Experimental determination of black hole spins

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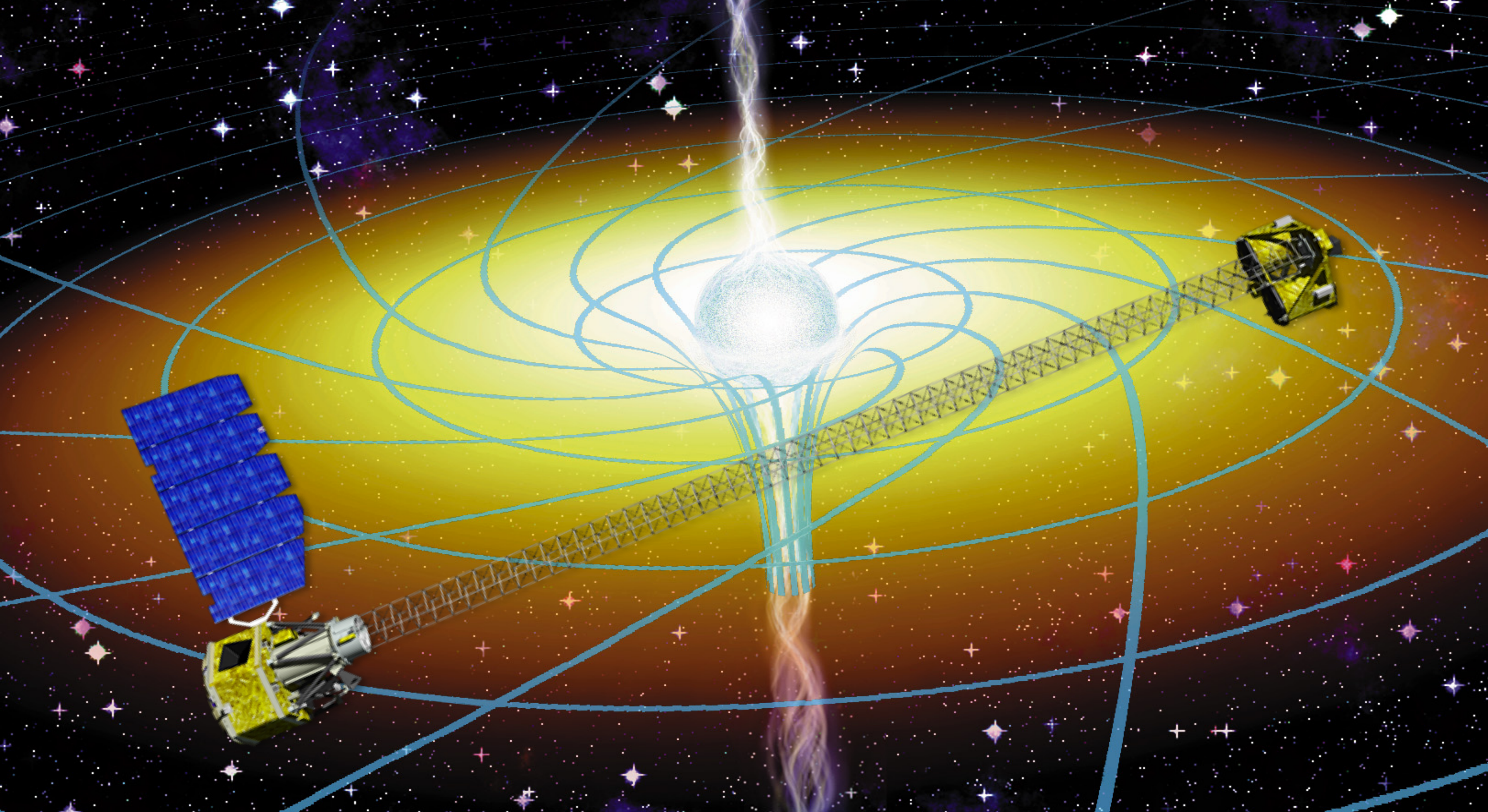
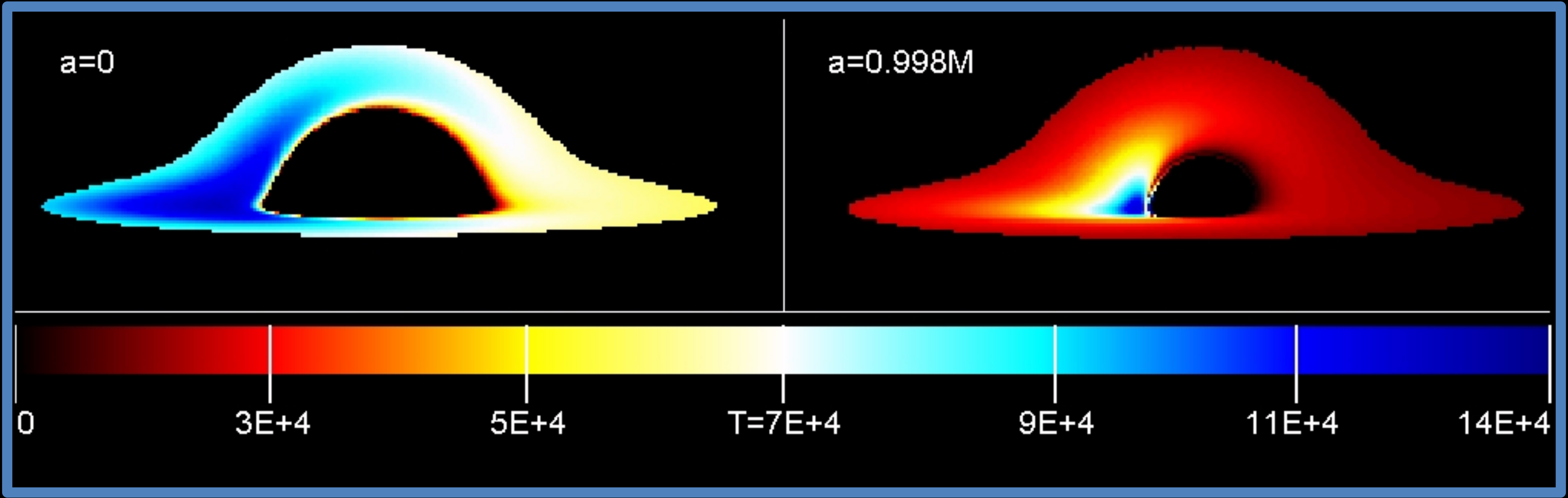


Measuring black hole spins

GR effects on emission from close to the event horizon



GR effects depending on spin value:

Gravitational redshift, Radius of innermost stable orbit

Measuring black hole spins: main methods

- Continuum fitting (McClintock et al.)
  (stellar mass BHs with known mass, distance, disk inclination)
- Gravitational waves from merging BHs
  (a few detected so far by LIGO/Virgo)
- Binary supermassive black holes (OJ 287)

- X-ray variability (time lags, PCA…)

- X-ray spectroscopy (iron K-alpha, soft excess, Compton hump…)

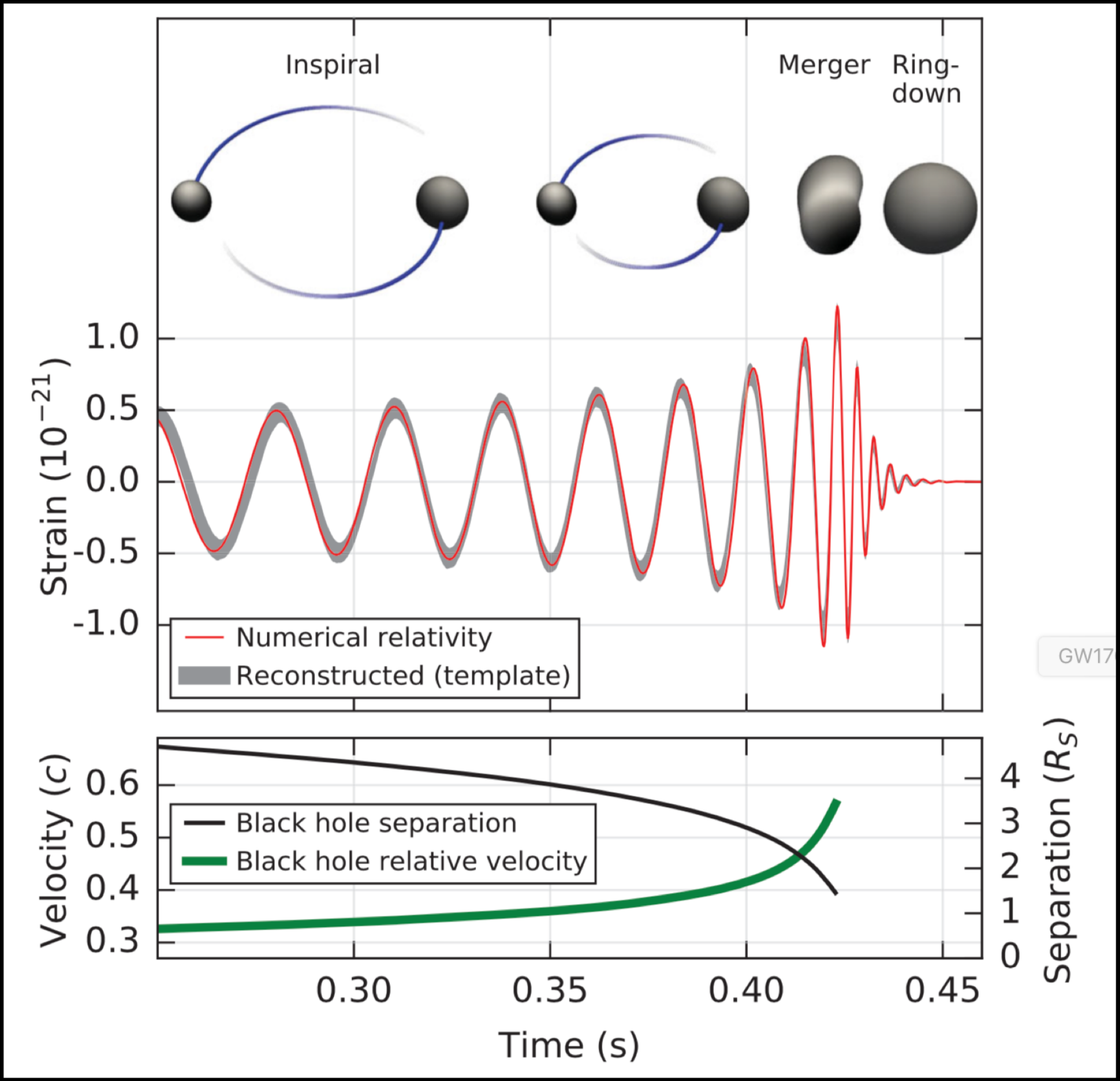
Measuring black hole spins: continuum fitting

Emission from disks truncated at the ISCO, with known mass, distance and inclination angle. Model: SS disk modified for GR effects (Novikov+73)

	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	$< 0.3^{\mathrm{b}}$	Davis et al. 2006
8	A0620–00	0.12 ± 0.18	Gou et al. 2010

McClintock et al. 2011

Measuring black hole spins: gravitational waves



Final black hole spin:

$0.68^{+0.05}_{-0.06}$

$0.74^{+0.06}_{-0.06}$

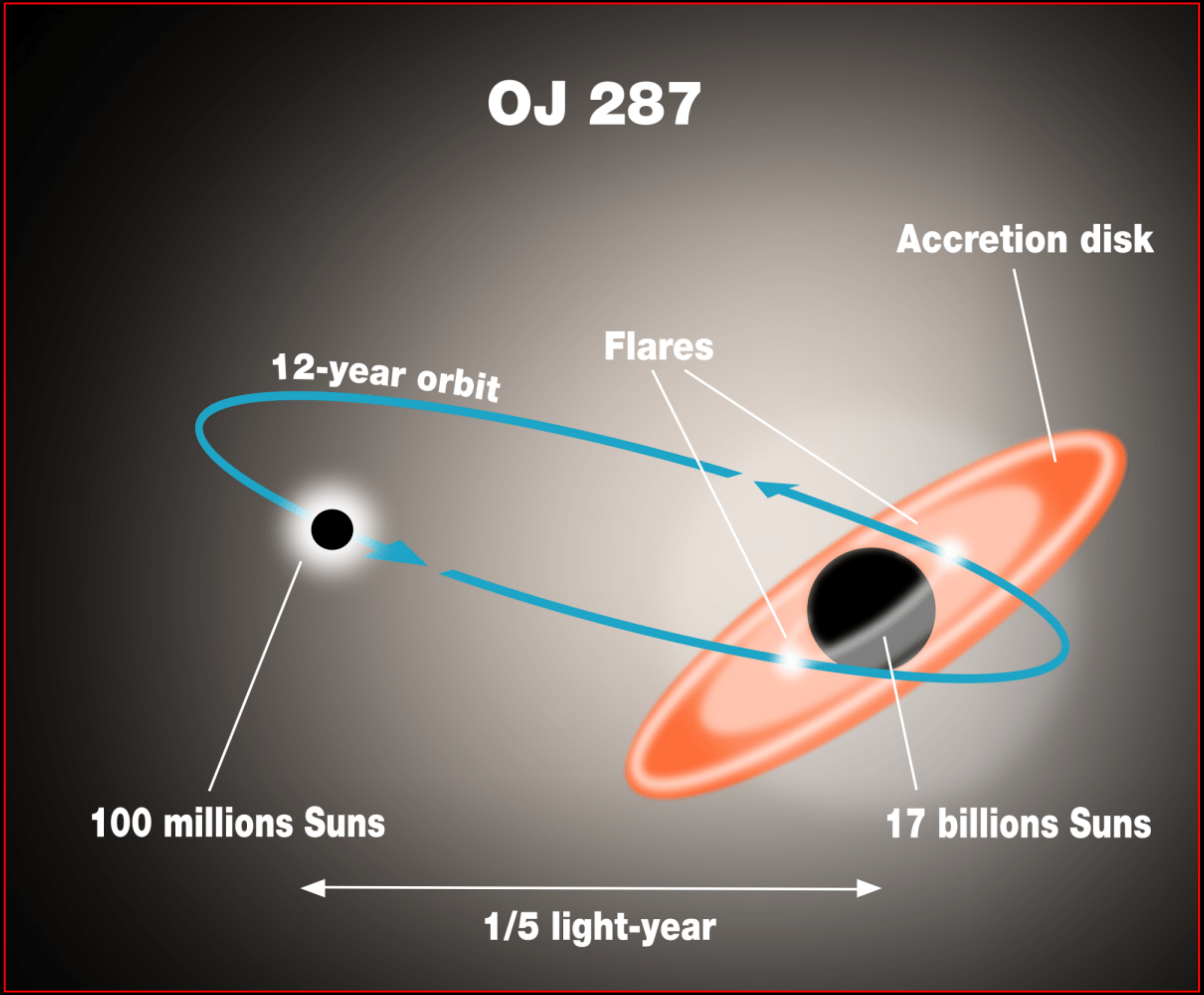
$0.64^{+0.09}_{-0.20}$

$0.69^{+0.04}_{-0.05}$

$0.70^{+0.07}_{-0.05}$

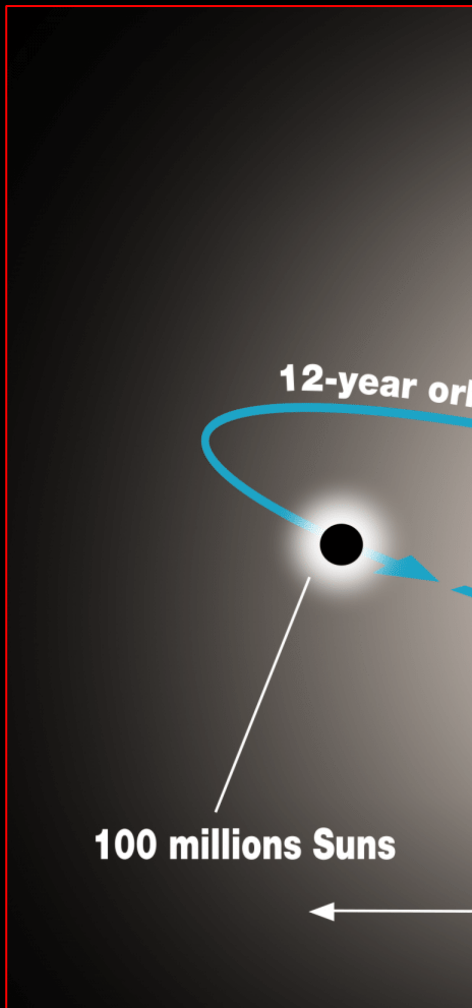
Masses from 7 to 62 M_{SUN}

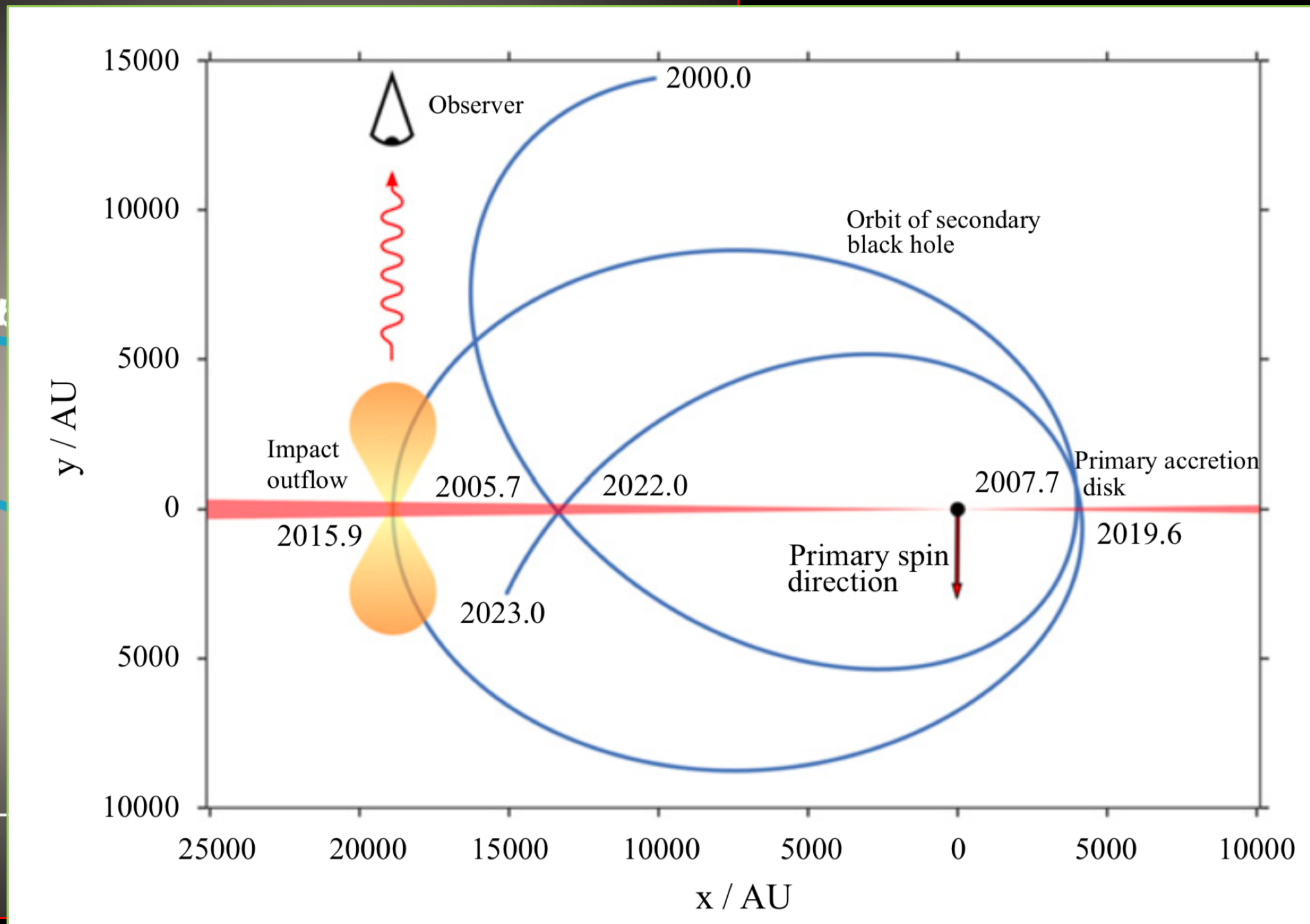
Measuring black hole spins: binary SMBH OJ 287



Valtonen et al. 2008, 2016

Measuring black hole spins: binary SMBH OJ 287

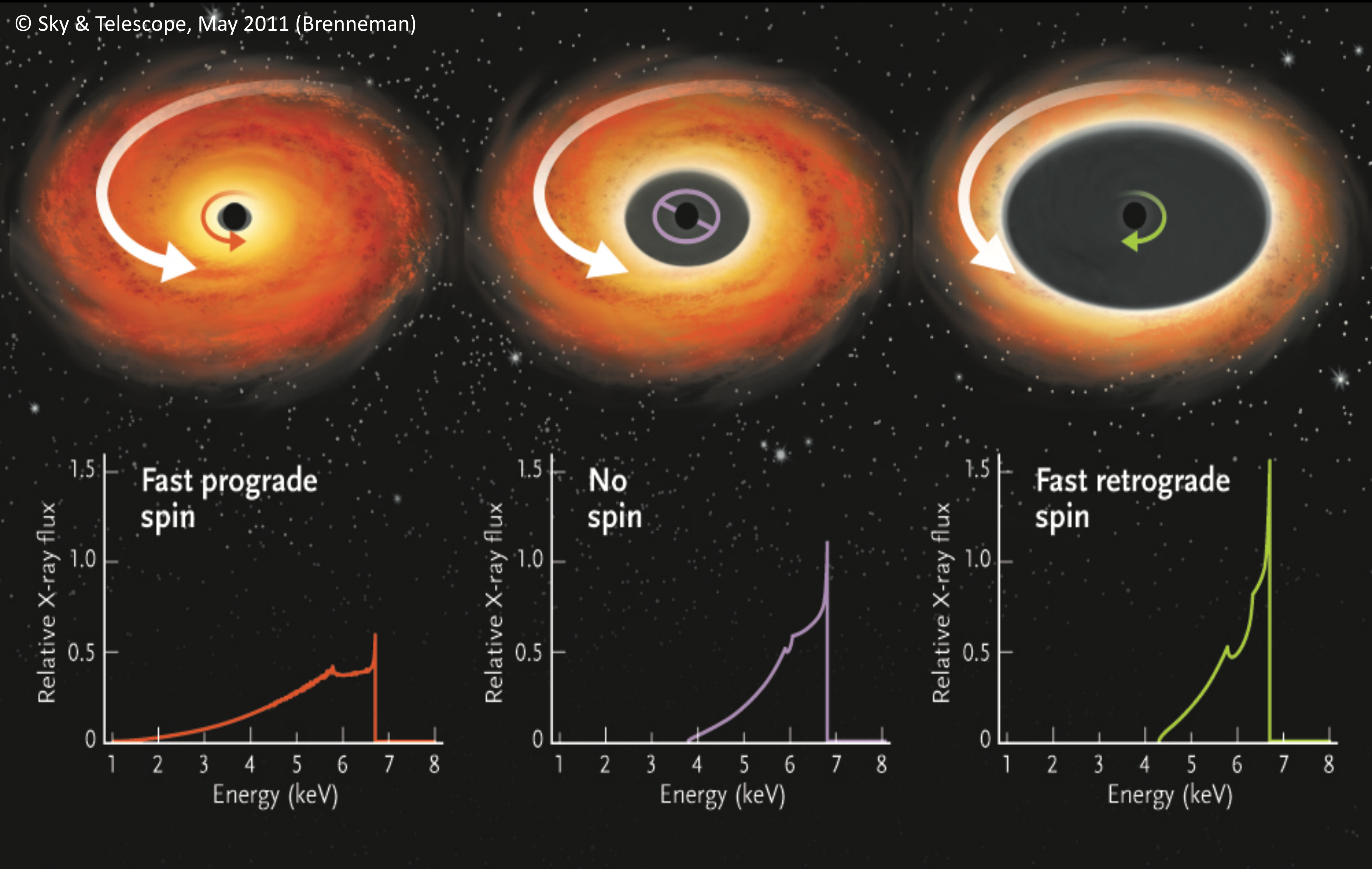




Valtonen et al. 2008, 2016

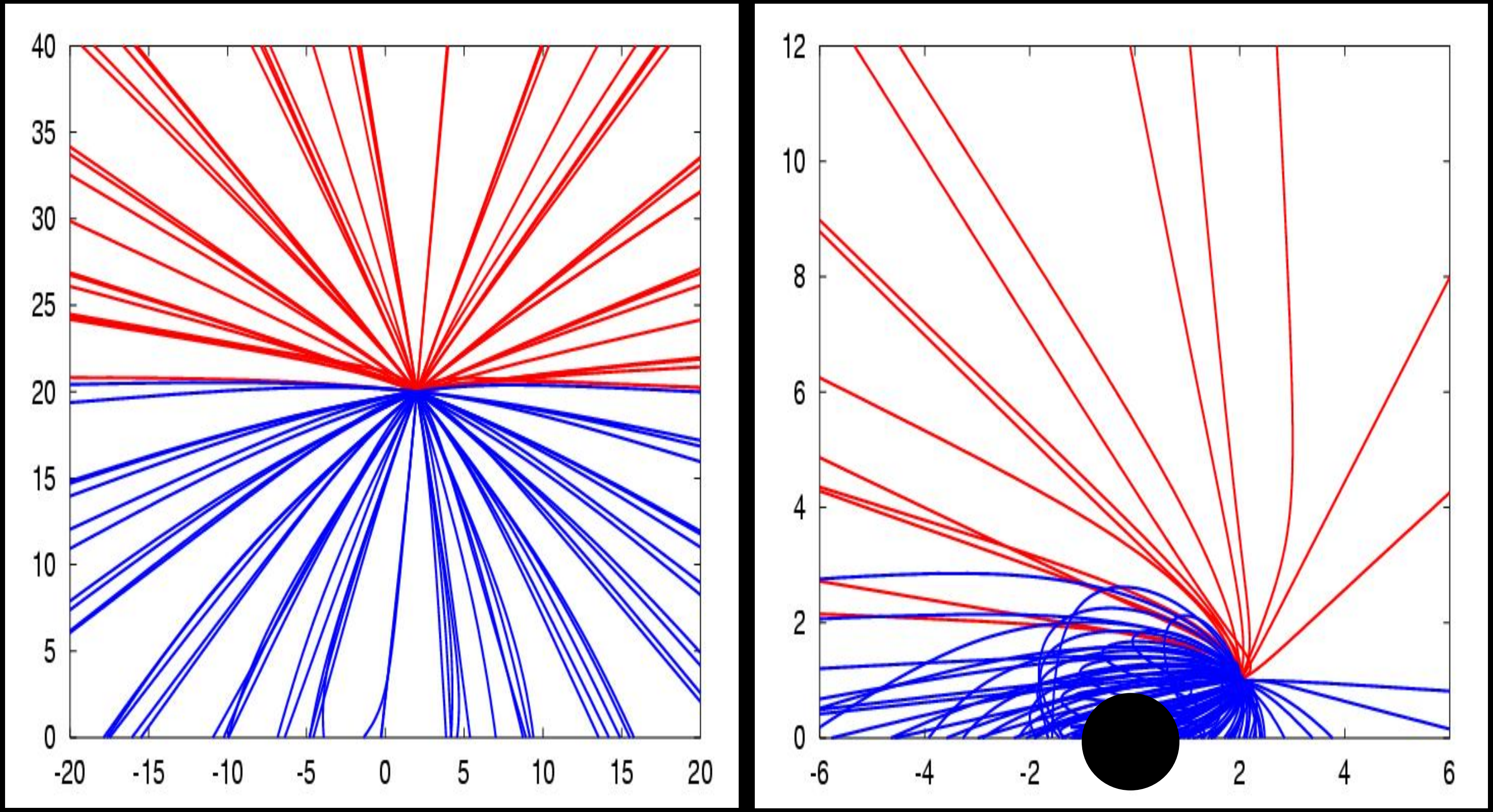
Spin: $0.313^{+0.01}_{-0.01}$

SMBH Spins from Reflection



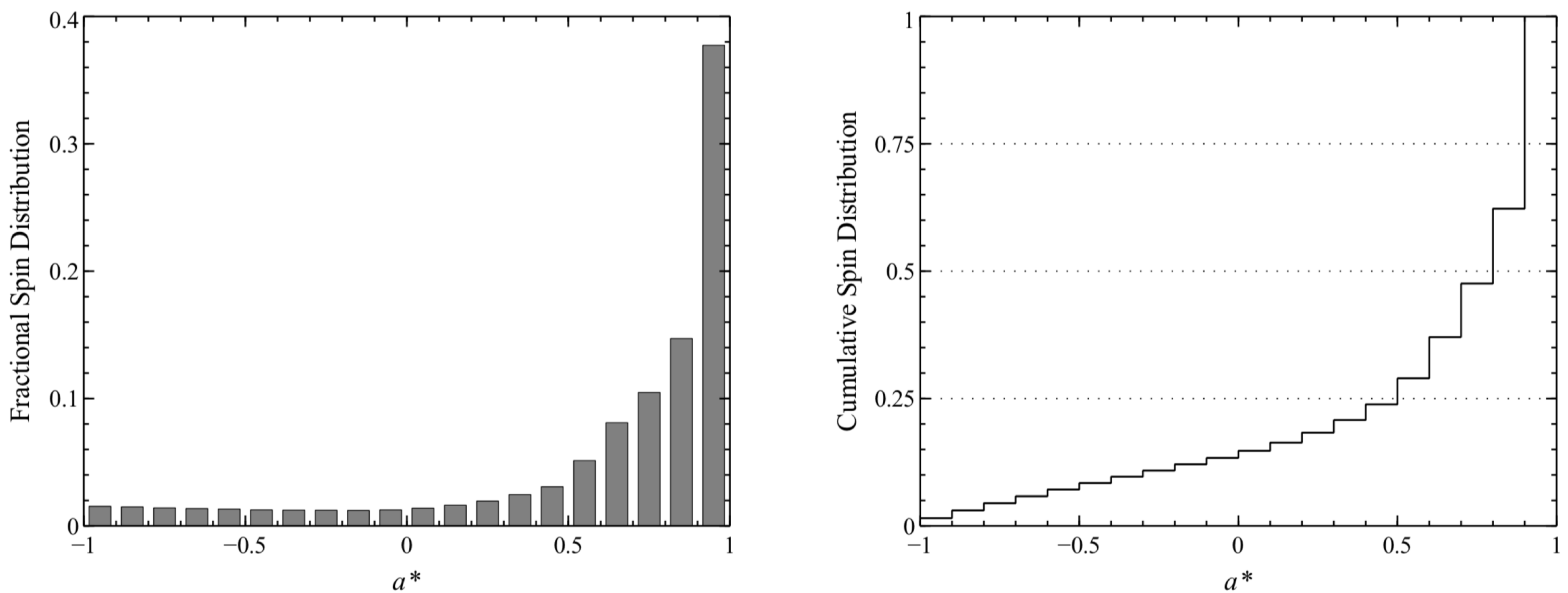
SMBH Spins from Reflection

Enhancement of the reflection component due to GR curvature



Miniutti & Fabian 2004, Fabian 2012

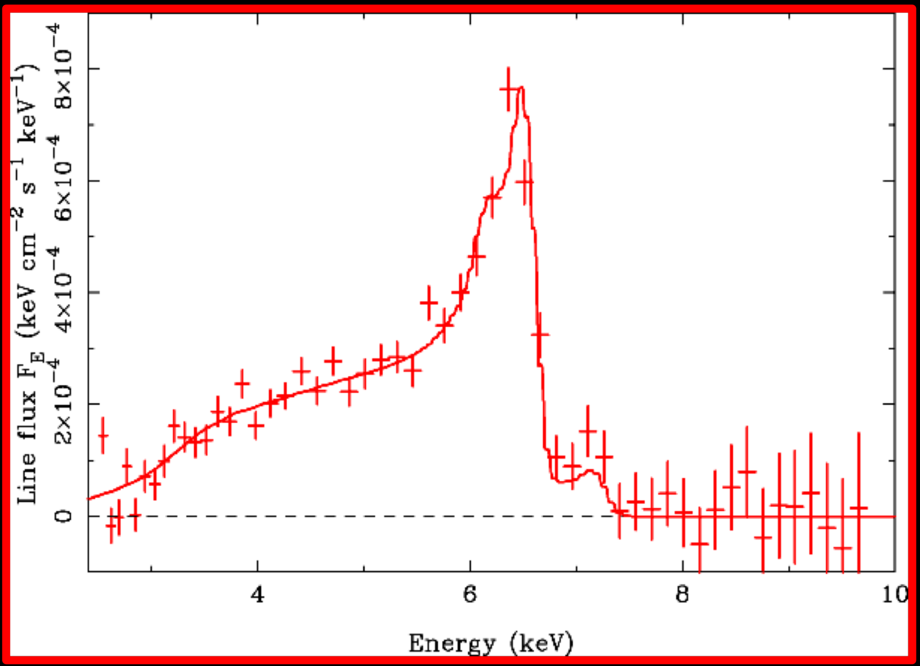
SMBH Spins from Reflection



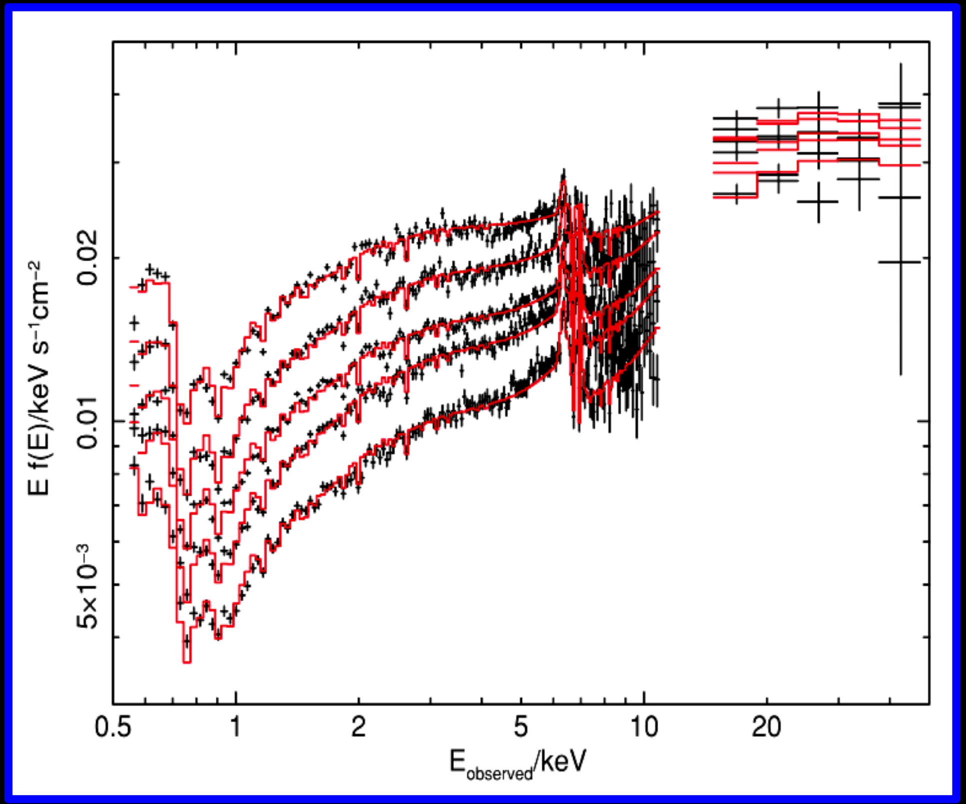
Spin distribution for 25 “bare” AGN, Walton et al. 2013

SMBH Spins from Reflection

MCG-6-30-15



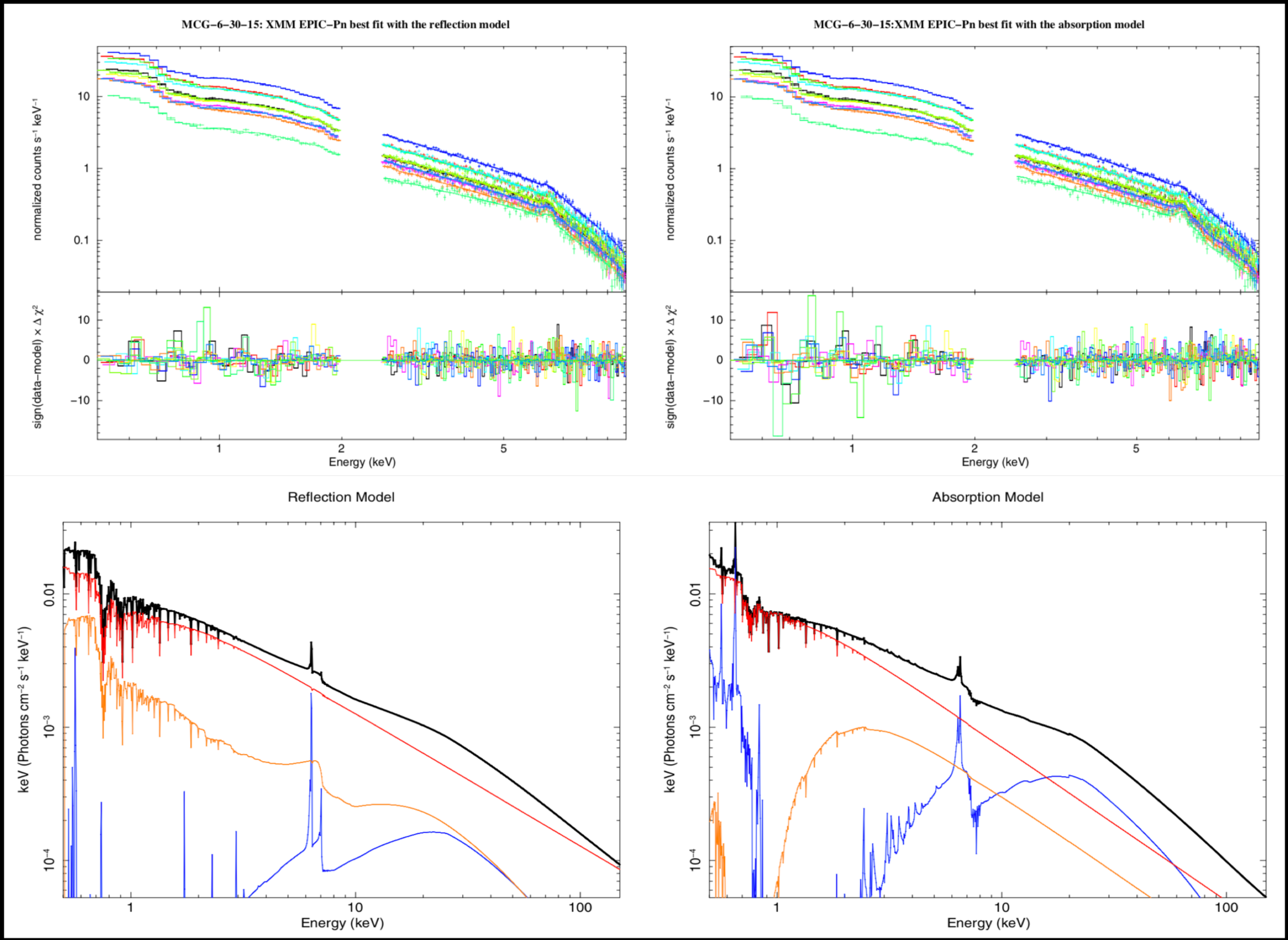
Variable ionized absorption



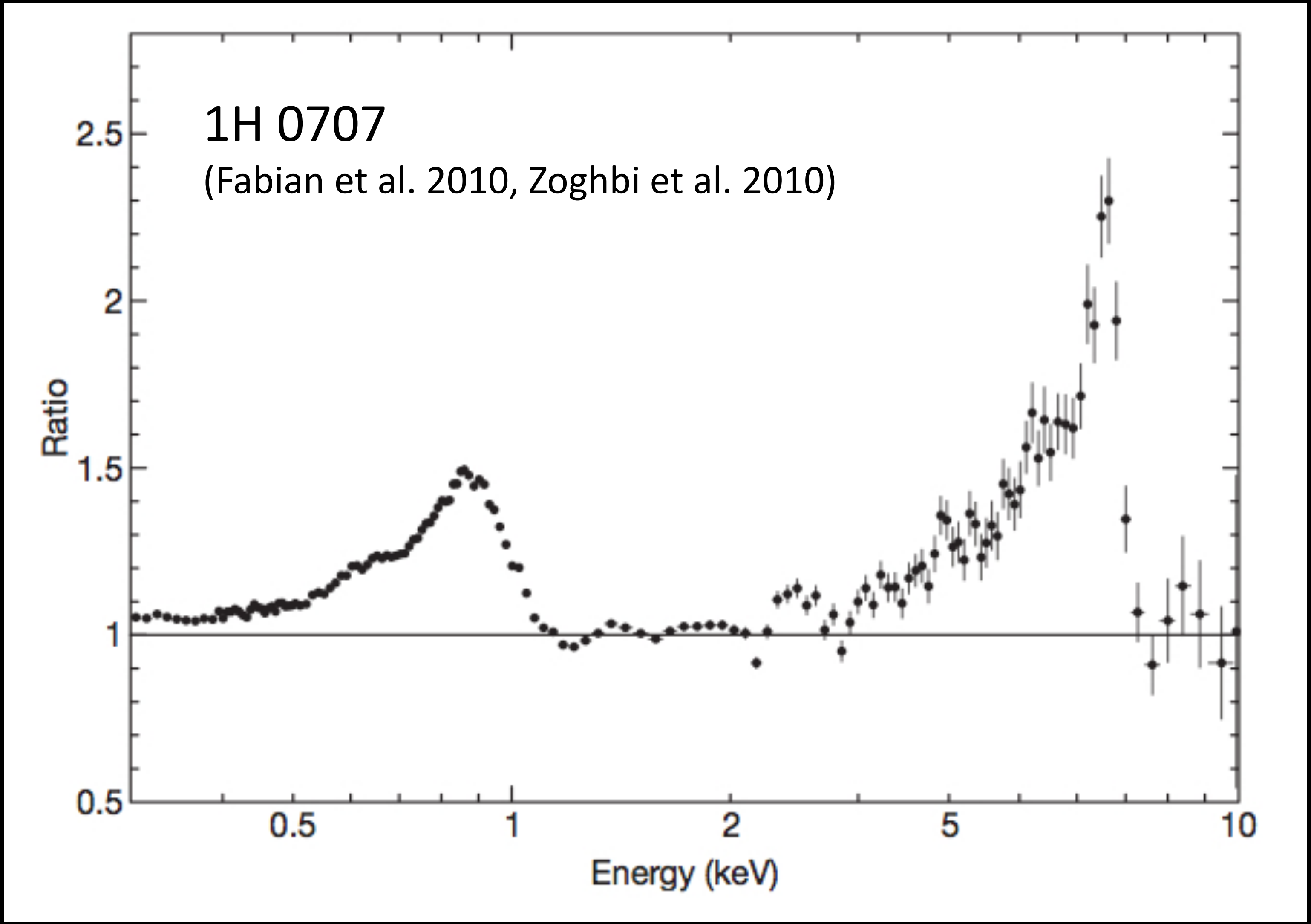
(Miller, Turner et al. 2009)

SMBH Spins from Reflection

MCG-6-30-15, 3 XMM orbits+NuSTAR (Marinucci et al. 2014)

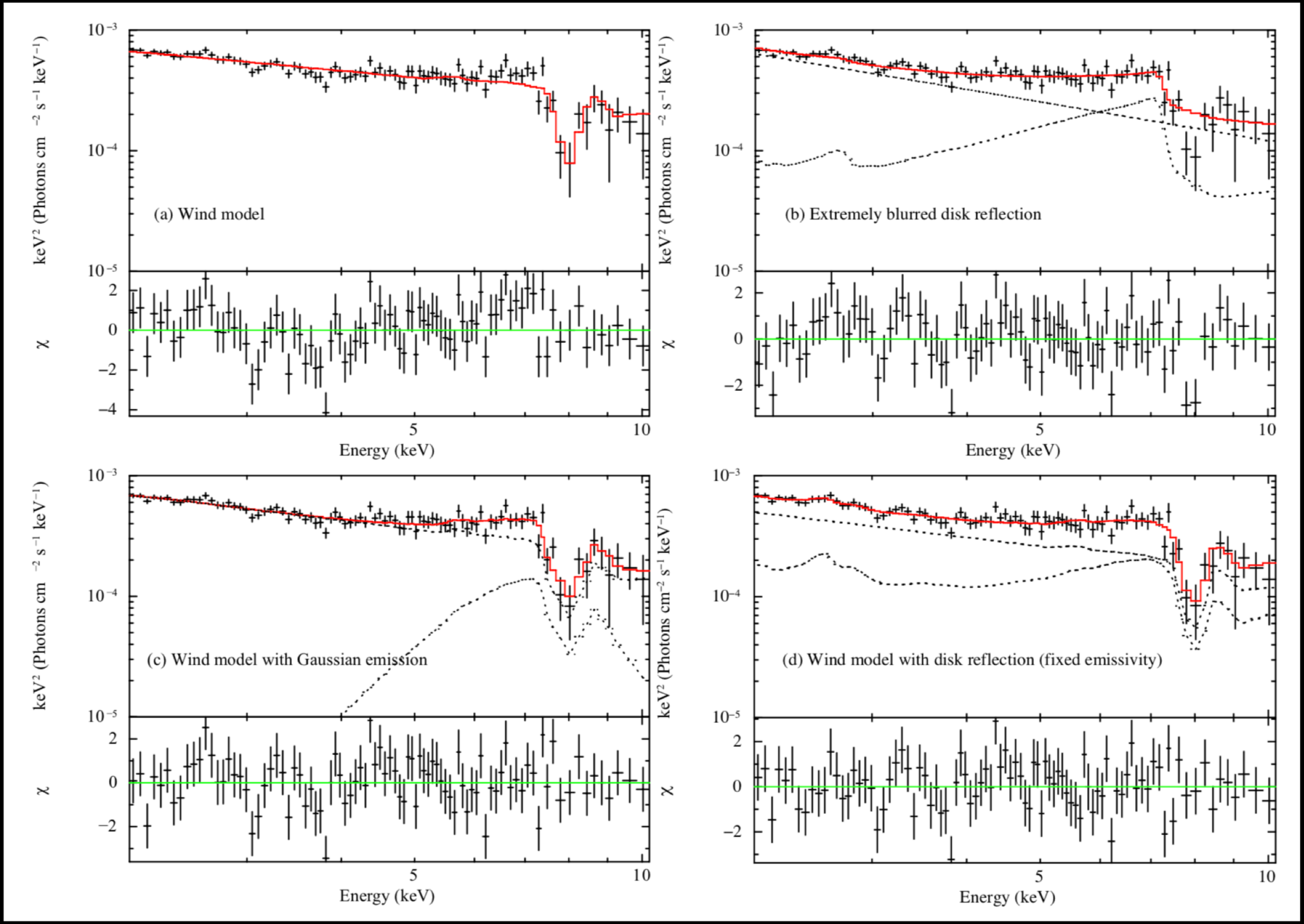


SMBH Spins from Reflection



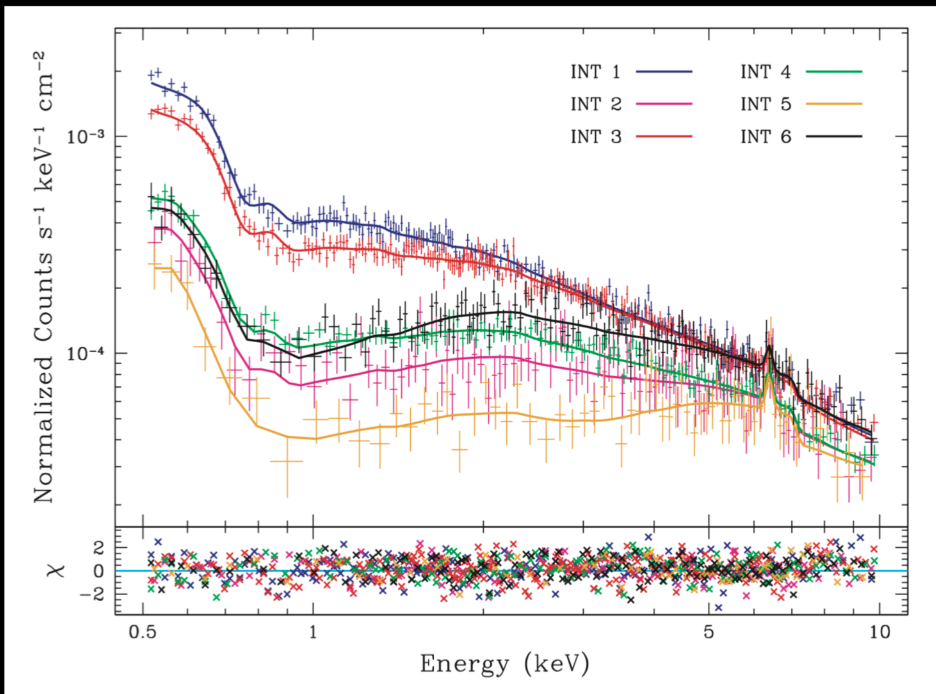
SMBH Spins from Reflection

1H0707: a model with a strong wind (similar to PDS 456) fits equally well (Hagino et al. 2015)



SMBH Spins from Reflection

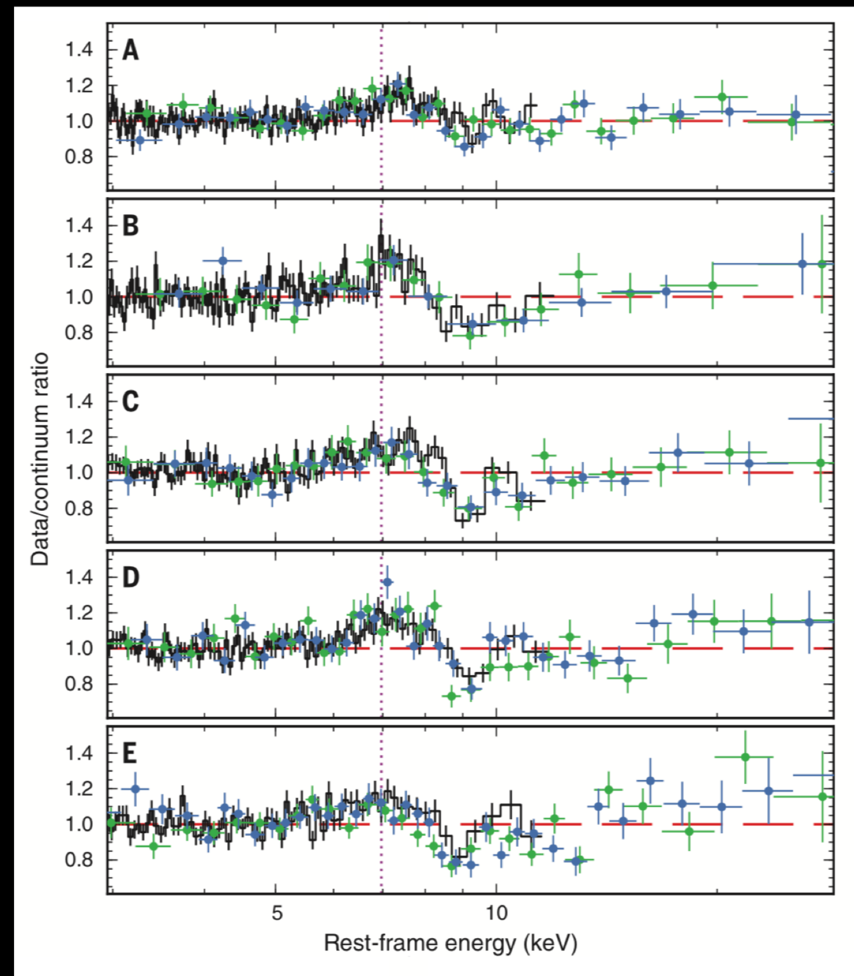
NGC 4395 (Nardini & Risaliti 2011)



Average spectrum unusually flat,
Becomes normal if variable neutral absorption is allowed

Other examples of complex winds/absorbers (NGC 1365, NGC 4051, IRAS 13224, ….

PDS 456 (Nardini et al. 2015)



Huge outflow with v~0.2 c

SMBH Spins from Reflection

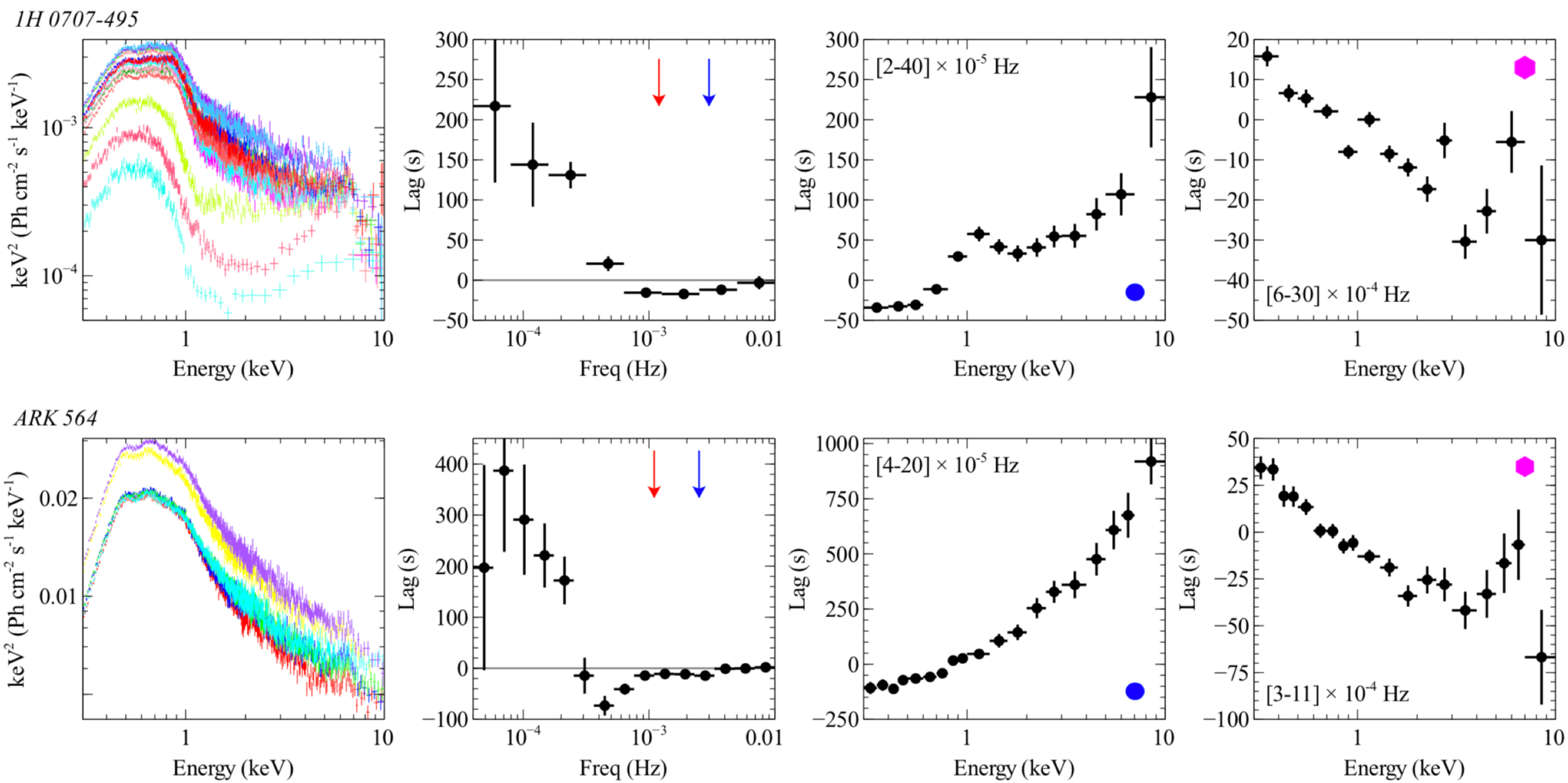
(My) CONCLUSION:
Even if the relativistic reflection component is present (and strong), the presence of other components (variable ionized absorption, winds…) make the spin measurement unreliable.

Possibly, the best cases are the most extreme: a point source close to the event horizon of a maximally rotating black hole produces a huge Compton hump, difficult to reproduce with variable absorption.

(see Elias Kammoun’s talk)

SMBH Spins from time lags

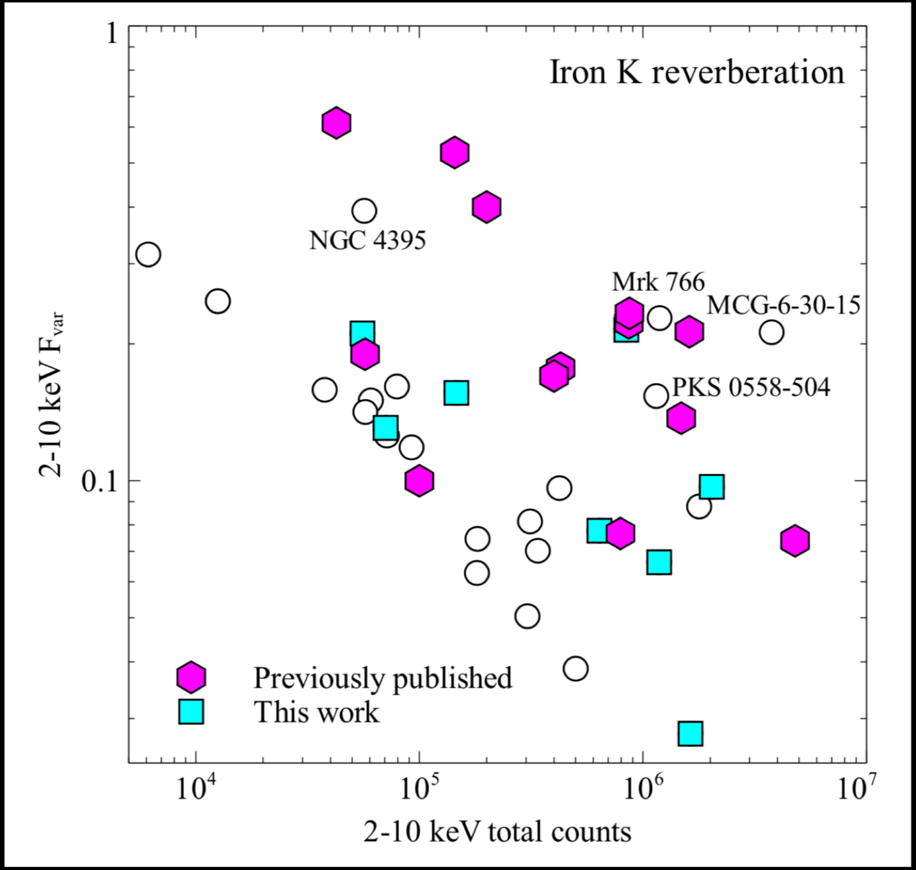
IRON-K LAGS

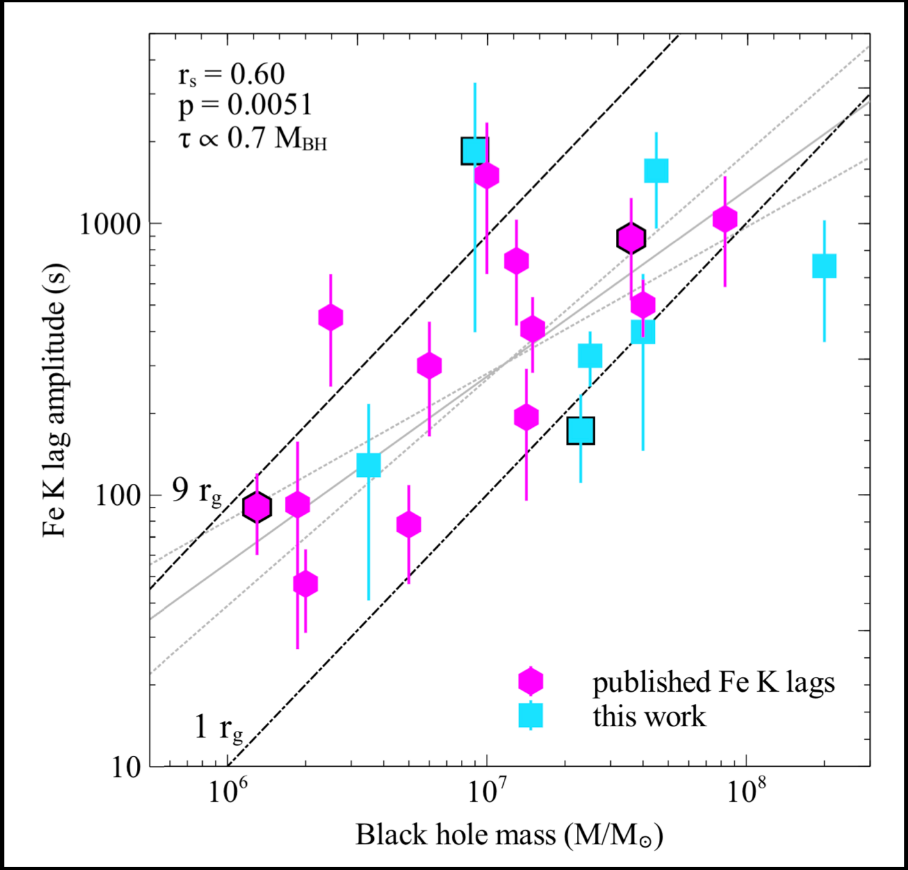


Kara et al. 2016

SMBH Spins from time lags

IRON-K LAGS

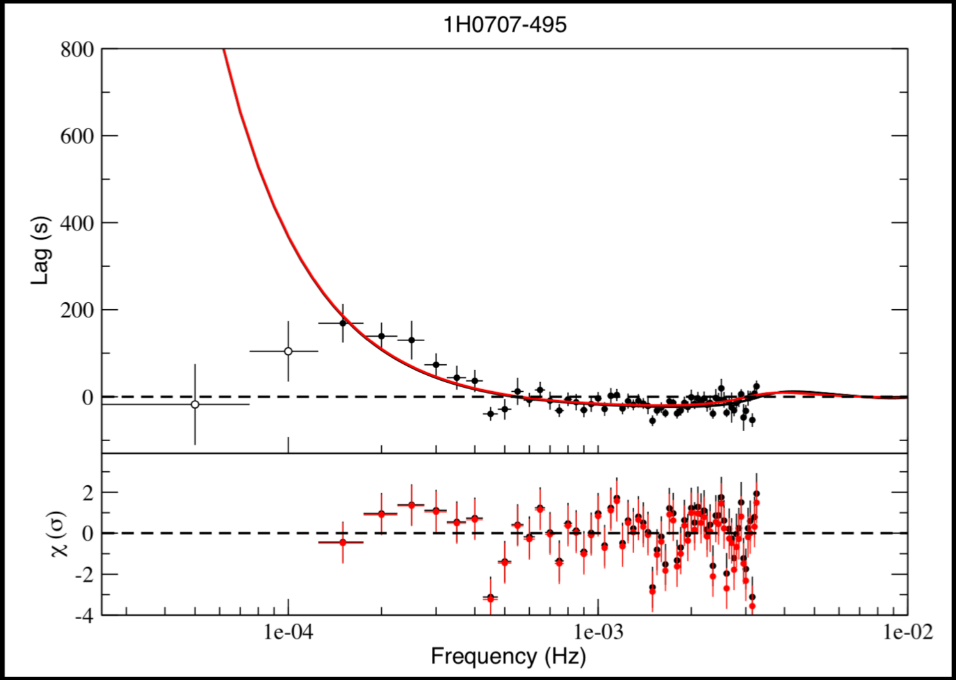


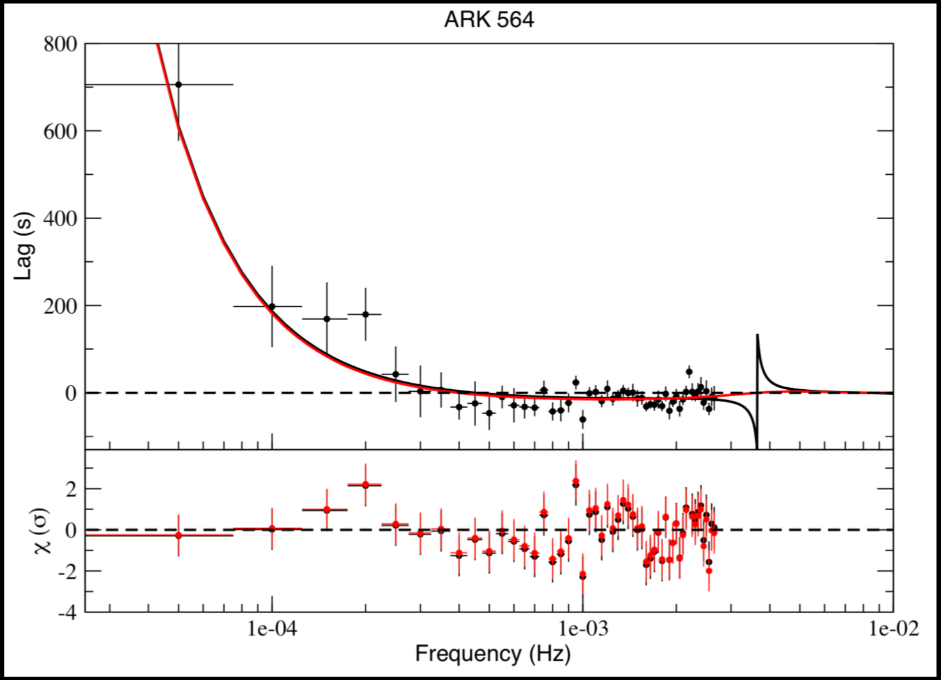


Kara et al. 2016

SMBH Spins from time lags

Modelling the iron-K lags with a lamp-post geometry





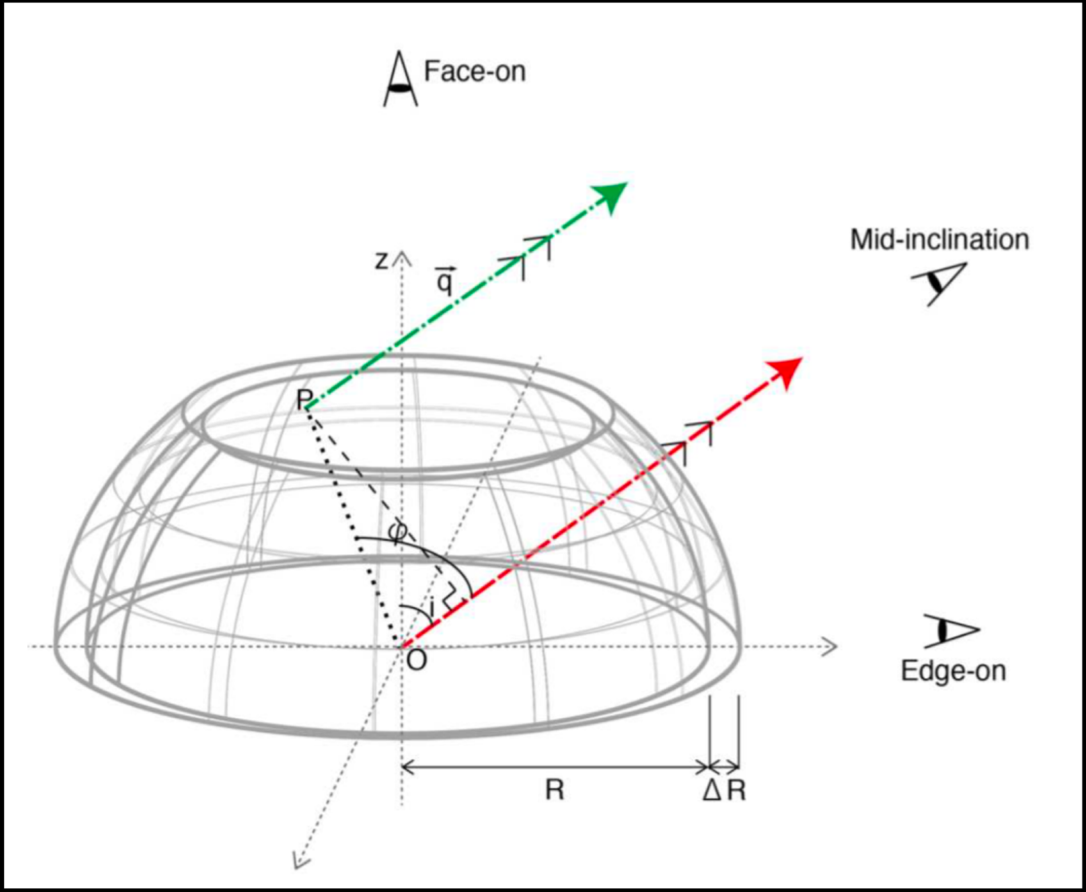
No spin dependence

Caballero-Garcia et al. 2018

Epitropakis et al. 2016

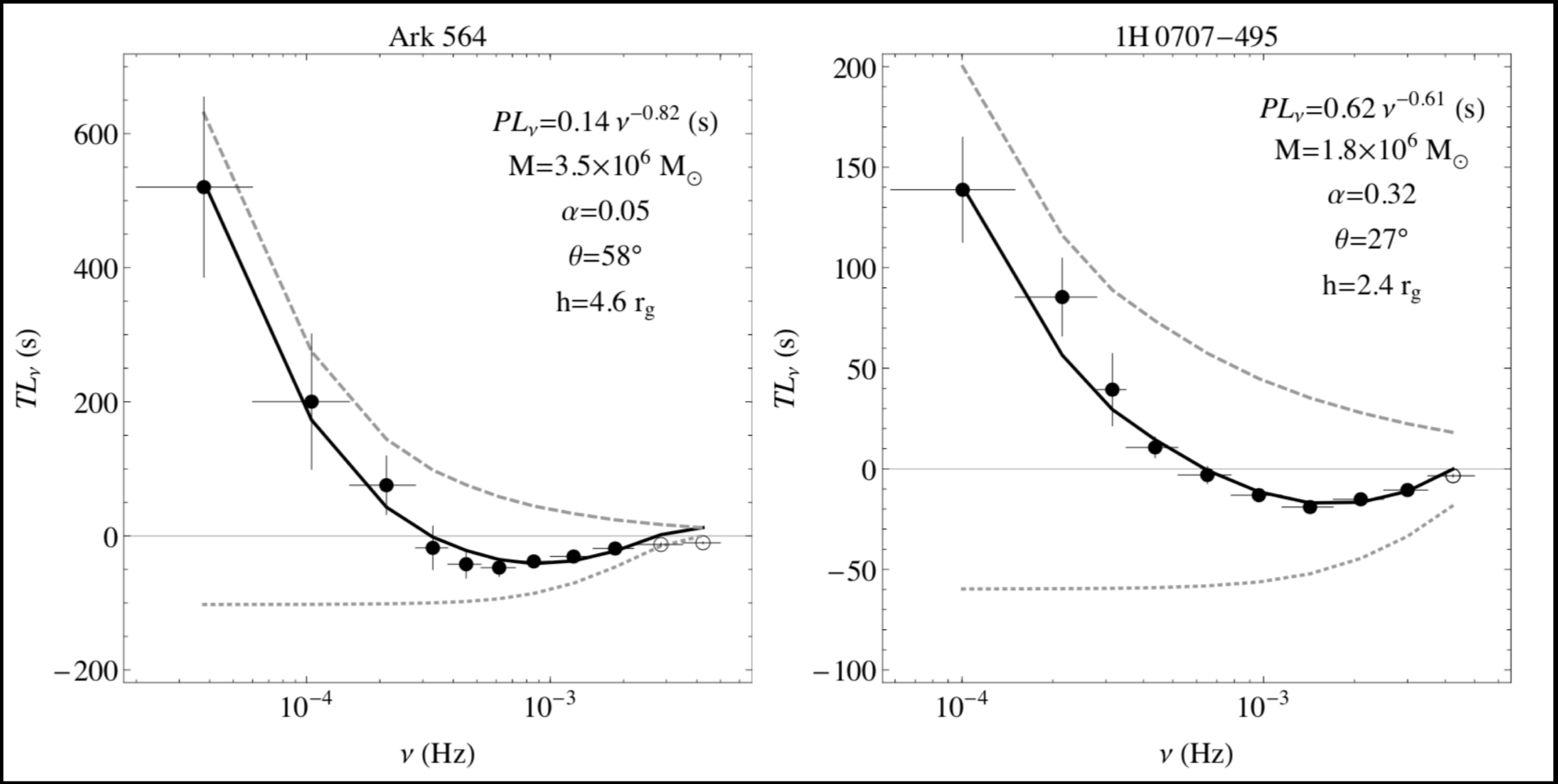
SMBH Spins from time lags

<u>However:</u>
Very short time lags may be due to interaction with a surrounding shell (dilution with the primary component, Mizumoto et al. 2018)



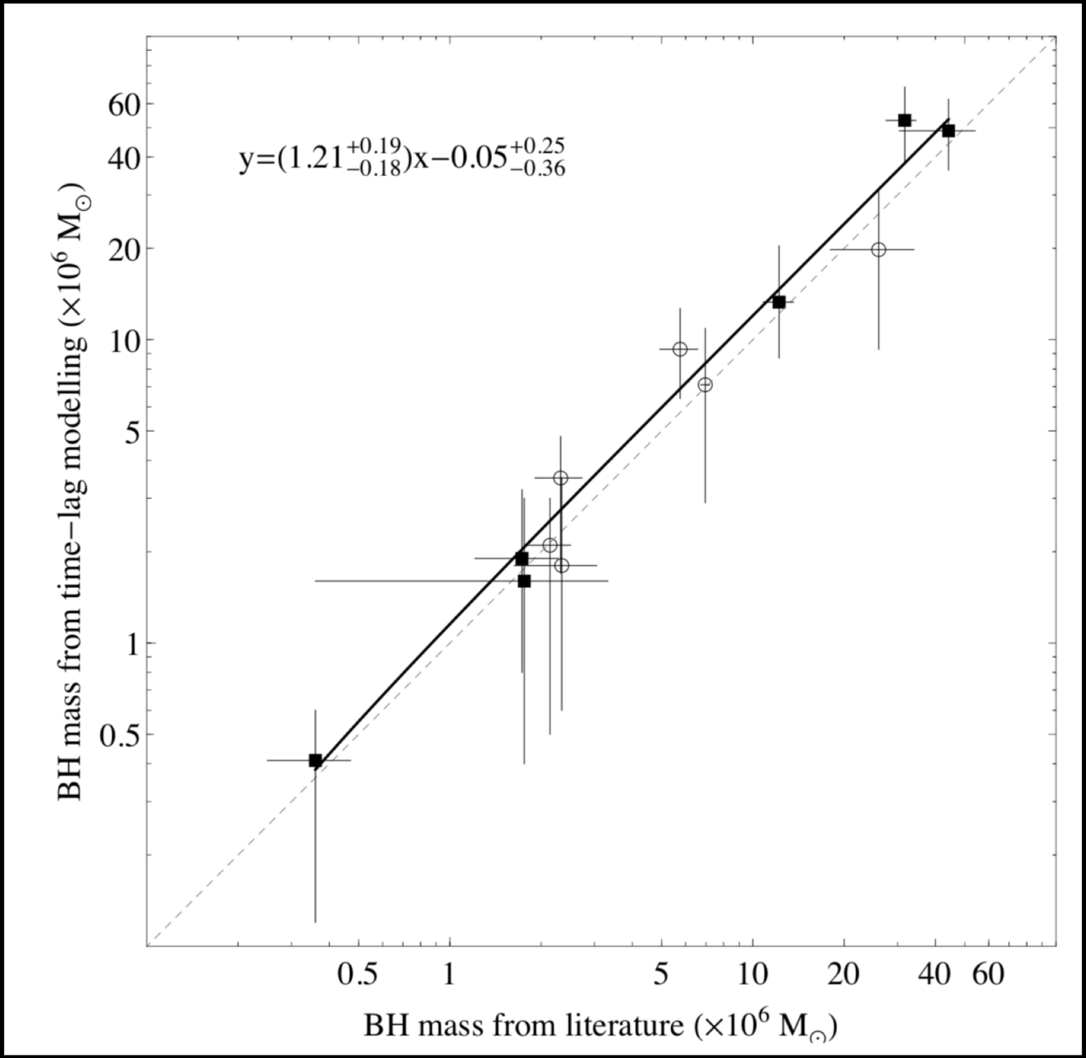
SMBH Spins from time lags

Modelling the <u>soft</u> lags with a lamp-post geometry



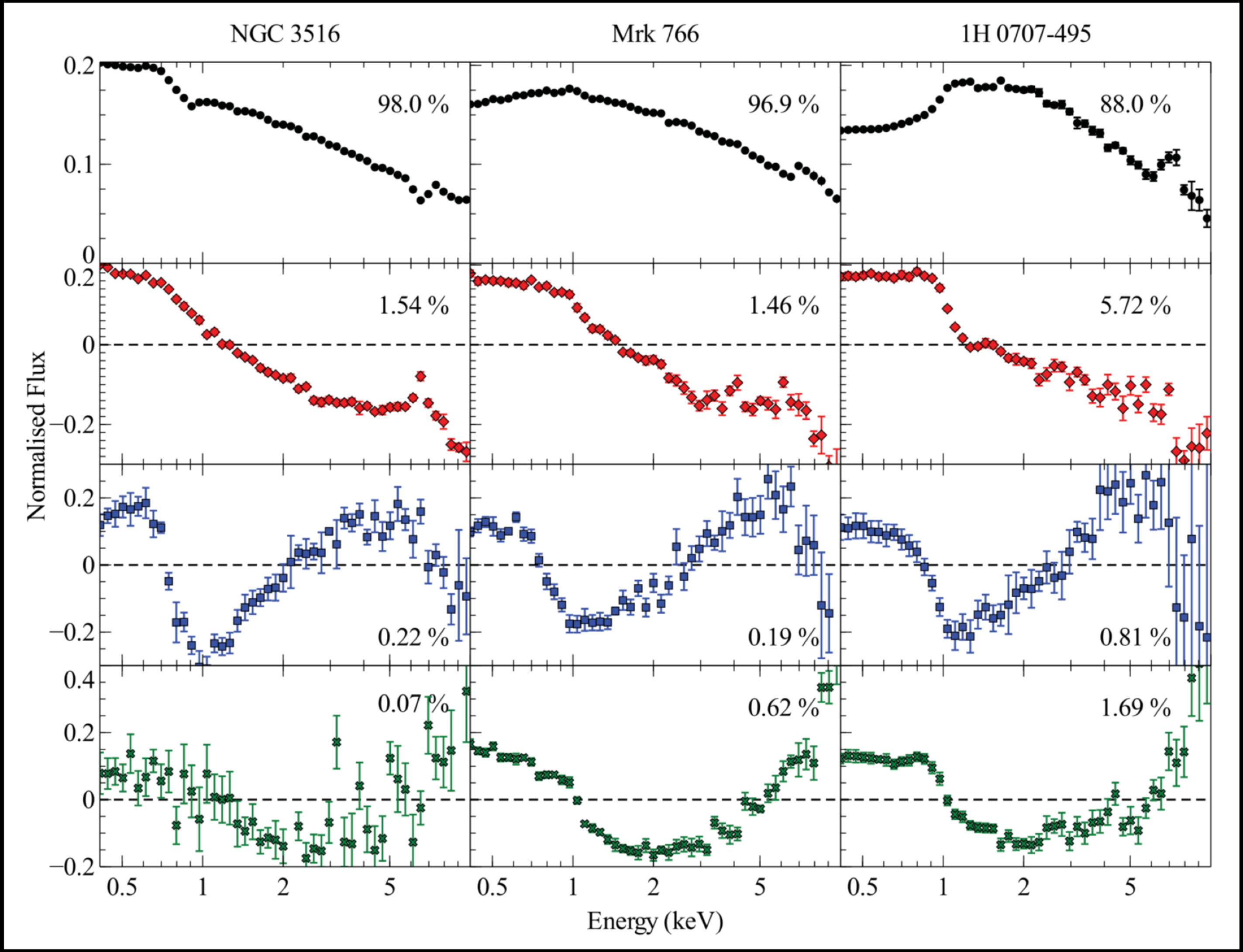
Emmanoupoulos et al. 2016

SMBH Spins from time lags



Emmanoupoulos et al. 2016

SMBH Spins from PCA



Parker et al. 2015

Can we measure black hole spins?

- In a few specific cases, **YES** (stellar mass BHs, OJ 287, merging BHs)

- In general:
  Are there spin-dependent GR signatures in the X-ray spectra and light curves of AGNs ? **YES**
  Can we isolate them and measure the BH spin? **NO**

  Will there be any improvement in the future?
  - with just more area (longer XMM+NuSTAR obs, Athena…) but CCD resolution **NO**
  - with high-resolution X-ray spectra **MAYBE**