Working with Beatriz Barbuy on **bulge globular clusters**

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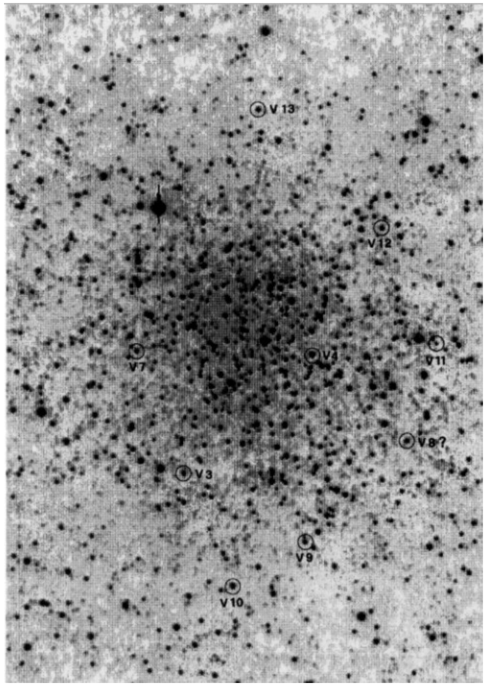
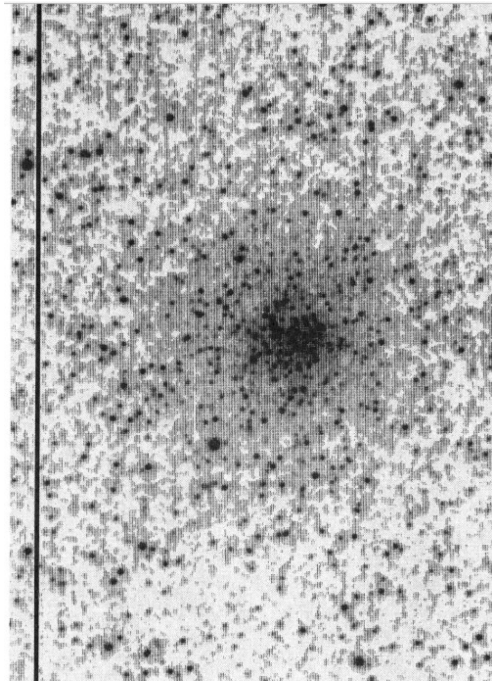
First meeting at La Silla, 1986-87, first observations of NGC 6553
-Eduardo Bica PHD thesis, 1987-1988: **list** of metal rich bulge clusters
-1990 **first paper** on **NGC 6553** (OBB)
-1991 Terzan 1, 1992 **NGC 6528**

About 5 papers/year (10 nr) in the first decade





First ESO application with Beatriz and Eduardo, 1987
First paper: The Messenger, 1989

EUROPEAN SOUTHERN OBSERVATORY

Organisation Européenne pour des Recherches Astronomiques dans l'Hémisphère Austral
Europäische Organisation für astronomische Forschung in der südlichen Hemisphäre

ESO - SECTION VISITING ASTRONOMERS
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APPLICATION FOR OBSERVING TIME AT LA SILLA, CHILE* PERIOD
(Please fill in with typewriter)

1. Short title of proposed programme (10 words maximum)
Verification of the metallicity of the globular cluster NGC 6553

2. Abstract (Concise summary of the proposal)
We intend to obtain spectra of individual stars in this supposedly super-metal-rich globular cluster. The objective is to proceed to a detailed analysis , in order to determine the overall abundance of this cluster. Therefore, lines of FeI,II, TiI,II of different intensities are to be looked for. If lines of other elements can also be measured, those would also be studied.

3. Telescope(s) and number of requested nights. Mark with "S" if simultaneous observations are essential

3.6 m	2.2 m	1.5 m	1.4 m CAT	1 m	0.50 m	Schmidt	GPO	1.5 m Danish	0.50 m Danish	0.61 m Bochum	0.90 Dutc
4											

4. Indicate required equipment. Fill in page 5) in detail

5. Indicate first and second choice for specified period

Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
X	X										

6. Moonlight preferences
Dark time ☐
Grey time ☐
No restrictions ☒

7. If a long-term project indicate the number of nights
a) already awarded to the project
2 runs of 2 nights each
b) required to complete the project (excluding those requested in this application)
if good weather, this one could be enough

8. Name of applicant and mailing address
B. Barbuy
Universidade de São Paulo
Depto. de Astronomia
C.P. 30627
Sao Paulo 01051
Brazil

9. Co-authors (name and institution)
S. Ortolani
Osservatorio Astronomico di Padova
Vicolo Osservatorio 5
35100 Padova
Italy

E. Bica
Observatoire de Paris-Meudon
92195 Meudon Pl Cedex, France

10. Name and nationality of the observer: S. Ortolani (italian) or B. Barbuy (brazilian)

*)

14. Agreement: If observing time is allotted, applicant(s) and observer(s) will act according to the "Instructions for Visiting Astronomers"

Name(s)	Position at Institution	Date	Signature
B. Barbuy	Profa. Livre-docente	6/10/87	Beatriz Barbuy
S. Ortolani	Associate Professor	6/10/87	BBarbuy for S. Ortolani
E. Bica	preparation of PhD	6/10/87	BBarbuy for E. Bica

The Peculiar Colour-Magnitude Diagrams of the Metal-Rich Globular Cluster NGC 6553

B. BARBUY, Universidade de São Paulo, Brazil
E. BICA, Universidade Federal do Rio Grande do Sul, Brazil
S. ORTOLANI, Osservatorio Astronomico, Padova, Italy

1. Introduction

NGC 6553 = GLC 88 (R.A. = $18^h 05^m 11^s$, DEC. = −25° 55.′1; 1950.0) is a metal-rich globular cluster of low Galactic latitude (l = 5°.253, b = −3°.029) at a heliocentric distance of about 5.7 kpc (Webbink, 1985), in the direction of the Galactic centre.

It shows the following interesting properties: (1) it is one of the most metal-rich galactic globular clusters (Morgan, 1959; van den Bergh, 1967; Bica and Pastoriza, 1983; Zinn and West, 1984); (2) it is a good example of an inner bulge globular cluster; (3) it shows a core with relatively dispersed, and therefore resolvable stars.

For these reasons, we decided to investigate NGC 6553 in detail: in a first important step, we obtained colour-magnitude diagrams (CMD) from B, V, R and I images, and then we identified members suitable for a detailed spectroscopic study in order to determine the cluster metallicity for a second step.

In this work, we present some of the resulting CMDs, and discuss the impact of these observations for studies of super-metallic populations.

2. Observations

BVRI frames were obtained at the 1.5-m Danish Telescope, equipped with the high resolution CCD ESO # 8. The frames used were taken with a seeing of about 0.8 arcsec.

The reductions were done at the ESO Garching computer centre using the Daophot and Romafot packages, in Midas environment.

3. Colour-Magnitude Diagrams

Due to its high metallicity, NGC 6553 presents a peculiar CMD morphology, as it can be seen in the V vs. (B-V) diagram for the whole field (Fig. 1a) and for giant stars only (Fig. 1b); as well as in the V vs. (V-I) for the whole field (Fig. 2a) and for giants only (Fig. 2b). The giant stars in this diagram, as well as in the other diagrams where we present the same selection for different colour combinations, are divided in two groups with different symbols according to their V-I colour (higher or lower than 3.2, roughly corresponding to the giant turnover in the V vs. (V-I) diagram).

3a. Morphology of the Red Giant Branch (RGB)

Figure 2a shows that the RGB forms an arc, and that the stars at the RGB tip are as faint as the horizontal branch (HB) stars. This is due to a strong molecular opacity of TiO bands in the B, V and R filters, whereas in the I filter only the weak FeH Wing-Ford band is present in these spectral types. This is clearly seen in Figure 2b where only stars from the upper RGB are selected. The curvature of the RGB arc might be used as a metallicity indicator.

The amplitude of the distortions that the RGB undergoes depends on the relative strength of the opacity in the different filters. The effect is so strong in the V vs. (B-V) diagram (Fig. 1) that it might be misleadingly interpreted as a wide giant branch arising from a metallicity dispersion. We thus leave a cautionary remark for CMD observations of composite metal-rich populations in galaxy nuclei, which become available with large telescopes and the Hubble Space Telescope.

On the other hand CMDs using I magnitudes as luminosity indicator do not

The metallicity and the age of the galactic bugle, a controversial issue in the ‘80s: Rich, Renzini, Minniti…

-Globular clusters: low latitude metal rich clusters (Zinn, 1985),

-Minniti, 1995: METAL-RICH GLOBULAR CLUSTERS WITH R<3 KPC: DISK OR BULGE CLUSTERS?

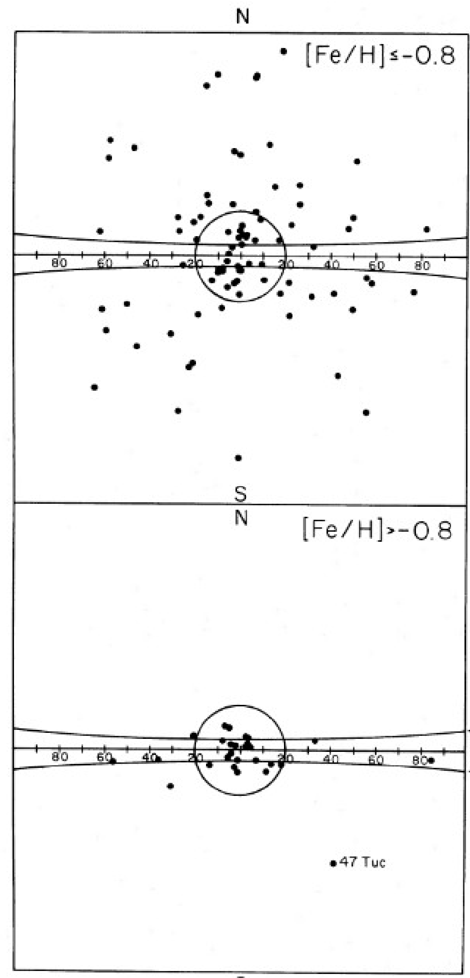


Fig. 3.—These diagrams are polar plots of the sky centered on the galactic center. The points are the locations of the clusters in Table 1 given by their θ and $\tilde{\omega}$ coordinates. The horizontal lines are the galactic equator on which scales of $\tilde{\omega}$ have been placed. The curved lines are lines of $\pm 5°$ galactic latitude. Circles where $\tilde{\omega} = 20°$ have been drawn to illustrate the appearance of a spherical distribution about the galactic center. This diagram illustrates that the metal-rich clusters have a flattened spatial distribution, whereas that of the metal-poor clusters is essentially spherical.

We compare the metal-rich globular clusters within 3 kpc of the galactic center with the underlying stellar population. On the basis of kinematics, spatial distribution, and metallicity, we argue that these clusters may be associated with the galactic bulge (as concluded by Frenk & White 1982) rather than with the thick disk.

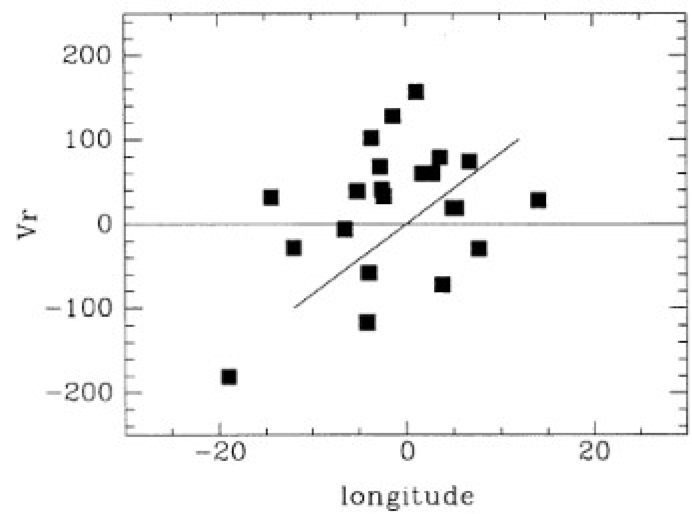


Fig. 4. Velocities for the metal-rich clusters within 30° of the galactic center, along with the bulge rotation (solid line) found by DM94. Note that the solid line is not a fit to the clusters. Compare this figure with Fig. 1 of Whitford (1993).

First refereed paper, NGC 6553, 1990.
Old, with very bright AGB stars: effect of metallicity

High-metallicity effects in *BVRI* colour-magnitude diagrams: the globular cluster NGC 6553 ★

S. Ortolani [1], B. Barbuy [2], and E. Bica [3]

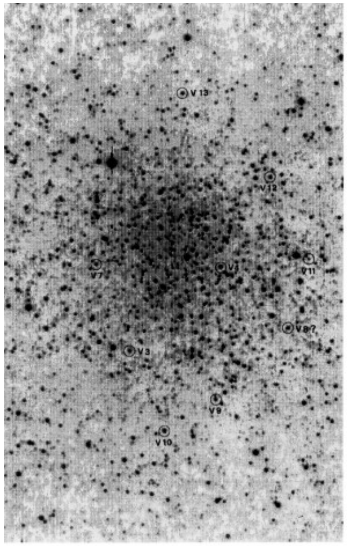


Fig. 1. *V* image of the cluster. The variable stars are identified by circles. The field is about 3′ × 4′. North is up and west to the left

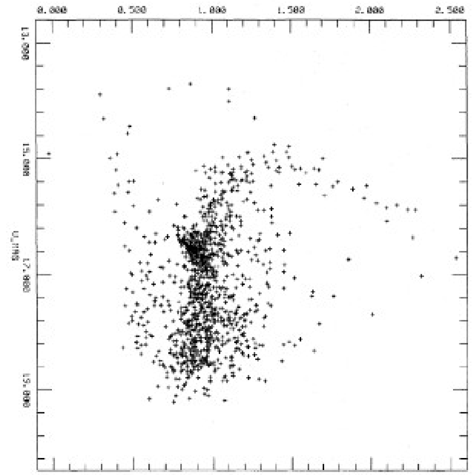


Fig. 5. CMD in V vs. $(V-R)$

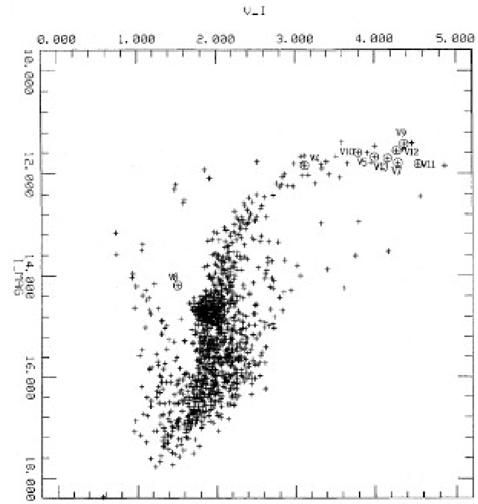
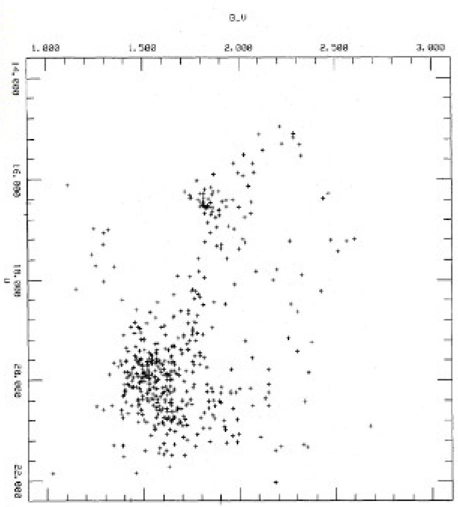
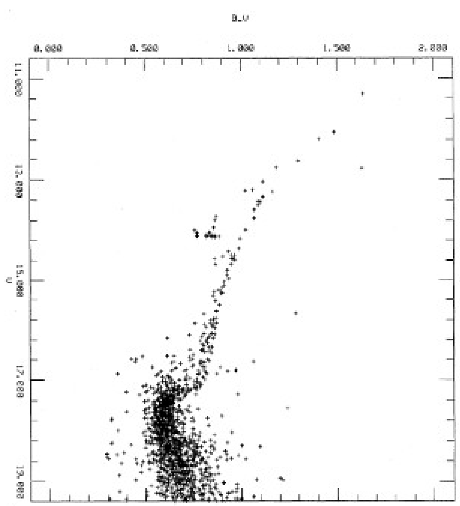


Fig. 6. CMD in I vs. $(V-I)$ for bright stars (non-saturated frame). The variable stars are identified



a



b

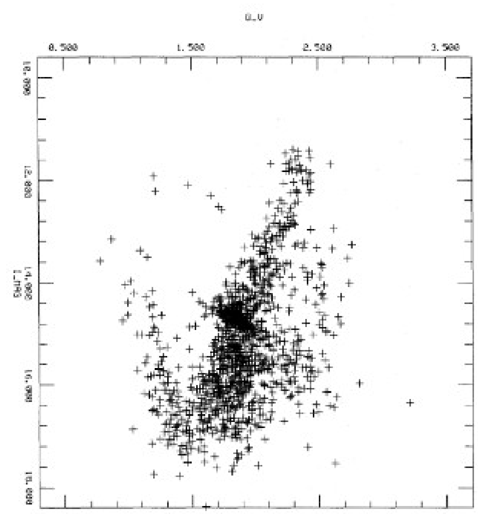


Fig. 7. CMD in I vs. $(B-V)$ for bright stars (non-saturated frame)

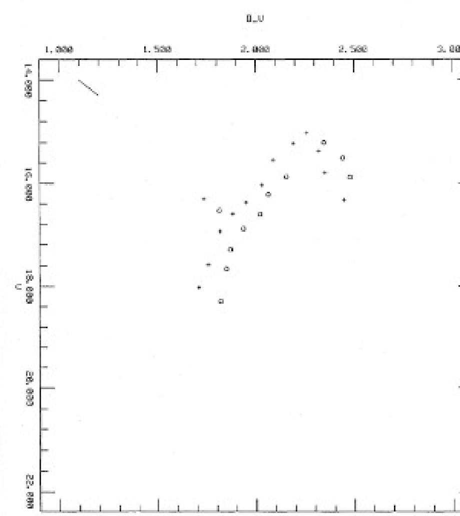


Fig. 8. Mean locus of CMD for the upper ($500 \leq Y \leq 800$ pixels) and lower ($Y \leq 300$) strips of frame, showing a clear differential reddening. The direction of the reddening vector is shown in the upper left corner of the figure

The controversial issue of the bright giants in the bulge

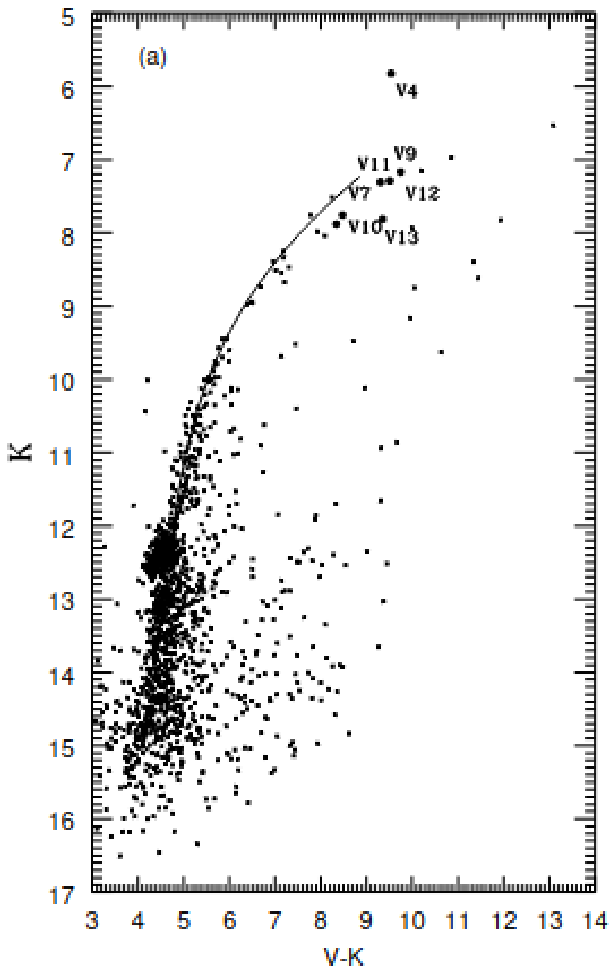
A result from NGC 6553 data: the brightness of metal rich, **old** giants (Guarnieri et al., 1996, 1997)

THE ASTROPHYSICAL JOURNAL, 477: L21–L24, 1997 March 1

ON CALIBRATING BRIGHTEST ASYMPTOTIC GIANT BRANCH STARS AS AGE INDICATORS: THE BULGE GLOBULAR CLUSTER NGC 6553 AND THE AGE OF M32[1]

MARIA DONATA GUARNIERI,[2,3] ALVIO RENZINI,[3,4] AND SERGIO ORTOLANI[5]
Received 1996 July 22; accepted 1996 December 9

ABSTRACT



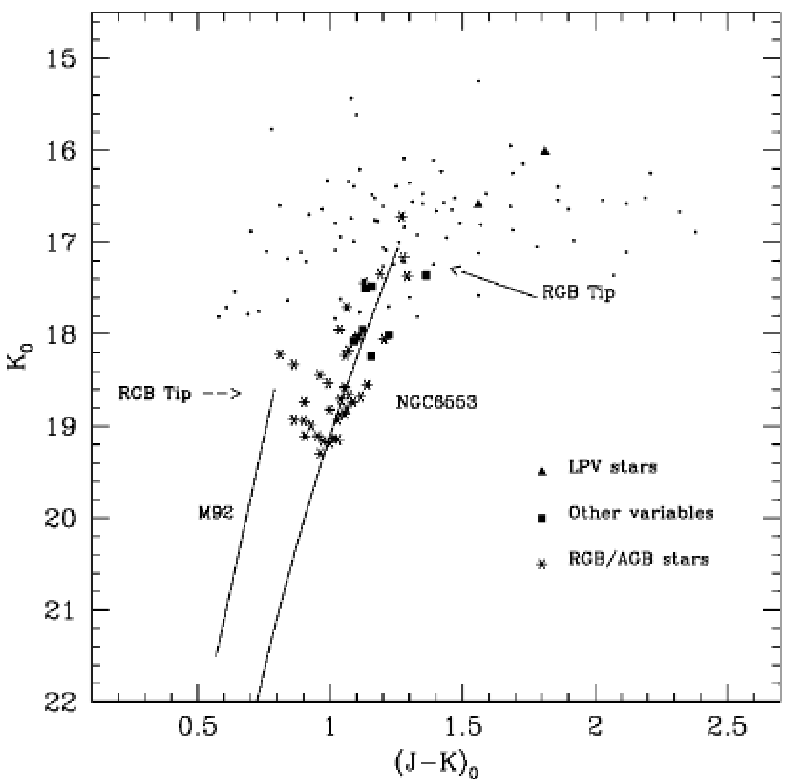


FIG. 3.—The K_0–$(J-K)_0$ color-magnitude diagram of stars in M32 (Freedman 1992), with the brightest variable and nonvariable stars in NGC 6553 superimposed, as they would appear if at the same distance of M32.

NGC 6522, intermediate metal poor cluster (Barbuy et al., 1994; Terndrup and Walker, 1994; Terndrup et al., 1998)

NGC 6522: an intermediate metallicity globular cluster projected on the Baade Window★

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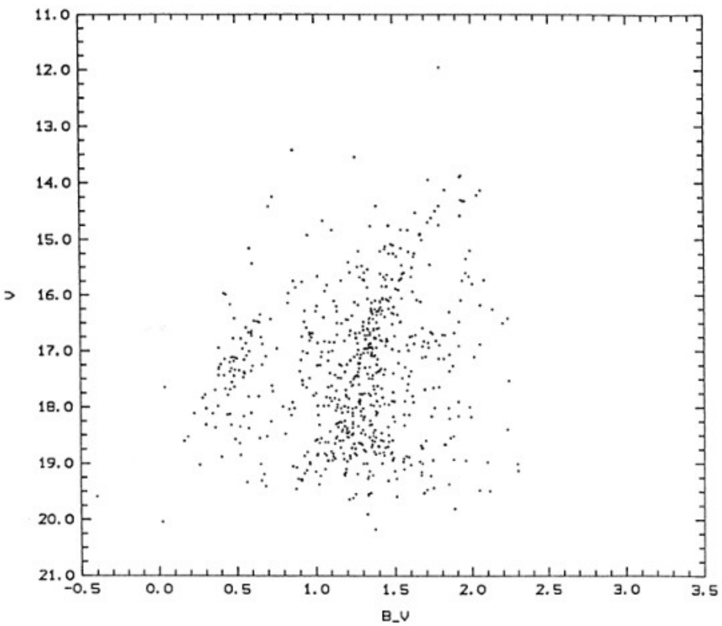
[2] Università di Padova, Dept. di Astronomia, Vicolo dell'Osservatorio 5, I-35123 Padova, Italy
[3] Universidade Federal do Rio Grande do Sul, Dept. de Astronomia, CP 15051, Porto Alegre, 91500-970, Brazil

Received 20 September 1993 / Accepted 7 October 1993



The Astronomical Journal, 115:1476–1482, 1998 April

THE PROPER MOTION OF NGC 6522 IN BAADE'S WINDOW[1]

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and
Elaine M. Sadler
School of Physics, University of Sydney, Sydney, NSW 2006, Australia; ems@physics.usyd.edu.au
Received 1997 October 30; revised 1997 December 16

ABSTRACT

We have detected seven stars with a common proper motion that are located within 2.′5 of the globular cluster NGC 6522 in the Baade's window field of the Galactic bulge. We argue that these stars are members of the cluster, and derive a weighted mean proper motion and heliocentric radial velocity of $\bar{\mu}_l = 1.4 \pm 0.2$ mas yr^{-1}, $\bar{\mu}_b = -6.2 \pm 0.2$ mas yr^{-1} and $\bar{v} = -28.5 \pm 6.5$ km s^{-1}. We rederive the distance to NGC 6522 [$(0.91 \pm 0.04)R_0$, where R_0 is the Galactocentric distance] and metallicity ([Fe/H] $= -1.28 \pm 0.12$), making use of recent revisions in the foreground extinction toward the cluster ($A_V = 1.42 \pm 0.05$). We find the spatial velocity of the cluster and conclude that the cluster stays close to the Galactic center, and may have experienced significant bulge/disk shocking during its lifetime.

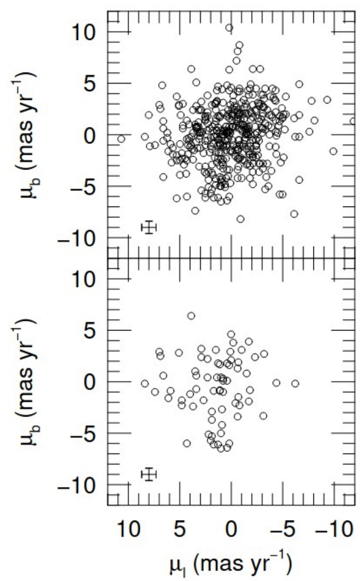


Fig. 1.—Proper-motion vector point diagrams for all stars in the Baade's window survey (SJW; *top*) and those stars located within 2.′5 of the cluster center that have radial velocities near that of NGC 6522 (*bottom*). The units are milliarcseconds per year. The error bar in the lower left-hand

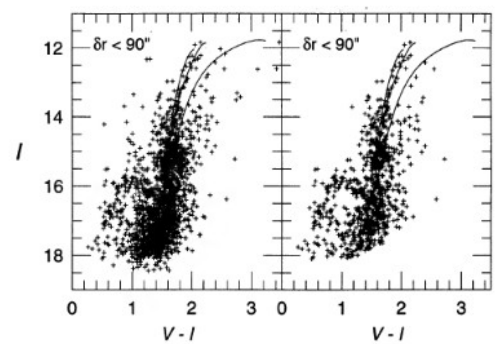


Fig. 5. Color–magnitude diagram in *I*, *V*−*I* for stars within 90″ of the cluster center before (left panel) and after (right panel) subtraction of the bulge CMD. The solid lines show giant branches for (left to right) NGC 6397, NGC 6752, and 47 Tucanae, respectively, as compiled by DaCosta & Armandroff (1990). These giant branches have been shifted to the observed plane using the reddening and distance to NGC 6522 as described in the text.

NGC 6553, the first bulge cluster **PM cleaned,** 4 years (Zoccali et al., 2001); NGC 6522, ground +HST (Rossi et al. 2015)

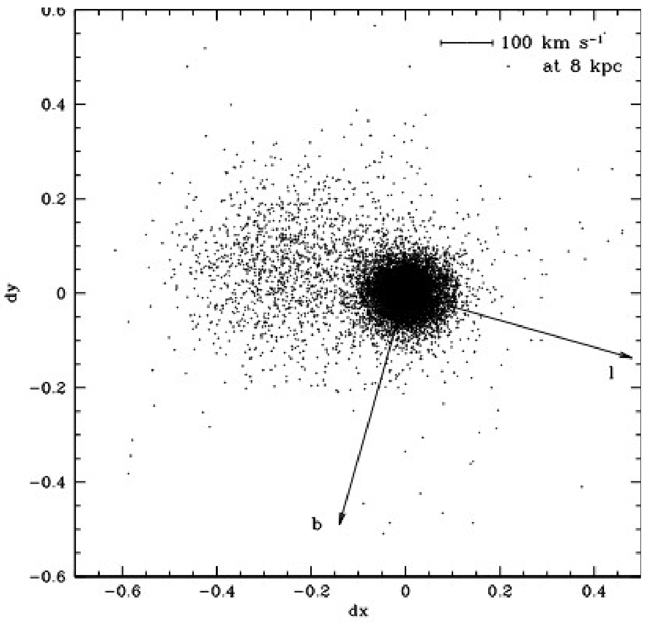


FIG. 3.—Relative proper motions (*dx*, *dy*) in pixels between the tw epochs. The arrows show the direction of increasing Galactic longitude (and latitude (*b*).

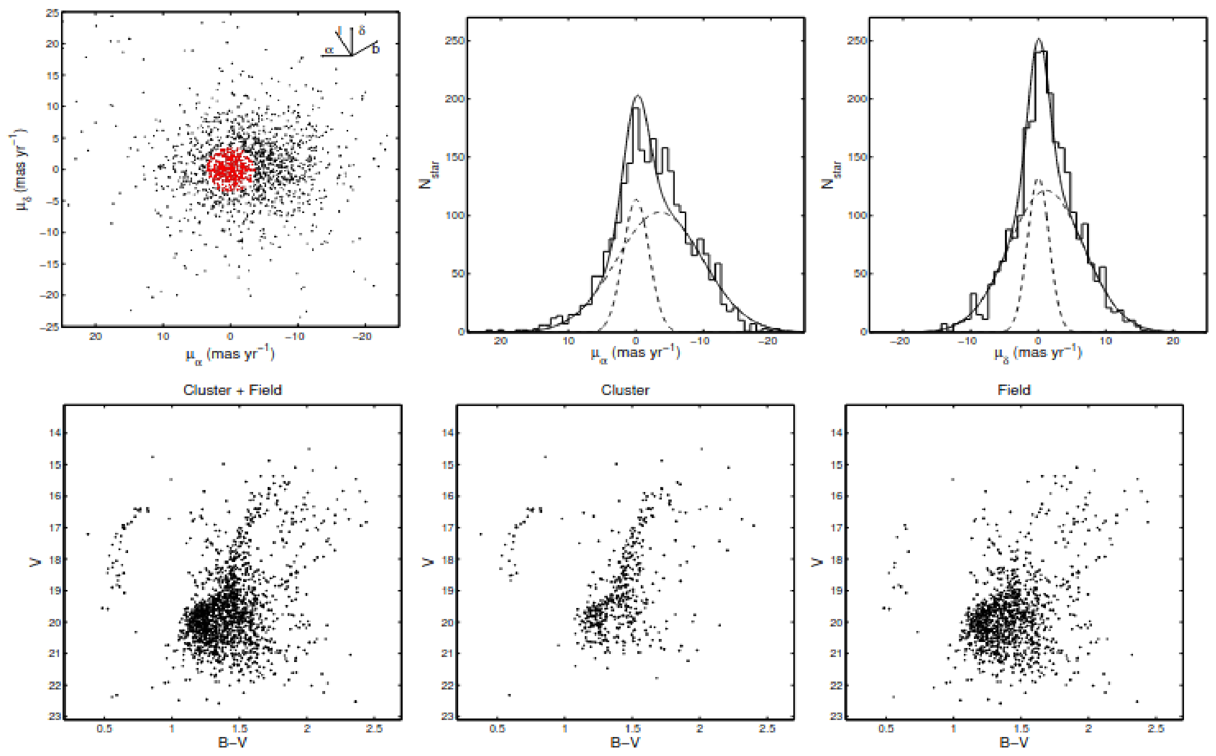


Figure 21. Proper motion and CMD decontamination of NGC 6522 from Danish Telescope–NTT and NTT–HST data.

Globular clusters and the bar, Rossi L., 2013 (from Bica, Barbuy, Ortolani, 2010)

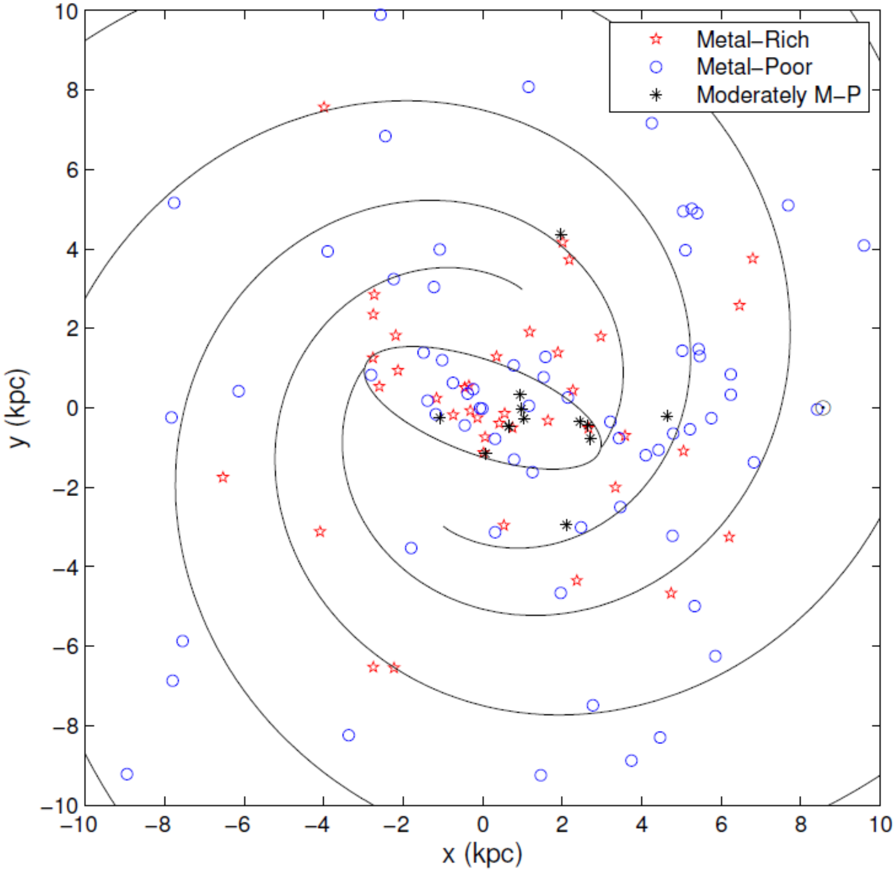


Figure 1.4: Spatial distribution of GCs projected on the Galactic plane from the North Galactic Pole.

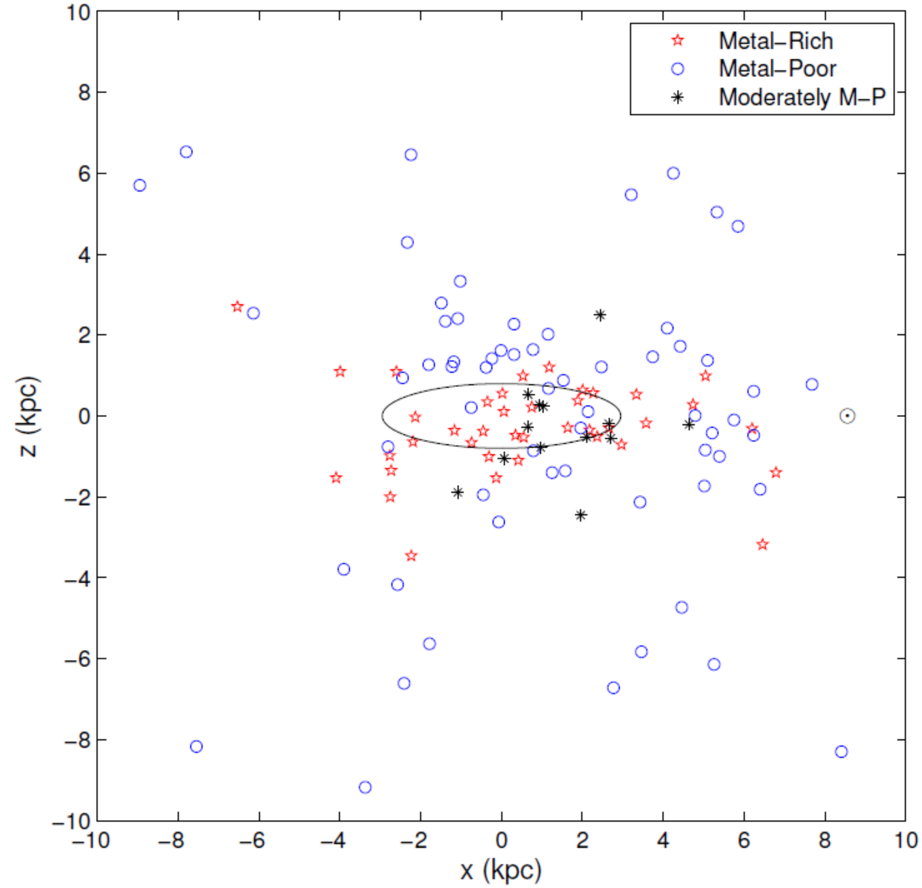
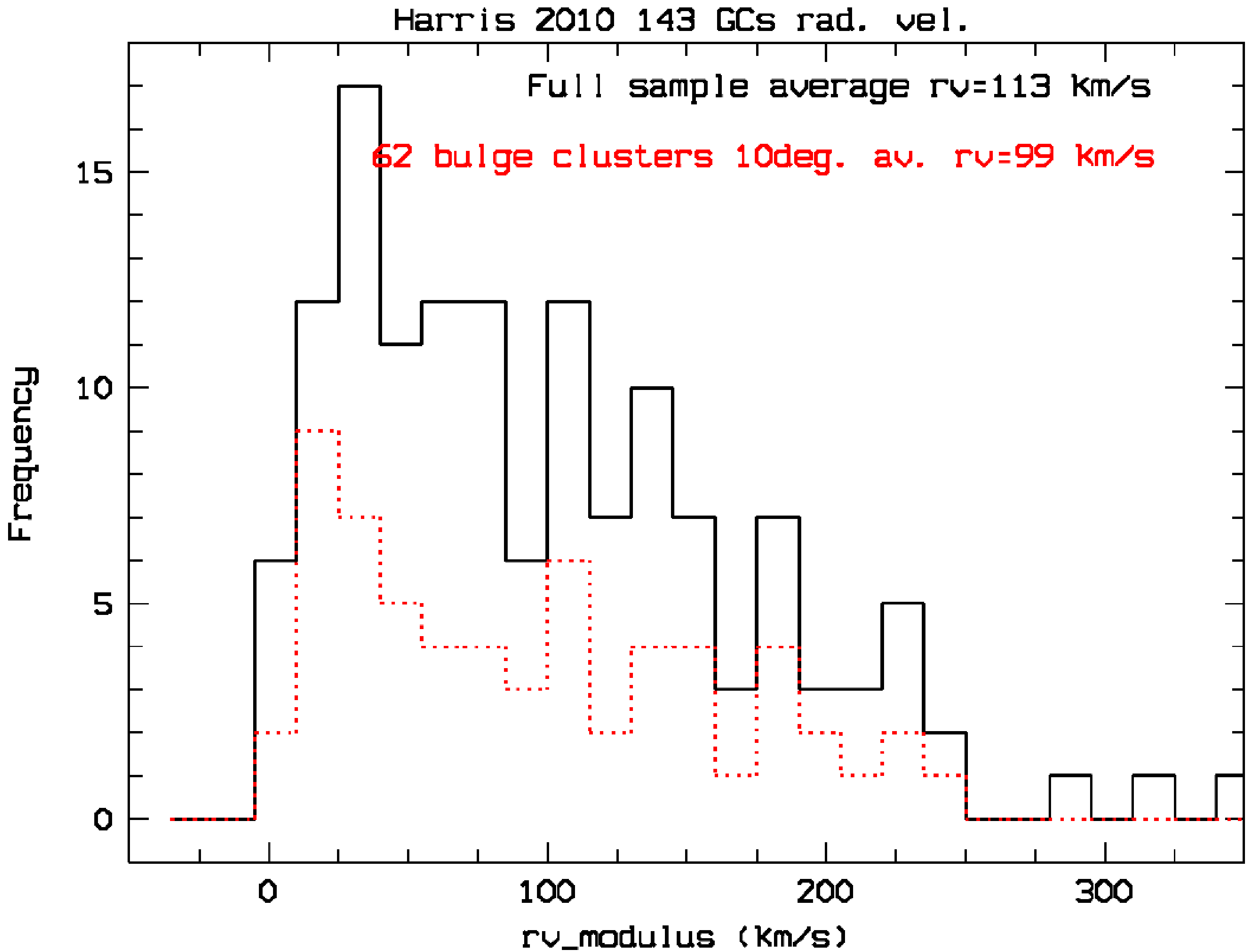
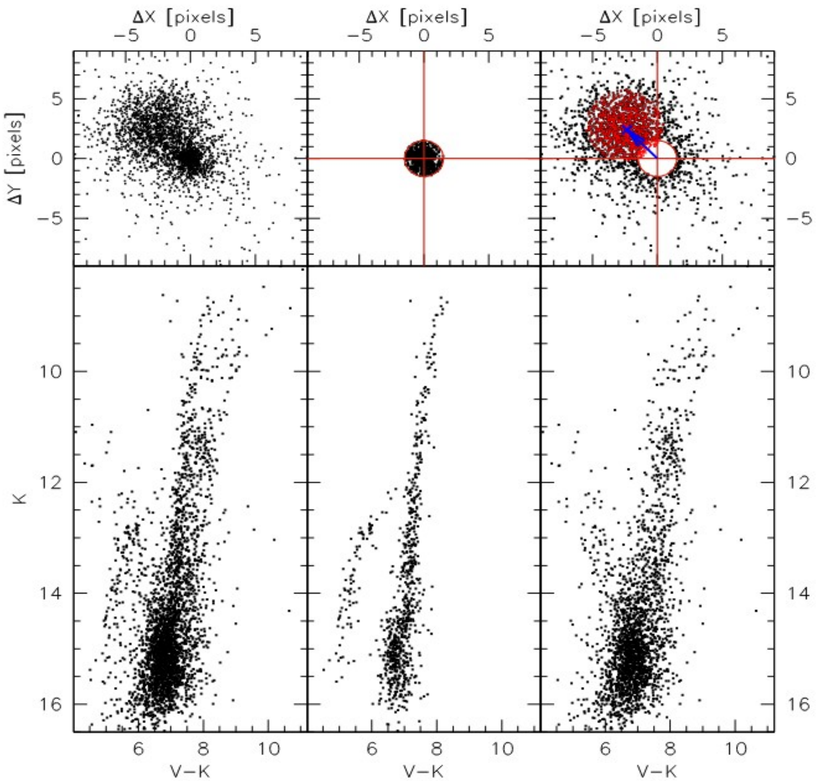


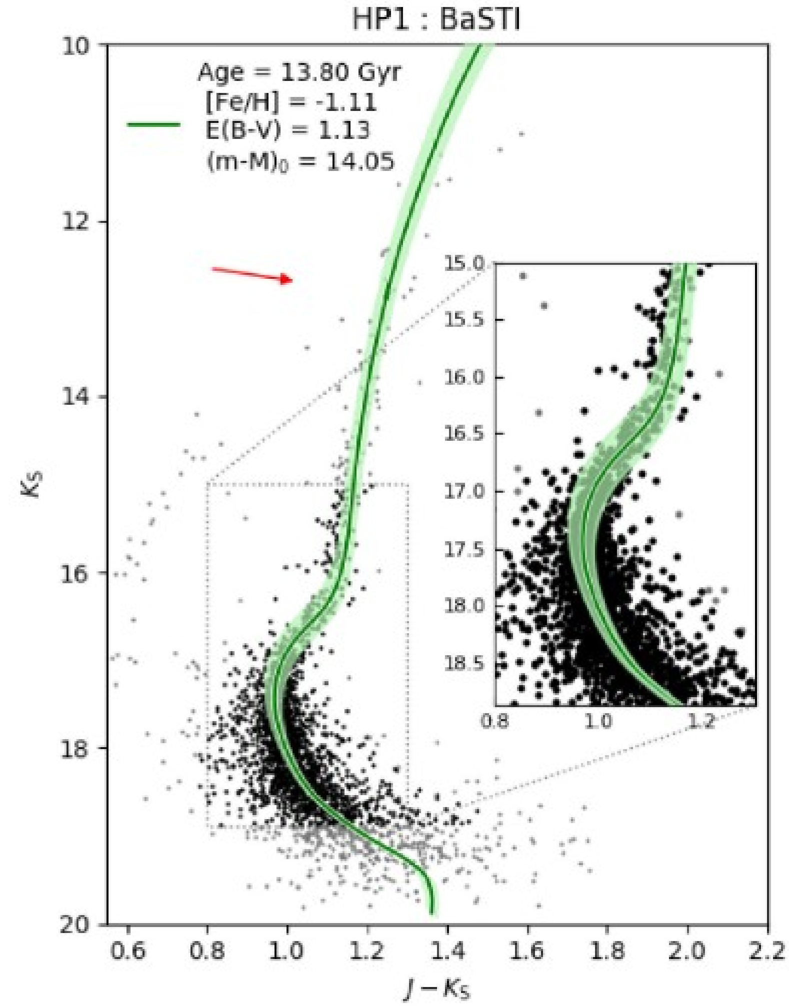
Figure 1.5: Spatial distribution of GCs projected on the x–z plane.

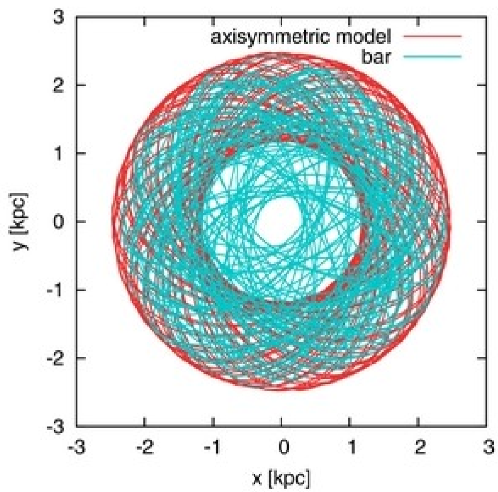

Harris 2010 143 GCs rad. vel.
Full sample average rv=113 km/s
62 bulge clusters 10deg. av. rv=99 km/s
Frequency
0
5
10
15
0
100
200
300
rv_modulus (km/s)

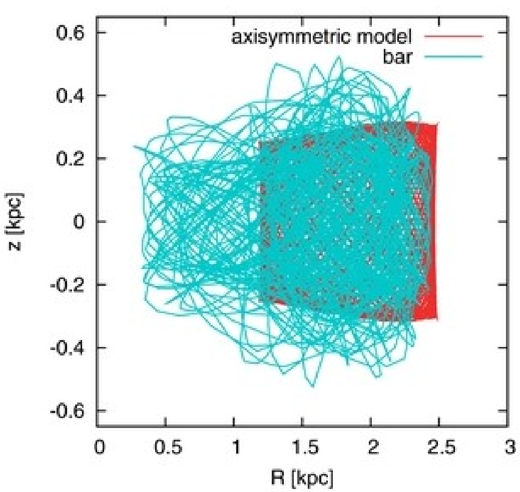
A blue HB GC example: HP1, [Fe/H]=-1.0

(Ortolani et al., 2011, Barbuy et al, 2016, Kerber et al., 2019)

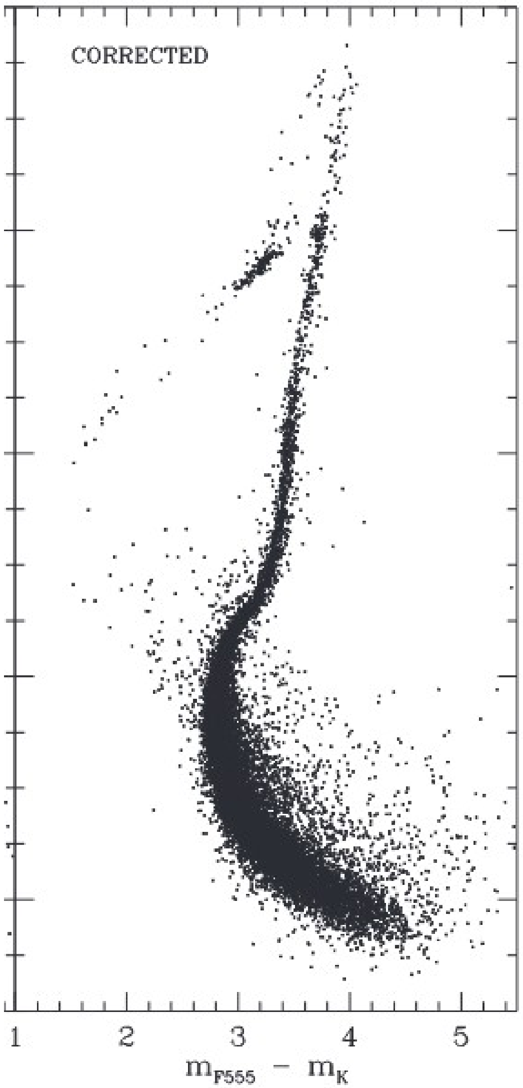






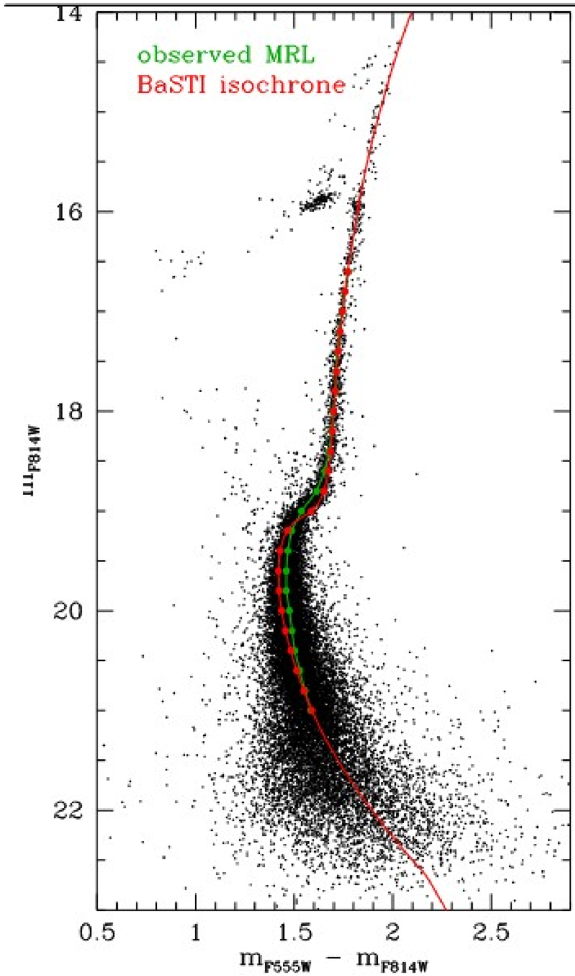


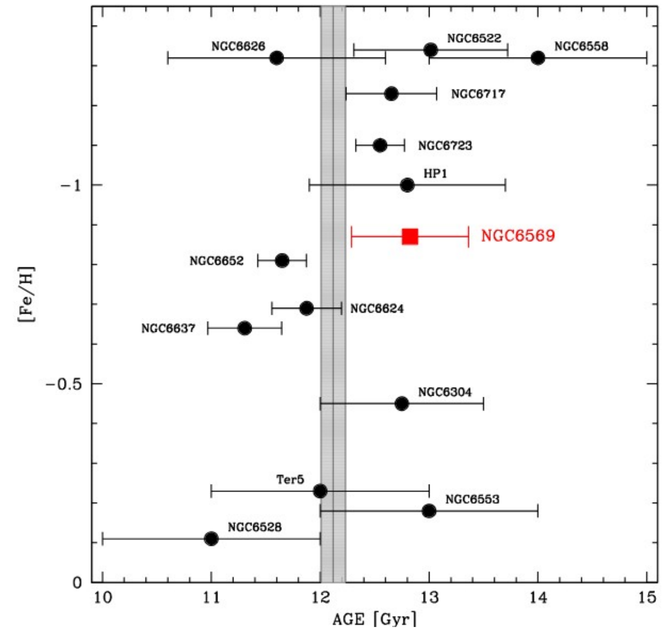
NGC 6569 (Saracino et al., 2019) + Geisler, Cohen ...



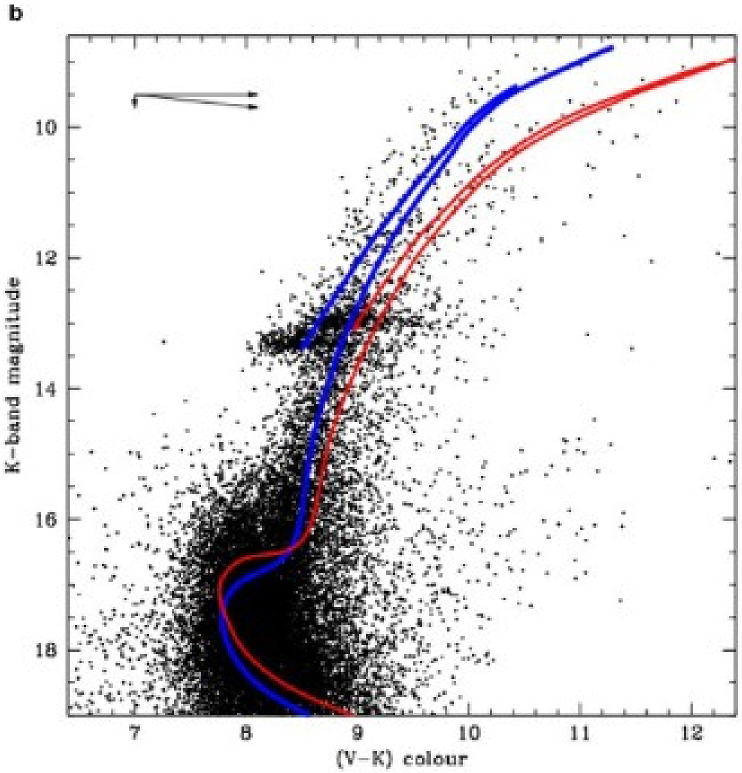
Best-fit Parameter Values for the DSED, VR, and BaSTI Models

	DSED Isochrone	VR Isochrone	BaSTI Isochrone
$E(B-V)$ [mag]	0.53 ± 0.01	0.525 ± 0.010	0.52 ± 0.01
$(m-M)_0$ [mag]	$14.96^{+0.06}_{-0.06}$	$14.95^{+0.06}_{-0.06}$	$14.94^{+0.06}_{-0.06}$
Age [Gyr]	$12.51^{+0.88}_{-0.82}$	$13.13^{+0.94}_{-0.90}$	$12.91^{+1.05}_{-1.01}$





Terzan 5: 12 and 6 Gyr (Ferraro et al., 2009), Liller 1: 12-1 Gyr (Dalessandro et al., 2022) + UKS1 (Fernandez-Trincado et al., 2020) + … see also Souza et al., 2024: building blocks ?



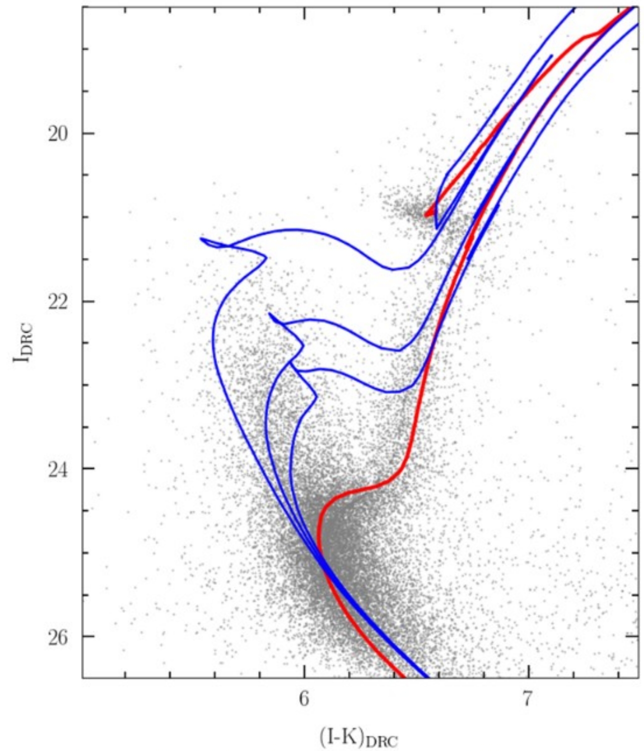
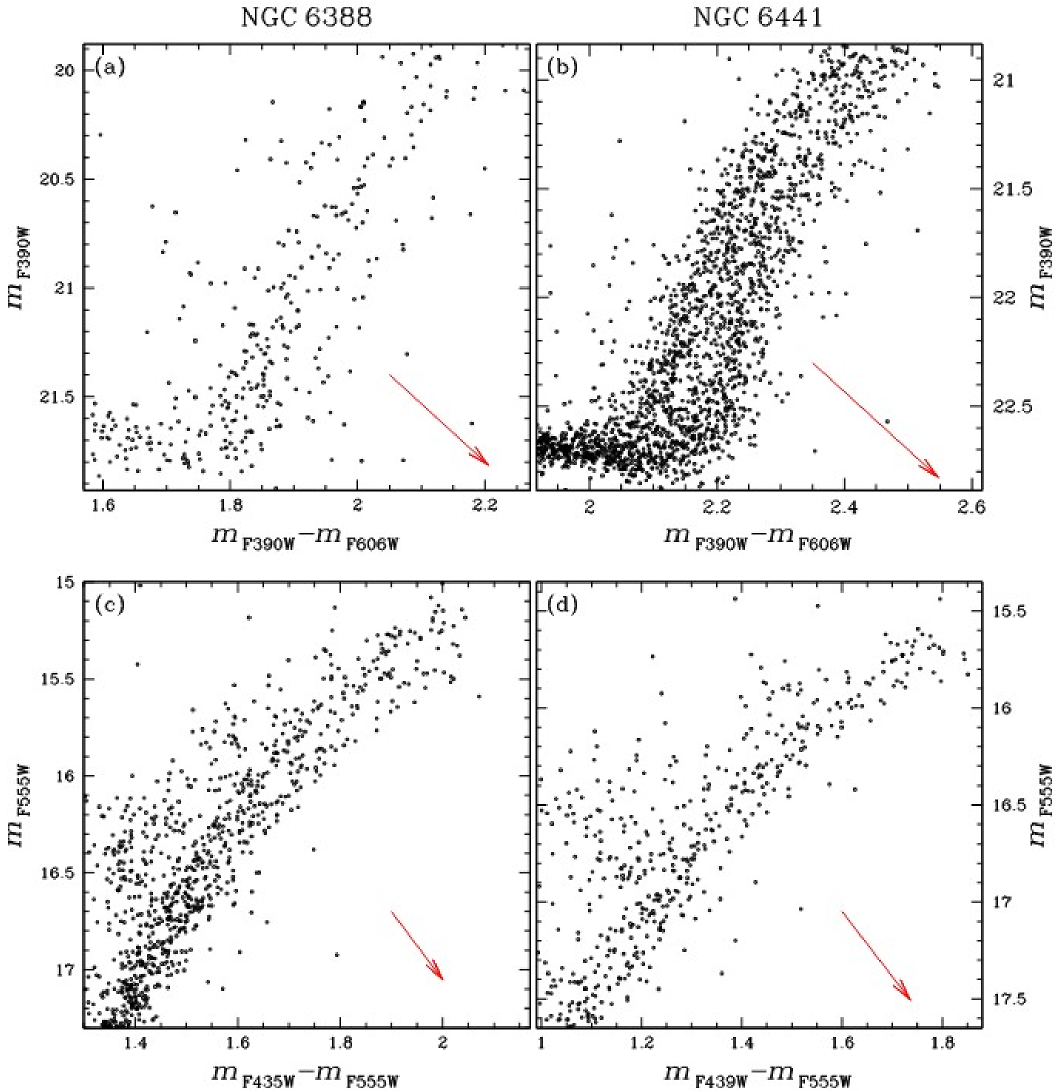


Figure 4. Sample of isochrones overplotted to the differential reddening-corrected and PM-selected CMD of Liller 1 (gray dots): in red the 12 Gyr old isochrone with $[M/H] = -0.3$ that nicely reproduces the old stellar population; in blue three young isochrones (of 1, 2, and 3 Gyr, from top to bottom) at larger metallicity $[M/H] = +0.3$, which are needed to reproduce the locus occupied by the young population.

Multipopulations in bulge clusters, Bellini et al., 2013

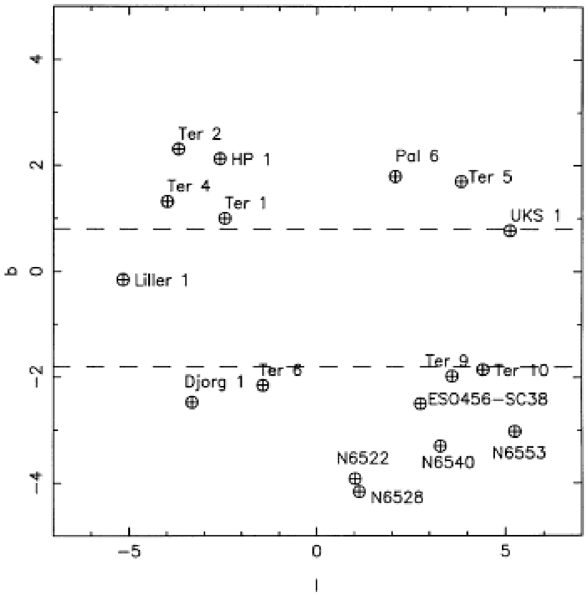
THE INTRIGUING STELLAR POPULATIONS IN THE GLOBULAR CLUSTERS NGC 6388 AND NGC 6441*

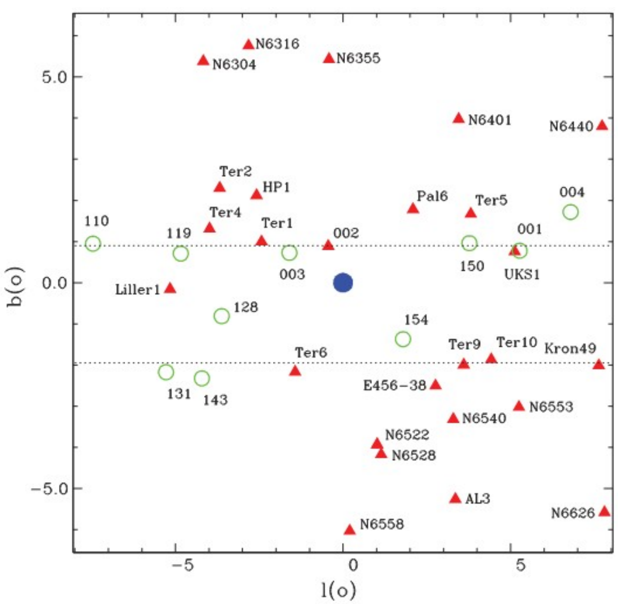
A. Bellini[1,2], G. Piotto[2], A. P. Milone[3,4], I. R. King[5], A. Renzini[6], S. Cassisi[7], J. Anderson[1],
L. R. Bedin[6], D. Nardiello[2], A. Pietrinferni[7], and A. Sarajedini[8]



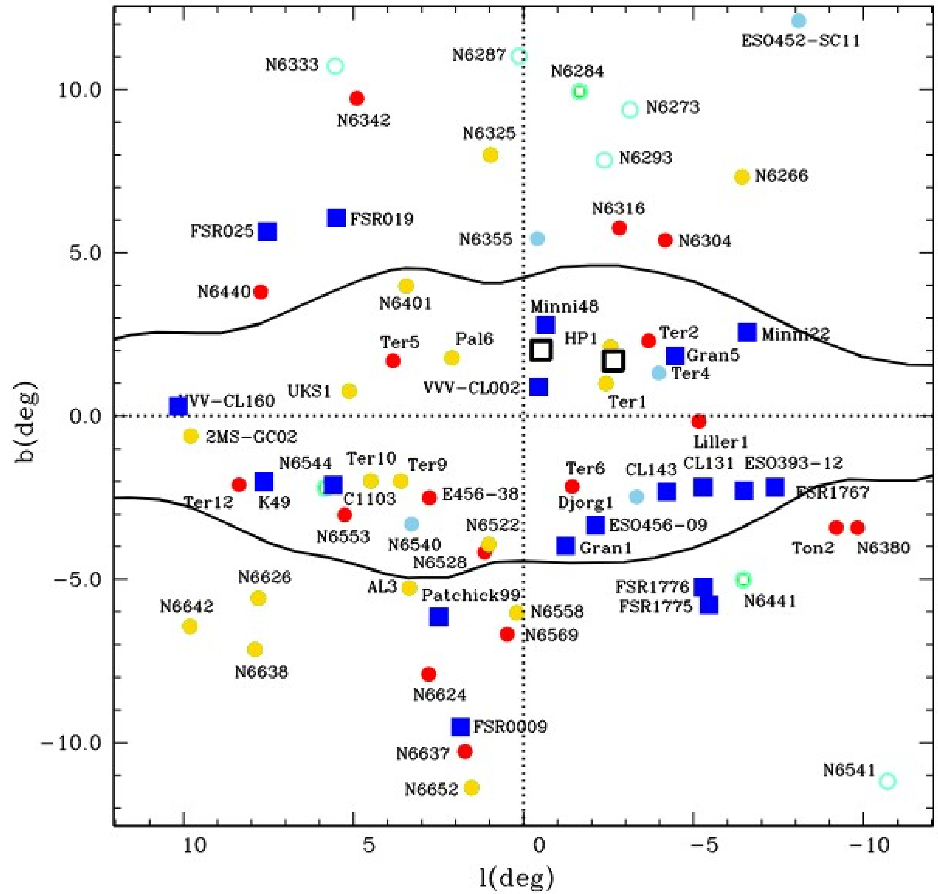
Bulge cluster catalogues: Barbuy et al., 1994, Bica et al., 2016, Bica et al., 2024

(see also Garro et al., 2024)



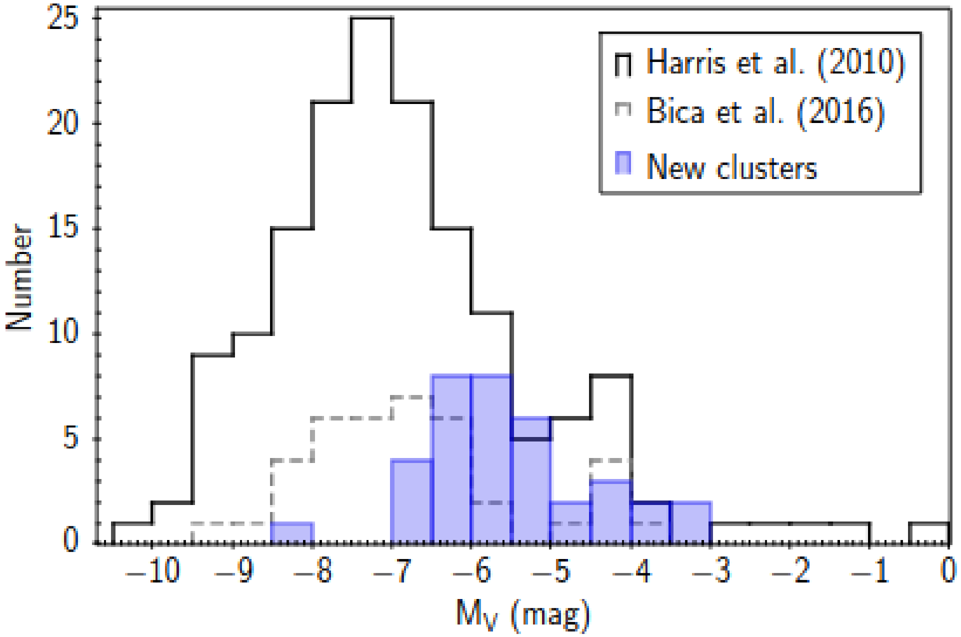


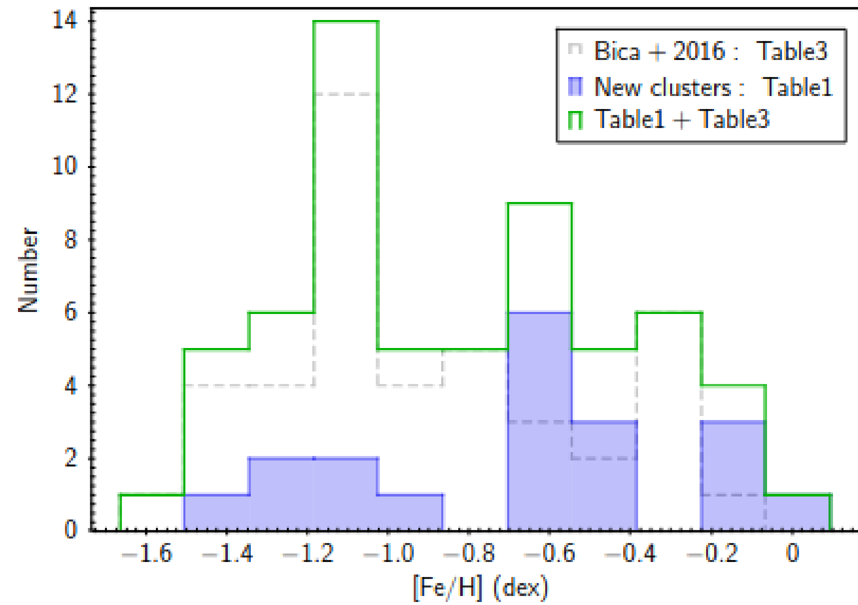
Bica, E., et al.: A&A, 687, A201 (2024)

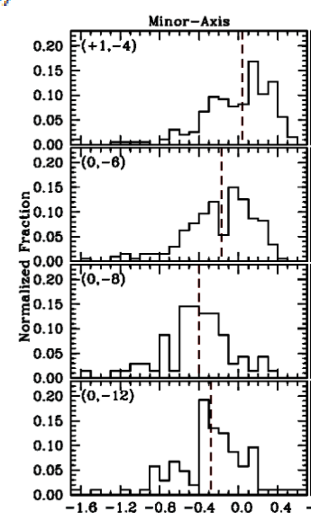


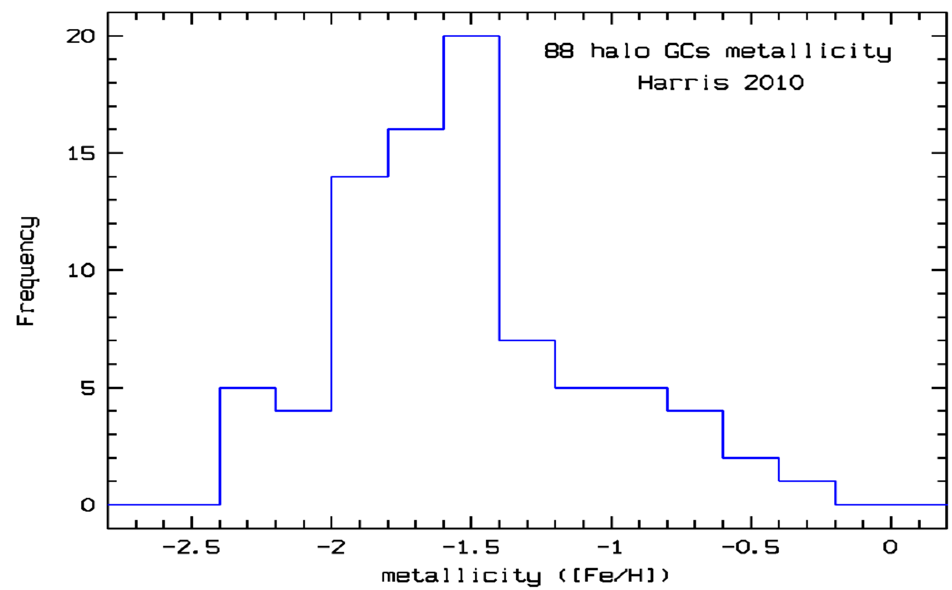
Absolute total magnitude of 22 “new” GCs, almost doubling the bulge clusters (Bica et al., 2024): no bright clusters are missing.

Halo Gcs metallicity from Harris et al., 2018, bulge field, Zoccali 2008

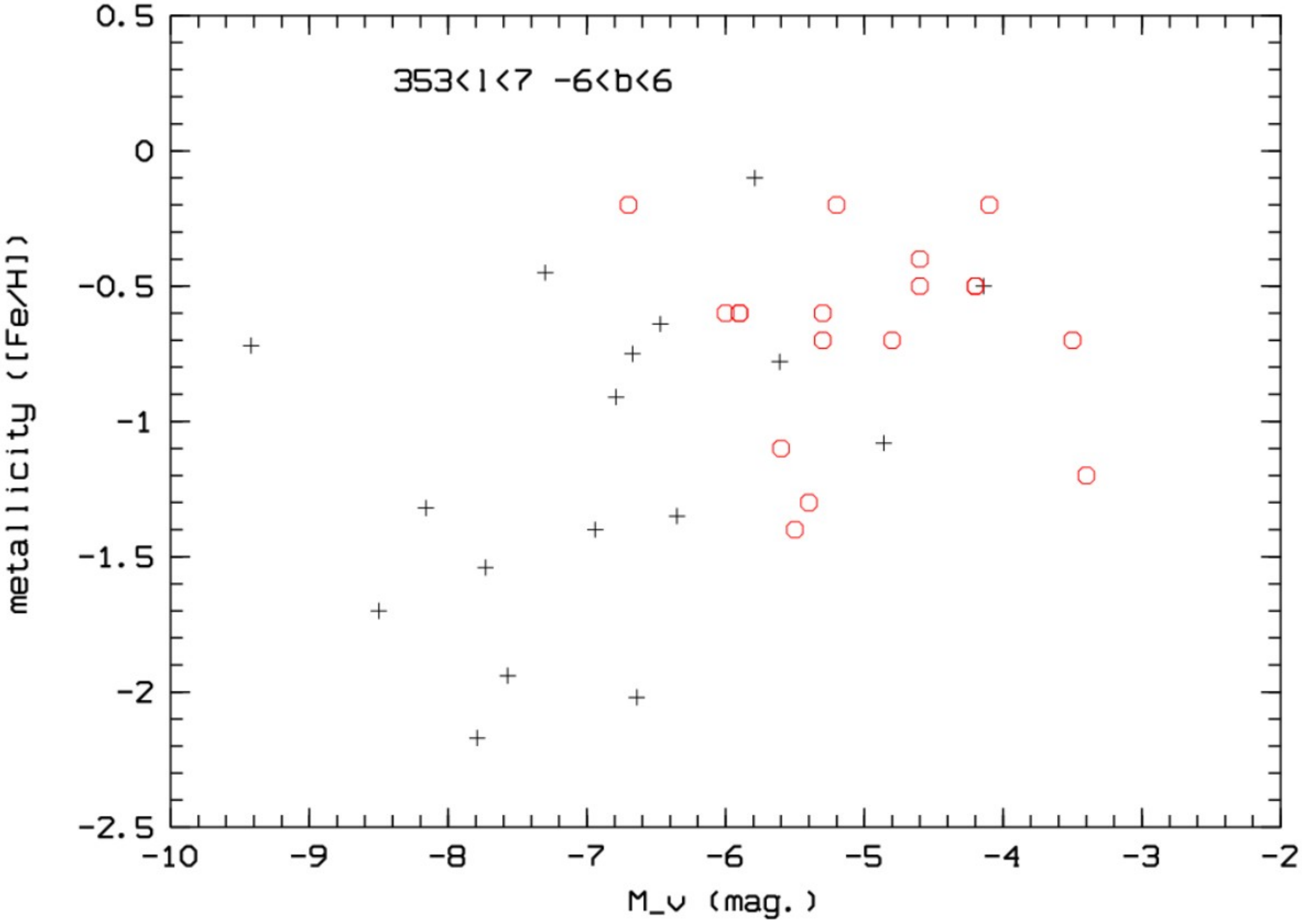




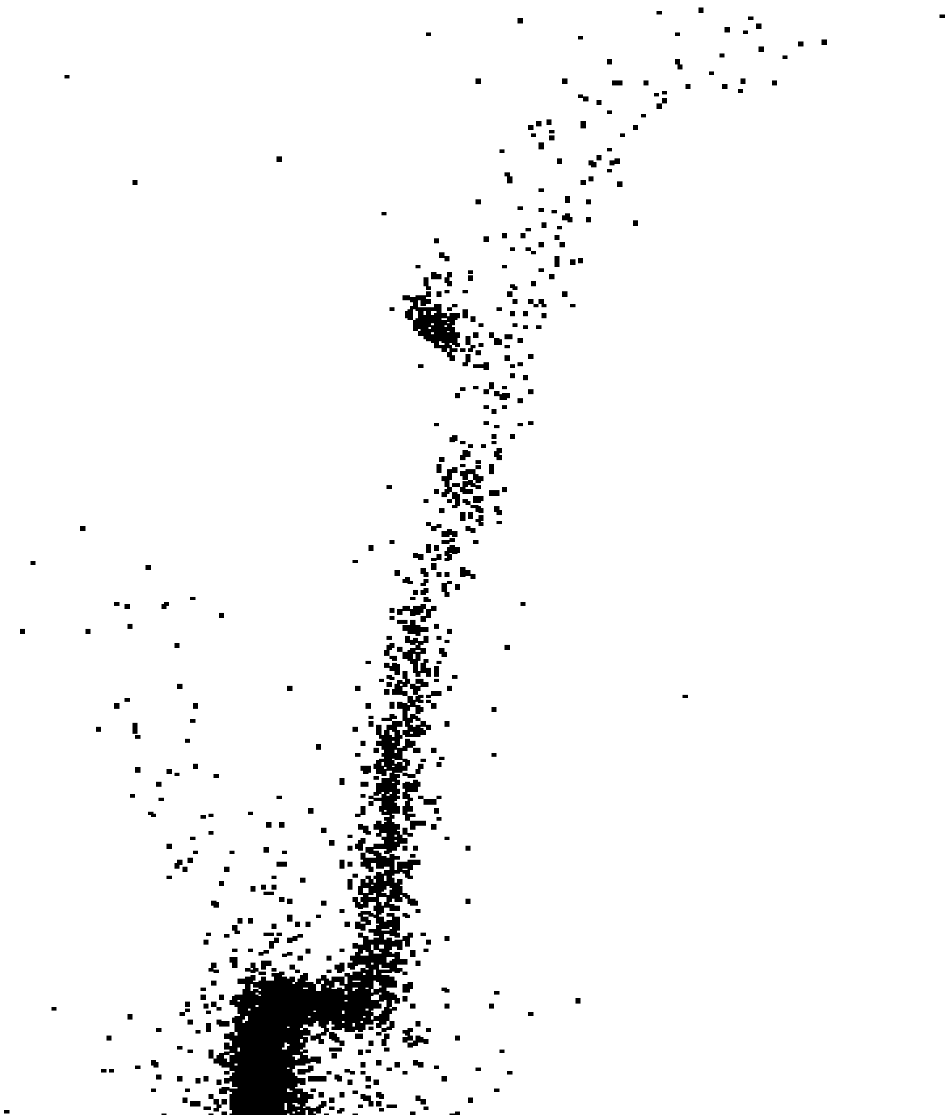




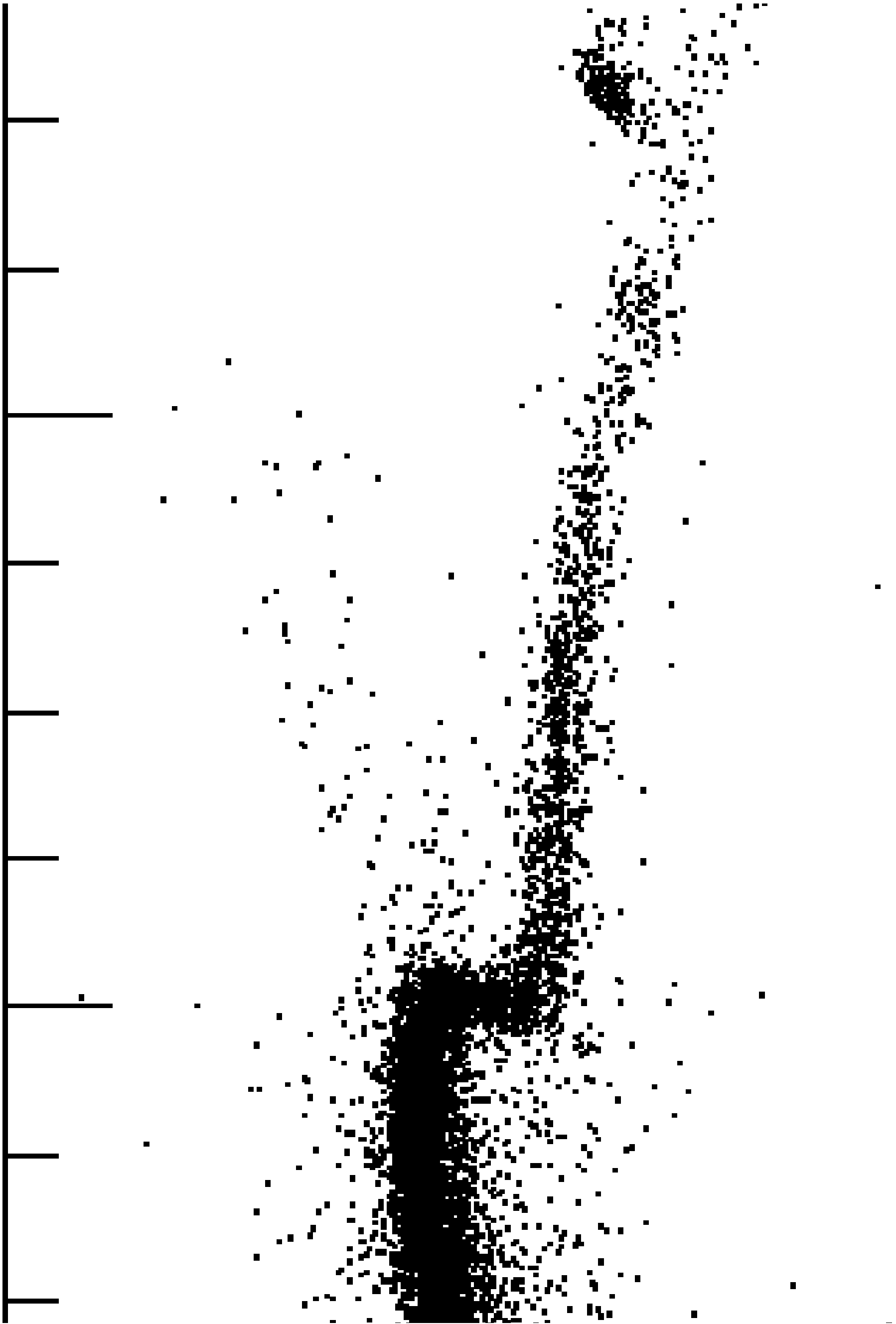
Metallicity-integrated magnitude relation ?

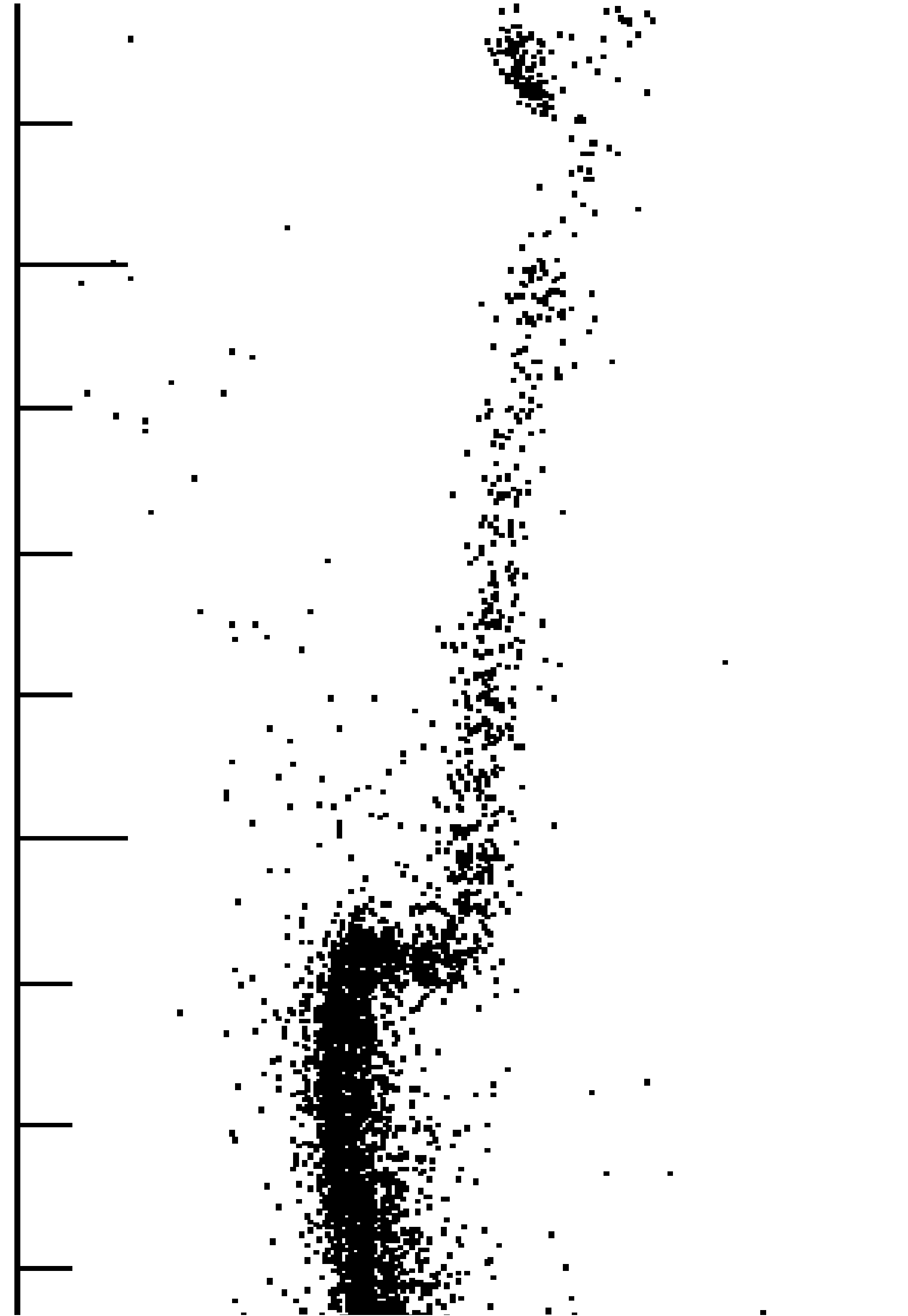


NGC 6553, differential reddening correction
(Data reduction from Nardiello)

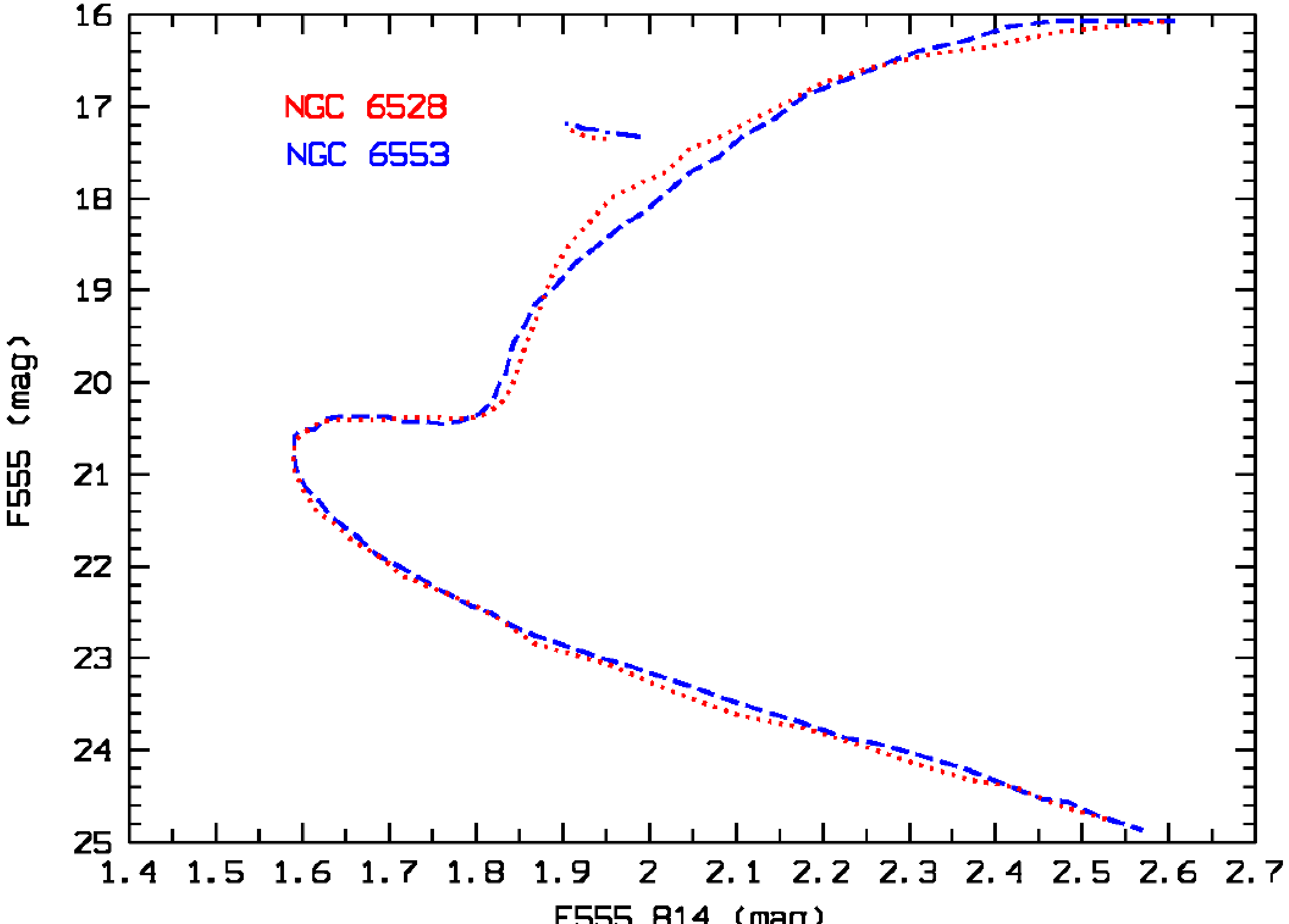


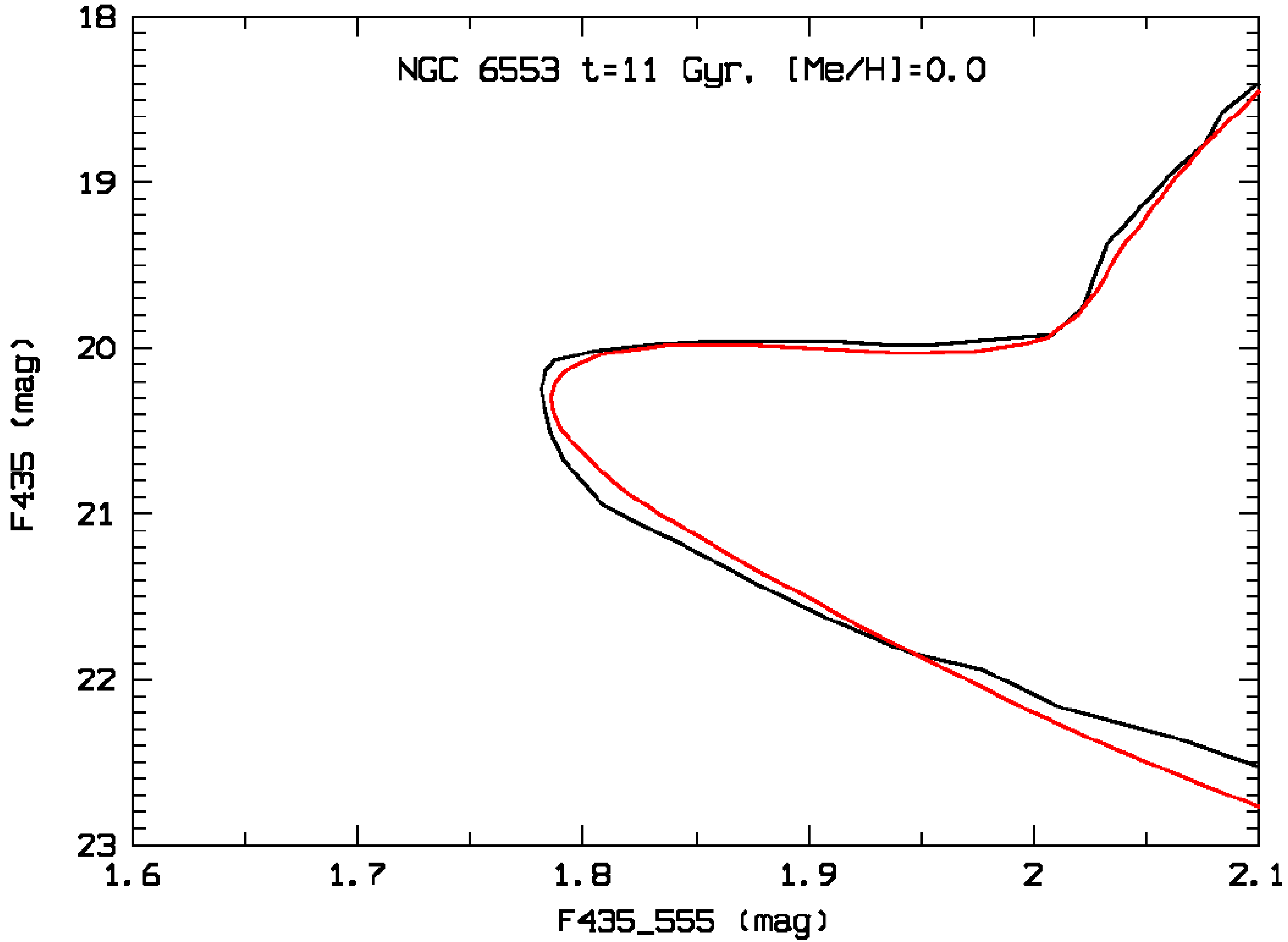
NGC 6553 and 6528 (from Nardiello)





NGC 6528 and 6553: twin clusters





NGC 6553 t=11 Gyr, [Me/H]=0.0
18
19
20
21
22
23
F435 (mag)
1.6
1.7
1.8
1.9
2
2.1
F435_555 (mag)

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The *Hubble Space Telescope* UV Legacy Survey of Galactic Globular Clusters. XX. Ages of single and multiple stellar populations in seven bulge globular clusters

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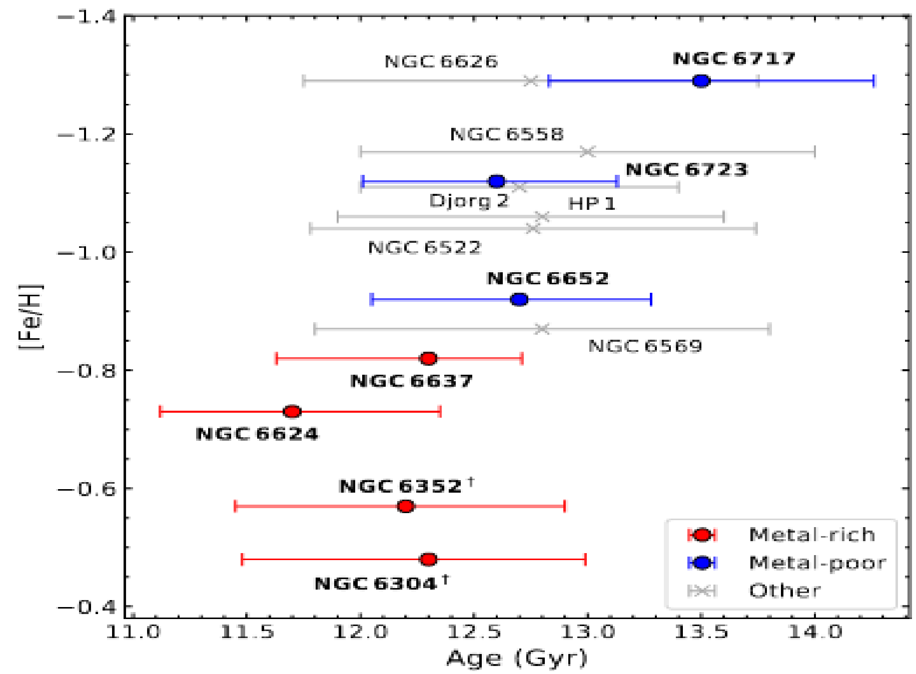


Figure 12. Distribution of the derived ages vs. metallicities in the range $-1.3 < [Fe/H] < -0.4$. The circles represent the seven sample bulge GCs (four moderately metal-rich in red and three moderately metal-poor in blue). The gray markers correspond to the other bulge GCs that have accurate age measurements in the literature: NGC 6626 and NGC 6522 (Kerber et al. 2018); NGC 6558 (Barbuy et al. 2018b); HP 1 (Kerber et al. 2019); NGC 6569 (Saracino et al. 2019); and Djorg 2 (Ortolani et al. 2019). Those marked with † correspond to $[\alpha/Fe] = +0.2$.

Plotnikova et al., 2024; Bonfanti et al., 2018: effect of atomic diffusion on ages

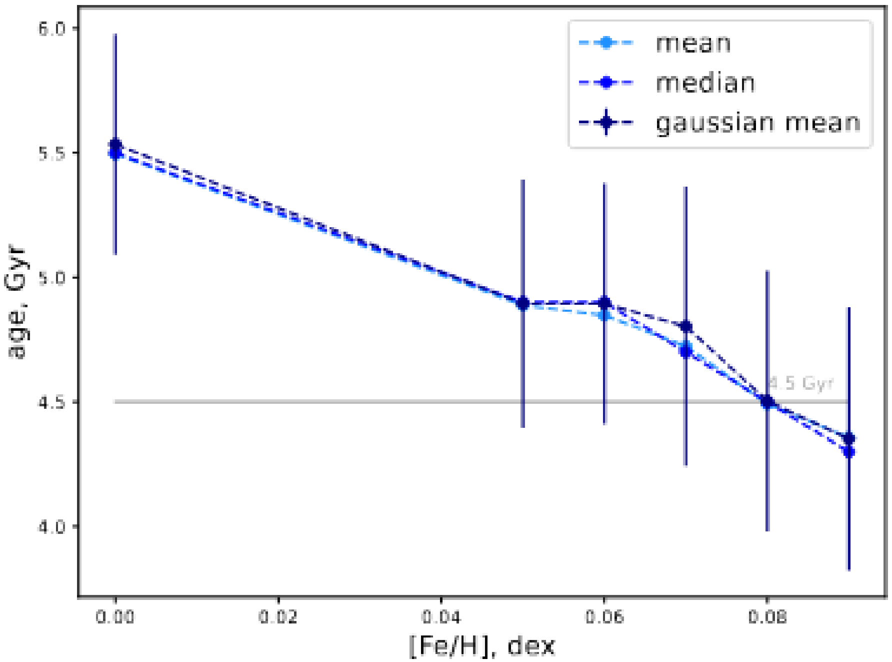


Fig. 2. Age of the Sun calculated for different values of metallicity to calibrate isochrones for the influence of atomic diffusion at the solar age. Light blue represents the mean values for the Sun's age, blue is the median, and dark blue is the Gaussian mean. The gray line is the most accurate estimate of the Sun's age Connelly et al. (2008); Amelin et al. (2010).

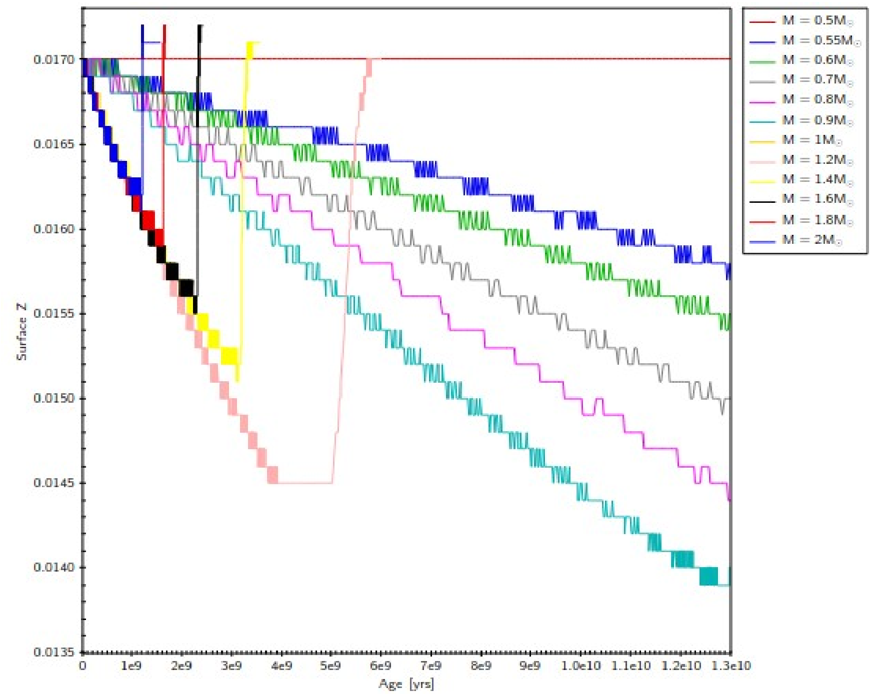
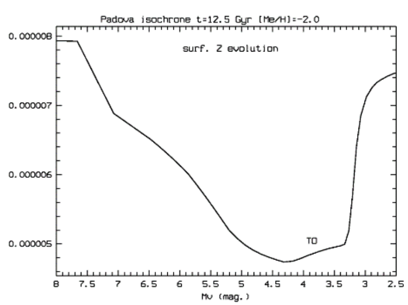
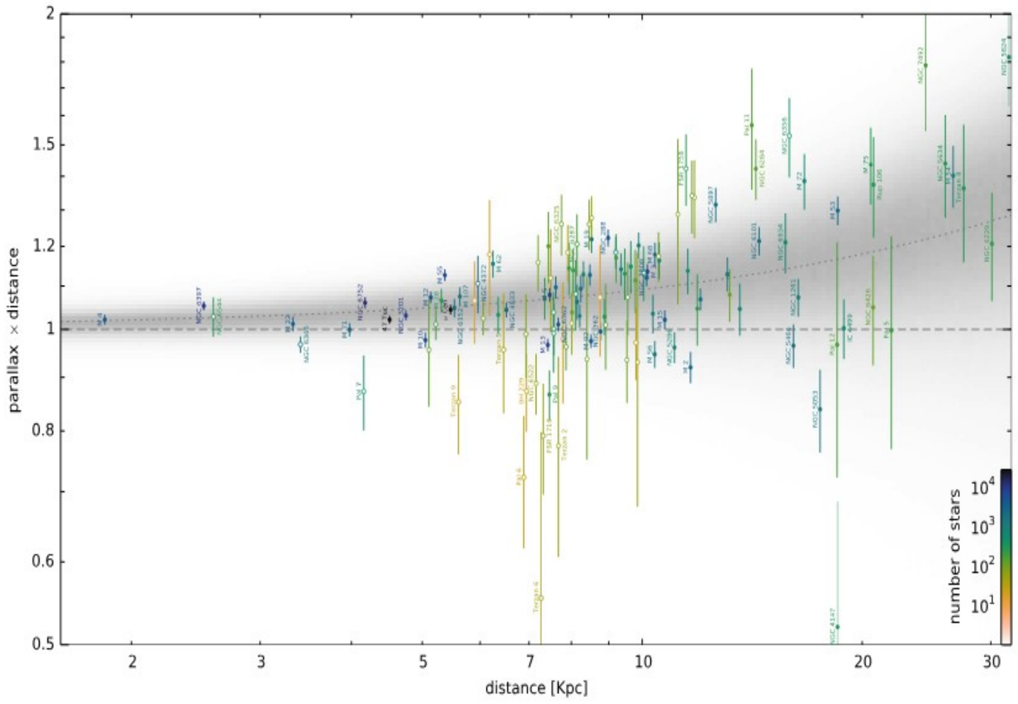
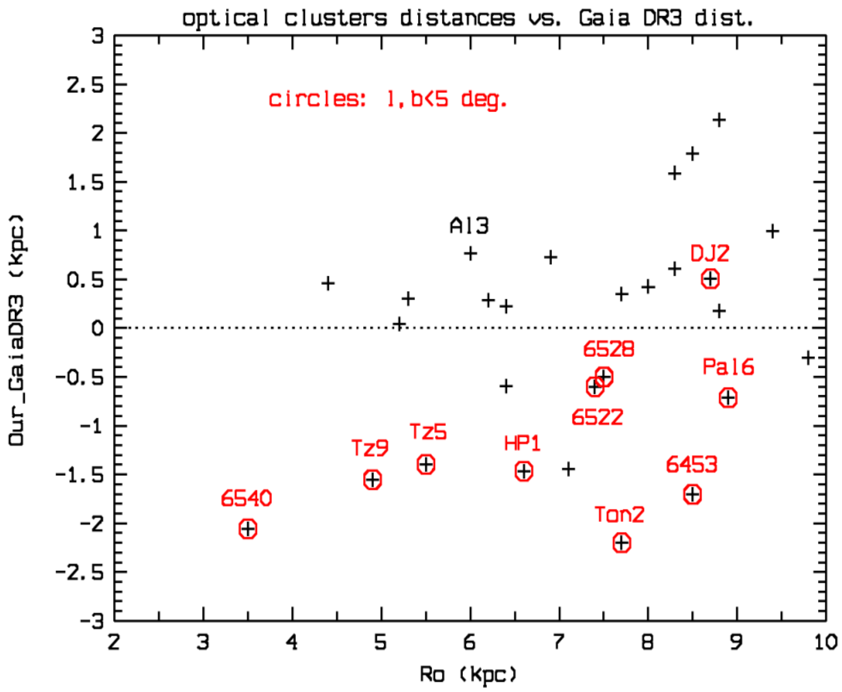


Fig. 3. Evolution with time of the surface metallicity Z for stars of different masses characterized by the same initial metallicity $Z_{\mathrm{ini}} = 0.017$. The ruggedness of the curves is due to the discrete steps in the model, and it has been smoothed while implementing our routines.

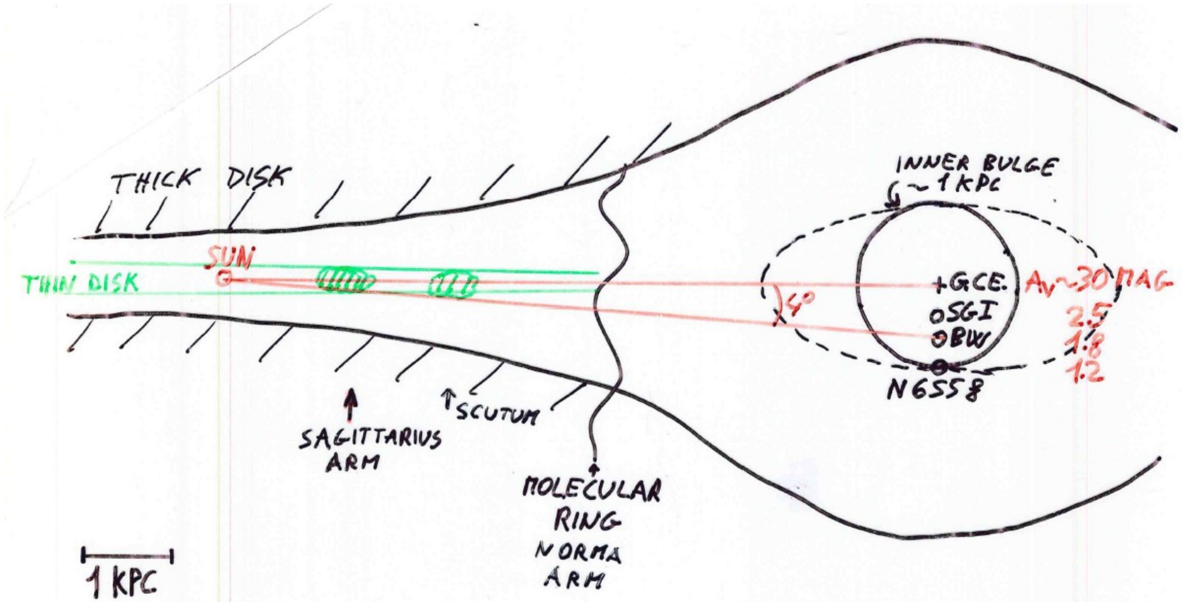


Distances ! 0.5-0.7 mag. distance modulus difference with respect to Gaia DR3, at 4<D<8 kpc
(left: from Vasiliev and Baumgardt, 2021)





Line of sights, and reddening in the direction of the Galactic Bulge (lower plot from Arp, 1965)



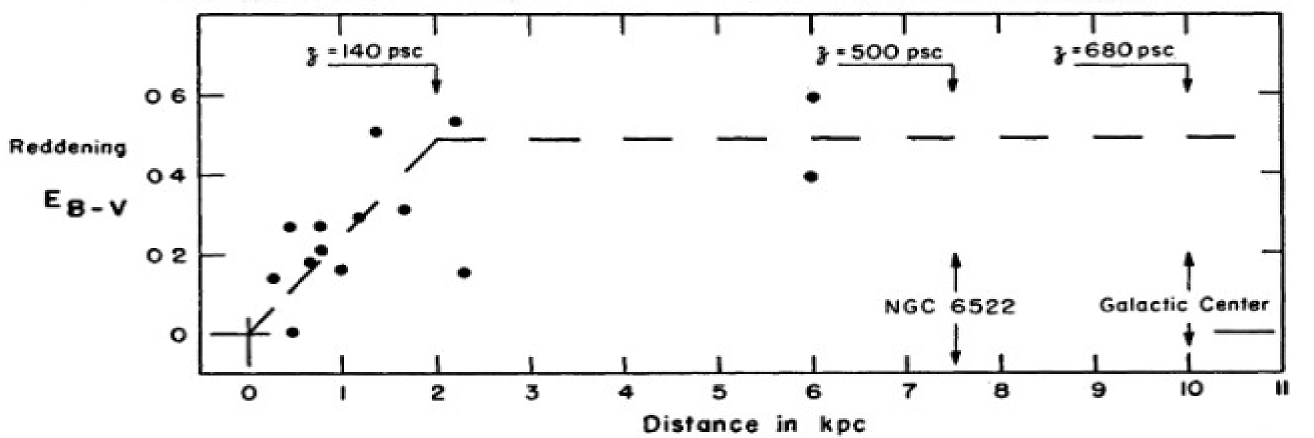


Fig. 2.—Correlation of reddening with distance in the direction of NGC 6522. Reddening values lerived from $U - B$, $B - V$ measures of field stars. Height above the galactic plane at various distances ılong the line of sight are marked z.

Thank you Beatriz and congratulations !