New wavelength determinations of mid-infrared fine structure lines by ISO-SWS[1]

H. Feuchtgruber[2,3], D. Lutz[3], D. A. Beintema[2,4], E. A. Valentijn[2,4,6], O. H. Bauer[3], D. R. Boxhoorn[2,4], Th. de Graauw[4,6], L. N. Haser[3], G. Haerendel[3], A. M. Heras[2], R. O. Katterloher[3], D. J. M. Kester[4], F. Lahuis[2,4], K. J. Leech[2], P. W. Morris[2,4], P. R. Roelfsema[2,4], A. Salama[2], S. G. Schaeidt[2,3], H. W. W. Spoon[3], B. Vandenbussche[2,5], E. Wieprecht[2,3]

ABSTRACT

We report accurate new wavelengths for 29 mid-infrared ionic fine structure lines, based on observations with the Short Wavelength Spectrometer (SWS) on board the Infrared Space Observatory (ISO). Our results originate from observations of NGC 7027, NGC 6543, NGC 6302, the Circinus galaxy, Sgr A West and W51 IRS2. The obtained accuracies ($\lambda/\Delta\lambda$) range from $3 \cdot 10^4$ to $1 \cdot 10^5$, depending on instrumental mode and uncertainty in radial velocities.

Subject headings: – Atomic data – Line: identification – Infrared: ISM: lines and bands

1. Introduction

The Short Wavelength Spectrometer (SWS, de Graauw et al. 1996) on board ESA's cryogenic Infrared Space Observatory (Kessler et al. 1996) is in operation since december 1995. Its high sensitivity and full coverage of the wavelength range 2.4 – 45μm allow spectroscopy of transitions that were unobservable from groundbased or airborne telescopes. As accurate wavelengths from laboratory or astronomical measurements were previously unavailable for many fine structure transitions of highly ionized species, the SWS Instrument Dedicated Team has initiated an effort

---

[1]Based on observations made with ISO, an ESA project with instruments funded by ESA Member States (especially the PI countries: France, Germany, the Netherlands and the United Kingdom) and with the participation of ISAS and NASA. The SWS is a joint project of SRON and MPE.

[2]ISO Science Operations Centre, Astrophysics Division of ESA, P.O. Box 50727, E-28080 Villafranca/Madrid, Spain

[3]Max-Planck-Institut für extraterrestrische Physik, Postfach 1603, D–85740 Garching, Germany

[4]Space Research Organisation of the Netherlands and Kapteyn Institute, P.O. Box 800, 9700 AV Groningen, the Netherlands

[5]Institute for Astronomy, University of Leuven, B-3001 Heverlee, Belgium

[6]Kapteyn Astronomical Institute, P.O. Box 800, 9700 AV Groningen, the Netherlands

to quickly provide improved wavelengths for lines that may be of relevance in a variety of sources being observed with ISO SWS. We make use of observations obtained both with the SWS grating spectrometer (resolving power R$\sim$1000-2000) and the SWS Fabry-Perot (FP) with resolving power R$\sim$30000.

The absolute wavelength calibration of the SWS grating section established during the performance verification (PV) phase of ISO has an uncertainty of 0.5-1.0 steps of the grating scanner (Valentijn et al. 1996). This value in instrumental units can be translated into the actual wavelength uncertainty for every spectral line and typically corresponds to $\lambda/\Delta\lambda = 1 \cdot 10^4$. These numbers represent the intrinsic accuracy of the grating wavelength calibration as obtained from a large set of observations in PV. The wavelength accuracy of an *individual* SWS grating observation may however be affected by the pointing accuracy of the satellite and the structure of the target, which can cause apparent wavelength shifts up to 100 km/s due to offsets between center of slit and actual source position. This is about three times as large as the instrumental accuracy. In order to take full advantage of the excellent intrinsic accuracy we have employed a scheme where in the same observation other accurately known lines are used for reference (See Sect. 2 for details). This procedure also accounts for uncertainties in the source velocity.

The absolute Fabry-Perot wavelength accuracy is 2 FP steps in the range 11.4 μm to 26.0 μm and 1 FP step for the wavelength range above 26 μm, corresponding to individual errors of the spectral lines of typically $\lambda/\Delta\lambda = 1 \cdot 10^5$. Pointing effects on the FP wavelength determinations are negligible. Slight mispointings cause a detuning of the order-sorting grating profile with respect to the FP transmission, which translates into a loss of a few percent of flux, but no measurable wavelength shift. No spectral ghosts have been identified in SWS spectra, which could lead to misidentifications of the lines. The FP wavelength calibration has proven to be stable on a timescale of more than one year, while the grating wavelength calibration shows a slight time dependent shift. This effect is however neglected here as it is smaller than 0.1 grating scanner step per month and all new wavelengths reported here were determined from observations close to the actual calibration during PV. In addition, note that a shift that is constant for the whole scanner range will be absorbed by the reference line procedure.

2. Observations and data reduction

We have analyzed observations of the planetary nebulae NGC 6543, NGC 7027, and the Circinus galaxy made during PV and observations of NGC 6302, Sgr A West, and W51 IRS2 from various guaranteed time proposals. This paper exclusively focusses on wavelength determinations, detailed discussions of the sources are presented elsewhere. Note that only those observed lines for which we could improve the wavelengths are mentioned here. Lines with accurately known wavelengths, including most of the reference lines, were measured on several other targets for wavelength calibration purposes (Valentijn et al. 1996). Our observations include scanning Fabry-Perot line observations (AOT SWS07), grating line observations (AOT SWS02) and low

Table 1. Summary of new wavelength determinations

Ion	Transition $u-l$	Vac. Wavelength* [μm]	Restwavenumber* [cm^{-1}]	χ_{lower} [eV]	χ_{upper} [eV]	Obs. Date	Target
[Si IX]	$^3P_2$-$^3P_1$	2.58423±(23)	3869.63±(33)	303.17	351.10	28-Jan-96[a]	Circinus
[Al V]	$^2P_{1/2}$-$^2P_{3/2}$	2.90519±(37)	3442.12±(43)	120.0	153.83	11-Dec-95[b]	NGC 7027
[K VII]	$^3P_{3/2}$-$^2P_{1/2}$	3.19053±(15)	3134.28±(14)	99.4	117.56	18-Feb-96[b]	NGC 6302
[Ca IV]	$^2P_{1/2}$-$^2P_{3/2}$	3.20671±(15)	3118.46±(14)	50.91	67.27	11-Dec-95[b]	NGC 7027
[Mg IV]	$^2P_{1/2}$-$^2P_{3/2}$	4.48668±(30)	2228.82±(15)	80.14	109.24	19-Dec-95[a]	NGC 7027
[Ar VI]	$^2P_{3/2}$-$^2P_{1/2}$	4.52952±(31)	2207.74±(15)	75.02	91.01	19-Dec-95[a]	NGC 7027
[K III]	$^2P_{1/2}$-$^2P_{3/2}$	4.61802±(47)	2165.43±(22)	31.63	45.80	11-Dec-95[b]	NGC 7027
[Na VII]	$^2P_{3/2}$-$^2P_{1/2}$	4.68472±(33)	2134.60±(15)	172.15	208.44	18-Feb-96[b]	NGC 6302
[Mg VII]	$^3P_2$-$^3P_1$	5.5032±(12)	1817.10±(41)	186.51	224.95	18-Feb-96[b]	NGC 6302
[MgV]	$^3P_1$-$^3P_2$	5.60985±(63)	1782.58±(20)	109.24	141.27	19-Dec-95[a]	NGC 7027
[K IV]	$^3P_1$-$^3P_2$	5.9820±(12)	1671.68±(35)	45.80	60.91	11-Dec-95[b]	NGC 7027
[Si VII]	$^3P_0$-$^3P_1$	6.4922±(11)	1540.29±(25)	205.05	246.52	18-Feb-96[b]	NGC 6302
[Na III]	$^2P_{1/2}$-$^2P_{3/2}$	7.3177±(12)	1366.54±(23)	47.29	71.62	11-Dec-95[b]	NGC 7027
[Ne VI]	$^2P_{3/2}$-$^2P_{1/2}$	7.6524±(12)	1306.78±(21)	126.21	157.93	11-Dec-95[b]	NGC 7027
[Fe VII]	$^3F_4$-$^3F_3$	7.8145±(12)	1279.67±(20)	99.1	124.98	11-Dec-95[b]	NGC 7027
[Na VI]	$^3P_2$-$^3P_1$	8.61059±(88)	1161.36±(12)	138.39	172.15	18-Feb-96[b]	NGC 6302
[Fe VII]	$^3F_3$-$^3F_2$	9.5267±(11)	1049.68±(12)	99.1	124.98	11-Dec-95[b]	NGC 7027
[Ar V]	$^3P_1$-$^3P_0$	13.1022±(2)	763.231±(11)	59.81	75.02	31-Dec-95[c]	NGC 7027
[Mg V]	$^3P_0$-$^3P_1$	13.5213±(2)	739.576±(11)	109.24	141.27	31-Dec-95[c]	NGC 7027
[Ne V]	$^3P_2$-$^3P_1$	14.3217±(2)	698.242±(10)	97.12	126.21	31-Dec-95[c]	NGC 7027
[Na VI]	$^3P_1$-$^3P_0$	14.3964±(21)	694.62±(10)	138.39	172.15	18-Feb-96[b]	NGC 6302
[Ne III]	$^3P_1$-$^3P_2$	15.5551±(3)	642.878±(9)	40.96	63.45	31-Dec-95[c]	NGC 7027
[Ar III]	$^3P_0$-$^3P_1$	21.8293±(20)	458.10±(4)	27.63	40.74	23-Dec-95[a]	NGC 6543
[Ne V]	$^3P_1$-$^3P_0$	24.3175±(3)	411.226±(6)	97.12	126.21	31-Dec-95[c]	NGC 7027
[O IV]	$^2P_{3/2}$-$^2P_{1/2}$	25.8903±(3)	386.245±(5)	54.93	77.41	31-Dec-95[c]	NGC 7027
[Fe III]	$^5D_2$-$^5D_3$	33.0384±(66)	302.678±(60)	16.19	30.65	19-Feb-96[b]	Sgr A West
[S III]	$^3P_1$-$^3P_0$	33.4810±(3)	298.677±(3)	23.34	34.79	27-Jan-96[c]	NGC 6543
[Si II]	$^2P_{3/2}$-$^2P_{1/2}$	34.8152±(5)	287.231±(5)	8.15	16.35	9-May-96[c]	W51 IRS2
[Ne III]	$^3P_0$-$^3P_1$	36.0135±(3)	277.674±(3)	40.96	63.45	27-Jan-96[c]	NGC 6543

[a] Grating line scan

[b] Full low resolution grating scan

[c] Fabry-Perot line scan

*Numbers in brackets give errors on last decimals

Note. — χ_{lower} and χ_{upper} denote excitation and ionization potentials resolution full grating scans (AOT SWS01). The different spectral and spatial resolutions for these modes are described by de Graauw et al. (1996). The data reduction of all measurements was done using the SWS Interactive Analysis software package. Gaussian fits to the spectral lines provided the center wavelengths, which first were corrected for the sum of heliocentric and the mean ISO radial velocity shift. Typical changes of the later shift during the observations reported here are of the order of 0.2 to 0.3 km/s, deviations from the mean value were therefore neglected.

2.1. Use of reference lines

The resulting center wavelengths are corrected further to consider velocity errors. For that purpose, we determine offsets between observed and predicted wavelengths for simultaneously observed reference lines with well known rest wavelengths. In case of grating observations, the velocity error may have a pointing-induced component. Since SWS has three different apertures which are used in sequence, we require that reference wavelengths for a particular line have to be taken from observations using the same SWS aperture, i.e. the same pointing. This is because SWS observations with different apertures constitute independent pointings, so that the ISO blind pointing accuracy of about 3.5″ (Kessler et al. 1996) may have to be considered. Pointing effects are, however, negligible within a single aperture observation since the short term pointing jitter is much smaller (about 0.5″). In some cases, there are apparent small velocity differences even between different lines on the same source. Since it is well known that in sources like the Circinus galaxy there exist velocity shifts between high and low excitation lines (Oliva et al. 1994), we have tried to account for this by using reference lines with excitation potential close to the one of the line to be determined.

While wavelengths of narrow lines measured with the FP are to first order not affected by pointing errors, an additional uncertainty of 1 km/s is included in the error estimates to account for spatial variations of the velocity across the source, which are a potential problem at the spectral resolving power of the FP even for sources like planetary nebulae. The SWS slit sizes, however, are larger or equal 14″ x 20″ depending on the slit used and therefore give a good average of the intrinsic source velocities of the selected targets. For example, our prime target NGC 7027 is smaller than our aperture, and NGC 6543 is only slightly larger than the small dimension of the slit. Our basic assumption is that the centers of gravity of the velocity profiles for different species agree within the quoted uncertainty, a detailed match of spatial or velocity structure is not required. This assumption is supported by the FP wavelength calibration procedure and its verification (Valentijn et al. 1996). The agreement between the calibration derived from calibration sources internal to SWS and verification on lines with accurately known wavelengths in astronomical sources is excellent for a variety of sources, including some planetary nebulae.

In several cases we had detections on more than one target, here we selected the observations with best signal to noise and best reference wavelength frames. The new wavelength determinations together with some other line properties can be found in Table 1. The framework of fine structure reference lines which were used for the indvidual observations of our targets is listed in Table 2. The offset listed in Table 2 gives, for a particular observation, the difference between observed and literature wavenumber of the reference line. Apart from literature wavenumbers, Table 2 also includes rest wavenumbers which were determined during independent observations by the SWS grating or FP on other targets. 'SWS error' denotes the measurement uncertainty in the SWS observation of the reference line. Together with the uncertainty of the literature wavenumber, it is propagated into the error of new wavelength determinations that are tied to this line.

2.2. NGC 7027

A full SWS grating scan at reduced resolution ($\approx$ max res. /2) from 2.36 μm to 45.2 μm and grating line scans at many wavelengths provided a large number of line detections in this high excitation planetary nebula (Beintema et al. 1996). FP observations on 9 spectral lines were carried out. Table 1 includes all line observations where the wavelength accuracy could be improved. The fine structure reference lines can be found in Table 2, in addition we included hydrogen recombination lines as references.

No significant deviations between observed and predicted wavelengths were detected for the reference lines in all three applied SWS observing modes, adopting the heliocentric velocity $+8.8\pm 0.6$ km/s from Schneider et al. (1983). Hyperfine splitting of the [Na IV] line has been reported by Kelly & Lacy (1995). Due to the lower spectral resolution of the SWS it was not possible to resolve the hyperfine components, but the center wavelength we determined is in perfect agreement with their results.

2.3. NGC 6543

Wavelengths for the ionic lines from [S III] at 33.48 μm and [Ar III] at 21.83 μm are provided by the observations on the low excitation planetary nebula NGC 6543 (Beintema et al. 1996). All other observed lines were already detected in NGC 7027 with better signal to noise.

The grating observations on NGC 6543 are in excellent agreement with the reference lines adopting the heliocentric velocity -66.1 ± 0.4 km/s (Schneider et al. 1983), therefore no shift had to be applied to the [Ar III] 21.83 μm line. For the [S III] 18.71 μm line observed by the FP we get a wavenumber of $534.399\pm0.006\,\mathrm{cm}^{-1}$ differing slightly ($< 2\sigma$) from that reported by Kelly & Lacy (1995). Our value has a slightly higher error but agrees better with previous observations by Moorwood et al. (1980) and Moorwood et. al. (1978).

Table 2. Summary of reference wavenumbers. See section 2 for explanations.

Obs. Date	Target	Ion	Transition $u-l$	Ref. Wavenumber	Offset [cm^{-1}]	SWS error [cm^{-1}]	Reference [cm^{-1}]
11-Dec-95[b]	NGC 7027	[Ar II]	$^2P_{1/2}$-$^2P_{3/2}$	1431.5831±0.0007	0.03	0.25	Yamada et al. 1985
11-Dec-95[b]	NGC 7027	[Ar V]	$^3P_2$-$^3P_1$	1265.57±0.04	-0.01	0.20	Kelly & Lacy 1995
19-Dec-95[a]	NGC 7027	[Ar II]	$^2P_{1/2}$-$^2P_{3/2}$	1431.5831±0.0007	0.02	0.13	Yamada et al. 1985
19-Dec-95[a]	NGC 7027	[Ar III]	$^3P_1$-$^3P_2$	1112.176±0.015	-0.05	0.07	Kelly & Lacy 1995
19-Dec-95[a]	NGC 7027	[Na IV]	$^3P_1$-$^3P_2$	Hyperfine splitting	-	0.07	Kelly & Lacy 1995
19-Dec-95[a]	NGC 7027	[S IV]	$^2P_{3/2}$-$^2P_{1/2}$	951.430±0.01	0.02	0.05	Serabyn, priv. com.
31-Dec-95[c]	NGC 7027	[Ne II]	$^2P_{1/2}$-$^2P_{3/2}$	780.424±0.001	0.002	0.012	Yamada et al. 1985
31-Dec-95[c]	NGC 7027	[S III]	$^3P_2$-$^3P_1$	534.387±0.005	0.01	0.015	Kelly & Lacy 1995
23-Dec-95[a]	NGC 6543	[Ar III]	$^3P_1$-$^3P_2$	1112.176±0.015	-0.05	0.07	Kelly & Lacy 1995
23-Dec-95[a]	NGC 6543	[S III]	$^3P_2$-$^3P_1$	534.387±0.005	0.02	0.03	Kelly & Lacy 1995
22-Mar-96[c]	NGC 6543	[S III]	$^3P_2$-$^3P_1$	534.387±0.005	0.012	0.006	Kelly & Lacy 1995
18-Feb-96[b]	NGC 6302	[Si VII]	$^3P_1$-$^3P_2$	4026.84±0.20	-0.54	0.48	Reconditi & Oliva 1993
18-Feb-96[b]	NGC 6302	[Mg VIII]	$^2P_{3/2}$-$^2P_{1/2}$	3302.56±0.27	-0.62	0.38	Reconditi & Oliva 1993
18-Feb-96[b]	NGC 6302	[Ar VI]	$^3P_{3/2}$-$^2P_{1/2}$	2207.74±0.15	-0.05	0.29	Table 1 (NGC 7027)
18-Feb-96[b]	NGC 6302	[Ar II]	$^2P_{1/2}$-$^2P_{3/2}$	1431.5831±0.0007	0.04	0.25	Yamada et al. 1985
18-Feb-96[b]	NGC 6302	[Ne VI]	$^2P_{3/2}$-$^2P_{1/2}$	1306.78±0.21	0.02	0.21	Table 1 (NGC 7027)
18-Feb-96[b]	NGC 6302	[Ar III]	$^3P_1$-$^3P_2$	1112.176±0.015	-0.03	0.07	Kelly & Lacy 1995
18-Feb-96[b]	NGC 6302	[Ne V]	$^3P_2$-$^3P_1$	698.242±0.01	0.02	0.10	Table 1 (NGC 7027)
28-Jan-96[a]	Circinus	[Si IX]	$^3P_1$-$^3P_0$	2540.84±0.25	0.00	0.20	Oliva et al. 1994
28-Jan-96[a]	Circinus	[Ar III]	$^3P_1$-$^3P_2$	1112.176±0.015	-0.02	0.07	Kelly & Lacy 1995
28-Jan-96[a]	Circinus	[Ne V]	$^3P_2$-$^3P_1$	698.242±0.010	0.05	0.05	Table 1 (NGC 7027)
28-Jan-96[a]	Circinus	[S III]	$^3P_2$-$^3P_1$	534.387±0.005	0.00	0.03	Kelly & Lacy 1995
28-Jan-96[a]	Circinus	[Ne V]	$^3P_1$-$^3P_0$	411.226±0.006	0.02	0.04	Table 1 (NGC 7027)
19-Feb-96[b]	Sgr A West	[S III]	$^3P_2$-$^3P_1$	534.387 ±0.005	-0.016	0.06	Kelly & Lacy 1995
19-Feb-96[b]	Sgr A West	[Fe III]	$^5D_3$-$^5D_4$	436.205±0.038	0.04	0.08	Erickson et al. 1989
19-Feb-96[b]	Sgr A West	[S III]	$^3P_1$-$^3P_0$	298.677±0.003	0.007	0.016	Table 1 (NGC 6543)
9-May-96[c]	W51 IRS2	[Ne II]	$^2P_{1/2}$-$^2P_{3/2}$	780.424±0.001	-0.005	0.012	Yamada et al. 1985
9-May-96[c]	W51 IRS2	[Ne III]	$^3P_1$-$^3P_2$	642.878±0.009	-0.005	0.009	Table 1 (NGC 7027)
9-May-96[c]	W51 IRS2	[S III]	$^3P_1$-$^3P_0$	298.677±0.003	0.002	0.003	Table 1 (NGC 6543)
9-May-96[c]	W51 IRS2	[Ne III]	$^3P_0$-$^3P_1$	277.674±0.003	0.000	0.003	Table 1 (NGC 6543)

[a] Grating line scan

[b] Full low resolution grating scan

[c] Fabry-Perot line scan

2.4. NGC 6302

This extremely high excitation planetary nebula is a unique source of infrared fine structure lines (Pottasch et al. 1985, 1996, Ashley & Hyland 1988, Reconditi & Oliva 1993) One low resolution full grating scan from 2.36 μm to 45.3 μm added new rest wavelengths for transitions of K, Na, Mg and Si ions at high ionization energies. The 7 fine structure reference lines listed in table 2 provide the information on pointing and velocity errors. For wavelengths below 5 μm, hydrogen recombination lines are available as additional references and fit the reference frame deduced from the fine structure lines.

The observed lines in NGC 6302 had to be shifted on average by 35 km/s with respect to the heliocentric velocity of -39$\pm$2km/s given by Acker et al. (1992), probably due to a pointing error. The error of the [Si VII] 6.49 μm line is larger because the line is weak. We find the rest wavelengths for the reference lines [Si VII] at 2.48 μm and [Mg VIII] 3.028 μm at somewhat longer wavelengths than Reconditi & Oliva (1993), but still consistent within the errors. The other reference lines match well however, and there is no reason to expect large velocity differences between ions of different ionization energies within this planetary nebula.

It should be noted that we do not detect the 9μm [Mg VII] line which was found at 9.009 μm by Kelly & Lacy (1995) in NGC 7027. The presence of the strong 5.5 μm [Mg VII] line however indicates that this ion is present, and a strong 9.009 μm line would be expected for the density and electron temperature of NGC 6302. Since it is unlikely that the [Mg VII] atomic data are wrong by the large factor required to suppress the 9.009 μm line, it appears that the weak feature detected by Kelly & Lacy (1995) is not due to [Mg VII]. This is supported by the fact that the [Mg VII] 5.5 μm line was not detected by SWS in NGC 7027, which is of lower excitation than NGC 6302. Likely the 9μm [Mg VII] line in NGC 6302 is blended with [Ar III] 8.991 μm at the SWS spectral resolving power of 2000.

We attribute the lines at 8.61 μm and 14.39 μm to [Na VI]. The presence of both, lower an higher ionized sodium, [Na III], [Na IV] and [Na VII] supports this identification. At first glance, the identification of the line at 3.19 μm with [K VII] could be questioned because of the nondetection in NGC 6302 of lower ionization stages of potassium. Lines of [K III] and [K IV] were detected in the lower excitation planetary NGC 7027. We have run a simplified photoionization model using Cloudy (Ferland 1993), which reproduced the NGC 6302 Neon line fluxes of various ionization stages. However, this model predicts the [K VII] line to be the brightest of the [K III] to [K VII] series of ionic lines. The measured upper limits for the lower excitation [K] lines in the SWS spectrum of NGC 6302 are consistent with the flux values of the model predictions.

2.5. Circinus Galaxy

The rich SWS spectrum of this Seyfert galaxy is discussed by Moorwood et al. (1996). A better rest wavelength can be determined for the 2.58 μm line of [Si IX]. A somewhat complex reference procedure had to be used because different species may have different intrinsic velocities. The accuracy is determined by excluding first differential pointing errors between apertures 1 and 2 using the [Ne V] 14.3 and 24.3μm lines. Both lines show the same shift of 51 km/s. Having excluded such a differential pointing error, it is best to use the [Si IX] 3.94 μm line as a reference for the 2.58μm line, in order to avoid possible velocity shifts between lines from the NLR and coronal lines. The shift of the [Si IX] 3.94 μm line with respect to the observation of Oliva et al., 1994 is 33 km/s. Therefore the lines in table 1 include a shift by this velocity and a correction for the heliocentric velocity of 439$\pm$2km/s (Freeman et al. 1977). A similar shift found for the other reference lines [Ar III] and [S III] gives confidence that we can propagate the error of the 3.94 μm line together with an additional uncertainty of 10 km/s into the error of the 2.58 μm transition.

2.6. Sgr A West

For our observation of Sgr A West the SWS slit centers were located at the position of the radio source Sgr A*. The full low resolution grating scan on this target (Lutz et al. 1996) provides a new rest wavelength for the [Fe III] transition at 33.038 μm. Out of the many lines detected on this target we have chosen the [S III] 18.71, 33.48 μm lines together with the [Fe III] 22.925 μm line as reference frame. Special care has to be taken in deducing a rest wavelength from an observation of this region, since the spatial and velocity structure are complex. Also, the distribution of [Fe III] emission is different from other low ionization lines (Lutz et al. 1993, Lacy et al. 1991). To account for these effects, we have adopted a two step reference line procedure. First, measurements of the [S III] 18.71μm and [Fe III] 22.925 μm lines were analysed to determine the apparent velocity offset between the [S III] and [Fe III] emitting media, the [Fe III] emission was found to be offset by 36 km/s. These two lines have rest wavelengths determined from non-ISO obervations, and are observed with the same pointing. Second, the [S III] 33.48 μm line was used in the standard manner as reference line for the pointing in which also the [Fe III] 22.925 μm line is observed, and the offset [Fe III]/[S III] determined in the first step was applied on top. Our total error estimate includes measurement uncertainties, uncertainties in the three reference wavelengths involved, and an additional 30 km/s uncertainty we have introduced since the [Fe III]/[S III] offset may differ somewhat for the two apertures involved which are not identical in size.

2.7. W51 IRS2

This Fabry-Perot observation centered on the W51 IRS2 H II region was carried out to improve the rest wavelength of the [Si II] 34.8 μm line. Instead of applying a heliocentric correction for this target we directly used the 4 reference lines from [Ne II], [Ne III] and [S III] observed with the FP to provide a consistent velocity frame.

3. Conclusions

The ISO Short Wavelength Spectrometer has been used to obtain new rest wavelengths for mid-infrared fine structure lines. For high excitation lines in particular, the accuracy achieved significantly improves previous values which were frequently based on energy level differences reconstructed from UV/optical spectroscopy, being differences of similar sized large numbers and hence intrinsically inaccurate. The new wavelengths should be useful for a wide range of mid-infrared spectroscopic studies.

This work was suported by DARA grants 50 QI9402 3 and 50 QI 8610 8. SWS acknowledges contributions from KU Leuven, Steward Observatory and Phillips Laboratory.

REFERENCES

Acker et al., 1992 Strasbourg-ESO catalogue of galactic planetary nebulae, ESO

Ashley M.C.B., Hyland A.R., 1988, ApJ, 331, 532

Beintema D. A., van Hoof P. A. M., Lahuis F., et al., 1996, A&A, 315, L253-257

Erickson E. F., Haas M. R., Simpson J. P., Rubin R., Colgan S., 1989 Bull. American Astron. Soc 21, 1156

Ferland G.J., 1993, Department of Physics and Astronomy Internal Report, University of Kentucky

Freeman K. C., Karlsson B., Lynga G., Burrell J. F., van Woerden H., Goss W. M., Mebold U., 1977, A&A, 55, 445-458

de Graauw Th., Haser L. N., Beintema D. A., et al., 1996, A&A, 315, L49-L54

Kelly D. M., Lacy J. H., 1995, ApJ, 454, L161-L164

Kessler M. F. K., et al., 1996, A&A, 315, L27-L31

Lacy J.H., Achtermann J.M., Serabyn E., 1991, ApJ, 380, L71-L74

Lutz D., Krabbe A., Genzel R., 1993, ApJ, 418, 244-254

Lutz D., Feuchtgruber H., Genzel R., et al., 1996, A&A, 315, L269-L272

Moorwood A. F. M., Baluteau J.-P., Anderegg M., Coron N., Biraud Y., 1978, ApJ, 224, 101

Moorwood A. F. M., Baluteau J.-P., Anderegg M., Coron N., Biraud Y., Fitton B., 1980, ApJ, 238, 565

Moorwood A. F. M., Lutz D., Oliva E., et al., 1996, A&A, 315, L109-L112

Oliva E., Salvati M., Moorwood A. F. M., Marconi A., 1994, A&A, 288,457

Pottasch S.R., Preite-Martinez A., Olnon F.M., Raimond E., Beintema D.A., Habing H.J., 1985, A&A, 143, L11-L13

Pottasch S.R., Beintema D., Dominguez-Rodriguez F.J., Schaeidt S., Valentijn E., Vandenbussche B., 1996, A&A, 315, L261-L264

Reconditi M., Oliva E., 1993, A&A, 274, 662-666

Serabyn, E., 1991, private communication

Schneider, S. E., Terzian, Y., Purgathofer A., Perinotto M., 1983, ApJS, 52, 399

Valentijn E. A., Feuchtgruber H., Kester D. J. M. et al., 1996, A&A, 315, L60-L63

Yamada C., Kanamori H., Hirota E., 1985, J. chem. Phys., 83, 552