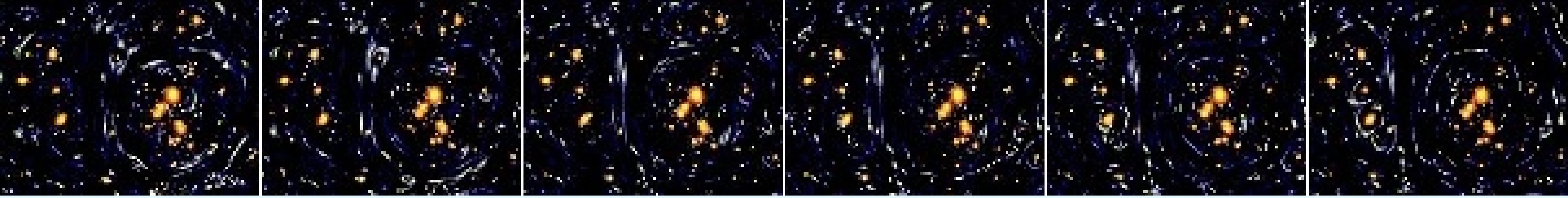

Dynamical evolution of the Orion Trapezium

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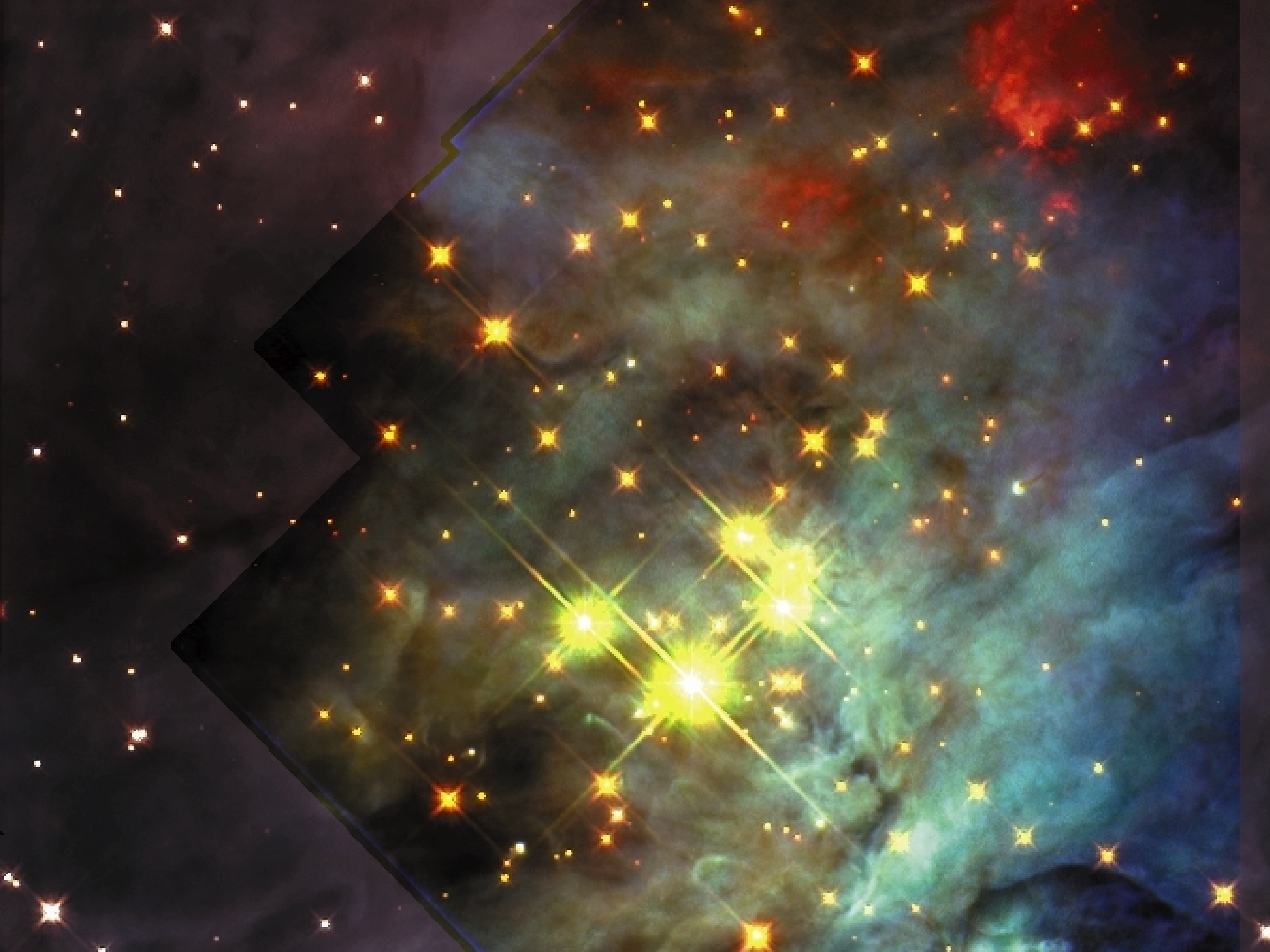
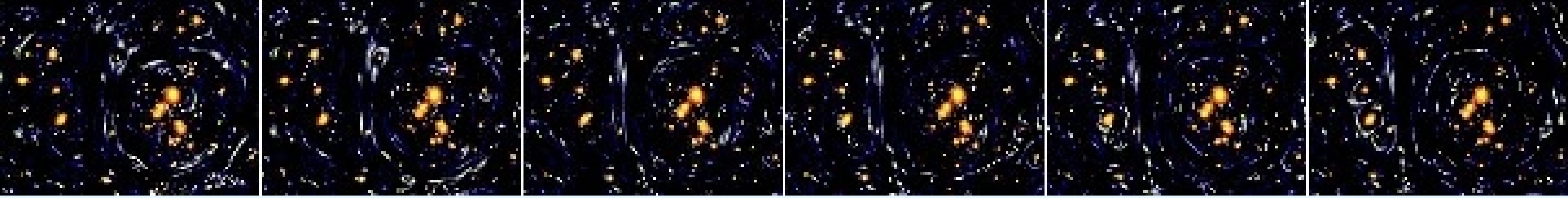
ADeLA 2016, Bogotá, Colombia





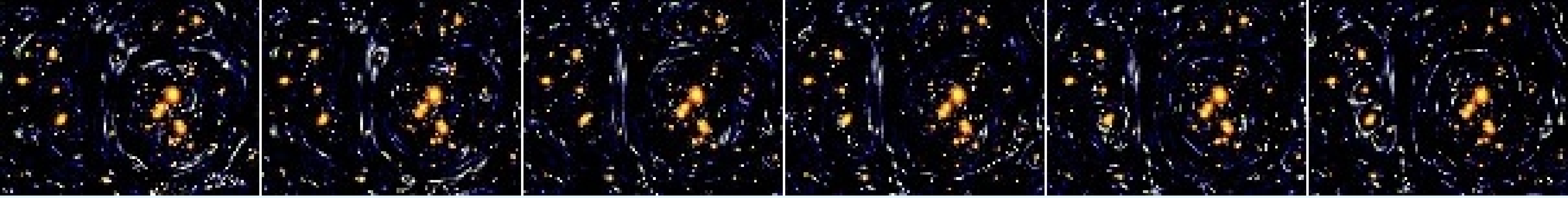
Very few studies on dynamical evolution of trapezia exist.
Models of simulated systems by:

-Allen & Poveda 1974; found lifetimes of trapezium-like systems of about 500,000 yr

-Pfamm-Altenburg & Kroupa 2006; found much shorter lifetimes, around 5000 yr

But: their definition of trapezia was different, they used different stability criteria and different values for the masses

And: neither attempted to use observed values for the actual Orion trapezium

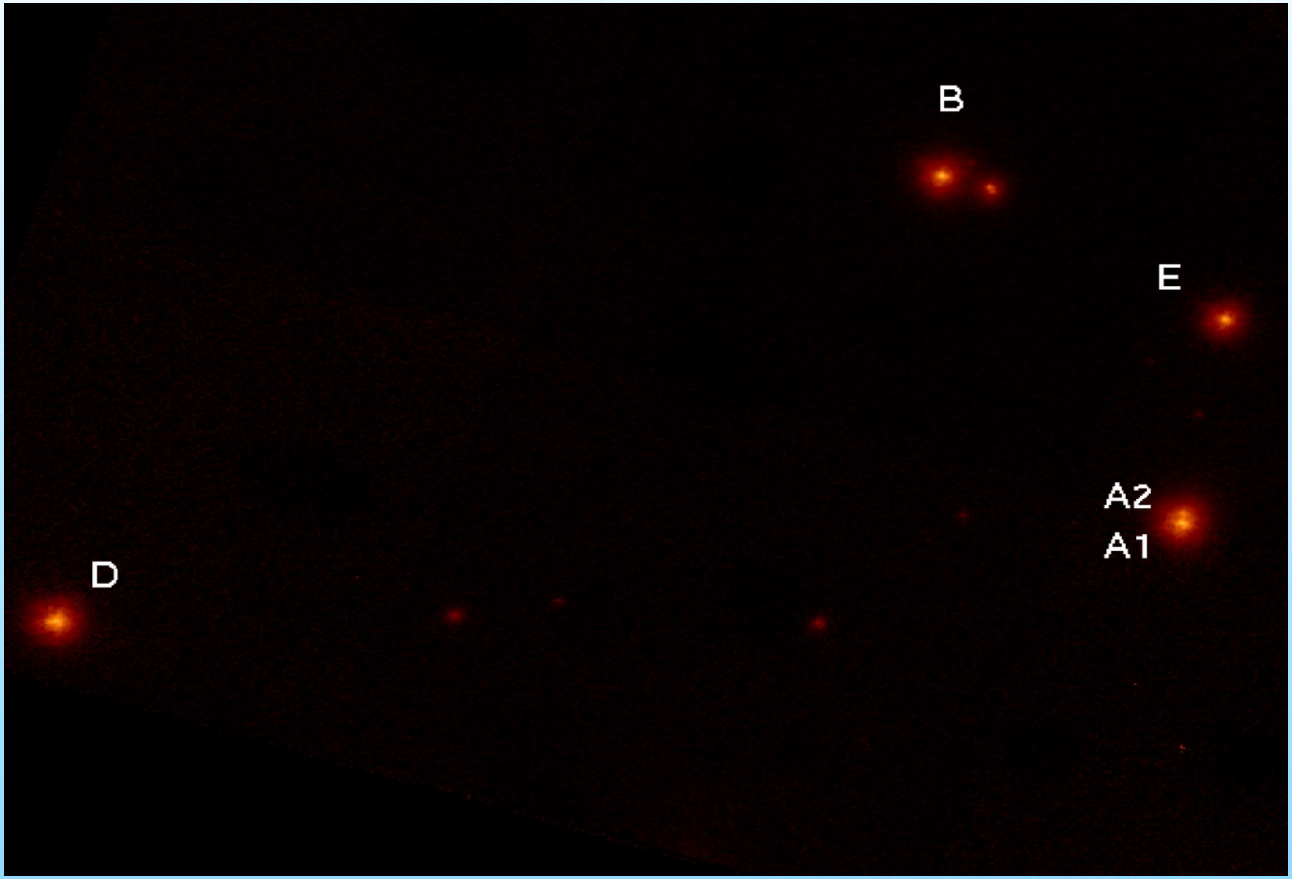


-Allen et al. (2015) using transverse motions and radial velocities of Close et al. (2013) modelled the dynamical evolution of the sub-trapezium (or mini-cluster) Theta^1 Ori B, and found its lifetime to be less than 30,000 yr.

-Recently, transverse motions of bright Orion Trapezium members were obtained (Olivares et al. 2013), by combining historical separation and PA measures with diffracto-astrometry measures on HST images.

-This motivated us to attempt to model the dynamical evolution of the Orion Trapezium by N-body simulations using radial velocities and masses from the literature.

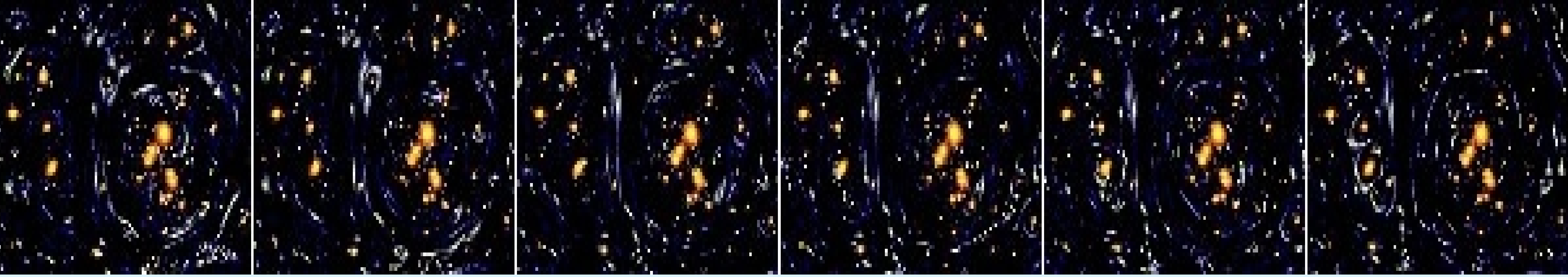
Problem: Multiplicity in the Orion Trapezium



Upper part of the Theta 1 Ori cluster as imaged over 30" × 30" FOV at Gemini with the Hokupaa AO system.. Note that "A1" is really a spectroscopic binary (A1-A3), where the unseen companion A3 is separated from A1 by 1 AU (Bossi et al. 1989).

=> A: TRIPLE

Also E: escaping spectroscopic binary (Costero et al. 2008)



Main difficulty: Multiplicity in the Orion Trapezium

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

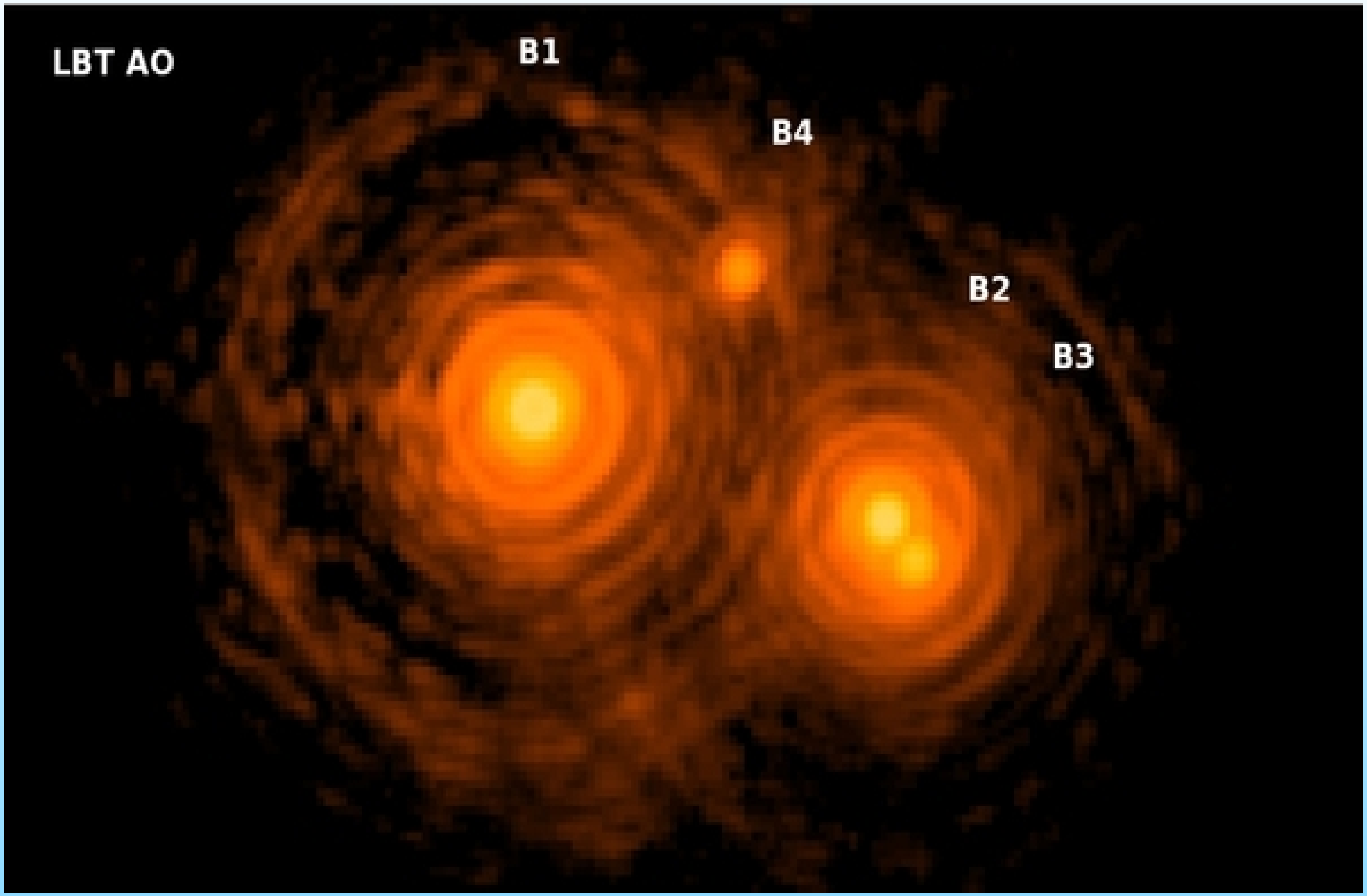
A: eclipsing and spectroscopic binary with a probable interferometric companion

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

D: spectroscopic binary

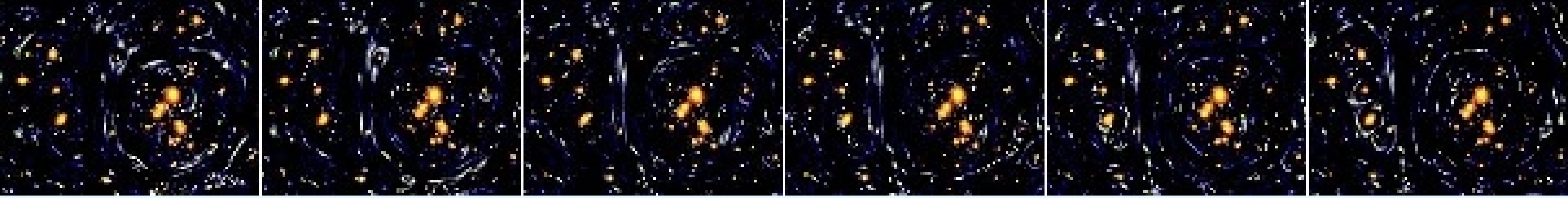
E: escaping spectroscopic binary

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



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

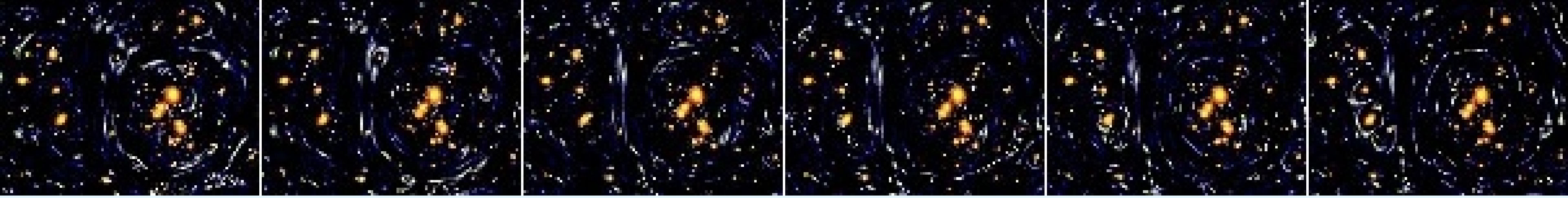
Allen et al. (2015) tried to answer the questions:

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

Are orbits B2-B3, (B2+B3)- (B1+B5) long-term stable?

-Precise positions and relative (planar) velocities are available.

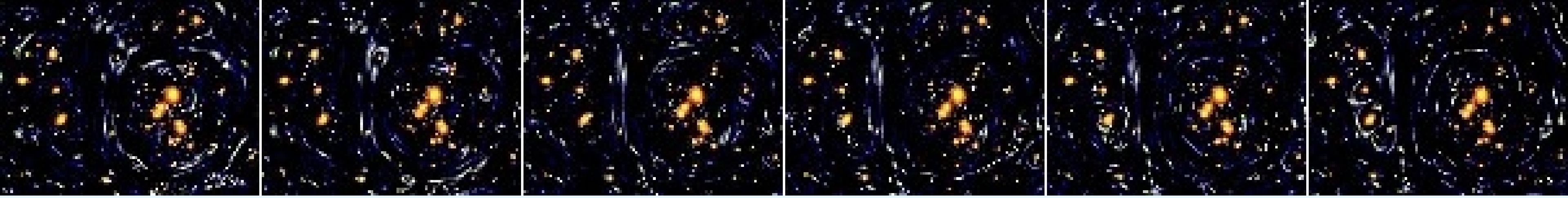
-Since z-positions and radial velocities are unknown we used N-body Monte Carlo simulations to provide insight.



Results

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

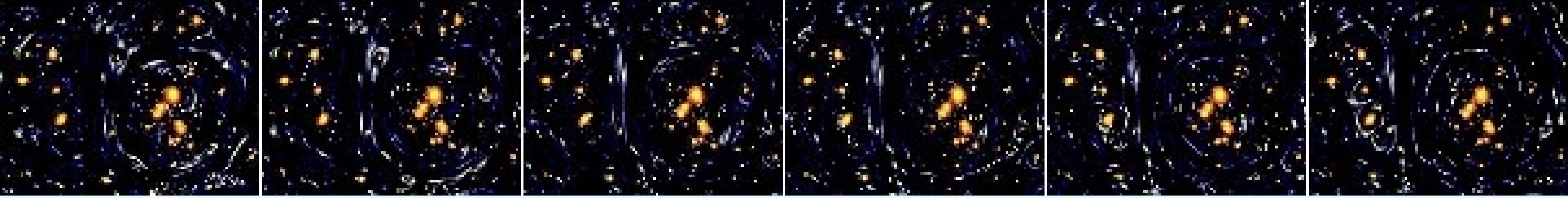
	5	10	100
Stable	29, 39, 35	18, 26, 22	1,1, 4
Triple	43, 40, 49	42, 46, 55	19, 28, 31
Dissolved*	28, 21, 16	40, 28, 23	80, 71, 45
*Double^2	6, 1, 0	6, 4, 4	7, 5, 9



Other results, some expected, some surprising:

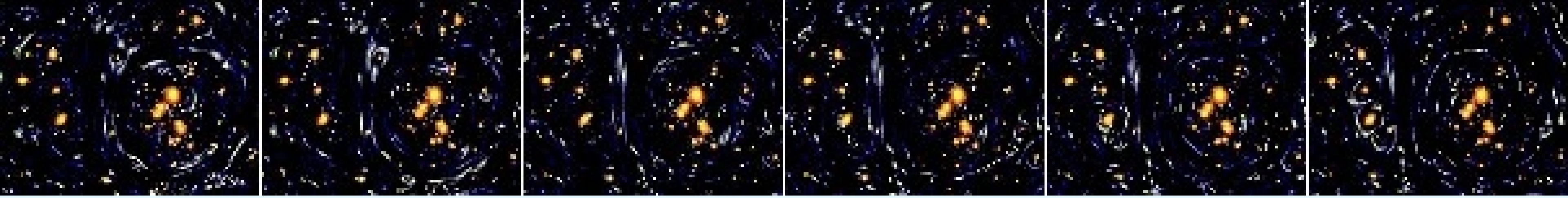
- Groups evolve and disintegrate in very short times.
- Most massive stars (B1+B5)-B2 form a close binary in 49-60 % of the cases. Many binaries are formed, some with major semi-axes as small as 6 AU
- The putative initial binary (B2-B3) hardly ever survives
- Most escaping stars are low mass, but in 2-5% of the cases the most massive star (B1+B5) escaped.
- Most escapers are low V, but some runaway stars (7%) with

  V > 3Ve (21 km/s) are produced.



Theta^1 Ori B: Summary

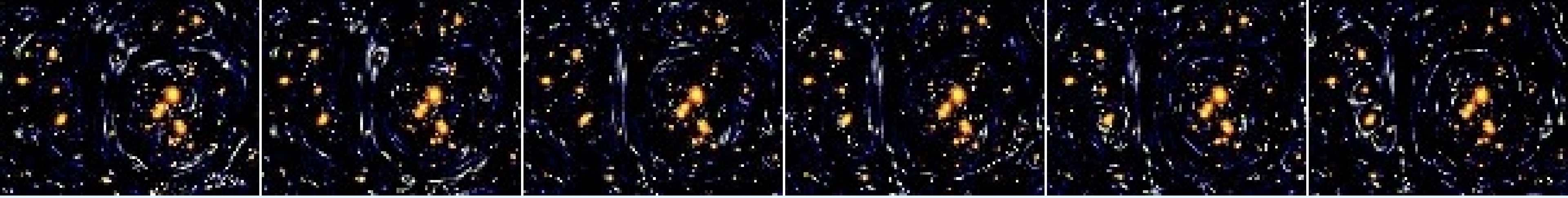
- The quintuple, low mass system (sub-trapezium) Theta^1 Ori B is a bound group, but extremely unstable dynamically. We showed that it will probably disintegrate in less than 30,000 yr, producing low velocity escapers and perhaps a runaway star, both early and late in its dynamical evolution.



Modelling 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

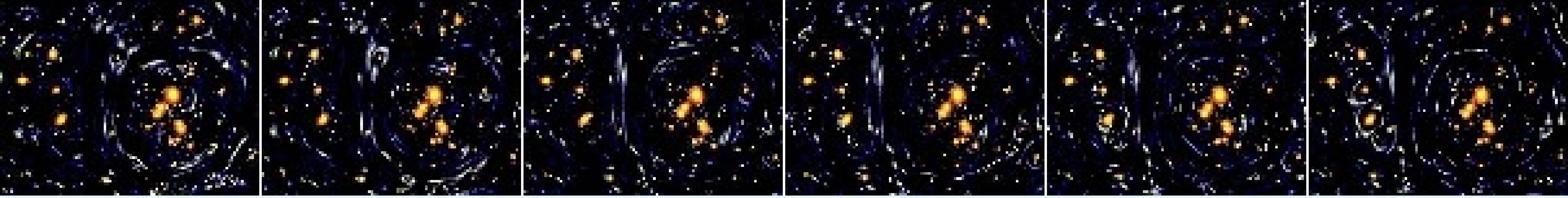
B:-1.3 +-1.0

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

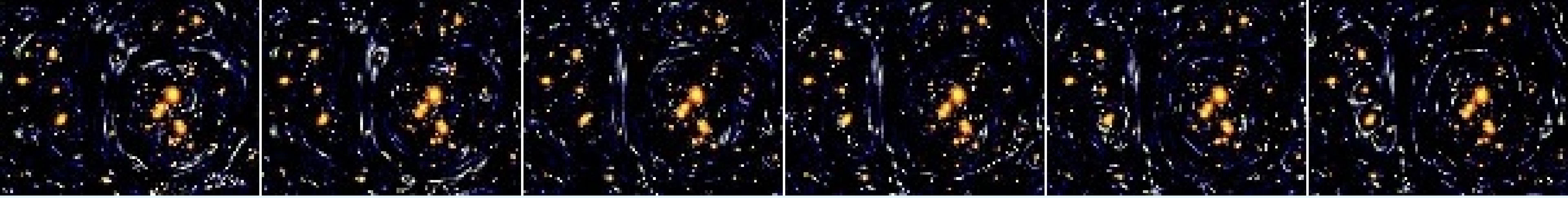


Modelling now the Orion Trapezium

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

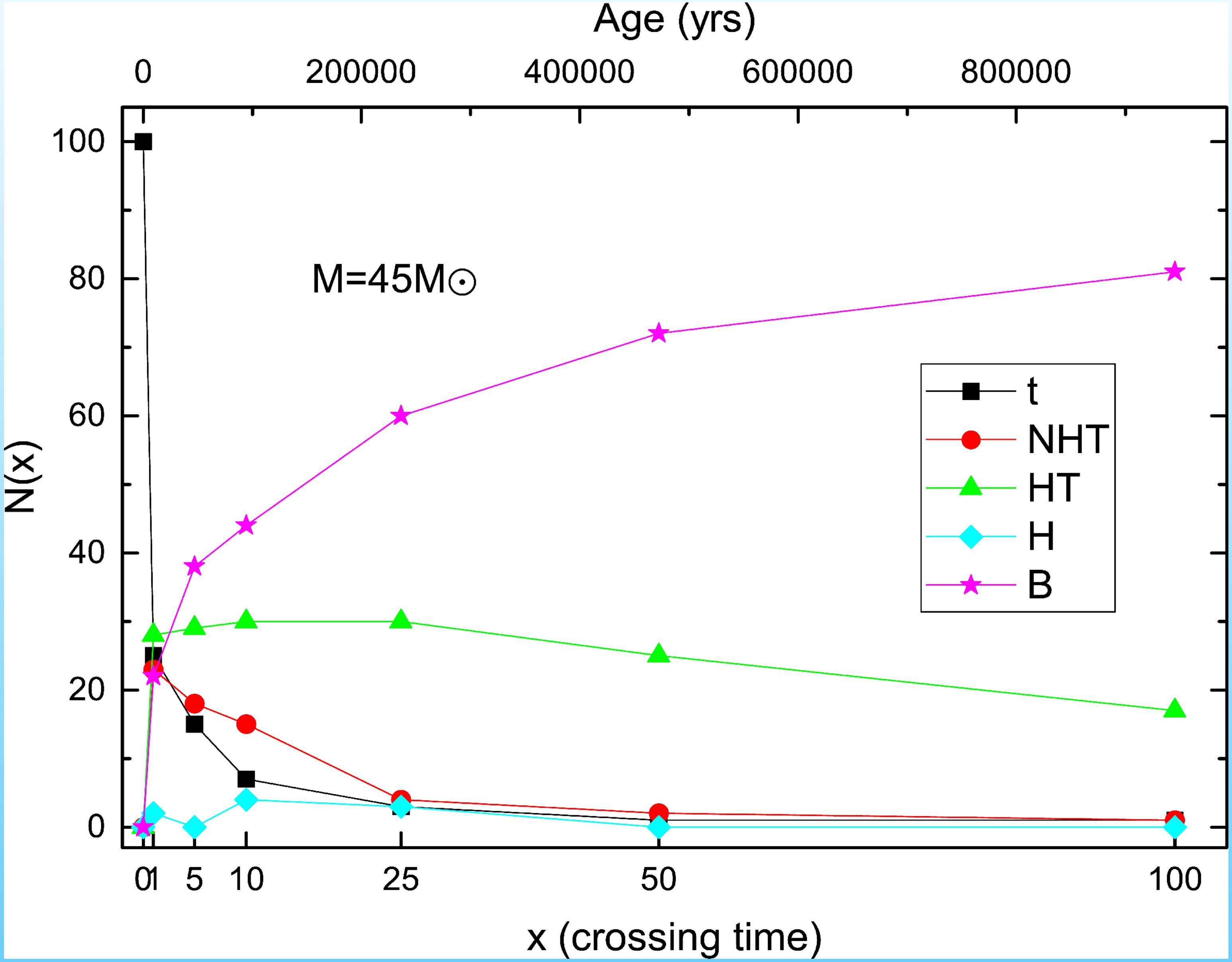
– All components will be considered as point masses for the N-body integrations



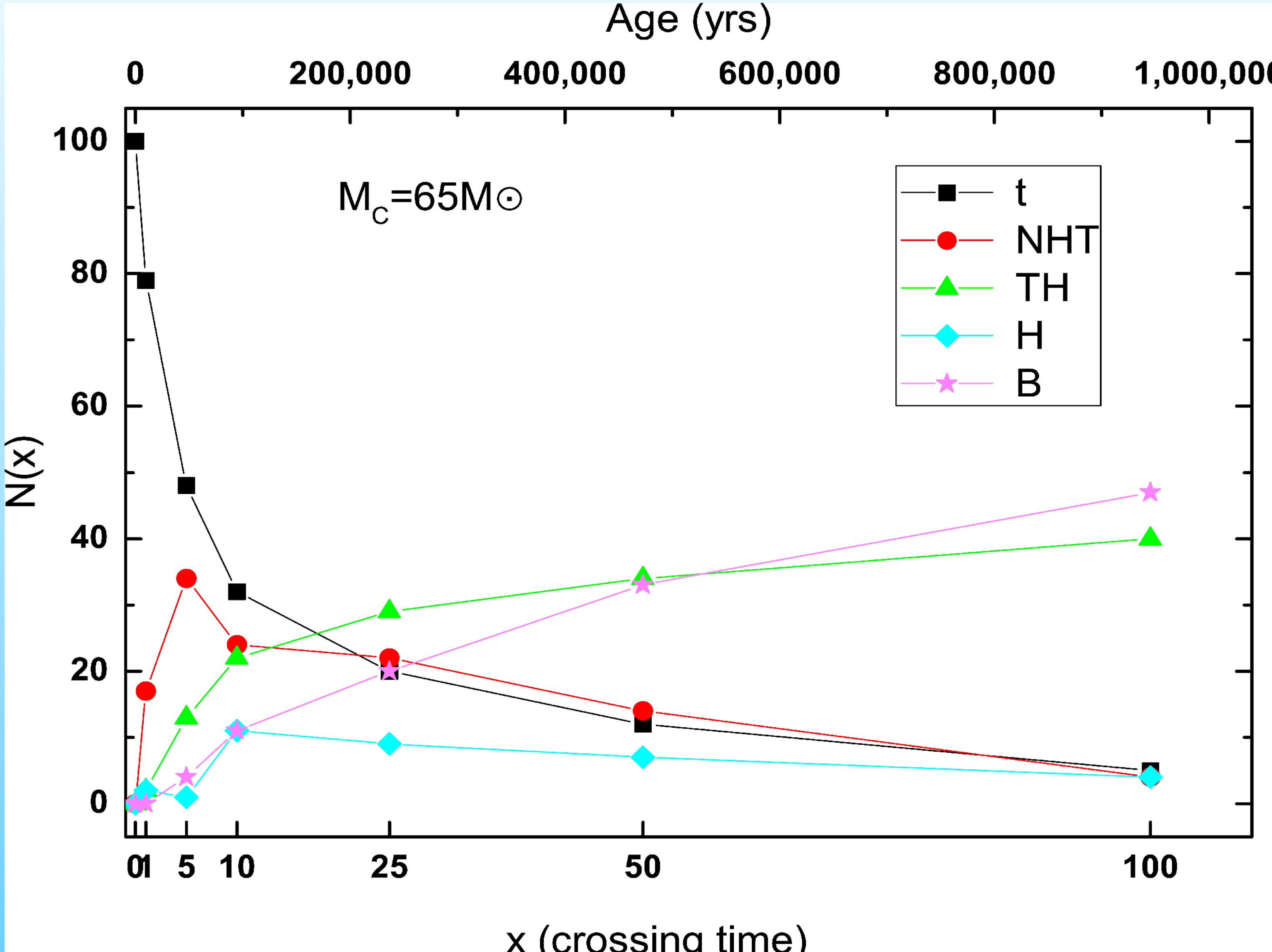
Monte Carlo models of the Orion Trapezium

- -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.

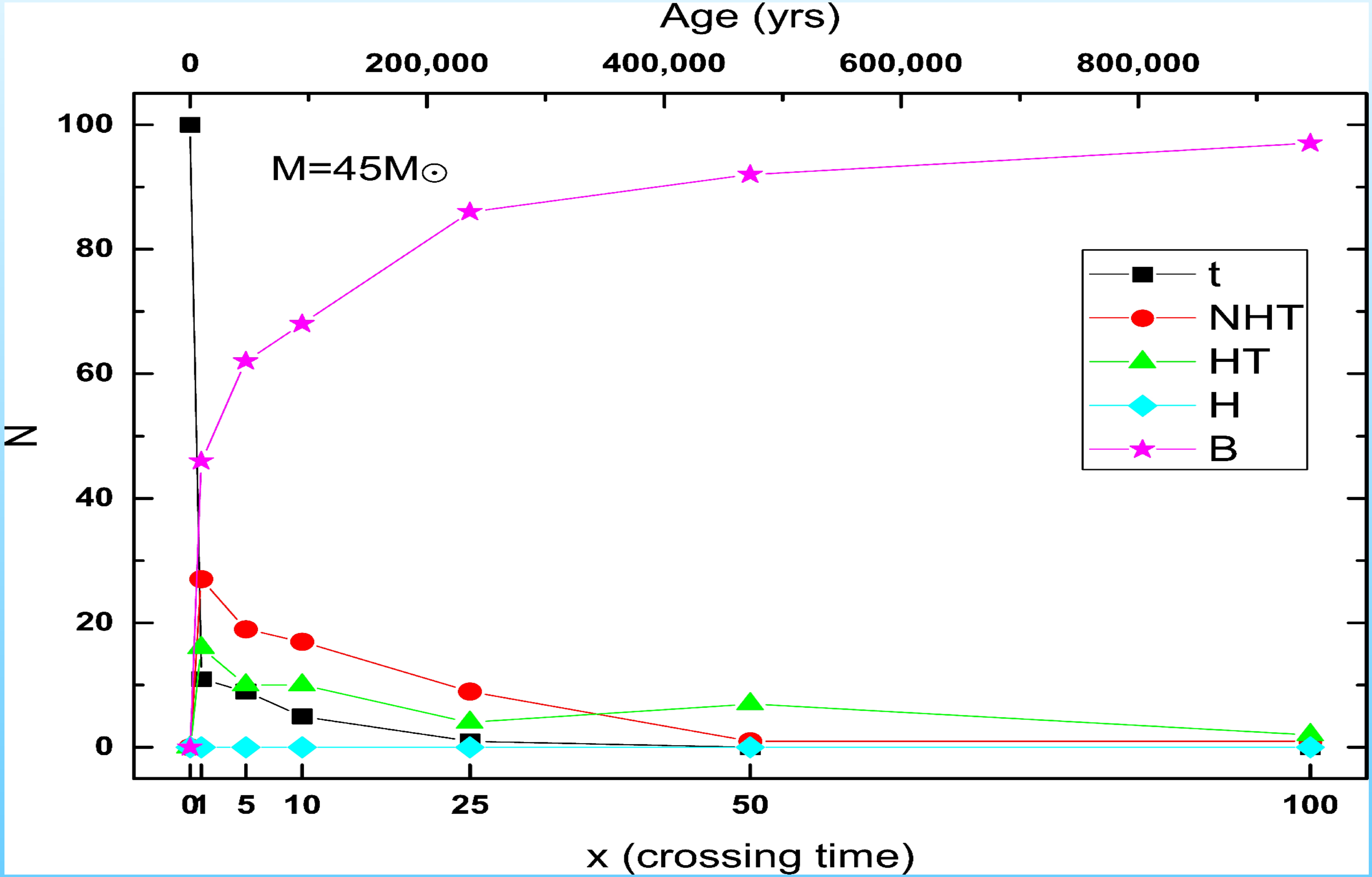
Results: lifetimes



Results: lifetimes

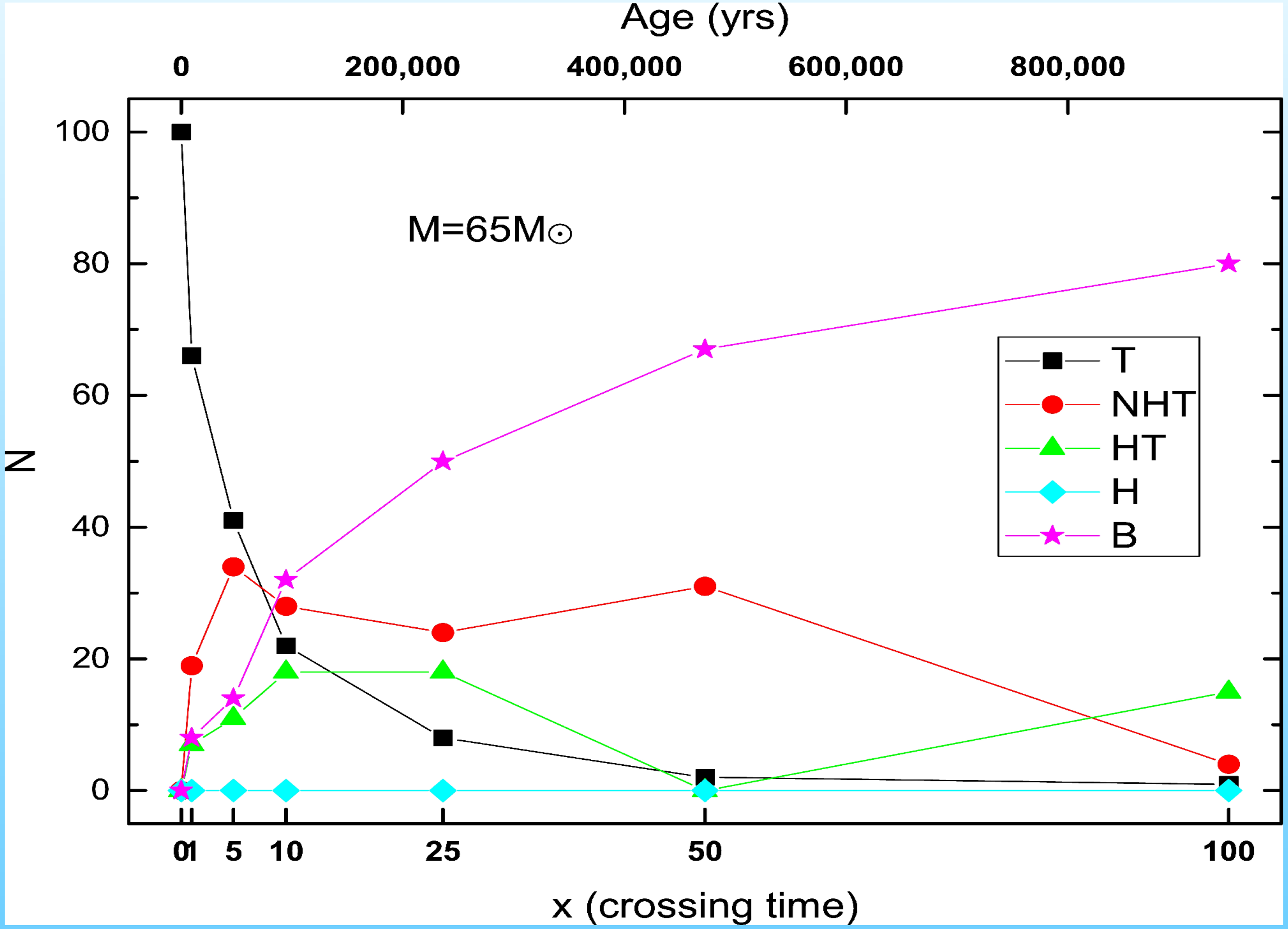


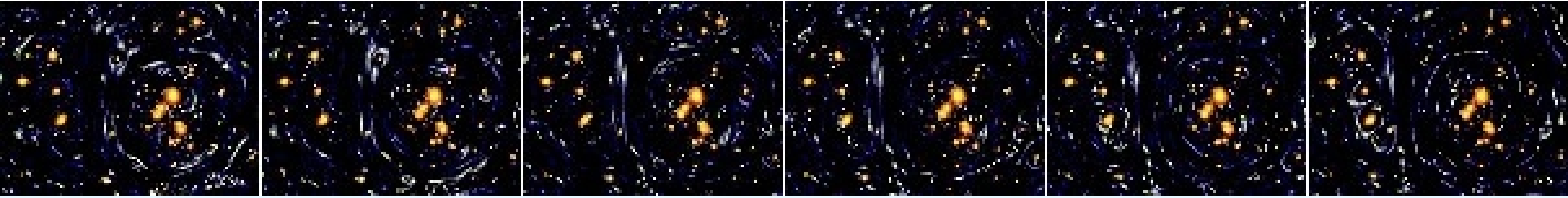
Results:`observed´ lifetimes
(S < 40,000 AU)

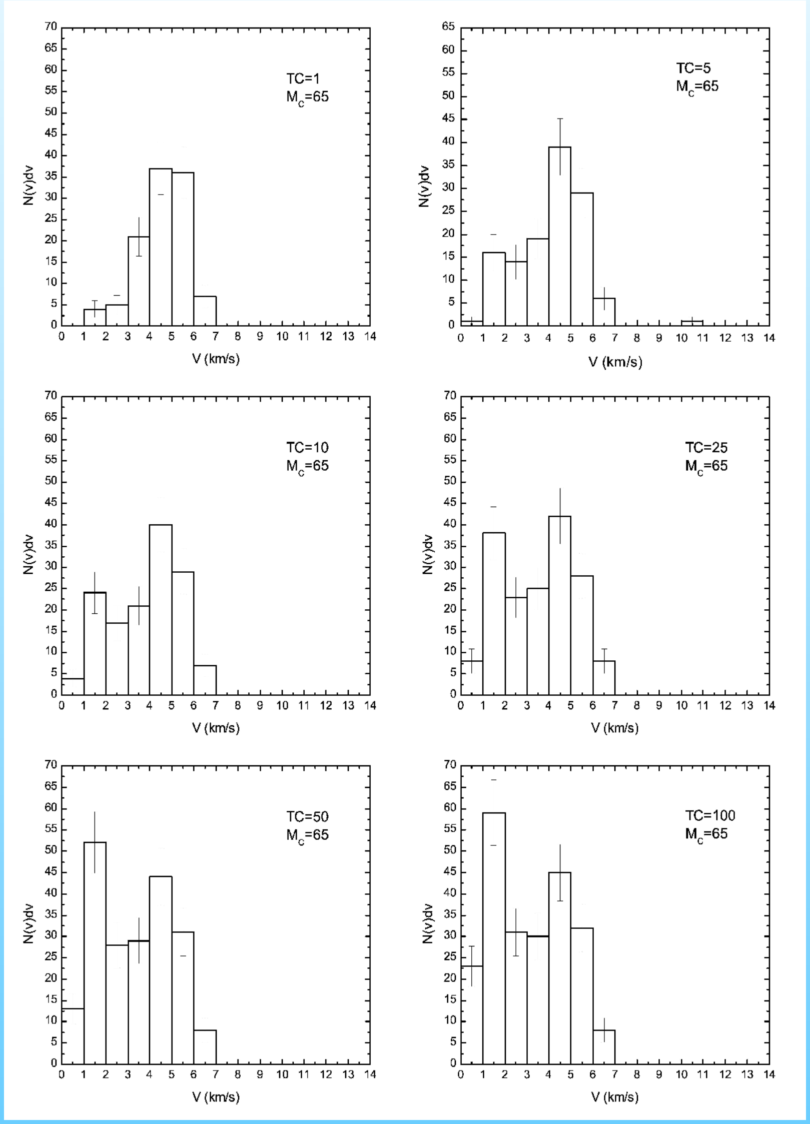


Results: `observed´ lifetimes

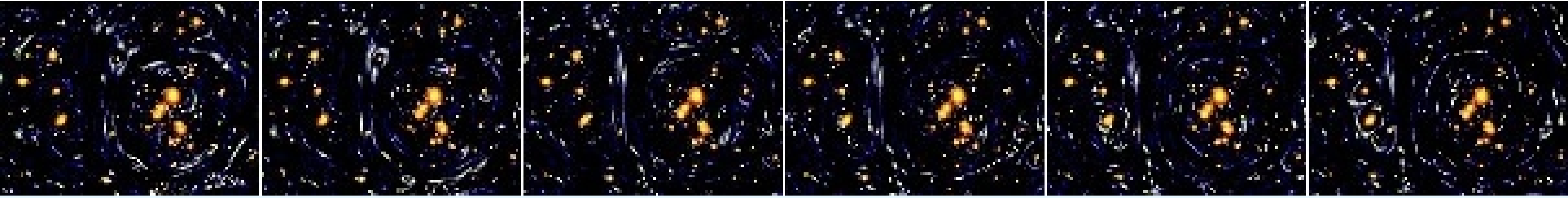
S < 40,000 AU

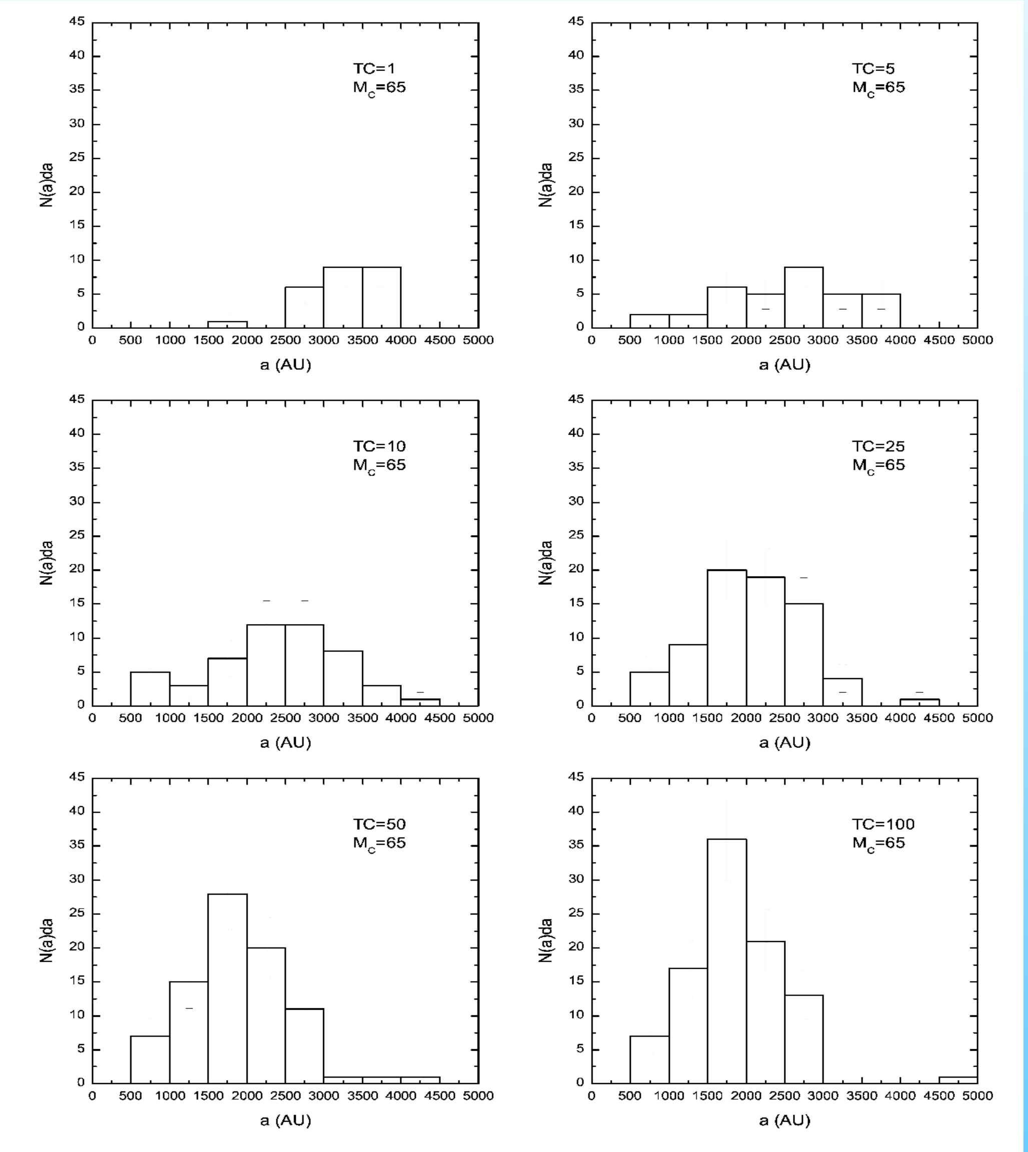




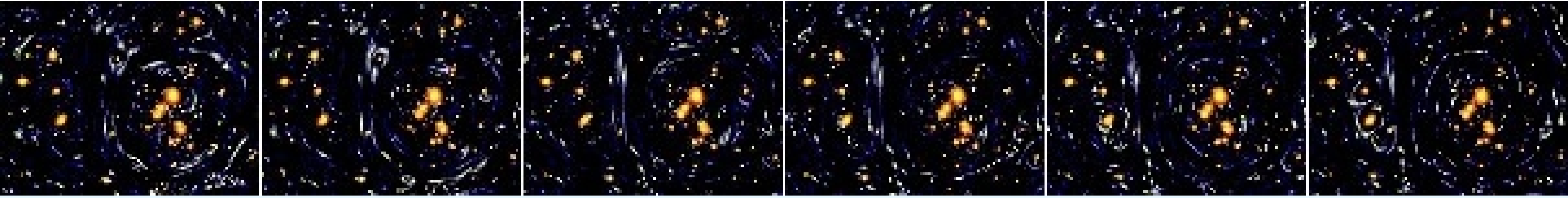


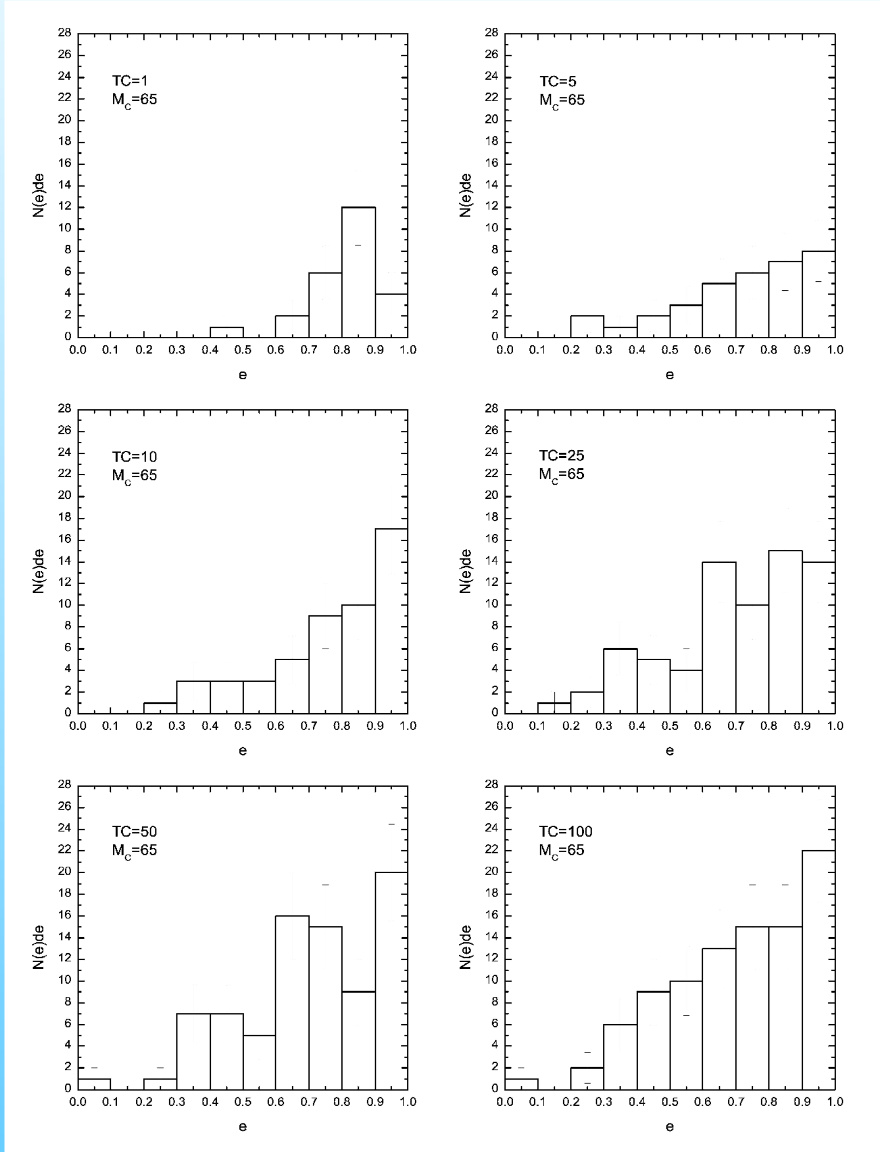
Velocity distribution of ejected stars (only slow escapes)



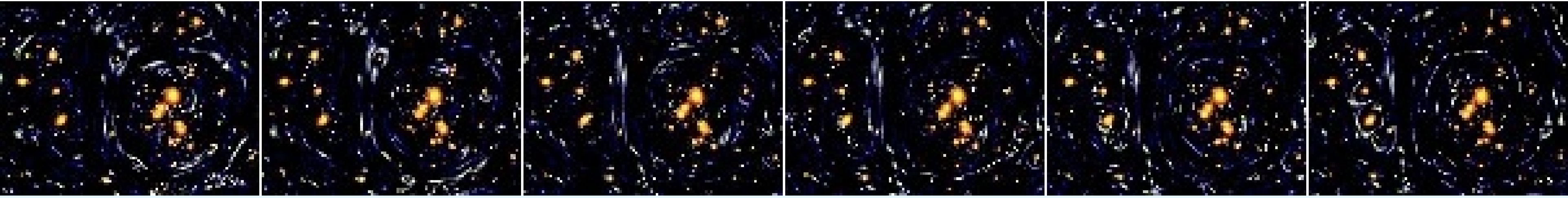


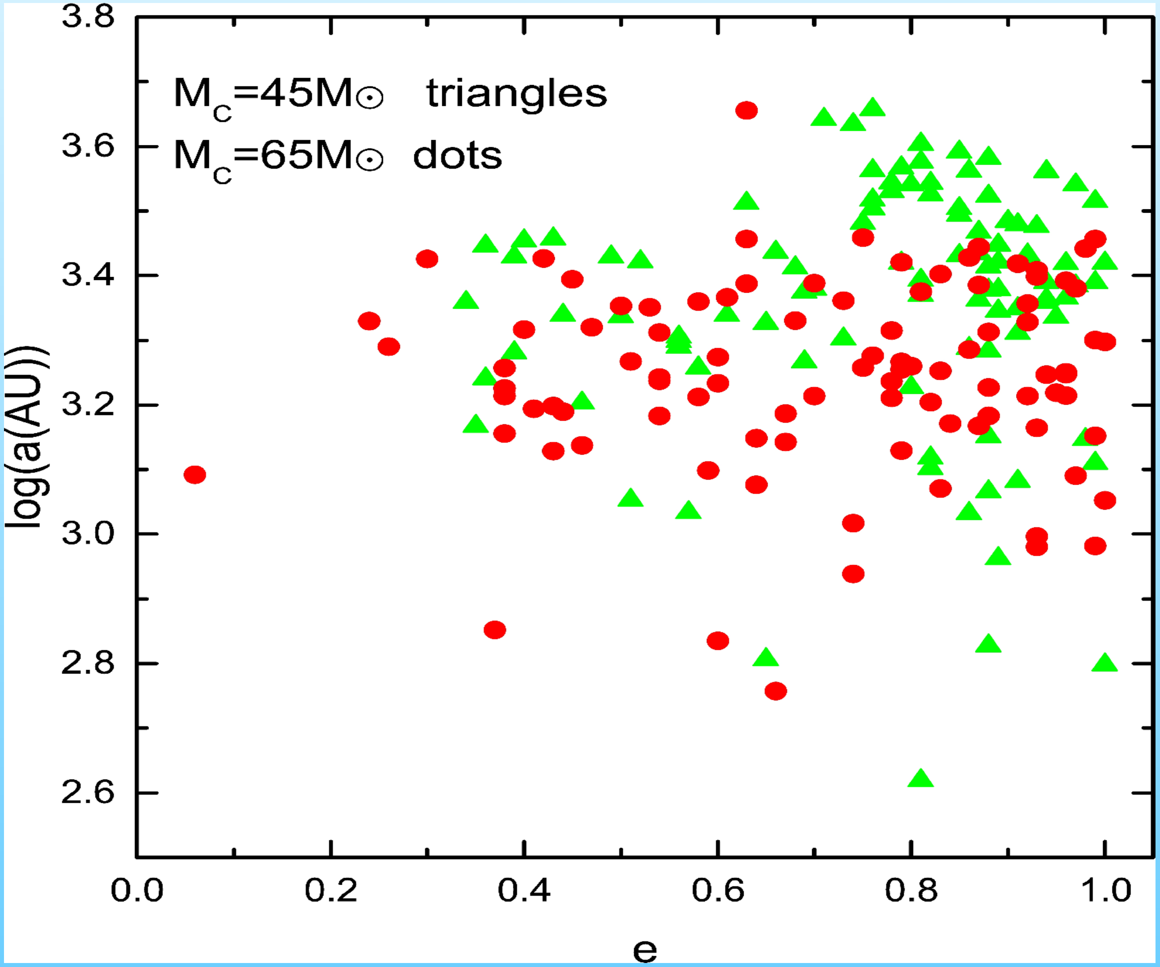
Major semiaxes distribution of binaries formed (wide binaries)



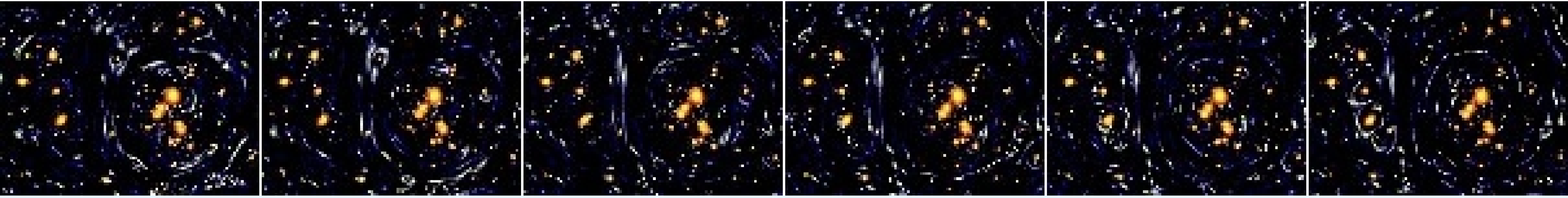


Eccentricity distribution of binaries formed (tends to thermal)





Major semiaxes - eccentricity relation of binaries formed (few e < 0.3)



Results: summary

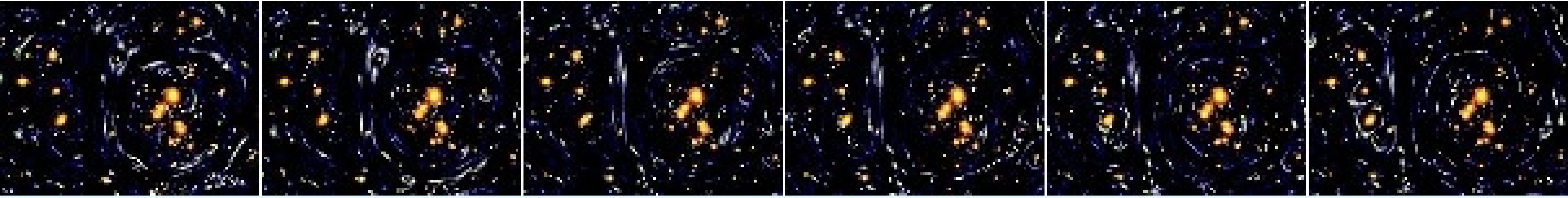
- Lifetimes (<10,000 yr) are too short with M(C) = 45 Mo

- 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



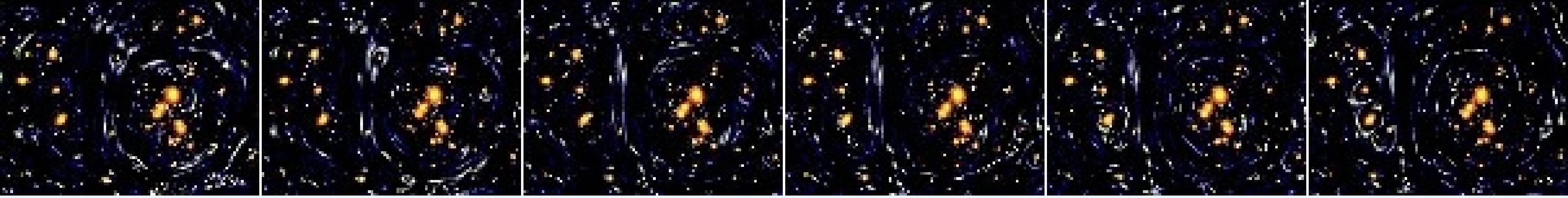
Results: summary-cont

- The end result of integrations is a tight binary or a hierarchical triple

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

- No very close encounters occurred

- The properties of binaries formed (distribution of major semiaxes, of eccentricities, the period-semiaxis relation) are compatible with observations



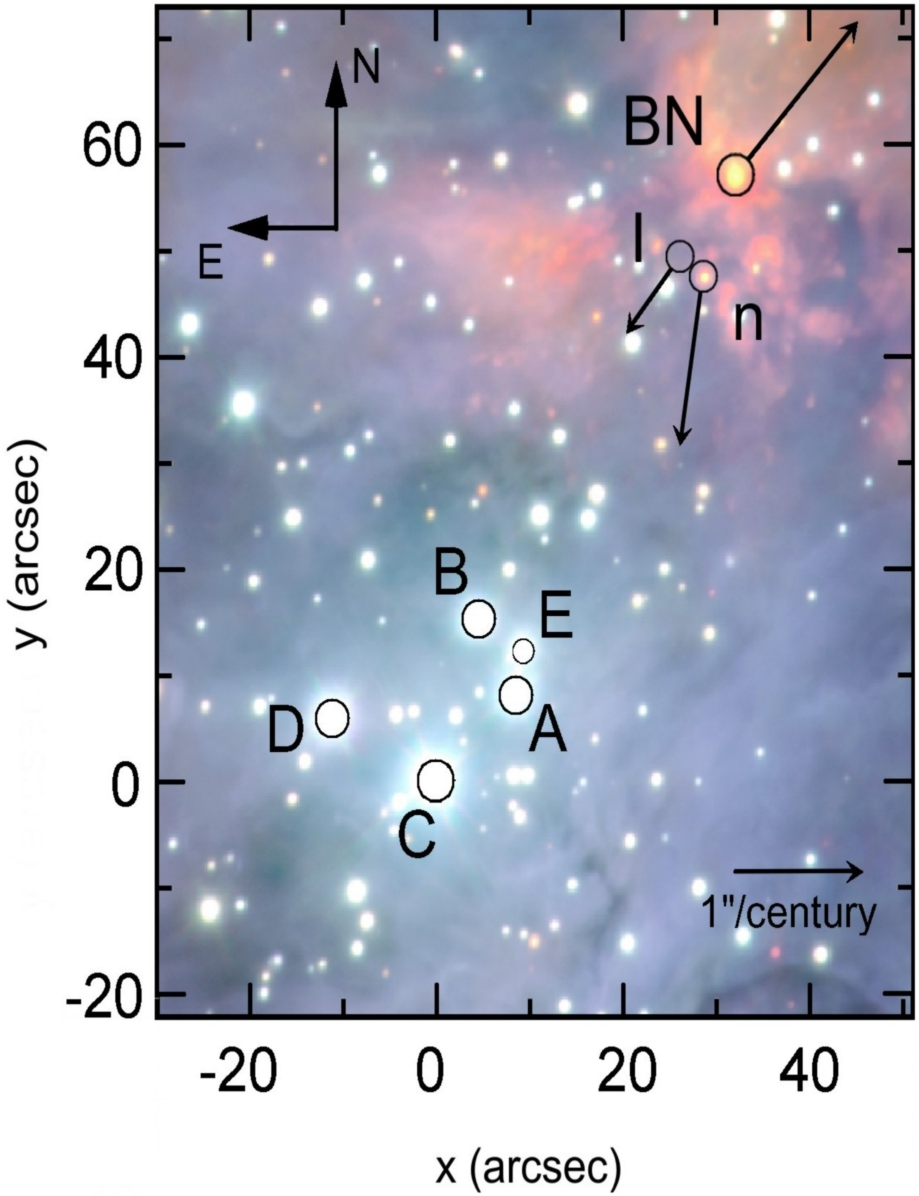
Discussion

A possible problem: is the disintegration too rapid?

-There are other extremely young structures in the Orion region.
Examples: -the BN-I-n object (500 years),
-the Orion Nebula itself. Its illumination age is about 15,000 yr (O´Dell et al. 2009)

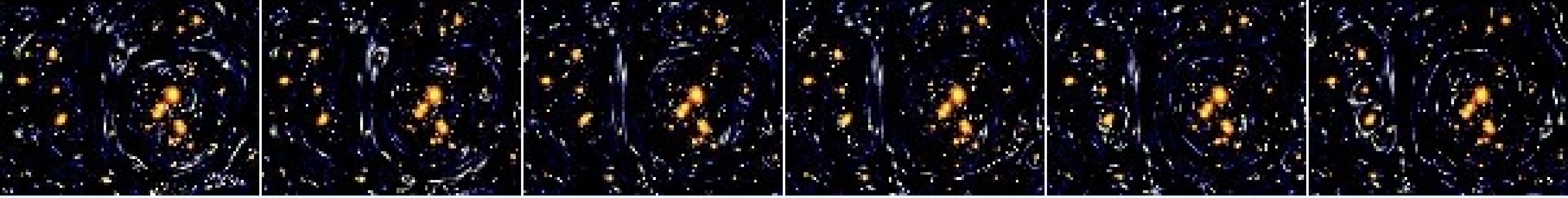
-The dynamical age of Theta^1 Ori agrees with that we found for one of its components (B: the mini-cluster): < 30,000 years

-Let us not forget that masses and radial velocities (especially for C) are very uncertain



- Radio sources BN, I and n are proto-stars with very high velocities

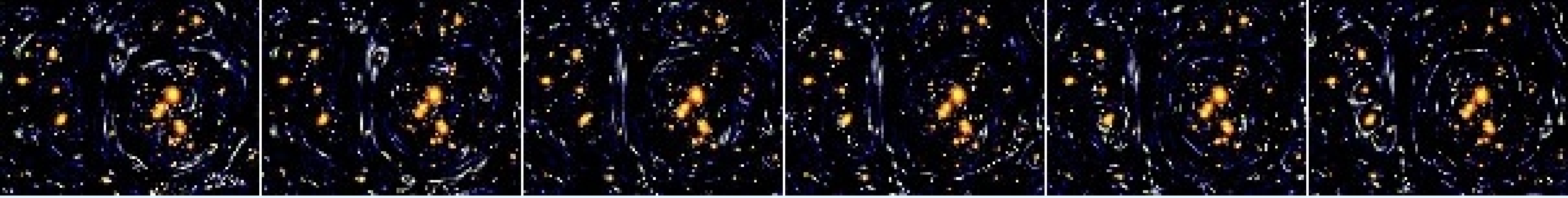
-They were explained as the result of violent interactions that occurred 500 years ago...
(Rodríguez et al. 2005)



Conclusion

- The lifetimes we find by Monte Carlo N-body simulations of the dynamical evolution of Orion Trapezium-like systems are implausibly short with the “best“ value for the mass of component C (45Mo)

- With a larger mass for C (65 Mo), still compatible with some observational determinations, they become comparable to the ages of other young structures in the Orion region, which range from about 500 to 15,000 - 30,000 years.



Muchas gracias