Resolving the nature of the dipping/flaring branch in Cygnus X-2

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1. Abstract

We resolve a long-term general confusion between flaring and dipping in Cygnus X-2. Using one-day multi-wavelength observations with XMM, Chandra and the European radio network, we show that the so-called flaring/dipping actually consists of absorption dips due to partial covering of the extended ADC Comptonized emission by structure in the outer disk. Examination of RXTE ASM data over 15 years shows that dipping occurs at all orbital phases but is peaked at phase ~0.7 corresponding to the impact of the accretion stream on the outer disk.

2. Dipping / flaring confusion

The Z-track Low Mass X-ray Binary Cygnus X-2 exhibits 3 branches: Horizontal (HB), Normal (NB) and Flaring (FB). In flaring, the intensity and the hardness increase. Dipping is seen as intensity decreases, but when plotted in a colour-colour diagram appears very similar to the standard flaring branch. Therefore, it has been commonly believed that there are two types of flaring, one consisting of intensity flares, and the second being of 'a dipping type', and important consequences of this confusion followed. Dipping misinterpreted as flaring suggested that the mass accretion rate was highest on the FB giving birth to the standard view in which Mdot increases monotonically on the Z-track in the sense HB-NB-FB [8]. In contrast, it has been shown from spectral analysis of the Cygnus X-2 like Z-track sources (Cyg X-2, GX 340+0 and GX 5-1) [1], that Mdot is actually lowest in flaring and that it consisted of unstable nuclear burning. This was based on the agreement of the observed onset of unstable burning on the neutron star with the theoretical criterion for the onset of unstable He burning [3].

3. What is dipping?

Some LMXB, called dippers, exhibit intensity dips in their lightcurves which were soon attributed to obscuration by the bulge at the outer accretion disk due to the high (65-80 degrees) inclination of such systems [6][9]. Church et al. (1997) showed that dipping in LMXB sources can be explained in terms of the 'Extended ADC' [4] in which the predominant X-ray emission is from an extended accretion disk corona, plus blackbody emission of the neutron star. During dipping, the bulge in the outer disk progressively overlaps an increasing fraction of the ADC. The extended nature of the corona has since then been strongly supported [7][10].

4. Multi-wavelength observation

We have investigated dipping in Cyg X-2 in a 1-day multi-wavelength campaign using XMM, Chandra and the European VLBI (**Bałucińska-Church M., Schulz N. S., Wilms J., Gibiec A., Hanke M., Spencer R. E., Rushton A. & Church M. J., A&A, 530A, 102B, 2011**).

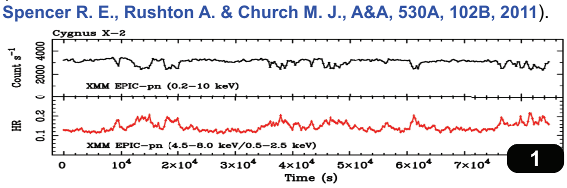


Fig. 1 shows dipping in the multi-wavelength XMM data [2], with intensity dips accompanied by increases in hardness suggesting photoelectric absorption - stronger at lower energies.

5. The nature of dipping

The results show clearly that dipping consists of absorption events as seen in the dipping class of LMXB and is unconnected with flaring.

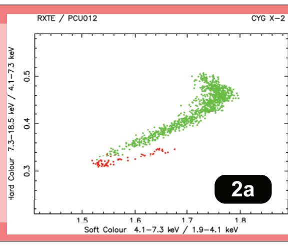
The remarkable lack of absorption of neutron star blackbody in Cyg X-2 is probably associated with the inclination of 62.5 deg, a few degrees less than in the dipping LMXB such that the absorber does not overlap the NS in the line-of-sight.

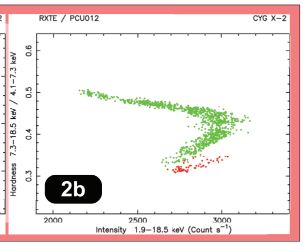
The occurrence of dipping predominantly at the Soft Apex of the Z-track between the NB and FB as often seen in Cyg X-2 was partly responsible for the dipping/flaring confusion. However, we can now suggest that a possible reason for this is that the absorber in the outer disk may be totally ionized at the highest luminosities of the sources, and only in the least luminous state at the Soft Apex does recombination allow some photoelectric absorption.

6. Dipping masquerading as flaring

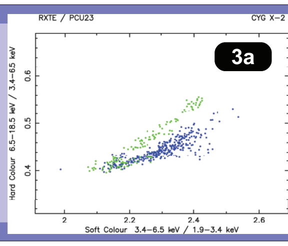
Flaring and dipping in Colour-Colour and Hardness-Intensity diagrams

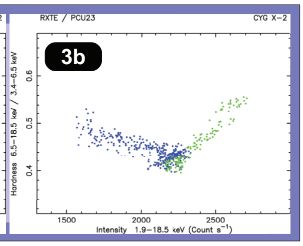
RXTE observation P20053 when Cygnus X-2 exhibited **flaring**. It corresponds to the Flaring Branch (red), which looks almost the same in both colour-colour (**2a**) and hardness-intensity (**2b**) diagrams. The Horizontal and Normal Branches were also traced and are shown in green.





RXTE observation P70016 when Cygnus X-2 exhibited **dipping**. Dipping points (blue) form a branch looking like a flaring branch in colour-colour (**3a**). Still, from hardness-intensity (**3b**) it is clear that dipping corresponds to intensity drops and not real flares.





Results

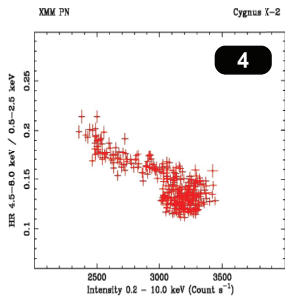
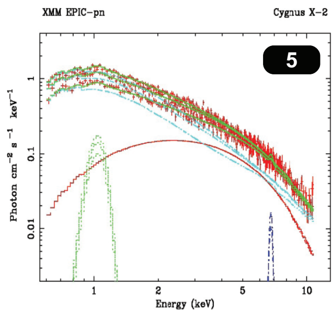


Fig. 4 presents the hardness-intensity variation from the XMM-Newton observation of Cygnus X-2 [2]. Spectral fitting results show that the source was sitting at the Soft Apex of the Z-track .

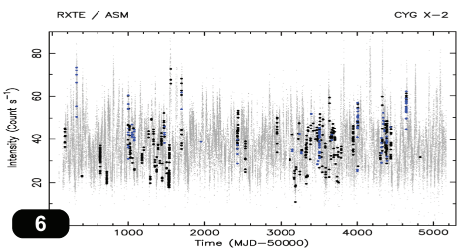
Spectral analysis at several depths of dipping is shown in Fig. 5. Only the Comptonized emission (light blue) was removed in dipping while remarkably, the neutron star blackbody (red) was not, in strong contrast with the dipping LMXB in general.

The table shows that the covering factor f of the ADC by absorber increased to 42% in dipping and the column density increased to 45×10^{22} cm-2 consistent with absorption by material in the outer disk.

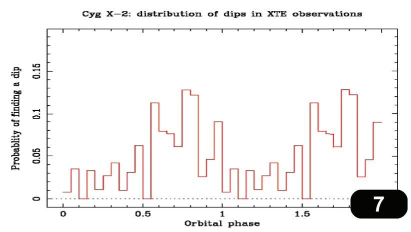


Spectrum	f	N_H	$\chi^2/d.o.f.$
Non-dip	0.0	0.0	223/194
Intermediate dip	0.182±0.019	13^{+13}_{-6}	187/192
Deep dip	0.421±0.015	45^{+20}_{-12}	223/192

Long-term distribution of dipping with orbital phase



15-year-long ASM lightcurve of Cyg X-2 with dip events marked in blue and XTE pointed observations in black is presented in Fig. 6. Dipping occurs commonly in Cyg X-2 and we used the distribution of dipping to calculate its relation to the orbital phase.



The distribution of dipping with orbital phase is shown in Fig. 7. Dipping occurs at all phases indicative of absorption in the outer disk. The predominance of dipping at phase ~ 0.7 is consistent with absorption in the bulge where the accretion stream impacts.

7. Conclusions

- **We show that dipping is not a type of flaring but is absorption by structure in the outer disk and peaks at orbital phase 0.7 indicating absorption in the bulge where the accretion flow impacts.**
- **The concentration of dipping at the Soft Apex where the source has the lowest intensity may show that only at this position is the outer disk not totally ionized.**
- **The argument that the Cyg-like sources (Cyg X- 2, GX 340+0 and GX 5-1) all have high inclination, distinguishing them from the Sco X-1 like sources is not valid, as we have also shown that dip-like events in GX 340+0 and GX 5-1 are *NOT* absorption events [5].**
- **That mass accretion rate does not increase in flaring [1] removes the motivation for the "standard view" that it increases along the Z-track in the direction HB → NB → FB.**

8. References & Acknowledgements

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