

SUBJECT: Flux-Torque Correlations in SMC X-1

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SMC X-1 is a high-luminosity X-ray pulsar (near or above Eddington luminosity) that is being spun up at a fairly rapid rate ($\nu/\dot{\nu} \approx 2,000$ year) with no known spin-down episodes. For these reasons we have felt that SMC X-1 is a good candidate for observing luminosity-torque (F - α) correlations, and we requested and obtained *RXTE* observations for this purpose.

Our preliminary results are a bit puzzling. The final two figures of our draft (Figs. 13 and 14) summarize our findings. Figure 13 compares the power spectra of X-ray flux and angular acceleration over a range of analysis frequencies. It can be seen that the two power spectra are similar, and the similarity is particularly striking if the spectra are normalized by their respective squared mean averages (bottom panel). Similar behavior in the spectra of the two quantities seems almost essential for an observable correlation between them. Furthermore, similar fractional amplitudes in luminosity and torque variations are predicted by most models. However, the two power spectra diverge at the lowest analysis frequencies, where the flux spectrum flattens while the angular acceleration spectrum is somewhat red (“pink”) with a logarithmic slope close to -1 .

Figure 14 shows the F - α correlation diagram, based on *Ginga* as well as *RXTE* observations. The upper panel is based solely on our *RXTE* data, with fluxes and angular accelerations determined concurrently from individual 8-hour pointings. The data were taken near the beginning of a high flux state, and the large uncertainties in some of the flux determinations are due to a correction for absorption. The uncertainties in the angular acceleration (α) are comparable to the scatter and therefore mask a correlation that might be present. These uncertainties (in α) can be substantially reduced, however, by increasing the data interval for each estimate from 8 hours to 1.3 days (spanning two consecutive pointings), and in Fig. 14(b) the correlation pairs are based on this longer interval. Also included in this plot are two points from *Ginga* observations, each based on an approximately 3-day data span. Vertical error bars indicate conventional uncertainties in the angular acceleration, while horizontal error bars include an estimated uncertainty due to an unavoidable sampling mismatch between F and α .

The lower panel of Figure 14 also includes a point representing the long-term average flux (based on *RXTE* ASM observations) and average angular acceleration (derived from reported pulse frequencies). These averages are *not* concurrent (the pulse frequency determinations largely predate the ASM flux observations), so the error bars on this point are not uncertainties per se but serve to indicate the repeatability of each mean inferred from its power spectrum. (The large error bar on the angular acceleration is due to the

“pink” nature of its spectrum at low frequencies – any two adjacent estimates of the angular acceleration averaged over the same time span are expected to differ by roughly the amount indicated.)

What picture emerges from this correlation diagram? There is an indication of a correlation for the *RXTE* observations alone, but the trend line does not pass close to the point representing the long term average F and α nor close to the point from the 1988 *Ginga* observations. That is, there appears to be a short-term correlation (for at least five days in the case of the *RXTE* observations) that is washed out over longer time scales. This picture is consistent with the power spectra shown in Figure 13, wherein the α spectrum contains a component of excess “pink” noise at low frequencies not present in the F spectrum. In other words, the angular acceleration continues a mildly divergent “walk” (not, strictly speaking, a standard “random walk”) that the flux somehow does not follow. The main question is: *is this interpretation theoretically viable?* If so, what are the implications for matter accretion in this source?



Fig. 13.—Power density spectra of (a) angular acceleration and (b) X-ray flux for SMC X-1, plotted with common scales for direct comparison. Solid lines indicate trends in regions where there are supporting power estimates, and dashed lines indicate possible trends in intermediate regions. (See captions to Figs. 12 and 15 for full descriptions of the angular acceleration and flux spectra, respectively.) (c) Trends for the angular acceleration and flux spectra plotted together, after normalization by their respective squared long-term means ($\bar{\alpha} = 2.29 \times 10^{-11} \text{ Hz s}^{-1}$, $\bar{F}_X = 2.9 \text{ RXTE ASM counts s}^{-1}$).

Fig. 14.—Correlation between X-ray flux (μJy at 10 keV) and angular acceleration for SMC X-1. (a) Correlation based on individual 8 hour pointings from the 1996 *RXTE* observations. X-ray flux observations have been divided by the mean high–low light curve to remove the effect of absorption near the beginning of the high state, and horizontal error bars indicate the uncertainty in this correction due to the uncertainty in determining the turn-on for this high–low cycle. Vertical error bars indicate the corresponding least-squares uncertainties in the angular acceleration. (b) Correlation pairs on a 1.3 day time span based on *RXTE* observations in 1996 are indicated by open circles with error bars. Correlation pairs on longer time spans are indicated by filled circles with error bars and labels: *Ginga* 1988 (2.8 days), *Ginga* 1988 (3.4 days), and *RXTE* 1996 (4.3 days). For comparison, a point representing the long-term mean flux (from *RXTE* ASM observations) and mean angular acceleration (from published pulse frequencies) is indicated by a filled square and the label (\bar{F} , $\bar{\alpha}$). Indicated uncertainties in the X-ray flux include an estimated contribution due to incomplete sampling. For the four *RXTE* points, this uncertainty has been combined in quadrature with an estimated contribution due to the uncertainty in the high state turn on. Indicated uncertainties in the angular acceleration for the six local determinations are conventional errors from the least squares analysis.

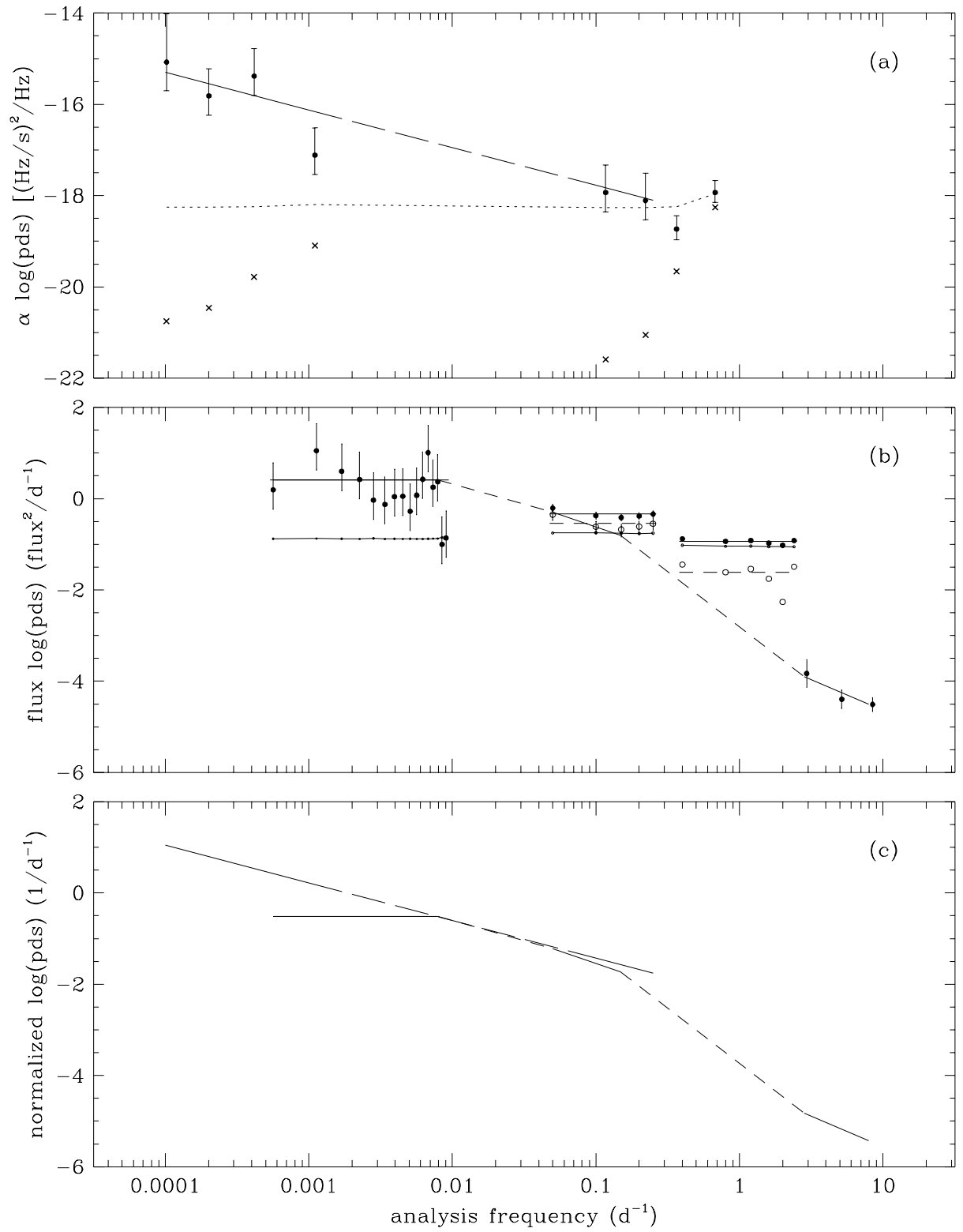


Fig. 13

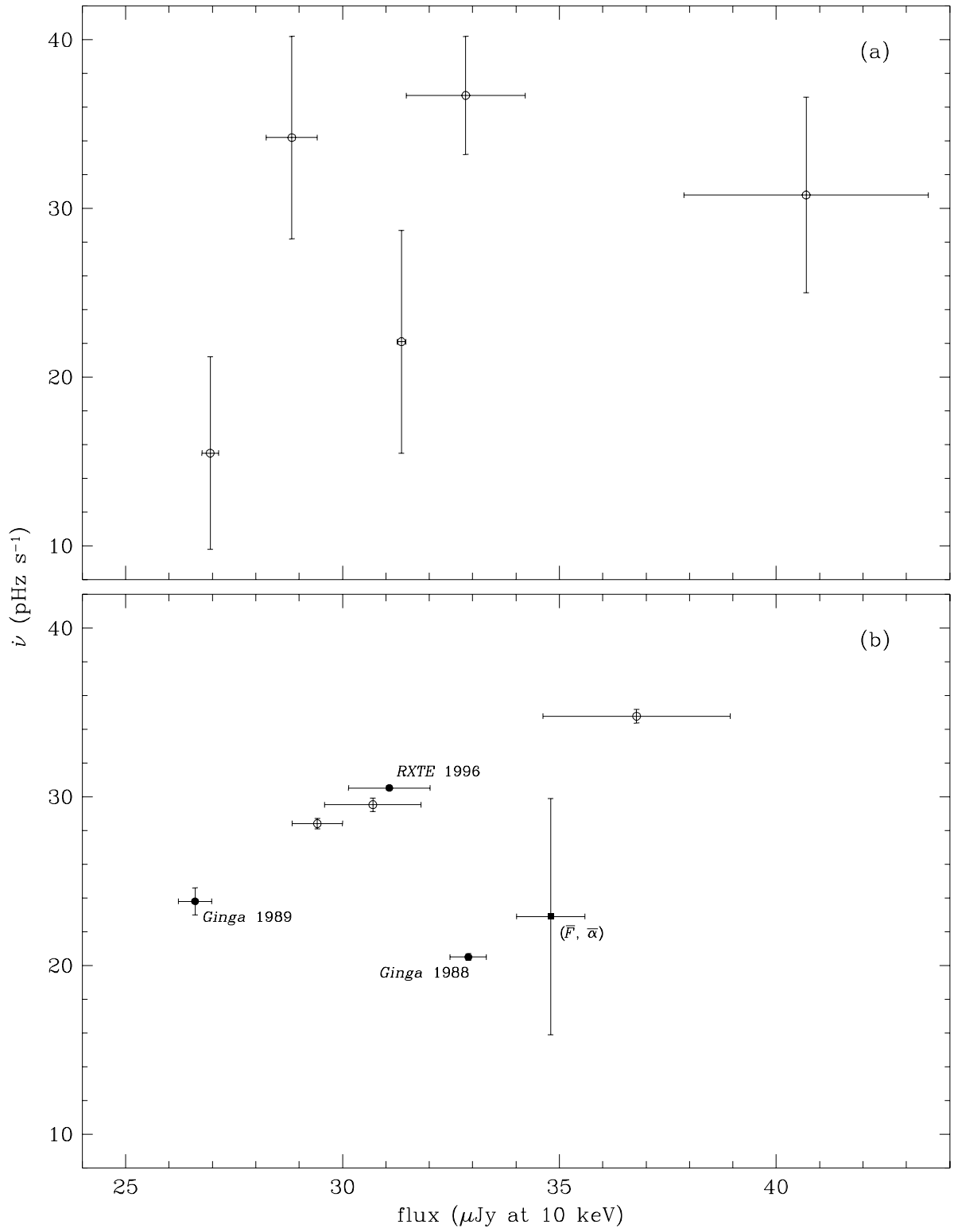


Fig. 14