Overview of MIRC Observations of Be Stars in 2015

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CHARA

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Outline

- Overview of science goals
- Detecting the faint companion in the Be star 59 Cyg
- A work in progress – trying to understand systematic errors and correlations between fit parameters

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Properties of Be Stars

- Rapidly rotating B-type stars that eject gas into a circumstellar disk
- Evidence for the disks
  - Rotationally broadened emission lines
  - IR excess
  - Linear polarization
  - Spatially resolved through interferometry
- Variable on time-scales of days to decades

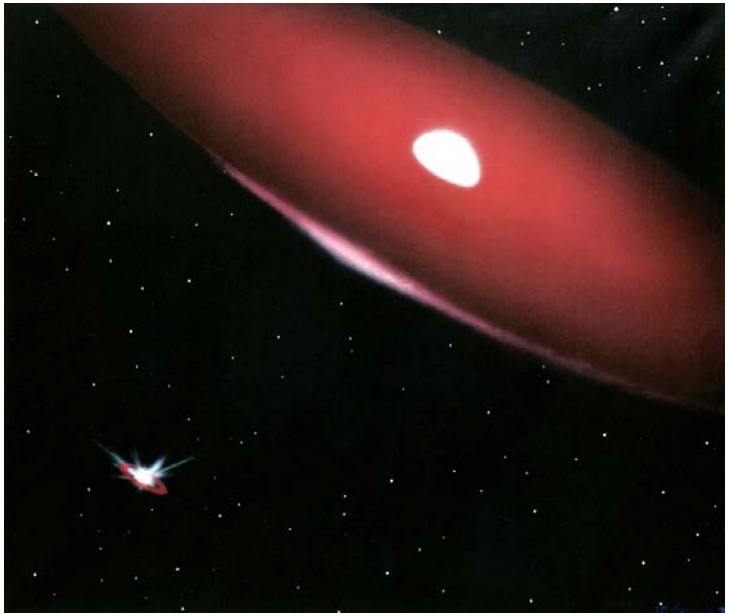


Image Credit: Bill Pounds

Be Stars: One-armed Spiral Oscillations

Density enhancement that moves outward through the disk

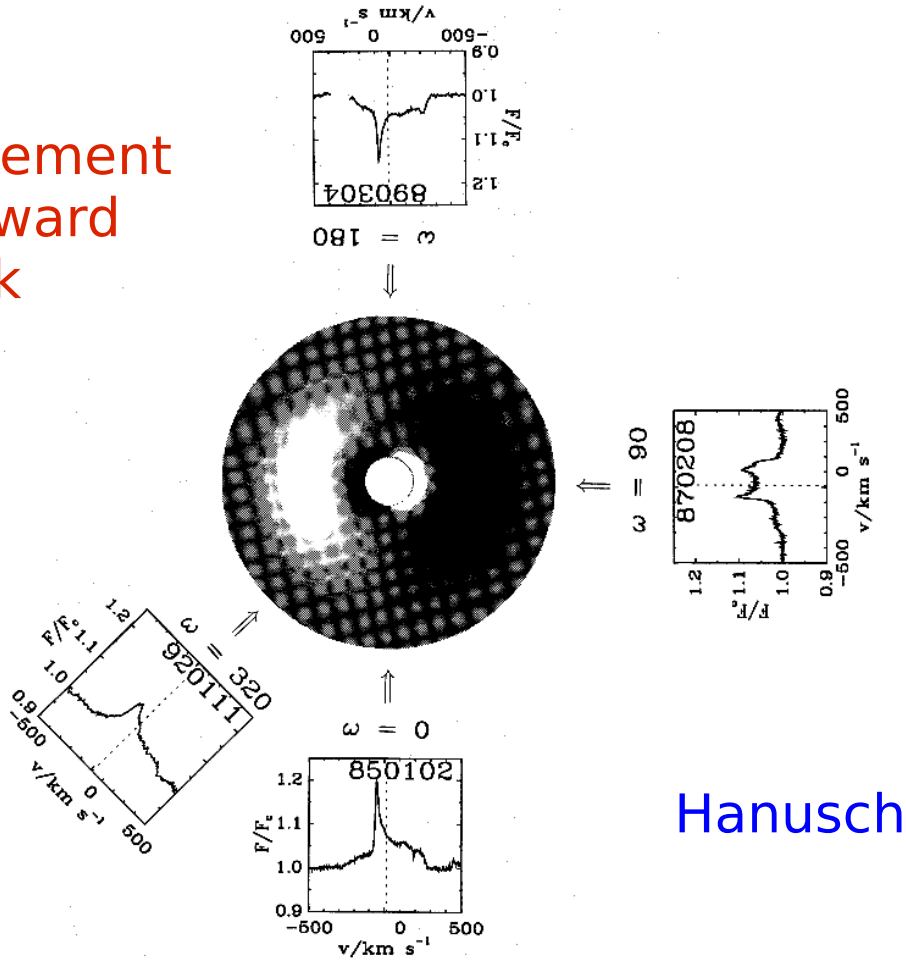


Fig. 16. Distorted part of the density field, σ_1 (as taken from Okazaki 1991), and observed Fe II λ5317 profiles of δ Cen, plotted at approximate angles $\omega = 0°, 90°, 180°, 320°$ corresponding to the mutual orien tation of the observer and the precessing nodal line of σ_1. Particles in the disk rotate counterclockwise. Dark areas denote $\sigma_1 < 0$, bright ones $\sigma_1 > 0$

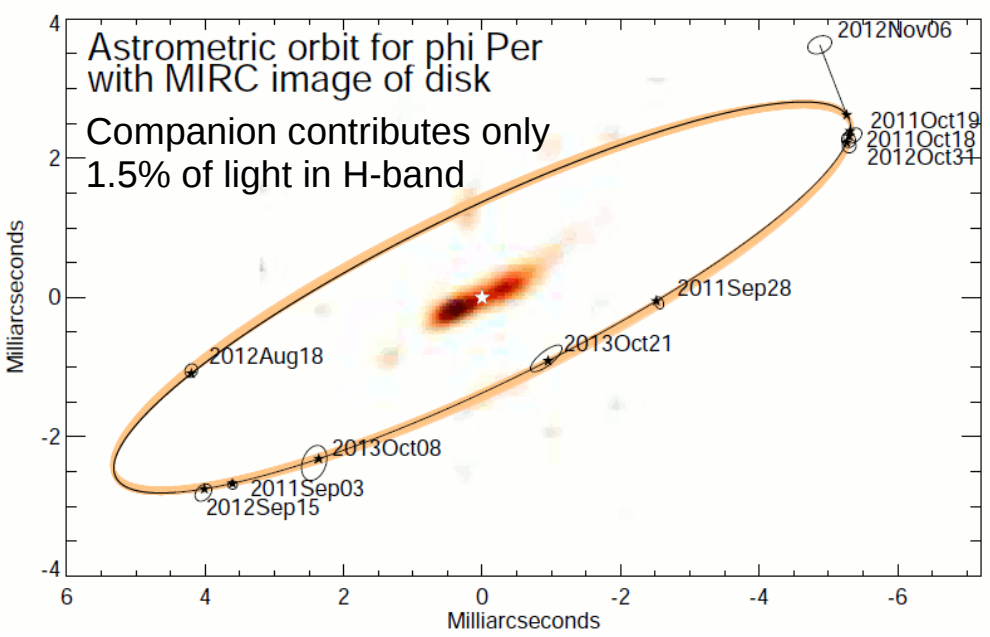
Hanuschik et al. 1995

Role of Binarity in Be Stars

- Rapid rotation could be the result of a past mass transfer result (de Mink et al. 2013, Pols et al. 1991)
- Companion would lose most of its envelope and appear as a stripped down stellar remnant: neutron star, white dwarf, or helium star.
- Most high mass X-ray binaries consist of Be + neutron star (Reig 2011)
- Subdwarf companions detected in three Be binaries - spectral signature in UV light:
  - Phi Per (Gies et al. 1998), FY CMa (Peters et al. 2008), 59 Cyg (Peters et al. 2013)
- Companions difficult to resolve spatially because of high contrast and close separations (P: 28-127 days)

Goals of MIRC Be Star Program

- Search for faint companions through precision closure phase measurements



Mourard et al. (2015)

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- Search for faint companions through precision closure phase measurements
- Compare disk dimensions in H-band with size measured at other wavelengths to estimate gas densities in the disks
- Compare disk properties over multiple years to determine the extent of long-term structural variations in the disks

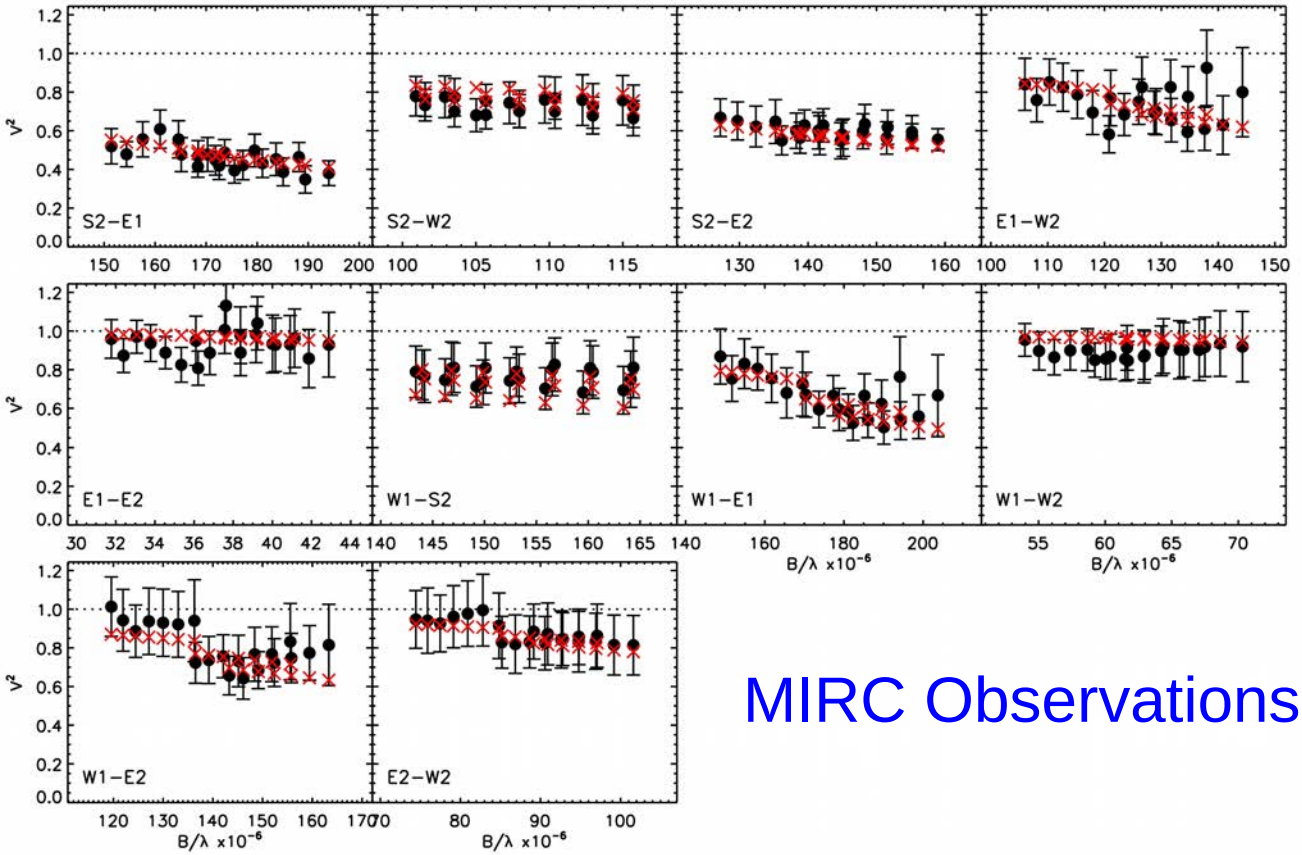
Summary of Be Star Observations in 2015

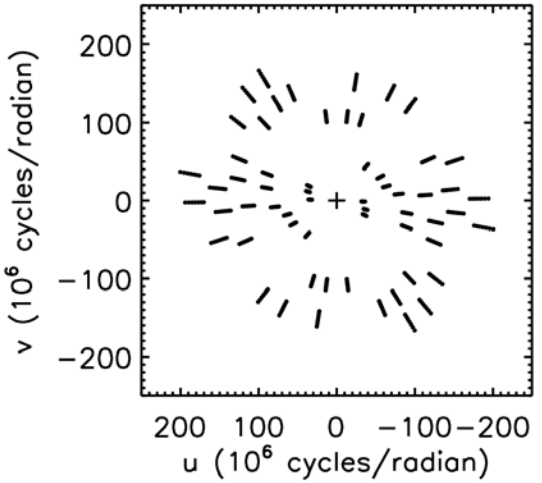
- UT 2015 May 24+25: no observations, bad weather conditions
- UT 2015 Jul 16+21: no observations, bad weather and bad voltage regulator on VME card
- UT 2015 Jul 26+30, Aug 3:
  - One full nights, two half nights
  - 59 Cyg (3 nights), Gam Cas (1n), Phi Per (1n)
- UT 2015Nov 21+22+23+24:
  - Could only track fringes on the brightest targets
  - Gam Cas (3n), Phi Per (2n), Zet Tau (3n), Eta Tau (3n)

Hot Subdwarf Companion in Be Star 59 Cyg

- Spectral Type: B1.5Ve + SdO
- V = 4.8 mag, K = 4.5 mag
- Parallax: 2.30 ± 0.42 mas
- Speckle companion ~ 170 mas (Mason et al. 2009)
- SB1 radial velocity curve (e.g. Harmanec et al. 2002)
- Hot subdwarf companion detected in UV spectra (Peters et al. 2013)
  - Double-lined spectroscopic orbit (P = 28 days)
  - Companion contributes 4% of UV Flux

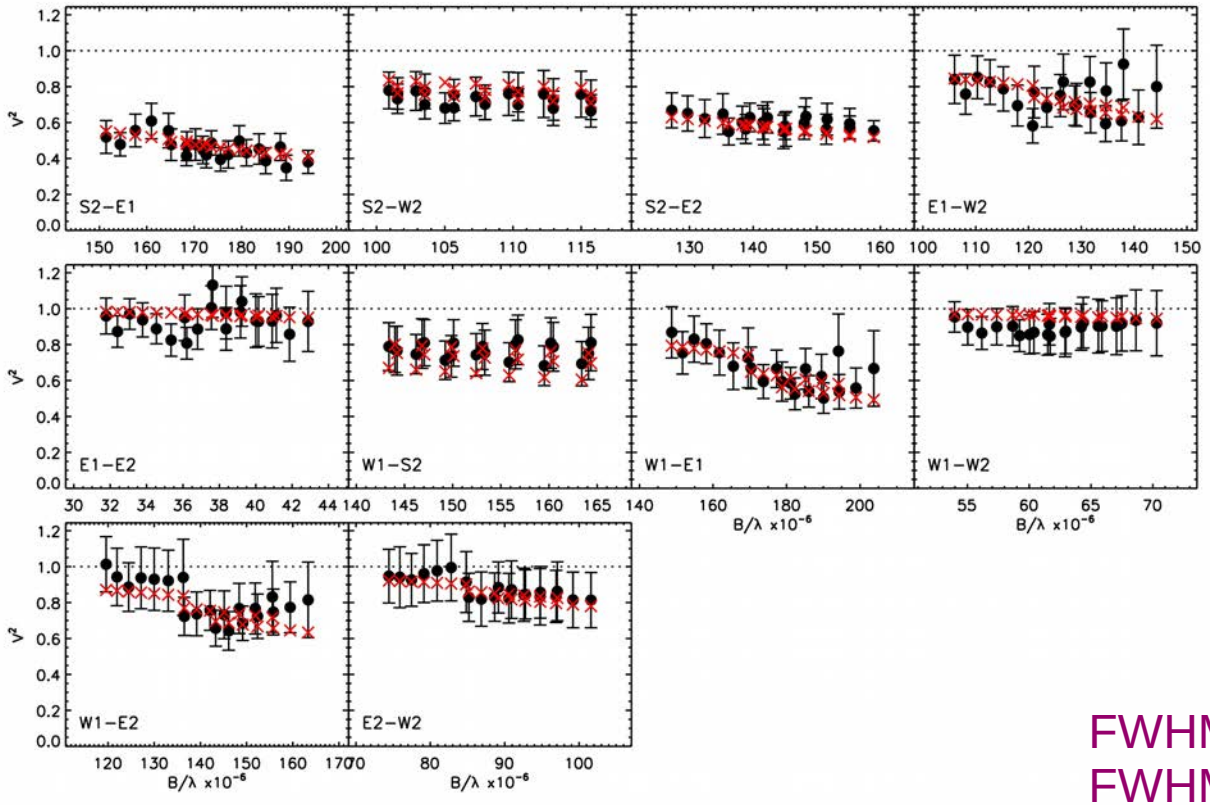
59 Cyg – 2014Aug08

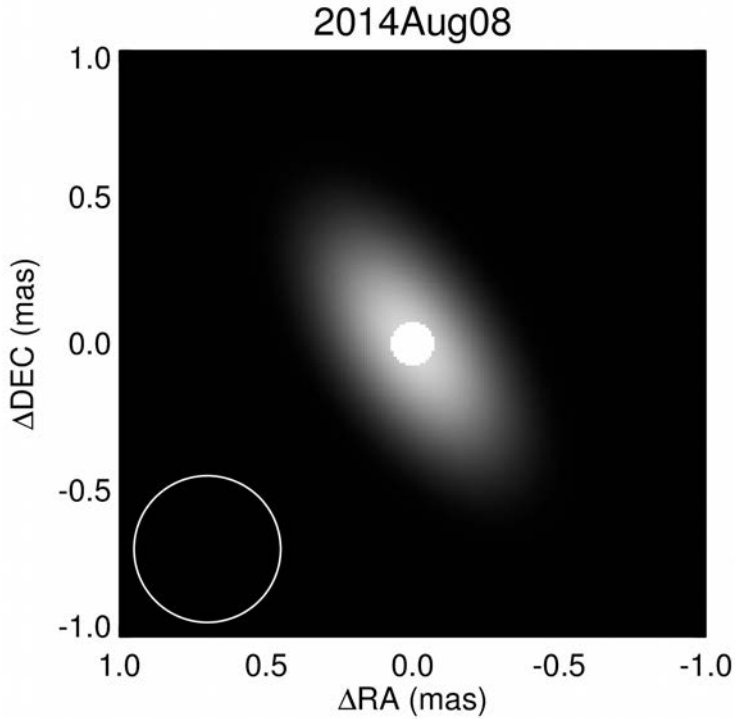




MIRC Observations - 5T

59 Cyg – 2014Aug08

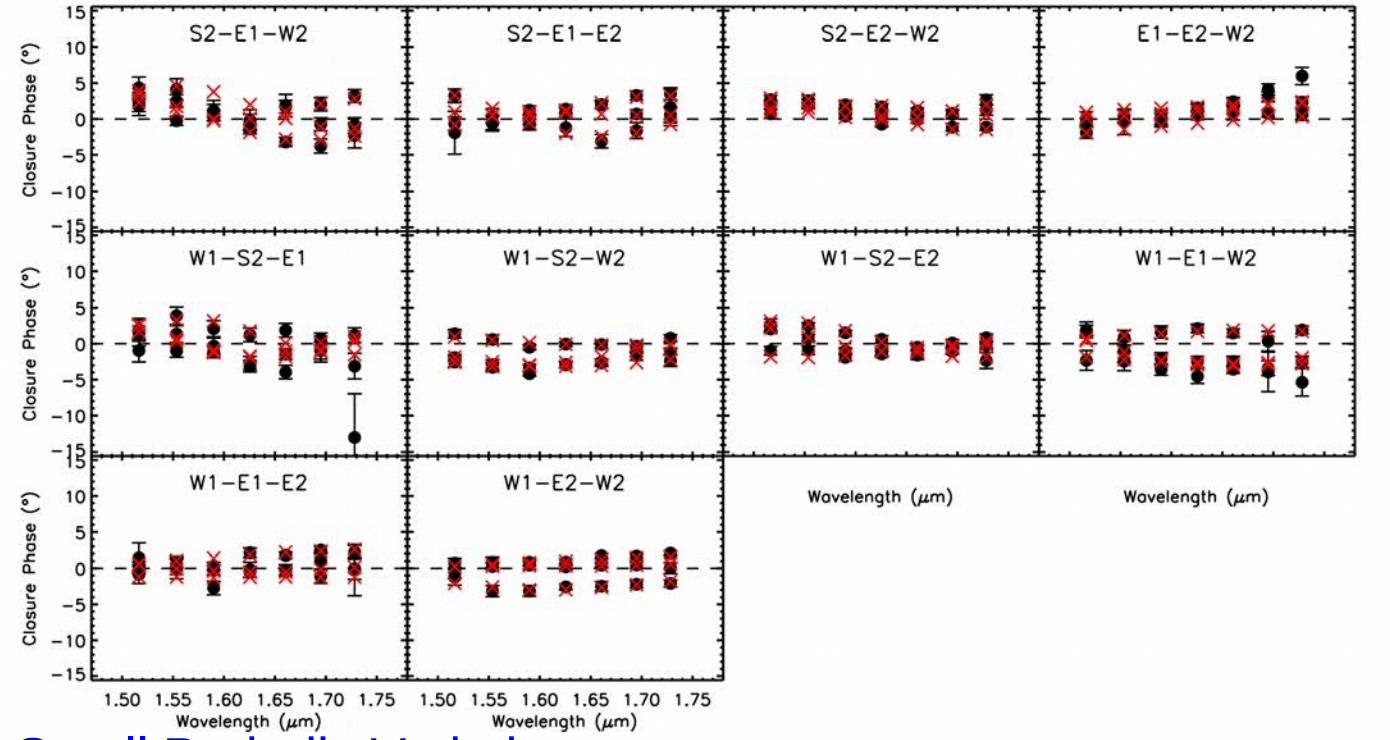




Fit Geometric Model:
- UD star + Elliptical Gaussian Disk

FWHM major = 0.64 mas
FWHM minor = 0.32 mas
fstar = 52%
fdisk = 48%
UD = 0.15 mas (fixed, Touhami et al. 2013)

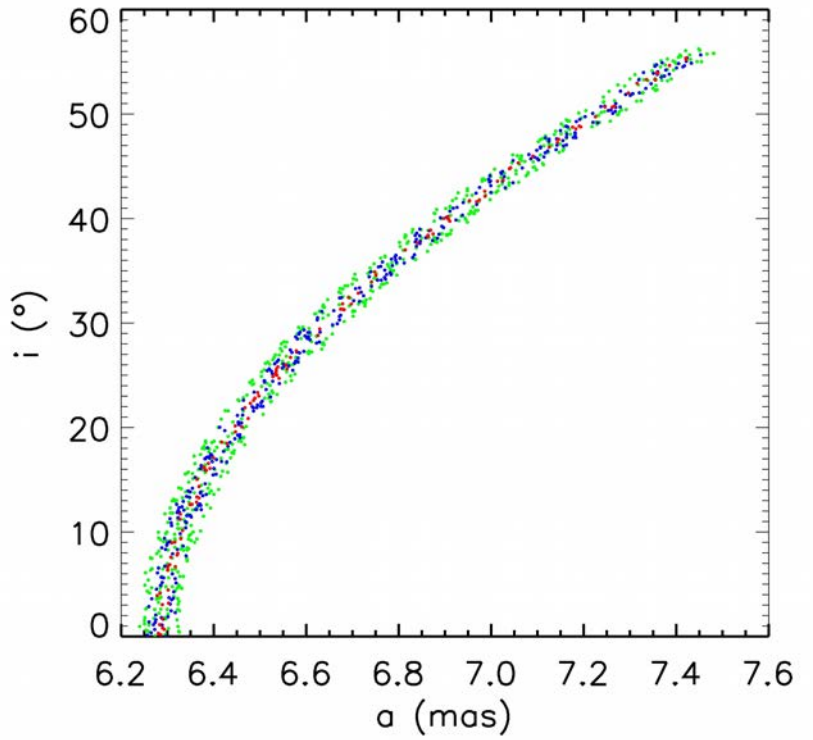
Closure Phases - 59 Cyg: 2014Aug08

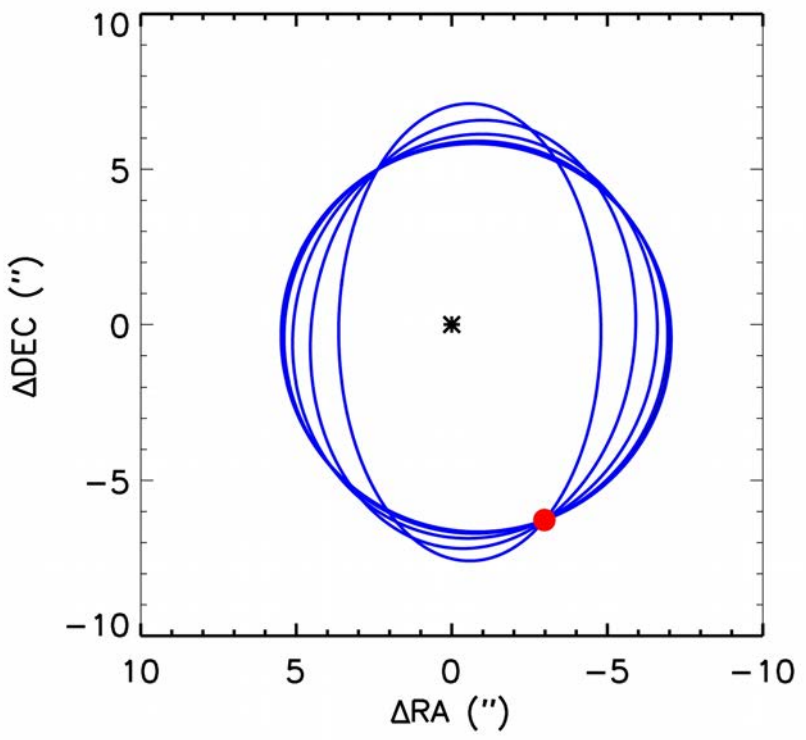


+ Small Periodic Variation
+ Fix geometric model of UD star + Asymmetric Gaussian Disk
+ Solve for binary companion parameters:

Sep = 6.89 ± 0.02 mas, PA = 205.2° ± 0.2°
Companion contributes 2% of total flux

Orbital Fits for 59 Cyg





+ Fix P, T, e, ω from SB2 orbital parameters

+ Perform 3-dimensional χ^2 search to explore ranges for a, i, Ω

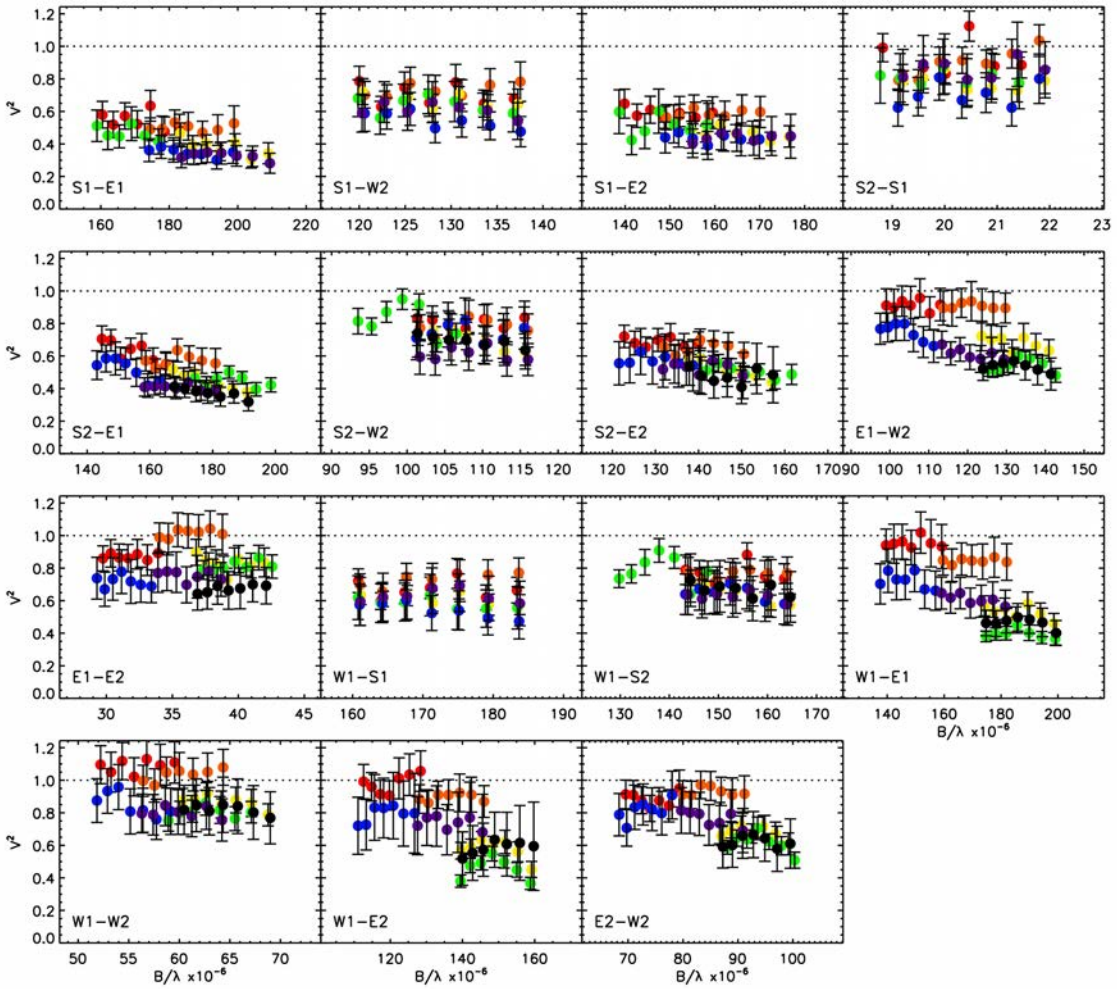
+ Maximum i yields:

M1 = 10.6 $M_\odot$ and M2 = 1.03 $M_\odot$

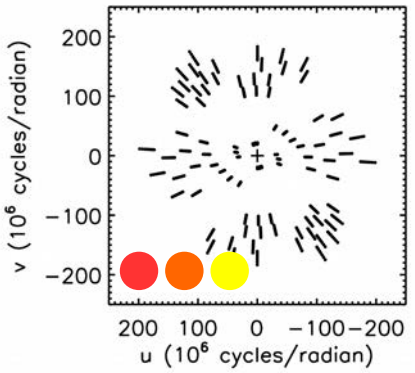
Summary of 59 Cyg MIRC Observations in 2015

- Goal: map orbital motion over a full period of 28 days
- UT 2015 Jul 16+21
  - No observations: bad weather and VME voltage regulator failure
- UT 2015 Jul 26+30, Aug 3:
  - One full night, two half nights
  - 59 Cyg (3 sets, 1 set, 3 sets)

59 Cyg – 2015 MIRC Observations



2015Jul26



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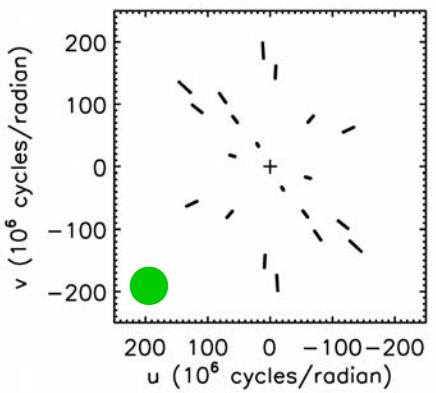
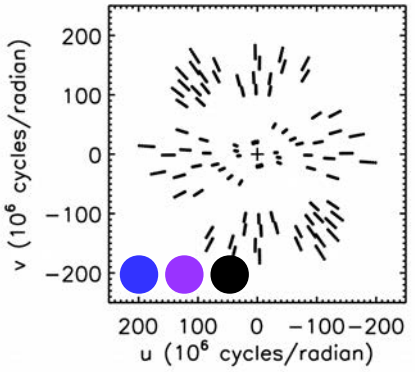
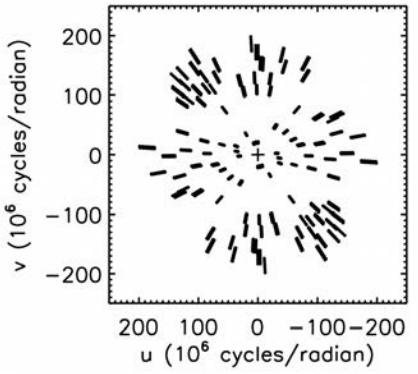


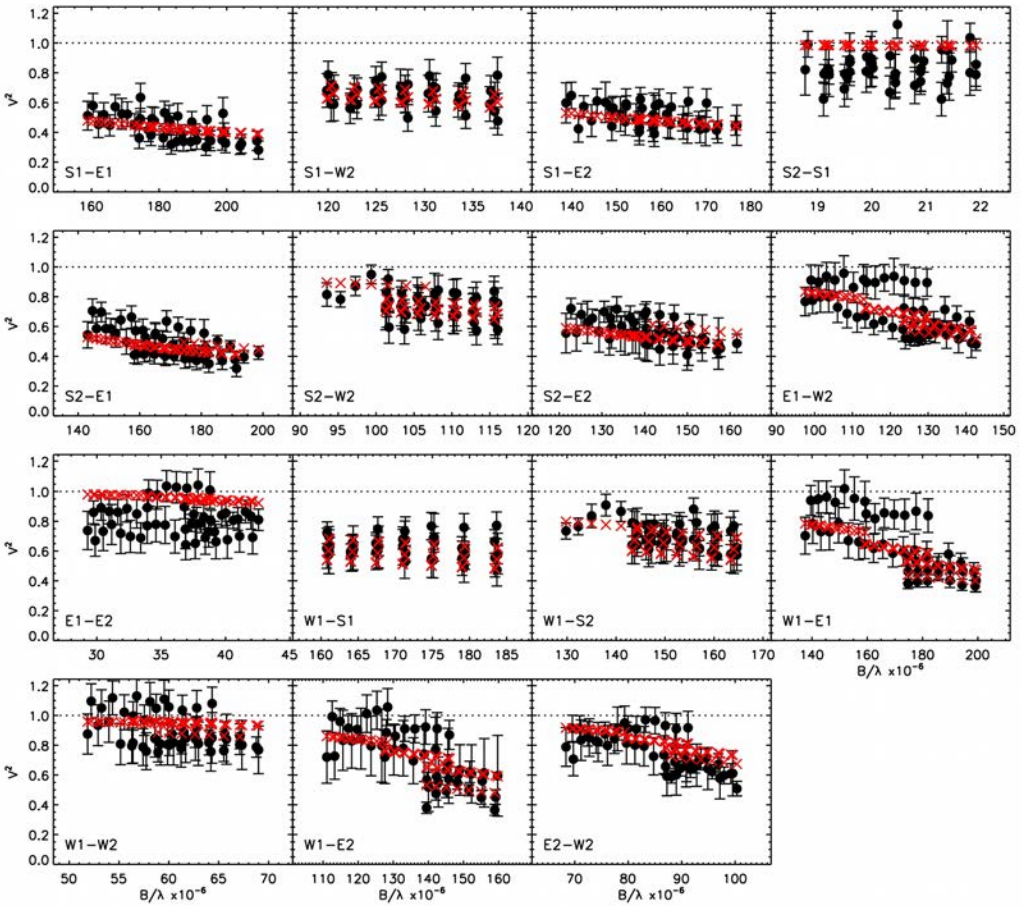
2015Aug03

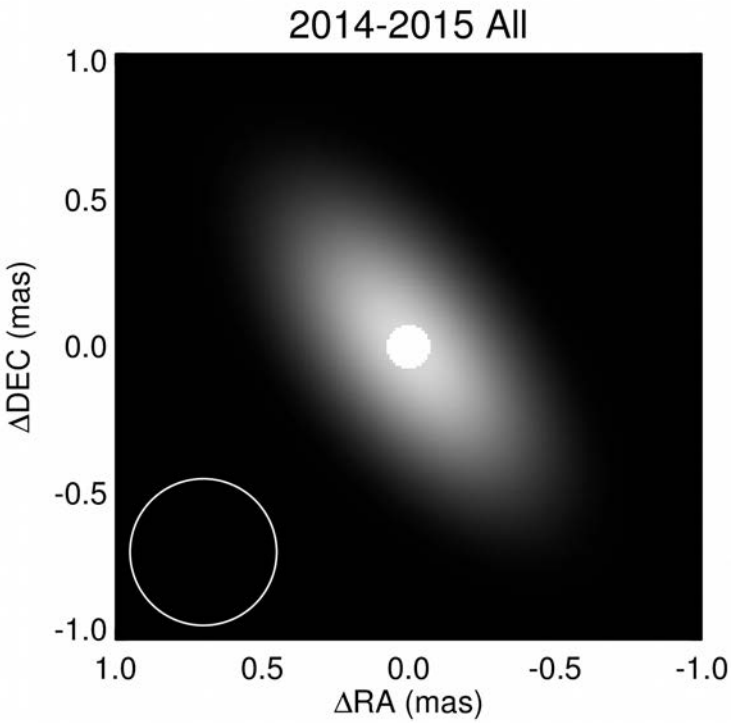


2015 - ALL



59 Cyg – 2015 MIRC Observations

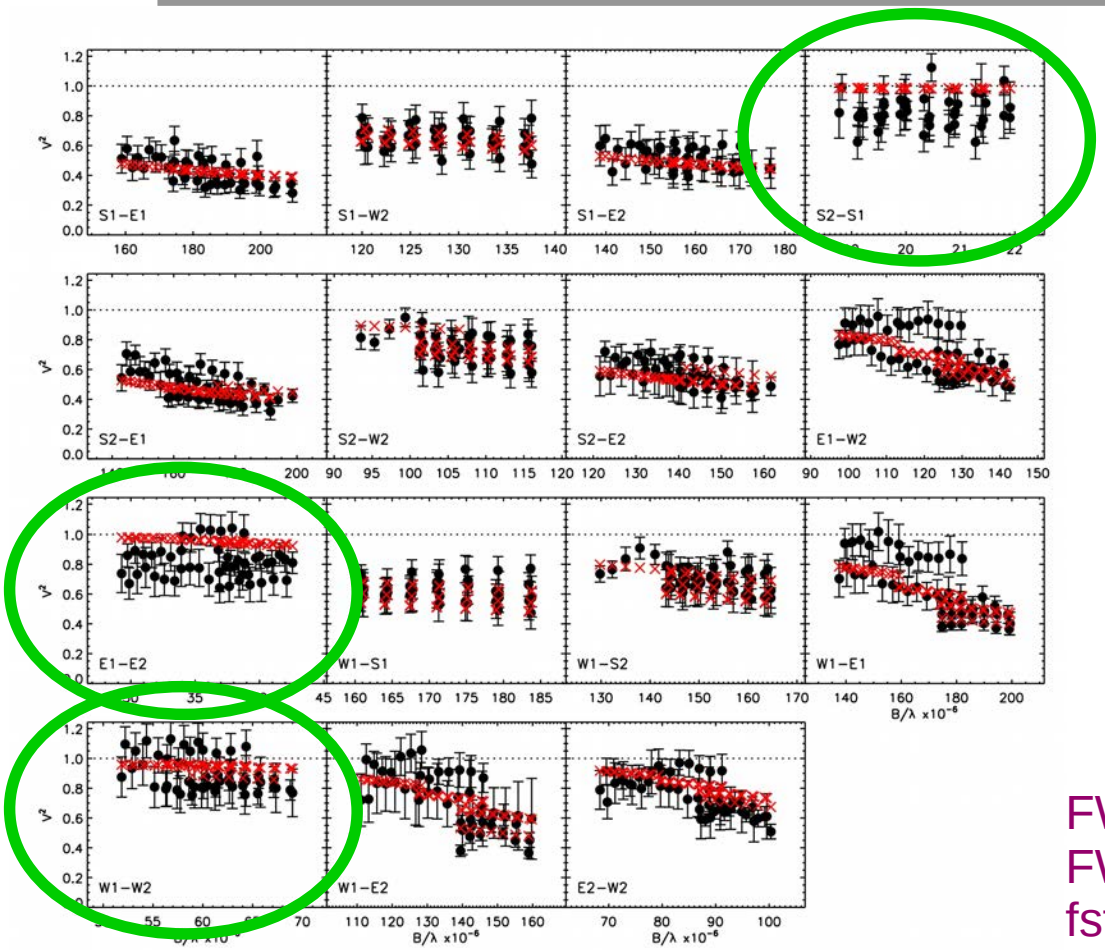


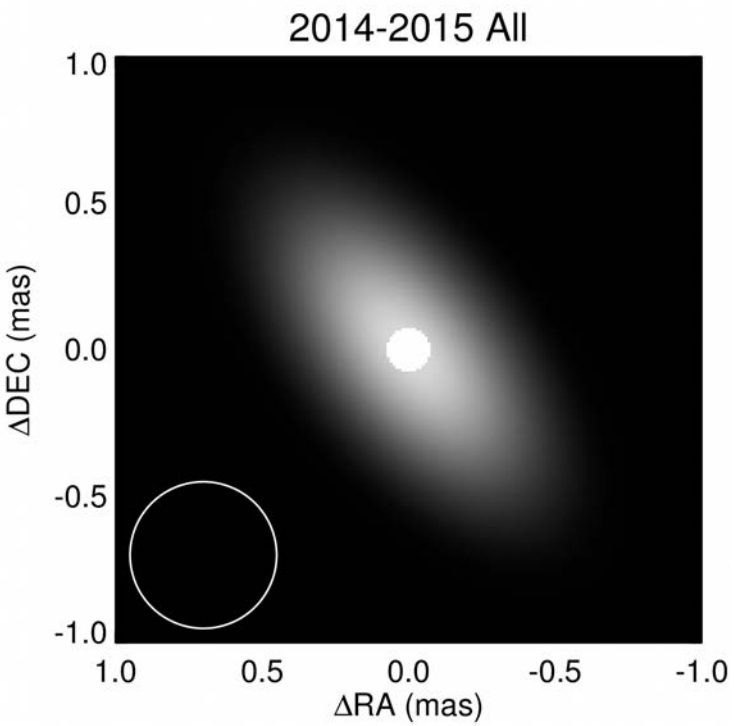


Fit Geometric Model:
- UD star + Elliptical Gaussian Disk

FWHM major = 0.81 mas
FWHM minor = 0.41 mas
fstar = 61%
fdisk = 39%
UD = 0.15 mas (fixed, Touhami et al. 2013)

59 Cyg – 2015 MIRC Observations





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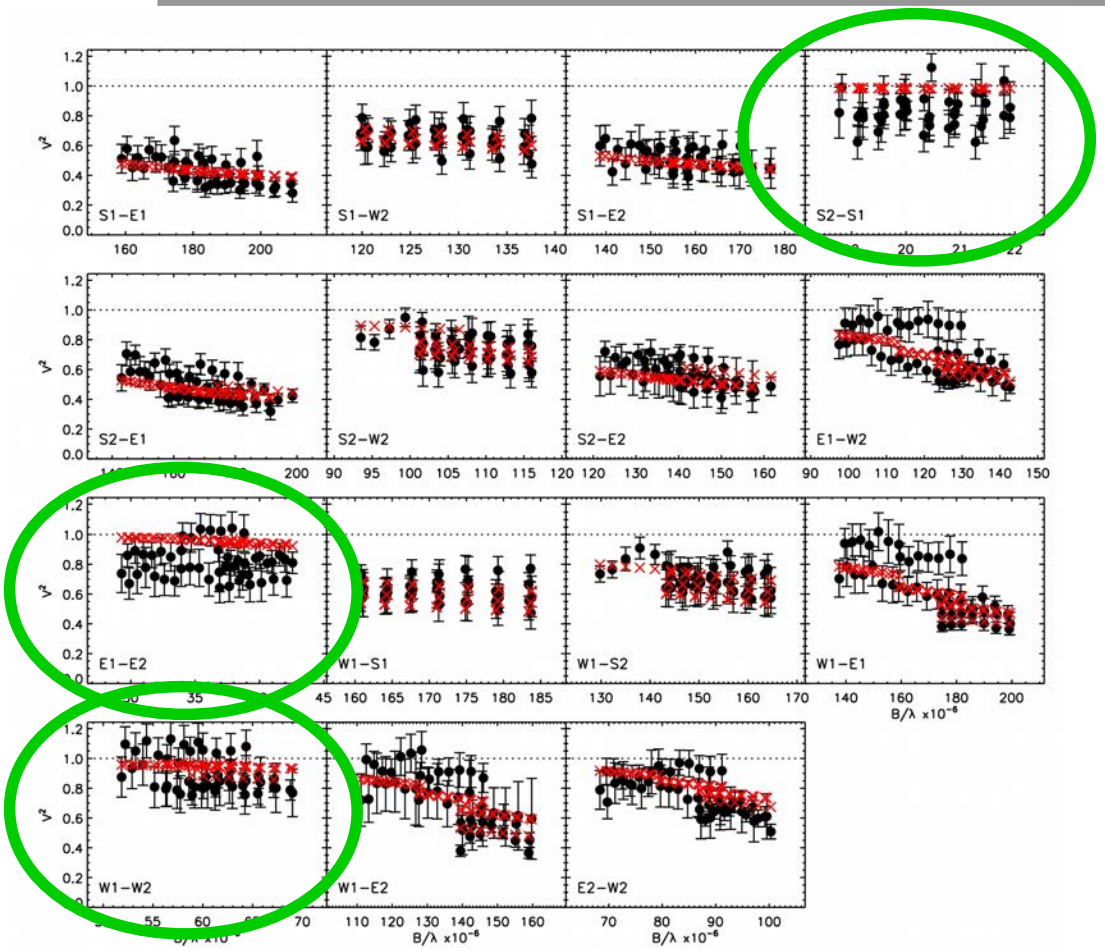
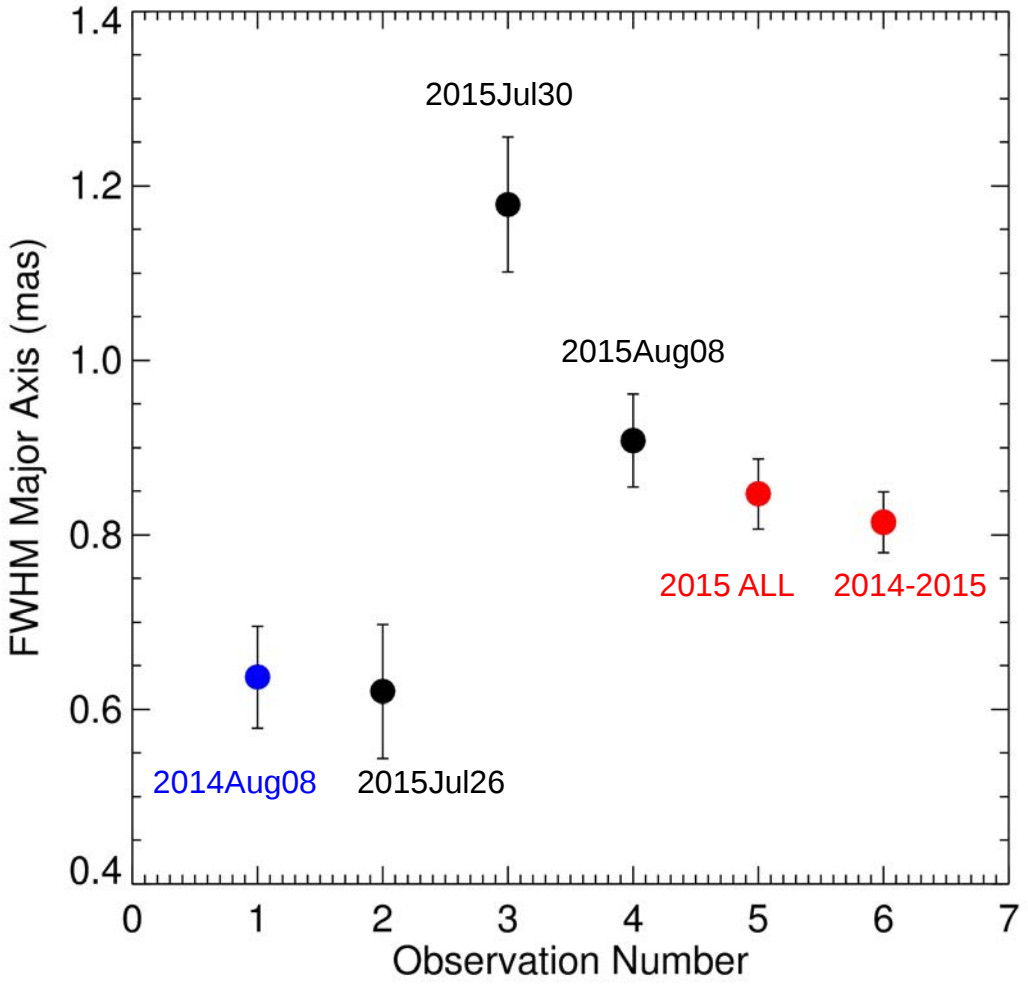


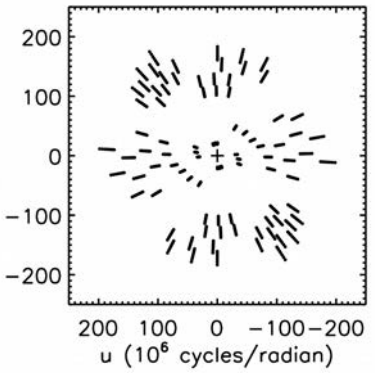
Need to include effect of wide companion on short baselines?

sep = 170 mas
ΔV = 2.8 mag

59 Cyg – Disk Size Measurements



2015Jul26



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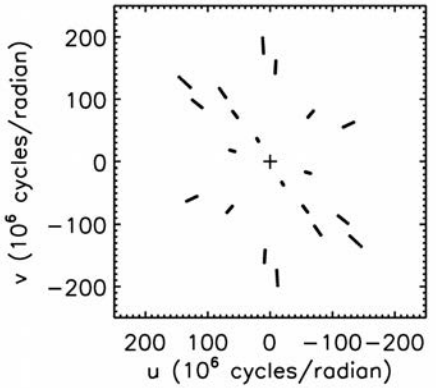

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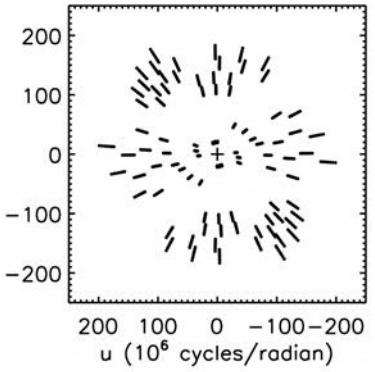
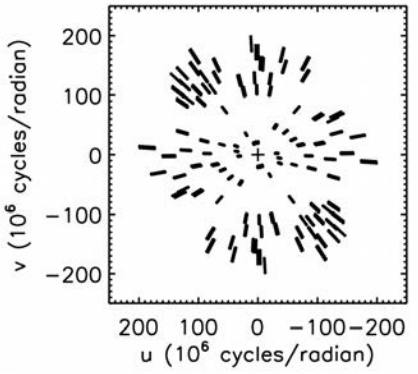
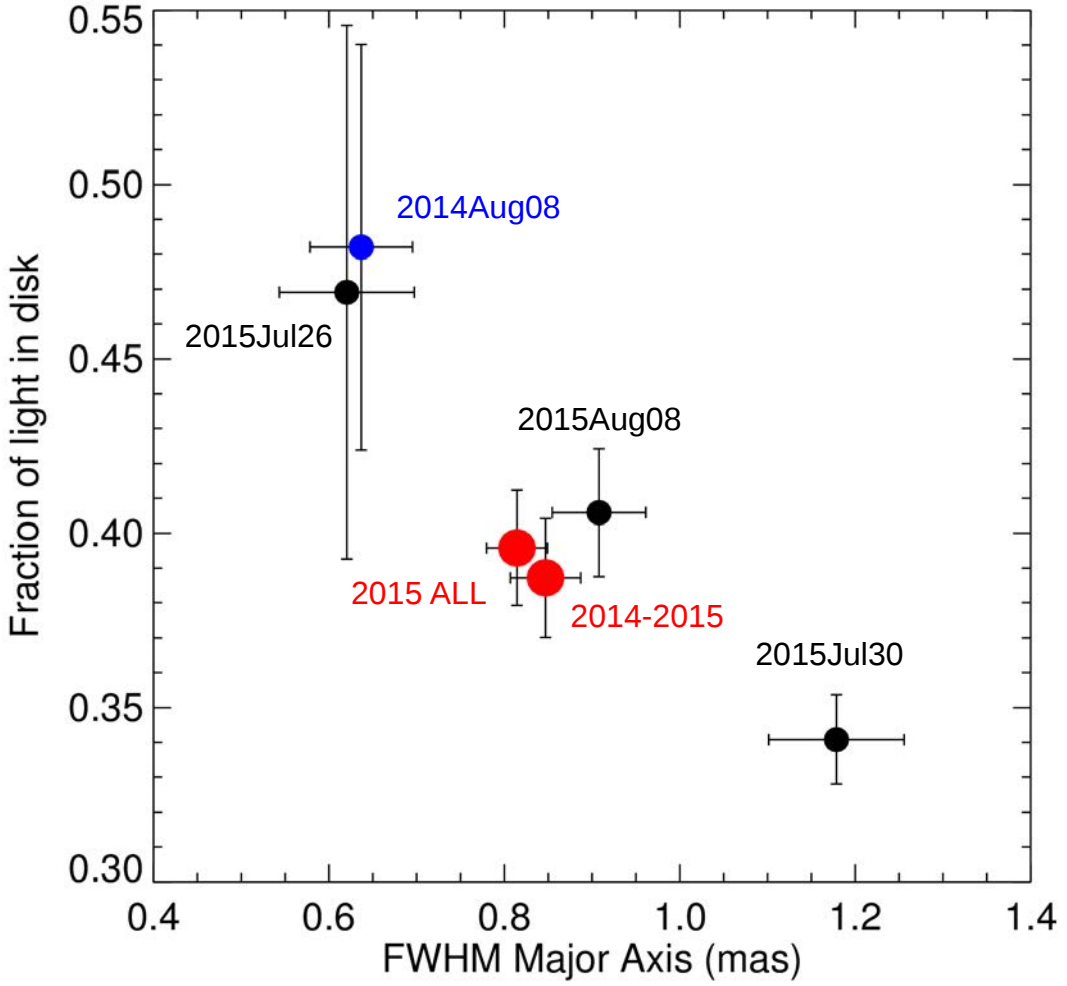
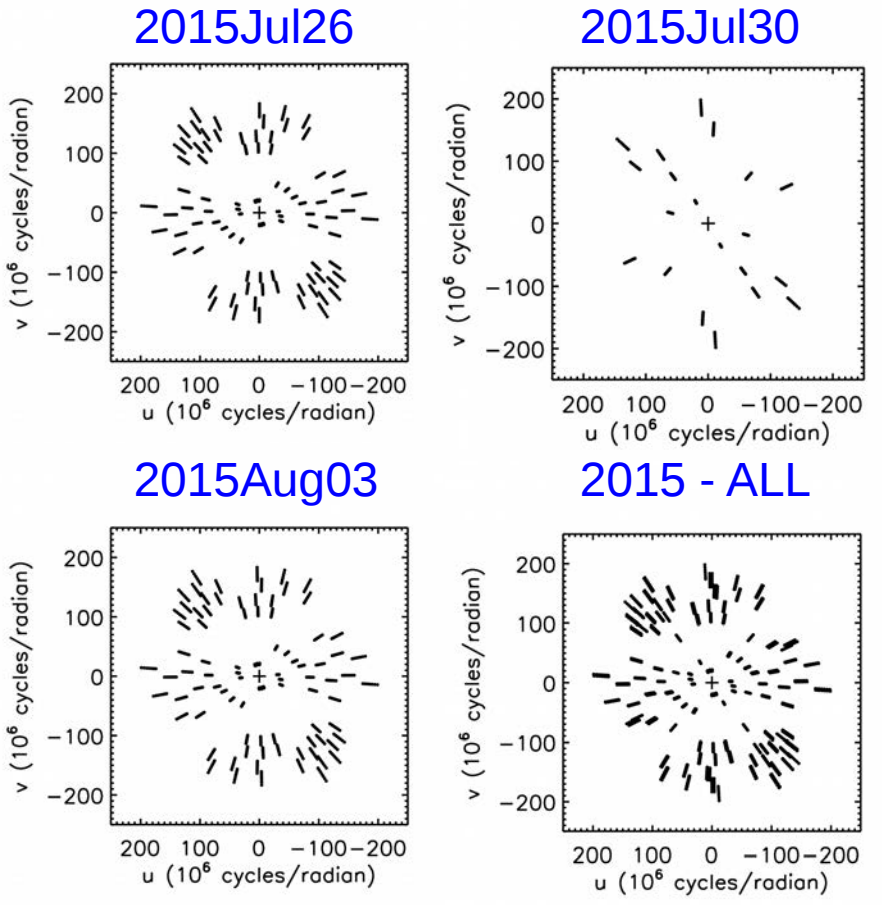


2015 - ALL



59 Cyg – Correlations Between Size of Disk and Flux in Disk





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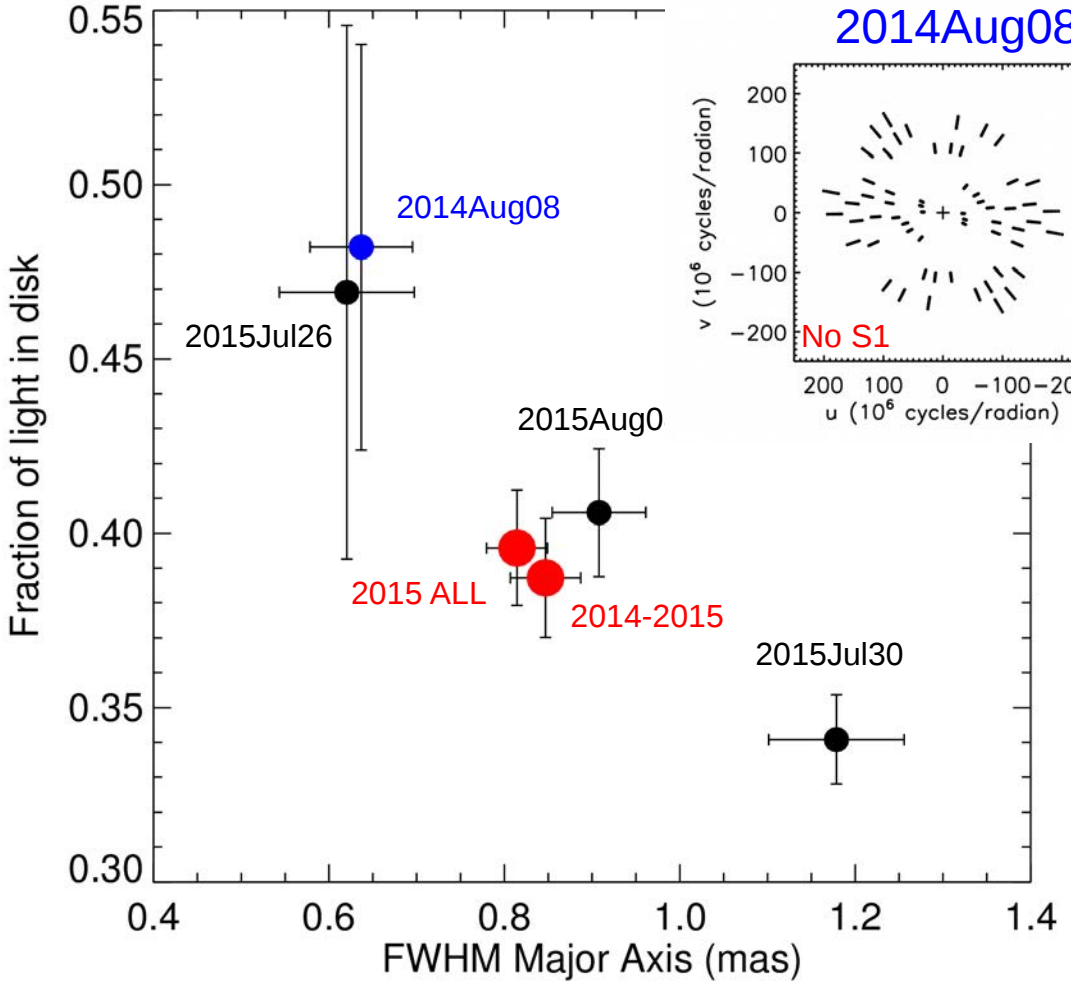
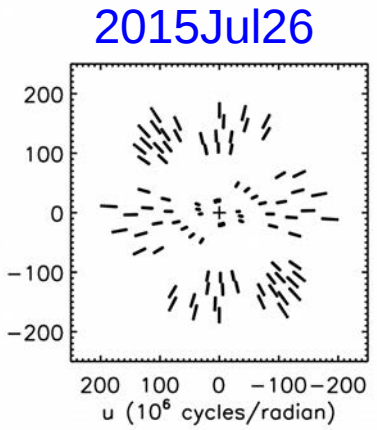
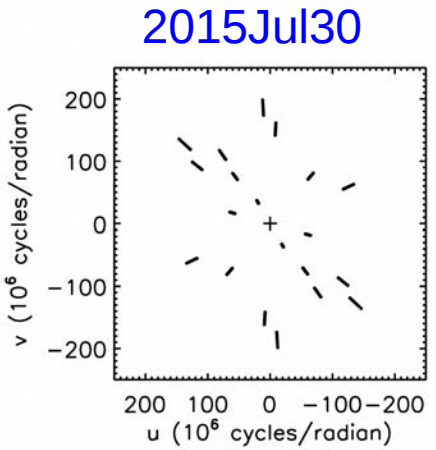
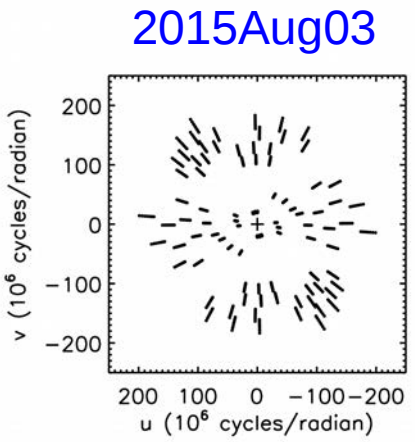
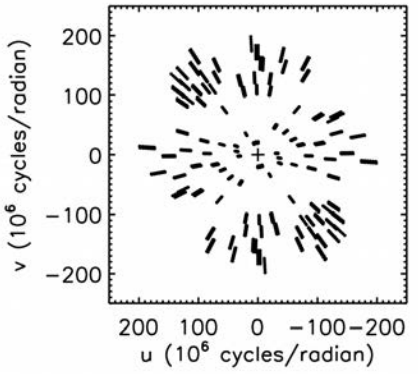


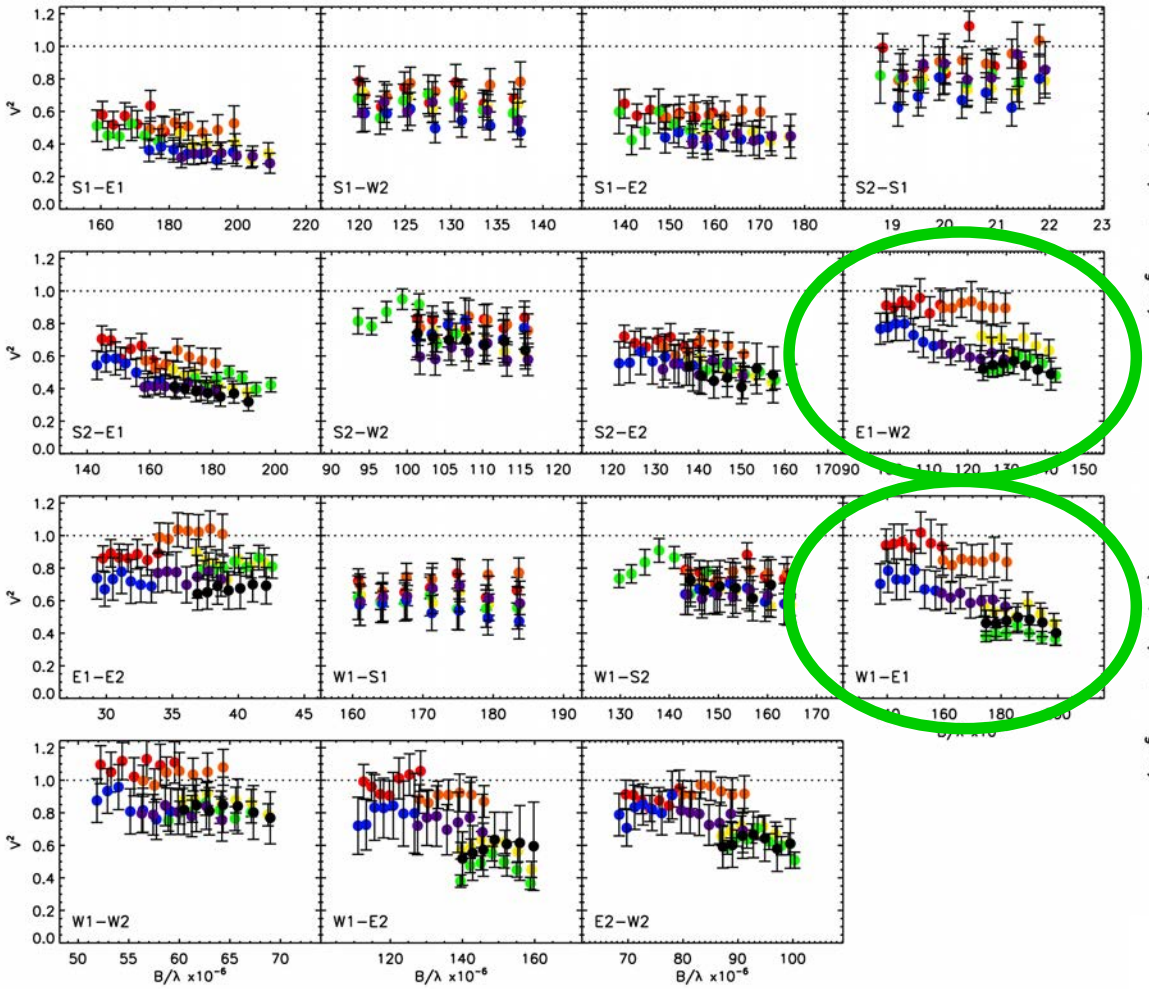


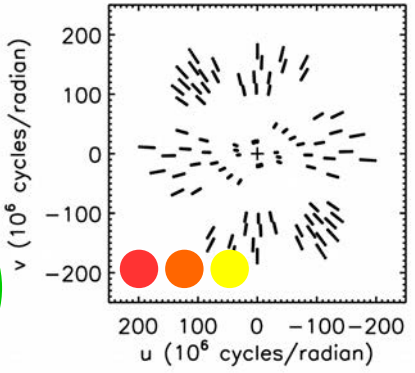


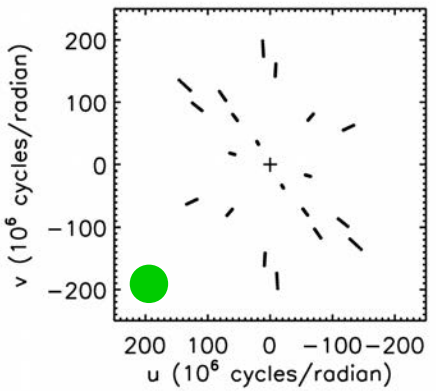


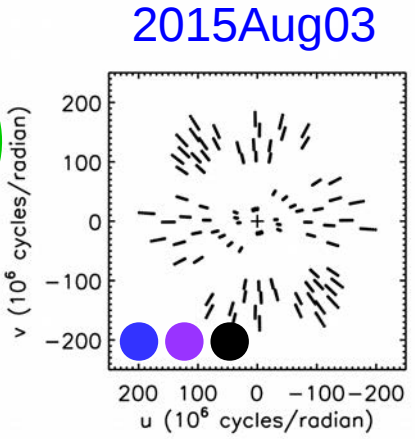


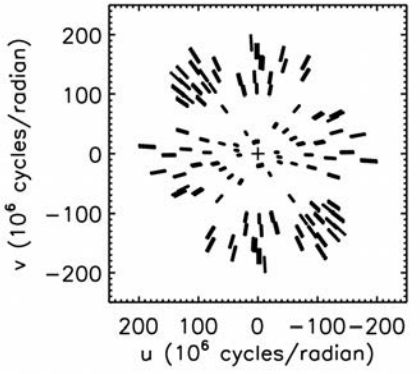
59 Cyg – Correlations Between Size of Disk and Flux in Disk



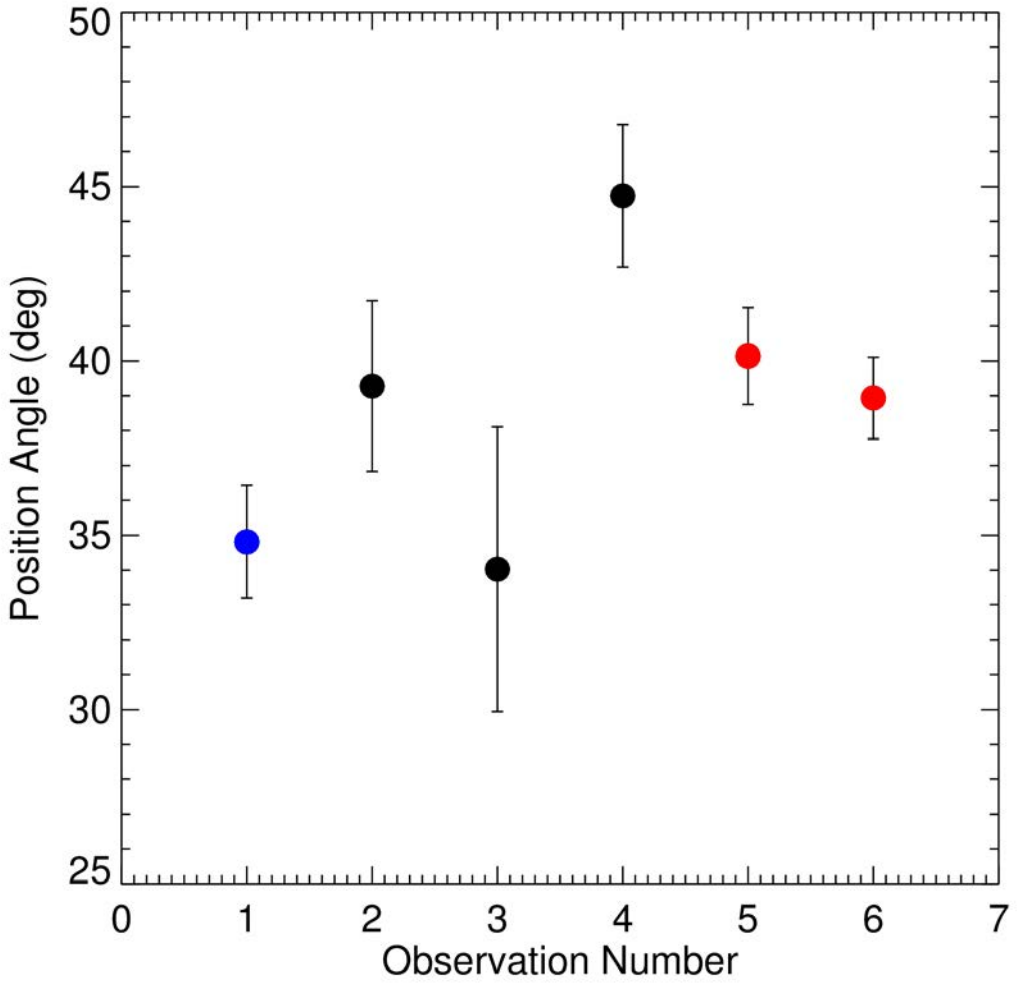


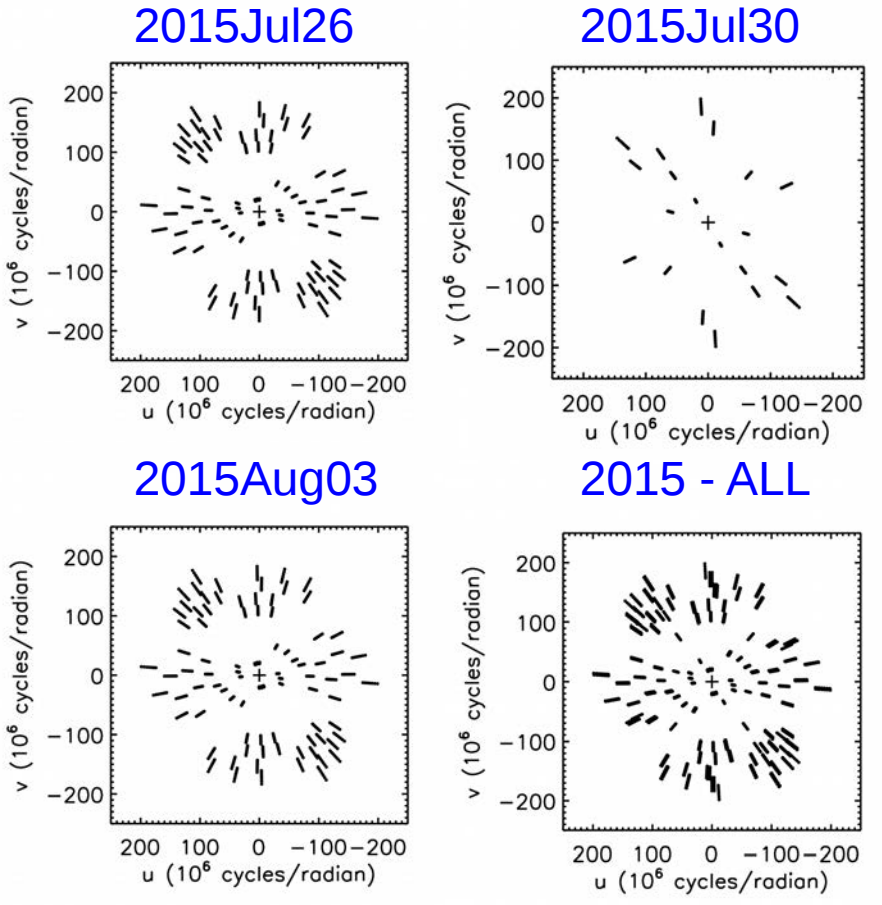




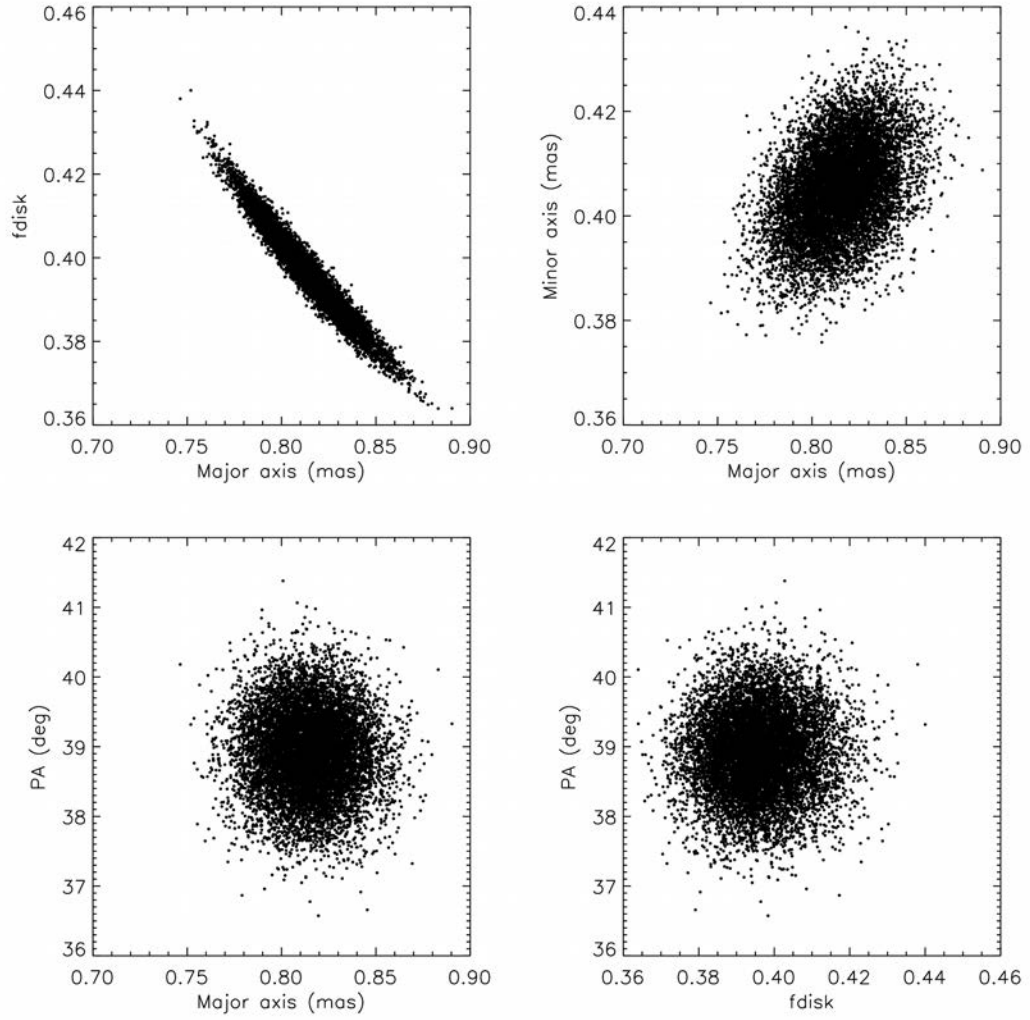


59 Cyg – Disk Position Angle





Explore Calibration Errors



Randomly vary visibility calibration on a per baseline basis:

sig Cyg – main calibrator
$\theta = 0.527 \pm 0.16$
(Masestro et al. 2013)

(Equivalent to 5% error in vis2 at 331 m)

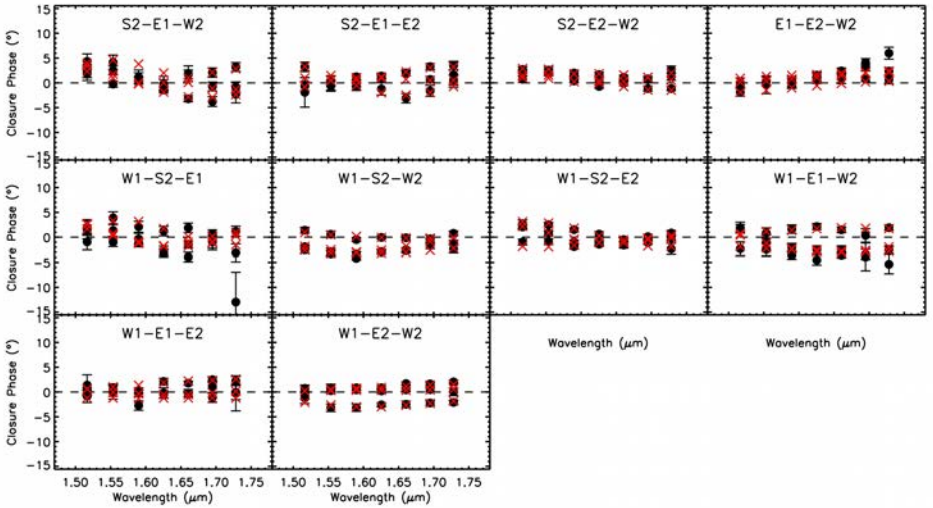
N = 10,000 iterations

Binary Grid Search Routines

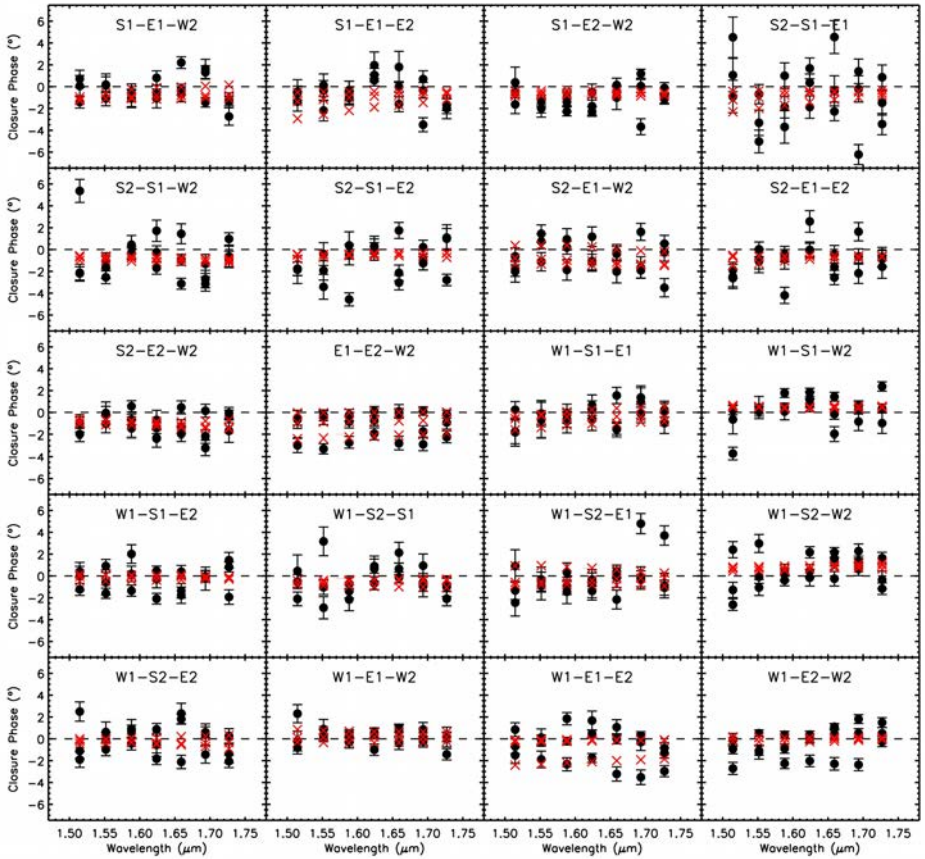
- Method 1
  - Fix elliptical or asymmetric Gaussian disk parameters
  - Search through a grid of binary separations in RA and DEC
  - Optimize binary position and flux contribution of disk, star, companion at each step in grid
- Method 2
  - Search through grid of binary separations in RA and DEC
  - Optimize all parameters for binary and disk at each step
- Method 3
  - Fit orbital parameters directly to visibilities and closure phases from all epochs simultaneously
  - Fit global symmetric, elliptical disk parameters

59 Cyg – Closure Phases

2014Aug08



2015Jul26



2014Aug08
sep = 6.89 mas, PA = 205.2°, fcomp = 1.9%

2015Jul26
sep = 1.46 mas, PA = 198.1°, fcomp = 1.5%

59 Cyg – Orbit Fitting Woes

- Not yet able to find consistent orbit that fits the positions measured from all nights of data
- Further analysis needed
  - Investigate correlations between binary companion, disk asymmetries, shaded star
  - Is it best to use global disk parameters or parameters optimized to epoch?
    - Which parameters to fix: stellar diameter, flux ratio?
  - Explore orbit fit directly to interferometric data further – grid a,i,Ω
  - Effect of wide companion
- Progress is slow - code takes a long time to run

Looking to the Future

- Work on binary detection in 59 Cyg
- Continue to investigate role of systematics and correlations when fitting disk parameters
- H-band disk sizes – sample of 8 Be stars with good data recorded with MIRC
  - Elliptical Gaussian disk fits
  - Physical disk models
    - John Monnier, Andrea Lin, Aaron Sigut