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FLOYDS Manual and Pipeline 2.0.0

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ABSTRACT

Context. The Las Cumbres Observatory Global Telescope Network (LCOGT) has recently deployed two new, robotic spectrographs on the Faulkes telescopes, FTN and FTS. This document details the characteristics of the spectrograph, the data reduction pipeline we have developed, and the data products that the user can expect.
Aims.
Methods. Results. Instrumentation: spectrographs – Methods: data analysis – Techniques: spectroscopic
Conclusions.

Key words.

1. Overview of the FLOYDS instruments

FLOYDS are a pair of nearly identical, low dispersion, robotic spectrographs deployed at the 2m Faulkes Telescopes, North and South (FTN and FTS). The instruments were designed with supernova classification and monitoring in mind, with a large wavelength coverage (∼320 to 1000 nm) and a resolution (R∼300 to 600, depending on wavelength) well-matched to the broad features, but heterogenous nature, of these transient events. The design uses a low dispersion grating (235 l/mm) and a cross-dispersed prism in concert to work in first and second order simultaneously. A folded all-reflecting camera focuses first and second order light onto the CCD. This allows a ∼320 to 1000+ nm wavelength coverage in a single exposure. A 30″ slit length allows both orders to fit on the chip with no order overlap (Figure 1). Four such 30″ slits are available at each spectrograph, with widths that bracket the median seeing at each site (0.″9, 1.″2, 1.″6 at FTN; 1.″2, 1.″6 and 2.″0 at FTS) and a 6″ slit width for spectrophotometry. Since the FLOYDS spectrographs are mounted on the 2m telescopes' Cassegrain rotator stages, the slit may be oriented along any desired position angle on the sky (note that this is not necessarily a good idea, though, given the very broad wavelength coverage of FLOYDS). An Andor Newton 940 CCD controller package, with an e2V 42-10 CCD (13.5 μm pixels and a 2048×512 format), is used with a broadband ultraviolet-enhanced coating. The Andor Newton CCD package is thermo-electrically cooled to -70 C, with negligible dark current. Spectra do fringe above ∼700 nm, but this can be corrected when a flat field is taken at the same position as a science frame. Wavelength calibration is accomplished with a Mercury Argon (HgAr) lamp, and flat fielding with a combination of a tungsten halogen and high-powered xenon lamp (whose light are combined with a dichroic). The calibration unit housing these lamps sits in a cabinet near the telescope with a fiber connection to FLOYDS. A deployable arm in the FLOYDS instrument can direct light from the calibration unit into the spectrograph, and accompanying optics delivers light with an f/10 beam, mimicking the actual Faulkes telescopes. An example of a typical raw spectrum is shown in Figure 1. A typical calibration arc is shown in Fig. 2, and a representative flat is shown in Fig. 3

2. Inputing your observations into the Phase 2 GUI

Installing and basic operation of the the Faulkes Telescopes' phase 2 GUI is beyond the scope of the FLOYDS manual; ask your local expert if you need help. Here we will focus on those aspects of the phase 2 specific to FLOYDS, with the understanding that the reader already knows the basics of the phase 2.

A typical observation group will consist of three or four individual observations, using the phase 2 parlance, consisting of the actual science exposure, as well as flat fields and wavelength calibrations at the science position (Fig 4). First set up your monitoring (or other) group as you normally would for other FT instruments, specifying the appropriate observing conditions and timing window.

The next step is to begin populating your group. Start by making instrument configurations for FLOYDS. The FLOYDS button is the one on the far left in the phase 2 'Instrument Configs' window. You will need, at minimum, three different configurations – one for your target, one for flat field calibrations and one for wavelength calibrations. We

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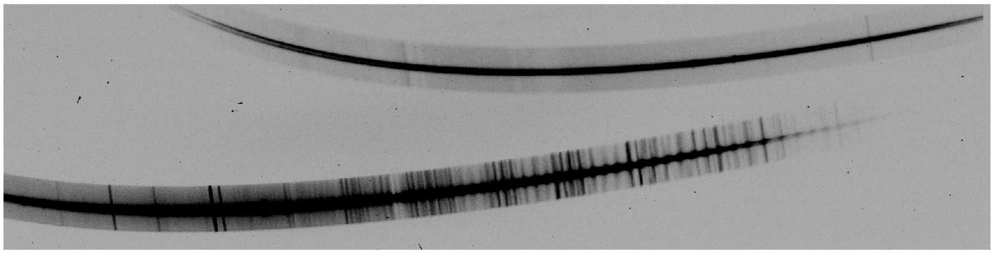

Fig. 1. A raw FLOYDS spectrum of a recent SN: SN2013ek (Valenti et al. 2013), which nicely illustrates the data format. The top trace is second order light, with a wavelength coverage of ∼320-570 nm, while the bottom trace is first order light, spanning ∼550-1000+ nm.

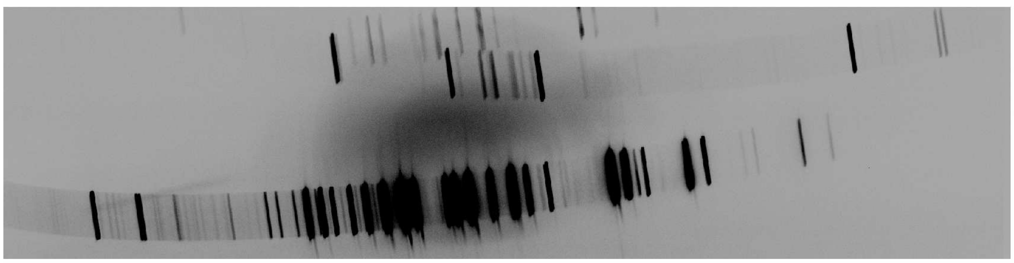

Fig. 2. Representative arc frame from FLOYDS at FTS. You will note there is some ghosting of first order light that just barely passes through second order. This ghosting is in the inter-order space for FTN FLOYDS, as the prism was tilted slight to prevent overlap with second order. Some scattered light is also visible in the inter-order regions; it registers at the ∼1% level.

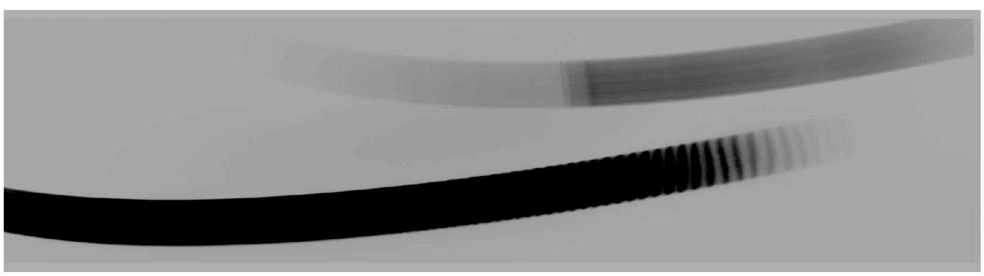

Fig. 3. A typical FLOYDS flat field frame.

will discuss the science configuration in the next section, on Acquisition strategies (§ 2.1). For your flat and wavelength calibration configurations, remember to click on the appropriate radio button, and your slit of choice (you can make a calibration configuration for each slit you plan on using, for convenience). Do **not** highlight any acquisition strategy other than 'None', and do not specify an acquisition time for good measure, as it will cause FLOYDS to take an acquisition image, and try to implement your acquisition strategy. That is not what you want for your calibrations.

The next configuration to make is the one for your science object. The purpose of the science configuration is to tell FLOYDS what acquisition strategy to adopt, which we discuss in its own subsection now. Be sure, in addition, to mark the 'Sky' radio button so that the calibration arm is retracted.

2.1. Acquisition

There are three acquisition options, one of which must be specified for any observation where the 'Sky' radio button is marked, and FLOYDS is looking on sky. Here we discuss each in turn, and you should look to Figure 5 for visual guidance. First, note that for each option you need to specify an acquisition time. A good, typical acquisition time is 20-30 sec (note that the input time is in milli-seconds, and so you should say 20000-30000 ms). Do not put in too short an acquisition time, even if your offset star is expected to be bright (see below); the current acquisition code expects there to be more than 3-4 stars in the field, otherwise the acquisition does not proceed. This is to guard against taking spectra in very poor conditions.

The first acquisition method is to do a world coordinate system (WCS) solution. To select this method, simply click 'WCS Solved' in the phase II GUI, and specify an acquisition exposure time. In brief, if you choose this method, FLOYDS will use a tailored call to astrometry.net (Lang et al. 2010). If a WCS solution is successfully found, FLOYDS will then offset to the object nearest to the expected coordinates of the target, as long as it is within 1 arcsecond. Make sure that your acquisition image is deep enough that the target will be visible. FLOYDS will not acquire an object if it is not detected in the image. Also, this method is not full-proof. The WCS algorithm does not always solve (although it should be said that it never seems to solve *incorrectly*), especially in compromised (e.g. cloudy) conditions. In this situation, FLOYDS should abort the observation cleanly without charging you time.

The second method is to simply acquire the brightest object within the FT pointing circle. In this instance, the acquisition image is used to find the brightest object within 30 arcseconds of the pointing center, and this object is placed directly on the slit. This is a good, quick option if you are confident that your object is the brightest within a region greater than ∼1 arcminute or so. To select this method, simply click 'Brightest Object' in the phase II GUI, and specify an acquisition time long enough that at least a few stars will be visible in the field. Note – to reiterate, FLOYDS will not attempt to acquire if there are only one or two stars in the field (presuming the conditions are too poor, or something else is wrong), so do make sure that your acquisition image is long enough.

Finally, there is the 'Offset Brightest' acquisition method. It is analogous to the 'Brightest Object' method mentioned above, in that it keys off of the brightest object within $30''$ of the Faulkes pointing error circle. After identifying this object, and the offset to it, however, an *additional* offset is applied to place the slit on the science target. This method is analogous to the 'blind offset' technique for spectroscopic acquisition employed at most telescopes. Be sure to fill in the 'Offset RA' and 'Offset DEC' regions in the instrument configuration (see Figure 5). These numbers should indicate the distance **from the offset star to your target**, in arcsec. RA positive is East and DEC positive is North. Do not forget the cos(DEC) term when calculating your RA offsets. Up to now, we have experimented with offsets up to ∼2 arcmin in size. Anything much larger than this, and you are in uncharted territory. As will be reiterated below, you must specify your offset star as the 'target' in the separate 'Targets' GUI, since this is where you want the telescope to slew to. The specified offset will then put your true science target into the slit.

The acquisition technique you decide on should fit your science goals, and the knowledge you have about your target. We have found that the third technique, 'Brightest Offset', is quite robust and can recommend it for any situation where you have an appropriate, relatively isolated offset star candidate.

2.2. Completing the Observing Group

At this point, you should have a set of FLOYDS configurations, and it is time to specify the target RA and DEC in the 'Targets' GUI. This is straightforward, except in one case. If you are using the 'Brightest Offset' option for your acquisition, make sure you put in the offset star coordinates, and not your actual science target. During the acquisition process, FLOYDS will offset to your target if you put in the correct offsets, but we want the telescope to slew to the position of your offset star and go from there. Also note that even for your calibration observations before and after a science observation that you will want to specify the target RA and DEC – the whole point is to take calibrations at your science position.

With a target and appropriate configurations in hand, build up your observing group. For a screen shot of an observation GUI, so you can visualize the following discussion, see Figure 6. At the moment, we recommend an initial flat field, followed by your science target, wavelength calibration, and possibly a second flat field. We have found that sandwiching your observations with flat fields can help remove fringing effects in the data reduction process. We recommend exposure times between 20-30 seconds for the flat field observations, and 70 seconds for the wavelength calibrations. Obviously, the exposure time for you science observation is your own problem. In each observation, you can specify the slit angle with the 'Rotator' menu. There are only two viable options for FLOYDS: SKY or VFLOAT. Choosing SKY lets you pick the slit position angle of your observation, which you can fill in on the 'Angle (deg)' selection. The other option, VFLOAT, will set the angle to the parallactic angle – we did not choose the name of this option, sorry. In this case, do not fill in the 'Angle (deg)' selection. Please consider using the parallactic angle for your observations, due to the very broad wavelength coverage of FLOYDS. Whatever angle you choose, maintain that angle consistently throughout your observations within a group – e.g. use the same position angle for your flats and wavecals as you do for you science target. This will again help ensure you are taking proper calibrations.

A couple of final notes. Leave the 'Mosaicing' section as is, as building up mosaic images are not relevant for FLOYDS. Also turn the Autoguider 'ON' for your science observation and 'OFF' for your calibration observations. The 'Maybe' option is not appropriate for any FLOYDS situation.

This should be it. You have now built up a FLOYDS observation. Check your exposure times and observation window, and let it go.

3. Description of the data reduction pipeline

The FLOYDS pipeline is a set of python packages based on four main modules: *pyraf*, *pyfits*, *pylab*, and *numpy*. It has been tested with python version 2.5,2.6 and 2.7, pyfits (3.0, 3.1), pyraf (1.1, 2.0) on OS X 10.6,10.7,10.8, centos 6, centos 5, ubuntu 10, but it can run on almost all operative system as far as there is a running version of *iraf* on the machine, and a running version of python (version 2.x) with the modules mentioned previously.

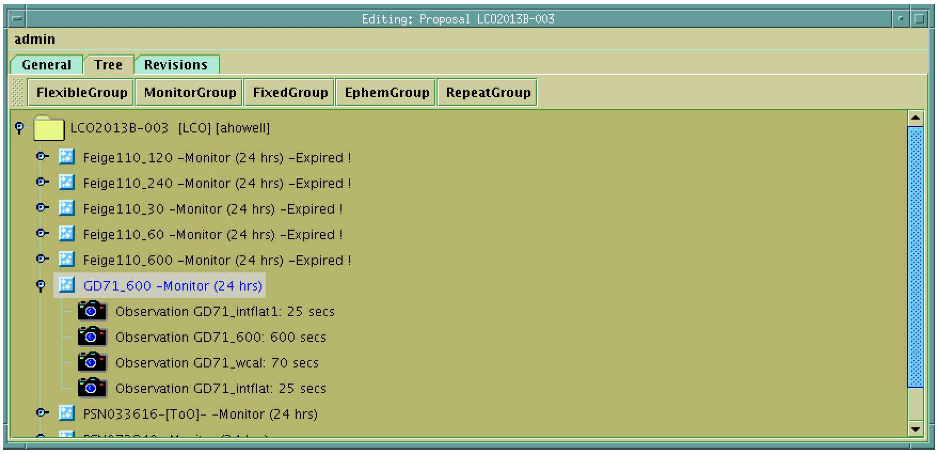

Fig. 4. A screen shot of the phase 2 GUI, highlighting a FLOYDS observation. Note that the observing group consists of four observations – an initial flat field, followed by the actual science observation, followed by a wavelength calibration and an additional flat field. This is a typical setup for a FLOYDS observation.

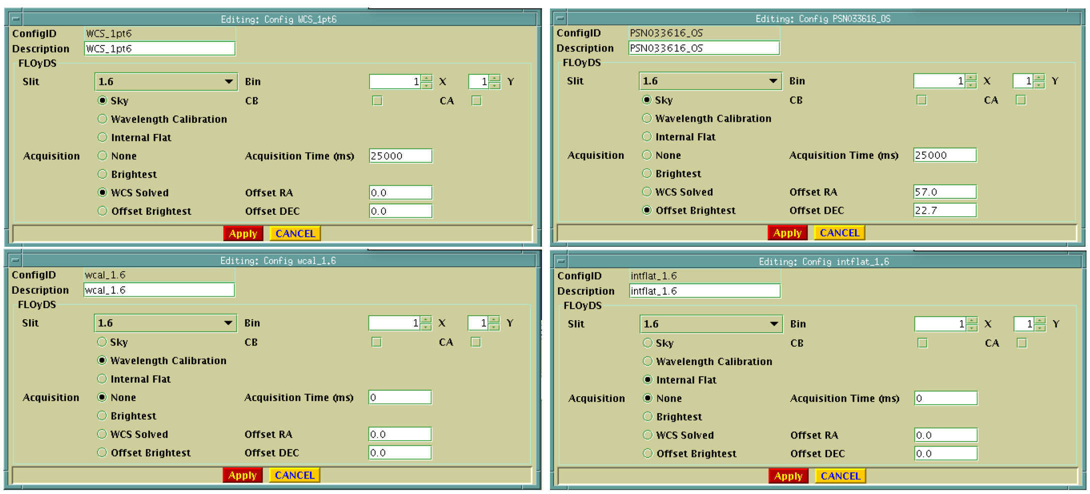

Fig. 5. A montage of FLOYDS configurations. Note, you must always select the appropriate slit. **Upper Left** An illustration of a WCS-solve acquisition configuration. Note that 'Sky' is marked, indicating that FLOYDS is looking through the telescope, and that an acquisition time is specified. The WCS Solved radio button is marked. **Upper Right** A 'brightest offset' configuration, as indicated by the marked 'Offset Brightest' radio button. The sky ratio button is marked, along with an appropriate acquisition time. The key here is that the 'Offset RA' and 'Offset DEC' regions are filled in. This should indicate the distance to go **from the offset star to your target**, in arcsec RA positive is East, and DEC positive is North. Note that you must specify the offset star position as your target, otherwise the observations will not execute as you wish. **Bottom Right** A wavelength calibration configuration. 'Wavelength Calibration' is marked, along with 'None' for acquisition. **Bottom Right** An internal flat lamp configuration. 'Internal Flat' is marked, along with 'None' for acquisition. No image with the guide camera will be taken prior to the flat lamp exposure.

3.1. Installation

The package can be downloaded in a tar format at the following link: *https://dl.dropboxusercontent.com/u/28579834/floyds-2.1.0.tar.gz* and contains the the following files/directory:

- **bin** (directory): this is the directory where executable files are stored. These files will be copied in the *installation-path* bin directory. There are three executable files in the bin directory (**floydsfixheaders**, **floydsspec**, **floydsauto**) that will be explained in detail in Sec 4.
- **src** (directory): contains the core part of the pipeline
- **setup.py** (*distutils* installation script): this is the executable script that should be run to install the FLOYDS pipeline
- **README.txt** (file): contains the instructions to install the pipeline

To install the pipeline the following steps should be executed:

- *tar -xvf floyds-version.tar*
- *cd floyds-version*
- *python setup.py install*

Once the pipeline is installed a new directory, called *floyds*, should have been created in the *PYTHONPATH* directory containing several python files (containing all the functions used in the pipeline) and the following sub directories:

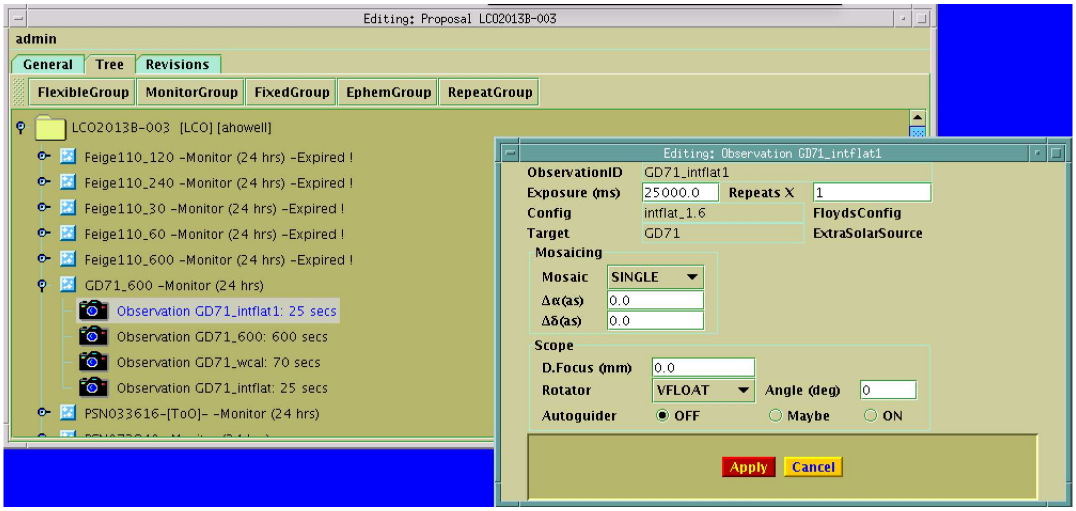

Fig. 6. A screen shot of the phase 2 GUI, and the editing of an observation, which just happens to be a flat field in this case. Make sure to specify the correct Config and Target, as we have discussed in § 2. Another important portion of the Observation GUI is setting the proper rotator angle – in particular, we recommend the VFLOAT option, which sets the slit to the parallactic angle. Guiding should be 'OFF' for flats and wavelength calibrations, and should be 'ON' for science observations.

– *doc*: This directory contains useful documentation on FLOYDS
– *standard*: This directory contains parameters files (all standard calibration files, tables for arc line identifications, extinction curves, etc.)
– *archive* This directory contains all the calibration files used for wavelength calibration, flux calibration. If some calibrations frames are missing for a specific night, calibrations are performed using calibrations stored in this directory (using the frame closest in time to the observations).

4. FLOYDS Data reduction pipeline

The FLOYDS pipeline runs in two different modes: *automatic reduction* and *interactive reduction*. The *automatic reduction* is run by an executable script **floydsauto** on a linux machine at LCOGT headquarters as soon as new observations are automatically downloaded and archived from FTN and FTS. This script produces the tar file with the observations and data products for users, FLOYDS data product 1 (FDP1). If users are not happy with this reduction, they can do an *interactive reduction* with the executable script **floydsspec**.

4.1. Overview

4.1.1. Steps common to both modes

The initial steps taken by the automatic and interactive reductions are:

– *Splitting arms*: The first and second order are divided into *blue* and *red* arms as a first step. From here on, all the data are analyzed separately and only combined at the end.
– *X-axis rectification*: The spectra are initially curved, so they are straightened (rectified) along the x-axes using a Legendre polynomial. Different functions are used for FLOYDS at FTN and FTS. Commissioning tests indicated the instruments are stable enough to use a fixed transformation function for all the data. We do this, rather than computing the transformation from each data set. This ensures that the rectification will be successful even for data with a low signal-to-noise ratio.
– *Trimming*: The frame is then trimmed in order to exclude the part with no signal.
– *Cosmic ray cleaning :* The 2D images are cleaned of cosmic rays using the *lacosmic* Laplacian cosmic ray rejection algorithm[1] of van Dokkum (2001). We use a modified *python*[2] implementation that avoids the use of the *scipy* package.
– *Y-axis rectification*: The blue and red parts of the frame are rectified along the y-axes using a Legendre polynomial. This produces a rough wavelength calibration. Typical rectified blue and red frames are shown in Figure 7.
– *Fringing correction*: The fringing correction is performed by dividing the science frame by the normalized flat field. Flat fields are normalized using the pyraf task *apflatten*, which normalizes the flat frames by dividing the flat field by a surface obtained with low order polynomial fit of the flat frame. This task give a better result that the iraf task *response* in cases where the flat is not homogeneous along the spatial axes. However, *apflatten* needs to have as input a trace to follow for the 2D polynomial fit. Since the frames are already rectified, we use as a trace a linear function at the center of the frame parallel to the x-axes.

[1] http://www.astro.yale.edu/dokkum/lacosmic/
[2] See http://obswww.unige.ch/~tewes/cosmics_dot_py/

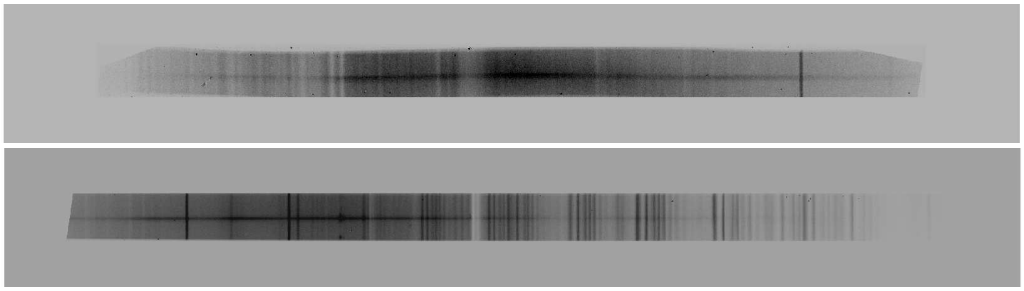

Fig. 7. Blue and red frames after rectification along x- and y-axes and cosmic rejection.

Calibration arc and flat field frames are usually taken as part of the same observation block as the science frame and are rectified in the same way as the science frame. Observations of a flat taken soon before or after the science frame are strongly suggested since the FLOYDS CCDs suffer intense fringing in the red. Before and after flats may improve the fringing correction. If a flat field has not been observed in the same observation block of the science exposure, another from the same night is used. In the case of interactive reductions, a flat from the reduction directory may be used instead.

When a flat field frame was not observed soon after the science frame, distortion may cause a misalignment between the two. This can result in a poor fringing correction. FLOYDS pipeline 2.0 tries to apply a shift and to scale the fringing flat to get a better fringing correction. Further investigations are underway to find a better solution, but for now we include in the FDP1 both frames corrected and not corrected for fringing, and the normalized flat frame, to give the user the option to apply the flat field correction independently.

From here on the *interactive reduction* and *automatic reduction* proceed differently.

4.1.2. Automatic reduction

The *automatic reduction* applies the following steps to the rectified, cosmic corrected, fringing corrected 2D frame:

1. Check wavelength calibration with sky lines or telluric lines.
2. Flux calibration of the 2D frame using a sensitivity function from the archive.
3. Fast extraction of the blue and red frames.
4. Merge blue and red 1D spectra.

While the 1D spectrum may be useful for a fast check of the data quality, we consider the 2D wavelengh and flux calibrated image the best starting point for user who wants to use the automatic reduction. We encourage users to manually perform the last 3 steps of the reduction:

1. *Extraction*: Depending on the science topic, different users may need different extraction parameters, for example, the aperture extracted, background extraction window, or multiple extractions.
2. *Wavelength calibration*: The 2D frames produced by the automatic calibration have been calibrated during the rectification (which uses a fixed solution) and a shift (computed with telluric or sky lines) has been applied. The arc frame observed soon after the science frame is not used by the automatic reduction, but it is provided and can be used to improve the wavelength calibration up to few tenths of an Å. The wavelength calibration performed by the automatic reduction should be accurate to 1-2 Å.
3. A check on the absolute flux calibration should be done using a standard frame observed during the same night.

4.1.3. Interactive reduction

The *interactive reduction* uses the rectified, cosmic corrected, fringing corrected 2D frame, and applies the following steps:

1. *Extraction of the spectra*: This is performed using the *IRAF* task *apall*.
2. *Wavelength calibration*: The wavelength calibration is done using the arc frame observed closest in time to the observation, using the *IRAF* task *identify*.
3. *Check wavelength calibration with sky or telluric lines*: This is computed in a similar way to the automatic reduction, but using the third dimension of the extracted spectrum.
4. *Flux calibration*: If a standard has been observed the same night, the pipeline should recognize the standard frames and extract and calibrate the standard frame in the same way as it is done for the science observations. Then a sensitivity function is computed using the *IRAF* task *standard* and *sensfunction*. These files are then used to flux calibrate the science frame. If there are no standards observed the same night, a sensitivity function from the archive is used.
5. *Telluric correction*: A telluric correction is applied using a a model of the atmospheric absorption to correct for the H_2O and O_2 absorption. The model was computed by F. Patat using the Line By Line Radiation Transfer Model

(LBLRTM Clough et al. 2005). Details on the model and the parameters used can be found in Patat et al. (2011). The pipeline scales the model spectrum so that the intensities of H_2O and O_2 absorptions match those observed in the spectrophotometric standards, hence creating multiple model telluric spectra per night. Each science spectrum is than corrected for telluric absorption by dividing it by the scaled absorption model which is most closely matched in time i.e. the closest match between the standard star observation time and the science observation time. If no standards were observed the same night the telluric correction is performed with a file obtained from a different night stored in the archive or selected by the user.

4.2. floydsspec

floydsspec is the executable used to perform the *interactive reduction*. In this section we will present the syntax and main options available to use this task. When the pipeline is installed, **floydsspec** should be run in the directory containing the raw FLOYDS data. The script is able to recognize the different types of data and lead the reducer to perform all the steps described above. **floydsspec** does not need input file lists if all the raw data are in the directory where the user is running it. A list of files can be given as input if the user wishes to reduce only a subset of data. Option "-*h*" will show all available options.

```
$floydsspec  (basic command)
$floydsspec -h   (help on options)
$floydsspec listfiles   (to only reduce data included in listfiles)
$floydsspec  -i   -A  (recommended syntax: interactive, automatic [see below])
Usage: floydsspec   [listfile -i -A -C --listflat list (use raw flat frames from this list) .....]

Options:
  --version             show program's version number and exit
  -h, --help            show this help message and exit
  -i, --interactive     run the script in interactive mode [recommended]
  -c, --classify        try to classify the reduced spectrum using SNID (if
                        installed)
  -C, --cosmic          removes cosmic rays using lacosmic
  -v, --verbose
  -A, --Automatic       extract spectrum with previous parameters in the
                        database
  -t, --trace           trace extraction with another frame
  -d, --dispersion      interactively choose the disperasion line where
                        aperture and background are selected
  -r REBIN, --rebin=REBIN
                        rebin blue part [pixels]
  --fringing=FRINGING   fringing correction      [1] response,   [2] computed
                        on 1d images minimizing scatter,   [3] using apflatten
  --noflat              skip flat correction
  --listsens=LISTSENS   use sensitivity curve from this list
  --listflat=LISTFLAT   use the raw frames in this list for the flat
  --listarc=LISTARC     use the raw frames in this list for the arc
  --listatmo=LISTATMO   use the closest tellurich file from this list for
                        the telluric correction
```

The options $--listatmo$ allow you to use a specific tellurich file[3] to correct for atmospheric absorption from a list of files you provide. The option $--listsens$ allow you to use a specific sensitivity function from a list of sensitivity functions that you provide. These files must have been produced with the FLOYDS pipeline. The option $-i$ is turns on the interactive mode for extraction, line identification, wavelengh calibration checking, and computing the sensitivity function. If the interactive mode is not on, all these steps are done automatically. The option $-A$ allows the user to rereduce some of the spectra from one night, but not all. You can choose which spectra to extract again and which ones should be skipped.

4.3. floydsauto: Data product automatic reduction

floydsauto is the executable used to perform *automatic reduction*. We do not report here all the options available for this executable, since this script has been optimized to run at LCOGT in order to produce the automatic data products for external users. We will focus on data products. **floydsauto** runs every day with a cron job on the last 5 days of observations. For each night, it divides the observations using the *PROPID*[4], reduces the data, and groups them in tar files. Each tar file will have in the name the Proposal ID, the telescope, the date of observations, and the MJD[5] when

[3] the tellurich file is a spectrum equal to one everywhere exept in correspondance of the tellurich lines.
[4] *PROPID* is a unique number that identifies different proposals
[5] The number reported is actually not the MJD, but MJD ± 1 day. This number will update at midnight local time in order to remain the same as far as the reducer compute the reduction during day-time and during the same day.

the reduction was performed. If a standard star was observed the same night, a tar file of automatic reductions for the standard frames will also be produced. The tar file for standard prereduced frames will all start with "STD", e.g.:

```
LCO2013A-003_fts_20130727_56503.tar.gz
STD_fts_20130727_56503.tar.gz
```

Each tar file will contain the following files:

```
ESO323G077_offset_fts_20130727_red_2.0_56505_1.fits            (Trimmed raw red part of the science frame)
ESO323G077_offset_fts_20130727_blue_2.0_56505_1.fits           (Trimmed raw blue part of the science frame)
arc_ESO323G077_fts_20130727_red_2.0_56505_1.fits               (Trimmed raw red part of the arc frame)
arc_ESO323G077_fts_20130727_blue_2.0_56505_1.fits              (Trimmed raw blue part of the arc frame)
flatESO323G077_offset_fts_20130727_red_2.0_56505_1.fits        (Trimmed raw red part of the flat frame)
flatESO323G077_offset_fts_20130727_blue_2.0_56505_1.fits       (Trimmed raw blue part of the flat frame)

ttESO323G077_offset_fts_20130727_red_2.0_56505_1.fits          (rectified red part of the science frame)
ttESO323G077_offset_fts_20130727_blue_2.0_56505_1.fits         (rectified blue part of the science frame)
ttarc_ESO323G077_fts_20130727_red_2.0_56505_1.fits             (rectified red part of the arc frame)
ttarc_ESO323G077_fts_20130727_blue_2.0_56505_1.fits            (rectified blue part of the arc frame)
ttflatESO323G077_offset_fts_20130727_blue_2.0_56505_1.fits     (rectified blue part of the flat frame)
ttflatESO323G077_offset_fts_20130727_red_2.0_56505_1.fits      (rectified red part of the flat frame)

nttESO323G077_offset_fts_20130727_red_2.0_56505_1.fits         (flat-field corrected red part of the science frame)

ttESO323G077_offset_fts_20130727_blue_2.0_56505_1_2df.fits     (2D flux calibrated blue frame)
ttESO323G077_offset_fts_20130727_red_2.0_56505_1_2df.fits      (2D flux calibrated red frame)
nttESO323G077_offset_fts_20130727_red_2.0_56505_1_2df.fits     (2D flat-field corrected, flux calibrated red frame)

nttESO323G077_offset_fts_20130727_merge_2.0_56505_1_2df_ex.fits (fast reduction 1D spectrum)
```

In summary, the extension "*2df*" indicates a flux calibrated spectrum, the prefix "*tt*" indicates that the frame has been geometrically *transformed* along x- and y-axes, "*n*" indicates that the frame has been flat field corrected. The typical science name is composed (in order) of object name, telescope, observation date, "blue" or "red" (indicating second or first order), slit width, and MJD date when the reduction was performed.

The tar file also includes extra files to help the user understand if the observations were performed correctly. It includes a pdf file with the acquisition image and first guiding images, together with some useful plots with information on the guiding and the flux of the guiding star during the full exposure. An example of the summary pdf file is shown in Fig. 8.

Filenames are of the form:

```
LCO2013A-003_fts_20130727_56503.tar
LCO2013A-003_fts_20130727_56503.pdf
```

5. FLOYDS pipeline step by step

In this section we will describe in detail each step of the pipeline, focusing on the output.

5.1. Wavelength calibration

The lamp used for calibration is an HgAr lamp. In most arcs 20-30 lines are clearly visible and widely distribuited along the first order, while 5-10 lines are visible in the second order. Since the geometrical rectification is already providing a rough wavelength calibration, a low legendre polynomial order is used to better solve the wavelength calibration. An arc file from the archive is used as reference, which for most cases gives the wavelengh calibration without need of adjustment from the reducer. An exemple of the line identifications is shown in Fig. 9

The following keywords are usually added to the science frame to keep track of the accuracy of the calibration:

```
SPERES_R=     474.2613249124601 / Spectral resolving power
LAMRMS_R=               0.0189 / residual RMS [nm]
LAMNLINR=                 16.0 / Nb of arc lines used in the fit of the wavelengths
SPE_ER_R=             0.004725 / statistical uncertainty
ARCRED  = 'arc_nttPSN031752_fts_20130730_red_2.0_56504_1_ex' /  reference arc
DCLOG2  = 'REFSPEC1 = arc_nttPSN031752_fts_20130730_red_2.0_56504_1_ex'
SHIFTR  =                 -5.0
```

5.2. Flux calibration

The FLOYDS spectra are flux calibrated using the *iraf* task *standard*, *sensfunction* and *calibrate*. The standard frames are automatically identified from the coordinates and compared with their tabulated values. The FLOYDS spectrograph

Table 1. FLOYDS spectrophotometric standards. All data in this table are taken from Simbad.

Standard Name	RA (FK5, J2000)	DEC (FK5, J2000)	Proper motion (mas/yr)	V mag	Sp. Type	Instrument
GD71	05 52 27.614	+15 53 13.75	85, −174	13.032	DA1	FTS/FTN
LTT 3218	08 41 32.50	−32 56 34.0	−1031.7, 1354.3	11.85	DA5	FTS
GD153	12 57 02.337	+22 01 52.68	−46, −204	13.35	DA1.5	FTN
BD+28d4211	21 51 11.07	+28 51 51.8		10.47	FTN	
BD+75d325	08 10 49.31	+74 57 57.5		9.51	FTN	
Feige34	10 39 36.71	+ 43 06 10.1		11.12	FTN	
G191-B2B	05 05 30.6	+52 49 54		11.781	FTN	
HZ43	13 16 22.0	+29 05 57		12.914	FTN	
EG274	16 23 33.837	−39 13 46.16	76.19, 0.96	11.029	DA2	FTS
EG131	19 20 34.923	−07 40 00.07	−60.87, −162.15	12.29	DBQA5	FTS
LTT 7379	18 36 25.941	−44 18 36.93	−177.05, −160.31	10.22	G0	FTS
LTT 7989	20 11 12.08	−36 06 06.5	522, −1691	11.5	M5V	FTS
Feige110	23 19 58.398	−05 09 56.16	−10.68, 0.31	11.5	sdO	FTS/FTN

sensitivity functions have a specific shape in the second order with two deep absorptions around 3800 Å and 4400 Å (see Fig. 10). In order to reproduce this specific shape, the FLOYDS pipeline computes the sensitivity function in two steps: a first step with the full second order range (3000-6000 Å) is fitted with a low order function (usually 10-12), and a second step is focused on a smaller window with a higher order in order to reproduce the two deep absorptions. The two blue sensitivity functions are then merged into a single sensitivity function. Because of this, specific standards with a dense and wide coverage of tabulated flux are required. The standard stars that are usually used for FLOYDS are reported in Table 1.

The 2D frames (2df) after being flux and wavelength calibrated have the following units: 10^{-20} erg cm^{-2} s^{-1} Å^{-1}

5.3. Checking wavelength calibration

Both automatic and interactive reductions include a check of the wavelength calibration using the sky lines or telluric adsorptions. This is computed by cross-correlating the sky lines either with a frame of sky lines observed in the past, or the telluric adsorptions with a telluric model. These frames are stored in the directory "*standard*". If the check on the wavelength calibration is performed on 1D frames, the third dimension of the file (produced by the iraf task *apall* is used. If the check is performed on 2D wavelength calibrated frames, a median along the spatial axis is used. During the interactive reduction some plots are shown to the user for feedback. An example of these plots is shown in Fig. 11.

5.4. Fringing correction

At the moment fringing correction is only applied to the red part of the spectrum. A KEYWORD is added to the science frame if the fringing correction is applied. Science frames with name starting with '*n*' have been corrected for fringing. While reducing the data in interactive mode, if the correction for fringing is poor, users may try to use the option –*fringing 2* and check if this improves the fringing correction. The KEYWORDs identifying the flat field used to correct for fringing are reported below.

```
FLATRED = 'flat_20130401_R642_56463.fits'
FLATBLUE = 'flat_20130401_R642_56463.fits'
```

References

Clough, S., Shephard, M., Mlawer, E., et al. 2005, Journal of Quantitative Spectroscopy and Radiative Transfer, 91, 233
Lang, D., Hogg, D. W., Mierle, K., Blanton, M., & Roweis, S. 2010, AJ, 137, 1782, arXiv:0910.2233
Patat, F., Moehler, S., OBrien, K., et al. 2011, Astronomy & Astrophysics, 527, A91
Valenti, S., Graham, M. L., Howell, D. A., et al. 2013, The Astronomer's Telegram
van Dokkum, P. G. 2001, Publications of the Astronomical Society of the Pacific, 113, 1420

Appendix A: FDR1 FITS Keywords description

This section contains details of the FLOYDS specific FDR1 FITS keywords and their definitions for users.

A.1. Cosmic ray rejection

FLOYDS uses the Laplacian cosmic ray rejection algorithm[6] of van Dokkum (2001). If the boolean value is set to T, then the rejection algorithm has been applied, otherwise it has not.

[6] http://www.astro.yale.edu/dokkum/lacosmic/

```
LACOSMIC=  T / TRUE if Laplacian cosmic ray rejection has been applied
```

A.2. Wavelength calibration

The arc frame used for wavelength calibration is always recorded and the frame is available in the data product. The frame is labelled with the object name that it is attached to, the date of observations, grism and slit combinations used, and the MJD[4] when it was reduced. The number of arc lines used in the fit is given by `LAMNLIN`, and the root mean square of the residuals to the fit is listed as `LAMRMS`, formally calculated as

$$\mathrm{LAMRMS}_B = \frac{\sqrt{\sum_{i=1}^{N} R_i^2}}{N} \tag{A.1}$$

$$\mathrm{LAMRMS}_R = \frac{\sqrt{\sum_{i=1}^{N} R_i^2}}{N} \tag{A.2}$$

where R_i is the residual of the wavelength fit for the ith arc line and N is the number of arc lines (`LAMNLIN`). This assumes that errors are randomly distributed and without any systematic errors, which is true as far as we can tell for FLOYDS. Hence the statistical uncertainty in the wavelength solution at any point is approximately given by the value (`SPE_ERR_R`), where

$$\mathrm{SPE\_ERR\_}B = \frac{\mathrm{LAMRMS_B}}{\sqrt{\mathrm{LAMNLINB}}} \tag{A.3}$$

$$\mathrm{SPE\_ERR\_}R = \frac{\mathrm{LAMRMS_R}}{\sqrt{\mathrm{LAMNLINR}}} \tag{A.4}$$

As described above, the wavelength positions of the skylines in the science frame (or telluric lines for bright standard stars) are checked and a linear shift is applied. This is listed in the keyword `SHIFT_B` in Angstroms. The keyword `SPEC_SYE` aims at capturing any further systematic error in the spectral coordinate system that is found during the observation and reduction process. After the systematic `SHIFT` is applied to correct the skylines to rest, we find no further systematic effects in FLOYDS wavelength calibration and hence set this to zero in all cases. After the wavelength solution is determined and the `SHIFT` applied, the values for minimum and maximum wavelength are determined and the following are calculated and inserted as keywords:

```
ARC     = 'arc_SN2013XYZ_20130401_Gr11_Free_slit1.0_56448_1.fits'
LAMRMS_R  =                0.0136 / residual RMS [nm]
LAMRMS_B  =                0.0136 / residual RMS [nm]
LAMNLINR =                   9.0 / Nb of arc lines used in the fit of the wavel. s]
LAMNLINB =                   9.0 / Nb of arc lines used in the fit of the wavel. s
SPE_ER_R= 0.004533333333333334 / statistical uncertainty
SPE_ER_B= 0.004533333333333334 / statistical uncertainty
SHIFTR   =                   2.0
SHIFTB   =                   2.0
SPE_RESB=    418.0955936041426 / Spectral resolving power
SPE_RESR=    430.0955936041426 / Spectral resolving power
```

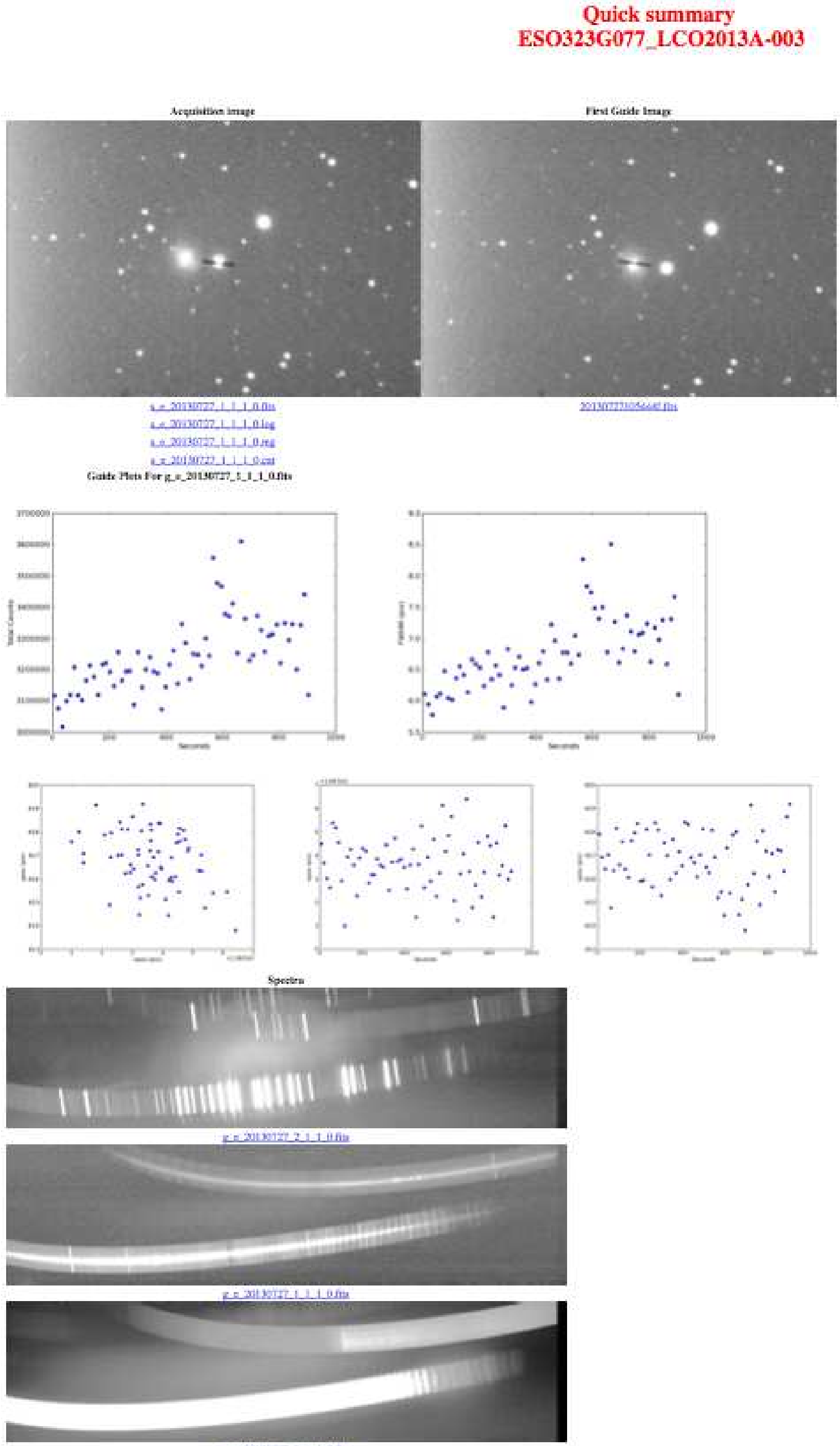

Fig. 8. Summary page for each observation. The acquisition image is visible on the top left, while first guiding image is shown on the top right. The total counts of the guiding star during the full exposure are shown in the two next plots, while guiding star position in x and y coordinate and as a function of the time are shown in the next three plots. Raw science, arc and flat frames complete the summary pdf page.

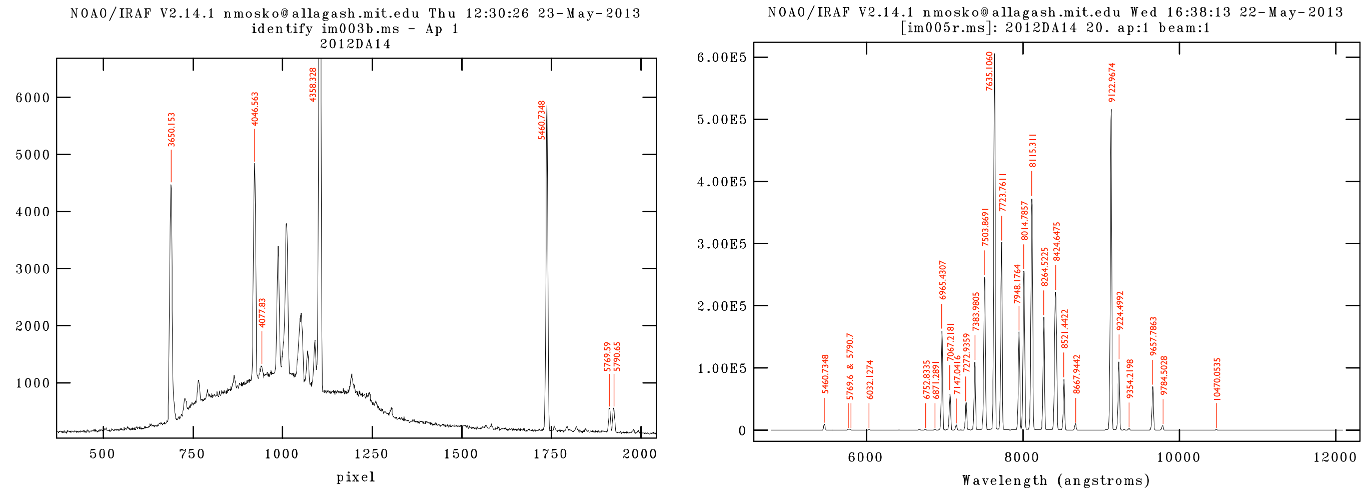

Fig. 9. Line identifications for the first and second order of the arc frame.

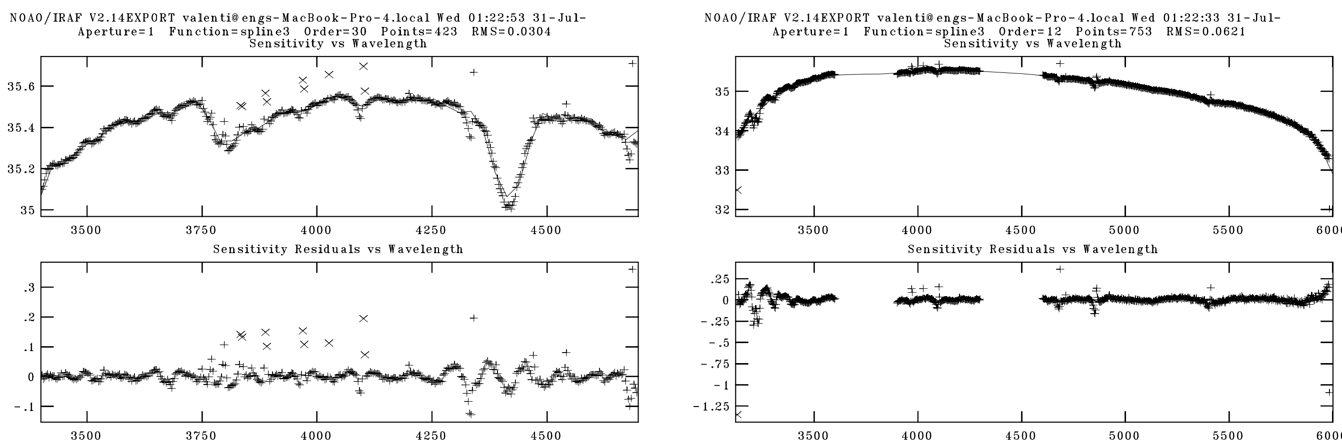

Fig. 10. Comparison of the rapid and final reductions for the classification spectrum of SN 2012fx, taken with Gr#13 and a 1″ slit on 2012 August 26.

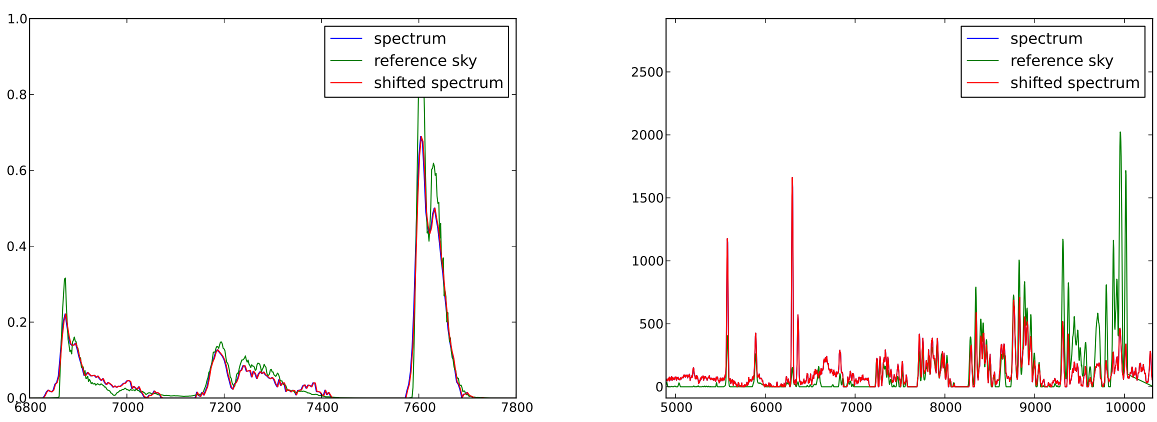

Fig. 11. Comparison of the observed telluric absorption and sky lines with a template from the archive.