OUTLINE

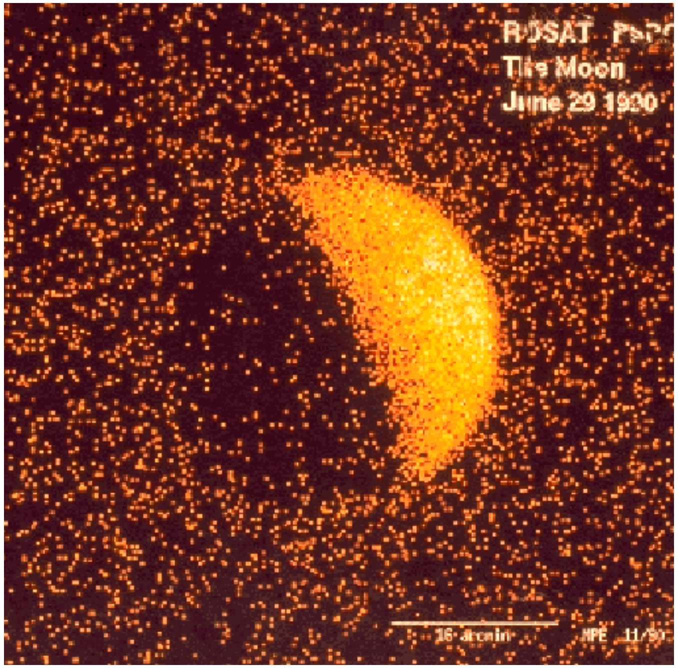
I. "INTRODUCTION TO XRB"

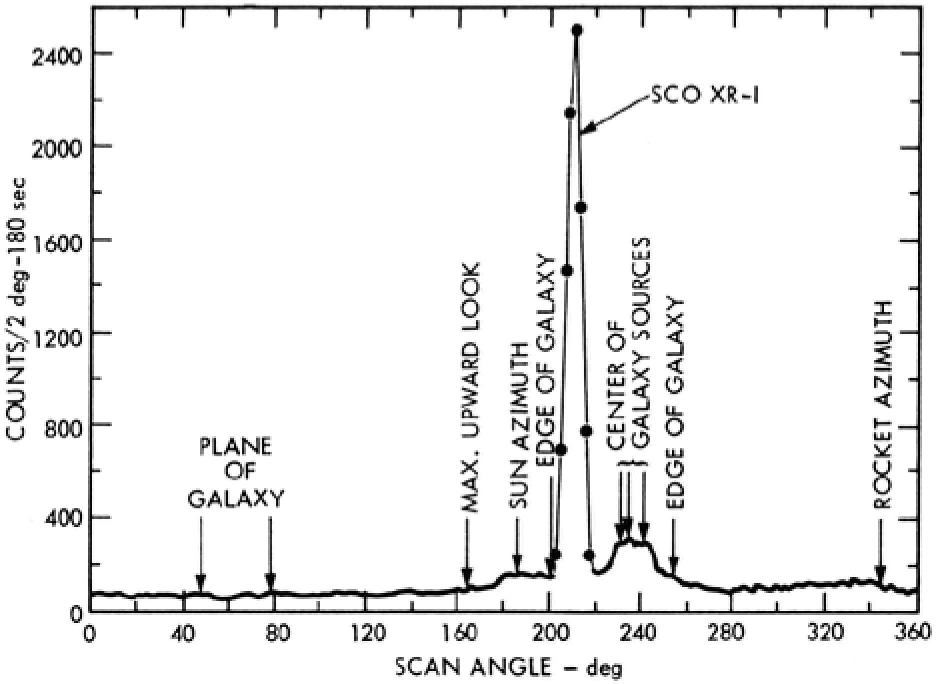
- Look at the moon and discover Sco - X1
- Binaries: emitting process?
- How does the flow go?
- Is there a surface?
- Birth and evolution
- Accretion, X-rays, ok. Are they always there? Spectra in detail?

II. LMXB (BH/NS): is there a logic in what we see?

III. LMXB NS: we try and propose one

Look at the moon and discover Sco - X1





Sco X-1, the first cosmic X-ray source (other than the Sun), discovered in 1962 by Giacconi

Optical: there are about one hundred stars visually brighter than Sco X-1.

X-rays: it dominates the sky. It degrades detectors!

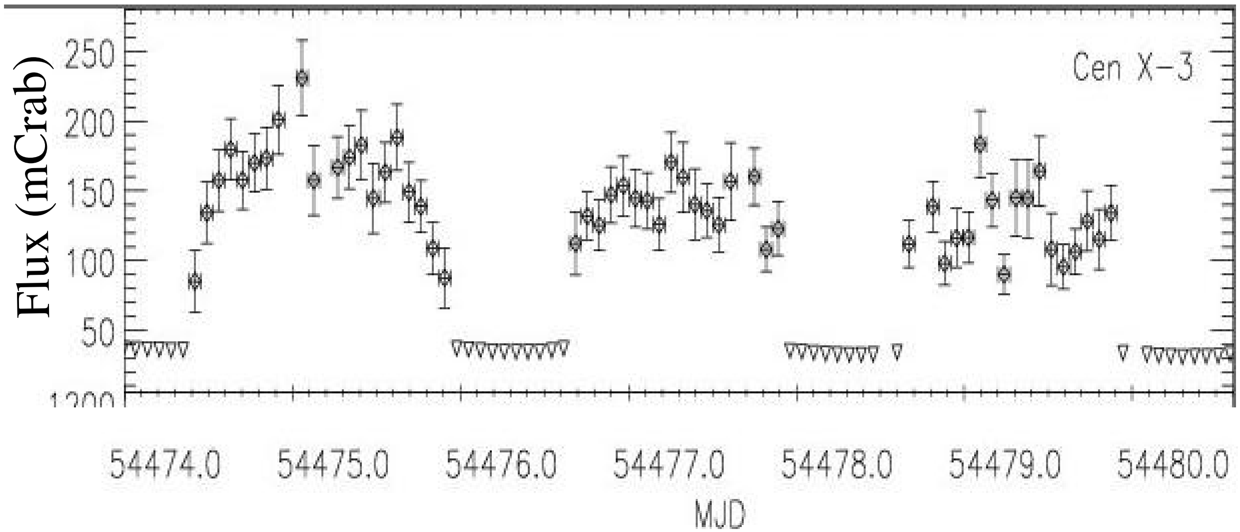
Image from "Exploring the X-ray Universe" (Charles & Seward)

Uhuru launched in 1970, over 300 discrete sources: Cen X-3

Giacconi et al 1971: pulsations!
Later Doppler shifts and eclipses (Schreirer et al. 1972)

Period: 2.09 d
Pulsation: 4.84 sec

Binary system in which the X-ray emitting object was a NS



(Feroci et al 2010)

BOX 1 – **Spin and size**

The centrifugal force must be less than force of gravity

$M v^2 / R = G M m / R^2$

$v = 2 \pi R / P$

$$R < (G M P^2 / 4 \pi^2)^{1/3}$$

P=1 sec
$M = 1 M_?$
R = 1500 km maximum size

WD: R=10 000 km
NS: R=10-15 km
[BH: $R_{sh} = 2 G M / c^2 \sim 3 (M / M_?)$ km]

(Close) binary system in which the X-ray emitting object was a NS

Binaries: emitting process?

1. Which mechanism releases energy?
2. Why in X-rays ?

1. ACCRETION: release of gravitational energy of mass *m* onto M

Particle mass *m*, at distance R from star of M, maximum energy that can be extracted is $E = m c^2$;

$$L_{acc} = G M M_{dot} / R$$ rate at which grav. en. is released

$L = \eta\ M_{dot} c^2$ (erg / sec) $(\eta = G M / R c^2)$

~ 0.1 NS
~ 0.06 – 0.42 BH
~ 0.001 WD
~ 10^{-6} Sun!

NS: $10^{-8}\ M_{?}\ yr^{-1} \rightarrow L \sim 10^{38}$ erg/sec

2. Why in X-rays? T_{rad} = ?

For an accretion luminosity L from a source of radius R we define
T_b as the T the source would have if it were to radiate the power as BB

$$T_b = (L / 4 \pi R^2 \sigma)^{1/4}$$

T_{th} temperature the matter would have if its gravitational potential energy were turned entirely in thermal energy

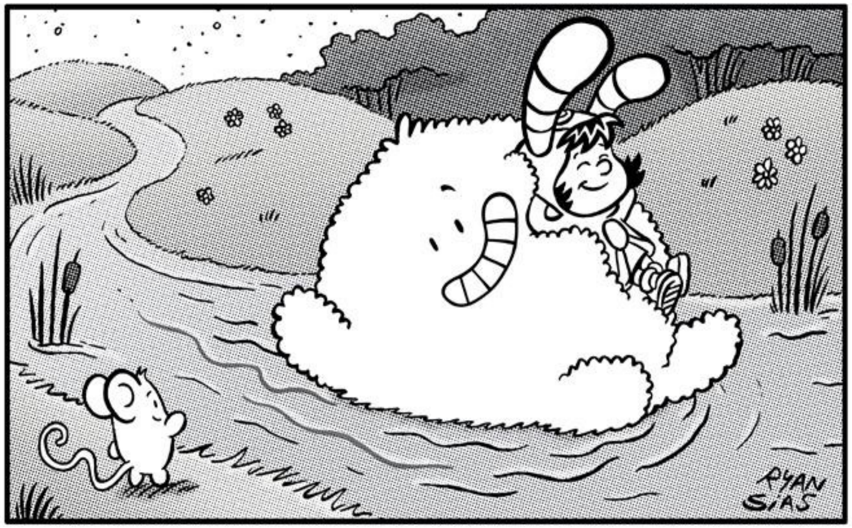
$$T_{th} = G M m_p / 3k R$$

- If the accretion flow is optically thick $T_{rad} \sim T_b$
- If opt. thin, the accretion energy is converted into rad $T_{rad} \sim T_{th}$

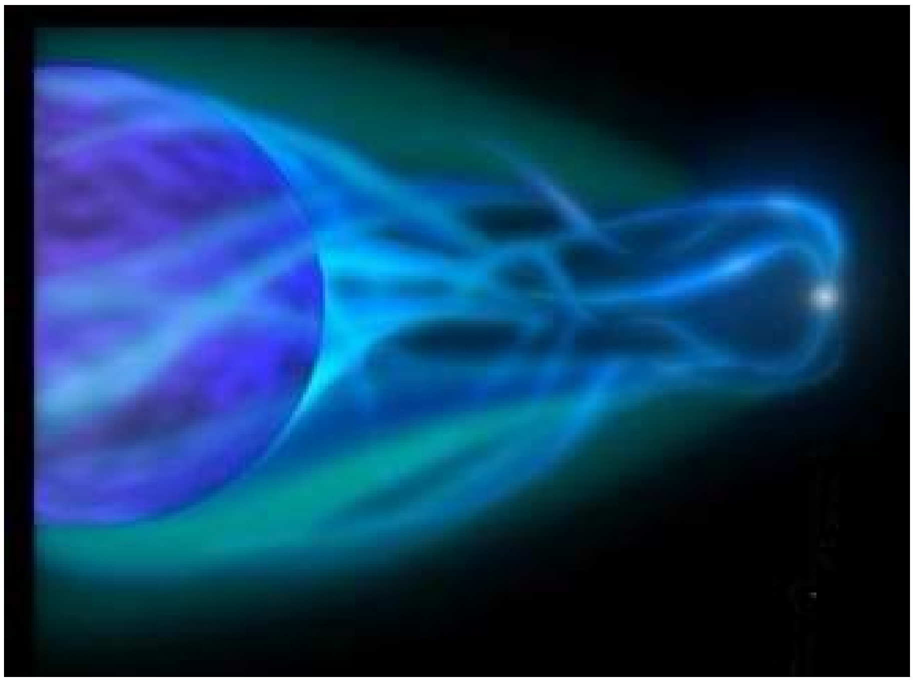
$$\mathbf{T_b \leq T_{rad} \leq T_{th}} \; ; \quad \text{(°°see you later°°)}$$

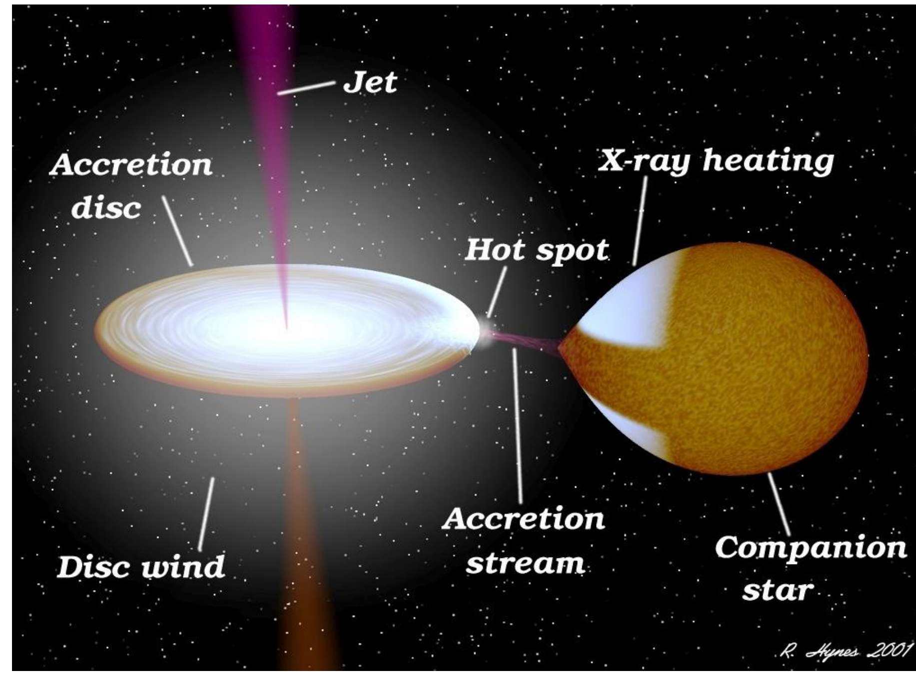
NS(10^36 erg/sec) : $1 \text{ keV} \leq E \leq 50 \text{ MeV}$; WD(10^33 erg/sec) : $6 \text{ eV} \leq E \leq 100 \text{ keV}$

How does the flow go?



It depends on the companion!





HMXB: young

$M \sim> 10\ M_?$

OB star wind!

LMXB: old

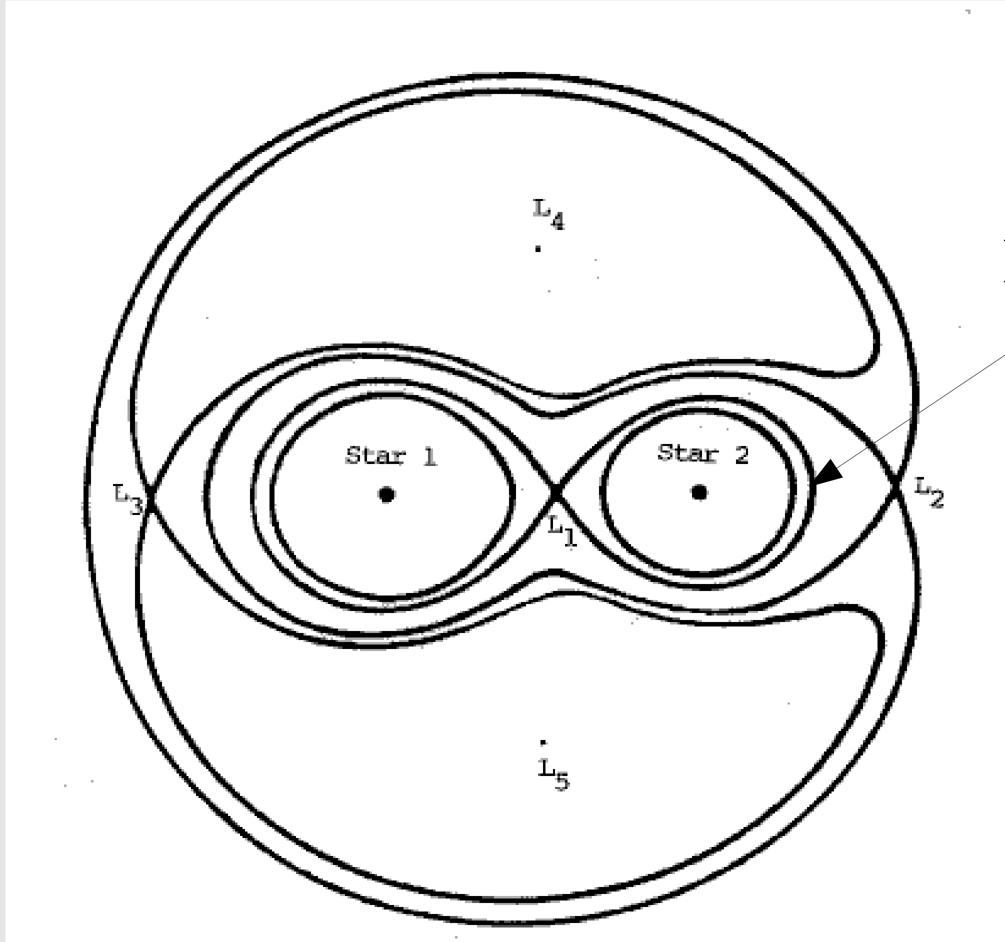
$M \sim< 1M_?$

late type KM: no wind

BOX 2

Equipotential surfaces

Five points where the forces cancel out: Lagrangian points.

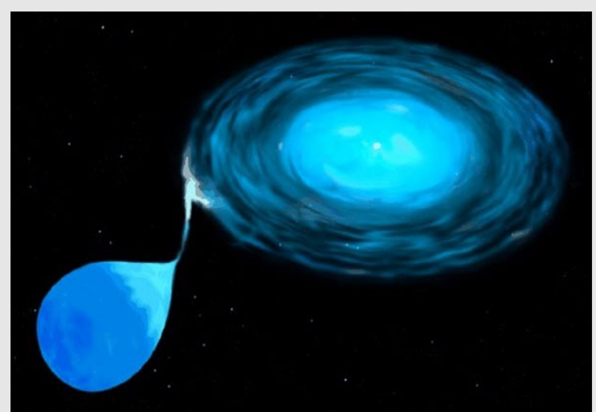


Roche Lobe

The **transfer of matter** is subject to the combined gravitational potential of the pair of stars.

Equipotential surfaces and Lagrangian points in a close binary system

Once matter crosses, it forms a disk



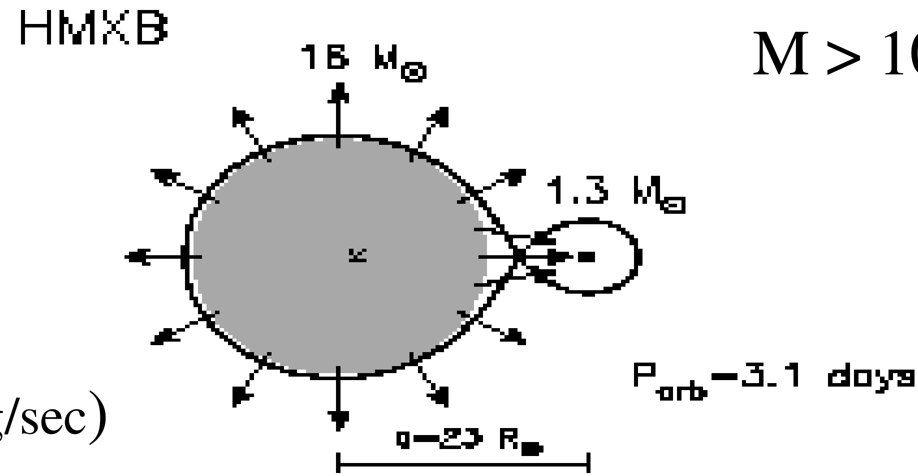
HMXB: wind accretion

(accretion disc)

$M^{w}_{dot} \sim 10^{-6} M_{?} yr^{-1}$

But $M_{dot} \; \alpha \; M^{w}_{dot} / V_{w}^{4}$

$\sim 10^{-11 -10} \; M_{?} yr^{-1}$ ($L \sim 10^{35\ 36}$ erg/sec)



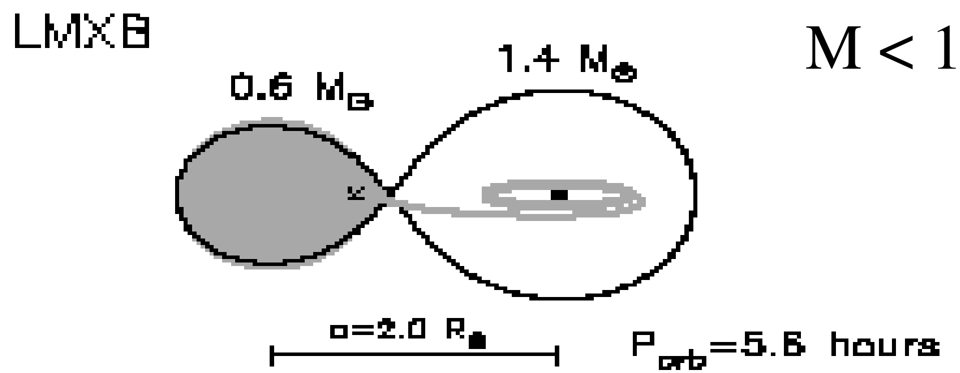
$M > 10 \; M_{?}$

LMXB: accretion disc

$M_{dot} \sim 10^{-11 -8} \; M_{?} yr^{-1}$

($L \sim 10^{35\ 38}$ erg/sec)

(!! spin up NS !!)



Tauris and van den Heuvel 2003

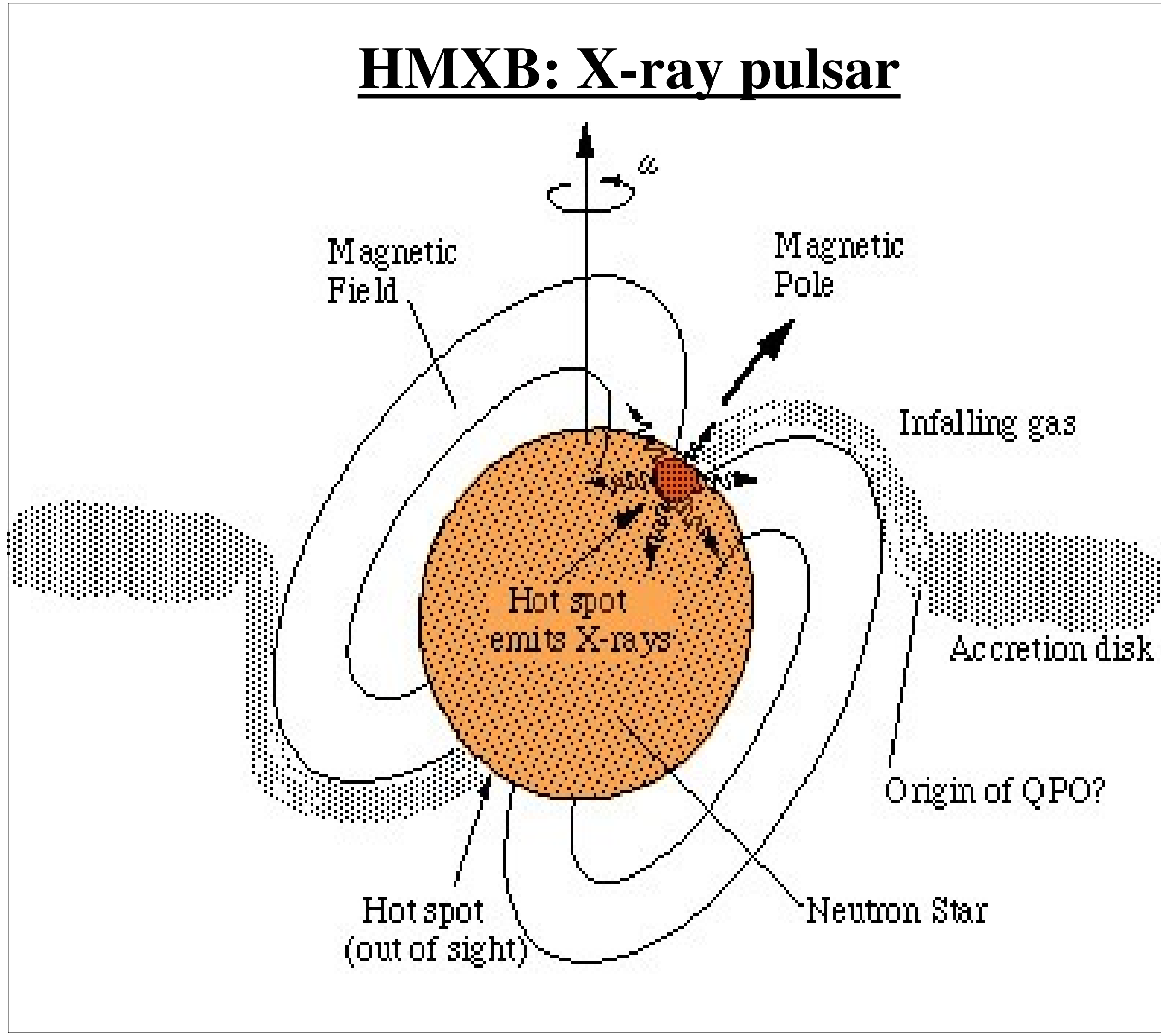
$M < 1 \; M_{?}$

What about IMXBs $1 \; M_{?} < M < 10 \; M_{?}$?? Not stable !

SUMMARY BOX 1

- Interacting to get emission
- Accretion
- X – γ rays

HMXB	LMXB
OB	K,M
Young	**Old**
Wind	Disk



Also the compact object is: Young – Old! Impact on magnetic field (10^{12} G for HM vs 10^{9} G for LM)!

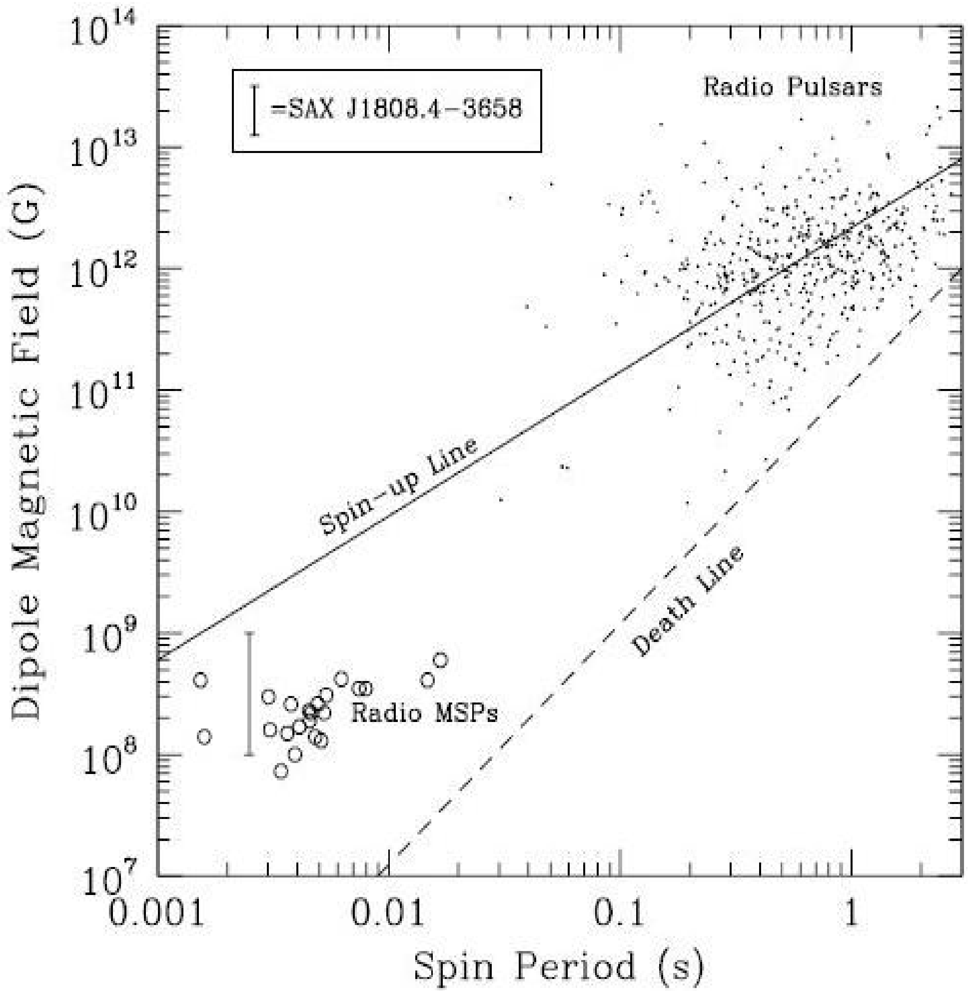
So, if I see a pulsation it's a HMXB. Excellent!

NO

- GX 1+4 (LMXB): P= 114 sec (Liu et al 2007). Magnetic field wins over M_{dot}?

- Not only: accretion powered msec pulsars (AMPs in LMXBs)!

13 sources known today (Riggio et al., 2011) with period as short as 1.6 msec!



(Psaltis & Chakrabarty 1999)

Accretion powered msec in LMXBs as progenitors of the radio MSPs! (?)

- Accretion via disc spins-up NS
- Donor mass falls, no transfer, LMXB switches off

Is there a surface?

One thing is certain: if X-ray pulsar or msec pulsar → NS!

Any other way to SEE THE SURFACE?

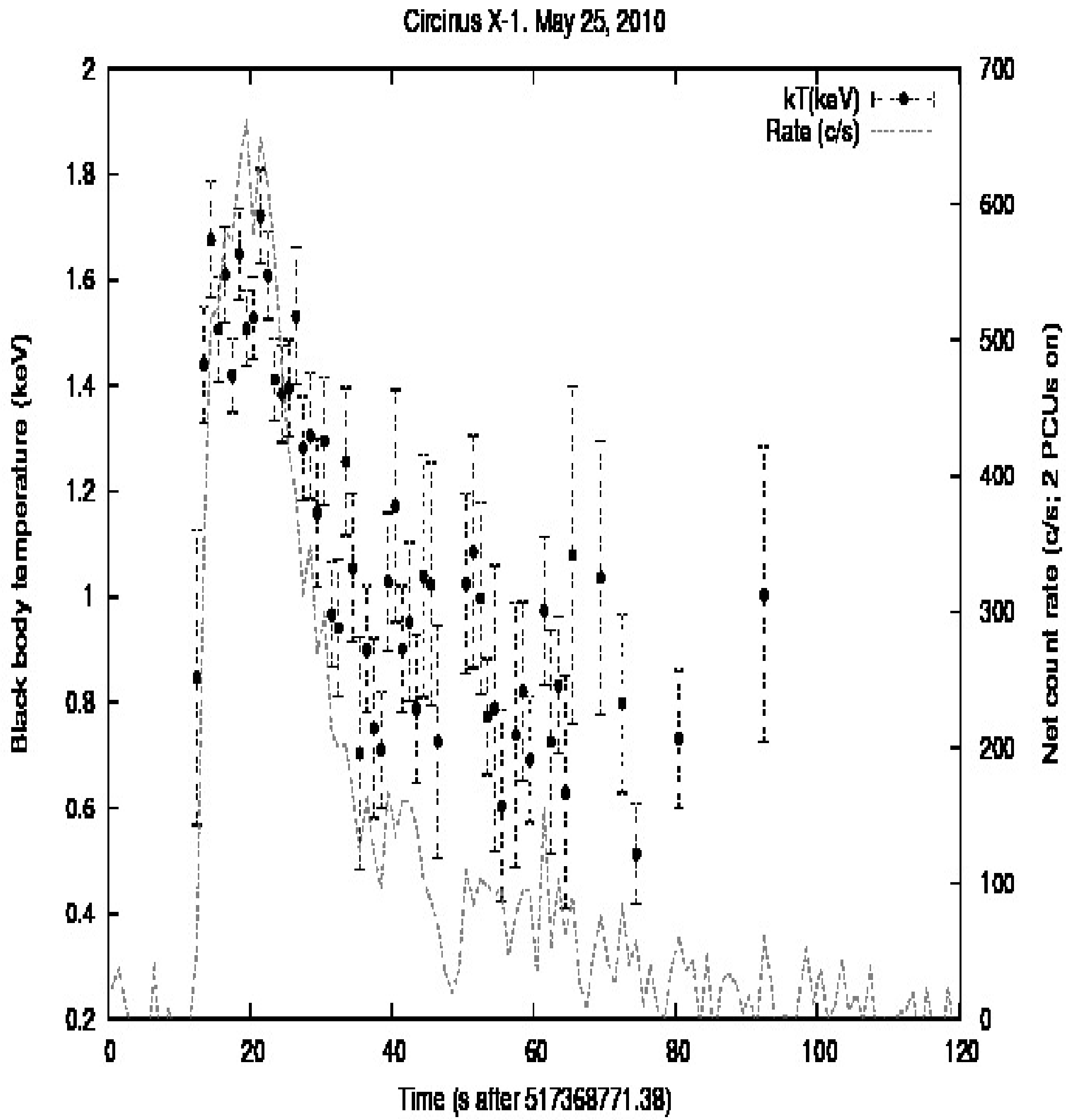
YES!

X-ray bursts

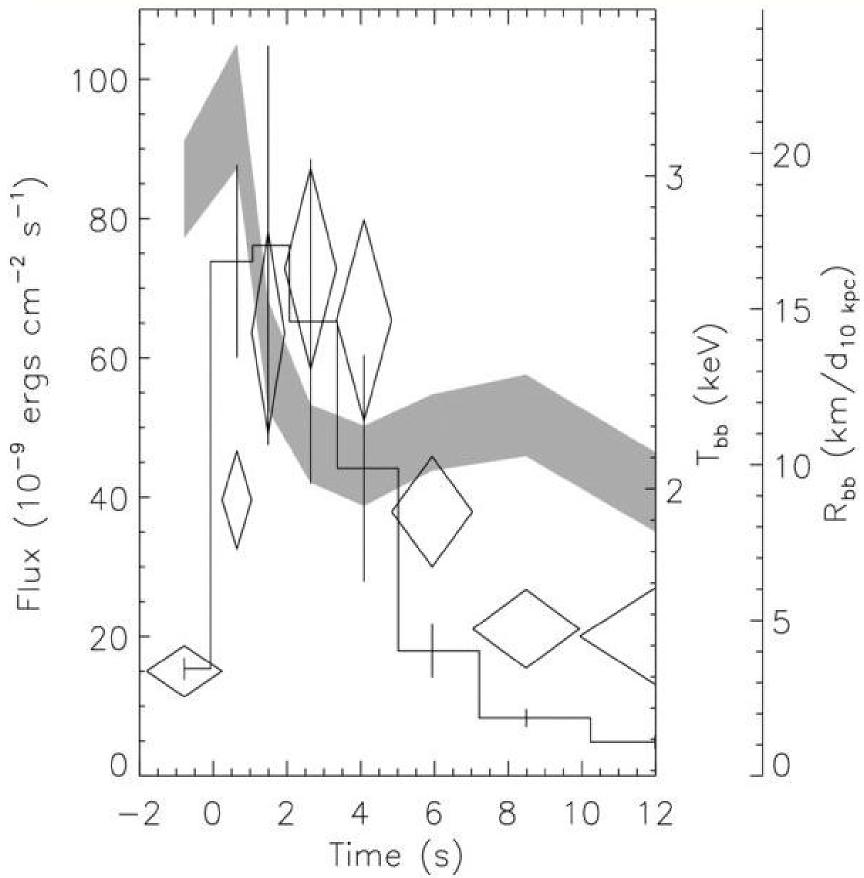
- Type I: thermo-nuclear flashes in the surface layers of accreting NS, powered by nuclear energy (unstable burning, ~10 m, 10^8 gr cm^{-2} : ~80/190 LMXBs). Most on a persistent continuum but a few burst-only sources (Campana 2009)

- Type II: disc instability, powered by gravitational energy (2 sources)

(Linares et al 2010)



4U 1728–34



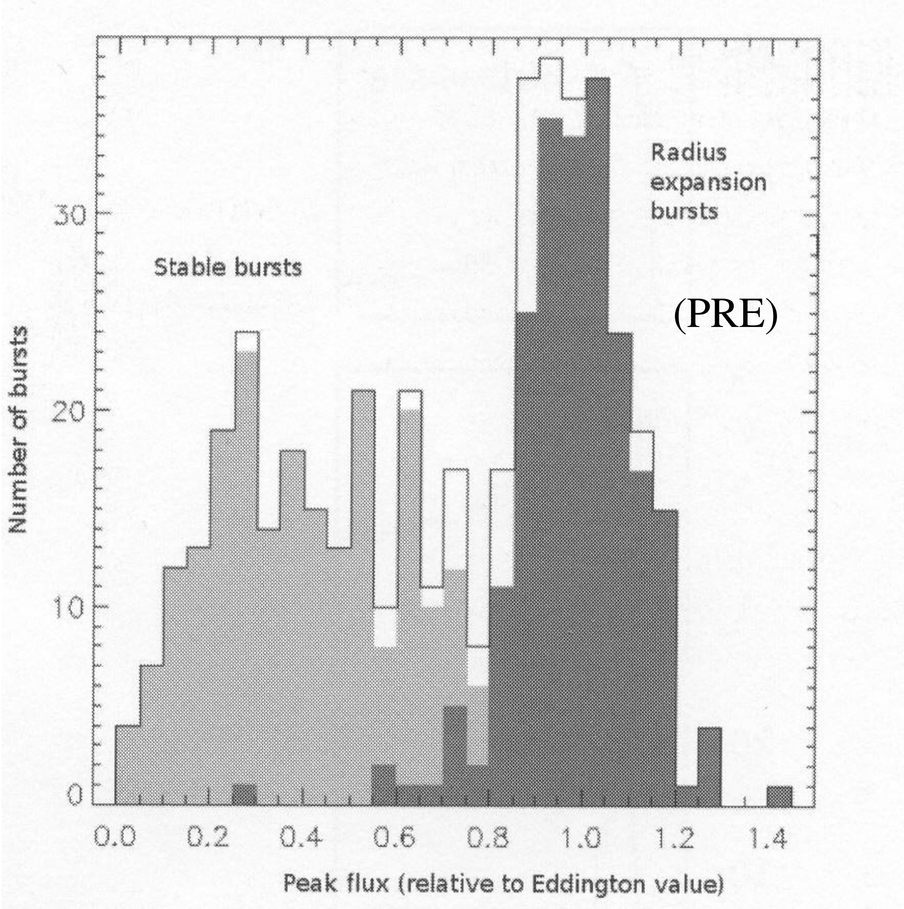
(Galloway et al., 2010)

NS surface cools down:

$$4 \pi d^2 F_x = 4 \pi R^2 \sigma T^4$$

For a known *d* a radius equal to ~10 km is obtained NS (disc is to rare) … … but not always constant!

(Galloway et al., 2003)



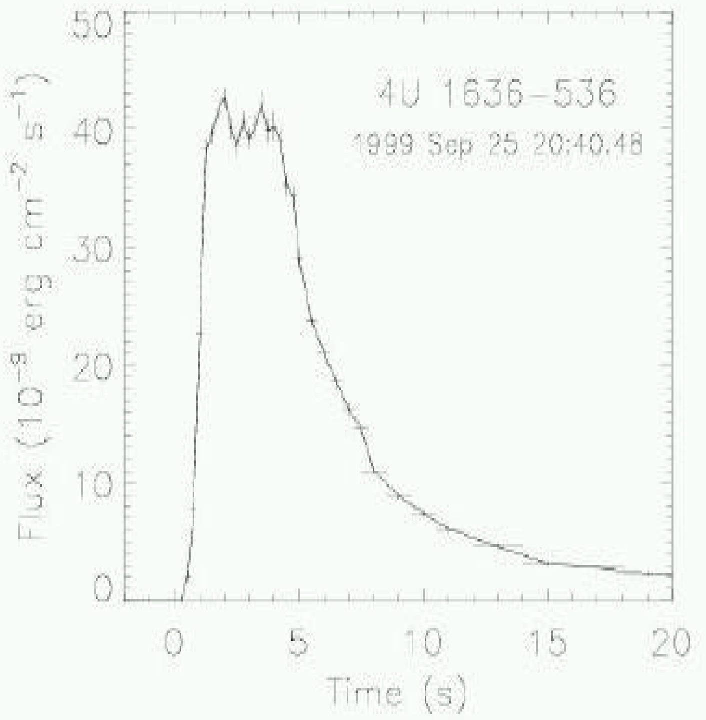


Fig. 1.20. A typical Type I X-ray burst from the neutron-star source 4U 1636−36. The flat top of the burst lightcurve is characteristic of Eddington-limited (or radius-expansion) bursts (courtesy D. Galloway).

You can't accrete EVERYTHING! There is a luminosity at which radiation pressure stops accretion:

$$L^{H}_{Edd} \sim 1.3\ 10^{38}\ (M / M_?)\ \text{erg / sec}\ ;\ \ M^{dot}_{Edd} \sim 1.5\ 10^{-8}\ M_?/\ \text{yr}\ ;$$

$$[L^{He}_{Edd} \sim 2\ L^{H}_{Edd}\ ]$$

We saw:

- ✓ msec X-ray pulsations (AMP)
- ✓ type I bursts (10 km and more...whole NS)

Also the combination of the two has been detected: burst oscillations!

Some (a dozen) type I X-ray bursts produce a hot spot and before it spreads to the whole surface a periodicity has been detected. Is it the NS spin?

AMP SAX J1808.4-3658 showed burst oscillations at the NS spin period (Chakrabarty et al 2003)!

OK, so it is reasonable to think that NS are always spinning but you need certain conditions to see them (X-ray pulsar, AMP, type I or II bursts).

WHAT IF NOTHING IS THERE? NS or BH?

How to be sure there is a BH? Gravitational potential for NS and BH are similar...

- If you see the surface you know it is a NS (pulsations, bursts, oscillations)

- If the mass of the C.O is > 3 M_o then it is believed to be a BH

$$f(M) = M^3_{opt} \sin^3 i \; / \; (M_x + M_{opt})^2 \quad \underline{\alpha} \quad K^3_x \, P$$

K_x is the observed radial velocity amplitude (km/s)

P orbital period (days)

Table 1: Twenty confirmed black holes and twenty black hole candidates[a]

Coordinate Name	Common[b] Name/Prefix	Year[c]	Spec.	P_{orb} (hr)	f(M) ($M_\odot$)	M_1 ($M_\odot$)
0422+32	(GRO J)	1992/1	M2V	5.1	1.19±0.02	3.7–5.0
0538–641	LMC X–3	–	B3V	40.9	2.3±0.3	5.9–9.2
0540–697	LMC X–1	–	O7III	93.8[d]	0.13±0.05[d]	4.0–10.0:[e]
0620–003	(A)	1975/1[f]	K4V	7.8	2.72±0.06	8.7–12.9
1009–45	(GRS)	1993/1	K7/M0V	6.8	3.17±0.12	3.6–4.7:[e]
1118+480	(XTE J)	2000/2	K5/M0V	4.1	6.1±0.3	6.5–7.2
1124–684	Nova Mus 91	1991/1	K3/K5V	10.4	3.01±0.15	6.5–8.2
1354–64[g]	(GS)	1987/2	GIV	61.1[g]	5.75±0.30	–
1543–475	(4U)	1971/4	A2V	26.8	0.25±0.01	8.4–10.4
1550–564	(XTE J)	1998/5	G8/K8IV	37.0	6.86±0.71	8.4–10.8
1650–500[h]	(XTE J)	2001/1	K4V	7.7	2.73±0.56	–
1655–40	(GRO J)	1994/3	F3/F5IV	62.9	2.73±0.09	6.0–6.6
1659–487	GX 339–4	1972/10[i]	–	42.1[j,k]	5.8±0.5	–
1705–250	Nova Oph 77	1977/1	K3/7V	12.5	4.86±0.13	5.6–8.3
1819.3–2525	V4641 Sgr	1999/4	B9III	67.6	3.13±0.13	6.8–7.4
1859+226	(XTE J)	1999/1	–	9.2:[e]	7.4±1.1:[e]	7.6–12.0:[e]
1915+105	(GRS)	1992/Q[l]	K/MIII	804.0	9.5±3.0	10.0–18.0
1956+350	Cyg X–1	–	O9.7Iab	134.4	0.244±0.005	6.8–13.3
2000+251	(GS)	1988/1	K3/K7V	8.3	5.01±0.12	7.1–7.8
2023+338	V404 Cyg	1989/1[f]	K0III	155.3	6.08±0.06	10.1–13.4
1524–617	(A)	1974/2	–	–	–	–
1630–472	(4U)	1971/15	–	–	–	–
1711.6–3808	(SAX J)	2001/1	–	–	–	–
1716–249	(GRS)	1993/1	–	14.9	–	–
1720–318	(XTE J)	2002/1	–	–	–	–
1730–312	(KS)	1994/1	–	–	–	–
1737–31	(GRS)	1997/1	–	–	–	–
1739–278	(GRS)	1996/1	–	–	–	–
1740.7–2942	(1E)	–	–	–	–	–
1743–322	(H)	1977/4	–	–	–	–
1742–289	(A)	1975/1	–	–	–	–
1746–331	(SLX)	1990/2	–	–	–	–
1748–288	(XTE J)	1998/1	–	–	–	–
1755–324	(XTE J)	1997/1	–	–	–	–
1755–338	(4U)	1971/Q[l]	–	4.5	–	–
1758–258	(GRS)	1990/Q[l]	–	–	–	–
1846–031	(EXO)	1985/1	–	–	–	–
1908+094	(XTE J)	2002/1	–	–	–	–
1957+115	(4U)	–	–	9.3	–	–
2012+381	(XTE J)	1998/1	–	–	–	–

[a]See McClintock & Remillard (2006; and references therein) for columns 3–5, Orosz (2003) for columns 6–7, plus additional references given below.

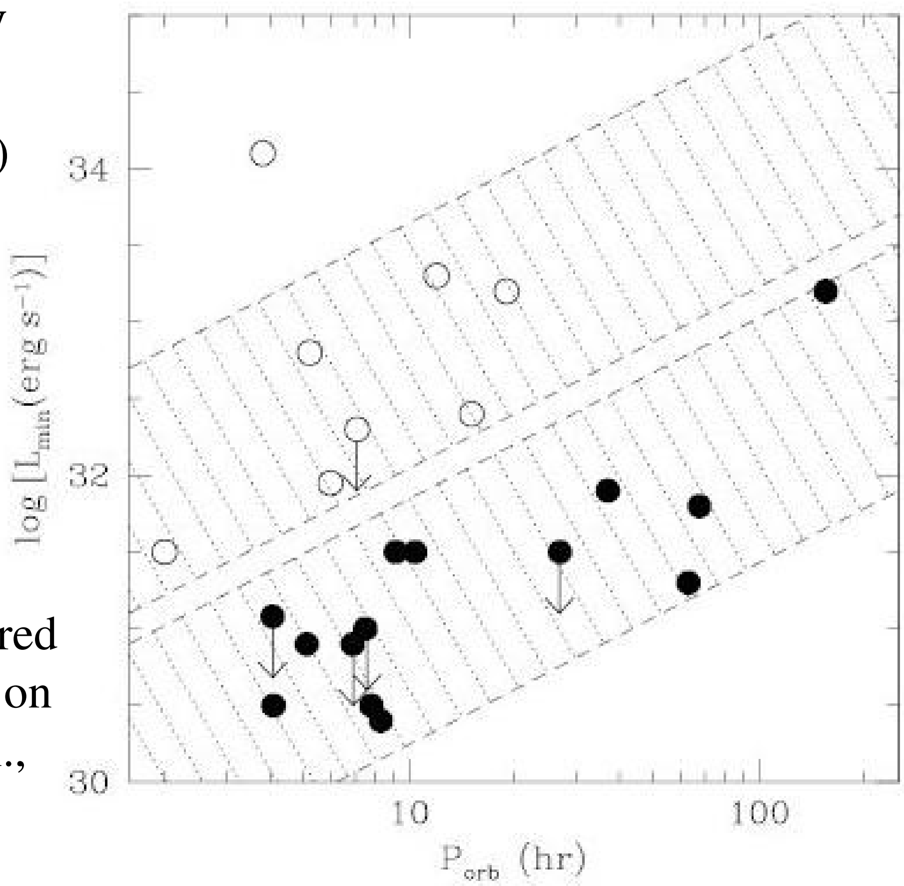
If none of this is possible?

Look for similar properties to KNOWN BH like timing or spectral but

1. NS end up doing most of it :-(
2. BH are an amazing zoo

Quiescent luminosity

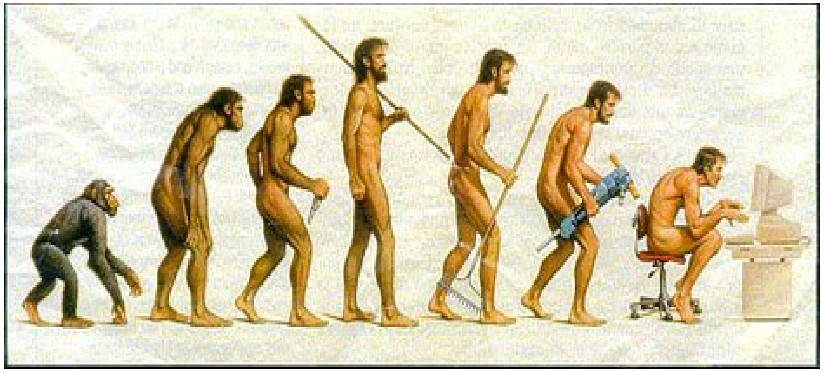
(Narayan & McClintock 2008)



Observed NS cooling rate compared to theoretical cooling curve hints on stellar constituents! (Cackett et al., 2008)

Luminosities (0.5–10 keV) of BH transients (filled circles) and NS transients (open circles) versus the orbital period.

Birth and evolution



How many??

Our Galaxy has $\sim 10^{11}$ stars and about half are in binary systems.

The number of XRBs is "slightly" lower

HMXBs (Liu et al 2006, 2005): 242

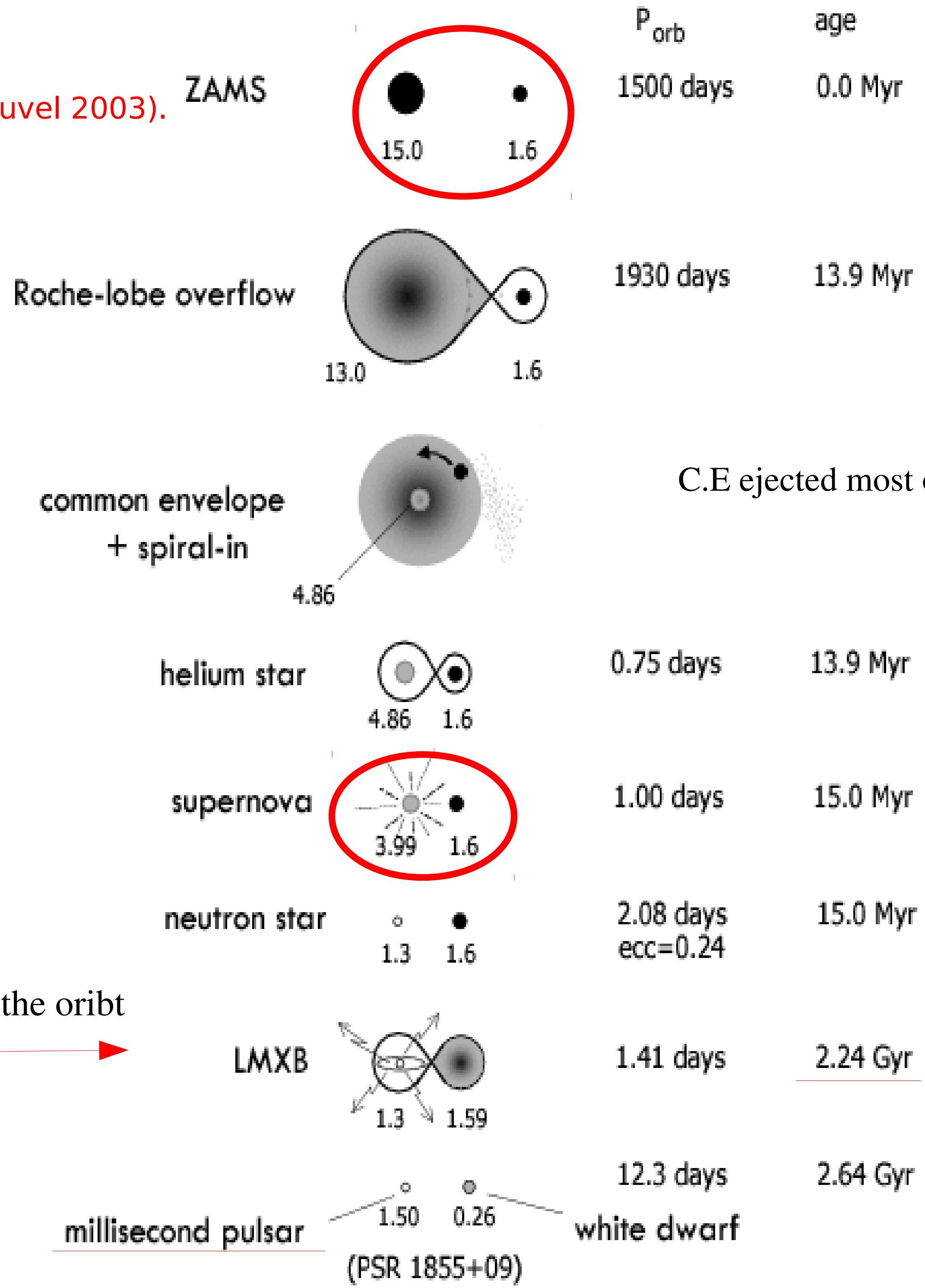
LMXBs (Liu et al 2007): 187

Could be many reasons for such a low number

- We are seeing the brightest ones: observational bias
- They are not easy to form: intrinsic property

LMXB

(Tauris and van den Heuvel 2003).



C.E ejected most of times

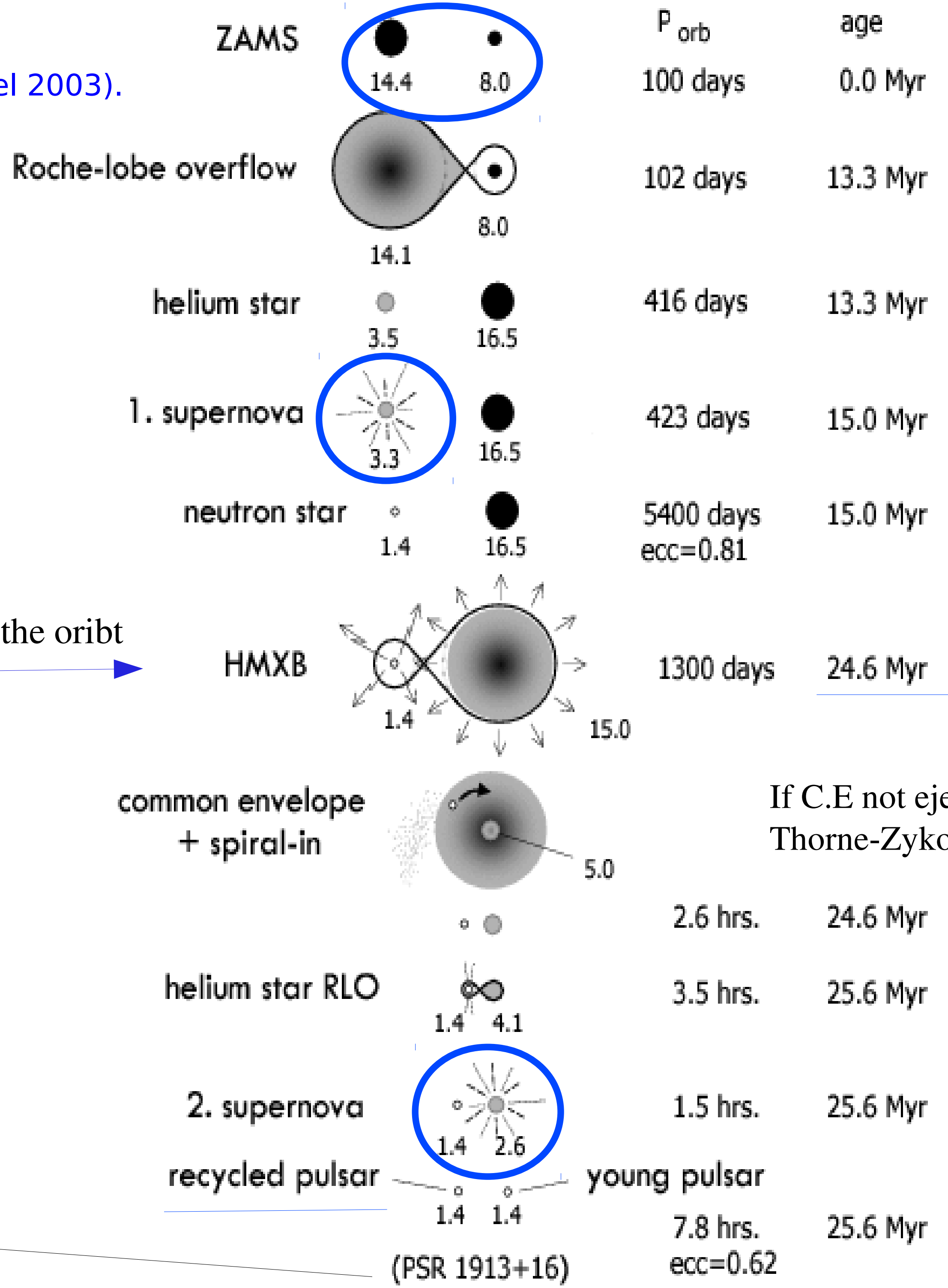
More massive explodes

Accretion circularises the oribt

(not the only way...
but ok to have an idea)

HMXB

(Tauris and van den Heuvel 2003).

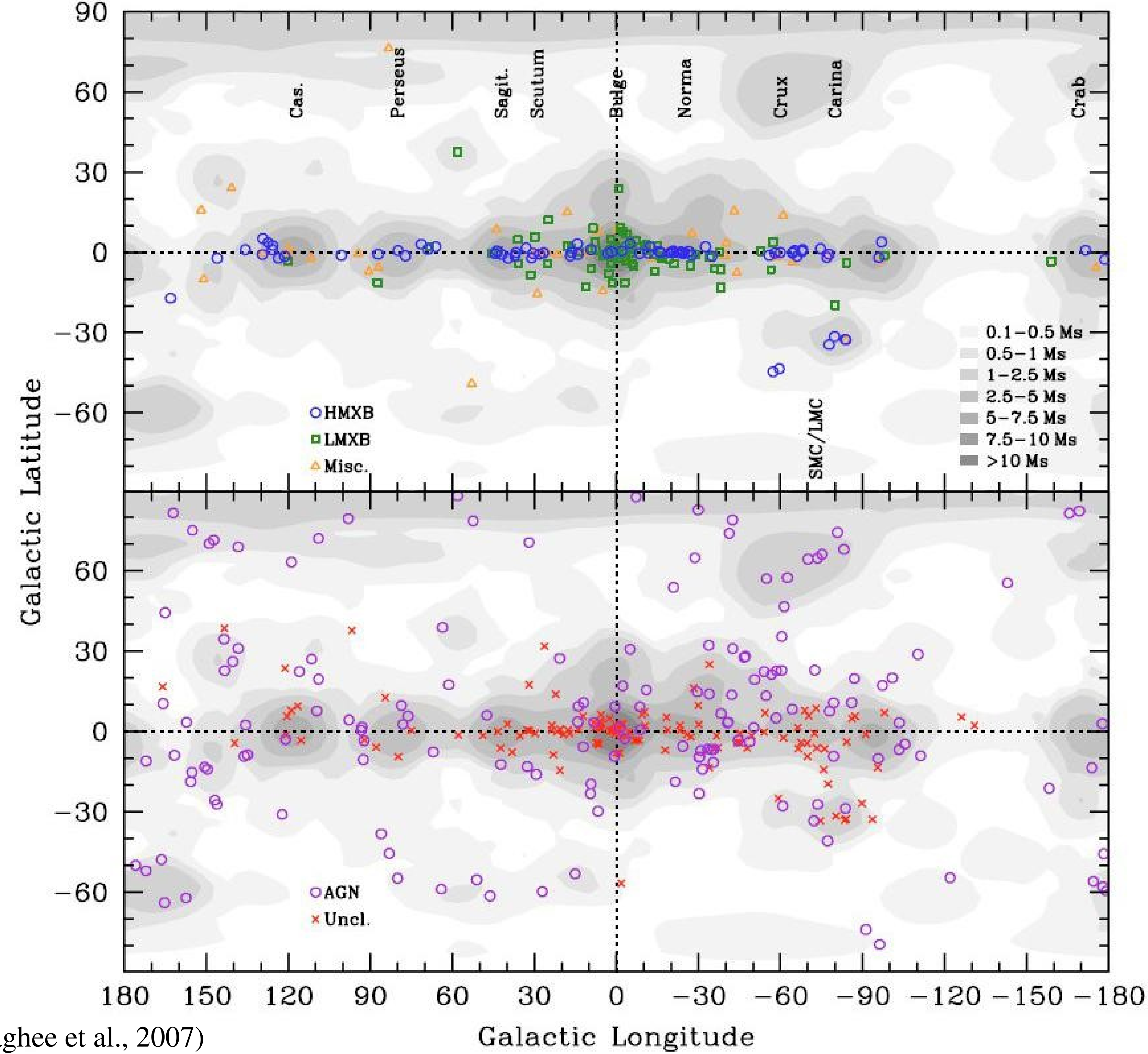


Less massive explodes

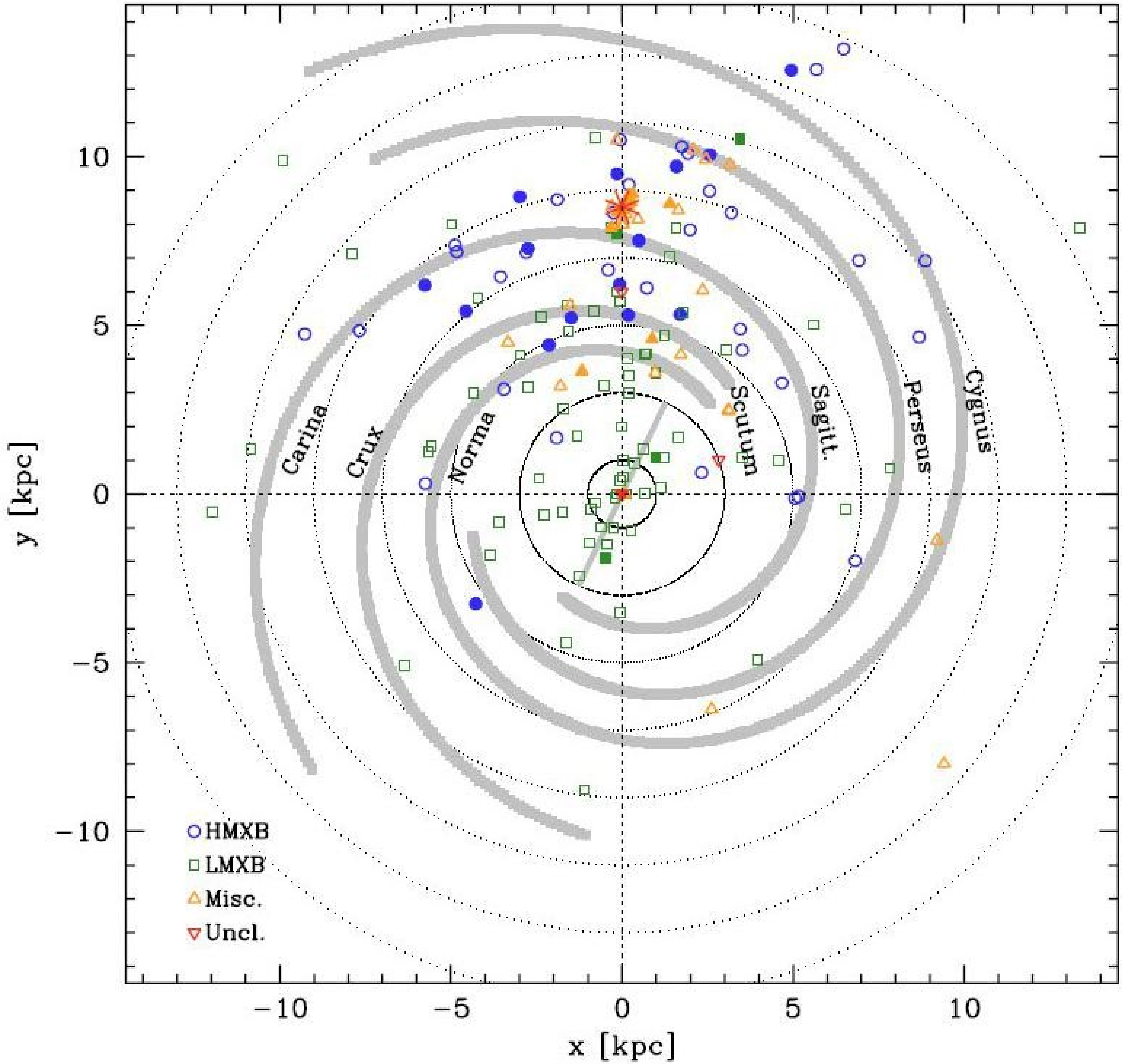
Accretion circularises the oribt

If C.E not ejected
Thorne-Zykov object

Coalesce: GRB?



(Bodaghee et al., 2007)



(Bodaghee et al., 2007)

SUMMARY BOX 2:

Interacting to get emission

Accretion

X – γ rays

HMXB	**LMXB**
OB	K,M
Young	Old
Wind acc.	Disk acc.
Gal Plane	Gal Bulge
B~10^{12} G	B~10^{9}G
X-ray pulsars	X-ray pulsars (few)
-	msec pulsations
-	type I, II bursts
NS/BH	NS/BH