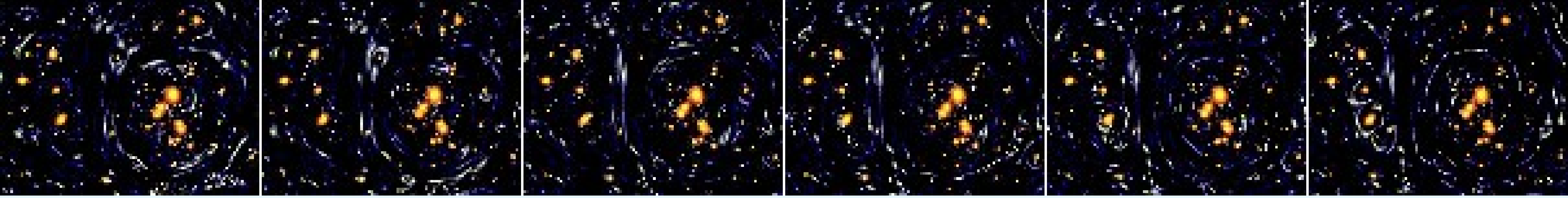
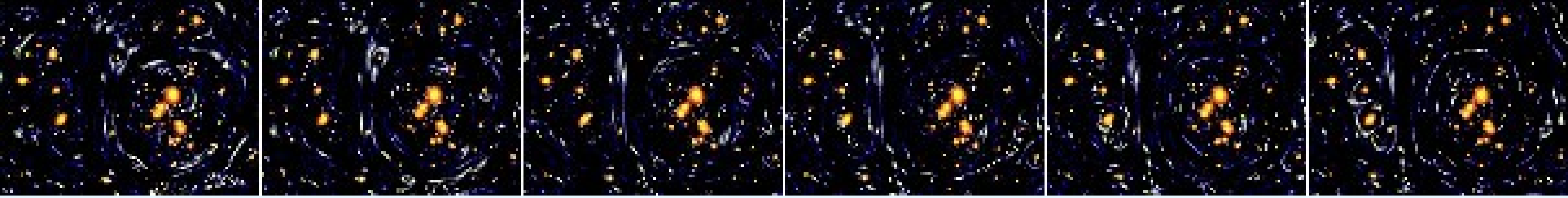


Extremely short dynamical lifetimes of young massive stellar groups

Christine Allen

Instituto de Astronomía, UNAM, México

Collaborators: R. Costero, A. Ruelas-Mayorga, L.J. Sánchez



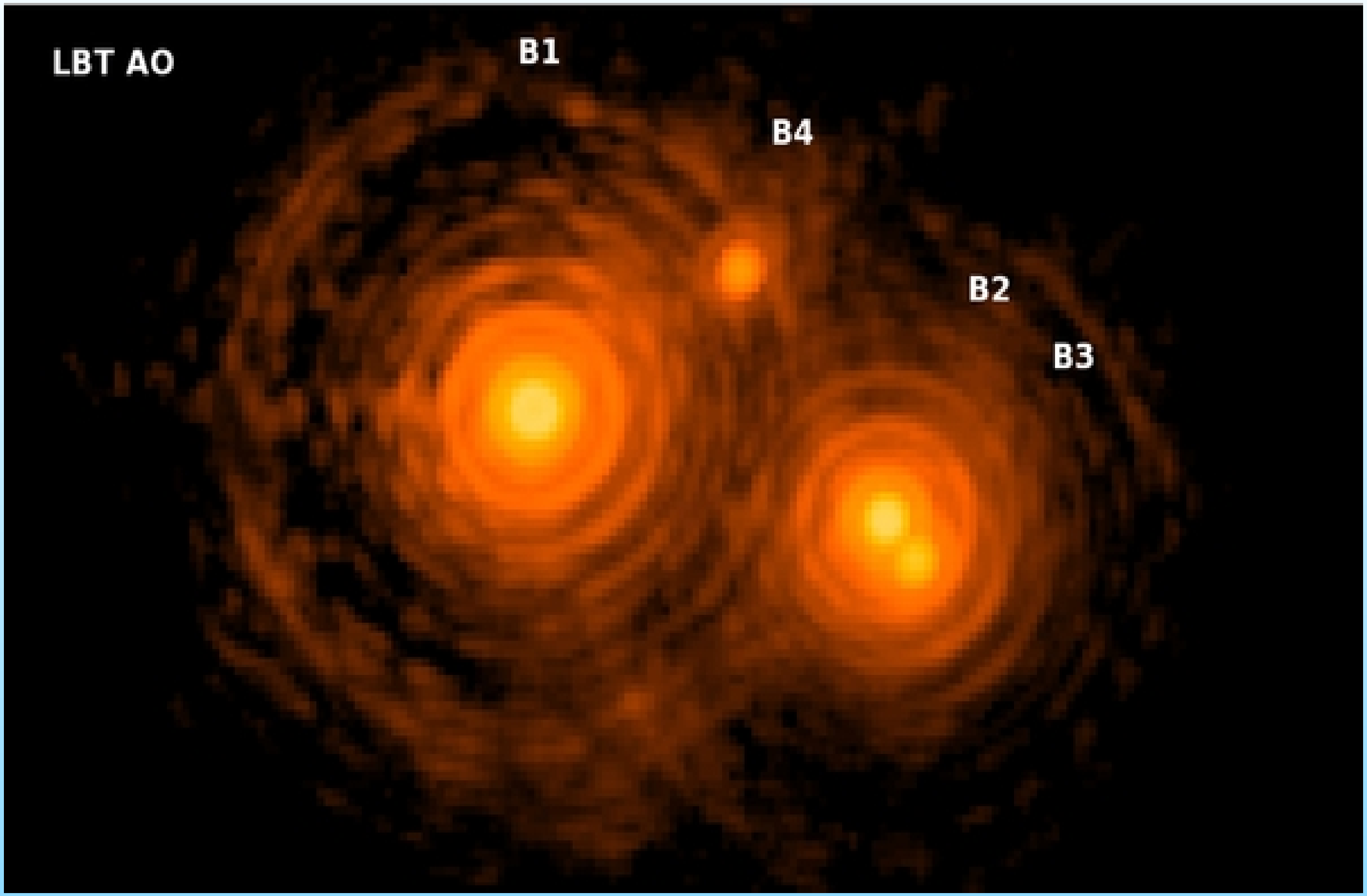
-Massive star formation is thought to occur in groups

-We have modelled the dynamical evolution of several young groups:

-The minicluster Theta 1 Ori B
-The Orion Trapezium itself
-10 additional massive (O-B3) trapezia

-We perform N-body integrations, using as initial conditions best available data for planar positions, transverse velocities, radial velocities, masses, and distances. Unavailable data are modelled randomly, within realistic intervals

The system Theta[1] Ori B (2013)



LBT AO Brγ (2.16 μm) images of the θ1 Ori B group. Resolution 006. Logarithmic color scale. North is up and east is to the left. Strehl is ~75% (Close et al. 2013).

Note that the object "B1" is really an eclipsing spectroscopic binary (B1-B5), where the unseen companion B5 orbits B1 every 6.47 days (Abt et al. 1991).

The system Theta[1] Ori B (now)

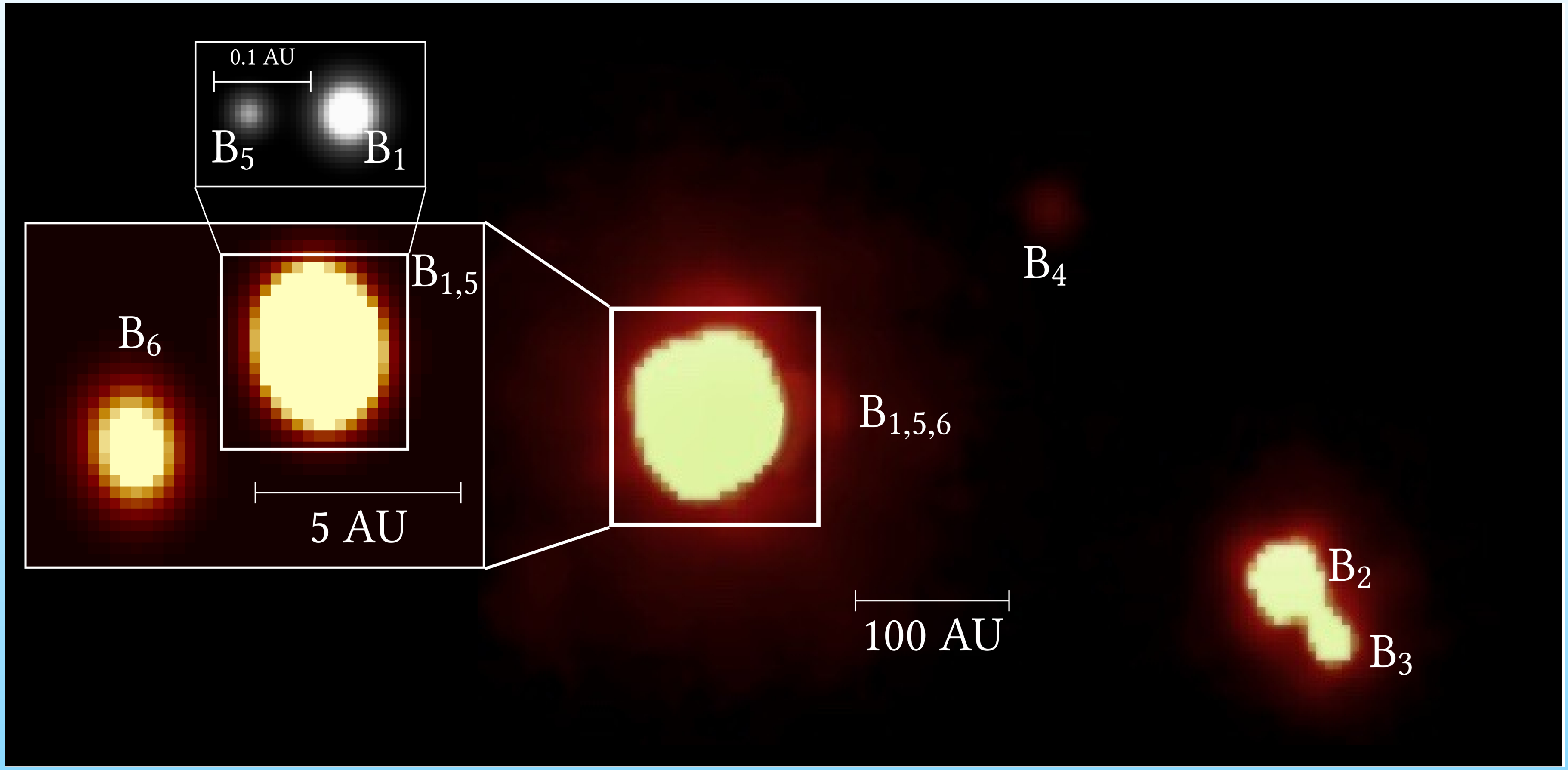
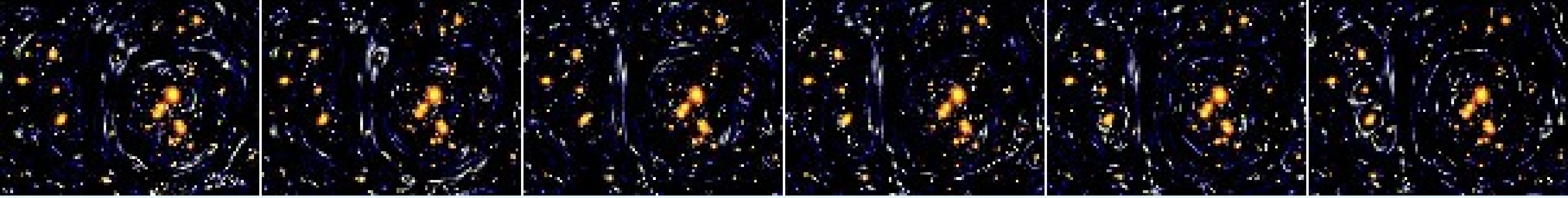


Image in H band. Companion B6 at 13 mas (5.3AU) separation. Martina et al. 2018 GRAVITY Collaboration



The system Theta[1] Ori B

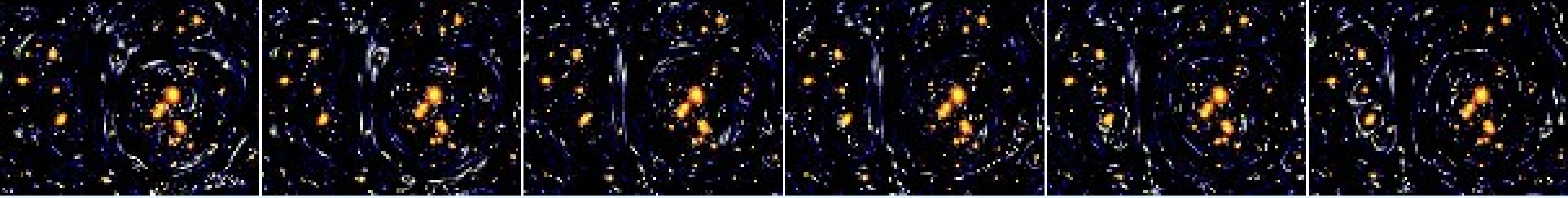
Allen et al. (2015) tried to answer the questions:

Is the group Theta[1] Ori B long-term stable?

Is orbit B2- B3 long-term stable?

-Precise positions and relative (transverse) velocities were available.

-Since z-positions and radial velocities were unknown we used N-body Monte Carlo simulations to provide insight.



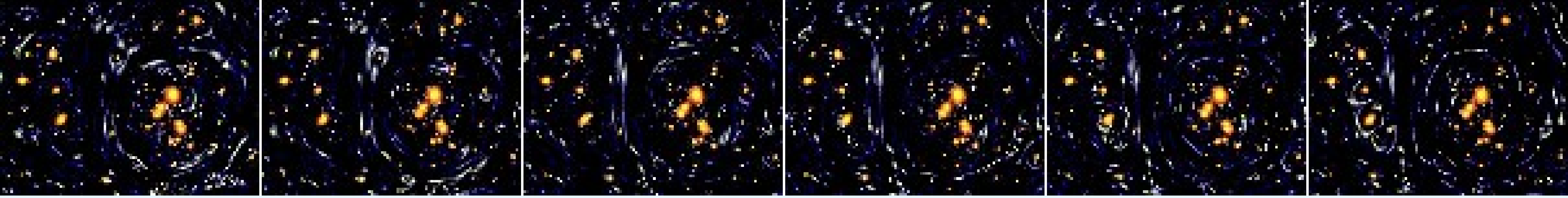
The system Theta^1 Ori B

Are our results still valid with new data?

-System B1+B5 was assumed to act like point mass
  New system B1+B5+B6 also acts like point mass

-Mass of B1+B5 was taken as 14 Mo
  New mass of B1+B5+B6 is (7+2+5) = 14 Mo

-Orbit of B6 around B1+B5 is now in process (Costero et al. 2019). Detailed interaction of B1+B5+B6 with other components will be modelled in the future

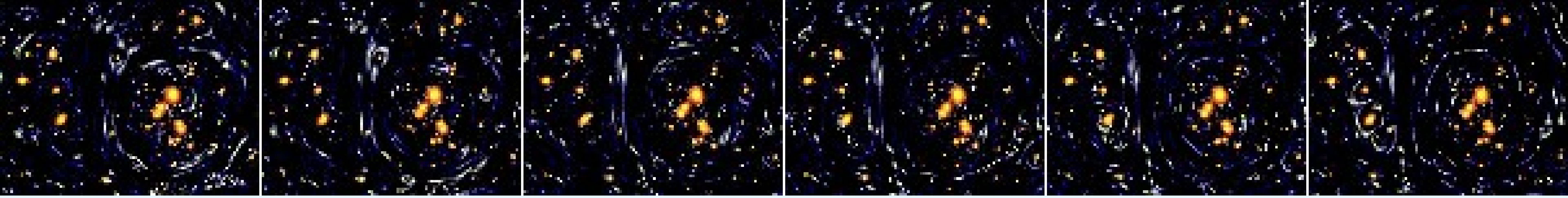


Results

Three sets were computed, 100 realizations each.

Tc= 5, 10, 100 (1500-30 000 years)

	5	10	100
Stable	29, 39, 35	18, 26, 22	1,1, 4
Triple	43, 40, 49	42, 46, 55	19, 28, 31
Dissolved*	28, 21, 16	40, 28, 23	80, 71, 45
*Double^2	6, 1, 0	6, 4, 4	7, 5, 9



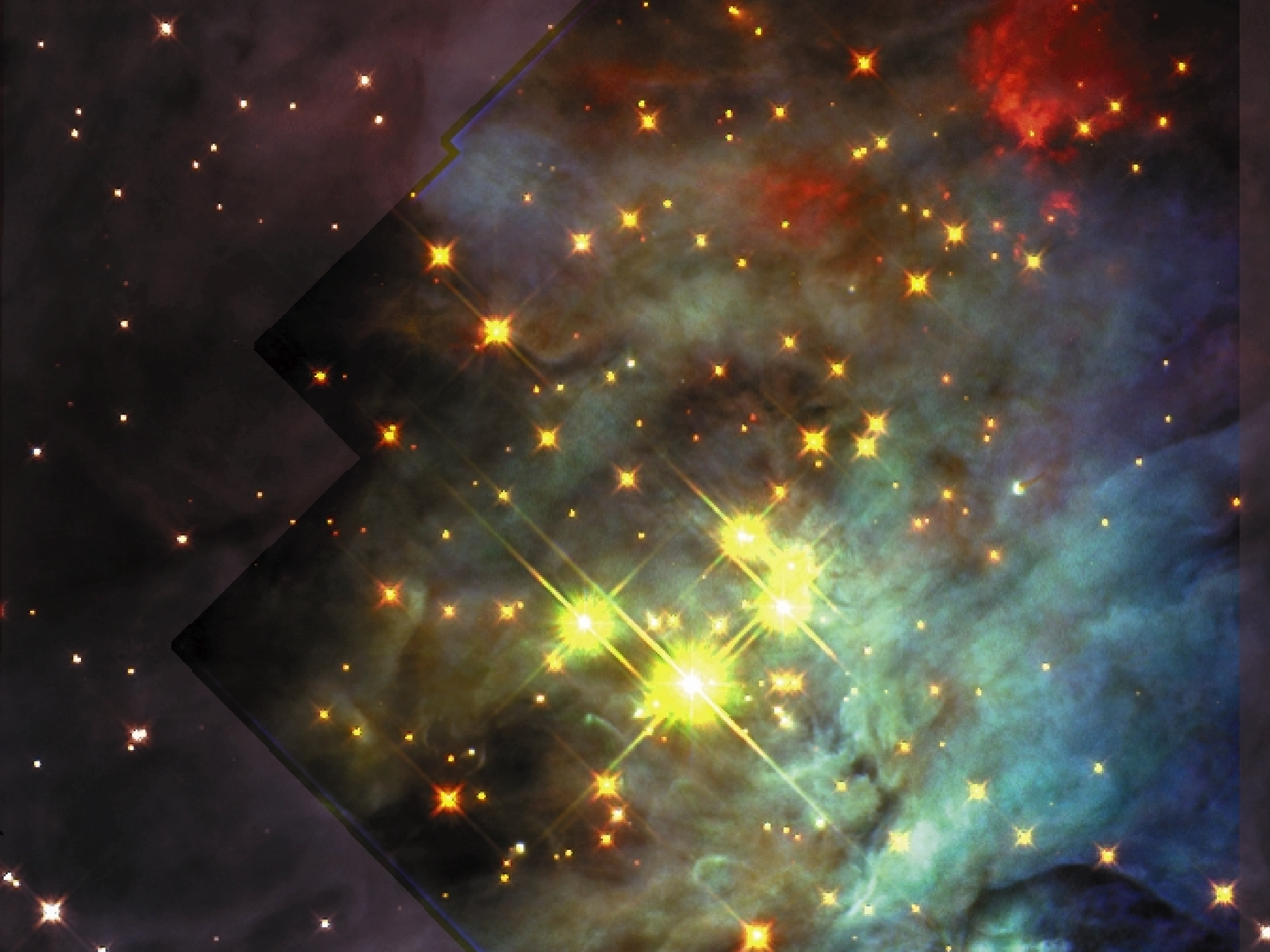
Theta^1 Ori B: Summary

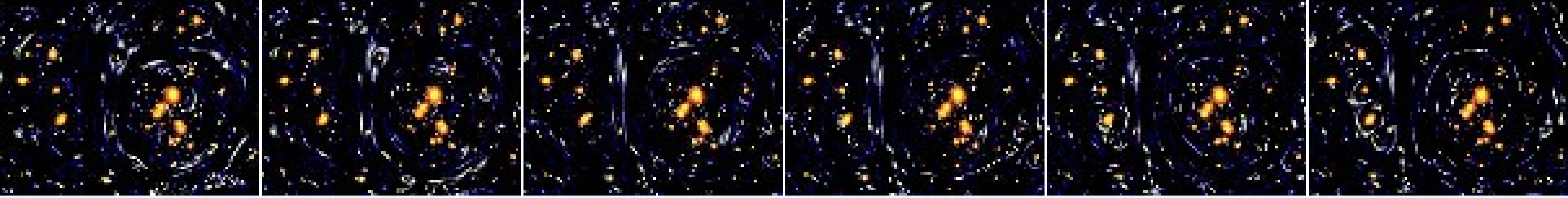
- The sextuple system Theta^1 Ori B is a bound group, but extremely unstable dynamically.

- It will probably disintegrate in less than 30,000 yr, producing binaries (<a>=80 au, but some as close as 6 au), triples, and many escapers.

- Most escapers are low velocity, but some runaway stars were produced (7% with v>21 km/s).

- The orbit B2-B3 is rapidly disrupted

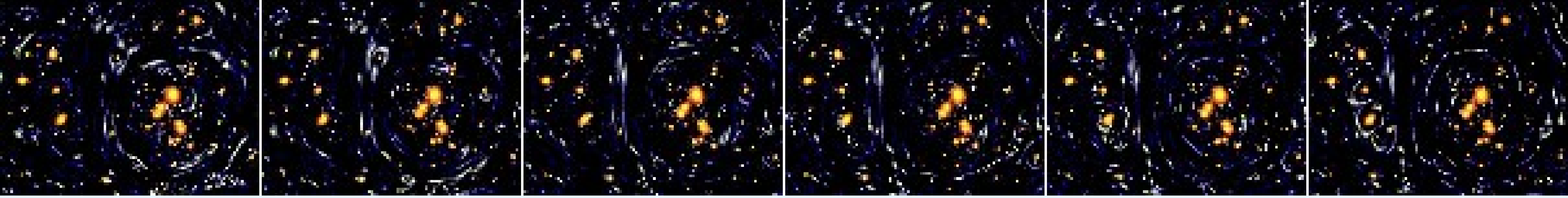




Modeling now the Orion Trapezium

Transverse velocities (with respect to to C):

separation velocities	projection angle
A: -2,3 (+-0,7) km/s	221.9 degrees
B: -1.4 (+-0.9)	72.9
C: 0.0	0.0
D: -0.9 (+-0.6)	151.8
E: +5.7 (+-0.8)	51.5



Modelling now the Orion Trapezium

Systemic radial velocities (with respect to to C):

A: 0.7 +-1.0

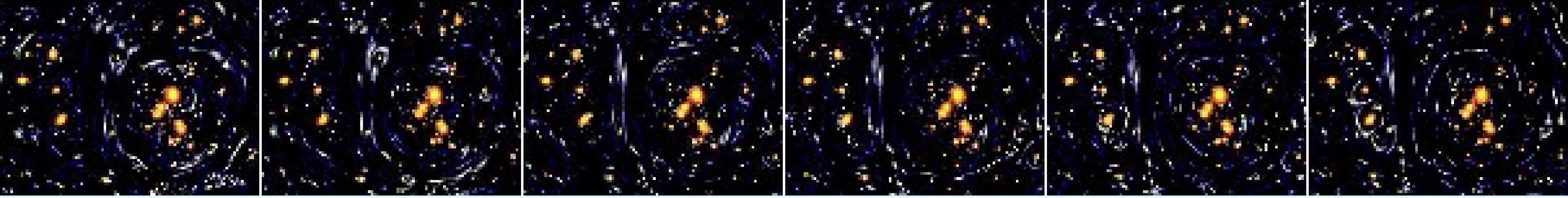
B:-1.3 +-1.0

C: 0.0

D: 5.1+-3.0

E: 7.0 +-1

NB. In order for none of the bright components to have radial velocities exceeding the escape velocity we took the average of the two best observational values for C



Modelling now the Orion Trapezium

Aggregate masses of the components:

A: 27 (+-1.35) Mo

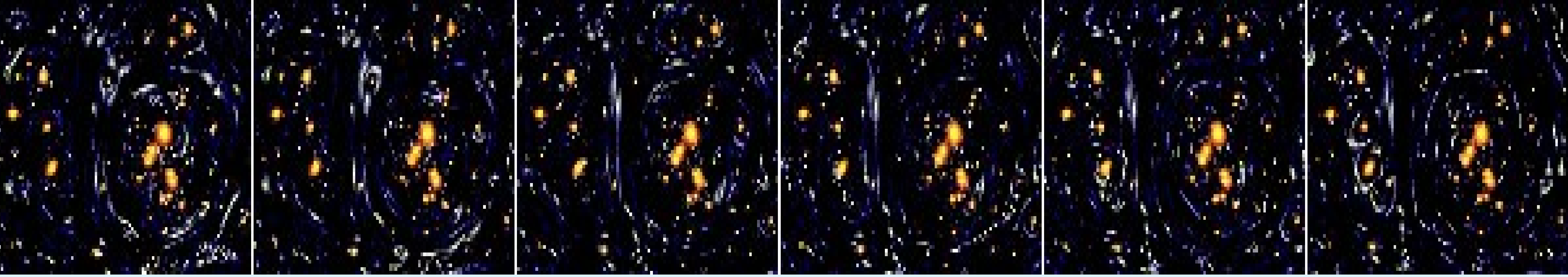
B: 15 (+-0,75) Mo

C: 45 (+-10) Mo, or 65(+-3.25) Mo

D: 25 (+-1.25) Mo

E: 7 (+-0.35) Mo

– All components will be considered as point masses for the N-body integrations



Main difficulty: Multiplicity in the Orion Trapezium

C: astrometric and spectroscopic binary, possibly with a third companion. It is also an oblique magnetic rotator

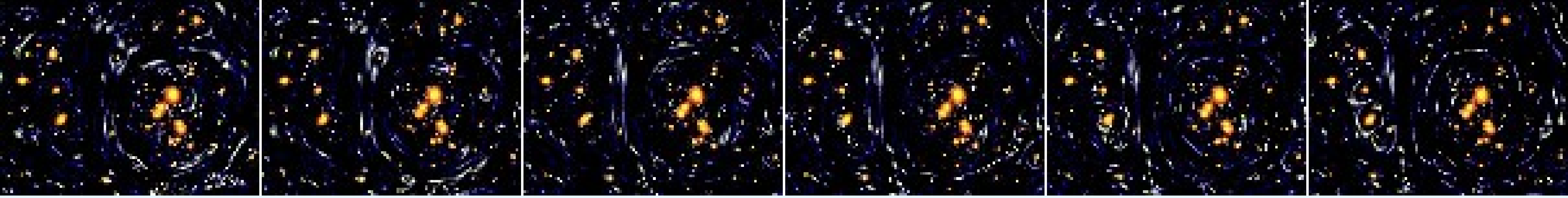
A: eclipsing and spectroscopic binary with a probable interferometric companion (now confirmed)

B: eclipsing binary, with a third star, and with three additional interferometric companions, i.e. it is a sextuple mini-cluster

D: spectroscopic binary (now with 3^{rd} close companion)

E: escaping spectroscopic binary

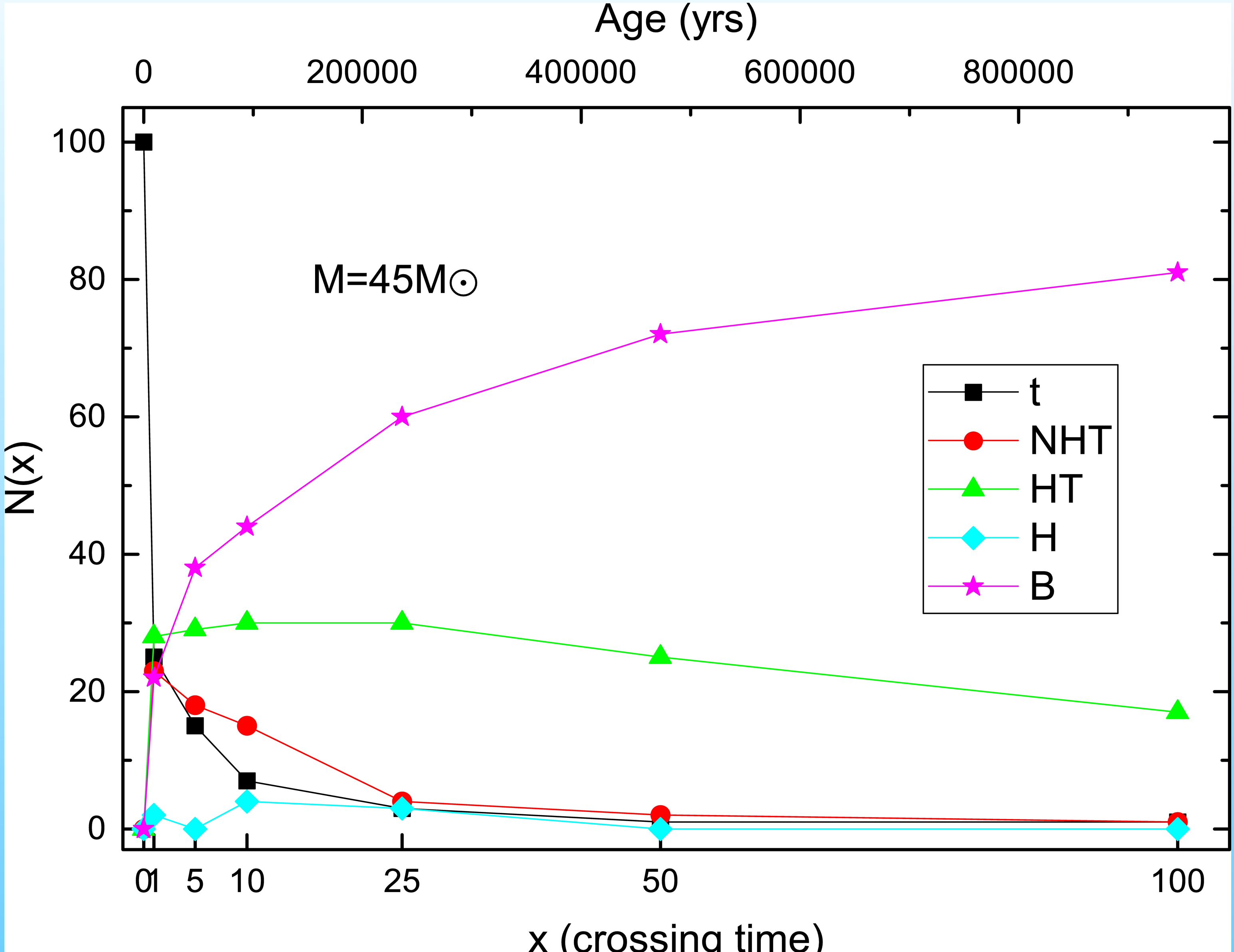
Hence, systemic velocities and masses are VERY difficult to obtain, and have large observational uncertainties



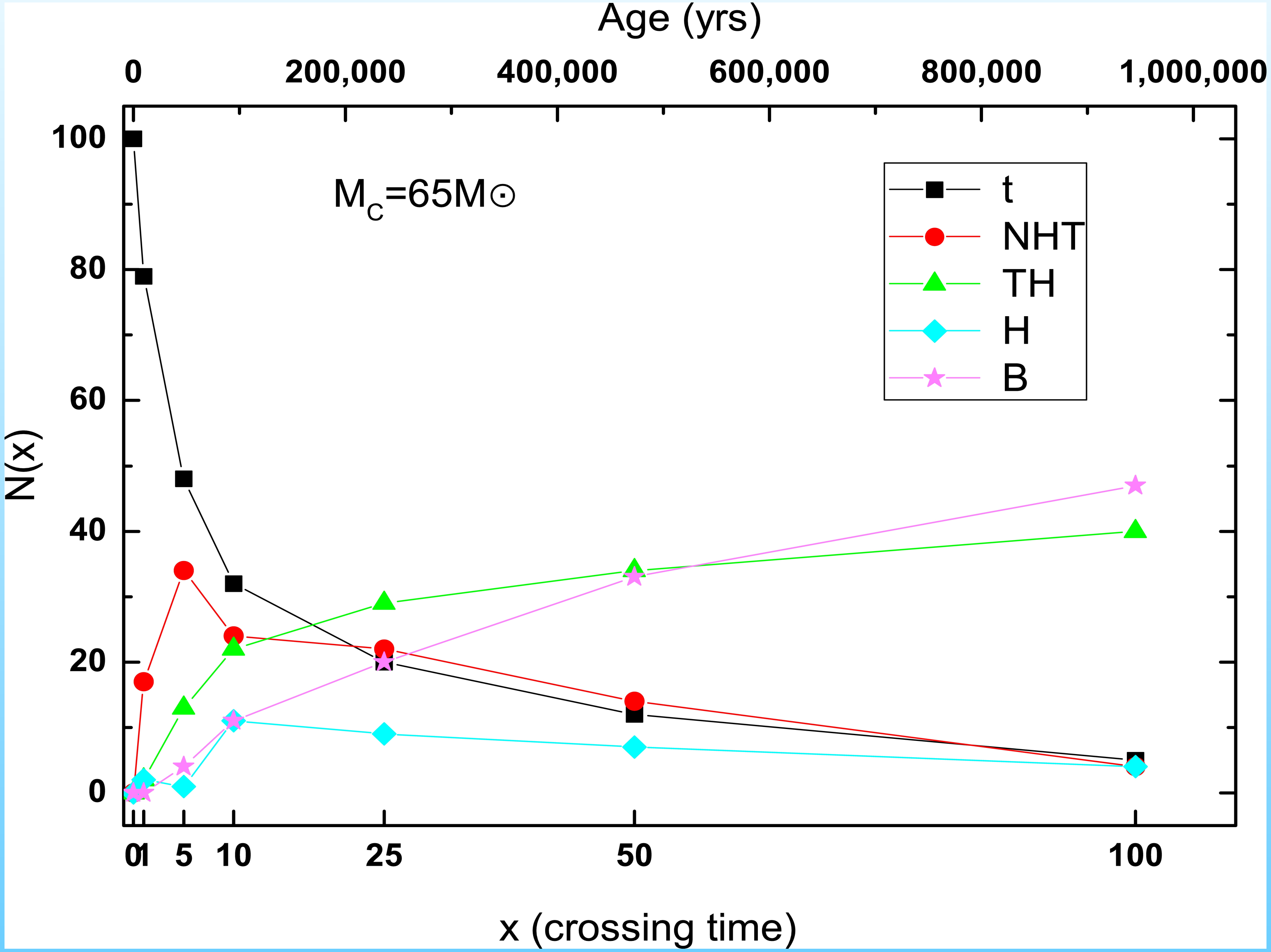
Monte Carlo models of the Orion Trapezium

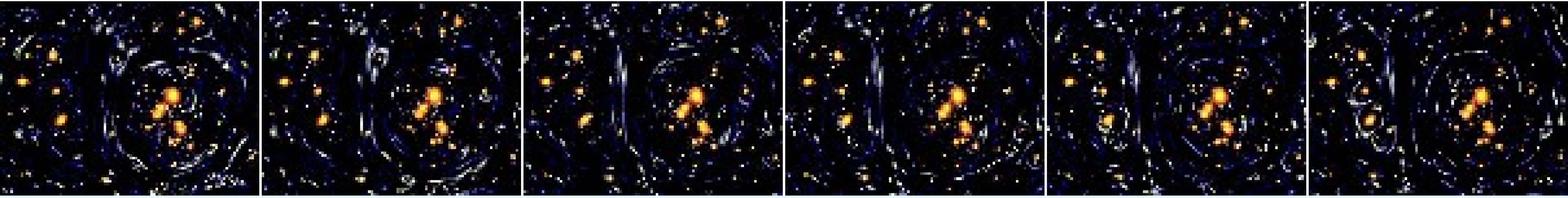
- -As initial conditions we take the planar positions and velocities of Olivares et al (2013)
- -z-positions are randomly assigned, with a dispersion of 1500 AU
- -Radial velocities and masses are taken from the literature- with caution!
- -Random perturbations compatible with observational uncertainties are applied to all quantities
- -For the integrations we use the Mikkola&Aarseth code, which includes chain regularization.

Results: lifetimes



Results: lifetimes





Orion Trapezium results:

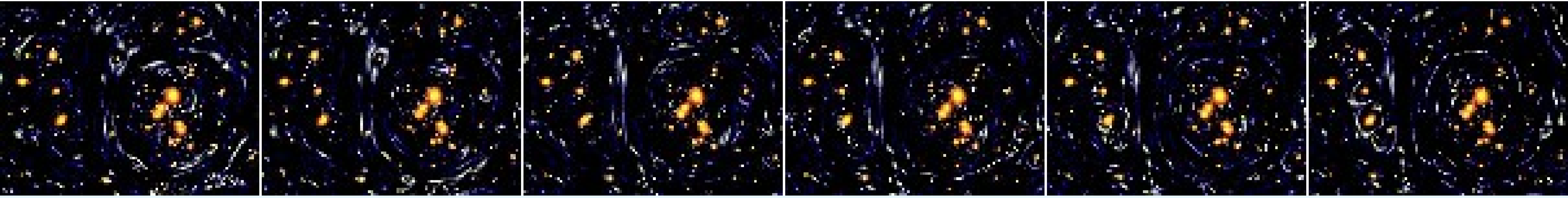
- Lifetimes (<10,000 yr) are extremely short with M(C) = 45 Mo

- Lifetimes more reasonable (about 30,000 yr) with M(C) = 65 Mo

- The dynamical lifetime of the Orion Trapezium agrees with the age (<30,000 years) we found for one of its components, the mini-cluster Theta^{1} Ori B, provided we assume M(C) = 65 Mo.

- Star E always escapes right at the beginning (within 2-3 thousand years)

- Reversing the runs, Star E is recaptured in 26% of the cases



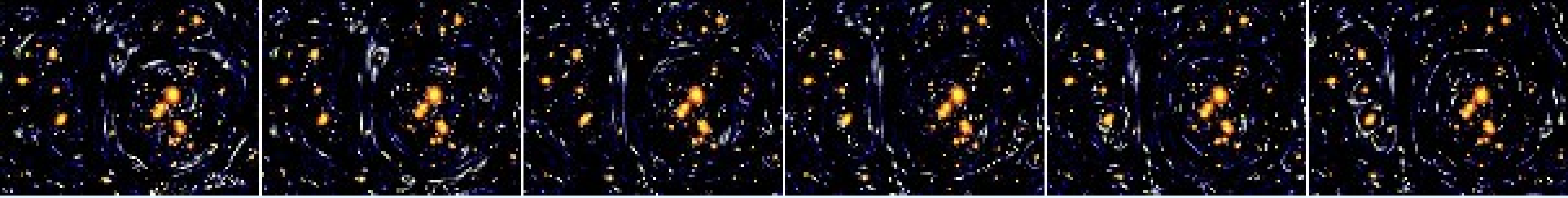
Orion Trapezium results-cont.

- The end result of integrations is a wide binary ($\langle a \rangle = 2000$ au) or a hierarchical triple. No closer binaries ($a < 250$au) were formed

- The ejected stars have low velocities. No runaways were formed.

- No very close encounters occurred

- The properties of the resulting binaries (distribution of major semiaxes, of eccentricities, the period-semiaxis relation) are similar to those observed.



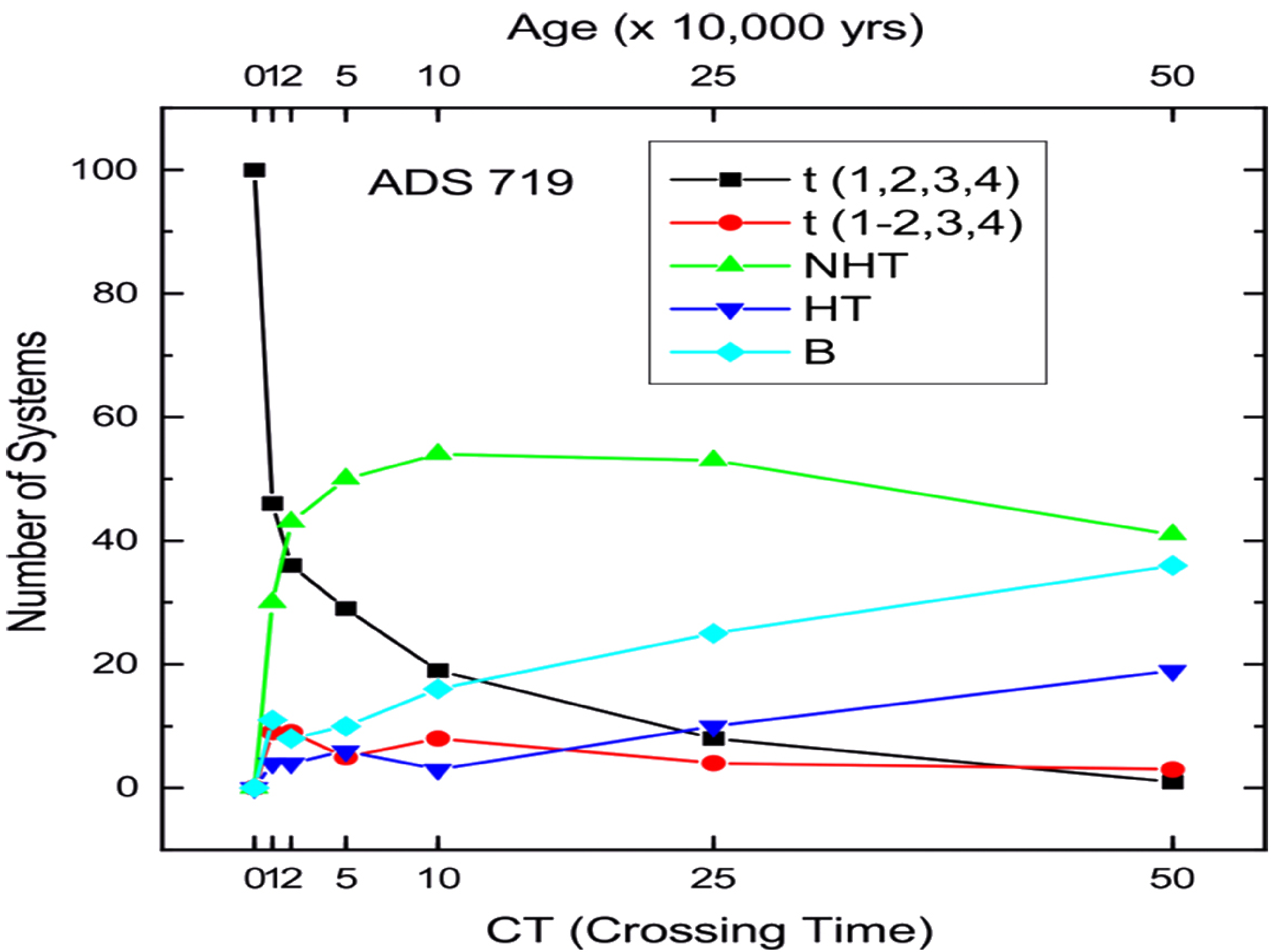
Other massive trapezia

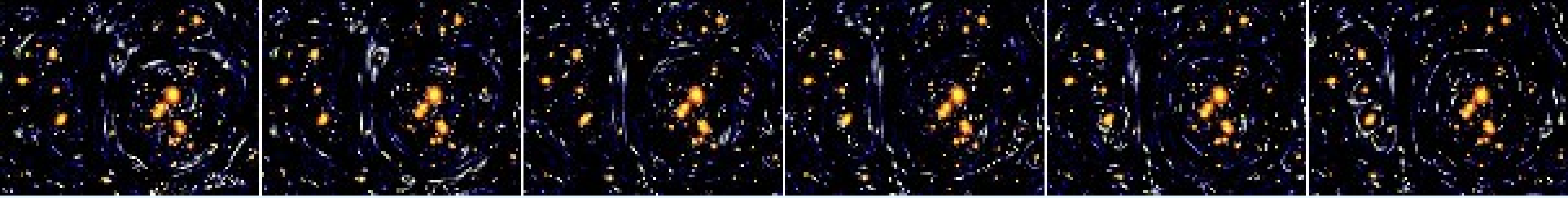
-From the literature we collected data for 10 additional trapezia of types B3 and earlier, so as to minimize contamination by optical or pseudo-trapezia

-We obtained Monte Carlo realizations of 100 systems for each trapezium and performed N-body integrations.

-Most systems turned out to be unbound. Since the masses are quite uncertain (due to undetected companions, etc.) we doubled their value. A few additional systems became bound.

ADS 719 Lifetimes





Other trapezia-results

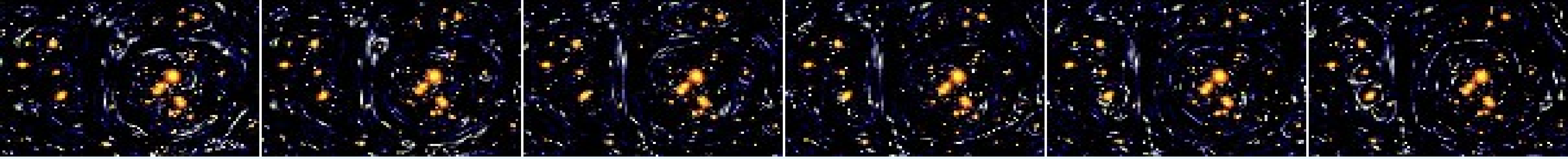
-Lifetimes for bound systems (ADS 719) are around 15 000 years

-Many non-hierarchical triples survive for as long as 300 000 yr

-Unbound systems disperse in less than 10 000 years

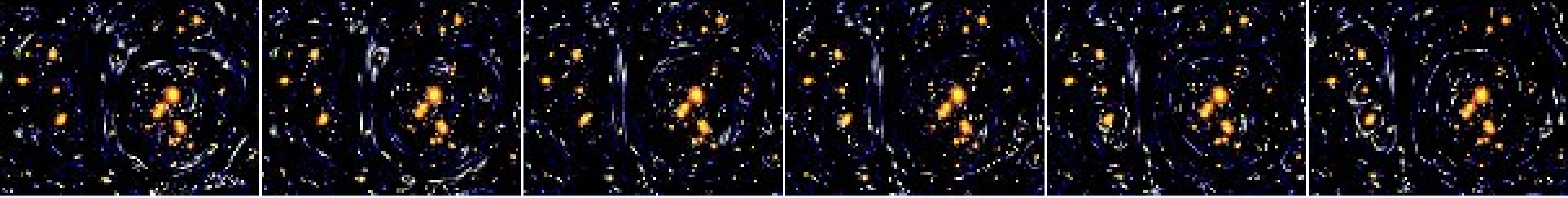
-Doubling the values of the (uncertain) masses a few more systems become bound, with similar lifetimes

-Frequency distributions of major semiaxes and eccentricities of binaries formed were obtained. Those of bound systems resemble observed distributions of wide binaries.



Conclusions

- The (future) dynamical lifetimes we find by Monte Carlo N-body simulations of the Orion Trapezium and other massive trapezia are all very short.
- With a larger mass for the systemTheta^1 Ori C (65 Mo), lifetimes become comparable to the ages of other young structures in the Orion region (from about 500 to 15,000 - 30,000 years).
-N-body simulations of 10 O-B3 trapezia result in many unbound systems, and very short lifetimes (15 000 yr for bound systems).
-Doubling the masses results in slightly longer lifetimes and a larger number of bound systems.
-Many binaries are formed, with properties similar to observations. This is relevant to problem of observed massive star multiplicity (with separations from a few to thousands au).



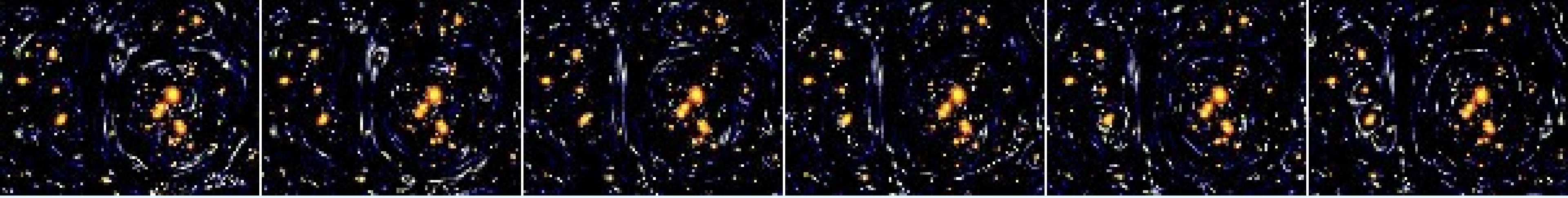
Discussion

A possible problem: are the disintegration times too short?

-In the Orion region there are other extremely young structures. Examples: the BN-I-n object (500 years, Rodriguez et al. 2005, Gomez et al. 2008), the Orion Nebula itself (illumination age: 15,000 yr, O´Dell et al. 2009)

-The dynamical age of Theta^{1} Ori agrees with that of one of its components (B: the mini-cluster): about 30,000 years

-We should remember that masses and radial velocities are very uncertain (problem of multiplicity)



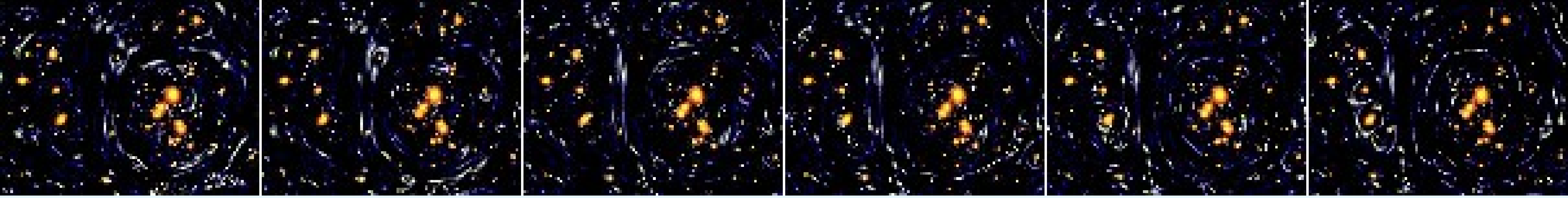
Discussion (cont.)

-If O-stars are formed in trapezium-like groups, then the extremely short dynamical lifetimes and the large number of unbound systems imply that trapezia should be rare in the field.

-Indeed, there are about 800 O-stars (B<12, Maiz-Apellaniz et al. 2013), but we found only 3 true O-trapezia.

-The mean age of an O-star is about 500,000 yr, large compared to the dynamical lifetimes (<50,000 yr). If O stars are formed in trapezium groups, there should be about 80 observed O-trapezia.

-The scarcity of field trapezia is compatible with their extremely short lifetimes (<10,000yr). Only a few survivors are found!



Thank you