

## Scope of ODI Software

- Oct 16<sup>th</sup> 2008 -

### 1. ODI Background

The One Degree Imager (ODI), currently under construction by the WIYN Consortium, will image a one square degree field of view on the sky. The heart of the camera will be a focal plane made of 64 innovative Orthogonal Transfer Array CCDs (OTAs) totaling one billion pixels. One of the specific scientific goals, and the main design criterion for the camera, is to fully exploit the excellent image quality provided by the WIYN telescope. Image quality will be actively improved by electronic tip/tilt image motion compensation during an exposure over the entire field of view, a feat possible with the OTAs.

The pixel structure of OTA detectors allows charge shifting in the imaging area not only up and down as in conventional CCDs, but also to the left and right (“orthogonal transfer”). By moving the charge in the detectors during a science integration following the jitter of the optical image, the image blur can be substantially reduced; the delivered image quality typically improves by 0.1”. Image motion is probed by the motion of bright stars, where bright refers to about 15<sup>th</sup> magnitude as the faint limit. Regions of interest around the bright guide stars are read out in video mode at frequencies of typically 10 to 30 Hz. An OTA detector consists of an 8x8 array of small cells, each covering a field of about 1'x1' on sky. These 64 cells can operate as almost independent CCDs (therefore the “array” in OTA). The *array* nature of OTA detectors thus allows them to serve both as a guide star probes (where bright stars are located) and as the imaging array with active image motion stabilization. Note that ODI will deploy an 8x8 array of OTA detectors, each having 8x8=64 cells. In total, there will be  $(8 \times 8) * (8 \times 8) = 4096$  cells.

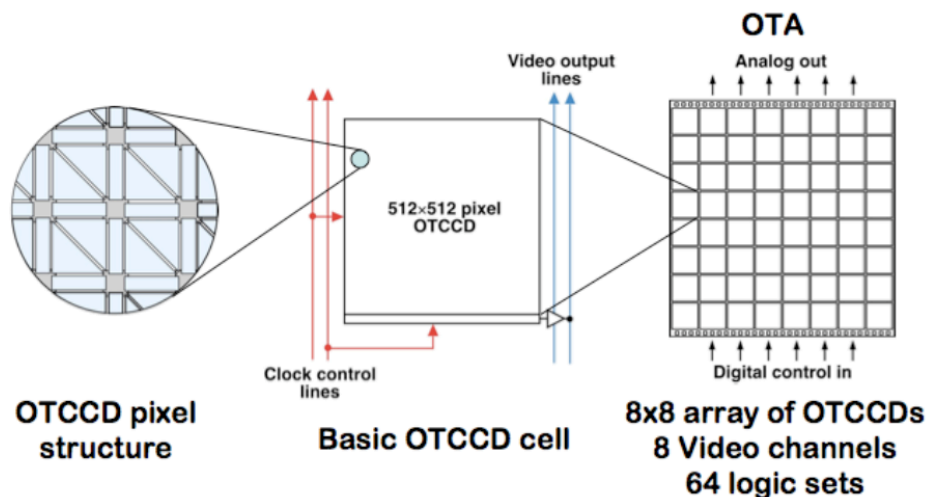


Fig. 1 - OTA detector design showing the pixel structure and cellular design.

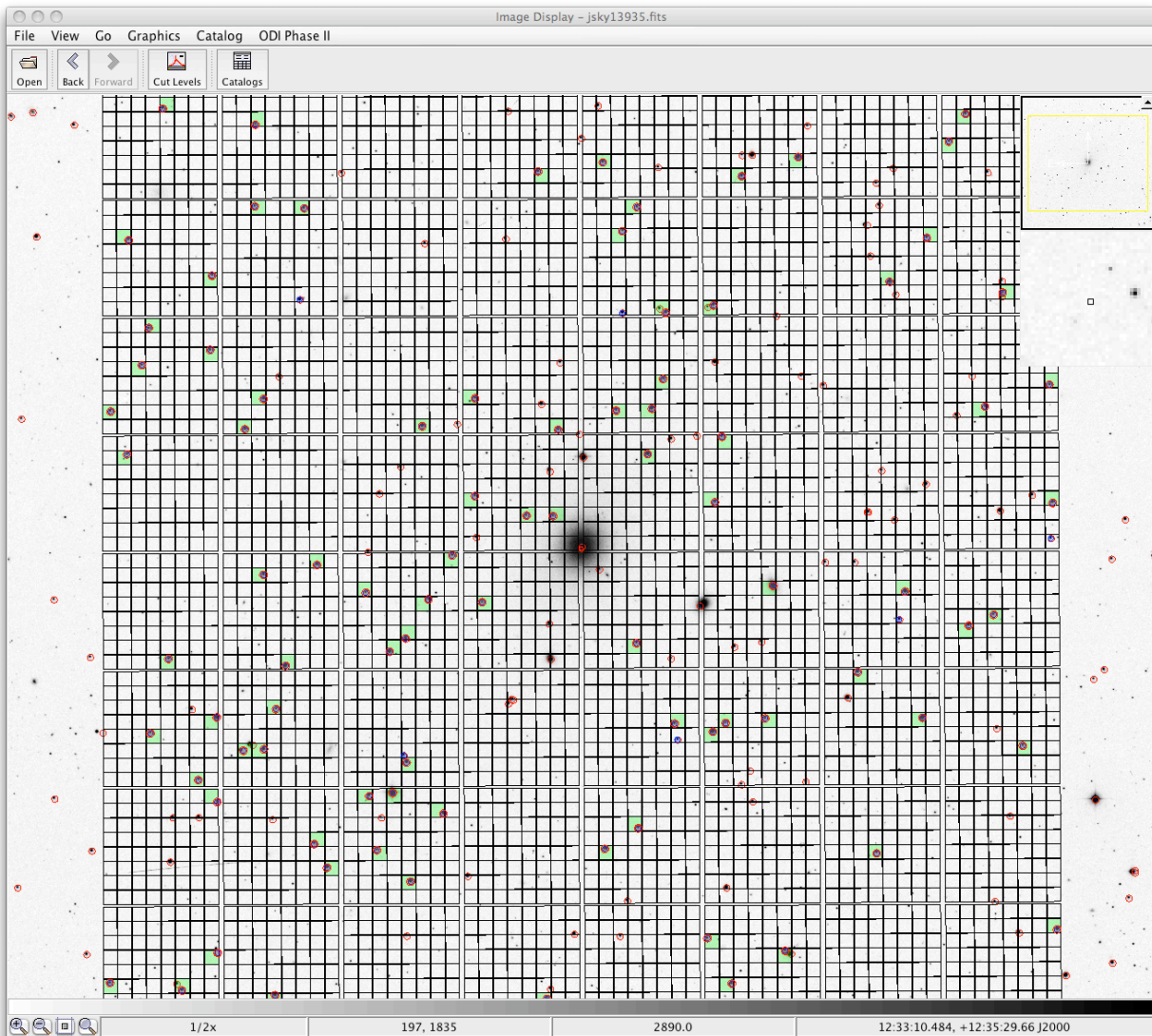


Fig. 2 - Focal plane layout of ODI superimposed on a DSS image of the galaxy M87. The scale is about  $1.2^{\circ} \times 1.2^{\circ}$ . The 64 OTA detectors and their cell arrays are visible. Potential guide stars are marked with red circles, whereas such OTA cells to be used in guide star video mode are shaded green.

Active image motion compensation will be done over the entire field of view. To compensate image motion created by guide errors or wind shake, the same motion correction is applied over the entire field of view (*“coherent guide mode”*). Typical corrections rate are of order of 10-30Hz, defined by the guide star video rate. In a more advanced mode, image motion that is caused by atmospheric turbulence will be compensated in smaller  $\sim 4' \times 4'$  large patches (this is the size of the isokinetic patch at WIYN). This more advanced mode is referred to as *“local guiding”*.

Note that for the local image motion compensation correction mode, one bright guide star is required for each  $4' \times 4'$  large area on the sky, which corresponds to  $\sim 250$  guide

stars over the one degree field of view. For the coherent guide mode, about 4 guide stars in the corners of the field of view are sufficient. In either case, the positions of guide stars have to be known to a few arcseconds, and setting up numerous guide stars will require computer support.

OTA detectors are a co-development with the PanSTARRS survey project at IfA, Hawaii. Fundamental technologies are shared with this project, including the CCD controller (“Stargrasp”) and wiring internal to the Dewar.

In contrast to other currently planned large-area imaging surveys, ODI is devised as a facility instrument at the WIYN 3.5m telescope with general user access; thus the camera hardware and software system is not tailored for a single science case. A broad range of usage scenarios will be supported. The baseline operating scenario (as defined in the ODI Science Requirement Document, SRD) foresees that ODI will be operated in visitor mode. WIYN might wish to enhance the operating mode in the future.

## **2. Software Scope**

The ODI Software shall enable:

1. Control of the instrument and archiving of the instrument status in a database;
2. Computer-assisted data acquisition in modes that utilize image motion compensation as enabled by OTA CCDs;
3. Observation planning, with emphases being on guide star selection and dithering;
4. Data quality assessment as defined in the Science Requirements Document (SRD);
5. An initial data reduction (“Tier I”) to remove basic instrument signatures.

Each of these goals are detailed further below. Note that *the ODI Software does not include a science-level data reduction system*. It also does *not* require any developments implementing innovative observing modes like queue observing. At this point in time, it is planned that ODI will be used in classical (visitor) mode although the possible implementation of queue scheduling and service observing is being evaluated by the WIYN Consortium. Hence the ODI Software framework shall have the potential for future growth into advanced operating models such as queue observing.

## **3. Instrument Control and Status Monitoring:**

The instrument control system will provide modules that control the shutter, filter mechanism, atmospheric dispersion compensator, and the dewar cryogenic system. Additional modules will provide operator-supervised access to the telescope control system. The services of these modules will be orchestrated by the data acquisition system, i.e., they will not be integrated into a single ODI instrument control software, but built as independent control systems that are supervised and invoked through network calls.

An engineering level interface will allow maintenance operations of the instrument on a lower level. A watchdog system will put the instrument into safe fallback modes in case of significant failures. The instrument control software will also monitor the status of the instrument and archive diagnostics such as telemetry from temperature sensors, filter configuration and positions, atmospheric dispersion compensator, and temperature measurements from the Dewar thermal control system.

#### **4. Data Acquisition:**

The data acquisition system provides services to operate the CCD controller in OTA-specific modes. The data acquisition system also contains the user interfaces and executes observations. It will coordinate the instrument hardware modules (filters, atmospheric dispersion compensator, shutter), telescope pointing and offsetting, exposures utilizing OTA observing modes, and the final image readout.

Specifically the OTA observing modes are defined as:

##### **1. ODI as a static imager (SRD 2.1.1a)**

Four guide stars in the corners of ODI's field of view will optionally be utilized to guide the telescope and instrument rotator, but no attempt will be made to use on-chip image motion compensation.

*This mode enables quick snap-shot science without overhead for guide star acquisition, and will also be utilized to obtain calibration data such as flat fields and pre-imaging for guide star acquisition.*

##### **2. ODI as a coherently guided imager (SRD 2.1.1.b)**

About four bright guide stars (that could be located in the corners of the field of view) are utilized to probe the correlated image motion caused by guiding errors and wind shake. This fast correlated image motion is corrected by using the OT capability of ODI at a rate of ~20Hz. The slow portion of the guide star signal can be used for telescope and instrument rotator tracking.

*This mode enables active image motion compensation with the benefit of improved delivered image quality with a low observational overhead, and is expected to be the most commonly used operating mode of ODI.*

##### **3. ODI as a locally guided imager (SRD 2.1.1.c)**

Local guide stars (i.e., at least four per detector) will be used to correct for local image motion. The guide signal of selected guide stars can track the telescope and instrument rotator.

*This mode will also compensate for image motion caused by atmospheric turbulence and will result in slightly improved image quality compared to mode 2. However, this mode requires one bright (~15th mag) guide star per 4'x4' on sky, and this mode will not be available on the entire sky due to the lack of a sufficient number of guide*

*stars.*

#### **4. ODI as shutterless photometry machine (SRD 2.1.2)**

For up to 8 guide stars per detector that are predefined (e.g., from an ODI preimage) ,shutterless photometry is collected.

*The purpose of this mode is to allow simultaneous fast photometry of small objects at rates from 20Hz to ~0.1 Hz. The photometry will be derived from the guide star video stream. For photometric monitoring at slower rates (i.e., longer exposure times), repeated static exposures with shutter operations would be the preferred way.*

#### **5. ODI with non-sidereal tracking (SRD 2.1.1.d)**

In addition to the coherent guide mode, a non-sidereal telescope *tracking* signal will be generated to allow observation of moving solar system objects.

*This mode will enable wide-field observations in the solar system.*

The ODI operational modes will be implemented and commissioned in increments; the intended priority of implementation is reflected in the mode's ordering above.

Data will be read out through 512 parallel channels that are bundled through 32 ethernet connections. Note that 8 cells on a detector share one output channel. The raw data of each detector will be stored in a multi-extension FITS file; there will be 64 extensions per file, where one extension is used per cell. Thus data of each detector will be stored in one multi-extension FITS file; there will be 64 such files per exposure. The data format will be compatible with the PanSTARRS raw data format to utilize as much of their existing quick-look and science-level data reduction software as possible.

The raw data will contain header information of the telescope and instrument status, the observing mode and metadata that is essential to analyze the data (in particular the history of the image shifts on the detector). Raw data will have a reference to the instrument status database, so detailed information of the observatory conditions at the time of observations can be recovered. The data acquisition process ends with a raw fits image written to hard drive.

It will be the responsibility of the observing team to transfer raw data onto a portable storage medium, such as external USB hard drives. The uncompressed raw data size is of order of 2GB per image, with an expected data volume of order of 1TB per night. Data can be compressed in a lossless manner.

### **5. Observation Planning:**

Orthogonal Transfer Array observational modes depend on the availability and assignment of guide stars to probe the actual image motion. The number of guide stars can range from 4 to 512, depending on the selected OTA mode. The guide star setup of OTA modes requires preparation to reduce observing overhead, although the initial

accuracy of stellar coordinates is not excessively demanding ( $\sim 1''$  when guide windows are defined, or  $\sim 30''$  when only a cell is defined. Compare this to the required accuracy of  $\sim 0.1''$  for multi-slit mask spectroscopy setups). Software support to predict guide star coordinates from catalogs and to automatically generate guide star configurations and dither patterns will be available in order to:

1. Make the complexity of the instrument manageable for the observer;
2. Predict which OTA-specific observing modes are feasible, considering the required luminosity of guide stars ( $\sim 15$ th mag) and number (ranging from 4 to 250 for guiding, up to 512 for targeted fast photometry);
3. Reduce the overhead in the guide star acquisition process.

The suite of observing planning tools shall enable the astronomer to prepare an observation off site, and to execute a predefined observation definition at the telescope. These tools should be designed in such way that they can be integrated into a more advanced operational mode of WIYN, such as queue observations which include a workflow for complete observation run preparation outside the WIYN environment.

## **6. Data Quality Assessment (“Quick Look”):**

Quick data quality assessment and visualization capabilities are part of the ODI project. The quick-look software will be used by the observer during observations at the observatory to decide if the acquired data will be useful for the intended science program. The main drivers for the quick look tool are:

1. Assess delivered image quality and background level in images;
2. Check objects of interest for proper exposure time and signal to noise ratio;
3. Get an overview of the overall image to judge, e.g., stray light, defects, etc.

The quick look can be a combination of an image navigator based on an image resampled to a smaller display size, from which smaller sections can be selected for a fully-functional image display that allows analysis at a pixel level; an example of such a tool is Saoimage in conjunction with IRAF. For the quick look capability the data have to be corrected for overscan levels variations, as otherwise the image will simply look like a checkerboard (note that there are 4096 output channels with different bias and gain values).

## **7. Tier I data reduction:**

Tier I level data reduction refers to the removal of the instrumental signature. WIYN defined two more levels of data reduction capability: Tier II where data are resampled and stacked, and Tier III where object catalogs are extracted.

ODI was initially conceived as a PI-science oriented instrument, including a Tier I data pipeline. *A scientific data reduction pipeline beyond Tier I is therefore not part of the ODI instrument project.* Tier I data reduction involves low-level data calibration steps to remove basic instrument signatures, such as overscan subtraction, bias removal, flat field correction (including correction of the flat field for OT shifting), fringe correction, and first order world coordinate system adjustment. The ability to quickly combine subsets of dither sequences is foreseen, although dithers would be shifted by integer pixels only.

The Tier I pipeline will be supported only at the WIYN facility, i.e., it does not have to be released outside the WIYN environment. The observing team will be responsible for copying the instrument pipeline reduced data on a portable storage medium such as an external USB drive.

### ***8. Integration in Advanced Operating Modes:***

Eventually, WIYN would like to allow for the possibility to operate ODI in queue observing mode. This implies that the ODI software design has to allow for future expansion, or for adaptability to front-end automated (or semi-automated) interfaces. Such potential future expansions include:

1. Ability to run remotely defined observing programs, i.e., through observing block scripts or interpreters that integrate into a sophisticated queue observing work flow.
2. Extended data quality assessment tools.
3. More sophisticated data management and distribution work flows.
4. Interfacing to an advanced science data reduction pipeline.

*Note that these extensions are not part of the ODI Instrument project and are therefore not subject of this review.*