Image reduction of the CTIO 0.9-m observations

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September 3, 2018

ABSTRACT

This report describes the data reduction of the slitless images acquired in 2016-2017 during 5 distinct runs at CTIO 0.9-m telescope. The primary objective is to develop data collection protocols for LSST auxiliary telescope. In particular, we use these observations to demonstrate that a real time extinction curve with low-resolution spectroscopy can be used to characterize the evolution of the atmospheric transmission. This report presents and discusses the observation strategy, it explicits the steps of an automated analysis pipeline, from the extraction of the spectra to the measurement of equivalent widths and to the production of atmospheric transmission curves.

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Introduction

The photometric calibration of the LSST survey will impact many scientific applications: photometric error can result in systematic variations in photometric colors of galaxies, photometric redshifts, outlier fractions and sample selection. The error may be a function of sky position, wavelength, seeing, and time, and is affected by observing strategy as well as uncertainties in atmospheric and Galactic modeling. Practically, the components which contribute to the calibrated magnitude error budget can be separated into three categories: above the atmosphere contributions, the atmosphere, and the telescope itself. The project has decided to derive strategies to adress each of them separately. In particular, the spatial and temporal variability of the atmospheric transmission will be monitored in real time by an on-site auxiliary telescope. The strategy shall be to use this telescope to acquire spectra from standard stars nearby the science field and use them to correct the effective passband model from the short time scale variation of the atmospheric transmission.

This report presents the analysis of the preparatory observations that were made during five runs at the CTIO 0.9-m telescope, in March, August, November, December 2016 and January 2017. The observation campaign was meant to measure the atmospheric transmission above the LSST site with a low resolution slitless spectrometer, similar to the instrument and site conditions of the auxiliary telescope that is currently under construction. In this report, we focus on two aspects: the first aspect is a detail description of an automated image reduction pipeline that is being developed to extract the atmospheric transmission curves, starting from the raw images. The second objective is to test and discuss the overall performance of the auxiliary telescope strategy.

Section 1 describes the set up of the CTIO 0.9-meter telescope in its slitless spectrometer mode. Section 2 presents the observation campaigns and the dataset that was collected. The next two sections focus on the automated production of atmospheric transmission curves: section 3 enumerates the steps of the image processing up to the spectrum extraction, and section 4 explicits the analysis of the spectra. Specific aspects of the lessons learned from the CTIO 0.9-m campaigns are adressed in the appendices.
The imager is a 2048 by 2048 CCD camera from Site model SH424A. Each pixel measures 24 µm x 24 µm and is delimited by channel stops in the serial direction and 3 gates in the parallel direction. The frame is split into 4 areas of 1024 by 1024, each one read by an amplifier located at each corner of the device. The field size is 13.6 arcmin square, and the pixel size 401 mas/pixel. The device specifications from the manufacturer indicates a typical full well of 200k e− and a readout noise of 5–7 e−. The document also provides the quantum efficiency.

Two filter wheels are located at ~6-cm and ~8-cm away from the focal plane. The dispersing set up uses Ronchi gratings: a 200 lines/mm and a 400 l/mm resolution grating have been tested. They were occasionally used in conjunction with a broadband filter in the second filter wheel so as to perform specific studies of sky background suppression and second order light contamination calibration.

2. Observations

The observation campaigns primary objective is to refine the methodology for using dispersed imaging for the determination of atmospheric transmission. In this perspective we have collected a dataset of both calibration images and on-sky frames we can use for software development.

A campaign of observations at CTIO 9-m telescope has started in March 2016 and has been followed by four subsequent visits in August, November, December 2016 and January 2017. The details of the data taken for all these runs is detailed in the appendix A.

2.1. Ronchi grating dataset

As an illustration, a slitless images is shown figure 1. The order 0 image of HD205905 falls at the lower left corner of the upper right amplifier and its spectrum is dispersed along the serial direction. Since the readout electronic of this amplifier has proven to be unstable, the subsequent runs have priviledge dispersions on the lower right amplifier (see section xx for details).

During run 5 (January 2017), the Ronchi grating with 400 l/mm has been tested and compared to the Ronchi 200 l/mm images. The findings are discussed in Appendix C.

2.2. Calibration procedure

Four independent path are available to determine the instrumental throughput: Quantum Efficiency (QE) curve from the manufacturer, direct calibration against standard stars coupled with an atmospheric model, monochromatic flatfields, and lastly, monochromatic spots (CBP) illuminations.

A monochromatic flatfields dataset have been obtained March 6th 2016. It covers 8 wavelength in the range 450 - 950 nm. At each, step an image with and without the grating in the light path has been taken. The beam intensity has been monitored by a calibrated photodiode (Hamamatsu S2281, calibration traceable to NIST). The illumination is continuously sampled to account for short time scale variability. Although it is indicated that the detector is a Tek2K_3, it should be noted that neither the overscan section nor the image area (one pixel less) match to NIST. The findings are discussed in Appendix C.

3. Images processing

The scheme shown on figure 2 outlines the main steps of the image processing pipeline. The software that is being used to reduce the observation can be found here: https://github.com/p201-sp2016/atmosx.

A CBP was installed under the dome during the January run. Each day for three days, a full band calibration took place, with and without Ronchi grating in the light path. The CBP beam currently suffers from a lack of power.

A comparison of these four different approaches is presented in section 3.3.

2.3. Atmospheric transmission

Atmospheric transmission can be described with small number of parameters: Precipitable Water Vapor (PWV); Aerosol Optical Depth (AOD) amplitude and slope; Ozone (O3); plus, given barometric pressure and zenith distance, Rayleigh scattering and O2 absorption.

The optical transmission spectrum of the atmosphere, its impact on high-precision photometry and the use of dedicated instrument to monitor it is described in the reference Stubbs et al. (2007).

3.1. Overscan and bias subtraction

The first step of the image reduction is to subtract the median overscan and to trim the amplifiers region.

The serial and parallel profiles of the overscans are shown on the figures 3 and 4 for different type of image. We observe that the profiles are flat in both directions for low level illumination such as in dark and science exposures. A strong gradient appears in the serial direction for the flatfield image where the illumination level is ~ 30 kADU. A spike is visible in the channel that

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1 https://github.com/Mondrik/atmosx
2 http://www.astro.gsu.edu/thenry/SMTARS/0.9m.events
could correspond to the 32 pixels period darker column that is seen in the image frame (see figure 1).

The next step is to build a master-bias by median-stacking the bias images. The master-bias is subtracted to all the images so as to remove stable patterns introduced by the electronic readout. For this run, there are no bias images available, instead, dark images with 30-s exposure time were taken. Given the low level of the dark current, about $4.5 \times 10^{-7}$ electrons/pixel/30s, they can be used instead of bias images to remove the electronic signatures. An image of the master-dark is shown on figure 5. A small difference in the pedestals is seen, as well as a few hot columns and a bright area on one amplifier. Darker horizontal lines also appears on the two top segments. They are related to periodic darker columns that are found on individual dark, with a stable period of 32 pixels, but a variable phase. The rms-histogram of the master-dark is shown figure 6. The distribution is asymmetric. The various instabilities of the electronic contributes to the skewness toward higher count of the rms distribution. Another contribution are the cosmics that should be removed from the distribution.

### 3.2. Object detection and footprint selection

The selection of the footprint is determined by combining two informations : the position of the zeroth order image of the reference star and the direction of dispersion. The position of the star is obtained automatically using SExtractor software (Bertin & Arnouts 1996). Since the finding of the star is obtained from a dispersed, not-flatfielded image, the default extraction parameters have to be adjusted. In particular, the contrast parameter setting to deblend objects is lowered from 0.005 down to 0.0005, so as to increase the separation between spurious detections. Then, the brighter object from the aperture photometry catalog is assumed to be the reference star. Starting from its coordinates, two rectangles, with variable size depending of the grating being used, are extracted along the dispersing direction. Both m+1 and m-1 orders are processed.

From a footprint, the spectrum profile is extracted using several methods : an aperture measurement, a Gaussian, a Voigt and a Moffat functions fitting (figure 7). While the Voigt profile is a better approximation of the actual profile, the fitting is unstable. On figure 8, from the green and orange curves showing the two width parameters of a Voigt function as a function of wavelength, oscillations are observed and not understood yet. The $\sigma$ of the Gaussian, although underestimating the width of the spectrum (figure 7, green), produces a stable estimates as a function of wavelength (figure 8, blue curve). This profile is fitted with a parabola between 400-nm and 900-nm and used as a measurement of the seeing.

The orientation of both m+1 and m-1 spectrum is studied from the center of the Gaussian fit of their profiles as a function of pixel in the dispersion direction (figure 9). A slope is determined between pixel [600:800] and represented as a function of time on figure 10. It is found that all the spectra are slightly tilted downward, and, strangely, m-1 and m+1 slopes are different and anticorrelated (figure 11). The impact of the atmospheric refraction is parametrized as the mean offset of the center of the spectra and the linear fit extrapolated between pixels [300:400], represented as a function of parallactic angle. Both orders are consistently impacted in the same way (figure 12).

The method successfully found the spectrum of interest on all the Ronchi/clear images from run 2,3 and 5. In the future, the normalization by a synthetic flat, before searching for the footprint, could prove to be more robust.

#### 3.2.1. Rejection of cosmics and hot pixels

Hot pixels or cosmics lying in the footprint are flagged using the Laplacian detection method published in van Dokkum (2001). The algorithm is based on the measurement of the seeing and the noise level of the image background to select cosmic-rays of arbitrary shapes by the sharpness of their edges. The background statistics, $\sigma$-rms and mean, is determined from the pixels in the footprint belonging to the SExtractor sky map. Pixel to pixel variation which exceed 5 $\sigma$-rms variation, or that is sharper than the seeing scale, are flagged, and optionally replaced by a local mean.

The image quality of the dispersed images is too low to reliably detect the clump of stars from their second moments and deduce the seeing from it ($\sigma_{\text{rms}}=\sqrt{\sum_{i} \sum_{j} (I_{i,j}-\bar{I})^2}$). Rather, the seeing is determined from the spatial profile of the spectrum footprint.

The efficiency of the algorithm has been tested by measuring the number of cosmics in a dark image and a stellar field, then on the sum of both images. The ratio of the number of detections in both case being an assessment of its performance. The result is about 99% of common detections. In the 800 by 60 pixels rectangles of the footprints, the total number of flagged pixels is typically between 0 and 5.

#### 3.3. Flatfielding and calibration

The purpose of flatfielding a slitless image is twofold : it is used to correct both for the detector response non uniformity due to imperfection and defects as well as for the QE variation of the camera. If for direct optical images the correction is simply performed by dividing the images by the median-stack of normalized flatfields, obtained in the same band for a given night; the flatfielding of slitless images is more complex : The QE calibration is obtained from monochromatic flatfields without a disperser in the filter wheel, while the optical imperfections should be identified with the disperser on, so that they impact the image in the same way as in the science mode.
As a first study, Master-flats have been assembled in each band using twilight images. An exemple of master-flat in the r-band is shown on the figure 13. The different between the gains of the 4 amplifiers is clearly visible, as well as cosmetic defects on the optics. A shadow appears at the top of the field of view. The master-flats in the other bands (g,i,z) are fairly similar, with residuals from diffraction patterns and a small color term (fig 14).

For dispersed images, different positions receive light from different wavelengths. The flatfielding task aims at recovering the illumination pattern from the dispersion of the first order of the grating by normalizing the instrumental response as a function of position and wavelength:

\[ N_{ADU}(r, \lambda) = B(r, \lambda) \cdot T(r, \lambda) \cdot QE(r, \lambda)/g \]

Where B is the light beam, T is the transmission of the telescope, QE and g are respectively the Quantum efficiency and the gain of the camera. The monochromatic flatfields, with a known \( B(r, \lambda) \) are combined to build synthetic flatfields which are used as calibrator of \( T(r, \lambda) \cdot QE(r, \lambda)/g \).

3.3.1. Spectrum extraction and first estimation of the dispersion relation

A first, coarse estimation of the dispersion relation is required to calibrate the imager’s portion where the footprint of the spectrum lies. The pixel to wavelength transformation can be determined by either knowing the geometry of the disperser set-up, or by a visual inspection of known spectral features on the raw, uncalibrated spectrum.

As a matter of fact, a systematic analysis of the images reveals that this electronic signature is connected with a significant variability in the measurement of equivalent width (see section 4.3).

The pixel to wavelength transformation can be estimated knowing the grating spacing \((a)\) and the distance \((d)\) between the focal plan and the grating. They are related in the following way:

\[ \text{Pixel} = d \times \left( \frac{\lambda/a}{\sqrt{1 - (\lambda/a)^2}} \right) \]

The distance \(d\) between the lower wheel and the upper end of the CCD deware was estimated to be between 5 and 10 cm. When using known spectral features from uncalibrated spectrum, we find \(d=5.3\) cm, compatible with the on site evaluation.
Fig. 5. Master-dark combining 11 30-s exposures acquired August 22, 2016. A small difference in the mean value (∼4.5 e⁻/pix/30) of the dark currents is visible. Periodic fainter horizontal columns are also seen on the two upper frames, as well as hot columns and a bright area on the right.

The removal of spurious features in the spectrum due to cosmetic defects is currently performed using broadband flatfields. The reasons are twofold: firstly, the S/N ratio is tremendously improved with respect to the monochromatic dataset, secondly, the image one row offset between the first run and the latter is disturbing. The method is to build a synthetic map of the defects by ponderation of each g, r, i, z masterflat as a function of the local pixel to wavelength transformation. The result is presented on the figure 17 which shows a zoom on two spectra of the same object but dispersed at two different location on the focal plan: one lies on a defect (purple line) and the other does not (green line). The blue curve illustrates the bad correction that is obtained when using the low S/N monochromatic flatfield. The orange curve shows the good quality of the correction when using stacks of broadband flatfields. The yellow curve, the correction applied to an image without defective pixels, is presented as a null test.

3.4. Telescope throughput calibration

As explained in section 2.2, four distinct ways of calibrating the telescope throughput are available. In this section we detail them and compare their results.

The more straightforward is to apply the manufacturer QE curve multiply by the reflectivity curve of the two aluminium
Fig. 10. HD14943, run 4, the slopes are converted into an angle and represented as a function of Julian Date.

Fig. 11. All the spectra are tilted downward, and, strangely, m-1 and m+1 slopes are different and anticorrelated mirrors. The reflectivity curve that we used comes from the Subaru Telescope.

A calibration can also be obtained using the monochromatic flatfields dataset. A synthetic flatfield is constructed for each

Fig. 12. Mean offset of the center of the spectra and the linear fit extrapolated between pixels [300:400], represented as a function of parallactic angle. Both orders are consistently impacted in the same way.

footprint. In each one of them, a vertical position, where the first order fell on the frame, is determined for each wavelength of the calibration dataset and the response of the detector is linearly interpolated in between. A limitation of the synthetic flatfield is that it does not correct for local cosmetic defects of the camera.

Fig. 13. r-band master-flat combining 12 5-s exposures acquired August 23, 2016. The different gain of the 4 amplifiers are visible, as well as cosmetic defect on the optics and a shadow at the top of the field of view. The relative amplitude of the shadow and of the cosmetic defects evolve as a function of the illumination wavelength.

Fig. 14. Images of the residuals of flatfield differences. Top left : g-i, top right : g-r, bottom left : i-z and bottom-right : r-i. Differences in the diffraction pattern of the speckles appears, as well as a small color term.
Fig. 15. Spectrum (a) with and (b) without subtraction of a master-dark. After the subtraction, a small slope is removed while the spyskes remain. (c) with subtraction of the serial profile of the background.

Fig. 16. Median profile in the serial direction of the background of the field HD205905.

Fig. 17. Visual evaluation of the quality of the removal of spurious features in the spectrum introduced by defective pixels. Due to a much higher S/N, the use of the broadband dataset (orange) performed better than the monochromatic flatfields (blue). The yellow curve, the correction applied to the image without the defect is shown as a null test.

The figure 18 illustrates the impact of such defect on the spectrum extraction. It shows two spectra of the same star but taken at two different location of the focal plan: for one of them (purple curve), darker pixels (seen from 650-nm flatfield) introduce a spurious feature in the spectrum. The problem is to implement these features into the synthetic flatfields taking into account that their intensities evolve as a function of wavelength.

A third calibration was made available during January 2017 run using the Collimated Beam Projector.

A fourth calibration scheme is accessible using forward modeling of standard stars.

The dispersion relation of the set up is needed to convert the pixel position into wavelength. Once the wavelength solution is known, the calibration of the spectrum can be performed, either from manufacturer datasheet or from our monochromatic flatfields. A linear transformation from pixel coordinates to wavelength is adjusted using a forward model of the stellar and atmospheric features of the observation. First, a calibrated SED of the observed star

A last calibration can be estimated by dividing an uncalibrated observation by a star with a calibrated SEDs, assuming a fiducial atmospheric curve. A stellar SED from STIS/NICMOS instruments on the Hubble Space Telescope (Bohlin et al. 2001) is first converted from Flam units to photons number and then convolved with a fiducial model of the atmosphere at the CTIO site. Lastly, the spectrum is converted into electrons using the QE of the camera and its resolution is downgraded to match the ~1 arcsec seeing of the observations. Given the converging beam of the F/13.5 telescope, a significant smearing occurs as the de-
focus becomes more significant at larger wavelength. A corrective term is added to the forward modeling:

$$\delta(\lambda) = \frac{I}{f/D} \left( \frac{1}{\sqrt{1 - (\lambda/a)^2}} - 1 \right)$$

This variation of the PSF as a function of the distance from the center of the field of view could also be determined by fitting the profile of the spectrum in the spatial direction.

Figure 19 superimposed the four response curves. The blue line corresponds to the manufacturer QE curve. The green line shows the result from the CBP (run 5). The red line shows the result from forward modeling of HD14943 (also run 5). Lastly, the triangles indicate the results from the monochromatic flatfields dataset (run1), distinguishing the solution for the four amplifier frames. Both for the CBP and the monochromatic flatfields, an important level of straylight may contaminate the calibration.

4. Spectra analysis

4.1. Second order light de-contamination

The second order light contamination is determined from a set of Ronchi plus filter exposures. The current set of observation is the following:

1. 7 images with g-filter + Ronchi 200 from November 2016
2. 4 images with FGC715S+ Ronchi 200 from January 2017
3. 4 images with FGC715S+ Ronchi 400 from January 2017

The second order is out of the image frame for the exposures taken with Ronchi 400. Dataset (1) is composed of 4 HD14943 images, one first low flux and then 3 higher fluxes image, followed by 3 high-flux, MuCol images. Figure 20 presents the resulting spectra (in m+ direction), using either aperture or Gaussian PSF photometry. The contamination coefficients are found by determining the ratio of the light between [760:1060]-nm, and half that. They are shown on figure 21 for the first dataset. Note that the result is identical for the m− direction when looking at the m− direction.

These results raises two questions:

1. Is the variation between 750-nm and 800-nm physical?
2. Where does the offset come from?

The answer to question 1) is rather no. The feature is likely due to a mis-calibration of the wavelength solution, because the spectrum has not enough features/span to determine precisely enough the pixel-to-wavelength solution. This interpretation is supported by the analysis of the January dataset, where the problem is enhanced (plots not shown in this analysis).

For question 2) we should either consider a linearity issue or a flux dependent background subtraction bias. Regarding the linearity issue, more data could help figuring this out:

- A set of direct image with increasing exposure time to determine the non-linearity.
- A set of g-filter + Ronchi with increasing exposure time, then corrected from the non-linearity.
4.2. Automated search for absorption features

The linear relation applied to determine a first order pixel to wavelength transformation is not a sufficiently accurate representation of the dispersion relation of the instrument. There is also an error in the wavelength calibration of each spectrum (1-2 nm) that is due to an error (≤1 pixel) on the determination of the centroid of the saturated first order light. To set each spectrum on the correct scale, an algorithm which automatically finds absorption lines in the observations and in a reference template is developed. Lines that are found on both spectra are matched and used to derive an improved wavelength solution.

The algorithm that has been implemented in the reduction pipeline runs without using a prior on the positions of the lines. Instead, it models the spectrum \( S(\lambda) \) as the sum of a continuum \( C(\lambda) \), a noise modulation \( N(\lambda) \), and the lines \( L(\lambda) \):

\[
S(\lambda) = C(\lambda) + L(\lambda) + N(\lambda)
\]

The algorithm iterates the fitting of these components starting by assuming a smooth continuum from a median filtering. At each step of the iteration, lines are separated from the continuum by a -3σ clipping of the residuals of the data to the smoothing function. As the solution is iterated, the biased on the continuum estimation, due to strong lines, is incrementally reduced. Once the extraction has converged, when no more points are removed, the continuum underlying each line is estimated by linearly interpolating between the mean values of the data points surrounding the lines. The algorithm is tested using a simulated atmospheric model with \( O_2 \) lines. The figure 22 illustrates the result for an atmospheric model plus a noise added with \( S/N=50 \) on each bin. The continuum is shown in red, the lines are drawn in black, and the linear interpolation of the underlying continuum is indicated by the blue segments.

The extraction is repeated with \( S/N \) ratio between 30 and 1000. The relative variation of the equivalent widths of the \( O_2 \) lines as a function of their individual \( S/N \) is presented figure 23. The error remains below 10%, down to \( S/N=20 \).

4.3. Rescaling the wavelength solution

The figure 24 compares the agreement of the observed spectrum with a template model, before (a) and after (b) rescaling the wavelength solution, using lines automatically found (figure 25). A zoom on the absorption features reveals the enhancement agreement between the two spectra.

4.4. Extraction of \( O_2 b \) equivalent width

The \( O_2 b \) line is extracted from ~140 spectra of HD14943 taken during run 3 and the equivalent width (EW) is measured (figure 26). The result is also presented on figure 27 as a function of time and airmass. Each night is distinguished by a different color and the size of the EW is normalized by the mean value of the run, times .2 to scale the axis. The observation strategy has been to take a sequence of three images in a raw each time a given star was observed. Looking at the relative variation of the \( O_2 \) EW in these sequences, it is found that the repeatability of the measurement is ~3%.

A much stronger variability is sometimes observed: an example is shown on figure 28 with a sequence taken during the night 0 (purple segments). The short timescale involved prevents this variation from being the manifestation of a genuine atmospheric evolution.

Ongoing study Looking at the spectra (figure 29) allows to verify that this is not caused by an error in the automated wavelength calibration. The smaller EW extracted from the second spectrum is caused by some sort of smearing. The only difference found between these two observations is the presence of the periodic pattern on the smeared image (figure 30). This electronic instability seems to be associated with a mean increase of the pedestal level (figure 31, amplifier 22). However this effect is not involved in other case of smearing. As a matter of fact, one of the author confesses that he is unable to identify the vari-
Fig. 24. Comparison of a template and the observation, before (a) and after (b) rescaling the wavelength solution.

Fig. 25. Automated finding of absorption features and measurement of their equivalent widths.

Fig. 26. Equivalent width of O\textsubscript{2}b line from ~140 spectra of HD14943 taken during run 3 and scattered as a function of airmass.

4.5. Lessons learnt

The electronic readout of the CTIO .9-m telescope introduces a trail signal after bright object in the serial direction. This is clearly seen looking at the two images of the same star shown figure 32. As the star image gradually approaches the separation between two amplifiers, the bright trail at the right of the object is suppressed. It indicates that part of the spreading of the PSF toward the right is not a property of the illumination but rather an electronic artefact.

Trails in the serial direction have also been seen on the Chinese lunar telescope (Wu et al. 2016), they are quantified and removed using hot pixel in dark frames. We should also do something about them because they contribute to blur the spectrum. Implement the optimal extraction method described in Horne (1986).

Miscellaneous questions:

- On the images (figure 32) are also seen aigrettes associated with the star. Does that also contaminates the spectrum?
- If there is another object contaminating a footprint, what is the best way to remove it? Use the direct image to subtract it? Implement some kind of 1-D deblender? A subtraction using a direct image may need to be realigned which may not be what we want to do. Should we rotate the field?
- Do we need a photon transfer curve (PTC) to measure the gains? This could be useful to reconstruct a spectrum that would fell on two amplifiers.
Fig. 27. Equivalent width measurement of $O_2$ b line from ∼140 spectra of HD14943 taken during run 3 represented as a function of time and airmass. Each night is distinguished by a different color and the size of the EW is normalized by the mean value of the run, times .1 to scale the axis. Looking at the relative variation of the measurement in a short timescale sequence, it is found that the repeatability of the measurement is ∼3%, with an occasional larger variability (which needs to be investigated).

Fig. 28. Zoom on the center of figure 27. The sequences from night 0 and night 1 manifest a large variability on short timescale which are unlikely to be genuine atmospheric variations. These should be investigated.

- If the quality of the PSF is lower at the edge of the FoV, should we center the spectrum on the camera instead of the object?
- Should we adjust the focus of the telescope between direct and dispersed images?

SExtractor segmentation image has the pixel value belonging to a given object set to the object number in the SExtractor catalogue. It could be used in case deblended is needed.

Acknowledgements. The authors wish to thank ...

References
Fig. 31. Serial overscan profiles for the four amplifiers (a11, a12, a21, a22) for both images (70-71) shown figure 30. On Amplifier 21, the periodic pattern gets slightly fainter between image 70 and 71. While it simply appears on amplifier 22.

Fig. 32. Two dispersed images of the same star, the first one away from the amplifier separation and the second one close to the separation. The observation that a trail toward right in the serial direction is greatly reduced on the image where the star is close to the amplifier separation indicates that it is an electronic artefact rather than a property of the image.


Appendix A: Campaign details
All the images taken are saved here:
@128.103.100.06:/data/nas/CTIO_0p9m
Along with their logs in the repositories.

– Run 1: Two nights March 5th-6th, 2016. Calibration dataset: bias, PTC and Monochromatic domeflats with and without Ronchi. The objectives is online here: https://confluence.lsstcorp.org/pages/viewpage.action?spaceKey=LTS&title=CTIO+0.9+meter+test+run%2C+March+2016
– Run 2: three nights, August 23rd to 25th, 2016. Darks, broadband and semrock flatfields during the first night.
– Run 3: Four night, November 21st to 26th, 2016. Bias, Dark, PTC in r-band, flat in g, z and Semrock
– Run 4: Four night December 10th to 14th, 2016.

The table A.1 indicates the stars being observed, along with their coordinates and the number of images taken for each one. The Pole star (HD108344) can be used as a pseudo-constant airmass comparison star. ~30-60 sec exposures are expected for most of the targets.

From a pair of CALSPEC standard A-B, we could use A for determination of the atmosphere, and then B to demonstrate that we can use an atmospheric model derived from star A to calibrate star B.

Appendix B: Gain measurement from PTC
A photon transfer curve (PTC) is built from pairs of flatfields acquired in November 2016. The result of a quadratic fit of the four channels is shown on figure B.1 along with the gains (g) that it provides. A set of bias were also acquired at the same time, it indicates a read-out noise around 5 ADUs.

Appendix C: Ronchi 200 Vs Ronchi 400
The 400 l/mm Ronchi grating enables a better resolution on the bluer lines than the 200 l/mm one. But it does not do so well in the red part. Maybe because of the enhancement of optical distortions as discussed in Moniez+Dagoret report? figure C.2

Appendix D: Processing using the DM-Stack
Appendix D.1: Obs_ctio0m9 package set up
As of May 2017, the DM-Stack can be used to process the images. The setup is the following:

```
source loadLSST.bash
setup lsst_apps
setup -j obs_ctio0m9 -r /git/obs_ctio0m9
```

And the 'obs_ctio0m9' package:

```
setup -j obs_ctio0m9 -r /git/obs_ctio0m9
```

Which needed a special version of packages 'ip_isr' and 'obs_base':

```
git clone https://github.com/lsst/ip_isr
git fetch
```

```
git checkout tickets/DM-9370
git clone https://github.com/lsst/obs_base
```

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Table A.1. Number of observations for each object and their coordinates.

<table>
<thead>
<tr>
<th>Image Type</th>
<th>ICRS coordinates</th>
<th># of observations</th>
</tr>
</thead>
<tbody>
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<td></td>
<td>RA</td>
<td>DEC</td>
</tr>
<tr>
<td>Beta Vir</td>
<td>11:50:50.40</td>
<td>01:38:18.2</td>
</tr>
<tr>
<td>HD60753</td>
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Appendix D.2: Command line tasks

There are three command line tasks to reduce the images. The first two are the classification of the calibration frames and of the science frames :

```
ingestCalibs.py output_calib_rep raw_images
ingestImages.py output_prod_rep raw_images
```

Then the processing of the image :

```
processCcd.py output_prod_rep --calib output_calib_rep --id visit=Uniqueld --output rep_processed
```
Fig. C.1. Comparison of spectra obtained from a 200 l/mm Ronchi grating (a) and a 400 l/mm Ronchi grating (b). The Ronchi 400 l/mm enable a better resolution on the bluer lines.

Fig. C.2. Increase of spot size as a function of wavelength for the two gratings.