Is Multiplicity Universal?

SACY: A study of nearby loose associations

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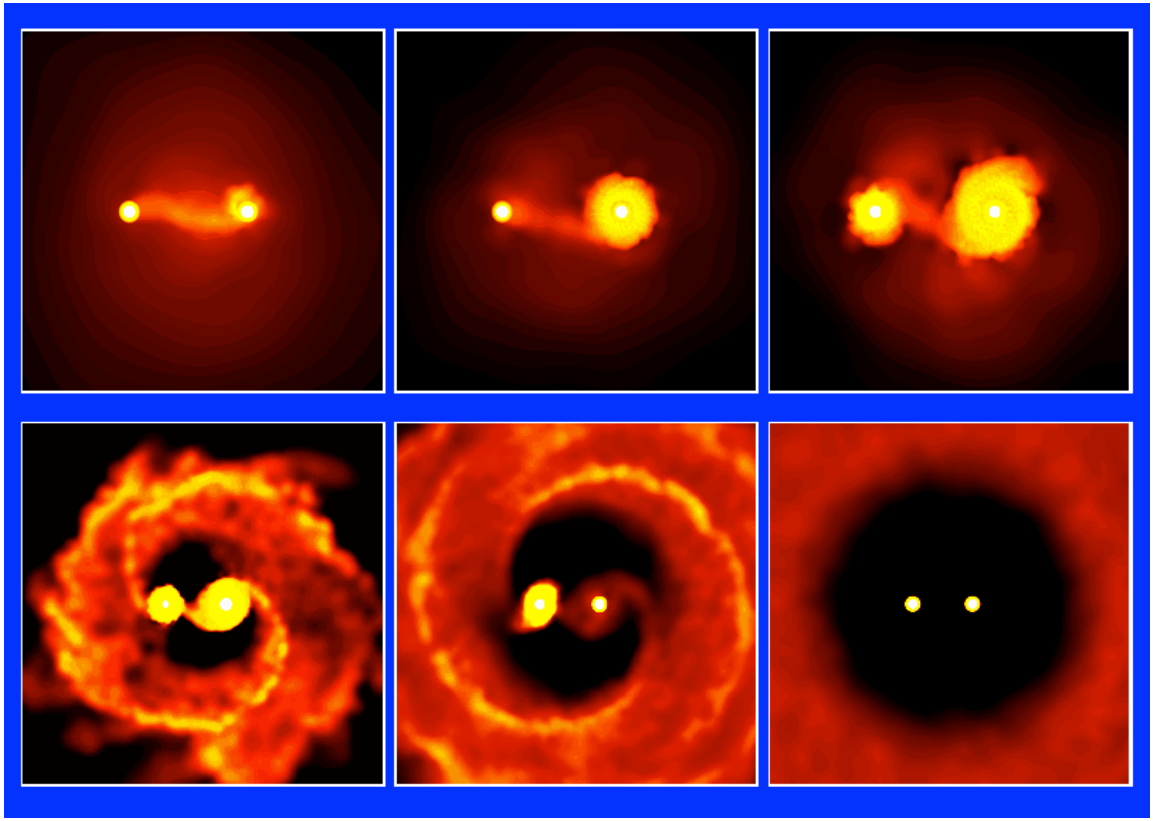
Why do we care about multiplicity?



Bate & Bonnell (1997)

Why do we care about multiplicity?

"To understand galaxies we need to understand stars, but since most are members of binary and multiple star systems, we need to study and understand binary stars...

...And sometimes binary stars are the only way to understand single stars ..."

R. Izzard (2009)

Multiple System Formation: Where does it all begin?

Molecular cloud collapses and fragments

↓

Distribution of pre-stellar cores

↓

Binary / Multiple systems created in these pre-stellar cores ★

(the future with ALMA)

↓

Systems evolve through accretion processes / disk interaction
(separation, system mass and mass ratio)

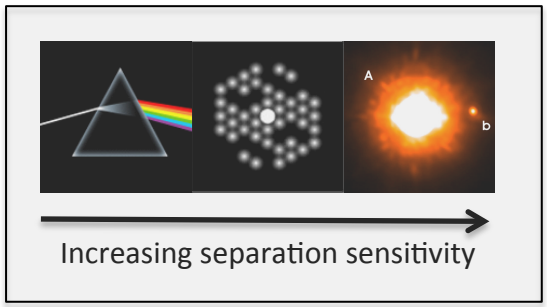
↓

Eventually ‘emerge’ from their envelopes

Multiple System Formation: Observing Populations

1. **Population of stars**
(Coeval, known mass distribution, density, age, distance)

2.



3. **Frequency of multiple systems**
$F(M_1)$

- **Mass Ratio, M_2 / M_1**
- **Separation distribution**

And repeat…

Multiple System Formation: 99 problems…

Density

Sensitivity in period

Age

Extinction

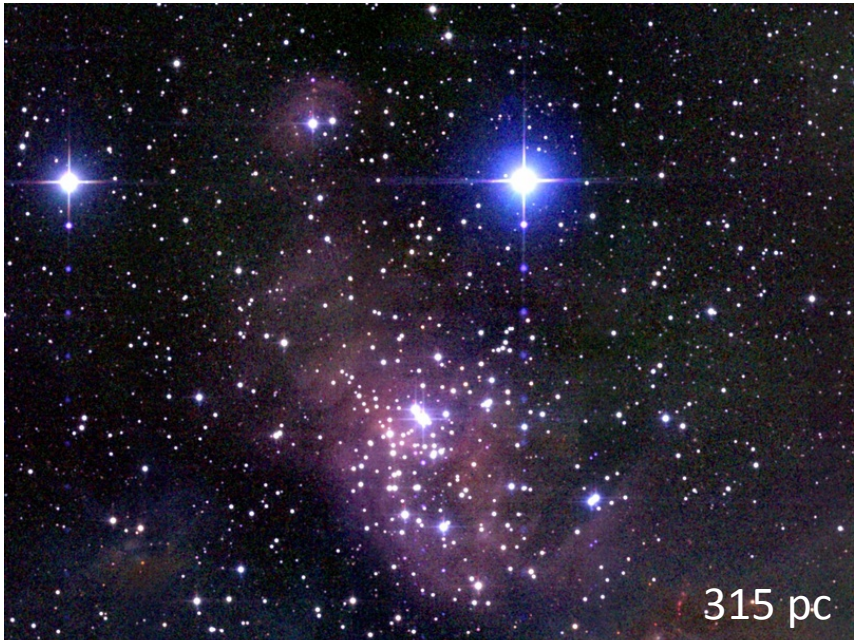
Mass: M_1

Mass: M_2

Sensitivity in mass ratio

Where can we study it?

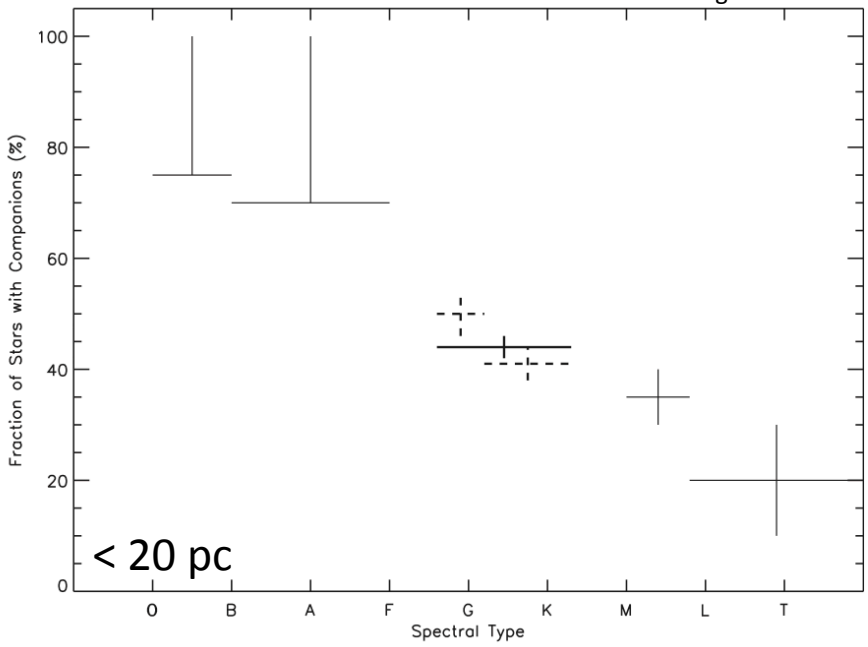
Nearby Clusters (IC 348)



‘Coeval’ population, but difficult to study

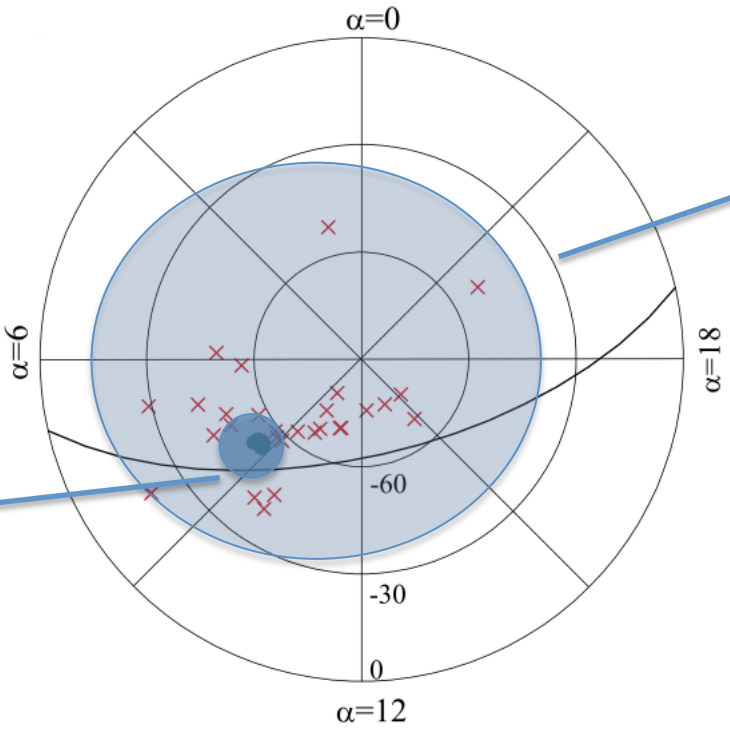
The Field

Raghavan 2010



Mixture of stars, but powerful statistics

Associations: What are they?

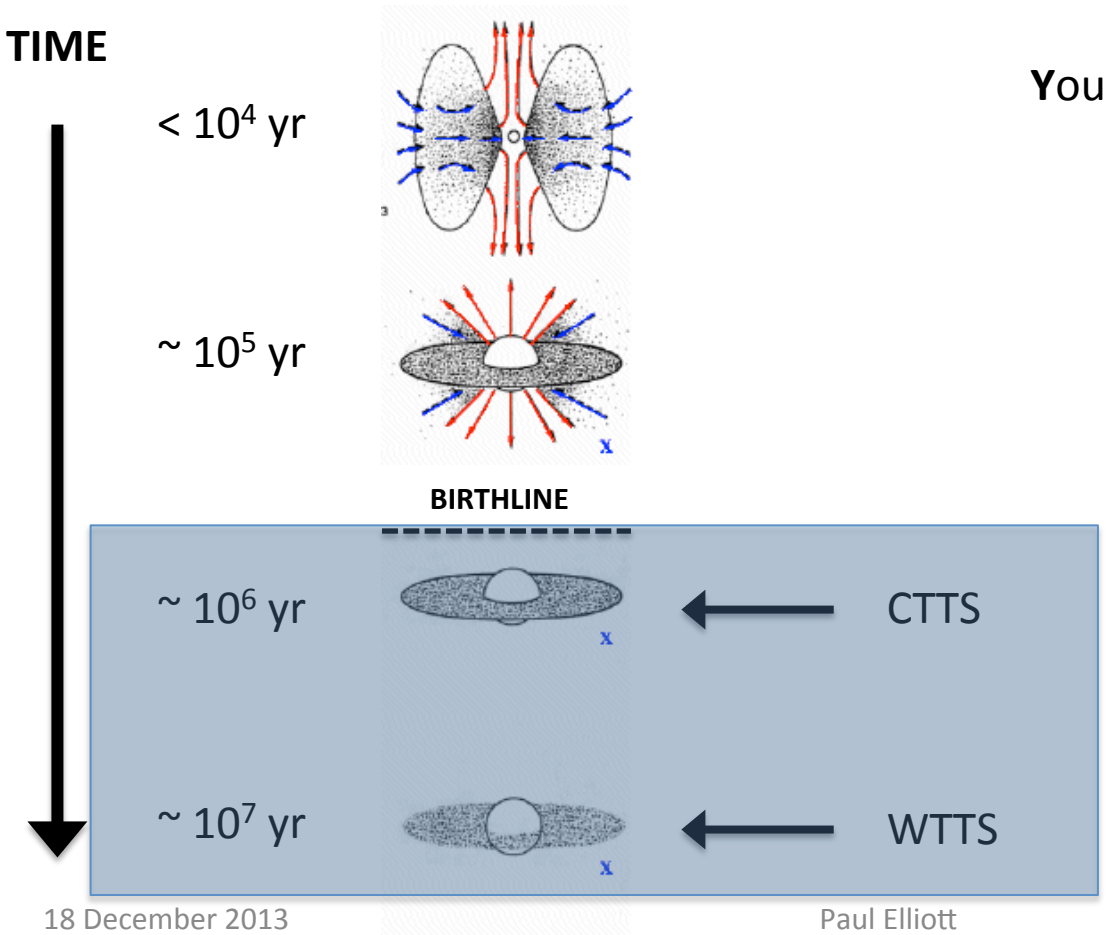


Argus association

IC 2391

Torres 2006

Associations: Member types



Young **S**tellar **O**bject Sequence

Crucial time for planet formation / evolution

SACY: The Sample

TW Hydrae

8 Myr, 48 pc

Octans

20 Myr, 141 pc

Tucana-Horologium

40 Myr, 48 pc

Beta Pic (…moving group)

10 Myr, 31 pc

SACY

AB Doradus

70 Myr, 34 pc

Columba

30 Myr, 82 pc

Argus

40 Myr, 106 pc

Epsilon Chamaeleontis

6 Myr, 108 pc

Carina

30 Myr, 85 pc

SACY: How the sample was formed

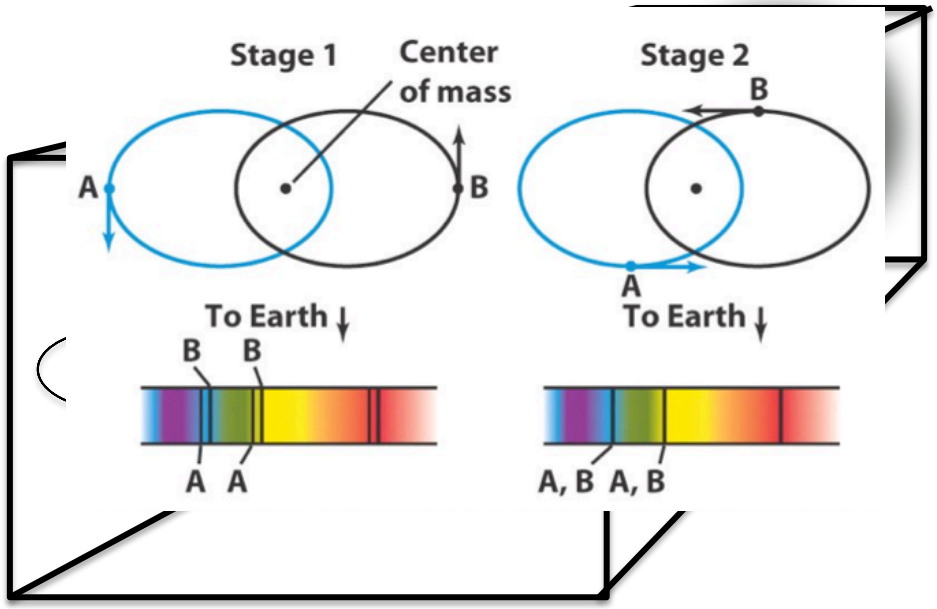
i. Later than G0

ii. Belonging to TYCHO-2 / Hipparcos catalogs

iii. Optical counterparts to ROSAT bright sources

Method Analysis: Example system

Distance: 10 pc



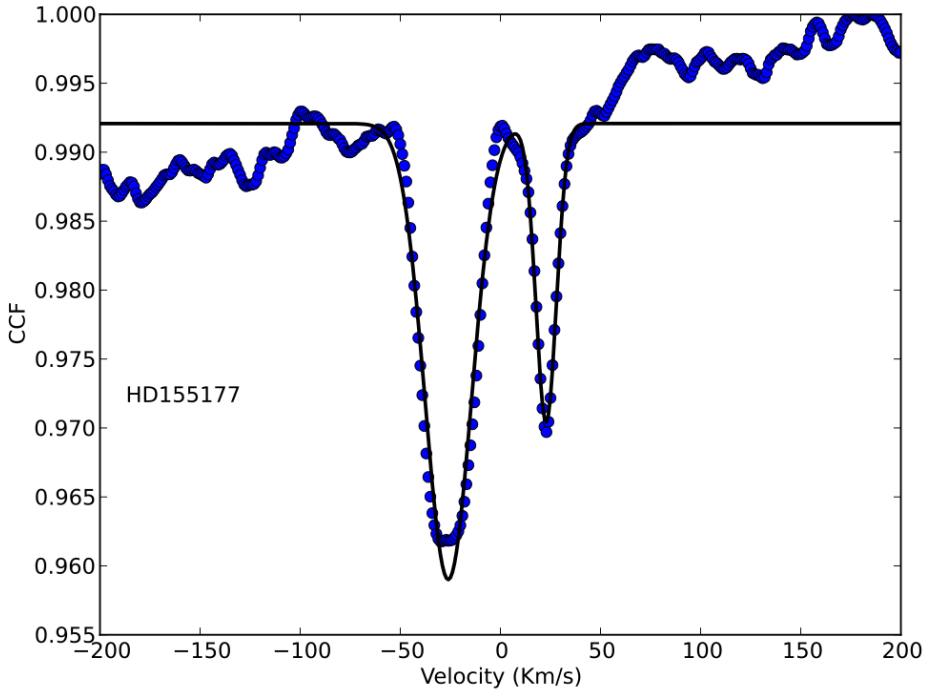
Adaptive Optics (NACO):

Ang. Res.	< 0.4''
Physical Sep.	4 A.U.

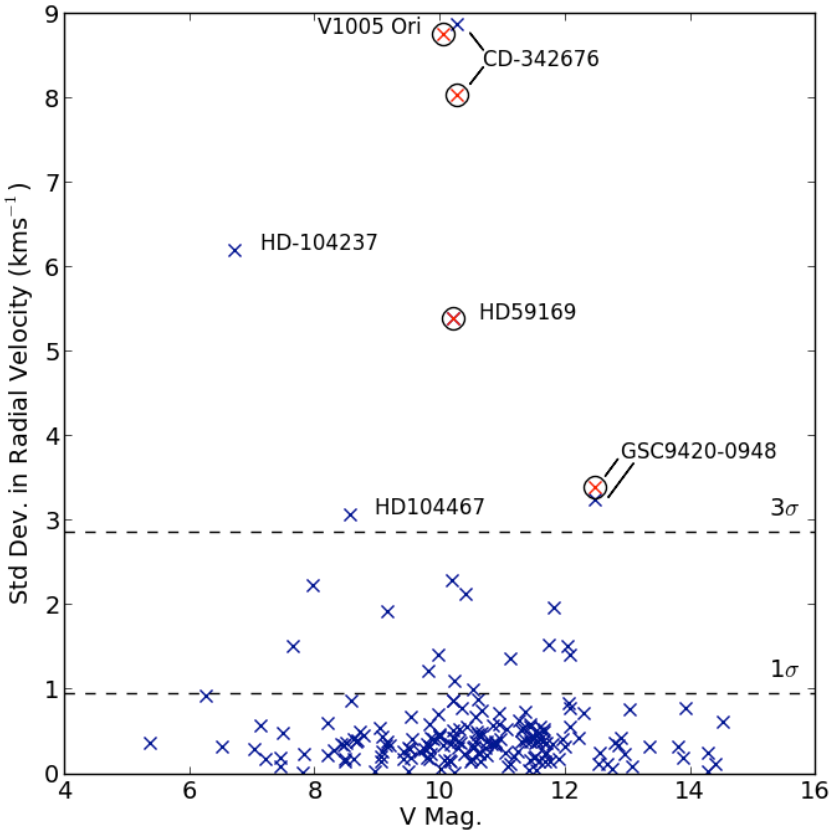
High Res. Spectra (UVES):

Vel. Accuracy.	1 km/s
Physical Sep.	~ 4 A.U.

Method Analysis: SB2 Systems

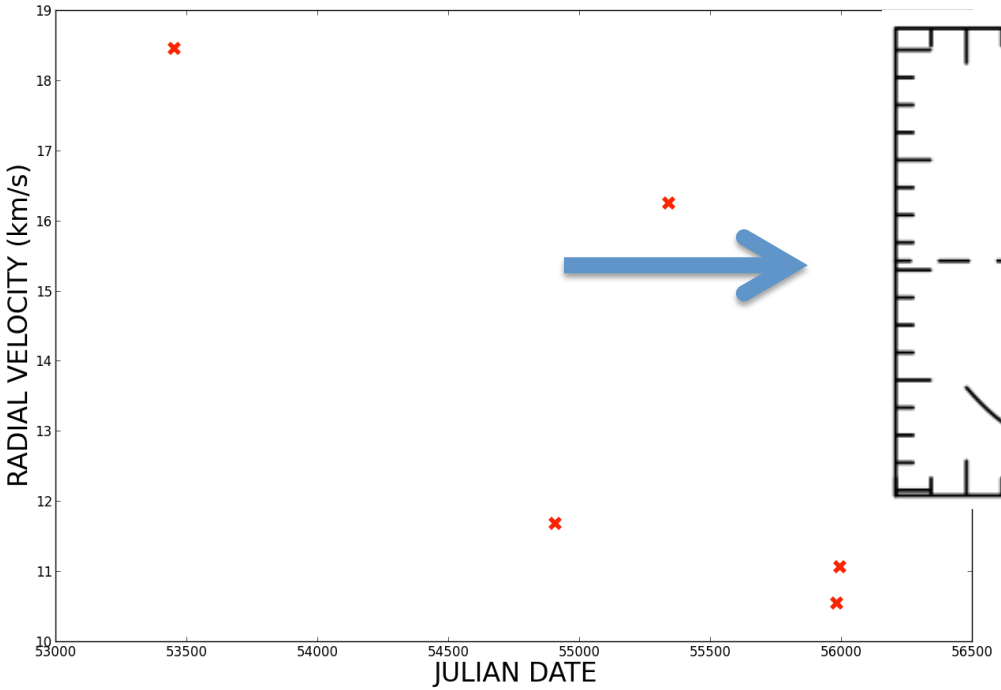


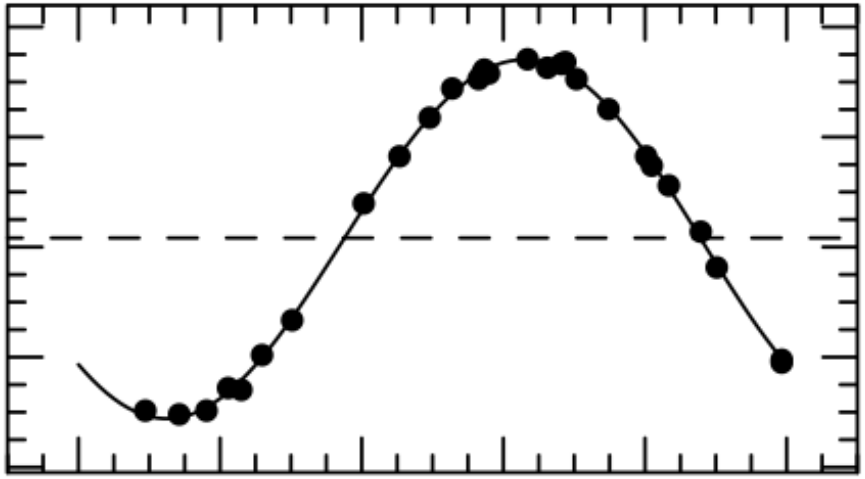
Method Analysis: SB1 Systems



SACY: Individual Targets

The reality of the data:





Latham 2002

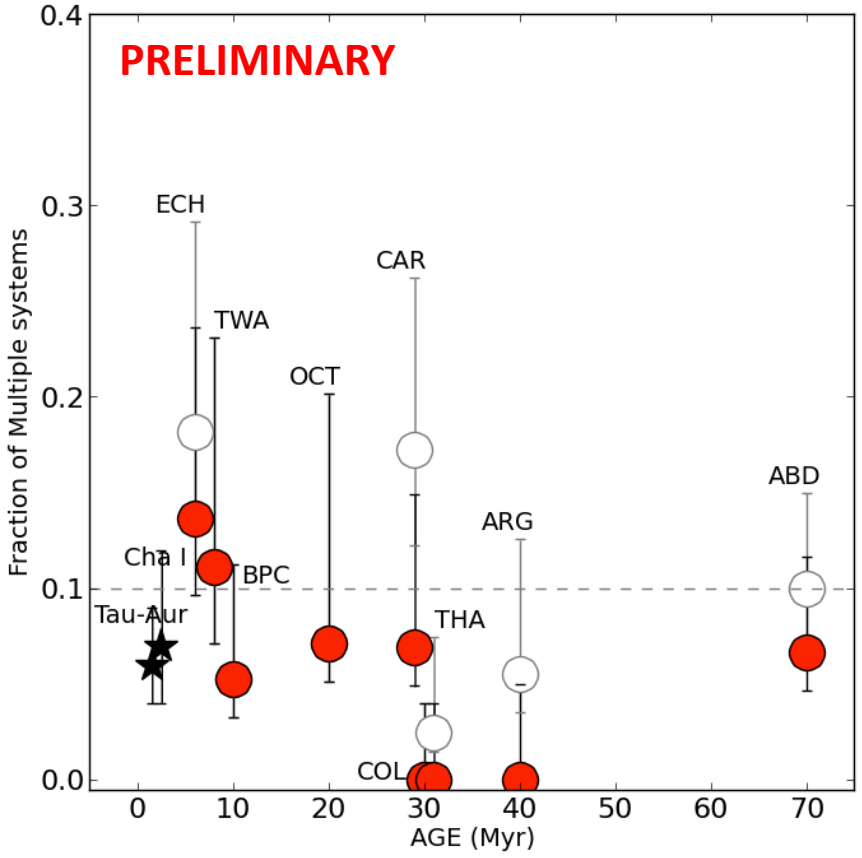
SACY: Multiplicity Fractions

$$F = \frac{B + T + Q}{S + B + T + Q}$$

More robust against missed companions,

i.e. *B* and *T* have the same effect on *F*

SACY: Age vs. Frequency



Scatter but no time evolution

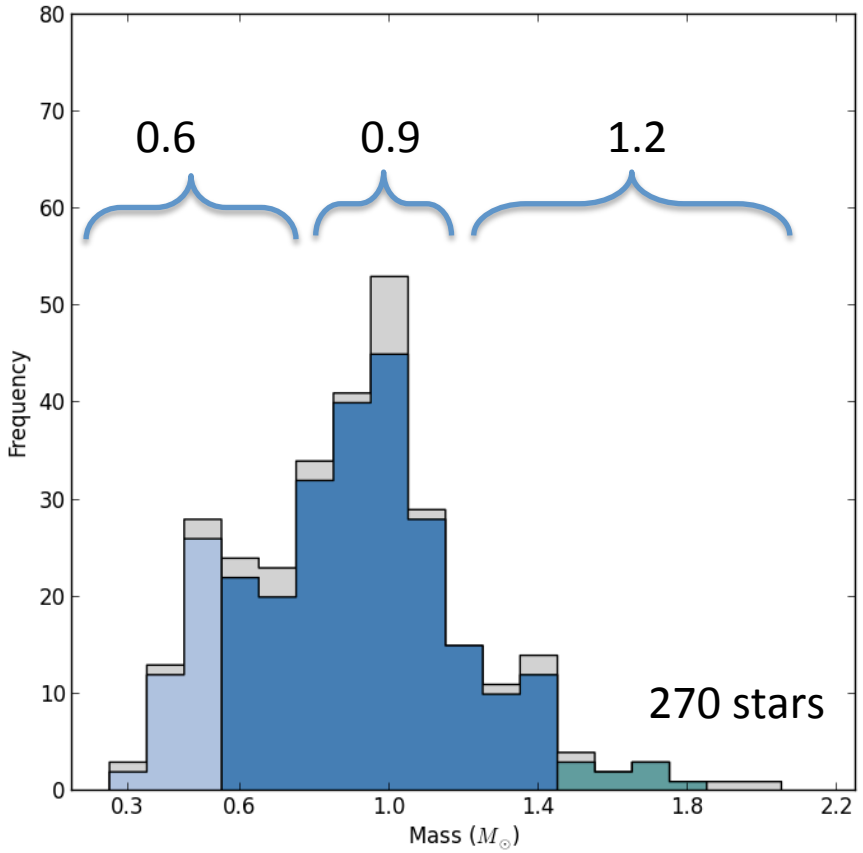
Raghavan 2010

$0.073^{+0.014}_{-0.012}$

~ Gyrs

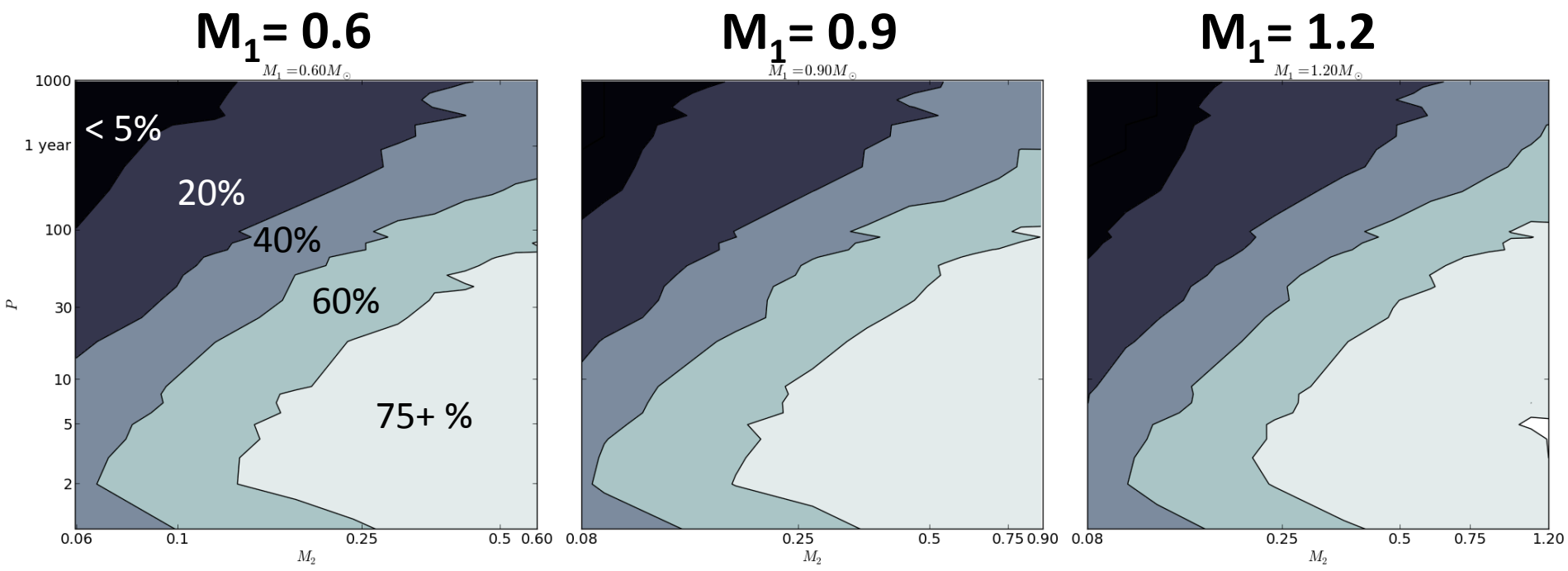
SACY: Mass Distribution

Average masses in equal number bins:

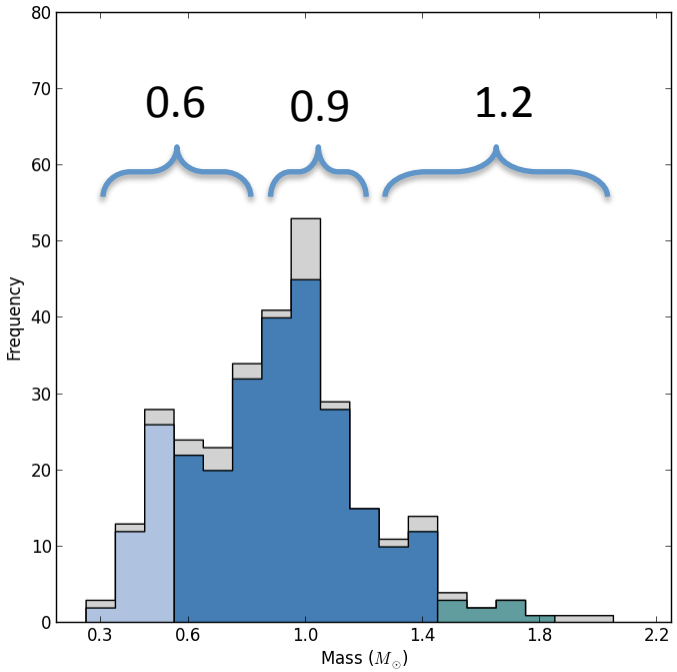


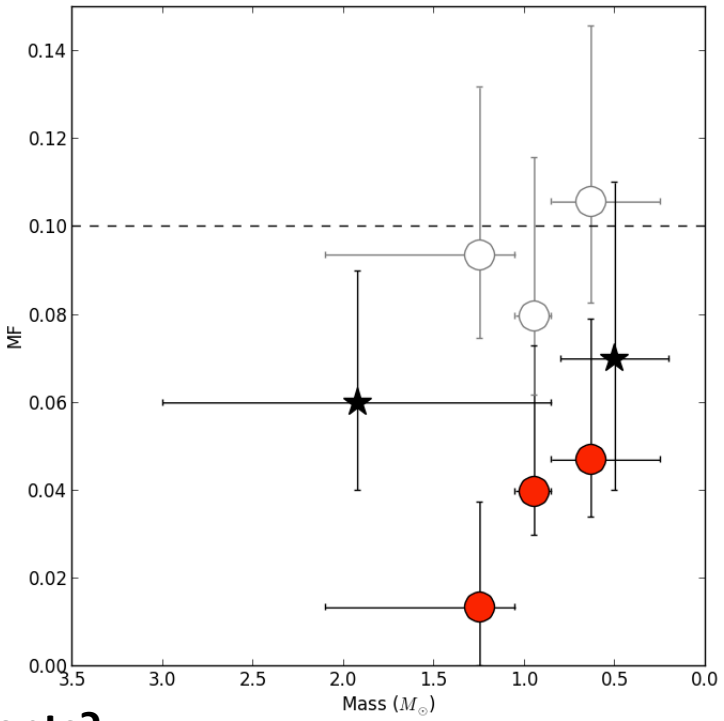
SACY: Accounting for Biases

Simulated binaries:



SACY: Mass vs. Frequency





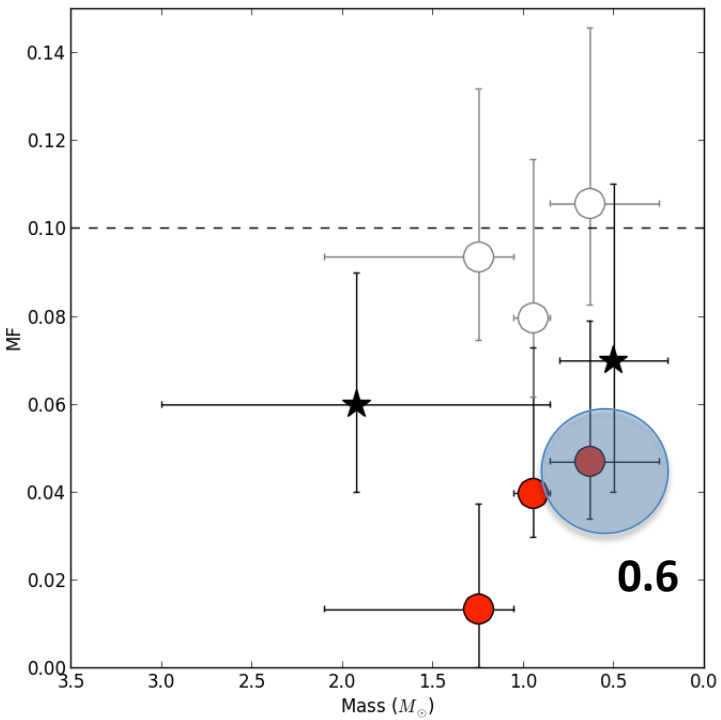
How does this compare with other environments?

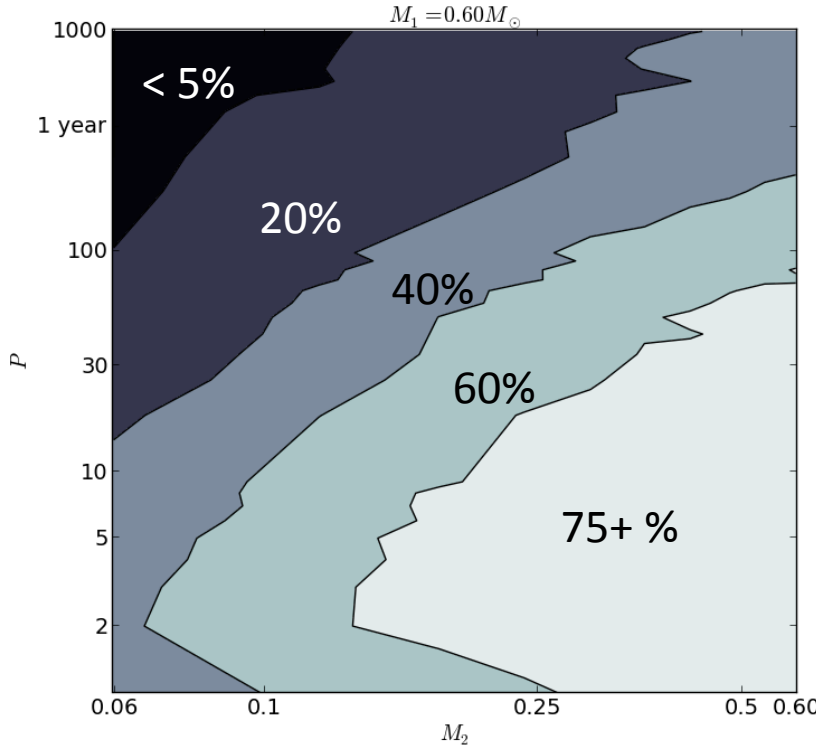
We ***must*** define an orbital range (*P*) and Secondary mass range (M_2)

SACY: Mass vs. Frequency

P [1 - 200 days]
M_2 [0.08 - 0.6]

Nguyen 2012





SACY: Mass vs. Frequency

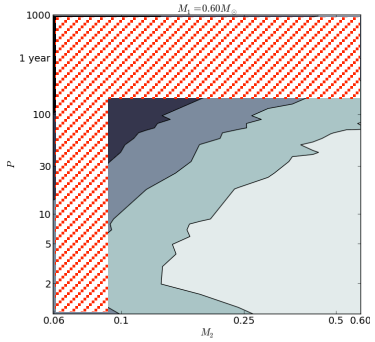
Primary Mass: 0.6

Percentage of detected systems in range

$$\mathcal{P} = \frac{\sum_{m=M_{2,\min}}^{M_{2,\max}} \sum_{p=P_{\min}}^{P_{\max}} \mathcal{M}(m,p)\mathcal{D}(m,p)}{\sum_m \sum_p \mathcal{M}(m,p)\mathcal{D}(m,p)}$$

→ **78%**

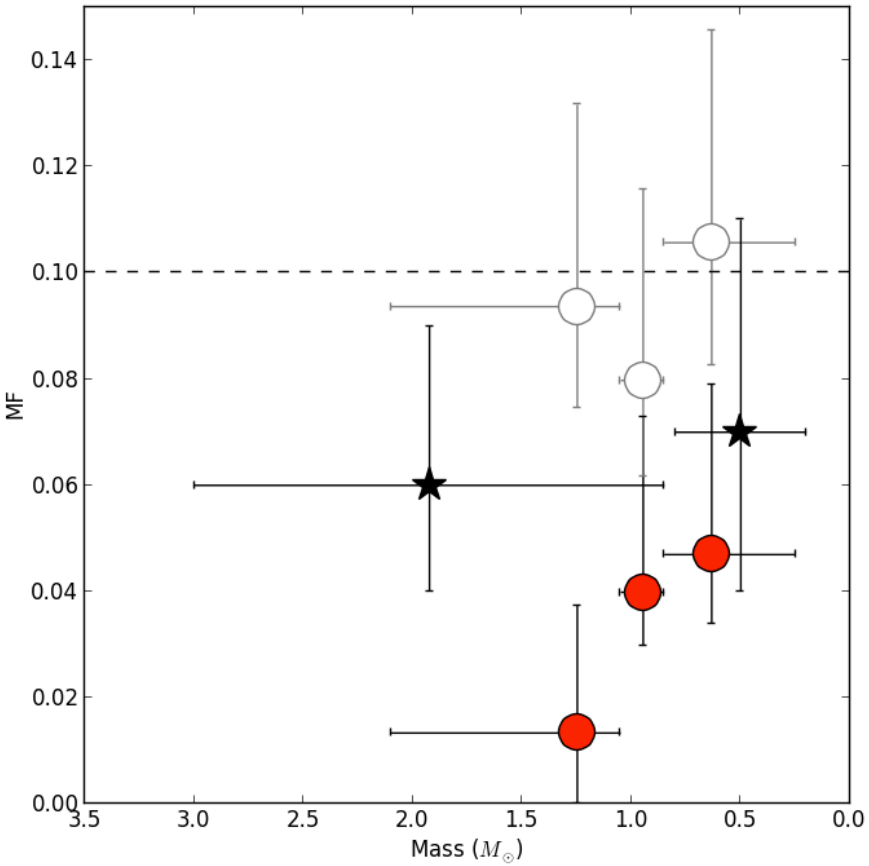
Average Detectability in P and M_2 range



→ **73%**

$F_{corrected} = F_{obs}$ x 0.78 / 0.73

SACY: Mass vs. Frequency



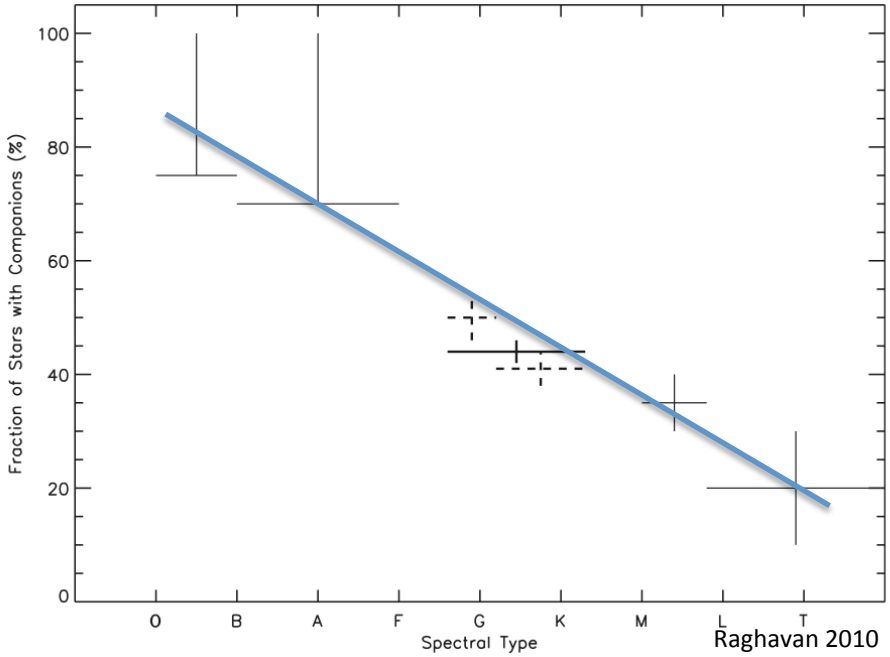
Compatible with other SFR regions and the field

Expected: Little / no dynamical processing

Compatible with universal star formation

SACY: Mass vs. Frequency

In the field: Clear dependence with mass



Raghavan 2010

Potentially explained by binding energy of system, B. Energy α Mass

Lower mass systems more easily disrupted

SACY: Mass vs. Frequency

Interaction timescale:

$$\tau \sim \frac{1}{\sigma n v_{rel}} \longrightarrow$$ Wide binaries in nearby SFR, ~ Gyr

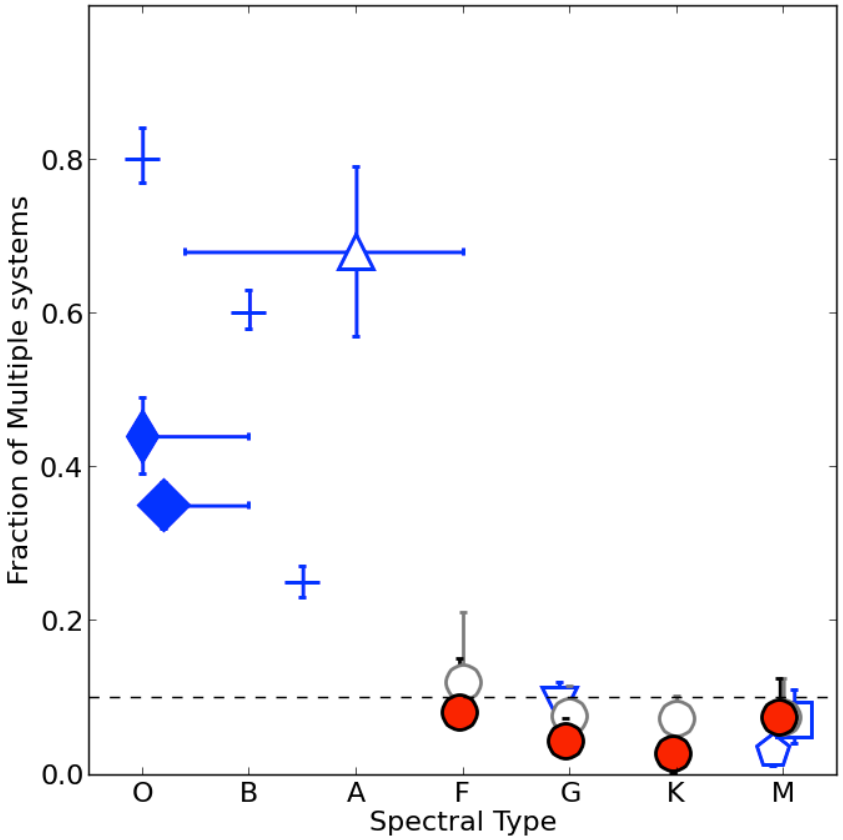
$\sigma = \pi r_*^2$ Interaction cross-section

For nearby SFR only important at distances greater than 10^4 A.U. i.e. **NOT** spectroscopic

Nguyen 2012

SACY: Mass vs. Frequency

SBs at a larger range of masses:



Refs: Nguyen 2012, Raghavan 2010, Duquennoy and Mayor 1991 Fischer and Marcy 1992, Chini et al 2012., Baines et al 2006, Sana and Evans 2011, Sana et al 2013

Why do we observe mass dependence for very close systems?

Direct outcome of star formation?

(Statistics need refinement, work is well underway)

SACY: Mass vs. Frequency

Possible explanations for relationship:

Accretion

Interaction with circumbinary disk

Dynamical interactions in small multiple systems

<= 10^5 yrs

Becoming more important with mass?

Bate, Bonnell and Bromm 2002

SACY: Star Formation

Using the hypothesis of universality:

1. Investigating the star formation process:

- Gain information/'clues' of the processes from our results

2. Test the hypothesis:

- Use ages and densities to our advantage: Loose associations, Nearby SFR and the field
- 'Remove' dynamical effects and biases (The tricky bit)
- Do we gain compatible results regardless of the environment?

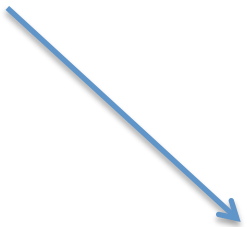
SACY: What the future holds

My Future work

Obtain fractions of wider binaries from existing NACO data

Combine all fractions for continuous and comprehensive multiplicity fraction

Compare to other environments



Is Multiplicity Universal?

Thank you