PAVO Science and Instrument Review

Michael Ireland… plus

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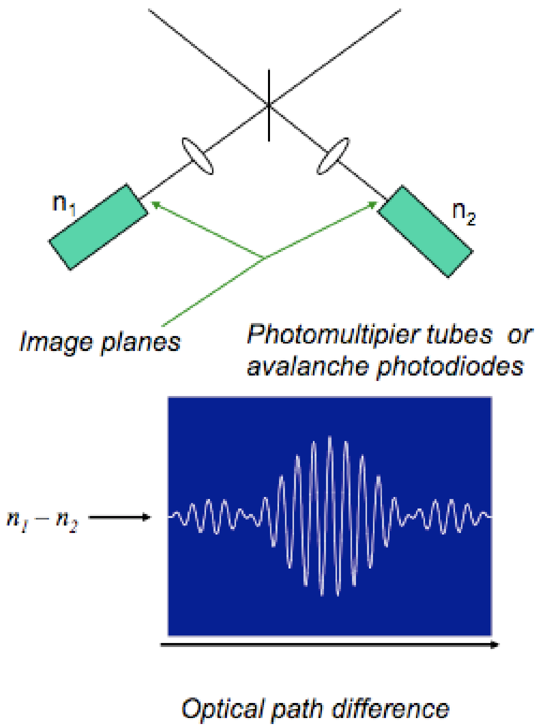
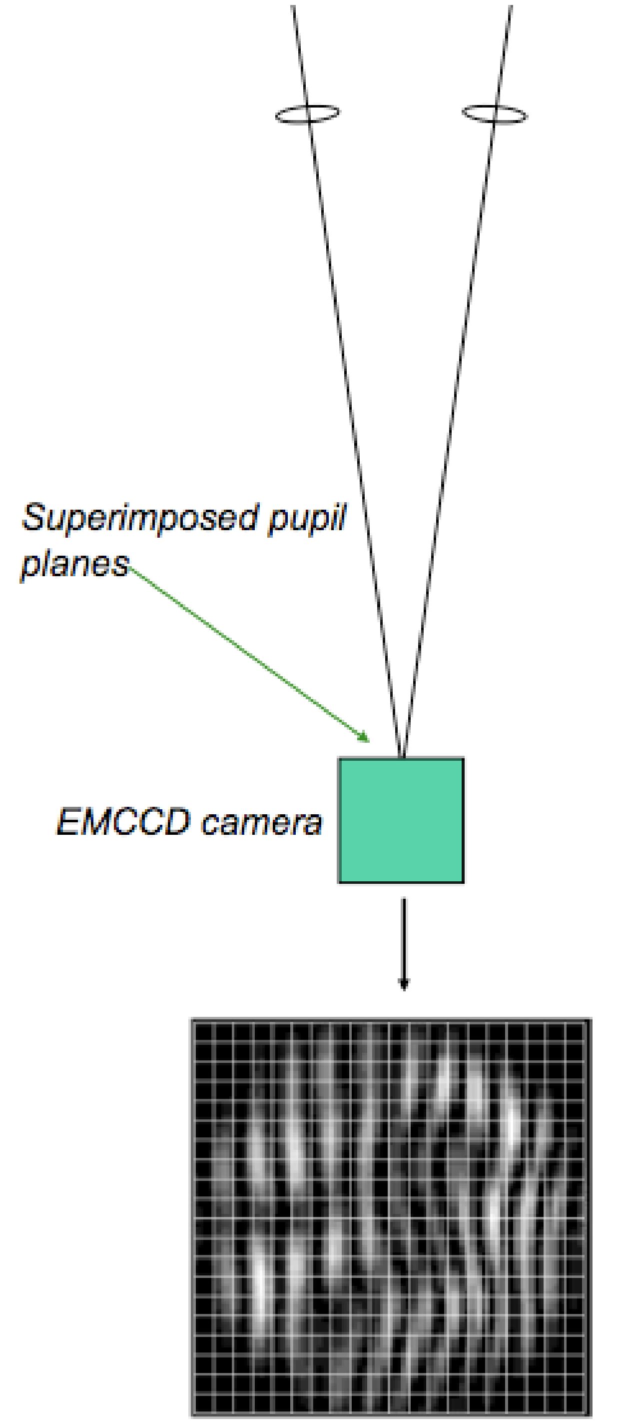
Outline

1. Concept and optics revision.
2. Difficulties and Comparison to MIRC/Vega
3. Analysis and instrument paper progress.
4. Preliminary science examples:
   a) Diameters of asteroseismology (Kepler) targets.
   b) Distance to the Pleiades.

PAVO Design

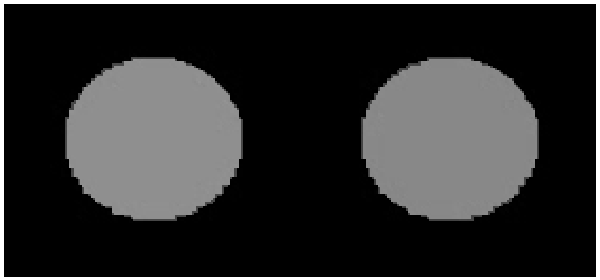
- Use a large aperture by fine sampling of a spatially-modulated fringe pattern.



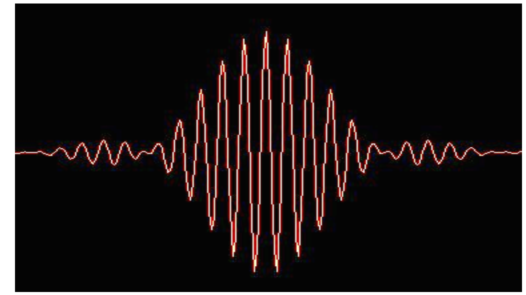


PAVO: Precision Astronomical Visible Observations

Output 1 Output 2

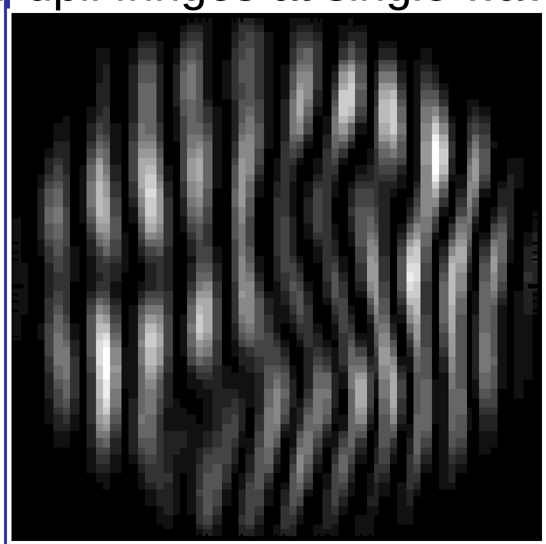


Difference Signal



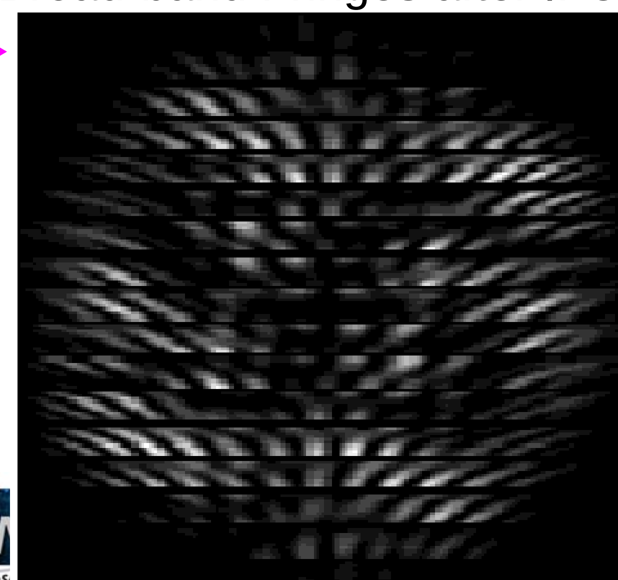
- SUSI/CHARA Classic… Full pupil summed in a two “pixels”, temporal modulation.
- PAVO: 120 (SUSI) and 6000 (CHARA) pixels over the pupil, spatial modulation.
- Spectral dispersion enables group-delay tracking.

Pupil fringes at single wavelength

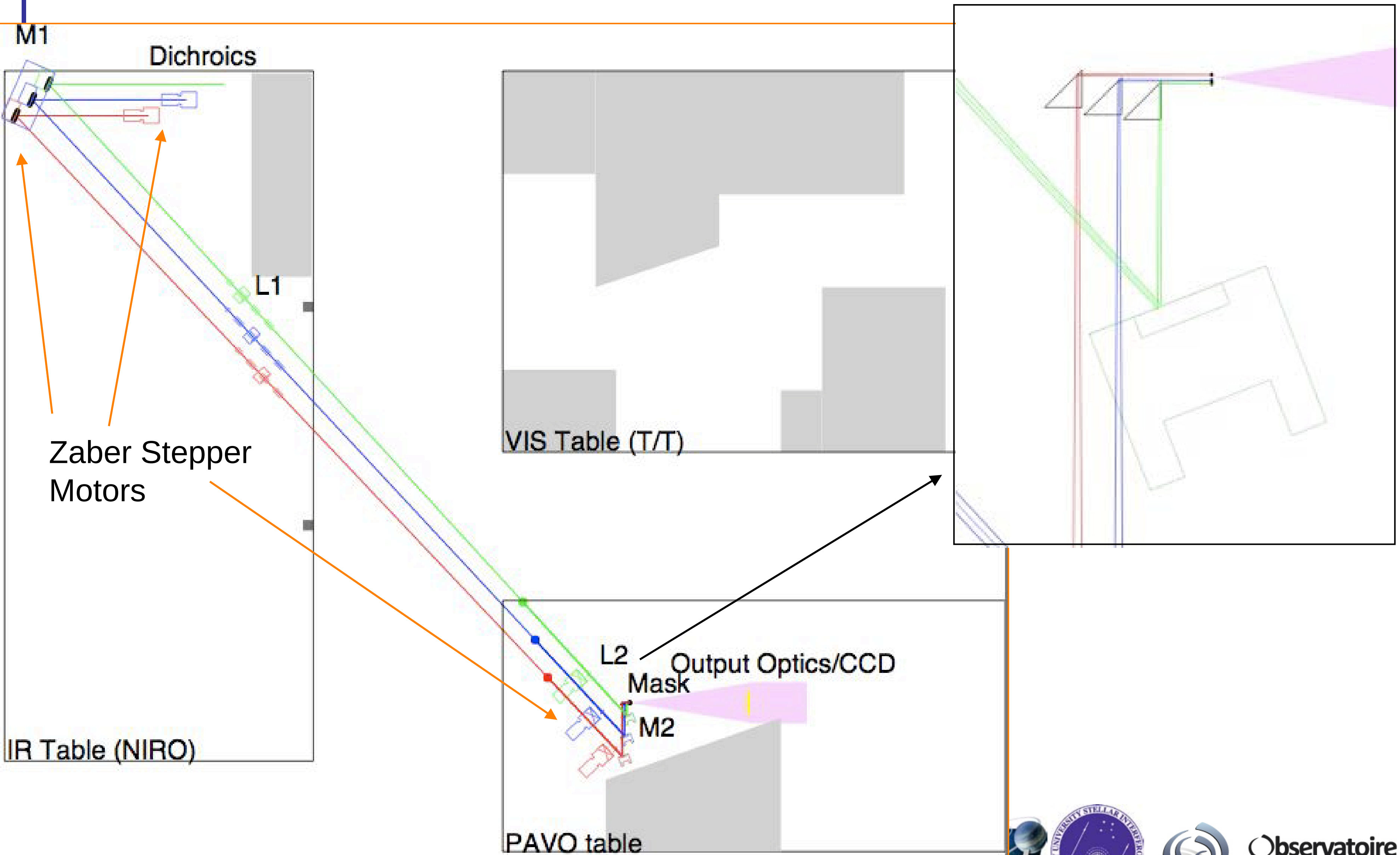


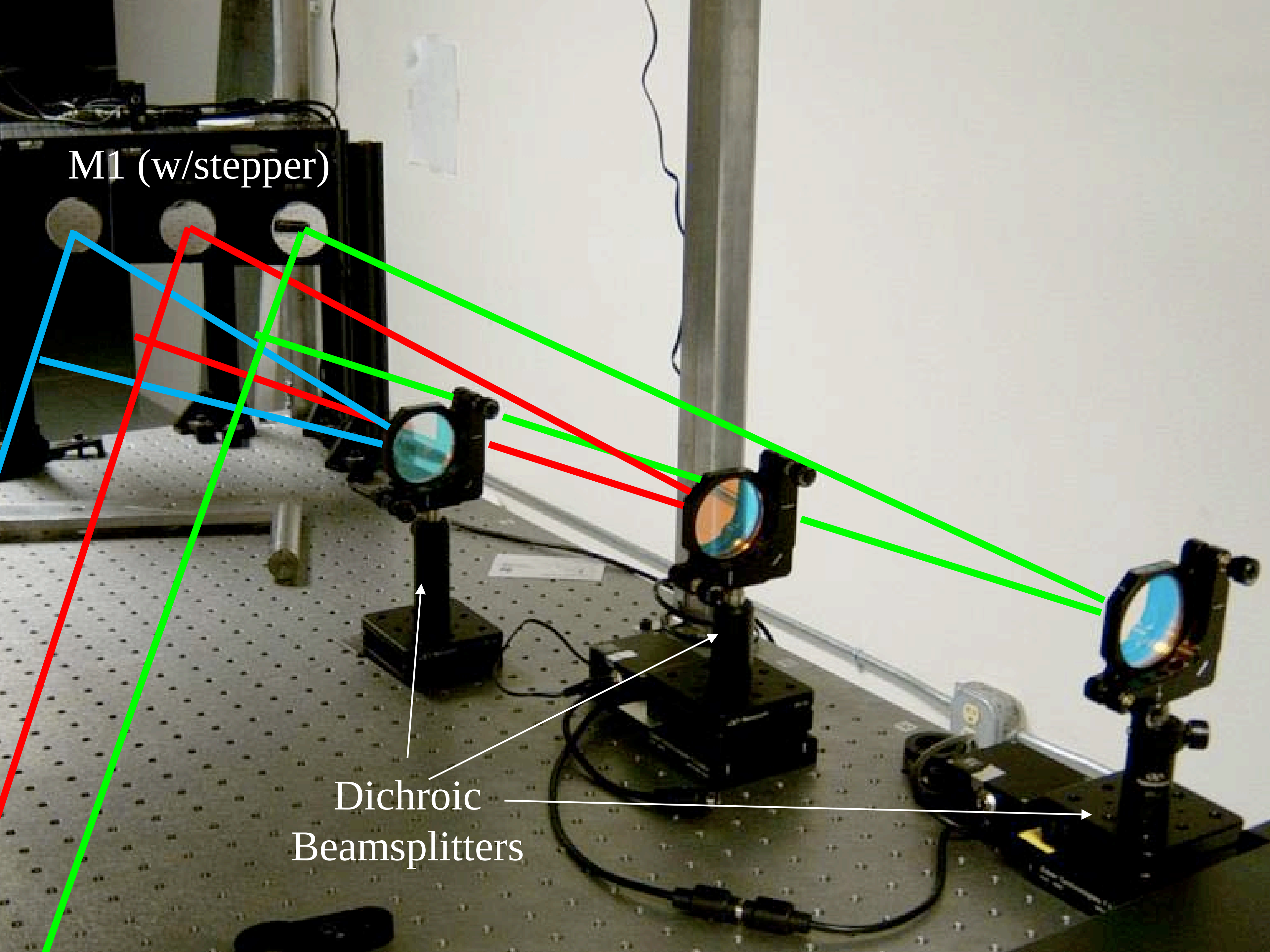
Integral Field Unit
CHARA: 16 lenslets
Think of a data *cube*

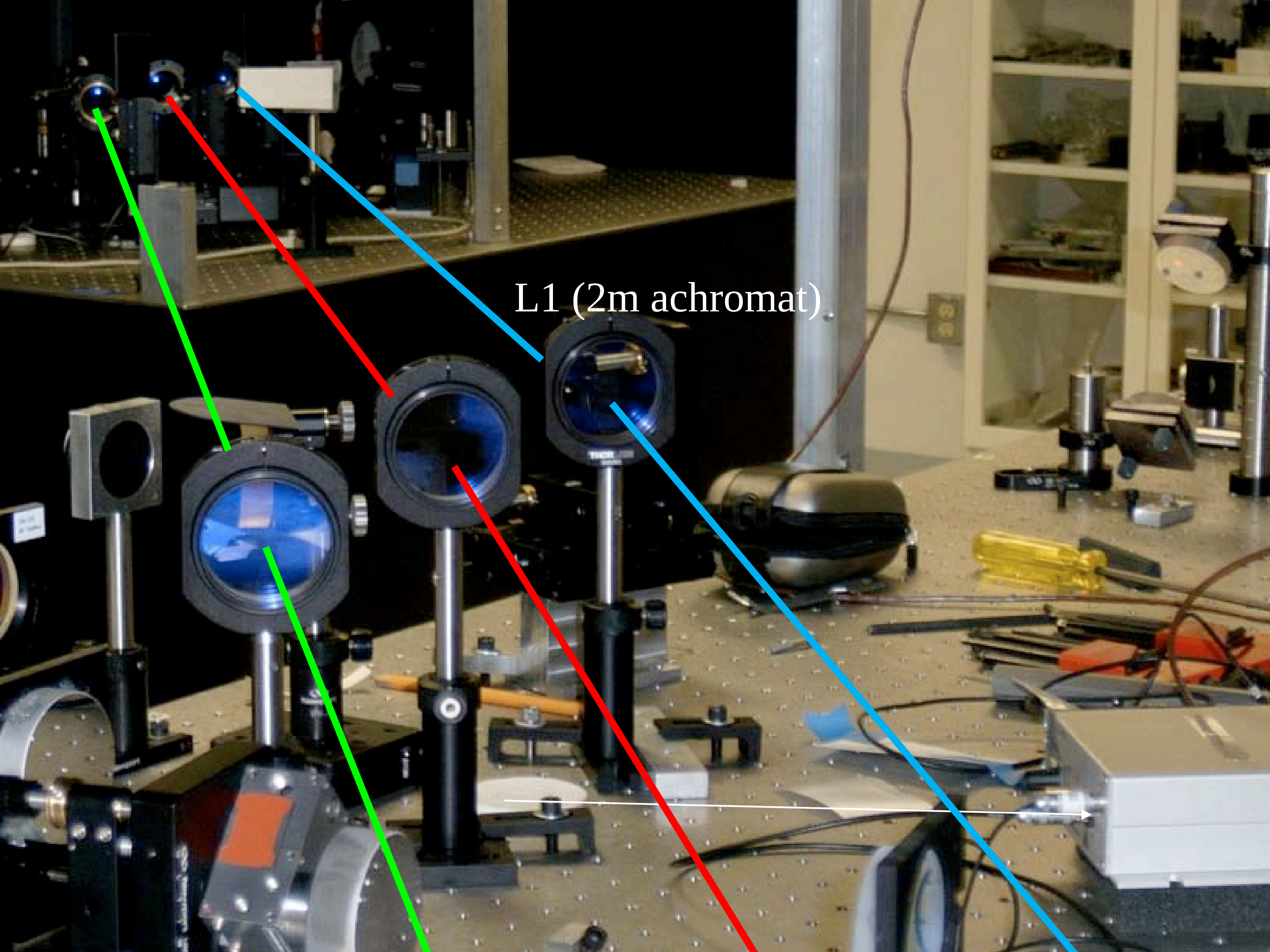
Broad-band Fringes after IFU

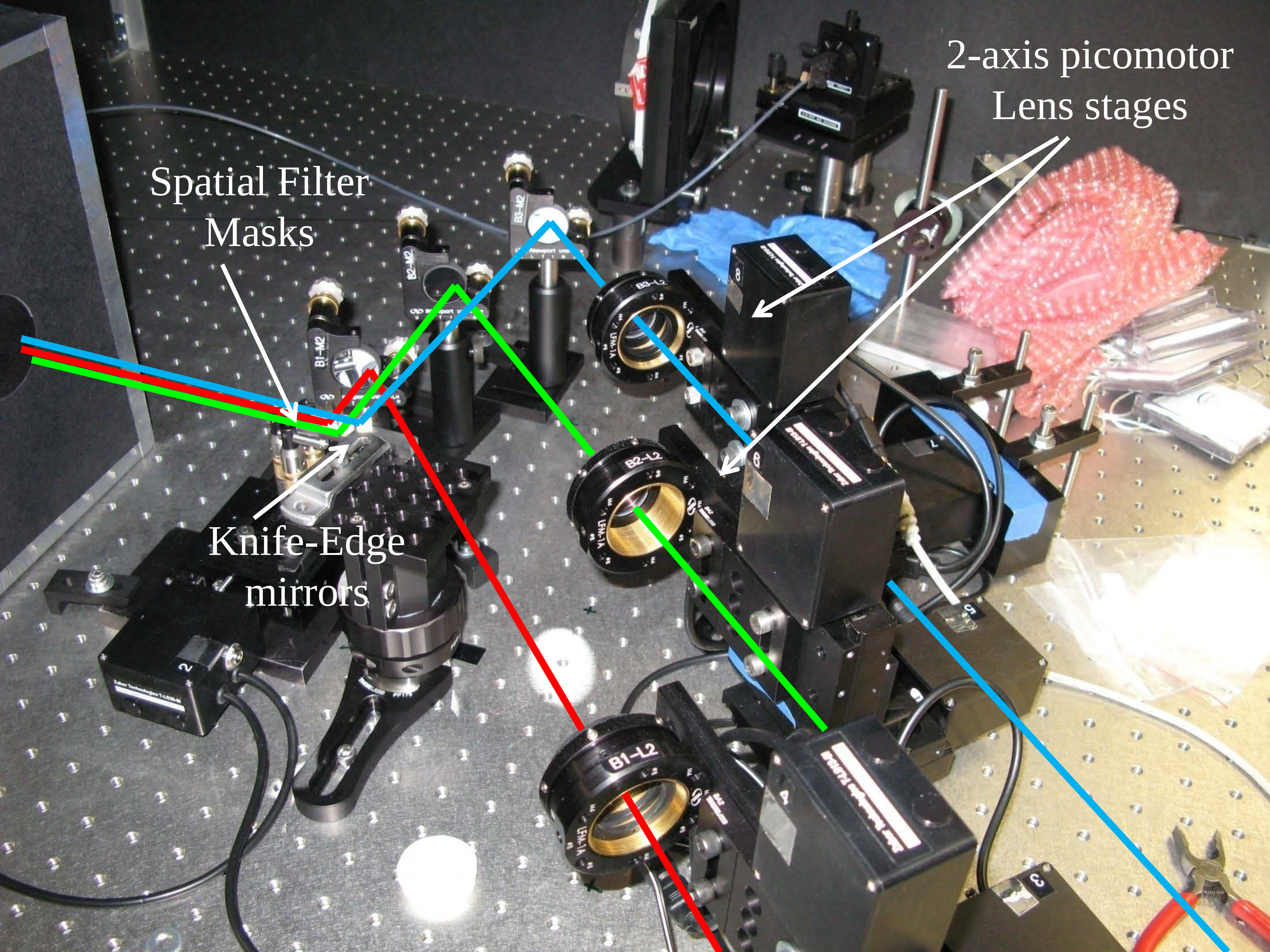


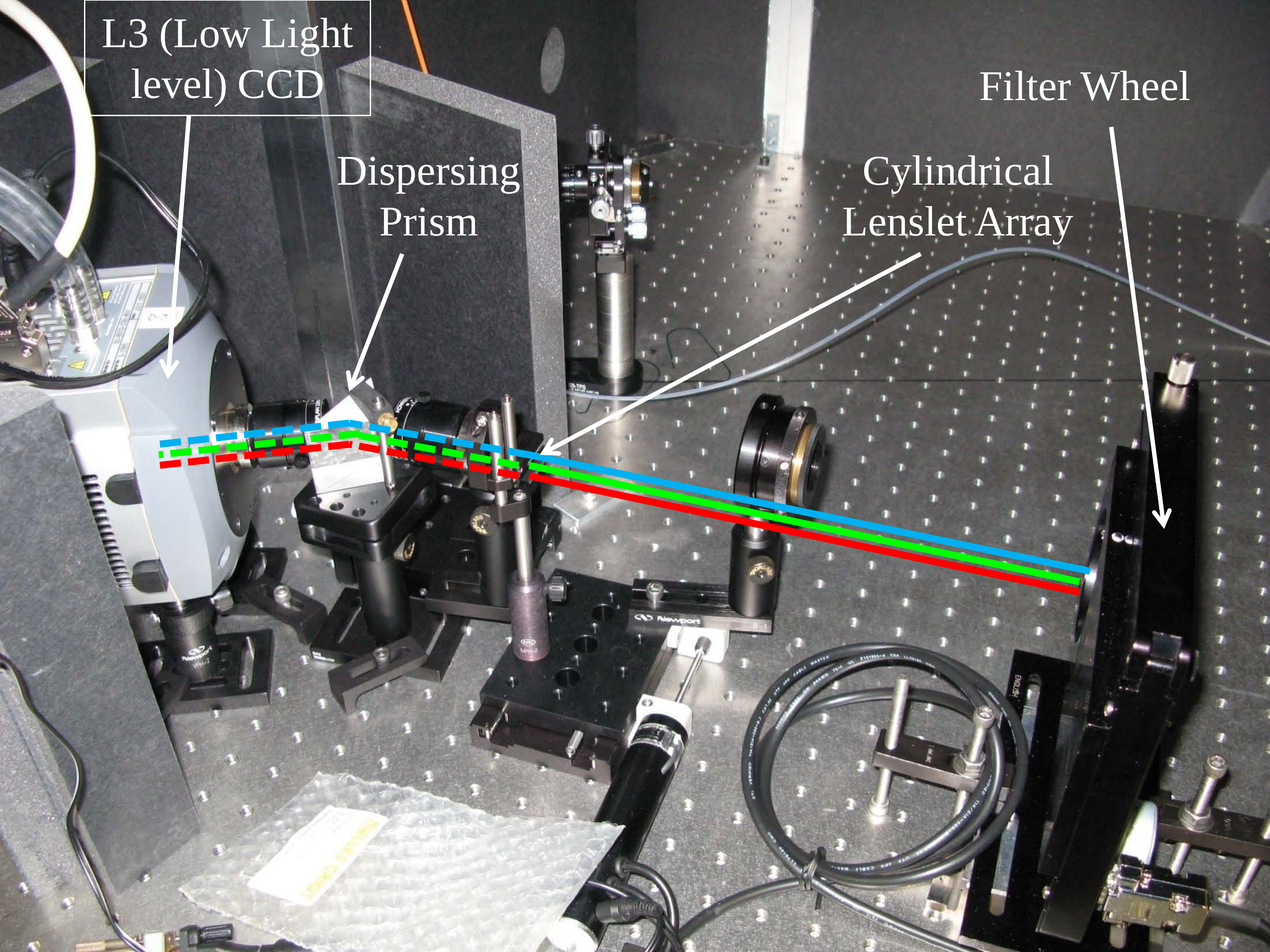
Optics at CHARA




M1 (w/stepper)
Dichroic
Beamsplitters


L1 (2m achromat)


2-axis picomotor
Lens stages
Spatial Filter
Masks
Knife-Edge
mirrors
B1-M2
B2-M2
B3-M2
B3-L2
B2-L2
B1-L2


L3 (Low Light level) CCD
Dispersing Prism
Cylindrical Lenslet Array
Filter Wheel

PAVO Throughput

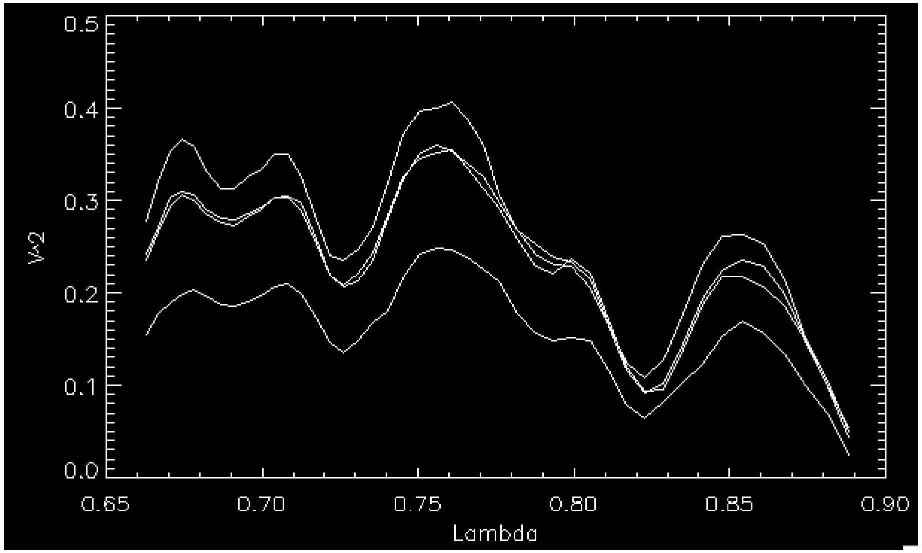
- Measured on Atlas and calibrators, W1W2S2, 21 Sep 2008. 3.6 ADU/photon.
- Zero-point is R=4.1, for 1 photon/pix/exposure at 10 millisec, corresponding to ~0.7% throughput * QE. PAVO should be 50% (mask/aberrations), 70% (optics @ 1.5% per surface) and 70% (camera). i.e. 3% for CHARA.
- MIRC's zero-point mag is 5.7…. i.e. to operate at the same S/N regime, we need 28 times surface brightness.
- PAVO should therefore work for 200,000 K stars just as well as MIRC works for 10,000 K stars. Problem – there are no 200,000 K stars!

PAVO Advantages

- PAVO has ~2.6 times more effective exposures and should have ~100 "independent" fringes on the detector, so should operate at 16 times lower S/N per pixel. So, *in principle* PAVO should be able to image the same stellar classes as MIRC, just 2.5 times more distant and 2 mags fainter.

V^2: Single Baseline

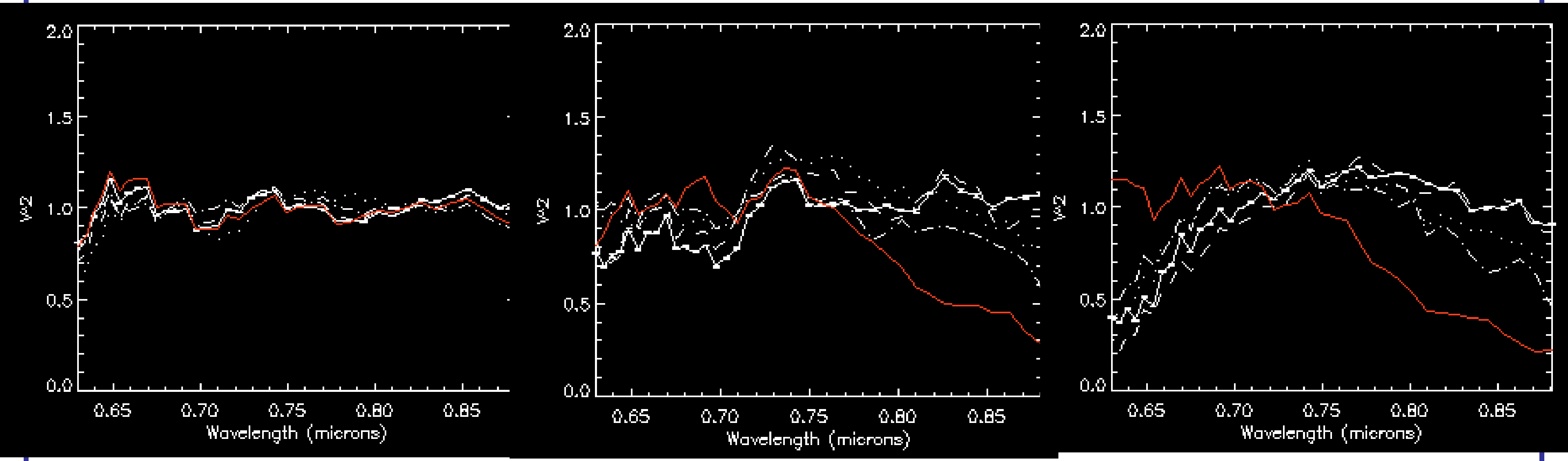
- "foreground-subtraction" now OK.
- Even with good foreground subtraction, there are calibration issues whenever a W telescope is used with an S, and S with an E etc but not on W1W2, S1S2 or E1E2.
- These were blamed on polarization…



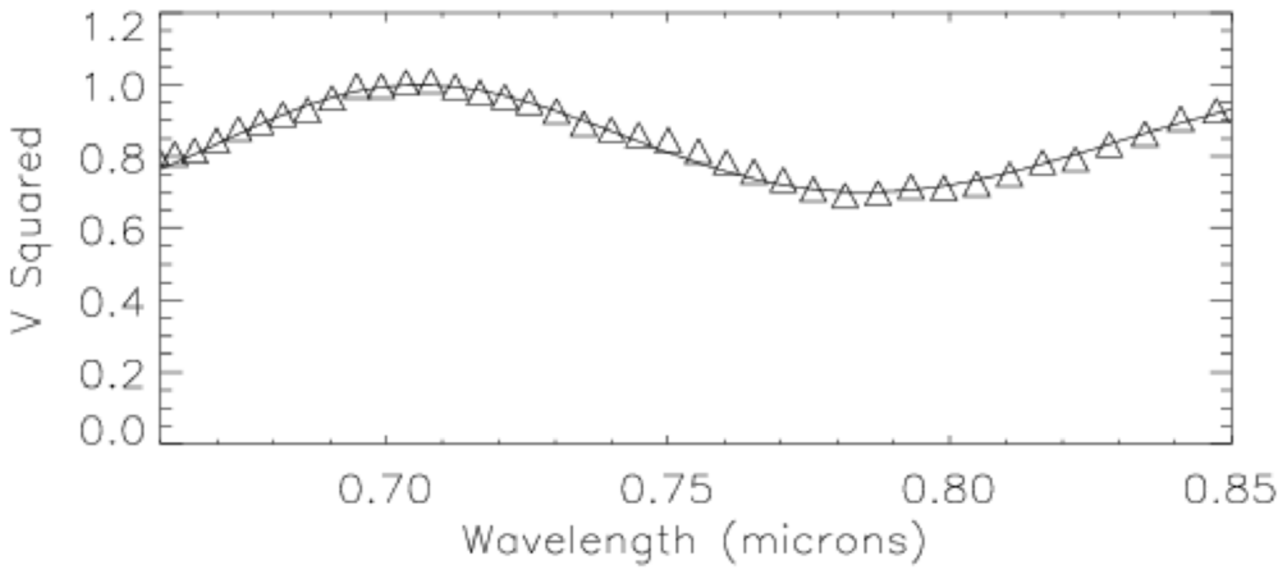
HD 187340, HD 175305, HD 196502, HD 201908

Polarization Tests

- W1W2, W2E1, W1E1
- Solid: No polarizer. Dotted/Dashed: Linear polarizer rotated. Red: ¾ wave plate in E1.



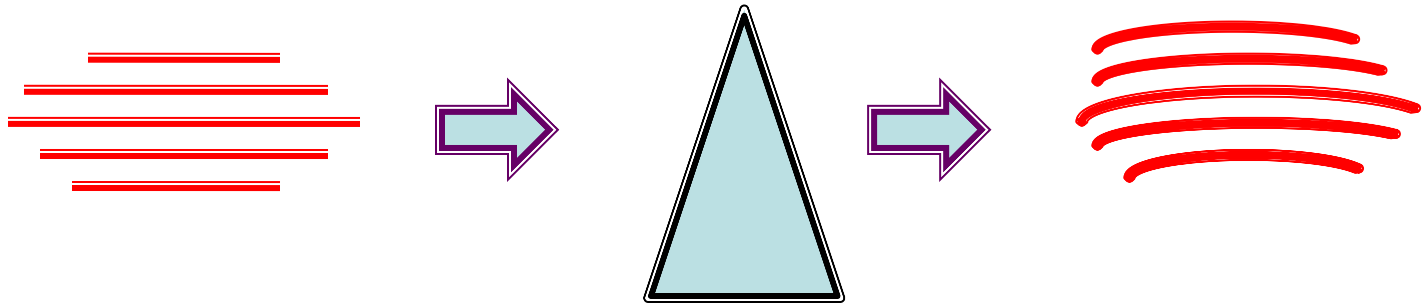
Example V^2 Science (2009 talk…)



4 minutes (including overheads) on the binary HD 28294 (76 Tau, HIP 20873, vB 68), a Hyades binary that had not been previously resolved. Calibration at the percent level. This binary was resolved on S1S2, has a projected separation of 24 mas (error <0.2 mas) and a contrast ratio of 2.6 magnitudes.

Distortion Solution and Photon-Bias

- A monochromatic source imaged through a prism results in distorted images: each wavelength ends up curved.



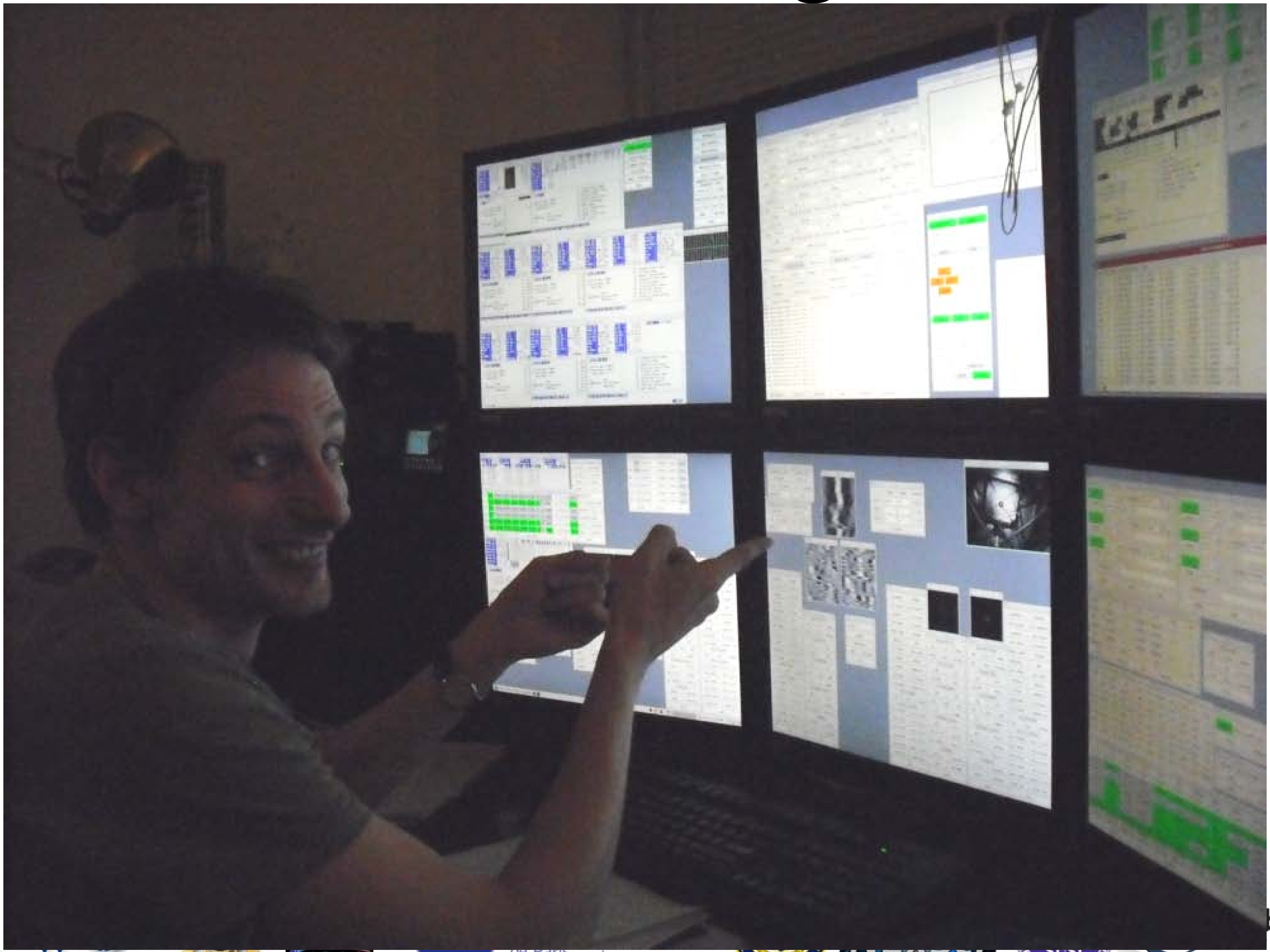
Distortion Solution and Photon-Bias

- To neatly separate fringes from different baselines in reasonable computational time, we need a Fourier transform.
- Interpolating prior to a Fourier transform means that the photon bias in V^2 measurements changes as a function of wavelength and pupil position.

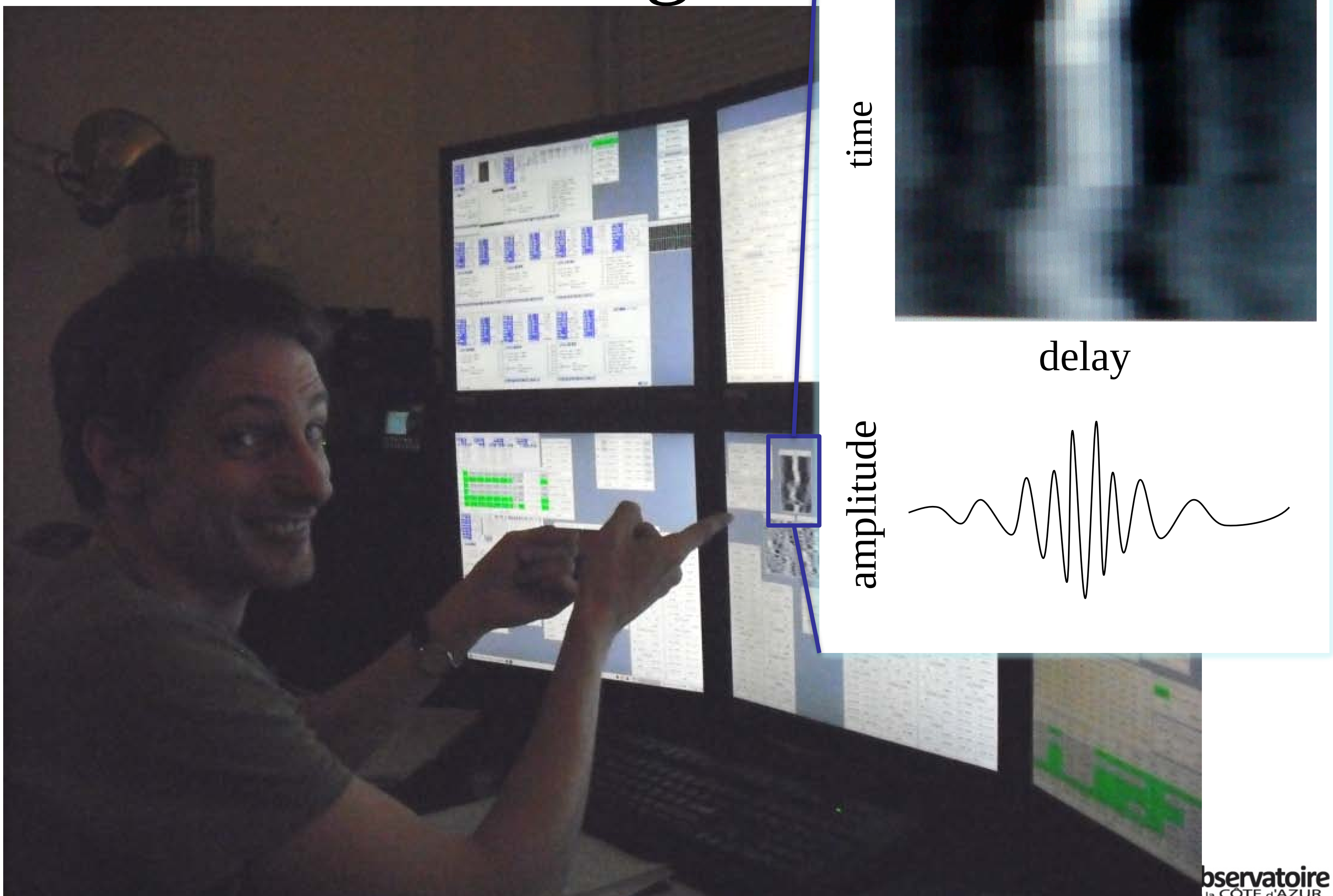
Analysis Pipeline Progress (for details, come on Friday or chat after)

- Photon bias works reasonably for 1 and 3-baseline data, right down to the PAVO mag limit.
- We have tools to reject times when PAVO tracks on noise, and a file-by-file analysis.
- We have a second complete V^2 estimator that works well on faint stars without a F.T. (but has some cross-talk).
- A reliable data simulator has been developed, to help test pipeline changes.

2009 Fringes!!

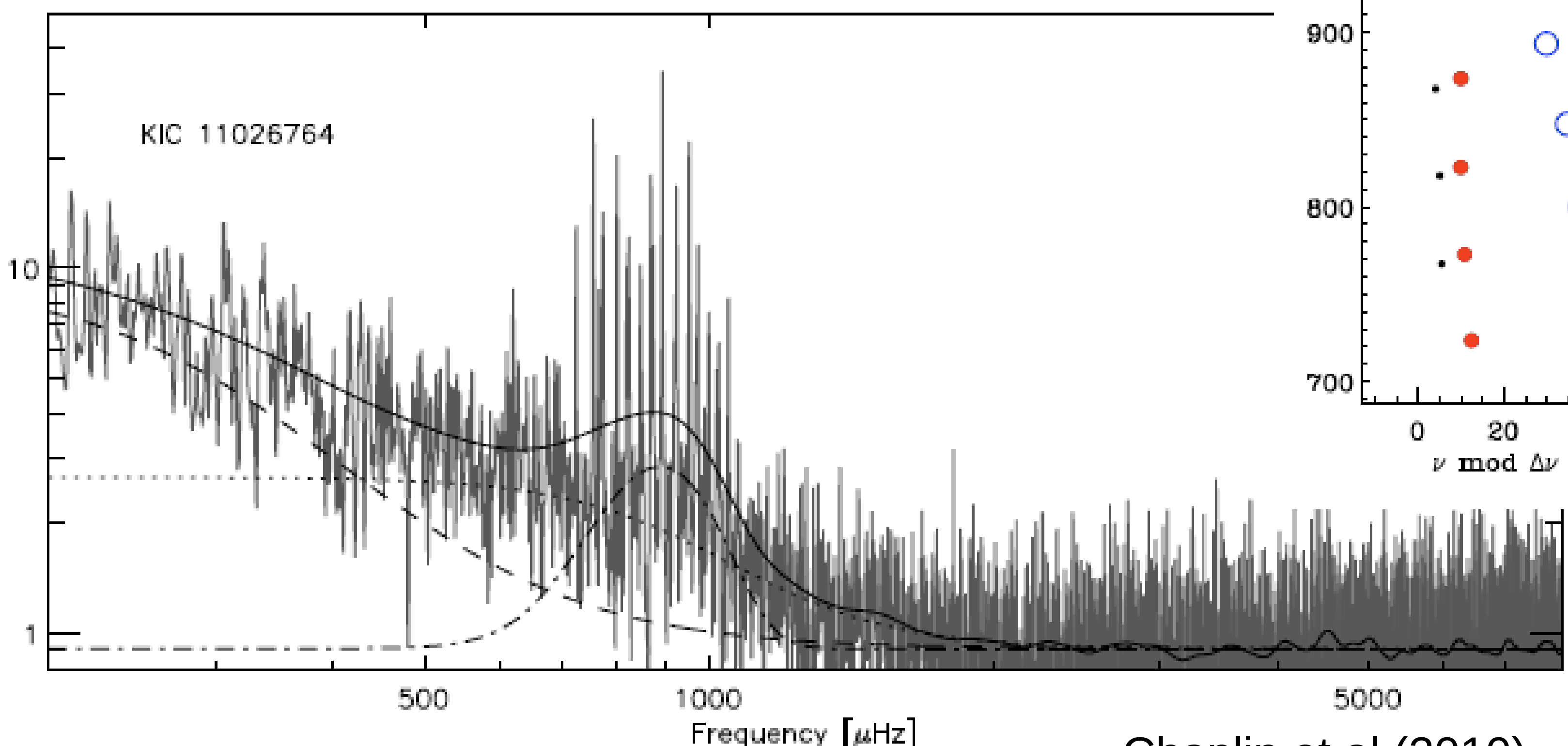


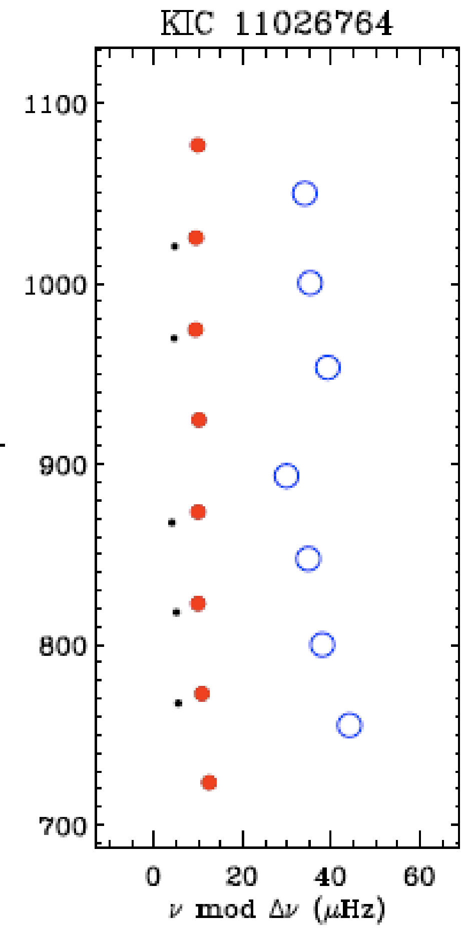
Fringes!!



Science Examples

Kepler for Asteroseismology (and planets)

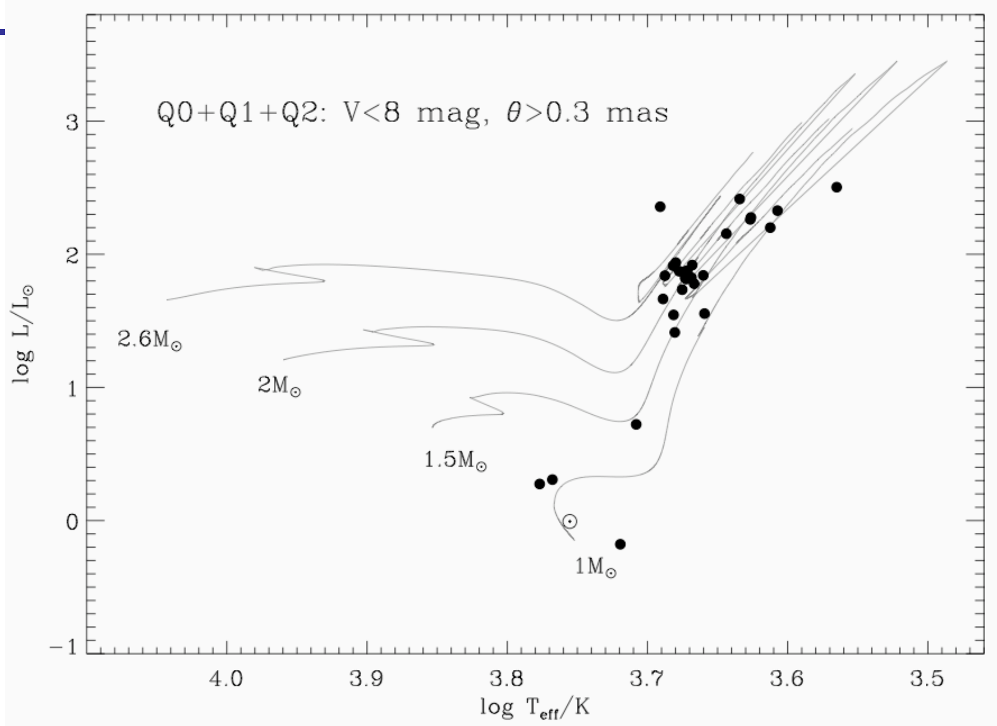




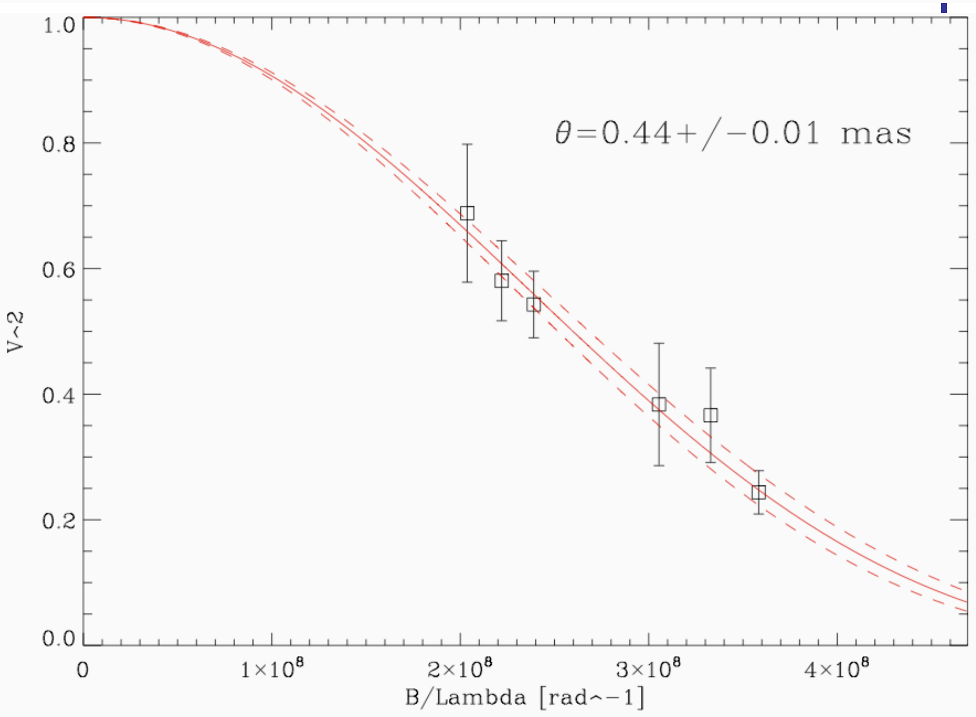
Chaplin et al (2010)

Modeling Kepler asteroseismology targets needs accurate linear radii. Kepler stars are too small and faint for any beam combiner other than PAVO

Kepler stars observed in Q0/Q1/Q2 with potential PAVO follow-up observations

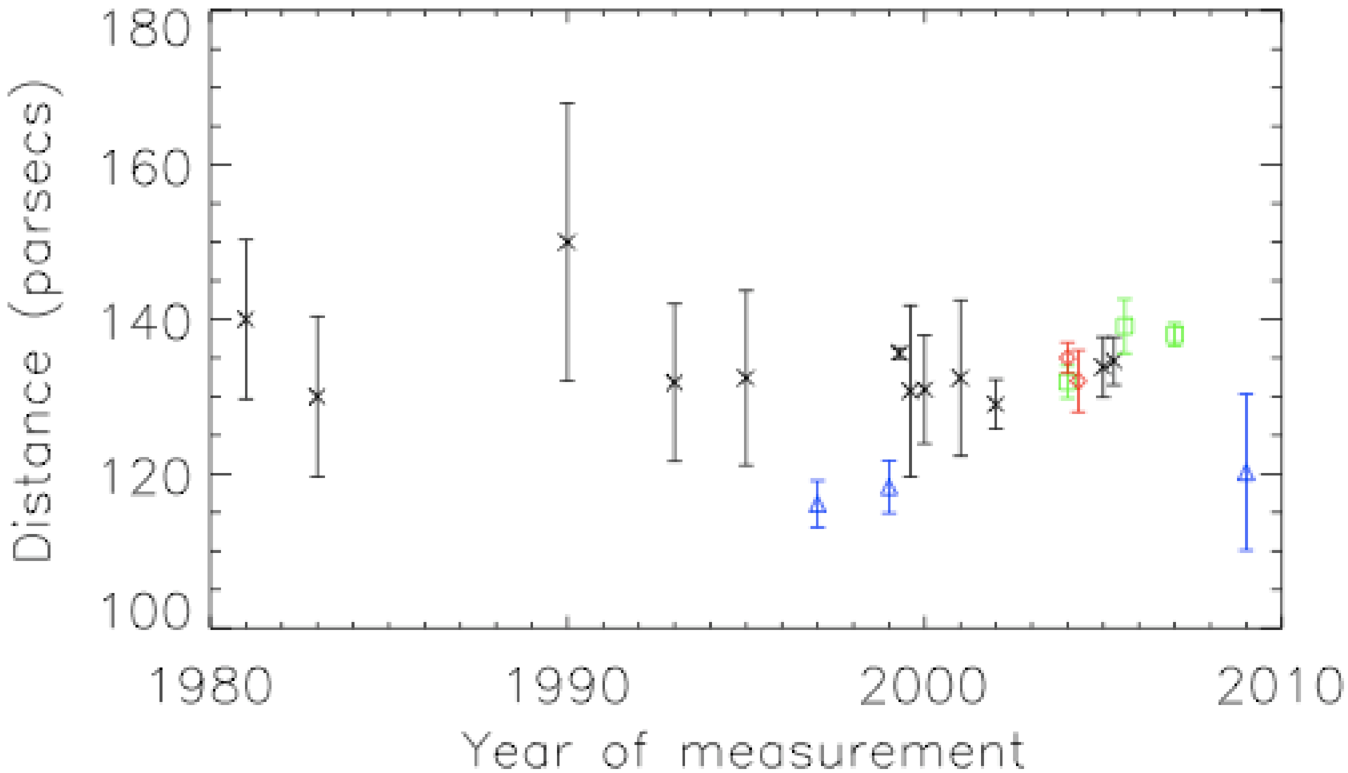


preliminary PAVO data of metal-poor sub-giant with strong oscillation signal observed in Q2
→ δΘ/Θ ~ 2%
→ δR/R ~ 4%

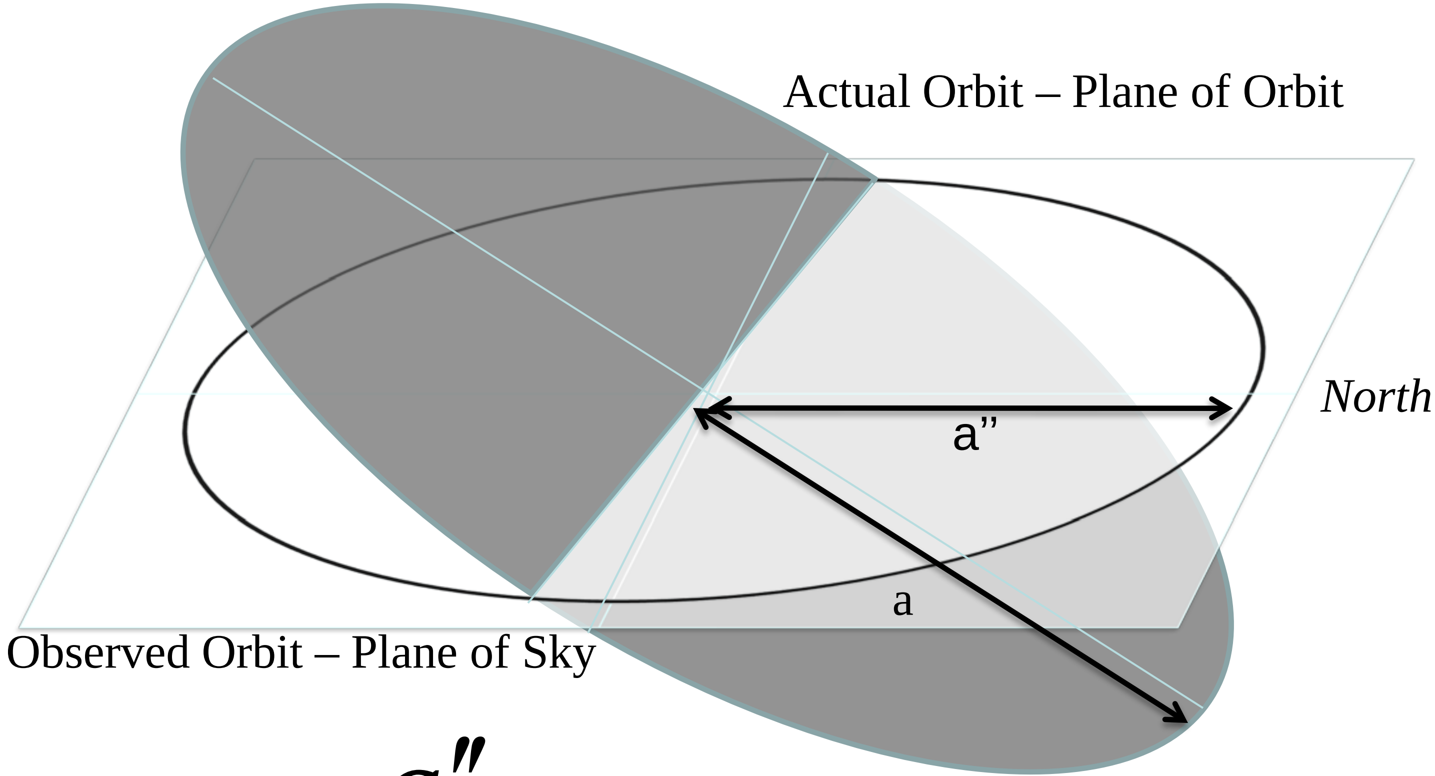


Pleiades Distance Contraversy

- HIPPARCOS (blue points) has been inconsistent with other (direct and indirect) methods.



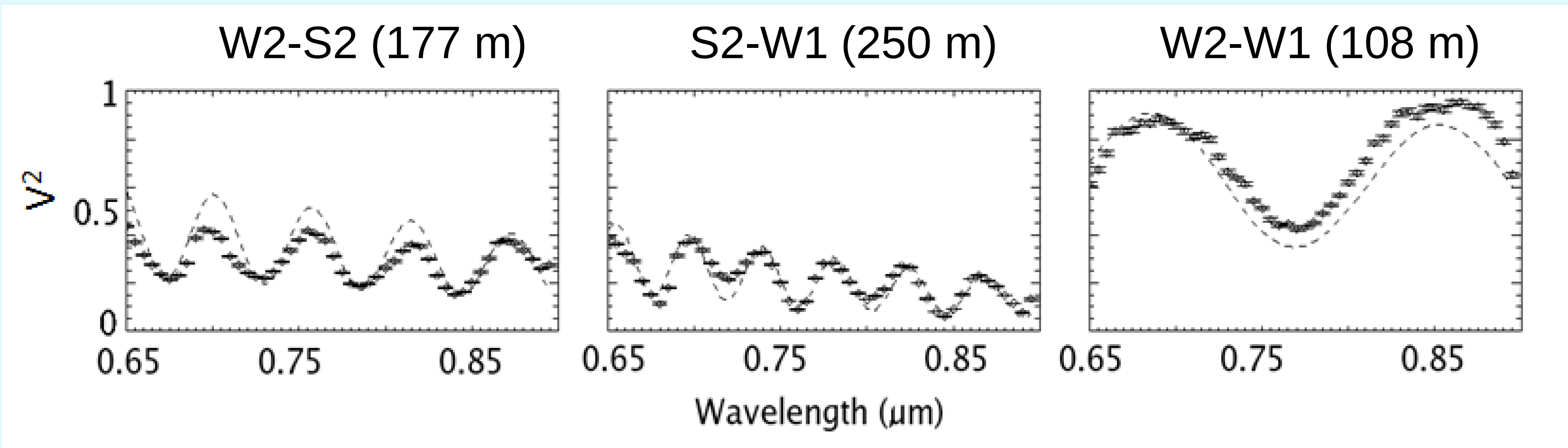
Distance to Binaries



$$\pi_{pl} = \frac{a''}{a}$$

ATLAS

Spectroscopic binary, V magnitude: 3.54



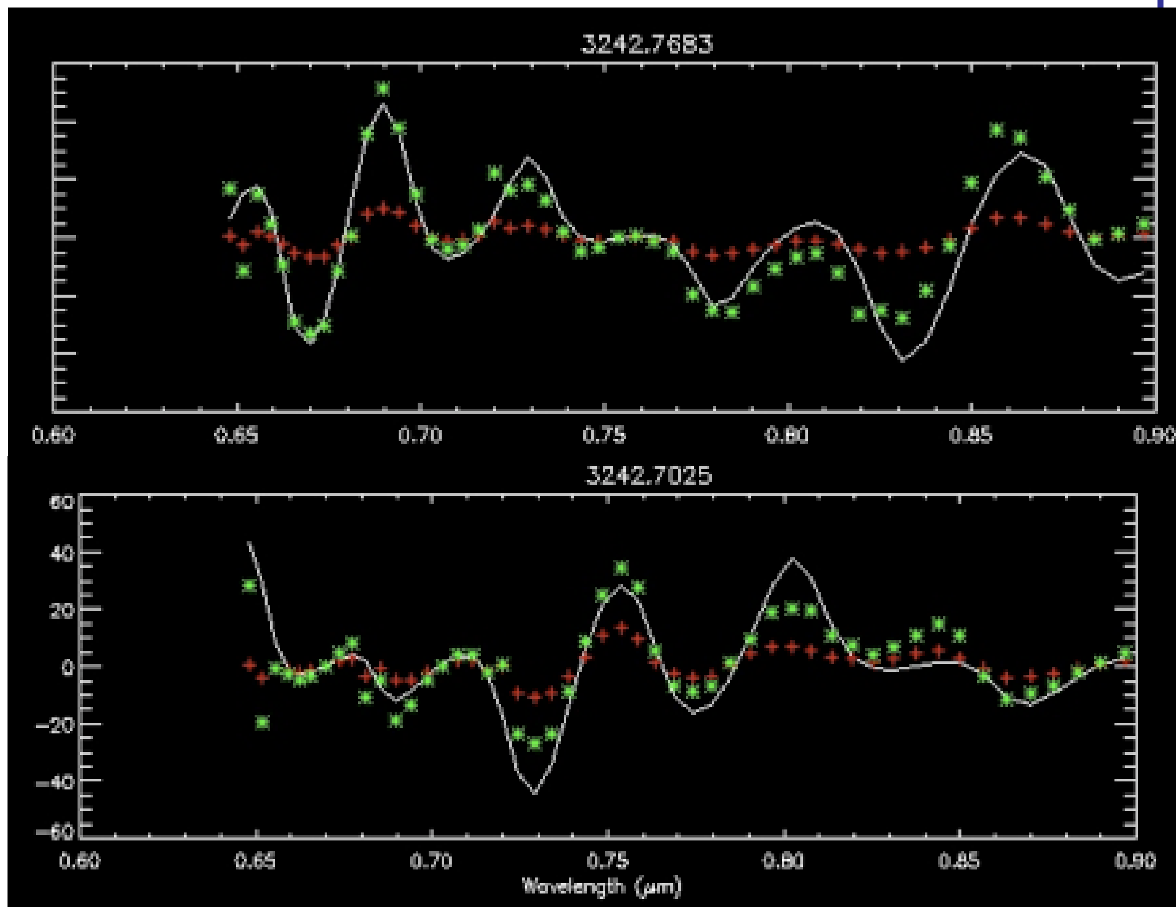
- 8 epochs – 3 baselines. 1 example above
- χ^2 minimisation
- V2 gave a" = 13.00 ± 0.02 mas
- First PAVO 3 telescope analysis

Closure-Phase…bias dominated

Atlas: brighter and less-resolved than most PAVO targets.

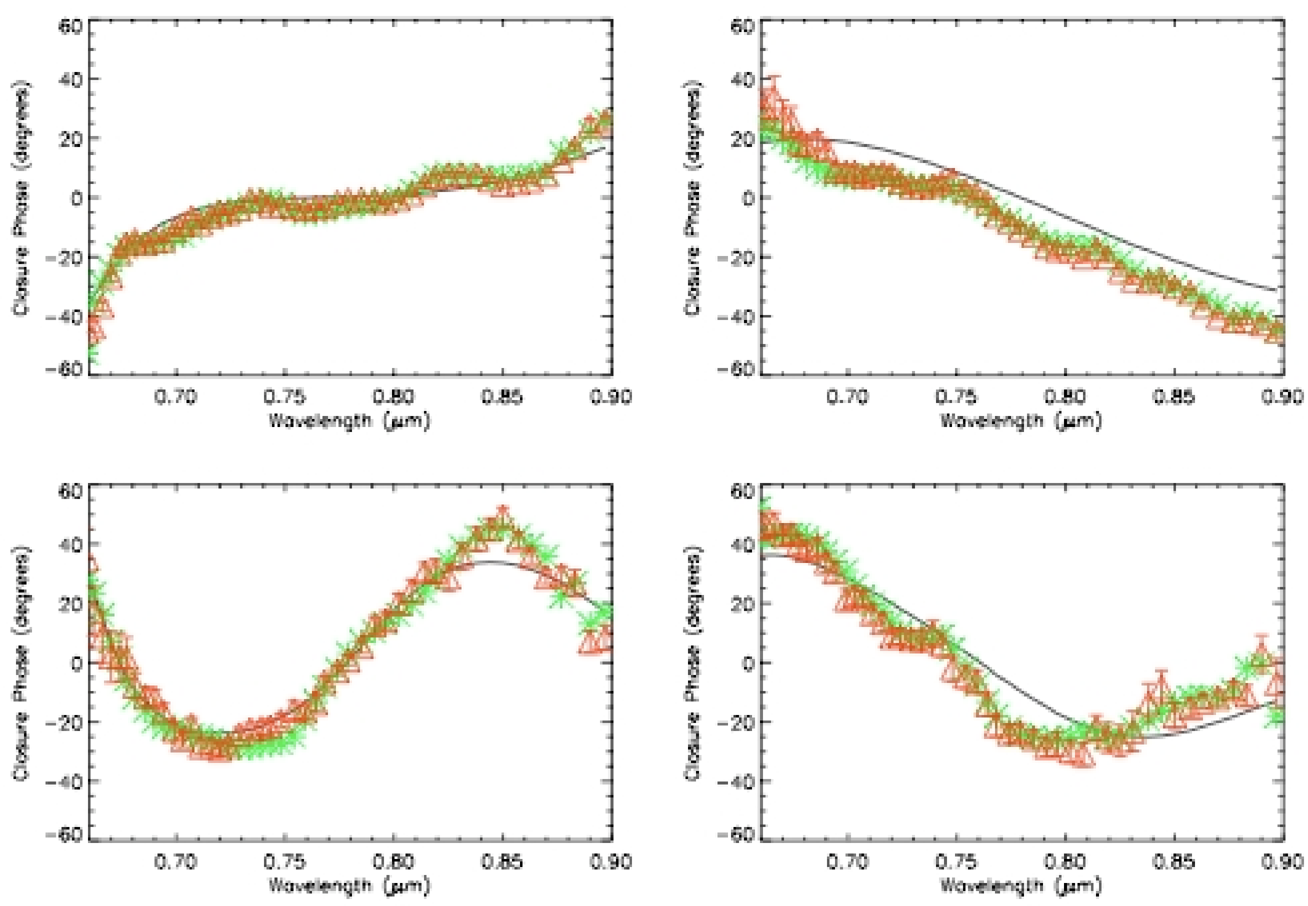
Red Crosses: Raw Closure-phase

Green Asterisks: Bias-subtracted closure-phase.



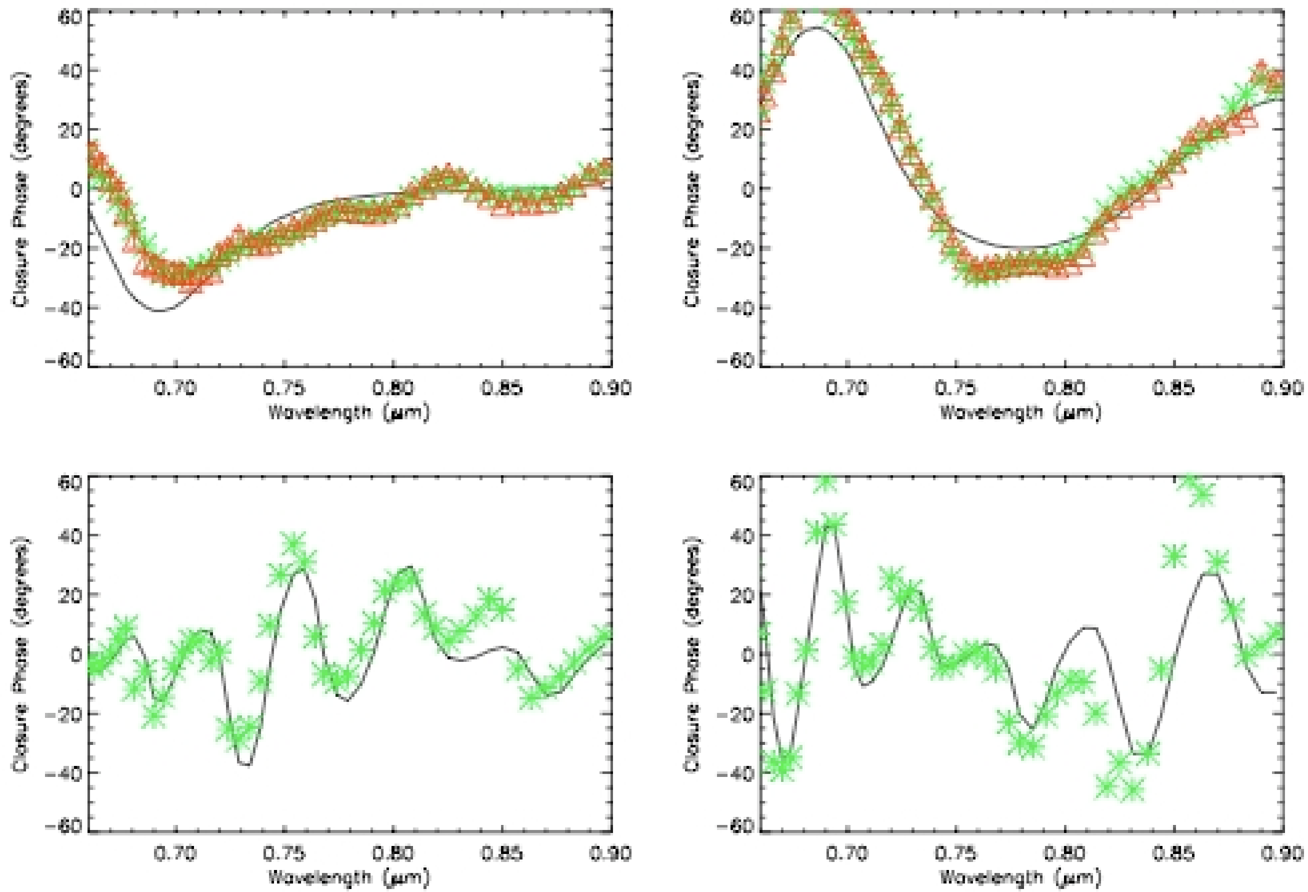
Closure-Phase…basically working

Atlas: First
4 data sets



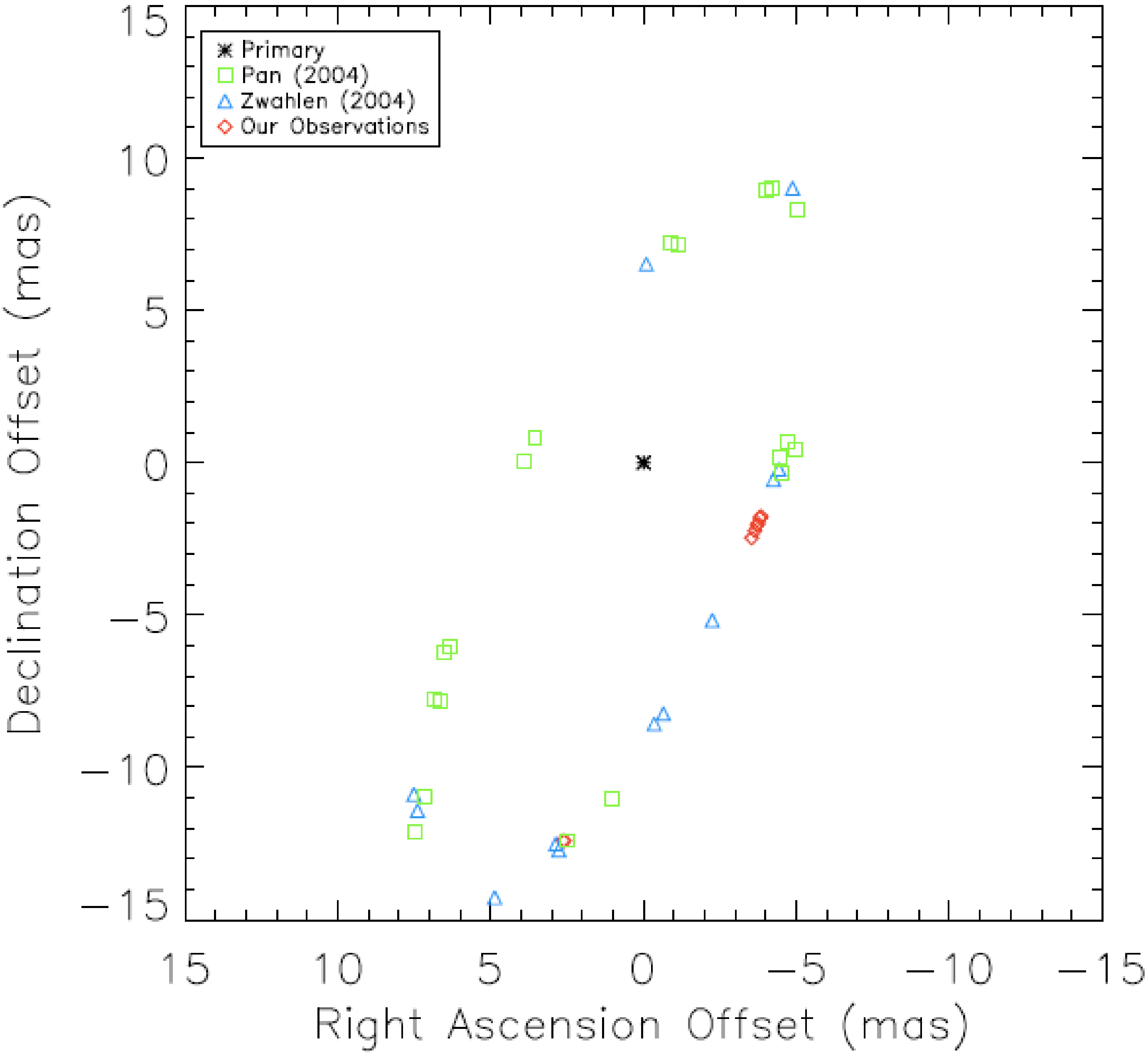
Closure-Phase…basically working

Atlas: Last
4 data sets



CHARA Collaborati

Atlas Orbit



Updated Pleiades Distance

Parameter	Value
i (deg)	107.660 ± 0.107
β	0.223 ± 0.015
Ω (deg)	153.843 ± 0.133
a'' (mas)	12.995 ± 0.020
R_1 (mas)	0.482 ± 0.010
R_2 (mas)	0.373 ± 0.062

➔ d = 133.1 ± 3.1 pc

HD 23642 (eclipsing binary) gives 131.5 ± 13 pc… but we're certain that the error here can be improved. This detail has been delaying the (just about complete) paper.

Summary

Since last year…

- Plenty more data, particularly on low-V^2 sources. Record of R=8.2 not exceeded.
- Pipeline is working reasonably well on faint stars for V^2, and bright stars for closure-phase.
- Calibration difficulties remain, but it is (past) time to see what we can get out of existing data.