Cosmic-Lab: The GLOBULAR CLUSTER LABORATORY





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verifica della teoria dell'Evoluzione Stellare SSP interpretazione delle Ammassi Globulari galassie non risolte traccianti della VECCHI (12 Gyr) storia di formazione della Via Lattea (=> delle galassie) ALTE DENSITA studio degli effetti della dinamica su evoluzione stellare

(e viceversa)

Dynamics in GCs



GC are the only stellar systems able to undergo nearly all the physical processes known in stellar dynamics over a time scale significantly shorter than the Hubble time. This dynamical activity can generate exotica

4-5 Master theses are available on the following topics

- 1. Studying the observational properties of exotic stellar populations: properties of BSS + their progenitors (binaries) and progeny (E-BSS) in GCs
- 2. A new understanding of the physics of dense stellar systems: a new generation of SD and VD profiles
- 3. Searching for relic fragments of the Galactic Bulge
- 4. Beyond the MW: exploring the LMC clusters



Blue Straggler Stars



NON previste dall'evoluzione di stelle singole

COLLISIONS



MASS-TRANSFER



Blue Straggler Stars (BSS)





Hence BSS are crucial gravitational probes to test GC internal dynamical processes.



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The dynamical clock

Ferraro et al.12 (Nature,492,1028)+ Ferraro et al. 2018 (ApJ,860,36)

BSS are heavy stars ($M_{BSS} = 1.2-1.4 M_{\odot}$) orbiting a "sea" of "normal" light stars ($M_{mean} = 0.4 M_{\odot}$): they are subject to **Dynamical Friction (DF)** that progressively makes them sink toward the cluster center



The dynamical clock

Ferraro et al.12 (Nature,492,1028)+ Ferraro et al. 2018 (ApJ,860,36)



THE DYNAMICAL CLOCK

dynamically young



dynamically old

The dynamical clock

Ferraro et al (2018,ApJ,860,36)



A "stellar scale" to search for E-BSS

Ferraro et al (2016, ApJ,816,70)

After the MS phase BSS will appear photometrically indistinguishable from genuine low-mass cluster stars. Hence a tool able to reveal their different mass is needed



A "stellar scale" to search for E-BSS

Ferraro et al (2016, ApJ, 816,70)



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A "stellar scale" to search for E-BSS

Ferraro et al (2016, ApJ, 816,70)

The abundances obtained from neutral lines are independent of the adopted gravity, the abundances from ionized absorption lines are quite sensitive to gravity (mass).



Hence the BALANCE between the chemical abundances derived from **neutral** and **ionized** absorption lines can be used to determine the correct gravity of the star (hence its MASS !!).

Which is the binary fraction in GCs?



Sollima et al (2007, MNRAS, 380,781)

1. Studying the properties of BSS + their progenitors (binaries) and progeny (E-BSS) in GCs

Photometric data from HST and from the INDIAN ST + VLT & high resolution spectra from Magellan & VLT **4-5 Master theses are available on the following topics**

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A NEW UNDERSTANDING OF THE PHYSICS OF DENSE STELLAR SYSTEMS

From the observational point of view, we need:

CLUSTER STRUCTURE

(core radius, concentration, center, etc)

KINEMATICS

(velocity dispersion profile, rotation curve)





THE PROJECT

- A proper determination of the cluster structure, from A NEW GENERATION STAR DENSITY PROFILES FROM RESOLVED STAR COUNTS covering the entire cluster extention
- 2. A detailed knowledge of the internal kinematics, from A NEW GENERATION OF VELOCITY DISPERSION & ROTATION PROFILES FROM THE RADIAL VELOCITY OF INDIVIDUAL STARS over the entire cluster extension





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EXTERNAL REGIONS

- Cluster size
- Tidal tails
- Extra-tidal halos

- Rotation
- Dark Matter??
- Tidal heating



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A NEW GENERATION OF STAR DENSITY PROFILES



Determination of the centre



even an error of a few 0.1" is sufficient to artificially flatten the derived profile and hide the central cusp!





The MIKiS survey: the sample

Ferraro et al (2018, ApJ, 860, 50)



(i) they are massive (M > $5 \times 10^5 M_{\odot}$)

(ii) they span a large range of Log ρ , c and relaxation times

(iii) they cover different stages of dynamical evolution, including PCC

(iv) They span different environmental conditions (sampling both the bulge/disk and the halo populations)

The MIKiS survey

+ ESO LP 195.D-0750 (PI: Ferraro): 101 hours (SINFONI) + ESO LP 193.D-0232 (PI: Ferraro): 194 hours (KMOS + FLAMES)

The SINFONI Revolution

IFU spectroscopy (SINFONI@VLT, OSIRIS@Keck)

Unconventional use → extract a spectrum for every resolved star (instead of integrated-light spectroscopy)

SINFONI RECONSTRUCTED



The SINFONI Revolution

NGC6388

SINFONI

HST/HRC



→ V_r for 52 individual stars at r<2" !!!!!!! (~0.13 pc) **NGC2808**



V_r for 800 individual stars at r<12" !!!!!!

Velocity dispersion profile

$\sigma(r)$ from the dispersion of V_r in radial bins of \geq 50 stars

(following the Maximum Likelihood method of Walker et al. 2006)





2. A new understanding of the physics of dense stellar systems

Photometric data from HST + Wide Field ImagingProper motion from HST and Gaia& spectra from the MIKiS survey at the VLT

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SSP? -- STARS IN GGCs ARE NOT CHEMICALLY HOMOGENEOUS IN LIGHT ELEMENTS

Gas enriched by **p-capture processes** (high-temperature extension of the CNO cycle)



function of [O/Fe] for 19 GGCs (Carretta et al. 2009)

STARS IN GENUINE GGCs ARE NOT CHEMICALLY HOMOGENEOUS IN LIGHT ELEMENTS & HELIUM BUT THEY ARE QUITE HOMOGENEOUS IN IRON !!!

There are only 2 major exceptions known within the GALAXY with quite large iron difference (Δ [Fe/H]~ 1 dex) :

ω Centauri in the MW halo



Terzan 5 in the MW bulge









Reconstructing the SFH of Terzan5



The ages of the two sub-populations provide the timescales of the enrichment processes:

- 1. First period of star-formation occurred 12Gyr ago and formed the metal-poor and – intermediate pops
- 2. 4.5 Gyr ago the super-solar component formed out of the gas ejected by SNell and SNela

This would suggest Terzan5 to have M_{ini} >> M_{present} (~10⁸ M_O)

Terzan5 – working hypothesis

- Bulges at high-z are clumped
- Proto-clouds locally fragments in massive clumps of gas
- They evolve towards the center of the galaxy and there they interact to form the bulge

Terzan5 did not merge/ dissolve but evolved and self-enriched as an independent stellar system



Noguchi et al. (1999); Immeli et al. (2004); Elmegreen et al. (2008)

Searching for Ter5 – like stellar systems



3. Searching for relic fragments of the Galactic Bulge Multi Conjugate AO IR observations with GEMINI & high resolution spectra with Keck and VLT **4-5 Master theses are available on the following topics**

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Extending these studies to the LMC



Exploring the LMC clusters Deep HST photometry with HST & high resolution spectra VLT

Ammassi stellari binari nella LMC

Sono legati gravitazionalmente? Sono nati dalla stessa nube molecolare (stessa eta' e metallicita') ?

