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

Science Results

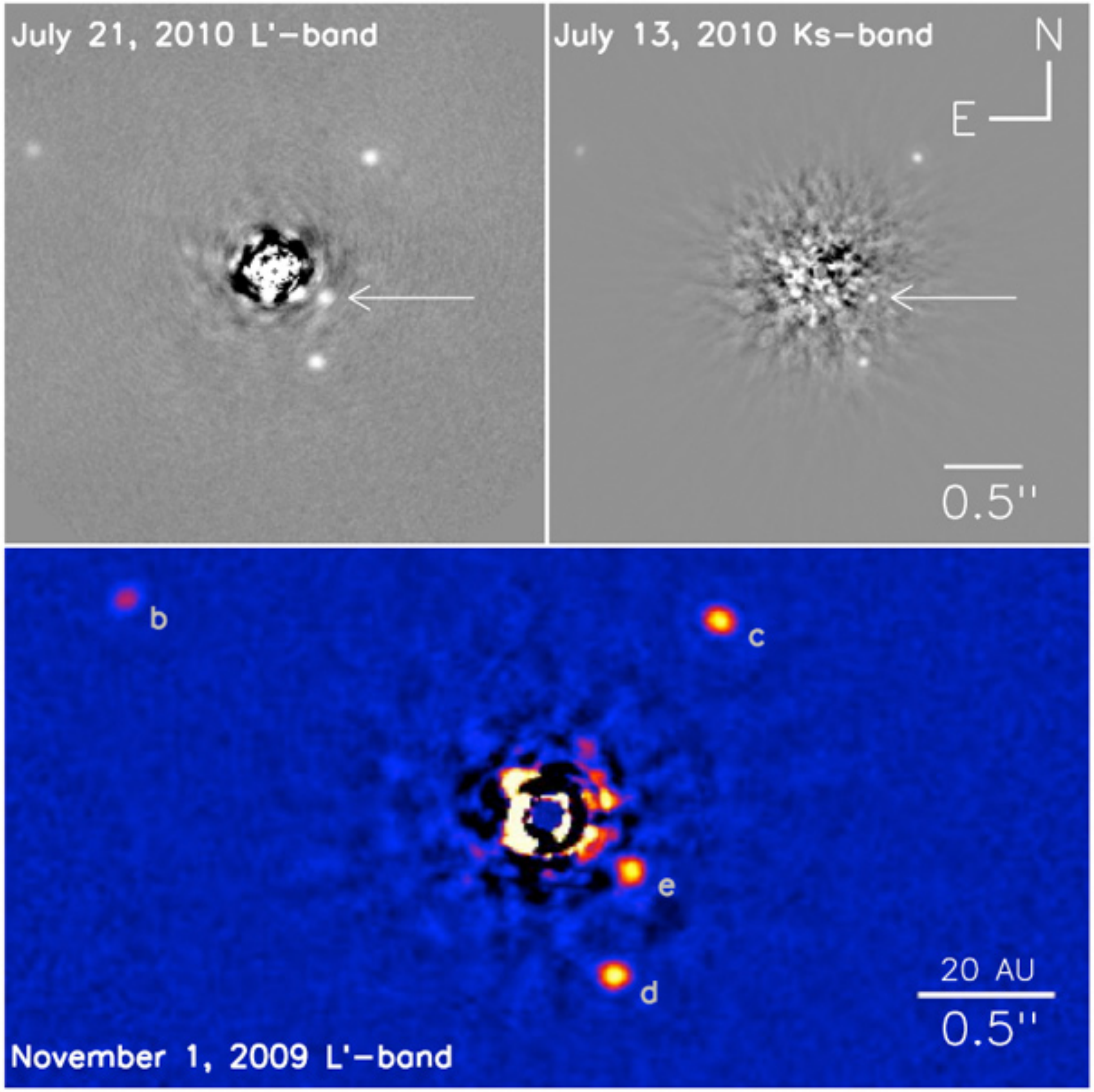
System	AO System/ Science Camera	Special Observational Techniques	λ observed	HR8799 Planets imaged (b/c/d/e)	SED (Temp of planets) (Yes/No)	Orbits/ Positions (Yes/No)	Strehl ratio
LBT	FLAO/ PISCES	ADI/2D star subtraction	H, Ks	b,c,d,e	No	Yes	80+%
Keck	Keck AO/ NIRC2	ADI, LOCI	H, K, L	b,c,d,e	Yes	Yes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

AO System Parameters

System	Telescope Diameter	Site/r_o	DM and dof	WFS Type	AO Bench location (Cassegrain? Nasmyth?)
LBT	8.4	13 cm	627 DSM	Pyramid	Bent Gregorian
Keck	10	20-25 cm	249 Contin. Face Sheet	S-H	Nasmyth
MMT	6.5	12 cm	336 DSM	S-H	Ritchie-Chretien Seconday

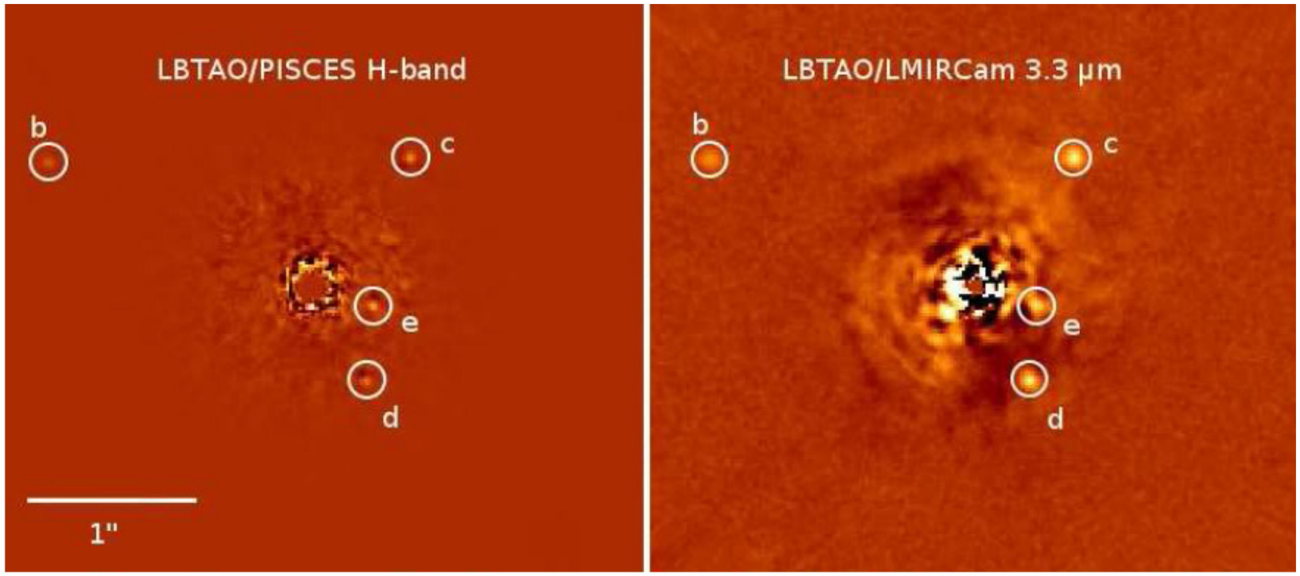
Here are images of the HR 8799 planetary system with these three AO systems

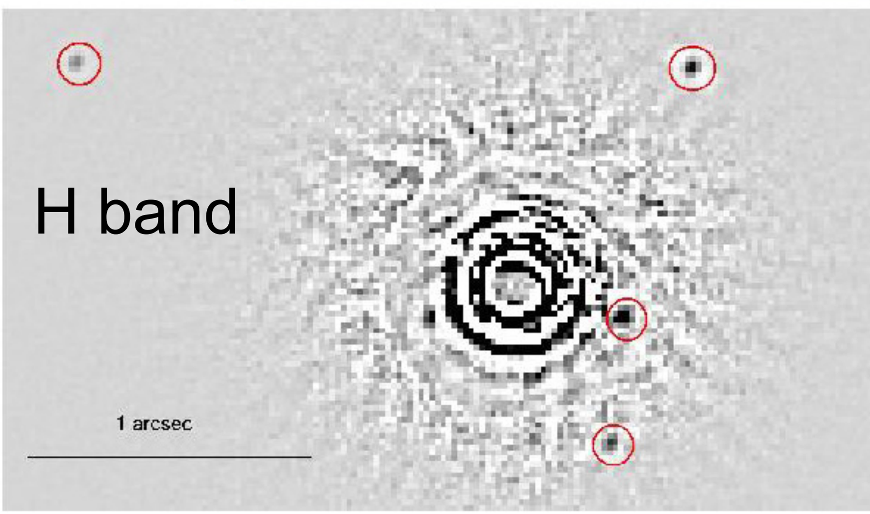
Keck 2 AO



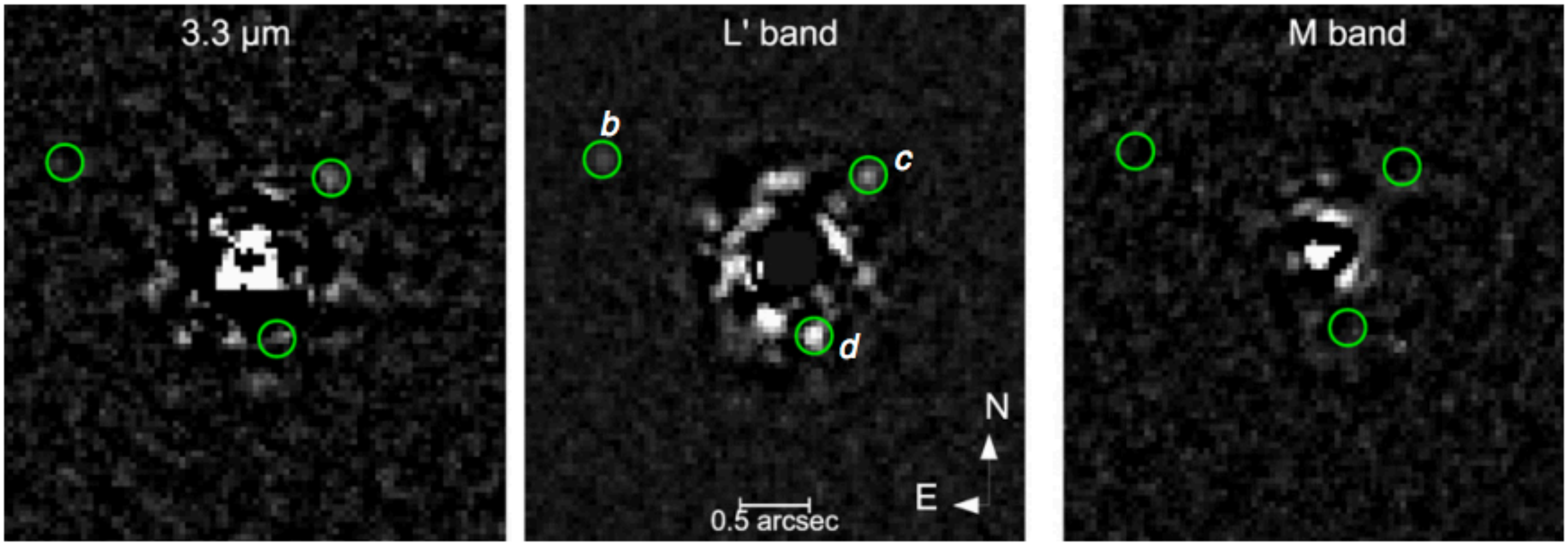
July 21, 2010 L'–band
July 13, 2010 Ks–band
N
E
0.5''
b
c
e
d
20 AU
0.5''
November 1, 2009 L'–band

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?

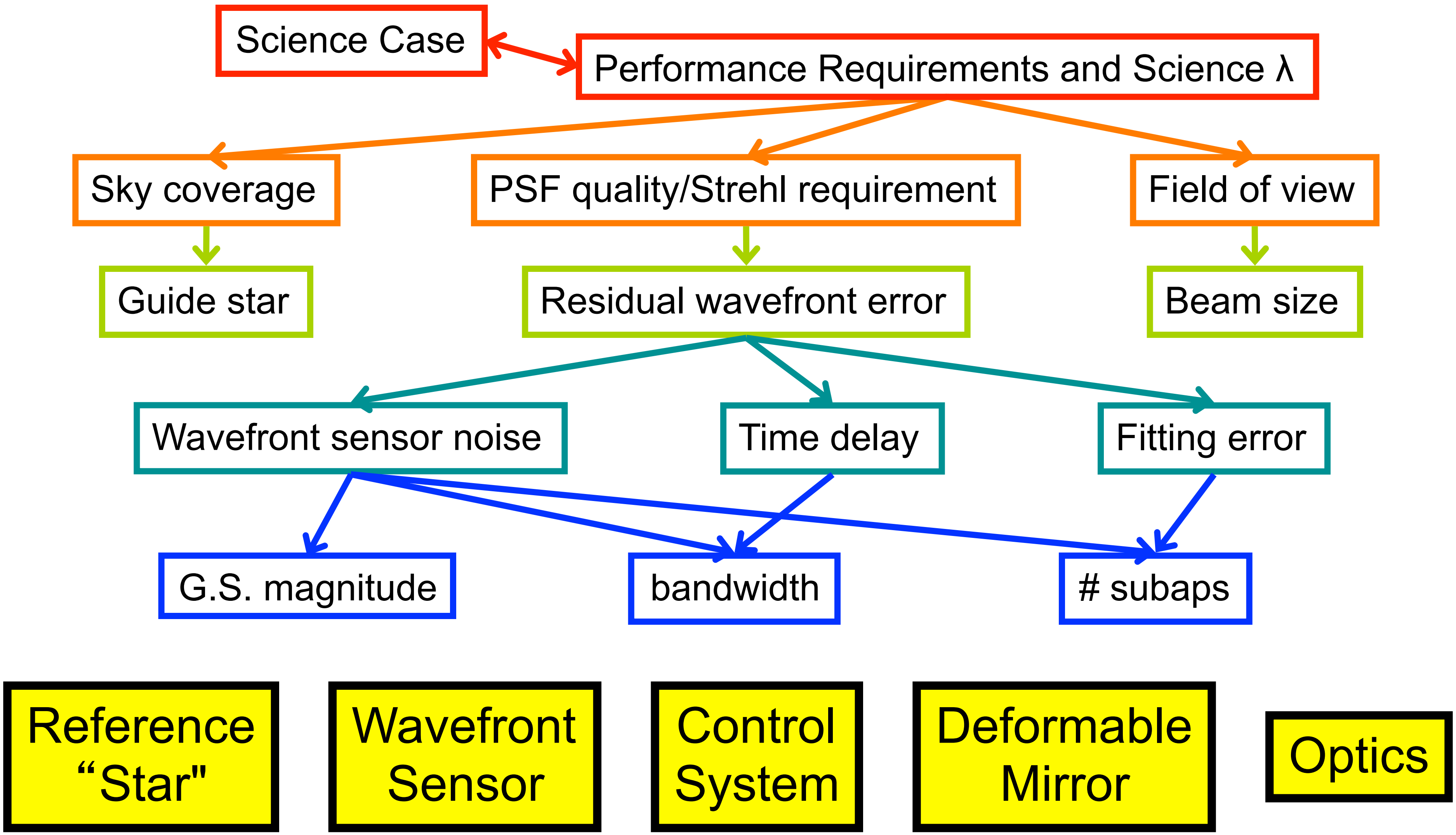
Where are we going with this?

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



This slide based on flow charts and concepts from O. Guyon's talk on AO system design: Astronomy at *2009 CfAO AO Summer School* at UCSC, R. Parenti's chapter 2 in AO Engineering Handbook ed. R. Tyson 2000, and J. Hardy chapter 9 AO for astronomical telescopes 1998.

Performance Requirements: Example

(Step 1) Science Case	(Step 2) Performance Requirements -- Physical Parameters	(Step 3) Performance Requirements -- Observables to Measure
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_{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 Ican 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
      - Instrument White Papers:
        - » http://sites.nationalacademies.org/BPA/BPA_049522
    - Planetary Science White Papers:
      - http://www8.nationalacademies.org/ssbsurvey/publicview.aspx
- 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 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:
  - 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.

- 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:
  - 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

Project Management: Levels of Design Reviews

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

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

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!