Optical/IR Interferometry and Exoplanet Science

Mark Swain

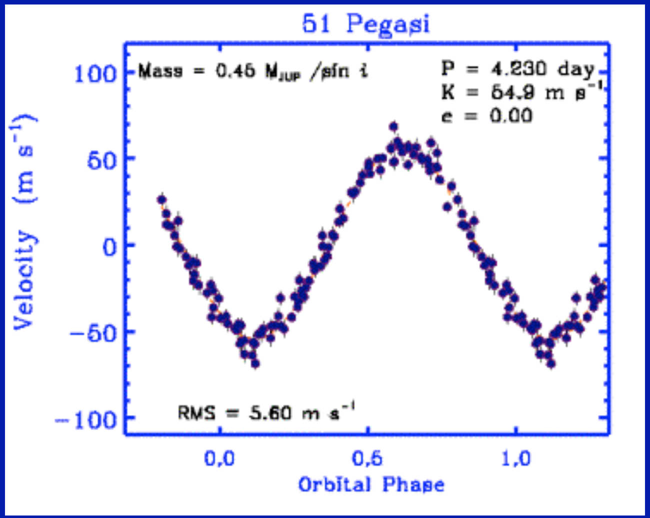
Jet Propulsion Laboratory & California Institute of Technology

Authors View

The subject of exoplanets is rapidly growing and is one of the most vigorous fields in astrophysics today. Unfortunately, the contribution of optical/IR interferometry has been primarily unfilled promises. No major changes in our understanding of exoplanets have resulted from interferometer observations. The future prospects are better and interferometry will likely have an eventual impact in this field. However, optical/IR interferometry must confront the prospect that many of the most compelling questions in the field of exoplanets can, and are, being answered by other means.

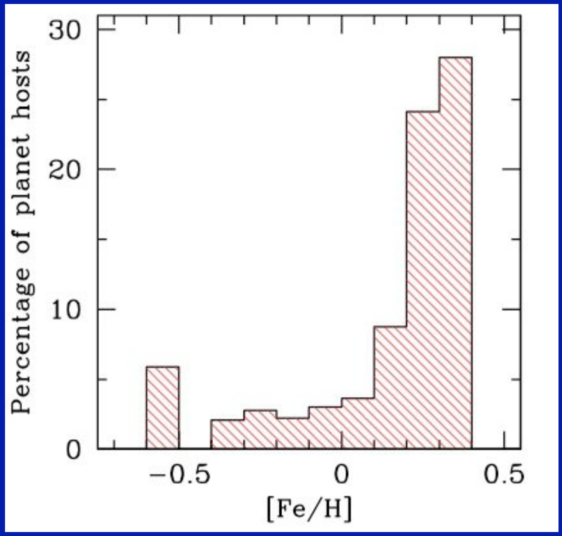
Overview of the Field

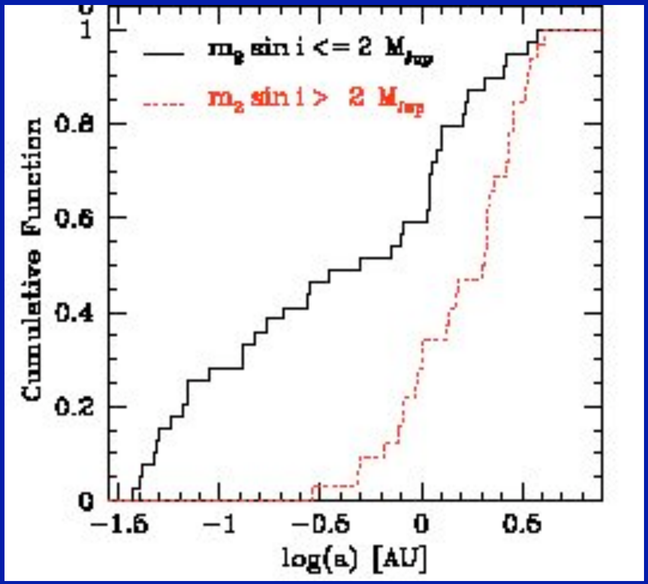
- Currently ~210 extrasolar planets and counting
  - RV (~200)
  - transit techniques (~12)
  - Micro-lensing (~4)
- Population studies
  - Correlation of planet properties with host star
  - Inferences about formation and evolution
- Physical properties
  - Statistical characterization
  - Individual planets
- Extensive theoretical work
  - Formation and evolution
  - Atmospheric physics



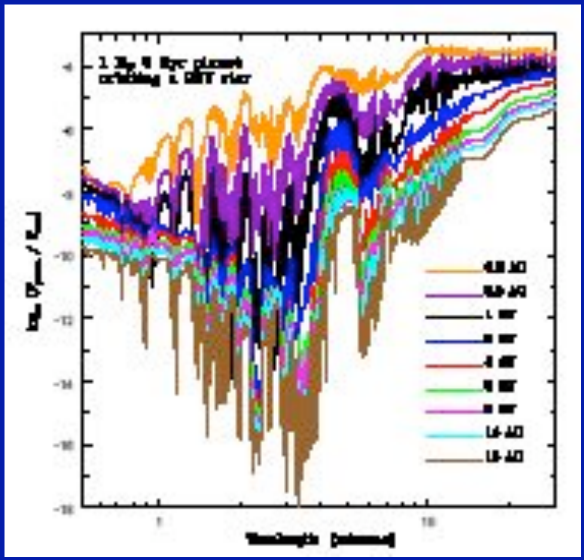
Observational highlights from population studies

- Planets are relatively common
- Jupiter mass planets abound
- Planets more likely to form around metal rich stars
- Planets migrate
- Planets form relatively quickly





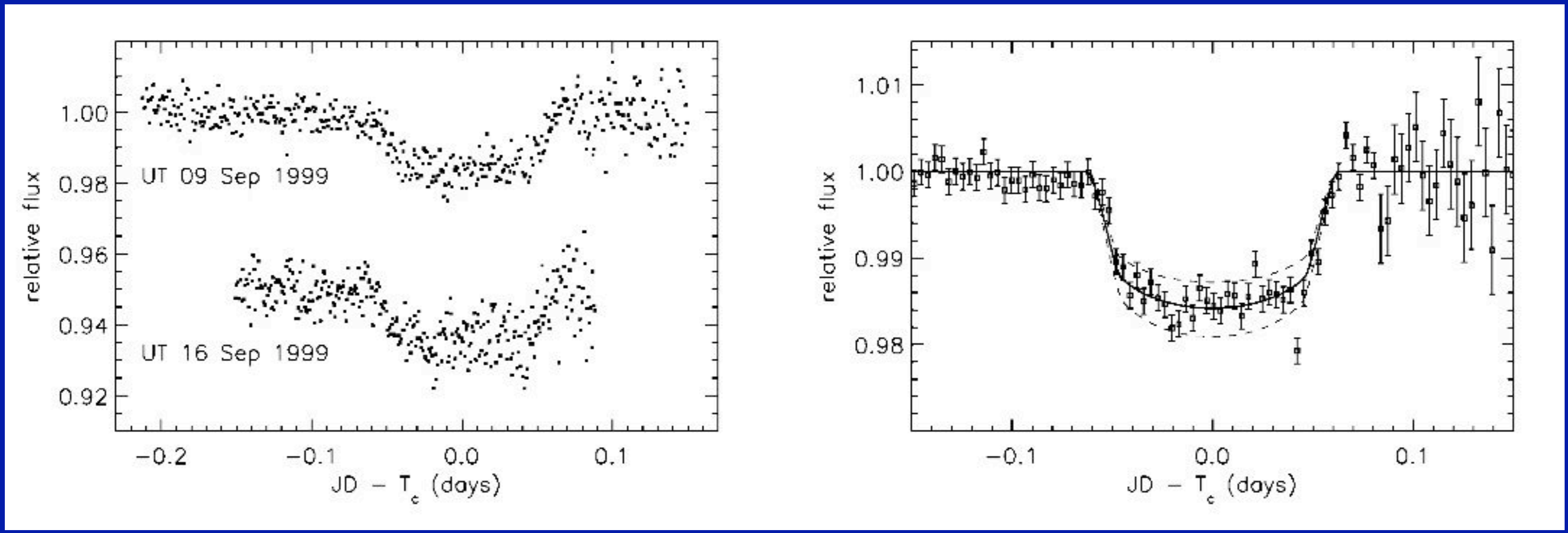
Some Key Questions:



- Formation
  - What is the formation mechanism
  - What governs whether planets form
  - What is the distribution for types of planets formed
- Evolution
  - How do planets interact with the disk
  - How common is migration and what controls it
  - What determines the metallicity of the planet
- Properties
  - What are the basic physical conditions
  - What determines the planet spectrum
  - What molecules are present

Transiting Planets

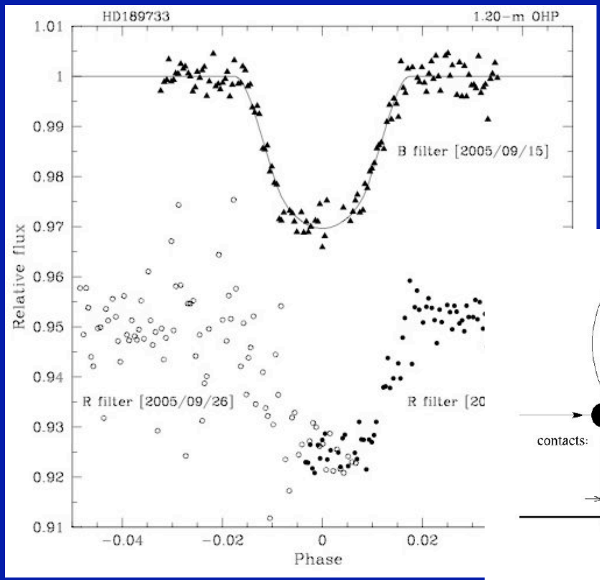
Why all the fuss?

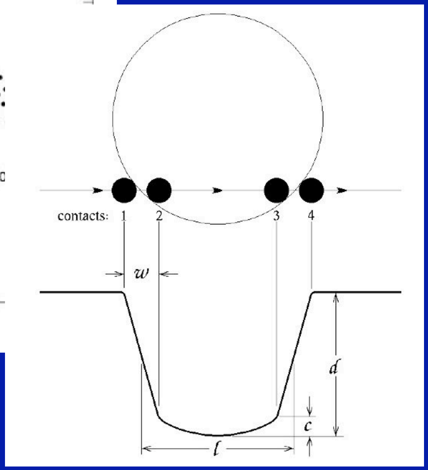


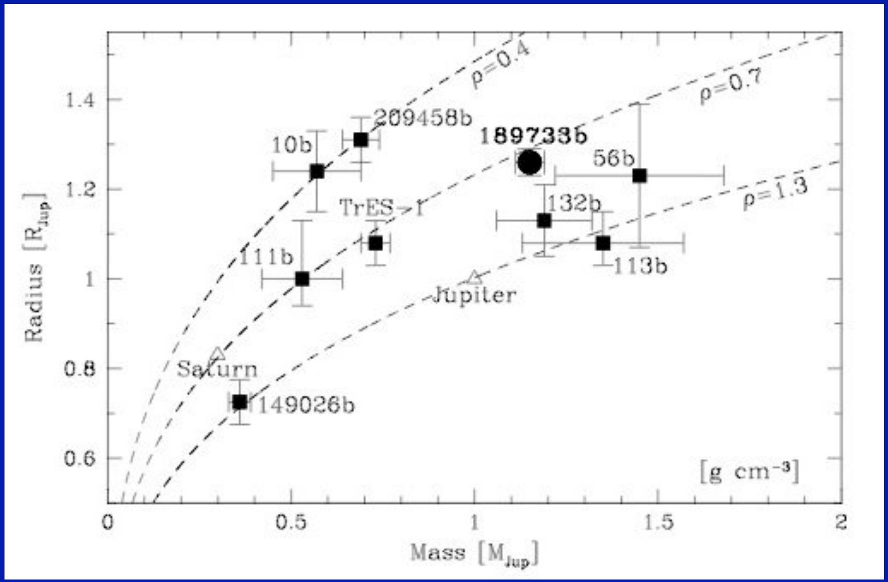
209458b - Charbonneau 2000

Transiting systems: initial impact

- Began with 209458b light curve.
- Allowed measurement of planet mass and density.
- Distinguished transiting planets from RV planets.
- Catalyzed numerous groups to start transit surveys.

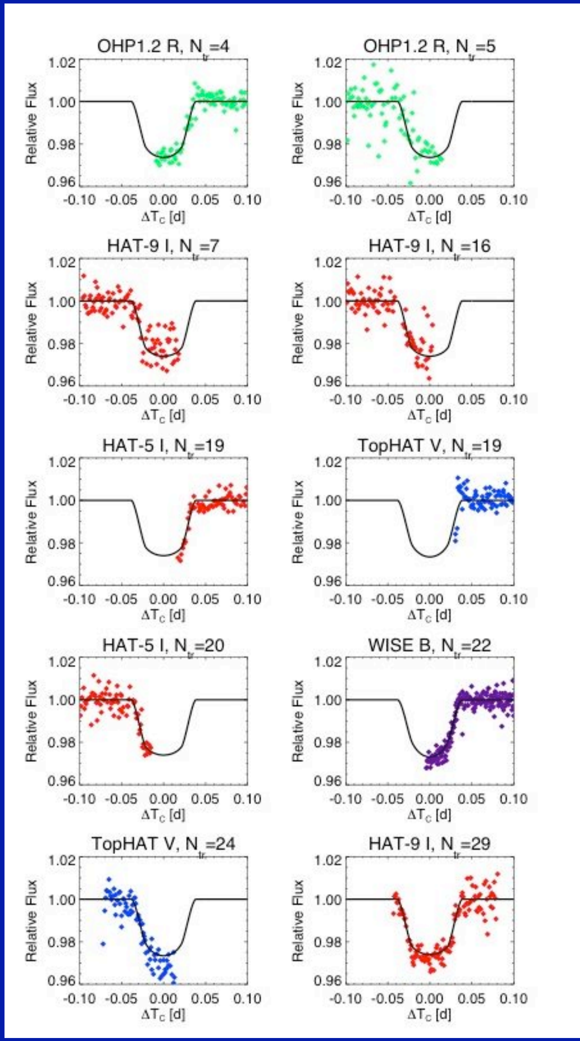






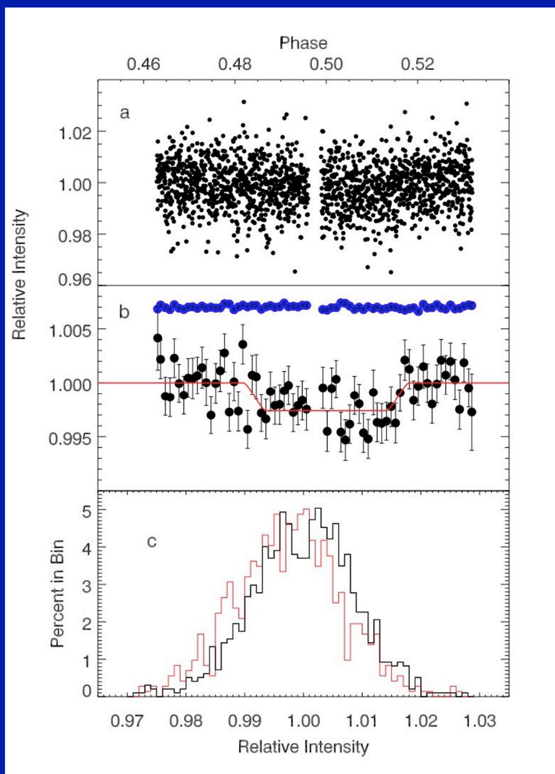
Transiting Systems: topics discussed which are potentially observable

189733b - Bakos 2006

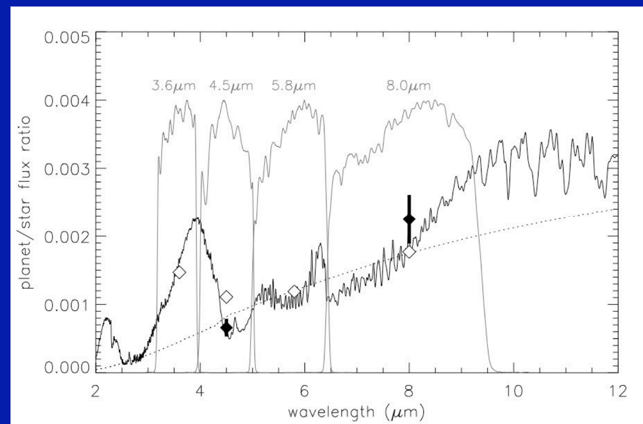


- Temperature a function of wavelength and orbital phase.
- Dayside/nightside temperature difference ~400 K.
- Heat advection and observable signatures of large-scale zonal winds.
- Chemical differences between nightside and dayside.
- Observable signatures of clouds or “surface” structure.
- Atmospheric vertical temperature profile.
- Metallicity effects on planet emission.
- Cloud formation and destruction.

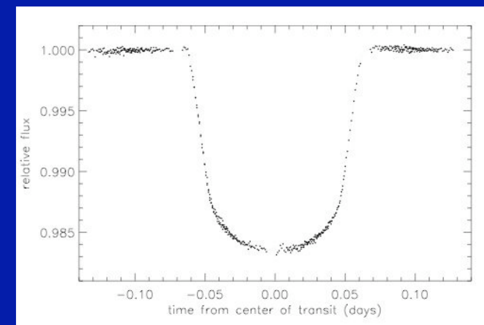
Transit measurement highlights



209458b - Deming 2004



209458b - Charbonneau 2004



209458b - Brown 2001

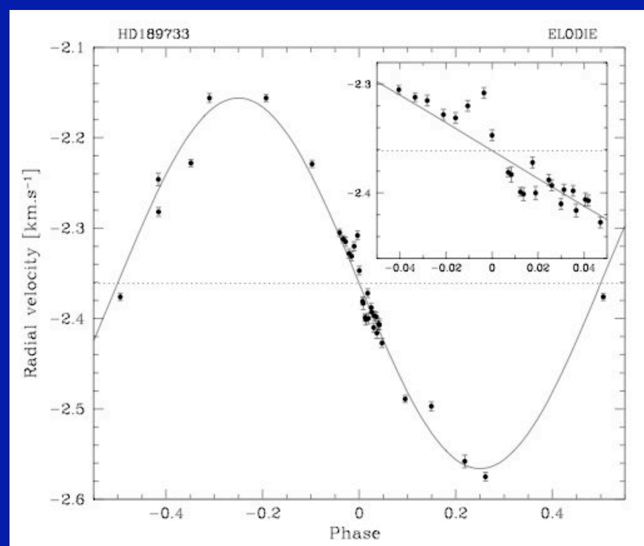
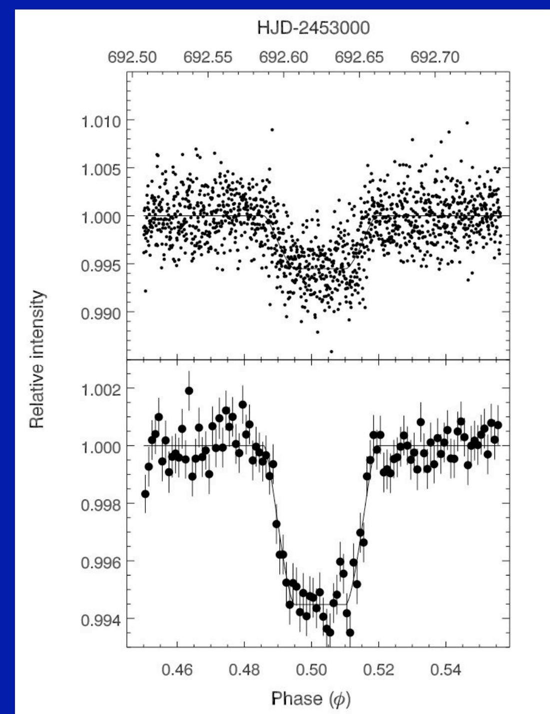


Fig. 2. Phase-folded radial velocity measurements of HD 189733 superimposed on the best Keplerian solution. Error bars represent the photon-noise uncertainties. The inset shows a zoom near phase zero where radial velocities exhibit the Rossiter-McLaughlin effect.

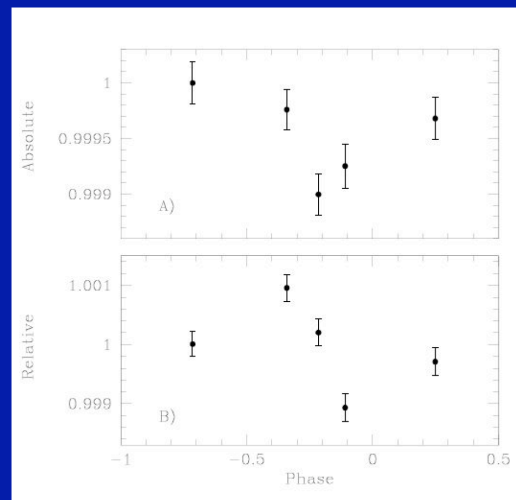
189733b - Bouchy 2005



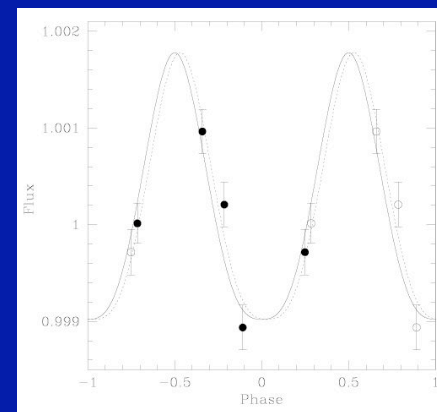
189733b - Deming 2006

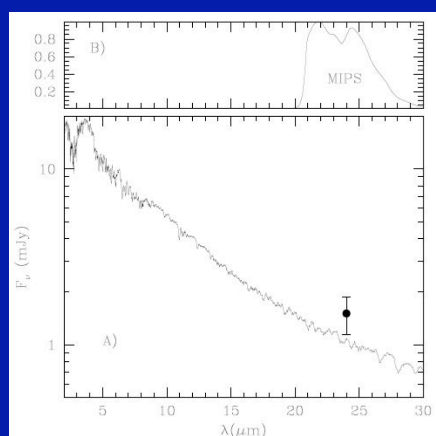
Spitzer MPIS observations of υ Andromeda b

- Non-transiting planet
- 24 μm photometry
- Achieved SNR~5000:1
- 1977 K dayside
- Extreme day/night ΔT
- Profound implications for interferometry
  - IF signal reduction
  - Single aperture potential

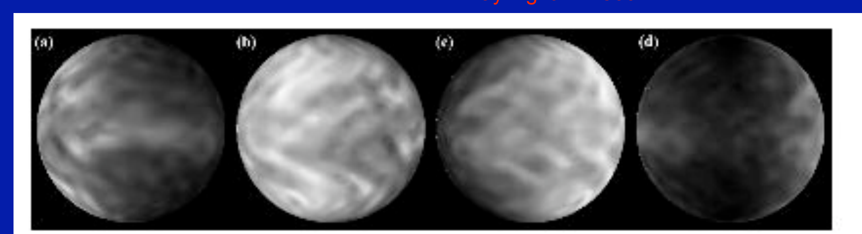


Harrington et al. 2006





Day/night ΔT=500K



Cooper & Showman 2005

Transit theory highlights

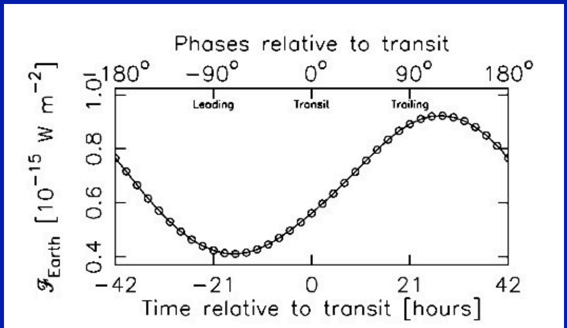
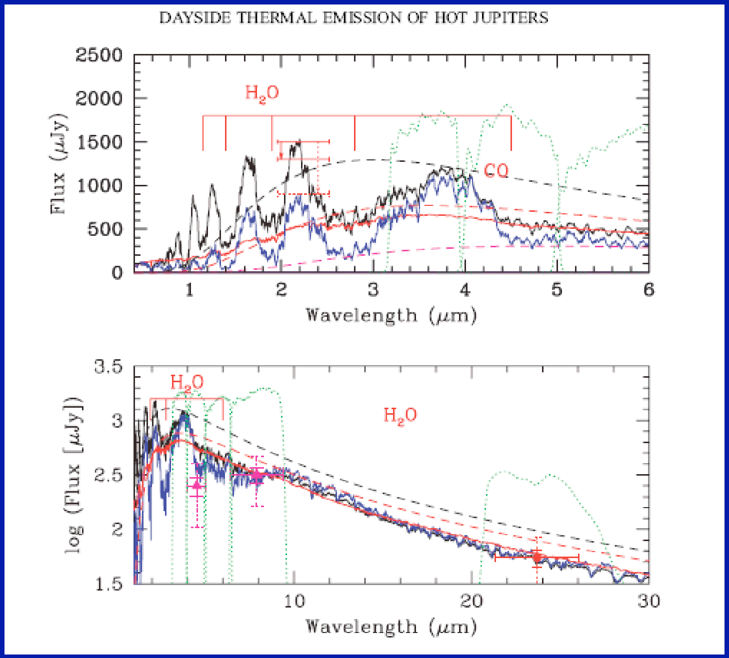
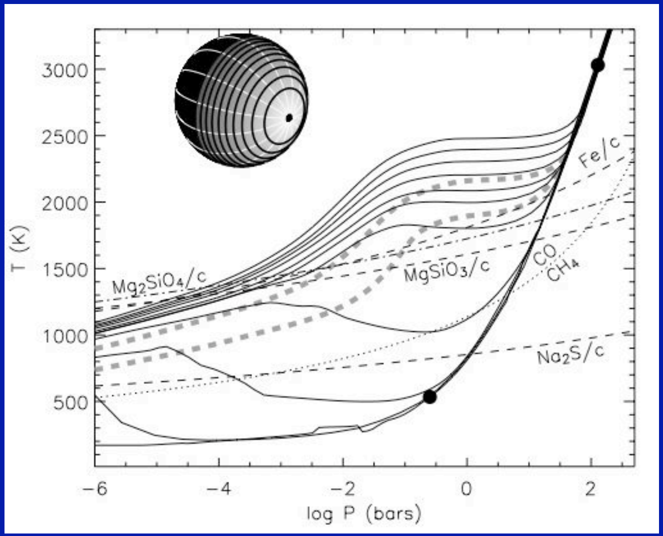


Fig. 3.—Synthetic light curve of the 220 mbar layer of our model atmosphere for HD 209458b. This simulation predicts peak emission from the planet 14 hr *before* the time of the secondary eclipse.

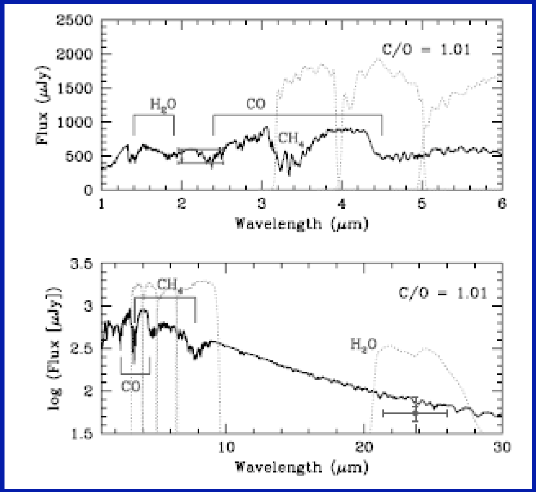
Cooper et al 2005



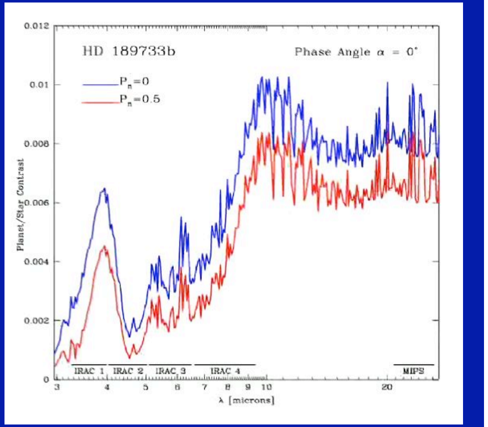
Seager et al 2005



Barman et al 2005



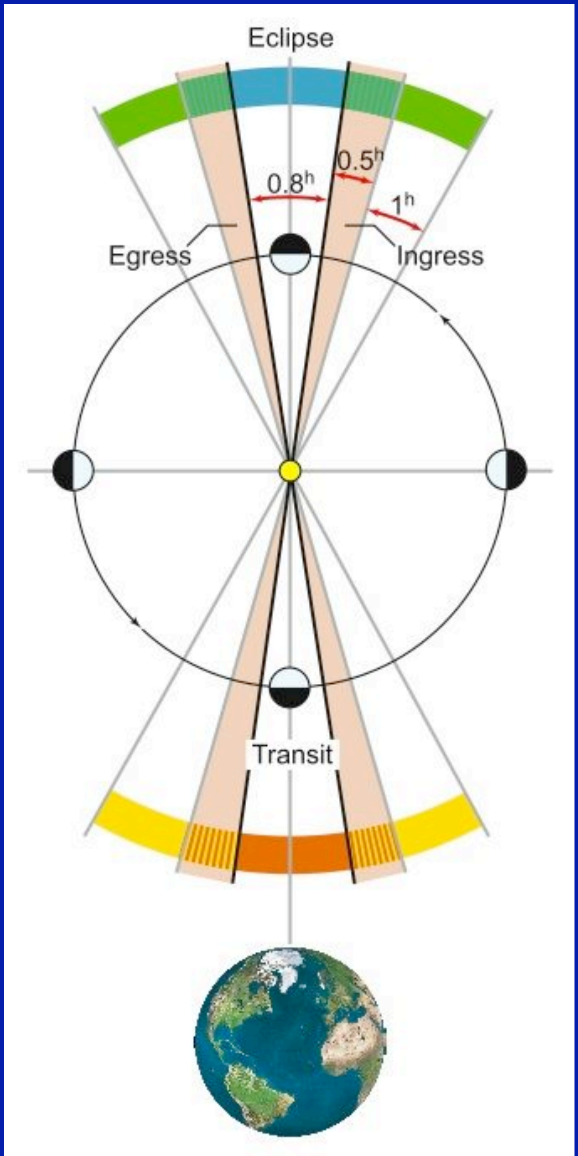
Seager et al 2005



Burrows et al 2006

How the secondary eclipse technique works

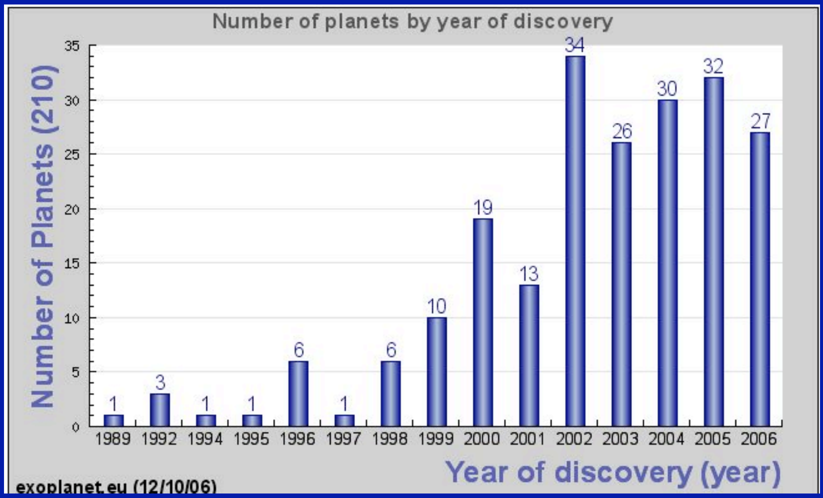
- Observe star when planet is in eclipse.
- Subtract stellar signature.
- Similar approach for possible for nightside.
- Ingress-Egress departure from expected light curve probes "surface" structure.
- Orbital phase based changes in light curve do not require an eclipse but would rely on similar difference approach.



More on transits: what's in the pipeline

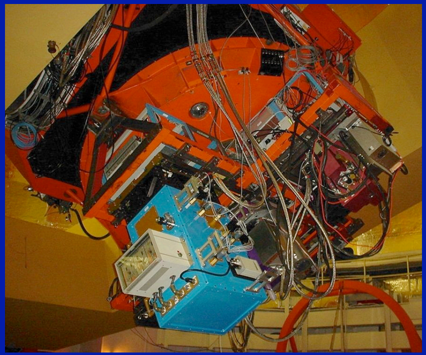
- The data:
  - Dayside flux 3 to 24 microns
  - 5-15 micron spectra of dayside
  - 4 to 8 micron orbital phase resolved light curves
  - 1.4-2.4 micron dayside spectra
- The science:
  - Determination of temperature as a function of wavelength
  - Dayside/nightside temperature difference
  - Detection or limits of advection signatures
  - Identification of molecules governing the atmospheric radiation balance (dayside/nightside chemical changes)
  - Estimation of metallicity and effect on emission
  - Strong implications for weather (wind and cloud formation)

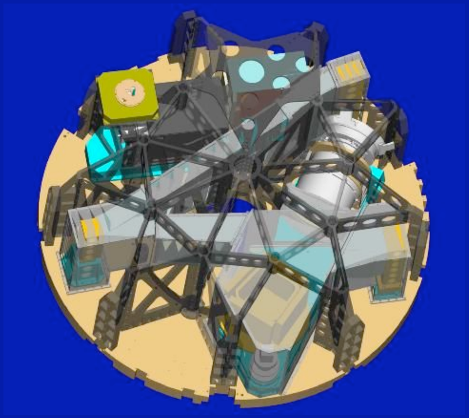
What’s in the pipeline for surveys



- RV everywhere
  - Lots of programs
  - Lower masses
  - Multiple planet systems
  - Better sky coverage
- Transit surveys
  - Lots of programs
  - Hundreds of candidates per year
  - Extensive follow up programs
- Extensive targets for detailed study of individual objects

Exoplanet spectroscopy attempt: a case study

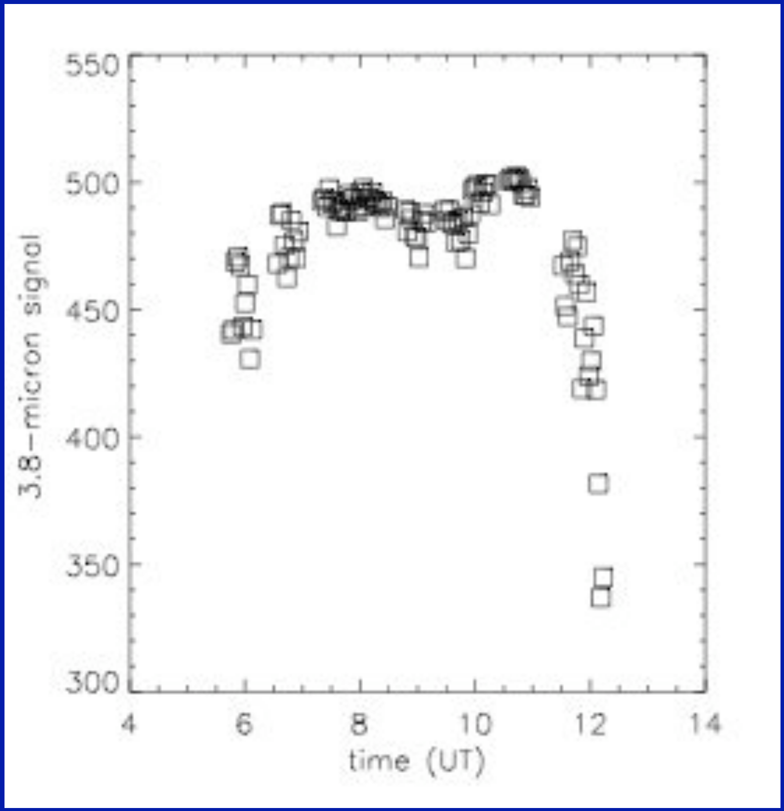




- It started as an interferometry project…
- Five proposals
- Four accepted
- 4 nights IRTF
- 2 half nights VLT
- 1 night VLTI
- 10 HST orbits

Results to date?

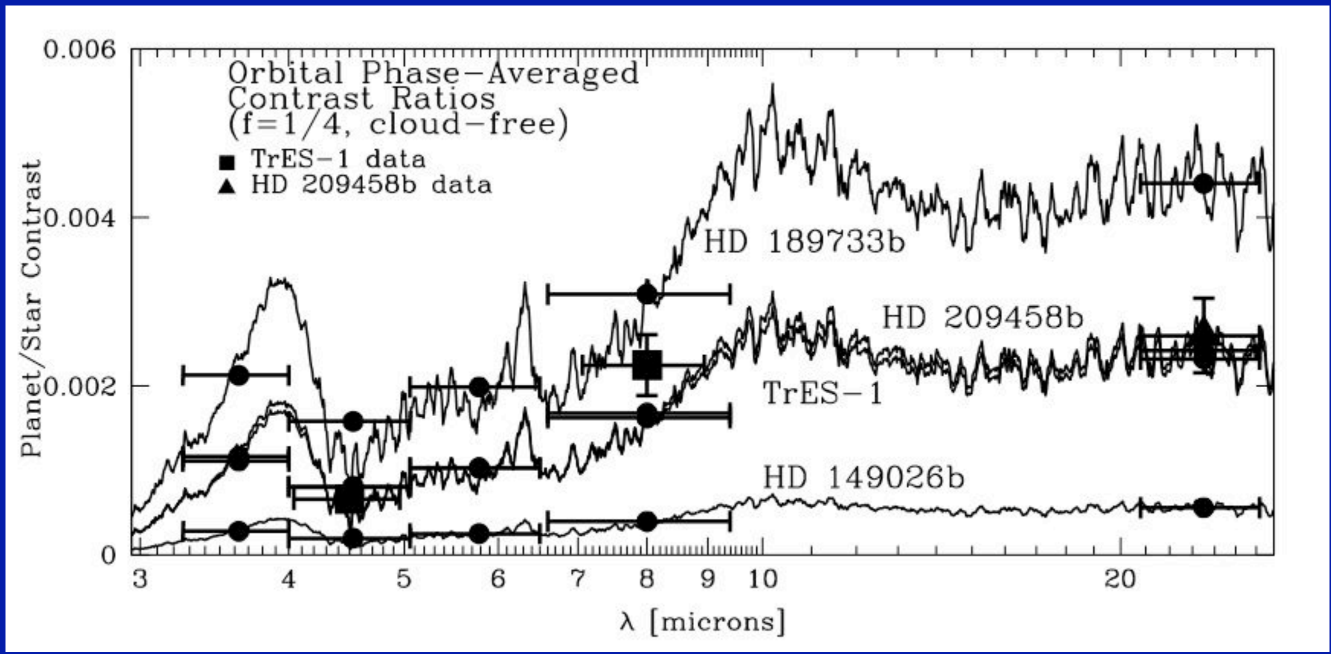
- AMBER: run weathered out
- VLT SPIFFI: bad weather for first run but ok weather for second - data in hand
- IRTF: bad weather on one night out of 4- data reduction in progress.
- HST orbits to be scheduled ~ March 07.



Sky time - the essential ingredient

- Debugging precision modes requires lots of sky time.
- Ex: 4 nights of IRTF time for secondary eclipse spectroscopy.
  - Involving foremost secondary eclipse observer.
  - Second major effort with IRTF/SPEX.
  - New calibration ideas.
  - Extensive experience base from VLT and Keck.
- Allocation ~10 nights before the first detection.
- This is a simple instrument and a simple experiment - published limit is ~3000:1 dynamic range.
- How many nights do you need to get to 10,000:1 dynamic range using closure phase?

Exoplanet Atmospheres: where is the discovery space?



Charbonneau 2006

- and perhaps K band…

Plausible interferometry exoplanets science: ~10 year time horizon

Key Science	Technique	Instrument	Time Frame	Potential Impact
Exozodi	Nulling	KI nuller LBTI	1-3 yr 3-6 yr	limited modest
Planet detection	Astrometry	PTI PRIMA	1-3 yr 7-10 yr	limited significant
Planet flux, spectra	Closure phase	MIRC AMBER MATISE (?)	2-5 yr 2-5 yr 7-10 yr	limited modest significant
Planet signature in disks	Closure phase & Imaging	MIRC AMBER MATISE (?) LBTI MROI New instr.	2-5 yr 2-5 yr 7-10 yr 3-6 yr 5-10 yr 5-10 yr	significant significant significant modest++ limited ?

Interferometric imagers and instruments - possible exoplanet science potential

- LINC/NIRVANA
  - Large unique discovery space potential but mostly not connected with exoplanets
  - YSO disk imaging; will the dynamic range/resolution be sufficient to detect exoplanet related structure?
- Single aperture interferometry instrument concepts;
  - Single aperture nullers
  - Spatially filtered, non-redundant pupil
  - Interferometric spectrometer

Looking Ahead: where does interferometry fit in?

- The picture in ~ 2 to 4 years:
  - Hundreds of planets
  - Dozens of transiting planets
  - Well established statistical trends
  - Detailed knowledge of atmosphere 2 or 3 hot-Jovians
  - Measurements of a “hot rock” near an M star
  - People gearing up for secondary eclipse methods with JWST

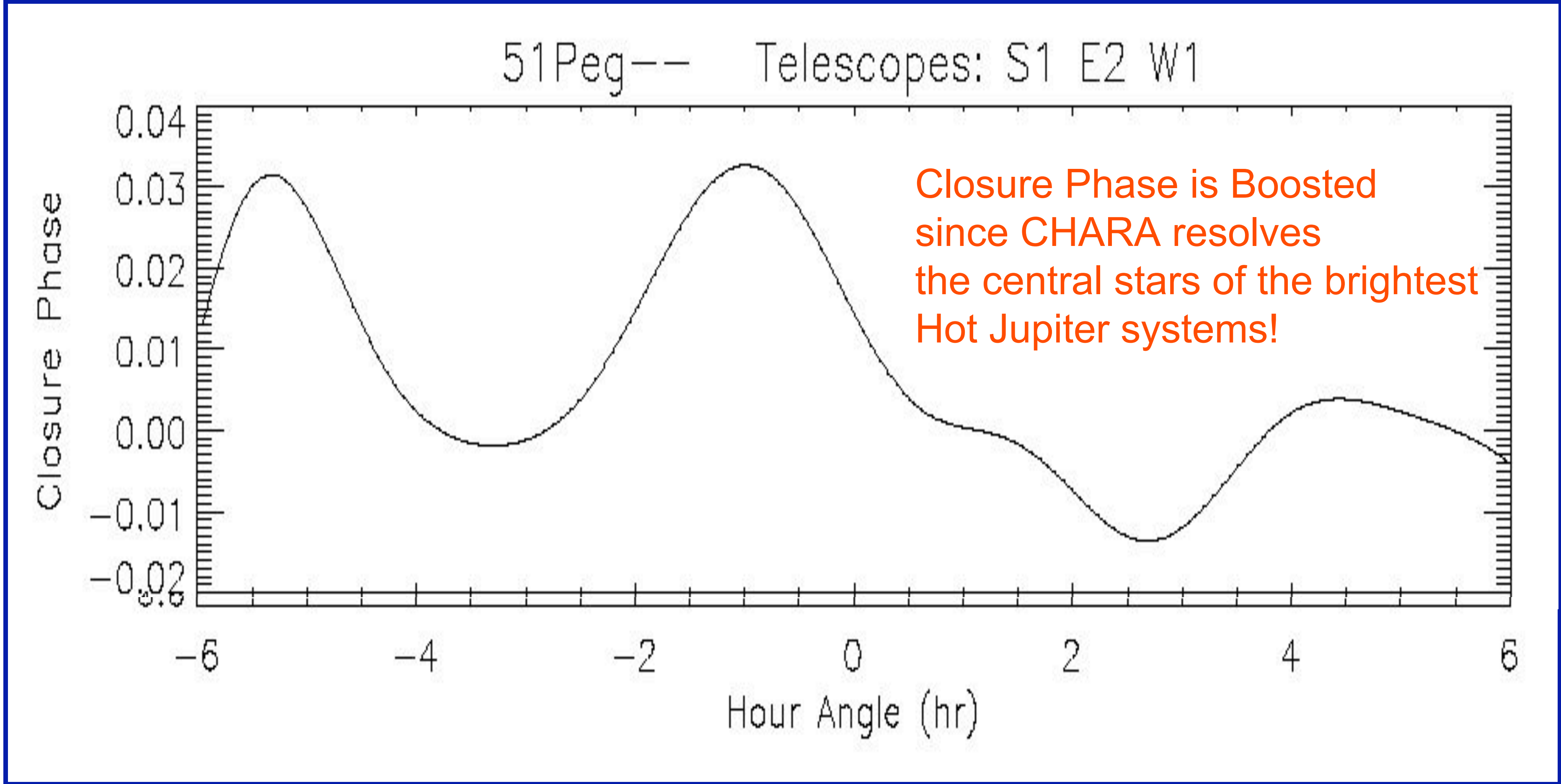
- To have an impact…
  - Find lots of planets
  - Find planets around new hosts
  - Measure lots of hot-Jovian spectra
  - A few spectra of warm planets
  - Characterized the disks where planets may be forming

Exoplanet Interferometery
- draft recommendations -

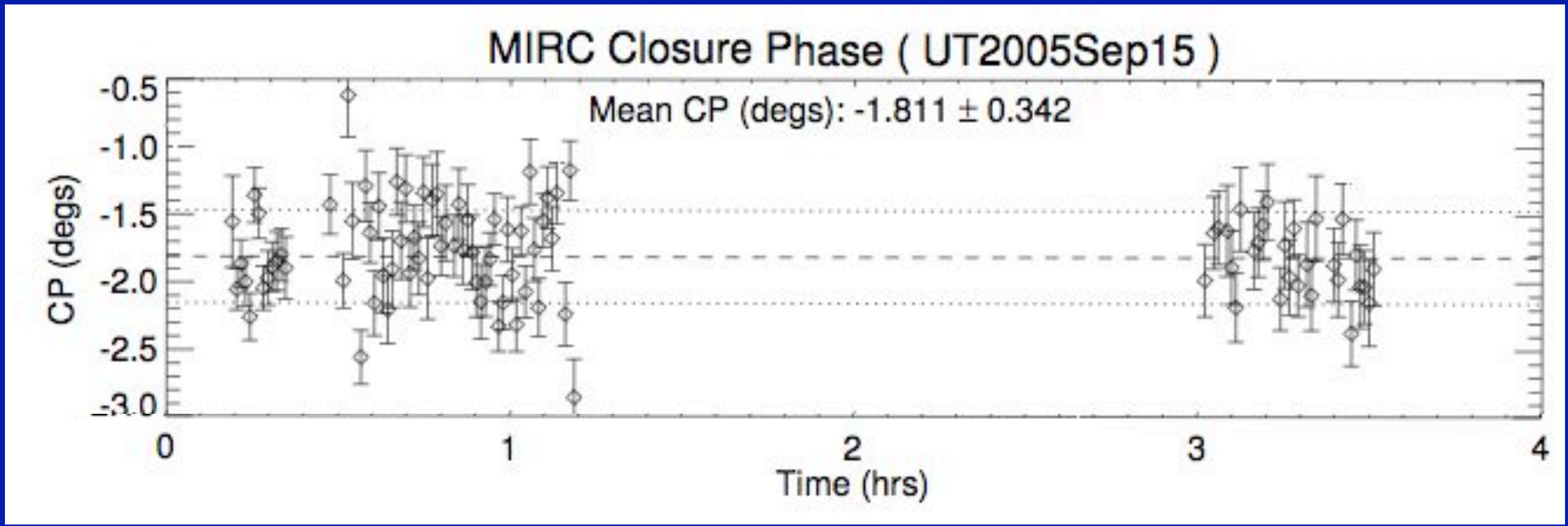
- Do not, unless the instrument is extraordinary, base the raison d'etre for a new interferometer on exoplanet science.
- Do provide large blocks of time to debug high-precision modes.
- Do provide guest instrument access.
- Do provide closure phase capability.
- Do provide L band.
- Do provide active fringe tracking for K>7.
- Let KI/LBTI do nulling.
- Let VLTI do astrometry.
- Consider upgrade to CHARA as an intermediate step.
- NPOI++ possibly useful with major modifications?

Hot Jupiters at CHARA

-- and KI/VLTI



First Peek at CHARA Closure Phases



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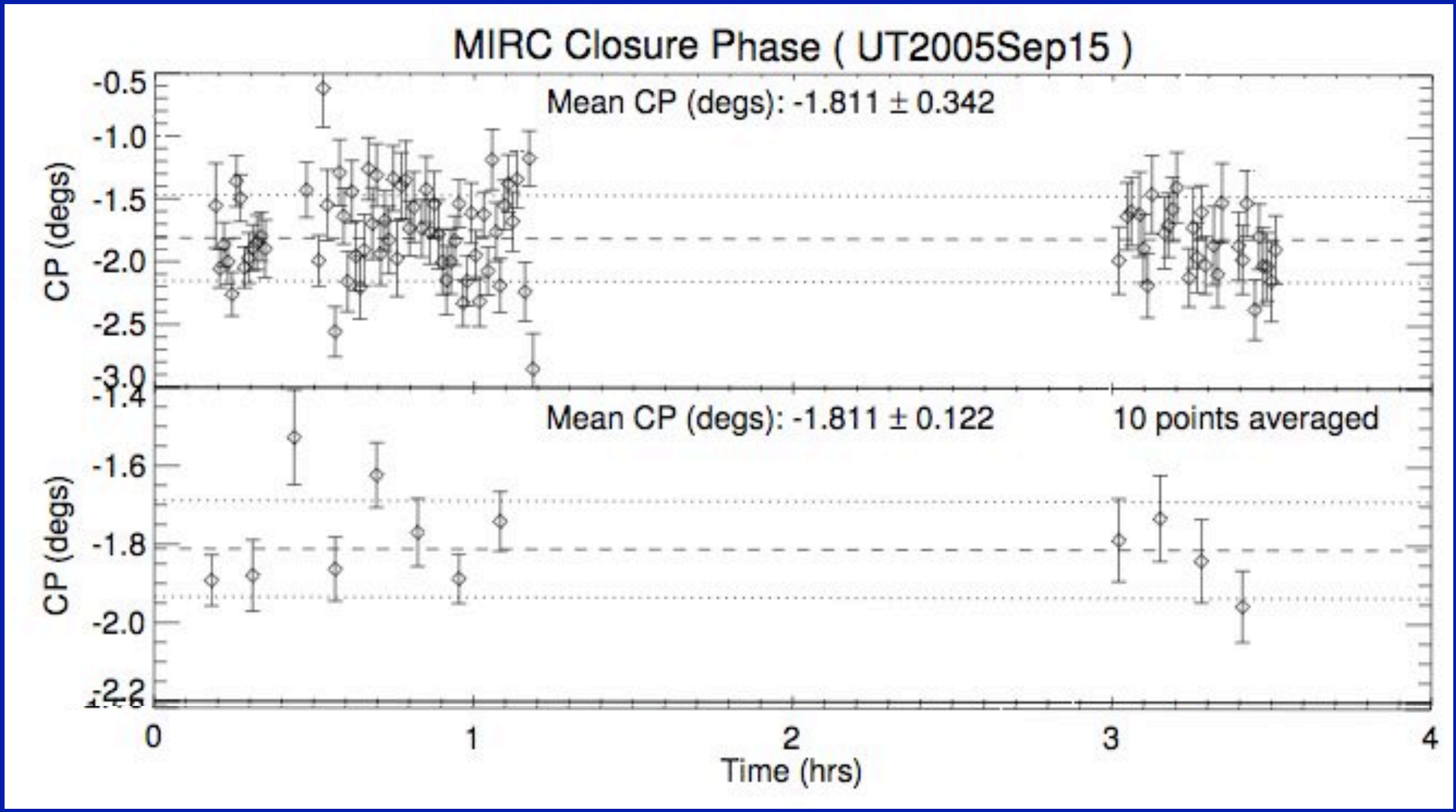

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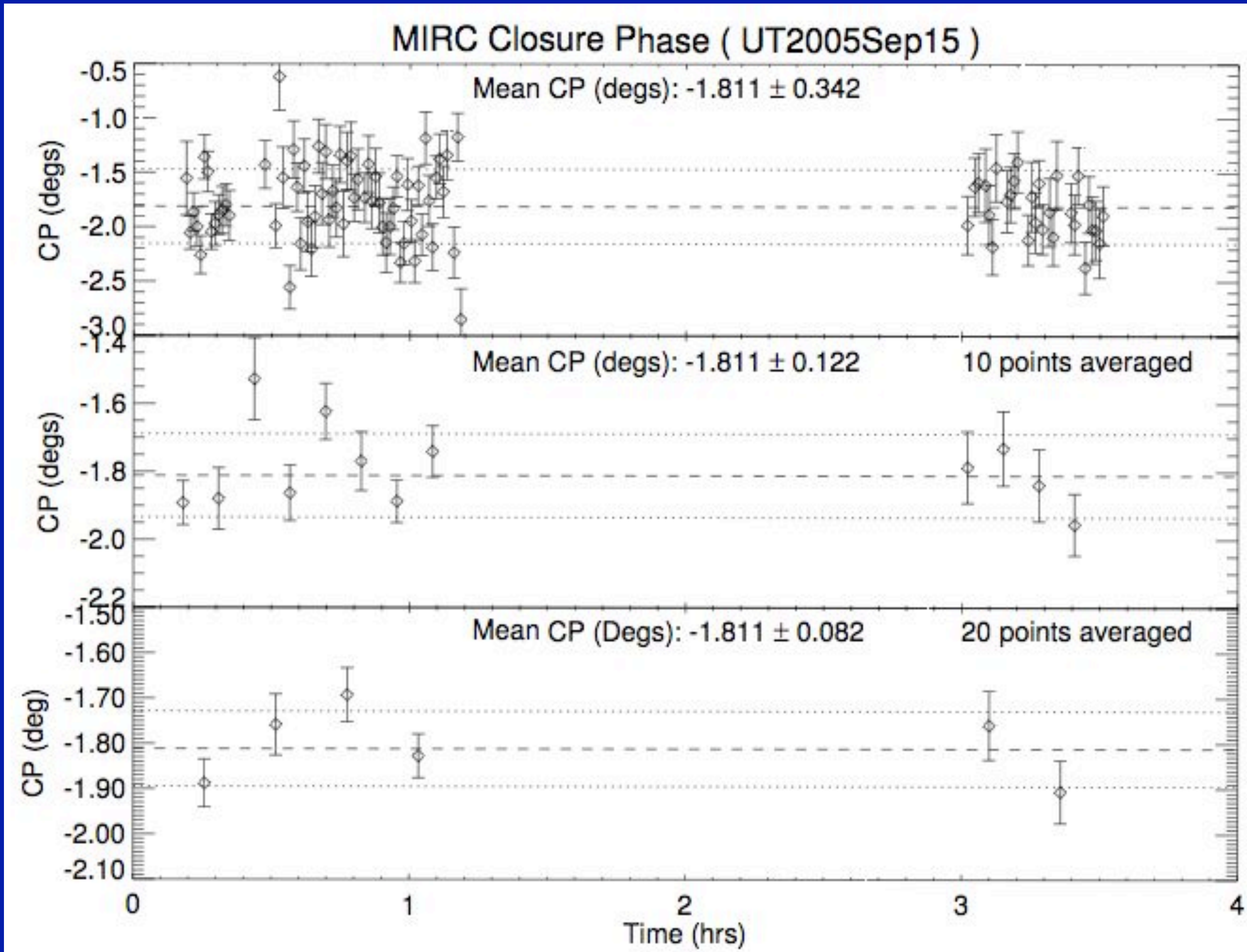

Zhao et al

YSO/Exoplanet Interferometery
- draft group think -

- Structure of planet forming disks: (Initial conditions, efficiency, migration - detection)
  - Req: imaging-uv, 0.5-23 um, 1.5 km, high dynamic range).
- Exoplanet dynamics: follow up known planets, astrometric search.
  - Req: 10 microarcsec astrometry, stars RV can't do, K=17
- Masses/diameters of young stars: (gravity, age).
- Resolving planetary diameters/rings etc: (rings, atmosphere).
- Exoplanets mass, orbital radius, age: photons, spec. of planets.
- Structure of debris disks: exozodi, dust composition, ast. Belts
  - High dynamic range, spectroscopic.
- Accretion process/geometry (onto star): .
- Stellar B field structure & rotation: spot rotation etc.
- Themes:
  - creation and evolution of planetary systems
  - Star formation and early stellar evolution
- Instrument priorities (ordered)
  - Imaging, H-N, 10^4-10^6 dynamic range, ~0.05 AU in Torus, ~20x20 pix