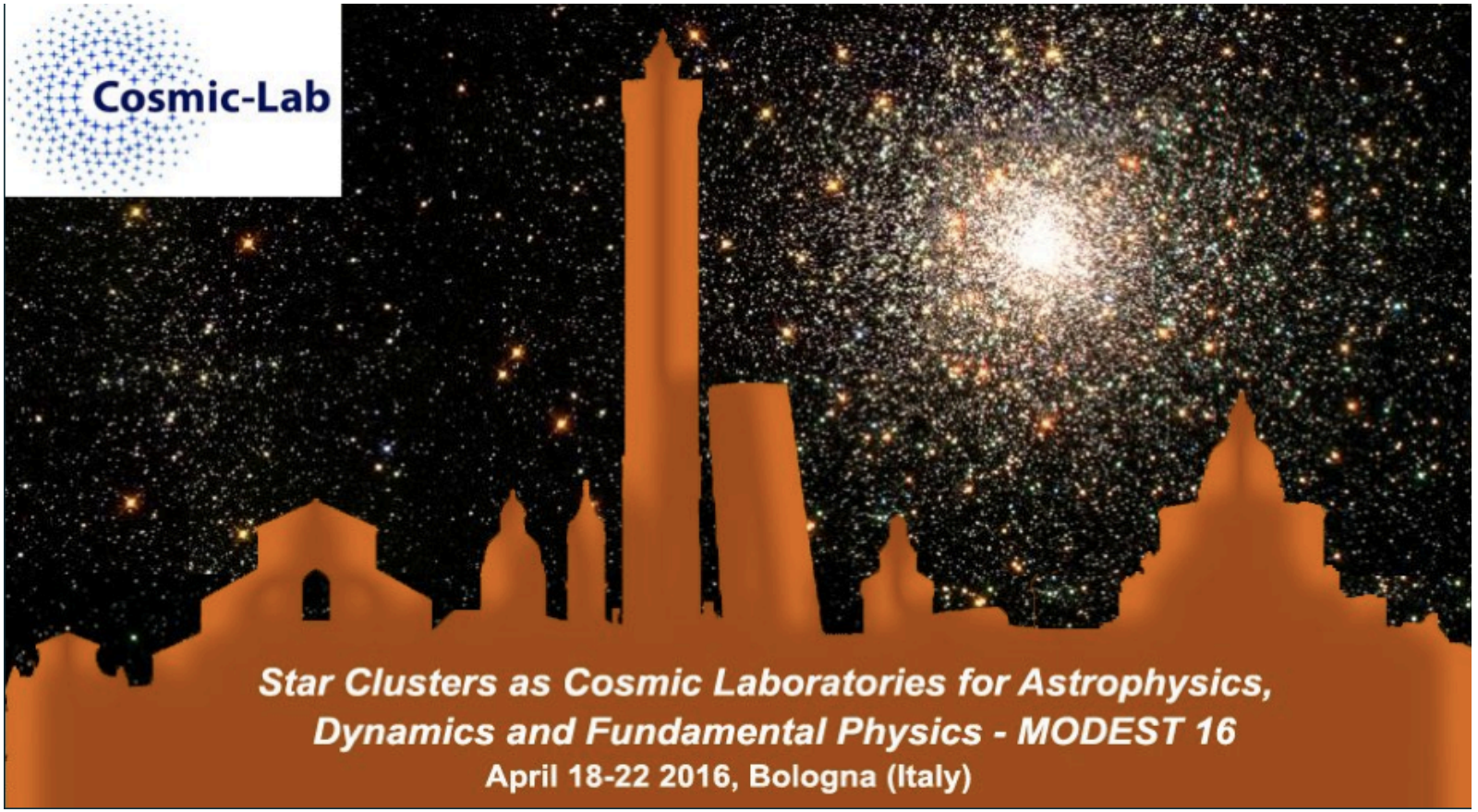


The COSMIC-LAB project: overview & results

FRANCESCO R. FERRARO

Physics & Astronomy Department – University of Bologna (Italy)

Bologna, April 18, 2016

THE PROJECT

Cosmic-Lab

- 5-year project funded by the European Research Council (ERC) with a grant of 1.9 MEuro

- *Advanced Research Grant* (2010 call)
  270 projects funded out of 2000 evaluated (13.8%),
  21 Italian project approved (7%)
  9 in Universe Sciences (3%)
  Cosmic-Lab is the only Italian project approved in Universe Sciences

- PI: Francesco R. Ferraro (Dip. of Physics & Astronomy – Bologna)

- The project started on May 1st 2011 and it will end on April 30th 2016

Cosmic-Lab

- 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 COSMIC-LAB REPORT

Consolidation of the research group:

- 2 5-year RTD-A (tenure track) positions
- 13 2-year Post-Doc positions
- 7 3-year PhD positions (4 fully funded+3 co-financed)

The COSMIC-LAB team currently counts 10 researchers
(the PI + 1 AP + 2 Researchers + 3 Post-Docs +3 PhDs)

COSMIC-LAB REPORT

Telescope time assigned to the project:

The scientific activity of the project has been deeply connected with the access to the major astronomical observational facilities (telescopes and satellites): more than 200 orbits with HST and 600 hours at the 8-10 m-class telescopes in 60 months

- HST: Cycle 19 = 39 orbits
  Cycle 20 = 28 orbits
  Cycle 21 = 15+131 orbits
  Cycle 22 = 2 orbits

- ESO-VLT : Period 87= 6 nights + 15 hours
  Period 89= 3 nights + 3 hours
  Period 90= 5 nights + 21 hours
  Period 91= 2 nights + 24.5 hours
  Period 92= 3 nights + 33 hours
  Period 93= **225 hours**
  Period 95 = **120 hours**
  Period 97 = 40 hours

Large Programmes

- GEMINI/Keck/SUBARU: 7.5 hours/3 nights/3nights

THE COSMIC-LAB REPORT

Published papers:

61 papers have been published in peer-reviewed journals.
This corresponds to a rate of 1 paper/month (over 60 months of activity)

- 45 in the *Astrophysical Journal*
- 6 in the *Astrophysical Journal Letters*
- 5 in *MNRAS*
- 3 in the *Astronomical Journal*
- 1 in Astronomy & Astrophysics
- **1 in *Nature***

Invited/contributed talks:

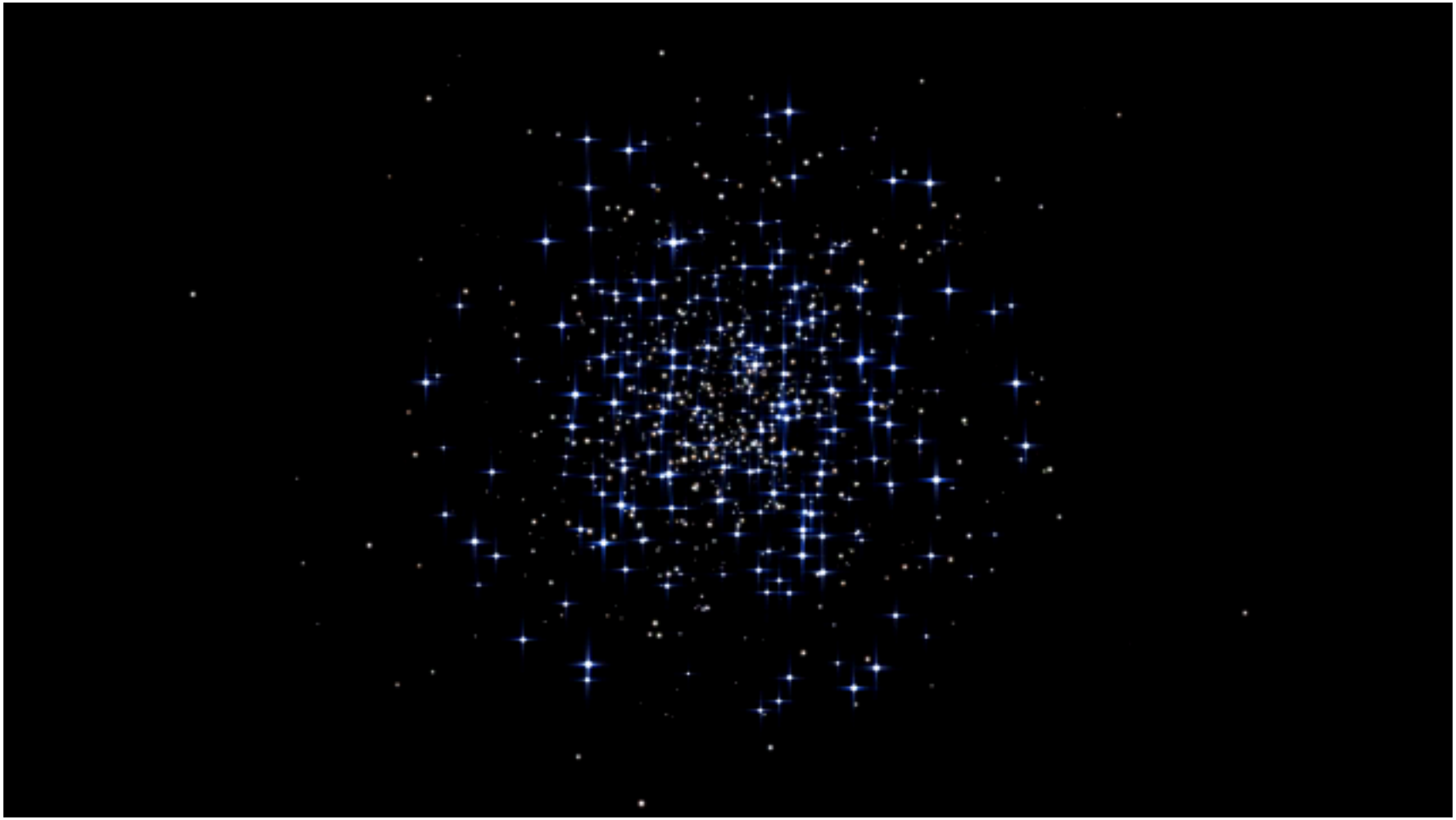
- 62 invited/contributed talks have been given at (31) international conferences and/or at the major science institutes over the world.

COSMIC-LAB REPORT

The project web-page: http://www.cosmic-lab.eu/

The entire scientific activity of the project (in terms of scientific results, products and tools, amount of awarded telescope time, press releases, freely downloadable images and videos, job opportunities) are listed in the project web-page

WHY GCs?

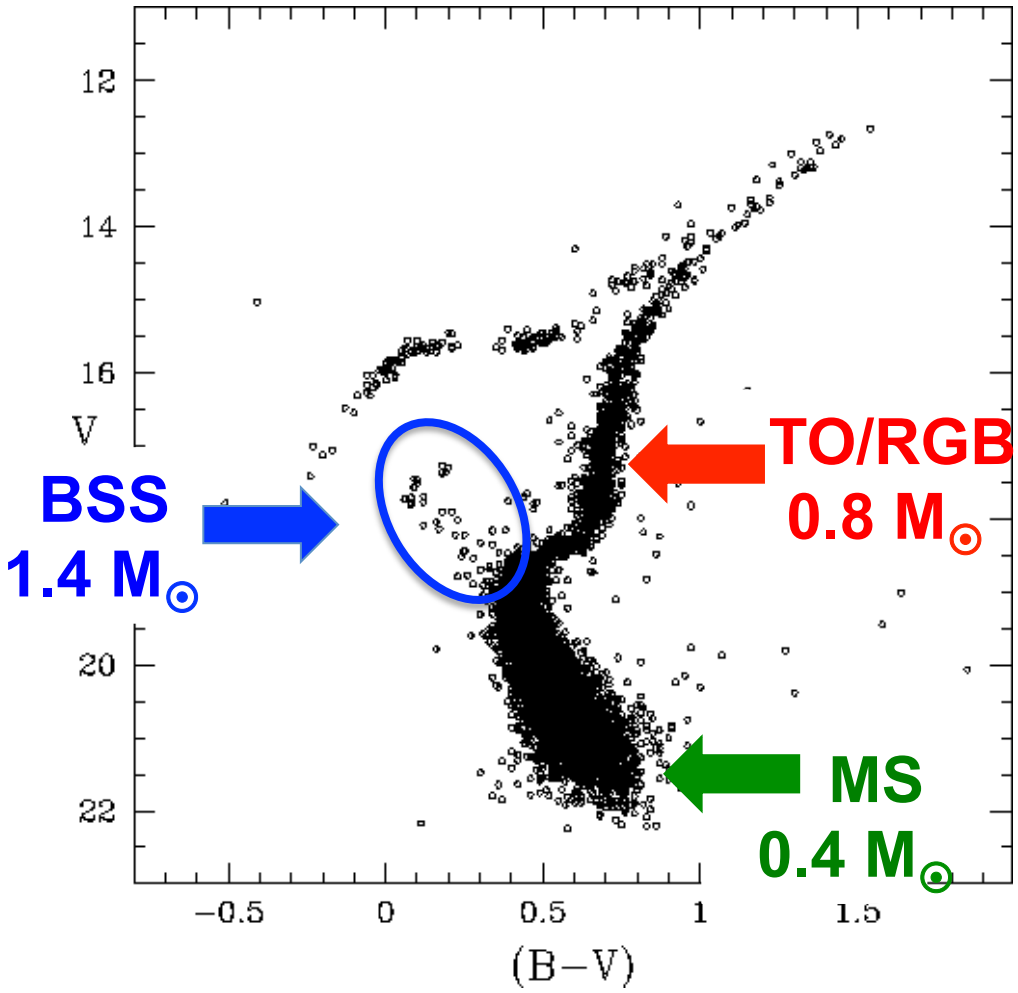


GC are the only cosmic structures able to undergo nearly all the physical processes known in stellar dynamics over a time scale significantly shorter than the Hubble time.

This dynamical activity can generate **exotica**

BSS with Cosmic-Lab

Blue Straggler Stars (BSS)



BSS
more massive
than normal stars

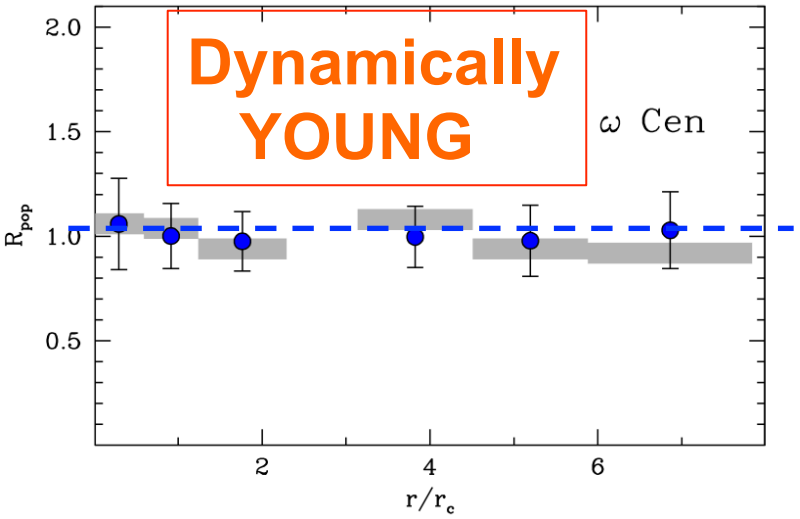
BSS are heavy stars orbiting a "sea" of light stars. Thus, they are subject to **dynamical friction** that progressively makes them sink toward the cluster center. Hence BSS are crucial gravitational probes to test GC internal dynamical processes.

The dynamical clock

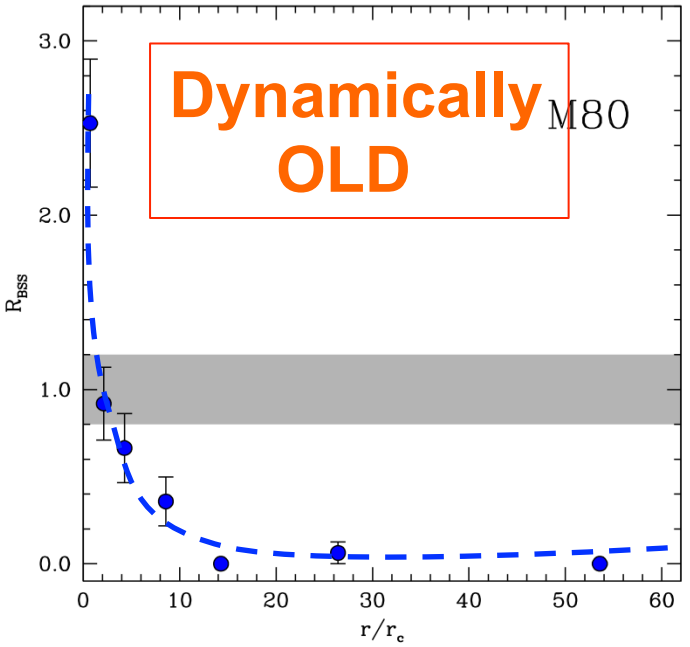
Ferraro et al (2012,Nature,492,393)

The BSS radial distribution (over the entire cluster extension) in 25 stellar systems shows a variety of cases

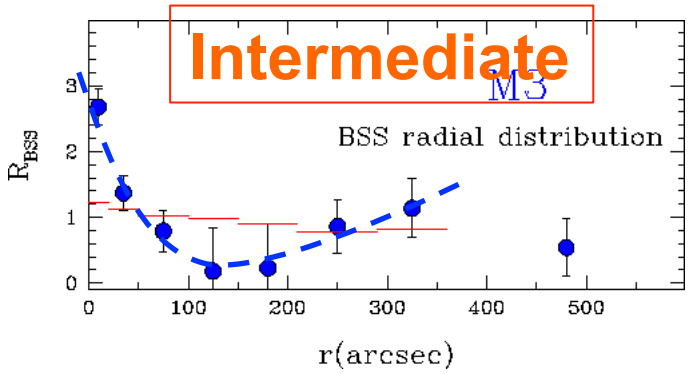
"Flat"



"Unimodal" (single-peak)



"bimodal"

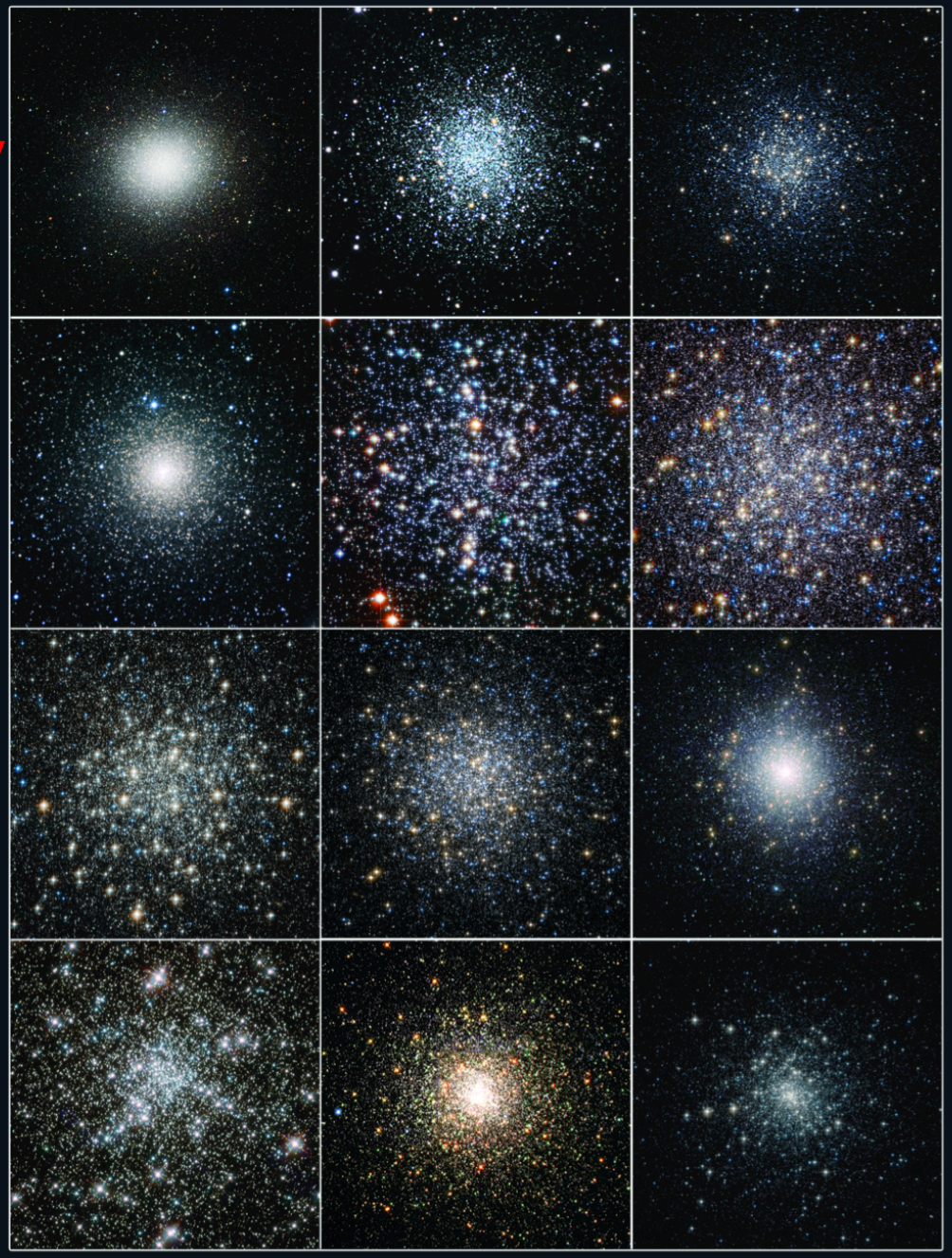


The BSS radial distribution is shaped by dynamical friction, which progressively segregates BSS at larger and larger radii

..... THE DYNAMICAL CLOCK.....

THE DYNAMICAL CLOCK

dynamically young



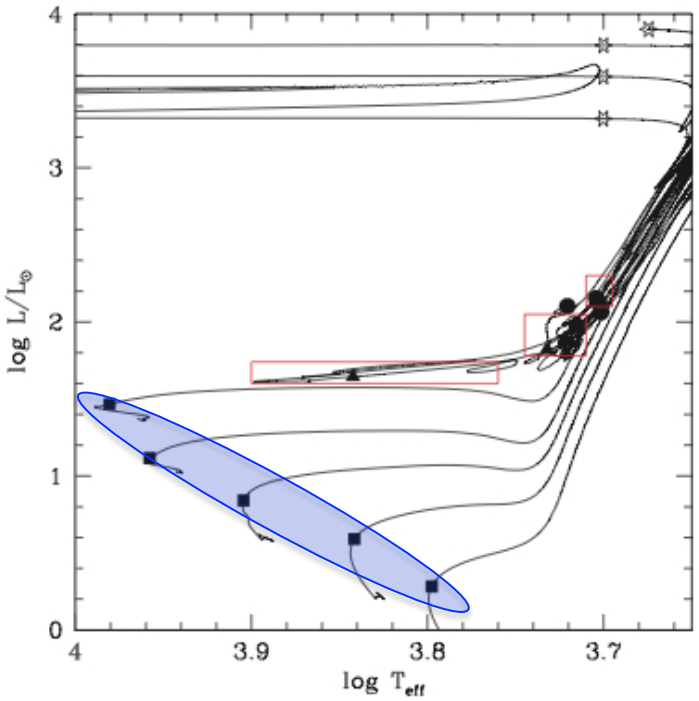
dynamically old

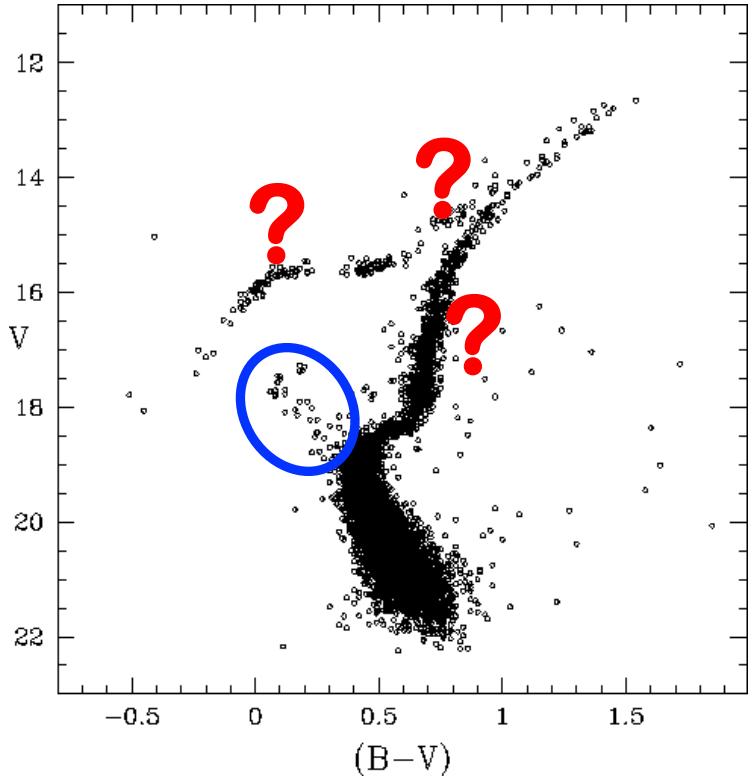
A “stellar scale” to search for E-BSS

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

Sills et al 2009, ApJ,692, 1411

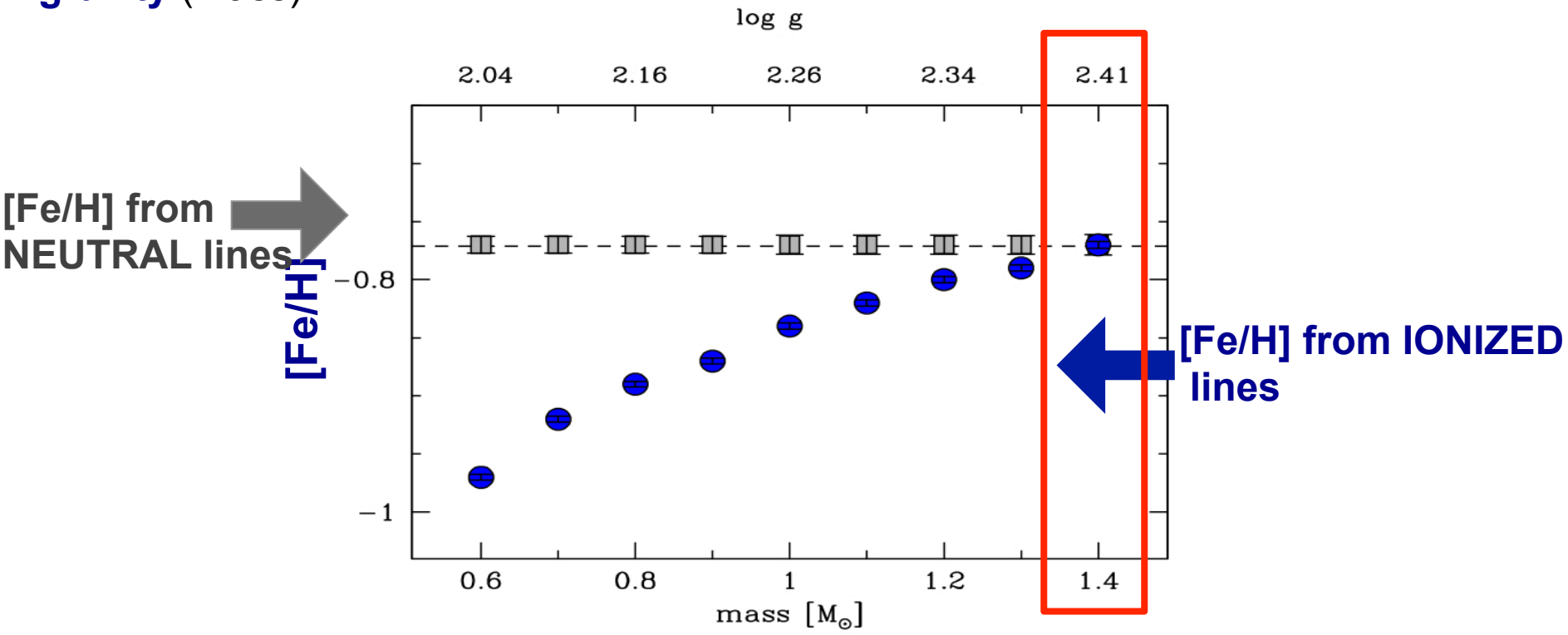




A “stellar scale” to search for E-BSS

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

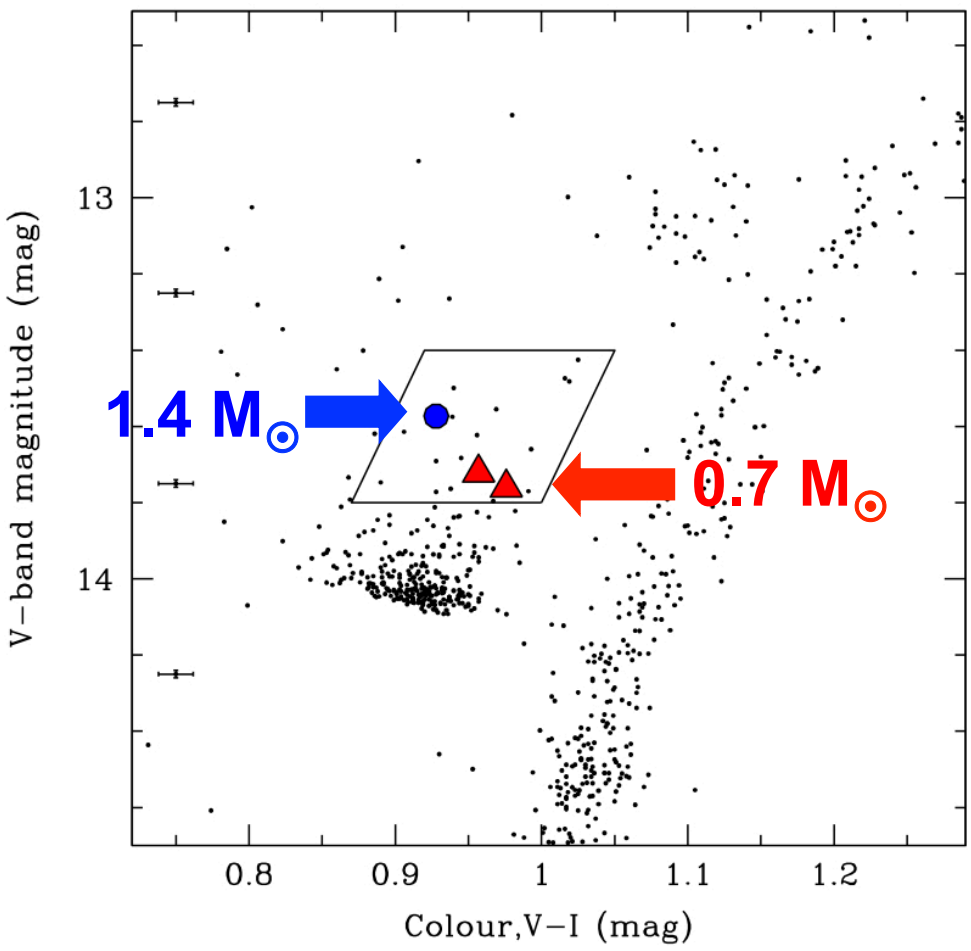
The abundances obtained **from neutral lines are independent of the adopted gravity,** the **abundances from ionized absorption lines are quite sensitive to gravity** (mass).

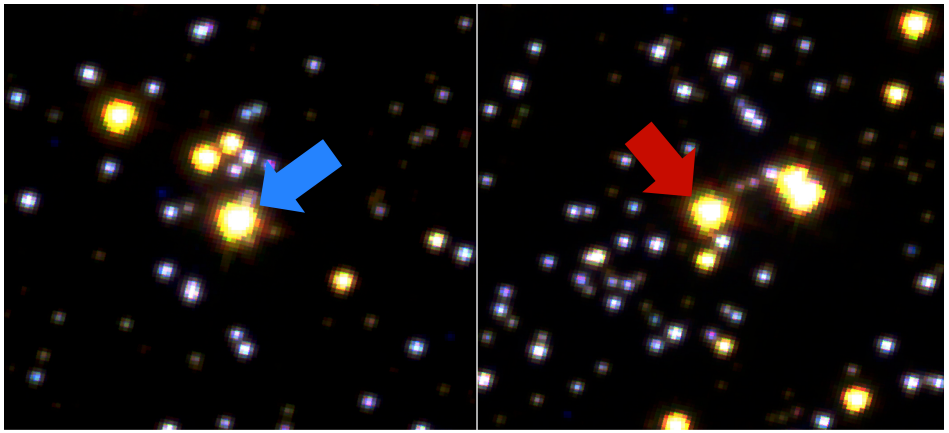


Hence the BALANCE between the chemical abundances derived from **neutral** and **ionized** absorption lines can be used to determine the correct gravity of the star (hence its MASS !!).

A “stellar scale” to search for E-BSS

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





1.4 M⊙ 0.7 M⊙

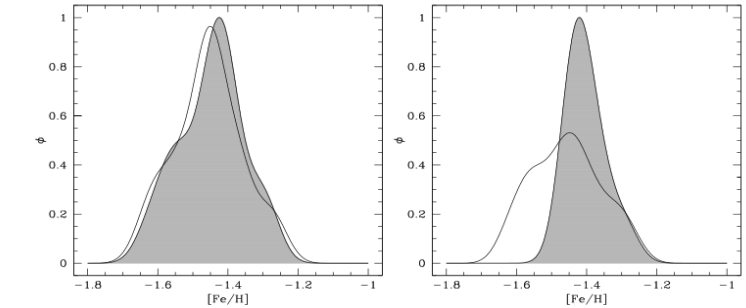
According to its position in the CMD and to the estimated temperature (T = 5000K) and gravity (logg = 2.5 dex), this object is probably an **evolved Blue Straggler Star caught during its He-burning phase.**

A crucial Side result

Non Local Thermal Equilibrium in AGB stars

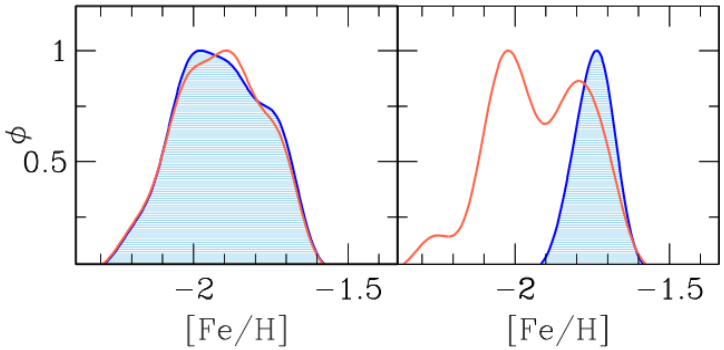
Lapenna et al (2014,ApJ, 797,124)

This effect **under-estimates the iron abundance derived from neutral lines** with **no impact on ionized lines**



NGC3201

Mucciarelli et al (2015,ApJ, 801,69)



M22

Mucciarelli et al (2015,ApJ, 809,628)

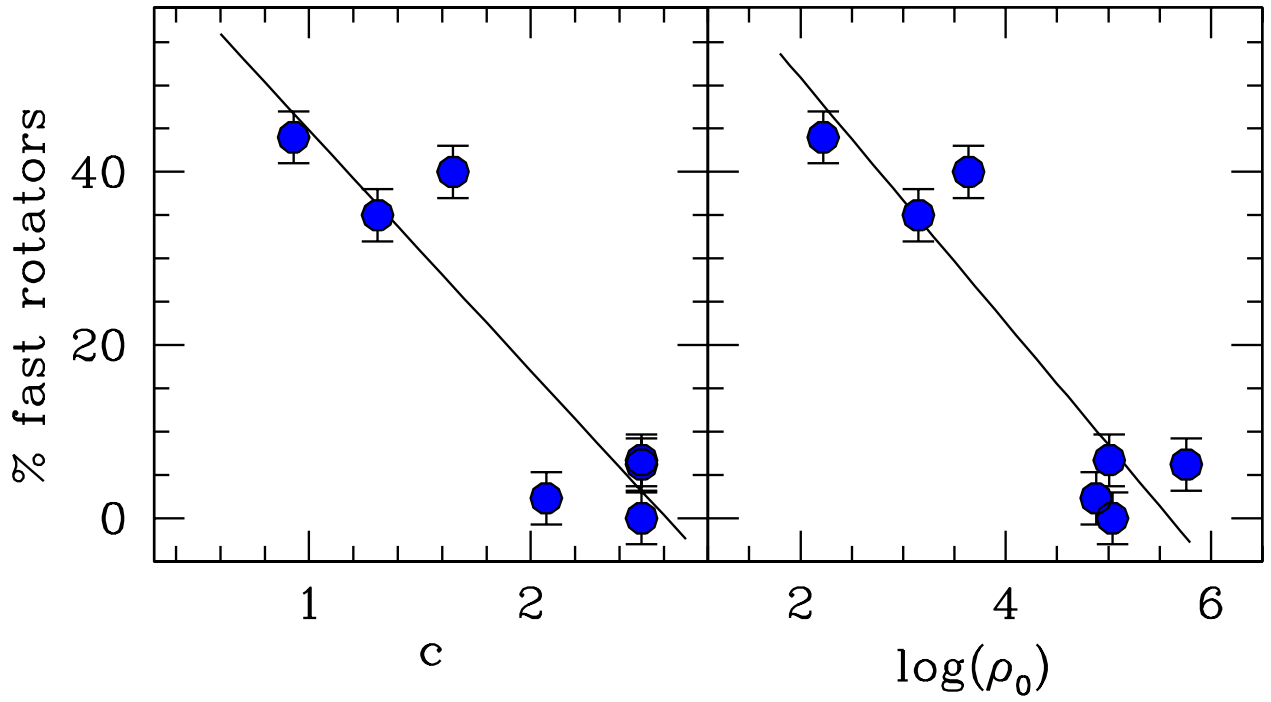
The small iron spread (Δ[Fe/H]~0.2 dex) detected in a few GCs can be spurious

(talks by **Lapenna** and **Mucciarelli** on Friday)

Fast and slow rotating BSS

Ferraro et al (2016, in prep)

Rotational velocities have been measured from the broadening of the absorption lines in high resolution spectra for 300 BSS in 7 GGCs (47 Tuc, Omega Cen, M4, NGC6397, M30, NGC6752, M55) acquired during several campaigns with the FLAMES spectrograph. Fast rotator stars are defined as rotators with $v_{rot} > 40$ Km/s.



FR-BSS prefer loose environment !

BSS results

A more detailed presentation of the Cosmic-Lab results concerning BSS will be given in three talks later today:

Dalessandro - the dynamical clock, the stellar scale and the double BSS sequence phenomenon

Beccari - Comparison among different diagnostics of mass segregation

Alessandrini - results from N-body simulations to explore alternative way to quantify the level of segregation of BSS and to study the impact of different ingredients (dark remnant, binaries, etc) in the segregation process

MSP companion search with

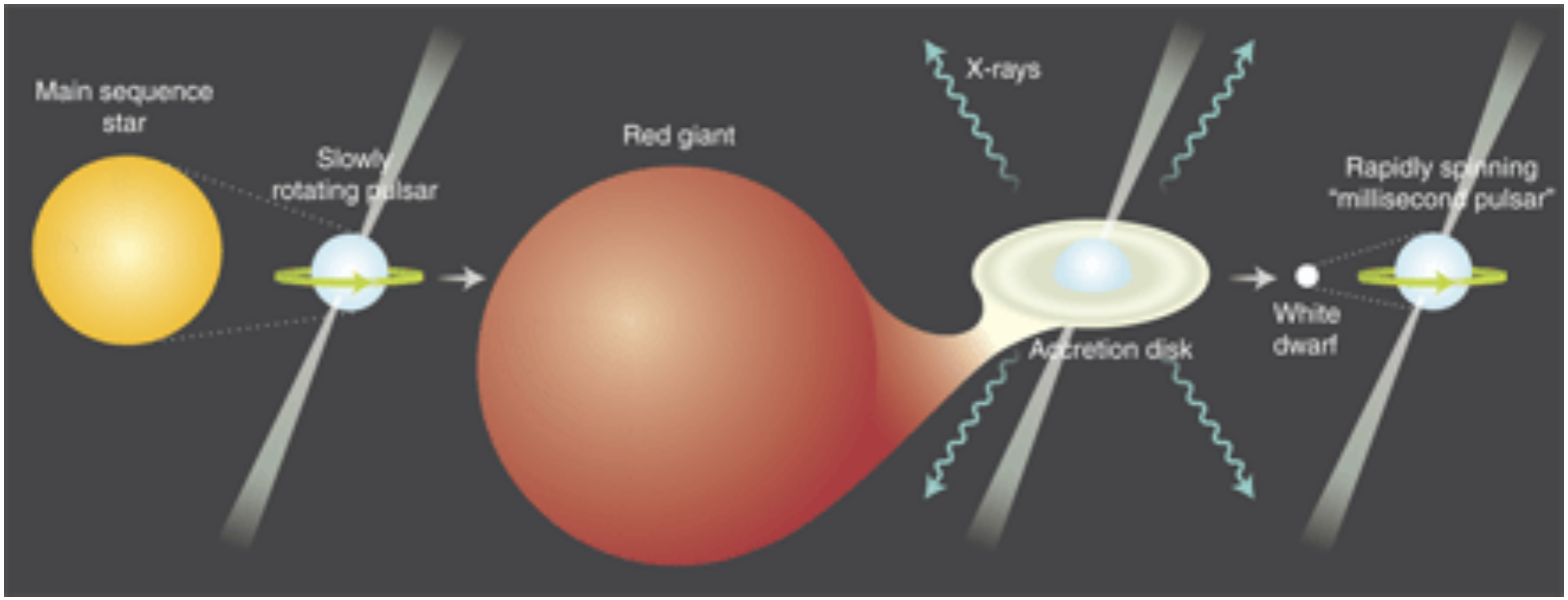
Millisecond pulsars (MSP)

MSP (recycled-pulsars):

pulsars with $dP/dt < 10^{-17}$ (OLD) and $P \sim 10^{-3}$ sec (RE-ACCELERATED)

RE-CYCLING SCENARIO (Bhattacharya et al. 1991):

- binary system: NS + evolving companion
- mass accretion from an evolving companion spin up the pulsar

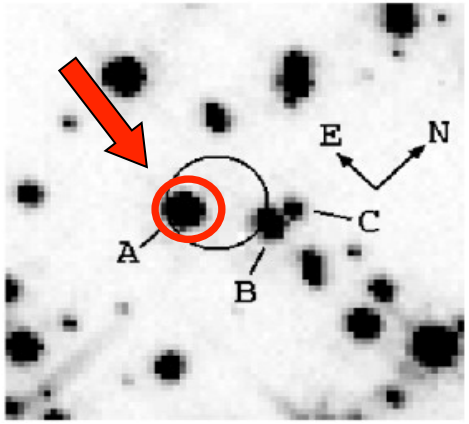


MSP optical companion in GCs

The optical identification of MSP companion is of paramount importance:

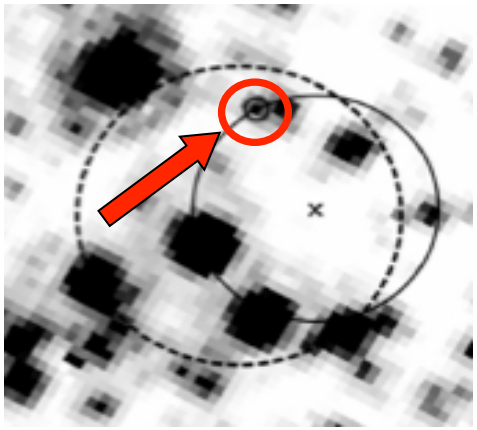
1. **companion mass** (from its position in the CMD) ➔ **NS mass**
2. The shape of the **companion light curve** allows to understand the phenomena occurring on the companion surface and in the intra-binary space
3. Spectroscopic survey can lead to the **velocity curve and chemistry**, thus proving hints on the system past evolution

COM 6397A



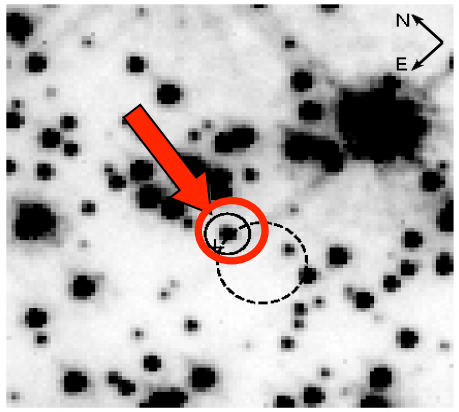
(Ferraro et al. 2001)

COM 6266B



(Cocozza et al. 2008)

COM-M28H



(Pallanca et al. 2010)

MSP optical companion in GCs

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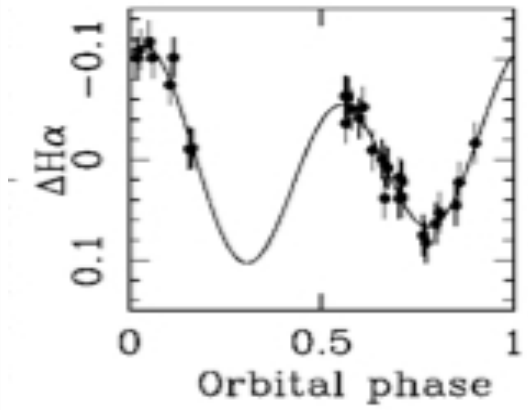

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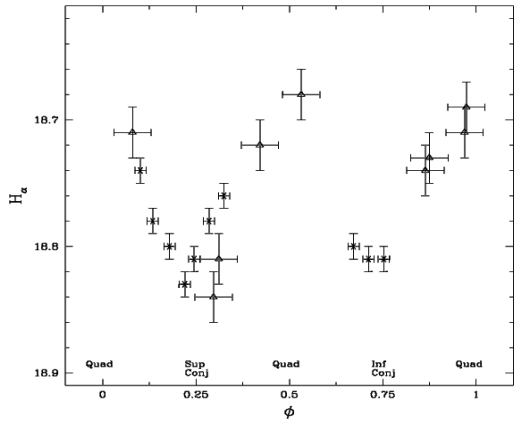
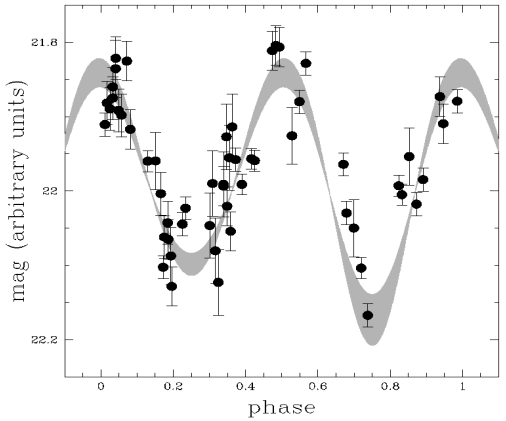
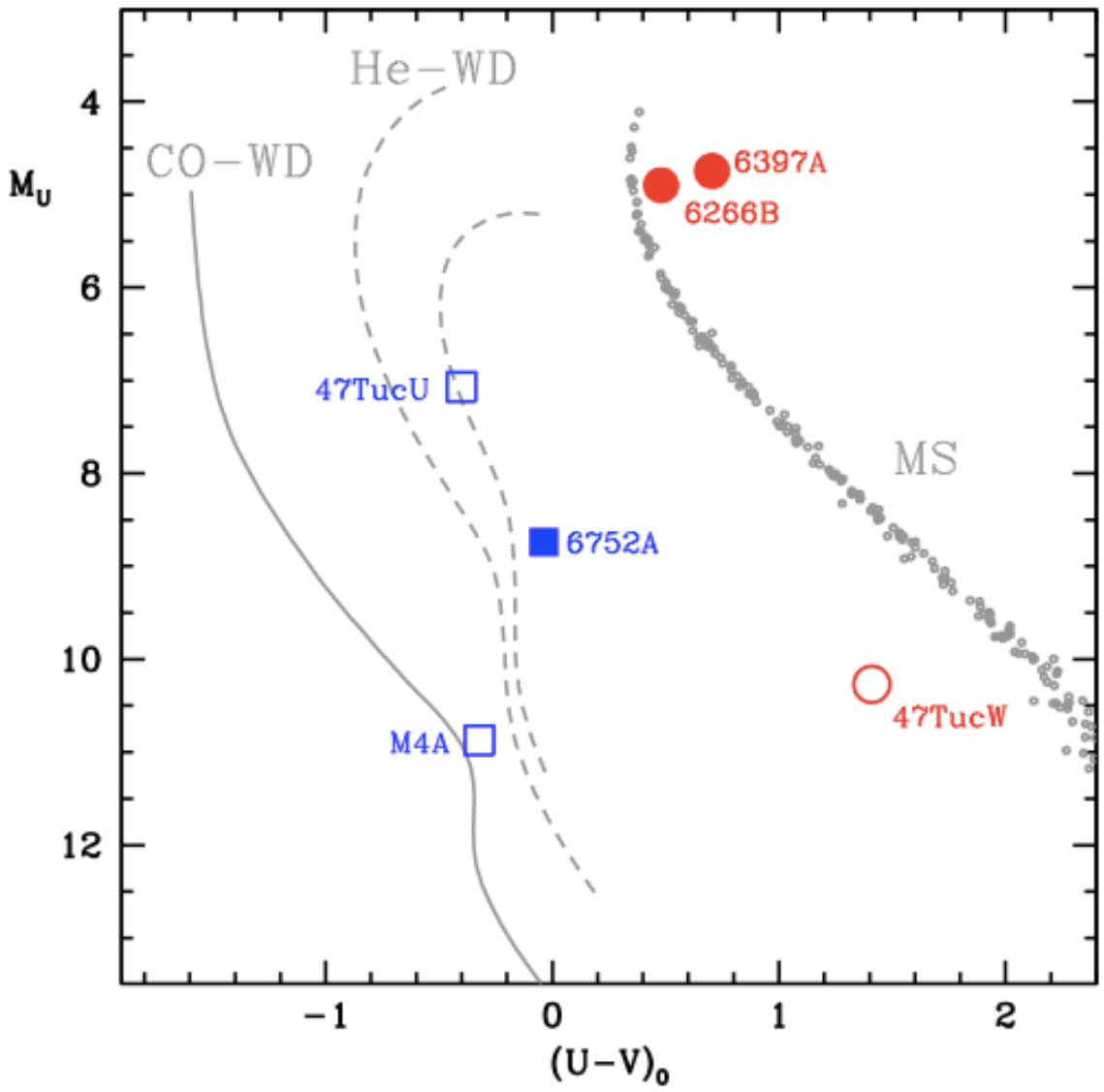


COM-M28H

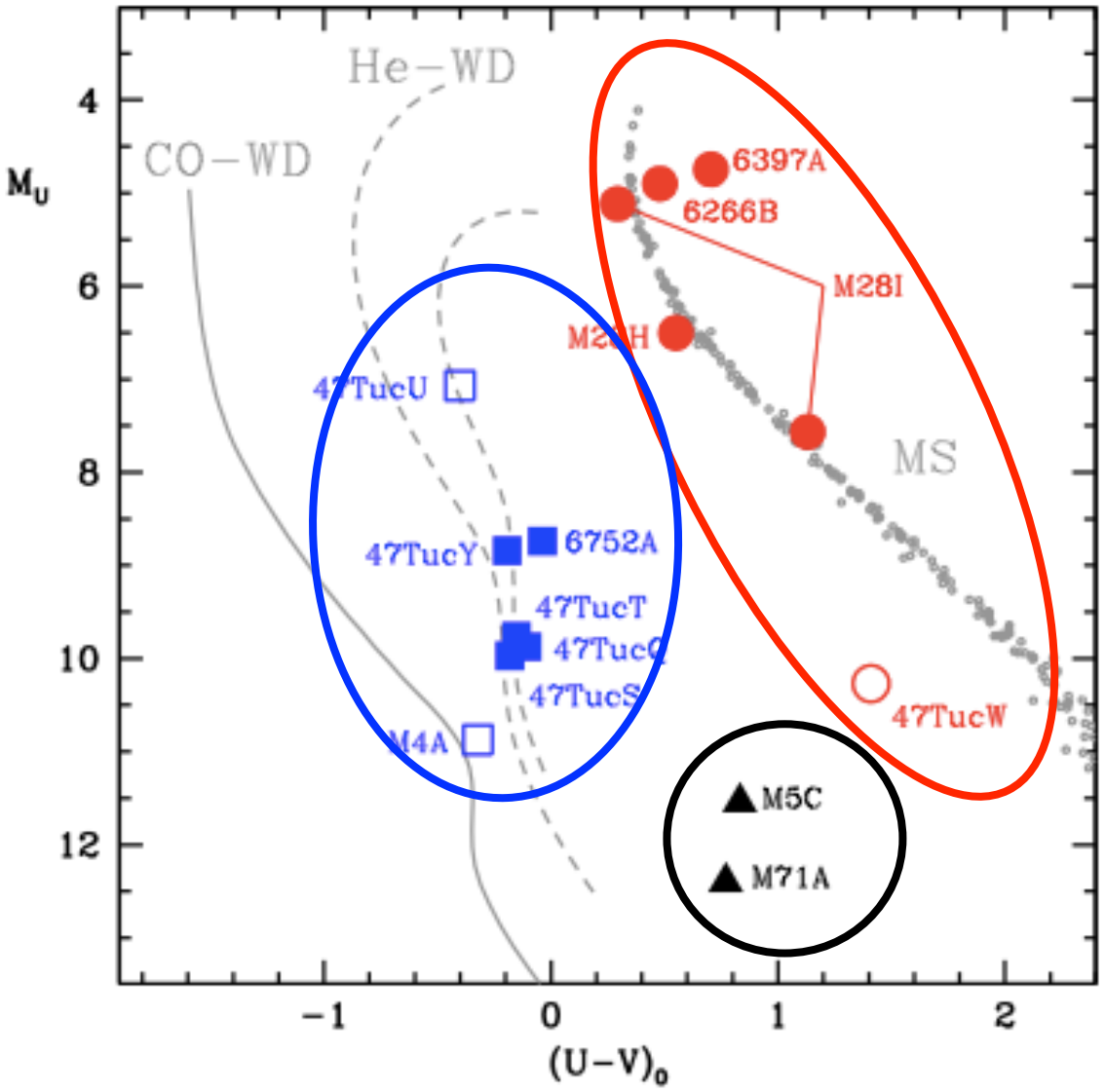


MSP optical companions in GCs



Only 6 optical companions were known before the Cosmic-Lab project

MSP optical companions in GCs



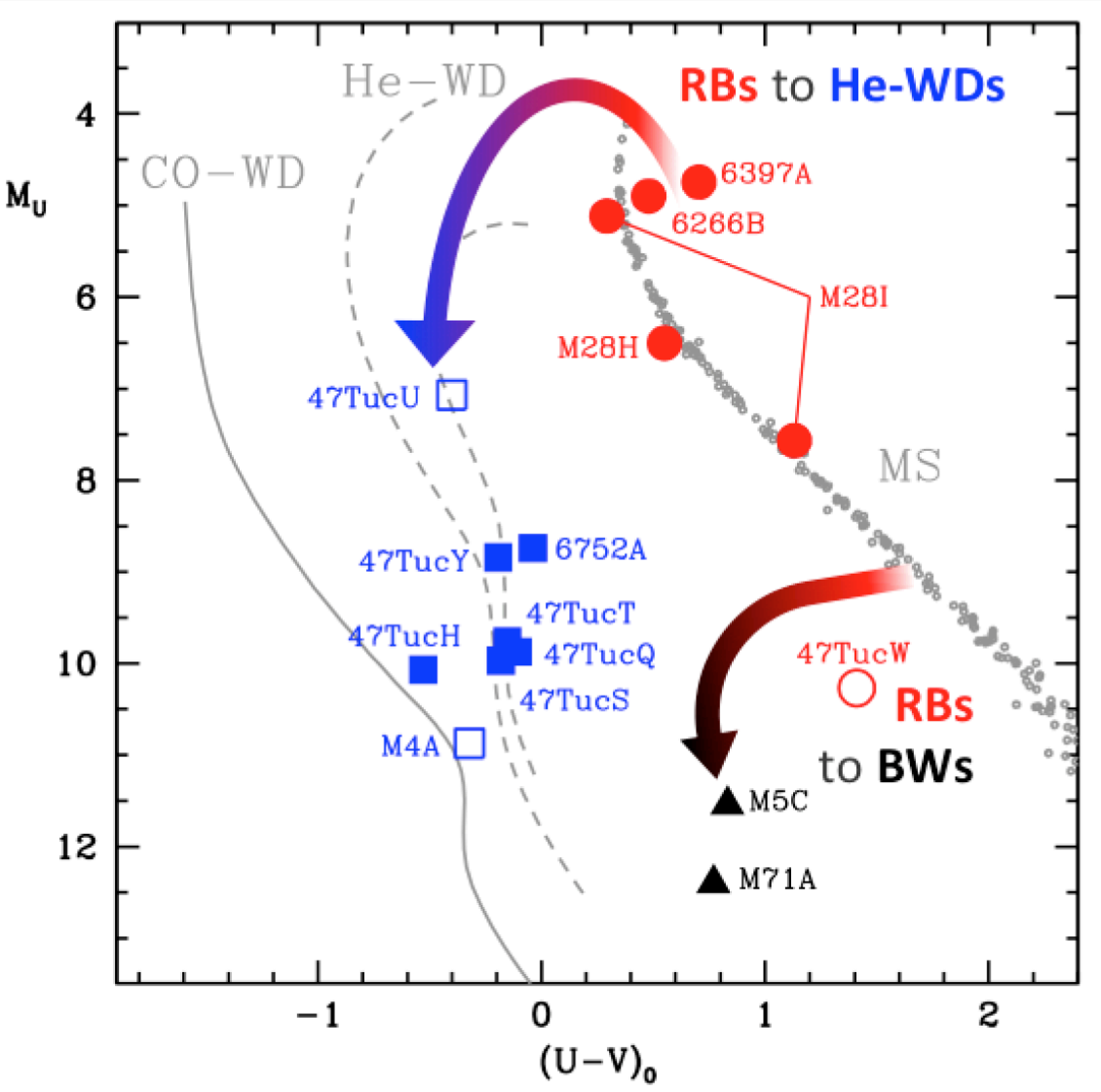
8 new companions identified within Cosmic-Lab:

4 He-WDs (canonical degenerate companions as expected as "final stage" of the pulsar recycling process)

2 Redbacks (non-degenerate bloated/tidally distorted companions)

2 Black Widows (very low mass companions)

MSP optical companions in GCs



14 Companions identified so far:

7 He-WDs (canonical degenerate companions)

5 Redbacks (non-degenerate bloated/tidally distorted companions)

2 Black Widows (very low mass companions)

MSP results

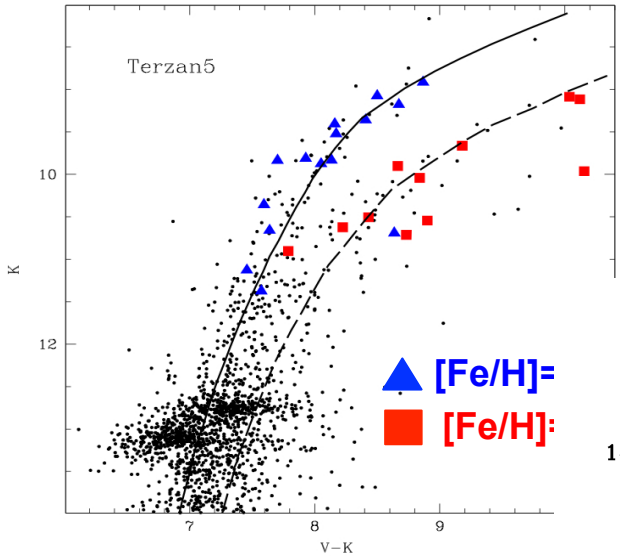
A more detailed presentation of the Cosmic-Lab results concerning MSPs will be given in two talks tomorrow:

Pallanca - The status of the MSP companion search

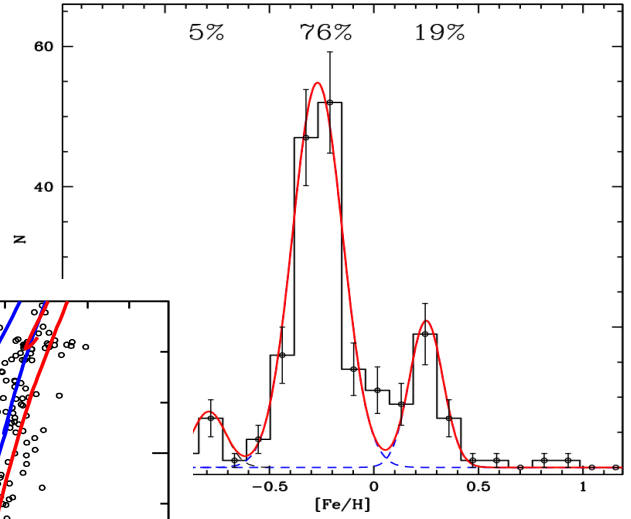
Cadelano - The case of the black widow in M71

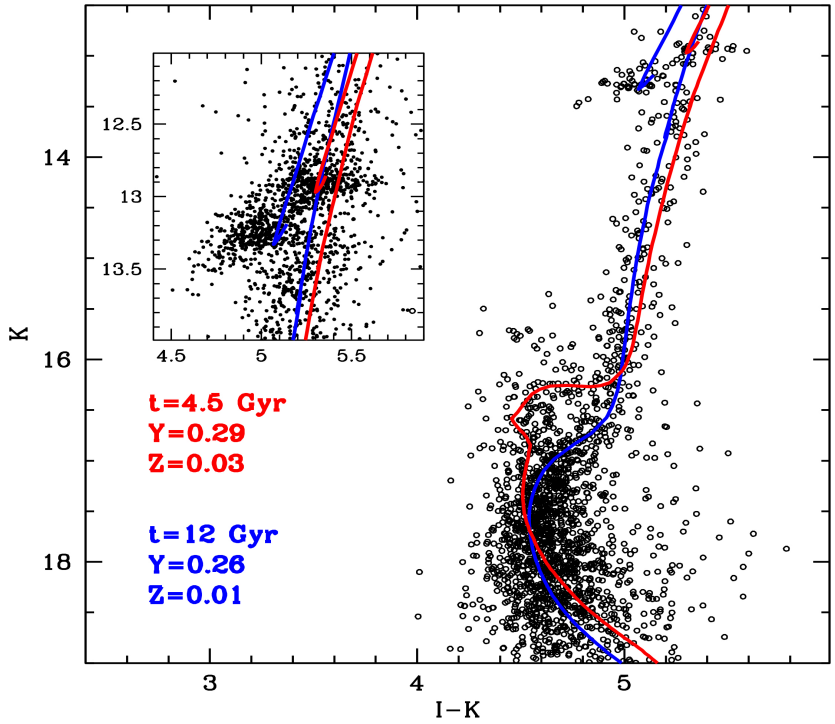
Understanding Terzan5, the largest Galactic furnace of MSPs

Terzan 5 harbors the largest known population of MSP in the Galaxy: ~25% of the entire MSP population in GCs.
We have collected convincing evidence that this stellar system is not a genuine GC



Multi iron stellar populations spanning 1 dex !!





Multi age:
12 Gyr
4.5 Gyr !!

see the talk of **Massari** on Friday

IMBH search
with

The IMBH search in GCs

✓ They are expected in GCs

- **Extrapolation of the "Magorrian relation" to GC mass scales**

✓ IMBH FINGERPRINTS in GCs

(e.g., Baumgardt +05; Miocchi 2007; Heggie +07; Trenti +07, +10; Dukier & Bailyn +03; Maccarone 2004; Gill +08; Vesperini & Trenti 2010; Umbreti+12)

1) **Shallow cusp in the star density profile**

2) **cuspy velocity dispersion profile**

3) presence of **high-velocity stars** (even $v \sim 100$ km/s)

4) **quenching of mass segregation**

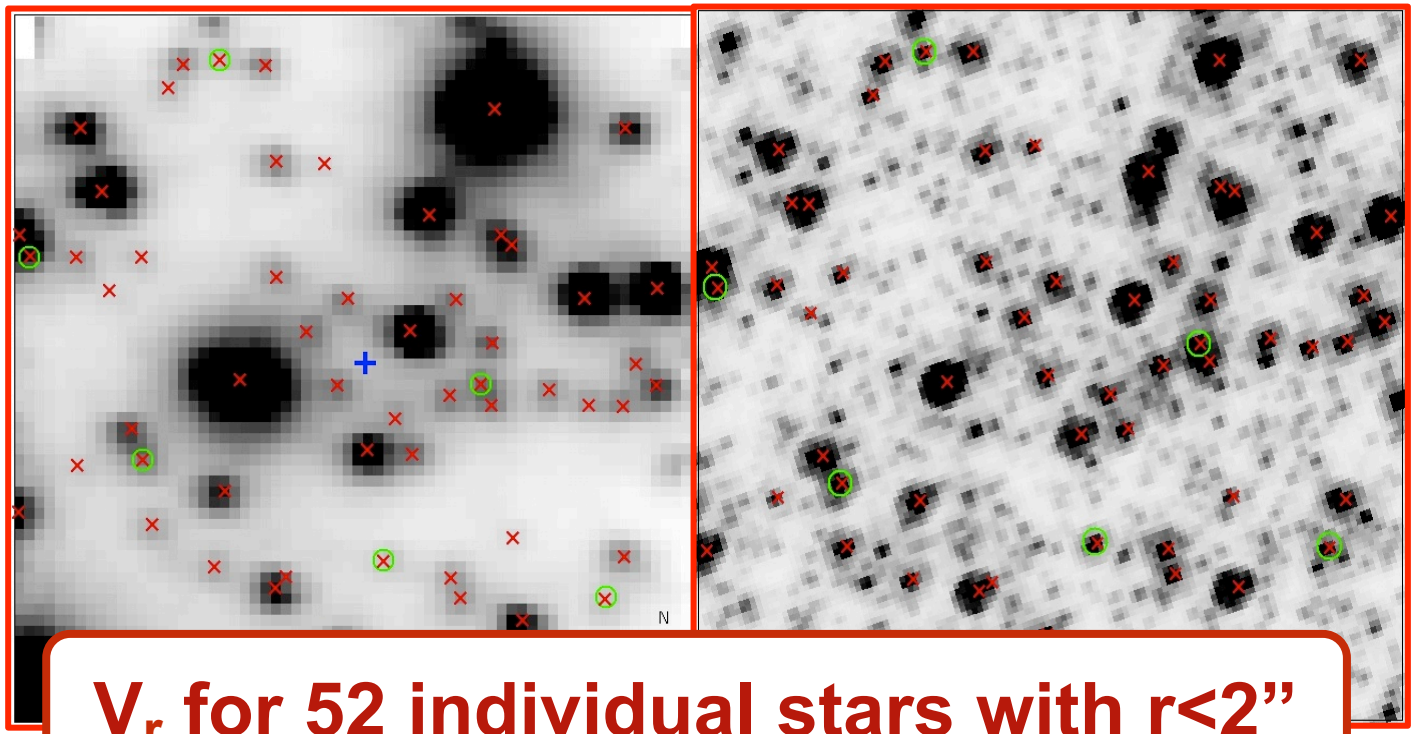
5) **X-ray and radio emission** from accreting gas

The IMBH search in GCs: a methodological approach

Because the velocity dispersion measures from integrated light spectroscopy can be severely affected from shot noise, we propose to derive the velocity dispersion profile by measuring the radial velocity of individual stars with AO-corrected IFU spectroscopy.

NGC6388

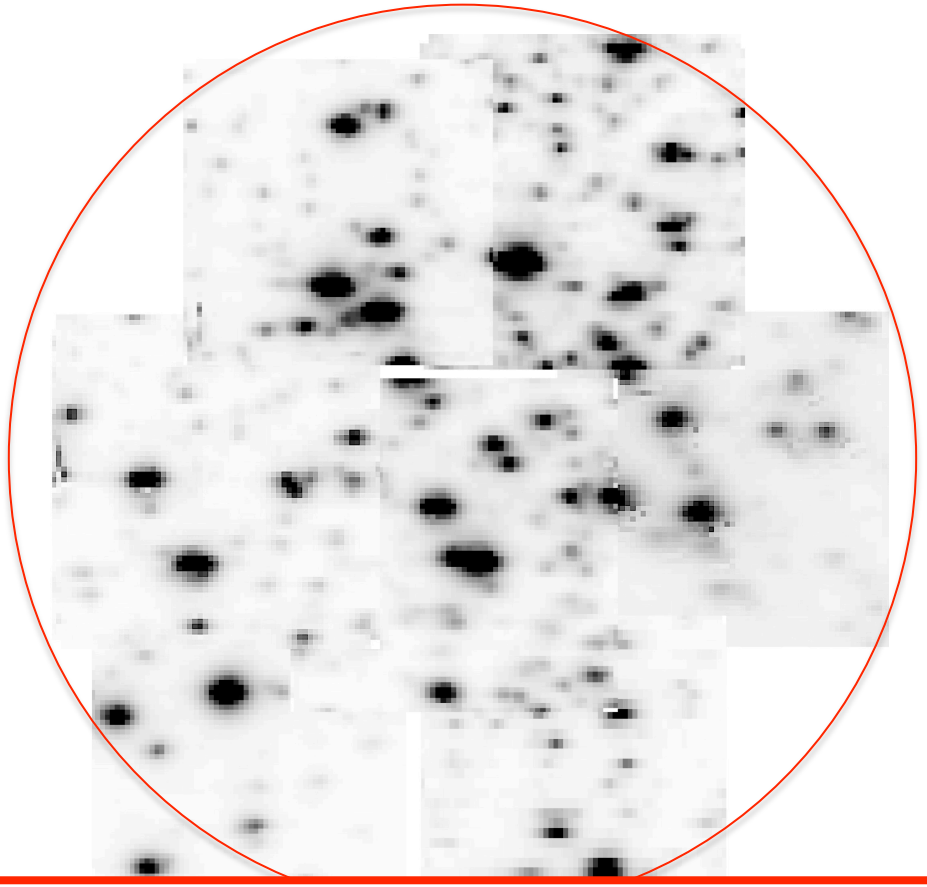
SINFONI RECONSTRUCTED **HST/ACS-HRC**



V_r for 52 individual stars with r<2”

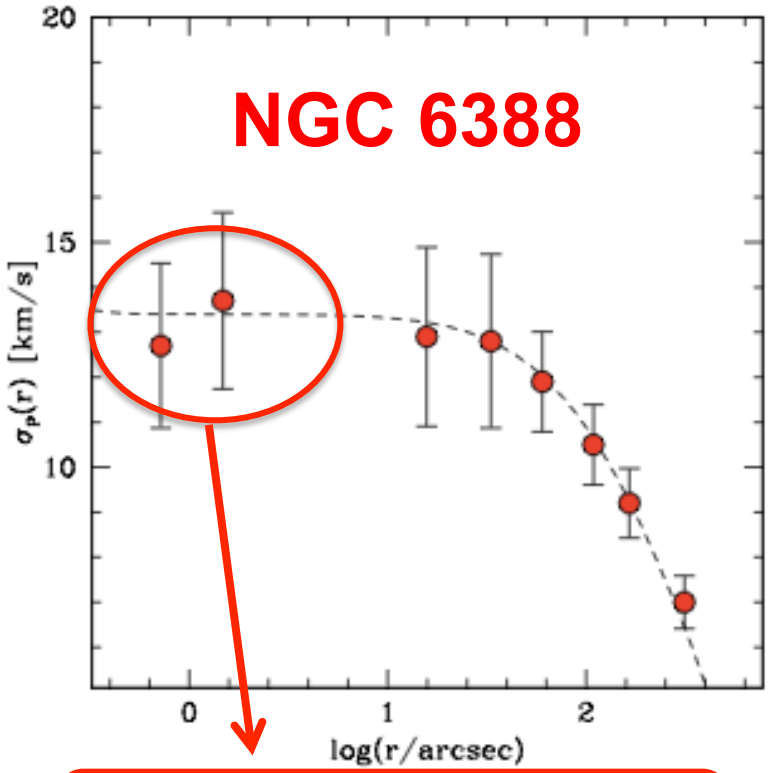
Very preliminary results for NGC 2808

A mosaic of 9 SINFONI fields

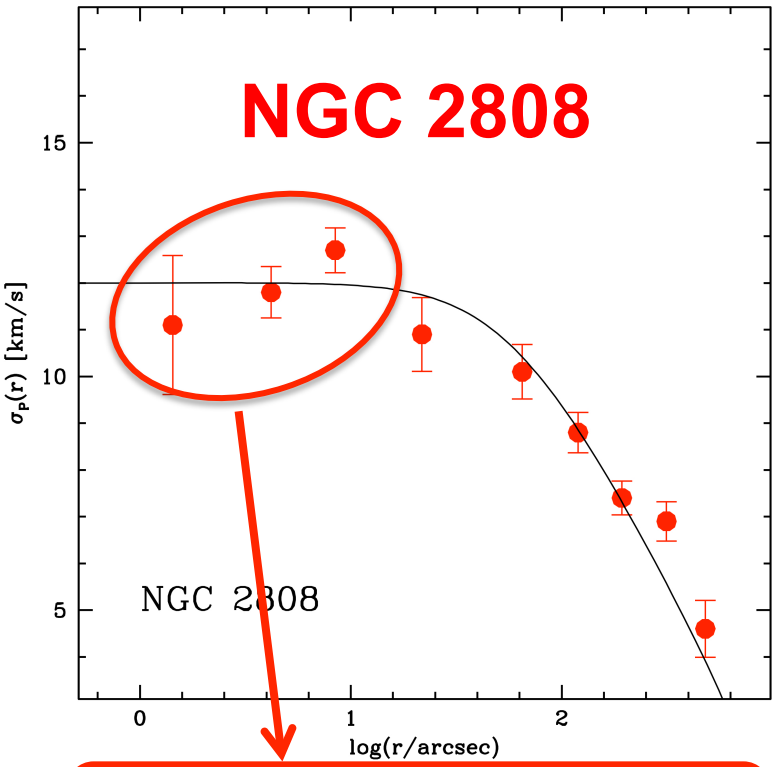


V_r for 800 individual stars at r<12" !!!!!!

The IMBH search in GCs: a methodological approach

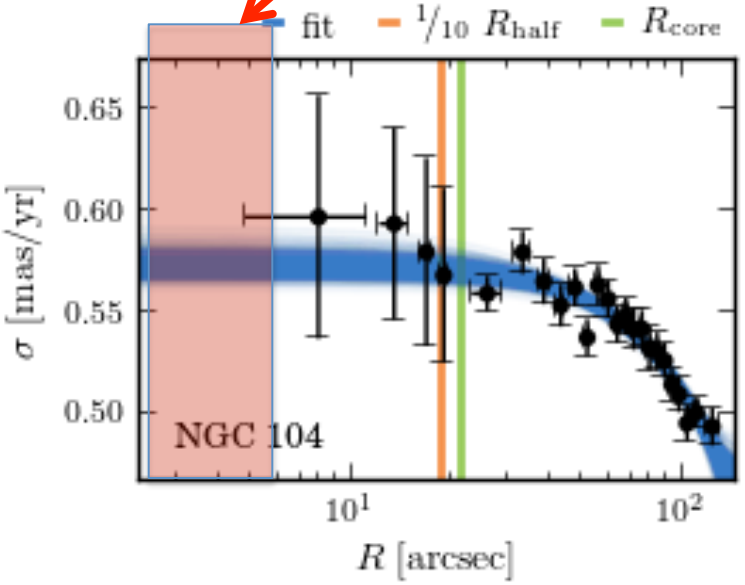


52 stars at r<2" !!!

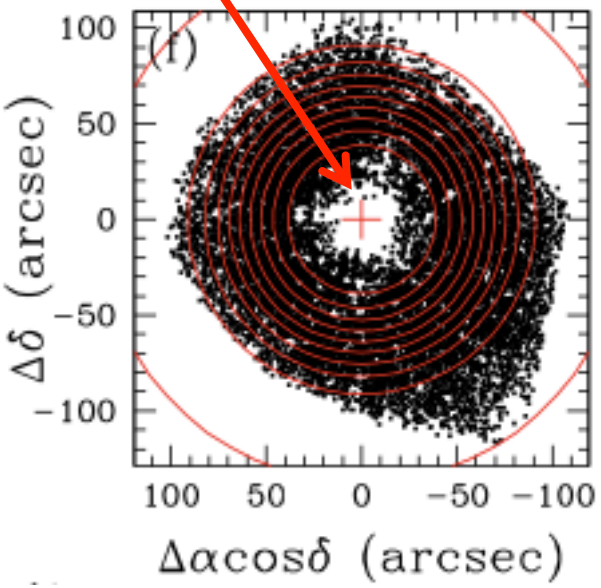


800 stars at r<12" !!!

In high-density clusters Proper Motions are still missed in the very central regions (stellar crowding)

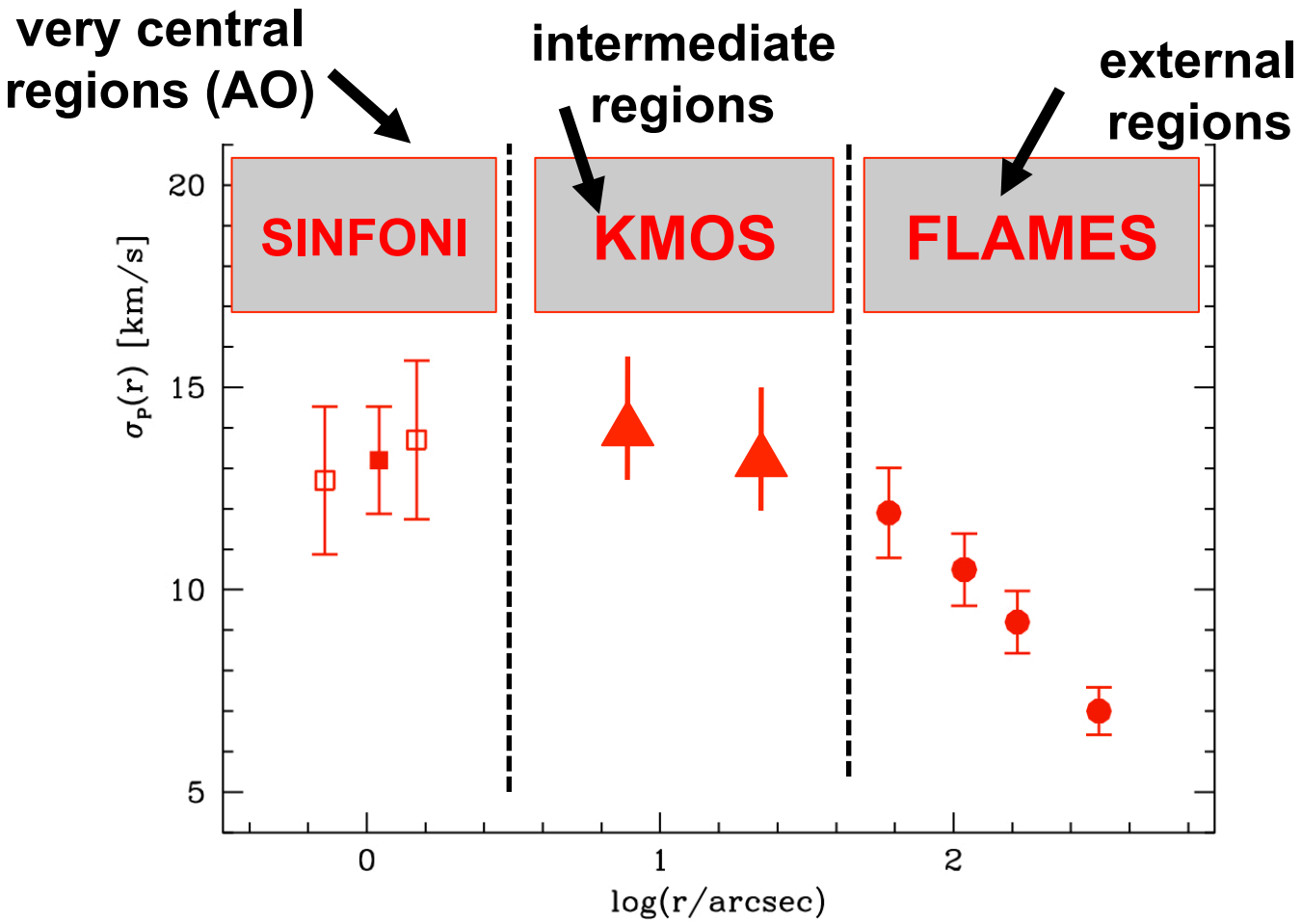


Watkins et al. 2015
(47 Tuc)



Bellini et al. 2014
(M15)

A MULTI-INSTRUMENT APPROACH



see **Lanzoni 's talk** on Wednesday

THE PROJECT

- opened new perspectives in the study of these three fascinating classes of objects
- was a breeding ground for the formation of young researchers
- offered a great opportunity to enjoy the research in Astrophysics

Cosmic-Lab

Thanks to all the people that contributed to the project

Thanks to all of you for coming.
Enjoy the Conference !