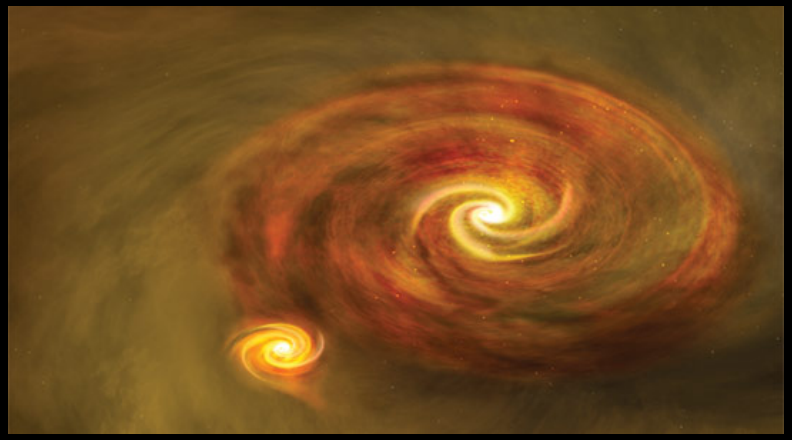
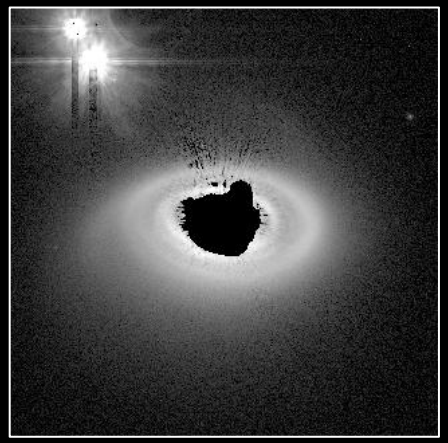
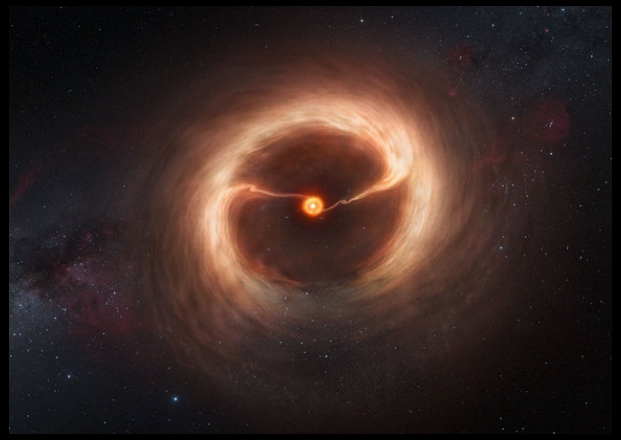




Herbig AeBe stars: multiplicity

Gaspard Duchêne

UC Berkeley

IPAG (U. Grenoble Alpes/CNRS)

Herbig Ae/Be stars: The missing link in star formation - ESO Workshop - April 7-11 2014

Stellar multiplicity is …

- … a direct tracer of the star formation process
  - *e.g.*, core fragmentation *vs.* disk fragmentation
- … a unique tool
  - to measure masses of HAeBe stars
  - to independently estimate ages of HAeBe stars
- … a key player for disk structure and evolution

Stellar multiplicity is …

- … a direct tracer of the star formation process
  - *e.g.*, core fragmentation *vs.* disk fragmentation
- … a unique tool
  - to measure masses of HAeBe stars
  - to independently estimate ages of HAeBe stars
- … a key player for disk structure and evolution
- … a really annoying nuisance!

Stellar multiplicity is …

- … a direct tracer of the star formation process
  - *e.g.*, core fragmentation *vs.* disk fragmentation
- … a unique tool
  - to measure masses of HAeBe stars
  - to independently estimate ages of HAeBe stars
- … a key player for disk structure and evolution
- … a really annoying nuisance!
- … an inescapable reality!

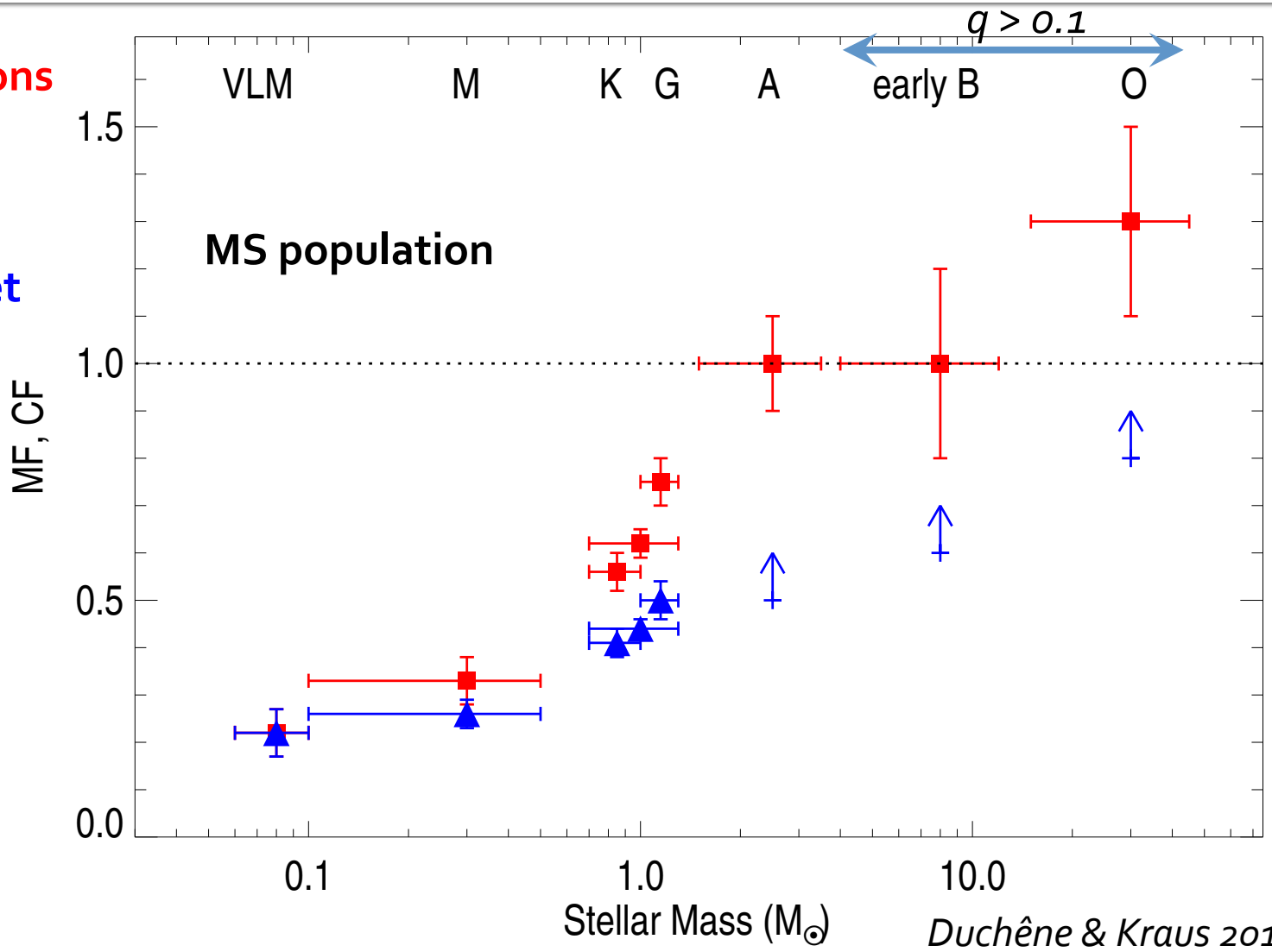
Outline

- Setting the stage
  - Methods
  - Limitations
- General multiplicity statistics
- Other topics of interest
  - Disk orientation
  - X-ray emission
  - Transition disks

Multiplicity *vs.* stellar mass

# of companions per target

# of multiple system / target

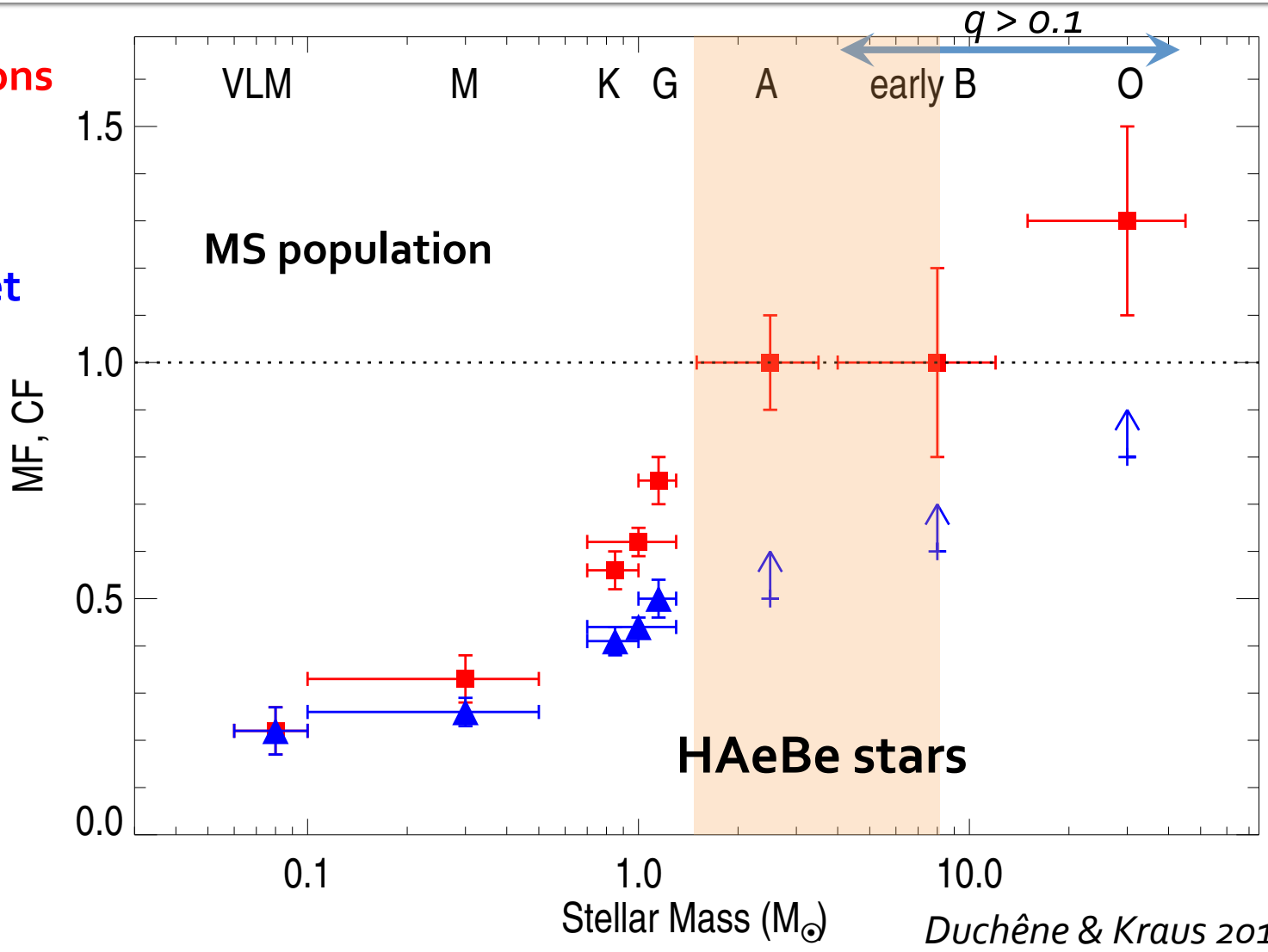


Duchêne & Kraus 2013

Multiplicity *vs.* stellar mass

# of companions per target

# of multiple system / target

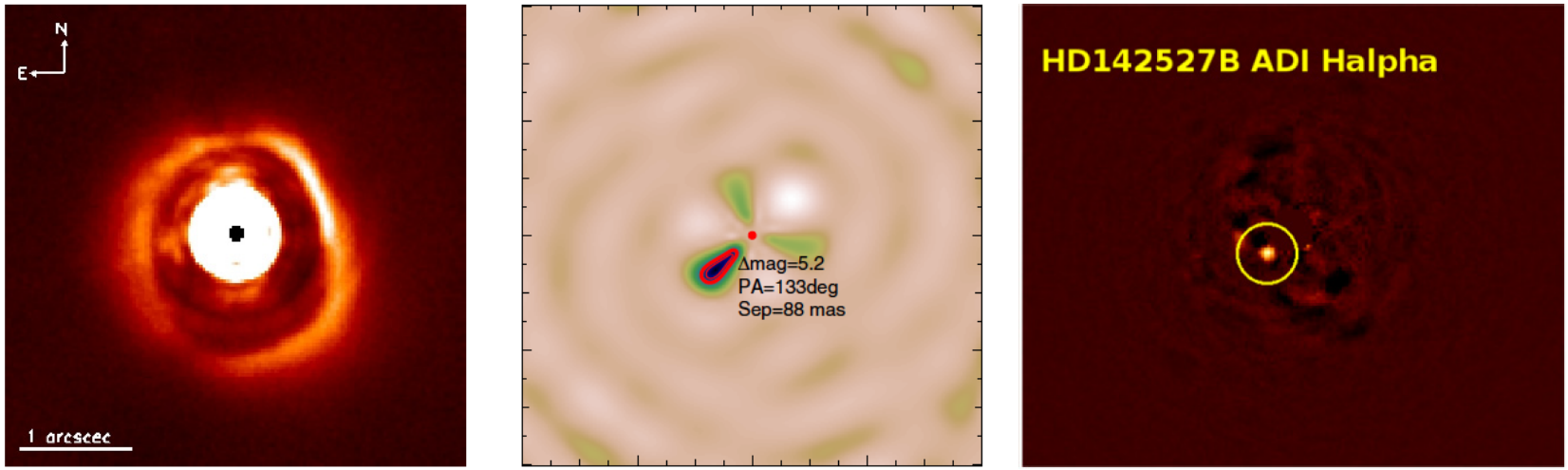


Duchêne & Kraus 2013

Searching for companions

- In depth studies of individual objects
  - Gap clearing in HD 142527

Rameau+2012; Biller+2012; Close+2014



Searching for companions

- In depth studies of individual objects
  - Gap clearing in HD 142527
- Global understanding can only be achieved with systematic surveys
  - Spectroscopic (RV, spectrum blending)
  - Imaging (direct, speckle, AO, aperture masking)
  - Long-baseline interferometry
  - Spectro-astrometry/polarimetry

What makes a good survey?

- Large sample (N> 100)
- Volume-limited sample and/or small range of distances
- Homogenous selection criteria
- Tight range of targets' stellar properties
- Uniform observing technique (e.g., imaging contrast, RV precision, …)
- Multi-epoch (RV variations, CPM)

HAeBe surveys are not optimal!

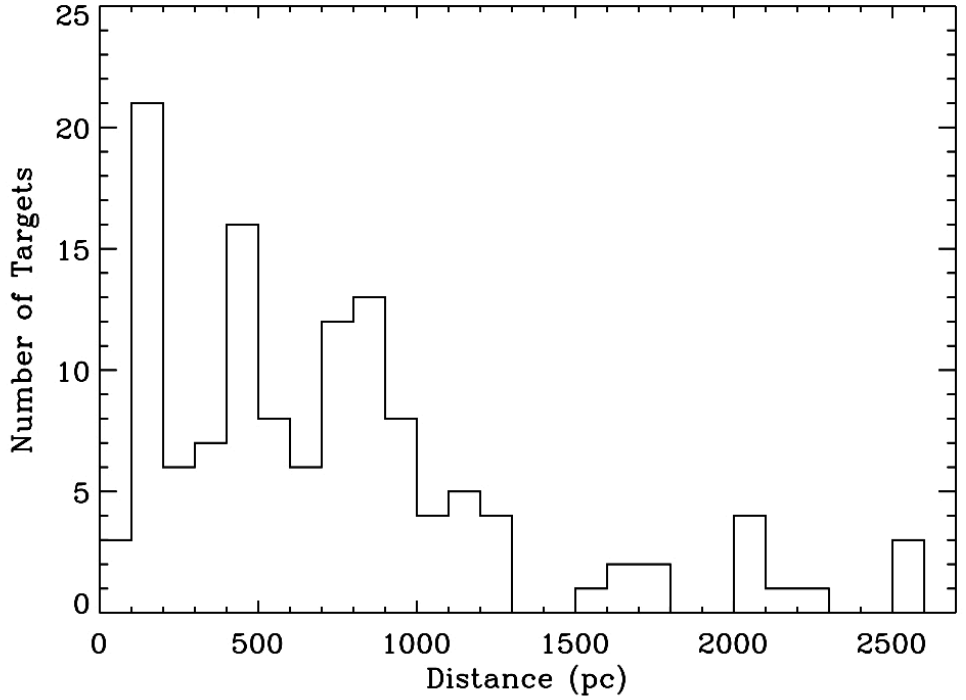
- Large sample (N> 100)
- ~~Volume-limited sample and/or small range of distances~~
- ~~Homogenous selection criteria~~
- ~~Tight range of targets' stellar properties~~
- ~~Uniform observing technique (e.g., imaging contrast, RV precision, …)~~
- Multi-epoch (RV variations, CPM)

A multi-faceted challenge

- Broad range of masses in HAeBe stars
  - Can we lump them in a single sample?

A multi-faceted challenge

- Broad range of masses in HAeBe stars
- Large (uncertain) and diverse distances
  - ~1 order of magnitude range



Thomas+ (in prep.)

A multi-faceted challenge

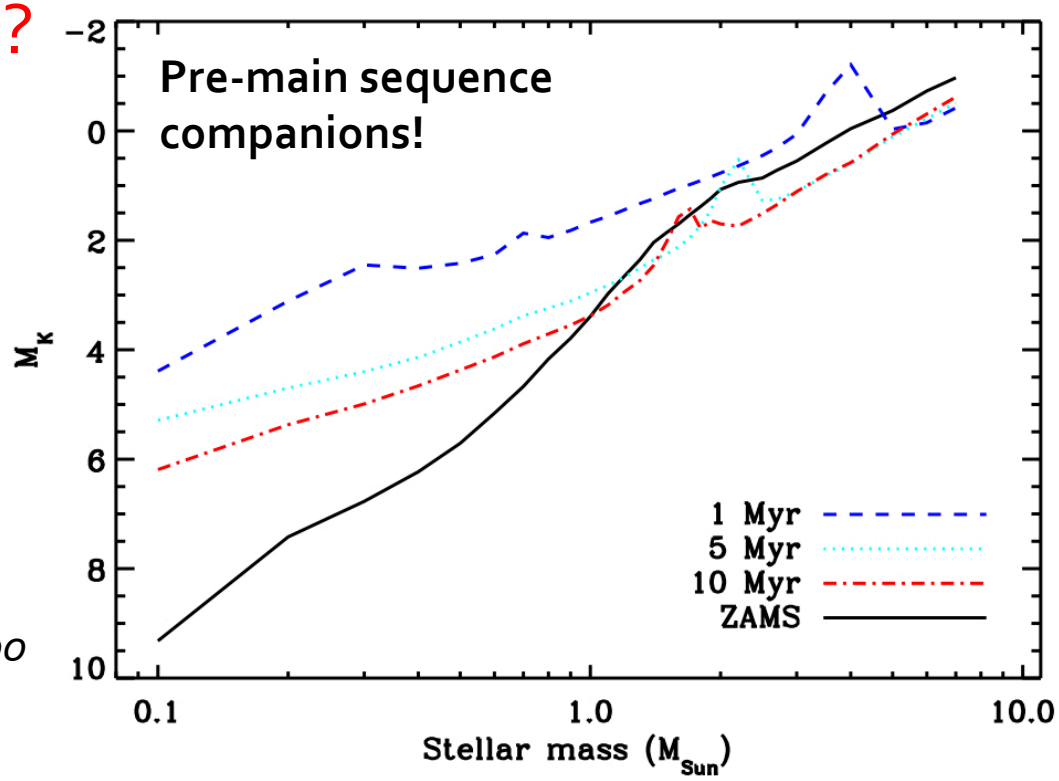
- Broad range of masses in HAeBe stars
- Large (uncertain) and diverse distances
- Fast rotation
- Emission lines
- Uncertain stellar properties

A multi-faceted challenge

- Steep mass-luminosity relationship limits ability to detect low-mass companions…

A multi-faceted challenge

- Steep mass-luminosity relationship limits ability to detect low-mass companions…
  - Not so bad after all?



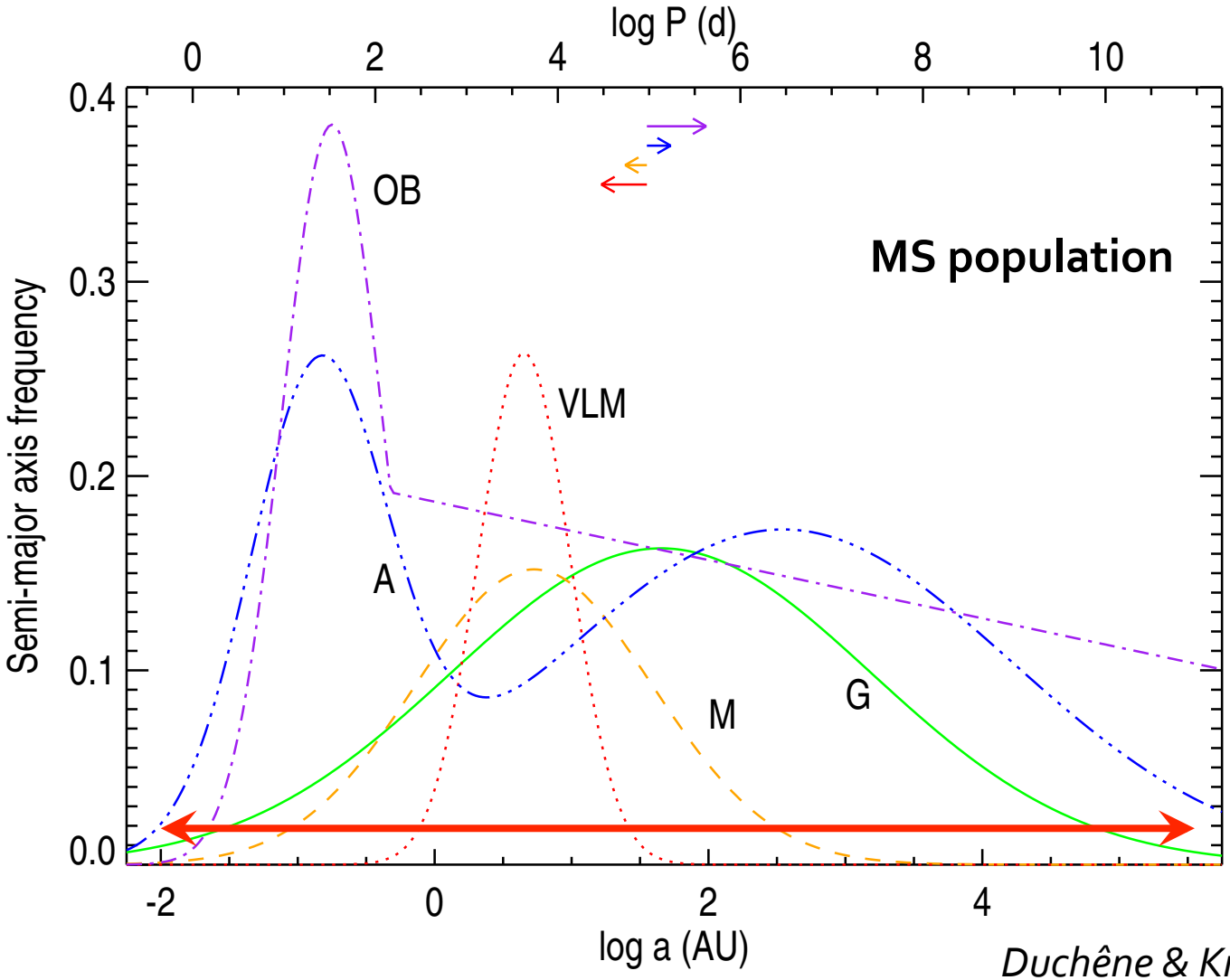
Siess+2000

A multi-faceted challenge

- Steep mass-luminosity relationship limits ability to detect low-mass companions…
  - Not so bad after all?
- PMS companions = potential for disk and accretion that can confuse interpretation

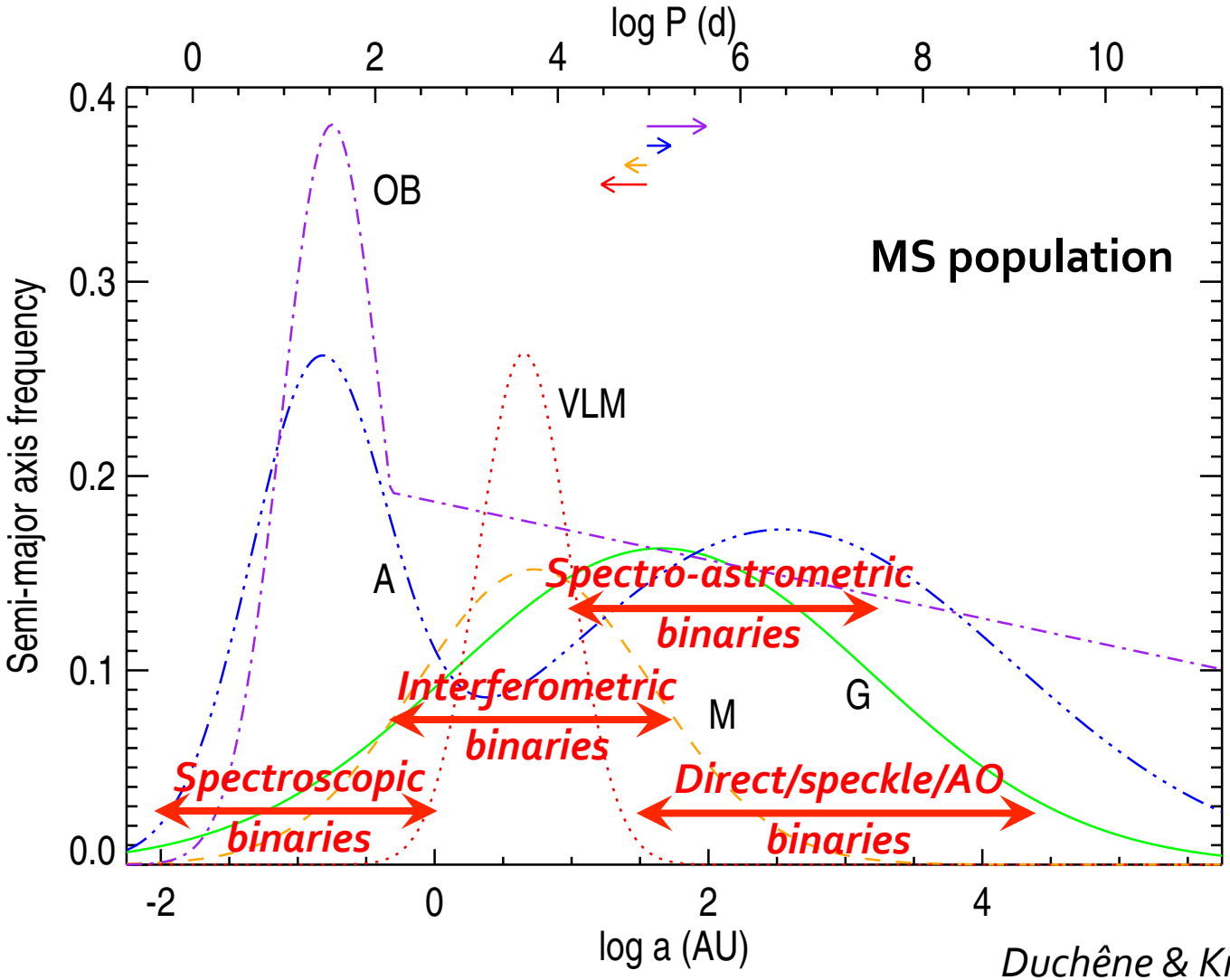
General multiplicity statistics

Orbital period distribution



Duchêne & Kraus (2013)

Orbital period distribution

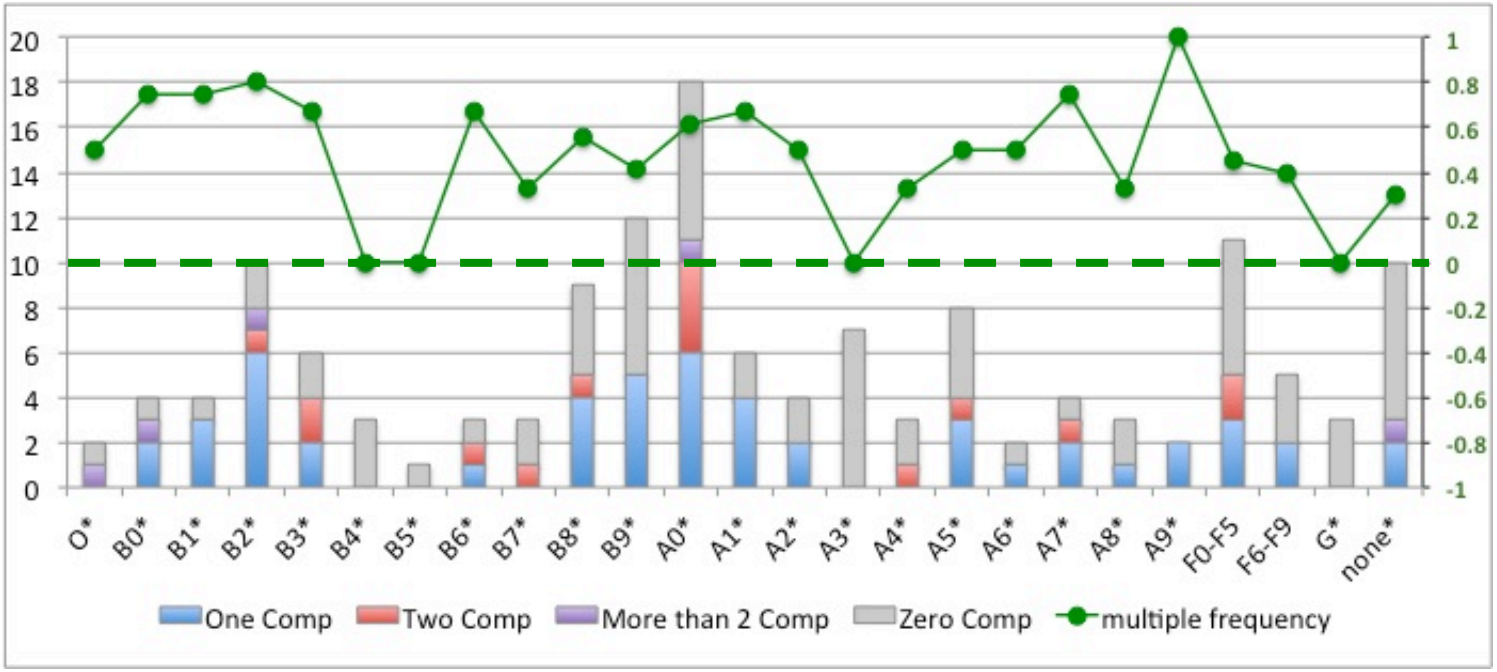


Duchêne & Kraus (2013)

Visual binaries

- Multiple methods: direct, shift-and-add, lucky imaging, speckle interferometry, AO

Thomas+ (in prep.)



See also: Pirzkal+ 1997; Leinert+ 1997; Bouvier & Corporon 2001; Doering+ 2009

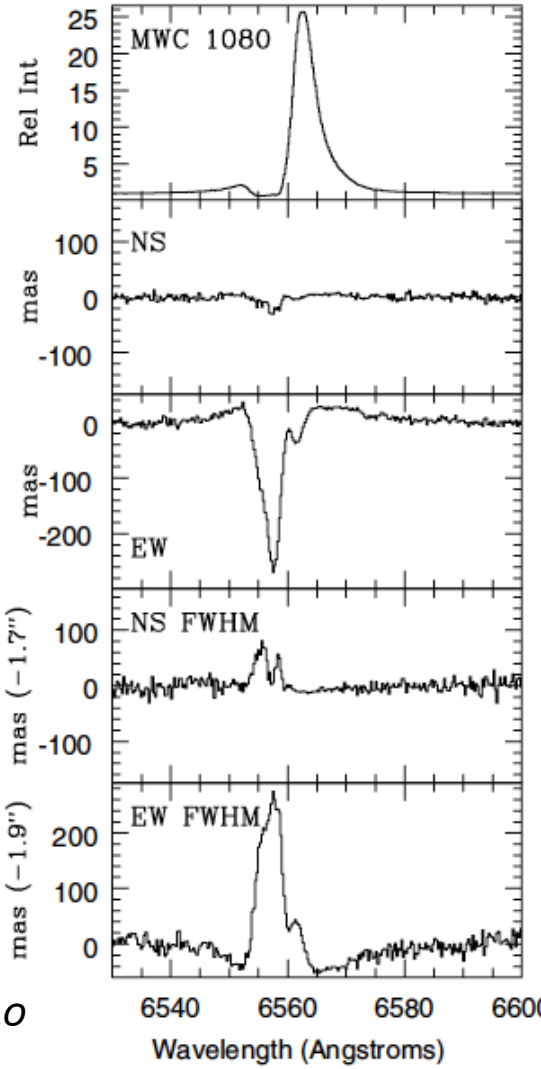
Visual binaries

- Multiple methods: direct, shift-and-add, lucky imaging, speckle interferometry, AO
- Consistent results: ~ 25% per decade of projected separation
  - ~50% in 50-5000 au range

- See posters by Rodgers, Briceño and Csépány

Spectro-astrometric binaries

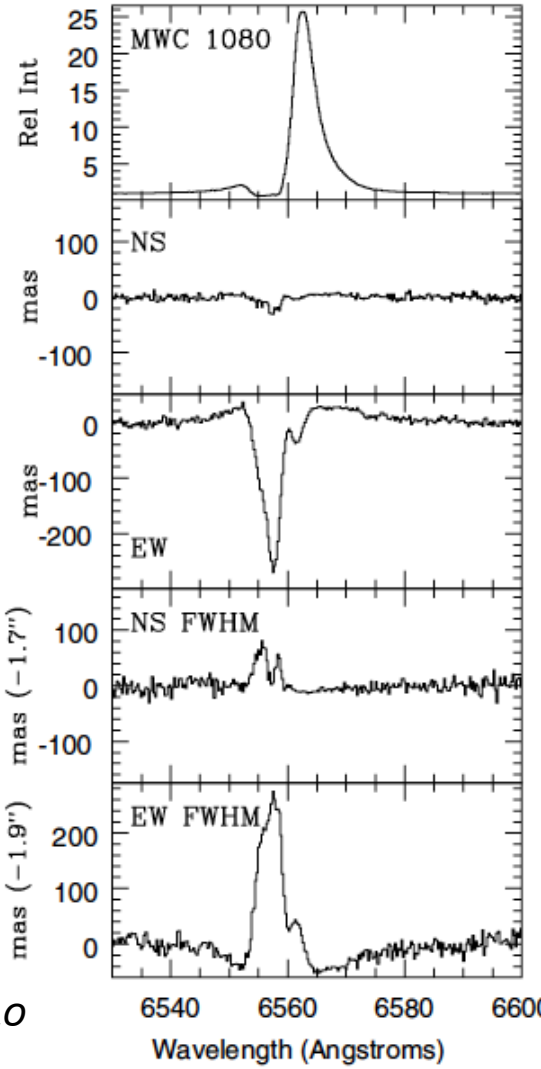
- Sensitive to >0.1" binaries



Baines+2006; Wheelwright+ 2010

Spectro-astrometric binaries

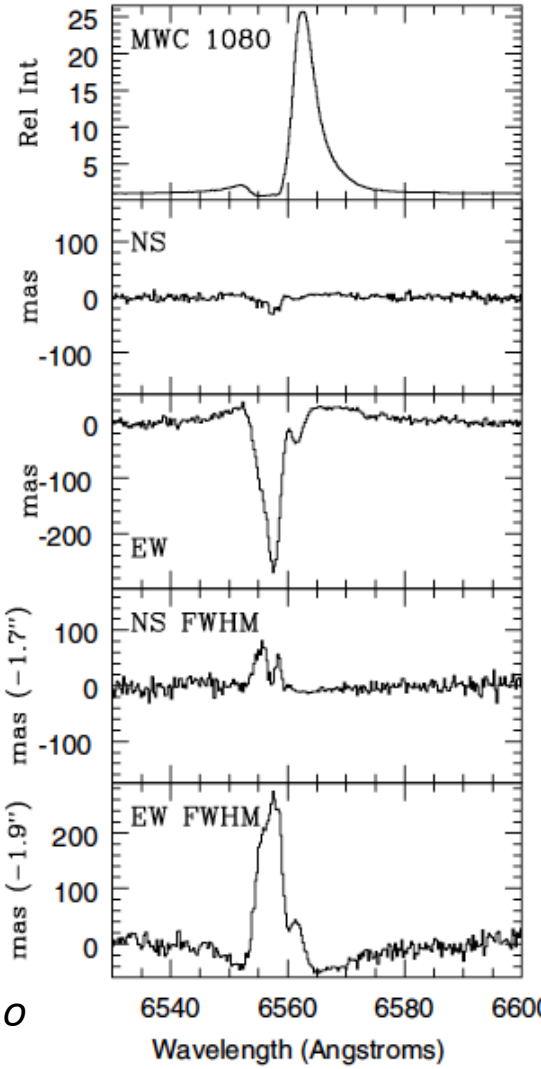
- Sensitive to >0.1" binaries
- Very high binary fraction
  - ~ 70-75%
  - Above imaging surveys



Baines+2006; Wheelwright+ 2010

Spectro-astrometric binaries

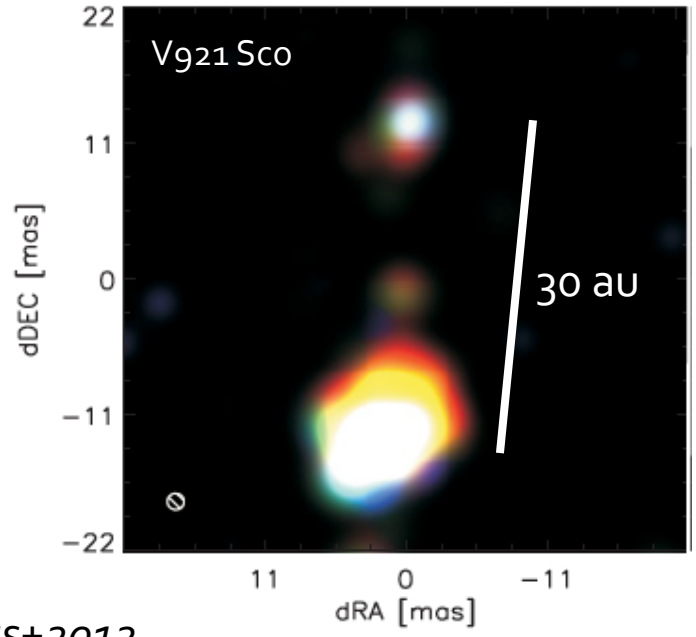
- Sensitive to >0.1" binaries
- Very high binary fraction
  - ~ 70-75%
  - Above imaging surveys
- Can be fooled by emission knots?
  - Example of AB Aur



Baines+2006; Wheelwright+ 2010

Interferometric binaries

- Probes separations ~ 0.5 – 50 au

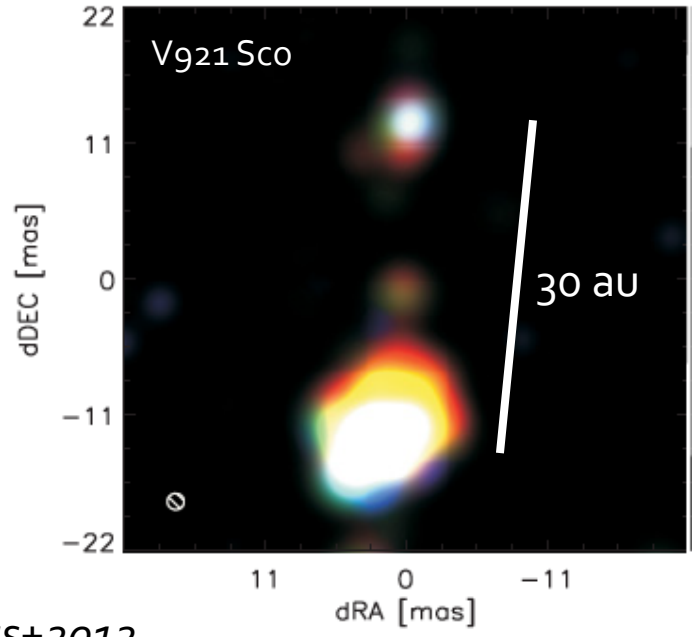


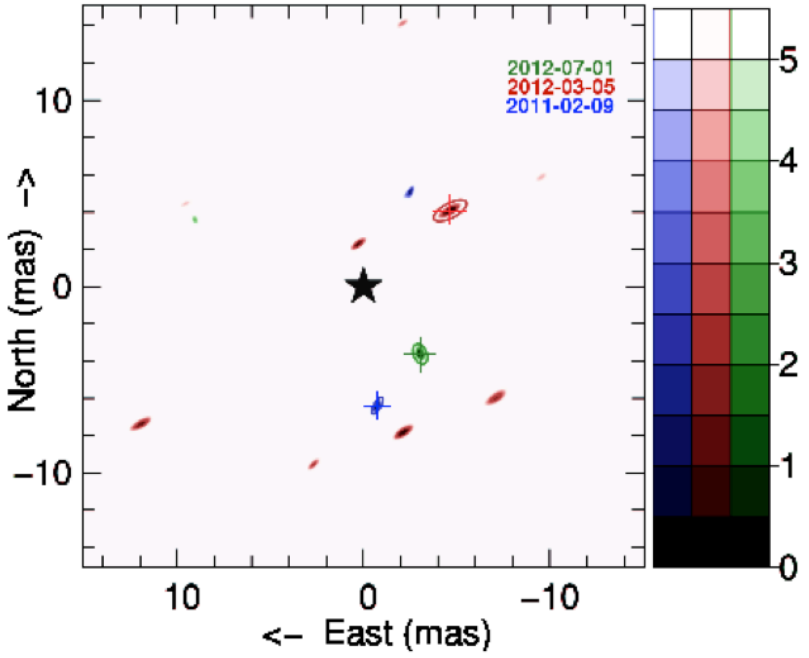
Kraus+2012

Interferometric binaries

- Probes separations ~ 0.5 – 50 au
- PIONIER survey: ~15-20% companions (most newly discovered)

Anthonioz+ (in prep)





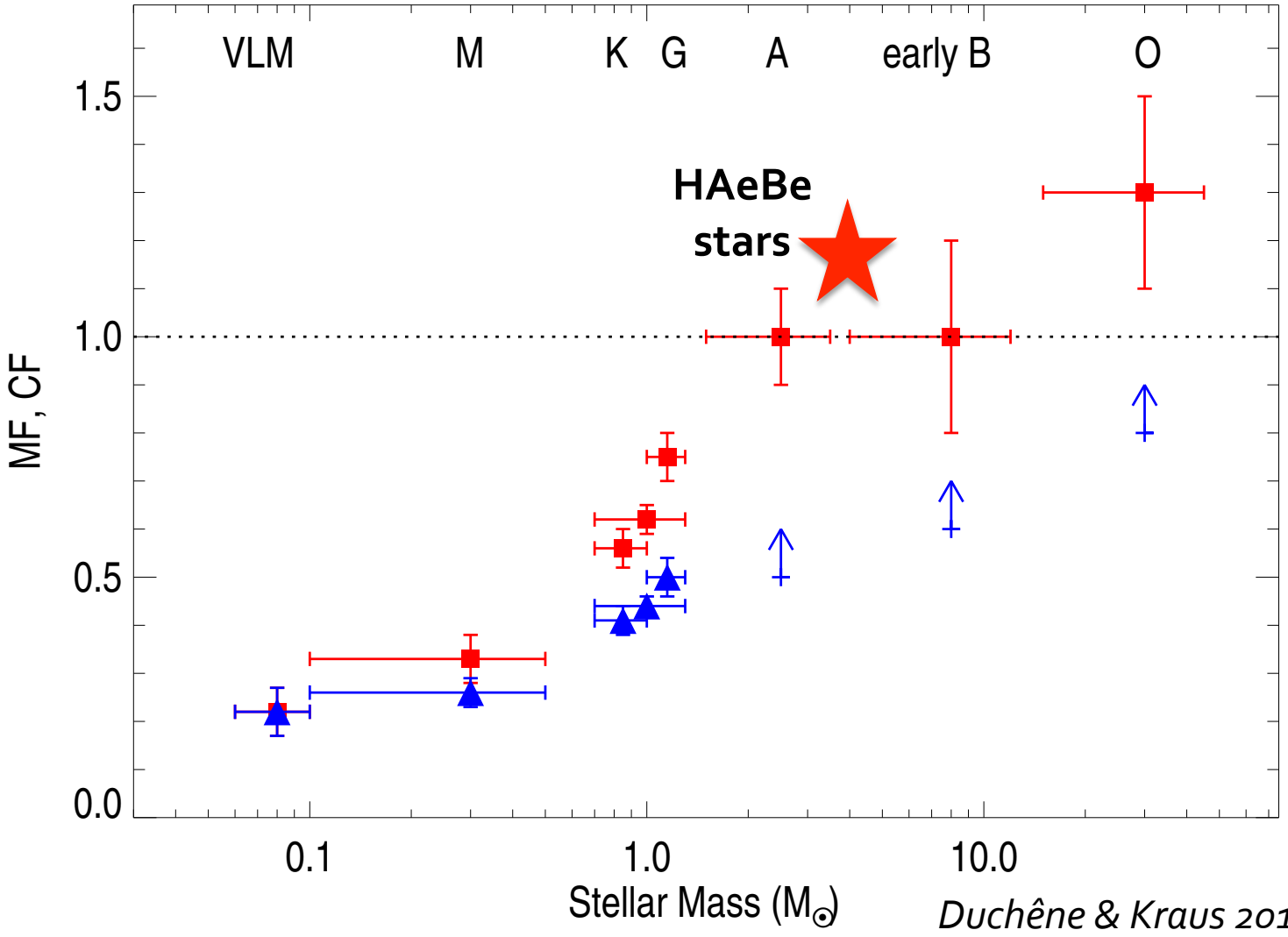
Kraus+2012

Spectroscopic binaries

- A number of individual systems known, but very few statistical surveys
- "Low" observed fraction: ~10-15%
  - Limited completeness, esp. for faster rotators
  - Suggested 35% "corrected" fraction out to P~100d (~ 0.5-1 au)

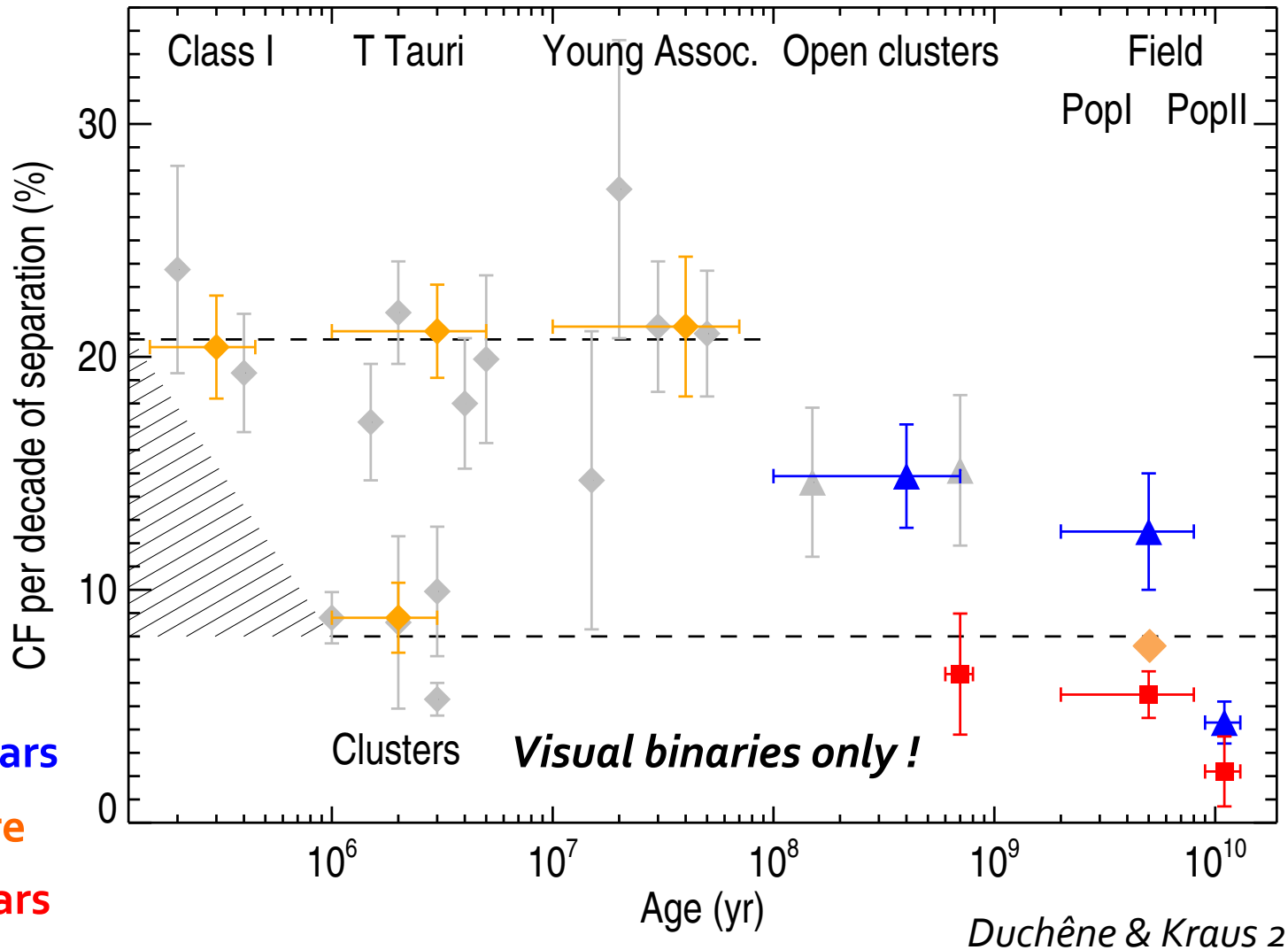
Corporon & Lagrange 1999; Alecian+ 2013

Global multiplicity fraction



Duchêne & Kraus 2013

Global multiplicity fraction



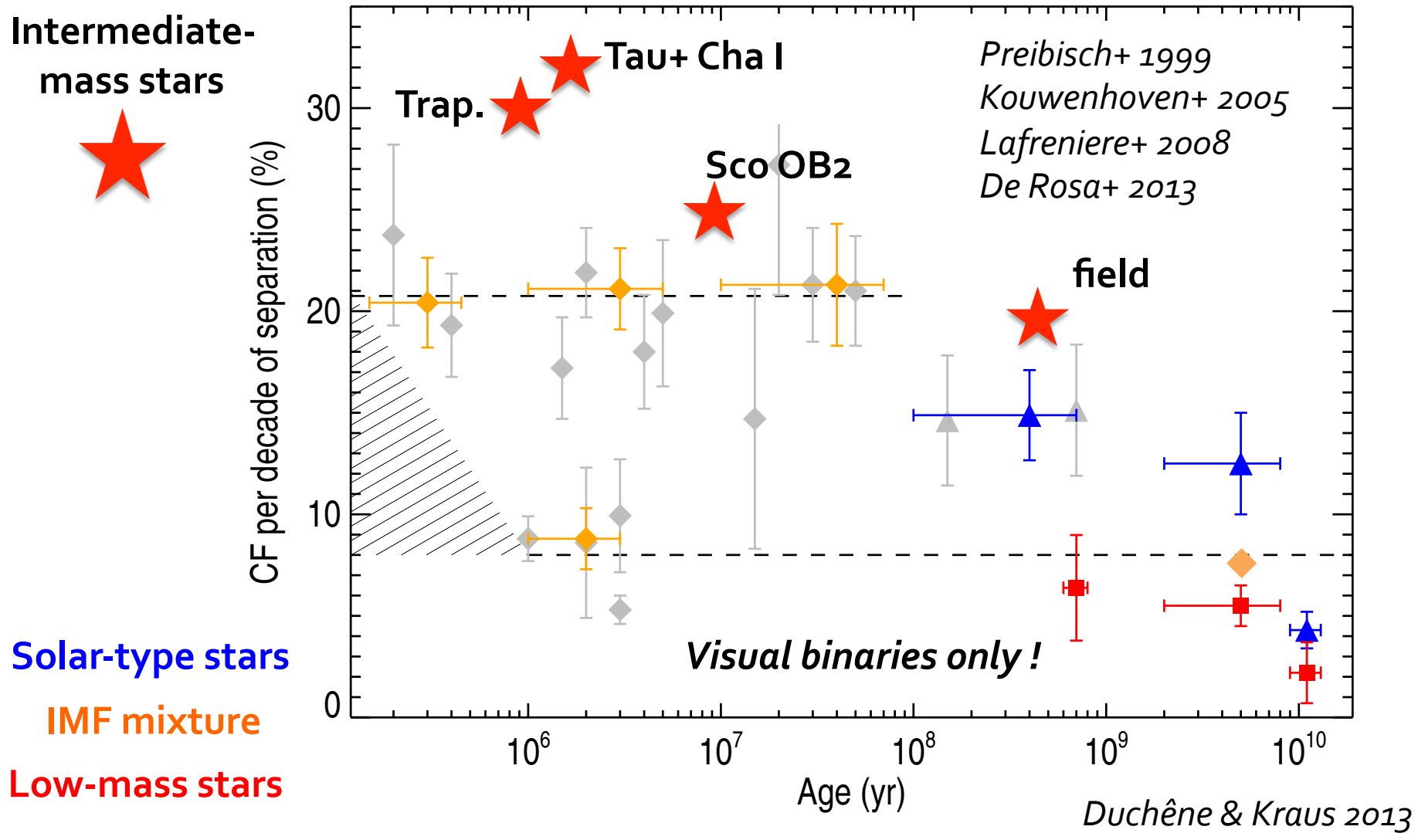
Solar-type stars

IMF mixture

Low-mass stars

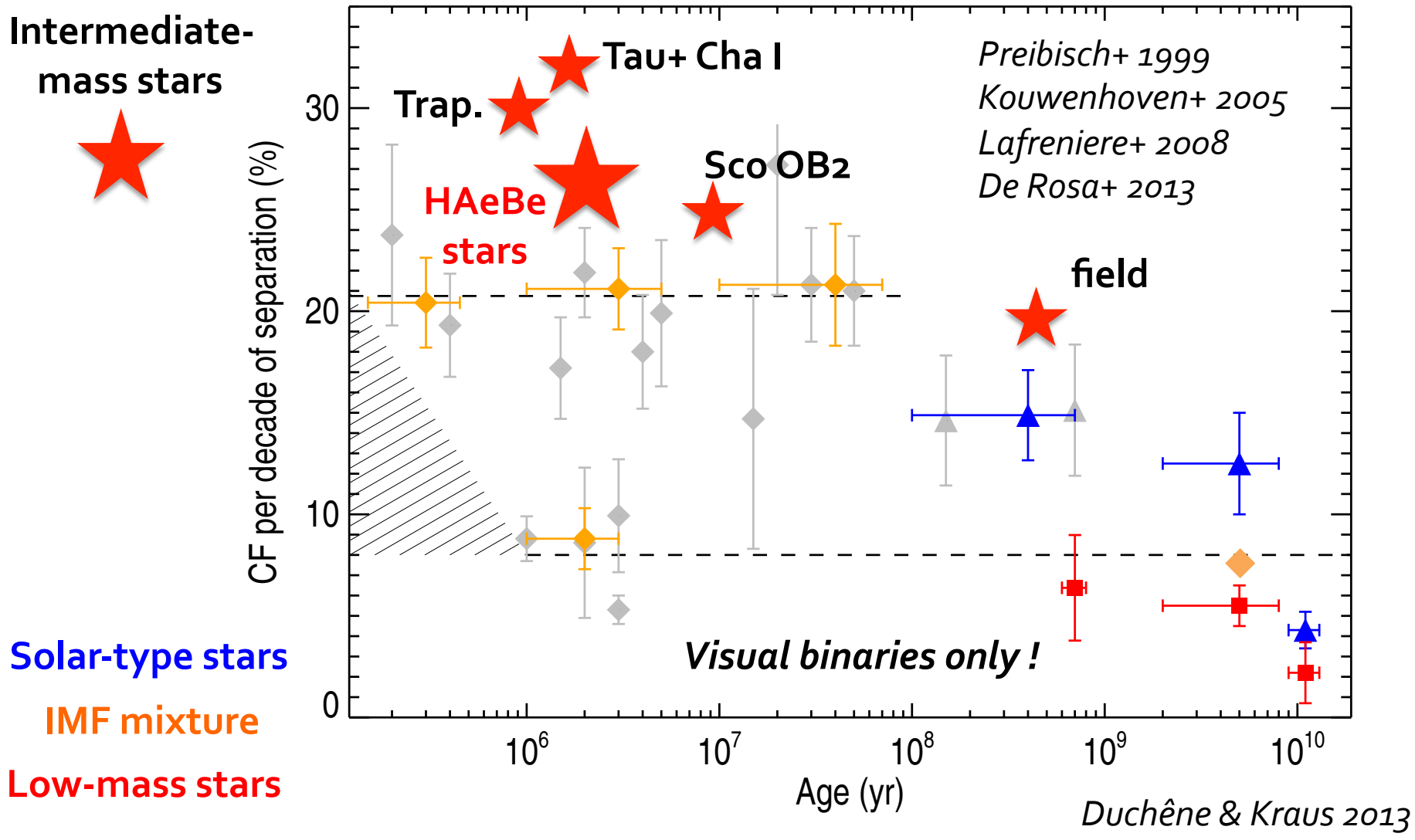
Duchêne & Kraus 2013

Global multiplicity fraction



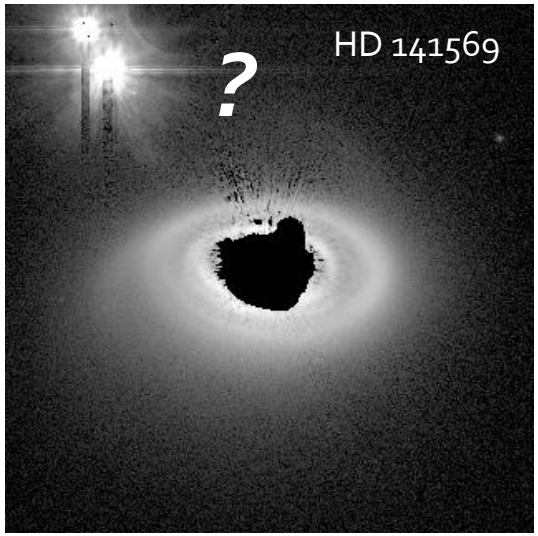
Duchêne & Kraus 2013

Global multiplicity fraction

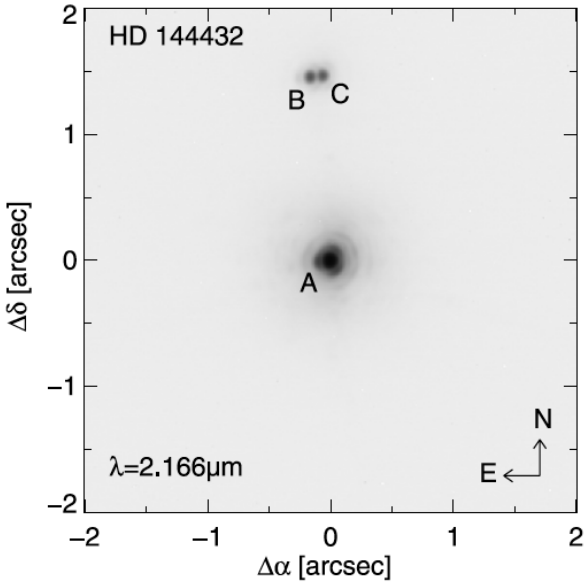


High-order multiplicity

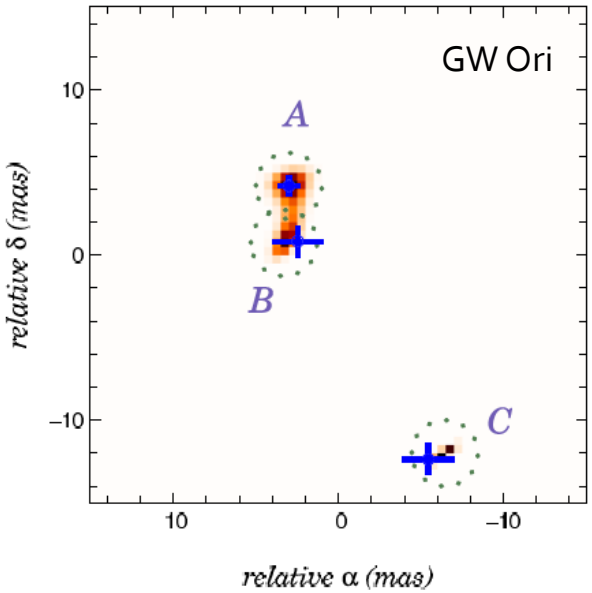
- Several examples known, but no statistical understanding yet



Clampin+2003



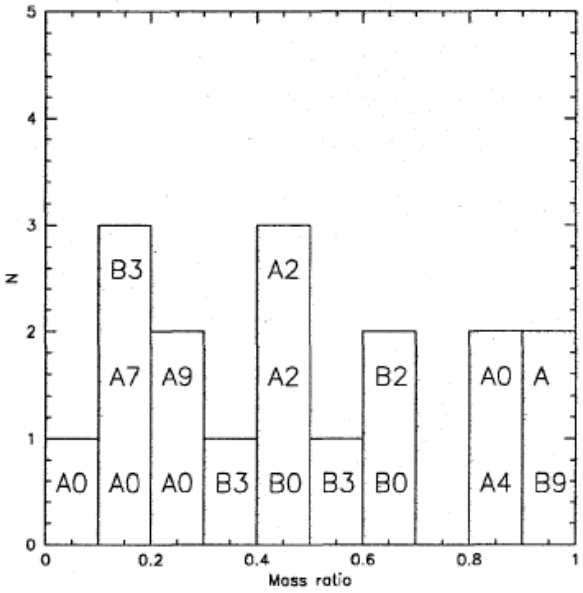
Müller+2011



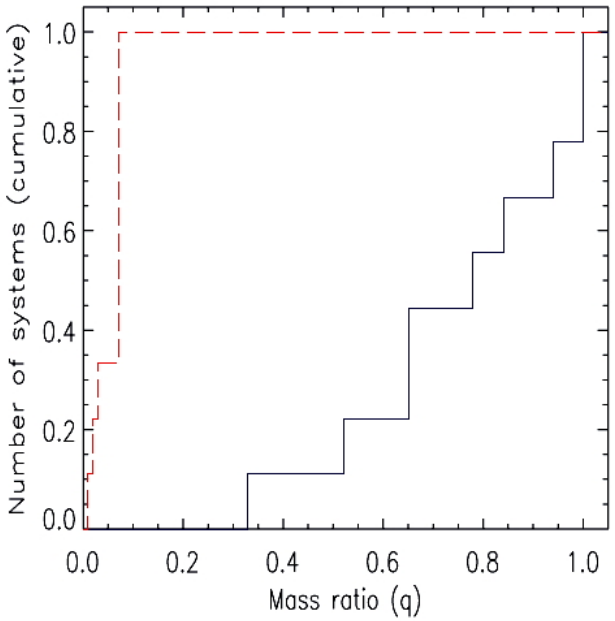
Berger+2011

Mass ratio distribution

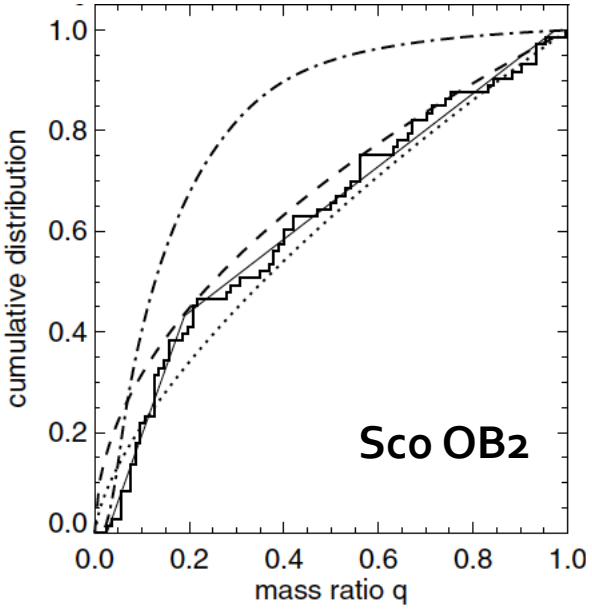
- Hard to assess without spectroscopic data; even then, serious selection bias
  - "Flatish" *q* distribution for visual binaries (≠ IMF)



Bouvier&Corporon 2001



Wheelwright+2010

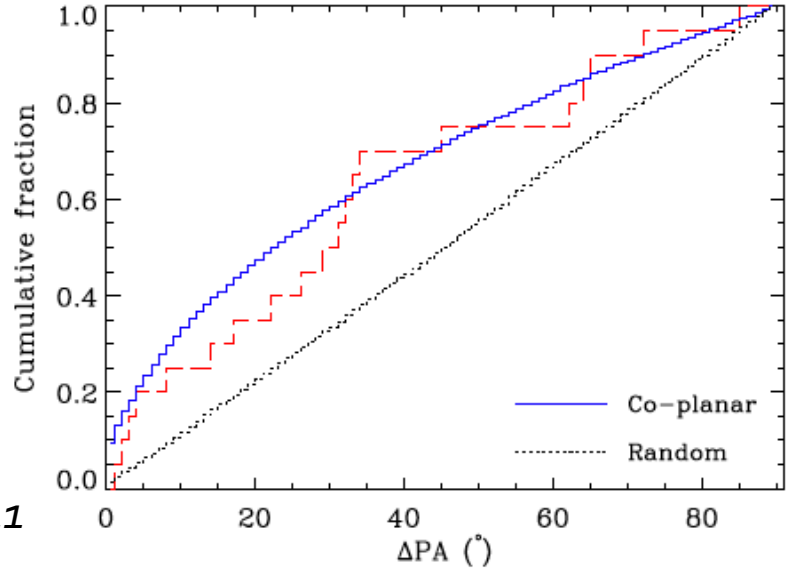


Kouwenhoven+2005

Other topics of interest

Disk orientation in binaries

- No known system where both the disk and orbital plane are firmly established
- Statistical analysis suggests preferred alignment between disk and orbital planes

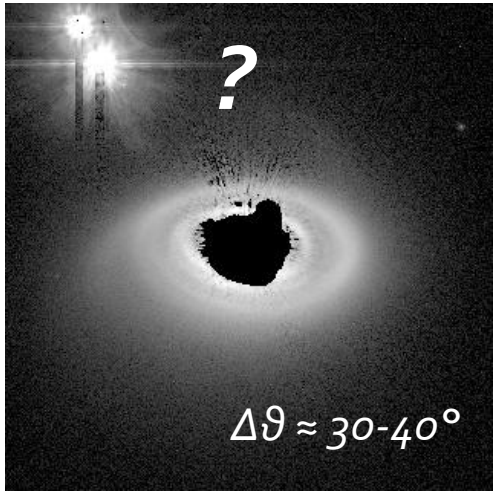


Wheelwrigth+2011

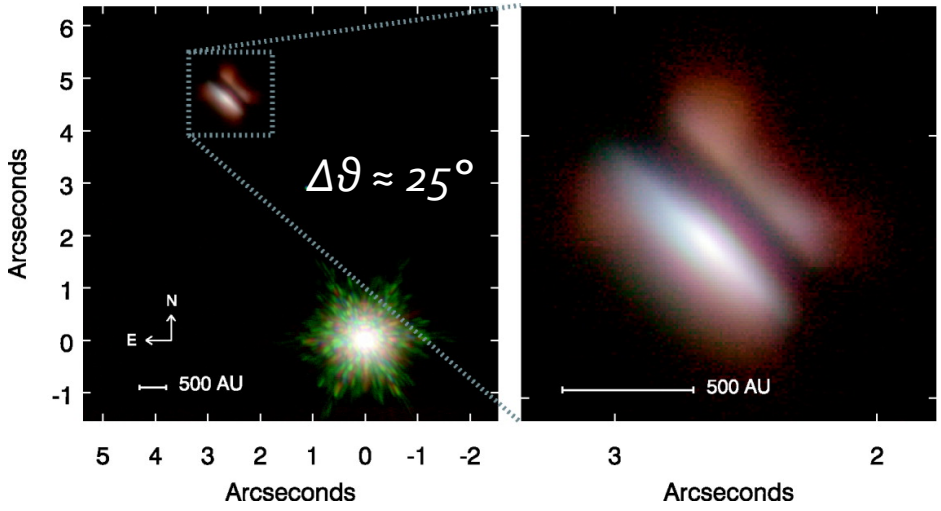
Disk orientation in binaries

- No known system where both the disk and orbital plane are firmly established
- Statistical analysis suggests preferred alignment between disk and orbital planes
  - Several "counter-examples"

Perrin+2006; Hornbeck+2012

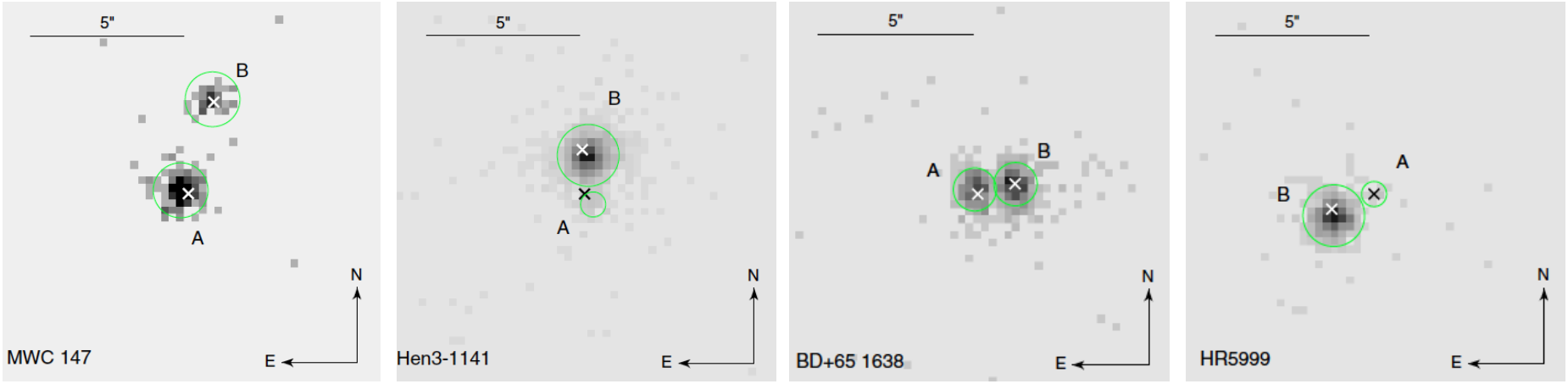


Clampin+2003
Reche+2009



Multiplicity and X rays

- X-rays in HAeBe stars often ascribed to an active lower mass companion
- Highly plausible for any one system, but can it account for all detections?

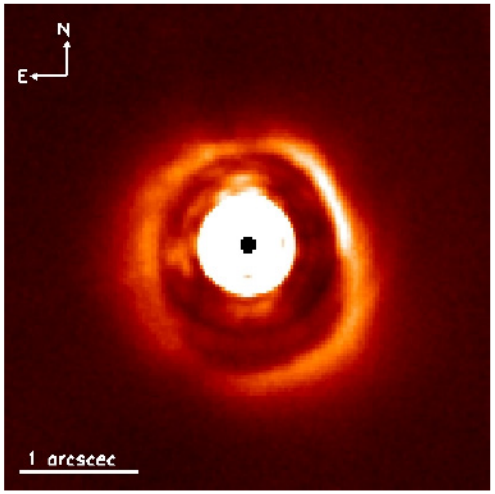


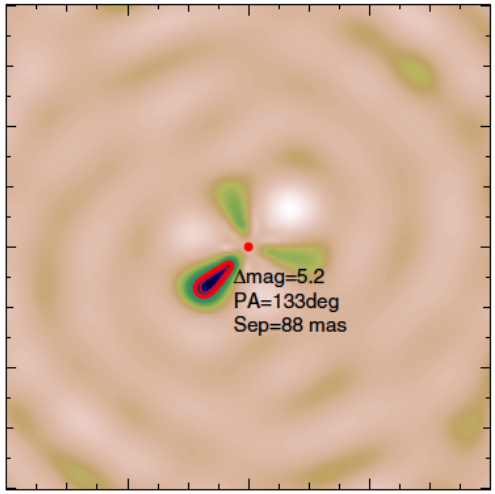
Stelzer+ 2006, 2009

Transition disks & multiplicity

- Can inner hole be explained by stellar comp.?
  - HD 142527: an outlier or a typical system?

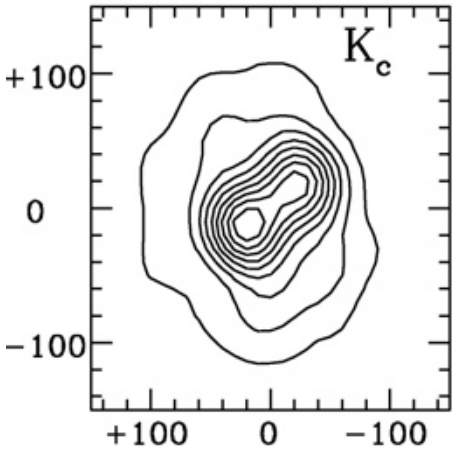
Rameau+2012; Close+2014



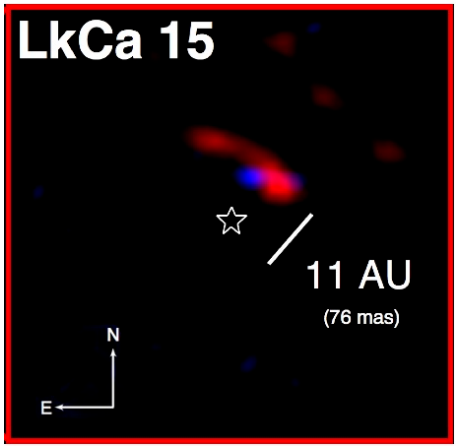


Transition disks & multiplicity

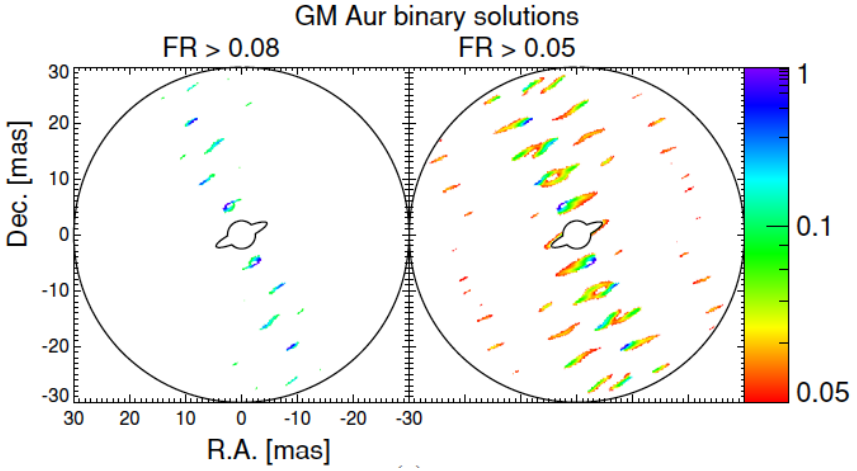
- Can inner hole be explained by stellar comp.?
- T Tauri transition disks: CoKu Tau 4 is a binary, LkCa 15 has a planet, but nothing else…



Ireland & Kraus 2008



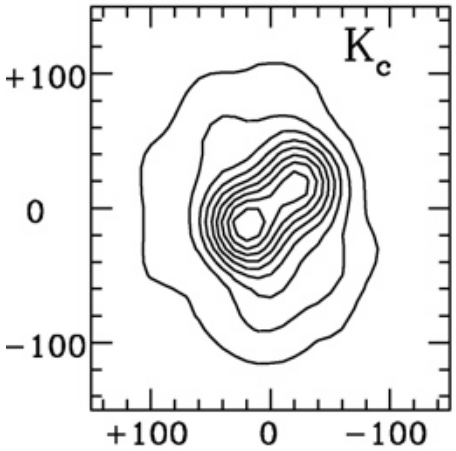
Kraus+ 2012



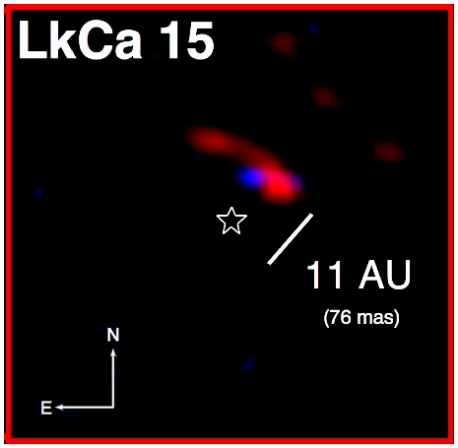
Pott+2010

Transition disks & multiplicity

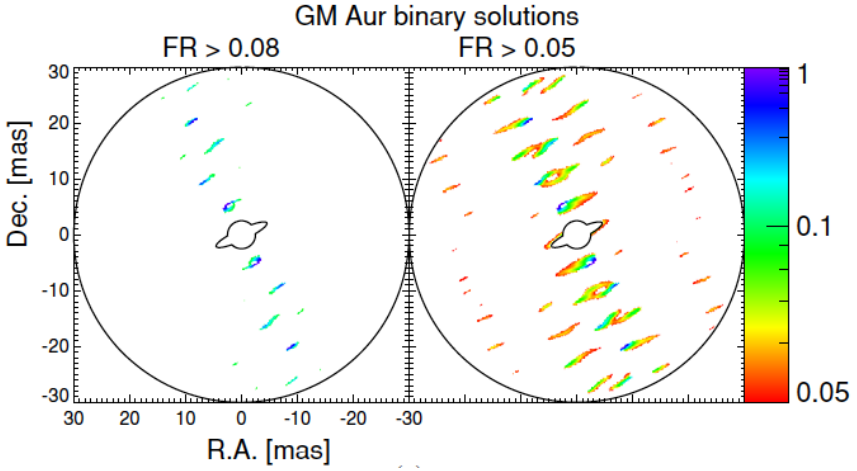
- Can inner hole be explained by stellar comp.?
- T Tauri transition disks: CoKu Tau 4 is a binary, LkCa 15 has a planet, but nothing else…
- Probably true for HAeBe systems as well



Ireland & Kraus 2008



Kraus+ 2012

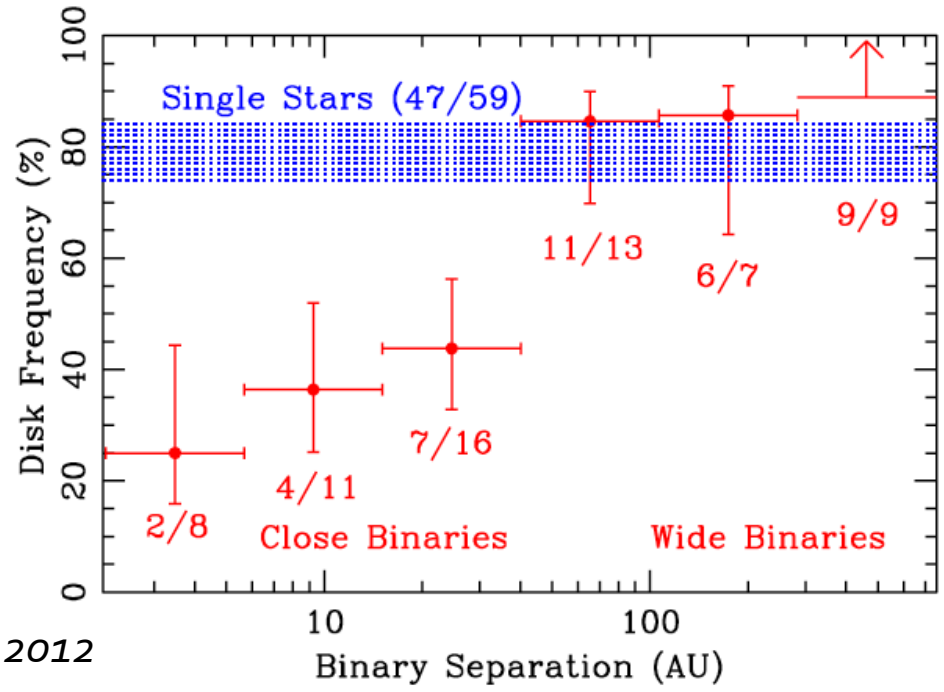


Pott+2010

Binaries and disk survival

Binaries and disk survival

- Wide binaries hardly affect disks, and SBs can live within a circumbinary disk
- Intermediate-separation binaries are strongly disruptive for disks



Kraus+ 2012

Binaries and disk survival

- Wide binaries hardly affect disks, and SBs can live within a circumbinary disk
- Intermediate-separation binaries are strongly disruptive for disks
- Are HAeBe samples systematically devoid of companions in the 5-50 au range?
  - Time will tell, but I suspect so…

Summary

- Multiplicity is prevalent in Herbig AeBe stars
  - Consistent with other populations of young AB stars
- Multiple levels of concern
  - Small-sized, inhomogeneous surveys
  - Undetermined selection and detection biases
  - Proper statistical analysis still missing!
- Does it make sense to study only Herbig AeBe stars and not all young AB stars?