Pulse profile variations in GX 1+4

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Abstract

The symbiotic accreting X-ray pulsar GX 1+4 shows significant changes in its pulse profile together with strong, irregular luminosity variations typical for this source class. We present results of a comparative study of profiles obtained over more than five years with INTEGRAL. Contrary to previous results we do not find a strong dependency of pulse shape on luminosity.

GX 1+4

GX 1+4 is an X-ray pulsar accreting from the slow stellar wind of its companion, the M6III giant V2116 Oph [1]. The X-ray flux is very variable on all timescales, from seconds to decades. In the years after its detection the source remained bright and spun up strongly. During an extended low state in the 1980s the previously strong spin-up reverted to a strong spin-down [2], that has been ongoing ever since, increasing the pulse period from ~110 s to ~160 s in the last three decades [3].

As in many accreting pulsars, the pulse profile of GX 1+4 is strongly energy dependent, with a more complex profile at lower energies, changing into a simple single-to-double shape above ~20 keV. In addition, the profile has been found to vary very significantly between observations, especially when comparing data from the spin-up with profiles from the spin-down period [4].

In previous studies, a dependency of the profile shape with luminosity was found, especially a correlation of the asymmetry parameter α (ratio of pulsed flux in phase 0.5-0.75 to that in 0.25-0.5) on the intensity at 20 keV [5].

Data & analysis

We have analysed IBIS/ISGRI data from ~5½ years of serendipitous INTEGRAL observations covering GX 1+4. The data were reduced using the OSA8 analysis software, using `ii_light` to create lightcurves with 10s resolution.

These lightcurves were folded with known periods from [6] in order to create pulse profiles. Since individual observations are usually too far apart to allow phase connection, we have chosen the primary minimum of the profile as phase zero, following [7], adjusting by eye from comparison with a profile of medium brightness. Other methods, like minimizing the area between a profile and a normalized reference yield mostly the same result.

Due to the relatively short integration times, individual profiles are relatively noisy. Thus, we smoothed the profiles before calculating quantitative parameters like α. We used various ways to classify the different profiles, besides α as defined above, we tested also other ratios (e.g., peak heights), slopes of the rising and falling flanks, pulse fractions and the pulsation significance expressed by calculating χ^2 relative to the mean flux.

In the end, the different methods arrive at the same qualitative result. For comparison with [5], we have decided to present α in Figures 1 and 4.

Results & Conclusion

Looking at individual pulse profiles during times of rising or falling flux — see examples in Figure 2 — one is tempted to see a trend from a broad, featureless peak at low fluxes via a more asymmetric intermediate flux towards a double-peaked profile at higher fluxes. But ***no clear trends emerge if the complete data set is taken into account***. We also note that ***profiles at similar brightness levels can appear very different***, as shown in Figure 3.

There is a slight preference for "trailing edge bright" (α > 1, class A of [5]) profiles in our data, but again with no evident trend on luminosity and with the brightest examples actually rather falling in class B ($\alpha \leq 1$) — see Figure 4.

We note though that our data so far only covers a relatively low intensity range, compared to the observations quoted in [5], where high intensities are mainly from the spin-down phase.

We conclude that in the current mode of accretion GX 1+4 shows trends in the pulse profile evolution on time scales of days to weeks, but on longer time scales the distribution appears to be basically random.

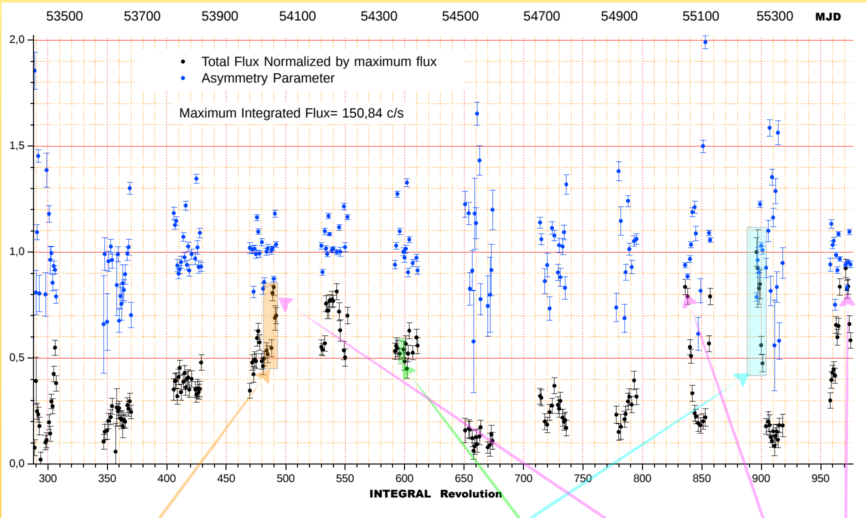

Figure 1: Long-term light flux evolution of GX 1+4 as observed by INTEGRAL (black) and the asymmetry parameter α as defined by [5] in blue. There is no evident correlation with flux.

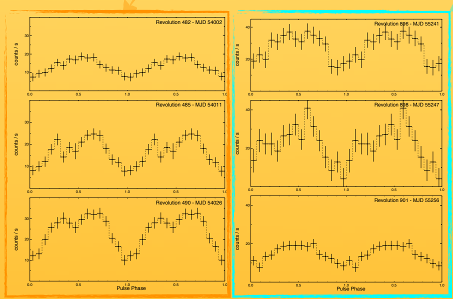

Figure 2: Examples of 20-40 keV pulse profile evolution with flux, for increasing luminosity (left) and decreasing luminosity (right) over the course of several INTEGRAL revolutions.

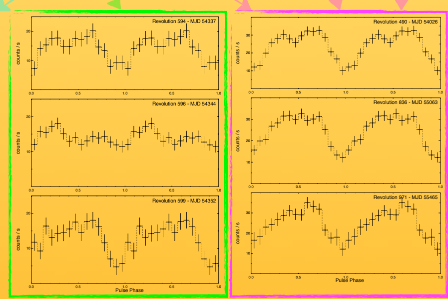

Figure 3: Examples of different 20-40 keV pulse profile shapes for observations at different times but similar flux.

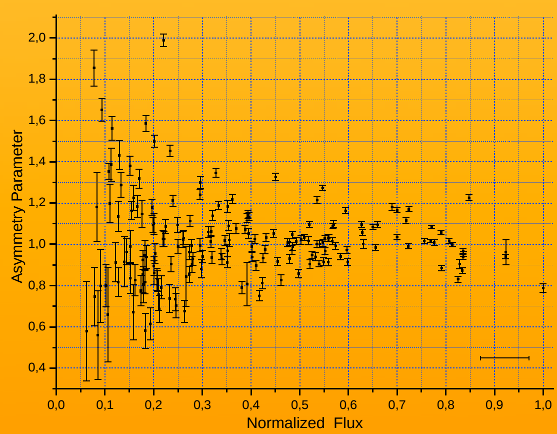

Figure 4: Asymmetry parameter α as defined by [5] versus observed flux, normalized to the brightest observed value. A typical uncertainty in flux is given by the horizontal bar. When the source is weak, the profile shape is not well defined, for higher luminosity there is an apparently random scatter around symmetric profiles.

References

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