The Galactic Population of Accreting Black Holes

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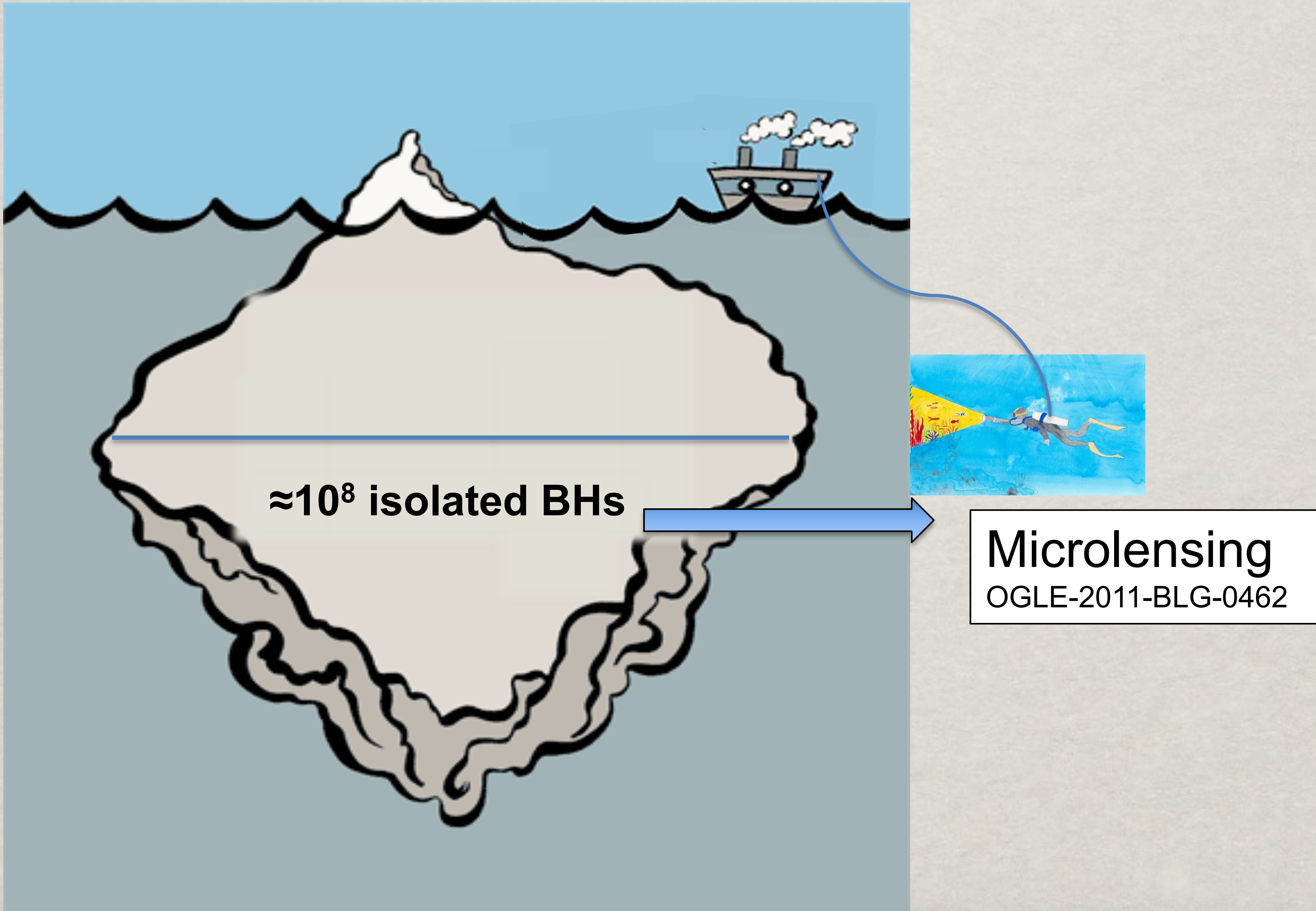
AGENCIA ESTATAL DE INVESTIGACIÓN

BH populations in the MW



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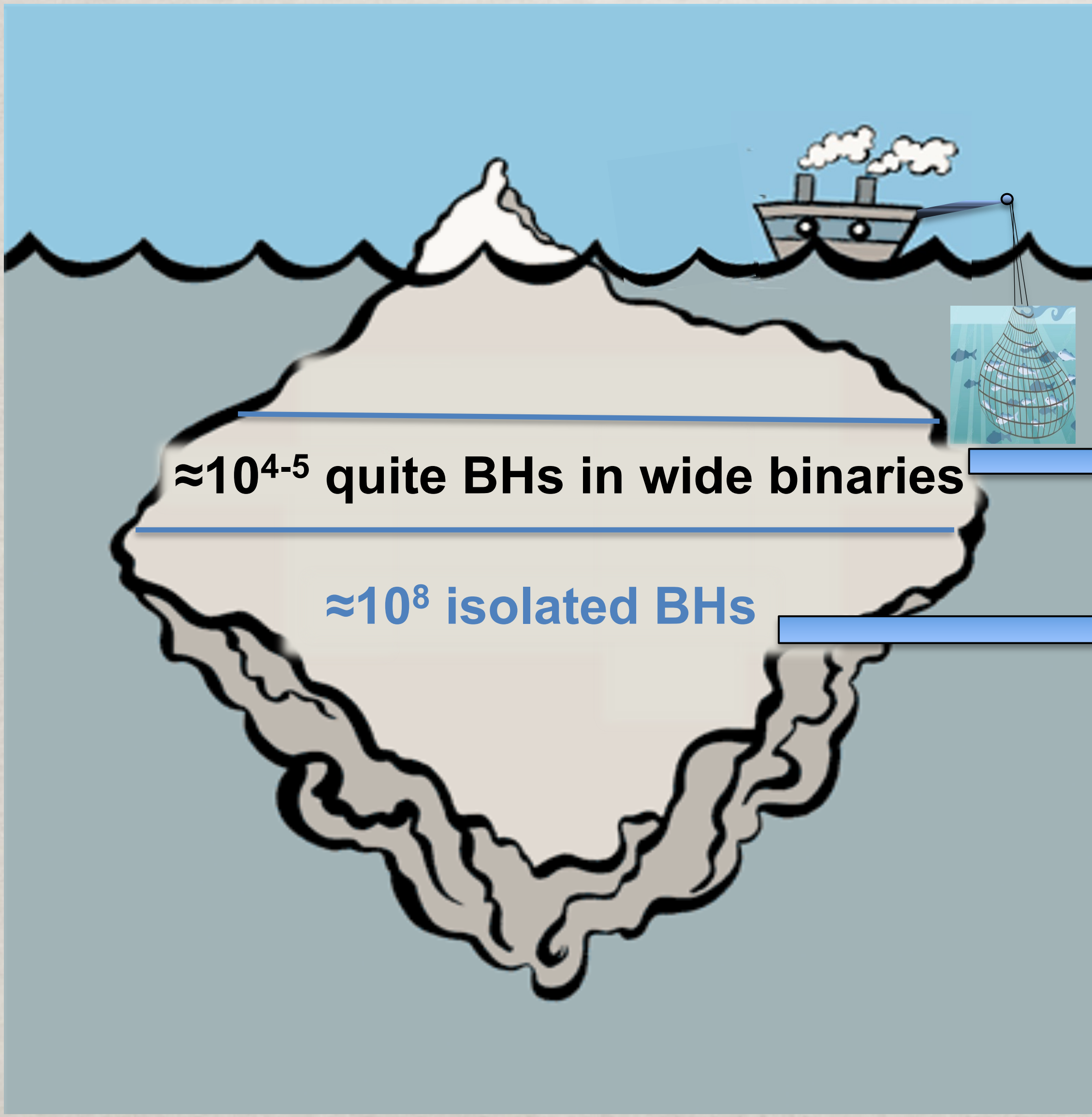
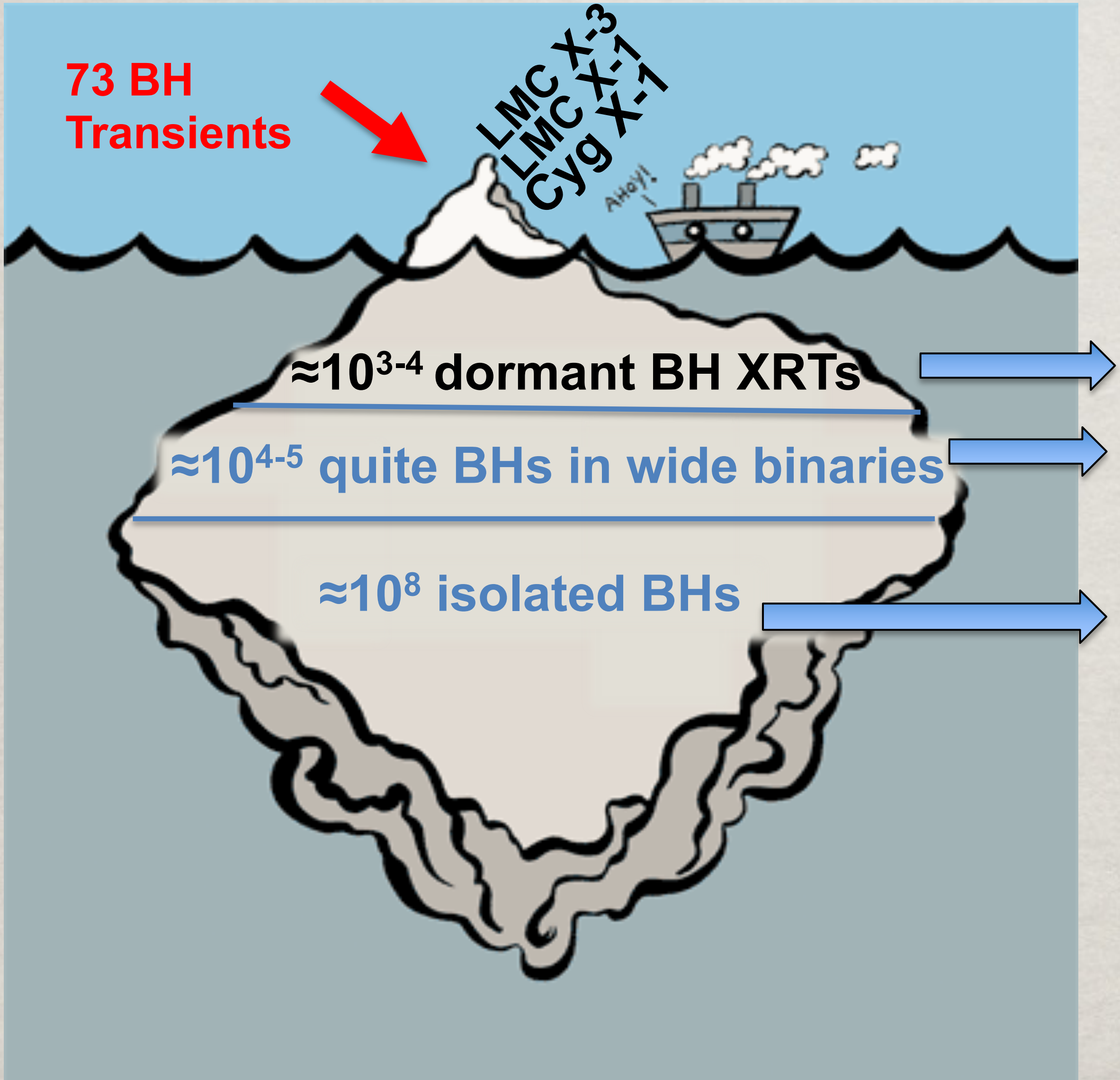


Astrometry & RVs
3 Gaia BHs + VFTS243 + NGC 3201 + HD130298

Microlensing
OGLE-2011-BLG-0462

BH populations in the MW



ACCRETION

Astrometry & RVs

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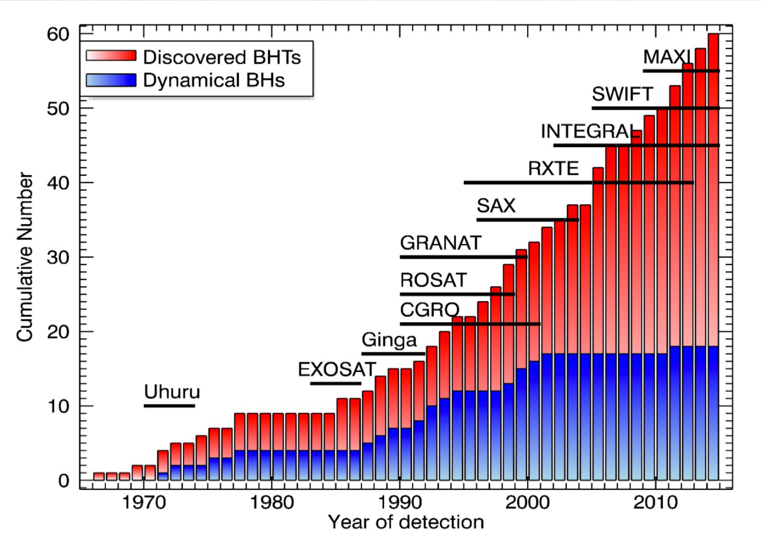
Corral-Santana et al. 2016 (www.astro.puc.cl/BlackCAT)

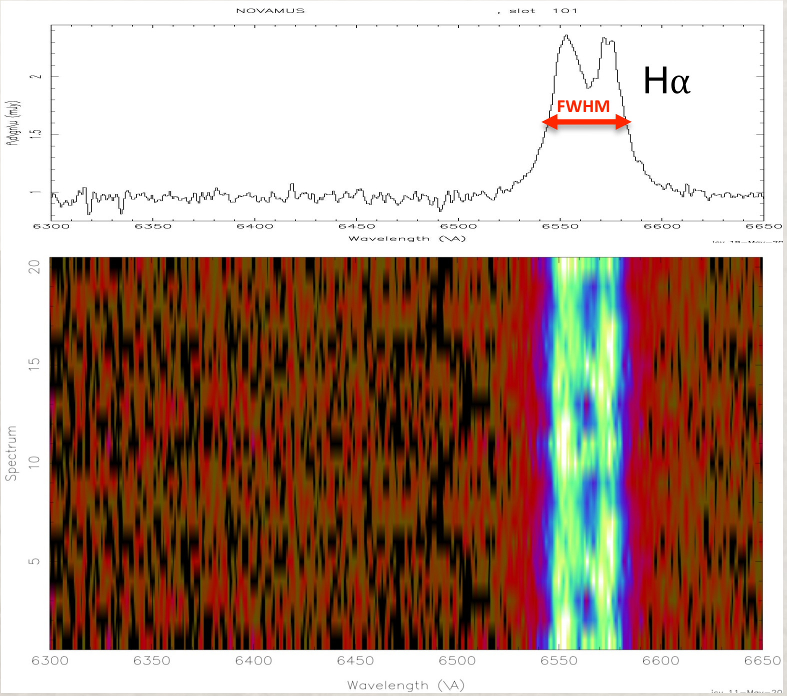


73 BH XRTs discovered in ~60 yr of X-ray astronomy, but only ~33% dynamically confirmed

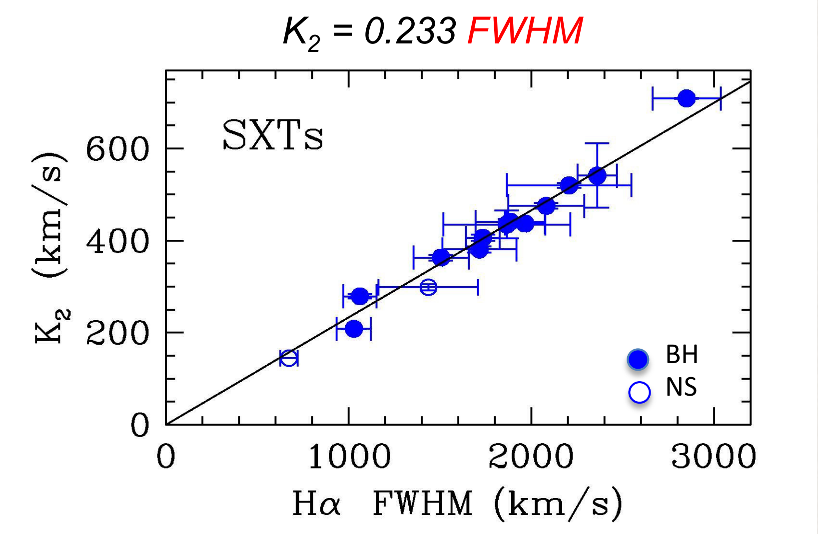
20 dynamical BHs

Remaining XRTs are “lost” in quiescence because become too faint (R≳22) for dynamical studies with 10m-Telescopes

Black holes in (very) faint XRTs



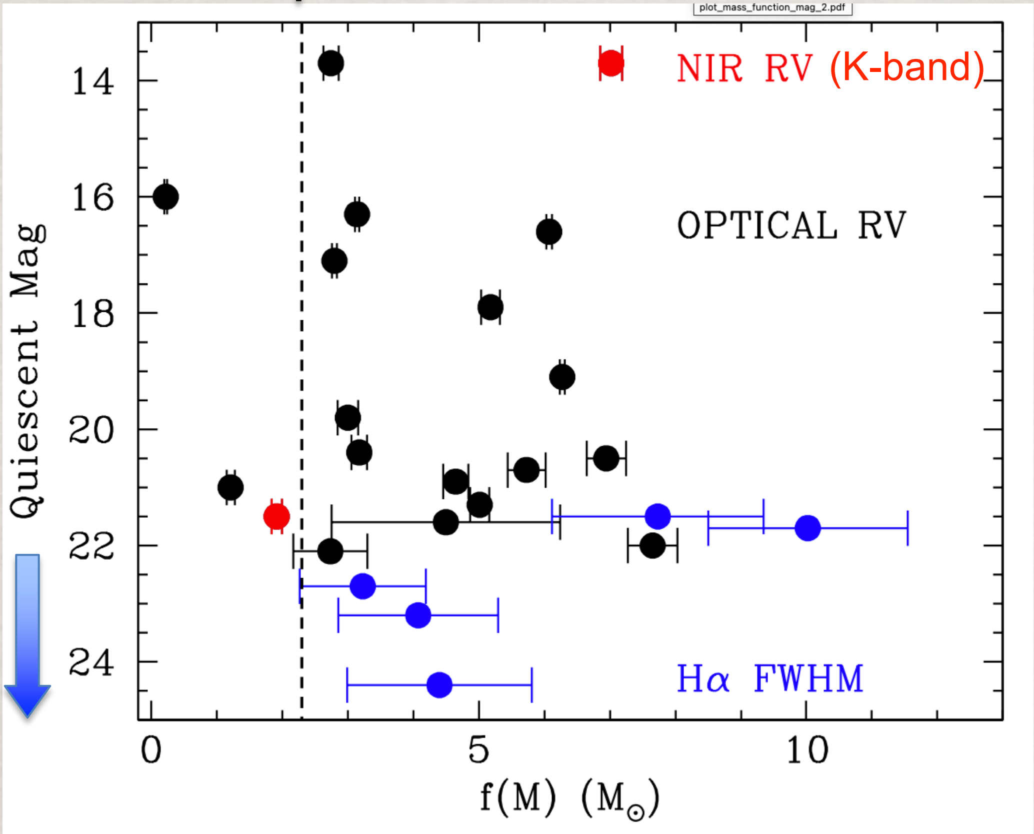
Fundamental scaling between dynamics of disc and donor (Casares 2015)



FWHM + P_{orb} → **Mass function *f(M)***

Census of confirmed BH XRTs

Max NS mass (GW170817; Ruiz+2018)



≈ 3 mag deeper

V4641 Sgr
GRS 1915+105
4U 1543-475
GRO J1655-40
V404 CYG
A0620-00
MAXI J1820+070
XTE J1118+480
N MUS 91
N Vel 93
MAXI J1305-704
BW Cir
N OPH 77
GRO J0422+32
GS 2000+25
GX339-4
XTE J1859+226
XTE J1550-564
XTE J1650-500
Swift J1753-0123
Swift J1357-0933
KY TrA
GRS 1716-249
MAXI J1659-152

FWHM-K$_2$ allows increasing the **census of dynamical BHs** by ~25%

Weighing BHs

$$f(M) \equiv \frac{P_{\rm orb} K_{\rm c}^3}{2\pi G} = \frac{M_{\rm BH} \sin^3 i}{(1+q)^2}$$

$q=M_c/M_{BH} \Longrightarrow V_{rot} \sin i$

Inclination $i \Longrightarrow$ modelling ellipsoidal light curves

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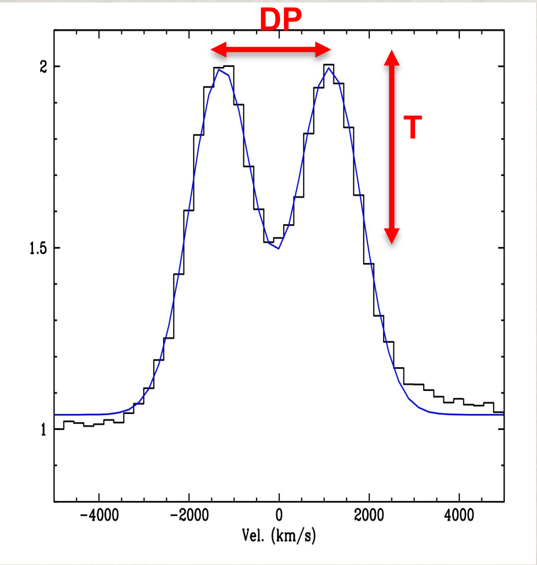
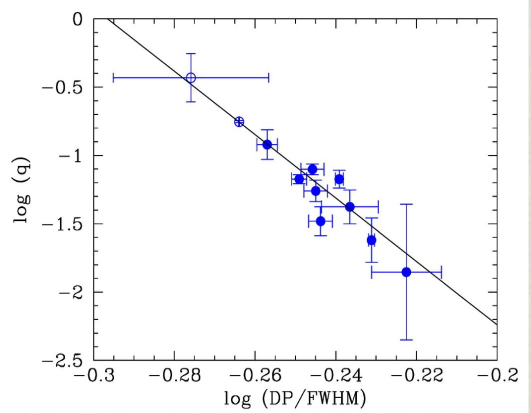
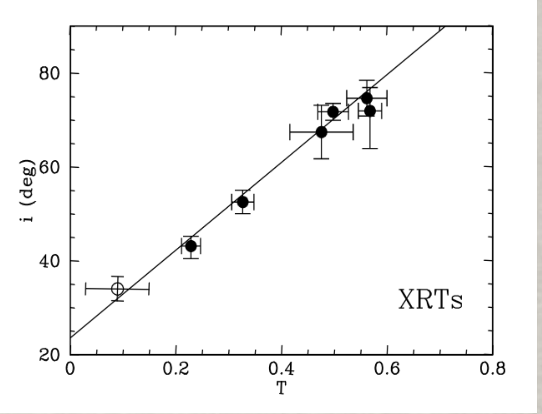
Inclination i → modelling ellipsoidal light curves

If the companion is undetected …





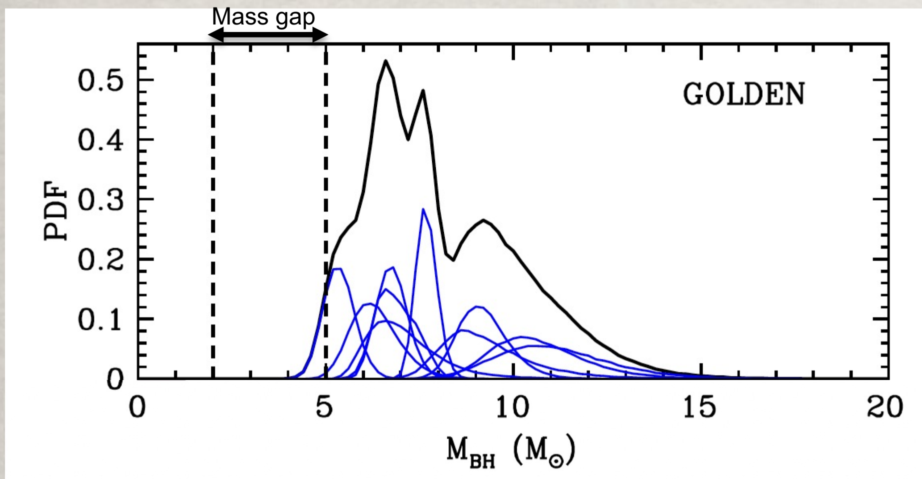
$\log q = -6.88 - 23.2 \ \log (DP/FWHM)$



$i(\mathrm{deg}) = 93.5\ T + 23.7$

The 3 Hα-scaling relations allow estimating BH masses when the companion is undetected (too faint, veiled or blended with interloper)

Revisiting BH masses in XRTs



The Golden Sample

Name	P_{orb} (d)	K_c ($\mathrm{km\,s^{-1}}$)	q	i (deg)	M_{BH} ($M_\odot$)	M_c ($M_\odot$)
XTE J1550-564	1.5420333(24)	363.1± 6.0	0.033±0.006	74.7±3.8	$9.13^{+0.72}_{-0.61}$	$0.30^{+0.07}_{-0.06}$
N. Mus 91	0.43260249(9)	406.8± 2.7	0.079±0.007	$43.2^{+2.1}_{-2.7}$	$10.94^{+1.65}_{-1.34}$	$0.86^{+0.16}_{-0.13}$
MAXI J1305-704	0.394(4)	554± 8	0.05±0.02	$72.0^{+5.0}_{-8.0}$	$9.07^{+1.36}_{-0.90}$	$0.46^{+0.22}_{-0.20}$
GS 2000+25	0.3440915(9)	519.9± 5.1	0.042± 0.012	67.5±5.7	$6.90^{+1.07}_{-0.73}$	$0.29^{+0.10}_{-0.09}$
A 0620-00	0.32301415(7)	435.4± 0.5	0.067± 0.010	52.6±2.5	$6.25^{+0.70}_{-0.58}$	$0.42^{+0.09}_{-0.08}$
XTE J1118+480	0.16993404(5)	708.8± 1.4	0.024± 0.009	71.8±1.8	$7.67^{+0.29}_{-0.26}$	$0.18^{+0.07}_{-0.07}$
GRS 1915+105	33.85(16)	126 ±1	0.042±0.024	64.0±4.0	$10.52^{+1.36}_{-1.05}$	$0.45^{+0.29}_{-0.24}$
MAXI J1820+070	0.68549(1)	417.7± 3.9	0.072± 0.012	66.2-90	$6.83^{+0.60}_{-0.47}$	$0.49^{+0.10}_{-0.10}$
V4641 Sgr	2.81730(1)	211.3±1.0	0.45±0.04	72.3±1.4	$6.74^{+0.46}_{-0.41}$	$2.96^{+0.46}_{-0.42}$
GRO J1655-40	2.62168(14)	215.5±2.4	0.26±0.04	68.7±1.5	$5.30^{+0.45}_{-0.40}$	$1.39^{+0.32}_{-0.29}$

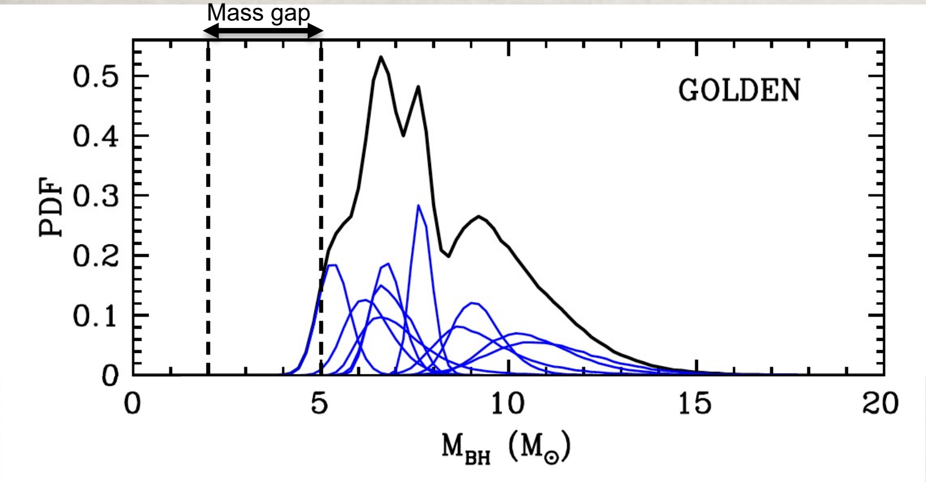
Observables obtained following the **gold standard** i.e.:

(1) *P_{orb} , Kc* $\lesssim$ 1% from radial velocity curve of donor star

(2) *q* from *V_{rot} sin i* of donor's absorption lines

(3) *i* from ellipsoidal modelling of donor's light curve, corrected for disc veiling (in"passive state"), X-ray dips or radio jets

Revisiting BH masses in XRTs



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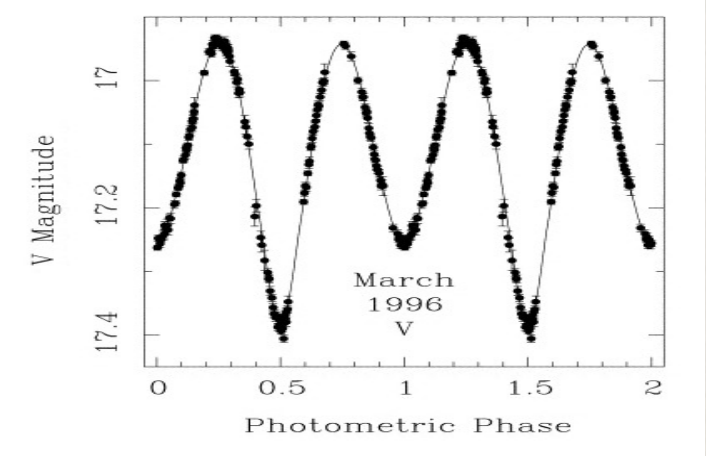
Tomaso Belloni's BH mass in GRO J1655-40

GRO J1655-40



Inclination	Mass Ratio	BH Mass	
69.5±0.1º	0.33±0.01	7.02±0.22 $M_\odot$	(Orosz & Bailyn 97)
70.2±1.9º	0.38±0.04	6.3±0.5 $M_\odot$	(Greene +01)
68.7±1.5º	**0.26±0.04**	**5.4±0.3 $M_\odot$**	(Beer & Podsiadlowski 02)

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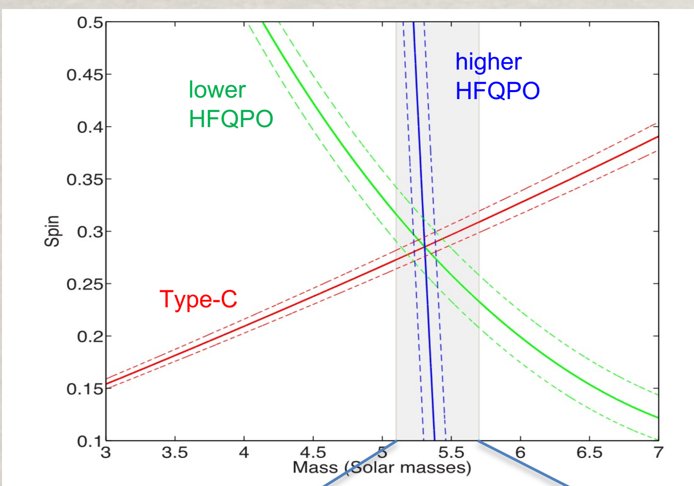
Relativistic Precession Model (Stella &Vietri 98)



Beer & Podsiadlowski 02

MNRAS **437,** 2554–2565 (2014) doi:10.1093/mnras/stt2068
Advance Access publication 2013 November 27

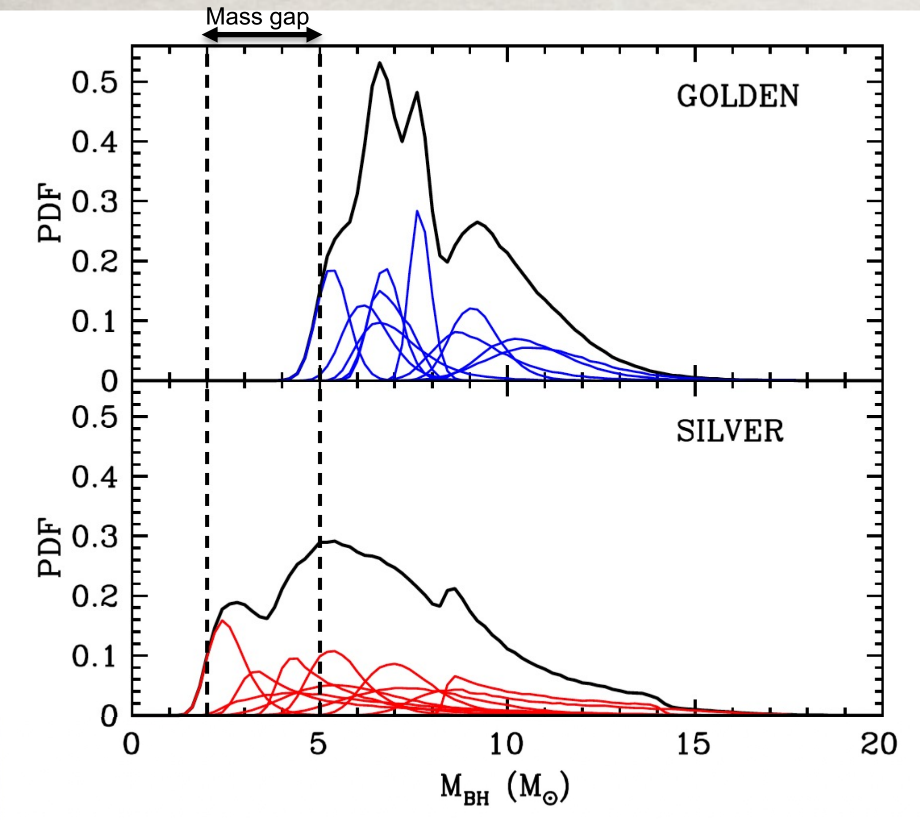
Precise mass and spin measurements for a stellar-mass black hole through X-ray timing: the case of GRO J1655−40

S. E. Motta,[1★] T. M. Belloni,[2] L. Stella,[3] T. Muñoz-Darias[4] and R. Fender[4]

3 simultaneous QPOs allow constraining BH Mass & Spin

$\boxed{M_{BH}=5.31\pm 0.07\ M_\odot}$

Revisiting BH masses in XRTs



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BW Cir	2.54451(8)	279.0±4.7	0.120±0.035	50–90	$9.77^{+3.35}_{-1.77}$	$1.18^{+0.60}_{-0.44}$
GX 339-4	1.7587(5)	219±3	0.18 ±0.05	37–90	$4.33^{+3.45}_{-1.17}$	$0.81^{+0.67}_{-0.33}$
4U 1543-474	1.1163(5)	124±4	0–0.5	18–28	$5.44^{+3.47}_{-1.92}$	$1.35^{+1.80}_{-1.04}$
N. Oph 77	0.5213(13)	441±6	0–0.053	61.6±4.4	$7.16^{+1.10}_{-0.84}$	$0.19^{+0.14}_{-0.13}$
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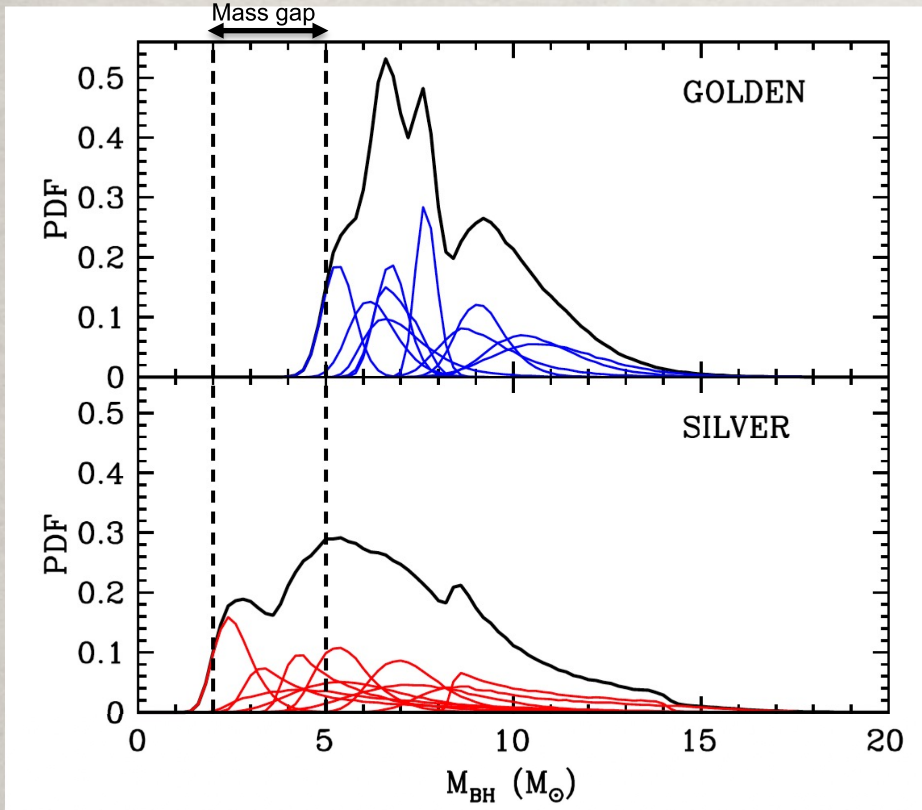
N. Vel 93	0.2852060(14)	475.4±5.9	0.055±0.010	59.7±4.3	$5.48^{+0.87}_{-0.67}$	$0.30^{+0.08}_{-0.07}$
XTE J1859+226	0.276(3)	562±40	0.07±0.01	66.6±4.3	$7.55^{+1.97}_{-1.62}$	$0.53^{+0.17}_{-0.13}$
GRO J0422+32	0.2121600(2)	372±10	$0.116^{+0.079}_{-0.071}$	55.6±4.1	$2.56^{+0.58}_{-0.48}$	$0.31^{+0.26}_{-0.19}$

(1) P_{orb} , *Kc* and *q/i* following the gold standard

(2) *q and/or i* from Hα-scaling or, alternatively, geometrical constraints (e.g. lack of X-ray eclipses, zero veiling …)

Revisiting BH masses in XRTs



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MNRAS **517**, 1469–1475 (2022) https://doi.org/10.1093/mnras/stac2142
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Black hole mass and spin measurements through the relativistic precession model: XTE J1859+226

S. E. Motta[1,2★] T. Belloni,[1] L. Stella[3] G. Pappas[4] J. Casares[5,6] A. T. Muñoz-Darias[5,6] M. A. P. Torres[5,6] and I. V. Yanes-Rizo[5,6]

M_{BH}=7.85± 0.45 $M_\odot$

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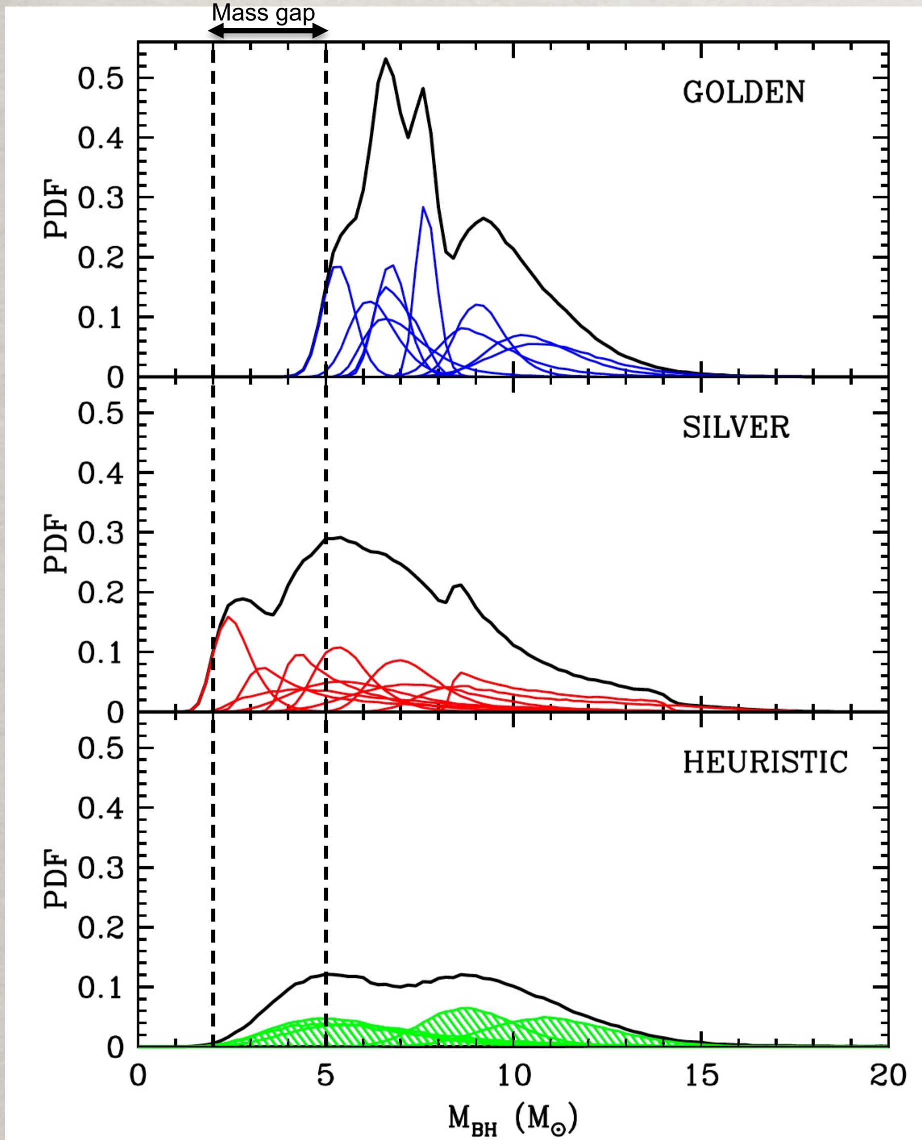

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XTE J1550-564	1.5420333(24)	363.1± 6.0	0.033±0.006	74.7±3.8	$9.13^{+0.72}_{-0.61}$	$0.30^{+0.07}_{-0.06}$
N. Mus 91	0.43260249(9)	406.8± 2.7	0.079±0.007	$43.2^{+2.1}_{-2.7}$	$10.94^{+1.65}_{-1.34}$	$0.86^{+0.16}_{-0.13}$
MAXI J1305-704	0.394(4)	554± 8	0.05±0.02	$72.0^{+5.0}_{-8.0}$	$9.07^{+1.36}_{-0.90}$	$0.46^{+0.22}_{-0.20}$
GS 2000+25	0.3440915(9)	519.9± 5.1	0.042± 0.012	67.5±5.7	$6.90^{+1.07}_{-0.73}$	$0.29^{+0.10}_{-0.09}$
A 0620-00	0.32301415(7)	435.4± 0.5	0.067± 0.010	52.6±2.5	$6.25^{+0.70}_{-0.58}$	$0.42^{+0.09}_{-0.08}$
XTE J1118+480	0.16993404(5)	708.8± 1.4	0.024± 0.009	71.8±1.8	$7.67^{+0.29}_{-0.26}$	$0.18^{+0.07}_{-0.07}$
GRS 1915+105	33.85(16)	126 ±1	0.042±0.024	64.0±4.0	$10.52^{+1.36}_{-1.05}$	$0.45^{+0.29}_{-0.24}$
MAXI J1820+070	0.68549(1)	417.7± 3.9	0.072± 0.012	66.2-90	$6.83^{+0.60}_{-0.47}$	$0.49^{+0.10}_{-0.10}$
V4641 Sgr	2.81730(1)	211.3±1.0	0.45±0.04	72.3±1.4	$6.74^{+0.46}_{-0.41}$	$2.96^{+0.46}_{-0.42}$
GRO J1655-40	2.62168(14)	215.5±2.4	0.26±0.04	68.7±1.5	$5.30^{+0.45}_{-0.40}$	$1.39^{+0.32}_{-0.29}$

The Silver Sample

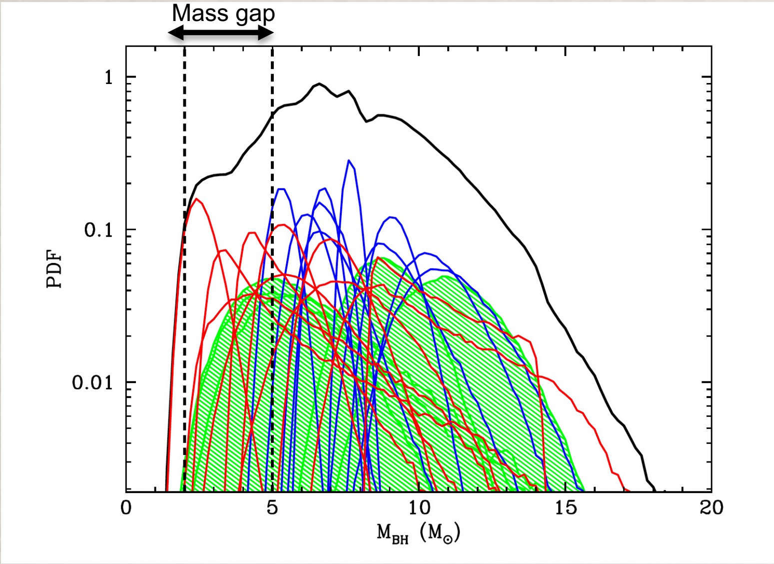
Name	P_{orb} (d)	K_c (km s^{-1})	q	i (deg)	M_{BH} ($M_\odot$)	M_c ($M_\odot$)
V404 Cyg	6.471170(2)	208.4±0.5	0.067±0.005	52–70	$10.21^{+2.31}_{-1.43}$	$0.68^{+0.16}_{-0.10}$
BW Cir	2.54451(8)	279.0±4.7	0.120±0.035	50–90	$9.77^{+3.35}_{-1.77}$	$1.18^{+0.60}_{-0.44}$
GX 339-4	1.7587(5)	219±3	0.18 ±0.05	37–90	$4.33^{+3.45}_{-1.17}$	$0.81^{+0.67}_{-0.33}$
4U 1543-474	1.1163(5)	124±4	0–0.5	18–28	$5.44^{+3.47}_{-1.92}$	$1.35^{+1.80}_{-1.04}$
N. Oph 77	0.5213(13)	441±6	0–0.053	61.6±4.4	$7.16^{+1.10}_{-0.84}$	$0.19^{+0.14}_{-0.13}$
Swift J1727.8-1613	0.45017(4)	390±4	0.13±0.07	41–74	$5.69^{+3.31}_{-1.43}$	$0.78^{+0.71}_{-0.44}$
XTE J1650-500	0.3205(7)	435±30	0–0.09	53.2±4.8	$5.82^{+1.94}_{-1.43}$	$0.25^{+0.23}_{-0.18}$
N. Vel 93	0.2852060(14)	475.4±5.9	0.055±0.010	59.7±4.3	$5.48^{+0.87}_{-0.67}$	$0.30^{+0.08}_{-0.07}$
XTE J1859+226	0.276(3)	562±40	0.07±0.01	66.6±4.3	$7.55^{+1.97}_{-1.62}$	$0.53^{+0.17}_{-0.13}$
GRO J0422+32	0.2121600(2)	372±10	$0.116^{+0.079}_{-0.071}$	55.6±4.1	$2.56^{+0.58}_{-0.48}$	$0.31^{+0.26}_{-0.19}$

The Heuristic Sample

Name	P_{orb} (d)	K_c (km s^{-1})	q	i (deg)	M_{BH} ($M_\odot$)	M_c ($M_\odot$)
N. OPH 93	0.278(8)	521±52	0.02–0.25	61±15	$6.39^{+3.21}_{-1.94}$	$0.50^{+0.32}_{-0.27}$
KY TrA	0.26(1)	501±52	0.01–0.31	57±13	$5.76^{+3.14}_{-1.86}$	$0.45^{+0.32}_{-0.28}$
Swift J1753.5-0127	0.136(1)	820±36	0.023±0.006	79±5	$8.83^{+1.32}_{-1.17}$	$0.20^{+0.07}_{-0.06}$
Swift J1357.2-0933	0.106969(23)	967±49	$0.040^{+0.003}_{-0.005}$	$87.4^{+2.6}_{-5.6}$	$10.98^{+1.77}_{-1.60}$	$0.44^{+0.09}_{-0.08}$
MAXI J1659-152	0.10058(2)	750±80	0.02–0.07	70–80	$5.32^{+1.92}_{-1.54}$	$0.23^{+0.14}_{-0.10}$

Donor undetected → All quantities (except P_{orb}) derived from Hα-scaling or geometrical constraints

Revisiting BH masses in XRTs



- Peak at ~6-9 $M_\odot$ (Ozel+10, Farr+11, Kreidberg+12)
- BHs within the 2-5 $M_\odot$ gap (e.g. GRO J0422+32)
- Maximum BH mass (99.73% percentile) at 15 $M_\odot$ (Belczynski+10)

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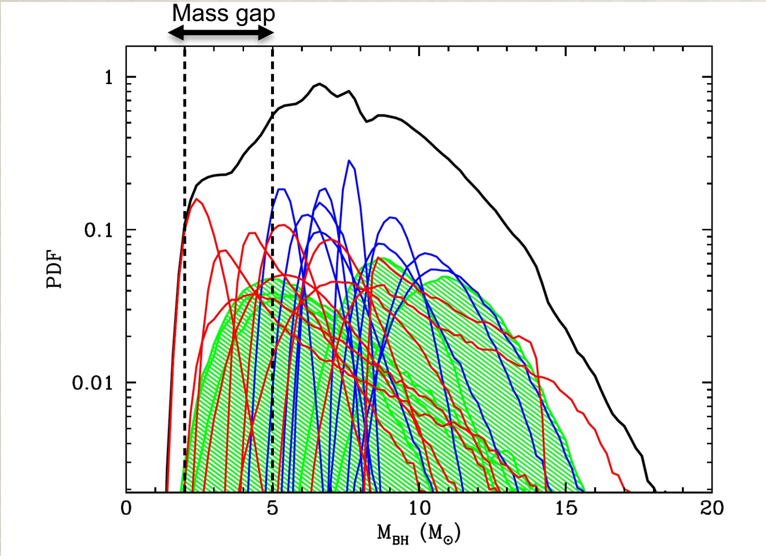

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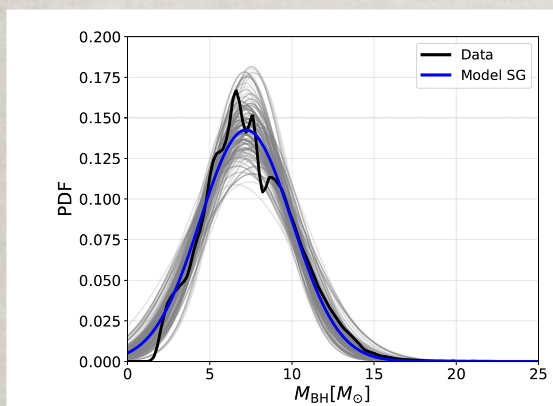
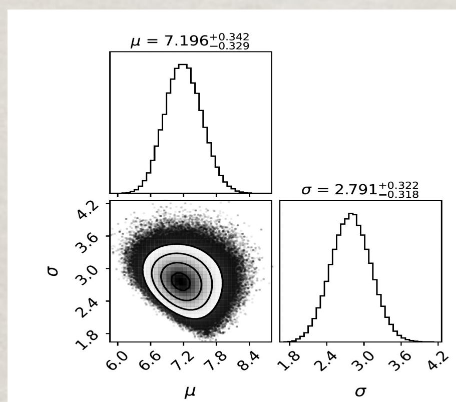
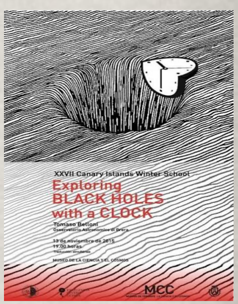




Well described by simple Gaussian but functional form still limited by poor statisitcs

Conclusions

- We have **revised and updated** BH masses in 25 Galactic XRTs, including 5 faint systems based on Hα-scaling relations: 60% increase wrt previous works



- 2 BH masses derived through X-ray timing and are in **excellent agreement** with the optical values (Belloni!!)

- Observed distribution well described by a simple Gaussian, with peak at 7.2 $M_\odot$ and paucity of systems between 2-5 $M_\odot$, but no sharp gap. More BH masses still required

- See posters by Sara Navarro-Umpiérrez and Gastón Escobar for a new strategy to unveil quiescent BH transients using a blind photometric survey: *Mini-HαWKS*