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

\[
\begin{align*}
M(\text{comp}) & \quad M(\text{Cep}) \\
\begin{array}{c}
i = 60 \\
i = 90
\end{array}
\end{align*}
\]
Cepheid Masses

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

![Graph showing temperature discrimination with different wavelengths for B9 V, A0 V, A1 V, and A4 V.]
Cepheid Masses

• Measured Cepheid masses
• Lines: predictions from decreasing overshoot from l to r
M(Comp)/M(Cep)
S Sge: Companion Mass

![Graph showing the relationship between M(comp) and M(Cep) with two lines indicating i = 60 and i = 90.](image)
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

\[ M(\text{comp}) \text{ vs. } M(\text{Cep}) \]

- \( i = 60 \)
- \( i = 90 \)

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

Graph showing the orbital velocity over orbital phase for Y Car, with labels for Companion and Cepheid.
# Multiplicity

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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