Modeling of X-ray Binary Populations in Elliptical Galaxies

Tassos Fragos

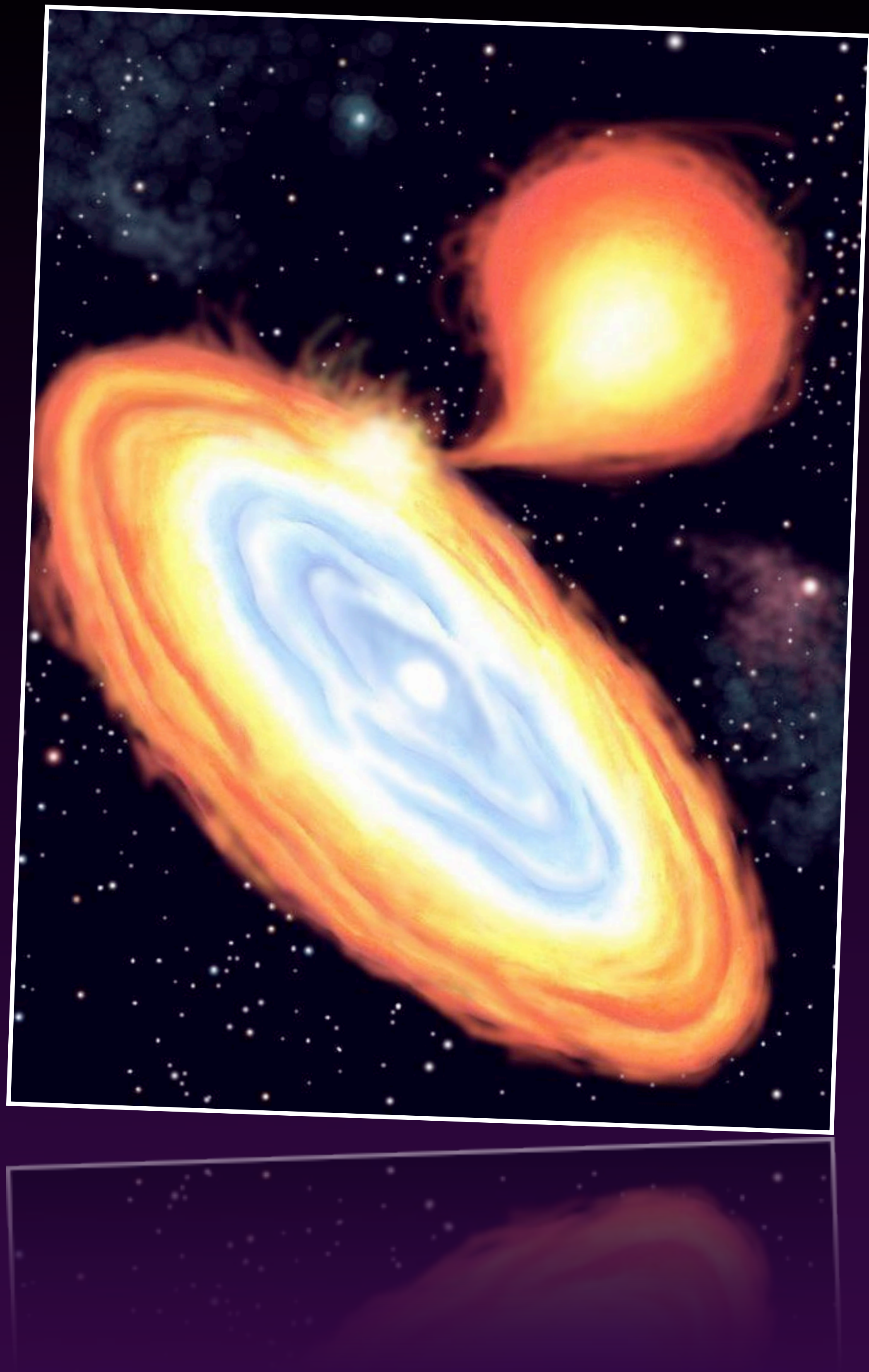
NORTHWESTERN UNIVERSITY

with:

V. Kalogera, G. Fabbiano, D.-W. Kim, N. Brassington

September 25th, 2009 *Chandra's First Decade of Discovery*

Low mass X-ray binaries (LMXBs)



RLOF X-ray Binaries

Donor star:

MS, Giant, WD/degenerate

low-mass: $<1M_{\odot}$

Orbital Periods:

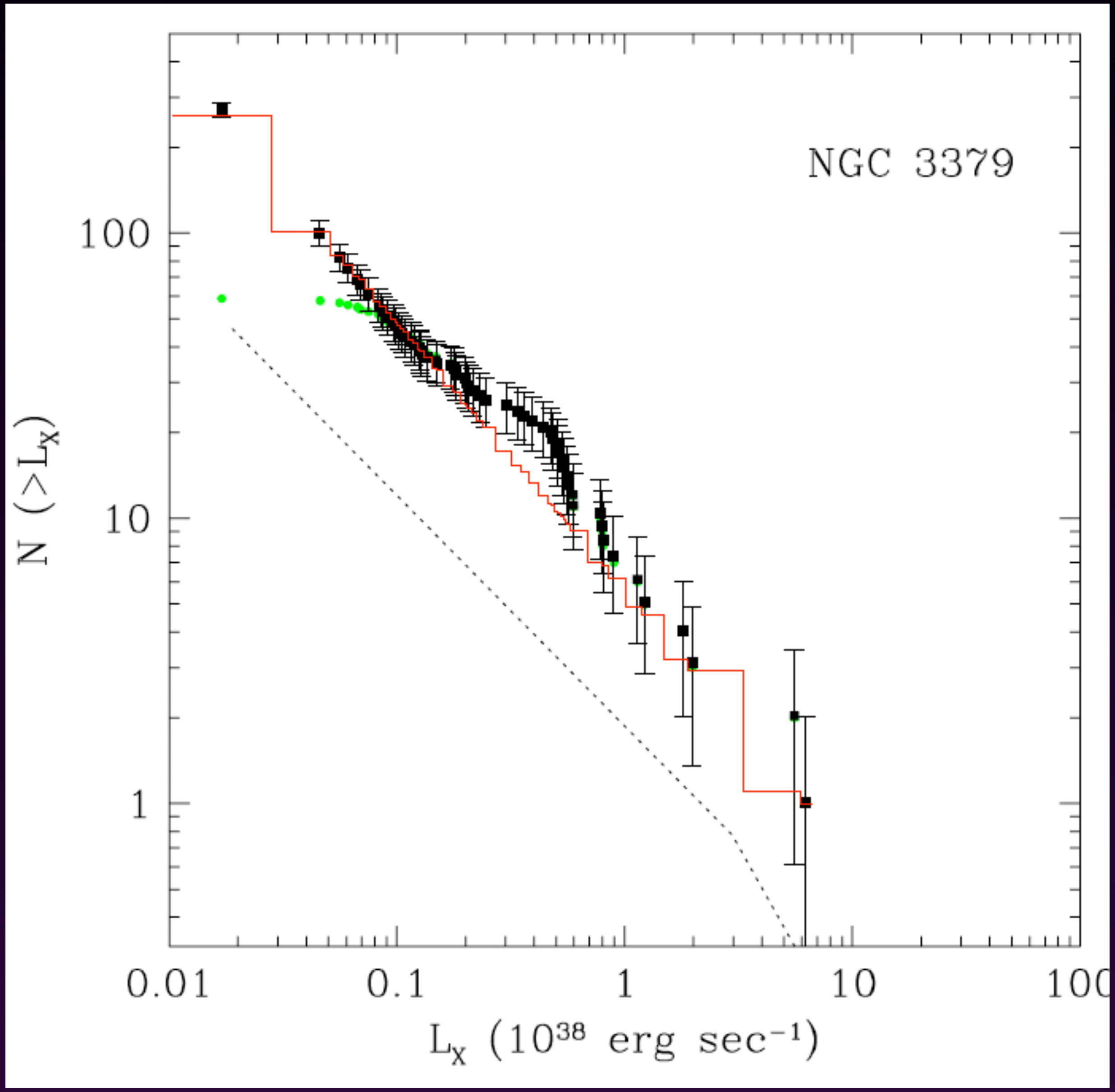
minutes to ~10 days

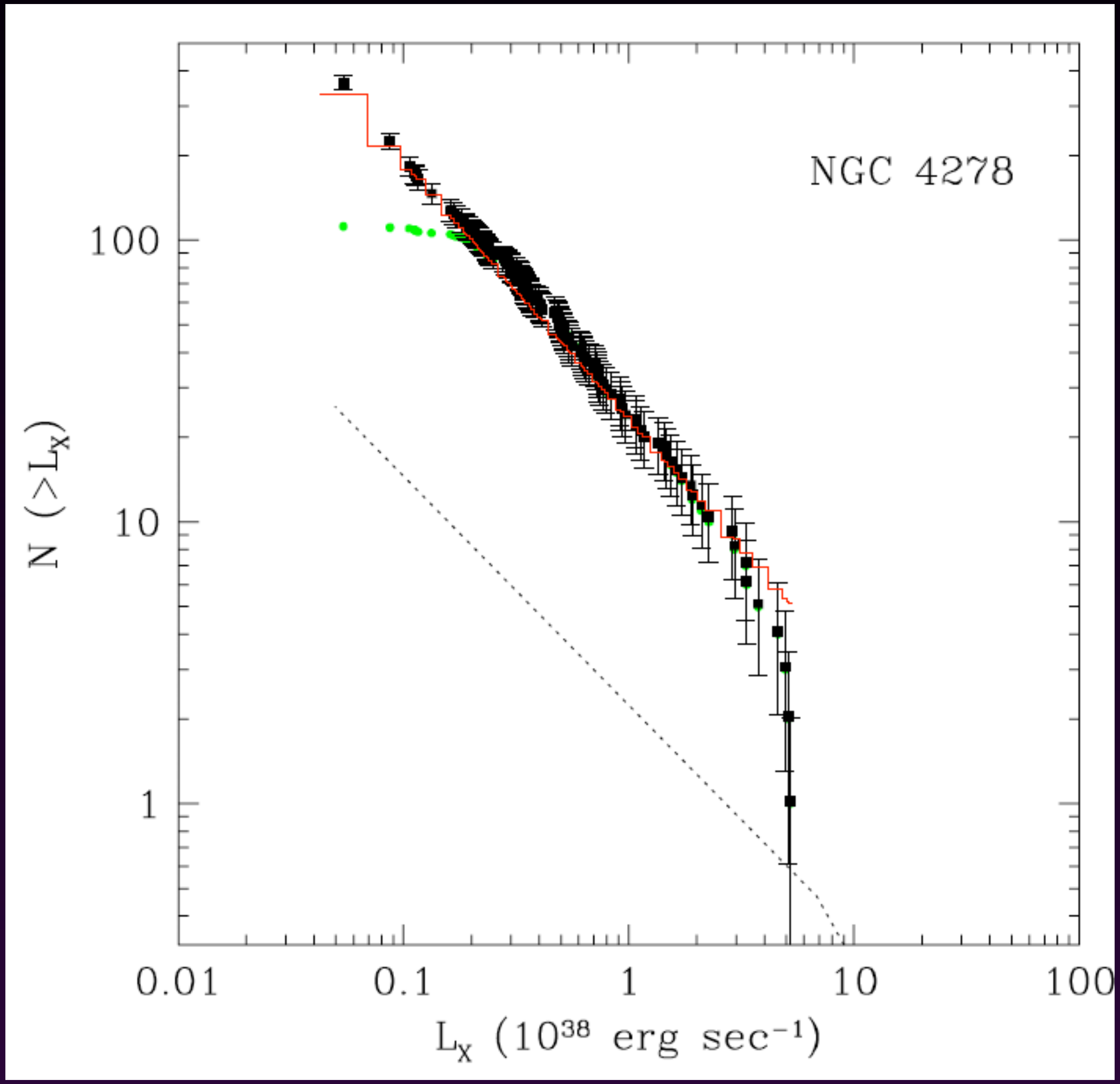
Persistent or Transient

- **Persistent phase:**
  ~10 Myr - ~1 Gyr
- **Transient phase:**

$$DC = \frac{T_{outburst}}{T_{outburst} + T_{quiescence}}$$

XLFs in elliptical galaxies: NGC3379 and NGC4278





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

Kim, D.-W. et al. 2006, Brassington, N. et al. 2008,2009

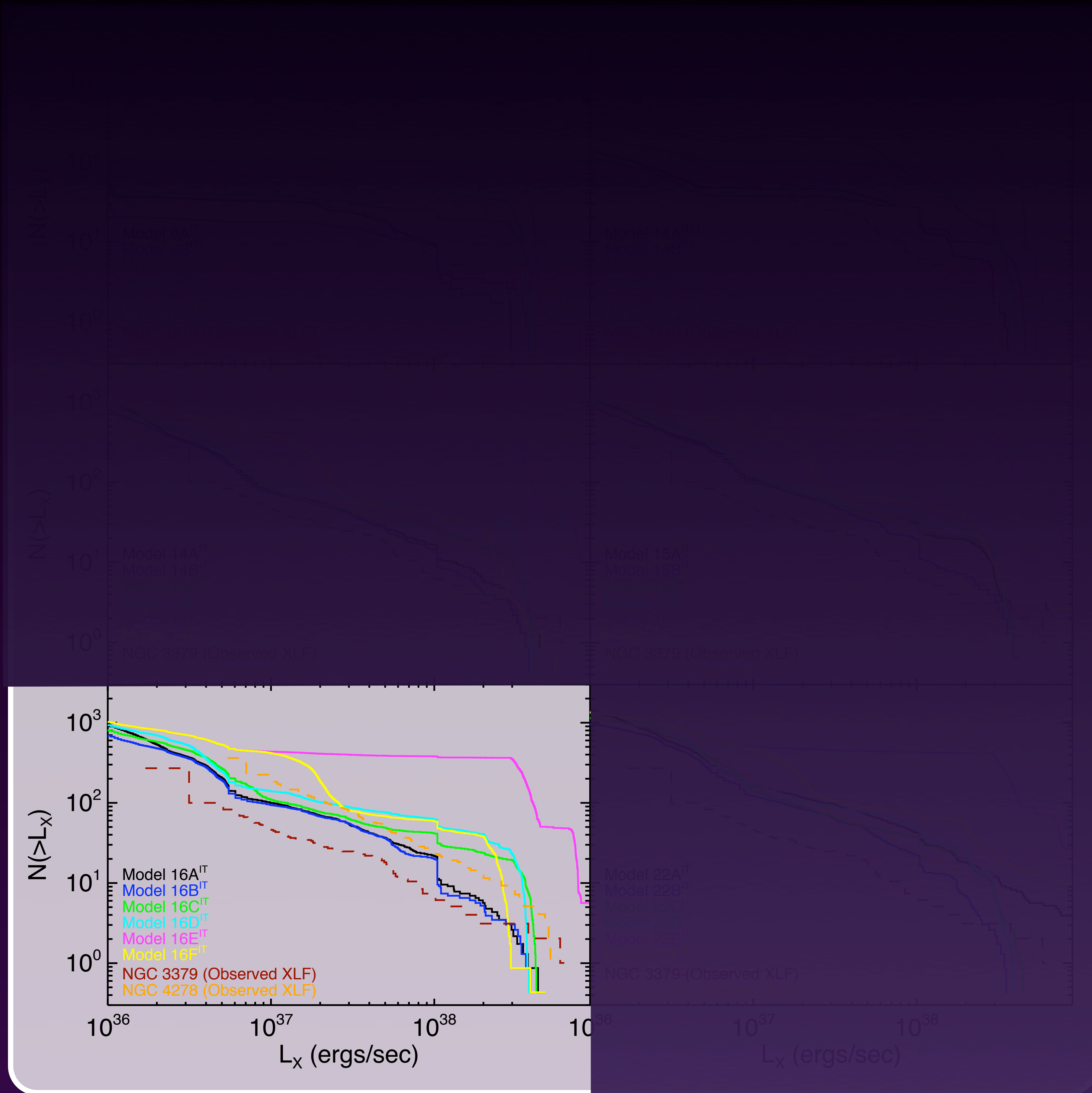
Population synthesis simulations

- **Star formation conditions:**
  time and duration, metallicity, IMF, binary properties

- **Modeling of single and binary evolution:**
  - Fitting formulae for single stars
  - Orbital evolution due to angular momentum loss mechanisms
  - All types of mass transfer phases
  - Compact object formation: masses and SN kicks
  - X-ray phase

Our population synthesis (PS) code: **StarTrack**
(Belczynski et al. 2008)

Field LMXB models I

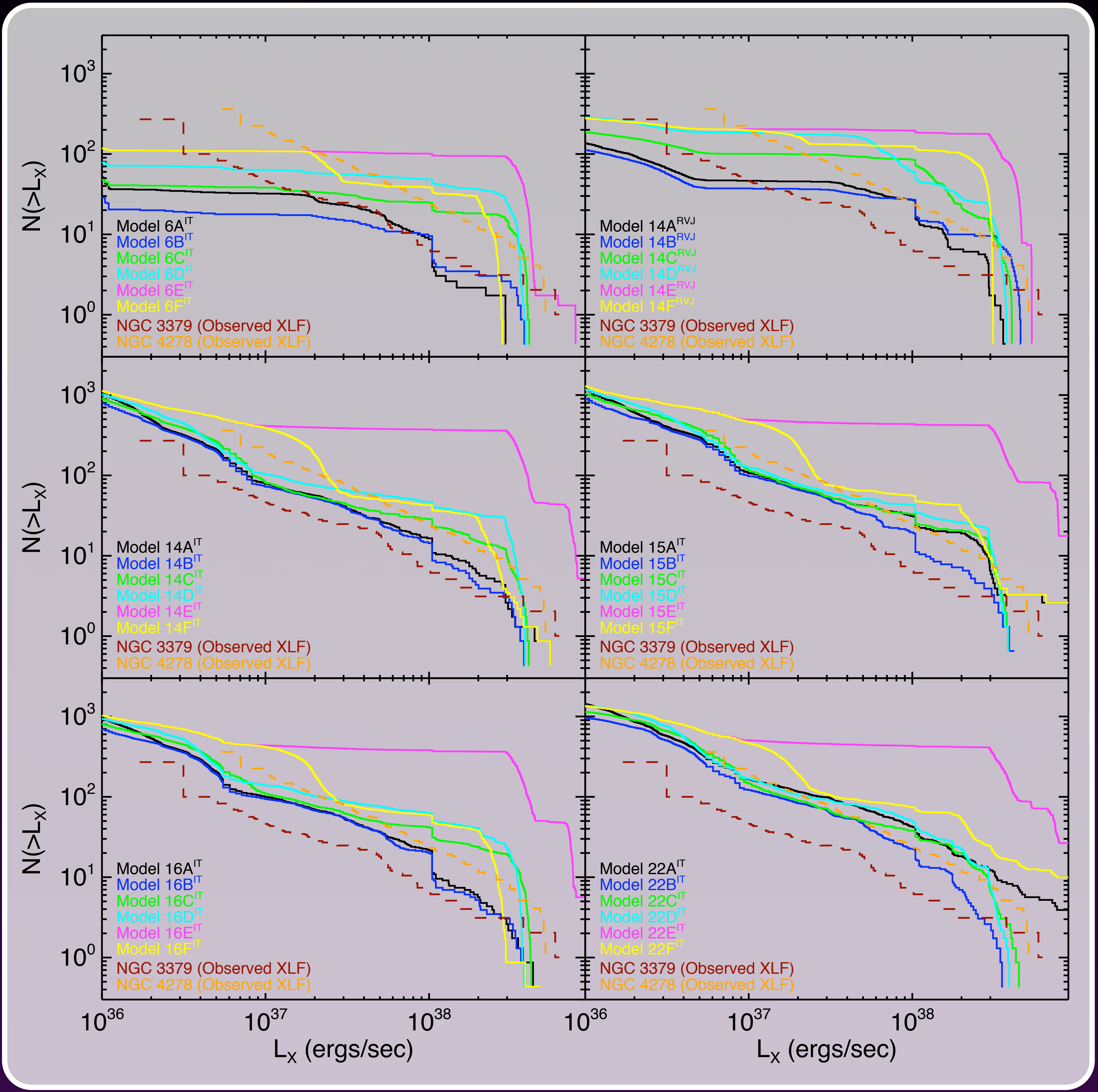


- Some models are **consistent with the observed XLF** both in **shape and normalization**

- Comparison with observations **excludes widely used assumptions** (**magnetic braking, transients**)

Fragos et al. 2008

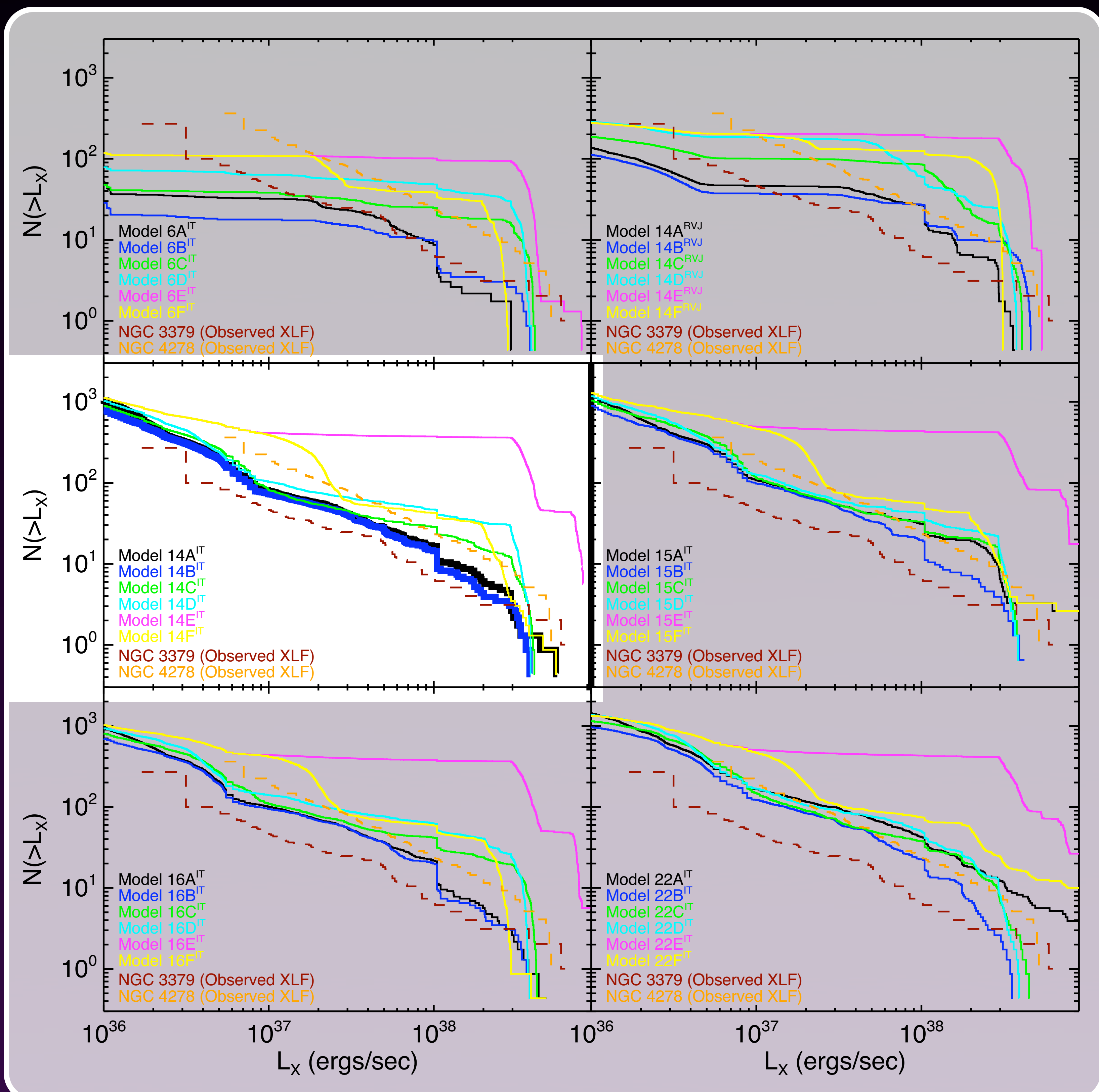
Field LMXB models I



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

Fragos et al. 2008

Field LMXB models I

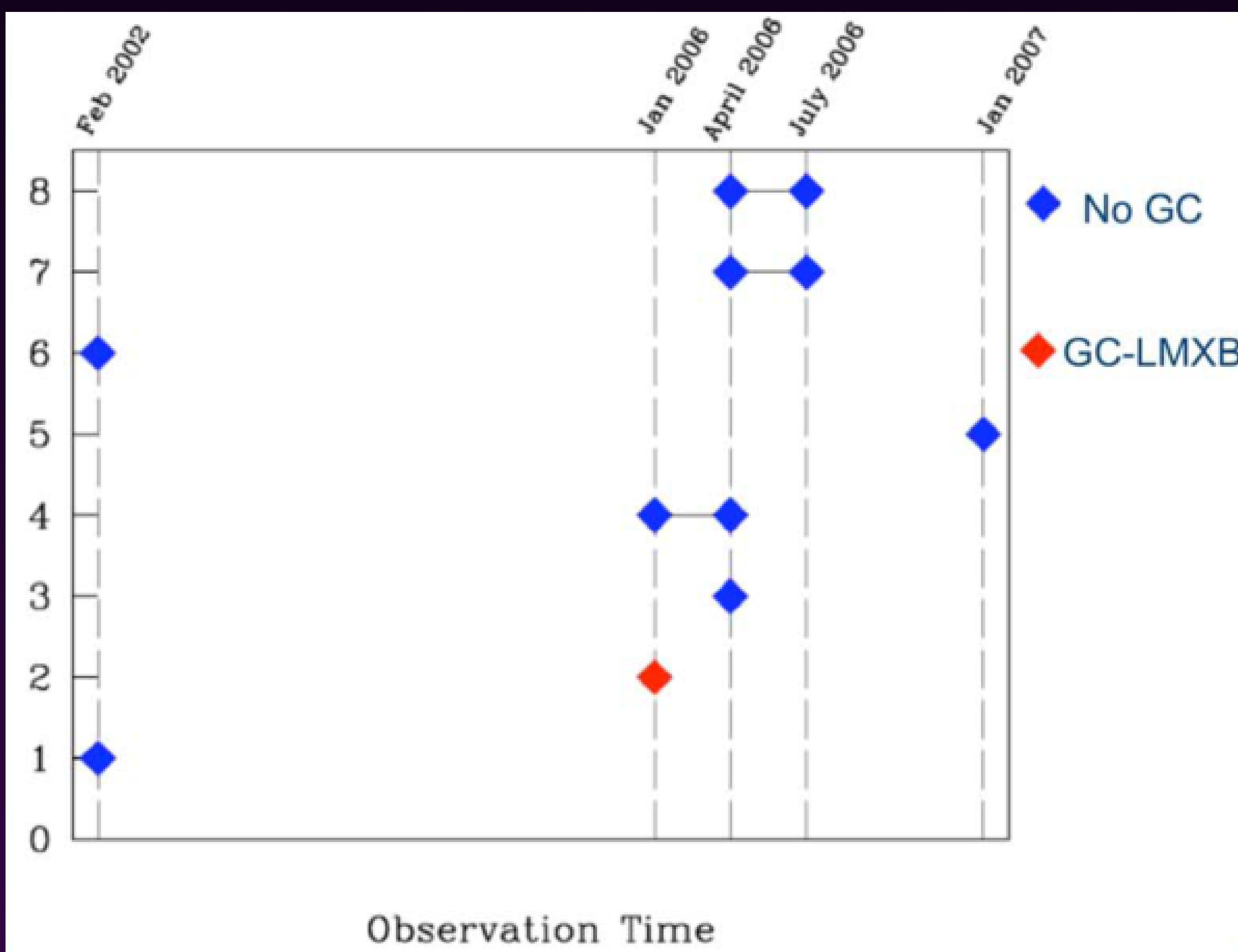


- Some models are **consistent with the observed XLF** both in **shape and normalization**
- Comparison with observations **excludes widely used assumptions** (**magnetic braking, transients**)

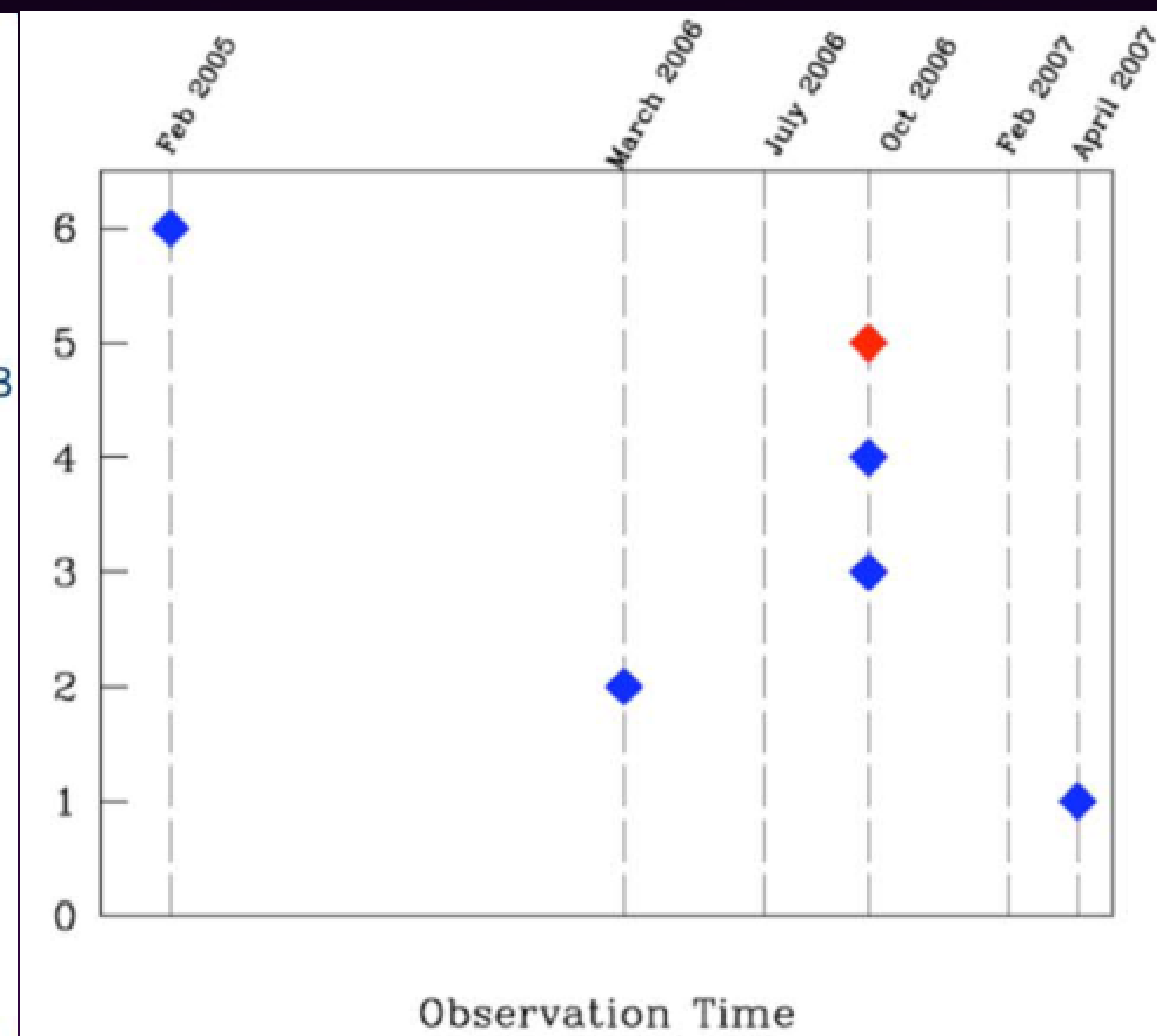
Fragos et al. 2008

Identified transient LMXBs in deep *Chandra* surveys

NGC 3379



NGC 4278



Brassington, N. et al. 2008, 2009

Modeling Transient LMXBs

StarTrack keeps track of all binary properties including $\dot{M}$

- Duty cycle derived from binary properties:

$$DC = \left(\frac{\dot{M}_d}{\dot{M}_{crit}}\right)^2 \text{ (Dobrotka et al. 2006)}$$

- No accretion during quiescence, disk empties during outburst

- Max. acc. disk mass: $$M_{\rm disk,max} = \int_{R_{\rm NS}}^{0.7 R_{\rm RL,1}} \Sigma_{\rm max}(R) 2\pi R dR$$

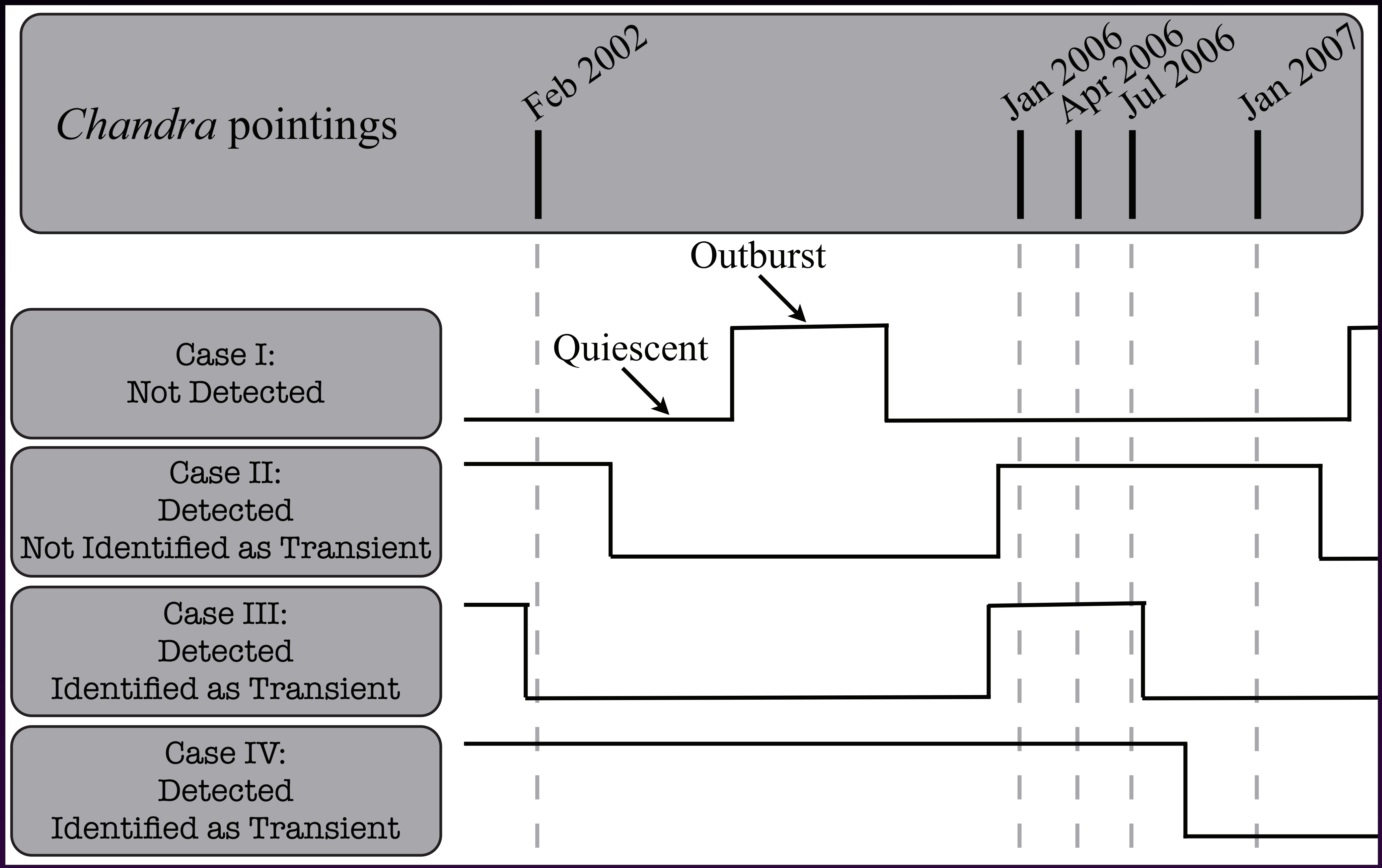
$$\Sigma_{\rm max} = 644 \left(\frac{M_1}{M_\odot}\right)^{-0.37} \left(\frac{R}{R_\odot}\right)^{1.11} \text{ g cm}^{-2} \text{ (Piro \& Bildsten, 2002)}$$

- Recurrence time:

$$T_{\rm outburst} = \frac{DC}{1-DC} \times T_{\rm quiescent}$$

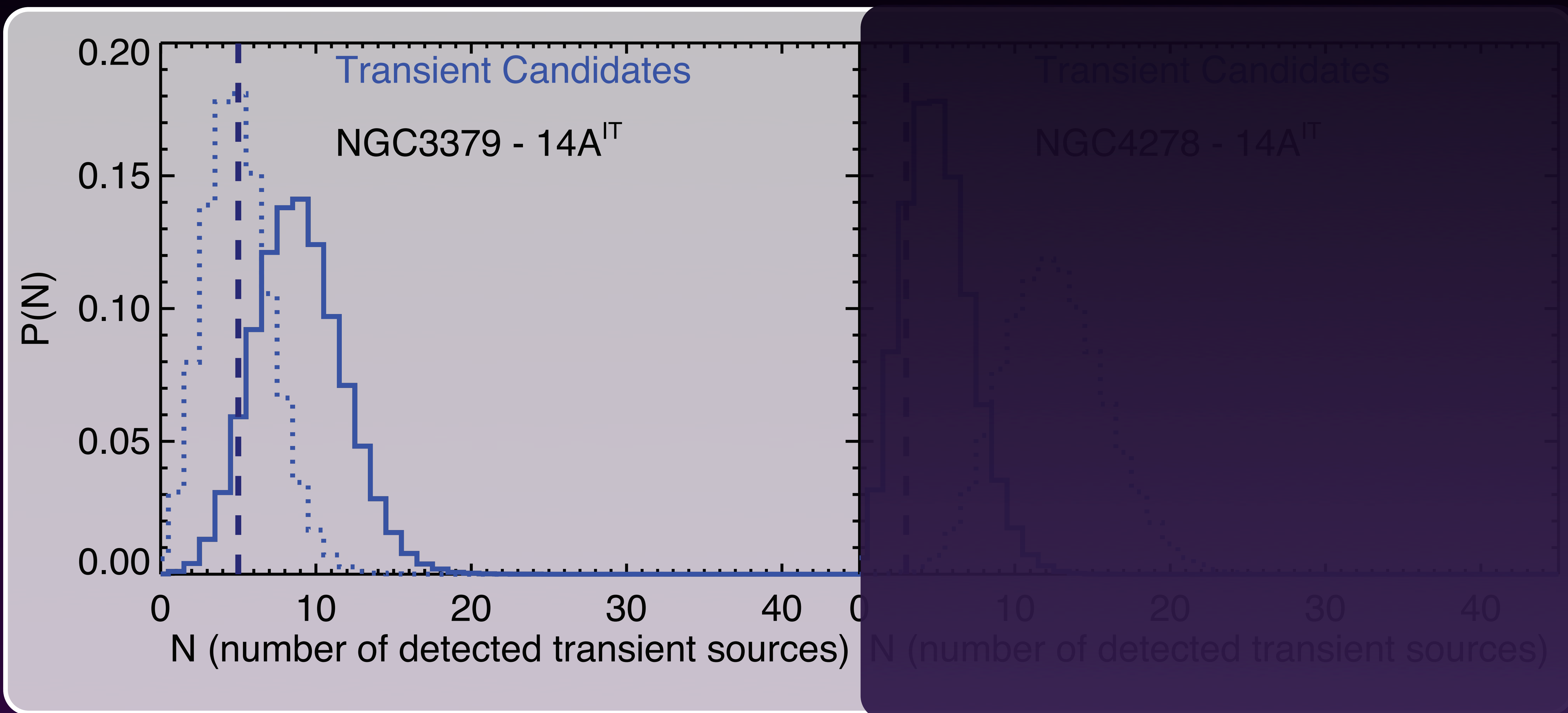
$$T_{\rm quiescent} = \frac{M_{\rm disk,max}}{\dot{M}_{\rm d}}$$

How can we compare our models to the observations of transient sources?



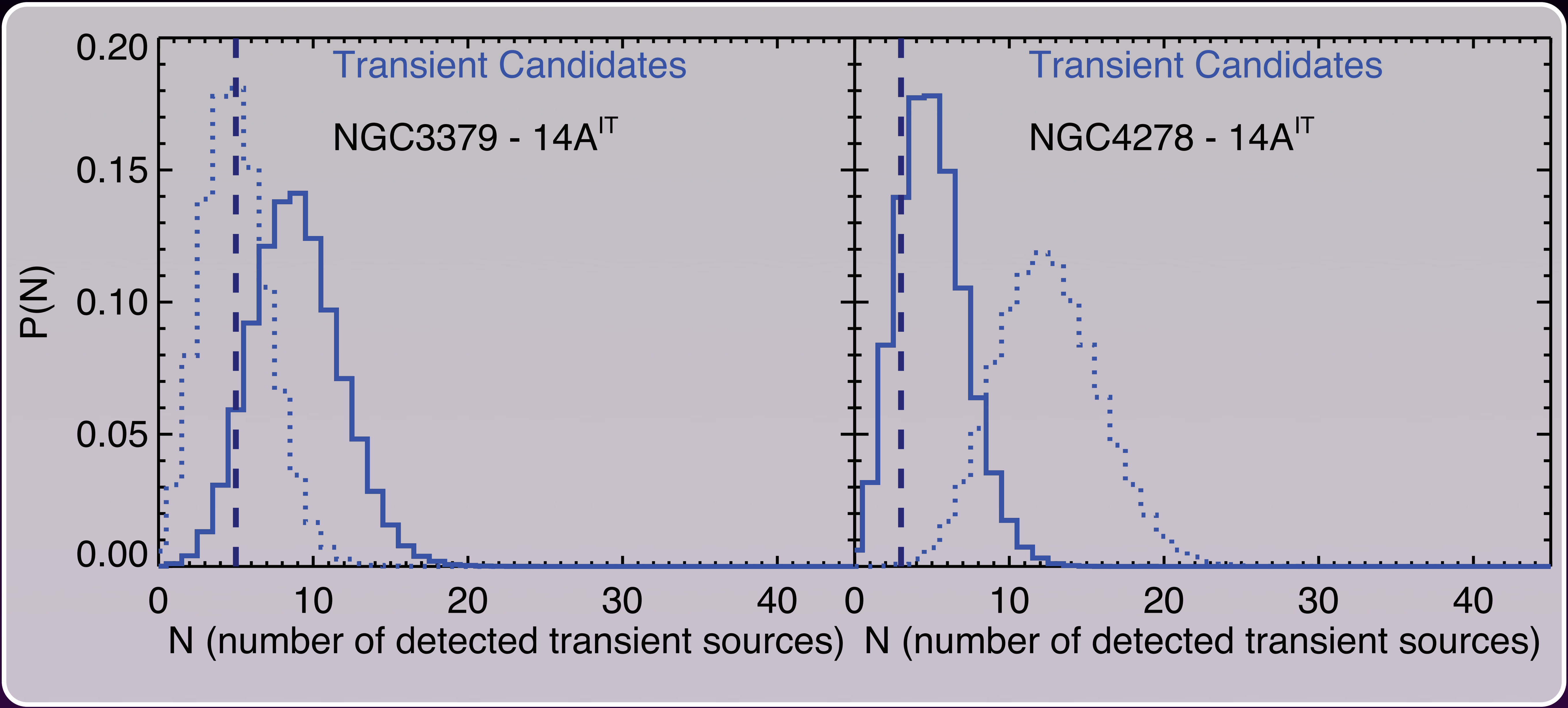
Calculate the probability that a transient LMXB is identified as transient

Modeling the detection of transient LMXBs



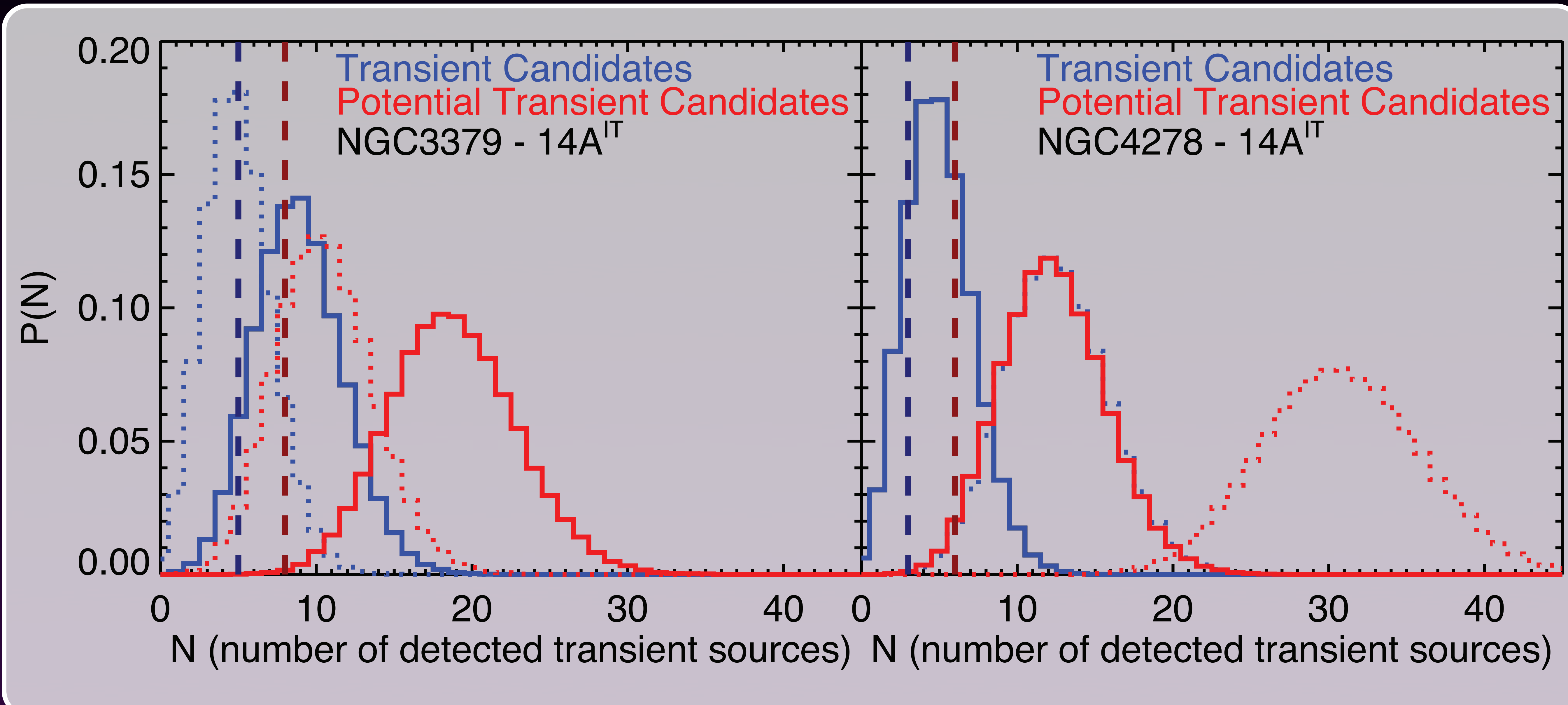
Fragos, T. et al. 2009

Modeling the detection of transient LMXBs



Fragos, T. et al. 2009

Modeling the detection of transient LMXBs



Fragos, T. et al. 2009

Conclusions

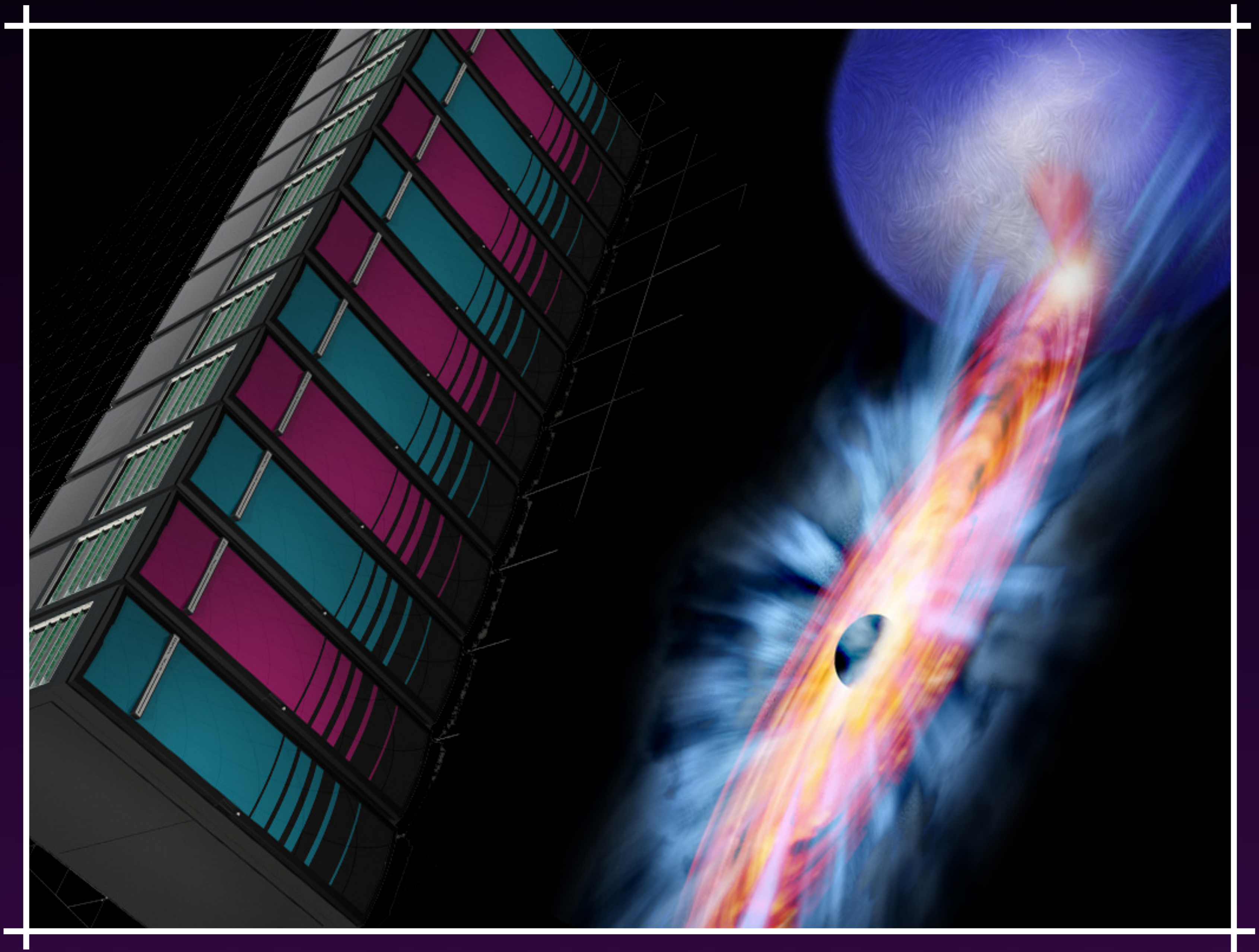
- We find that **field LMXB populations** ***can have an important contribution*** to the observed XLFs of elliptical galaxies.

- **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.

- A *simple but physically motivated* prescription for transient LMXBs is *consistent with the observations*. This enables us to pose an *additional constraint* on our models and *break model degeneracies*.

- The *number of transient sources* looks *proportional to the stellar mass of the galaxy* rather than the number of its GC. This suggests that *LMXBs formed through evolution of primordial field binaries* are *dominant in GC-poor elliptical galaxies*

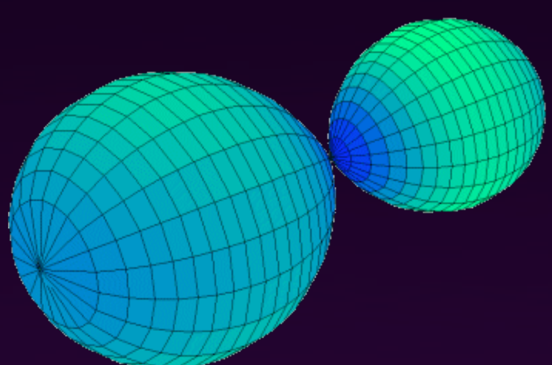
A new computational tool for XRB modeling



Development so far...

EZ, a stripped down, rewritten version of *Eggleton*'s stellar evolution code, is **redesigned and converted** to a **thread safe library**.

The library includes **memory management** for **multiple stars** and **openMP parallelization**, suitable for **HPC environments**.

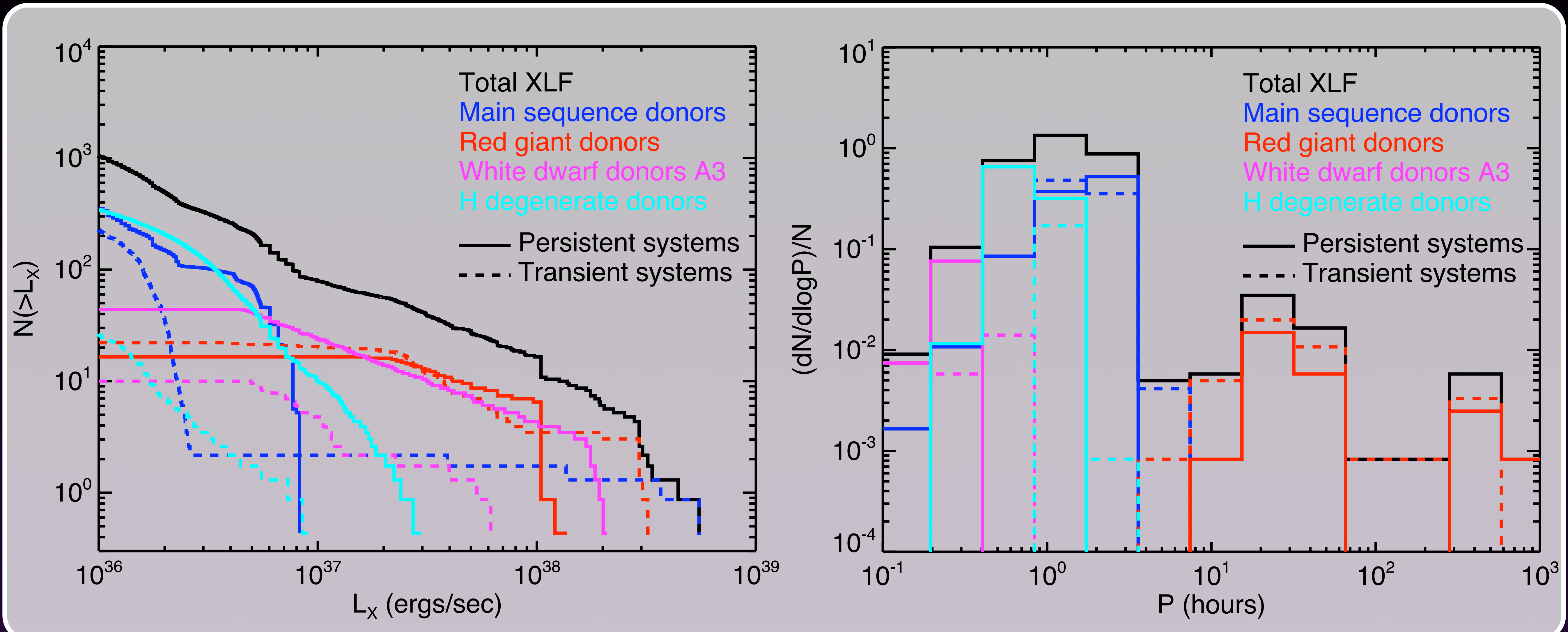


A **mass-transfer driver**, which includes **detailed treatment of tides**, is developed.

Flexible and robust Python interface, which allows seamless **integration with stellar dynamics codes**.

At least **10 times faster than current state of the art**:
- **Single star evolution** in less than **30sec**
- **Binary star evolution** in less than **3min**

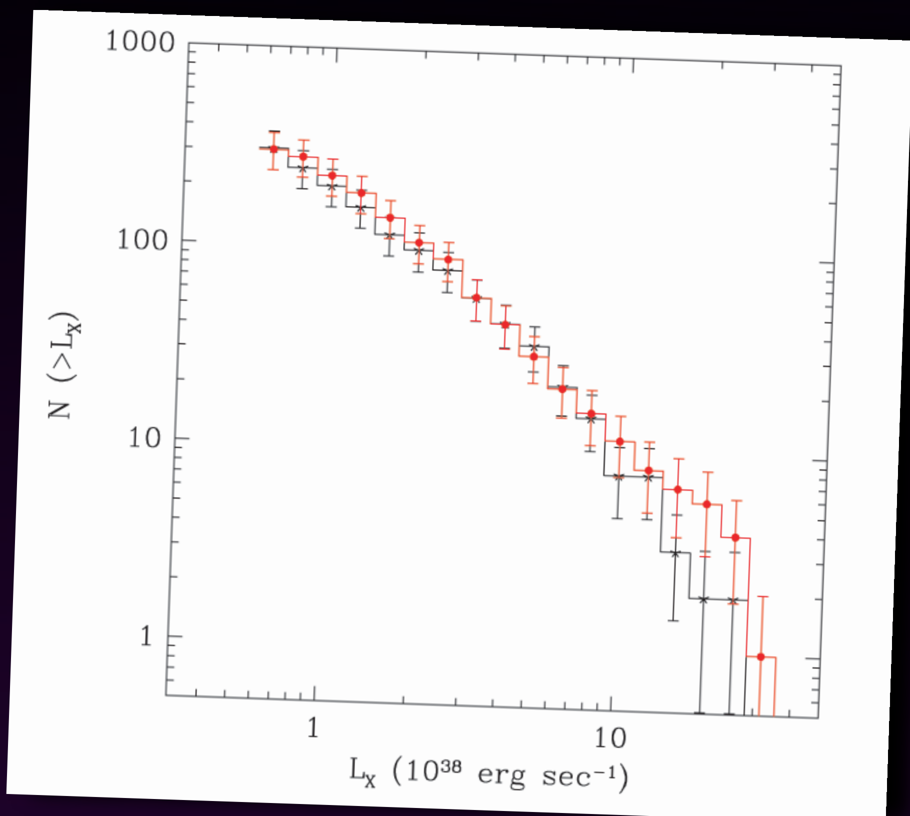
Field LMXB models II

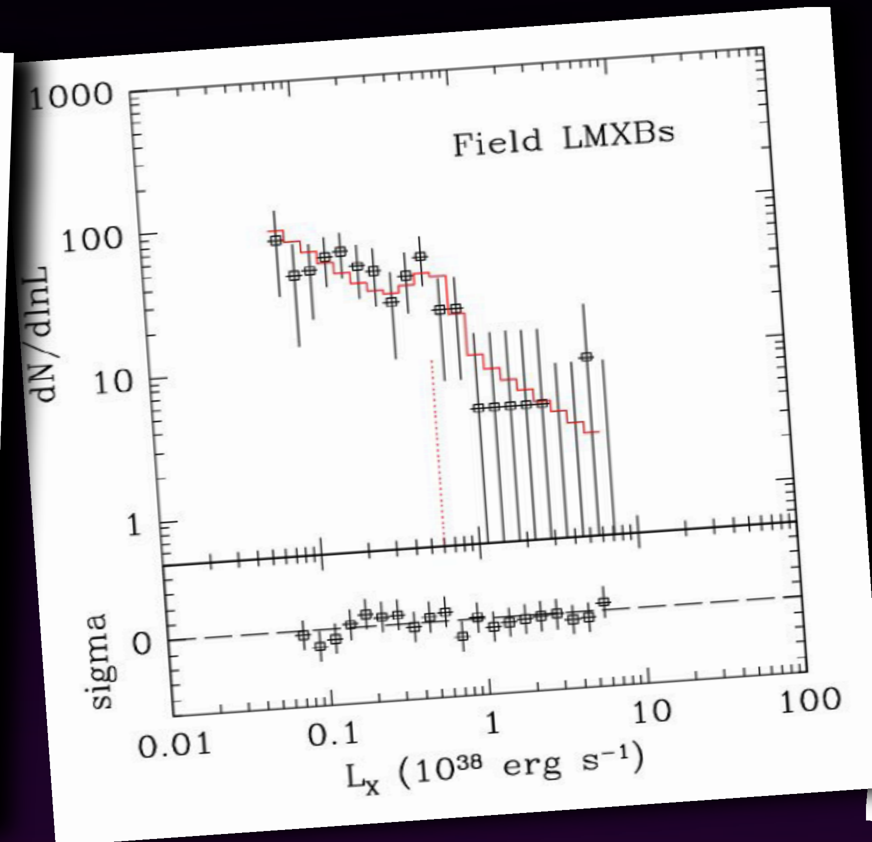


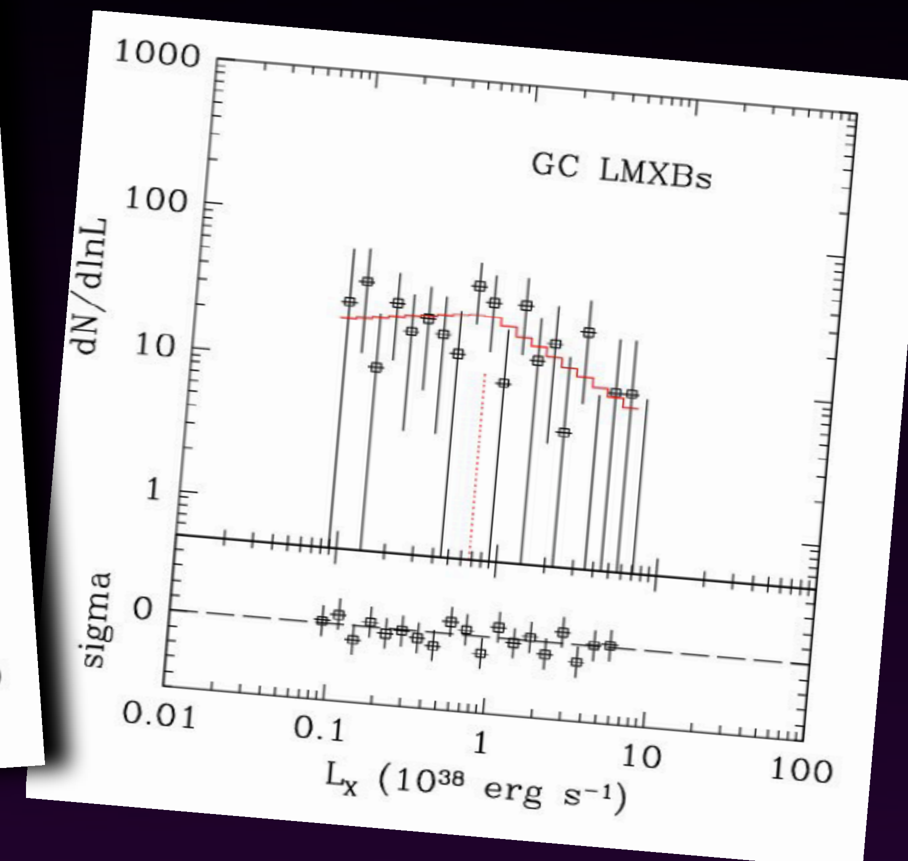
Different LMXB sub-populations contribute to **different X-ray luminosity ranges** of the XLF.

Fragos et al. 2008

Motivation…

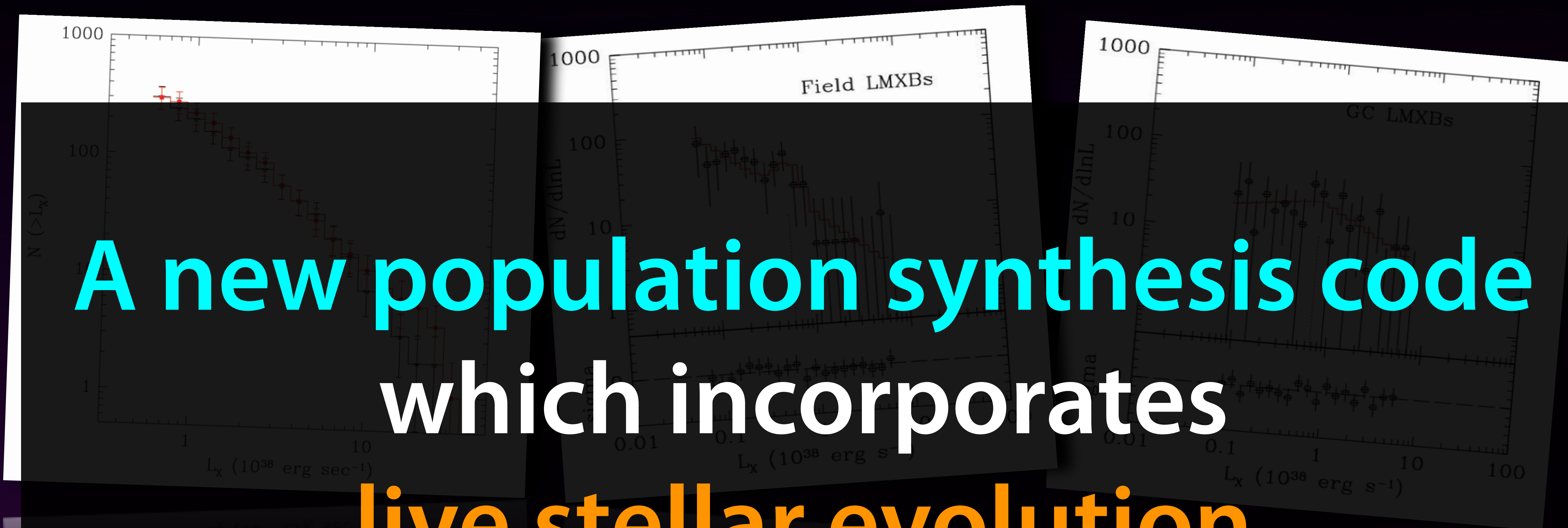






More **realistic modeling** is necessary in order to understand the **complexity** of the **observed extragalactic XRB** populations

Motivation...



A new population synthesis code

which incorporates

live stellar evolution

and

detailed mass transfer calculations

More **realistic modeling** is necessary in order to understand the **complexity** of the **observed extragalactic XRB** populations

How can we improve our models?

How can we improve our models?

Single star evolution

How can we improve our models?

Single star evolution

Dynamical formation

How can we improve our models?

Single star evolution

Dynamical formation

Stellar collisions

How can we improve our models?

Single star evolution

Dynamical formation

Stellar collisions

Mass transfer on thermal timescale

How can we improve our models?

Single star evolution

Dynamical formation

Stellar collisions

Mass transfer on thermal timescale

Mass transfer in eccentric orbits

How can we improve our models?

Single star evolution

Dynamical formation

Stellar collisions

Mass transfer on thermal timescale

Mass transfer in eccentric orbits

Tidal Evolution

How can we improve our models?

Single star evolution

Dynamical formation

Stellar collisions

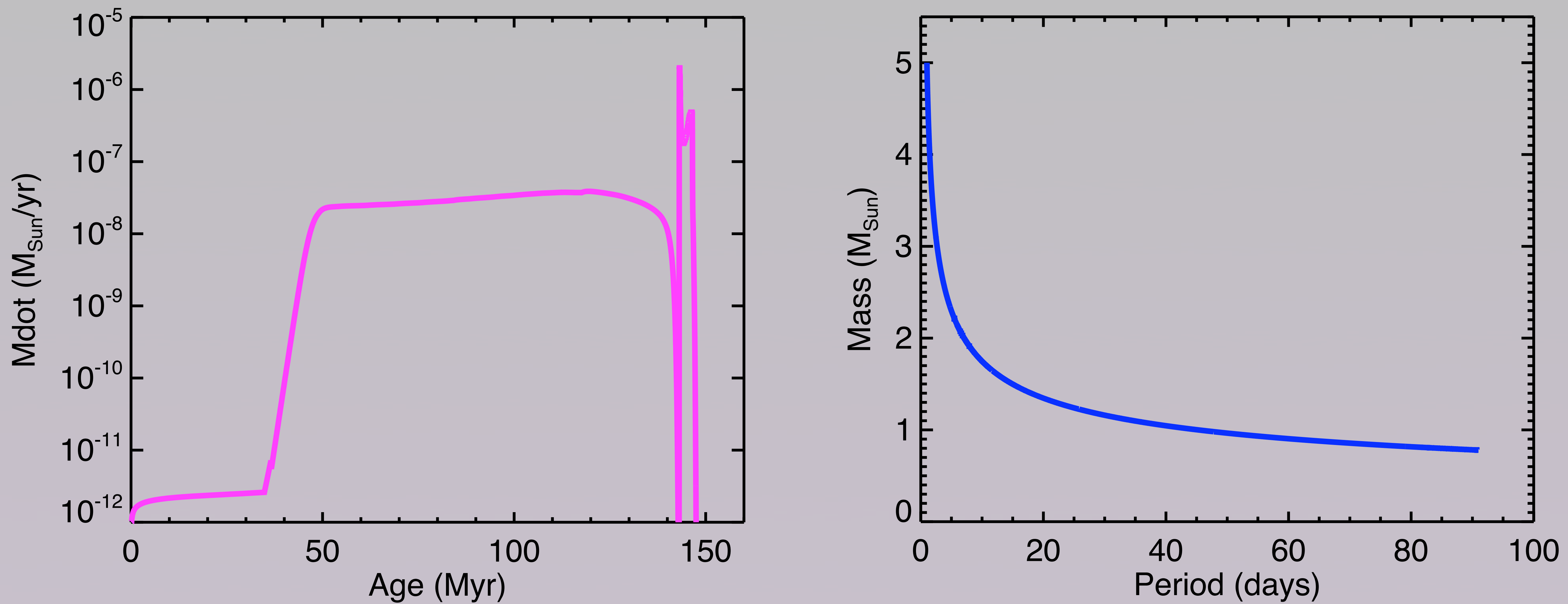
Mass transfer on thermal timescale

Mass transfer in eccentric orbits

Tidal Evolution

Common envelope phase

Demo I



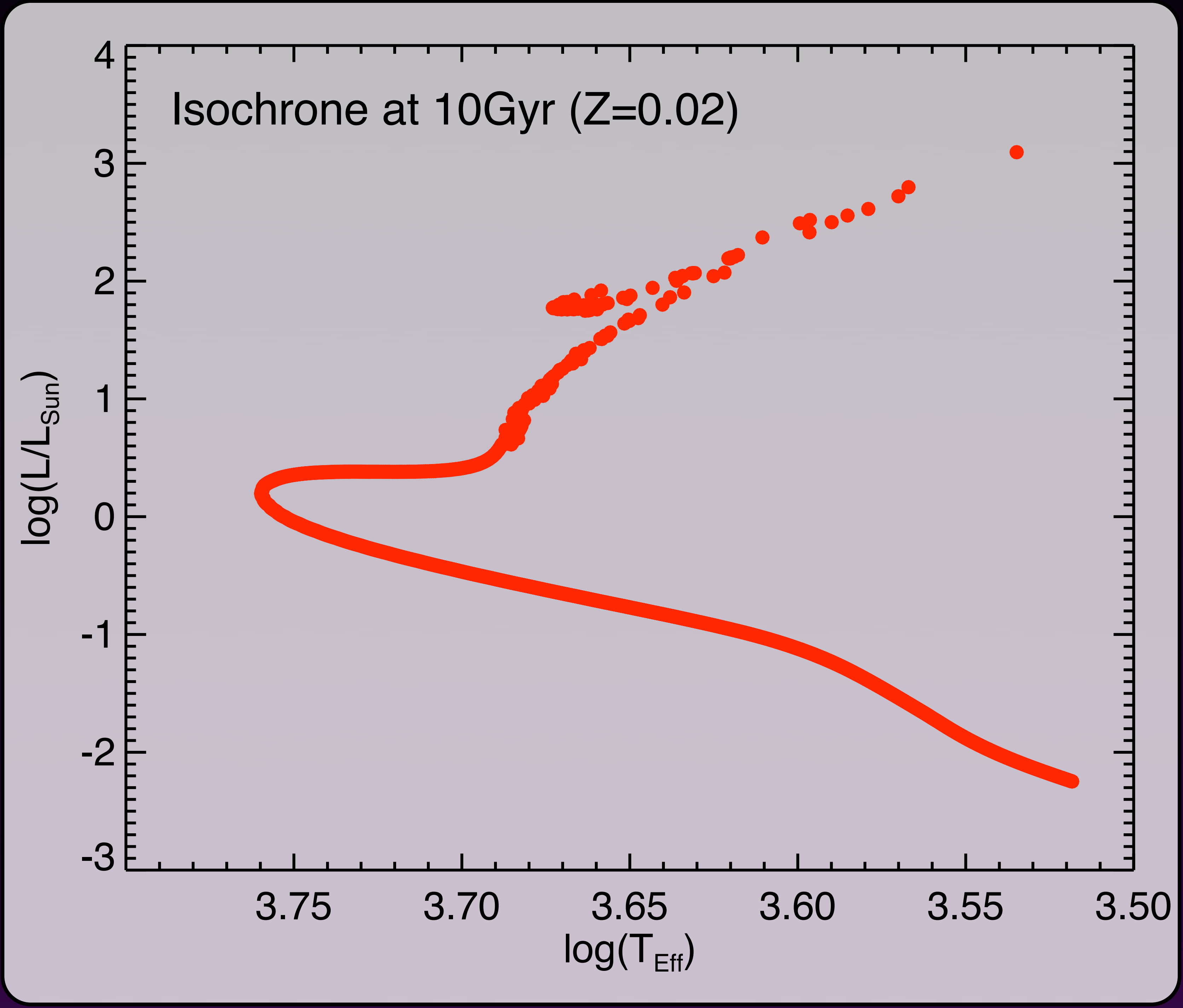
Mass transfer between an 8M BH and a 5M MS star.

Phase I: MT during MS (Nuclear timescale)

Phase II: MT during RG (Thermal timescale)

Execution time: **4m:31s** (2.0GHz C2D)

Demo II

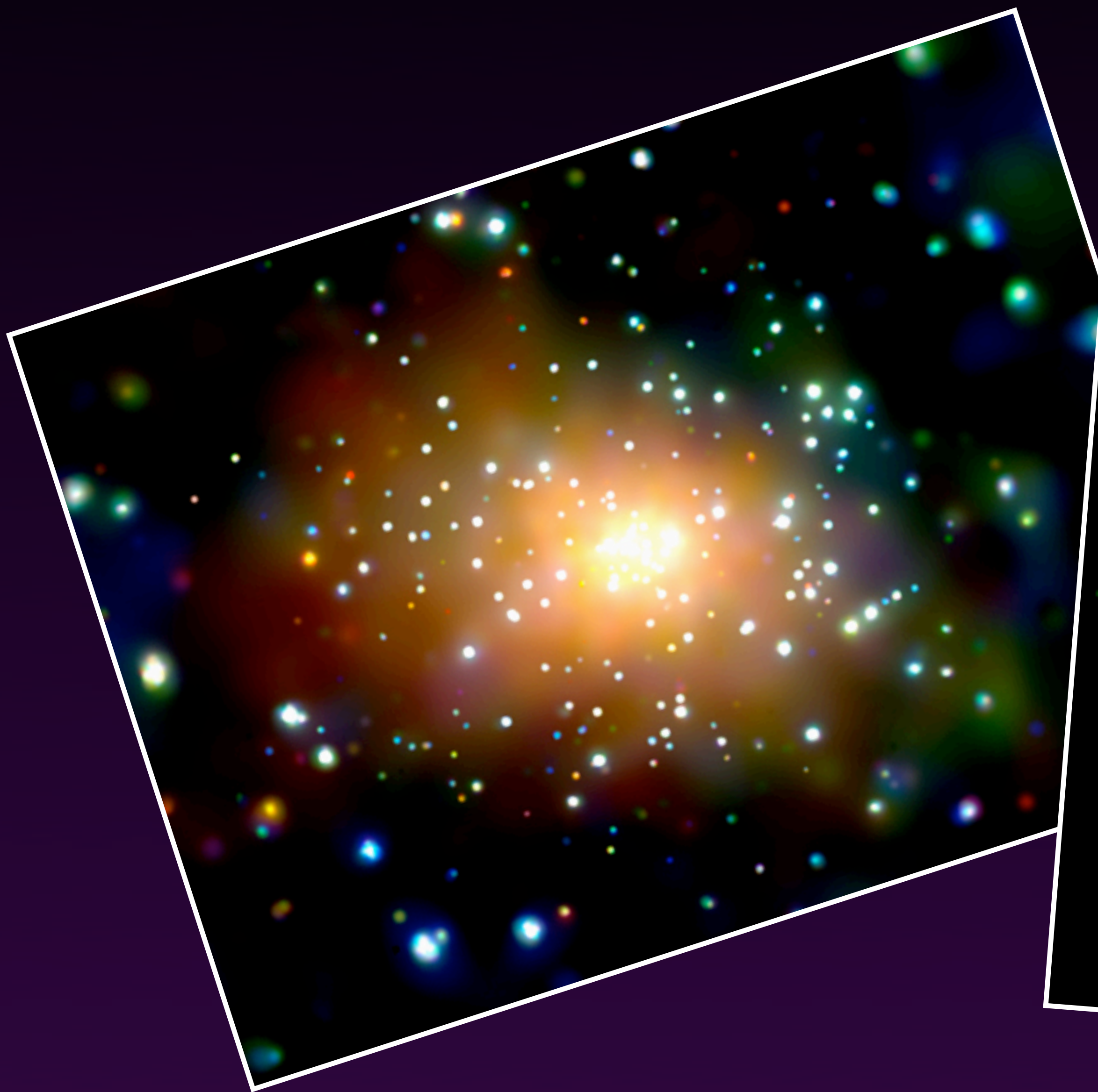


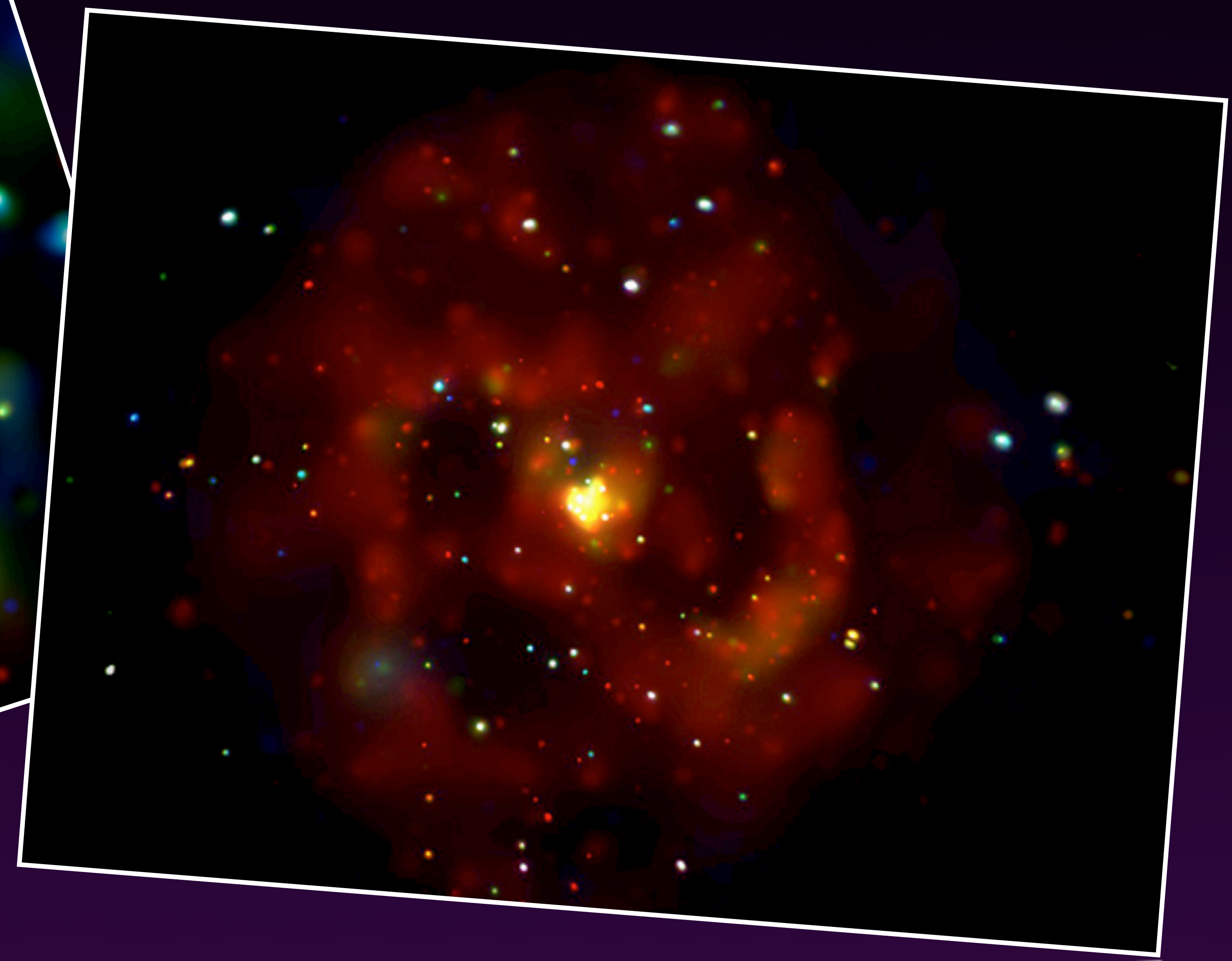
Evolution of 9000 stars
on 16 CPUs
with openMP

Execution time:
36m:25s
(2.3GHz Opteron)

Extragalactic LMXB populations:

Models for the elliptical galaxies NGC3379 and NGC4278





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