Discussion session F:
what do globular clusters tell us about
the formation of
massive clusters and about their early evolution

The early life of stellar clusters,
Copenhagen,
7th of November 2014

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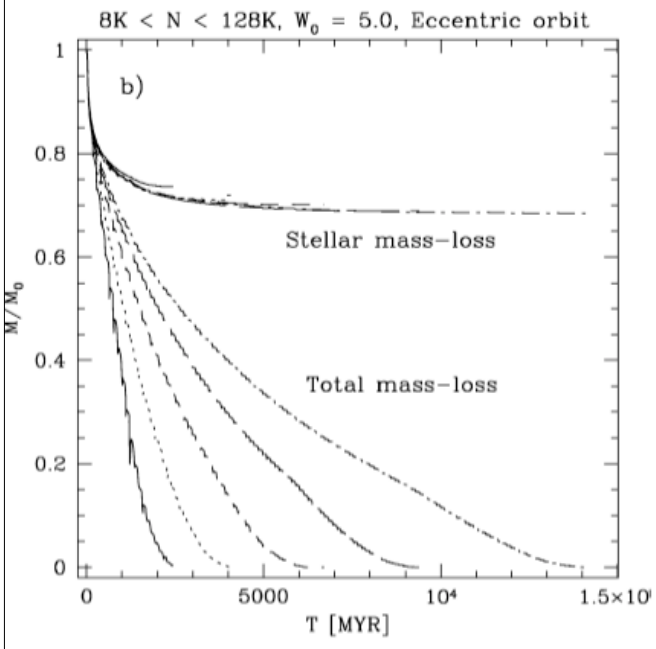
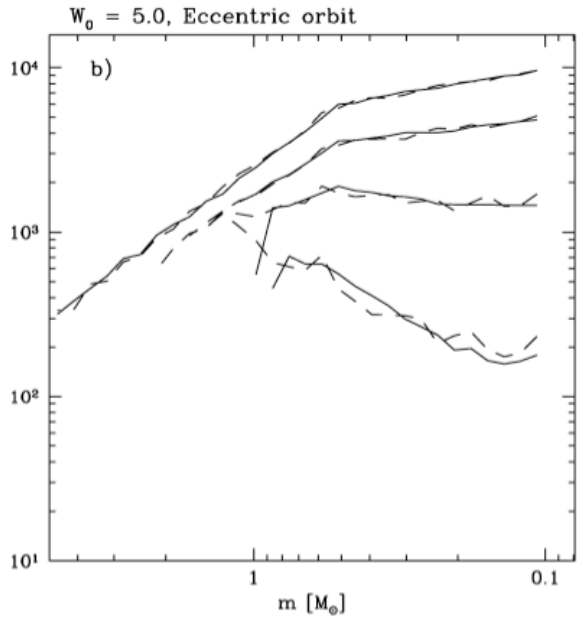
Classical Ansatz:

A GC evolved "backwards' with Nbody leads to an object not much different to its present-day appearance **:**
it will be of similar radius and >50% more massive.

Baumgardt & Makino 2003





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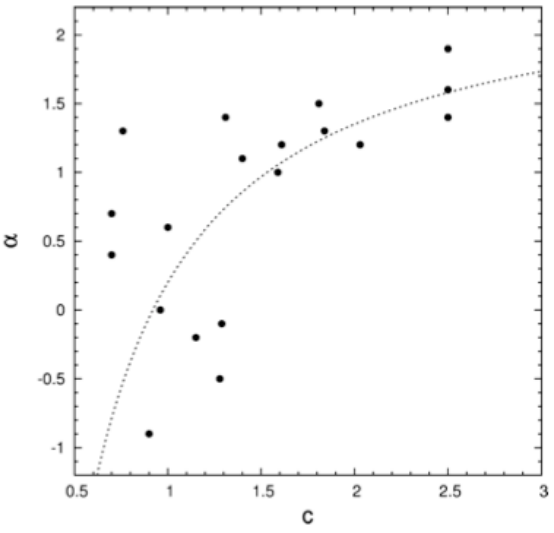
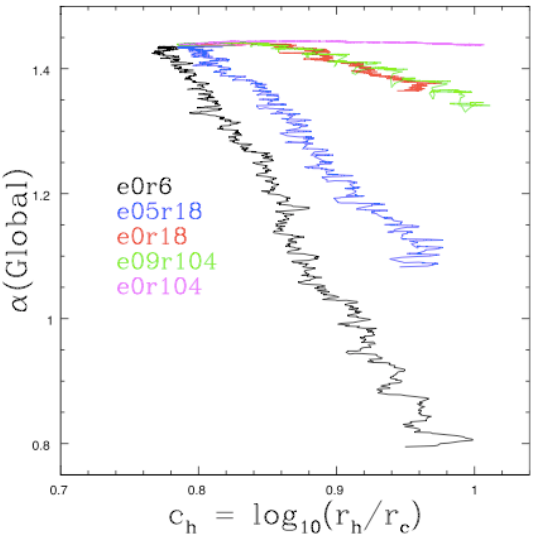
This ansatz to infer the ics fails though because it cannot account for the *alpha--concentration* data

DeMarchi, Paresce & Pulone (2007)



Leigh et al. (2013)



Physical Ansatz:

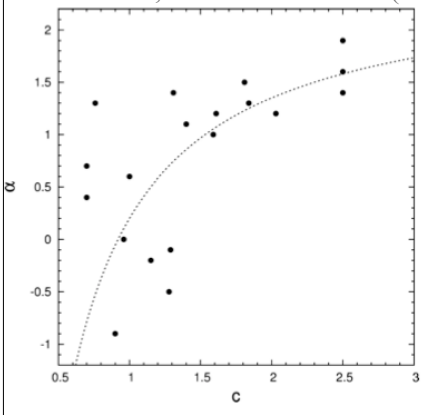
A GC forms mass segregated and suffers residual-gas expulsion
==> very different to its present-day appearance **:**
it would have been <1pc and >10 times more massive.

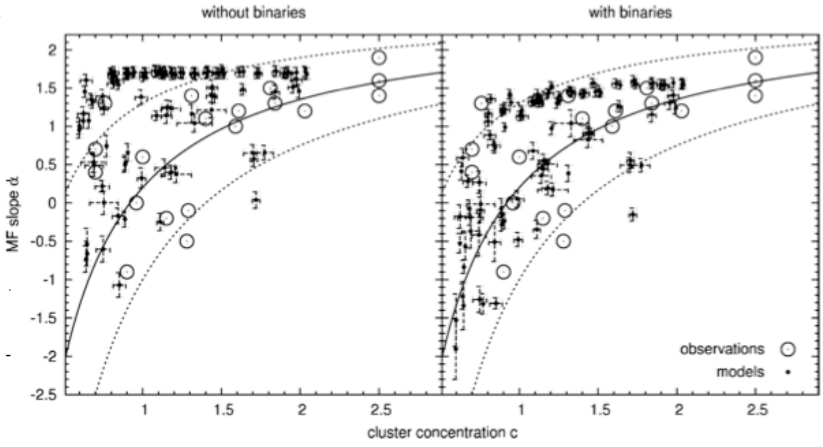
Goodwin 1994 ...

This ansatz to infer the ics can account for the *alpha--concentration* data

Marks et al. (2008)

DeMarchi, Paresce & Pulone (200





Simulations over a Hubble time of Pal 4 and 14 nicely confirm these results.

Zonoozi et al. (2011, 2014), Haghi et al. (in prep.)

Consistent with M/L constraints

A GC forms mass segregated and suffers residual-gas expulsion
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Observed: metal-richer (redder) GCs have lower M/Lv ratios, in contradiction to expectations from population models

Strader et al. (2009)

Theory based on residual-gas expulsion :
Metal-richer young GCs stronger coupling of gas to feedback
==> more violent gas expulsion
==> more loss of low-mass stars
==> lower M/Lv ratios

Marks & Kroupa (2010)

Consistent with chemical constraints

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Very young GCs must have been >10 times more massive for these scenarios to work :

Slow mass loss in disks from fast rotating massive stars
Decressin ... Charbonnel ... et al. (2007)

Winds from fast rotating binary massive stars
de Mink et al. (2009)

Winds / ejecta from AGB stars
D'Antonna, Vesperini, . . .

==> this needs much larger loss of 1st generation stars to make the observed population ratios : possible through gas expulsion and more concentrated 2nd generation.
But questions remain . . .

One important aspect : ***top-heavy IMF*** (Marks et al. 2012; Prantzos & Charbonnell 2006)

Possible alternative : element anti-correlations (e.g. Na-O) and multiple populations stem from merged binaries

Jiang, Han & Li (2014, ApJ).

Multiple Populations

"*Prof. Hosein Haghi's Tree*" (Gardens of the Geological Museum, Copenhagen, Nov. 2014)

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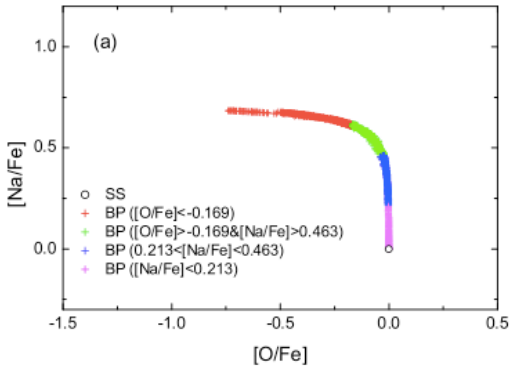

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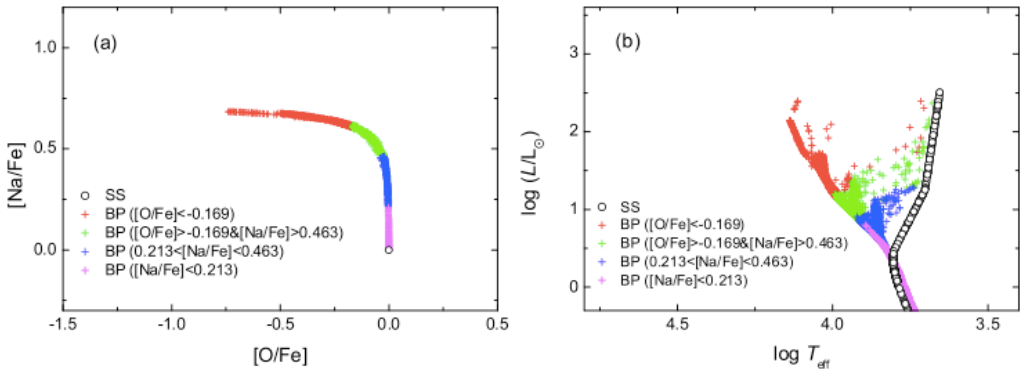

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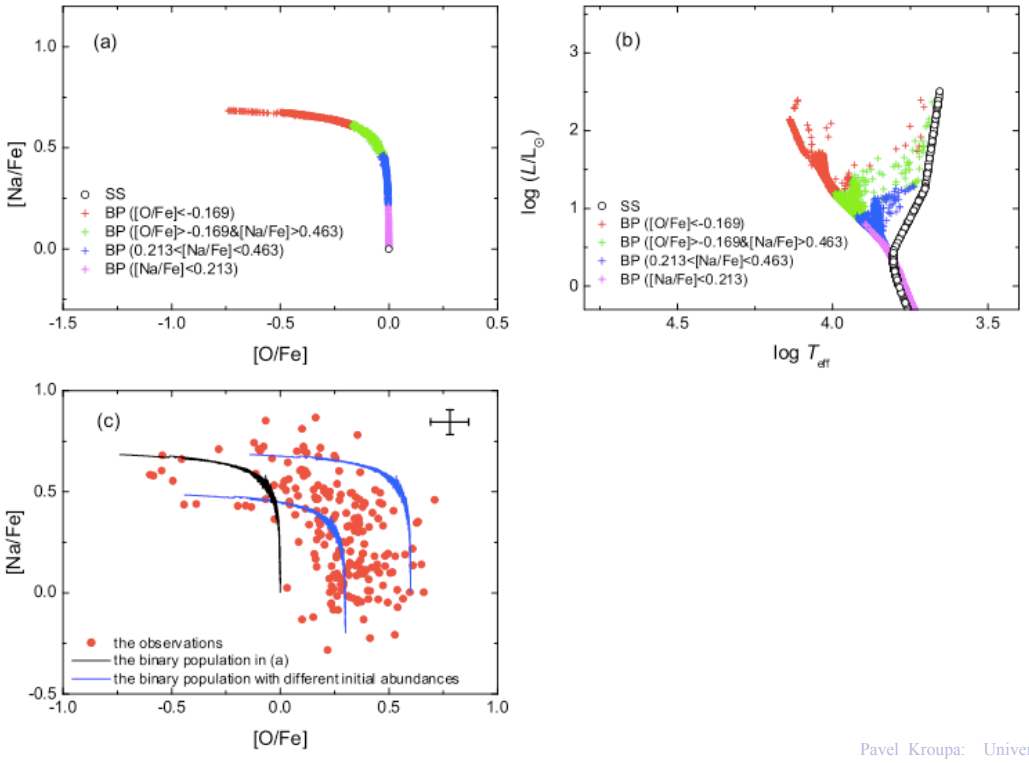

Pavel Kroupa: University of Bonn

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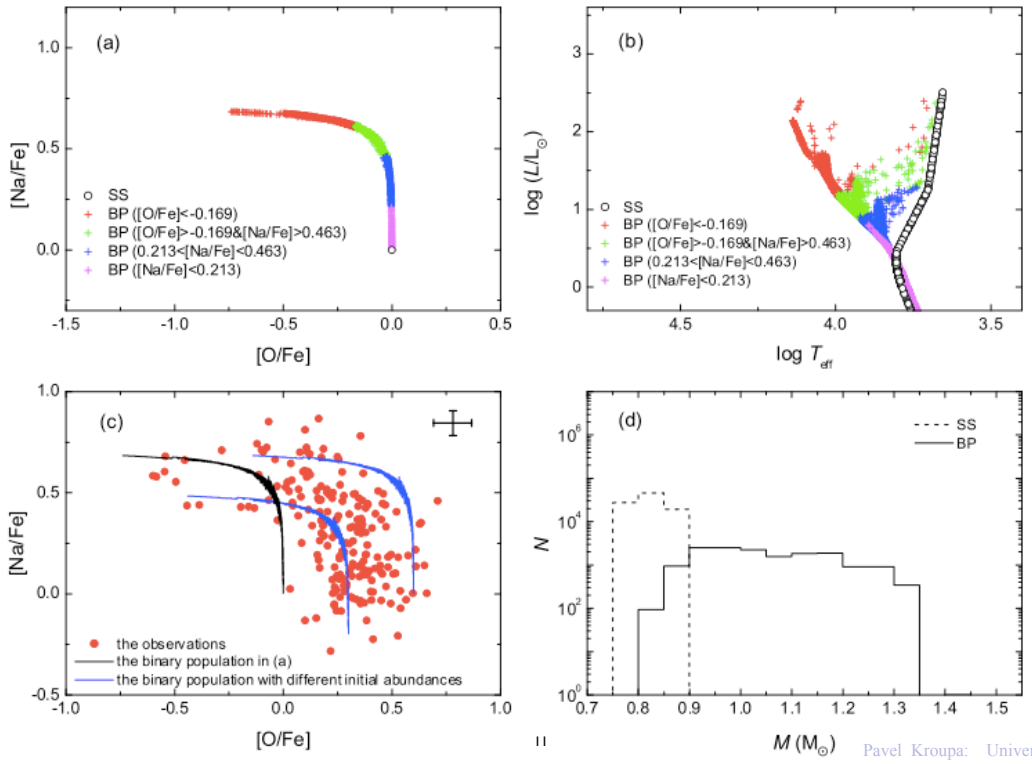
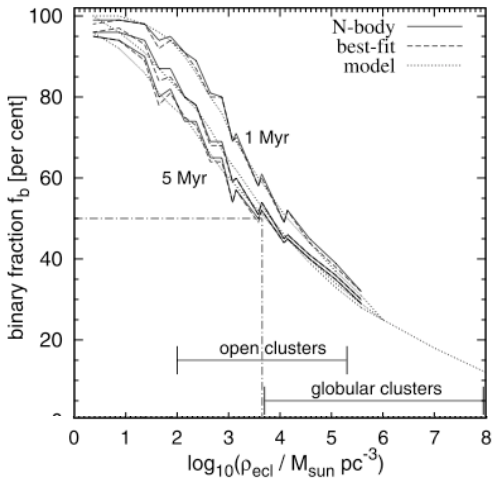


Binaries

A GC forms mass segregated and suffers residual-gas expulsion ==> very different to its present-day appearance : it would have been <1pc and >10 times more massive.

==> GCs destroy their initial (high) binary population efficiently, nicely consistent with current star formation in Galaxy

Marks et al. (2011)



Consistency with universal initial binary populations :

For the present-day binary fractions within and outside the half-mass radius of GCs to be explained, the initial binary population had to be essentially as in the current Galactic star formation.

Leigh et al. (2014)

"We show that the observed present-day binary fractions outside the half- mass radius can break this degeneracy. In this regard, our results are the most consistent with high initial binary fractions and high initial densities, since these conditions are needed to reproduce the observed anti-correlation between the total cluster mass and the observed binary fractions outside r_h."

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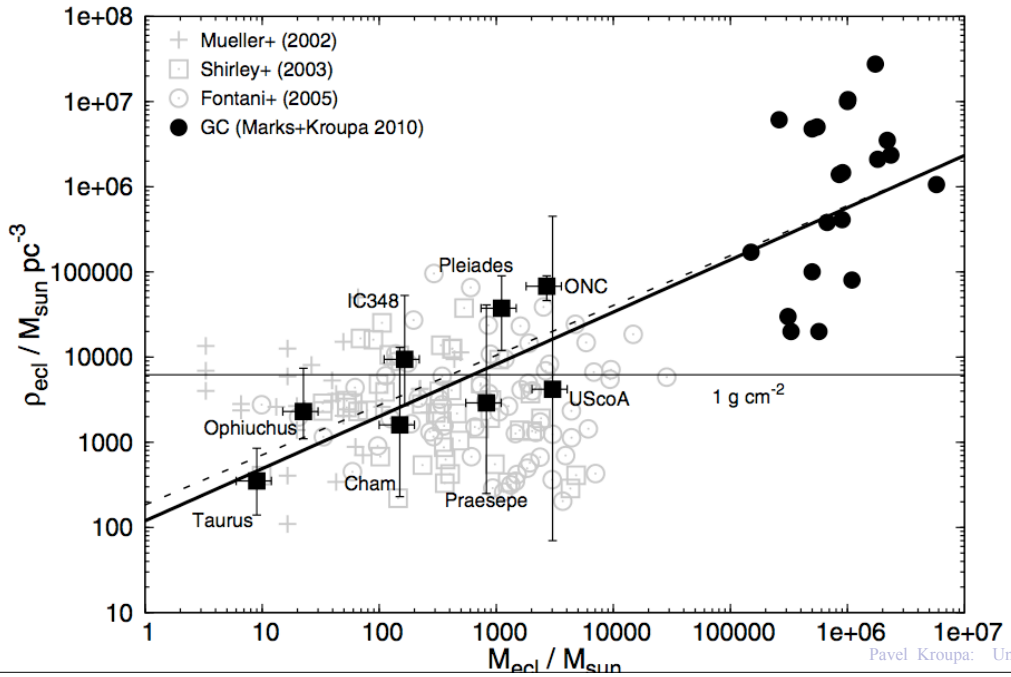
==> an overall self-consistent picture emerges :

Marks & Kroupa A&A 543, A8 (2012)



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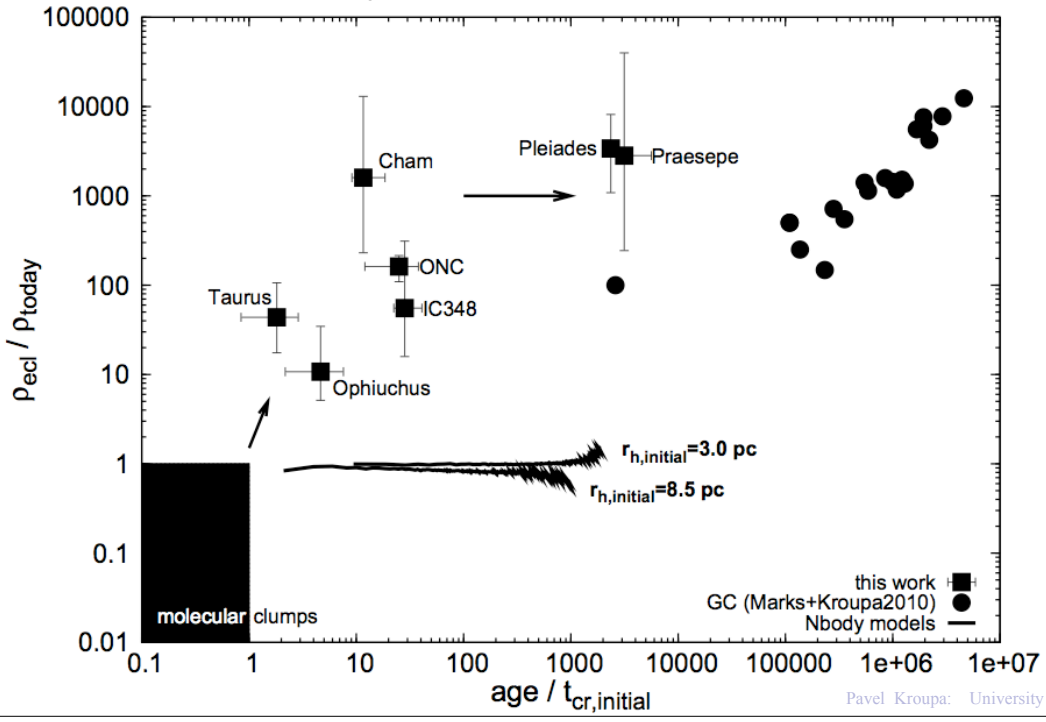
M. Marks and P. Kroupa: Inverse dynamical population synthesis 2012



Gas-expulsion

The work of Sambaran Banerjee on NGC3603 and R136, together with previous work on the ONC and the Pleiades suggests that

$$SFE = 0.33, \quad \tau_{\rm delay} = 0.6 \ {\rm Myr}; \quad t_{\rm gas} = \frac{r_{\rm h}}{10\,{\rm km/s}}$$

are astonishingly universal (some variation for extreme star-burst clusters (Marks & Kroupa 2010)