User's Guide to Reducing NIR XD Spectra via XDSpres

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Contents

Abstract

This manual explains the use of the XDSpres routine, developed to reduce cross-dispersed spectra from the Ohio State Infrared Imager/Spectrometer. We base our explanations in the belief that the reader is already familiar with IRAF routines, although new to reducing Cross-dispersed and/or echelle spectra. If you are completely new to IRAF we strongly recommend reading first *A User's Guide to CCD Reductions with IRAF* by Philip Massey and *A User's Guide to Reducing Slit Spectra with IRAF* by Phil Massey, Frank Valdes and Jeannette Barnes, both documents are available at *http://iraf.noao.edu/docs/spectra.html*

1 Installation

1.1 Site Installation

This type of installation allows every user on this machine to use the software, therefore it requires that you have administrator priveleges. Here is an example of a typical installation with common paths.

1. Move the tar file containing the package to the desired directory.

```
%> mv xdspres.tar.bz2 /iraf/iraf/extern/
```

2. Move to that directory and unpack the tar file containing the package.

   `%> cd /iraf/iraf/extern/xdspres/`

   `%> tar -xvf xdspres.tar.bz2`

3. Add the following lines to the extern.pkg file, before the keep statement. This file is usually located at /iraf/iraf/unix/hlib/.

   `reset xdspres = /iraf/iraf/extern/xdspres/`

   `task $xdspres = xdspres$xdspres.cl`

1.2 User Installation

If you want an installation at the user level, follow the next steps, where arthurdent is the user's login.

1. Create a directory in which to extract the package, for instance:

   `%> mkdir /home/arthurdent/xdspres/`

2. Move the tar file containing the package to that directory.

   `%> mv xdspres.tar.bz2 /home/arthurdent/xdspres/`

3. Move to that directory and unpack the tar file containing the package.

   `%> cd /home/arthurdent/xdspres/`

   `%> tar -xvf xdspres.tar.bz2`

4. Add the following lines to your login.cl file, before the keep statement.

   `reset xdspres = /iraf/iraf/extern/xdspres/`

   `task $xdspres = xdspres$xdspres.cl`

   WARNING! If you choose a local instalation, the xdspres package will not appear in the list of installed packages when you start IRAF.

2 Flat-fielding (*xdflat*)

Flat-fielding data of XD spectroscopy is trickier than single slit spectroscopy due to the blazing of different orders. If you take a look at your flat image with *SAOImage DS9* you will notice that the region where the bands should be is over illuminated, since the light from the flat-field lamp is already dispersed. Therefore we must select these regions and normalize them independently of the dark area of the CCD. Moreover, wavelengths of the order of micrometers begin to show thermal emission from the telescope itself, which requires exposures with the flat-field lamp off (hereafter "flat-off"). Subtracting the later from the normal flat-field exposures (hereafter "flat-on") yields an image without the instrument emission component.

The task *xdflat* of the XDSpres package is designed to perform the following procedures: linearize the images, combine exposures of the same kind ("on" or "off"), subtract flat-off from flat-on and normalize the flat-field image. Lets take a look at the parameter page for *xdflat*, where we have placed some example values, S06B_0930.0004.fits being the first image.

```
PACKAGE = xdspres
   TASK = xdflat

prefix  =           S06B_0930.  Image name prefix
(comb   =                  yes) Subtract and combine flat exposures?
(first  =                    4) First image number
(last   =                   18) Last image number
```

```
(key    =                object) Header keyword
(keyon  =            xdflat-on) Value of keyword for flat on
(keyoff =           xdflat-off) Value of keyword for flat off
(out1   =                  flat) Name of subtracted flat
(apflt  =                   yes) Normalize flat?
(out2   =                  Flat) Name of normalized flat
(f_funct=               spline3) Flattening function
(f_order=                    30) Order of the flattening function
(apid   =     xdspres$xdap.tab) Aperture identification table
(inter  =                    no) Perform tasks interactively?
(mode   =                     q)
```

prefix: Sets the prefix for the input flat-field image names. It is important not to add the trailing zeros here, since the task already has a way of dealing with them. Putting S06B_0930.00 in this field would result in an attempt to open file S06B_0930.000004.fits.

comb: Chooses wheter to combine and subtract the flat-off from flat-on. If any thing should go wrong with the extraction process, after the subtraction has taken place, this option could be set to `no`, to avoid unecessary processing.

first: The number of the first flat-field image. There is no need for the trailing zeros.

last: The number of the last flat-field image.

key: The script searches for this keyword in the header of the image to discriminate between flat-on and flat-off.

keyon: The value of the keyword set in the last parameter that corresponds to a flat-on.

keyon: Analogous to the above, but with respect to flat-off.

out1: Name of the image yielded by the subtraction of flat-off from flat-on.

apflt: Chooses whether to run the task *apflatten*, which normalizes the apertures.

out2: If *apflt* is set to "yes", this will be name of the normalized image.

f_funct: Function that will be fitted to the flat-field in order to remove illumination effects.

f_order: Order of the aforementioned function.

ref: This parameter is passed directly to *apflatten* if you wish to use same apertures of another image.

The task *irlincor* from the CTIO package is used to apply the linearity correction. This task utilizes a 3rd order polynomial with the following coefficients:

Table 1: *irlincor* coefficients

Order	Coefficient
0	1.00108
1	-3.328396e-2
2	0.166216
3	-6.844057e-2

After linearizing each image, *xdflat* will look for the keyword defined in `key` to discriminate between flat-on and flat-off, writing them accordingly in a list. All the images of the same kind are averaged via *imcombine* and the flat-off average is subtracted from the flat-on average.

When *xdflat* is done with the averaging and subtraction of the different exposures, it will attempt to extract the flat, turning the two-dimensional image into three one-dimensional spectra. To these spectra the flattening function will be fitted, and later applied to the two-dimensional image. The purpose of using a function of such a high order is to remove the very complicated pattern of illumination that is intrinsic to the instrument, from the flat correction.

3 Everything else (*doosiris*)

Doosiris is a long CL script that includes all the steps from the raw images to the fully reduced one dimensional spectra. It was designed to be highly automated with the more tedious and repetitive work being concealed. Nevertheless, careful users can choose a more interactive approach to extraction and wavelength calibration.

3.1 Reduction process outline

I have put below the general steps that are followed in a near-infrared spectral data reduction, since it is much easier to assemble a puzzle after taking a look at the picture on the box.

- Linearize the images.
- Subtract sky exposures from the object ones in order to remove telluric emission lines.
- Combine object exposures.
- Extract the object spectra.
- Extract the sky spectra.
- Perform wavelength calibration by identifying OH lines in the sky spectra.
- Extract the standard star spectra.
- Remove telluric absorption lines from the object spectra.
- Perform flux calibration.

3.2 *doosiris* parameters

The lines below provide a very brief explanation on each parameter for the *doosiris* script, which is intended for quick reference. Detailed discussion is found in the next sections.

```
PACKAGE = xdspres
   TASK = doosiris

prefix  =   ./raw/s06b07_0930.  Image name prefix
(outpre =              ngc104_) Output image name prefix
(lsc    =                  yes) Linearize, subtract and combine science exposures?
(inter  =                  yes) Perform extraction interactively?
(num1   =                  110) First image number
(num2   =                  139) Last image number
(objseq =          ngc104_.seq) File containing the sequence of object/sky images
(apid   =     xdspres$xdap.tab) Aperture identification table
(nflat  =          ./flat/Flat) Normalized flat image
(skyim  =              sky104_) Output name for sky image
(id     =                  yes) Identify OH lines interactively?
(refskyj=                     ) Reference image for OH line identification (J band)
(refskyh=                     ) Reference image for OH line identification (H band)
(refskyk=                     ) Reference image for OH line identification (K band)
(linelis=  xdspres$ohlines.dat) File containing the OH lines list
(statm  =             xdspres$) Path to the star atmospheric models
(starn1 =                  147) First star image number
(starn2 =                  159) Last star image number
```

```
(seqstar=                  ab) Sequence of star images
(star   =            hip2578_) Star output prefix
(jmag   =               5.061) Star's J magnitude
(hmag   =               5.156) Star's H magnitude
(kmag   =               4.985) Star's K magnitude
(mode   =                   q)
```

prefix: Prefix of the input science images. Ex: s06b07_0930. would be the prefix for an image named s06b07_0930.0057.fits.

outpre: Prefix for output processed images.

lsc: Chooses whether to perform pre-processing procedures, namely: linearization, subtraction (object - sky) and combination.

inter: This parameter is passed directly to the tasks responsible for finding, editing, tracing and extracting the apertures.

num1: Number appended to the input image prefix for the first image of the sequence.

num2: Last number in the input sequence.

objseq: Name of the ASCII file containing the order in which object and sky exposures are arranged. If you do not know the order *a priori* this field can be left blank, leading *doosiris* to create the file during the interactive idenfication process.

apid: A file containing numbers, beams and names for the apertures. This parameter is passed to *apdefault*.

nflat: Normalized flat image to be applied. This is the output produced by *xdflat*.

skyim: Output name for processed sky images.

id: Perform wavelength calibration interactively?

refskyj: Name of a sky image with features already identified, in the case that the last option is set to "no".

linelis: Name of the file that contains the wavelengths of OH lines. The package contains a list extracted from Oliva 1992.

statm: Path to atmospheric models of the standard star. Kurucz 1993 models for an A0V star are provided with the *xdspres* package.

starn1: Number for the first star exposure.

starn2: Number for last star exposure.

seqstar: Sequence of star images: "ab" for two different positions at the slit and "abc" for three different positions.

star: Output prefix for processed star images.

jmag: Star's magnitude in the J spectral band.

hmag: Star's magnitude in the H spectral band.

kmag: Star's magnitude in the K spectral band.

3.3 Preliminary steps

Before any of the procedures that are specific to each image, the script applies the linearity correction to every image. In order to avoid applying the correction on an already corrected image, which lead to erroneous results, the script looks for the "lincor" keyword in the image header. If "lincor" is set to "yes" the script skips the correction, and if the keyword is not found the correction is applied and the header is updated.

At this stage *doosiris* gathers information about the airmass ("secz" in the header) from all the science exposures, including those of the standard star, that will be needed in the flux calibration.

3.4 Subtraction Object - Sky

The spectral region covered by the osiris spectrograph is crowded with telluric emission and absorption features. The later will be discussed in section 3.9 because it requires the extraction of a comparison star.

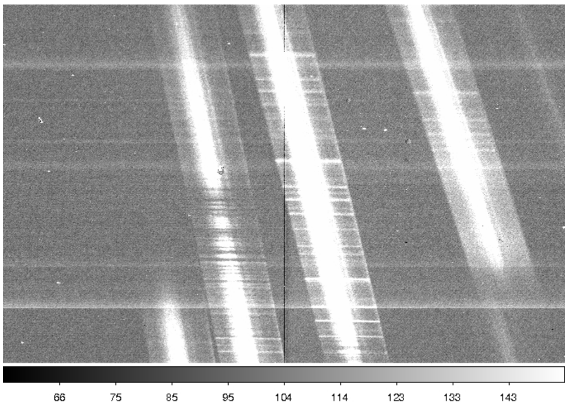


Figure 1: Science exposure

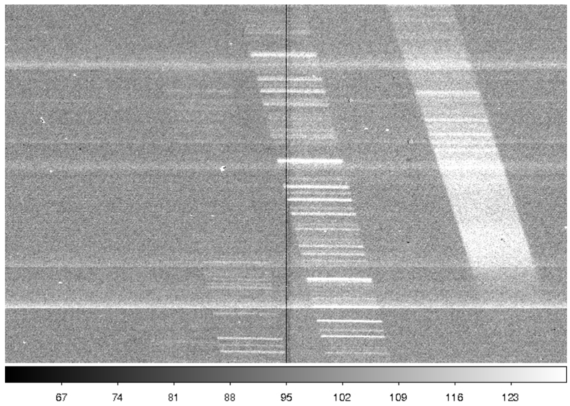


Figure 2: A nearby dark region of the sky

The emission lines though, can and should be removed prior to any extraction procedure. Figures 1 and 2 are respectively object and sky images.

The first thing to notice is the diference in the profile along the horizontal axis. If you take a closer look to the dispersion bands (the almost vertical stripes) you'll notice that the object exposure shows intensity differences as you move horizontally in the same stripe, it's clearly more intense in the middle. The sky, on the other hand, shows no such features, being almost completely flat in that direction. In our case the typical count within the dispersion axis in the sky exposure is very close to half the typical counts in the center of each band in the object exposure. Perhaps the reader will find it easier to point out the difference between sky and object exposures by overploting them with *implot*.

Doosiris offers two different ways to perform the identification of the object and sky images. The first one, which I recommend if it is your first time reducing these images, displays each exposure via *SAOImage DS9* and asks the user to inform the nature of the image, typing "a" for an object exposure and "b" for sky exposure, or any other letter if you do not want to use that image at all. If, on the other hand, you are certain about every image, you can place the correct order in an ASCII file, containing as many lines as there are images, that will be read by *doosiris*. Such a file is automatically written if you choose to identify each image interactively, so that if you need to reduce the same images again you can skip the identification process.

After a sucessful identification the script will make a copy of the images with the following terminology: `outpre//i//s`, where `outpre` is the chosen output prefix, `i` is an integer starting at `num1` and ending in `num2`, `s` is "a" in the case of an object exposure and "b" in the case of a sky exposure, and "`//`" represents a concatenation. At the same time, a cosmic ray removal is performed via the *crutil.cosmicrays* task.

The actual subtraction takes place before any combination of images. Since the sky changes very rapidly, the script chooses the sky exposure that is closest to the science exposure in the order of images. A file named "subtraction.log" is written with all the operations that were performed.

3.5 Combining images

By the time the identification of object and sky exposures is being done, the script appends the name of each image to a list that serves as input to *imcombine*. The combination of images is actually a summation, where the highest and lowest values for each pixel are rejected. All the already subtracted object images are stacked together, as well as all the sky images. The latter will be used in wavelength calibration.

3.6 Extraction

This is the part where the two-dimensional images become one-dimensional spectra. There are three apertures to be extracted in the 2d image, that roughly correspond to J,H and K bands, and that *doosiris* will attempt to extract. All the extraction procedures are performed automatically unless you choose to do them interactively.

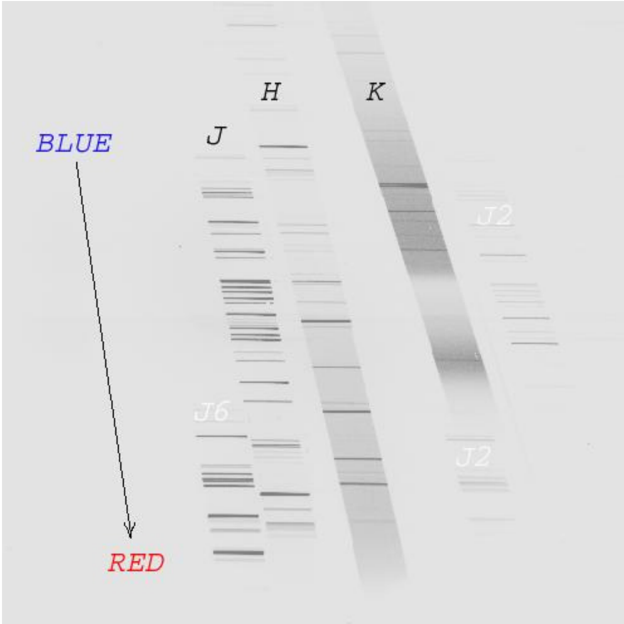


Figure 3: Order map for the cross dispersed mode Acessed at http://www.ctio.noao.edu/instruments/ir_instruments/osiris2soar/manual/xdisp.html, January 18, 2011. Keep this picture in mind if you choose to do aperture tracing interactively.

After the extraction, there are basically two ways of treating spectra, or two formats: onedspec or multispec. In the first each spectrum is recorded at a different single lined FITS file, the second yields a single FITS file with muliple lines, each containing the spectrum extracted from a different aperture. *Doosiris* works with the former, but whereas *apall* names the different files with four digit numbers matching the apertures, this script names files as *_j, *_h and *_k.

3.7 Wavelength Calibration

Usually, in optical spectroscopy, the wavelength calibration is done by examining the spectrum of a comparison lamp of rarefied gases, like Thorium-Argonium, which have lots of visible emission lines. Since we are working in a region of the eletromagnetic spectrum which has plenty of sky emission lines (mostly due to OH), we'll use the sky as our comparison spectrum. In order to have a perfect correspondence between science and sky exposures, *doosiris* uses the aperture definitions of the object, proceeding directly to the extraction of the combined sky image.

If you have chosen to interactively identify the OH features (by setting `id = yes`), *doosiris* will call the *identify* task, with the first (meaning J band) aperture already loaded. Identifying three or four well spaced lines is enough to fit a fair dispersion curve. The two other bands will be prompted to you after writing the dispersion curve to the database. Choosing line identification to be automatic will cause *doosiris* to attempt a match between a previously identified set of sky spectra, which has to be specified in the `refsky` parameters.

A file containing wavelength coordinates of OH spectral features is needed in either case, automatic or interactive identification. The one provided with *xdspres* is based on Oliva 1992.

3.8 Standard Star

In order to remove the atmospheric absorption from the science spectra, one needs to have an standar star spectrum, with very few stellar lines. A0V stars make excellent standard stars for this spectral region because the only stellar lines present in their spectrum are well known hydrogen lines that can be easily removed by

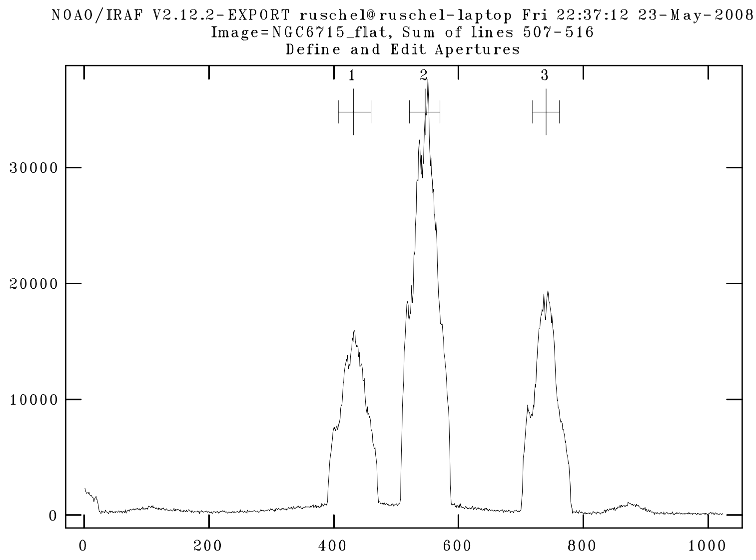


Figure 4: Example of aperture editing of an extended source.

comparison with an atmospheric model, like those found in Kurucz 1993.

Since a star occupies only a small fraction of the slit, object - sky pairs can be replaced by observing the star in different positions along the slit, which greatly reduces telescope time. *Doosiris* is prepared to accept two formats of standard star observation, namely two or three different positions. In either case, exposures with the star in the same place are combined and extracted individually, and the resulting spectra is summed.

3.8.1 Removal of star's atmospheric lines

The extraction process can be completely automatic, but since the apertures are going to be redefined, a little tweaking with the wavelength scale is needed to match the star spectra first to the atmospheric models, and second to your science spectra. Removing the absorption features present in the spectrum of the star is critical to make sure that only telluric absorption is going to be removed from the science spectrum.

In principle the process is very straightforward, one would just have to divide the spectrum of the star by a normalized spectrum, with absorption lines having values less than one. However atmospheric models and the recently extracted star have different scales that need to be matched, in order to achieve a meaningful result, which brings us to the *telluric* task.

Figure 6 shows an example of the adjustment between the star's J band spectrum and the corresponding atmospheric model. The only appreciable line in this band is Pa β, at 12818 Å. At this stage you should try different shifts and scaling factors to achieve the best match. The resulting spectrum, the one in the middle of the top window at fig. 6, will be used on the next step. For details on *telluric* see help page for this task.

3.9 Removal of telluric features

Once the absorption lines due to the stellar atmosphere have been removed, you get a spectrum that is essentially a blackbody with lots of telluric absorption, the only thing left to do with it is a normalization. This will remove differences in illumination, leaving just telluric lines with values different than one. *Doosiris* utilizes the *continuum* task here, fitting a polynomial to the unabsorbed regions of the spectra and returning the ratio between the two.

Then the *telluric* task is called again, this time to actually remove the telluric absorption from the science spectra. Figure 7 shows an example of the interactive matching between science and telluric spectrum in the J band.

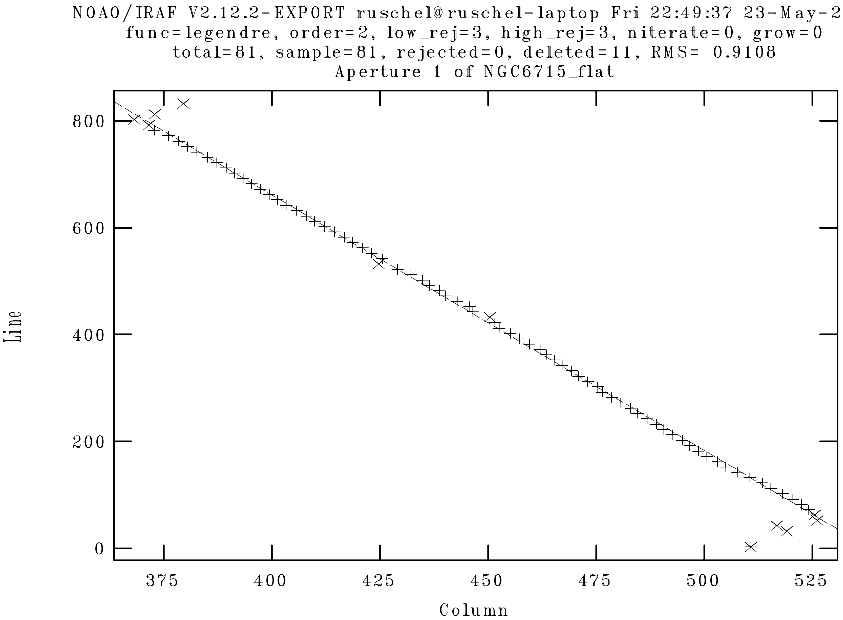


Figure 5: Example of aperture tracing.

3.10 Sensibility function

Appart from sensibility variations intrinsic to the detector, cross-dispersed spectra adds an illumination compponent inherited in the blazing of different orders. To map these variations in illumination *doosiris* utilizes the recently fitted "continuum" of the standard star. Unabsorbed regions, that translate into sample regions for continuum fitting, were identified with the aid of NSO/Kitt Peak FTS data produced by NSF/NOAO [1].

The *standard* task makes a comparison between the fitted continuum and the blackbody fluxes for a set of bandpasses. The output of this last task is used by *sensfunc* to estimate the sensibility function that will be applied to the science spectrum via *calibrate*. When finished you are left with a fully reduced spectrum.

A OH Spectral Atlas

The images below were taken from the OSIRIS Manual, and are meant to guide the

[1]available at http://www.eso.org/sci/facilities/paranal/instruments/isaac/tools/spectroscopic_standards.html

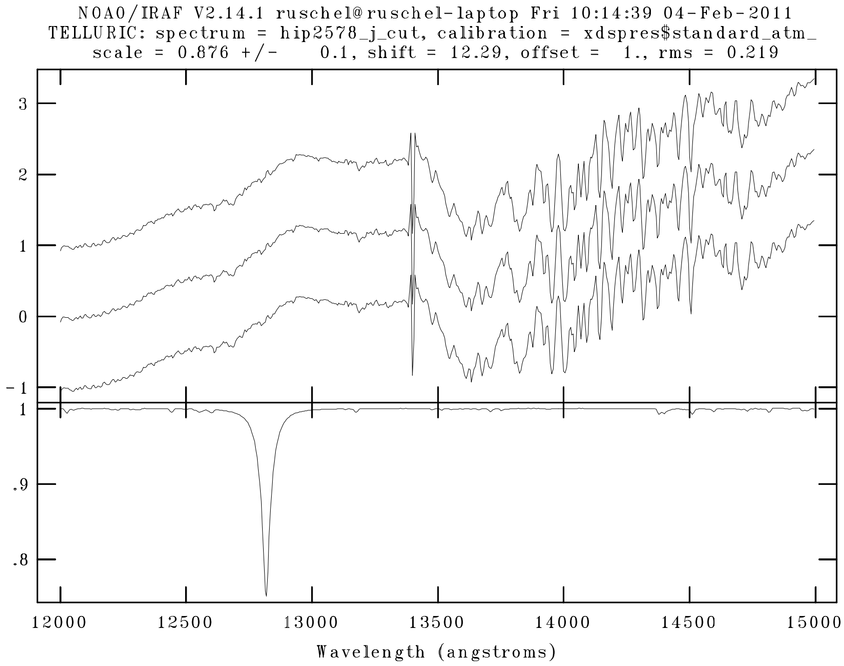


Figure 6: Fitting stellar atmospheric model to the standard star's spectrum.

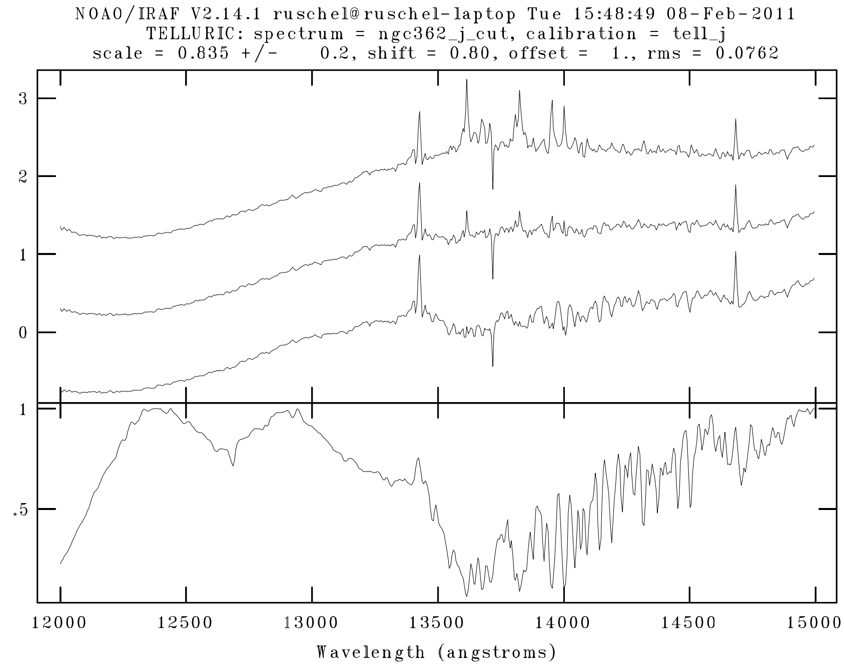
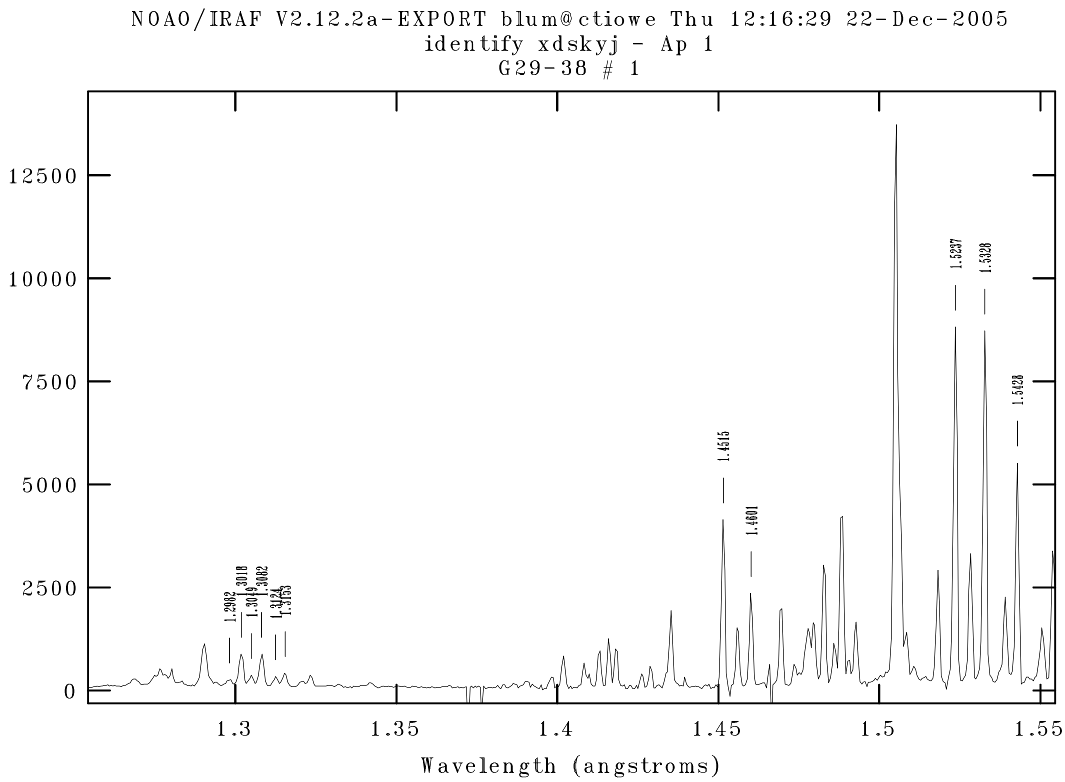
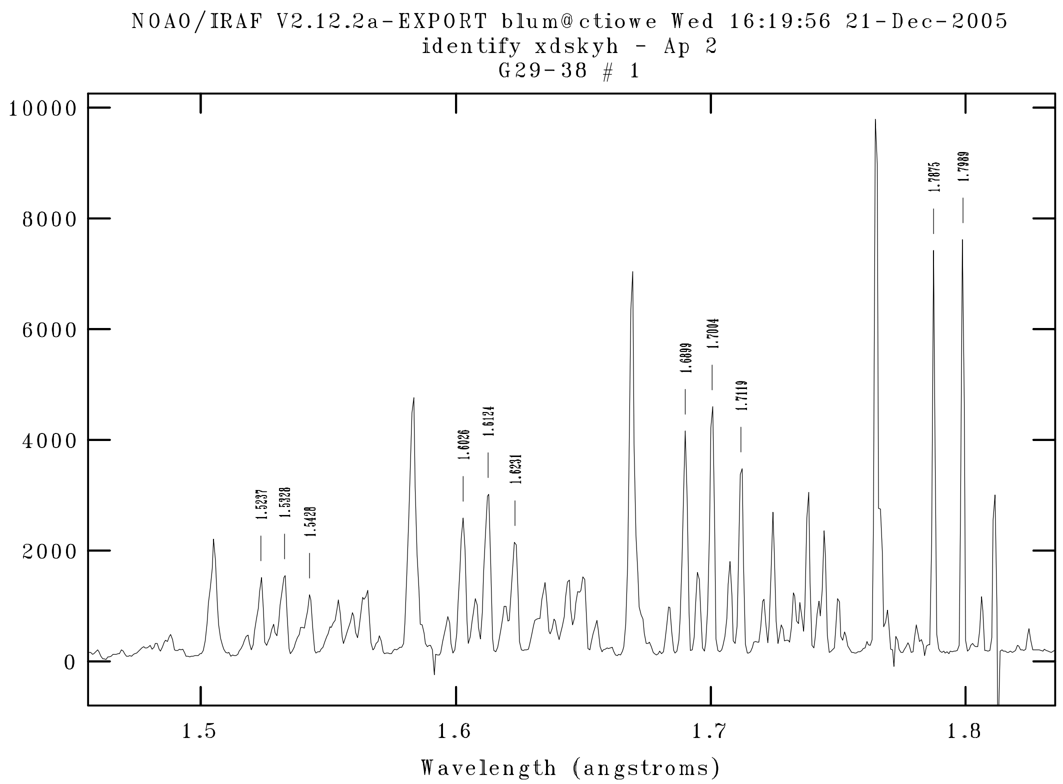
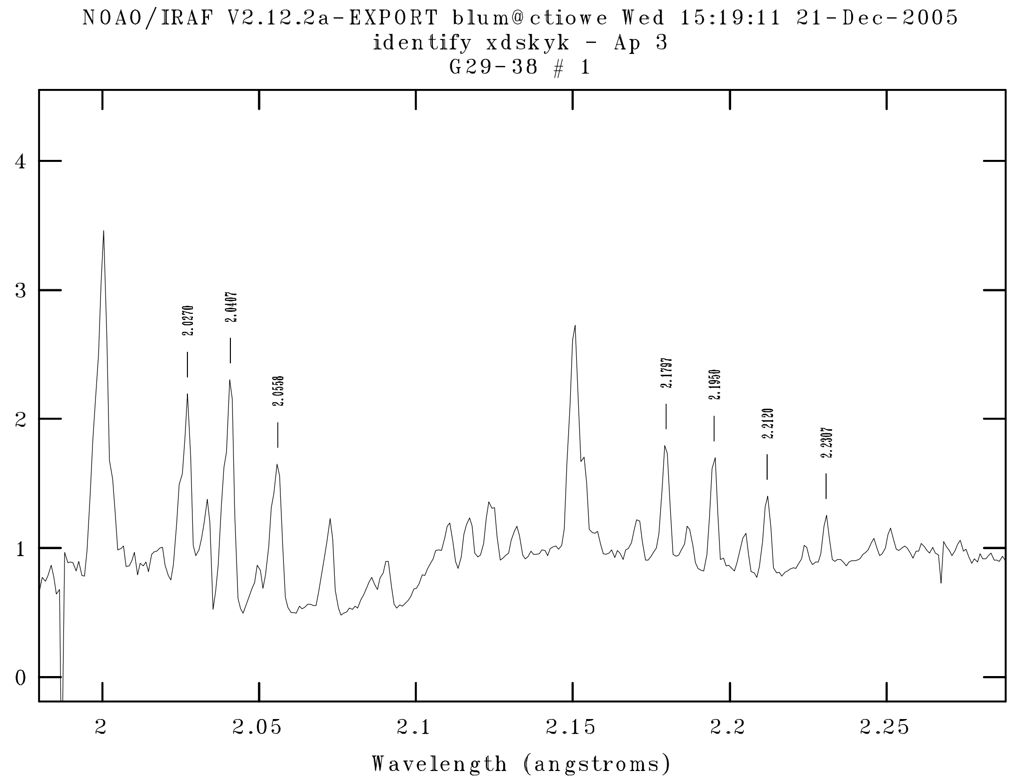


Figure 7: An example of telluric line removal from the science spectra


NOAO/IRAF V2.12.2a-EXPORT blum@ctiowe Thu 12:16:29 22-Dec-2005
identify xdskyj - Ap 1
G29-38 # 1
12500
10000
7500
5000
2500
0
1.3
1.35
1.4
1.45
1.5
1.55
Wavelength (angstroms)
1.2982
1.3018
1.3082
1.3124
1.3153
1.4515
1.4601
1.5237
1.5328
1.5428


NOAO/IRAF V2.12.2a-EXPORT blum@ctiowe Wed 16:19:56 21-Dec-2005
identify xdskyh - Ap 2
G29-38 # 1
10000
8000
6000
4000
2000
0
1.5
1.6
1.7
1.8
Wavelength (angstroms)
1.5237
1.5328
1.5428
1.6026
1.6124
1.6231
1.6899
1.7004
1.7119
1.7875
1.7989


NOAO/IRAF V2.12.2a-EXPORT blum@ctiowe Wed 15:19:11 21-Dec-2005
identify xdskyk - Ap 3
G29-38 # 1
4
3
2
1
0
2.0270
2.0407
2.0558
2.1787
2.1950
2.2120
2.2307
2
2.05
2.1
2.15
2.2
2.25
Wavelength (angstroms)