NPOI Visible Light Combiners

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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)

- \text{E6-AE (s2f2)}
- \text{AE-AC (s1f3)}
- \text{AC-AW (s3f6)}
- \text{AW-W7 (s3f2)}

\text{SNR}

Visibility vs Baselines length (m)
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
VISION creates interference patterns

Non-redundant V-groove Array

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
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 incorporates visibility loss due to pixelation, and beam intensity mis-match.
A) We added frames with fringes from beam pairs 14 and 25 together, and fit a multi-fringe model.

B) We mapped out $\chi^2$ space for our model, finding a degeneracy of $\sim2\%$ in the fitted visibility parameters for beam pairs 14 and 25 at $3\sigma$ 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:

\[ B_{1,ijk} = B_{0,ijk} - 2 \left( |C_{ij}|^2 + |C_{jk}|^2 + |C_{ki}|^2 \right) + 6N + 6N_{\text{pix}} \sigma^2_{\text{RN}} \]

- 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)
Noise Properties of the Data match theory

![Graph 1: Theoretical Power Spectrum Bias vs. Foreground Power Spectrum Bias](image1)

![Graph 2: Theoretical Triple Product Bias vs. Foreground Triple Product](image2)
System visibility for Calibrator stars is stable to $0.01-0.02$
Known orbit for binary star $\zeta$ Orionis $\Rightarrow$ Expected Amplitude & Phase

Measured Amplitude & Phase $=$ Expected Amplitude & Phase $\checkmark$
Future work for VISION

• Install new 2\textsuperscript{nd} generation extra-low noise EMCCDs
  – Andor CCDs $\rightarrow$ 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), 2\textsuperscript{nd}/3\textsuperscript{rd}/4\textsuperscript{th} zeros
    • Imaging, parametric fitting
  – Diameters / shapes, binaries, etc.
    • \textit{No} stars are spherically symmetric