Understanding Supernova Kicks and Black-Hole Spins in Galactic X-ray Binaries

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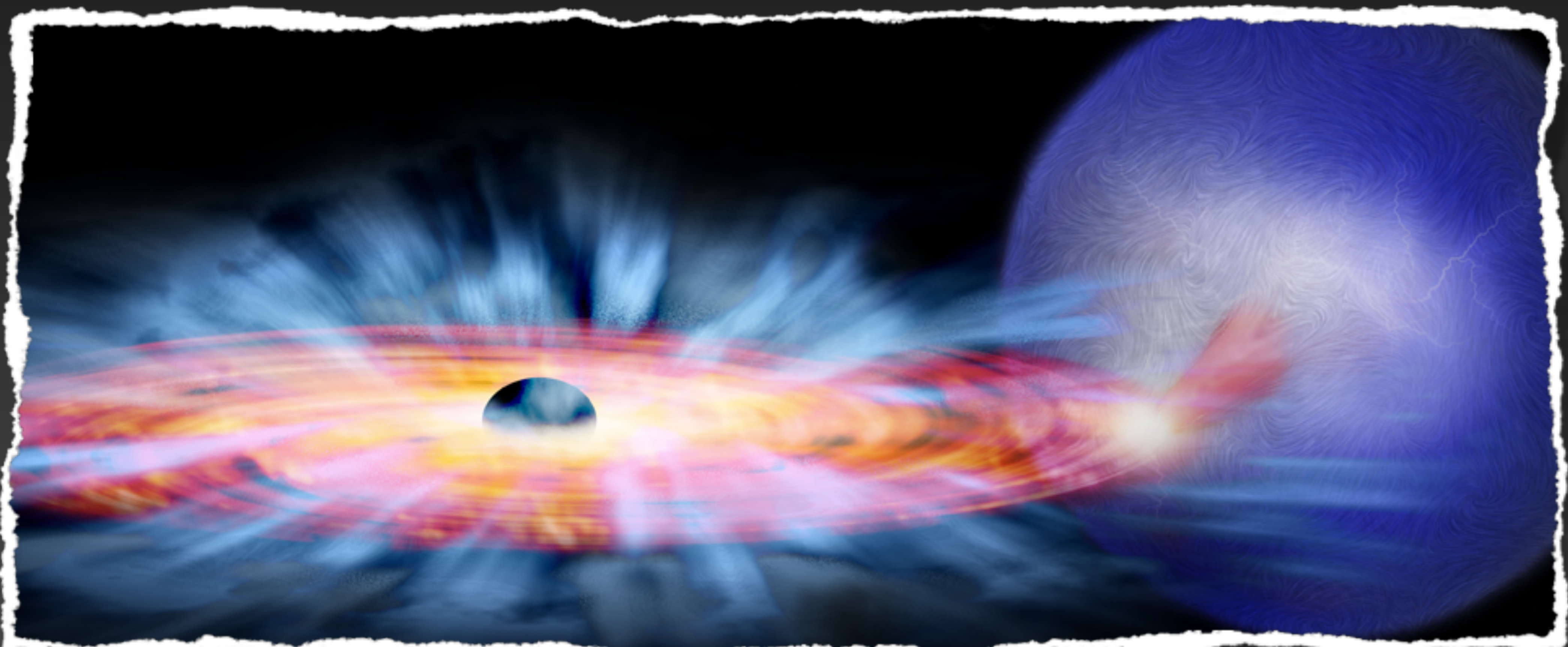

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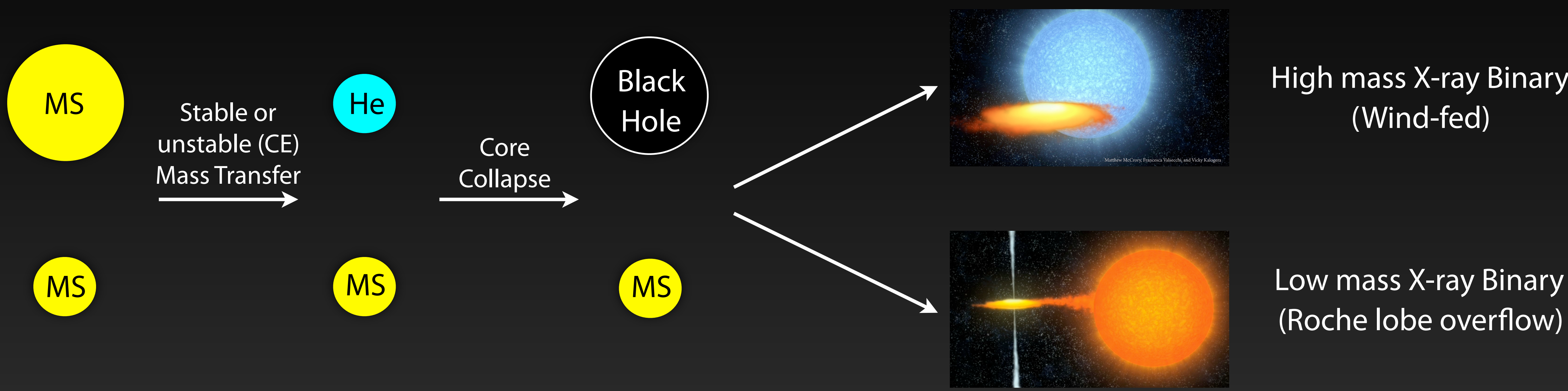
FNSNF
FONDS NATIONAL SUISSE
SCHWEIZERISCHER NATIONALFONDS
FONDO NAZIONALE SVIZZERO
SWISS NATIONAL SCIENCE FOUNDATION

Going backwards in time



Currently observed properties: Donor's position on the H-R (T_{eff} vs. L) diagram, BH and donor masses,orbital period, position in the galaxy and 3-D systemic velocity

Step 1: Model the mass-transfer phase

Step 2: Model the detached post-SN secular evolution

Step 3: Find the peculiar velocity post BH formation

Step 4: Compute the orbital dynamics involved in core collapse

Derive limits on immediate progenitor mass and natal kicks magnitude

Results so far...

System	Observed Current BH mass ($M_\odot$)	Post-SN BH mass ($M_\odot$)	Immediate Progenitor mass ($M_\odot$)	Natal Kick (km/s)
XTE J1118+480 (late-type, P<1d)	**8.0 ± 2.0** (McClintock et al. 2001, Wagner et al. 2001, Gelino et al. 2006)	**6.0 – 10.0** (Fragos et al. 2009)	**6.5 – 20.0** (Fragos et al. 2009)	**80 – 310** (Fragos et al. 2009)
GRO J1655-40 (early-type, P>1d)	**6.3 ± 0.5** (Greene et al. 2001) **5.4 ± 0.3** (Beer & Podsiadlowski 2002)	**5.5 – 6.3** (Willems et al. 2005) **3.5 – 5.4** (Willems et al. 2005)	**5.5 – 11.0** (Willems et al. 2005) **3.5 – 9.0** (Willems et al. 2005)	**30 – 160** (Willems et al. 2005) **≤ 210** (Willems et al. 2005)
LMC X-3 (early-type, P>1d)	**6.98 ± 0.56** (Orosz et al. 2014)	**5.2 – 8.1** (Sorensen et al. 2016, in prep.)	**11.2 – 21.9** (Sorensen et al. 2016, in prep.)	**≥ 140** (Sorensen et al. 2016, in prep.)
Cygnus X-1 (wind-fed, high mass)	**14.81 ± 0.98** (Orosz et al. 2011)	**13.8 – 15.8** (Wong et al. 2012)	**15.0 – 20.0** (Wong et al. 2012)	**≤ 77** (Wong et al. 2012)
IC10 X-1 (wind-fed, high mass)	**23.0 - 34.0** (Orosz et al. 2011)	**23.0 - 34.0** (Wong et al. 2014)	**>31.0** (Wong et al. 2014)	**≤ 130** (Wong et al. 2014)
M33 X-7 (wind-fed, high mass)	**13.5 – 20.0** (Orosz et al. 2007, Valsecchi et al.2010)	**13.5 – 14.5** (Valsecchi et al.2010)	**15.0 – 16.1** (Valsecchi et al.2010)	**≤ 850** (Valsecchi et al.2010)

Willems et al. 2005, ApJ, 625, 324
Fragos et al. 2009, ApJ, 697, 1057
Valsecchi et al. 2010, Nature, 468, 77
Wong et al. 2012, ApJ, 747, 111
Wong et al. 2014, ApJ, 790, 417
Sorensen et al. 2016, (In preparation)

Results so far...

System	Observed BH m (M	s	Natal Kick (km/s)
XTE J1118+480 (late-type, P<1d)	8.0 ± (McClintock et al. et al. 2001, Gelir		80 – 310 (Fragos et al. 2009)
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LMC X-3 (early-type, P>1d)	6.98 ± (Orosz et a	prep.)	≥ 140 (Sorensen et al. 2016, in prep.)
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M33 X-7 (wind-fed, high mass)	13.5 – (Orosz et a Valsecchi et	)	≤ 850 (Valsecchi et al.2010)

Repetto et al. 2012, 2015

Name	$V_\perp$ (km/s)	V_{nk} (km/s)
3 4U1543-47	95	80
XTEJ1550-564	22	10
GROJ1655-40	36	0
1659-487	113	-
1819.3-2525	160	190
GRS1915+105	5	0
GS2023+338	10	0
GROJ0422+32	25	10
A0620-003	10	0
GRS1009-45	40	15
XTEJ1118+480	80	70
1124-683	50	40
XTEJ1650-500	20	-
1705-250	420	450
XTEJ1859+226	80	-
GS2000+251	15	0

See also Janka 2013, MNRAS, 434,1355

Willems et al. 2005, ApJ, 625, 324
Fragos et al. 2009, ApJ, 697, 1057
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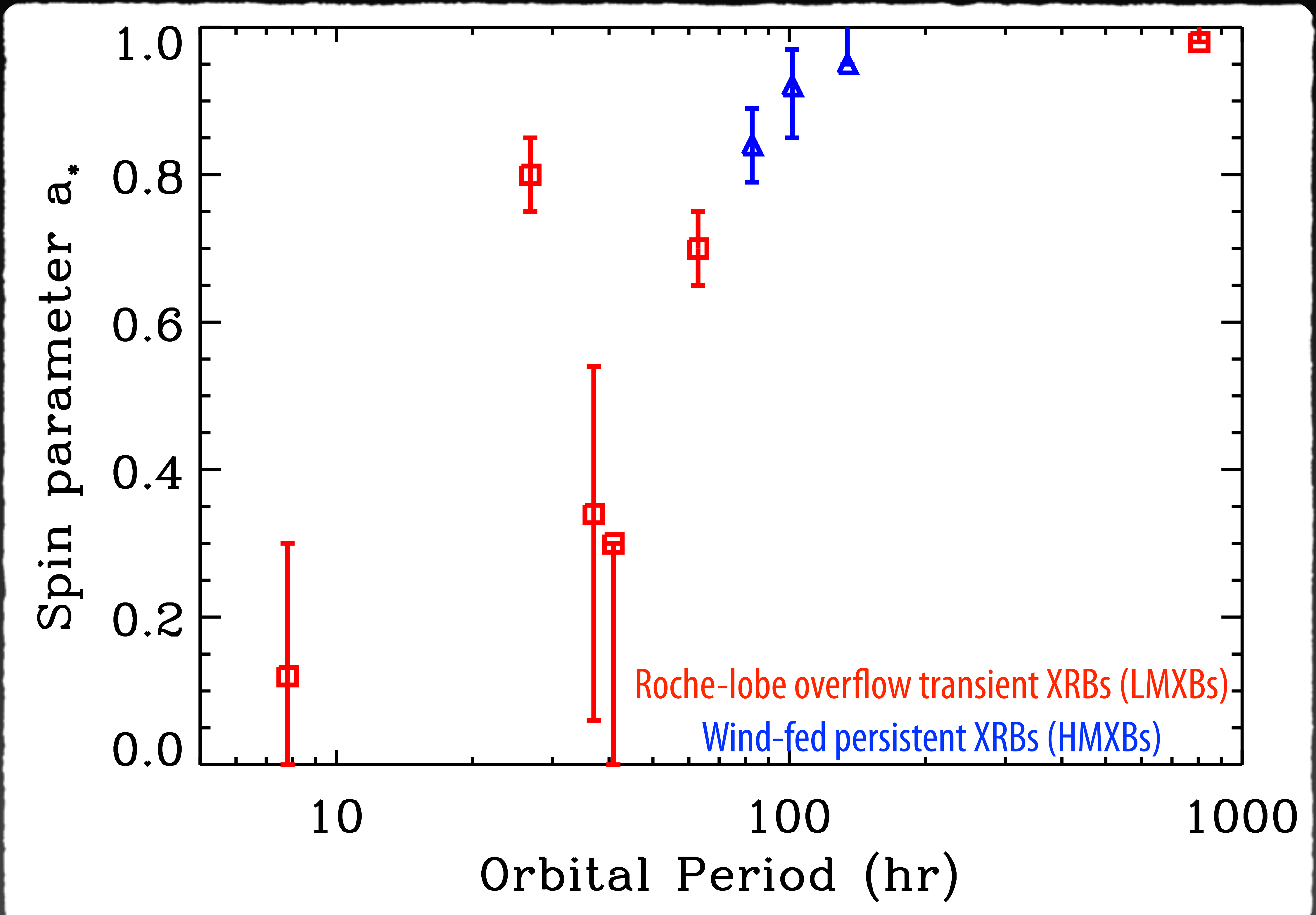
The origin of black-hole spin



The spin of 9 stellar BHs measured with the ***continuum fitting method***

McClintock et al. (2011, 2013)

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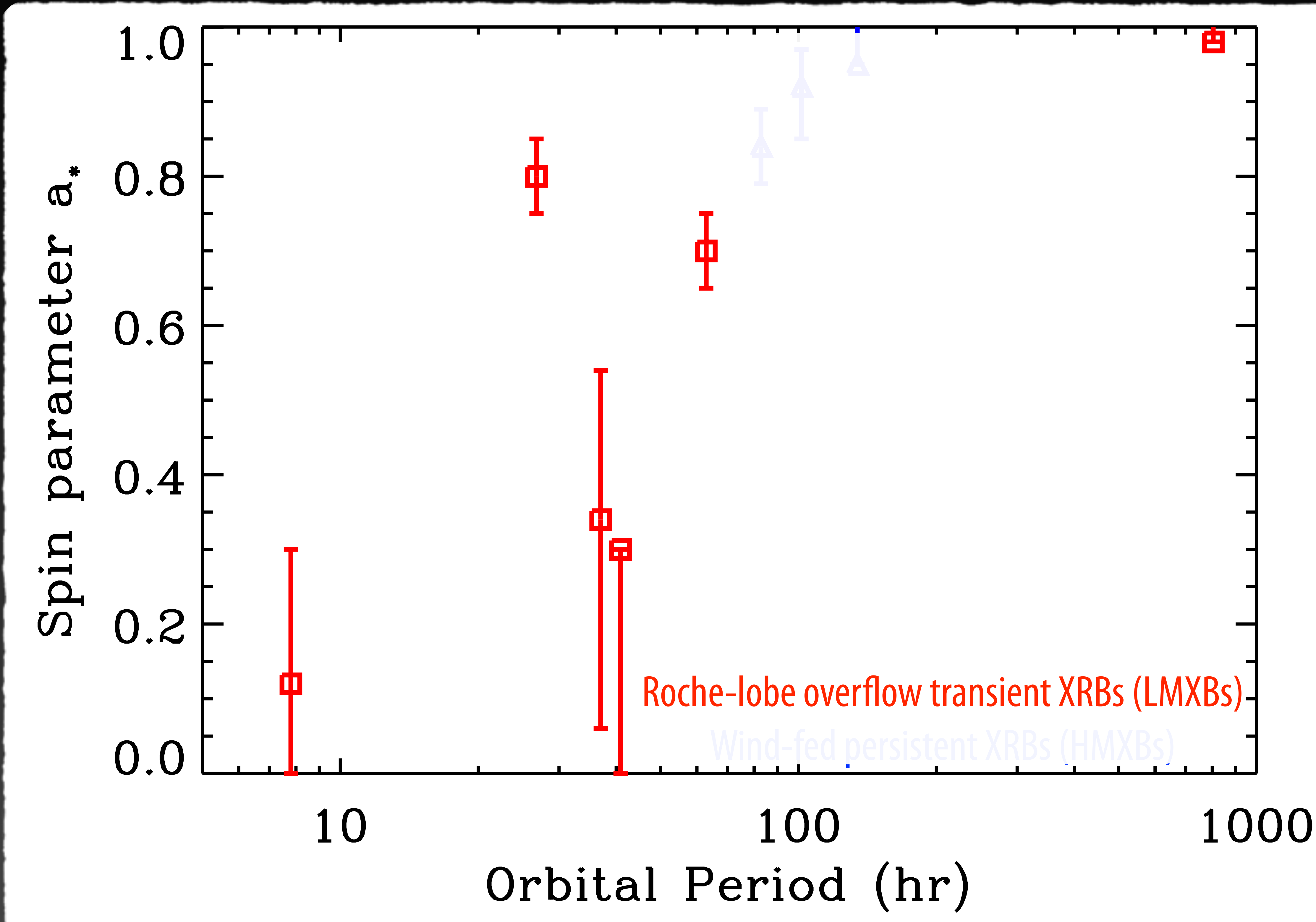

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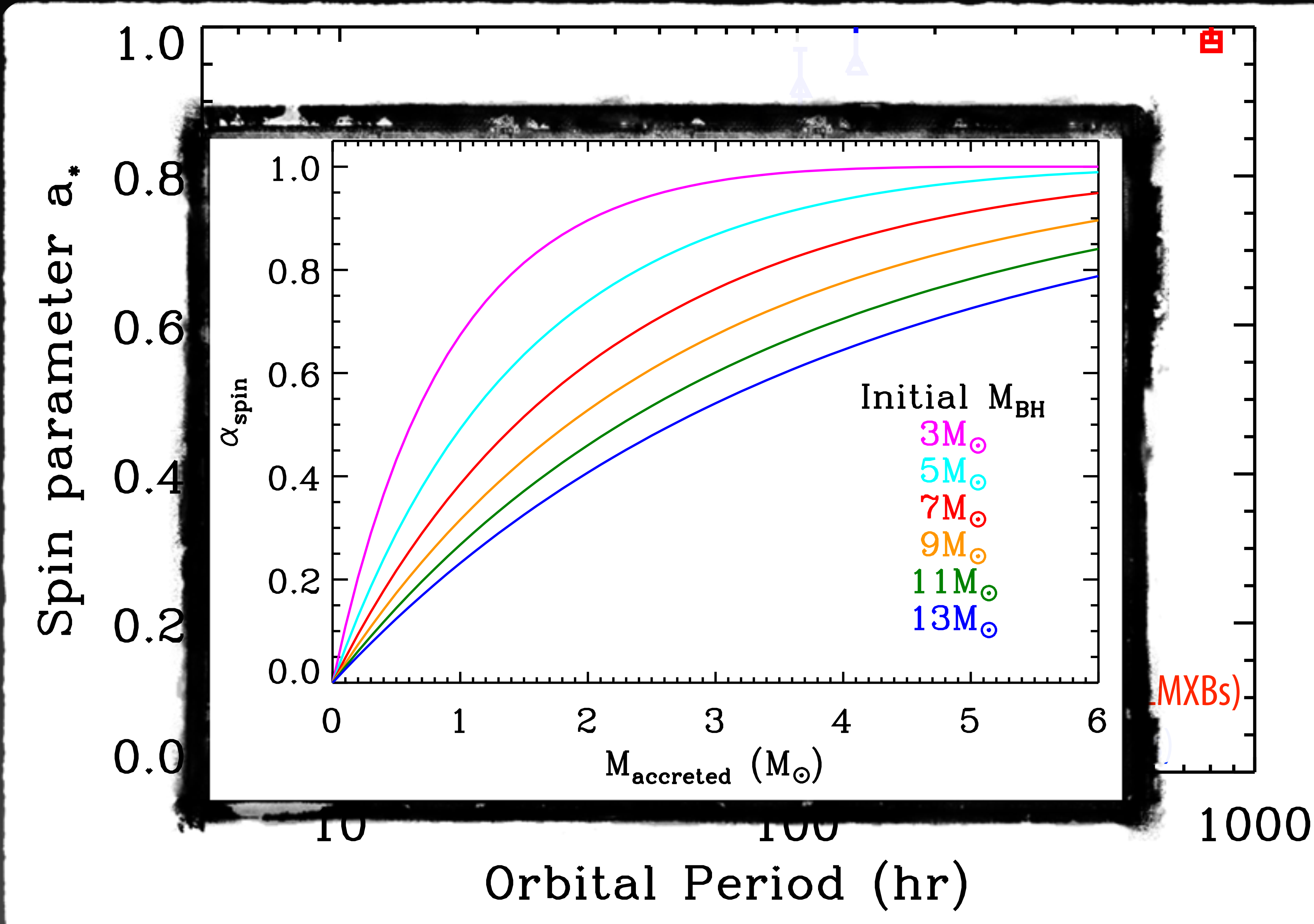

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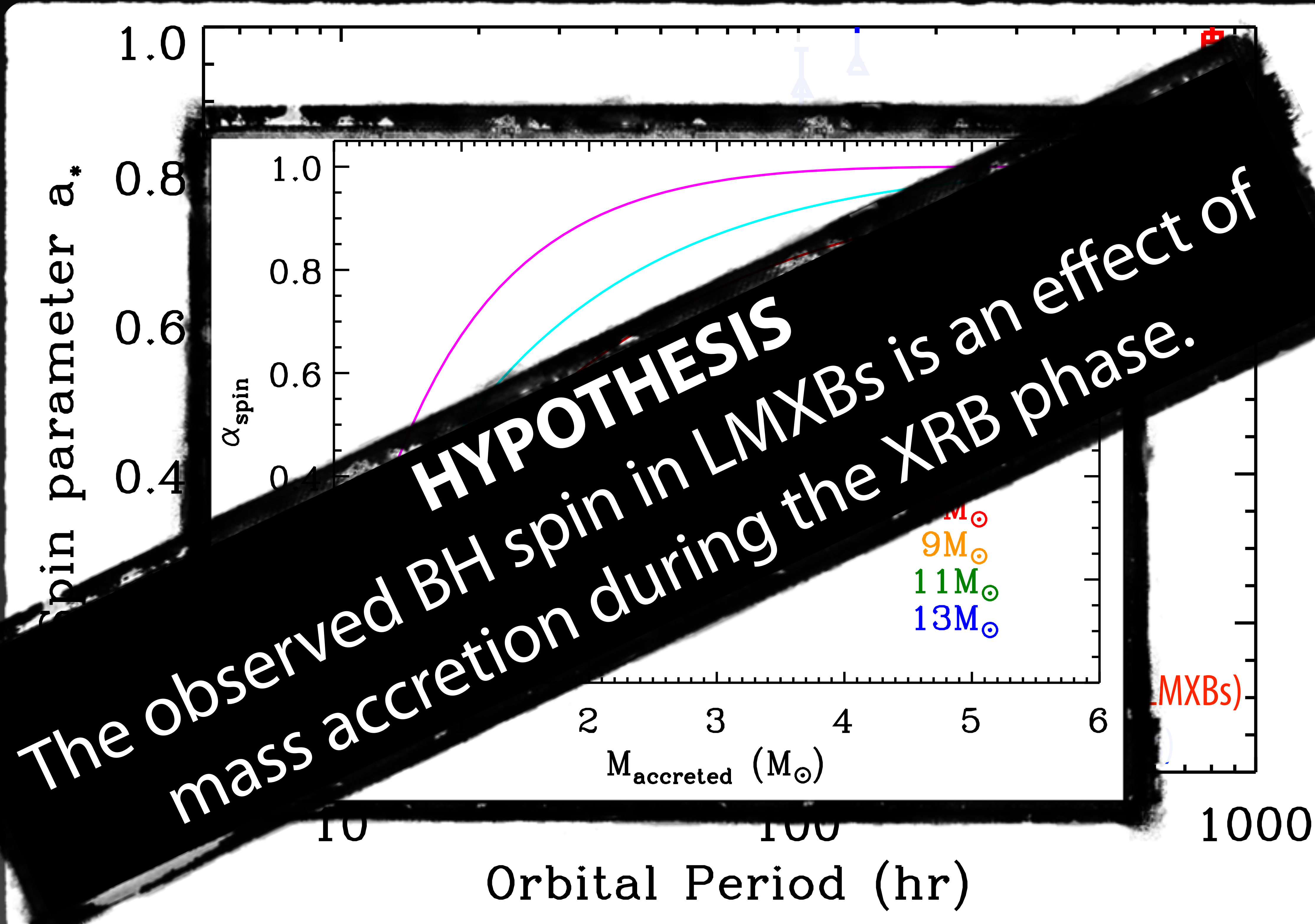

HYPOTHESIS

The observed BH spin in LMXBs is an effect of mass accretion during the XRB phase.

The spin of 9 stellar BHs measured with the ***continuum fitting method***

McClintock et al. (2011, 2013)

Sample of Galactic BH LMXBs

	M_{BH} ($M_\odot$)	M_2 ($M_\odot$)	P_{orb} (days)	T_{eff} (K)	a_*
GRS 1915+105	12.4±2.0	0.52±0.41	33.85	4100-5433	0.95±0.05
4U 1543-47	9.4±2.0	2.7±1.0	1.116	9000±500	0.8±0.1
GRO J1655-40	6.3±0.5	2.4±0.4	2.622	5706-6466	0.7±0.1
XTE J1550-564	9.1±0.61	0.3±0.07	1.542	4700±250	0.34±0.2
A0620-00	6.61±0.25	0.4±0.045	0.323	3800-4910	0.12±0.19
GRS 1124-683	6.95±1.1	0.9±0.3	0.433	4065-5214	0.25±0.15
GX 339-4	8.0±1.0*	--	1.754	--	0.25±0.15
XTE J1859+226	8.0±1.0*	--	0.383	--	0.25±0.15
GS 2000+251	8.0±1.0*	0.35±0.05	0.344	3915-5214	0.05±0.05
GRO J0422+32	8.0±1.0*	0.95±0.25	0.212	2905-4378	--
GRS 1009-45	8.5±1.0	0.54±0.1	0.285	3540-4640	--
GS 1354-64	8.0±1.0	--	2.545	4985-6097	--
GS 2023+338	9.0±0.6	0.54±0.05	6.471	4100-5433	--
H1705-250	6.4±0.75	0.245±0.0875	0.521	3540-5214	--
V4641 Sgr	6.4±0.6	2.9±0.4	2.817	10500±200	--
XTE J1118+480	7.55±0.325	0.17±0.07	0.17	3405-4640	--

Fragos & McClintock (2015) - ApJ, 800, 17

* No reliable BH mass measurement is available. Using fiducial value from Ozel et al. (2010)

† Spin estimates from Steiner et al. (2013) using the BH spin - jet power correlation (Narayan & McClintock, 2012)

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Grid of Mass-Transfer Calculations

- **~26,000 Detailed mass-transfer (MT) Calculations using MESA (Paxton et al. 2013; vs. 5527)**
  - $M_2 \rightarrow 0.5\text{-}10\ M_\odot$, $dM_2 \rightarrow 0.1\text{-}0.2\ M_\odot$
  - $P_{Orb} \rightarrow 0.2\text{-}100$ days, $P_{Orb} \rightarrow 0.05\text{-}5$ days
  - $M_{BH} \rightarrow 3\text{-}10\ M_\odot$, $dM_{BH} \rightarrow 1\ M_\odot$
- **MT sequence termination criteria:**
  - $P_{Orb} > 365$ days
  - $M_2 < 0.03\ M_\odot$
  - Age < 13.7Gyr
  - Donor star is not degenerate.
- **MT is fully conservative**

The origin of black-hole spin

Retrieved binary properties at the onset of RLO

	$M_{BH,init}$ ($M_\odot$)	$M_{2,init}$ ($M_\odot$)	$P_{orb,init}$ (days)
GRS 1915+105	3-10	1.0-10.0	0.6-30.0
4U 1543-47	3-10	2.2-6.4	0.6- 1.1
GRO J1655-40	4- 6	2.6-5.0	0.7- 1.7
XTE J1550-564	7- 9	0.9-1.5	0.3- 0.9
A0620-00	5- 6	1.1-1.8	0.6- 0.8
GRS 1124-683	4- 8	1.0-1.8	0.3- 0.9
GX 339-4	3- 9	0.6-8.8	0.2- 1.7
XTE J1859+226	5- 9	0.6-1.8	0.2- 0.9
GS 2000+251	5- 9	0.9-1.8	0.3- 0.9
GRO J0422+32	5- 9	0.8-1.5	0.3- 0.7
GRS 1009-45	6-10	1.0-1.6	0.6- 0.8
GS 1354-64	3- 9	1.6-6.8	0.6- 2.4
GS 2023+338	7- 9	1.0-2.0	0.6- 2.0
H1705-250	4- 6	1.0-1.5	0.4- 0.9
V4641 Sgr	3- 4	7.0-7.8	1.2- 1.7
XTE J1118+480	6- 7	1.0-1.8	0.6- 0.8

Fragos & McClintock (2015) - ApJ, 800, 17

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	$M_{BH,init}$ ($M_\odot$)	$M_{2,init}$ ($M_\odot$)	$P_{orb,init}$ (days)	M_{acc} ($M_\odot$)
GRS 1915+105	3-10	1.0-10.0	0.6-30.0	0.0-9.0
4U 1543-47	3-10	2.2-6.4	0.6- 1.1	0.0-4.0
GRO J1655-40	4- 6	2.6-5.0	0.7- 1.7	0.5-3.2
XTE J1550-564	7- 9	0.9-1.5	0.3- 0.9	0.6-1.2
A0620-00	5- 6	1.1-1.8	0.6- 0.8	0.7-1.3
GRS 1124-683	4- 8	1.0-1.8	0.3- 0.9	0.3-1.1
GX 339-4	3- 9	0.6-8.8	0.2- 1.7	0.0-5.8
XTE J1859+226	5- 9	0.6-1.8	0.2- 0.9	0.1-1.5
GS 2000+251	5- 9	0.9-1.8	0.3- 0.9	0.1-1.3
GRO J0422+32	5- 9	0.8-1.5	0.3- 0.7	0.2-1.0
GRS 1009-45	6-10	1.0-1.6	0.6- 0.8	0.5-1.3
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GS 2023+338	7- 9	1.0-2.0	0.6- 2.0	0.4-1.4
H1705-250	4- 6	1.0-1.5	0.4- 0.9	0.9-1.4
V4641 Sgr	3- 4	7.0-7.8	1.2- 1.7	2.3-2.6
XTE J1118+480	6- 7	1.0-1.8	0.6- 0.8	0.7-1.6

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	$M_{BH,init}$ $(M_\odot)$	$M_{2,init}$ $(M_\odot)$	$P_{orb,init}$ (days)	M_{acc} $(M_\odot)$	a_*
GRS 1915+105	3-10	1.0-10.0	0.6-30.0	0.0-9.0	0.01-1.00
4U 1543-47	3-10	2.2-6.4	0.6- 1.1	0.0-4.0	0.01-1.00
GRO J1655-40	4- 6	2.6-5.0	0.7- 1.7	0.5-3.2	0.26-0.94
XTE J1550-564	7- 9	0.9-1.5	0.3- 0.9	0.6-1.2	0.21-0.44
A0620-00	5- 6	1.1-1.8	0.6- 0.8	0.7-1.3	0.34-0.59
GRS 1124-683	4- 8	1.0-1.8	0.3- 0.9	0.3-1.1	0.12-0.62
GX 339-4	3- 9	0.6-8.8	0.2- 1.7	0.0-5.8	0.01-1.00
XTE J1859+226	5- 9	0.6-1.8	0.2- 0.9	0.1-1.5	0.02-0.63
GS 2000+251	5- 9	0.9-1.8	0.3- 0.9	0.1-1.3	0.05-0.57
GRO J0422+32	5- 9	0.8-1.5	0.3- 0.7	0.2-1.0	0.09-0.49
GRS 1009-45	6-10	1.0-1.6	0.6- 0.8	0.5-1.3	0.15-0.50
GS 1354-64	3- 9	1.6-6.8	0.6- 2.4	0.0-5.1	0.01-1.00
GS 2023+338	7- 9	1.0-2.0	0.6- 2.0	0.4-1.4	0.13-0.49
H1705-250	4- 6	1.0-1.5	0.4- 0.9	0.9-1.4	0.40-0.63
V4641 Sgr	3- 4	7.0-7.8	1.2- 1.7	2.3-2.6	0.85-0.94
XTE J1118+480	6- 7	1.0-1.8	0.6- 0.8	0.7-1.6	0.29-0.59

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XTE J1550-564	7- 9	0.9-1.5	0.3- 0.9	0.6-1.2	0.21-0.44
A0620-00	5- 6	1.1-1.8	0.6- 0.8	0.7-1.3	0.34-0.59
GRS 1124-683	4- 8	1.0-1.8	0.3- 0.9	0.3-1.1	0.12-0.62
GX 339-4	3- 9	0.6-8.8	0.2- 1.7	0.0-5.8	0.01-1.00
XTE J1859+226	5- 9	0.6-1.8	0.2- 0.9	0.1-1.5	0.02-0.63
GS 2000+251	5- 9	0.9-1.8	0.3- 0.9	0.1-1.3	0.05-0.57
GRO J0422+32	5- 9	0.8-1.5	0.3- 0.7	0.2-1.0	0.09-0.49
GRS 1009-45	6-10	1.0-1.6	0.6- 0.8	0.5-1.3	0.15-0.50
GS 1354-64	3- 9	1.6-6.8	0.6- 2.4	0.0-5.1	0.01-1.00
GS 2023+338	7- 9	1.0-2.0	0.6- 2.0	0.4-1.4	0.13-0.49
H1705-250	4- 6	1.0-1.5	0.4- 0.9	0.9-1.4	0.40-0.63
V4641 Sgr	3- 4	7.0-7.8	1.2- 1.7	2.3-2.6	0.85-0.94
XTE J1118+480	6- 7	1.0-1.8	0.6- 0.8	0.7-1.6	0.29-0.59

Fragos & McClintock (2015) - ApJ, 800, 17

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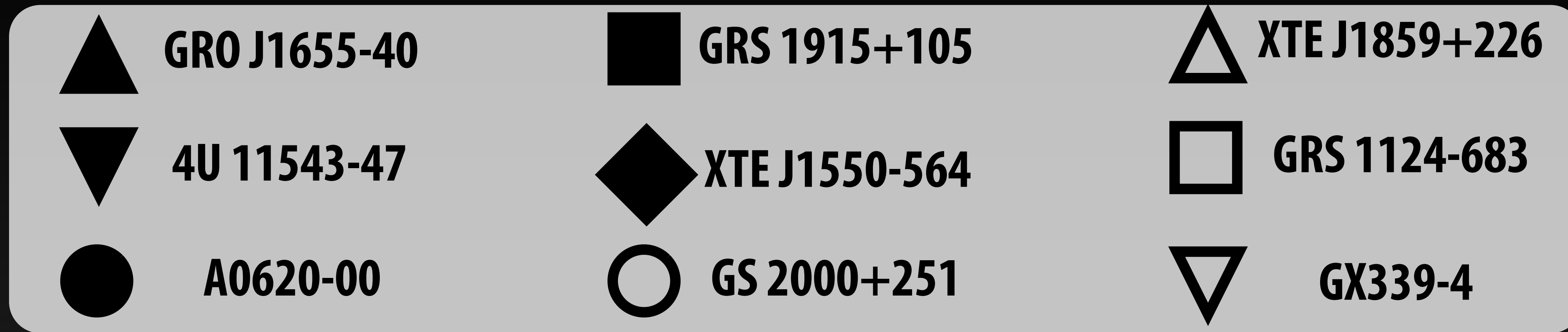
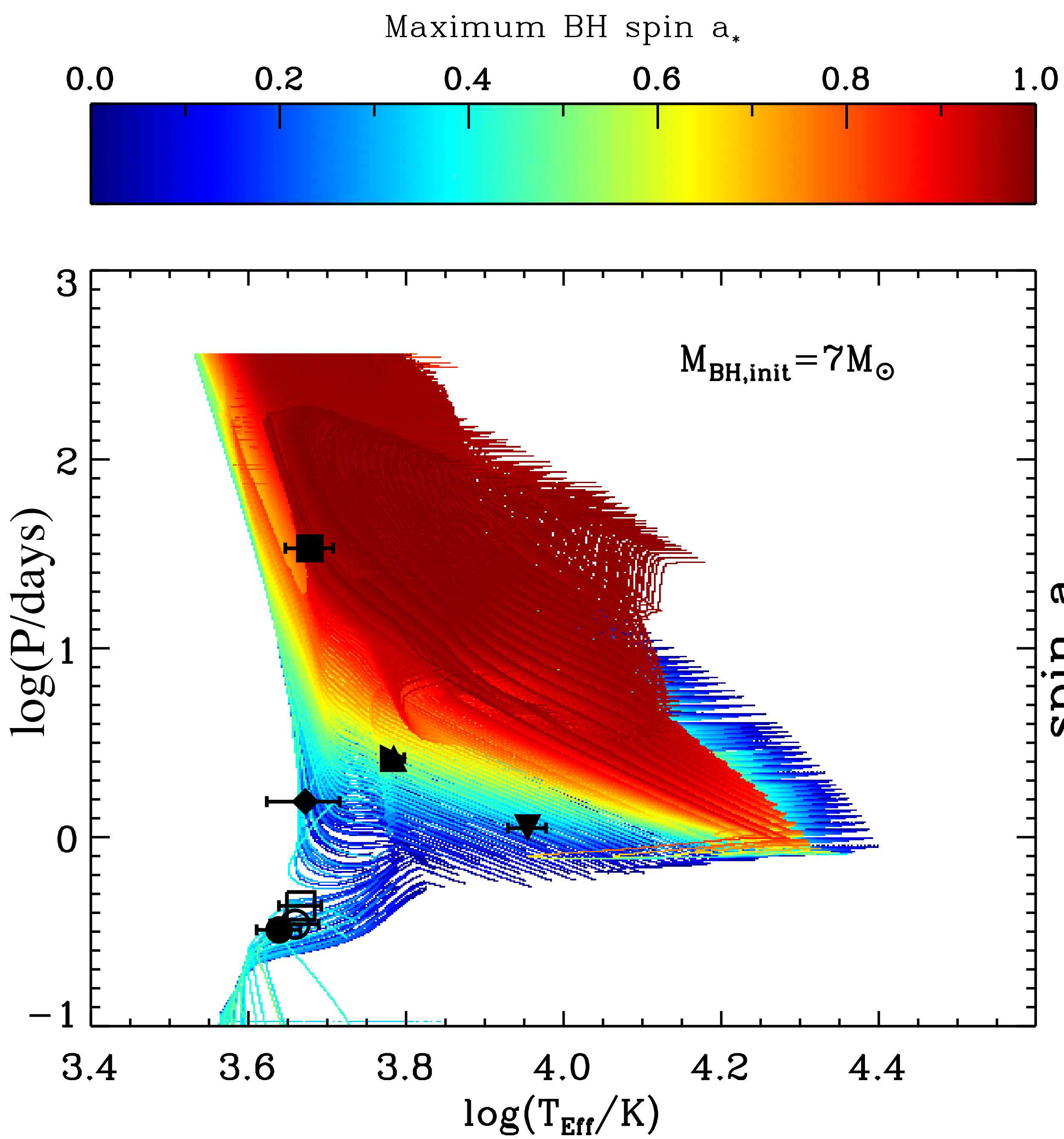
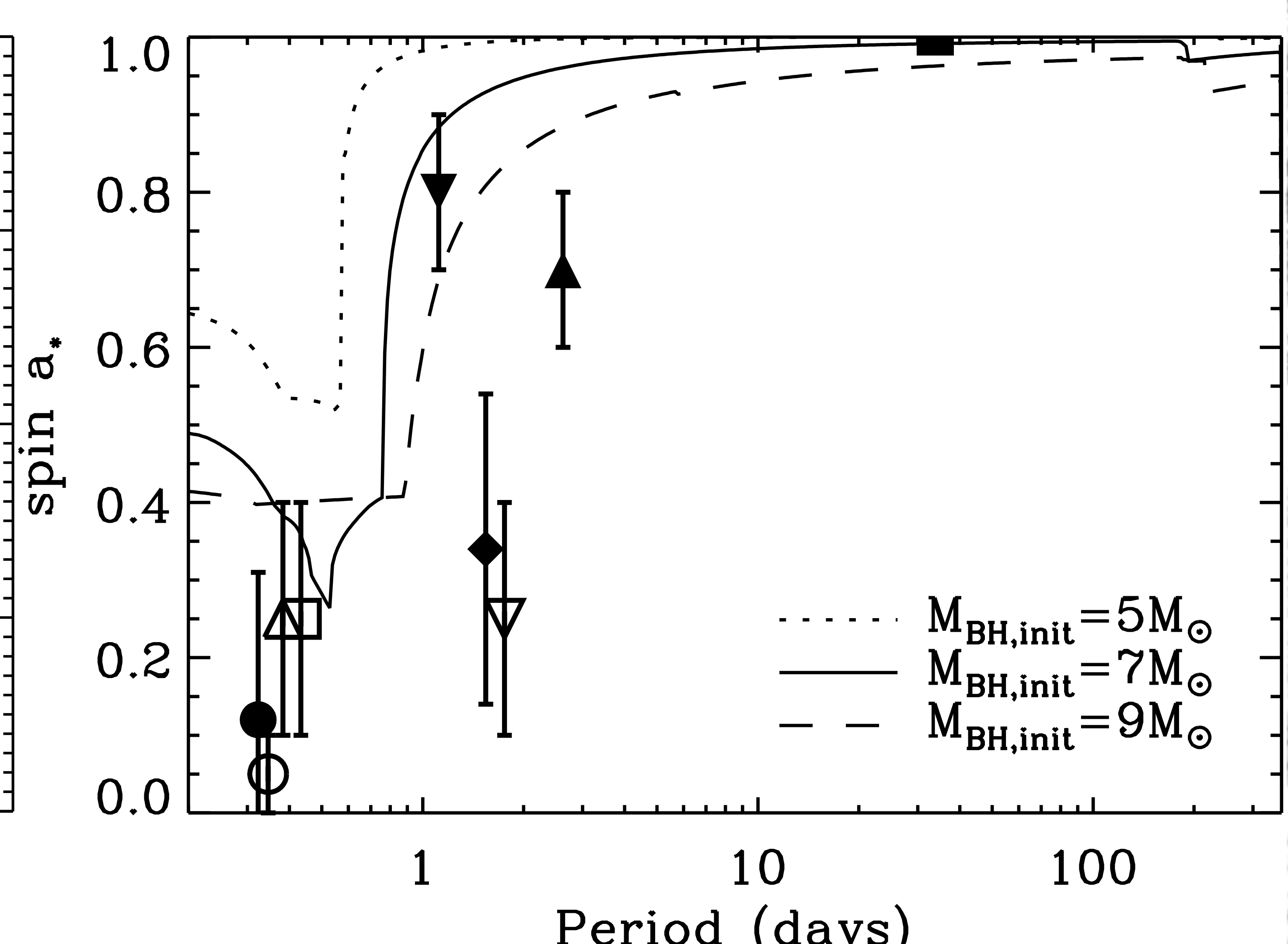
XTE J1859+226	5- 9	0.6-1.8	0.2- 0.9	0.1-1.5	0.02-0.63
GS 2000+251	5- 9	0.9-1.8	0.3- 0.9	0.1-1.3	0.05-0.57
GRO J0422+32	5- 9	0.8-1.5	0.3- 0.7	0.2-1.0	0.09-0.49
GRS 1009-45	6-10	1.0-1.6	0.6- 0.8	0.5-1.3	0.15-0.50
GS 1354-64	3- 9	1.6-6.8	0.6- 2.4	0.0-5.1	0.01-1.00
GS 2023+338	7- 9	1.0-2.0	0.6- 2.0	0.4-1.4	0.13-0.49
H1705-250	4- 6	1.0-1.5	0.4- 0.9	0.9-1.4	0.40-0.63
V4641 Sgr	3- 4	7.0-7.8	1.2- 1.7	2.3-2.6	0.85-0.94
XTE J1118+480	6- 7	1.0-1.8	0.6- 0.8	0.7-1.6	0.29-0.59

Maximum Black Hole Spin

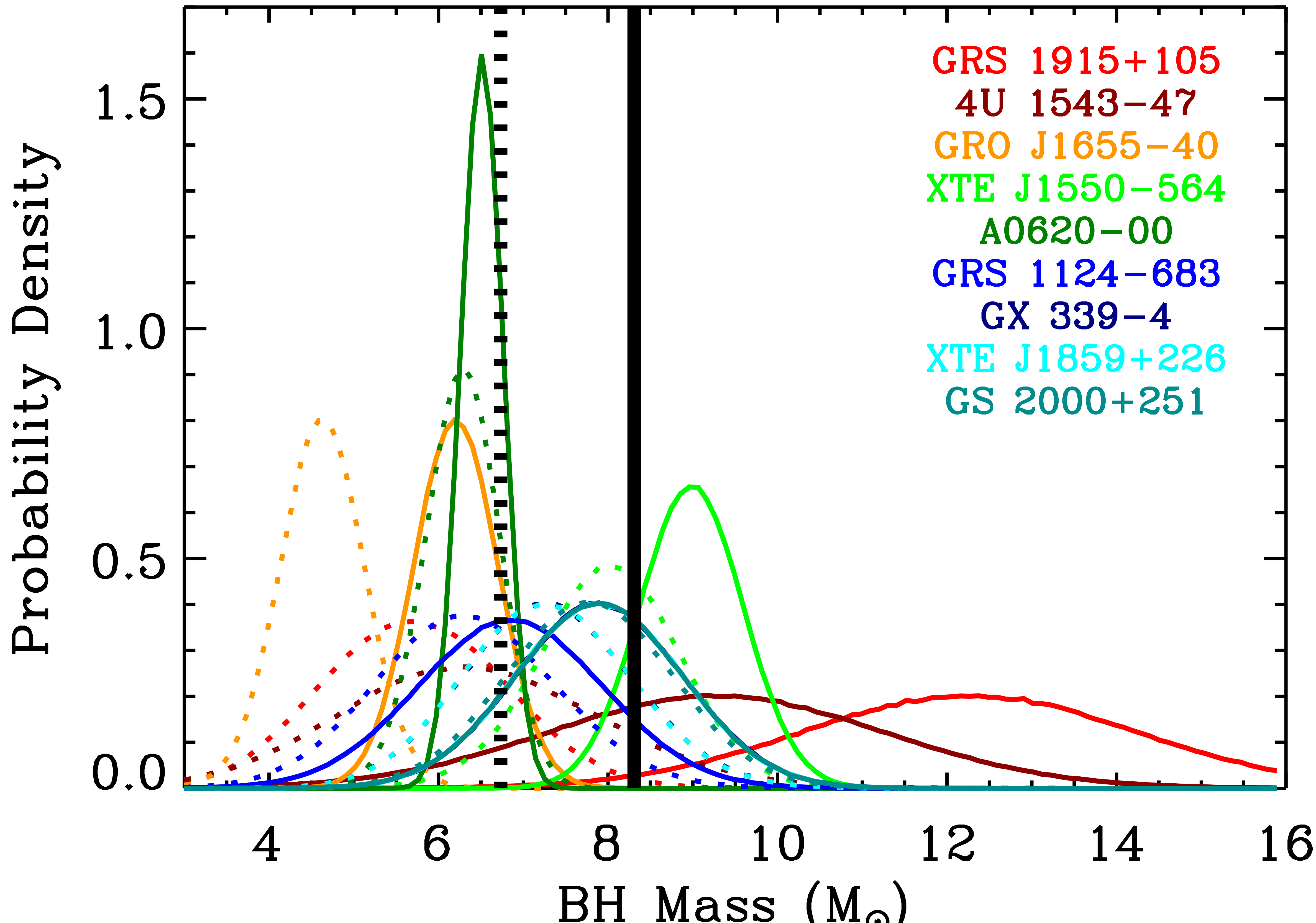




Fragos & McClintock (2015) - ApJ, 800, 17



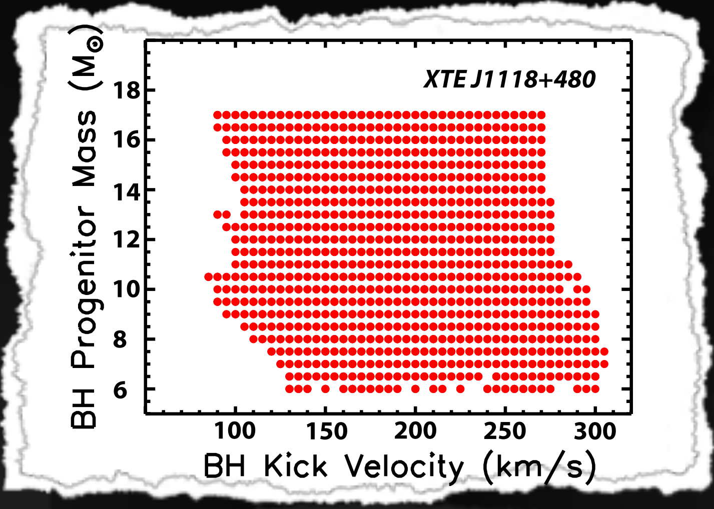
Implications on birth black-hole mass

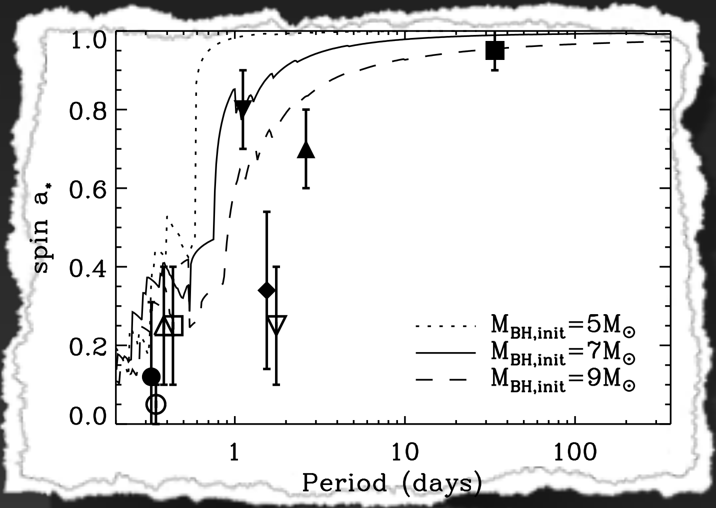


Fragos & McClintock (2015) - ApJ, 800, 17

Summary

The **detailed evolutionary history** of six nearby BH X-ray binaries, taking into account **all available observational constraints** was examined. Doing so, we **derived limits** on **immediate progenitor mass** and **natal kicks magnitude**.





We test the hypothesis that **the observed BH spin in LMXBs is an effect of mass accretion** during the XRB phase. We put **constraints on the maximum BH spin** based on the **observed properties of a system**.

Assuming that the observed BH spin in LMXBs is due to accretion, we find that **the observed M_{BH} spectrum** in these systems **can differ significantly from the initial one.** Indication for bimodal distribution of birth BH masses