Evolution of second generation stars in stellar disks of globular and nuclear clusters

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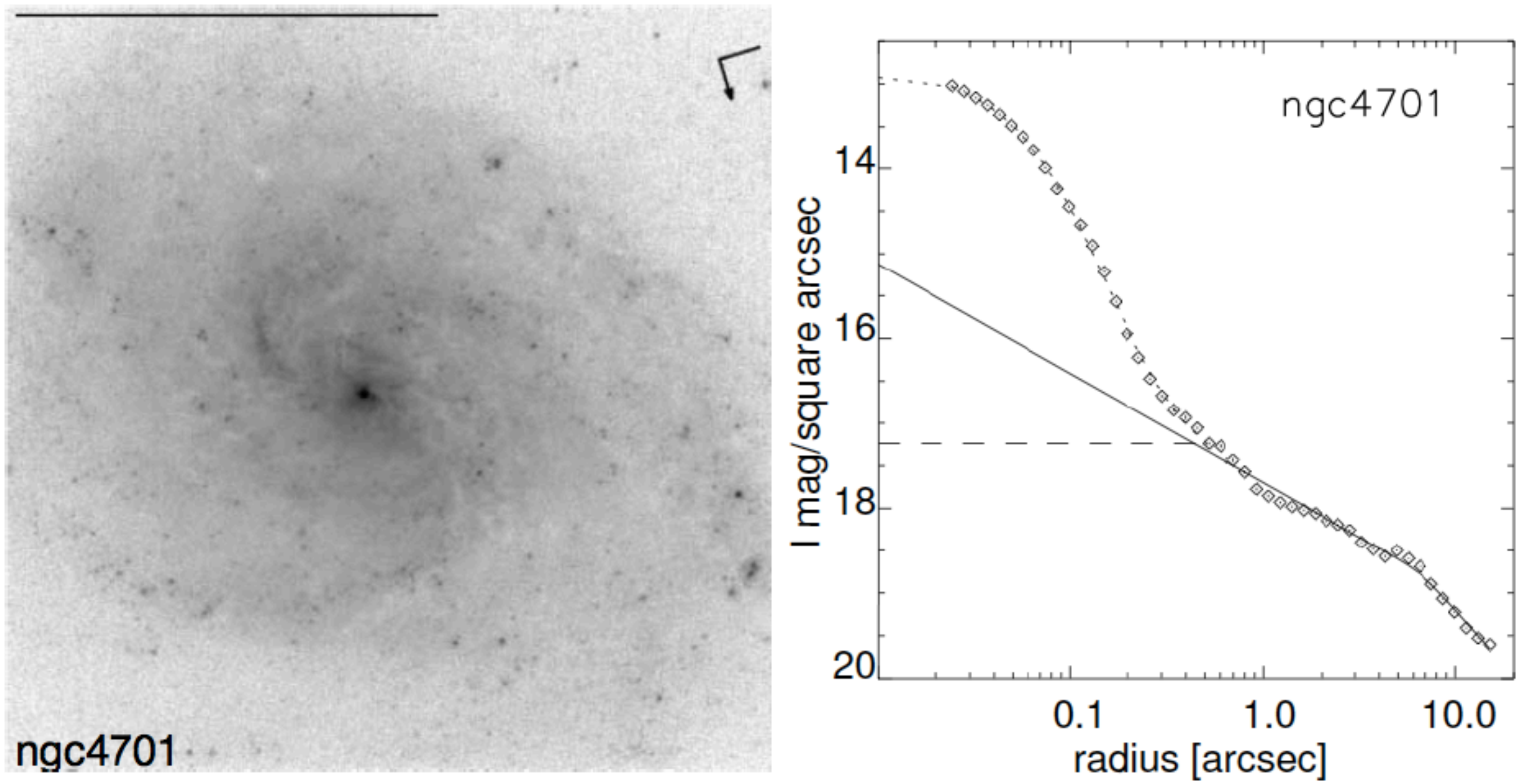
Outline

- Dense stellar clusters: Nuclear star clusters and Globular clusters;
- Young stellar disks in nuclear clusters;
- Multiple stellar generations in globular clusters;
- ω Centauri: peculiarities and its central disk;
- The evolution of a stellar disk in a dense stellar system;
- Conclusions.

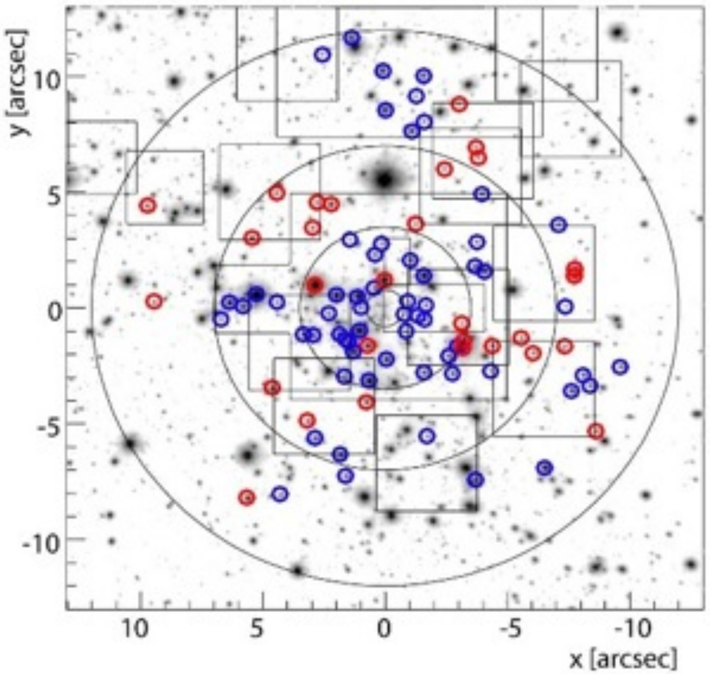
Nuclear star clusters (NCs)



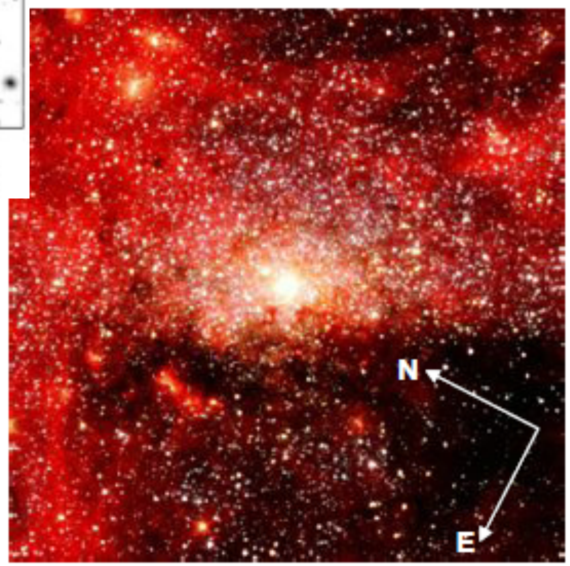
NCs have typically half-light radii of 2 – 5 pc and masses of 10^6 – $10^7 M_\odot$. They are present in ~75% of spirals and dwarf galaxies.

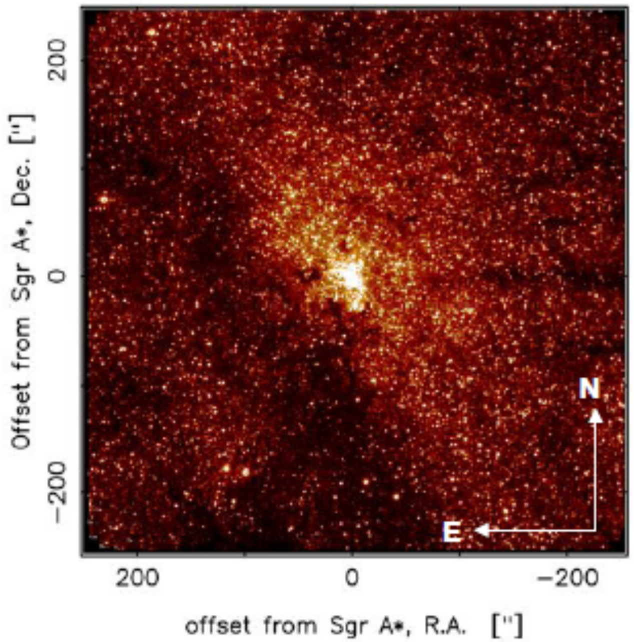
Disks in Nuclear Clusters

NCs, including the Galactic one and the one in M31, host distinct young stellar populations in disk like structures.



The Galactic Nucleus [Bartko et al. 2009; Böker et al. 2010]





Globular clusters (GCs): single stellar population systems?

Globular clusters:

✓r_h < 10pc;

✓N ~ 10^5-10^6;

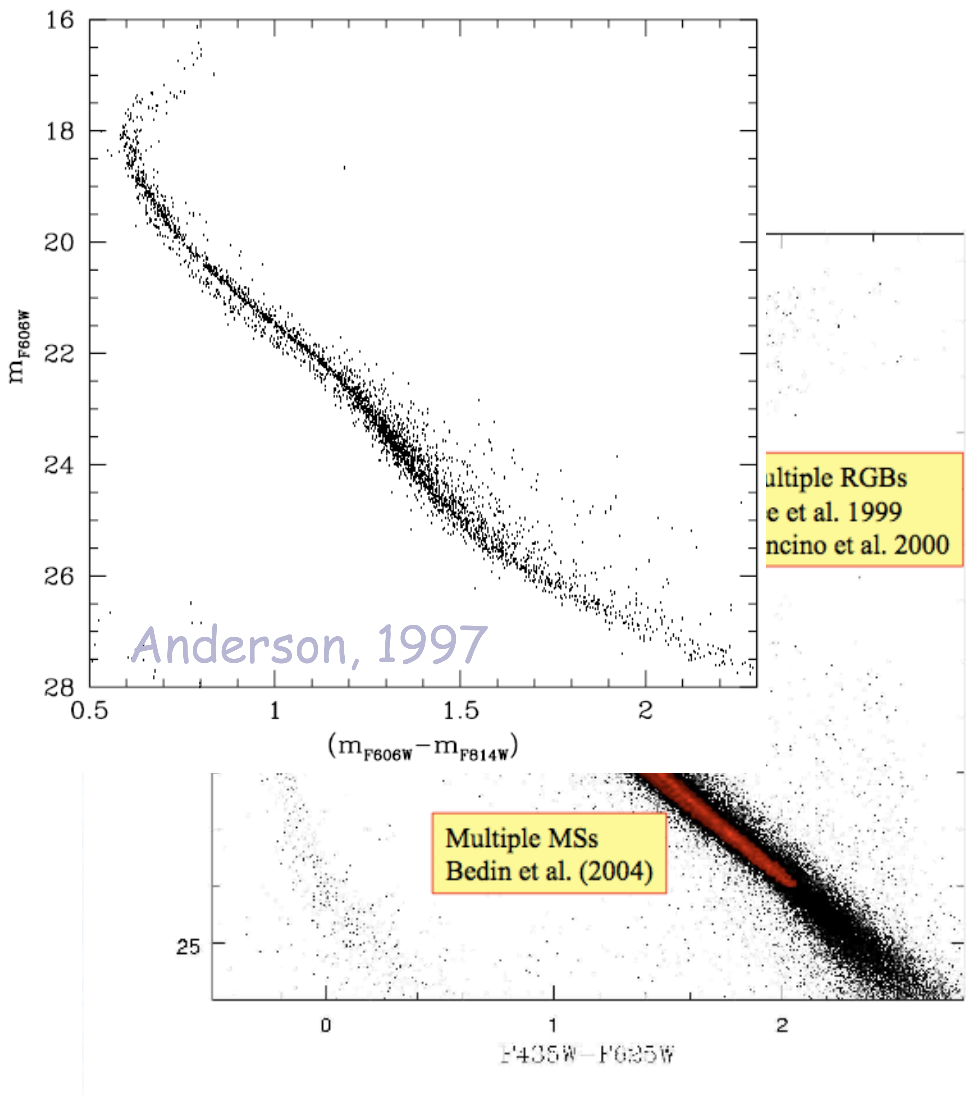
✓M ≤ few × 10^6 $M_\odot$

Considered SSP systems:

Born at the same time with the same chemical composition.

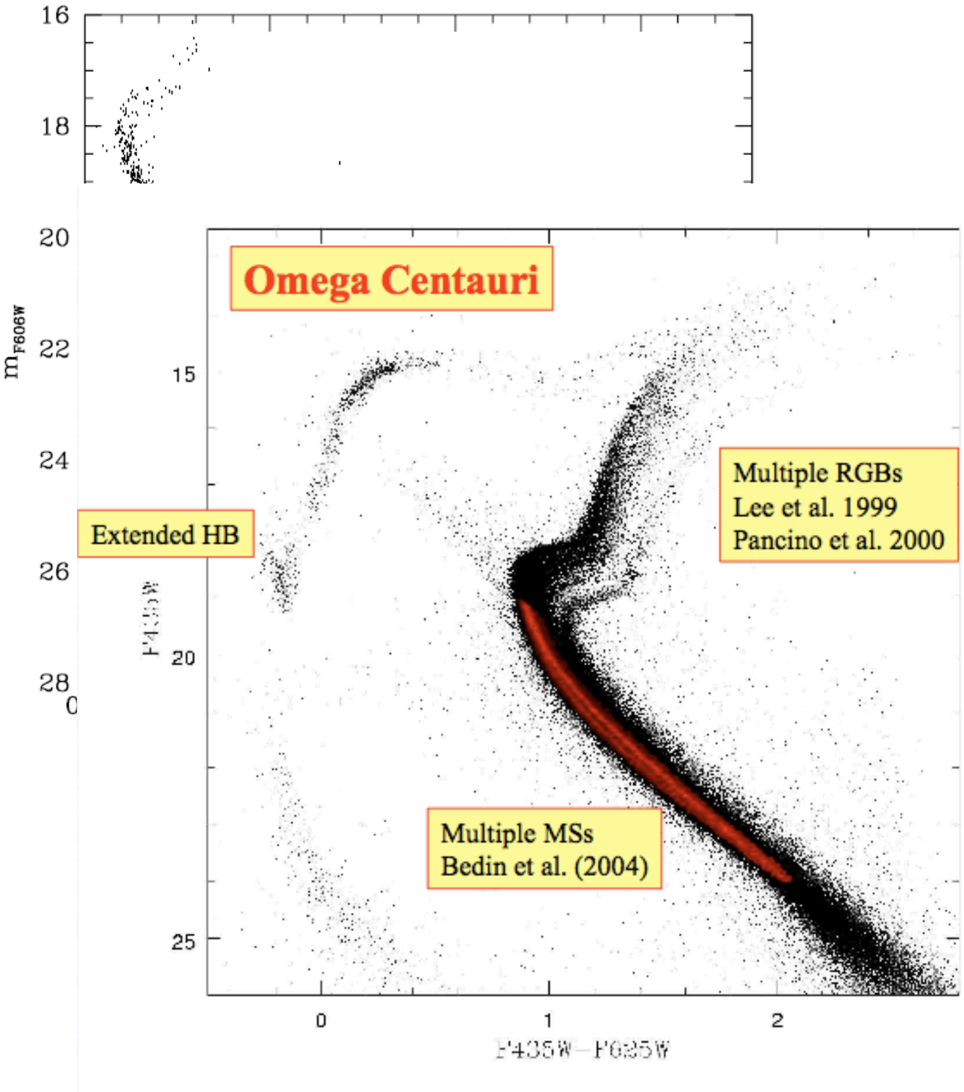
Stars have different masses (distributed according to an IMF).

Multiple stellar generations in GCs



- ✓Stars in globular clusters are not chemically homogeneous (see Gratton 2012 and references therein).
- ✓Star-to-star abundance variations of some light elements;
- ✓Overabundance of helium in younger stars;
- ✓The formation of MSGs is still debated: gas ejected from AGB stars?

Multiple stellar generations in GCs



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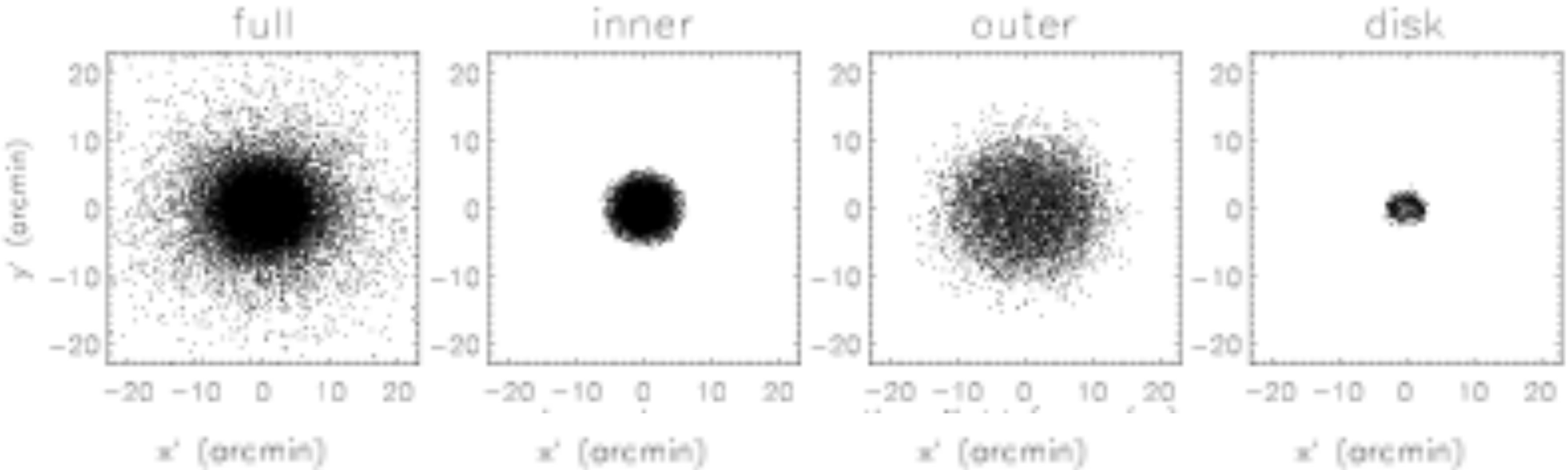
An anomalous cluster: ω Centauri

Very massive ($2.5\times10^6 M_\odot$, Van de Ven et al. 2006);

- ✓Very luminous;
- ✓Flattened structure;
- ✓Wide range of metallicities;
- ✓Multiple stellar populations.

A central disk in ω Centauri



Van de Ven et al. (2006)

Radius between 1 and 3 arcmin and average flattening of ~0.60; contributing about ~ 4% to the total mass of the cluster, i.e. ~ 10^5 $M_{\odot}$.

Its presence could be closely related to the existence of MSGs in ω Cen and inside other GCs (Bekki 2011, 2010).

The stellar disk evolution

● We studied the dynamical evolution of a central disk structure by means of N-body simulations (Mastrobuono-Battisti & Perets 2013, ApJ, Mastrobuono-Battisti & Perets in Prep.);

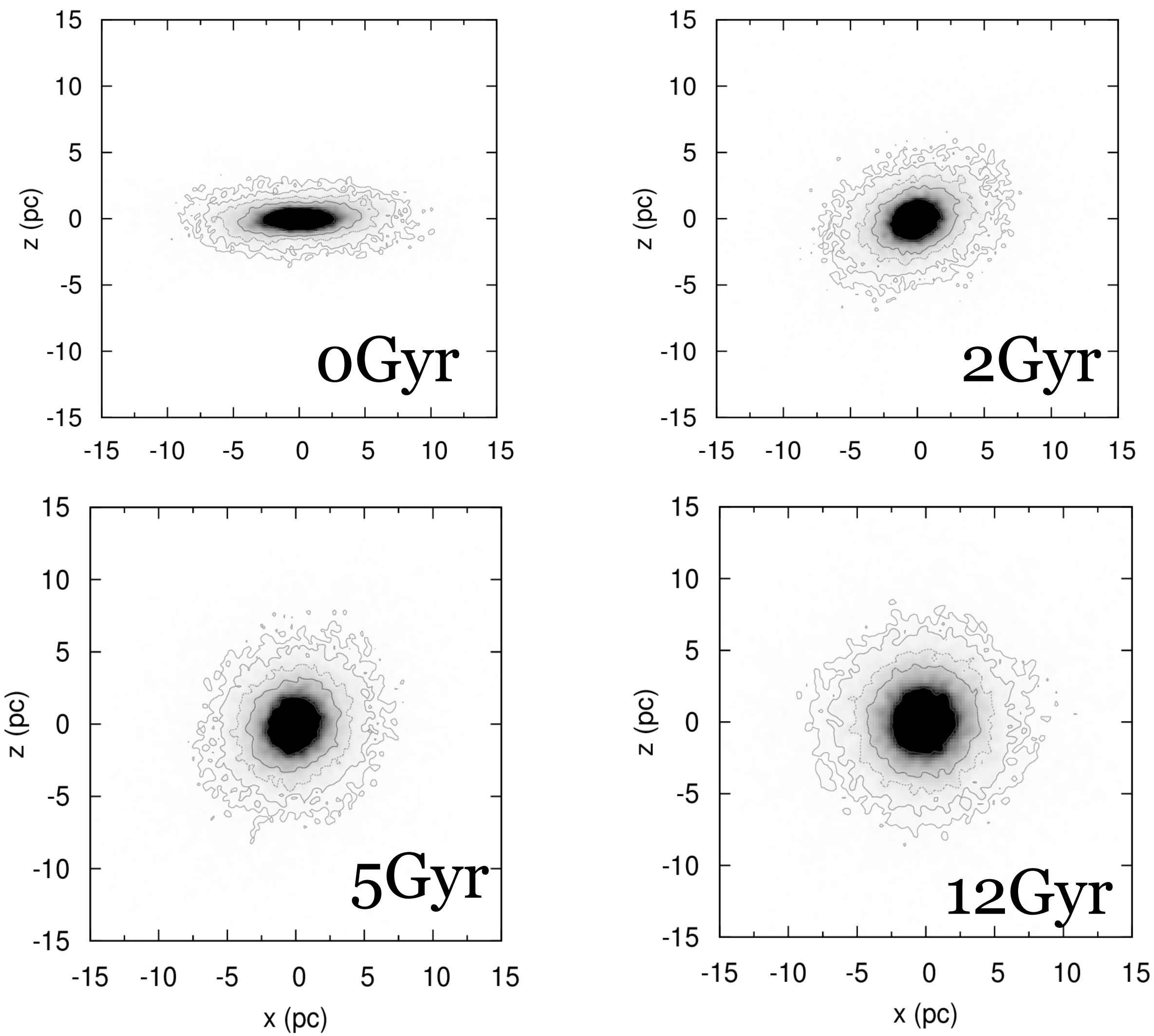
● These simulations were done using φGrape and φGPU (Harfst et al. 2006, Berczik et al. 2013): direct N-Body codes;

Different sets of simulations with several initial conditions:

ω Cen like initial conditions: r_c = 4.6 pc, W0 = 5.5 (Meylan 1987) and $2.5 \cdot 10^6$ $M_\odot$, N=100,000. The disk mass is 10^5 $M_\odot$; R=4.5 pc, velocity dispersion similar to that observed and N_d=4000. $\varepsilon = 5 \cdot 10^{-3}$ pc

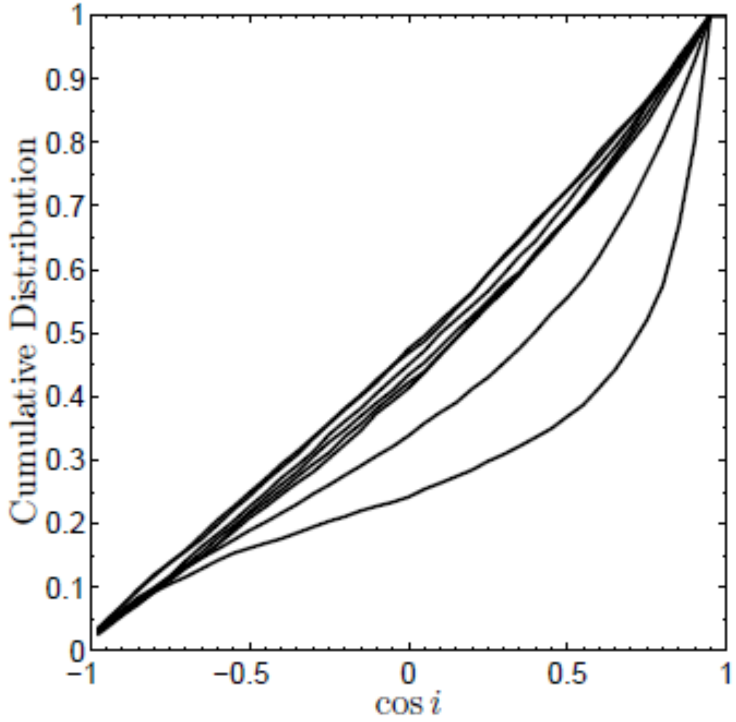
A generic dense stellar cluster: King model with r_c = 4.5 pc, W0 = 6 (Meylan 1987) and 10^6 $M_\odot$, N=50,000. The mass of the disk is 50%, 40% and 30% of the initial mass of the cluster. 3 disks, with R=4pc. $\varepsilon = 10^{-4}$ pc

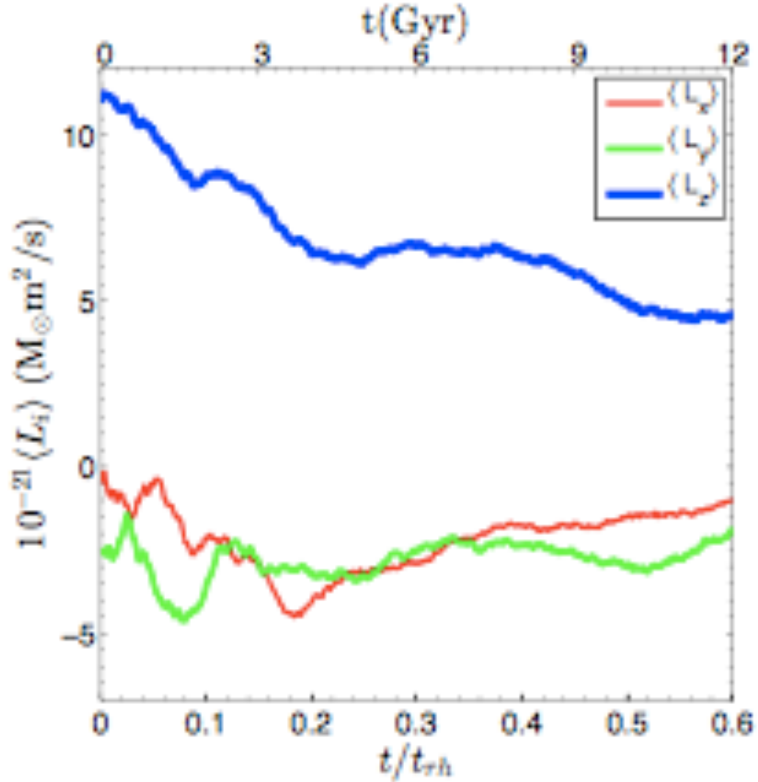
Isodensity contours: the edge-on view of the disk



Mastrobuono-Battisti & Perets (2013)

Orbital inclination and angular momentum

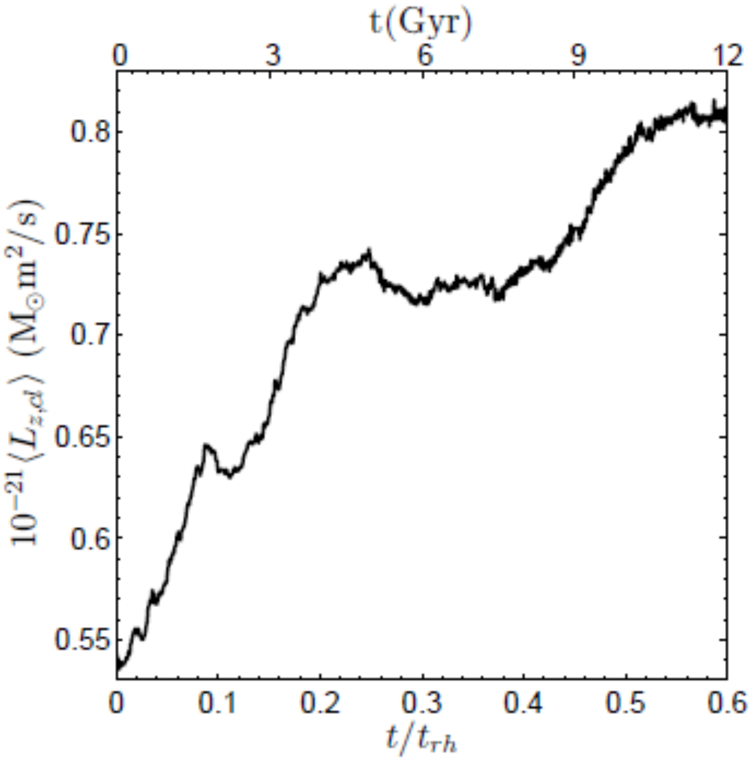


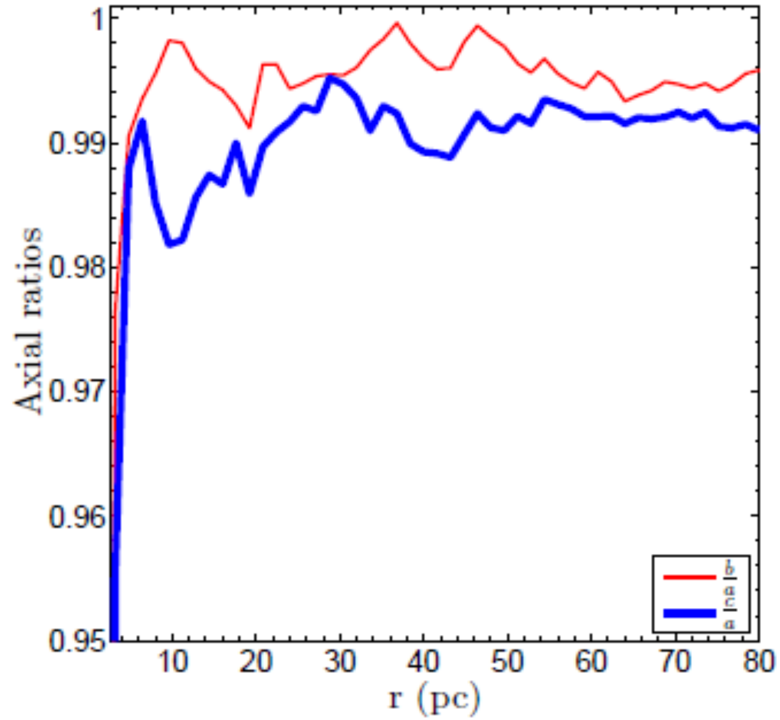


Mastrobuono-Battisti & Perets (2013)

The initial disk becomes more isotropic with time. It loses angular momentum that is redistributed among the stars in the cluster (MB & Perets 2013).

Angular momentum and velocity dispersion



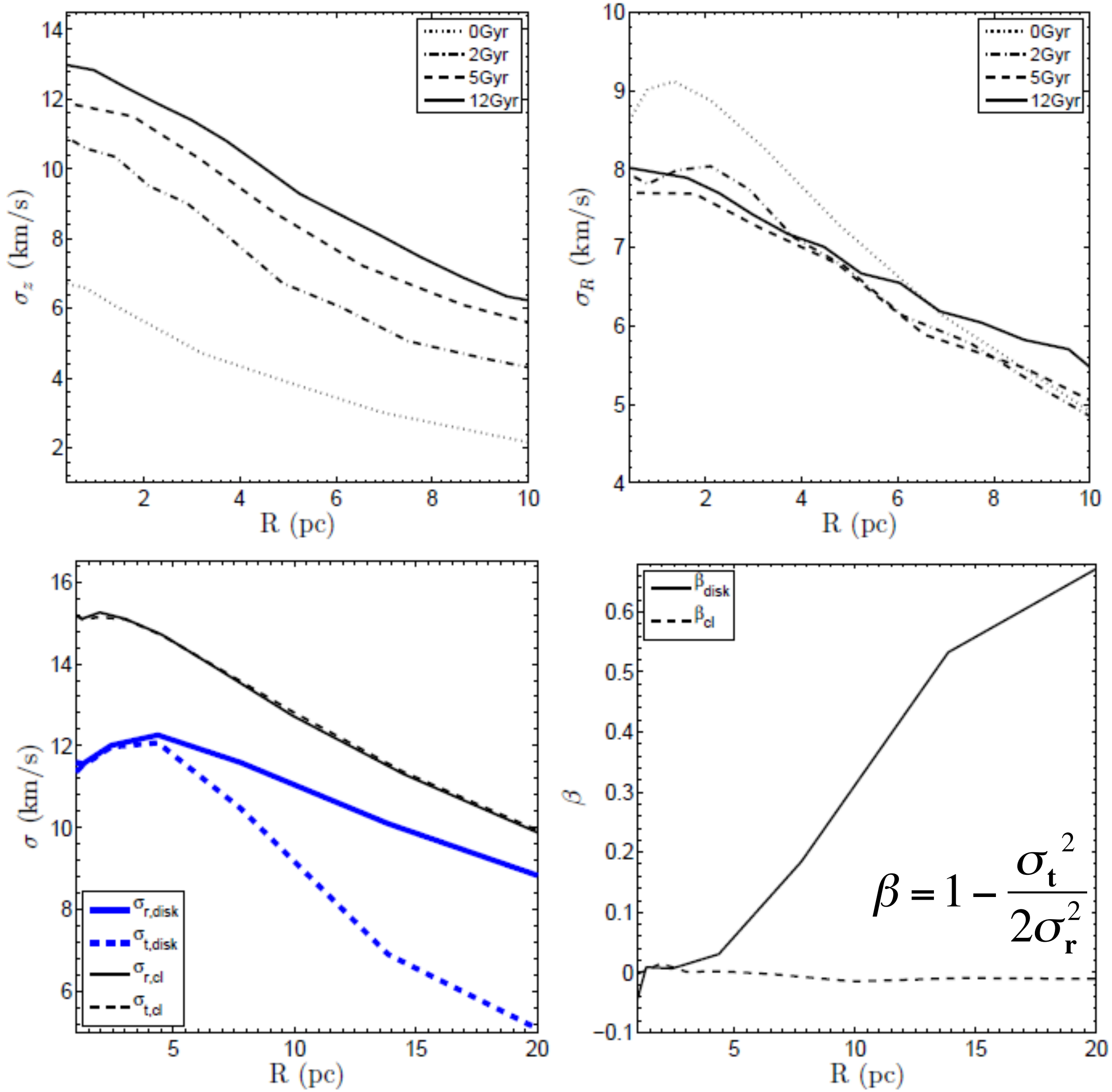


As the second generation disk stars isotropize they exchange angular momentum with the first generation cluster stars, a process which consequently leads to the slight flattening of the host cluster.

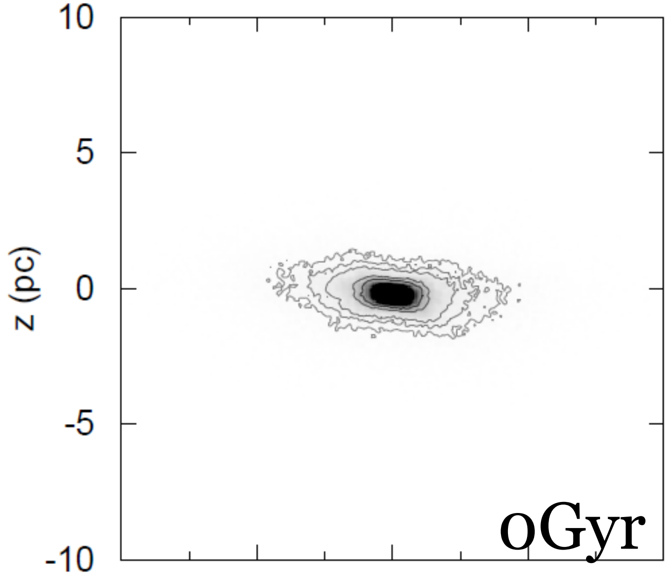
Kinematical signatures of the disk

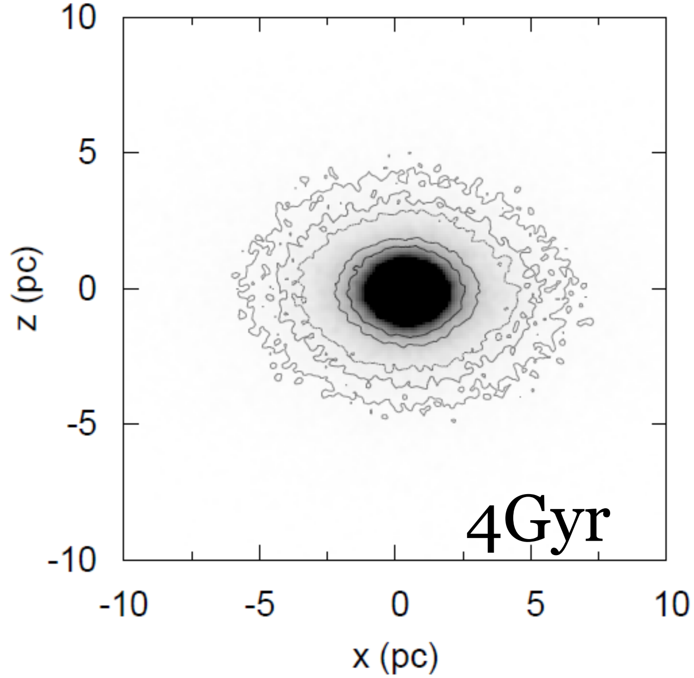
The disk leaves kinematical signatures even after the long term evolution of the system.

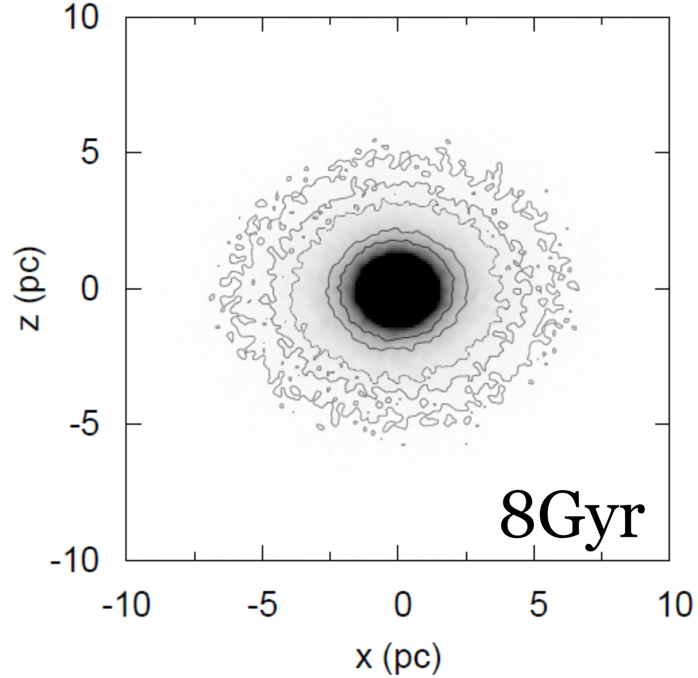
Richer et al. (2013) have found similar properties in 47 Tuc.



Repeated stellar formation episodes in disks: 50%

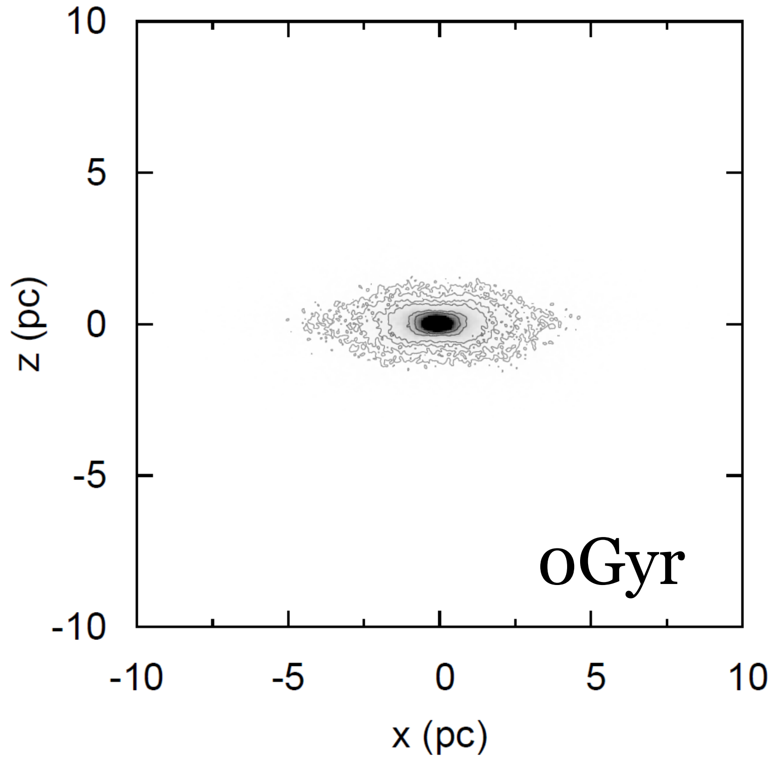


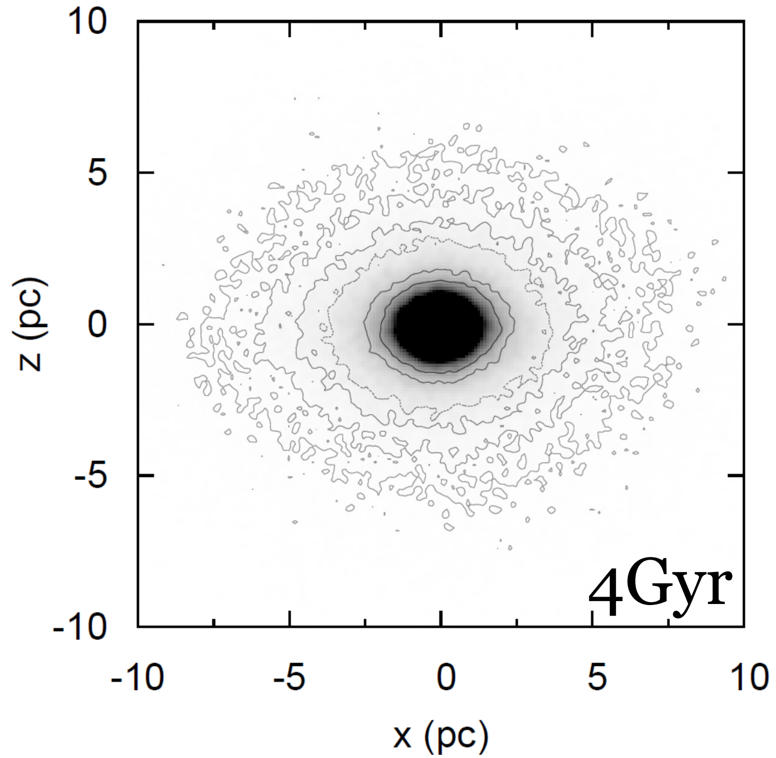




After 8Gyr of integration the central disk-like structure, formed by the 3 original disks has not yet become isotropic, we plan to simulate the system for 4 more Gyr.

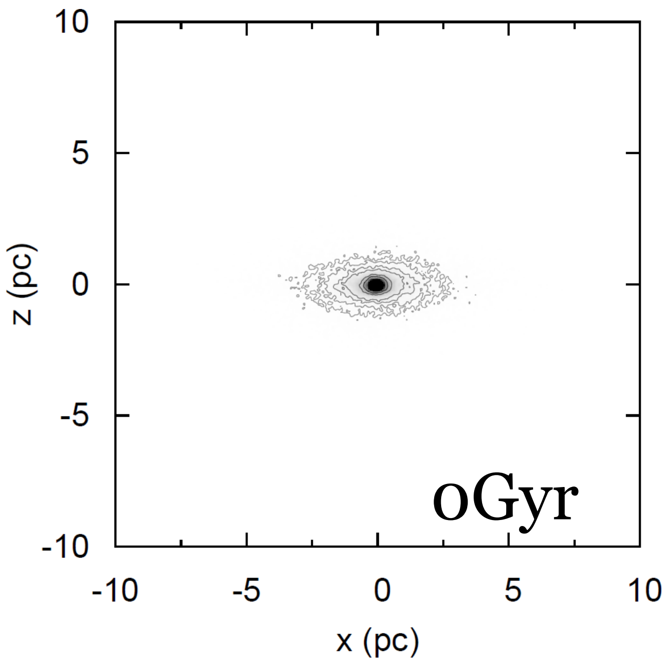
Repeated stellar formation episodes in disks: 40%

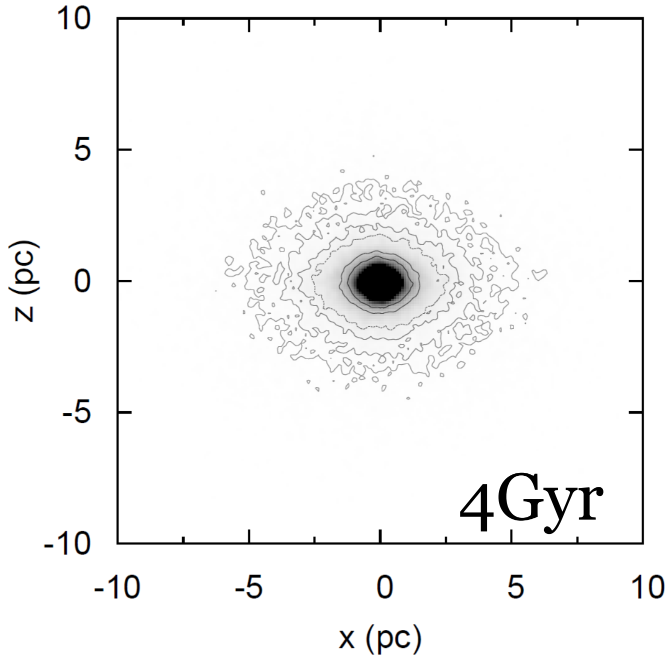


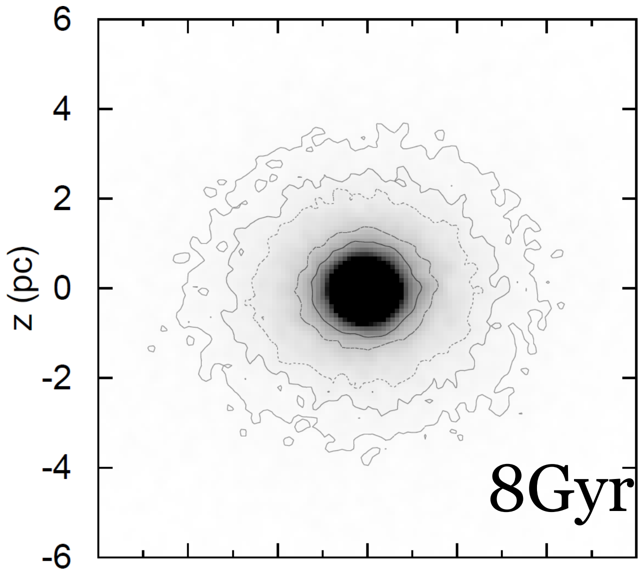


In this case we have only 4Gyr of simulation, the disk-like structure looks more isotropic and extended than in the previous case.

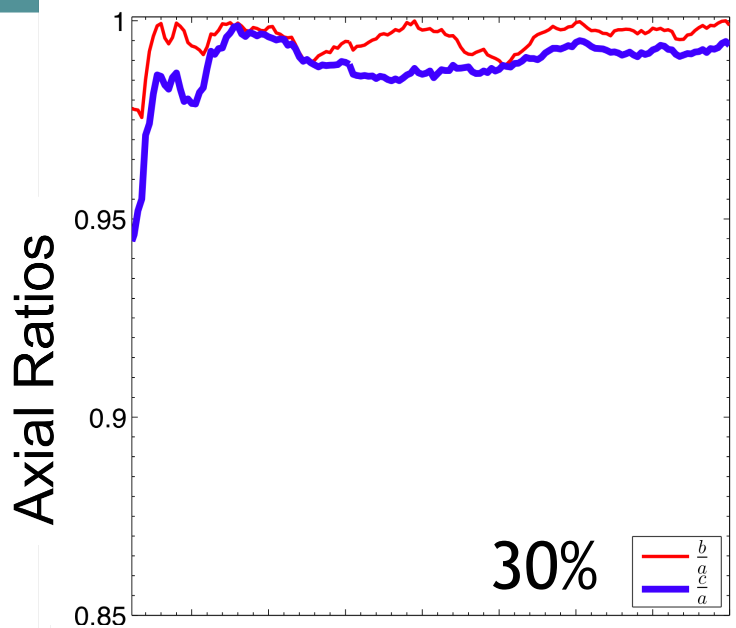
Repeated stellar formation episodes in disks: 30%

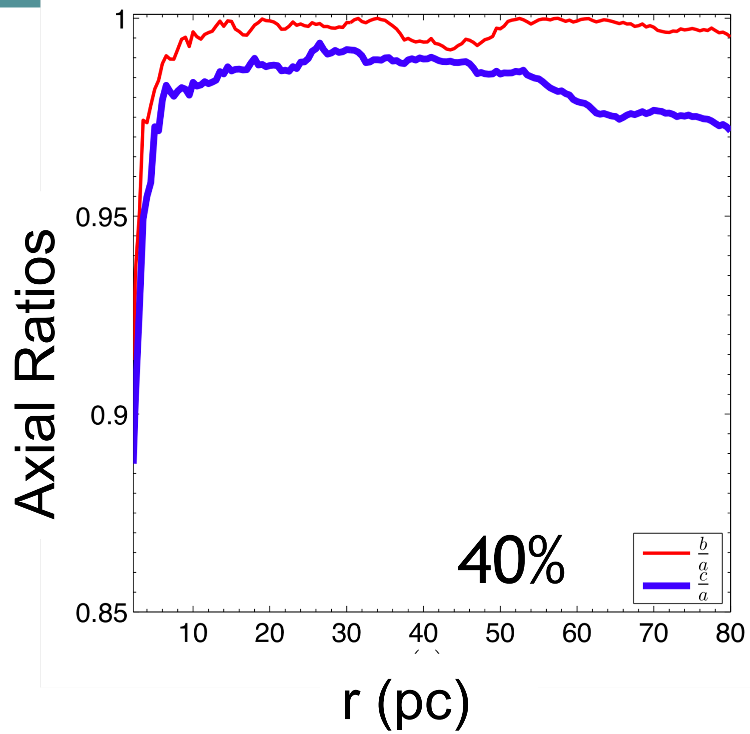


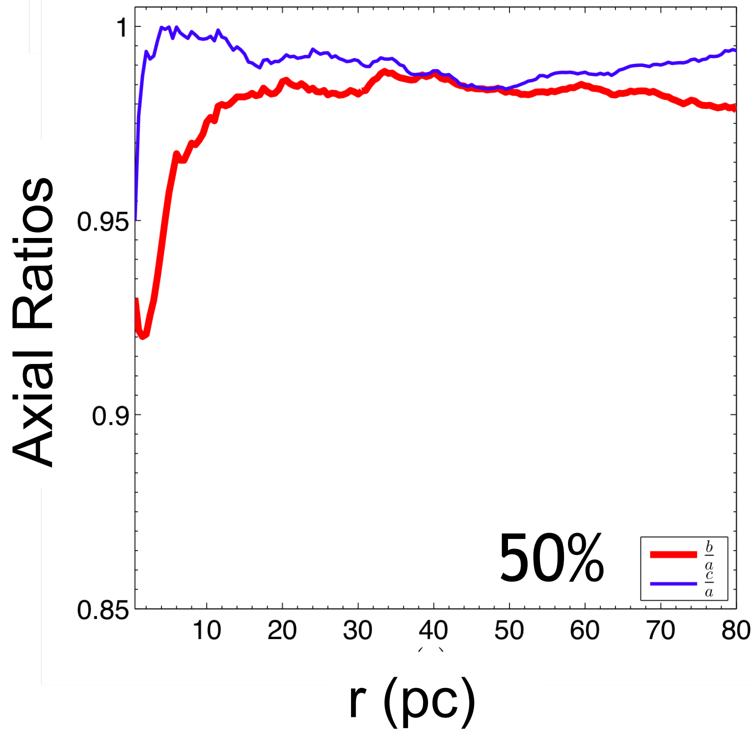




Fabricius et al. 2014 found a relation between the tight correlation between central rotation and outer ellipticity. After 4Gyr we find that the external ellipticity of the simulated clusters is related to the mass of the disks (ε≈0.01, 0.006, 0.002).





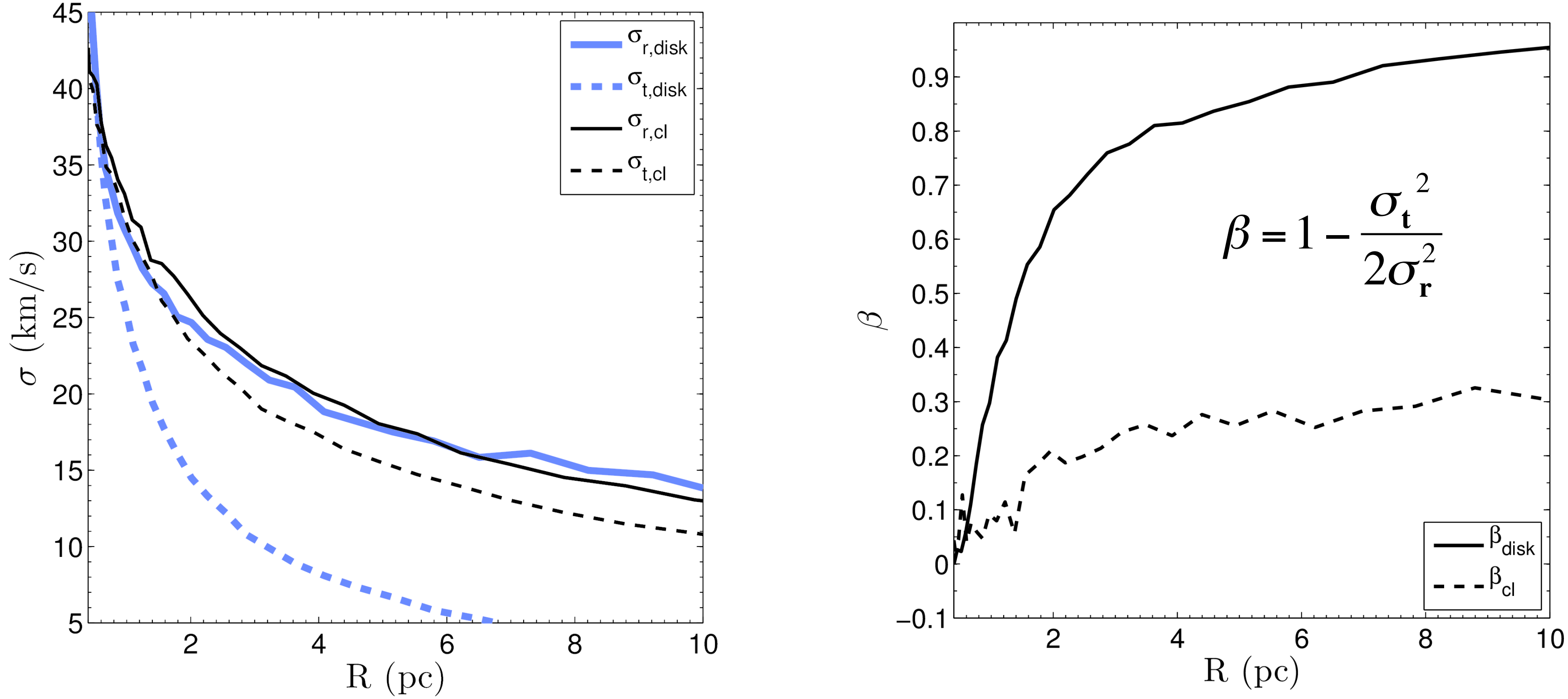


Axial ratios for the spherical components in the 3 simulations run, after 4Gyr.

b/a

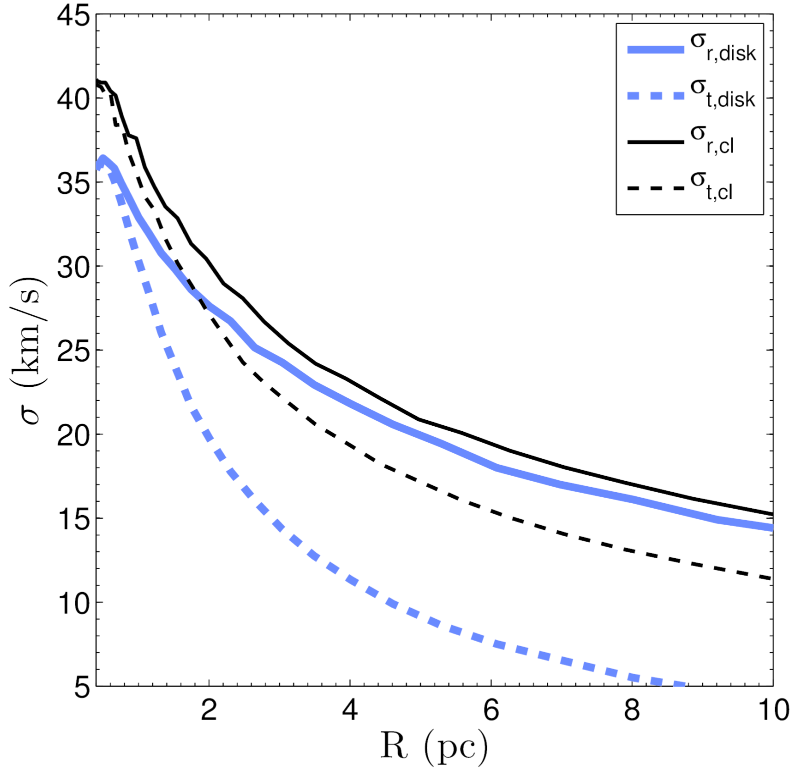
c/a

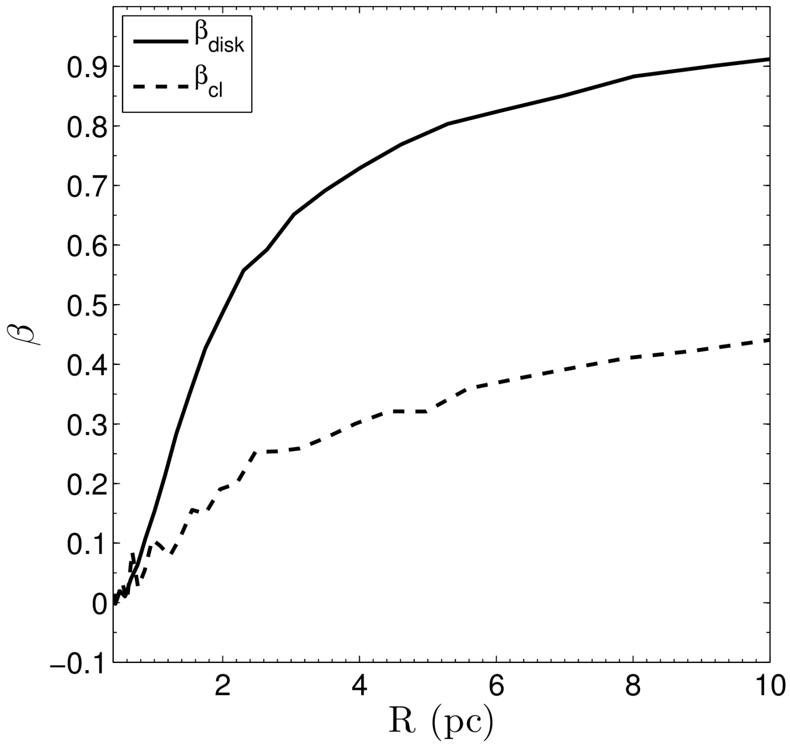
Velocity dispersion and anisotropy after 4Gyr: 30%



30% simulation: velocity dispersion of the disk and of the spherical component. Anisotropy parameter of the same sub-systems. We included the 3 disks together.

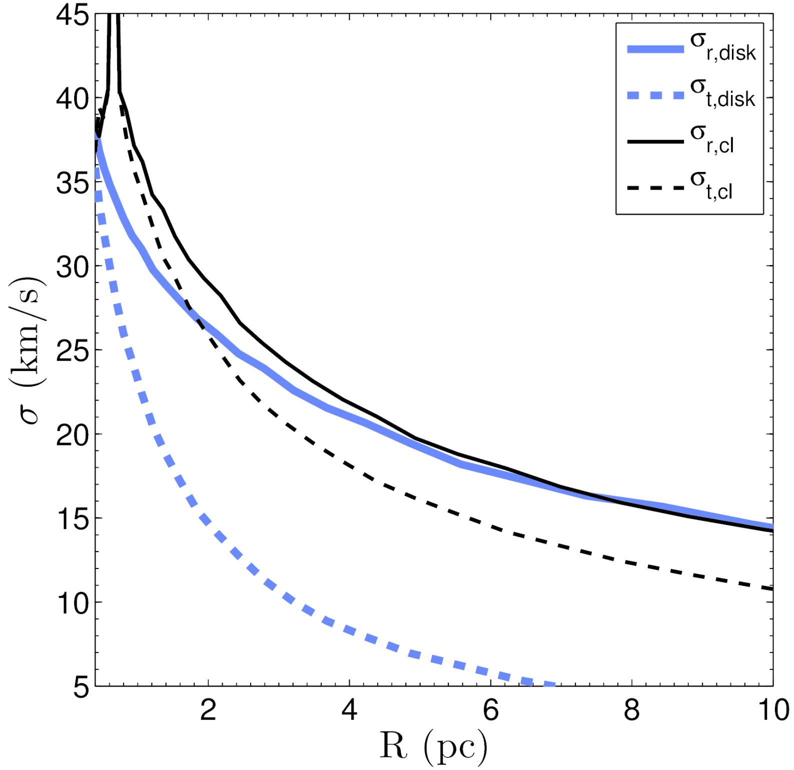
Velocity dispersion and anisotropy after 4Gyr: 40%

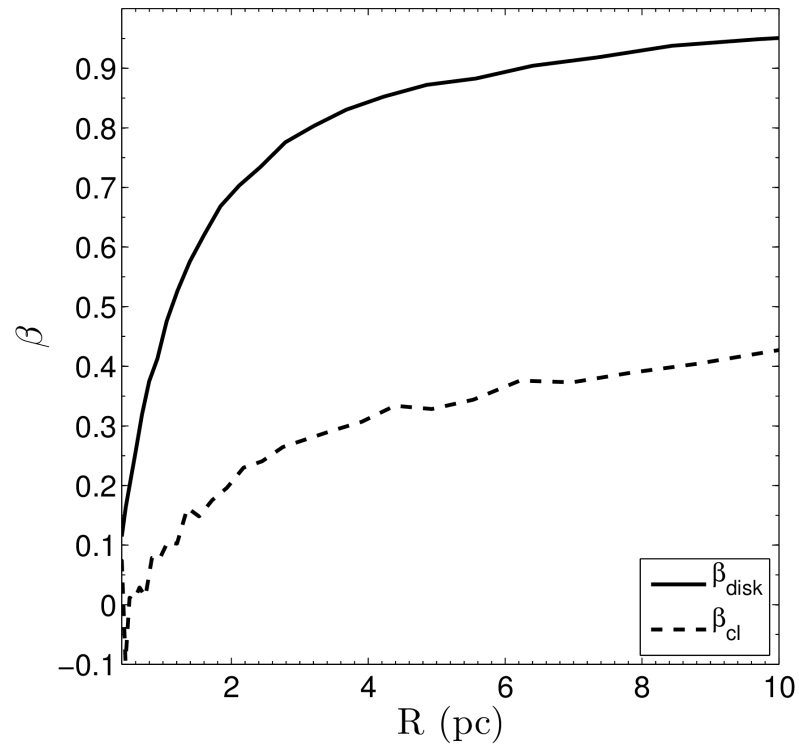




40% simulation: velocity dispersion of the disk and of the spherical component. Anisotropy parameter of the same sub-systems. We included the 3 disks together.

Velocity dispersion and anisotropy after 4Gyr: 50%





50% simulation: velocity dispersion of the disk and of the spherical component. Anisotropy parameter of the same sub-systems. We included the 3 disks together.

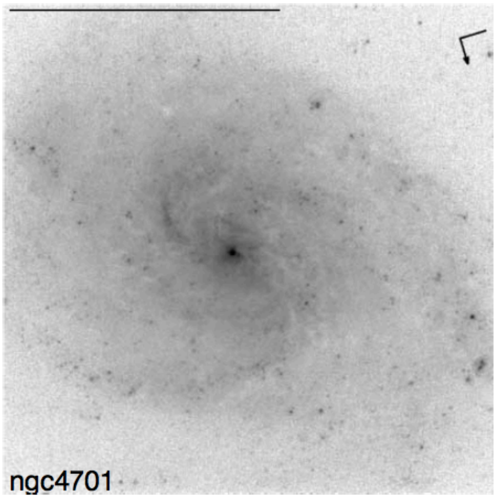
Conclusions

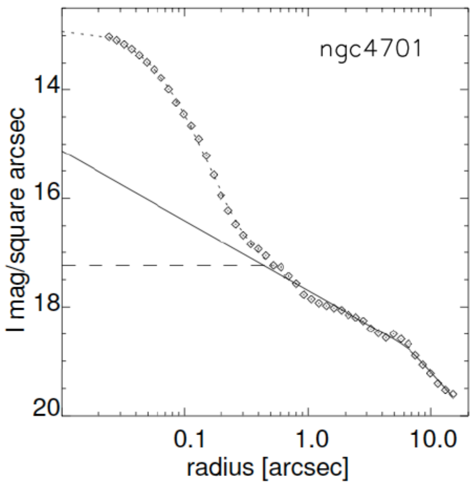
- GCs are made of several generation of stars whose origin is still unclear;
- Second generation stars could be born in disks;
- N-body simulations to explore the long-term evolution of stellar disks embedded in dense stellar cluster;
- The disks evolves toward isotropy but it leaves several kinematical and spatial signatures of its presence;
- Moreover it affects the evolution of the cluster;
- Second generation stellar populations in GCs and NCs with longer relaxation times are likely to show stronger anisotropies;
- From the signatures we can infer the dynamical age of the stellar populations.

Thank you!

Stellar clusters

Open clusters



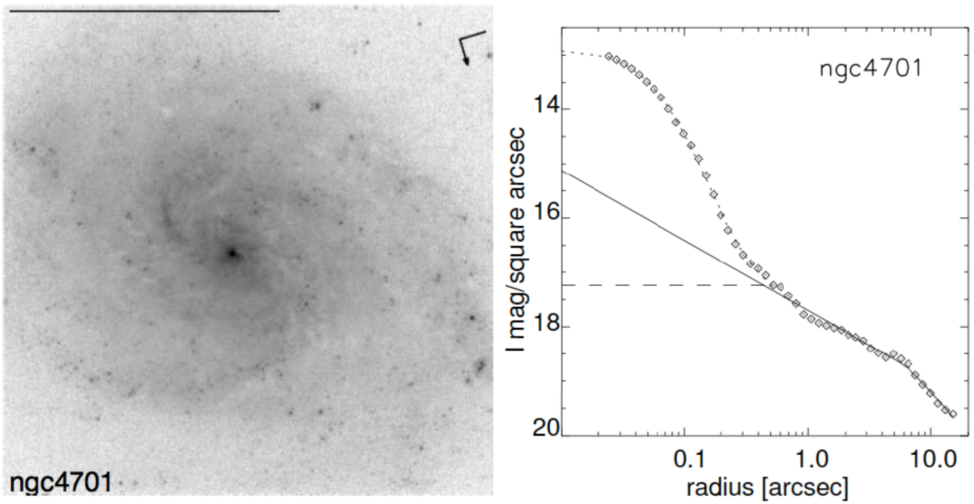


Globular clusters

and Nuclear clusters

Stellar clusters

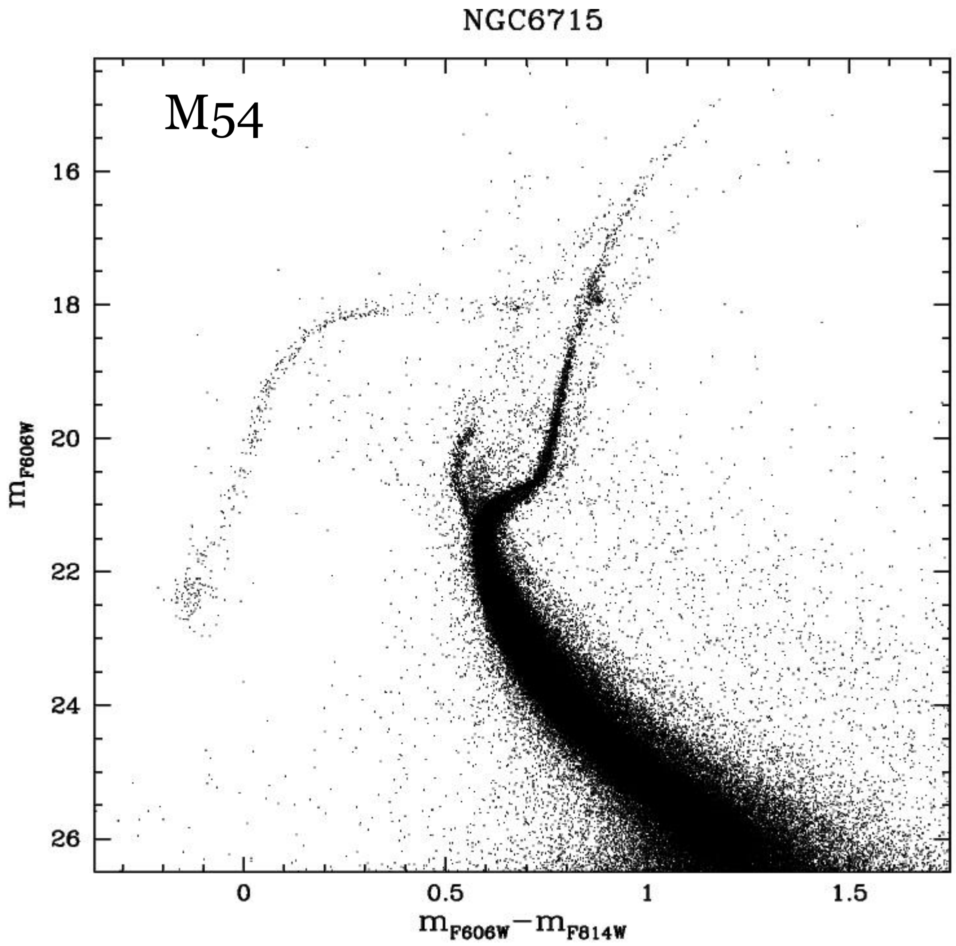
Open clusters

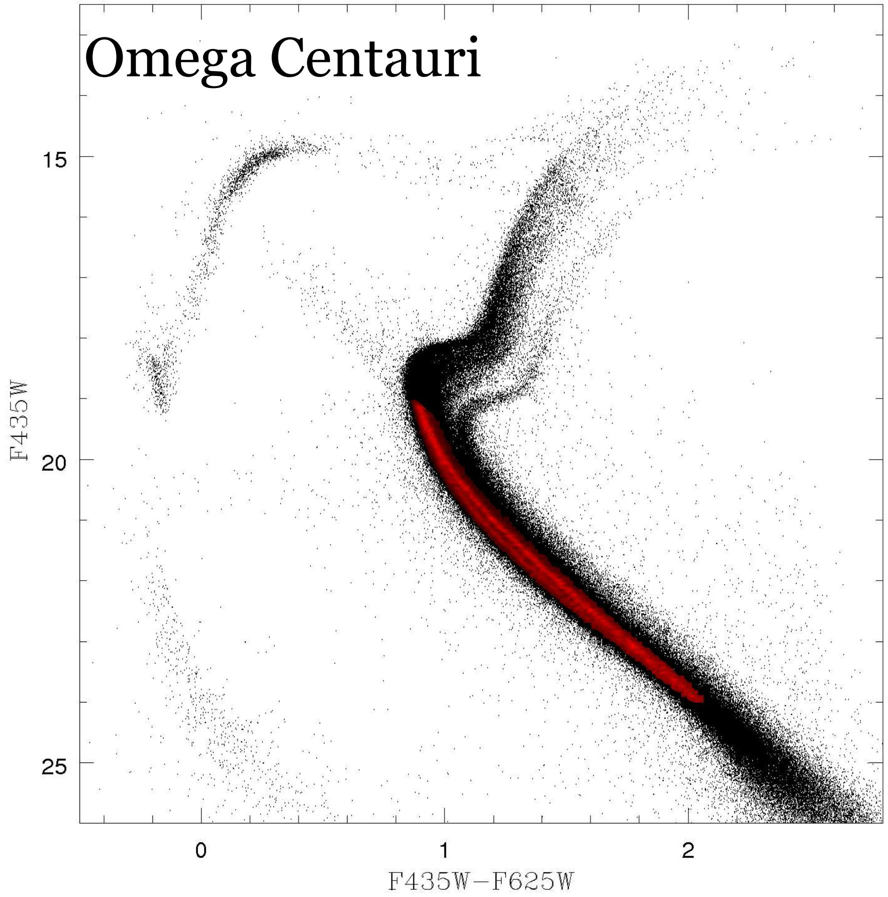


Globular clusters

and Nuclear clusters

Is ω Centauri a GC?





Various simulations

Label	N	$m_{*,1}$ $M_\odot$	$m_{*,2}$ $M_\odot$	M_{disk} $M_\odot$	r_d pc	potential
S1,2,3	4000	25	0	10^5	4.5	isolated
S4	4000	25	0	10^5	4.5	tides
S5	10000	25	12.5	1.5×10^5	4.5	isolated
S6	2500	100	10	10^5	4.5	isolated
S7	8000	12.5	0	10^5	4.5	isolated

Different initial conditions for the disk, to check our assumptions.

Rescaling

We used less numerous and more massive stars to represent the cluster. We also used a softening length. Thus we had to rescale the time of the system to the properties of the real counterpart. We used Aarseth and Heggie (1998) prescription:

$$t = t^* \frac{t_{rx}}{t^*_{rx}}, \qquad t_{rx} = \frac{0.065\sigma^3}{\rho m G^2 \ln \Lambda}, \qquad t = t^* \frac{m^* \ln \Lambda^*}{m \ln \Lambda},$$

$$t = t^* \frac{m^* \ln(r_t/\epsilon)}{m \ln(N)}$$