High-contrast imaging using today's infrared interferometers

10.2 milliarcseconds

John Monnier & Ming Zhao (U. Michigan)

w/ Ettore Pedretti, Nathalie Thureau (St. Andrews),

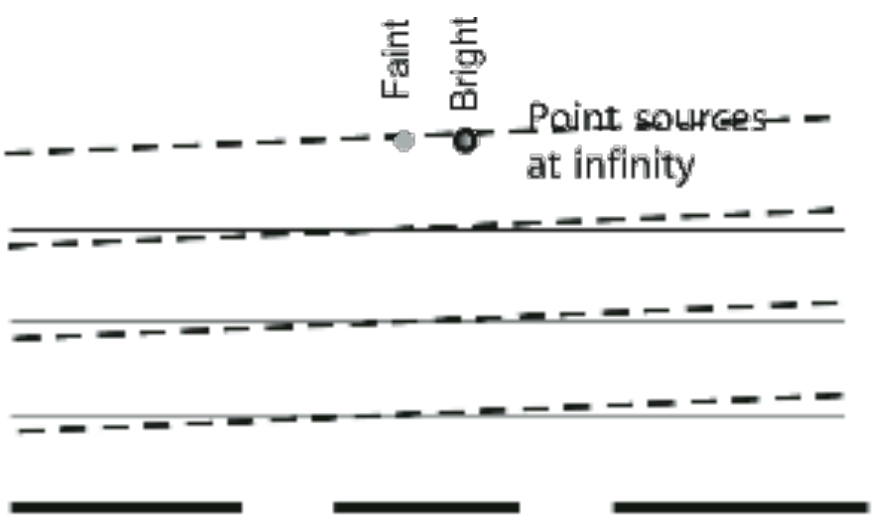
T. ten Brummelaar (GSU/CHARA)

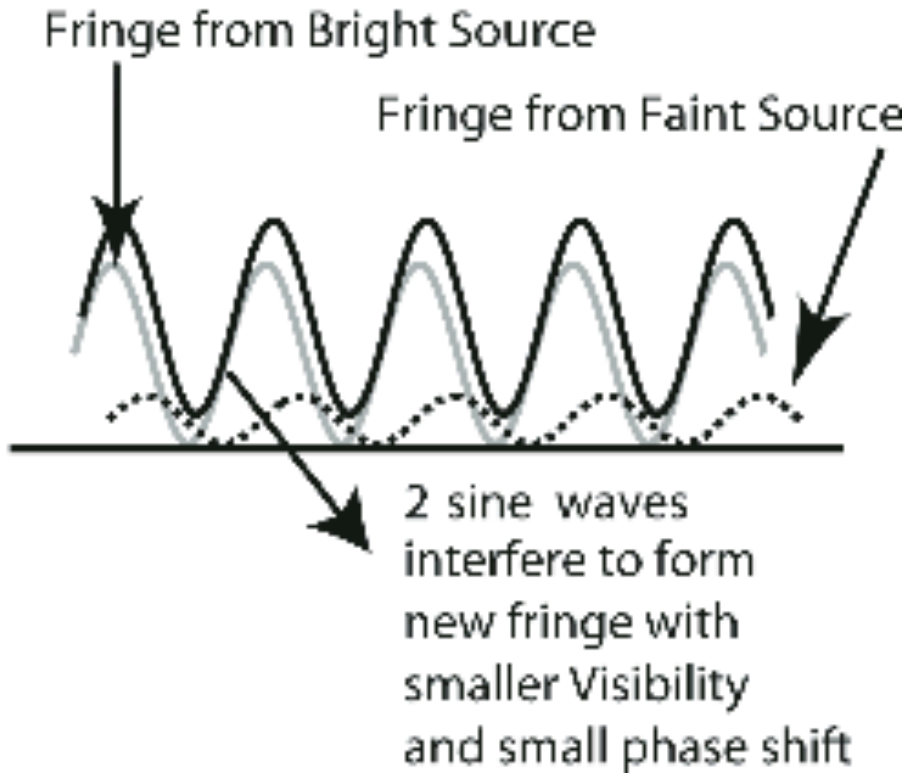
Why imaging?

- Complete orbital elements
  - Inclination removes sin i degeneracy in mass
- Movie of orbit can reveal temperature differences on planet surface
- Low resolution spectroscopy
- Direct measurement of stellar diameter

Refs: Lopez & Petrov 2000; Segransan 2002; Monnier 2002; Joergens & Quirrenbach 2004; Vannier et al. 2005, Millour et al. 2005; Beuzit et al. 2006

Planet-induced Phase Shift

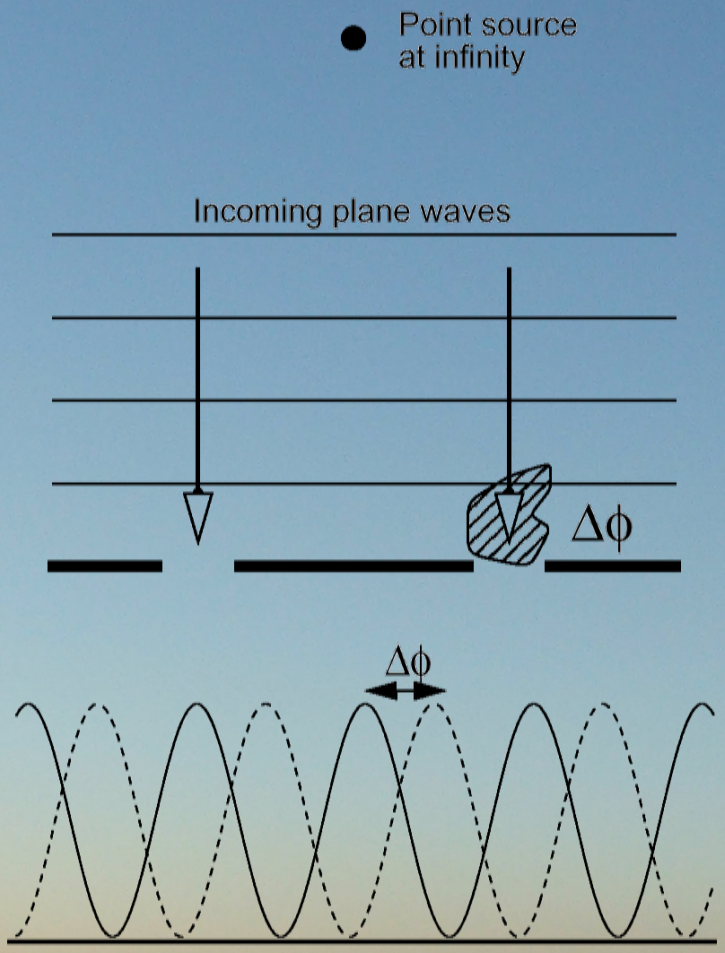




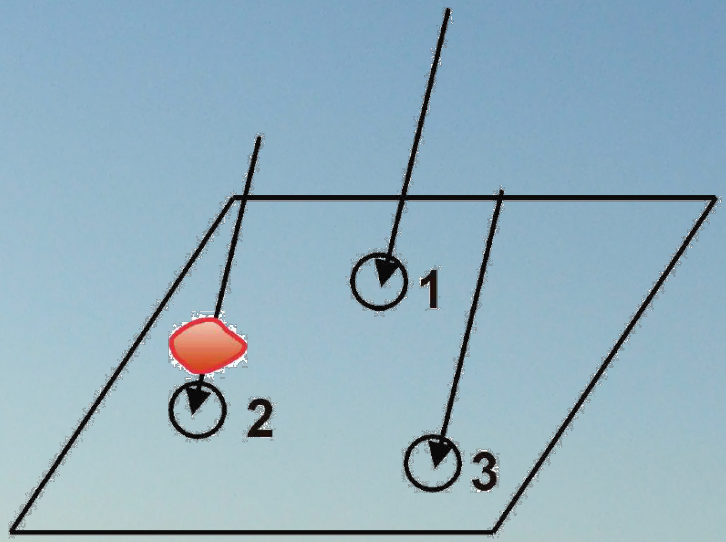
$$|V| \approx 1 - 2\alpha \sin^2 (\pi \frac{\vec{b}}{\lambda} \cdot \vec{\delta})$$

$$\Phi_V \approx \alpha \sin (2\pi \frac{\vec{b}}{\lambda} \cdot \vec{\delta})$$

Atmosphere Corrupts the Phase



The "Closure Phase" Is Not Corrupted



Observed Intrinsic Atmosphere

$$\Phi(1\text{-}2) = \Phi_0(1\text{-}2) + [\phi(2)-\phi(1)]$$
$$\Phi(2\text{-}3) = \Phi_0(2\text{-}3) + [\phi(3)-\phi(2)]$$
$$\Phi(3\text{-}1) = \Phi_0(3\text{-}1) + [\phi(1)-\phi(3)]$$

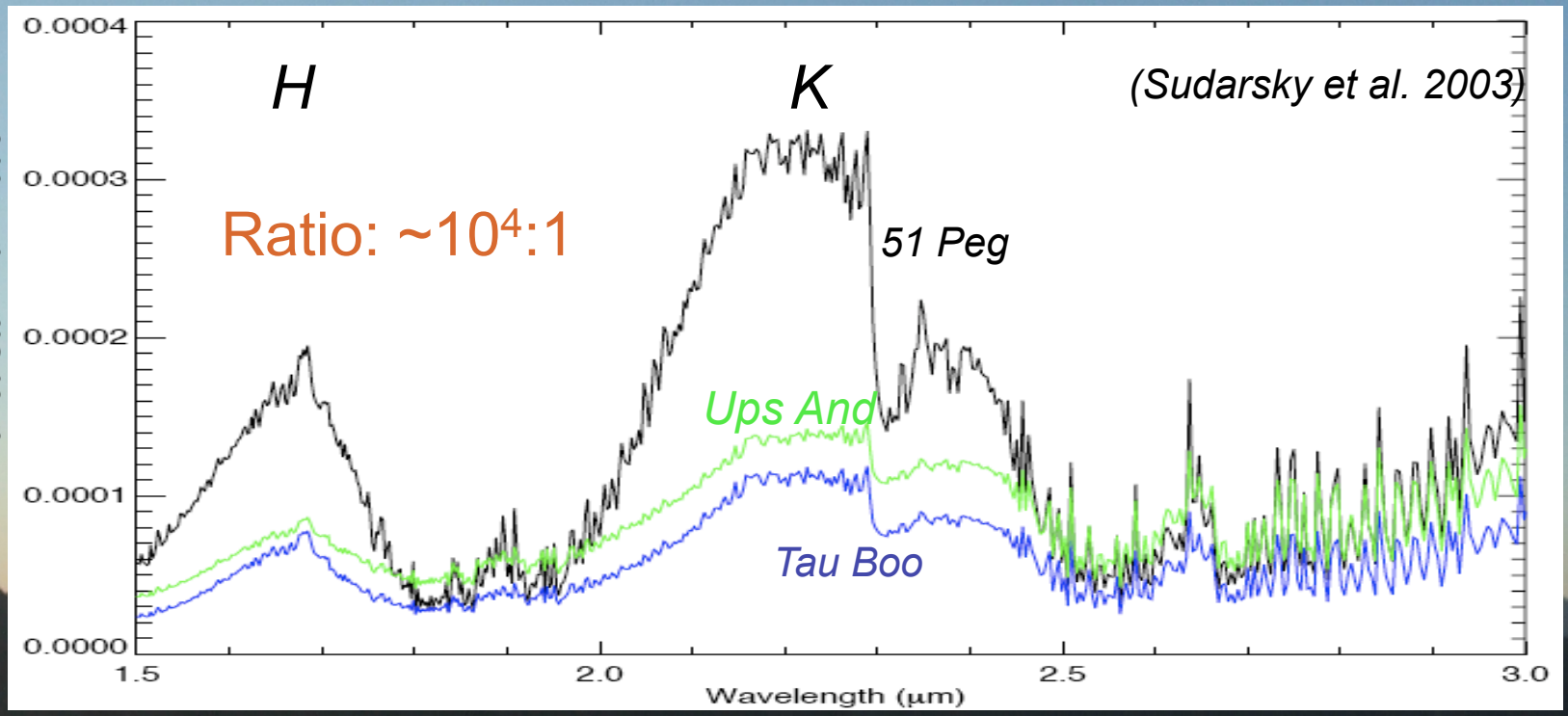
$$\text{Closure Phase } (1\text{-}2\text{-}3) = \Phi_0(1\text{-}2) + \Phi_0(2\text{-}3) + \Phi_0(3\text{-}1)$$

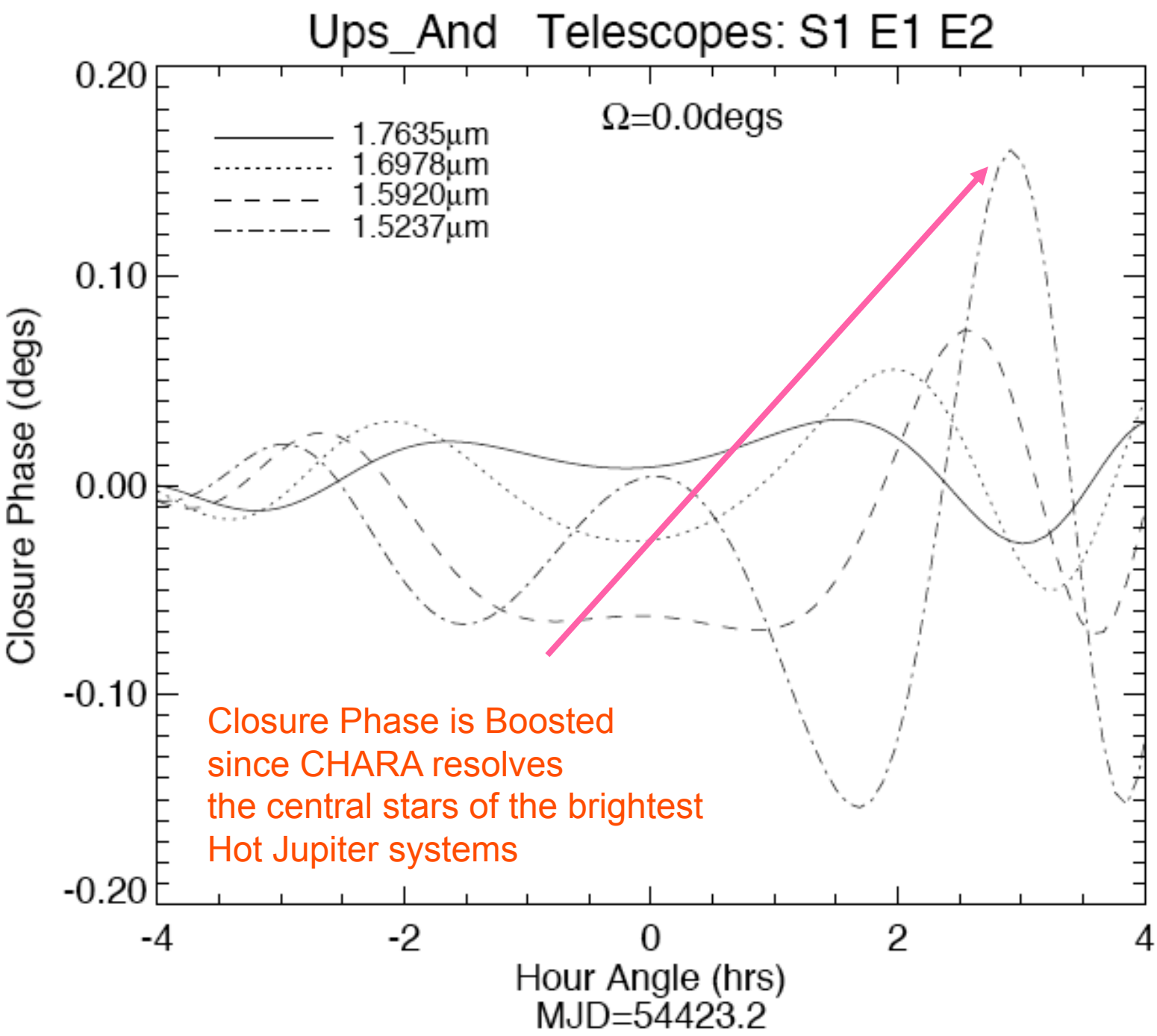
Closure Phase Method

- Need angular resolution to resolve star to planet separation (~2 milliarcsconds for nearby cases)
- Need many photons to beat down photon noise
  - 51 peg provides ~10^6 photons per 0.1 sec per 0.05 mu BW at H band for 1 m telescopes
- Uncertainty: calibration
  - Must use special combiners
- Who: CHARA, VLT Interferometers
  - must have at least 3 telescopes and LONG >100m baselines to resolve hot Jupiter systems

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
υ And	13.5	2.957	2.859	4.6170	0.034	0.059	(4.42)	2450088.64	0.569
τ 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



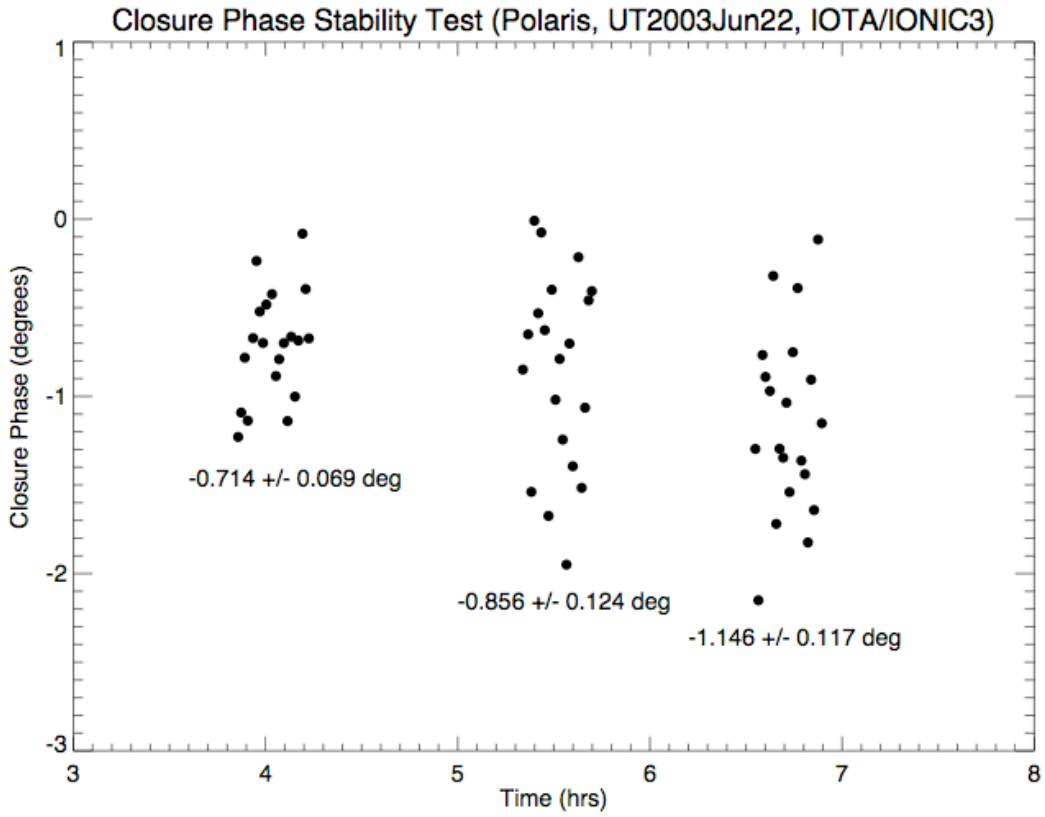

Ups_And Telescopes: S1 E1 E2
Ω=0.0degs
1.7635μm
1.6978μm
1.5920μm
1.5237μm
Closure Phase (degs)
0.20
0.10
0.00
-0.10
-0.20
-4
-2
0
2
4
Hour Angle (hrs)
MJD=54423.2
Closure Phase is Boosted
since CHARA resolves
the central stars of the brightest
Hot Jupiter systems

Precision Closure Phase -- State of the Art

IOTA Interferometer:

statistical
+/- 0.07 degs

Systematic
+/- 0.20 degs



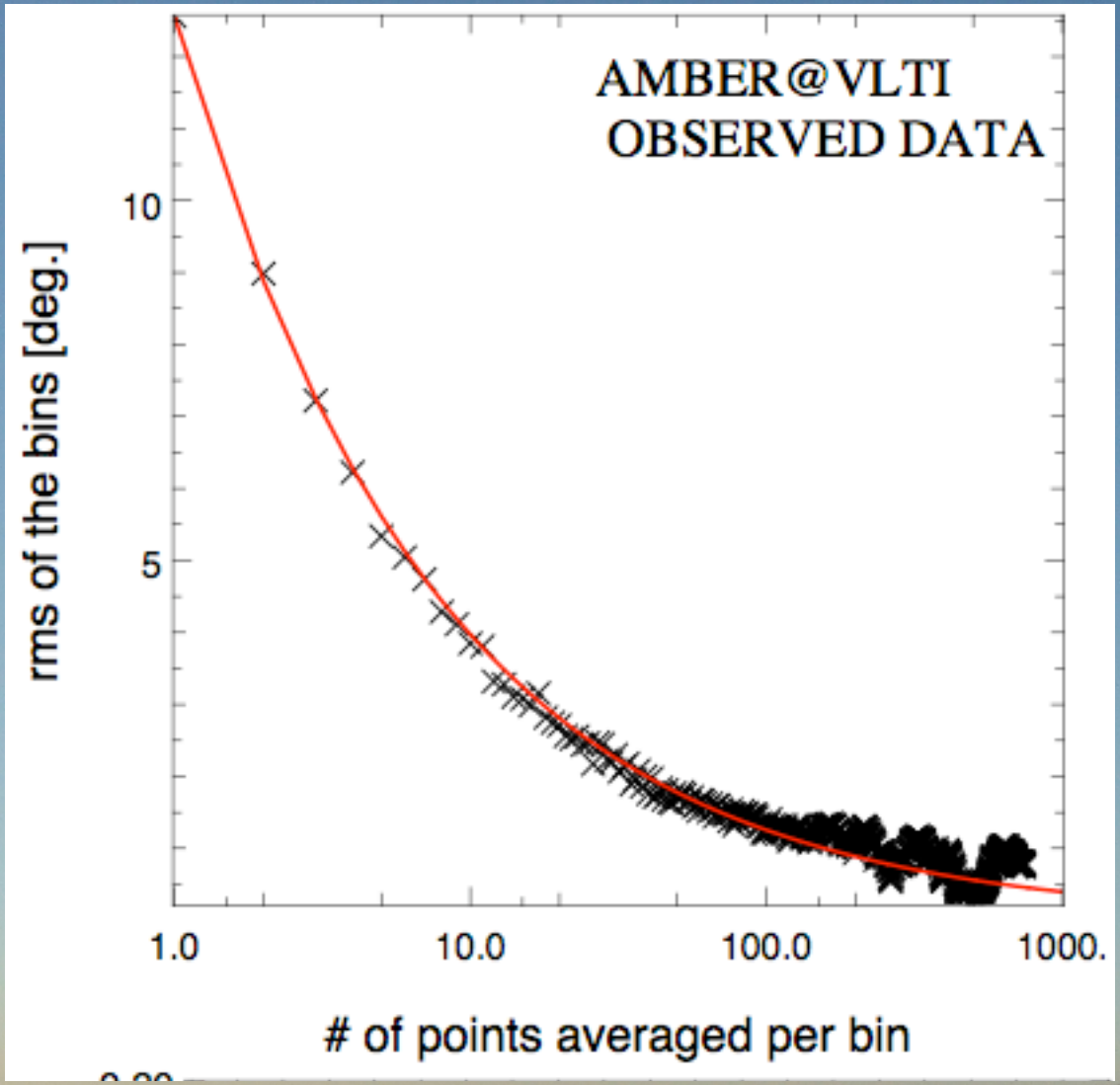
Monnier et al.

Precision Closure Phase -- State of the Art

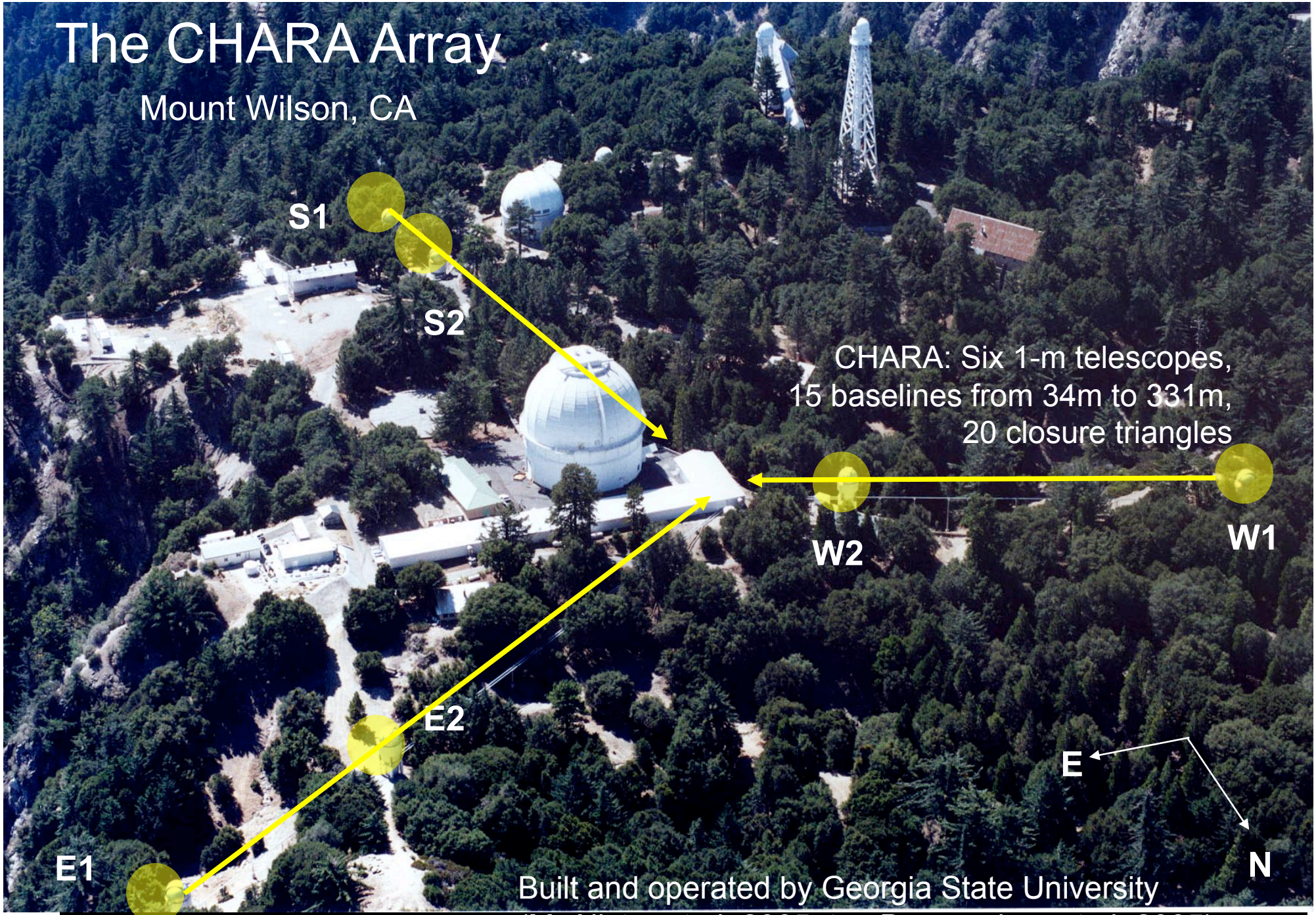
VLTI Interferometer:

statistical
+/- 0.06 degs
[Differential phase]

statistical
+/- 0.6 degs
[Closure Phase]



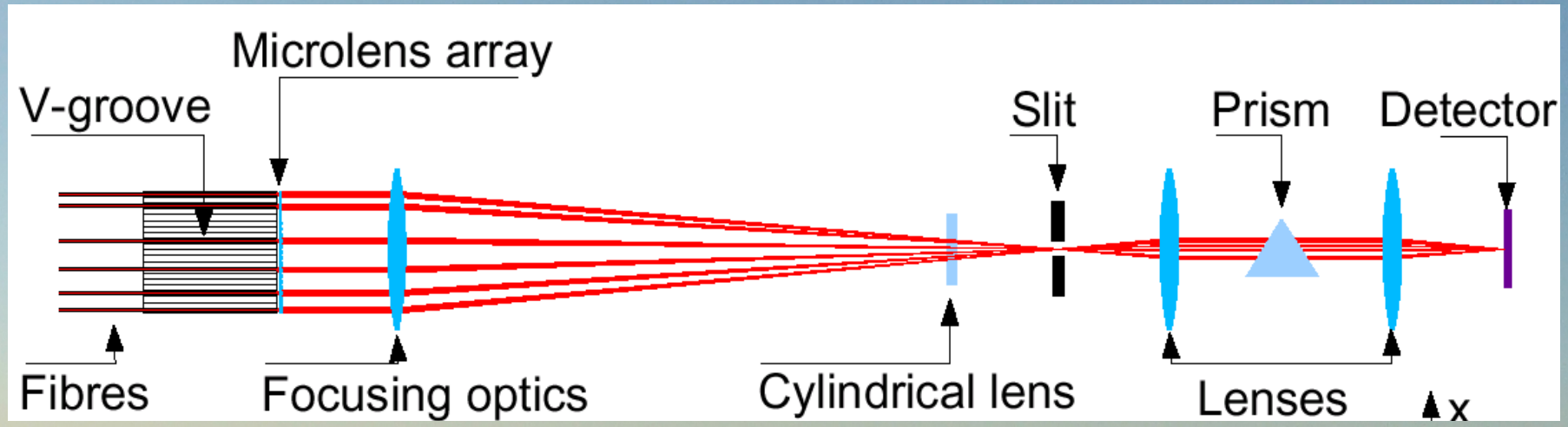
Segransan et al.; Millour et al. 2005


The CHARA Array
Mount Wilson, CA
S1
S2
CHARA: Six 1-m telescopes,
15 baselines from 34m to 331m,
20 closure triangles
W2
W1
E2
E
N
E1
Built and operated by Georgia State University
(McAlister et al. 2005; ten Brummelaar et al. 2005)

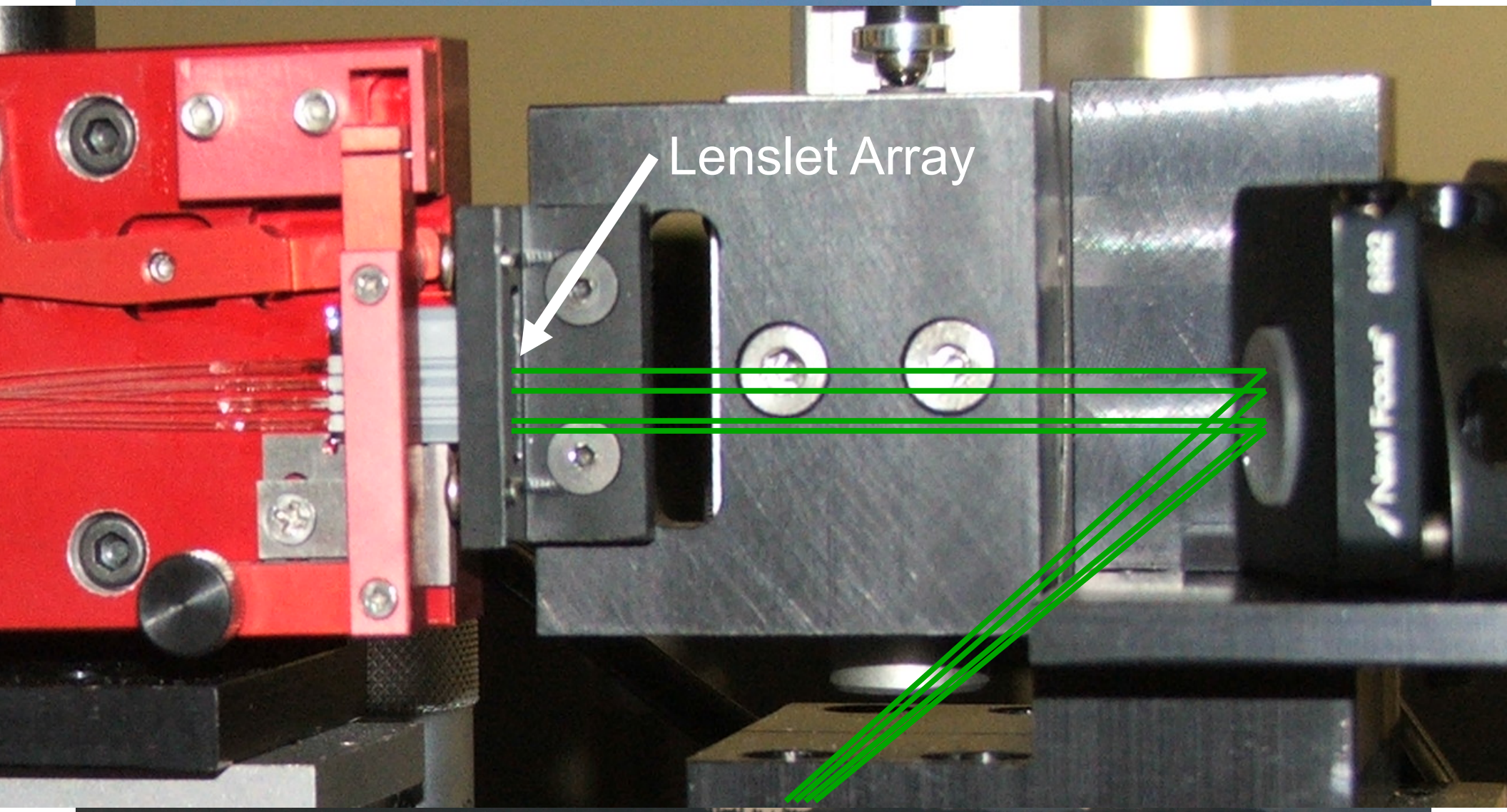
MIRC: Michigan Infrared Combiner

- Uses single mode fibers
- Image plane combination

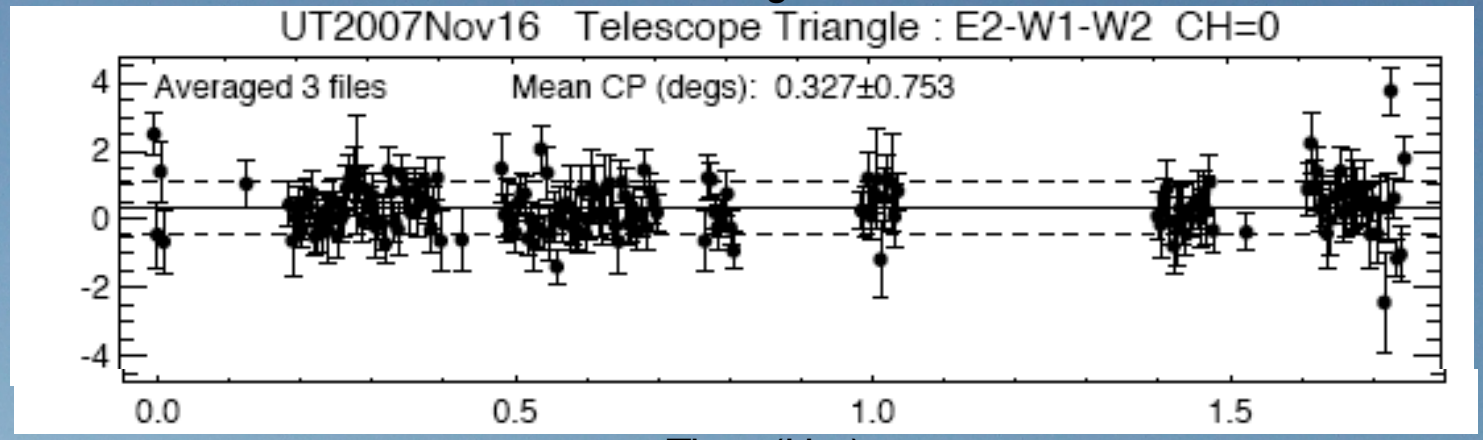
=> stable and precise closure phase



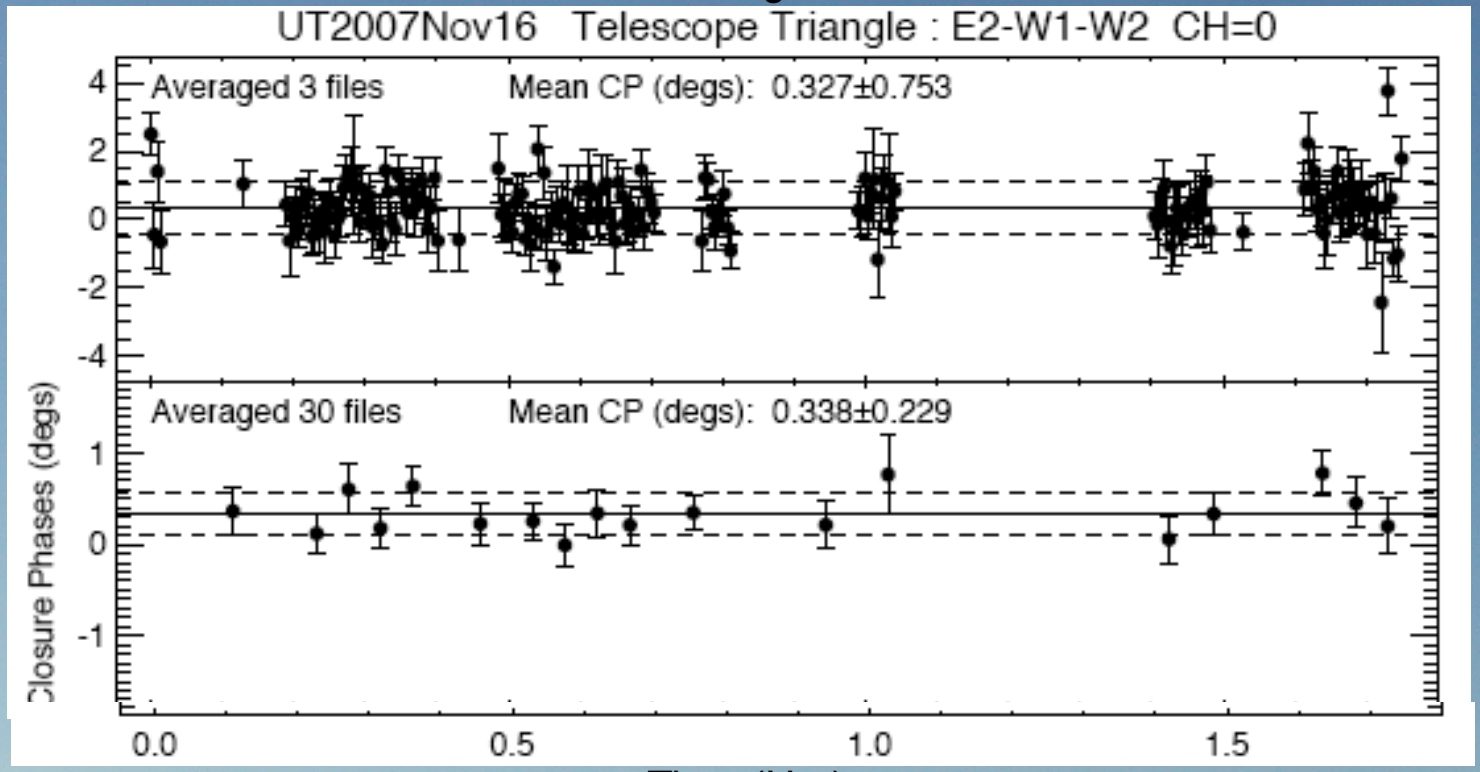
(Monnier et al. 2004)


Lenslet Array

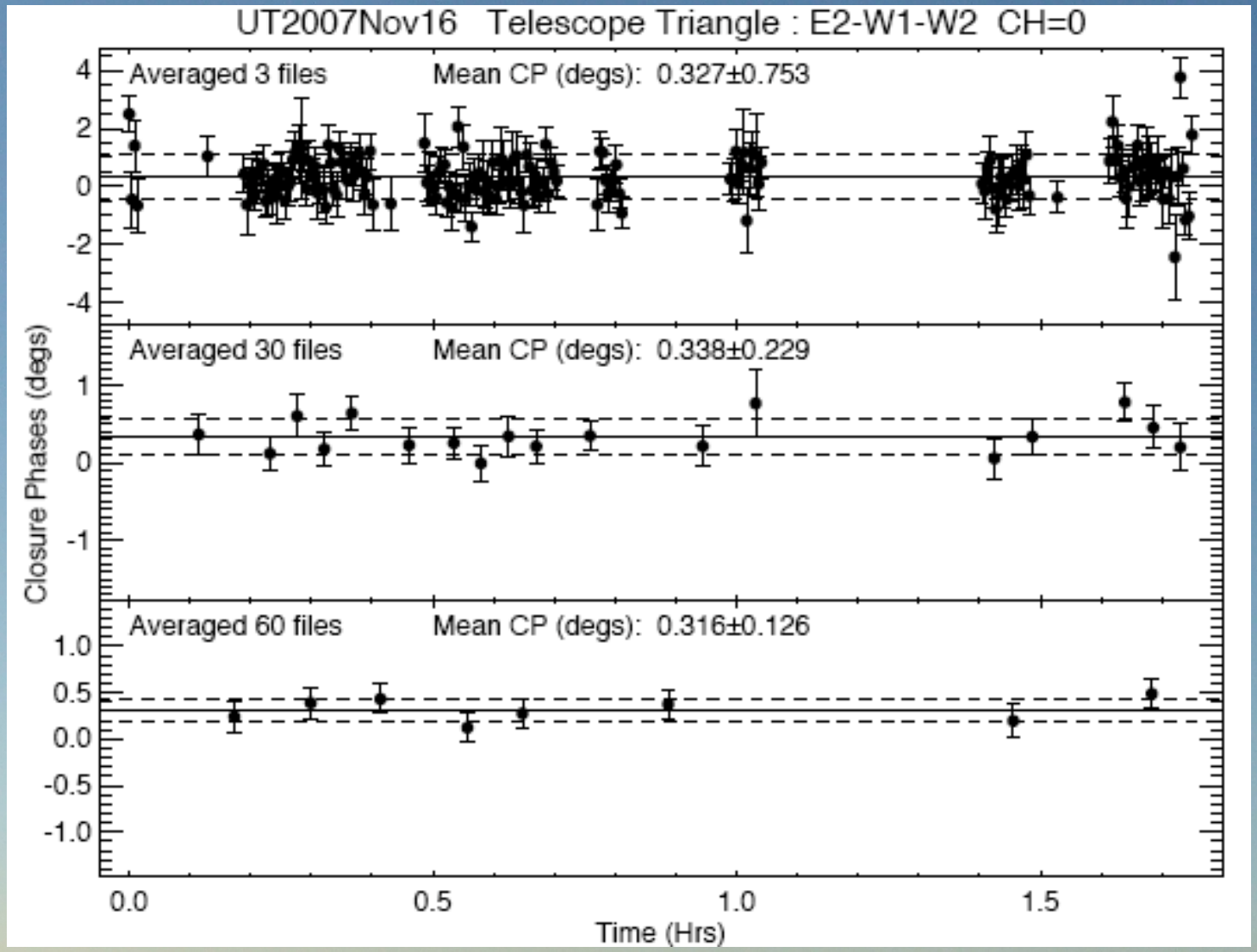
Short triangle ~ 0.8 mas resolution



Short triangle ~ 0.8 mas resolution

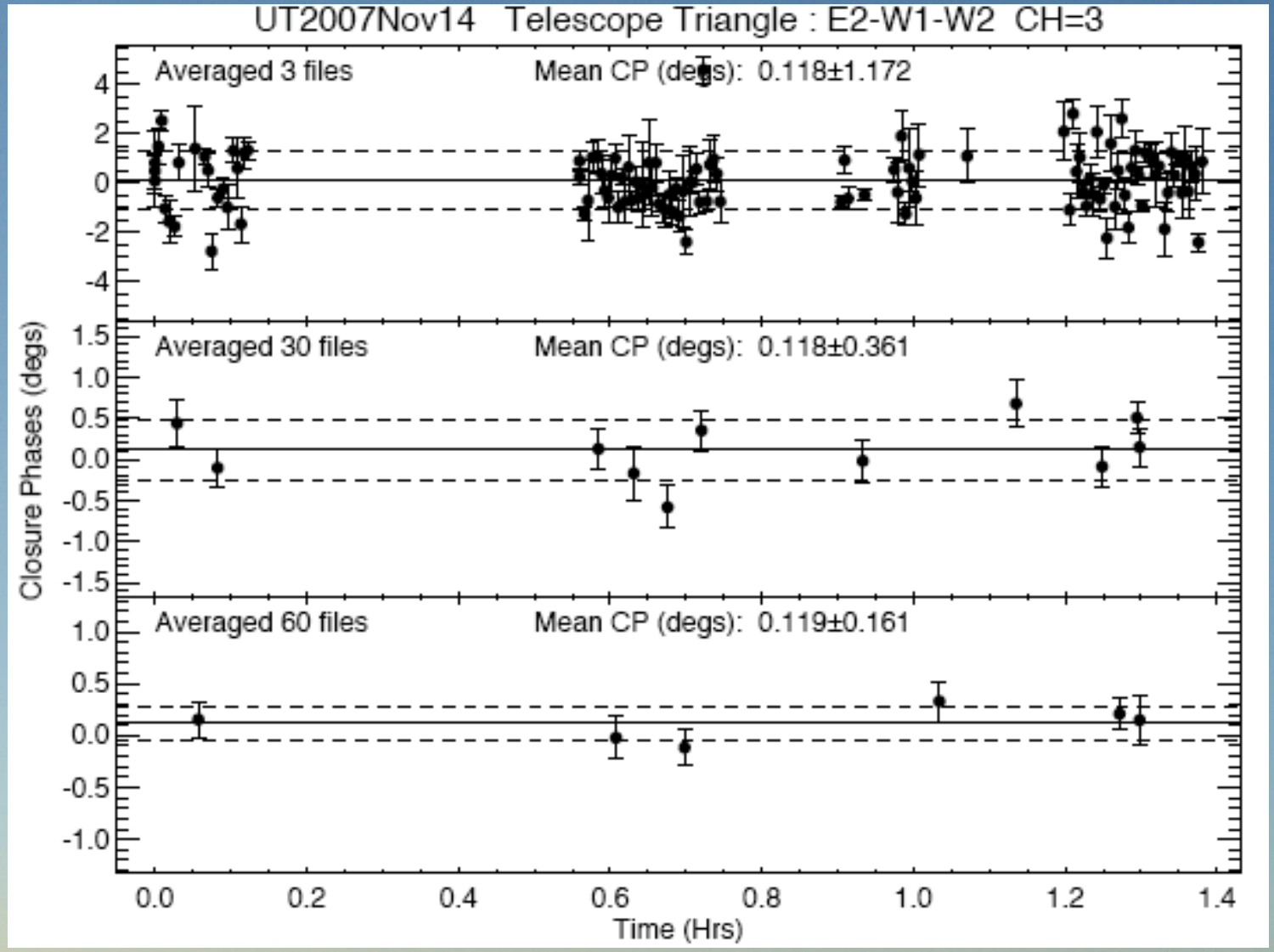


Short triangle ~ 0.8 mas resolution



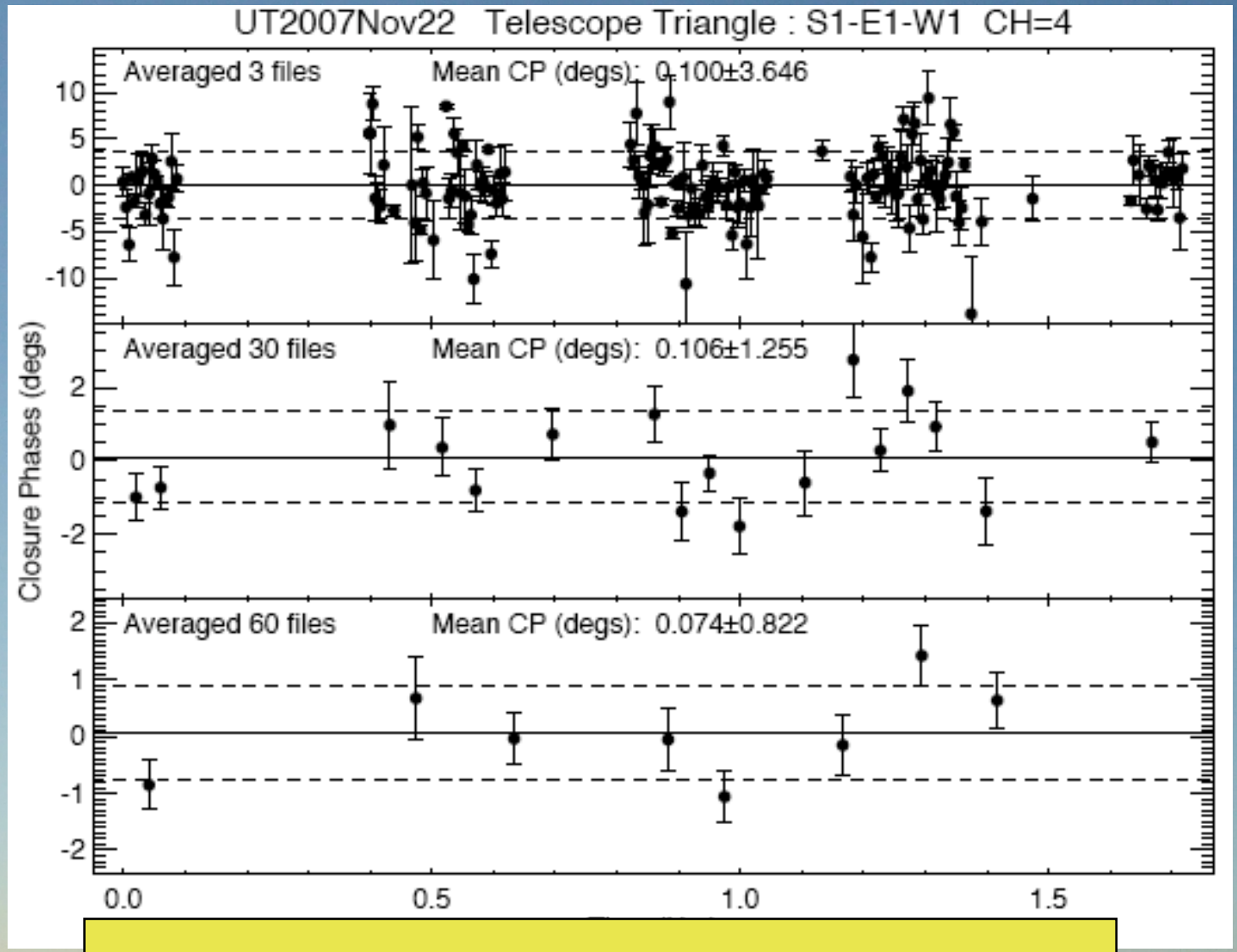
Averaging the whole 1.7 hours=> 0.045^{o}

Short triangle ~ 0.8 mas resolution



Averaging the whole 1.4 hours=> 0.066º

Long triangle ~ 0.5 mas resolution

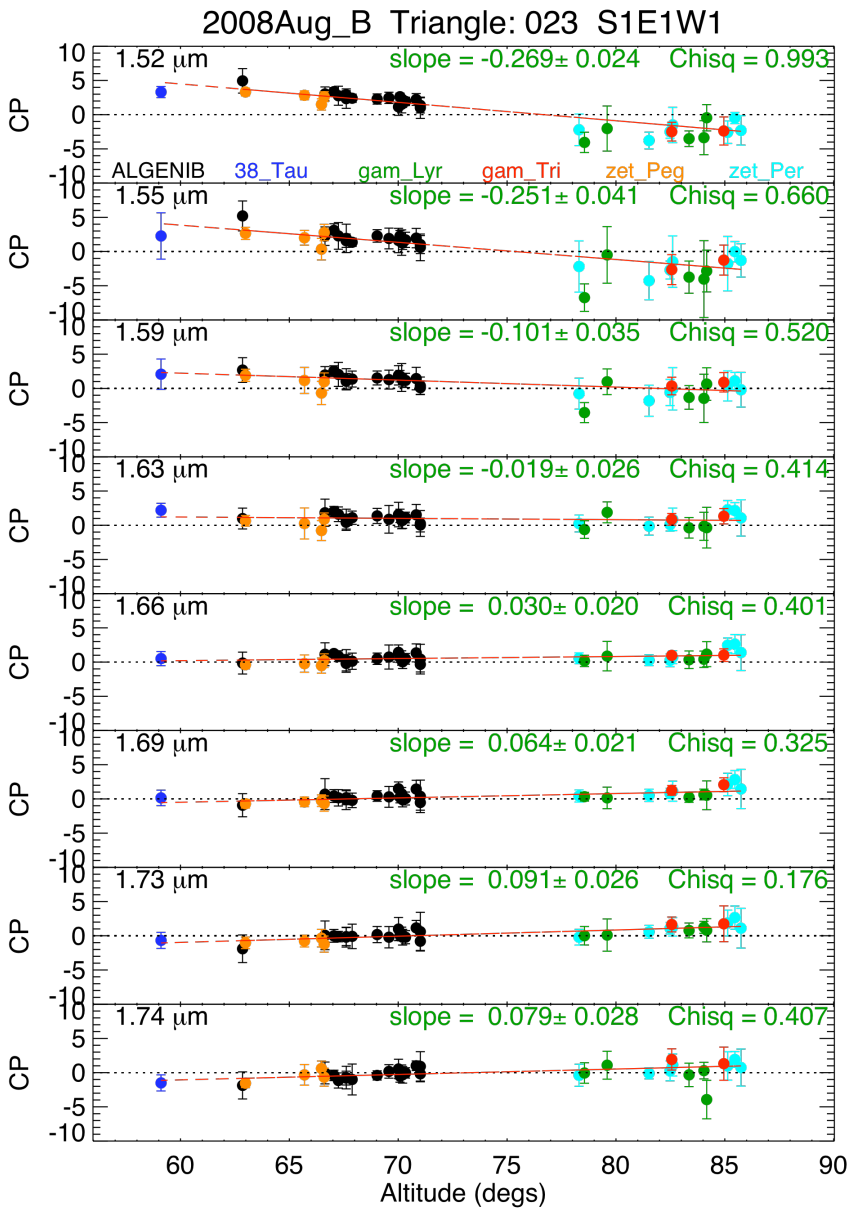


Need 6x S/N for 3σ detection!

Zhao 2009

Astronomy

Significant CP correlations with telescope az and/or alt suggest polarization (or dispersion) effects



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On the horizon…

- We have established precision at 10^-3 level.
  - Need another factor of 10
  - Still not sure the cause of drifts (polarization?)
- Active efforts to detect hot Jupiters
  - VLTI: HD 189733, Tau Boo,..
  - CHARA: Ups And, Tau Boo
  - New Campaign planned this fall, with improved CHARA/MIRC performance

See 2009 PhD by Ming Zhao (U. Michigan -> JPL)