Telescope Calibration & Alignment
or
Wavefront Sensing

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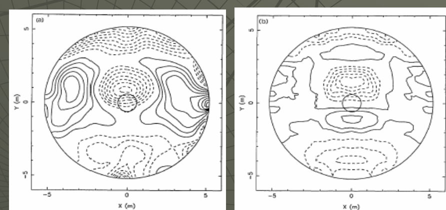
Profile

- Gene Serabyn
  - JPL
    - Senior Research Scientist 3/1998 –
    - Infrared interferometry, nulling, coronagraphy
  - Caltech
    - Visiting Associate 1/1987 –
    - Sub-millimeter wavefront sensing, spectroscopy, imaging

Scope

- Submillimeter Wavefront Sensing System
  - To optimize the telescope's main beam efficiency,
    - Need detailed knowledge of the telescope surface shape.
  - Metrology can hold a given shape,
    - but need to know what the shape is.
  - Mechanical models need to be calibrated.



  - Goal: Measure the wavefront reflected by the telescope, somewhere in the telescope's observing passband
  - Scope: Proof-of-concept design that meets the accuracy requirement

Scope

- Use of large-format submm arrays is assumed
  - Opens the door to "optical" techniques
- Wavefront quality (pupil plane) and image quality (focal plane) are Fourier conjugates
  - Not a vital trade at this point
- Proven CSO approach used as a sanity check
  - Previously, accuracy of 9 μm achieved

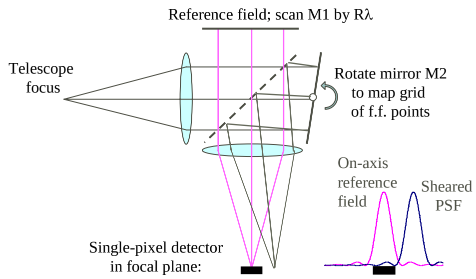
Requirements for Subsystem

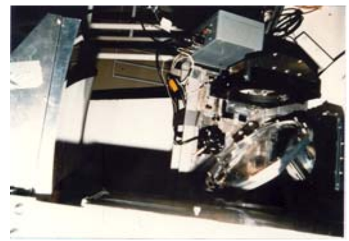
- Wavefront map of the combined primary/secondary reflector surfaces
  - Accuracy – small contributor to the error budget
    - a few (1-3) μm
  - Lateral resolution
    - – lo-res (gravitational flexure; ≈1 point per panel)
      - 16×16
    - – goal (panel shapes)
      - 32×32 to 48×48 pixels
  - Time resolution – small elevation angle range
    - 5-10° (under an hour)
  - Measurement interval – access “every few months”
    - (translates to source availability; number and flux)
  - Measurement wavelength – use a facility “submm” camera
    - 0.3 to 3 mm

Key Design Issues and Parameters

- Accuracy goal is a factor of 3 beyond current systems
- Small number of appropriate astronomical sources
- Examine:
  - Ultimate measurement accuracy
    - Dependence on source flux and thermal background noise
  - Optimal measurement wavelength

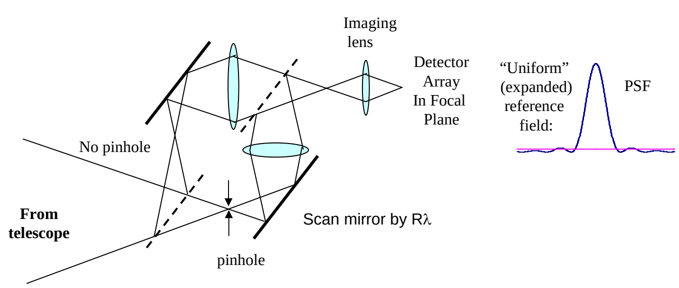
System Design: Option 1





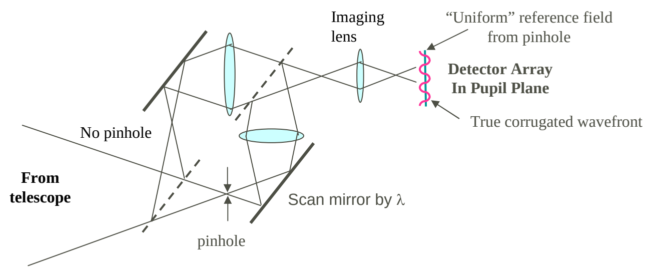
- Shearing interferometer: focal plane sensing with single pixel detector
- Proven at CSO:
  - 9 μm accuracy
  - 15×15 and 21×21 maps made
  - few hour measurement timescale achieved
- Can be improved significantly in terms of efficiency
- Point-by-point approach will always introduce systematic errors

System Design: Option 2



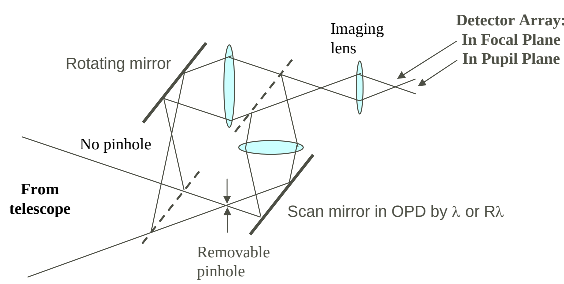
- Focal-plane Point Diffraction Interferometer
- Spreads out the energy of the reference beam
- Makes use of array detectors to instantaneously sense full focal plane field
- Lower instantaneous SNR per point
- Gains in the areas of stability and systematics

System Design: Option 3



- Pupil-plane Point Diffraction Interferometer
- Switch to pupil-plane sensing in this approach, as in the optical
- Only need to scan one mirror by 1-λ

System Design: Hybrid Option



Hybrid Interferometer: focal-plane and/or pupil-plane sensing

Supporting Analysis I

- FOV large:
  - $32F\lambda \approx 300\ \lambda \approx 0.1 - 1.0$ m
- Mirrors large:
  - Of order 1-2 m if long wavelengths are included

Supporting Analysis II

- Ultimate sensitivity of submm wavefront sensors depends on:
  - Phase measurement accuracy in the presence of long-λ background noise
- Start with pupil plane measurement case:
  - Phase accuracy: $\phi = 1/SNR = sqrt(N_{background})/N_{signal}$
  - Signal:
    - Source flux per subaperture
      - (only Mars, Uranus, Neptune are small and bright enough)
    - Atmospheric and instrumental transmission (T)
  - Noise:
    - Number of background modes transmitted by cold stop
    - Bose-Einstein statistics: $\Delta n = sqrt(n(n+1))$

Supporting Analysis III

- End with:
  - $\Delta x \approx \lambda/(100T\sqrt{t})$
  - Approximately proportional to λ
    - (Both signal and noise vary with λ differently)
    - Short wavelengths have higher accuracy (assuming reasonable atmospheric transmission)
  - Calculate time to reach 3-σ sensitivity of 3 μm (in a sq. m).
    - Assume $T_{inst} \approx 0.1$ (largely the pinhole)
    - Assume $T_{atm}(350) = 0.7$; $T_{atm}(1300) = 0.97$

λ (μm)	Time (sec)
350	25
1300	240

Critical Risk Assessment

- Fifteen years ago, the CSO shearing interferometry approach reached an accuracy of 9 μm with a less than optimized system.
- To reach better sensitivities, the choice is:
  - Improve a known technique, or try a new approach
- The hybrid system described allows both
- The new approaches can be tried at existing telescopes before CCAT (if funding is available)
- Theoretical sensitivity limits are quite good.
  - Feel confident that a factor of 3 can be gained.
- The main fundamental problem is thus the limited number of sources which are bright enough and small enough (< λ/D).
- Next phase concerns are then instrument-definition related: detailed throughput, sensitivity and aberration analyses, a diffraction analysis of the pupil plane approach,