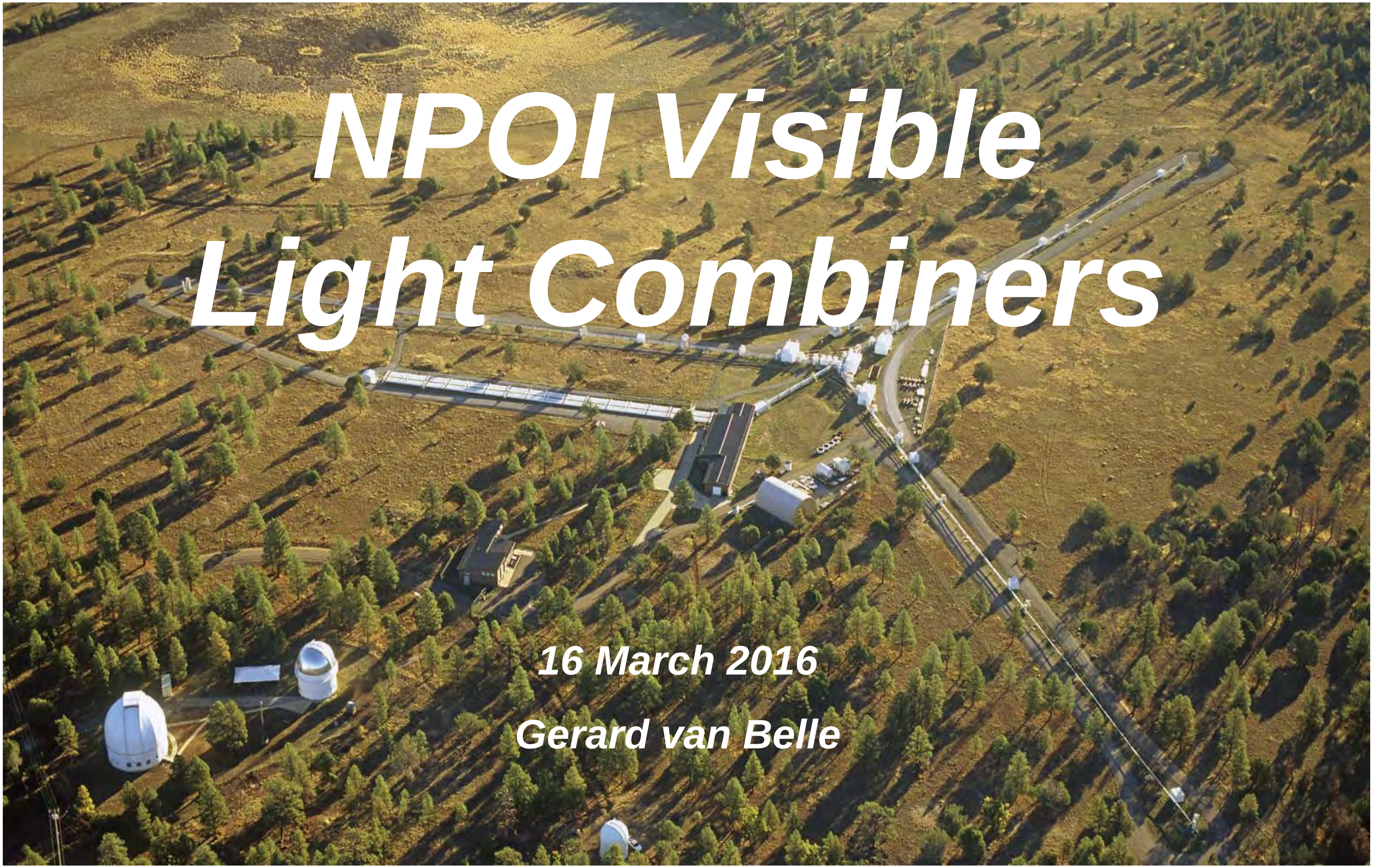

NPOI Visible Light Combiners

16 March 2016

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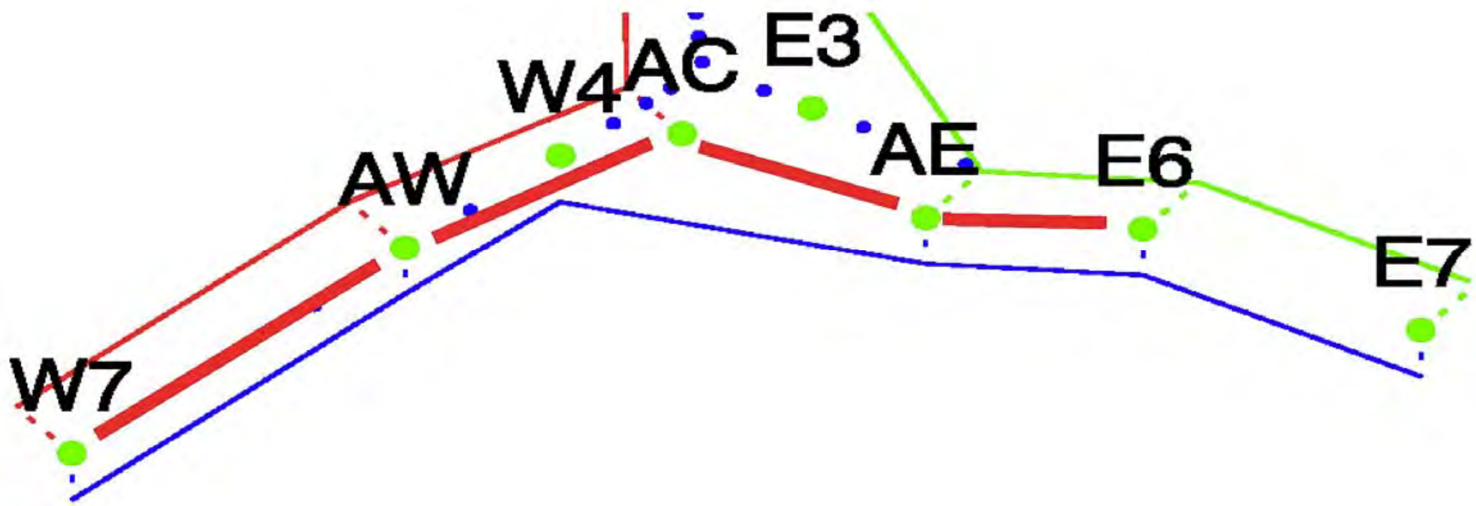
Georgia State University · NSF · NOAO · l'Observatoire de Paris · LESIA · The University of Michigan · NExScI NASA Exoplanet Science Institute · SUSI · Observatoire de la Côte d'Azur

NPOI Beam Combiners

- New Fringe Engine for NPOI “Classic” beam combiner
  - NSF funded (NMT)
  - Data capture all of 3 spectrometers, all night long
    - Currently half of 2 spectrometers, 30sec buffer
  - Hardware finished (AZES), firmware & software development
  - On-sky testing (Mar 2015, Sep 2015, Feb 2016) of baseline bootstrapping past 3rd zero
- VISION:
  - NSF funded (TSU)
  - 6-beam, visible-light analog of MIRC
    - 16 Dec 2013: First bootstrapped fringe tracking (5 stations).
    - Currently fringe tracking to 4th magnitude
    - Instrument paper (Garcia+ 2016, PASP) in print, commissioning complete

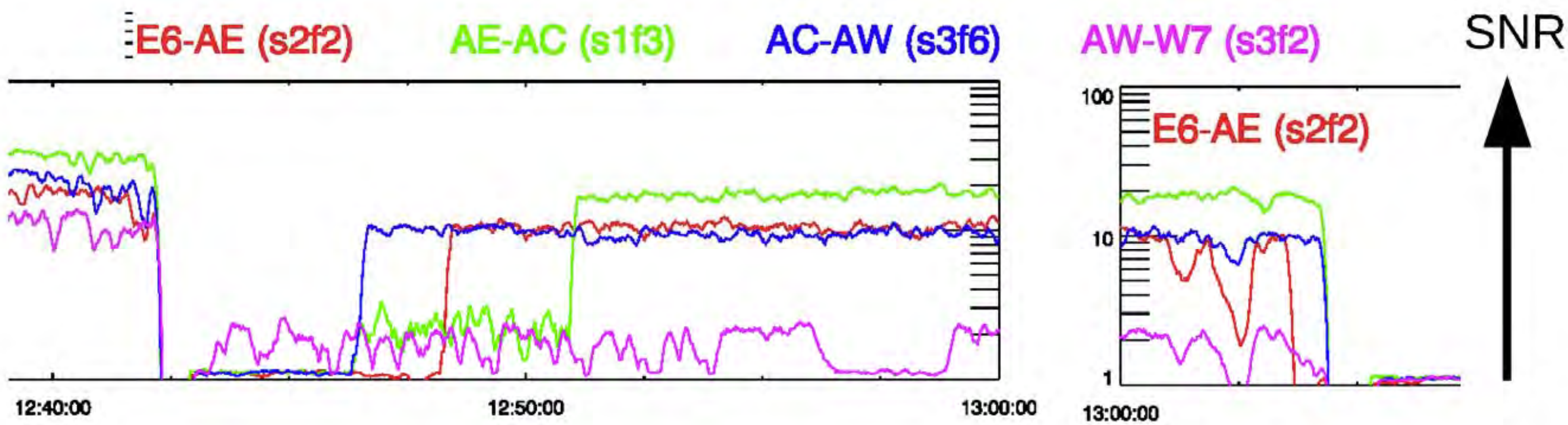
New Classic: 5-station Bootstrapping

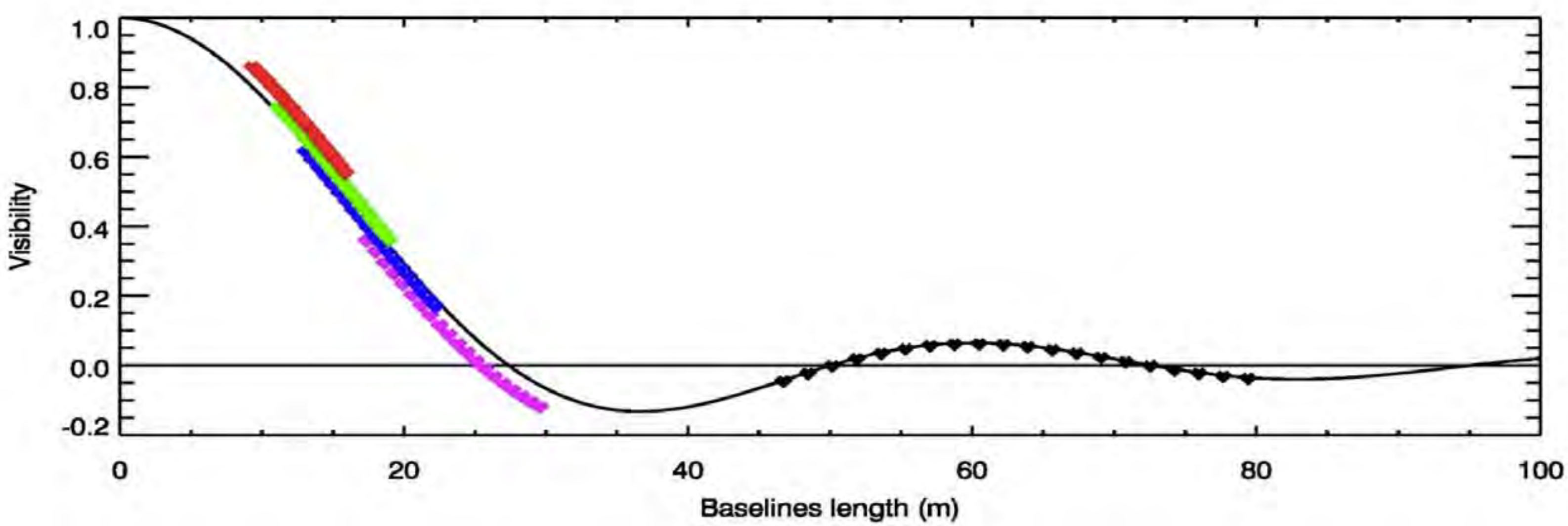
- In January 2015 we observed ν UMa, d=4.6 mas, V=3.5 on the W7-AW-AC-AE-E6 station chain



- Notice AE-E6 and AC-AE are the shortest. W7-AW is very long

NC: 5-station Bootstrapping (II)





VISION Instrument Design

- 6-way simultaneous beam combiner
- Simple design: Fringes are made directly on a modern EMCCD
- Photometric channels on an EMCCD for calibration
- Fast fringe searching from an R=200 spectrograph
- Single-mode polarization maintaining fibers spatially filter light for increased visibility precision

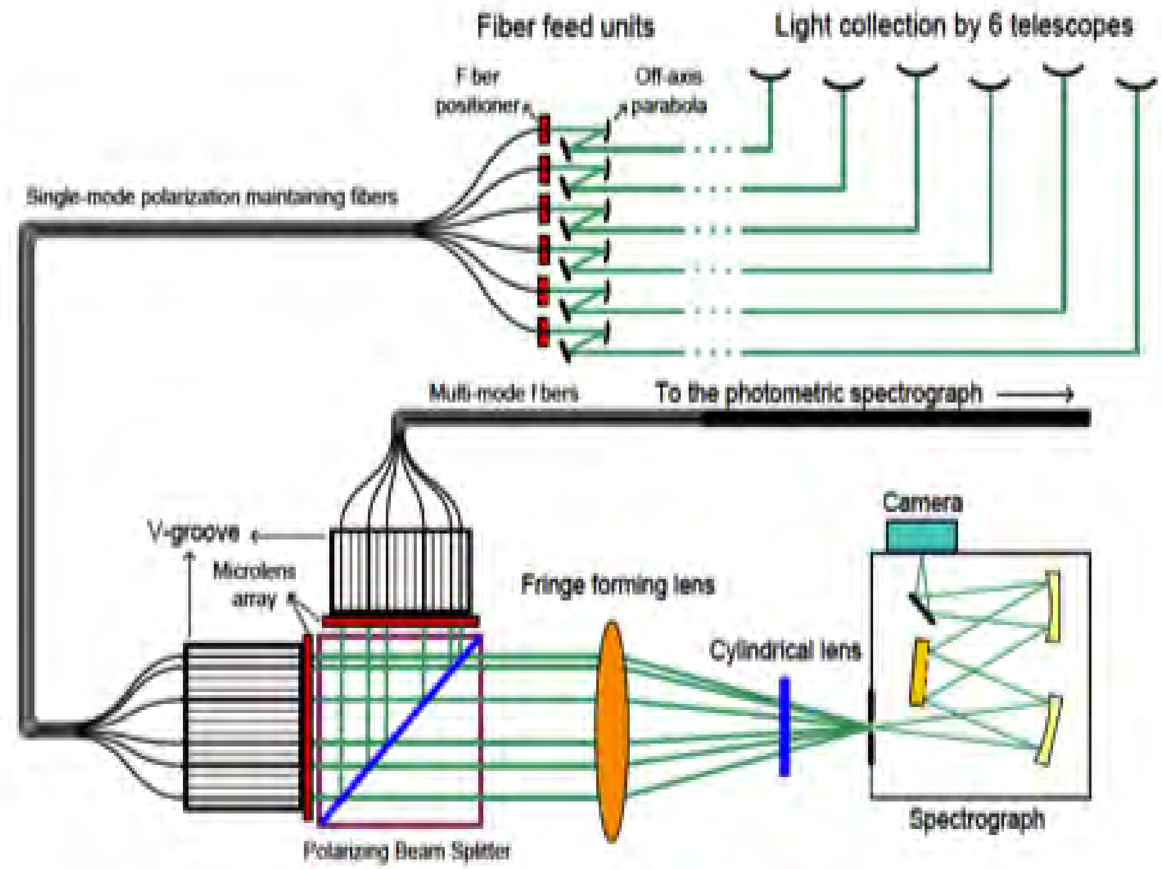
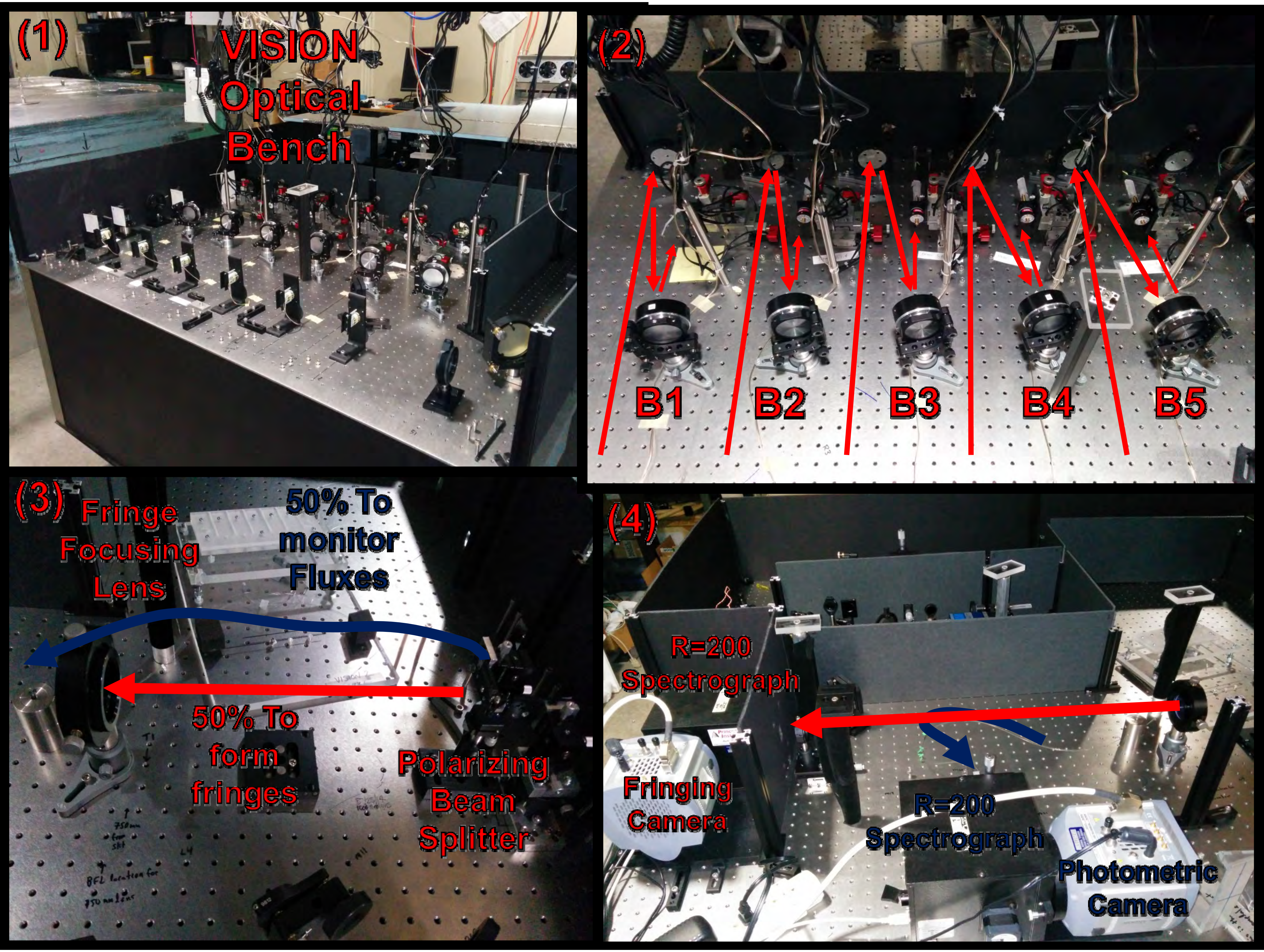
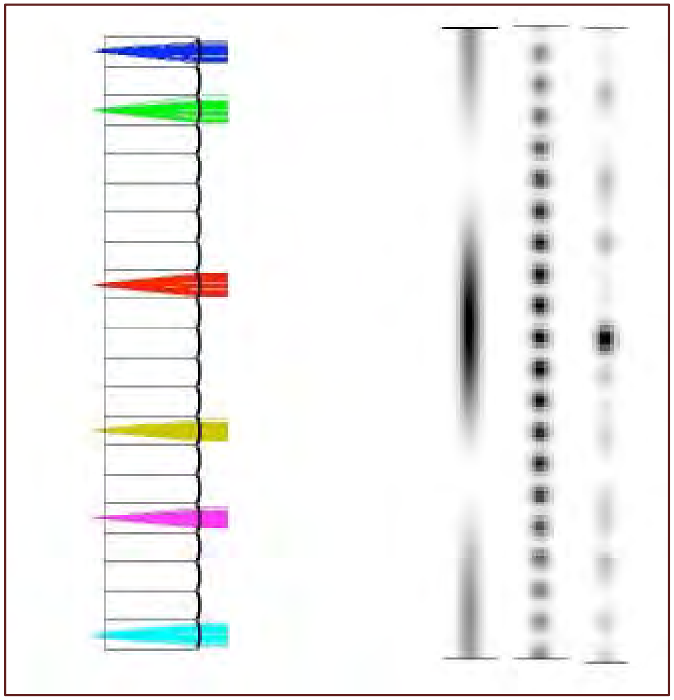


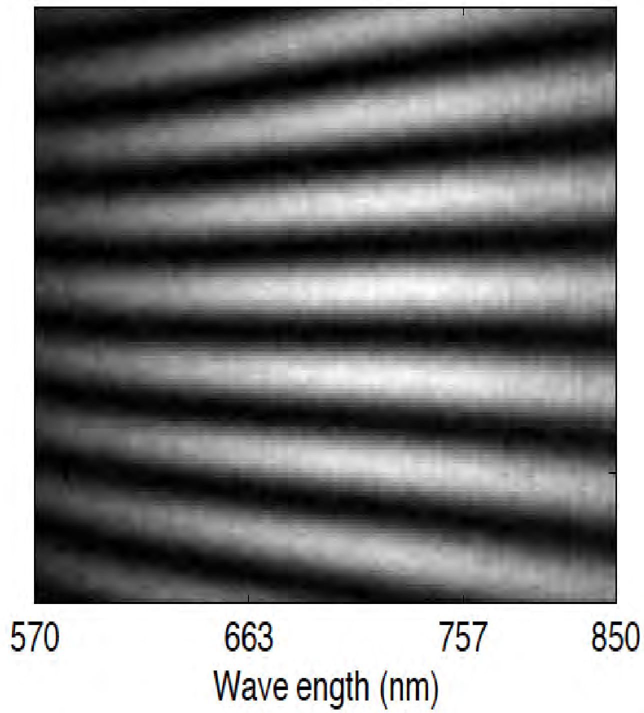
Figure 1. Schematic layout of VISION.


(1)
VISION Optical Bench
(2)
B1
B2
B3
B4
B5
(3)
Fringe Focusing Lens
50% To monitor Fluxes
50% To form fringes
Polarizing Beam Splitter
(4)
R=200 Spectrograph
Fringing Camera
R=200 Spectrograph
Photometric Camera

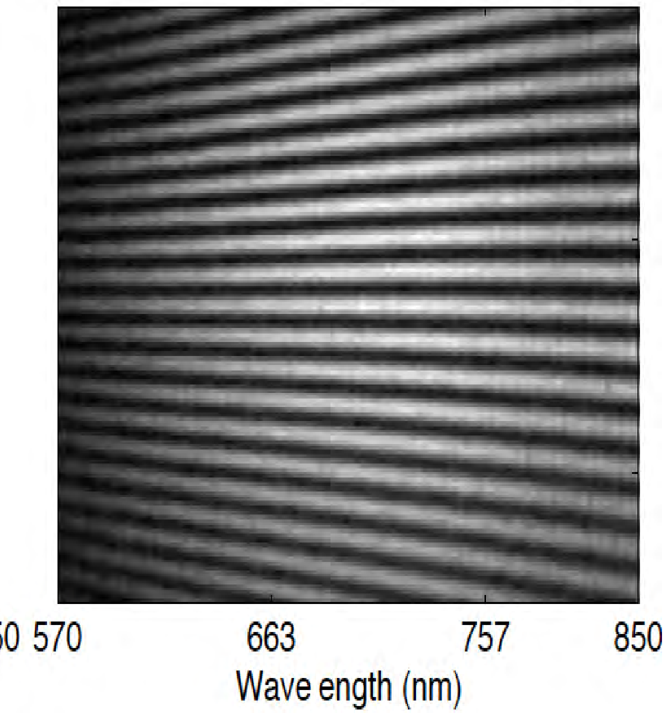
VISION creates interference patterns



Non-redundant V-groove Array



Small Fiber Spacing

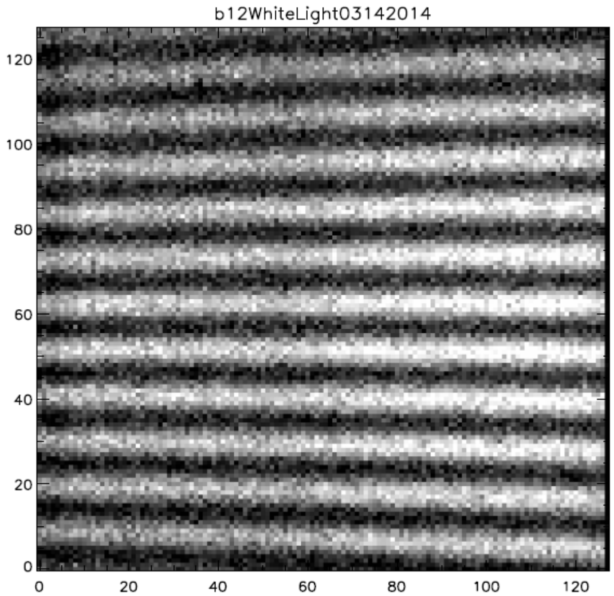


Large Fiber Spacing

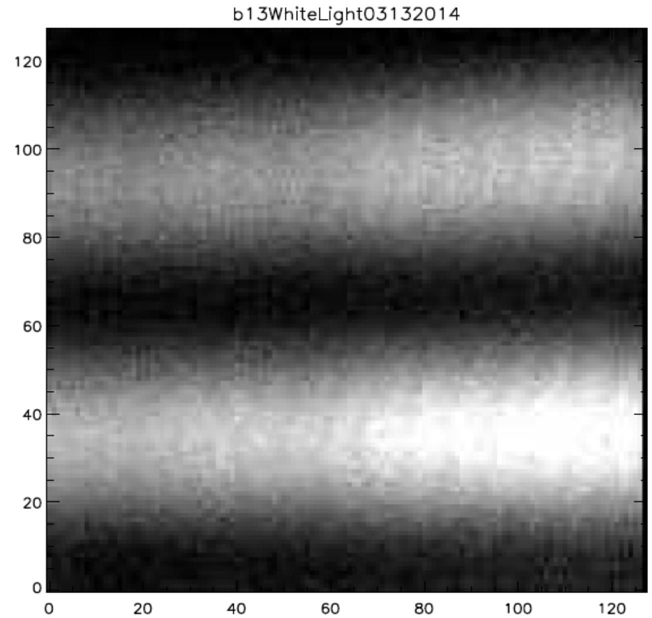
Derive Amplitude of Interference pattern + Phase of Interference pattern -> Reconstruct Image

Example of Internal Fringes

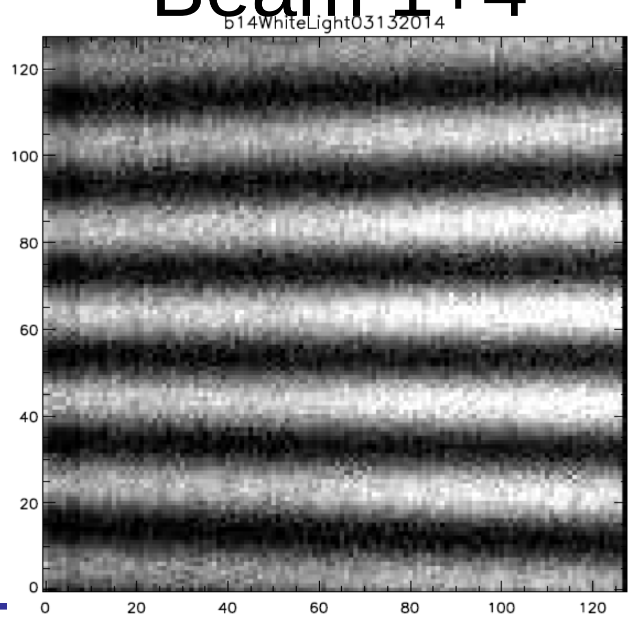
Beam 1+2



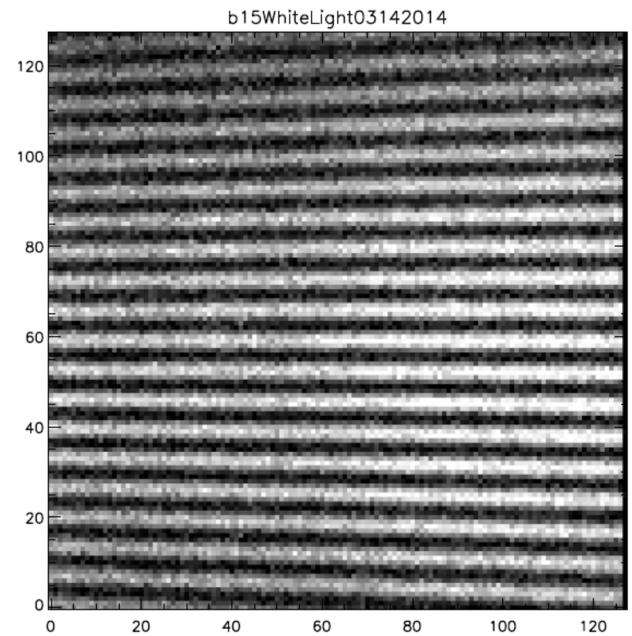
Beam 1+3



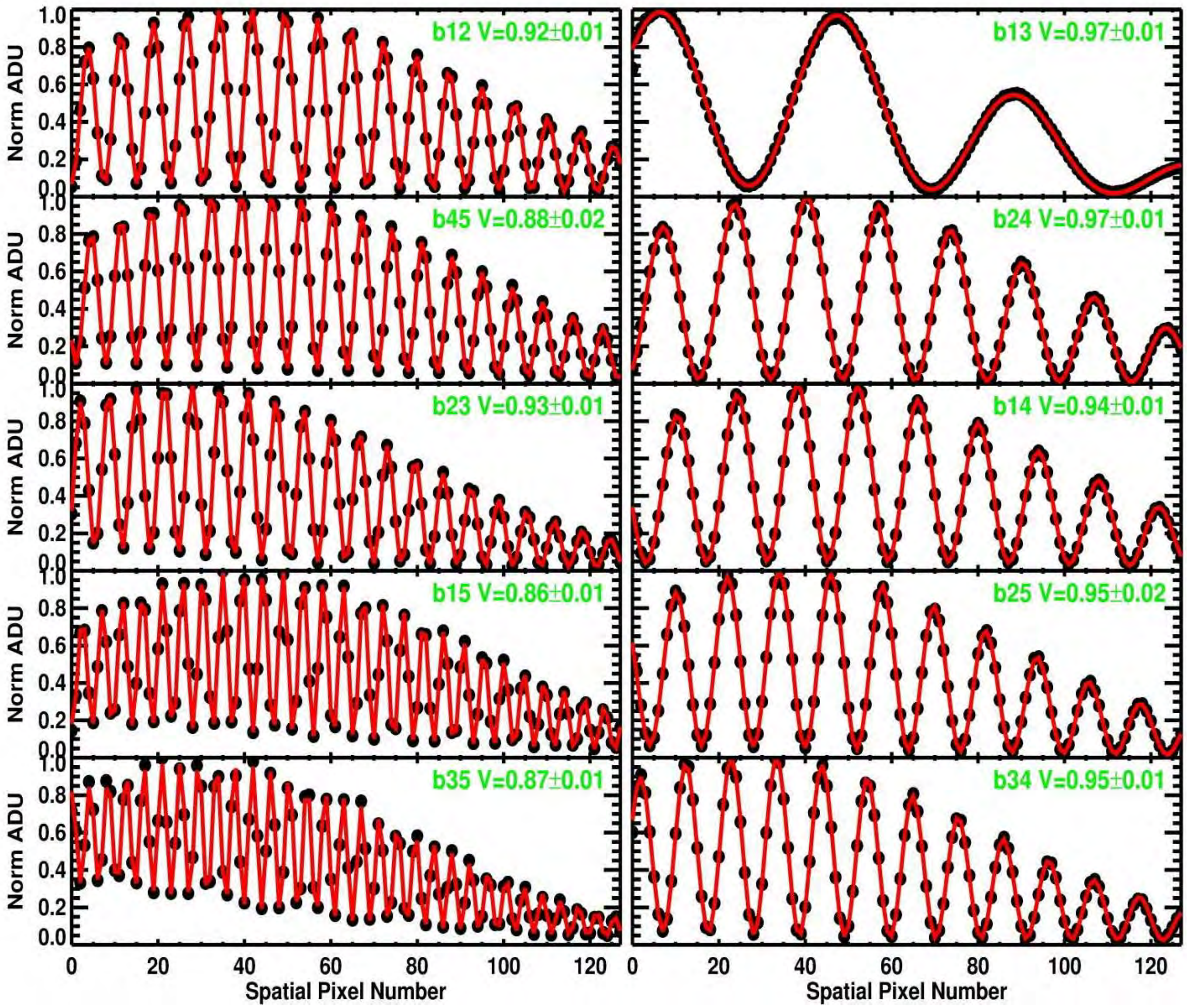
Beam 1+4



Beam 1+5

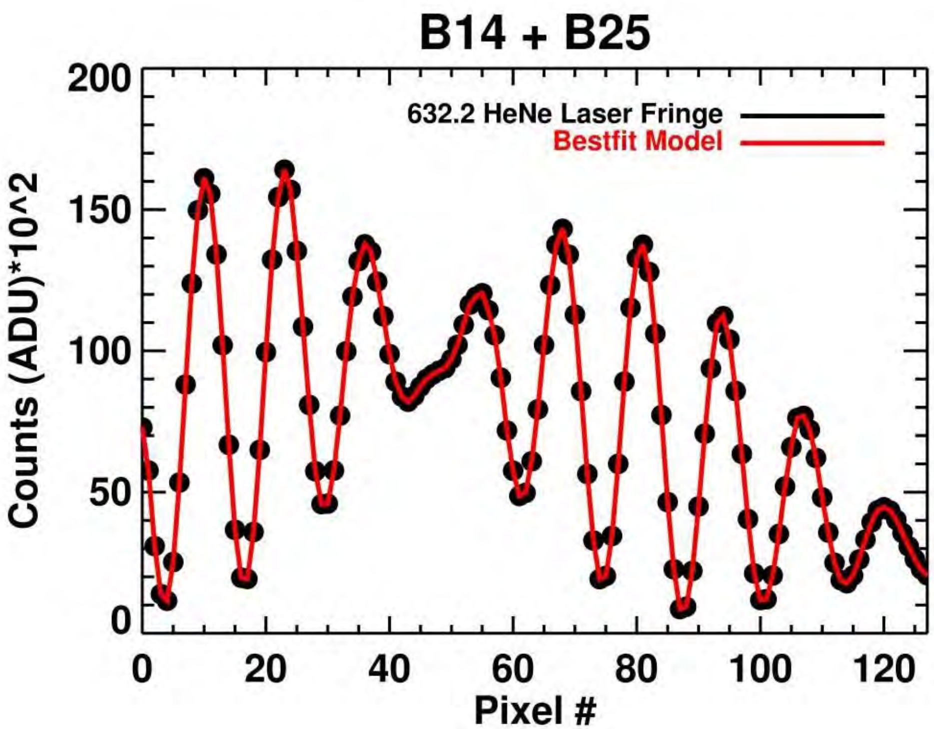


Fringe fitting & Cross Talk (I)



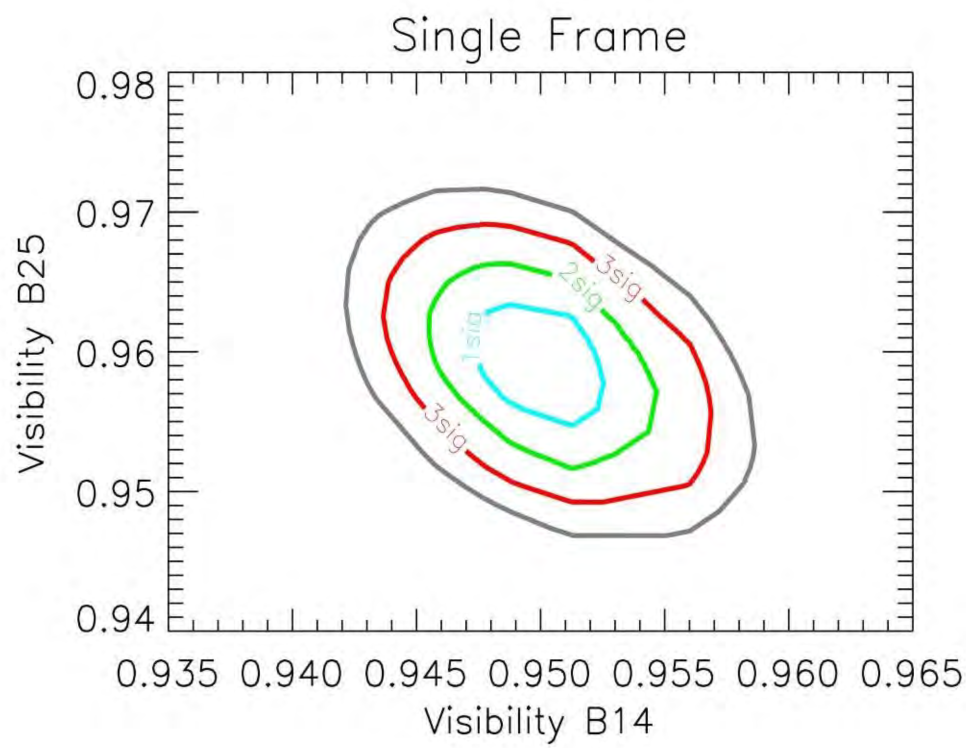
- We attempted a fringe fitting approach to see if this solves the issue of overlapping power spectra from different beam pairs (crosstalk) which exists at ~1-5% level.
- Fits to fringes with HeNe laser, 2 ms exposures, for all 10 beam pairs.
- Residuals to fits are at the <5% level.
- Fringe model incoporates visibility loss due to pixelation, and beam intensity mis-match.

Fringe fitting & Cross Talk (II)



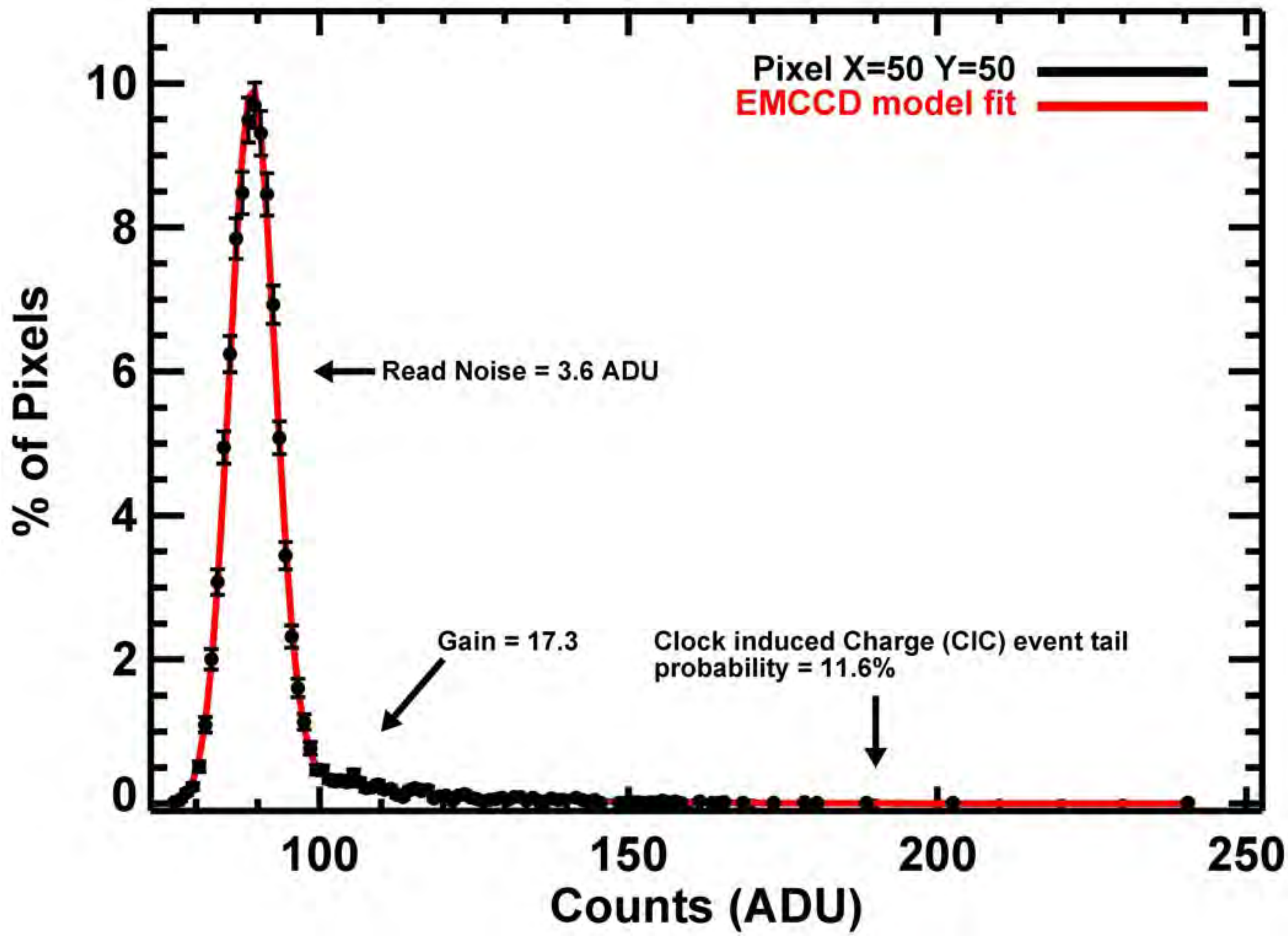
A) We added frames with fringes from beam pairs 14 and 25 together, and fit a multi-fringe model

B) We mapped out χ^2 space for our model, finding a degeneracy of ~2% in the fitted visibility parameters for beam pairs 14 and 25 at 3σ contour (red)



VISION EMCCD Use

- Analysis of read noise, gain, and clock induced charge rate
- Implications for other use of EMCCDs
- CIC rate of VISION Andors: poor
  - Replacement Nüvü cameras on order



Correction for Closure Phase Bias

- New correction for an EMCCD:

$$B_{1,ijk} = B_{0,ijk} - 2\left(|C_{ij}|^2 + |C_{jk}|^2 + |C_{ki}|^2\right) + 6N + 6N_{pix}\sigma_{RN}^2$$

  - EMCCD output is non-Poissonian due to the stochasticity of the electron multiplying gain (§ 5.3 of Garcia+ 2016)

- Wirnitzer+ (1985) photon noise correction:

$$B_{1,ijk} = B_{0,ijk} - \left(|C_{ij}|^2 + |C_{jk}|^2 + |C_{ki}|^2\right) + 2N$$

  - See also Basden & Haniff (2004), Gordon & Buscher (2012)

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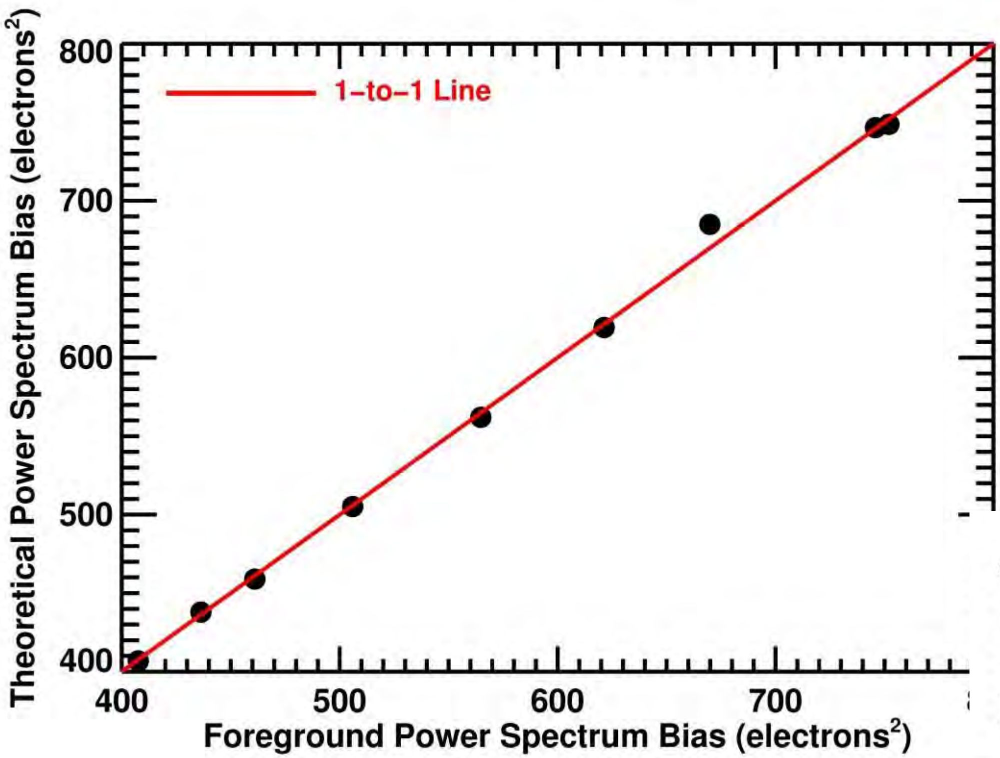
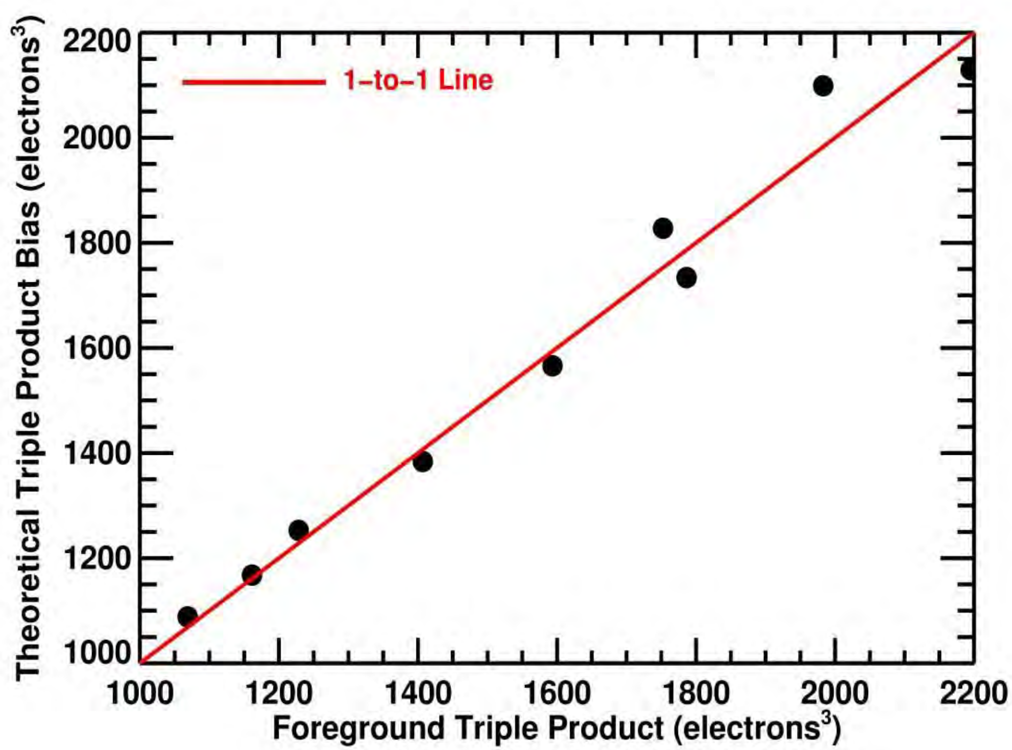
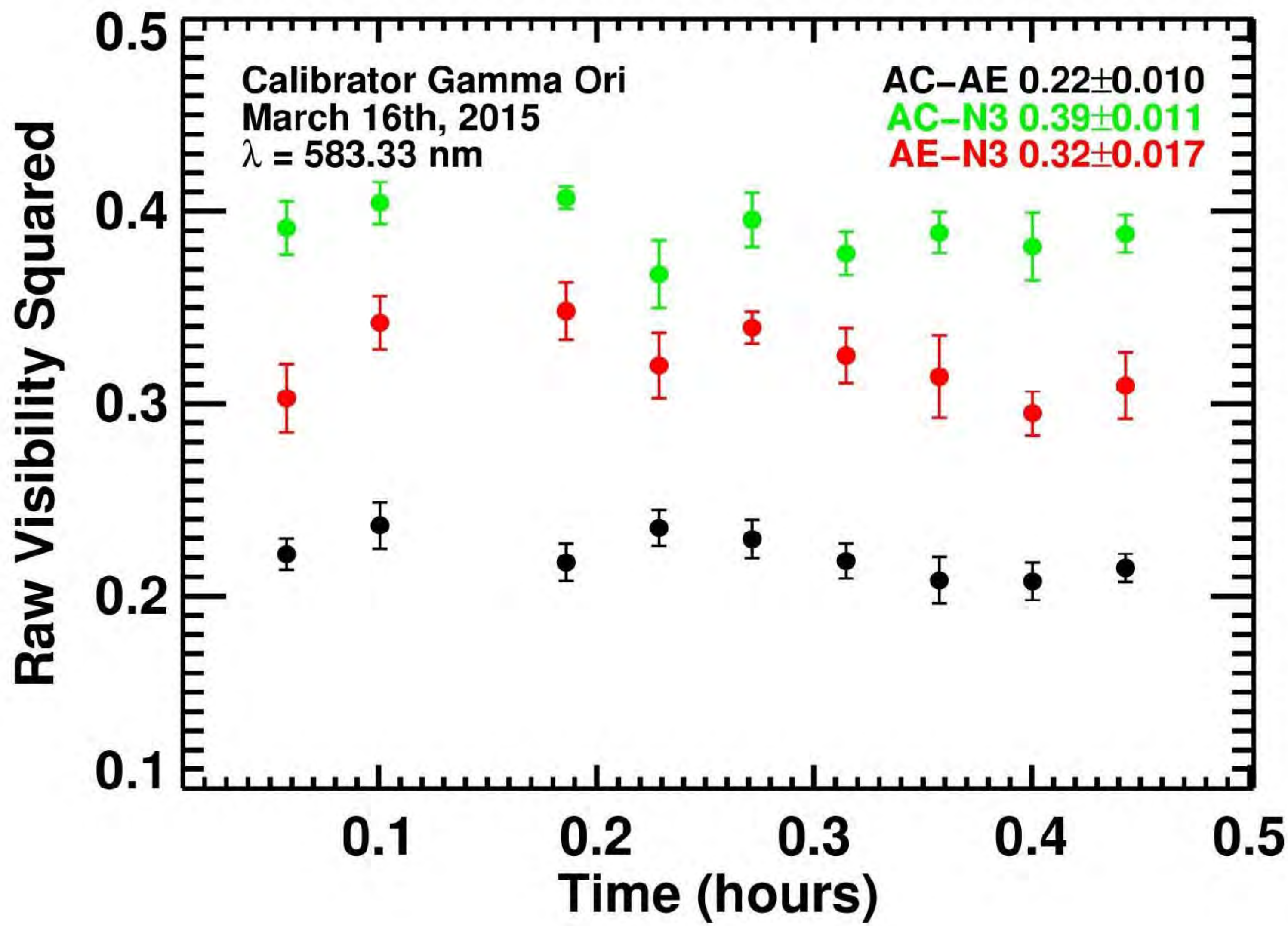
Noise Properties of the Data match theory

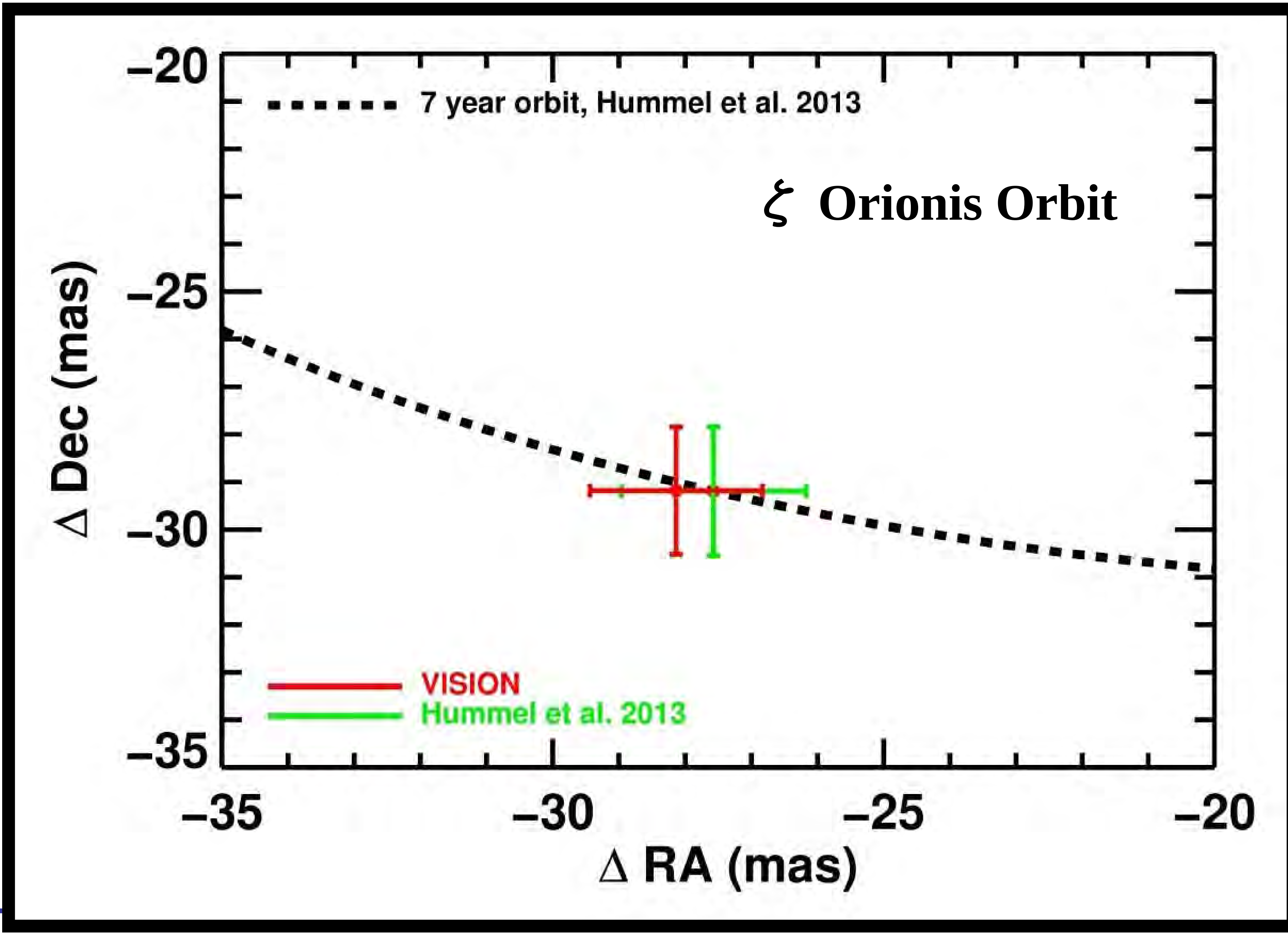




System visibility for Calibrator stars is stable to 0.01-0.02



Known orbit for binary star ζ Orionis ➔ Expected Amplitude & Phase
Measured Amplitude & Phase = Expected Amplitude & Phase ✓



Future work for VISION

- Install new 2nd generation extra-low noise EMCCDs
  - Andor CCDs → Nüvü CCDs, optimized for low CIC
  - Funded by DURIP
- Begin robust science program
  - High spatial-frequency observations of highly resolved stars
    - Past first zero (LD), 2nd/3rd/4th zeros
    - Imaging, parametric fitting
  - Diameters / shapes, binaries, etc.
    - *No* stars are spherically symmetric