Star Formation: Multiplicity in Massive Stars

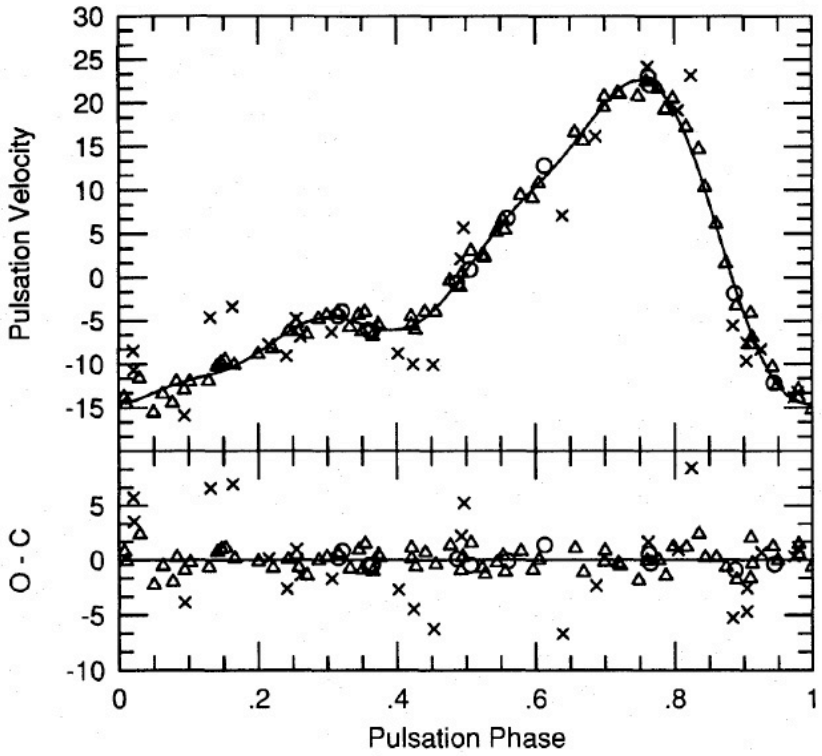
Multiple Systems

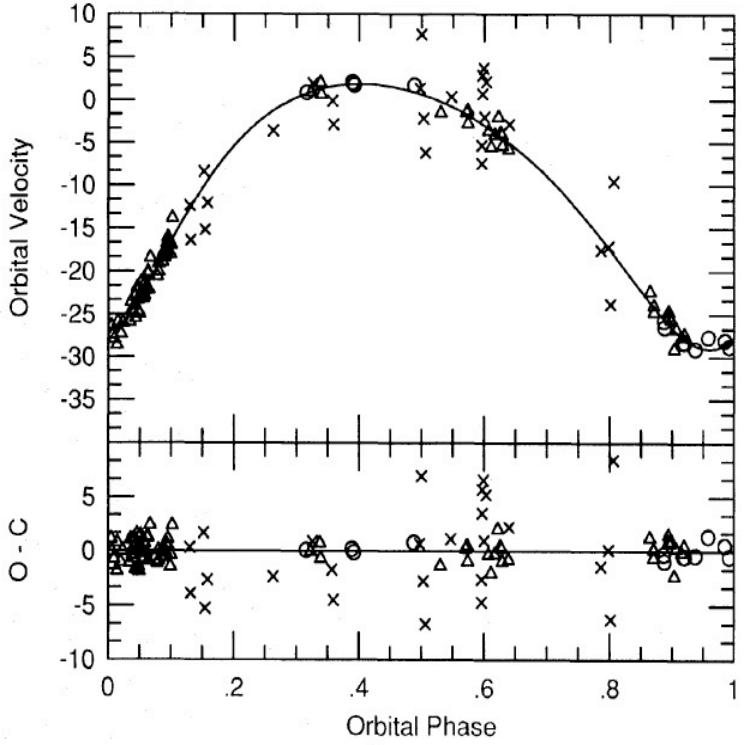
- Generally: better completeness from several techniques
- E.g. ground + satellite ultraviolet
- Ground: orbit

Cepheids

- 5-7 Msun
- Formerly B stars
- Field stars
- Young ~50 Myr
- Evolved: but binary status unchanged from ZAMS
- EXCEPT for P < 1 yr
- Evolution largely without mass loss
- Cool primary + hot secondary

S Sge Case Study





Ground Based Orbit

Mass Function

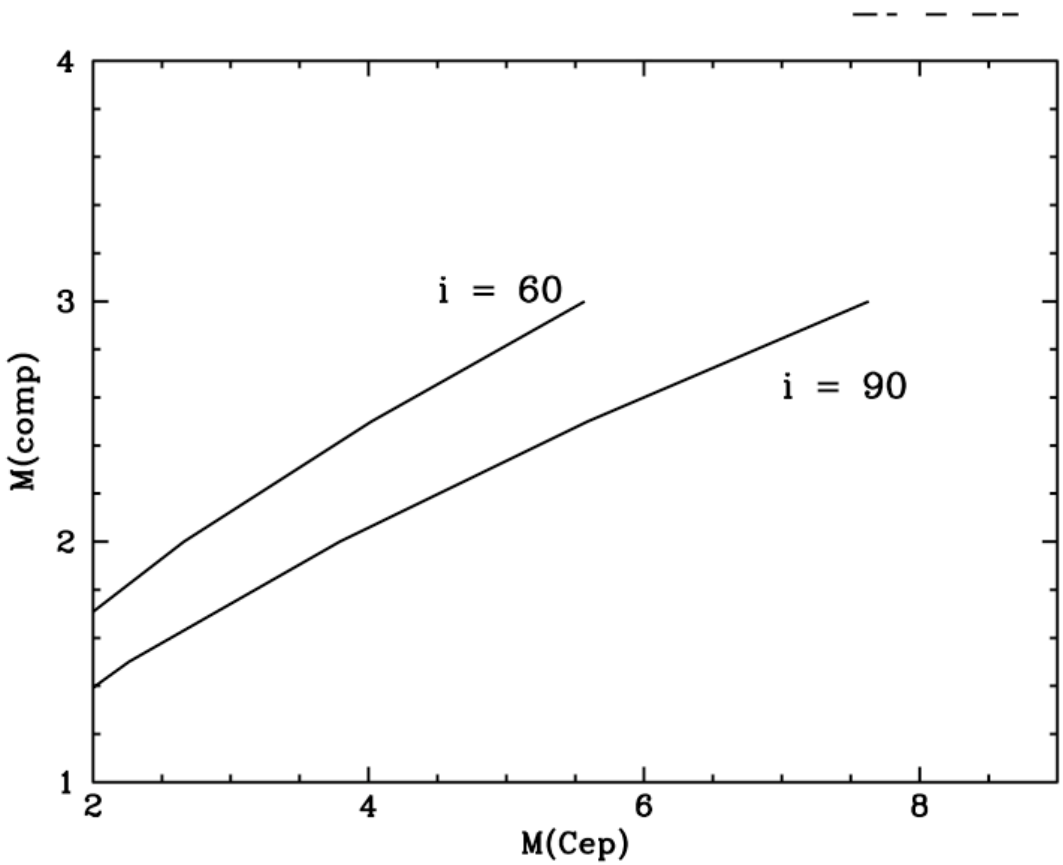
•From a single line spectroscopic binary:

$$f(M,m) = \frac{m^3 sin^3 i}{(M+m)^2} = \frac{A^3 sin^3 i}{P^2}$$

where M, m are primary and secondary masses, A is the semi-major axis of the *primary*, i is the inclination

•For each inclination, there is a relation between M and m

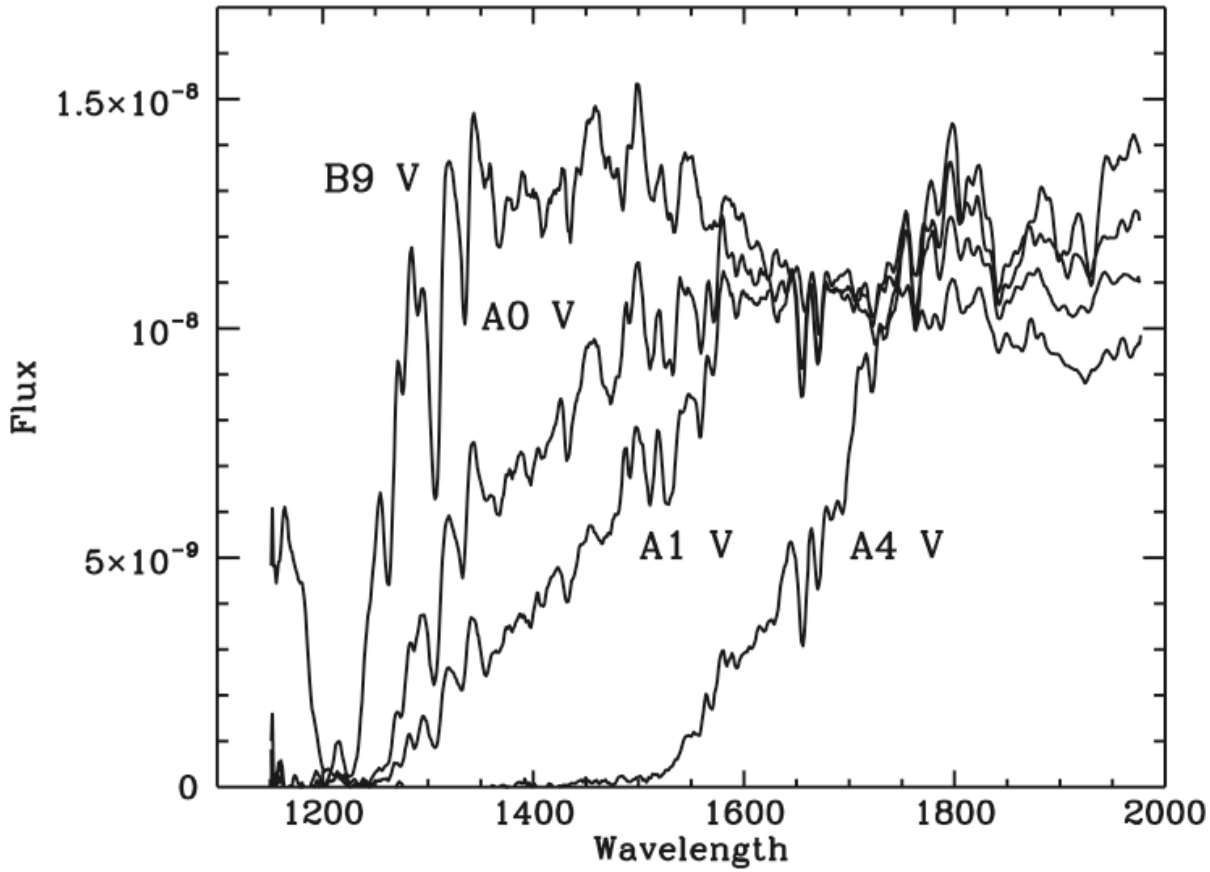
S Sge: Mass Function



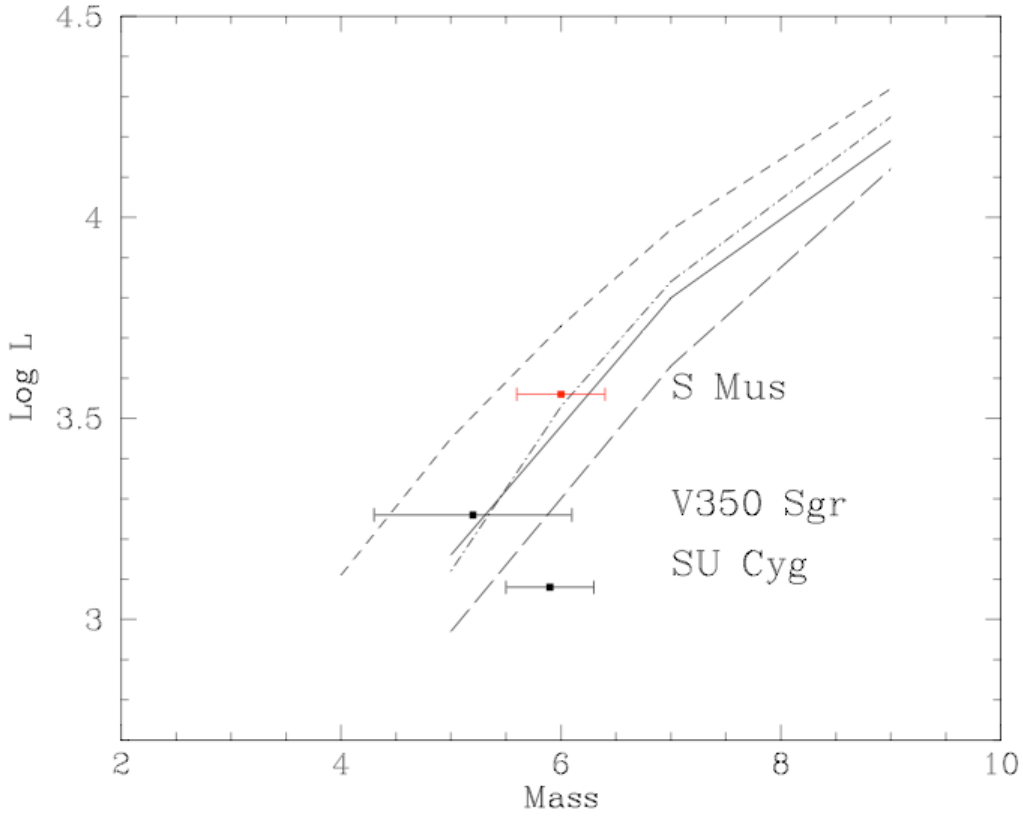
Cepheid Masses

- Cepheid + hot companion
- Cepheid ground based orbit
- Companion orbital velocity amplitude from HST or IUE
- Companion mass from temperature

Temperature Discrimination



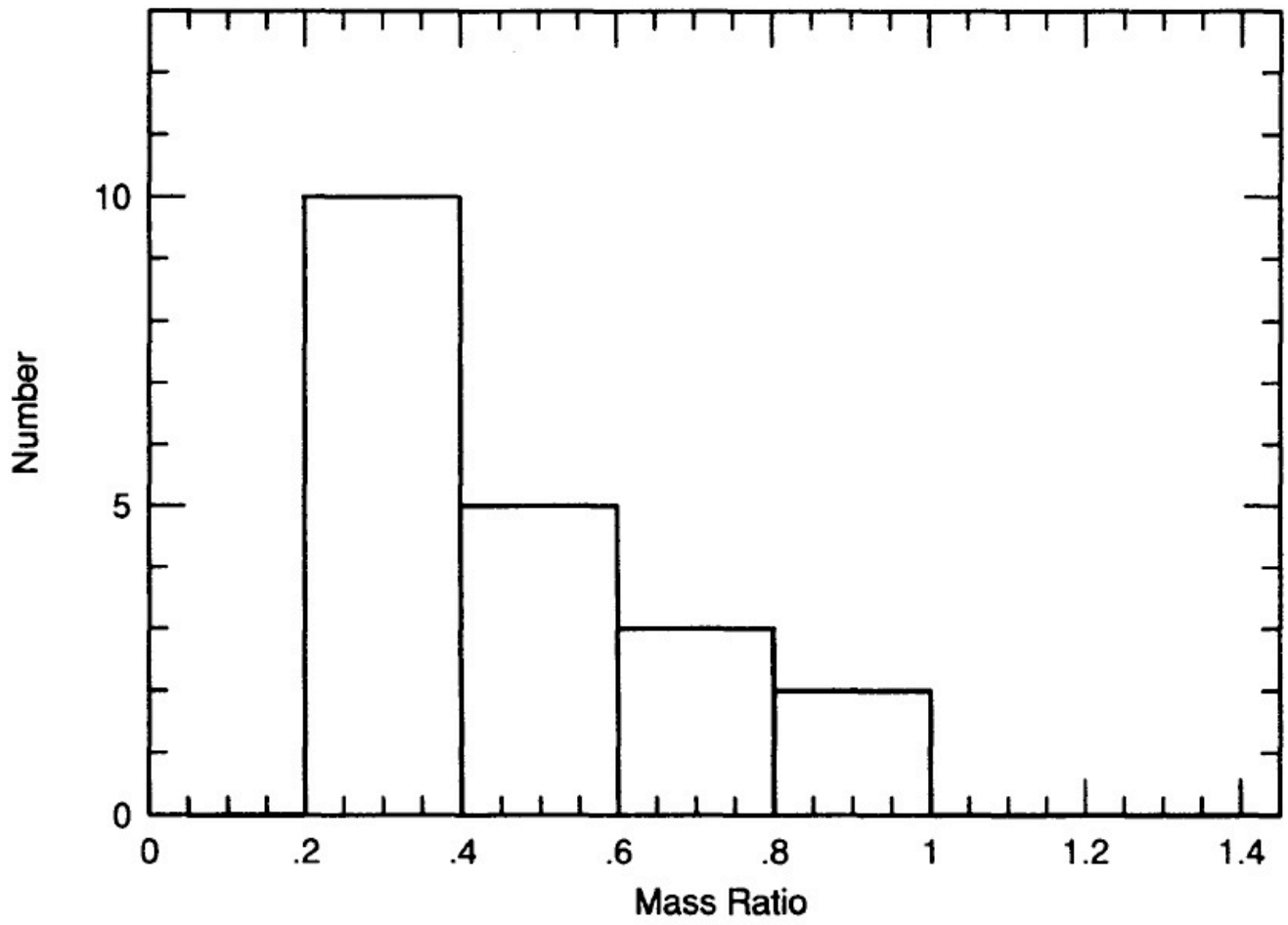
Cepheid Masses



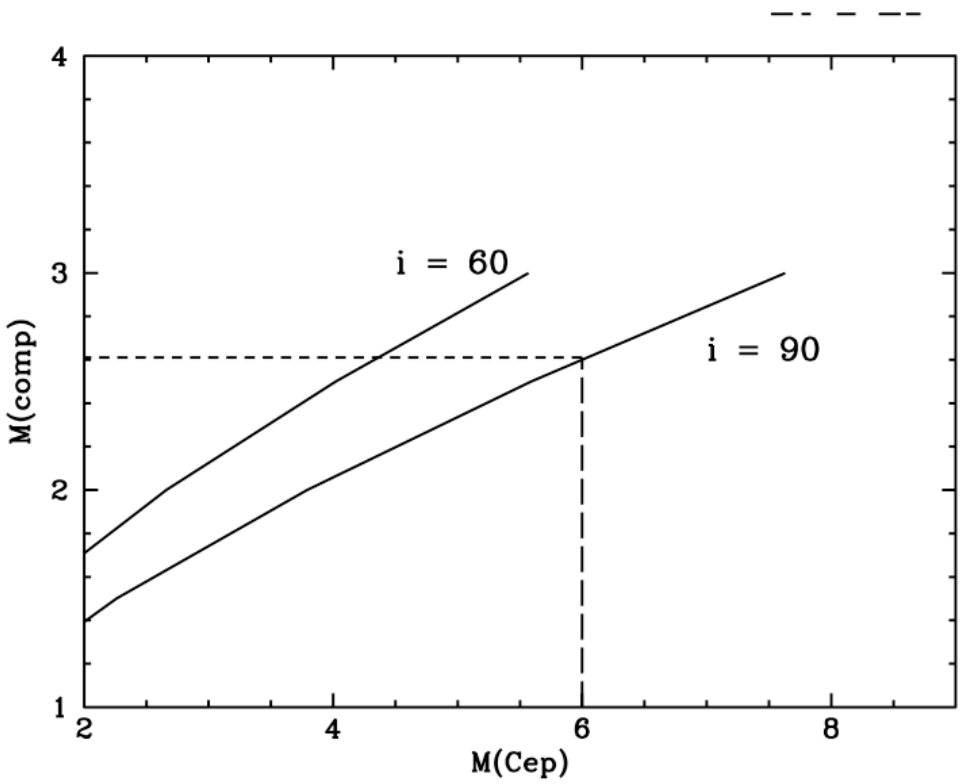
•Measured Cepheid masses

•Lines: predictions from decreasing overshoot from l to r

M(Comp)/M(Cep)



S Sge: Companion Mass

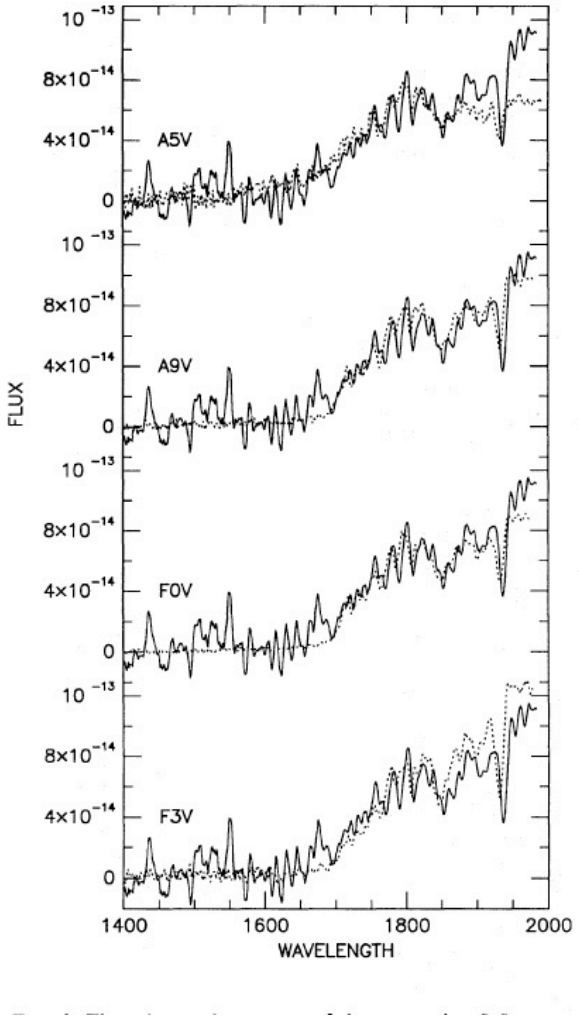


S Sge: IUE spectrum

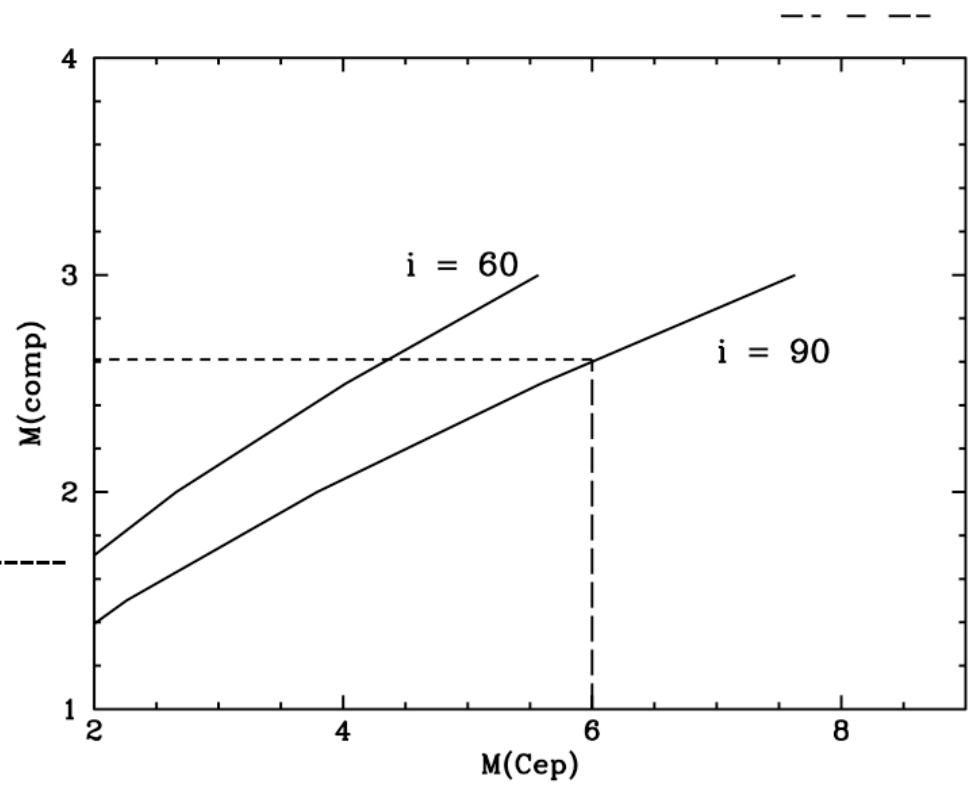
Spectrum of companion corrected for Cepheid

Slope: A9 V - F0 V

=> M = 1.7 - 1.5 M(sun)



S Sge: Companion Mass



S Sge B-----
IUE

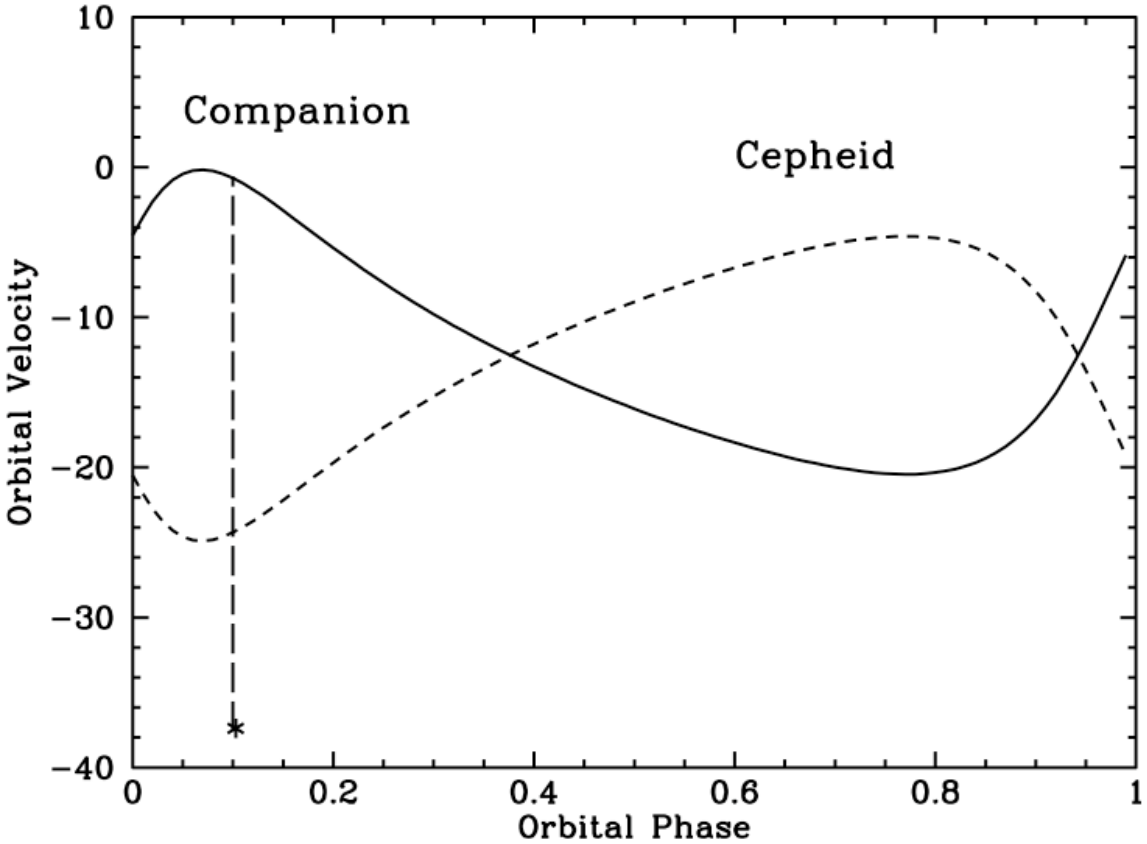
Case Study: Y Car

Ground based orbit for Cepheid

Hot companion dominates in ultraviolet

Measure companion velocity with HST STIS

Y Car: HST Velocity



Multiplicity

Star	P d	Ecc	Triple	High Res	Orbit Source	Multip. Source
U Aql	1856	0.16	y	H	1	Evans, et al. 2005b
FF Aql	1430	0.09			1	Evans et al. 1990
RX Cam	1113	0.46			3	
Y Car	993	0.46	y	H	1	this paper
YZ Car	657	0.14			5	
DL Cas	684	0.35			1	
AX Cir	6532	0.19			5	
SU Cyg	549	0.34	y	I	1	Evans and Bolton, 1990
V1334 Cyg	1937	0.20	?	I	2	Evans 2000
Z Lac	381	0.01			1	
S Mus	505	0.08		H	1	
AW Per	13100	0.55	y	I	1	Evans, et al 2000
S Sge	676	0.23	y		1	Evans et al. 1993
W Sgr	1780	0.52	y		1	Massa and Evans, 2005
V 350 Sgr	1108	0.27		H	1	
V636 Sco	1318	0.26	y	H	1	Böhm-Vitense, et al, 1998
α UMi	10969	0.66	y		1	Kamper 1996
U Vul	2510	0.58			3,4	
No IUE						
BY Cas	563	0.22			6	
VZ Cyg	725	0.05			6	
MW Cyg	441	0.04:			3,6	

References for orbit: 1. Evans, 1995; 2. Evans, 2000; 3. Imbert, 1996; 4. Gorynya, 2004; 5. Petterson, et al. 2004; 6. Gorynya, et al. 1995

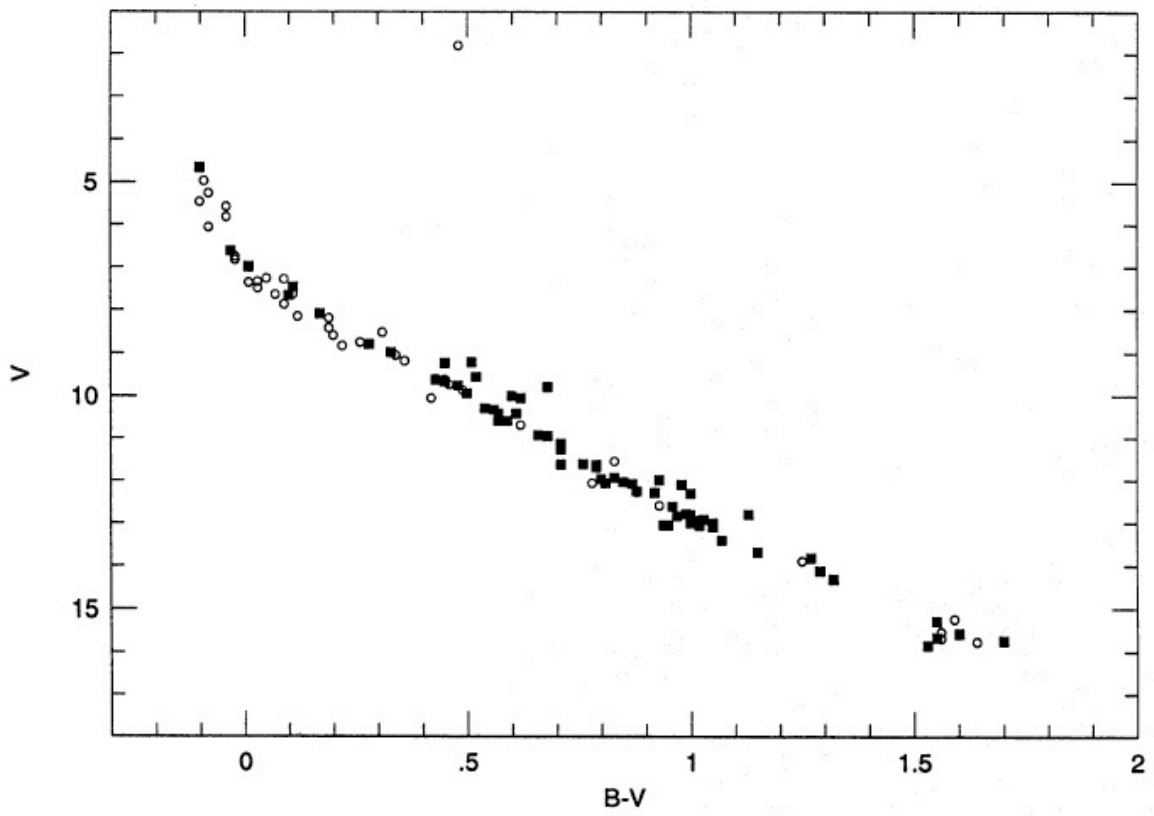
Cepheid Multiplicity

- At least 44% of well-studied Cepheid binaries are triples
- Over estimate: highest mass secondaries are the most likely to be studied
- Under estimate: not a full census of distant companions
- Under estimate: only 8 of 18 systems have high resolution spectra of companions

More?

- What about low mass companions?
- No full amplitude Cepheid has been detected in X-rays (only maybe Polaris)
- Cepheid companions must themselves be very young stars

X-rays: Alp Per (ROSAT)



•Randich, et al. 1996

Low Mass Companions

- Young cool companions would be picked up
- Conversely if there are no X-ray sources, there are no companions
- Similar arguments hold for B stars

Summary

- High fraction of triples among well studied Cepheid binaries
- Combining ground + UV + X-ray hard to hide companions over very large mass range