Detection of the Faint Companion Around the Be Star 59 Cygni

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Outline

- Physical Properties of Be stars
- Overview of interferometric observations of Be stars
- Role of binarity in Be stars
- MIRC observations on 59 Cyg

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

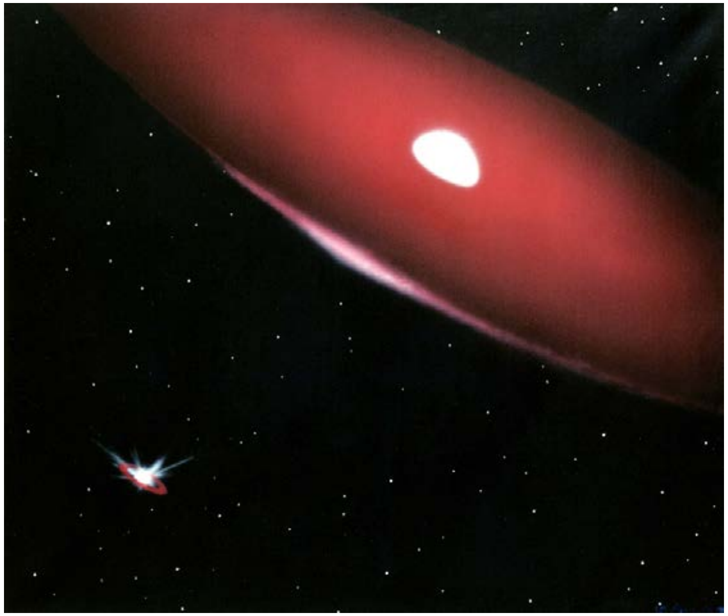
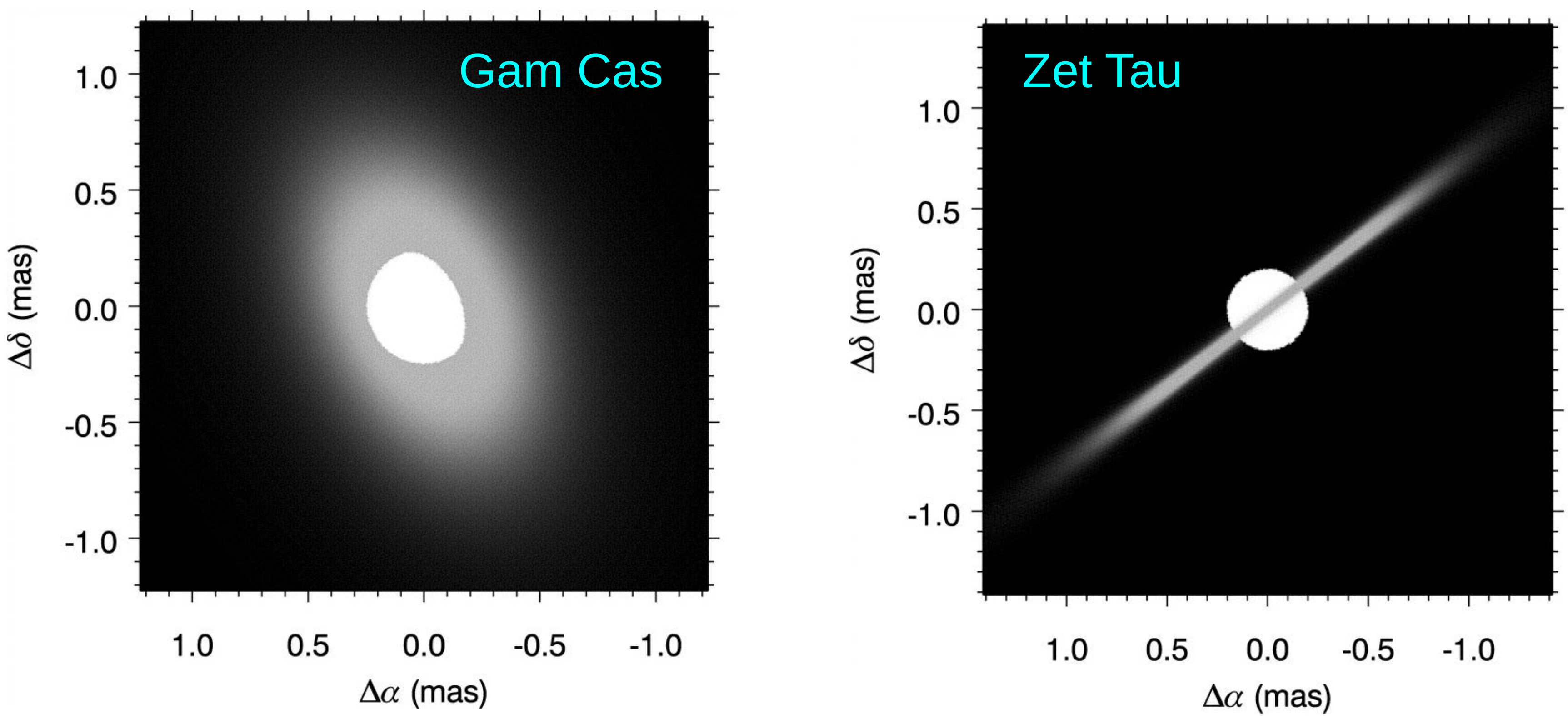


Image Credit: Bill Pounds

Interferometric Observations of Be Star Disks

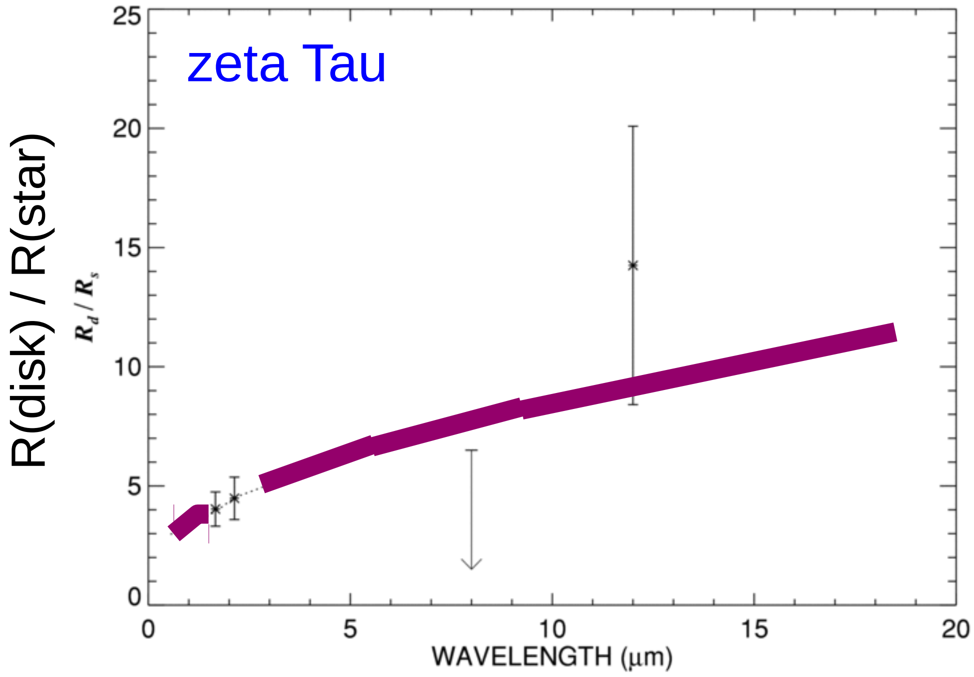
- Geometry and size

Gies et al. 2007



Interferometric Observations of Be Star Disks

- Geometry and size
- Multi-wavelength structure



Isothermal decretion disk model:

- base density
- radial density exponent
- inclination
- PA

Touhami et al. 2011

- Gies et al. 2007,
- Meiland et al. 2009,
- Schaefer et al. 2010

- Probes the density structure of the disk

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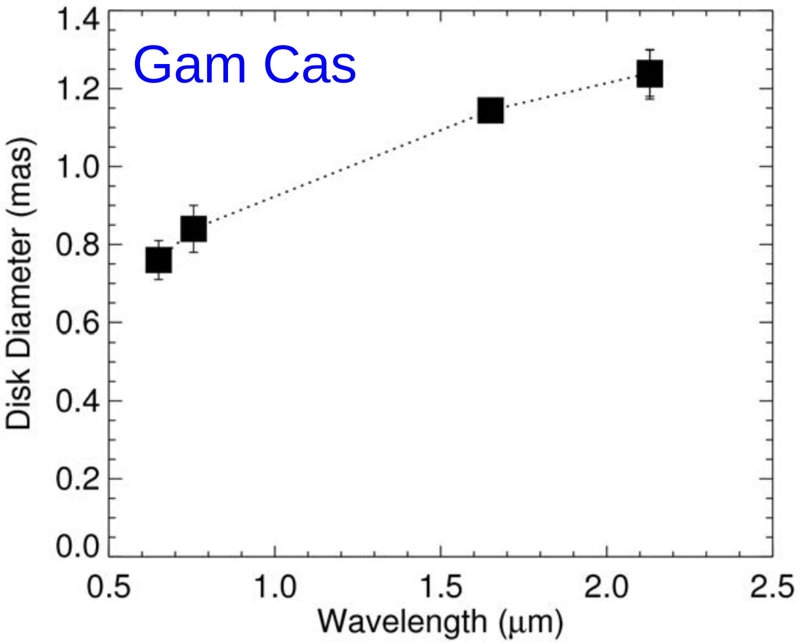

References:
Stee et al. 2012
Meilland et al. 2012
Touhami et al. 2013

+ additional CHARA data

Work in progress...

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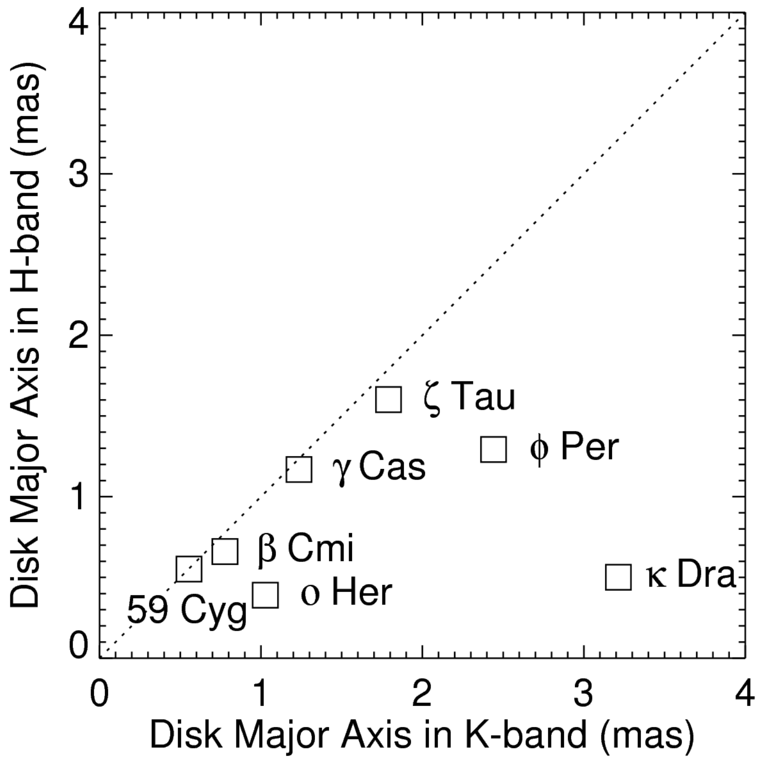

- K-band diameters from CLASSIC (Touhami et al. 2013)
- H-band diameters from MIRC

Full survey:
24 stars - K'
20 stars - H

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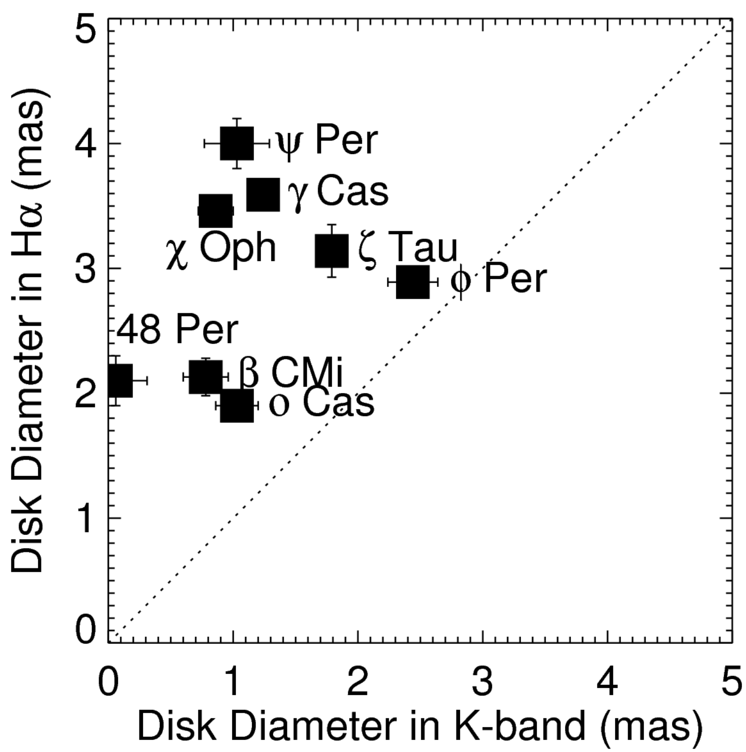


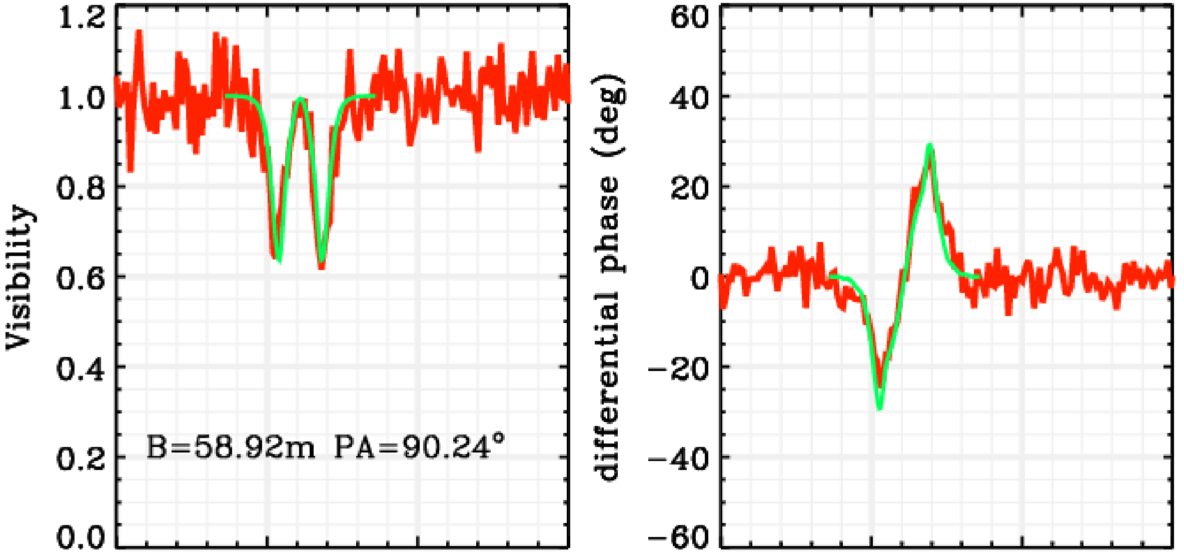
Hα sizes:
Tycner et al. (04, 05, 06,08),
Delaa et al. (2011)

K' sizes:
Touhami et al. 2013

- Hα diameters are larger than K' continuum sizes
- Differences result from larger Hα opacity and hydrogren ionization structure of the disk (Gies et al. 2007)

Interferometric Observations of Be Star Disks

- Geometry and size
- Multi-wavelength structure
- Kinematics



Meilland et al. 2012

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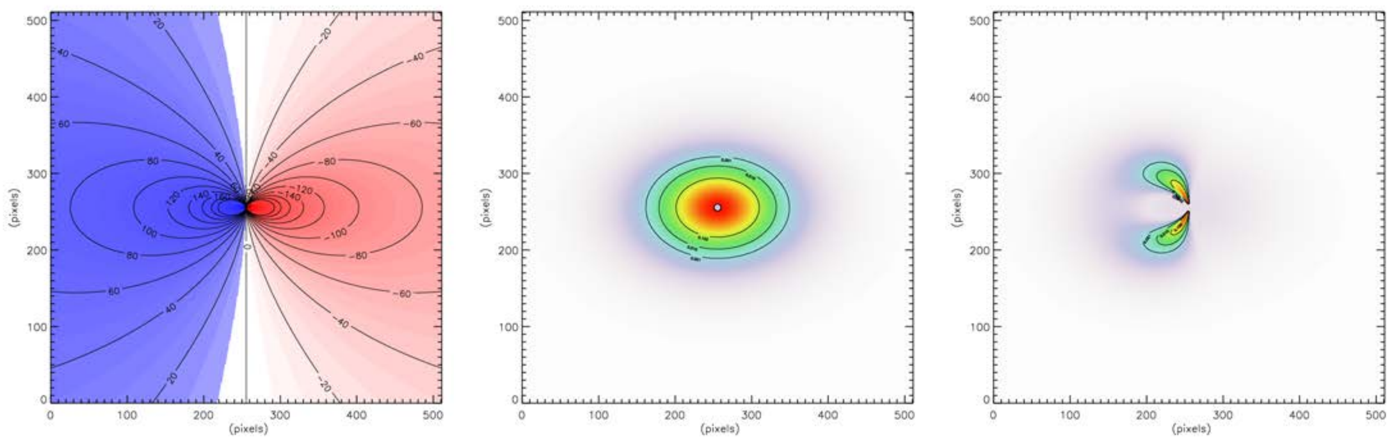
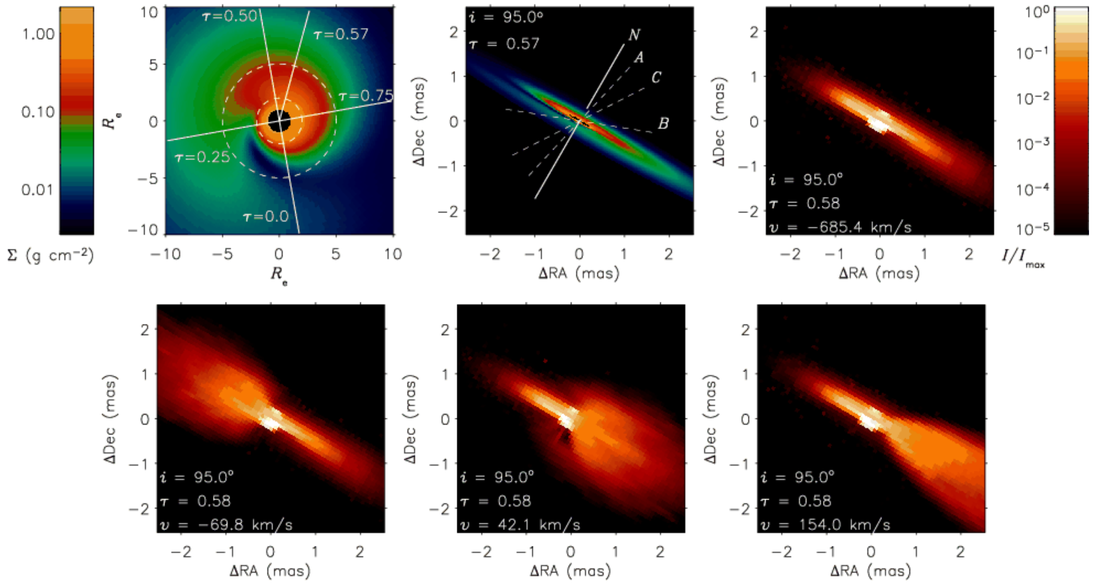


Velocity Map — Integrated Intensity Distribution — Emission in narrow λ-channel

Interferometric Observations of Be Star Disks

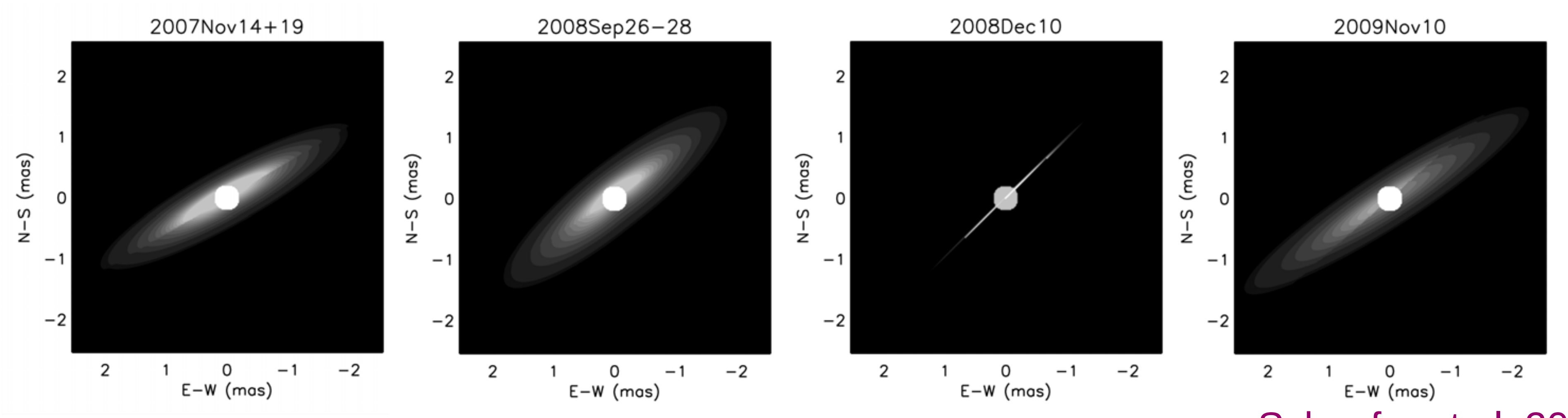
- Geometry and size
- Multi-wavelength structure
- Kinematics
- Asymmetric structures



Carciofi et al. 2009

Interferometric Observations of Be Star Disks

- Geometry and size
- Multi-wavelength structure
- Kinematics
- Asymmetric structures
- Long-term campaign to monitor changes in the disks



Schaefer et al. 2010

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- Origin of rapid spin of Be stars is unknown
  - Spin up as core H-burning ends due to redistribution of internal angular momentum (Ekstrom et al. 2008; Granada et al. 2013; Granada & Haemmerle 2014)
  - Mass and angular momentum transfer in a binary. Companion would lose most of its envelope and appear as stripped down stellar remnant: neutron star, white dwarf, or Helium-star (Pols et al. 1991; de Mink et al. 2013)

Role of Binarity in Be Stars

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- 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)

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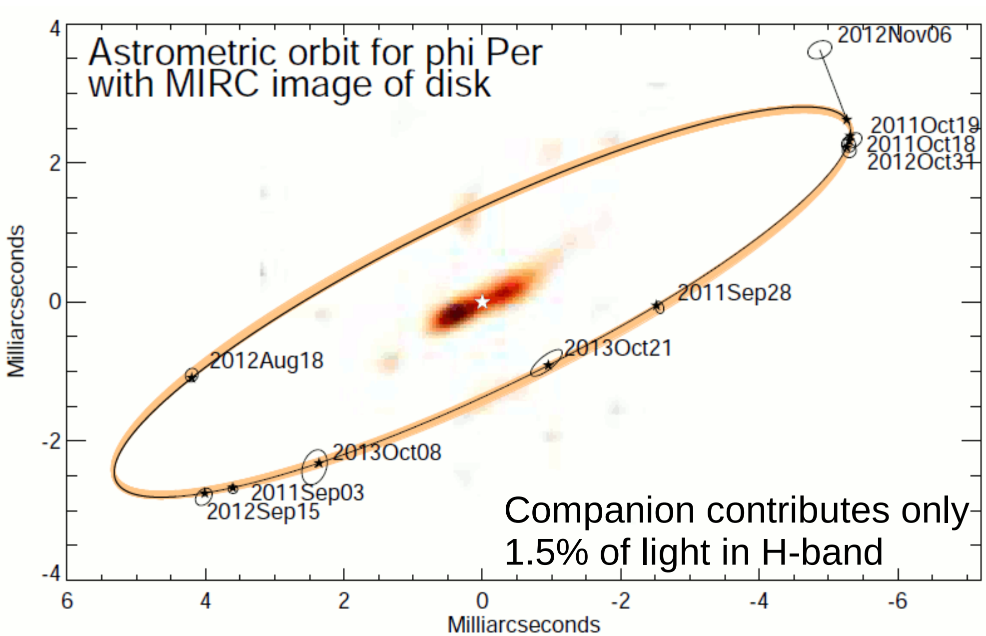
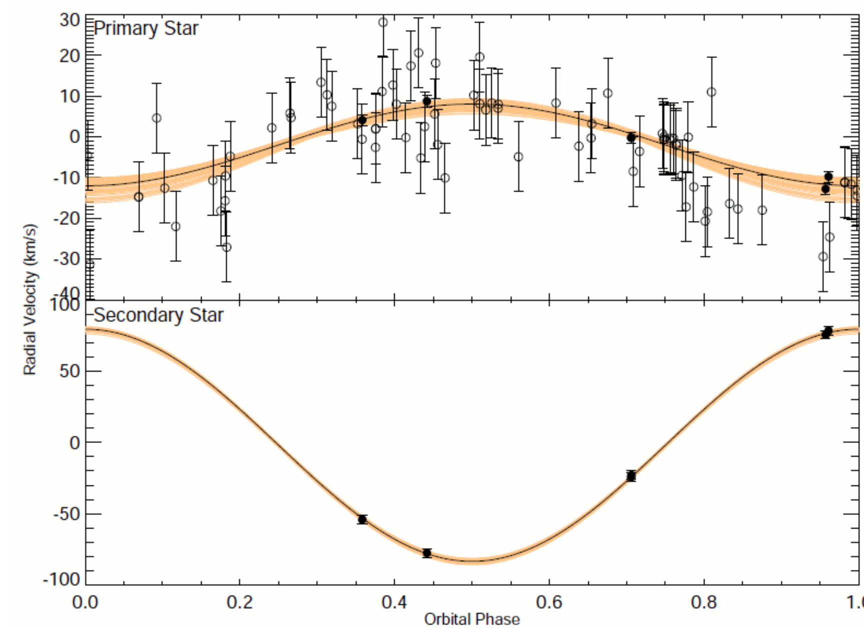
  - FY CMa (Peters et al. 2008)
  - 59 Cyg (Peters et al. 2013)
- Companions difficult to resolve spatially because of high contrast and close separations (P: 28-127 days)
  - Precision closure phases with MIRC

Spatially Resolved Orbit for Phi Per

Visual Orbit



SB2 Radial Velocities



Orbital Parameters:

P = 126.7 days

e = 0

a = 5.89 ± 0.02 mas

i = 77.6° ± 0.3°

Masses and distance:

$M_a = 9.6 \pm 0.3\ M_\odot$

$M_b = 1.2 \pm 0.2\ M_\odot$

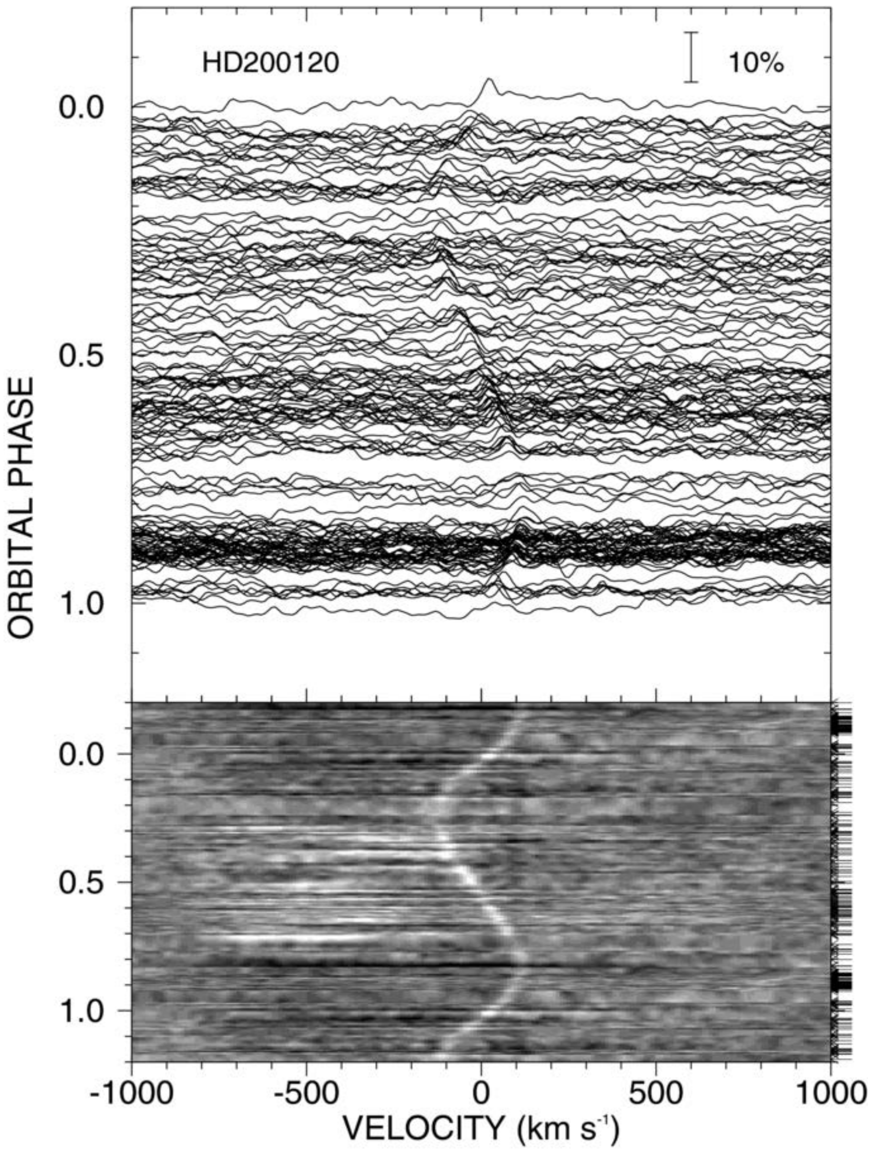
d = 186 ± 3 pc

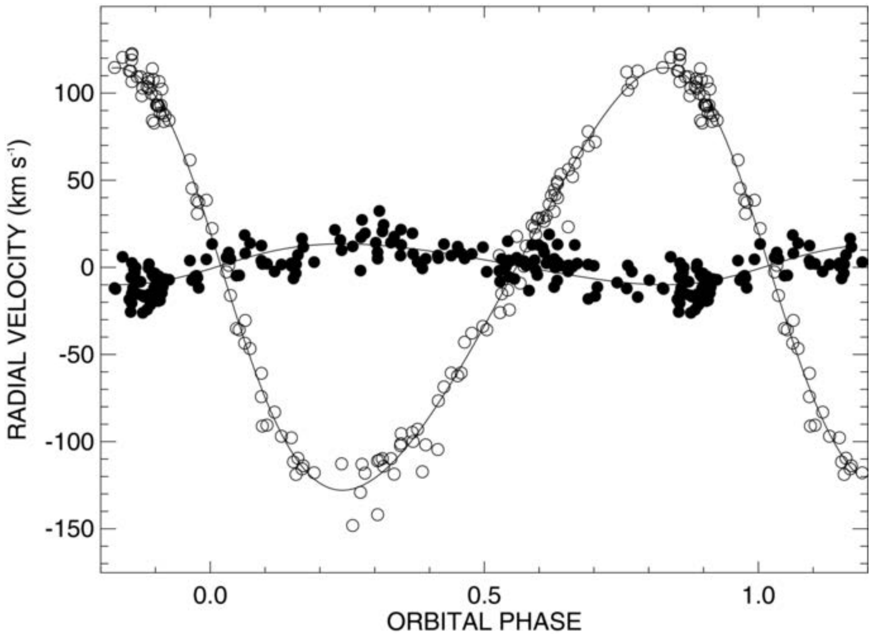
Mourard et al. 2015

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 Ab ~ 208 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
  - Companion contributes 4% of UV Flux

Hot Subdwarf Companion in Be Star 59 Cyg





SB2 Orbit:

$P = 28.187 \pm 0.001$ days

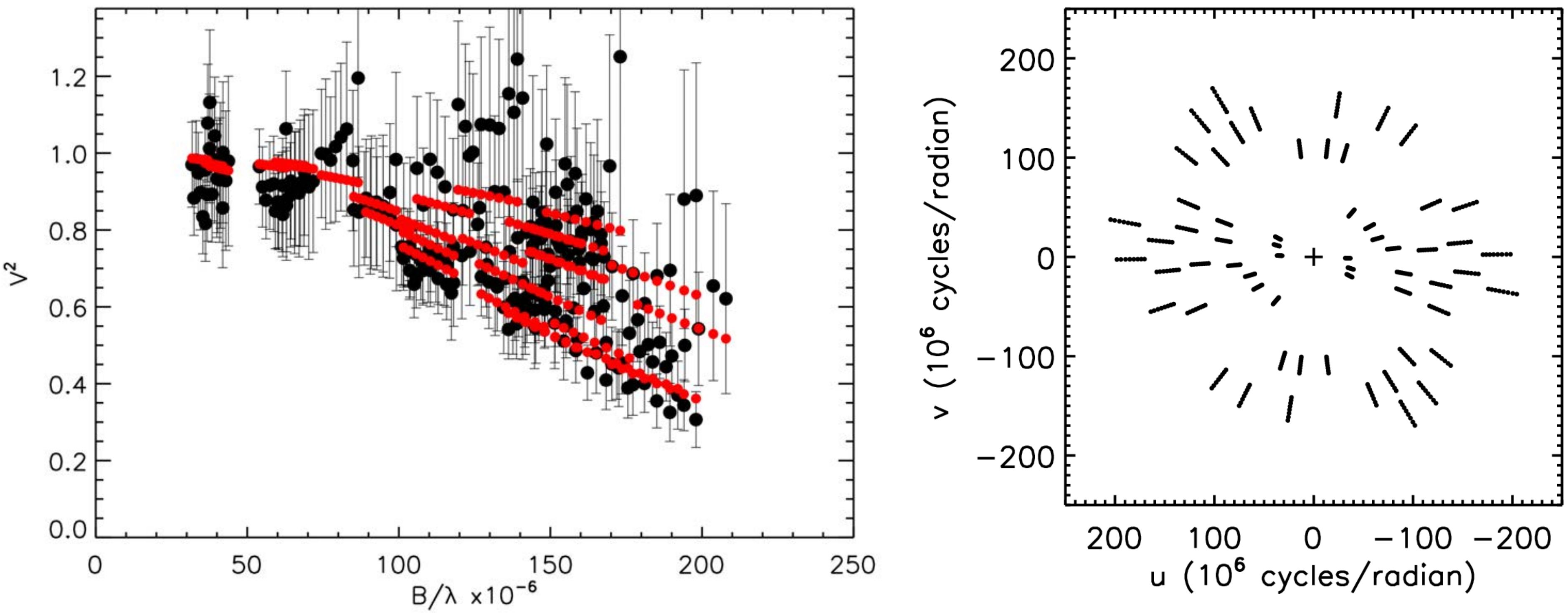
$e = 0.141 \pm 0.008$

$M_1 \sin^3 i = 6.08 \pm 0.14\ M_\odot$

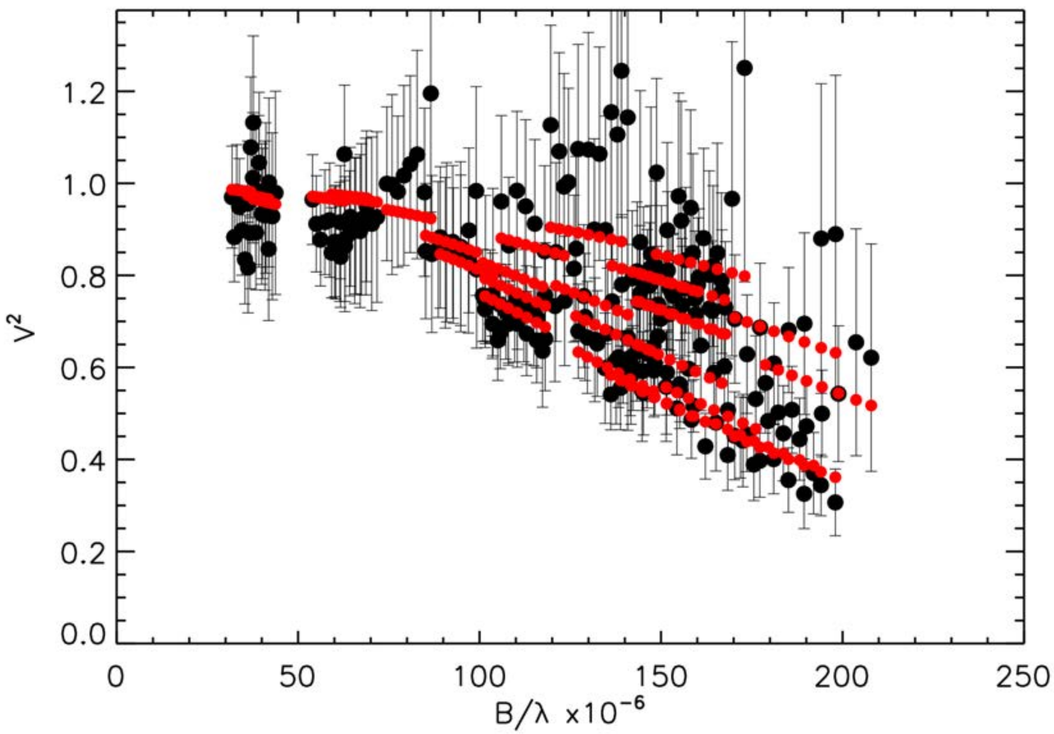
$M_2 \sin^3 i = 0.59 \pm 0.05\ M_\odot$

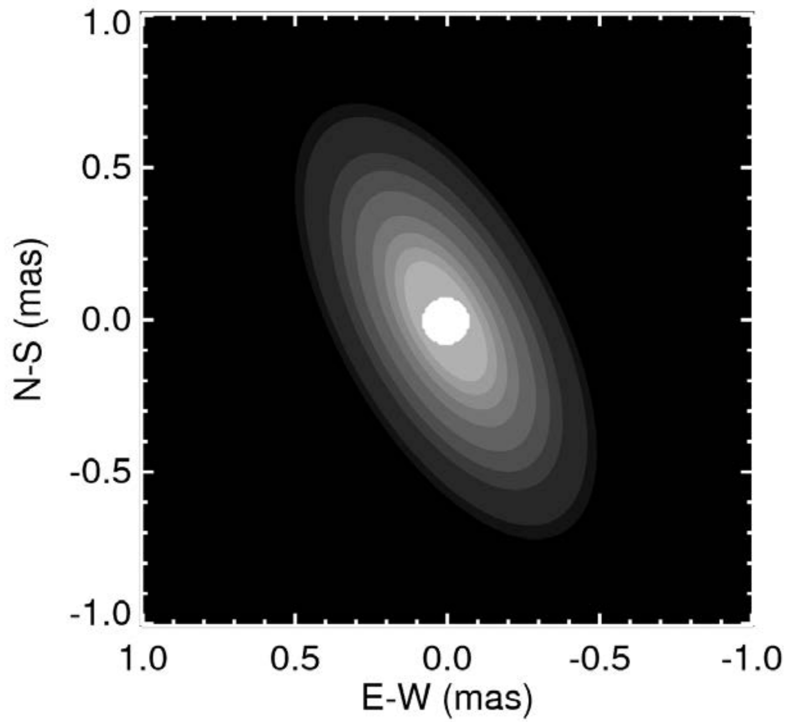
Peters et al. 2013

MIRC Observations of 59 Cyg: UT 2014 Aug 8



MIRC Observations of 59 Cyg: Geometric Disk Model





Fit Geometric Model:
- UD star + Elliptical Gaussian Disk

Assume UD = 0.149 mas
(Touhami et al. 2013)

FWHM major = 0.552 mas
FWHM minor = 0.249 mas
fstar = 38%
fdisk = 62%

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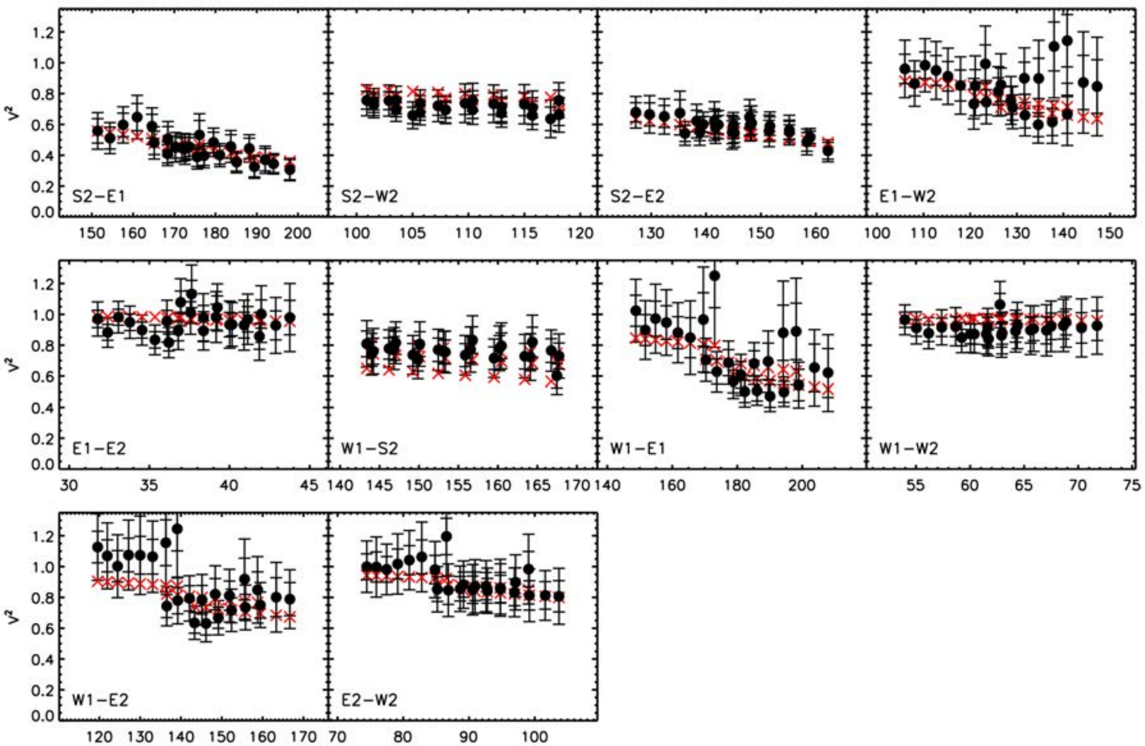

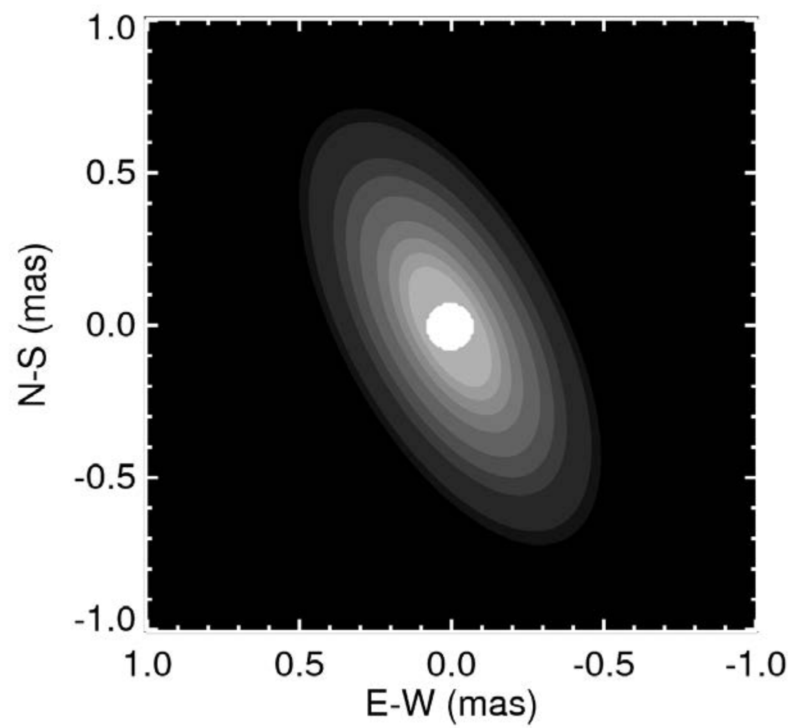

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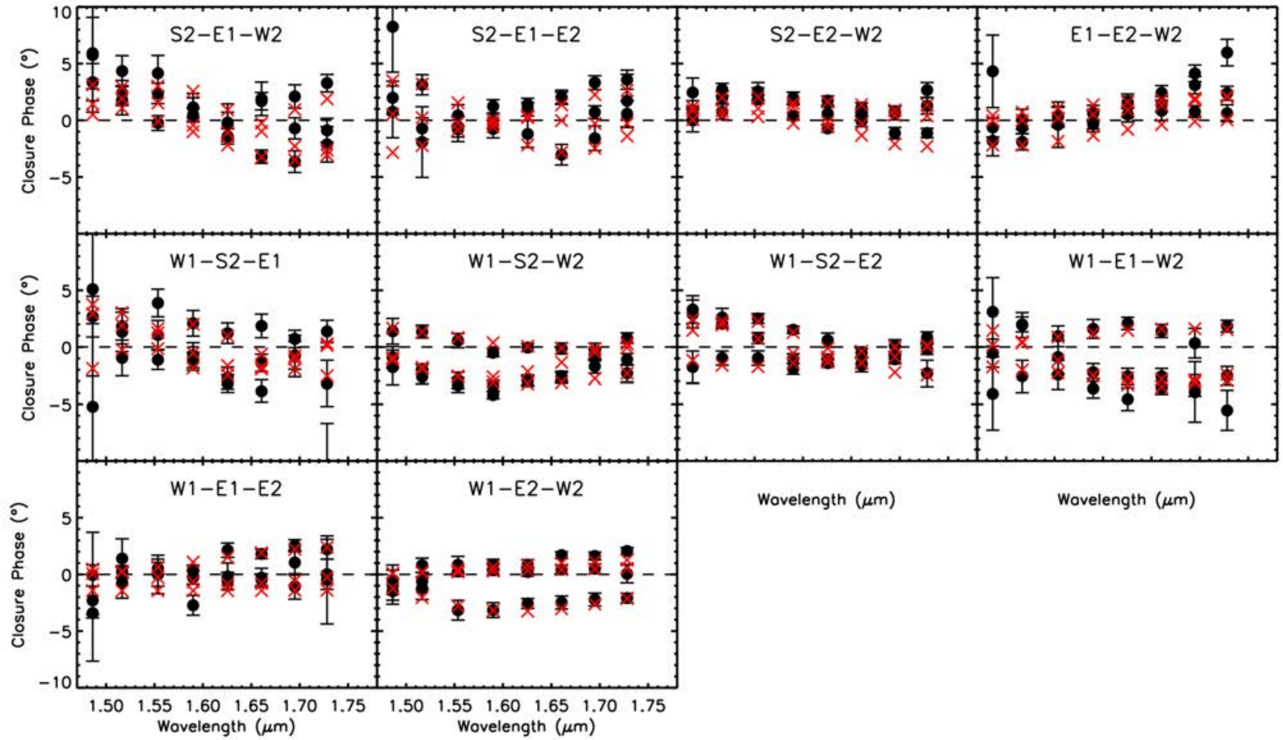
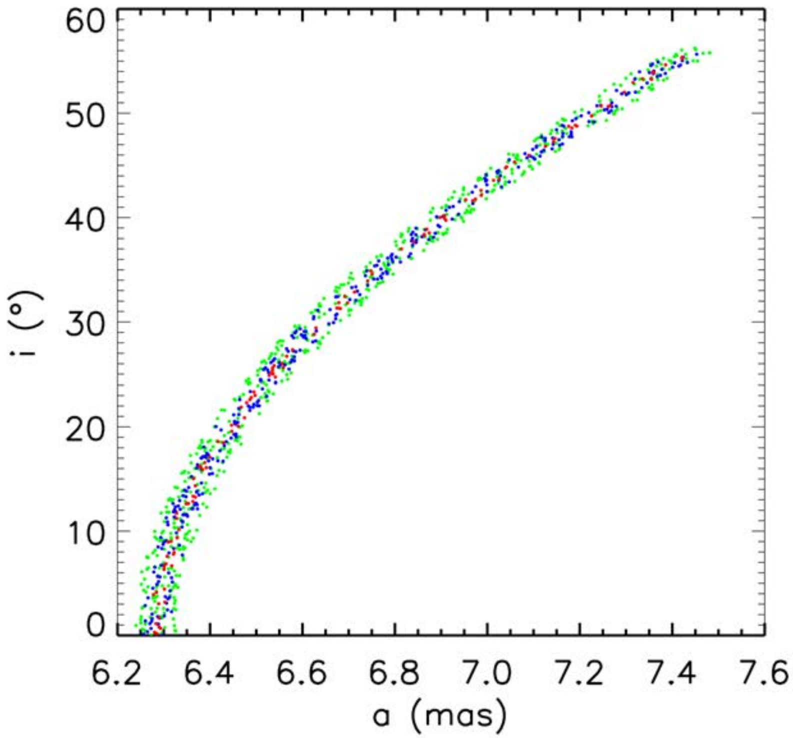
Closure Phases for 59 Cyg

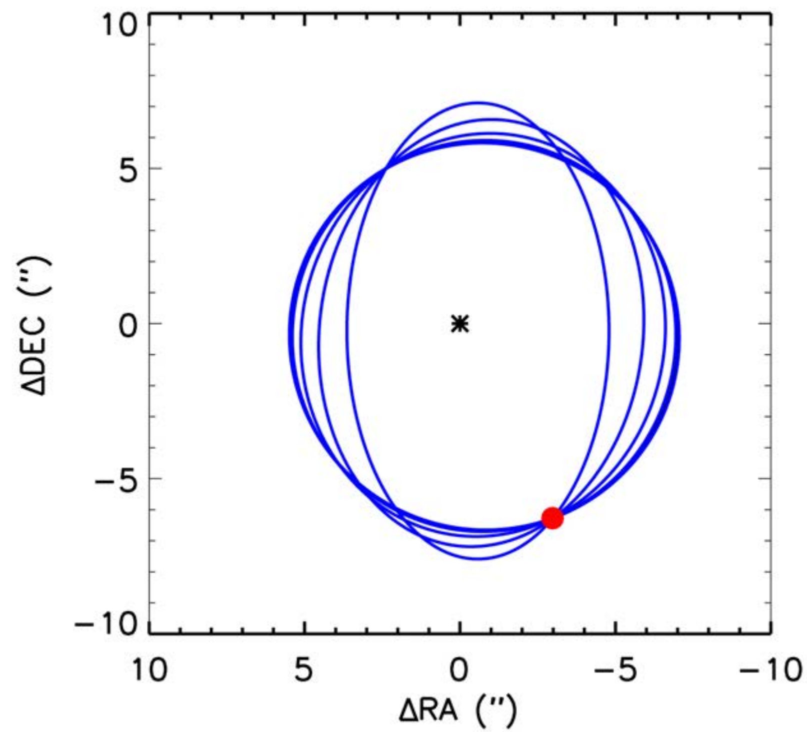


+ Small Periodic Variation
+ Fix geometric model of UD star + Elliptical Gaussian Disk
+ Solve for binary companion parameters:

Sep = 6.94 ± 0.02 mas, PA = 205.39° ± 0.15°
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 $M_\odot$

Looking Ahead

- Awarded MIRC time in 2015A:
  - July 15, 20, 25, 29, Aug 2
- Goals:
  - Map orbit of 59 Cyg over complete orbit of 28 days
  - Monitor disks in a larger sample of bright Be stars

Maybe present a full orbit for 59 Cyg at this time next year?