Binaries, GRBs and Hypercritical Accretion.

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Punchline

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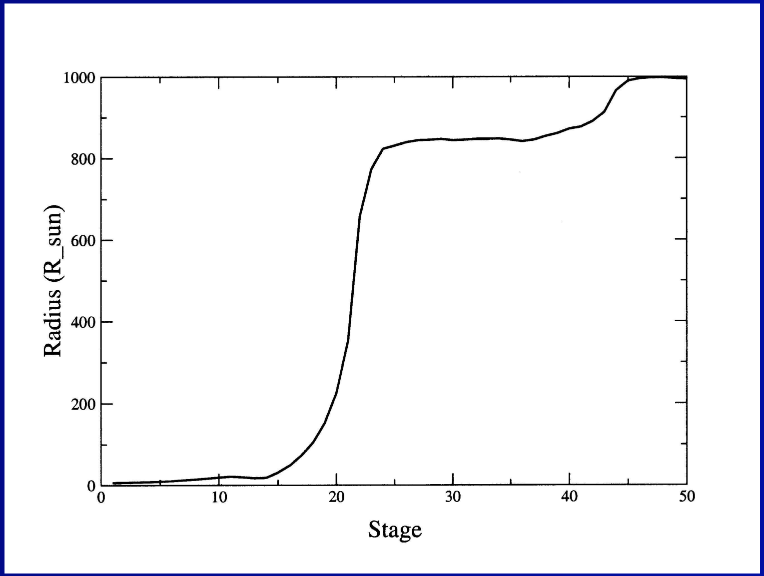
- Our BHB evolution model applied to a few massive systems, the lack of evidence of a NS 22 years after SN 1987A, and the evolutionary track of low mass DNSs suggest a rather low maximum NS mass.

Motivation

- We observe 15 Galactic Black Hole Binaries (BHBs) and 3 extragalactic.
- Recent (Smithsonian-Harvard-MIT) measurements of Kerr parameters ($a_\star$'s) in Black Hole Binaries (BHBs) confirm predictions of our model (LBW).
- There is about one Gamma-Ray Burst observed every day, each with an energy on the order of those for Supernovae.
- Our model is capable of predicting and reproducing the Kerr parameter (and energies) of observed systems and events.
- $a_\star$'s for massive BHBs strongly suggest the need of hypercritical accretion onto low-mass compact objects.
- After 22 years, where's the NS in SN 1987A?
- Masses of DNSs are rather small, suggesting a low maximum NS mass.

The A, B, C of Mass Transfer

- Case A: Occurs during Main Sequence (H burning)
- Case B: Begins at H-shell burning; continues during He burning.
- Case C: Occurs at the later stages of He burning. So it keeps the He core covered. Prevents too much mass loss.



The black-hole-progenitor star must be tricked into believing it is evolving as a single star, or else too much mass is lost through mass transfer and winds for a black hole to form.

Tidal Locking and Kerr Parameter

- The common envelope evolution tidally locks the two stars.
- Given that the material in the He star is highly ionized and that there is a strong magnetic field traversing the star we expect the black hole to be locked with the infalling He-star.
- Given the tidal lock it is possible to have a good estimation of the angular momentum of the pre-collapse-primary star and therefore obtain the Kerr parameter of the black hole at the time it was formed (right before the GRB/HN event).
- $a_\star$ will decrease by powering up the GRB/HN.
- $a_\star$ can be increased by transferring mass to the black hole.

Kerr Parameter and Mass Accretion

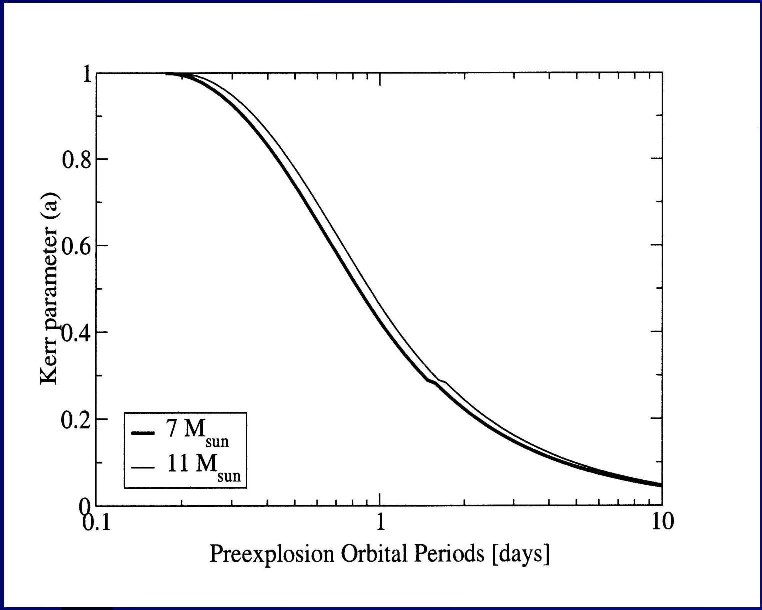


Figure 1: The Kerr parameter of the black hole, at the time of formation, from the collapse of a tidally locked He star, as a function of the orbital period. The result has little dependance on the mass of the He star.

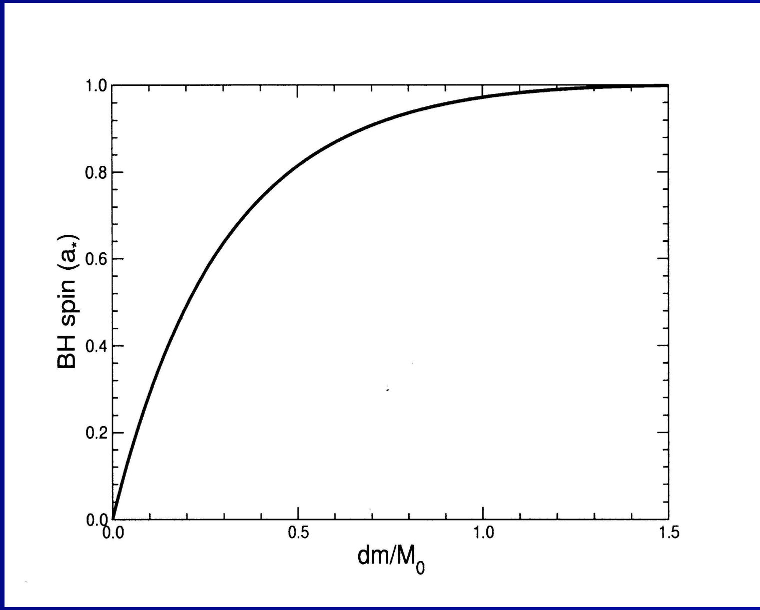


Figure 2: Black hole spin $a_\star$ is given in units of $[GM/c^2]$ and δm is the total rest mass of the accreted material. Note that M_0 is the mass of the non-rotating initial black hole. Here we assumed that the last stable orbit corresponds to the marginally stable radius (Brown et al. 2000b).

Measuring Kerr parameters

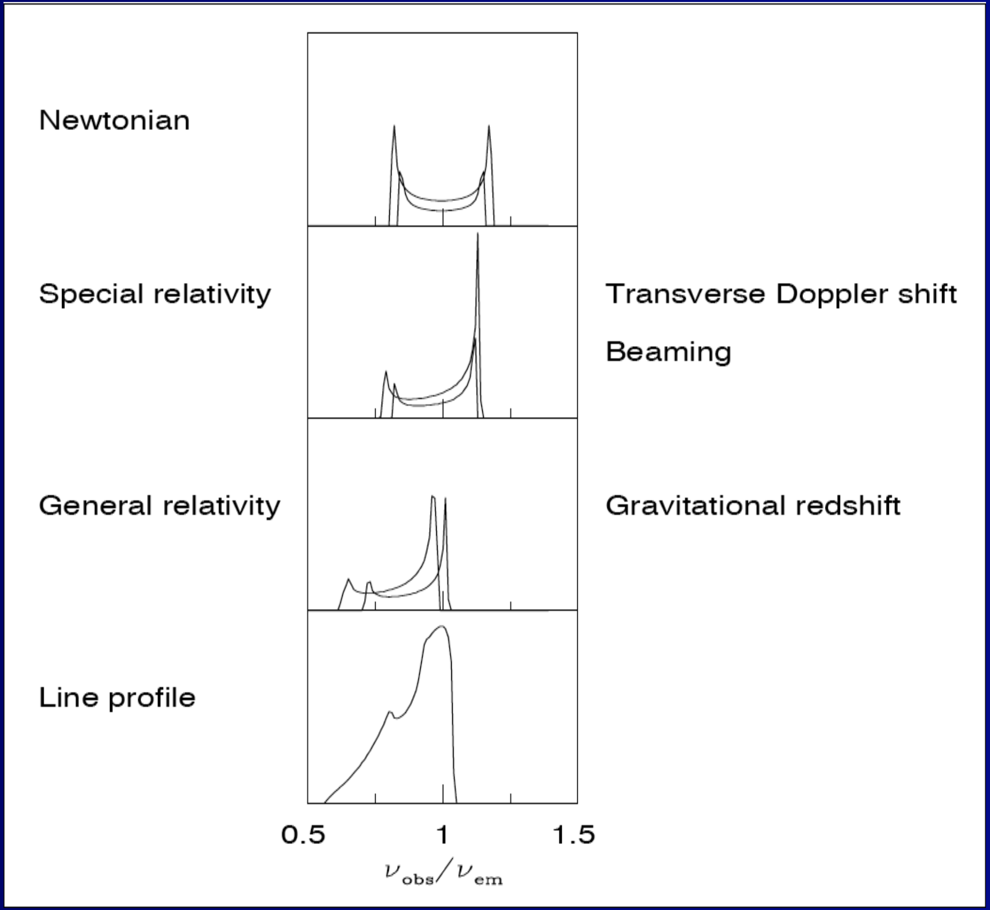


Figure 3: Fabian and Miniutti (2005). The profile of an emission line is modified by Doppler and relativistic effects.

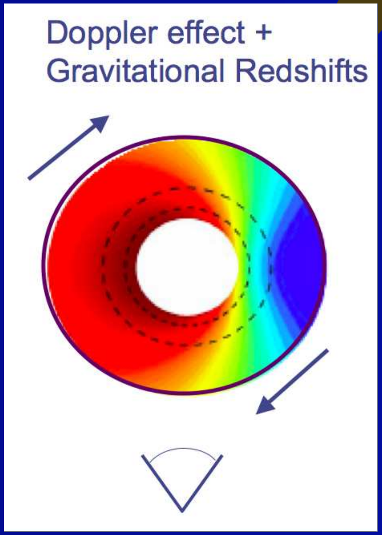


Figure 4: Disk.

Blandford-Znajek Mechanism

- The magnetic field $\vec{B}$ rotates along with the forming black hole.
- Electrically-charged plasma from the collapsing core cannot keep up with the fast rotation of the BH-anchored $\vec{B}$ field.
- The resulting energy from the Faraday Law generator comes out in the Poynting vector direction, whose average points in the rotational axis direction.

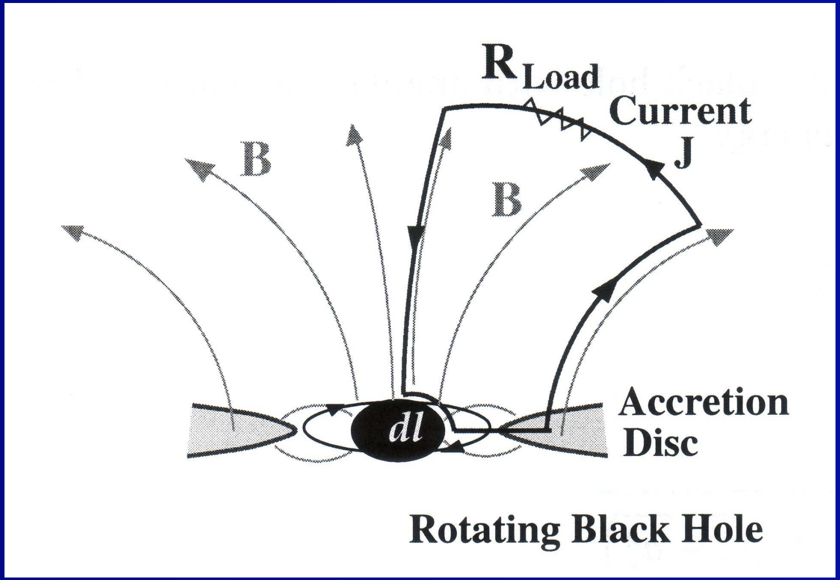
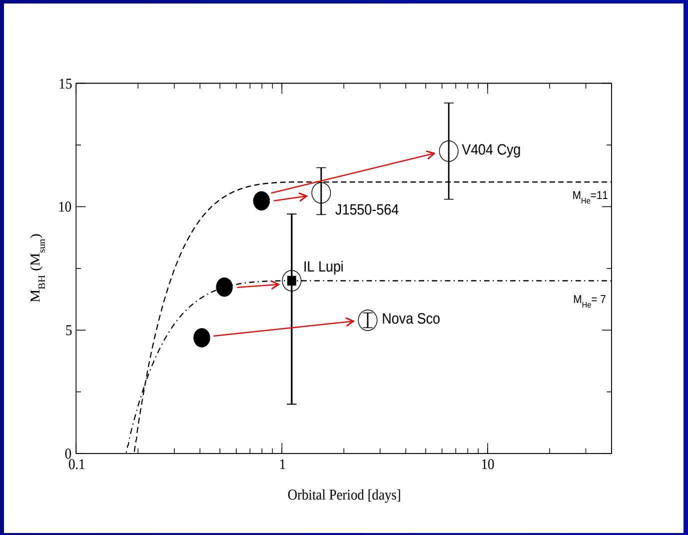
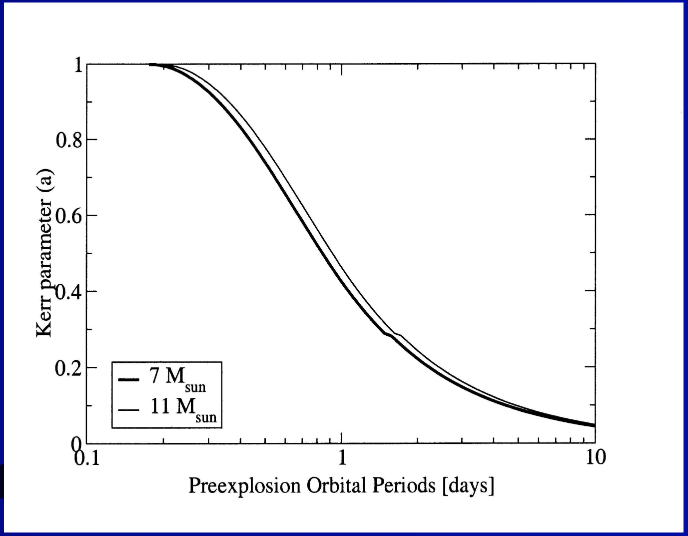


Figure 5: Lee et al., 2000. The black hole and the accretion disk work like an electric motor with the armature (the infalling material) going around the black hole.

Galactic Examples

Reconstructed pre-explosion orbital period vs. black hole masses of SXTs with evolved companions. The reconstructed pre-explosion orbital periods and black hole masses are marked by filled circles, and the current locations of binaries with evolved companions are marked by open circles. The solid lines are ideal polytropic He stars, but both IL Lupi and Nova Scorpii were evolved from $11 M_\odot$ He stars. This figure is obtained from Fig. 11 of LBW. We can then calculate the Kerr parameters: $a_\star = 0.8$.





BHBs

Name	M_2 $[M_\odot]$	m_2 $[M_\odot]$	M_{now} $[M_\odot]$	m_{now} $[M_\odot]$	Model $a_{\star,2}$	Meas. $a_\star$	P_{now} [days]	E_{BZ} $[10^{52}$ ergs]
AML: with main sequence companion								
J1118+480	~ 5	< 1	$6.0 - 7.7$	$0.09 - 0.5$	0.8	-	0.170	~ 43
Vel 93	~ 5	< 1	$3.6 - 4.7$	$0.50 - 0.65$	0.8	-	0.285	~ 43
J0422+32	$6 - 7$	< 1	$3.4 - 14$	$0.10 - 0.97$	0.8	-	0.213	$50 - 60$
1859+226	$6 - 7$	< 1	$7.6 - 12$		0.8	-	0.380	$50 - 60$
GS1124−683	$6 - 7$	< 1	6.95	$0.56 - 0.90$	0.8	-	0.433	$50 - 60$
H1705−250	$6 - 7$	< 1	$5.2 - 8.6$	$0.3 - 0.6$	0.8	-	0.521	$50 - 60$
A0620−003	~ 10	< 1	11.0	0.68(18)	0.6	-	0.323	~ 44
GS2000+251	~ 10	< 1	$6.0 - 14$	$0.26 - 0.59$	0.6	-	0.344	~ 44
Nu: with evolved companion								
GROJ1655−40	~ 5	$1 - 2$	$5.1 - 5.7$	$1.1 - 1.8$	0.8	$0.65 - 0.75$	2.61	~ 43
4U1543−47	~ 5	$1 - 2$	$2.0 - 9.7$	$1.3 - 2.6$	0.8	$0.75 - 0.85$	1.12	~ 43
XTEJ1550−564	~ 10	$1 - 2$	$9.7 - 11.6$	$0.96 - 1.64$	0.5	-	1.55	~ 30
GS2023+338	~ 10	$1 - 2$	$10.3 - 14.2$	$0.57 - 0.92$	0.5	-	6.47	~ 30
XTEJ1819−254	$6 - 7$	~ 10	$8.7 - 11.7$	$5.50 - 8.13$	0.2		2.81	$1 \sim 1.2$
GRS1915+105	$6 - 7$	~ 10	14(4)	1.2(2)	0.2	> 0.98	33.5	$1 \sim 1.2$
Cyg X−1	$6 - 7$	$\gtrsim 30$	~ 10.1	17.8	0.15	-	5.60	$.5 \sim .6$
Extragalactic								
LMC X−1	~ 40	~ 35	$9.0 - 11.6$	30.6 ± 3.2	0.05	$0.81 - 0.94$	3.91	$< .2$
LMC X−3	10.25	4	$5 - 11$	6 ± 2	0.43	< 0.26	1.70	~ 11
M33 X−7	~ 90	~ 80	$14.2 - 17.1$	70.0 ± 6.9	0.05	0.77(5)	3.45	$.3 - 1.1$

Table 1: Parameters at the time of formation of the black hole and at present time. Subindex 2 stands for values at the time the black hole is formed, whereas subindex now stands for recently measured values.

M33 X — 7

- $M_{BH} \sim 15 M_\odot$.
- $M_{sec} \sim 70 M_\odot$.
- Low metallicity.
- $P = 3.45$ days.
- Low natal $a_\star \lesssim 0.05$.
- Fast present $a_\star \sim 0.77$.
- Hypercritical Accretion!!
- Not enough energy for a GR-B/HN.

LMC X — 1

- $M_{BH} \sim 10 M_\odot$.
- $M_{sec} \sim 31 M_\odot$.
- Low metallicity.
- $P = 3.91$ days.
- Low natal $a_\star \lesssim 0.05$.
- Fast present $a_\star \sim 0.90$.
- Hypercritical Accretion!!
- Not enough energy for a GR-B/HN.

DNSs

Name	M_1 $[M_\odot]$	M_2 $[M_\odot]$	Difference $[M_\odot]$	Pulsar period [ms]
B1534+12	$1.3332^{+0.0010}_{-0.0010}$	$1.3452^{+0.0010}_{-0.0010}$	0.0120	37.9
J1906+0746	$1.248^{+0.018}_{-0.018}$	$1.365^{+0.018}_{-0.018}$	0.117	144.1
J0737−3039	$1.337^{+0.005}_{-0.005}$	$1.250^{+0.005}_{-0.005}$	0.087	22.7, 2773
J1756+2251	$1.40^{+0.02}_{-0.03}$	$1.18^{+0.03}_{-0.02}$	0.22	28.5
J1829+2456	$1.30^{+0.05}_{-0.05}$	$1.27^{+0.11}_{-0.07}$	0.03	4.1
B1913+16	$1.4408^{+0.0003}_{-0.0003}$	$1.3873^{+0.0003}_{-0.0003}$	0.0535	59
2127+11C	$1.349^{+0.040}_{-0.040}$	$1.363^{+0.040}_{-0.040}$	0.014	30.5
J1518+4904	$1.56^{+0.13}_{-0.44}$	$1.05^{+0.45}_{-0.11}$	0.51	40.9
J1811+1736	$1.62^{+0.22}_{-0.55}$	$1.11^{+0.53}_{-0.15}$	0.51	104

Table 2: Compilation of double-neutron-star binaries. The first seven NS-NS binaries are included in Fig. 6 (next slide), the last two have error bars which are to large to tell whether the ZAMS masses of the progenitors were within 4% or not.

DNSs

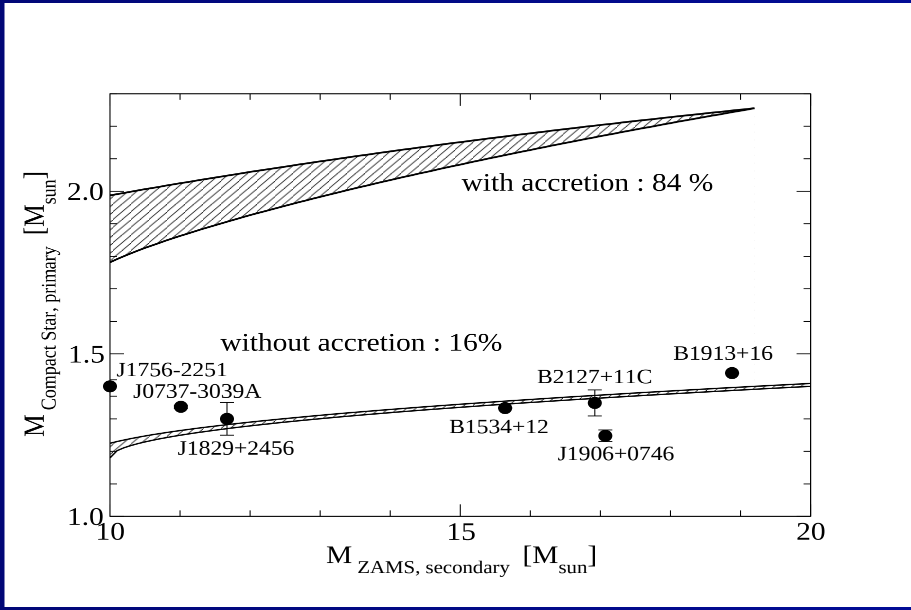


Figure 6: Masses of primary compact stars in 7 well-measured NS-NS binaries with and without hypercritical accretion during H red giant stage of secondary star. Note that the 84% corresponds to $M_{\rm cs,primary} > 1.8 M_\odot$. There is uncertainty in the final primary compact star masses due to the extra mass accretion, $\sim (0.1 - 0.2) M_\odot$, during the He giant stage. This may increase the primary compact star masses for both “with” and “without” hypercritical accretion. Note that with our maximum NS mass of $1.8 M_\odot$, all primary compact stars with hypercritical accretion would become ‘low-mass BHs’.

Conclusions

- Case C mass transfer is essential to produce BHBs.
- Without tidal locking the He-Star model does not have the rotational energy to produce GRB/HN explosions.
- BZ mechanism extracts the energy from the Kerr-BH and the disk.
- We have shown that Black Hole Binaries produce GRB/HN explosions during the collapse of the primary star into a black hole.
- Our model supports the Collapsar model by supplying the rotational energy in a natural way and explains, through the “Goldilocks” scenario, the Subluminous GRBs.
- Hypercritical accretion is further supported by LMC X—1 and M33 X—7.
- No evidence of a NS in SN 1987A and low DNS masses (and their formation mechanism) support the idea of a low maximum NS mass.