Eclipse Mapping the Flickering Sources In The Dwarf Nova
HT Cassiopeia

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Abstract
We report results of the eclipse mapping analysis of an ensemble of light curves of HT Cas. The fast response of the white dwarf (WD) to the increase in mass transfer rate, the expansion rate of the accretion disc at the same time, and the relative amplitude of the high-frequency flickering indicate that the quiescent disc of HT Cas has high viscosity, $\alpha \approx 0.3 - 0.7$. This is in marked disagreement with the disc-instability model and implies that the outbursts of HT Cas are caused by bursts of enhanced mass-transfer rate from its donor star.

1. Introduction
Flickering is the intrinsic brightness fluctuation of $0.01-1$ mag on timescales of seconds to dozens of minutes that is seen in light curves of T Tau stars, mass-exchanging binaries and active galactic nuclei. It is considered a basic signature of accretion, and may be used to probe the anomalous viscosity that powers accretion discs. Earlier studies [1] led to the suggestion that there are mainly two sources of flickering in Cataclysmic Variables: the stream-disc impact region at disc rim and a turbulent inner disc region in the vicinity of the WD. More recent studies found that low- and high-frequency flickering may arise at different locations and be related to distinct causes [2].

HT Cas is a well-studied 106 min period eclipsing SU UMa type dwarf nova with strong flickering activity, probably arising from close to its WD [1]. Aside of its infrequent outbursts ($V \sim 13$ mag), it shows transitions from a bright state ($V \sim 16.4$ mag) to a faint state ($V \sim 17.7$ mag) on timescales of days to months. This behaviour is reminiscent to that of the VY Scl novalike stars, and is similarly interpreted in terms of a significant change in mass-transfer rate [3].

2. Observations and Data Analysis
Time-series of white-light photometry of HT Cas were collected between 2007 and 2009 with the 1.2 m telescope at the Astronomical Station Kryoneri, in Greece. The data comprise 63 eclipse light curves and frame a 2 d long transition from faint to bright state in 2007 January. The light curves of HT Cas and of a comparison star of similar brightness are shown in Fig. 1. The scatter with respect to the mean level is significantly larger in HT Cas and is caused by a combination of flickering and long-term brightness changes. The scatter is larger for increasing brightness state, indicating that the flickering amplitude varies with mass transfer rate. There is a clear reduction of scatter during the eclipse of the WD.

We applied the 'single' and 'ensemble' methods to the light curves of the bright and intermediate states to derive the orbital dependency of its steady-light, long-term changes, and low- and high-frequency flickering components [2]. In order to derive maps of the accretion disc only, the contribution of the WD was removed from the steady-light light curves before applying the eclipse mapping method.
Fig. 1. Ensemble of light curves of HT Cas. Top: the light curves of a comparison star of similar brightness; the scatter is caused by Poisson noise. Middle: light curves of the bright (black), faint (red) and intermediate transition (green) states. Bottom: light curves of the bright state after subtraction of the average orbital curve. Vertical dashed lines mark the ingress/egress phases of the WD.

3. Results

The rise from the faint to the intermediate state takes 1 d, and from that to the bright state another 1 d. Eclipse maps show enhanced emission along the stream trajectory in the intermediate and bright states (Fig. 2), indicating that the rise in brightness is caused by an increase in mass transfer rate. In response to that, the disc increases in brightness by a factor 3, and the WD at disc center brightens by a factor 2 – probably as a consequence of accretional heating [4]. The newly added disc gas reaches the WD at disc center quickly after mass transfer recovery (∼1 d), implying a disc viscosity parameter $\alpha_{\text{quies}} \approx 0.5$. Furthermore, the disc expands (at $v \approx +0.4 \, \text{km s}^{-1}$) in response to the increased mass transfer rate, also implying $\alpha_{\text{quies}} \approx 0.3 - 0.5$. Both results point to a highly viscous quiescent disc in HT Cas, in marked contrast to the expectations of the disc-instability model ($\alpha_{\text{quies}} \sim 10^{-2}$) [5].

While the increase in mass transfer rate leads to clear gas stream overflow, there is no corresponding increase in the orbital hump modulation (to signal enhanced gas inflow in the bright spot at disc rim). A high viscosity disc has relatively low density and is easily penetrated by an enhanced gas stream flow [6]. In these cases, the common idea that pronounced orbital hump modulation would be expected in response to an increase in mass transfer rate [5] is misleading.

Fig. 3 shows ‘ensemble’ and ‘single’ flickering maps and the corresponding radial
dependency of their relative amplitude. High-frequency ('single') flickering is concentrated in the innermost disc regions, whereas low-frequency ('ensemble' minus 'single') flickering is distributed over a larger region, with enhanced emission from near the circularization radius. The WD does not flicker. If one divides the flickering maps by steady-light maps including the WD the relative flickering amplitude goes to zero at disc center. On the other hand, dividing the flickering maps by the corresponding disc-only steady-light maps reveals that the flickering amplitude increases sharply towards disc center. The ensemble flickering amplitude reaches $\sim 40\%$ near disc center. The low-frequency flickering at $R \sim R_{\text{circ}}$ may be related to the mass-transfer process (unsteady gas inflow or turbulence/shocks generated at the impact of infalling matter with disc gas $^{[1]}$).

Assuming that the inner disc flickering is caused by fluctuations in energy dissipation rate induced by MHD turbulence $^{[7]}$, its relative amplitude yields a direct measurement of the disc viscosity parameter and its radial dependency. We find $\alpha(r) \approx 0.7 \left[ r/(0.1 R_{L1}) \right]^{-2} \left[ 52 H/r \right]^{-1}$, in agreement with our previous estimates.
Fig. 3. Left: ensemble and single data (green dots) and model light curves. Center: eclipse maps in a logarithmic grayscale. The notation is similar to that of Fig. 3. The scalebar depicts the log(intensity) scale. Right: Relative amplitude of the flickering as a function of radius (in units of RL1, the distance from WD to the inner Lagrangian point), derived by dividing each flickering map by the steady-light map of the corresponding brightness state. Dotted lines show the 1-σ limit on the amplitude, and a vertical dashed line indicate the circularization radius.

4. Conclusions
The fast response of the WD to the increase in mass transfer rate and the expansion rate of the disc from the faint to the bright quiescent states imply a highly viscous disc in HT Cas, $\alpha_{\text{quies}} \simeq 0.3 - 0.5$, in disagreement with predictions of the disc-instability model. High-frequency flickering arises from the inner disc regions and seems connected to turbulence in the disc itself. The low-frequency flickering shows a more extended distribution, with a ring of emission near the circularization radius. Both components rise sharply towards disc center. If inner disc flickering is caused by MHD turbulence, the disc viscosity decreases with radius as $\alpha(r) \propto r^{-2}$.

References
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