OBSERVATION OF V 0332+53 OVER THE 2004/2005 OUTBURST WITH *INTEGRAL*

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ABSTRACT

We present the spectral and temporal analysis of the 2004/2005 outburst of the transient X-ray pulsar V 0332+53 as observed with *INTEGRAL*. After the discovery of the third cyclotron line in phase averaged spectra (Kreykenbohm et al., 2005; Pottschmidt et al., 2005), detailed pulse phase spectroscopy revealed remarkably little variability of the cyclotron lines through the 4.4 s X-ray pulse (Pottschmidt et al., 2005). During the decline of the outburst, the flux was observed to decay exponentially until 2005 Feb 10 and linearly thereafter. The spectrum was found to become harder with time, while the folding energy remained constant. The energy of the fundamental cyclotron line increased with time from 26.5 keV in the *RXTE* observation up to 29.5 keV in the last *INTEGRAL* one indicating that the emission region is moving closer to the surface of the neutron star.

Key words: Pulsars: V0332+53 - stars: magnetic fields.

1. INTRODUCTION: V 0332+53

The recurring transient X-ray pulsar V 0332+53 was discovered in 1983 in *Tenma* data (Tanaka, 1983). Subsequently, a larger outburst was found to have occurred in the summer of 1973 when analyzing *Vela 5B* data (Terrell & Priedhorsky, 1984). The analysis revealed a 4.4 s pulse period and an indication for a 34.25 d orbital period (Stella et al., 1985). The optical counterpart is the O8–9 star BQ Cam (Negueruela et al., 1999).

Analysis of the *Tenma* data revealed a spectral shape similar to that seen in other accreting X-ray pulsars with a flat power law, an exponential cutoff, and a cyclotron resonant scattering feature (CRSF) at an energy of $\sim$28 keV.

In 1989 September the source experienced another outburst, this time observed by *Ginga* (Makino, 1989). With the energy range of the Large Area Counters adjusted to cover the 2–60 keV range, CRSFs were detected at 28.5 and 53 keV.

Most recently, V 0332+53 went into outburst in 2004 November and was seen by the *RXTE*/All Sky Monitor (ASM) to reach an intensity of $\sim$1 Crab in the 1.5–12 keV band (Remillard, 2004). A long series of observations with *RXTE* and *INTEGRAL* were made throughout the outburst.

2. FLUX EVOLUTION

During the decline phase, the observed fluxes first decay exponentially up to MJD 53412, followed by a linear decrease (see Fig. 1). The decay timescales are different at lower and higher energies: while a decay time of 30 d is observed above 20 keV, it is only 20 d below 15 keV. Such behavior is typically observed in systems where an irradiated disk is present which, however, is not the case for V 0332+53. Since $L_X \propto \dot{M}$, this picture suggests that $\dot{M} \propto M_{\rm disk}$. The transition to the linear phase would then be triggered by a yet unknown change in the disk.

3. SPECTRAL EVOLUTION

To study the evolution of the spectrum over the outburst, we used the simple cutoffpl model, modified by two Gaussian absorption lines to model the CRSFs at $\sim$27 keV and $\sim$51 keV for all observations. While the folding energy remains constant at $\sim$7.5 keV, the power law index Γ decreases from -0.18 in the first observation to -0.4 in the last observations – the spectrum of
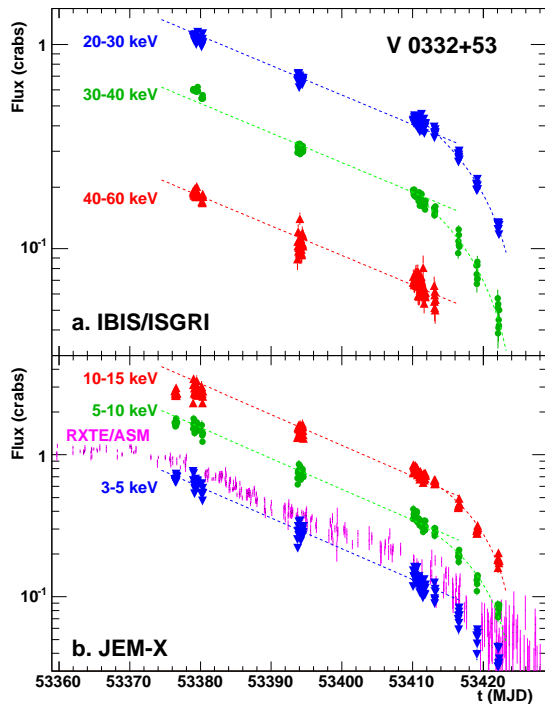
Figure 1. *Flux evolution for V 0332+53 as observed by the INTEGRAL instruments ISGRI and JEM-X (Mowlavi et al., 2005).*

V 0332+53 hardens over the outburst. The fundamental cyclotron line also changes over the outburst: the energy increases from 27.5 keV in the first *INTEGRAL* observation to 29.5 keV in the last observations. Moreover, during the previous *RXTE* observation, the fundamental CRSF was observed at 26.3 keV (Pottschmidt et al., 2005) resulting in a total increase of more than 3 keV. This change is highly significant: fitting the last *INTEGRAL* observations with a CRSF energy fixed to 27.5 keV results in strong residuals and a completely unacceptable fit. The same holds true for the continuum: fixing the other continuum parameters also results in unacceptable fits. The determination of the parameters of the second CRSF, however, is problematic for the second half of the observations as with decreasing flux, statistics become poor.

4. DISCUSSION

The exponential decay of the flux and the transition to a linear phase later is frequently observed in SXTs and dwarf novae (King & Ritter, 1998). While the emission mechanism is entirely different for V 0332+53, the similarity is striking and a yet unidentified change in the disk can be assumed to trigger the transition to the linear phase. The luminosity dependence of the energy of CRSFs had already been observed previously (Mihara, 1995) and was assumed to be due a change in height of the CRSF formation region in the accretion column. Based on our data, we derive a change in height of
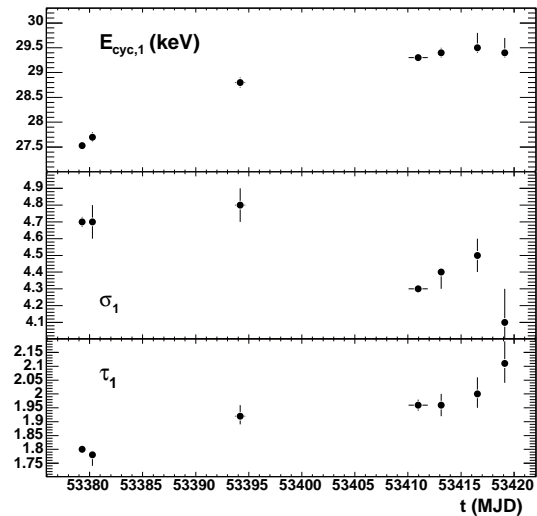

Figure 2. *Evolution of the spectral parameters of the fundamental CRSF during the decay of the outburst (Mowlavi et al., 2005).*

$\sim$300 m; however, a slightly different picture is also possible: the CRSF emission region can be assumed to be extended along the accretion column. The observed broad CRSFs would then be superposition of many narrower lines, each from a different height in the column. As the accretion rate drops, the extend of the emission region and its height both decrease and hence the energy of the CRSF increases while it gets narrower as is observed for V 0332+53 (see Fig. 2).

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