JWST and the ELTs: An Ideal Combination
ESA/ESO Workshop, Garching, April 13-16, 2010

star clusters: future generation of diagnostic tools from high resolution (spatial & spectral) IR observations

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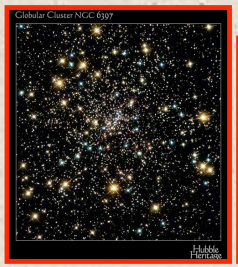
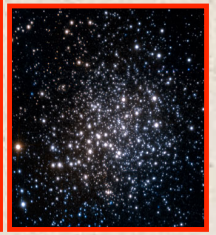
star clusters

Galactic

NGC 6397

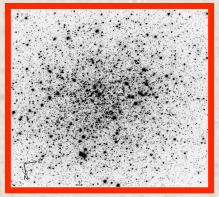


Terzan 5



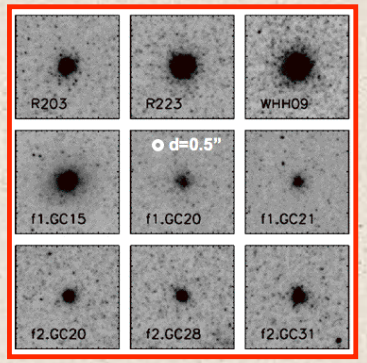
Local Group

SMC-121

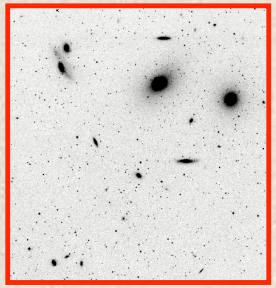


M31-G1

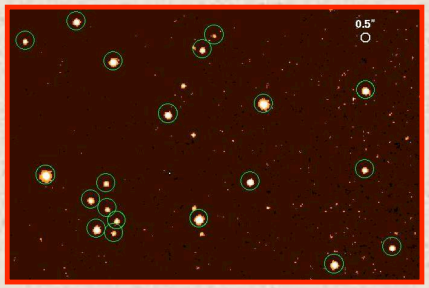
Centaurus



Virgo Cluster



M87



valuable tools for theoretical and observational astronomy across a wide range of disciplines from cosmology to stellar evolution & dynamics

easily observable in external galaxies out to large distances

major star-forming episodes in galaxies accompanied by significant cluster formation

star clusters stellar populations & metal content strictly connected with those of their host galaxies

important witnesses of the epoch and homogeneity of cosmic reionization, and of the role of dark matter in the formation of structures in the early Universe

see e.g. Brodie & Strader 2006, ARA&A 44, 193

star clusters

all canonical evolutionary sequences ➔

pre-MS & MS down to the H-burning limit

SGB, RGB, HB and AGB

post-AGB and WD cooling sequence

stellar evolution, chemical enrichment & nucleo-synthesis

exotic objects ➔

blue straggler stars, cataclysmic variables, milli-second pulsars, intermediate mass BHs (?)

stellar dynamics, binary evolution, environment

star clusters

with the current generation of telescopes/instruments ➔ evolved stellar populations of star clusters

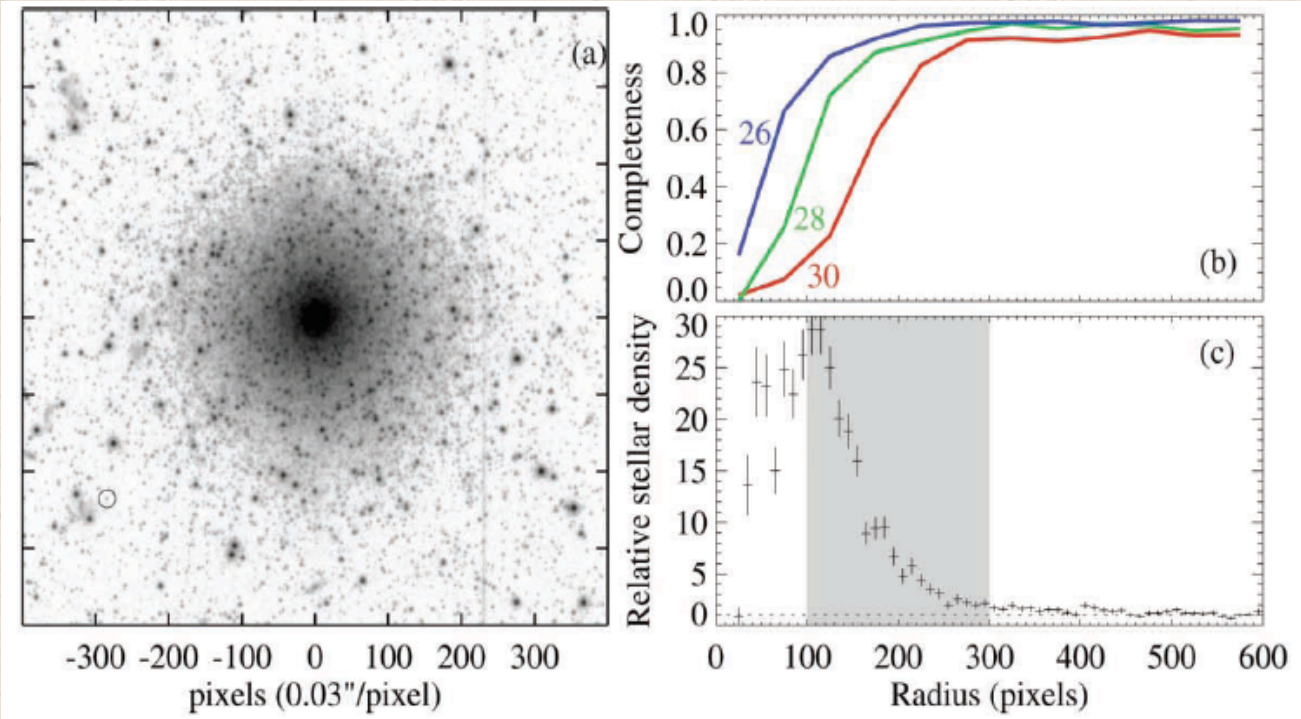
HST & 8-10m ground based telescopes at their limit….

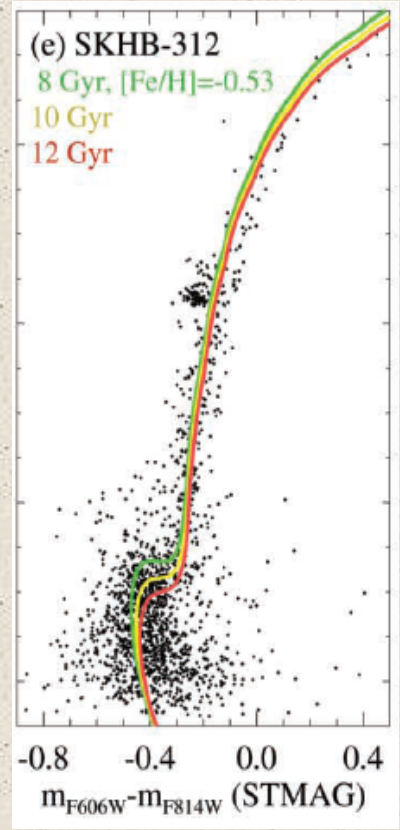
<u>in terms of sensitivity</u>:

- ✓**HST-ACS: photometry down to the MS turn-off of old GCs out to ~ M31**

star clusters

✓HST-ACS: photometry down to the MS turn-off of old GCs out to ~ M31





pixel: 30 mas

integration time: 39hrs in F606W & 45hrs in F814W

Brown etal 2003;2004

star clusters

HST & 8-10m ground based telescopes at their limit….

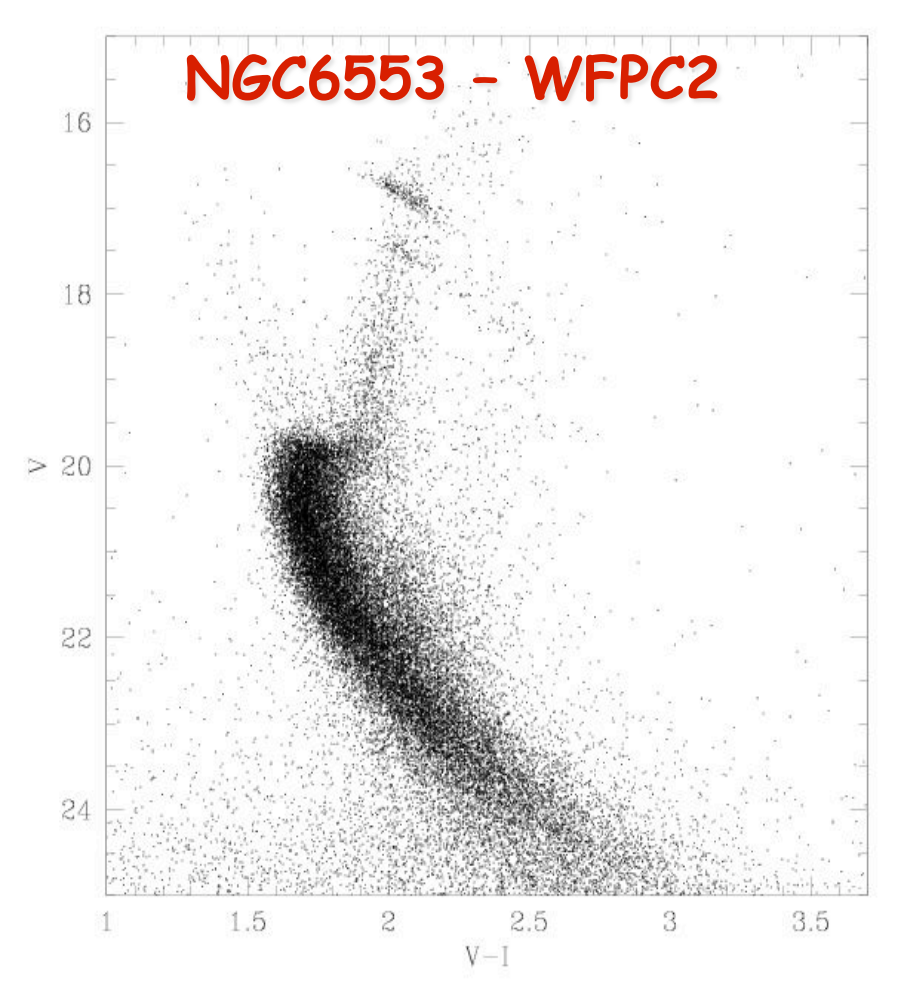
in terms of sensitivity:

- ✓HST-ACS: photometry down to the MS turn-off of old GCs out to ~ M31
- ✓nearIR AO+VLT/Keck & HST: photometry down to the MS turn-off of Bulge GCs

star clusters

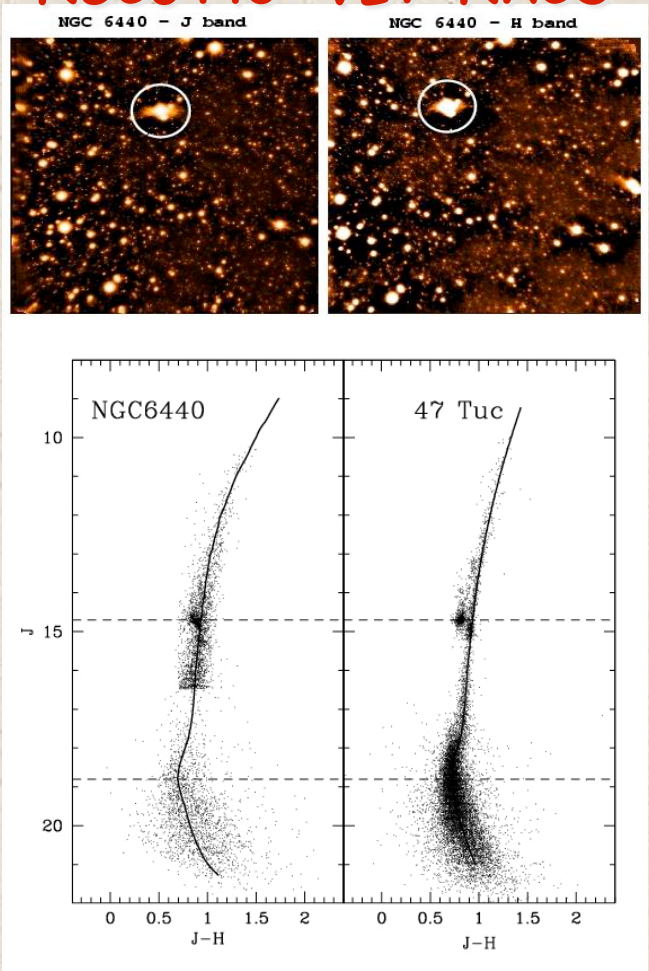
✓AO+VLT/Keck & HST: photometry down to the MS turn-off of Bulge GCs

NGC6553 - WFPC2



Zoccali etal 2001

NGC6440: VLT-NACO



Origlia etal 2008

star clusters

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in terms of sensitivity:

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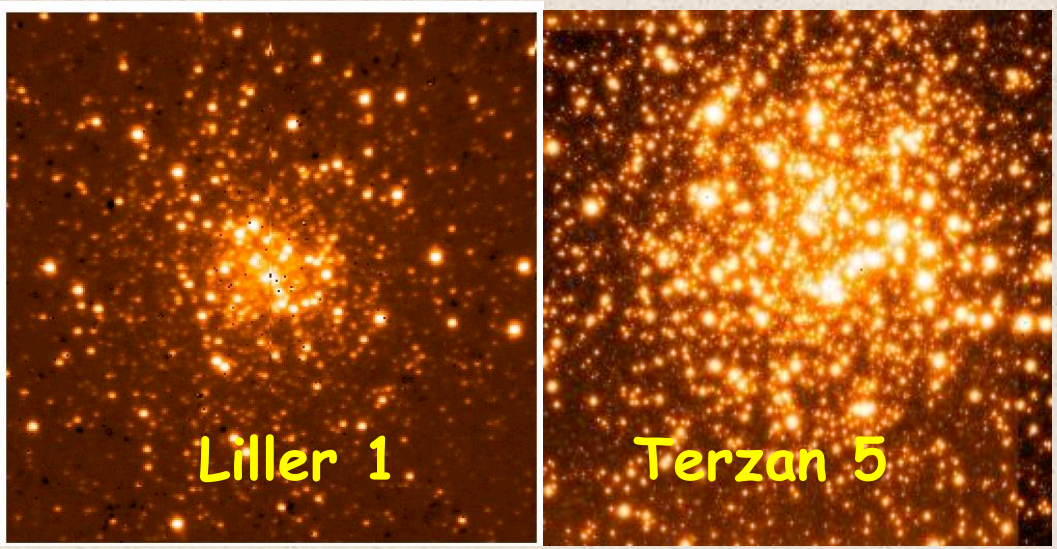
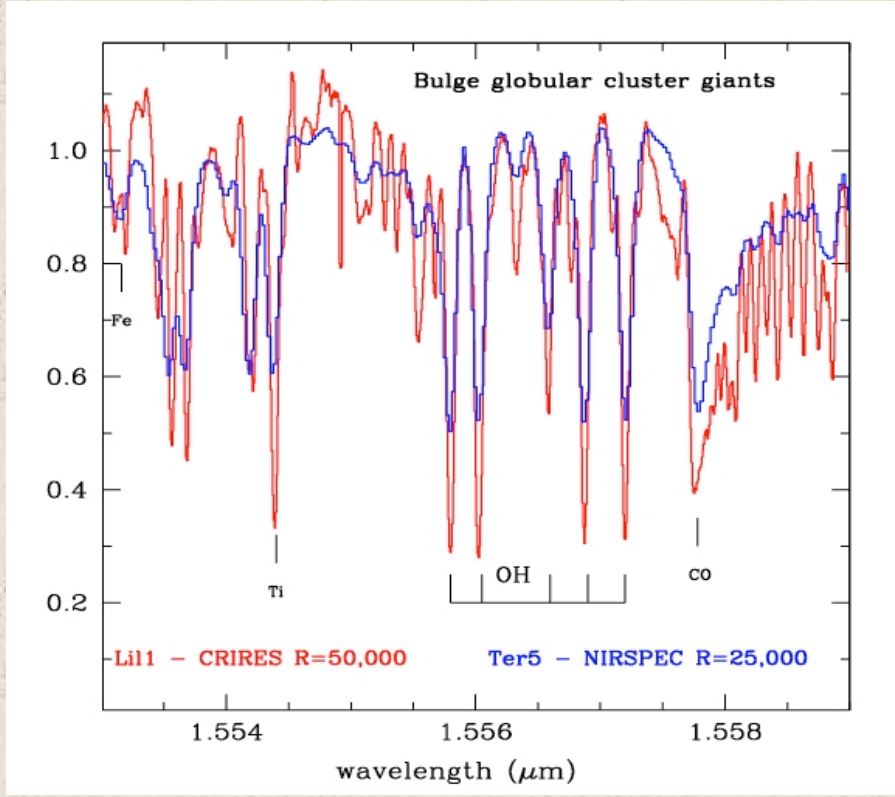
- ✓**medium-high resolution spectroscopy of giant stars in the Galactic Bulge GCs**

star clusters

✓medium-high resolution spectroscopy of giant stars in **Galactic Bulge GCs**



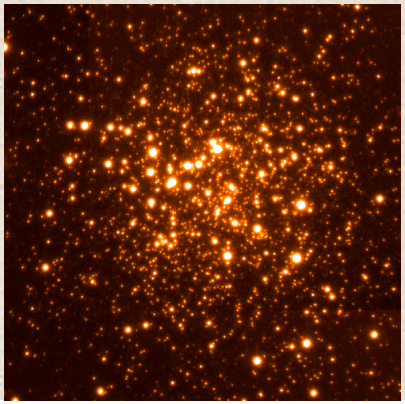
Origlia & Rich 2004



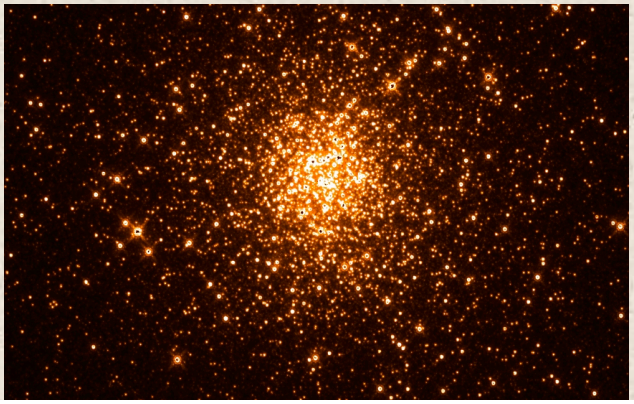
star clusters

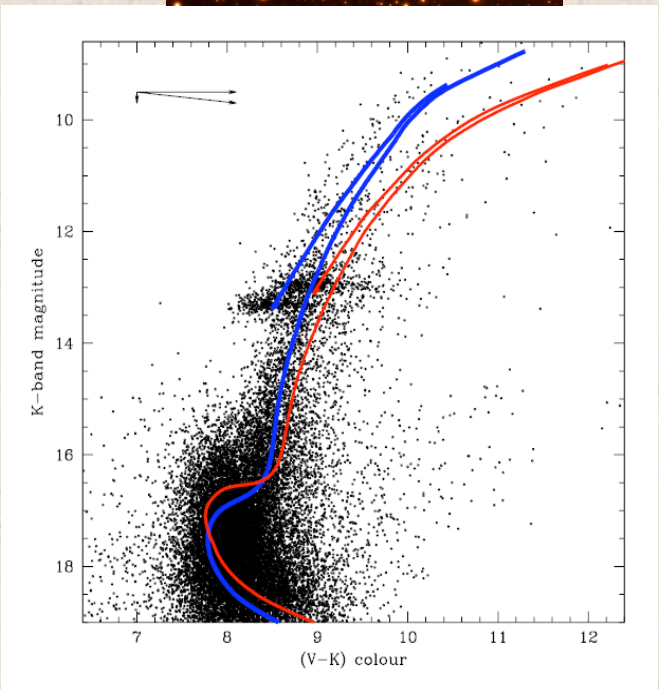
Terzan 5: remnant of a primordial building block in the Bulge

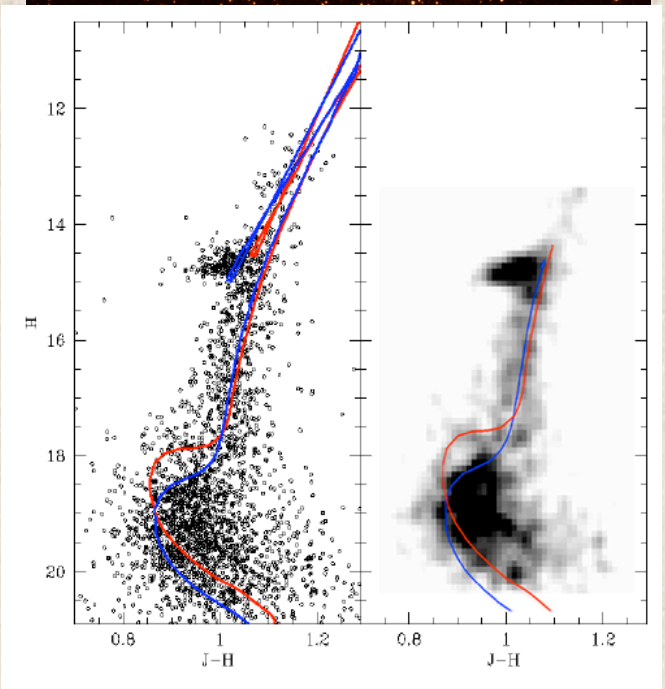
VLT-MAD



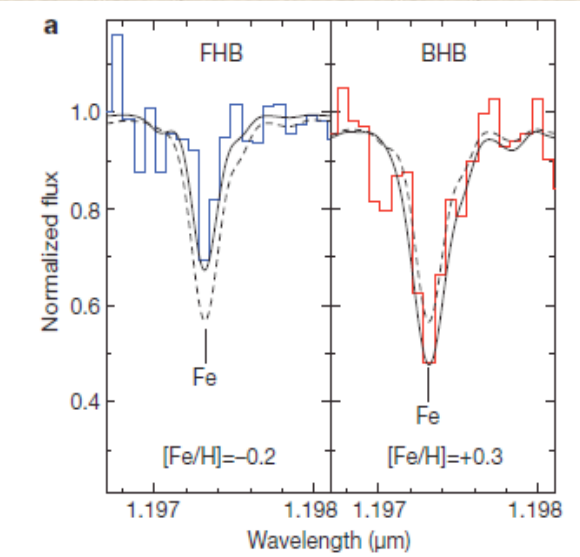
HST-WFC3







Keck - NIRSPEC



Ferraro etal 2009, Nature, 462, 483

star clusters

HST & 8-10m ground based telescopes at their limit….

in terms of sensitivity:

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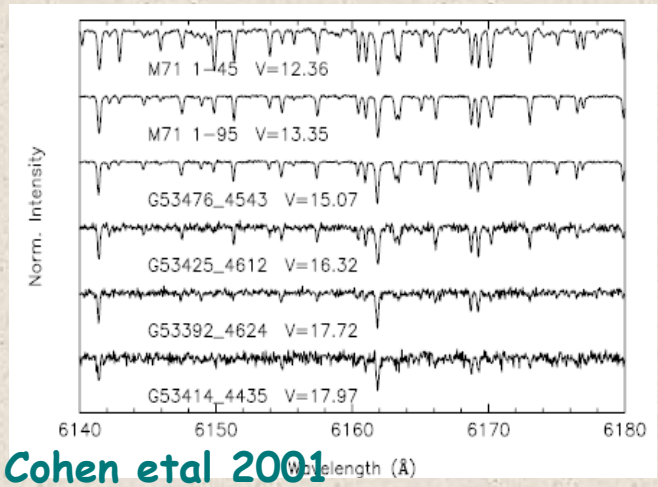
- ✓nearIR AO+VLT/Keck & WF3: photometry down to the MS turn-off of Bulge GCs
- ✓medium-high resolution spectroscopy of giant stars in the Galactic Bulge GCs
- ✓low-medium resolution spectroscopy of MS stars in Galactic Halo GCs

star clusters

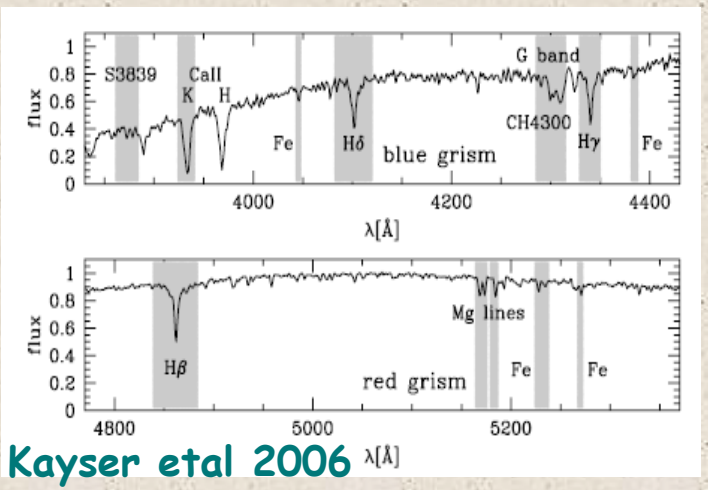
✓low-medium resolution spectroscopy of MS stars in **Galactic Halo GCs**

M71: Keck-HIRES



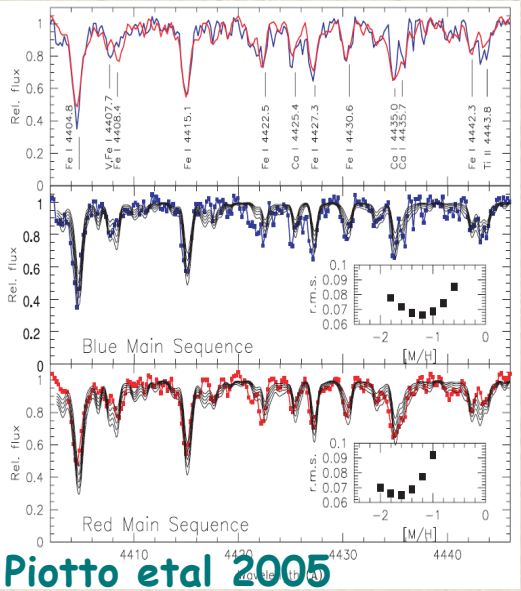
Cohen etal 2001

ω Cen: VLT-FORS



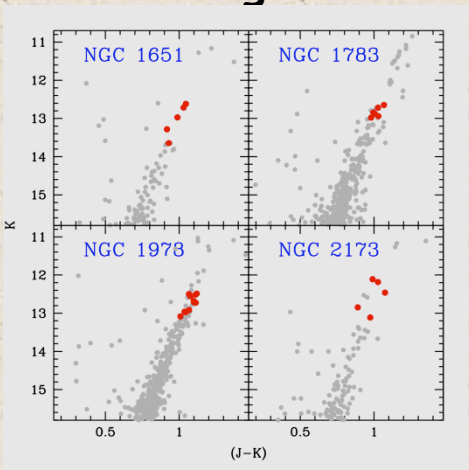
Kayser etal 2006

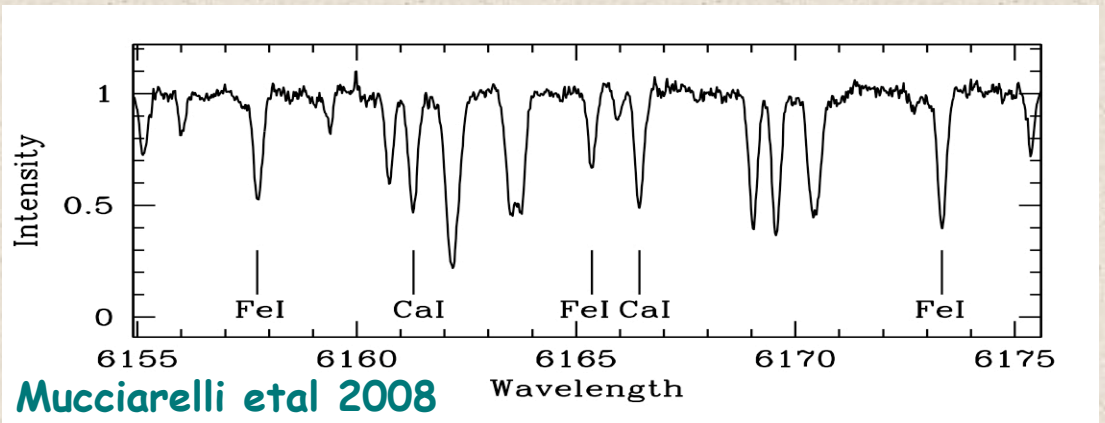
ω Cen: VLT-FLAMES



Piotto etal 2005

✓medium-high resolution spectroscopy of giant stars in the **MC GCs**





Mucciarelli etal 2008

VLT
UVES
FLAMES

star clusters

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in terms of sensitivity:

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- ✓medium-high resolution spectroscopy of giant stars in the Galactic Bulge GCs
- ✓low resolution spectroscopy of MS stars in Galactic Halo GCs

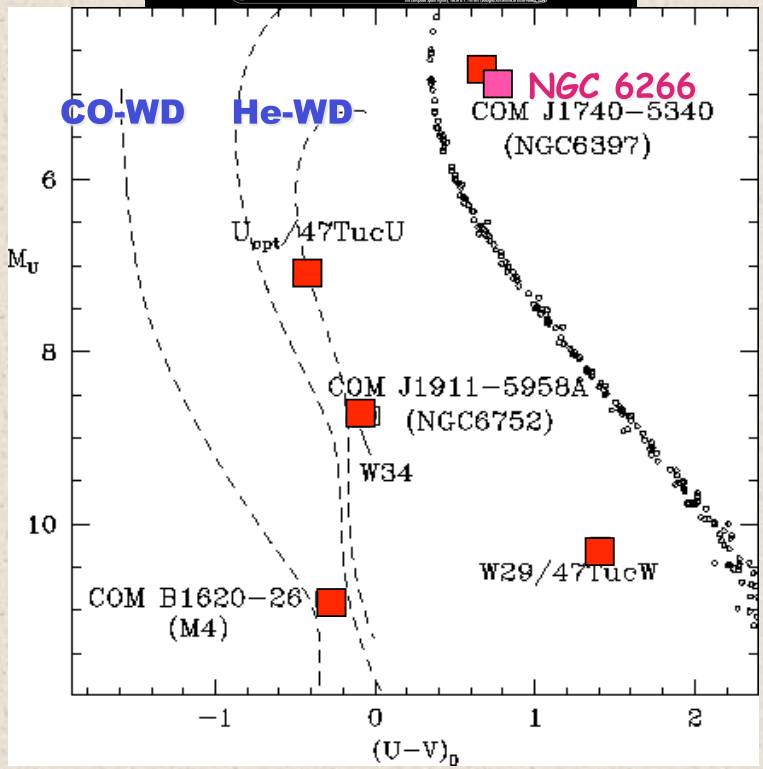
in terms of spatial resolution:

- ➢ prohibitive crowding in the core (~central parsec(s)) even in most Galactic GCs
- ➢ stars not resolved out of the LG, even in the outer regions

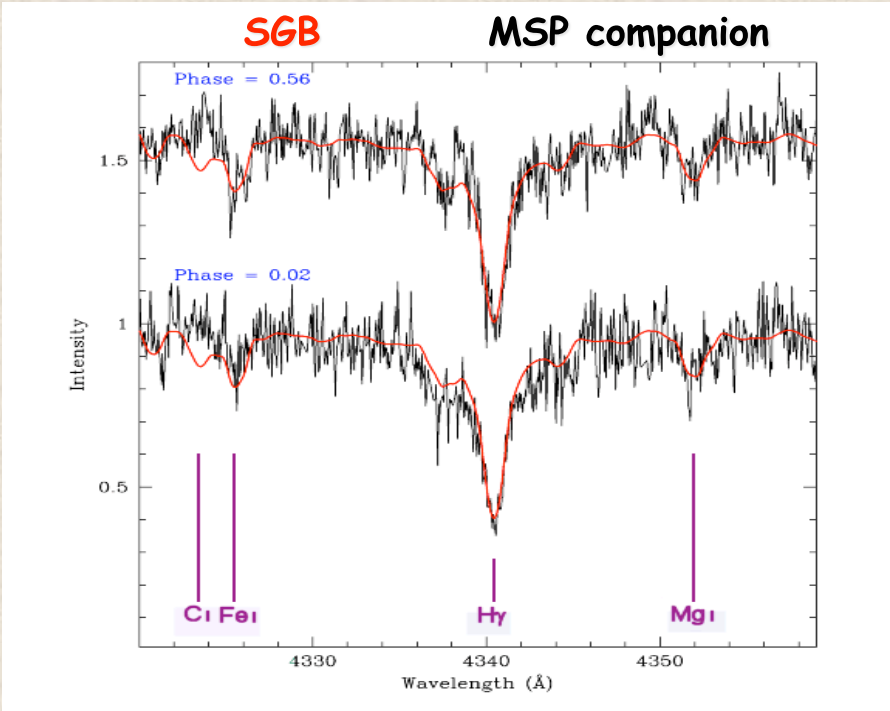
star clusters - exotic objects

Galactic GCs host 50% of the known MSPs

the MSP re-cycling scenario: binary system with a NS spun up by mass accretion from an evolving companion ➔ new born MSP + core of a peeled star which lost most of its envelope



NGC 6266 - UVES@VLT spectroscopy



Ferraro etal 2002

star clusters - exotic objects

IMBHs detections

high-resolution photometry & kinematics + detailed dynamical modeling

to date: 2×10^4 $M_\odot$ BH in G1 in M31

from density profile, velocity dispersion profile, specific dynamical models (Gebhardt et al. 2005), **X-ray emission** (Pooley & Rappaport 2006), **radio emission** (Ulvestad et al. 2007)

+ temptative suggestions for:

M15 from density & velocity dispersion profiles
(Newell et al. 1976; … Bash et al. 2007; $M_{BH} \sim$ few 10^3 $M_\odot$)

NGC 6752 from anomalous position of MSP
(Colpi et al. 2003; $M_{BH} \sim$ few 10^2 $M_\odot$)

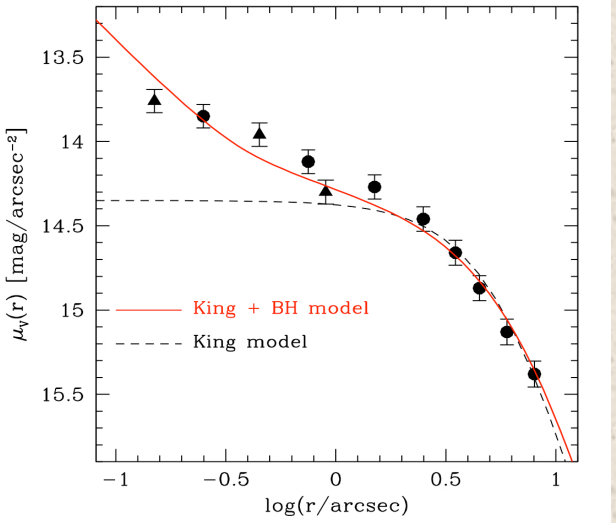
47Tuc from velocity dispersion profile
(McLaughlin et al. 2006; $M_{BH} = 900 \pm 900$ $M_\odot$)

NGC 2808, M80, M13, M62, M54, NGC 6388
from inner slope of density profile
(Noyola & Gebhardt 2006; Miocchi 2007; $M_{BH} \sim 10^2 - 4 \times 10^3$ $M_\odot$)

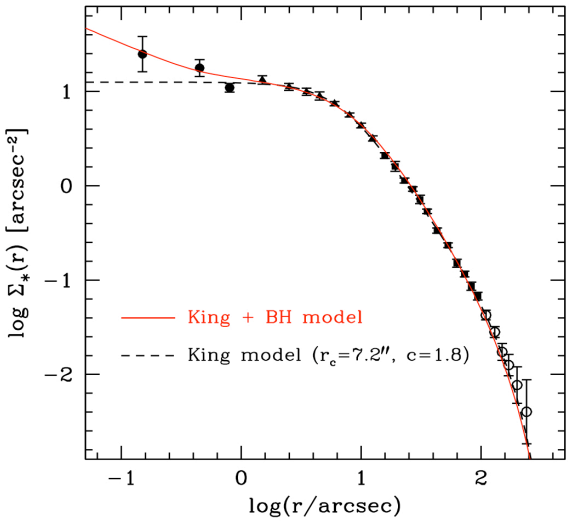
star clusters - exotic objects

IMBH signatures

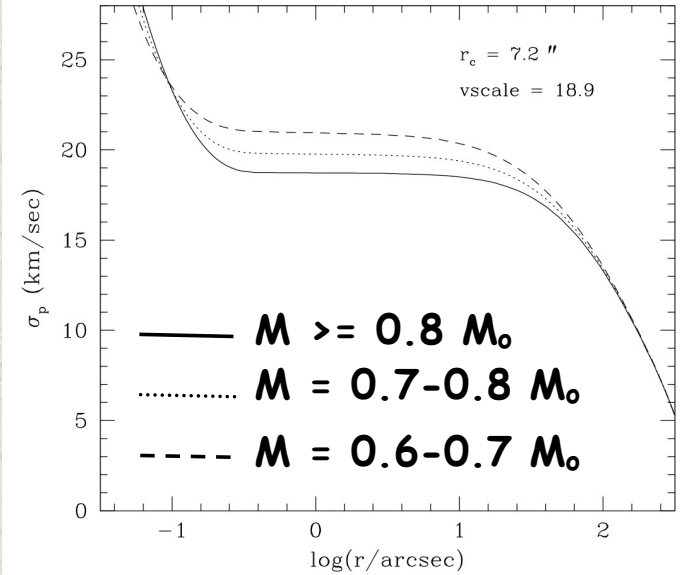
surface brightness profile



projected density profile



expected velocity dispersion profile



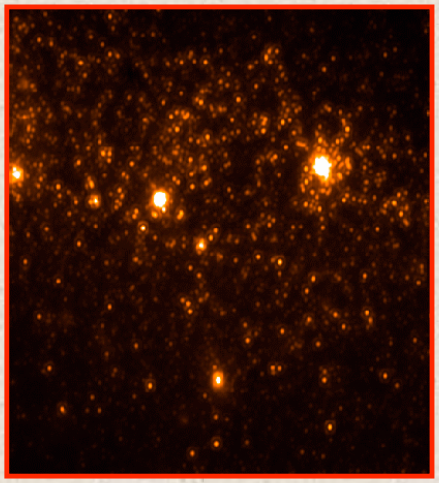
NGC6388: c=1.8; r_c=0.5pc (≅7.2″), D=13.2 kpc

M_{BH}~6x10^3 M_o r_h=0.07 pc (≅1.1″)

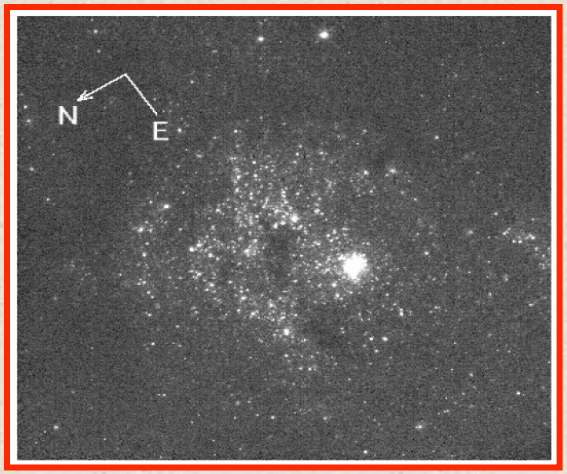
Lanzoni etal 2007, ApJ, 668, L139

super star clusters

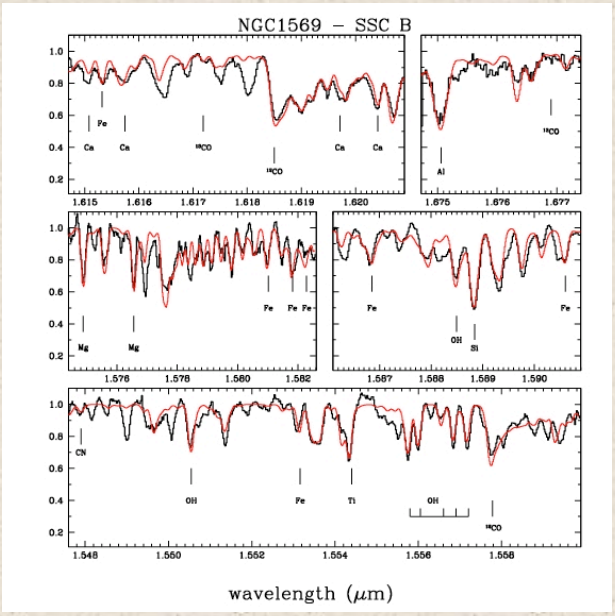
NGC 1569 ~2 Mpc
NICMOS@HST

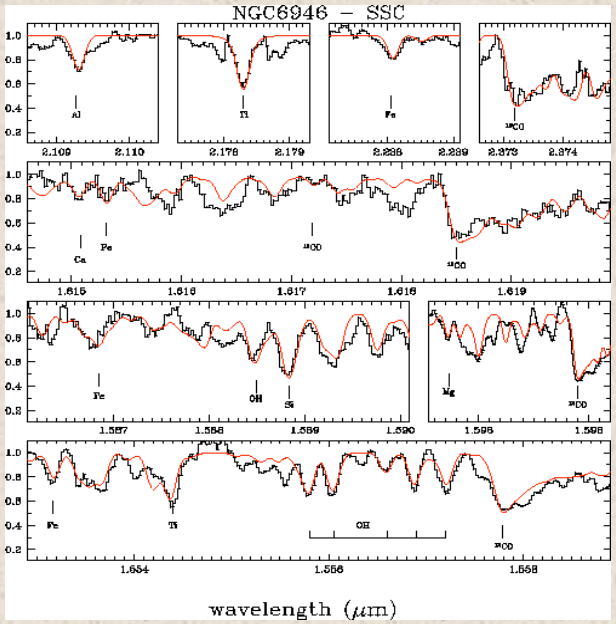


NGC 6946 ~6 Mpc
WPC2@HST



unique tracers
of the IMF
in SB galaxies





KeckII NIRSPEC spectra

chemical abundances
dynamical masses

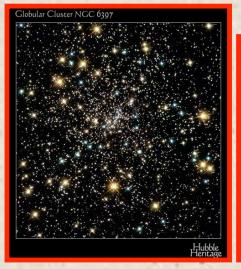
(σ~10 km/s, M_{dyn}~10^6 M_o)

Larsen, Origlia, Brodie & Gallagher, 2006, 2007

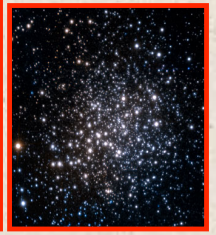
star clusters

Galactic

NGC 6397

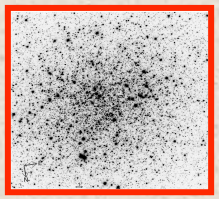


Terzan 5



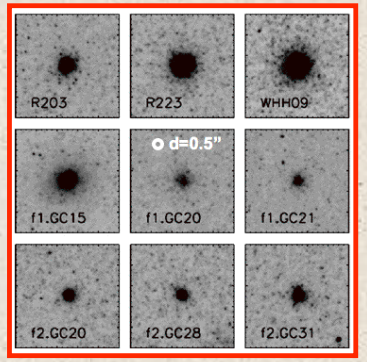
Local Group

SMC-121

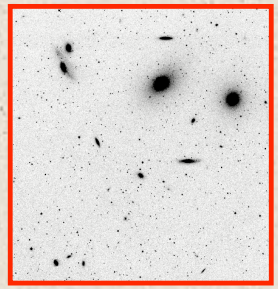


M31-G1

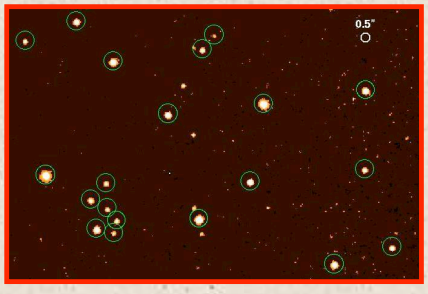
Centaurus



Virgo Cluster



M87



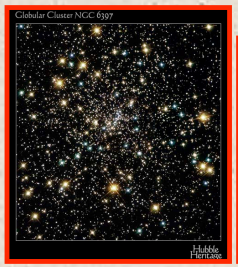
…future science

with the next generation of
high spatial & spectral resolution
telescopes/instruments…

star clusters - photometry

Galactic

NGC 6397



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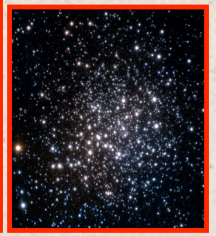

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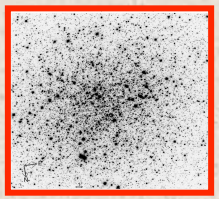

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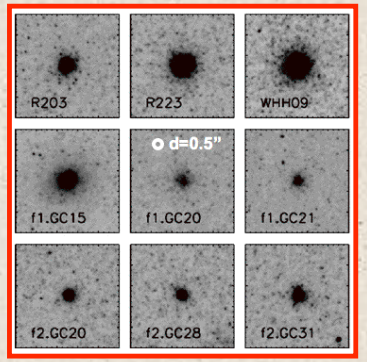

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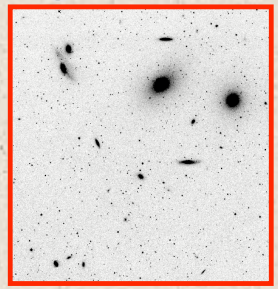

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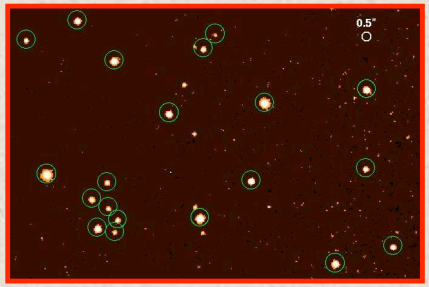


JWST 6.5m $FWHM_H$~50mas

NIRCam photometry H_{lim}~27
turn-off out to the LG ➔ age
H-burning limit in Galactic GCs ➔ multiple MS, present day MFs

E-ELT 42m $FWHM_H$~8mas

MICADO photometry H_{lim}~27
cores of Galactic GCs
individual bright giants in the outer region out to ~Virgo

also IRIS/WIRC on TMT & HRCAM on GMT…

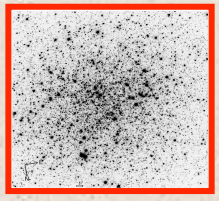
star clusters - chemistry

E-ELT 42m $FWHM_H$~8mas

individual star spectroscopy

Terzan 5

SMC-121



SIMPLE R=100,000 H_{lim}~20

OH,CO,CN lines, many atomic lines

SGB-MS stars
out to MCs

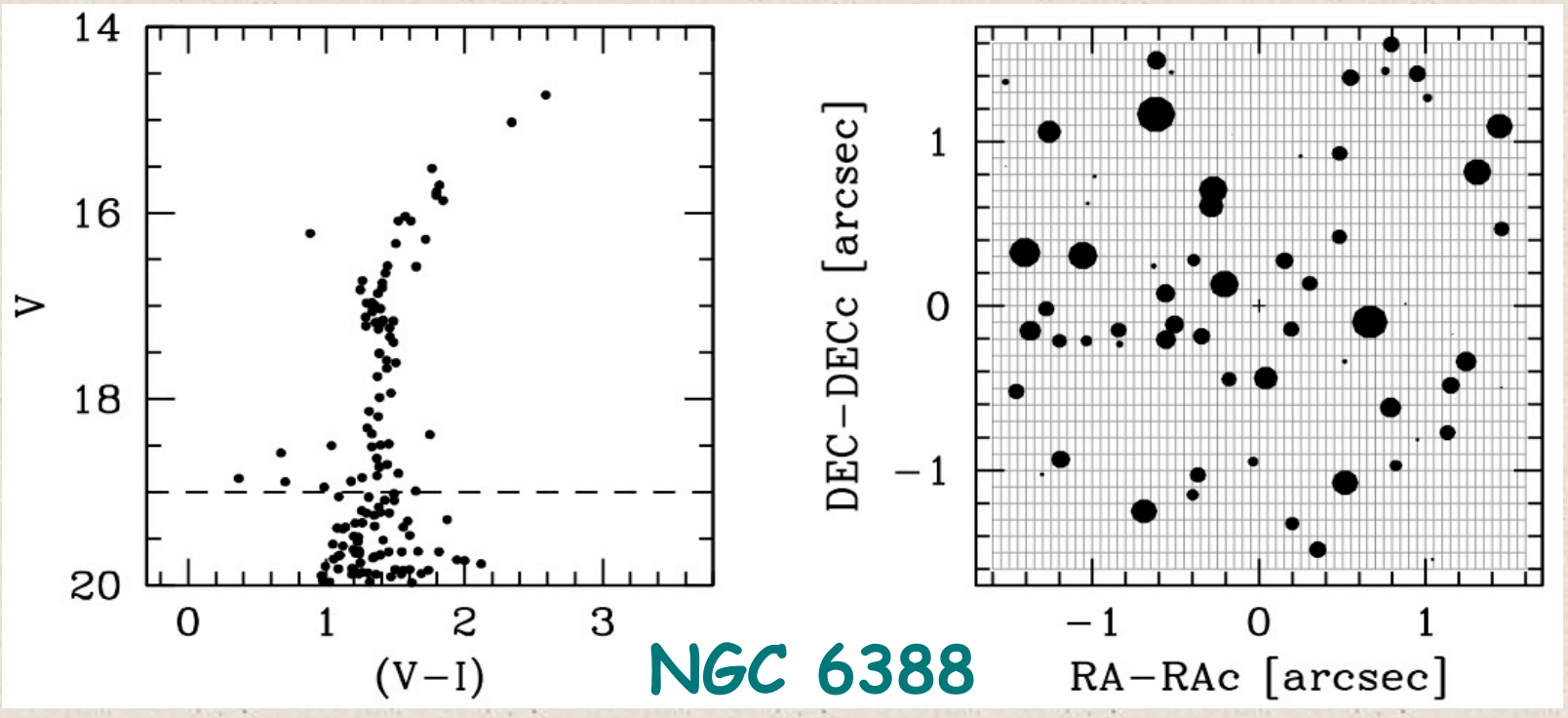
Fe,CNO+isotopes,α & other metal abundances

M31-G1

also NIRES on TMT & NIRS on GMT…

evolved giants
out to 1~Mpc

star clusters - IMBHs



velocity dispersion profiles

IFU spec

- SINFONI: V_{rad} for ~70 stars at K<16 within 3.2"x3.2" ➔ σ profile in radial bins of 0.5"-1.0"
- HARMONI: V_{rad} for ~10^3 stars at K~20 ➔ σ profile in radial bins of 50-100mas
- VLT+AO,HST ➔ JWST,MICADO imaging: proper motions

extragalactic star clusters

E-ELT 42m $FWHM_H$~8mas

integrated spectroscopy

HARMONI R=20,000 H_{lim}~22

$\Delta v \cong 15$ km/s, $\sigma_{int} \cong 6.4$ km/s

$M_{dyn} > 10^5 M_o$ ➔ very massive GCs

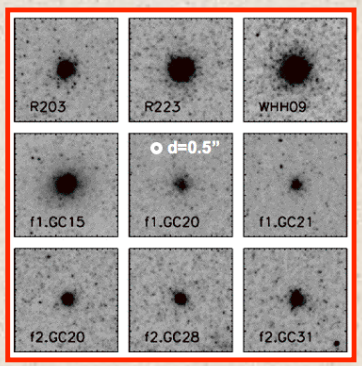
SIMPLE R=100,000 H_{lim}~20

$\Delta v \cong 3$ km/s, $\sigma_{int} \cong 1.3$ km/s

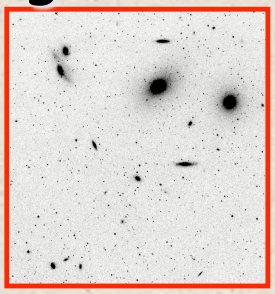
$M_{dyn} \cong$ a few $10^4 M_o$ ➔ Magellanic-like GCs

Fe, CNO, α & other metal abundances

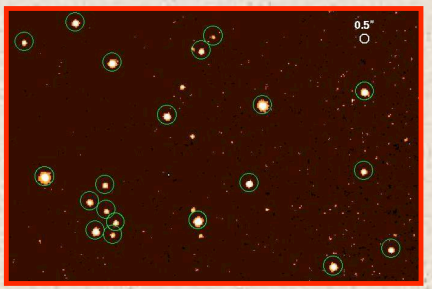
Centaurus



Virgo Cluster



M87



extragalactic star clusters

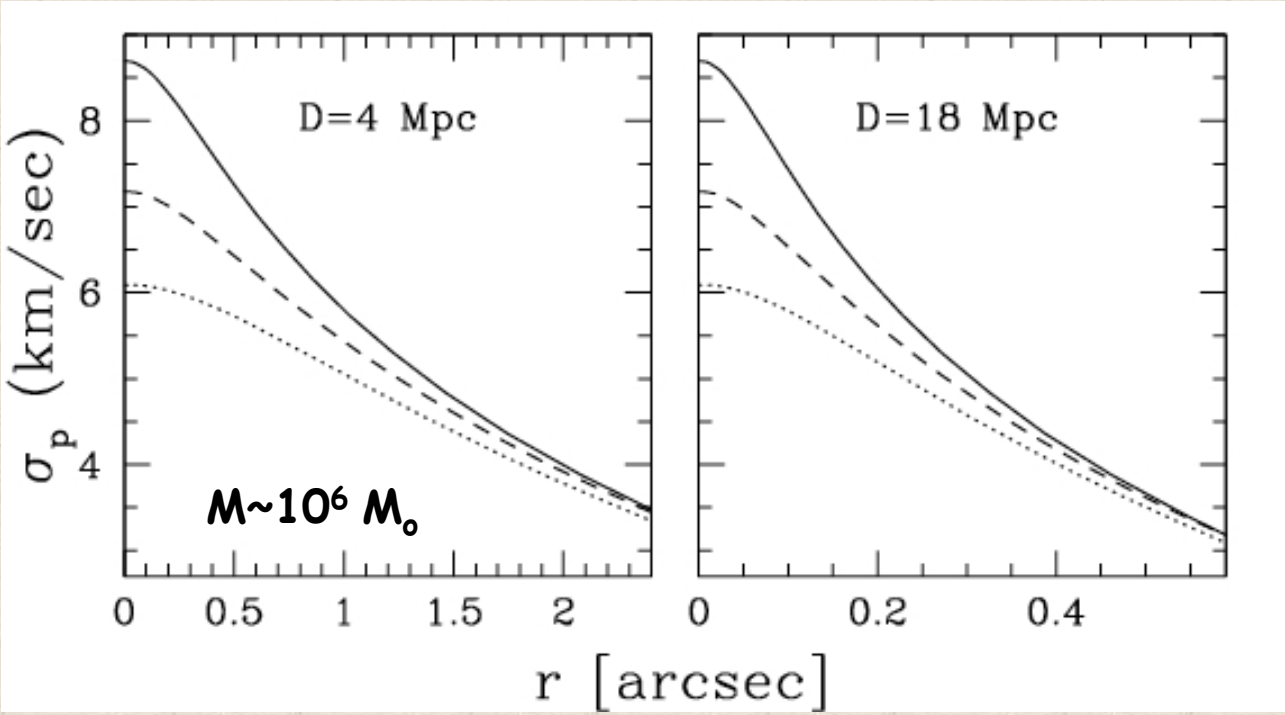
E-ELT 42m $FWHM_H$~8mas

integrated spectroscopy

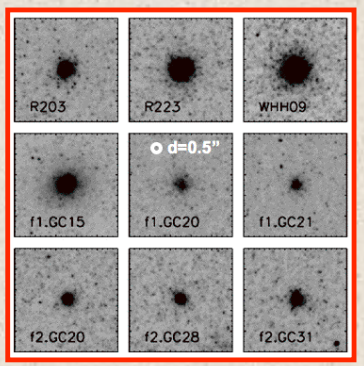
SIMPLE R=100,000

H_{lim}~20 in 50mas spatial bins

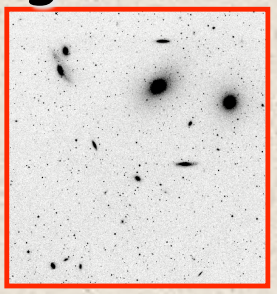
$\Delta v \cong 3$ km/s, $\sigma_{int} \cong 1.3$ km/s



Centaurus



Virgo Cluster



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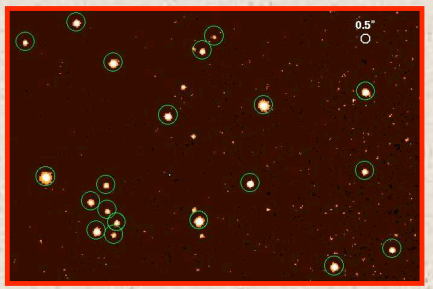

star clusters - CS envelopes/disks

winds & mass loss affect all the stellar evolutionary stages ➔ CS envelopes/disks in

pre-MS stars
evolved giants
massive, young stars

JWST MIRI
E-ELT METIS

crucial to characterize the physics & chemistry of CS disks/envelopes in star clusters of any age with major impact on stellar evolution modeling