CHARA Array Observations of Disks around Be Stars

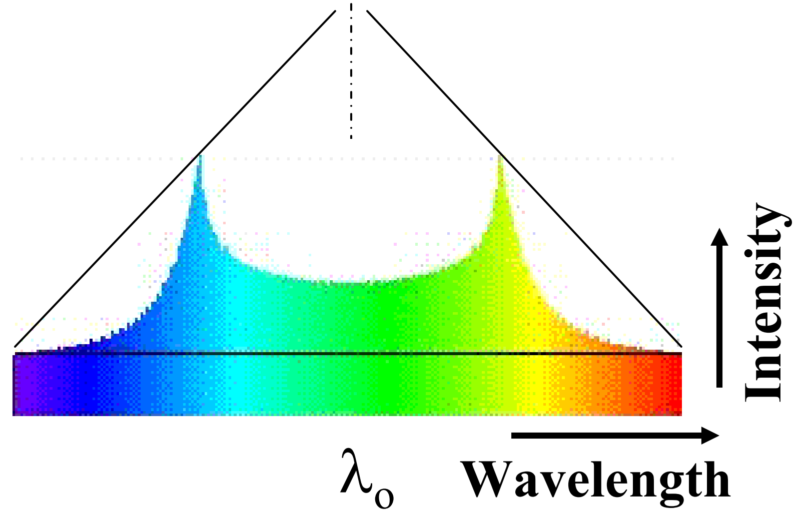
Douglas R. Gies (and friends)
CHARA
Georgia State University

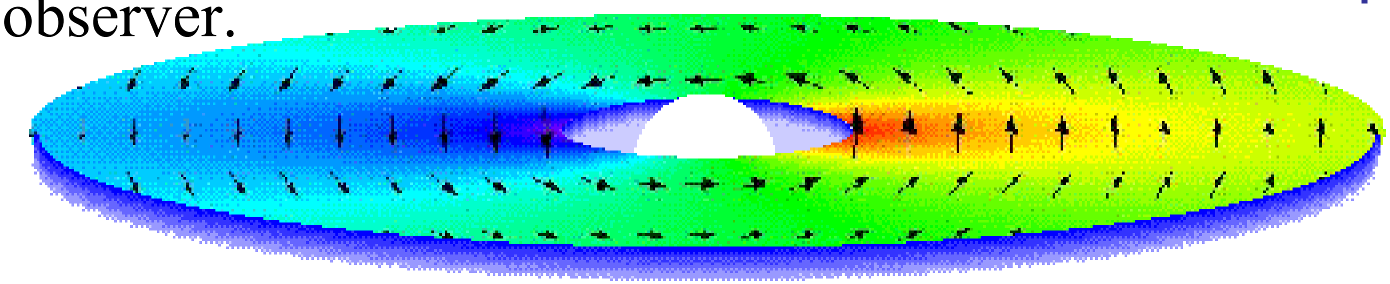
Be stars: rapidly rotating, massive stars with circumstellar disks

- B spectral type stars (11 – 30 kK) that are relatively unevolved (core H-burning)
- **Circumstellar gas disks** revealed by <u>*emission lines*</u> (hydrogen Balmer series), <u>*infrared excess*</u> continuum emission, and <u>*linear polarization*</u> (of scattered star light)
- Disk features inherently time variable: B → Be → B …(months to decades)

“e” = emission lines in the spectrum

- Detailed spectra show emission intensity is split into peaks to blue and red of line-center.
- This is from Doppler shift of gas moving toward and away from the observer.

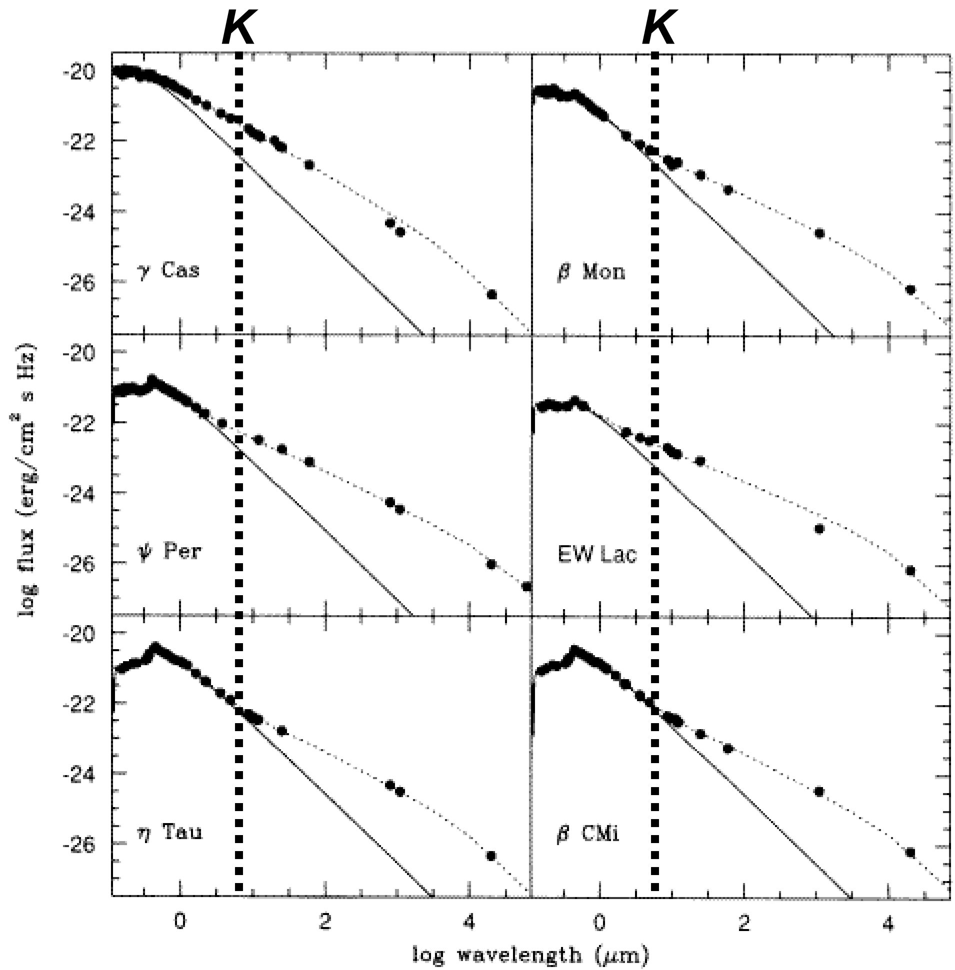




- Indicates a disk of gas orbits the star.

Resolution with the CHARA Array

- Hα disks resolved (Stee et al. GI2T; Tycner et al. NPOI)
- Expect IR excess from ionized gas f-f and b-f emission
- Should appear in *K*-band ($\lambda = 2.1\mu m$)



Waters et al. (1991)

CHARA Array Observations

(Gies et al. 2007, ApJ, 654, 572)

- *K*-band interferometric observations (2003 – 2005) of Be stars γ Cas, φ Per, ζ Tau, κ Dra
- Moderate to long baselines
- CHARA Classic beam combiner
- Represents first resolution of NIR disks of northern Be stars
- Southern Be stars resolved by VLTI/Amber (α Ara, κ CMa; Meilland et al. 2007a,b)

Models of K-band Visibility

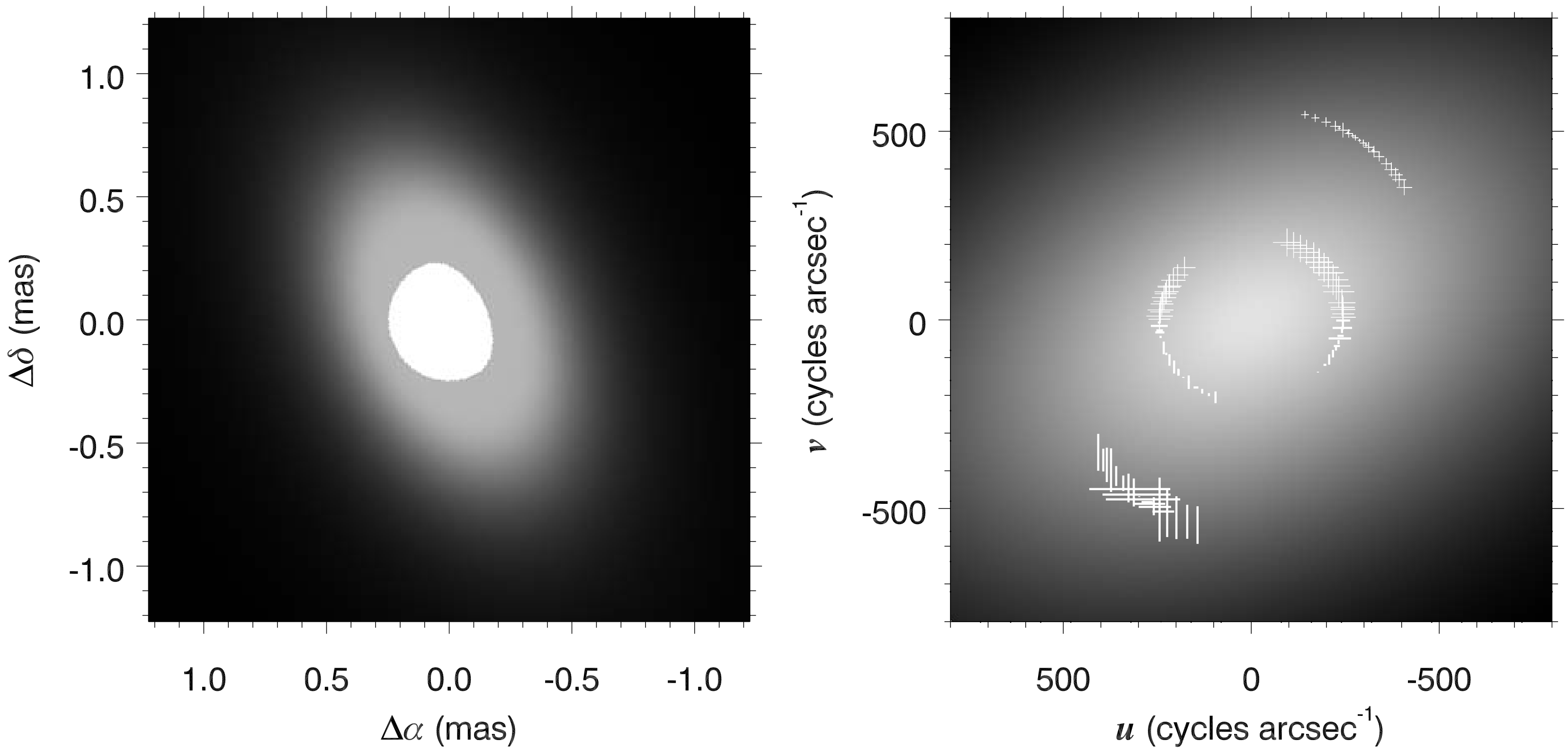
- Uniform disk star with set angular diameter (π, R_s)
- Disk geometry (Hummel & Vrancken 2000)
  $\rho(R,Z) = \rho_0 R^{-n} \exp[-0.5(Z/H(R))^2]$
  ρ_0 = base density (g cm^{-3})
  n = radial density exponent
  $H(R) = R^{3/2} C_s / V_K$ = disk scale height
- Observer parameters
  i = inclination of disk normal
  α = position angle (E from N) of disk normal

Models of *K*-band Visibility

- Isothermal disk
  $T_d = 0.6\ T_{\rm eff}$(star) (Carciofi & Bjorkman 2006)
  maximum emission: Planck function for T_d
- IR free-free and bound-free optical depth
  (Waters 1986; Dougherty et al. 1994)
- IDL code: integrates ρ^2 along rays through disk
  $$I = S_d\,(1 - e^{-\tau}) + S_* \, e^{-\tau}$$
  S_d = source function for disk
  S_* = source function for uniform star
- Fourier transform images to get visibility V
  (Aufdenberg et al. 2006)

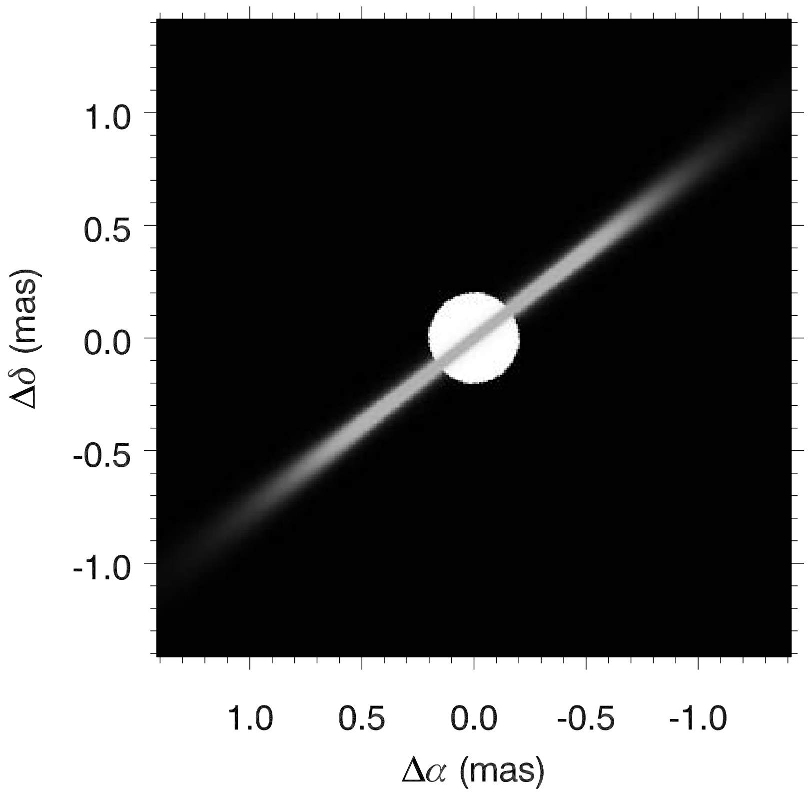
γ Cas: single star fit

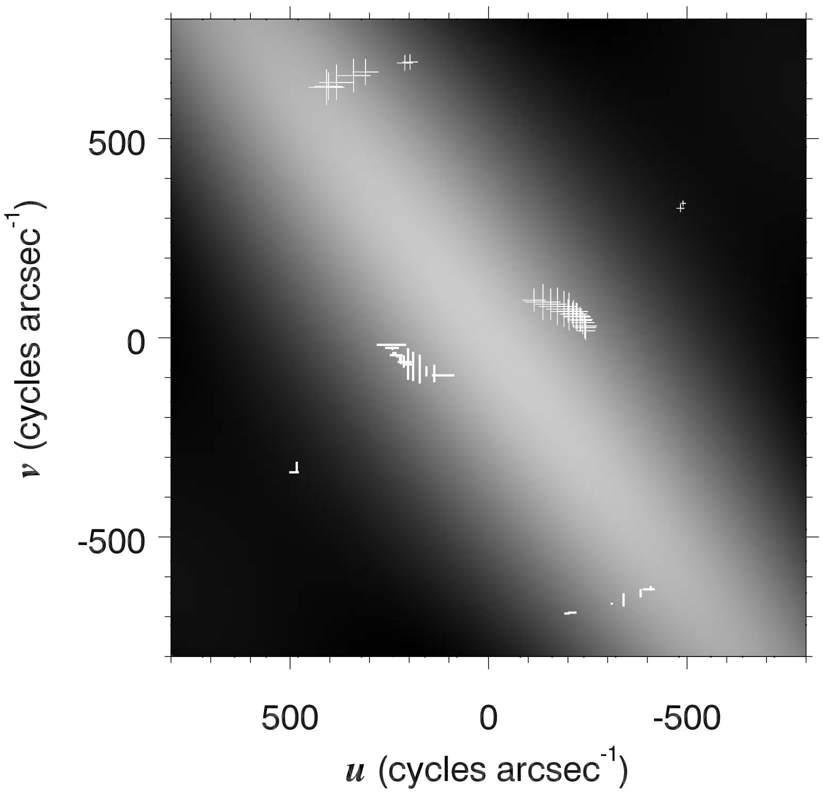
$\alpha=116^{\circ}$, $i=51^{\circ}$, $\rho_0=7\times10^{-11}$, $n=2.7$



ζ Tau: single star fit

α=38°, i=90°, ρ_0=2x10^{-10}, n=3.1



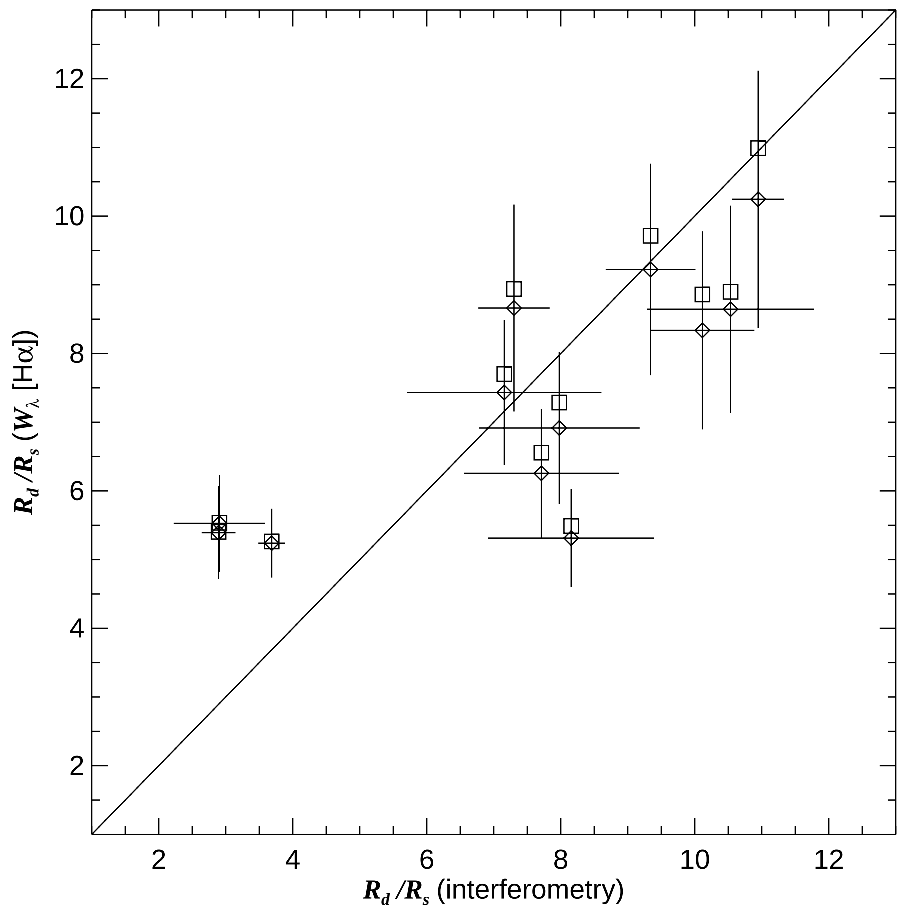


Checks: Hα Interferometry

Parameter	γ Cas	φ Per	ζ Tau	κ Dra
α (MkIII)	109	28	32	…
α (NPOI)	121	29	28	…
α (CHARA)	116	49	38	21
i (MkIII)	46	63	>74	…
i (NPOI)	55	>55	>74	…
i (CHARA)	51	69	90	26
θ (MkIII)	3.5	2.7	4.5	…
θ (NPOI)	3.6	2.9	3.1	…
θ (CHARA)	2.0	2.3	1.8	1.8

Predicting Disk Sizes from Hα

- Grundstrom & Gies 2006, ApJ, 651, L53
- Use same models to estimate disk HWHM for observed Hα strength
- With parallax, predict angular size of disk
- Recent Hα observations from KPNO Coudé Feed (Grundstrom 2007)



NASA IRTF

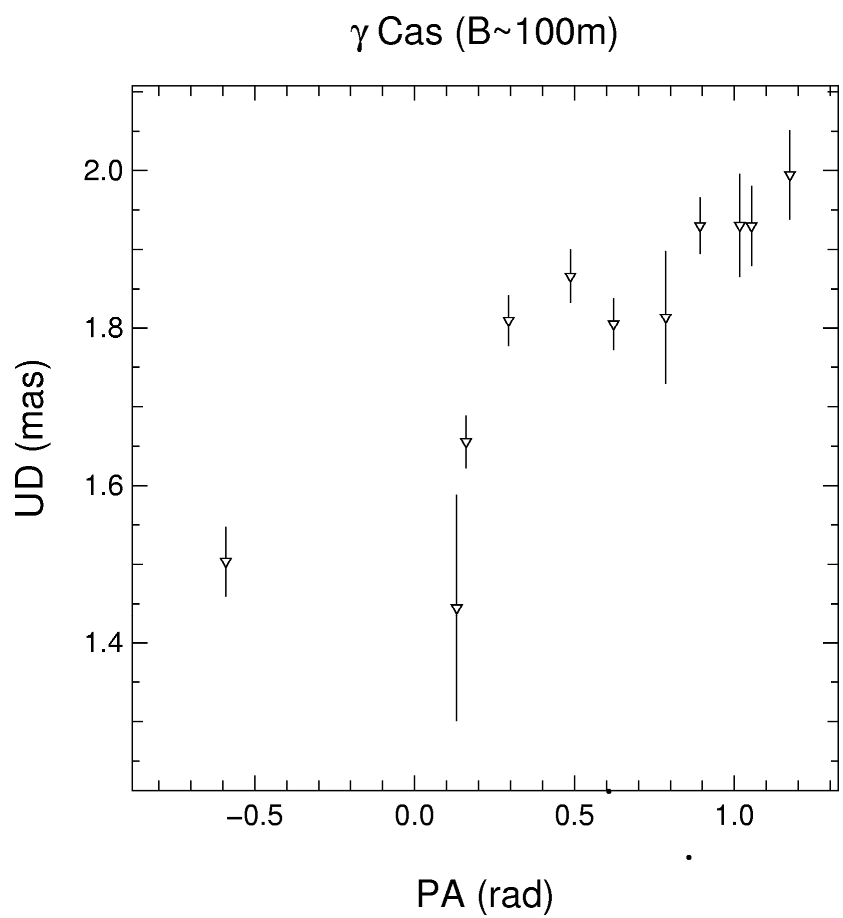
- Need contemporary measurement of NIR excess flux from disk
- 2006 September run at ITRF Hawaii for Spex observations of 12 Be stars
- Reductions underway (Richardson)

Future CHARA Observations

- Enlarge the sample of Classic observations of northern Be stars (from Grundstrom survey)
- υ Cyg (resolved by Baines; August 2006)
- Other good targets with disks 2 mas or larger: β Psc, ο Cas, ψ Per, η Tau, 48 Per

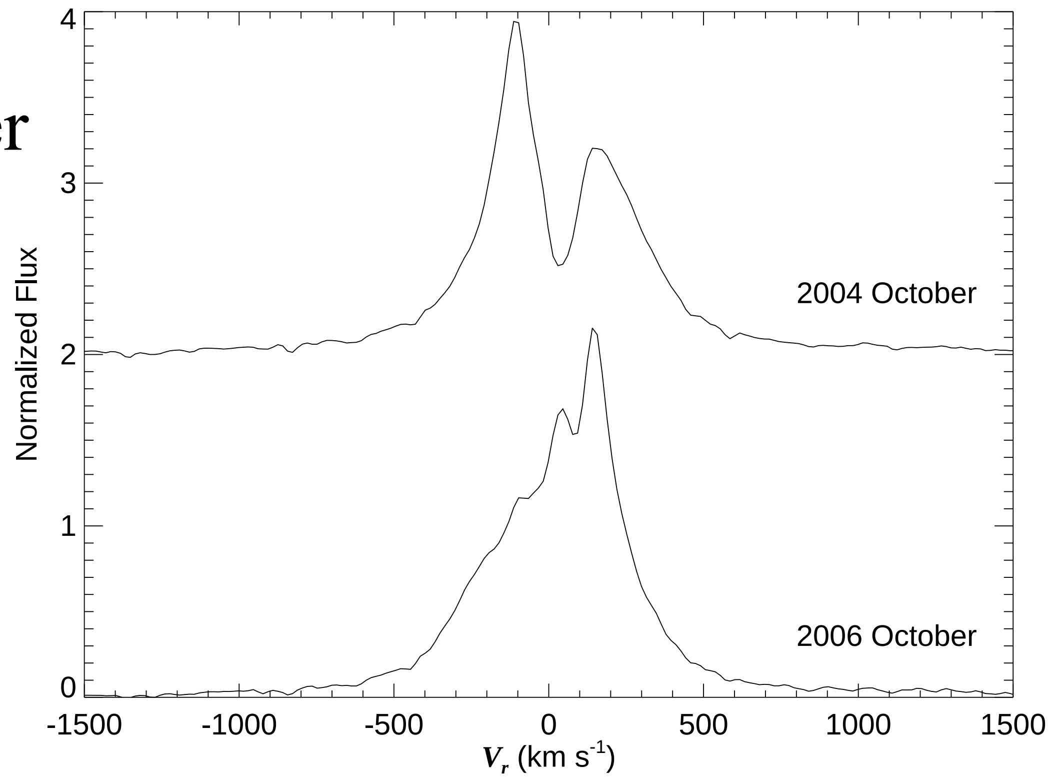
Future CHARA Observations

- In depth studies of individual targets: γ Cas and ζ Tau with FLUOR and MIRC
- Example: FLUOR observations from 2006 November of γ Cas (Touhami, Merand)



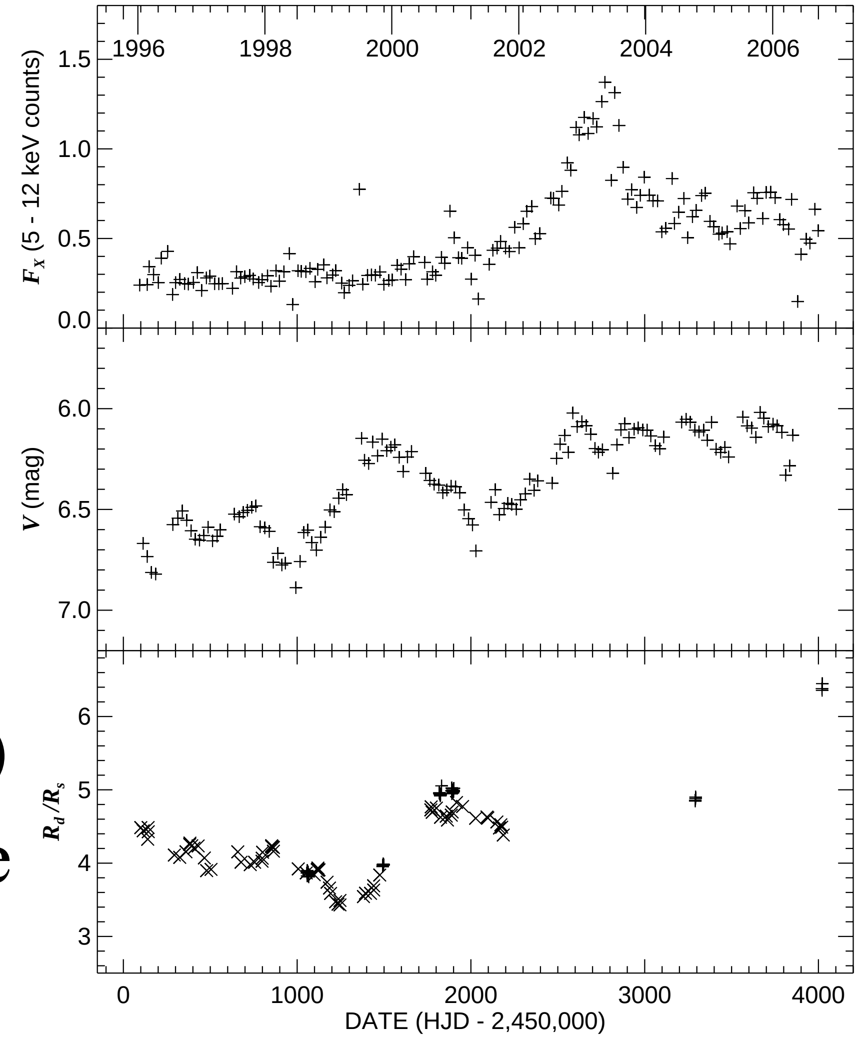
Future CHARA Observations

- Disk structures: spiral arms and other asymmetries
- Example: Hα changes in the spectrum of ζ Tau (Grundstrom 2007)



Future CHARA Observations

- Disk structures:
  long term evolution
- Example:
  Time lags in the optical continuum and Hα variations in the spectrum of X Per (Grundstrom et al. 2007)
- Is NIR flux formed close to star like visual flux?



Future CHARA Observations

- Disks in interacting binaries experiencing mass transfer
- Example:
  β Lyr accretion disk and bipolar outflows from Hα observations (Harmanec 2002); angular diameters of the donor and disk are ≈ 1.6 and 3.2 mas
- MIRC program planned