ON THE CORRELATED X-RAY AND OPTICAL EVOLUTION OF SS CYGNI

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We present an analysis of simultaneous RXTE/ASM and optical AAVSO observations of SS Cygni over a ~6 yr period. By summing the X-ray flux over multiple outbursts, phased using the optical light curve, we find that the hard (3-12.2 keV) X-rays are suppressed during outburst. This confirms the trend seen in the few outbursts previously observed. The several outbursts of SS Cygni observed with the more sensitive RXTE/PCA also show depression of the hard X-rays during optical outburst. We quantify the time lags between the optical and X-ray outbursts, and the time scales of the hard X-ray spectral recovery from outburst. The optical light curve of SS Cygni exhibits anomalous or "mini" outbursts. During these events, the hard X-ray and optical flux increase is correlated. We also investigated the optical and X-ray evolution of SS Cygni during quiescence using the RXTE/ASM and AAVSO data. Our results suggest that the hard X-ray flux declines between one outburst and the next. We discuss our observational results in the framework of the theoretical models of the accretion flow in dwarf novae systems.

INTRODUCTION

★ SS Cygni is a dwarf novae (DN) cataclysmic variable

main characteristic of DN are recurring outbursts with timescales of days to years, which can last days to weeks

★ SS Cygni displays outbursts every ~50 d

⇨ source goes from V~12 in quiescence to V~8.5 at outburst
⇨ outbursts are bimodal, wide and narrow outbursts last ~20 and ~12 d, respectively

★ The main site of X-ray emission in DN is believed to be the boundary layer between the white dwarf and the accretion disk

source is found to have a hard and ultra-soft X-ray component

★ The hard and soft X-ray components display different behaviour during quiescence and outburst

⇨ outburst starts in the optical, after a short delay the hard X-ray component is seen to flare, soft X-ray outburst starts as the hard flare ends, hard X-ray emission is suppressed below its quiescent level

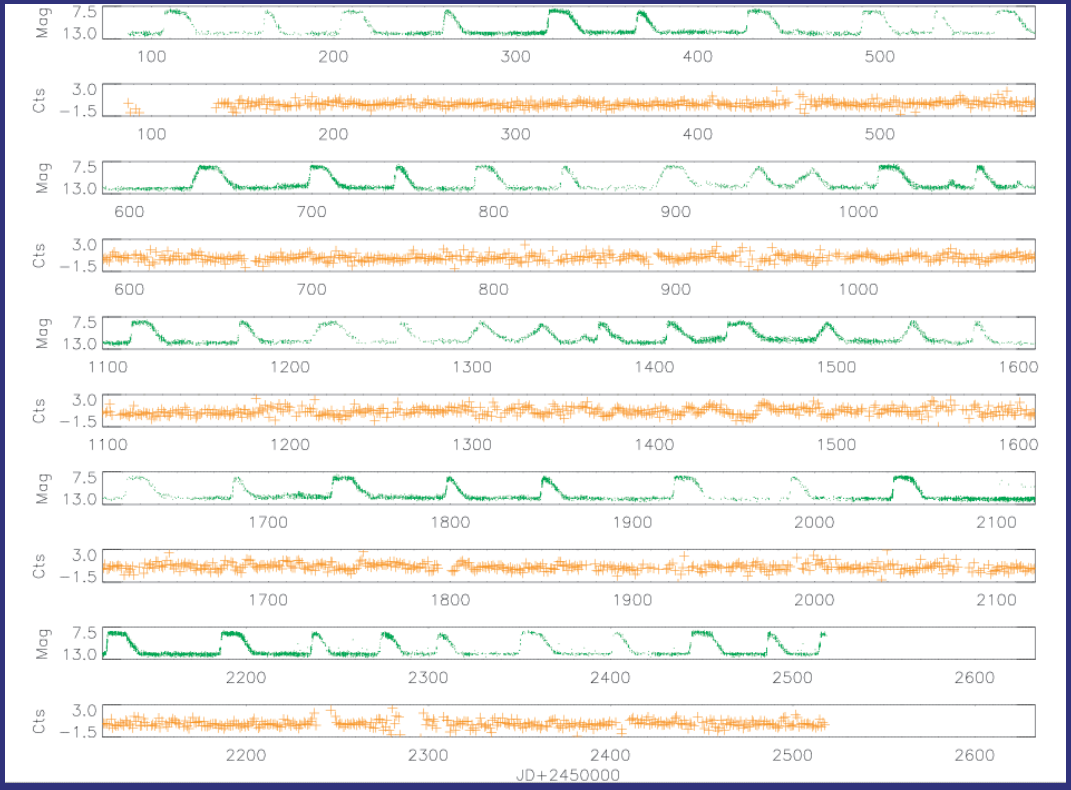
⇨ the soft X-ray emission follows the optical behaviour closely during the peak of the optical outburst, but the soft X-rays decline faster

⇨ at this time the hard X-ray component brightens again, then decays to quiescence over a longer period than the optical

COMPARISON OF AAVSO AND ASM DATA

Optical and X-ray light curves of SS Cygni from 1996 January 4 to 2001 August 30

optical data is from the AAVSO, X-ray data is from the RXTE/ASM



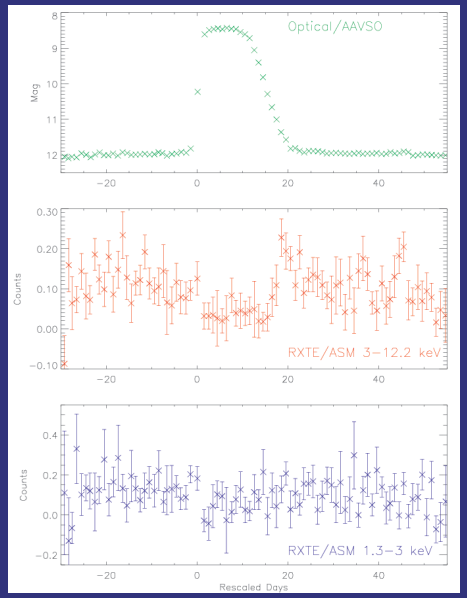
optical outbursts are obvious, however, it is difficult to see any response in the X-rays

OUTBURST

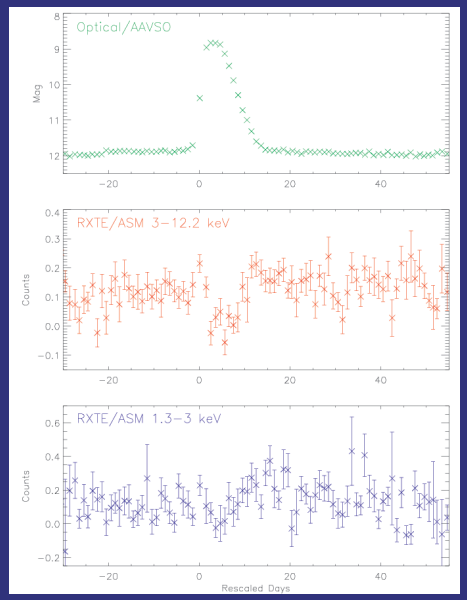
★ To improve the signal to noise, average the optical and X-ray data

⇨ use the optical data to define a characteristic timescale for the wide, narrow and anomalous outbursts : 16, 9 and 3 d respectively

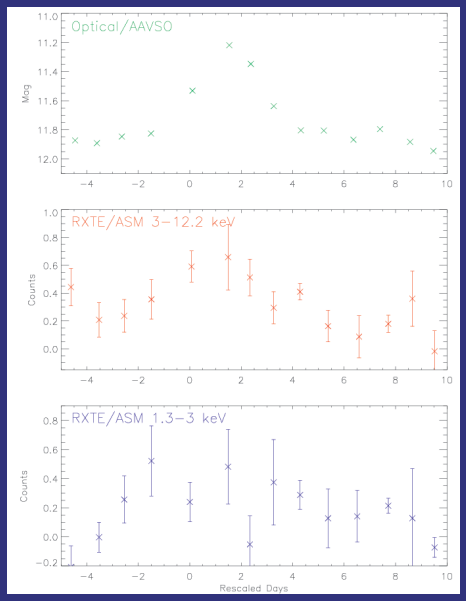
⇨ rescale the optical and X-ray data on these timescales



WIDE



NARROW



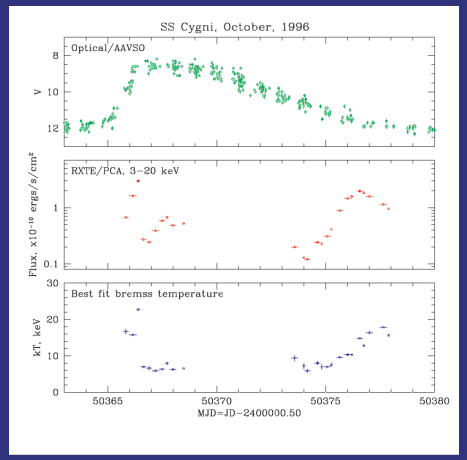
ANOMALOUS

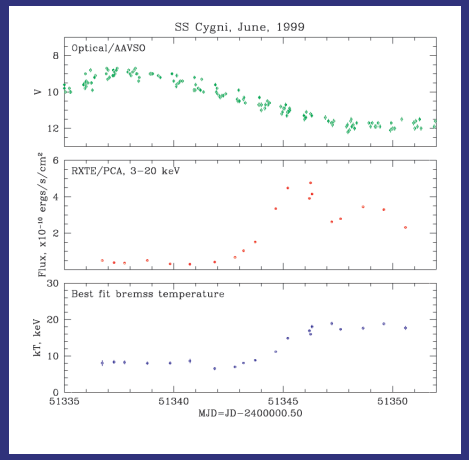
★ Results for wide and narrow outbursts indicate that the hard X-rays are suppressed during optical outburst, in agreement with previous results

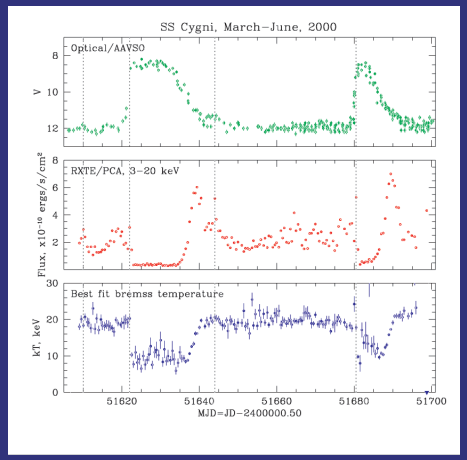
★ Data for anomalous outbursts indicate a positive correlation between the optical and hard X-rays

POINTED OBSERVATIONS OF SS CYGNI

★ Use archival RXTE/PCA data to investigate optical/X-ray outburst evolution







★ Morphology of hard X-ray evolution similar for all outbursts
- ⇨ rise of optical outburst coincides with a short X-ray luminosity "spike"
- ⇨ optical max is accompanied by an extremely low level of hard X-ray flux
- ⇨ decline of optical outburst corresponds to gradual increase of hard X-rays followed by a brief 2-4 d max

★ Periods of optical quiescence are generally characterised by relatively high levels of hard X-ray flux

CHARACTERISTIC TIMESCALES

★ Investigate the characteristic timescales of the hard X-ray luminosity transitions

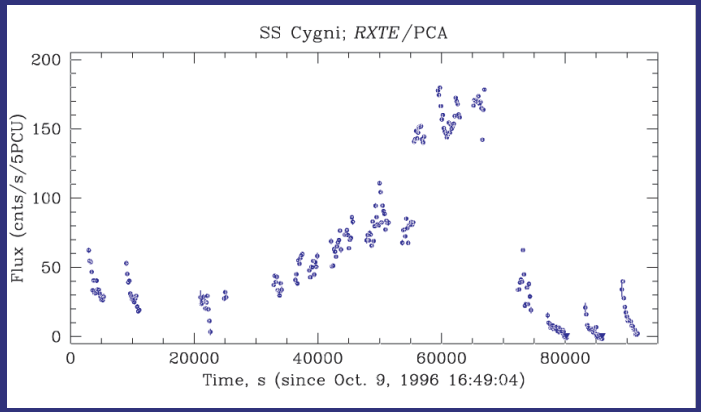
⇨ average duration of the X-ray "spike" (where X-ray flux increases several times and fades on a timescale of <1 d) which is coincident with an anomolous optical outburst is ~2 d with an almost symmetrical peak

⇨ exponential fits to the rising/decaying parts of the X-ray "spikes" (MJDs 51610 and 51644) give an e-folding time of ~0.5 d

⇨ X-ray "spike" corresponding to the beginning of the optical outburst have a shorter duration of <1 d

★ Data from 1996 October 9-11 allows a detailed study of source evolution during a "spike"

⇨ "spike" has asymmetrical shape with initial quasi-exponential rise with T_{fold} ~25000 s followed by an abrupt decline in <10000 s



★ An analytical approximation of the declining phase of the optical outburst and simultaneous rise of the hard X-ray flux suggest that the X-rays evolve faster than the optical light

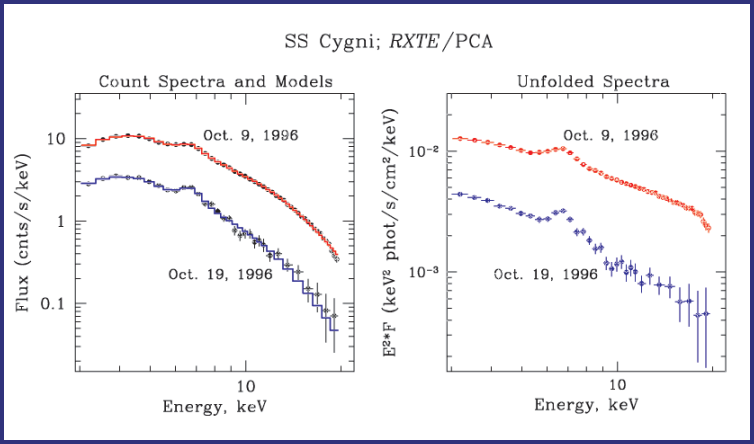
ENERGY SPECTRA

★ Previous studies of SS Cygni have shown the presence of two distinct spectral components

- ⇨ a hard component with characteristic cut-off at ~10-20 keV
- ⇨ an ultra-soft component with cut-off at ~60 eV
- ⇨ these components behave very differently during optical outburst and quiescence

★ PCA energy range allows the direct study of the hard spectral component without contamination from an ultra-soft component

★ Absorbed bremsstrahlung radiation model plus a Gaussian emission line at ~6.7 keV describe the data well in the 3-20 keV range



⇨ best-fit value for the characteristic temperature of the bremsstrahlung model varies between ~6 and ~26 keV the resulting model flux changes from ~10^{-11} to ~7×10^{-10} ergs s^{-1} cm^{-2}

HARDNESS-FLUX DIAGRAM

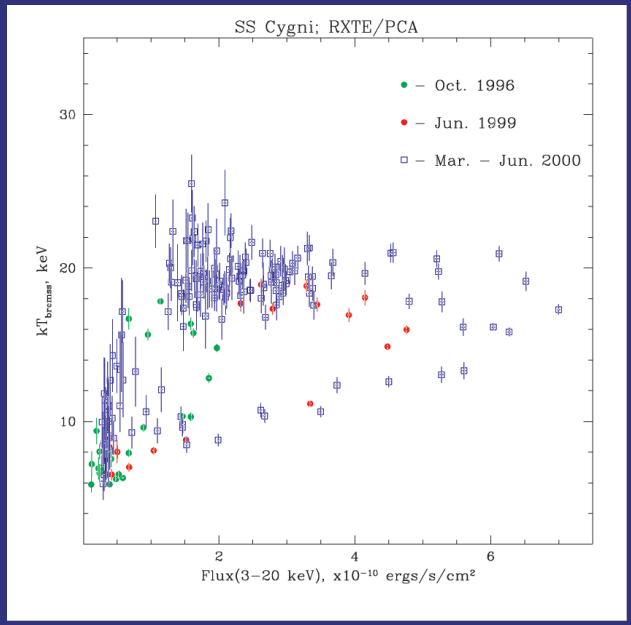
★ Relation between the level of X-ray flux and the best-fit value of kT_{brem}

⇨ each point represents the data averaged over one individual observation

★ Observations can be subdivided into 3 distinct groups according to their positions in the hardness-flux diagram

(1) densely populated group concentrated around ~20 keV in temperature and X-ray flux of ~2 x 10^{-10} ergs s^{-1} cm^{-2} , this group corresponds to the periods of optical quiescence with relatively high hard X-ray flux

(2) densely populated group concentrated around ~8 keV in temperature and X-ray flux of ~3 x 10^{-11} ergs s^{-1} cm^{-2} , represents the periods of optical/soft X-ray outburst, characterised by extremely low levels of hard X-ray flux



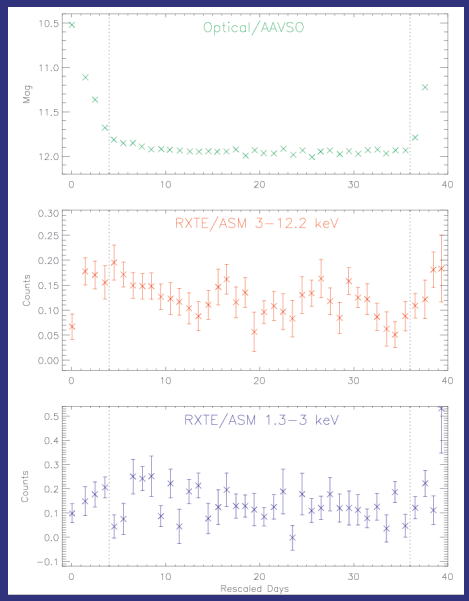
(3) sparsely populated group represents mostly the periods of transition between optical outburst and quiescence, characterised by rise of hard X-ray luminosity and general hardening of X-ray spectrum

INTER-OUTBURST

★ To study the optical and X-ray correlation during times of quiescence use a similar method as for the outburst data

define a characteristic timescale of 38 d and rescale optical and X-ray data onto this timescale

★ We find evidence for a 40% decline over the period of quiescence at a level of 3.3 sigma



CONCLUSIONS

★ The correlated hard X-ray and optical/soft X-ray evolution can be explained in terms of a two-component accretion flow model, consisting of the optically thick geometrically thin disk and quasi-spherical flow/optically thin corona-like structure

★ Initial increase in mass transfer rate in the outer part of the accretion disk (or close to the inner Lagrangian point) leads to the increase of hard X-ray flux from the optically thin corona-like structure on a timescale of the quasi-spherical flow of order of orbital period (see initial hard X-ray spike and anomalous outburst). Subsequent rise of the soft X-ray flux causes catastrophic Compton cooling of the optically thin region and an abrupt drop in the hard X-ray flux. The decline of the X-ray/UV/optical flux leads to the observed recovery of the hard X-ray flux/hardening of the X-ray spectrum