Herbig Ae/Be Multiplicity Study

www.ctio.noao.edu/~haebe

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Why study Herbig Ae/Be stars?

• Herbig Ae/Be stars (HAEBEs) are intermediate-mass (2-8 solar masses) pre-main sequence stars

• Bridge the gap between low-mass T Tauri’s and high-mass YSOs
  ⇒ star formation as a function of mass

• Studies to date scattered, incomplete
  • Much less than studies of T Tauri stars

• Why not? heterogeneous sample, large distance range for significant sample
Why study their multiplicity?

• Stars do not form in isolation, nor in homogeneous mass environments
  - HAEBE binary frequency comparable to, or greater than, T Tauri frequency

• Constrain star formation models as a function of mass
  - Do high mass stars form like low mass stars?
  - IF there is a break, it occurs in HAEBE class
  - T Tauri binary studies support fragmentation

• Effect of HAEBE stars on their companions
  - “zone of influence” as function of primary mass

  Note: difficult because of large delta-magnitude
Our project

Broaden the sample of multiple HAEBE systems, and investigate their characteristics

- Known Sample: Previous Surveys
- Broaden Sample: AO Imaging
- Verify companionship
- Investigate Companions: NIR Photometry & Spectroscopy, and Mid-IR Imaging
HAEBE Sample

• About 280 stars from Thé et al. 1994, Tables 1-4

• Supplemented with HAEBE stars from literature, e.g. ISO papers

• Spectral types ranging from early B to late F
HAEBE Sample

229 HAEBEs with spectral type assigned
AO Imaging

- GN+NIRI/Altair & VLT+NACO
- Deeper and Closer
  - $dK=2 \ @ 0.1''$
  - $dK=8 \ @ 1''$
- Larger Sample
- Nearly doubled candidate multiples
  35->66
  - $\approx 50\%$ are multiples ($>2$)

Note: $dK(B_0-K_0) \approx 7$, while $dK(A_0-K_0) \approx 3$
# HAEBE Multiplicity surveys

- previous & ours -

<table>
<thead>
<tr>
<th>Survey</th>
<th>$N_{tot}$</th>
<th>$N_{found}$</th>
<th>Res.</th>
<th>Sens.</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leinert et al 1997</td>
<td>26</td>
<td>11</td>
<td>~0.1”</td>
<td>~0.1”</td>
<td>Speckle interferometry</td>
</tr>
<tr>
<td>Pirzkal et al 1997</td>
<td>39</td>
<td>9</td>
<td>0.4”</td>
<td>K=10.5</td>
<td>Includes 1/2 of Leinert sample; wide FOV</td>
</tr>
<tr>
<td>Bouvier &amp; Corporon 2001</td>
<td>63</td>
<td>29</td>
<td>~0.1”</td>
<td>dK=6.5</td>
<td>35 in addition to previous; 20 new multiples; small FOV</td>
</tr>
<tr>
<td>This Work</td>
<td>&gt;80</td>
<td>46</td>
<td>0.06”</td>
<td>K~22, dK≤9</td>
<td>Northern sample so far; at least 25 new</td>
</tr>
</tbody>
</table>
Physically bound?

- **Spectral energy distribution**

  ![Spectral energy distribution graph](image)

  Photometry only
  SED unconstraint
  Uncertain IR excess
Physically bound?

- Spectral energy distribution
- Proper motion
  - PM available for 72 stars
  - Altair-NIRI images: 0.056"
    => 5.6 mas/yr for a 10 yr baseline
  - 17 objects with enough pm
  - 6 have ang.sep. and PA in literature

  3 companions candidates are moving together with primary;
  2 are located within error bars;
  1 companion is definitely not moving with HAEBE star
HIP 114995

Position of secondary relative to primary in 1997 & 2006, with the 2006 position as a baseline

pmRA = -18.63 mas/yr
pmDEC = -14.84 mas/yr

* pm (SIMBAD) indicates the position with respect to the primary if they did not have common proper motion
Physically bound?

- Spectral energy distribution
- Proper motion
- Statistical analysis
  - Probability of finding at least one unrelated source at an angular separation $\theta$:
  - Depends on
    - angular separation $\theta$
    - surface density $\Sigma$ (30')
    - (secondary magnitude)

\[ P(\Sigma, \Theta) = 1 - e^{-\pi \Sigma \Theta^2}. \]

80 pairs of stars (45 primaries)
2/3 of companions have a certainty of 95% of being related
P is probability to find at least one unrelated source within $\theta$

$P$ depends on $K_2$, $K$-magnitude of secondary star

Open symbols: probability is $> 1\%$

$P < 0.01\%$
$0.01\% < P < 0.1\%$
$0.1\% < P < 1\%$
$1\% < P < 10\%$
$P < 10\%$
Physically bound?

• **Spectral energy distribution**
  - Uncertain circumstellar extinction

• **Proper motion**
  - Multiple observations are needed
  - Only works for stars with fairly large proper motion
  - Not definitive in clusters

• **Probability based on surface density**
  - Applicable to large sample
  - Depends mainly on K magnitude of secondary
  - Not definitive in clusters
  - Fold in surface density, as function of spectral type
Summary of results

AO Imaging

• Combining those results with previous ones, the total number of HAEBE multiple candidates is 66. We nearly doubled the previously known sample. Survey continues...

• About 50% have more than one possible companion, suggesting a binary fraction potentially greater than 1.

• Proper motion study for 6 stars shows that 3 out of 6 stars move together, 1 does not.

• Statistical analysis based on surface density shows that 2/3 of candidates are likely to be companions, with 95% certainty.

• For stars in clusters it is more difficult to say something conclusive, both based on proper motion and on the statistics.
References

• Ours (so far)
  - Thomas et al. (2006, IAUS 240, 124)
  - AAS 2004 (2), 2006 (4), 2007 (3)
  - Bouvier & Corporon (2001, IAUS 200, 155)

• Others
  - Ducourant et al. 2006, A&A 448, 1235

• This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France