Class Project:

Focused Investigation

Astro 289: Adaptive Optics
Class Session #8
February 3, 2016

Thanks to Katie Morzinski for developing this series of activities
Purpose of Starter: To introduce existing AO systems and get you thinking about science goals and design choices

1. Comparing/contrasting several different AO systems and their results when imaging the same extrasolar planetary system (HR 8799)

2. Discussion

3. Goal-driven design: iterative
   - Science Case ↔ Performance Requirements

4. Expectations for final presentation / mini-CoDR
## HR 8799 Planetary System

### Observation Details

<table>
<thead>
<tr>
<th>System</th>
<th>AO System/Science Camera</th>
<th>Special Observational Techniques</th>
<th>λ observed</th>
<th>HR8799 Planets imaged (b/c/d/e)</th>
<th>SED (Temp of planets) (Yes/No)</th>
<th>Orbits/Positions (Yes/No)</th>
<th>Strehl ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>LBT</td>
<td>FLAO/PISCES</td>
<td>ADI/2D star subtraction</td>
<td>H, Ks</td>
<td>b,c,d,e</td>
<td>No</td>
<td>Yes</td>
<td>80+%</td>
</tr>
<tr>
<td>Keck</td>
<td>Keck AO/NIRC2</td>
<td>ADI, LOCI</td>
<td>H, K, L</td>
<td>b,c,d,e</td>
<td>Yes</td>
<td>Yes</td>
<td>60% ?</td>
</tr>
<tr>
<td>MMT</td>
<td>MMTAO</td>
<td>PSF subtractions 3.8 mic, 3.1, 4.8</td>
<td>b,c,d only at 3.8 mic</td>
<td>Yes</td>
<td>Yes</td>
<td>??</td>
<td></td>
</tr>
</tbody>
</table>
## AO System Parameters

<table>
<thead>
<tr>
<th>System</th>
<th>Telescope Diameter</th>
<th>Site/(r_0)</th>
<th>DM and dof</th>
<th>WFS Type</th>
<th>AO Bench location (Cassegrain? Nasmyth?)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LBT</td>
<td>8.4</td>
<td>13 cm</td>
<td>627 DSM</td>
<td>Pyramid</td>
<td>Bent Gregorian</td>
</tr>
<tr>
<td>Keck</td>
<td>10</td>
<td>20-25 cm</td>
<td>249 Contin. Face Sheet</td>
<td>S-H</td>
<td>Nasmyth</td>
</tr>
<tr>
<td>MMT</td>
<td>6.5</td>
<td>12 cm</td>
<td>336 DSM</td>
<td>S-H</td>
<td>Ritchie-Chretien Secondary</td>
</tr>
</tbody>
</table>
Here are images of the HR 8799 planetary system with these three AO systems
Keck 2 AO
LBT H-band (1.6 microns) and 3.3 microns
MMT AO 3.3 – 4.8 microns

2 planets detected

3 planets detected

0 planets detected
Discussion about comparative AO

Which AO system would you use for HR8799? What science would you be aiming at?

Which AO system would you use for finding other types of planets?

Why did they use different DM’s?

Why did they use different WFS’s?
Where are we going with this?

1. Flow Chart for **Goal-Driven Design**
2. Defining your Performance Requirements
3. Expectations for your Project at class presentation ("mini-CoDR")
Goal-driven design: Design AO system/select AO components based on science goals

Science Case

- Performance Requirements and Science λ
  - Sky coverage
  - PSF quality/Strehl requirement
  - Field of view
  - Guide star
  - Residual wavefront error
  - Beam size
  - Wavefront sensor noise
  - Time delay
  - Fitting error
  - G.S. magnitude
  - bandwidth
  - # subaps

Reference “Star”
Wavefront Sensor
Control System
Deformable Mirror
Optics

# Performance Requirements: Example

<table>
<thead>
<tr>
<th>(Step 1) Science Case</th>
<th>(Step 2) Performance Requirements -- Physical Parameters</th>
<th>(Step 3) Performance Requirements -- Observables to Measure</th>
</tr>
</thead>
</table>
| How many brown dwarfs are orbiting stars in the Hyades cluster? | • Parameter space for search: Brown dwarf dist. 5 - 250 AU from parent sta.  
• Minimum (and faintest) brown dwarf mass: 0.003 x M$_{\text{sun}}$ (L / T dwarf transition)  
• Contrast ratio between planet and star: 10$^{-4}$ at close separations | • Search space: 0.1-10 arc seconds from parent star.  
• Sensitivity limit: H-band magnitude~13  
• Contrast between planet and star: ΔH~10 magnitudes (factor of 10$^{4}$) |

Notes:

1 AU = distance from earth to Sun

H band is centered at a wavelength of 1.6 microns

Magnitude: “Faintness” as viewed from Earth.

\[ m_1 - m_2 = -2.5 \log_{10} \left( \frac{I_1}{I_2} \right) \]
Defining Performance Requirements based on Goal

• Resources:
  – Advisors
    • Your research advisor/colleagues/professors
    • Or I can put you in touch with an AO instrumentation expert in your field – please ask
  – White Papers for astronomy teams:
    • Astro 2010 Decadal Survey:
      – Science White Papers:
        » [http://sites.nationalacademies.org/BPA/BPA_050603](http://sites.nationalacademies.org/BPA/BPA_050603)
      – Instrument White Papers:
        » [http://sites.nationalacademies.org/BPA/BPA_049522](http://sites.nationalacademies.org/BPA/BPA_049522)
    • Planetary Science White Papers:

• Iterate with me by email.
Goal-driven design: Starting with science goal vs. starting with performance requirements

• What if you optimize your AO system to get the best performance?

• Performance requirement:
  – Get best possible contrast (dynamic range)
  – What is the faintest planet we can image next to a bright star?

• Leads to:
  – What might be the outcome of this design?

• What if you optimize your AO system to do the best on your science goal?

• Science goal:
  – Image exoplanets
  – How frequent are Jupiter-type exoplanets seen around solar-type stars?

• Leads to:
  – What might be the outcome of this design?
Goal-driven design: Starting with science goal vs. starting with performance requirements

• What if you optimize your AO system to do the best on your science goal?
• What if you optimize your AO system to get the best performance?

• Performance requirement:
  – Get best possible contrast (dynamic range)
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• Science goal:
  – Image exoplanets
  – How frequent are Jupiter-type exoplanets seen around solar-type stars?

• Leads to:
  – Observing hundreds of nearby stars and counting which ones have Jupiter-type exoplanets orbiting them.
  – This AO system would need such a bright natural guide star to measure the wavefront that it could only observe the ~10 brightest nearby stars that exist.

Science goal: Image exoplanets
What is the faintest planet we can image next to a bright star?
Leads to: Observing hundreds of nearby stars and counting which ones have Jupiter-type exoplanets orbiting them.
Expectations for Final Project Presentations: mini-CoDR

(CoDR = Conceptual Design Review)
Conceptual Design Review (CoDR)

• Basic science goal and performance requirements

• Purpose: Demonstrate feasibility of design to solve problem/answer question

• Describe system and sub-components but doesn’t have to show they’re the best design

• Identify areas of technical risk, for example new technologies or techniques

http://www.ing.iac.es/~docs/wht/naomi/wht-naomi-87/wht-naomi-87.html
mini-CoDR Expectations

1. Instrument name
2. Science goals
3. Performance requirements flowing from science goals
4. Proposed telescope/location
5. DM (type, dof)
6. WFS (type, sensitivity, # subapertures)
7. Science instrument (IR imager, optical spectrograph, …)
8. Block diagram of AO system
9. Type and magnitude of reference “star” (natural, laser)
10. Field of view
11. Wavefront error budget
12. Describe the main risks
Bonus @ mini-CoDR

1. Acronym for your AO system/instrument
2. Logo (!)
3. Your Roles: Principle Investigator (PI), Project Scientist, Project Manager, user
4. Optical layout
5. Observing plan/how data will be gathered
6. Plan for data reduction/pipeline
7. Project timeline
8. Estimate (guess?) total project cost
Project Due Dates

1. **Feb 9: General Science Topic and Collaborator(s).** Iterate with me. (But can re-visit as design proceeds.)

2. **February 11th:** **Specific science question you want to answer with your AO system**

3. **Feb 16: Performance Requirements** - First draft due. Iterate with me, especially if you need more help than White Papers and local experts.

4. **March 1st:** **Focused investigation (in class)**

5. **March 10th:** **Project Presentations**

6. **March 14th:** **Written report due**
FYI

Project Management Overview
1. Conceptual Design Review (CoDR)
   – a.k.a. Feasibility Design Review
2. Preliminary Design Review (PDR)
3. Critical Design Review (CDR)
4. Pre-Ship Review
5. Integration and Testing
6. Commissioning
7. Facility-Class Instrument

Note: Terminology and definitions are approximate, and vary from community to community
Conceptual Design Review (CoDR)

- Basic science goal and performance requirements
- Purpose: Demonstrate feasibility of design to solve problem/answer question
- Describe system and sub-components but doesn’t have to show they’re the best design
- Identify areas of technical risk, for example new technologies or techniques

http://www.ing.iac.es/~docs/wht/naomi/wht-naomi-87/wht-naomi-87.html
Preliminary Design Review

- Detailed science goal and performance requirements
- Operational requirements/constraints
- Timeline/plan for building
- Details about instrument design
- Cost/budget
- Alternate choices under consideration
- Plan for mitigating risks
Critical Design Review

- Full designs for individual components
- Full design for system
- Detailed plan for building
- Timelines and Gantt charts
- Budget review
- Scale models
- Simulations

http://www.ing.iac.es/~docs/wht/naomi/wht-naomi-87/wht-naomi-87.html
Final Stages

• Pre-Ship Review
  – Do subsystem components meet spec? Are they ready to ship to telescope?

• Integration and Testing
  – Put all components together and run performance tests under realistic observing conditions

• Commissioning
  – On-sky testing of anything that couldn’t be tested in lab, and in regular observing mode

• Facility-class Instrument
  – At this stage, the instrument is finished “engineering” and is now ready for “science” by the wider user community!