

# Resolved Stellar Populations: globular clusters



OAS BOLOGNA

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ISTITUTO NAZIONALE DI ASTROFISICA  
OSSERVATORIO DI ASTROFISICA E SCIENZA DELLO SPAZIO DI BOLOGNA

# Resolved Stellar Populations: Globular Clusters



**GCs are valuable probes of their hosts**

- GCs trace star-formation and assembly histories of galaxies
- Nucleosynthetic processes governing chemical evolution
- Structure and dark-matter distribution

**Enable statistical significant studies of sub-populations with major impact in testing stellar evolution theory and dynamics**

- Stellar Evolution
- Interplay between dynamics and stellar evolution

# Resolved Stellar Populations: Globular Clusters

## Main Collaborations:

UniBO, UniPD, OAPD

UCLA, University of Indiana (USA)

University of Liverpool (UK)

PUC, Univ. de Concepcion (Chile)

University of Tokyo (Japan)

University of Queensland (Australia)

Obs. de Strasbourg (France)

STScI, ESO, ESA



Michele  
Bellazzini



Angela  
Bragaglia



Francesco  
Calura



Eugenio  
Carretta



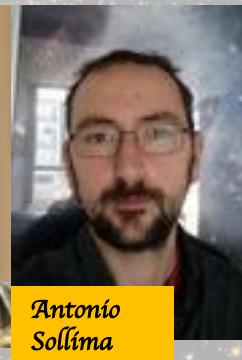
Giuliana  
Fiorentino



Lívia  
Origlia



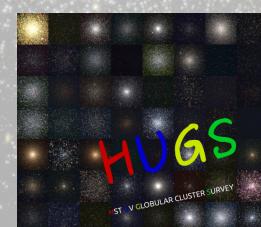
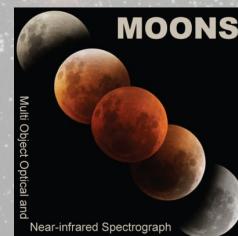
Emanuele  
Dalessandro



Antonio  
Sollima



Monica  
Tosi



# Resolved Stellar Populations: Globular Clusters



I. Formation and early evolution

II. Structure, kinematics and dynamical evolution

III. Tracers of the Galactic Bulge/inner Galaxy formation

# I. Multiple populations globular clusters

OAS people involved: A. Bragaglia, M. Bellazzini, F. Calura, E. Carretta, E. Dalessandro  
UniBO, UniPD, OAPD, University of Liverpool, University of Indiana, STScI, ESO



Our knowledge of globular clusters has been deeply revolutionized in the last 20 years

## GOAL

### Understanding GC formation and early evolution

#### a) Huge observational effort

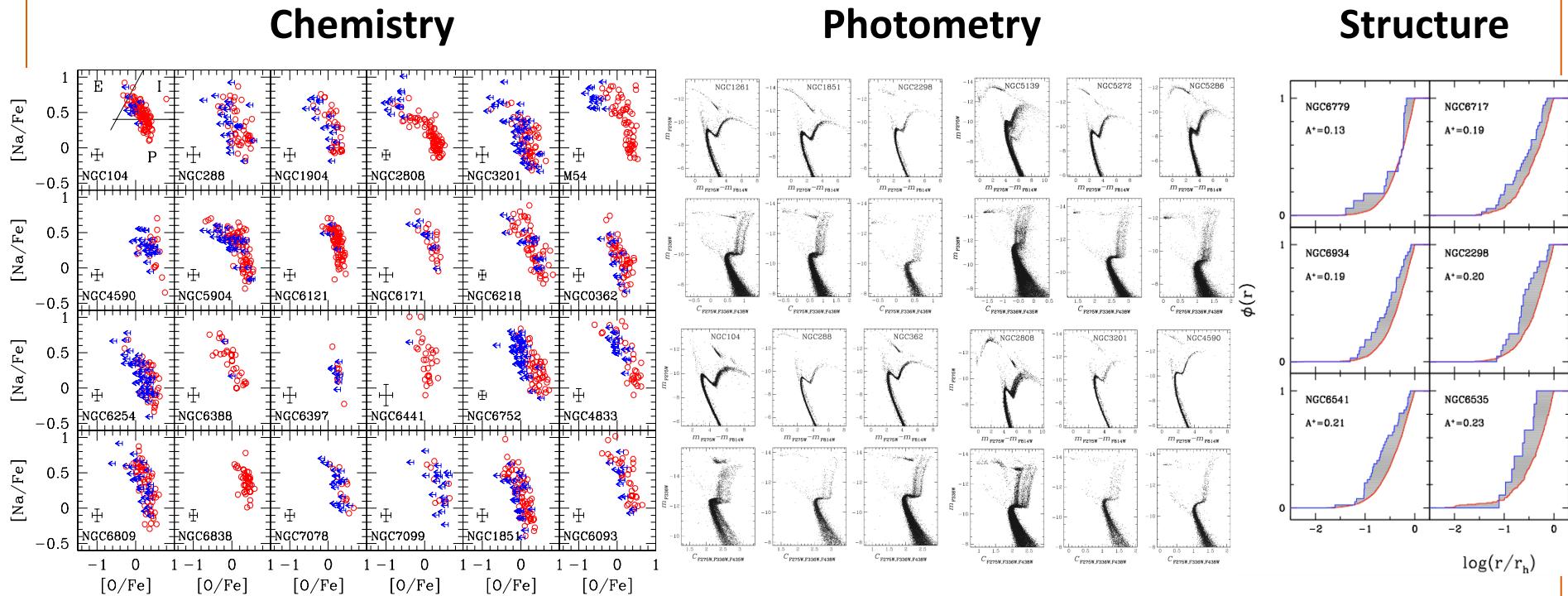
- >350 HST orbits: 1 Legacy Survey – 1 Large Programme - 1 Medium Programme + GO proposals
- >120 ESO-VLT nights (FLAMES, UVES, X-Shooter)
- >20 nights at other facilities (Magellan, LBT, INT, TNG ... )



# I. Multiple populations in globular clusters

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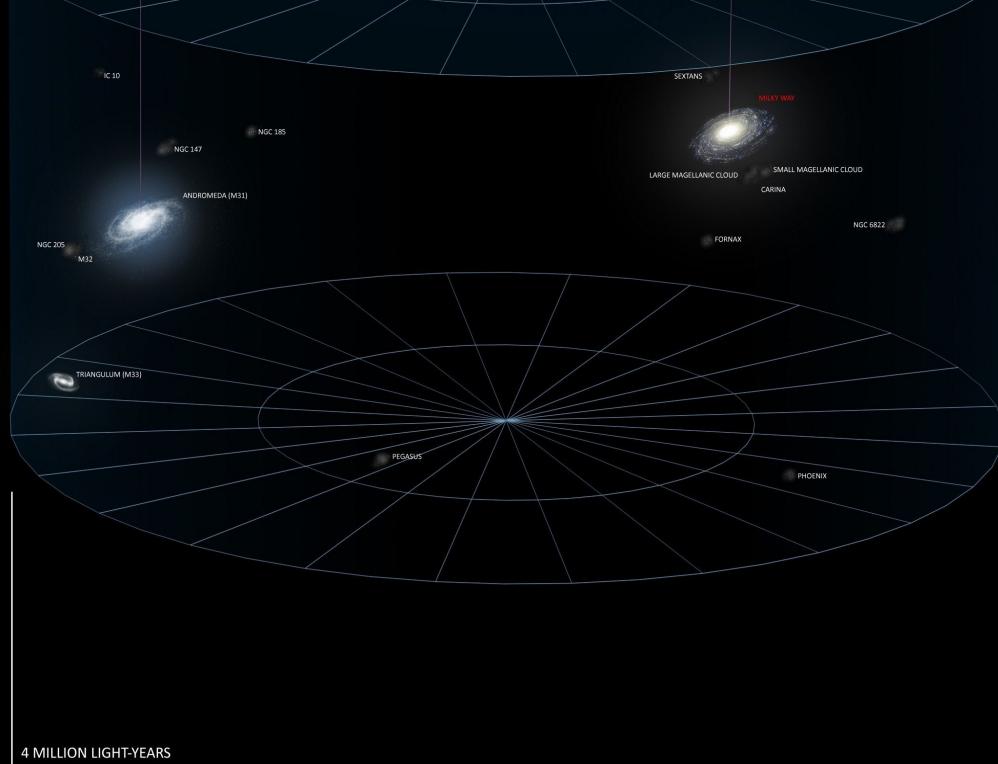


The largest and most homogeneous spectro-photometric characterization of MPs in GCs

# I. Multiple populations in globular clusters

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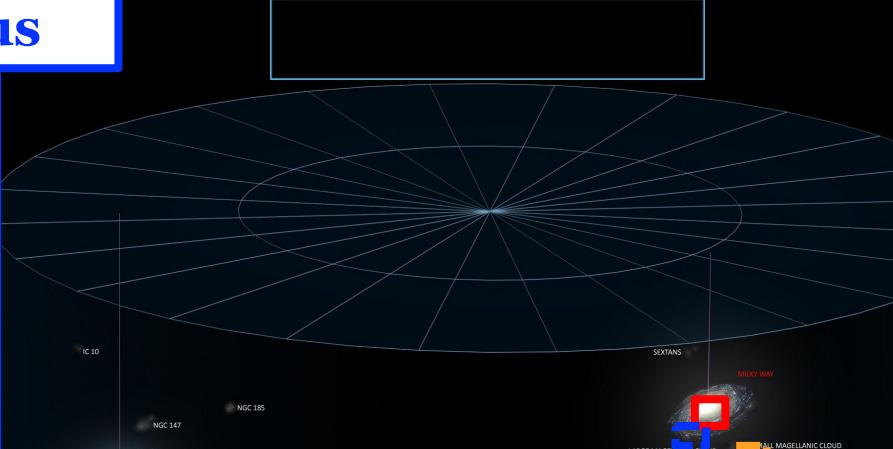
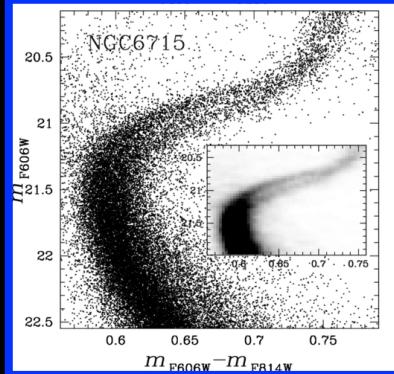
MP is an ubiquitous phenomenon in globular clusters



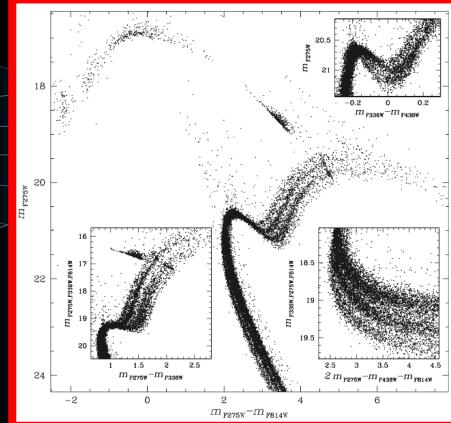
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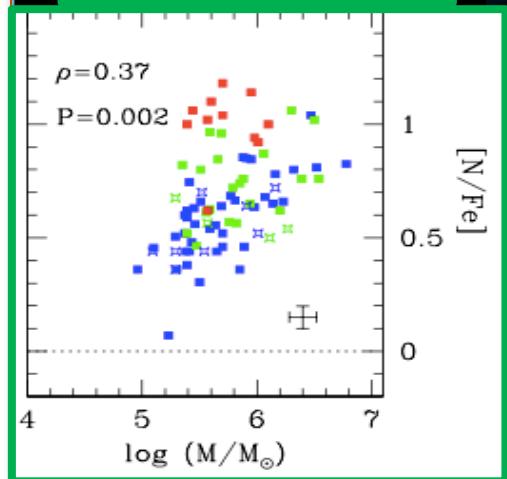
M54/Sagittarius



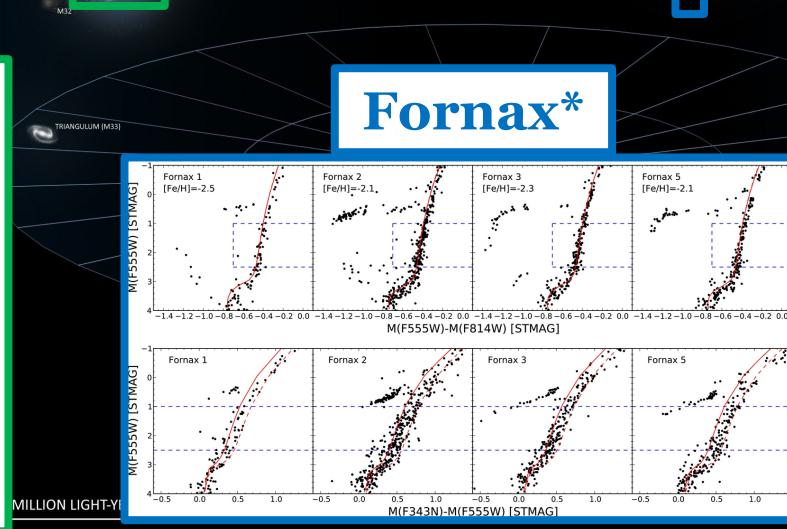
NGC2808/MW



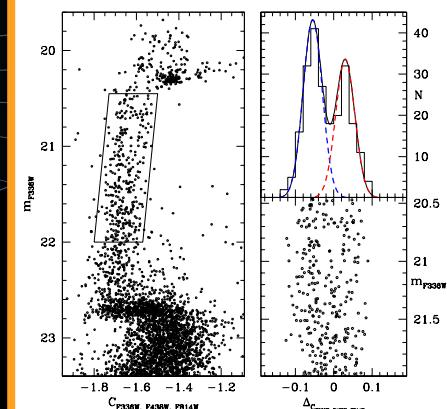
M31



Fornax\*

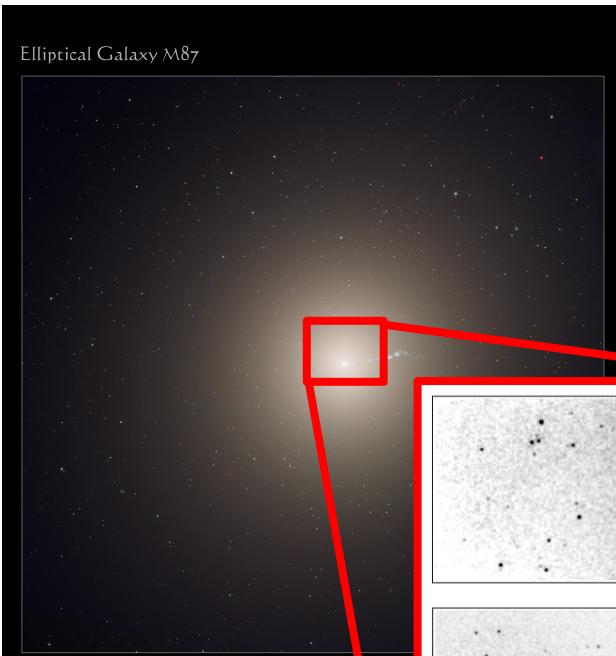


NGC121/SMC



# I. Multiple populations in globular clusters

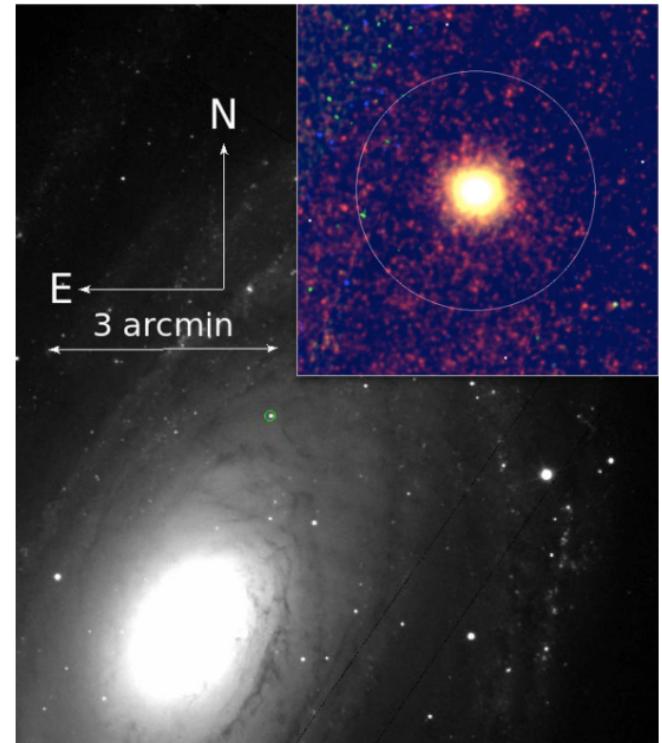
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M87 GC  
SYSTEM

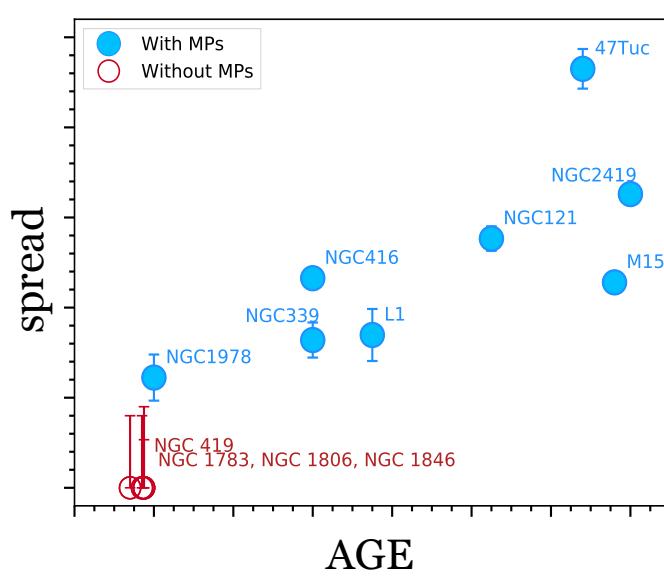
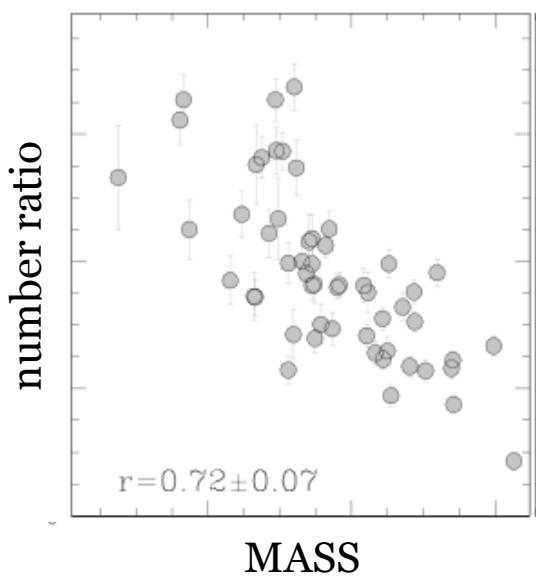
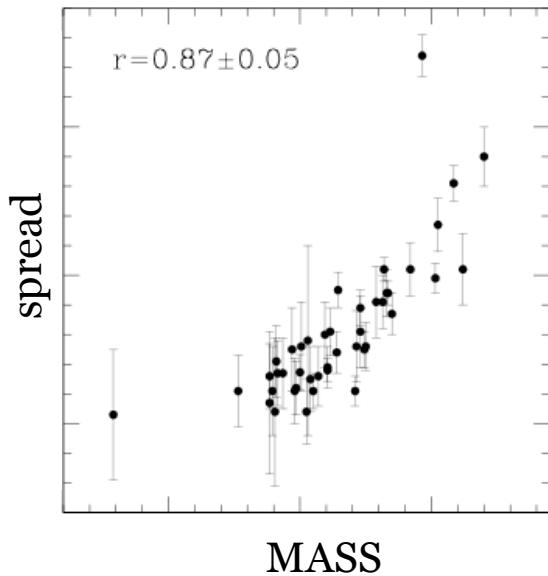


M81 GC  
SYSTEM



# I. Multiple populations in globular clusters

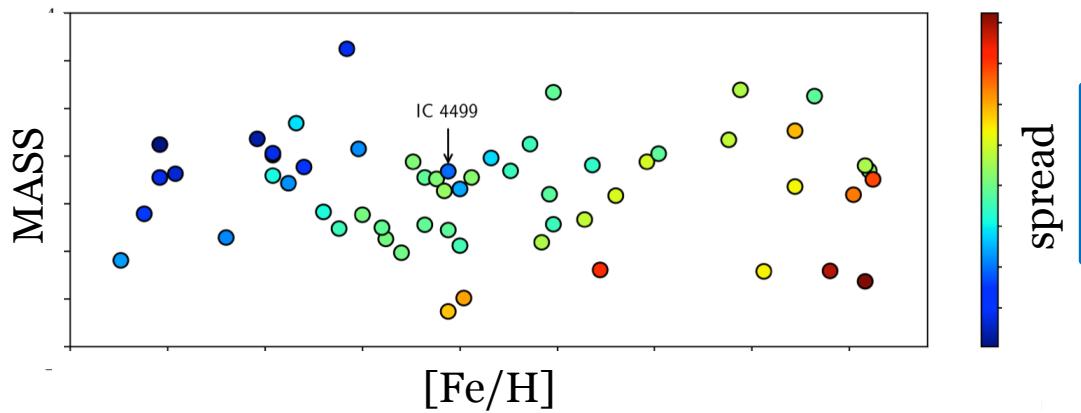
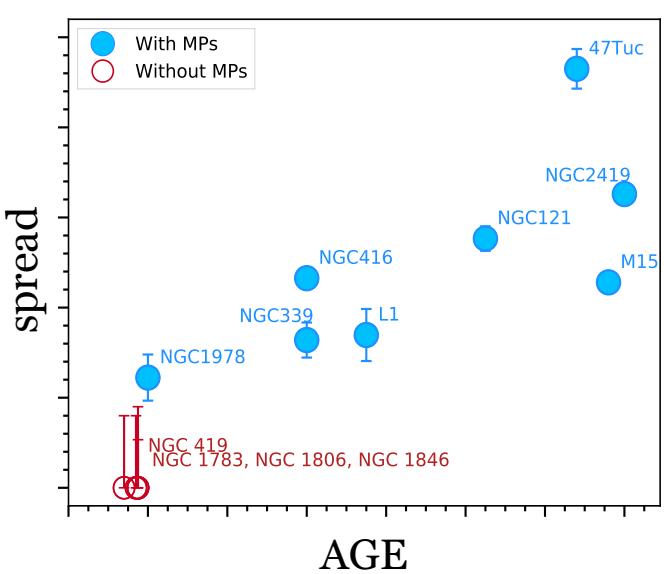
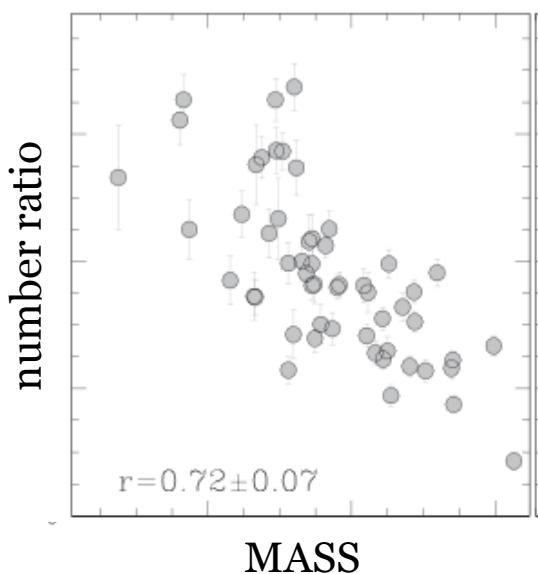
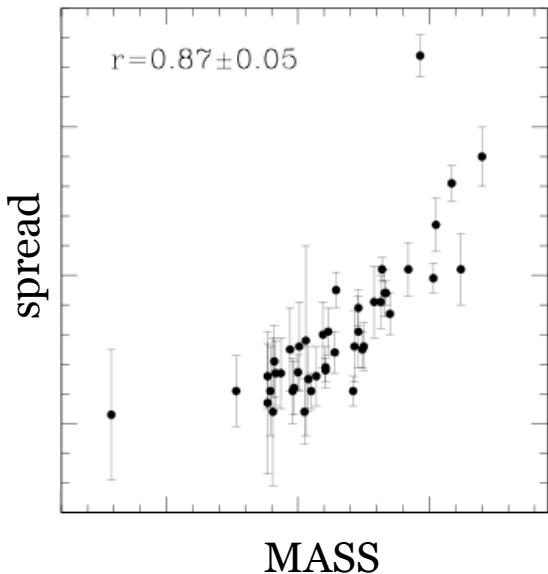
OAS people involved: A. Bragaglia, M. Bellazzini, F. Calura, E. Carretta, E. Dalessandro  
UniBO, UniPD, OAPD, University of Liverpool, University of Indiana, STScI, ESO



Mass and age are key ingredients in shaping MP properties

# I. Multiple populations in globular clusters

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***formation environment  
can possibly play a role***

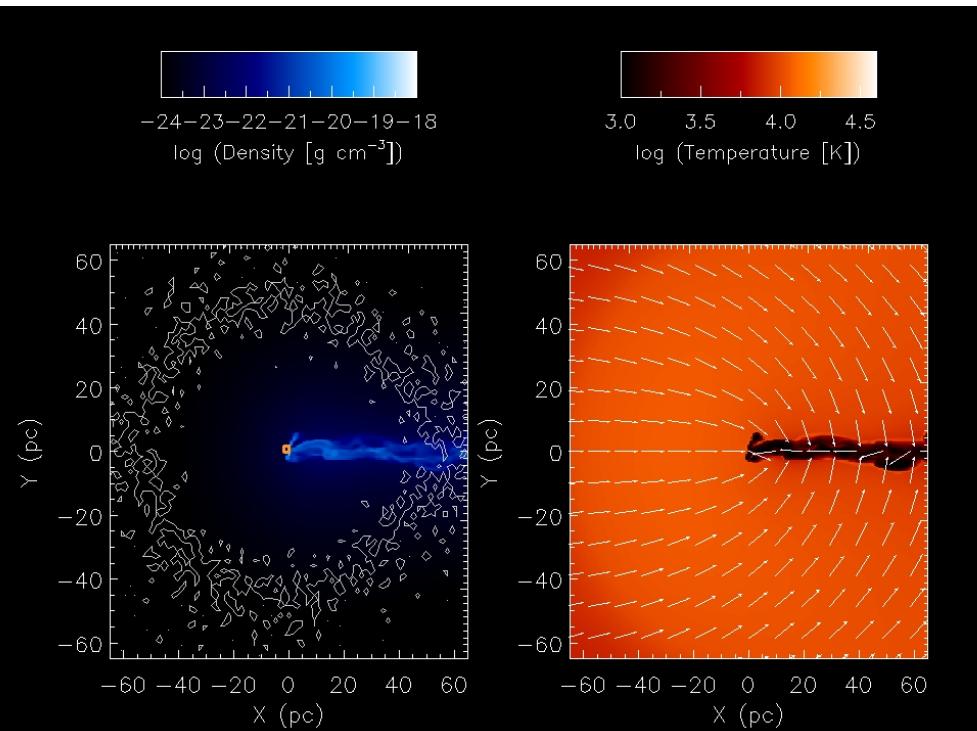
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## b) A new theoretical approach

ad-hoc hydrodynamical + N-body simulations following  
the early evolution (<100 Myr) of massive systems



- Physical mechanisms at the basis of cluster formation (Universe properties at high-z)
- Possible contribution to host galaxy mass

## II. Internal kinematics in GCs

OAS people involved: M. Bellazzini, E. Dalessandro, L. Origlia, A. Sollima

UniBO, University of Indiana, University of Tokyo, ESO, ESA

GOAL

Perform a leap forward in the knowledge of the physics and  
internal dynamics of dense stellar systems

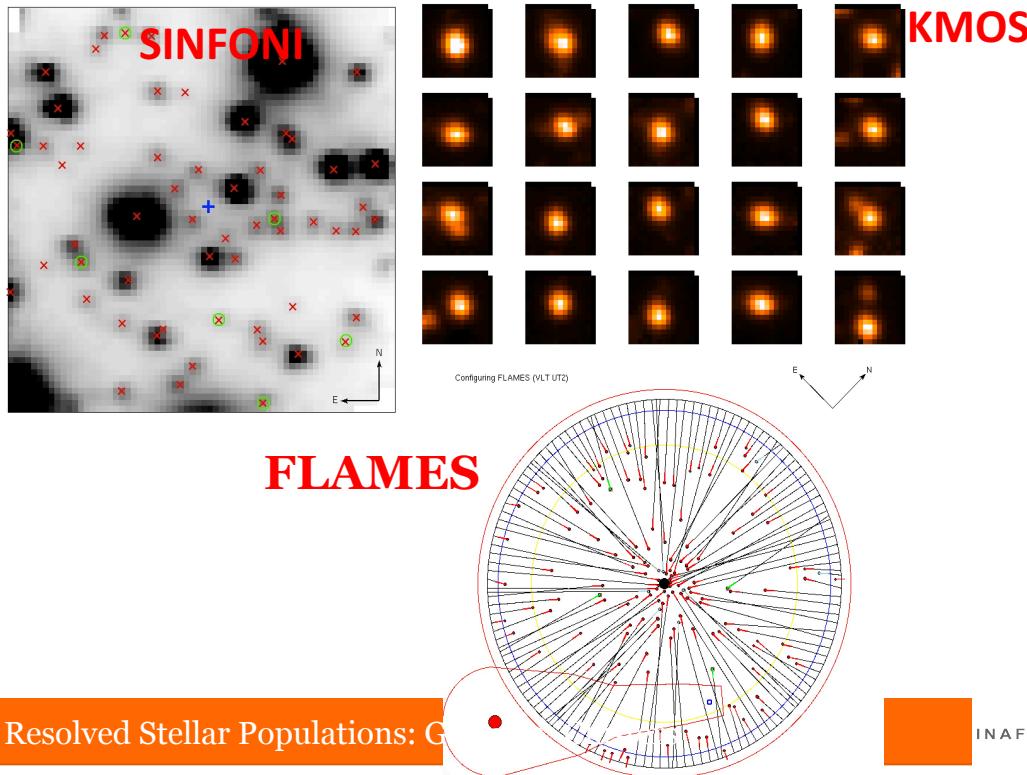
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UniBO, University of Indiana, University of Tokyo, ESO, ESA

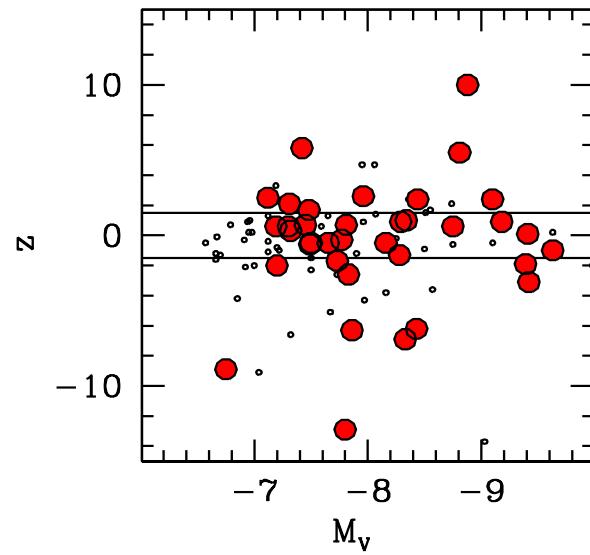


### MIKiS: The Multi-instrument Kinematic Survey of Galactic GCs

- ESO Large Programme 193.D-0232 194 hr acquired with KMOS+FLAMES (PI: Ferraro)
- ESO Large Programme 195.D-0750 101 hr with SINFONI (PI: Ferraro)
- ESO programmes on specific targets 50 hr with FLAMES (PI: Dalessandro)



Representative of the Galactic cluster population



## II. Internal kinematics in GCs

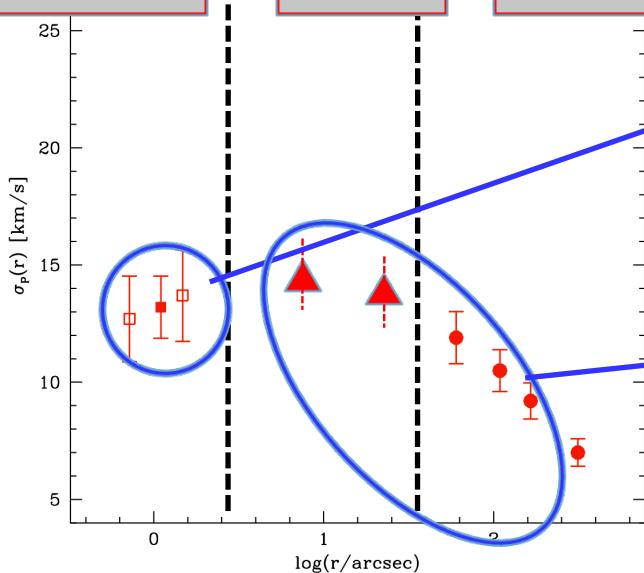
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UniBO, University of Indiana, University of Tokyo, ESO, ESA

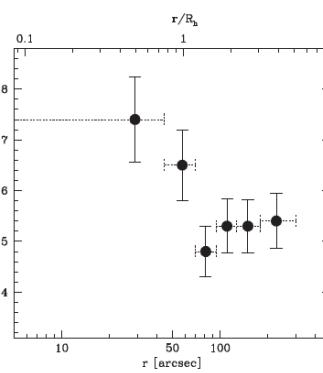
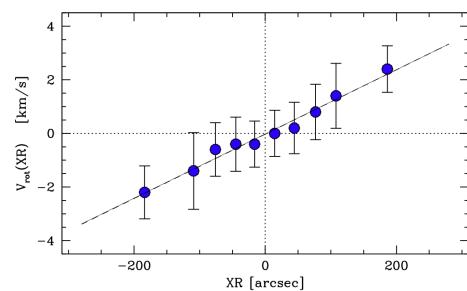
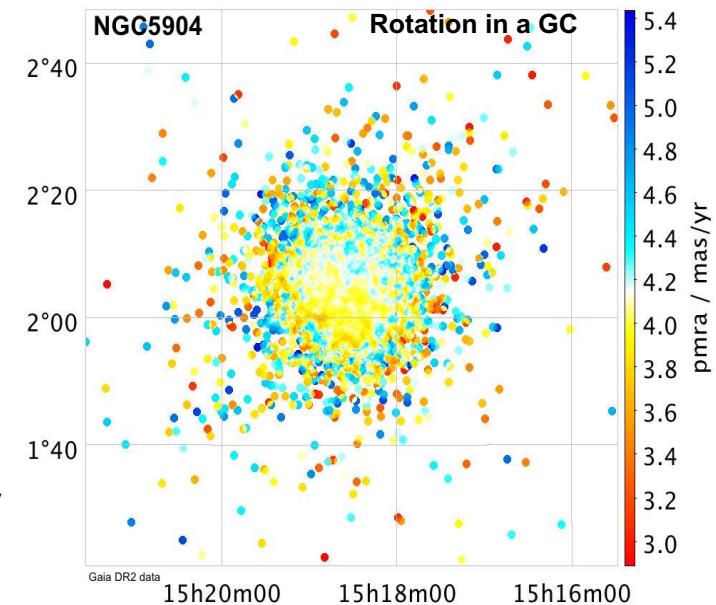
SINFONI

KMOS

FLAMES

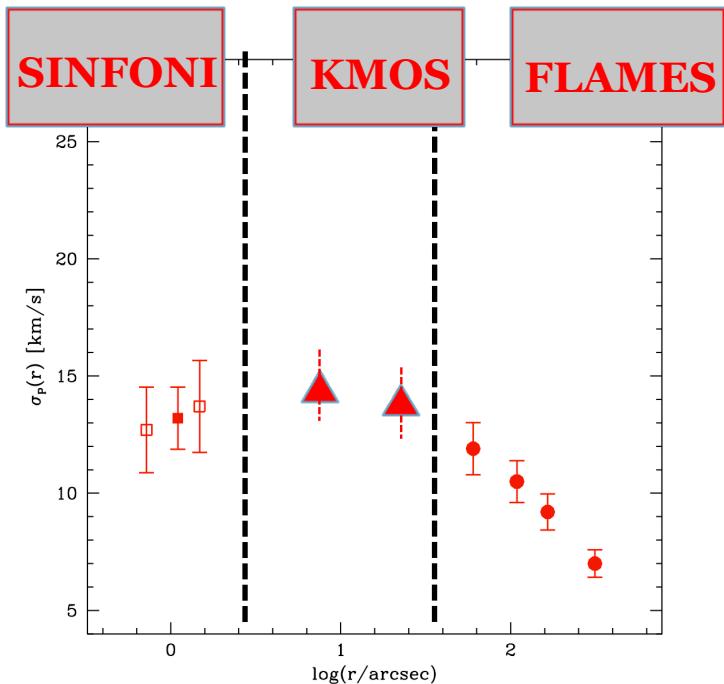


- Central VD cusp (IMBH?)
- High-velocity stars
- Rotation
- Rotation
- Potential escapers/ Extra-tidal tails
- Dark Matter??

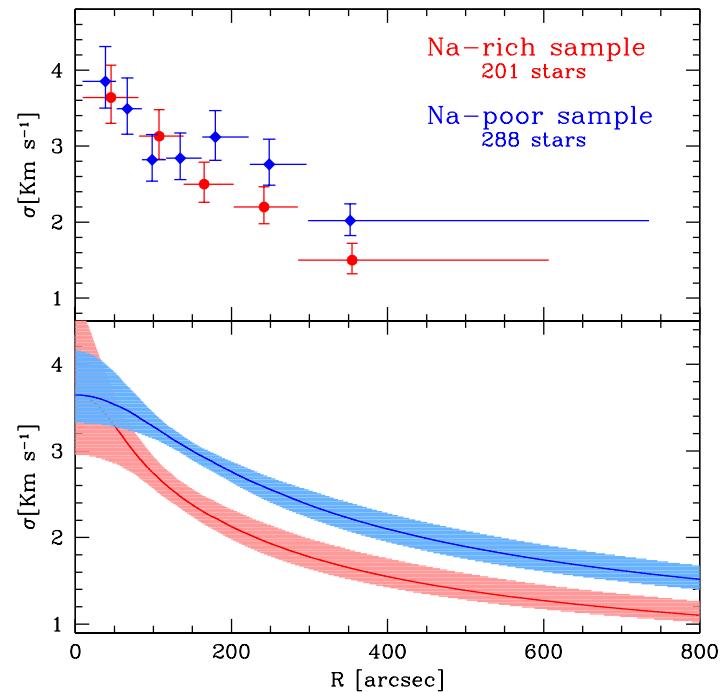


## II. Internal kinematics in GCs

OAS people involved: M. Bellazzini, E. Dalessandro, L. Origlia, A. Sollima  
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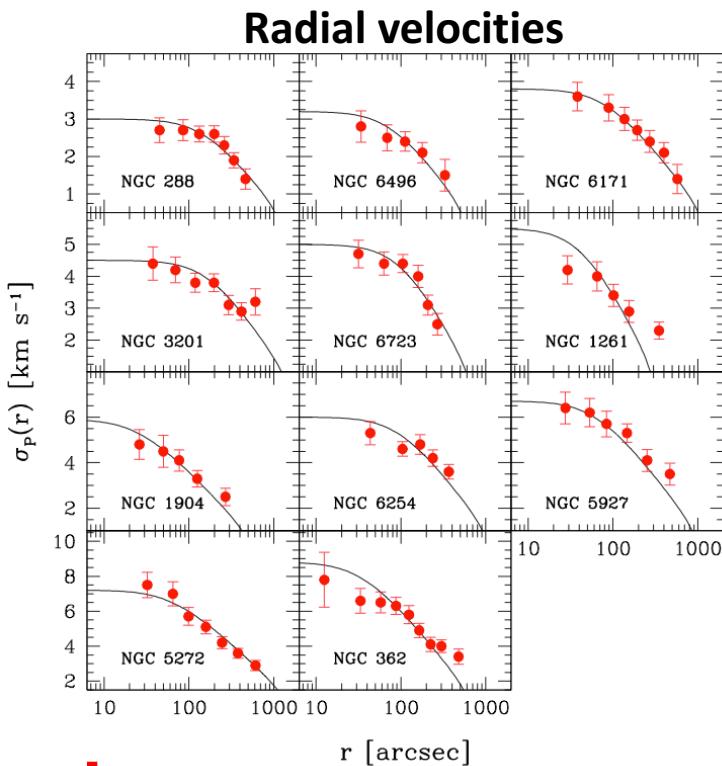
Crucial constraints on the MP formation scenarios



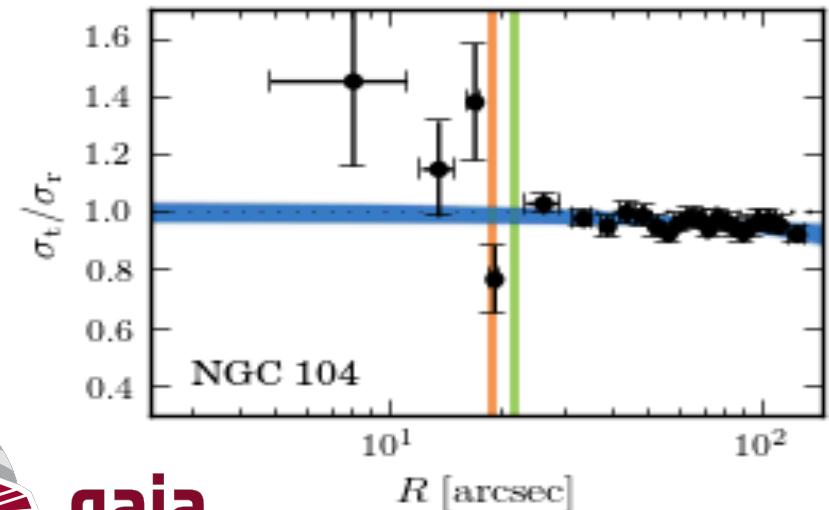
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OAS people involved: M. Bellazzini, E. Dalessandro, L. Origlia, A. Sollima

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### Proper motions



gaia



+ internal proper motions from multi-epoch HST and GAIA

- provide the FIRST 3D velocity map
- radial anisotropy profiles
- rotation inclination angles



## II. Internal kinematics in GCs

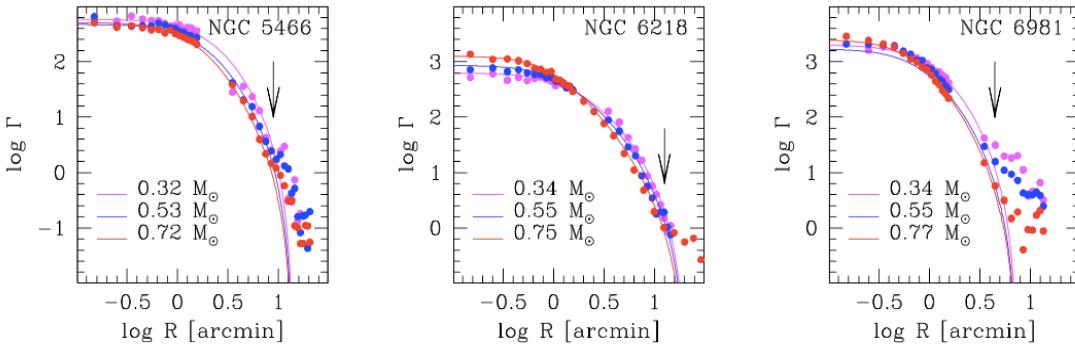
OAS people involved: M. Bellazzini, E. Dalessandro, A. Sollima

UniBO, University of Indiana, University of Tokyo, ESO, ESA



Detailed modeling by means of Monte-Carlo and N-body simulations

- Mass and mass segregation

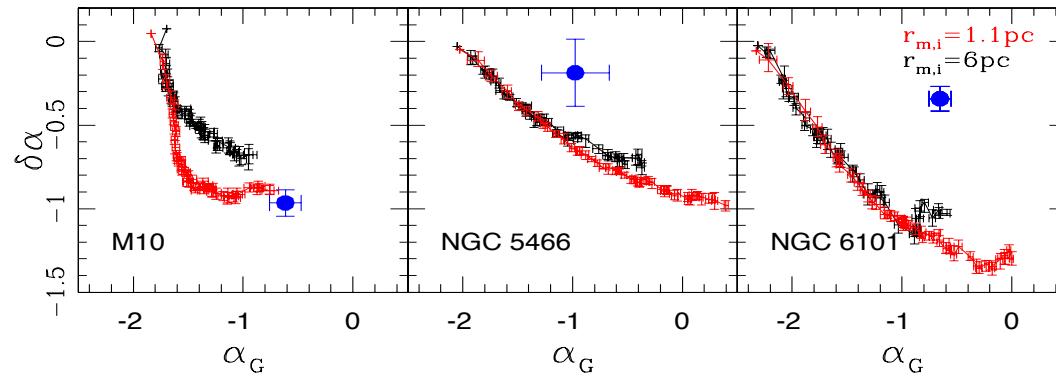


→ Dynamical age

→ Interaction with the  
Galactic potential

→ Origin of exotic objects

- IMF and the role of environment



→ Cluster initial conditions

## II. GCs as tracers of the Galaxy mass assembly

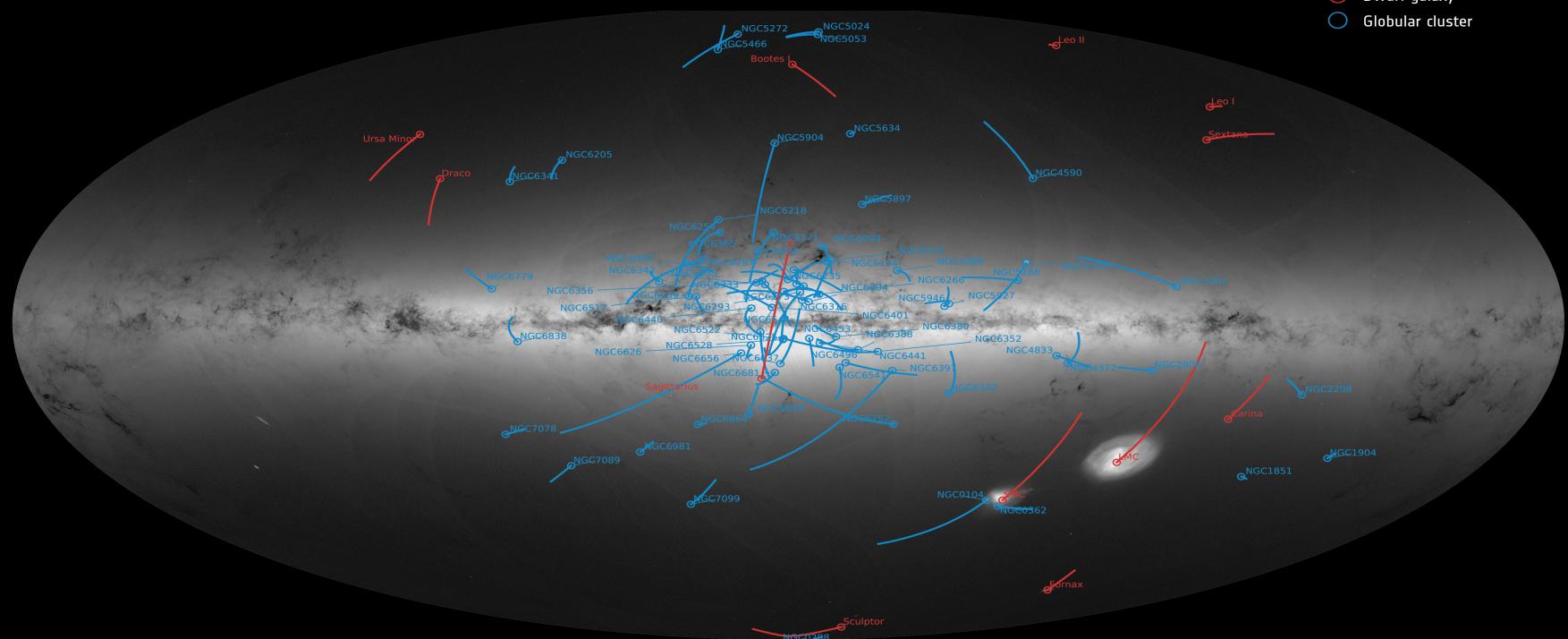
OAS people involved: M. Bellazzini, E. Dalessandro, A. Sollima  
UniBO, University of Indiana, University of Tokyo, ESO, ESA



### Structure and building-up of the MW



- Dwarf galaxy
- Globular cluster

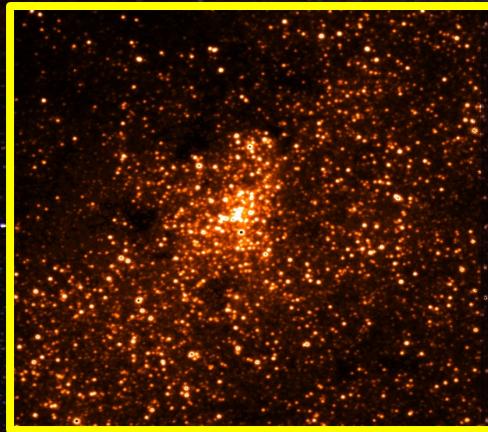


### III. Star clusters in the MW central regions

OAS people involved: E. Dalessandro, L. Origlia

UniBO, UCLA, Universidad de Concepcion, ESO

Nuclear star cluster



Inner bulge  
star clusters

GOAL

tracing bulge formation and evolution

accurate ages, chemistry and 3D-kinematics

# III. Star clusters in the MW central regions

OAS people involved: E. Dalessandro, G. Fiorentino, L. Origlia

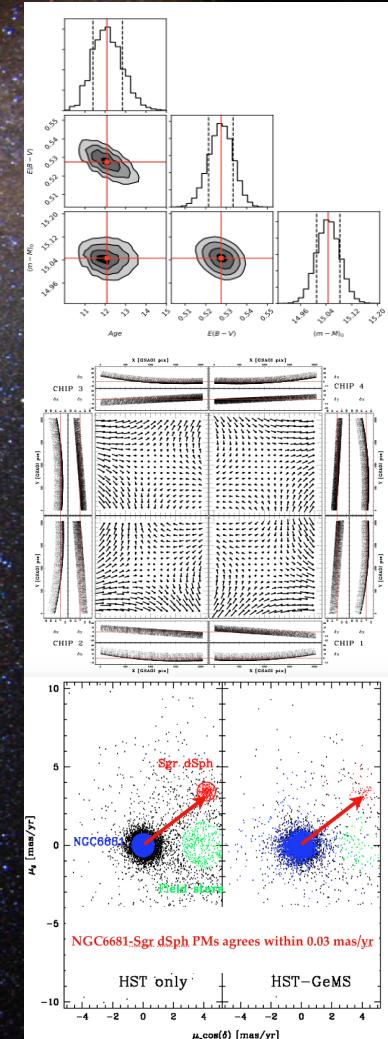
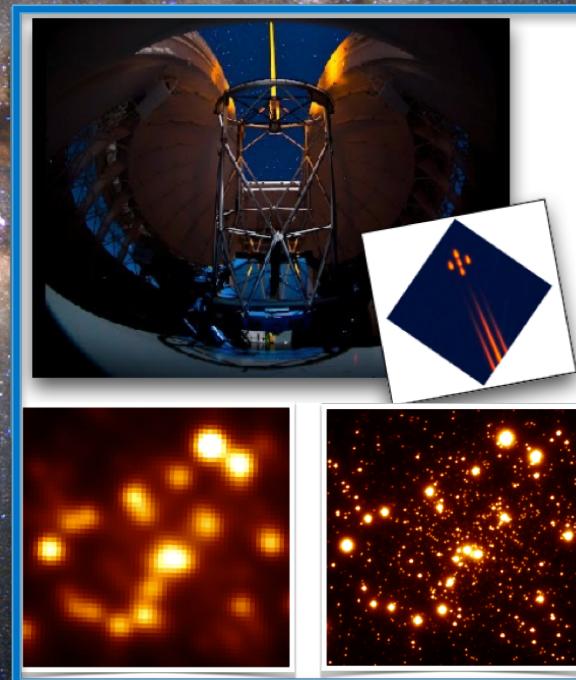
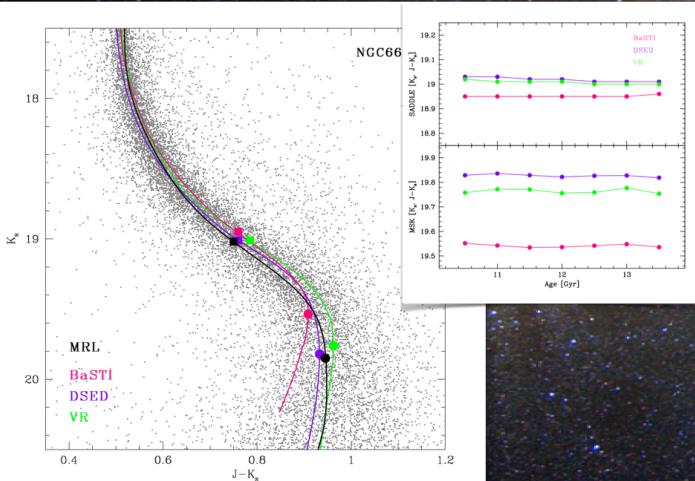
UniBO, UCLA, Universidad de Concepcion, ESO, University of Groningen, NRCC

## accurate ages

high reddening  $\rightarrow$  IR high-resolution imaging

- ground-based MCAO imaging with GeMS/GSAOI@Gemini
- near-future: JWST, MICADO@ELT

deep photometry and  
precise astrometry for  
future PM determination



# III. Star clusters in the MW central regions

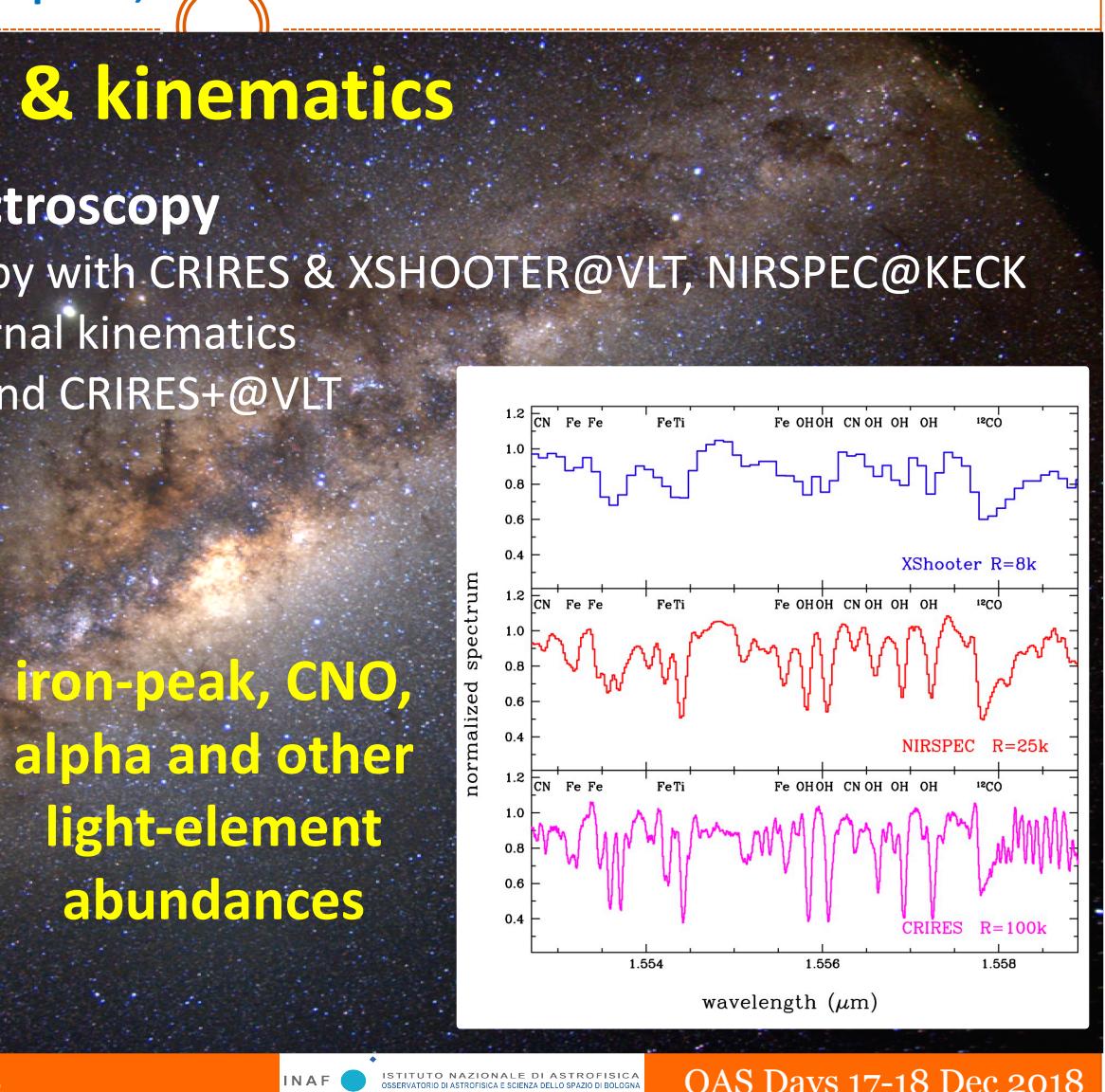
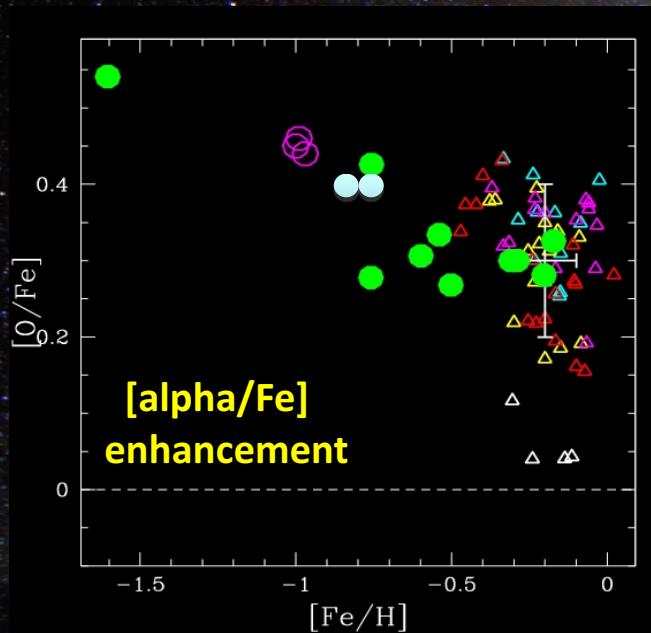
OAS people involved: E. Dalessandro, L. Origlia

UniBO, UCLA, Universidad de Concepcion, ESO

## accurate chemistry & kinematics

### high reddening → IR spectroscopy

- medium-high res spectroscopy with CRIRES & XSHOOTER@VLT, NIRSPEC@KECK
- the MiKis survey for the internal kinematics
- near-future: MOONS @VLT and CRIRES+@VLT



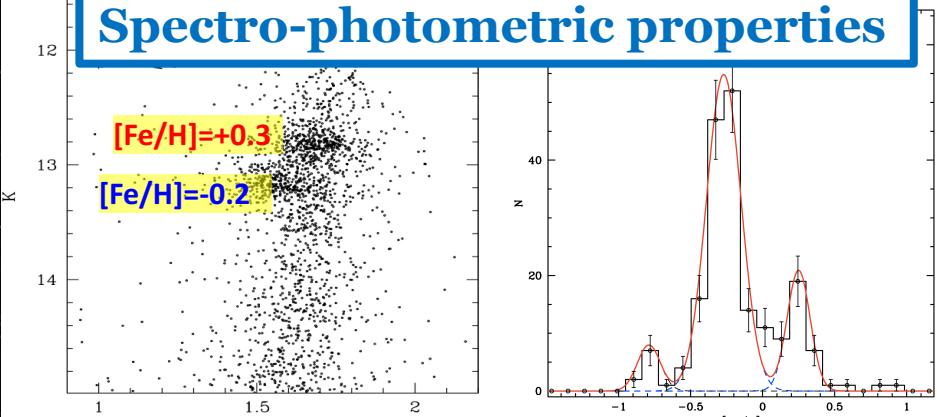
# III. Star clusters in the MW central regions: Terzan5

OAS people involved: M. Bellazzini, E. Dalessandro, L. Origlia, A. Sollima

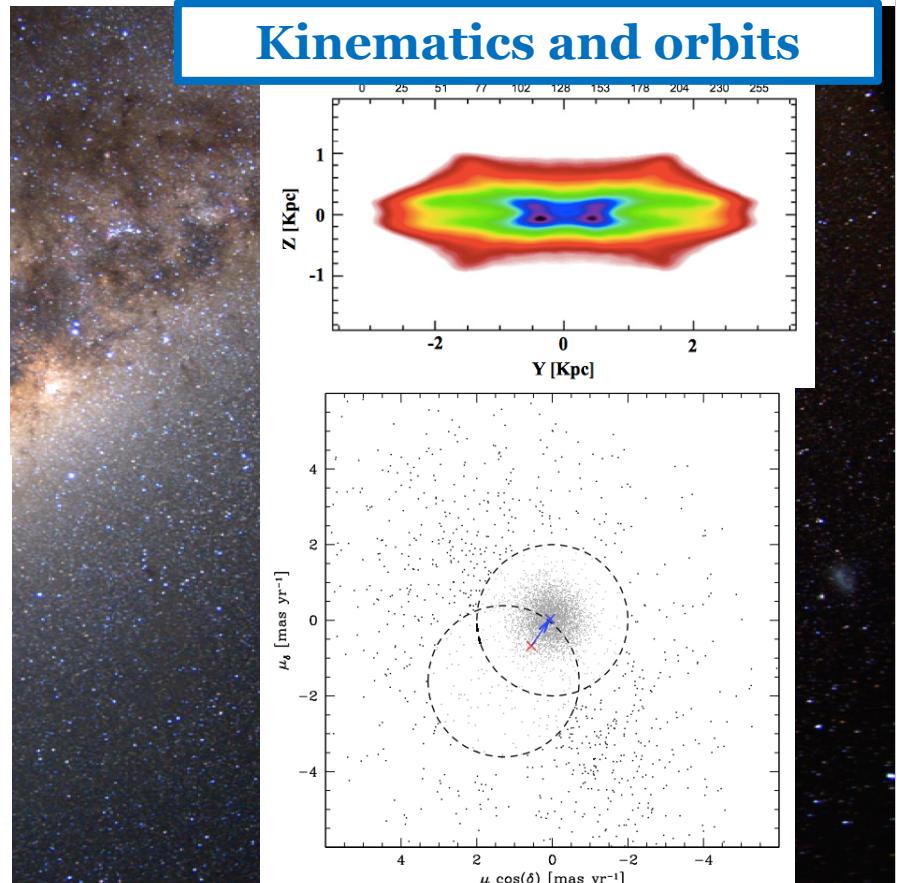
UniBO, UCLA, Universidad de Concepcion, ESO

Extensive photometric and spectroscopic campaign using  
HST, ESO, Keck, Gemini

## Spectro-photometric properties



## Kinematics and orbits



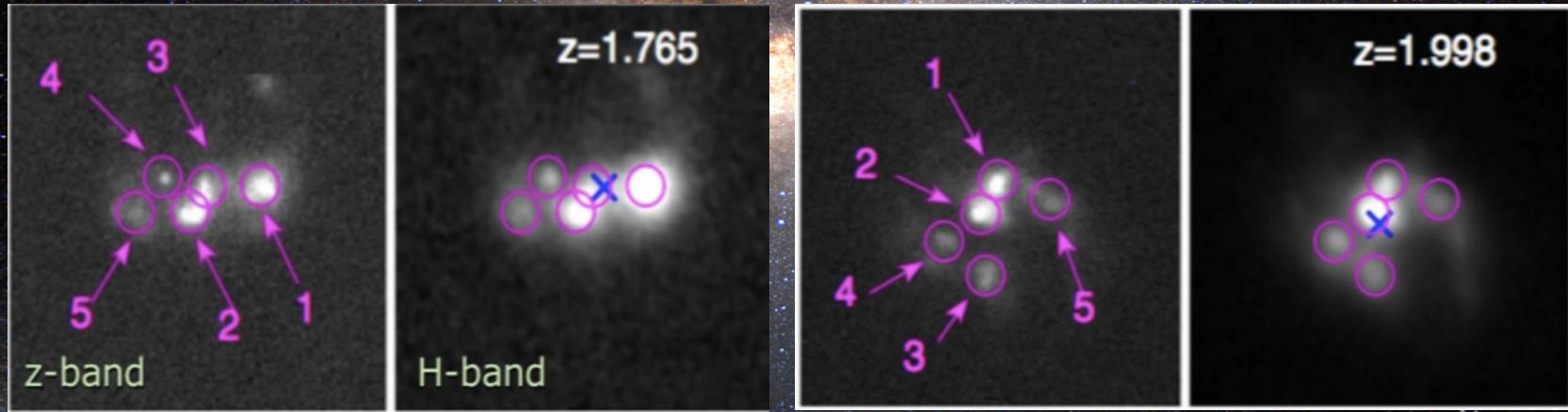
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OAS people involved: M. Bellazzini, E. Dalessandro, L. Origlia, A. Sollima

UniBO, UCLA, Universidad de Concepcion, ESO

a fossil/seed fragment of the Bulge that did not merge but evolved  
and self-enriched

impact on our understanding of extra-galactic bulges and nuclear regions of disc galaxies



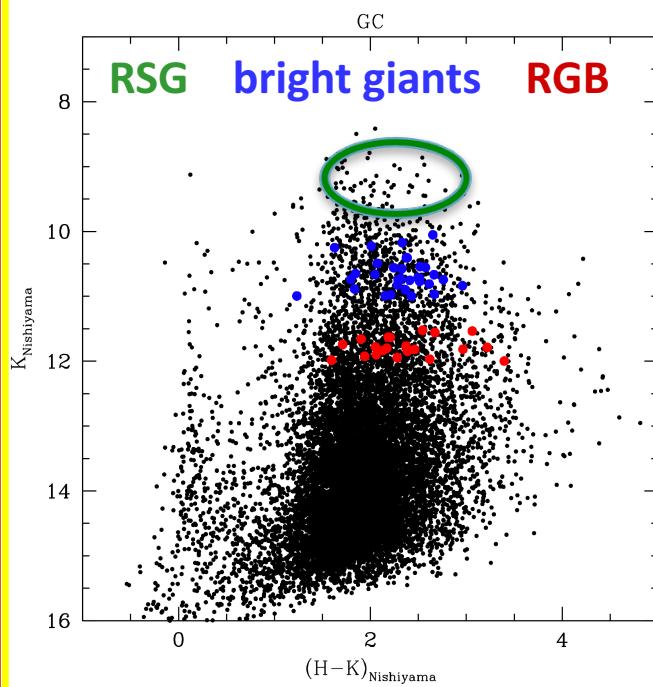
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OAS people involved: L. Origlia

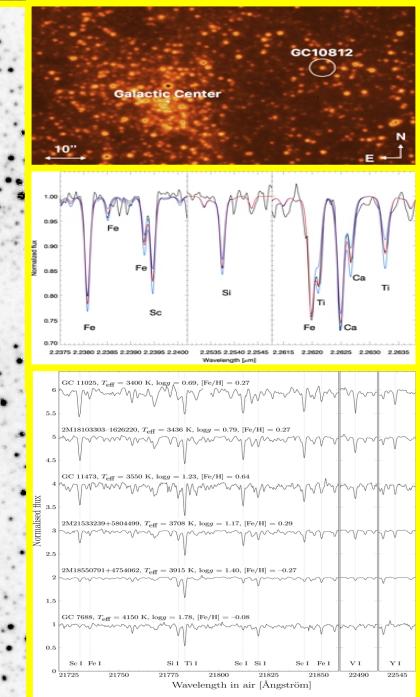
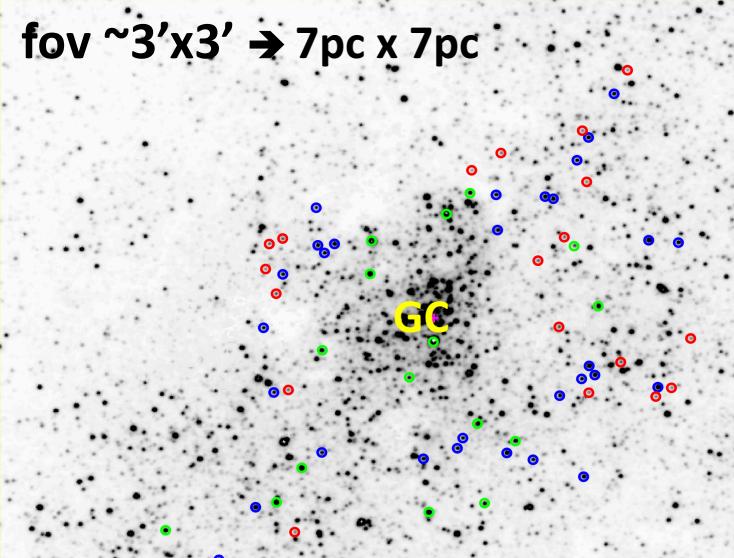
UniBO, UCLA, University of Lund, ESO



the nuclear star cluster  
multi- age+metallicity SPs, huge reddening:  $Av \sim 30$  mag!  
detailed chemistry and kinematics with NIRSPEC@Keck and XHOOTER@VLT



fov  $\sim 3' \times 3' \rightarrow 7\text{pc} \times 7\text{pc}$



### III. Star clusters in the MW central regions

OAS people involved: M. Bellazzini, E. Dalessandro, L. Origlia

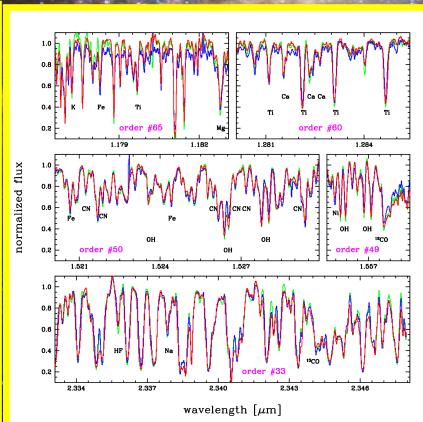
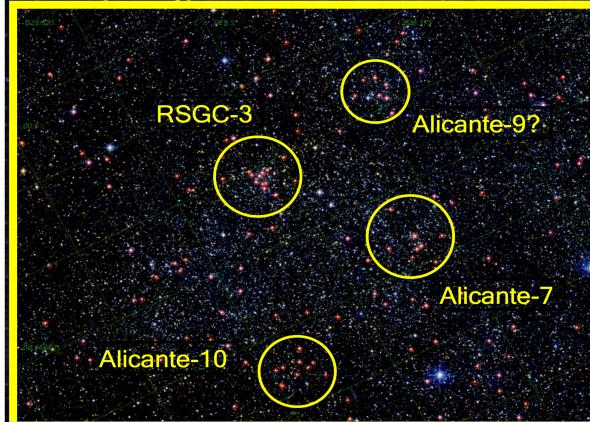
UniBO, ESO



## Scutum & h,chi Persei: multiple young star clusters & associations

detailed chemistry and kinematics with GIARPS@TNG (SPA LP - PI: Origlia )

**Scutum complex at  $d_{GC} \sim 3.5$  kpc**  
tracing gas inflows and SF triggered  
by interaction between the spiral arm  
and the central bar



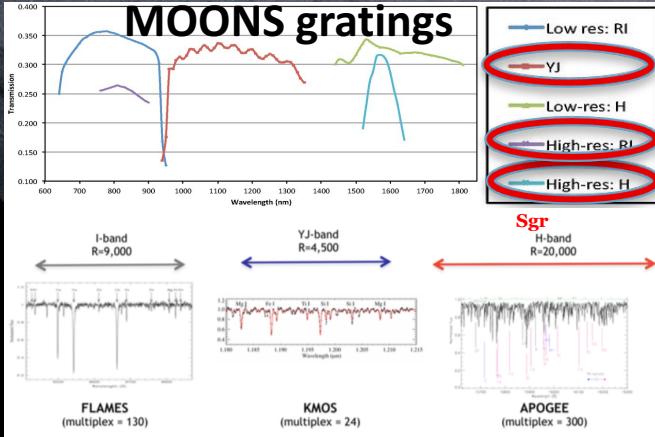
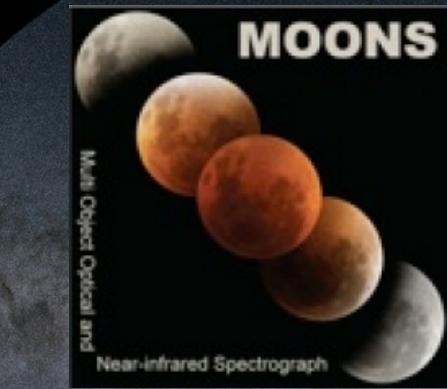
**h,chi Per complex at  $d_{GC} \sim 10$  kpc**  
tracing SF in the outer disc  
3D kinematics with Gaia



# MOONS at the VLT: the GTO Galactic Survey

OAS people involved: E. Dalessandro, L. Origlia, M. Bellazzini, A. Bragaglia, G. Clementini, M. Tosi  
UniBO

Massive (>0.5M stars) chemistry and kinematics of the stellar pops  
in the central regions of the MW, LMC and Sgr dwarf galaxy



Bulge and Southern emisphere disk



Sgr dwarf spheroidal



Magellanic Clouds