Self-Calibrating Multiple Systems

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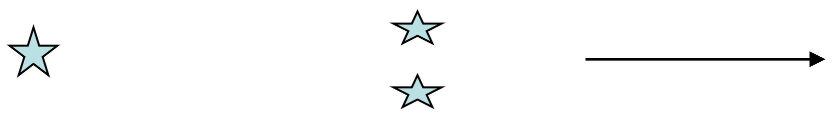
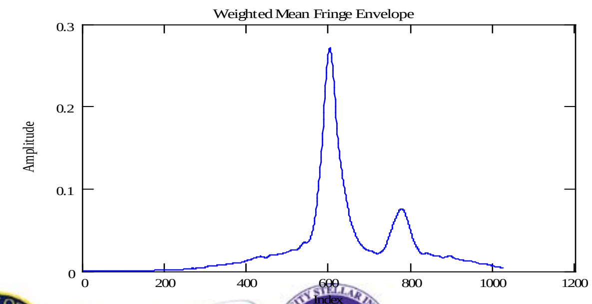
Outline

- Overview
- Side-lobe interference problem
- HD 157482 & CHARA 96

Project overview

- Find hierarchical triple systems where:
  - the close binary and the wide component are at a suitable separation to create two fringe packets
  - the wide component would be a good calibrator for the close binary
- Orbits derived for these binaries will give mutual inclinations between the close and wide orbit





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Current Progress

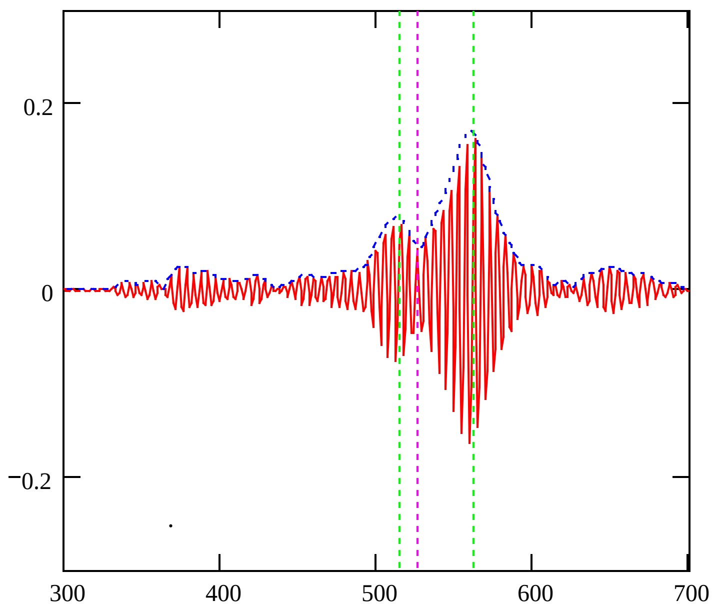
- Main target list
  - HD 157482: Paper submitted
  - HD 3196, 35411, 193322 (CHARA 96), 206901: Orbit fitting in progress
  - HD 98353, 107259, 129132: data reduction in progress
  - HD 115955 & 163151: new SFP discoveries!

Current Progress

- Auxiliary targets:
  - Recently, bracketed observations of 2 targets were conducted when their SFPs were too far apart to observe simultaneously
  - Expanded target list to include wider separations; 40 new possible SFP system found using the Multiple Star Catalog
  - 11 of those 40 attempted; no new SFP systems detected

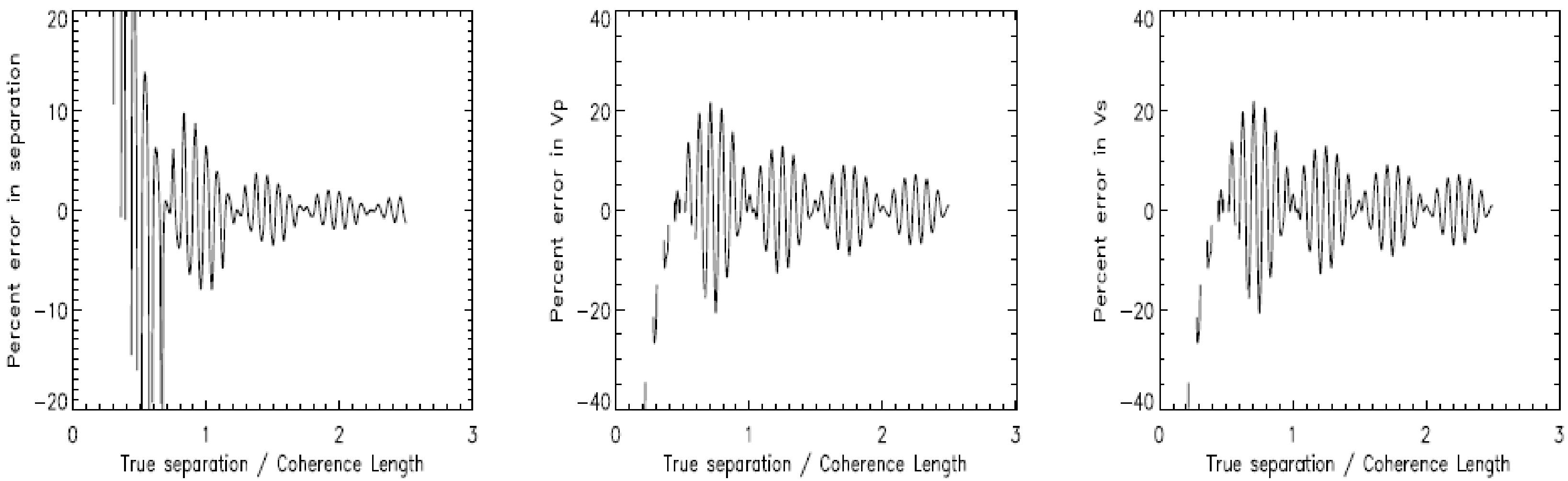
Side Lobe Interference

- Side-lobe interference between primary and secondary packets is present in some data



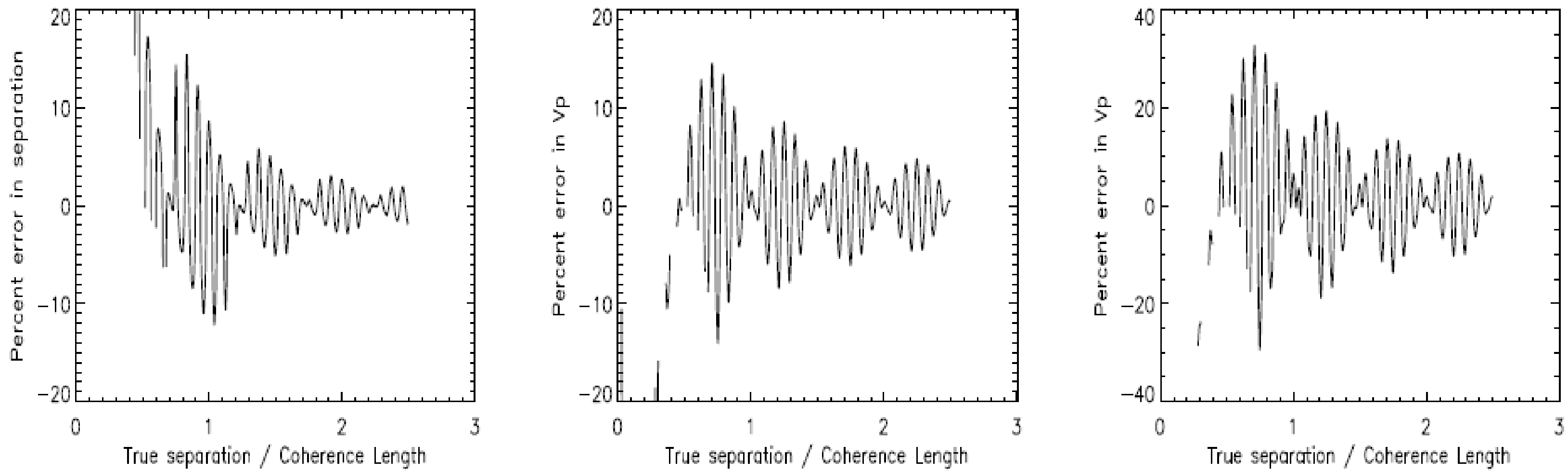
Impact of side-lobe interference

Vratio = 1



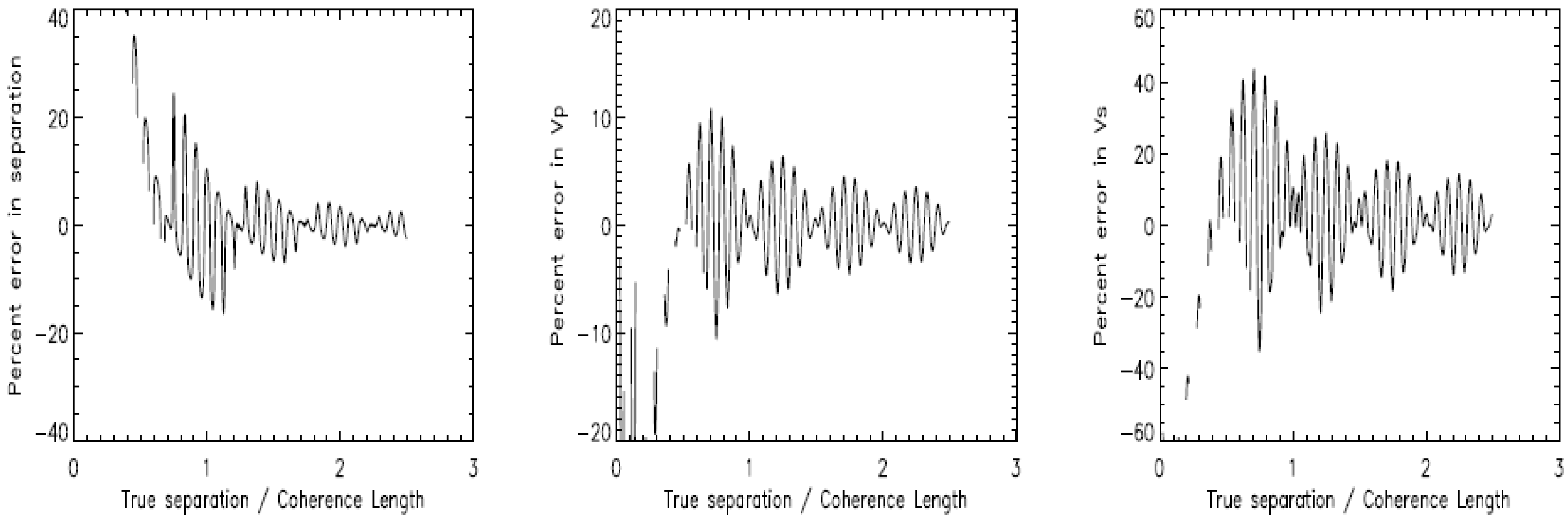
Impact of side-lobe interference

Vratio = 1.5



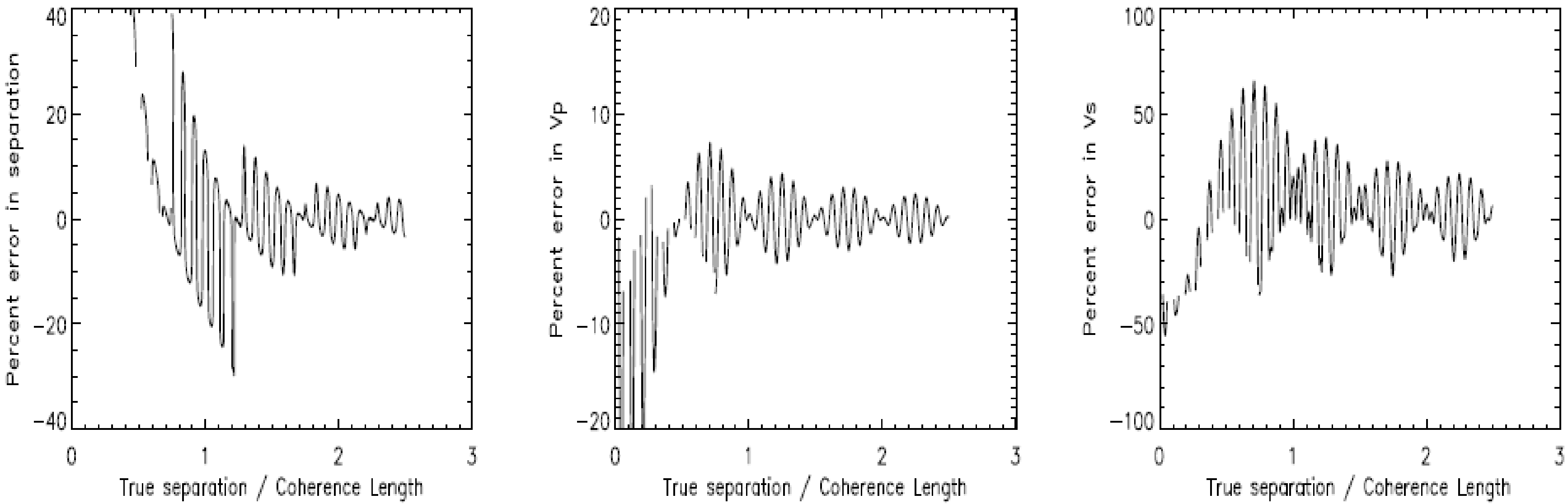
Impact of side-lobe interference

Vratio = 2



Impact of side-lobe interference

Vratio = 3

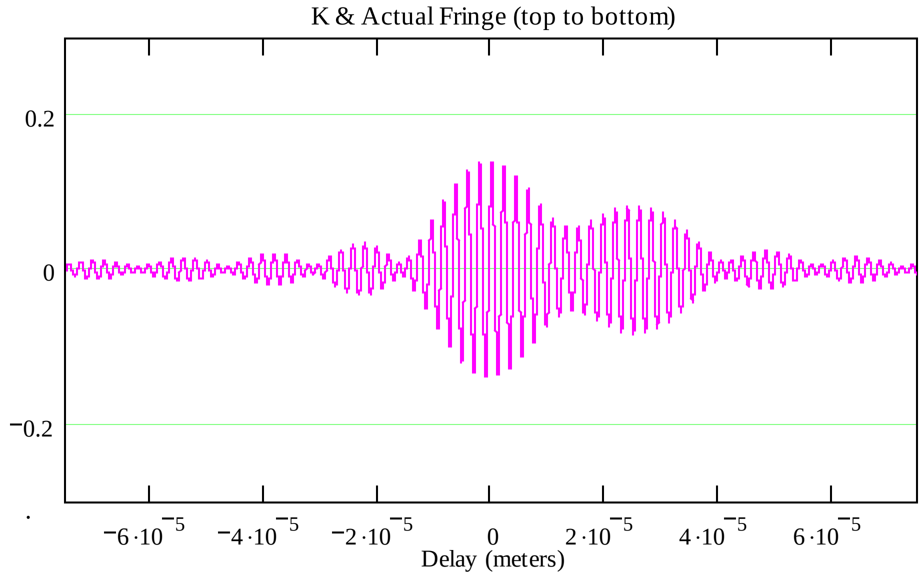


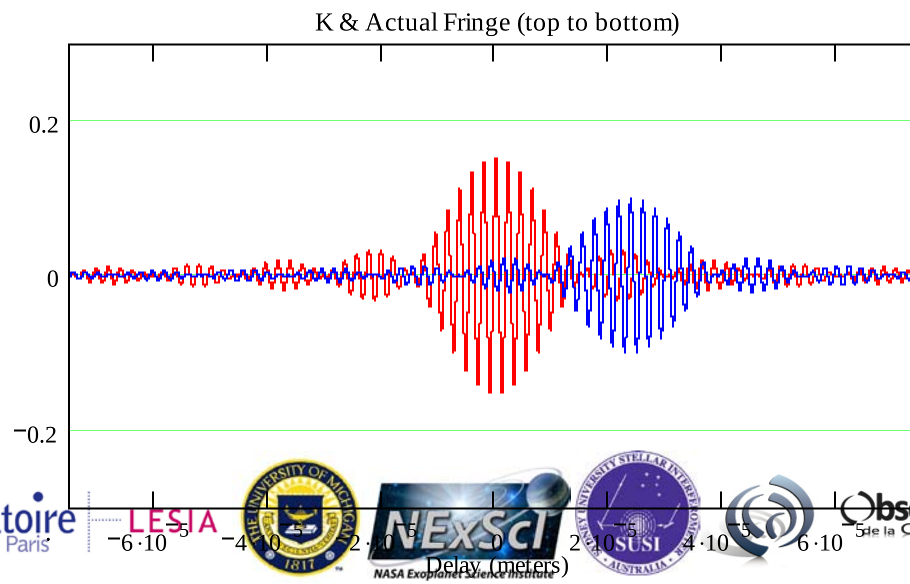
Side-Lobe Interference

- 3 possible methods for correcting
  - Break overall fringe packet into component parts
  - Fit sinusoid to data
  - Fit fringe packets simultaneously

Breaking into components

- Use wide orbit of the triple system to determine what the true separation should be.
- Find the combination of visibilities that would interfere to produce the observed result.





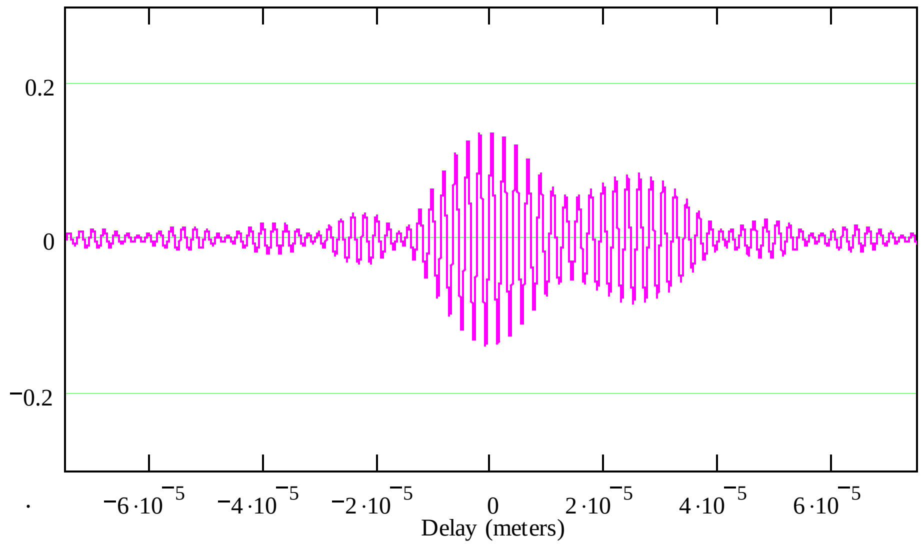
Breaking into components

- Observed:

  $V_p = 0.137$

  $V_s = 0.083$

  $V_{ratio} = 1.66$

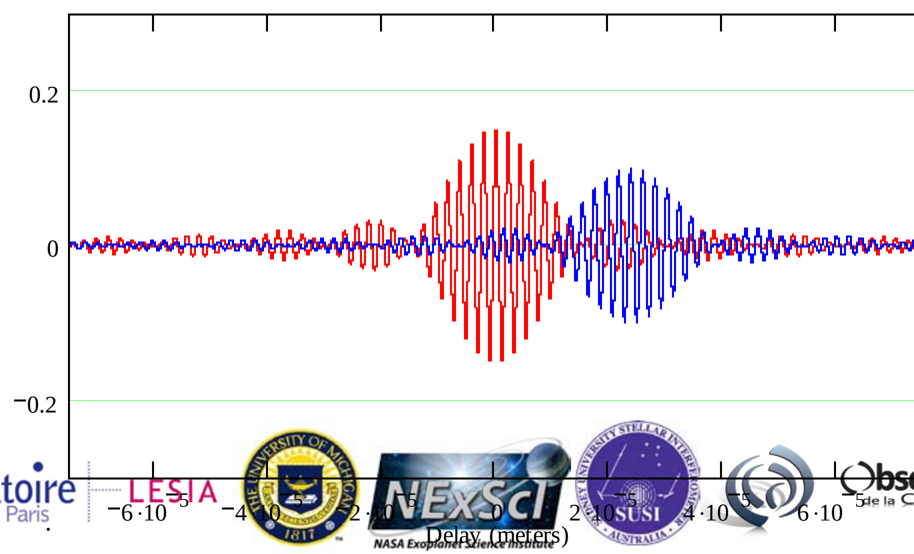


- Broken into components:

  $V_p = 0.150$

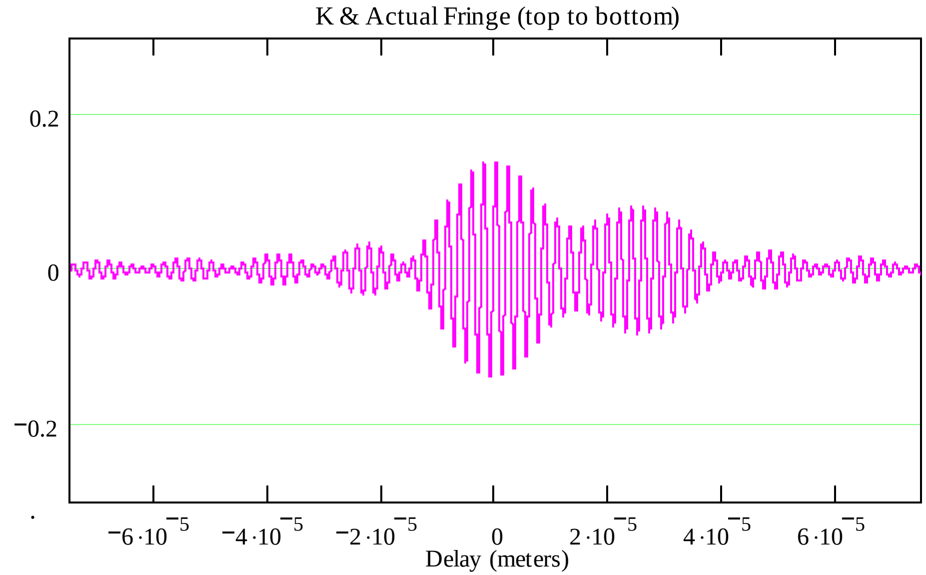
  $V_s = 0.100$

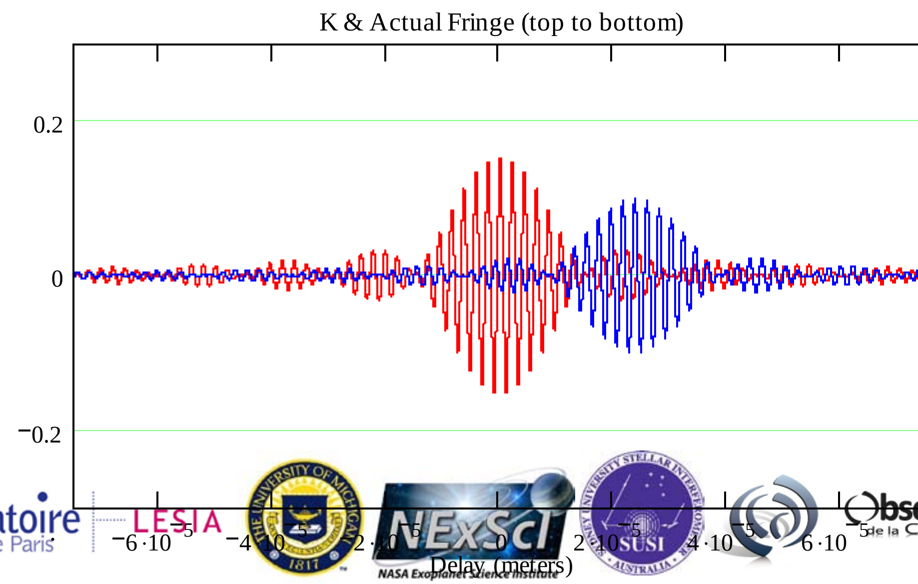
  $V_{ratio} = 1.50$



Breaking into components

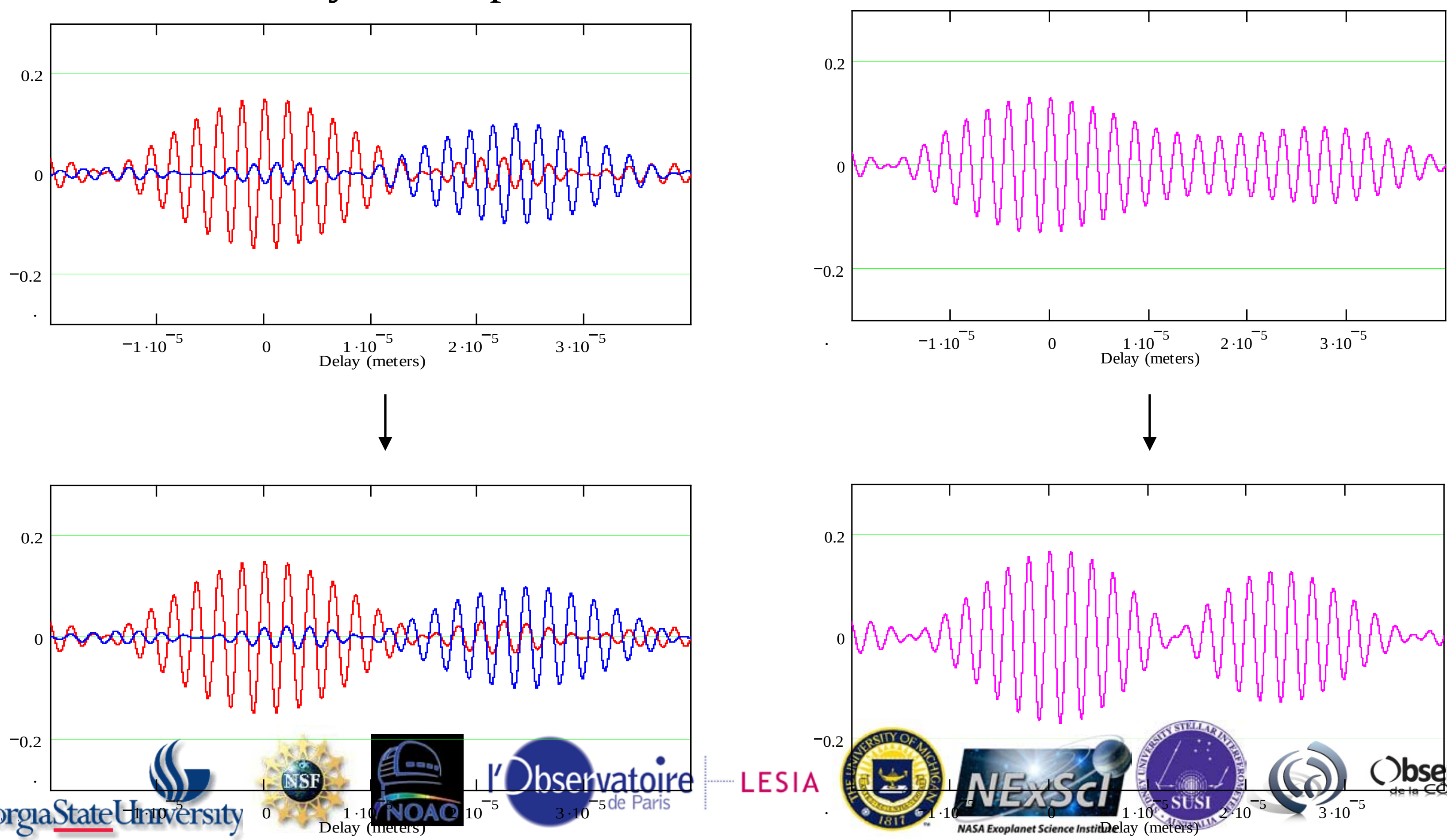
- Drawback: this method requires extreme precision in the wide orbit





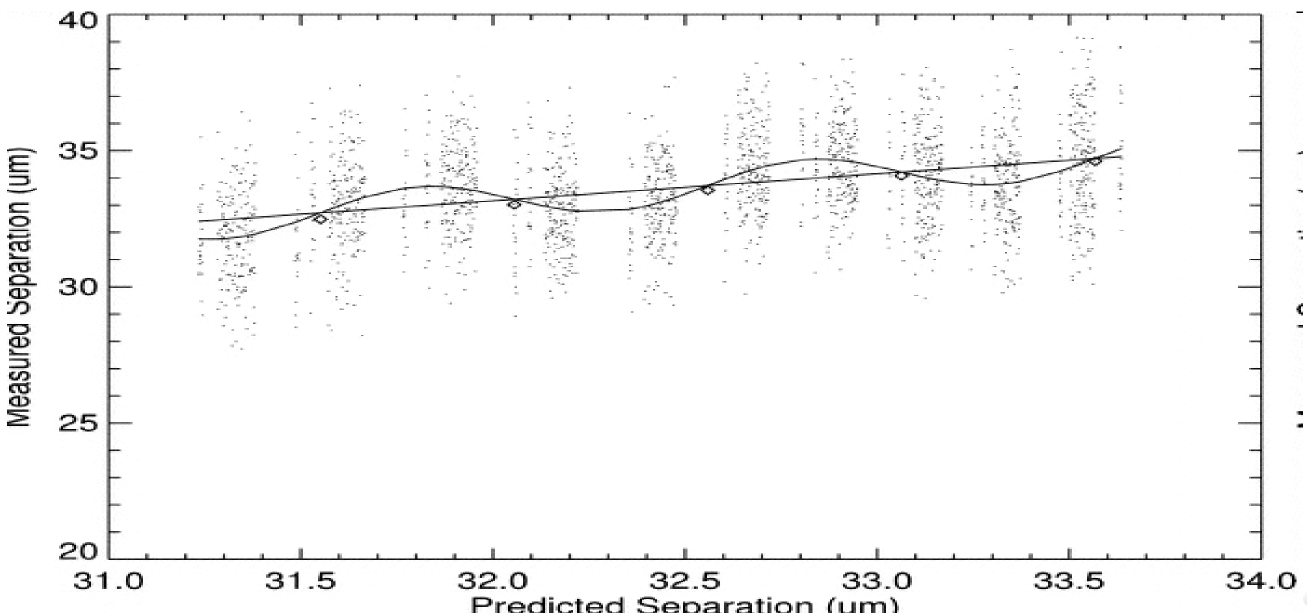
Fitting a sinusoid

- Over the course of the night, the secondary will move relative to the primary
- Movement may encompass both destructive and constructive interference



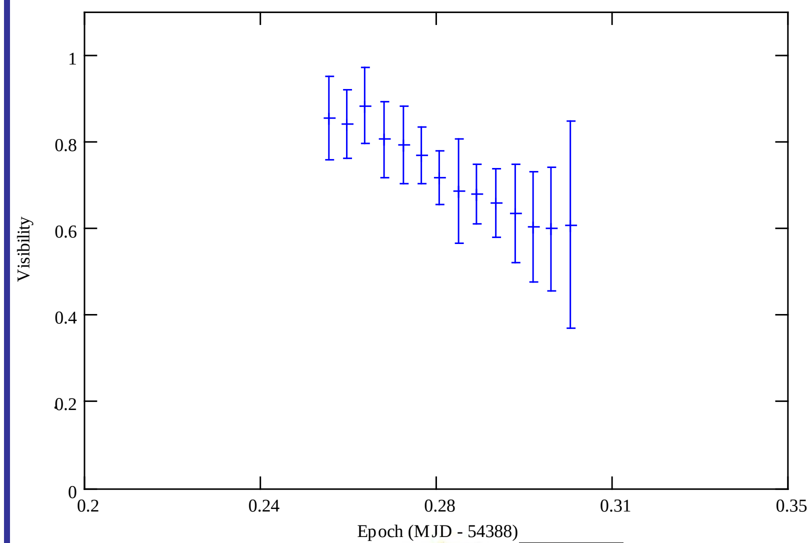
Fitting a sinusoid

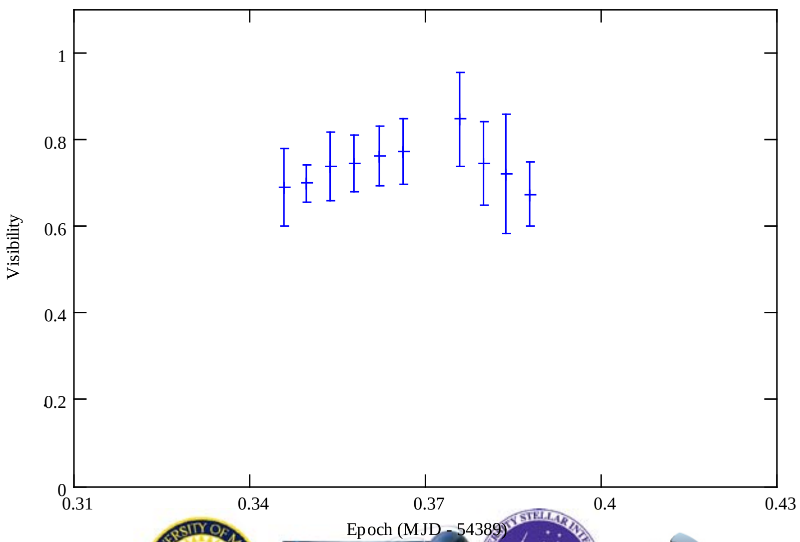
- The visibility ratio will fluctuate sinusoidally with time, as will the calibrated visibility
- By fitting a sinusoid, the influence of the side lobes can be corrected for



Fitting a sinusoid

- Drawback: Need a lot of data (sometimes several hours worth) to get a full curve
- Also, visibility will change anyway because of baseline rotation and close pair’s orbital motion





Fitting fringe packets simultaneously

- Expand the equation for fitting a single fringe:

$$I(D) = \phi_0 \frac{\sin(\pi\phi_1\phi_2 D)}{\pi\phi_1\phi_2 D}\cos(2\pi\phi_2\phi_3 D + \phi_4)$$

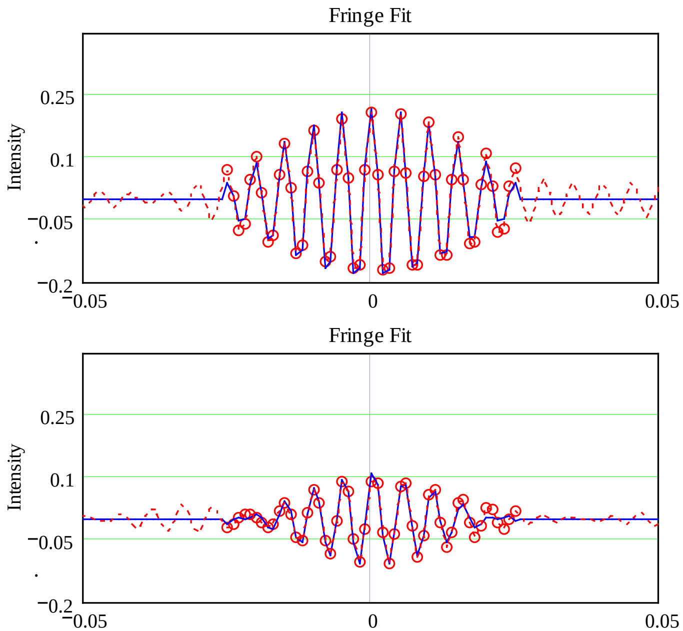
ϕ_0: visibility of the packet

ϕ_1: inverse of the coherence length

ϕ_2: group velocity of the dither mirror

ϕ_3: wave number

ϕ_4: phase shift



Fitting fringe packets simultaneously

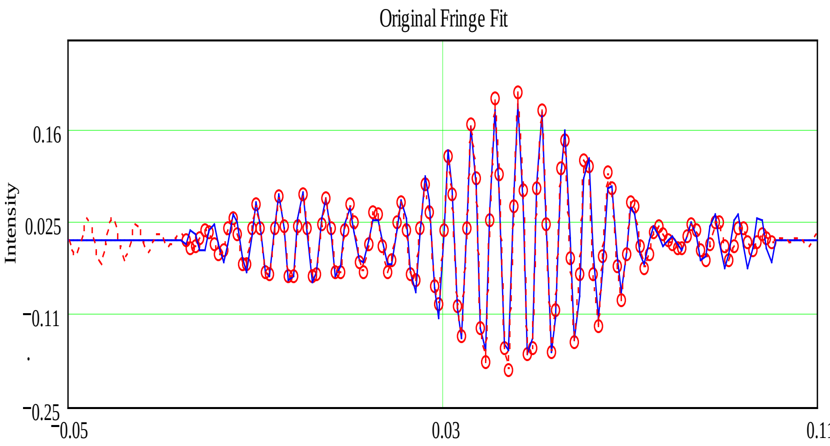
- Into:

$$I(D) = \phi_0 \frac{\sin(\pi\phi_1\phi_2 D)}{\pi\phi_1\phi_2 D}\cos(2\pi\phi_2\phi_3 D + \phi_4) + \phi_5 \frac{\sin[\pi\phi_1\phi_2(D-\phi_6)]}{\pi\phi_1\phi_2(D-\phi_6)}\cos[2\pi\phi_2\phi_3(D-\phi_6)+\phi_4]$$

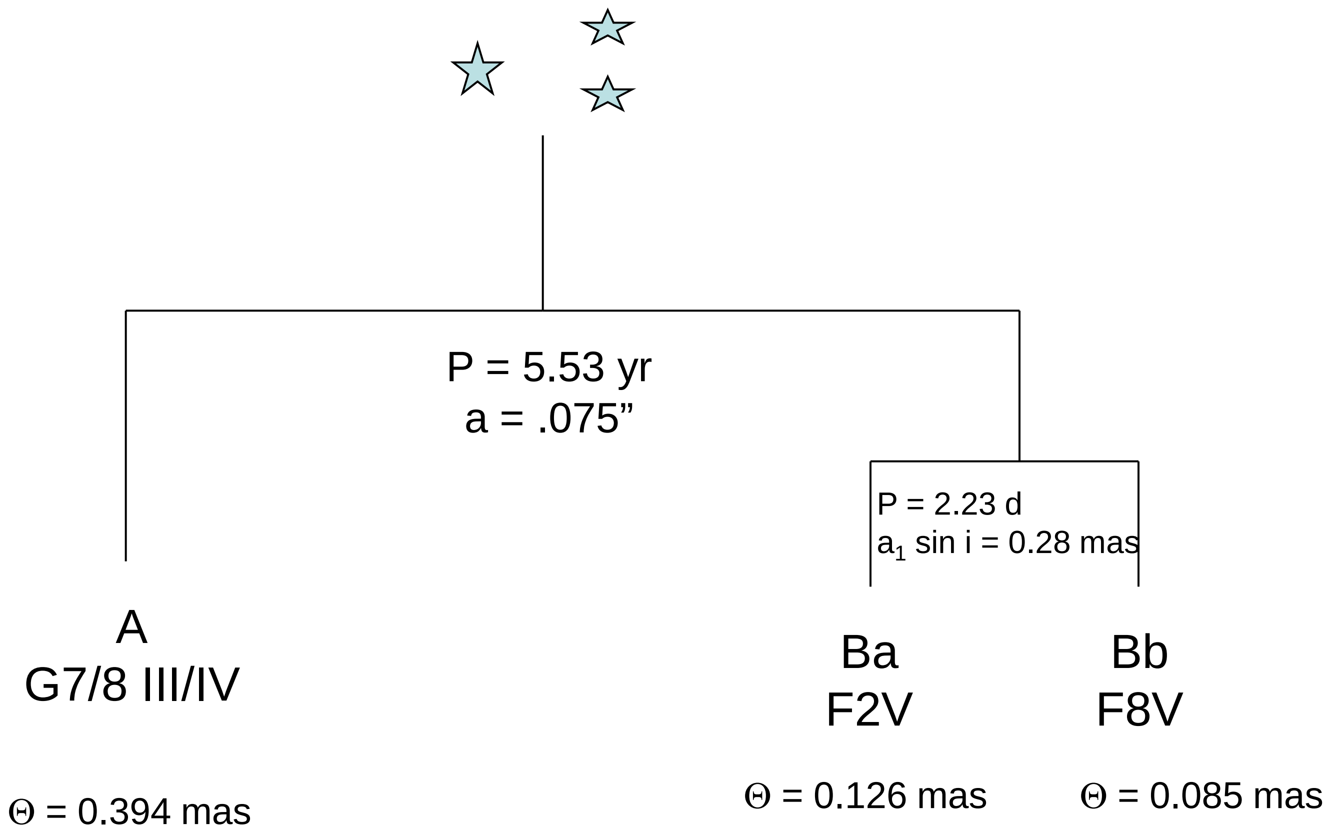
ϕ_0: visibility of the left packet

ϕ_5: visibility of the right packet

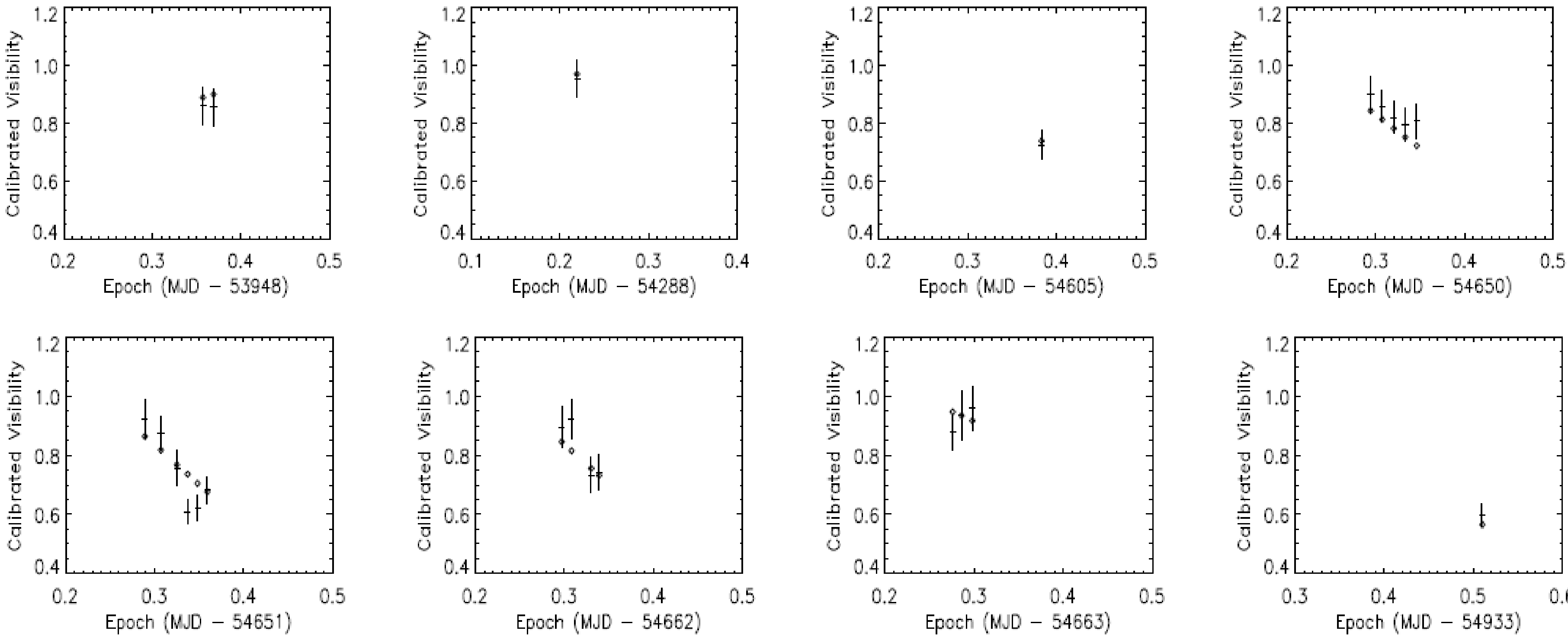
ϕ_6: separation of the two packets



HD 157482 (V819 Her)



HD 157482 (V819 Her Orbit)



Points represent 3-4 data sets averaged together

HD 157482 (V819 Her B) Orbit

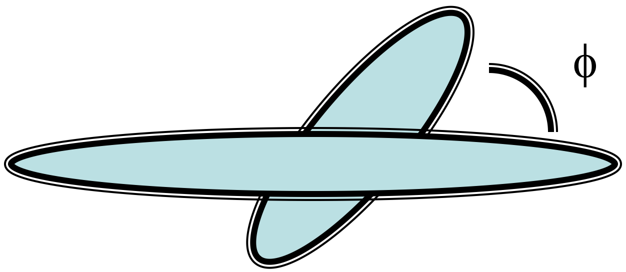
Element	Value	Muterspaugh et al. (2008)
Fixed Elements:		
P (days)	2.2296334 ± 1.6 x 10^{-6}	2.2296330 ± 1.9 x 10^{-6}
α sin i (mas)	0.6641 ± 0.0230	
e	0	0.0041 ± 0.0033
ω (degrees)	0	227 ± 47
Θ_p (mas)	0.126 ± 0.002	
Θ_s (mas)	0.085 ± 0.002	
Varied elements:		
T_{node} (MJD)	52626.872 ± 0.039	52627.17 ± 0.29
α (mas)	0.6646 ± 0.0156	0.6657 ± 0.0058
i (degrees)	87.6 ± 5.5	80.70 ± 0.38
Ω (degrees)	131.3 ± 2.7	131.1 ± 4.1
Δm_{close}	1.24 ± 0.16	1.38 ± 0.14
Δm_{wide}	1.127 ± 0.037	

Mutual Inclination

- Mutual inclination is the angle between planes of the wide orbit and the close orbit

$$\cos \phi = \cos i_{Close} \cos i_{Wide} + \sin i_{Close} \sin i_{Wide} \cos (\Omega_{Wide} - \Omega_{Close})$$

- Can give clues to formation processes of multiple systems



Mutual Inclination

$$\cos\phi = \cos i_{Close} \cos i_{Wide} + \sin i_{Close} \sin i_{Wide} \cos(\Omega_{Wide} - \Omega_{Close})$$

i_{Close} = 87.6 deg
Ω_{Close} = 131.3 deg

i_{Wide} = 56.2 deg
Ω_{Wide} = 143.7 deg

$\phi = 33.5 \pm 5.5$ degrees

(Muterspaugh (2008): $\phi = 26.3$ degrees)

- Sterzik & Tokovinin (2002): This type of mutual inclination suggests a very oblate initial gas cloud with strong initial rotation

Masses

- $P = 2.2296334 \pm 1.9 \times 10^{-6}$ days
- $a = 0.04572 \pm 0.00300$ AU

- $M_{1+2} = 2.565 \pm 0.505\ M_{¤}$
  - Scarfe et al. (2004): $2.64 \pm 0.08\ M_{¤}$
  - Muterspaugh et al. (2008): $2.560 \pm 0.067\ M_{¤}$

- $M_1 = 1.487 \pm 0.293\ M_{¤}$, $M_2 = 1.078 \pm 0.212\ M_{¤}$
  - Muterspaugh et al. (2008): $M_1 = 1.469 \pm 0.040\ M_{¤}$, $M_2 = 1.090 \pm 0.030\ M_{¤}$

Age

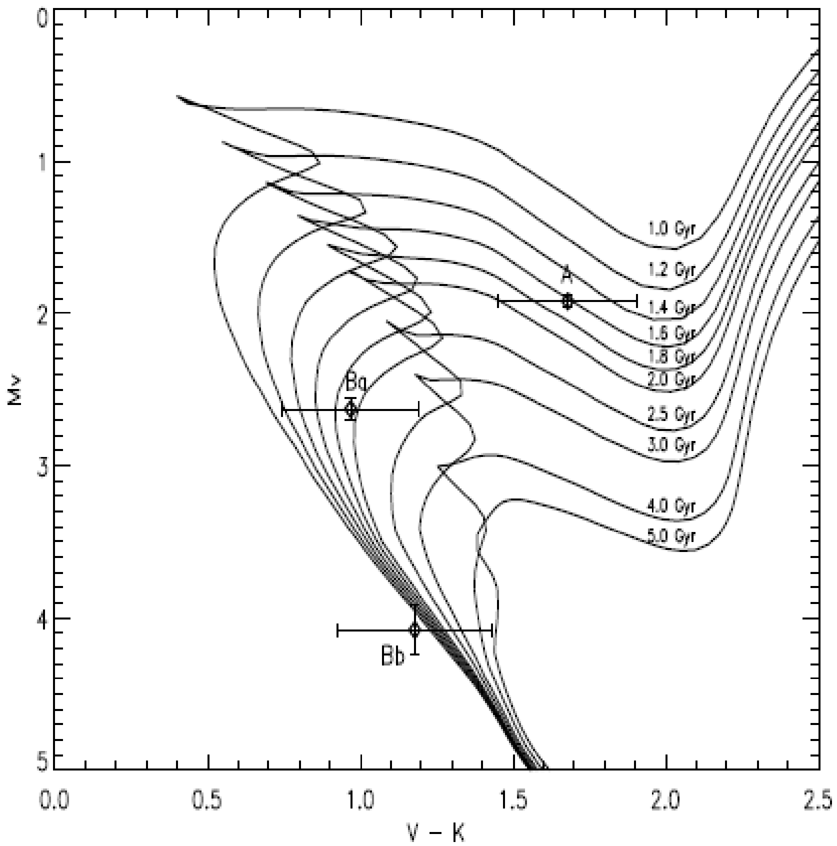
- Individual component K magnitudes determined by values derived for Δm_{close} and Δm_{wide}, and overall K magnitude from Muterspaugh et al. (2008)

- V magnitudes adopted from Scarfe et al. (2004)

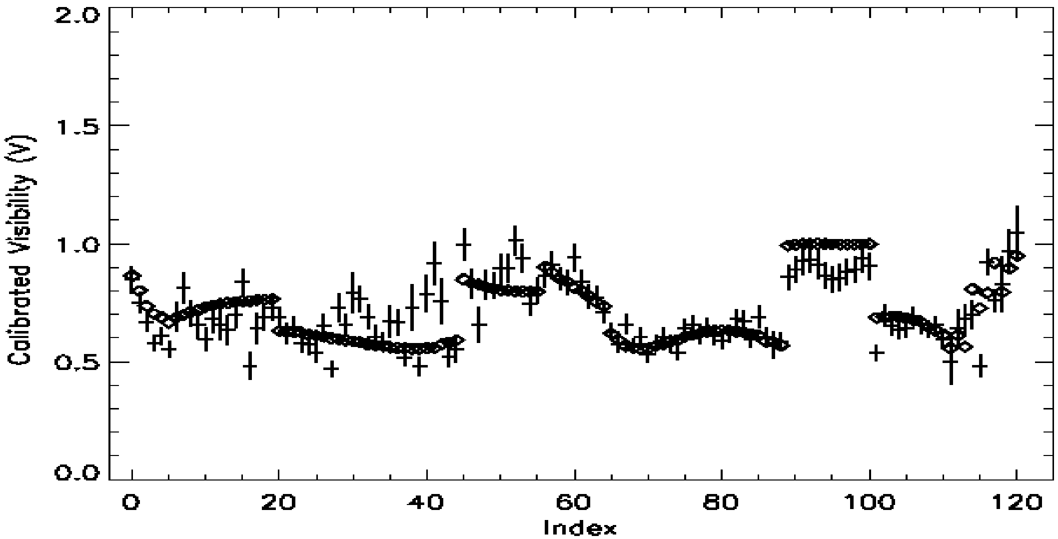
	AB	B	A	Ba	Bb
M_V			1.92 ± 0.04	2.63 ± 0.07	4.08 ± 0.16
m_V			6.11 ± 0.05	6.82 ± 0.08	8.27 ± 0.16
m_K	4.1 ± 0.22	5.55 ± 0.22	4.43 ± 0.23	5.86 ± 0.22	7.10 ± 0.25
$V - K$			1.68 ± 0.23	0.96 ± 0.23	1.17 ± 0.30

Age

- Age = 1.8 $\pm$ 0.3 Gyr
  - Scarfe et al. (2004): Age = 1.5 $\pm$ 0.3 Gyr



CHARA 96 (Preliminary Orbit)



P = 311.745 days
T = 46917.512 MJD
e = 0.29
ω = 293 deg
α = 2.81 mas

i = 61 deg
Ω = 132 deg
$\Delta m_{close} = 1.4$
$\Delta m_{wide} = 0.3$

CHARA 96 Masses

- Wide spread in values for parallax
  1. Hipparcos: 472 pc
  2. Roberts et al. (2010): 741 pc
  3. Mason et al. (1998): 1200 pc

- So, much wider spread in masses
  1. $M_{1+2} = 3.20\ M_{¤}$
  2. $M_{1+2} = 12.39\ M_{¤}$
  3. $M_{1+2} = 52.63\ M_{¤}$

- Spectroscopic orbit of McKibben et al. (1998) suggests $M_{1+2} = 38\ M_{¤}$