Wolf-Rayet Phenomena in Massive Stars and Starburst Galaxies
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ISO spectroscopy of nearby starburst galaxies

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Abstract. We present spectroscopic mid-IR observations of prominent starburst galaxies obtained with the Short Wavelength Spectrometer onboard the *Infrared Space Observatory*. The wavelength range accessible by *ISO*-SWS (2.5–45 μm) contains a large number of emission lines of atomic and molecular hydrogen and several other atomic species. In this paper we discuss the interpretation of the [NeIII] 15.5 μm/[NeII] 12.8 μm line-ratio, the faint [OIV] 25.9 μm line and the pure rotational lines of molecular hydrogen observed in our target galaxies.

1. The [NeIII]/[NeII] line-ratio

We have used *ISO*-SWS to observe 16 starburst galaxies in the mid-IR. Beside the two starburst templates, M 82 and NGC 253, our sample contains nuclear starbursts in nearby H II galaxies and barred spirals, starburst rings and starbursts in merger systems. Due to the low extinction in the mid-IR the deeply embedded star-forming regions can be observed directly with *ISO*-SWS.

The observed fine-structure line-ratios probe the density of the ionized gas and the hardness of the ionizing radiation field in our starburst galaxies (Kunze, 1998). The [NeIII] 15.5 μm/[NeII] 12.8 μm ratio is of special interest, as it is fairly independent of chemical abundances, instrumental effects (same aperture and detectors) and extinction. The observed ratios of 0.05 to 10 together with population synthesis/photo-ionization calculations show a clear need for stars more massive than 30 $M_\odot$ in the starburst IMF. Higher upper mass cutoffs up to 100 $M_\odot$ cannot be ruled out, especially in case of short burst ages.

2. Faint [OIV] emission

A faint emission in the [OIV] 25.9 μm high-excitation line has been detected in about 60 % of our starburst galaxies (Lutz *et al.* 1998). The observation of this line is surprising, since it is not produced in measurable quantities in H II regions around hot main-sequence stars, which are the main energy source of starburst galaxies. SWS raster-observations along the major axis of M 82 show, that the [OIV] emission is spatially resolved and that the [OIV]-line radial velocities follow the CO 'rotation curve' by Götz *et al.* (1990). Various energy sources can be responsible for the faint [OIV] emission. In case of the extended [OIV] emission of M 82, a weak AGN can be ruled out as energy source, because an AGN related origin would require a much larger [NeIII]/[NeII] ratio than observed. Similar arguments vote againts 'super-hot stars' with an extremely hard ionising

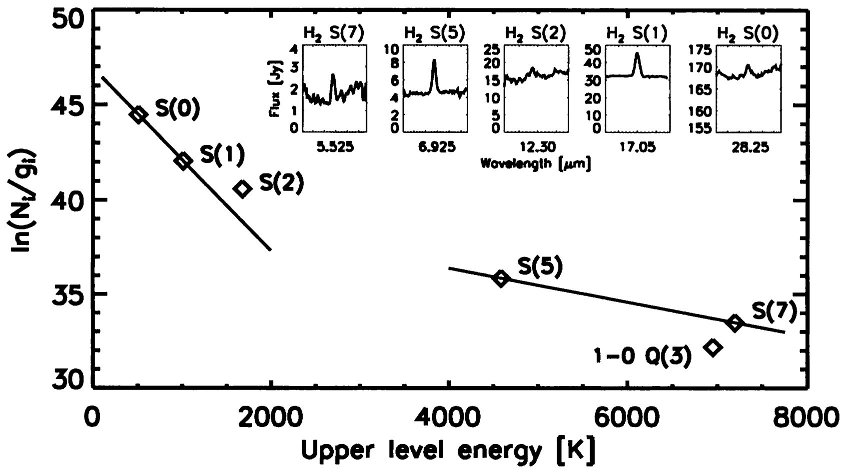

Figure 1. Excitation diagram of molecular hydrogen in NGC 253.

spectrum. The most plausible explanation for the faint [OIV] line is provided by ionizing shocks. Shock models with appropriate parameters and comparison with shock excited galactic templates (*e.g.*, RCW 103) predict line intensities similar to the observed ones.

3. Molecular hydrogen

The pure rotational transitions of molecular hydrogen in starburst galaxies have been observed for the first time with *ISO*-SWS. Excitation diagrams are used to derive temperatures for the emitting gas (see Fig. 1). The H_2 (0-0) S(1) line originates in our targets in warm molecular hydrogen of typically 120-200 K. The H_2 (0-0) S(5) and S(7) lines trace a gas component with a higher excitation equivalent to a temperature of about 1000 K (up to 1700 K in IC 342). The warm component of the H_2 gas accounts for 3-5 % (up to 9 % in M 82) of the total CO mass. The hotter component contributes much less. The H_2 gas in the lower states might be partially excited by collisions due to the local kinetic temperature. The excitation of the higher states however is, as comparison with PDR models and observations of galactic templates (*e.g.*, S 140, Timmermann *et al.* 1996) imply, dominated by UV fluorescence.

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