Lecture 2

Optical systems for space-based scientific remote sensing

University of Arizona

January 24, 2013

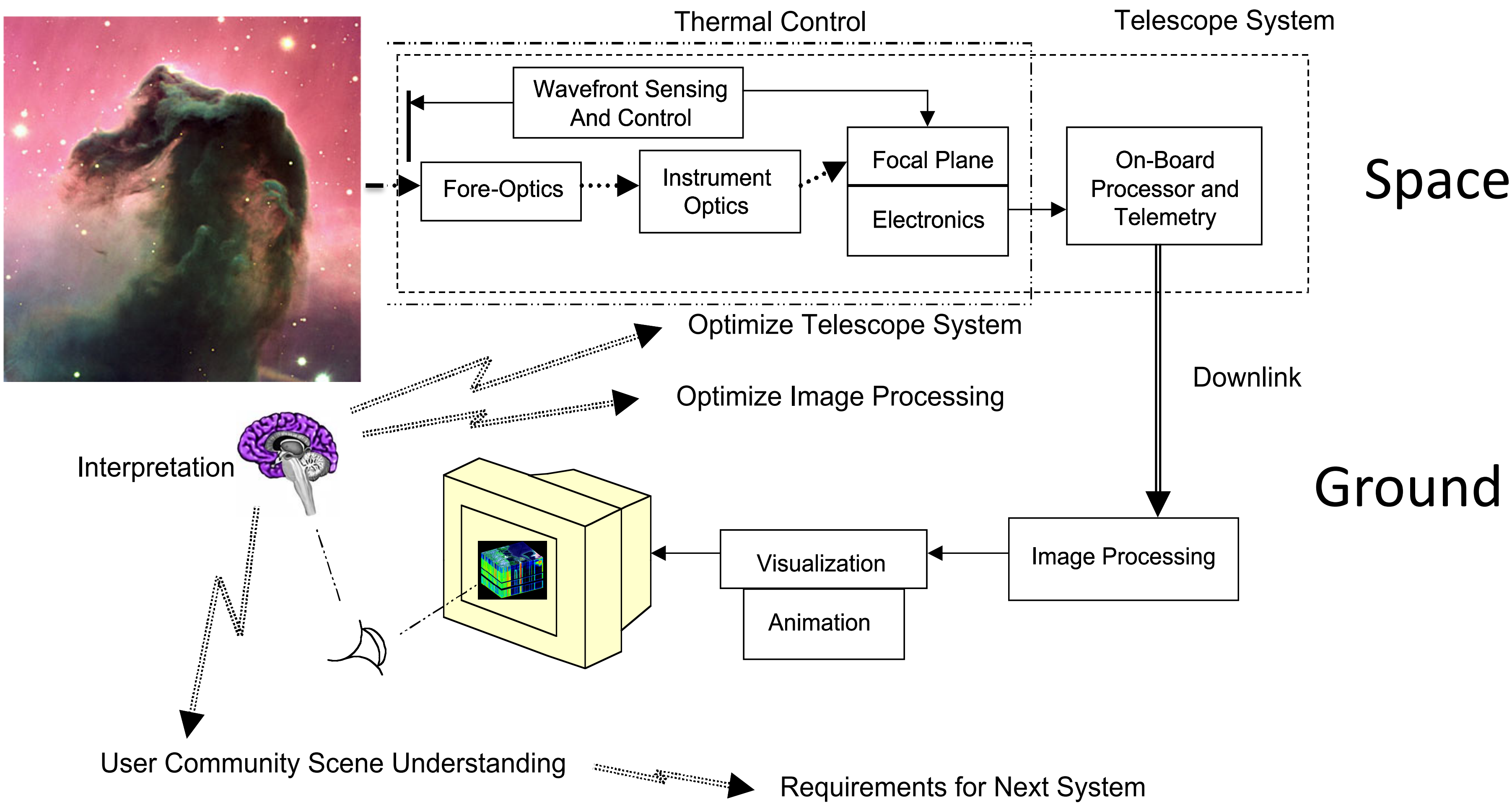
Dr. James Breckinridge

Pasadena, CA.

jbreckin@optics.arizona.edu

Space Telescope Optical System:

The optical system scientist works from the source through the interpretation

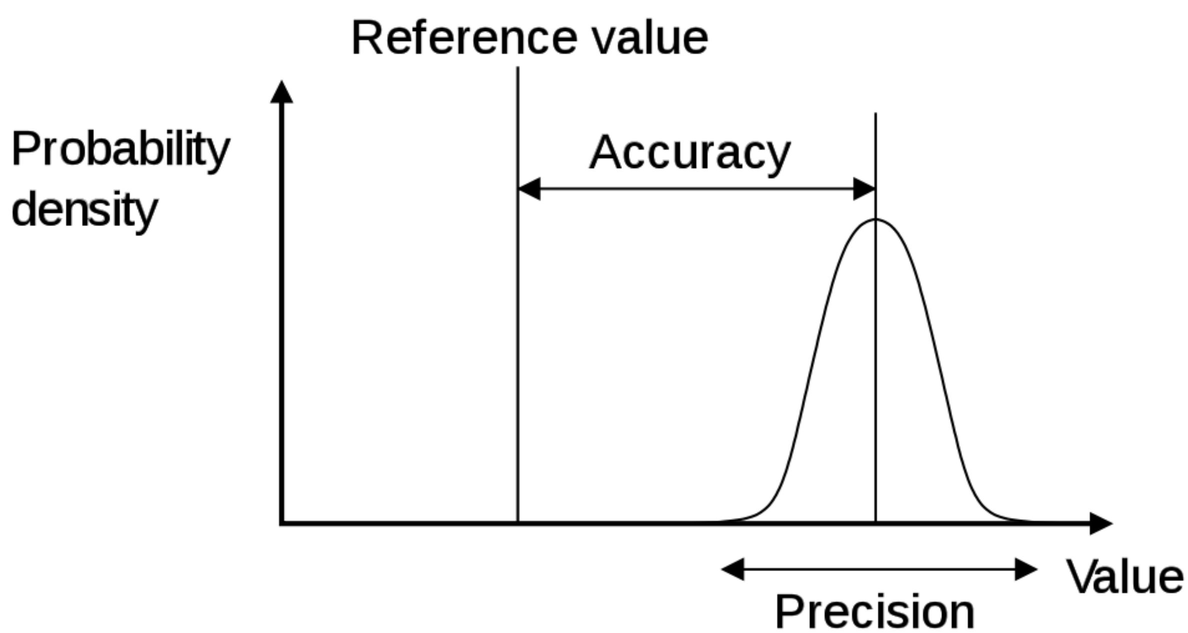


System development process

- Science
  - "Determine the scope of global warming"
- Science measurement objectives
  - "Measure the annual abundance of CO_2 to an accuracy of 0.1%"
- Functional requirements (constraints on the instrument & system)
  - "the needed signal to noise is 60:1, global measurements, season…"
- Create a System architecture
  - "Telescope with spectrometer, low earth orbit, down link capacity, multiple spacecraft, emission or absorption, …. "
- Develop a point design
  - "Grating or Fourier transform spectrometer, spectral resolution, $A\Omega$??"
- Model source, telescope/instrument and data processing to demonstrate the science measurement objectives have been met.
- Is new technology needed?

Example of a science measurement requirement

- Mission studies
  - Science measurement requirement
    - *Measure the central intensity of an absorption line at 483.56 nm in the spectrum of a 14th magnitude star with 5% accuracy at the 95% confidence level*



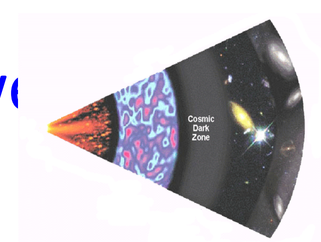
Today

Thursday, January 24, 2013

- Telescope system architectures
  - Filled, segmented, sparse, interferometers
- The NASA process
- Overview of large ground based telescopes
- Requirements development
  - Science measurements, technology risk map science into realized engineering

****

- Diameter increases angular resolution
- Area increases radiation collected – more pow



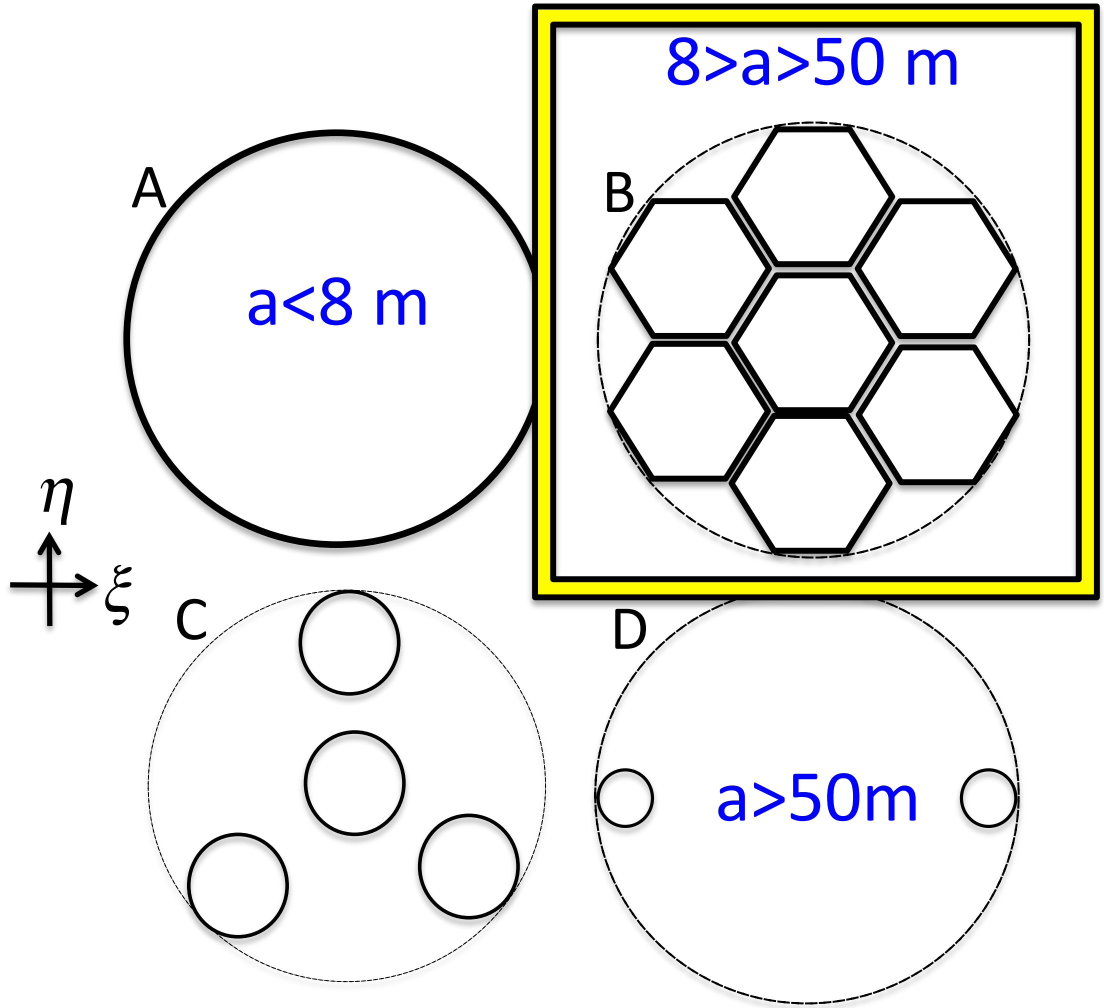
Today

Telescope aperture

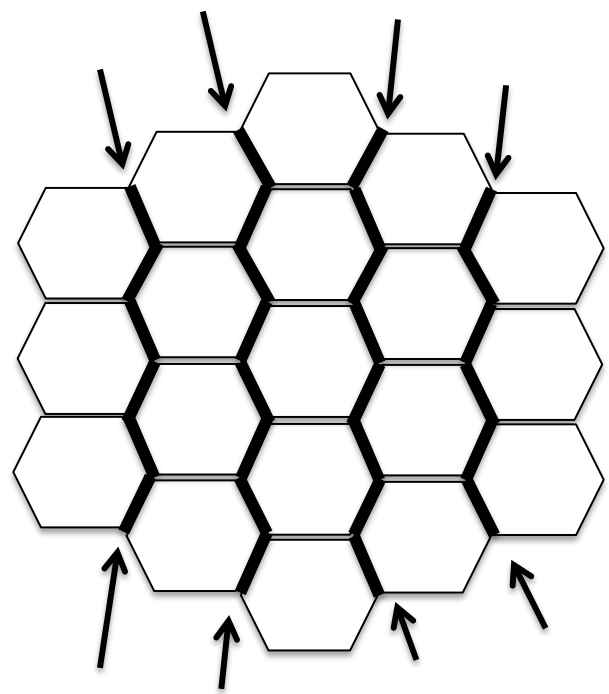
- Cannot always afford a monolith
  - Replace the stiffness needed for an optical telescope with electronics
    - Wavefront sensing & control
    - Optical metrology
- Segmented
- Sparse
- Interferometry
  - Spatial interferometry
  - ~~Temporal frequency interferometry (FTS)~~

Segmented apertures

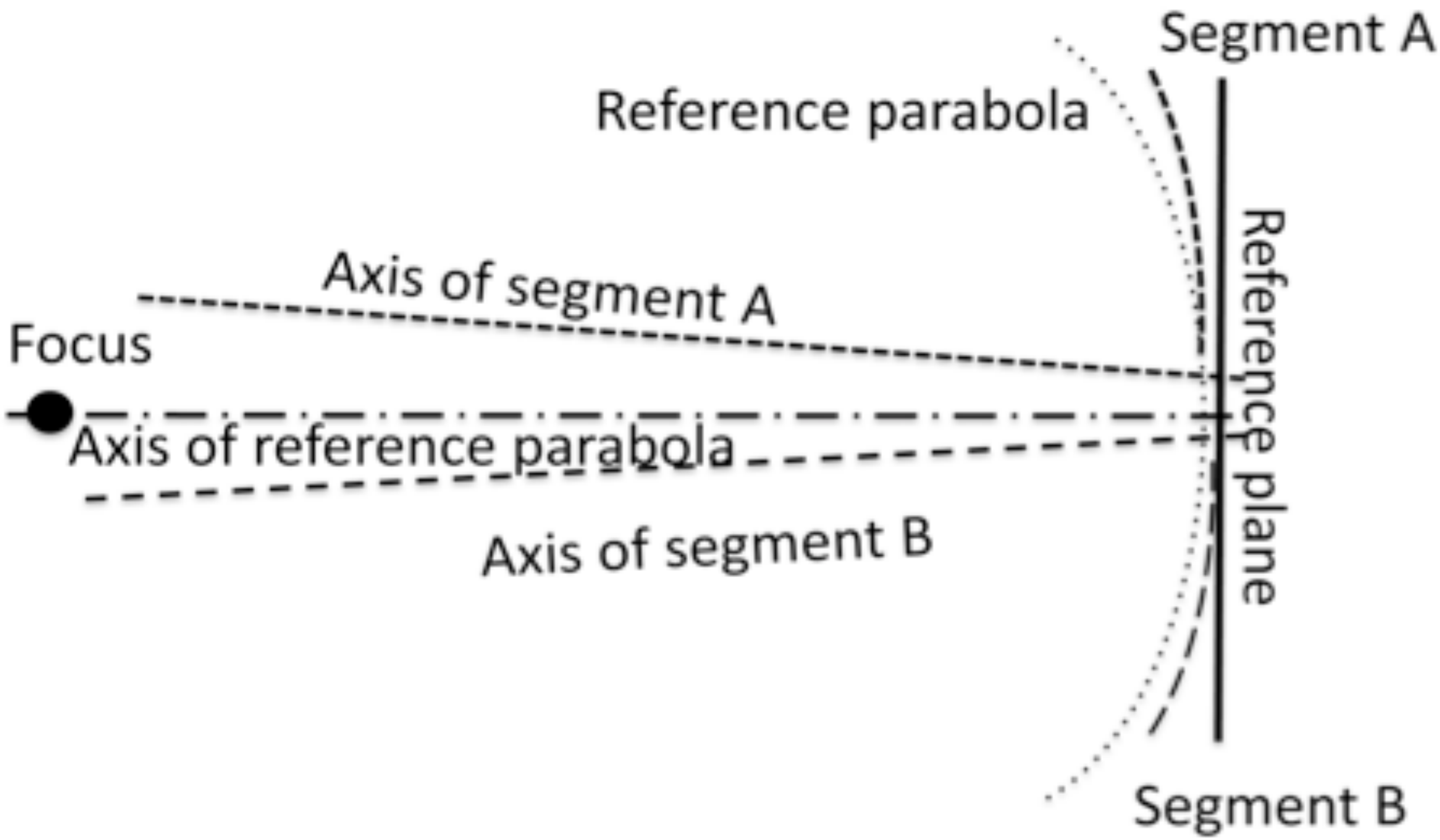
- What kind of aperture are you going to build?



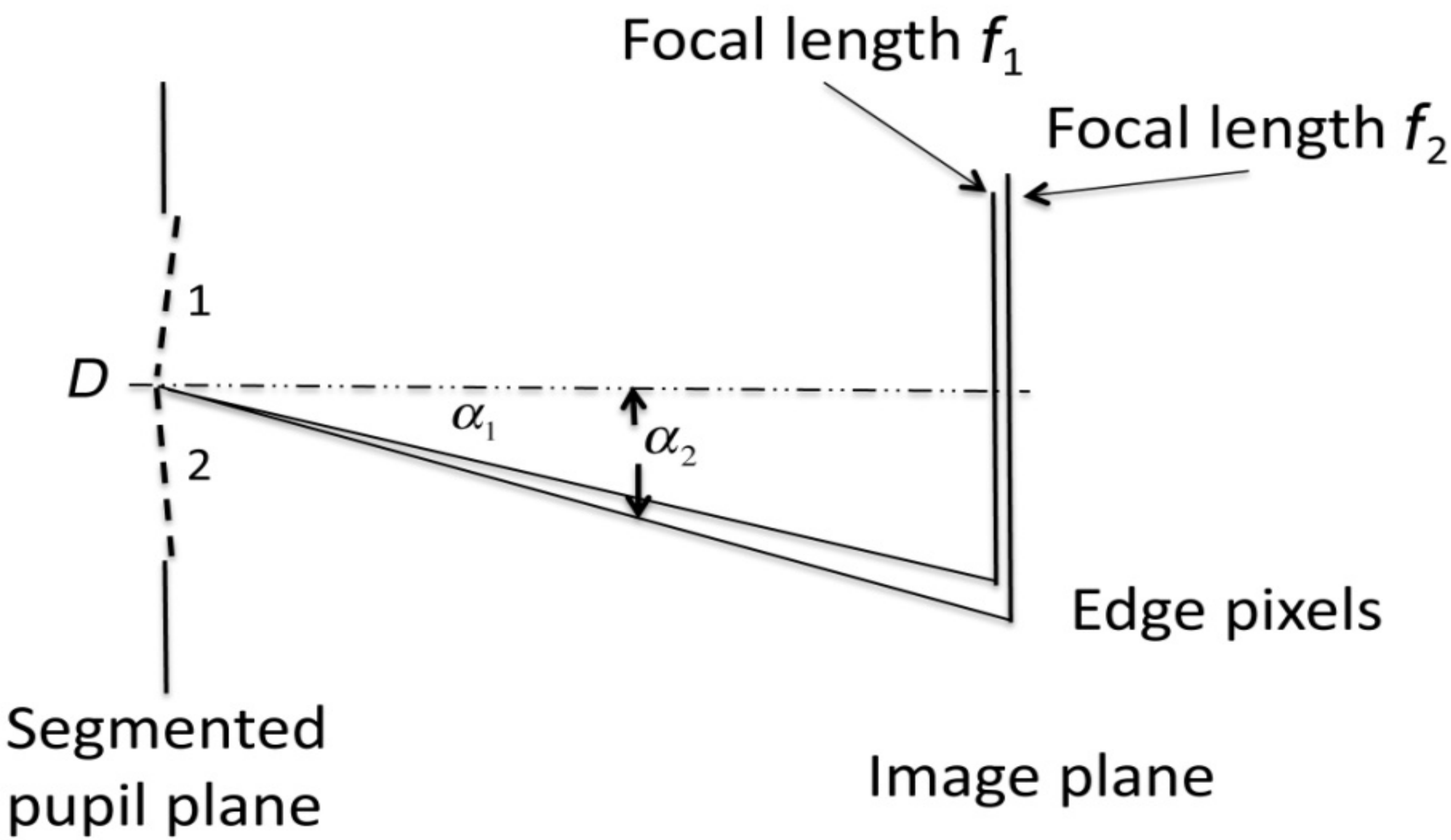
JWST mirrors are mounted on a backplane and the backplane folds at 4 hinge lines – segments have mm gap!



Segment radii of curvature tolerance

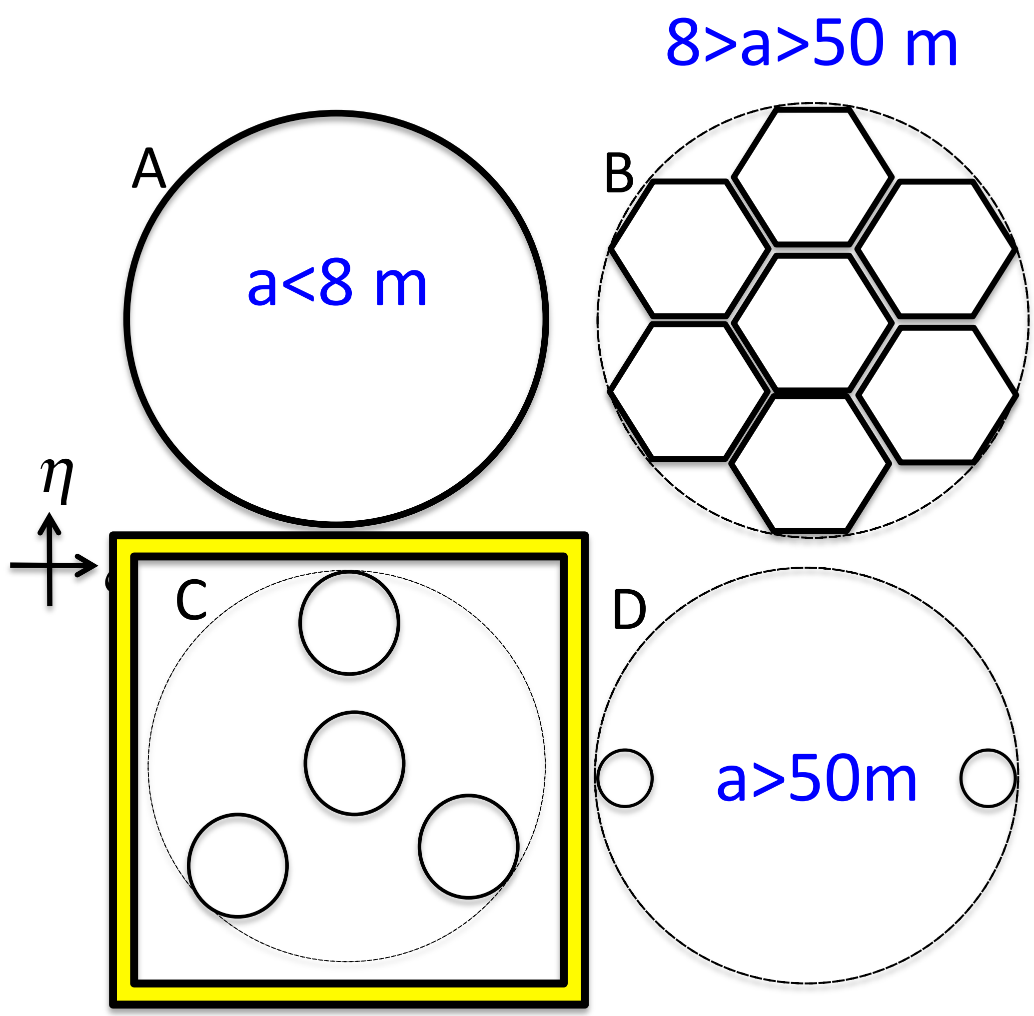


Tolerance on the radius

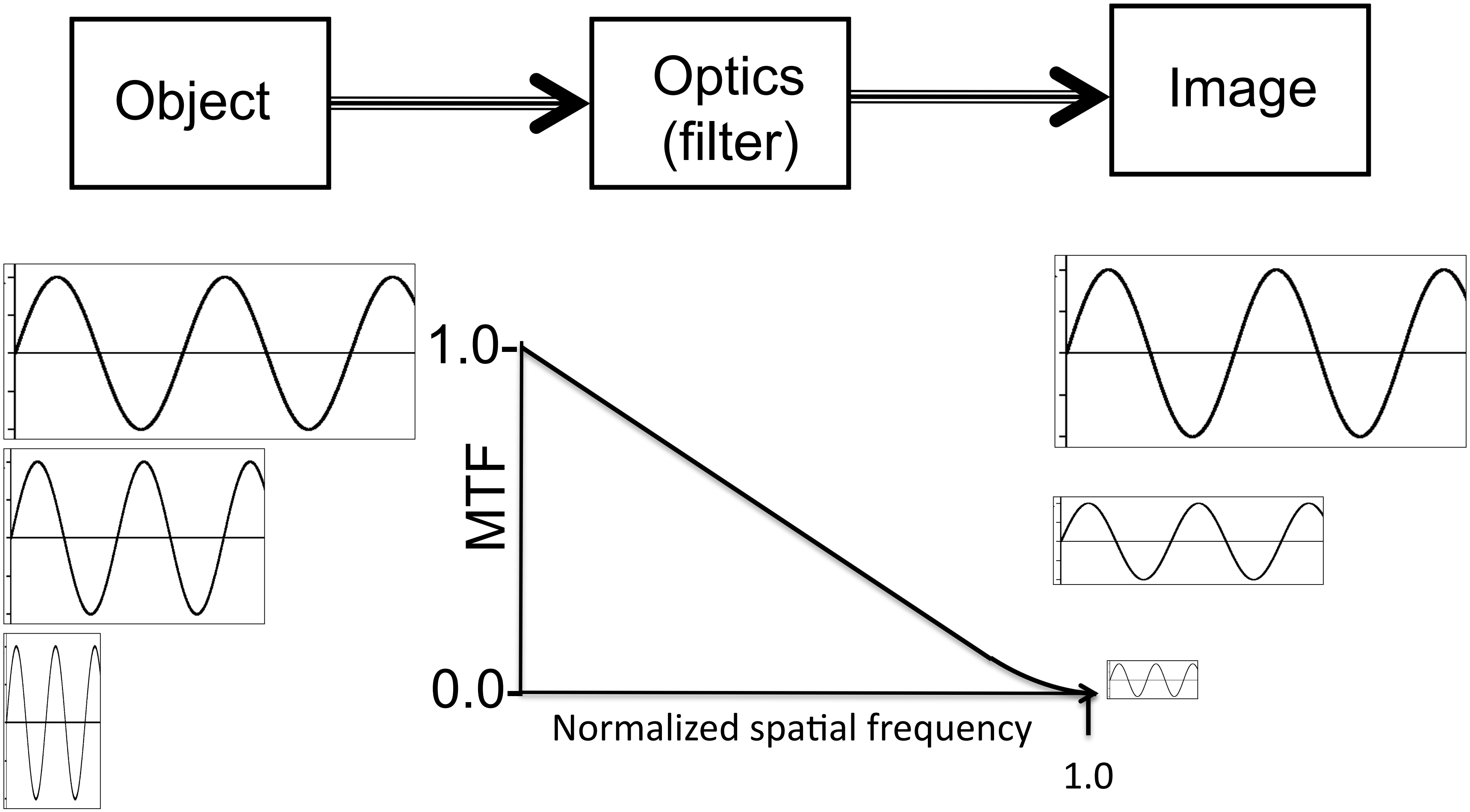


Sparse apertures

- Redundant
- Non-redundant
- Smallest telescopes to reconstruct filled aperture angular resolution

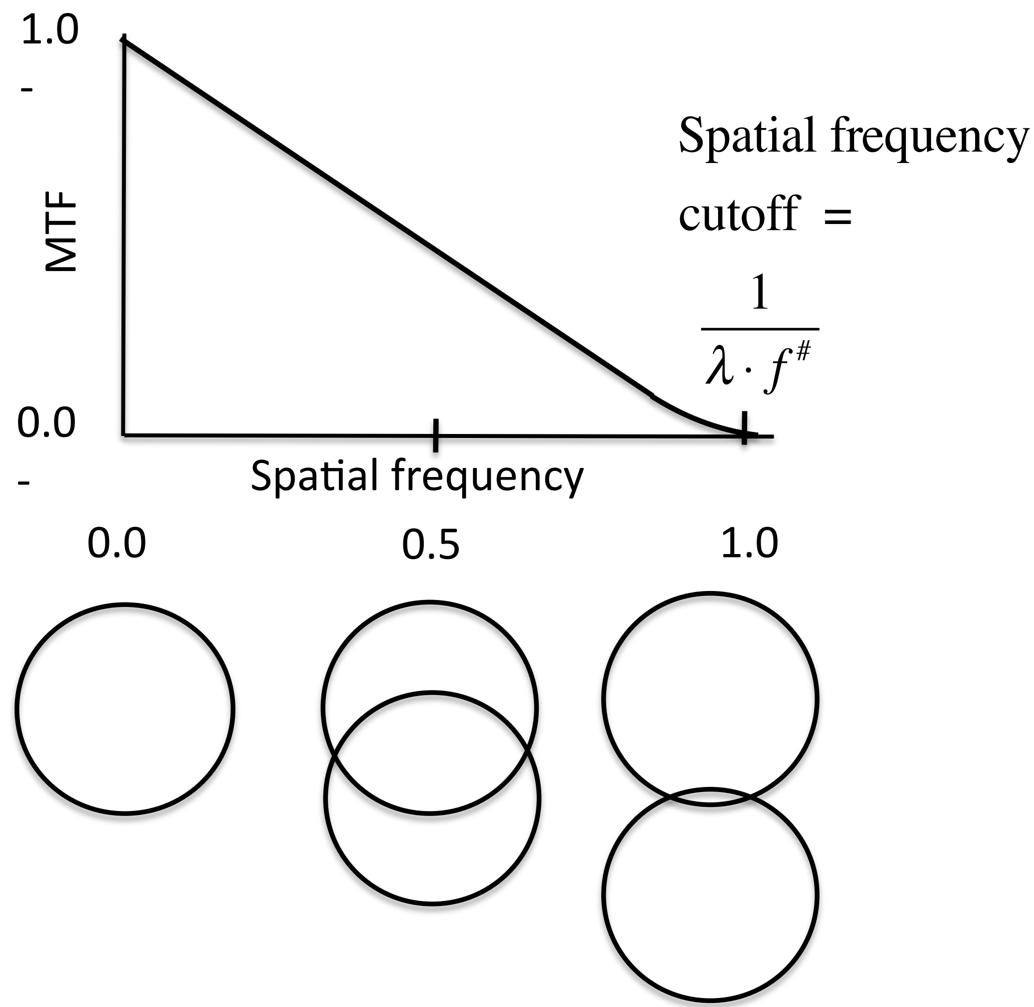


The telescope is a spatial frequency filter

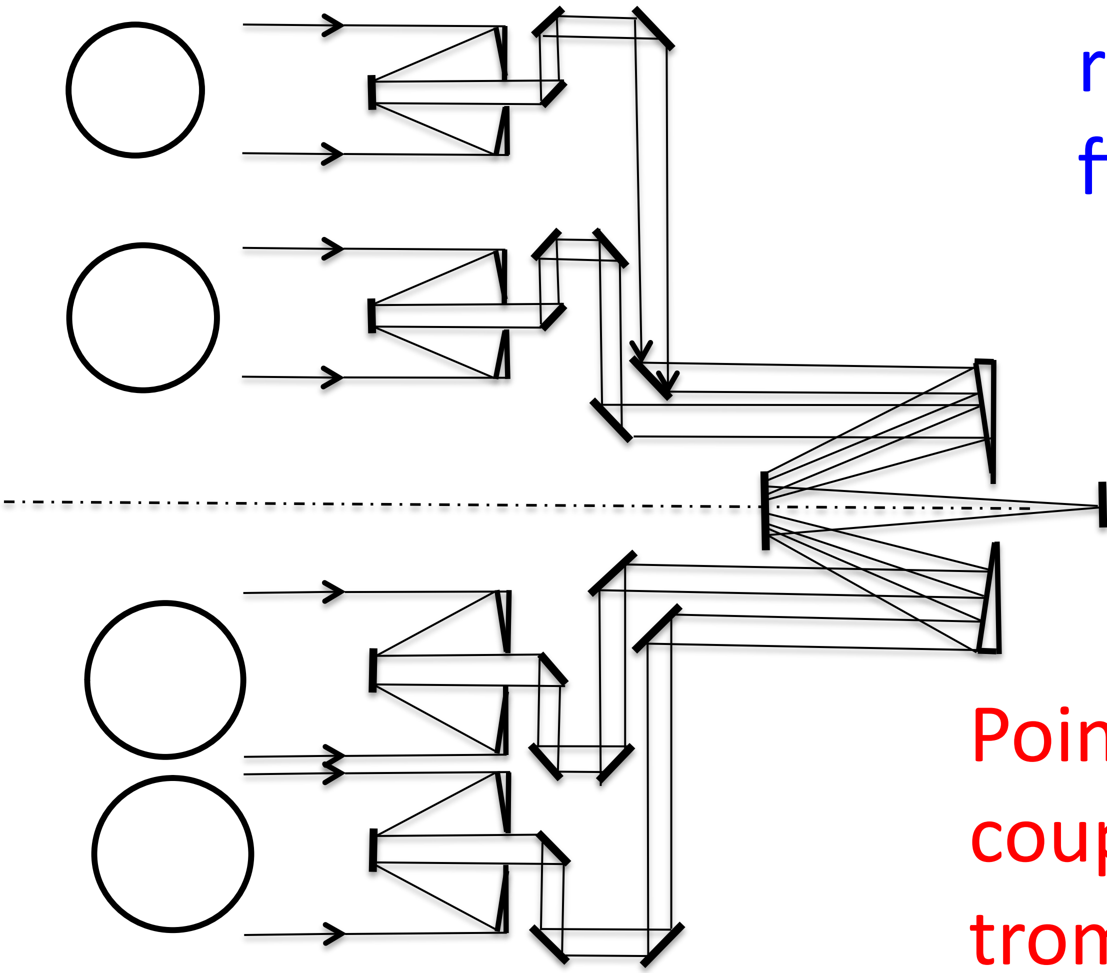


The modulation transfer function (MTF) is related to the autocorrelation of the pupil

Assumes a diffraction-limited system



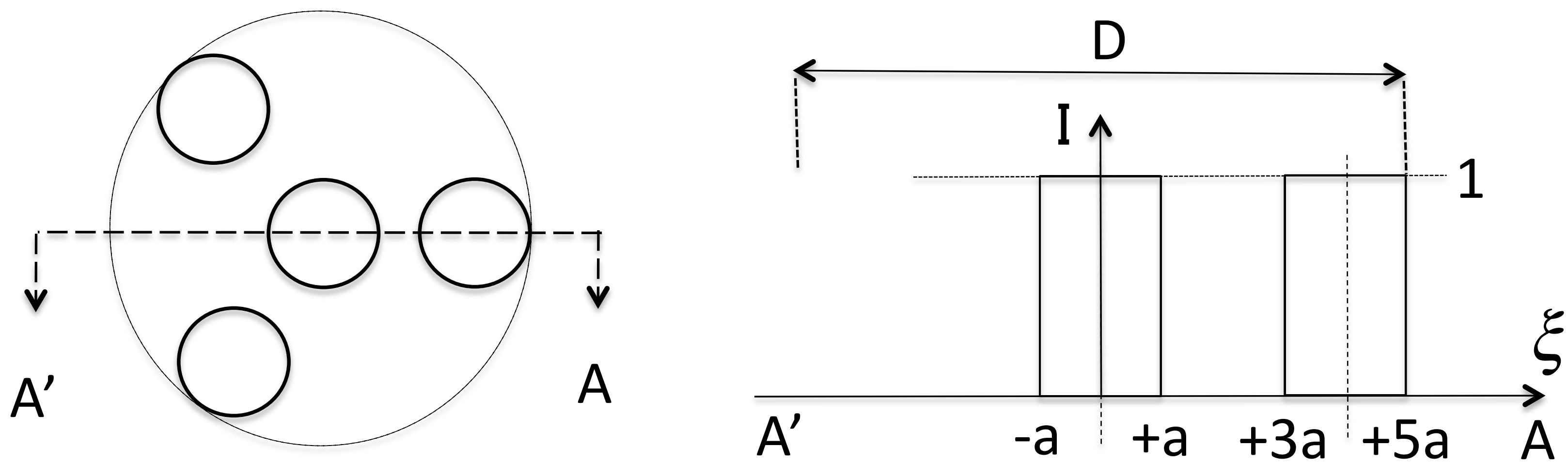
Sparse Aperture (Difficult in space)



Line apertures require rotation to fill out the ξ, η plane

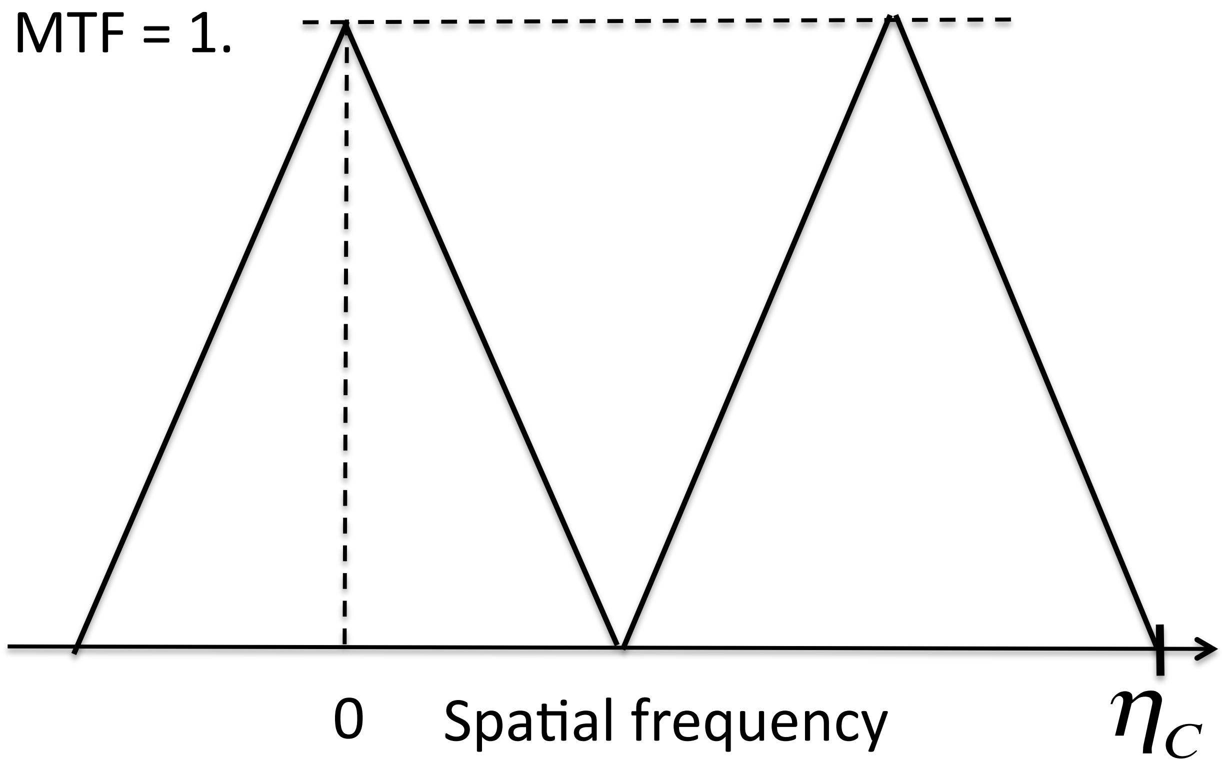
Pointing and tracking issue coupled with optical trombones to adjust OPD

Sparse aperture telescope (pupils)



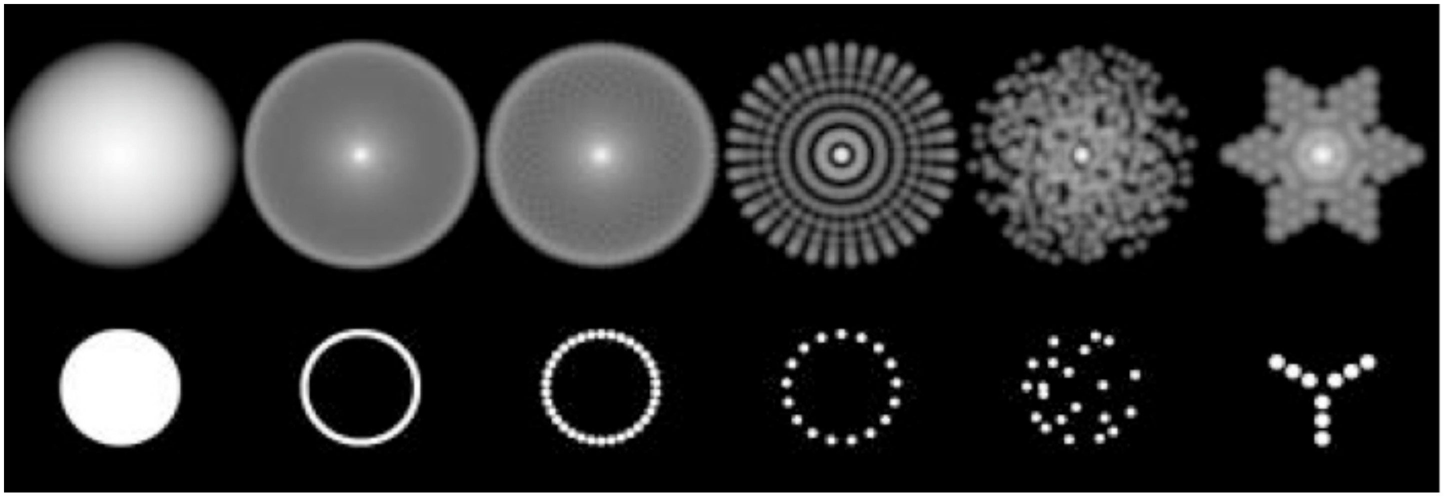
$$T(\xi,\eta) = circ\left[2a\xi, 2a\eta\right] + circ\left[2a\xi, 2a(\eta - 4a)\right]$$

The modulation transfer function (MTF) is the autocorrelation of the pupil



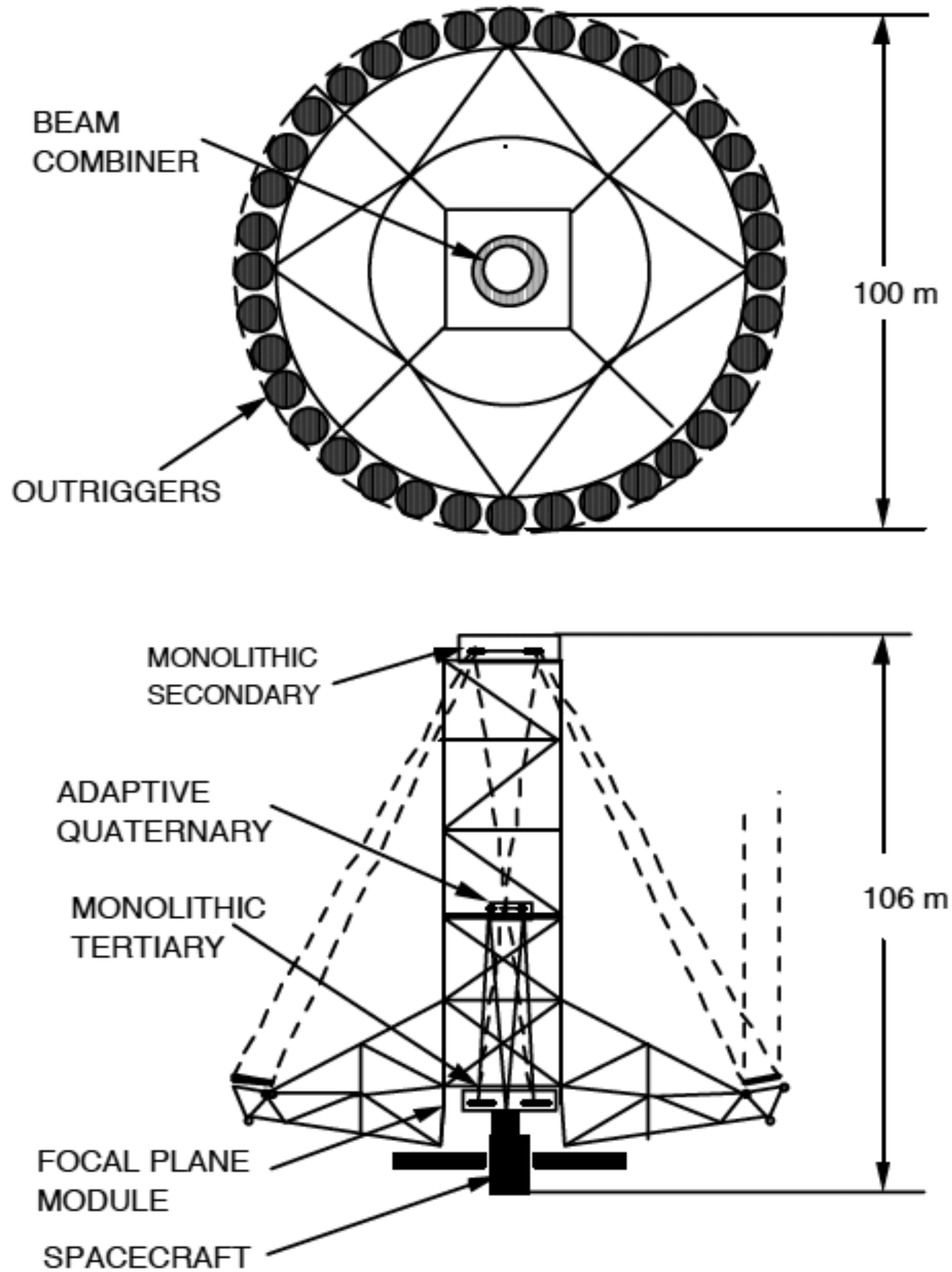
Since they do not overlap the pupil is said to be minimally redundant

PSF for Sparse apertures



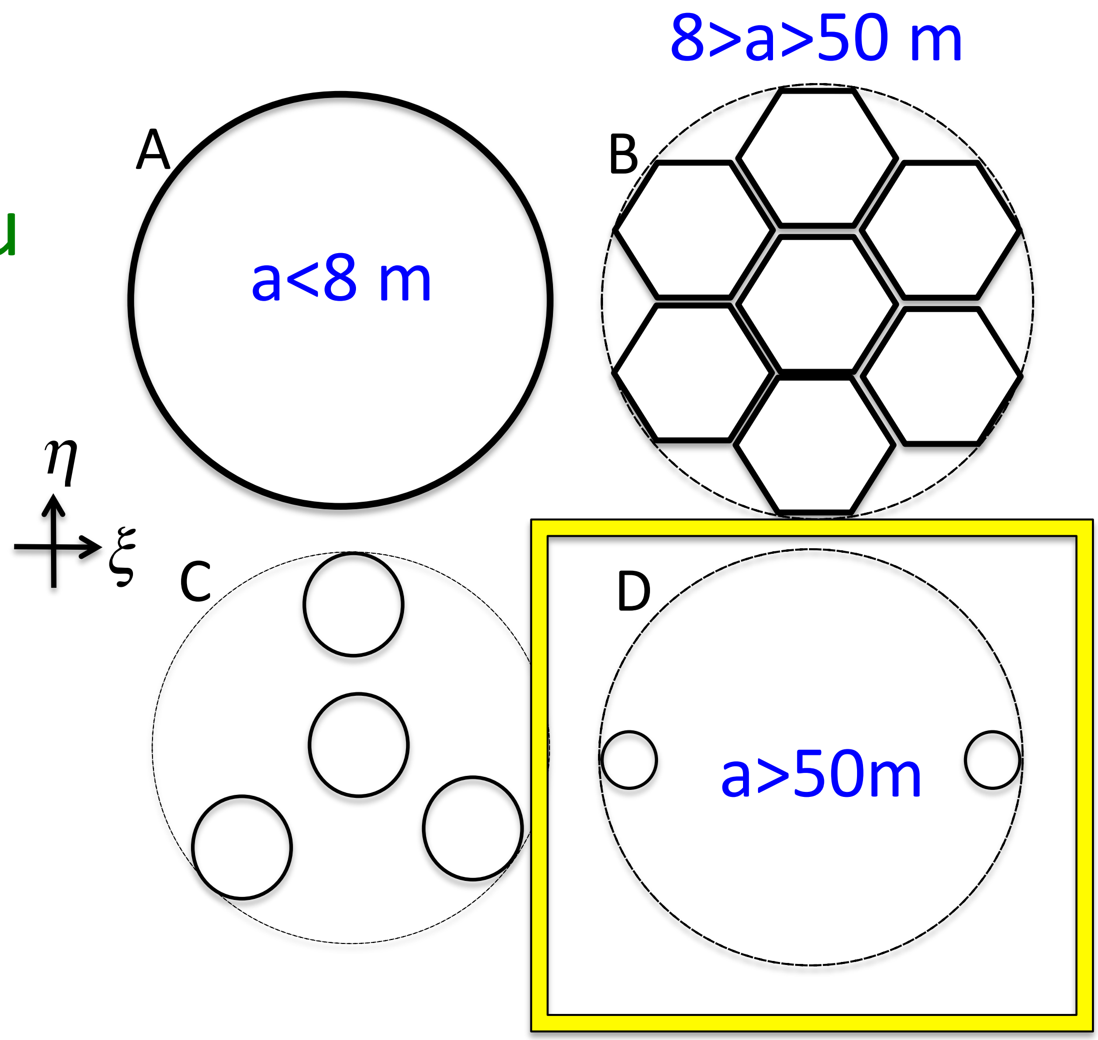
$$I_i(x,y) = \left| \mathcal{F}\left\{ t_2(\xi,\eta) \right\} \right| \otimes I_O\left(x,y\right)$$

Sparse aperture deployable space telescope design by Aden Meinel

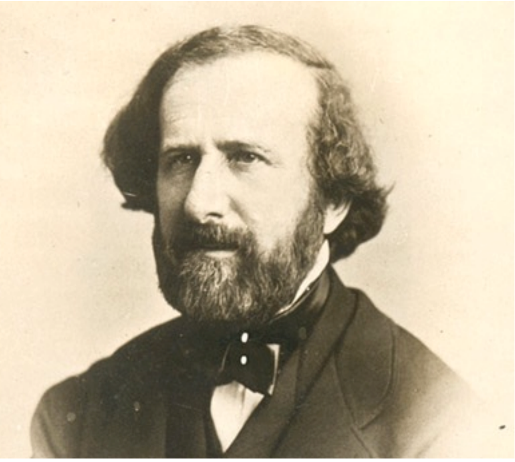


interferometer aperture

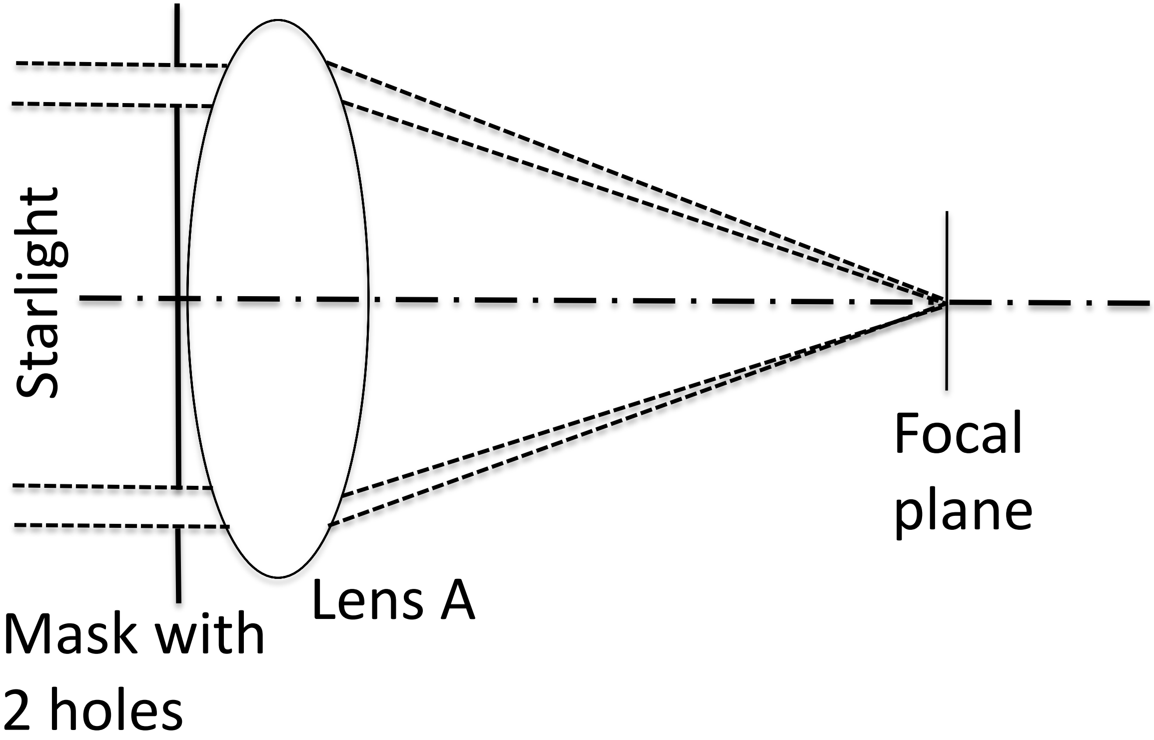
- What kind of aperture are you going to build?
- Angular resolution is more important than power at the image plane



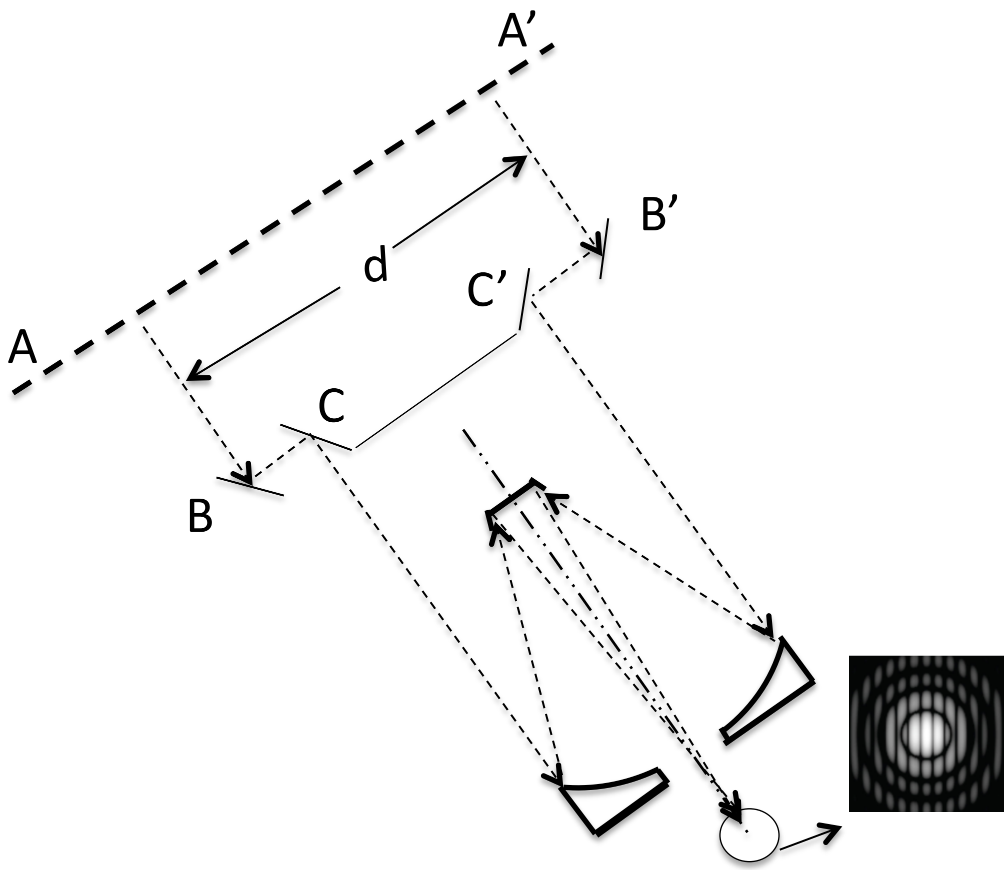
Fizeau Interferometer



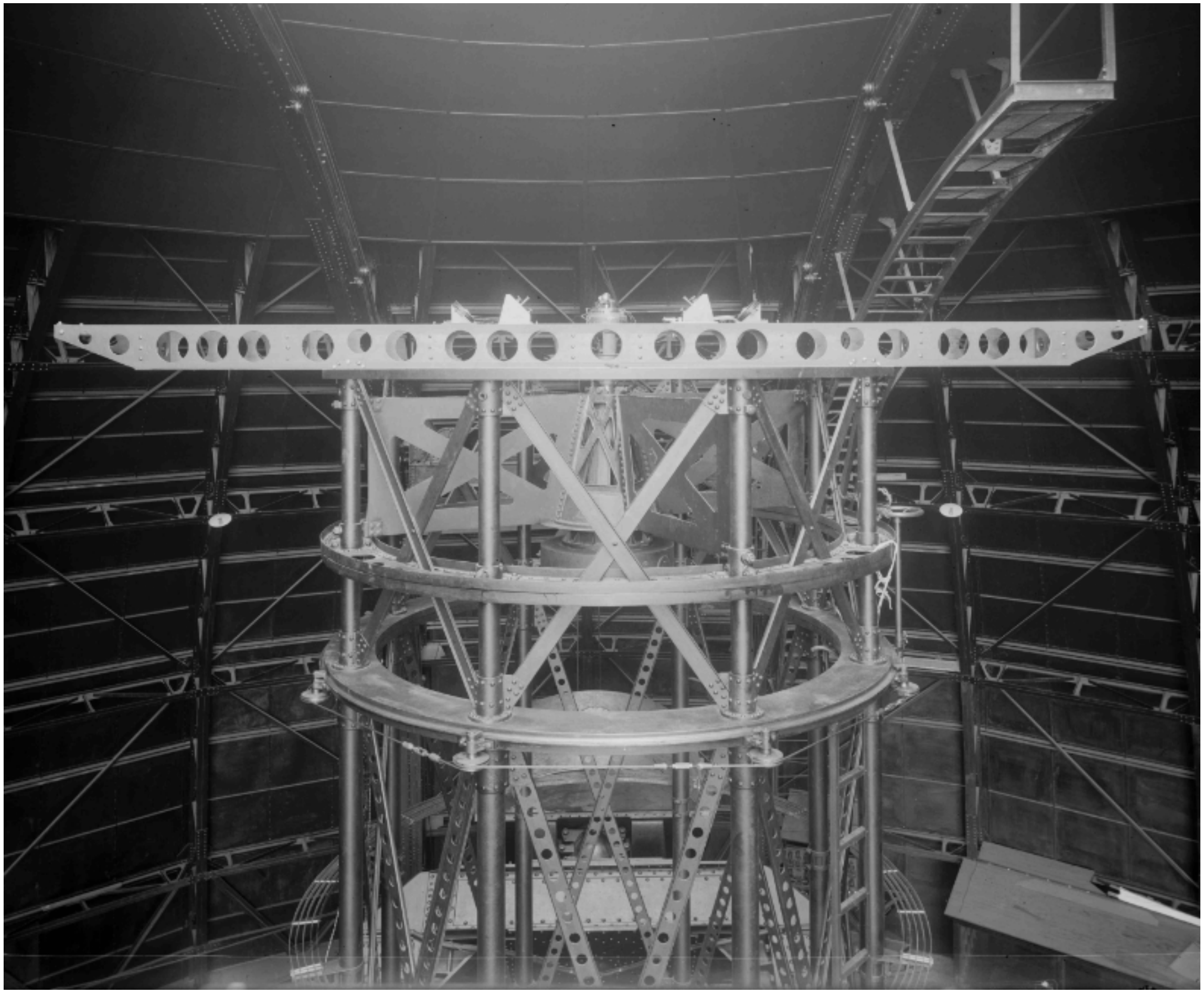
He took Young's **WHITE-LIGHT** double slit experiment and used its principles for astronomy



Michelson's WHITE LIGHT Interferometer 1920

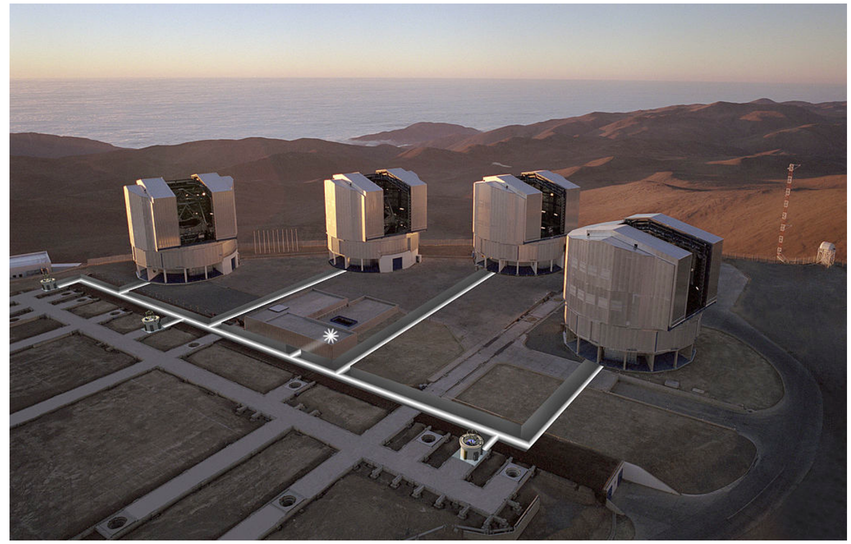


Michelson's Interferometer @ 100-inch



Interferometer

- ESO very large telescope interferometer (VLTI) – Paranal Chile
- Navy prototype optical interferometer (NPOI) – Flagstaff, AZ
- Center for high angle resolution astronomy (CHARA)



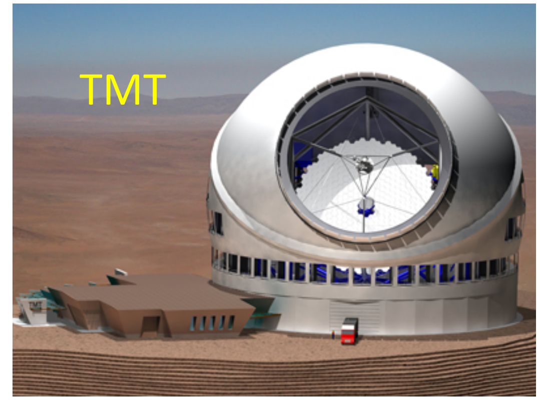
Era of ELTs (2016 -)

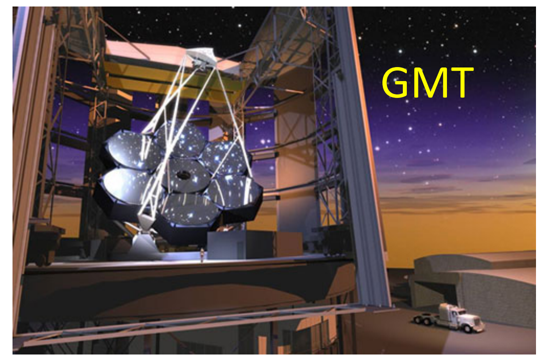
A new generation of 20-42m ELTs is being designed:

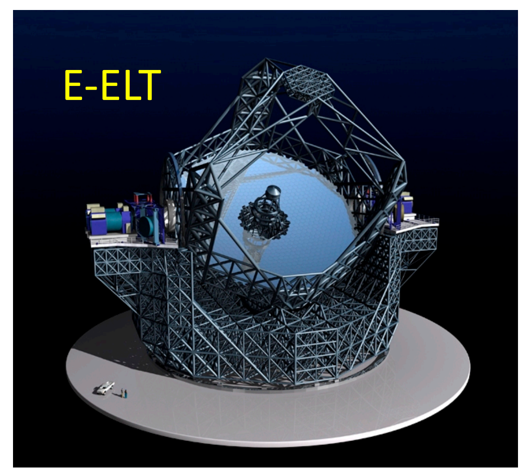
• Thirty Meter Telescope (www.tmt.org) - Caltech, UC, Canada + poss. Japan - 30m f/1 primary via 492 × 1.4m segments - $80M design underway (2004-2009) - $760M construction cost (FY2006) - major fund-raising already underway

• Giant Magellan Telescope (www.gmto.org) - Carnegie, Harvard, Arizona, Texas, Australia + others - 21m f/0.7 primary via 6 × 8.2m segments - funds for $50M design study being raised

• European ELT (www.eso.org/projects/e-elt) - 42m f/1 primary with 900+ ×1.4m segments - 5 mirror design - 57M Euros design underway (2007-)

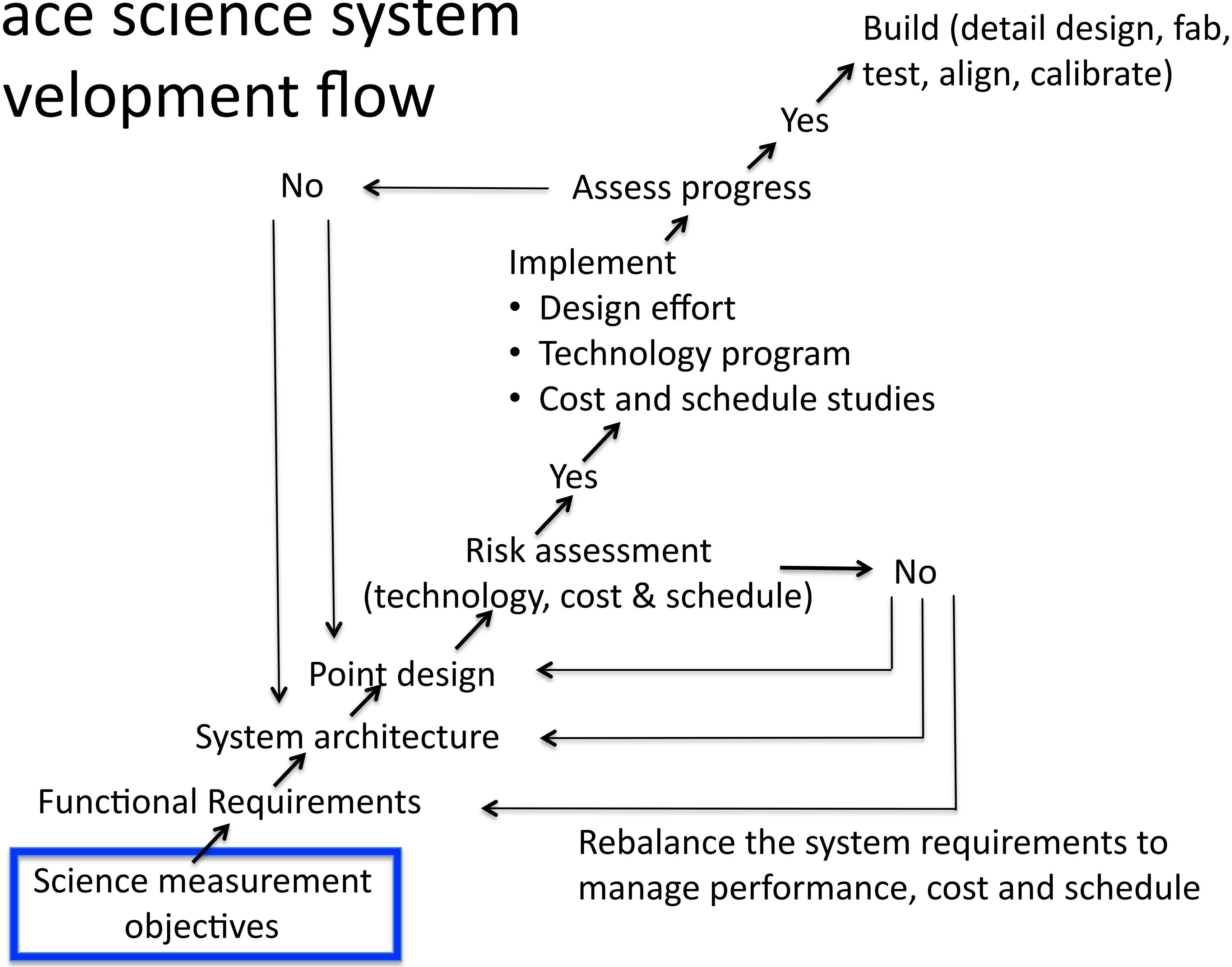






How will these AO-designed ELTs affect ground-space synergy and space astronomy?

Space science system development flow



How do we build a large, complicated system?

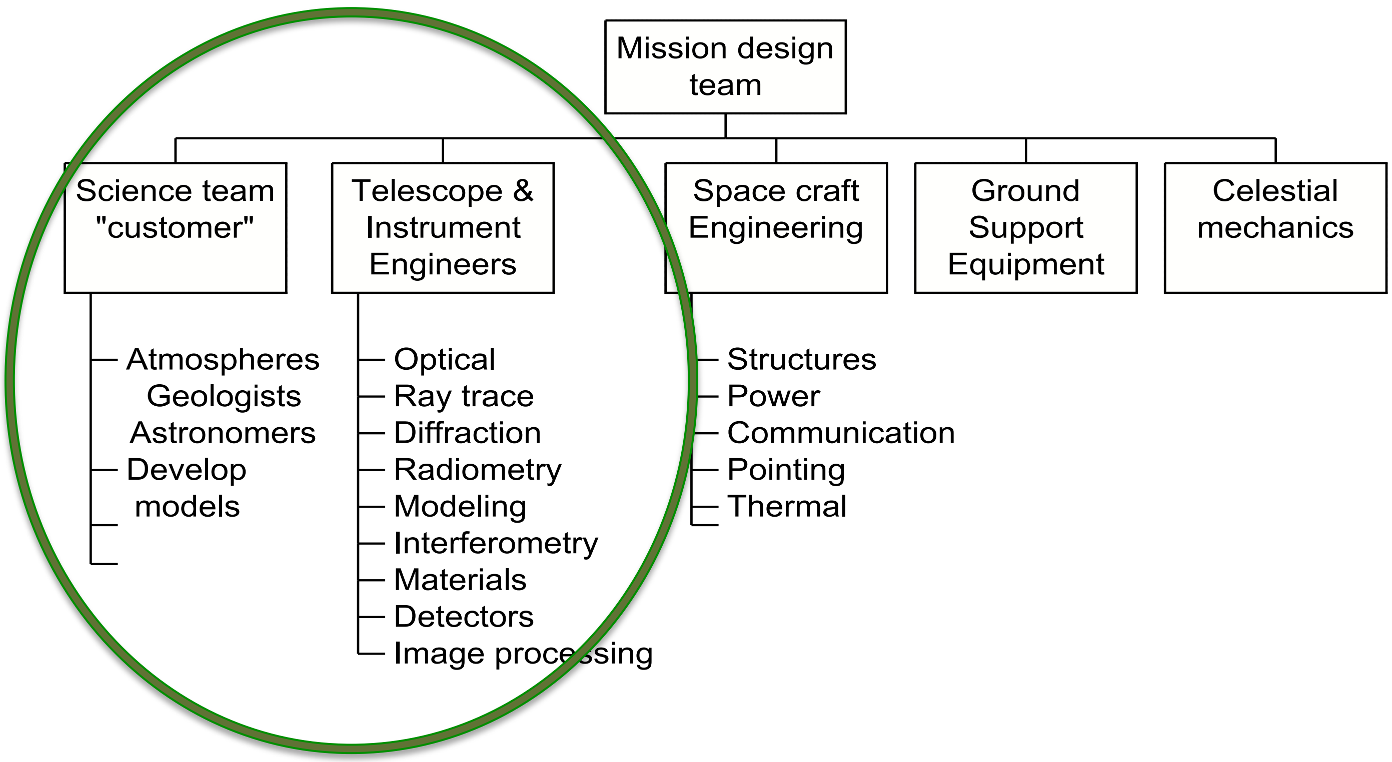
- Create a work-breakdown structure (WBS)
- Assign personnel to jobs in the WBS you know they can do – or accept responsibility to do
- Create a work plan with schedule, cost and performance
  - Develop a list of tasks that need to be done
  - Negotiate with your team who is going to do which task
  - Ask each one how long it will take them to do their tasks and what the cost is

What is a work break down structure?

- Identifies all tasks required
- Presents tasks in a format aligned with doing the work
  - talent, skill level and software & equipment
- Provides a structure for the schedule
- Every WBS is different because no two telescopes, instruments, staffing and facilities are the same.
- Create a WBS to enable you to manage success of the project/task

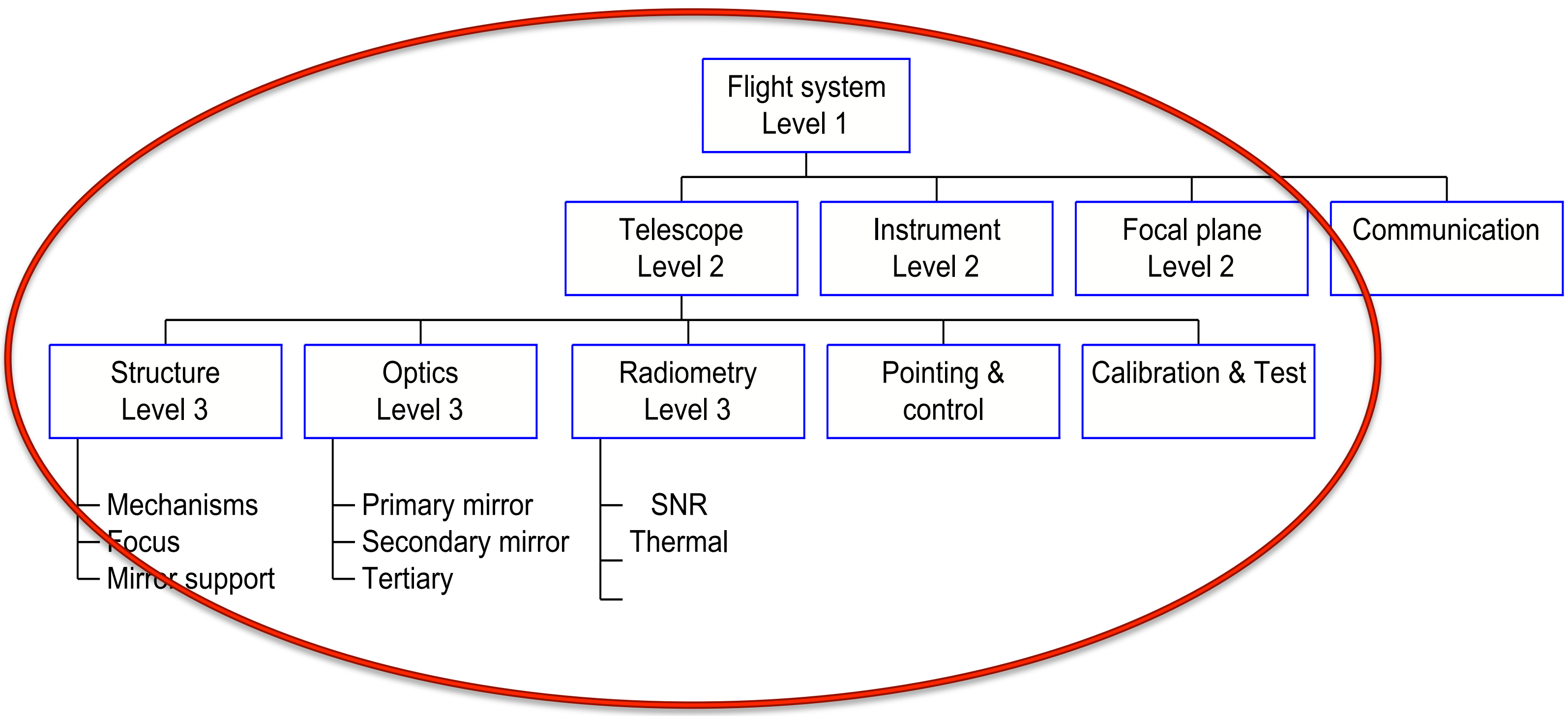
Mission development

- Create ideas for new missions to make new high priority measurements
- Develop justification for the mission
  - Performance, schedule, cost

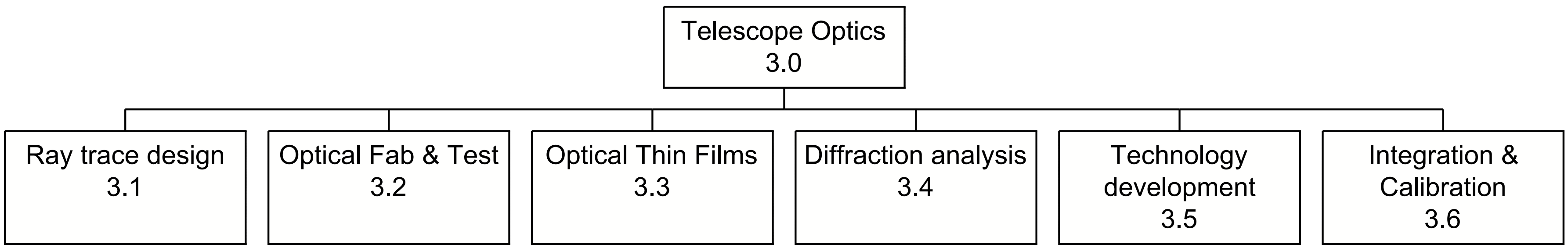


Where do we start?

- Develop system requirements
- Divide the system up into manageable subsystems
  - Work break-down structure
- One person's subsystem is another person's system.



Example WBS



Each box is assigned a leader & given a $$ budget to accomplish work

Tasks accept work from others, provide additional work and then makes deliveries of his product

Project Milestones

1. Mission concept review (MCR)
    - Science clearly stated measurement concept
2. System definition review (SDR)
3. Preliminary design review (PDR)
    - Assembly drawings
4. Critical design review (CDR)
    - Detail design complete ready to "cut metal (glass)"
5. Pre-ship readiness review

Next time Examples of Technology

- Adaptive mirror 2048 x 2048 with 10 micron stroke running at 500Hz
- 2048 x 2048 back ground limited array detectors with 10 micron pixels sensitive at 5 micron wavelength
- Laser guide star adaptive optics
  - Speed
  - Stable performance
- Blacks at 50 microns wavelength

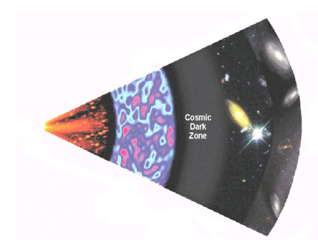
Next time Technology

- With ~100 engineers each charging $8K per month a project cannot stop and wait for technology to be developed.
- If the technology to design, build, integrate, align, test and calibrate the optical system is not "off the shelf" then a technology development program is needed to make the technology "ready for flight" & the project is not started.
- Communicate the readiness of your technology using the technology readiness level scale (TRL)
- TRL communicates technical maturity to the non-expert (often the funding source)

Review today

Thursday, January 24, 2013

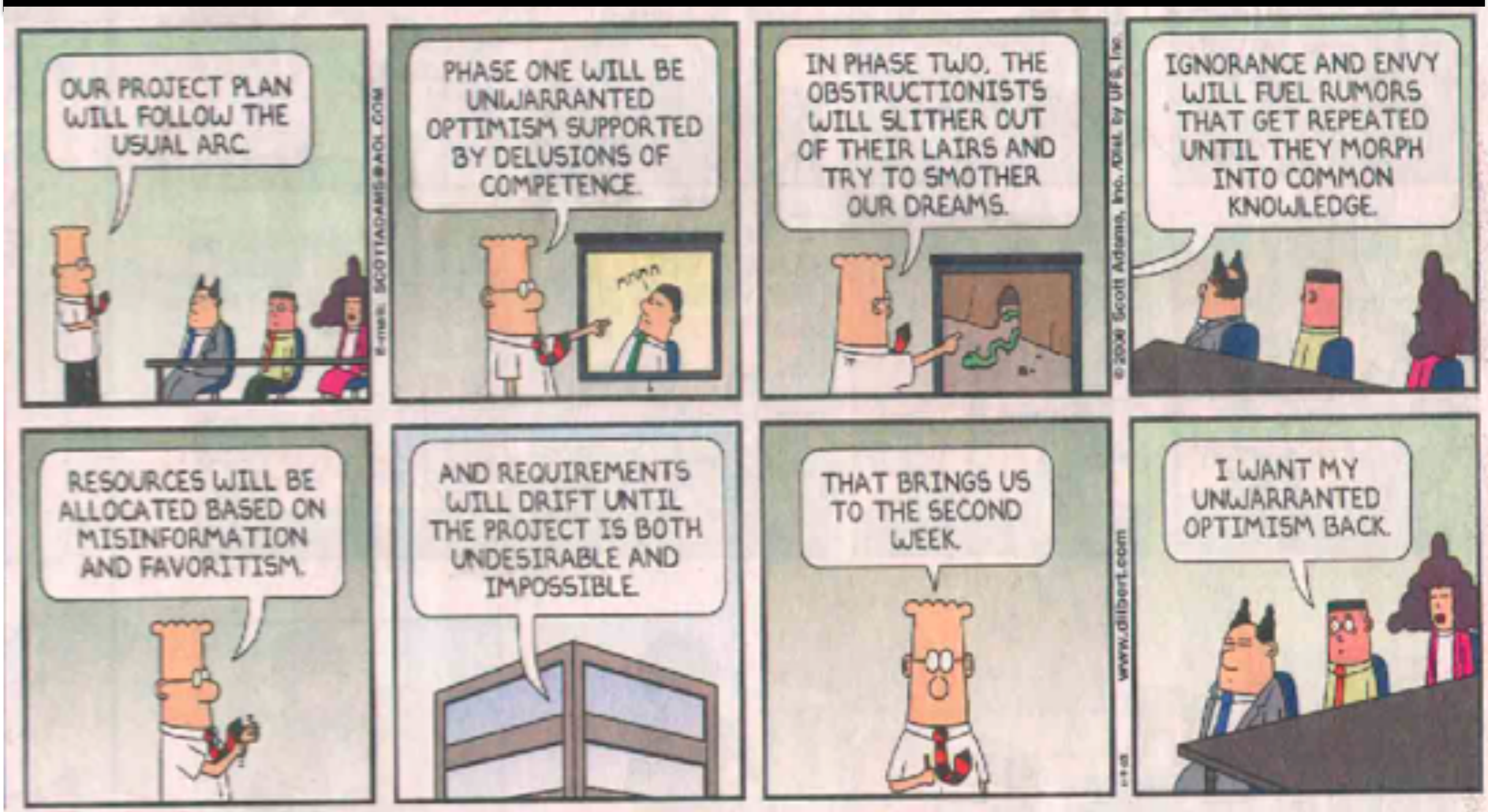
- Telescope system architectures
  - Filled, segmented, sparse, interferometers
- The NASA process
- Overview of large ground based telescopes
- Requirements development
  - Science measurements, technology risk map science into realized engineering



Review today

Tuesday January 29, 2013

- Technology development
  - Mission specific
  - Science measurement enabling
- Your design of space science telescopes –In addition to optics what do we worry about:
  - Radiation, electrostatics, thermal, launch vibration, pointing & control, scattered light (coronagraphs), cosmic rays, south Atlantic anomaly, optical contamination
- Science in the noise
- The *DECADE* report


OUR PROJECT PLAN WILL FOLLOW THE USUAL ARC.
PHASE ONE WILL BE UNWARRANTED OPTIMISM SUPPORTED BY DELUSIONS OF COMPETENCE.
IN PHASE TWO, THE OBSTRUCTIONISTS WILL SLITHER OUT OF THEIR LAIRS AND TRY TO SMOTHER OUR DREAMS.
IGNORANCE AND ENVY WILL FUEL RUMORS THAT GET REPEATED UNTIL THEY MORPH INTO COMMON KNOWLEDGE.
RESOURCES WILL BE ALLOCATED BASED ON MISINFORMATION AND FAVORITISM.
AND REQUIREMENTS WILL DRIFT UNTIL THE PROJECT IS BOTH UNDESIRABLE AND IMPOSSIBLE.
THAT BRINGS US TO THE SECOND WEEK.
I WANT MY UNWARRANTED OPTIMISM BACK.
E-mail: SCOTTADAMS@AOL.COM
© 2008 Scott Adams, Inc./Dist. by UFS, Inc.
www.dilbert.com