Hot Plasma Emissions in the Ultra-compact Binary Pulsar 4U 1626-67

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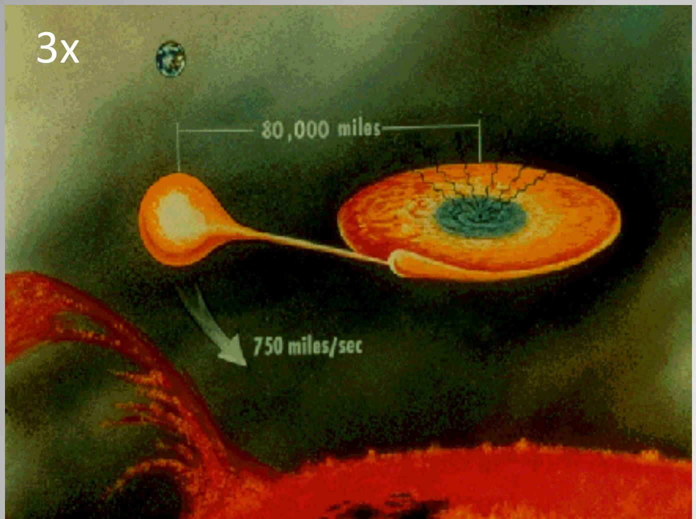


Ultra-compact binary: P_{orbit} = 42 min, $a_X \sin i < 8$ *lt-ms*

➔ $a_x \ll 3.4 \times 10^5$ *km*

(< Earth-Moon system)

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

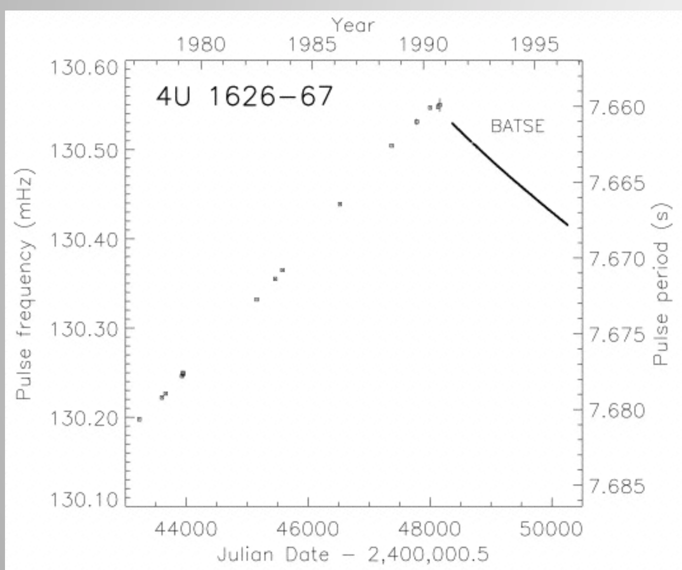
P_{spin} =7.66 sec; i ~ 20 °;

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

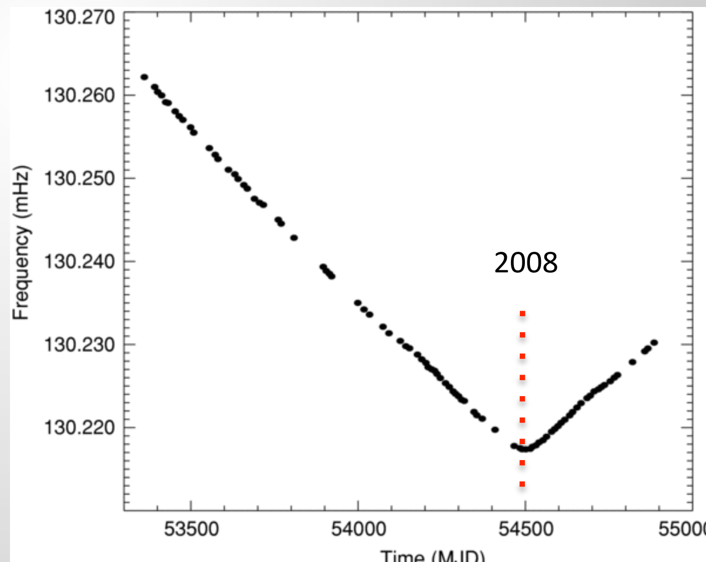
$L_x > 10^{36}$ erg/sec ; D > 3 kpc [5 – 13 kpc]

(From Chakrabarty et al. 1997, Chakrabqrty 1998)

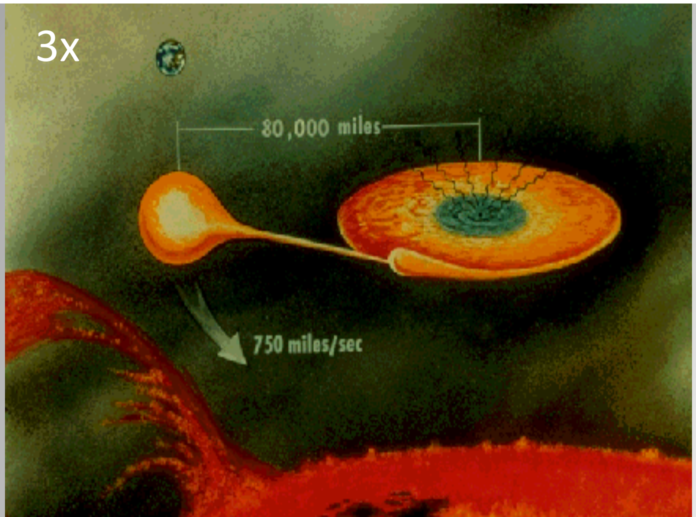
Torque reversal history:



Chakrabarty et al. 1997



Camer-Arranz et al.2010



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

➔ $a_X << 3.4\times10^5$ *km*

(< Earth-Moon system)

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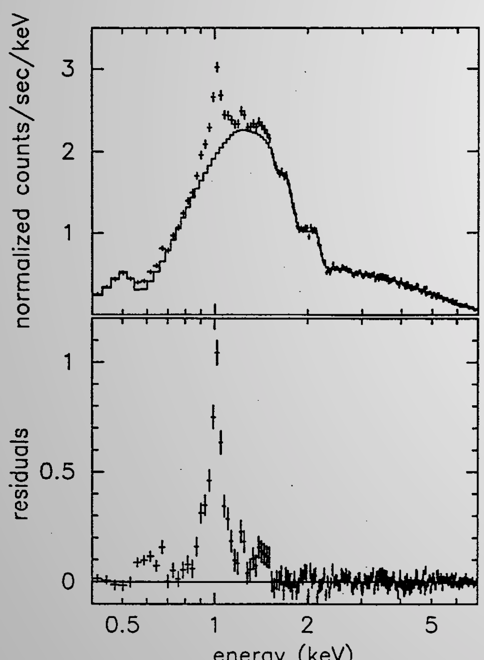
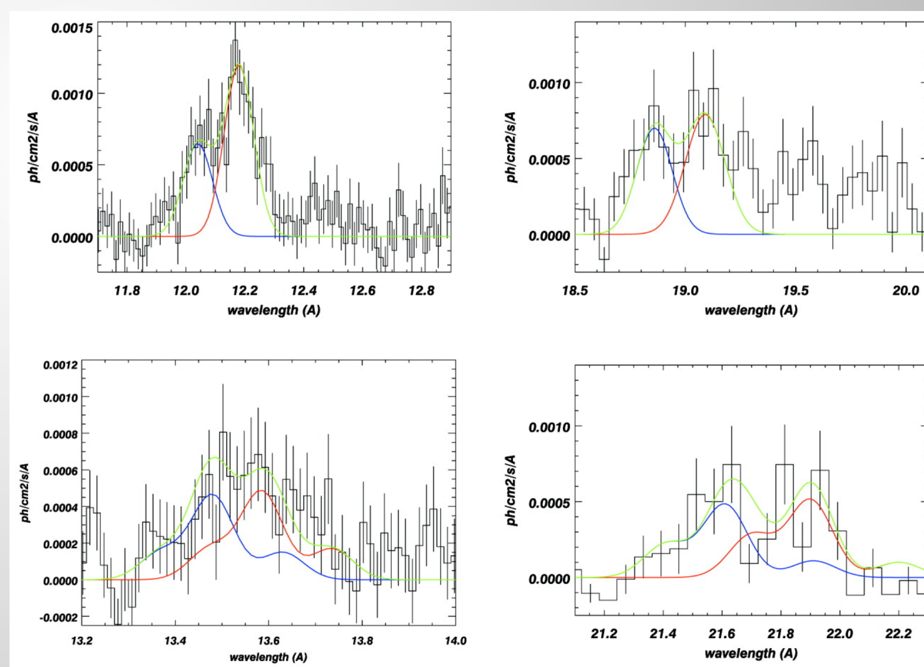


Angelini et al. 1995 : ASCA



Schulz et al.2002 : Chandra

MKI

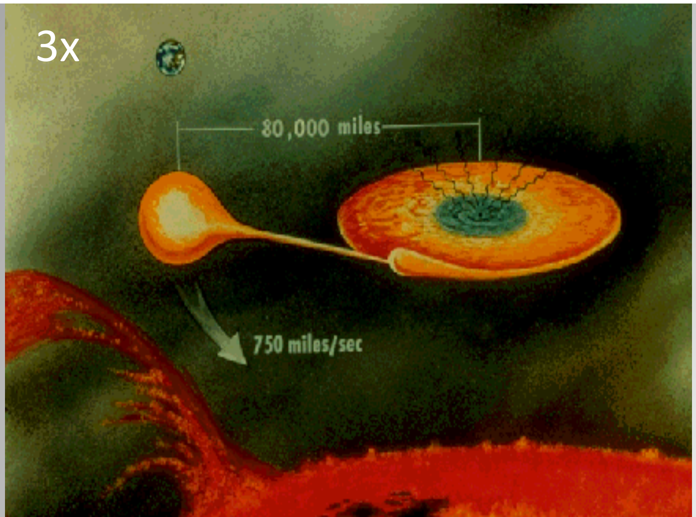
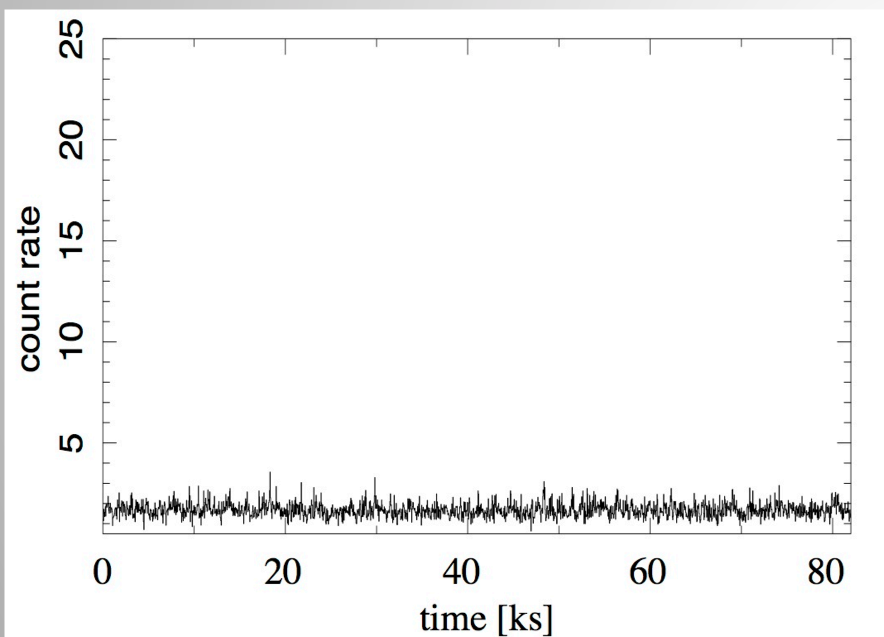
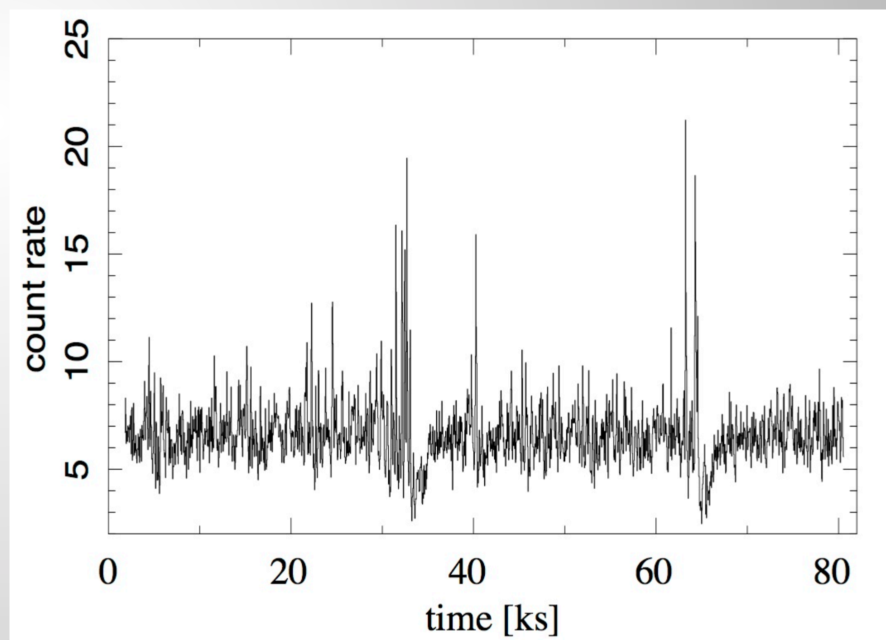


TABLE 1: CHANDRA HETGS X-RAY OBSERVATIONS

Obsid	Start Date [UT]	Start Time [UT]	Exposure [ks]	HETG 1st rate cts s^{-1}
104	Sep 16 2000	14:57:01	40	2.41
3504	Jun 03 2003	02:30:01	97	1.68
11058	Jan 14 2010	11:53:01	80	6.80





Schulz et al. 2016

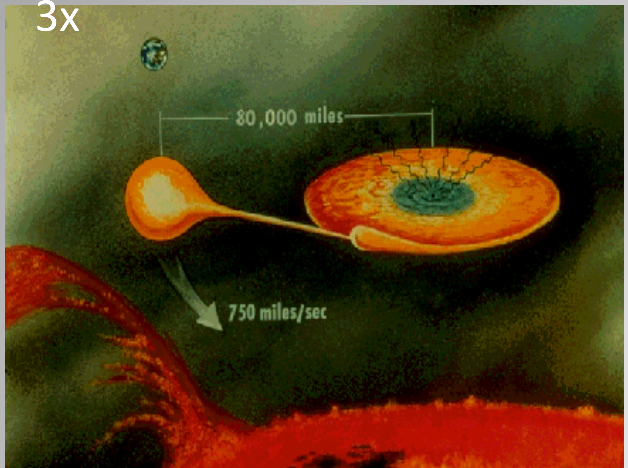
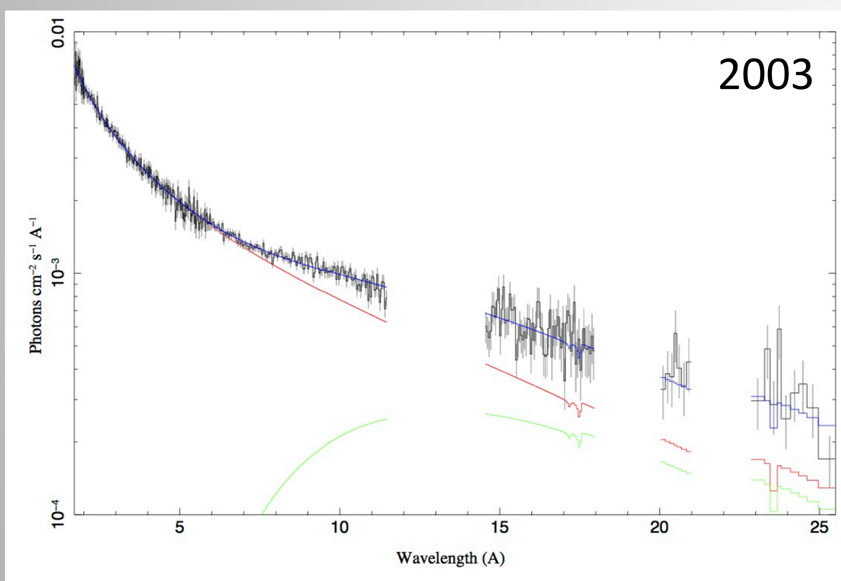
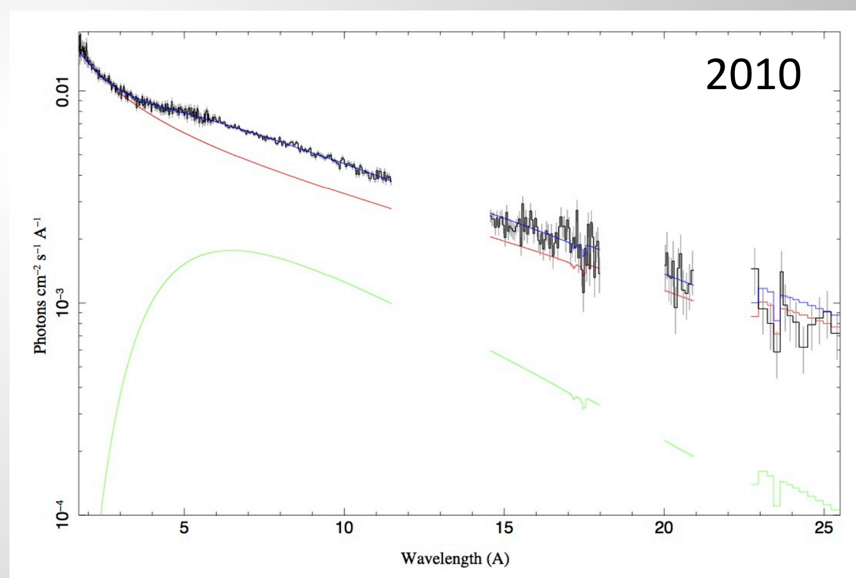


TABLE 2 CONTINUUM: TBNEW*(POWERLAW + BBODYRAD)

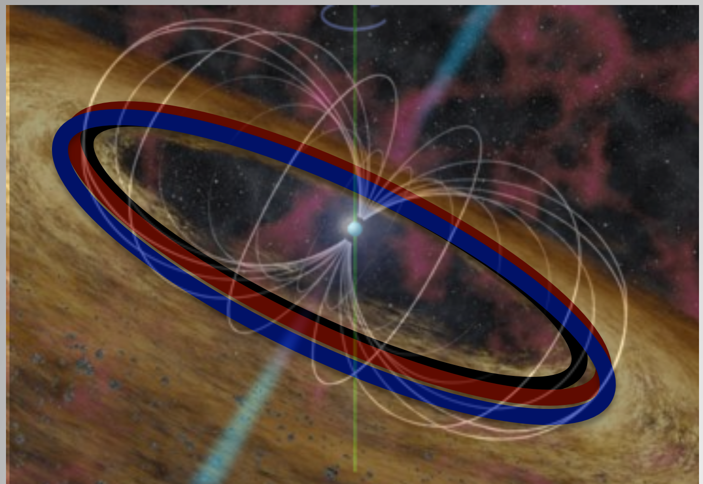
OBSID	Date [UT]	N_H (1)	A_{pl} (2)	Γ –	R^2_{bb}/D^2 (3)	kT_{bb} keV	f_x (4)	χ^2_ν
104	Sep 16 2000	$1.30^{+0.14}_{-0.13}$	$1.21^{+0.01}_{-0.01}$	$0.87^{+0.01}_{-0.01}$	$405.3^{+81.6}_{-70.0}$	$0.23^{+0.01}_{-0.01}$	2.2	0.94
3504	Jun 03 2003	$1.21^{+0.14}_{-0.15}$	$0.82^{+0.01}_{-0.01}$	$0.79^{+0.01}_{-0.01}$	$464.8^{+83.0}_{-72.3}$	$0.21^{+0.01}_{-0.01}$	1.7	1.05
11058	Jan 14 2010	$1.25^{+0.05}_{-0.05}$	$3.82^{+0.02}_{-0.02}$	$1.18^{+0.01}_{-0.01}$	$89.7^{+4.2}_{-4.0}$	$0.48^{+0.01}_{-0.01}$	4.6	1.25

(1) 10^{21} cm^{-2}; (2) 10^{-2} ph Å^{-1} cm^{-2} s^{-1}
(3) km^2/[10 kpc]^2; (4) 10^{-10} erg cm^{-2} s^{-1}





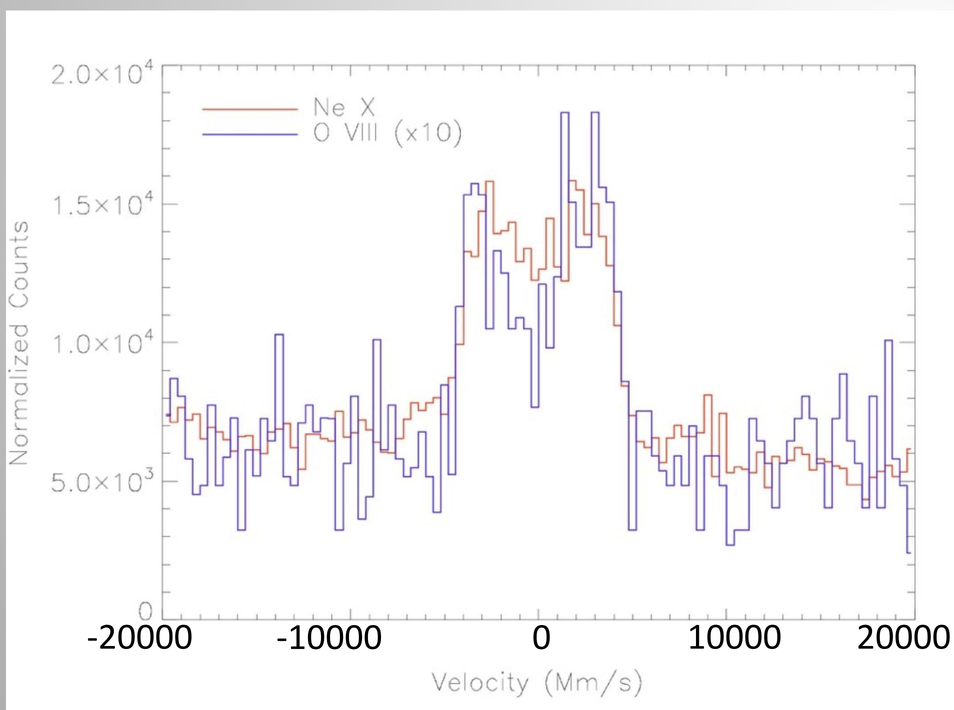
Schulz et al. 2016

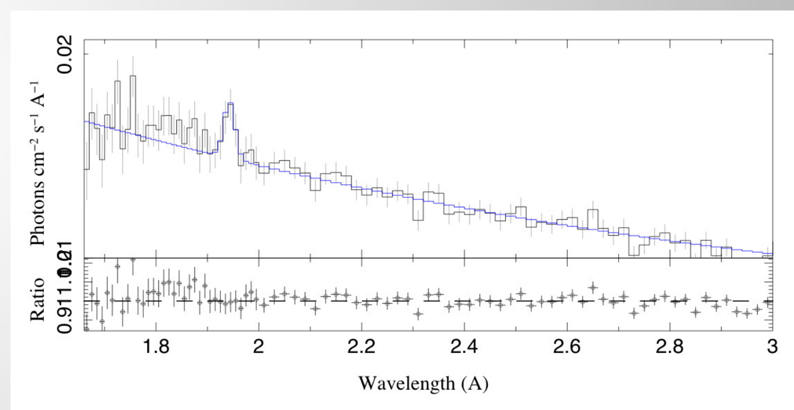


O/Ne Doppler lines: +/- 4000 km s^{-1}

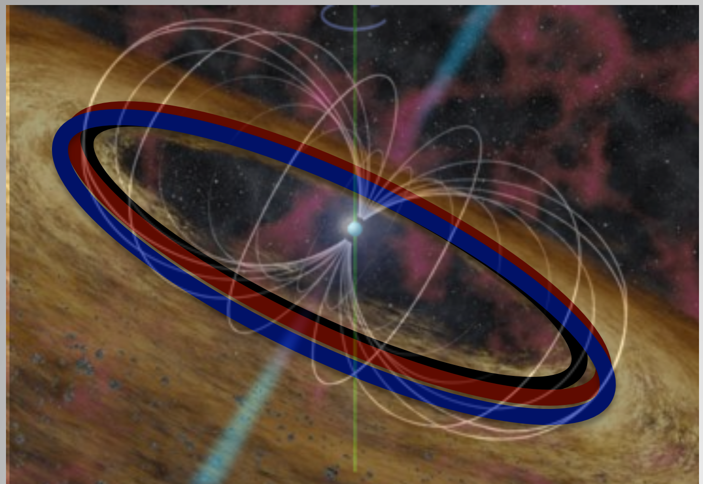
Fe K Fluorescence line: narrow, resolved? [1.7 sigma]

No broad relativistic OVIII observed as in other UCB
(Madej et al. 2010, 2011; Schulz et al. 2010)





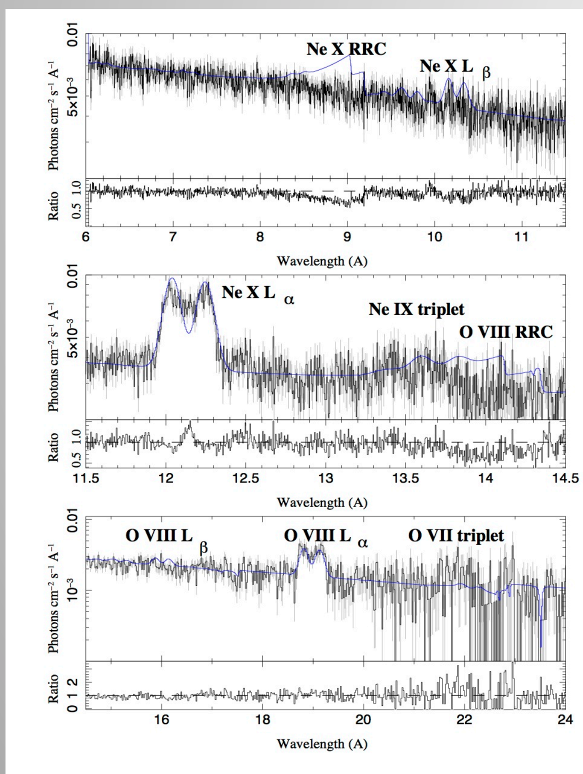
See Koliopanos et al., next talk



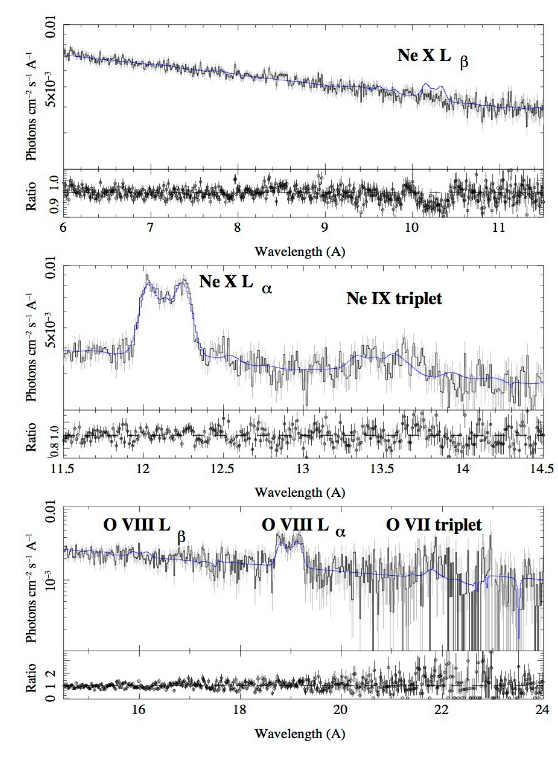
Ne/O Emission is from collisional ionized plasma
Plasma is CO dominated, no H
Plasma is hot: T = [1.1, 10.0] MK in all observations
VEM limits emission volume

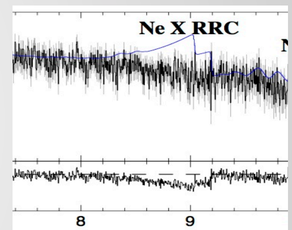
Emission measure is limited to Ne X and C IV, i.e. no lower temperatures than 1 MK

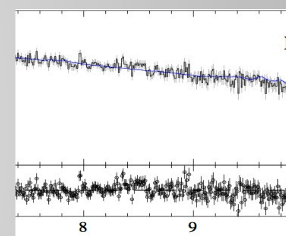
Photo-ionized model: XSTAR

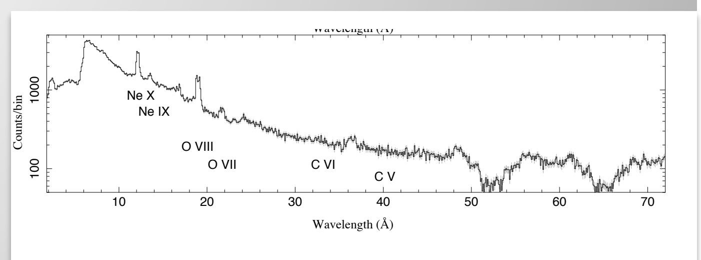


Collisional model: APED









MKI

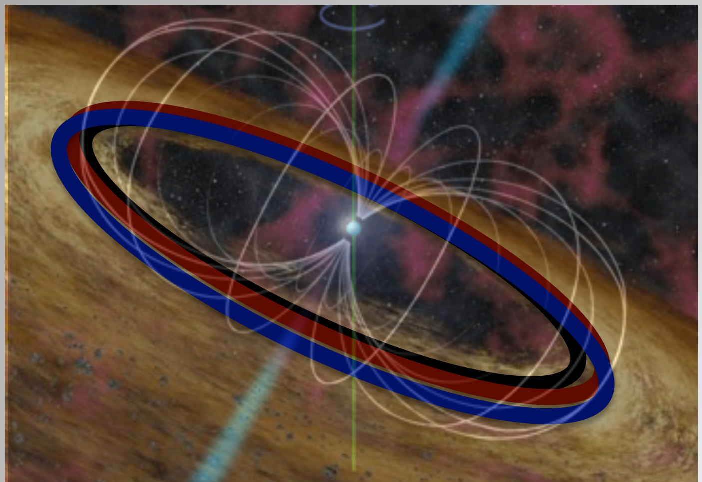
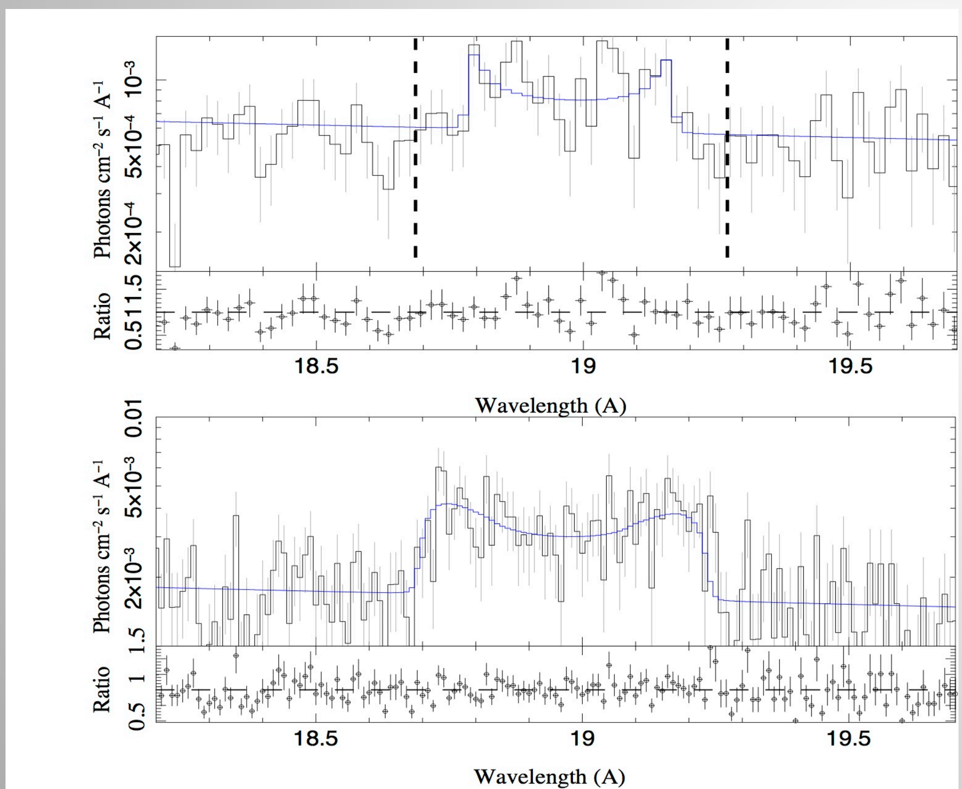


TABLE 5 DISKLINE FIT PARAMETERS BEFORE AND AFTER THE 2008 TORQUE REVERSAL

Line	Torque reversal	λ_{Dl} Å	A_{Dl} (1)	q	$R_{in}(M)$ 10^3GM/c^2	$R_{out}(M)$ 10^3GM/c^2	i deg.	χ^2_ν
Ne x	before	12.13±0.01	0.17±0.04	-4.6	$3,9^{+0.7}_{-0.9}$	$94.3^{+5.6}_{-81.0}$	$38.2^{+6.7}_{-4.5}$	1.21
O viii		18.97±0.01	0.18±0.05	-4.6	$4.0^{+1.6}_{-0.9}$	$4.0^{+19.1}_{-1.1}$	tied	–
Ne x	after	12.13±0.01	0.19±0.01	-3.6	$1.8^{+0.2}_{-0.5}$	$10.9^{+10.2}_{-2.8}$	tied	–
O viii		18.97±0.01	0.22±0.03	-3.6	$1.7^{+0.2}_{-0.1}$	$3.8^{+1.3}_{-0.6}$	tied	–

(1) 10^{-2} ph cm^{-2} s^{-1}

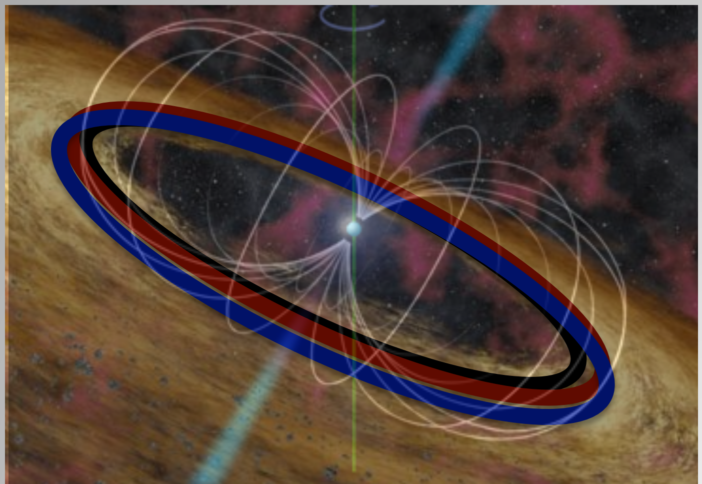


O VIII before torque reversal

R_{in} = 8.3 x 10^8 cm $R_{in} > R_{co}$

O VIII after torque reversal

R_{in} = 3.7 x 10^8 cm $R_{in} < R_{co}$



Distance estimate for 4U1626-67

For accretion disk spin-up of a pulsar, we expect

$$2\pi I \dot{\nu} = \dot{M}\sqrt{GMr_{in}}$$

From observations after the 2008 torque reversal, we have

$$\dot{\nu} = 4\times10^{-13}\ \mathrm{Hz/s}$$

$$r_{in} = 1700\ \frac{GM}{c^2}$$

Thus,

$$\dot{M} = 7\times10^{15}\ \mathrm{g/s} \quad \text{(independent of NS mass)}$$

This implies an accretion luminosity of

$$L = \frac{GM\dot{M}}{R} = 2\times10^{36}\left(\frac{M}{2M_\odot}\right)\ \mathrm{erg/s}$$

But we know that X-ray flux after the torque reversal is

$$F_X = 5.2\times10^{-10}\ \mathrm{erg/cm^2/s} \quad \text{(unabs., 0.3–10 keV)}$$

so we can infer

$$d = \left(\frac{L}{4\pi F_X}\right)^{1/2} \approx \boxed{5.6\left(\frac{M}{2M_\odot}\right)^{1/2}\ \mathrm{kpc}}$$

Given the NS mass uncertainty, this implies 4.5-5.5 kpc.

Summary - What have we learned so far

1. Plasma line emissions from Ne/O/C are from a collisionally ionized plasma of very limited volume located close to the magnetospheric radius.
2. The heated plasma has temperatures ranging from ~1 MK to 10 MK. The heating mechanism is unknown. The closeness to R_{mag} may suggest shock heating of disk plasma at the magnetosphere
3. The Doppler lines from Ne, O, and C are now clearly identified as disk lines reinforcing the notion that we observe a disk plasma at R_{mag} and plasma density of 10^{15} g cm^{-3}
4. The disk lines before and after torque reversal reveal an inclination of 38^o almost twice the value previously assumed. It appears consistent with a CO white dwarf companion.
5. The disk lines also show that the inner radius of the hot plasma region crosses the R_{co} before and after torque reversal suggesting that R_{mag} is also crossing.
6. The data after torque reversal also show a barely resolved narrow Fe K line with an origin in the accretion disk, but likely not at the inner disk radius (see also Koliopanos&Gilfanov 2015).
7. Ne appears to be enhanced in the collisional heated plasma suggesting a general enhancement in the plasma and a more evolved CO white dwarf.
8. Finally, the data after the 2008 torque reversal (spin up) allow a distance determination of 4.5 to 5.5 kpc, clearly ruling out significantly larger values.