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Studies of the peculiar nova V4332 Sgr

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Abstract. We discuss our recent observations of the interesting but enigmatic nova-like variable V4332 Sgr. The object shows a remarkably rich near-infrared and optical spectrum with several unusual spectral features generally not seen in classical novae. Our results support the emerging consensus that V4332 Sgr, and its possible analog V838 Mon, constitute a new class of eruptive variables. Our results indicate that a cold circumstellar disc containing gas, dust and water ice surrounds the object. Though the cause of the outburst in these objects is not completely understood, we propose a plausible planetary-capture scenario to explain the eruption of V4332 Sgr.

Keywords : V4332 Sgr, novae, Infra-red spectroscopy, CO, AlO, water ice

1. Introduction

There has been considerable interest recently in the outbursts of two interesting nova-like variables V4332 Sgr and V838 Mon. V4332 Sgr erupted in 1994 with an outburst amplitude of ~ 9.5 magnitude in the visible region. In the detailed study done by Martini et al., (1999) during its outburst, it was shown that V4332 Sgr did not conform to known categories of eruptive variables like classical novae, symbiotic novae or born-again AGB stars. V4332 Sgr showed a rapid cooling over three months (from 4400 to 2300K) and evolved into a cool M giant/supergiant. In stark contrast, the ejecta from classical nova generally evolves to the coronal stage with high ionization lines corresponding to a typical temperature of a million degrees Kelvin. A similar temporal and spectral behaviour as V4332 Sgr has also been observed in the recent outburst of the nova-like variable V838 Monocerotis (Munari et al., 2002) which erupted in January 2002. Since then V838 Mon has generated considerable interest primarily because of the spectacular, expanding light-echo seen around the object (Henden et al., 2002 for the initial detection of the light-echo;

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Bond et al., 2003 for striking HST images of it; Crause et al., 2005 for a mosaic showing the expansion in the different BVRI bands). A consensus appears to be emerging that V838 Mon and V4332 Sgr - along with another similar object M31 RV (Rich et al., 1989) which erupted in M31 in 1988 - could belong to a new class of eruptive variables (Munari et al., 2002; Kimeswenger et al., 2002; Bond et al, 2003). However the cause of the explosion in V838 Mon-type of objects is still poorly understood. New mechanisms are being proposed. Soker and Tylenda (2003) explain the eruption as a merger event between two main-sequence stars, with the release of gravitational energy as the source of the nova-like outburst. Retter and Marom (2003) propose that the outburst is caused by an expanding star engulfing its planets. These mechanisms are in distinct contrast to a classical nova outburst wherein a thermo-nuclear runaway (TNR) on the surface of a white dwarf - in a binary system - leads to the nova eruption. The TNR occurs in the matter accreted by the white dwarf from its Roche-lobe filling secondary companion.

We present some of our recent results on V4332 Sgr here and discuss some of the inferences that can be drawn on the circumstellar environment of the object and also the possible cause of its eruption. Spectroscopic and photometric observations of V4332 Sgr, which were begun in 2003 and are continuing till today, were mostly done using the 3.8m UK Infrared Telescope, Hawaii. The details of these observations are not presented here but can be found in the published references cited in the next section. A detailed near-IR study of V838 Mon, based on observations between end of 2002 to beginning of 2005 from the 1.2 meter Mt. Abu telescope, is in preparation. This work will address, among other aspects, the evolution of the first and second overtone CO bands seen prominently in V838 Mon; several AlO bands and also the presence of water in V838 Mon. The initial near-IR results on V838 Mon from Mt. Abu observations inearly 2002 (i.e. soon after its outburst) are described in Banerjee and Ashok (2002).

2. Results

Several interesting results, some of them rare detections, have been found by us in V4332 Sgr. These are (i) the detection of several bands of the AlO radical in emission in the 1.0-2.5 micron region (Fig. 1). Many of these AlO molecular features, arising from the A-X band system, are first detections (Banerjee et al., 2003). The only other object in which similar AlO bands have been found is V838 Mon thereby showing another spectral similarity between these objects. A detailed modeling of the AlO bands indicates a low rotational temperature of 200-300K. (ii) The presence of the AlO bands paved the way to search for radioactive ^{26}Al - an isotope of great interest to γ-ray astronomers - which is expected to be synthesized in a nova explosion (Banerjee et al., 2004a). However, we did not find any significant trace of ^{26}Al in V4332 Sgr but could set a limit to the ^{26}Al/^{27}Al ratio in V4332 Sgr to be less than 0.1 (iii) The detection of unusually strong emission in the resonance lines of KI and NaI (Fig. 2) in the optical spectrum (Banerjee and Ashok, 2004).

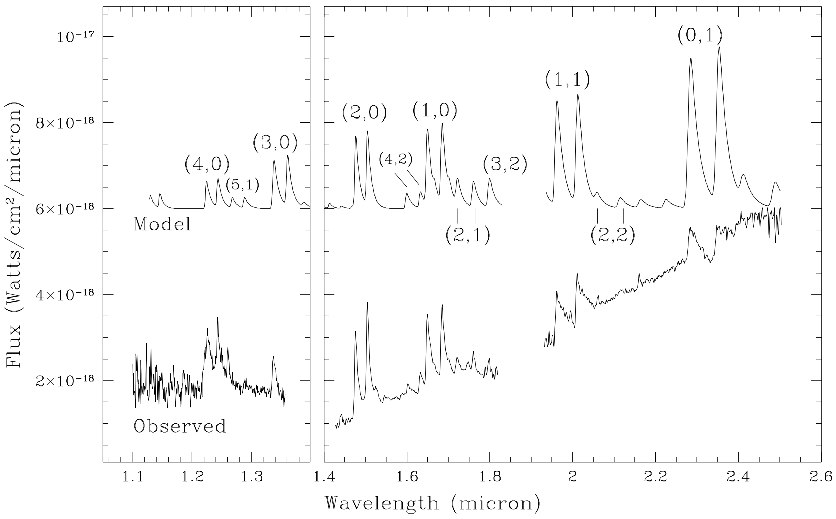

Figure 1. The A-X bands of AlO in V4332 Sgr in the near-infared JHK bands in early 2003 (From Banerjee et al. 2003)

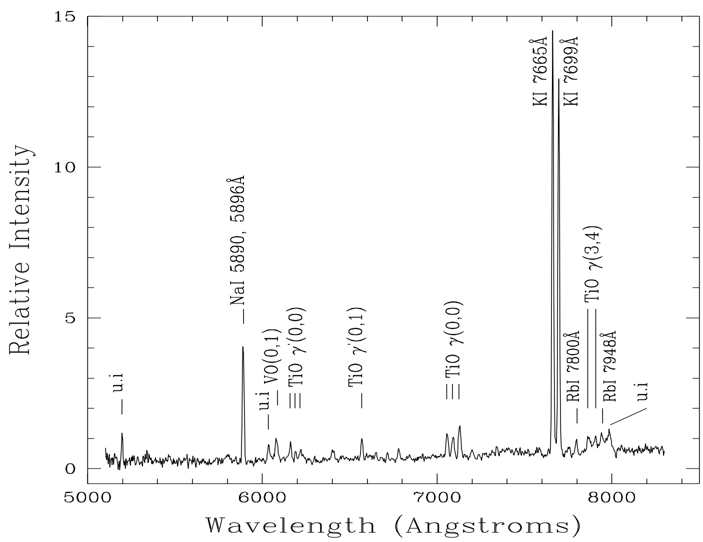

Figure 2. The optical spectrum of V4332 Sgr in September 2003 from the Himalaya Chandra Telescope, Hanle (From Banerjee and Ashok, 2004)

The optical spectrum also shows several other molecular lines in emission from species as TiO, VO and ScO (Banerjee and Ashok, 2004; Tylenda et al., 2004). The presence of molecular lines in the optical spectrum indicates low environmental temperatures.

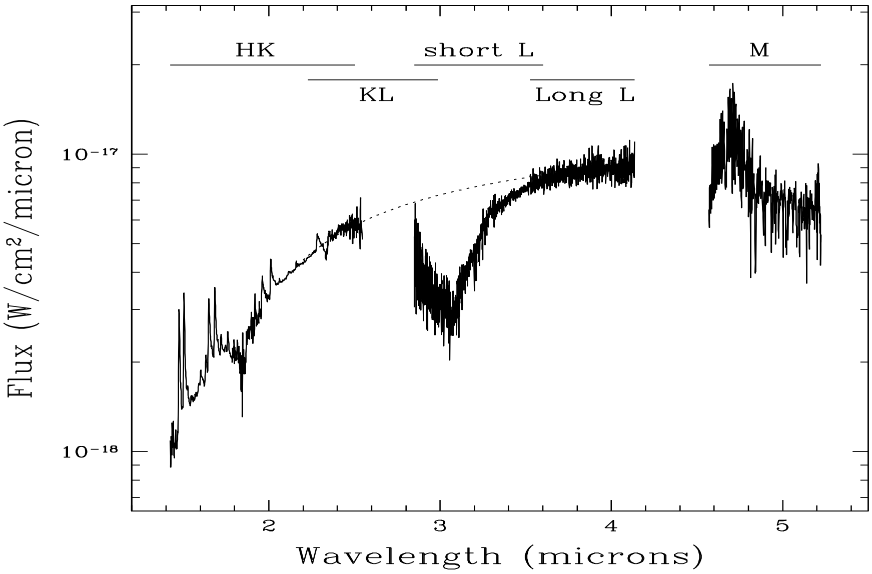

Figure 3. The near-IR spectrum of V4332 Sgr is shown by bold line. The extent of the individual spectra - used to obtain the composite spectrum - are marked with straight lines on top. The deep absorption feature at 3.05 μm due to water ice may be seen. A continuum fit between 2.2 and 4.13 μm to obtain the optical depth of the 3.05 μm ice feature is shown by a dotted line. The gaps in the spectra at 2.65 and 4.4 μm are due to lack of atmospheric transmission in these regions. The considerable IR excess due to dust, peaking at $\sim$ 4.5μm, is also evident (Observations from UKIRT; From Banerjee et al., 2004b)

The atomic lines of KI and NaI also indicate low excitation conditions in case they are collisionally excited since the excitation energies for these lines are in the range of 1.5 to 2 eV (iv) The intriguing detection of a deep 3.05μm water-ice feature (Fig. 3) which has not been detected earlier in any nova (Banerjee et al., 2004b). Modeling of the 3.05μm feature yields a temperature of 30-50K (v) Emission in the ^{12}CO fundamental band at 4.67 microns - very rarely seen in a nova and perhaps never with the rovibrational lines so clearly resolved as detected here (Fig 4) (Banerjee et al., 2004b). Based on modeling of the CO bands, a rotational temperature in the range of 300-400K is implied.

These results allow two important conclusions, apart from other inferences, to be drawn on the nature of V4332 Sgr. First, the low temperatures detected in V4332 Sgr - strikingly at odds with that expected in classical novae ejecta - validate that V4332 Sgr is a new kind of object. Second, the observations strongly support the presence of a circumstellar disc (CSD) around the object (Banerjee et al., 2004b). Such a disc geometry is possibly the only viable one in which different facets of the observed data can be consistently explained in totality viz. the simultaneous detection in V4332 Sgr of i) the central star's light to be seen in unobscured manner (the central star's SED is

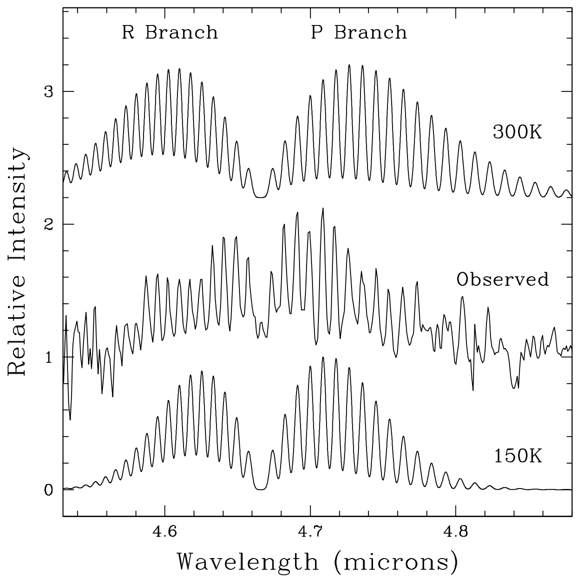

Figure 4. Model and observed plots for the ^{12}CO fundamental emission in V4332 Sgr. Though the S/N of the spectrum is slightly inadequate, the relative strengths of the rotational lines of the R and P branches are better reproduced by the 300K model than the 150K model. This is specially so for the higher R and P branch lines which become weak for the 150K model fit. (From Banerjee et al. 2004b; UKIRT observations)

well fit by a blackbody at 3250K i.e. M5 type star) (ii) a strong IR excess from dust emission which is seen (see Fig 3) but which nevertheless does not obscure the central star's visible light and (iii) the spectral lines of all species (KI, NaI, TiO, AlO, CO) being in emission rather than in absorption. (iv) the deep ice feature with a measured optical depth of 1 is expected to create an extinction of 14-15 mags. in the central star's light had it been along the line-of-sight (Whittet, 1992). In a disc geometry such extinction could be avoided.

Such CSDs containing ice, dust and gas (with spectral lines associated with the gas being in emission) are typically seen around young objects like T-Tauri stars, YSOs and Herbig AeBe stars. It would therefore appear that V4332 Sgr is a young object. The reason for a nova-like explosion to occur in a M type star surrounded by a CSD is unclear. Since conventional mechanisms fail to explain the outburst, we seriously considered whether a planetary capture could have caused the outburst in V4332 Sgr. It is believed that planet formation begins in such CSDs from the coagulation and accretion of ice, gas and dust particles (Lissauer, 1993) to form planetesimals leading thereafter to planetary formation. Thus it is likely, that the ingestion of a planet could be responsible for the 1994 outburst of V4332 Sgr. It may be noted that a similar mechanism has already been suggested for the eruption of V838 Mon (Retter and Marom, 2003). The capture of a planet by its host star is being given serious consideration today in view of the large number of stars (more than 100) known to have planets. Many of these exo-planets, mostly Jupiter-sized, are at incredibly close distances (less than 0.05 A.U) to the host star leading to investigations about the stability of their orbits. There are other considerations too, related to the enhanced metallicity seen in stars-hosting-planets, which support the possibility of such stars having ingested planets in the past.

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