Overview of MIRC Observations of Be Stars in 2015

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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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How do we make sense of the data?
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
Density enhancement that moves outward through the disk

Hanuschik et al. 1995

Fig. 16. Diagonal part of the density field, \( \rho \) (ex. taken from Hanuschik 1995), and observed Fe II A5517 profiles of 6 Com, plotted at approximate angles \( \omega = 0^\circ, 90^\circ, 180^\circ, 360^\circ \) corresponding to the central orientation of the observer and the processing nodal line of \( \phi \). Particles in the disk rotate counter-clockwise. Dark areas denote \( \phi < 0 \); bright areas \( \phi > 0 \).
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)
Goals of MIRC Be Star Program

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- Compare disk dimensions in H-band with size measured at other wavelengths to estimate gas densities in the disks
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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 2015 Nov 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 - 2014 Aug 08

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
+ Fix P, T, e, ω from SB2 orbital parameters
+ Perform 3-dimensional $\chi^2$ search to explore ranges for a, i, $\Omega$
+ Maximum i yields:

\[ M_1 = 10.6 \, M_\odot \quad \text{and} \quad M_2 = 1.03 \, M_\odot \]
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

2015Jul30

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

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

Need to include effect of wide companion on short baselines?

sep = 170 mas
ΔV = 2.8 mag
59 Cyg - Disk Size Measurements

![Graph showing FWHM Major Axis (mas) vs Observation Number]

- **2014Aug08**
- **2015Jul26**
- **2015Aug08**
- **2015Jul30**
- **2015Aug03**
- **2015 ALL**
- **2014-2015**

![Images showing observation data for different dates]

- **2015Jul26**
- **2015Jul30**
- **2015Aug03**
- **2015 - ALL**
59 Cyg - Correlations Between Size of Disk and Flux in Disk

2015 Jul 26
2015 Jul 30
2015 Aug 03
2015 - ALL

2014 Aug 08
2015 ALL
2014-2015
59 Cyg - Correlations Between Size of Disk and Flux in Disk
59 Cyg – Correlations Between Size of Disk and Flux in Disk
59 Cyg - Disk Position Angle

Position Angle (deg)

Observation Number

2015Jul26

2015Aug03

2015Jul30

2015 - ALL
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
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