Stellar multiplicity in young star forming regions

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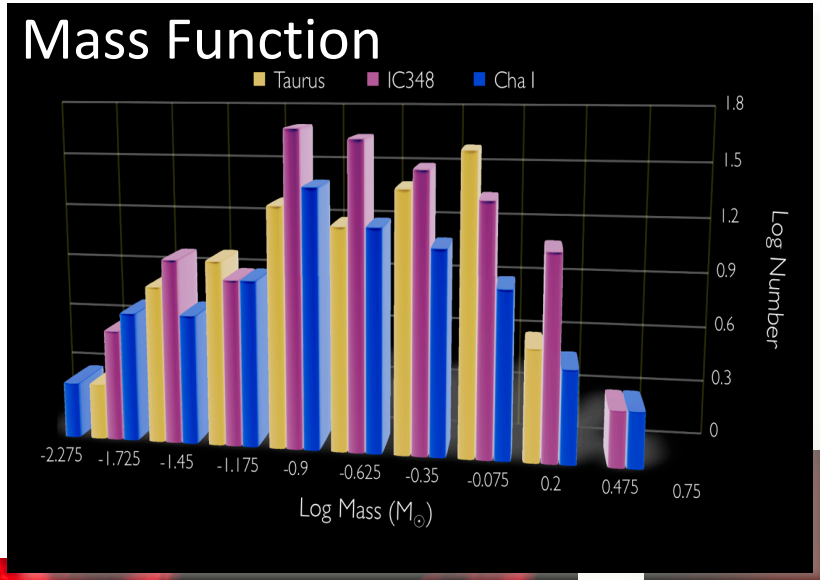
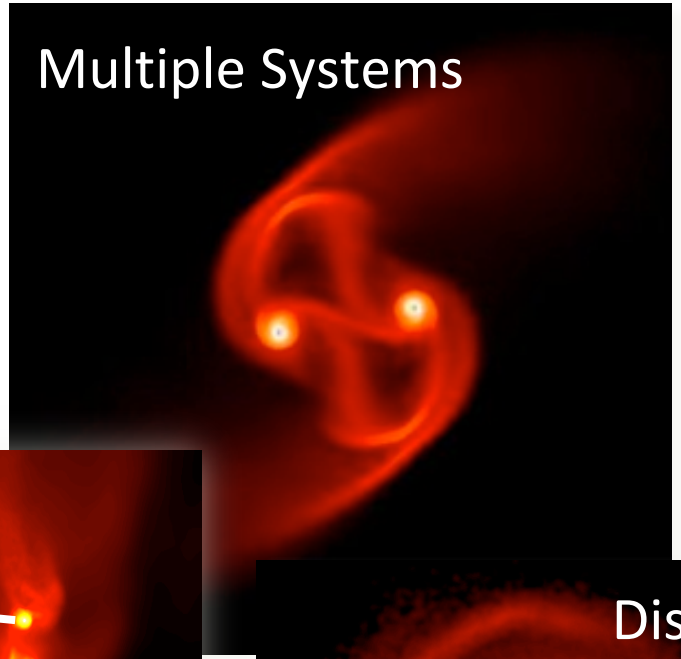
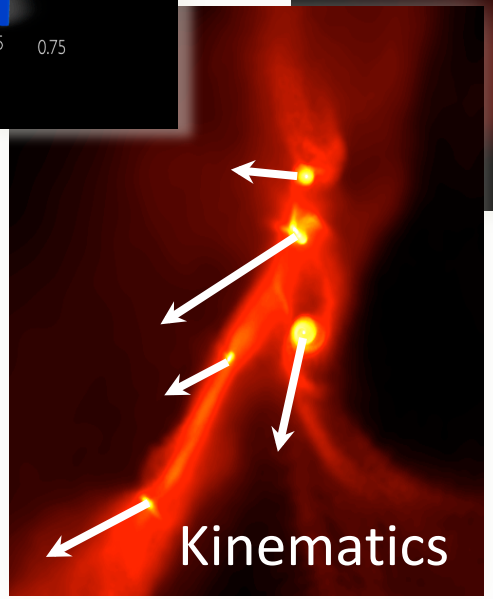
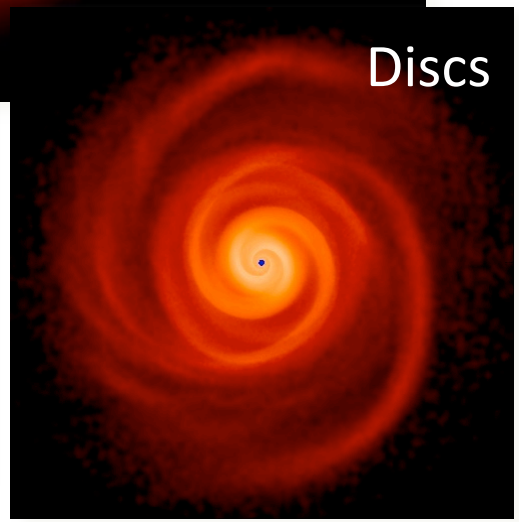
Cluster formation products









What are the stellar statistical properties at birth ?

Open issues on multiplicity

- How do multiples form ? Core fragmentation with N=1-3 ?
- Correlation primary mass - max separation − median separation → Preferred spatial scale for fragmentation depending on core mass ?
- IMF in young clusters correspond to the *system* IMF (<1000 AU systems not resolved) → If the *system* IMF appears universal, is the multiplicity frequency also universal ?
- What is the CMF/IMF connection ?
- Flat mass ratio distribution for m>0.3Msun but steeper at lower masses → Lower limit of companion masses ? What about planetary-mass objects at large separation?

Fragmentation process

Taurus

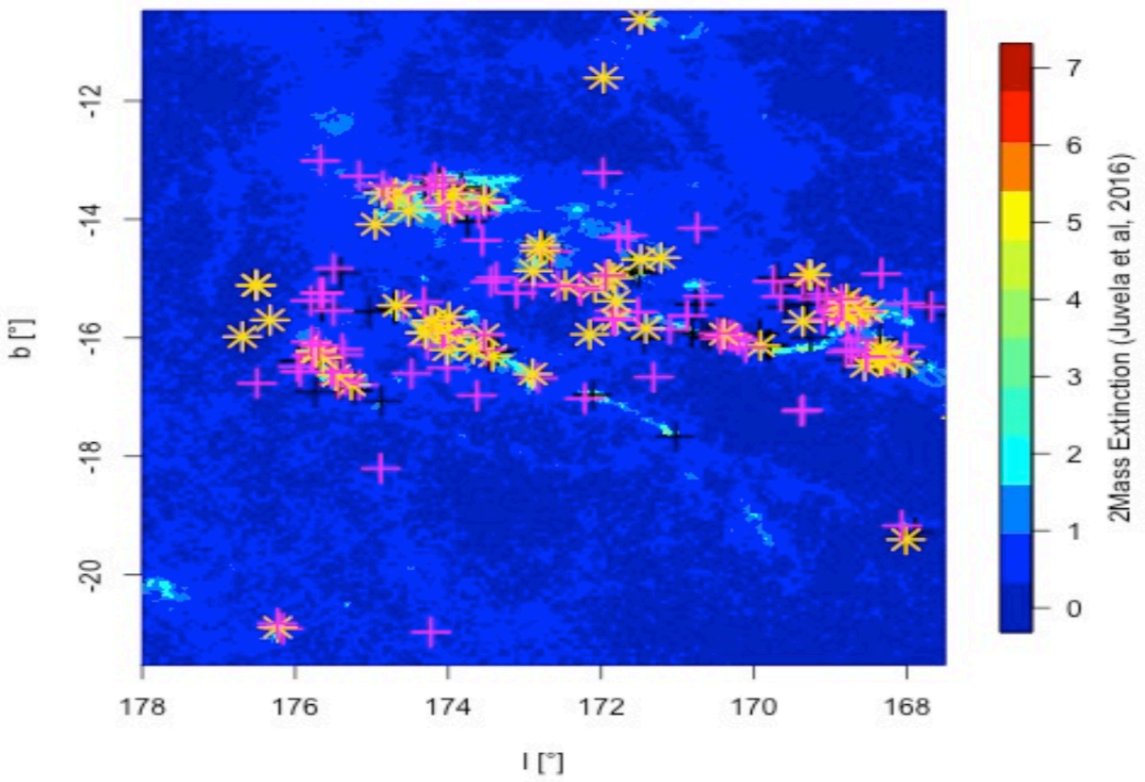
Spatial distribution and multiplicity in Taurus

- Complete catalog of Taurus members observed in HRA
- If companion <1000 au → multiple (M); If not → single (S)

Multiple systems appear more concentrated along the filaments

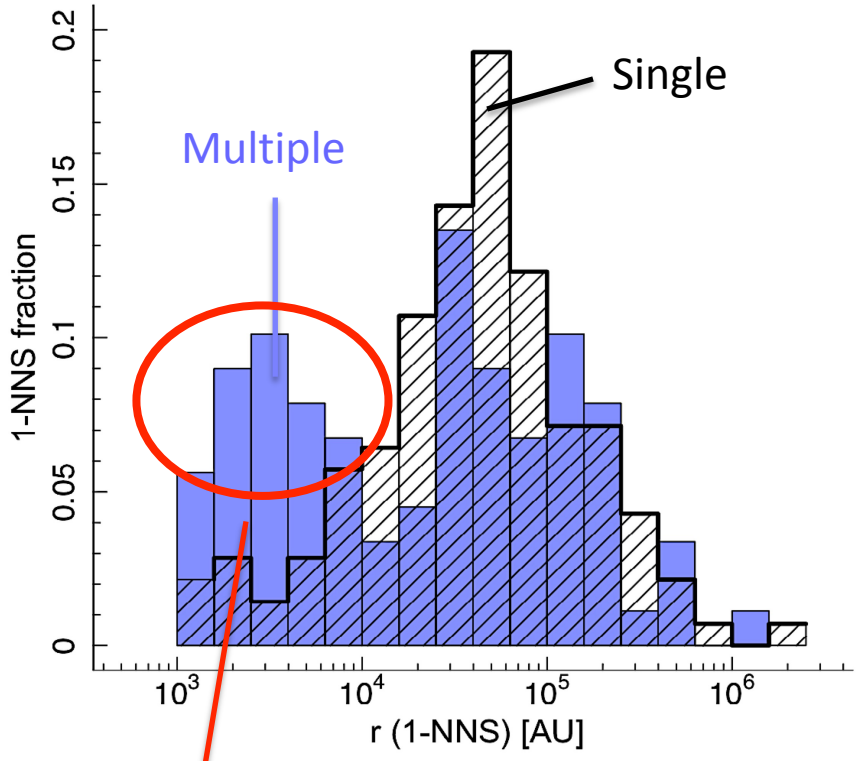
* Multiple

+ Single



Spatial distribution and multiplicity in Taurus

- 1st nearest-neighbour separation (1-NNS) distribution



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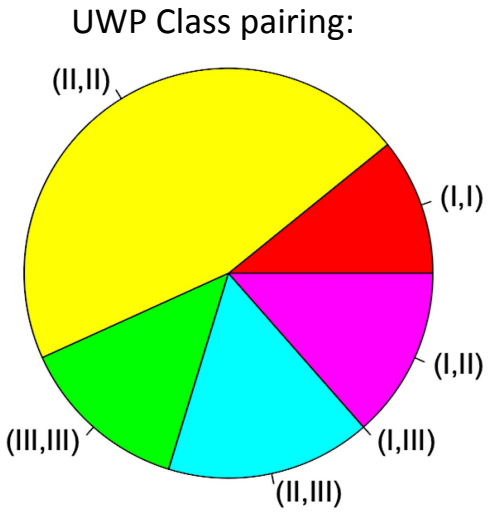
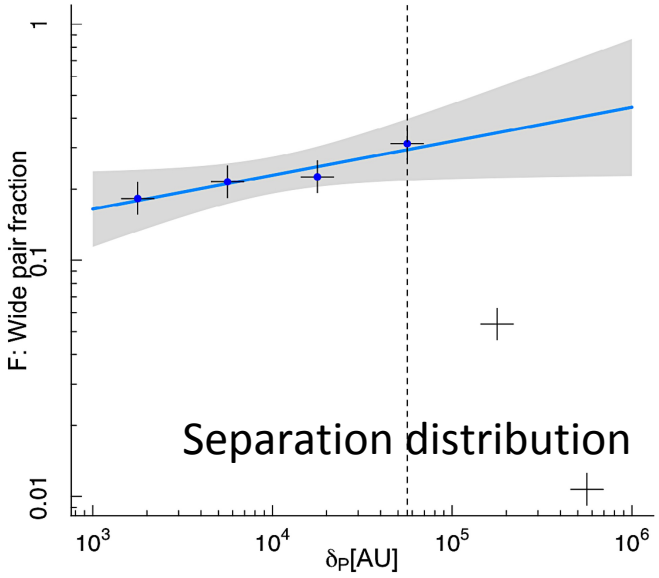
Probability 3x higher to have a companion within 10 kau

Ultra wide pairs (UWPs)

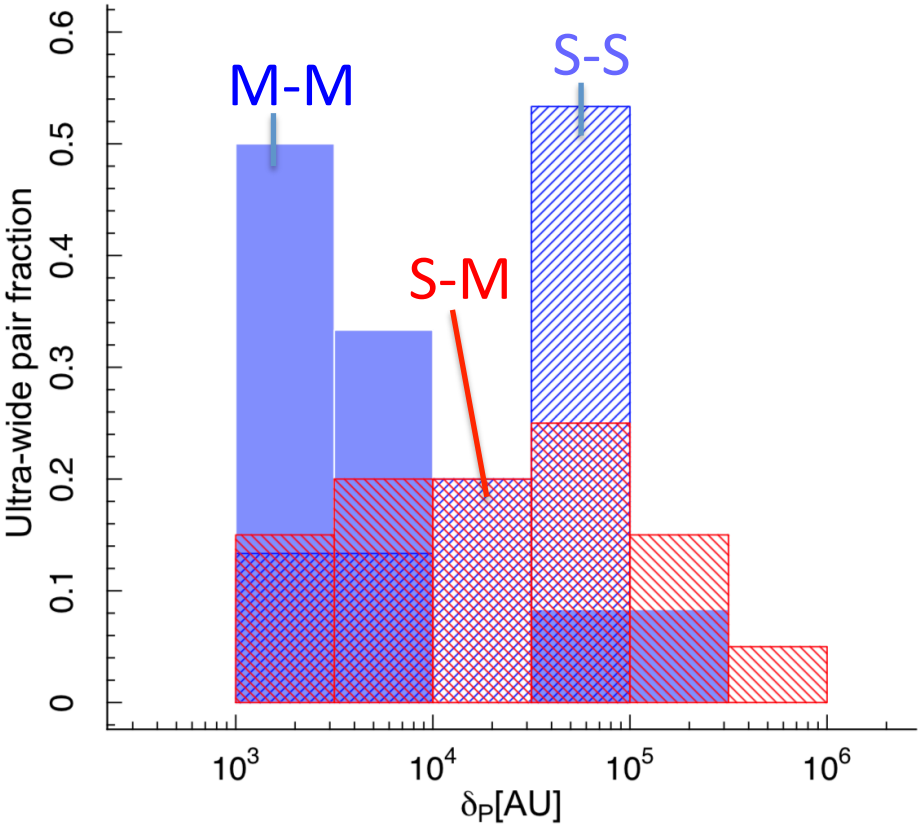
- UWPs defined as mutual nearest neighbour couples
- Separation range 1-60 kau
- Probable coeval physical pairs:
  - Pairs (<5kau) known to be physically linked (Kraus et al. 2009)
  - Separation distribution compatible with Opik law, extended to 60kAU
  - Class pairing not random

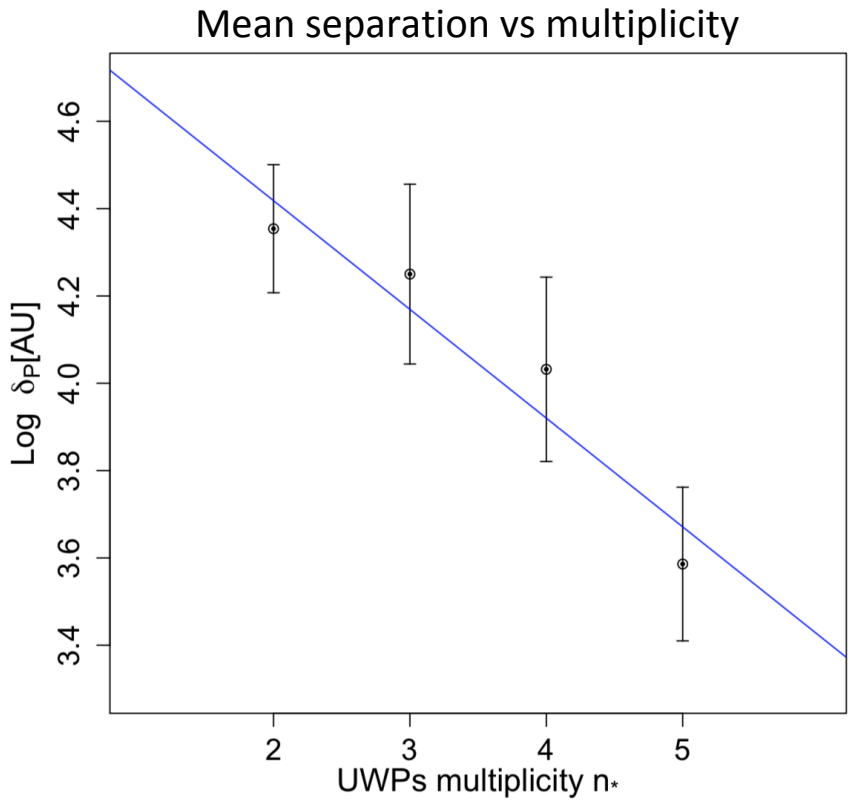




UWP properties

- Multiple-Multiple (M-M) pairs have shorter separation
- Degree of multiplicity increases as the separation decreases





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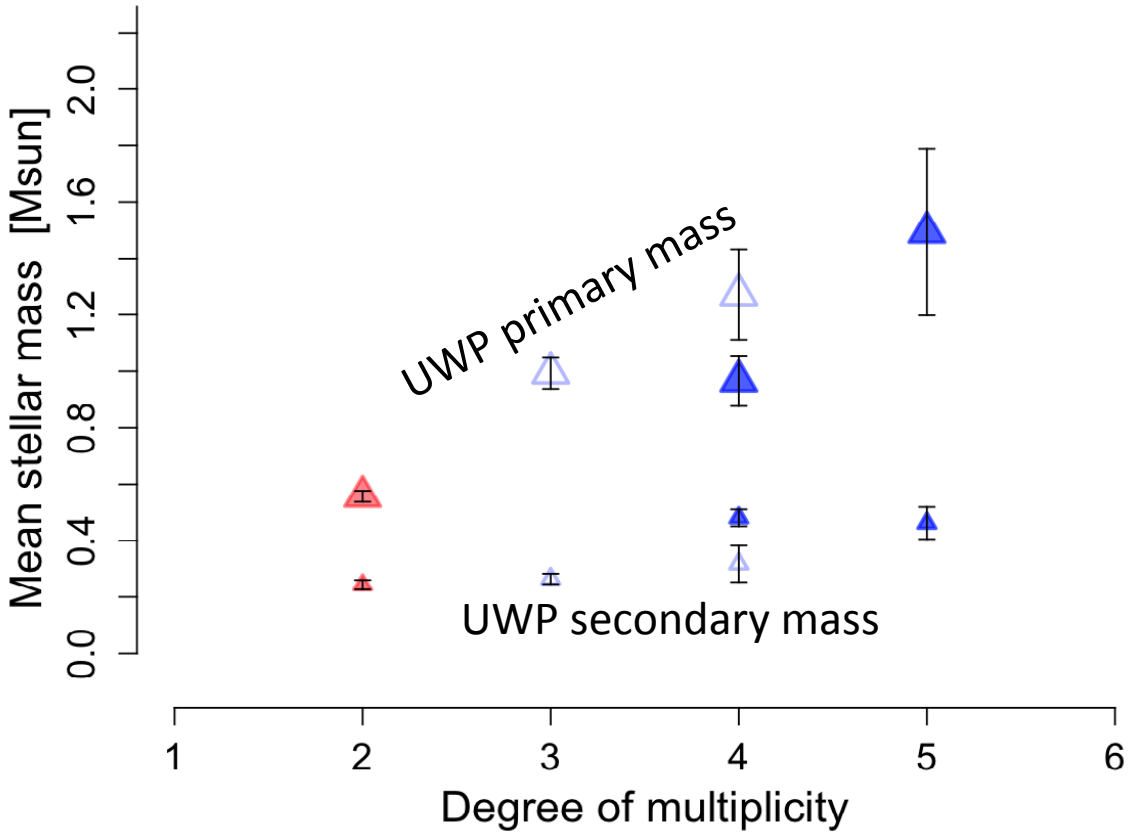
UWP properties

- Degree of multiplicity increases with primary mass



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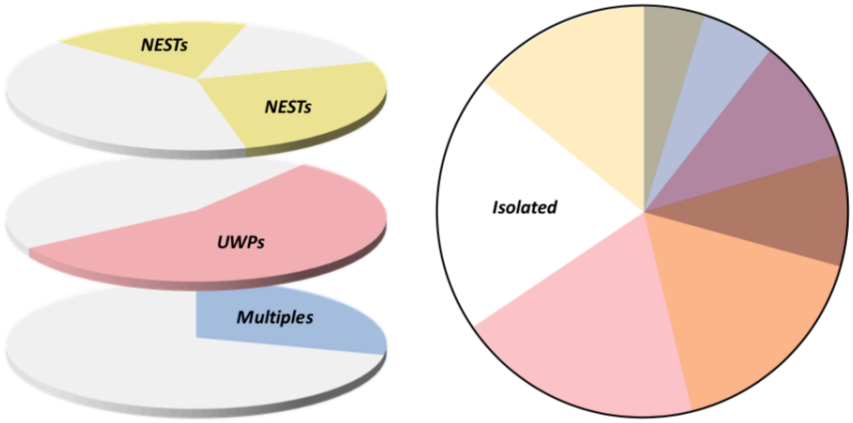
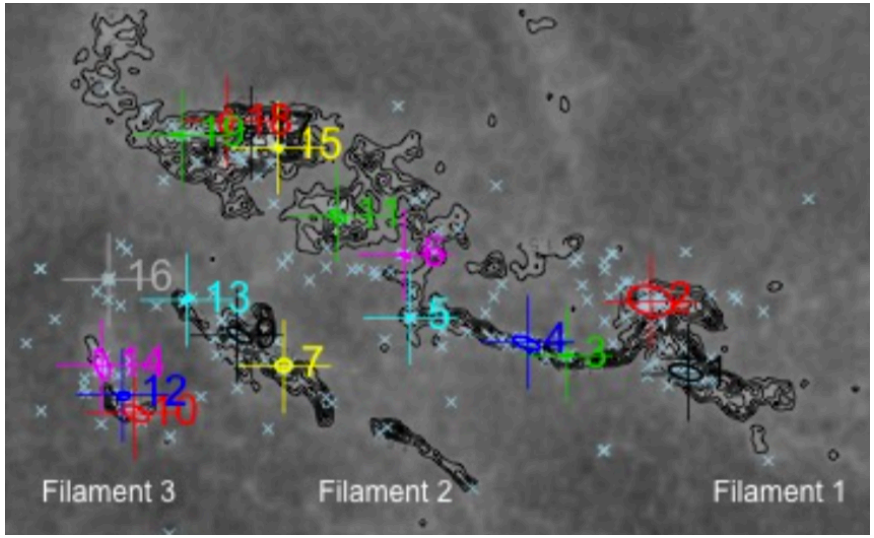
Origin of UWP

- Current density in Taurus too low to disrupt them by dynamical interactions → pristine imprint of star formation ?
- May be the descendants of multiple prestellar/Class 0 objects observed at radio/millimeter wavelengths (e.g. Tobin et al. 2010, 2016) and the precursors of wide systems (10–100 kAU) identified in older moving groups (Floriano-Alonso et al. 2015; Elliott et al. 2016)
- MM pairs (<10kau) may form from a single core fragmentation
- SS pairs (>30kau) would be formed by another mechanism
- Denser, more massive cores would produce higher multiplicity systems → cascade fragmentation ?

Elementary structures in Taurus

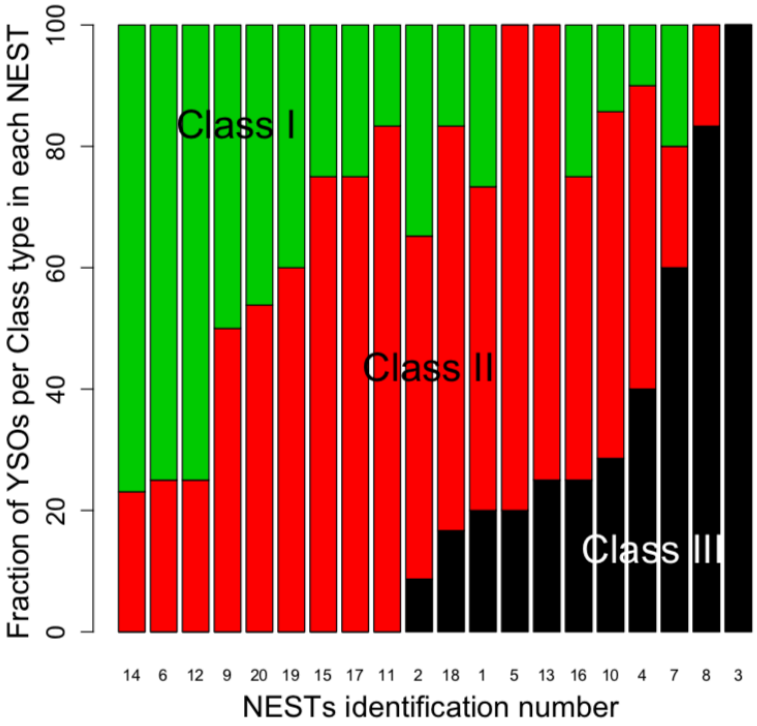
- ~ half of the UWPs are within larger stellar overdensities, called NESTs (Nested Elementary STructures)
- 20 NESTs identified in Taurus using *dbscan* algorithm with 99.85% significance level above random
- Located along the filaments
- ~45% of stars are in NESTs
- Each NEST contain 4-23 stars
- Mean stellar density ~340 pc^{-2}



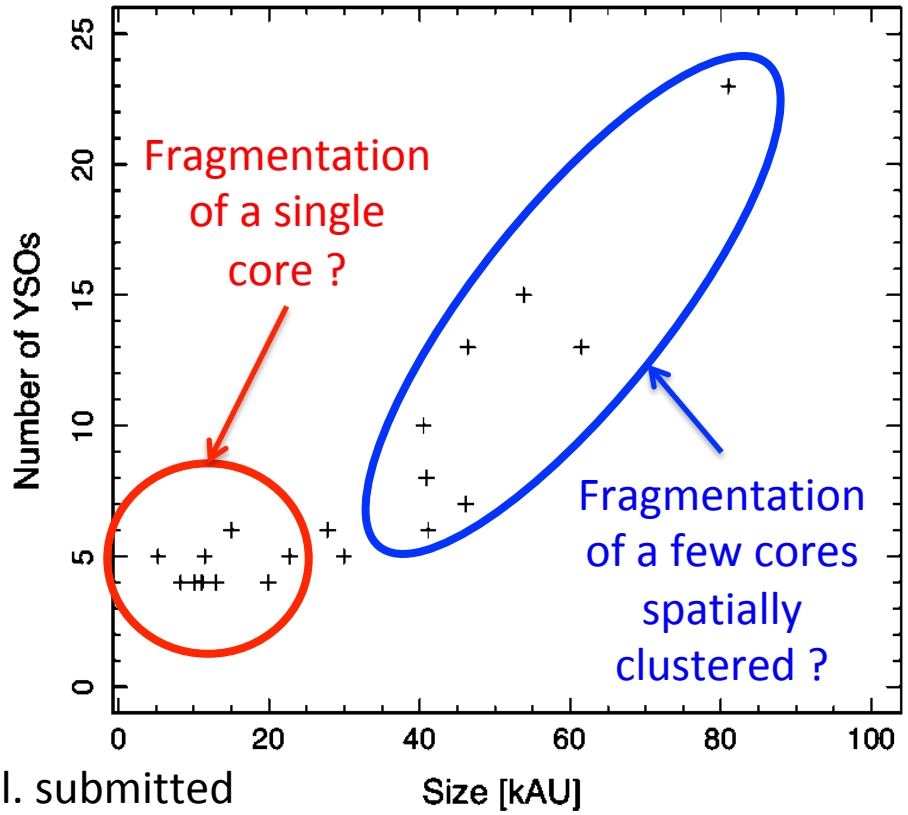


Star formation in Taurus

- ~75% of class 0/I in only 11 NESTs → **preferred sites of star formation** but some of them are getting infertile



- Bimodal size-star number relation → **2 fragmentation scenarii**



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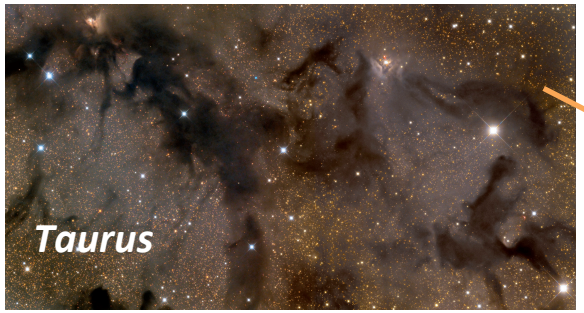
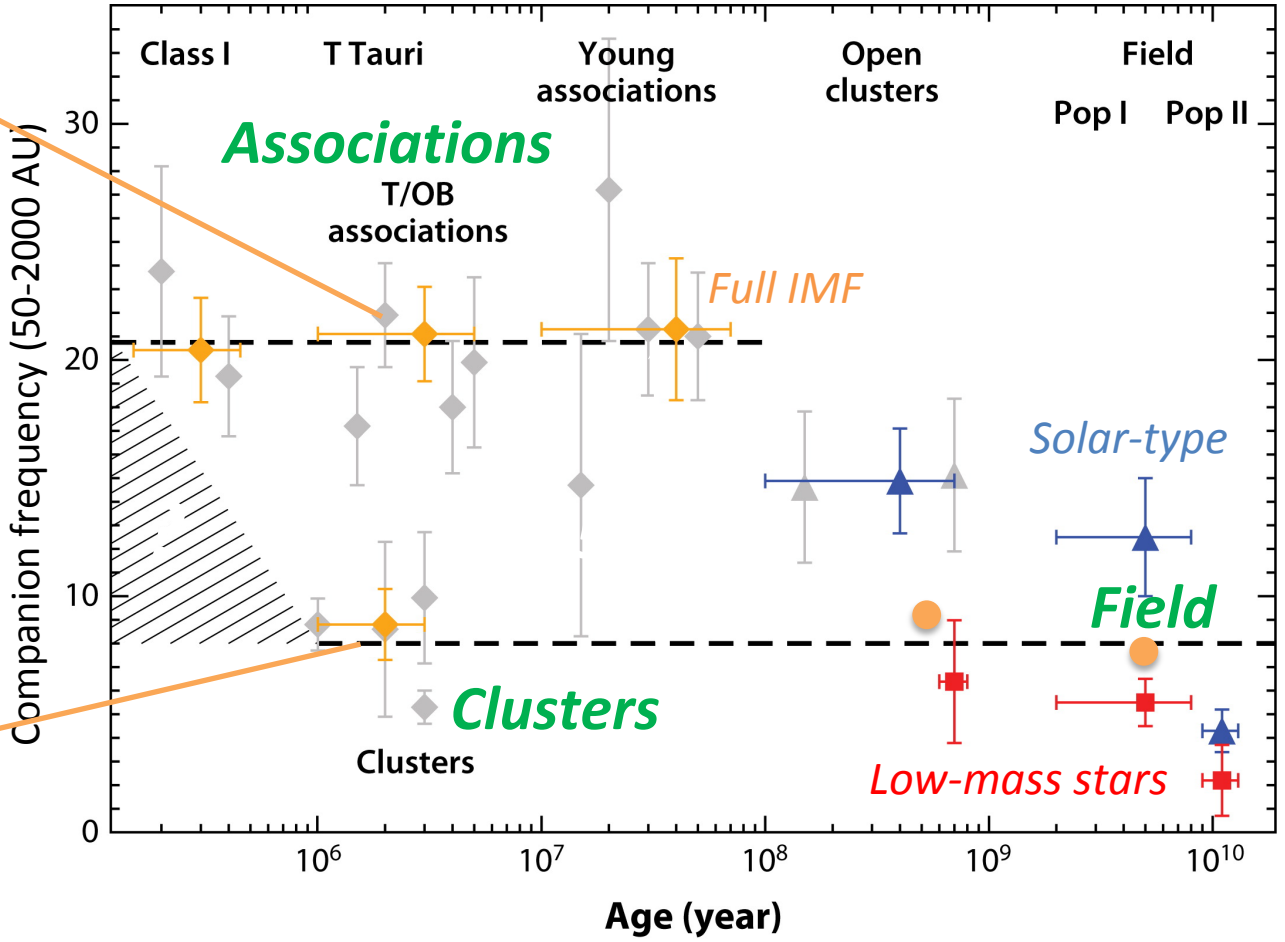
Universality of stellar multiplicity

ONC

Visual companion frequency: a dichotomy?

$$CSF = \frac{B + 2T + 3Q}{S + B + T + Q}$$

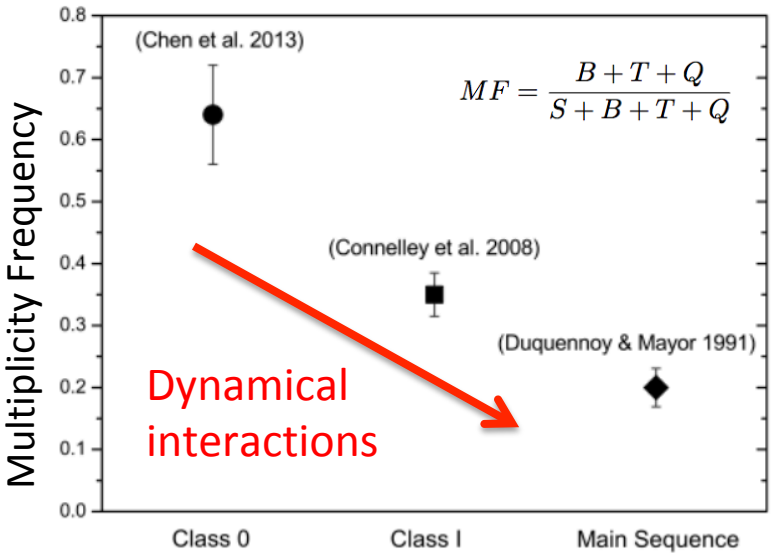




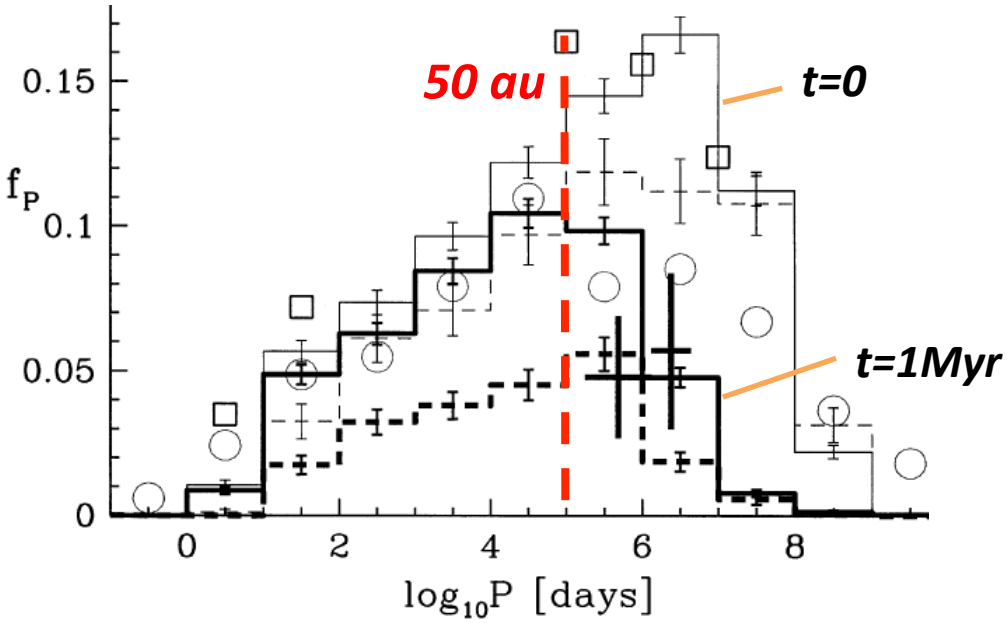
Duchêne & Kraus 2013

Effect of dynamical evolution

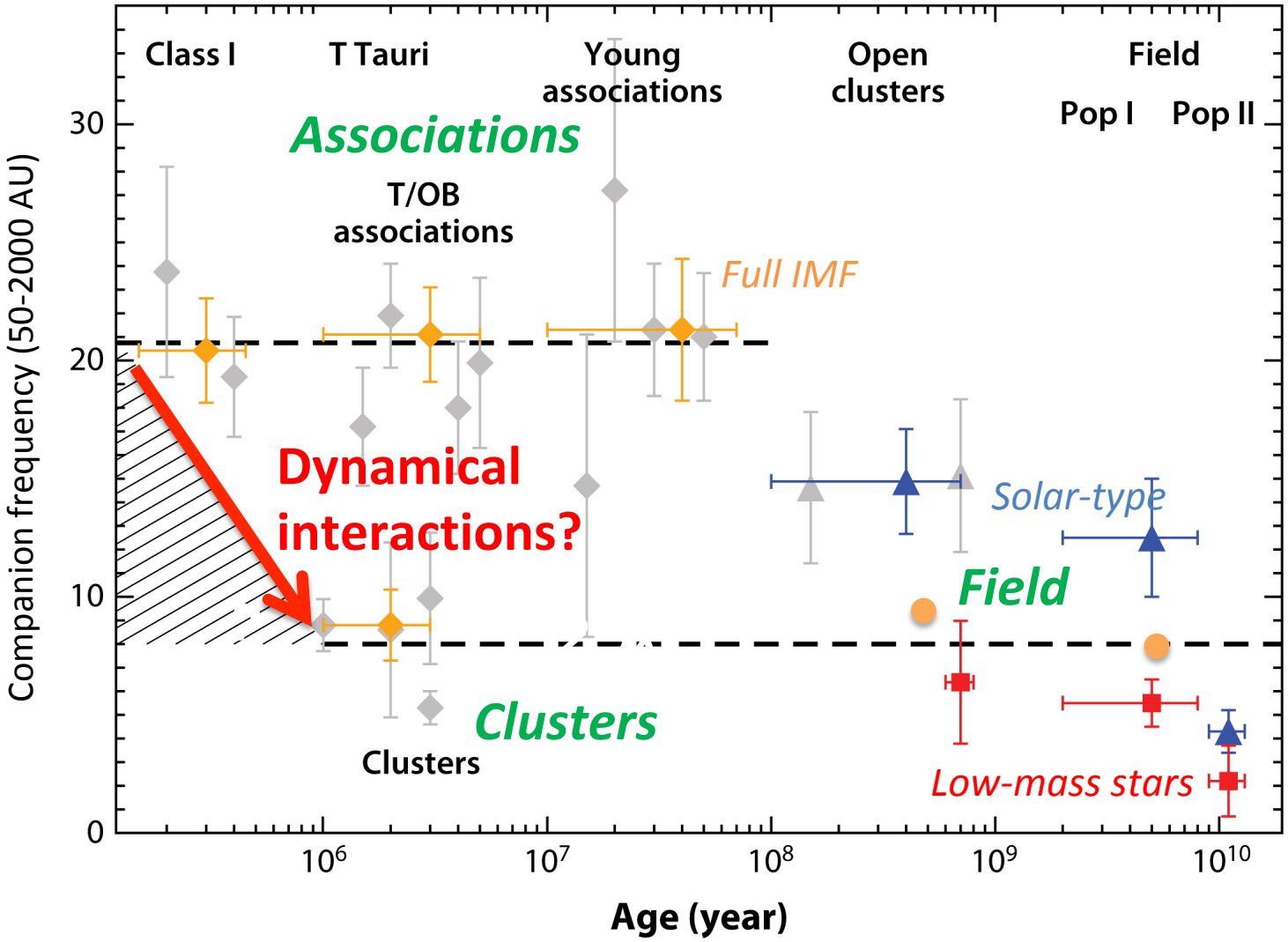
- Most stars were born in multiple systems (Reipurth et al. 2016)
- Rapid decay of wide systems in cluster environments (e.g. Kroupa 1995, Marks & Kroupa 2012): $t_{cross} = R / \sigma_V \sim 1$ Myr



Chen et al. 2013



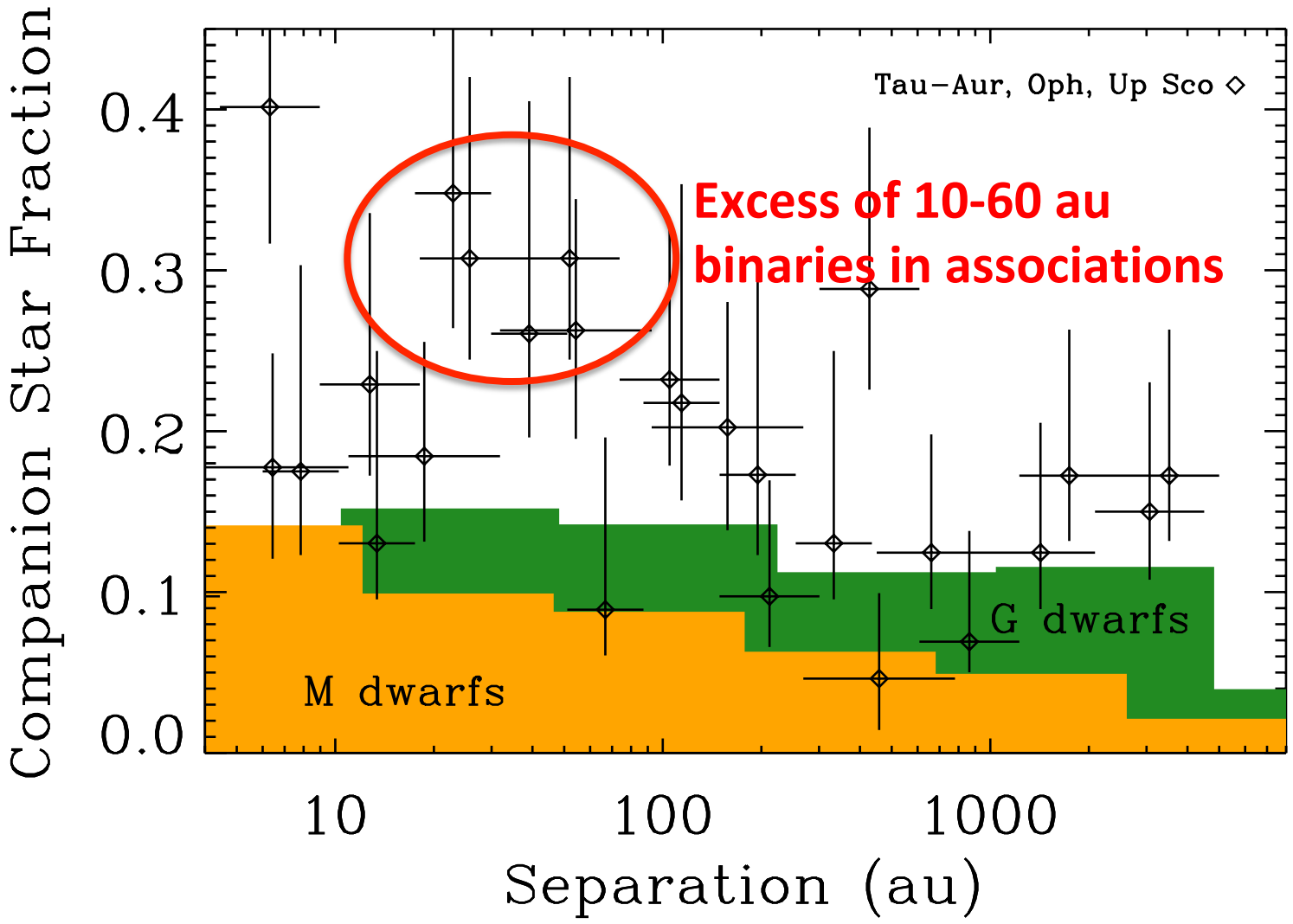
Kroupa et al. 2001



Apparent visual companion dichotomy compatible with universality

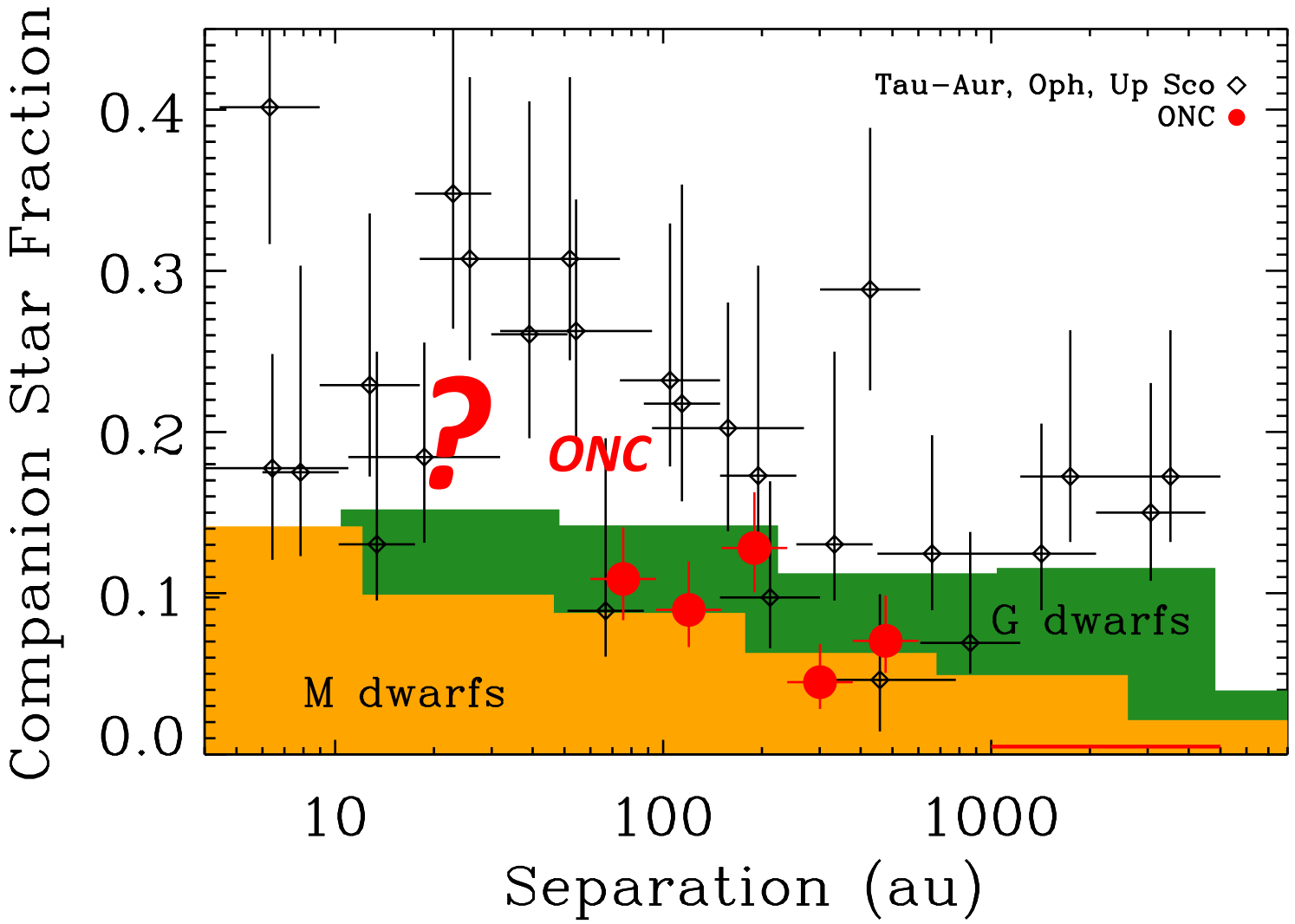
→ Need to look at the whole separation distribution

Separation distribution



Raghavan+2010, Ward-Duong+2015
Kraus+2008,2009,2011, Cheetham+2015

Separation distribution

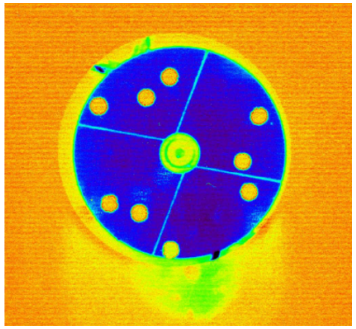


Raghavan+2010, Ward-Duong+2015
Kraus+2008,2009,2011, Cheetham+2015
Reipurth+2007, Scally+1999

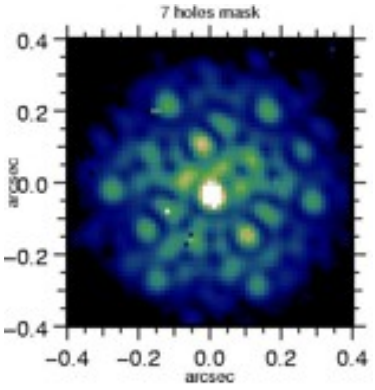
Tight binaries (< 50 au) in the ONC

- At 400 pc, separations of 0.025 - 0.1”
- Even with adaptive optics on large telescopes, this is a very challenging task! → aperture masking tecnique

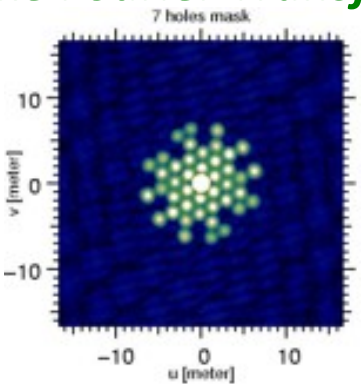
Place this in pupil plane



Take an image



Take Fourier Transform

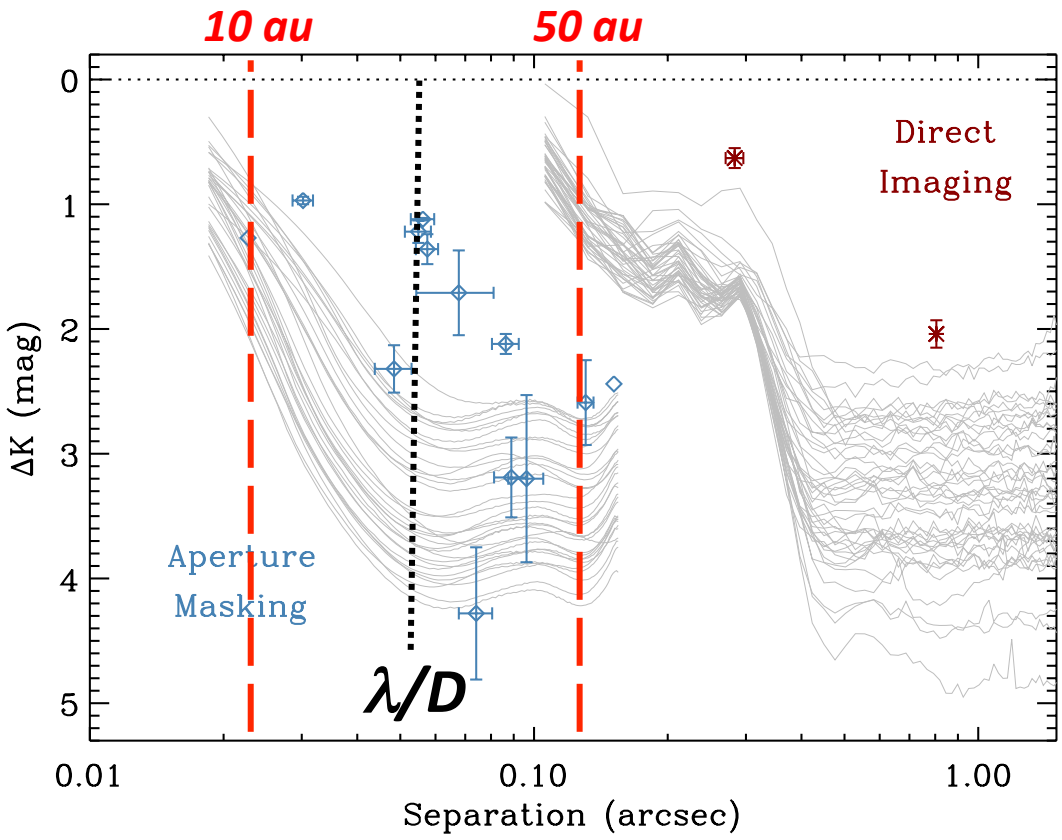


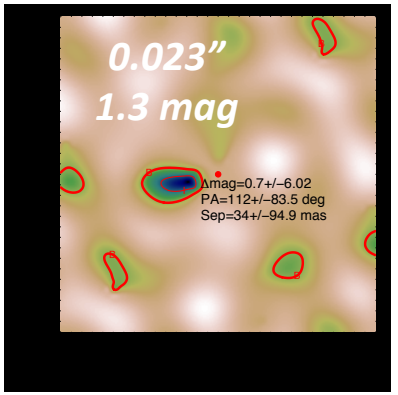
Fit binary model

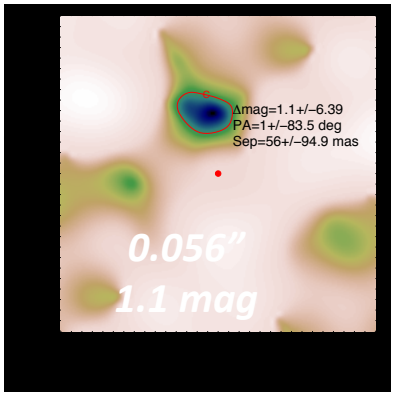
- VLT/NaCo SAM observations
- 42 ONC members: 7.5 < *K* < 9.5; 0.3 − 2.5 Msun

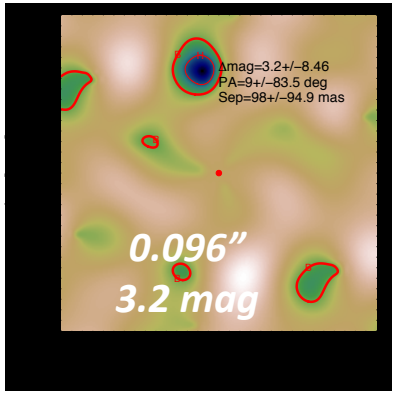
Survey results

- 13 companions in 0.02-0.2” range
- No trend with location, nor stellar mass

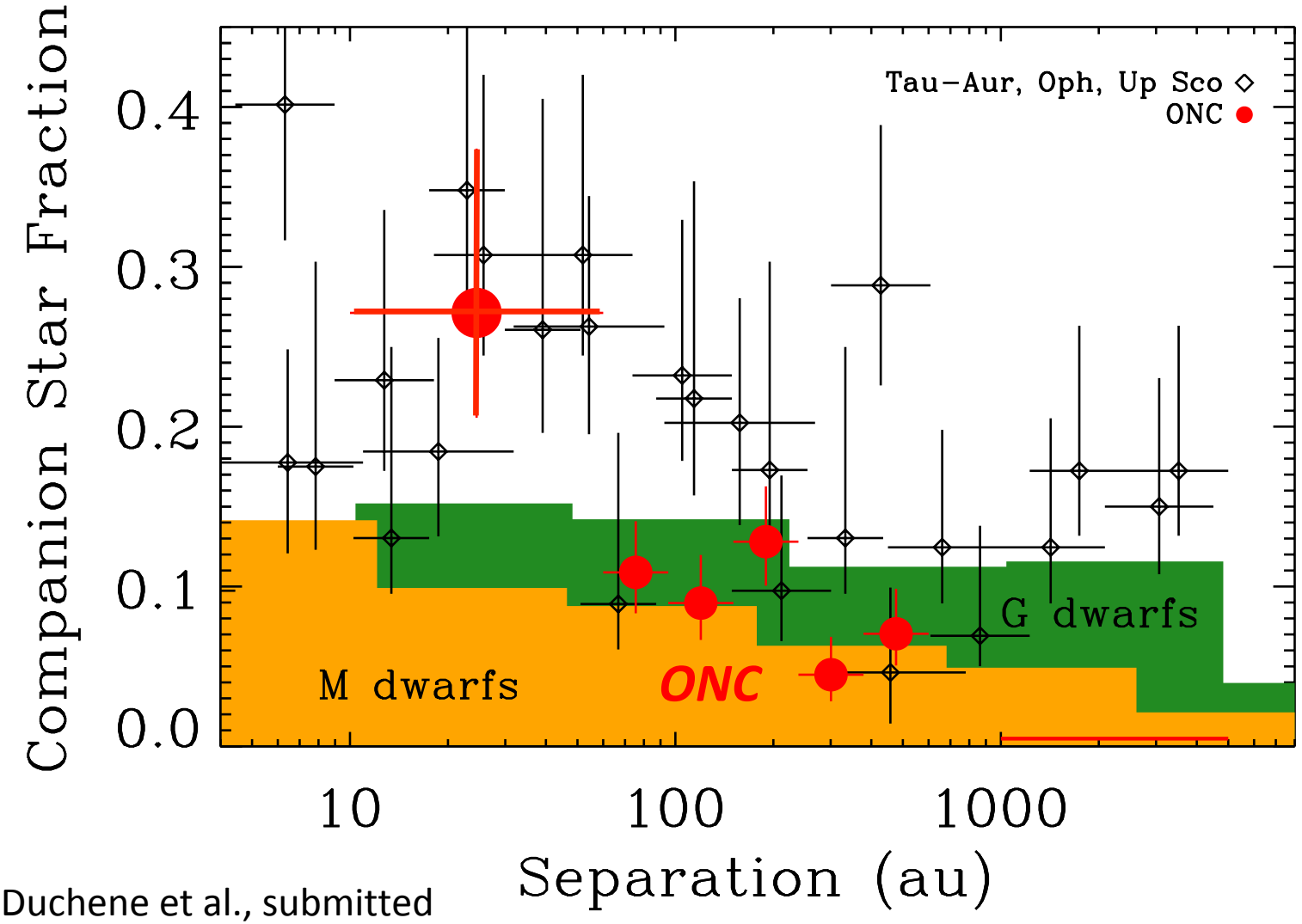








High multiplicity in the ONC! (10-50 au)

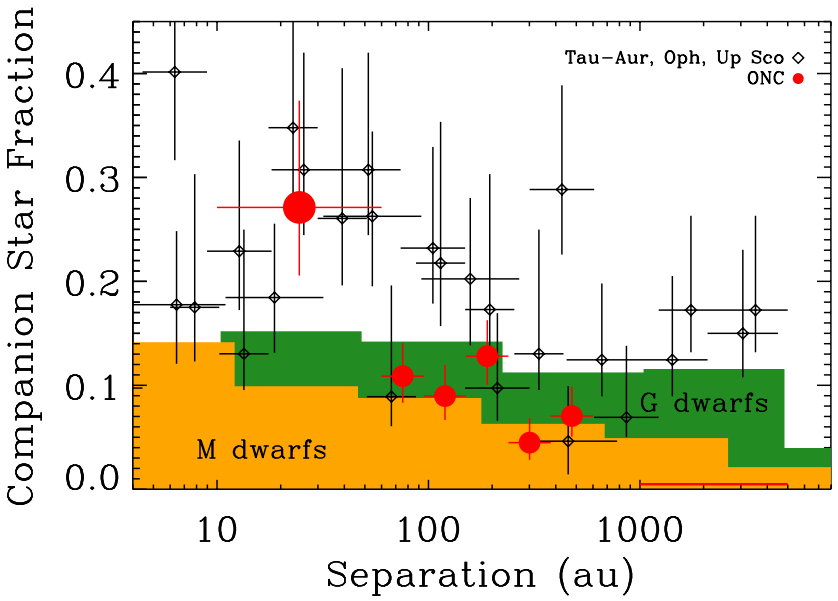


Raghavan+2010, Ward-Duong+2015
Kraus+2008,2009,2011, Cheetham+2015
Reipurth+2007, Scally+1999

Duchene et al., submitted

Universality ?

- The ONC is as binary-rich as Taurus (< 50 au)
- Multiplicity may indeed well be universal at birth and subsequently dynamically evolved
- But then, where do field stars come from?
  - Not from associations
  - Nor ONC-like clusters
  - Even denser clusters?
    - Unlikely (cluster counts)
  - Do close binaries evolve?



Duchene et al., submitted

Summary and perspectives

- Cascade fragmentation of the most massive cores may be at the origin of the wide (<20kau) multiple systems (UWP and NESTs) with N~5 in Taurus
- Wider systems (>30kau) form from a few cores instead

→ Gaia will help to confirm the status of UWP and NESTs and study their kinematics

- Multiplicity frequency may be universal but wide systems rapidly (<1Myr) processed
- But where does the field come from ?

→ Look at even shorter separation (ELT)

→ Probe low q (<0.1) multiple systems (JWST/ELT)