HOW TO GET RID OF FRINGES IN SIRTF/IRS DATA

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ABSTRACT

The InfraRed Spectrograph (IRS) is one of three instruments on board the Space Infrared Telescope Facility (SIRTF) scheduled for launch in Spring 2003. It will take low and high resolution spectra from $\sim 5-40\mu$m. Interference of light waves reflected on the surfaces of filters, detectors, and other components in the SIRTF/IRS light path is expected to result in significant fringing in the measured spectra of astrophysical sources. Fringes associated with the IRS detectors have been observed in spectra measured in a laboratory set-up. Although precise fringe characteristics remain to be measured in orbit, it is clear that reliable defringing methods are essential in order to warrant an accurate analysis of interstellar features.

Key words: instrumentation: spectrographs – methods: data analysis – infrared: general

1. INTRODUCTION

Initial defringing algorithms have been developed for the SIRTF/IRS instrument. The InfraRed Spectrograph IRS (Roellig 1998) is one of three instruments on board the Space Infrared Telescope Facility SIRTF (Fanson 1998) scheduled for launch in Spring 2003. The IRS is an echelle spectrograph composed of four modules. Two modules will provide low resolution ($R = \lambda/\delta\lambda = 60-120$) spectra from $5.3-40\,\mu$m and another two modules will take high resolution ($R\sim 600$) spectra from $10-37\,\mu$m.

In the IRS wavelength range many spectral features of ices, silicates, PAH's, molecular bands and unresolved molecular and atomic emission and absorption lines can be observed. The presence of fringes in the spectra will hinder the detection and/or analysis of these often very weak spectral features.

The development effort for the IRS defringing forms part of the SIRTF-Legacy program "From Molecular Cores to Planet-Forming Disks" (PI, N.J. Evans), which will obtain IRS spectra of ~200 young stellar objects in Perseus, Ophiuchus, Chamaeleon, Lupus and Serpens (co-I's E.F. van Dishoeck and G.A. Blake). The work is done in collaboration with the IRS Instrument Team and the SIRTF Science Center. The developed algorithms form an integral part of the SIRTF/IRS data analysis environment SMART[1] and have also been made available to the SSC for distribution to the general observer.

2. INSTRUMENTAL FRINGES

Fringes originate from interferences on plane-parallel surfaces in the light path of the instrument. These surfaces act as Fabry-Pérot etalons, each of which can add unique fringe components to the source signal. In the infrared wavelength range surfaces separated by a few mm up to a few cm form the most efficient FP's. Fringes are therefore expected to be seen in the SIRTF/IRS spectra and have indeed been observed in spectra measured in a laboratory set-up.

In principle the instrumental fringes are removed from the observed spectrum by calibrating out the response of the instrument. However, due to the nature of the fringes this calibration will for most observations be imperfect. The detailed fringe pattern is mainly determined by the wavelength scale and the resolution. Small offsets in wavelength (offsets much less than a resolution element) can change the position and spacing of the fringe peaks. These offsets can result from an imperfect wavelength calibration or from an off-center location of the source in the slit. The extent of the source determines the effective resolution and thus the amplitude of the observed fringes.

Reliable defringing routines will therefore be needed to achieve the highest possible signal to noise. Such defringing methods have also proven to be essential in extracting weak features from data from the Short Wave-

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[1] SMART is code developed at Cornell University for the analysis of SIRTF/IRS data. Additional plug-in modules for peak-up photometry have been developed at Arizona University and for defringing at Leiden University, SRON Groningen and Caltech.

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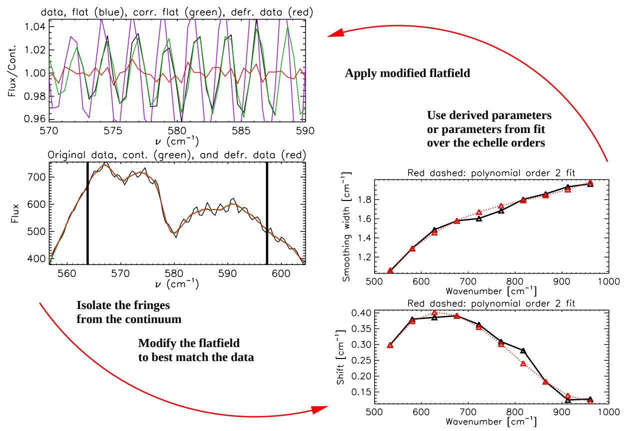

Figure 1. Modifying a flat-field in practice. For each echelle order the shift and resolution correction is determined. Shown in the left plot are the corrections for one Short High (SH) order. Subsequently, there is the choice to either use the derived correction values or an interpolated version of these to correct the flat field before applying it to the observed spectrum. This is shown in the tight plot.

length Spectrometer (SWS) on board the Infrared Space Observatory (ISO) (e.g. Lahuis & van Dishoeck 2000 and Lahuis et al., this volume)

3. DEFRINGING ALGORITHMS

Two algorithms have been developed for the defringing of the IRS spectra. The first method minimizes fringe residuals by correcting the flat field to best match the data. The second method uses a robust method of iteratively fitting sine functions. The two methods can be used either separately or in combination. In the latter case the fringes are first removed by optimizing the flat field to the data and then the sine-wave fitting is used to remove residual fringes in the data. In-orbit data are needed to test both methods to the extreme and it may well depend on the specific observation which method or combination of methods will work best.

In order to analyze the fringes it is essential to first isolate the fringes from the underlying continuum signal. In addition, any unresolved spectral features present in the spectrum need to be identified. These features will influence the correlation of the fringes of the flat field and the observation, as well as the parameter estimates in the sine-wave fitting. The masking of the unresolved spectral features is fully automatized. In the unlikely event this should not work, the user can of course define these by hand.

4. FLAT FIELD MODIFICATION

The first method minimizes the fringe residuals in the data by matching the fringes in the IRS flat field with the fringes in the science observation. The fringe phase is a function of source position in the slit, while the spectral resolution depends on the filling factor of the source in the slit. Straight division of observation and flat field is thus expected to give residual fringes in a nominal observation. To avoid this, the flat field fringe phase (i.e. wavelength scale) is therefore shifted and the flat field spectral resolution is matched to that of the observation by smoothing or artificially enhancing the fringe amplitudes. Subsequently, the modified flat field fringe spectrum is multiplied back into the flat field 'continuum' and the astronomical spectrum is divided through the modified flat field, giving a spectrum with minimal fringe residuals. Figure 1 gives a short overview of the whole flat field modification procedure.

5. SINE WAVE FITTING

The second method uses robust sine-wave fitting to remove the fringes. The starting point is the optical theory on Fabry-Pérot interference from which an approximation is derived which is computationally stable and easy to implement.

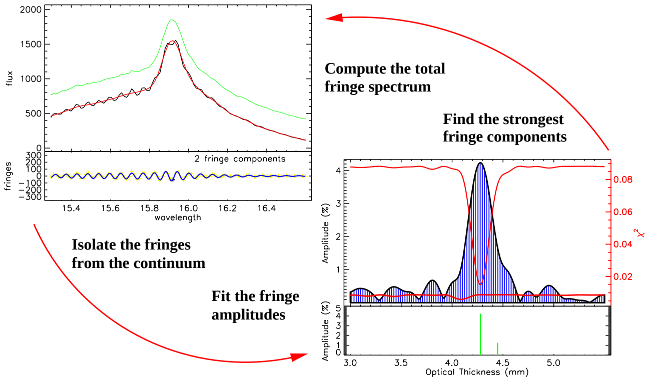

Figure 2. Sine-wave fitting in practice. In the left figure the original data with continuum are plotted. Offset the final defringed spectrum is shown. In the lower panel the continuum subtracted data and the computed fringe spectrum are plotted. In the right figure the derived fringe amplitude and the effective decrease in chi-sq are plotted for the selected range of optical thickness. In the lower panel the selected fringe components are shown.

5.1. FABRY-PÉROT INTERFERENCE

The transmission function of a Fabry-Pérot element is given by the Airy function:

$$I_t = \frac{T^2}{(1-R)^2} * \frac{I_o}{1+(\frac{4R}{(1-R)^2}) * \sin^2(wD\pi)} \tag{1}$$

with:	R	reflectance [%]	$R + T + A = 1$
	T	transmission [%]	
	A	absorption [%]	$A \simeq 0$ on the surface
and:	D	optical thickness	$2nd$
	d	mechanical thickness	$\sim 500\,\mu$m
	n	refractive index	~ 4.3 for the SH detectors
	w	wavenumber [cm^{-1}]	

where R, T, A and n are functions of w and d is a function of the position on the detector wafer. For a reflectance of a few percent the transmission function may be approximated by $I_t = A\cos(2\pi wD + \alpha)$. This can be rewritten into a computationally more handy form as:

$$I_t = A_f \cos(2\pi wD) + B_f \sin(2\pi wD) \tag{2}$$

This is the basic formula which was used in the ISO-SWS defringing algorithm (see Kester 2001 and Lahuis & van Dishoeck 2000) which has been adapted for use with the SIRTF/IRS data.

5.2. FRINGE CHARACTERISTICS

The detailed fringe spectrum is determined by the reflectance and the optical thickness. The reflectance determines the modulation depth given by $(1-R)^2/(1+R)^2$. The optical thickness (i.e. the mechanical thickness and the reflective index) determines the position of the transmission maxima ($w_{max} = N/D$ with N the FP-order which ranges from approximately 250 to 400).

It is clear that any change in one of the parameters will modify the spectral shape of the fringe system. The reflectance and the reflective index are known to change with wavelength and the mechanical thickness of the detector wafer can vary with detector position.

Once enough high quality in-orbit data are received and more about the IRS instrument and its calibration is learned the fringe model will be improved. For example, the definition of an accurate model for the wavelength dependence of the reflective index and reflectivity will be attempted.

5.3. IMPLEMENTATION

In the current implementation all parameters are assumed to be constant. This is a reasonable assumption when data over a small wavelength range are considered like those from one IRS echelle order. Limiting ourselves to this small wavelength range, the fringes in Short-High (SH) data can be fitted with one main component.

Figure 2 gives an overview of how this is currently implemented. First the fringes are isolated from the continuum. Then A_f and B_f in formula (2) are fitted for a limited range of optical thicknesses. The strongest fringe components are selected and the fringe spectrum is computed and divided out of the spectrum. It is possible to use this procedure on both the astronomical observation and the flat field and subsequently divide a defringed observation with a defringed flat field. It is also possible to use this procedure to remove residual fringes from the standard flat-fielded spectrum. High quality in-orbit data are needed to test which option is best.

6. CONCLUSIONS

We have written a working set of IRS defringing tools before the launch of SIRTF. This will allow us to improve the reduction of the IRS spectra from the Evans Legacy program in an early phase of the mission. It will also help us and the IRS calibration experts to better understand the IRS instrument in orbit. With the arrival of in-orbit data the IRS fringe characteristics can be further determined. The defringing algorithms will also be improved, e.g. by improving the physical fringe model and extending the model from 1-D to 2-D. It is our and the SSC's intention to make a stable version of the defringing algorithms available to the general observer as soon as possible.

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