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The Red Rectangle: Solid State Components of Varying Composition in the Outflow

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Abstract. We report the discovery of broad mid-infrared resonances in the outer regions of the Red Rectangle outflow (Markwick-Kemper *et al.* 2005). The peak position and the strength of the resonances vary spatially, but the full width at half maximum, as well as the shape of the feature, appears remarkably constant. While emission due to polycyclic aromatic hydrocarbons (PAHs) is also present at these locations, we show that PAHs cannot be the carriers of these new components. Instead, we argue that these resonances are caused by solid state components, perhaps simple Mg-Fe-oxides. The presence of such O-rich species in the otherwise C-rich outflows further complicates the picture of the formation and chemistry of the Red Rectangle nebula.

Keywords. infrared: stars — ISM: dust, extinction — ISM: individual (HD 44179; Red Rectangle) — stars: AGB and post-AGB — stars: circumstellar matter

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The Red Rectangle is a relatively nearby system (estimates range from 300–700 pc), consisting of a post-AGB star HD 44179 with a circumstellar disk and a biconical outflow. The disk is seen almost exactly edge-on, providing superb conditions to study the emission from the outflows. The system shows a remarkable chemistry. Besides the so-called Extended Red Emission (Schmidt *et al.* 1980), for which the carrier is still unknown, there are emission features related to diffuse interstellar bands (Scarrott *et al.* 1992), and a wealth of PAHs detected in the outflow (Bregman *et al.* 1993). In contrast, the circumstellar disk contains predominantly oxygen-rich silicate dust (Waters *et al.* 1998). Optical imaging obtained with the Hubble Space telescope reveals that the biconical outflow shows a large amount of substructure, tracing variations in the physical conditions (Cohen *et al.* 2004). The question arises whether these variations in the physical conditions give rise to differences in the chemical composition of the outflows.

We have obtained infrared spectroscopy from 10–19.5 μm at a resolution of $R \sim 600$ using Infrared Spectrograph (IRS) aboard Spitzer. We looked at three different pointings, about 30″ away from the central star, in the northern outflow. The high-resolution slits are 5 pixels long, while the point spread function is ∼2–3 pixels wide. We have performed sub-slit extractions with a width of three pixels. Figure 1 shows spectra obtained at pointings inside and outside the biconical shape of the outflow. Besides the PAHs emission around 11 μm, there are two very strong features present at $\lambda > 13$ μm: one at 13–16 μm and one longwards of 17 μm. The peak position and the relative strength vary spatially, while the FWHM and the shape remain remarkably constant.

We rule out that the feature is due to PAHs (Markwick-Kemper *et al.* 2005). Instead, we argue that it is due to a solid state carrier. A possible explanation of the $\lambda > 17$ μm features could be provided by simple Mg-Fe-oxides. Figure 1 shows the comparison with laboratory spectroscopy (Henning *et al.* 1995). The change in peak position could be

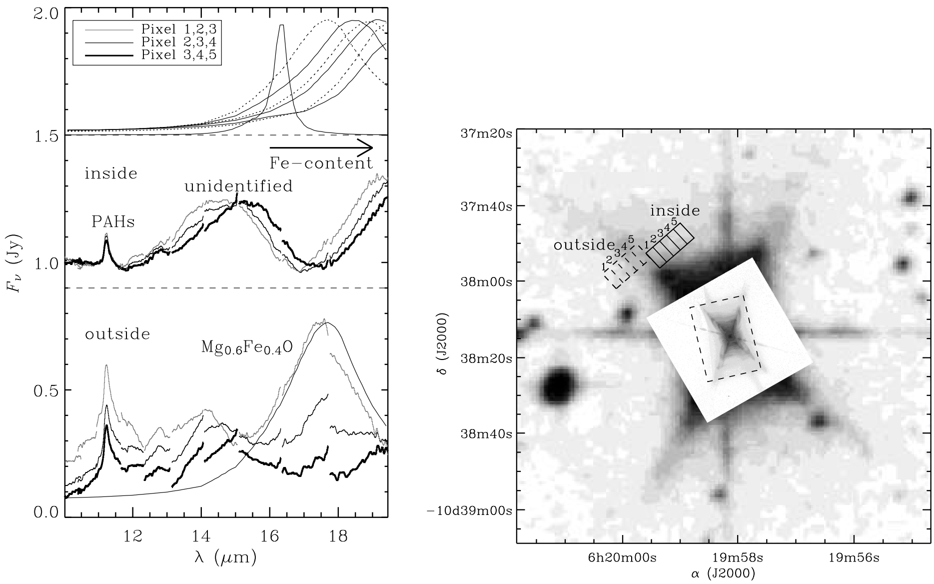

Figure 1. *Left:* IRS high resolution spectra (bottom two panels) compared with the laboratory spectroscopy of simple oxides of varying composition (top panel). The map on the *right* shows the slit and pixel positions of these observations.

explained with a change in composition. The features at 13–16 μm remain unidentified, but we are looking into mixtures of the simple oxides with either spinels or silicates.

The presence of oxides in the C-rich outflow of the Red Rectangle paints a complex picture of circumstellar chemistry, as does the suggested presence of PAHs in the disk (Vijh *et al.* 2005). The origin of the O-rich species in the outflow is unclear. It could be a relic from earlier mass loss, or it could be caused by stellar wind erosion of the circumstellar O-rich disk. Moreover, the varying composition is yet to be explained.

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Discussion

Bowey: Have you considered temperature shifts for the origin of the finer detail changes in the 14–16 μm feature positions between slit pointings?

Markwick-Kemper: Yes, we have. Besides composition, such effects as temperature changes and grain properties affect the spectral appearance. However, temperature specific optical properties are not yet available for the oxides.

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