Monitoring Changes in Be Star Disks Using MIRC

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Motivation for the Project

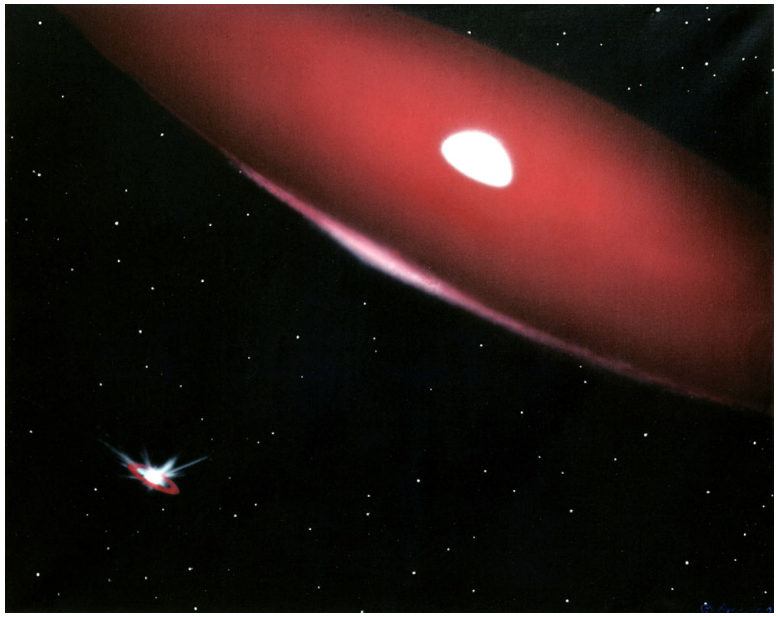
- MIRC program to measure asymmetries in the disks of Be stars
- Long-term monitoring to follow changes in the disks

Outline

- Four epochs of MIRC data on Zeta Tau
  - Results and Interpretation
- Promising targets for the future

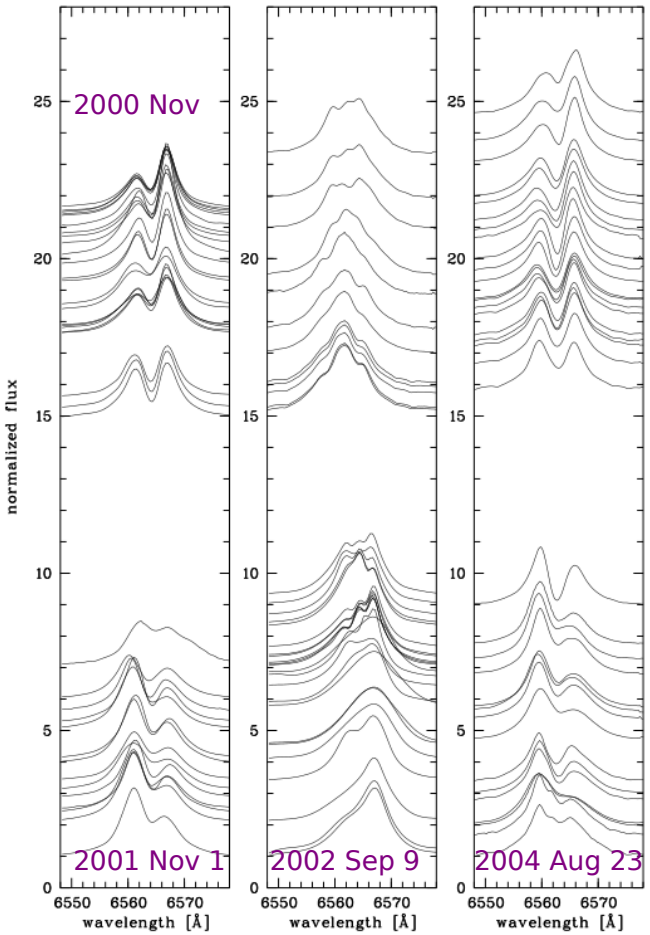
Be Star Properties

- Rapidly rotating B-type stars that eject gas into a circumstellar disk
- Evidence for disks observed in Hα emission lines, IR excess flux, linear polarization
  - e.g. Porter & Rivinius 2003
- Variable on timescales of days to decades



Bill Pounds

Hα Profile Variability



Pollmann & Rivinius 2008

One-armed Spiral Oscillations

Density enhancement that moves outward through the disk

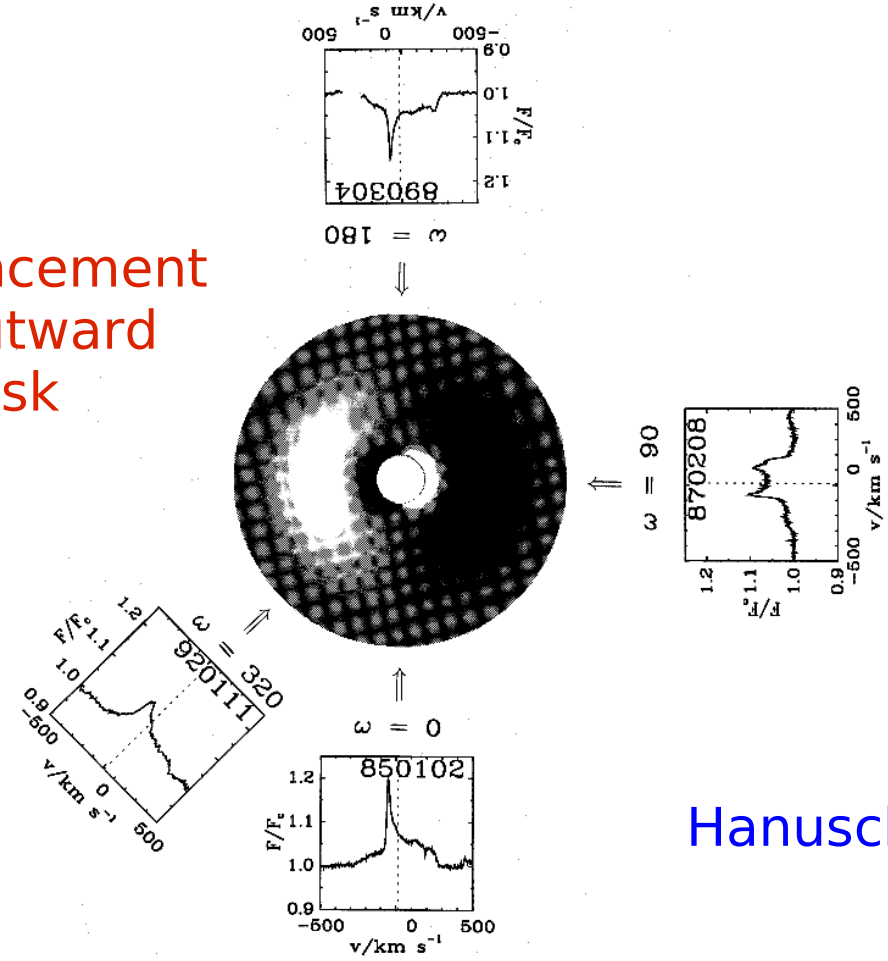
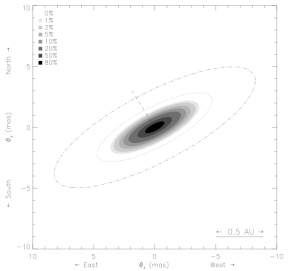


Fig. 16. Distorted part of the density field, σ_1 (as taken from Okazaki 1991), and observed Fe II λ5317 profiles of δ Cen, plotted at approximate angles $\omega = 0°, 90°, 180°, 320°$ corresponding to the mutual orientation of the observer and the precessing nodal line of σ_1. Particles in the disk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

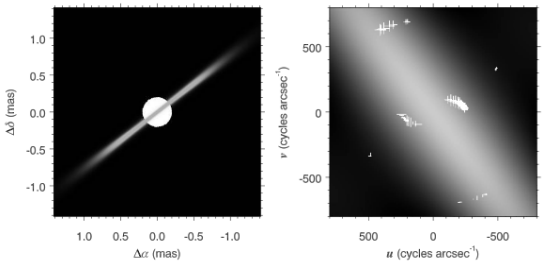
Hanuschik et al. 1995

Summary of Previous Interferometric Observations of Zeta Tau

- Elliptical shape of Zeta Tau disk
  - Circumstellar material in a flattened disk inclined nearly edge-on to the line of sight
    - Mark III – Quirrenbach et al. (1994, 1997)
    - COAST – Baldwin & Haniff (2002)
    - NPOI – Tycner et al. (2004)

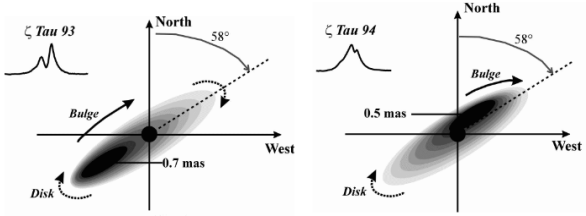


- Geometry and density structure of the disk
  - Isothermal disk model in Keplerian rotation
    - CHARA-Classic – Gies et al. 2007

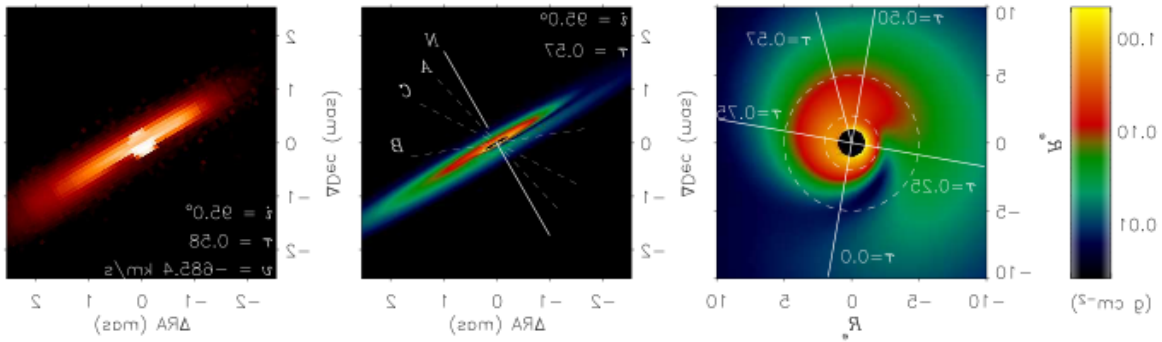


Summary of Previous Interferometric Observations of Zeta Tau

- Asymmetry detected – differential phases
  - Shift in position of bulge in disk
    - GI2T – Vakili et al. (1998)

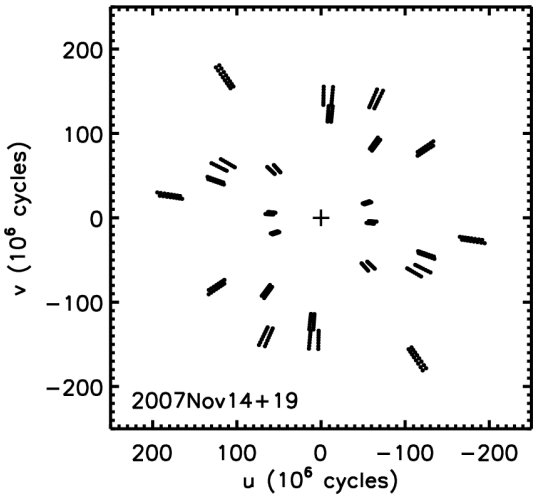


- Consistent with oscillation pattern created by one-armed spiral in disk
  - Visibilities and differential phases
    - VLTI AMBER – Stefl et al. 2009, Carciofi et al. 2009

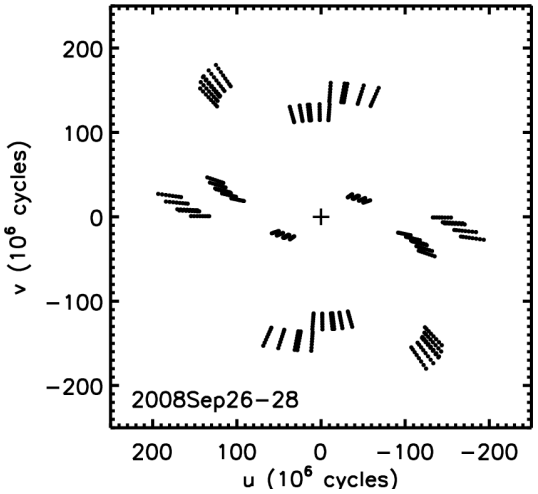


Four Epochs of MIRC Observations:

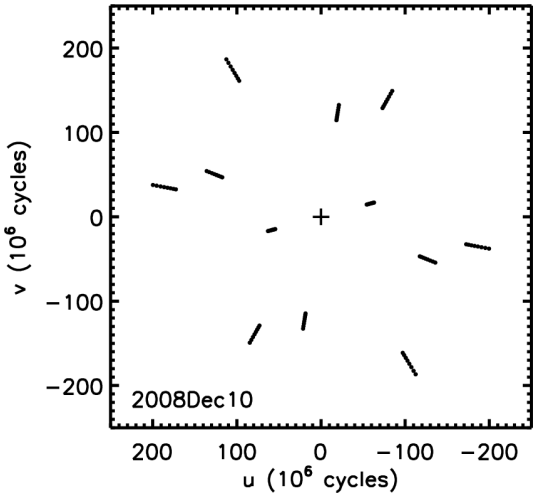
Zeta Tau



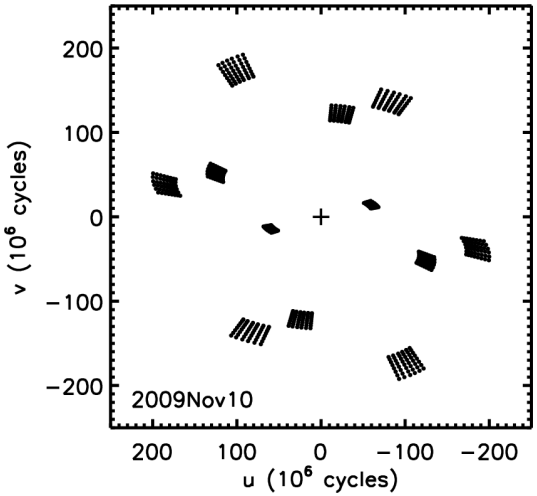
2007Nov
S2E2W1W2
S1E1W1W2



2008Sep
S1E1W1W2

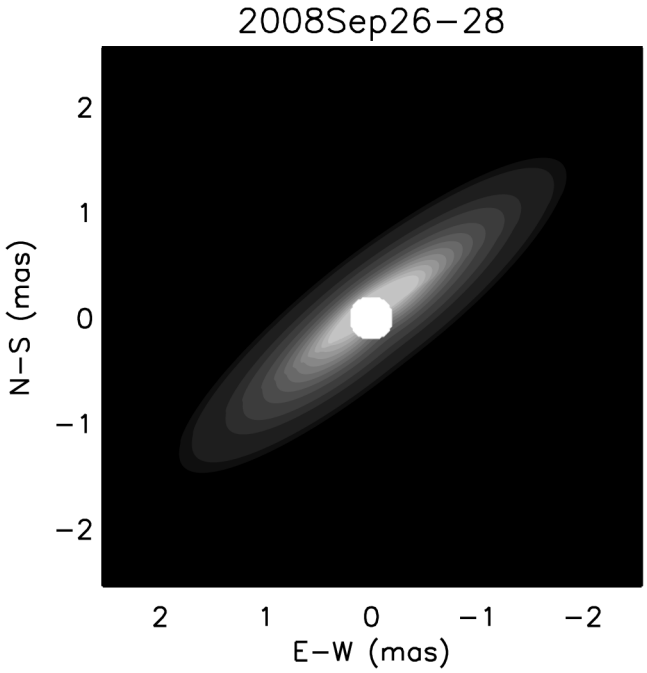


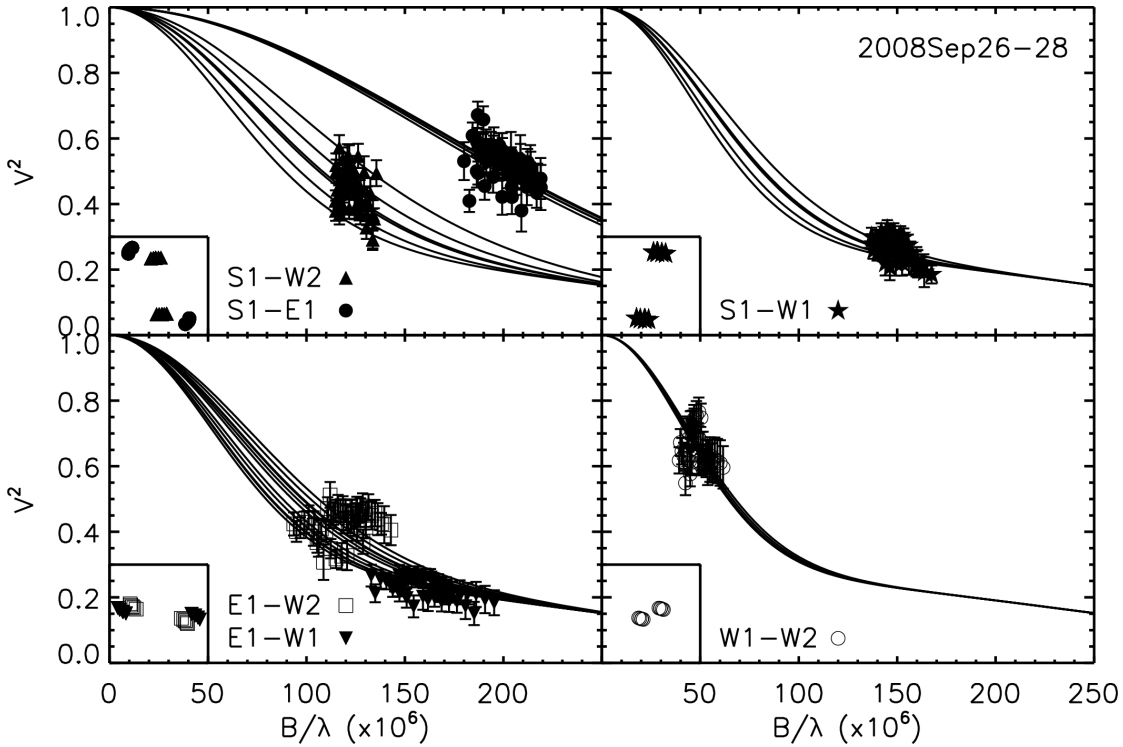
2008Dec
S1E1W1W2



2009Nov
S1E1W1W2

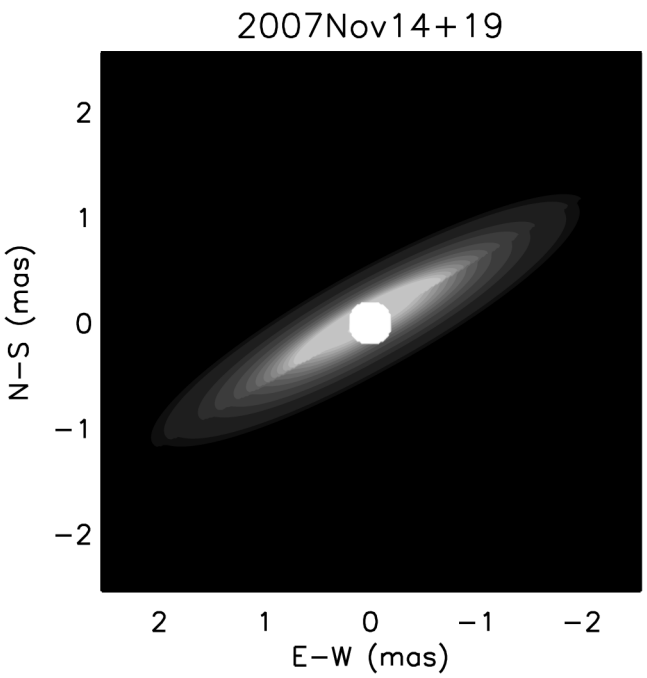
MIRC Visibilities

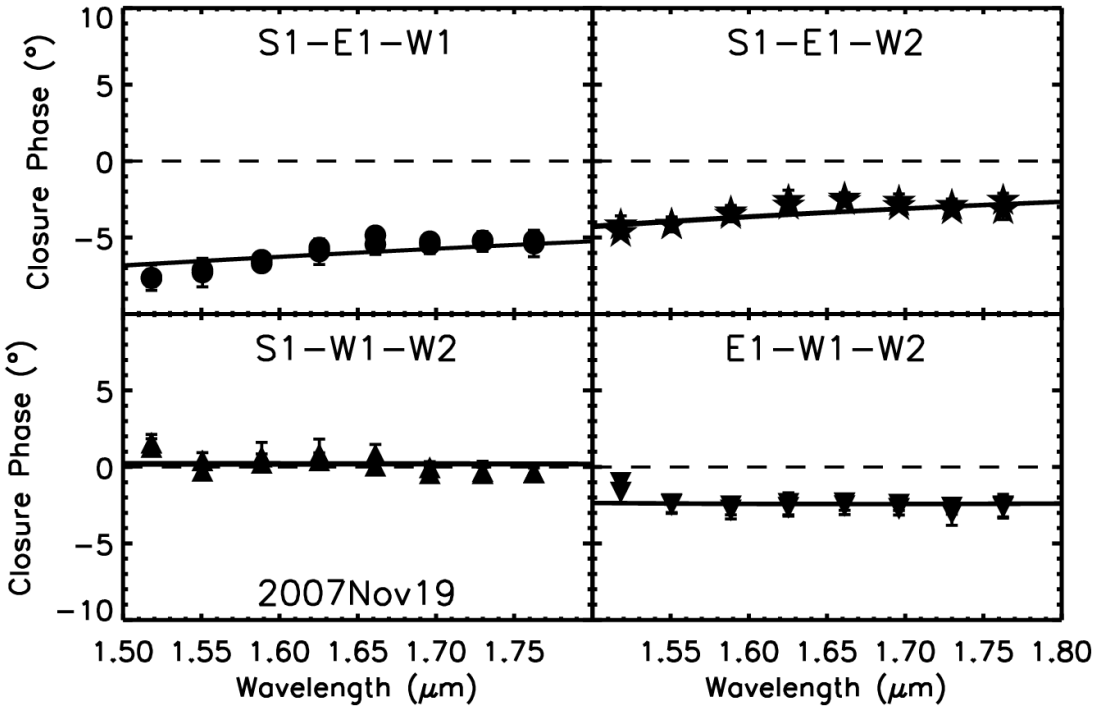




Elliptical shape and Orientation of Zeta Tau disk

Non-zero Closure Phases





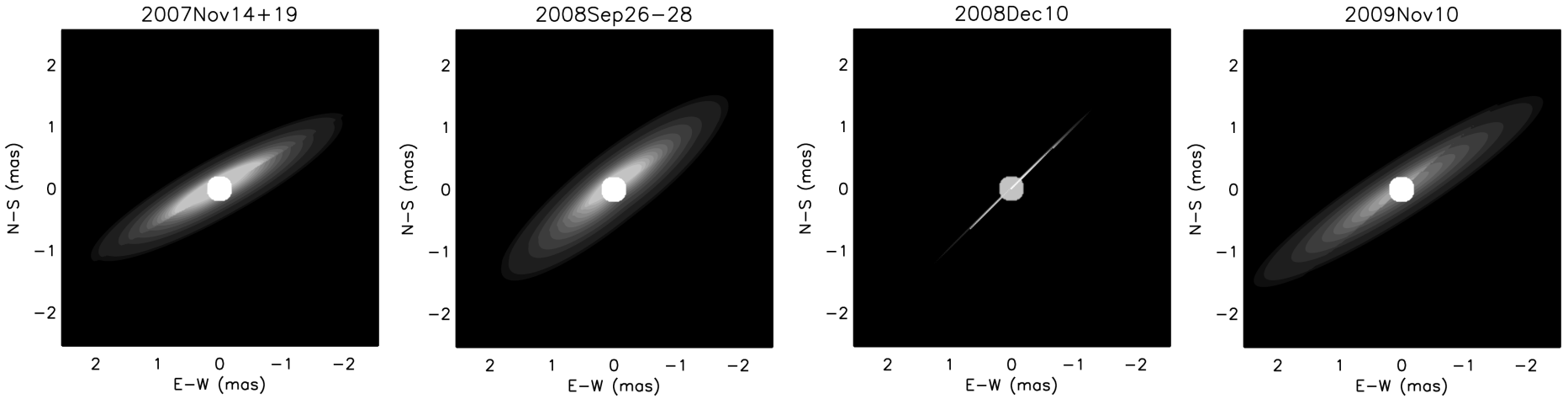
Asymmetry in the light distribution of Zeta Tau

Geometric Modeling of Zeta Tau

Skewed Elliptical Gaussian

- Central star with fixed uniform diameter of 0.40 mas
- Elliptical Gaussian circumstellar disk
  - modulated as a function of azimuth by a sinusoid
  - causes brightness distribution to peak on one side of disk and places a depression in the brightness on the other side

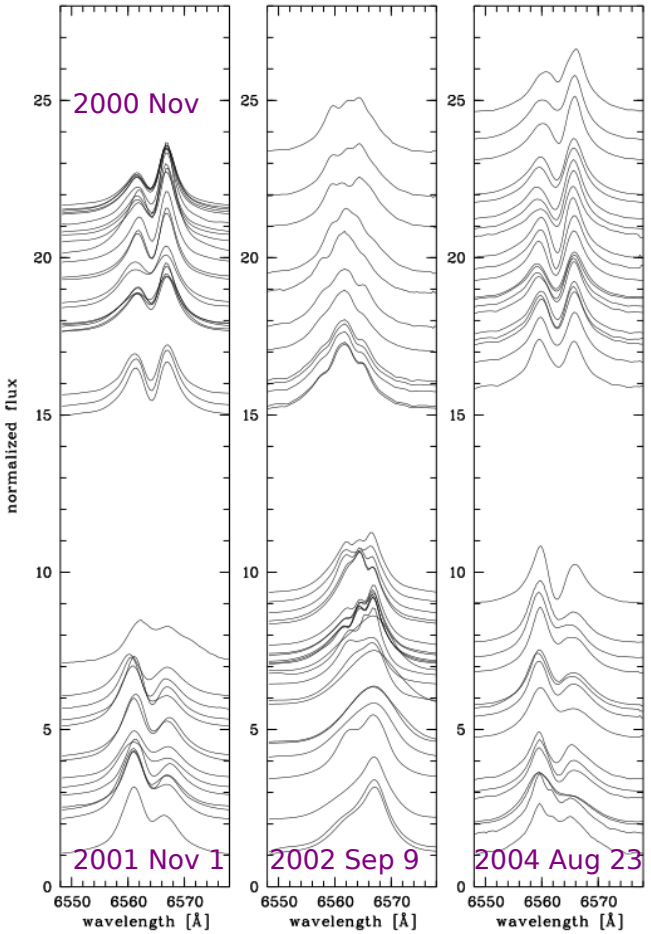
Geometric Models of Zeta Tau



- FWHM Major Axis ~ 1.8 mas
- On average, the central star contributes ~ 55% of the light in the H-band
- Change in position angle of the major axis??? 10-15°
- Motion of the asymmetry?

Hα Profile Variability

- V/R ratio:
  - Ratio between the relative heights of the blue (violet) and red-shifted emission line peaks

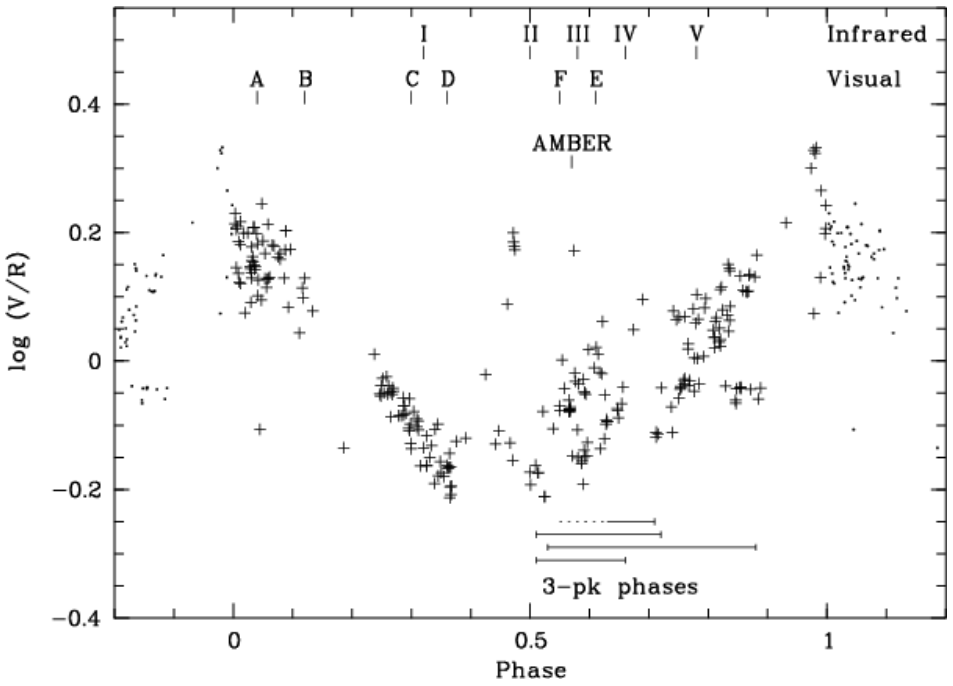


Pollmann & Rivinius 2008

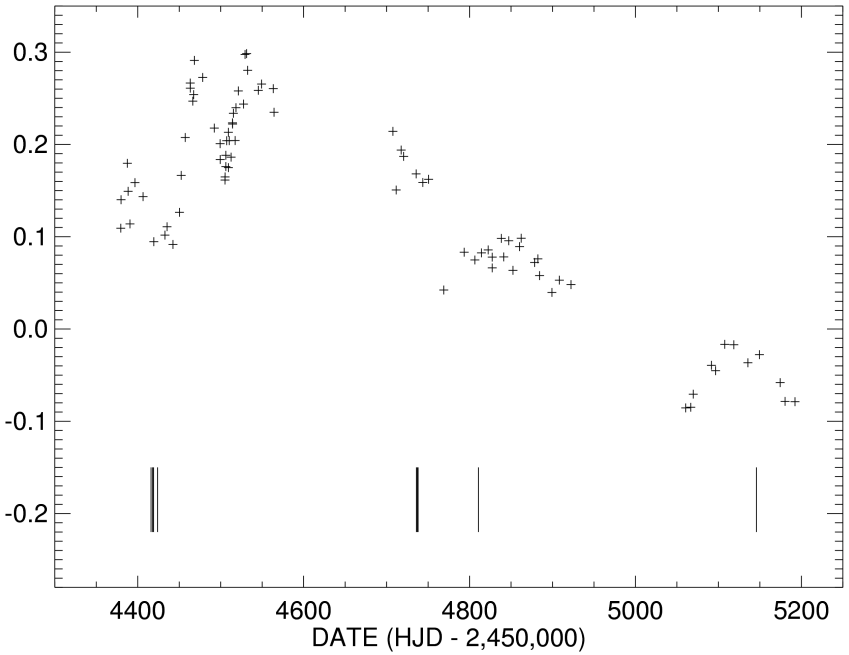
Hα Profile Variability

- V/R ratio varies with a cyclical period of 1429 days
- Can be explained by one-armed spiral oscillation models

Stefl et al. 2009



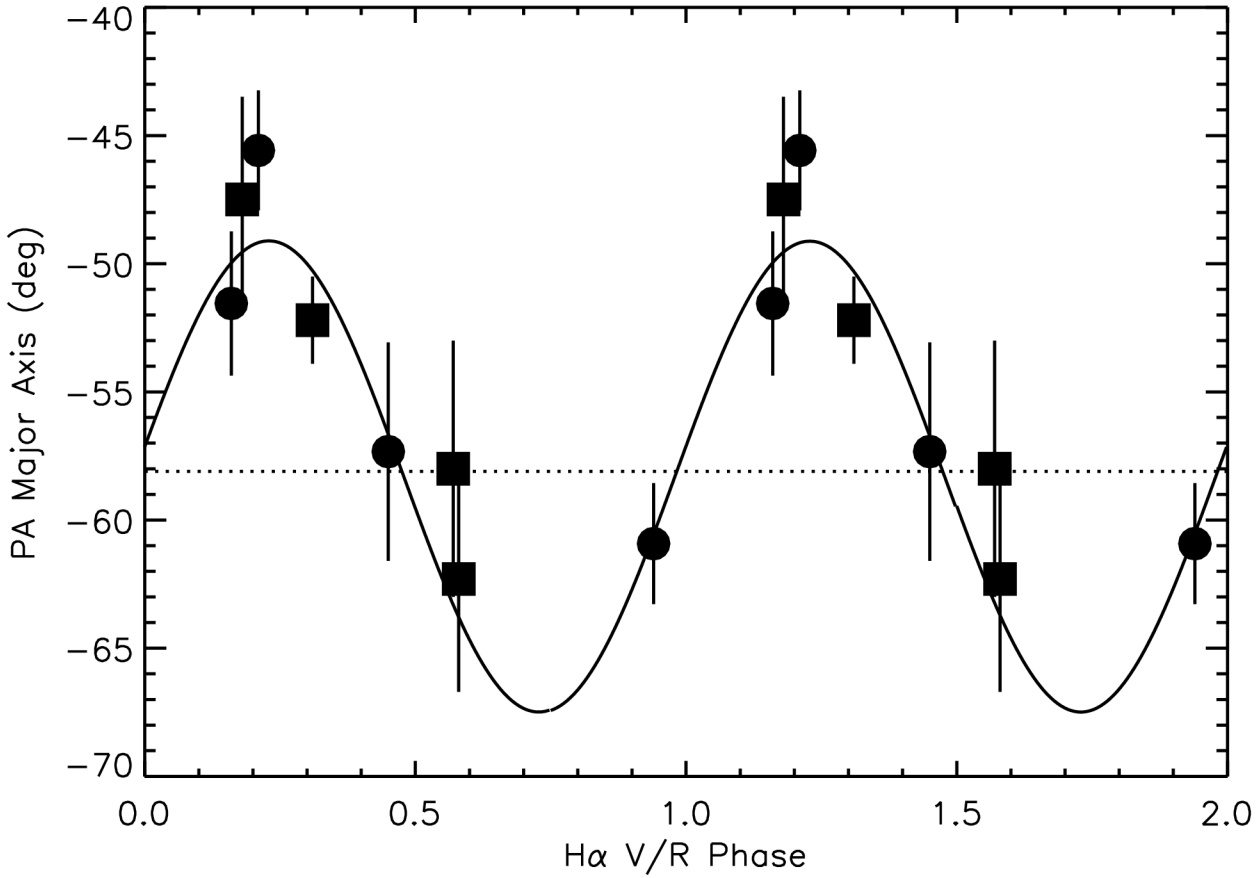
V/R Variation Continued Through Time Span of the MIRC Observations



Noel Richardson & Doug Gies

- Spectra downloaded by from Bess database maintained at GEPI Laboratory of the Observatorie de Paris-Meudon
- Two spectra from Univerisity of Toledo Ritter Observatory (courtesy of E. Hesselbach & K. Bjorkman)
- One Spectra from Kitt Peak National Observatory Coude Feed Telescope (courtesy of E. Grundstrom)

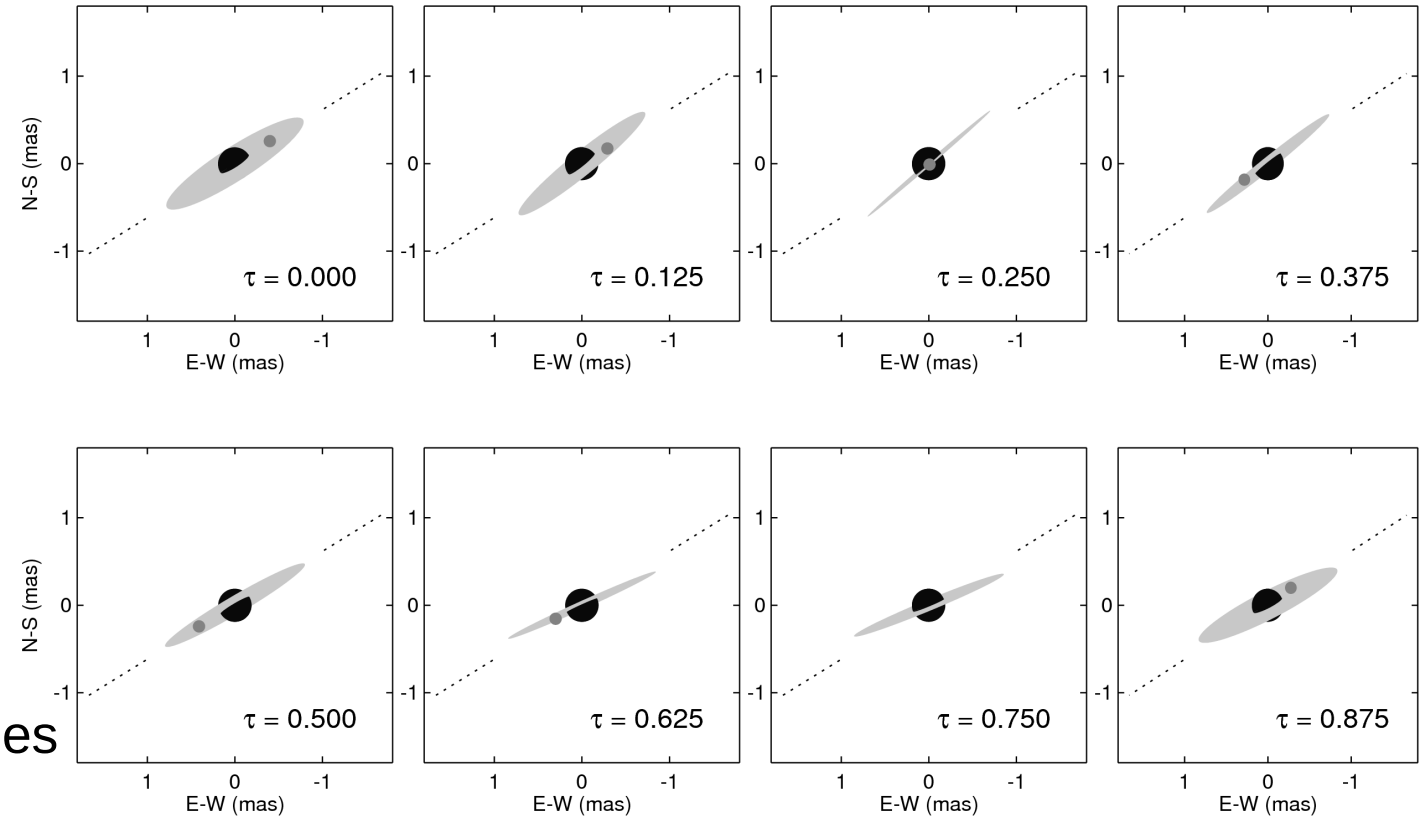
Disk Position Angle vs. Hα V/R Phase



Mean position angle: -58.3° ± 0.9°
Semi-amplitude: 9.2° ± 1.2°
Maximum occurs at τ = 0.23 ± 0.08

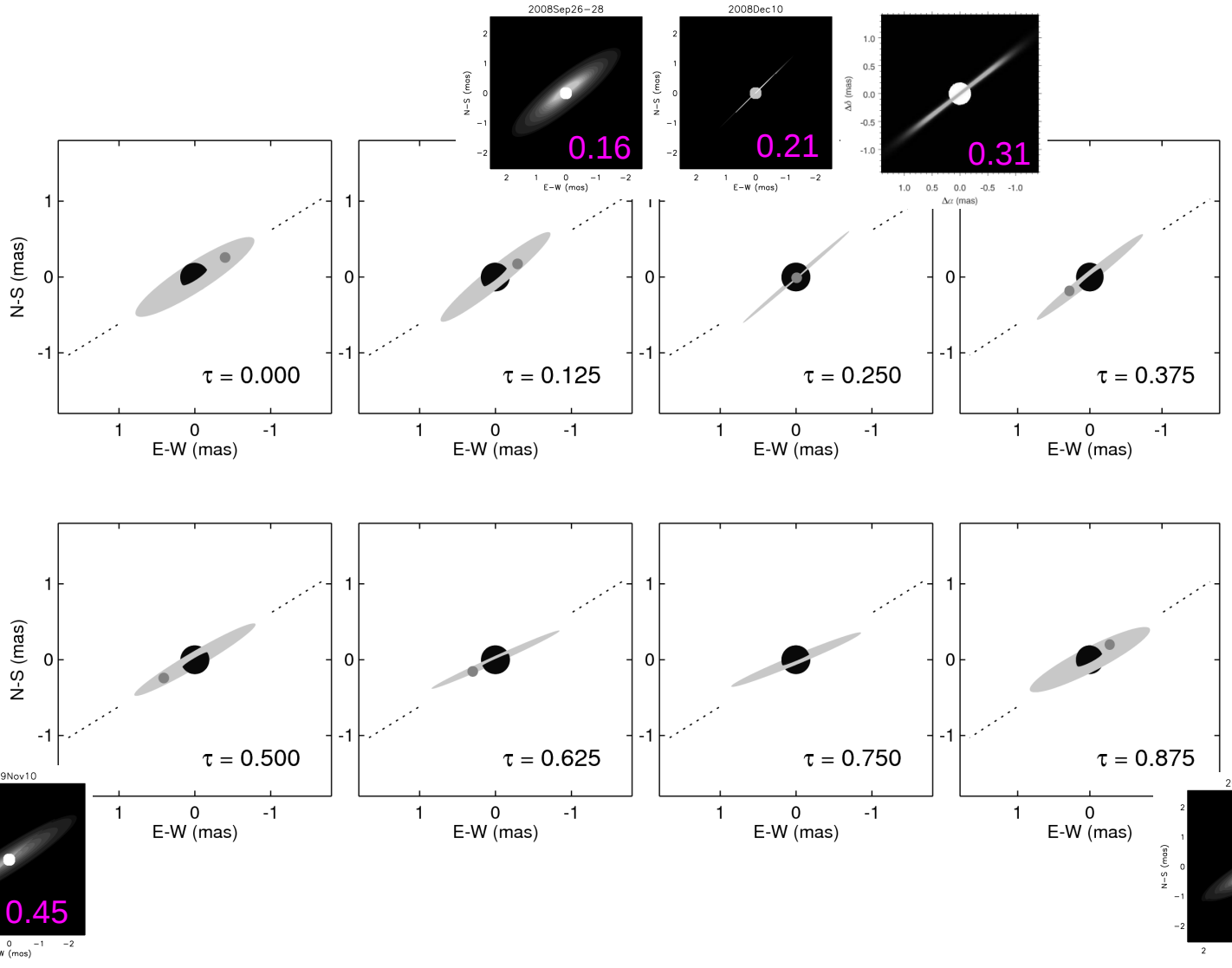
Mean position angle from linear polarization: -58.1° ± 1.2°
(McDavid 1999; Stefl et al. 2009)

Disk Precession?



Doug Gies

Tilt of disk associated with one-armed spiral density enhancement

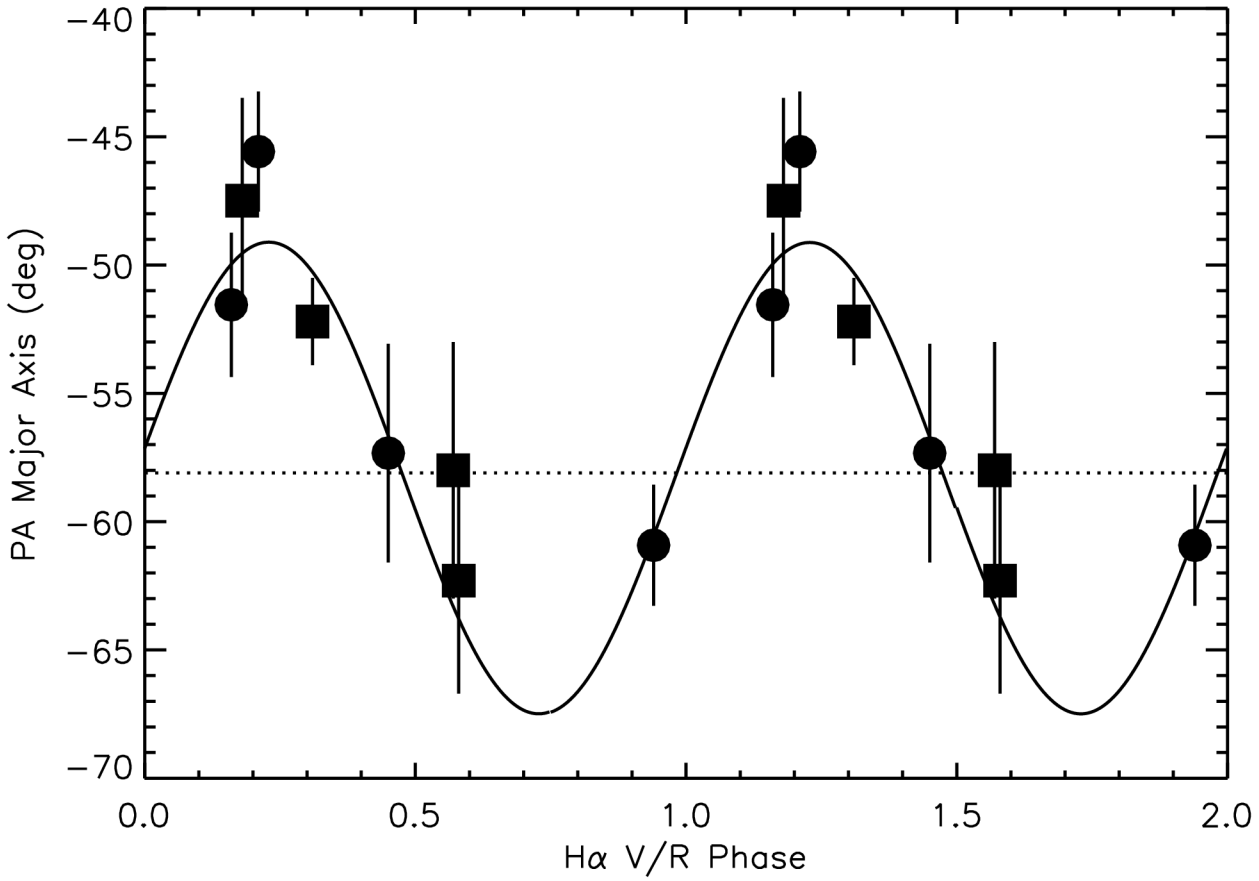

2008Sep26−28
0.16
2008Dec10
0.21
0.31
N-S (mas)
E-W (mas)
Δδ (mas)
Δα (mas)
τ = 0.000
τ = 0.125
τ = 0.250
τ = 0.375
τ = 0.500
τ = 0.625
τ = 0.750
τ = 0.875
2009Nov10
0.45
2007Nov14+19
0.94

Very Interesting....
but is it real???

Very Interesting.... but is it real???

- Systematic effects in calibration?
  - MIRC visibilities good to ~ 10% (prior to X-chan)
  - Calibration could affect different baselines in different ways affecting relative size of major and minor axis
  - Monte Carlo simulations suggest an uncertainty in the PA ~ 5°
  - Observations on multiple night runs are consistent with each other when fit separately (2008 Sept 26-28)
- Sampling of UV-coverage?

Disk Position Angle vs. Hα V/R Phase



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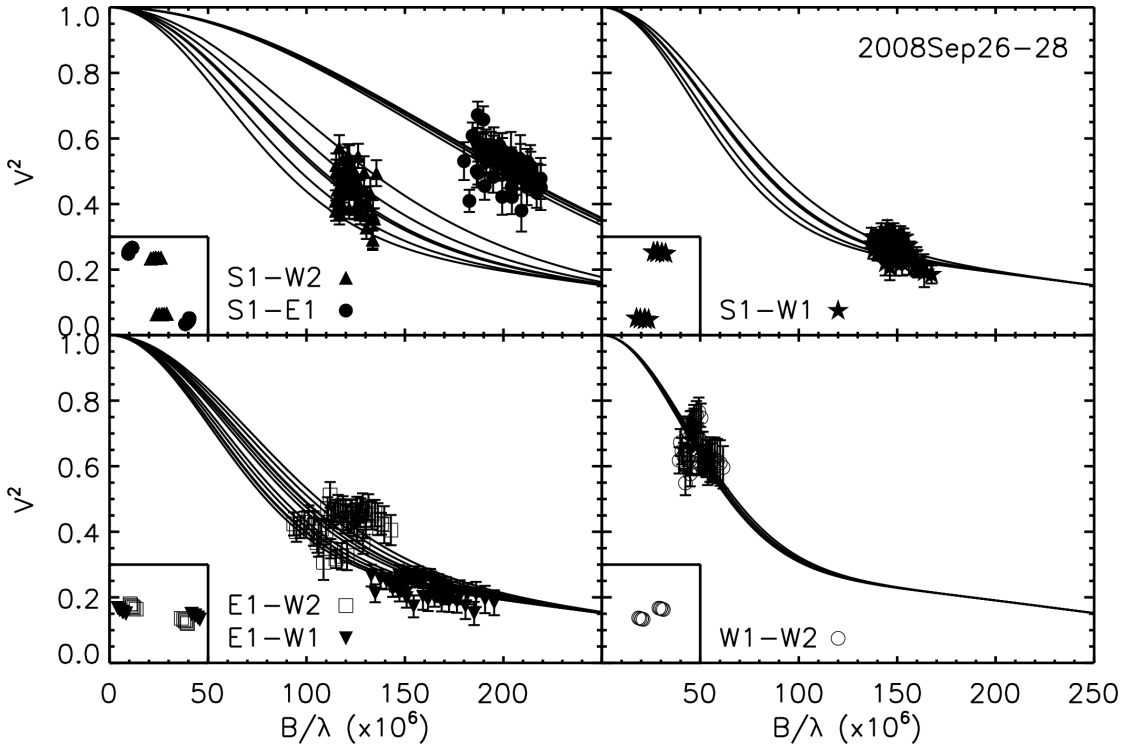
2008 Sept 26, 27, 28



Position angle consistent within 0.5 degrees between nights

Very Interesting.... but is it real???

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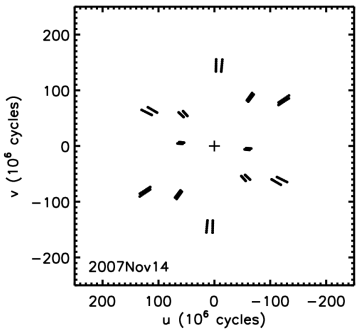
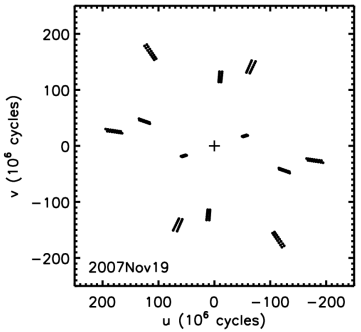
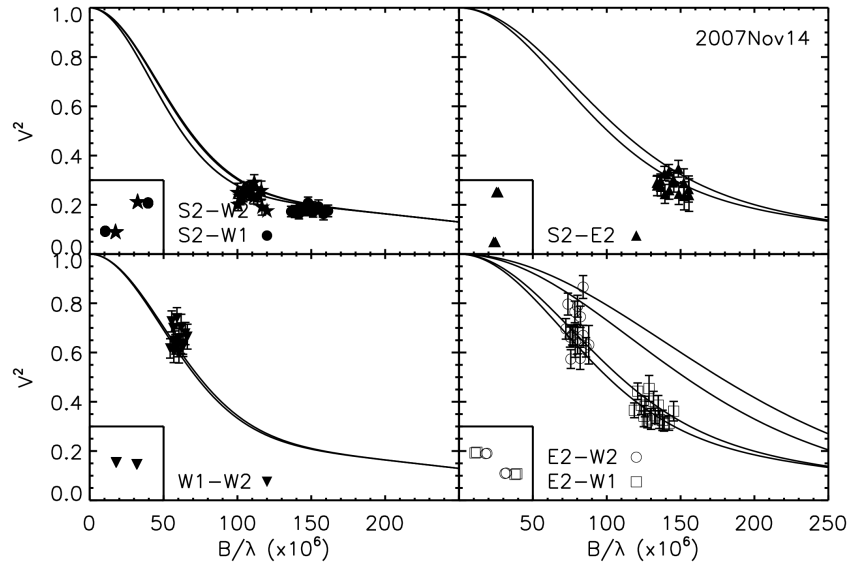
UV Sampling?

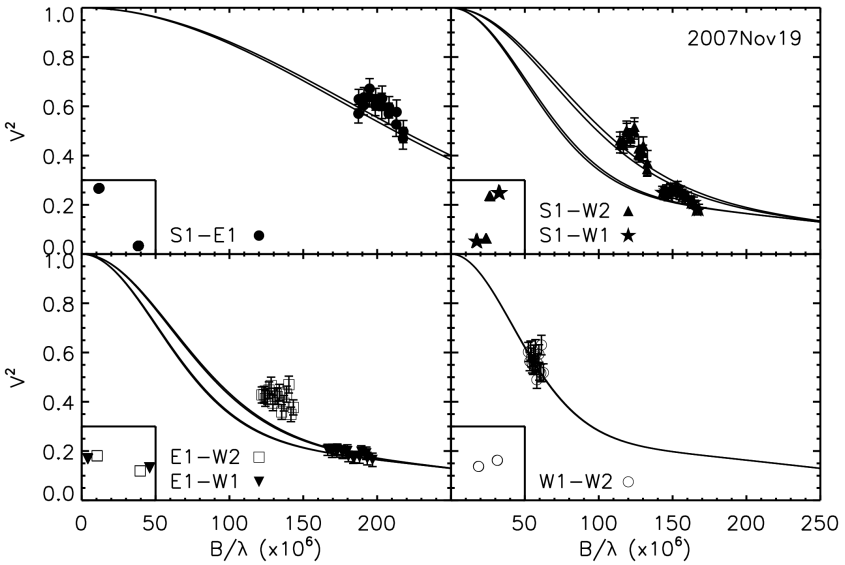




Inner Array - S2E2W1W2

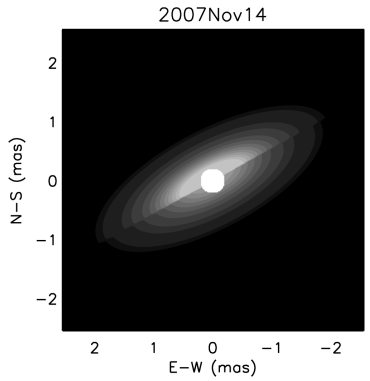


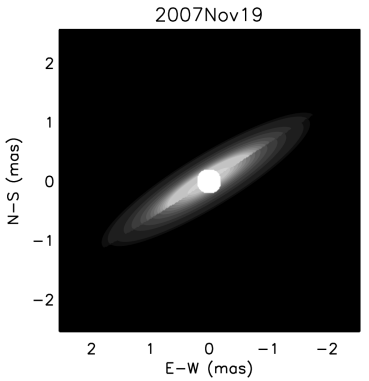
Outer Array - S1E1W1W2



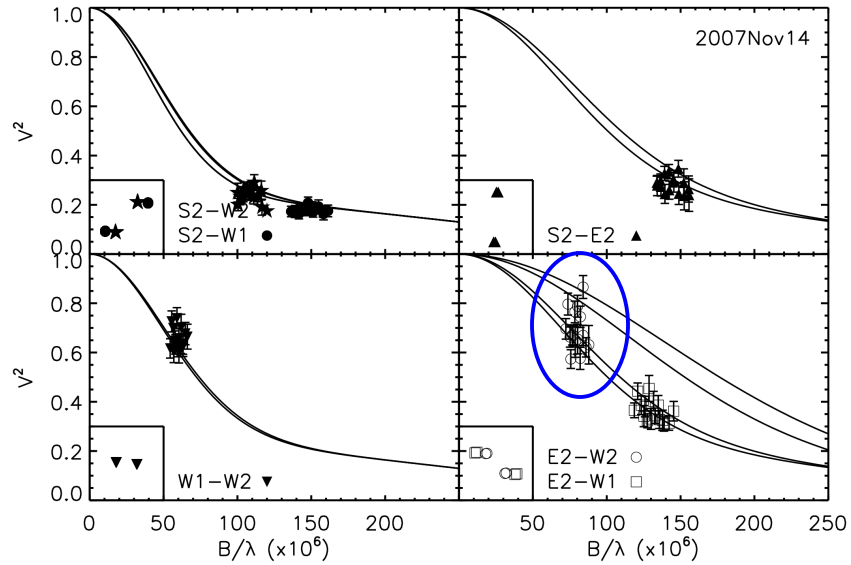
Position angle consistent within 3 degrees

UV Sampling?

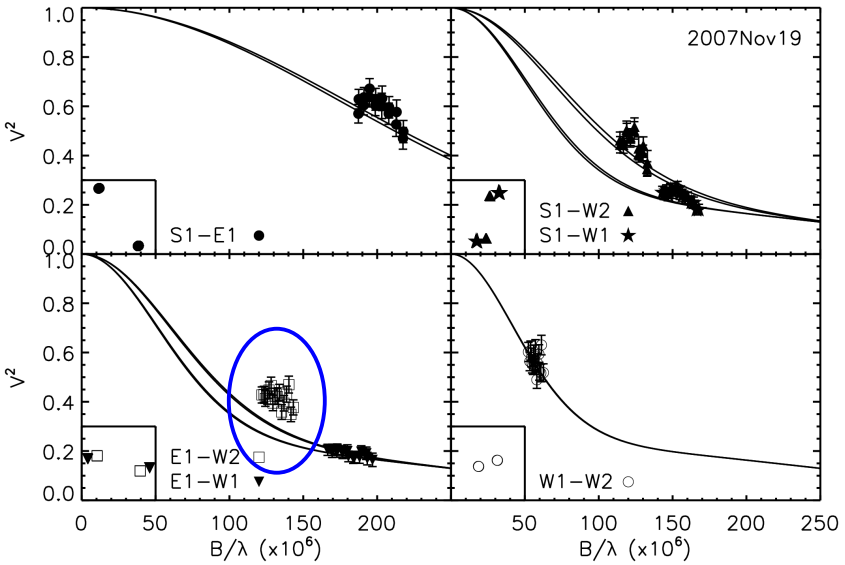




Inner Array - S2E2W1W2



Outer Array - S1E1W1W2

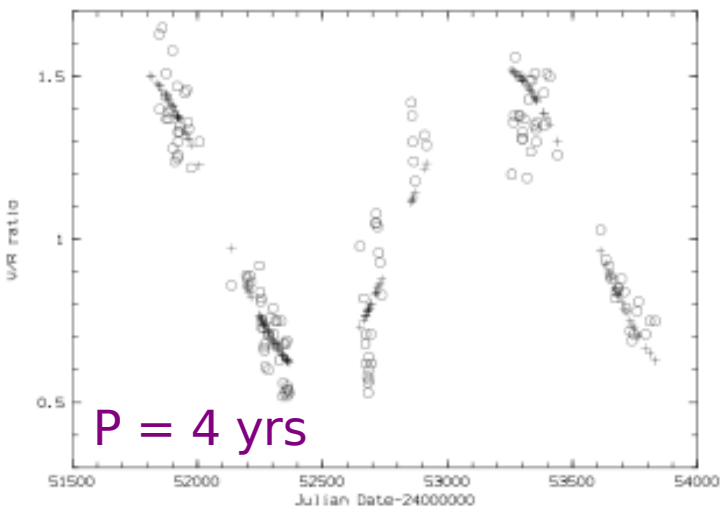


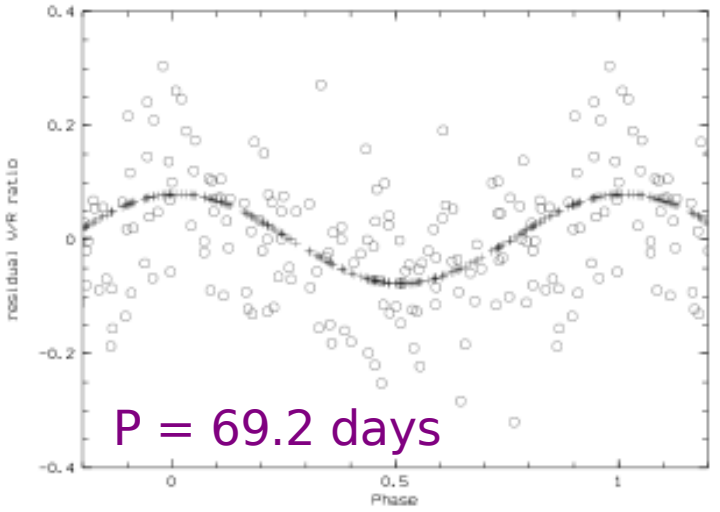
Extended polar wind component???
(e.g. Achernar – Kanaan 2008, Kervella et al. 2009)

Very Interesting.... but is it real???

Maybe?

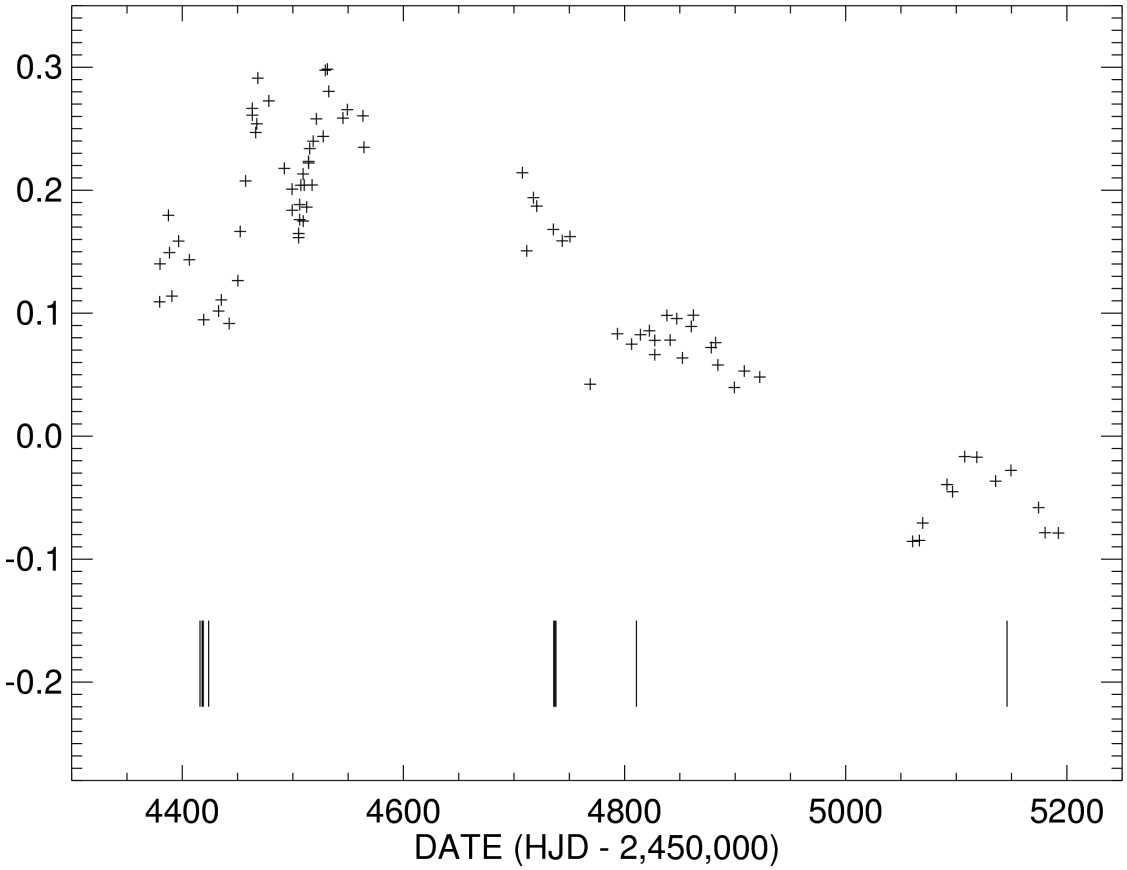
More Evidence in Support of Precession?





Pollmann & Rivinius 2008, Zeta Tau

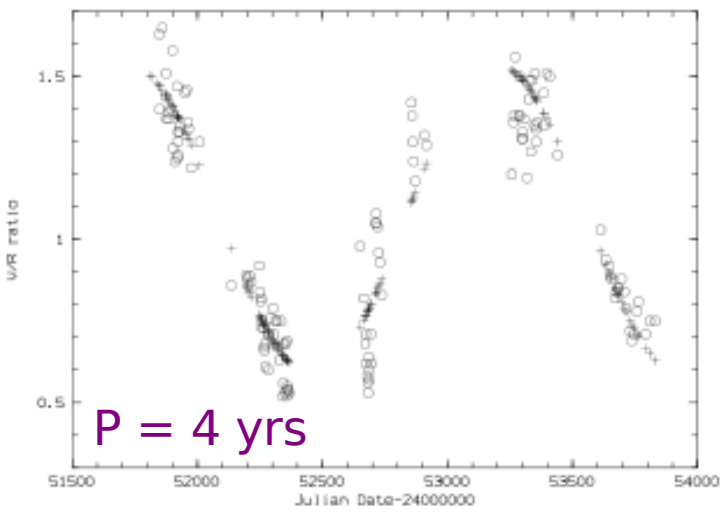
V/R Variation Continued Through Time Span of the MIRC Observations

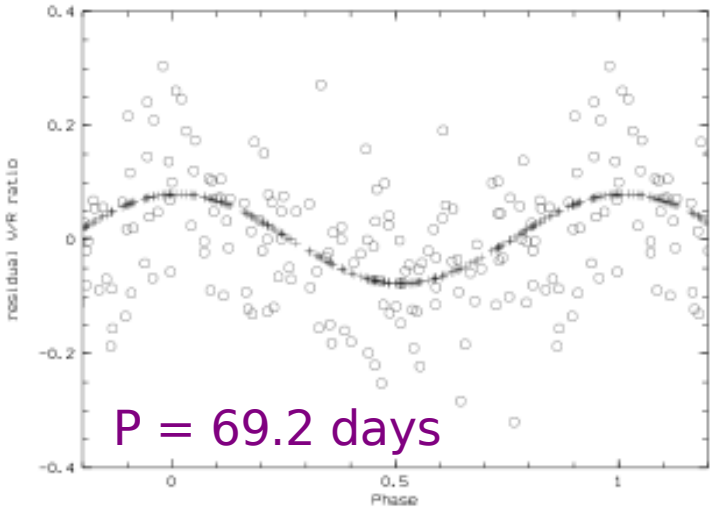


Precessional vs. Orbital Period

- Zeta Tau has a spectroscopic binary companion in a 133 day orbit (Ruzdjak et al. 2009)
- Any tilt of the Be star's disk will be modulated by the tidal force of the binary companion
- Approximately twice each orbit, a tilted disk will experience in tidal torque in the direction of coalignment with the orbital plane
  - Nodding motion (e.g. X-ray binaries, Collins & Scher 2002)
- Nodding period: $$Pn = \frac{Pp\ Pb}{2(Pp - Pb)} = 73.1 \text{ days}$$
- Close to V/R modulation period of 69.3 ± 0.2 d (Pollmann & Rivinius 2008)

More Evidence in Support of Precession?





Pollmann & Rivinius 2008, Zeta Tau

But...

What About the Polarization angle?

- Intrinsic polarization angle has remained remarkably stable over the last decade (McDavid 1999; Stefl et al. 2009)
- No evidence of changes as large as those seen in the interferometric data

Is There a Resolution?

But...

What About the Polarization angle?

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- No evidence of changes as large as those seen in the interferometric data

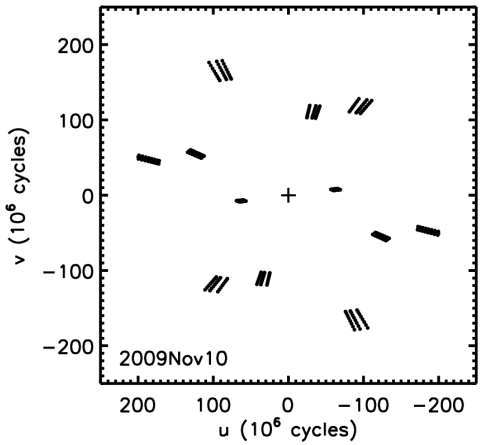
Is There a Resolution?

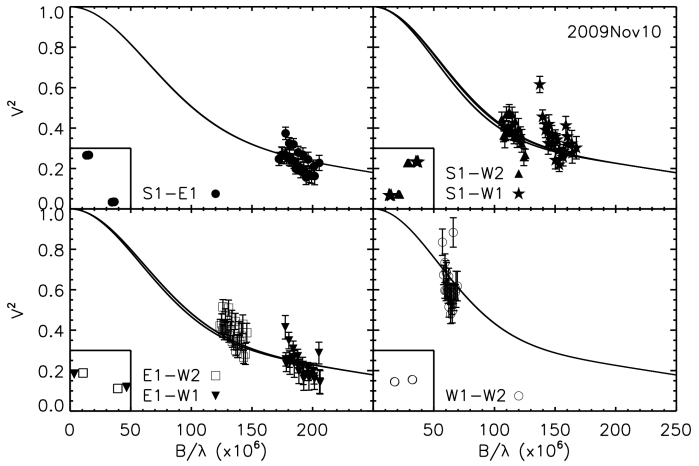
- Polarization probes scattering radiation from the innermost part of the disk where it is probably co-aligned with stellar equator (source of ejected material)
- Tilt associated with larger scale structure of spiral oscillation in disk – measured by interferometry

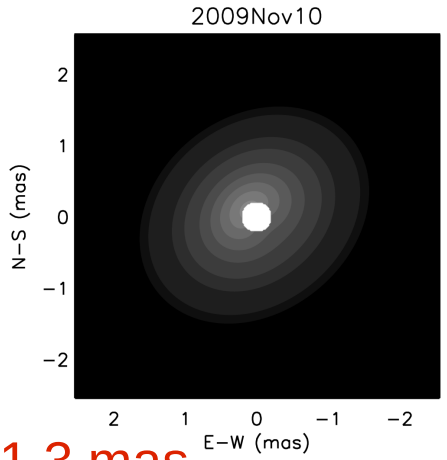
Other Be Stars Observed with MIRC

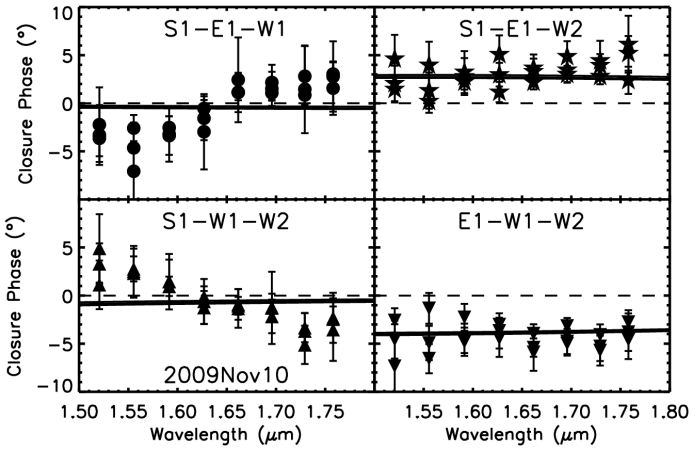
- Gam Cas, Phi Per
  - Monnier, Zhao, Che, Pedretti, Thureau
- Delta Sco, Omi Her
  - Touhami, Gies, Schaefer
- Beta CMi, Eta Tau

Other Be stars Observed with MIRC: Beta CMi









Major ~ 1.3 mas
Minor ~ 1.0 mas

Future Work

- Short-term: Finish paper on Zeta Tau results
- Short-long: Continue MIRC program on Be stars
- Long-term: Compare precession model with full 3-dimensional models for one-armed spiral oscillation