ADVECTION-DOMINATED ACCRETION MODEL OF X-RAY NOVA MUSCAE IN OUTBURST

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We present a model for the high-low state transition of the X-Ray Nova GS 1124-68 (Nova Muscae 1991) observed by Ginga. The model consists of an advection-dominated accretion flow (ADAF) near the central black hole surrounded by a thin accretion disk. During the rise phase of the outburst, as the mass accretion rate increases, the transition radius between the thin disk and the ADAF moves closer to the center, until the thin disk extends all the way in to the last stable orbit. The transition radius increases again during decline. We reproduce the basic features of the spectra taken during and after outburst, and the light curves in the soft and hard X-ray bands. We estimate that the accretion rate in Nova Muscae decreased exponentially with a time scale $\sim 95$ days during decline.

1 Introduction

A bright X-ray nova GS 1124-68 (Nova Muscae 1991) was discovered by the Ginga ASM on January 8, 1991. Subsequent optical observations showed that the system is a short period spectroscopic binary with a mass function of $3.1 M_\odot$, which makes it a strong black-hole candidate.

Like other black hole X-ray novae in outburst, Nova Muscae underwent large changes in its X-ray luminosity and spectral characteristics during outburst (Figs 1(a), 2). These changes are usually described in terms of a succession of spectral states. The highest luminosity corresponds to the “very high” state, characterized by a photon index of $\sim 2.5$ in the X-ray range 2-20 keV. The “high” state has a lower bolometric luminosity with practically no emission above 5-10 keV. At yet lower luminosity, we have the “low” state where most of the energy comes out in hard X-rays; the X-ray spectrum is usually well characterized by a power-law with a photon index $\sim 1.5 - 1.7$. Finally, at the lowest luminosities, there is the “quiescent state”.

2 Modeling the State Transitions in Nova Muscae

We model Nova Muscae as a black hole of mass $M = 6 M_\odot$, accreting gas from its companion at a rate $\dot{m}$ (in units of $\dot{M}_{\text{Edd}} = L_{\text{Edd}}/(0.1 c^2)$). From the outer edge at a radius $r_{out}$ (all radii are in units of $R_{\text{Schw}} = 2GM/c^2$) to a transition radius, $r_{tr}$, the gas accretes via a cool thin disk plus a hot corona formed by
Figure 1: (a) Spectra of GS 1124-68 on days 3 (very high state), 62 (high state), 130, 197 (low state), and 238 of the outburst (in order of decreasing 1 keV flux).

(b) Corresponding model spectra with the following parameters: \((\log \dot{m}, \log r_{tr}) = (0.2, 0); (-0.4, 0); (-1.0, 0.5); (-1.1, 3.9); (-1.6, 3.9)\). A distance of 5 kpc was assumed.

The top curve in Fig. 2(b) shows our model spectrum corresponding to the very high state, while the next curve shows the high state.

Approximately 150 days after the peak of the outburst, \(\dot{m}\) drops below \(\dot{m}_{\text{crit}} \approx 0.09\), and at this point the inner regions of the disk evaporate away completely and \(r_{tr}\) begins to increase. This corresponds to the high-low state
transition which was observed in Nova Muscae between 150 and 200 days after the peak. With increasing time, the transition radius continues to move outward until it reaches its quiescent value of \( \log(r_{tr}) = 3.9 \) (determined from the width of the \( H_\alpha \) line in quiescence\(^3\)). At this point the system is in the low state with \( \log \dot{m} \approx -1.1 \) and the X-ray spectrum is a pure power law. At later times, as \( \dot{m} \) decreases further, the system switches to the quiescent state.

Our model light curve of Nova Muscae is shown in Fig. 2 together with the data. For the model we used the scaling: \( \text{Time} = 13 \log(r_{tr}) - 95 \log(\dot{m}/2.51) \) days.

The model satisfactorily reproduces the observed variations in both soft and hard X-rays.

In other work, we find that the high-low transition in Cyg X-1 can be explained through variations in \( r_{tr} \), just as in Nova Muscae.

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