Pyramid Wavefront Sensing for Extreme Adaptive Optics

LAUREN SCHATZ, JARED MALES, MICHAEL HART, OLIVIER DURNEY, LAIRD CLOSE, OLIVIER GUYON, KATIE M. MORZINSKI, JENNIFER LUMBRES, KELSEY MILLER
Outline

- The MagAO-X system overview
- Pyramid Wavefront Sensing Ongoing Research
Why Direct Imaging?

- With direct imaging we can:
  - Use spectrometer and polarimeters on planets
  - Look for evidence of life on other planets

Why is this so hard to do?

- Atmospheric turbulence
- Contrast

SCExAO+CHARIS

(Extreme AO+ Integral Field Spectrograph)

Males 2014
History and Context:

MagAO → MagAO 2k → MagAO-X

MagAO
- 585 adaptive secondary mirror
- Clone of LBTAO
- PWFS
- On 6.5m Magellan Clay
- 1kHz speed
- Clio IR camera (1-5 microns)
- VisAO (.6-1 microns)

MagAO-2K
- 2kHz upgrade
- 300 to 400 controlled modes (degrees of freedom) on DM

MagAO-X
- Builds off of MagAO and SCExAO
- Three phase development
Overview

- Visible-to-near-IR “extreme” exAO system
- 2048 actuator BMC DM
- >70 % Strehl at H-alpha
- 3.7kHz speed
- Coronagraphs delivering contrasts $<10^{-4}$ from 1-10 $\lambda/D$
- PWFS
- LOWFS
- Imagers and spectrographs
• WFS
• Coronagraphs
• Science Cameras
Coronagraph

University of Leiden:
Frans Snik, David Doelman, Christoph Keller, Matthew Kenworthy

MagAO: Clio+vAPP Coronagraph

Vector Apodizing Phase Plate (vAPP) Coronagraph

Phase-Induced Amplitude Apodization PIAACMC
Pyramid Wavefront Sensor
**Pyramid Wavefront Sensor**

- Focal plane is split by pyramid
- Wavefront Sensing done in pupil plane
- Benefits from the full resolution of the telescope
- # Pixel in pupil = # of degrees of freedom controlled (actuators)
Sensitivity

MPYRWFS modeled >> modulation than on sky MPYRWFS

Guyon 2005
PWFS Design for MagAO-X

Schatz et. al. in prep
Differences from Arcetri Design

- OAP that forms pyramid focus **after** TTM
- TTM in collimated space
- No dynamic focus on pyramid
  - Designed to be fixed with respect to the coronagraph
  - Focus comes from M2 compensation
Expected Performance

• Achromatic prism
• Designed by Arcetri
• Same pyramid in LBTAO and MagAO

Schatz et. al. in prep

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requirement</th>
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</thead>
<tbody>
<tr>
<td>Wavelength Range</td>
<td>600-1000 nm</td>
</tr>
<tr>
<td>Pupil Size</td>
<td>56 pixels; 2.688 mm</td>
</tr>
<tr>
<td>Pupil Separation</td>
<td>60 pixels; 2.880 mm</td>
</tr>
<tr>
<td>Pupil Tolerances</td>
<td>Δ &lt; 1/10th pixel; 2.4 μm</td>
</tr>
<tr>
<td>Lens Diameter</td>
<td>10 mm &lt; D &lt; 20 mm</td>
</tr>
</tbody>
</table>
Controlled modes > # of actuators on DM

Schatz et. al. in prep
Expected performance of PWFS

- Expected pupils on OCAM
- 8th mag guide star
- Log stretch
MagAO-X Raw Contrast Performance

- 30 Second exposure times
- 25 %-ile seeing conditions

~$10^{-4}$ Contrast

Better than $10^{-3}$ Contrast

Better than $10^{-2}$ Contrast

8<sup>th</sup> Mag GS

10<sup>th</sup> Mag GS

12<sup>th</sup> Mag GS

vAPP design by David Doelman
WFS Testbed

Unmodulated Pyramid Pupils

Olivier Guyon, Nemanja Jovanovic, SCExAO team

Schatz et al. in prep
3PWFS Simulations

Trying to understand difference in sensitivity and contrast for extended object wavefront sensing and imaging.

- 3PWFS
- 4PWFS
- Reflective/refractive

Benefits:
- Easier to manufacture
- Potential detector savings
- Potential gains in SNR

Schatz et. al. in prep

Path-finding for a reflective 3PWFS for GMagAO-X for GMT

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Acknowledgements

Jared Males
Advisor, MagAO-X P.I.

Michael Hart
Co-advisor

Kelsey Miller

Jhen Lumbres

Alex Rodack

Justin Knight

Logo PDR Approved
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