The strange 12 years long outburst with a series of echo outbursts in KS 1731-260

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Abstract

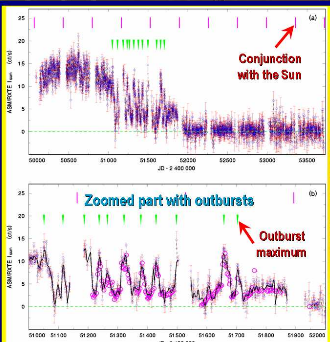
Thermal instability of accretion disk should appear when a persistent low mass X-ray binary (LMXB) goes into quiescence. We analyze the complicated X-ray activity of one such case, KS1731-260. On the decline from a strange, 12 years long outburst, it went through a series of so-called echo outbursts with the properties similar to the 'ordinary' soft X-ray transients. We interpret the onset of echo outbursts as a decrease of the mass transfer rate which lead to a transition from a thermally stable to unstable disk. The X-ray spectrum at the peak of the echo outburst is consistent with that in the high state/main outburst. The echo outbursts are outside-in. A series of heating and cooling fronts are formed and the disk just reached a steady-state at the outburst peak. We show that the individual echo outbursts are dependent on each other in KS1731-260. KS 1731-260 provides a link between persistent and transient systems.

Low-mass X-ray binaries (LMXBs) – classified either as persistent or transient (e.g. Lewin et al. 95)
Transient sources – outbursts (X-ray flux rises by several orders of mag (e.g. Chen et al. 97)). Thermaly unstable disks (e.g. Dubus et al. 01).
Persistent sources – X-ray flux varies by a factor of few. Steady-state disks.

KS 1731-260 – remarkable LMXB. Discovered with *KVANT/MIR* in 1990 as a source which turned on only recently. It remained in the high state for ~12.5 years. Neutron star (NS) accretor (Sunyajev et al. 90). Luminosity continued to decrease even in quiescence (Wijnands et al. 02). X-ray emission in quiescence attributed to the cooling NS, not to accretion (Wijnands et al. 01).

Subjects of our analysis:

- Activity of KS 1731-260 during transition from a persistent X-ray source to a transient and hibernation
- X-ray color variations and their role in assessment of the relation of the high state (main outburst) and echo-outbursts in KS 1731-260



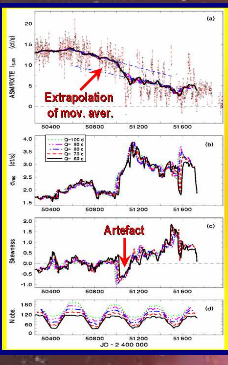
KS 1731-260

Small circles: *ASM/RXTE* data (1.5-12 keV) (one-day means)

Large open circles: PCA data from Galactic center scans (Wijnands et. al. 01); intensities re-calculated using count-rate of Crab nebula to match the *ASM* data.

Smooth solid line – fit by the code HEC13 (Vondrak 69, 77; Harmanec)

Only clearly defined echo-outbursts with the maximum of the fitted curve I_{sum}>7 ct/s are marked



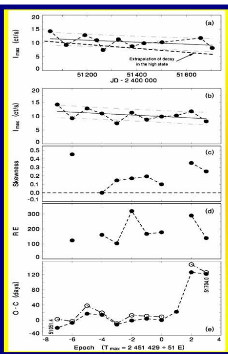
Moving averages

(a) Light curve smoothed by two-sided moving averages for various values of the semi-interval *Q*

(b) Smoothed residuals σ_{res} of fits (measure of amplitude of the flux variations)

(c) Smoothed skewness of residuals (measure of asymmetry of the light curve)

(d) Number of obs. in each mean.



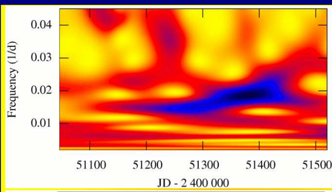
Time evolution of parameters of echo-outbursts (determined from HEC13 fits):

(a, b) Variations of the peak flux I_{max}.

(c) Skewness of outburst – measure of asymmetry of outburst (depends mainly on three parts – the rising branch, shape and duration of maximum flux, decaying branch). Skewness > 0 (rise faster than decay)

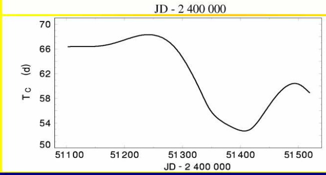
(d) Relative energy (*RE*) of outbursts (in dimensionless units): *RE* is obtained by integration of outburst light curve.

(e) O-C diagram for the recurrence time T_C of outbursts.
Moments of peak intensity – solid circles.
Moments of crossing I_{sum}=7 ct/s on decaying branch – open circles.
Numbers at points – moments of outburst maxima in JD-2400000



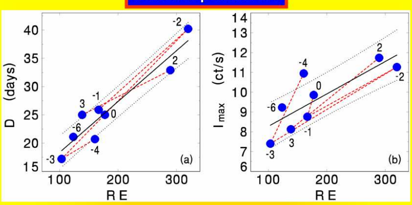
Recurrence time of outbursts

Weighted wavelet Z-transform (WWZ) of X-ray curve during the interval of echo outbursts (method of Foster 1996)
WWZ – determination of period and amplitude of unevenly sampled time series.



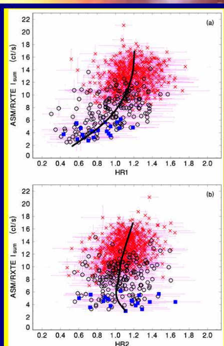
Evolution of recurrence time T_C of outbursts determined by WWZ-transform.
This curve represents the maximum WWZ in each JD.

Outburst parameters



(a) Relation between Relative Energy (*RE*) and Duration *D* of outbursts
(b) Relation between *RE* and Peak Flux I_{max} of outbursts.
Quantities determined from HEC13 fits
Linear fits and their standard deviation
Numbers at points - epoch of outburst E
Strong correlation between *RE* and *D*. Correlation between *RE* and I_{max} slightly weaker, but still clearly present. Outbursts with higher peak intensity are thus longer.

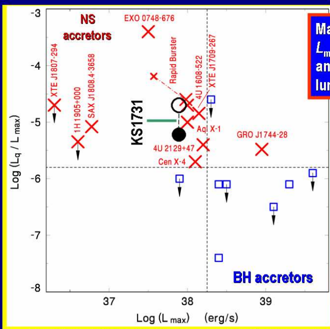
Hardness vs. flux



Relation between *HR1* and *HR2* and I_{sum}, σ_{HR}<0.3.
Thick line – HEC13 fits

$HR1 = [I_B(3\text{-}5\ \mathrm{keV})] / [I_A(1.5\text{-}3\ \mathrm{keV})]$
$HR2 = [I_C(5\text{-}12\ \mathrm{keV})] / [I_B(3\text{-}5\ \mathrm{keV})]$

Three states of activity resolved:
- high state (crosses)
- outbursts (open circles)
- quiescence between outbursts (solid boxes)



Maximum luminosity L_{max} vs. ratio of max. and quiescent luminosity L_q of SXTs

Position of KS 1731-260 is consistent with the neutron star SXTs.

RESULTS

- On this remarkable system we show that the transition from persistent X-ray source to quiescence (or even hibernation) goes through a series of outbursts with the properties similar to SXTs.
- We interpret the echo-outbursts in KS1731-260 as a decrease of the mass inflow rate from the donor which lead to a transition from a thermally stable to unstable disk.
  - Peak intensity of the echo-outbursts lies on the extrapolation of a gradually decaying level of emission prior to the onset of instability.
  - Evolution of the X-ray hardness ratios *HR1* and *HR2* with I_{sum} shows that the X-ray spectrum at the peak of the echo-outburst is consistent with that in the high state (main outburst). The disk thus appears to achieve steady-state during the maxima of echo-outbursts. They appear to be a continuation of the spectral evolution exhibited in the high state.

- Evolution of *HR1* and *HR2* bears a resemblance to that in 4U1820-30 (Simon 2003) and suggests that KS1731-260 is atoll, too.
- The rise of the echo-outbursts steeper than the decay implies that the heating front starts in the outer disk region (outside-in type of outb.). Alternative explanation by an optically thin advection-dominated accretion flow (ADAF) is unlikely because the disk did not get into real low state between most echo-outbursts (I_{sum} was clearly above the quiescent value; a series of heating and cooling fronts thus formed). The luminosity between echo-outbursts is much higher than observed later by XMM by Wijnands et al. (2002).
- Relatively smooth profiles of the O-C curve and WWZ suggest that the individual echo-outbursts are dependent on each other in KS1731-260. Their recurrrence time T_C ungergoes complicated, non-monotonic variations, accompanied by the complicated variations of the outburst parameters. This cannot be explained purely by a steadily decreasing mass inflow from the donor (e.g. also viscosity changes are needed).

- We interpret the ~12.5 years lasting 'main outburst' as being caused by a real increase of the mass outflow from the donor, and not by the thermal instability of the disk alone. The reason is that the luminosity in the long-lasting main outburst remains only slightly higher than the typical luminosity of the peaks of the echo-outbursts. This can be explained if the disk was kept in steady-state by the increased mass inflow from the donor.
- The state of long-term activity of "classical" SXTs is not the same as in KS1731-260. Well observed SXTs (e.g. Aql X-1, 4U1608-52) display outbursting activity in which the disk alternates between cold and hot state. On the contrary, the disk in KS1731-260 was depleted during a short time and this system may be in a hibernation state now.
- Long-term activity of KS1731-260 provides a link between persistent and transient LMXBs.