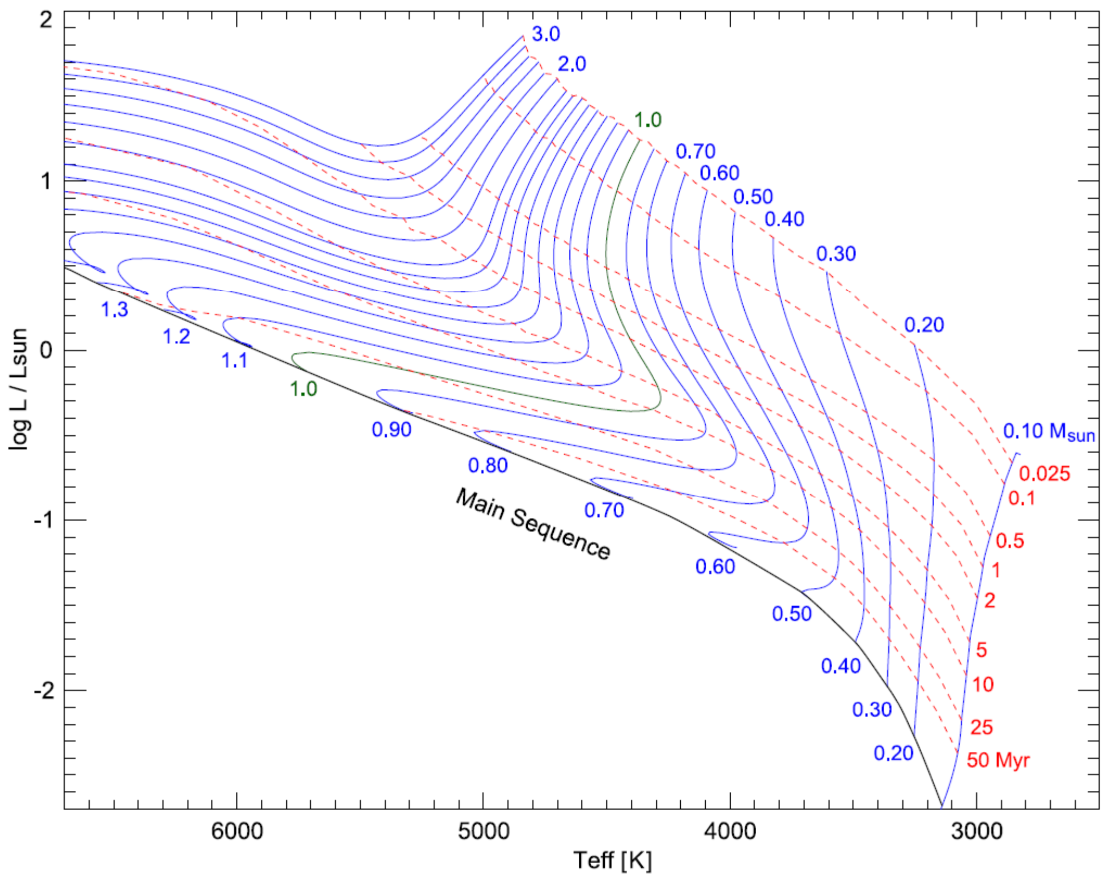
Part III

Early stages in stellar evolution



PhD course originally developed by René Liseau
Updated to Master level course by Alexis Brandeker

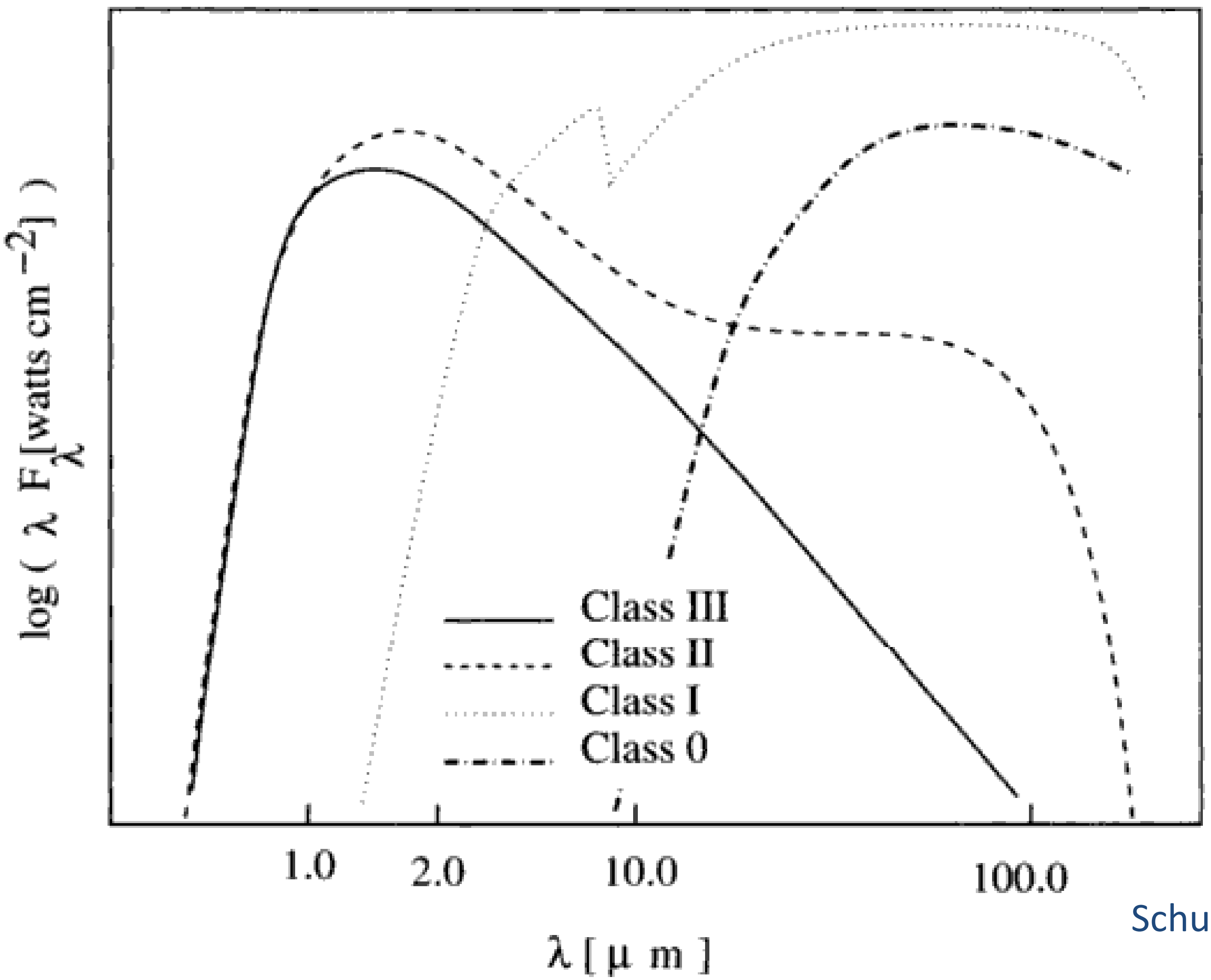
Early stages in stellar evolution

- 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

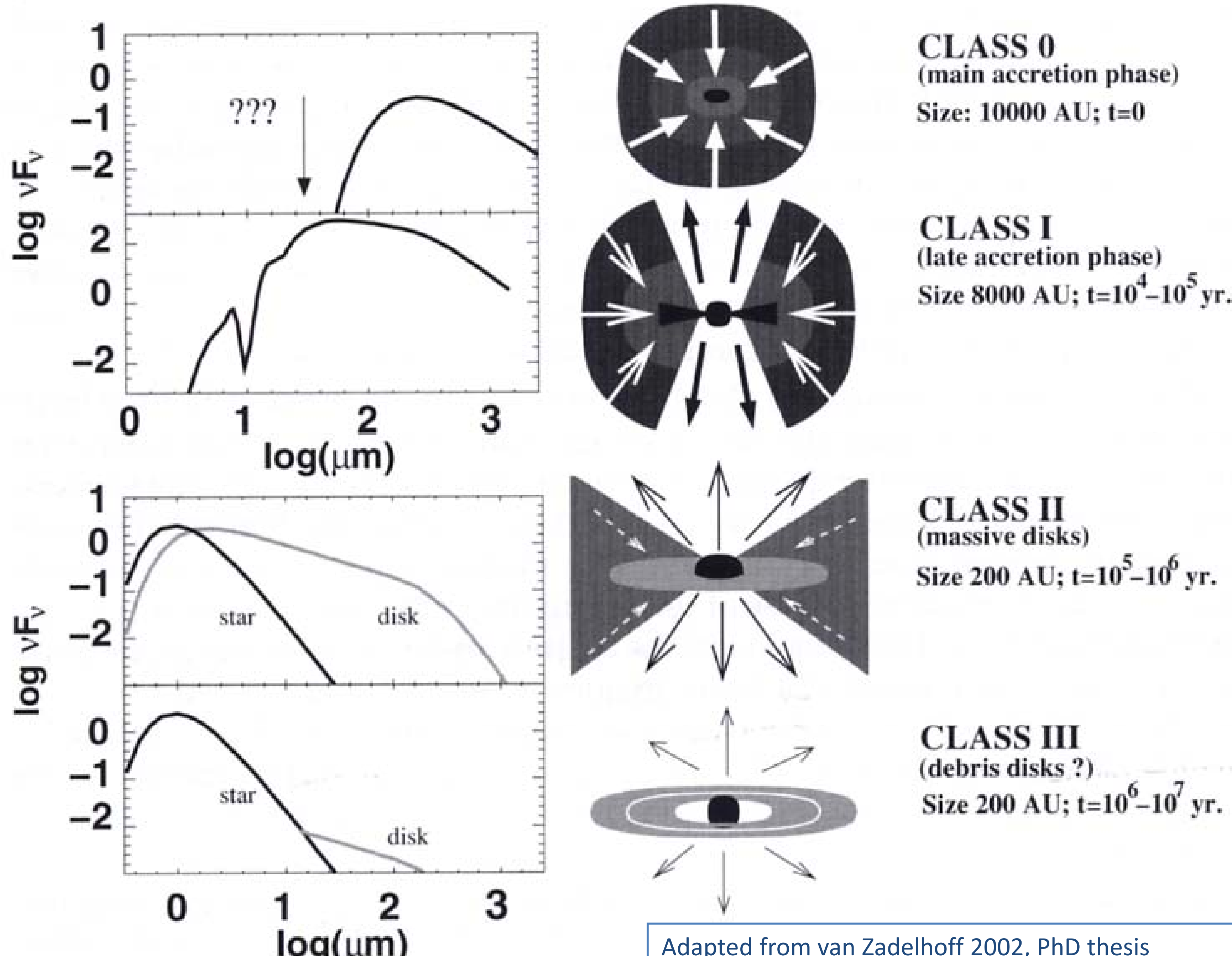
Observational signs of youth

- 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

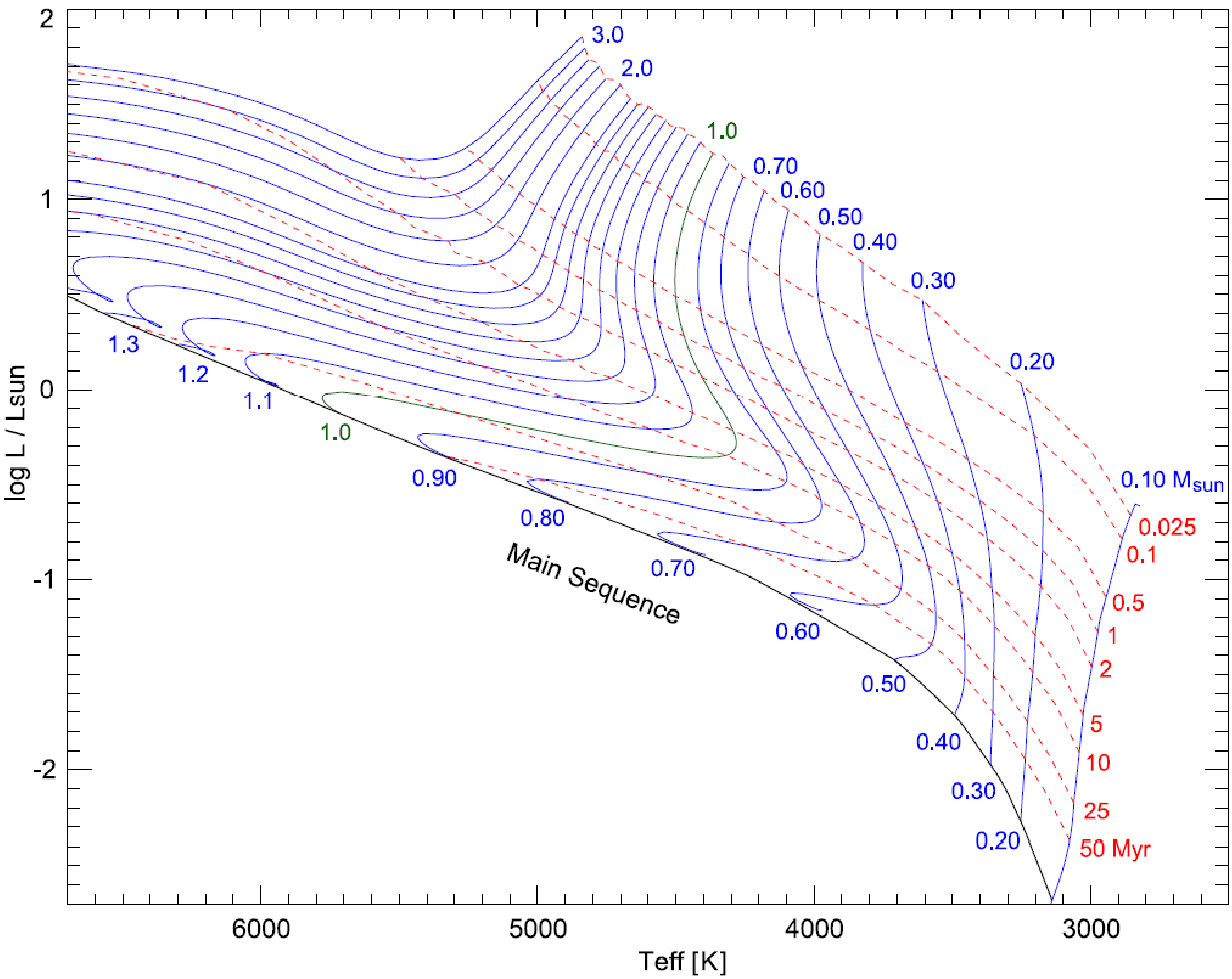
PMS classification



Schulz (2006)

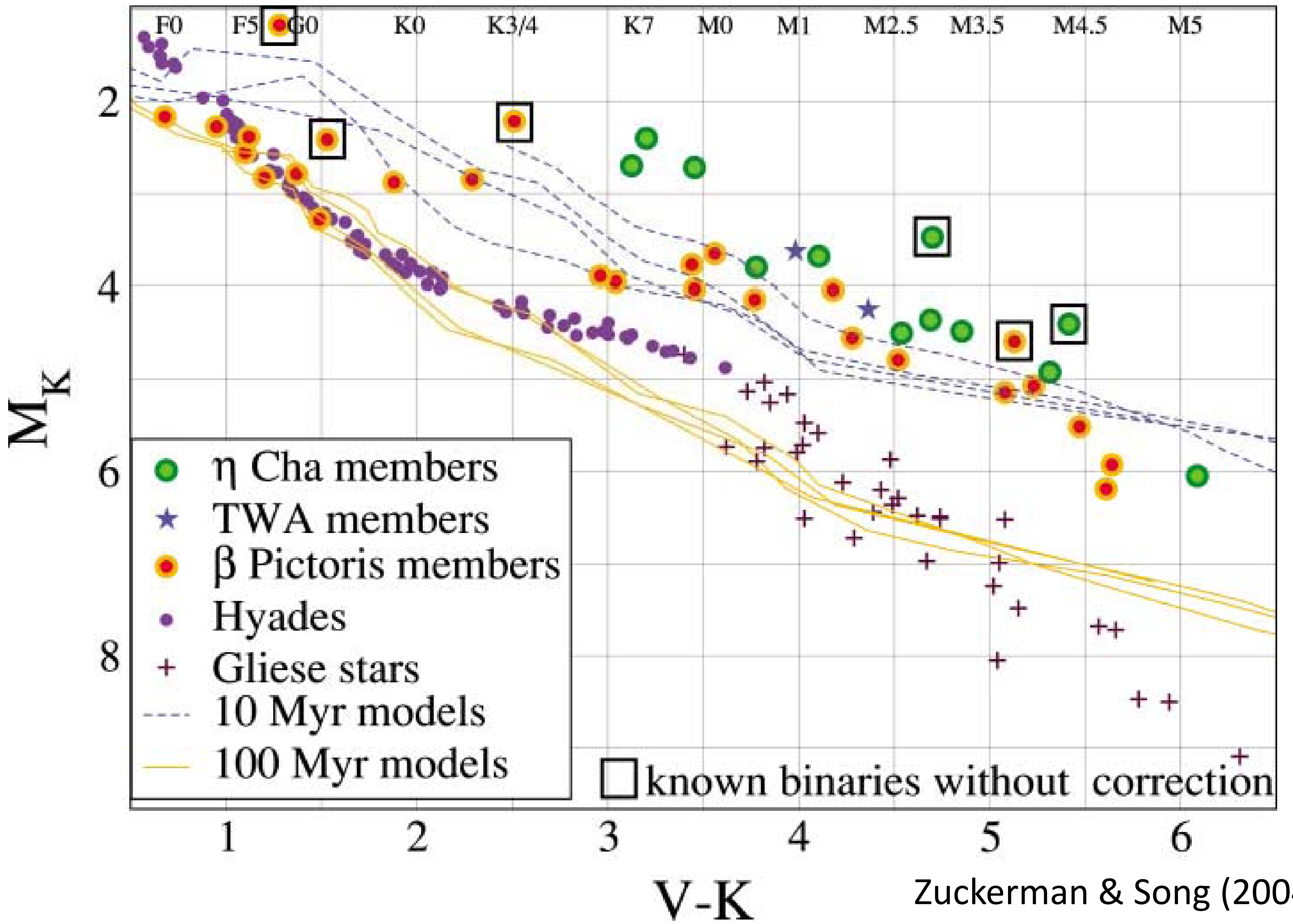


Adapted from van Zadelhoff 2002, PhD thesis



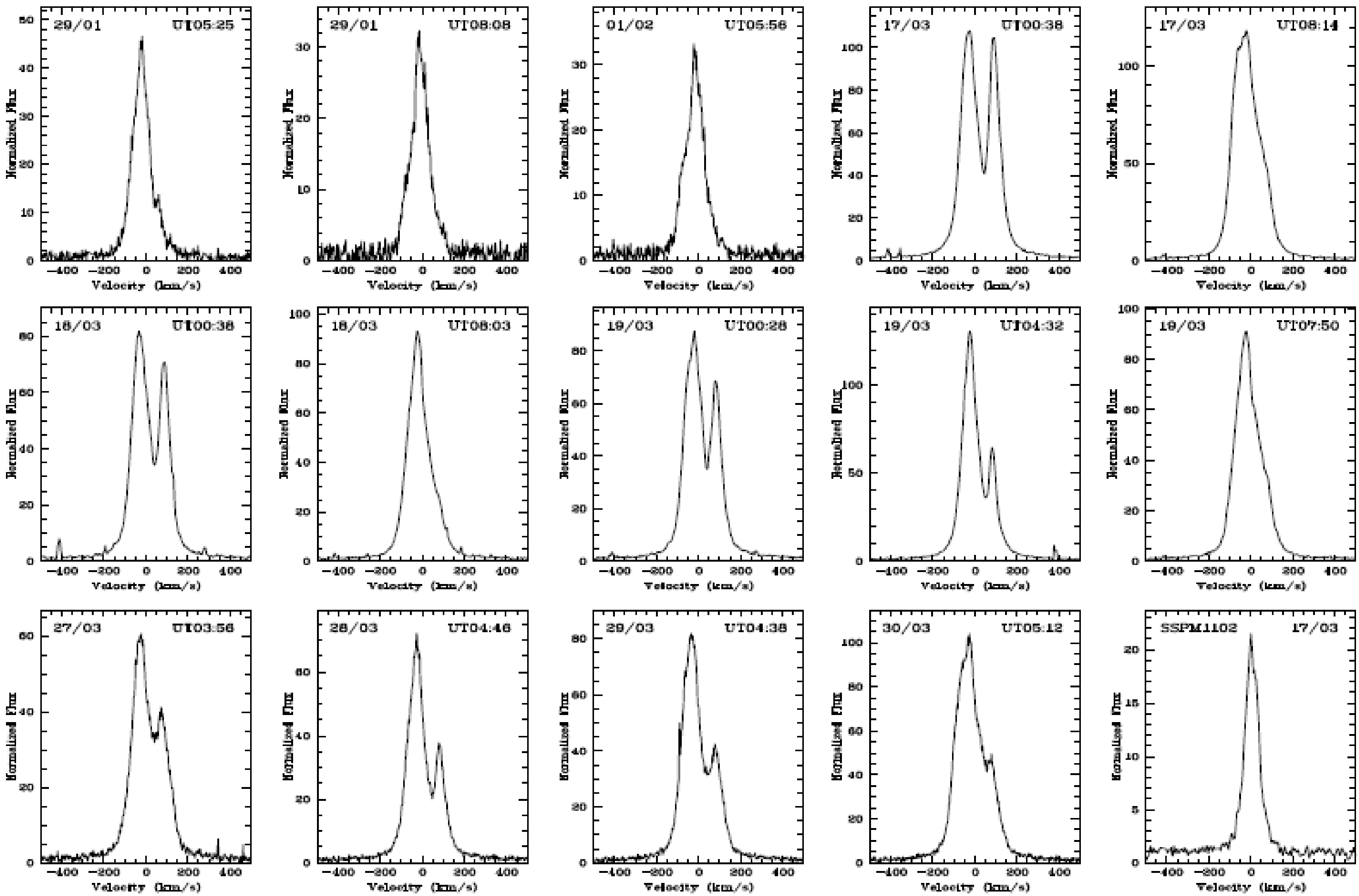
Dotter et al. 2007

Colour-magnitude diagram

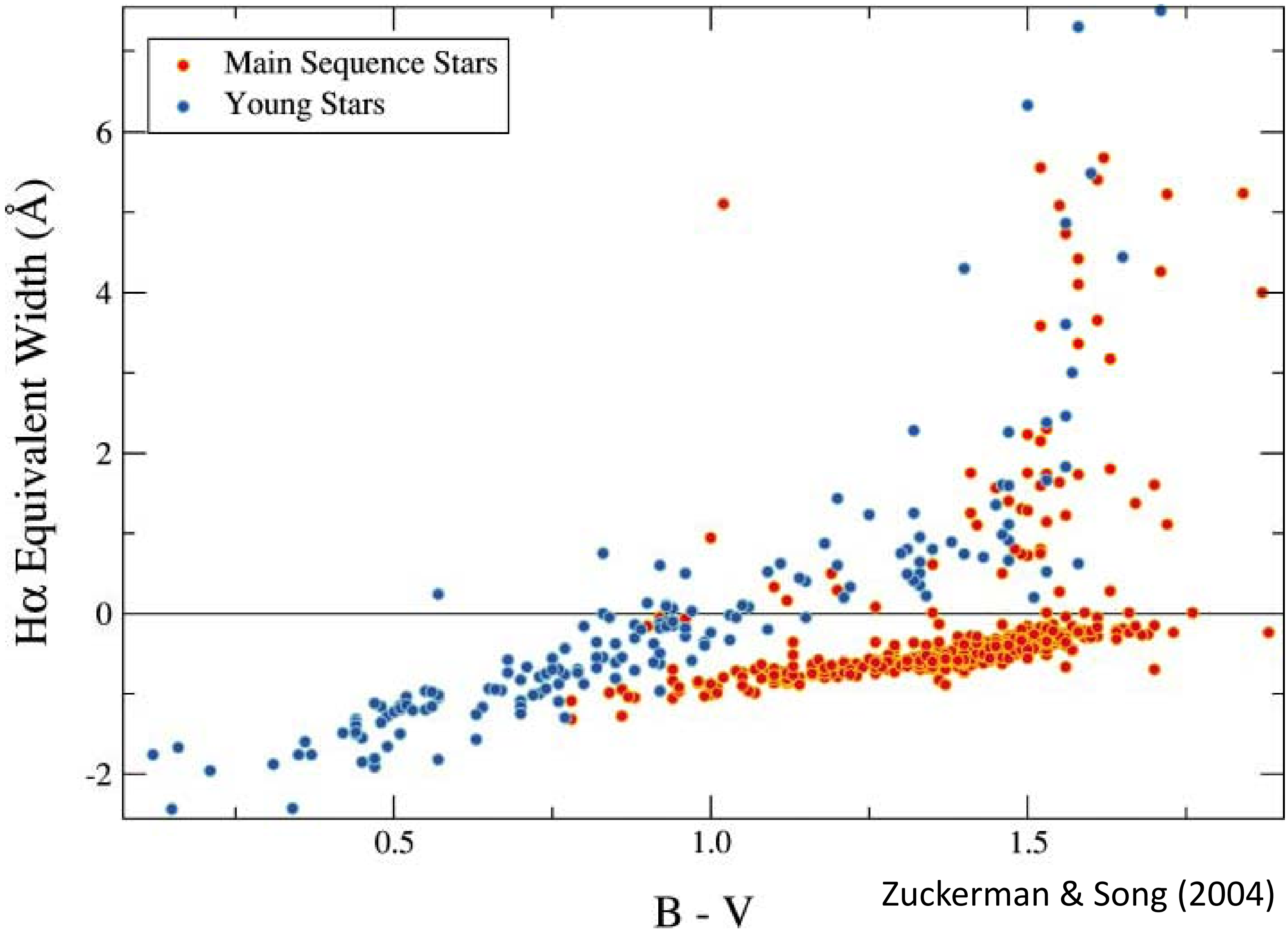


Zuckerman & Song (2004)

Accretion/activity (2MASS1207)

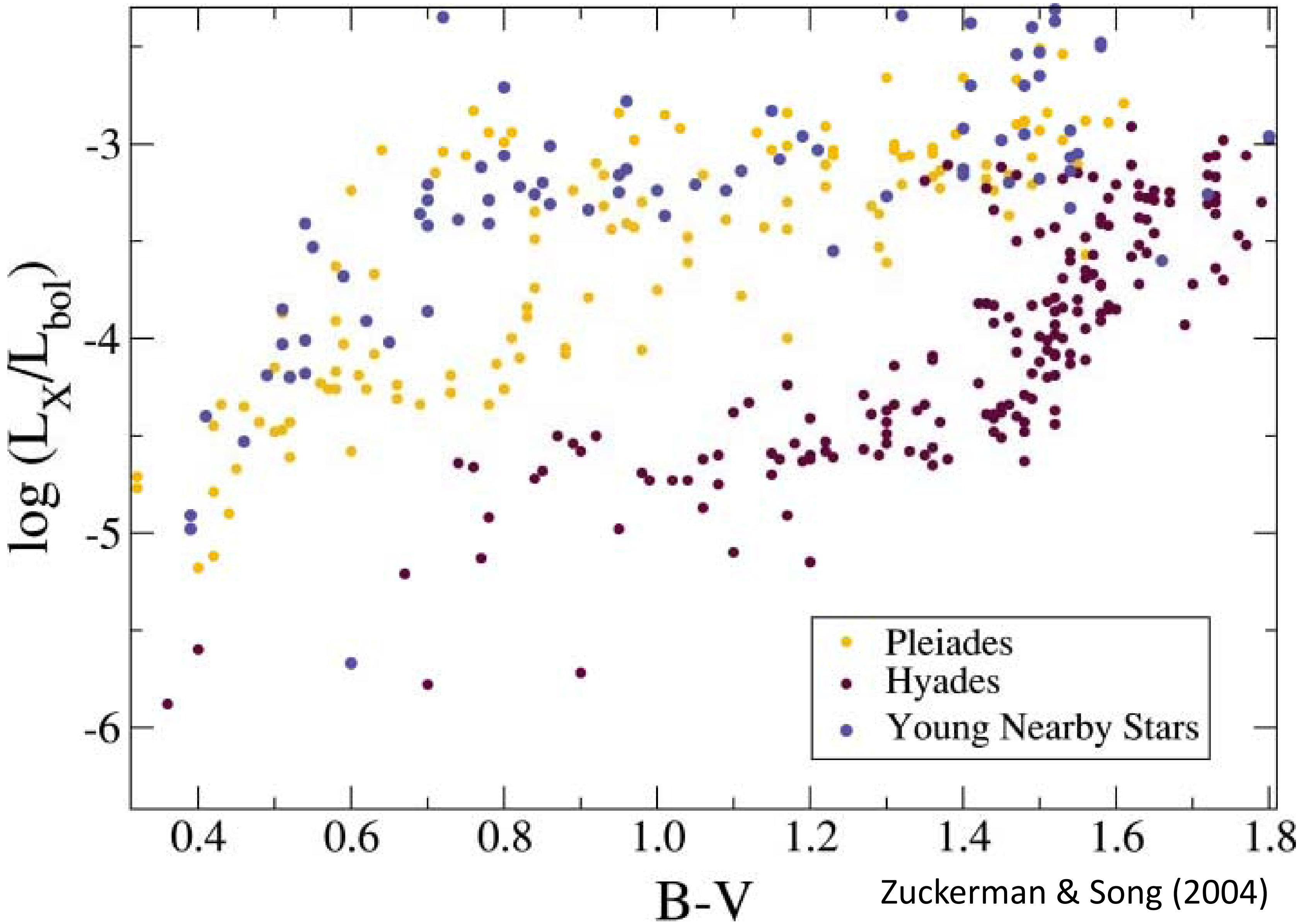


Activity: Hα



Zuckerman & Song (2004)

Activity: X-rays



Zuckerman & Song (2004)

Lithium burning

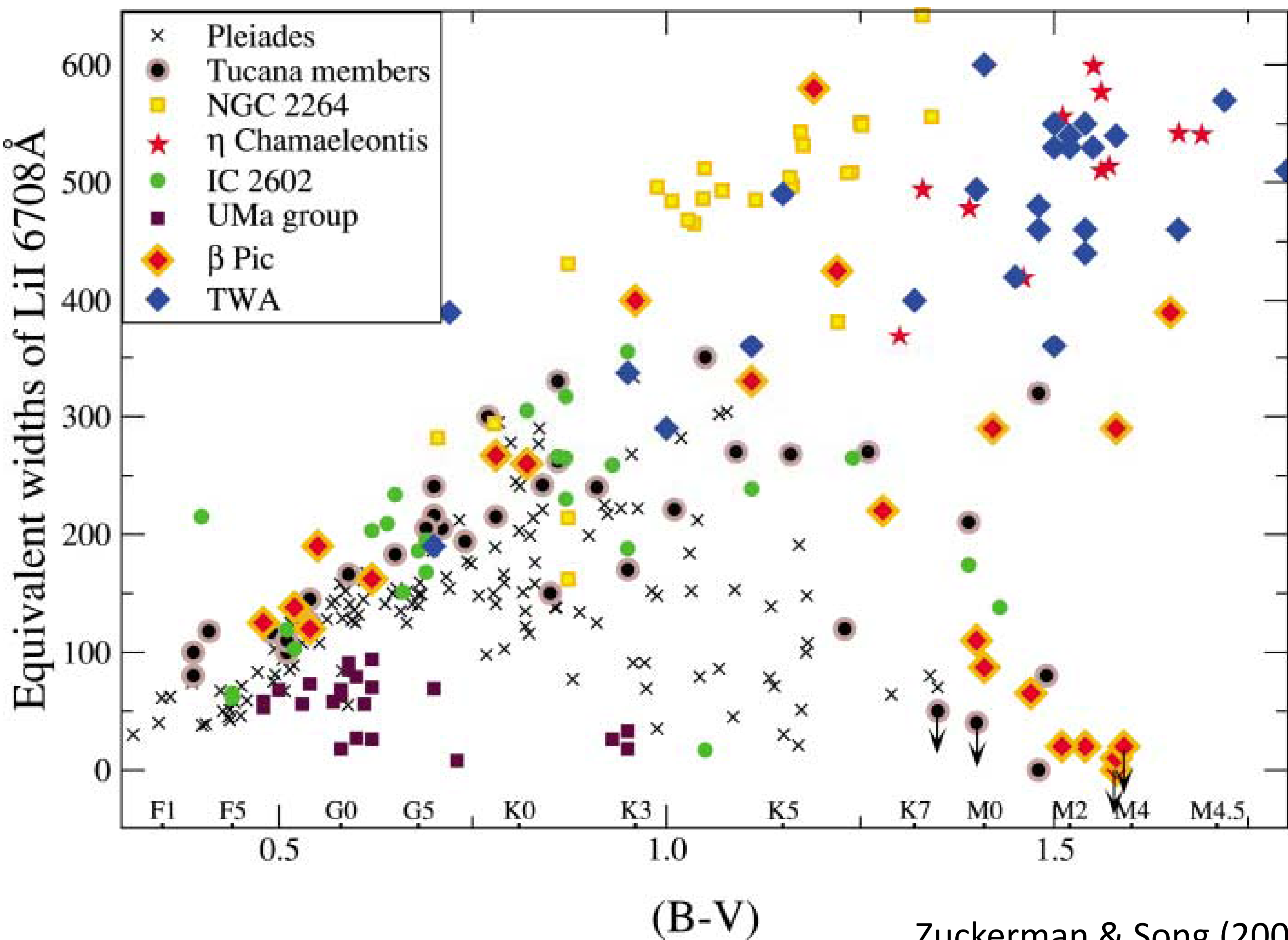
$$p^+ + {}^6Li \rightarrow {}^7Li$$

$$p^+ + {}^7Li \rightarrow {}^8Be$$

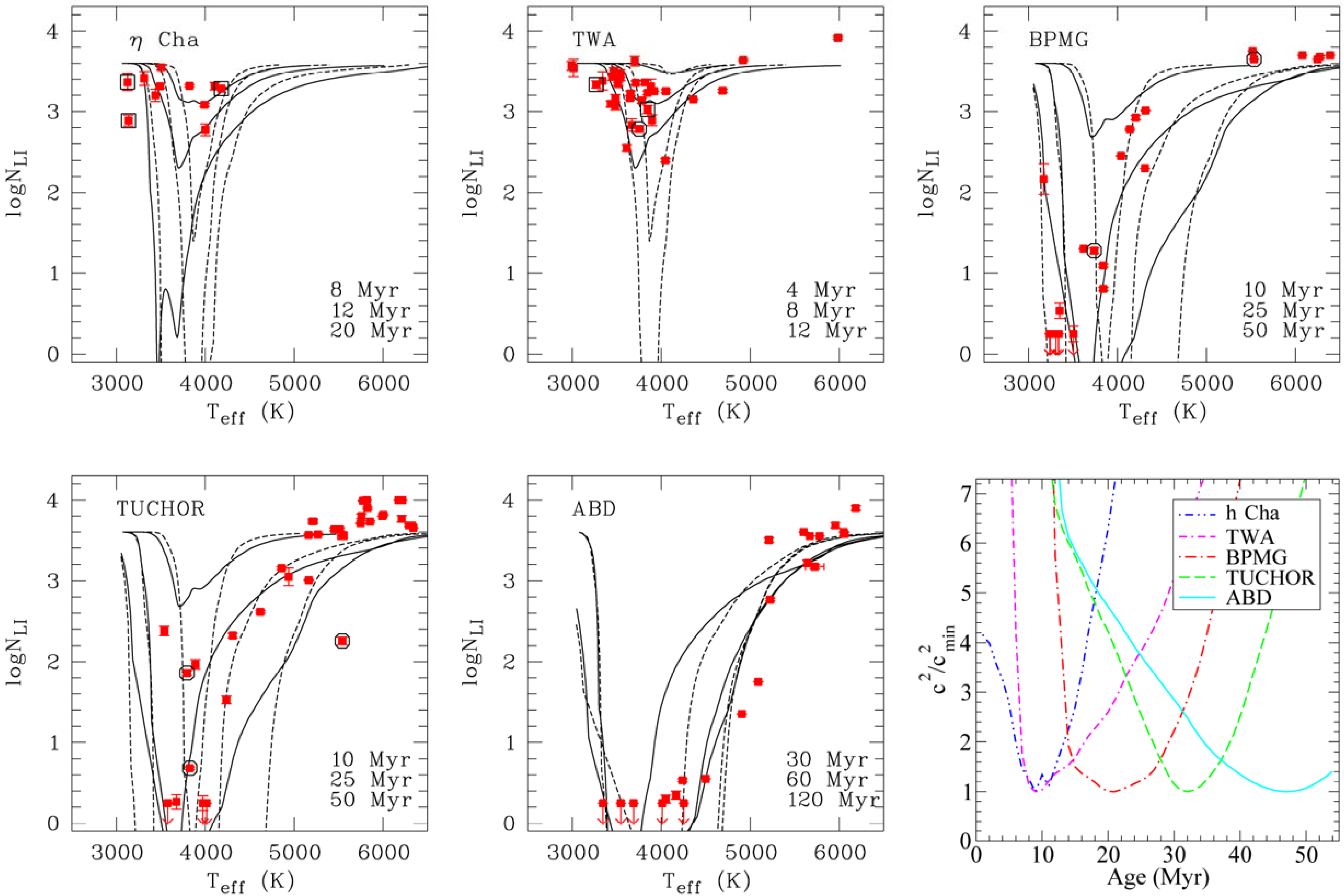
$${}^8Be \rightarrow {}^4He + {}^4He + \text{energy}$$

Temperature sensitive: ~ 2.5 million K required

Lithium



Zuckerman & Song (2004)



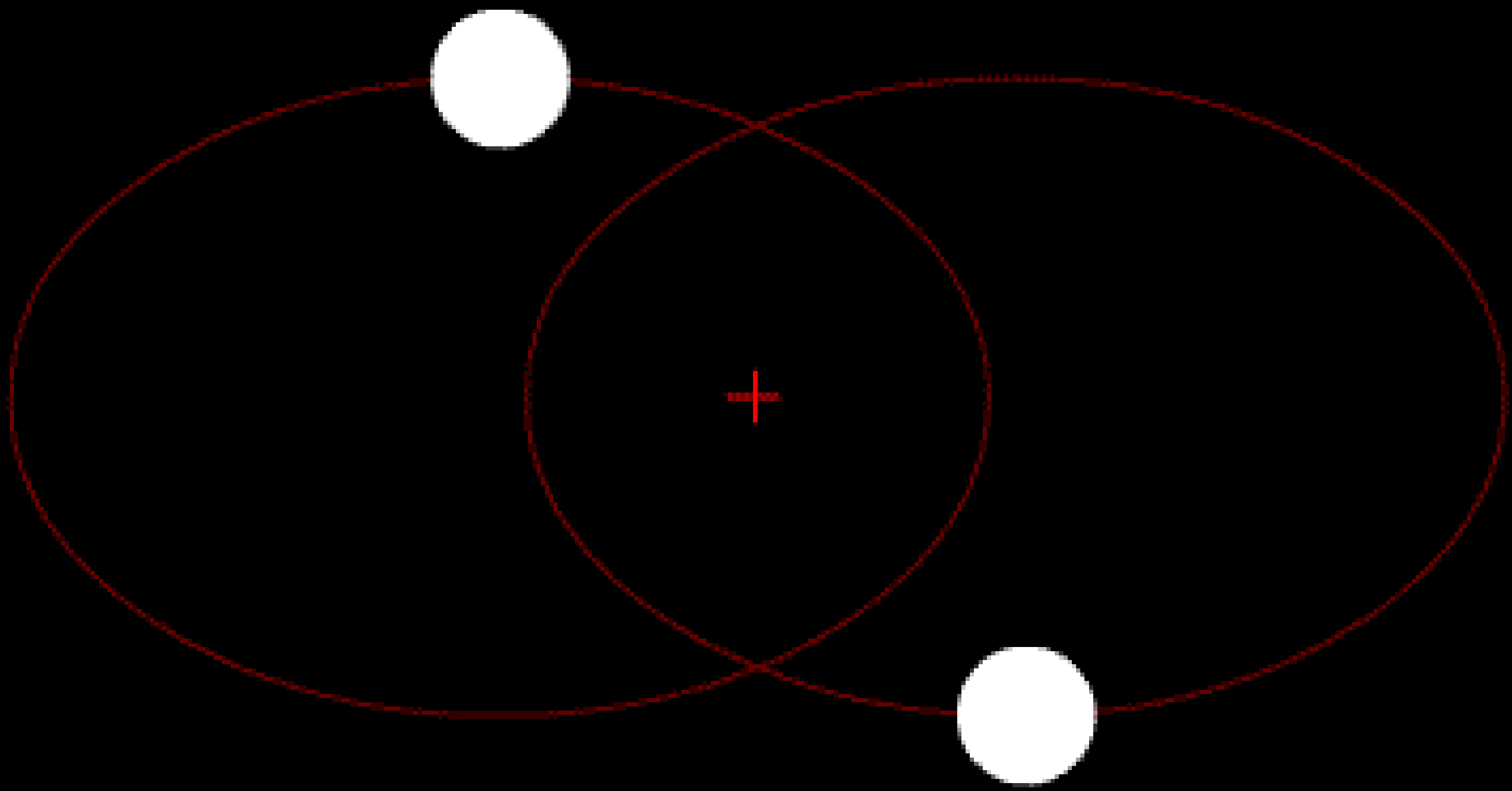
η Cha
8 Myr
12 Myr
20 Myr
TWA
4 Myr
8 Myr
12 Myr
BPMG
10 Myr
25 Myr
50 Myr
TUCHOR
10 Myr
25 Myr
50 Myr
ABD
30 Myr
60 Myr
120 Myr
logN_LI
T_eff (K)
h Cha
TWA
BPMG
TUCHOR
ABD
c^2/c^2_min
Age (Myr)

How sensitive is star formation to environment?

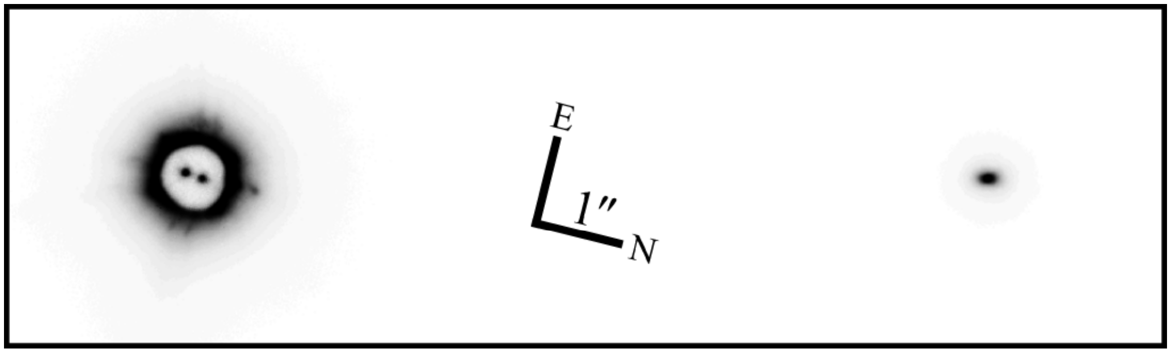
Diagnostics:

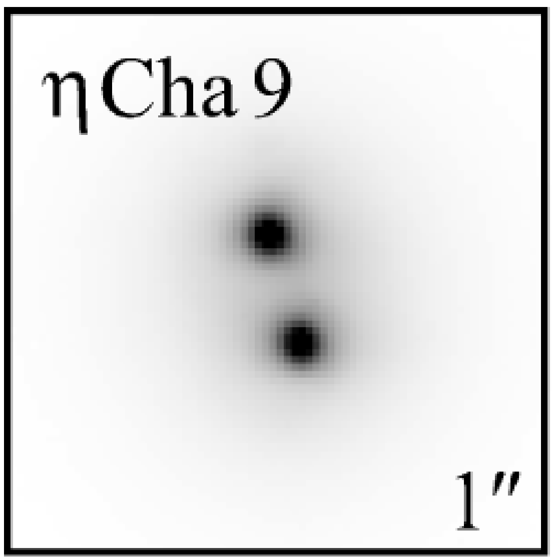
- Mass function (stars/BDs?)
- Multiplicity (fraction of multiples? Configurations?)

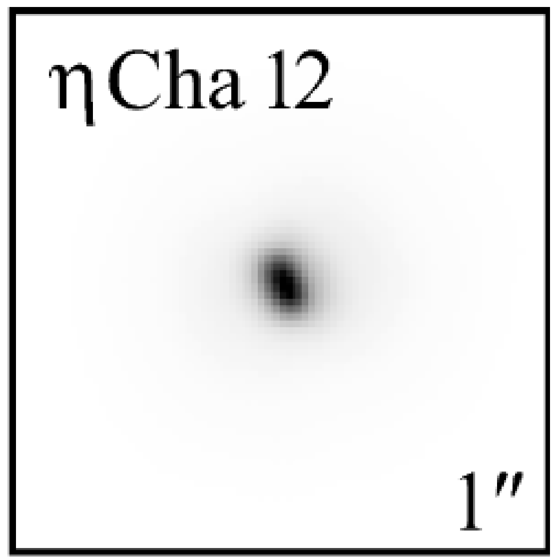
Multiplicity



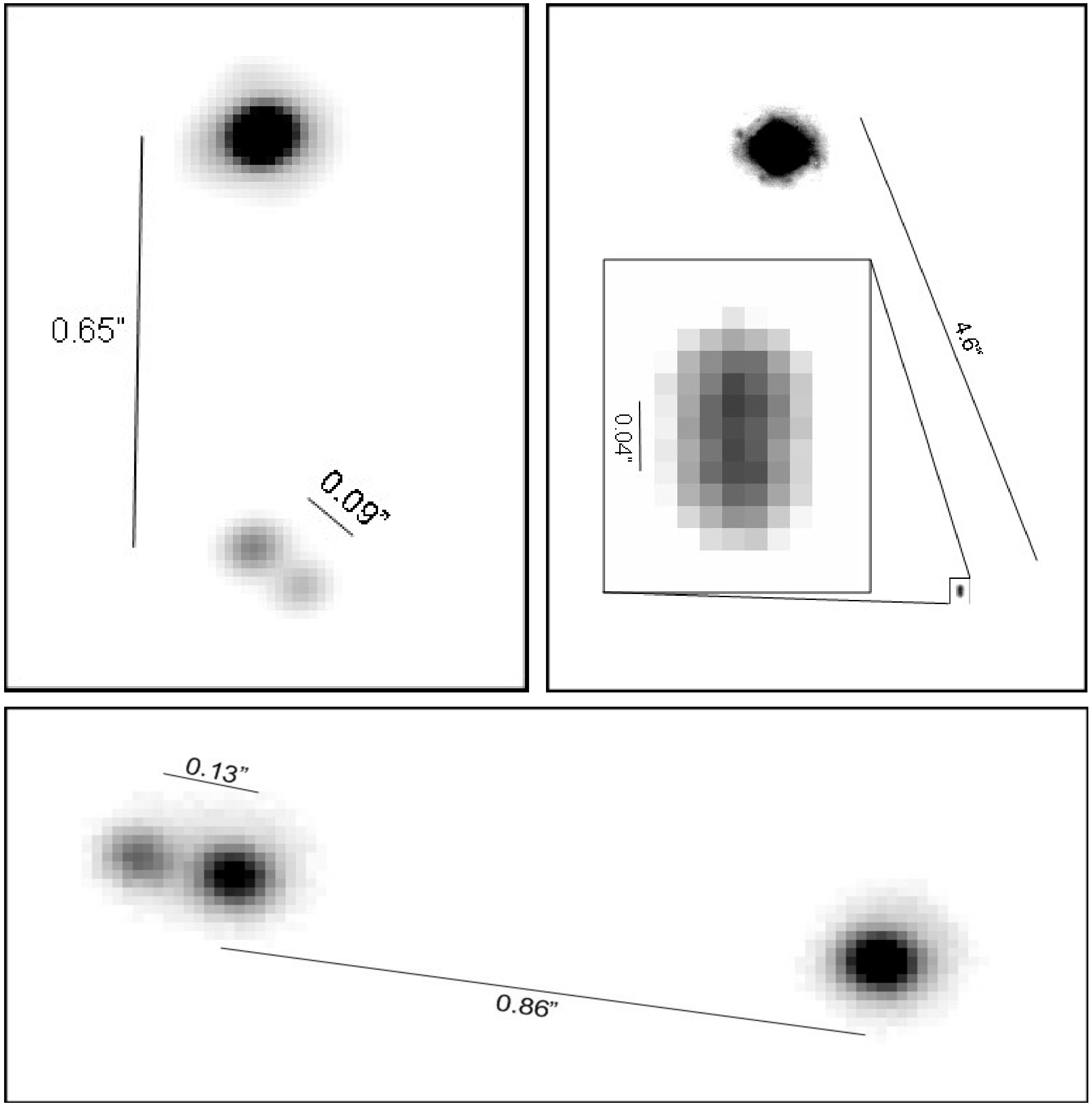
Optical binaries



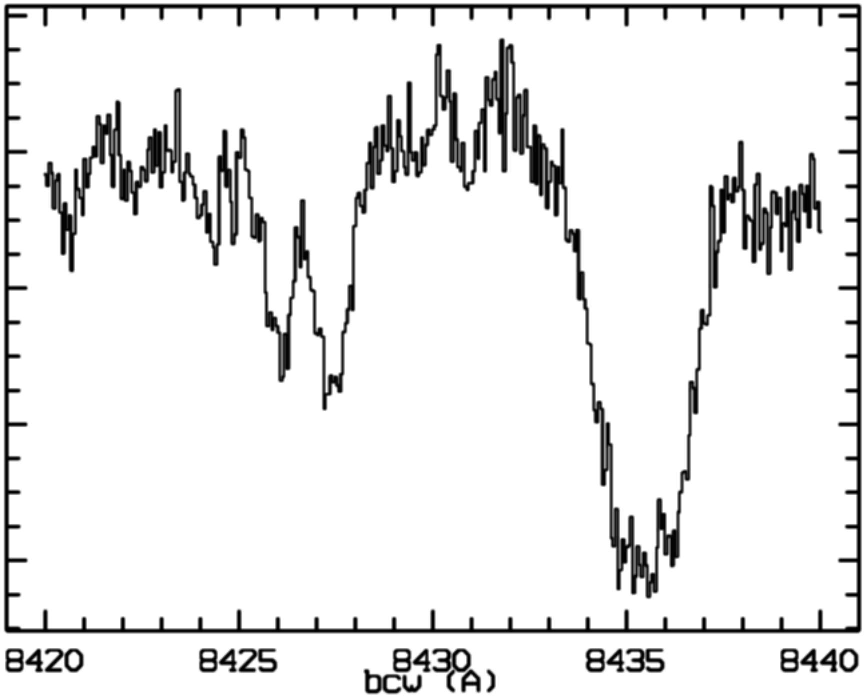




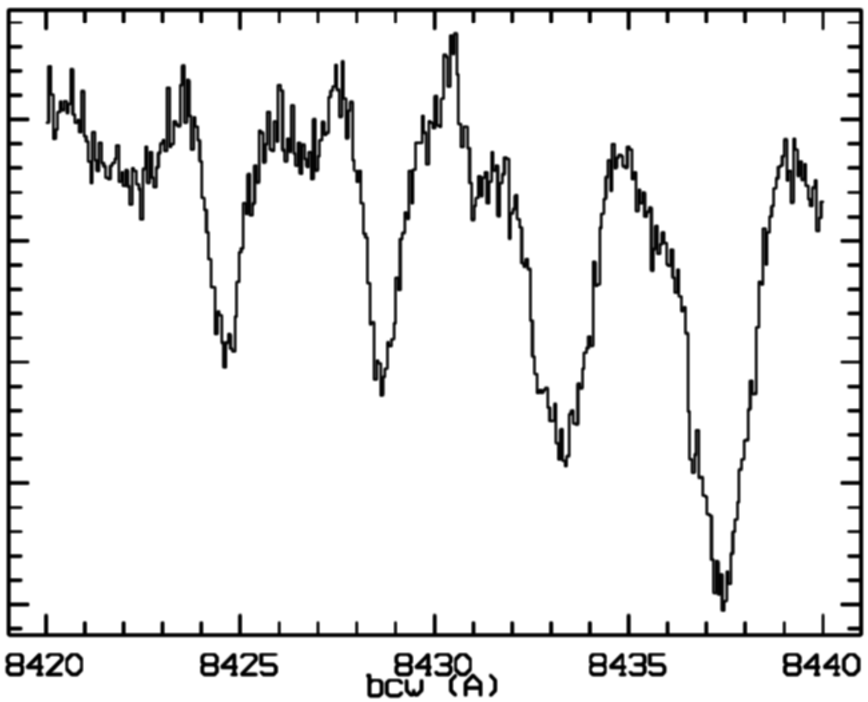
Optical triples



Double-lined spectroscopic binary

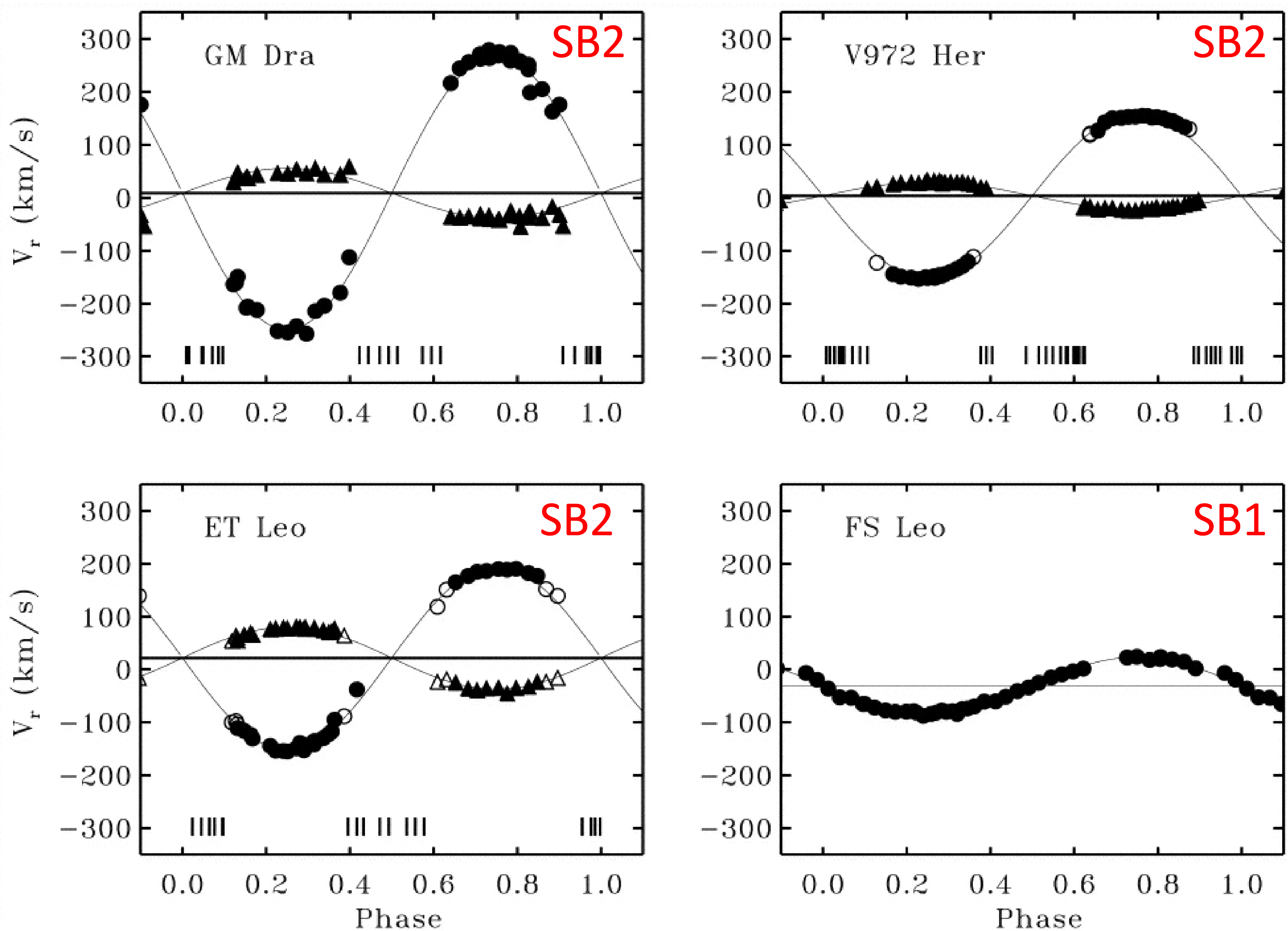


Epoch 1



Epoch 2

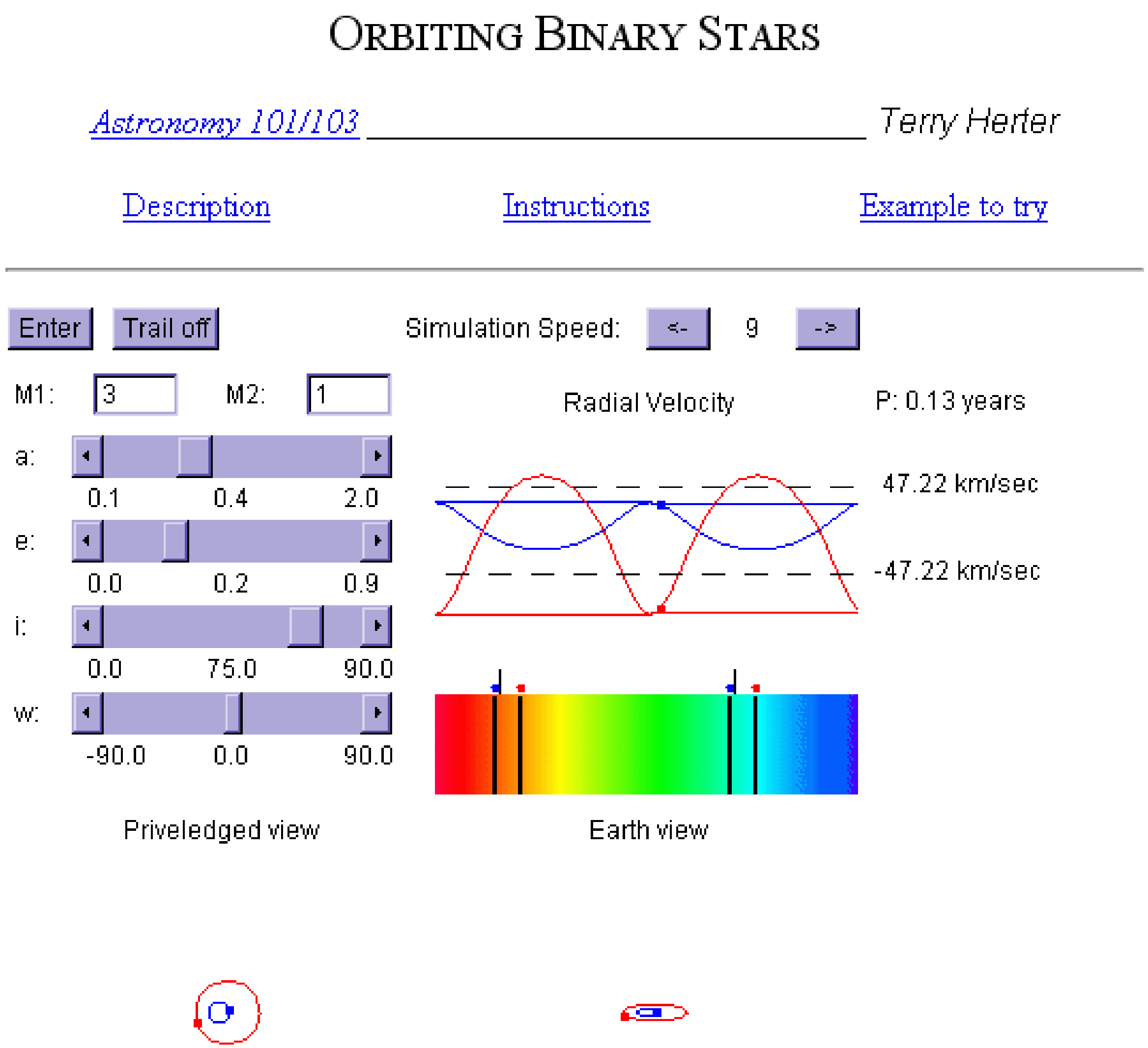
Spectroscopic binaries



Rucinski et al.

Spectroscopic binary simulator

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



Sensitivity

- Adaptive optics: a > 40 mas (6 AU @ 150 pc)
- Interferometry: a > 3 mas (0.5 AU @ 150 pc)
- Spectroscopic binary: P < 5 yr (3 AU for 1 M_{sol})

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

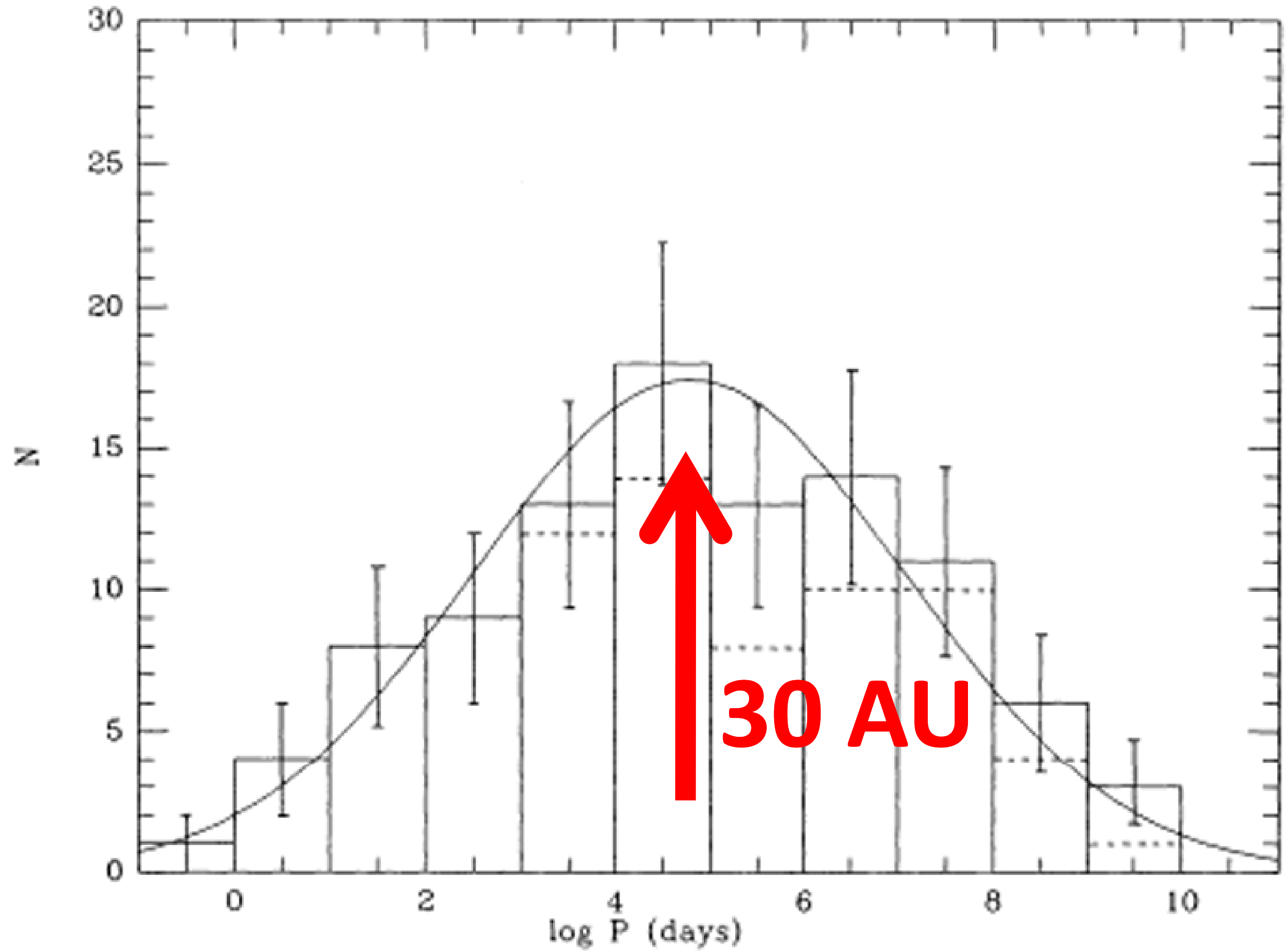
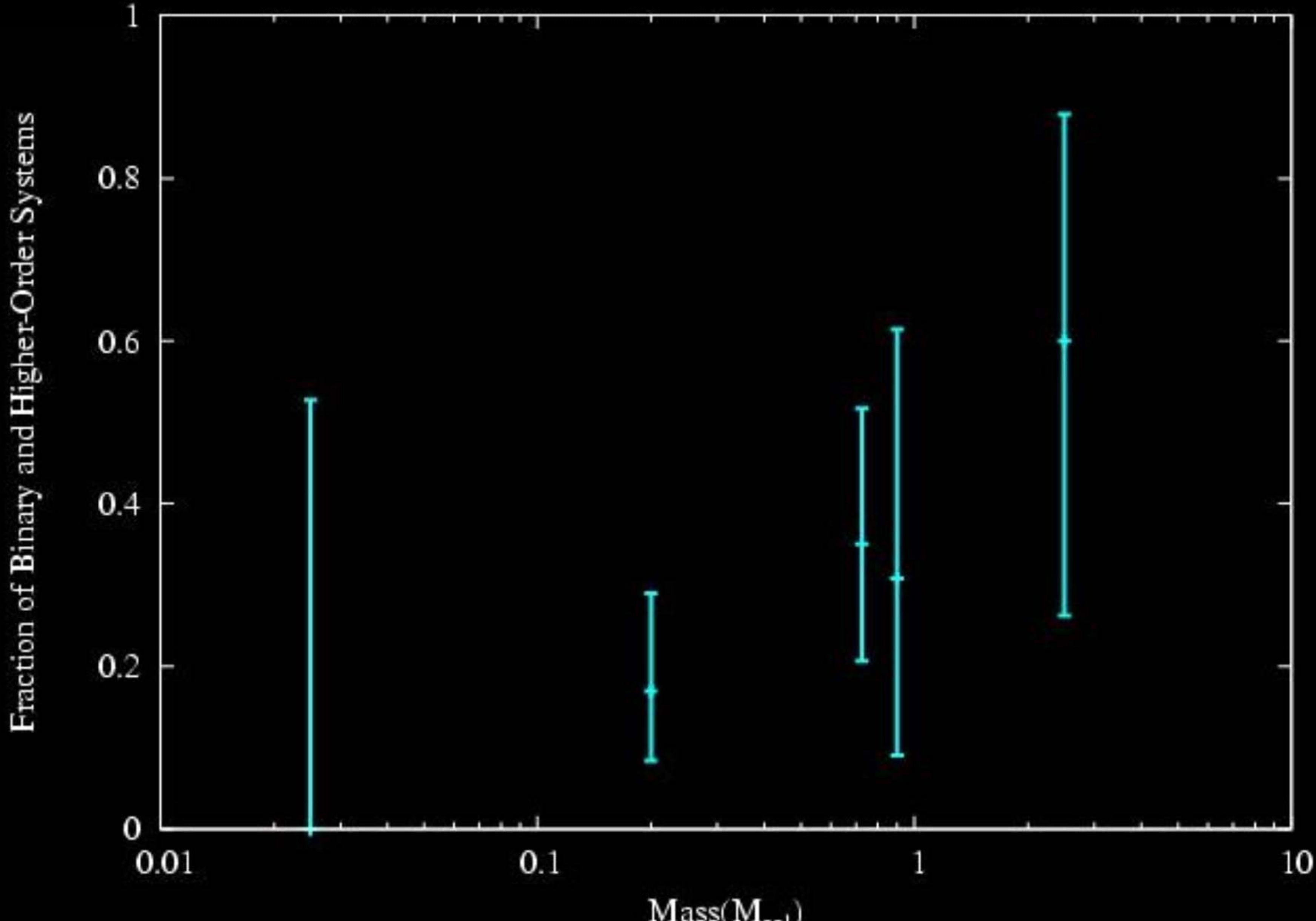


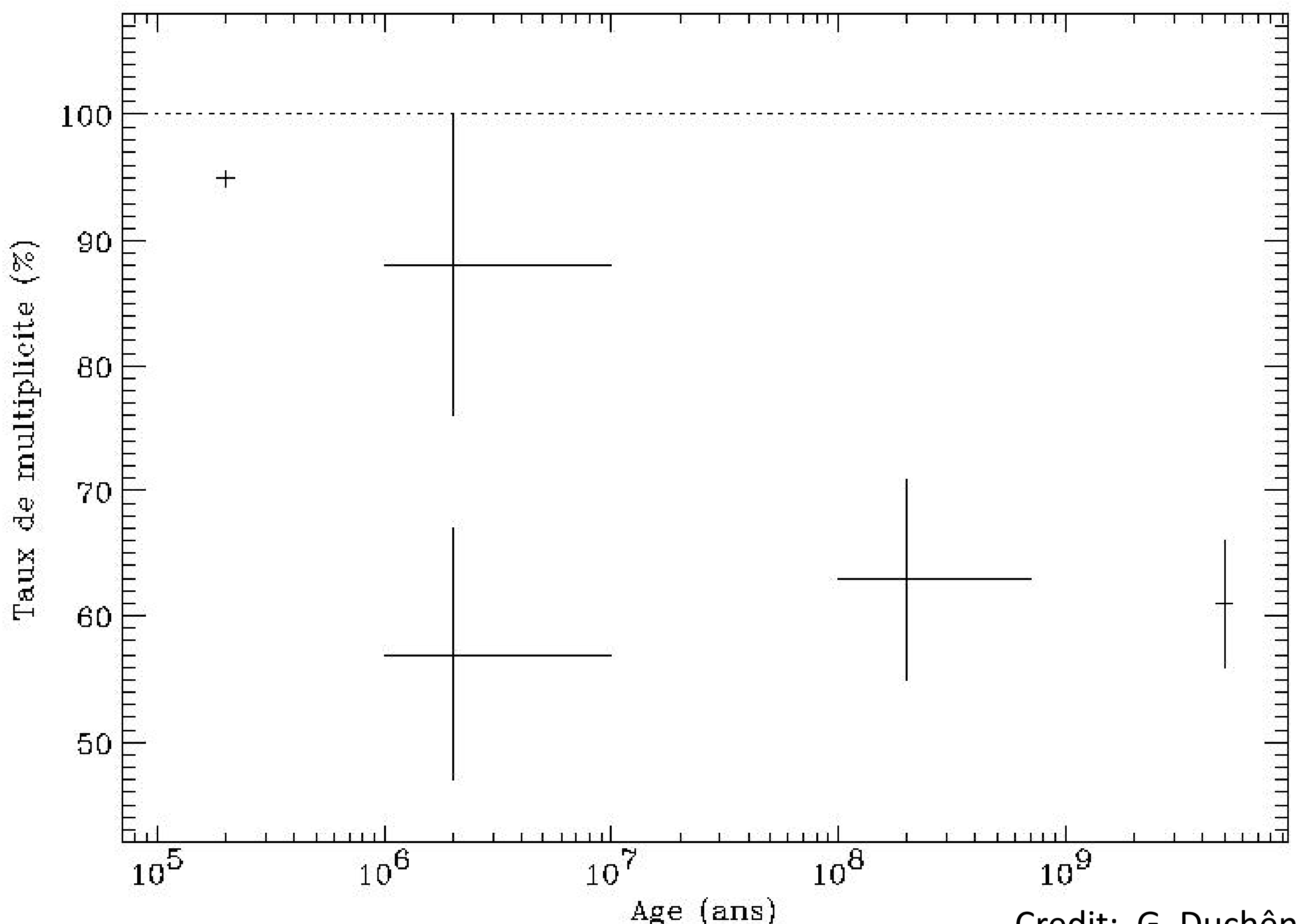
Fig. 7. Period distribution in the complete nearby G-dwarf sample, without (dashed line) and with (continuous line) correction for detection biases. A Gaussian-like curve is represented whose parameters are given in the text

Duqennoy & Mayor (1991)

Multiplicity fraction as a function of mass



Multiplicity fraction as a function of age



Credit: G. Duchêne