Status of the Be **stars** Survey Project
CHARA Meeting – Nice, March 2009

Observations of Be Star Circumstellar disks with the CHARA Array

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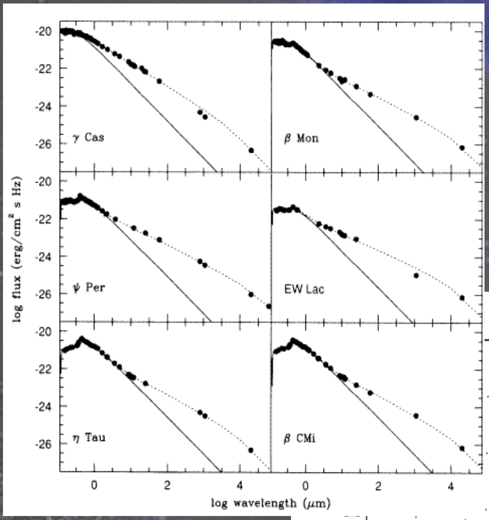
Georgia State University · NSF · NOAO · l'Observatoire de Paris · LESIA · The University of Michigan 1817 · NExScI NASA Exoplanet Science Institute · SUSI Sydney University Stellar Interferometer Australia · Observatoire de la Côte d'Azur

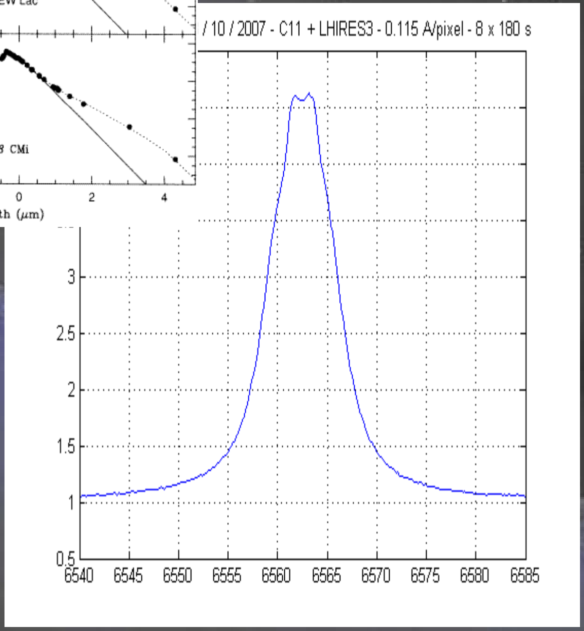
Outline

- The purpose of this project
- Observations of Be Stars with CHARA Classic and FLUOR.
- Model description and first results
- Ongoing and Future Work

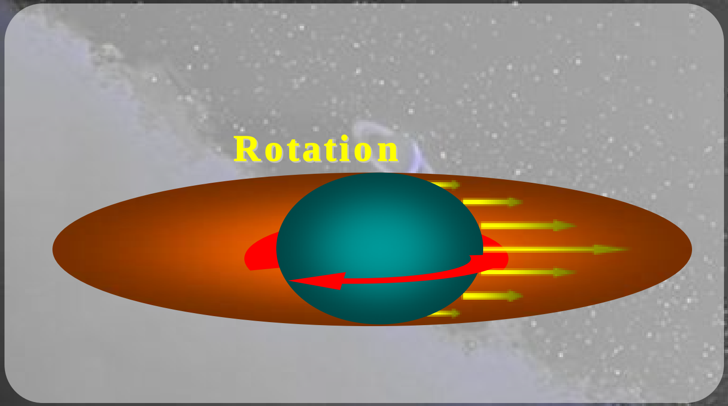
What's a Be star

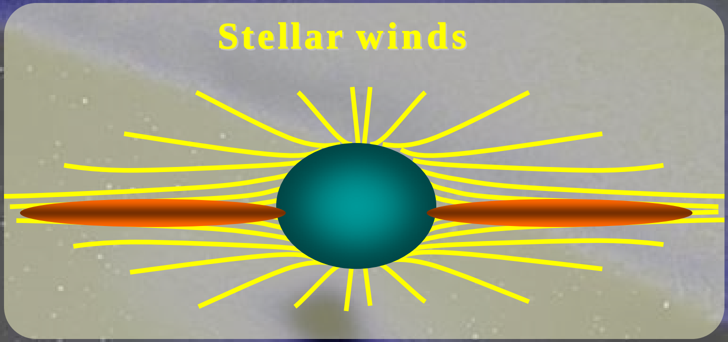
- Be stars are rapid rotator
- Spectroscopy suggests that Be stars rotate at velocities close to their critical velocities
- ***<u>Circumstellar gas disks</u>*** revealed by: emission lines, infrared excess continuum emission, and linear polarization of scattered star light
- Variability: B → Be → B (months to decades)

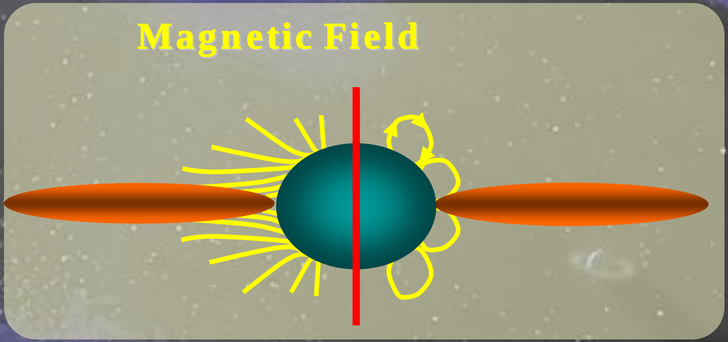


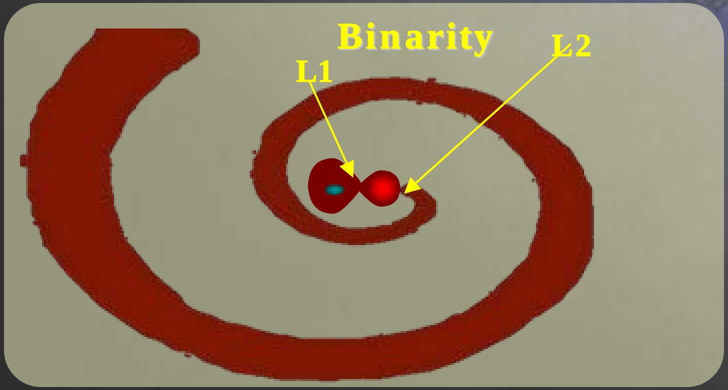


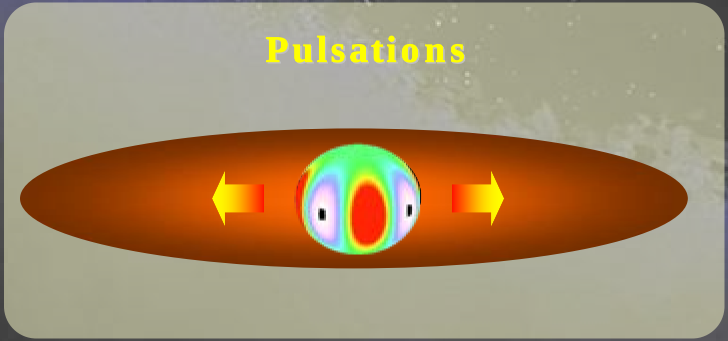
Circumstellar Envelope Formation











CHARA Array Observations

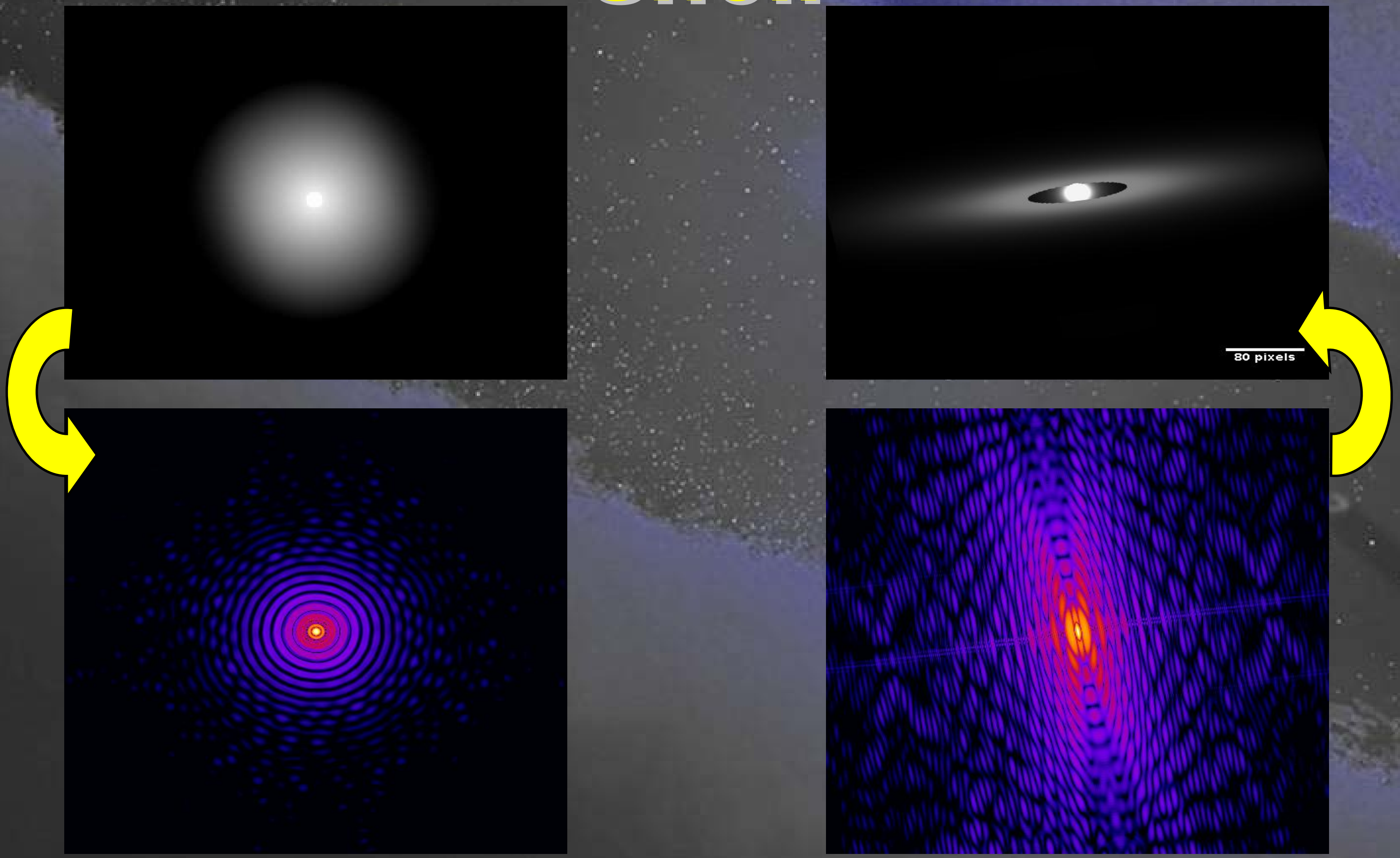
- A survey of 25 bright Be stars in the *K*- band.
- Previous observations of four classical Be stars published by Gies et al, 2007.
- Project started in late 2006,

  60% of the project accomplished so far.
- Disks of 15 Be stars were resolved at long baselines of the array using the Classic and FLUOR Beam Combiners
- Predicted Angular Diameters from the emission line equivelent width (Grundstrom et al., 2006)

Target List

HD	HR	RA(2000)	DEC(2000)	Vmag	θ_s	T_{eff}	W(Hα)	θ_d	θ_J	
149757	6175	16 37 09.4	-10 34 02.0	2.56	0.494	28610	-3.0	1.55	...	Oph
191610	7708	20 09 25.6	+36 50 22.6	4.79	0.193	19460	-1.0	0.73	0.56	28 Cyg
200120	8047	20 59 49.5	+47 31 15.4	4.69	0.221	23870	-12.3	1.22	0.40	59 Cyg
202904	8146	21 17 55.0	+34 53 48.8	4.32	0.266	20460	-22.8	2.14	1.26	upsilon Cyg
212076	8520	22 21 31.0	+12 12 18.7	4.72	0.150	23340	-23.8	1.12	0.52	31 Peg
212571	8539	22 25 16.6	+01 22 38.6	4.63	0.233	27770	-2.8	0.79	0.66	pi Aqr
217891	8773	23 03 52.6	+03 49 12.2	4.37	0.280	13530	-11.7	2.31	1.27	beta Psc
004180	0193	00 44 43.5	+48 17 03.7	4.43	0.600	14400	-31.2	7.24	1.89	omicron Cas
005394	0264	00 56 42.5	+60 43 00.3	2.29	0.450	30240	-32.5	3.43	1.48	γCas
010516	0496	01 43 39.6	+50 41 19.4	4.09	0.264	28760	-28.8	1.95	0.89	phi Per
022192	1087	03 36 29.3	+48 11 33.5	4.25	0.349	16840	-40.1	4.24	1.00	psi Per
023630	1165	03 47 29.0	+24 06 18.5	2.87	0.719	12410	-2.7	4.67	1.84	Alcyone
023862	1180	03 49 11.2	+24 08 12.2	4.96	0.262	12890	-15.4	2.53	0.75	Pleione
024534	1209	03 55 23.1	+31 02 45.0	6.10	0.084	28000	-24.4	0.58	...	X Per
025940	1273	04 08 39.6	+47 42 45.0	3.96	0.387	16720	-26.6	3.81	1.58	48 Per
037202	1910	05 37 38.7	+21 08 33.2	3.03	0.430	20050	-20.2	3.30	0.66	ζTau
58715	2845	07 27 09.0	+08 17 21.5	2.89	0.733	11740	-1.8	4.86	1.97	beta CMi
109387	4787	12 33 28.9	+69 47 17.7	3.88	0.405	14174	-20.3	3.92	0.72	kappa Dra
138749	5778	15 32 55.8	+31 21 32.9	4.15	0.338	14440	2.8	1.21	...	theta CrB
142983	5941	15 58 11.4	-14 16 45.7	4.94	0.211	17790	-24.1	1.88	0.67	48 Lib
143275	5953	16 00 20.0	-22 37 18.2	2.29	0.484	27000	-8.0	2.17	...	delta Sco
148184	6118	16 27 01.4	-18 27 22.5	4.42	0.390	30700	-37.6	3.17	1.12	chi Oph
164284	6712	18 00 15.8	+04 22 07.0	4.64	0.260	21650	-7.5	1.30	0.74	66 Oph
166014	6779	18 07 32.6	+28 45 45.0	3.84	0.530	9800	6.7	2.17	...	omi Her
203467	8171	21 19 22.2	+64 52 18.7	5.19	0.200	17087	-25.4	1.86	0.57	6 Cep
209409	8402	22 03 18.8	-02 09 19.3	4.70	0.301	12770	-18.0	3.09	0.94	Omi Aqr
217675	8762	23 01 55.3	+42 19 33.5	3.63	0.480	14140	4.7	1.36	0.52	Omi And

Why Interferometry: Disk vs Shell



Models of *K*-band Visibility

- Uniform disk star with a set of initial physical parameters: (M_s , R_s T_{eff} , π,)
- Disk geometry (Hummel & Vrancken 2000)

$$\begin{cases} \rho(r,z) = 0 \text{ , } r < r_0 \\ \rho(r,z) = \rho_0 (r/r_o)^{-n} \exp(-1/2(z/H)^2), \; r > r_0 \end{cases}$$

r_0 = inner disk radius (R_0)
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

- Temperature profile is distance-dependant

$$T(r) = T_0 (r/r_0)^{-q}$$

T_0 = Temperature at the inner radius of the disk (°K)
q = radial temperature exponent

- Considering the free-free and bound-free opacity, the total flux is given by:

$$F_\nu = \frac{\kappa_\nu}{D^2} \int\int B_\nu(T(r)) \rho^2(r,z) \, r \, dr \, d\theta \, dz$$

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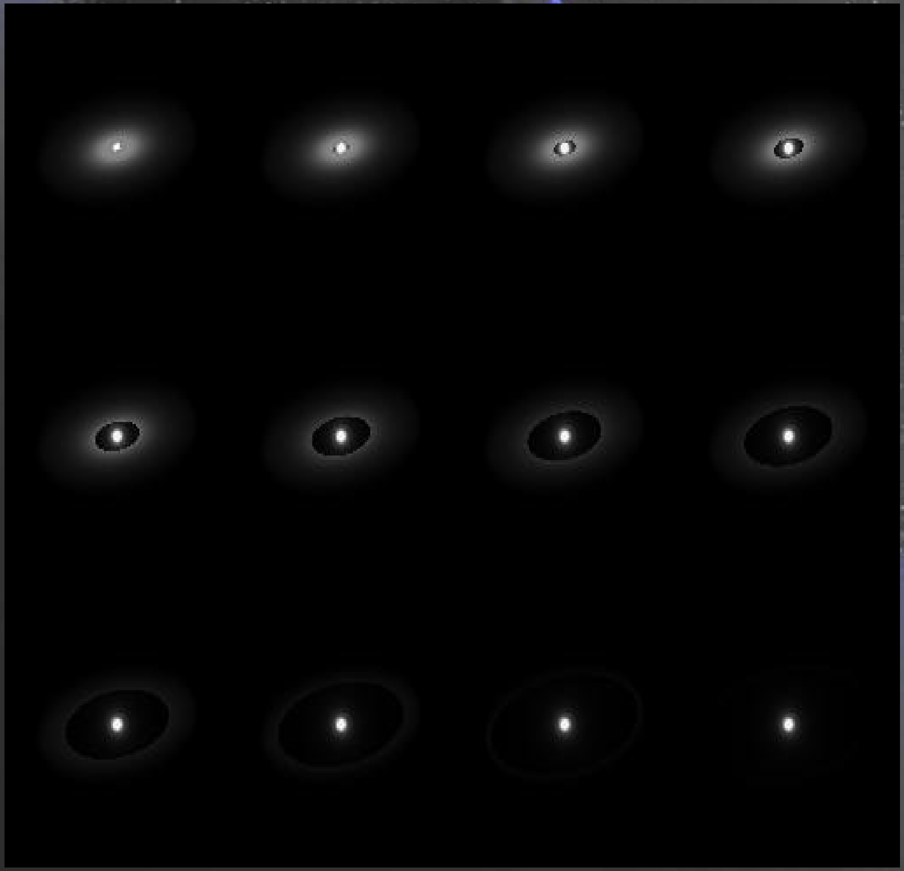
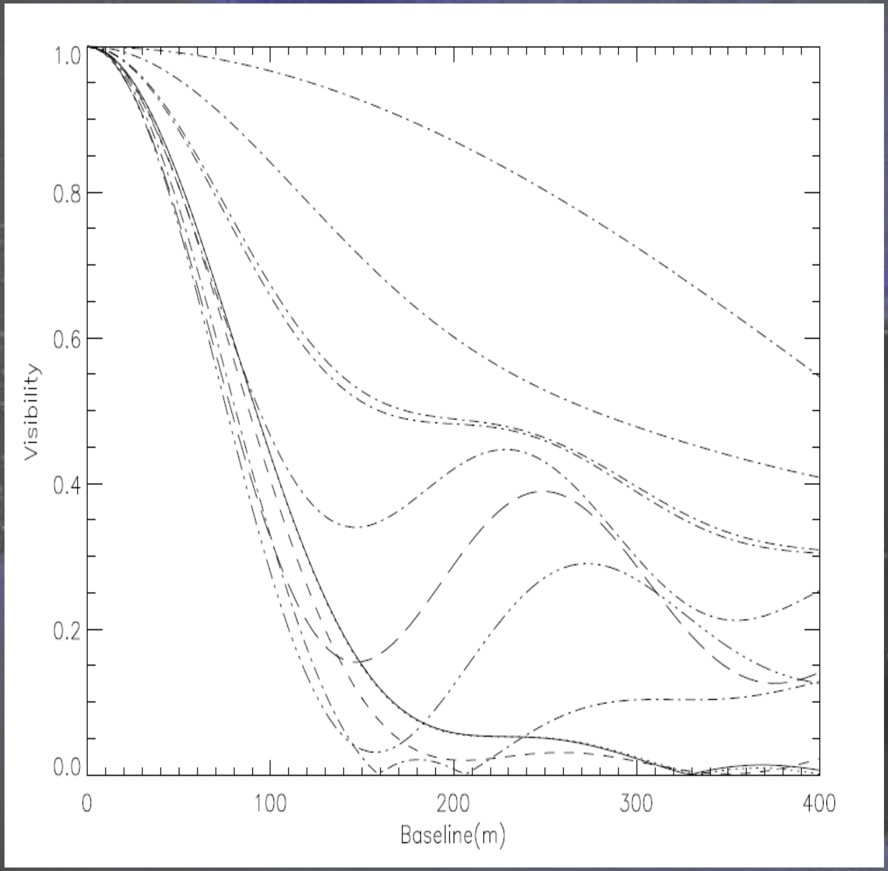
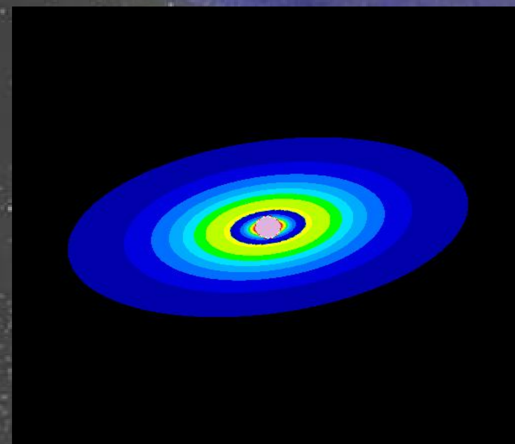
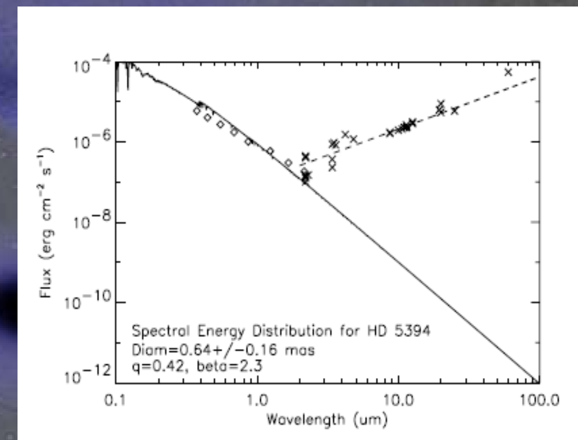
Inner Disk Determination





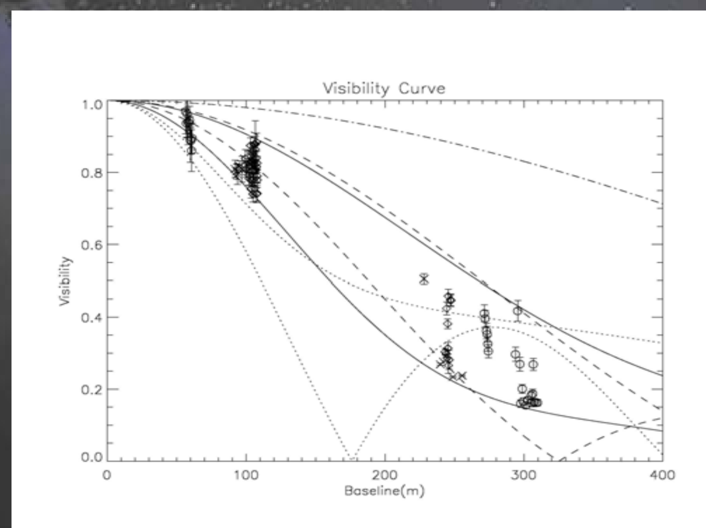
The case of Gamma Cas





<u>*Best fit Parameters:*</u>

$\rho 0 = 9.2\ 10^{-11}$ (g cm^{-3})
n = 3.2
q = 1.2
r*0* = 2 Rs
i = 43 (deg)
α = 117 (deg)
FWHM= 1.71 (mas)
η = 0.84
Vrot= 432 km/s



Omicron Cas and Zeta Tau:

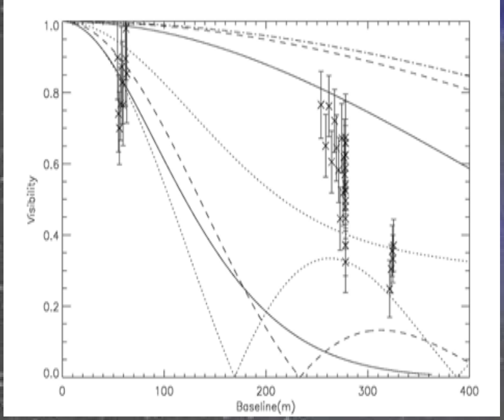
Best fit Parameters:

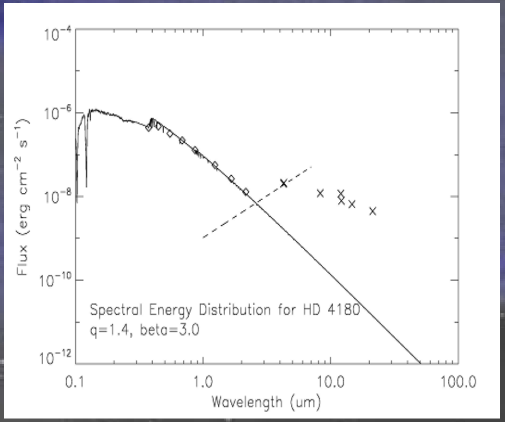
O cas:

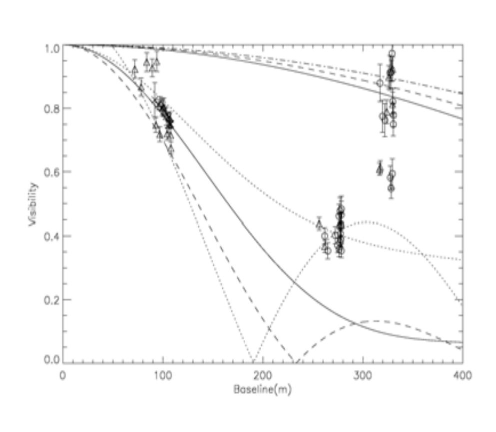
$\rho 0$ = $5.7\ 10^{-11}$
n = 2.9
q = 1.4
r0 = 1.8 Rs
i = 55 (deg)
α = 98 (deg)
FWHM= 1.32mas
η = 0.7
Vrot= 264 km/s

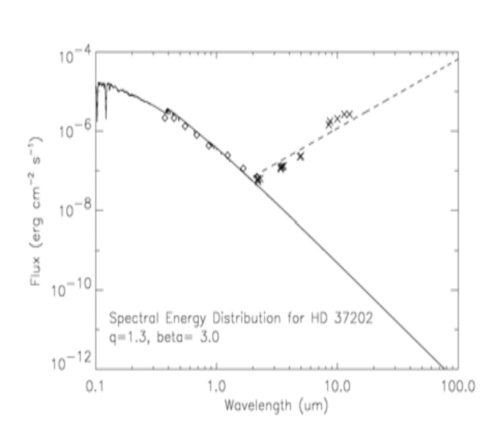
Zeta tau:

$\rho 0$ = $11.3\ 10^{-11}$
n = 3.5
q = 1.3
r0 = 2.4 Rs
i = 85 (deg)
α = 57 (deg)
FWHM= 1.65mas
η = 0.3
Vrot= 321 km/s

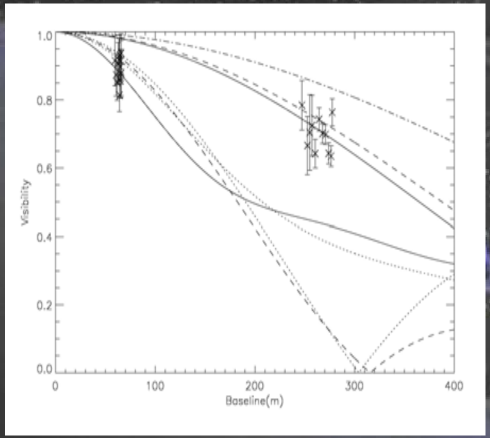


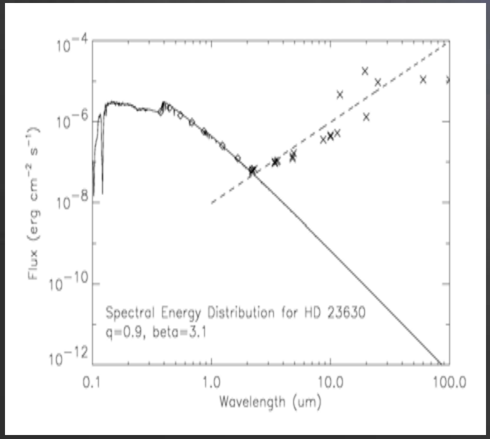






Alcyone and Pleione:



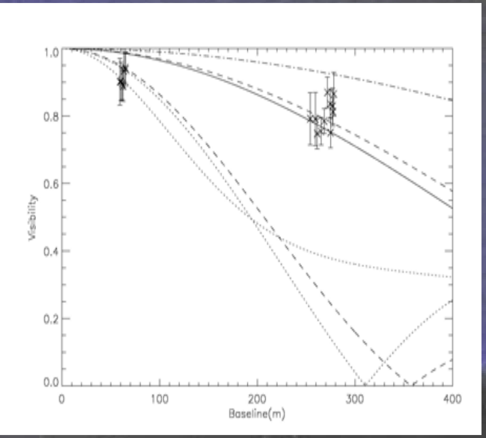


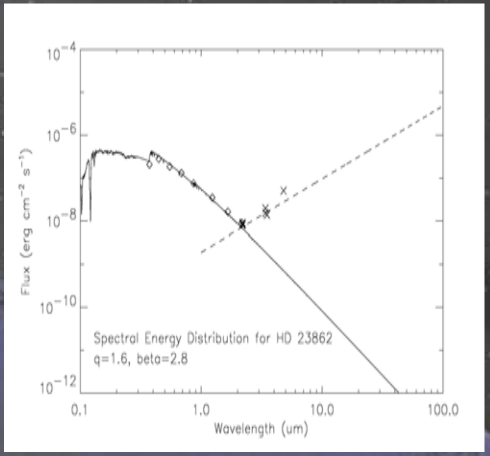
Alcyone:

ρ0 = 1.6 10-^{11}
n = 3.4
q = 0.9
r*0* = 2.7 Rs
i = 45 (deg)
α = 62 (deg)
FWHM= 1.18mas
η = 0.7
Vrot= 244 km/s

Pleione:

ρ0 = 8.1 10-^{11}
n = 3.3
q = 1.5
r*0* = 2.8 Rs
i = 68 (deg)
α = 57 (deg)
FWHM= 1.05mas
η = 0.6
Vrot= 250 km/s





Disk Densities and IR Excess

Parameter	γ Cas	O Cas	ζ Tau	Alcyone	Pleione
E(V-K) (K model)	0.93	1.23	0.83	0.14	0.33
E(V-K) (Dougherty et al.)	0.85	0.70	0.65	0.09	0.26
PA (Model)	117	98	57	62	55
PA (Yudin et al.)	110	83	37	---	---
Log(ρ0) (model)	-10.1	-11.3	-10.0	-10.8	-9.9
Log(ρ0) (IRAS, Waters et al.)	-10.6	-11.6	-10.8	---	---

Ongoing and Future Work

- Continue the observations to complete the survey – gain in sensitivity with the new CLASSIC and MIRC
- Contemporaneous Spectroscopy measurements at Lowell
- Time evolution of disks
  follow expansion and dissipation
- Structures in Be disks
  asymmetries, *spiral arms*
- Find signatures of the companions

Thank you

Collaborators:

- Douglas Gies, GSU/CHARA
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- Theo Ten Brumelaar, GSU/CHARA
- Gerard Van Belle, ESO/VLTI
- Chris Tycner, CMU
- Erika Grundstrom, Vanderbilt University
- The CHARA crew