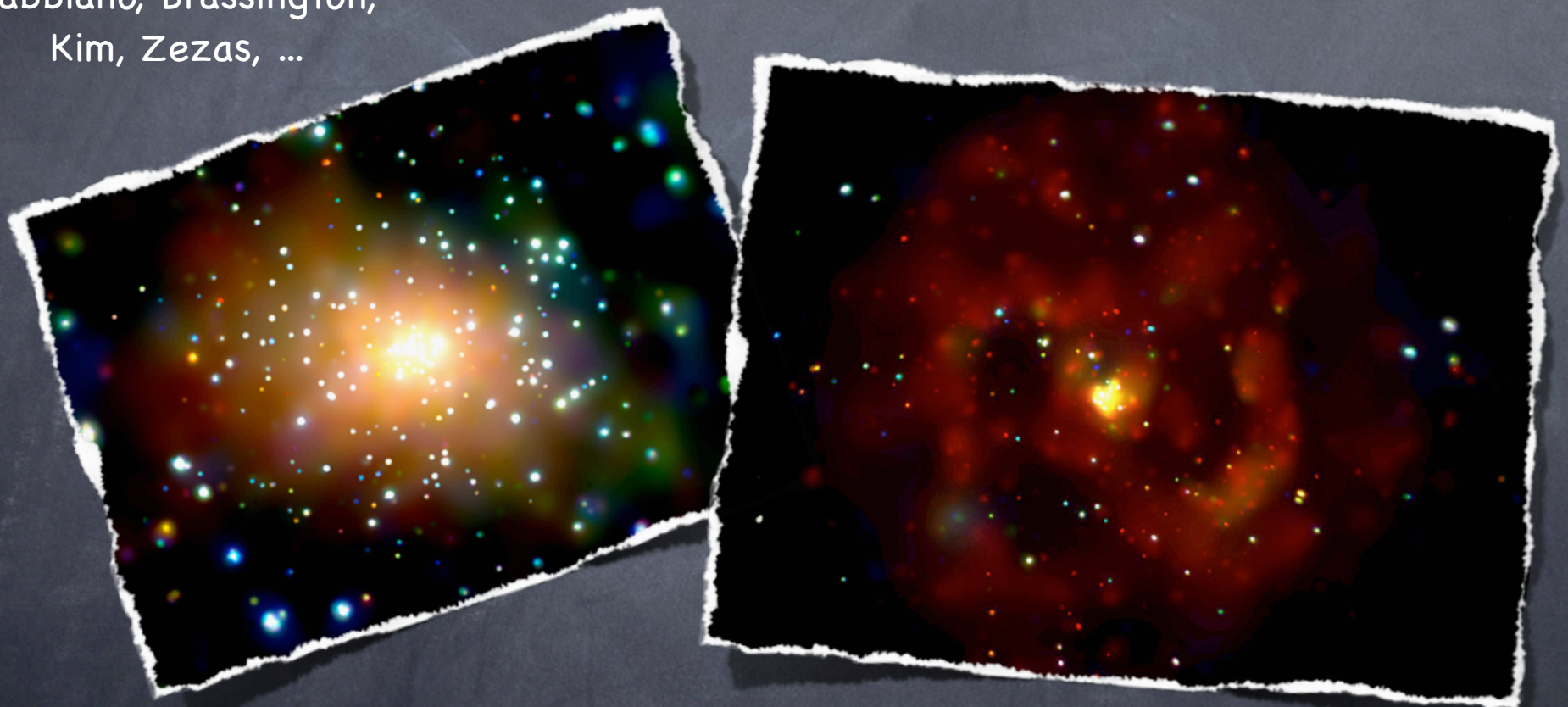




Extragalactic LMXB populations:

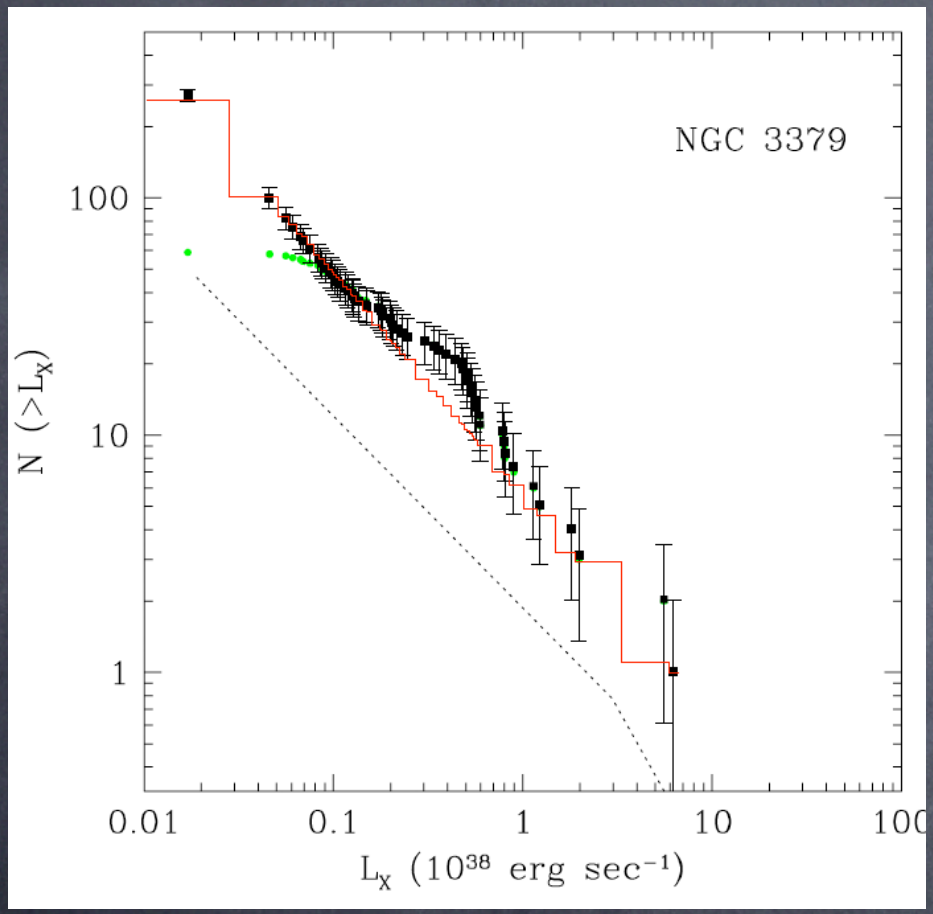
Models for the elliptical galaxies NGC3379 and NGC4278

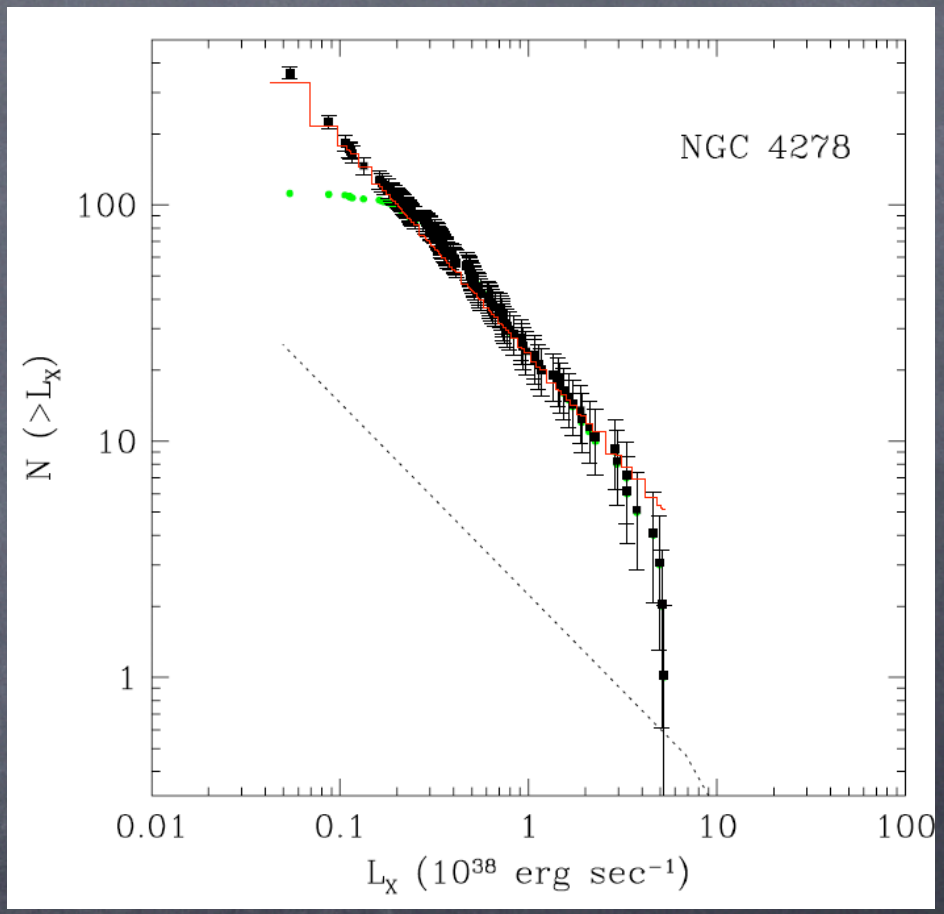
Fragos, VK, Belczynski,
Fabbiano, Brassington,
Kim, Zezas, ...



credit: NASA/UMass/Z.Li & Q.D.Wang/U.Leicester/U.London/R.Soria & K.Wu.

XLFs in elliptical galaxies: NGC3379 and NGC4278

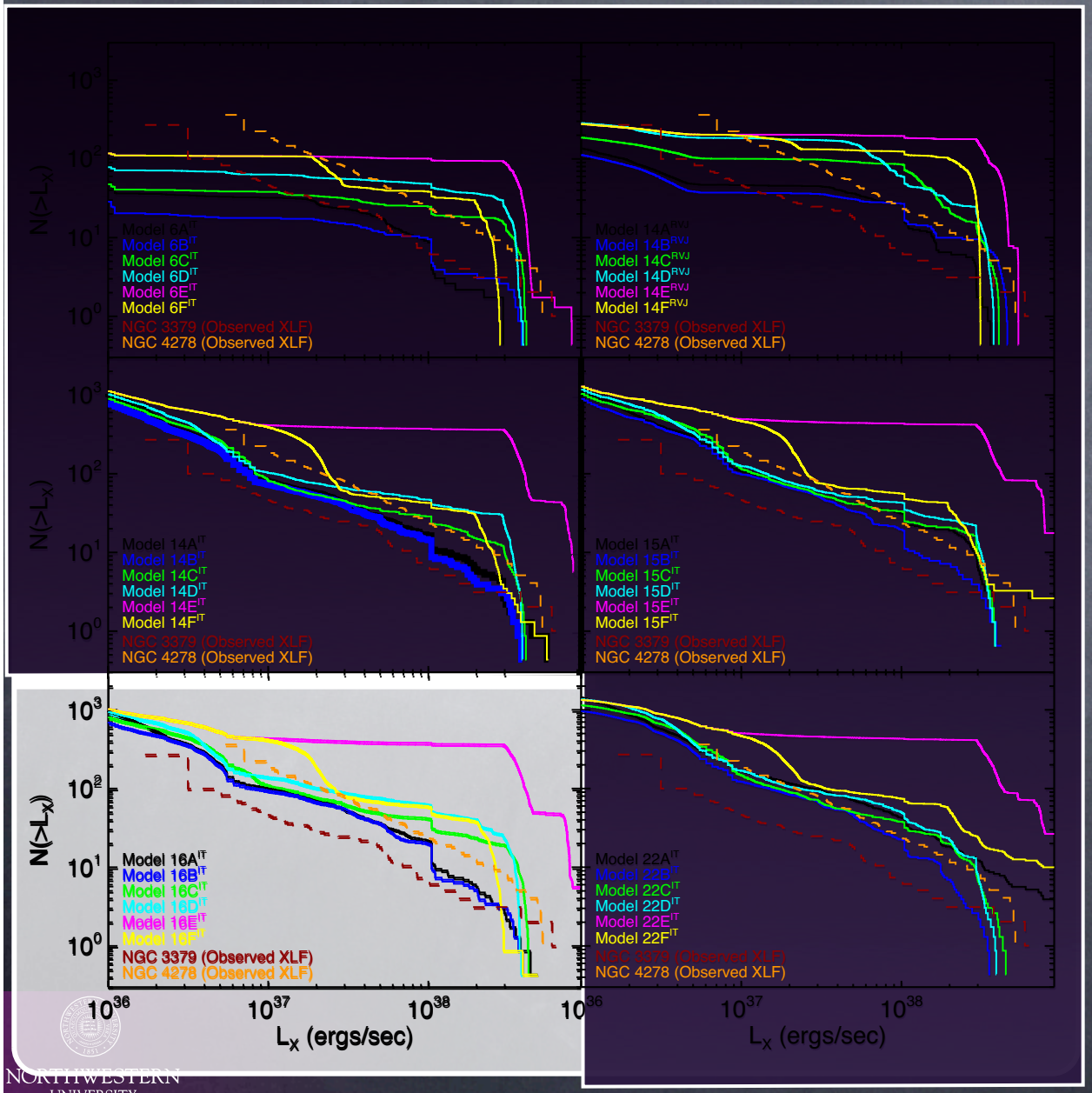




~1 Ms Chandra monitoring survey (PI: G. Fabbiano)

Field LMXB models I

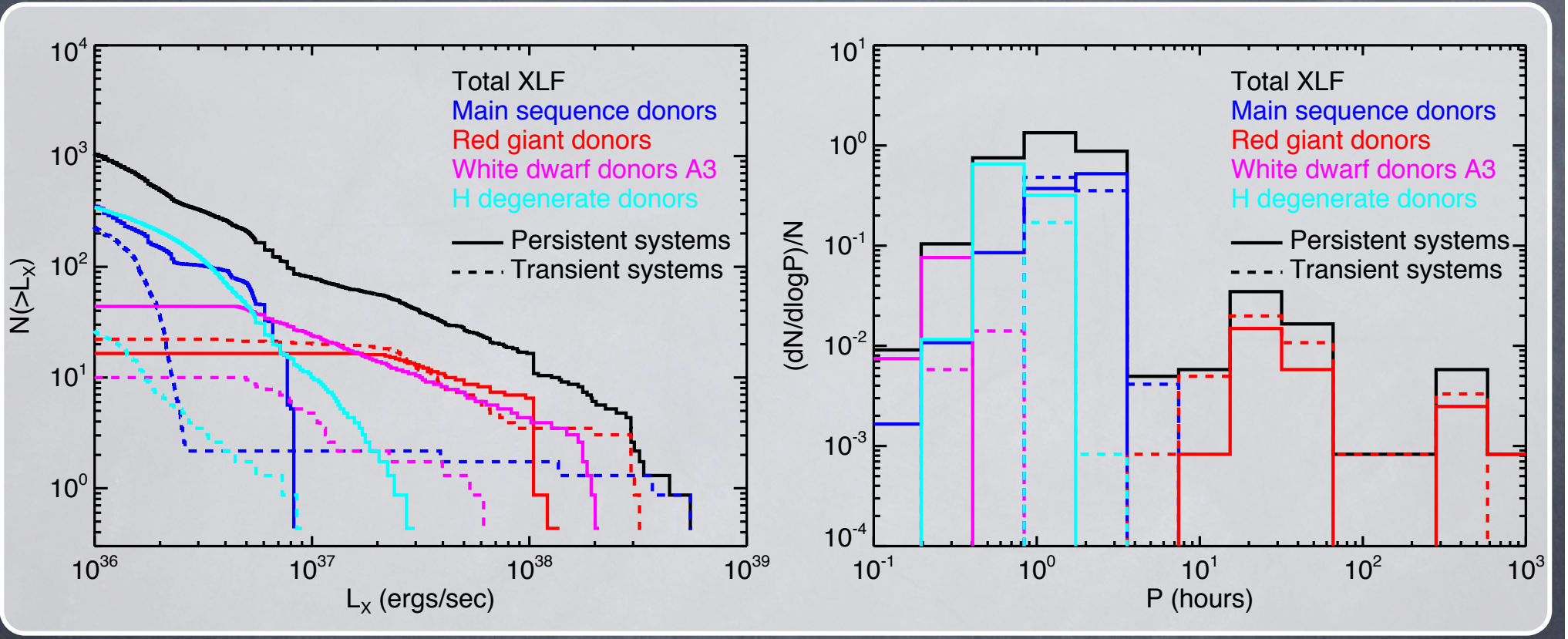
Fragos et al. 2008



- Some models are **consistent with the observed XLF** both in **shape and normalization**
- Comparison with observations **excludes widely used assumptions** (**magnetic braking, transients**)

Field LMXB models II

Fragos et al. 2008



Different LMXB sub-populations contribute to **different X-ray luminosity ranges** of the XLF.

Conclusions -

Fragos et al. 2008

- We find that **field LMXB populations** ***can have an important contribution*** to the observed XLFs of elliptical galaxies.
- **Different LMXB sub-populations** contribute to **different X-ray luminosity ranges** of the XLF.
- At **X-ray luminosities above 10^{37} erg/s**, **NSs with RG or WD donors** dominate the XLF.
- The **ratio of transient to persistent sources is ~20**. **Realistic modeling** of the outburst phase of transient LMXBs **is necessary**.

Population Synthesis Modeling

what to expect in the near future ...

from Tassos Fragos (CfA/ITC)
and collaborators

- live, self-consistent stellar evolution and mass transfer
- treatment of mass transfer in eccentric binaries
- coupling to full stellar dynamics: cluster modeling ...

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