A PIONIER's View on Symbiotic and Related Stars

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B. Lazareff & the PIONIER team

For the history buff

Fleming (1912)

HD catalogue – Stars with Peculiar Spectra, displaying bright emission lines

Merrill (1919)

R Aqr: bright [O III] nebular lines on top of a normal M giant spectrum

Merrill & Humason (1932)

3 new Stars with Combination Spectra: CI Cyg, RW Aqr, AX Per. In these, TiO bands of a M giant are blended with Balmer, He II, [O III] and [Ne III] emission lines

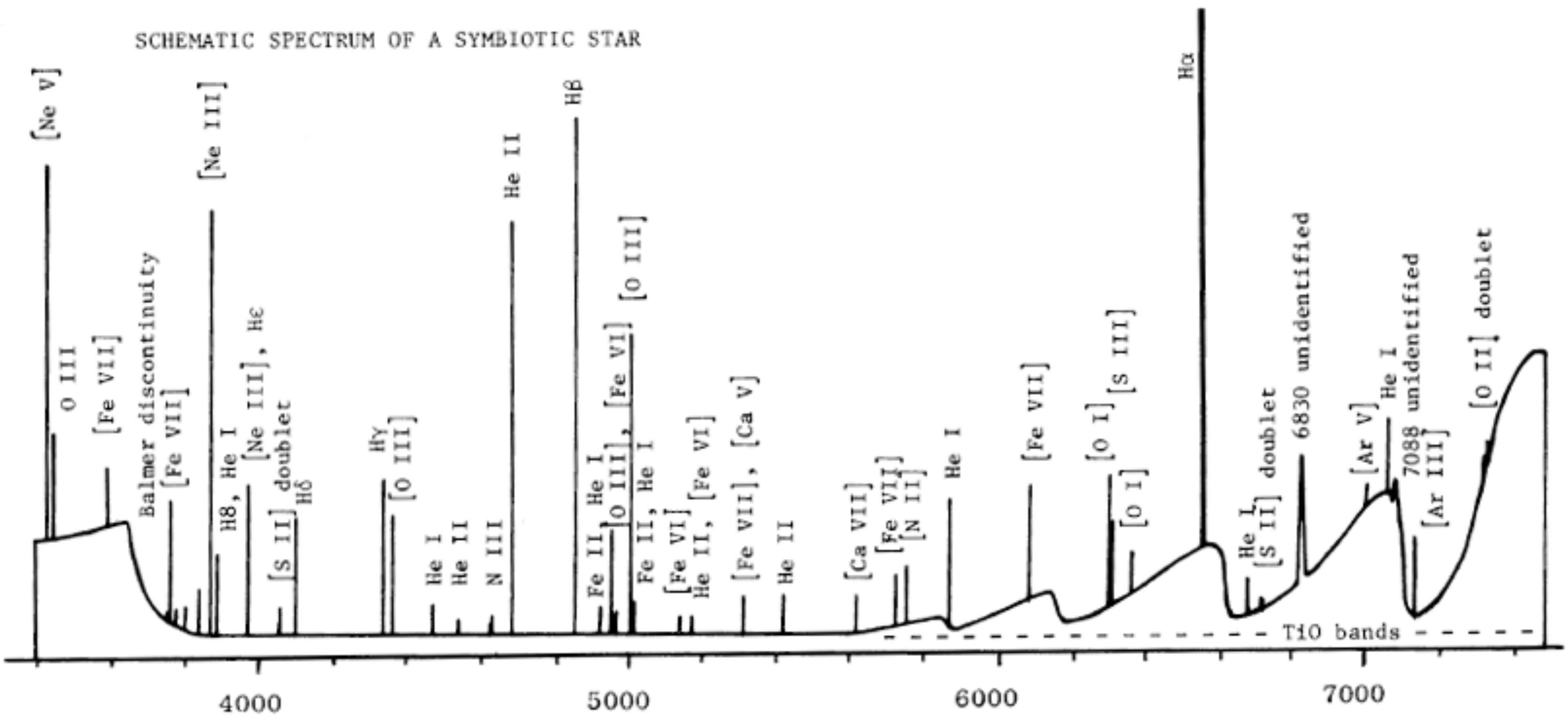
For the history buff

Merrill (1941)

Coined the term *Symbiotic Star* : a cool red giant and a small hot companion seem to live in general harmony (although with occasional disagreement; Kenyon 1986)

Oxpeckers eat the parasites off of large animals like this African buffalo. But they're also parasites themselves, keeping wounds open and picking at scabs.
Natphotos/Digital Vision/
Getty Images
howstuffworks.com

Spectrum of Symbiotic Star



Defining a Symbiotic Star

Kenyon (1986):

1. Presence of absorption bands typical of late-type giants, e.g. TiO, H2O, CO, CN, VO, and absorption lines from CaI, CaII, FeI, NaI

2. Presence of strong emission lines of H and He, and either

- bright lines of ions with high ionisation potential (e.g. [O III])

- an A or F-type continuum with additional absorption lines from H I and He I (when in outburst)

Defining a Symbiotic Star

Boyarchuk (1969):

object should show irregular optical variability

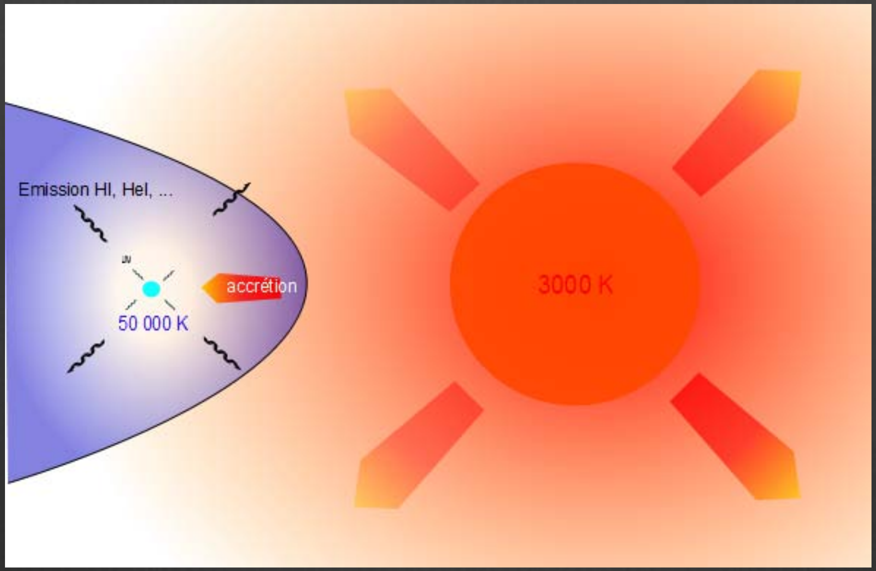
Nussbaumer (1982):

the object cannot be simply classified as something else

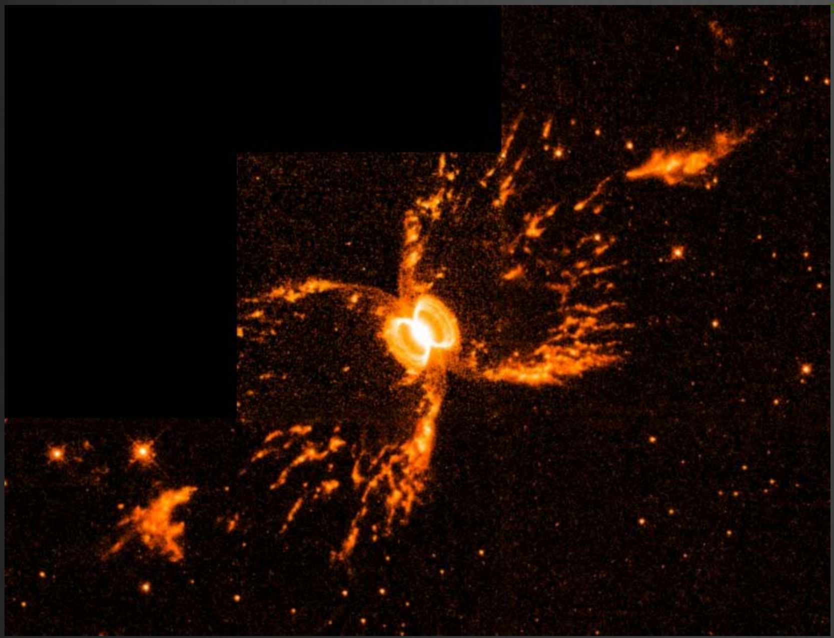
"*It can be said that every known symbiotic star has, at one time or another, violated all the classification criteria.*" (Kenyon 1986)

Binaries

- Current accepted model: Symbiotic stars are interacting binaries containing a cool giant (G, K, M) and an accreting hot star (main sequence or white dwarf)



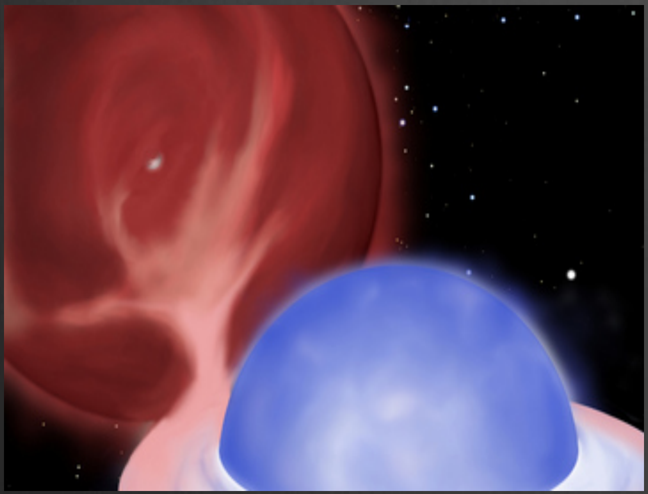
Binaries



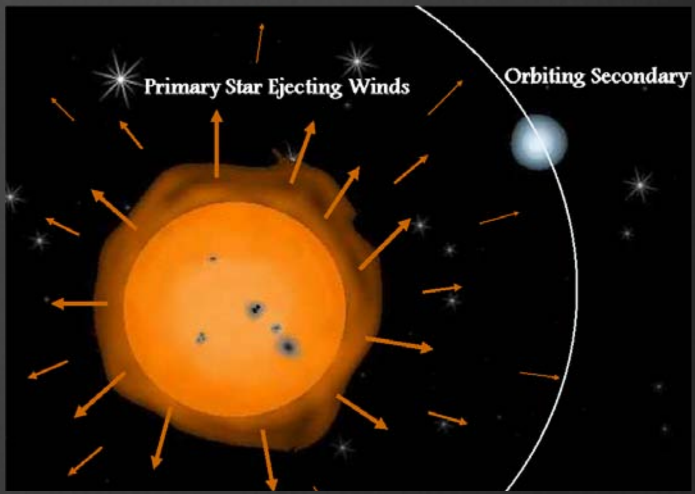
- About 40 symbiotic systems with orbital period known
- Orbital period: 100 – 1400 d
- Giant have larger mass-loss rates than single giants of the same spectral type: why?
- origin of mass transfer?

Binaries

- Symbiotic stars can be divided into two categories based on the nature of the components:

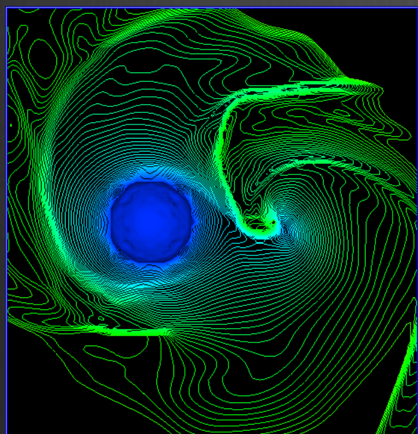


(a) a lobe-filling giant and a A-F main sequence star

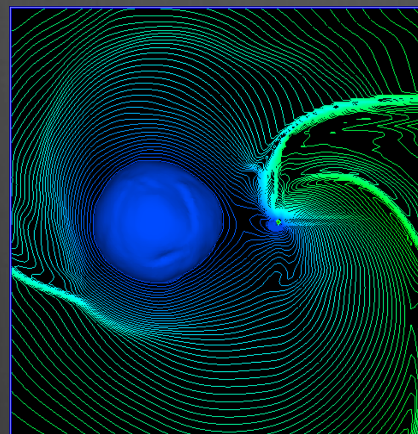


(b) a white dwarf or subdwarf and a red giant losing mass in a stellar wind

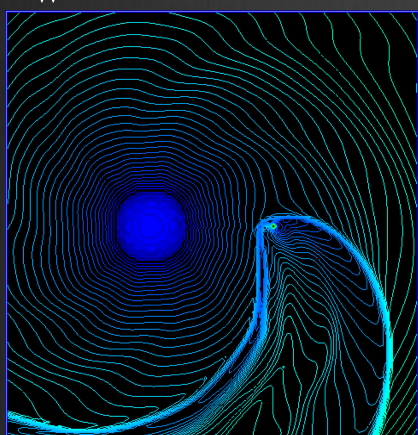
WIND Mass Transfer



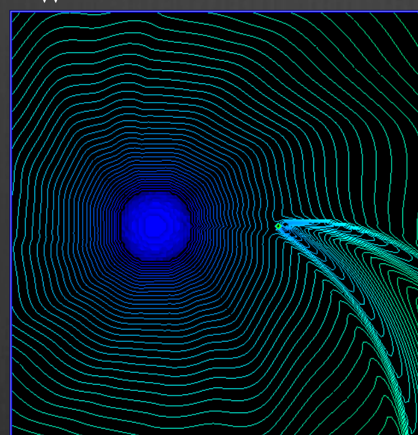
$v_w = 0.03$



$v_w = 0.10$



$v_w = 1.35$



$v_w = 3.78$

Nagae, Oka, Matsuda, Fujiwara, Hachisu, Boffin, 2004;

See also Boffin & Anzer 1994; Theuns, Boffin & Jorissen 1996

Example: q=3

Varying wind velocity with respect to orbital speed

Flows very different - from Bondi-Hoyle type (but with asymmetry) to very complex ones

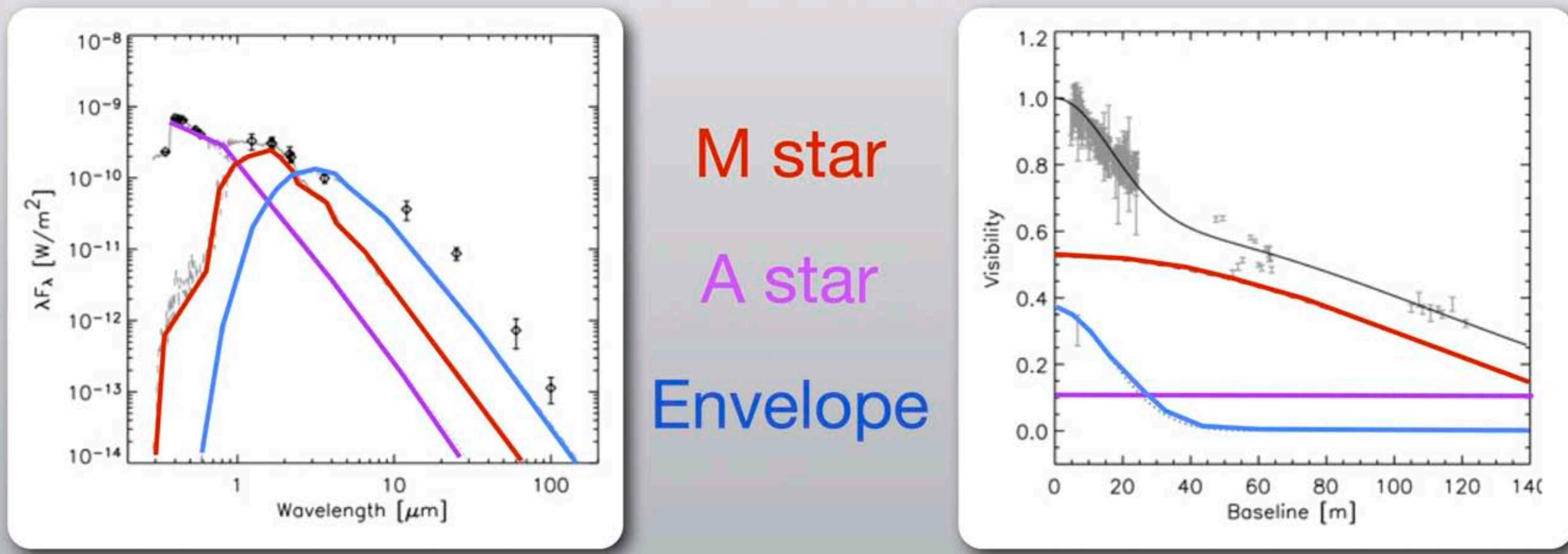

SS Lep

SS Lep = HD 41511

- V = 5.0 !
- M4 III star + A1 companion
- P = 260.3 d
- M giant is least massive of two : mass transfer reversal (Algol)
- The A star radius ~ 10 times A V radius : swollen by accretion?
- A star is rapidly rotating : spin accretion?

Welty & Wade 1995

VINCI



Verhoelst et al. 2007, Welty et al. 1995, Jura et al. 2001

The system is surrounded by a circumbinary disc, probably fed by the RLOF, which thus appears to be non conservative

SS Lep before PIONIER

	System		A star	M star
d [pc]	279 ± 24 [a]	SpT	A1V [b]	M6III [c]
P [d]	260.3 ± 1.8 [b]	$T_{\rm eff}$ [K]	9000 [c,d]	3500 [c,d]
e	0.024 ± 0.005 [b]	θ [mas]	0.53 ± 0.02 [c]	3.11 ± 0.32 [c]
i	$30° \pm 10°$ [c]	R [$R_\odot$]	~ 15 [c]	110 ± 30 [c]
$f(M)$	0.261 ± 0.005 [b]	F [%]	11 ± 7 [c]	60 ± 50 [c]
$1/q$	4 ± 1 [b,c]	M [$M_\odot$]	$2 \sim 3$ [a,b]	$0.4 \sim 1$ [a,b]

Notes. d is the distance, P the orbital period, e the eccentricity, i the inclination, $f(M)$ the mass function, $q = M_M/M_A$ the mass ratio. For the stars, SpT is the spectral type, $T_{\rm eff}$ the temperature, θ the apparent diameter, R the linear radius, F the flux contribution at $2.2\,\mu m$, and M the mass. References: (a) Van Leeuwen 2007; (b) Welty & Wade 1995; (c) Verhoelst et al. 2007; (d) Blondel et al. 1993

AMBER & PIONIER

Table 2. VLTI Observation log of SS Lep for the AMBER and PIONIER observations.

Run	Date
A1	11-11-2008
	13-11-2008
A2	26-12-2008
A3	21-02-2009
	28-02-2009
A4	07-04-2009
P1	28-10-2010
	30-10-2010
P2	29-11-2010
P3	07-12-2010
P4	22-12-2010

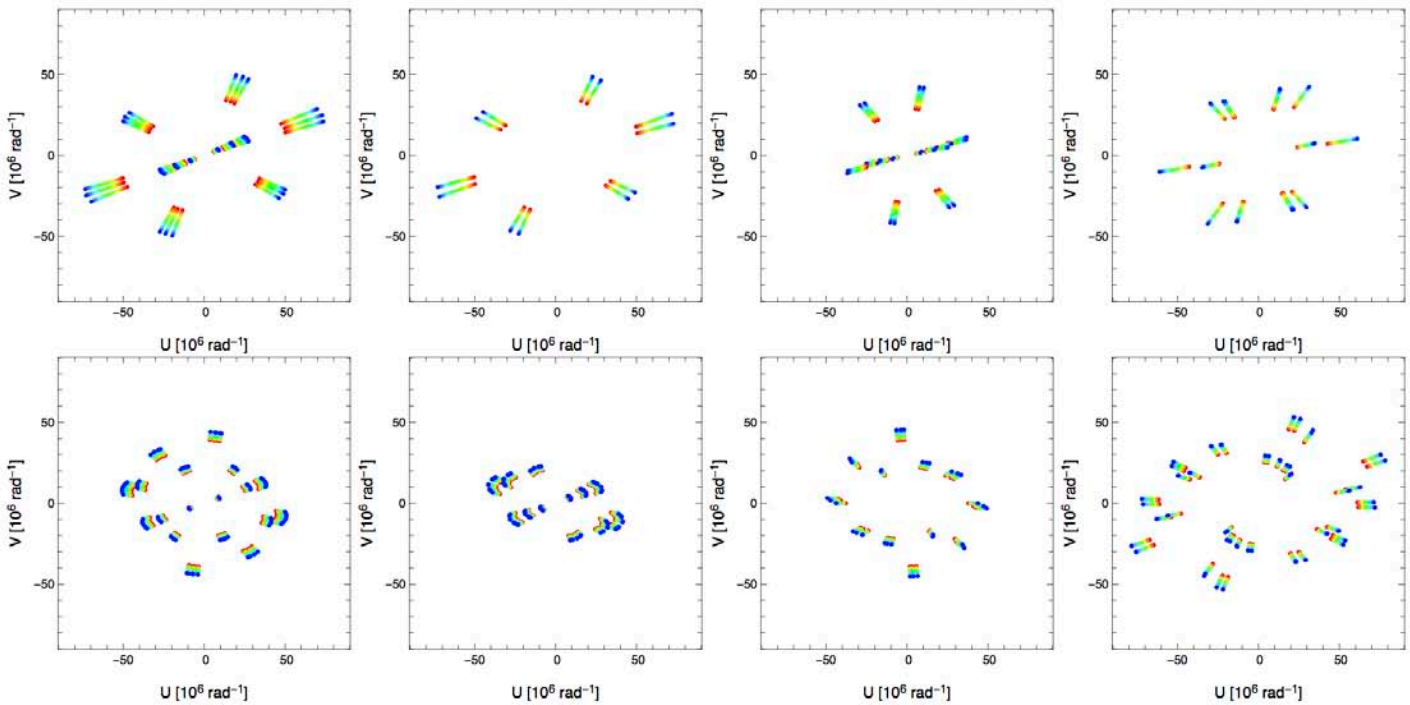
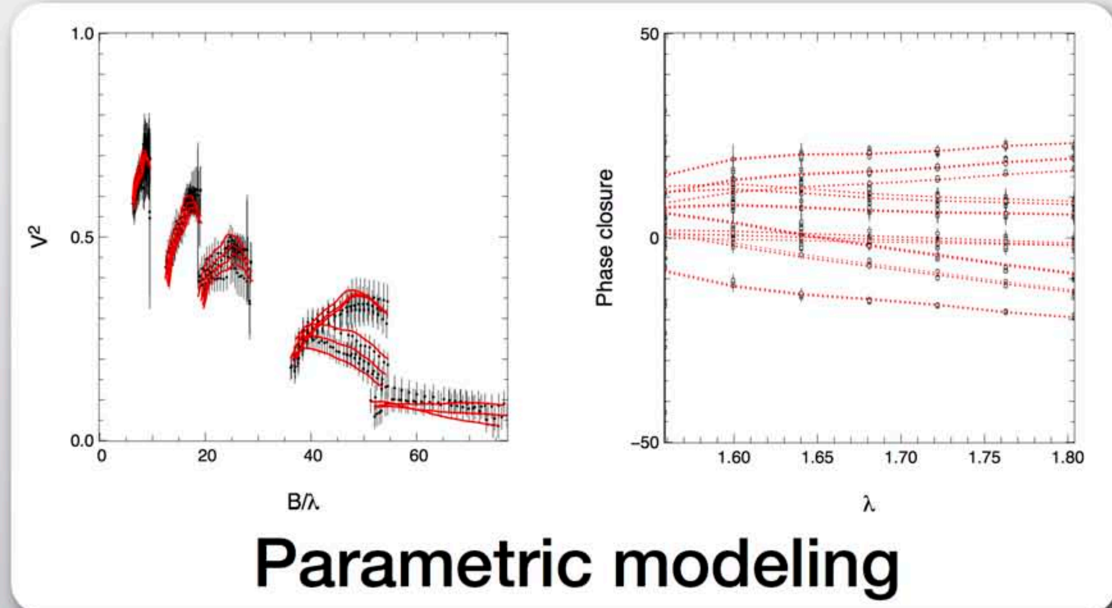
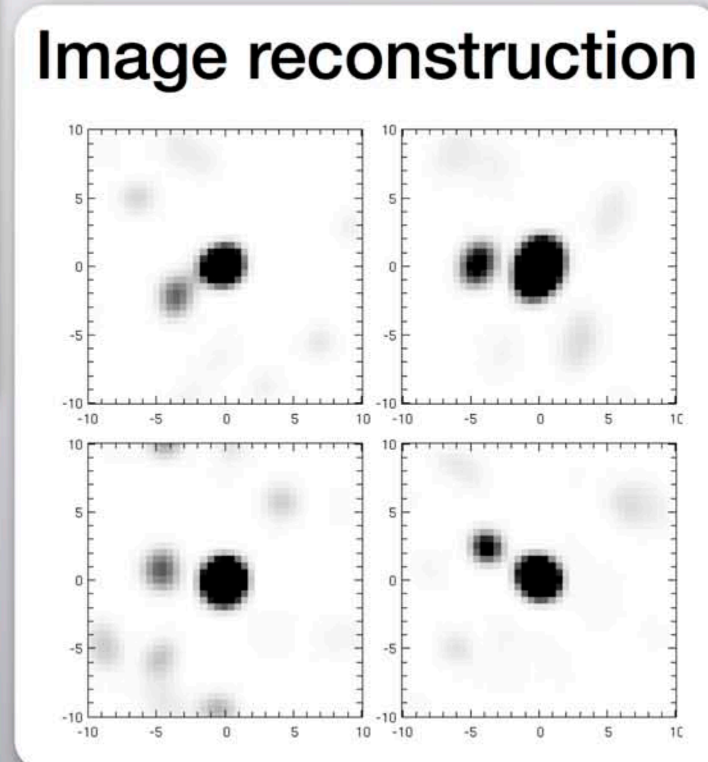


Fig. A.1. *(u,v)*-plane coverage for observations of SS Lep (top: AMBER; bottom: PIONIER).

Analysis



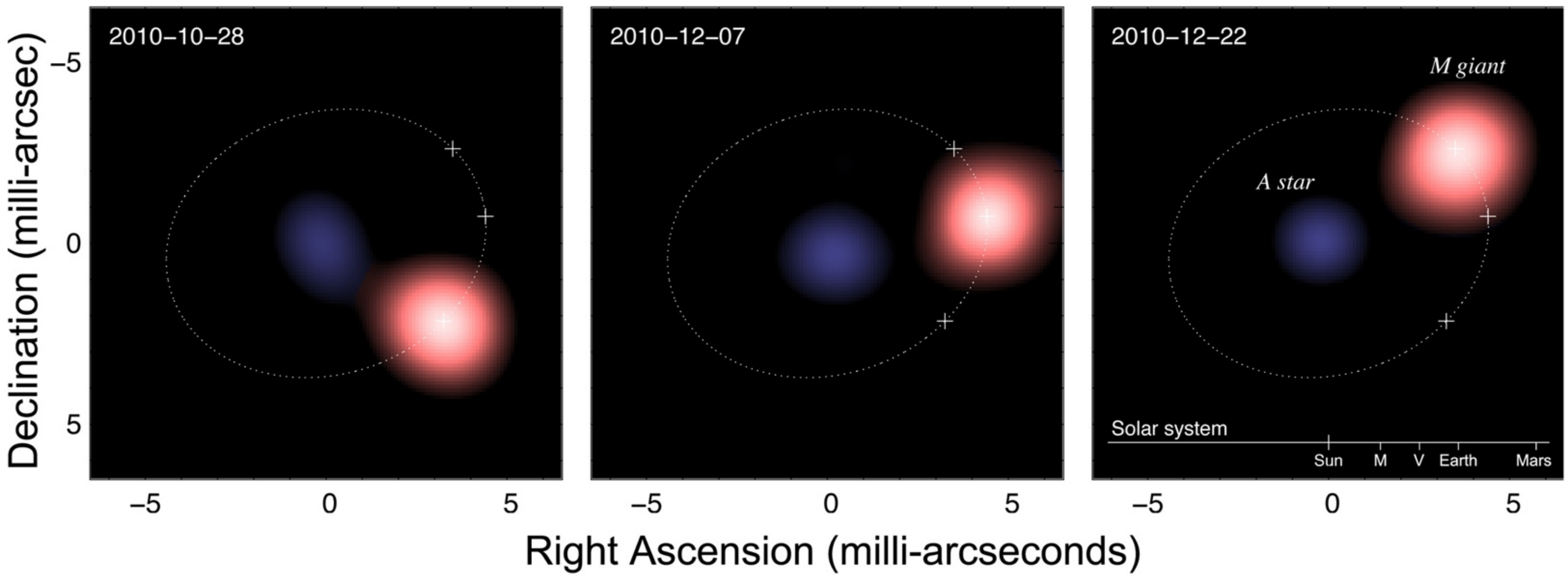
M giant, A star (unresolved) and envelope
6 degrees of freedom



Blind, Boffin, Berger+ 11

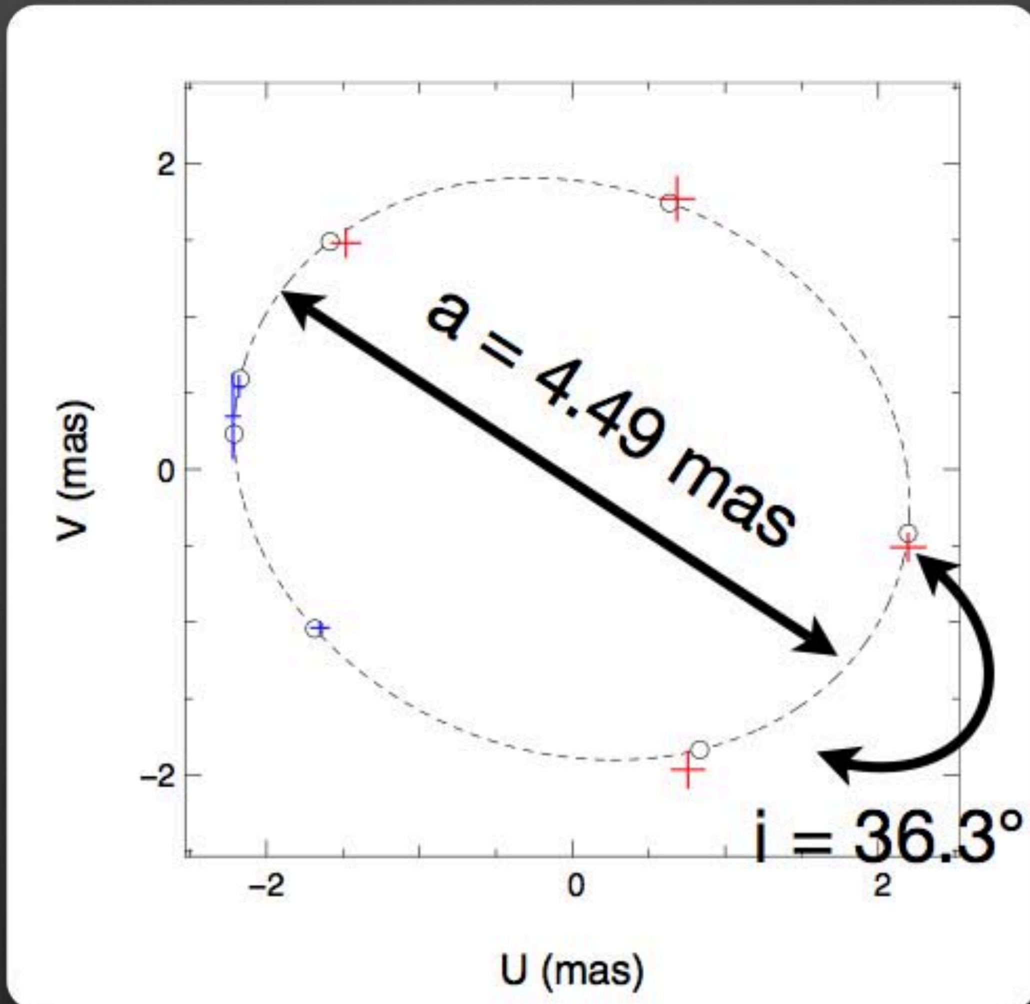
Image Reconstruction

- PIONIER data - 2 month-span



Blind, Boffin, Berger+ 11

Orbit



Blind, Boffin, Berger+ 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 $M_\odot$

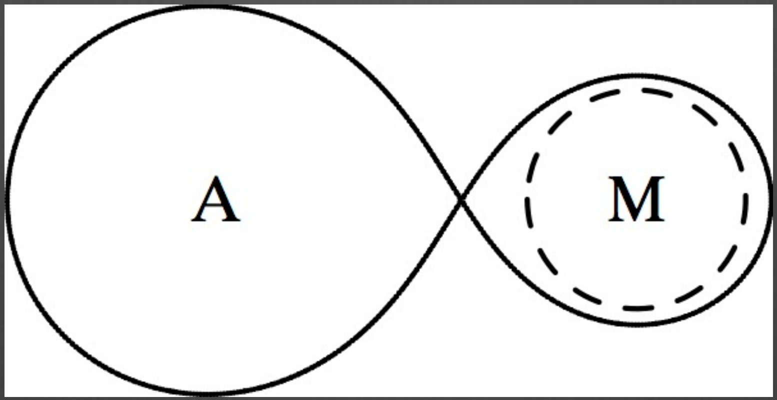
Blind, Boffin, Berger+ 11

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
Roche lobe filling		

Blind, Boffin, Berger+ 11

Roche lobe overflow?

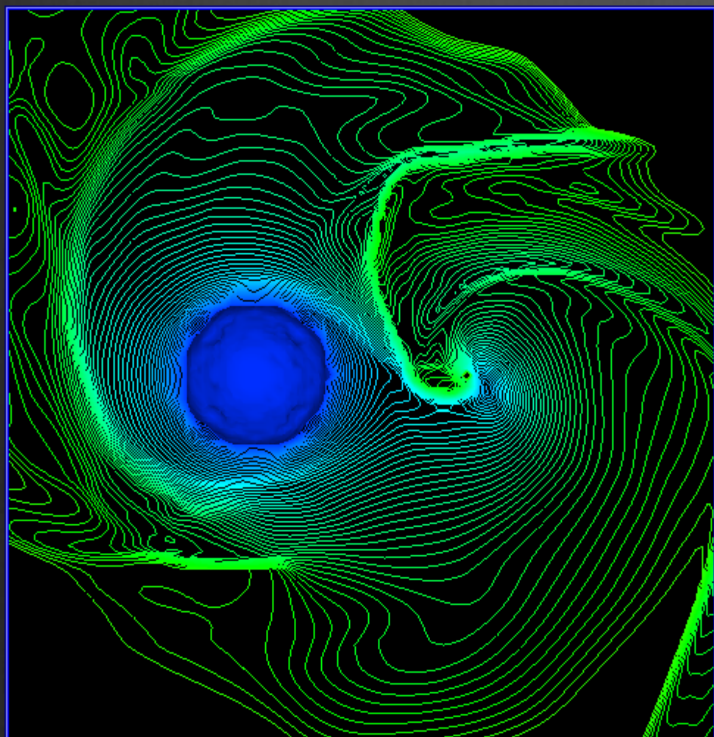


	Before	Now
diameter $\varnothing_M$ [mas]	3.11 ± 0.32	2.208 ± 0.007
d [pc]	330 ± 70	279 ± 24
$\varnothing_M$ [$R_\odot$]	220 ± 60	132 ± 5
Roche lobe filling	140%	86%

Blind, Boffin, Berger+ 11

No Roche lobe overflow!

Mass Transfer



Are we in a transient phase of stable RLOF prior to CE phase?

Or is it the case of wind RLOF?

v_w~5-15 km/s, while v_{orb} ~ 30 km/s

But this requires invoking the CRAP mechanism to have enough mass loss in lifetime of star

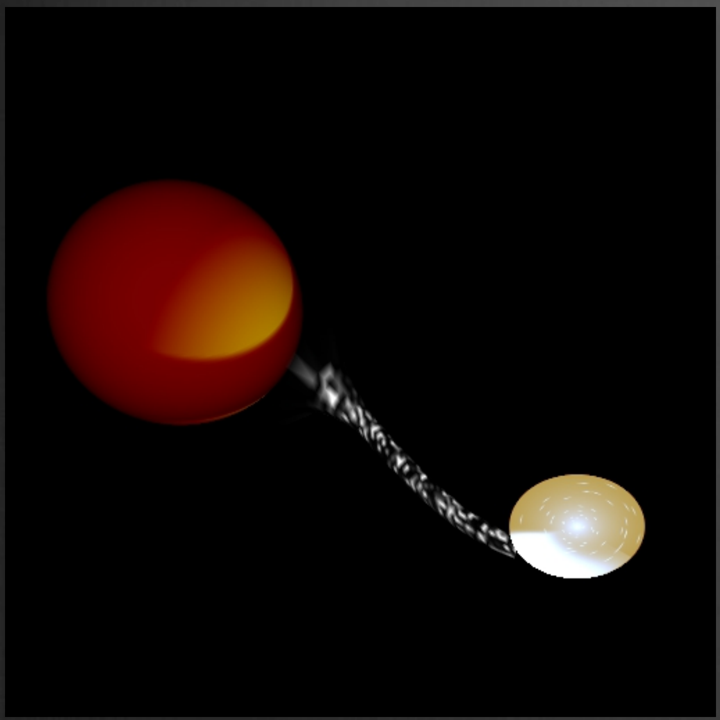
A-star: Really fat or donut-shaped?

From the SED, $R_A = 18\ R_\odot$ >> typical radius of A star

If real, this may be due to a mass accretion
at a rate ~ $5\ 10^{-5}\ M_\odot$/yr (Kippenhahn & Meyer-Hofmeister 1977)
 - **high!**

Is the A star really so fat?
Break-up velocity for A star of this size is 186 km/s!
But $v \sin i$ = 118 km/s (Royer et al. 2002)
If assume star rotates in plane of binary system → v = 196 km/s!

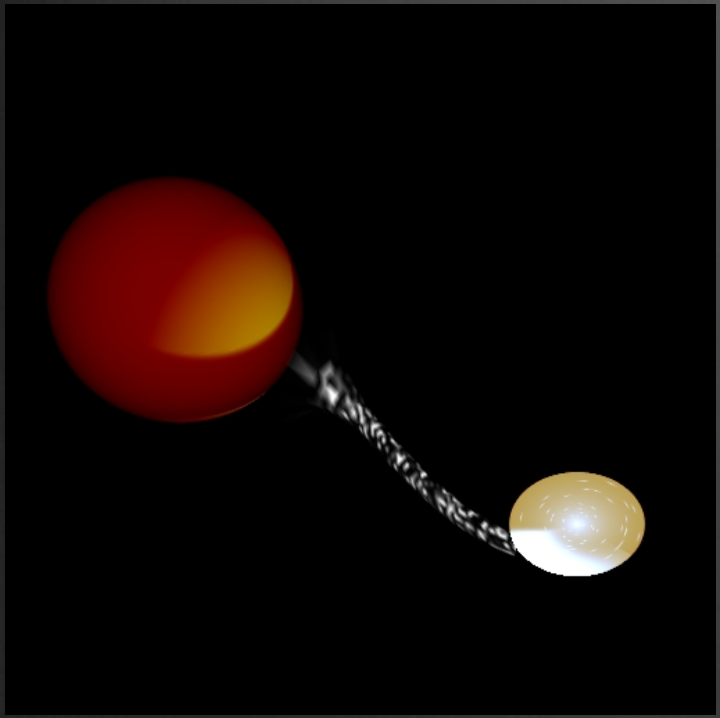
A-star: Really fat or donut-shaped?



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!

A-star: Really fat or donut-shaped?



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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!

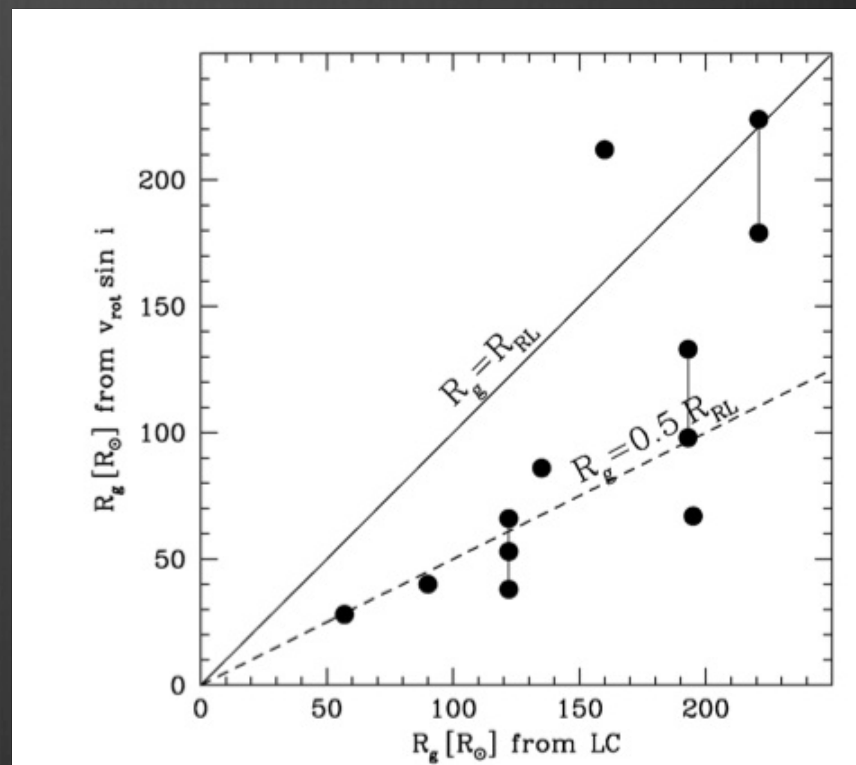
Symbiotic and related stars

- 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



“continually embarrassing problem of symbiotic systems”

Possible explanations (Mikolajewska 2007):

- **the radius derived from *v* sin *i* is biased:** no synchronism or the assumption of a spherical giant in combination with a simple limb-darkening law biases the *v* sin *i* determination
- **the Roche potential** used for the ellipsoidal variability **needs to be adapted** by including radiation effects, e.g., Schuerman 72, Dermine+ 09
- **the red giant atmosphere may be very extended and stratified** so that the different methods probe different radii, due, e.g. to an extended atmosphere or a stellar wind filling the Roche lobe (cf SS Lep).

PIONIER mini-survey

089.D-0527 PI: M. Hillen

Table 1. Measured diameter of our target stars.

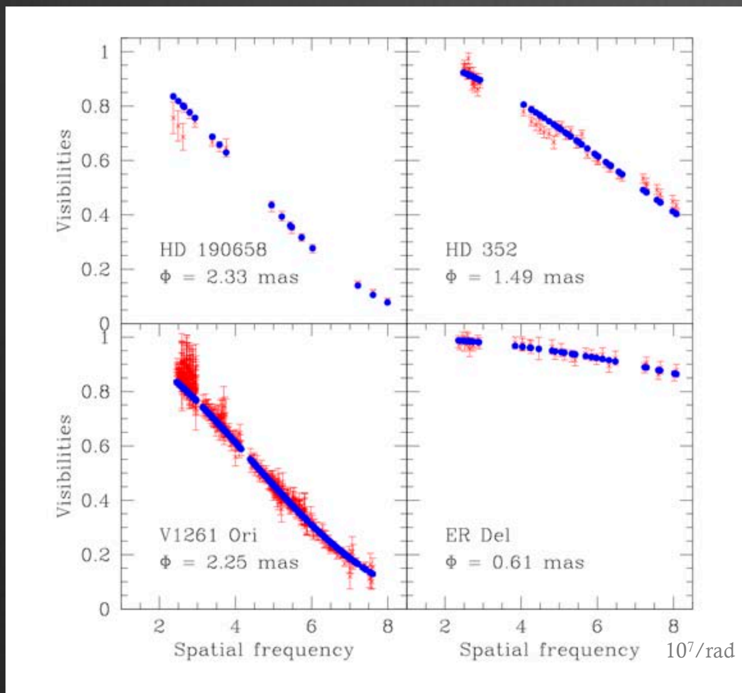
Star designation		Date	Diameter (mas)	Error (mas)	$\chi^2_{\rm red}$
V1472 Aql	HD 190658	2012-07-03	2.33	0.03	0.82
AP Psc	HD 352	2012-08-13	1.49	0.02	2.48
V1261 Ori	HD 35155	2012-03-03	2.25	0.08	0.87
ER Del	–	2012-08-13	0.61	0.04	0.80
FG Ser	–	2012-07-03	0.83	0.03	0.69
	–	2012-08-13	0.94	0.05	0.26
AG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

Boffin, Hillen, Berger+, submitted

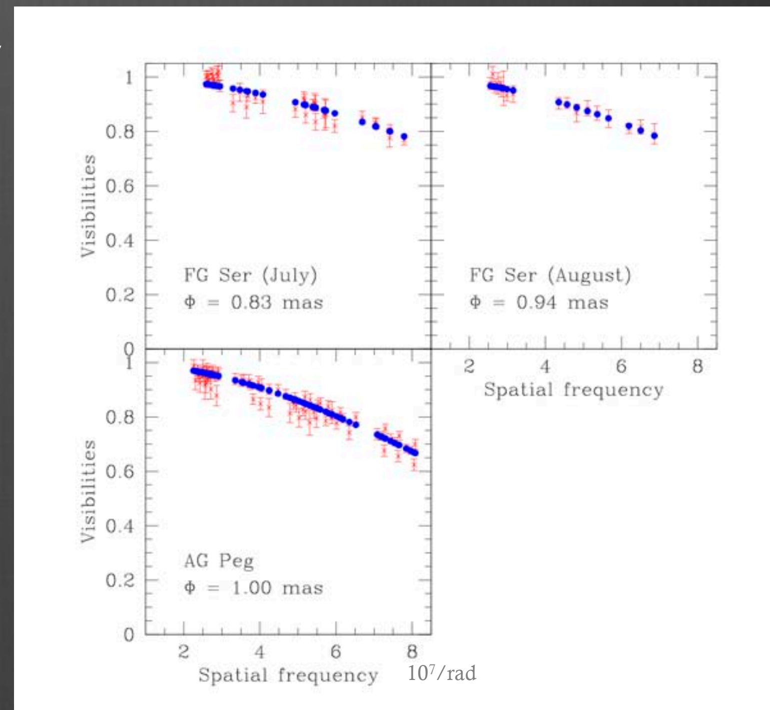
$$\sigma^2 = N_{\rm sp}\,\sigma^2_{\rm litpro} + 0.0001\,\Phi^2$$

Visibilities

V^2



V^2



Can generally be fitted with a simple uniform disc

Boffin, Hillen, Berger+, submitted

Adding background

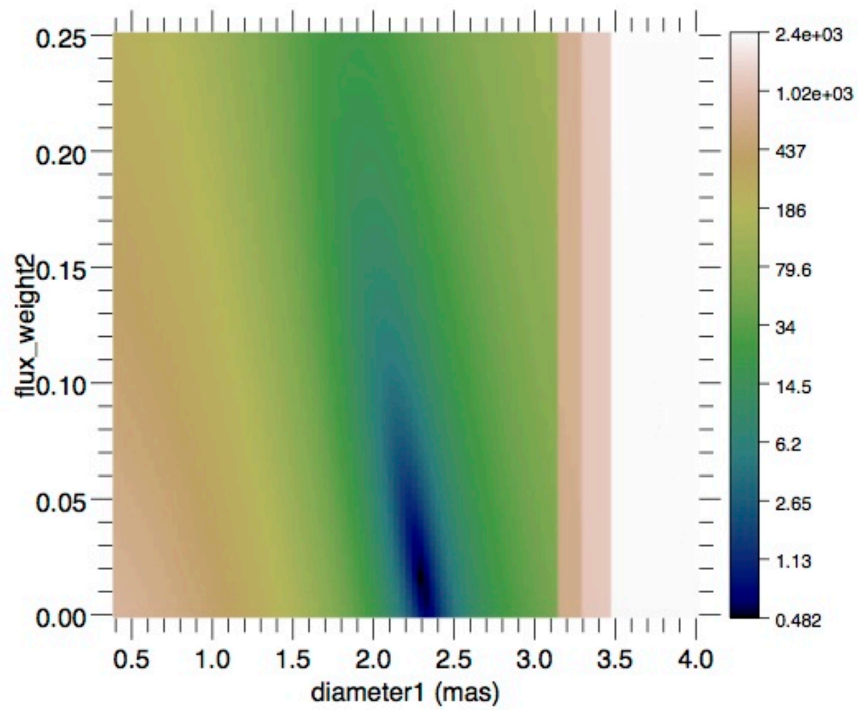


Fig. 12. Reduced χ^2 maps for HD 190658: shown is the reduced χ^2 (logarithmic scale) as a function of the angular diameter (x-axis) and the relative flux level of the background (y-axis) based on our PIONIER data. These maps were computed using `LITpro` assuming a uniform disc plus background model. It appears clearly that the minimal reduced χ^2 corresponds to the model without any added background.

Methodology

- Diameter from PIONIER data (in mas)
- Hipparcos distance (when available) → physical radius (in $R_\odot$)
- If no Hipparcos distance, use R-M-L relation for giants
- Assume typical BC_K vs (J–K) relation for giants to derive distance-independent T_{eff} from diameter
- From spectroscopic binary mass function, f(m), can relate M_G to M_c for given inclination
- From orbital period and masses, get semi-major axis and thus Roche lobe radius

HD 190658 : M2.5 III

- $P = 199$ d and $e \leq 0.05$ → second shortest orbital period among M giants
- Ellipsoidal variations (Samus 07, Tabur+ 09)
- It is a "sister case" of SS Lep
- For $0.8 < M_G < 3\ M_\odot$, $0.4 < M_c < 0.9\ M_\odot$, $R_L \sim 73$–$110\ R_\odot$
- Hipparcos parallax $\pi = 7.92 \pm 1.07$ mas (van Leeuwen 07)
  → radius = $31.6 \pm 4.3\ R_\odot$
  → $R/R_L \sim 0.3 - 0.4$

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  → radius = $31.6 \pm 4.3\ R_\odot$
  → $R/R_L \sim 0.3 – 0.4$
  But system shows ellipsoidal variations!

HD 190658 : M2.5 III

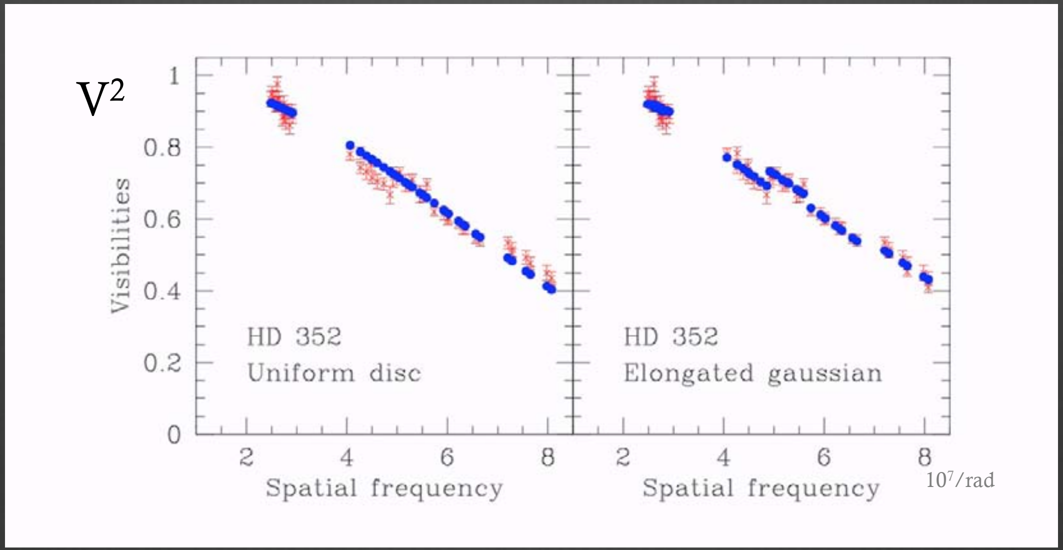
- D. Pourbaix: reprocessing of Hipparcos data taking into account the orbital motion: $\pi = 2.4 \pm 1.0$ mas!
  System is 3 times further away!
- This leads to $R=104 \pm 56\ R_{\odot}$
- $R/R_L \sim 0.43 - 1$
- $T_{eff} \sim 3300$ K
- $L \sim 1100\ L_{\odot}$

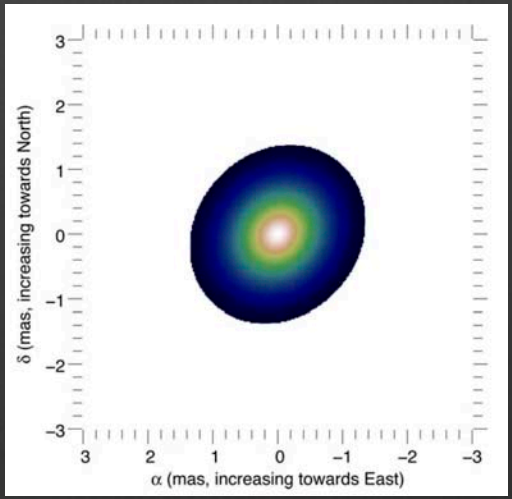
Boffin, Hillen, Berger+, submitted

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
- $\pi = 3.58 \pm 0.48$ mas (van Leeuwen 07)
- PIONIER: R = 0.745 mas → $R = 45 \pm 6\ R_{\odot}$
- $R_L \approx 50\ R_{\odot}$ → $R/R_L \approx 0.9 \pm 1$!

HD 352 - Elongated

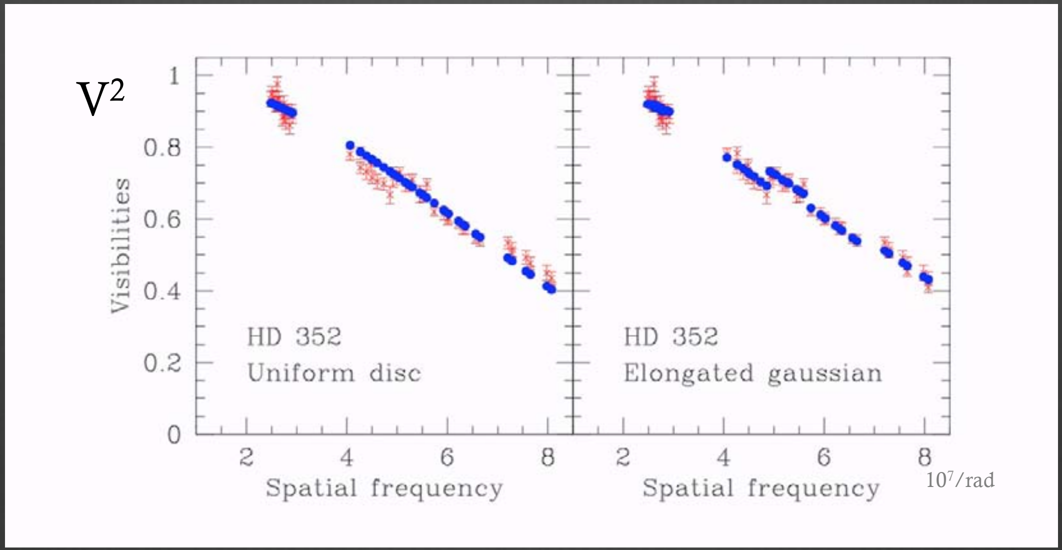


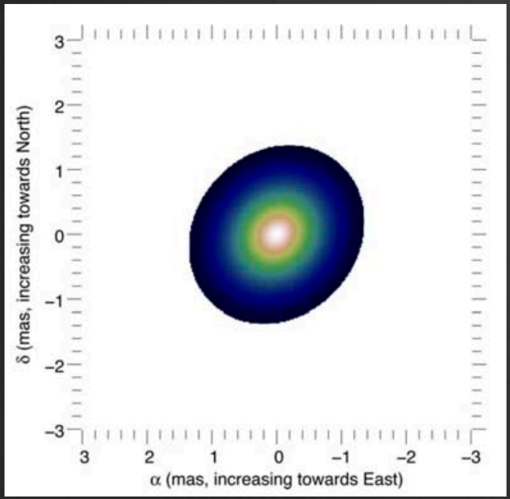


Elongation ratio: 1.16

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

FG Ser

- P = 633.5 d
- Was observed twice, 41 day apart, and gave 2 different diameters!
- 0.83 ± 0.03 mas and 0.94 ± 0.05 mas
- No Hipparcos distance ☹
- Assume star on red giant → $R/R_L \sim 1$ for all M_G
- Is synchronised

→ Need further monitoring!

PIONIER mini-survey

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

Star	Parallax (mas)	$T_{\rm eff}$ (K)	Radius ($R_\odot$)	$M_{\rm bol}$	$f = R/R_L$	$v \sin i$ 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, Hillen, Berger+, submitted

SUMMARY

- PIONIER has provided a complete new view on symbiotic stars
- We revisited SS Lep with PIONIER/VLTI:
  - Mass ratio lower than previously thought
  - M star does not fill its RLOF
  - System currently in wind RLOF configuration?
  - The A star is not inflated but more likely surrounded by a disc
- Interferometry also allows to determine distortion of star (tidal effect) and measure precisely their radius. Coupled with precise light curve modelling, this will constraint the systems.
- Main limitations: distances → GAIA welcome!


Thank
you!