Part III
Early stages in stellar evolution

PhD course originally developed by René Liseau
Updated to Master level course by Alexis Brandeker
Early stages in stellar evolution

• L15 – General Overview / Pre-collapse phase I
• L16 – Pre-collapse phase II
• L17 – Collapse phase I
• L18 – Collapse phase II
• L19 – Circumstellar disks I
• **L20 – Pre-main-sequence evolution**
• L21 – Circumstellar disks II – debris disks
Observational signs of youth

- Elevated position in H-R diagram
- Atmospheric lithium abundance
- Active chromosphere (X-ray, emission lines)
  - Variability
- Accretion signature (Hα, veiling...)
- Circumstellar material (IR excess)
- Fast rotator
- By association with other young stars
- Proximity to molecular clouds
PMS classification

Schulz (2006)
Adapted from van Zadelhoff 2002, PhD thesis

CLASS 0
(main accretion phase)
Size: 10000 AU; t=0

CLASS I
(late accretion phase)
Size 8000 AU; t=10^4−10^5 yr.

CLASS II
(massive disks)
Size 200 AU; t=10^5−10^6 yr.

CLASS III
(debris disks ?)
Size 200 AU; t=10^6−10^7 yr.
Colour-magnitude diagram

Zuckerman & Song (2004)
Accretion/activity (2MASS1207)
Activity: Hα

Zuckerman & Song (2004)
Lithium burning

\[ p^+ + ^6Li \rightarrow ^7Li \]

\[ p^+ + ^7Li \rightarrow ^8Be \]

\[ ^8Be \rightarrow ^4He + ^4He + \text{energy} \]

Temperature sensitive: \(~ 2.5 \text{ million K required} \)
Lithium

Zuckerman & Song (2004)
How sensitive is star formation to environment?

Diagnoses:

- Mass function (stars/BDs?)
- Multiplicity (fraction of multiples? Configurations?)
Multiplicity
Optical binaries
Optical triples
Double-lined spectroscopic binary

Epoch 1

Epoch 2
Spectroscopic binaries

Spectroscopic binaries

GM Dra

V972 Her

ET Leo

FS Leo

Rucinski et al.
Spectroscopic binary simulator

http://instruct1.cit.cornell.edu/courses/astro101/java/binary/binary.htm

**Orbiting Binary Stars**

*Astronomy 101/103*  
Terry Herter

<table>
<thead>
<tr>
<th>Description</th>
<th>Instructions</th>
<th>Example to try</th>
</tr>
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<td>Radial Velocity</td>
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<tr>
<td>47.22 km/sec</td>
<td>-47.22 km/sec</td>
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Privileged view  
Earth view
Sensitivity

- Adaptive optics: $a > 40$ mas ($6 \text{ AU} @ 150 \text{ pc}$)
- Interferometry: $a > 3$ mas ($0.5 \text{ AU} @ 150 \text{ pc}$)
- Spectroscopic binary: $P < 5$ yr ($3 \text{ AU}$ for $1 \text{ M}_{\odot}$)
Binary benefits

• Calibrators of PMS evolution models
  – Caveat: models assume single star – binary formation might be different

• Independent distance estimate (for angularly resolved spectroscopic binaries)
Main-sequence stars

Fig. 7. Period distribution in the complete nearby G-dwarf sample, without (dashed line) and with (continuous line) correction for detection biases. A Gaussian-like curve is represented whose parameters are given in the text.

Duqennoy & Mayor (1991)
Multiplicity fraction as a function of mass
Multiplicity fraction as a function of age

Credit: G. Duchêne