Modeling the Luminosity Function of Galactic Low-Mass X-Ray Binaries

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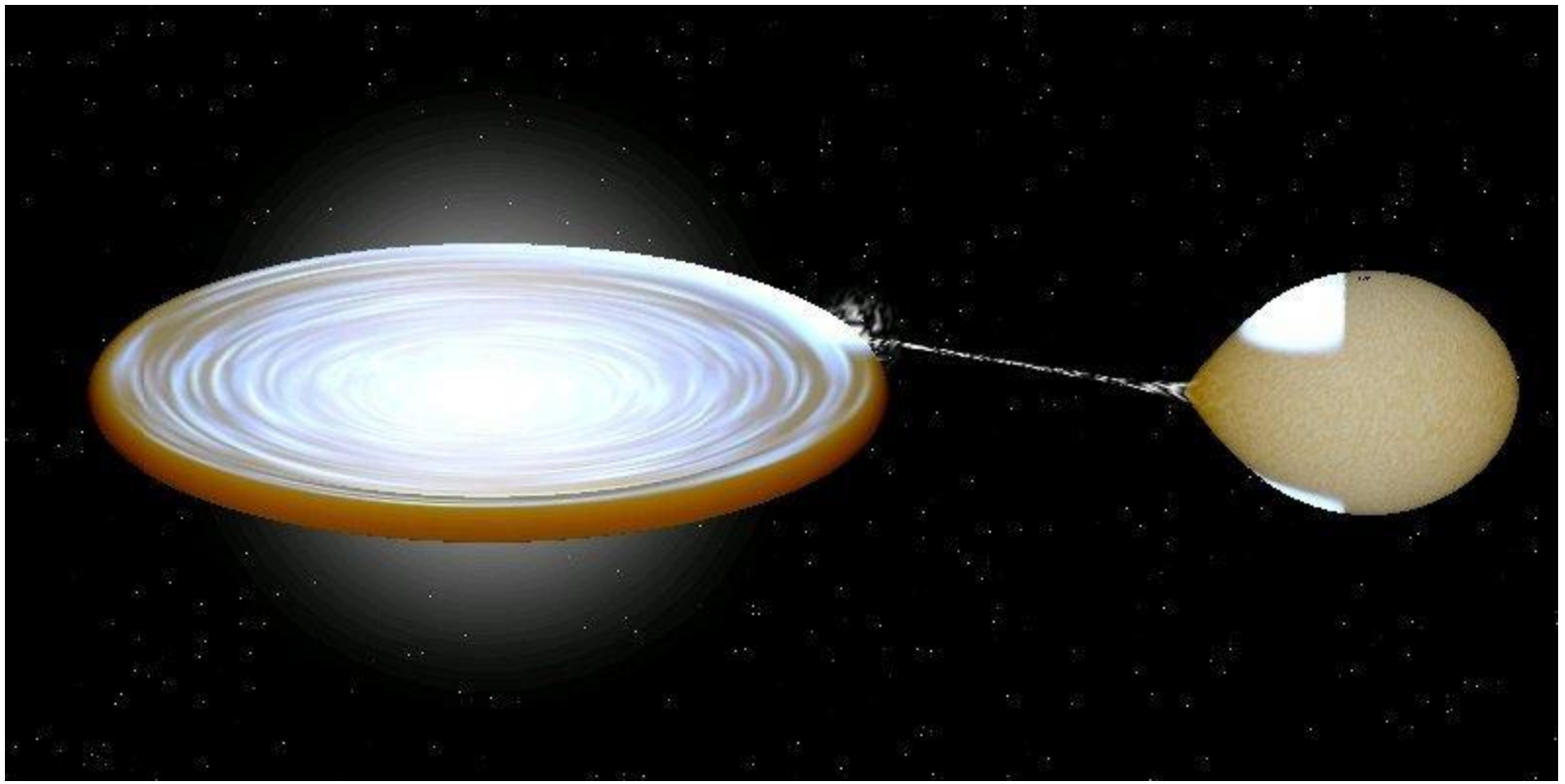
Based on MR, AK, KP, Ritter 2011, AA 526 A94;
AK, KP, MR 2014, Ast. Lett. 40, 29

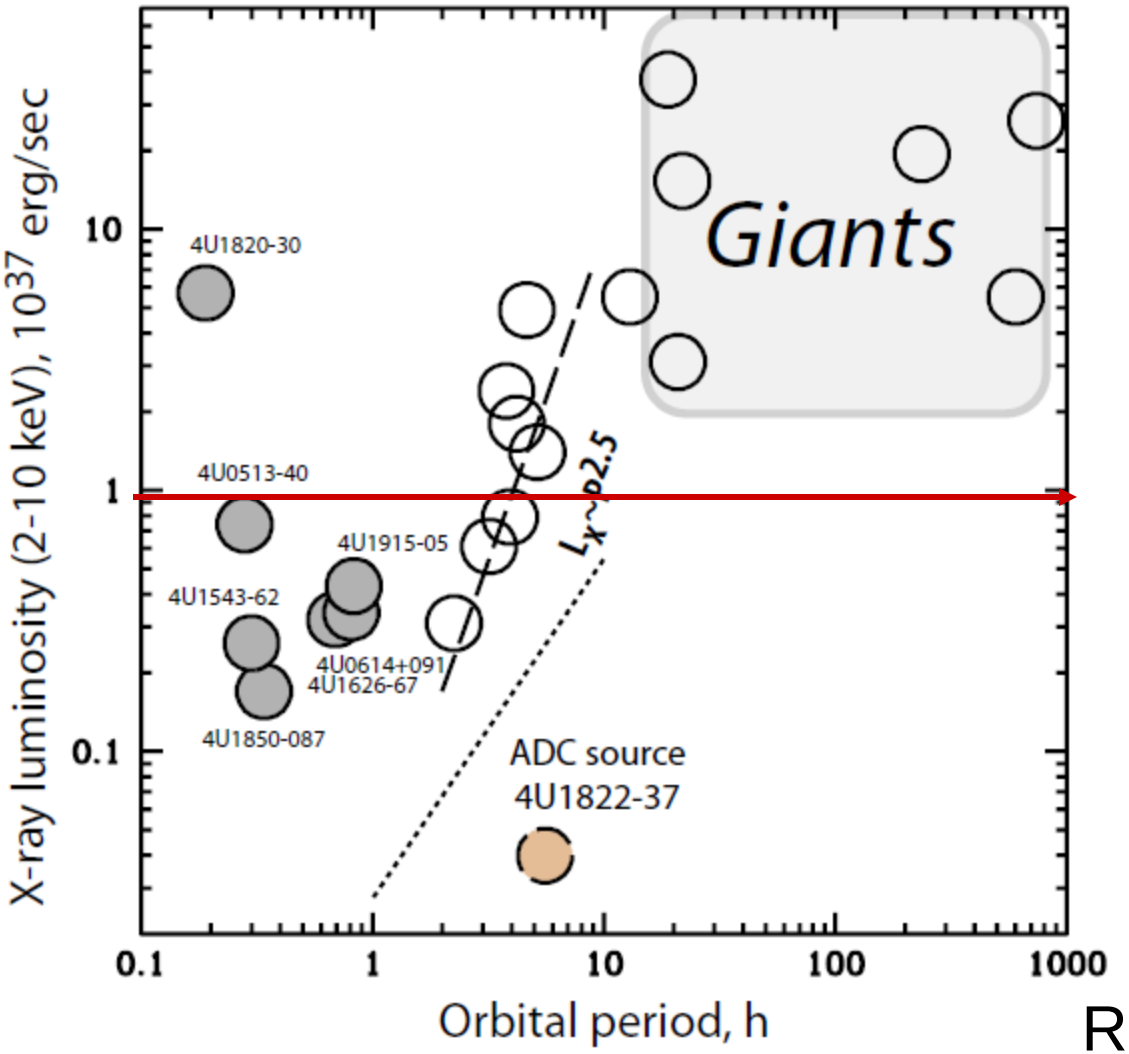
Low-mass X-ray binaries



NS accreting from low-mass star (RLOF or wind)

P_{orb}~O(hours)-days

Galactic steady LMXBs



$R=R_l(a)$

$M \sim R$

➔ $M=f(Porb) \sim M_{sun}$

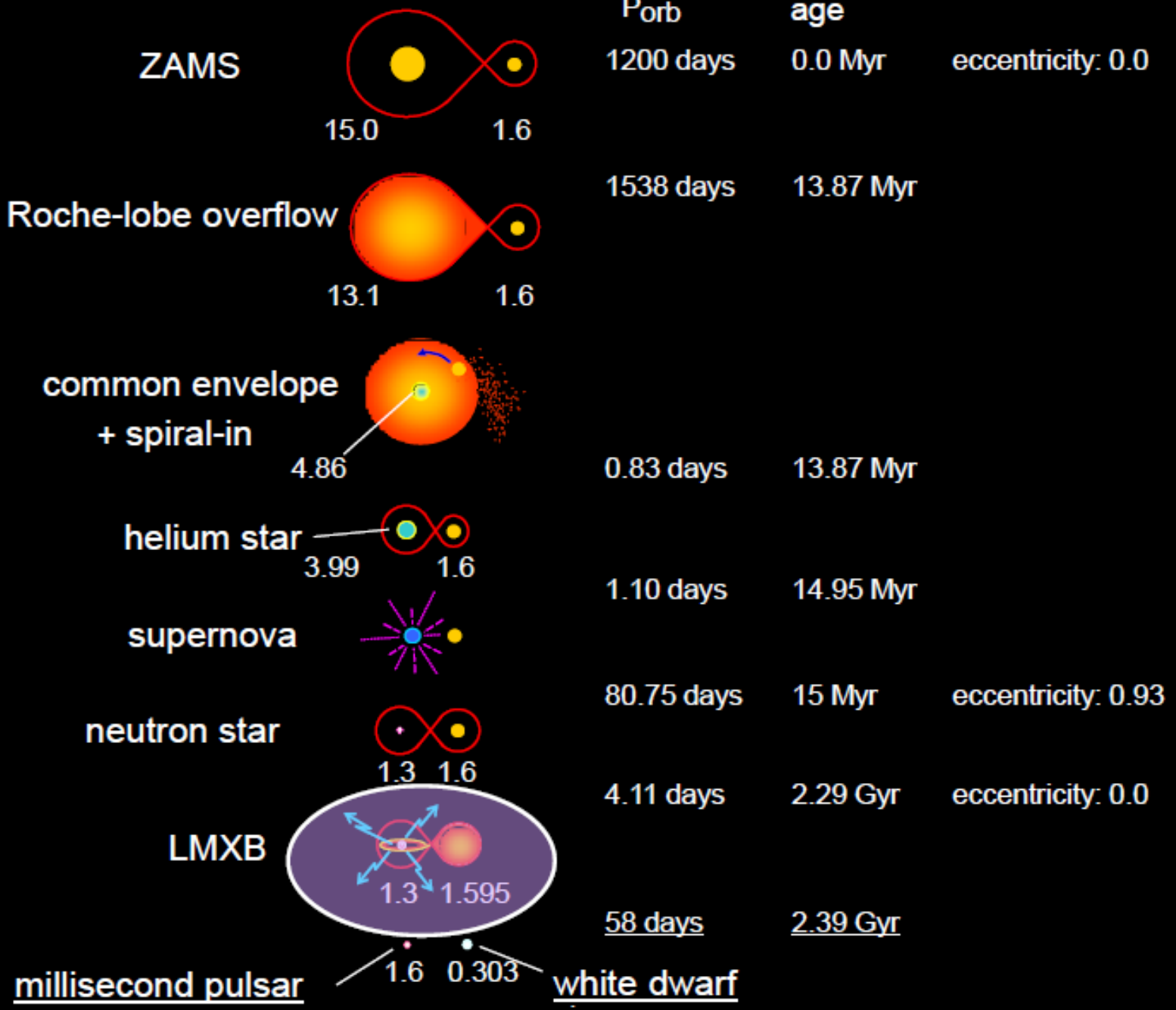
Revnivtsev et al. 2011

Motivation

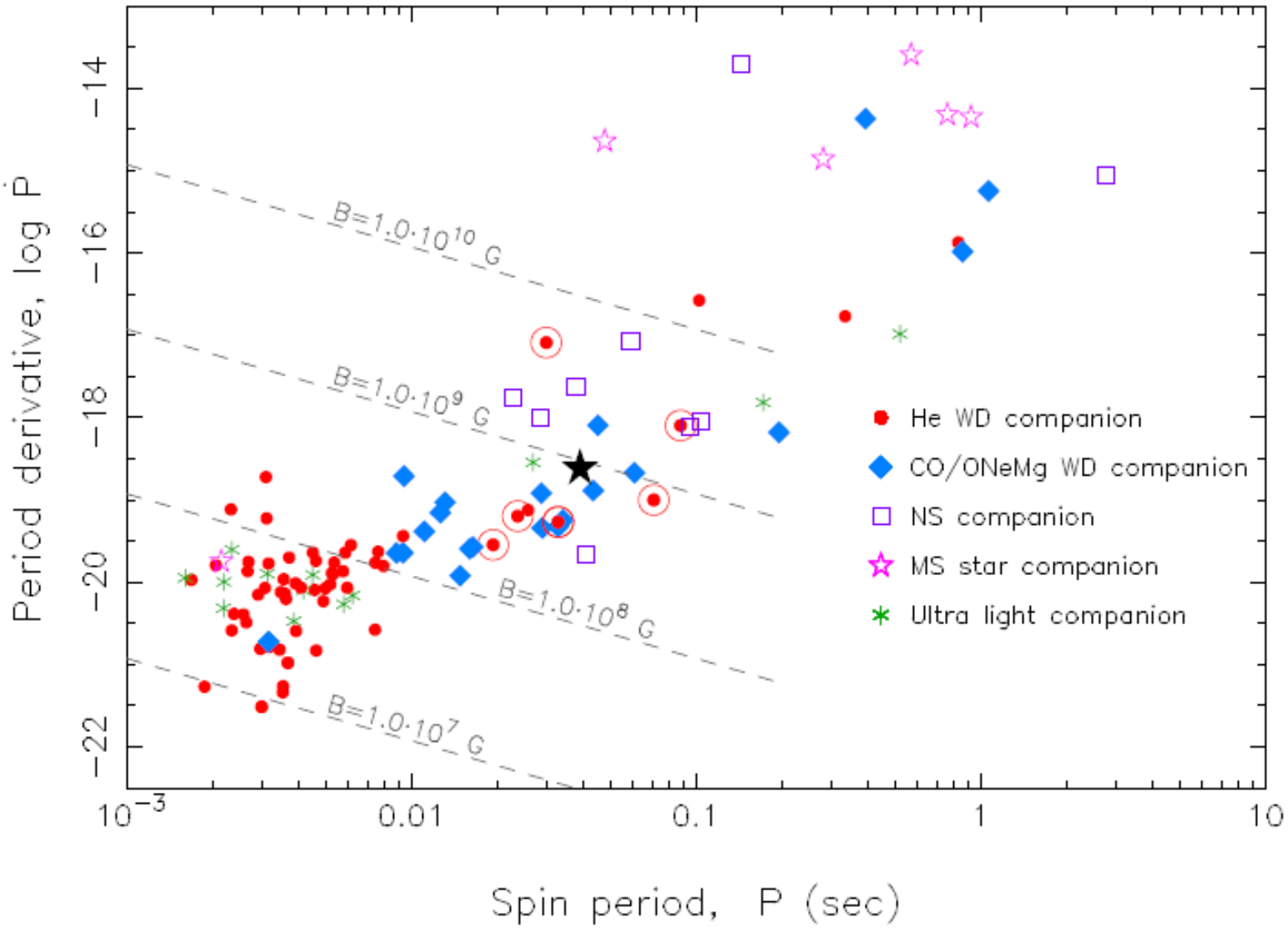
- Constraints on NS formation and evolution parameters from modeling of X-ray luminosity function and time evolution of LMXB population

Evolution of LMXB

LMXB ➔accreting MSP ➔ MSP

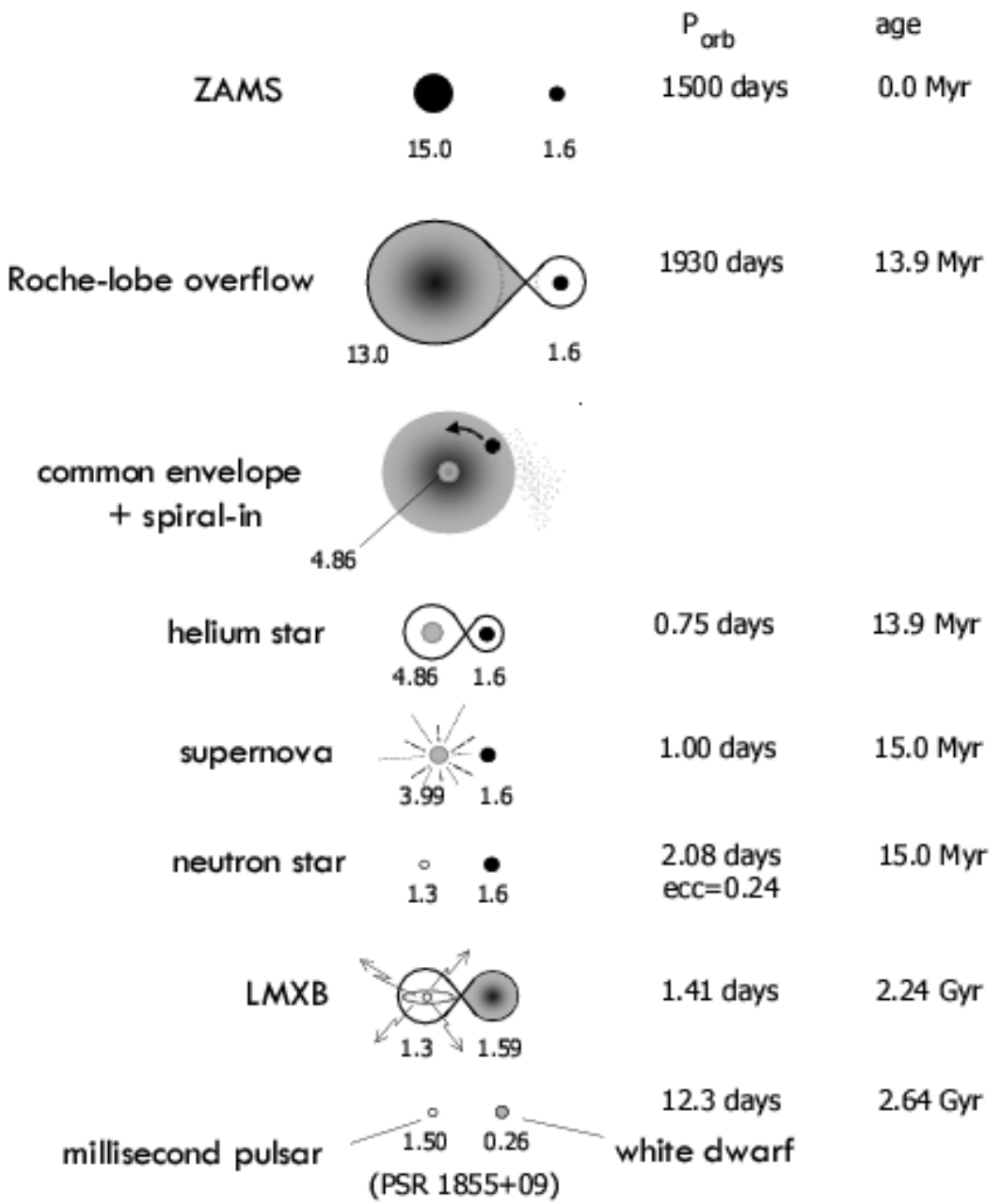

Porb
age
ZAMS
1200 days
0.0 Myr
eccentricity: 0.0
15.0
1.6
Roche-lobe overflow
1538 days
13.87 Myr
13.1
1.6
common envelope
+ spiral-in
4.86
0.83 days
13.87 Myr
helium star
3.99
1.6
1.10 days
14.95 Myr
supernova
80.75 days
15 Myr
eccentricity: 0.93
neutron star
1.3
1.6
4.11 days
2.29 Gyr
eccentricity: 0.0
LMXB
1.3
1.595
58 days
2.39 Gyr
millisecond pulsar
1.6
0.303
white dwarf

Binary pulsars in P-Pdot diagram



Key parameters

- Common envelope treatment
- Supernova explosion (NS mass, kick velocity, magnetic field)
- Angular momentum removal (magnetic stellar wind and GW emission)



LMXB evolution: modified BSE code (MSE, Kuranov et al 14)

- BSE (Hurley et al 2000, 2002)
- Analytical description of stellar evolution based on detailed evolutionary calculations (P. Eggleton code)

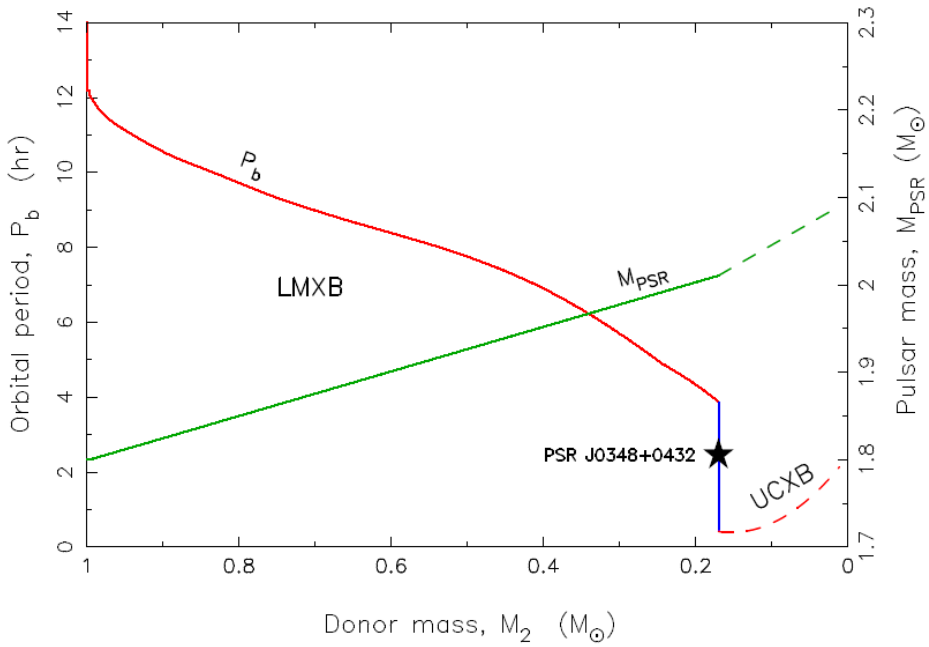
- MSE:
- BSE
- + modified MSW treatment
- + detailed treatment of accreting compact stars

Evolutionary parameters

- NS mass:
  8-10 M_{sun} → 1.25 M_{sun} (ECSN)
  10-30 M_{sun} → 0.38+0.12xM (Zang+'08)
- NS kick: 3D Maxwellian, 300 km/s
- Common envelop: α-formalism, α_{CE}=0.5-2
- Non-conservative: MSW, GW

Evidence for massive NS:

- Initially massive?
- Hypercritical accretion during CE stage?
- Observational support: evolutionary history of PSR J0348+0432 (M~2 M_{sun}) (Antoniadis et al 13)



Population synthesis

- Modified BSE code (Kuranov, PK, Revnivtsev 2014)

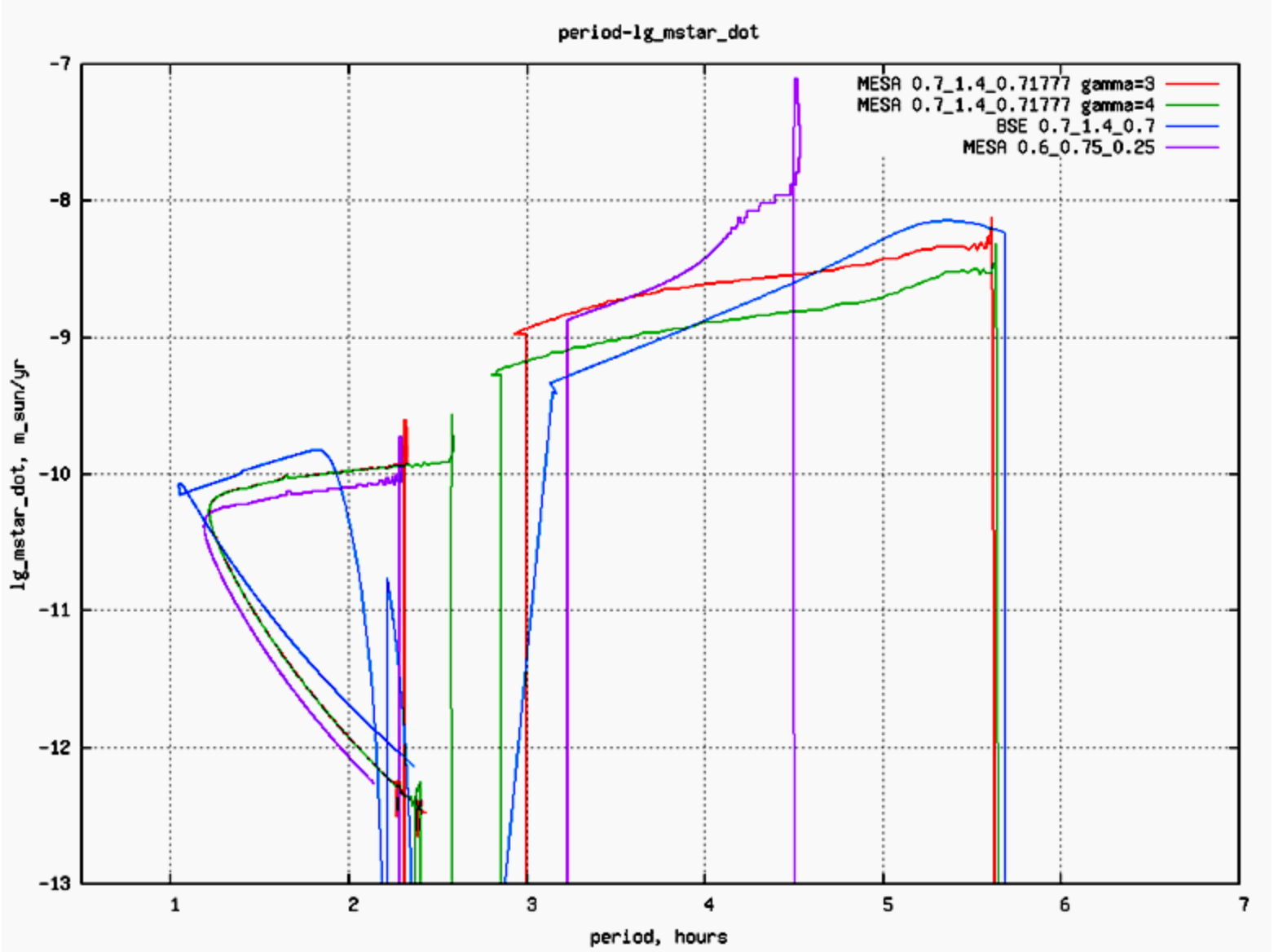
- NEW: Comparison with MESA code

http://mesa.sourceforge.net

(B.Paxton+'14)

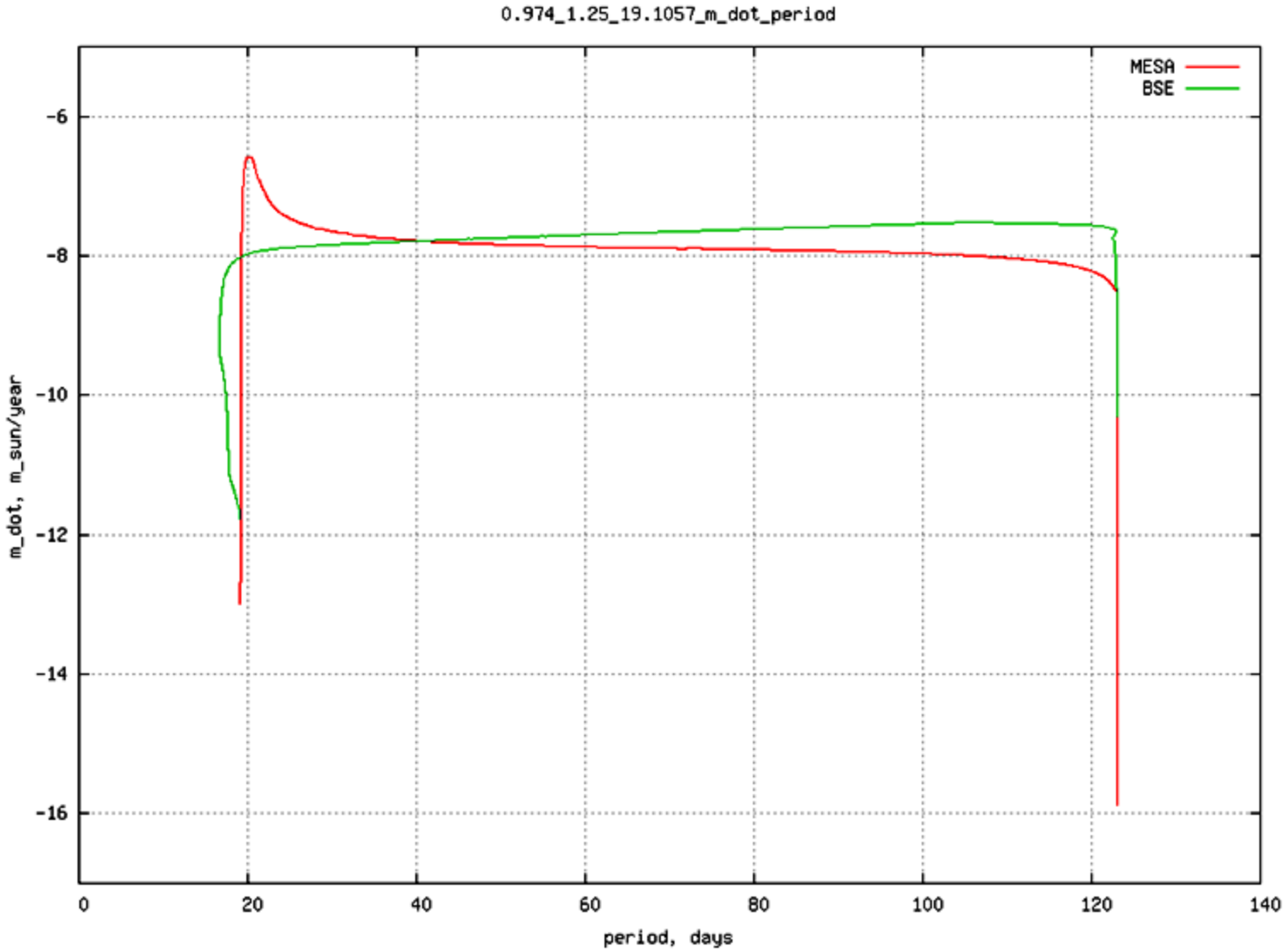
Bright LMXB: MESA vs MSE

MS+NA



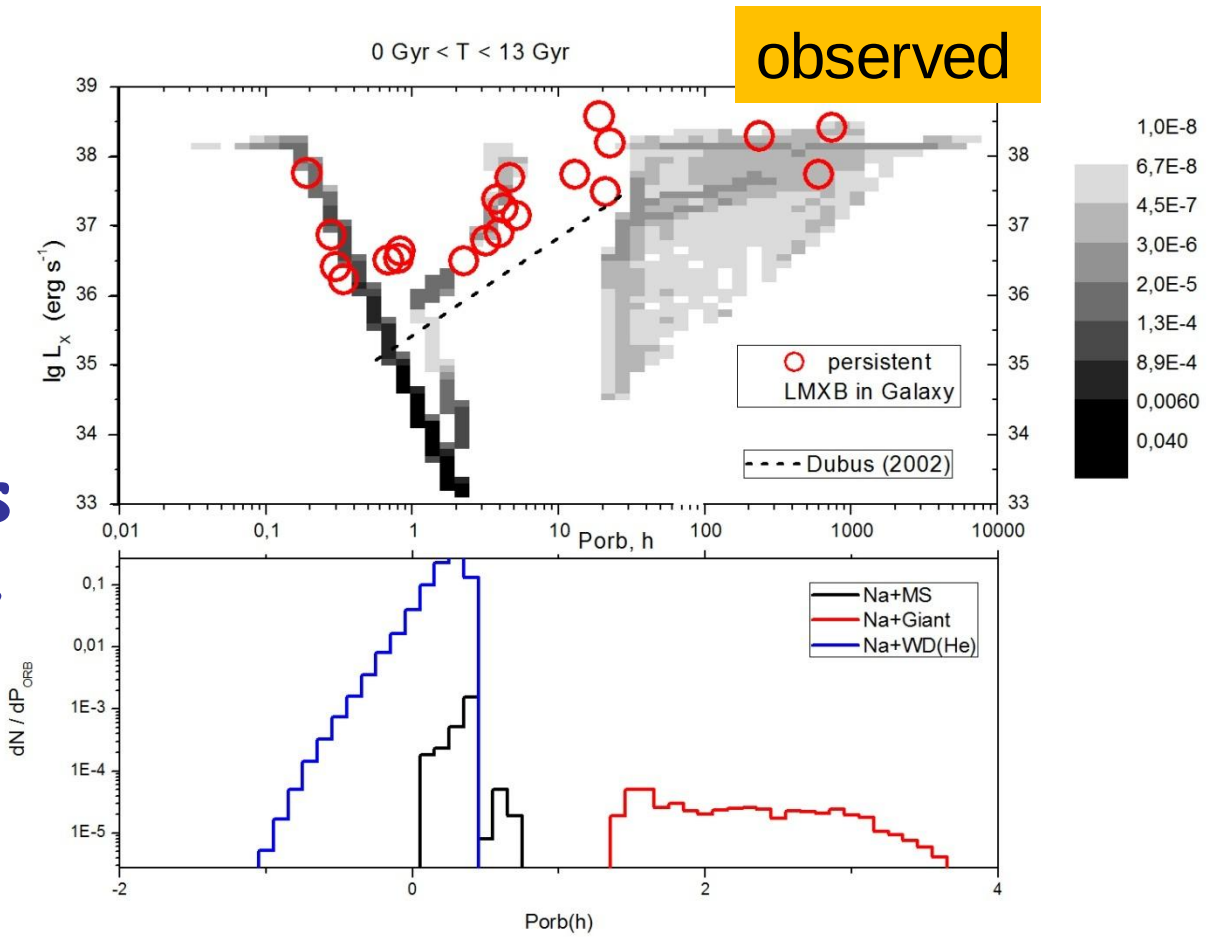
Bright LMXB: MESA vs MSE

RG+NA

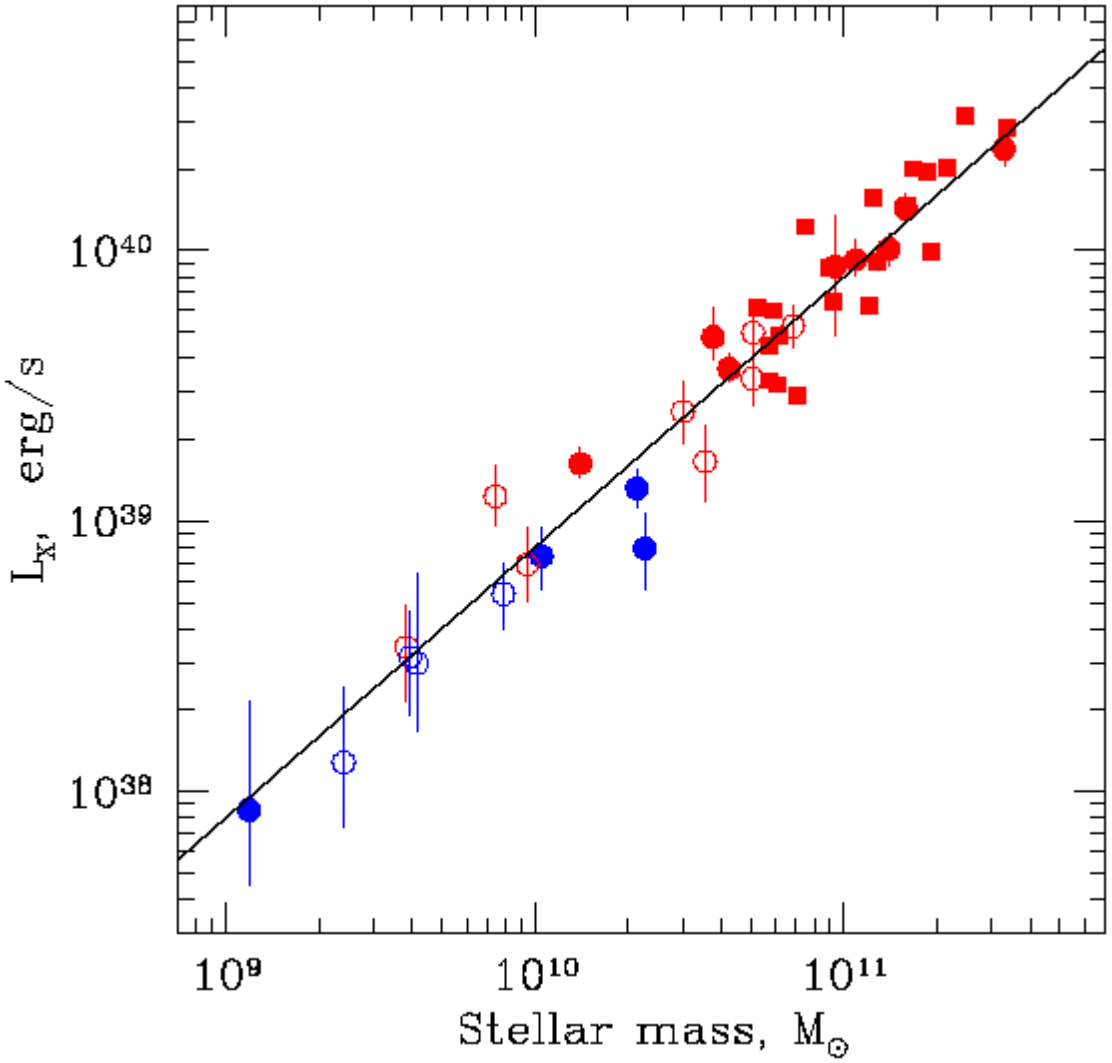


Best-fit model for persistent galactic LMXBs

- CE efficiency ~1-2 (standard values)
- Standard magnetic stellar wind parameters
- NS kick velocity 100-300 km/s
- NS mass range 1.25 (ECSN), 1.4-1.8 M_o

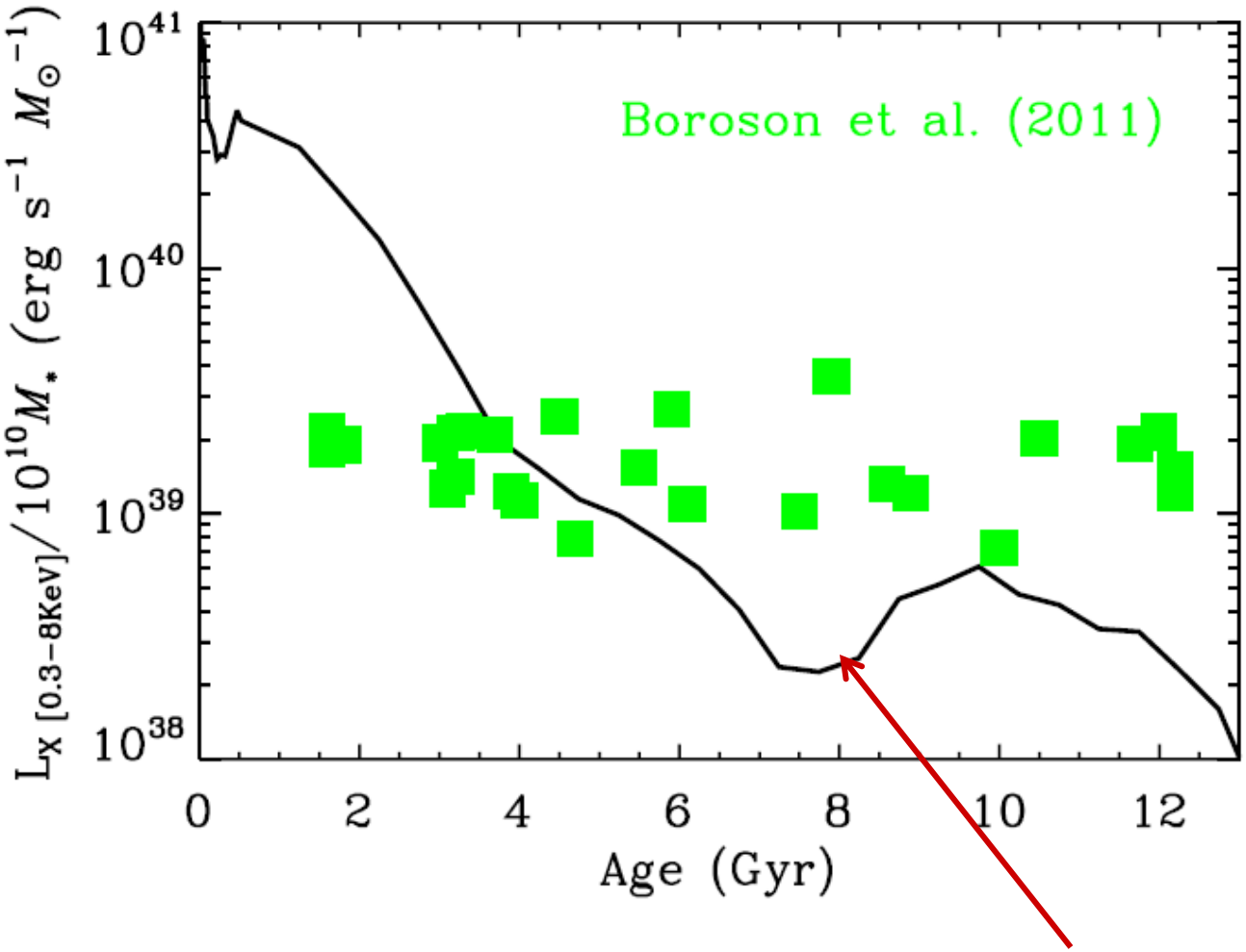


X-ray luminosity as a measure of galaxy mass

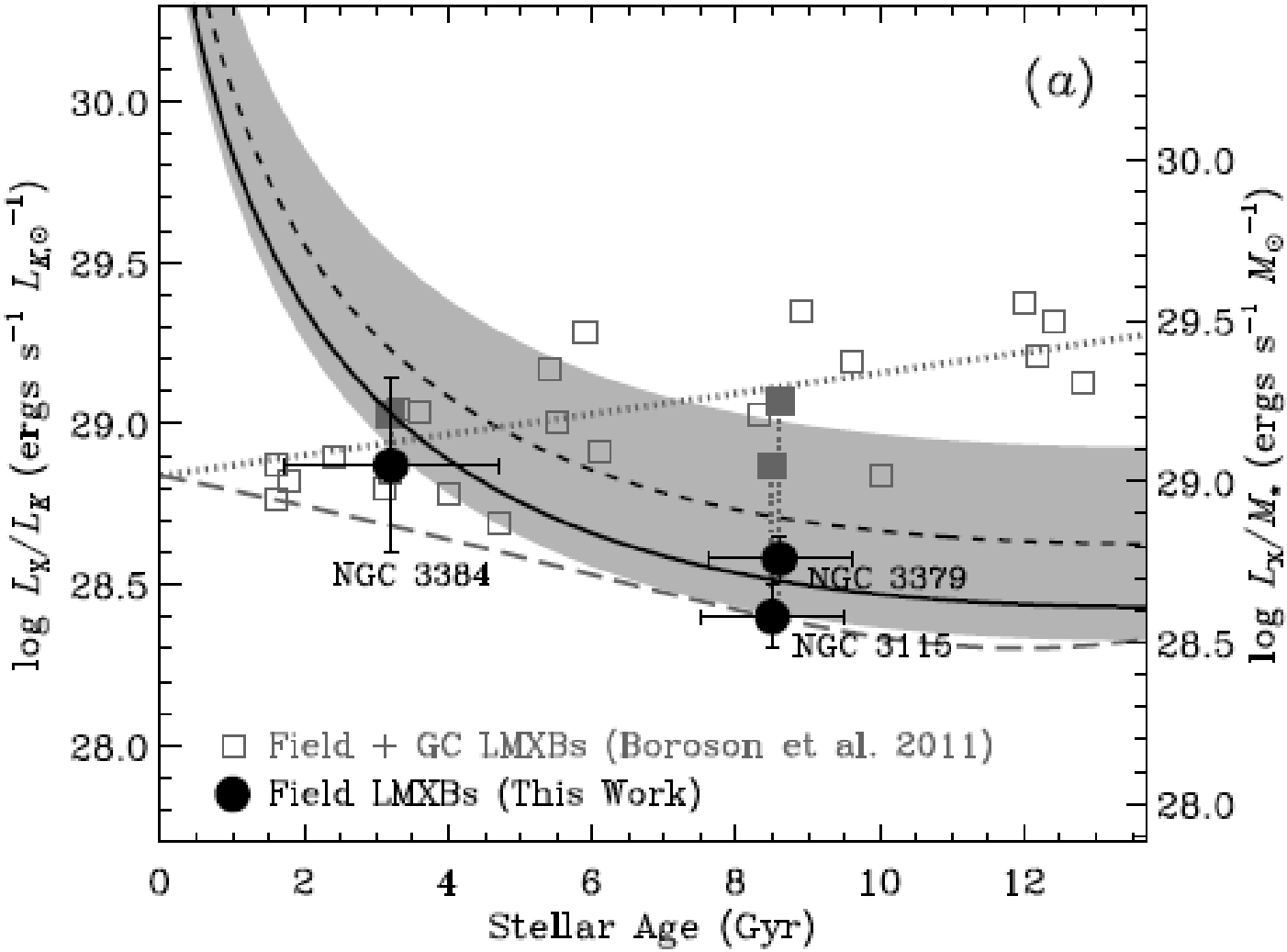


M. Gilfanov 2014

LMXB evolution in elliptical galaxies

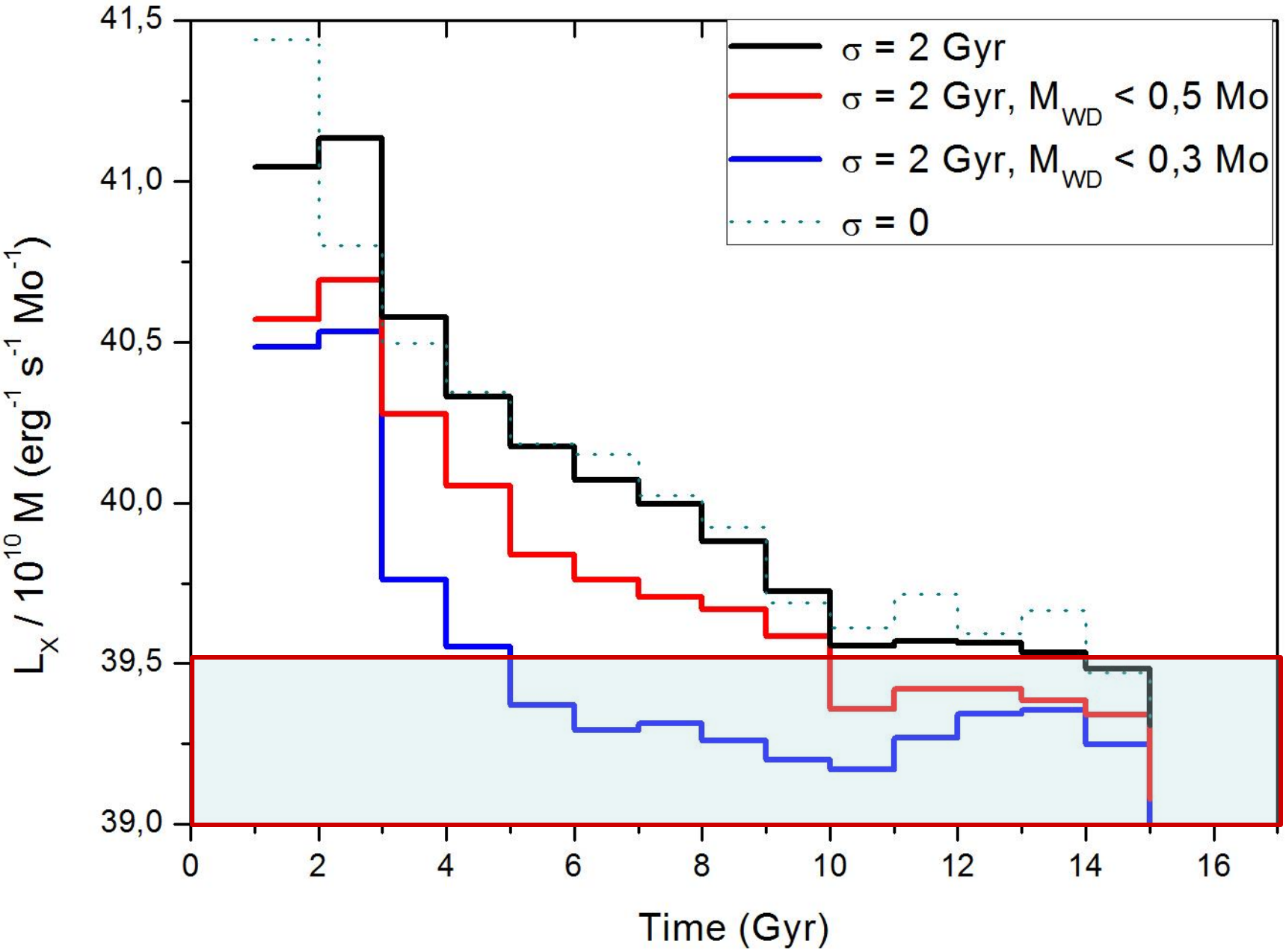


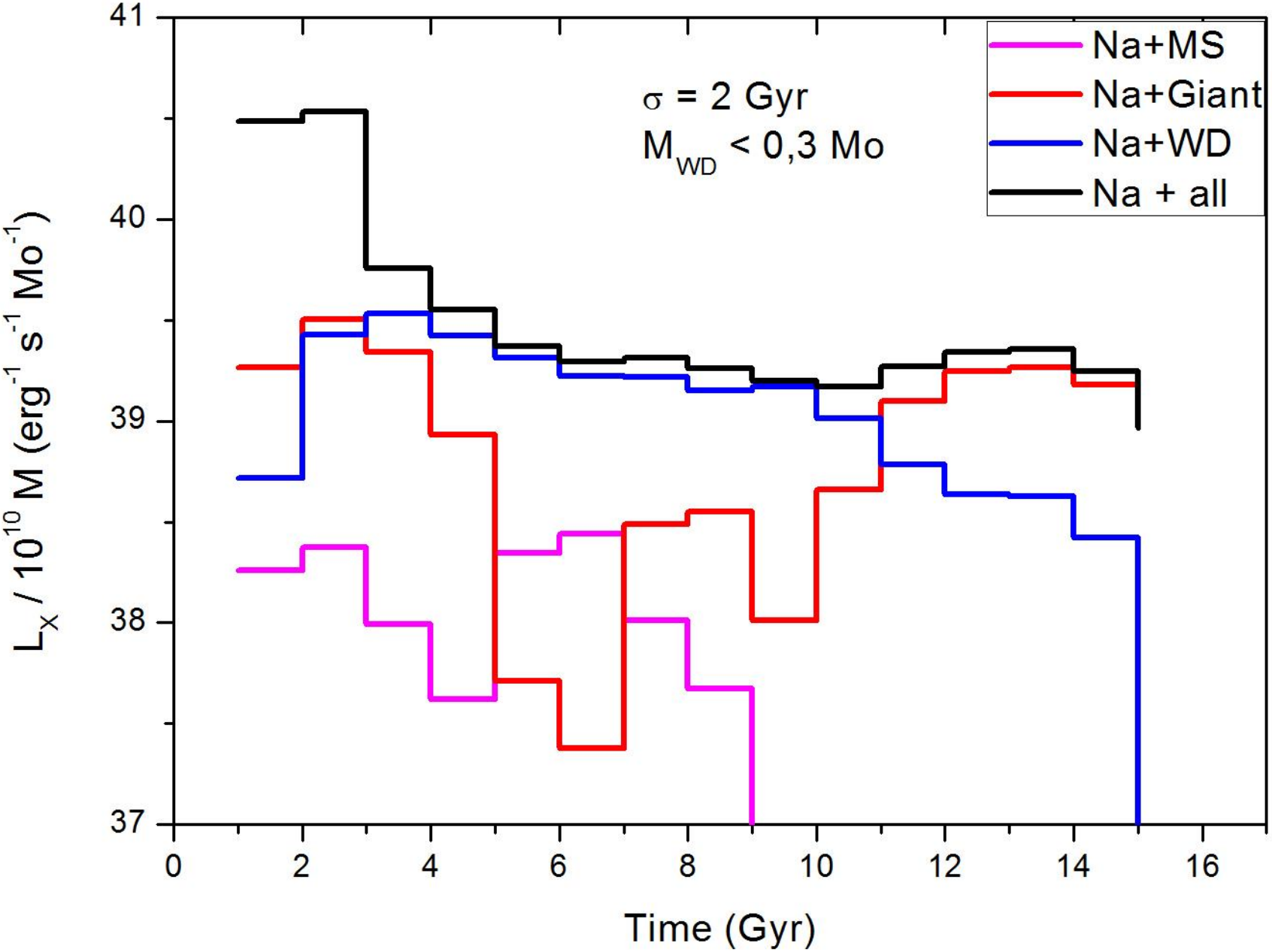
Fragos et al. 2013 model



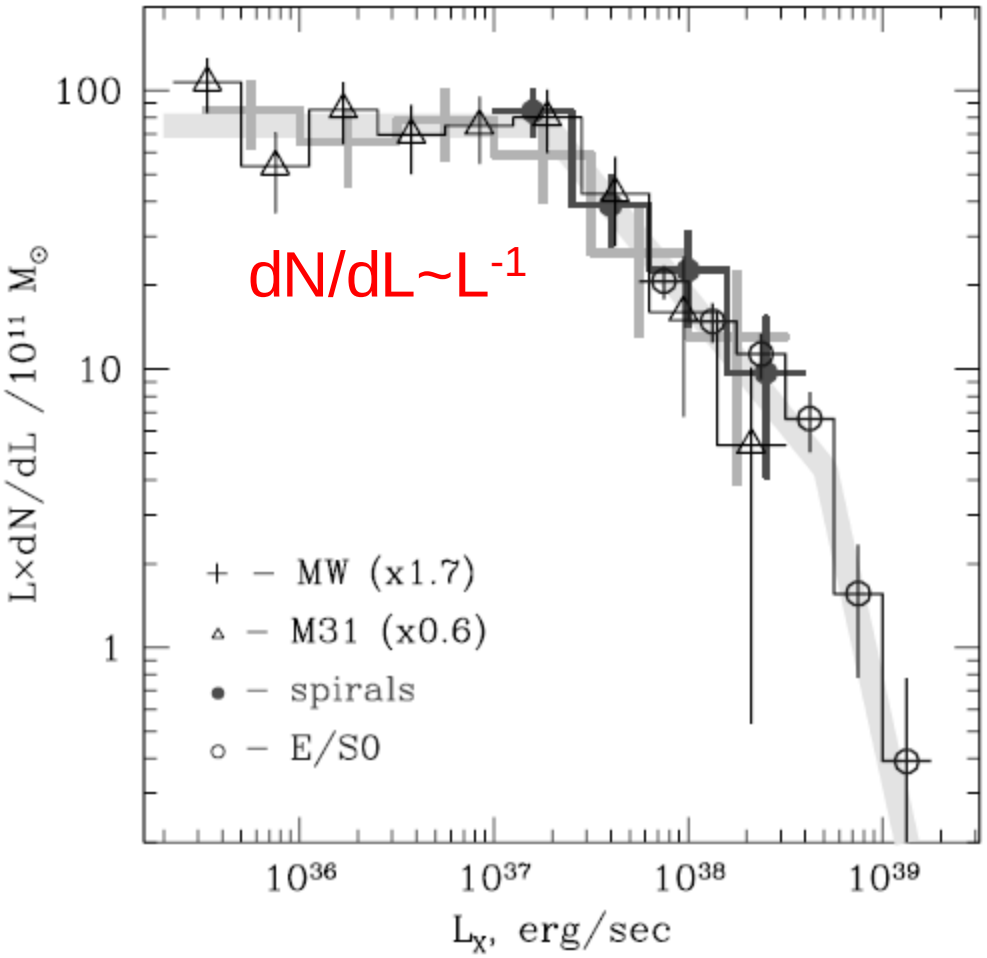
Add GC sources?

Lehmer+'14 (arXiv:1405.2069)

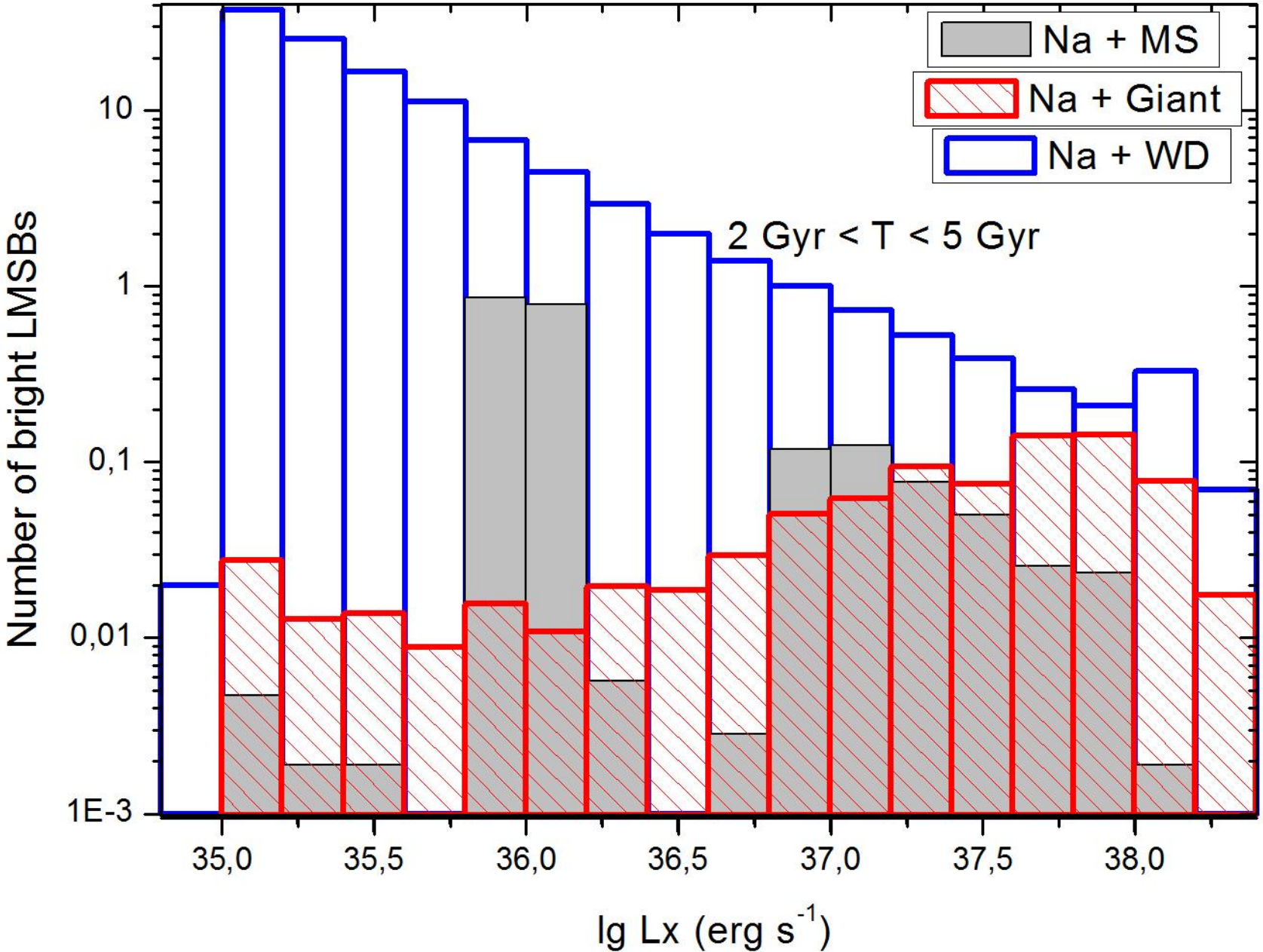

σ = 2 Gyr
σ = 2 Gyr, M_WD < 0,5 Mo
σ = 2 Gyr, M_WD < 0,3 Mo
σ = 0
L_X / 10^10 M (erg^-1 s^-1 Mo^-1)
Time (Gyr)
41,5
41,0
40,5
40,0
39,5
39,0
0
2
4
6
8
10
12
14
16

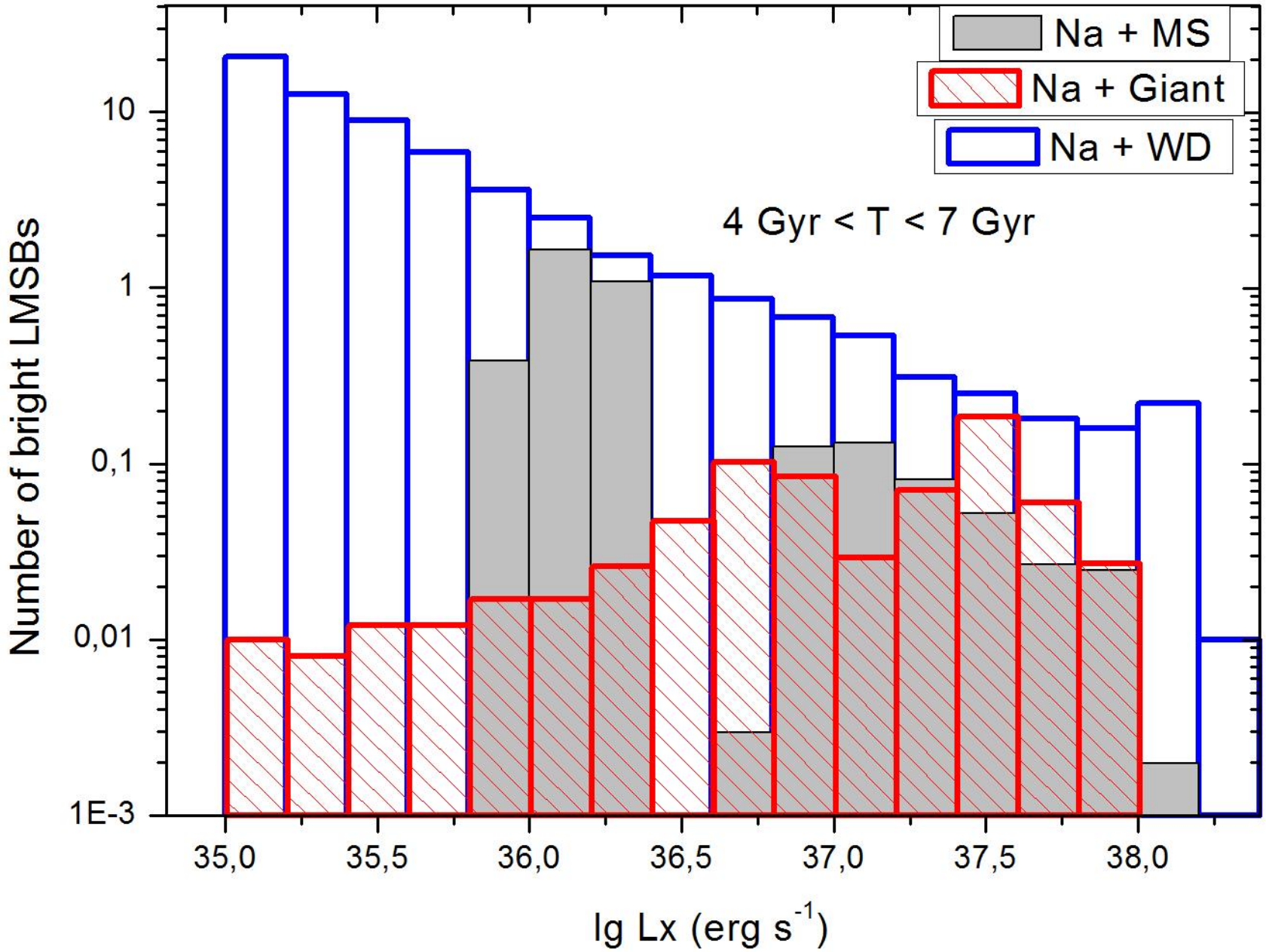

Na+MS
Na+Giant
Na+WD
Na + all
σ = 2 Gyr
M_WD < 0,3 Mo
L_X / 10^10 M (erg^-1 s^-1 Mo^-1)
Time (Gyr)
41
40
39
38
37
0
2
4
6
8
10
12
14
16

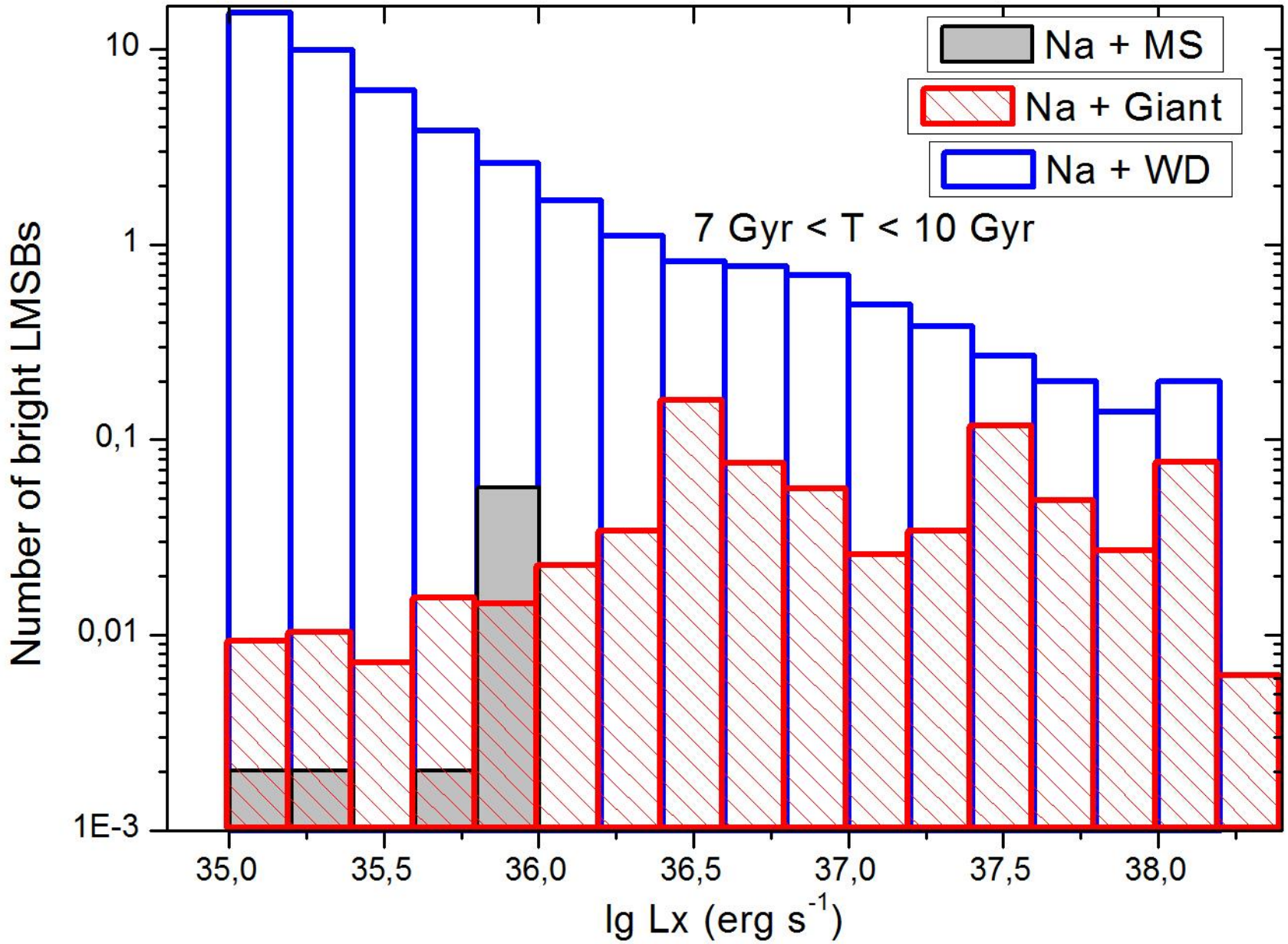
LMXB luminosity function evolution with time

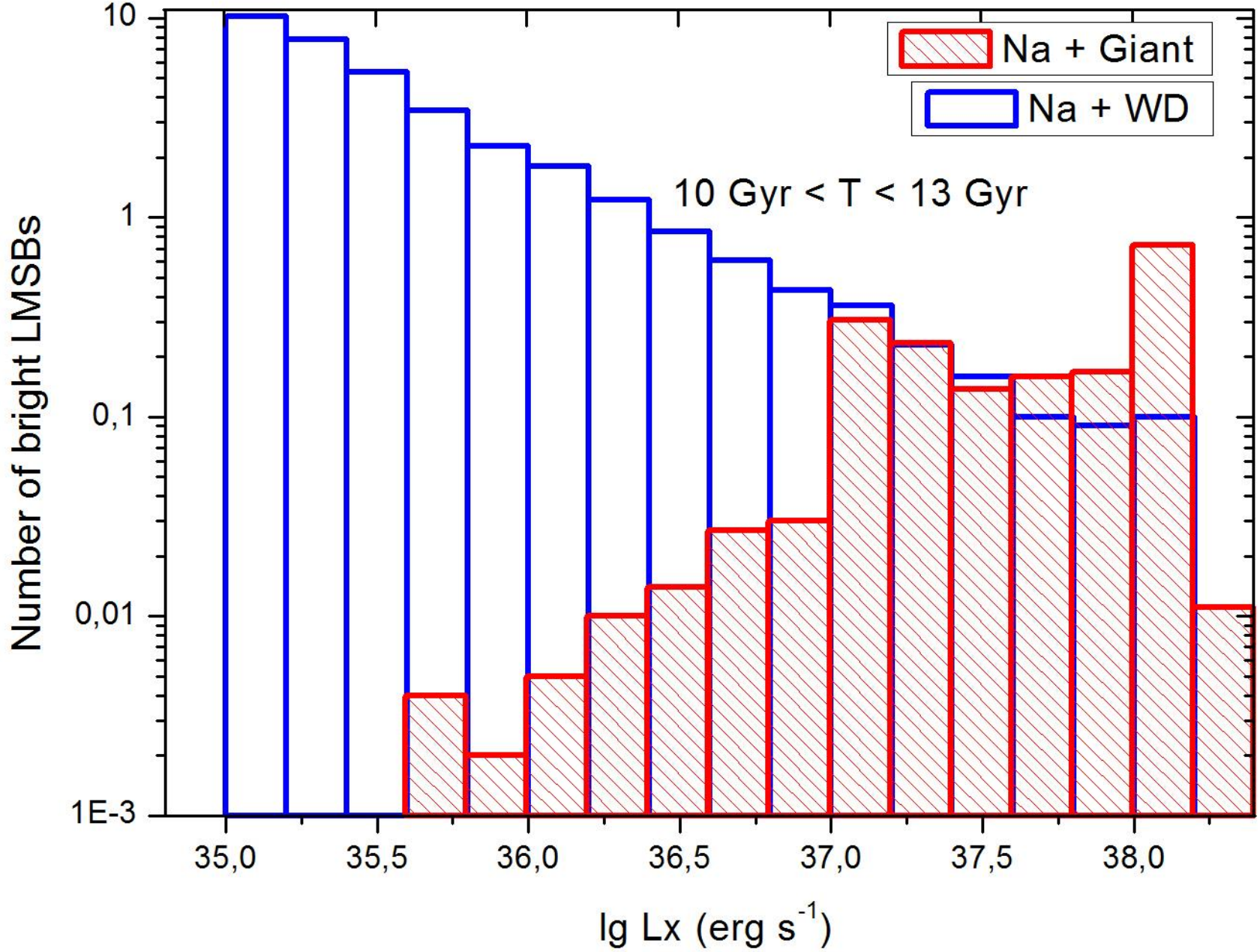


Gilfanov 2004

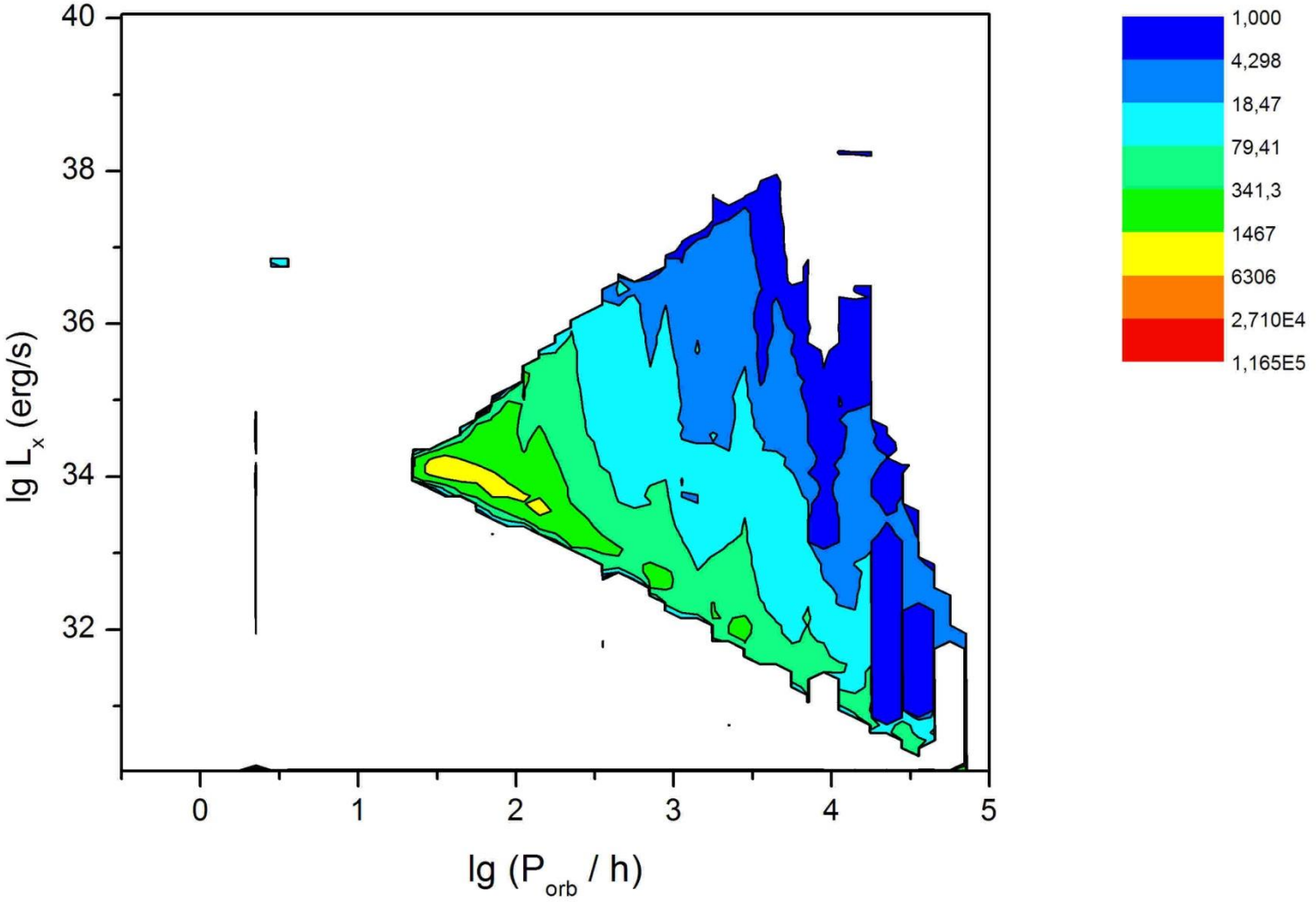

Na + MS
Na + Giant
Na + WD
2 Gyr < T < 5 Gyr
Number of bright LMSBs
10
1
0,1
0,01
1E-3
35,0
35,5
36,0
36,5
37,0
37,5
38,0
lg Lx (erg s-1)


Na + MS
Na + Giant
Na + WD
4 Gyr < T < 7 Gyr
Number of bright LMSBs
10
1
0,1
0,01
1E-3
35,0
35,5
36,0
36,5
37,0
37,5
38,0
lg Lx (erg s-1)


Na + MS
Na + Giant
Na + WD
7 Gyr < T < 10 Gyr
Number of bright LMSBs
10
1
0,1
0,01
1E-3
35,0
35,5
36,0
36,5
37,0
37,5
38,0
lg Lx (erg s-1)


Na + Giant
Na + WD
10 Gyr < T < 13 Gyr
Number of bright LMSBs
10
1
0,1
0,01
1E-3
35,0
35,5
36,0
36,5
37,0
37,5
38,0
lg Lx (erg s-1)

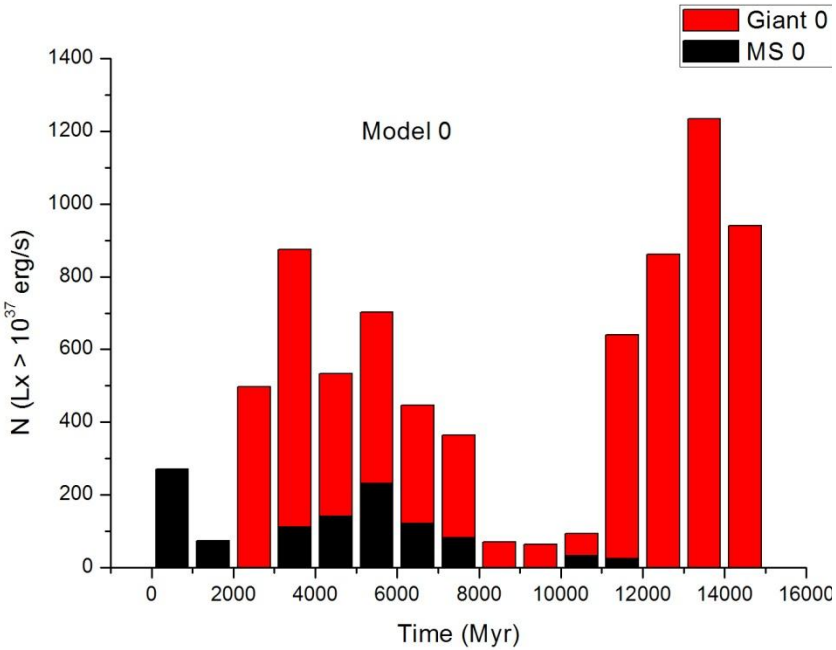
Wind-accreting LMXBs



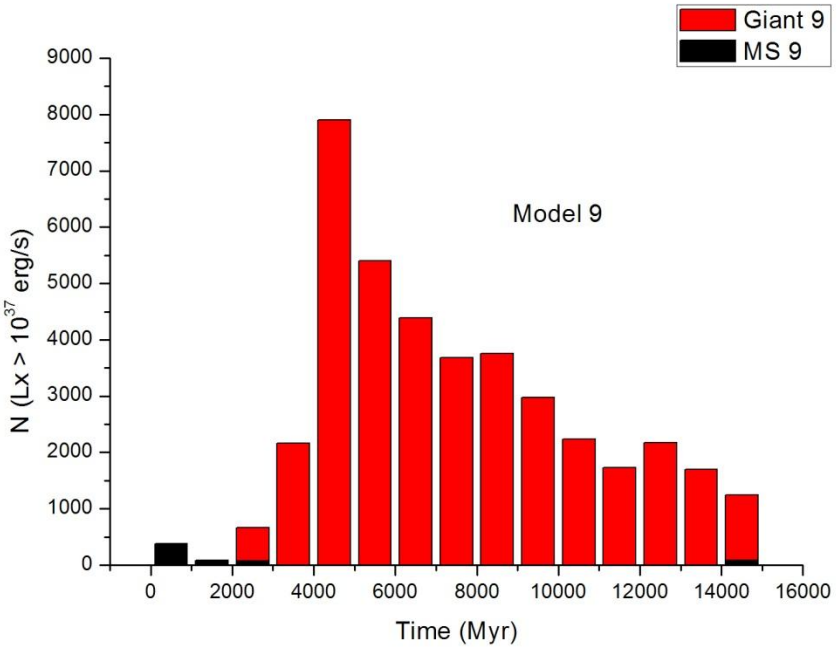
Conclusions

- LMXB evolution can be successively reproduced by MSE code
- Bright LMXB checked by MESA code (MS+NA, RG+NA, (He, CO) WD+NA)
- Ab initio massive NS formation is required
- LMXBs accreting from evolved giants form high-luminosity end of LMXB XLF
- LMXB population after star-formation burst does not strongly decrease with time, consistent with observed LMXB evolution in elliptical galaxies

M=1.25-1.4


Giant 0
MS 0
Model 0
N (Lx > 10^37 erg/s)
Time (Myr)
0
200
400
600
800
1000
1200
1400
0
2000
4000
6000
8000
10000
12000
14000
16000

M=1.8


Giant 9
MS 9
Model 9
N (Lx > 10^37 erg/s)
Time (Myr)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
0
2000
4000
6000
8000
10000
12000
14000
16000