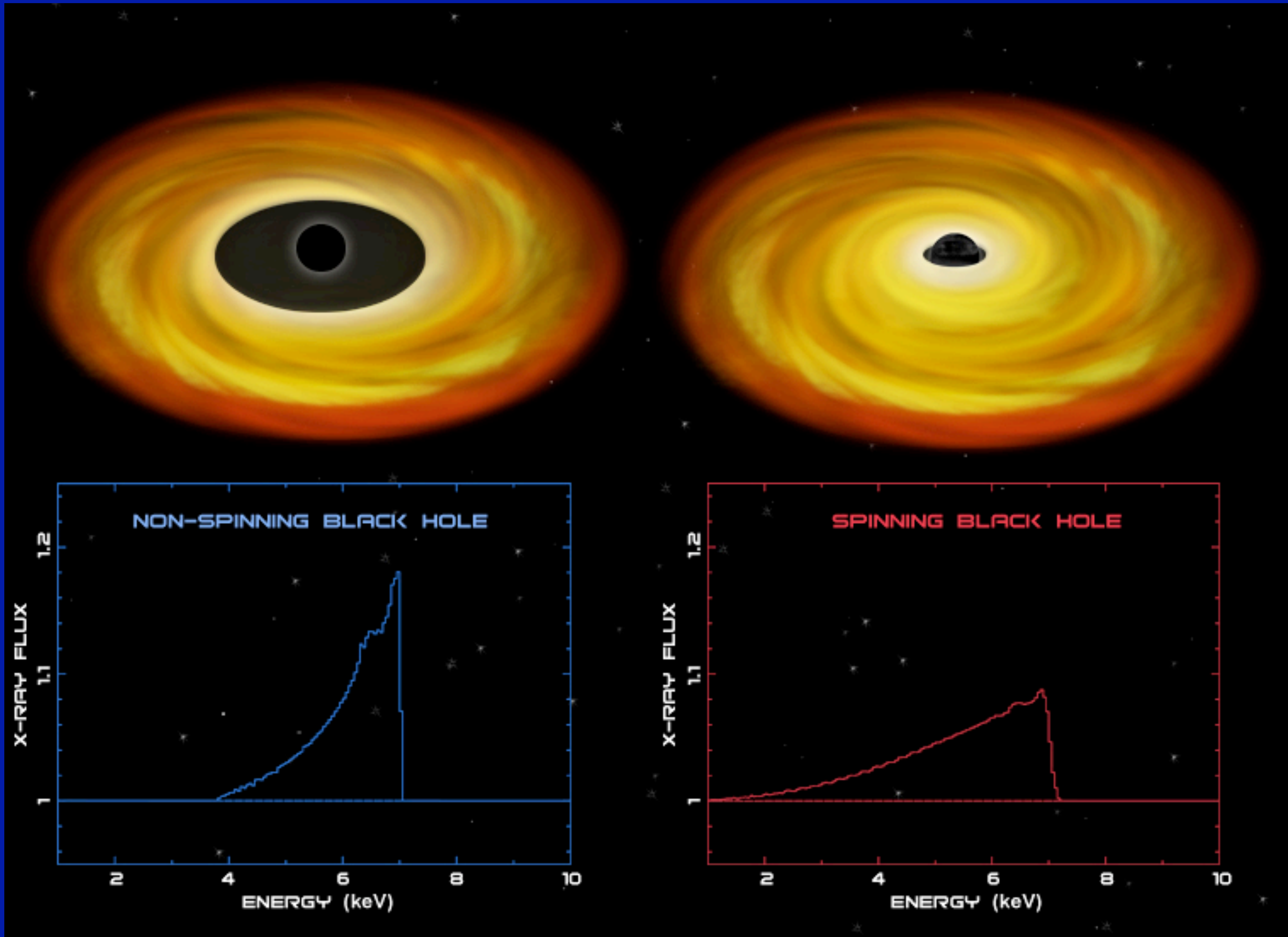
Measuring the Spins of Accreting Black Holes

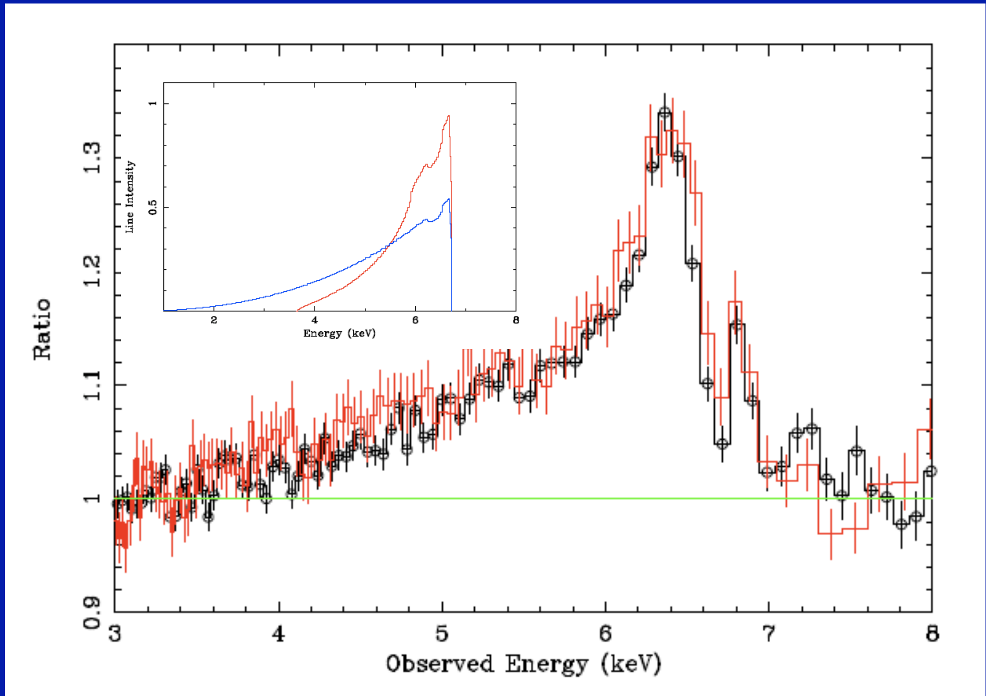
Jeffrey E. McClintock[1], Ramesh Narayan[1], Shane W. Davis[2], Lijun Gou[1], Akshay Kulkarni[1], Jerome A. Orosz[3], Robert F. Penna[1], Ronald A. Remillard[4], James F. Stei

ABSTRACT

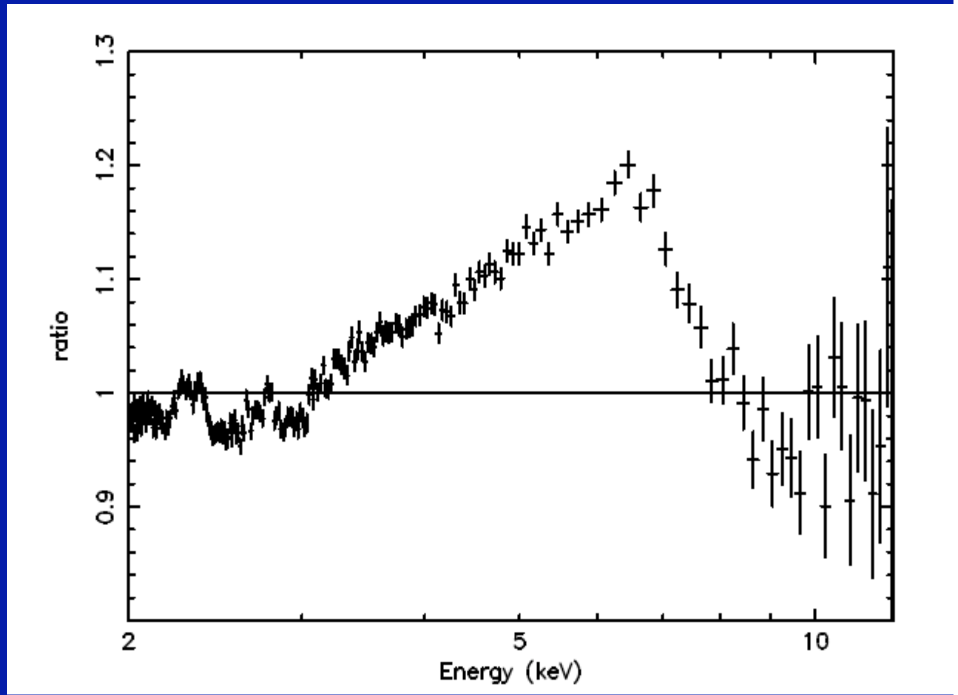
A typical galaxy is thought to contain tens of millions of stellar-mass black holes, the collapsed remnants of once massive stars, and a single nuclear supermassive black hole. Both classes of black holes accrete gas from their environments. The accreting gas forms a flattened orbiting structure known as an accretion disk. During the past several years, it has become possible to obtain measurements of the spins of the two classes of black holes by modeling the X-ray emission from their accretion disks. Two methods are employed, both of which depend upon identifying the inner radius of the accretion disk with the innermost stable circular orbit (ISCO), whose radius depends only on the mass and spin of the black hole. In the Fe Kα method, which applies to both classes of black holes, one models the profile of the relativistically-broadened iron line with a special focus on the gravitationally redshifted red wing of the line. In the continuum-fitting method, which has so far only been applied to stellar-mass black holes, one models the thermal X-ray continuum spectrum of the accretion disk. We discuss both methods, with a strong emphasis on the continuum-fitting method and its application to stellar-mass black holes. Spin results for eight stellar-mass black holes are summarized. These data are used to argue that the high spins of at least some of these black holes are natal, and that the presence or absence of relativistic jets in accreting black holes is not entirely determined by the spin of the black hole.


NON-SPINNING BLACK HOLE
SPINNING BLACK HOLE
X-RAY FLUX
1
1.1
1.2
2
4
6
8
10
ENERGY (keV)

A supermassive black hole

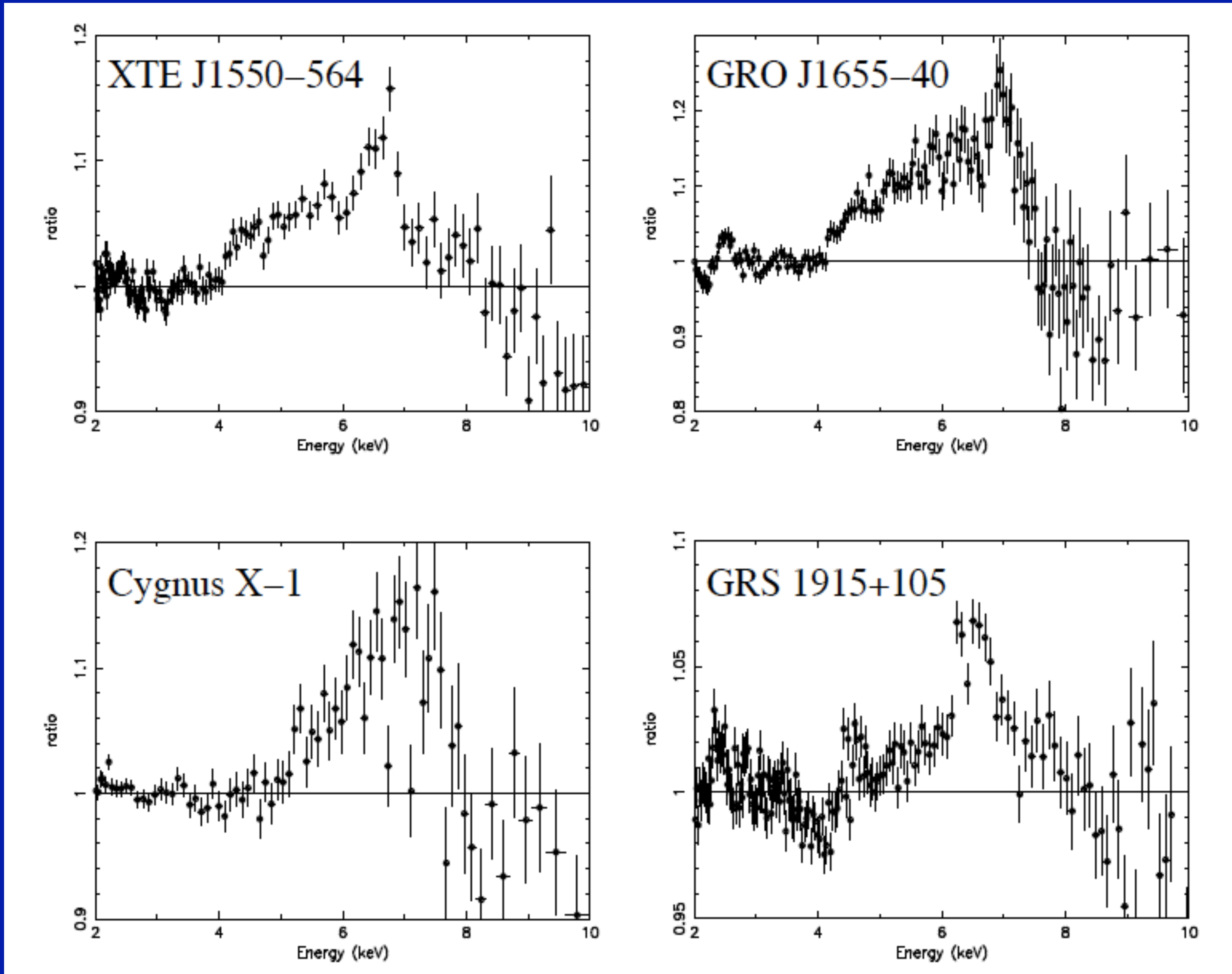


A stellar mass black hole



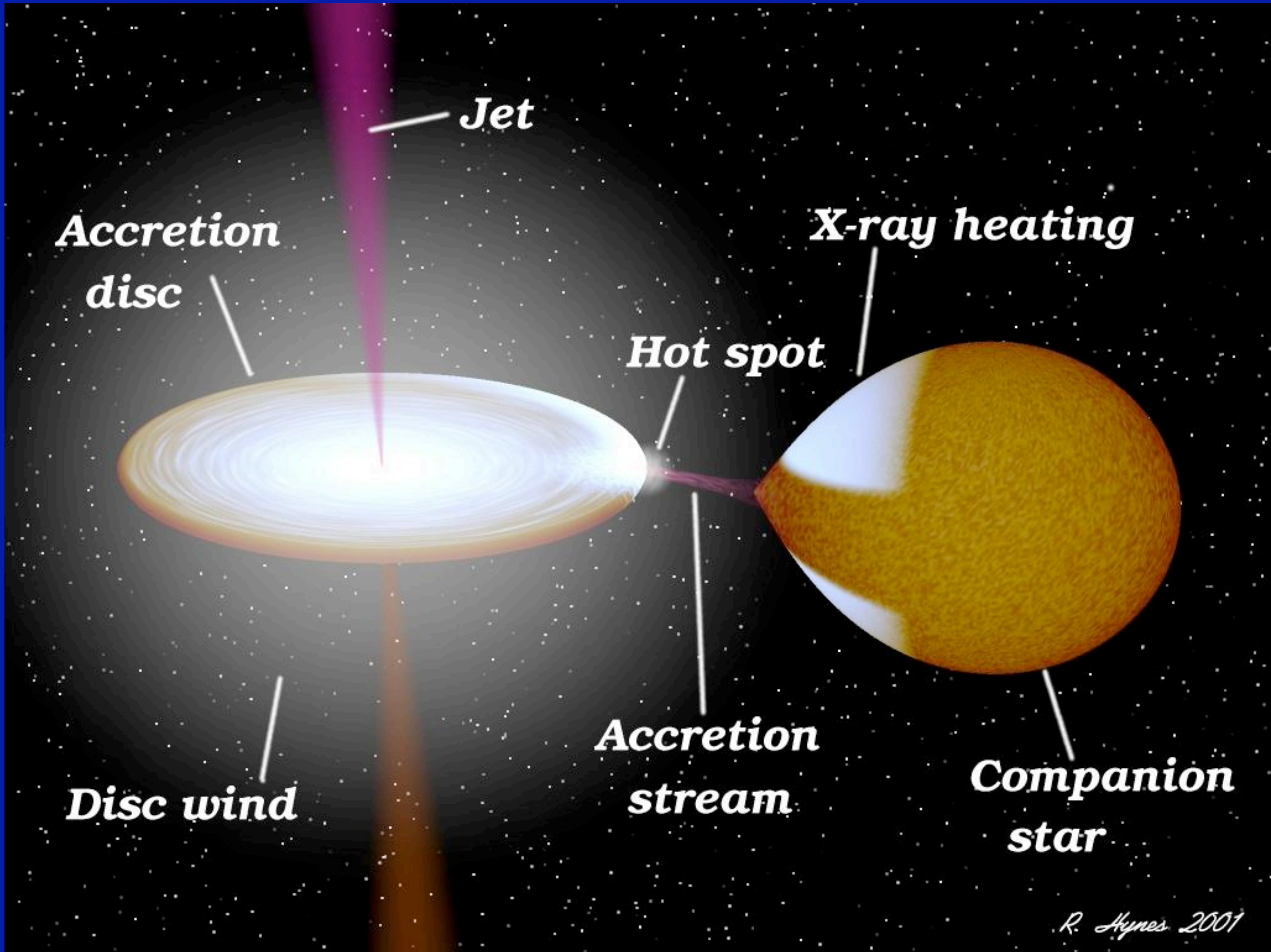
Two examples of iron emission lines in X-ray spectra of what appear to be rapidly spinning black holes

From Miller 2007, ARAA

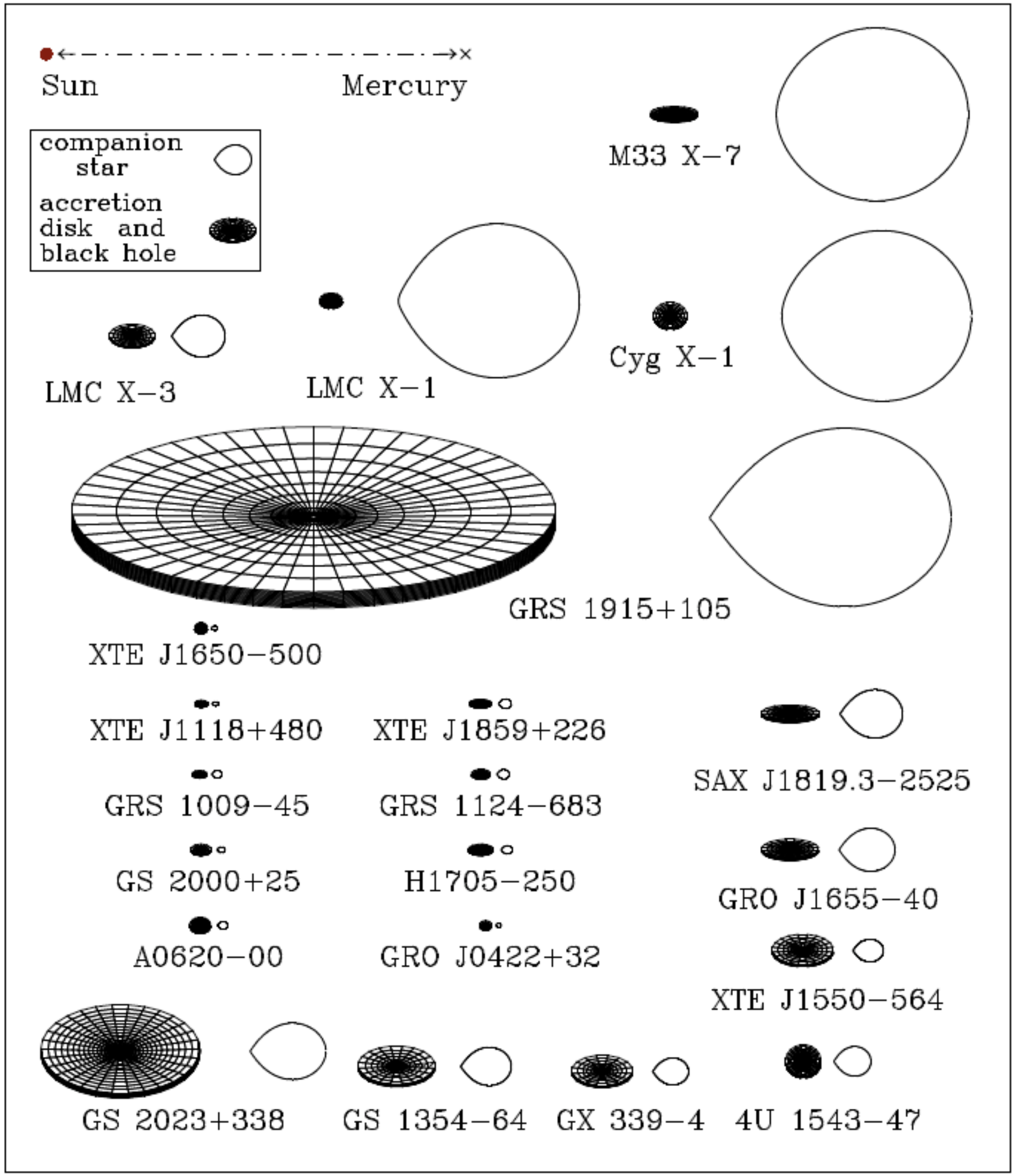


X-ray iron lines of four stellar mass black holes

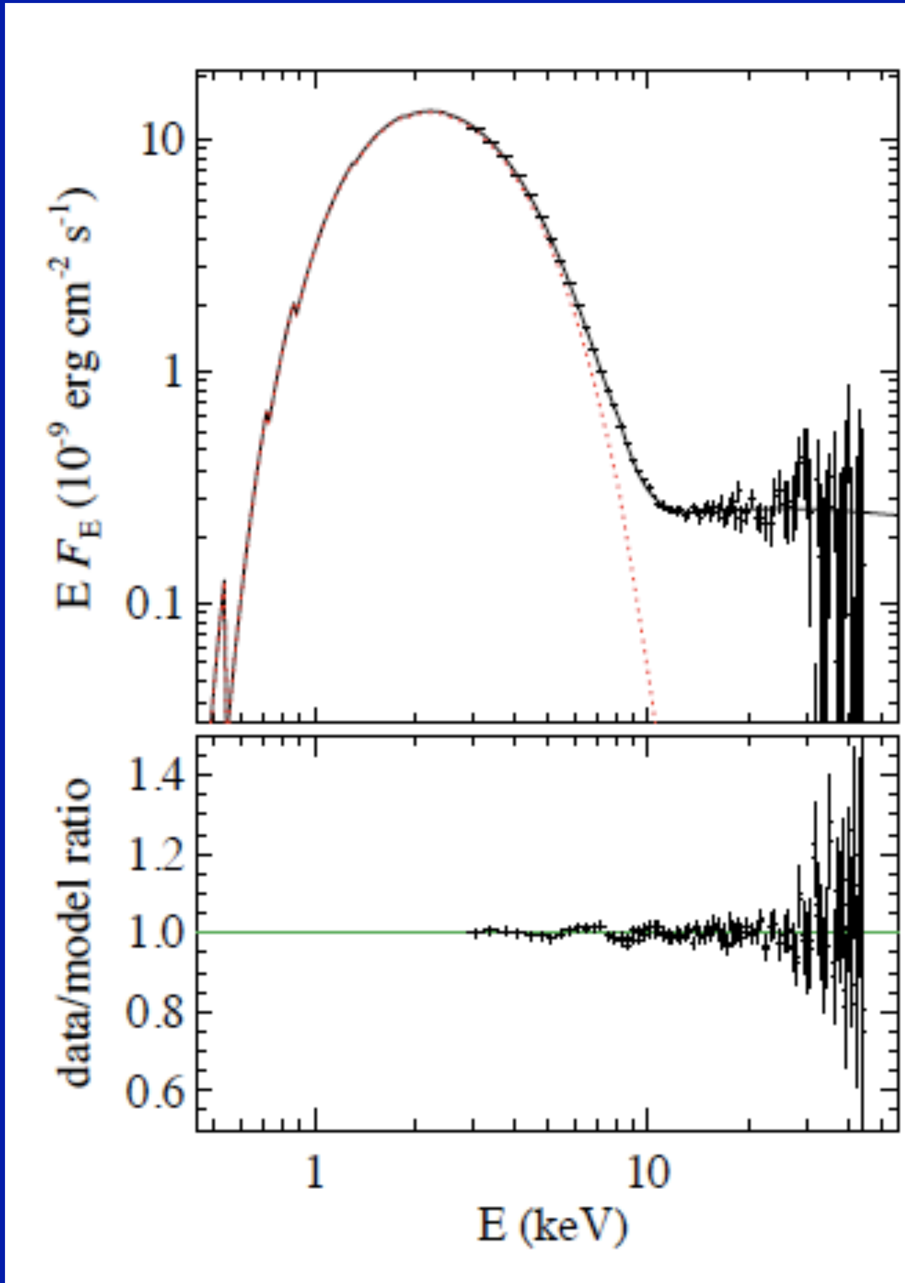
From Miller 2007, ARAA



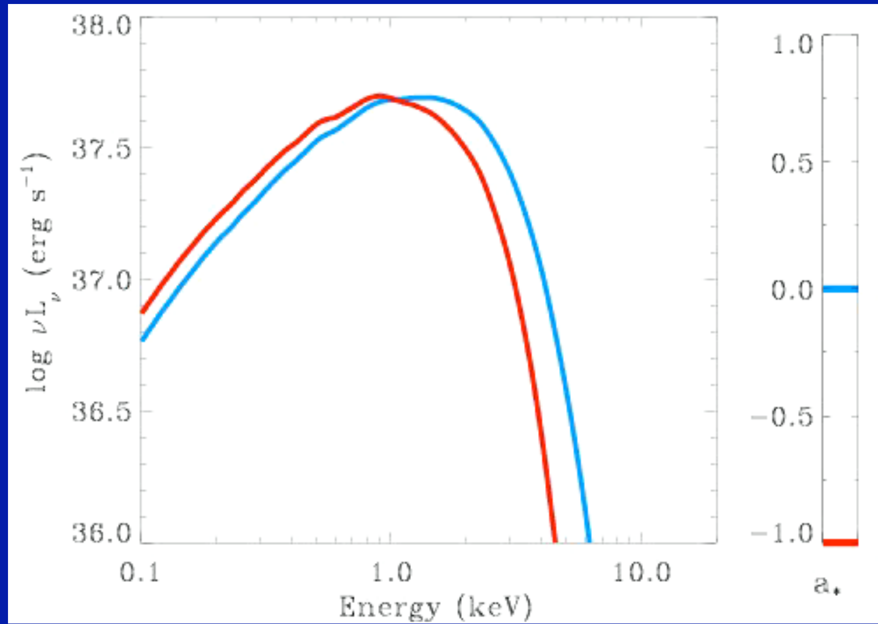
Jet
Accretion disc
X-ray heating
Hot spot
Accretion stream
Companion star
Disc wind
R. Hynes 2001



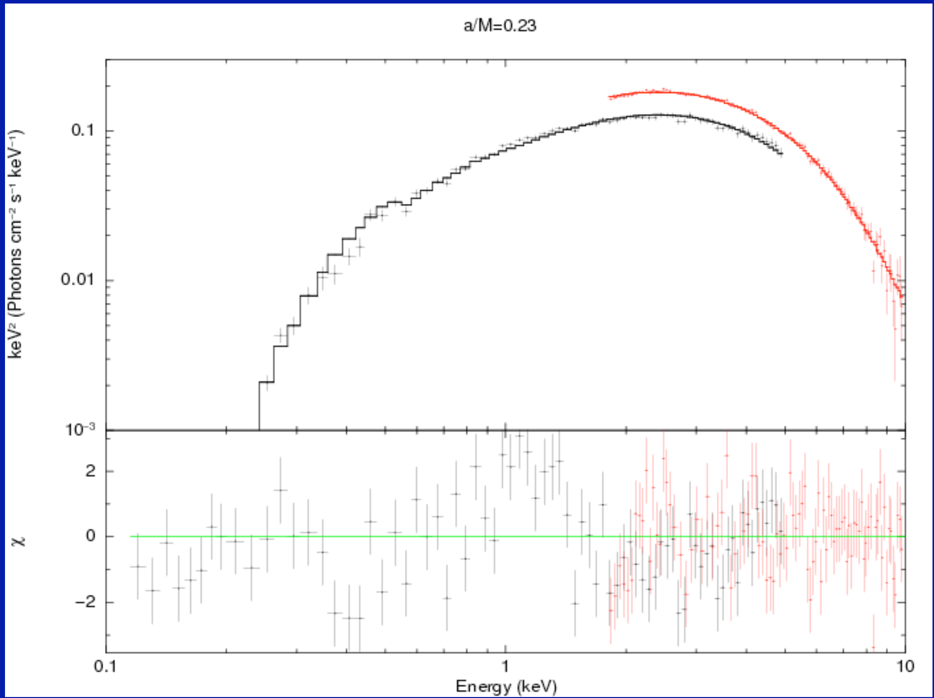
Sun
Mercury
companion star
accretion disk and black hole
M33 X−7
LMC X−3
LMC X−1
Cyg X−1
GRS 1915+105
XTE J1650−500
XTE J1118+480
XTE J1859+226
SAX J1819.3−2525
GRS 1009−45
GRS 1124−683
GS 2000+25
H1705−250
GRO J1655−40
A0620−00
GRO J0422+32
XTE J1550−564
GS 2023+338
GS 1354−64
GX 339−4
4U 1543−47

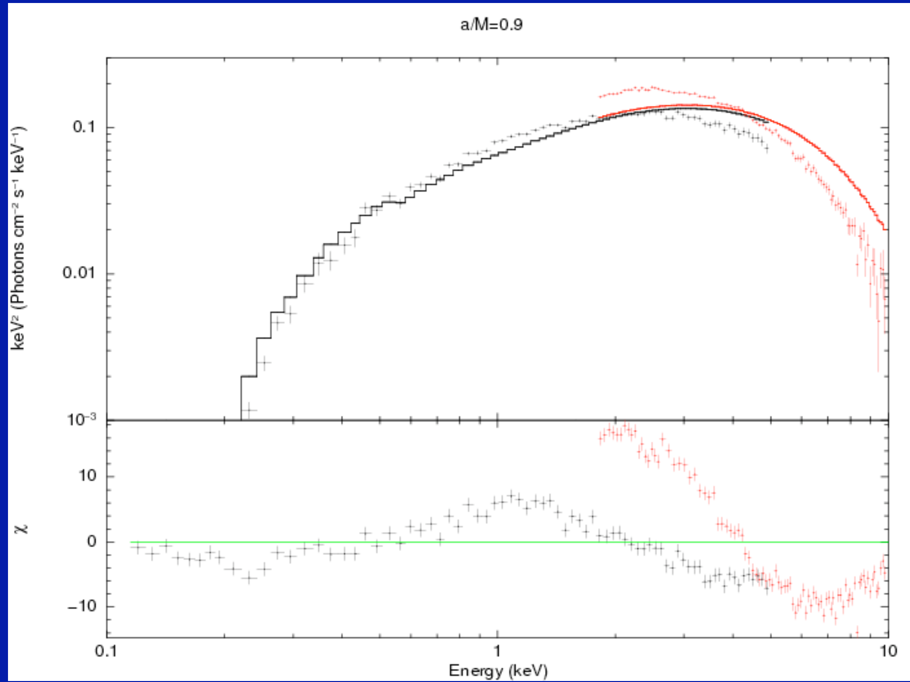


E F_E (10^{-9} erg cm^{-2} s^{-1})
10
1
0.1
data/model ratio
1.4
1.2
1.0
0.8
0.6
1
10
E (keV)



38.0
37.5
37.0
36.5
36.0
log νL_ν (erg s^{-1})
0.1
1.0
10.0
Energy (keV)
1.0
0.5
0.0
−0.5
−1.0
a_*





Fitting the X-ray spectrum of the stellar mass black hole LMC X-3 with a moderate spin (23% of the maximum) and high-spin (80% of the maximum). The high-spin model predicts too much emission at higher energies. The moderate spin fits the data well.

From Shane Davis, Canadian Institute for Theoretical Astrophysics

Table 1. Spin Results to Date for Eight Black Holes[a]

	Source	Spin a_*	Reference
1	GRS 1915+105	> 0.98	McClintock et al. 2006
2	LMC X–1	$0.92^{+0.05}_{-0.07}$	Gou et al. 2009
4	M33 X–7	0.84 ± 0.05	Liu et al. 2008, 2010
3	4U 1543–47	0.80 ± 0.05	Shafee et al. 2006
5	GRO J1655–40	0.70 ± 0.05	Shafee et al. 2006
6	XTE J1550–564	$0.34^{+0.20}_{-0.28}$	Steiner et al. 2010b
7	LMC X–3	< 0.3[b]	Davis et al. 2006
8	A0620–00	0.12 ± 0.18	Gou et al. 2010

[a]Errors are quoted at the 68% level of confidence.

[b]Provisional result pending improved measurements of M and i.

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