Mem. S.A.It. Suppl. Vol. 19, 362

Memorie della
Supplementi

VST processing facility: first astronomical applications

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Abstract. VST–Tube is a new software package designed to process optical astronomical images. It is an automated pipeline to go from the raw exposures to fully calibrated co-added images, and to extract catalogs with aperture and PSF photometry. A set of tools allow the data administration and the quality check of the intermediate and final products. VST-Tube comes with a Graphical User Interface to facilitate the interaction between data and user. We outline here the VST–Tube architecture and show some applications enlightening some of the characteristics of the pipeline.

Key words. Image Processing, Astronomical Techniques, Astrophysical Data

1. Introduction

Several pipelines have been developed in the last years to process astronomical images. Most of them are tailored to specific instruments; others are more flexible and can be applied to a variety of instruments. A non–exhaustive list includes the SDSS pipeline (Lupton, Gunn, Ivezić & Knapp 2001), CASU (Irwin 2004), Astrowise (Valentijn 2006), EIS (Hook, Arnouts, Benoist & da Costa, 2001), TERAPIX (Bertin 2002), Theli (Schmithuesen, Thomas, Trachternach, Bomans, & Schirmer 2007), MegaPipe (Gwyn 2009), NEWFIRM (Swaters, Valdes & Dickinson 2009), QUEST (Andrews 2008), Pan-STARRS (Magnier et al. 2005), SUBARU (Ogasawara 2003), MACHO (Axelrod 1998).

Here we present a new software package called VST–Tube, developed to process raw astronomical images (typically in the optical bands) and to make them suitable for scientific exploitation. It has been conceived (but is not restricted) to process mosaicised images such as those that will be produced by OmegaCam, the imaging camera of the VLT Survey Telescope (VST) (Capaccioli, Mancini & Sedmak 2005). The VST–Tube pipeline allows automatic processing (from the raw frames to a stacked image, astrometrically and photometrically calibrated) of a set of exposures distributed in one or more observing nights, limiting the user intervention to the pipeline configuration and to the data preparation stages. A series of LOG files keep track of the various input parameters and of the configuration, so to allow reproducible results.

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VST–Tube can run on a normal laptop as well as in a distributed processing environment such as a Beowulf cluster (more effective for mosaicised exposures). It comes with a graphical user interface (VST-GUI) to simplify the usage and the access to intermediate and final results, and to all the quality control checks done during the processing, offering an intuitive approach through the menu bar at the window top. Some additional tools are already available to analyze the raw data and the pipeline results. In order to make the approach even simpler, a series of balloons and messages pops appear at pointing the mouse on almost the totality of the widget windows.

In this paper we describe the software architecture and show three examples of successfully processed images which enlighten the characteristics of VST-Tube.

2. VST–Tube pipeline: general description

VST–Tube has been designed to process homogenous sets of astronomical exposures, that is sets of images taken with the same instrument and instrumental setup, but under different night sky conditions. The input data are the science and calibration exposures acquired with a single or a multi-chip optical camera, the instrument and the pipeline configuration files, and a certain number of options to be chosen at the beginning in order to define the processing strategy. The output are co-added images where the instrumental effects have been removed. The latter include overscan and bias correction, flat-field correction, CCDs mosaic gain harmonization, fringing pattern removal (where applicable), illumination correction, relative and absolute astrometric and photometric calibrations. Weight and flag maps, including cosmic ray traces, are also produced. Eventually, a catalog of sources with aperture and PSF photometry can be automatically extracted.

The VST–Tube pipeline is configured through a Graphical User Interface (GUI). Written in PYTHON, it uses C libraries for Fits files manipulation and external packages for calibration and quality assessment. Just the GUI and the pipeline Python codes, excluding external packages and libraries, consist of about 60,000 lines of code.

VST–Tube has been conceived as a general purpose pipeline, *i.e.* applicable to various telescopes and to rather different science cases. In fact, the characteristics of VST–Tube are not only speed and reliability but also versatility in either treating different problems or in easily integrating user provided special subroutines. It has been designed to satisfy the general requirements of producing catalogs of astronomical sources with point–source broad–band photometry with an absolute precision of $\sim 3\%$ and a relative precision of $\sim 1\%$ for repeated observations. The absolute astrometric accuracy is limited by that of the reference catalog (typically ~ 0.3 arcsec), while the relative accuracy for repeated observations is ~ 0.03 arcsec. It must be clear that the level of accuracy in the final calibration depends on the characteristics of the science and calibration files.

The following is a short account of how VST–Tube works. Details on the structure and on the recipes will be reported in forthcoming papers.

2.1. VST–Tube in action

VST–Tube pipeline allows the user to create his own reduction strategy. Combining a number of parameters and reduction settings, the pipeline can be configured to meet the user needs and scopes. In a typical session, the human intervention, all made through the GUI, consists in loading the instrument and the pipeline configuration files, selecting all the images of a given target that we want to reduce (in a given filter but not necessarily in just one observing night), choosing the method to produce the master calibration files (there are several options depending on the set of available data), selecting the kind of output we want to obtain (for example, the creation of a single final mosaic or of a mosaic for each exposure), and then switching on the reduction.

The data input of the pipeline, properly prepared (see later), are indicated as the Object. The name Object is both used to designate the target and the tree directories created in the preparation phase, logging and archiving the intermediate and final products of the reduction process.

Let us assume that the images we want to process come from a mosaicised instrument. In the zero–th step the data, in Multi-Extention Fits (MEF) format, are prepared to be processed. A Fits header analyzer, according to the instrument configuration parameters, catalogues the files and puts them in lists that identify the type of image. For each night and filter, the raw data will be classified in Bias, Flat, Dome, Dark, Standard, Science. A directory tree structure is created which contains the images, already transformed in Single-Extention-Fits (SEF), and all the intermediate and final pipeline products. A series of quality control checks are carried out on the images in order to reject those which do not satisfy a priori requirements. At this stage malformed Fits header keywords, where applicable, are fixed, and the World Coordinate System keyword values corrected in case of an inaccurate telescope pointing model. Quite often it happens that a header keyword, even for the same instrument, keeps changing during the instrument life. It is possible to define aliases in the instrument configuration file for some of the main keywords in order to identify univocally that keyword. Other simple checks, such as exposure time and median pixel value level, are checked against the allowed range defined in the instrument configuration file. After this preparatory phase the images can be processed. All of the pipeline products belonging to one run are identified through a RUN-ID, which is the time when the processing started. This string is added to the names of all the pipeline products to easily identify them even without the help of the GUI.

While drawing the main characteristics of our pipeline, we decided to use public domain software whenever possible. We also adopted SVN (see http://subversion.apache.org/) as a source code manager. The software is developed for the UNIX environment. Another early decision was to have a pipeline working without a database (DB). The input data, and intermediate and final products, are distributed in an intuitive directory tree, so that, even without the pipeline GUI, it is easy to mine the filesystem for some particular result.

The present tree structure was reached after a long improving process. We decided to avoid the DBs to make our pipeline as simple as possible (also from an administrative point of view) and flexible enough to allow software modifications and changes of the data processing model while remaining consistent with the previous SW versions.

3. Science verification

VST–Tube was developed as multi-instrument pipeline and tested on a wide range of science cases. In this Section we present some examples, either published or still in preparation, pointing out the peculiarities of each case and the quality of the final results.

3.1. CFHT12K F14 field

We used VST–Tube to reduce a very difficult set of early 4 deg^2 CFHT12k images (VVDS-14h field (Garilli 2008), (McCracken et al. 2003)): very sparse (distributed over 51 nights), with few calibration data, with two CCDs (no. 0,6) of the mosaic which had to be excluded (the pipeline was modified to handle mosaics with unequal number of CCDs), with small offsets in the dithering for both the science images and the calibration data (making it difficult to remove objects), with almost no overlap in neighboring pointings, very strong patterns in the raw images, many non–photometric nights, and many corrupted headers or incomplete information.

In spite of the difficulties, the images where successfully processed and calibrated, and the results published (Lamareille et al. 2009). To verify the photometric accuracy, we made a comparison with SDSS observations of the same field. Figure 1 shows the magnitude residuals against SSDS's as function of Right Ascension and Declination. The standard deviation is better than 0.05 mag in the R band.

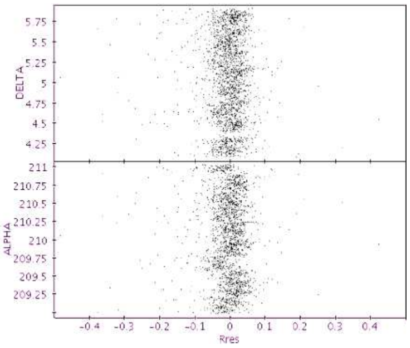

Fig. 1. VST–Tube photometry of CFHT12k F14 field in R filter against SDSS's as a function of RA and Dec. Residual differences are better than 5%.

3.2. WFI@2.2m NGC3115

A very tight test on the accuracy of the instrumental signature removal is through the brightness surface profiles of nearby galaxies. A good example is that of the galaxy NGC 3115 since, with a standard isophotal major diameter of 8.63', it cover most of the field of view of the wide field imager WFI@2.2m. WFI archive data in BVR bands of NGC3115 were retrieved and processed with VST–Tube. A critical aspect was the harmonization of the gain correction among the CCDs of the WFI mosaic. The difficulties arise from the lack of suitable data to produce a superflat (in order to better flatten the instrumental background) and from the size of the galaxy, which covers most of the field of view. In order to test the quality of the VST–Tube results, the surface brightness profiles along the main axis of the galaxy were extracted and compared with a very accurate and deep photometric study by Capaccioli (Capaccioli, Held & Nieto 1987), where wide–field photographic plates and CCD data for more than 35000 seconds of observations were used. The figure 2 (Capaccioli, Grado & Limatola 2010) shows the comparison of the light profiles along the minor axis measured on a mosaic produced with VST–Tube (solid line) (total exposure time 4200 seconds) and literature profile (Capaccioli, Held & Nieto 1987). The profiles agreed within .1 magnitude down to a surface brightness of 27.5 *mag* arcsec^{-2}.

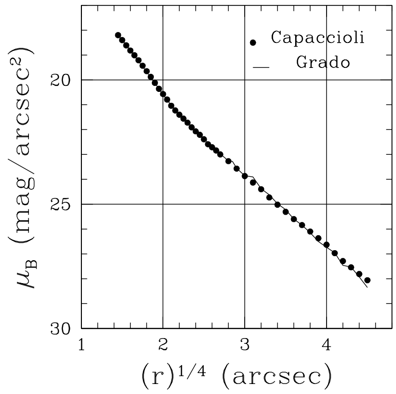

Fig. 2. Surface brightness profile comparison of NGC3115. The solid line is the profile measured on WFI@2.2m data in B Johnson band (4200 seconds total exposure time). The dotted profile comes from Capaccioli et al. (see text)

3.3. WFI@2.2m NGC6723

The last example is the processing of a crowded stellar field: the globular cluster (GC) NGC6723 (Ripepi et al. in preparation). WFI BVI images with 120 phase points in each band were processed and the catalogs automatically extracted with PSF photometry. The final mosaics, one for each exposure, were registered also in pixels in order to have catalogs with sources in the same physical position and make easier the subsequent analysis with Stetson's tools (Stetson 1987). Figure 3 shows, as an example, two RRLyrae light curves found in the cluster. The rms of the residuals with respect to truncated Fourier series fits is better than 1%.

4. Acknowledgement

The seed of this work was planted several years ago at the European Southern Observatory (Grado, Quinn, Wicenec, Devillard & Suchar 2001). For that reason one of the author (AG) wish to thanks Peter J. Quinn, Miguel Albrecht, and Andreas Wicenec. We also acknowledge the early contribution by Alfredo Volpicelli and Massimiliano

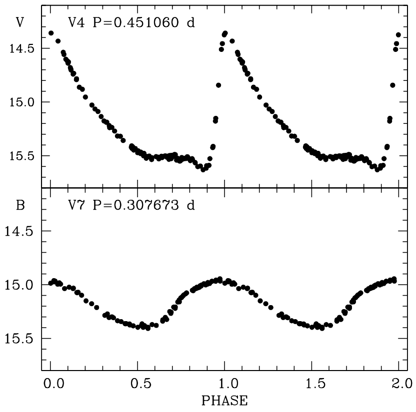

Fig. 3. VST–Tube processing of the globular cluster NGC6723. Light curves of two RRLyrae in the field.

Desiderio. We thank the Terapix group for providing QualityFits, Simone Zaggia for useful discussions and for providing the PSF photometry pipeline. Thanks to Mario Radovich for providing Photcal (the tool for the absolute photometric calibration) and to Mike Pavlov for the useful suggestions and discussions. This work has been partially funded by the Regione Campania and by the Banco Napoli – Fondazione, for which we thank the President, prof. A. Giannola.

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