The Hot Inner Disk Environment and Torque Reversals in 4U 1626-67

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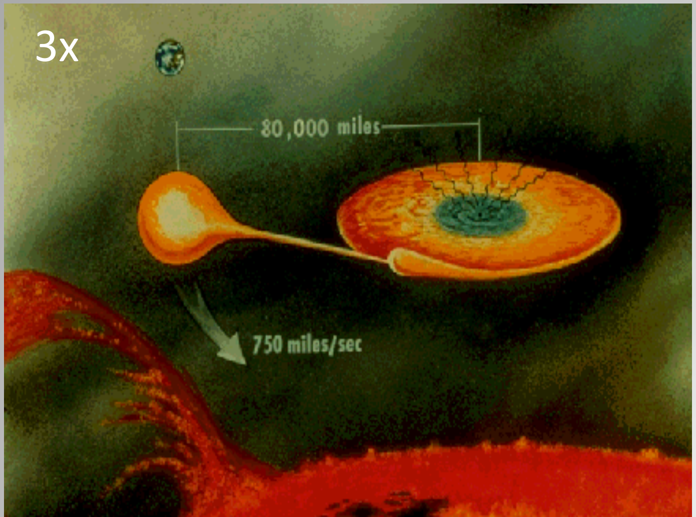


Ultra-compact binary: P_{orbit} = 42 min, $a_X \sin i < 8$ *lt-ms*

➔ $a_x << 3.4 \times 10^5$ *km*

(< Earth-Moon system)

Degenerate He or CO white dwarf (0.02-0.06 M_{sun})

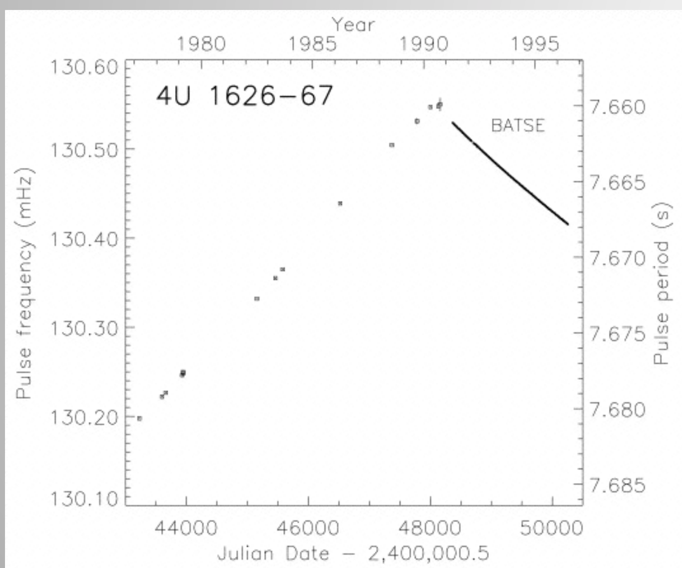
P_{spin} =7.66 sec; i ~ 38 º ;

$M_{acc} \sim 10^{-10} M_{sun}$; B ~ 6-8x10^{12} G, R_{co} = 6.5 x 10^8 cm

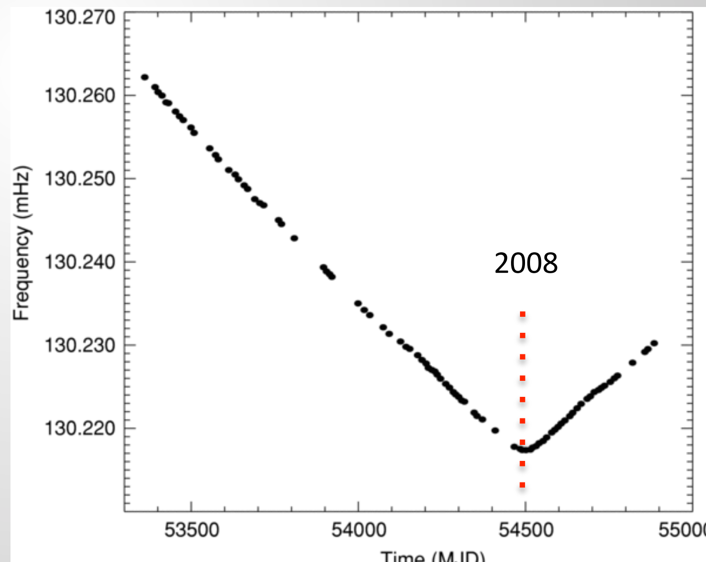
$L_x > 10^{36}$ erg/sec ; D =3.5 +/- 0.5 kpc

(From Chakrabarty et al. 1997, Chakrabqrty 1998, Schulz et al. 2019)

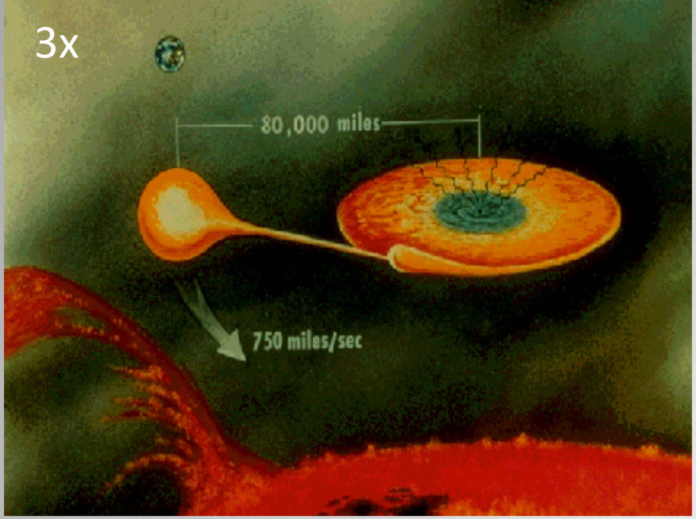
Torque reversal history:



Chakrabarty et al. 1997



Camer-Arranz et al.2010



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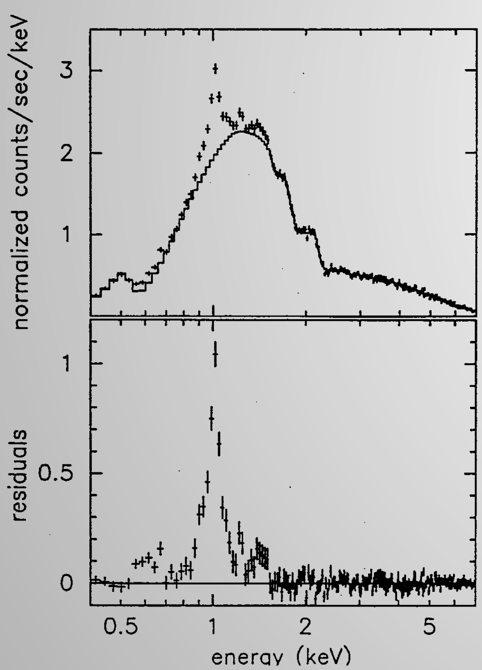
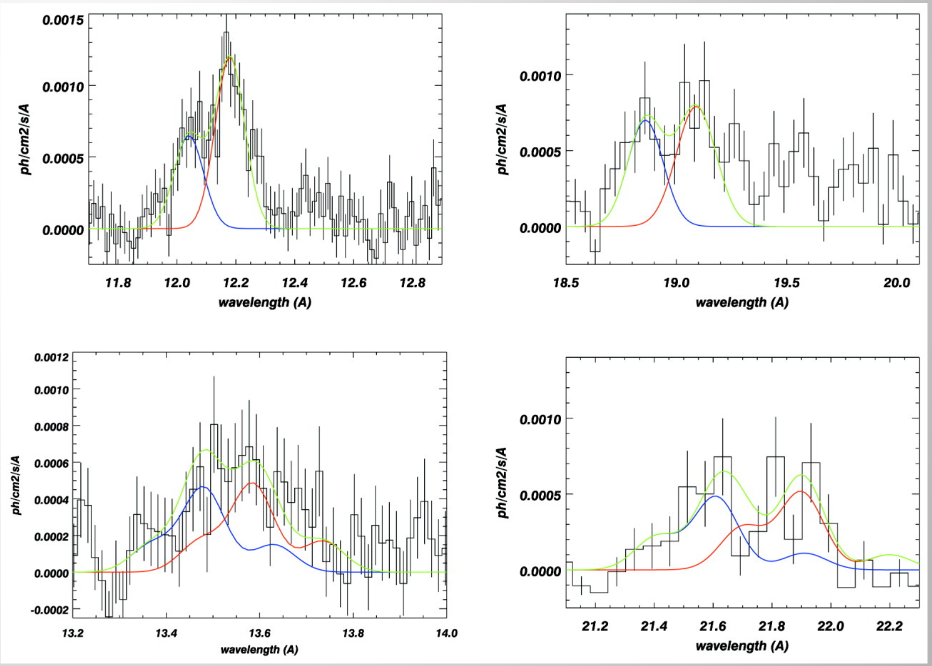
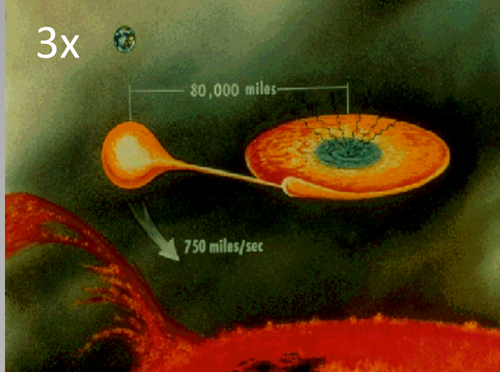


Angelini et al. 1995 : ASCA



Schulz et al.2002 : Chandra



Schulz et al. 2023

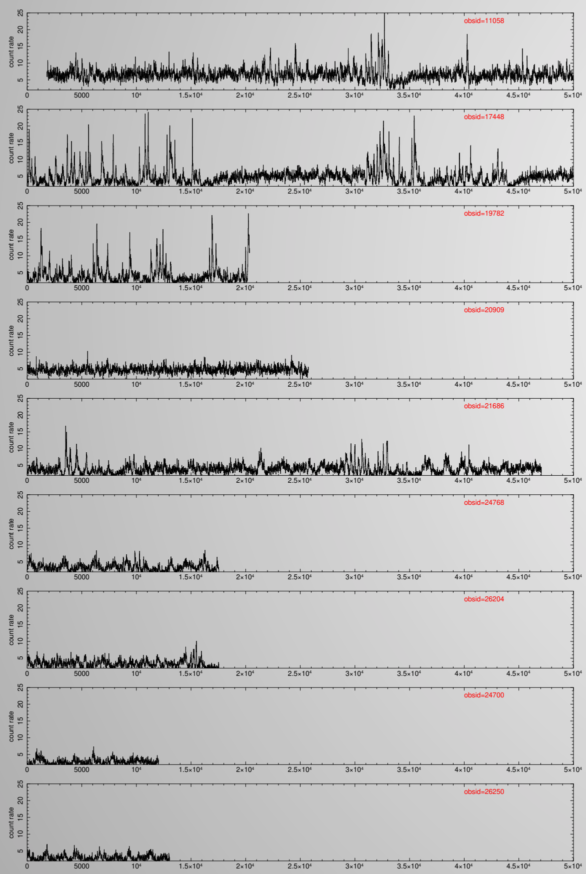
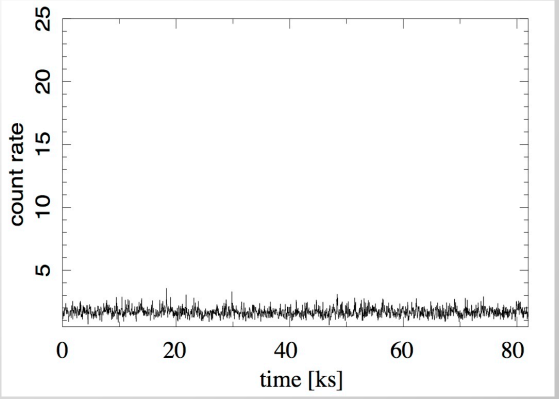


Figure 1. Light curves of all involved OBSIDs. The data are binned by 10 second bins.

Table 1. CHANDRA HETGS AND LETGS X-RAY OBSERVATIONS

Obsid	Start Date [UT]	Start Time [UT]	MJD [d]	Exposure [ks]	Count rate cts s^{-1}	Grating
104	Sep 16 2000	14:57:01	51803.62	39.5	2.41	HETGS
3504	Jun 03 2003	02:30:01	52793.10	94.8	1.68	HETGS
11058	Jan 14 2010	11:53:01	55210.50	76.9	6.80	HETGS
16686	Jul 08 2014	15:47:48	56846.66	23.0	3.21	LETGS
15765	Jul 11 2014	01:05:13	56849.05	59.4	3.66	LETGS
16637	Jul 13 2014	19:09:00	56850.80	49.5	3.65	LETGS
17448	Jun 11 2016	03:26:40	57550.13	48.9	4.86	HETGS
19782	Dec 31 2017	21:03:24	58118.88	19.9	4.24	HETGS
20909	Jan 03 2018	18:12:05	58121.76	25.1	4.80	HETGS
21686	Dec 28 2018	16:06:41	58489.67	45.9	3.95	HETGS
24768	Nov 12 2021	20:54:18	59530.87	17.1	3.48	HETGS
26204	Nov 13 2021	07:14:56	59531.30	17.1	3.40	HETGS
24700	Jan 05 2022	21:50:43	59584.91	11.8	2.88	HETGS
26250	Jan 06 2022	06:23:35	59585.27	12.7	3.00	HETGS

After torque reversal 2008



Before torque reversal 2008

Schulz et al. 2002

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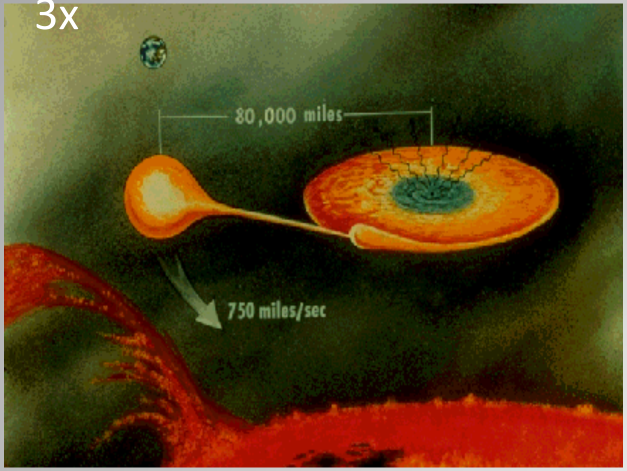
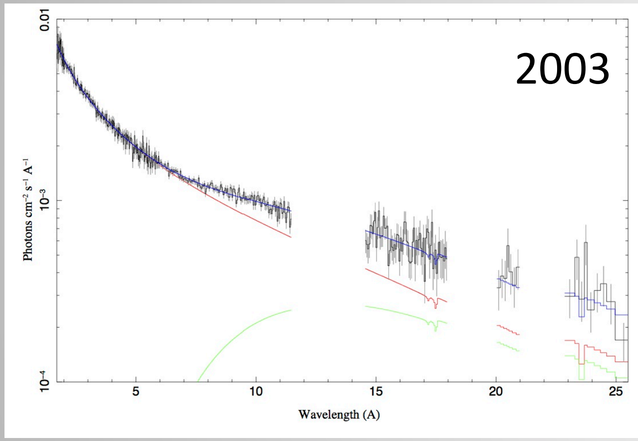
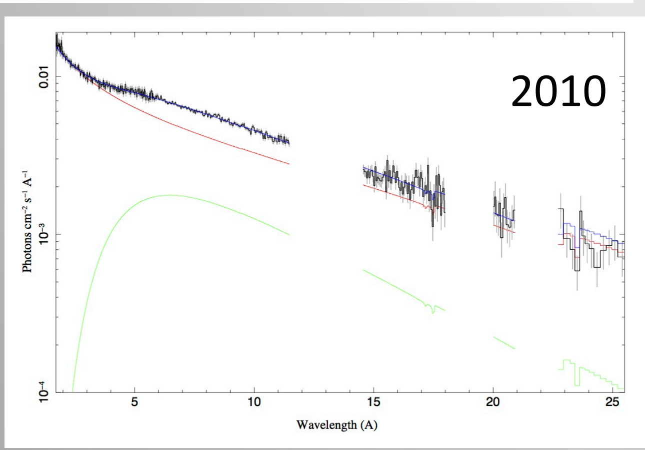


Table 2. C0NTINUUUM FIT PARAMETERS

Year	N_H (1)	A_{pl} (2)	A_{Gamma}	R_{bb} (3)	kT_{bb} keV	f_x i(4)	chi^2
2000	1.30 ± 0.14	1.21 ± 0.01	0.870 ± 0.010	$405.0\,^{487.0}_{335.0}$,	0.230 ± 0.010	2.200	0.940
2003	1.21 ± 0.15	0.82 ± 0.01	0.790 ± 0.010	$465.0\,^{536.0}_{381.0}$,	0.210 ± 0.010	1.700	1.050
2010	1.25 ± 0.05	3.82 ± 0.02	1.180 ± 0.010	$90.0\,^{94.0}_{86.0}$,	0.480 ± 0.010	4.600	1.250
2014	1.53 ± 0.12	3.80 ± 0.40	1.180 ± 0.060	$114.0\,^{175.0}_{95.0}$,	0.520 ± 0.030	5.200	1.110
2016	1.71 ± 0.34	2.94 ± 0.27	1.060 ± 0.060	$146.0\,^{171.0}_{127.0}$,	0.420 ± 0.020	4.300	1.170
2017/18	1.26 ± 0.44	3.07 ± 0.31	1.110 ± 0.060	$162.0\,^{200.0}_{137.0}$,	0.410 ± 0.020	4.200	1.220
2018	1.08 ± 0.47	2.34 ± 0.27	1.010 ± 0.070	$147.0\,^{175.0}_{126.0}$,	0.430 ± 0.020	3.800	1.090
2021/22	1.11 ± 0.53	2.54 ± 0.27	1.155 ± 0.065	$135.4\,^{165.5}_{113.5}$,	0.420 ± 0.022	3.335	1.109

2) 10^{-2} photons $cm^{-2}\ s^{-1}$; (3) R^2/D^2_{10kpc}; (4) erg $cm^{-2}\ s^{-1}$; 2017/18 = co-added obsids 19782 and 20909; 201
ds 15785, 16636 and 16637 (LETG); 2021/22 = co-added obsids 24700, 24768, 26204, 26250;





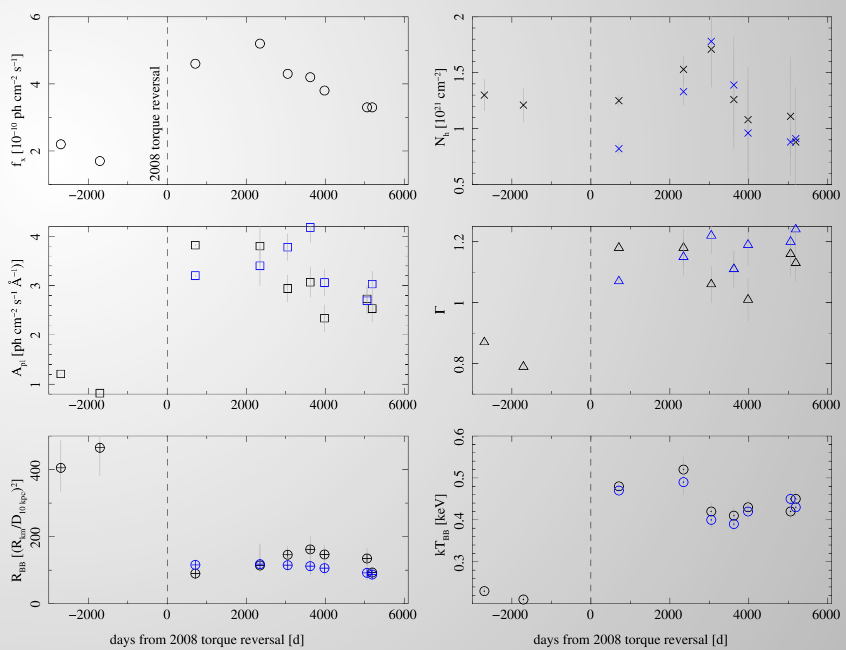
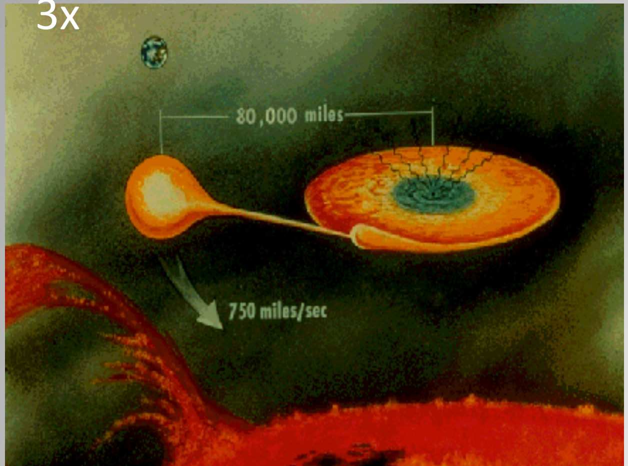
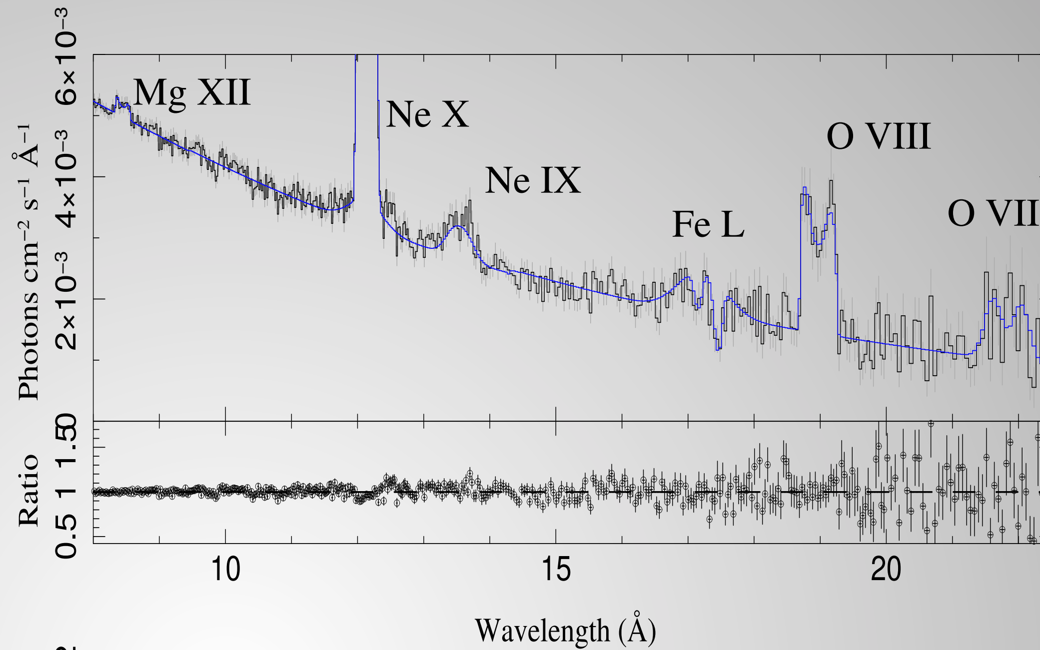


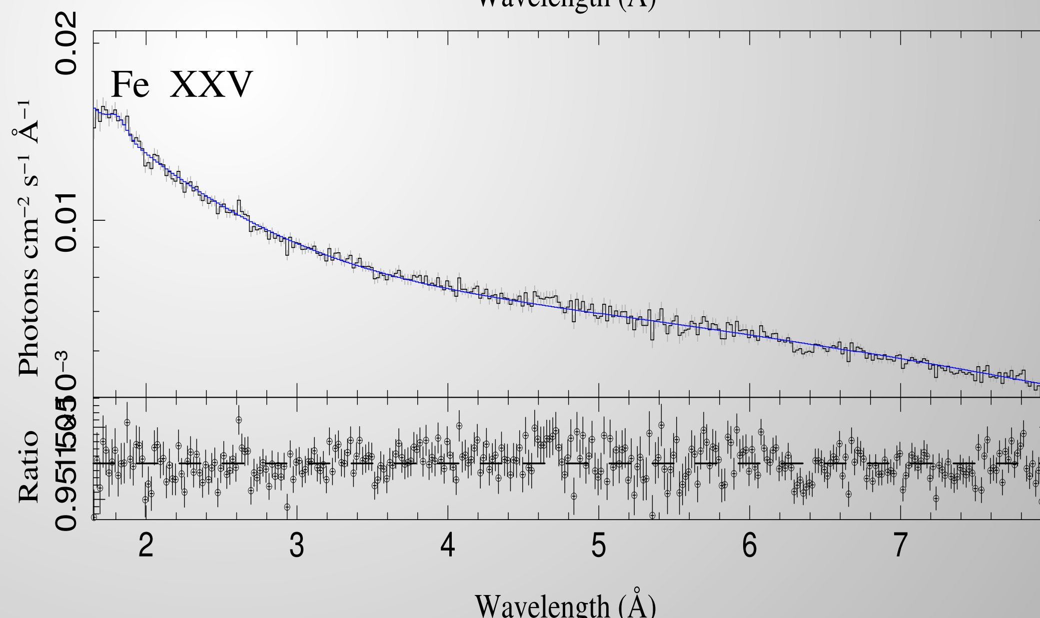
Figure 3. Continuum parameters over a time span of about 20 years..

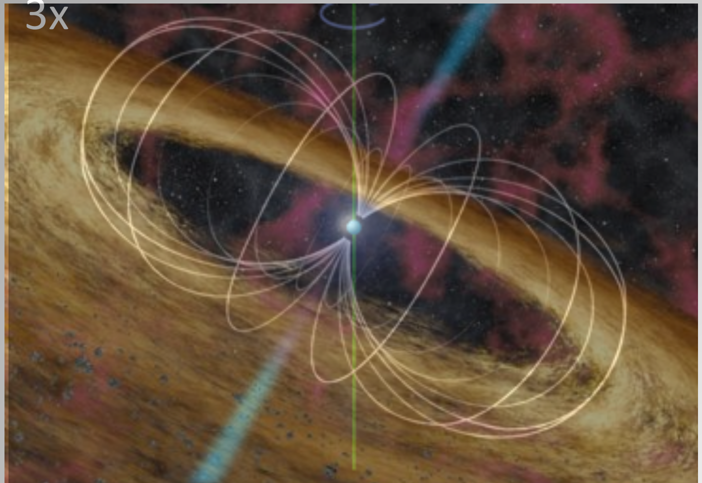


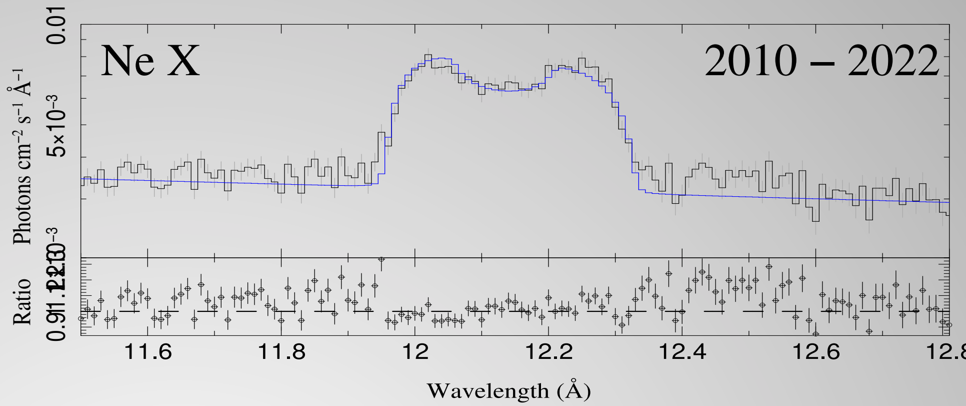


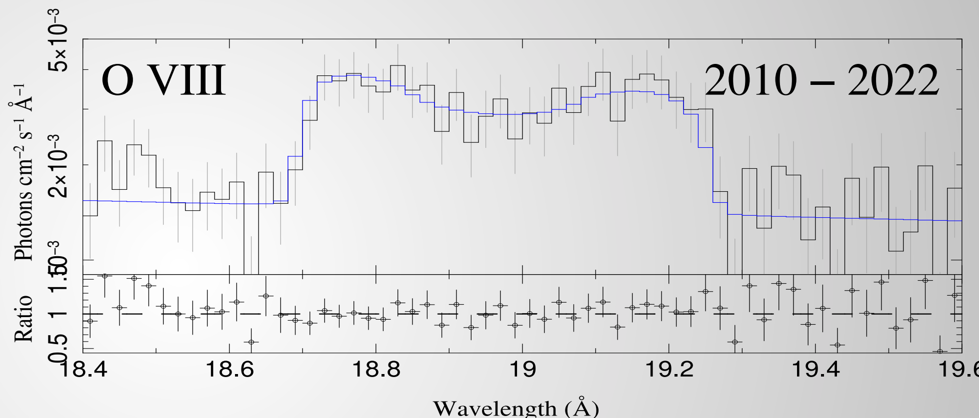
Integrated 396 ks spectrum (year 2010 or later):

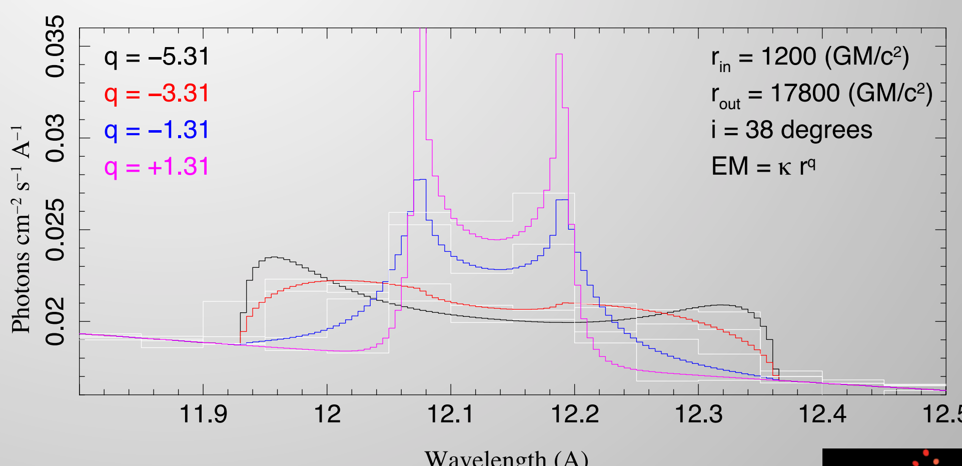
- O VII, O VIII disklines
- Ne IX, Ne X disklines
- Mg XII diskline
- Fe XXV diskline
- Fe L fluorescence











Some results from the line fits:

→ Besides the disklines we do not see any RRCs in the spectrum

→ Line ratios match up more with a collisional rather than photo-ionized spectra

→ The diskline fit pins the bulk of the emissions tightly to the innermost parts of the disk

Line emission is collisional in nature

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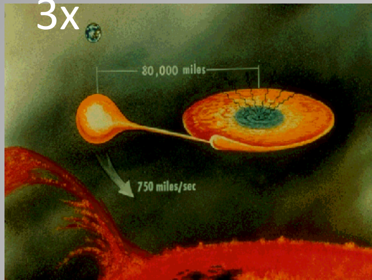
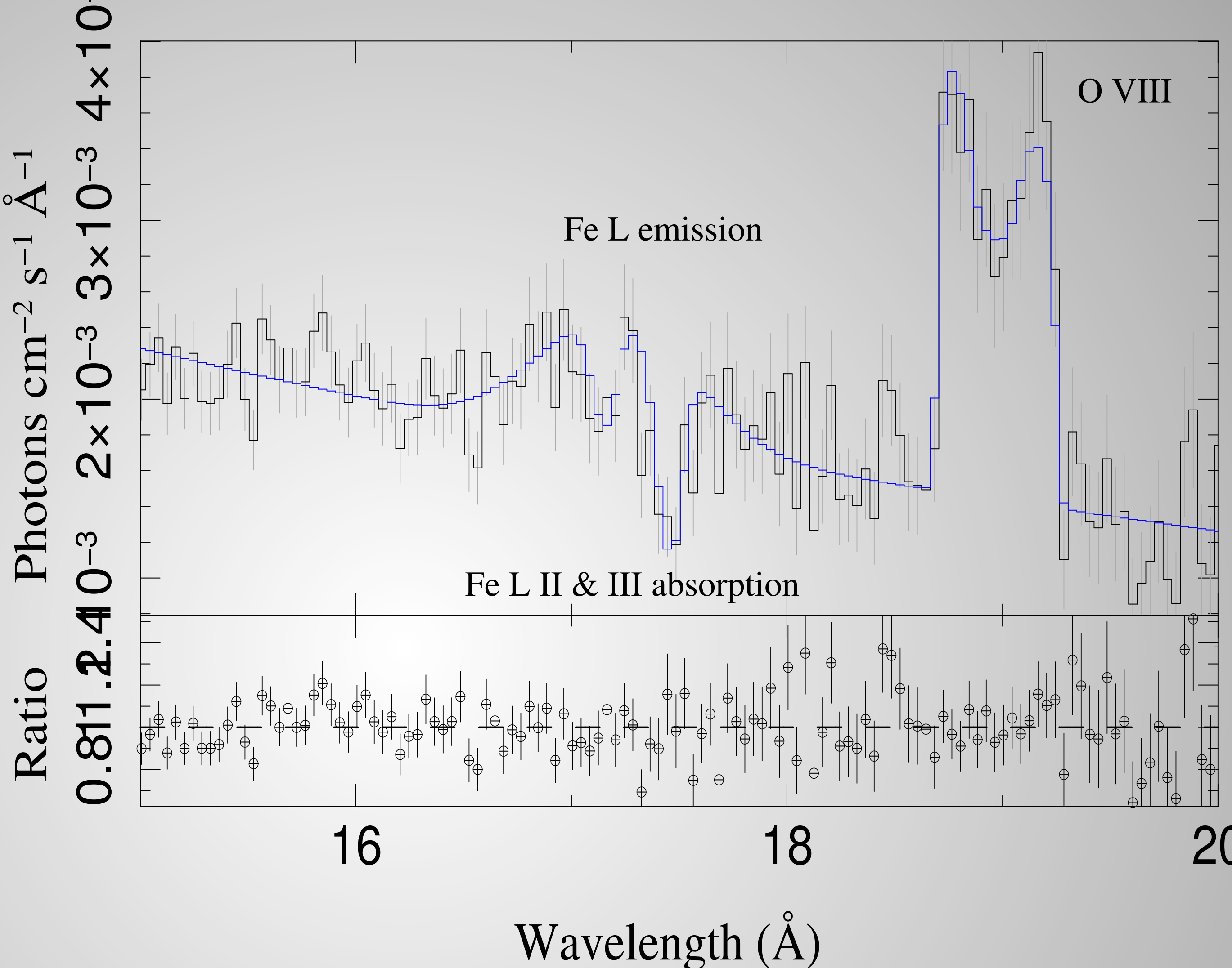


Hemphill et al. 2021 reported unidentified line emission between 16 A and 18 A.

→ Broad Fe L line fluorescence
→ Absorption lines match Fe L II & III edge absorption



→ This can only be the case if the broad Fe L line also has a diskline shape.

Supports the assumption that the inner disk is heavily fragmented allowing for illuminated hot parts and cool shadowed regions

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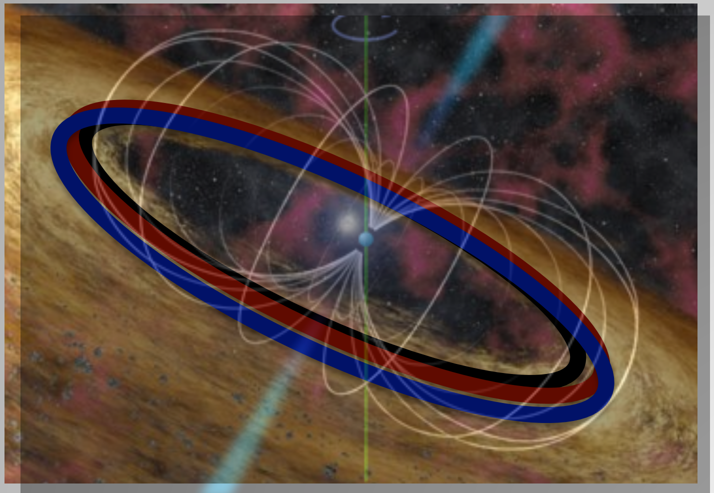
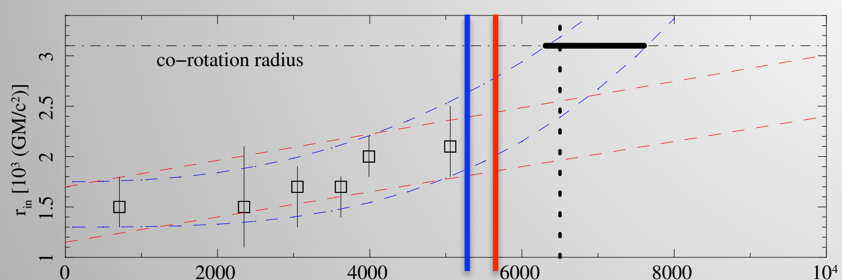


We monitored the disklines (Ne X) over the last decade and studied the relation of the diskline parameters with observed torque reversal events.



ure 7. The Ne X disk line parameter r_{in} after the 2008 torque reversal. The blue lines project a non-linear quasi-quadratic evol
e inner disk line radius towards the value of the disk co-rotation radius. The thick black line is the resulting window for the proj
torque reversal event. The dotted vertical line marks the next torque reversal even based on time between the 1990 and 2008 e
red lines mark a linear evolution of the inner disk line radius.

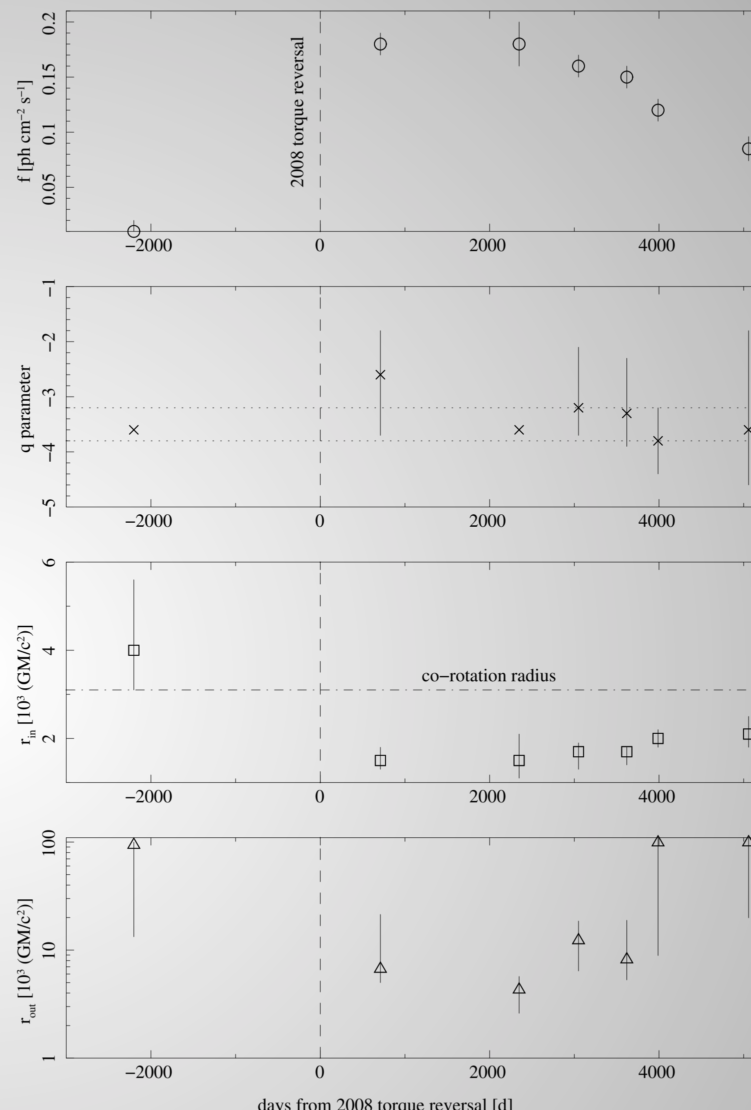


Figure 5. Ne X disk line parameters over a time span of 20 years.

Torque reversal of 2023 (spin down to spin up)

Most recent Chandra HETG DDT

Summary - A quick history of HETG studies of 4U 1626-67

1. Schulz et al. 2001, ApJ, 563, 941
   The detection of double peaked line emission establishing the Ne and O lines detected by ASCA (Angelini et al 1995, ApJ, 449, 41) as Doppler lines
2. Krauss et al. 2007, ApJ, 660, 605
   Confirming the double peaked line shapes and placing constraints on Ne and O abundances. Predicting that 4U 1626-67 would enter quiesence in the next decade.
3. Schulz et al. 2019, arXiv191111684S
   Provided a strong case that plasma is collisionally ionized and fitted the double peaked lines with diskline functions. Furthermore it was argued that collisional APED models work better than photo-ionized XSTAR models. Demonstrated that the inner disk radius crosses the co-rotation radius during torque reversal to to spin down.
4. Hemphill et al. 2021, ApJ, 920, 142
   Confirmed the collisional nature of the plasma emissions. Discovered unexplained emissions between 16 A and 18 A in LETG data.
5. Schulz et al. 2023, ApJ in preparation
   Presents a decade long monitor of continuum and diskline properties, Attempts to relate diskline properties to torque reversal events. Provides possible evidence to enhanced Fe L diskline emission and Fe L absorption.
   Provide evidence for inner disk fragmentation.