Mem. S.A.It. Vol. 80, 117

Memorie della

Mid-IR excess in the globular cluster 47 Tuc

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Abstract. Mid-infrared (MIR) Spitzer IRAC data of the 47 Tuc suggest the presence of stars, both of main sequence and evolved phases, that present a sizeable MIR color excess. The cross-correlation of MIR and optical catalogs suggest that the quoted MIR-color excess might be caused by dusty disks.

Key words. Stars: circumstellar matter – Stars: Population II – Galaxy: globular clusters

1. Introduction

The present data of 47 Tuc have been taken as part of our IRAC Guaranteed Observing Time (GTO) Program 623 on November 14, 2004 (AORID 7860992). We observed the cluster in all the four IRAC bands in High Dynamic Range (HDR) mode, combining exposures of 0.6 and 12 sec frames in each pointing position. The whole area of the cluster was covered with a map of ~22′× 26′, with a 13 points cycling dither pattern (medium scale size) in each map position. The total integration time for each sky position was of 135 sec or more. For the central part of the cluster are also available in the Spitzer Archive data taken on September 21, 2005 as part of the Cycle 2 General Observer Program 20298. These observations (AORID 14502656), covering a strip ~5′× 15′centered in the densest regions of 47 Tuc, were also executed by using the IRAC HDR mode 0.6 and 12 sec frames in all IRAC bands, but with a much larger numbers of dithers and repeats, for a total exposure of ∼ 940 sec or more on each sky position. A detailed description of the calibration and reduction procedures will be available in a forthcoming paper. The final catalog includes ∼ 42,000 with at least one measurement in two different MIR photometric bands. Ground-based multi-band (U, B, V, I) data were collected with different telescopes and several reduction strategies were used to perform the photometry. The number of images per band are $4U$, $76B$, $83V$, and $81I$ and cover a field of view of $\approx 20' \times 18'$ across the center of the cluster. These data have been calibrated into the standard Johnson-Cousins sys-

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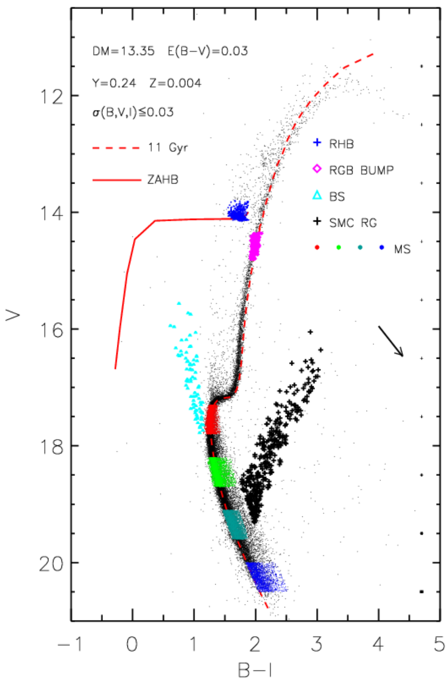

Fig. 1. V,B-I color-magnitude diagram of 47 Tuc. Stars belonging to different evolutionary phases have been marked with different symbols and colors. The red dashed line shows a cluster isochrone with Z=0.004 Y=0.238 and age of 11 Gyr. The red solid line shows the ZAHB for the same chemical composition. The black arrow shows the reddening vector, while the error bars on the right display intrinsic photometric errors.

tem using a large and homogenous set of local standard stars (Stetson 2000). The accuracy in the absolute zero-points is typically better than 0.02 mag. The final catalogue includes $\sim 173,000$ stars with at least one measurement in two different optical photometric bands. The observed ground-based and space photometric catalogues were re-scaled to a common geometrical system within ROMAFOT (Buonanno & Iannicola 1989).

2. Comparison between theory and observations

The theoretical models used in this paper have been computed with an updated version of the FRANEC evolutionary code which takes into account the element diffusion and up-to-date input physics (Cariulo et al. 2004). We adopted the bolometric corrections and color index by Bessell, Castelli & Plez (1998) for the optical bands, while for the IRAC ones we had to integrate the energy distribution from the homogeneous set of Atlas9 Kurucz atmospheric models (Castelli & Kurucz 2003) over the instrumental transmission curves from the Spitzer Science Center web site[1]. Fig. 1 shows the optical $V, B-I$ Color-Magnitude Diagram (CMD) of 47 Tuc, where we selected different evolutionary samples, with overimposed our theoretical isochrone of 11 Gyr Z=0.004 and Y=0.238. We adopted a distance modulus of $\mu_0 = 13.3 \pm 0.15$ and a reddening of $E(B-V) = 0.03 \pm 0.02$ (Zoccali et al. 2001; Percival et al. 2002; Gratton et al. 2003). Once the best isochrone has been chosen by fitting the data in the $V, B-I$ diagram, in order to compare theory and observations in the other passbands we applied suitable extinction coefficients by Cardelli et al. (1989) and Mathis (1990) (see the forthcoming paper for details). The analysis of the optical-MIR CMDs suggests the presence of a significant color-excess ($\Delta B - IRAC \sim 2$), when compared with their predicted distributions, in stars of MS and evolved evolutionary phases (red HB and RGB bump). Current evidence can hardly be caused by photometric errors. Stars plotted in the different optical-MIR CMDs were selected according to photometric accuracy (see labeled values). The adopted selection criteria imply that in the deepest CMDs we only plotted objects with at least ten σ $(B, B-[3.6])$, five σ $(B, B-[4.5])$ and four σ $(B, B-[8.0])$ detection limits above the background. This indicates that MSTO stars (red dots) present a MIR color excess that is as high as 2 mags. The compelling evidence that the color-excess among evolved and MS stars presents a very similar slope is suggesting that the excess cannot be

[1] http://ssc.spitzer.caltech.edu/

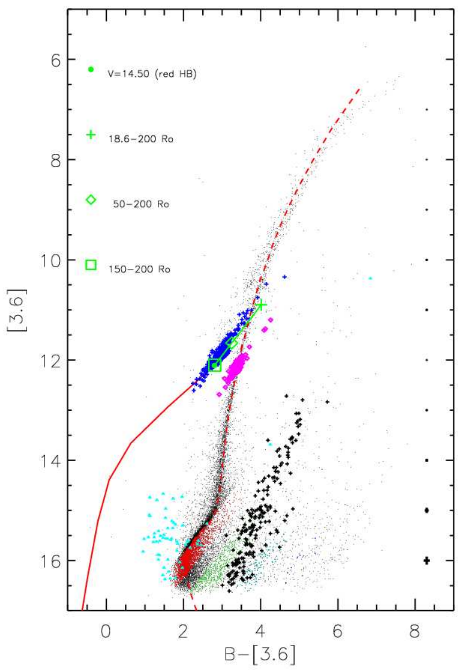

Fig. 2. [3.6],B-[3.6] CMD of 47 Tuc. Lines and symbols are the same as in fig. 1.

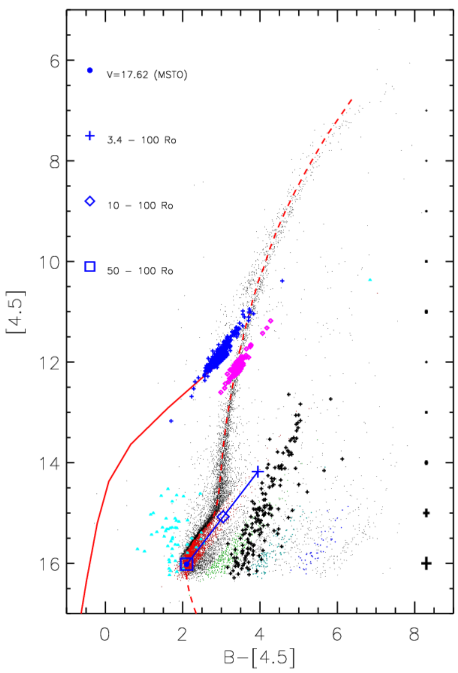

Fig. 3. [4.5],B-[4.5] CMD of 47 Tuc. Lines and symbols are the same as in fig. 1.

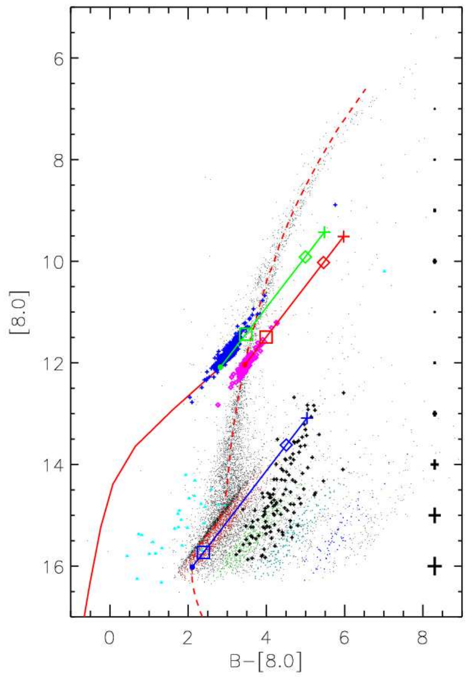

Fig. 4. [8],B-[8] CMD of 47 Tuc. Lines and symbols are the same as in fig. 1.

caused by systematic errors in the photometry, since the signal to noise ratio of the two samples is significantly different. Moreover, it is worth noting that the stars showing the color-excess are not centrally concentrated and their radial gradient is very similar to canonical cluster stars. The possible occurrence of differential reddening across the cluster does not account for this feature, since the reddening vector in these optical-MIR CMDs is horizontal. We checked that the observed MIR-color excess cannot be produced by binaries or photometric blends with cool stars, such as RG, VLMS stars or BDs. Moreover, the excess cannot be caused by blends with high redshift quasars. A possible source of the observed MIR-color excess might be the thermal radiation from circumstellar dust. This dust cannot be distributed in spherically symmetric envelopes, since it would be responsible to extinction in the optical bands. This is clearly the case for the mass losing stars with $B - I > 3.5$ and $V < 12.5$. On the other hands, geometrically thin circumstellar disks, or rings, of dust heated by the stellar radiation to a temperature of a few hundred K, are powerful sources of MIR radiation. Furthermore, this geometrical configuration would cause little or no extinction at optical wavelengths.

2.1. The disk hypothesis

In order to test the working hypothesis that the MIR-excess might be produced by circumstellar dusty disk, we computed the emission of systems composed by a star with a flat and passive opaque ring. For the model of the ring we followed the equations 1 and 3 by Jura (2003). We selected three different evolutionary phases: RGB Bump ($V = 14.12$, $B - I = 1.77$), TO ($V = 17.62$, $B - I = 1.33$) and red HB ($V = 14.50$, $B - I = 1.99$). On the basis of the fit with the cluster isochrone and the ZAHB we estimated for these model stars the mass, luminosity and effective temperature. Figures 2, 3 and 4 show the tracks of template stars with disks of different inner temperature in the IRAC-optical CMDs. The solid green line plotted in Fig. 2 shows the shift that the template HB star might undergo, in the [3.6], $B - [3.6]$ CMD, due to the presence of disks of different size. The large green symbols (plus, diamond, square) mark the magnitude excess caused by disks with the same outer edge and increasing inner edges (see labeled values). The closer the inner edge of the disk to the star, the larger the excess is. The disk with the largest inner radius produce only a marginal flux contribution, as the excess is peaked at longer wavelengths due to the lower temperature of the dust, farther away from the star. Disk models for MS and RGB bump stars are plotted in the B-[4.5] (fig.3). Finally, fig. 4 shows the models for all types of stars in the 8.0 vs. B-[8.0] CMD. Note that, regardless the spectral type of the adopted stellar structure, the slope of the disk models is the same. The MIR excess is produced without any appreciable extinction at visible wavelength, since the disks are geometrical thin. Within the disk hypothesis a single physical mechanism might account for the MIR magnitude excess of both evolved (red HB, RGB Bump) and MS TO stars, providing a natural explanation on why the magnitude excess is very similar when moving form the the [3.6]-band to the [8.0]-band.

3. Conclusions

Deep MIR-data taken by the Spitzer telescope, with IRAC, of the galactic GC 47 Tuc suggest a significant MIR color excess for main sequence and evolved stars. Furthermore, this MIR-color excess might be caused by dusty disks, as the cross-correlation of MIR and optical catalogs showed the lack of any extinction in the stars with MIR color excess.

References

Bessell, M. S., Castelli, F. & Plez, B., 1998, A&A, 333, 231
Buonanno, R., & Iannicola, G., 1989, PASP, 101, 294
Cardelli, J.A., Clayton, G.C., Mathis, J.S., 1989, ApJ, 345, 245
Cariulo, P., Degl'Innocenti S., & Castellani, V., 2004, A&A 421, 1121
Castelli, F., & Kurucz, R. L., 2003, in IAU Symp. 210, "Modelling of Stellar Atmospheres", ed. Piskunov N.E., Weiss W.W., Gray D.F. (San Francisco: ASP)
Gratton , R. et al., 2003, A&A, 408, 529
Jura, M., 2003, ApJ, 584, L91
Mathis, J. S., 1990, ARA&A 28, 37
Percival, S. M., Salaris, M., van Wyk, F., & Kilkenny, D., 2002, ApJ, 573, 174
Stetson, P. B., 2000, PASP, 112, 925
Zoccali, M. et al., 2001, ApJ, 553, 733