Volume Title
*ASP Conference Series, Vol. **Volume Number***
Author
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The QuickReduce data reduction pipeline for the WIYN One Degree Imager

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Abstract. Optimizing one's observing strategy while at the telescope relies on knowing the current observing conditions and the obtained data quality. In particular the latter is not straight forward with current wide-field imagers, such as the WIYN One Degree Imager (ODI), currently consisting of 13 detectors, each of them read out in 64 independent cells.

Here we present a fast data reduction software for ODI, optimized for a first data inspection during acquisition at the the telescope, but capable enough for science-quality data reductions. The pipeline is coded in pure python with minimal additional requirements. It is installed on the ODI observer's interface and publicly available from the author's webpage. It performs all basic reduction steps as well as more advanced corrections for pupil-ghost removal, fringe correction and masking of persistent pixels. Additional capabilities include adding an accurate astrometric WCS solution based on the 2MASS reference system as well as photometric zeropoint calibration for frames covered by the SDSS foot-print.

The pipeline makes use of multiple CPU-cores wherever possible, resulting in an execution time of only a few seconds per frame. As such this QuickReduce pipeline offers the ODI observer a convenient way to closely monitor data quality, a necessity to optimize the observing strategy during the night.

1. The challenge of observing with modern multi-detector imagers

Astronomy in particular in recent times is a largely data-driven science, and ground-breaking discoveries are often made with the newest instruments. While imaging the sky is hardly new, modern wide-field imagers offer larger sky coverage at better sensitivities, allowing us to probe deeper into the history of the universe. However, choosing the optimal observing strategy requires to keep a close eye on the current sky-conditions, a highly non-trivial task when faced with multiple CCD detectors being read out in different channels, each with its own characteristics. Having real-time access to data that is reduced far enough to have most instrument signatures removed is hence critical for guiding the observing program and obtaining the best possible data.

2. WIYN and the One Degree Imager

The One Degree Imager is the new flagship camera on WIYN, the Wisconsin-Indiana-Yale-NOAO telescope, located at the National Observatory on Kitt Peak near Tucson, Arizona (Harbeck et al. 2010). Its current version, partial ODI or pODI, consists of 13 Orthogonal Transfer Arrays, each consisting of 64 imaging cells of 490x484 pixels. Each sub-array is read out independently from all others and thus has its own detector characteristics, in particular overscan level and gain. In total, each exposure results in 832 independent images. To address difficulties associated with handling ODI's large data volumes, WIYN has devised the ODI Portal, Pipeline, and Archive (PPA). The pipeline described here is implemented into PPA and allows for user-specified data reduction capabilities in the cloud - without having to download the raw data first.

3. QuickReduce: Algorithm and Features

The QuickReduce (QR) pipeline was originally conceived as a tool to support commissioning of ODI to assess data quality while observing. Starting at that time it quickly became a test-bed to rapidly prototype corrections and develop specific reduction recipes, as well as to cross-check the Automatic Calibration pipeline (AuCaP), an IRAF-based pipeline developed by NOAO. At the time of writing, QR performs the following reduction steps: As a first step before any corrections are done, QR creates a catalog of saturated pixels to later mask pixels affected by saturation and/or persistency effects. The basic instrument de-trending consists of (in order of execution) crosstalk-correction, overscan subtraction, bias, and dark subtraction, followed by correction for non-linearity on a cell-by-cell basis, and finally flatfield correction. During this reduction, all 64 cells of any given OTA are combined into one monolithic 4K×4K image.

After primary detrending QR uses the catalogs of saturated stars of the present frame to mask out all pixels in columns above saturated pixels as these are affected by charge smearing due to issues with the charge transfer efficiency of the current detector generation. Furthermore, saturated stars leave downward trails that become fainter with time; these are masked out using catalogs of saturated stars in earlier frames.

Fringing, caused by interference of night sky emission lines in the thin detector material, affects observations in the i' and z' bands. To minimize fringing in the exposure, QR uses static fringe maps generated from long exposures taken under dark sky conditions. While the structure of the fringing does not vary with time, the amplitude of this effect is strongly time-variable. To derive fringe scaling factors, QR implements the method described in Snodgrass & Carry (2013) that works both fast and reliable in all cases inspected so far.

Next, SourceExtractor (Bertin & Arnouts 1996) is used to create source catalogs for use during astrometric and photometric calibration. Large-scale image distortions are accounted for by using a distortion model pre-computed using SCAMP (Bertin 2006) that is assigned to each frame before source extraction. OTA-wide estimates of the sky-background are computed by random sampling the sky in small apertures, while avoiding areas close to detected sources to yield an unbiased sky sample.

Up to this point, all 13 OTAs have been reduced in parallel, and besides the actual data frames we have a large number of sky-samples, fringe scalings and guesses at the telescope pointing error. All this data is now collected to compute more robust, global sky background values and fringe scaling factors. Astrometric calibration is achieved by matching the ODI source catalog to 2MASS, allowing for telescope offsets and rotation as free parameters. Typical WCS accuracies achieved via this technique are better than rms ≤ 0.2 arcsec. Global fitting of a WCS solution allowing for changes in distortion have been attempted but did not produce sufficiently reliable results without user intervention. Finally, photometric calibration is achieved by cross-referencing with stellar catalogs from SDSS.

QR also includes functionality to remove pupil-ghost images both flat-fields and science frames. As the position of the pupil-ghost image changes after swapping filters in and out of the instrument, a technique was devised to compute the pupil-ghost directly from data taken with different rotator angles, eliminating all gaps between cells and detectors, making the resulting templates applicable to all data.

4. Implementation - parallel python

Python as programming language was chosen for a number of reasons, the experience of the author and the availability of important packages for scientific computation and handling of astronomical data, easy handling of FITS files, as well as broad support in and beyond the astronomical community being some of them. It soon became clear that this choice also comes with significant performance advantages. To further speed up processing and owing to the nature of ODI as 13 independent detectors the data reduction process is largely parallelized using python's multiprocessing package. This optimization leads to processing times for basic de-trending (correction until flat-fielding) of a 13 OTA exposure with data throughputs of $\geq$ 10 Mpixels/second on a 6-core machine with fast I/O, including solid state and RAM drives. Memory usage, on the other hand, was not considered as a limiting factor, and the pipeline in turn requires 4 – 8 GB of RAM, depending on the amount of calibrations to be performed.

5. Pipeline execution - locally or in the cloud

To run the pipeline on observed data, WIYN users currently have to download all raw data, including calibrations, to their machine. Due to the amount of data (a typical calibration dataset alone has $\sim$ 20 GB) this might not be feasible for all users. For this reason we are currently implementing the QR pipeline as a user-workspace into the ODI Portal, Pipeline, and Archive (PPA), hosted at the Pervasive Technologies Institute (PTI) at Indiana University (IU; visit http://www.odi.iu.edu; also see contributions by A. Gopu Gopu et al. (2013) and M. Young Young et al. (2013) in this proceeding). This user-workspace enables users to select science frames and calibration data from the ODI archive and run the QR pipeline on the cloud using computing resources at PTI/IU. The goal is to allow users to a) fully reduce their data without having to download the raw data; b) perform basic analysis functions such as creating source catalogs or image cutouts; and c) only download the data products they need from the portal. This eliminates both potentially long downloads as well as the requirements to have the required computing resources, a tremendous advantage for researchers in particular at smaller or teaching-oriented institutions. As such it resembles, e.g., the on-the-fly processing of HST data at STScI coupled with the user-interface of the HST High Level Science Archive, but applied here – for the first time – to data of a ground-based observatory.

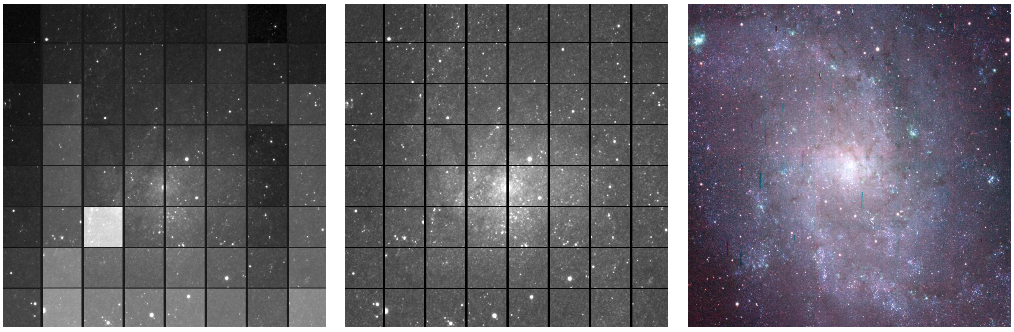

Figure 1. Example of M33 before, during and after reduction. Left image: Raw data of central OTA; Middle panel: Same OTA as on the left, after flat-fielding. Right panel: RGB image constructed from fully reduced frames in g,i,z filters.

6. Results and summary

Shown in Figure 1 are data products at several stages throughout the reduction process. Some details still remain to be implemented to improve the pipeline, but the current performance is very promising and illustrates the performance of WIYN's newest imager.

In summary, QuickReduce presents a modern approach to a fast and efficient data reduction for the WIYN One Degree imager as example of modern wide field imager. It it coded in python with minimal external dependencies and in particular does not rely on IRAF. The code is parallelized to benefit from modern multi-core CPUs, achieving reduction times for each $\sim$ 200 Mpixel frame of $\leq 20 - 60$ seconds depending on the number of reduction steps. It is integrated into the Observers interface at the telescope, allowing to quickly judge data quality, essential for efficient observing. It is also integrated into the ODI Portal, Pipeline and Archive (http://www.odi.iu.edu), giving users access to reduced data without having to download the significant amounts of raw data generated by ODI. Lastly, QR is publicly available from the author's website at http://members.galev.org/rkotulla/research/podi-pipeline.

Acknowledgments. I thank the organizers of this ADASS XXIII meeting for financial support. This research was funded by two grants from WIYN Observatory.

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