The WIYN One Degree Imager (ODI)

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ABSTRACT

The WIYN One Degree Imager (ODI) will be a well-sampled (0.11" per pixel) imager that provides a full one degree square field of view (32K x 32K pixels). ODI will utilize high resistivity, red sensitive, orthogonal transfer (OT) CCDs to provide rapid correction for image motion arising from telescope shake, guider errors, and atmospheric effects. ODI will correct the full field of view by deploying 64 array packages having a total of 4096 independently controllable OTCCDs that can correct individually for local (2 arcmin) image motion. Each array package is an orthogonal transfer array (OTA) of 64 CCDs arranged in an 8x8 grid. Each CCD has 512x512 pixels. We expect the median image quality at the WIYN 3.5m telescope in RIZ to be 0.52", 0.43", and 0.35" FWHM. ODI makes optimal use of the WIYN telescope, which has superb optics, excellent seeing characteristics, a natural 1.4 degree field of view (with a new corrector), and can serve as a pathfinder for LSST in terms of detectors, data pipelines, operations strategies, and scientific motivation.

Keywords: CCDs, orthogonal transfer, image motion, wide-field, surveys, LSST

1. INTRODUCTION

The WIYN Observatory, a consortium of 4 institutions (University of **W**isconsin – Madison, **I**ndiana University, **Y**ale University, and the **N**ational Optical Astronomy Observatory), is developing a large imager for its 3.5m telescope on Kitt Peak. The telescope was designed and built to provide excellent image quality over a one-degree field of view (FOV) and its builders have exceeded their goals. The native median delivered image quality (DIQ) in the R-band is ~0.7", with occasional long periods of 0.4" images. The DIQ is smaller than 0.5" about 20% of the time. With low-order adaptive optics (tip/tilt correction on natural guide stars), the R-band median DIQ drops to about 0.52" and the 20% point drops to about 0.35". At redder wavelengths, the DIQ with tip/tilt will obviously be even smaller. The goal of the One Degree Imager (ODI) project is to provide an optical camera with excellent pixel sampling and tip/tilt correction over the full 1 degree square. The characteristics of ODI are summarized in Table 1.

The challenge for an optical wide-field imager is to overcome the atmospheric limitation imposed by the isokinetic patch. Typically, the angle on the sky for which image motion is highly correlated is ~4 arcmin (radius of ~2' from a guide star). Figure 1 (left) demonstrates that this angular scale is approximately correct at WIYN (Claver et al 1998[1]) and is somewhat better than at CFHT[2] (at least on the nights for which the data were obtained). Figure 1 (right) illustrates how image quality degrades with distance from the guide star at WIYN using the WIYN Tip/Tilt Module[3] (WTTM) that provides image motion correction over a 4' field.

Table 1. Summary of ODI Features

Field of View	1 degree by 1 degree
Pixel scale	0.11" per pixel
Array size, pixels	32K x 32K
Array size, inches	16-inch x 16-inch
Image size	2 Gbytes
Limiting mag (BVRI; for S/N=10 in 1 hour)	26.2, 26.1, 25.9, 25.5
Median DIQ (RIZ)	0.52", 0.43", 0.35"
Readout time	2 seconds
Spectral Range	UBVRIZ

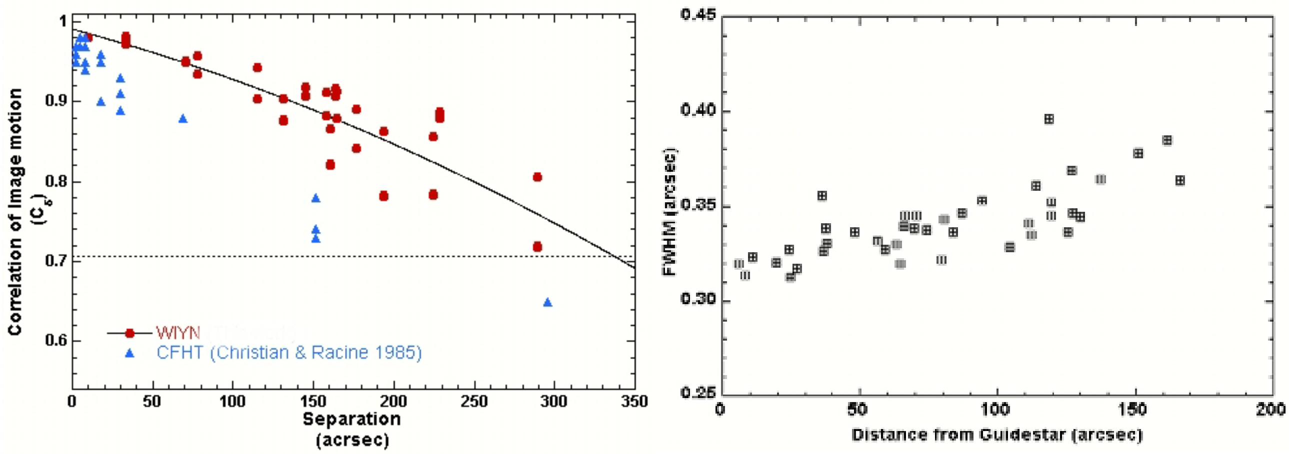

Figure 1. The left panel illustrates the degree of image motion correlation with distance from the guide star for WIYN and CFHT. Below a correlation factor of 0.707, images are damaged by guiding. The correlation angle at WIYN, where we define the useful angle as the radius for which the correlation is >90%, is typically about 120". The right panel shows how the FWHM varies with distance from the guide star at WIYN, using WTTM to fast-guide. Within 2 arcmin of the guide star, the PSF degrades <10%.

Our motivation for focusing on the image quality with this imager is driven by the significant improvement in information collection rates by improving the PSF. For stars and unresolved objects that are more or less uniformly distributed on the sky, the information rate is:

$$M = \frac{A\Omega\varepsilon}{d\theta^2} \ .$$

This metric depends on the effective collecting area, A, the solid angle field of view on the sky, Ω, the overall system throughput, ε, including detector sensitivity and duty cycle, and the image quality, $d\theta$. Each of the parameters contributing to M can be extended in complexity to contain second order components. With the One Degree Imager (ODI), the WIYN telescope will provide a combination of image quality and field of view that cannot be matched by any other facility in the "US System" (or elsewhere, currently). For example, M(WIYN+ODI) will be ~8 M(Mayall/Blanco+Mosaic). Forward-looking facilities such as LSST will have higher performance, but ODI complements the goals of LSST very effectively with its tip/tilt correction, variety of imaging filters, community availability, diverse scheduling opportunities, and earlier implementation.

2. OVERVIEW OF THE ONE DEGREE IMAGER (ODI)

Progress toward improving *M* has been most easily accomplished by building larger and larger cameras with mosaics of CCDs to increase the detected field of view, Ω. Construction of 8-10m telescopes has improved *M* by increasing *A*, but this is a costly approach. Improvements in ε and $d\theta$ have been less impressive. Detector efficiency has improved with some gains in their QE, which is typically >60% across most of the optical spectrum, leaving little room for dramatic advances except in the <380 and >900 nm ranges. Similarly, duty cycle improvements derive from slightly shorter readout times (down to ~30 seconds). Improvements in $d\theta$, though, have been nearly non-existent for wide-field imagers, although impressive gains have been made with high order adaptive optics (AO) and space-based systems by sacrificing field of view. Because the gain with image quality enters as the square, attention needs to be directed toward this parameter. Low order AO systems, such as those offered with orthogonal transfer CCDs (OTCCDs[4]), offer the potential for very significant gains in *M* over arbitrarily wide fields of view. This project exploits these detectors.

2.1 Detectors

The ODI team is just beginning the development effort to build a new paradigm of optical detector called an Orthogonal Transfer Array (OTA). The OTA provides the means for local tip/tilt correction in the silicon, allowing for removal of telescope shake, guider errors, and atmospheric image motion, over an arbitrarily wide FOV. The proposed device being developed at MIT Lincoln Laboratory is summarized below and discussed further by Tonry at this conference.

The basic device is illustrated in Figure 2. It consists of an 8×8 array of OTCCDs, each of which, in turn, is comprised of a 512×512 array of 12×12-µm pixels. The array is closely packed to minimize dead space between imagers; the fill factor for the sensor is >97%. The device will constitute a 4K×4K imager on a die size of ~25 cm^2. Four of these die fit on a 150-mm wafer. The division of the detector's large area into sub-cells of 512x512 is a tradeoff between the parameters of overhead of inter-CCD gaps, lost area from dead cells, readout speed, and sample size within the atmospheric isokinetic patch, yet it offers these major advantages:

- Higher yield and lower cost by isolating defects
- Fast readout (2 seconds) since each CCD cell has its own amplifier
- Autoguiding using CCD cells with bright stars
- Image motion compensation over arbitrarily large fields by charge shifting

A key capability of an OTA is its ability to quickly and independently control, shift charge, and read out each of the 64 imagers. One can read an individual "guide" cell at 50 Hz, and the entire 4Kx4K imager can be read out in 2 seconds.

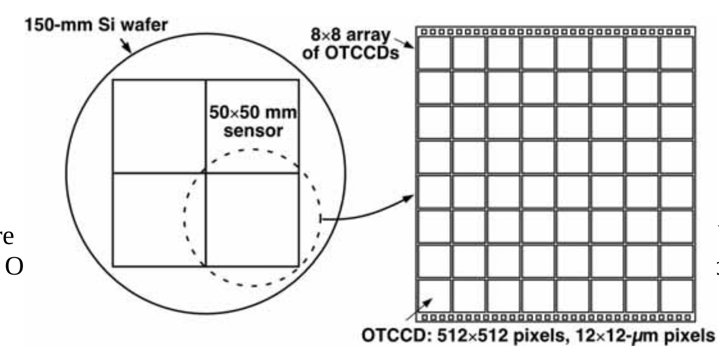

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Table 2. Key Features of the OTA

Number of OTCCDs	64 (8×8 array)
OTCCD size	512×512 pixels
Pixel size	12×12 µm (0.11" x 0.11")
Parallel clock rate (max.)	200 kHz
Serial clock rate (nominal)	1.0 MHz
Read noise	<5 e^- rms
Read time (all 64 CCDs)	~2 s
Binning	Arbitrary in both directions
Charge clear	Fast serial dump in one parallel clock cycle per row

Typically, one selects ~5 cells per OTA for guiding, while 2 cells are statistically likely to be defective and would be shut down, and the remaining 57 cells serve as science arrays (see Figure 3). These estimates apply to the full focal plane of 64 OTAs (32K X 32K pixels) anywhere in the sky. Consequently, one can monitor the *spatial* coherence of the image motion across the FOV over time and apply *predictive* algorithms to improve the guide corrections, or to reduce the rate required for correction, thereby allowing for correction with fainter stars.

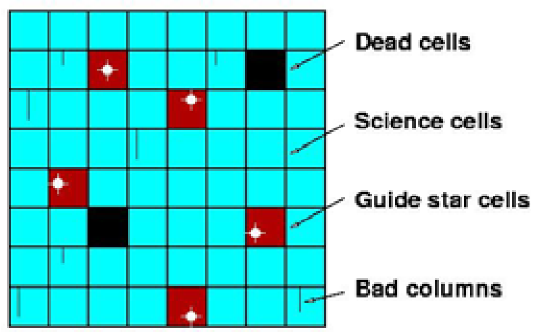


Figure 3. Typically, there will be ~5 "guide" stars available anywhere in the sky that are read out quickly, at ~20-50 Hz. Point flaws in the detectors will occur, on average, at a rate of 2 per OTA, rendering 2 of the 64 cells as "dead"; these will be disconnected. The remaining 512x512 pixel cells are good science cells and will collect photons during long integrations. Bad columns and blooming due to bright stars are delimited by the 512x512 cell structure.

The effectiveness of tip/tilt improves as one moves further to the red, becoming diffraction limited in the IR. Thus, the enhanced red sensitivity (see Figure 4) of these detectors, as noted by the MITLL curve, is a necessity for the camera to be maximally effective. Data from the WIYN Tip/Tilt Module (WTTM[3]) indicate that the median seeing at WIYN with the OTA imagers will be approximately 0.52", 0.43", and 0.35" in R, I, and Z, with the Z-band DIQ often falling at 0.2" or below.

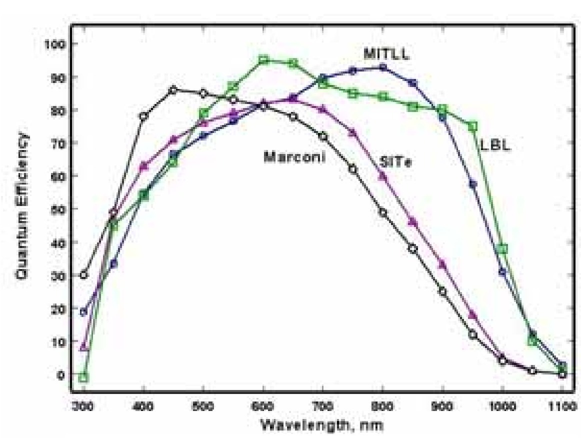


Figure 4. QE curves for a variety of CCDs.

Compare, for example, the Hα+[NII] WTTM image of the Ring Nebula (Figure 5 left) with that from HST (Figure 5 right). The WIYN image is somewhat sharper for the following reasons. First, the well-sampled image has been deconvolved using the Lucy algorithm to yield roughly 0.25" FWHM. Second, the HST PSF has considerable power in its wings, thereby degrading the apparent resolution of extended objects. The key point is that WIYN+ODI has the potential to provide images of this quality across a 1 degree field – something that is neither available nor planned.

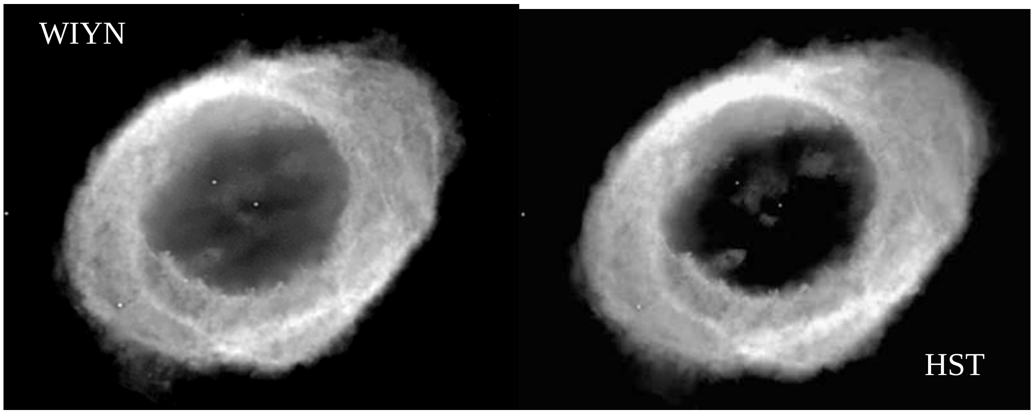


Figure 5. WIYN+WTTM image (left) and HST image (right) of the Ring Nebula. The spatial resolution of both images is comparable.

2.2 Demonstration of the OTA

As part of an NSF technology proposal, a demonstration camera will be built for WIYN consisting of 4 OTAs to produce an 8Kx8K imager. This camera, called QUOTA for the "QUad" of OTAs, will serve as a testbed for developing the detectors, electronics, software, and operations model for ODI.

2.3 Electronics

The electronics needed to run the detectors will be the new acquisition and control system being developed by Barry Starr at NOAO. Each board of the control system accommodates the full 8 channels of video output from a single OTA. Development of the software to run an OTA will take place under the QUOTA effort, and requires 4 controller packages. Thus, 64 control packages are needed for ODI, where each controller package will be physically located behind the footprint of its OTA.

2.4 Camera Components

The key components needed that extend beyond most imagers of today are a large dewar, shutter, and filter changing mechanism. The focal plane for ODI is ~16 inches on a side and is built up from an array of 8 mounting/cooling bars, with 8 OTAs attached to each bar. Figure 6 illustrates one concept for constructing the focal plane array. Cooling of the CCD arrays will be provided by a closed cycle cooler of some variety. We have considered Cryotigers, but a large number of them are needed to maintain the temperature against the large heat load of the 16-inch focal plane.

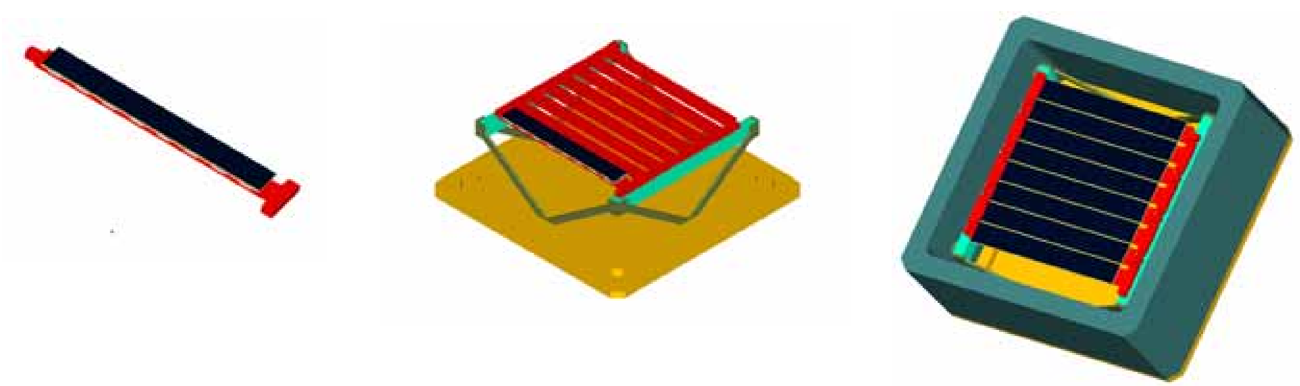
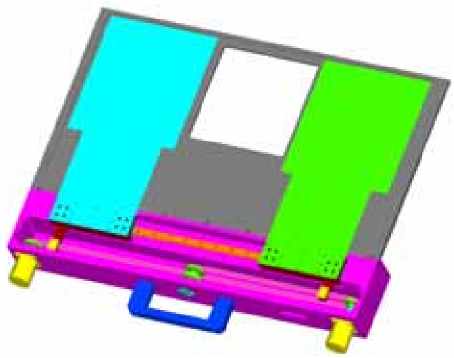


Figure 6. The ODI focal plane of 64 OTAs is assembled from 8 subsystems of 8 OTAs mounted on a cooling bar.



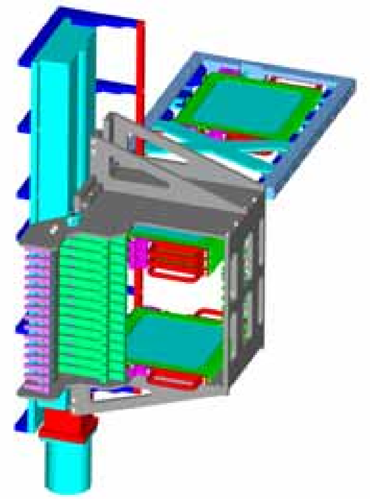


Figure 7. Concepts for the shutter mechanism (left) and the filter exchanger (right) are based on hardware at the Magellan telescope .

Preliminary concepts for the shutter and filter mechanism were based on existing Magellan hardware. The dual-blade shutter design (Figure 7, left) allows for accurate exposure times by placing the two blades close to each other for very short exposures, if necessary. The filter "server" mechanism (Figure 7, right) follows the "juke box" approach. Note that the filters must be 17-inches on a side. These components are all large. A challenge will be to develop the design within the constraints of the weight (1600 lbs) and torque (2230 ft-lbs) limits of the telescope's Nasmyth port bearing.

2.5 Optics

The WIYN telescope provides a native 1 degree *diameter* field of view. Preliminary studies of the telescope optics and mechanical bearing indicate that a square field of 1 degree on a side (1.4 degree diagonal) can be achieved, but with vignetting. The unvignetted field is actually larger than the original telescope design – about 1.1 degree in diameter. At the extreme corner pixel, the vignetting losses approach 40%. We are investigating mechanical modifications to reduce this loss.

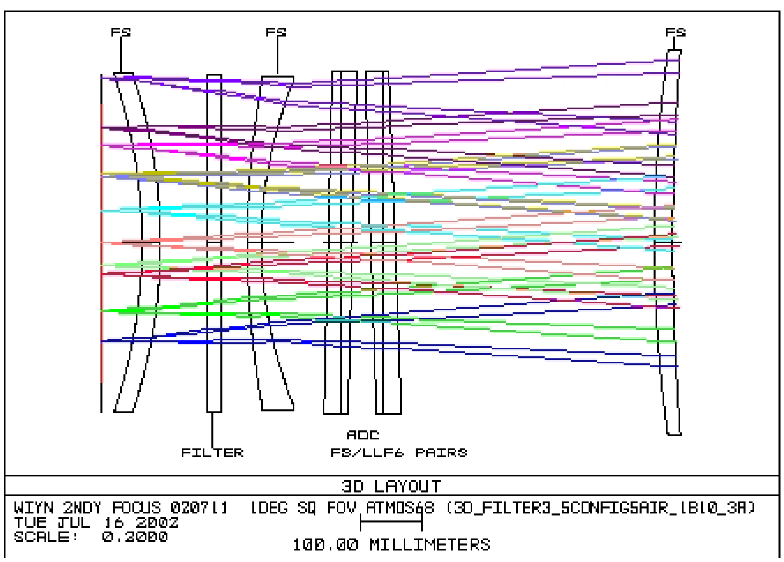


Figure 8. Ray diagram for a 1.4 degree corrector for the WIYN telescope.

We have made good progress toward a corrector design[5] that yields nearly perfect images (1 pixel FWHM or less) across the full 1.4 degree diameter from the 3000 – 10,000 Å with bandpasses delimited by typical UBVRIZ filters. The glass for this 3-element fused silica corrector (Figure 8) weighs about 117 kg when an atmospheric dispersion corrector is included (although the ADC necessarily contains some UV absorbing glass). The design allows the ADC to be swapped with a pure fused silica "dummy" for use in the UV. In Figure 8, the focal plane is to the left. Moving to the right, we have the final element of the corrector, which also serves as the dewar window, then a 1-inch thick filter, another silica element, the 2 pairs of wedged elements comprising the ADC (made of fused silica and LLF6), and finally, the leading element of the corrector (at the right).

2.6 Filters

Many existing wide-field imagers, and all larger ones, require difficult-to-obtain filters. Because the WIYN ODI imager will work very well with narrow-band filters in the telescope's f/6.3 beam, we anticipate that the scientific demand for narrow-band observations will exacerbate the filter procurement process. One solution is to build filters from 2X2 mosaics of 8.5-inch filters. This approach offers several advantages. First, the smaller items can be delivered without any technology development. Second, they can be supported by a cross-brace at the intersection of the 4 filters to improve mechanical and optical stability. While the brace will cast a vignetting shadow of a few mm, the OTAs can be deployed to fall outside the shadow. Thus, we have a gap in the focal plane, but gaps already were part of the design and must be dithered out for a gap-free image. Thus, there is little to be lost with this approach.

2.7 Computers and Software

Tthe data volume per night will be 2-4 Tbytes. The data rate will be 1 Gbyte/second during the 2 second readout time. A parallel computing architecture provides a necessary and straightforward solution to managing the data flow. Nevertheless, the data system must be engineered carefully. Among the principal concerns are:

1. Image format – one big file is too cumbersome. A 64 level multi-extension FITS format file is workable.
2. Storage medium for several nights of data (10-15 Tbytes) to stage pipeline reductions
3. Mechanism to take away reduced data from telescope, either for a PI run, or for archival into a distribution system (e.g., NVO)
4. Data compression technology – a factor of 2 is achievable without loss, but we may wish to consider slightly lossy techniques that achieve 10X compression factors.
5. Real-time display of 32K x 32K for quick-look verification
6. What should be required of the quick-look tools?
7. Reduction pipeline – this is a fully parallel process (i.e., straightforward) until one combines a dither sequence of 10-20 images.
8. Are specialized tools needed to reduce the data? Yes, a feature (e.g., a star) is accumulated over several pixels due to the image motion correction, and so, flat-fielding must account for the pixel-to-pixel variations over which each feature was integrated.
9. What is the optimum granularity for parallelism in the acquisition, processing, and storage phases? Each activity may require a different optimization strategy ranging from one CPU+disk per 512x512 CCD (of which there are 4096 CCDs) to more modest (and sensible) quanta. Probably, one CPU+disk per OTA (64 CCDs) is a natural and reasonable choice.
10. The user interface must be devised to include user feedback on the state of the image motion correction and the automatic identification of guide stars at each dither position.
11. Generation of catalogs – or, is this part of NVO/LSST?

3. SCIENCE DRIVERS

The scientific scope for ODI is similar to that proposed for LSST, but a few important differences are notable. While LSST is designed with a bigger aperture, faster beam, and shorter settling time to allow fast pointing and short exposures for tracking fast varying/moving objects, ODI is expected to have better image quality, and its slow beam allows the use of narrow-band interference filters. Several areas of investigation that are topical today, will benefit from an early deployment of ODI, while others, such as a comprehensive census of Near Earth Objects and Kuiper belt objects cannot reasonably be completed without LSST. Early deployment of ODI will thus provide some early results, as well as help develop LSST observing strategies, data pipeline experiments, and distribution technologies. We mention first a sample of topics for which WIYN+ODI is very well suited, and later discuss those where ODI can play an auxiliary role to LSST.

1. **Planet detection via the transit method** – When a planet transits its host star, a small eclipse can be seen as a cyclical photometric decline in the star's apparent brightness. Only one star/planet system has been found in which an eclipse is evident, and it is easily seen with small telescopes. An attempt to find many planets around stars was undertaken with the HST by repeatedly observing a globular cluster. No planets were detected despite excellent ensemble photometry down to a few tens of micro-mags. If planets fail to form around low metallicity hosts, then the next place to look is in open clusters where a more diverse set of compositions can be observed. WIYN+ODI provides an unprecedented field of view, sensitivity, and efficiency for planet searches in open clusters. It will be possible to find planets as small as Neptune (4X larger than Earth, 3X smaller than Jupiter). In addition to clusters, surveys can be performed in the field to expand the range of stellar ages and metallicities, especially in the Galactic plane, where the number of stars observed per field is very large.

2. **White dwarf luminosity function** – The shape of the faint end of the white dwarf luminosity function is sensitive to the age of the parent population. Currently the white dwarf luminosity function is poorly constrained, being defined by <50 objects. Consequently, model fits for the age of the Galactic Disk range from 6-12 Gyrs. By surveying moderate areas of the sky to faint limiting magnitudes, one can greatly increase the number of white dwarfs used to define the luminosity function. ODI's very good image quality improves the discrimination of faint white dwarfs from the hundreds of thousands of non-stellar objects in the one degree field. Using broadband colors plus the addition of two intermediate width filters, one for MgH and one for CaH, one can weed out contaminating stellar objects from true white dwarfs. At faint limiting magnitudes, though, galaxies with colors similar to white dwarfs become a major contaminant. The enhanced image quality of ODI allows these galaxies to be identified by their non-stellar morphology to better than 90% in 0.5” FWHM seeing. With ODI one can probe multiple directions in the Galaxy to isolate nearly pure disk and thick disk white dwarf samples, thereby enabling self-consistent exploration of ages in the Galaxy using a single age technique.

3. **Variable star inventory of the nearby Universe and their use in several extant problems** – The wide-field and fast readout of ODI allows one to survey all the northern Local Group and nearby galaxies at cadences ranging from seconds to years. Thus, one can construct catalogs of all the variable objects (whether synoptic or secular) down to limiting magnitudes of 23.5 (1 minute) to 26.5 (1 hour) in Local Group galaxies. This permits a host of interesting problems to be addressed with a self-consistent data set: a) Cepheid distances to many galaxies within ~5 Mpc, which in turn helps to map the local expansion flow (this provides an independent estimation of the mean mass density of the Universe); b) the discovery of RR Lyrae stars in Local group galaxies and their implications for the relative presence of ancient stars (ages > 10 Gyrs); c) the systematic study of Long Period Variables and how their properties change with metallicity (this has not been extensively studied beyond the Magellanic Clouds due to lack of both field size and image quality); d) the RR Lyrae (Pop II) and Cepheid (Pop I) distance scales, which are based on independent premises, remain unreconciled at the 0.2 mag level (the discovery and measurement of both kinds of variables in a number of different LG galaxies with varying metallicities can provide necessary data constraints for resolving this problem); e) what is the effect of metallicity on the Cepheid PL relation? By measuring the PL relation across the faces of M31, M33, NGC 6822, for example, one can determine the magnitude of the metallicity effect from hundreds of Cepheids drawn from a wide range of metallicities; f) for nearer galaxies like the dwarf spheroidals, we can identify all the cataclysmic variables, and identify all variables down to very deep limits ($M_V \sim +7$).

4. **Z > 6 Lyα survey for proto galaxies** – ODI's excellent red response at 0.9μm in combination with excellent image quality allows one to search for redshift ~6.5 QSOs, AGN, or Ly-alpha emitting protogalaxies in the OH emission "window" between 0.89μm and 0.93μm. The SDSS has found three QSOs at redshifts > 6. These objects are bright, but are extremely rare, with surface densities of 1/400 sq. degree. Otherwise, only one faint protogalaxy has been discovered at z~6.5. An ultra-deep imaging survey with ODI to AB=27.5 (~200 hours) has the potential to discover fainter but more common objects, bridging the gap between objects discovered with the SDSS, and the extremely faint, but common protogalaxies that should be seen by NGST. This deep survey should discover several z~6.5 objects per field and would provide a reliable observational estimate of the star formation rate in the very early universe.

5. **Galaxy Halos --** Recent imaging in the halo of M31 and in our own galaxy shows considerable evidence of star-streams, which reveal themselves as star count density enhancements that look like tidal tails. They are inferred to be the tidal remnants of infalling satellite galaxies. It is crucial to know how ubiquitous and extensive these features are, and what fractions of galaxy halos are made from such accretion. In CDM cosmology, large galaxies are made by the cannibalization of smaller ones, and a quantitative study of this phenomenon by imaging the halos of M33, M81, NGC2403, and M101 is a big step in this direction. The M31 work has reportedly taken 92 contiguous fields at various telescopes – the deployment of ODI makes an extension of this work to other galaxies much more efficient, and therefore tractable. Note also that this study benefits from the ability to separate stars from background galaxies by image morphology alone. This will be possible for the galaxies listed above given the expected image quality from WIYN+ODI.

Among the LSST science drivers where ODI may provide some early insight are:

- Kuiper Belt Objects
- Near-Earth Objects
- Transients and fast variables
- Proper motions, astrometry, parallax
- Strong and weak lensing
- High redshift supernovae

Consider the case of two of these as an example of how ODI can contribute:

6. **KBOs and NEOs** – Current KBO searches using KPNO and CTIO 4m telescopes have found ~200 KBOs, extending identifications to 1000 AU. With the very good images, 3X larger survey area, fast readout, and high QE expected from ODI at WIYN, ~150 KBOs will be found per night. A similar increase in discovery rates will be seen for NEOs, rising from about 12 to 70 per night. At the other end of the scale, some moving objects are expected to be as large as Pluto, but distant and faint. Thus, ODI may be able to find new Solar planets, new bodies around existing planets, probe the KBO distribution to large distances, and provide a test bed for strategies intended to find NEOs.

4. TECHNICAL RISKS AND UNRESOLVED ISSUES

The principal risk in constructing ODI today is the unavailability of the detectors. By May 2003, though, the MITLL development should be far enough along to validate the concept of the OTA. The expectation of federal funding for QUOTA and Pan-STARRS (AKA "POI") for similar detectors, plus WIYN internal funds strongly mitigates this risk.

Software presents a very significant sub-component of the project. There are many elements noted in Section 2.7, but almost all of these need to be resolved for other survey activities in the community. For ODI, the unique software challenges lie in addressing all 64 OTAs as a single focal plane device. This activity is needed twice – once when applying global image motion corrections, and second, when combining a sequence of dithered images into a single seamless image. A contract is being prepared for a 5-month study of the entire software system required for ODI.

Because the OTA and controller architecture is highly parallel, with the data being directed to something like 64 computers in a cluster, the image motion correction must collect small data segments from each of the parallel CPUs, then compute the global corrections and command charge motion in each of the ~4000 CCDs addressed by the 64 control systems. The design of the software architecture must allow for rapid collection, analysis, and dissemination of small data packets.

The "stacking" of dithered images is a solved problem, but has never been applied to images of this size (32K x 32K pixels = 2 Gbytes per image). Resolving this demand is one of the critical design issues for ODI's post-acquisition software system, although other wide-field imagers under development (see Table 3) will face similar problems sooner.

This processing step must be completed at the telescope in order to relieve the requirement for storing/transporting the much larger volume of data represented by the set of 10-20 dithered frames per field. The raw data rates are expected to produce 2-4 Tbytes per night, and so, some form of near real-time reduction is needed to avoid building a huge archive at the telescope. It is time to take another serious look at data compression techniques, both lossless and lossy.

We do not yet know if there are any mechanical limitations for installing ODI on WIYN. Engineering studies to meet the weight and torque limits are in progress.

Operationally, WIYN will have to be scheduled in a very different way than it is currently. Many of the proposed projects require large blocks of time over several years, whereas WIYN today is operated as a "classical" facility. [Note that the first production "non-classical" queue-scheduled facility was WIYN.] We envision a mix where, for example, 30-50% of the time goes to dedicated ODI surveys in a queue/service mode, 20-30% goes to short PI runs with ODI, and ~30% of the time is allocated for other instruments. While the change in operations does not represent a risk, the implementation plan remains to be developed.

5. COMPARISON TO OTHER LARGE FORMAT CAMERAS

Wide-field optical imagers have made extremely popular instrumentation projects during the past decade, starting with the Hawaii 8Kx8K mosaic imager[6] and followed by the NOAO/KPNO and NOAO/CTIO imagers[7], the ESO WFI[8], and a variety of similar cameras. These have several common properties: they typically utilize 2Kx4K pixel CCDs as the basic building block, they tend to have focal plane diameters of 6-8 inches, and they have readout times of 30 seconds or more. Recent advances have been evolutionary, using additional 2Kx4K CCDs per imager, leading to focal planes as large as 18Kx18K (CFHT and SAO Megacams). A summary of the characteristics of the more advanced cameras is given in Table 3.

Table 3. Characteristics of the Advanced Wide-Field Imagers

Telescope/Imager	Aperture, m /f-ratio	Field, Deg^2	Nr. Pixels	Pixel Size, arcsec	Readout Time, sec	Seeing, R-band	Metric, M
CFHT/Megacam	3.6/4.1	1.00	20K x 18K	0.18	20	~0.7"	2.5
MMT/Megacam	6.5/5.0	0.16	16K x 16K	0.09	30	~0.65"?	1.3
LSST/DMT	(6.9)/1.2	7.00	47K x 47K	0.20?	4?	~0.6"?	100
Subaru/Suprime	8.2/2.0	0.25	10K x 8K	0.20	60	~0.6"	2.6
WIYN/ODI	3.5/6.3	1.00	32K x 32K	0.11	2	~0.5"	5.3

In this table, the "metric", M, refers to the equation in Section 1, and is scaled to the LSST at a value of 100%. We assume a typical exposure time is 2 minutes when calculating the impact of readout time on system efficiency. This is a compromise between the fast optical systems that will saturate in longer exposures, and the slower beam systems that can accommodate a long exposure.

We see that WIYN/ODI performs very well according to this metric, and as observations push further to the red, WIYN/ODI performs better yet with its red-sensitive CCDs and greater gain from tip/tilt correction at longer wavelengths. Furthermore, with its slow f/6.3 optical beam, WIYN/ODI provides the best platform for narrow-band surveys among the wide-field imagers. Note also that LSST performs extraordinarily well according to this metric, even at the effective 6.9-m aperture (true physical diameter is 8.4-m).

6. BUDGET

We are in the process of contracting for conceptual design studies that will enable us to budget more accurately for the construction phase of the project. A rough idea of the cost, which includes estimates for designing the components listed, is given in Table 4.

Table 4. Approximate Budget for ODI

OTAs: Design and wafer fab, two lots	$1.0M
Electronics & computers	$0.6M
Shutter/Filter assembly	$0.3M
Software	$1.0M
Dewar & coolers	$0.3M
Hardware design	$0.3M
Filters (UBVRIZ)	$0.2M
Corrector	$0.5M
TOTAL	$4.2M

7. SCHEDULE

A rough time estimate for first light of ODI would be 2 years after first delivery of OTAs for the QUOTA camera, or Fall 2005. Full implementation of ODI could be complete a year later if funding permits. Thorough commissioning for an instrument this complexity will extend an additional ~6 months.

8. RETURN TO THE COMMUNITY

As a wide-field multi-color survey camera spending ~50% of its time on major projects, ODI will generate images of interest to a diverse community. The data obtained for the major projects (as opposed to the "3-night" PI runs) will be made available to the community very quickly. Indiana University (a WIYN partner) is home to the "Distributed Storage Services Group", that routinely deals with Tbytes of data (see: http://www.indiana.edu/~dssg), and the DSSG is considering whether it can store/serve ODI data for the community. WIYN also expects to make this subset of ODI data available through the NVO, should that service be available on the same time frame.

9. REFERENCES

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