Interpretation of the 115-day Periodic Modulation in the X-ray Flux of NGC 5408 X-1

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Abstract

We comment on the recent observation of a 115-day modulation in the X-ray flux of the ultraluminous X-ray source (ULX) NGC 5408 X-1, and in particular, the interpretation of this modulation as the orbital period. We suggest that this modulation may instead be due to a precessing jet, and is thus ***superorbital*** in nature. Comparing the properties of this ULX with those of the prototype micro-quasar SS 433, we argue that NGC 5408 X-1 is very similar to SS 433: a hyper-accreting stellar-mass black hole in a shorter-period binary. If the analogy holds, the 115-day modulation is best explained by the still poorly-understood physics of inner-disc/jet precession.

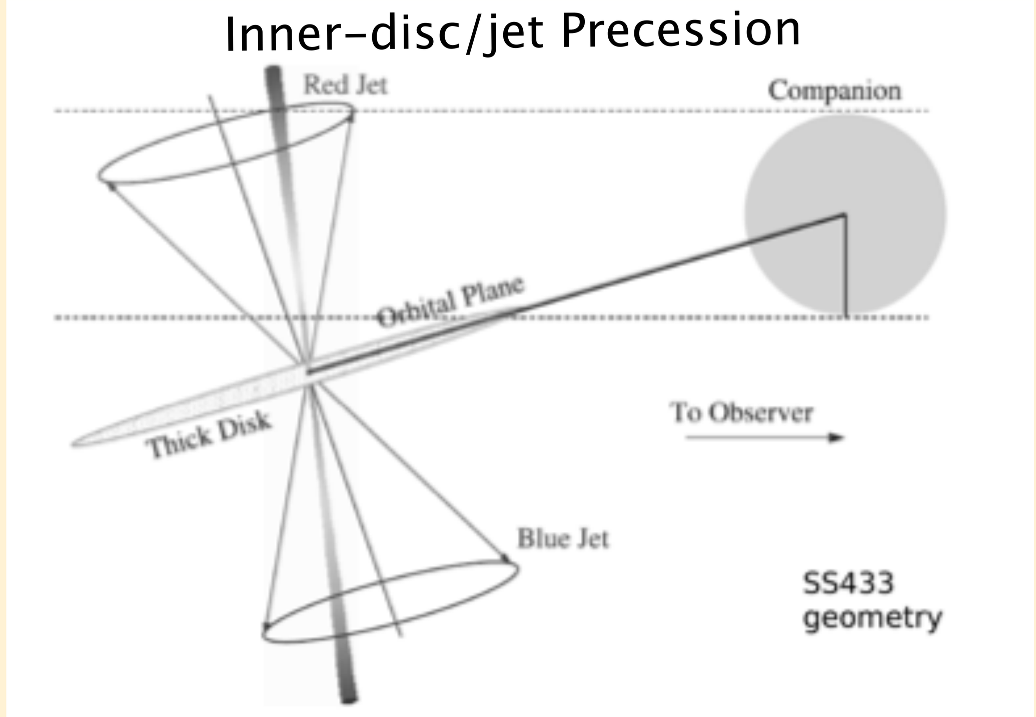
Introduction

- What are ULXs?
  - Extragalactic X-ray sources with $L_X > 10^{39}$ ergs/sec
  - Not consistent with nuclear emission (e.g. AGN)
  - Not a foreground or background source (e.g. Quasar)
  - Too bright to be simply explained by accreting stellar-mass black holes or neutron stars
  - Well fitted with multicolor disk (MCD) blackbody models, suggesting the presence of intermediate-mass black holes (IMBHs) of mass ~ $10^{2\text{-}4}$ $M_\odot$

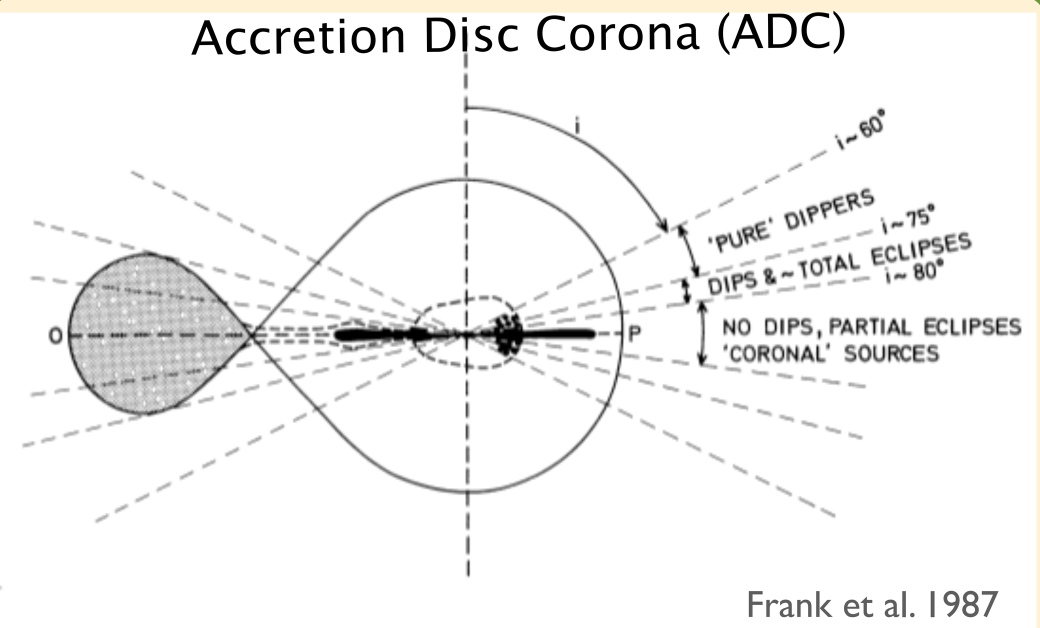
- What causes ULXs to appear so bright? Some possibilities are:
  - beamed emission along the line of sight from stellar-mass black holes
  - Super-Eddington mass transfer onto stellar-mass black holes
  - sub-Eddington accretion onto IMBHs

- The nature of NGC 5408 X-1:
  - L_X ~ few x 10^{40} erg/sec & low-frequency QPO present
  - Like SS 433, engulfed in a large photo-ionised nebula
  - 115 day modulation in its X-ray flux
  - Is it an IMBH (e.g. Strohmayer 2009) or a HMXB with stellar-mass BH similar to SS 433?

Inner-disc/jet Precession

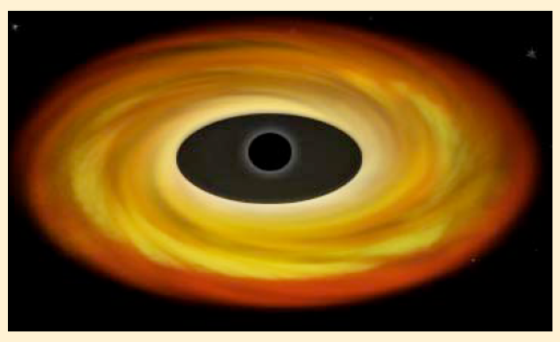


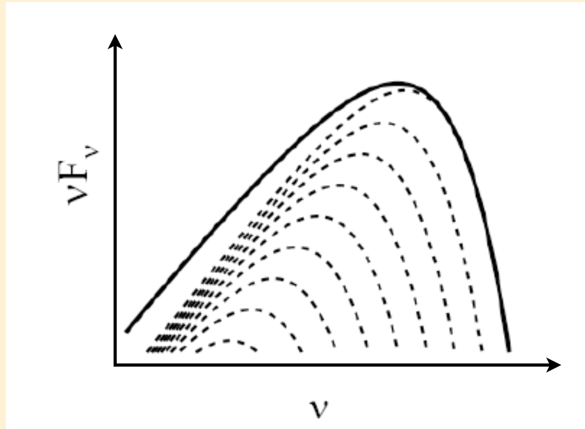
Accretion Disc Corona (ADC)



Frank et al. 1987

Multicolor Disk (MCD) Blackbody Model





$T_{\rm eff} \propto R^{-3/4}$

$R_{isco} = 6GM/c^2$

$kT_{in} \propto (\frac{M}{10M_\odot})^{-1/4}$

$$F_\nu^{\rm obs} = \frac{2\pi\cos i}{d^2}\int_{R_{\rm ISCO}}^{R_{\rm out}} I_\nu(R)\,RdR$$

- The ULXs occupy a distinct region of the luminosity-temperature diagram & are well fitted with MCD models

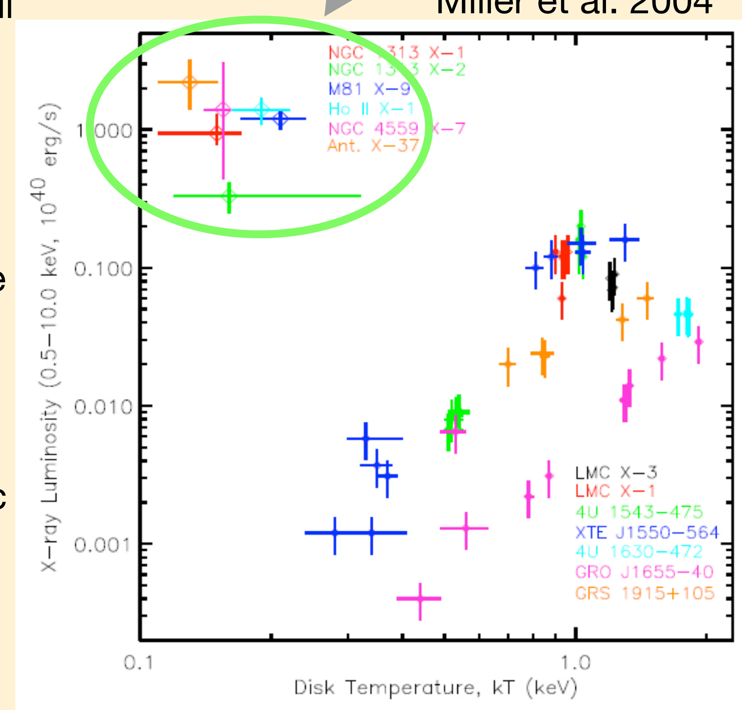
- The fact that the ULXs are much brighter than the stellar-mass black holes and yet have cooler disks suggest they might contain IMBHs

- $L_{Edd} \approx 1.3 \times 10^{38} (M/M_\odot)$ erg/sec

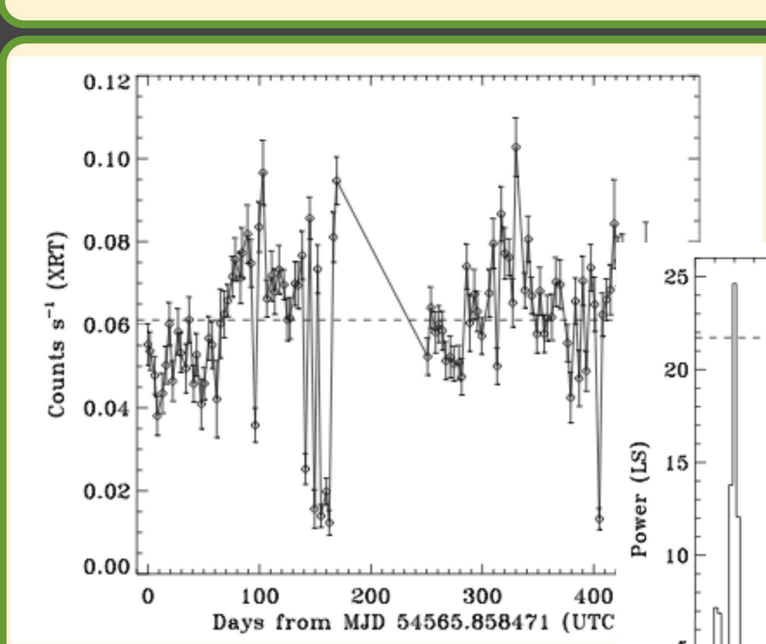
- For a 10 $M_\odot$ BH $L_{Edd} \approx 1.3 \times 10^{39}$ erg/sec

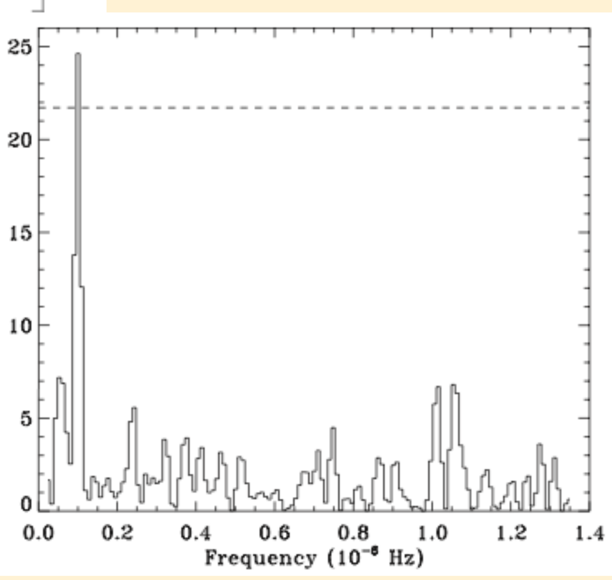
IMBH candidates

Miller et al. 2004



Strohmayer 2009





- 115-day modulatiion is real, but is it necessarily P_{orb}?

Alternative Interpretations of the ULX NGC 5408 X-1

- Broad-band spectral shape does not support the identification of a low-frequency QPO and energy spectra do not support the IMBH interpretation (Middleton et al. 2010).

- Perhaps NGC 5408 X-1 is an extragalactic example of an SS 433-like HMXB, but viewed at a lower inclination. In that case, NGC 5408 would be better described as a HMXB undergoing super-Eddington mass transfer.

- The 115-day modulation could be due to inner-disc/jet precession, which is known to occur in SS 433 and could better explain the modulation. A longer observing baseline may reveal intrinsic phase jitter if the modulation is indeed superorbital in nature.

- Currently, the observations cannot distinguish between an orbital or superorbital origin of the 115-day modulation; a next-generation X-ray telescope with larger collecting area than available on *Chandra* or *XMM-Newton* would help resolve its true nature.

Soria et al. 2006

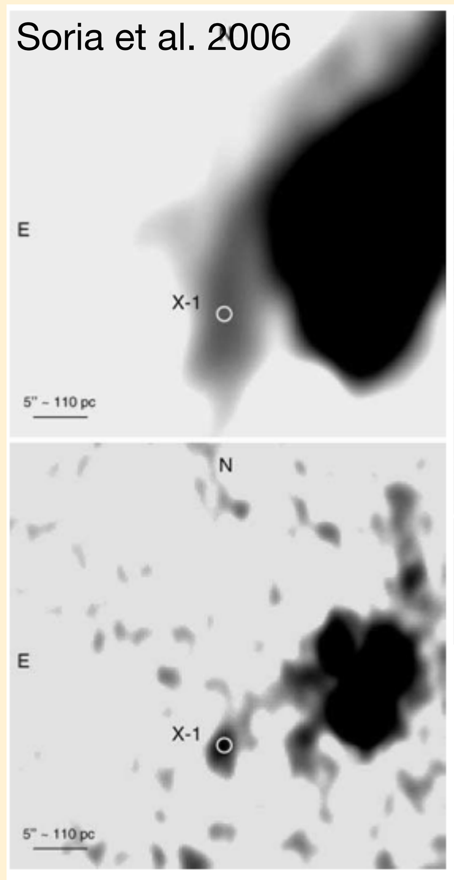


Figure 3. Top panel: radio map of the field obtained by combining the 1.3- and 2.4-GHz data. The *Chandra* position of the ULX is marked with an error circle of radius 0.6 arcsec. Bottom panel: radio image obtained by combining the 4.8- and 6.2-GHz maps.

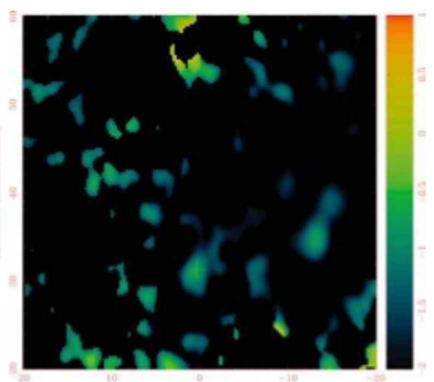
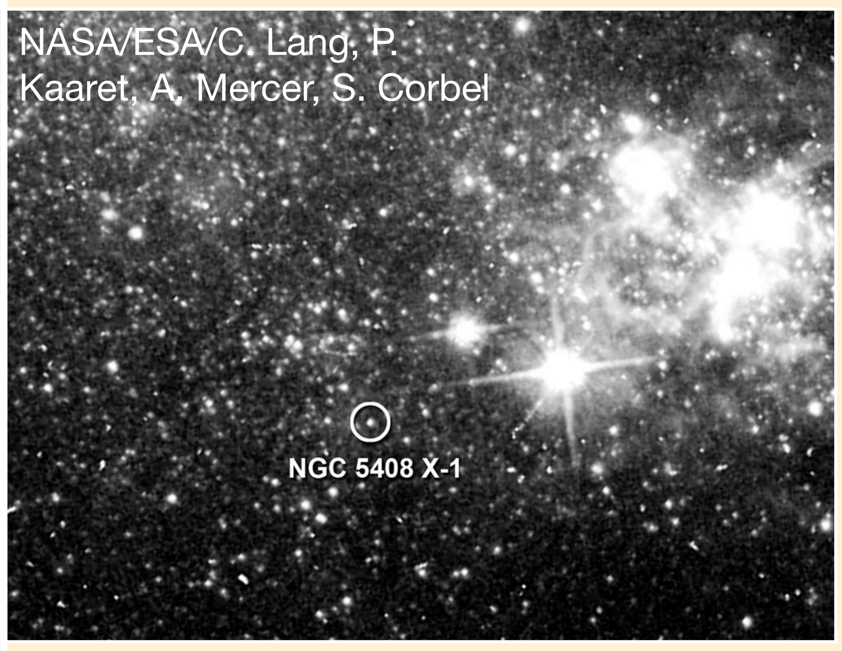


Figure 4. Ratio of the high- and low-frequency maps, showing that the ULX counterpart has a steep spectral index ($\alpha_R \approx -1$). The scale and orientation of the image is the same as in Fig. 3; the ULX position is marked with a cross.



- Soria et al. 2006: steep-spectrum radio lobes, similar to SS 433

- Lang et al. 2007: optically thin emission from extended from surrounding nebula

- Kaaret & Corbel: High excitation lines of He II λ4686 and [Ne V] λ3426 in its photo-ionised nebula

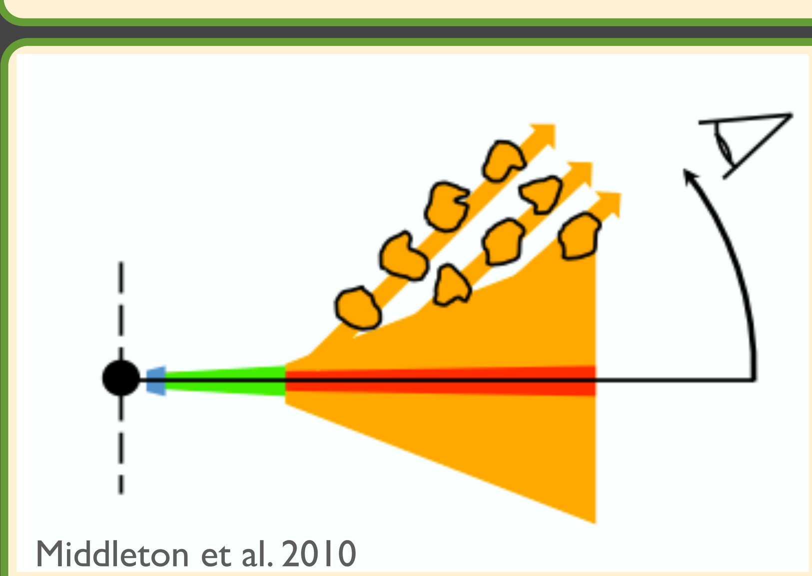
- cf. SS 433: (P_{orb} = 13.1 d, P_{nu} = 6.3 d, P_{sup} = 162.375 d)

- Strohmayer 2009: NGC 5408 X-1 flux modulation only determined to ± 4 days due to low number of cycles sampled

Table 1: Comparing QPO frequency and M_X in XRBs.

Source	P_{sup} [d]	f_{QPO} [Hz]	M_X [$M_\odot$]
NGC 5408 X-1	115.5 ± 4^a	0.010^a	—
SS 433	162.375 ± 0.011^b	0.100^c	4.3 ± 0.6^d
GRS 1915+105	590 ± 40^e	0.001–67^f	14 ± 4^g
GRO J1655-40	$\simeq 3^i$	0.1–$450^{j,k,m}$	6.3 ± 0.5^n
Cygnus X-1	$\simeq 300^p$	0.040–0.070^q	21 ± 8^p

[a]Strohmayer (2009). [b]Eikenberry et al. (2001). [c]Kotani et al. (2006). [d]Kubota et al. (2010). [e]Rau, Greiner, & McCollough (2003). [f]Morgan, Remillard, & Greiner (1997). [g]Greiner et al. (2001). [i]Hjellming & Rupen (1995). [j]Remillard et al. (1999). [k]Strohmayer (2001). [m]Remillard et al. (2002). [n]Greene et al. (2001). [p]Rico (2008). [q]Vikhlinin et al. (1994).



Middleton et al. 2010

- SS 433, a classic ADC source

- Intrinsic L_X of SS 433 is $10^{2\text{-}3}$ x higher; faint due to obscuration and/or mechanical beaming (Fabrika 2004; Begelman 2006)
- Viewed externally & at lower inclination, SS 433 would be inerpreted as ULX / IMBH

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