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Keck Interferometer: Current Engineering and Science Results

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Outline

- Keck Interferometer Context & Science Objectives
- KI Key Project Instrument Modes
  - Nulling
  - Differential Phase
  - Differential Astrometry
- Additional Instrument Modes
  - Parametric Imaging
  - Synthesis Imaging
- Operations Model & Scientific Program Structure
- Constituencies
  - Shared-Risk Teams
  - Key Project Teams
  - Guest Investigators
  - CIT, UC, and UH Investigators
- KI Science Synoptic Schedule

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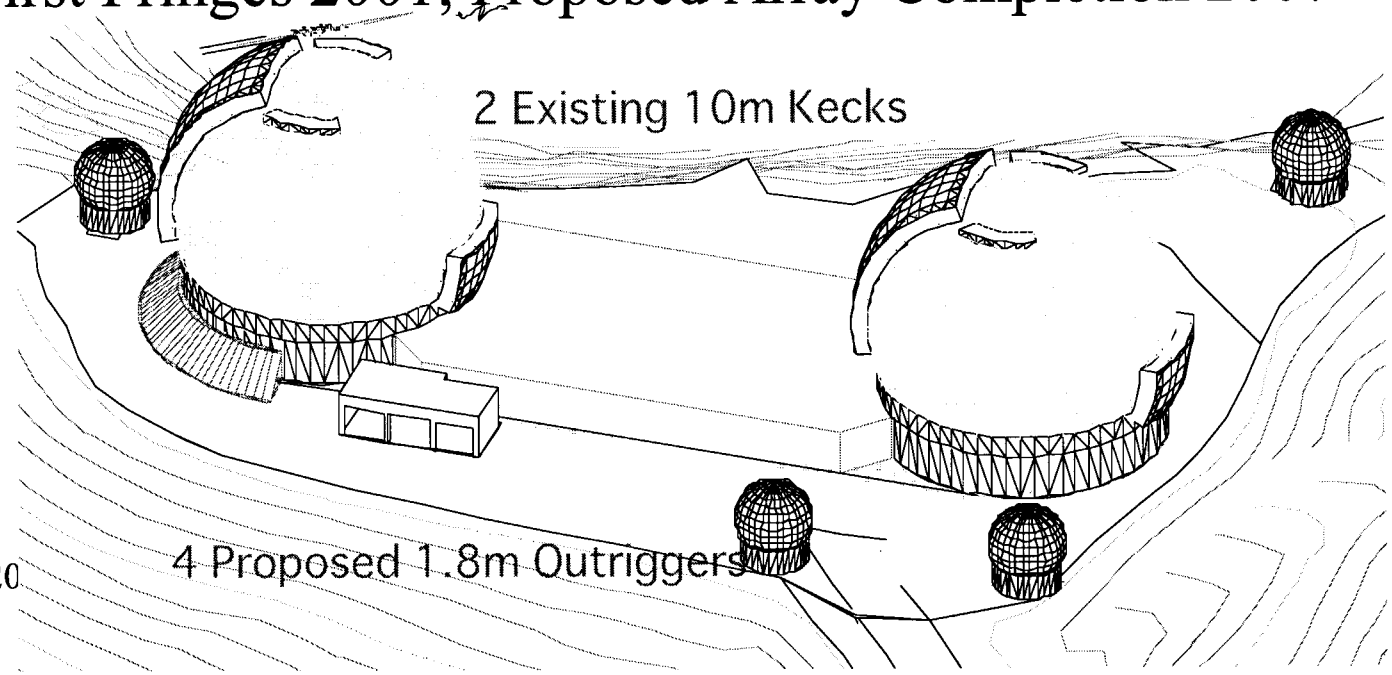
Keck Interferometer (KI)

- Keck Interferometer, Part of NASA's Origins Program (1997)
- Joint Development Effort: JPL, WMKO, and MSC/Caltech
- Phased Development of Science Objectives:
  - Differential Phase Detection of Hot Exo-Planets (e.g. 51 Pegasi B)
  - Nulling Detection of Exo-Zodical Emission
  - Astrometric Detection of Exo-Planets Orbiting Nearby Stars
  - Synthesis Imaging Capability
- First Fringes 2001; Proposed Array Completion 2007



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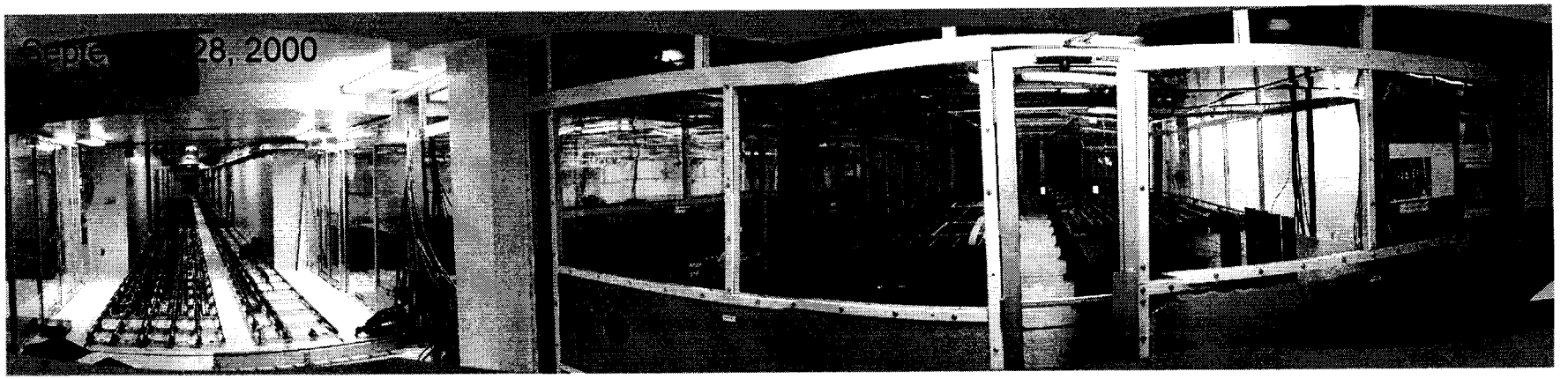
Interferometer Construction

Basement used as storage facility through 1998

Initial cleaning (above) and first equipment install (below)



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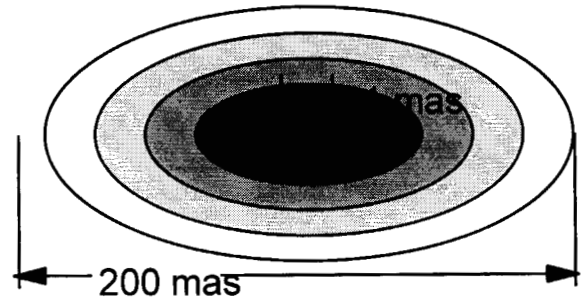
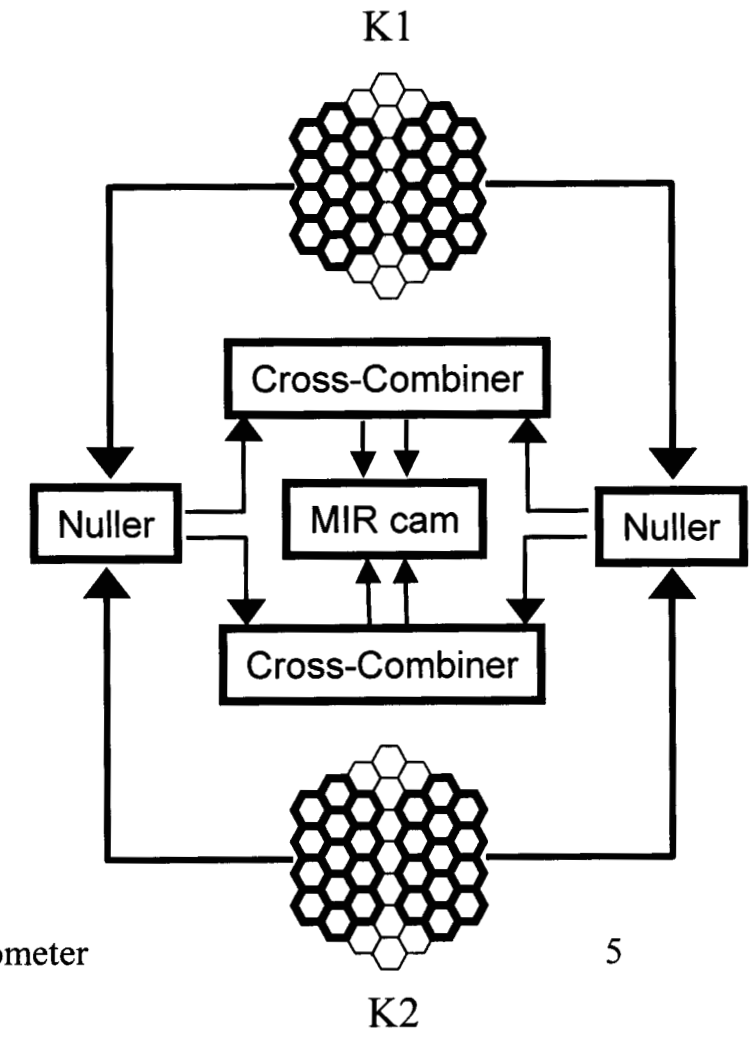
Nulling for Exozodiacal Dust Detection

- Characterize Exozodiacal Emission Around Nearby Stars to < 10 Solar-System Equivalents
- Observational Issues
  - Strong light from central star
  - Weak exozodiacal signal (10^{-4})
  - Strong 10-μm background
- Approach: Multi-Baseline Nulling
  - Send two beams to basement from each telescope
  - Null star on each of two K1-K2 baselines
  - Perform "standard" interferometry on the two nulled outputs



1AU radius disk at 10 pc



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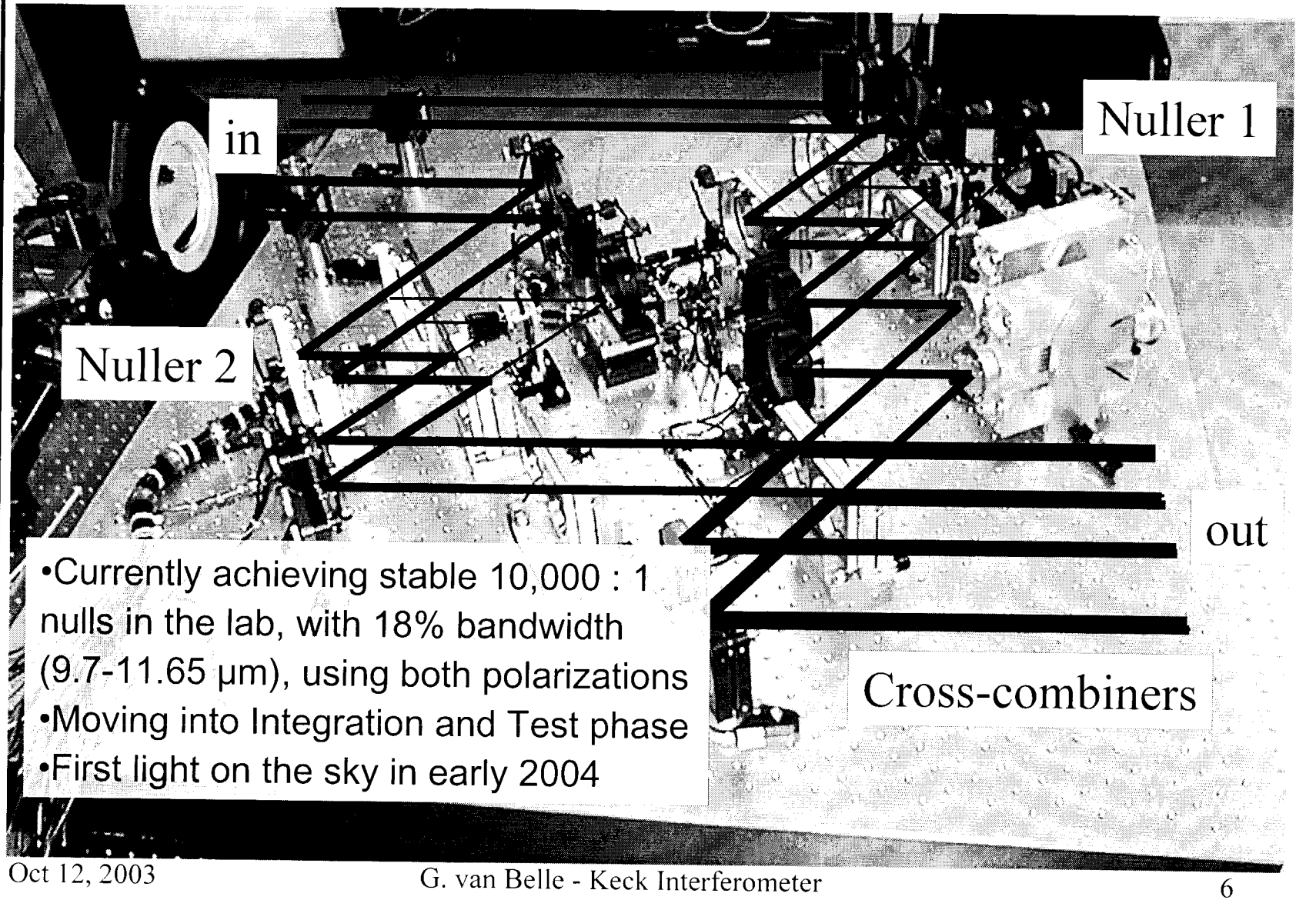
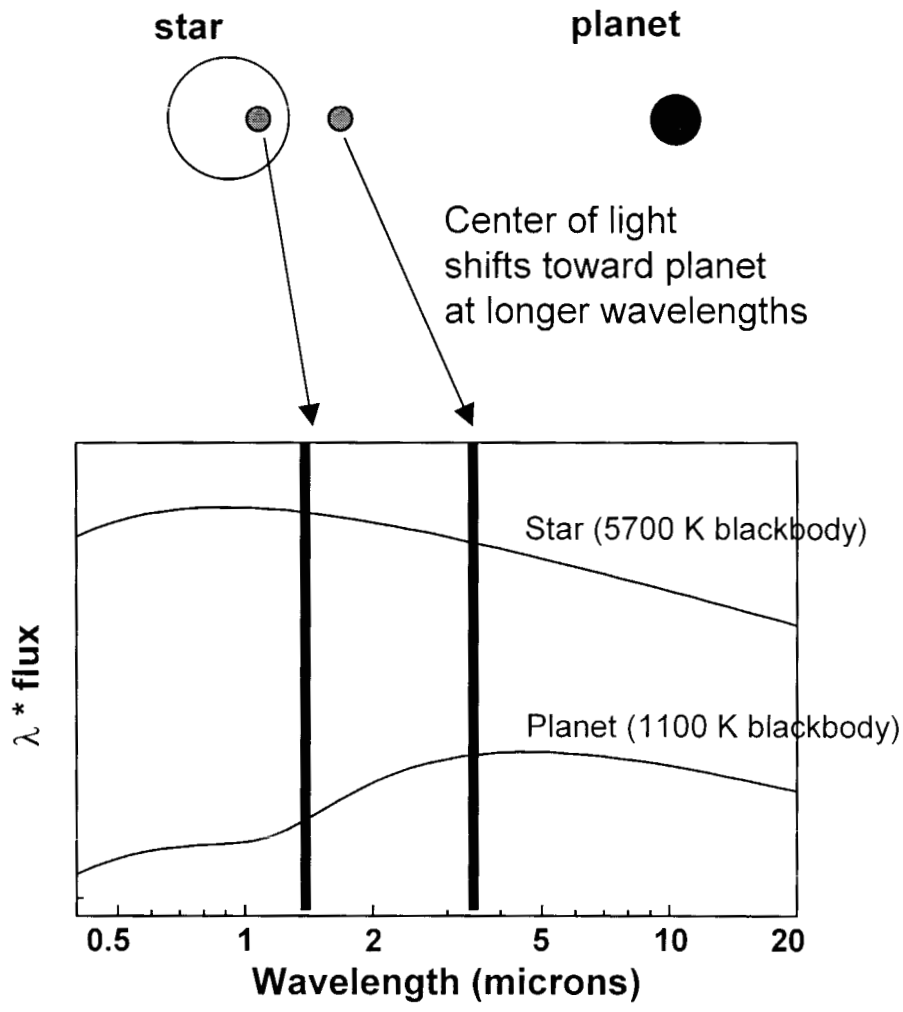
Nuller Currently in Laboratory Development



- Currently achieving stable 10,000 : 1 nulls in the lab, with 18% bandwidth (9.7-11.65 μm), using both polarizations
- Moving into Integration and Test phase
- First light on the sky in early 2004

Detecting Hot Jupiters Directly with Differential Phase

- Shift of system photocenter with wavelength
  - Manifests itself in the interferometer as a phase shift between bandpasses
- Phase difference can be measured
  - Common mode measurement, very precise
  - $\Delta\phi \sim 10^{-3}$ to 10^{-4}
- Direct detection of planet
  - Will allow spectroscopy



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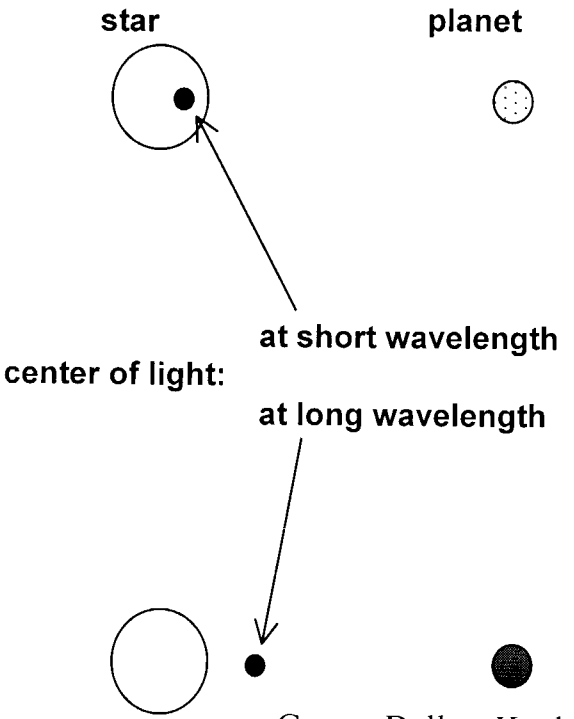
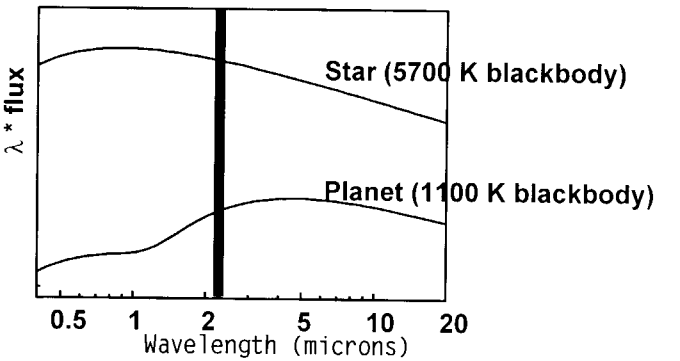
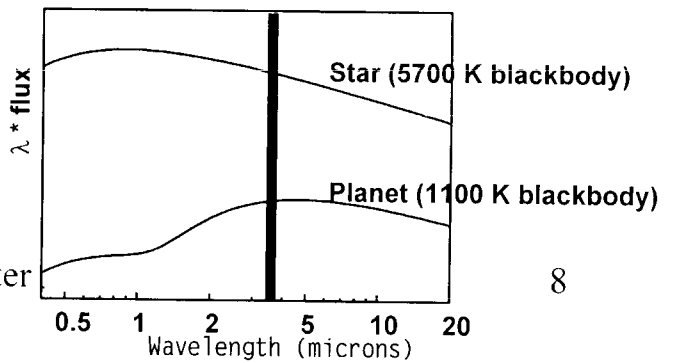
Detecting Hot Jupiters With Differential Phase

- Scientific Objectives
  - Direct detection of warm Jovian planets
    - Characterize orbital parameters (mass), low-dispersion spectra
- Observational Issues
  - Large color difference between components => wavelength-dependent centroid







(approximation for star-planet separation << fringe spacing)

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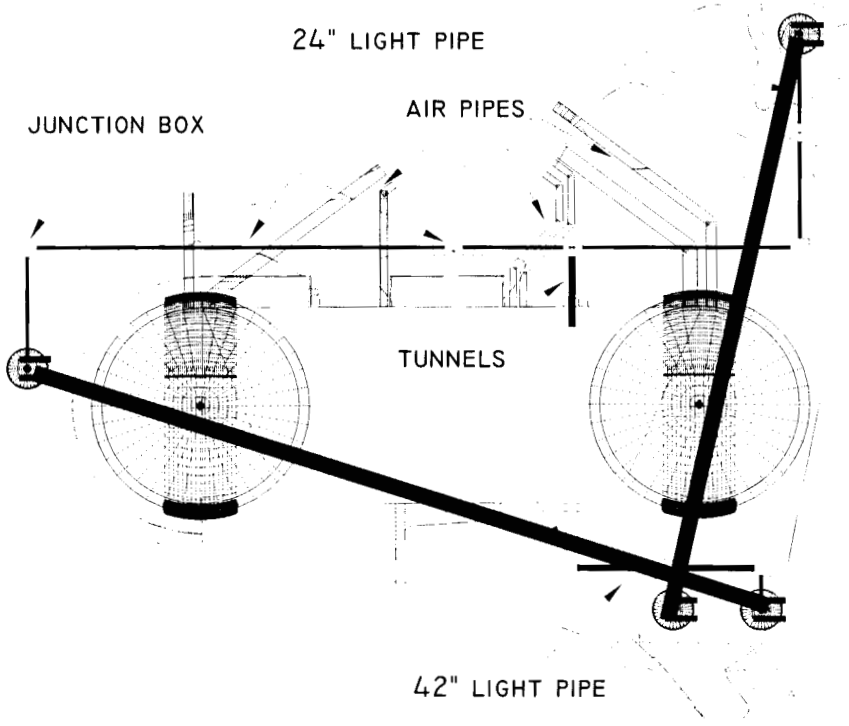
Astrometric Exoplanet Detection

- Science Objective
  - Survey 100's of nearby stars for planets to Uranus mass
  - Uses proposed outrigger telescopes for long-term survey
- Observational Issues
  - High-accuracy narrow-angle astrometry (30 μas ~ 2 * 10^{-10} rad)
  - Nominal K=17.3 isoplanatic ref. (Approx 35% sky coverage with two stars within 30")
- Proposed Instrument Architecture
  - Four 1.8-m outriggers
  - Orthogonal ~100m baselines
  - Dual-star feeds
  - End-to-end laser metrology
  - 30 μas per hour accuracy for differential astrometry



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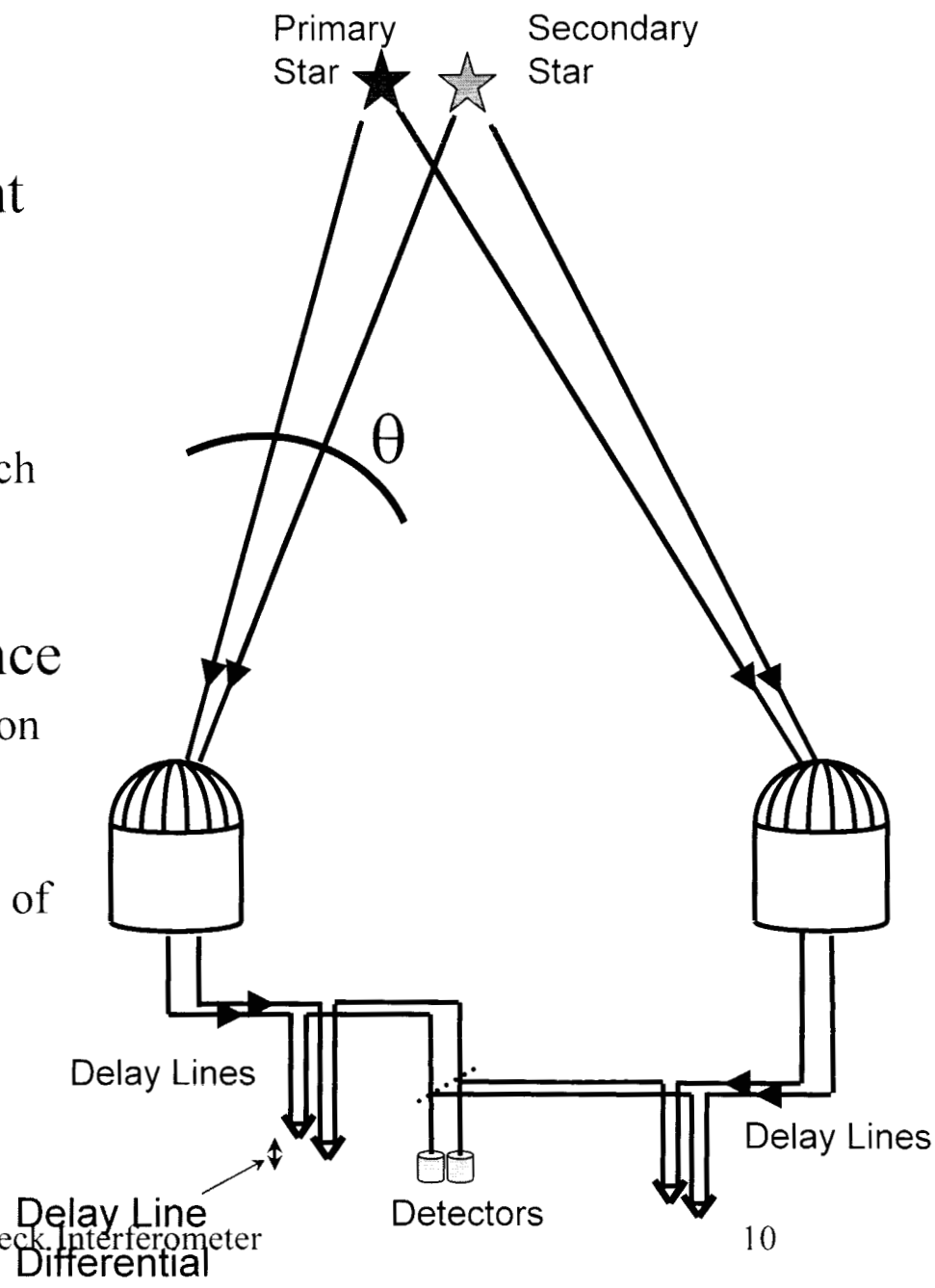
Dual Star Astrometry

- Primary star (target) - bright
  - Used to stabilize interferometer
- Secondary star - faint
  - Position reference
  - Located in same isoplanatic patch as primary star
  - Long integration times possible
- Delay line position difference
  - Proportional to angular separation between stars
  - Measured with laser metrology
  - Wobble in separation indicative of unseen companion



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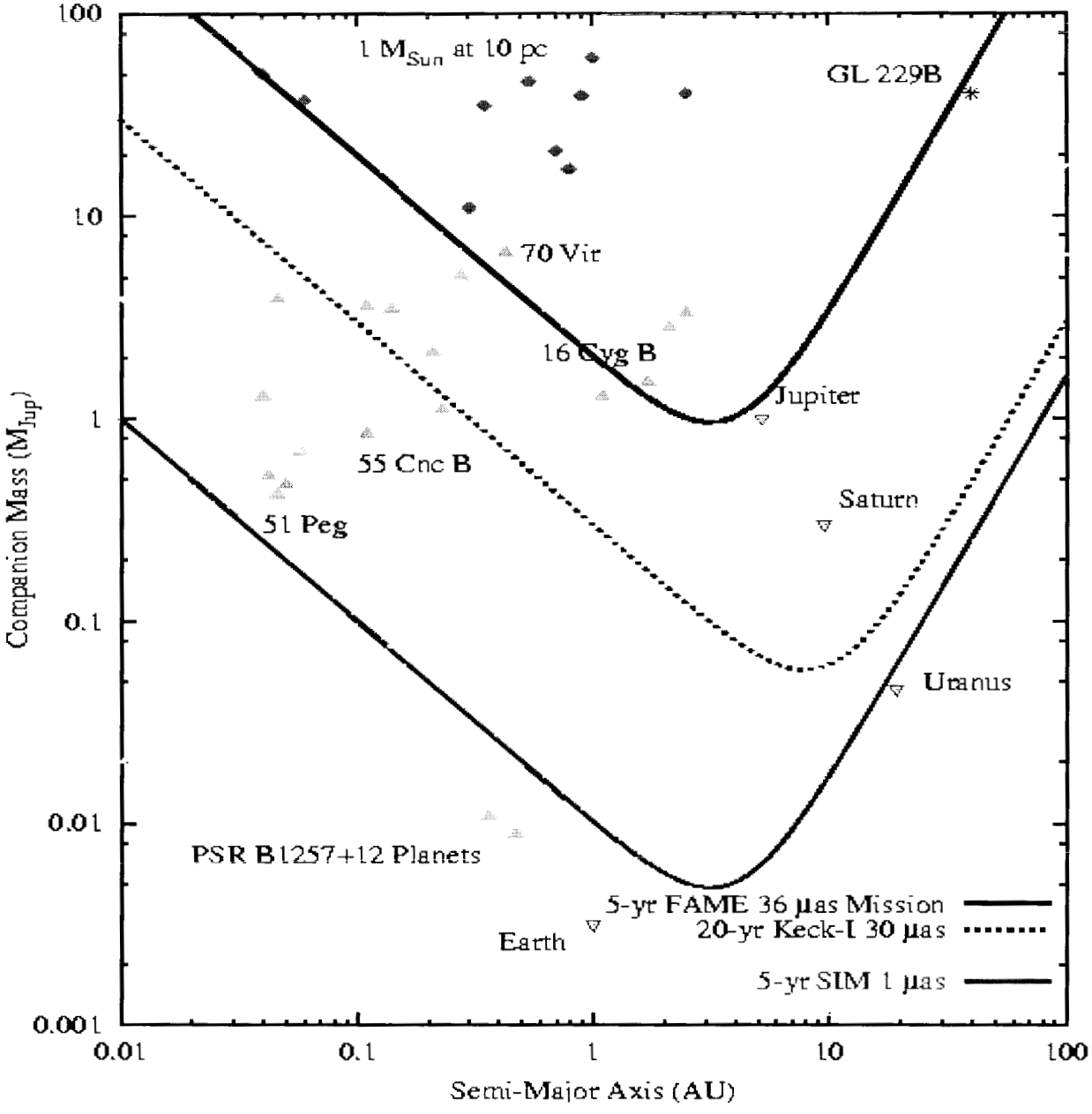
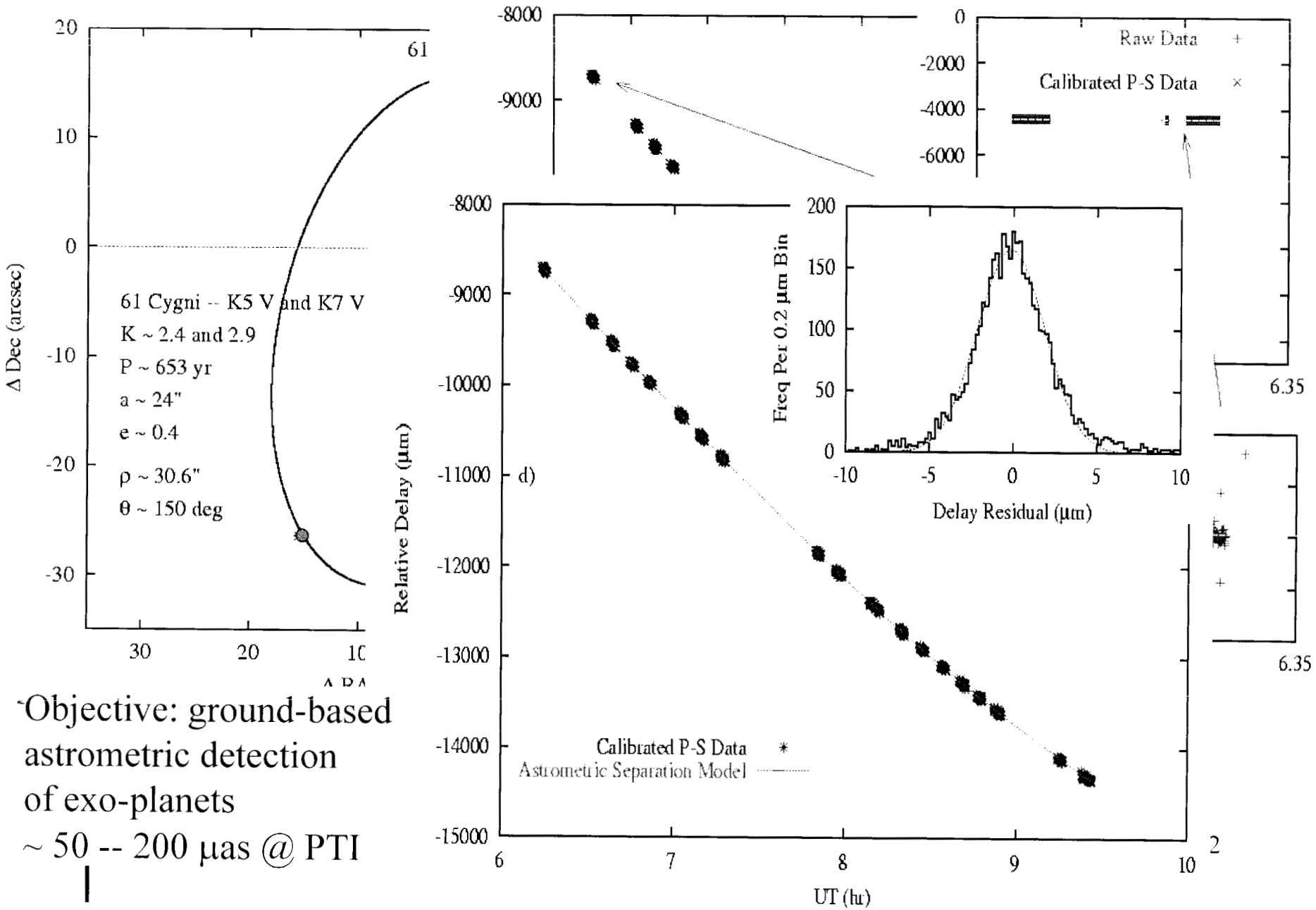
Space for Exoplanet Detection

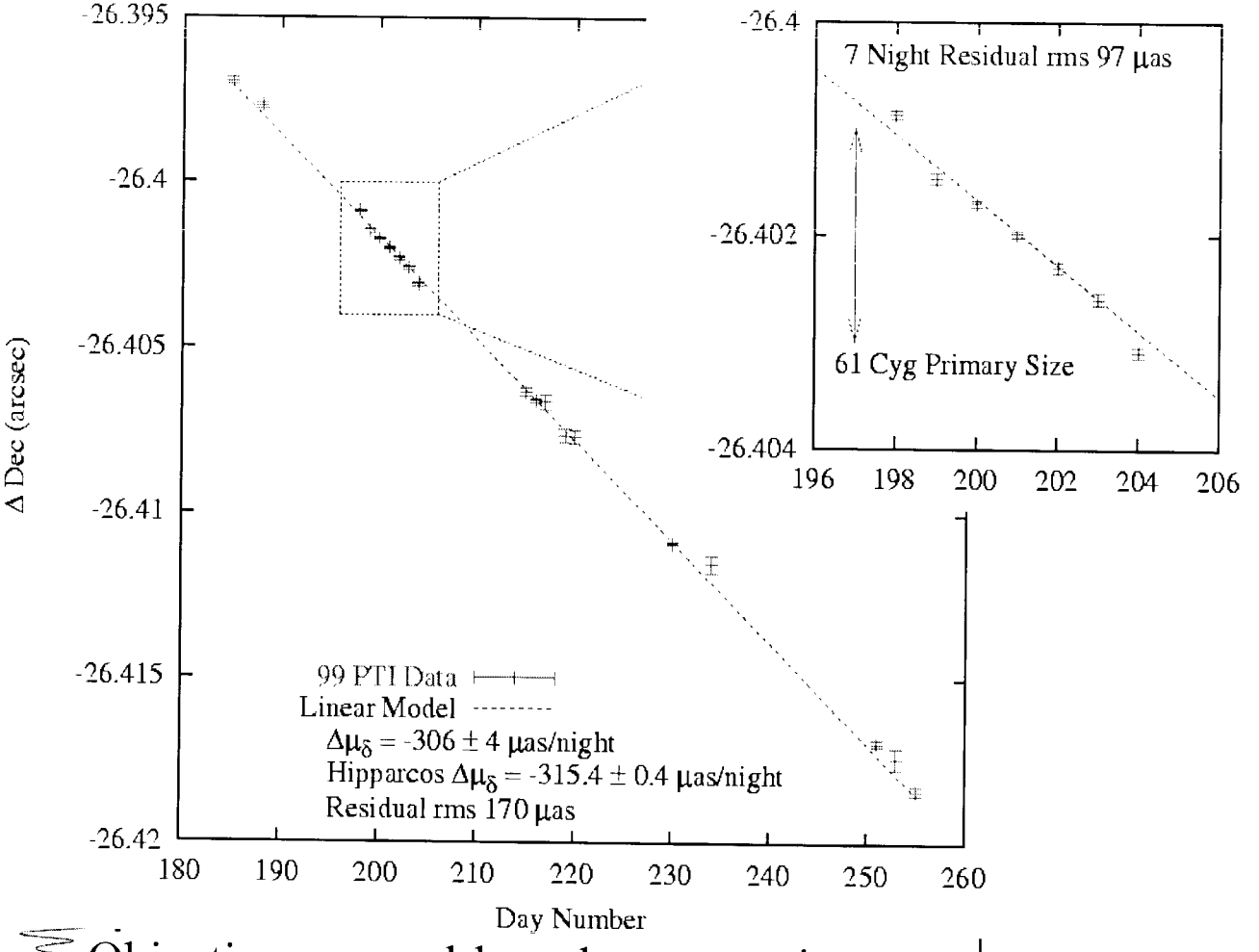


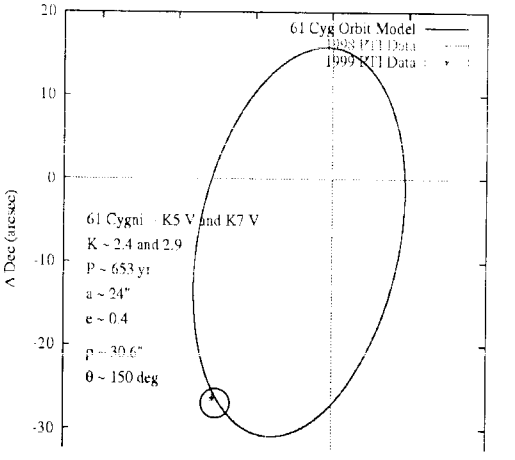
PTI Astrometry on 61 Cygni

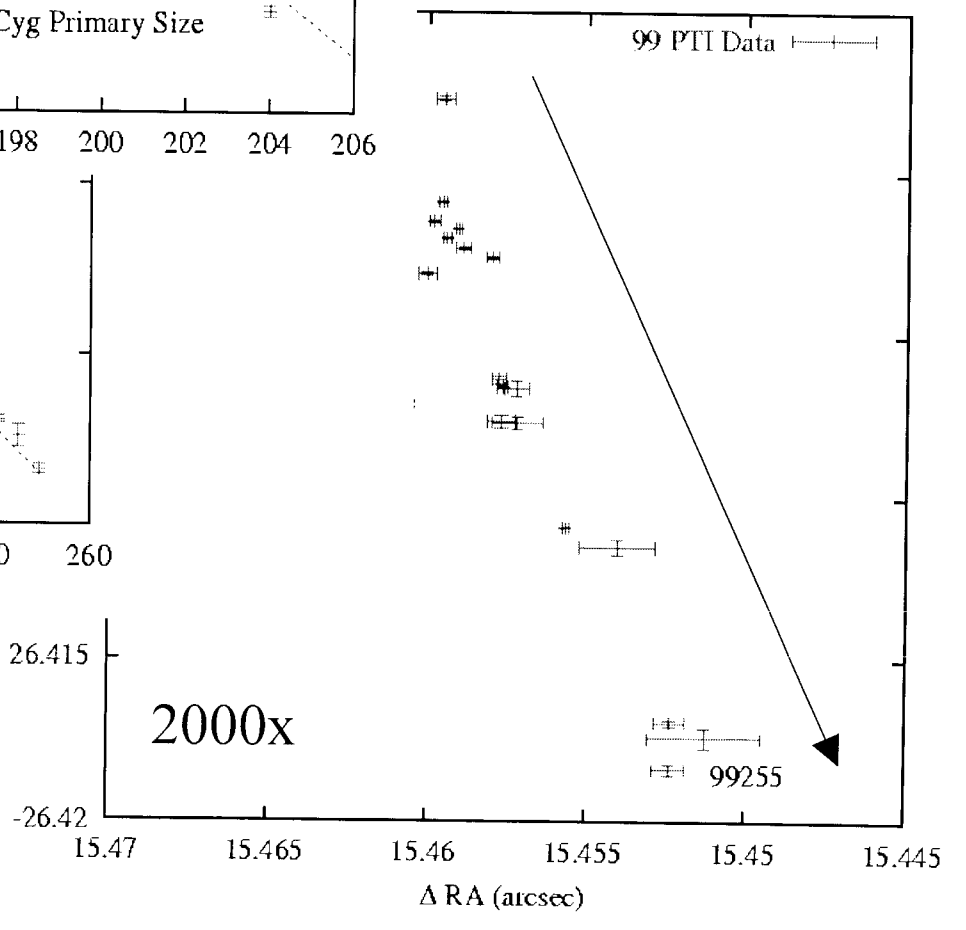


- Objective: ground-based astrometric detection of exo-planets
  ~ 50 -- 200 μas @ PTI

PTI Astrometry on 61 Cyg (2)







Objective: ground-based astrometric detection of exo-planets ~ 50 -- 200 μas @ PTI

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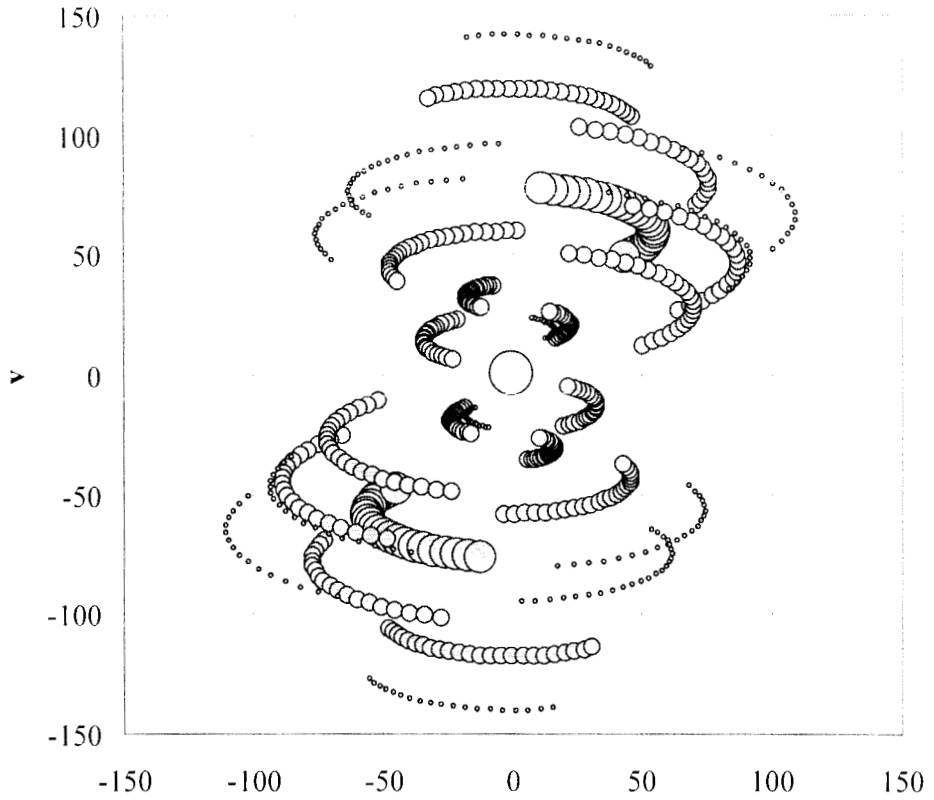
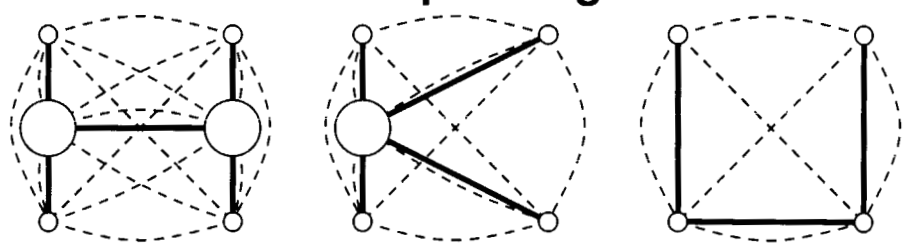
KI Synthesis Imaging

- Science/Instrument Objectives
  - Imaging with 6-element array
  - Good (u,v)-plane coverage
  - Broad community appeal
- Observational Issues
  - Nine of 15 baselines include a 10-m telescope
  - Background-limited sensitivity equivalent to two 4.4-m's
  - Other imaging options using OTs with 1 or 0 Kecks
  - Use cophasing to increase sensitivity
- Ultimate Sensitivity
  - K-K fringe tracking: K=14.1
  - OT-OT fringe tracking: K=10.8
  - Cophased imaging
    - K=19 for SNR >10 in 1000 s on a Keck-OT baseline
    - Requires K=11.6 isoplanatic ref



(u,v) coverage with proposed outriggers and existing Kecks

Science and cophasing baselines



— cophasing
--- science

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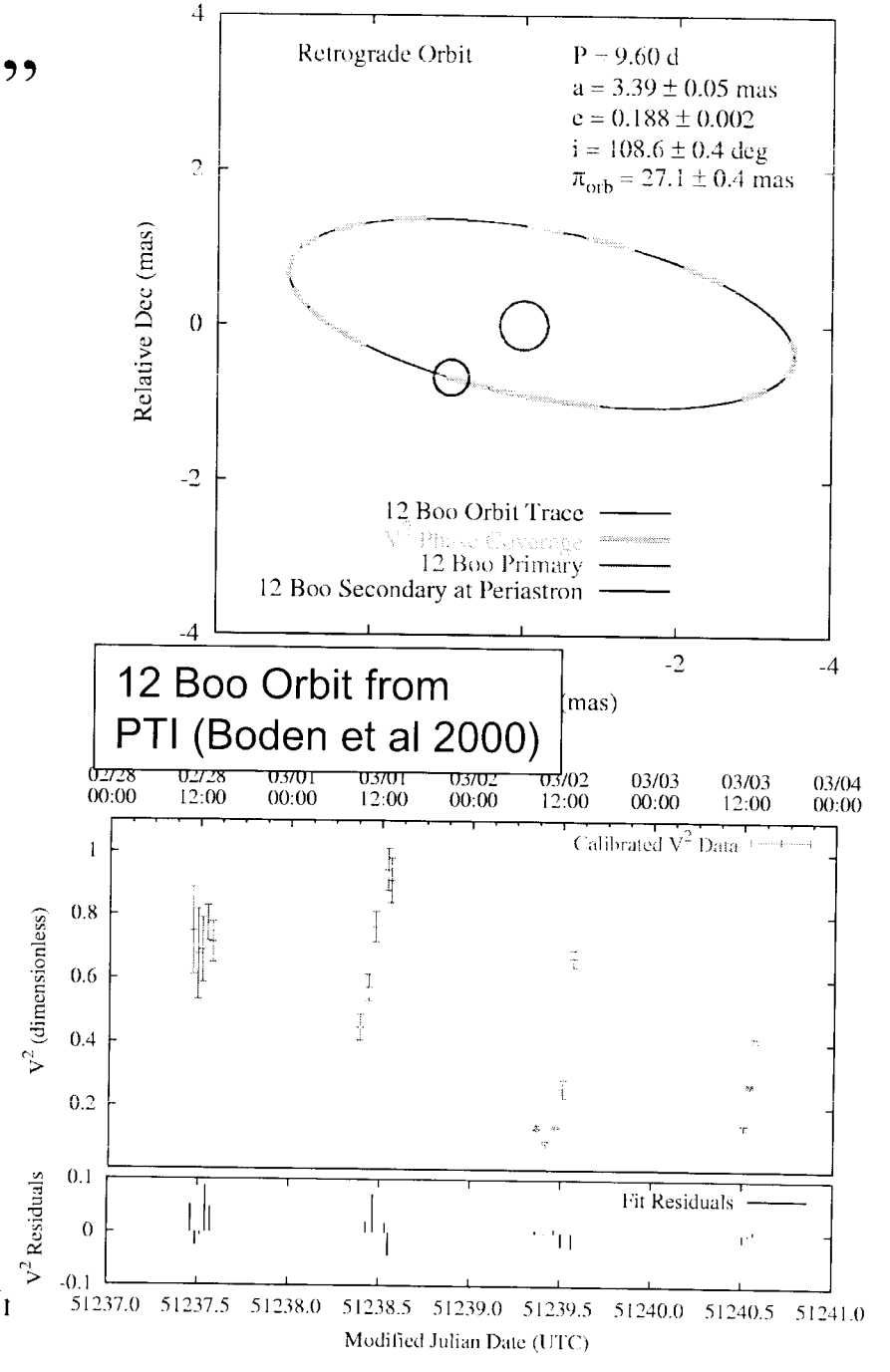
KI "Parametric Imaging"

- First KI Science results are Visibility Amplitude (V^2) Measurements
- Useful Addressing Questions Where Simple Morphological Models Apply
  - Stellar & circumstellar material sizes
  - Pulsating stars
  - Binary star orbits



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KI Science Operations Model

- KI is a Facility Instrument for the NASA, CIT, UC, and UH Communities
- Scientific Programs Supported By Three Broad Mechanisms:
  - Shared-Risk & Debugging Science
  - Key Project Programs (DP, Nulling, Astrometry)
  - Guest Investigator Program
- Until ~2004 we expect that investigators (especially Key Projects) will participate from Waimea
- In *Steady-State* (circa 2006) all observing will be queue-scheduled service observing by WMKO observing staff
- User Support & Access Through MSC

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Scientific Program Structure with KI

- Shared-Risk & Debugging Science
  - In All K-K Operational Modes
  - External Team(s) in 50%/50% Partnership With KI Development Team (JPL/ISC/WMKO) to form *KI Commissioning Team*
  - First KI NRA ~ March 2001, Selection in Oct 2001
  - Limited observing time available; Caltech observing time contributions
- Key Projects
  - Differential Phase *direct* detection of "Hot Jupiters"
  - Nulling detection and characterization of exo-zodical emission around nearby stars (& likely TPF targets)
  - Astrometric detection and characterization of Uranus-mass planets (planetary systems) around ~300 nearby stars
- Guest Investigator Program
  - Entrepreneurial, Peer-Reviewed use of KI facility capabilities for scientific investigations
    - 50% of NASA Keck allocation to be used for interferometry
    - CARA, UH, NOAO Participation – Supported by the MSC

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KI Science Constituencies

- KI Shared-Risk teams (FY 02 – FY04)
  - External Teams (50% Science Time -- < 20% KI Time)
    - Danchi et al
    - Monier et al
    - Kulkarni et al
    - Traub et al
  - Internal JPL/ISC/WMKO Team (50% Science Time < 20% KI Time)
  - Joint Target Selection & Science Planning
- KI Key Project Opportunities
  - DP & Nulling
    - Proposal solicitation & selection ~ Mid FY04
  - Astrometry
    - Proposal solicitation & selection ~ Early FY06
- Non-NASA Use: CIT, UC, & UH
  - To Date, CIT team (Sargent et al) only team to have proposed, been awarded time
  - Likely splits of outrigger time
    - NASA ~ 60%
    - CARA ~ 25%
    - UH ~ 15%
- Project Advised by KISWG

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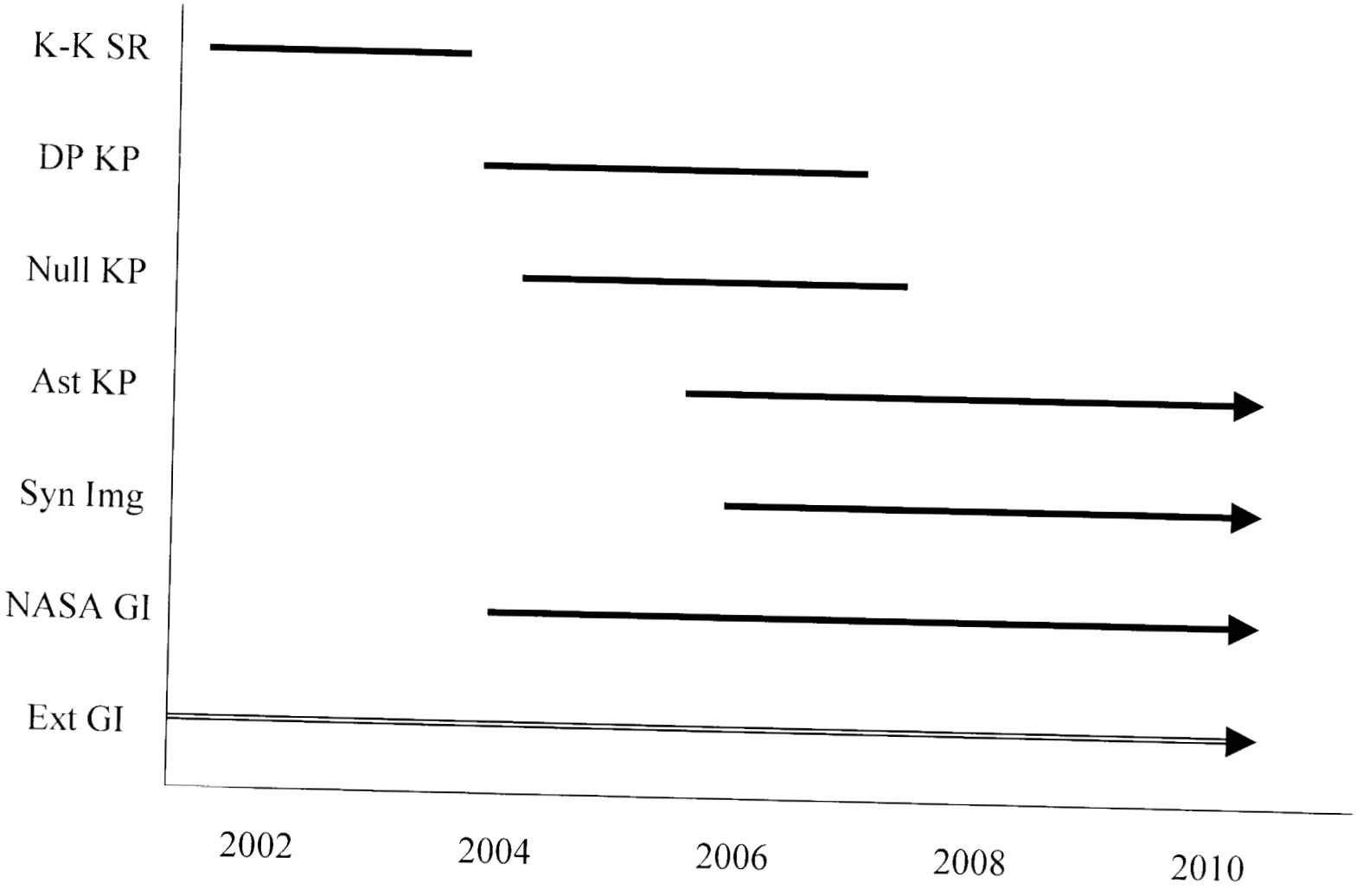
KI Science Synoptic Schedule



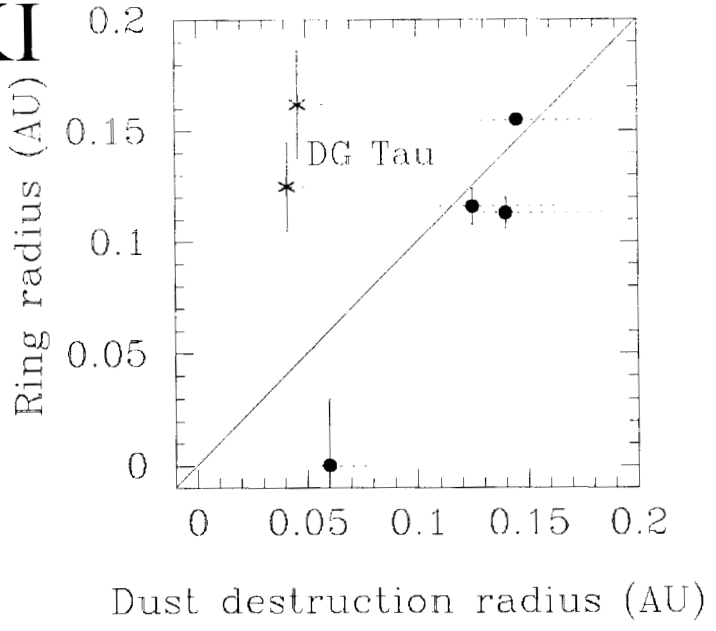
First Science Result from KI

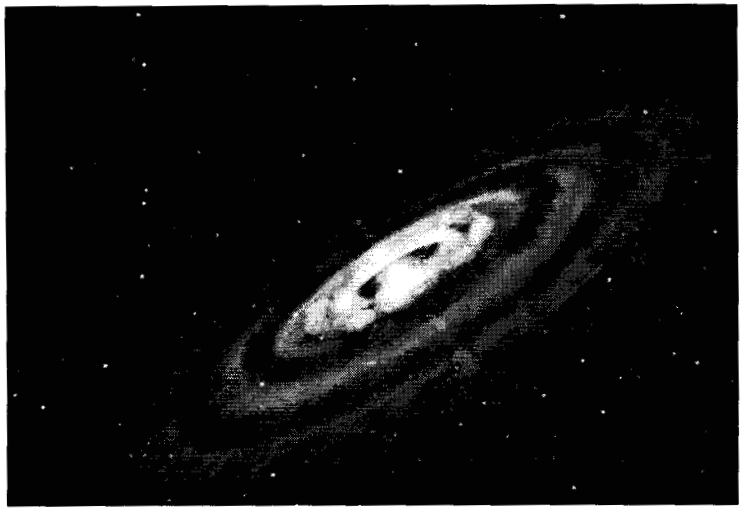
- Observations of the T Tauri star DG Tau (Colavita + 64 other authors)
- First science result from an AO-equipped interferometer
  - Faintest interferometer measure of a T Tauri to date
- Disk appears to be larger than dust destruction radius
  - In contrast to 4 PTI sources observed
- Web resources
  - JPL press release:

http://www.jpl.nasa.gov/releases/2003/93.cfm

  - MSC homepage:

http://msc.caltech.edu





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