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ASTROPHYSICS

First evidence of fully spatially mixed first and second generation in GCs

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- ✦ 5-year project
- ✦ *Advanced Research Grant* funded by the European Research Council (ERC)
- ✦ PI: Francesco R. Ferraro (Dip. of Physics & Astronomy – Bologna University)
- ✦ AIM: **to understand the complex interplay between dynamics & stellar evolution**
- ✦ HOW: using **globular clusters** as cosmic laboratories and

Blue Straggler Stars

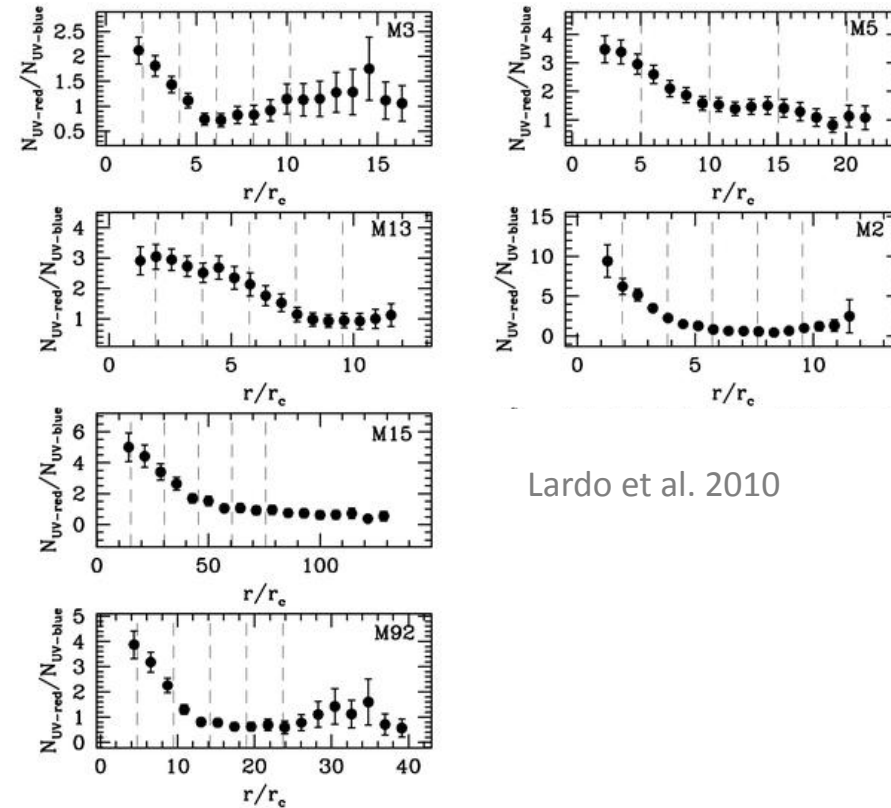
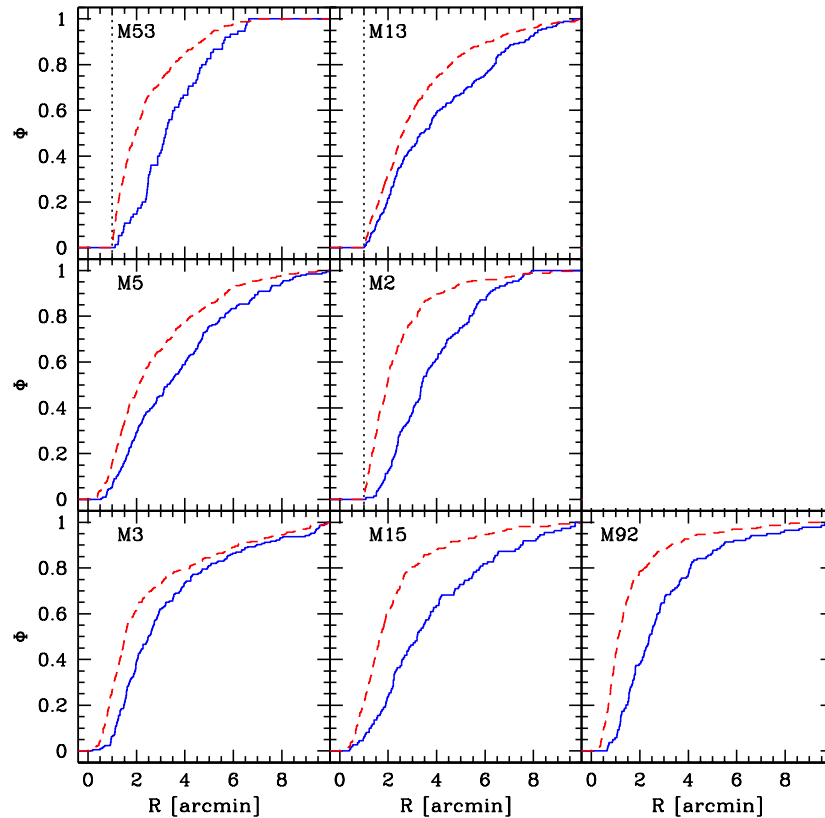
Millisecond Pulsars

Intermediate-mass Black Holes

} as probe-particles

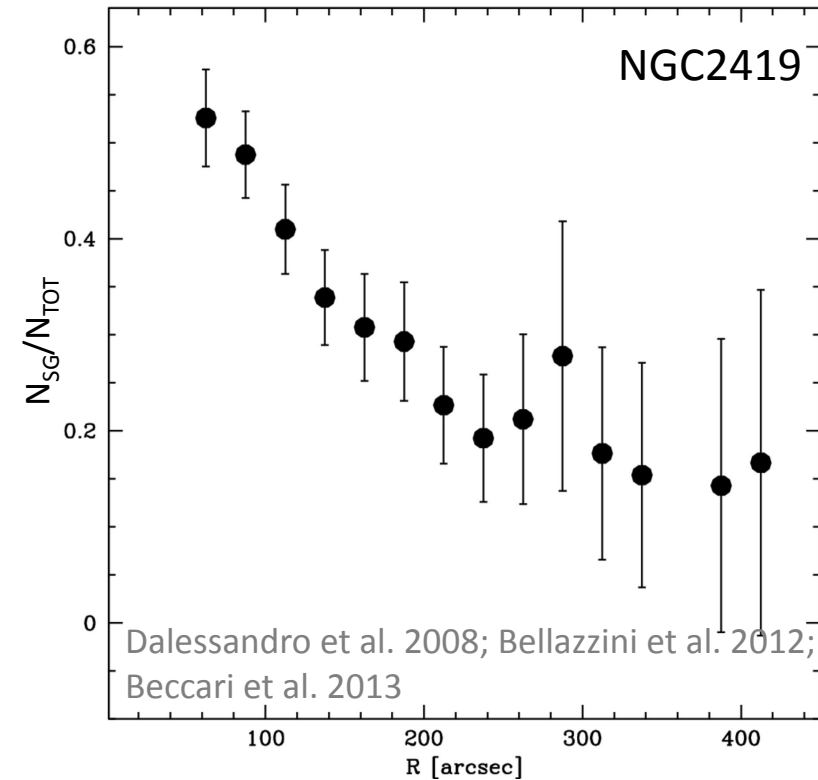
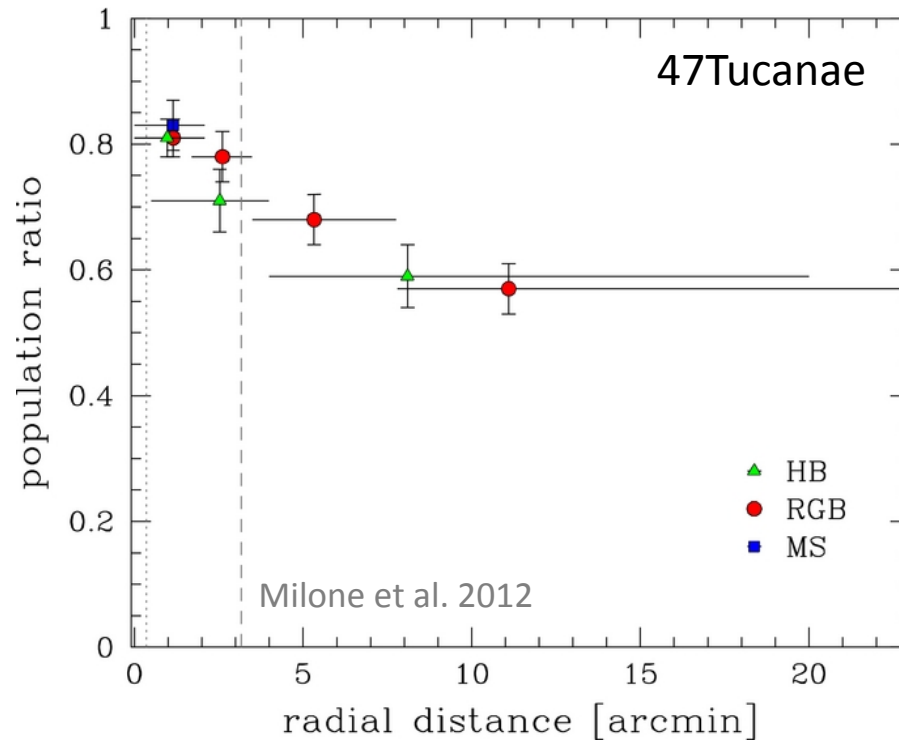
The radial distribution of MPs

The MP radial distributions are useful tools to understand the dynamical evolution of MPs and constrain their formation models



Lardo et al. 2010

The radial distribution of MPs



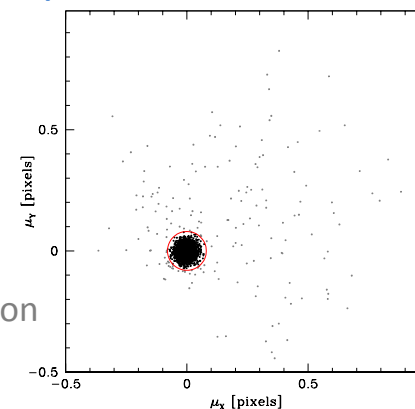
In ALL clusters observed so far **SG** stars have been found to be more centrally concentrated than **FG**

The case of NGC 6362

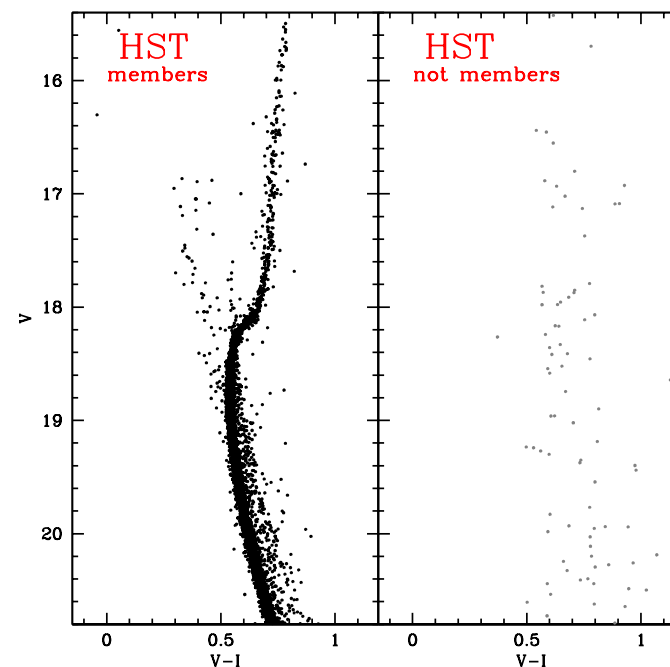
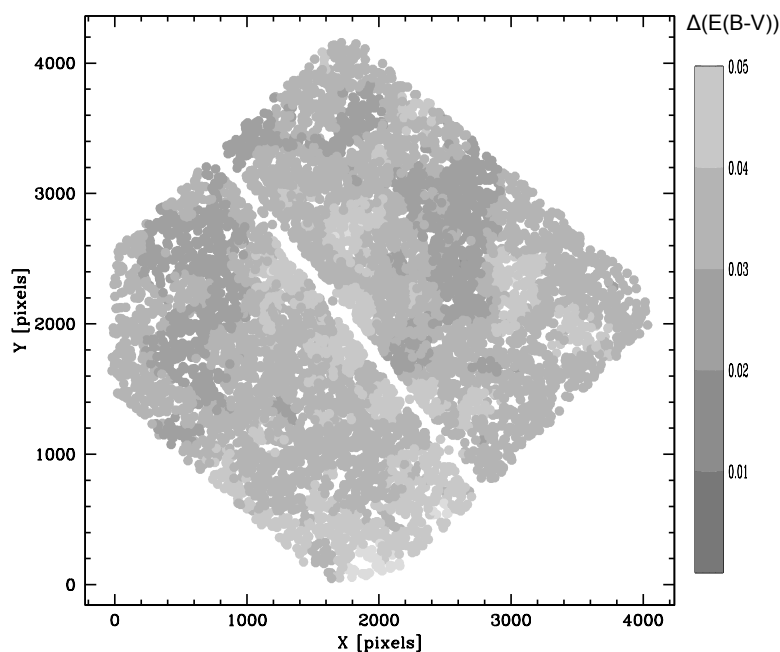
We covered the entire cluster extension by using multi-epoch **ACS** and **WFC3@HST** and **WFI@ESO** data in NUV and optical filters.

Dalessandro et al. (2014), in preparation

a) Proper Motion cleaned sample

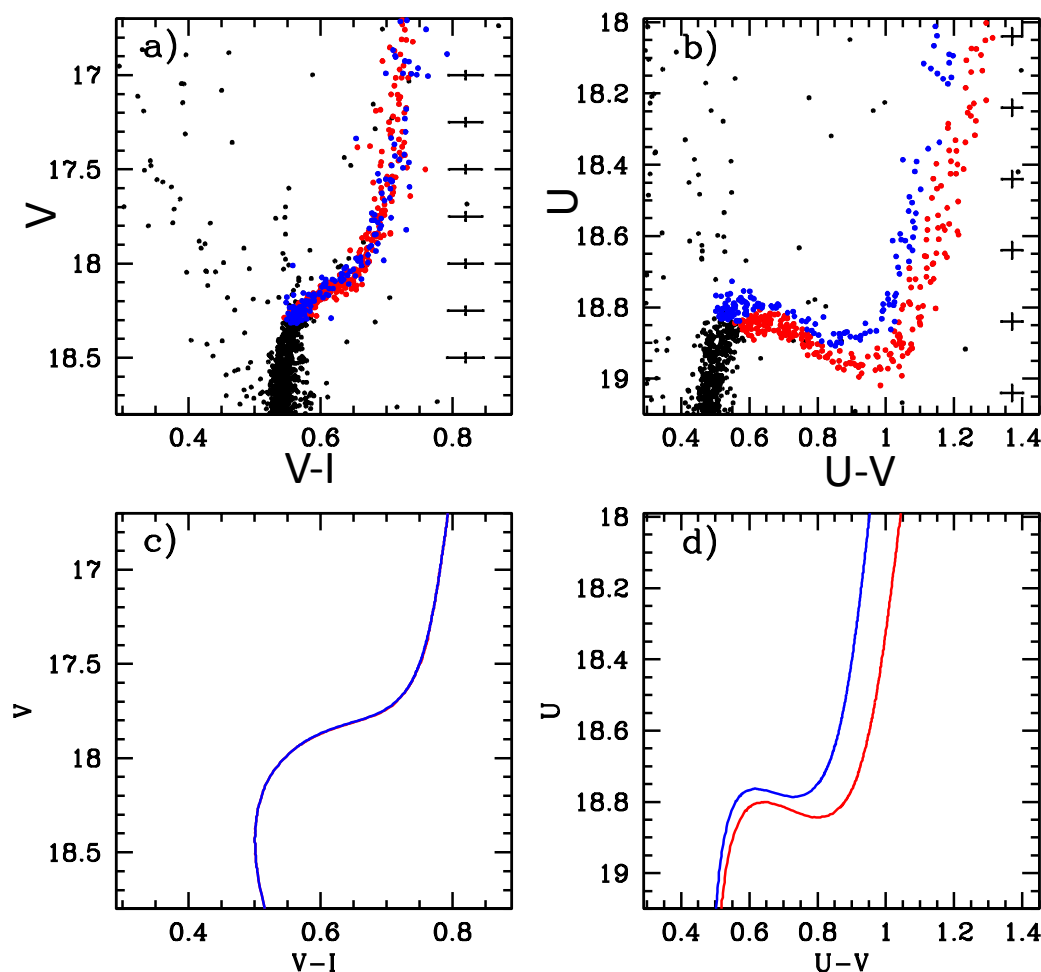


b) Differential reddening corrected

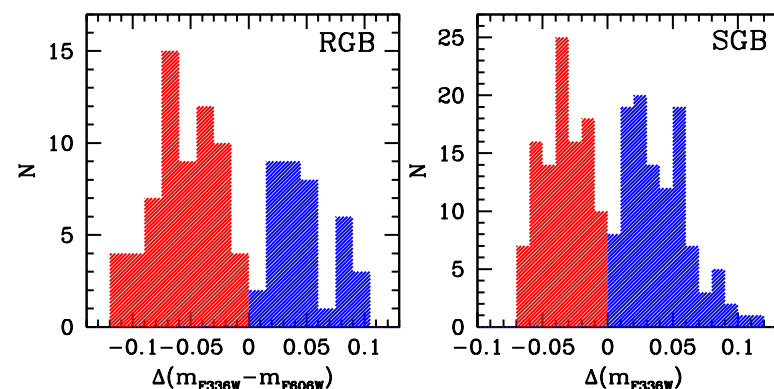


Multiple Populations in NGC 6362

Dalessandro et al. (2014), ApJL accepted

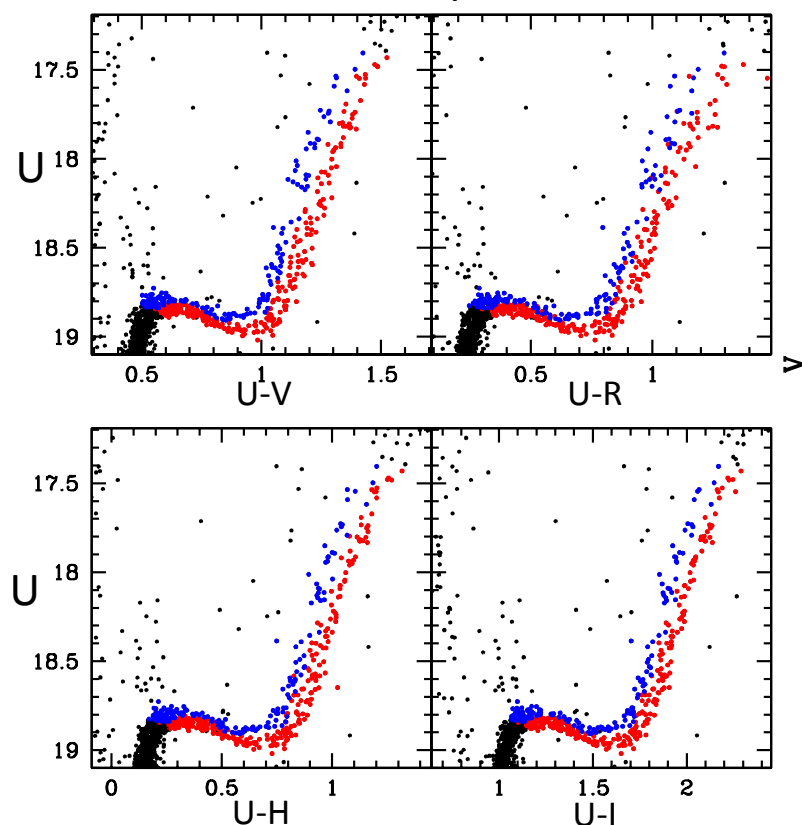


Both the SGB and RGB
clearly split in the (U-V,U)
CMD



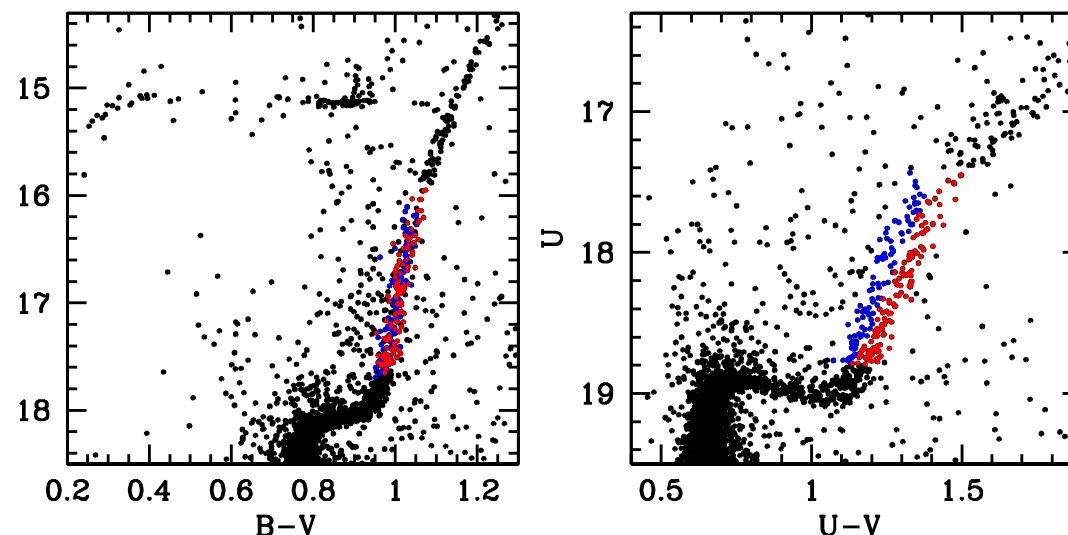
Multiple Populations in NGC 6362

HST sample



Dalessandro et al.(2014), ApJL accepted

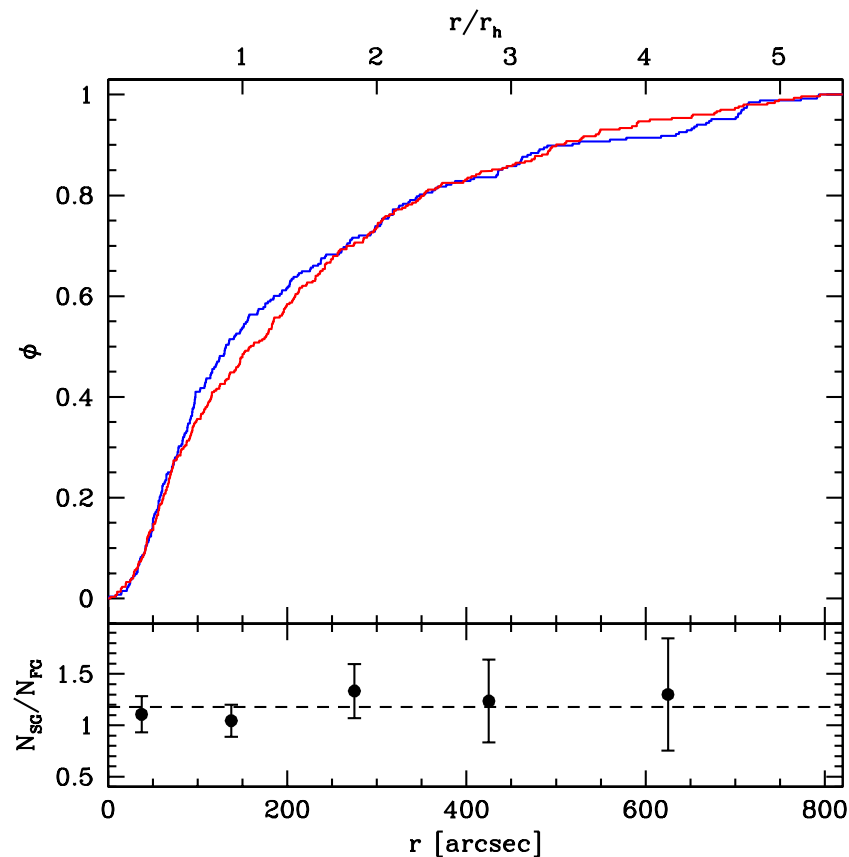
WFI sample



The same behavior is observed in any filter combination and in the external WFI sample

The radial distribution of MPs in NGC 6362

Dalessandro et al. (2014), ApJL accepted



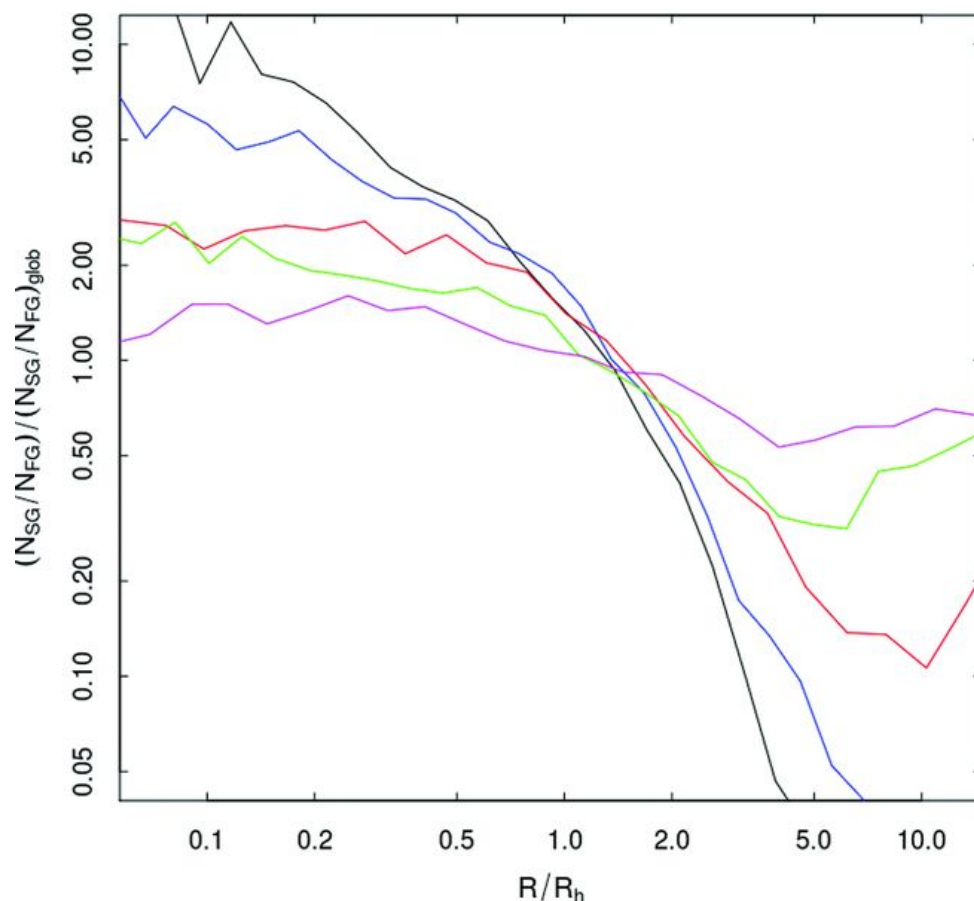
- the K-S test gives low probabilities that **FG** and **SG** are not extracted from the same parent population
- (N_{SG}/N_{FG}) shows a flat radial distribution at ~ 1.2

**This is the first evidence
ever collected of fully
spatially mixed FG and SG**

NGC 6362 is a unique case: what about theory?

Complete mixing is expected by theoretical models

Vesperini et al. (2013)



According to N-body simulations:

- #1. Complete mixing can occur in advanced dynamical stages (with timescales depending on the SG initial concentration)
- #2. Complete mixing can occur for clusters that lost at least the 60-70% of their mass during the long-term dynamical evolution
(see however Larsen et al. 2014)

#1: the dynamical state of NGC 6362

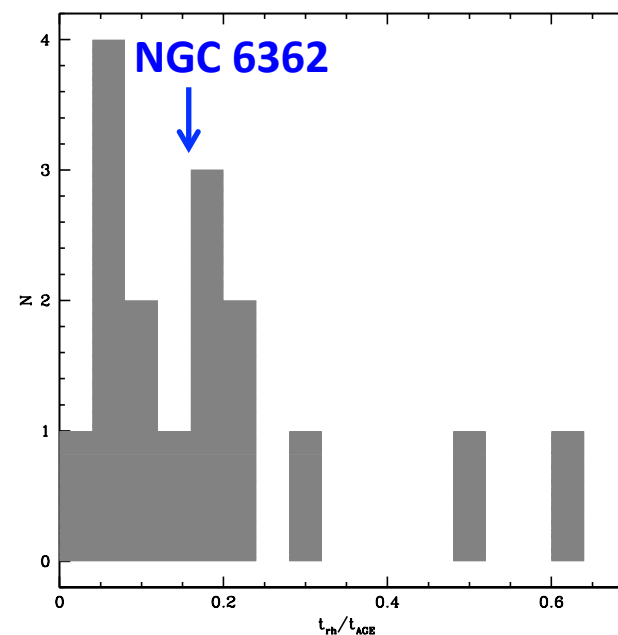
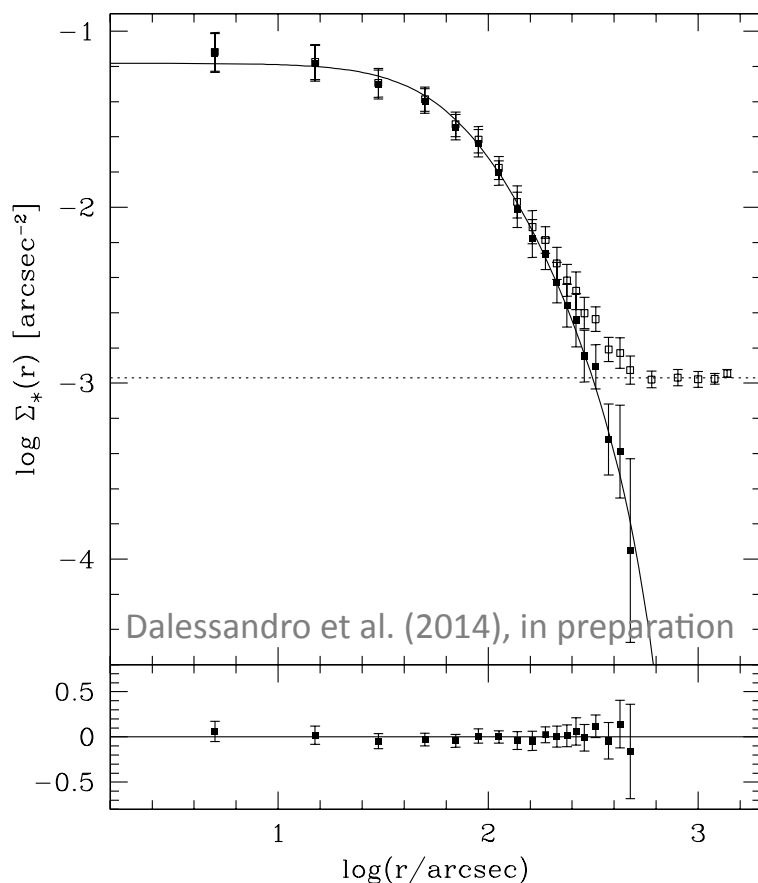
From the best-fit to the density profile we obtain

$$r_h \sim 150'' \text{ (5.6 pc)}$$

$$\text{which yields } t_{rh} \sim 1.7 \text{ Gyr}$$

$$t_{rh}/t_{age} \sim 0.15$$

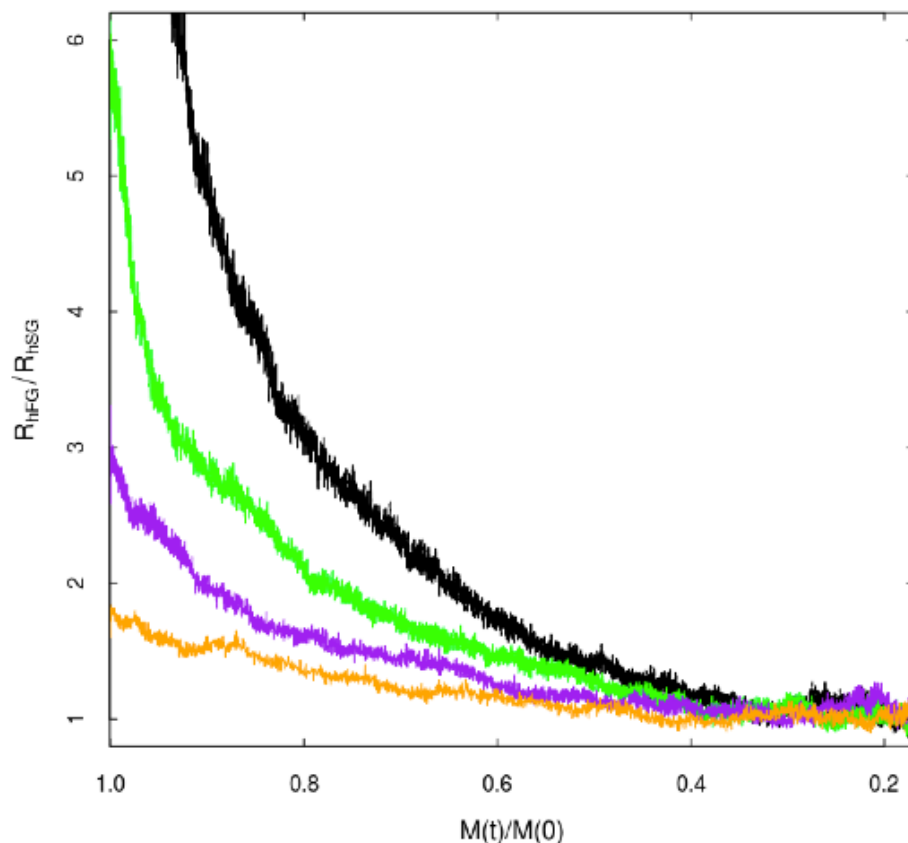
These values are fully compatible with those observed for other clusters with MPs radial trends



NGC 6362 should have experienced a more complicated dynamical history

NGC 6362 is a unique case: what about theory?

Vesperini et al. (2013)



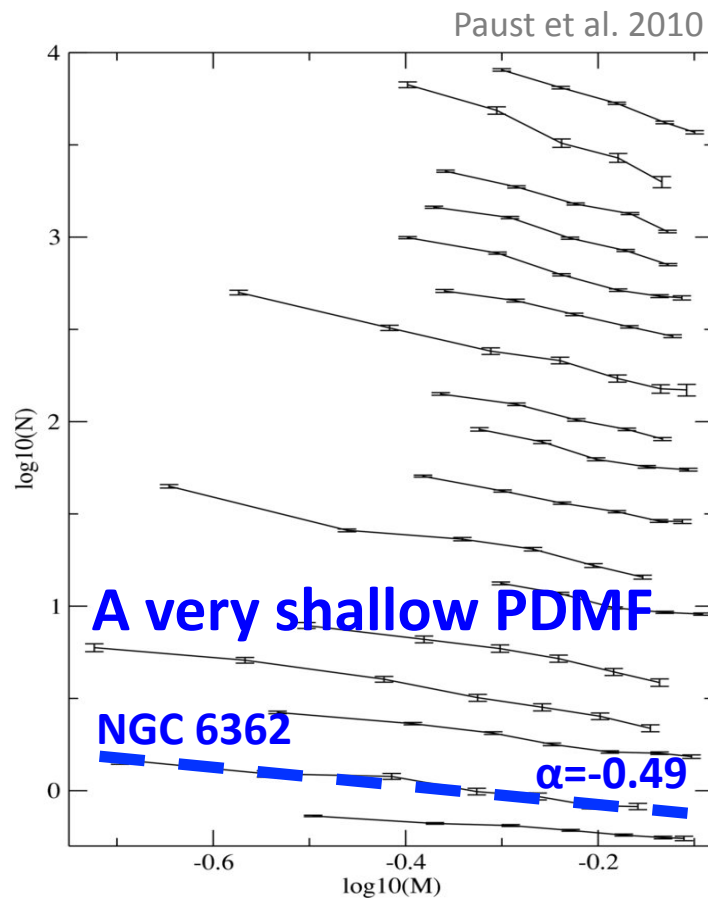
Theoretical models predict that:

#1. Complete mixing can occur
in advanced dynamical stages (with timescales depending on the SG initial concentration)

#2. Complete mixing can occur
for clusters that lost at least the 60-70% of their mass during the long-term dynamical evolution

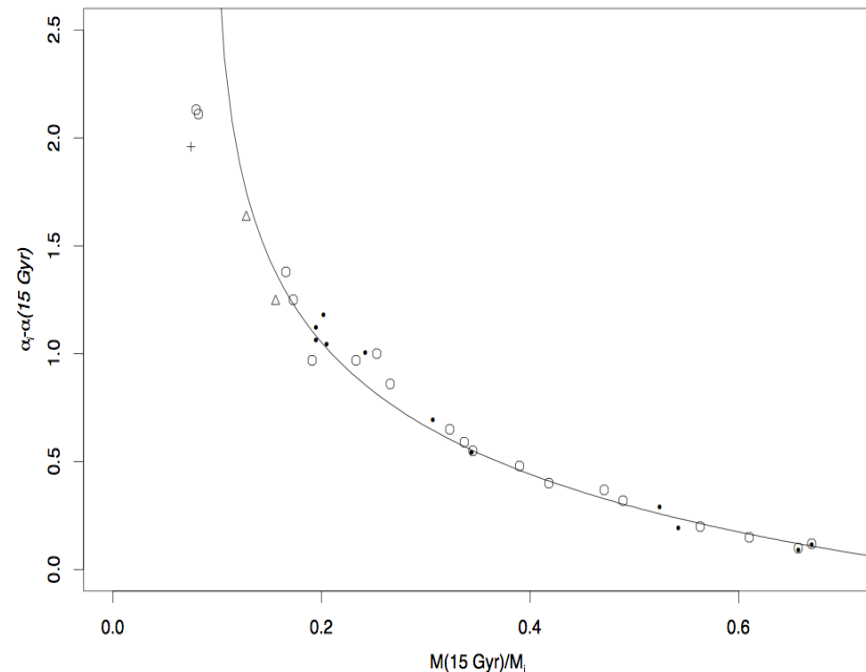
(see however Larsen et al. 2014)

#2: Observational evidence for a large mass loss



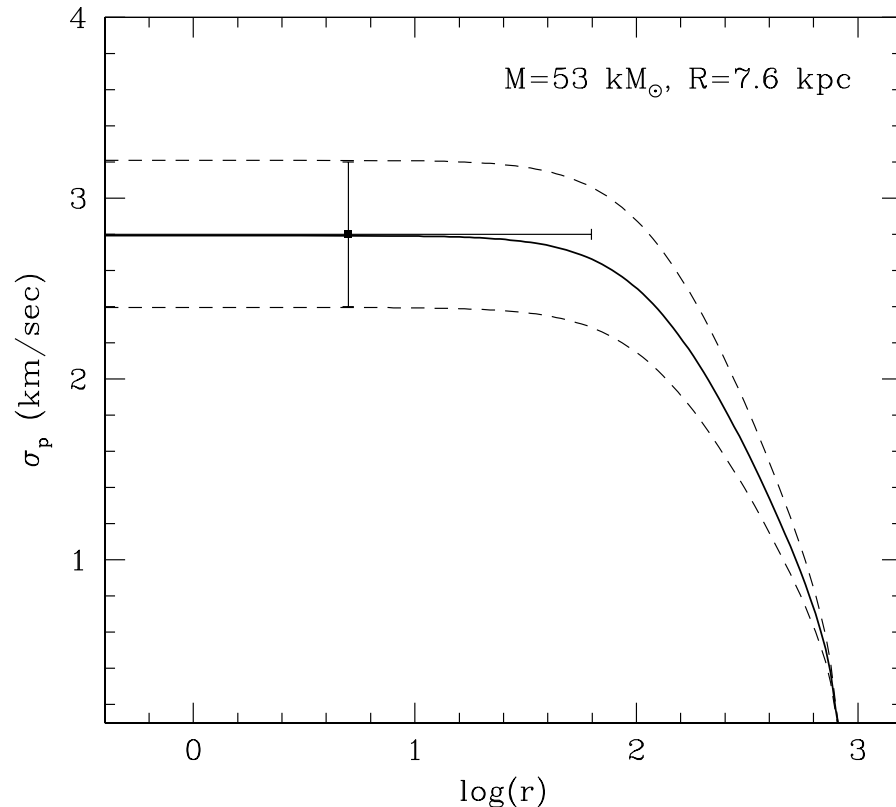
A short tidal destruction time (<10 Gyr) has been estimated for this system (Allen et al. 2006)

A very shallow PDMF can be indicative of large fraction of mass lost due to tidal effects (Vesperini & Heggie 1997; Webb et al. 2014)



It is likely that NGC 6362 lost up to **80% of its original mass** thus reaching a **totally mixed configuration**

The mass of NGC 6362



Dalessandro et al. (2014), in preparation

$$M_{PD} = (5.3 \pm 1.5) \times 10^4 M_{sun}$$

NGC 6362 is the least massive cluster where MPs have been detected so far

This is 2-3 times smaller than M 4 or NGC 288

The original mass should be fixed at

$$M_{initial} \approx (1 - 2 \times 10^5) M_{sun}$$

Constrain to the conditions for the onset of light-elements self-enrichment

Summary

- ✓ NGC 6362 is the first GC where totally spatially mixed MPs have been observed so far
- ✓ NGC 6362 might be the least massive GC hosting MPs
- ✓ Observational evidence and theoretical expectations show that NGC 6362 should have lost up to 80% of its original mass

What's next?

We are conducting an observational campaign
ESO Prop: [093.D-0618\(A\)](#); PI: Dalessandro

1. Characterize chemical patterns
2. Kinematical studies of NGC6362 and its surroundings

Thank you!

Visit our web-site: www.cosmic-lab.eu

