Multiple populations in GCs Distinct kinematic imprints of different pollution scenarios

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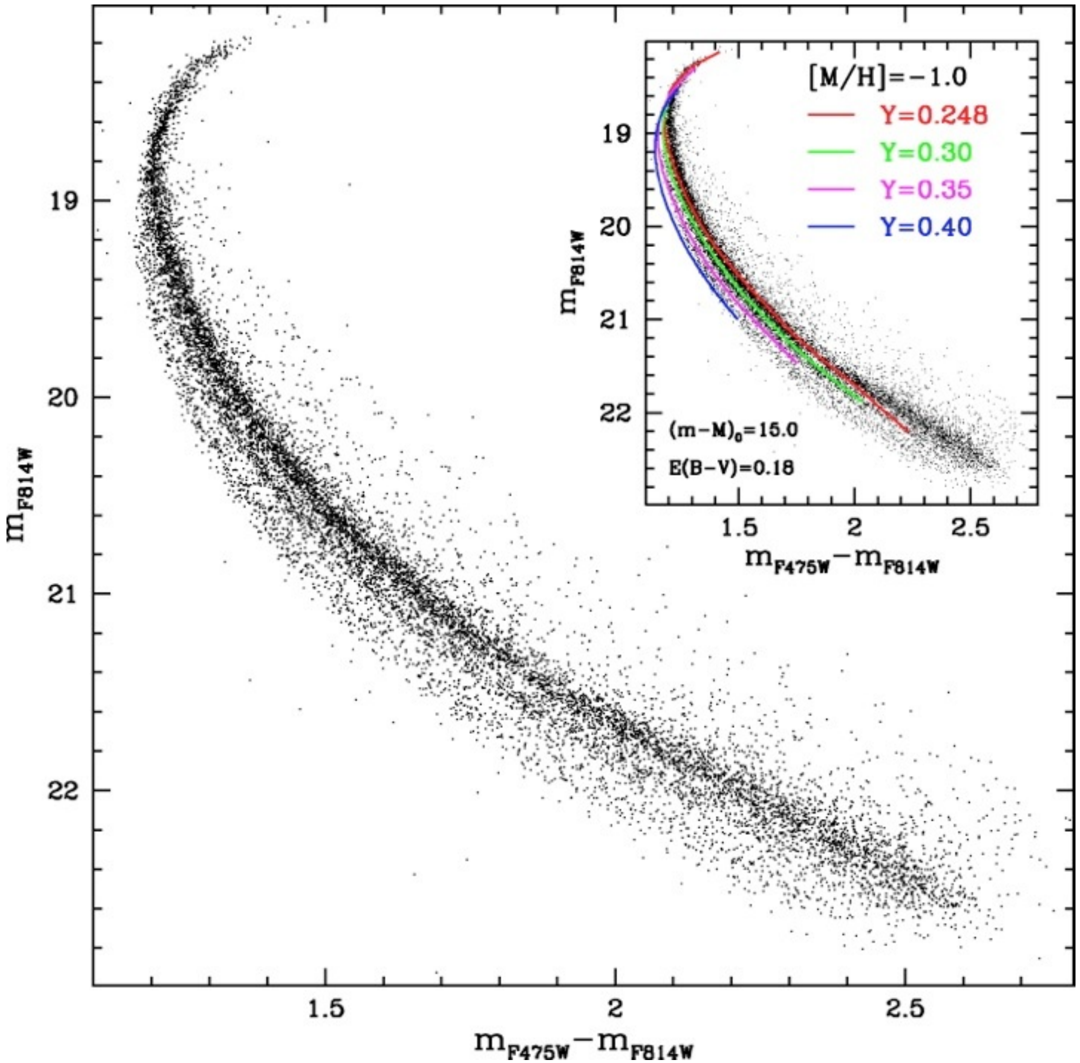
Bastian et al. (2013); Hénault-Brunet+ 2014, in prep

NGC 2808

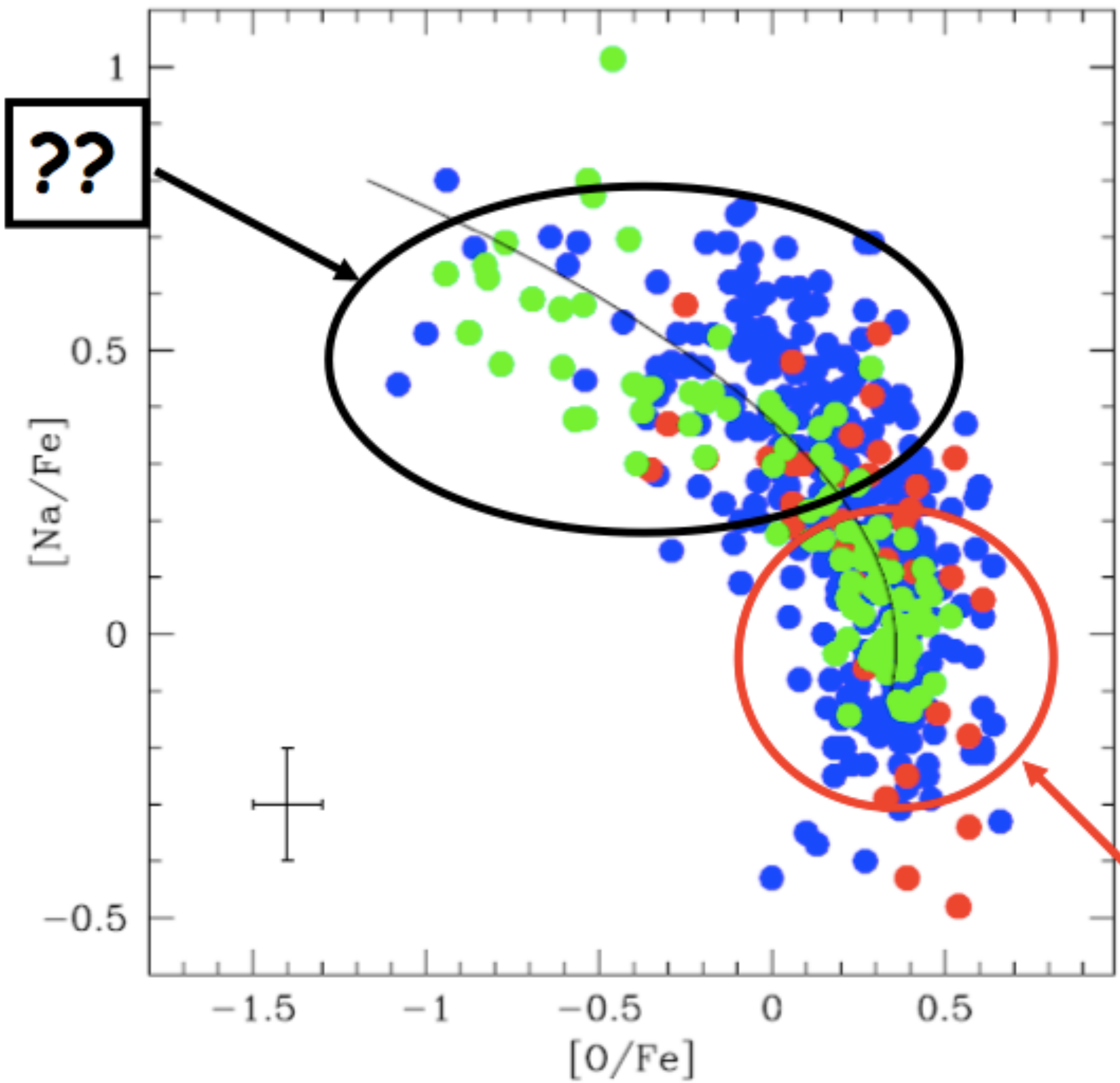


Piotto+ 2007

~60% stars on main sequence
"pristine" (or "first generation")

~40% of stars are He enriched
"polluted" (or "second generation")

Not due to age or metallicity differences, only He abundance can explain it



Carretta et al. 2006 A&A 450, 523

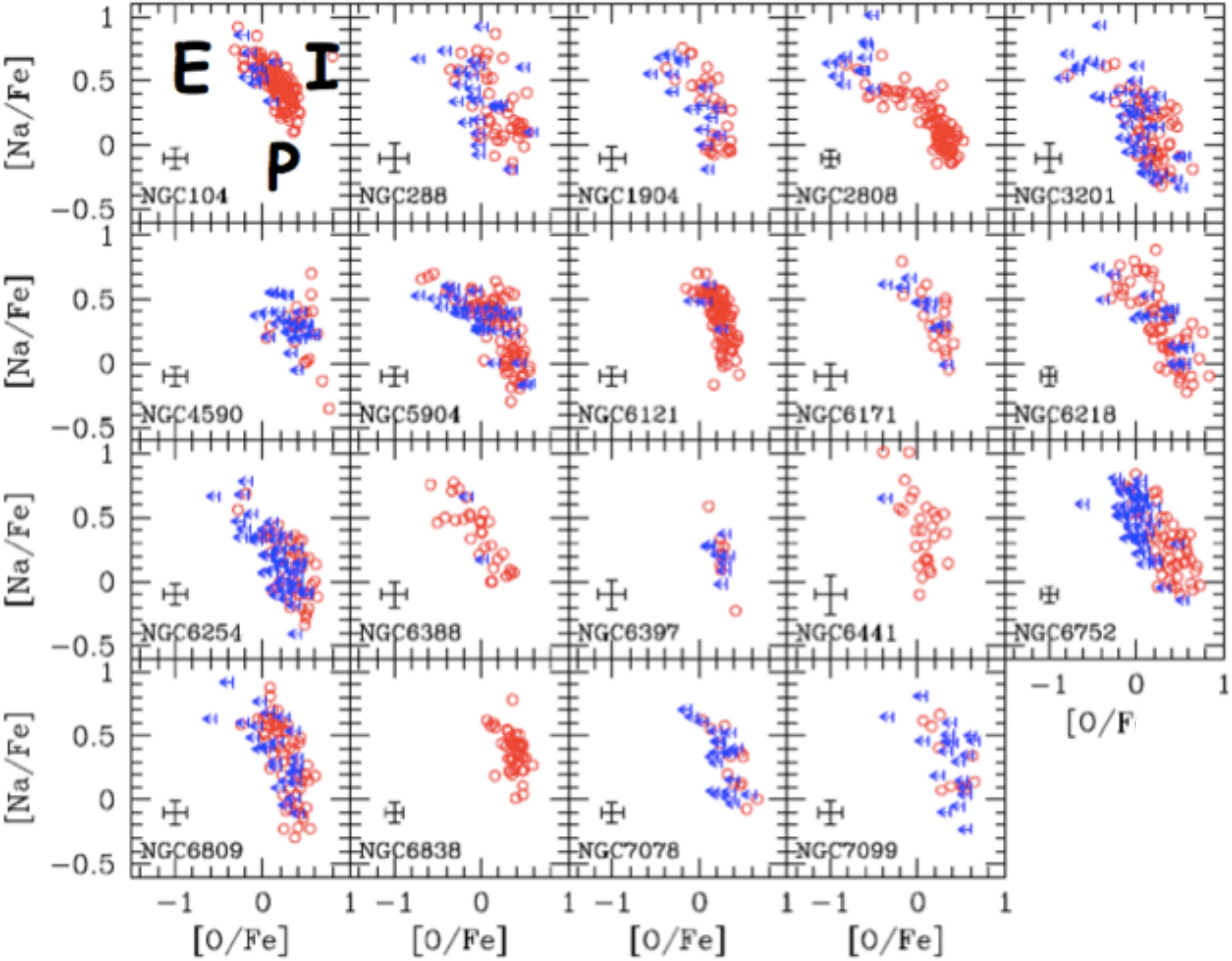
Na-O anticorrelation

collection of stars in about 20 globular clusters. Blue points are RGB stars from literature studies; red points are **scarcely evolved stars (turnoff or subgiant stars)** from Gratton et al. (2001) and Carretta et al. (2004); green points are RGB stars in NGC 2808 from the present study.

this is the range of abundances in low metallicity field stars

D'Antona 2012 (Vatican Observatory Summer School lectures)

Carretta et al. 2009a



more than 1200 red giant stars in 19 GCs

Observables

- Na-O anti-correlation
- Large Al spread, small (or no) Mg spread. Some spread in other light elements (e.g C, N). Little/no spread in Fe.
- Discrete main sequences/turn-offs, sub-giant branches, presumably due to discrete He abundances and/or CNO abundances
- Found in red (metal rich/younger) and blue (metal poor/older) clusters

Sources of the enriched material

- Only certain stars produce the right abundances: (SNe can't do it)
  - AGB stars (3-8 $M_\odot$)
  - Spin-stars (rapidly rotating O-stars)
  - Interacting/colliding massive binaries (O-stars)

Models of multiple populations in GCs

“Multiple generations” scenario

D’Ercole et al. 2008

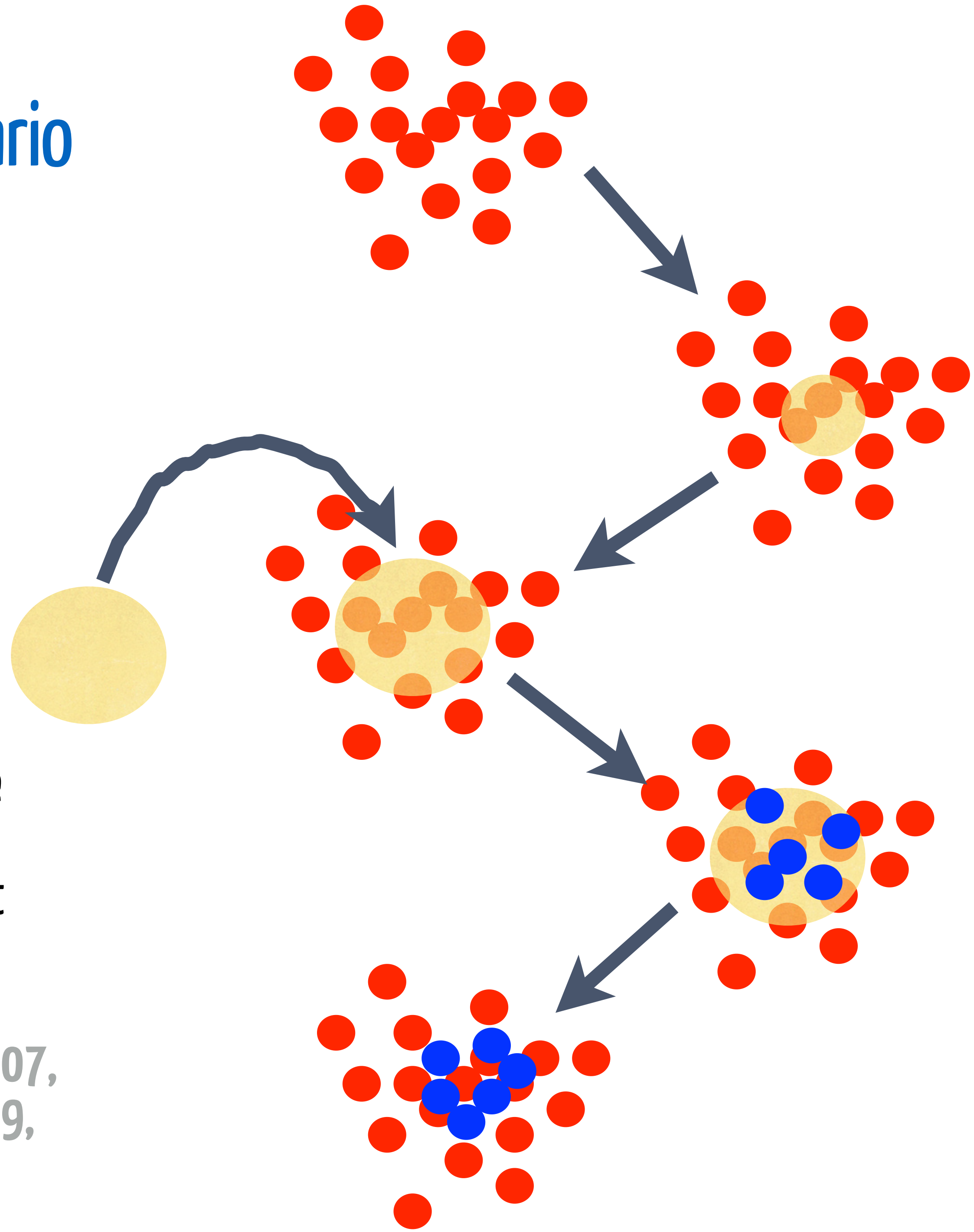
“Early disc accretion” model

Bastian et al. 2013

“Multiple generations” scenario

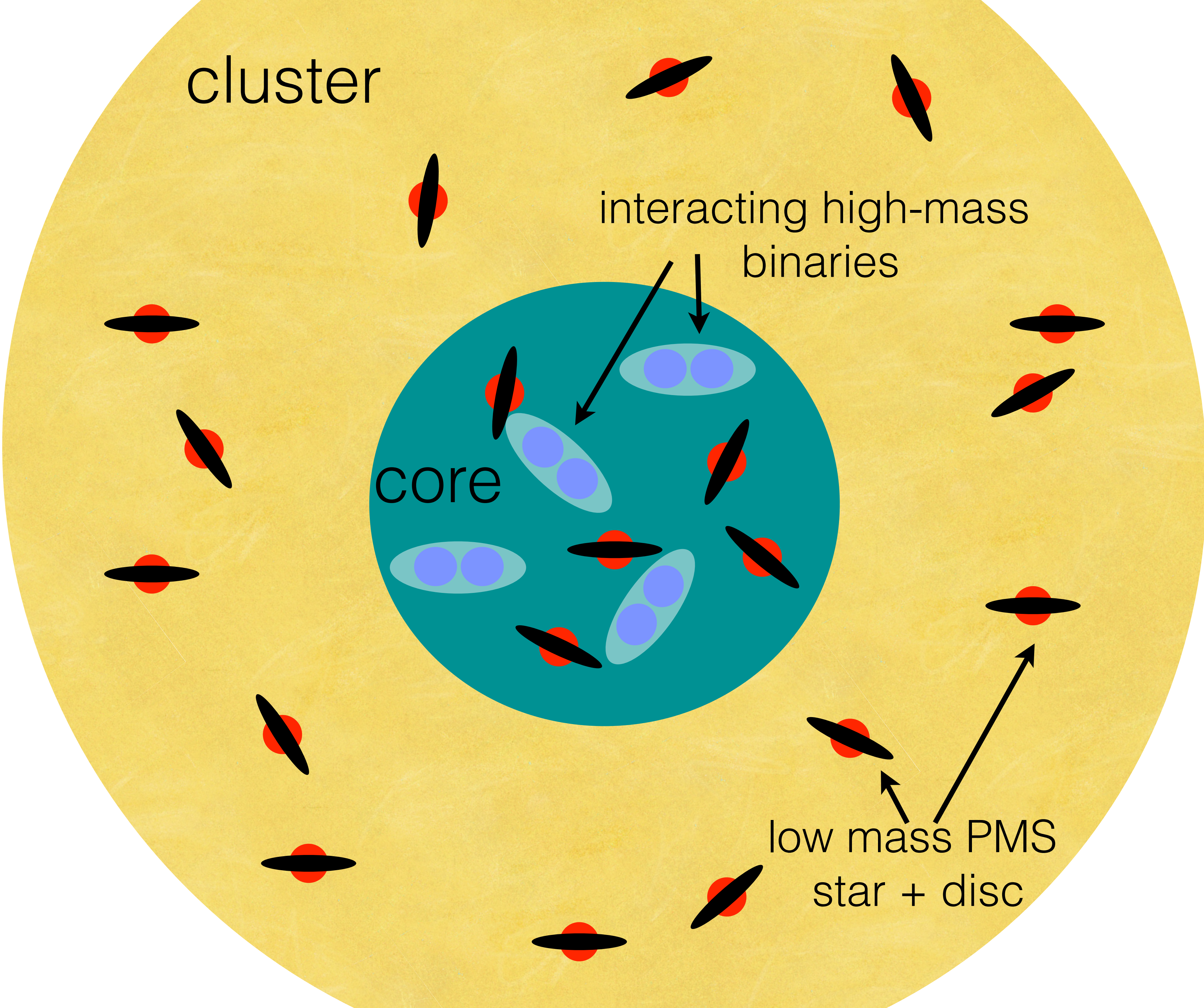
- The 1st generation forms
- T > 30 Myr, AGBs begin shedding material which collects in the centre of the cluster
- The cluster accretes (a lot) of “pristine gas” from the surroundings.
- The 2nd generation forms in the centre
- Most of 1st generation (~75%) is lost (the “mass budget” problem)

Bekki & Norris 2006, Decressin et al. 2007, D’Ercole et al. 2008, Vesperini et al. 2009, Conroy & Spergel 2011



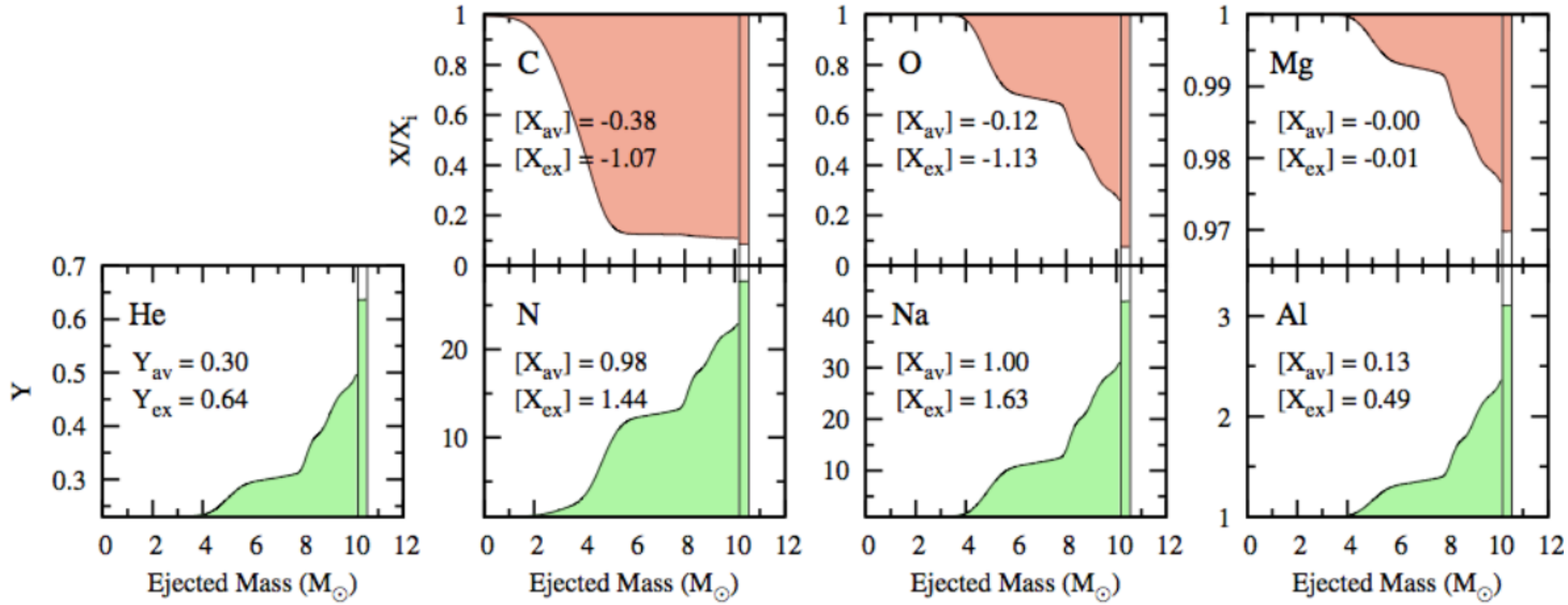
“Early disc accretion” model

- One burst of star formation (i.e. an SSP) - as observed in young clusters
- High-mass stars (binaries) form near the centre of the cluster
- Interacting binaries and spin-stars eject (low velocity) material into the cluster - this material has been processed by the high mass stars (70% of high mass stars are in binaries that will interact, Sana et al. 2012)
- Low-mass stars keep their discs for 5-10 Myr, which can entrain material as they move in the cluster, Throop & Bally 2008
- This will only happen to low-mass stars ($<2\ M_\odot$), as they stay in the pre-main sequence phase for >6 Myr
- The material eventually accretes onto the young star ($<$stellar mass)
  =>No mass budget problem!


cluster
interacting high-mass binaries
core
low mass PMS star + disc

1) Source of the enriched material

Interacting high mass binaries

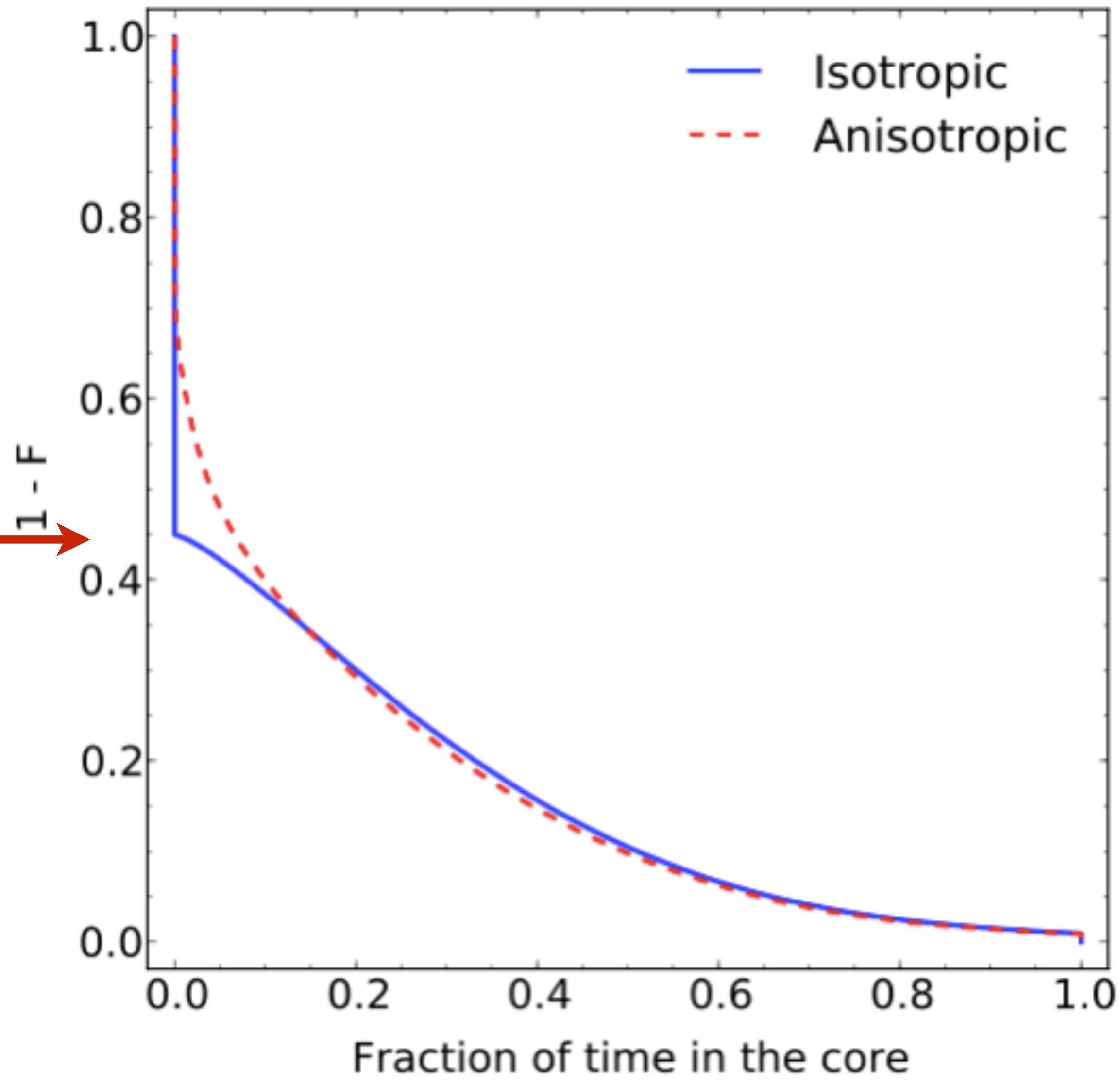


de Mink et al. 2009

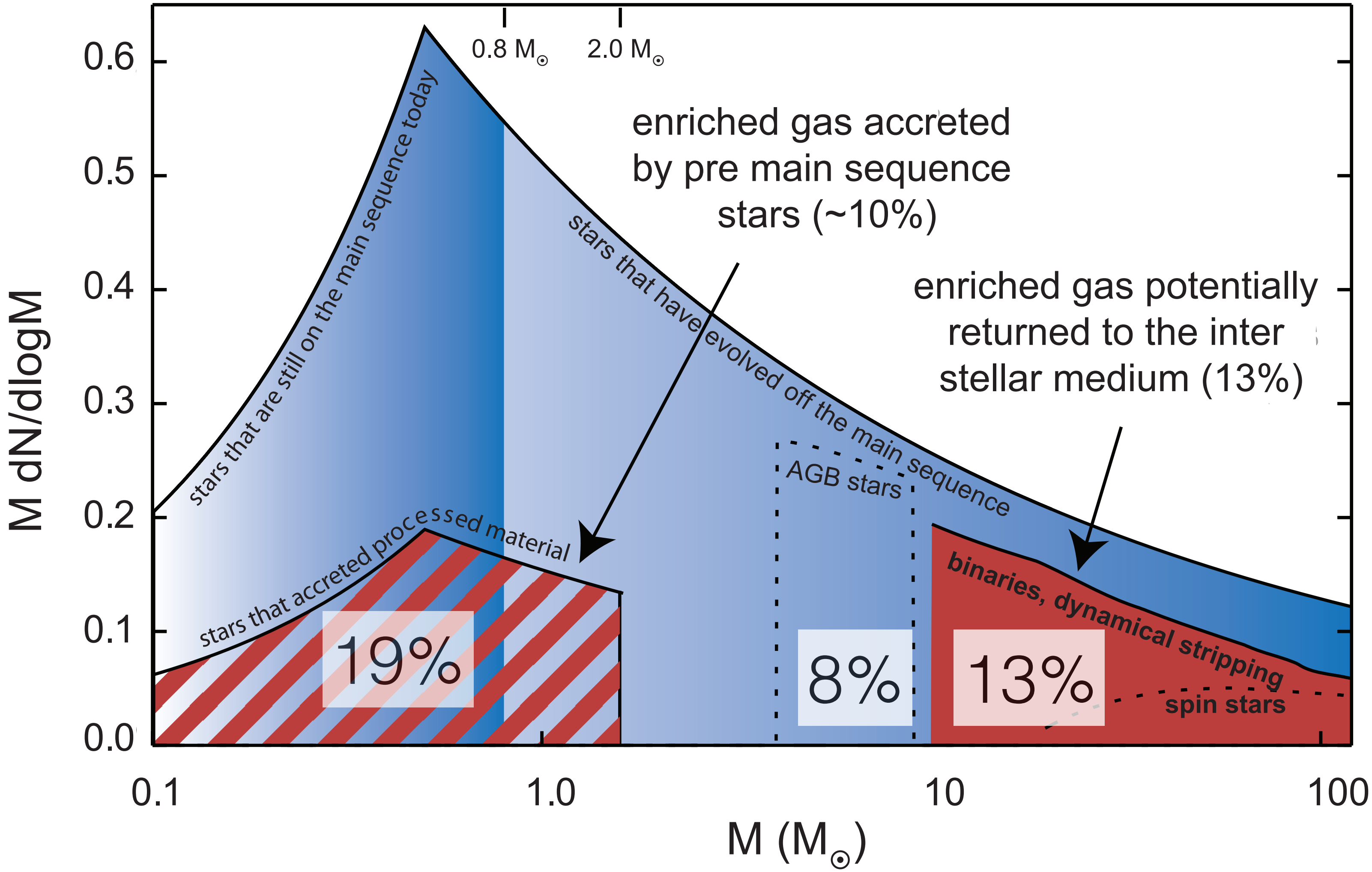
- The ejected envelope is very He rich
- Most abundances reproduced (trends and quantitatively) (Cassisi & Salaris 2014)
- Ejected at low velocities (<20-30 km/s)

2) Quantisation of He and other elements?

50% of stars
ever enter the core

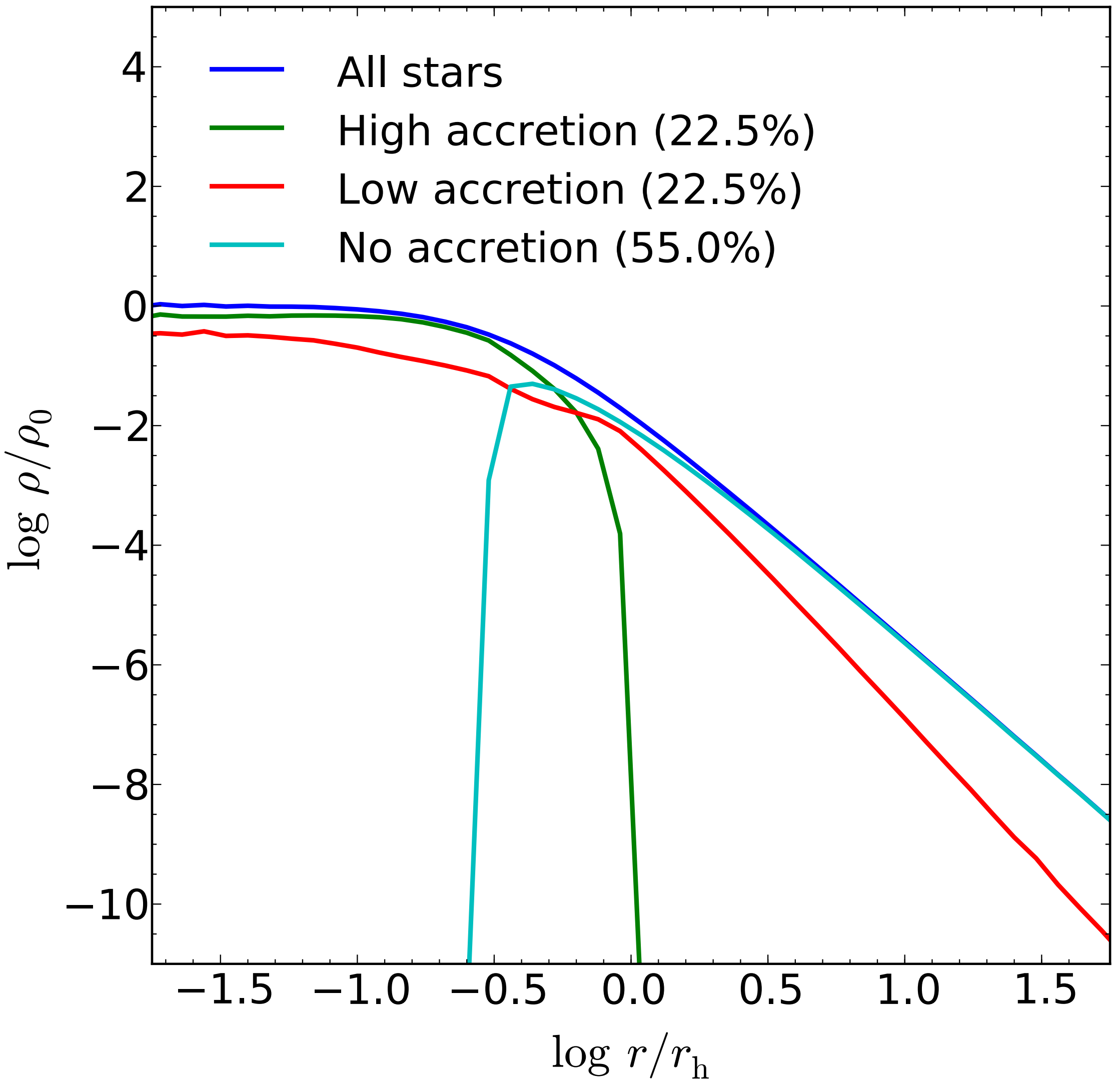


3) Mass budget problem?



Because a star is already in place to accrete the material, we can make the approximation that a star accretes <50%. In that case, <10% of the initial cluster mass needs to be accreted

4) Distribution of the stars in the cluster



Summary of the "early disc accretion" model

- The entire volume core is swept out every ~2 Myr
- Without invoking multiple episodes of SF, the model 1) accounts for the enrichment patterns observed, 2) Quantised abundances (and fractions), 3) doesn't have a "mass budget problem"
- Explains why young massive clusters are observed to be gas free from young ages (~2 Myr) and do not show evidence for extended SF
- Same effects should be visible in young massive clusters, although more difficult to see due to higher metallicity

Can we discriminate between scenarios using kinematics ?

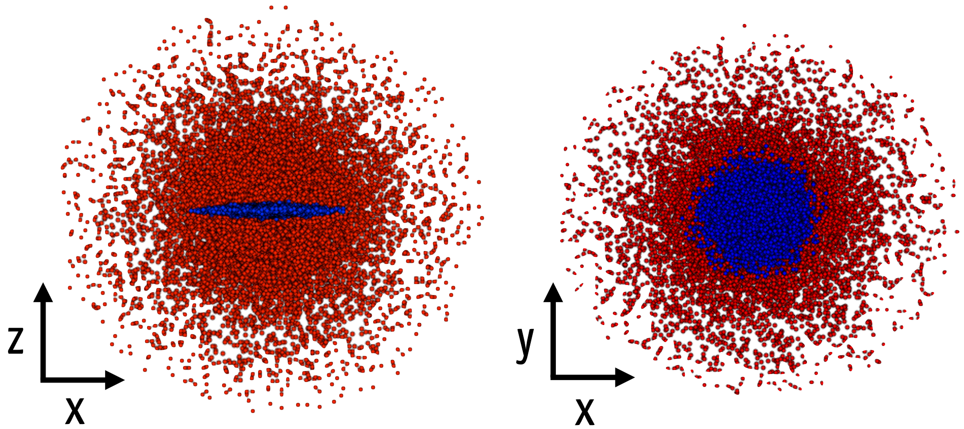
Can we discriminate between scenarios using kinematics ?

Early violent 1st generation mass loss	D'Ercole+ 2008
Spatial mixing of multiple populations	Vesperini+ 2013
Evolution of 2nd generation discs (ω Cen)	Mastrobuono-Battisti & Perets 2013
Long-term kinematics of different scenarios	Hénault-Brunet+ 2014, in prep

Multiple generations

e.g. D'Ercole+ 2008

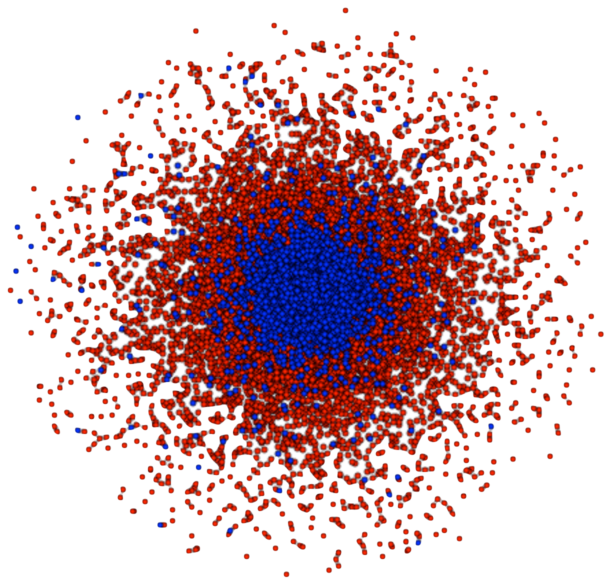
2nd generation forms preferentially in the central region of the cluster from gas expelled by the 1st generation



Early disc accretion

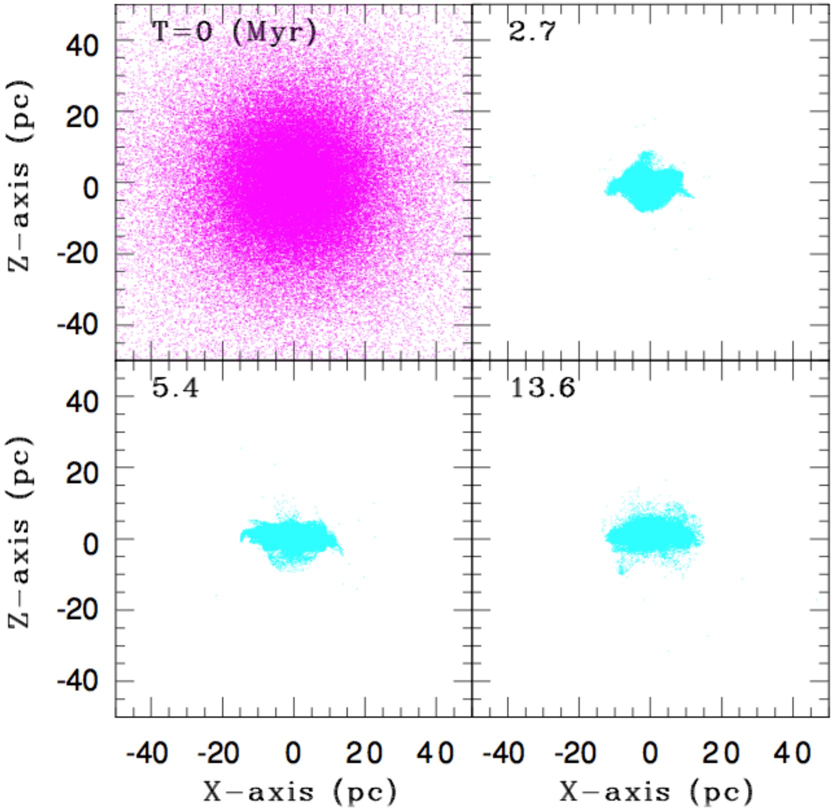
Bastian+ 2013

Stars accrete polluted material when crossing the cluster core



Multiple generations

Bekki 2010



Early disc accretion

Multiple generations

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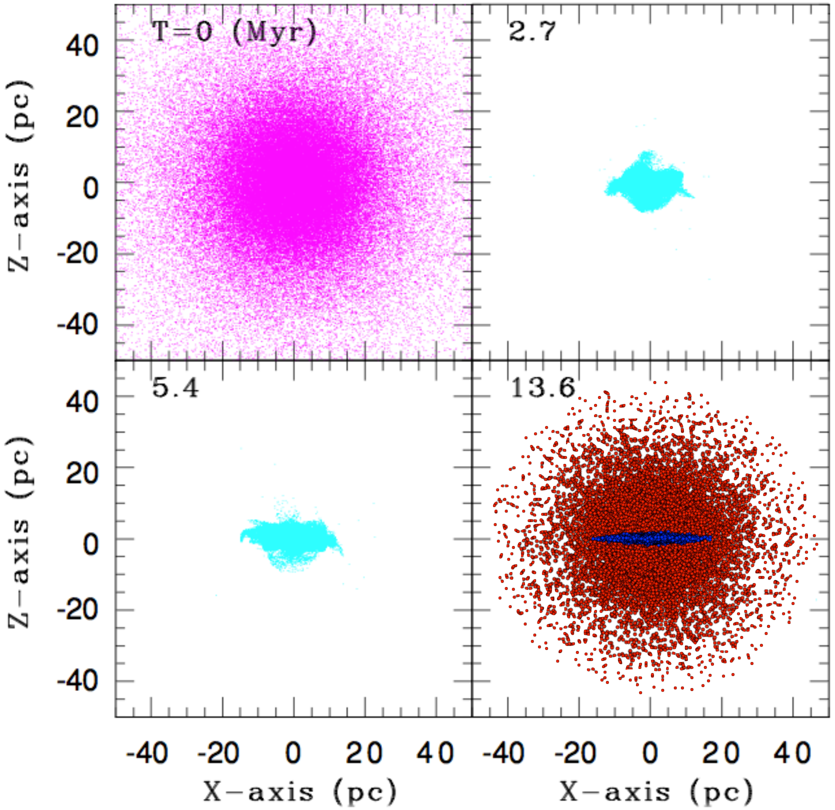

Early disc accretion

Multiple generations

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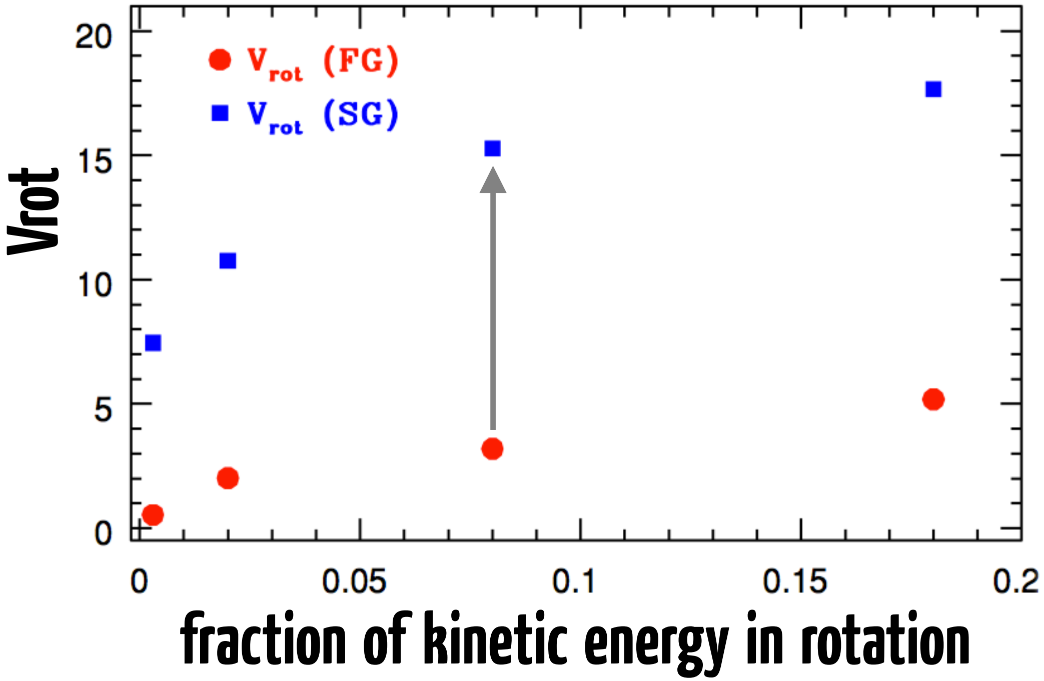

Early disc accretion

Multiple generations

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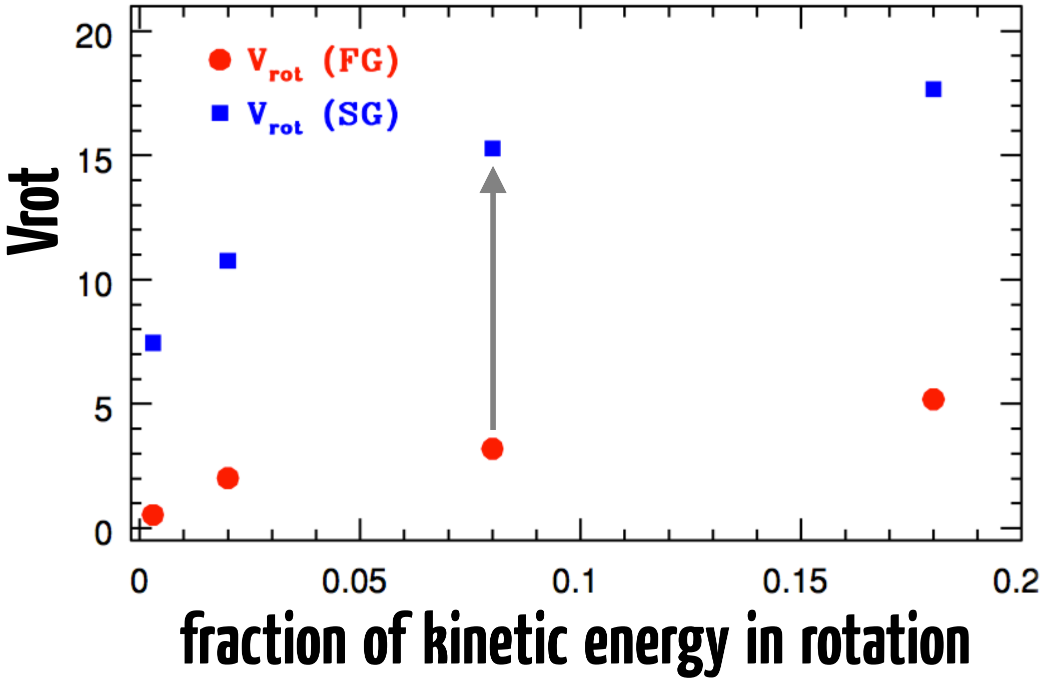
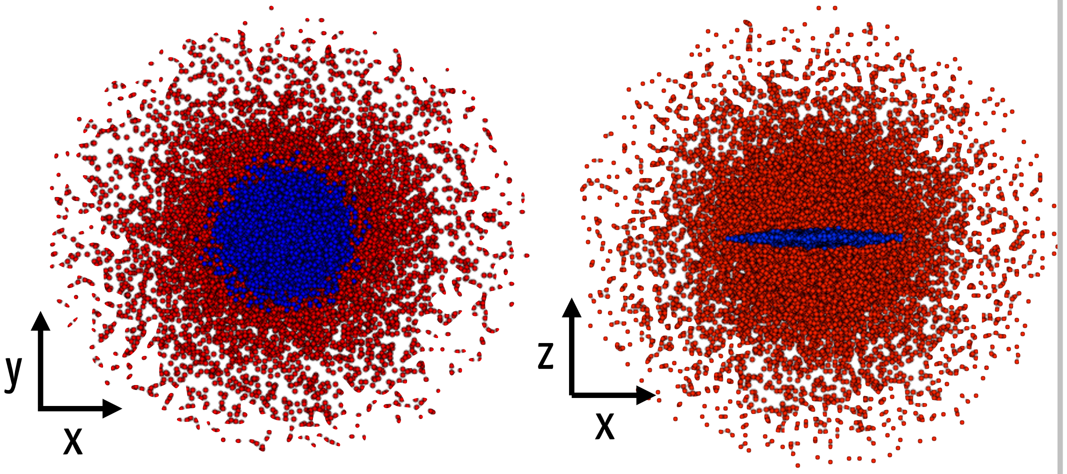


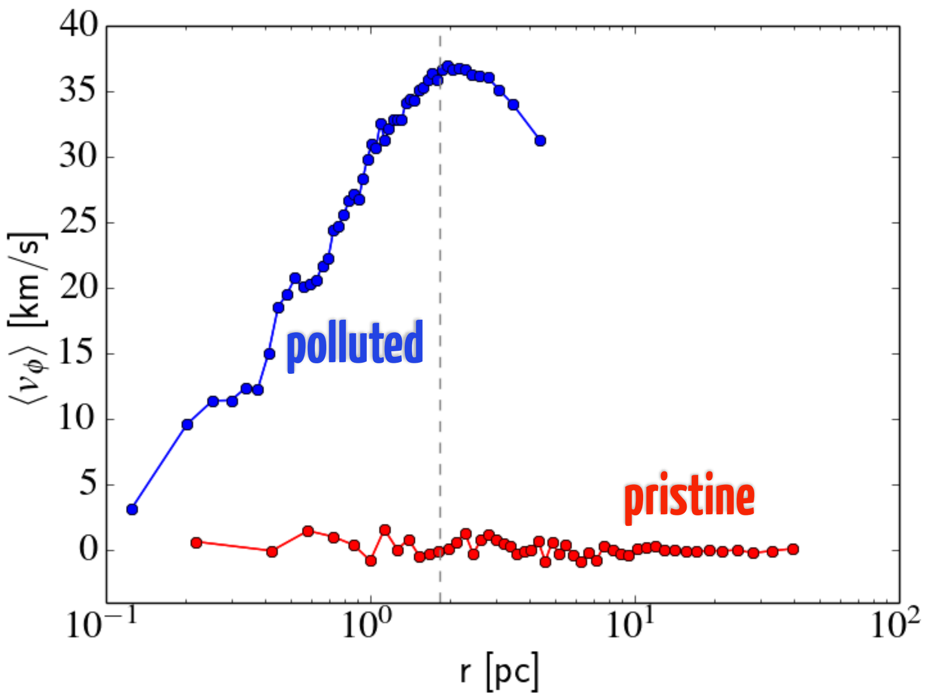
Evidence (and origin) of cluster rotation...

e.g. Fabricius+ 2014
Vesperini+ 2014
Bellazzini+ 2012
Hénault-Brunet+ 2012
Mackey+ 2013

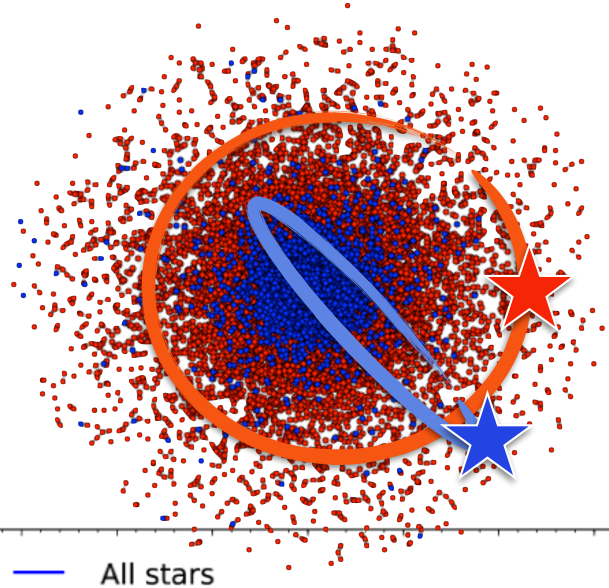
Early disc accretion

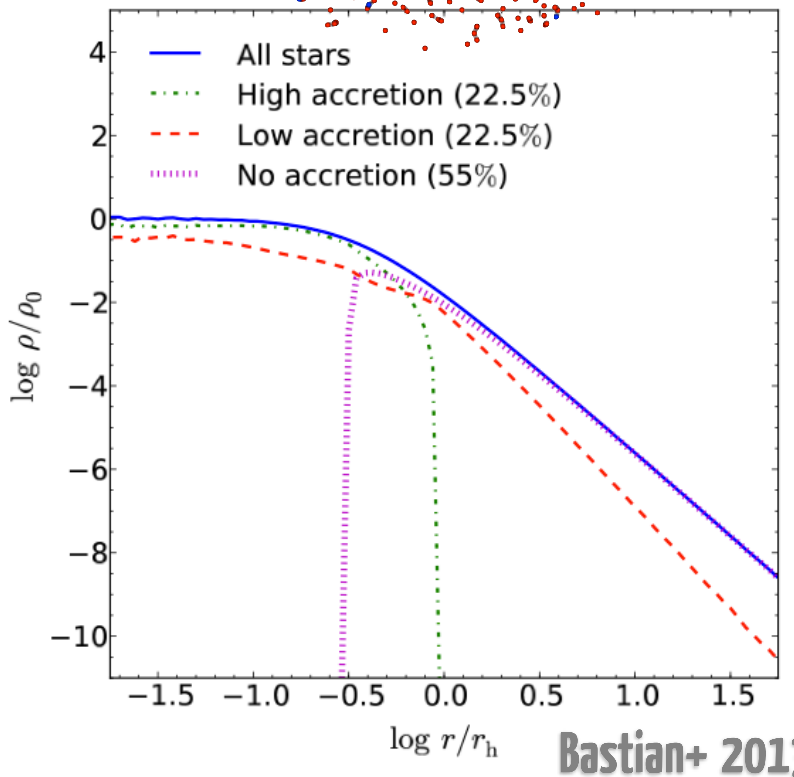
Multiple generations





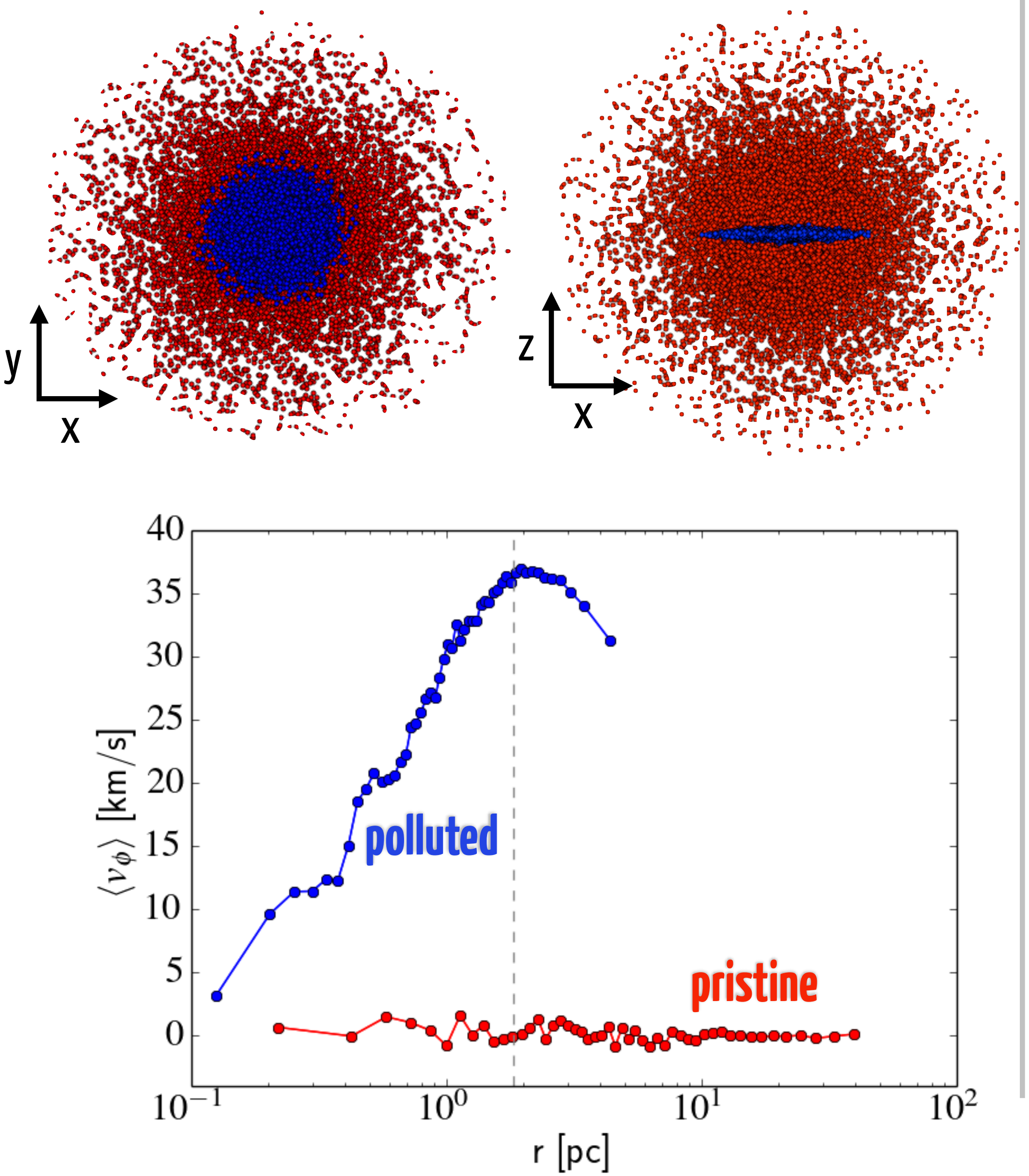
Early disc accretion



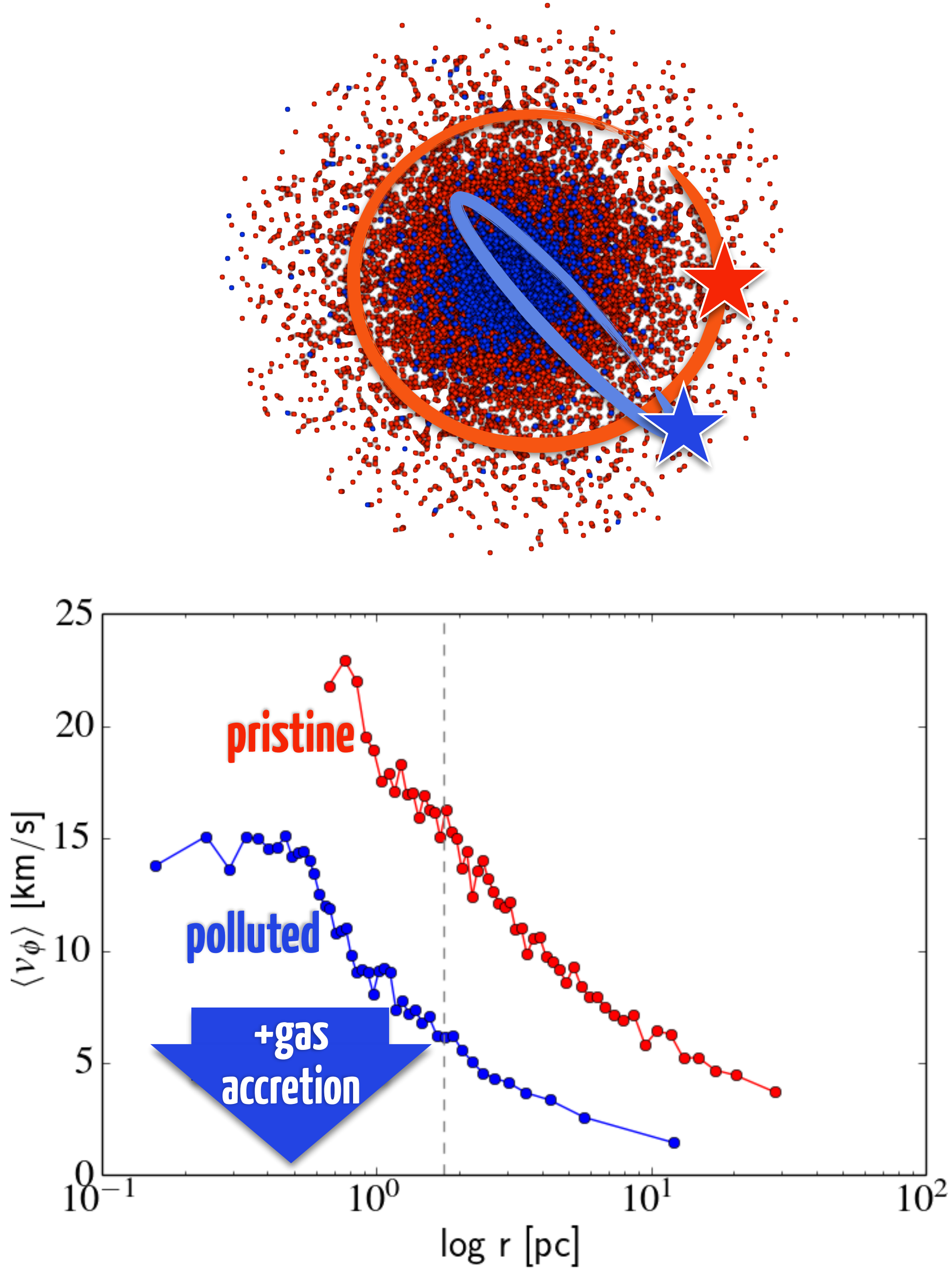


Bastian+ 2013

Multiple generations



Early disc accretion



Multiple generations

Negligible angular momentum in 1st generation after early mass loss

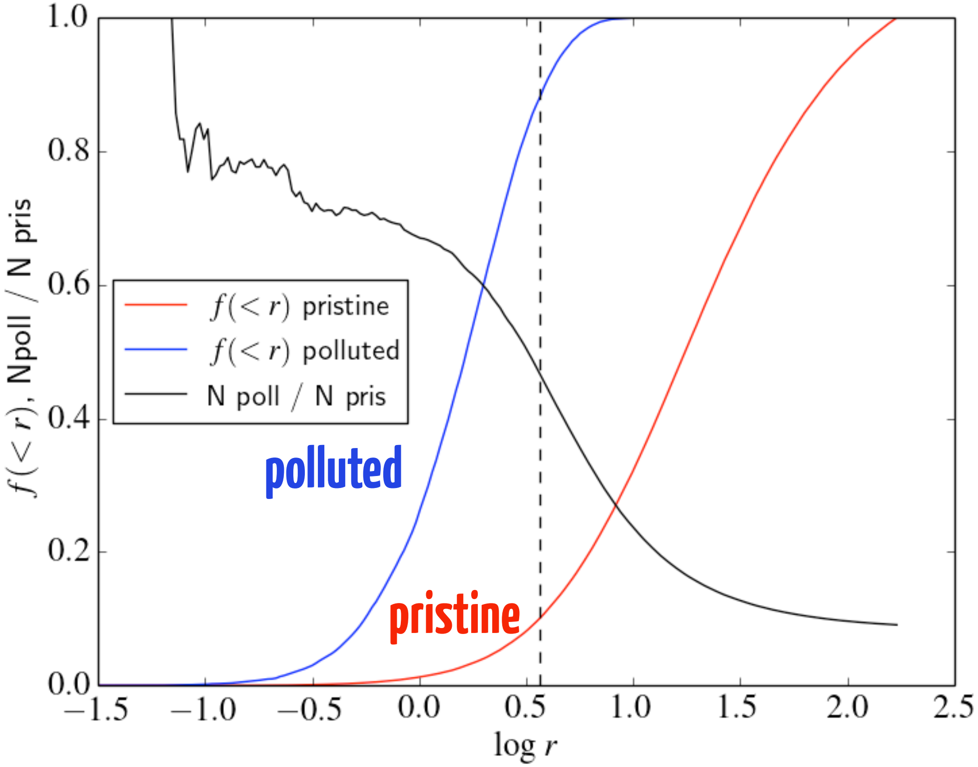
e.g. 2nd generation disc embedded in 1st generation cluster

M(1st) = 10xM(2nd)

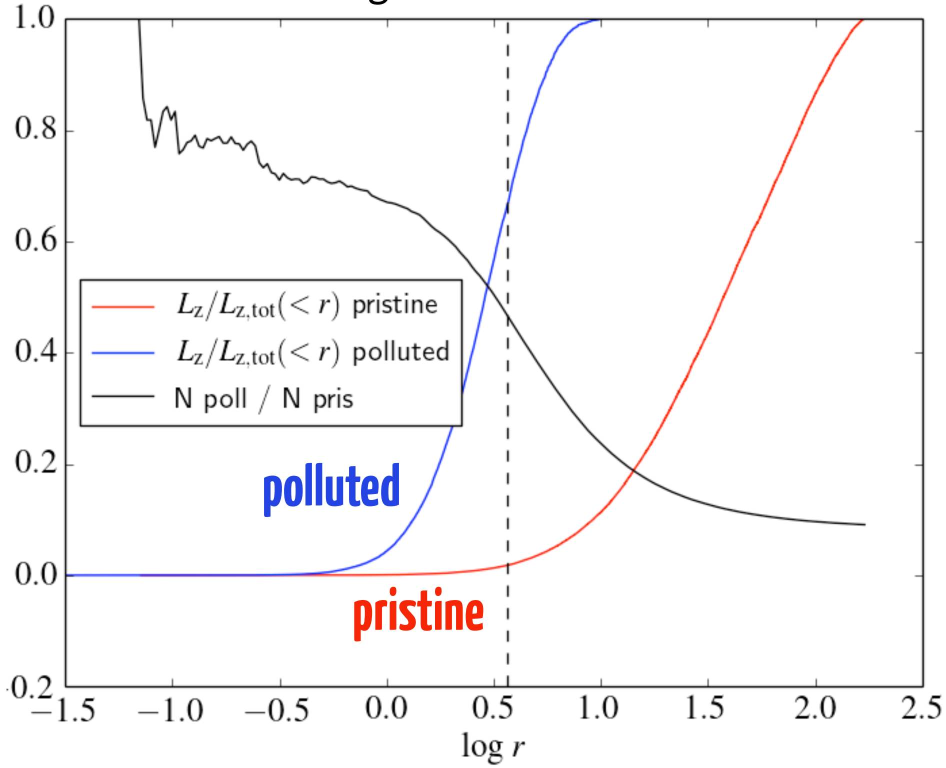
L(1st) = 20xL(2nd)

(before early mass loss)

Cumulative number distribution



Cumulative angular momentum distribution



Multiple generations

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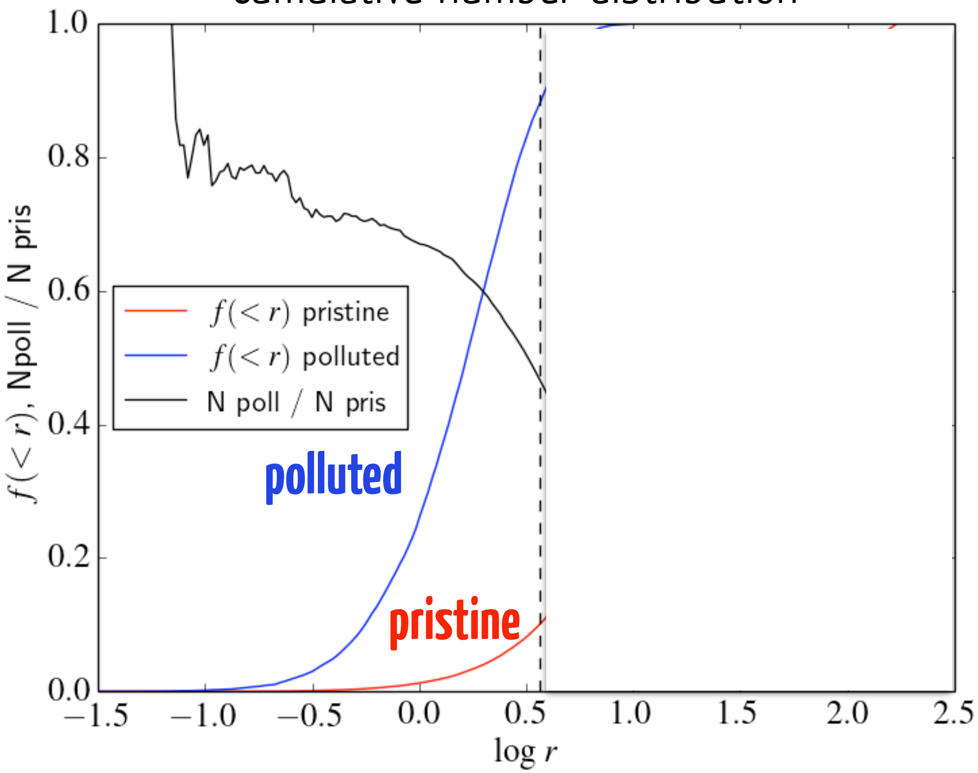
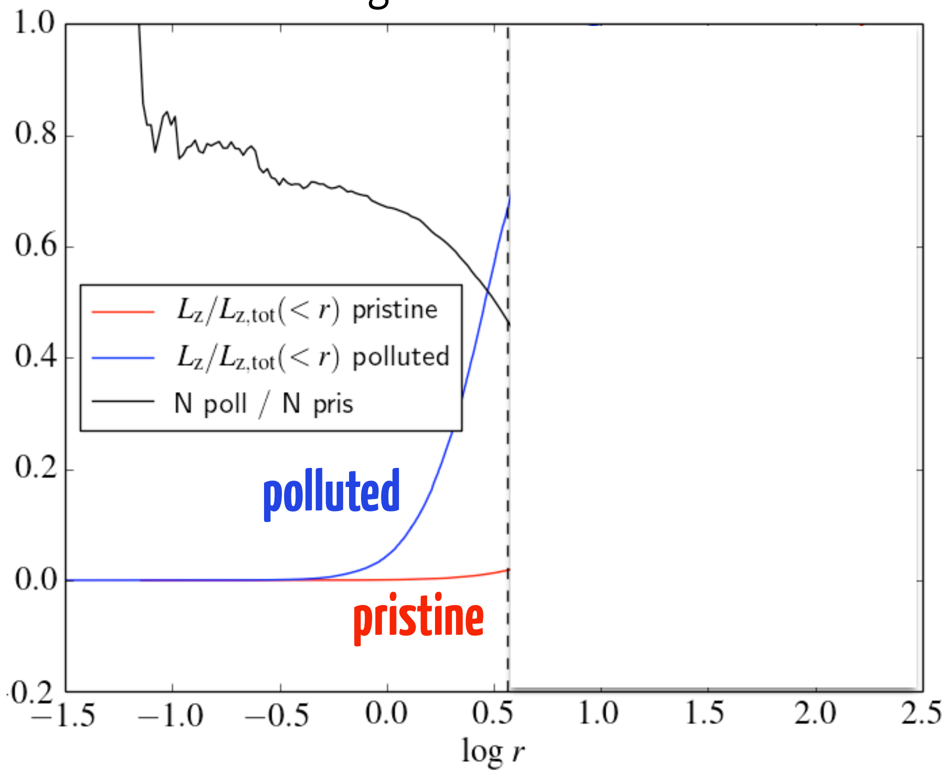


Cumulative angular momentum distribution



Initial conditions

Multiple generations

Disc + Spherical halo
(exponential) (Hernquist)

polluted pristine

$M_{disc} = M_{halo}$
$L_{halo} = 0$

$S_{rot} = [10\%, 20\%]$
(fraction of kinetic energy in rotation)

+ non-rotating spherical configurations for comparison

+ one disc+halo model w/o stellar evolution ran until dissolution

Early disc accretion

Isochrone model (Hénon 1959, 1960)

stars crossing the core → polluted
stars not crossing the core → pristine

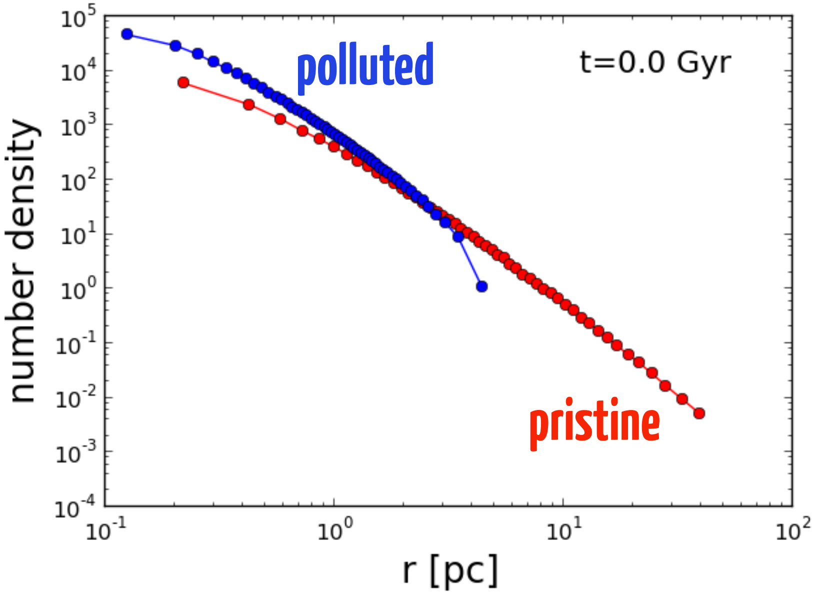
$S_{rot} = [0\%, 10\%, 20\%]$

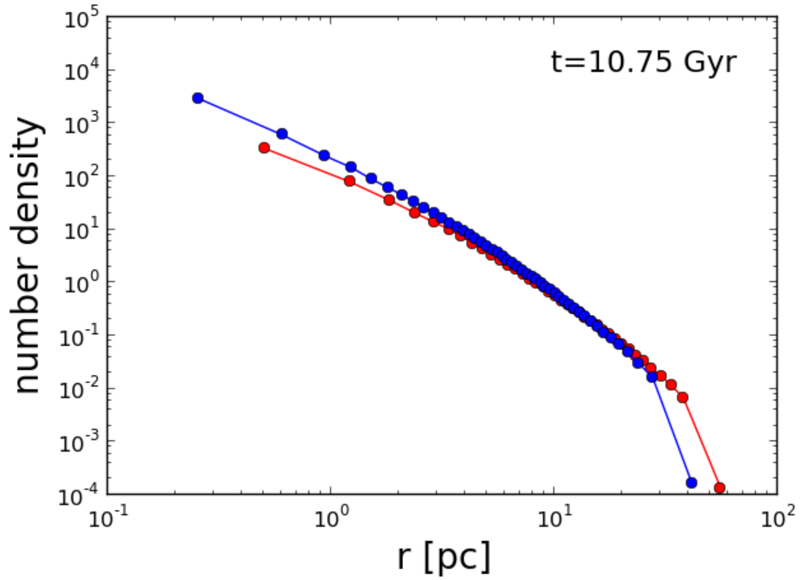
NBODY6 (Aarseth)

* $N = 10^5$
* scaled to 47 Tuc-like ICs (Giersz & Heggie '11)
* tidal field + stellar evolution
* evolved for ~11 Gyr

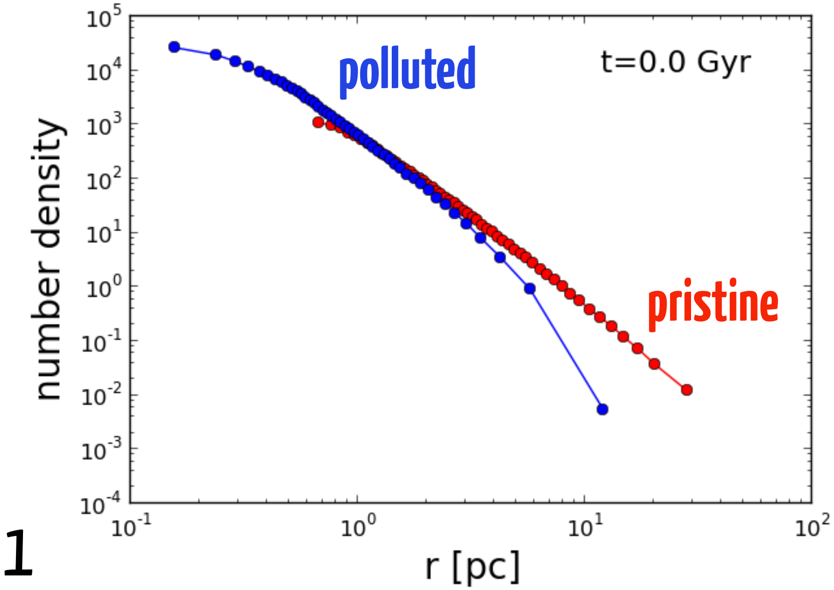
Spatial mixing

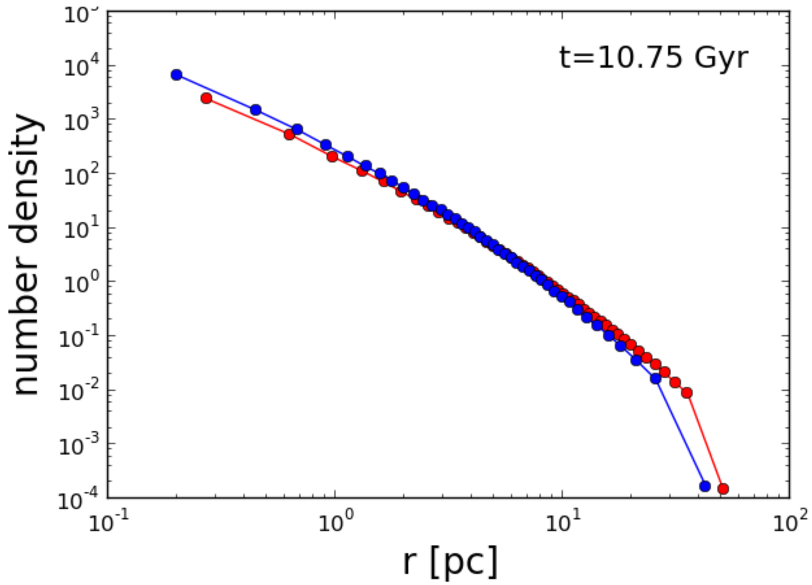
Multiple generations





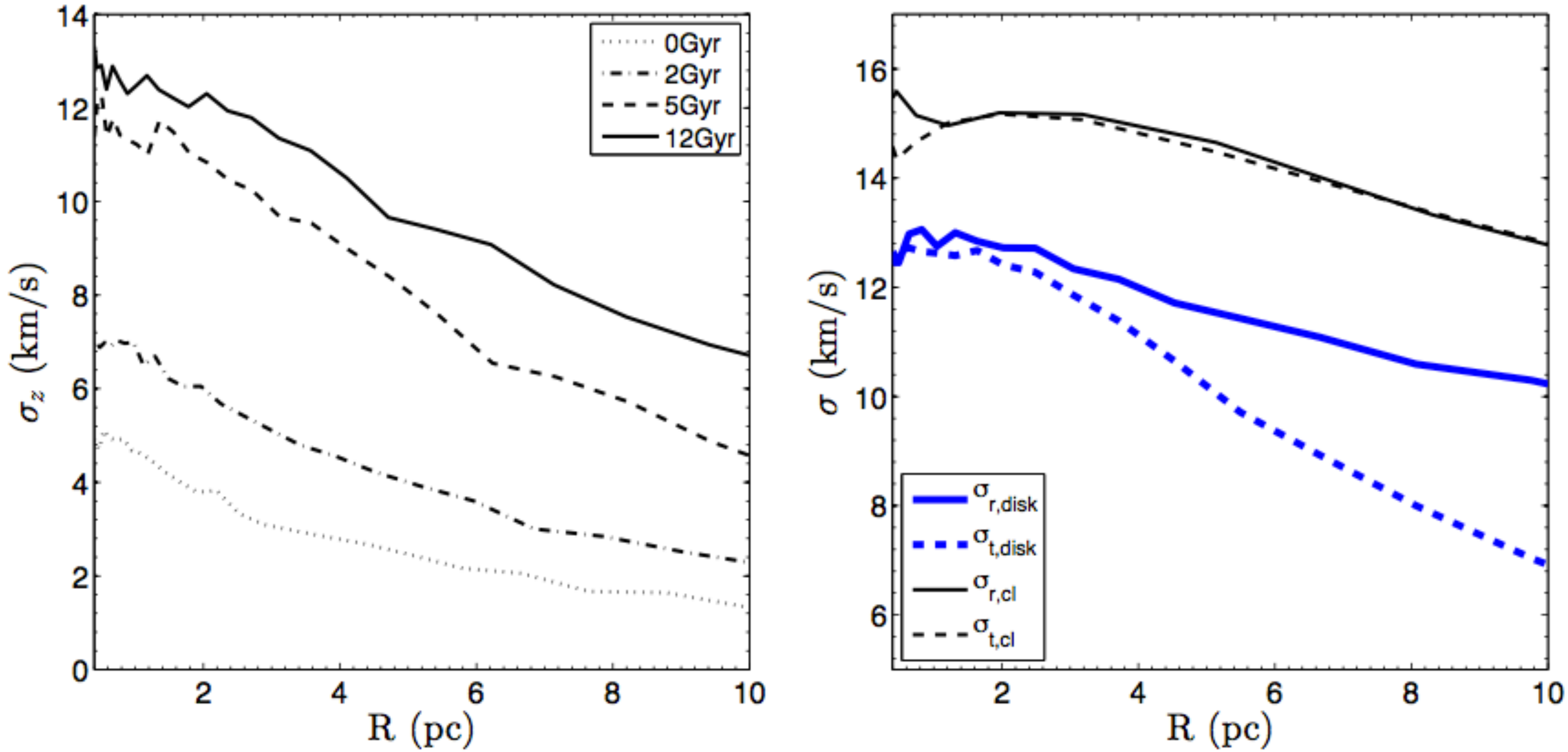
Early disc accretion





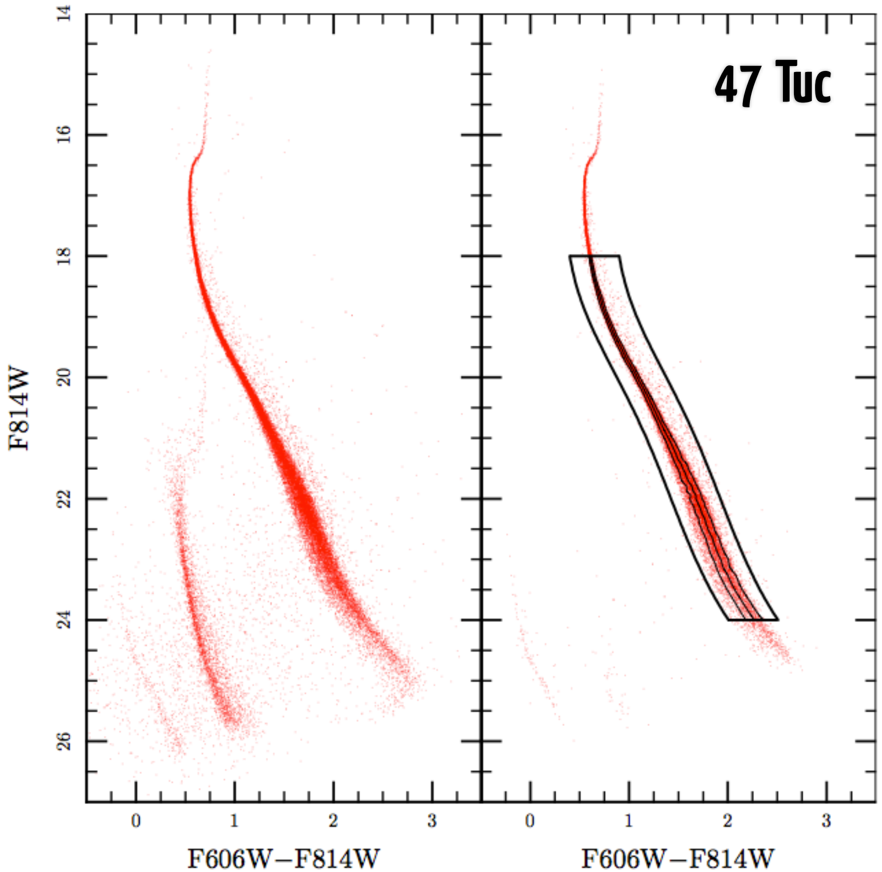
Srot = 0.1

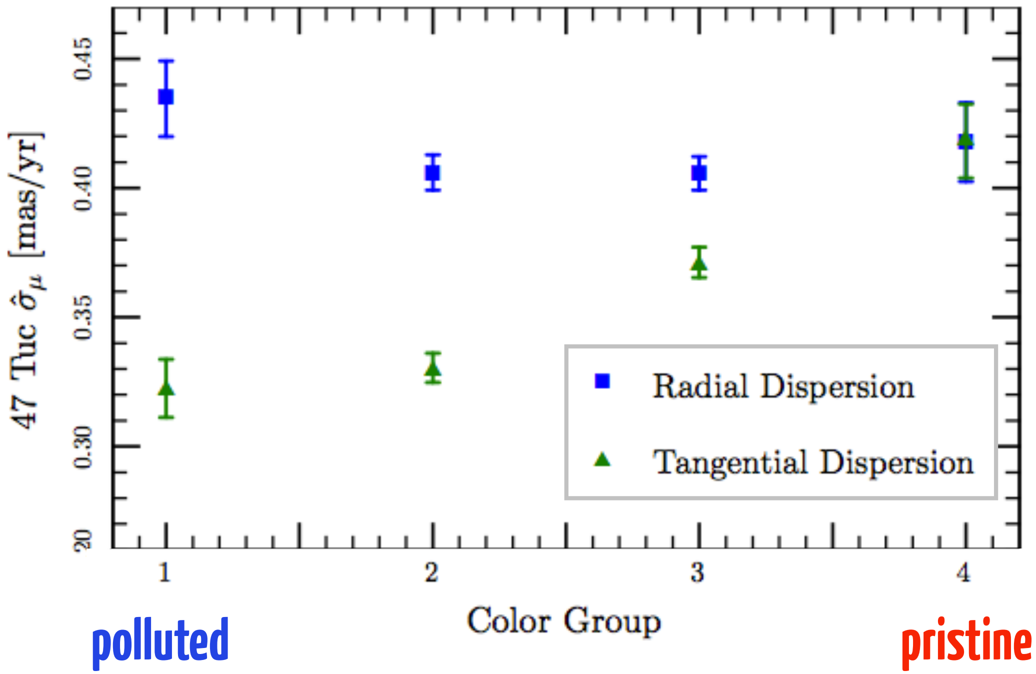
Velocity dispersion



Mastrobuono-Battisti & Perets 2013

Velocity anisotropy

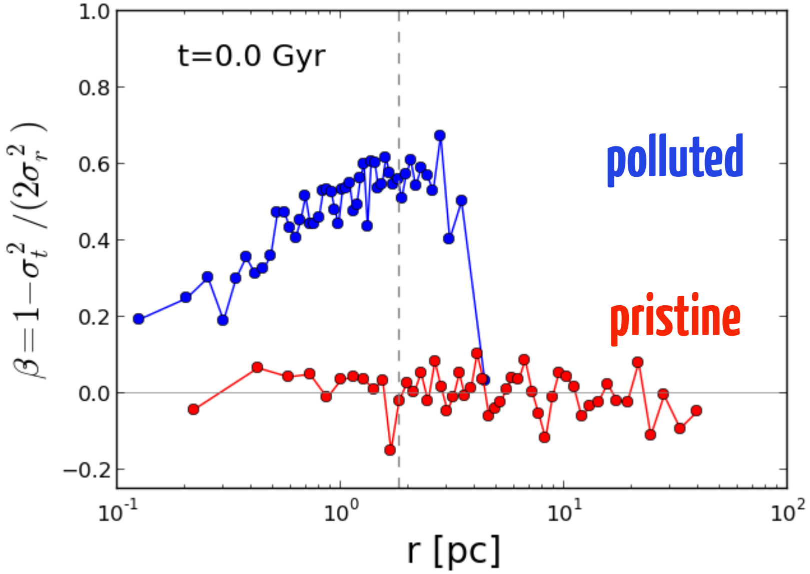


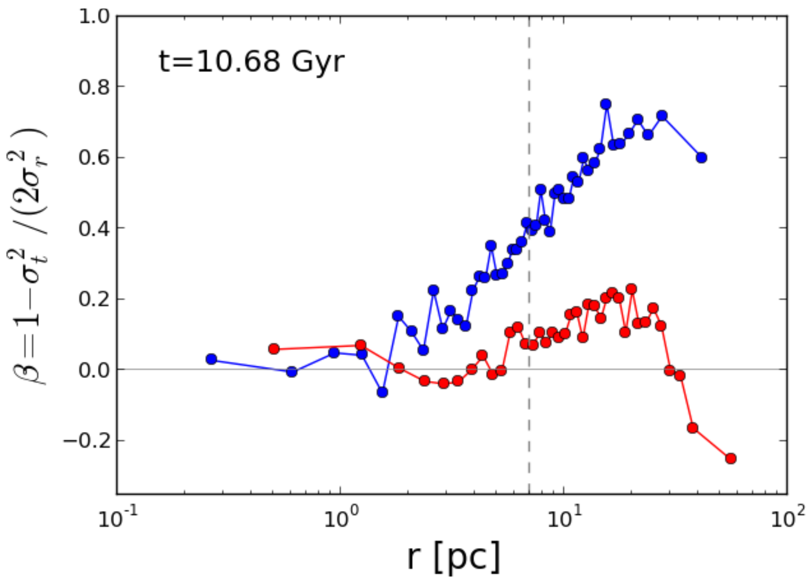


Richer+2013

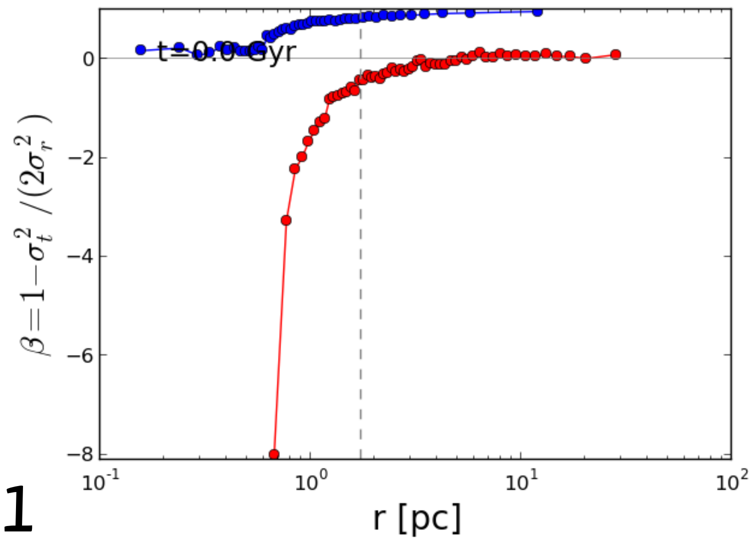
Velocity anisotropy

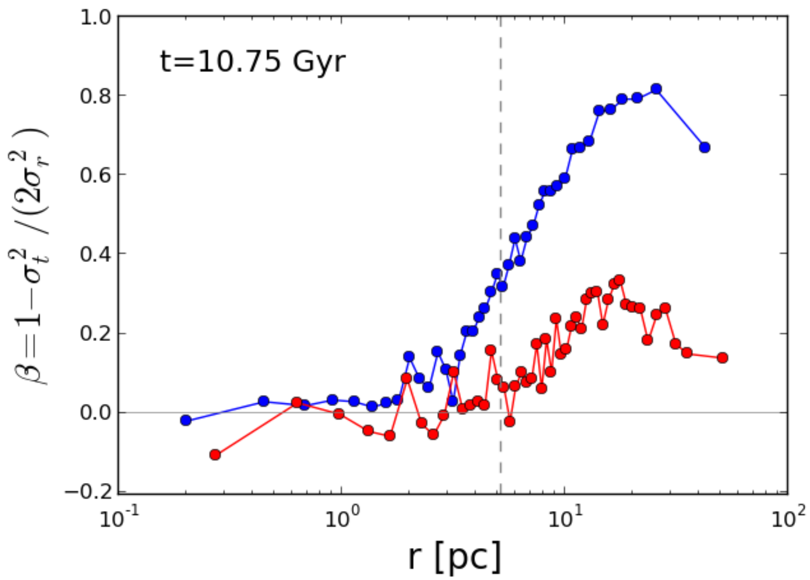
Multiple generations





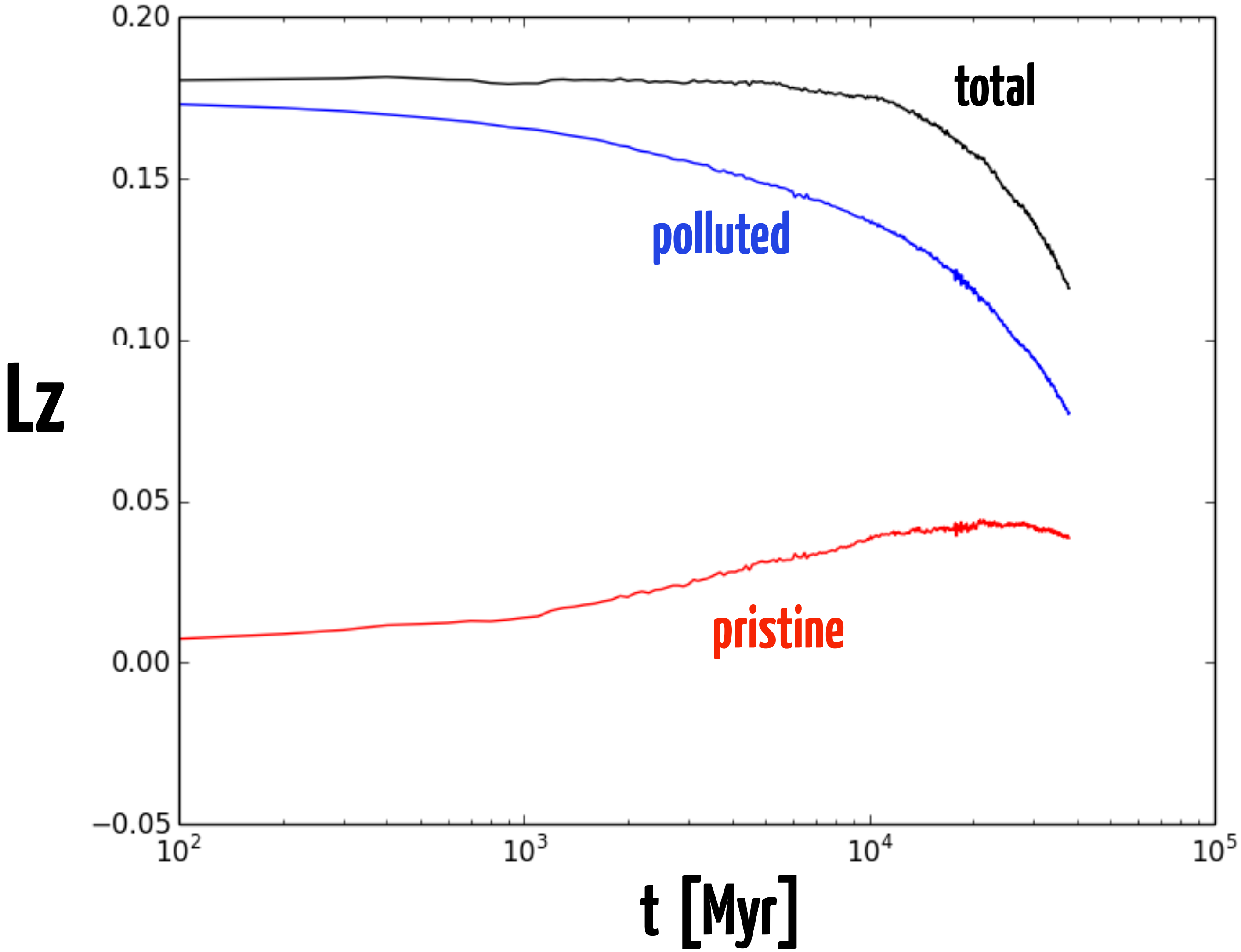
Early disc accretion





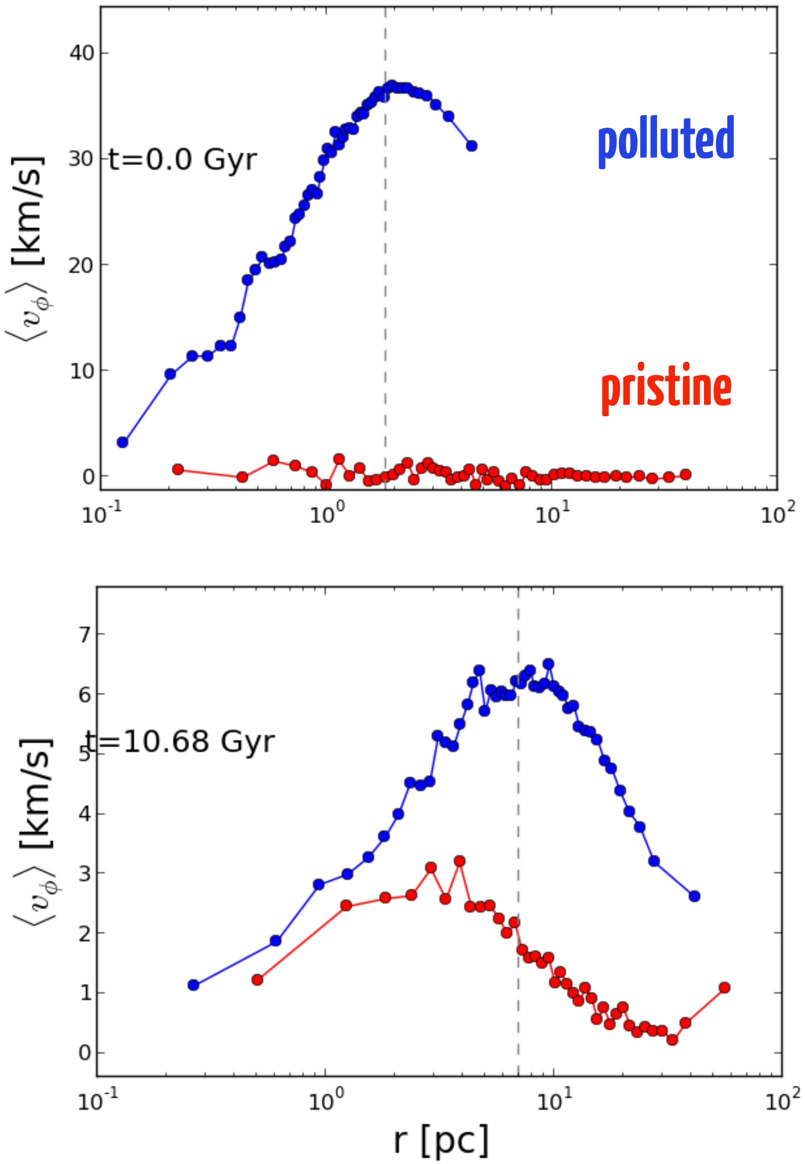
Srot = 0.1

(Differential) Rotation

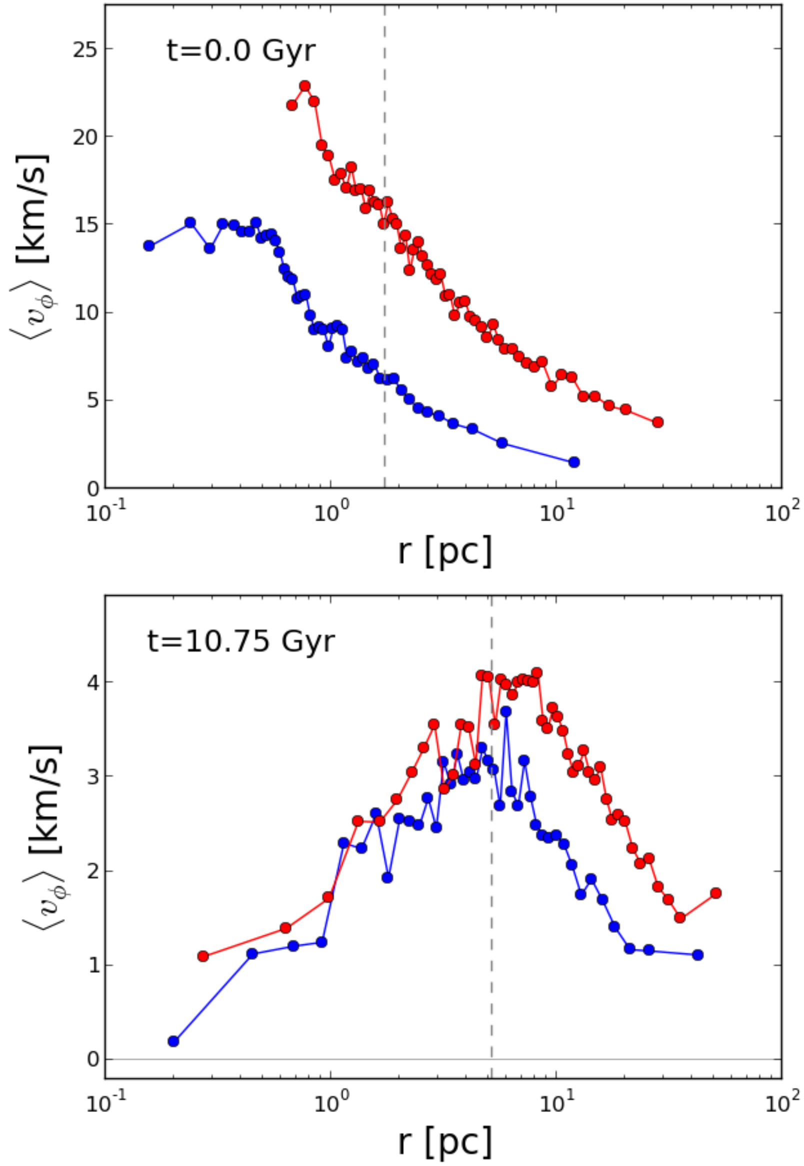


(Differential) Rotation

Multiple generations



Early disc accretion



(Differential) Rotation

Multiple generations | Early disc accretion

Bellazzini+2012

"No significant difference in mean rotation amplitude between Na-rich and Na-poor stars..."
(polluted) (pristine)

"Any marginal difference is in the opposite sense than expected, i.e. Na-poor samples tend to have larger rotation amplitudes than Na-rich samples."

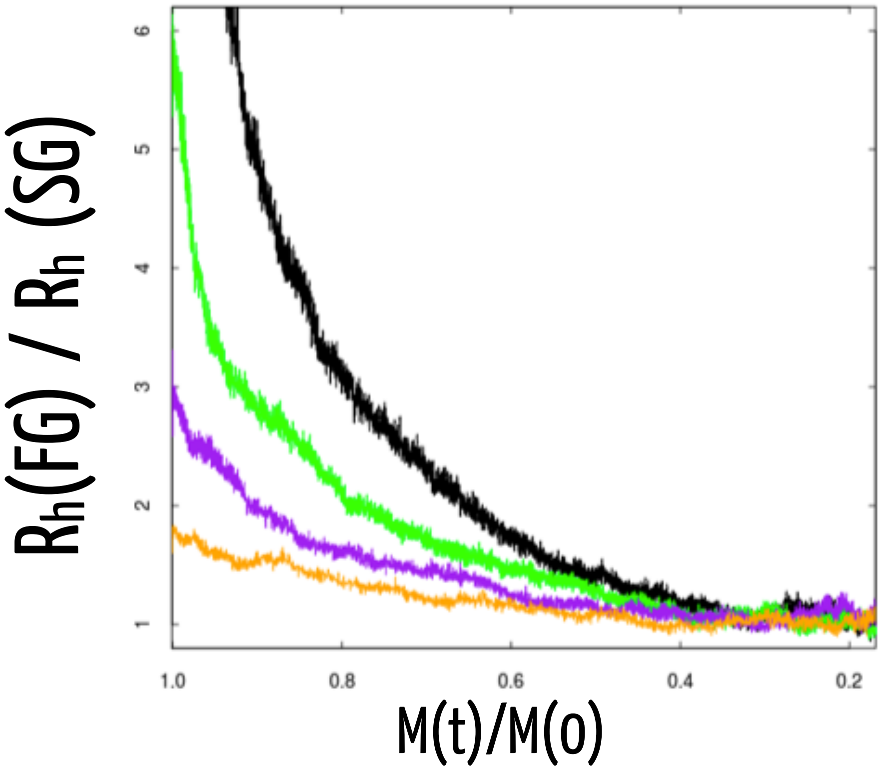
NGC6171: Na-poor = 5.5 km/s Na-rich = 0.5 km/s

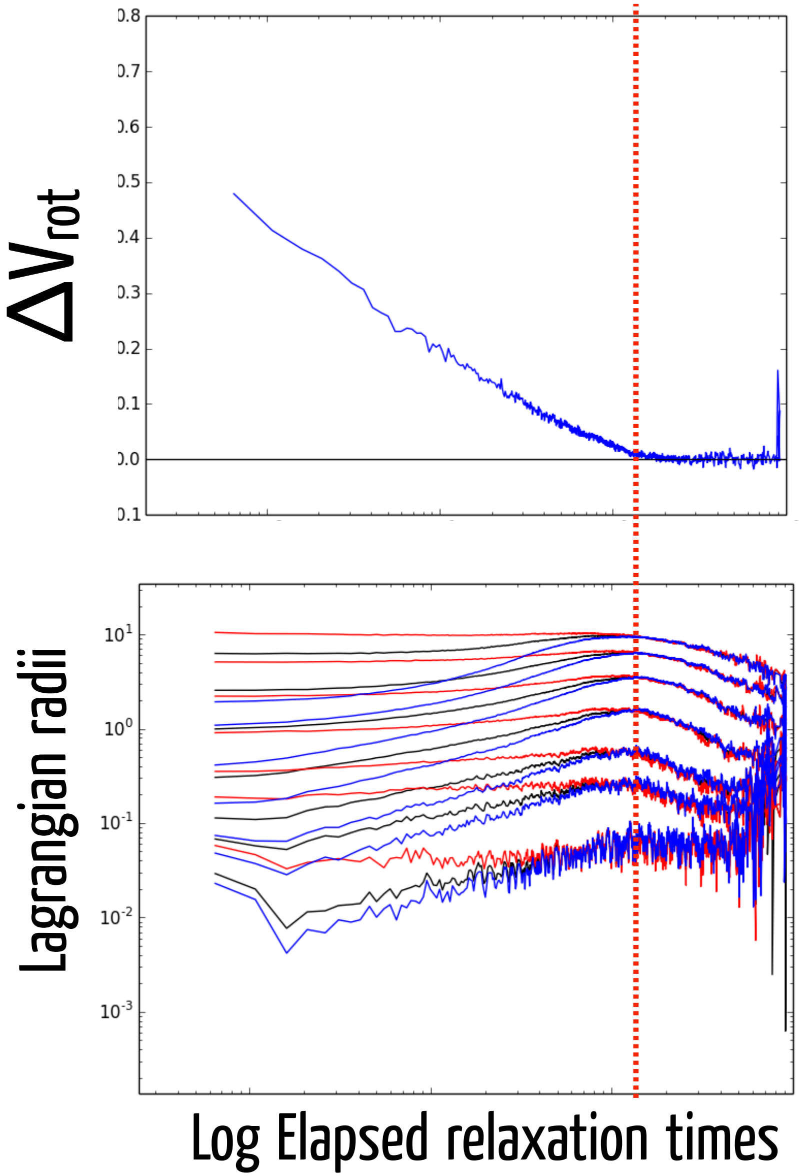
NGC7078: Na-poor = 6.5 km/s Na-rich = 1.0 km/s

When do kinematic imprints disappear completely?

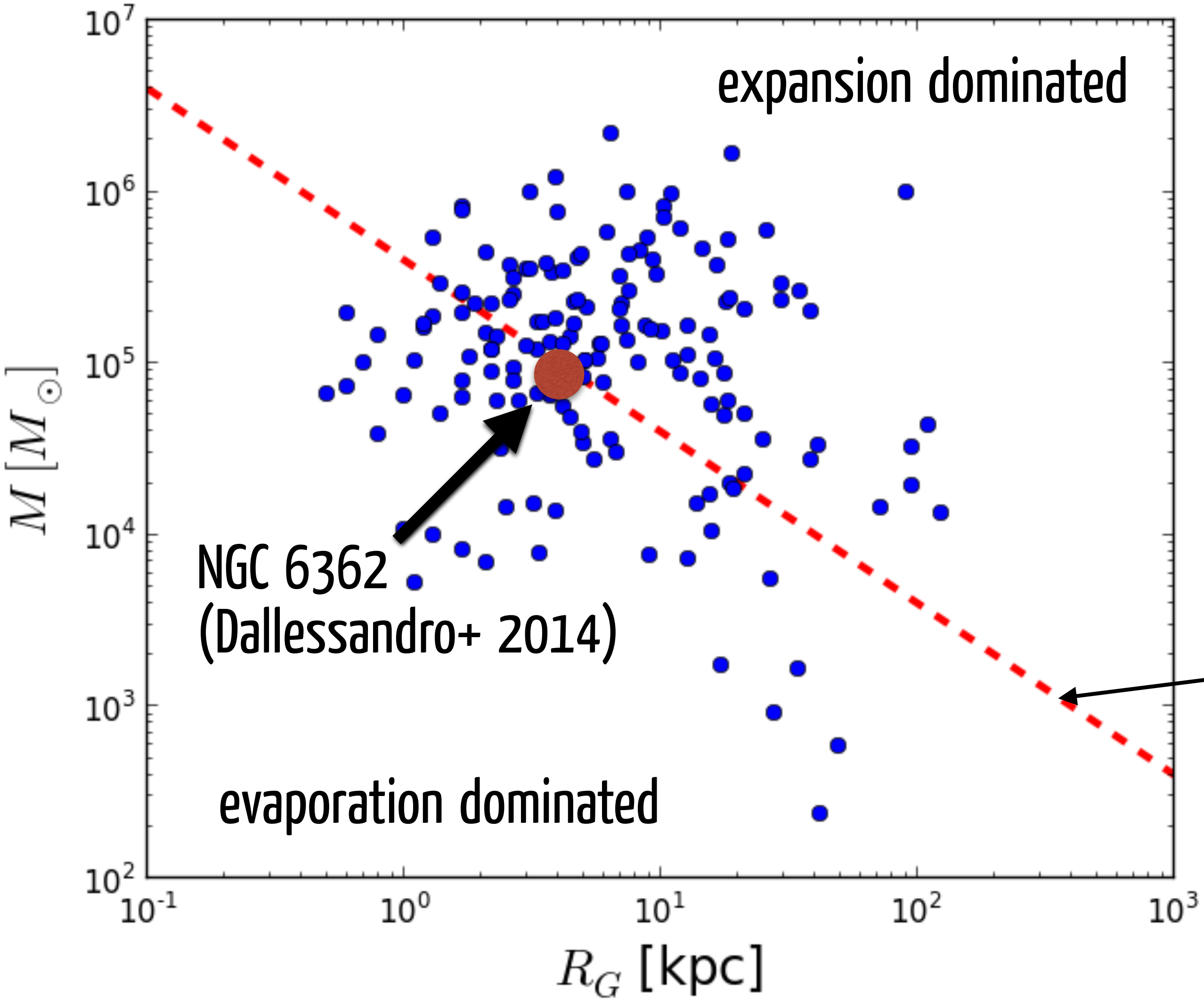
Vesperini+2013

Complete mixing when 60-70% of initial mass is lost





Which clusters are half-way their life?



$$M = 10^5\ \mathrm{M}_\odot \left(\frac{4\ \mathrm{kpc}}{R_\mathrm{G}}\right)$$

Gieles, Heggie & Zhao 2011

Data from Harris catalogue

Summary

1 ICs

"Multiple generations" vs "Early disc accretion"

=

different initial conditions (rotation)
for polluted and pristine stars

2 Long-term kinematic imprints

Multiple generations ⇨ ++ rotation in polluted stars

Early disc accretion ⇨ ++ rotation in pristine stars

Other signatures not clearly discriminant

(maybe a flattened distribution of polluted stars)

3 Real clusters!

Differential rotation ~few km/s, perhaps more

Expected to survive to the present epoch in a significant fraction of Galactic GCs