# MIRC Closure Phase Studies for Detection of Hot Jupiters

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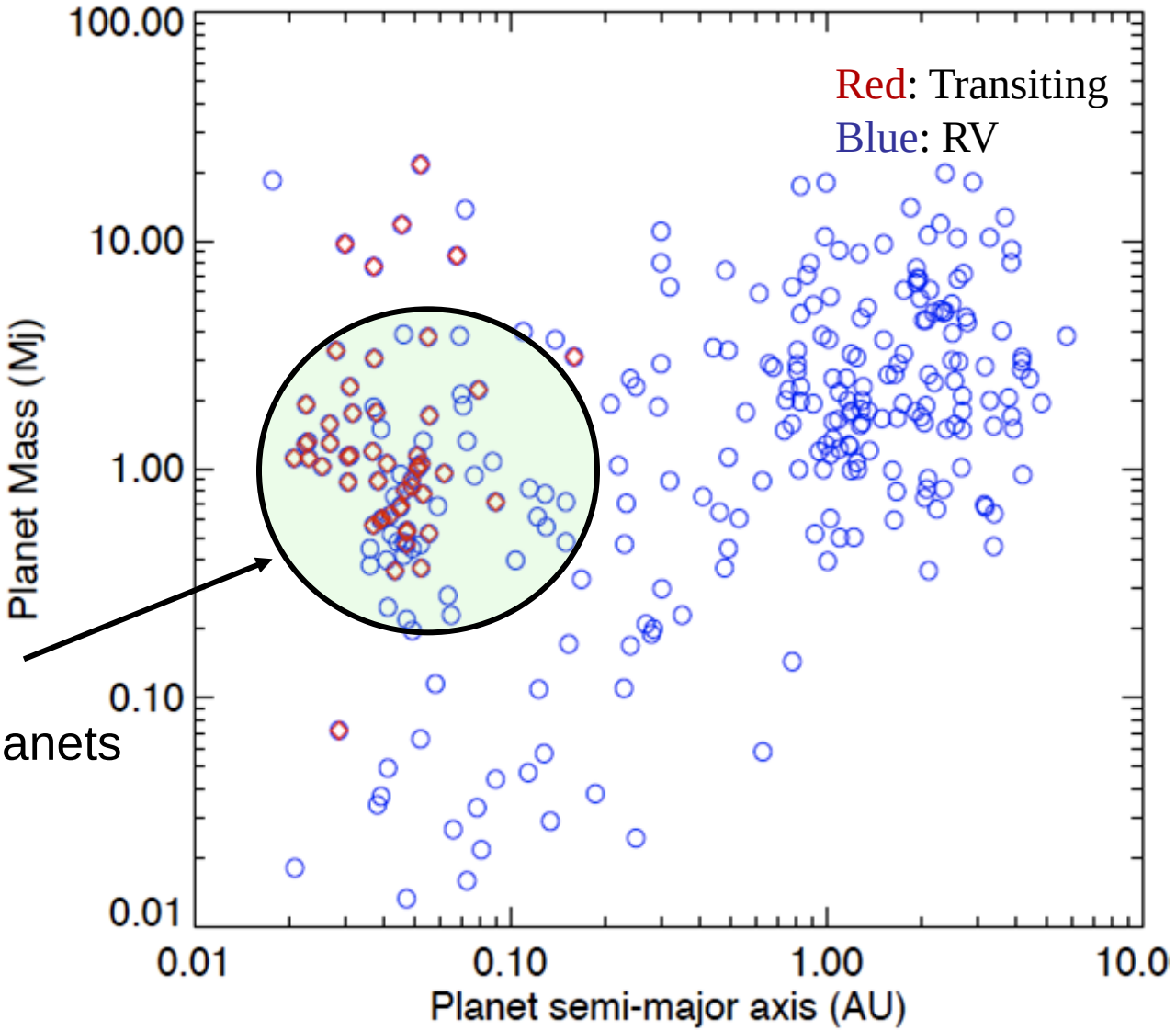
- ~430 exoplanets
- ~400 RV
- 69 Transiting

- ~20% of RV planets;
- >50% of transiting planets

# Hot Jupiters




(REF: The Extrasolar Planets Encyclopaedia)

# Why Hot Jupiters?

- Most approachable to characterize with current technologies
- Interesting features in the atmosphere:
  - Full of molecular bands: $H_2O$, $CH_4$, CO, $CO_2$
  - Clouds in the atmosphere, causing thermal inversion
  - Day-night flux variation: strong winds, heat redistribution

=> Atmospheric characteristics may be similar to those of super Earths

# Existing Direct Detections of Hot Jupiters

- 15 were directly detected by Spitzer, HST, and ground-based observations

  - Secondary transits:

    *HD 209458b, HD 189733b, Tres-1b, HD 149026b, OGLE-TR-56b, Tres-3b, CoRot-1b, HD80606b, XO-1b, Wasp-19b, Wasp-12b, Tres-2b, XO-2b*

    (Deming et al. 2005, 2006; Charbonneau et al. 2005; Harrington et al, 2007; Knutson et al., 2007, Snellen et al. 2009, Laughlin et al. 2009, Anderson et al, 2010, etc.)

  - Non-transiting:

    *HD 179949 b, Ups And b*

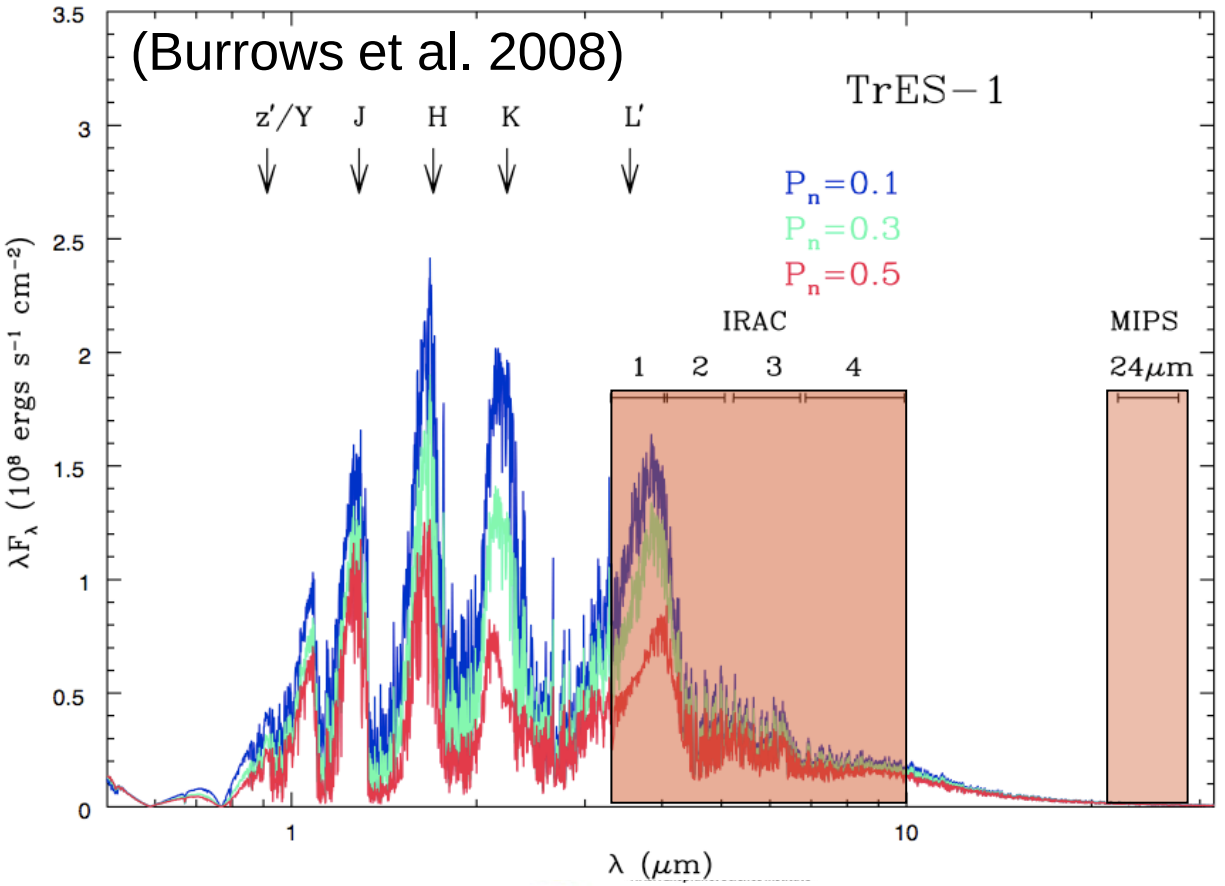
    (Harrington et al. 2006; Cowan et al. 2007)

# What can interferometry add to the science of hot Jupiters?

1). Spectral information in the near-IR

- Estimate global energy budget of hot Jupiters

• IRAC and MIPS cover only a small fraction of SED



# What can interferometry add to the science of hot Jupiters?

1). Spectral information in the near-IR
- Estimate global energy budget of hot Jupiters

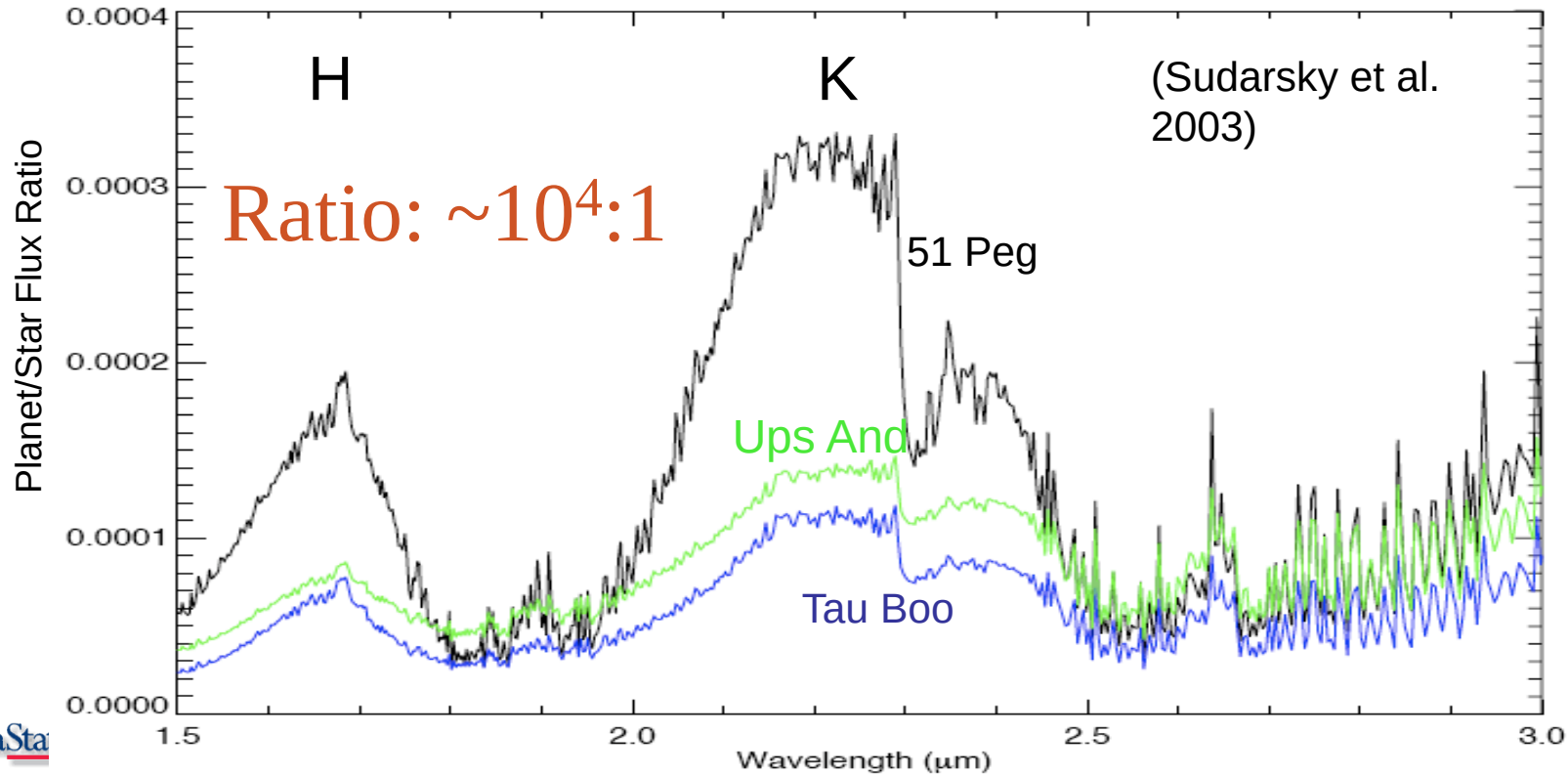
2). Day/night flux variation and flux calibration for non-transiting hot Jupiters
- Break down model degeneracy

3). Obtain inclination and determine accurate mass for non-transiting hot Jupiters
- Interferometers can see hot Jupiter systems as high contrast binaries

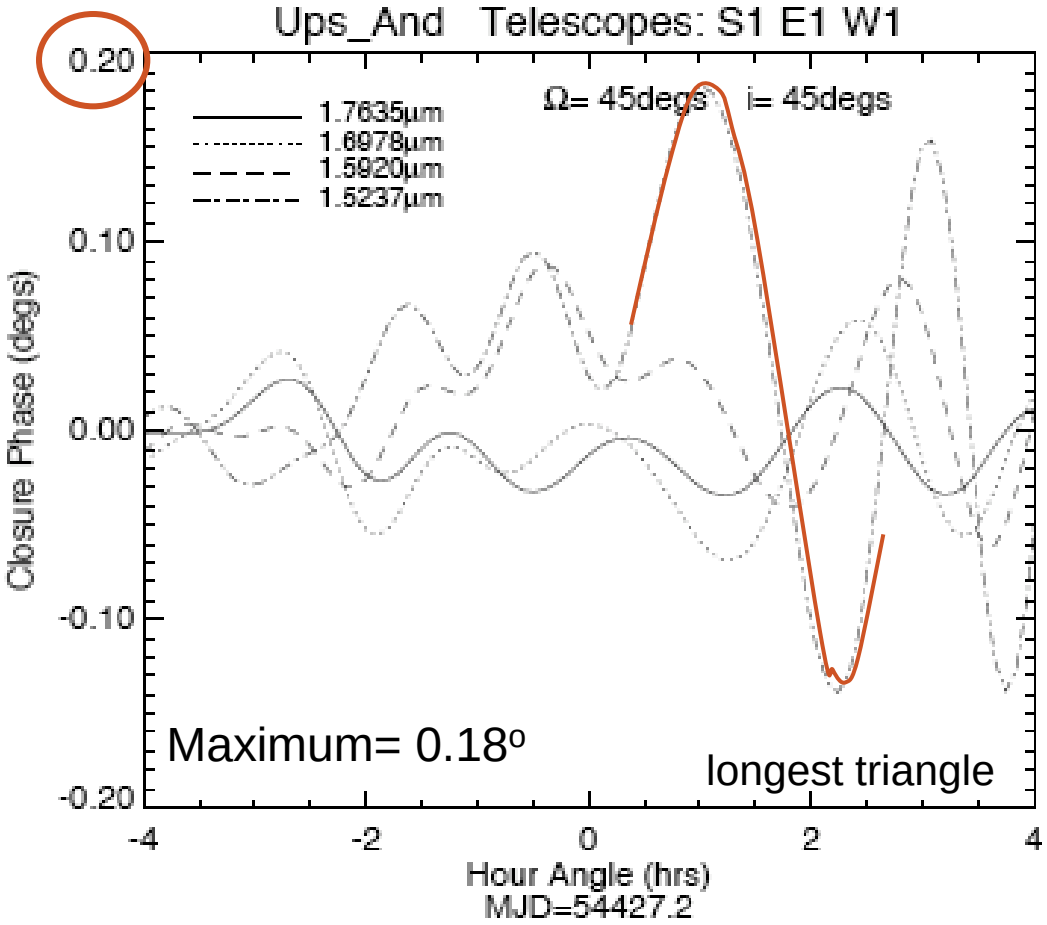
# Best Candidates

Table 1. Hot Jupiter candidates for CHARA-MIRC

| Star Name | Dist. pc | H mag | K mag | Period day | $e$ | Semimajor axis AU | (mas) | $T_0$ JD | $R_*$ mas |
|---|---|---|---|---|---|---|---|---|---|
| $\upsilon$ And | 13.5 | 2.957 | 2.859 | 4.6170 | 0.034 | 0.059 | (4.42) | 2450088.64 | 0.569 |
| $\tau$ Boo | 15.6 | 3.546 | 3.507 | 3.3128 | 0.018 | 0.049 | (3.13) | 2451653.968 | 0.45 |
| 51 Peg | 15.4 | 4.234 | 3.911 | 4.2310 | 0.01 | 0.051 | (3.31) | 2450203.947 | 0.35 |

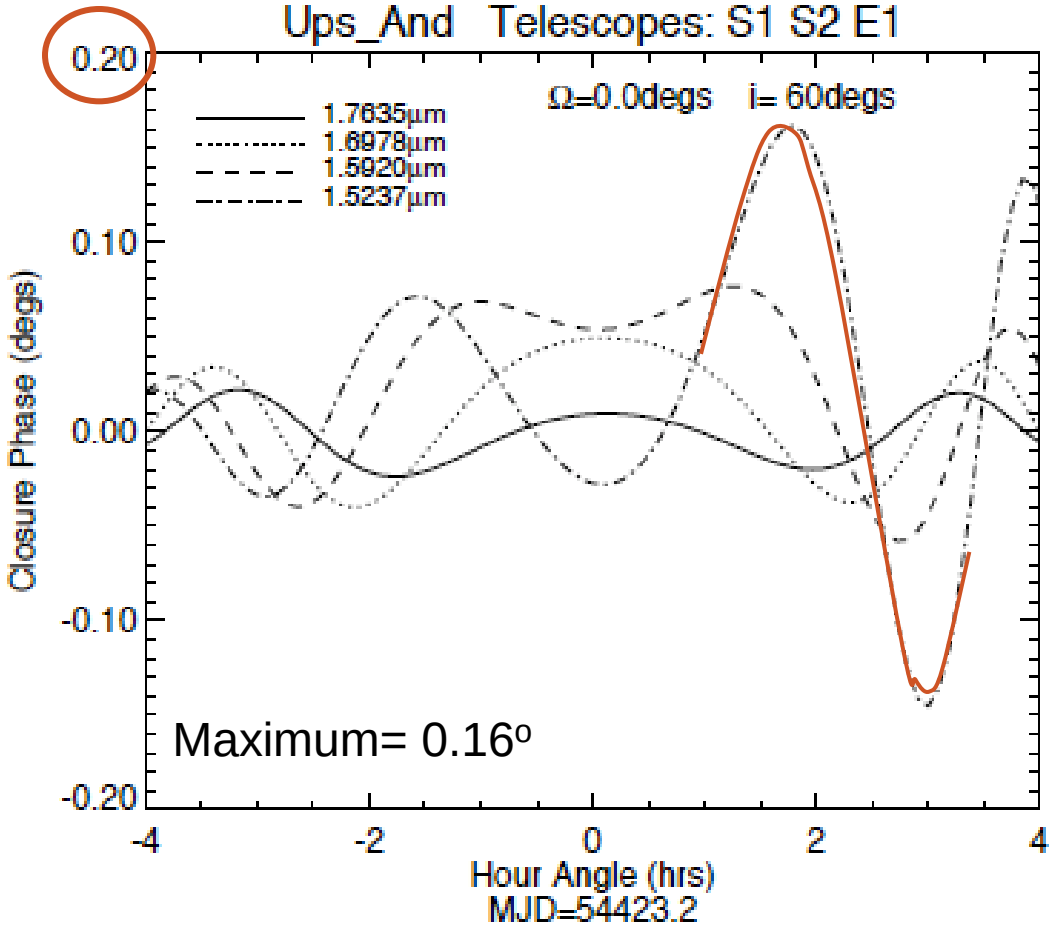


# Closure phase simulation

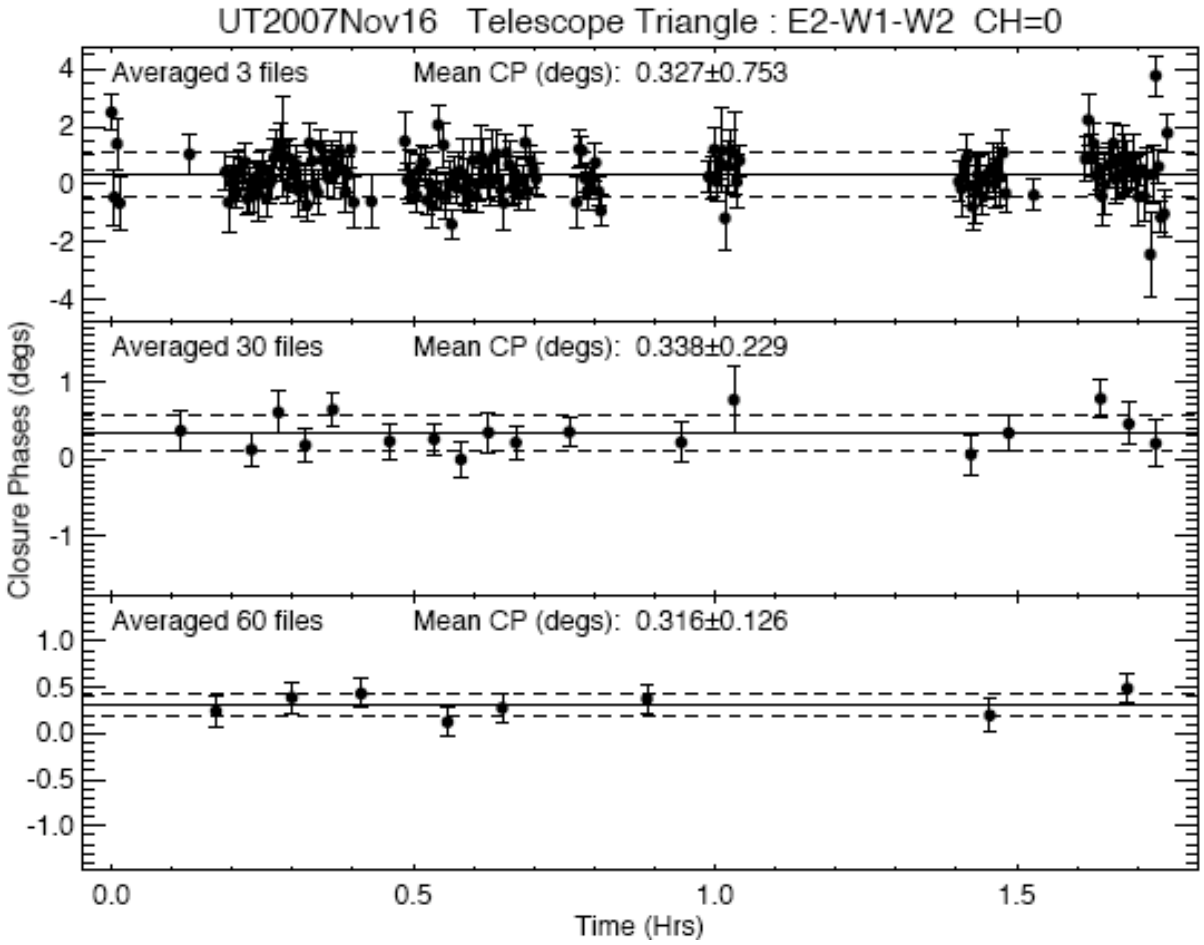



Precision requirement: < 0.18° for the highest resolution channel

# Closure phase simulation



# Closure phase precision - υ And

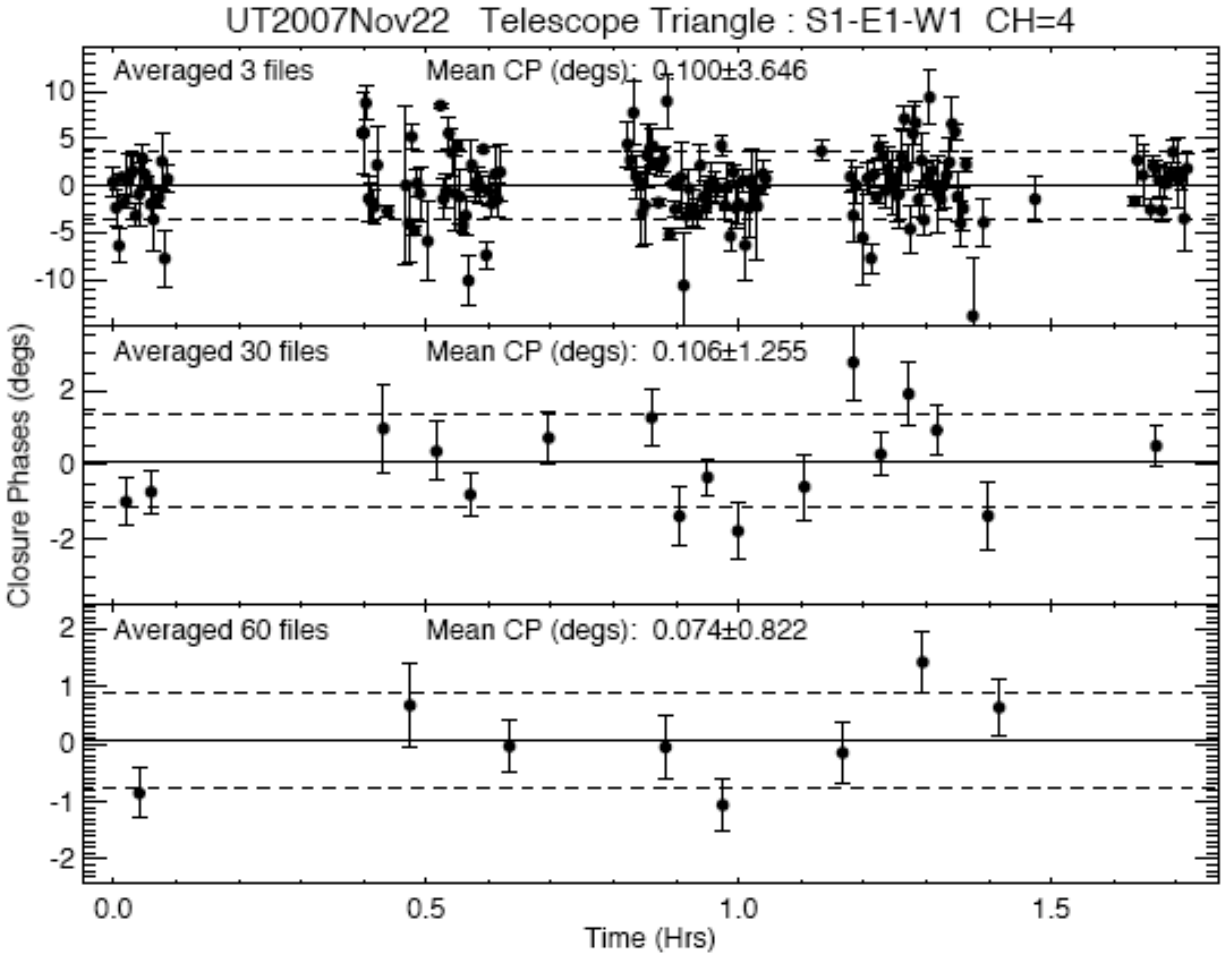



Short triangle

~ 0.8 mas resolution

Averaging the whole 1.7 hours=> 0.045º

# Closure phase precision - υ And




Long triangle

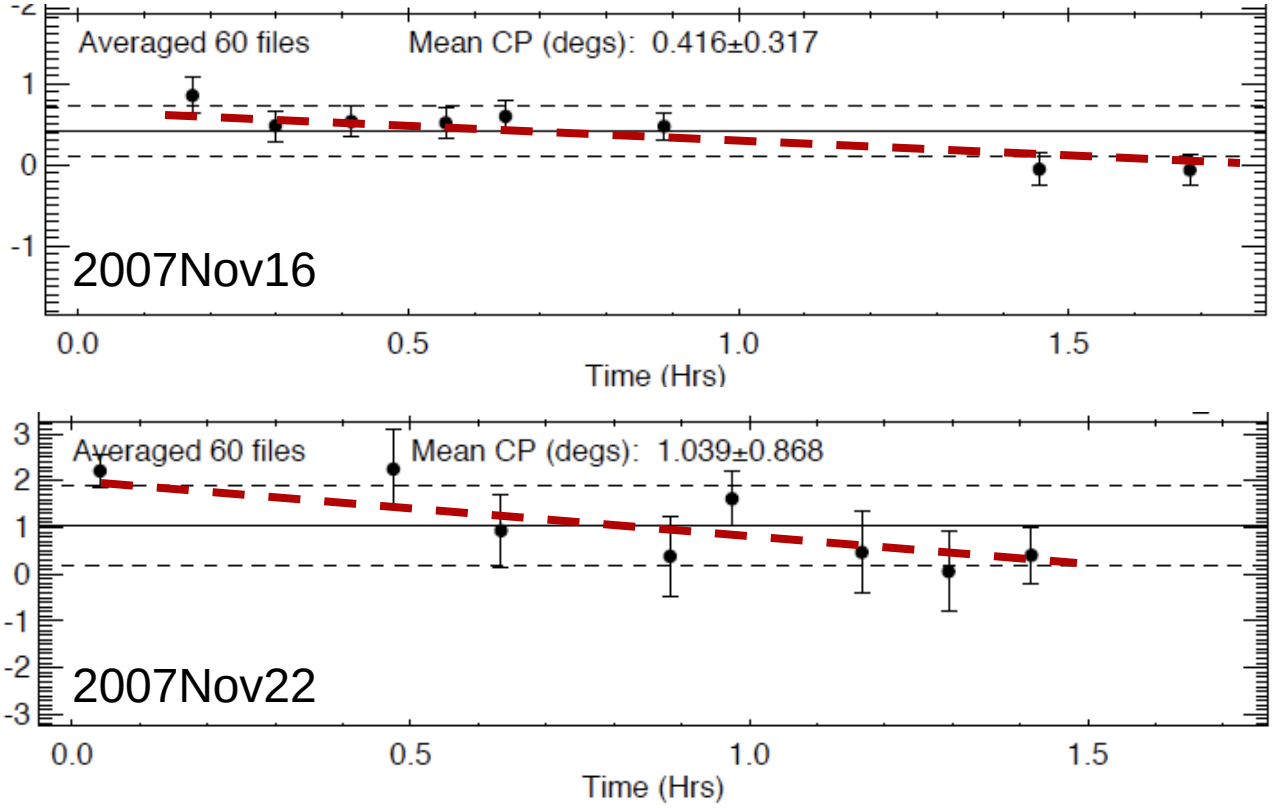
~0.5 mas resolution

Averaging the whole 1.7 hours=> 0.3º

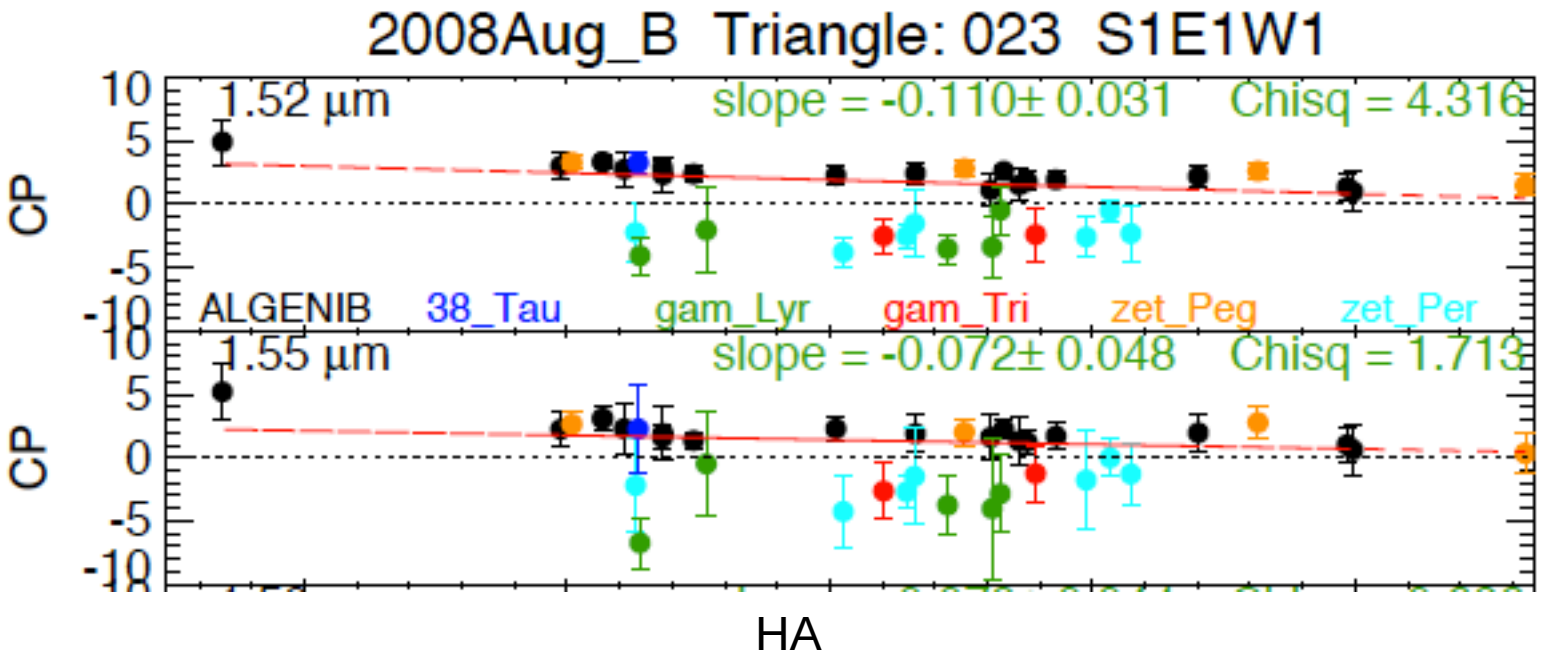
# Calibration Problems

- Closure phase drifts due to polarization or dispersion

Drifts in closure phase

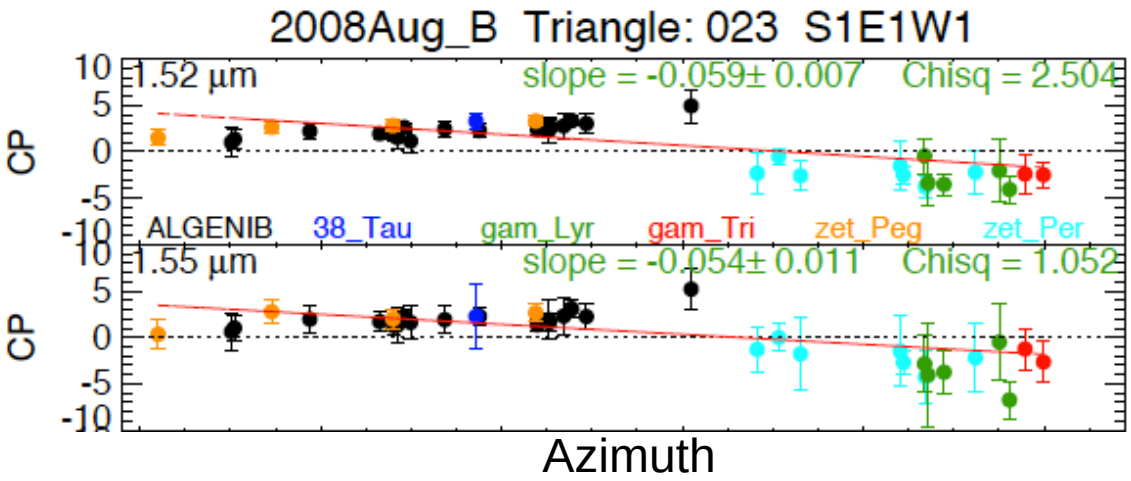


# Closure phase drifts

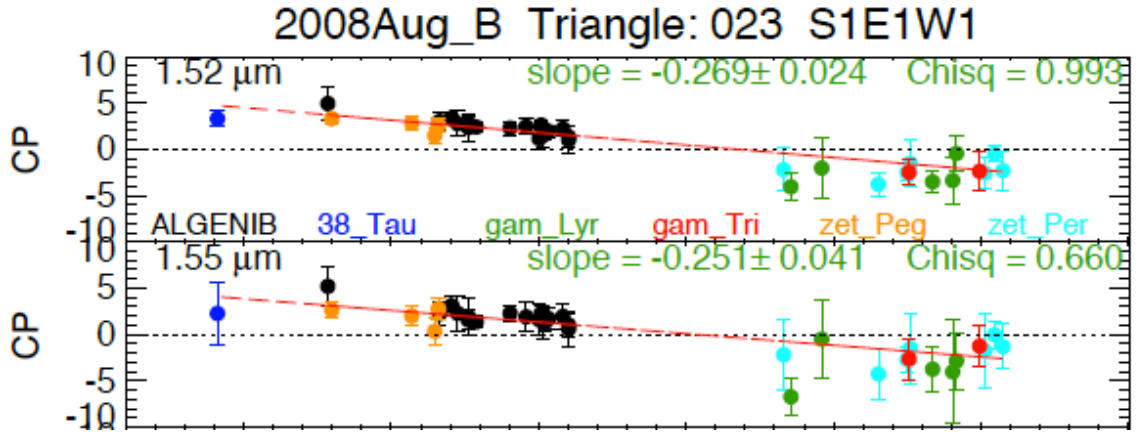



Closure phase is not a strong function of Hour Angle

# Closure phase drifts



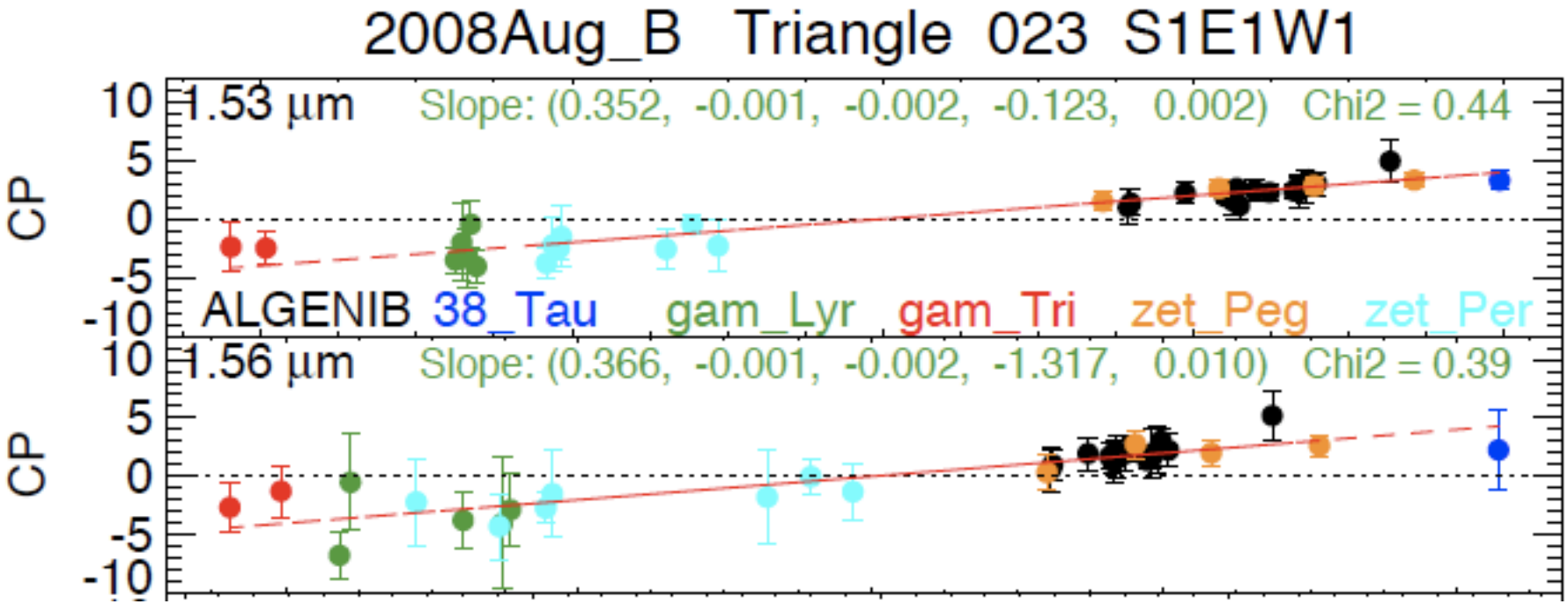

Azimuth




Altitude

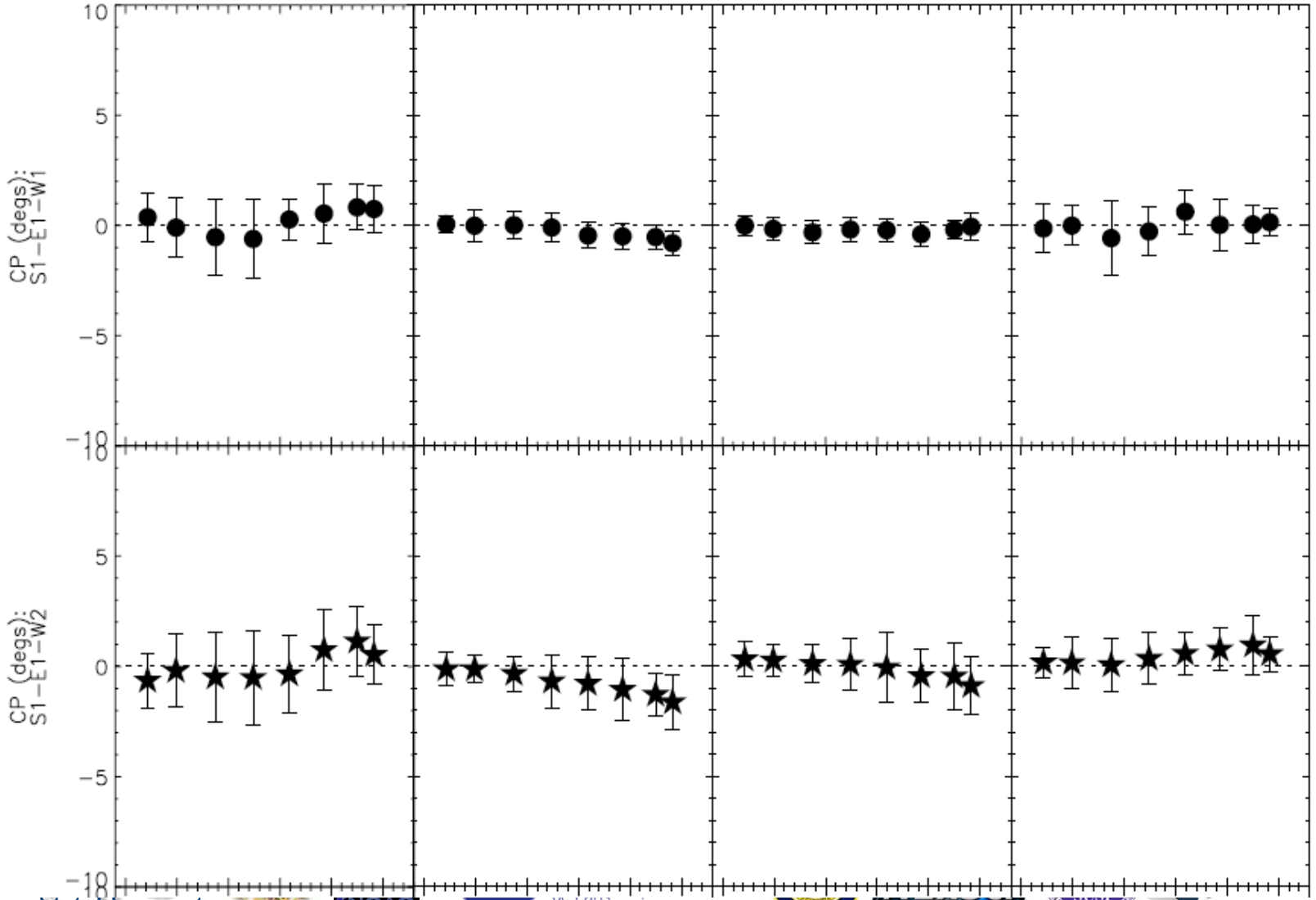
# Closure phase drifts

- Can be corrected by a quadratic surface function of Altitude and Azimuth




$$a1*AZ + a2*AZ^2 + a3*AZ*Alt + a4*Alt + a5*Alt^2$$

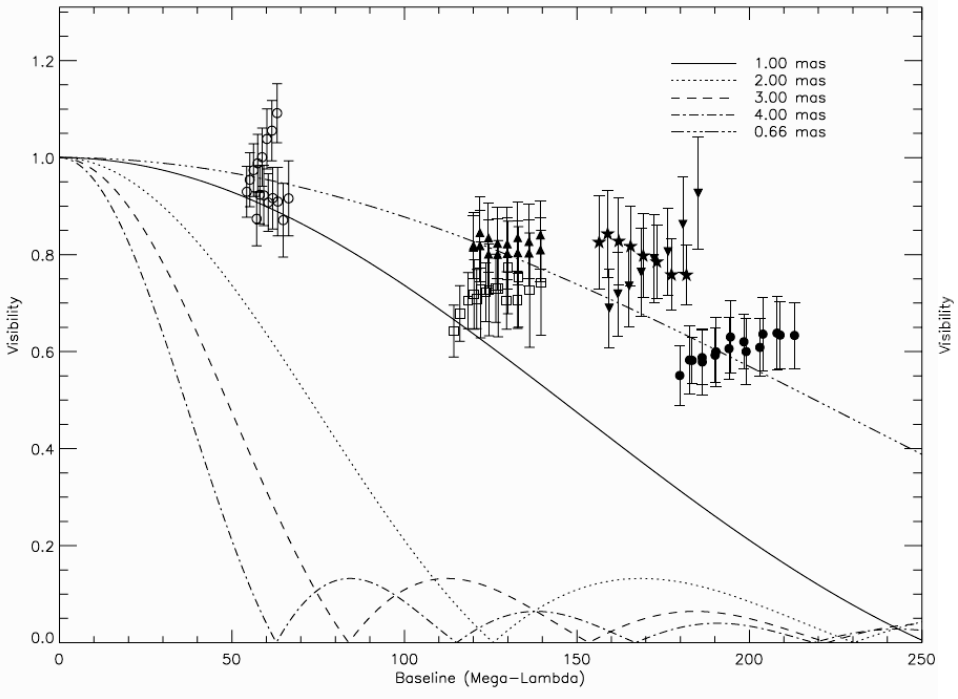
# After new calibration



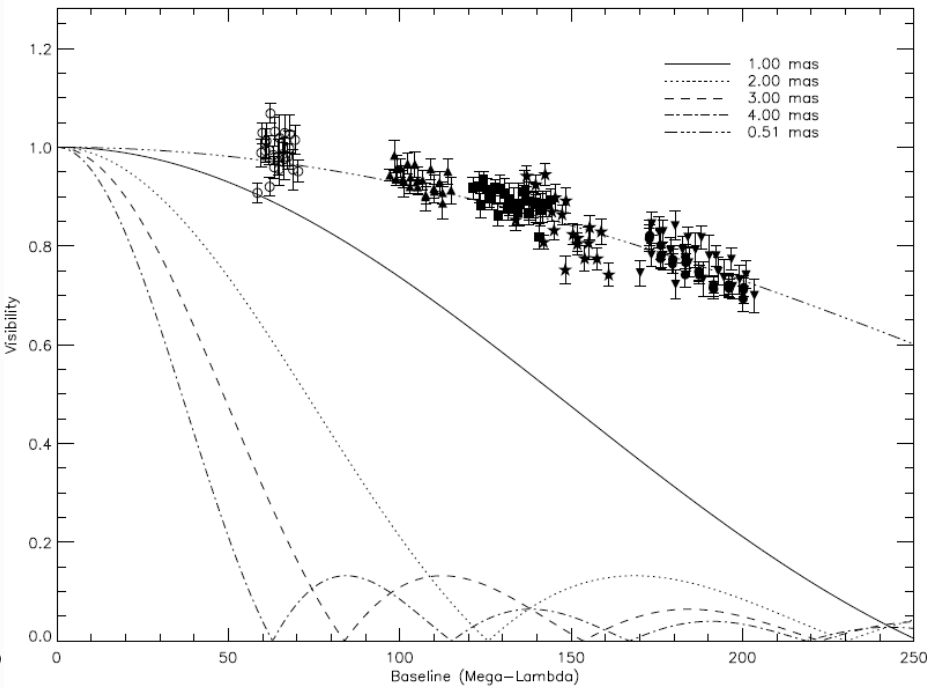
# Polarization test

- Visibilities look really good

Eps Per – 2008Nov07



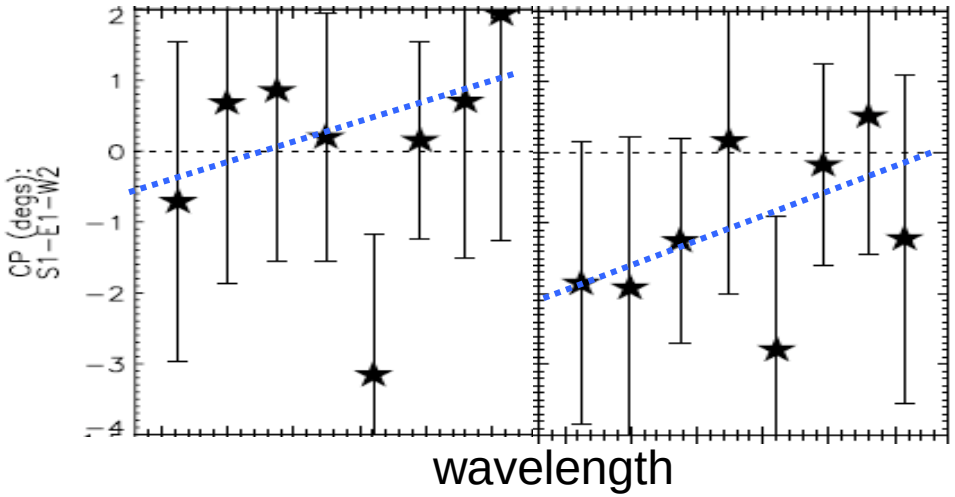

Eps Per- 2009Oct22 with polarizer



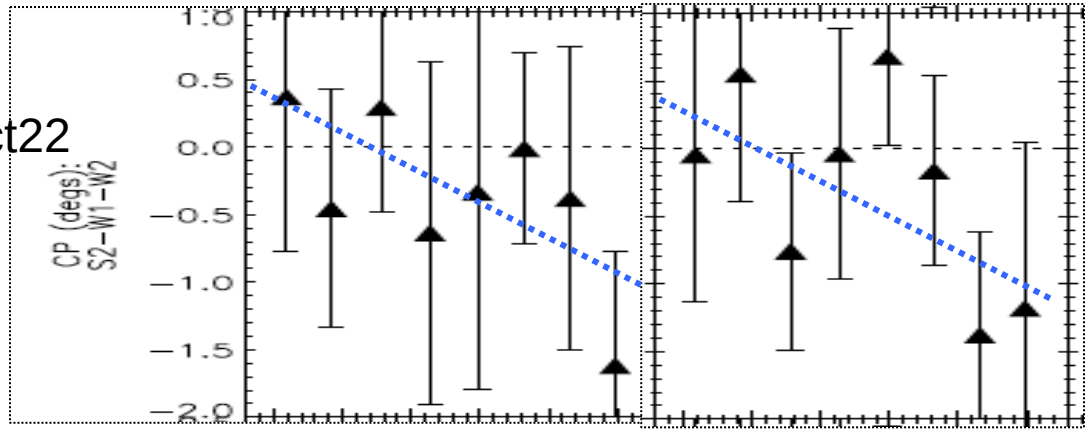
# Polarization test

**Polarization most likely not the major cause**

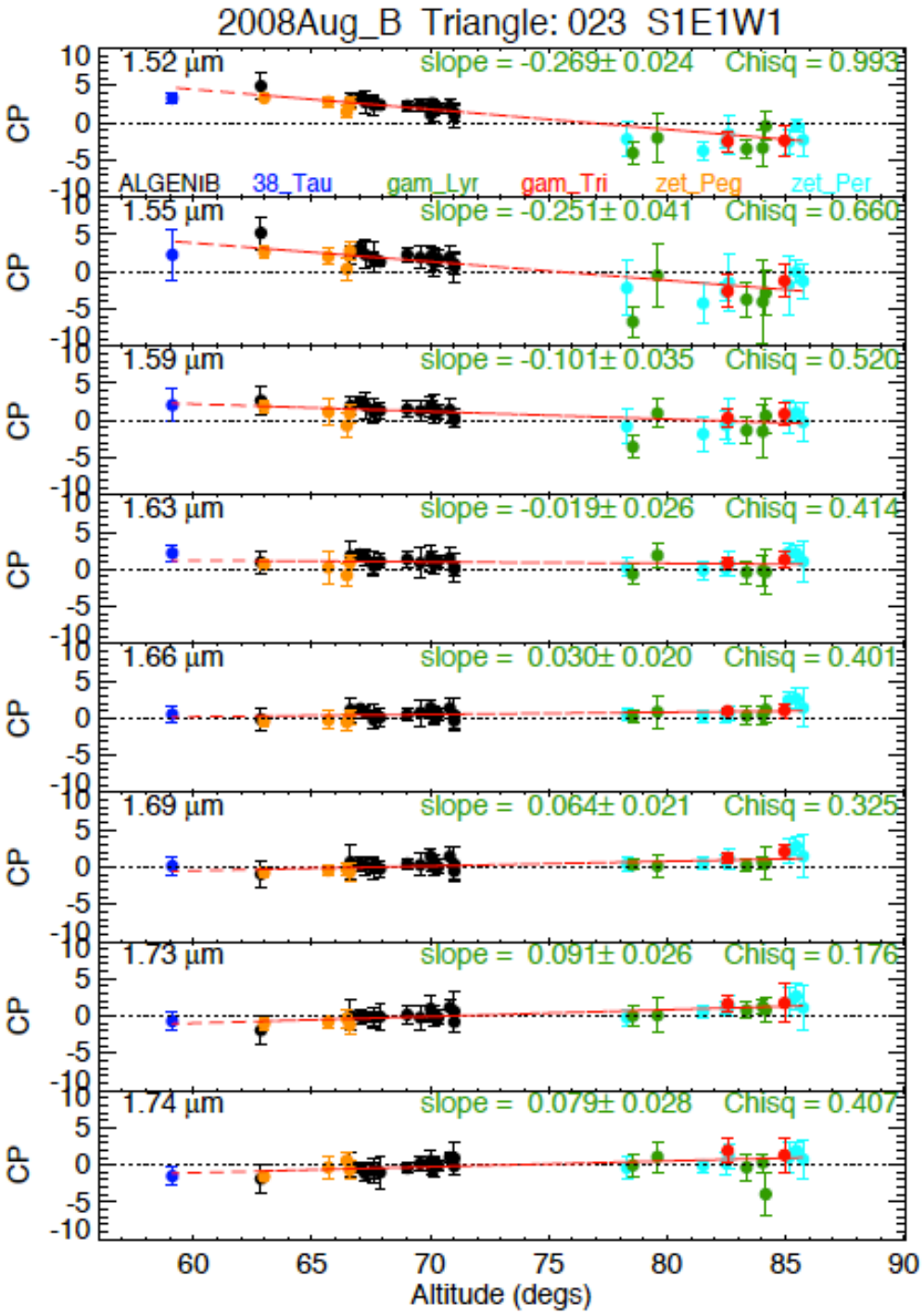
Eps Per in 2008Nov07




Eps Per in 2009Oct22
With polarizer



Dispersion may also be the cause of the slope drift (red lines)



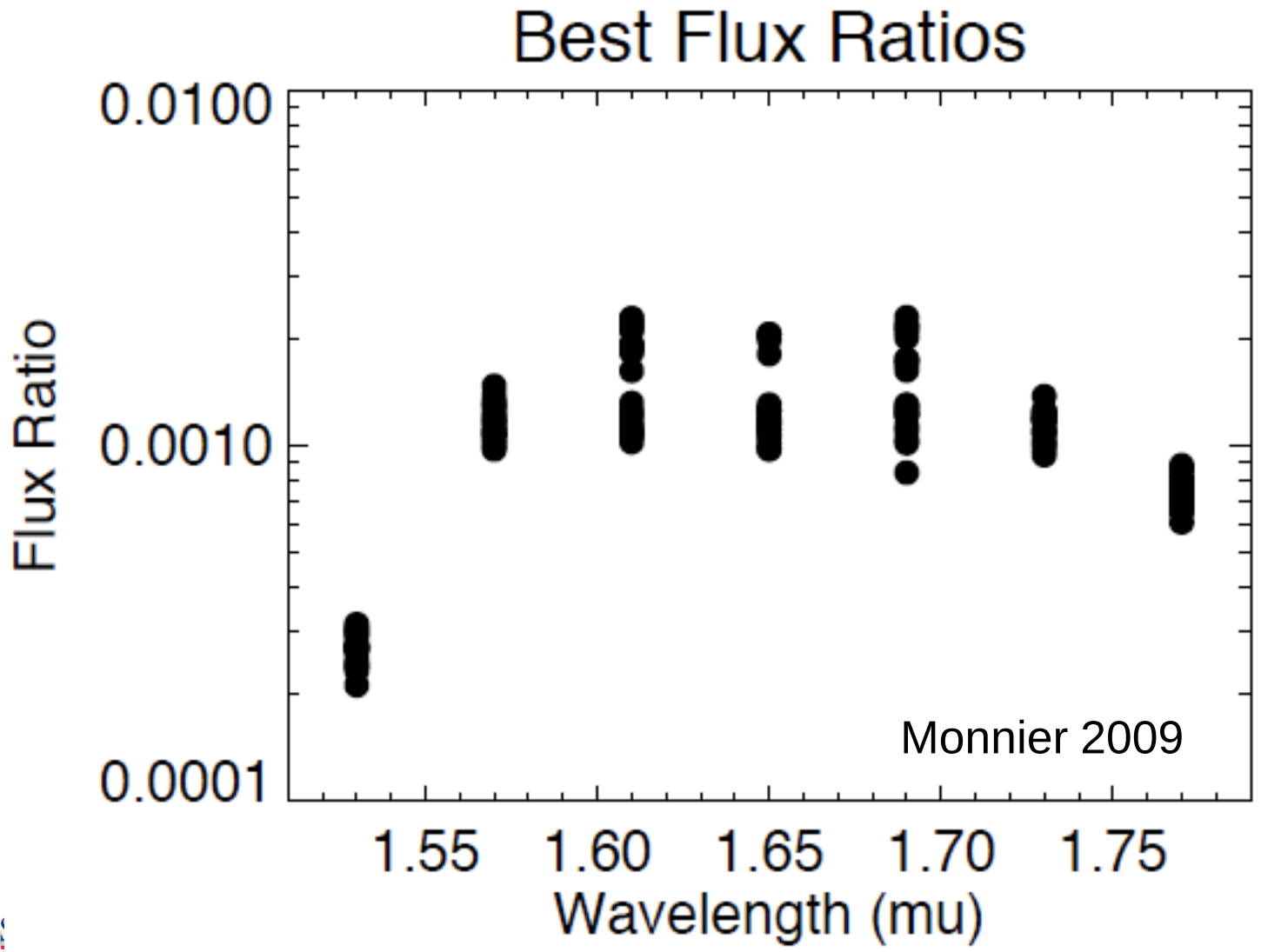
# Data Analysis Method

- Orbital parameters: $i$, $\Omega$
- Day/night flux variation: amplitude, phase
- Closure phase offset

$\Rightarrow$ Combined solution of multiple channels and nights

$\Rightarrow$ Testing on Eps Per and Ups And
- more data needed

# Preliminary upper limit for Ups And



# Improvements

- Calibration
- Data analysis
- Throughput - CHARA
- Efficiency – Photometric Channel (Che et al. 2009)
- Sensitivity – CHAMP (Monnier et al. 2009)

All improvements add together:
⇒ 10x S/N

# Future Work

- More investigations on calibration method
  - Use slit and grism to test the dispersion hypothesis

- More observations with high contrast binaries and Ups And with:
  - CHAMP + Photometric Channel (this year)
  - Calibrators at the same declination
  - New observing and calibration scheme

# Backup slides

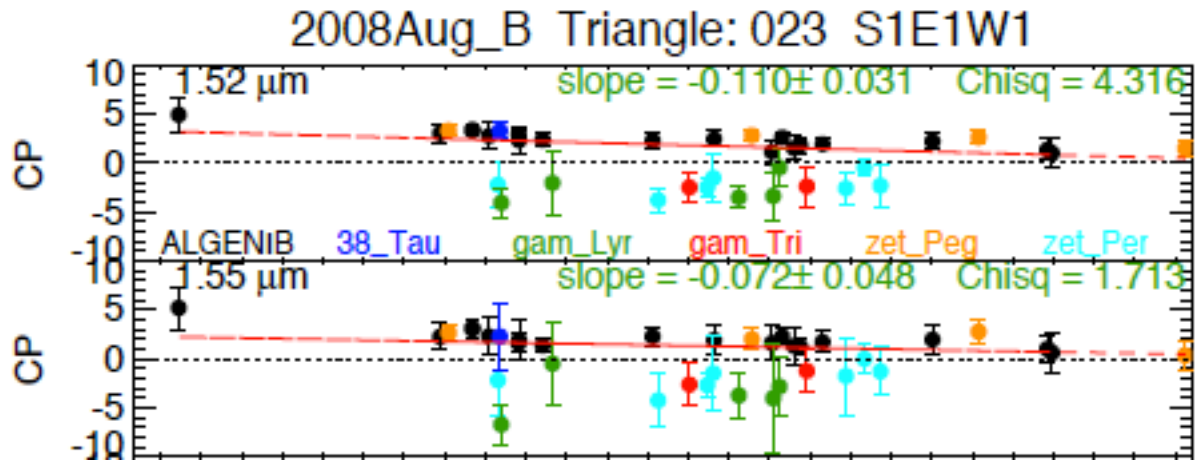
# Polarization test

- Observations with polarizer last Fall
  - Visibilities look really good
  - Closure phases look similar as before

⇒ Polarization is most likely not the major cause of closure phase drift

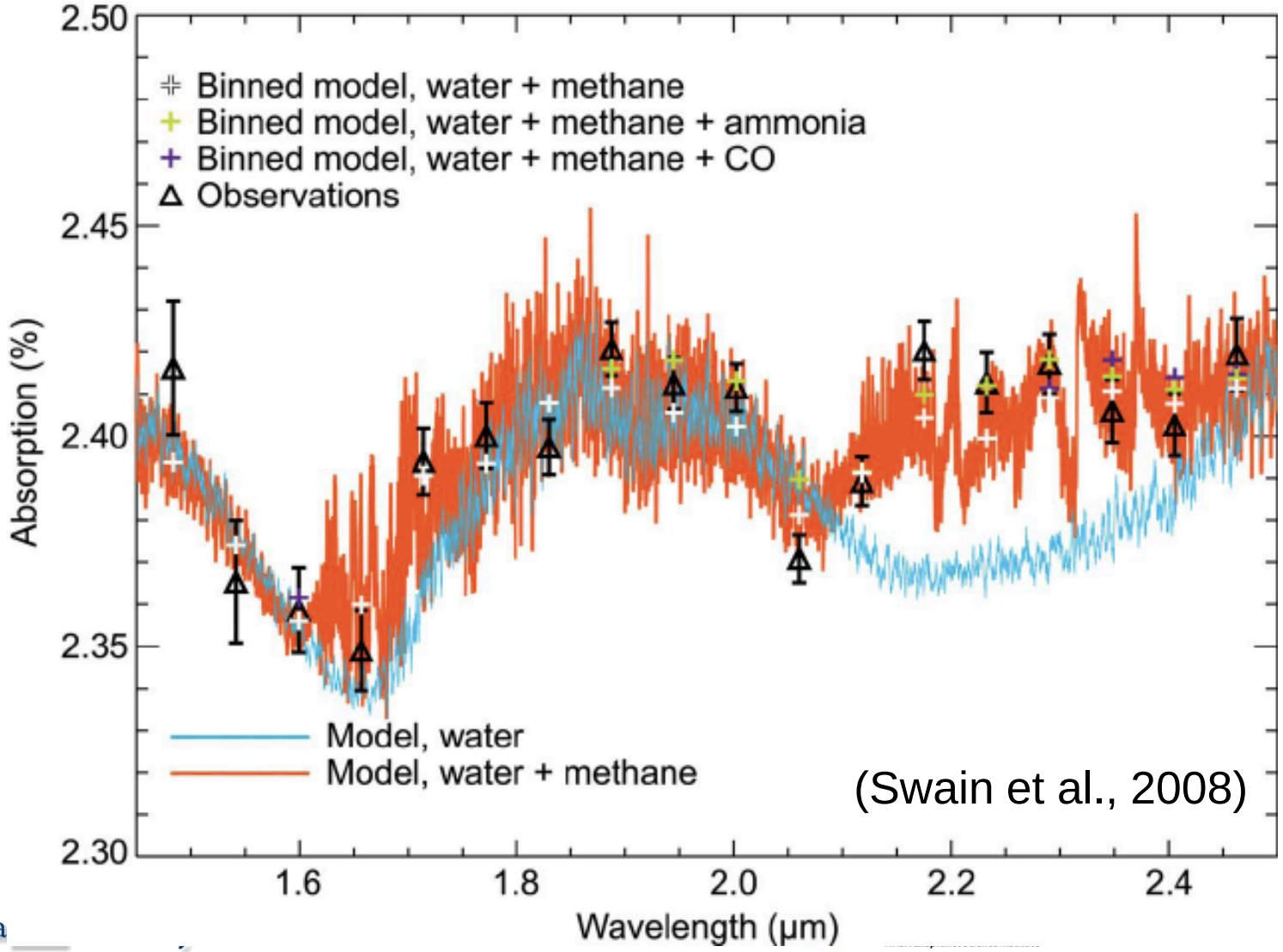
⇒ Possibly due to dispersion effects

  - ongoing tests with slits, more in 2010


2008Aug_B Triangle: 023 S1E1W1
1.52 µm
slope = -0.110± 0.031
Chisq = 4.316
CP
ALGENIB
38_Tau
gam_Lyr
gam_Tri
zet_Peg
zet_Per
1.55 µm
slope = -0.072± 0.048
Chisq = 1.713
CP

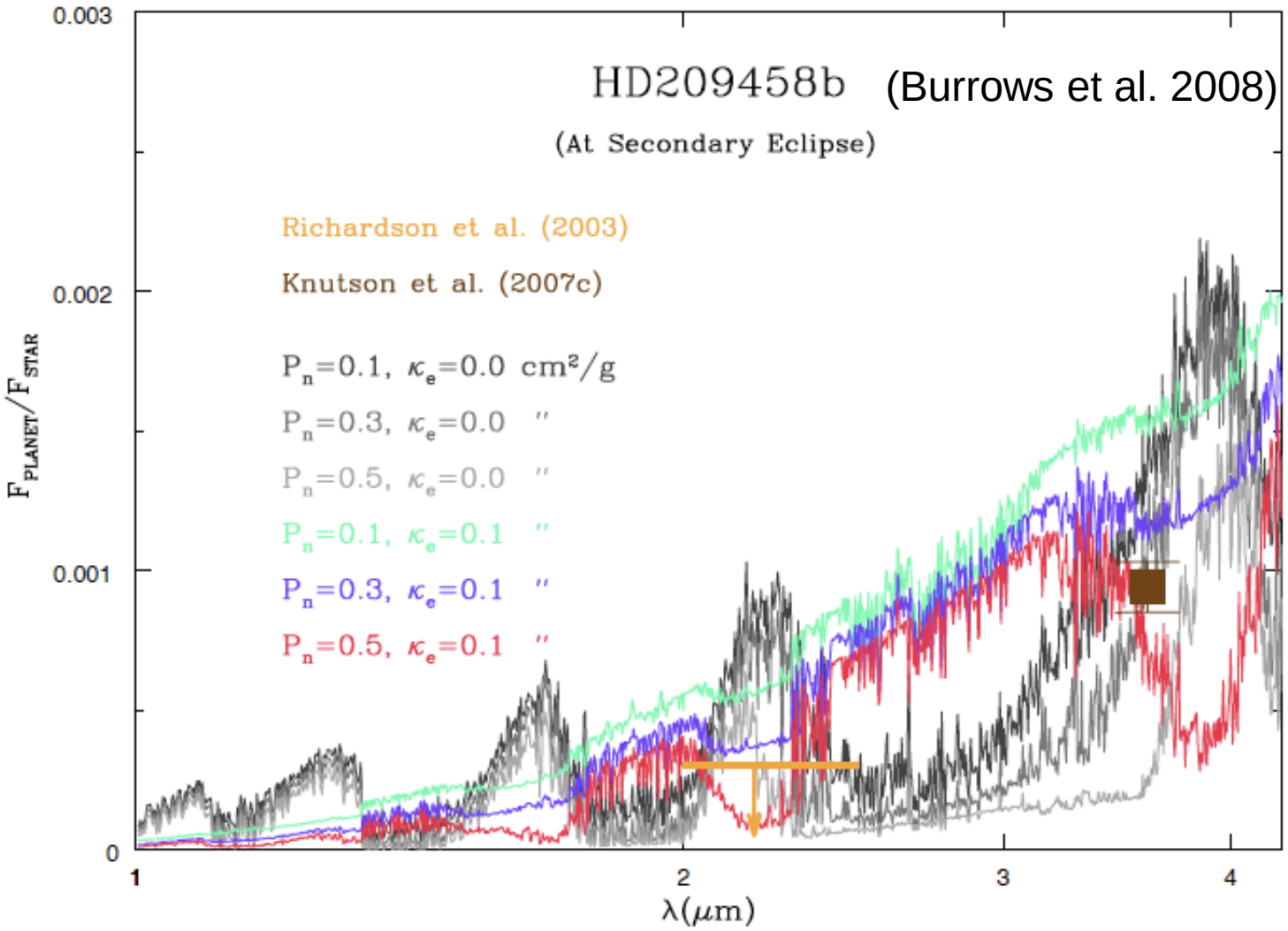
# Hot Jupiters

- Full of molecular bands



# Hot Jupiters

- Clouds in the atmosphere - thermal inversion



# Hot Jupiters

- Day/night flux variation, heat redistribution, etc.