The WIYN One Degree Imager: An Overview

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WIYN Observatory

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Outline

• ODI Motivation & Technology
• Construction Status
• Prototype QUOTA
• Resources and Timeline
View from the 4 meter telescope

- WIYN Consortium, telescope built in 1995:
  - University of Wisconsin, Madison (26%)
  - Indiana University, Bloomington (17%),
  - Yale, New Haven (17%)
  - National Optical Astronomy Observatory (40%)
WIYN: A modern telescope

- Optimized for image quality
  - active primary mirror support
  - careful thermal design
  - excellent optics

- 1° circular unvignetted field of view

- DIQ is atmosphere limited.
  - seeing of 0.35” on $z'$- and U-band science exposures reported.
  - Median seeing in R better than 0.7”.

Wednesday, September 2, 2009
Key Questions in Astronomy

• What is the nature of the Universe (Dark Energy) ?

• How do galaxies form and evolve (Dark Matter & Baryon interaction) ?

• How did the Galaxy form and evolve (Detailed study of baryons in a DM halo)?

• How do stars form and evolve (The first stars and early enrichment)?
Finding Answers

• Large Scale structure in the Universe (many degrees).

• Structure within Galaxy Clusters (a few degrees)

• Weak and strong lensing (few to many few degrees)

• Structure of galaxies (sub-arcsecond resolution for large z, but large samples)

• Structure of the Galactic halo (entire sky)

• Very rare objects (Extremely metal-poor stars, interacting binaries, ...)

• The astronomical community is building a plethora of new wide field imagers:
  • Skymapper, VST, VISTA, DECam, ODI, PanSTARRS, LSST, Hyper-Suprime Cam, ...
A One Degree Imager for WIYN

- Use WIYN’s 1° field of view.
- Utilize the excellent seeing of site & telescope.

Further enhance image quality by **active tip/tilt image motion compensation**.
- 20 Hz guide loop speed required, 50Hz goal.
- Shown to improve median seeing in R by 0.15”.

Median DIQ of ~0.55” in r’, capability of DIQ < 0.3” design goals.

- Sample the focal plane with 0.11” pixels -> 1GPixel camera.
- High observing efficiency, automated cadences:
  - shutter close to open <<20 sec in snapshot mode
- Provide on-site basic data reduction
  - Instrumental detrending, meta data, WCS...
Effect of Tip/Tilt motion on image quality

- Atmospheric turbulence, wind-shake cause image motion
- Some image motion is correlated, e.g., due to telescope shake
- Uncorrelated image motion due to atmospheric turbulence

(Not too new) Idea:
sense motion from a bright guide star and compensate for it
- Active secondary mirror (common in AO systems)
- Move detector (consumer digital cameras)
- Move electrons in detector (Orthogonal Transfer CCD)

New Idea: do it over 1° FoV
ODI’s Technical Motivation: High Image Quality Over 1°

• WIYN has excellent native seeing (median ~0.7” in R)

• WIYN has a 1° field of view

• Tip/Tilt performance at WIYN
  ➢ Improves seeing by ~0.14” in FWHM (typical in R)
  ➢ r’, i’, z’ medians become ~0.54”, 0.43”, 0.35”
  ➢ But, at 2 arcmin radius, atmosphere decorrelates: degrades 0.32” images by 10%

• Magnitude limit ~14.5mag.

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Orthogonal Transfer Array CCD

- Each cell is an independent CCD ~1’ on sky.
- Each cell can be read out in video mode.
- Each cell is either imaging or obtaining guiding information at up to 30Hz.
- Tip/tilt correction can be applied to each individual cell.
OTA Detector Development

- OT(A) concept invented by John Tonry (IfA)
- Collaborative development of OTAs w/ PanSTARRS project

- ODI works with STA/DALSA
- Wafer production complete.

- Processing of wafers done by ITL (University of Arizona)
  - Thinning, packaging, and testing
  - Mounting detectors on SiC focal plane

- Processing of carrier package ceramics dominant cause of delay in project!
OTA fast tip/tilt guiding

10-100ms

GS Integrate
Readout
GS Integrate
Readout

Centroid
Shift
Centroid
Shift
Readout

Weight of guide star $i$ on cell $j$:

$$\delta \vec{x}_j = \frac{\sum r_{ij} \cdot n \cdot \delta \vec{x}_i}{\sum r_{ij} \cdot n}$$

- $n=0$ equal weight, common mode only
- $n=1..2$ distance weighted
- $n=\text{large nearest neighbour}$
... on a 1° Field of View
OTA Operational Modes

- **Static Imaging**
  - Use focal plane as conventional imager.
  - *Snapshot programs, photometric standards*

- **Coherent Correction**
  - Sample only a few guide stars (e.g., one in each corner).
  - Correct 1° field for common-mode image motion.
  - Removes guide error, wind shake.

- **Local Correction (default mode)**
  - One guide star every 4 arcminutes; ~200 over 1°!!
  - Correct for atmospheric turbulence (tip/tilt only).
  - Correct in ~4’x4’ cells only.
  - Not fully possible everywhere on sky.

- **Targeted Photometry**
  - Use guide star for shutterless photometry.
  - Select guide star for science goals (vs. to optimise guiding).
  - up to 512 guide stars.
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ODI’s niche:

• High-resolution, wide-field imaging
Key instrument components
• Instrument Support Package.
• September 1st, *all drawing released*. 

Wednesday, September 2, 2009
Filter Mechanism

- Design challenge: filter size (42cm)
- Filter cost ($60k-$100k est.)
- Filter weight
- Safe handling
- Minimum of 8 live filters as requirements

- ~30 seconds filter change time
ODI Filters

• Initial Filter set:
  • SDSS u’g’r’i’z’
  • Ha
  • SDSS g’r’i’ ordered, received.
  • other orders pending.

ODI r’

ODI i’
ODI Filter Performance
Corrector Optics Design...

• Atmospheric Dispersion Compensator (ADC)
  • less than 2% distortion over 1° FoV

• 2-element Design
• One aspheric surface

• All optics received.
• Lenses coated or at coating.
• Prisms under evaluation for surface quality. Significant delay!
Shutter

- 2-blade design for accurate timing & short exposure times
- Designed and fabricated by the University of Bonn (Germany)
- Delivered and accepted.

- Homogeneous exposure, linear from 10ms to hours.
Prototype Camera QUOTA

- Prototype camera to test OTA detectors
- Potentially for prototype science

- Several on-sky campaigns on sky
  - latest two weeks ago

- Demonstrated so far:
  - Detector operations
  - WIYN’s image quality
  - On-chip guiding

- Shown in 2006 configuration:
  - two thick, two thinned Lot 2 devices

- Current configuration:
  - four thick Lot 3 devices
  - one coated with Lumigen for blue response.
OTA Imaging w/ QUOTA

- M 15
- SDSS r'
- 120 sec
OTA Imaging w/ QUOTA

- M 15
- SDSS r’
- 120 sec
FWHM as function of distance from guide star

Distance: 2’
FWHM: 0.66”

Distance: 4’
FWHM: 0.72”

Distance: 8’
FWHM: 0.78”
M51 seen by QUOTA:
• 50 min in U, 0.4" seeing
• 15 min in Y (red end of z')
• demonstration of sensitivity and image quality
• also demonstration of fringe behaviour
Resources

• ODI Web Page
  http://www.wiyn.org/ODI

• Exposure Time Calculator
  In the *Observing* section, follow the link to *Exposure Time Calculator*

• Guide Star Prediction Tool
  Experimental tool for guide star prediction.
  Not linked in ODI web page yet, but preview at:

  http://www.wiyn.org/quota/Software/odip2/
Expected Throughput

- 3x mirror reflections (Al coating)
- 8x reflection losses at optical surfaces (coatings, as built)
- PBL6Y, Fuse Silica
- CCD sensitivity
ODI Operational Model

• Observing:
  • Visitor Mode is baseline.
  • But allow complete observing run scripting in a Phase II tool.
  • Separate science intend from instrument operations.
  
  • Queue operations might be out there in the future.
  • Yale survey wants to initiate own queue mode. Expandable?
  
  • Future of WIYN-wide queue unclear.

• Data handling & reduction:
  • Baseline: Bring your own hard drive (0.5-4TB/night).
  
  • Working with IUTS on a comprehensive data handling storage / pipeline solution.
  • Centralised data reduction pipeline, comprehensive data calibration plan.
  • Not best possible calibration, but consistent & guaranteed data quality.
  • Data access via Internet 2.0. Some media shipment possible.

  • We should know more after this month’s WIYN Board meeting.
**ODI Time Line**

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<td>Focal Plane lab evaluation</td>
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<td>100% telescope access for ODI</td>
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**Other Milestones:**
- Early 2010 - Call for Science Demonstration proposals.
- May 2010 - Delivery of fully populated focal plane.

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**Daniel Harbeck**
2009/Sep/2

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Bonus Tracks
Availability of guide stars

• At least one guide star available per chip on whole sky.

• Pointing needs optimization!

• If very few guide stars are available, correct for correlated image motion only