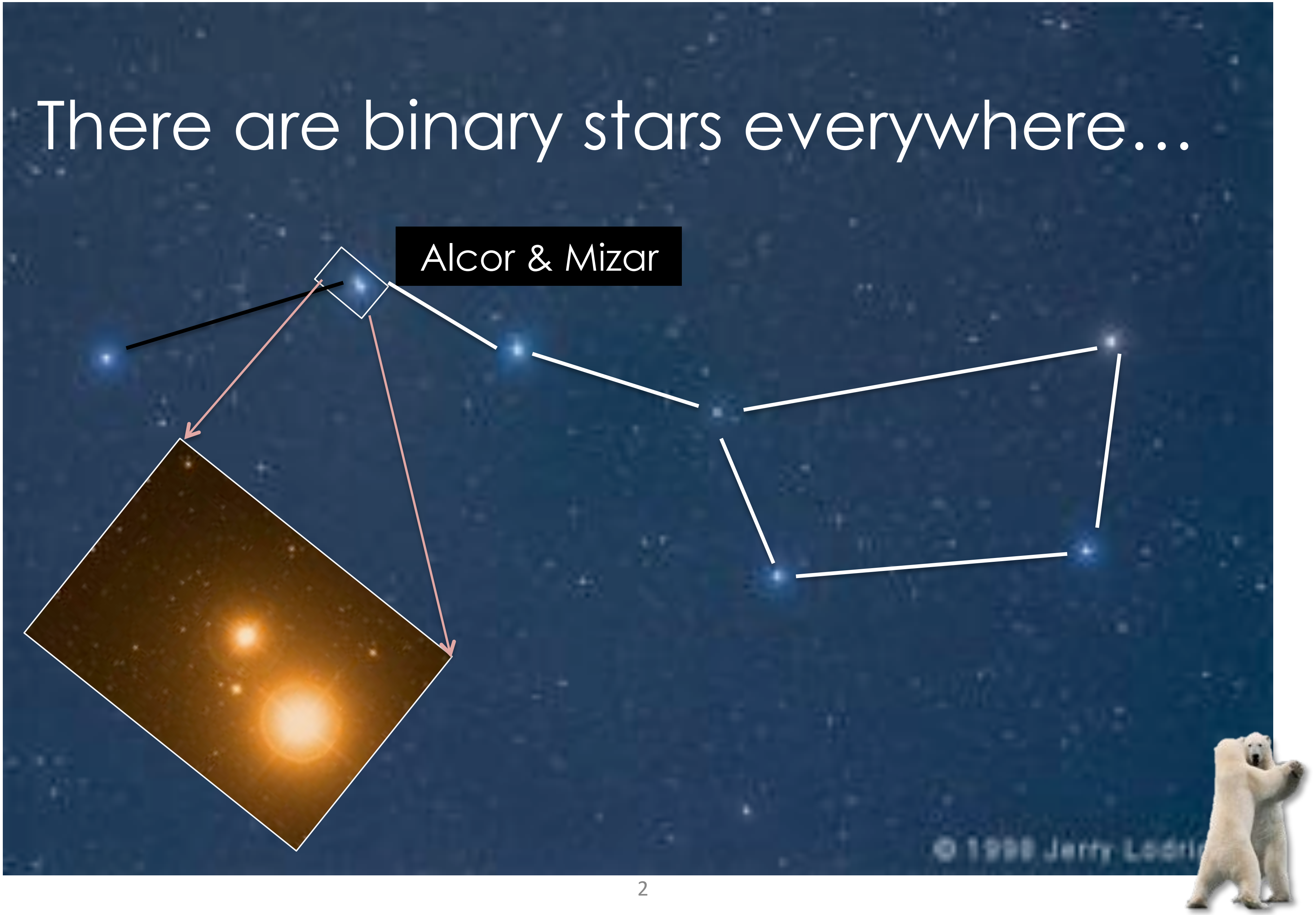
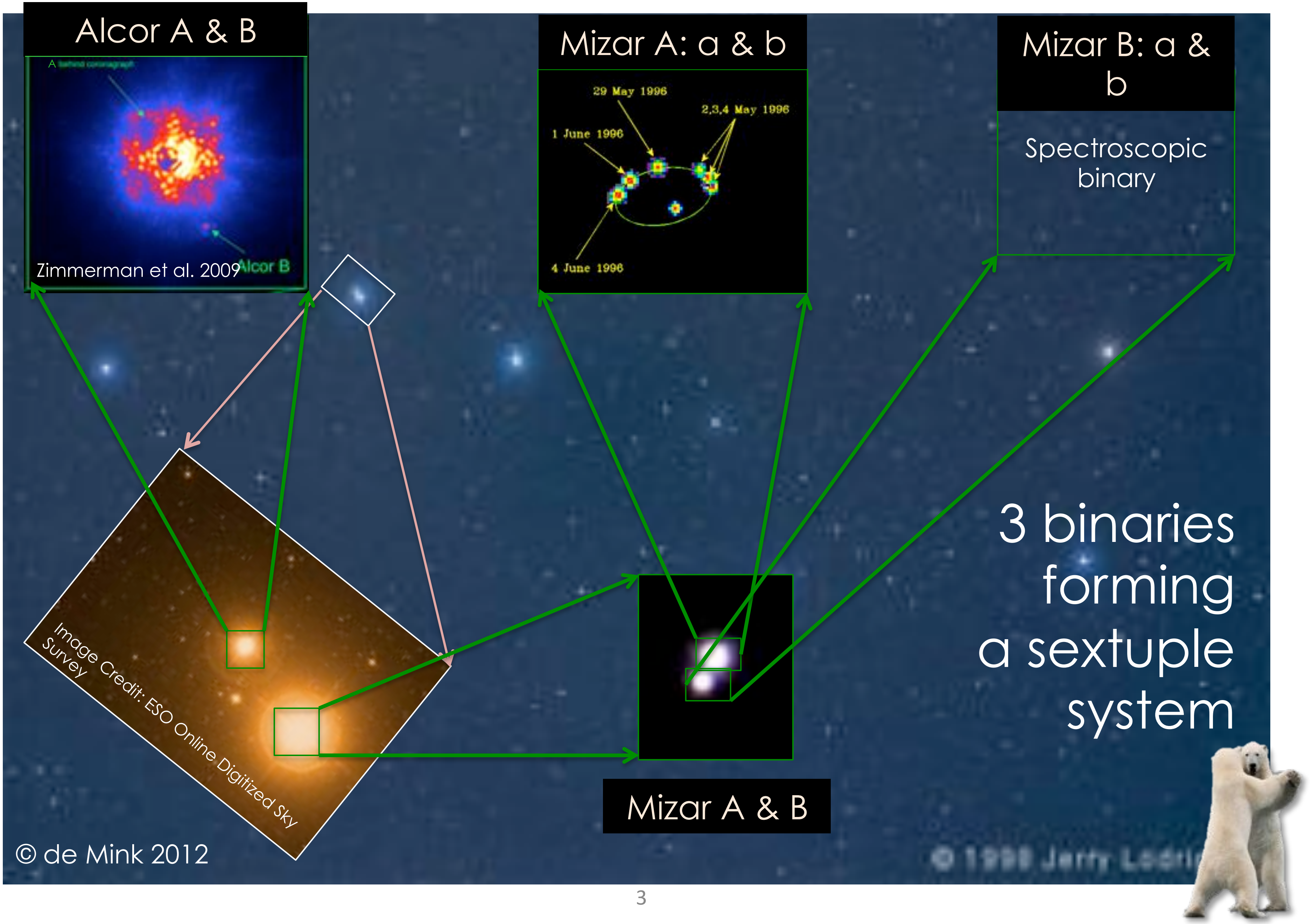
Binary stars

Henri Boffin
ESO

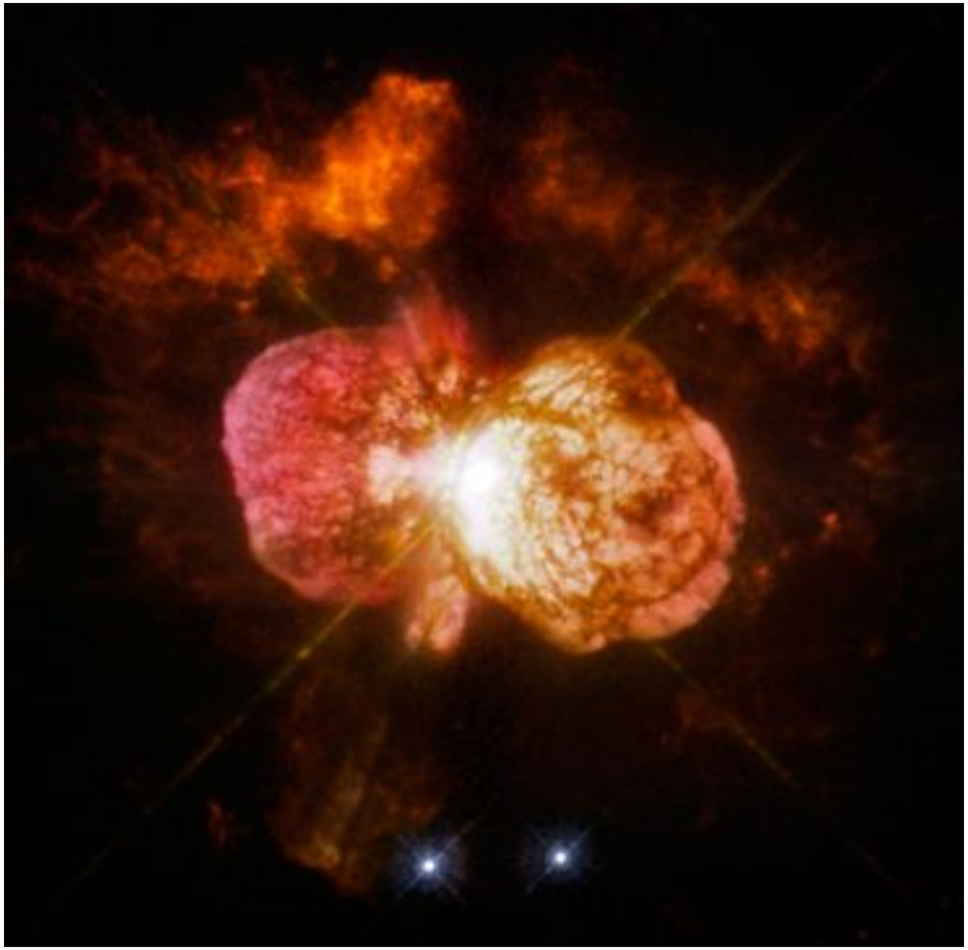
Nicolas Blind
MPE

There are binary stars everywhere…




Alcor A & B
A behind coronagraph
Alcor B
Zimmerman et al. 2009
Mizar A: a & b
29 May 1996
2,3,4 May 1996
1 June 1996
4 June 1996
Mizar B: a & b
Spectroscopic binary
Image Credit: ESO Online Digitized Sky Survey
Mizar A & B
3 binaries forming a sextuple system
© de Mink 2012

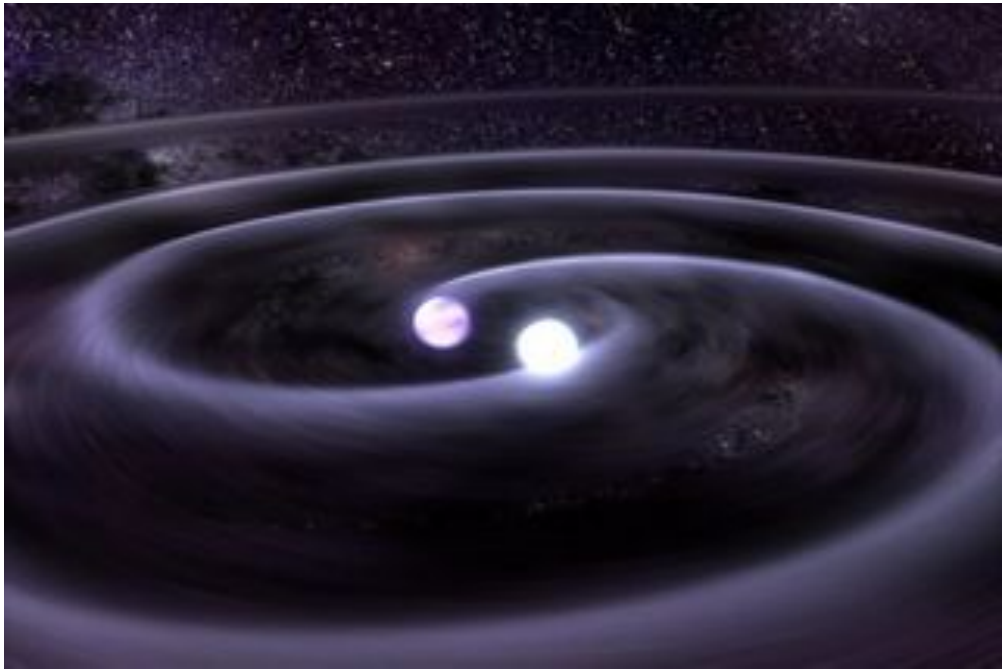
One extreme: Eta Carinae



- LBV 120 Msun + 30 Msun companion
- Eccentric system
- P = 5.5 years
- Undergo outburst

- The next Supernova in our Galaxy?

On the other side: SDSSJ010657.39-100003.3



Kilic+ arxiv:1103.2354

Detached binary

P = 39.1 min

2 WDs

A = 0.32 Rsun

Will merge in 37 Myr to become a sdB star

Another extreme: HM Cancri

arXiv: 1003.0658

Two white dwarfs

One is transferring mass to the other!

Orbital period **321 seconds**!

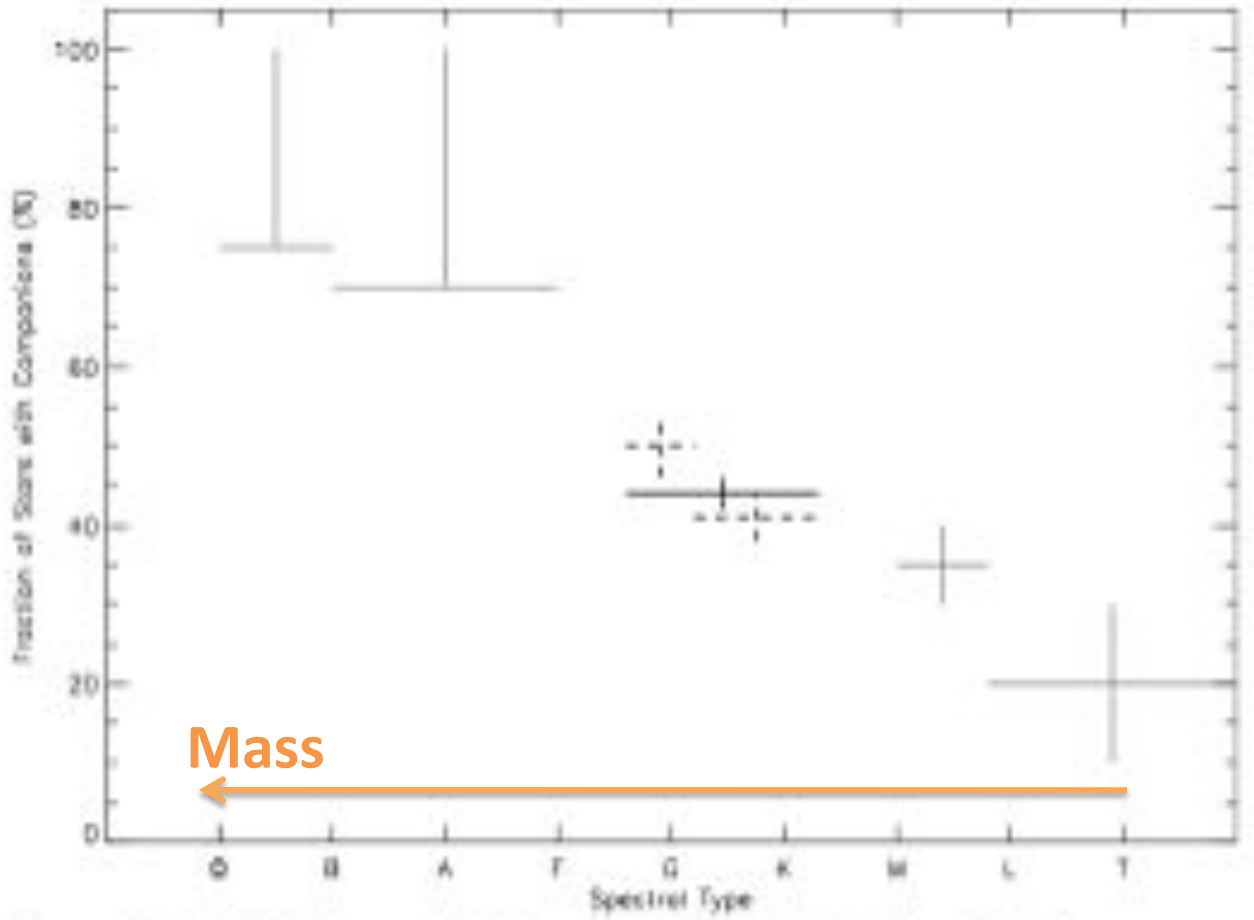
Distance between stars:
<100 000 km

Orbital velocity > 10^6 km/h

Masses: 0.27 and 0.55 Msun

Many stars are in Binaries!

Binary star fraction

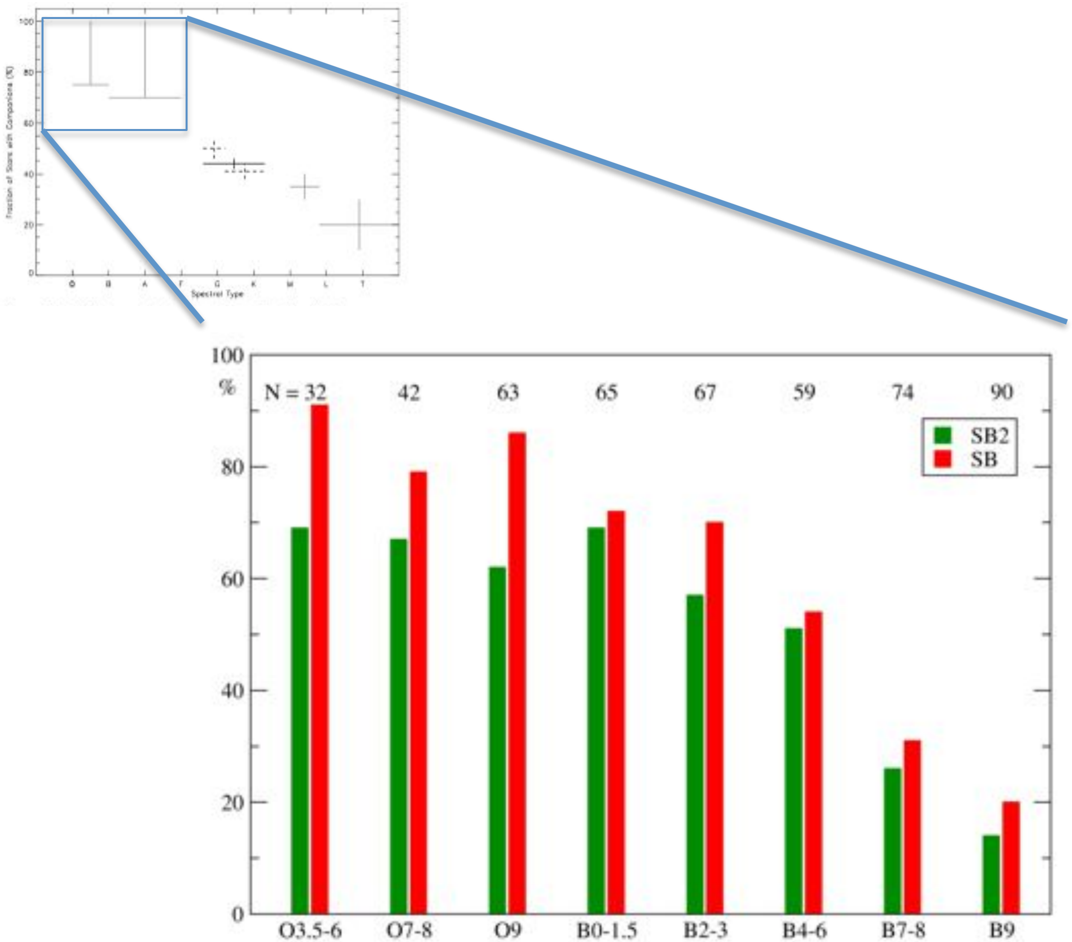


Multiplicity is function of M_A

Raghavan+ 10 (see also Clark+ 11)

Many stars are in Binaries!

Binary star fraction



Chini+ 12; see also Sana+12

the **close** binary fraction decreases from 90% (80 $M_\odot$) to 20% (3 $M_\odot$)

SB2:

Why Binaries?

"To understand galaxies we need to understand stars, but since most are members of binary and multiple star systems, we need to study and understand binary stars…

…And sometimes binary stars are the only way to understand single stars ..."

–R. Izzard (2009)

Why Binaries?

- Accurate stellar masses, radii, luminosities
- Help understand many events, e.g. PNe, novae, short gamma-ray bursts, Type Ia SNe, chemically peculiar stars, blue stragglers
- Galactic evolution: Type Ia Sne, novae

Why Binaries?

"Even though a star may be single now, it may well have been a member of a binary system in the past.

Indeed, whenever one is confronted with a new stellar phenomenon, it is probably advisable to first thoroughly explore the possibility of a binary interaction as a cause of the phenomenon before starting to adjust the input physics in the stellar calculation."

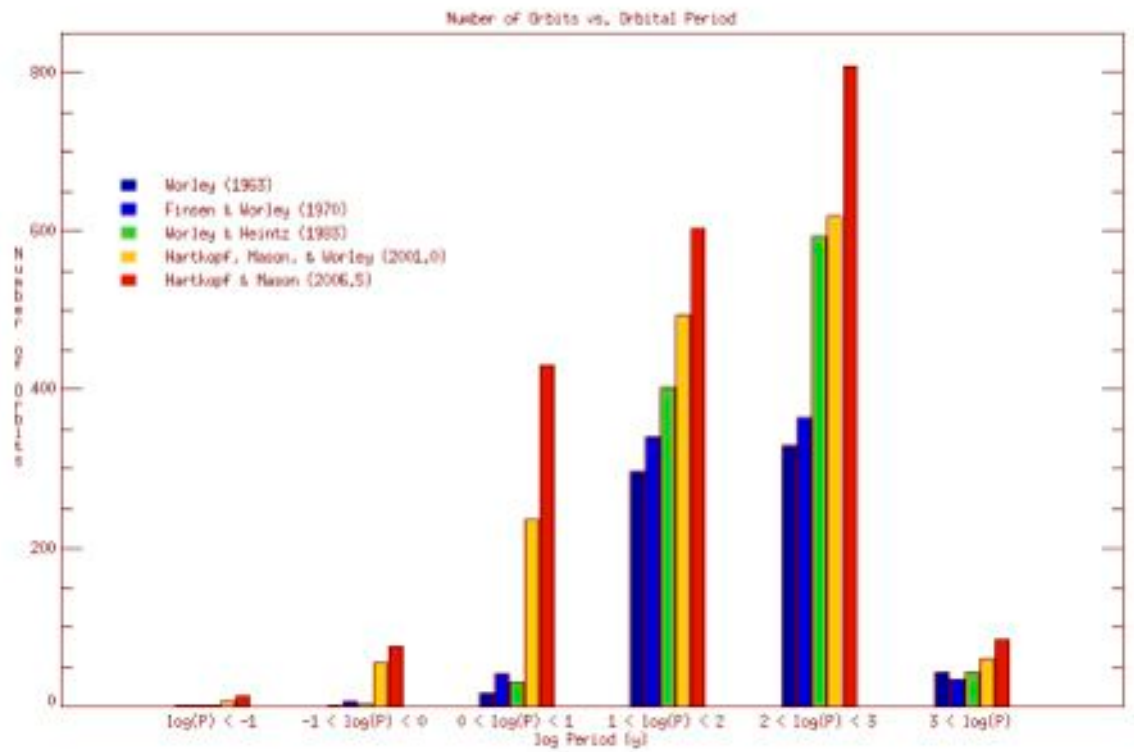
P. Podsiadlowski

Binary stars with interferometry: Expression of interests

- SB2, Masses of stars (J.L. Halbwachs)
- Symbiotic and associated (H. Boffin, N. Blind)
- Evolved binaries, e.g., post-AGB (M. Hillen)
- Binaries in general (T. ten Brumelaar)
- Binary Cepheids (A. Gallenne, N. Nardetto)
- Massive stars (F. Millour)
- Mass-radius relation (O. Creevey)
- B[e], LBVs, etc. (M. Borges Fernandes)
- Young Binaries (M. Simon)

Visual Binary

Number of orbits vs period



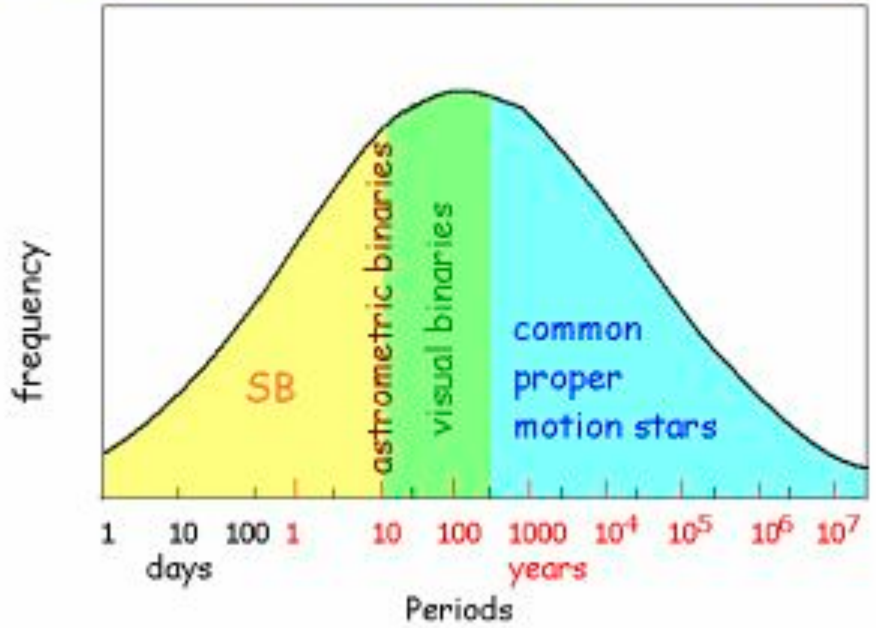
Frequency and period distribution

F7-K dwarfs: 56 % binaries.   M dwarfs: 26 % binaries

Log-Normal distribution from 1 day to 10 millions years

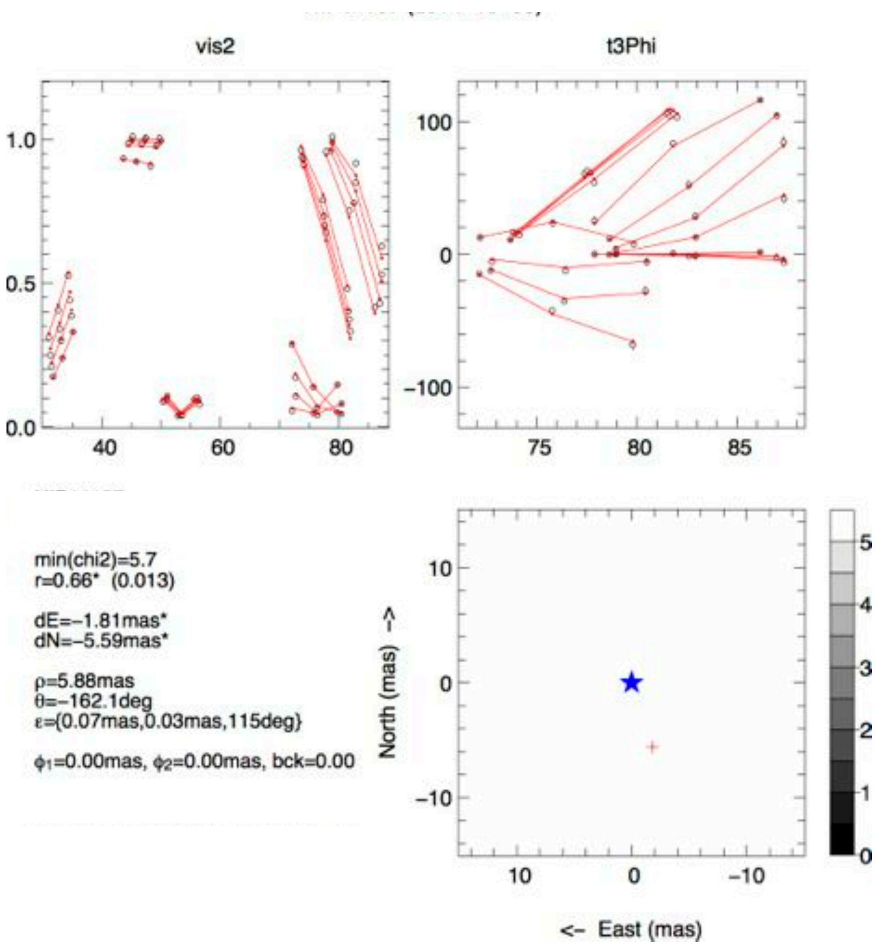
$\langle \log P_{days} \rangle = 4.8$

$\sigma_{\log P} = 2.3$



M dwarfs: less systems with a > 10 AU

SB2 Mass determination



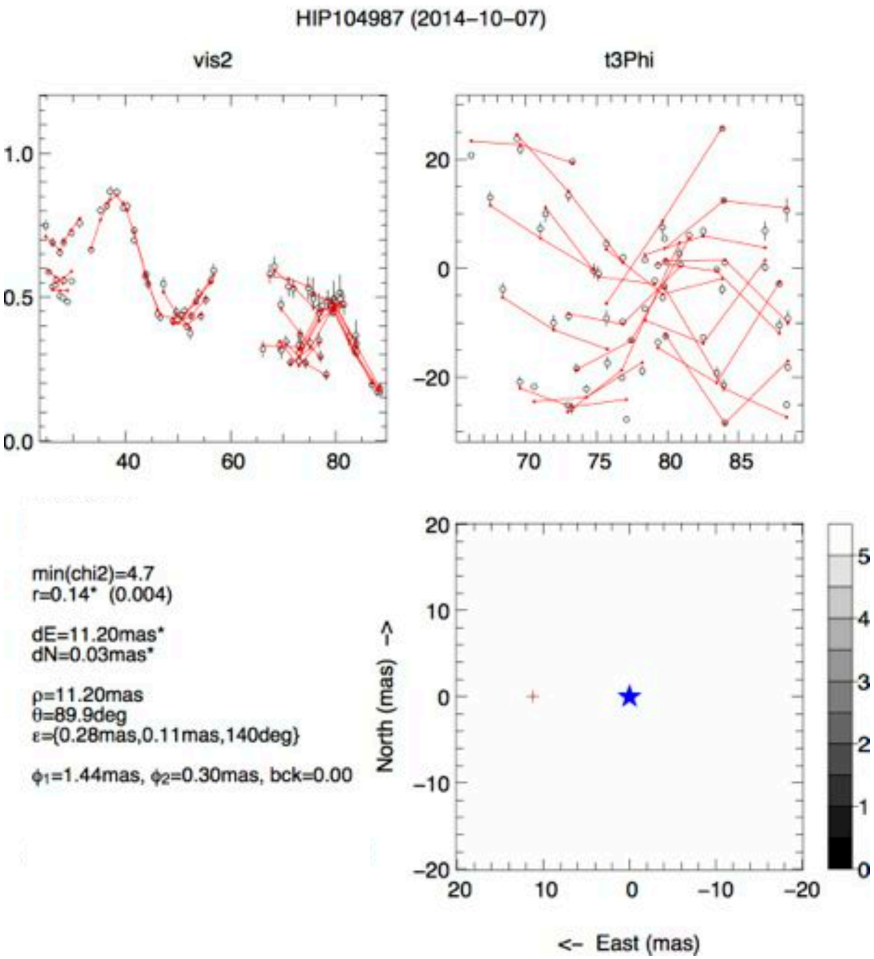
PIONIER Observations
Long baseline
H-band

K0V primary
P=43.3 days
e=0.761
d = 50 pc

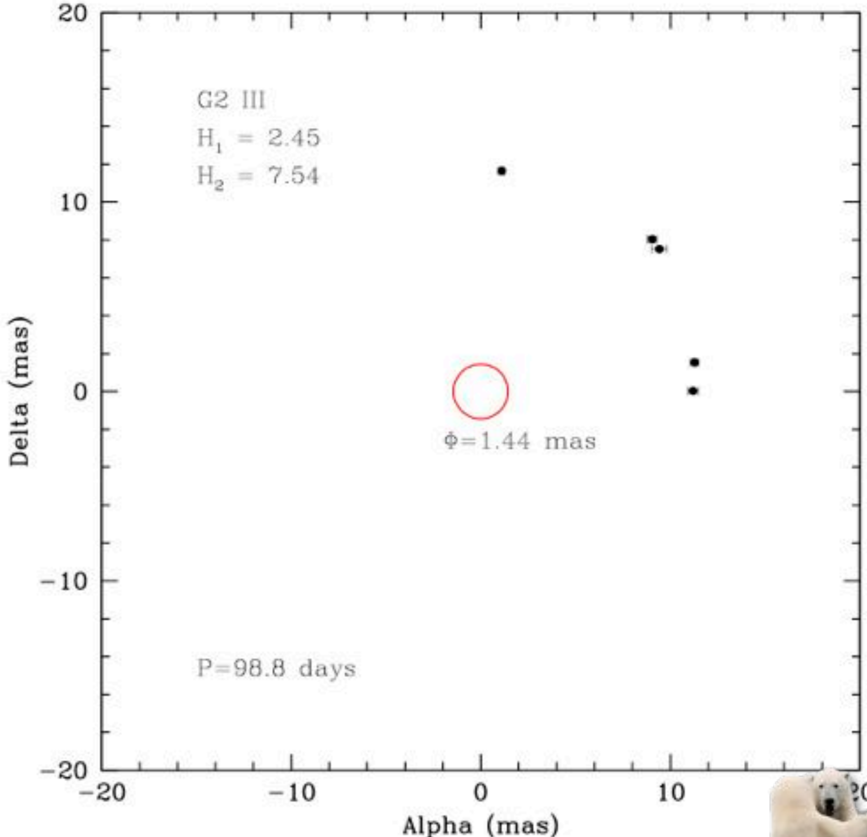
H1 = 7.18
H2 = 7.64
(q = 0.9)

H (sys) = 6.6; V = 8.8

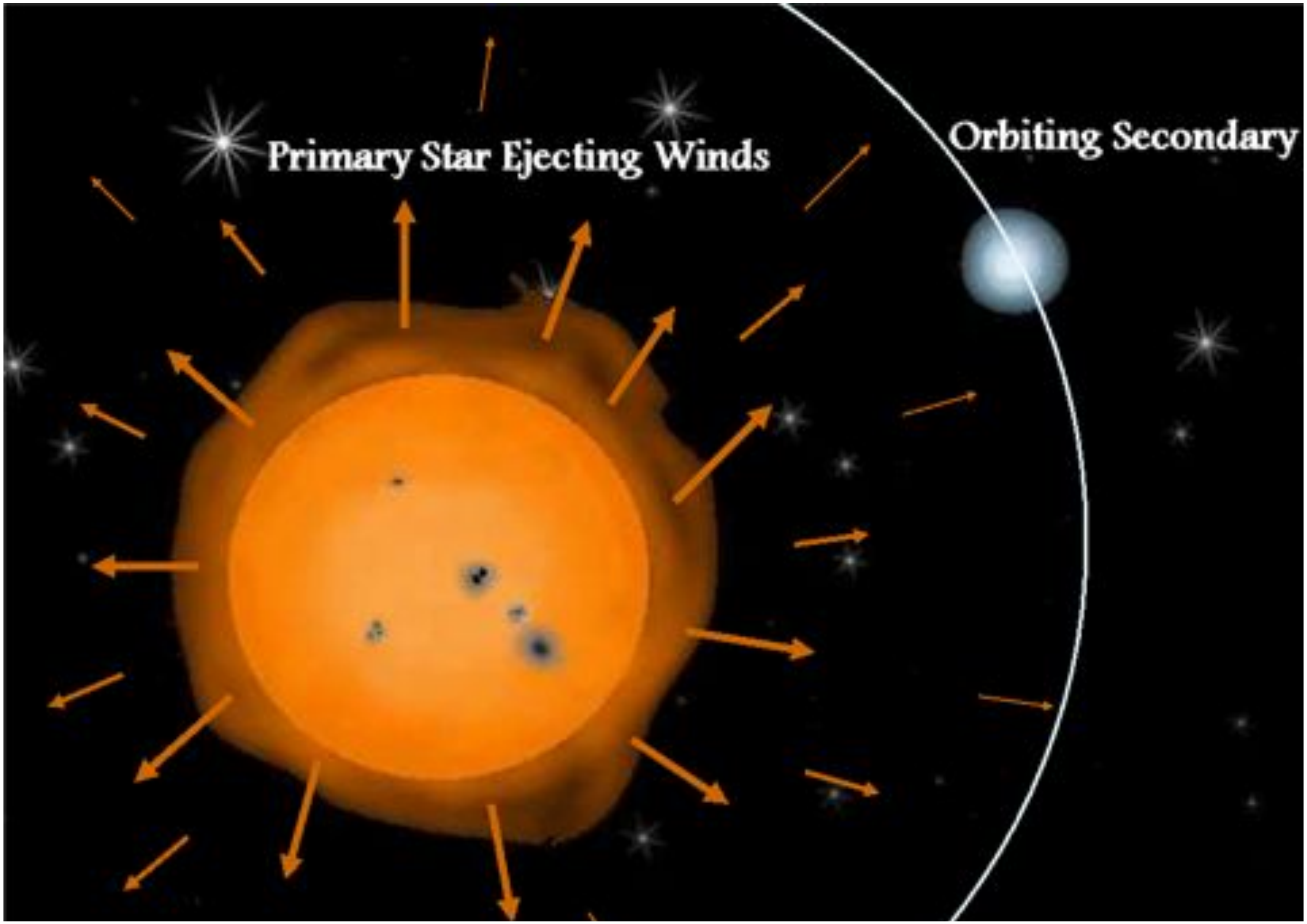
Another SB2



HIP104987 (2014-10-07)
vis2
t3Phi
min(chi2)=4.7
r=0.14* (0.004)
dE=11.20mas*
dN=0.03mas*
ρ=11.20mas
θ=89.9deg
ε={0.28mas,0.11mas,140deg}
φ1=1.44mas, φ2=0.30mas, bck=0.00
North (mas) ->
<- East (mas)



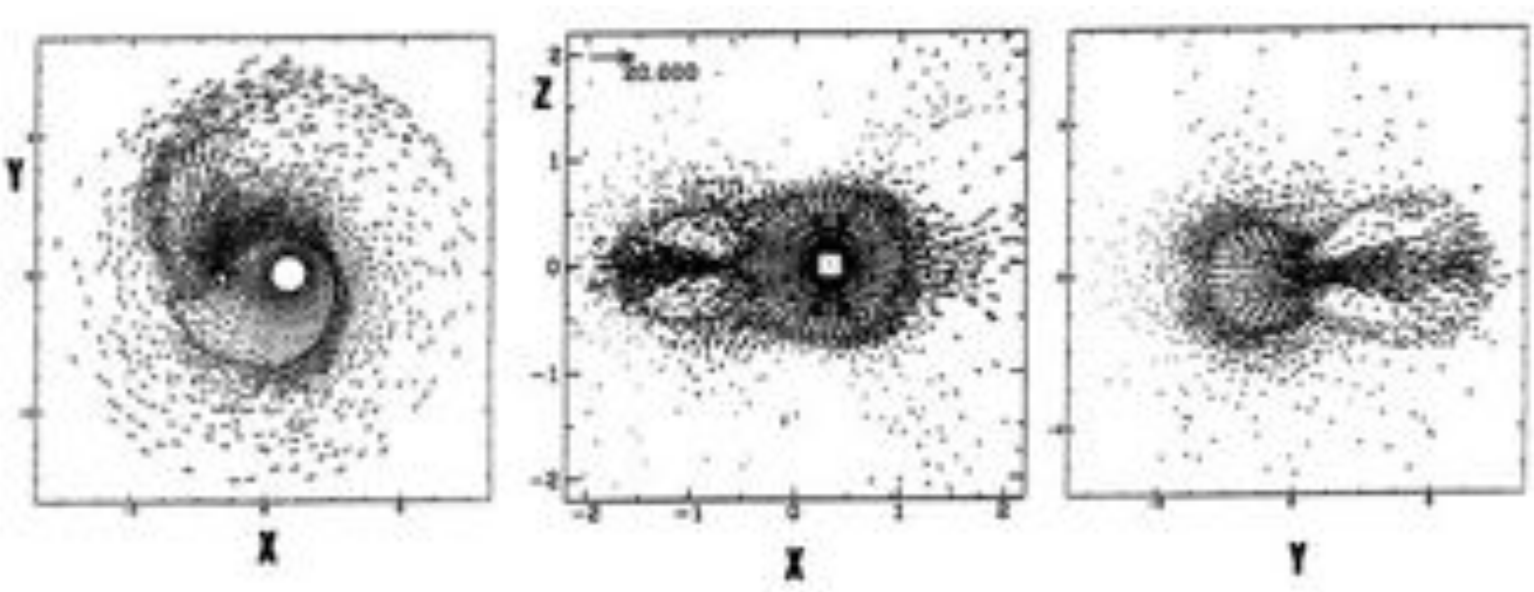
G2 III
H1 = 2.45
H2 = 7.54
Φ=1.44 mas
P=98.8 days
Delta (mas)
Alpha (mas)


Primary Star Ejecting Winds
Orbiting Secondary

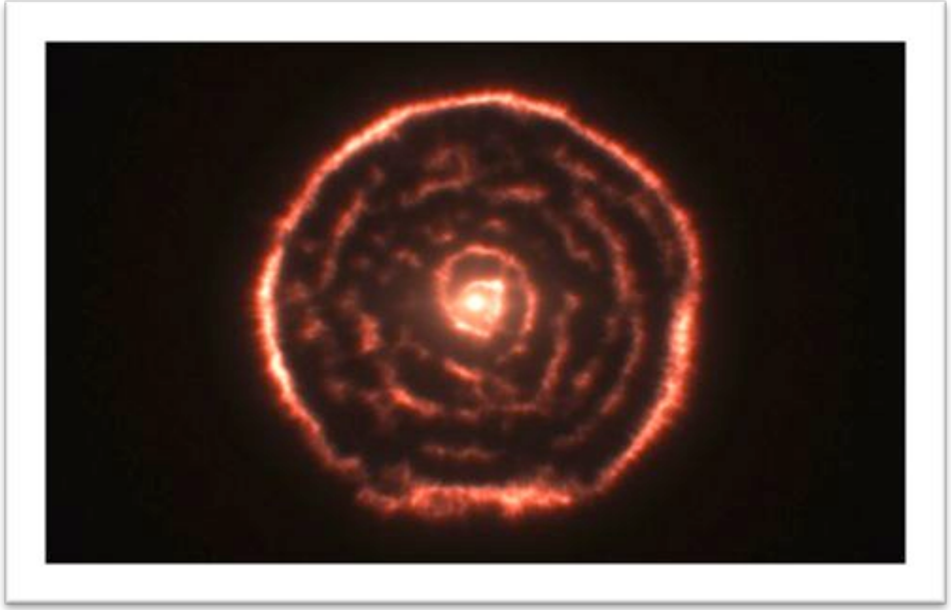
Boffin, Theuns & Jorissen 1994; Theuns, Boffin & Jorissen 1996

REAL SYSTEMS

- In AGB stars binaries of interest, the wind speed is smaller or comparable to the orbital velocity
- Not a Bondi-Hoyle (even modified) type flow
- Coriolis and centrifugal forces play a vital role
- v_w = 5–15 km/s < v_{orb} = 20–30 km/s



AGB star: R Scl

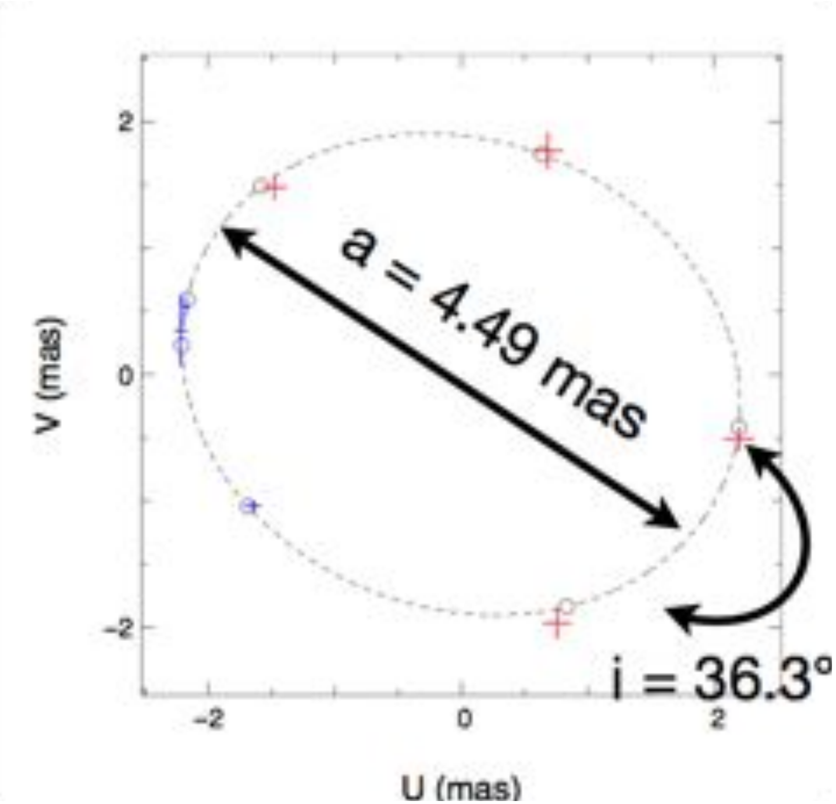


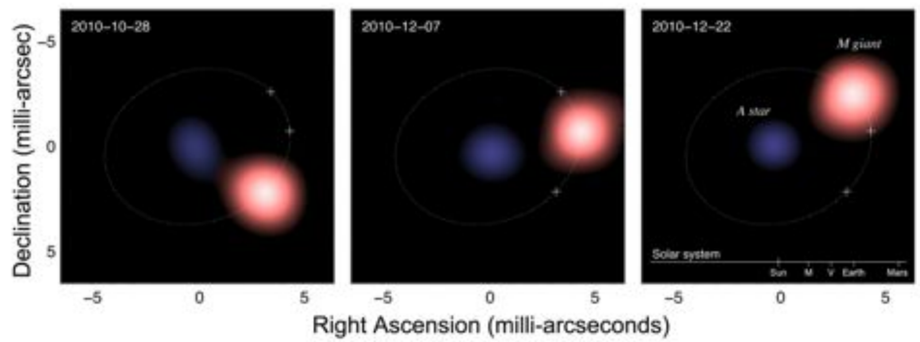
Maercker+ 2012 (ALMA)

a = 60 AU
P = 350 years (!)
$M1+M2 = 2\ M_{\odot}$

suffered a thermal pulse event about 1800 years ago that lasted for about 200 years

Visual Binary - Interferometry





SS Lep – symbiotic star
P = 260 days

Detect both components

Blind, Boffin+ 11

SS Lep: Masses

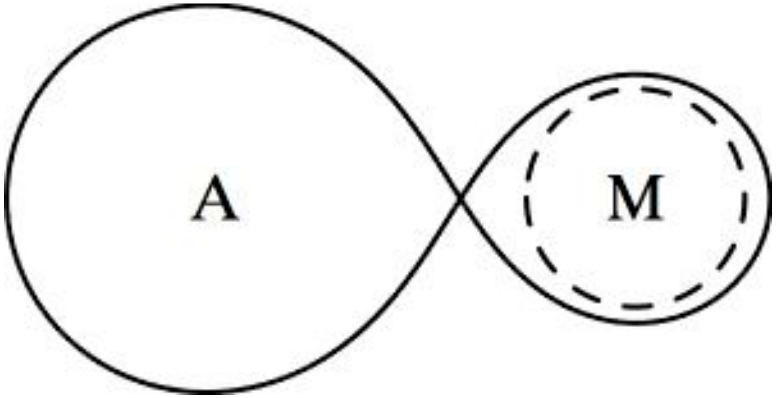
	Before	Now
d [pc]	330±70	279±24
M_A [$M_\odot$]	2~3	2.71 ± 0.27
M_M [$M_\odot$]	0.35~1	1.3 ± 0.33
M_A/M_M	4±1	2.17 ± 0.35

Mass ratio smaller than initially thought!

M giant initially more massive,
$M_M > 2.2\ M_\odot$
→ Lost at least 0.9 $M_\odot$
→ A star accreted at least 0.5 $M_\odot$

Blind, Boffin, Berger+ 11

Roche lobe overflow?

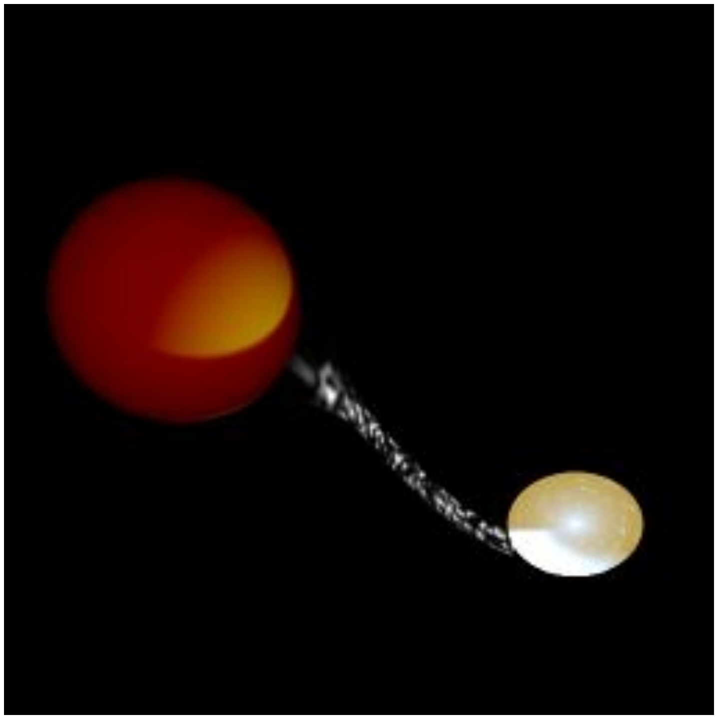


	Before	Now
diameter $\varnothing_M$ [mas]	3.11 ± 0.32	2.208 ± 0.007
d [pc]	330 ± 70	279 ± 24
$\varnothing_M$ [$R_\odot$]	220 ± 60	132 ± 5
	140%	86%

Blind, Boffin, Berger+ 11

No Roche lobe overflow!

A-star: Really fat or donut-shaped?



If matter goes through L_1 point,
one can compute the smallest radius of infalling material:
initially: $r_{min} = 9\ R_\odot >> 2\ R_\odot$ (R_A std);
now: $r_{min} = 20\ R_\odot > R_A$!
Material does not hit the A star

A disc should form instead!

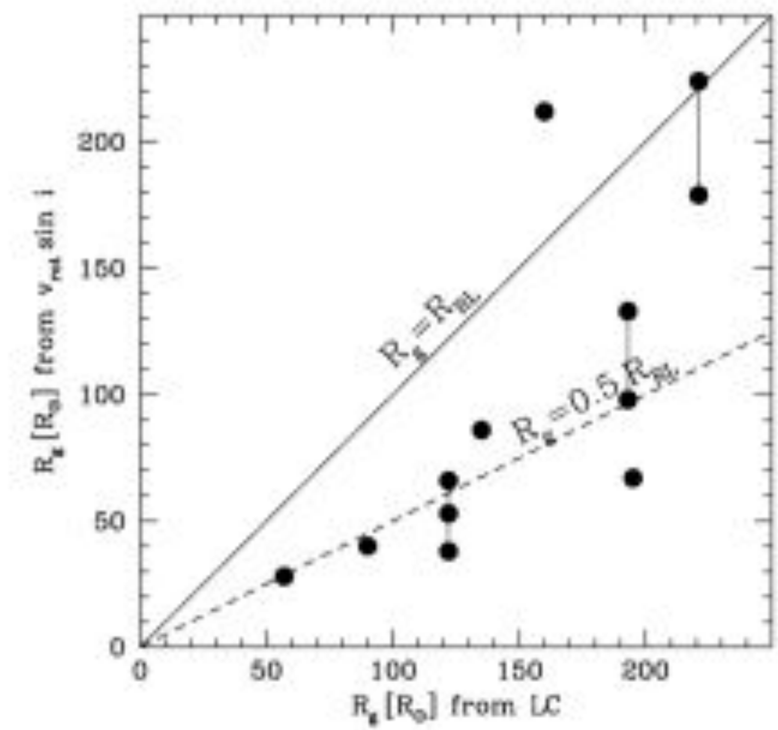
Need data with higher resolution to probe if there is a disc around the A star!

Symbiotic and related stars

- We cannot always gather as much information as with SS Lep
- But there is still much to do
- In particular to address the…

"continually embarrassing problem of symbiotic systems"

Their radii estimated from ellipsoidal variations in the light curve are systematically discrepant by a factor of 2 from radii derived from rotation velocities (*v* sin *i*)!



Mikolajewska 2007

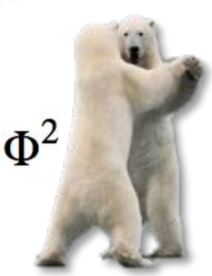
PIONIER mini-survey

Table 1. Measured diameter of our target stars.

Star designation		Date	Diameter (mas)	Error (mas)	$\chi^2_{\rm red}$
V1472 Aql	HD 190658	2012-07-03	2.33	0.03	0.82
AP Psc	HD 352	2012-08-13	1.49	0.02	2.48
V1261 Ori	HD 35155	2012-03-03	2.25	0.08	0.87
ER Del	–	2012-08-13	0.61	0.04	0.80
FG Ser	–	2012-07-03	0.83	0.03	0.69
	–	2012-08-13	0.94	0.05	0.26
AG Peg	HD 207757	2012-08-13	1.00	0.04	1.31

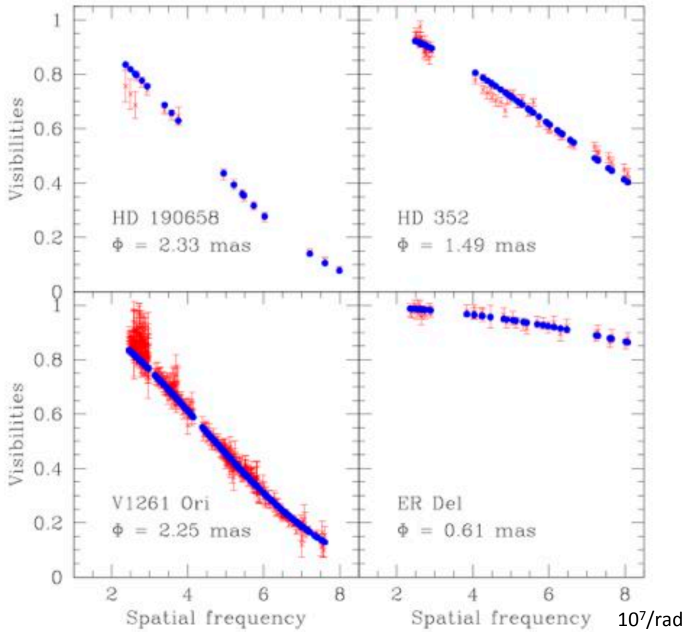
Boffin+, 2014

$$\sigma^2 = N_{\rm sp}\,\sigma^2_{\rm litpro} + 0.0001\,\Phi^2$$

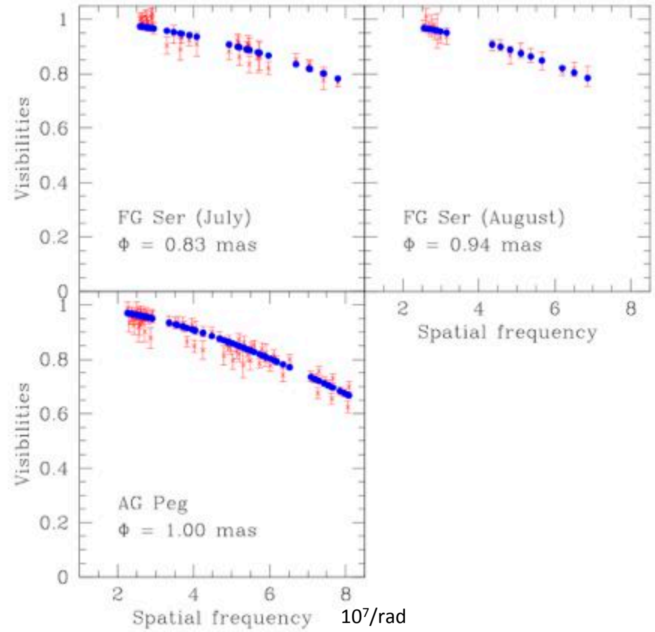


Visibilities

V^2



V^2



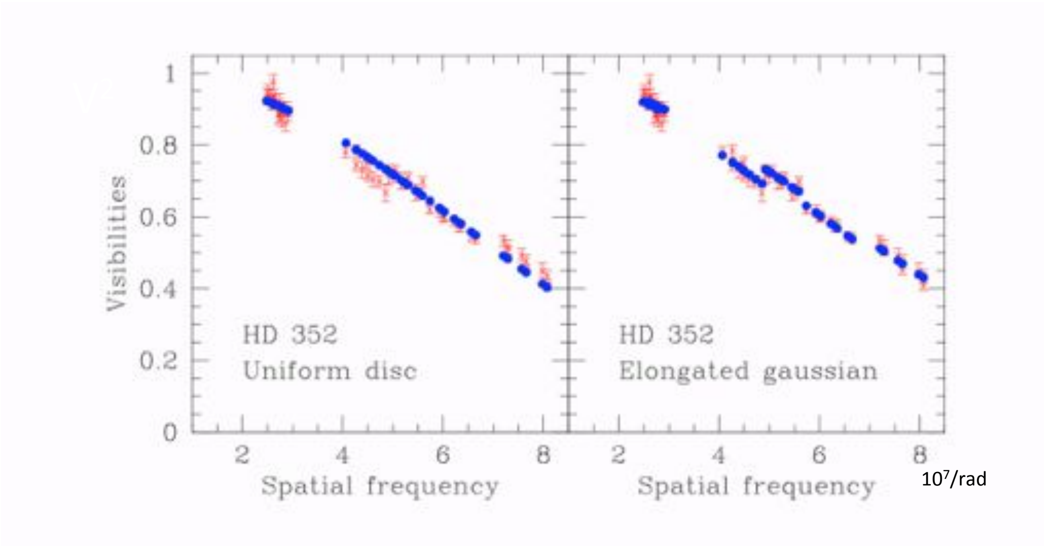
Can generally be fitted with a simple uniform disc

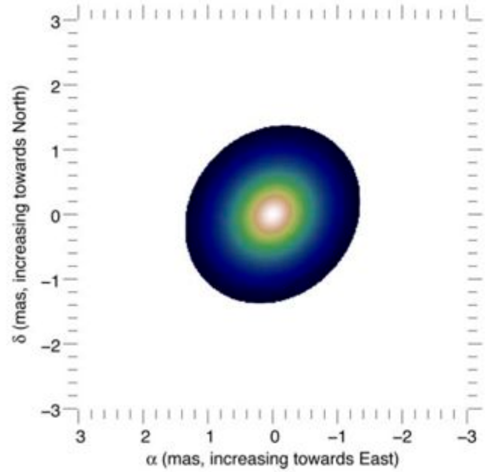
Boffin+, 2014

HD 352 = AP Psc = 5 Cet

- Semi-detached system? (Eaton & Barden 86, 88: hot secondary is immersed in dense lower atmosphere of K giant)
- P = 96.4371 d
- Ellipsoidal variations
- π = 3.58 ± 0.48 mas (van Leeuwen 07)
- PIONIER: R = 0.745 mas → R = 45 ± 6 $R_\odot$
- $R_L \approx 50\ R_\odot$ → $R/R_L \approx 0.9 \pm 0.1$!

HD 352 - Elongated

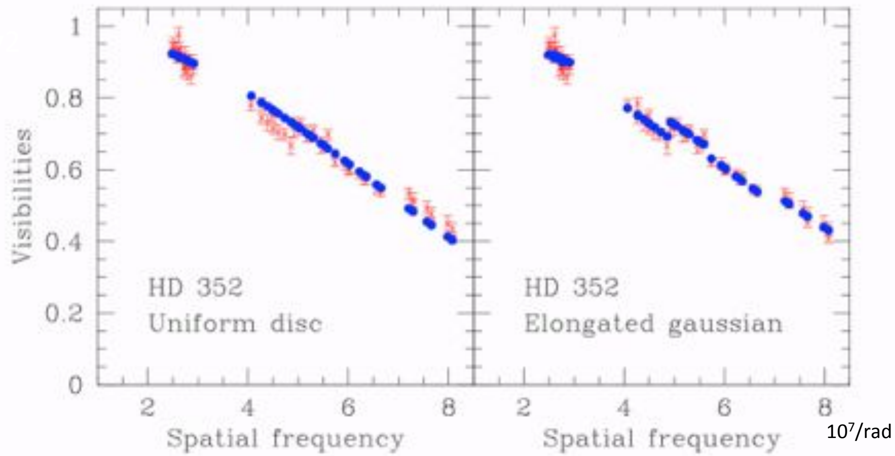


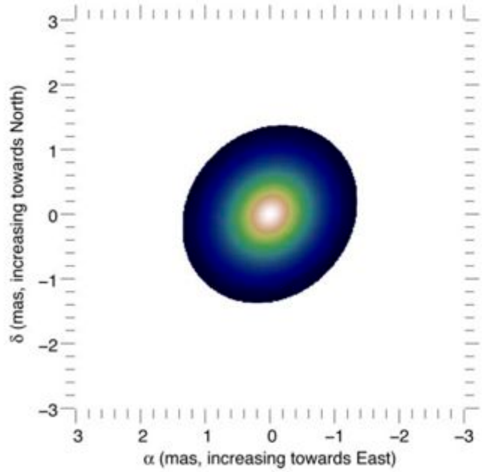


Elongation ratio: 1.16

1.38 x 1.6 mas

HD 352 - Elongated





Elongation ratio: 1.16

1.38 x 1.6 mas

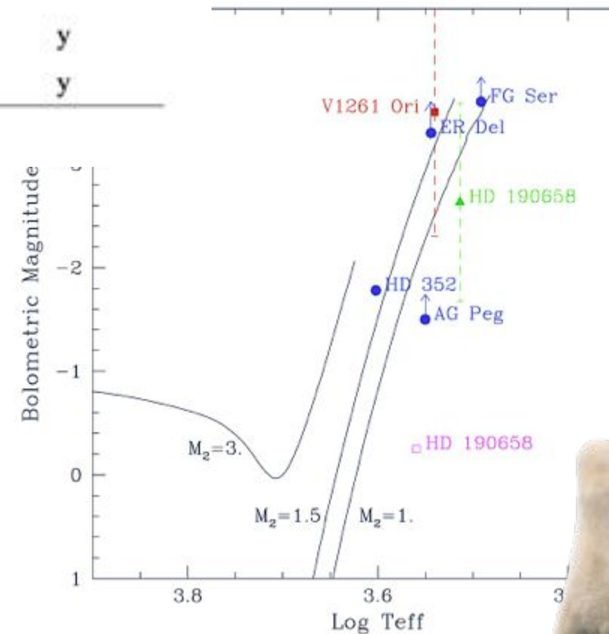
Need to:

- Have better data with longer baselines to confirm this
- Measure diameter as function of orbital phase
- Compare with LC models

PIONIER mini-survey

Table 6. Summary table of parameters of our target stars.

Star	Parallax (mas)	T_{eff} (K)	Radius ($R_\odot$)	M_{bol}	$f = R/R_L$	$v \sin i$ km/s	synchronised?
HD 190658	2.6:	3260	104:	−2.6:	0.4–1	?	–
HD 352	3.58	4000	44.7	−1.78	0.8–1	22	y
V1261 Ori	~ 1.96	3650	~ 120	−3.5	~0.3	< 4	n
ER Del	> 0.4	3500	> 115	< −3.3	0.2 – 0.3	< 4	–
FG Ser	< 0.6	3100	~ 160	< −3.6	~ 1	9.8	y
AG Peg	< 1	3550	> 47	< −1.5	0.25–0.55	8.5	y



Boffin+, 2014

Visible: Sample more stars

Sp. Type	M_V	M_H	D_V (pc)	D_H (pc)
O V	-5	-4	10,000 pc	2,500
B V	-3	-2.9	4,000	1,500
A V	1.5	1.3	500	215
G V	5	3.5	100	80
M V	9	4.8	16	44
WD	12	11.8	4	1.7
K III	0.5	-2.1	800	1000
M IIII	-0.6	-4.8	1300	3700

Visible: Sample more stars

Star	M_v	D_V (pc)
O V	-5	10,000
B V	-3	4,000
A V	1.5	500
G V	5	100
M V	9	16
K III	0.5	800
M IIII	-0.6	1300

One can thus reach the Bulge and GC!

At 10 kpc, a=0.1 mas
→ A=1 AU!

The total number of potential binaries to study is huge!

Visible: Sample more stars

- O V stars
  - D=150 pc   P ~ 6 – 1000 days; q > 0.04
  - D=1 kpc   P > 100 d; q > 0.1
  - D=10 kpc   P > 9 yrs; q ~ 1
- A V stars
  - D=10 pc   P < 100 d; q > 0.1
  - D=100 pc   P ~ 1 d to 10 yrs; q > 0.25
  - D=500 pc   P ~ 8 d to 100 yrs; q ~ 1
- G V stars
  - D=10 pc   P < 70d; q > 0.2
  - D=50 pc   P < 2 yrs; q > 0.5
  - D=100 pc   P < 6 yrs; q ~ 1