ISO OBSERVATIONS OF V723 CAS AND OTHER CLASSICAL NOVAE IN OUTBURST

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ABSTRACT

The ISO mission gave us a unique opportunity to follow the evolution of nova eruptions in detail in the infrared, and there was an active ISO target-of-opportunity programme to observe novae in eruption. Many of the ISO observations were near-simultaneous with ground-based observations, giving wavelength coverage over 100 octaves – another unique feature of this programme. This paper gives an overview of these observations and describes target-of-opportunity observations of the nova V723 Cas (1995), carried out with the SWS and LWS over a period of some 600 days.

Key words: classical novae; circumstellar material; coronal lines

1. INTRODUCTION

Classical nova eruptions occur in semi-detached binary systems containing a white dwarf and a main sequence dwarf. A thermonuclear runaway (TNR) occurs on the surface of the white dwarf and as a result, some $10^{-4}\,M_\odot$ of material, enriched in metals as a consequence of the TNR, is ejected at $\sim 10^3\,\mathrm{km\,s^{-1}}$. A nova eruption goes through an initial optically thick phase, followed by a free-free phase, a dust-formation phase, a nebular phase and a coronal phase; however not all novae produce dust, and not all novae go through a coronal phase (see Gehrz et al. 1998 for a recent review)

This paper presents an overview of the ISO nova target-of-opportunity (ToO) programme, and describes in some detail the IR evolution of nova V723 Cas (1995).

2. THE ISO NOVA ToO PROGRAMME

The Nova ToO programme was co-ordinated by M. Barlow, R. Gehrz and A. Salama; an overview of the programme, in terms of novae observed and the times since outburst of the nova observations, are given in Fig. 1. In general the observations consisted of full grating scans using AOT SWS-01 and LWS-01, with selected lines being observed in more detail with AOT SWS-02. In many cases ISO observations were accompanied by near-simultaneous ground-based observations in the optical or infrared.

Fig. 1 shows the novae observed. The energetics of a nova are well-described by the *speed class* (see Salama et al. these proceedings), and the novae listed in Fig. 1 cover a range of speed classes, from the very slow V723 Cas to the fast Nova Cru 1996. Nova Sgr 1998 was observed by ISO for the first time just before He depletion, otherwise the time coverage ranges from $\simeq$ 100 days (Sgr 96) to $\simeq$ 600 days for Cas 95.

3. NOVA V723 CAS

3.1. The visual light curve

Nova V723 Cas was discovered on 1995 August 24.5 (IAUC6213); Iijima & Rosino (IAUC6214) observed P-Cyg absorptions with blueshifts in the range −280 to $-400\,\mathrm{km\,s^{-1}}$. The visual light curve of V723 Cas (see Fig. 2) is extremely erratic, typical of a very slow nova. In particular it displays several 'flares', possibly a result of the interaction of ejecta having different velocities. Munari et al. (1996) and Chochol & Pribulla (1997) report large changes (Δmag $\simeq -0.7$) in the $(U-B)$ colour at the time of the first flare.

We base the speed class of V723 Cas on the decline of the visual light curve over the first 1000 days

Proceedings of the Conference "The Universe as seen by ISO", Paris, France, 20–23 October 1998 (ESA SP-427, March 1999)

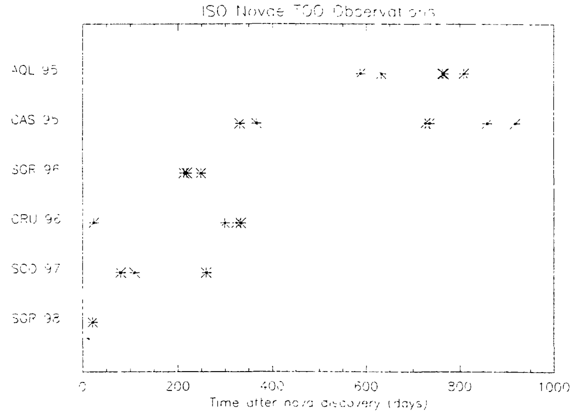

Figure 1. Overview of ISO nova observations. Note that, as novae evolve at different rates, the actual evolutionary phases observed differ from nova to nova.

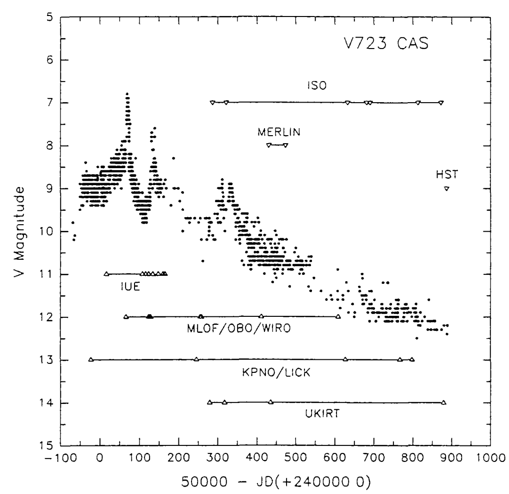

Figure 2. Visual light curve of V723 Cas, from observations posted on VSNET. Note the 'flares' in the visual lightcurve. Times of IUE, HST and selected ground-based observations are also shown.

(see Fig. 2). The time to decline from visual maximum by 3 magnitudes, t_3, is $\simeq$ 900 days (the value $t_3 \simeq 180$ days given by Chochol & Pribulla (1998) was based on a much shorter timebase). On the basis of the relationship between t_3 and white dwarf mass (e.g. Livio 1992), we infer that the mass of the white dwarf in the V723 Cas system is $\simeq 0.7\,M_\odot$. The reddening to the nova has been determined by Gonzalez-Riestra et al. (IAUC6295), on the basis of the strength of the interstellar '2200' extinction feature, to be $E(B-V) = 0.6$. The distance to the nova follows from the speed class (which determines the absolute visual magnitude at maximum) and the reddening; the distance for V723 Cas is 3.3 kpc.

Table 1. V723 Cas 1995 ISO Observation Log

TDT nr.	AOT	Obs. dur. (min)	Start Time (UT)		Reduced Julian Date
24800901	S01	109	22 Jul 1996	03 40 25	50286.7
24800902	L01	33	22 Jul 1996	05 30 07	50286.7
24800903	L01	33	22 Jul 1996	06 04 01	50286.8
28301904	S01	109	26 Aug 1996	01 53 05	50321.6
28301905	L01	33	26 Aug 1996	03 42 45	50321.7
59502003	S01	58	03 Jul 1997	11 38 47	50633.0
64500309	S01	58	21 Aug 1997	21 22 49	50682.4
64500310	L01	30	21 Aug 1997	22 21 05	50682.4
65400106	S01	58	30 Aug 1997	19 44 23	50691.3
77700106	S01	58	31 Dec 1997	11 55 42	50814.0
77700208	S02	52	31 Dec 1997	12 54 00	50814.0
83701909	S01	58	01 Mar 1998	18 30 05	50874.3

3.2. ISO, IUE and ground-based observations

An overview of most of our observations of nova V723 Cas is shown in Fig. 2. Over the period 63 to 211 days since outburst, nova V723 Cas was observed by IUE. Its spectrum was still dominated by absorption features. The nova was still in its optically thick, or "iron curtain" phase. Ground-based coverage in the near-IR was obtained from a variety of facilities including (spectroscopy) UKIRT, KPNO, and the Lick Observatory, and (photometry) MLOF, OBO, and WIRO. Until around 300 days after outburst, only recombination lines of H, He, N, S, O were detected. UKIRT-CGS4 observations showed for some He lines marked P-Cyg profiles, with terminal velocity of $\approx 1700\,\mathrm{km\,s^{-1}}$. Lines were generally double-peaked, with separation and FWHM of about $300\,\mathrm{km\,s^{-1}}$.

The ISO observation log is listed in Table 1, while the evolution of a selected part of the spectral coverage obtained with ISO (2.38 – 4.08 μm) is shown in Fig. 2. Fortuitously some of our observations coincided with some of the major flares in the visual light curve (see Fig. 2). Significant change in the line profiles were seen at that time (see 3.4 below). About 480 days after outburst, the first coronal line was detected during a dedicated observing run with the UKIRT-CSG4 spectrometer, the [Ca IV] line at 3.2 μm. The nova was leaving the optically thick phase. About six months later, further ISO observations were carried out. The same Ca line was again detected, together with the [Al V] λ2.9 line. The [Ca IV] λ3.2 flux seemed to follow the optical brightness variations that occurred during optical flaring. About four months later, coronal emission of Al, Ca and Si was seen with further KPNO and ISO observations: the nova had entered the coronal phase.

3.3. The ejected mass

We can estimate the ejected mass by following the evolution of Br-α (see Fig.2), which declines from an integrated (dereddened) flux of $11.9 \times 10^{-15}\,\mathrm{W\,m^{-2}}$ on day 283 to $2.1 \times 10^{-15}\,\mathrm{W\,m^{-2}}$ on day 827. The integrated flux declines with time as t^{-2}, consistent with the free expansion of a thin shell of constant

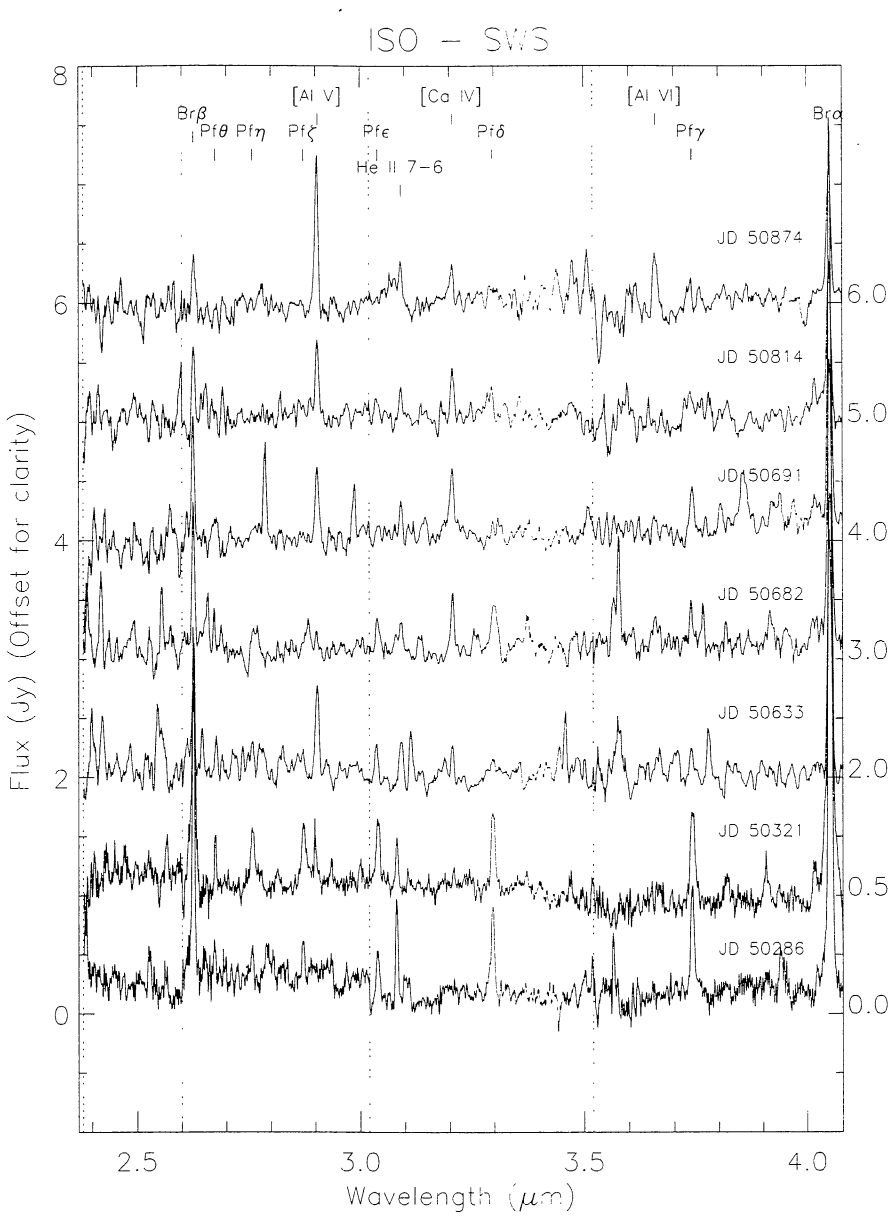

Figure 3. Evolution of the 2.4 – 4 μm spectrum of V723 Cas as seen by ISO-SWS over a $\sim$ 600 *day period. Principal emission lines are identified. Spectra are shifted for clarity, from the first one at the bottom, by the amount given (in Jy) at the right hand of the figure. The times of each observation are indicated, in terms of the reduced julian date.*

thickness. Assuming that Br-α is optically thin, the mass of H is

$$M_{\rm H}/\,{\rm M}_\odot \;=\; 0.314\; f_{15} n_{\rm e}^{-1} D{\rm kpc}^2 \qquad (1)$$
$$\simeq\; 8.2\times 10^{-5}\, D_{3.3} \qquad (2)$$

where f_{15} is the Brα flux in units of 10^{-15} W n^{-2} and $D_{3.3}$ is the distance in units of 3.3 kpc. The ejected mass is therefore $\sim 8.2\times10^{-5}\,\mu\,D_{3.3}\,{\rm M}_\odot$, where μ is the mean atomic mass per electron. With overabundances in the CNO elements as a result of the TNR, we might expect $\mu \simeq 1.5$.

3.4. Changes in line profiles

In general the emission line profiles can be described by double-gaussians, with an overall width associated with expansion velocities around 300 $km\,s^{-1}$. At the time of the light curve flares, however, there were significant changes in the profiles (see Fig. 4).

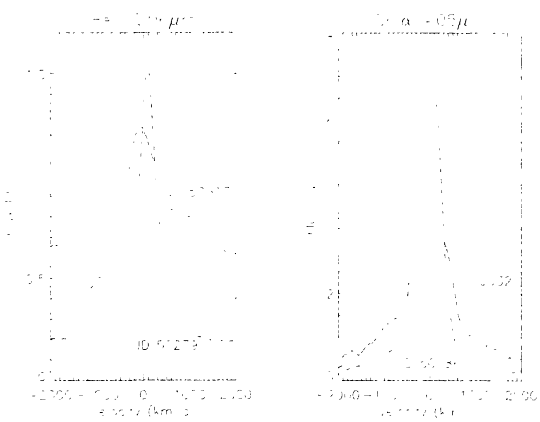

Figure 4. Change in line profile for quasi-simultaneous observations taken with UKIRT-CGS4 (left) and ISO-SWS (right) on a He I line and a H I line respectively during an optical flare. The flare in the optical light curve occurred on ~ JD...320; the observations on ~ JD...280 were carried out when the light curve was 'normal'. Note the line profile broadening, indicative of mass ejection at velocities of the order of 1000 $km\,s^{-1}$.

CONCLUSIONS

During the lifetime of ISO, six novae in outburst have been observed by the dedicated Target-Of-Opportunity team, covering a range of speed classes and evolutionary states, with ISO and ground-based facilities. In this paper we have presented some of the observations carried on nova V723 Cas, over a period of about 600 days. The nova was seen to be a very "slow" one and the implied mass of the white dwarf is close to the critical mass for the nova outburst to occur. The nova was observed during both the optically thick and coronal phases. The flares in its optical light curve were accompanied by changes in line profiles and intensity; this may indicate enhanced velocity fields in a scenario of continuous mass ejection with an accelerating wind. We are currently modelling the obtained line database coverage with the photoionization code CLOUDY (Ferland 1998). Current runs can account for the observed Ca flux, assuming an overabundance of 20 times over solar.

ACKNOWLEDGMENTS

We thank R. J. Rudy (Aerospace Corporation/ Lick Observatory) for assistance in obtaining ground-based IR data and R. Gonzalez-Riestra for providing details of the IUE observations of nova V723 Cas.

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