Formation and evolution of supergiant High Mass X-ray Binaries

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The Impact of Binaries on Stellar Evolution
ESO Worshop, München, July 3-7, 2017

Plan

- I. Introduction: *accreting binaries*
- II. Galactic distribution of HMXB
- III. Evolution and fate of HMXB
- IV. Conclusions

Kick-off of X-ray astronomy

- Discovery of X-rays by Röntgen in 1895, born in München, awarded the 1st Nobel prize in 1901!
- Discovery of the 1st extra-solar X-ray source (Sco X-1; Giacconi+1962), Nobel prize of Physics in 2002
- Looking forward for the Nobel prize for gravitational waves!

PHYSICAL REVIEW
LETTERS

VOLUME 9 DECEMBER 1, 1962 NUMBER 11

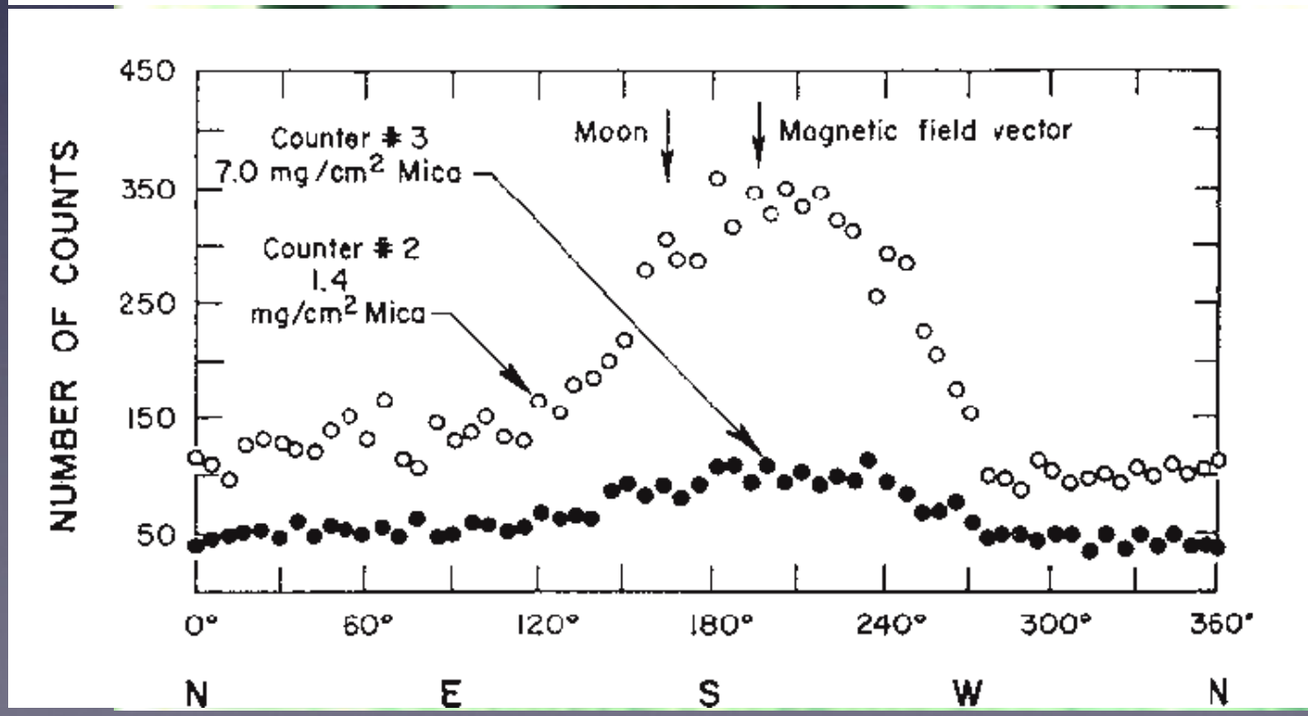
EVIDENCE FOR X RAYS FROM SOURCES OUTSIDE THE SOLAR SYSTEM*

Riccardo Giacconi, Herbert Gursky, and Frank R. Paolini
American Science and Engineering, Inc., Cambridge, Massachusetts

and

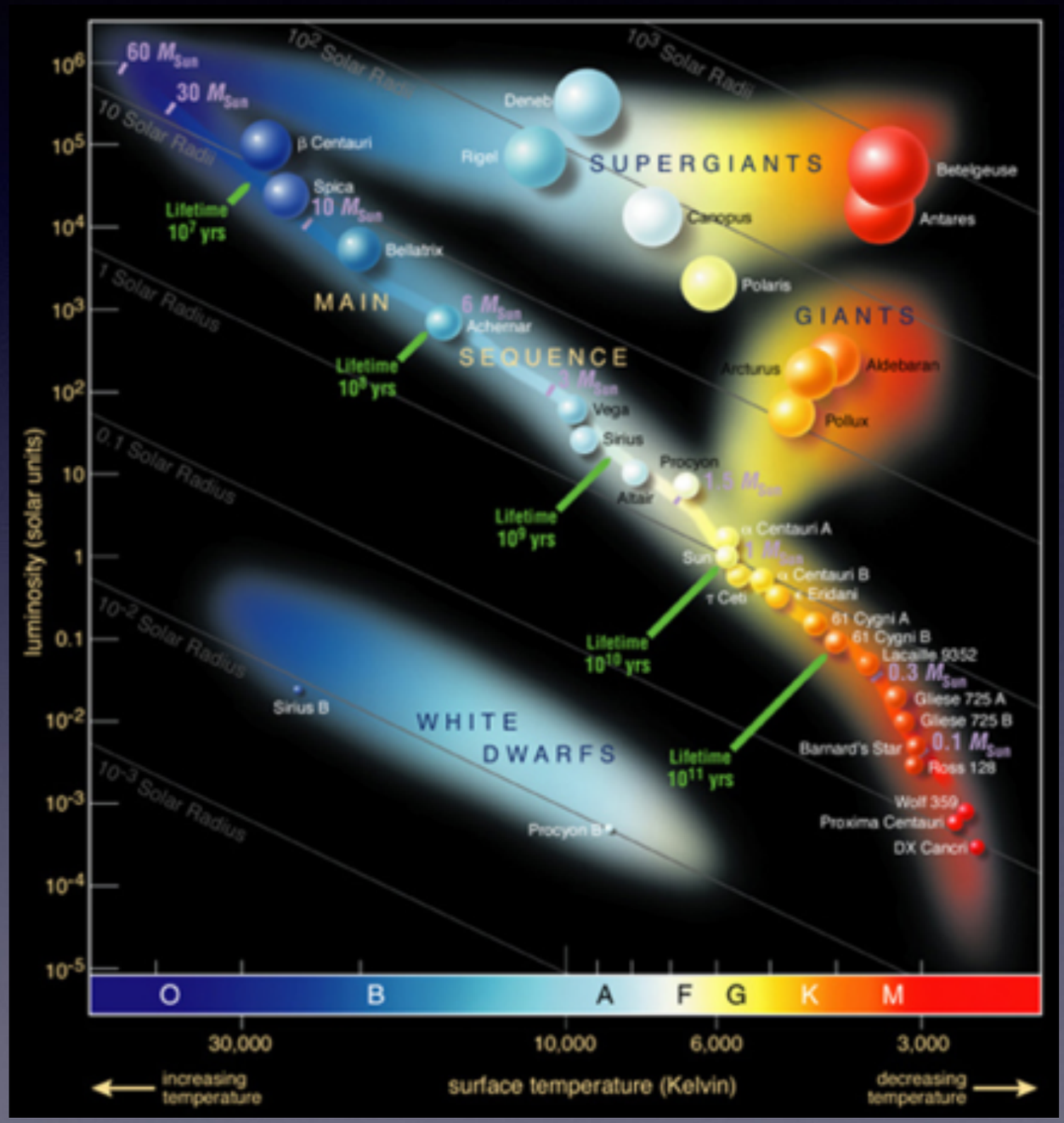
Bruno B. Rossi
Massachusetts Institute of Technology, Cambridge, Massachusetts

(Received October 12, 1962)



Stellar evolution

- HR diagram describes the evolution of a single, isolated star…
- …however, most stars belong to multiple systems: +70% of massive (OB) stars experience a binary interaction during their evolution (Sana+2012)
- Transfer of matter/angular momentum has a huge impact on binary evolution



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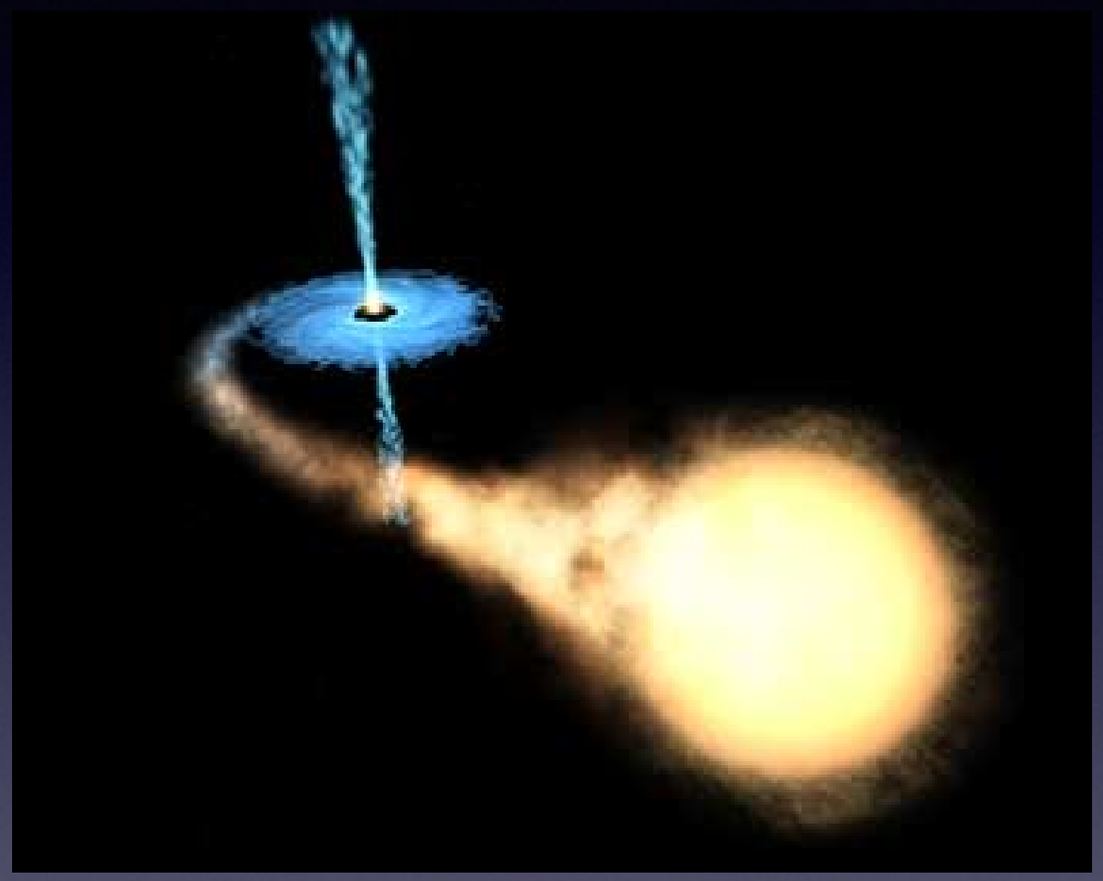
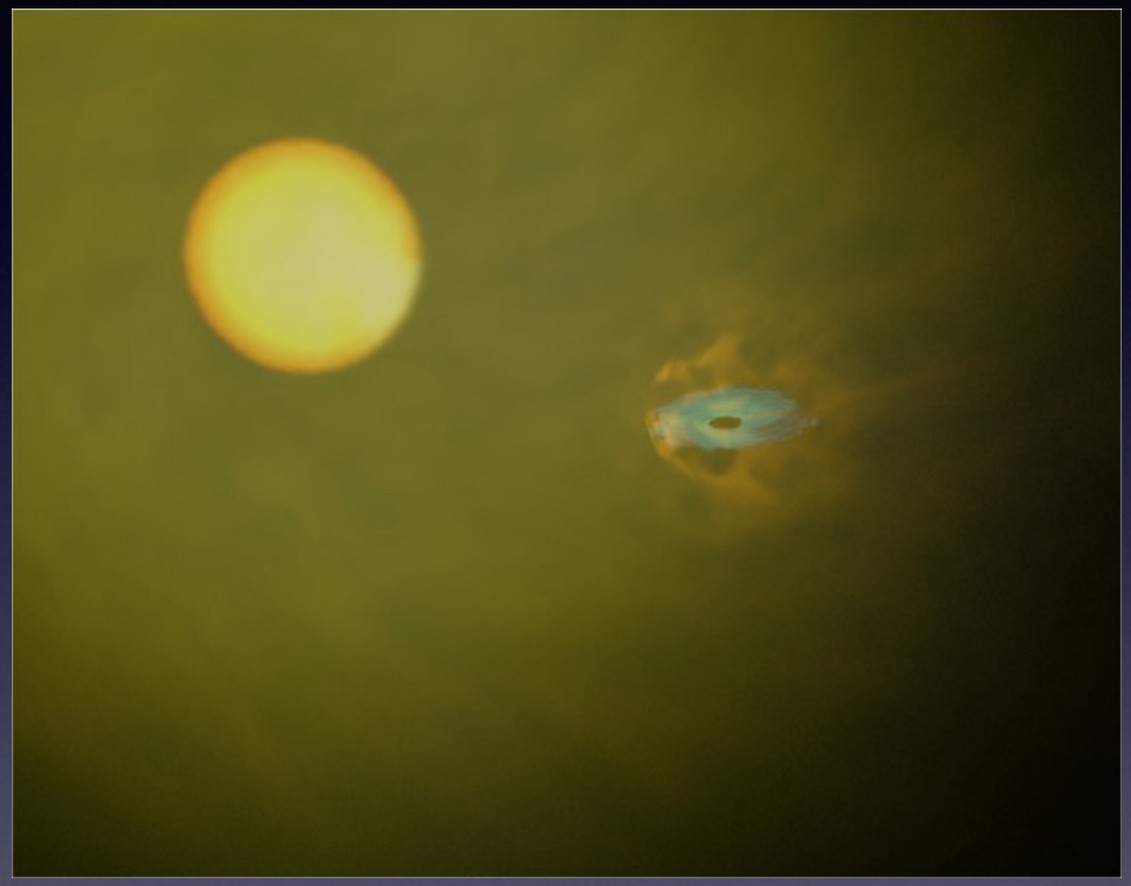
Accreting binaries



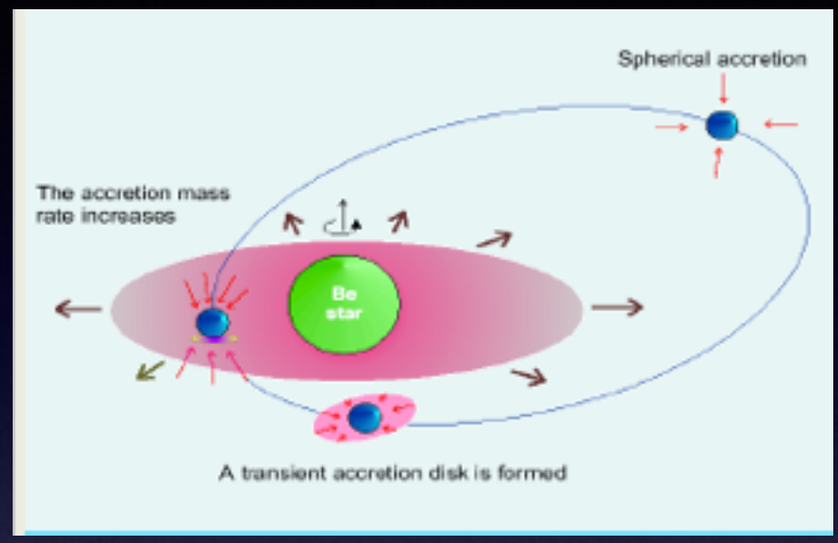
Low-mass X-ray Binaries
(~250 LMXB):
Roche lobe overflow



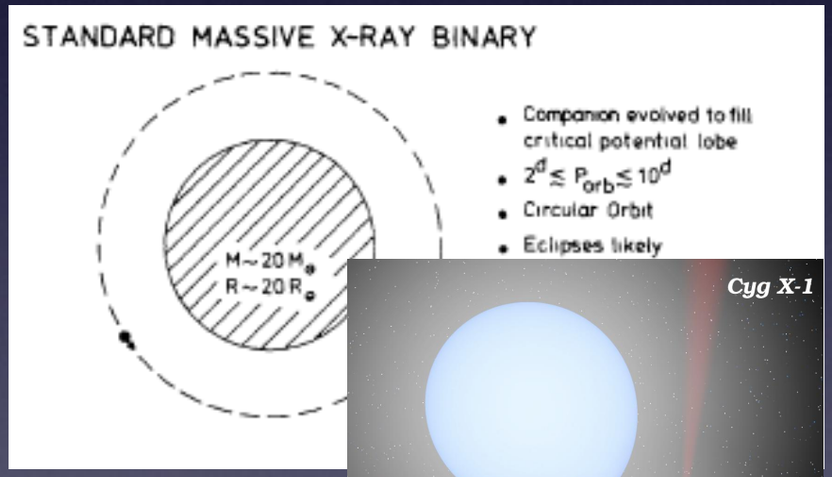
High-mass X-ray Binaries
(~167 HMXB):
Stellar wind accretion

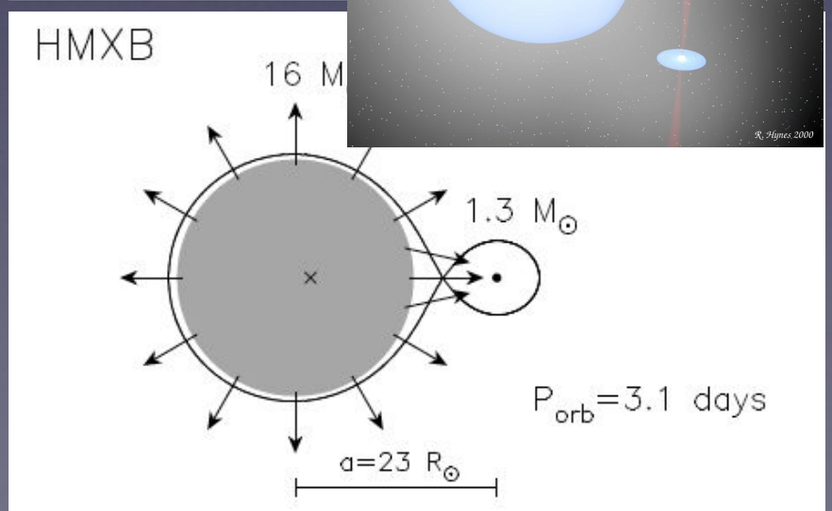
Galactic X-ray binaries

- HMXB:
  - Donor: Luminous early-type OB companion star (M>10M☼)



- 3 types depending on mass transfer:
  - **BeXB** (40): direct accretion from Be III-V star decretion disk
  - **sgXB** (36): spherical accretion from sg I/II stellar wind (500-1000 km/s) with CO in circular orbit, $L_X \sim 10^{35\text{-}40}$erg/s (Vela X-1, GX 301-2, 4U 1700-37…)
  - **RLO** (5): Beginning Atmospheric Roche Lobe Overflow





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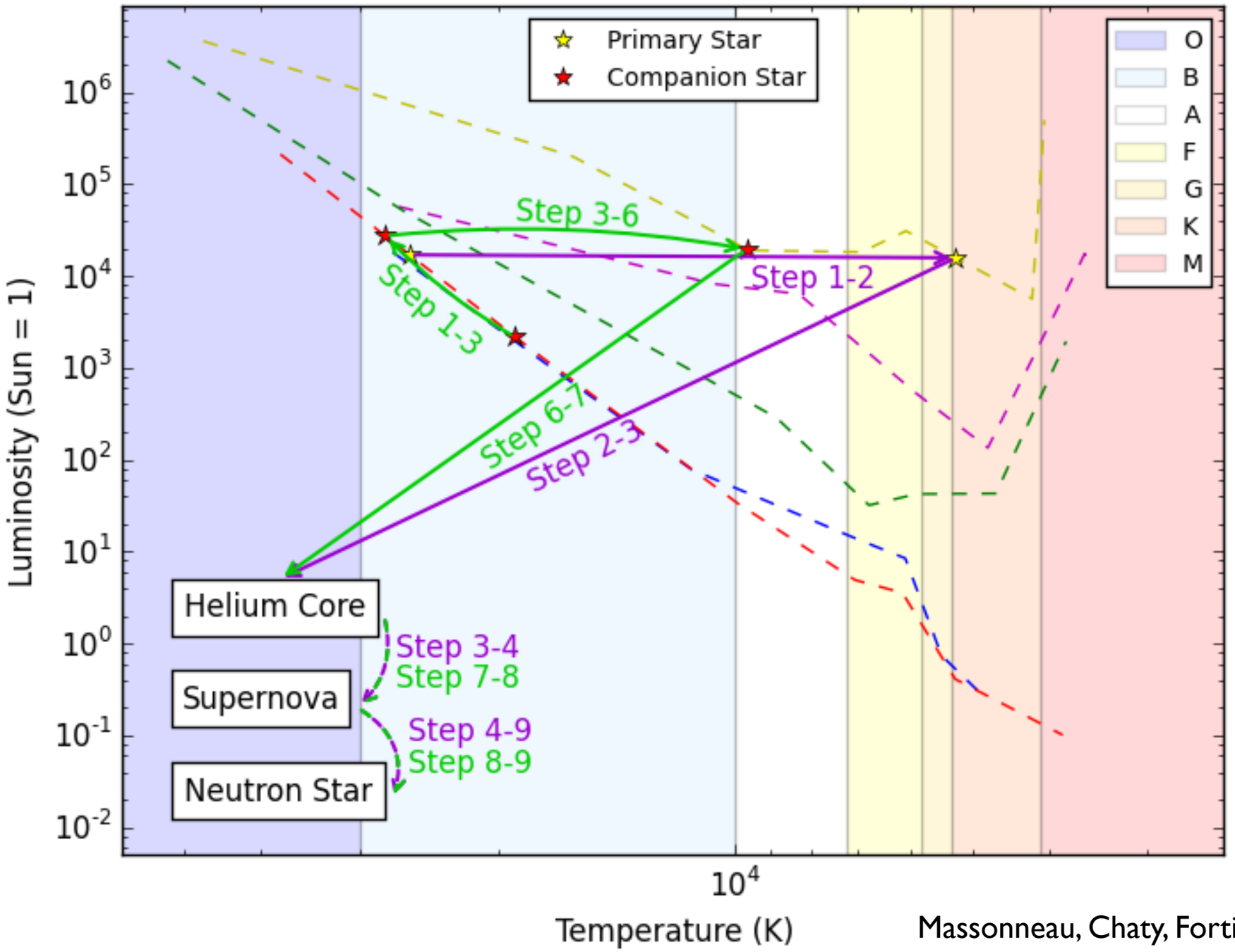
Stellar evolution



Massonneau, Chaty, Fortin, 2017

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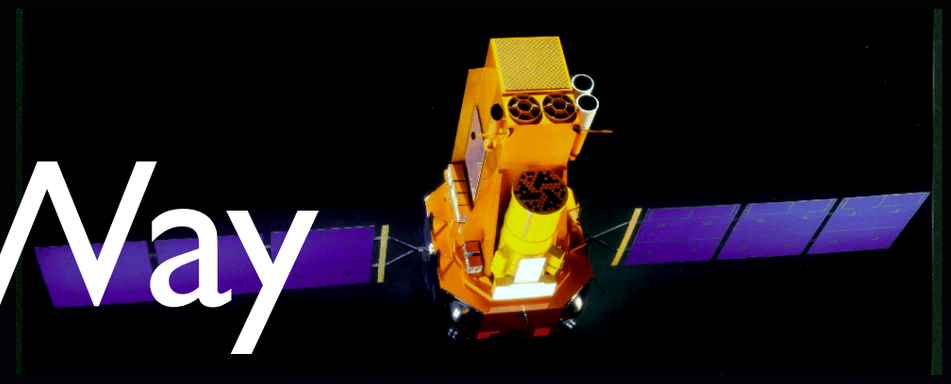
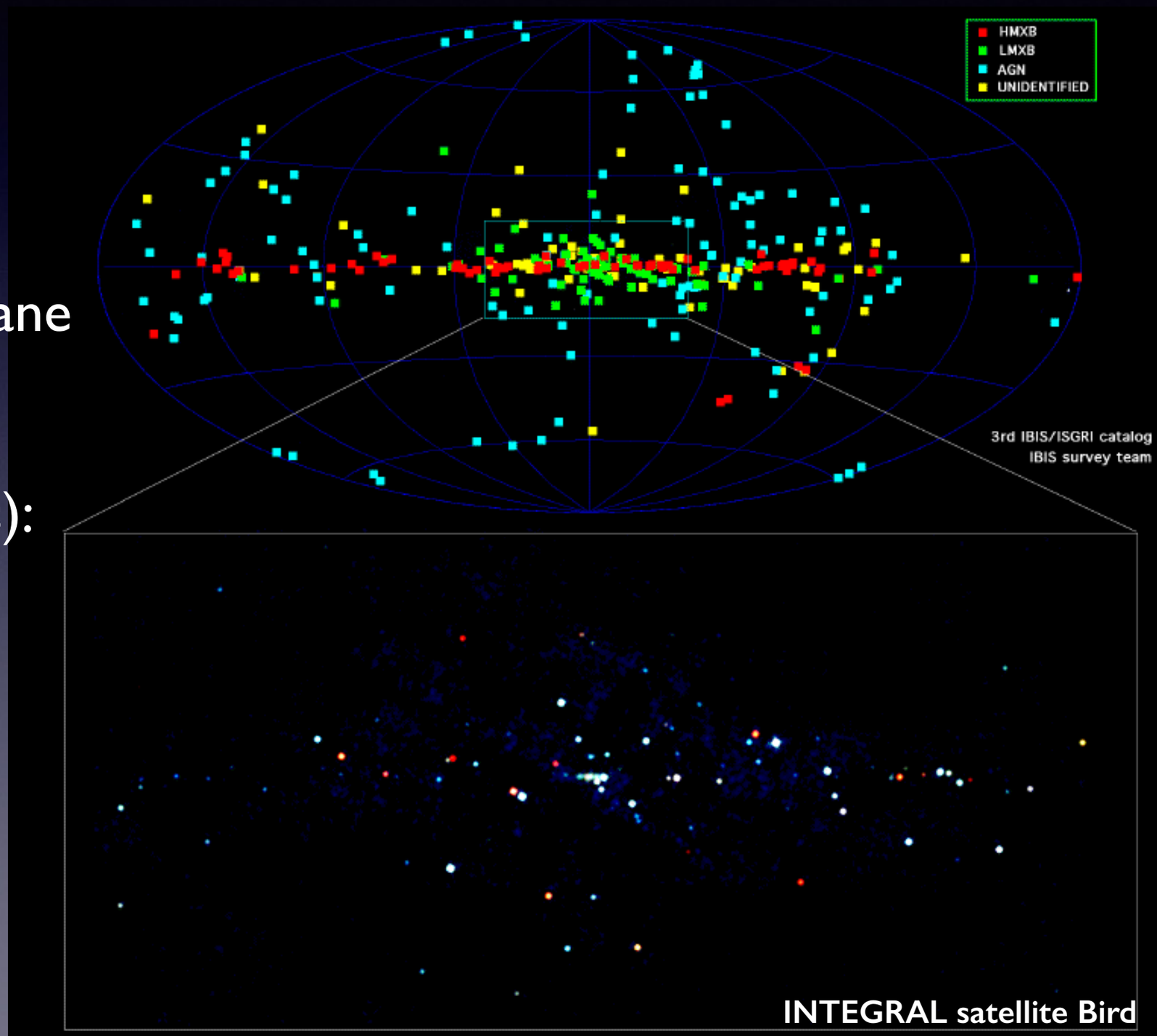
The Milky Way



- LMXB (old stars) in Galactic bulge, migration off the plane (|b|>3-5°)
- HMXB (young stars): on Galactic plane, towards tangential directions of spiral arms



INTEGRAL satellite Bird et al. 2010

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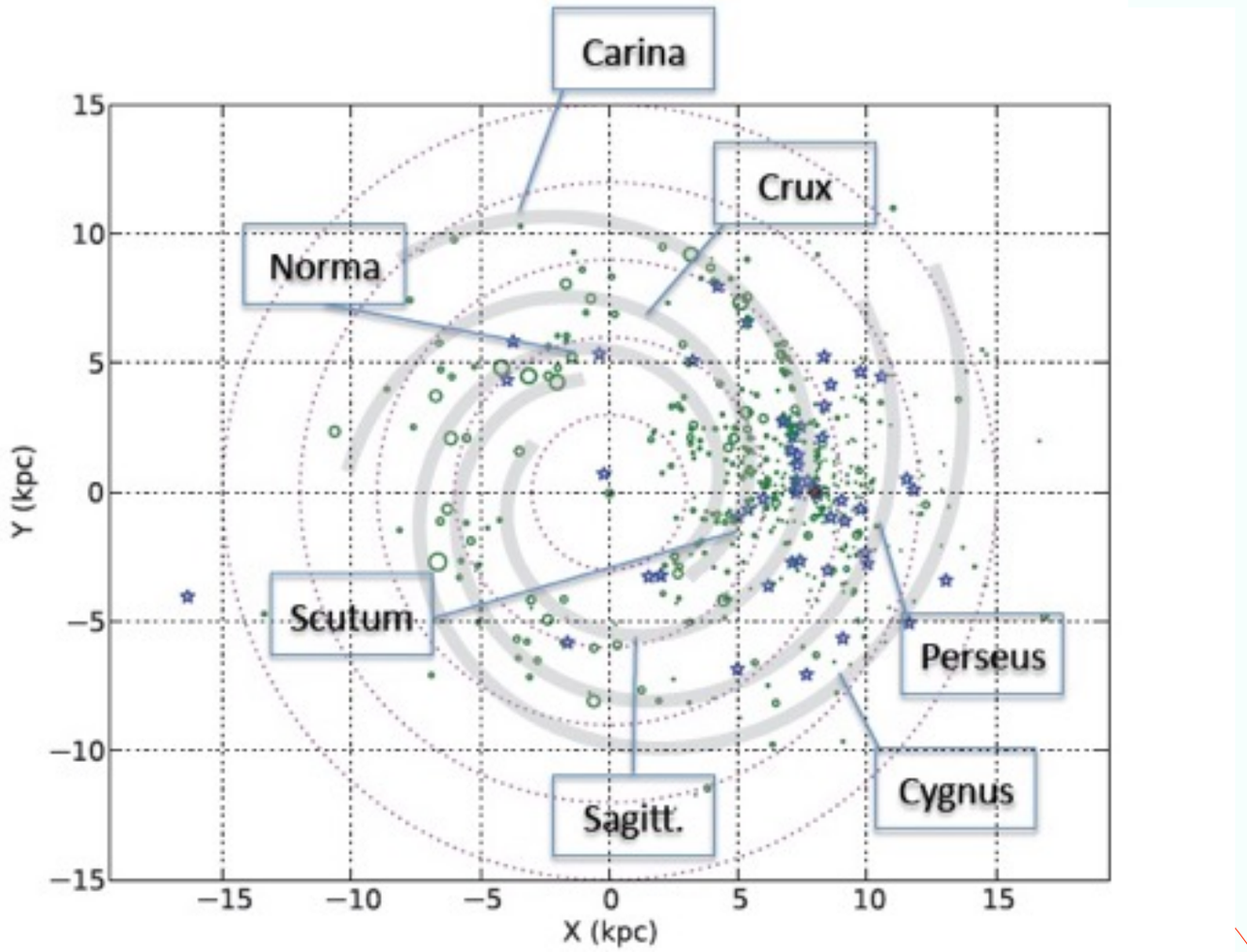
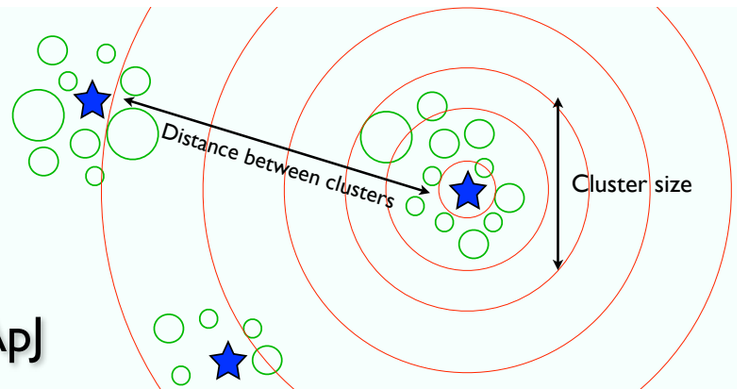
Galactic distribution of HMXB

- Fit (distance, A_v) of 46 HMXB on 4-spiral arm Galactic model
- HMXB clustered with Star Forming Complexes (Russeil 2003)
  - <size>=0.3 kpc
  - <distance>=1.7 kpc
- HMXB remain close to their birthplace!

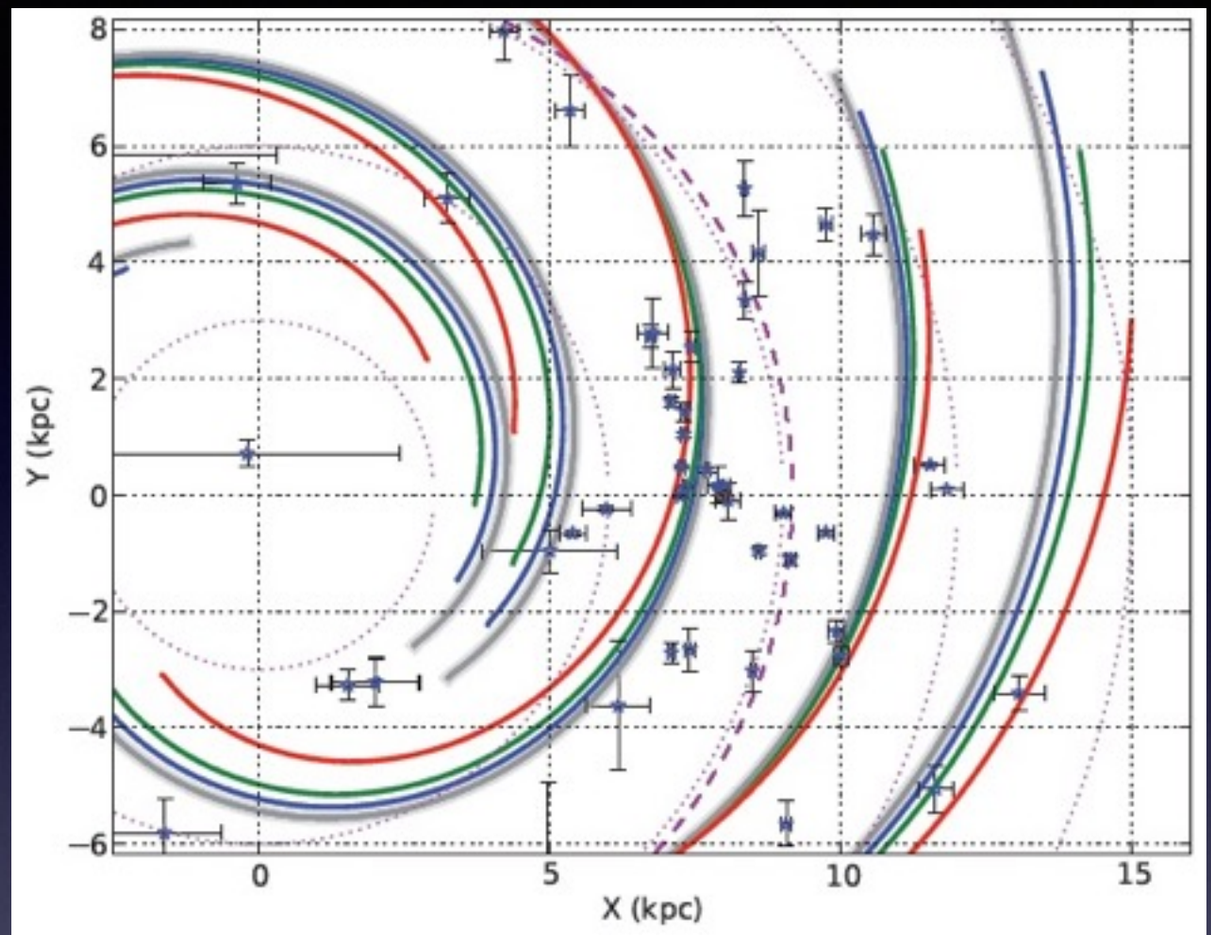




Coleiro & Chaty 2013, ApJ

Galactic distribution of HMXB

- Taking into account the Galactic arm rotation
- => HMXB distribution offset by ~10^7 yrs wrt spiral arms (delay between massive star birth & HMXB phase -10^5 yr-)
- => migration distance & kick (50-90 km/s)
- New stellar parameters available from Gaia!



SOURCE NAME	AGE (Myr)	MIGRATION DISTANCE (kpc)	UNCERTAINTY
		Be	
1A 0535+262	80	0.10	0.30
1A 1118-615	80	0.088	0.56
EXO 0331+530	60	0.25	0.080
GRO J1008-57	40	0.074	0.15
GX 304-1	40	0.048	0.59
H 1417-624	20	0.20	0.39
PSR B1259-63	60	0.037	0.51
RX J0440.9+4431	20	0.011	0.17
RX J1744.7-2713	60	0.10	1.0
		Supergiants	
4U 1700-377	80	0.15	0.28
IGR J16465-4507	20	0.087	0.052
IGR J18410-0535	60	0.013	0.11
H 1538-522	20	0.14	0.52

Coleiro & Chaty 2013, ApJ

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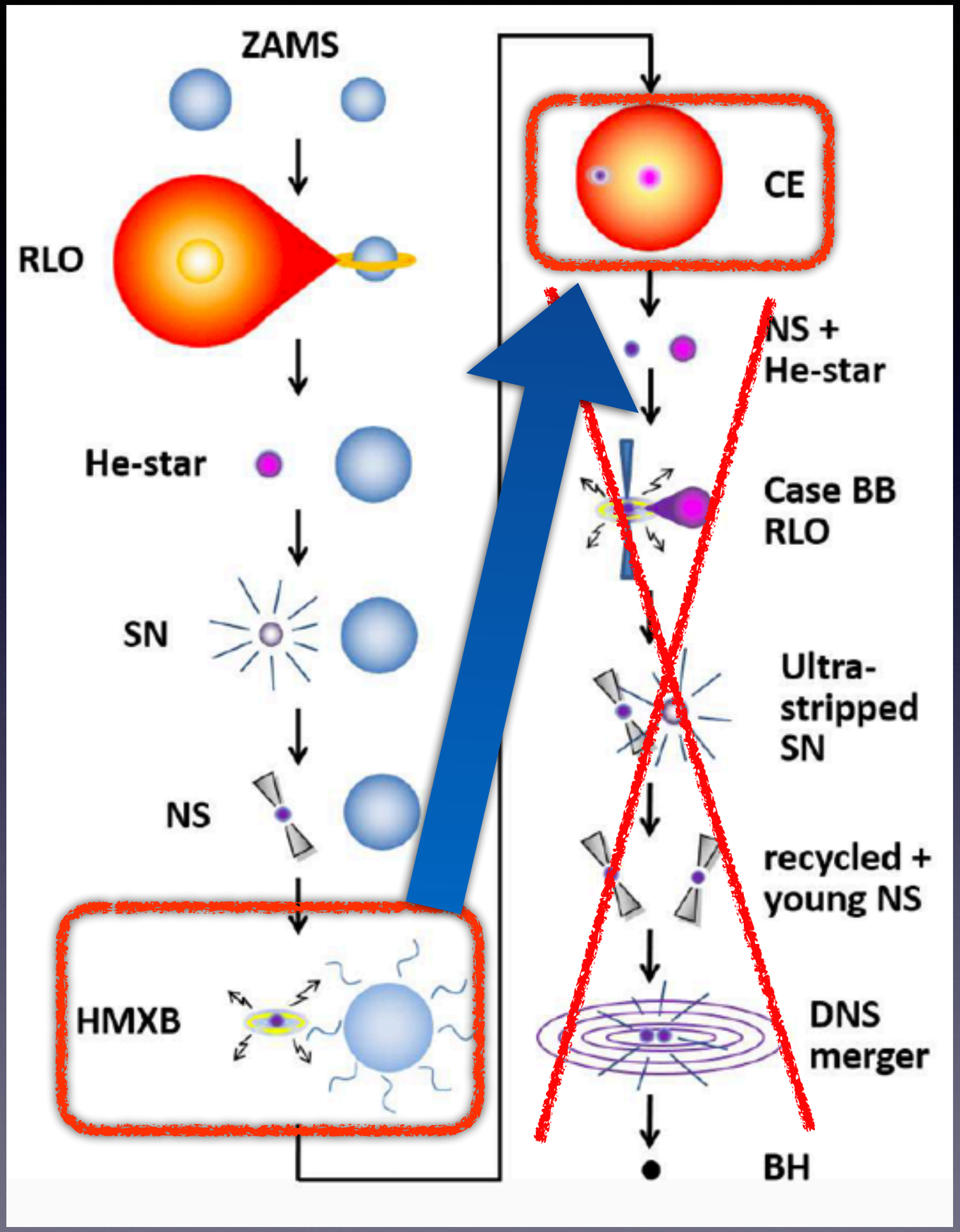
Evolution

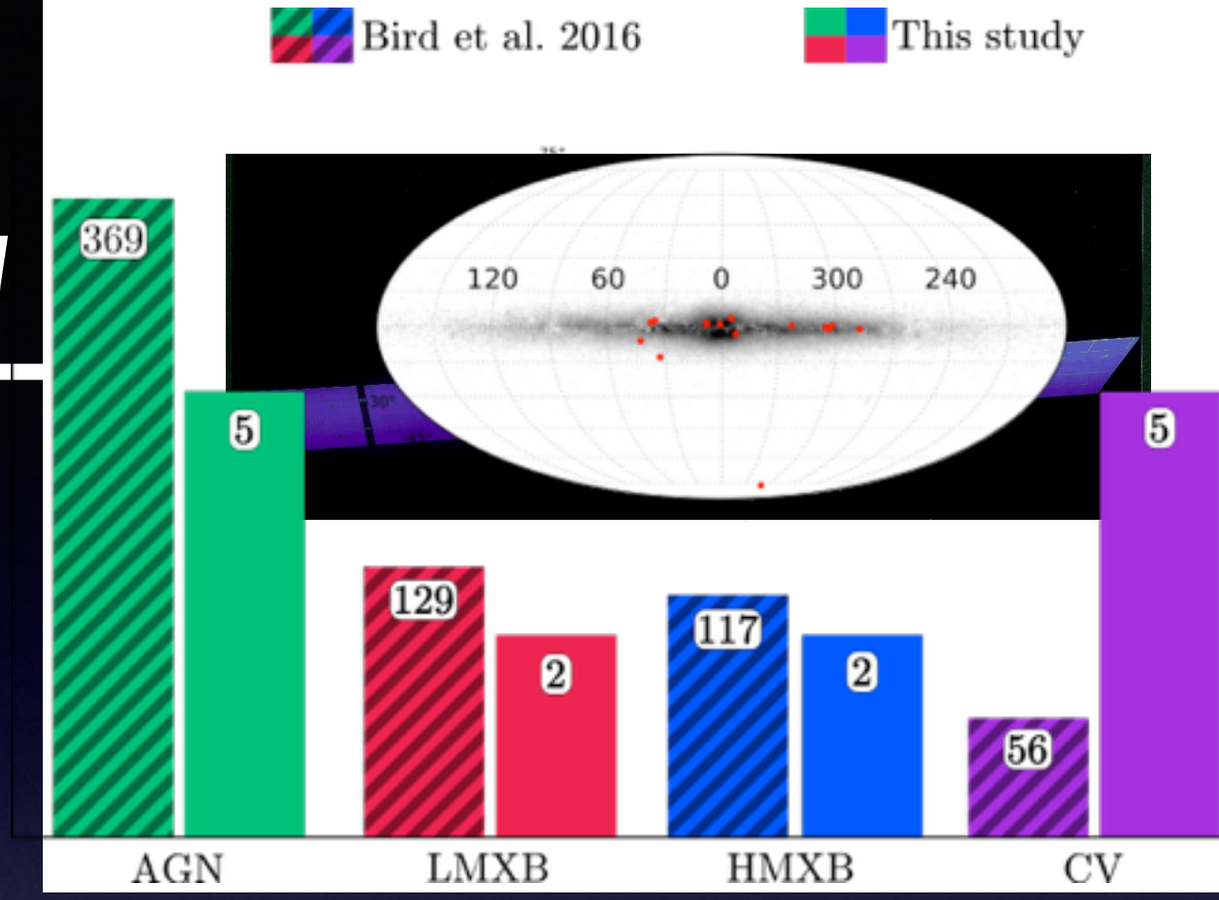
- « Classical isolated binary evolution »
- Long P_{orb} (>1yr) HMXB: Formation - RLO - 1st SN - HMXB - CE - 2nd SN -> double NS merging in BH
- Common Enveloppe Phase occurs **after HMXB!** (but before LMXB)
- Long P_{orb} HMXB will go through, survive CE, later merge
- But short P_{orb} HMXB will not go through, not survive CE! (Tauris +2017 ApJ)



Tauris+2017 ApJ

The *INTEGRAL* legacy (I)

- *INTEGRAL* (ESA satellite) quintupled the population of known sgHMXB (7-> 36)



Fortin+2017, see poster #24

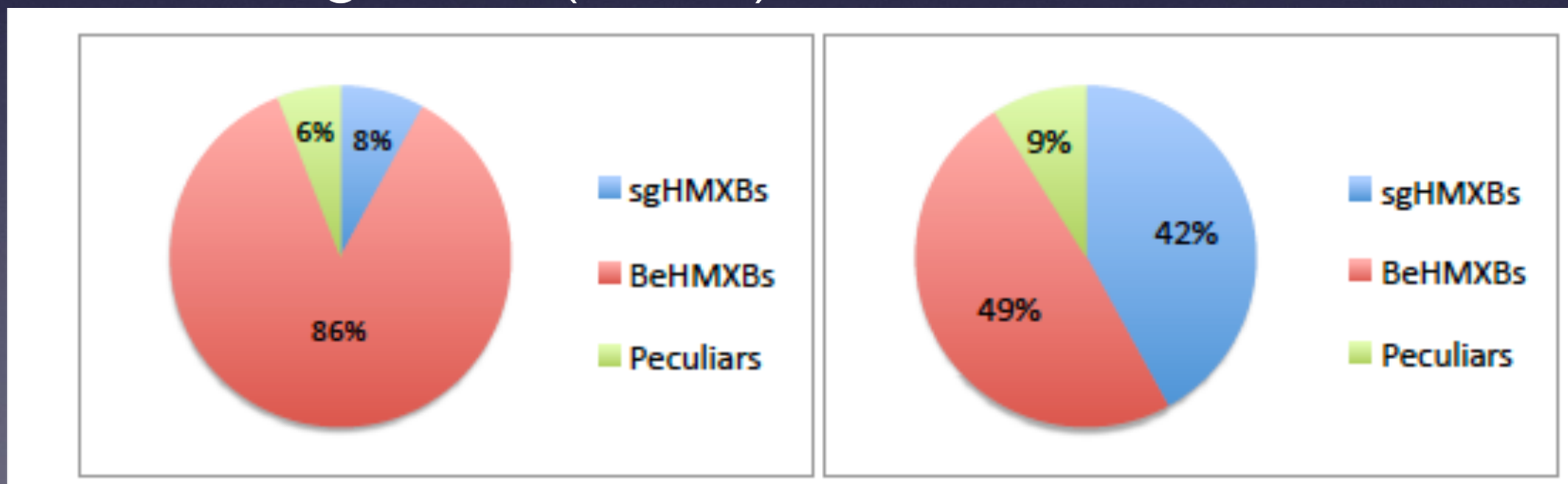


Fig. 8. *Left panel*: fraction (in percents) of confirmed (with spectral type) sgHMXB, BeHMXB and peculiar HMXB (such as B[e]HMXB) in Liu et al. (2000) catalog. *Right panel*: fraction (in percents) of confirmed (with spectral type) sgHMXB, BeHMXB and peculiar HMXB (such as B[e]HMXB) to date.

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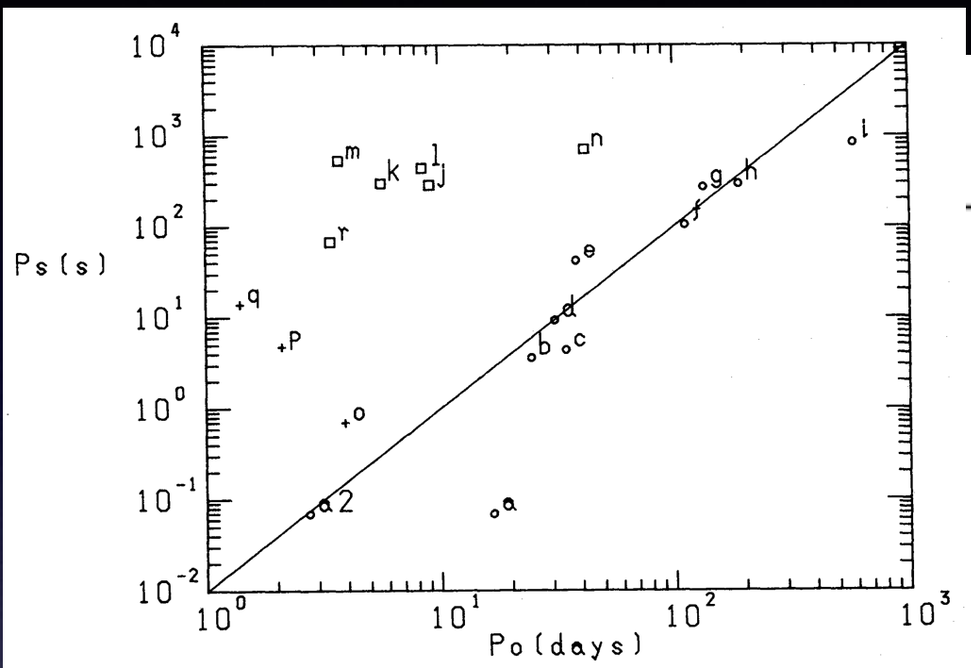
Coleiro+2013, Chaty 2013

The Corbet Diagramme revisited by *INTEGRAL*



Corbet 1986

NS-HMXB systems!

- Be: correlation NS $P_{spin} \propto (P_{orb})^2$
- Roche-lobe overflow
- sgXBs: no transfer of ang mom.

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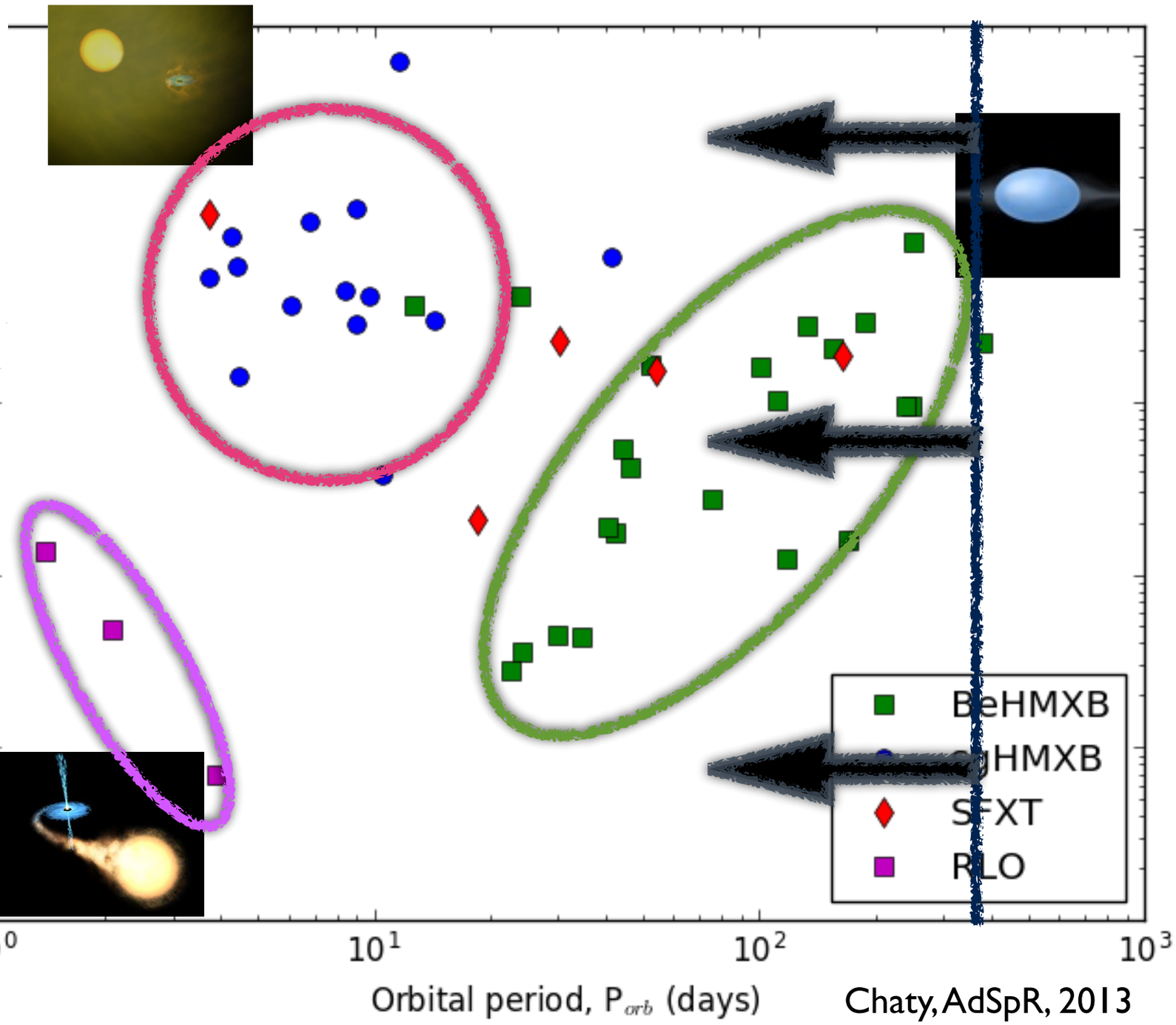
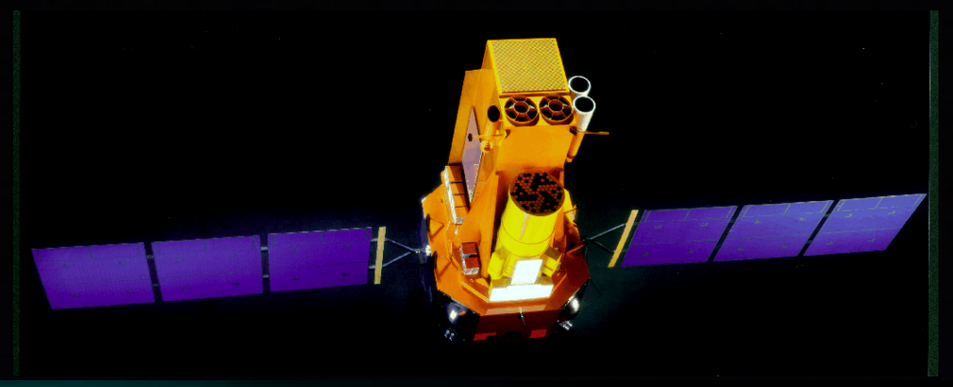
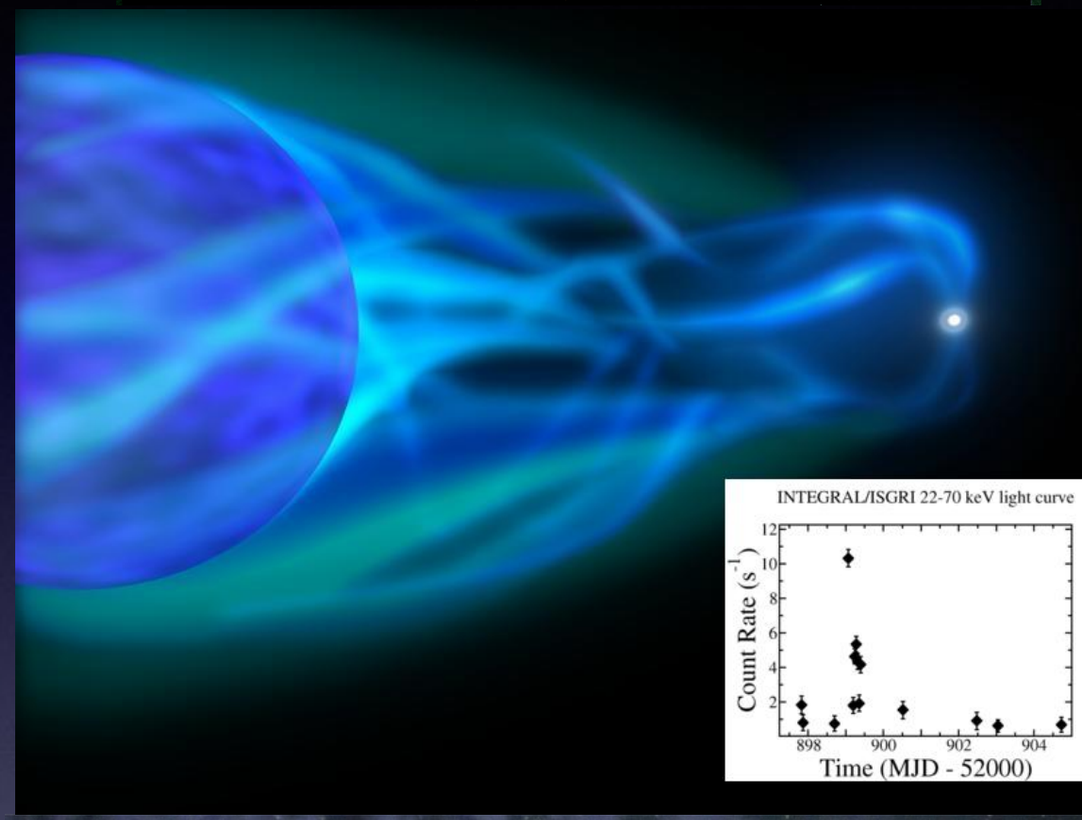


Chaty, AdSpR, 2013

The *INTEGRAL* legacy (II)





- *INTEGRAL* revealed 2 new categories:
  - Supergiant Fast X-ray Transients (SFXTs): fast and intense flares
  - Obscured (persistent) sgHMXBs: $N_H > 10^{23}$ cm^{-2}; short P_{orb} = 3.7-9.7d; $L_X = 10^{36}$ to 10^{38} erg/s; O8-B1 companions

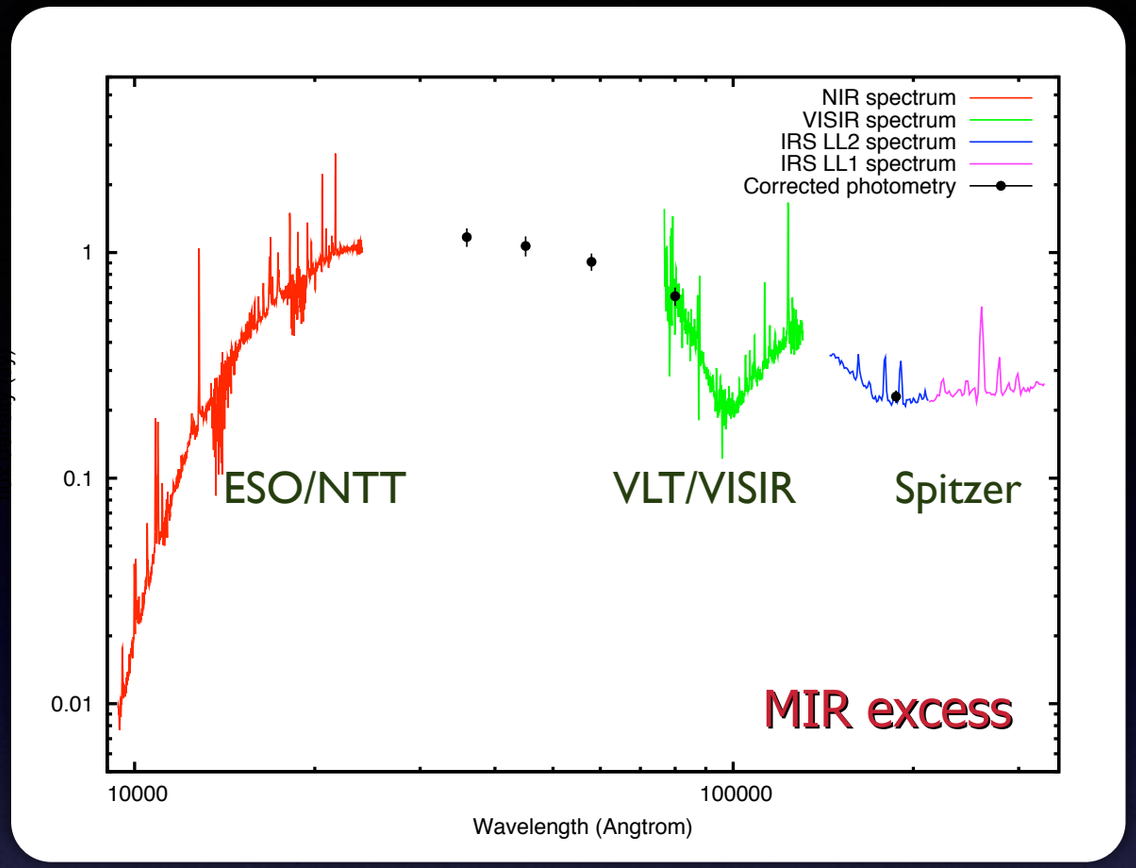
Chaty/ESA

Chaty 2013

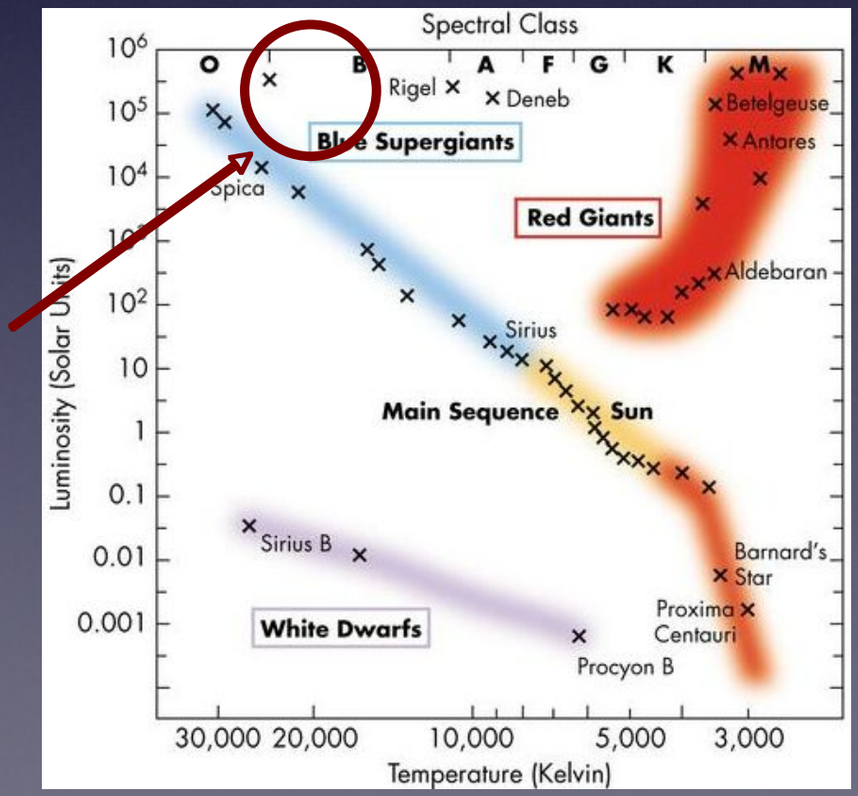
S. Chaty

Obscured sgHMXB:
IGR J16318-4848

- ESO/NTT-VLT+*Spitzer*+*Herschel* spectra: strong emission lines, MIR excess
  - Very absorbed: $N_H > 10^{24}$ cm^{-2}
  - Ionised (H/He) wind 400 km/s
  - Shocked [FeII] and dense (>$10^{5\text{-}6}$cm^{-3}) regions: NaI, Ne, Si…
- Luminous sgB[e] star with stratified circumstellar enveloppe:
  10^6 L☼, 30 M☼, 22 000 K, 20 R☼ = 0.1 au



Chaty & Rahoui 2012 ApJ



Filliatre & Chaty 2004 ApJ

Obscured sgHMXB:
IGR J16318-4848

- Herbig Ae/Be models: torus geometry (VLTI)
  - Disk rim: T = 5 500K, Thickness: ~0.7 R_*
  - Warm dust shell at 900 K, R_d = 12 R_*
- CO orbits within dense disk rim (P_{orb} 80d?)
- Evolution:
  - Binary system transiting to RLO -> deep spiral-in: pre-CE phase
  - If CO=NS : short P_{orb} HMXB will not survive CE
    => ideal Thorne-Zytkow candidate! (Tauris+2017 ApJ)
  - If CO=BH with q<3.5 : HMXB survives spiral-in => WR-XRB,
    P_{orb} ~days (van den Heuvel+2017)

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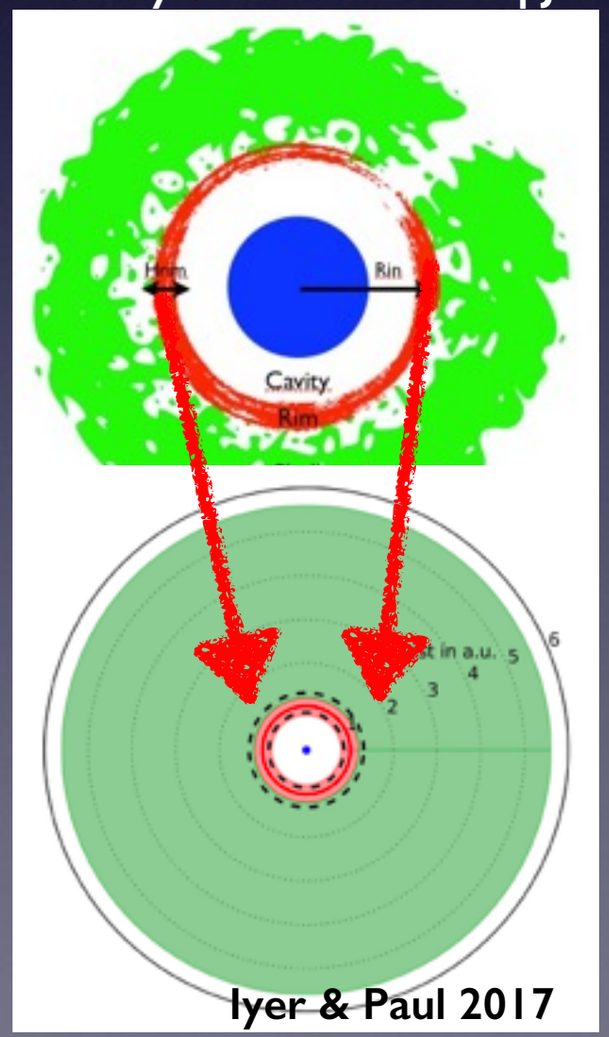
Chaty/ESA

Chaty & Rahoui 2012 ApJ

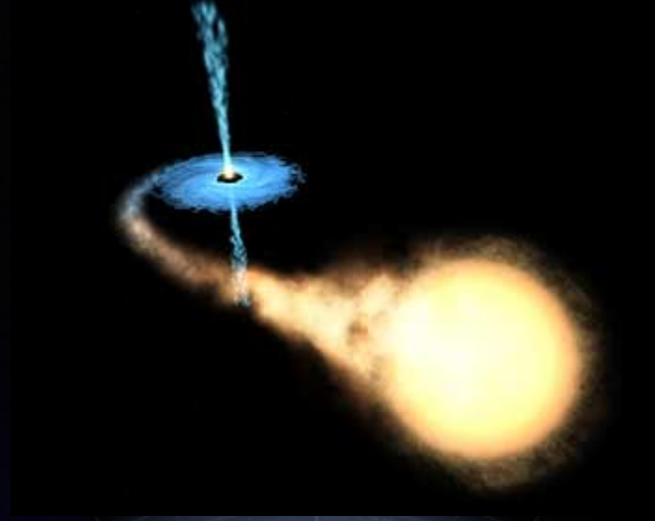


Iyer & Paul 2017

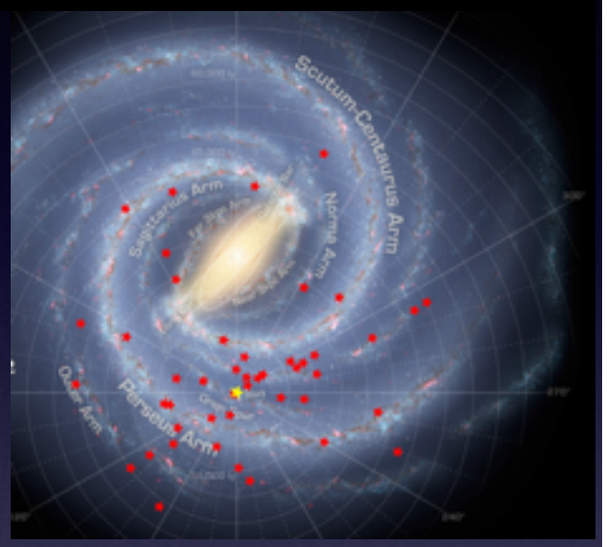
Statistics

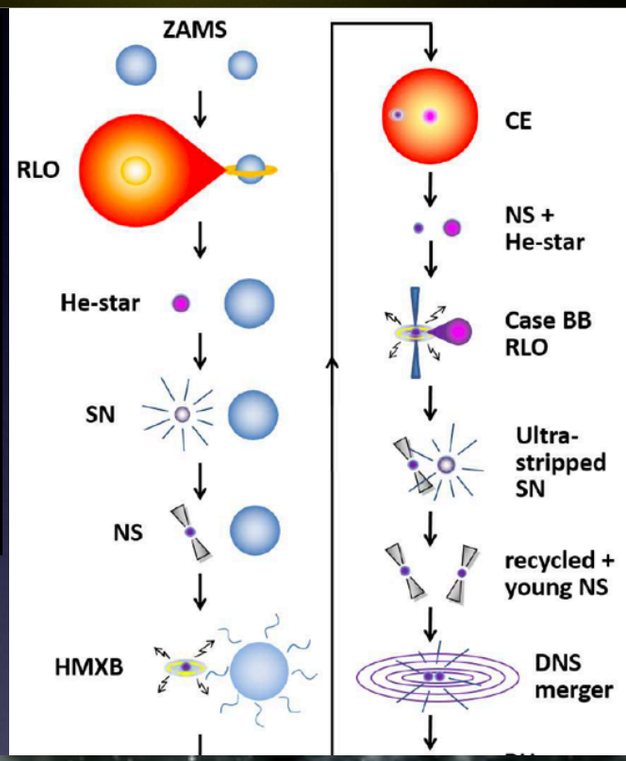
- ~20 000 O stars in Galaxy, 33% within double systems evolving through enveloppe stripping (Sana+2012)
- Assuming 50% of these systems (~1500) survive natal kicks (close orbits) and massive star last for ~10^7 yr
  => 1 HMXB forms every ~7000 yr, lasting for ~10^5 yr
- Short P_{orb} NS-HMXB will not survive CE -> TZ objects
- Short P_{orb} BH-HMXB will survive spiral-in -> WR-XRB, merge
- Long P_{orb} NS-HMXB -> DNS and merge after ~10^{10} yr

Conclusions



- Binaries: LMXB & HMXB
- Galactic distribution:
  HMXB correlated with SFC
  => age, migration, kick…





- The *INTEGRAL* revolution:
  quintupled the number of sgXB
- Evolution: HMXB are the best candidates for TZO or, if they survive the CE phase, DNS and merging