FIRST RESULTS AND DISCOVERIES WITH THE ISO SHORT-WAVELENGTH SPECTROMETER

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Abstract. The Short-Wavelength Spectrometer(SWS) is one of the four instruments on-board of ESA's Infrared Space Observatory(ISO), launched on 15 Nov. 1995. It covers the wave-length range of 2.38-45.2μm with a spectral resolution ranging from 1000-2000. An overview is given of the in-orbit performance and a summary of the main scientific results and discoveries obtained in the first 18 months of operation of the ISO-SWS.

1. Introduction to the ISO-SWS, a discovery machine.

The Short-Wavelength Spectrometer(SWS) (see de Graauw et al., ISO-1996, L49) is one of the two spectrometers on-board of ISO (see Kessler et al., ISO-1996, L27). The SWS covers the wavelength range from 2.38-45.2μm with a spectral resolving power of the order of 1000-2500. The requirement to cover four octaves has dominated the SWS optical design and for that reason two gratings had to be used, four detector bands and three entrance apertures. Using also its Fabry-Perot (F-P) etalons, which are located at the output of the long-wavelength (LW) grating section, the resolution can be increased to about 25,000 for the wavelength range from 11.4-44.5μm. The SWS instrument was developed, fabricated and space-qualified by the laboratories of the Space Research Organisation of the Netherlands (SRON) and the Max Planck Institute fuer Extraterrestrische Physik (MPE), with contributions from the Steward Observatory, the AGL Phillips Laboratory, Hanscom, USA and the Katholieke Universiteit at Leuven (KUL). The preliminary in-orbit flux calibration is described by Schaeidt et al.(ISO-1996, L55), together with an in-orbit determination of the Relative Spectral Response Function (RSRF). For details on the in-orbit wavelength calibration, the spectral resolution and instrumental profiles, see Valentijn et al.(ISO-1996, L60). The literature references given in this paper, labelled with "(ISO-1996)" refer to the special A&A issue on First ISO Results, published in November 1996, A&A, vol. 315, No. 2.

2. Observations of Dusty Interstellar and Circumstellar Material: Discovery of Crystalline Silicates.

Dusty envelopes surrounding evolved stars is one of the main aims of the SWS Guaranteeed time programme. First results of observations on Red Super Giants (RSG), Asymptotic Giant Branch (AGB), post-AGB stars and Planetary Nebulae (PN) have been reported by Justtanont et al.(ISO-1996, L217), Waters et al.(ISO-1996, L361), and Beintema et al.(ISO-1996, L253) respectively. One of the most remarkable new results are the rich emission spectra between 30 and 45μm observed toward a number of stars with oxygen-rich shells. They show many spectral features with a variety in shape and strength. It appears that many of these features coincide with laboratory spectra of crystalline silicates. See Waters et al. (ISO-1996, L361). One of the features, at 43μm, coincides with that of crystalline H_2O ice. Formation of crystalline silicates requires high densities and temperatures followed by a relatively long period of slow cooling. The detection of these materials gives interesting constraints on the formation of dust during the evolution of the star, particularly since similar bumps have been detected in shells surrounding LBV's (Lamers et al. ISO-1996, L229)

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and young Herbig Ae/Be stars (Waelkens et al. ISO-1996, L245). Observations taken toward three evolved C-rich stars (Beintema et al. ISO-1996, L369), one post-AGB star (HR 4049) and two PN's (IRAS 21282/5050, NGC 7027) show the spectra dominated by the well-known infrared emission bands, attributed to a.o. Polycyclic Aromatic Hydrocarbons (PAH's). The preliminary analysis given by Molster et al. (ISO-1996, L373) on the same set of sources as described by Beintema et al., indicate that the differences indeed reflect effects of radiation fields, physical conditions in the circumstellar disc or shell and the possible presence of large (>300 atoms) C molecules. An example of interstellar PAH studies is described by Roelfsema et al. (ISO-1996, L289). The ISO SWS spectra from 6-12μm, towards several compact HII regions show a strong similarity with the PAH spectrum of HR 4049. Others resemble the spectra of planetary nebulae. It appears indeed that the emission features are due to a whole family of PAH species.

3. Observations of Interstellar and Circumstellar Gaseous Material: Discovery of large quantities of warm H_2, H_2O, CO_2

The detection of circumstellar and interstellar molecular gasses is one of the areas where the preliminary observations with SWS have already given new and interesting results. The most interesting interstellar molecule, H_2, has its lowest rotational transitions in the SWS wavelength range. These have indeed been detected by SWS in the warm interstellar medium regions such as PDRs (see Timmermann et al , ISO-1996, L281), shocks (see Wright et al., ISO-1996, L301), around young stellar objects (see Wesselius et al., ISO-1996, L197) and PNs (see Beintema et al., ISO-1996, L253). Rotational temperatures derived from the line ratios range from 100 to 1000K and the measurements give important diagnostic information on the excitation mechanisms.

ISO allows, for the first time, unhindered access to the wavelengths of water and carbon dioxide. Many ro-vibrational lines of gaseous water have been observed, for the first time, in absorption against bright infrared sources associated with massive young stellar objects, see van Dishoeck and Helmich (ISO-1996, L177) and Helmich et al. (ISO-1996, L173). The ro-vibration absorption band at 6μm has lead to the determination of high excitation temperatures (> 200K) and a high H_2O abundance (10^{-5}), using models developed by Helmich. Such large water abundances can result from evaporation of grain mantles, but also from high-temperature gas-phase reactions. Observations of H_2O towards OH-IR sources and other evolved stars such as W Hydrae, have been reported by Justtanont et al. (ISO-1996, L217) and Neufeld et al. (ISO-1996, L237). SWS spectra of NML Cyg show not only the ro-vibrational absorption lines of H_2O, but also those of OH, CO and CO_2, and the pure rotational lines of H_2O in the 30 to 45μm range. Modelling the 2.7 and the 6.2μm H_2O bands indicate excitation temperatures of 500K and 100K for an inner and outer H_2O region. From the 4.6μm CO data and the 4.2μm CO_2 data, values of 300K and 250K respectively have been derived. One of the first high-resolution observations with the SWS Fabry-Perot resulted in the first detection of thermal water vapour emission from a circumstellar outflow. See a.o. Neufeld et al. (ISO-1996,L237) on their report of the detection of rotational H_2O lines toward W Hydrae. More recently, Justtanont et al. (1997) discovered CO_2 emission in SWS spectra of O-rich AGB stars with the 13μm dust feature. Strong emission lines at 13.48, 13.87, 15.40 and 16.28 μm were found in the spectra of Miras and semi regular variables.

4. Observations of Interstellar Ices: Making The Inventory.

The ubiquity of ices in molecular clouds has become evident from ground-based observations and most of the prominent features of the ice mixtures that have been identified are attributed to H_2O, CO, CH_4, CH_3OH etc. With the complete and unhindered wavelength coverage of the ISO-SWS instrument a large number of new results and detections can be expected and in fact have already been obtained. A full inventory of ices towards NGC 7538 IRS9 has been made by Boogert et al. (ISO-1996, L377) and Schutte et al. (ISO-1996, L333), while d'Hendecourt et al. (ISO-1996, L365) have studied the solid state features towards RAFGL 7009S . The most prominent features in these spectra are, besides the strong silicate absorption band, from H_2O, CO, CO_2, H_2CO, XCN and CH_4 ices. Large amounts of solid CO_2 have been detected toward a variety of sources such as young stellar objects embedded in molecular clouds and the Galactic Center. See also de Graauw et al. (ISO-1996, L345). Comparison of the line profiles of CO and CO_2 with those obtained in the laboratory indicate the presence of polar and non-polar layers in the ice mantles. A search for gaseous CO_2 towards the same sources by van Dishoeck et al. (ISO-1996, L349), showed that the abundance of gaseous CO_2 is less than 5% of the solid state abundance. This is in contrast to CO which is more abundant in the gas than in the solid state by a factor 10 to 100.

5. Observations of Galactic Nuclei: Determining the Powering Source of LIR's.

A powerfull method to determine the nature of the energy source in the nuclei of obscured luminous infrared galaxies is to study the excitation state of the mid- and far-infrared emission lines of the predominantly photoionized gas. The high excitation, so-called coronal, lines require a relatively harder radiation field than can be supplied by stellar sources and are therefore indicators for an AGN-type energy source. This capability of ISO-SWS spectroscopy has been nicely demonstrated by Lutz et al. (ISO-1996, L137) and Moorwood et al. (ISO-1996, L109). By taking several typical starburst and AGN sources as templates and measuring the line ratios of NeV/NeII and OIV/NeII and applying the subsequent criteria to the line ratios observed towards three luminous IRAS galaxies (Arp 220, NGC 6240, NGC 3256), it is clear that these nuclei are powered mainly by starbursts and that a contribution of an AGN plays a minor role. Although these conclusions are preliminary and based on the first SWS observations, they appear to become confirmed by further observations. Besides the ionic fine structure lines, one can detect in most of the nuclei of galaxies a number of rotational emission lines of molecular Hydrogen. The molecular gas detected this way is relatively warm (>100K) and accounts for a few to ten procent of the total molecular ISM component. See also Valentijn et al. (ISO-1996, L145), Kunze et al. (ISO-1996, L101), Rigopoulou et al. (ISO-1996, L125) and Sturm et al. (ISO-1996, L133).

6. Observations of Solar System Objects: Discovery of Gaseous H_2O and CO_2 in the Upper Atmospheres of the Giant Planets.

Sofar full SWS spectra have been obtained of Jupiter, Saturn , Uranus and of several asteroids. The latter were taken for flux calibration purposes. Preliminary analysis of the Jupiter (Encrenaz et al. ISO-1996, L397) and the Saturn (de Graauw et al. 1997) spectra show good agreement with the models. The main results for Jupiter are a. the first detection of thermal emission of CH_4 at 3.3μm showing evidence for a high temperature in the upper Jovian atmosphere (T=800K at P=0.16 microbar), b. a first spectroscopic detection of the Jovian cloud at 0.5 bar associated with NH_3 ice, and c. the first detection of the R(2) HD line at 37.7μm with the SWS Fabry-Perot, indicating a D/H ratio of 2.2×10^{-5}. The main results for Saturn are the detection of CO_2, CH_3C_2H and C_4H_2 in the stratosphere and the detection of H_2O in the troposphere. A major surprise came from the detection of gaseous H_2O in the upper atmospheres of Jupiter, Saturn, Uranus and Neptune, and CO_2 in Saturn and Neptune. See Feuchtgruber et al. (1997b). These molecules have likely an external source and their presence affects the photochemistry and energy budget of these atmospheres.

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