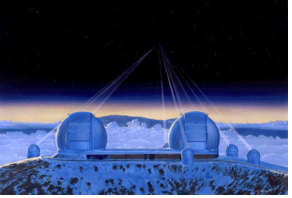
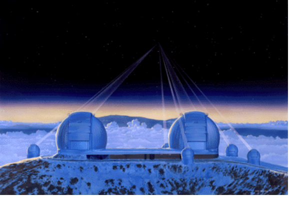


Pupil and Image Plane Combination

Mark Swain

July 11, 2003

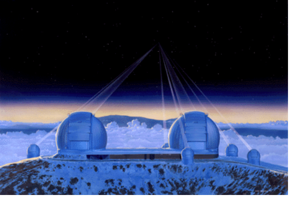
Michelson Summer School



Objectives and Terminology

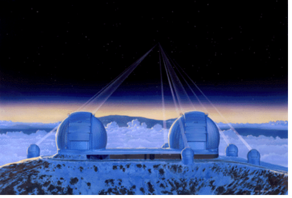
- What are the major differences between these two techniques?
- What science objectives make one approach preferable to the other?

- Pupil plane combination frequently called “Michelson” beam combination.
- Image plane combination frequently called “Fizeau” beam combination.
- I prefer to distinguish the techniques as “pupil image” combination and “object image” combination. This distinction is needed to permit wide field-of-view (FoV) pupil combination interferometry.
- D is the telescope diameter, B is the telescope separation in projection.

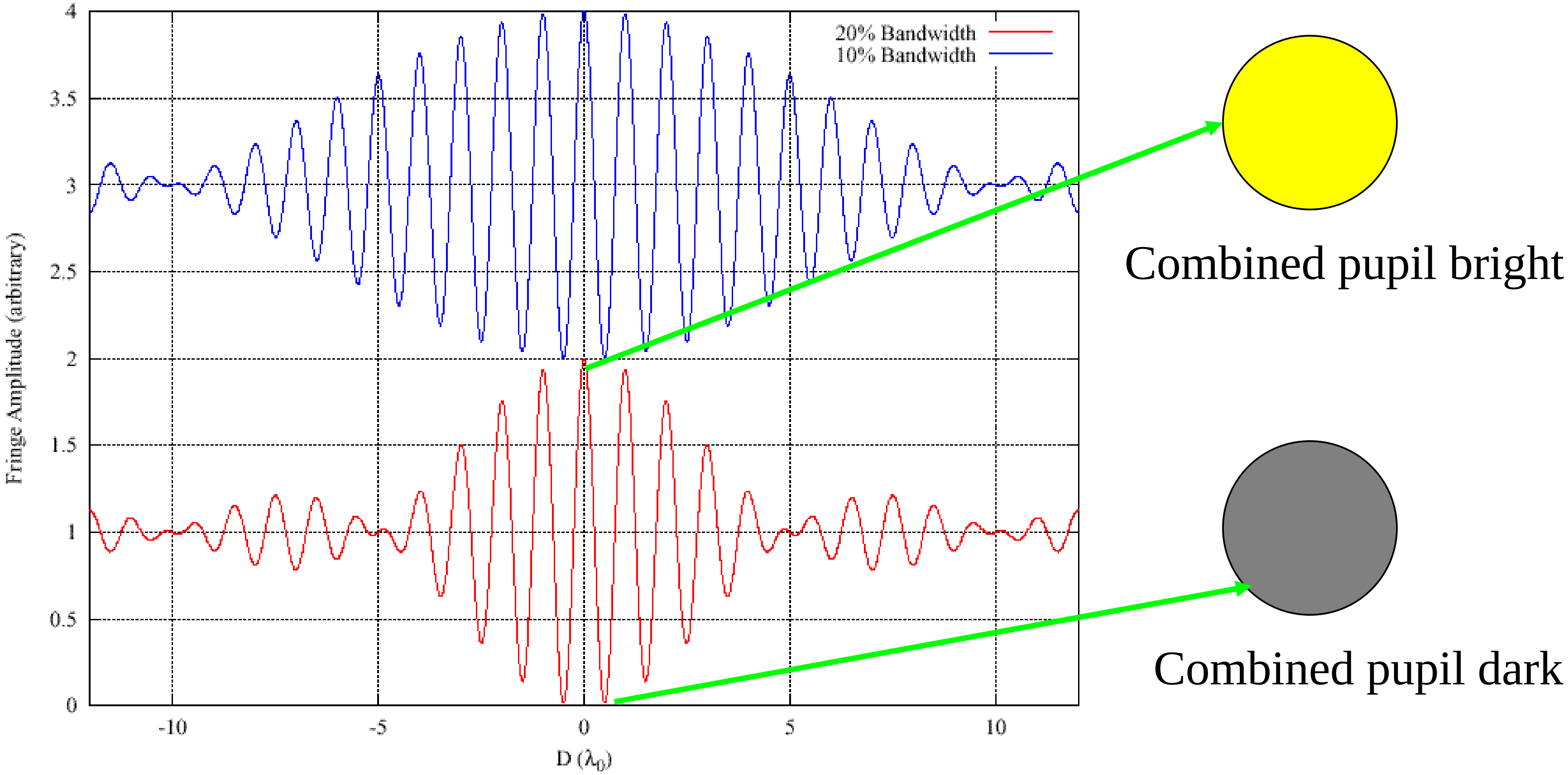


Summary

- Pupil combination has faint source (read noise limited) SNR advantage ~ B/D.
- A wide interferometric FoV is more easily achieved with image plane combination.
- If science your objective is requires FoV < 1.2 ?/D, there are a number of existing pupil plane combination interferometer possibilities.
- If science your objective requires FoV > 1.2 ?/D, something like LBTI or building a custom combiner is required.
- See Principles of Long Baseline Stellar Interferometry (chapter 3 by W. Traub) for a mathematical description of image combination.

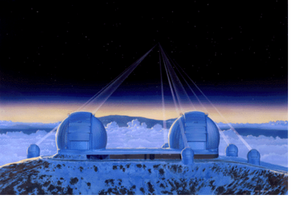


Pupil (image) Combination



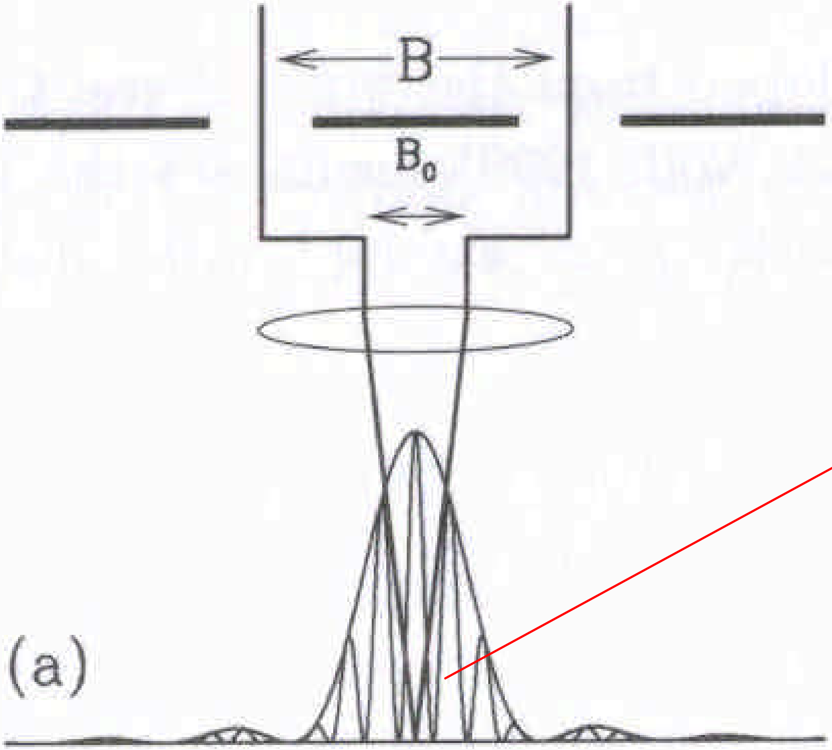
Combined pupil bright

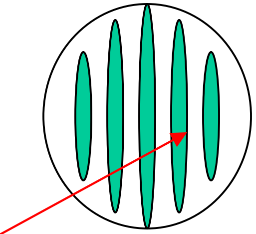
Combined pupil dark



Object Image Combination

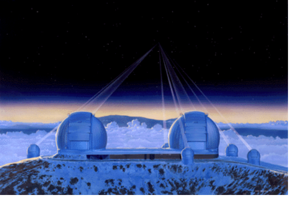
Sub-aperture diffraction spot crossed by fringes.



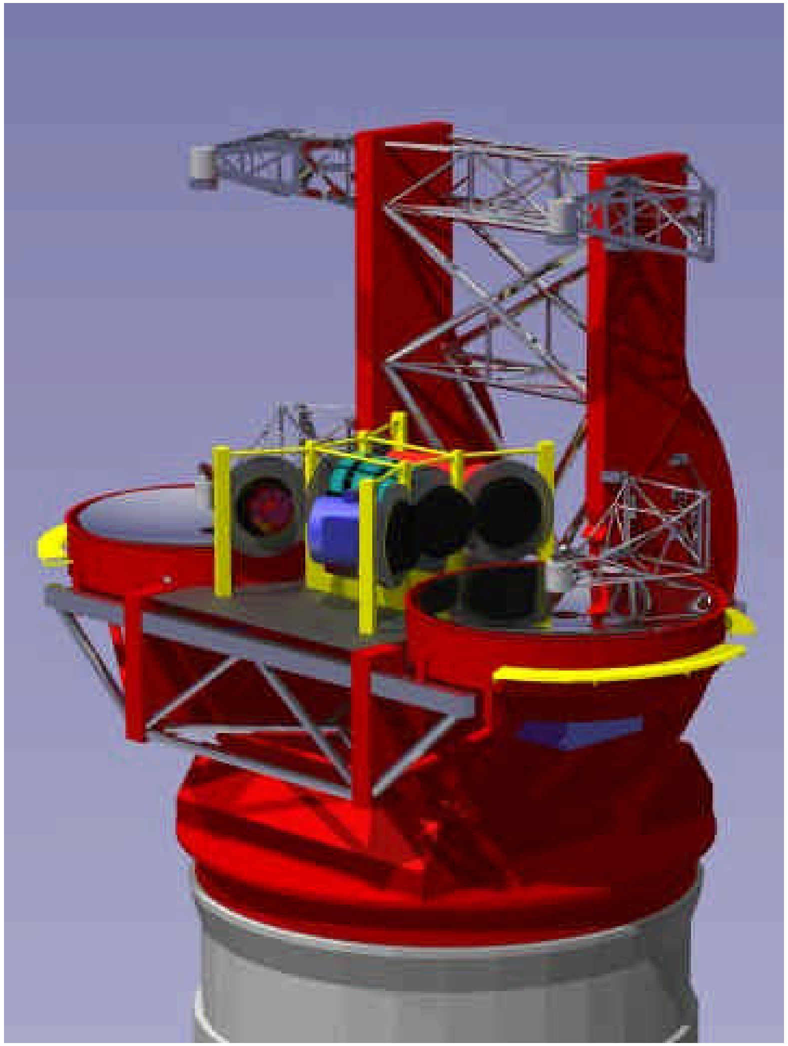


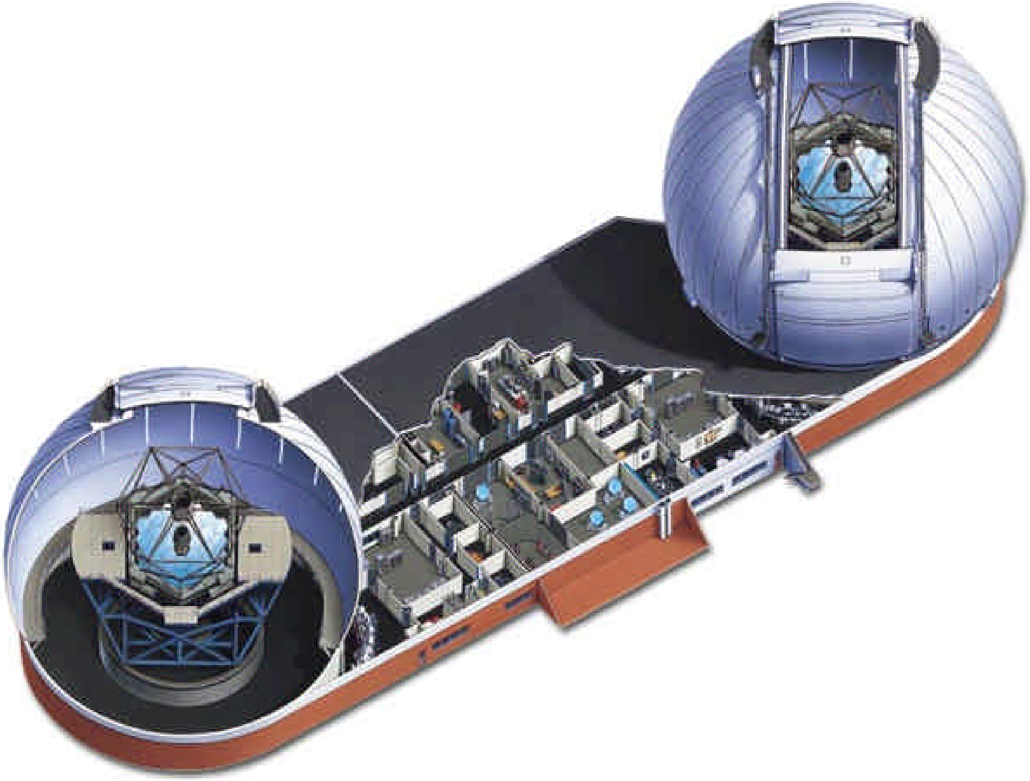
From Traub, Principles of Long Baseline Stellar Interferometry

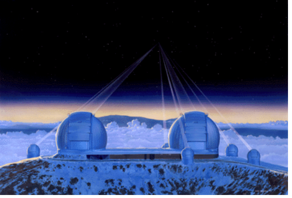
If input pupil geometry preserved at exit pupil, then the interferometric resolution is possible over the single telescope FoV.



Examples

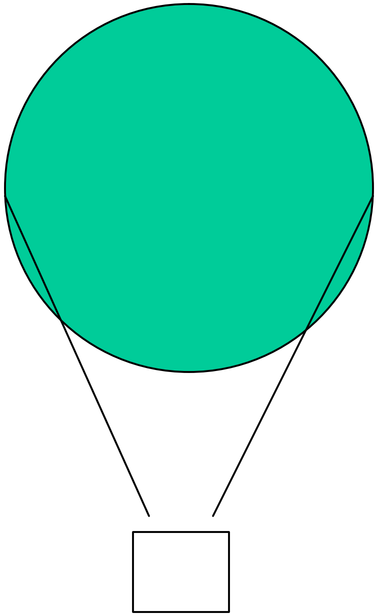






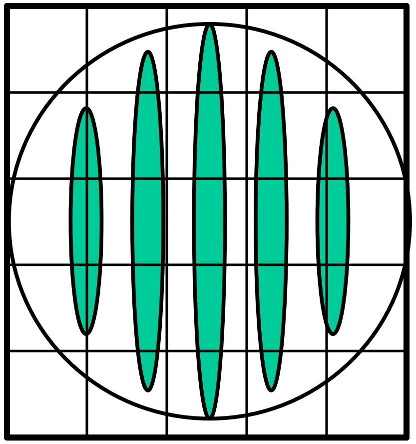
Detecting the Combined Light

Pupil combination

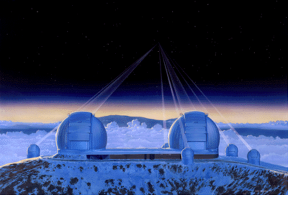


All the light goes to 1 detector pixel.

Image combination

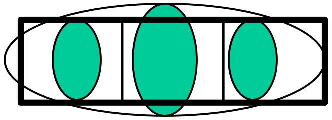


Light spread over ~ $(B/D)^2$ detector pixels.



Sensitivity Reduction for Object Image Combination

LBTI

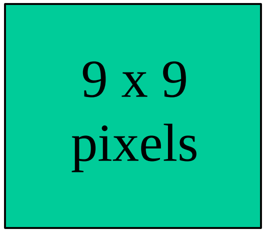


3 pixels

Anamorphic optics reduce object image combination SNR reduction (relative to pupil image combination) to ~ B/D.

SNR reduction ~ 1.7

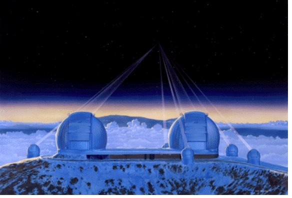
Keck Interferometer



Assume anamorphic optics similar to LBTI.

SNR reduction ~ 5.1

PTI: SNR reduction ~ 160!



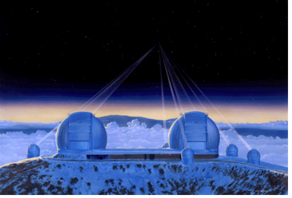
Other Advantages of Each Approach

Keck Interferometer

- Removes need for control of exit pupil tilt, shear, and focus which would be required for object image combination from non-co-mounted telescopes.
- Enables higher angular resolution than would be possible with co-mounted telescopes.
- Relatively easy to add additional telescopes to core interferometer infrastructure.

LBTI

- Minimize warm reflections (3) then cryogenic optics for optimized IR beam train.
- Well defined Lyot stop location.
- No need for long delay lines; easy to make delay lines cold.
- Data product (an image) more familiar to astronomy community.



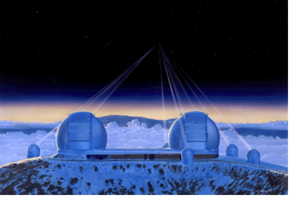
Science Objectives

Keck Interferometer

- Dust around nearby stars (using nulling).
- Spectra of “hot-Jovian” extrasolar planets (using differential phase).
- Detection of planets using stellar reflex motion (astrometry)
- No requirement for FoV to exceed telescope diffraction limit.

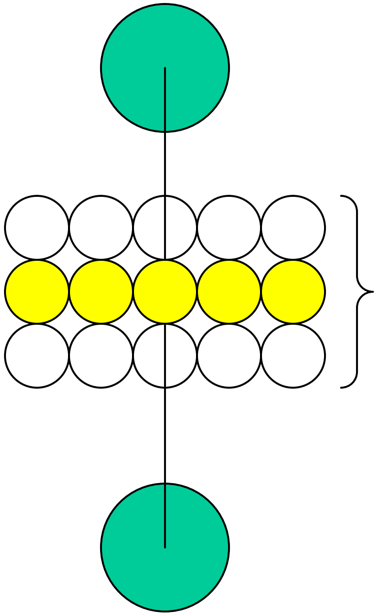
LBTI

- Infrared imaging of star forming regions and galaxies.
- General purpose instrument with 10x improvement in angular resolution and sensitivity over HST.
- Survey projects expected.
- FoV and complete *uv* coverage both strong design drivers.



Wide FoV Pupil Combination – Not Easy but Possible

- Image pupil
  - Post combination to get one row.
  - Precombination (with pair-wise combination) for 2-d array.
- Each row needs a precombination phase offset.
- Requires delay modulation of ~ ?B/D.
- Could potentially implement with integrated optics.



Pupil image projected onto the sky.

Phase offset for each row

F_n = +/- 2np D/B