Self-Calibrating Systems: An Update on η Orionis

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Self-Calibrating Systems

- Systems of multiplicity 3+
- Separation of close binary and wide component
  - large enough to resolve the two components
  - small enough to allow observations of both at the same time
- Visibility of wide component is used to calibrate the visibility of the binary star

“wide” system presents separated fringe packets

“close” system is a visibility binary
**η Orionis – A Hierarchical Quintuple System**

- **η Ori**
  - AB: \( \rho = 115 \) mas, \( \Delta m = 6.0 \), \( P = 10^5 \) yr
  - C: \( \rho = 1.7 \) mas, \( \Delta m = 1.3 \), \( P = 10^3 \) yr
  - A: \( \rho = 50 \) mas, \( \Delta m = 1.3 \), \( P = 9.2 \) yr
  - Aab: \( \rho = 1.0 \) mas, \( \Delta m = 0.8 \), \( P = 9 \) day (eclipsing)
  - Aa: \( \rho = 1.0 \) mas, \( \Delta m = 0.8 \), \( P = 9 \) day (eclipsing)
  - Ab: \( \rho = 1.0 \) mas, \( \Delta m = 0.8 \), \( P = 9 \) day (eclipsing)
  - B1 V
  - B1 V
  - B1 V
  - B3 V: β Cep var.
η Orionis

• η Ori is the prototype system for this study

• Aab,c system ($\rho \sim 50$ mas) was first resolved by speckle interferometry (McAlister 1976).

• Aab system ($\rho \sim 1$ mas) is an eclipsing binary and should be resolved at Array’s longest baselines.

• Aab = target system, Ac = calibrator
Observations

• $\eta$ Ori observed 128 times between Nov. 10, 2004 and Dec. 16, 2005; most of them on a 313 m baseline.

• Most observations lasted several minutes each; a few had durations of nearly 30 minutes.

• Shift-and-added separated fringe packet envelopes were produced to determine $V_{Aa}$ and $V_{Ac}$. 
Observations: The Good
Observations: The Bad

Ten Shifted Fringe Envelopes

Weighted Mean Fringe Envelope
Observations: The Ugly

Ten Shifted Fringe Envelopes

Weighted Mean Fringe Envelope
Calibration
(Following ten Brummelaar)

- First, must correct normalized visibility:
  Normalized $V$:
  \[ V_A = \frac{A_A}{<I_A>} \]
  \[ V_B = \frac{A_B}{<I_B>} \]
  where $A$ is the amplitude of the fringe and $<I>$ is the mean intensity of the scan

- For a single star, this is no problem, because the mean intensity of the scan is equal to the mean intensity of the star
Calibration

- When two stars are observed in the same scan, the mean intensity becomes the sum of the mean intensities of both components:
  \[
  V_A' = \frac{A_A}{<I_A + I_B>}, \quad V_B' = \frac{A_B}{<I_A + I_B>}
  \]

- Eventually, end up with
  \[
  \frac{V_A}{V_B} = \beta \left( \frac{V_A'}{V_B'} \right)
  \]
  where \( \beta = \frac{<I_B>}{<I_A>} = 10^{0.4\Delta m} \)

  and component B is designated as the fainter component
Determining $\beta$ for $\eta$ Ori

- In $\eta$ Ori, Ac is the fainter component, so
  \[ \frac{V_{Aab}}{V_{Ac}} = \beta \left( \frac{V_{Aab}'}{V_{Ac}'} \right) \]

- Assume a value for $V_{Aab}$ and $V_{Ac}$ for observations obtained at eclipse phases near $0^\circ$ and $180^\circ$ where the Aab system is unresolved and combine with observed $V_{Aab}'/V_{Ac}'$ to get $\beta$. 
Determining $\beta$ for $\eta$ Ori

• For a nearly edge-on orbit, angular diameters of 0.21 and 0.17 mas for Aa and Ab (De Mey 1996), semi-major axis of 0.5 mas, and an orbital phase of $25^\circ$, $V_{Aab} = 0.876$

• Furthermore, for orbital phases around $0^\circ$ and $180^\circ$ ($\pm 25^\circ$) in Aab, visibility difference between Aab and Ac is primarily dependent on $\Delta m$.

• For angular diameter of 0.17 mas, $V_{Ac} = 0.98$
Determining $\beta$ for $\eta$ Ori

- $V_{Aab} = 0.876$ and $V_{Ac} = 0.98$, combined with data from JD 53319 (where orbital phase was 25°) gives $\beta = 0.303$ and $\Delta m_K = -1.298$

- Apply this $\beta$ value, along with $V_{Ac} = 0.98$ to all other data sets to get calibrated visibility $V_{Aab}$. 
Calibrated Visibilities

Epoch Index

V

0 20 40 60 80 100 120

0.2 0.4 0.6 0.8 1 1.2
Orbit Results from OrbGrid

• OrbGrid performs a search within a definable grid space and calculates reduced \( \chi^2 \) at each grid point. It typically adopts the spectroscopically determined elements \( P, T, e, \omega \) and performs the search within a grid involving \( a, i, \Delta m, \Theta_A, \Theta_B, \) and \( \Omega \).

• For \( \eta \) Ori Aab, the simplest set of unknown orbital elements are the semi-major axis \( a \) and the nodal longitude \( \Omega \) as the remaining parameters are available elsewhere (or don’t matter much).
Orbit Results from ORBGRID

Input (De Mey et al. 1996):

\[ P = 7.9893 \text{ days} \]
\[ T = 46392.128 \]
\[ e = 0.0 \]
\[ i = 87.5^\circ \]
\[ \omega = 0.0^\circ \]

Best Fit:

\[ a = 1.1 \text{ mas} \]
\[ \Omega = 168^\circ \]

with

\[ \chi^2 = 2.9 \text{ for this fit} \]
Future work

• Hmm, not so good… For a better fit, we’ll try varying some of the other parameters, namely $T$ and/or $\Delta m_{Aab}$

• We hope to use this approach to derive orbits for 18 other self-calibrating systems. Some data for these has already been obtained.