Signature of the dynamical evolutionary state of GCs

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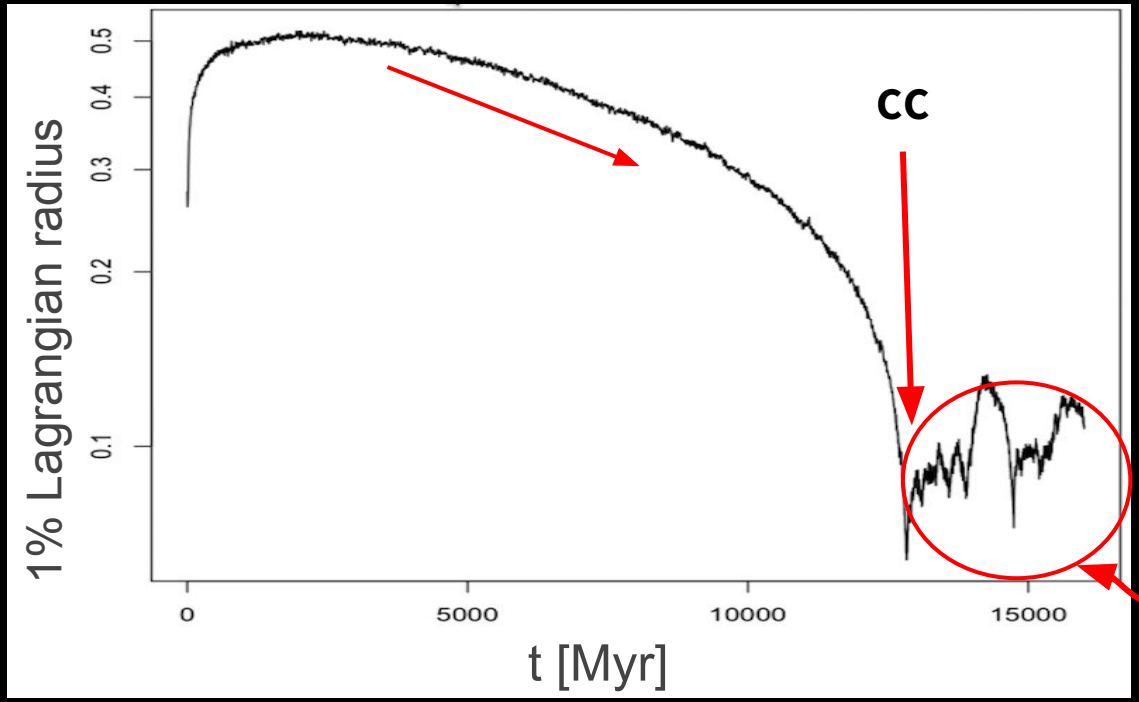
Dynamical Phases



1% Lagrangian radius- Radius containing 1% total mass of the cluster.

Core Collapse (CC)
(see eg. Spitzer 1987, Meylan and Heggie 1997)

CC halted by binary systems

Gravothermal oscillations
(see eg. Bettwieser and Sugimoto 1984, Makino 1996)

In the Milky Way, all GCs are ~11- 13 Gyr old ! What dynamical phases are they in?

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Cluster properties

- primordial binaries
- Dark remnants
- Tidal field of the galaxy ...

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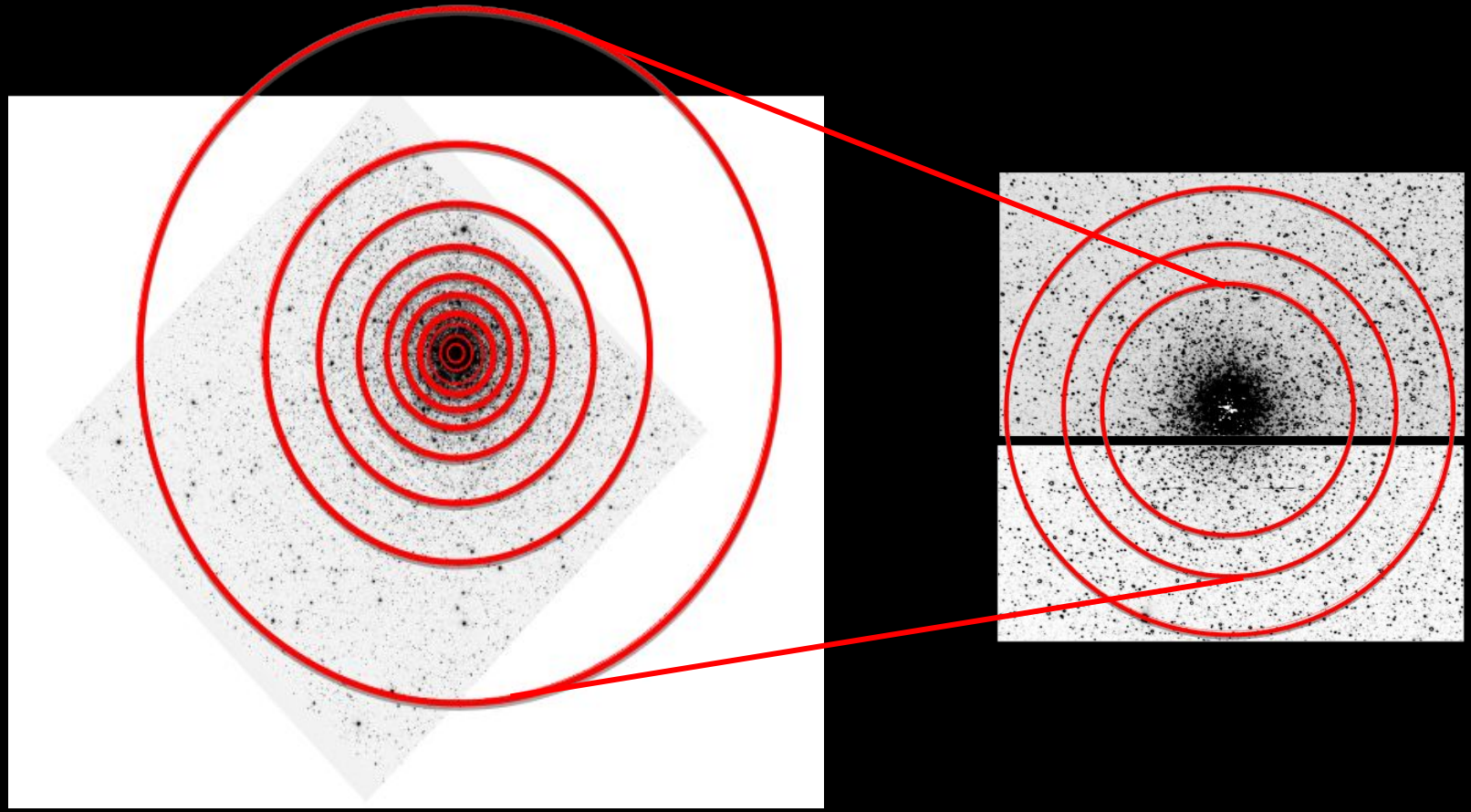
Clusters with same age may have different dynamical ages

Observed number density profiles of GCs



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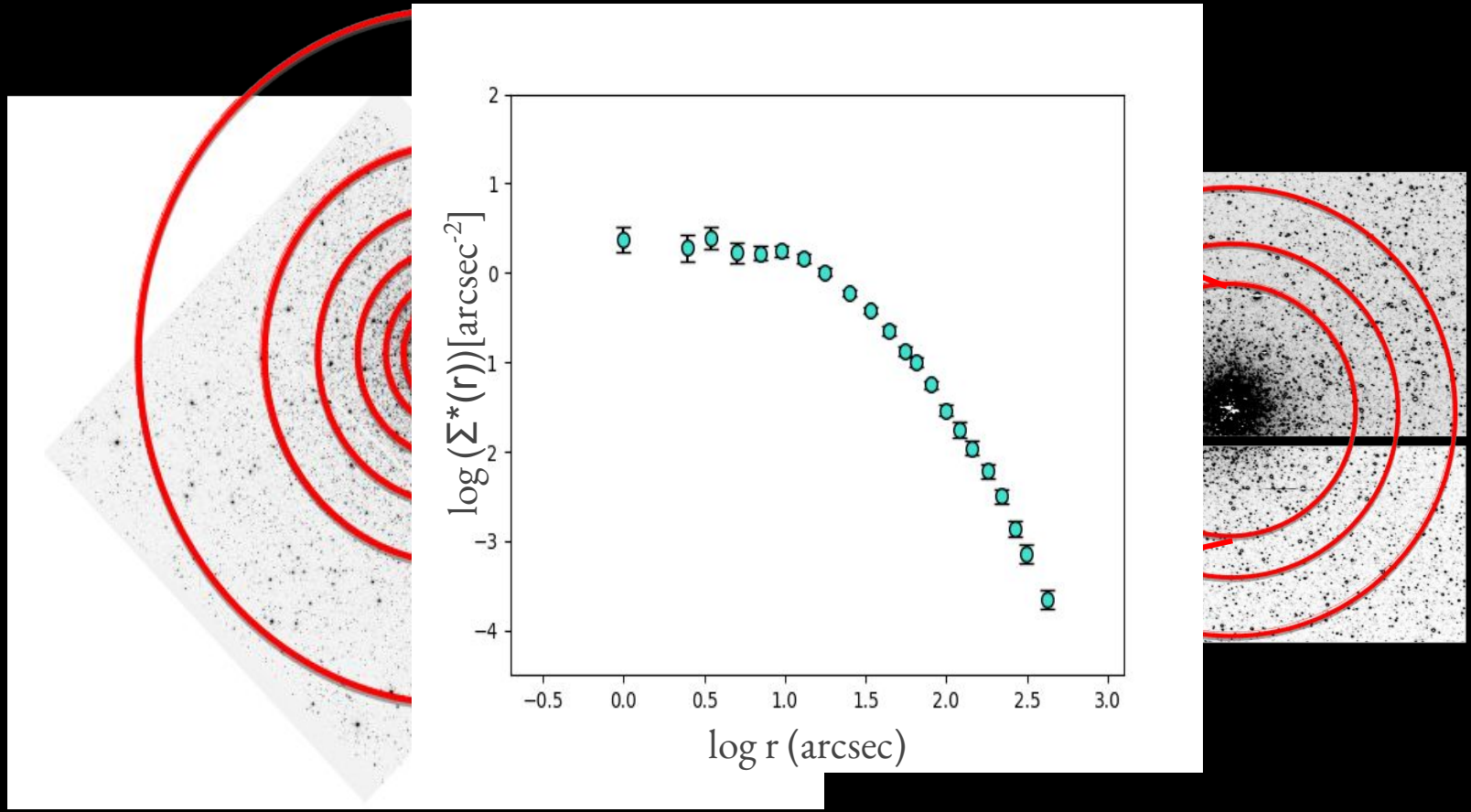

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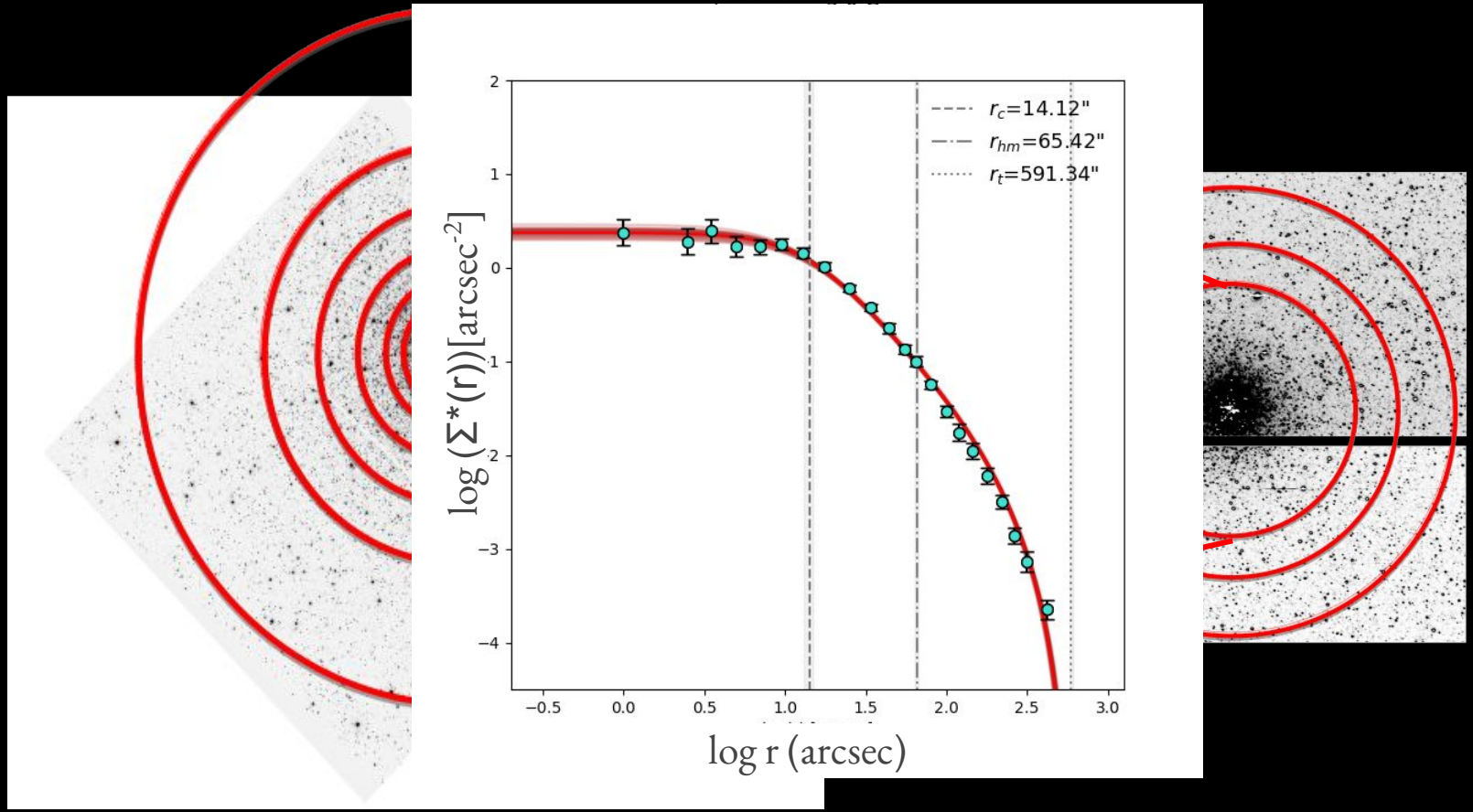
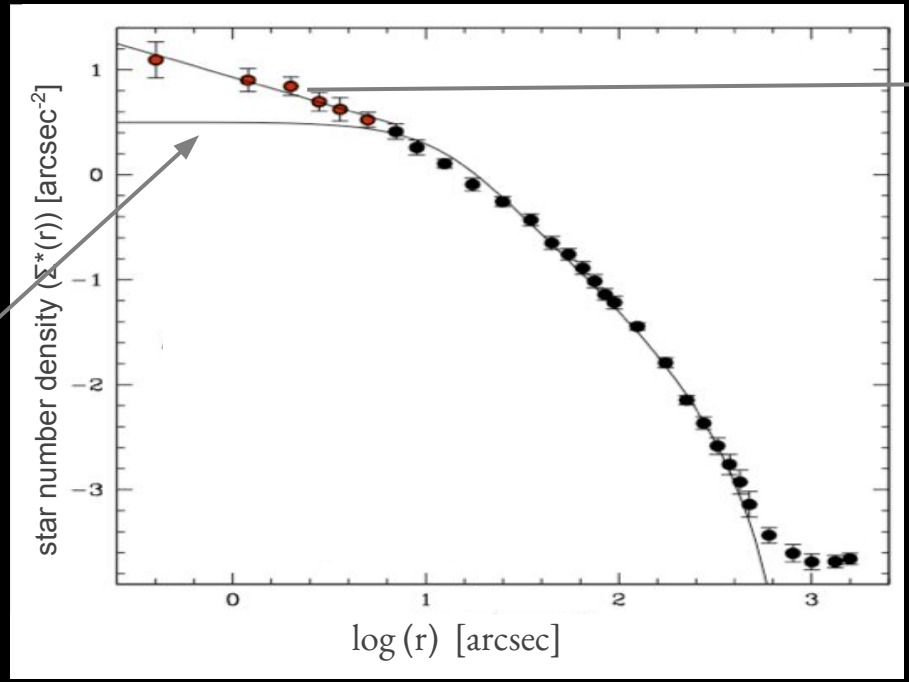


Density profile of Core Collapsed GC

King model can't reproduce density of post core collapse GCs which exhibit a **central power-law cusp**:



Density Cusp as a diagnostic

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Steep power-law cusp in the density profile near the centre

Post-Core Collapse Cluster

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Steep power-law cusp in the density profile near the centre

Post-Core Collapse Cluster

From Observations ⇒ only **15-20%** of GCs are PCCs

We may expect more (short central relaxation times).

Density Cusp as a diagnostic

Steep power-law cusp in the density profile near the centre

Post-Core Collapse Cluster

Is the presence of density cusp a reliable diagnostic??

Observational diagnostics of dynamical phases of GCs

To find alternative observational diagnostics to identify dynamical phases of clusters and study their dependence on cluster properties.

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Monte Carlo simulations of GCs (MOCCA code, Giersz et al. 2008)

Initial conditions :

- **500k** particles, no primordial binaries
- Stars distributed following **King model (concentration ~ 1.26)**
- **Kroupa** mass function (0.1- 100 $M_{\odot}$)

Observational diagnostics of dynamical phases of GCs

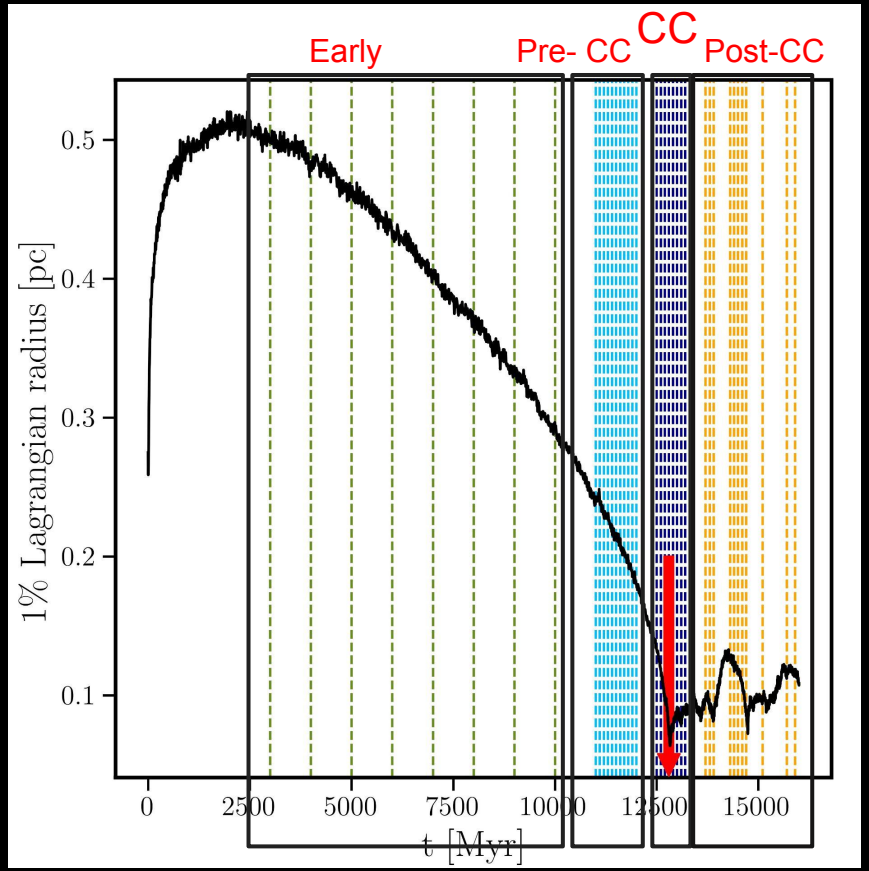
To find alternative observational diagnostics to identify dynamical phases of clusters and study their dependence on cluster properties.

Analysis of simulation -

as an observer

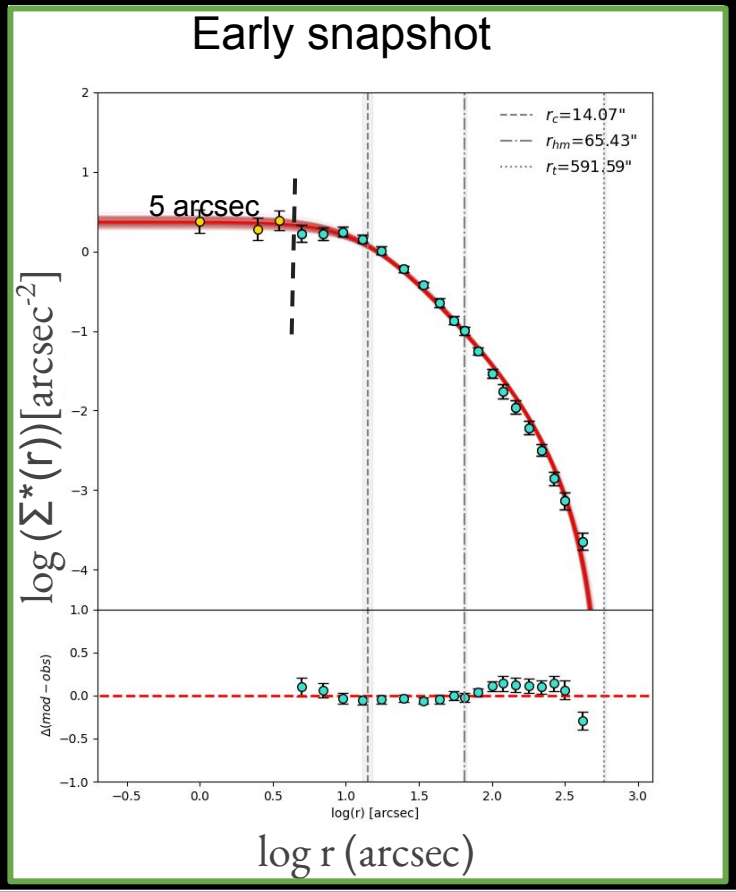
- 10 kpc away from us
- 2D Projection of cluster

‘Observing’ the simulated GC in different dynamical phases



Every snapshot of simulation is treated as an observed GC.

King model fitting to the (number) density profile

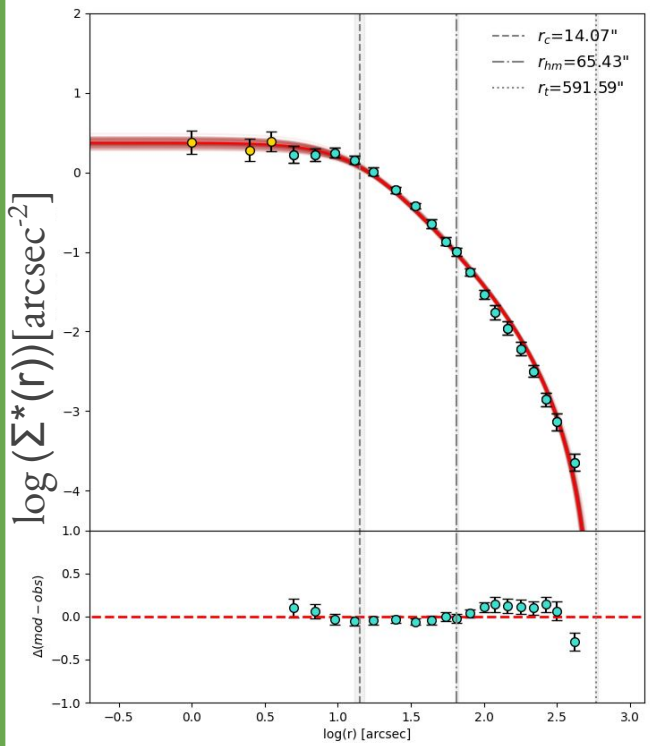


King model

'Observation'

King model fitting to the (number) density profile

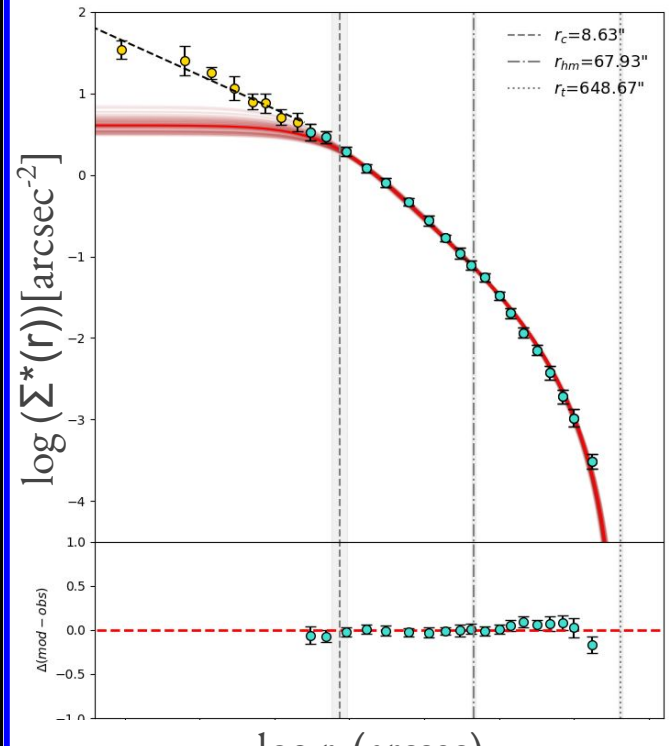
Early snapshot



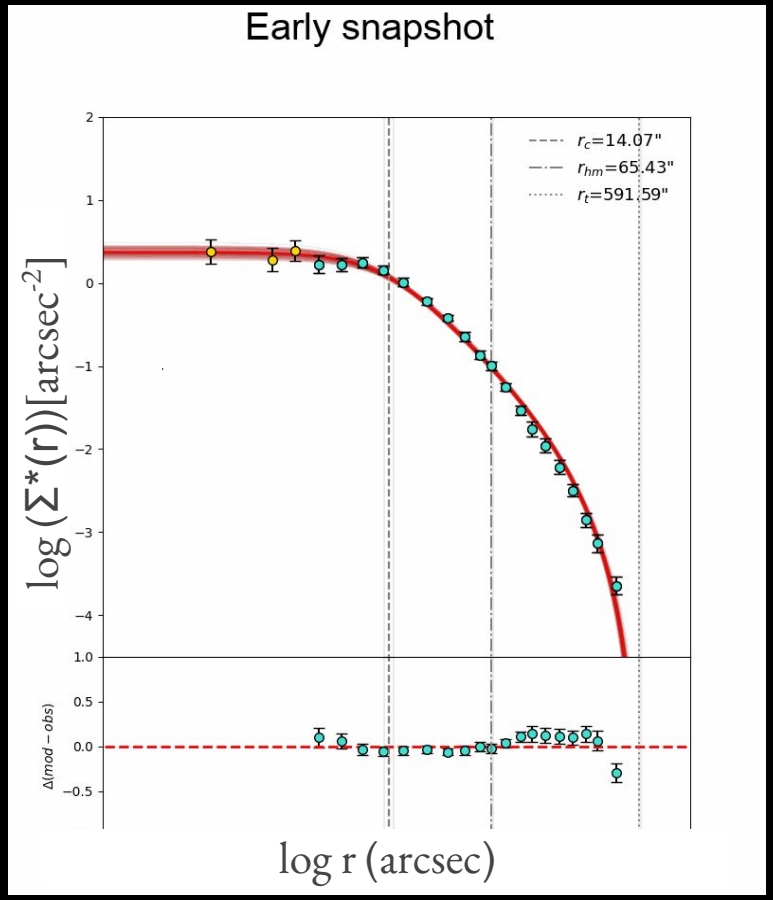
King model
'Observation'

Density cusp - dotted straight line fitting yellow points.

CC snapshot



Evolution of density profiles of 'Observed GC'



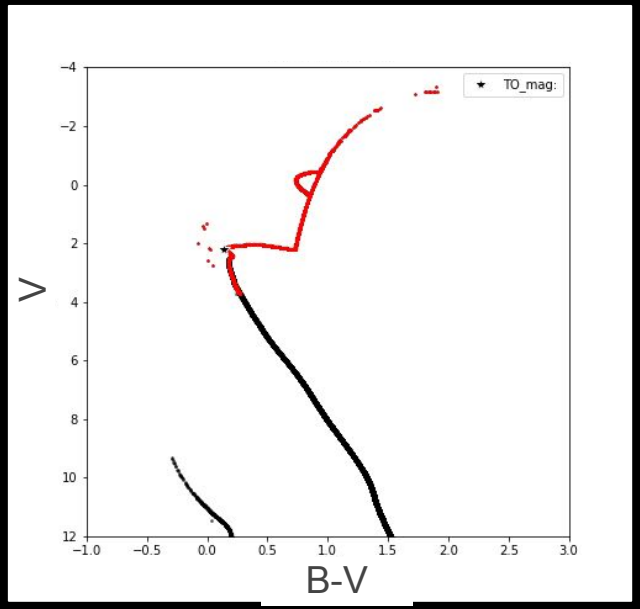
- Distance where density cusp ends- arbitrary choice
- In observations density cusp can be lost: low statistics and radial binning
- Density cusp could be less evident after CC due to Gravothermal oscillations!

New way!

Cumulative Radial Distribution of number of stars

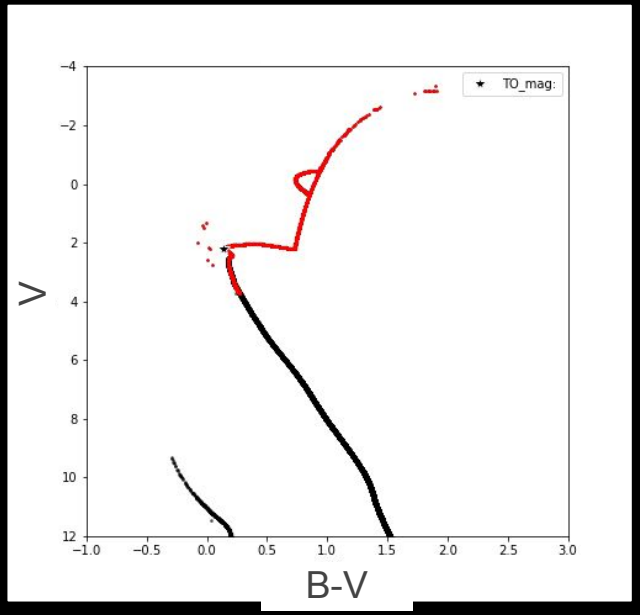
Star selection Criteria for Cumulative Radial Distribution

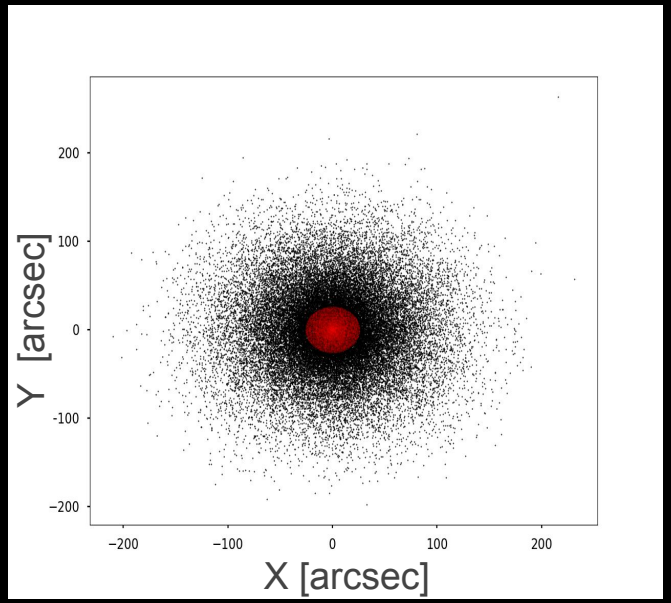
- Stars with $V < V_{TO}+0.5$



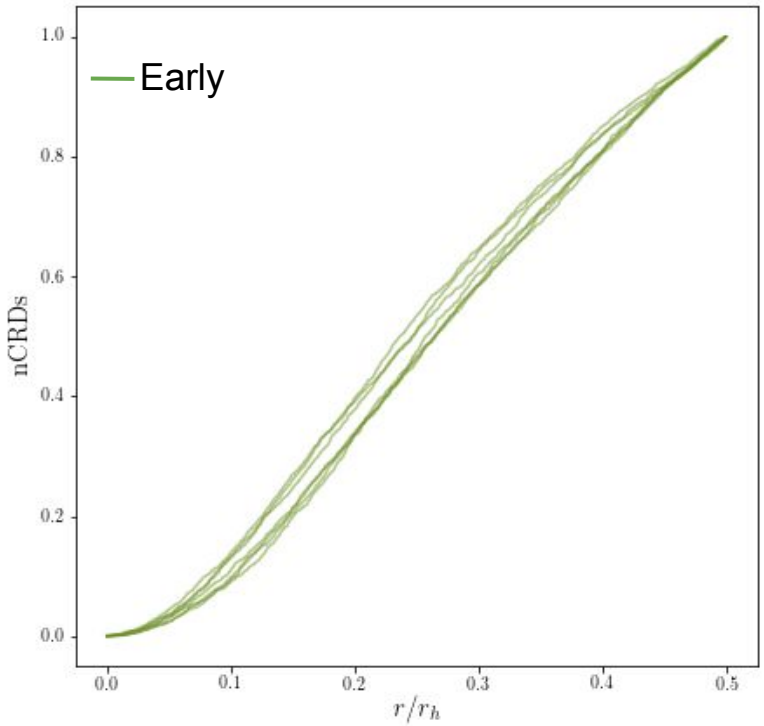
Star selection Criteria for Cumulative Radial Distribution

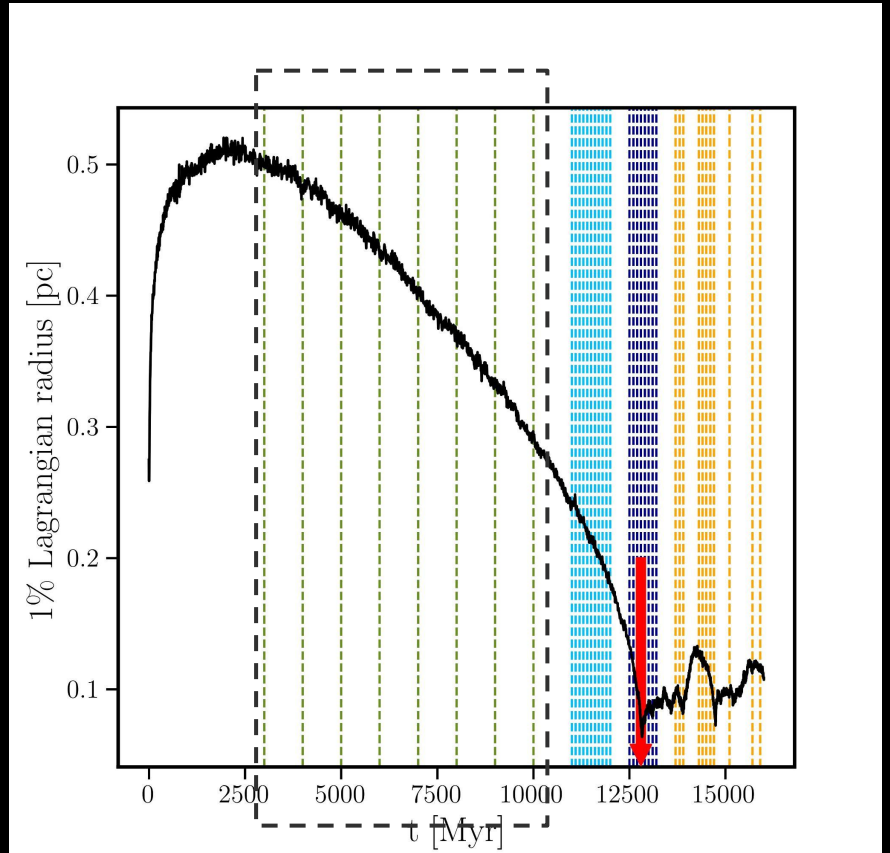
- Stars with $V < V_{TO}+0.5$
- CRD is built with stars within 0.5x half-mass radius (0.5 rh).





Normalised Cumulative Radial Distribution (nCRD)





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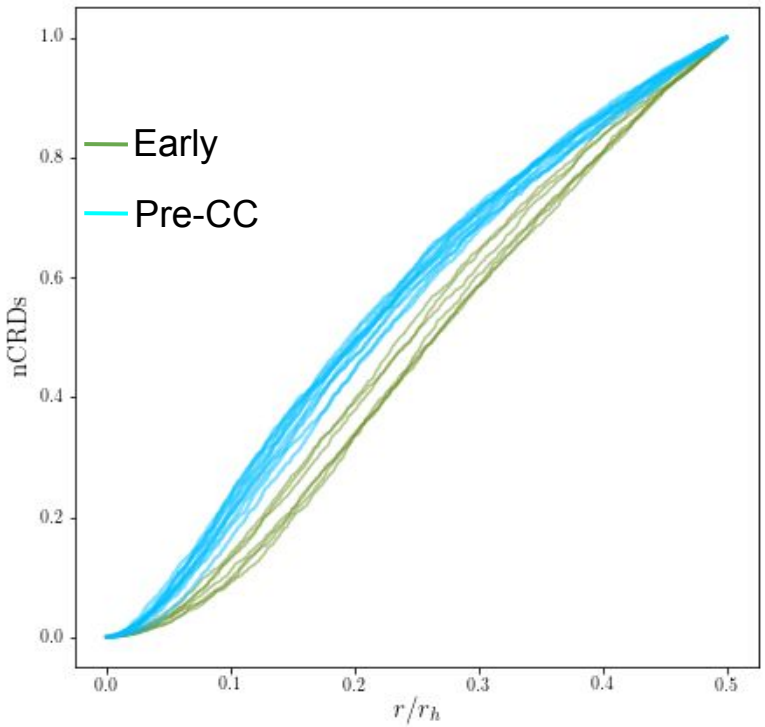

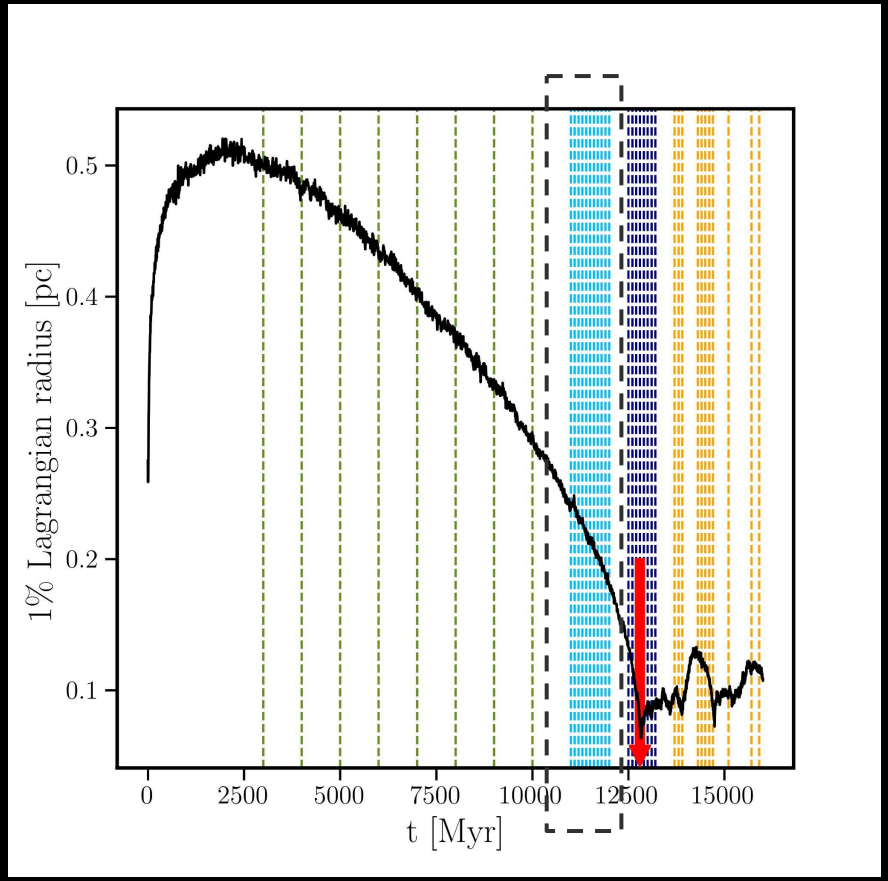

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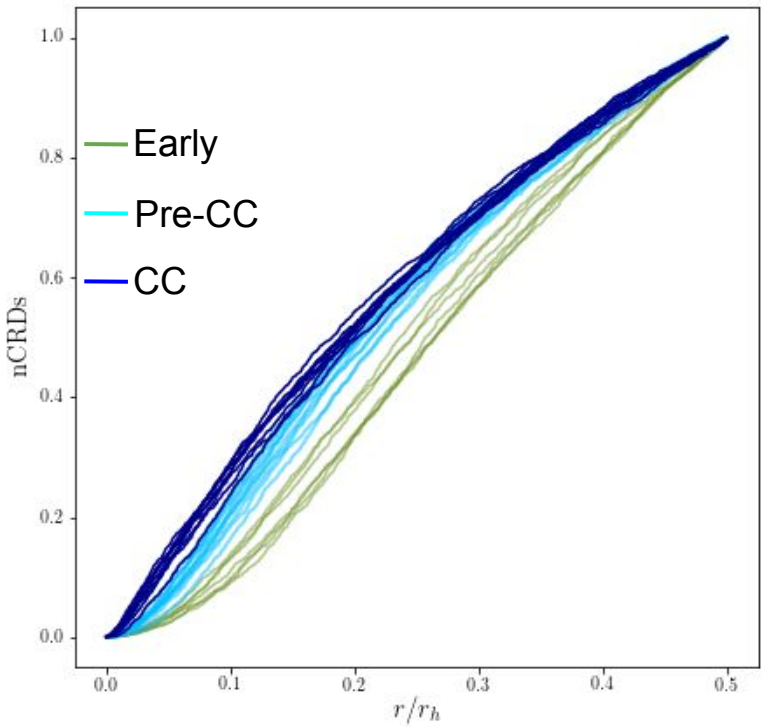

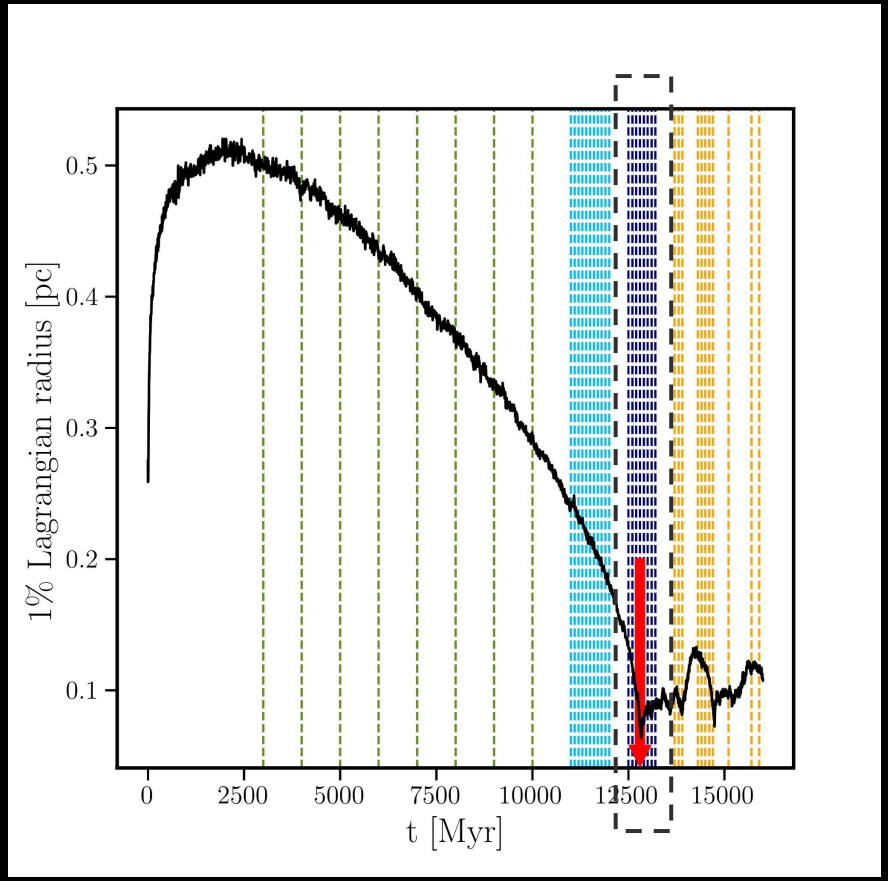

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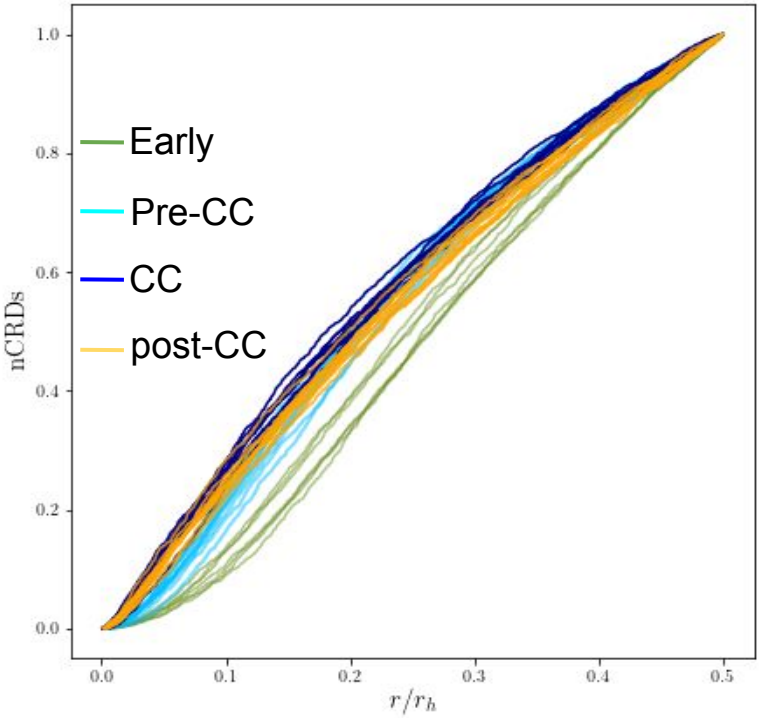

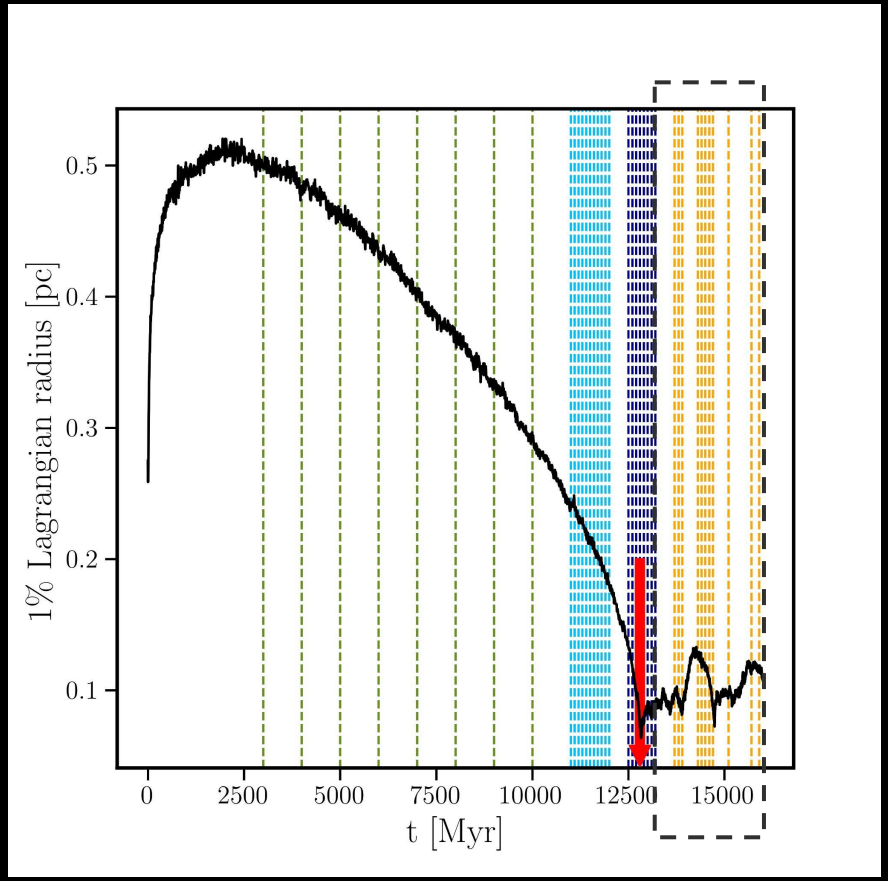

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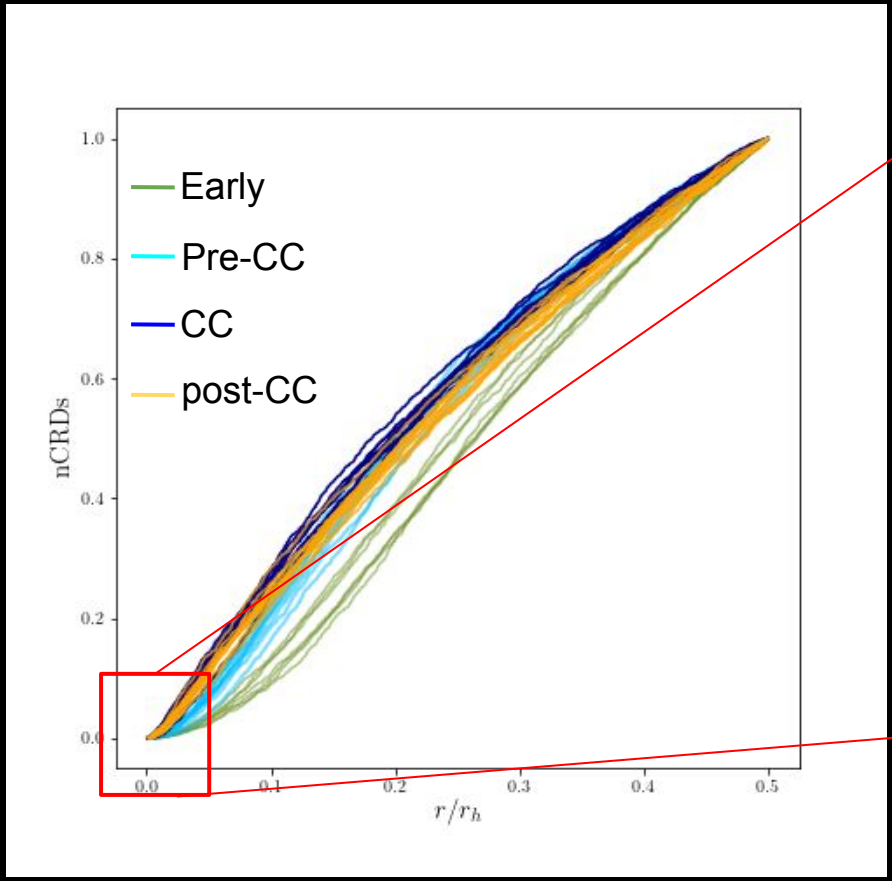
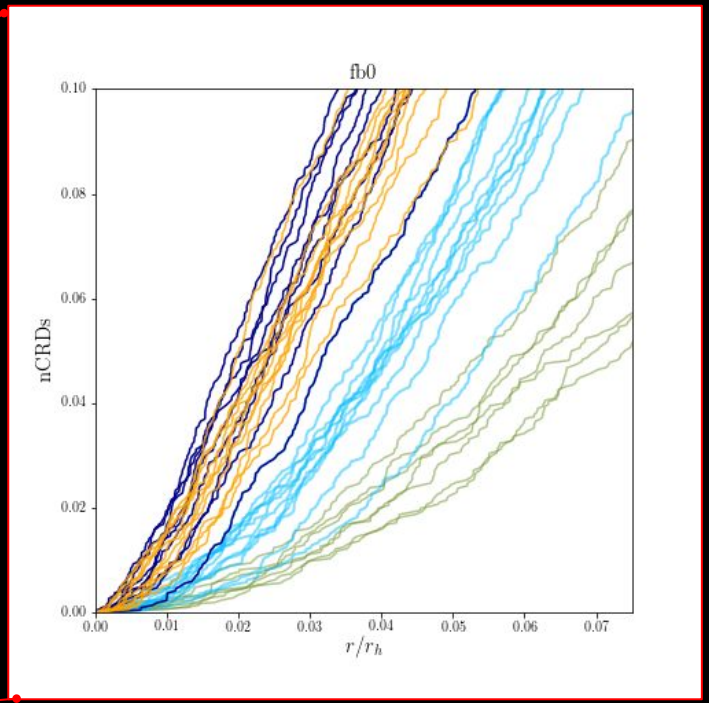
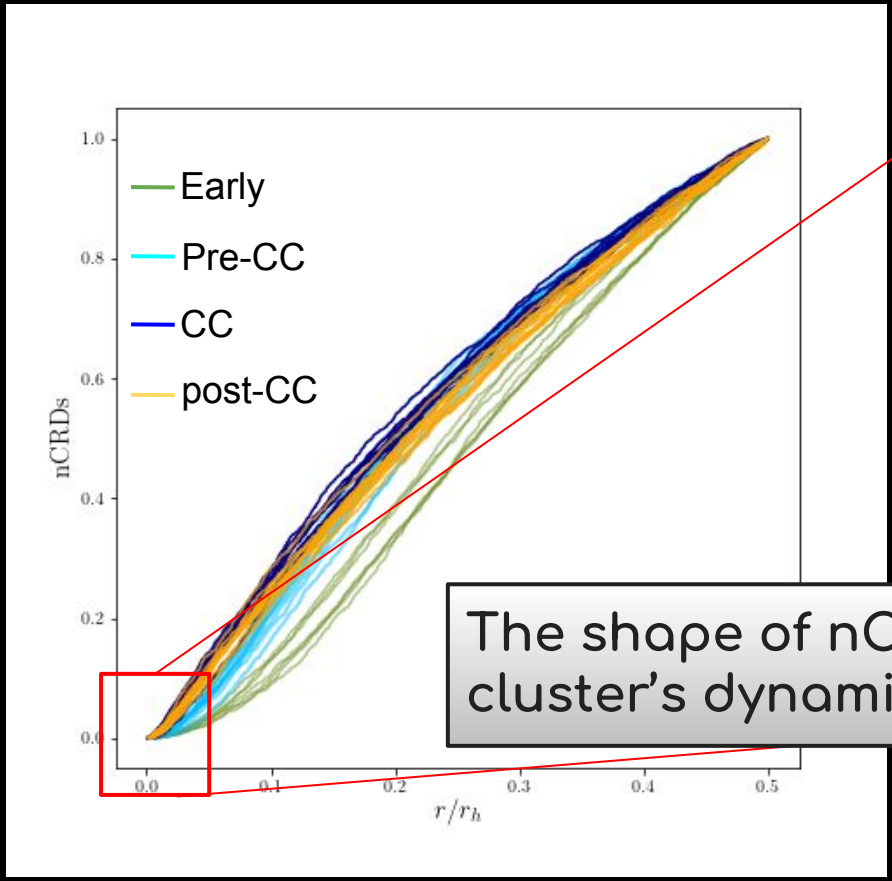
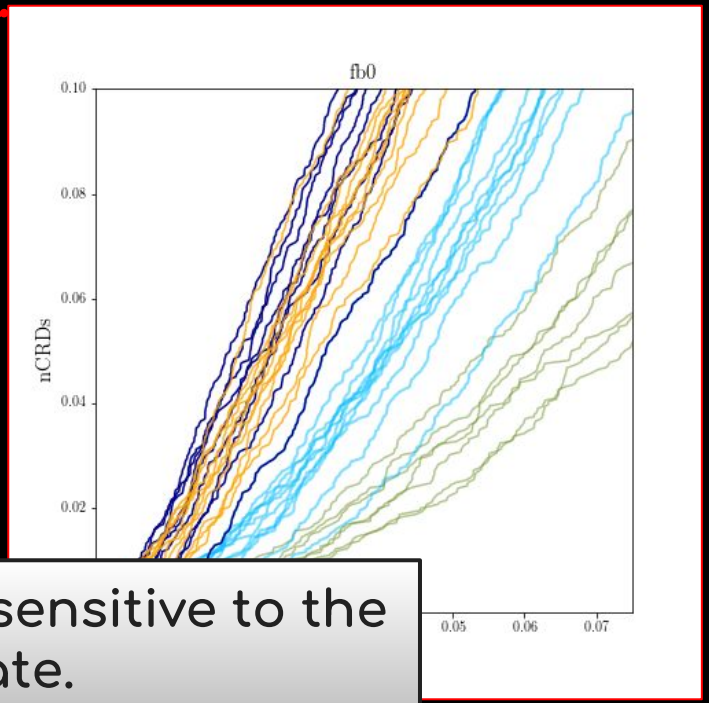




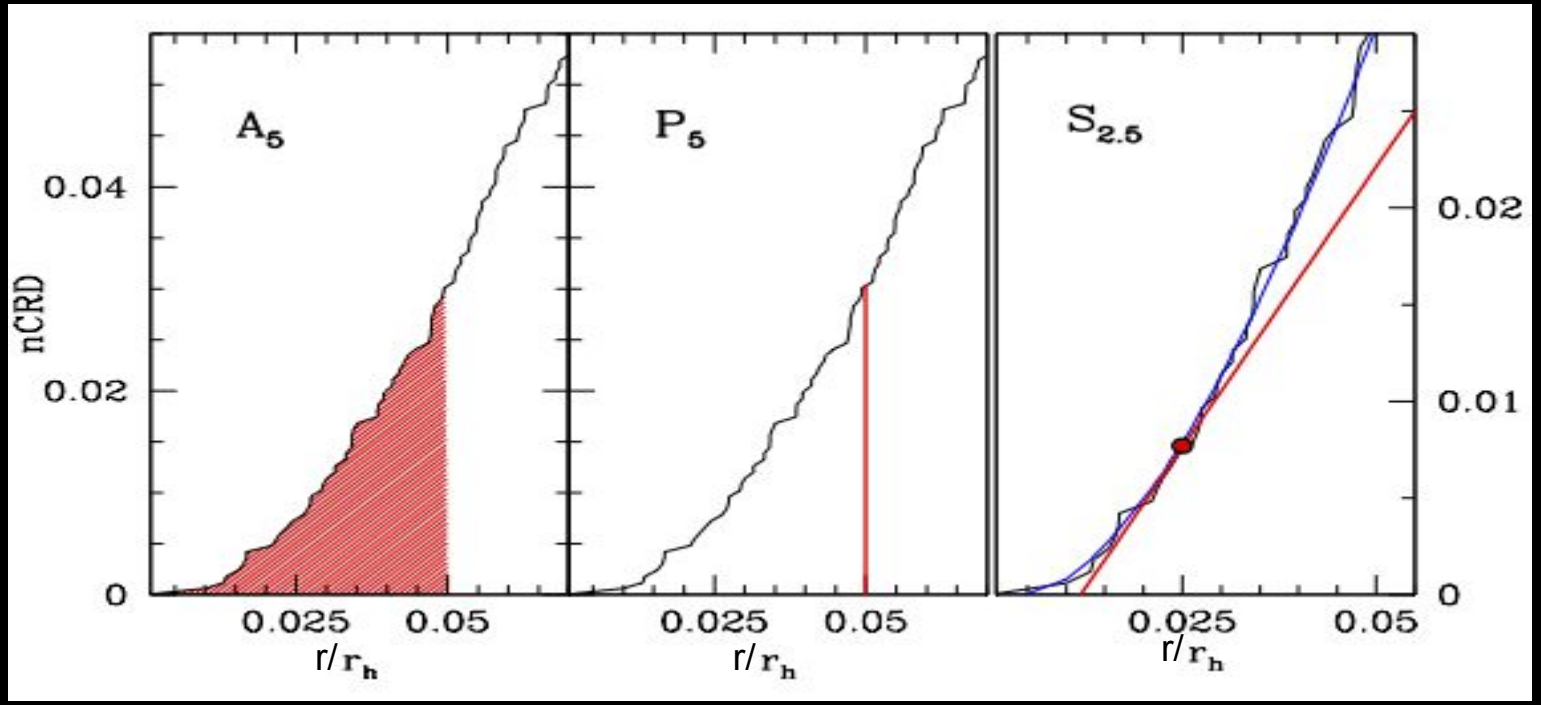
Normalised Cumulative Radial Distribution (nCRD)





The shape of nCRDs - sensitive to the cluster's dynamical state.

Parameters characterizing the shape of the nCRD



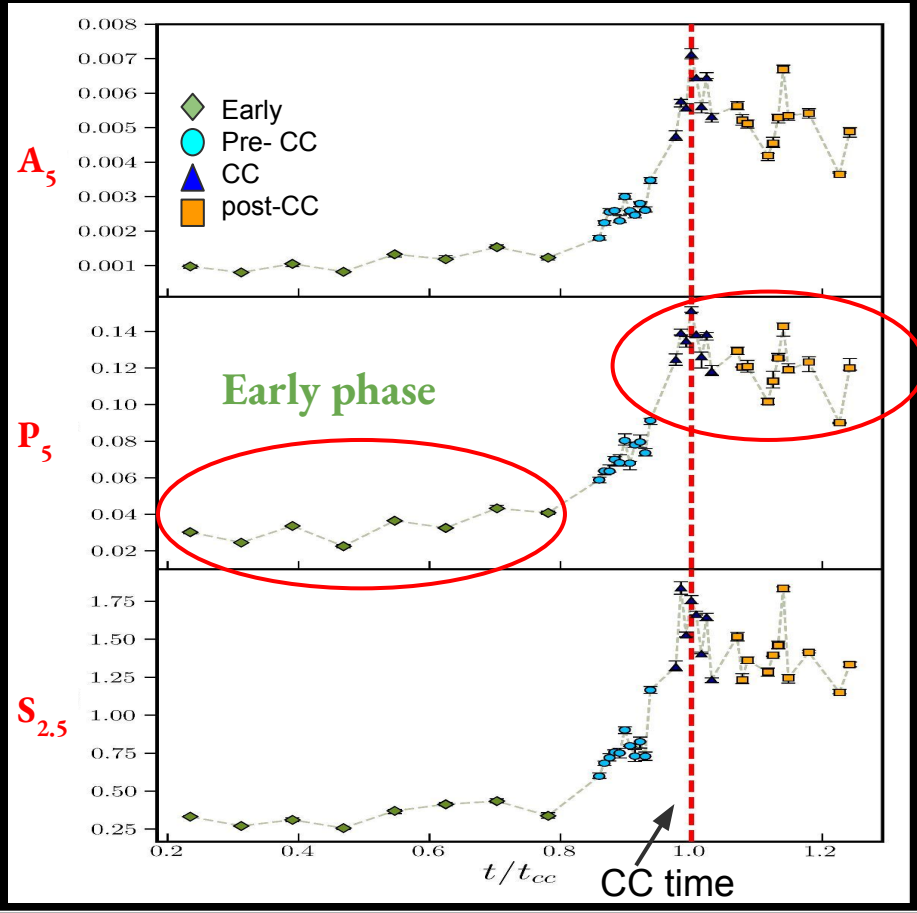
Area under nCRD within 5% rh - A_5

Percentage of stars at 5% rh - P_5

Slope of the tangent to nCRD at 2.5% rh - $S_{2.5}$

Bhat et. al, 2022, ApJ, 926, 118

RESULTS!



Bhat et. al, 2022, ApJ, 926, 118

To summarize...

- **Central density Cusp** alone is inadequate diagnostic of post-CC GCs.

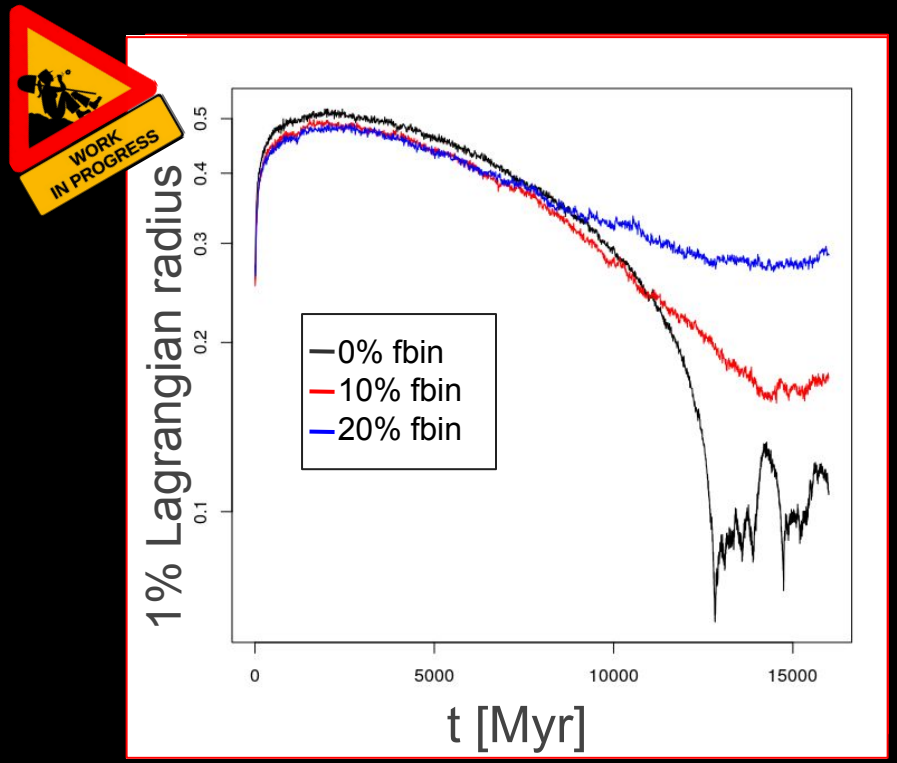
- The **3 new parameters derived from CRD** are highly sensitive to the dynamical evolution of GCs (Bhat et. al, 2022, ApJ, 926, 118)
  - Early Phase - constant low values, CC + Post-CC - high values (with fluctuations)
  - Potential to distinguish clusters in early phases of dynamical evolution from highly evolved ones.

What's Next?

How do different cluster properties affect in our parameters?

- primordial binary fraction.

Effect of Initial binary fraction on CRD parameters



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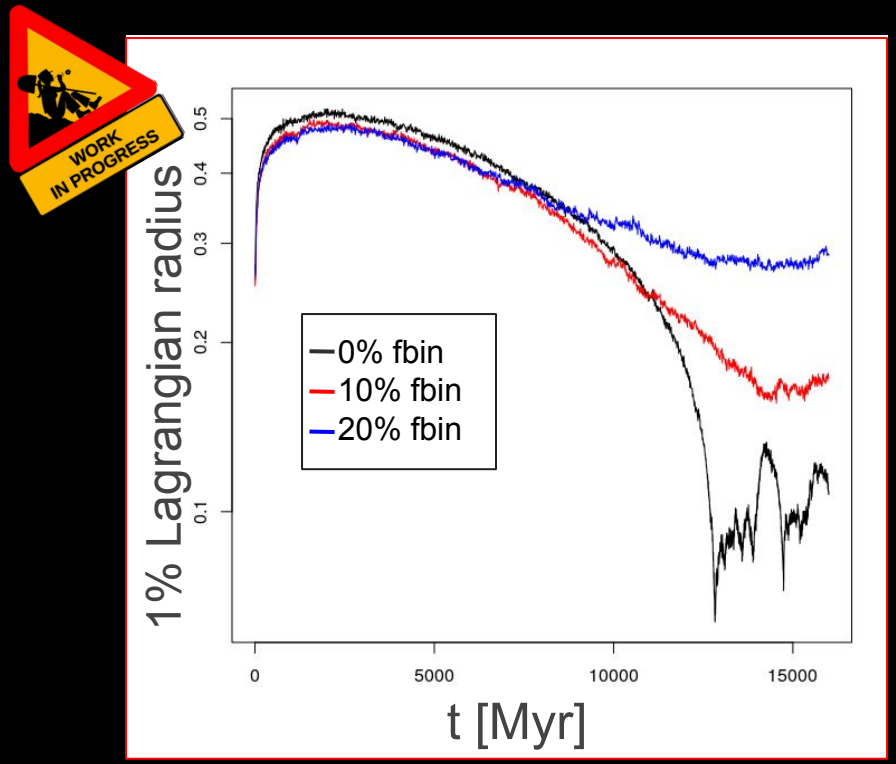
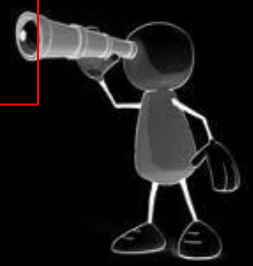


Increase in initial binary fraction → CC isn't too deep and this will be reflected in CRD parameters

How do different cluster properties affect in our parameters?

- primordial binary fraction.
- Dark remnants (IMBHs, Black-hole subsystems).
- Effect of tidal field of galaxy, concentration ...

Finally extending the analysis to observations



Thank you!