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Differential phase technique with the Keck Interferometer

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Outline

- Scientific motivation
- Keck Interferometer
  - visibility detection
- Hot Jupiters
- Experimental challenges

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Hot Jupiter Key Science

- Over 28 (and counting) extrasolar planets discovered through radial velocity surveys
- Several are located within 0.1 AU of the parent star
  - predicted effective temperatures from 1000-1500 K
  - examples: 51 Peg and τ Boo
- Planets are difficult to detect because of their small separations from the central star and large star/planet flux ratios
- For the close-in planets (orbital radii < 0.1 AU, angular separations of 1 to 10 milliarcsec)
  - Flux ratio in optical ~ 10^{8}
  - Flux ratio in infrared ~ 10^{4}
- Differential phase (DP) technique converts problem from intensity dynamic range to phase dynamic range
- Science goal is to measure the mass, effective temperature and spectral characteristics

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Keck Interferometer

- NASA funded, joint JPL/CARA project
- Project will connect the 10-m Keck telescopes and add 1.8-m outriggers
- DP uses the two 10-m Kecks (85 m baseline)
- Observing for the Hot Jupiter key science mode begins in 2001

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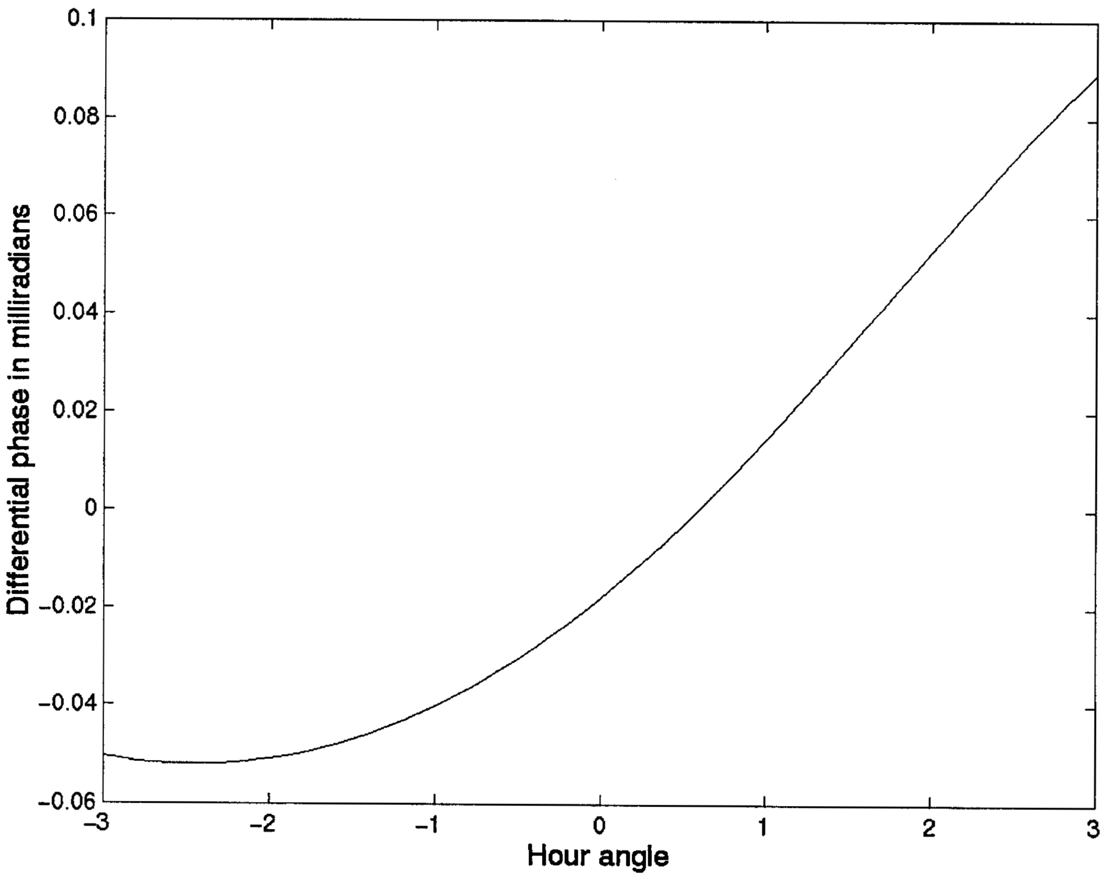
Visibility detection

- KI will use a stroked delay line with a 4 bin detection algorithm (same as Palomar Testbed Interferometer)
- Phase is simultaneously measured at 2 (or more) wavelengths to minimize systematics
- Observations possible in H to M bands (1.6 to 5 microns) with planned instrumentation
- Atmospheric dispersion compensator necessary for multi-band observations

DP measurements

- Differential phase signal produced by differences in the stellar and planetary spectra
  - each component will contribute different fractions of the total flux at different wavelengths
- Magnitude of DP signal depends on the projected baseline and will change with hour angle
  - this evolution is predictable and can be used to distinguish source and instrumental terms

Model DP signature



- 51 Peg model with blackbody spectra for planet (T = 1300 K) and star (T = 5770 K)

- DP for H to K band

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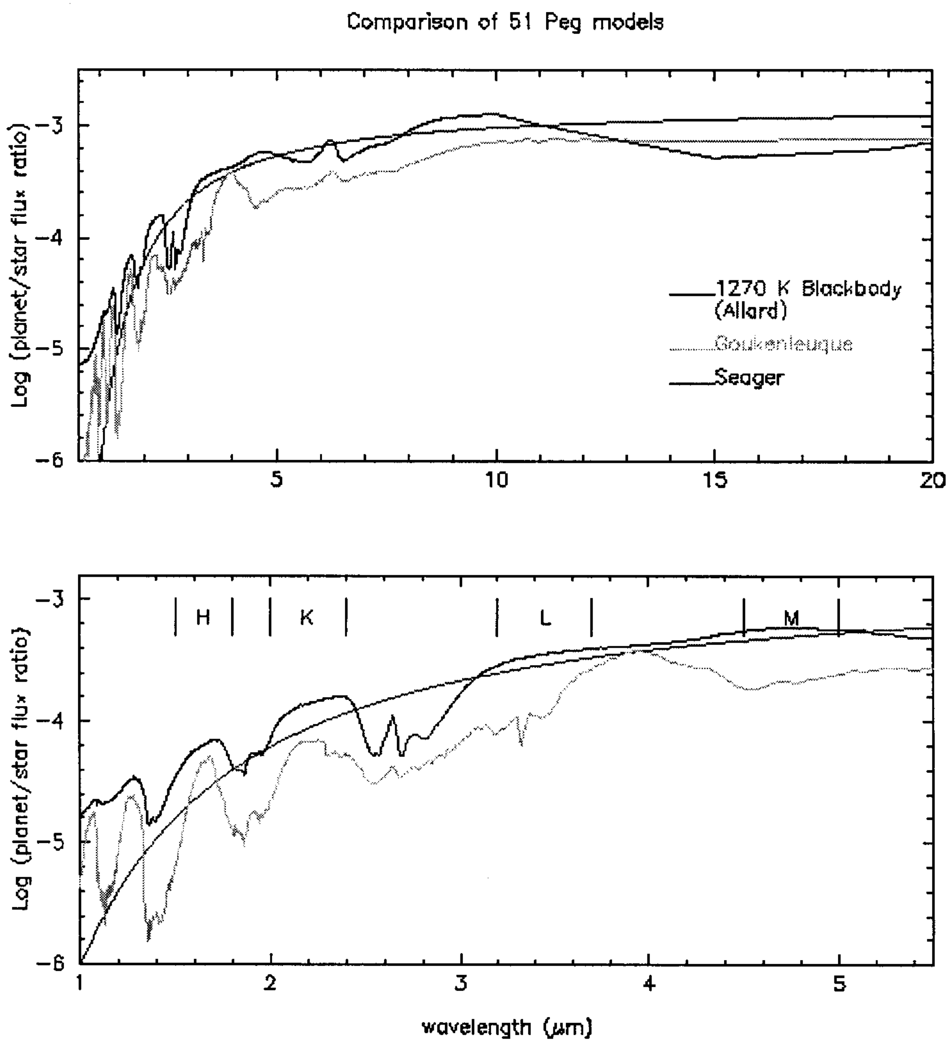
Hot Jupiter properties

- Radial velocity data yields orbital parameters and M/sin i
- Transit observations can yield planet mass and radii (example HD 209458), but only a small percentage of planets will transit the star
- The effective temperature and spectral features of the planetary atmosphere are not known
  - Stellar photons have a large impact on planet atmosphere and spectrum
  - Theoretical models have been calculated by several groups, who predict different spectra

Model spectra



- Model spectra for 51 Peg from three groups (led by Allard, Goukenleuque and Seager)
- Plotted as planet/stellar flux ratio

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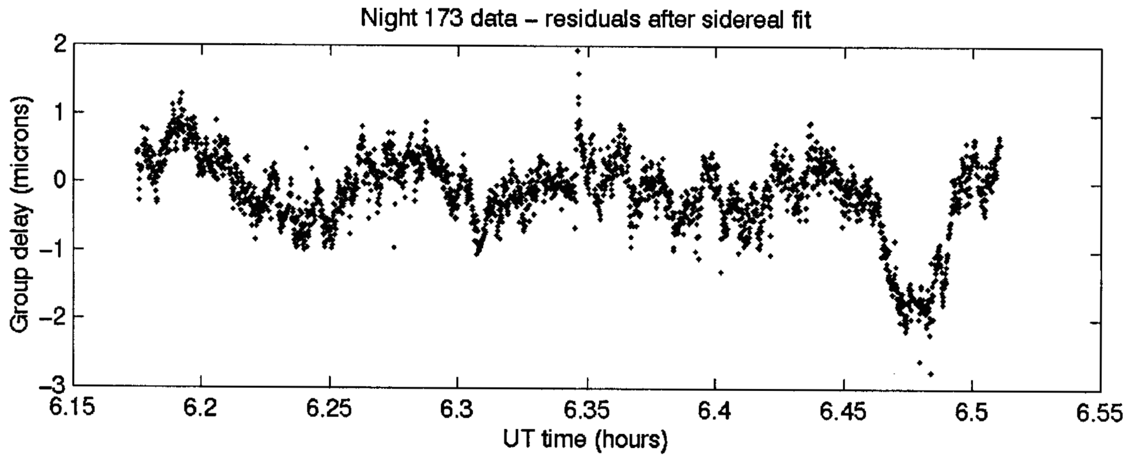
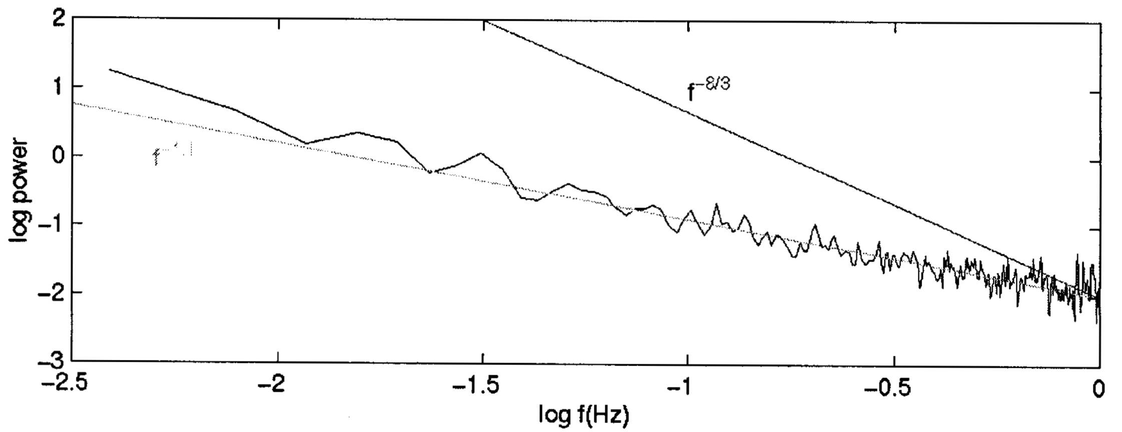
PTI observations

- Demonstration of method
- Use group delay as a proxy for DP
- Stellar binaries as test sources
- Noise in group delay much higher than expected
  - Water vapor dispersion in the infrared is 20 times higher than the value predicted by Edlen or Owens formula
  - Experiment and new modeling (R. Hill at NOAA) agree

Example group delay time series and PSD





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DP detection at PTI

- Stellar binary chosen to have large DP signature and within PTI observing limits
- Spectroscopic binary Iota Peg
  - Orbital parameters measured by earlier PTI study (Boden et al)
  - F5 and G8 main sequence components (6440 K and 5570 K blackbody temperatures)
  - maximum separation 10 milliarcsec

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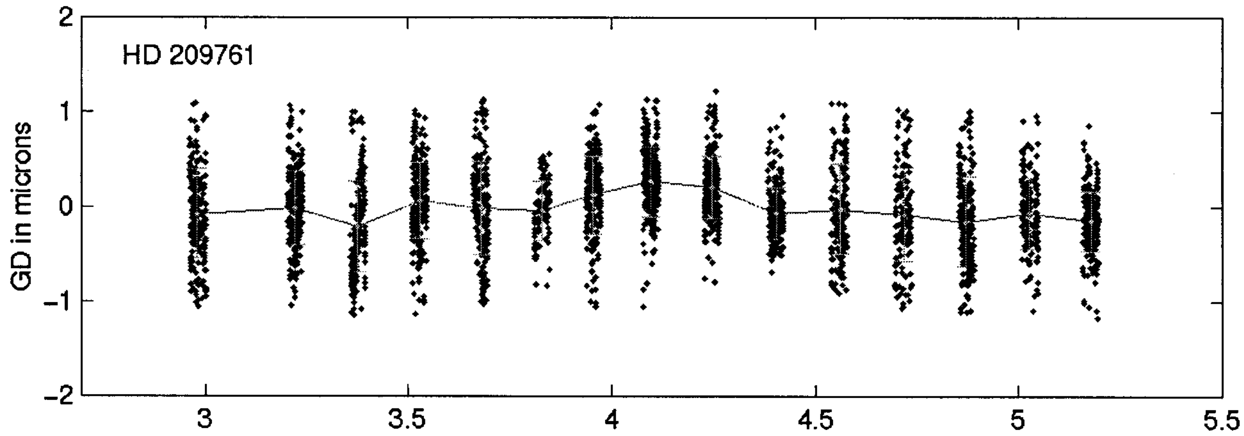
Data reduction

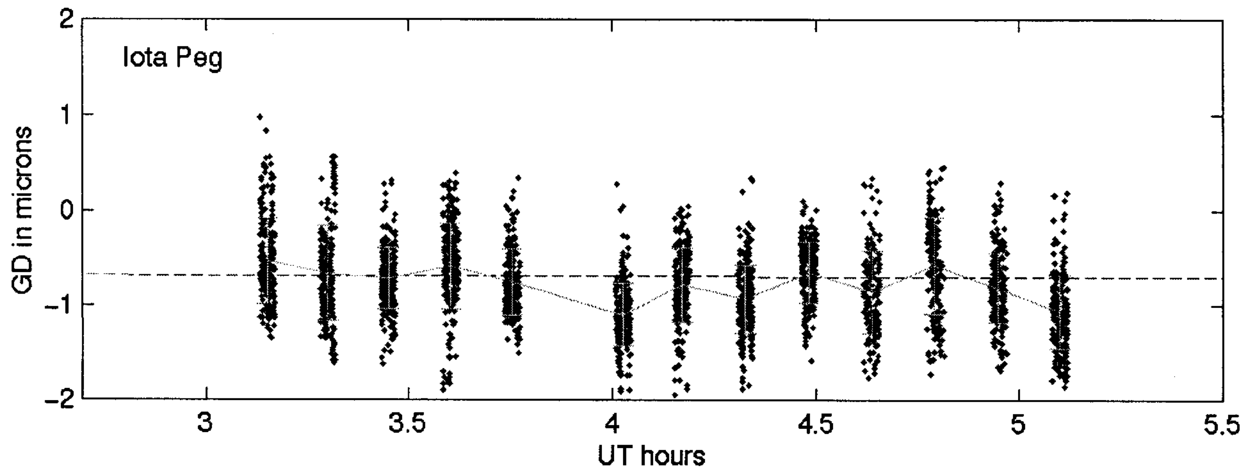
- Compensation of vacuum delay with air path causes sidereal signature in group delay
- Sidereal signature measured on calibrator (HD 209761) and removed from source
- Noise dominated by water vapor fluctuations
  - residuals from sidereal fit show coherent structure

Iota Peg results

Calibrator



Source



- data points are 0.5 sec measurements
- green line is average with error bars
- red line is predicted differential phase (no fit parameters)

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DP at Keck

- Sensitivity goal is 0.1 milliradians
- Water mitigation strategies
  - Dual star measurements when possible
  - Estimation of fluctuations through 1.9 micron water line or other external measurement
  - Use data at 3 wavelengths to separate water and source components
- Instrumental systematics also important
  - stroke length and stability
  - fringe tracking errors
  - wavelength calibration