Low-Mass X-Ray Binary Models for Ellipticals NGC3379 and NGC4278

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with
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Low-Mass X-Ray Binaries (LMXBs)

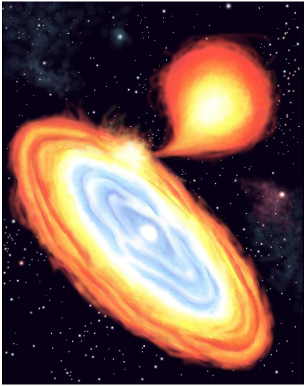

Illustration Credit: Tony Piro

LMXBs form in both:

- galactic field (isolated binaries)
- globular clusters (dynamical interactions)

Accretors:
NS or BH

RLOF Donors:
MS, RG, WD/degenerate
low-mass: $< 1\mathrm{M}_\odot$

Binary Periods:
minutes to ~ 10 days

Persistent or Transient

- Persistent phase:
  ~ 10 Myr – ~ 1 Gyr
- Transient phase:
  $\mathrm{DC} = \frac{\mathrm{T}_{\mathrm{outburst}}}{\mathrm{T}_{\mathrm{outburst}}+\mathrm{T}_{\mathrm{quiescent}}}$

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Observationally...

- Detect X-ray source populations
  - Spectra consistent with LMXBs
- Study X-ray Luminosity Functions (XLF)
  - Shape (components, evolution)
  - Normalization (what drives the LMXB content of a galaxy?)
- Study spatial distributions
  - Sources in the Field
  - Sources in GCs
- Study of source variability
  - Transients?
- Study of diffuse emission
  - Have the unresolved XRBs a significant contribution?

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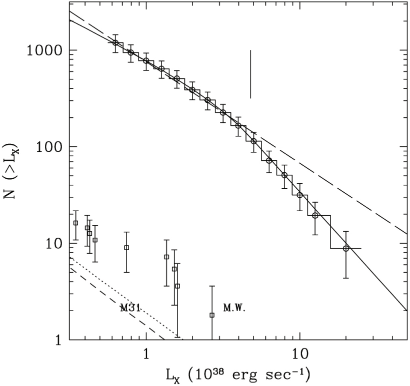
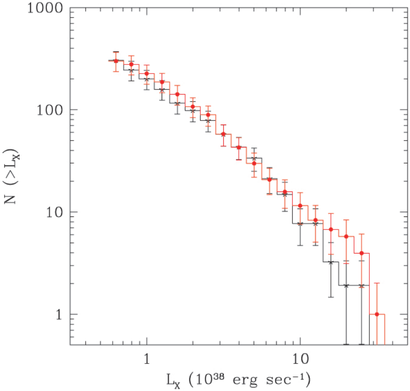
Kim & Fabbiano 2004



Kim, E. et al. 2006 – GC vs. Field



- E and S0 XLFs have similar shapes ($> 6 \times 10^{37}$ erg/s)
- Break at 4.5×10^{38} erg/s seen in composite XLF
- Slope consistent with Galactic and M31 LMXB XLFs
- Overall cumulative slope -1
- XLFs of GC and field LMXBs are consistent
  - cf. Fabbiano et al. (2007), Voss and Gilfanov (2007)

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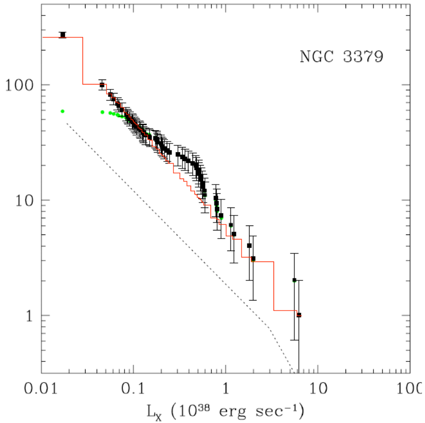
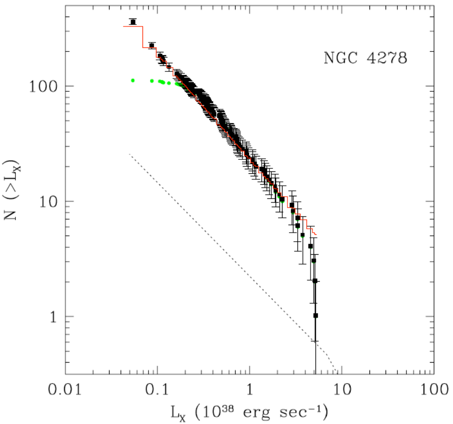
XLFs in ellipticals NGC3379 and NGC4278

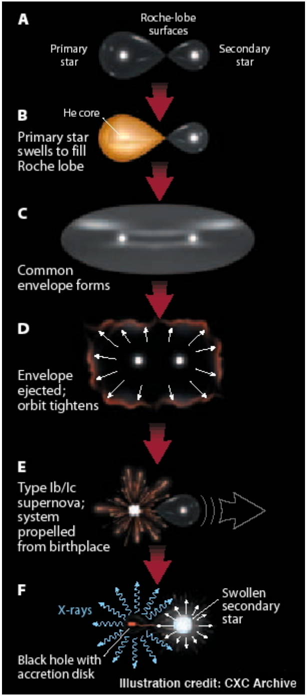
Fabbiano et al., Kim et al. 2006





$(3-4)\times 10^{36} - (5-6)\times 10^{38}$ erg/s

XLF slope: 0.9 ± 0.1



How do X-ray binaries form in galactic fields?

- Start from a primordial binary
- The system undergoes a Common Envelope (CE) phase, which results to orbital contraction and mass loss.
- The massive core soon reaches core collapse to form a compact object .
- The orbit shrinks further due to tides, magnetic braking and gravitational waves.
- An XRB is born when the secondary star overflows its Roche-lobe and mass gets accreted onto the compact object (BH or NS).

Population Synthesis Elements

- Star formation conditions:
  - time and duration, 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

Our population synthesis code: StarTrack (Belczynski et al. 2006)

Models for NGC3379 and NGC4278

Star Formation:	delta-function at t=0
Population Age:	9–10 Gyr
Metallicity:	Z=0.03 (1.5 x solar)
Total Stellar Mass:	$3 - 9 \times 10^{10}\,\mathrm{M}_{\odot}$
Binary Fraction:	50%
Initial Mass Function:	power-law index -2.7 (Scalo/Kroupa) or -2.35 (Salpeter)
CE efficiency:	20% – 100%
Stellar Wind Strength:	$\eta_{\mathrm{Wind}} = 0.25 - 1.0$
Magnetic Braking:	Ivanova & Taam (2003) or Rappaport et al. (1983)

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Ouburst phase of transient systems

Duty Cycle (DC)

$$DC = \text{constant} \qquad\qquad DC = \left(\frac{\dot{M}_{dn}}{\dot{M}_{crit}}\right)^2 \; \dagger \quad (1)$$

Outburst Luminosity

$$L_{outburst} \sim L_{Eddington} \quad (2)$$

$$L_x = \min\left[2 \times L_{Edd}, 2 \times L_{Edd}\left(\frac{P}{10h}\right)\right] \; \dagger\dagger \quad (3)$$

$$L_x = \min\left(2 \times L_{Edd}, \frac{GM_{acc}\dot{M}_{dn}}{R_{acc}} \times \frac{1}{DC}\right) \quad (4)$$

† Dobrotka et al. 2006 †† Portegies Zwart et al. 2004

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Different Population Synthesis Models

Model	α_{CE}	IMF	η_{wind}	$L_{x,NS}$	$L_{x,BH}$	DC_{NS}	DC_{NS}
A0	0.5	-2.7	1.0	eq.(4)	eq.(3)	eq.(1)	0.5%
B0	0.5	-2.7	0.25	eq.(4)	eq.(3)	eq.(1)	0.5%
B1	0.5	-2.7	0.25	eq.(4)	eq.(4)	1%	1%
B2	0.5	-2.7	0.25	eq.(4)	eq.(4)	7%	7%
B3	0.5	-2.7	0.25	eq.(4)	eq.(4)	15%	15%
B4	0.5	-2.7	0.25	L_{Edd}	L_{Edd}	10%	10%
B5	0.5	-2.7	0.25	eq.(3)	eq.(3)	10%	10%
C0	0.5	-2.35	1.0	eq.(4)	eq.(3)	eq.(1)	0.5%
D0	1.0	-2.7	1.0	eq.(4)	eq.(3)	eq.(1)	0.5%

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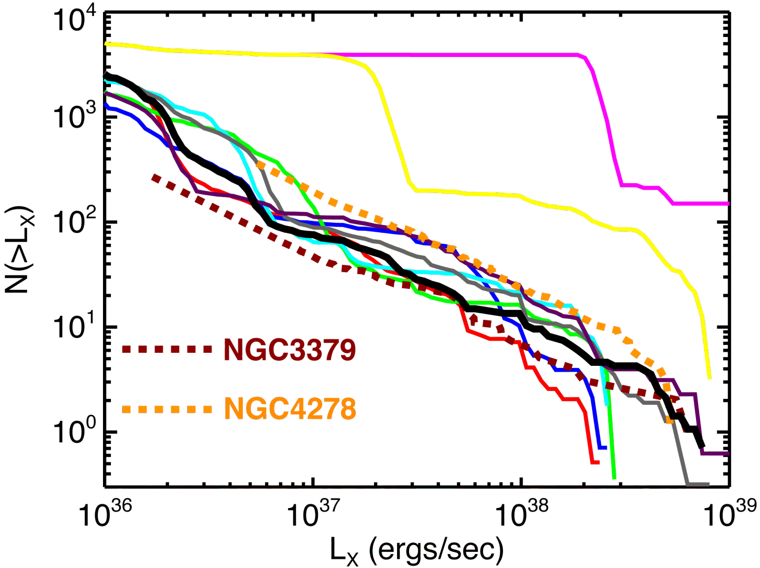
Field LMXB models: XLF



Model
A0
B0
B1
B2
B3
B4
B5
C0
D0

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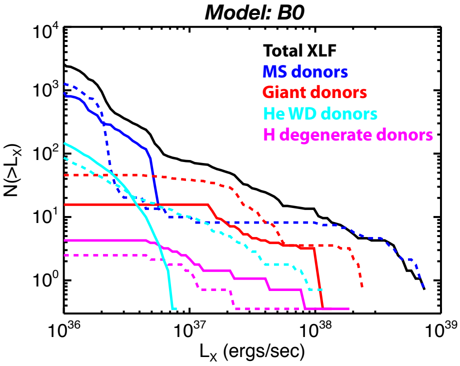
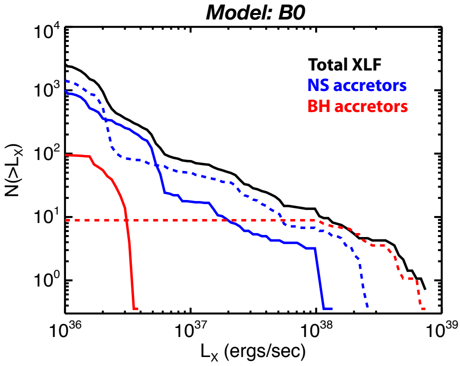
Fragos et al. (2008), ApJ in press, astro-ph/0801.1122

Field LMXB models: Contribution to the XLF from different sub-populations





The XLF is dominated by transient and persistent systems with red giant donors.

LMXBs with NS accretors greatly outnumber those with a BH accretor.

The high luminosity end of the XLF is dominated by BH systems.

Conclusions...

⇒ We find that field LMXB populations can have an important contribution in the observed XLFs of elliptical galaxies.

- We are able to exclude the majority of the models.
- There is no unique combination of population model parameters.

⇒ Slope and normalization of XLF in $\sim 5 \times 10^{36} - 5 \times 10^{38}$ erg/s can be explained, within the known uncertainties, by both:

- Field LMXBs with low-mass MS and RG donors
- GC ultra-compact NS-LMXBs (Bildsten & Deloye 2004)

⇒ The shape of the modeled XLFs is a more robust characteristic than their normalization.

⇒ The ratio of transient to persistent sources is ∼20.
Realistic modelling of the outburst phase of transient LMXBs is necessary.

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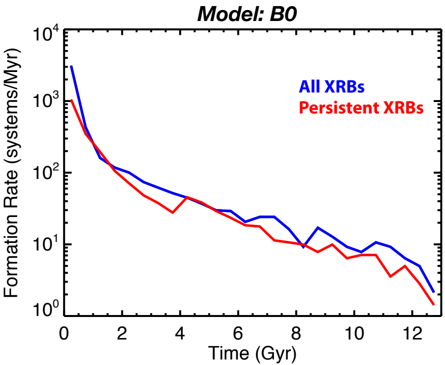
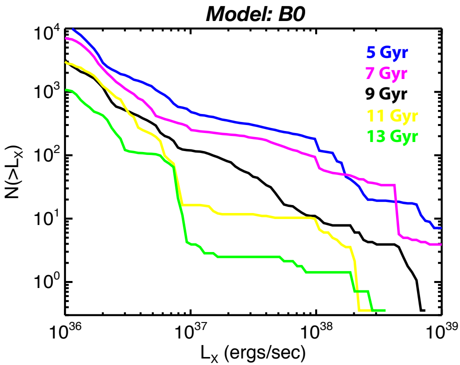
Field LMXB models: Time Evolution

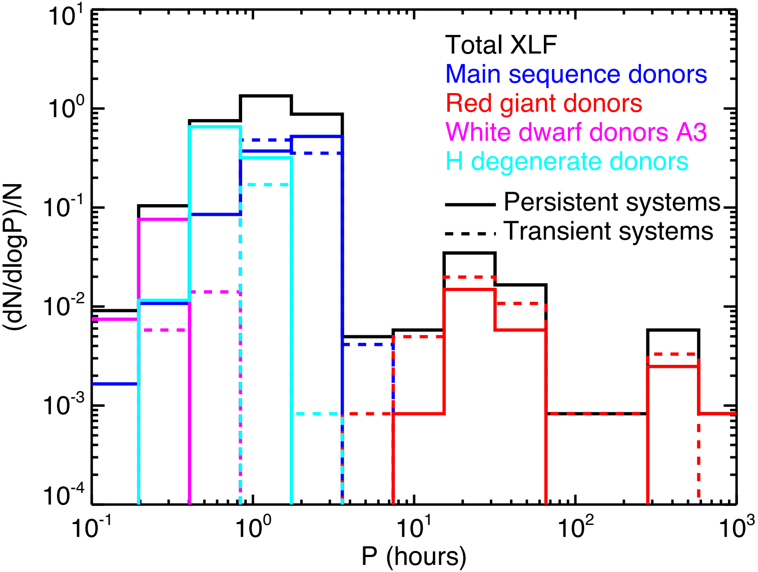




The field LXMB formation rate is sustained over long timescales.

Both the shape and the normalization of the XLF are strongly dependent on the age of the galaxy.

XLFs in ellipticals NGC3379 and NGC4278



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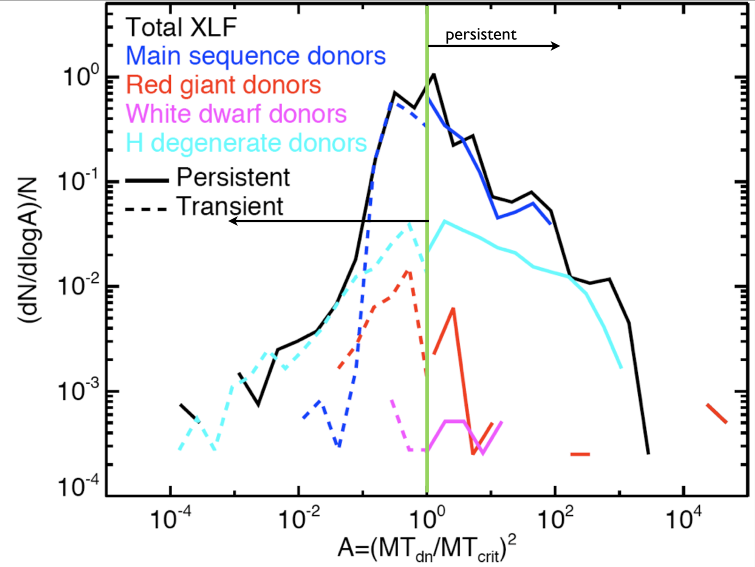

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Models for LMXBs in Globular Clusters

Bildsten & Deloye 2004

- NS with WD donors in ultra-compact binaries ($\sim 10\,\mathrm{min}$ periods)
- persistent, short-lived (1-10Myr), continually formed through dynamical interactions
- XLF slope (~ 0.8) and normalization consistent with observations (within uncertainties) up to $\sim 5 \times 10^{38}\,\mathrm{erg/s}$

Future work: StarTrack + FewBody (Ivanova, N. et al. 2004)

- Single and binary star evolution with StarTrack.
- Simplistic treatment of cluster dynamics: Two zone structure (halo and core), cluster properties do not change with time.
- Close interactions are calculated with FewBody (Fregeau, J. 2004), a numerical toolkit for small-N gravitational dynamics.

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