Estimation of Spin of the Galactic Black Hole Candidate GRS 1758-258 through X-ray Spectroscopy

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The Team





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A bit history

Black holes are characterized by their mass (m), Spin (a), and charge (q)

Solutions of Einstein's equation

Schwarzschild solution came in 1916, solved during WWI, which contains mass

Reissner-Nordström solution came 1921, which contains mass and charge

Kerr solution, which contains mass and spin, was found 1962

Kerr-Newman solution contains m, a, and q, and was published in 1964

Karl Schwarzschild

Classification of black holes

Mass (m), spin (a), and charge (q)

1. Based on Solutions of Einstein's equation

a. Schwarzschild BH: m
b. Reissner-Nordström BH: m, q
c. Kerr BH: m, a
d. Kerr-Newman BH: m, a, q

2. Astrophysical BHs: Characterized by their mass

a. Stellar mass BH: 5-100 solar Mass
b. Intermediate mass BH (IMBH): 10^3-10^5 solar Mass
c. Super massive BH (SMBH): 10^5-10^9 solar Mass

Black hole astronomy & astrophysics uncovers the intrinsic properties of them!

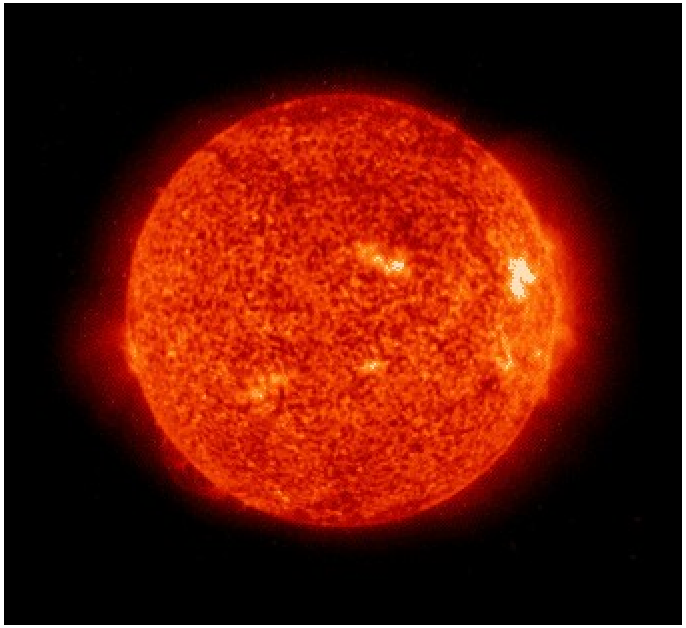
What is spin?

Every stellar object rotates which provides angular momentum (j) to the object.

When a star dies and collapses into a black hole, the radius shrinks.

However, to keep the j constant, the rotation speed must increase, assuming the mass remains constant.

Eventually, this rotation speed may reach ~ 1000 times per sec for extreme black holes.



How do we know the spin?

Spin values could be $-0.998 < a < 0.998$

$|a| \leq 0.998$ is the Thorne's limit. But, could be more.

Spin $a < 0$ means retrograde orbit.

Spin $a = 0$ means non-rotating BH.

Spin $a \geq 0$ means Prograde orbit.

For each case, the X-ray spectrum differs. Fitting the spectrum with appropriate model provides an estimation of the spin.

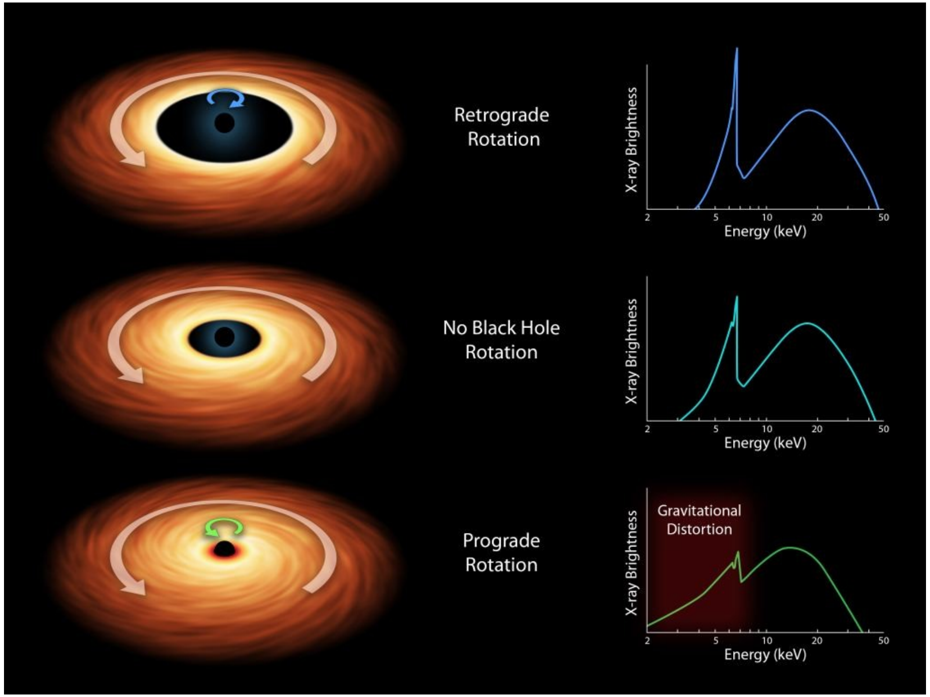
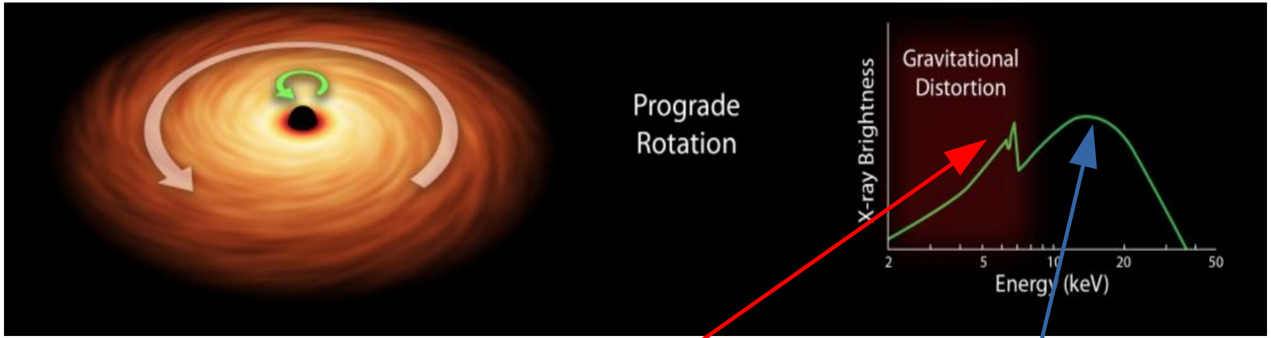


Fig. Credit: NASA/JPL-Caltech

How do we know the spin?



Spectral feature includes a Fe line and a Reflection hump

Fig. Credit: NASA/JPL-Caltech

GRS 1758-258: Our Object

A persistent black hole candidate. We have only three of them in our Galaxy.

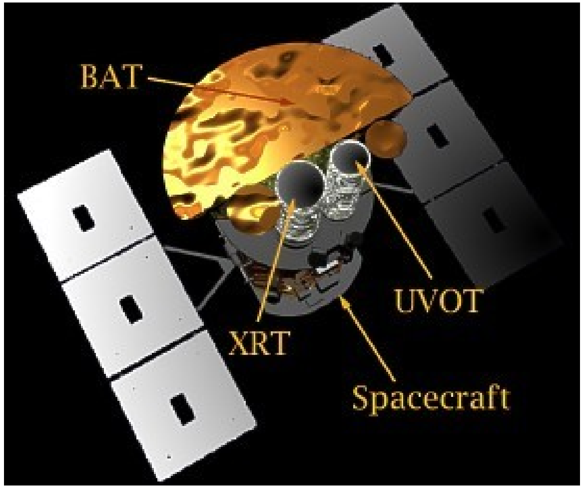
Other two are Cyg X-1 and GRS 1915+105.

Least explored compared to the other two sources.

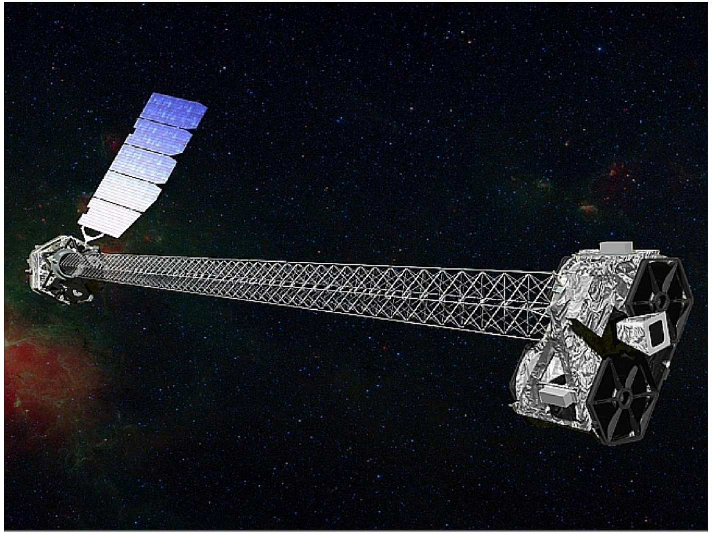
Discovered by GRANAT/SIGMA in 1990 (Syunyaev et al. 1991)

Orbital period is 18.45±0.10 days (Smith et al. 2002)

The data



Swift/XRT
(0.5-10 keV)



NuSTAR
(3-78 keV)

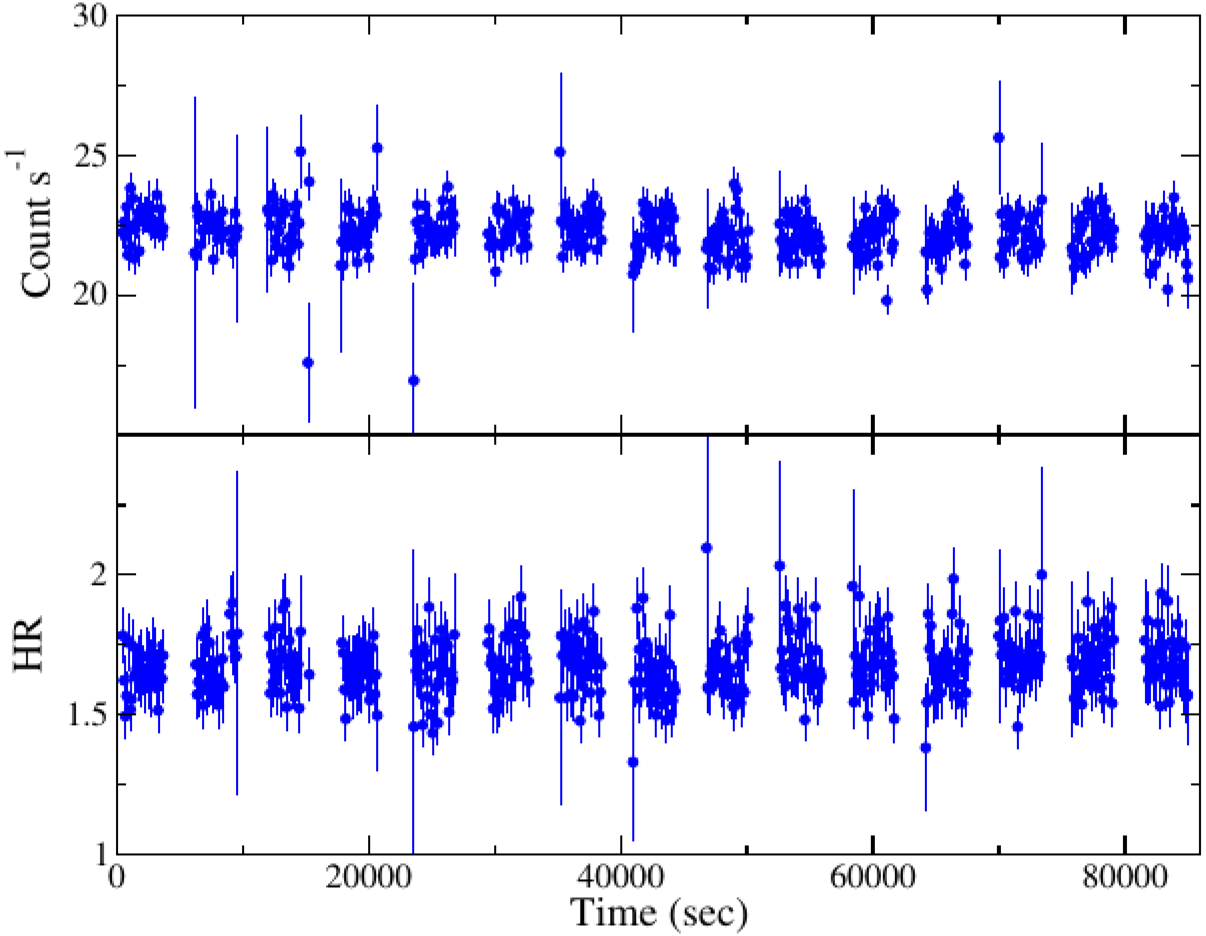
Table 1. Log of Observations of GRS 1758–258

Instrument	Date (UT)	Obs ID	Exposure (ks)	Count s^{-1}
NuSTAR	2018-09-28	30401030002	42	17.39 ± 0.02
Swift/XRT	2018-09-28	00088767001	1.7	7.88 ± 0.07

Fig. Credit: NASA/JPL-Caltech

Jana et al., 2022, ApJ, accepted

The NuSTAR light curve



(3-78 keV)

Hardness ration (HR):

Counts (6-30keV)/ counts (3-6)

Stable hard state

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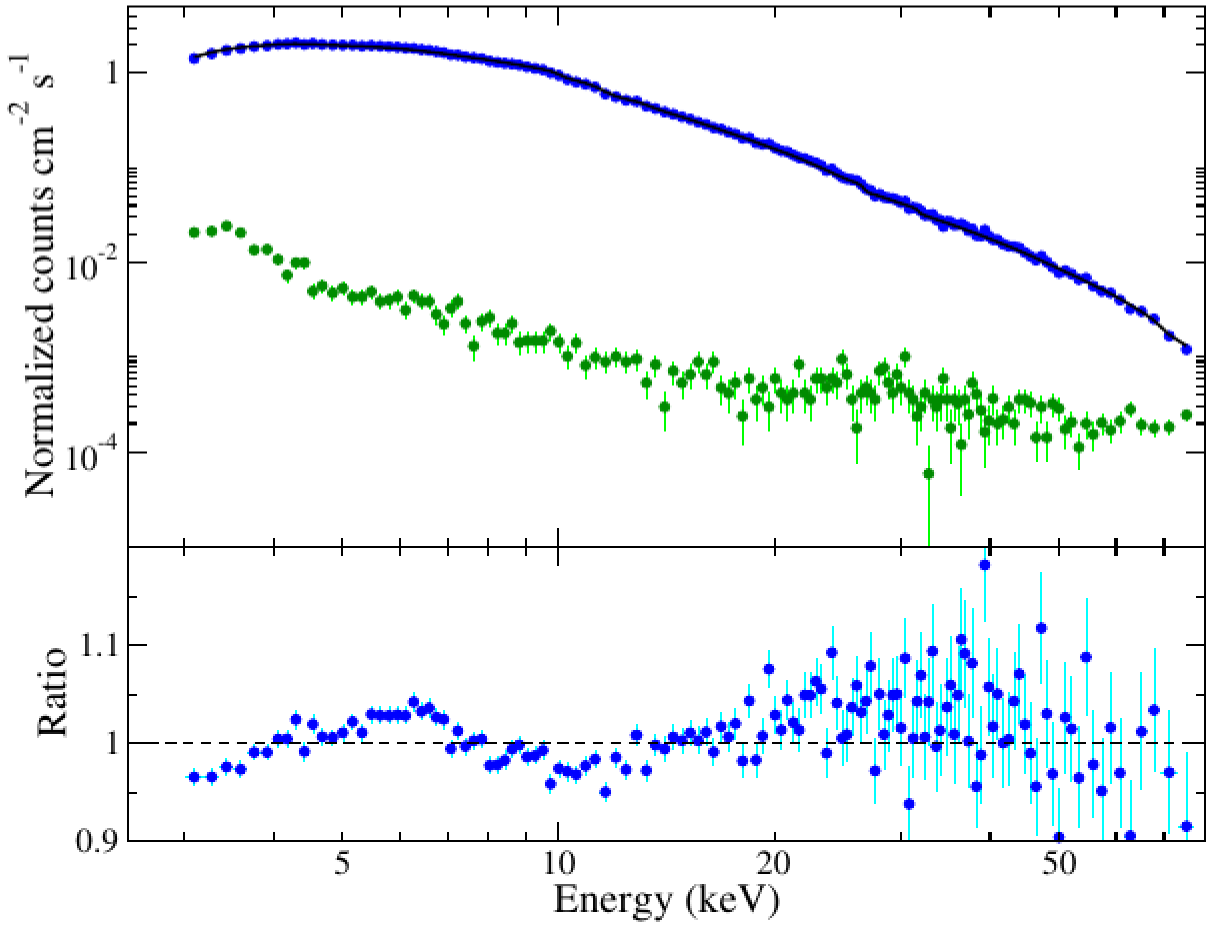
The NuSTAR spectrum: Powerlaw fit



(3-78 keV)

Blue data

Green Background

Look at the residue pattern!

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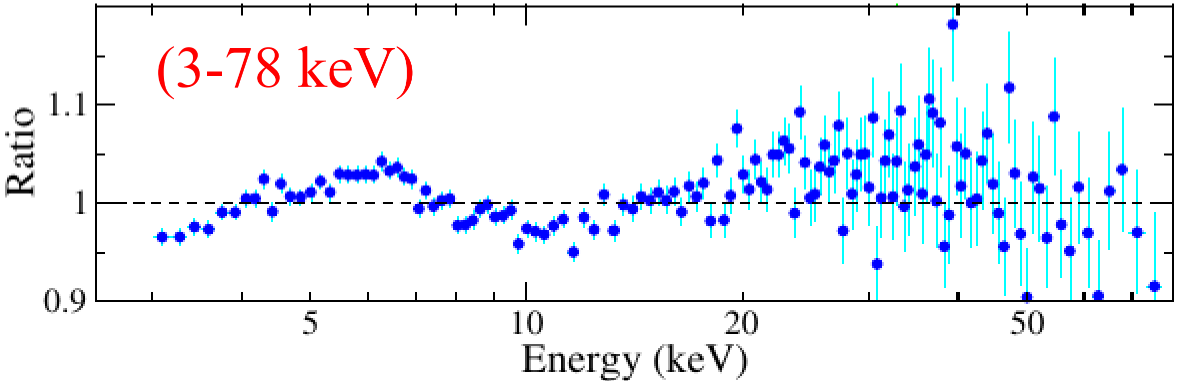
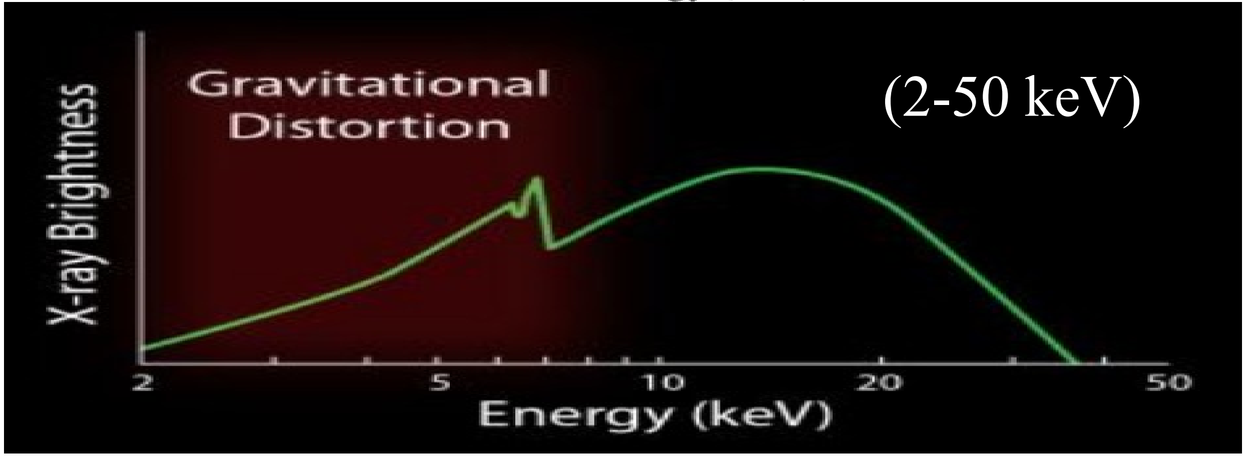
The NuSTAR spectrum: Powerlaw fit





Residue pattern!

Compare with theoretical curve!

Prograde orbit!

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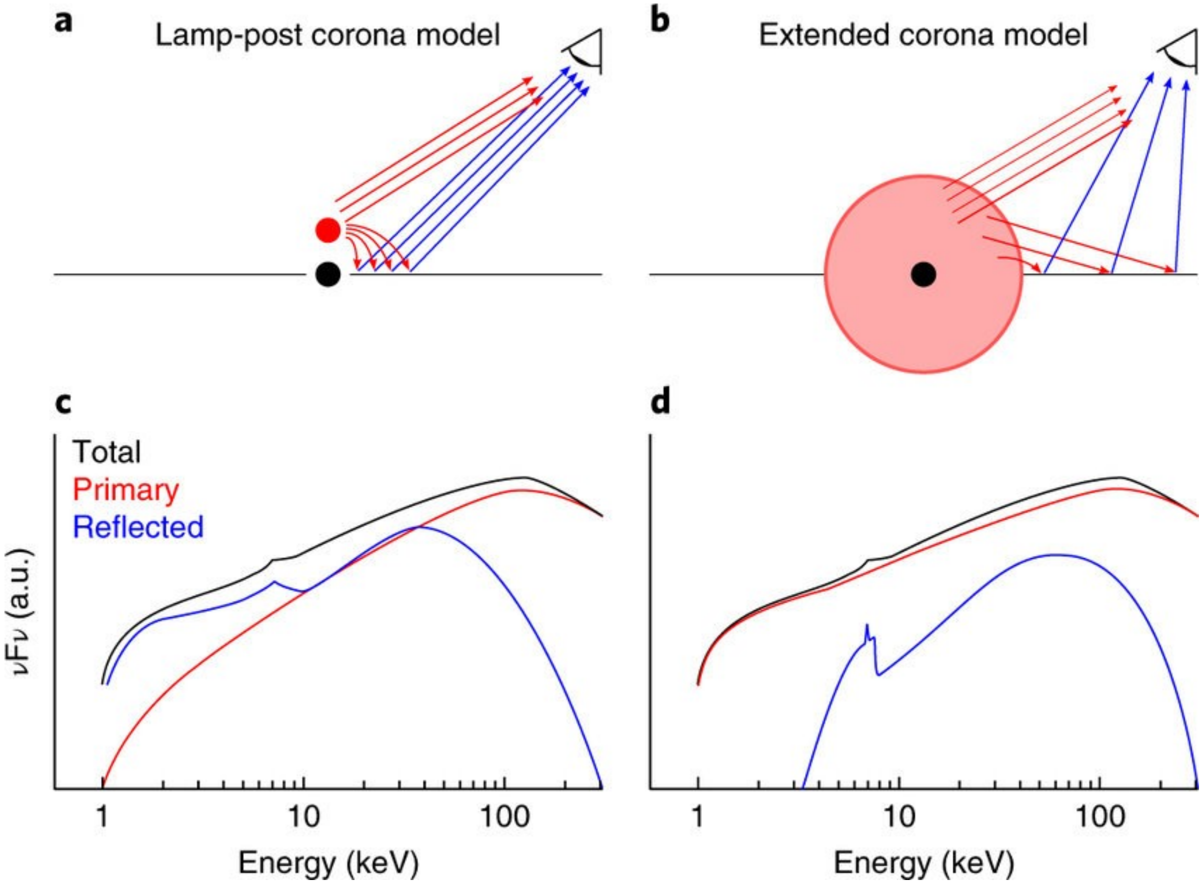
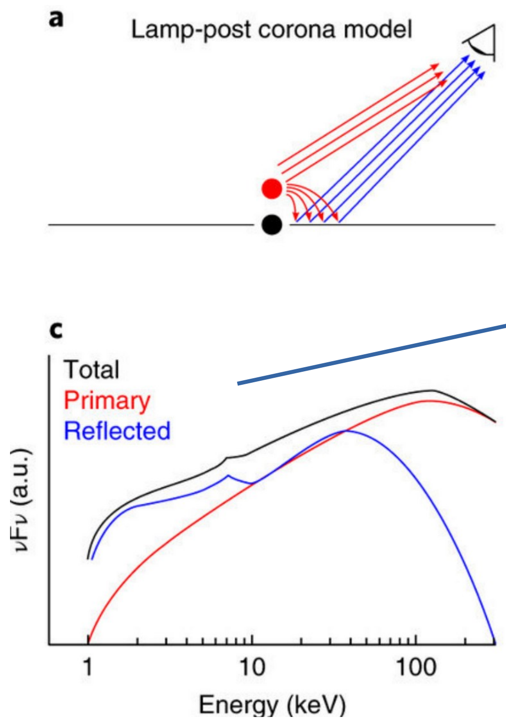
Relativistic model for spectral fit: RELXILL

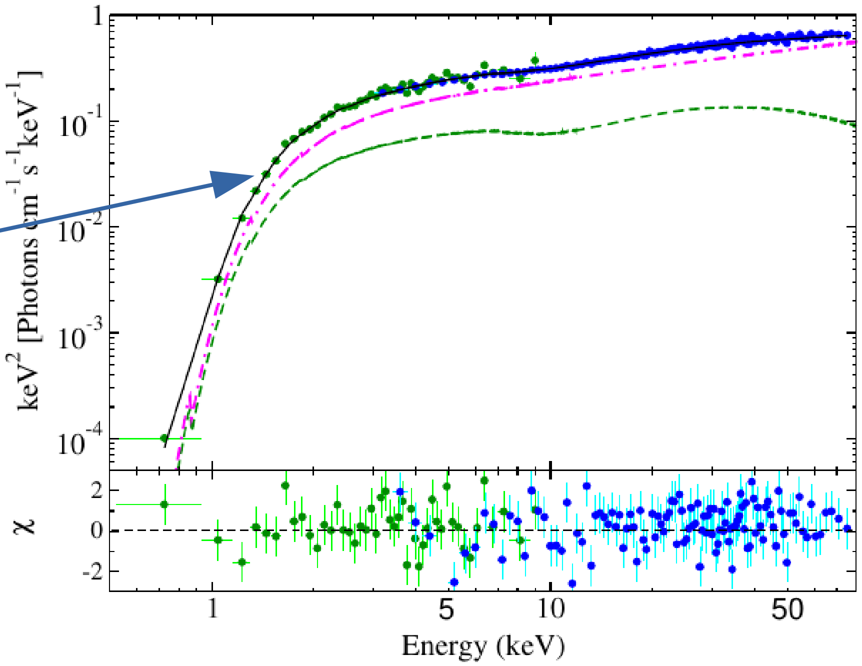


García & Kallman 2010;
García et al. 2013, 2014;
Dauser et al. 2014, 2016 and
References within

Colors don’t represent the
Energies! Fig. Chauvin et al., 2018, NatAs

Relativistic model for spectral fit: Key findings



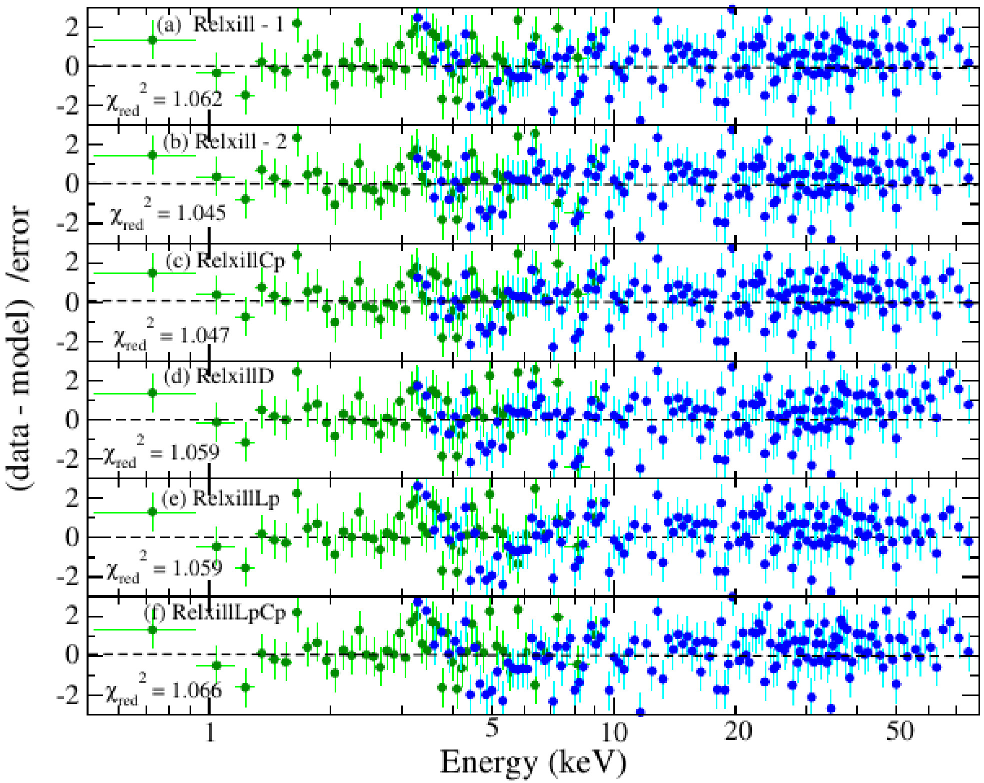


Well fitted spectrum. No excess residue.
Magenta: Primary
Green: Reflected

Colors don't represent the energies!
Fig. Chauvin et al., 2018, NatAs

Jana et al., 2022, ApJ, accepted

RELXILL: Various Flavours



Well fitted spectrum. Various flavours of RELXILL fits are shown. No excess residue.

Green: Swift/XRT
Blue: NuSTAR

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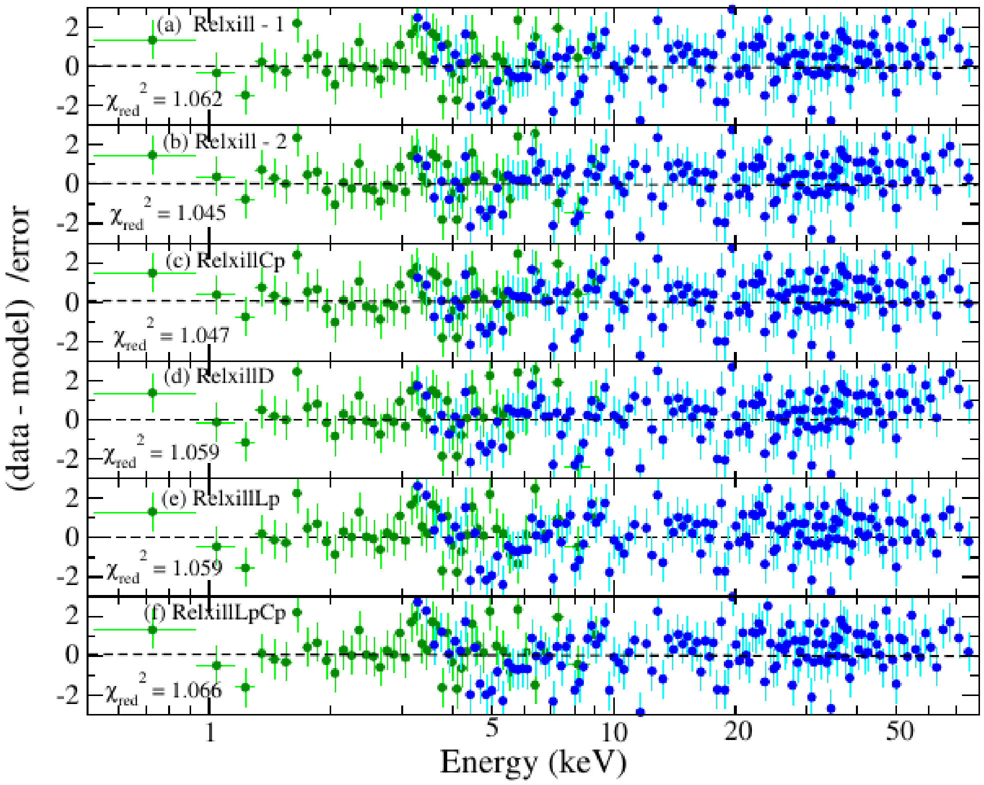
Spectral fits: Key Parameters



Photon index $\Gamma \sim 1.53 - 1.57$

Eddington ratio $L/L_{Edd} \sim 0.015$ or 1.5%

Corona temperature kT_e = 134-146 keV

Optical depth $\tau = 1.30 \pm 0.30$

Inclination i = 28° -37° degrees

Spin a* > 0.92

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Spectral fits: Table

Table 2. Spectral Analysis results

	CUTOFF	Relxill-1	Relxill-2	RelxillCp	RelxillD	RelxillLp	RelxillLpCp
$N_{\rm H}$ (10^{22} cm^{-2})	$0.86^{+0.18}_{-0.18}$	$2.55^{+0.01}_{-0.01}$	$2.56^{+0.02}_{-0.01}$	$2.54^{+0.02}_{-0.02}$	$2.53^{+0.02}_{-0.01}$	$2.53^{+0.03}_{-0.05}$	$2.52^{+0.02}_{-0.02}$
Γ	$1.56^{+0.02}_{-0.01}$	$1.54^{+0.01}_{-0.01}$	$1.53^{+0.02}_{-0.02}$	$1.56^{+0.02}_{-0.02}$	$1.54^{+0.02}_{-0.01}$	$1.57^{+0.01}_{-0.02}$	$1.53^{+0.02}_{-0.01}$
$E_{\rm cut}/kT_e$ (keV)	500^{+u}_{-28}	> 946	> 925	134^{+82}_{-29}	$300^{\dagger}$	> 911	146^{+68}_{-32}
$q_{\rm in}$	–	3^f	$6.78^{+0.05}_{-0.07}$	$6.51^{+0.06}_{-0.05}$	$7.09^{+0.07}_{-0.11}$	–	–
$q_{\rm out}$	–	3^f	$2.04^{+0.09}_{-0.06}$	$1.99^{+0.08}_{-0.07}$	$2.10^{+0.04}_{-0.06}$	–	–
$R_{\rm br}/h$ (R_g)	–	$10.8^{+2.5}_{-1.4}$	$4.8^{+1.5}_{-0.8}$	$5.3^{+1.7}_{-2.2}$	$4.5^{+1.6}_{-0.8}$	$3.4^{+0.6}_{-0.4}$	$3.7^{+0.9}_{-0.6}$
$R_{\rm in}$ ($R_{\rm ISCO}$)	–	$1.14^{+0.04}_{-0.03}$	$1.13^{+0.02}_{-0.04}$	$1.13^{+0.03}_{-0.03}$	$1.15^{+0.04}_{-0.03}$	< 1.04	< 1.04
a^*	–	$0.97^{+0.02}_{-0.01}$	$0.96^{+0.02}_{-0.02}$	$0.97^{+0.01}_{-0.02}$	> 0.98	$0.97^{+0.02}_{-0.05}$	$0.95^{+0.01}_{-0.03}$
i (degree)	–	31^{+2}_{-2}	32^{+2}_{-4}	29^{+2}_{-3}	37^{+2}_{-3}	27^{+2}_{-1}	28^{+2}_{-2}
$\log(n)$ (log cm^{-3})	–	$15^{\dagger}$	$15^{\dagger}$	$15^{\dagger}$	< 15.3	$15^{\dagger}$	$15^{\dagger}$
$\log \xi$ (log erg cm s^{-1})	–	$3.68^{+0.03}_{-0.07}$	$3.61^{+0.10}_{-0.12}$	$3.71^{+0.14}_{-0.11}$	$3.90^{+0.07}_{-0.15}$	$3.62^{+0.10}_{-0.12}$	$3.72^{+0.10}_{-0.13}$
$A_{\rm Fe}$ ($A_{\odot}$)	–	$2.75^{+0.07}_{-0.13}$	$3.16^{+0.19}_{-0.13}$	$3.16^{+0.10}_{-0.14}$	$2.99^{+0.11}_{-0.15}$	$3.17^{+0.11}_{-0.13}$	$3.28^{+0.12}_{-0.11}$
$R_{\rm refl}$	–	$0.31^{+0.02}_{-0.04}$	$0.23^{+0.02}_{-0.01}$	$0.21^{+0.04}_{-0.03}$	$0.16^{+0.02}_{-0.01}$	$0.48^{+0.03}_{-0.04}$	$0.46^{+0.03}_{-0.02}$
$N_{\rm PL}/N_{\rm rel}$ (10^{-3} ph cm^{-2} s^{-1})	$0.12^{+0.01}_{-0.01}$	$5.02^{+0.05}_{-0.03}$	$4.75^{+0.06}_{-0.05}$	$4.68^{+0.05}_{-0.07}$	$4.61^{+0.03}_{-0.04}$	$22.7^{+0.7}_{-0.5}$	$22.7^{+0.5}_{-0.8}$
χ^2/dof	1484/1165	1718/1618	1691/1617	1691/1617	1712/1617	1715/1619	1726/1619
$\chi^2_{\rm red}$	1.273	1.062	1.045	1.047	1.059	1.059	1.066
$F_{2-10\ \rm keV}$	$5.49^{+0.04}_{-0.03}$	$5.69^{+0.04}_{-0.05}$	$5.71^{+0.03}_{-0.04}$	$5.70^{+0.02}_{-0.03}$	$5.64^{+0.06}_{-0.05}$	$5.68^{+0.03}_{-0.04}$	$5.68^{+0.04}_{-0.05}$

* indicate fixed value in the model. ^{f} indicate the value is fixed during the analysis.
The $F_{2-10\ \rm keV}$ is in unit of 10^{-10} ergs cm^{-2} s^{-1}.
Errors are quoted at 1.6σ.

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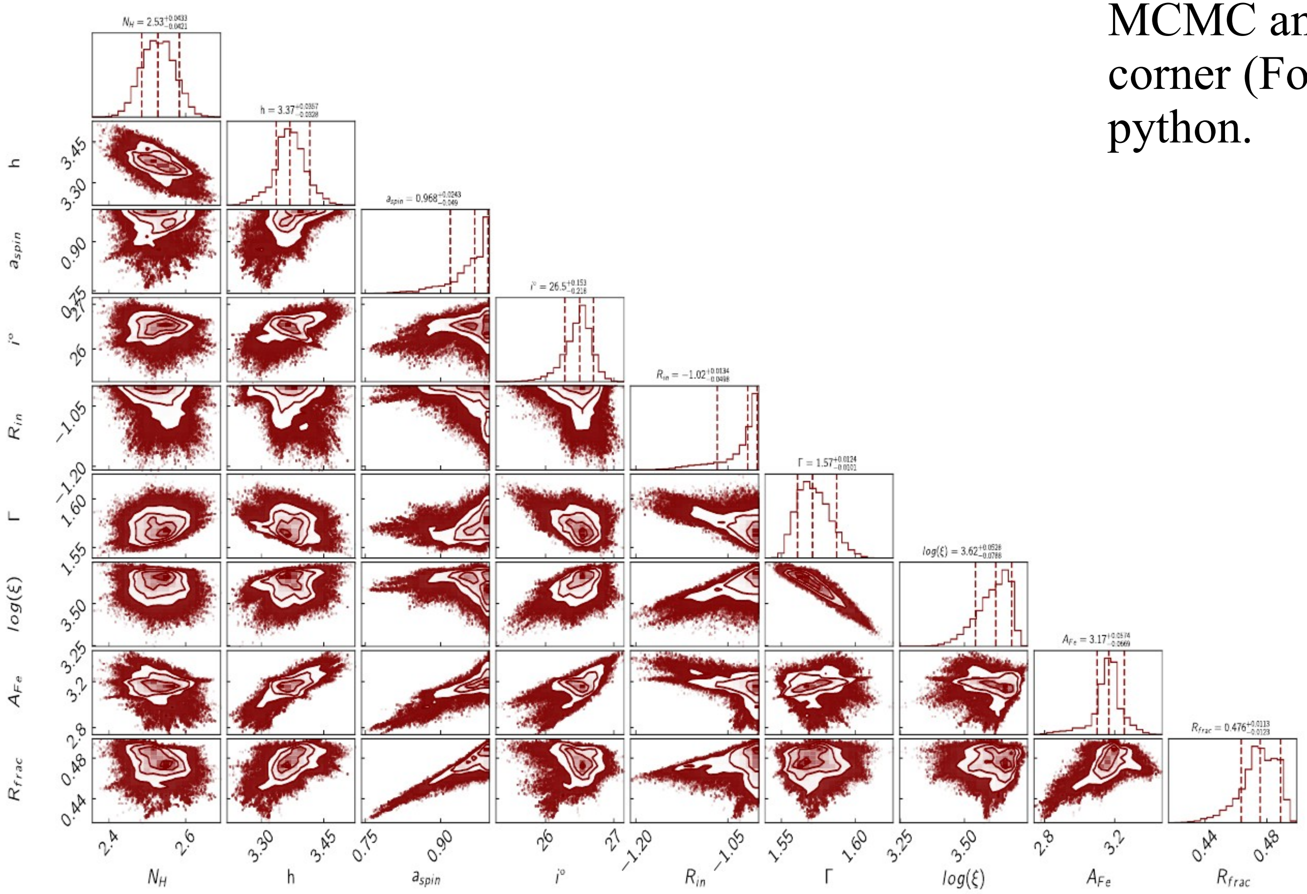
Jana et al., 2022, ApJ, accepted

Spectral fits: Error Estimation



MCMC analysis with the RelxillLp model. corner (Foreman-Mackey 2016) package in python.

Jana et al., 2022, ApJ, accepted


THANK
YOU!