The Keck Interferometer Nuller

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JPL
2003 Darwin/TPF meeting

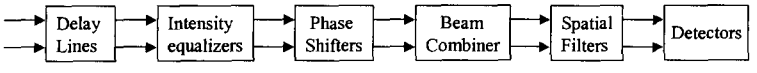
Outline

- Fully symmetric Nullers
- The Keck Interferometer Nuller

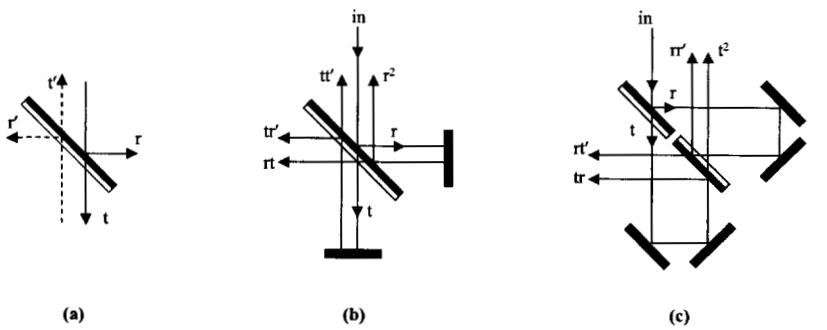
Fully Symmetric Nullers

Best of all possible nullers: completely symmetric, with sequential functions

- Separation of Nuller Functions:
  - Field flip
  - Beam combination
- Elimination of residual asymmetries:
  - Unbalanced reflections
  - Beamsplitter coating passes
  - Antireflection coating passes
- Dual-polarization nulling

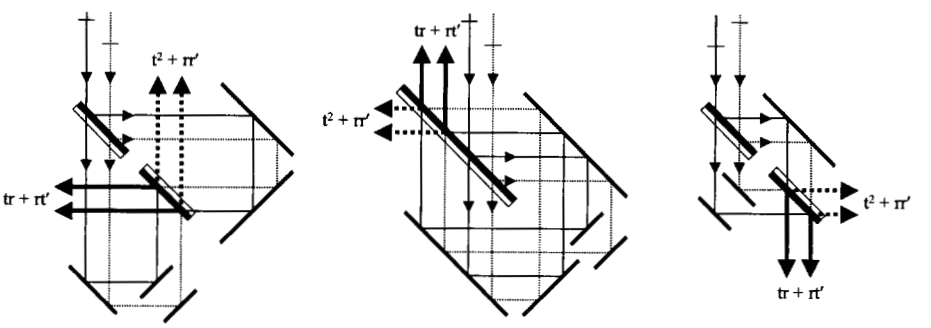


Double pass beamsplitters allow perfect subtraction



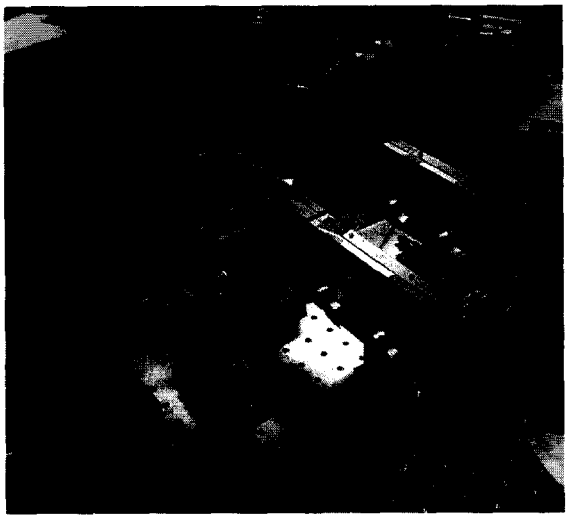
- Note: $rt - r't \approx 0$, but $rt' - rt = 0$ identically.
- Reversed pair of beamsplitters provides for a perfectly symmetric, constructive beam combiner
- Only needs to be preceded by a symmetric field reversal

Perfectly-symmetric, constructive 2-beam combiners



Michelson Sagnac Mach-Zehnder

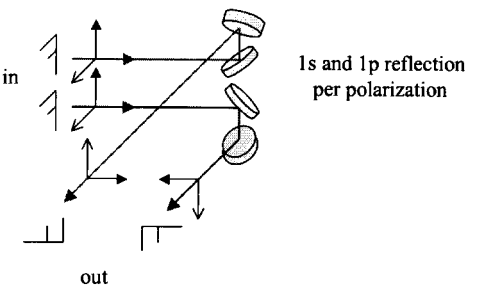
The Keck/TPF mid-infrared MMZ nullers



Beamsplitters

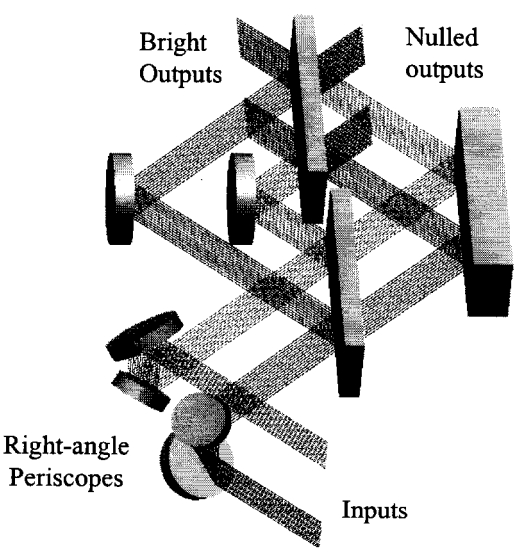
- Coatings are not a big issue in symmetric double-pass configurations:
  - Balanced outputs have $rt - r't = 0$
  - Phase effects cancel: $\Phi(rt) = \Phi(r't)$
- On the other hand, BS-pair symmetry is important:
  - Coating variations
  - Substrate thickness matching
  - Substrate uniformity
  - Alignment matching
- Note that flipped beamsplitter pairs provide a deep null independent of polarization, wavelength, and angle-of-incidence
- Substrate wedge angle does break symmetry slightly

Field flip with inverted right-angle periscope pair

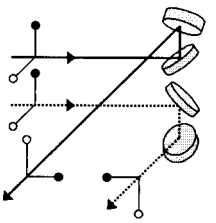


- Output fields and images rotated 180°
- Allows field flip prior to beam combination
- Needs constructive combiner to follow it

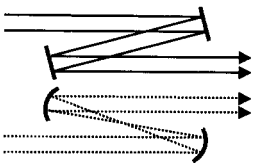
Perfectly-symmetric nuller



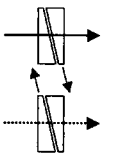
Field-reversal stages:



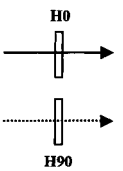
Right Angle Periscopes



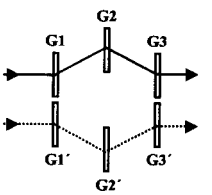
Extra Focus



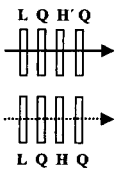
Dielectric Phase



Half Wave Plates



Grating Phase



Pancharatnam Phase

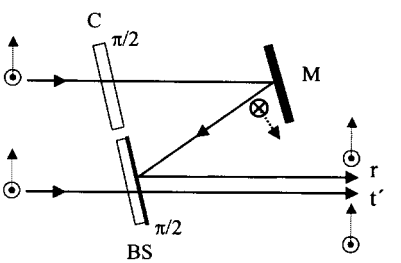
- Not all fully symmetric, some are lossy; but all could be used
- Keck will use Dielectric phase plates to counteract the atmosphere anyway, so we will use them for nulling too.

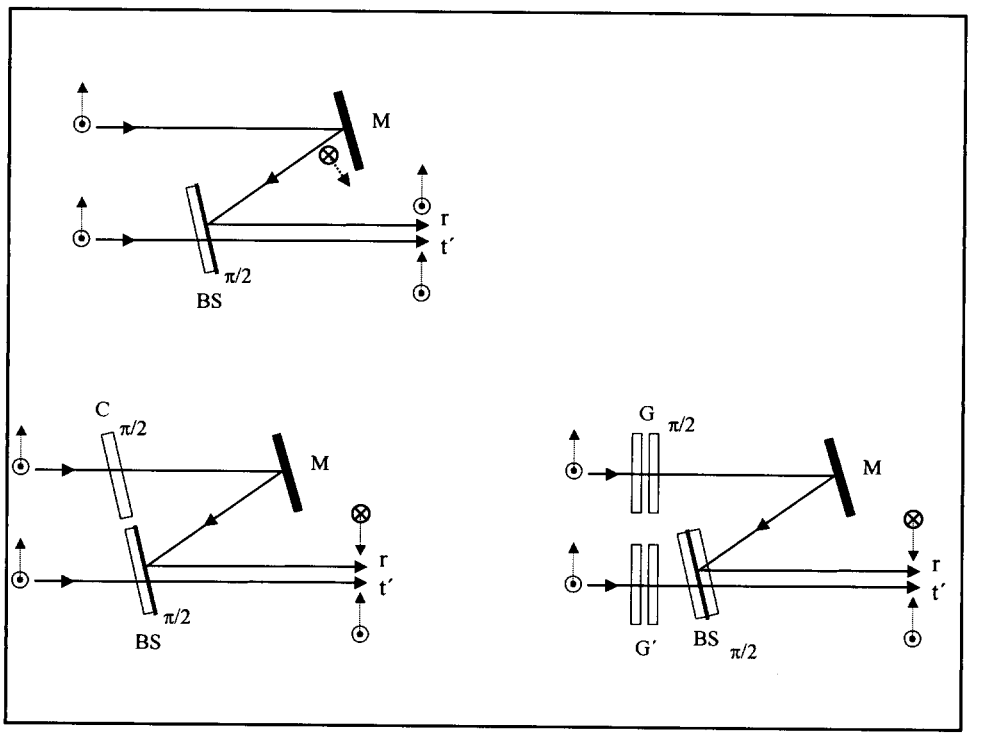
Nulling by Phase Retardation

- Extra mirror in one arm aligns the phasing of the two polarizations
- Thickness difference between BS & comp gives $\pi/2$ phase shift
- Ideal BS: phase(r) – phase(t) = $\pm\,\pi/2$

- Has been taken to telescopes (UofA)
- Stellar null depths ≈ 0.04
- Dust shells detected

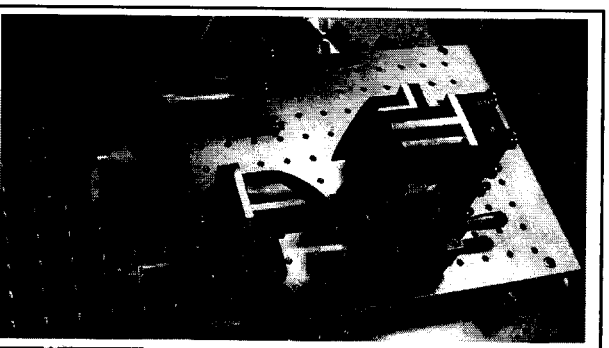
- But require:
  - Amplitude match: r = t
  - phase(r) – phase(t) = $\pm\,\pi/2$
- Also, unbalanced AR traversals exist
- Symmetric sandwich BS helps

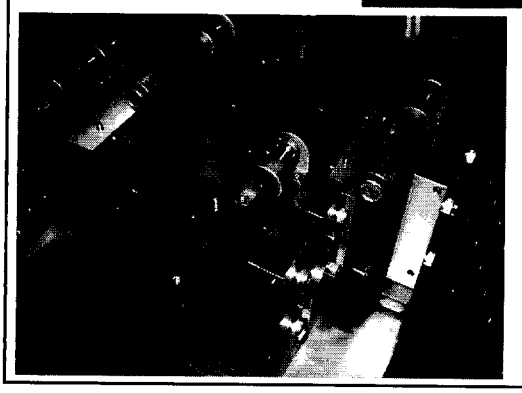




Field Flippers in the lab

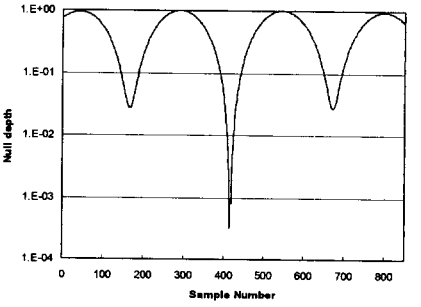
- Periscopes
- Dielectric prisms

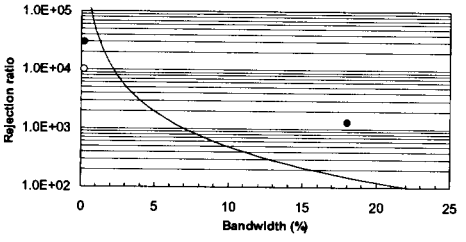


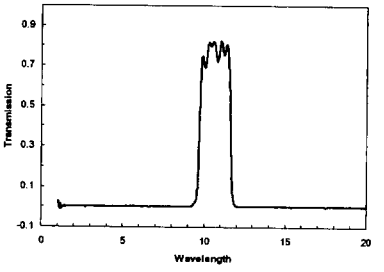


Dual-polarization nulling of broadband thermal MIR light

- Field reversal by dielectric plates
- Beam combination with MMZ
- Thermal filament source
- Filter - 33% BW: 9.5 – 13 μm
- No polarizers in beam
- CO_2 laser diode nulled to 500,000:1





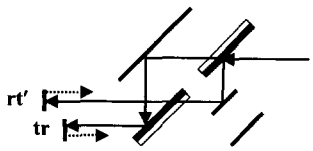


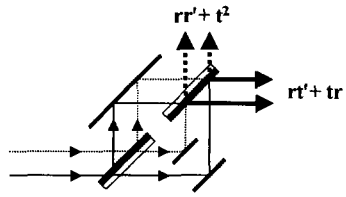
Ancillary Issues

- Symmetric light injection for testing nullers
- Intensity Balancing
- Beamsplitters
- Null control

Symmetric light injection

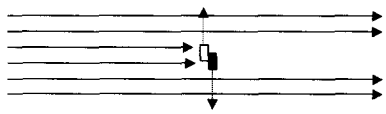
- Need a nuller to generate two symmetric beams
- Illuminate symmetric nuller in reverse



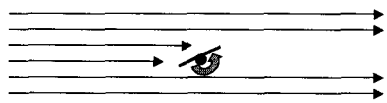


Intensity modulation

- Scatter small fraction of light out of beam
- Scissors:

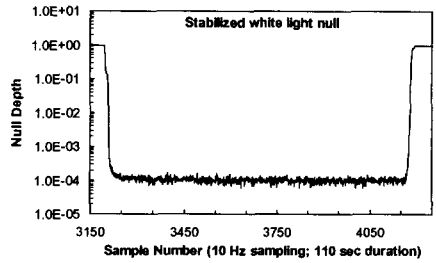


- Venetian blind:
  (rotating vane)



Null stabilization

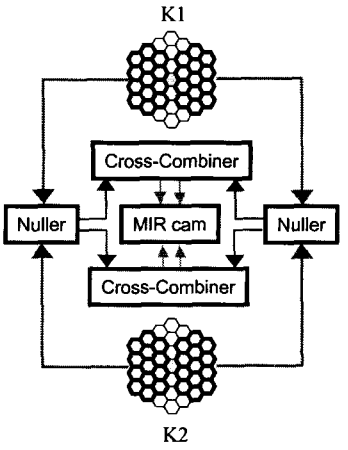
- Dithering (lab) → →
- Quadrature output (lab)
- 2nd (shorter- λ) control:
  Keck & LBT
- Slow on/off resets: Keck
- Metrology



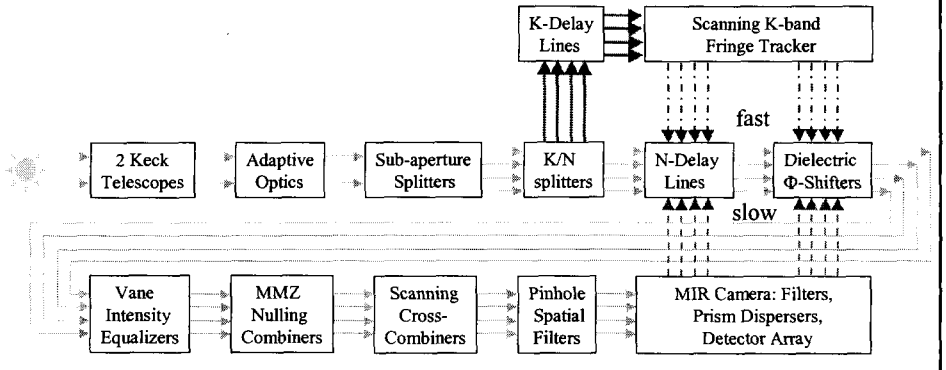
The Keck Interferometer Nuller

Nulling Architecture at Keck

- Need to remove two emission sources:
  - star (1)
  - thermal background (2)
- **(1) Multi-baseline nulling to remove star:**
  - Subdivide Keck apertures in half; send 2 beams to basement from each scope
  - Null star on each of two K1-K2 baselines
- **(2) Standard fringe-scanning interferometry to detect remaining exozodiacal light:**
  - Rapid 1-λ OPD scan between two nulled outputs provides exozodi fringe visibility
- Advantages:
  - Continuous operation of AO, fringe tracker, angle tracker, metrology, nuller
  - Same data format as K-band visibility data



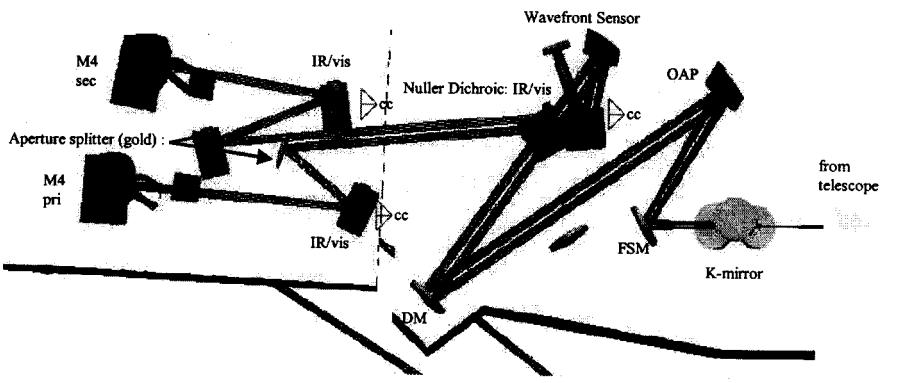
Keck Interferometer Nuller Architecture



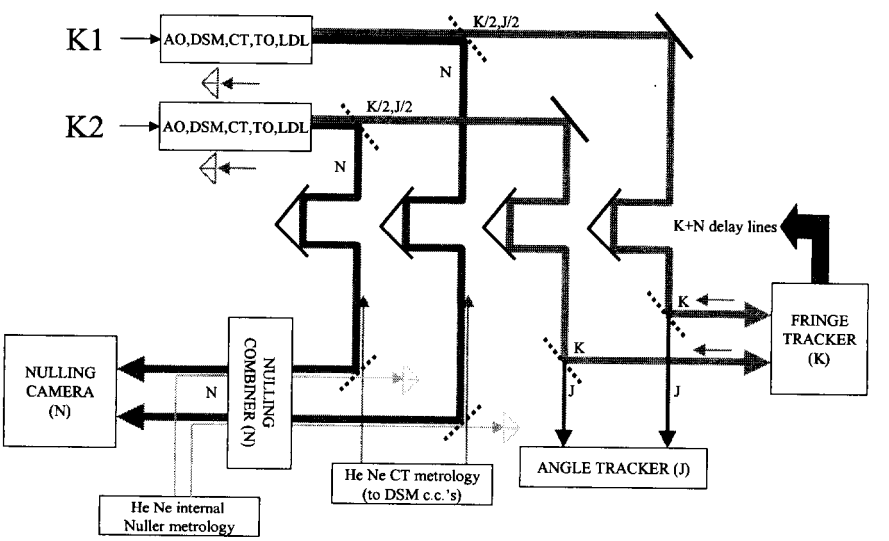
AO/DSM Layout for Nulling

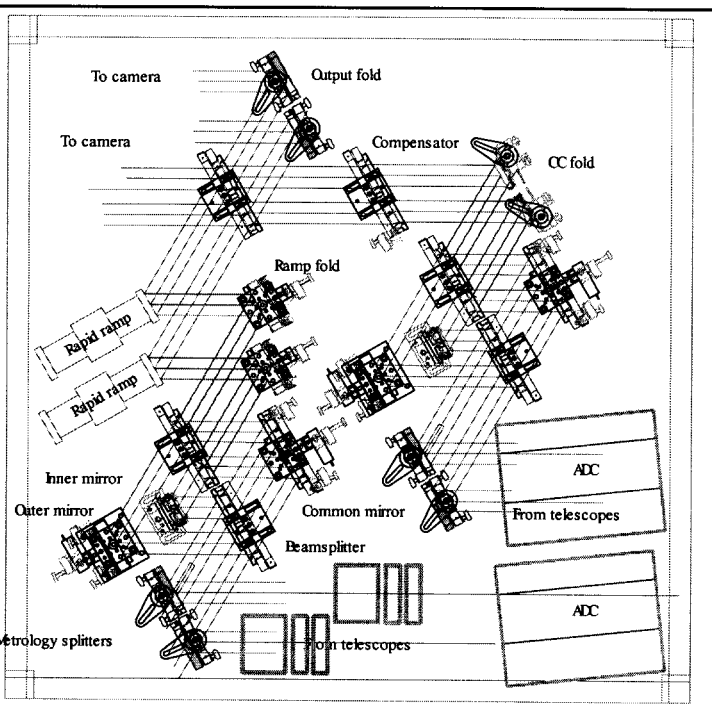
DSM
All collimated optics
Aperture split
(Full apertures available for beam train tests)

AO
Extract collimated beam prior to second paraboloid
Dichroic transmits Visible to WFS, reflects all IR

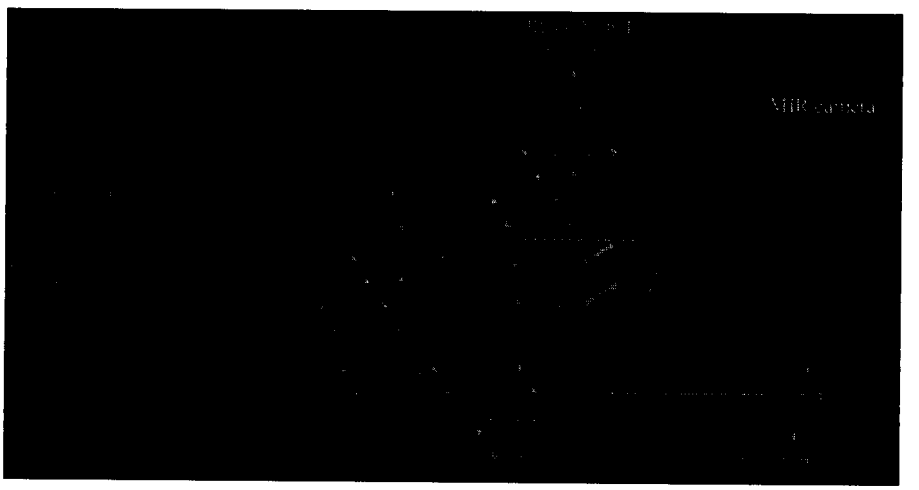


Cophasing Architecture

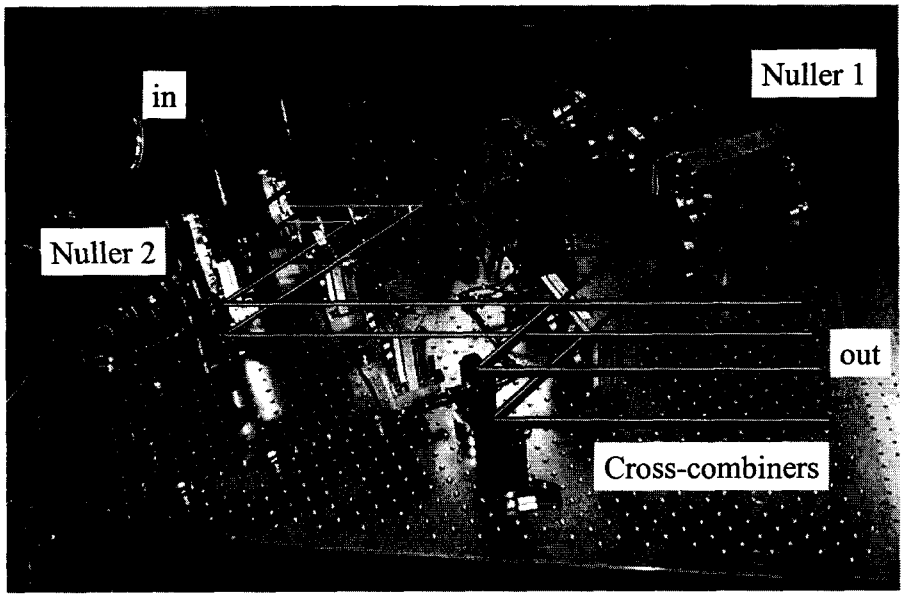


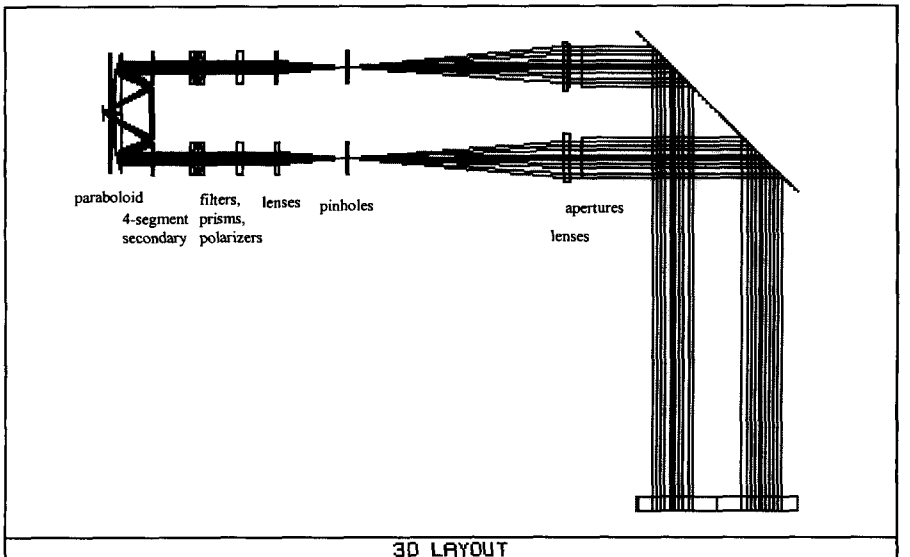


Nulling Optics Layout



Keck dual-nuller beam-combiner (2 nullers + 2 cross combiners)

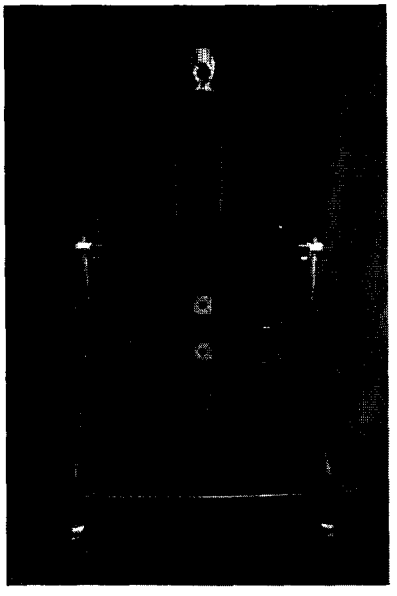




Four-beam MIR camera

MIR KALI Camera

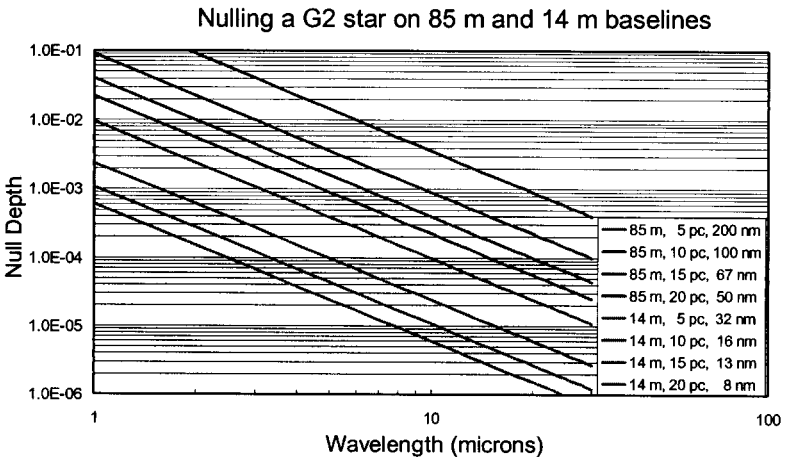
- 4 input beams
- Cold beam apertures
- Cold Pinholes
- Pupil imaging lens
- Direct view prisms
- 128x128 detector array



Nulling Science

- Dust shells
- Exozodiacal light
- Hot planets
- TPF: terrestrial planets

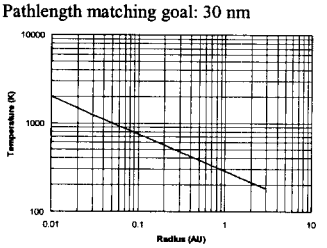
Stellar null depths vs. baseline and wavelength, and the required phase accuracy

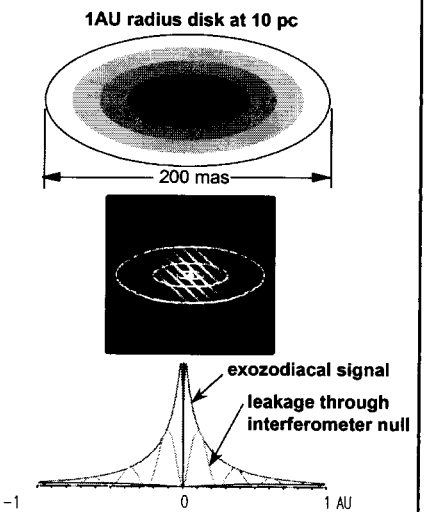


To achieve the baseline-limited null, require $\sigma_x < b\theta_d/4$

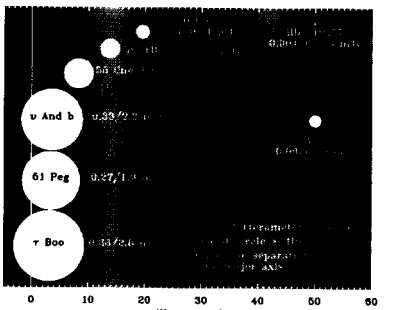
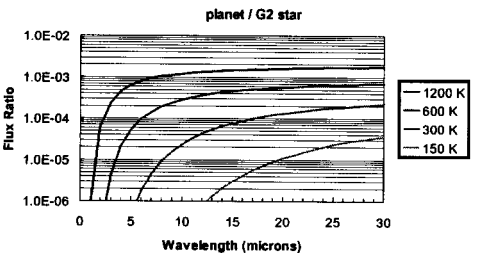
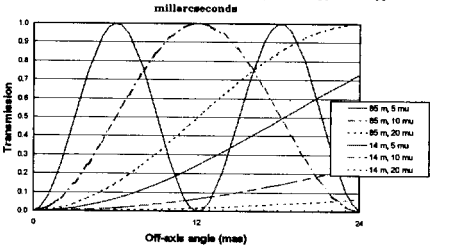
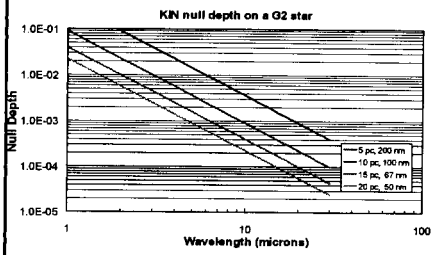
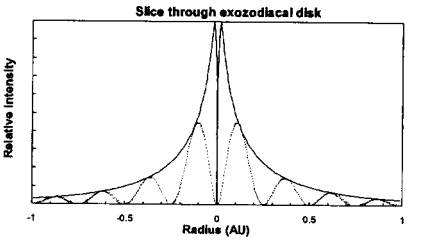
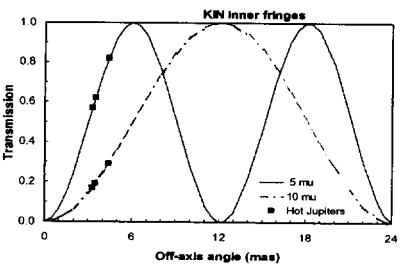
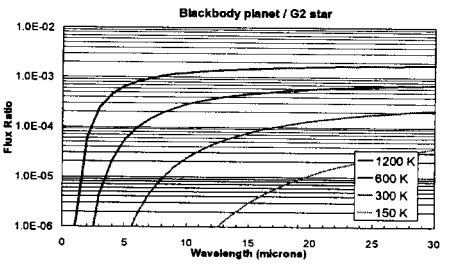
Exozodiacal disk detection with the Keck Nuller

- Angular sizes:
  - G-star diameter at 10 pc: 1 mas
  - 1 AU at 10 pc: 100 mas
  - Keck 10 um beam diameter: 200 mas
  - K1-K2 10 um fringe spacing: 24 mas
- Nulling at Keck:
  - On the order of 8 fringes across beam
  - Central achromatic null fringe on star
  - Stellar-diameter-limited null at 10 μm = 10^{-3}
  - Pathlength matching goal: 30 nm





Test	star	model	total flux uJy	Edge-On perp	KI fluxes Face-On	Edge-On par	Zodis for SNR = 5 noise in 5 hrs:		17 uJy
1	G2 @ 10pc	a) full zodi	120.0	47.7	45.6	36.4	1.8	1.9	2.3
2	(1 L.)	b) cutoff at 1AU	90.0	38.2	39.2	27.0	2.2	2.2	3.2
3		c) hole at 1AU	32.0	9.4	6.4	9.4	9.0	13.2	9.0

Hot planets from the ground?

- First fringe maximum: $\theta_{max} = \lambda/2b$
- Equilibrium temp. there: $T \approx 300\ (b_{10}/d_{10}\lambda_{10})^{1/2}$
- Orbital Period: $P \propto b^{-1.5}$
- Short periods and wavelengths will help!