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Document Title:	**One Degree Imager Science Requirements**		
Brief Description:	**This document defines the top-level requirements for the WIYN One Degree Imager based on its anticipated science use and its role in the US system of observing facilities.**		

Related Documents:	
Document Number/Title:	WODC 00-01-03: Scientific & Technical Requirements for the WIYN 3.5 meter Telescope.
Document Number/Title:	ODI-AD-01-004: ODI Data Reduction Pipeline Requirements Paper
Document Number/Title:	ODI TSIP Contract & Memorandum of Understanding

Document Acceptance and Concurrence		
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Revision History

Version	Author	Date	Sections Affected	Remarks
2.0	Daniel Harbeck	Apr 5 2007		Initial Blue Book Version
2.1	Daniel Harbeck	Apr 17 2007		Revised Version following up discussion of Apr 12th 2007 SAC meeting, and comments by Project Engineer.
2.2	Daniel Harbeck	Apr 21 2007		Further minor revisions following the SAC meeting on Apr 21 2007.

Preamble

The goal of the One Degree Imager Project is to provide a beyond state of the art imaging instrument to the WIYN 3.5m observatory community in time and within the allocated budget.

WIYN Board Resolution 2003-1:

Recognizing that the WIYN 3.5 meter telescope is the best wide field imaging telescope and recognizing that the addition of the One Degree Imager (ODI) will maintain WIYN at the forefront in high-technology wide-field imaging, the WIYN Consortium commits to design, develop and use its best effort to obtain the necessary funds to build the ODI for the WIYN telescope.

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About this document

This document defines the high-level science requirements for ODI and will be used to derive all lower-level definitions for ODI. It therefore serves the purpose of defining ODI, allowing the engineers to design ODI, and guide the instrumentation team in trade-studies.

The structure of this document is as follows: First we outline typical science cases that ODI will be used for, as they are derived from the TSIP proposal and additionally solicited use cases. From these science cases we derive a list of requirements for specific science goals. Each set of requirements will be justified, a high-level verification plan will be given, and the impact of not meeting the requirement – as understood at the time of writing – will be explained. The purpose of the verification plan sections is to help understanding the requirements and to support the later creation of a comprehensive technical testing and commissioning plan. The sections outlying the impact of not meeting the requirements will be valuable as a tool to prioritize the requirements should problems in their implementation occur. Combining the requirements, their justification, testing, and implication will help to not only understand the requirements, but also their intent.

Acknowledgement

The science case is based on the TSIP proposal to which many authors contributed. We also thank John Feldmeier and Greg Rudnick for additional input to the science section, and Bill van Altena for his insight into astrometry requirements.

I. Document Control

Any changes to ODI science requirements described in this document require approval by the WIYN Board. Changes to the requirements can be proposed to the ODI management, which will - in collaboration with the WIYN Science Advisory Committee and the ODI Science Working Group - evaluate their impact on the ODI project and the WIYN Observatory. The ODI management or the SAC will then present the requested change along with its impact statement to the Board for approval.

Definitions

Requirement - Requirements in this document define minimum capabilities ODI must deliver in order to make the instrument scientifically successful, and requirements must be met. Not meeting a requirement will mandate a WIYN Board approved waiver for that requirement, or a WIYN Board approved change in this document.

Goal – A goal specifies additional capabilities that are expected to significantly increase the success and impact of ODI compared to the basic requirements. Goals are to be understood in the sense of a strong recommendation, but there is no formal obligation to meet goals. Reaching goals must not drive the project's budget and schedule.

II. The ODI Science Case

1. The Distant Universe

1.1. Intracluster Stars as Diagnostics of Galaxy Interactions

A method of constraining models of structure formation is to study the properties of intracluster stars. Starlight between the galaxies of a cluster is a sensitive probe of the mechanics of tidal stripping, the distribution of dark matter around galaxies, and cluster evolution in general. Theory predicts that most intracluster stars were formed within a galaxy, and then were removed tidally via interactions with other galaxies and the dark matter potential as a whole. This so-called "Galaxy Harassment" (Moore et al. 1996) appears to be common in galaxy clusters. Intracluster stars also add metals and dust to the intracluster medium, making them an important component of the baryons within galaxy clusters. For nearby galaxy clusters, intracluster planetary nebulae (IPN) can serve to characterize the amount and the spatial distribution of intracluster starlight, and through follow-up spectroscopy of the [O III] line, also provide kinematical information. Through deep narrow-band imaging in the [O III] 5007 Å line, IPN can be detected easily in the Virgo, Fornax, and Ursa Major galaxy clusters using 4-m class telescopes.

Using deep narrow-band exposures on the KPNO 4-m, small portions of the Virgo cluster have been searched for IPN (Feldmeier, Ciardullo, & Jacoby 1998; Feldmeier et al. 2002, 2004). In a survey lasting three years, 0.97 square degrees of Virgo were searched, and a total of 318 IPN candidates were detected in relatively shallow fields. The total area searched is minuscule—only about 0.9% of the total angular area of the cluster. The entire 4-m survey could be duplicated with ODI in one night.

The following proposed series of ODI observations, which require only six dark nights for each part, illustrate the power of WIYN/ODI for pursuing this kind of research:

1. One deep [O III] field in the center of the cluster to a limiting flux of 2.0 × 10 -17 ergs cm–2 s-1 would allow us to probe the full line-of- sight spatial distribution of the intracluster light and obtain detailed information about the cluster core.

   Assuming observations four days past new moon, 0.6" seeing, a reasonable combined system throughput, Z_{tot} of 30.6%, and a 50 A FWHM [O III] filter, we can reach our deep flux limit (2.0 x 10-17 ergs s cm2) with a signal-to-noise of nine in 6.50 hours of exposures. Since these observations are sky-noise limited, the system throughput and the image quality will be critical in reaching this limit. If the seeing increases to 0.8", the exposure time effectively doubles.
2. Four shallower [O III] fields at large radii from the cluster center would probe the radial distribution of the intracluster light, which can be compared to models of intracluster star production. Models predict that the intracluster light will roughly follow an R1/4 distribution, but the exact dependence is a function of the dynamical history of the cluster. These fields also allow a search for intracluster tidal debris and arcs, a few of which have been detected in Virgo (http://burro.astr.cwru.edu/Schmidt/Virgo/).
3. A shallow Hα survey would detect intracluster novae. Intracluster novae have already been found in a small survey in the Fornax galaxy cluster (Neill & Shara 2004), and in Hα, such novae persist for up to three months (Ciardullo et al. 1990). With a modest synoptic component (observations once or twice a season), we could detect hundreds of intracluster novae. From this set of observations, samples of over 2000 IPN would become available to constrain the dynamical history of the Virgo cluster.

Additionally, we would find z=3.1 Lyα galaxies, rare high equivalent width [O II] emitters, and Type II AGN. Such interesting contaminants will represent ~ 20% of the candidate sample, or several hundred objects. Virgo is within reach of South African Large Telescope (SALT), and the University of Wisconsin is a member of the SALT consortium, providing members of the WIYN consortium access to deep follow-up spectroscopy.

1.2. Galaxies at High Redshift

The difference between seeing of 0.35” (median for ODI in the z band) and seeing of 0.7” (realized by most other ground-based surveys in their somewhat bluer primary bandpasses) is of particular importance for surveys of high redshift galaxies. Crowding is significant at 0.7” resolution, and causes galaxies to merge into clumps that are difficult or impossible to resolve without prior knowledge of galaxy positions (see Figure 1). At FWHM ~ 0.35”, each galaxy can be identified separately. Thus, ODI will be in the “HST regime” of studying faint galaxies, whereas other ground-based surveys will be limited by crowding. Furthermore, the critical objects are likely to be red, and ODI’s red sensitivity is well suited to finding such objects. This combination of red sensitivity and image quality will be unmatched by other wide-field imagers.

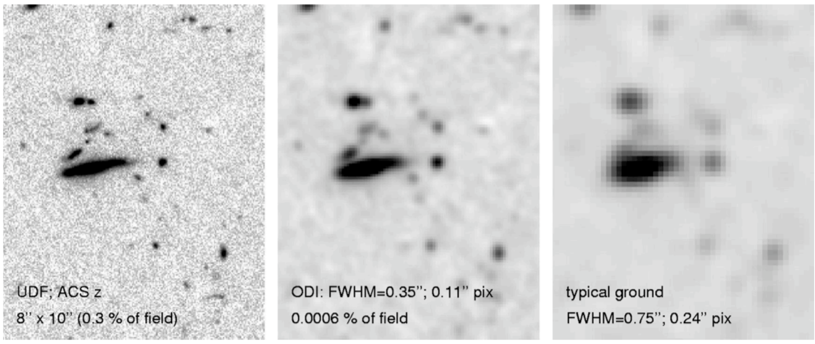

Figure 1 - Comparison of a portion of the UDF, smoothed to 0.35 and 0.7” seeing. Note that in 0.35” seeing, the individual galaxies can generally still be distinguished, in contrast to the 0.7” case.

As one example, ODI will excel at identifying galaxies at z>6 from z-band dropouts. Later in this proposal, we describe a survey designed to find ~1000 of these sources, two orders of magnitude more than are currently known. This estimate is based on the z=4 luminosity function re-normalized to the counts of z~6 galaxies in the HST Ultra-Deep Field (UDF) and parallel fields. The brightest spectroscopically confirmed z~6 galaxy has a z-magnitude of 24.5; ODI should reach z~26.

ODI’s red sensitivity will also make it a very efficient tool for discovering Ly_{α} emitters near the epoch of reionization. Reionization marks the time when star formation and/or accretion produced enough ultraviolet photons to dissociate intergalactic hydrogen into its component protons and electrons, ending the neutral epoch that began at the last scattering surface (z~1000). Recent work on spectra of quasars at z~6.3 have shown a Gunn-Peterson trough, i.e., a span of wavelength where all quasar light is absorbed by the Lyα transition of intergalactic hydrogen (Becker et al. 2001; Fan et al. 2002). This result indicates that the neutral gas content of the universe is significant at z=6.3, and hence we should be able to observe the beginning of the reionization era.

Lyα galaxies are easily found using large-area narrowband surveys at large ground-based telescopes (e.g., Cowie & Hu 1998; Hu, Cowie, & McMahon 1998; Kudritzki et al. 2000; Rhoads et al. 2000; Steidel et al 2000; Rhoads & Malhotra 2001; Ouchi et al 2003; Kodaira et al. 2003; Taniguchi et al. 2004). In the optical, the highest redshift windows between the night sky emission spectrum are at 8200 and 9200 A. The corresponding redshifts for Lyα emission (z=5.7 and 6.5) span the redshift where the Gunn-Peterson trough has been detected. Because Ly_{α} emission is scattered by neutral gas, Lyα sources will disappear from searches when the neutral fraction in the IGM is >30%, corresponding to early stages of reionization (e.g., Rhoads et al. 2003; Santos 2004). These early stages cannot be probed by the Gunn-Peterson test, which “saturates” with complete absorption of flux at neutral fractions <1% (e.g., Fan et al. 2002). Thus a survey showing the number of Ly_α sources vs. redshift for $5<z<7$ will reveal when reionization occurs.

At present, Ly_α survey instruments are limited to $\Omega < 1/3$ sq. deg. and seeing (FWHM) of $\theta > 1''$. Moreover, the quantum efficiency of currently available mosaic cameras is typically QE (9200 Å) ~ 0.3. The survey efficiency for a narrowband emission line search (in volume surveyed per unit time) is proportional to $A\Omega\times QE\times\theta$ -2, where A is the area of the primary mirror and Ω is the solid angle FOV of the camera. Using the baseline parameters for ODI ($\Omega = 1$ sq. deg., $\theta \sim 0.43''$ median seeing, and QE ~ 0.6), we estimate that this new instrument will be ~23 times more efficient than the KPNO 4m+Mosaic camera for a 9200 Å narrowband search, and about 4 times more efficient than Subaru+SUPRIME-CAM.

With ODI, it will be possible to survey several square degrees of sky for z~6.5 Ly_α galaxies in just a few nights, to star formation rates below 5 Msun year -1. The number of Ly_α sources depends both on reionization and the rate of galaxy formation. The measurements will therefore also contribute to our understanding of when young galaxies emit Ly_α and how Ly_α observations can be used to constrain models of galaxy formation.

Observations blueward of 5000 Angstroms (i.e. U and B-band) are advantageous in galaxy evolution studies for three main reasons. First, U-band data at $z>1.5$ probes the rest-frame UV SED around redshifted Lyman Alpha (λ_{rest}=1216Å), where intergalactic HI absorption results in a flux decrement compared to a source that is flat in fnu. By combining U-band data with observations from longer wavelengths (e.g. B or V-band data) it is therefore possible to constrain the redshift of relatively unextincted star-forming galaxies. These galaxies may have weak 4000 Angstrom/Balmer breaks that would not be distinguishable from moderate depth NIR data, highlighting the importance of the rest-frame UV data in constraining the redshift.

Second, data in the U and B-band provide flux measurements shortward of the 4000 Angstrom/Balmer break for galaxies at $z<0.5$. This is important for obtaining accurate photometric redshifts of galaxies at these epochs. This is because photometric redshift techniques key off of the position of breaks in the SED and therefore need to have photometric data points well to either side of the break to constrain its position.

Finally, the U and B-bands are important in measuring the star-formation rate (SFR) in galaxies at $0.3<z<1.0$. To obtain a proper accounting for all the star formation in a galaxy, it is necessary to add up both the starlight that is absorbed and reradiated by dust at 8-1000 microns and the starlight that directly escapes (e.g. Bell 2003, ApJ, 586. 794). Calibrations of the SFR from combinations of LUV and LIR are accurate to within an 0.3 dex systematic error (Bell 2003, ApJ, 586, 794). While massive galaxies at $0.3<z<1.0$ have their bolometric luminosities dominated by the far infrared emission, which dominates this error budget, lower mass galaxies are more optically thin and observations at $\lambda_{rest}<2800$ Angstroms are therefore necessary to probe the most recently formed, but unextincted stars. Observations in the U and B-band access this crucial wavelength regime at $0.3<z<1.0$.

2. The Local Universe

2.1. Mapping the Solar Neighborhood

Astrometry can be used to address a number of basic questions relating to the formation of our own galaxy, including the role of accretion events and the rate of chemical enrichment, the mass content of the galaxy, and models of stellar structure and evolution.

An investigation by Vieira, et al. (2004) of the centering precision obtainable with the OPTIC camera, which uses the orthogonal transfer (OT) technology, yields a precision ±2, ±4 and ±8 mas at V = 20.5, 22.0 and 23.5 mags, respectively for exposures with a fwhm of 0.6”. Scaling the observed V-band precision to the expected z-band fwhm of 0.35” should yield a precision much better than ±2 mas, however we adopt a conservative estimate of ±2.0 mas for the z-band astrometric precision.

In addition to reducing the FWHM of the image, the tip-tilt correction provided by OTA technology also provides a more stable isokinetic patch for the astrometric solutions. Scaling this value to the expected z-band FWHM yields an expected precision of ±1.0 mas. However, even if we adopt the more conservative estimate of ±2.0 mas, an observational program like that proposed by the survey described in section III, consisting of 26 4-minute exposures in the z-band during an initial 6-month period, followed by four observations two years later to improve the proper motion precision, will yield a parallax precision of ±0.66 mas and a proper motion precision of ±0.54 mas/yr. Because there will be several dozen QSOs/field at our magnitude limit, we will be able to establish our parallax and proper motion zero points at the 0.1 mas and 0.1 mas/yr levels.

The improved image centering precision provided by the OT CCDs enables us to probe 3 times more deeply in parallax and proper motion space for constant exposure time with the same distance and velocity precision. The faintest stars, which are currently quite poorly cataloged even in the immediate solar neighborhood, are extremely red, and will thus benefit from the red sensitivity of ODI. Specifically, we expect to be able to obtain ten-sigma parallax measurements out to 150 pc, down to a magnitude of z=22, or an absolute magnitude of around 16. Thus, we will be able to reach all stars on the hydrogen-burning main sequence, as well as significant numbers of brown and white dwarfs.

2.2. The Local Stellar Mass Density.

Through kinematical investigations of the vertical distribution of stars, it is possible to determine the total mass density (stars, gas, dust and dark matter), and to determine the spatial distribution of gravitating matter within the Galactic disk (e.g., Siebert et al. 2003, Korchagin et al. 2003). If we can accurately determine the local densities, we can then infer the amount of dark matter in the galactic disk. Knowledge of the dark matter concentration in the galactic disk is of principal importance to understanding its nature. Recent measurements for the dark matter in the local neighborhood indicate that up to 20 percent of the mass might be in a form of dark matter (Holmberg & Flynn 2000; Korchagin et al. 2003). A parallax survey of stars within 150 pc (ten-sigma parallaxes) can determine the local stellar density to an accuracy of 1.5%. The full-sky USNO A1.0 Catalog lists about 500 million stars for the limiting magnitude of about 21. Scaling to the 90 square degrees covered by the survey described in section III, we obtain a total of 4485 stars, or 50 “nearby” stars/1 sq. deg. field. The ODI survey will thus allow a determination of the local stellar density to an accuracy of 14% per field, or to 1.5% for the full 90-field sample, and to recognize density structures over a 150 pc radius.

2.3. Local Stellar Kinematics.

The accuracy of ODI measurements together with the depth of the observations, will enable us to measure the systematic variation of the kinematical properties of stars with stellar type. Based on Hipparcos data, Binney et al. (2000) used such information to determine the ages of stars in the solar neighborhood to a precision comparable with that for the ages of globular clusters. However, the Hipparcos catalogue is complete for the bright stars only, and the determination of the kinematical properties of stars becomes unreliable for the stars with B-V > 0.8 (see, e.g., Dehnen and Binney 1998). The stars below 1 Msun thus remain unexplored and with ODI data we will be able toextend the determination of the kinematical properties of stars down to 0.2 Msun.

2.4. Proper Motion Membership in Open Clusters.

The WIYN Open Cluster Study (WOCS) is designed to establish a baseline group of open clusters whose characteristics span the extremes of metallicity and age. A goal of WOCS is to establish these clusters as standards for astrophysical investigations. One of the important correlations to be defined is the variation of luminosity with temperature or color as a function of cluster metallicity. In the low-temperature regime, the stellar atmospheric structure becomes very complex, and observations must be used to constrain the theory. High quality data are also needed to constrain interior models, to put stellar structure in this mass range on a sound physical basis, and to understand the interior processes responsible for stellar activity at the faint end of the main sequence. The mass-luminosity relation, in particular, is still very uncertain.

Most open clusters lie near the Galactic plane and suffer substantial interstellar reddening in the line of sight. Thus, identifying cluster members among the many foreground and background field stars by photometric methods is generally unreliable, especially for fainter stars. Historically, proper motion studies for membership have been limited by first-epoch proper motion plates that reach to B~15. The deepest ground-based high-precision proper-motion membership determination to date is the WOCS study XVII, which reached V~20 (M≈0.5 Msun) in NGC 188 (Platais et al. 2003). This study used old photographic plates for the first-epoch positions and the CCD Mosaic on the Mayall 4-m to obtain the second-epoch positions. This study also demonstrated the feasibility of stitching together the individual elements of the Mosaic.

With WIYN/ODI, the WOCS team plans to extend that limit to V=23 for several additional clusters. First epoch observations covering a relatively small FOV will be obtained with QUOTA, an 8Kx8K OTA camera at WIYN with a 16’ field of view; second-epoch exposures will be obtained when ODI becomes available and will then be used as wide-field first-epoch positions for a planned wide-field third-epoch. This approach allows us to obtain the membership in the cores of the clusters in three years, and in the halo only three years later after ODI is completed. With ODI, we can achieve a precision of 0.8 mas/yr over a 1-deg field to V=23 using four z-band 4-minute exposures at each of two epochs separated by only three years. At 1 kpc, V=23 with 1 mag of extinction corresponds to M~0.2 Msun.

2.5. Initial Mass Function.

Determining open cluster initial mass functions is central to most questions of star formation and stellar populations. Determining accurate mass functions below 1 Msun has traditionally been difficult due to lack of deep proper-motion studies, and the need to make large corrections for diffusion of lower mass stars out of the cluster core because of mass segregation and evaporation. ODI overcomes both of these difficulties. The WOCS team plans to perform proper-motion studies on a set of rich young clusters with ages of 3-100 Myr (where tage<tevap). As a case in point, a study of the cluster NGC 2168 (100 Myr , 800 pc, E(B-V)=0.26) will yield a secure mass function down to 0.2Msun within a radius of 8 core radii.

2.6. Galaxy Formation and the Local Group

Using ODI’s excellent image quality and narrowband capabilities, it will be possible to test whether the predictions from specific models of the formation of structure in the universe are corroborated by observations of present day galaxies and the stars that they contain, and to obtain measurements of dynamical processes that continue to occur, such as mergers and cannibalism. A currently popular paradigm for structure formation states that small systems (dwarf galaxies) formed first and coalesced into larger structures. Thus, the distribution of ages and metallicities among the dwarf galaxies in the Local Group should be consistent with that in the stars in the halos of the Milky Way and M31. Alternatively, halos may have formed out of the (repeated) disruption of the disk by a “major merger”, or primarily by monolithic galaxy formation as in the ELS (Eggen, Lynden-Bell, & Sandage 1962) paradigm. Which of these halo formation processes is more significant? What fraction of stars in the halos of large galaxies has been accreted? Is this fraction consistent with the predictions from any specific theory? We will elucidate these questions with a two-pronged approach described below.

Remnants of Mergers with the Milky Way. The merging of dwarf galaxies and globular clusters with the Milky Way leaves trails of debris as witnesses to those unseen events. The identification of debris trails helps us to understand the formation and dynamical history of our Galaxy. While the tidal disruption of the Sagittarius dwarf galaxy is compelling evidence that the halo of our galaxy is accreting material from outside, there are very few known examples of tidal debris in our Galaxy. Part of the difficulty is that the RGB stars and HB stars (including RR Lyraes) are used to trace the known streams, but smaller or older tidal events may not be easily visible using tracers like these that represent a very small fraction of the parent population. Helmi & White (1999) estimate that there are 300-500 remnant streams in a one kpc3 volume centered on the Sun. How can we trace out these smaller and/or older tidal events? Proper motions provide one handle on the Galaxy halo population. Helmi & White (1999) estimate that a velocity resolution of 5 km/sec is needed to detect the remnant streams. Johnston (2001) predicts that a proper motion of 0.25 mas/yr at 21.5 mag. is necessary to identify the Sagittarius stream. As noted above, ODI's proper motion precision is ±0.54 mas/yr, yielding a velocity accuracy of 5 km/sec at a distance of 2.0 kpc. We predict from these data that 20-35 debris streams will be identified from 90 ODI fields, thus making it possible for us to set good limits on the validity of the Helmi & White predictions.

In addition, by choosing our filters carefully, we can detect streams from star count excesses at colors corresponding to F and G turn-off stars, which are relatively more numerous than RGB and HB stars from the same population. Such a survey requires wide field coverage and sub-arcsec image quality in order to use PSF discrimination techniques to eliminate background galaxy contamination. Follow-up imaging using narrowband filters, allows direct measurements of stellar line indices. The metallicity distributions of stars in and out of tidal streams provide further clues to how much of the halo has been built accretion.

Tracing the Halos of Local Group Galaxies. While a better knowledge of the history of the Milky Way halo will shed light on galaxy formation processes, it provides the history for only one galaxy. Is the Milky Way the norm? ODI will make it possible to pursue the complementary task of tracing the halos of other galaxies. Throughout the Local Group (LG), a 4-m class telescope that regularly delivers sub-arcsecond seeing can discover RR Lyraes to use them as tracers of ancient stars. Thus far, all LG galaxies that have been adequately searched have indicated a) the presence of an extended halo, and b) the presence of RR Lyrae stars in such halos, indicating that a non-negligible fraction of the stars in the halos are "ancient" (i.e. have globular-cluster-like ages). However, the survey is far from complete: on the one hand, a definitive case for a halo has not yet been made even for the Magellanic Clouds, while on the other, the dwarf spheroidals associated with the Milky Way have all been shown to have ancient stars. Even the very young and metal-poor dwarf irregular galaxy Leo A has RR Lyraes and RGB stars quite far from the central region of the galaxy, indicating both the existence of a halo and the presence of ancient stars therein (Dolphin et al. 2002; Vensevicius et al. 2004). Despite these demonstrations, the number of objects for which a halo and/or ancient stars have been confirmed is a small fraction of the known objects in the Local Group. A more extensive search in "all" known LG galaxies would build or destroy the case for the universal ubiquity of halos and/or ancient stars.

A particularly interesting case is M33. M33 has not yet been shown to have a field halo stellar population (Tiede et al. 2004). Its insignificant bulge and small number of globular clusters indicate that it has not been part of a major merger. The existence (or not) and age of M33's stellar halo is a very important issue to resolve: can a galaxy that is unperturbed by mergers still have a halo? Does the disk population of such a galaxy have ancient stars? Both these questions can be very effectively addressed by a search for RR Lyrae and RGB stars covering an extended area over and around M33. As RR Lyrae stars at the distance of M33 have an g'-band magnitude of m(AB)=25.5, good throughput and seeing are required for this kind of observations, in particular since a wide-area survey for variable stars would have to revisit fields at least four times per night. Thus, RR Lyrae stars in M33 (g=25.5) have to be detectable at a 5-sigma level in ~15 minute exposure with ODI under reasonable (0.6"-0.7") seeing conditions. As with the study of the halo of the Milky Way, this program requires a large field of view and exquisite (for ground-based telescopes) image quality. Follow-up deep narrow band imaging will also reveal the metallicity distributions in the various components of this galaxy.

2.7. ODI and the Time Domain - Variability Studies

OTA CCDs will provide the ability to perform high-speed, high-precision 2-D photometric observations over a wide field of view. An OTCCD prototype camera at WIYN has already demonstrated 10 msec readout, 1 mmag (and better) precision, and application of this unique ability to many programs such as extra-solar planets, stellar and cluster variability, Local Group galaxy studies (such as Cepheids), and other rare variable phenomena. Only two other high speed CCD cameras exist and they both use conventional frame transfer CCDs which have half their areas masked off, cannot perform tip-tilt corrections, and can provide only limited additional comparison stars, generally only one. OTAs will not suffer from any of these issues.

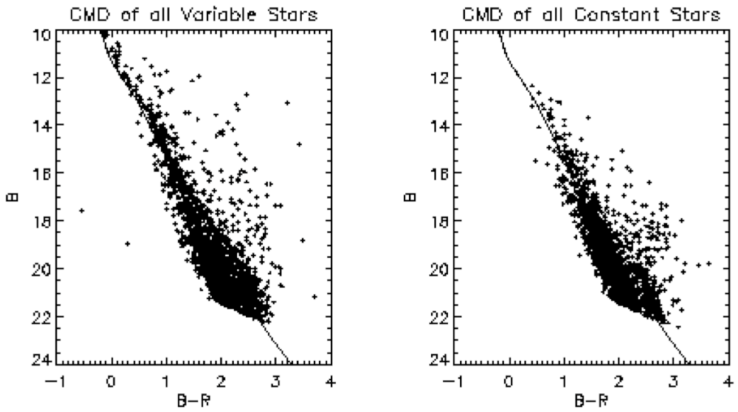

Figure 2 - Color magnitude diagrams for the young open cluster NGC 2301 separated into variable and non-variable stars. Note the upper main sequence stars are all variable and the lowest mass stars (M6V here) are not yet fully on the ZAMS. The precision obtained for the brightest 4.5 magnitudes was 1-2 mmags (Howell et al. 2005b).

One area that will benefit from the combination of the large field of view, the fast readout times, and the high-precision photometry achievable by ODI is the study of stellar variability in star clusters. As an example, we show the color-magnitude diagrams (CMDs) for the open cluster NGC 2301 (Howell et al. 2005b) separated by variability (Figure 2). We show here for the first time that the entire upper main sequence, and 56% of all the stars, are variable Another area where ODI can play an important role is in the study of transiting extra-solar planets. Extra-solar planets are being discovered in large numbers, and with the launch of Kepler in 2007, hundreds more are expected. Systems that transit their host star are particularly valuable, and much of the information in a transit is contained in the ingress and egress phases. Good time sampling and high photometric precision are essential to extract this information, and both capabilities already have been demonstrated for OT CCDs at WIYN.

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3. Yale Survey

As part of our obligation to provide community access to ODI, we propose to carry out a survey specifically designed to address several of the science goals listed above. Yale will commit 90 nights of its share of WIYN time to this survey over the first 3 years of ODI operations. Yale will invite outside collaborators to apply through NOAO to participate in planning and carrying out the survey.

The survey strategy, which is described below, is designed to meet the requirements described above for searching for high redshift galaxies and measuring parallaxes of nearby stars. A variety of other scientific goals can also be achieved, some of which are described below. The 90 night Yale commitment will cover a baseline strategy – additional nights may be committed by Yale or by applications to NOAO to extend the survey in a number of directions, depending on the interests of the internal and external members of the survey team.

3.1. The Baseline Survey Strategy.

A final survey design will be created in consultation with community collaborators, and we propose the following strawman plan as a basis for discussion: The baseline survey would consist of 1/3 of a night every 4th night, alternating between the first ~3 hours and the final ~3 hours of the night. The cadence would be a 3-min z exposure and a 6-min Y image, reaching approximately similar depths (z~24.5 at S/N=10 per image). Half the time (9 image pairs) will go to a single field (the "deep survey") while the other half would cover 9 fields once (the wide survey).

The deep field will be repeated each survey night for ~4 months, providing three fields to a depth of ~10 hours exposure time in z (limiting magnitude of z~27.5) each year. The individual images and one-night sums (limiting magnitude z~25.7) would be used for studies of time variable targets, including supernovae, while the total image stack would be used for deep field imaging. The "wide survey" would cover each of 45 fields once per month for six months. Thus 90 fields would be studied per year--these fields would continue to be studied over three years, finally providing a depth of slightly less than 1 hour exposure time in z for each field. Again, the individual fields could be used for studies of time variability (particularly parallax studies) while the sum could be used as a wide-field survey to z~26.0.

The community collaborators on this survey may wish to modify the baseline plan or extend the survey through proposals to NOAO. Possible additions to the baseline (depending on the interests of the participants) might include: 1) more fields, either for the deep or wide surveys; 2) greater depth, again, for either part of the survey; 3) additional filters; 4) special purpose fields centered on galaxy clusters or other targets of interest; 5) additional temporal coverage.

Most current z-band filters are defined by a blue cutoff around 8500 Å, with the red end of the bandpass defined by the CCD sensitivity. Given the higher red sensitivity of the OTAs, we will use a z-band that is defined entirely by the filter (e.g., 50% points at 8500 and 9500 Å). Then we could add a "Y filter" having a blue-end cutoff at 9500 Å and a red edge defined by chip response. Our z would have comparable sensitivity to current I-band surveys, and our Y would be comparable to most current z-bands. By the time our survey begins, several other surveys in standard optical bands (B-I) will have produced publicly available data. It may be advantageous to include some of these fields in our survey, extending previous surveys to the red, and improving their angular resolution.

3.2. Additional Scientific Goals.

The current interests of the Yale group focus on astrometry, high-z galaxies, and the time domain. Here we note other examples of science uses of the survey data that might be of interest to community participants. Weak lensing of galaxies provides a powerful constraint on cosmological parameters that is orthogonal to those provided by Type Ia supernovae and the CMB.

The half-light radii of the background galaxies used in weak lensing surveys (down to z~26) are $\lesssim$0.3” (Bouwens et al 2004, Ferguson et al 2004), so images with resolutions worse than 0.6" will significantly alter the shapes of the galaxies. This affects the weak lensing signal in two ways. First, it means that the number density of resolved galaxies is reduced. Because (in the weak lensing limit), the resolution of the mass reconstruction is proportional to the resolved galaxy density, the seeing affects the type of science that can be done. Second, the seeing affects the noise of the shape reconstructions, affecting the S/N of the lensing signal reconstruction. Thus, the image quality offered by WIYN/ODI is a significant driver in the improvement of weak lensing surveys.

Our proposed baseline 90-night survey, or an equivalent survey that doubled the area coverage, would enable us to constrain σ_8 and Ω_m to better than 10%, and provide a better measure of weak lensing than the CFHT Legacy Survey. ODI is in a position to be a premier instrument for weak gravitational lensing, combining the best image quality and FOV available in the northern hemisphere. Other kinds of lensing surveys (searches for strong lenses, cluster strong and weak lensing, and weak lensing tomography) will also greatly benefit from ODI.

Type Ia supernovae provided the first evidence for the existence of dark energy, and there are many on-going and planned surveys to use these standard candles to probe the properties of dark energy in greater detail. The combination of high sensitivity (due to the excellent seeing), large field, and red filters provides the opportunity for WIYN/ODI to make a significant contribution to this work. We plan to observe the same field every four days, an excellent cadence for SNe identification. The planned 90-night survey would be able to follow light curves to 1.5 magnitudes below peak brightness for supernovae with z<0.8. This redshift range is being explored by other surveys, but a very large sample is needed to explore possible second parameter corrections (i.e., possibly the kinetic energy of the photosphere), to evaluate the feasibility of obtaining redshift and luminosity corrections from precision photometry, and to quantify just how precise the photometry must be, which will serve as valuable input to the LSST observing strategy. The excellent image quality of WIYN/ODI will help to separate the supernova images from the background galaxy, and to improve the accuracy of the light curves. If the 90-night survey were supplemented with the additional time to obtain four times more exposure each night for the deep images, a single night's images would reach 26.5, thus providing light curve coverage of SNe with peak magnitudes of 25.0, appropriate for z=1.1. The expected rate of SNe in the redshift range 0.8<z 1.1 is ~100 SNe/year/degree. Given a detection efficiency of 50% (given weather, shifts from one target field to another, confusion with bright sources, etc.), a three year survey will generate ~150 such supernovae, doubling the number of z~1 supernovae expected to be found with HST.

4. The Scientific and Broader Impacts of ODI and Its Place in the Observing System

This proposal is responsive to several of the recommendations of the 2nd Community Workshop on the Ground-Based System (see the NOAO Web site for the report):

1. “It is desirable to further encourage participation of medium telescopes in TSIP itself; telescope time provided to the community ... could include a single large survey, so long as the community was involved in its definition and data were made available in a timely way;”
2. “Improved visible... detectors are needed, and federal resources should be invested into their development;”
3. “Instrument groups should collaborate more often;”
4. “Basic data reduction pipeline software should be included in the delivery of all facility instruments;”

5. “Ground- based O/IR facilities must recognize the challenge of producing archive-friendly data; observatories should establish prescriptions for acquiring calibration and metadata that support archival research and for making the data VO compliant;”
6. “VO and archival-based research must become an integral part of undergraduate and graduate-level curricula.”

We also note that ODI is an excellent precursor for LSST. LSST pipelines and image stacking algorithms can be tested with ODI data since many processing requirements are similar; the data from ODI will be a major contributor to the NOAO archive prior to the advent of LSST; and the archived data can be used to prototype and test the planned LSST education and outreach programs. Data obtained with ODI can also be used to refine the LSST observing strategies. One example is the exploration of how to classify SNe from light curves alone.

ODI data will become an integral part of graduate training, because WIYN has traditionally played a significant role in supporting thesis research. Each year, about 7 theses are completed with NOAO time, and 17 dissertations have been completed by university partner students over the life of the telescope. The university partners also involve undergraduates in WIYN programs, including remote observations.

III. Science Requirements

1. Instrument Performance

1.1. Field of View & Filling Factor

1. The field of view will be a 1° circle in the unvignetted area of the WIYN telescope.
    a. The goal is to provide a 1° square field of view.
    b. Requirements outlined in this document are goals for any additional imaging area outside the 1° circular unvignetted field.
2. The filling factor (imaging area) of the focal plane in static imaging mode will be at least 80%, with a goal of 85%. Only imaging area that satisfies all requirements in this document can be counted towards the filling factor.
3. At commissioning of the instrument no more than three dead cells (1cell is about 1'x1' in size) are permitted per detector, where no more than two adjacent cells can be dead.
4. During operations, not more than eight defective cells are allowable per detector. "Defective" is defined as not meeting the requirements outlined in this document. Should a detector have more than these eight dead cells it will be considered as defective.
5. No more than four detectors in the unvignetted focal plane must be defective. More than two adjacent defective detectors or a total of four defective detectors in the focal plane require an exchange of all malfunctioning detectors during the next servicing opportunity.
6. On any location of the sky accessible to the WIYN telescope the same orientation of the focal plane on the sky (e.g., North always up) must be achievable. It is a goal to allow different orientations on the sky at the choice of the observer.
7. All detectors must have the same orientation on the focal plane.

1.1.1. Science Justification

Deep surveys for galactic structure or galaxy evolution at high-z require a large coverage of the sky of the order of 10 and more square degrees; inclusion of the time domain in these large area surveys adds to the need for a large field of view. In order to facilitate such surveys in a reasonable amount of time and time resolution it essential that the field of view of the imager is as big as possible. The requirement for the 1° circular field of view is derived from WIYN's maximum unvignetted field of view that can be more easily calibrated than the vignetted field of view of WIYN. The goal of an even bigger 1° square field of view tries to maximize the imaging area while acknowledging that calibration in the incremental imaging region, i.e., making this region useful, will be more challenging.

Surveys, e.g., weak lensing surveys, require covering 100% of the imaging area through a dither sequence (except around very bright stars), and only small variations in the exposure time are allowable. E.g., in a 7-positon dither-sequence, each position on the sky must be exposed at least 5 times.

Large gaps in the imaging plane will make it impossible to achieve this requirement without allowing very large (>16' for two dead adjacent detectors) offsets between dither sequences. This, however, is not desirable because of variations in focal plane distortion over these large distances. In particular for weak lensing application the differential distortion within a dither pattern is to be kept as small as possible.

The filling factor of the focal plane directly translates into observing efficiency and should therefore be as high as technically possible. The minimum filling factor requirement of 80% is based on the following three factors:

1. Filling factor within one OTA detector
2. Space overhead for packaging and mounting to the focal plane
3. Allow on average 2 cells per detector to be dead.

The goal of 85% filling factor can thus be reached by (i) improving the packaging/mounting efficiency over the current design or (ii) allowing fewer defective cells per detector.

1.1.2. Verification plan

The filling factor and field of view can be calculated based on the design, and will be measured during commissioning once a final world coordinate system for the imaging area is established.

The requirement for the limit of dead cells and detectors will be verified through monthly health checks of the focal plane by doing a linearity test (e.g., photon transfer curve) of the focal plane as a part of a standard maintenance & monitoring plan.

1.1.3. Impact of not meeting the requirement

ODI with a reduced field of view or small filling factor (e.g., due to dead cells) would still be able to achieve great science, but at the expense of increased telescope time. Down to a 40 arc minutes rectangular field of view ODI could be considered useful, but below this threshold ODI would significantly lose its competitiveness and might not justify the invested effort and funding.

1.2. Delivered Image Quality

1. It is a goal that ODI does not reduce the image quality that the atmosphere and the telescope deliver. The goal of the ODI project is that image degradation by the instrument and telescope system is never larger than 20% during a site-seeing of 0.25’’ in any of the SDSS pass bands and the U-band filter in the airmass range from 1 to 1.3. This applies to exposures as long as 30 minutes.
2. ODI at the WIYN telescope must deliver images with 0.3’’ in the z-band in the airmass range 1.0 when atmospheric conditions allow. In the same airmass range, ODI must be capable of delivering a seeing of 0.5” in the g’-band and the U-band. These requirements must be met in an up to 30 minutes long exposure. For an airmass of up to 1.5 the delivered image quality must scale not worse than specified in 7).
3. ODI must overcome the effects of the atmospheric dispersion. The dispersion is to be corrected depending on the central wavelength and bandpass of the current filter, and the ambient conditions (temperature and humidity). In particular, the ADC must compensate for atmospheric dispersion in the broad SDSS g’-band filter up to an airmass of z=2 in the typical temperature range of the observatory.
4. The ellipticity e=(a-b)/b of point sources in the entire field of view must not exceed 0.15 in up to 30 minutes long exposures; a limit of e<<0.1 is the goal. The point spread function must not exhibit variations greater than 3% in FWHM and ellipticity when averaged on scales smaller than 4x4 arc minutes, with 8x8 arc minutes goal.
5. When used by an observer, on-chip tip/tilt guiding must improve the image quality in exposures as long as 30 minutes.
    a. It is a goal that he median seeing in ODI science images in the fast local tip/tilt mode will improve the delivered image quality in the r’ and i’ bands during the following seeing conditions by:

Seeing	1’’	0.7’’	0.5’’	0.3’’
Improvement	0.18’’	0.15’	0.12’’	0.05’’

6. All DIQ requirements must be met in 90% of the 1º circular unvignetted field of view, with 100% goal.
7. The seeing specifications are for an airmass of z=1 and are allowed to scale with the airmass as $S(z) = S(0) * z^{0.6}$.
8. The recorded images must not be under-sampled under the best-expected seeing conditions.

1.2.1. Science Justification

Studies of the high-redshifted universe require the recovery of structural information (e.g., weak lensing and galaxy evolution). The Yale survey critically requires images with a median resolution of 0.35” in the z’ band. Current weak lensing studies are done at a resolution of 0.7” and will benefit from any increment in image resolution. A key requirement also is to measure the ellipticity of resolved objects, and any instrument-determined ellipticity biases the intrinsic lensing signal and reduces the science output from weak lensing.

Stellar Populations studies in the Local Universe depend on an excellent image quality for two reasons: Overcoming crowding in dense environments and reaching faint limiting magnitudes, e.g., to study the halos of the Local Group galaxies M31 and M33. In particular from simulations with the CFHT Megacam exposure time simulator we conclude that ODI must allow obtaining images with at least 0.5” DIQ in the bluer bands.

Active tip/tilt guiding must not reduce the image quality. The given expected improvement, depending on the seeing, is derived from experience with the OPTIC camera at WIYN. I.e., these values reflect what is technically feasible with OT detectors.

Each increment in image quality will enable new science and thus adds an enormous scientific value to ODI. It is therefore important that ODI meets goal 1). Indeed, as the function of merit of an imager increases with the square of the DIQ, ODI shall actively improve the image quality by fast, local tip/tilt guiding over the entire field of view, if technically feasible.

1.2.2. Verification Plan

Record statistics on science images over the lifetime of ODI. In particular record seeing during commissioning and report the best obtained image quality, and map the achievable image quality over the field of view.

Due to the variety of seeing conditions and their statistical nature, the atmospheric conditions to verify the image quality specified here might not occur during the instrument commissioning. This could lead to the situation that ODI would be commissioned without having the image quality requirements demonstrated yet.

1.2.3. Impact of not meeting the requirement

Image quality was the main driver of ODI. Not meeting the requirements of this section will significantly reduce the scientific value of ODI to a degree where it might not be scientifically competitive. The goals in this section are designed to make ODI an outstanding instrument, enabling science niches no other observatory can currently access.

1.3. Availability of the Instrument

1. It is a goal to enable science operations with ODI in the NOAO semester 2010A.
2. ODI must be available as a static imager for regular science operations after commissioning.

   a. Fast photometry and fast-guided modes must be available for science operations no later than one year after commissioning of the static imaging mode. It is a goal to deliver all modes at the same time.
3. ODI will be permanently mounted on the current WIYN port.
4. ODI must be designed for a lifetime of 10 years.
5. ODI will be schedulable & operational (=meeting the requirements of this document) whenever WIYN is available for observers.
   a. ODI must be operational within the specifications of this document within one hour after a power loss of up to 24 hours at the facility. If the power loss if >24 hours the recovery time can be longer with a goal <6 hours.
   b. Uninterrupted continuous access to ODI and the telescope must be granted to the observer at least from 4 hours before sunset to 1 hour after sunrise. During this time no changes must be made to the instrument/telescope that affect the calibration of the instrument.
   c. One month of ODI downtime per year for regular servicing should be scheduled during the WIYN summer shutdown. The WIYN director can schedule additional downtime for maintenance.
   d. The requirements in this paragraph are valid only for regular science operations, i.e., when the safety of the instrument, telescope, and site allow.
6. ODI must be schedulable for parts of nights.
   a. The handover to a different observing program shall not take more than 15 minutes.
   b. The change to/from ODI from/to a different instrument shall not take more than 30 minutes.

Note: This is not a requirement for ODI since the scheduling and operational mode of the WIYN Observatory is not within the control of the ODI team. However, the ODI design must not inhibit an hourly scheduled mode of operations.

1.3.1. Science Justification

A timely delivery of the instrument is important for the competitiveness of ODI science. In order to deliver a useful instrument as early as possible it should be allowable to commission ODI as a static imager only, if required upgrades to implement the missing functionality are limited to software. The latter eliminates risk to the instrument due to unnecessary instrument handling.

The WIYN SAC decided during the Fall 2006 Board meeting – based on the outcome of the earlier Chicago meeting - that ODI shall be permanently mounted on the WIYN port. The next WIYN contract renewal will be for 10 years, and it is reasonable to plan for a similar lifetime for ODI.

ODI long-term projects such as the Yale survey require uninterrupted access to ODI over three years of operations. ODI must therefore be always available when WIYN is up and running, including after a facility shutdown, e.g., because of summer storms. The requirement for a fast recovery is designed to bridge a shutdown for up to one day/night due to storms, while it does not apply to conditions where the facility remains powerless for two or more consecutive days.

The Yale survey explicitly aims at observing targeted fields for only 3 hours per night, every few nights. This requires a new operational mode for WIYN. While the ODI instrumentation team cannot implement a new observing mode at WIYN, ODI's design must allow a smooth integration into a queue-style observing environment.

Especially for longer winter nights, the instrument should be available to the observer for the length of the night plus the time required to obtain calibration data. To ensure that calibration data is valid, no changes must be made to the instrument between obtaining calibration data and the night observing.

1.3.2. Verification Plan

Check that ODI's design does not preclude meeting these requirements, and long term monitoring of ODI's availability afterwards.

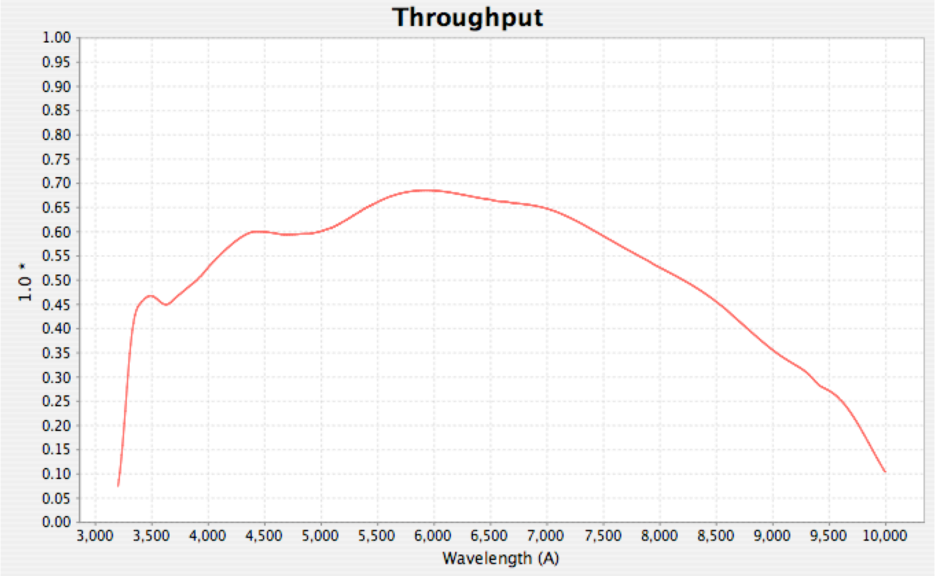
1.3.3. Impact of not meeting the requirement

Flexible scheduling and availability of ODI throughout the year is an enabler for the Yale survey. Thus, not meeting the requirements for ODI's availability will reduce the impact of the Yale survey, in particular in the area of exploring the time domain.

Modifying the instrument during observations and calibrations can render a whole set of calibration data invalid and might force the observer to redo all calibrations. Since afternoon calibrations will probably be directly fed into the data reduction pipeline, operations of the pipeline might also be impacted if actual calibration data are not available in time. Thus, any interruption of access to the instrument from the early afternoon to the following sunrise could reduce the efficiency of observing and pipelined data handling.

1.4. Sensitivity & Performance

1. The optical corrector and the detectors should have state of the art throughput and sensitivity.
2. It is a goal to reach the following ODI instrument (without filters) plus telescope system throughput curve:



3. Reflection losses at glass surfaces must – on average – be below 1% from 400nm to 900nm, and below 3% from 3500nm to 11000nm.
4. For each image readout the noise introduced by the detectors and readout system must not exceed 10e-, <6e- goal, for up to 30 minute exposures.
    a. A mode to support 2x2-binned detector-based readout must be supported.

1.4.1. Science Justification

The dominant factor determining the faint limit of ODI is the telescope's aperture and cannot be altered. This leaves room for throughput tuning only at the detector level, and an little bit at the selected coatings of the optics.

Justification z': the Yale survey critically depends on ODI's throughput beyond ~8500 Angstroms, as the z and y bands are needed for identifying and characterizing z=1-1.2 supernovae, z=1-1.5 galaxies, and galaxies at z~6.

Justification OIII: In order to reach the flux limit outlined in the Virgo PNe survey the system throughput (telescope and instrument and filter) at 501nm should be at least 30%.

Justification g' – Large area surveys for RR Lyrae stars in the M31 and M33 halos require that a 5-sigma detection at a limiting magnitude of g'(AB)=25.5 mag can be achieved in a 15-20 minute exposure under median seeing conditions (0.6''-0.7'').

Justification U – Imaging in the near ultraviolet remains a powerful technique for characterizing stellar populations in galaxies. This will be especially important as we enter into an era without space-based UV-imaging capabilities. For example, ongoing U-band studies of super-soft X-ray sources in M31 have a proven ability to detect their optical counterparts and measure variability as a means to physically characterize the binary systems. This work requires seeing of better than 1-arcsec and ability to reach U(Vega, Johnson)~22-23 with moderate S/N~10 in an exposure of ~1 ksec.

Sensitivity - Although the major gain of ODI's system throughput will come from the imaging area, the seeing, and the observing overhead, sensitivity and transmission of ODI's components also are major factor for achievable science. The Yale survey explicitly depends on a good sensitivity redder than 9000 Angstroms, in particular close to red sensitivity limit of CCDs near 1μm. Stellar populations studies depend on a medium to narrow band imaging in the blue range (3800-4500 Angstroms), and studies of both the nearby and the distant universe clearly benefit from a good U-band sensitivity.

Since most wide field imagers under construction or in operation focus on red sensitivity, ODI should pay special attention to the blue (<4000 Angstroms) wavelength range since this will enable a niche for WIYN that no other observatory will be filling. As the main purpose of AR coatings is reducing ghosting, the low sky level in the blue and thus a larger susceptibility to ghosting there should be considered when selecting coatings.

The SWG and SAC acknowledged the difficulty specifying a minimum requirement for the ODI system throughput. Therefore the throughput is specified as a goal, based on simulations of the expected throughput of the telescope (three mirror reflections), reflection losses of the coatings, throughput losses in the glass, and the QE curve of the CCD detectors.

Noise - In the case of narrow-band or U-band imaging exposures must be sky noise limited in a ten-minute exposure (i.e., 6 dither sequences for a one-hour on-sky exposure). At 3900 Angstrom one would expect ~0.14e^-/pixel/sec in a 20 Angstrom wide filter (sky rate from http://www.noao.edu/kpno/manuals/dim, extrapolated to the smaller pixel size of ODI and the wavelength of Ca H+K lines). Thus, a 10 minute exposure will produce ~84 e^-/pix, or a noise of 9e^-. The instrument noise must not exceed the sky noise contribution; given that we expect a higher blue sensitivity of the ODI detectors than in the model used here, and thus a higher sky count rate, an instrument noise limit of 10e^- appears reasonable, and a noise limit <6e^- is desirable.

Instrument noise includes any contributions by the instrument, including, but not limited, to: readout noise, transient bias structures, dark current noise, amplifier glow noise, and cross-talk. Noise contributions from sources light dark current are understood in the sense of residual shot noise after a feature has been subtracted.

A binned readout will reduce the readout noise for cases such as narrow-band imaging.

1.4.2. Verification Plan

Measure the throughput in all available filters based on spectro-photometric standard stars during commissioning. An implication is that filters covering the full visible spectrum will be available. Filter interfaces for Mosaic or QUOTA filters might be a solution for this issue.

Noise will be measured using multiple dark images of various lengths up to 30 minutes, while operating the telescope and instrument. One test will measure the noise in the difference of two bias images that were recorded at the end and at the beginning of a night.

1.4.3. Impact of not meeting the requirement

An insufficient throughput at the red end will not allow conduction the Yale survey in its currently proposed form. Neglecting the blue wavelength will reduce ODI's value for stellar population studies and will remove a special niche for WIYN. An overall low throughput of the instrument will can in part be bought back by longer integration times, while fast variability of fainter celestial sources might be lost as a science case.

2. Operational Concepts

2.1. Data Acquisition Modes

Under the assumption that ODI will utilize Orthogonal Transfer Array CCD devices, the following observing modes must be supported. In a fall-back solution without OTA CCDs some of these modes beyond static imaging should be implemented as feasible.

1. Imaging with the focal plane array, where a signal for telescope tip/tilt and instrument rotator guiding can be used.
    a. Imaging without fast tip/tilt guiding (static mode).
    b. Imaging with common-mode on-chip tip/tilt image motion correction - Guide star at each corner of the field of view will be used to derive a common-mode image motion signal for which the whole integrating focal plane will be corrected. The same guide stars can be used to derive a signal for telescope tracking.
    c. Imaging with local on-chip tip/tilt image motion correction - Up to four (requirement) guide stars per OTA detector will be used to provide a fast guiding signal for tip/tilt compensation in 4x4 arcmin^2 regions of interest. The guide loop speed must be at least 20Hz, including a 20ms exposure time for the guide stars.
    d. As an user option, a time-dependent offset must be added to the fast OT guide signal to allow for non-siderial tracking on the detectors in mode 1.b). This is a goal for mode 1.c).
2. Shutterless photometry – Windows of at least 3"x"3 size around objects will be read out at user-defined rate (with exposure times for the guide stars of 20ms to 40sec; The readout frequency at 20ms exposure time must be at least 20 Hz. The telescope must be guidable during the acquisition of the shutterless photometry.
3. In modes 1.b), 1.c), and 2.), or if guide stars are acquired to derive a telescope guiding signal, centroids and photometry (guide star data) of the guide stars will be saved to a file. At the choice of the observer, the guide star images will also be saved.
4. All observing modes must provide tools for automatic or manual pre-selection of guide stars:
    a. Automatic acquisition of guide stars from a pre-image without any additional input from the observer; the exposure time for guide stars will be set automatically or can be set as an optimization goal, e.g., to reach a certain guide rate or to accommodate a certain number of

tip/tilt corrections in a given integration time. The same guide stars should be used during a dither sequence, or, if impossible, a new set of guide stars would be selected from a new pre-image.

   b. Automatic acquisition of guide stars from pre-defined set of stars where their positions are known to within a OTA cell (e.g., from a star catalog), and only pre-images from the targeted cells will be obtained to find viable guide stars for the guiding process.
   c. Once a guide star configuration was successfully used it can be saved (including a full dither sequence). At a later time the same guide star configuration must be reusable after the telescope pointing was corrected from a short preimage.

5. All observing modes must be scriptable, including a request for a new telescope position and offsets. It must be possible to prepare observing scripts outside the WIYN environment. There must be unique identifier to link observing scripts and their resulting data products.
6. A goal is to provide an observing mode where only a central QUOTA unit will be used to allow small scale imaging projects and the use of small 6 inch filters from QUOTA or Mosaic.
7. ODI's design will be based on he assumption that an observer will be present on the mountain.

2.1.1. Science Justification

The motivation for building ODI was to provide efficient, wide field, high-resolution imaging capabilities to WIYN, enabling the science outlined in the ODI science case. The science cases can be classified into three categories:

- Deep high-resolution wide field-surveys
- Shallow medium to high resolution surveys in the fast (minutes to hours) variable time domain
- Shuttereless, targeted photometry of stars to cover the frequency domain from 20Hz to the limit set by the whole focal plane readout.

Experience from WIYN shows that the telescope itself generates a large fraction of tip/tilt image motions, i.e., coherent image motions. The first two categories can at a minimum level be served by the modes defined in requirement 1), with the option to increase the image quality by fast tip.tilt compensation. Requirement number 2) enables the fast, targeted photometry.

Simulations based on WTTM data have shown that at a tip/tilt guide loop speed of 20Hz there is a significant improvement in image quality compared to the uncorrected case: Without active tip/tilt guiding 70% of guide star centroids are off by more than half a pixel, whereas only 40% of guide stars are mis-centered at a simulated 20Hz guide loop speed. While the 20Hz guide loop speed is a limit of the chosen detector (OTA) architecture, it therefore also has a scientific justification.

To observe solar system objects the capability to do non-siderial tracking is required. Implementing this by keeping a set of guide stars fixed, but to systematically shift the charge on the OT detectors according to the expected proper motion appears a reasonable compromise between complexity of mode implementation and versatility. However, the proper motion of the objects would need to be known, and because of the small OT cell size of 1'x1' the spatial amount of non-siderial tracking will be restraint.

For a full guide star configuration of a 1° field of view about 200 guide stars will need to be defined. The need for observing efficiency dictates a computer-assisted guide star selection tool.

The rate at which a large quantity of data will be generated by ODI requires a scheme to identify data that was observed. Requirement 5) aims to offer the observer a system where observations can be easily planned and kept track of.

The goal 6) serves as an easy to use mode for the occasional small field observer and as tool for commissioning.

The complexity of the ODI instrument will require a tight integration of the control system into the telescope environment. Supporting a remote observing mode might be very costly and is therefore not a requirement.

2.1.2. Verification Plan

All observing modes and their support tools will be thoroughly tested during the commissioning phase.

2.1.3. Impact of not meeting the requirement

Not being able to deliver observing mode 1) will result in not accepting ODI as a WIYN instrument, since the instrument would provide no imaging capability. Not meeting requirements 2) would disable all science cases targeting fast variability on time scales below a few minutes. Not meeting requirement 3) would not improve the median and best DIQ at WIYN as promised by the ODI design.

2.2. Observing efficiency/Cadences

1. ODI must at least support following typical cadences[1]:
    a. Multi-color deep targeted observations – E.g., search for **PNe & Novae in Virgo**. The [OIII] intracluster PN survey needs one set of dithered observations in two narrow band filters (O[III], Ha) and two broad band filters (g' and r'). For the H-alpha nova survey, the cadence requirements are quite modest: Shafter, Ciardullo and Pritchet successfully detected novae in H-alpha around the Virgo galaxy M87, using only annual exposures. However, by increasing the cadence to once every two months, we increase the depth of the survey, and increase the number of novae found, and also allow for follow-up spectroscopy. Thus, dithered observations in H-alpha and r' with in two hours every two months need to be scheduled.
    b. Multi-color deep survey – E.g.: **Yale survey**. In each night where the survey is executed, obtain dithered (3 dither positions) exposures in two filters with a total shutter open time of 3min and 6 minutes in the z'-band and Y-band, respectively. Since three dither positions will not allow 100% filling factor, measures are required to ensure that observations of the same field in different filters line up within 4" (twice the amount of expected differential refraction in the field of view). Nine different shallow fields will be observed at every Yale survey night. One single deep field will be revisited every night for which a guide star configuration can be reused. Obtain dithered exposures (7 dithered positions) with a total shutter open times of 27 minutes and 46 minutes for the deep field.

       Per night, ~3 hours will be allocated for survey during which the program outlined in the last paragraph needs to be executed. During that time, the shutter will be open for 154 minutes, leaving 26 minutes overhead time for: (i) 2*7 (deep) + 9*3*2 (shallow) = 68 CCD readouts (ii) define guide stars for 9 different unknown fields, reassign well-known guide stars for one deep field (iii) apply 68 telescope offsets (<2º) with reallocation of guide stars, and (iv) keep the telescope in best focus. In addition, depending on the strategy of the survey, 11 filter changes (i.e., 11/68=0.16 changes per exposures) must fit into 40 minutes of total overhead time, with 26 minutes goal[2].

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[1] These cadences are selected to estimate the requirements for ODI's operational environment. The final cadence, e.g., for the Yale survey, will be adjusted later when the overall ODI performance is characterized.

[2] 26 minutes are derived from the plan to execute the proposed cadence in 3h total. However, the initiators of the Yale survey would rather have efforts invested into image quality than in an exceedingly fast cadence, and thus are willing to allow a longer overhead time of 45 minutes.

For the organization of the survey there should be away to keep track of the surveyed fields. The survey will require access to the telescope and to ODI 3 hours per night every four nights for three years. Data obtained for the Yale survey require a process to ship data to a central data reduction location (e.g., at Yale).

c. Single-filter wide & deep survey in the time domain – E.g.: **A survey for RR Lyrae stars in the M33 halo**. Observe a five-position dither sequence in the g'-band filter with a total shutter-open time of ~15 minutes (i.e., 3 minute exposures each) every 2 hours over two nights; do so for 4 (goal: 6) positions on the sky per night. Observations are done in fast, local guided mode to improve seeing and thus depths of survey. Reuse guide star configurations that were obtained during the first time a field was visited to (i) improve efficiency in guide star acquisition and (ii) return to the same positions on the sky to streamline data reduction. Images in a different filter (r') will be obtained at a later time to add color information.

   In order to re-use a guide star configuration the telescope pointing must be reproducible within two arc seconds. Not more than one exposure (of a dither sequence) must be lost per field and night.

d. **Multi-filter shallow wide area survey** – Cover a large area in two or more filters, but without dithering. Typically one would observe a series of neighboring fields in several filters. Once the telescope is in position, the cadence would be like: Either offset the telescope by ~1 degree or change the filter, acquire guide stars, and then expose for 5 minutes (split into two 2.5minutee exposures for cosmic ray rejection, but w/o dithering). The total overhead for this part of the cadence must be <3 minutes, .i.e, the total execution time must be <8 minutes.

   To cover a large area, the ODI control system must automatically execute cadences as described above to observe either a strip (1^{o}xN^{o}), or a rectangular region (M^{o}xN^{o}), in one to 8 filters.

e. **Fast photometry with full-frame readout using shuttered exposures**. This type of observation will be mainly governed by the imaging science requirements, with the following exceptions. The entire ODI system must be capable of obtaining and storing a full night of full-frame image data which is obtained with a shutter close to shutter open delay of <20 sec (<10sec goal) and exposure times as short as a few seconds. For example, in a typical 10 hour night, this type of observing could produce 800 full frames images. Guide stars for telescope guiding must be automatically recovered after a readout of the focal plane.

f. **Shutterless photometry with guide star stream**. This photometry mode makes use of the normal set of guide stars a given observer chooses for their science operations. We assume that these data are collected at a rate of 20 Hz or slower and that "OPTIC-like" real-time photometry is performed on each and every frame for each guide star. The data stream from this photometry must be saved and have header information which, at least, identifies the following: RA, DEC (J2000) of the guide star, x,y location and which OTA, the start time of each frame, the integration time of each frame, the filter used, the JD of the start of the observation sequence, and possibly some other information TBD. These data need to be stored in ASCII files and placed in a known location at the end of each observing night. The guide star imaging data can be saved at the observers choice. The stars observed are random. The data will be provided on-disk are the raw photometric time series data. Bias subtraction is required to occur within the guide loop (to allow tip-tilt corrections), e.g, by modeling of the bias, but no flat fielding needs to be performed. No "standard star" or other calibration data will be provided.

A planned "value added" program, the Serendipity program, will make use of the guide stars to perform ensemble differential photometry. The result of this operation (planned as an autonomous morning activity) will be to produce highly precise light curves (mag errors of ~0.01 mag or better) for each guide star.

g. Targeted fast photometry with guide star stream: This mode will consist of shutterless reads of a limited number of cells acting like guide stars. Since the number is limited, the readout rate is expected to exceed the 20Hz limit of regular tip/tilt operations; the total number of such video cells could be limited to no more than one per detector. The requirements for readout and real-time photometry as well as header and storage are the same as in mode e) above. The stars observed herein are chosen by the observer, and tools to set up a target list must be provided.

2.2.1. *Science Justification*

The cadences are derived from the needs of selected science cases outlined in the ODI Science case section. They were selected to cover the expected typical use cases, but with an emphasis to include such cases that will also be more demanding.

2.2.2. *Verification Plan*

The described cadences will be tested during commissioning. Aspects of the test will include: timing, reliability, and usability.

2.2.3. *Impact of not meeting requirement*

The outlined operational modes reflect expected typical use cases of ODI. Not being able to execute them at all would impose severe limitations on the usability of ODI and will thus impact the scientific success of the whole project. Not being able to execute these cadences within the specified time can in some cases be bought back with telescope time (e.g., Yale survey), while in other cases science is lost (e.g., rapid full-field photometry) since the higher frequency domain invariability could not be reached.

2.3. Quick-Look tools

1. Each ODI image must be displayed within 15 seconds after the readout process is finished. Displaying includes:
    a. Display one selected QUOTA-sized image, pre-processed for overscan & gain correction
    b. Display of a down-sampled image covering the whole focal plane, also pre-processed for overscan & gain correction. Ability to navigate in the image and select QUOTA-sized images for viewing as in a).
2. Standard tools must work with the image display to evaluate the image quality. E.g., the functionality of the mscred task mscexam under iraf must be available to analyze the displayed QUOTA unit.
3. Images that were obtained earlier during an observing campaign must be displayed within 15 seconds upon request and available to the same analysis as in 2).
4. The ability to coadd images that were observed during one dither sequence should be implemented. Co-adding and shifting images can be limited to integral pixel shifts without scaling operations. A co-added image should be available within 15 minutes after the last image of a dither sequence has been observed.

2.3.1. Science Justification

For the occasional ODI observer it is important to quickly verify that the images obtained meet the required quality for the intended science. Thus the observer must be able to browse through the whole 1º image and zoom into regions of interest. In these regions of interest the observer will want to check parameters such as seeing (focus), count rates of targeted objects, and sky levels.

Fast feed-back is required for the observer to move on with observations once a displayed image was verified. Thus the requirement to display an image is set to 15 seconds.

Different gains and bias levels in detectors and cells require that displayed images are corrected for these variation, as otherwise the observer would not be able to understand the displayed images.

It is equally important to display a picture that was observed earlier during a night to compare images.

2.3.2. Verification Plan

Extensive testing of the quick look tools in the lab before shipping the instrument to the mountain. Repeat the verification in the different environment of WIYN.

2.3.3. Impact of not meeting requirement

Not having a quick look tool for ODI data will virtually render the ODI system useless since the observer will not be able to judge the quality of the obtained data. Not meeting the timing requirements will reduce the observing efficiency of ODI.

2.4. Calibration Products

1. A standard calibration plan needs to be implemented to obtain data products for
    a. Weekly/monthly/post-servicing health checks
        i. Monitor the bias level (expected daily).
        ii. Test the linearity of all detectors with a photon transfer curve (expected monthly)
        iii. Update bad pixel masks (expected monthly)
        iv. Astrometric calibration for world coordinate system: expected 5 dithered exposures per filter every two month
        v. Photometric zero point calibration. Expected: 1 short exposure in a circumpolar field every two weeks.
    b. Instrument calibration
        i. Bias: Expected 10 per day
        ii. Dark current: Expected 10 per day at typical exposure times.
        iii. Dome Flats: Expected 5 per day and filter (up to nine, depending on the plan for the night).
        iv. Dome Flats under different instrument rotations and ADC configurations: Expected 5 per filter, instrument rotation, and ADC orientation; every 6 month.
        v. Sky Flats: Expected 7 night time exposures per filter, per month. Images can be science exposures and be flagged as viable for calibration products.
    c. Photometric calibration
        i. Provisions for 3 or more observations of standard star fields per filter per photometric night when a science program and observer demand these calibrations.

2. Obtaining the standard calibration products must be supported by the user interface. Where possible the process must be automated.

2.4.1. Science Justification

ODI will be a general facility instrument and not a survey. The complexity of ODI mandates that observers will be guided through the instrument's calibration process in order to allow a reasonable time between observations and published results.

The complexity of the instrument requires that a ODI supervisor is informed about the health of the instrument. Formalized health checks make this process efficient.

2.4.2. Verification plan

The calibration acquisition process will be excessively tested during commissioning.

2.4.3. Impact of not meeting requirements

Obtaining the required calibration products for ODI will be more complex than necessary, and potentially overwhelm an infrequent observer. The result would be a decreased efficiency in the sciene analysis of the data.

2.5. Filters

1. A minimum of eight filters will be available mounted in the instrument.
2. Exchanging of one filter (i.e., removing from instrument and replace with a different one) shall not take longer than one hour.[3]
3. The initial set of filters will consist of a set of SDSS g', r', i', and z' band filters, as well as of a Y-band filter and Johnson U-band filter. The need for further initial filters will be determined by the SWG & SAC.

2.5.1. Science Justification

The SWG & SAC found that 8 live filters should be available at a minimum for ODI to enable a diversity of science data to be taken within on block (e.g., one week) of filter configurations.

2.5.2. Verification Plan

The number of life filter slots is evident from the design; the functionality will be tested in the pre-shipping test. Filters will be tested before installation.

2.5.3. Impact of not meeting Requirement

Reducing the number of life filters will impact the diversity of observations that can be done during one time block of filter configurations. A higher frequency of mounting/dismounting the filter would be required, increasing the operational load at WIYN and the handling risk for the filters.

3. Instrument Calibration

The following section summarizes the calibration requirements for ODI.

1. The following criteria are requirements for the central circular unvignetted 1° field of view of ODI. They are goals in any imaging area in excess of the required area.

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[3] Compliance with requirement 1.3.5.b implies that filter exchanges can only happen during daytime.

3.1. Astrometry

1. Global astrometric solution accuracy requirement is 0.1" over a one-month period with a goal of 0.05".
2. Local astrometric accuracy requirement on scales up to 2' must be better than 0.002" with a goal of 0.001".

3.1.1. Science Justification

Relative image position precision from OTCCDs has been demonstrated to be 0.002" in the R-band with a projected precision of 0.001" in the Z-band. This precision will enable the determination of the stellar density in the solar neighborhood to an accuracy of 2%. It will be possible to search for remnants of merging satellite galaxies with the Milky Way by searching for common proper motions in the halo. Proper motion membership in Open Clusters will be determined from the bright stars to brown dwarfs in all of the nearby star clusters.

3.1.2. Verification plan

An extensive overlapping series of exposures on the standard astrometric cluster NGC 188 will be taken to map the focal plane, i.e. determine the optical field-angle distortion and the stability of the OTA ensemble. A similar backup series will be taken of one of the deep astrometric standard regions to support the calibration from NGC 188.

3.1.3. Impact of not meeting requirement

If the global astrometric accuracy requirement is not met, then it will not be possible to combine dithered images or to reliably place target objects in the narrow slits of modern spectrographs. If the local astrometric accuracy requirement is not met, then all of the above science programs will be seriously compromised and there will be little incentive to use the ODI for astrometry.

3.1.4. Impact of the accuracy requirements on an astrometric filter

A local accuracy of 0.001" requires that the tilts in the filter surfaces not deflect the beam from a reference perfectly flat filter by more than the positional accuracy requirement. A similar requirement is made on the uniformity of the index of refraction over the filter for the same reason. The large lever arm (distance from the filter to the OTA) aggravates this problem. This requirement is also required for precision photometry, since local irregularities in the flatness and index of refraction will introduce variations in the image PSF, which is a significant problem for precision photometry. Detailed mapping of the image displacements and PSF variations will probably be required to meet the requirement, but stringent flatness and index of refraction specifications for the filters will be necessary.

3.2. Conventional Photometry

1. Absolute photometry on science images must be possible to <1% for point sources, with <0.5% goal, over 90% of the field of view.
    a. The full well of the detectors must be at least 65k e^-, with 90k e^- goal. The ODI system must deliver the dynamical range of the detector.
    b. The linearity of the shutter/CCD system must be better than 0.5% for exposure times from 1 second to 30 minutes, in the dynamical range from the low level corresponding to the readout noise to the specified full well. The response of the CCD must be stable within the same limit over a period of at least 18 hours under different using profiles.
    c. The flat field residual error must not exceed 0.75% over the entire field of view.

   d. The photometric accuracy requirement is relaxed to <2% for the U band.

2. Relative photometry within each detector (i.e., comparing magnitude differences between stars, in different exposures, but with the same location of the stars on the detector) must be better than 0.2%, with <0.1% goal.
3. The shutter open/close time must be time-stamped to 1ms accuracy.
4. Real-time photometry based on guide stars must achieve a relative accuracy of 5% and be time stamped to 1ms resolution.

3.2.1. Science Justification

Studies of the metallicity of stellar populations require photometry with an accuracy up to 0.02mag, which translates into a relative flux error of 0.02/2.5 < 1%. Main instrument contributors to this error are linearity errors (from detector, shutter, and flat field) and a noisy background (readout noise, non-constant bias level, stray light).

Afternoon-calibrations (in particular flat-fields), standard star observations, and science object observations can be separated in time as much as 16 hours during long winter nights, however, calibration produces obtained in the afternoon must still be valid for observations taken in the early morning.

3.2.2. Verification plan

Test of photometric standard stars and test of consistency of photometry in dithered exposures. Compare repeated observations of the same field.

3.2.3. Impact of not meeting requirement

Fulfilling the requirements for photometry at the level as outlined in this section is mandatory to achieve the science goals of the proposed stellar populations studies; the requirements are therefore essential for the success of the instrument.

3.3. Shutterless photometry

1. Fast real-time photometry of guide star stars must be obtained with a relative accuracy of 0.01mag in the photon limited case.
2. Guide star photometry streams must contain meta-information to identify the object that was observed and at what time with an accuracy of 0.1ms.
3. Targeted fast photometry must be sustainable for two uninterrupted hours using 8 guide stars per detector at 20Hz.

3.3.1. Science Justification

Except for the first and last few guide star frames, the start time and exposure time of each guide frame must be known to 1/100th of the desired exposure time and guide rate. For a typical case, this requirement translates into start time and exposure time knowledge being good to +/- 100 microsec. This is based on a simulation of a search for a 0.1sec period of low amplitude in a bright star using 40 Hz sampling. For the 20 Hz case, this value relaxes a bit to 250 microsec. The longest shutterless readout time available must be at least 40 seconds (to connect the time domain with the shuttered reads).

3.3.2. Verification Plan

Monitor the stability of a field of stars and measure the relative photometric error.

3.3.3. Impact of not meeting requirement

Reducing the obtainable accuracy of the guide star photometry stream will lower the detection threshold in variability amplitudes.

4. Telescope Requirements

4.1. Telescope tracking & pointing

1. The telescope is expected to perform according to the "Scientific & Technical Requirments for the WIYN 3.5 Meter Telescope, WODC 00-01-03" Document.
    a. In particular must the telescope perform according to section 5, page 6&7 (pointing & tracking requirements).

4.1.1. Science Justification

For OTA-guided exposures it is crucial to predict available guide stars from an external catalog, such as the USNO catalog. With a pointing accuracy of 10" it is possible to predict coordinates of guide stars at least to the accuracy of a cell.

For repeated high-speed monitoring of variable stars and for searches of solar system objects it is required to return to an earlier saved configuration of OTA guide stars. Furthermore, once a guide star configuration is established, it is desirable to reuse the same guide stars during a dither pattern. In particular, one a suite of guide stars is established for the Yale survey, these guide stars can be reused without the need to re-acquire guide stars. This motivates the requirement for accurate blind offsetting.

Between the selection of guide stars from a pre-image and the start of a science exposure up to two minutes might pass. During this time insufficient telescope tracking must not move the guide stars out of their anticipated guide window of a typical size of 2"-4".

4.1.2. Verification Plan

During commissioning, the absolute pointing will be tested with ODI on a positions distributed on the entire accessible sky. A comparison with a reference catalog will reveal pointing inaccuracies. Blind offsetting will be tested at these locations.

In a series of short exposures over a five-minute period the unguided tracking performance will be tested on selected grid positions.

4.1.3. Impact of not meeting requirements

Requirement 1.a) is critical for the ODI mission since they enable the acquisition and reuse of guide stars. While requirement accurate pointing is affecting the ability to predict guide stars – and therefore supports the observing performance – blind tracking for a limited time is mission critical. If guide stars are lost during the blind tracking period the OTA functionality will not be useful.

Blind offsetting enables repeated fast targeted photometry. Not meeting this requirement thus might reduce the variety of science completed with ODI.

5. Data Products & Storage

5.1. Reduction Pipeline

1. The minimum requirement for the data reduction pipeline is defined in the ODI Pipeline Position Paper.

5.2. Data Format

1. Images that are delivered to a user are to be stored in files complying with the FITS standard.
    a. Images shall be delivered to the observer in chunks of 2x2 detector arrays (QUOTA units), or alternatively, in chunks of 4x4 detector arrays.
2. Each image has to contain a world coordinate system complying with the FITS standard that is accurate within 0.3”.
3. Each image needs to contain header information that complies with the NVO requirements.
4. Each image will contain header information describing the configuration of the instrument during the exposure, e.g., the rotation history of the ADC plates and the rotation history of the instrument rotator bearing.
5. Each image must have associated metadata describing the OTA shift history.
6. Ambient conditions and the seeing measurements from the focus sensor must be recorded for each image.
7. Information about the more detailed status of the instruments (i.e., temperature of each detector at a resolution <1minute, voltages of the CCD controller) are to be stored in a database that can be queried via the internet. In case that some operational parameters were not in their normal operation range a flag should be set in an image header pointing to the potential problem.

5.2.1. Science Justification

For the scientific success of ODI it is critical that ODI’s data will be readable with existing data reduction tools. The required header information outlined here is designed to trace the status of the instrument at the time of observations and thus to allow identifying any potential problems and to select the most appropriate calibration data.

5.2.2. Verification Plan

Verify the data format and header information during commissioning.

5.2.3. Impact of not meeting requirement

Non-standard image formats for ODI will complicate the data reduction process and therefore delay any science results based on ODI data. Missing header information could impact the instrument detrending process in the pipeline and thus lead to a violation of the calibration requirements.

5.3. Proprietary Period

1. Rights and distribution of ODI data must comply with the Memorandum of Understanding attached to the ODI TSIP contract.
    a. In particular will all data observed on University time become public after 18 month. WIYN sees the obligation to make this data public as fulfilled if data are made available to the NOAO archive shortly after observations (timescale of a week). The NOAO archive will not release data to the public before the proprietary period ends.
    b. The proprietary period must be extendable for thesis projects or other justified cases.
2. Guide star video stream and derived data will become public immediately, unless the observer opts in to protect the data with a proprietary period as defined in 1).

5.3.1. Science justification

The proprietary period is a direct requirement of the TSIP contract. The proprietary period for guide star data is removed to allow real-time serendipity projects based on the light curves of the guide stars.

5.3.2. Verification plan

TBD

5.3.3. Impact of not meeting requirement

There would be a violation of the TSIP contract if data would not become public after the proprietary period.

5.4. Data Storage & Access

1. Raw and pipeline reduced ODI data will be saved online at the facility for one week.
2. All raw data must be stored in an archive at the WIYN facility for the first year. It must be possible to ingest the raw data into the data reduction pipeline and to save the processed data as outlined in 3.b). After the first year, the WIYN SAC will assess this practice and the fate of the recorded data.
3. The observer will be able to store the data on portable hard drives or other appropriate exchangeable media.
    a. On the observer's request, raw data must be stored on a backup medium within 6 hours after the readout process of an image is complete. During the same time scale, data must be available to be copied to a different system (e.g., a Yale data reduction center on the mountain).
    b. Under the assumption that the data reduction pipeline was fed with the correct input data, the pipeline-reduced data of one night must be written to the observer's storage medium within 6 hour after the last image of an observing night was obtained (three hours goal). During the same time scale, pipeline reduced data must be available to be copied to a different system (e.g., a Yale data reduction center on the mountain).
    c. On request of the observer, data must be lossless compressed before writing them on the observer's medium (e.g., with gzip).
    d. A goal is to provide an interface to transmit data that was compressed with minimally lossy (<2%) algorithms over the network to a WIY partner's institute.
4. All ODI data (raw & pipeline reduced) will be made available to NOAO on the mountain during the one-week storage period. NOAO can ingest the data into their data archive for publishing this data after the appropriate proprietary period has passed.

5.4.1. Science Justification

The one-week data storage on-site will allow observers to verify their data is correctly backed up. Storing the raw data for a week will also allow reprocessing of the data should an error in the reduction process occur. Storing all raw data on the mountain for a year was an explicit request of the WIYN SAC to allow reprocessing data; the motivation was that confidence into the automatic pipeline processing needs to be built-up before trusting it.

Typically observers will leave the mountain by noon of the day following the last observing night. While this scheme might change, it is important that data will be backed up in time. Alternatively, data distribution via Internet (not really viable due to the sheer amount of data) or by ground shipping media would need to be established.

According to the TSIP proposal WIYN agreed to make all data observed with ODI public.

5.4.2. *Verification Plan*

The data pipelining and storage will undergo extensive testing during the commissioning phase.

5.4.3. *Impact of not meeting requirement*

IV. Summary of Key Requirements

Subject	**Requirement**
Field of view & filling factor	1º circular unvignetted field of view. 80% filling factor. One fixed orientation of the field of view on sky.
Availability	Whenever WIYN is scheduled. Allow for a one month servicing shutdown in the summer. Avaialble for observer 4 hours before sunset to 1 hour after sunrise. 1 hour recovery time after a <24 hour long shutdown.
Operational mode	ODI will be operated at the WIYN facility.
Lifetime and port	10 years, at the sole instrument at the WIYN port.
Image Quality	Deliver 0.3" in z-band at zenith, deliver 0.5" in g' and U band.
Tip/Tilt on-chip guiding	Must not degrade image quality.
Throughput	Defined as goal based on simulations including telescope, corrector, and detectors
Noise	Total instrument noise <10e^- in 30 minute long exposures.
Data Acquisition mode	• Static imaging • Static imaging with common mode tip/tilt correction @20Hz loop rate, optional non-sidereal tracking • Static imaging with local tip/tilt correction on 4'x4' cells @20Hz loop rate • Targeted shutterless photometry at 0.5Hz to 20Hz.
Shutter-close time	<20sec in repeated imaging mode. Requirement on observing cadences otherwise.
Filter loaded in the instrument	at least 8
Photometry	< 1% absolute photometry for point sources in 90% of field of view, flat-fielding of instrument <0.75%.
Astrometry:	<0.1" globally, <0.001" on 2' scale
Shutterless Photometry	< 0.01mag relative photometry
Telescope requirements	WIYN performs according to WODC 00-01-03.
Calibration	Standard calibration scripts will be available