Super-soft X-ray spectral evolution in novae

University of Leicester

K.L. Page & J.P. Osborne (on behalf of the Swift Nova-CV group)

http://www.swift.ac.uk/nova-cv

Swift has performed intensive monitoring of a number of novae as they pass through their super-soft X-ray phase. While Chandra and XMM-Newton can provide high-resolution grating spectra, important for identifying individual emission and absorption features and placing constraints on abundances, few observations are obtained with these instruments, thus providing only rare snapshots of the super-soft spectral evolution. With Swift, however, we can perform daily (if not hourly) monitoring, allowing us to follow the entirety of the super-soft phase in great detail. Spectral evolution is clear, often even when simply comparing the unfitted spectra. Here, we fit stellar atmosphere models to the X-ray spectra of some of the densely-observed Swift novae, investigating the evolution of temperature, emitting radius and X-ray luminosity throughout their super-soft phases.

Towards the end of their outburst, novae are predicted to go through a super-soft source phase, when the ejected material has become optically thin and the surface nuclear burning, with emission peaking in the soft X-ray band, becomes visible. During this time, it has been theorised that the nuclear burning would continue at constant bolometric luminosity, depleting the envelope mass; the effective radius of the photosphere contracts and the corresponding photospheric temperature rises (MacDonald et al. 1985). Fig. 1 shows a sample of X-ray spectra extracted for RS Oph (Osborne et al. 2011), revealing clear spectral changes which are supported by high-resolution grating spectra (e.g. Ness et al. 2007). Variations such as these motivated the fitting of the spectra obtained throughout the super-soft phase with stellar atmosphere models, such as the NLTE TMAP grids produced by Rauch et al.[1] which allow the estimation of temperature, effective radius and luminosity.

[1]http://astro.uni-tuebingen.de/~rauch/TMAF/flux_HHeCNONeMgSiS_gen.html

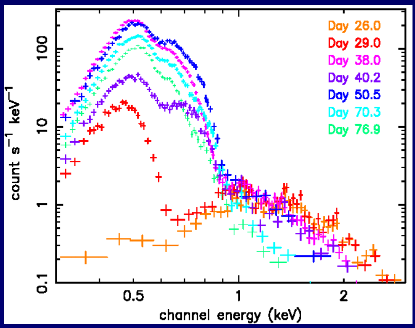

Fig. 1. Comparison of spectra during the outburst of RS Oph.

Fig. 2 Fits to the SSS phases. Magenta arrows indicate the times of grating observations obtained by XMM-Newton or Chandra.

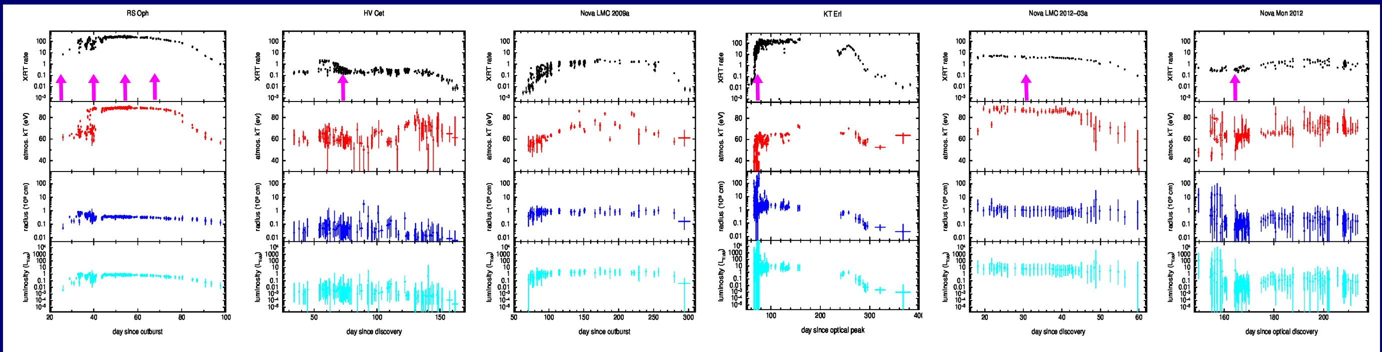

Table 1. Approximate distances and atmosphere grids[1] used.

Nova	Date of (last) outburst/ discovery	Distance (kpc)	Atmos. grid
RS Oph	2006-02-12	1.6	003
HV Cet	2008-10-07	48	003
LMC 2009a	2009-02-05	2.5 (est.)	011
KT Eri	2009-11-14	6.5	003
LMC 2012	2012-03-26	48	011
Mon 2012	2012-08-09	3.6	003

Results

Fig. 2 shows the time intervals over which super-soft X-ray emission dominates for a number of well-observed novae: the X-ray count rate (over 0.3-10 keV; most counts below ~ 1keV), fitted atmosphere temperature and effective radius and the inferred bolometric luminosity (normalised to the Eddington Luminosity for a 1 M_{Sun} star) are plotted. The vertical axis scales for the panels are the same for each nova. The light-curves show a range of behaviours, but all reveal at least some variability at the start of the SSS phase; this is discussed by Osborne et al. (2011) for RS Oph. All novae for which the end of the super-soft phase has been observed show a decline in temperature towards the end of the SSS phase, with this being most prominent for RS Oph and Nova LMC 2012-03a; the SSS emission is still ongoing in Nova Mon 2012. In the case of Nova LMC 2009a, a preceding temperature rise is also seen. With the exception of the under-luminous HV Cet (Beardmore et al. 2011), the luminosities during the bulk of the SSS phase appear to be close to the Eddington value. RS Oph and KT Eri show strong evidence for photospheric radial shrinkage, while the evidence is weaker in the other novae presented.

We have presented evidence of systematic spectral evolution in the super-soft X-ray spectra of novae. They tend to show roughly Eddington luminosities and, as the SSS fades (as expected), cooling and shrinkage of the effective radius. Considering this cooling and the corresponding decrease in energy for the RS Oph dataset, a heat capacity of ~5 x 10^{37} erg K^{-1} is inferred, consistent with the cooling of a ~ 10^{-4} M_{Sun} surface layer on the white dwarf.

References:
Beardmore et al., 2011, A&A, 545, A116; MacDonald et al., 1985, ApJ, 294, 263; Ness et al., 2007, ApJ, 665, 1334; Osborne et al., 2011, ApJ, 727, 124