The Evolving ISM in the Milky Way & Nearby Galaxies

Spitzer Observations of Supernova Remnant IC443

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ABSTRACT

We present Spitzer observations of IC 443 obtained with MIPS and IRS as part of our GTO program on the astrophysics of ejecta from evolved stars. We find that the overall morphology at mid/far IR wavelengths resembles even more closely a loop or a shell than the ground based optical and/or near IR images.The dust temperature map, based on the 70/160μm ratio, shows a range from 18 to 30 K degrees. The IRS spectra confirm the findings from previous near+mid IR spectroscopic observations of a collisionally excited gas, atomic and molecular, rich in fine structure atomic and pure H_2 rotational emission lines, respectively. The spectroscopic shock indicator, [Ne II] 12.8μm, suggests shock velocities ranging from 60-90 km s^{-1}, consistent with the values derived from other indicators.

Subject headings: infrared: ISM — ISM: individual (IC 443) — supernova remnants

1. Introduction

As one of the best examples of a supernova remnant (SNR) interacting with a molecular cloud IC 443 has been studied over all possible wavelength ranges, from the radio (see e.g. Leahy 2004), through the sub-mm (van Dishoeck et al. 1993) to the X-rays (see e.g. Troja et al. 2006, 2008), including TEV γ emission that is thought to be associated with pulsars

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(Albert et al. 2007; Humesky et al. 2007). At an estimated distance of 1.5 Kpc (Welsh & Sallmen 2003), IC 443 covers approximately a square degree over the sky. Until recently because of its relatively large size, most of IC 443 imaging data was a by-product of large sky surveys (IRAS, 2MASS, ROSAT, MSX, etc), and to this date the spectroscopic data only samples a handful of specific regions. The spectroscopic data, nevertheless, do confirm that the emission arising from IC 443 carries the signature of collisionally excited (atomic & molecular) gas, the result of a shock wave impinging on a nearby molecular cloud. (see e.g. Shull et al 1982; Graham et al. 1987, Burton 1987, van Dishoeck et al. 1993; Cesarsky et al. 1999, Oliva et al. 1999; Rho et al. 2001, Neufeld et al. 2007, Rosado et al. 2007, among others). Thus IC 443 continues to provide a excellent laboratory to study the evolution and interaction of a SNR with its surrounding medium.

In this communication we present the images obtained with the far infrared (FIR) photometer MIPS (Rieke et al. 2004), complemented with mid infrared (MIR) spectroscopy data obtained with IRS (Houck et al. 2004), both instruments on board of the Spitzer Space Telescope (Werner et al. 2004).

2. Observations

The MIPS & IRS observations are part of our GTO program (Rieke PID 77 and Houck PID 18) to study the physical characteristics of the ejecta from evolved stars. Although the observations were taken very early in the Spitzer mission, we have learned a handful of new things on data reduction as to provide the best possible images and spectra. The MIPS observations were obtained at three different epochs using fast scan mapping (3 sec per frame, 5 pointings per pixel), with scan legs offset of 148" to sample completely the 70 and 160um arrays. One of the remarkable features of the MIPS instrument is its capability to map large areas of the sky in a very efficient way, and therefore the new MIPS images at 24, 70 & 160μm capture the SNR in its entirety (Fig. 1). The IRS observations were carried out using both short and long high resolution modules at 5 fixed cluster positions (including an off-position) using 6 and 14sec ramps (one cycle), respectively. The off-position was used to remove the background from the on-target spectra.

3. Preliminary Analysis and Summary

The morphology of the IC 443 is shown in superb detail in the high angular resolution MIPS images (standard beam sizes of $6''$, $18''$ and $40''$ at 24, 70 & 160μm respectively).

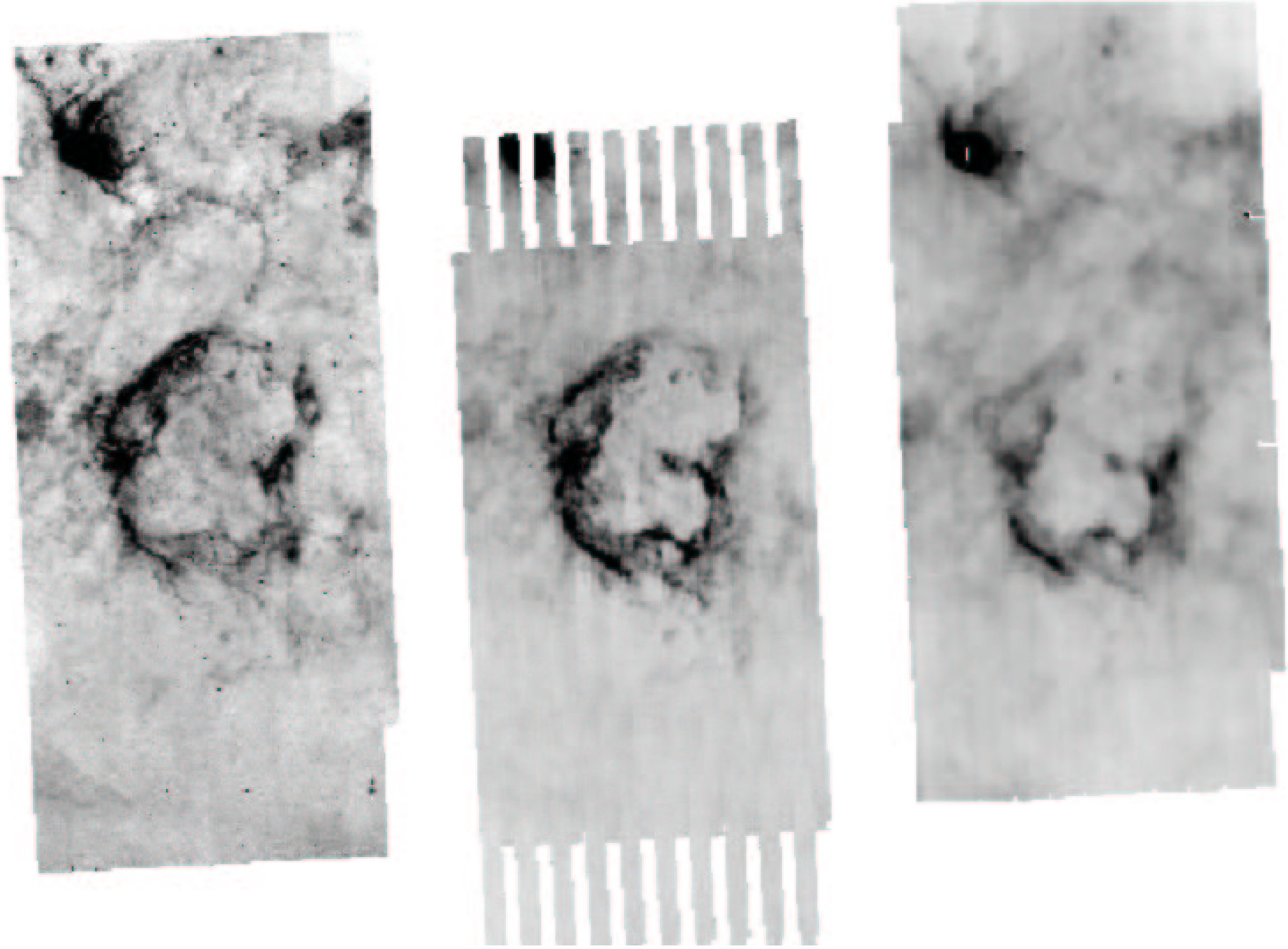

Fig. 1.— From left to right: MIPS maps of IC 443 at 24, 70 & 160μm. FOV$\sim$0.9°×1.9°. The bright source at the top of the image is IC 444 or IRAS 0655+2319. North is up and East is left

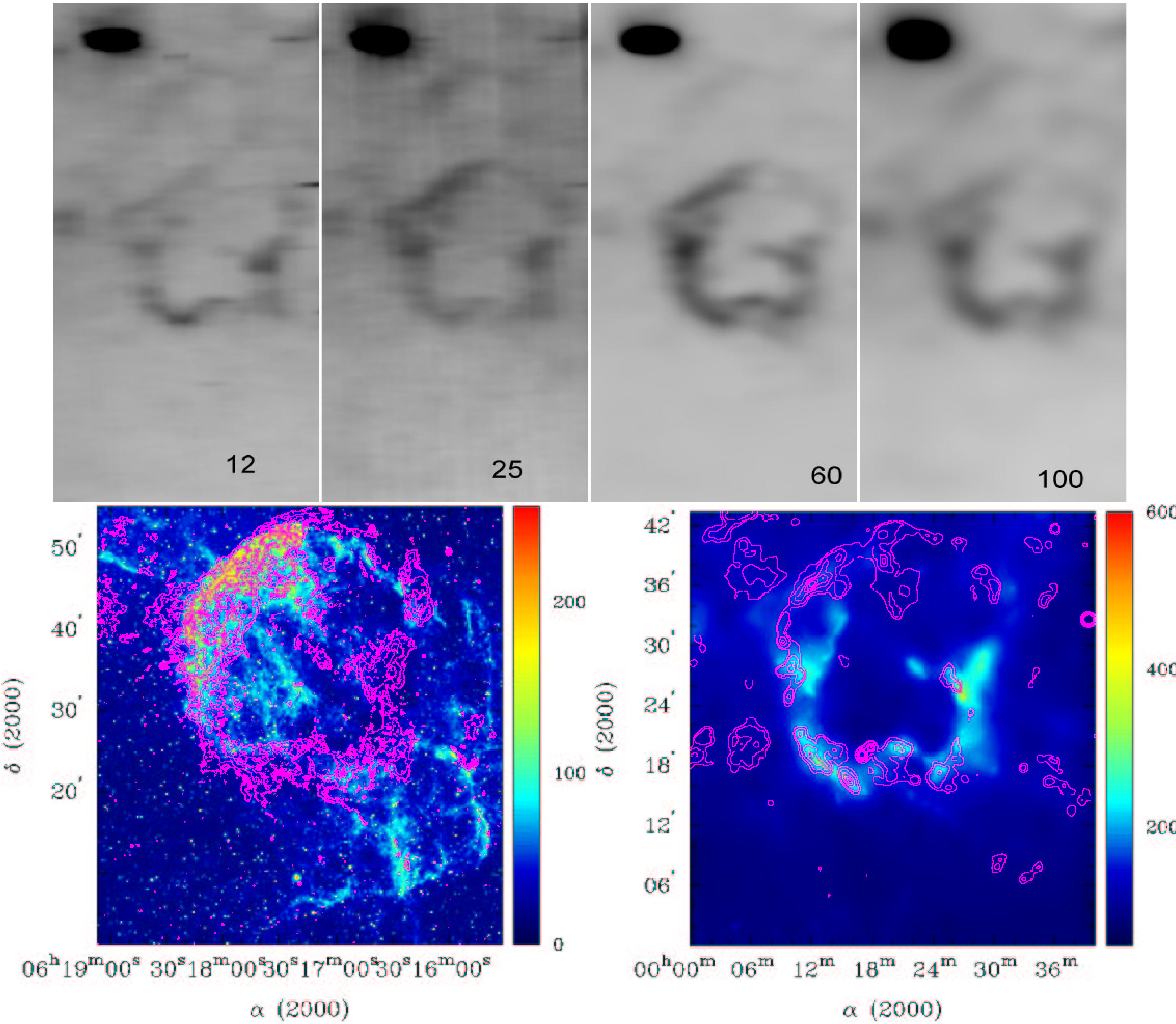

Fig. 2.— Top; IRAS HiRes fresco of IC 443 with a similar FOV as Fig 1. Bottom Left: Hα (false color) and MIPS 24μm (contours). Rigft: MIPS 160μm (false color) and HI 1.4 GHz (contours). The color scales are in MJy/sr and the FOV $\sim 0.9^\circ$ radius

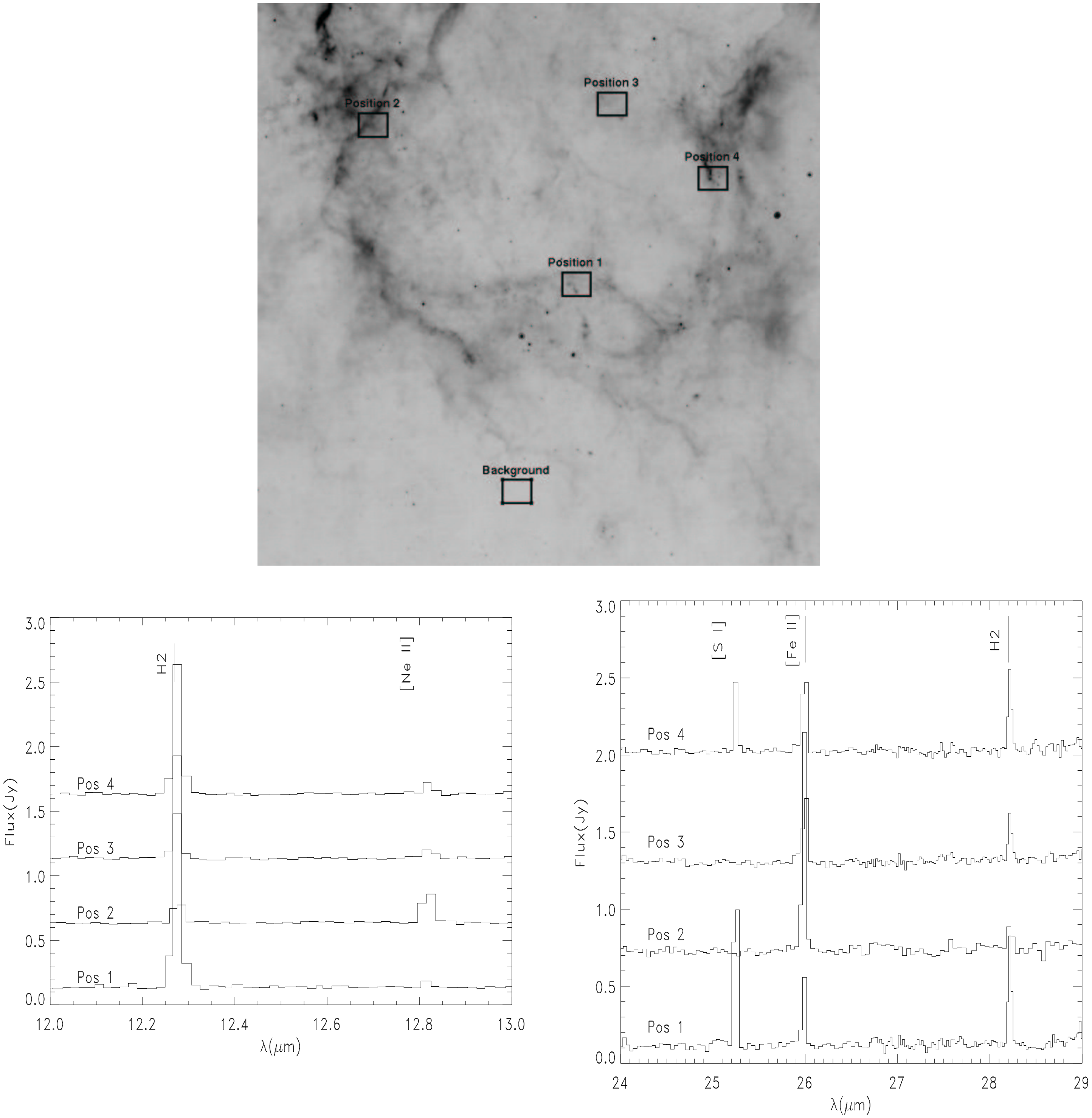

Fig. 3.— Top: A schematic view of the 5 IRS observed positions. Bottom: Sample spectra obtained with the IRS short & high resolution modules.

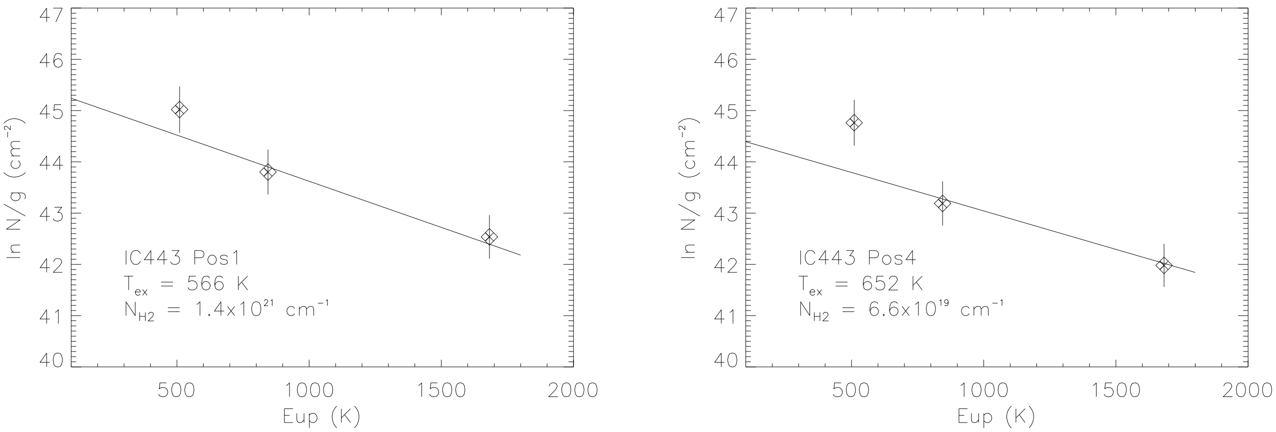

Fig. 4.— Excitation diagrams at positions one (left) and four (right) based on the three H_2 0-0 lines (12.23, 17.03 and 28.22μm) present within the wavelength range of our IRS spectra.

Nevertheless the overall shell morphology can be seen already in the IRAS images (Fig. 2 top, HiRes fresco first iteration; see also Braun & Strom 1986). The comparison with Hα (a tracer of the ionized gas) and 24μm confirms that a significant fraction of the emission at 24μm is due to fine structure atomic and H_2 molecular emission lines, and not necessarily to dust continuum emission from small dust grains. his conclusion is further supported by the IRS spectra (Fig. 3), which show strong [Fe II] 26μm and H_2 0-0 S(0) 28.2μm emission lines at the four observed positions, but no detected continuum emission.Indeed, except for the South Rim of the shell, the 160μm emission (a tracer of cold dust) does not match the morphology of the HI 1.4GHz emission (Fig. 2, bottom left), suggesting that a large fraction of the emission is not due to dust continuum. The 2MASS Ks observations at 2μm were interpreted as due to H_2 excitation from shocks (Rho et al. 2001), if this is the case, then is possible that [C II] 158μm contribute to the 160μm emission. Certainly [O I] 63μm has been detected in several positions across the shell (Rho et al. 2001), and is very likely to contribute significantly to the 70μm emission band. Even so, one can use the 70 to 160μm ratio to estimate the dust temperature, and at first approximation, we found a range of 18−30 K, with higher dust temperature at the NE, where the Hα and 24μm emission are brighter.

The IRS spectra, as expected from previous work in the NIR+MIR, contains a handful of atomic fine structure lines from Fe, Ne and Si, plus the H2 pure rotational lines (Fig. 3, bottom). The most interesting aspect is the obvious differences as a function position in the excitation along the shell. The standard shock indicator of [Ne II] 12.8μm suggests shock velocities ranging from 60-90 km/s, and consistent with some previous estimates to account for the emission of the atomic/ionic lines (Rho et al.2001).

Finally, the excitation diagrams derived from the three H2 lines covered by the IRS observations (12.23, 17.03 and 28.22μm) do also show differences in column densities and temperatures as a function of position, ranging from $T_{ex} \sim 300 - 600$ K and $N_{H2} \sim 6.6 \times 10^{19} - 1.4 \times 10^{21}$ cm^{-1} (Fig. 4) suggesting that the interaction between the shock wave and its environment is non-symmetric.

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