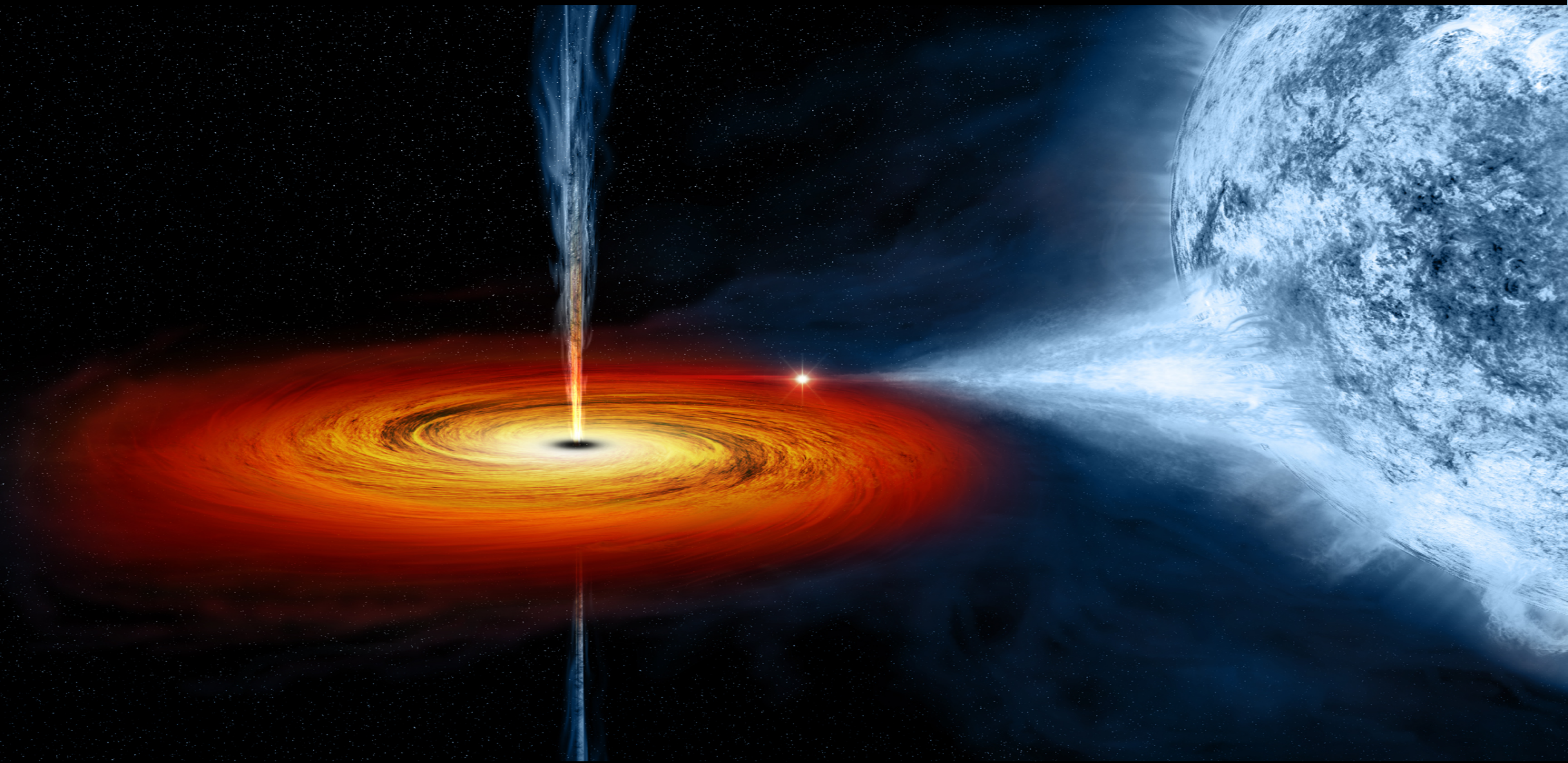
eXTP Spin Measurement for XRB BHs



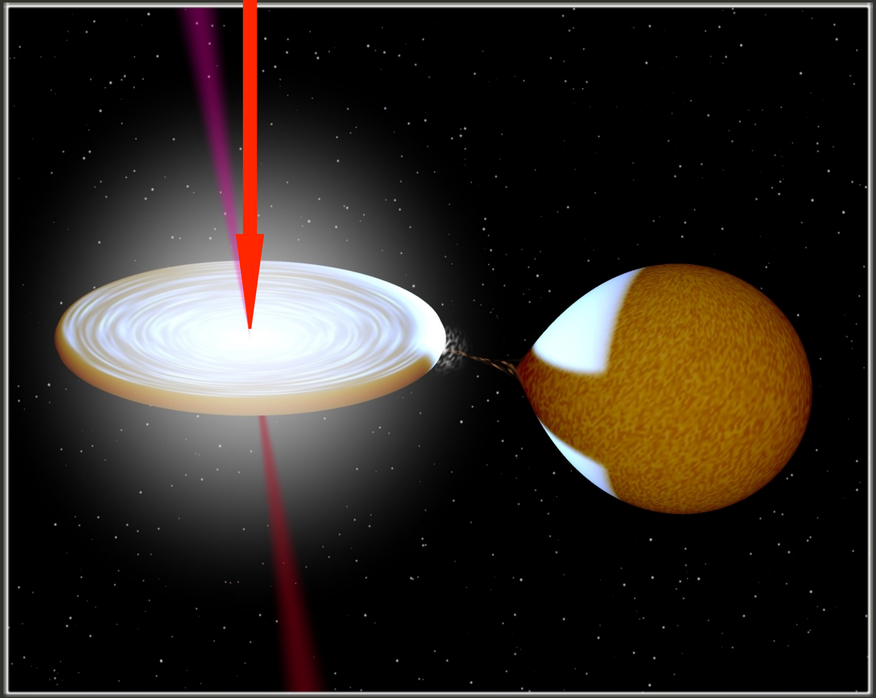
Lijun Gou (苟利军，NAOC, Beijing)

ROME@ Feb. 6th, 2016

Two Classes of Black Holes

Stellar-Mass: 10 $M_{\odot}$

Supermassive: $10^6 - 10^9$ $M_{\odot}$



Courtesy: Rob Hynes

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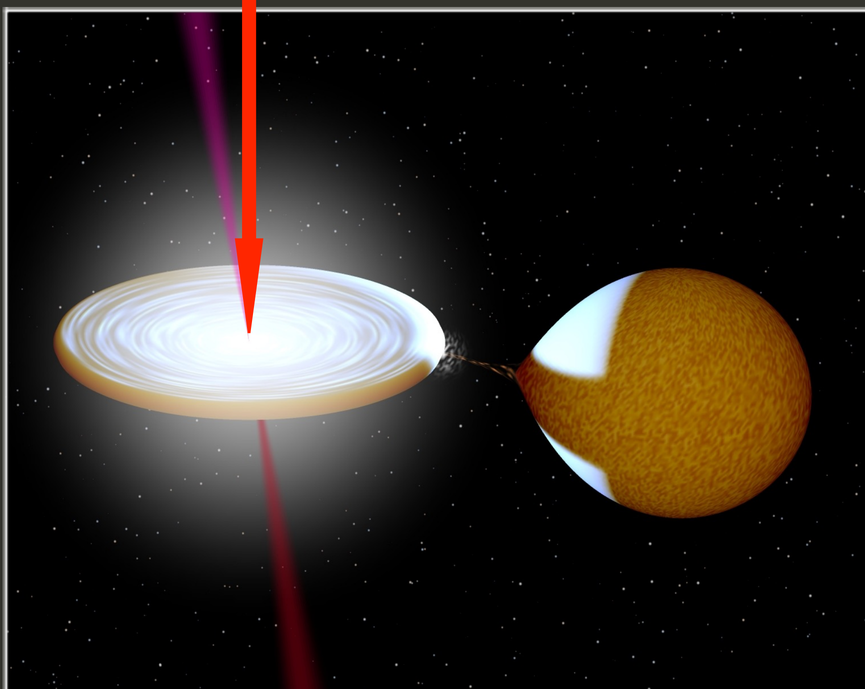
Stellar-Mass: 10 $M_\odot$



Courtesy: Rob Hynes

Supermassive: $10^6 - 10^9$ $M_\odot$

No-Hair Theorem

- Mass: M
- Spin: $a_* = ac/GM = J(c/GM^2)$ $(-1 \leq a_* \leq 1)$
  $(a_* = a/M$ by setting $c=G=1)$
- Electric Charge: Q

No-Hair Theorem

- Mass: M

- Spin: $a_* = ac/GM = J(c/GM^2)$ $(-1 \leq a_* \leq 1)$

$(a_* = a/M$ by setting c=G=1)

Charge neutralized and unimportant

No-Hair Theorem

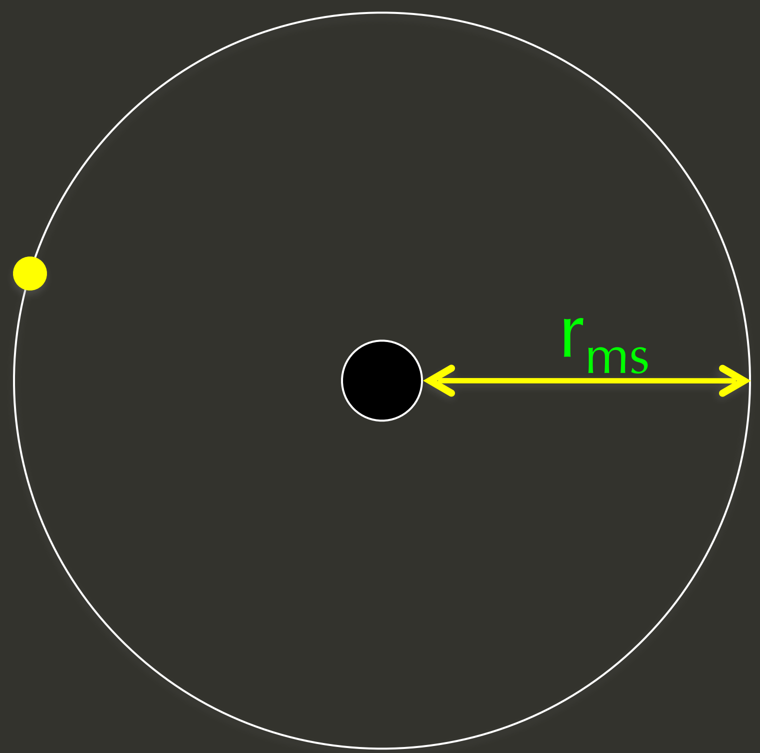
- Mass: M

- Spin: $a_* = ac/GM = J(c/GM^2)$ $(-1 \leq a_* \leq 1)$
  ($a_* = a/M$ by setting c=G=1)

Charge neutralized and unimportant

Kerr metric gives complete descriptions of astronomical BHs

Theoretical Foundation for Measuring Spin



$R >= R_{ms}$: Stable

$R < R_{ms}$: Unstable

$R_{ISCO} = R_{ms}$

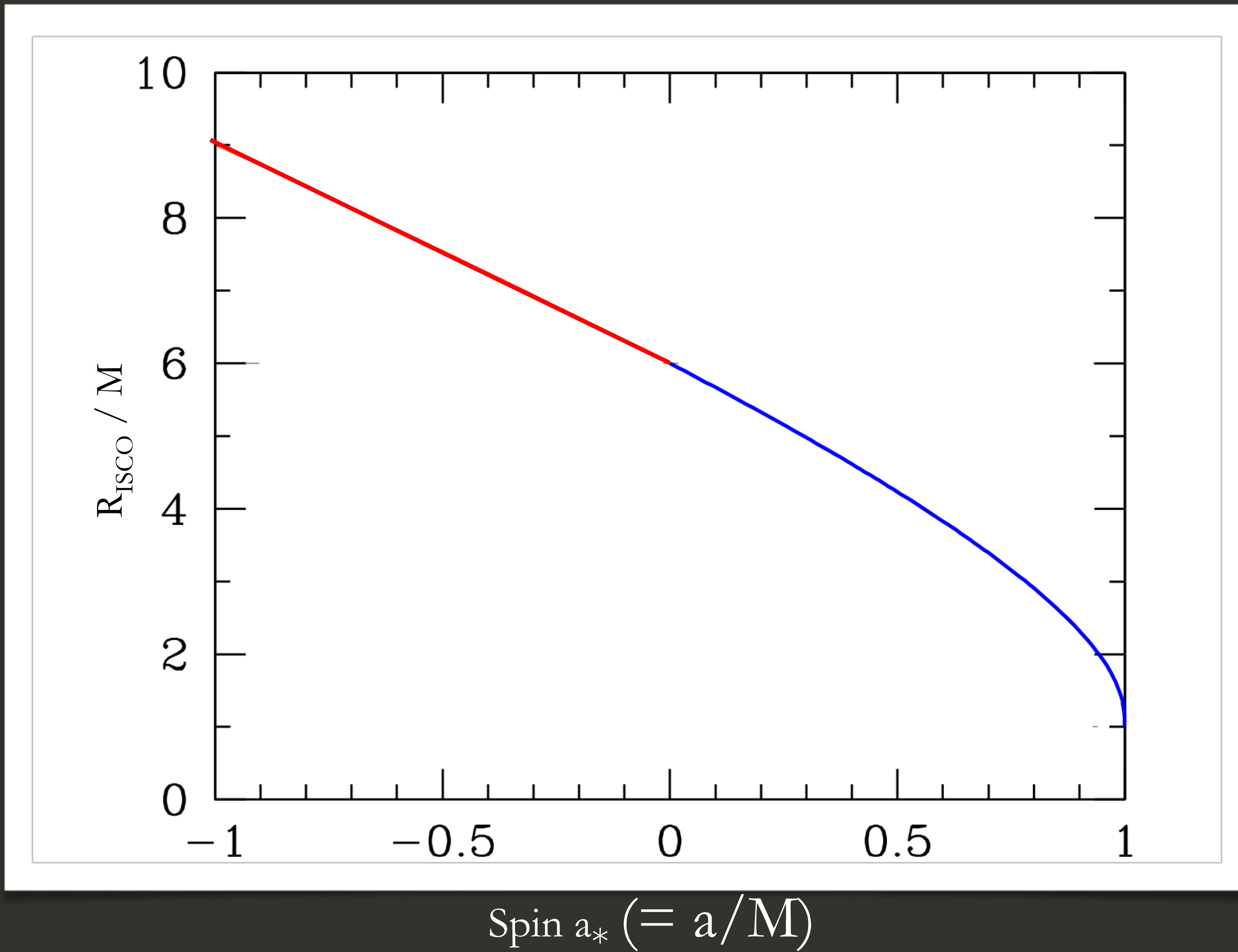
(ISCO: innner-most stable circular orbit)

Bardeen et al. 1972, ApJ, 172, 347

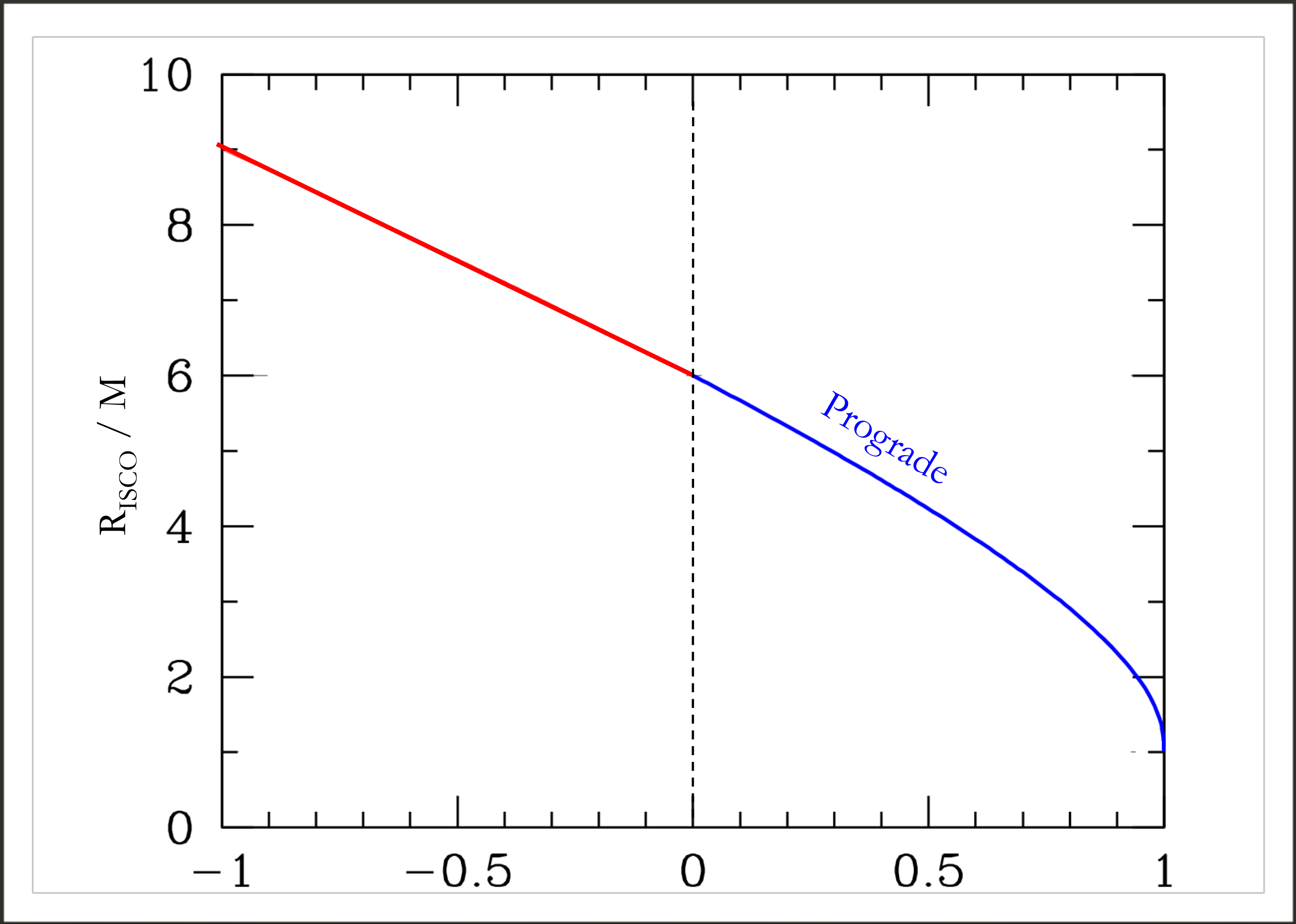
where r_{ms} is the radius of the marginally stable orbit,

$$r_{ms} = M\{3 + Z_2 \mp [(3 - Z_1)(3 + Z_1 + 2Z_2)]^{1/2}\}\,,$$
$$Z_1 \equiv 1 + (1 - a^2/M^2)^{1/3}[(1 + a/M)^{1/3} + (1 - a/M)^{1/3}]\,,$$
$$Z_2 \equiv (3a^2/M^2 + Z_1{}^2)^{1/2}\,. \quad (2.21)$$

Theoretical Foundation for Measuring Spin

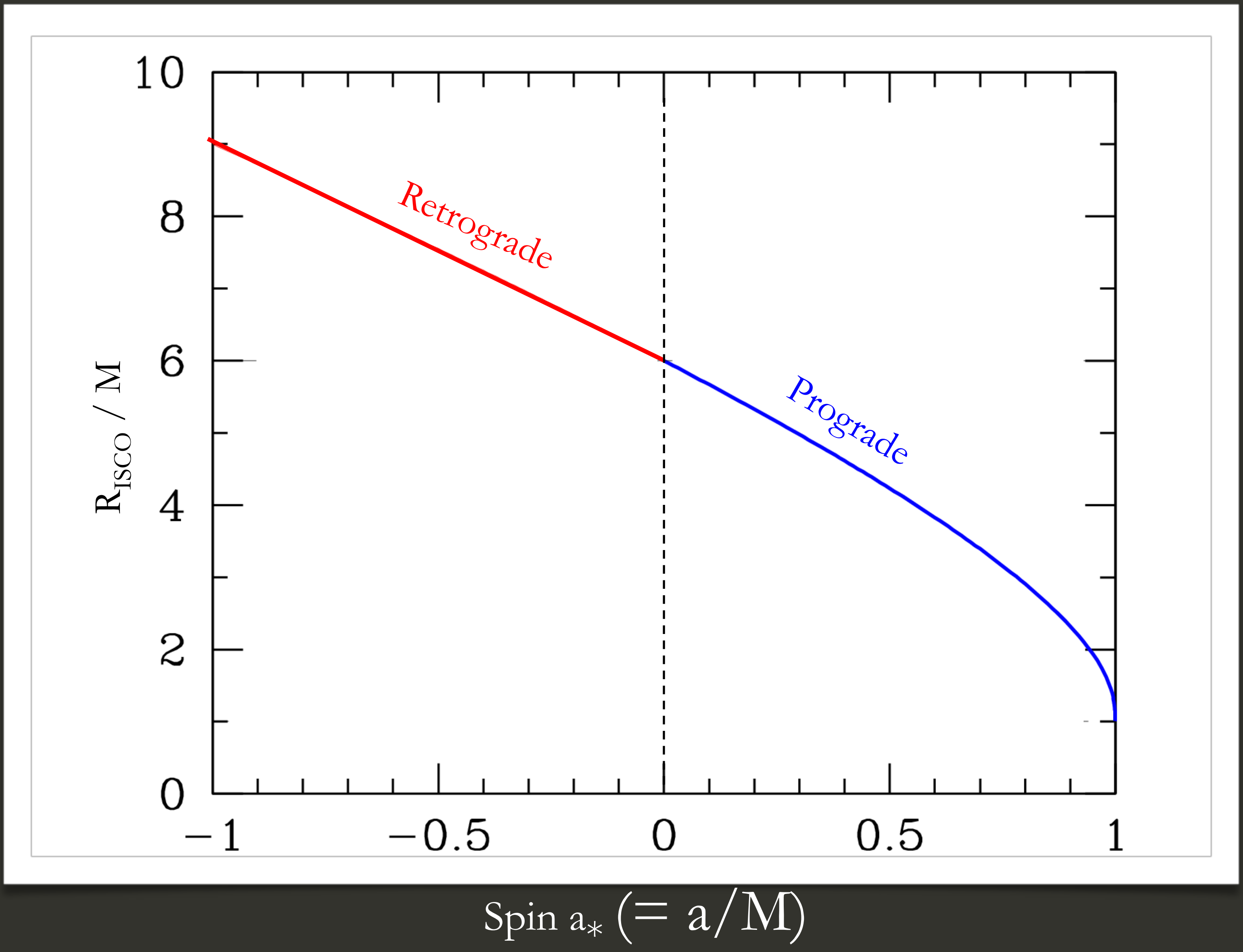


Theoretical Foundation for Measuring Spin

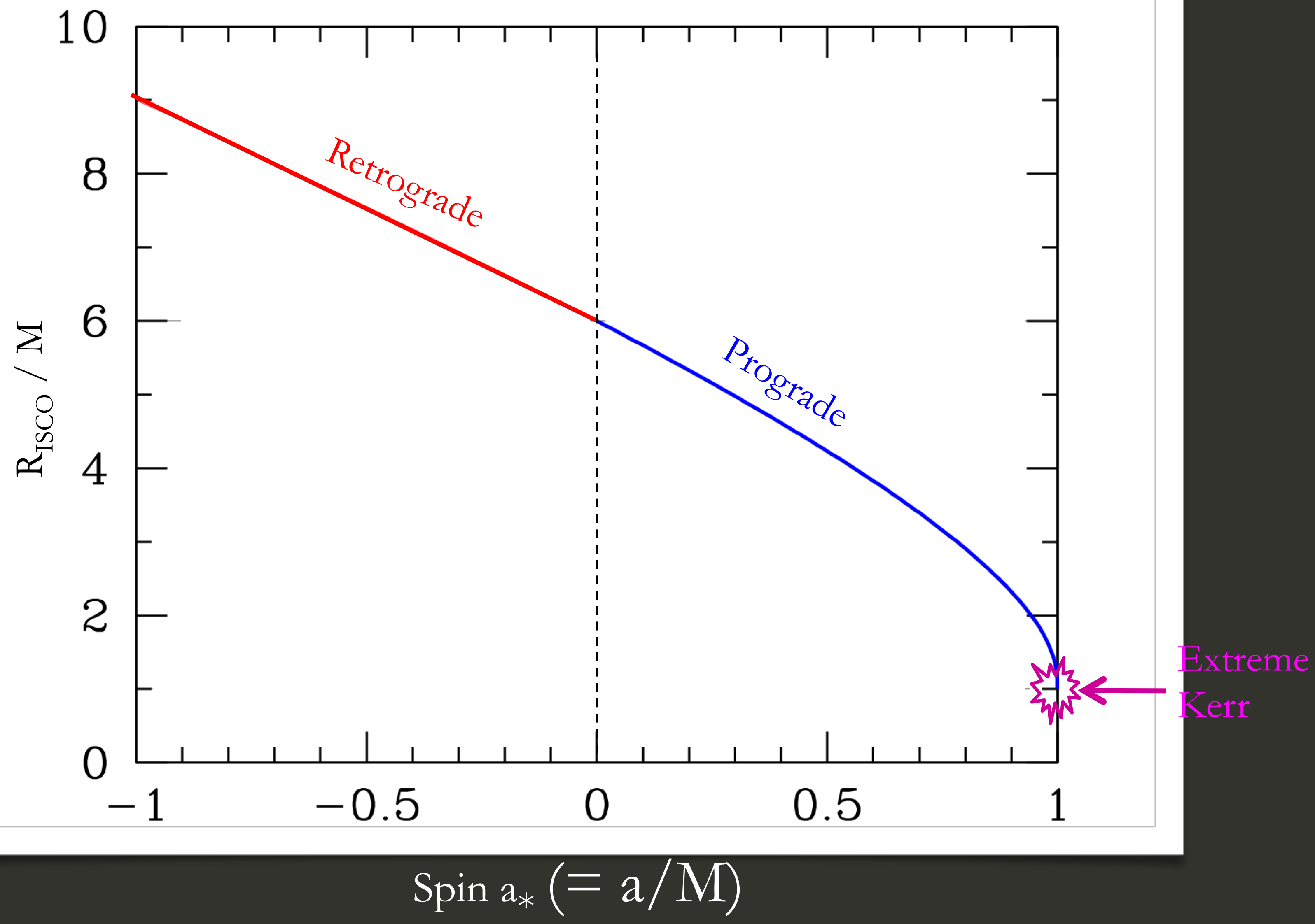


Spin a_* $(= a/M)$

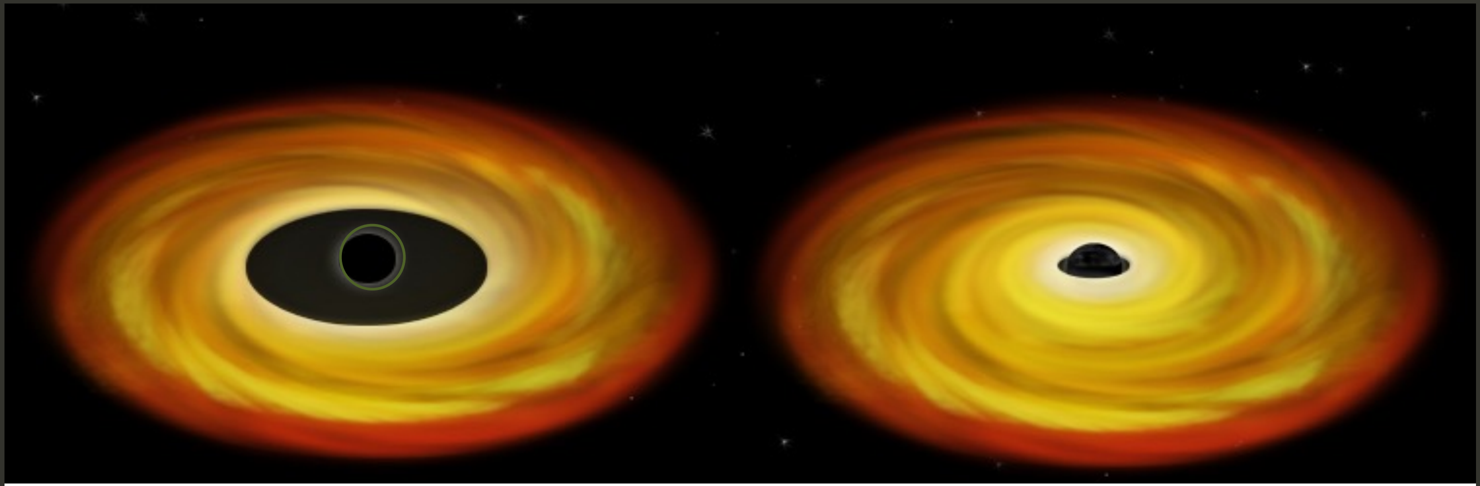
Theoretical Foundation for Measuring Spin



Theoretical Foundation for Measuring Spin



Innermost Stable Circular Orbit (ISCO)



$a_* = 0$

$R_{ISCO} = 6M = 90$ km

$a_* = 1$

$R_{ISCO} = 1M = 15$ km

Methods of Measuring Spin

Continuum Fitting (CF) Method

Stellar BHs only

➡ Fitting the thermal 1-10 keV spectrum of the accretion disk (Zhang, Cui & Chen 1997)

Fe-K Method

Both stellar and supermassive BHs

➡ Fitting the relativistically-broadened profile of the 6.4 keV Fe K line (Fabian et al. 1989)

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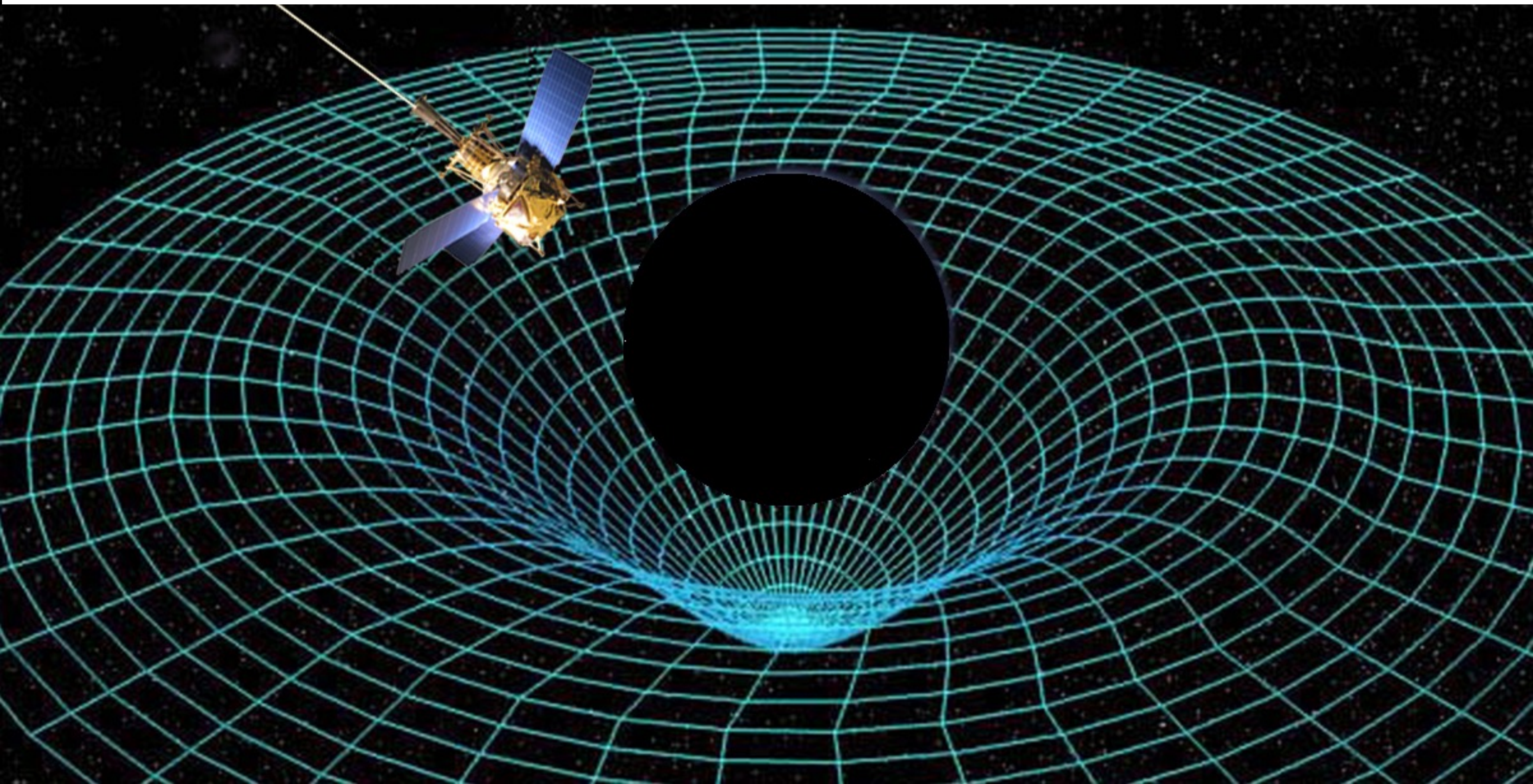
Promising Methods for the Future

✓ High-frequency X-ray oscillations (100-450 Hz)

✓ X-ray polarimetry

✓ Gravitational Wave

Continuum Fitting
(Stellar Black Holes Only)

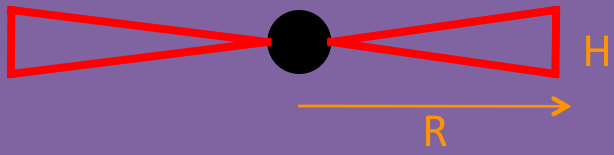


CF Method Requirements

➢ Observational side:

1. Spectrum dominated by accretion disk component
2. Thin disk spectra: $H/R < 0.03$ equivalent to $L/L_{Edd} < 0.3$

➢ Modeling Side:



3. Accurate system parameters: M, *i* and D

4. Disk models of spectral hardening (KERRBB & BHSPEC)

Li et al. 2005; Davis et al. 2005, 2006, 2009; Davis & Hubeny 2006; Blaes et al. 2006

Please refer to McClintock et al. (2014, SSRv) for details

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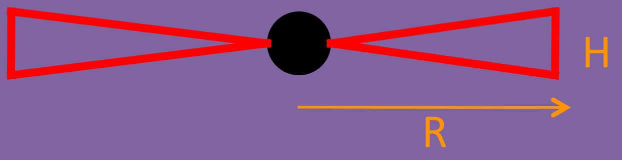

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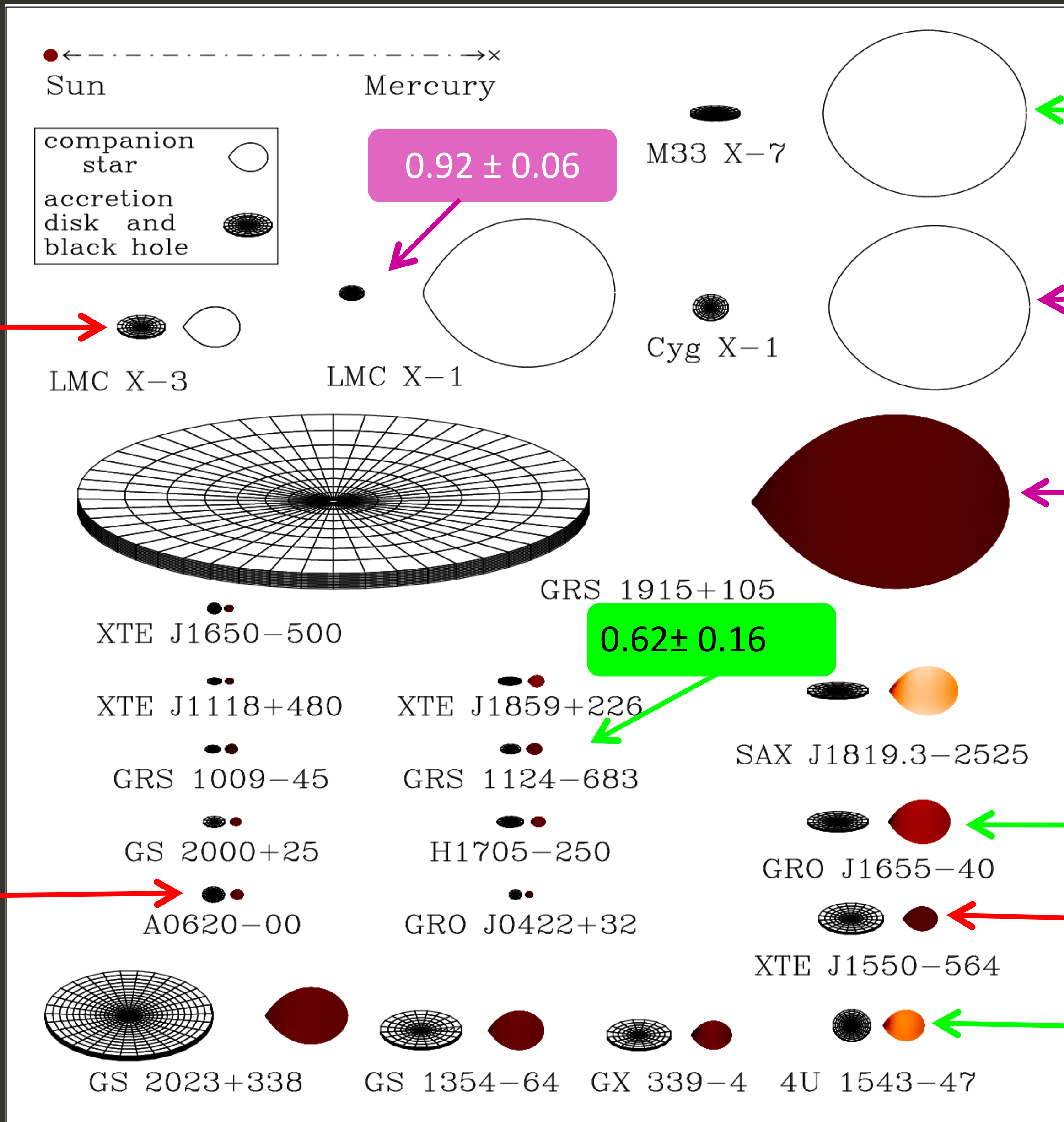
Assumption: alignment of BH spin and orbital angular momentum

Please refer to McClintock et al. (2014, SSRv) for details

Spin Summary For 21 BH Binaries (CF)



0.84 ± 0.05

0.92 ± 0.06

< 0.3

> 0.98

> 0.92

H1743-322:
a* =0.2 ± 0.3

0.62± 0.16

0.70 ± 0.05

0.12 ± 0.18

0.34 ± 0.24

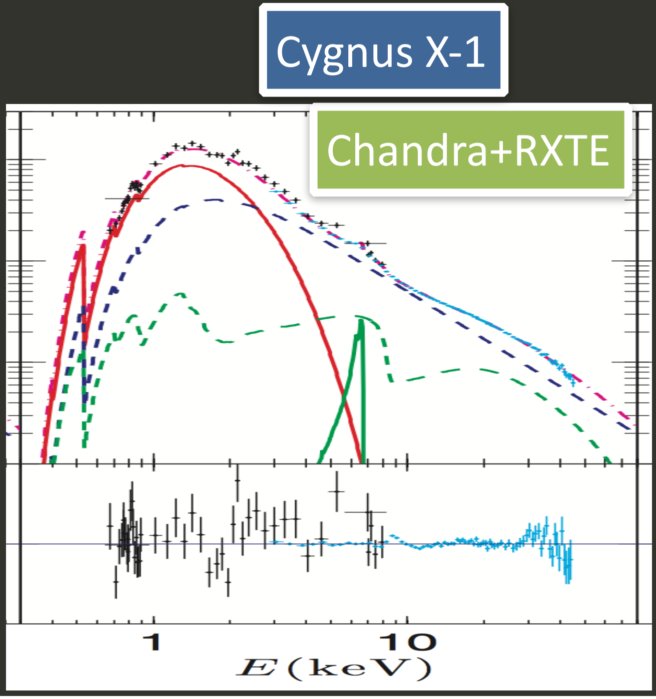
0.80 ± 0.05

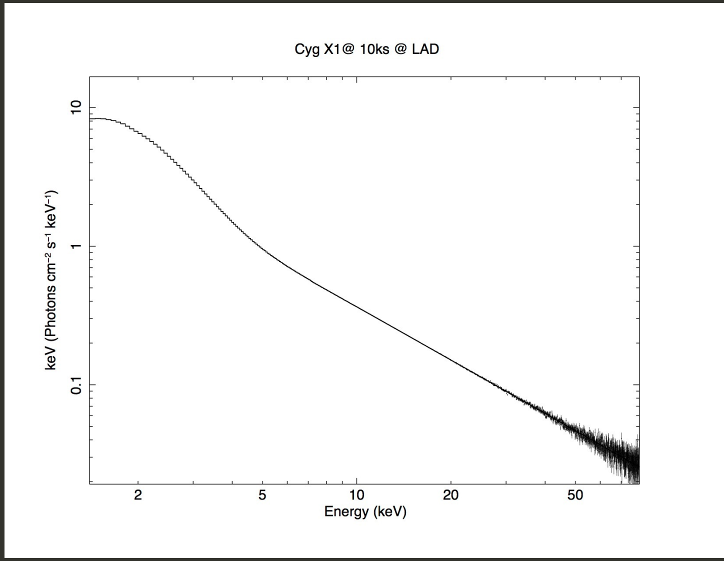
eXTP Capability

✓ eXTP has a much larger effective area compared to the current missions and cover a wide energy range (0.5-30 keV), therefore it has an advantage in constraining the spin measurement (higher S/N).

- LAD(2-30 keV): 6x RXTE/PCA, 35x XMM
- SPA(0.5-20 keV): 10x XMM

✓ Due to the large effective area, it may observe more distant BHs and constrain their intrinsic parameters.

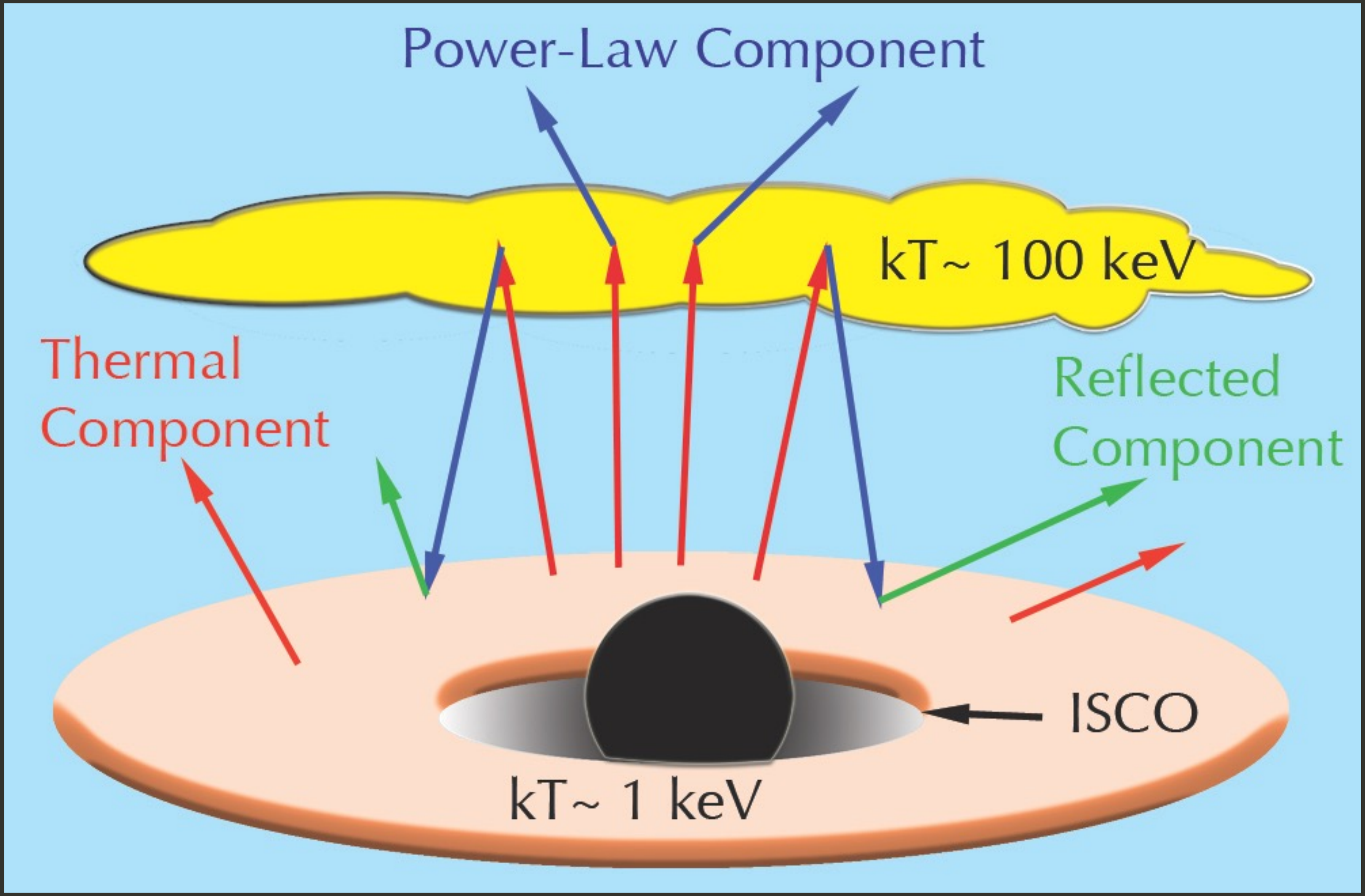




The Iron-Line Method

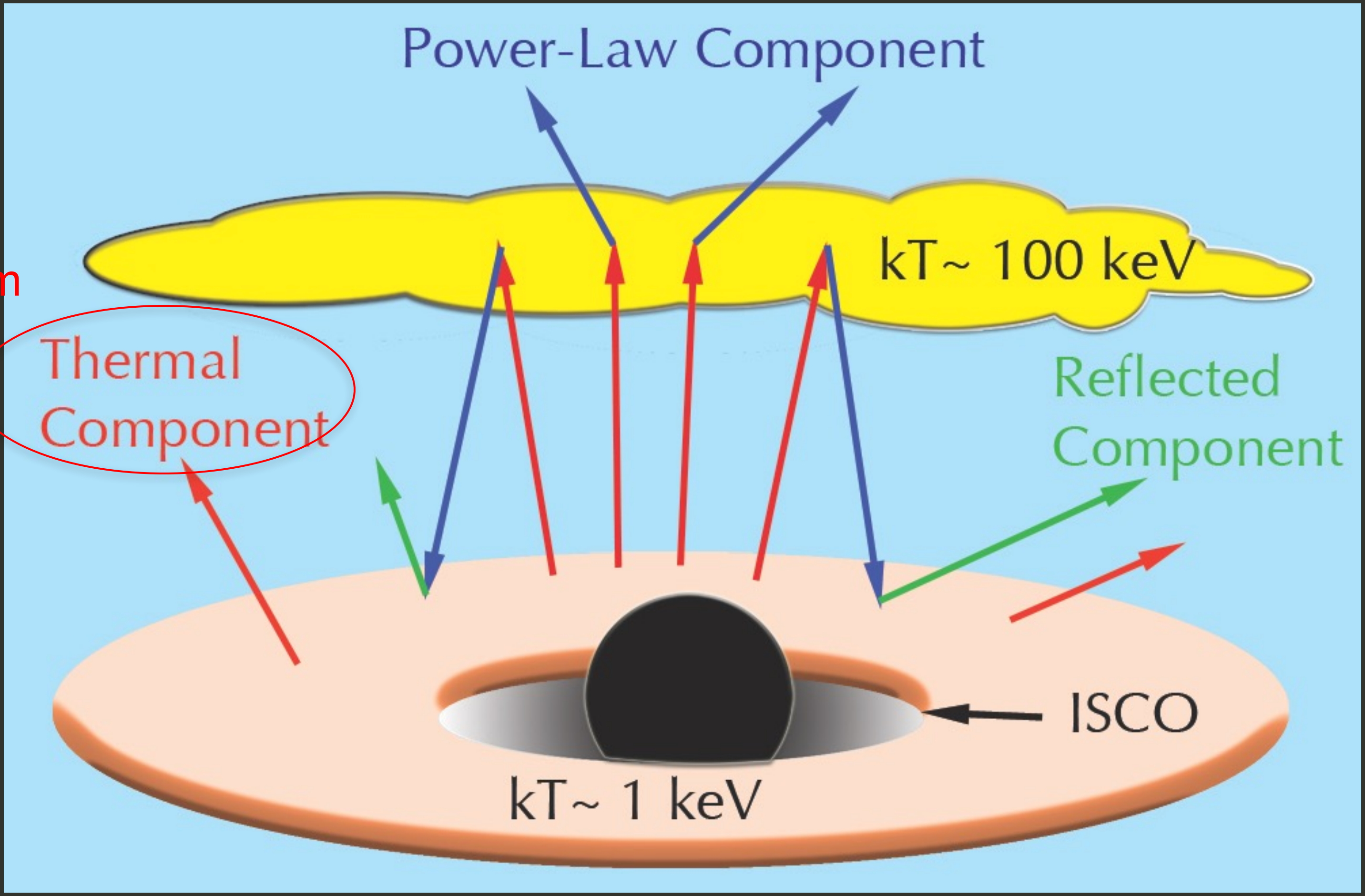
(both supermassive and stellar black holes)

Schematic Sketch of the X-ray Source



Schematic Sketch of the X-ray Source

Continuum
Fitting



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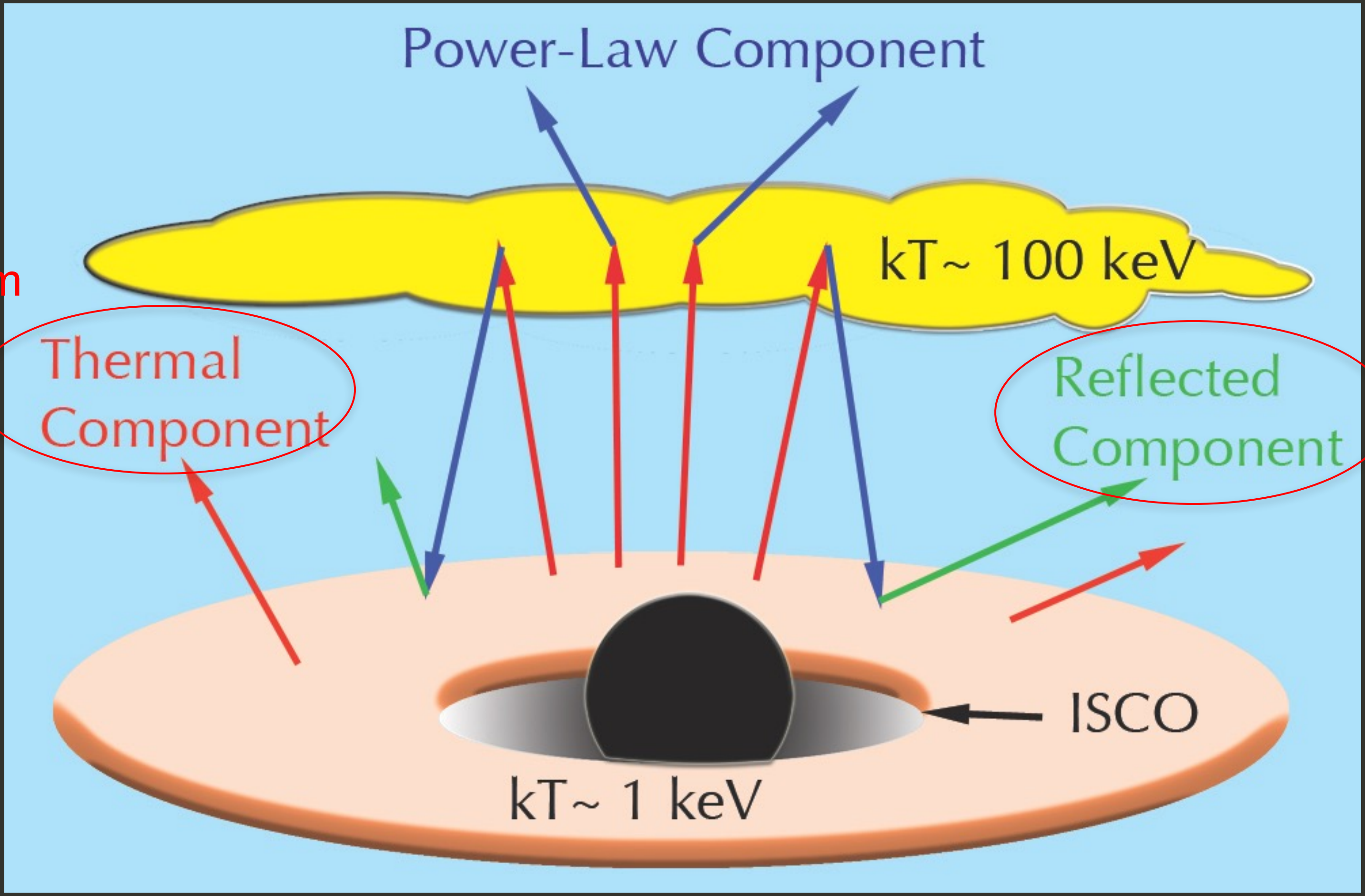
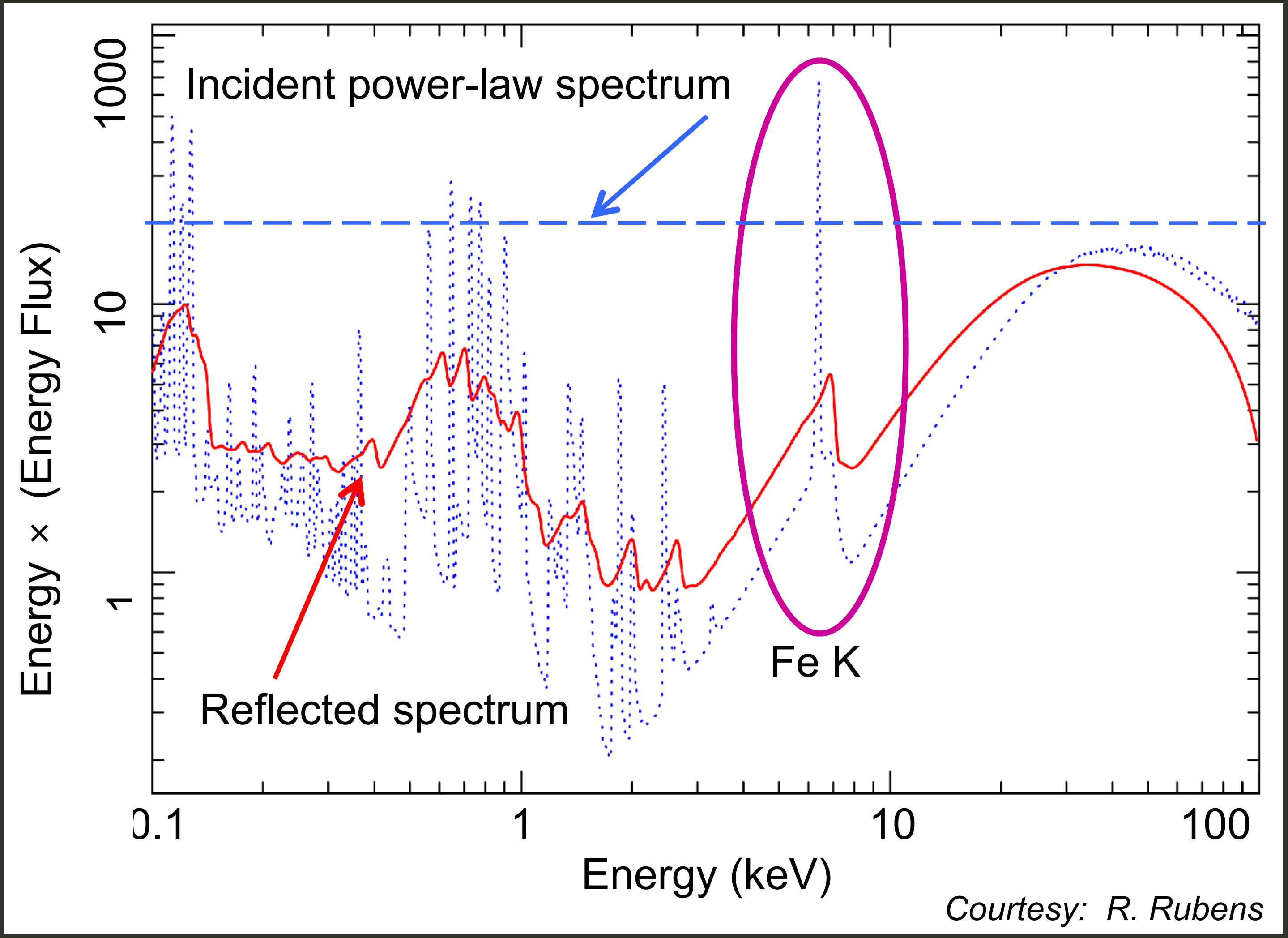
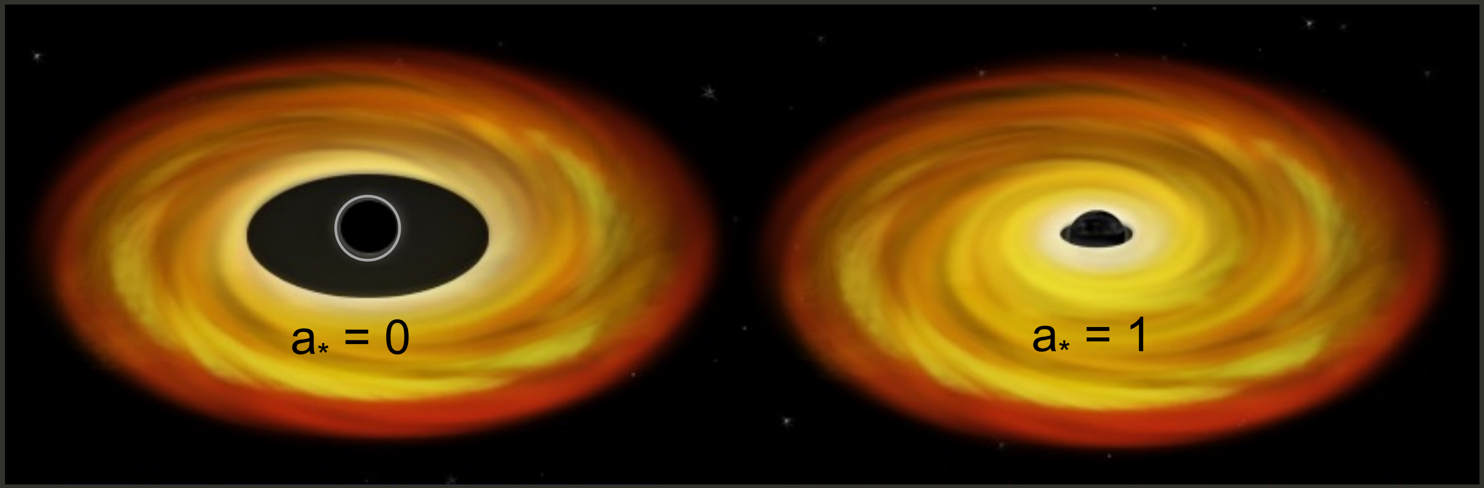


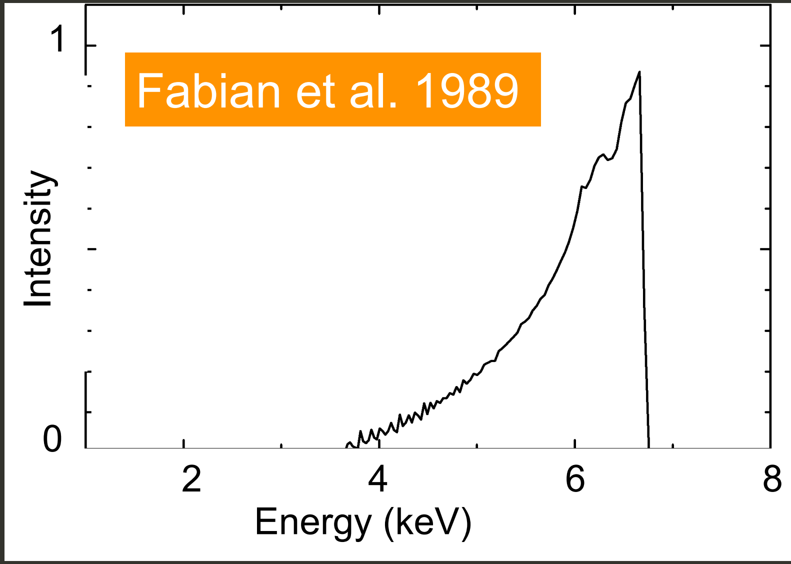
Iron Line

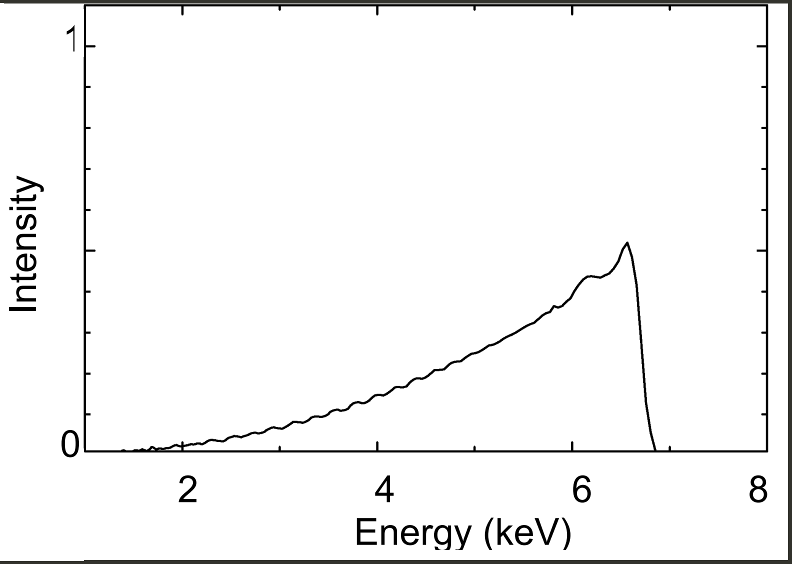
The "Reflected" Spectrum



Dependence of Fe K Line Profile on Spin







Models: Xillver (Garcia et al. 2010, 2013); Reflionx (Ross et al. 1999, 2005)

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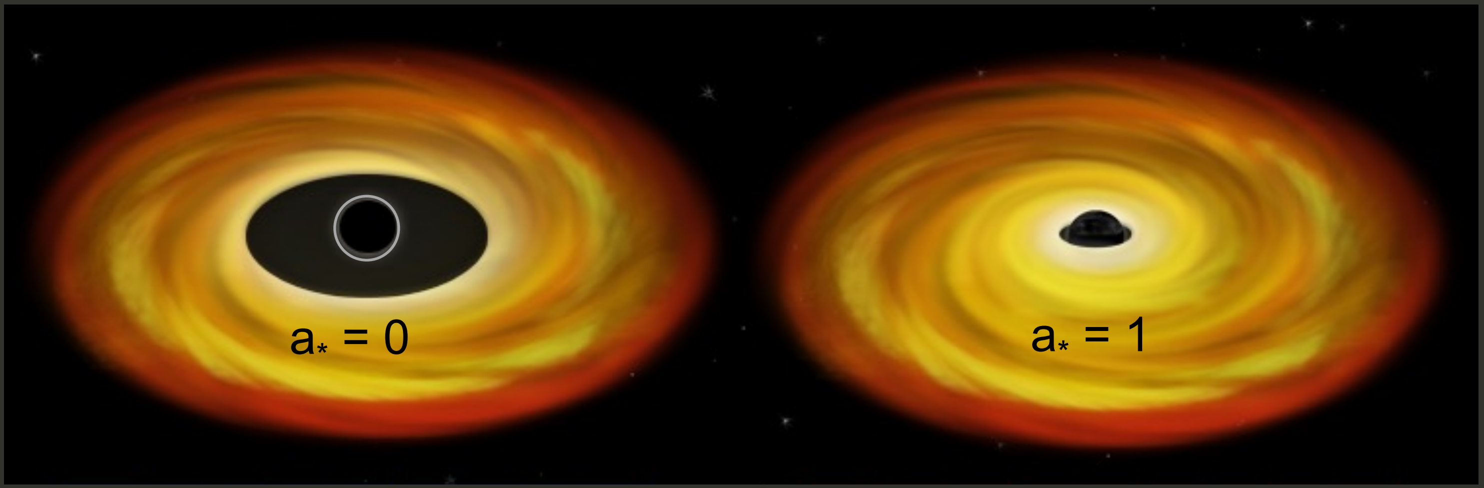
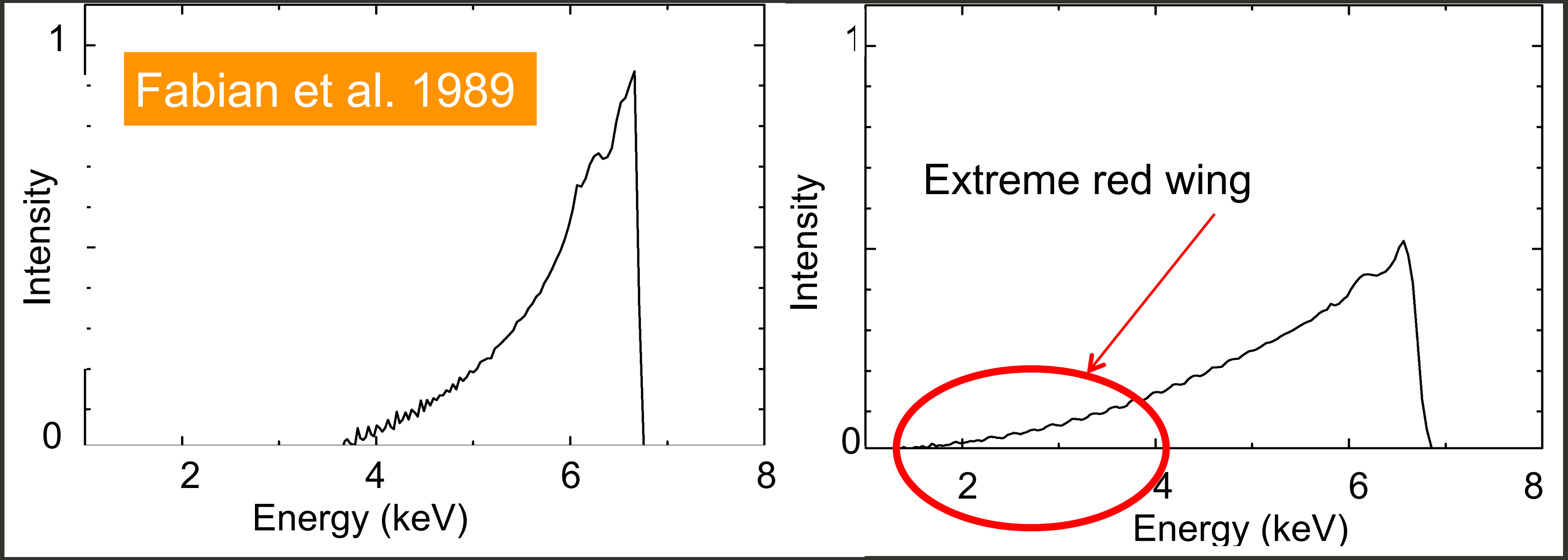




Models: Xillver (Garcia et al. 2010, 2013); Reflionx (Ross et al. 1999, 2005)

Fe-Line Spin Measurement for Stellar BH

Black Hole	Spin a_* (CF)	Spin a_* (Fe K)	Principal References
Cyg X-1	> 0.98	> 0.9	Gou ea. 2014; Fabian ea. 2012
GRS 1915+105	> 0.92	0.98 ± 0.01	Reid et al. 2014; Miller ea. 2014
LMC X-1	0.92 ± 0.06	$0.97^{+0.02}_{-0.25}$	Gou ea. 2009; Steiner ea. 2012
XTE J1550-564	0.34 ± 0.28	0.55 ± 0.1	Steiner, Reis ea. 2011
GRO J1655-40	0.7 ± 0.1*	> 0.9	Shafee ea. 2006; Reis ea. 2009
M33 X-7	0.84 ± 0.05		Liu ea. 2008, 2010
4U 1543-47	0.8 ± 0.1*		Shafee ea. 2006
LMC X-3	0.21± 0.12		Steiner ea. 2014
H1743-322	0.2 ± 0.3		Steiner & McClintock 2012
A0620-00	0.12 ± 0.19		Gou ea. 2010
Nova Mus 1991	~ 0.62		Chen, Gou ea. 2015
GX 339-4	< 0.9	0.93 ± 0.05	Reis ea. 2008; Kolehmainen & Done 2010
MAXI J1836-194		0.88 ± 0.05	Reis ea. 2012
Swift J1753.5		0.76 ± 0.15	Reis ea. 2009
XTE J1650-500		> 0.7	Walton ea. 2012
XTE J1752-223		0.52 ± 0.11	Reis ea. 2010
XTE J1652-453		< 0.5	Heimstra ea. 2010, Chiang ea. 2012
M31 uQ	< -0.2		Middleton ea. 2014

We may cross-check the spin results with the eXTP data

Continuum-Fitting vs. Iron-Line Profile

(1) The CF method needs much more requirement (e.g., M, i, & D) and one assumption on the inclination, however, the iron-line profile-fitting method doesn't.

(2) The result from CF is relatively more reliable because it is less affected by the subfigures of the spectra, so CF results can provide as a guide.

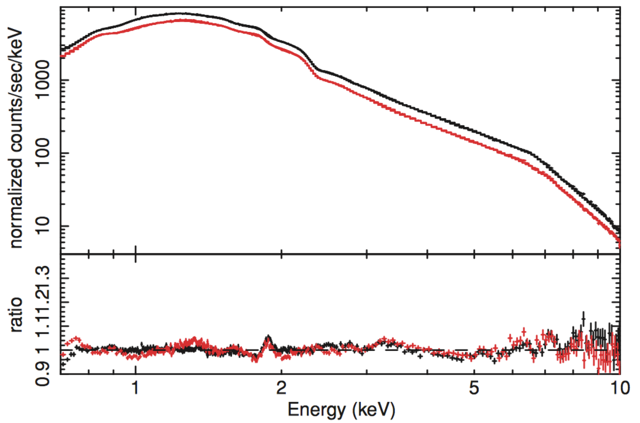
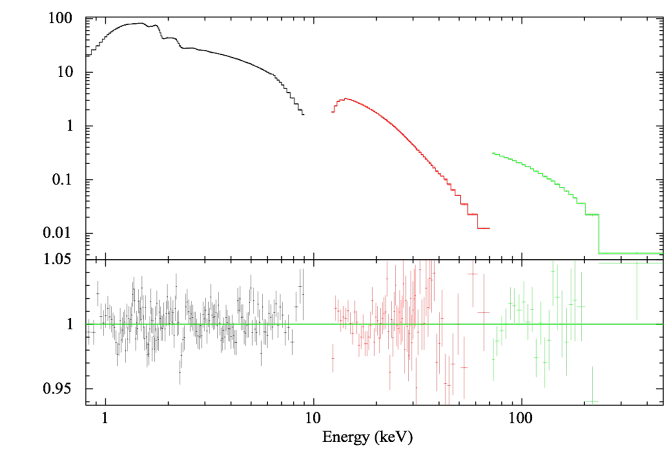


Figure 16. Plot above shows the *XMM-Newton* spectra of Cygnus X-1 fit with a relativistically blurred reflection spectrum and the "kerrbb" disk continuum model. The spin parameters in the disk reflection and continuum spectra were linked.



a_{*}=0.05 ± 0.01 (Miller et al. 2009; XMM)

a_{*}=0.97 ± 0.02 (Fabian et al. 2012; Suzaku)

a_{*}=0.88 ± 0.11 (Duro et al. 2011; XMM+RXTTE)

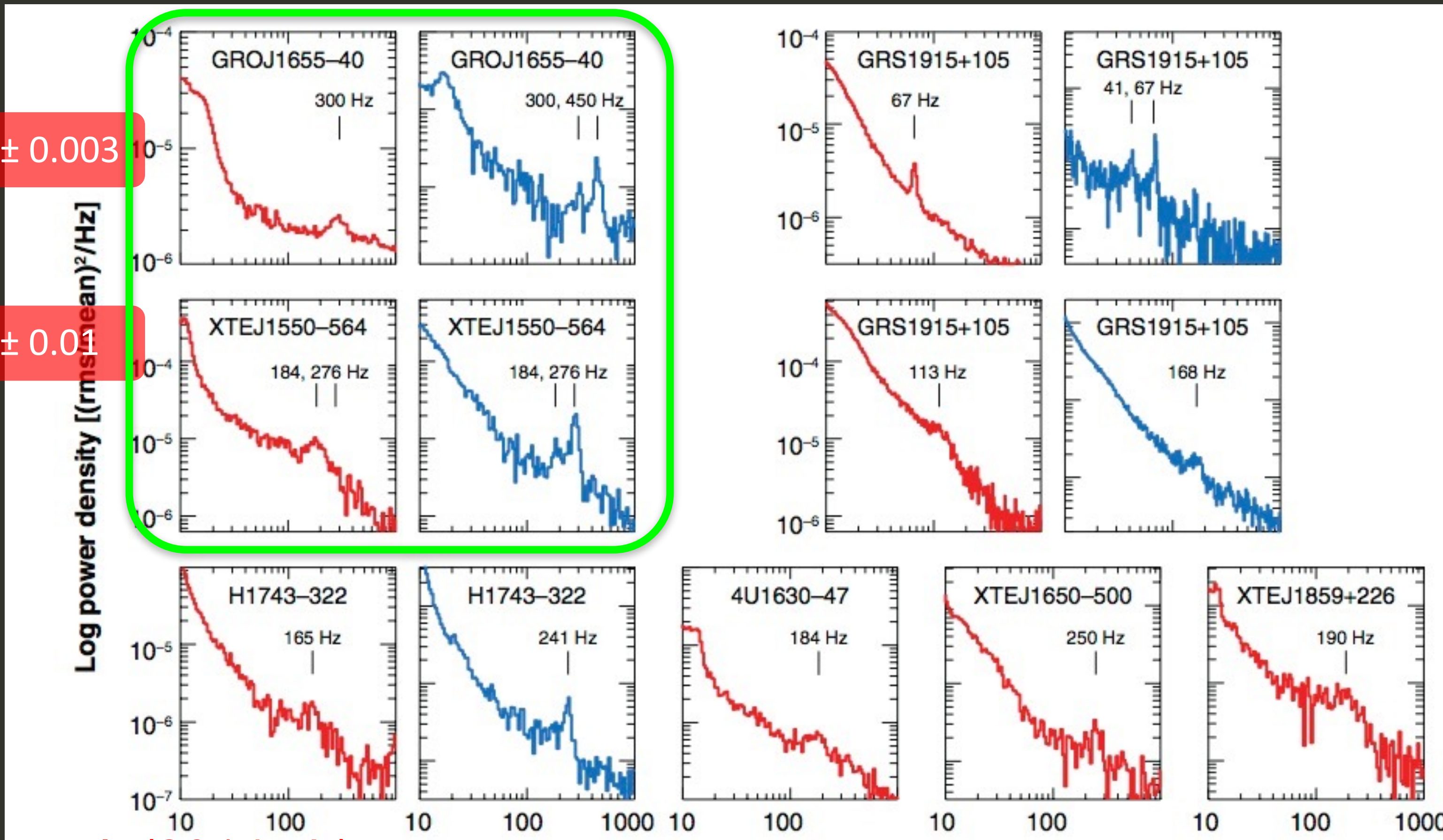
a*> 0.83 (Tomsick et al. 2014; Suzaku+NuSTAR)

Spin with Iron-Line for Cyg X-1

High-Frequency QPO Method

0.290 ± 0.003

0.34 ± 0.01



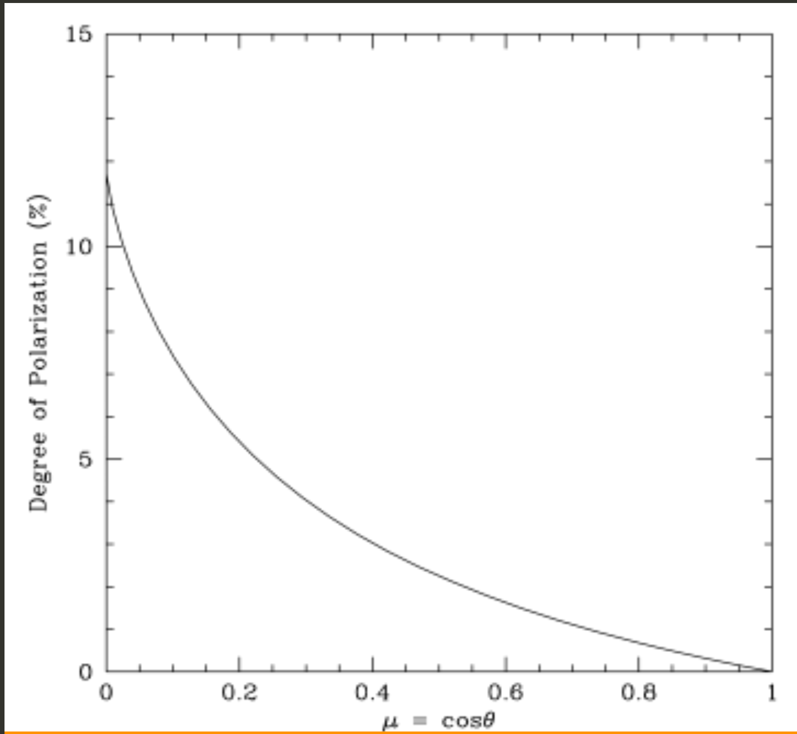
Motta et al. (2014a,b)

Remillard & McClintock (2006)

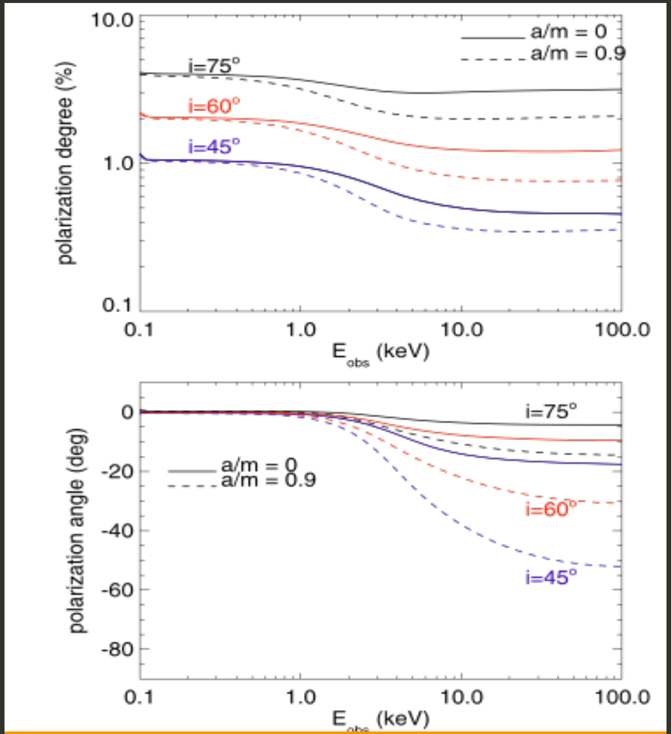
Relativistic Precession Model (RPM; Stella & Vietri 1999)

The QPO results strongly depends on QPO models, so results from CF and iron-line may help distinguish QPO models.

Polarimetry Method



Li, Narayan, & McClintock (2009)



Schnittman & Krolik (2009)

- ✓ eXTP has the polarimeter, which could help determine the inclination angle and spin parameter independently, hence help test CF assumption on the inclination angle besides cross-checking the spin parameter.
  - ★PFA (2-20 keV): 2x IXPE, same as XIPE

Summary

➢ The eXTP's unique capability of large effective area and broadband will provide higher S/N spectra, and we may readily put a better constraint on the spin parameter with CF method, and also cross-check the spin results from multiple methods.

➢ CF method is quite straightforward and less affected by the subfeatures of the speatra, so the results from CF method is relatively reliable, so it may act as guide for the results from other methods.

➢ The polarimetry method could be advanced in the eXTP era, and it will provide independently constraints on the inclination angle and other system parameters, and help test the inclination angle assumption for the continuum fitting method.