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AGE AND EXTINCTION OF THE ULTRAVIOLET EMITTING REGIONS IN M82

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RESUMEN

La galaxia M82 debido a su gran actividad de formación estelar y a su cercanía a la Vía Lactea ha sido objeto de múltiples estudios. Empleando imágenes de M82 que cubren diferentes bandas del espectro electromagnético, hemos logrado determinar la edad y extinción de la población estelar localizada en regiones con fuerte emisión ultravioleta (UV), estas regiones se encuentran en el núcleo y en el disco de M82. Además, usando las imágenes de la emisión UV de M82 y las propiedades de sus cúmulos estelares hemos cuantificado la contribución de éstos al flujo detectado en esta banda. Encontramos que en regiones nucleares la emisión UV es debida a los cúmulos estelares, mientras que en el disco su contribución disminuye a valores cercanos al 10%. Los resultados obtenidos nos han conducido a inferir que las estrellas de campo del disco de M82 pudieron haber sido parte de algún cúmulo estelar cuando nacieron.

ABSTRACT

The M82 galaxy has been the subject of several studies basically because it is relatively close to to the Milky Way and it displays a strong star formation activity. Using multi-band images of M82 we have determined the age and extinction of the stellar population located in regions with strong UV emission, these region are in the nucleus and the disk of M82. We also have employed the UV images of M82 and the physical properties of its stellar clusters to measure the contribution of the clusters to the detected UV flux. We found that clusters located in the nuclear regions are emitting all the observed UV flux, whereas clusters of the disk emit less than $\sim 10\%$. Based on the results obtained from this work we can infer that the field stars located in the disk of M82 could have been part of a stellar cluster when they were born.

Key Words: galaxies: star clusters — ultraviolet: general

1. INTRODUCTION

The ultraviolet (UV) range of the spectral energy distribution is a well known window to perform studies of several kinds of astrophysical phenomena, e.g. classifications of celestial sources (Bianchi et al. 2007), star formation (Rosa-González et al. 2007), galaxy evolution (Kaviraj et al. 2007), etc.

During the last five years, the *Galaxy Evolution Explorer* (GALEX) has been retrieving a wealth of information covering the UV interval. This observational data can be used to map recent bursts of star formation. It is commonly accepted that star clusters born embedded within giant molecular clouds (see Lada & Lada 2003, for a complete review), emit strongly in the UV, and form large HII regions. The star clusters experience several disrupting processes along their evolution which hinder our understanding of the role played by these objects in the galactic evolution (de Grijs & Parmentier 2007). The UV images of galaxies that contain a wide set of star clusters can be of great help in this direction.

M82 (NGC 3034) is an edge-on spiral galaxy classified recently with a morphological SBc type (Mayya et al. 2005). It is part of an interacting group of galaxies (Chynoweth et al. 2008) at a distance of 3.63 Mpc (Freedman et al. 1994). The interaction between M82 with the biggest member of the group (M81) about one gigayear ago brought an intense burst of star formation in the entire disk of M82 (Mayya et al. 2006). Images of M82 obtained by *GALEX* display regions with strong UV emission, which are distributed along the disk of the galaxy as well as in the perpendicular direction. Recently Hoopes et al. (2005) showed that the UV emission aligned with the minor axis is the stellar light scattered by dust, and gas which has been shock-heated. However, the UV flux detected along the disk is basically light emitted by field stars and star clusters. Mayya et al. (2008) detected 653 star clusters distributed along the disk of M82, some of which are massive star clusters ($\geq 10^5\ M_\odot$). It is possible that at least some of the observed disk UV emission is produced by these star clusters.

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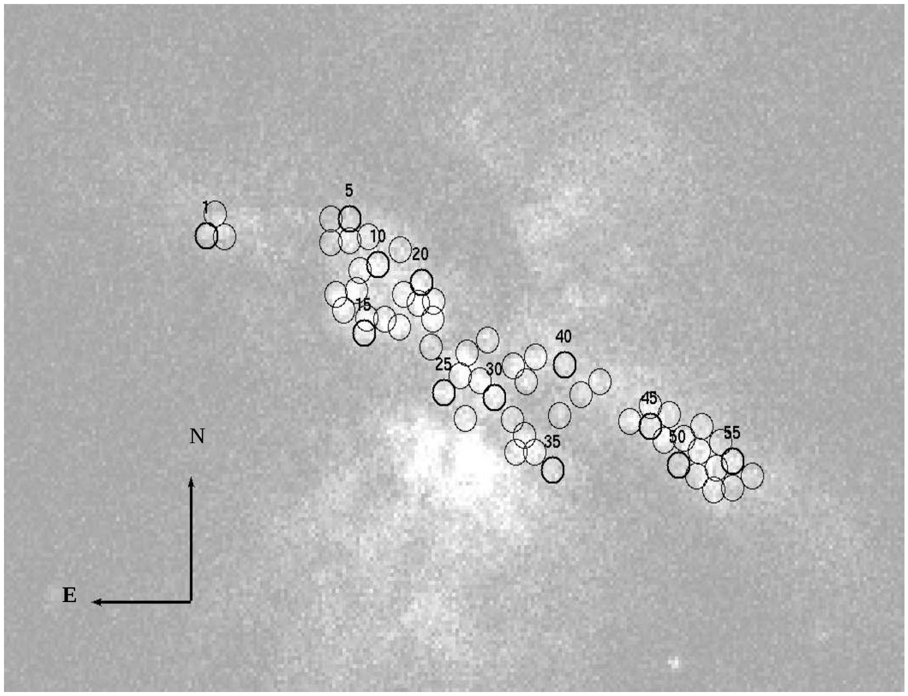

Fig. 1. This figure displays the position of the 59 apertures defined to study the flux emitted by the nucleus and the disk of M82. Labels correspond to remarked circles.

We use the multi-wavelength data available to investigate the nature of the UV emitting regions located in M82. We also estimate the contribution of the star clusters to the UV emission of M82. In § 2 we describe the observational data used. In § 3 we show the results of the multi-wavelength study to trace the age and extinction of the most bright regions detected in the far ultraviolet (far-UV) image , and in section § 4 we discuss the fraction contribution of the star clusters to the observed UV emission. Finally, we give our conclusions in § 5.

2. CONSTRUCTION OF SPECTRAL ENERGY DISTRIBUTIONS

The data used cover a wide wavelength interval, from the far-UV to the near infrared (near-IR). The UV images used in this work are from *GALEX* archive and cover the far-UV (1350–1750 Å) and near-UV (1750–2750 Å) bands. The optical images were obtained from different projects. The image in the U band (3000–4100 Å) was retrieved from the database of the *Sloan Digital Sky Survey* (SDSS), whereas the HST/ACS data in the F435, F555 and F814 bands were used as B, V and I images. For the near infrared data, we used the J, H and K images obtained with the *Cananea Near-Infrared Camera* (CANICA) attached to the 2.1 m telescope at *Observatorio Astronómico Guillermo Haro* (OAGH).

The disk of M82 presents large areas with strong UV emission whose nature is yet to be understood. We used the far-UV image to define 59 circular apertures distributed along the disk. Each aperture is of $5''$ diameter, matching the full width half maximum (FWHM) of the point spread function (PSF) of the *GALEX*'s detector. The selected regions enclose all the areas with strong far-UV emission. We point out that some of the bright complexes have several apertures associated with it. Figure 1 displays the positions of the apertures chosen. Aperture numbers between 24–32 and 36–39 correspond to the nuclear starburst.

The zero-points associated with each image were used to convert counts to fluxes in order to construct the spectral energy distribution (SED) of the 59 apertures.

3. DETERMINATION OF AGE AND EXTINCTION

The method used to estimate the age and extinction of the stellar population inside each aperture is described below:

• Theoretical SEDs of simple stellar population (SSP) computed by the Padova Group[3] were employed in this work. The set of theoretical SEDs covers an age interval from 1 Myr to 1 Gyr with variable

[3]Kindly provided by A. Bressan.

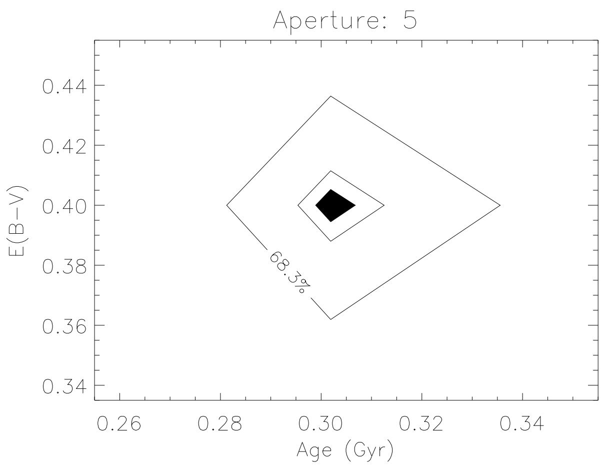

Fig. 2. The figure displays the results of the χ^2 process used to determine the age and extinction of the stellar population inside the aperture 5. The contour lines enclose age and extinction values of fits with 68, 90, and 95% of confidence level.

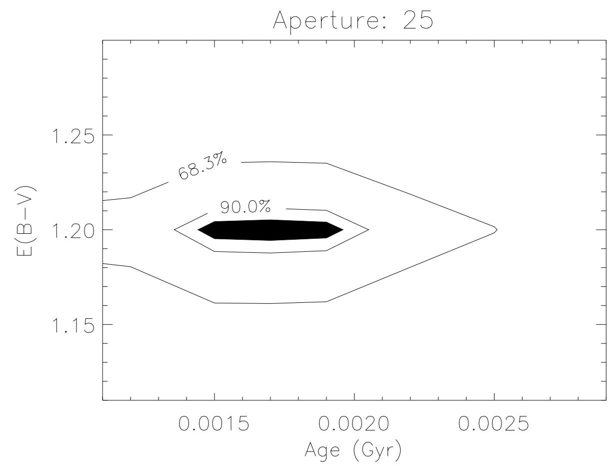

Fig. 3. Similar to Figure 2, but for aperture 25.

age step. Models with solar metallicity were used. These models use Kroupa's IMF (Kroupa 1998). The flux inside each photometric band was synthesized by integrating the SED over the response curve of the corresponding bands.

• Each SED was reddened using Calzetti et al. (2000) extinction curves with a color excess, $E(B-V)$, running from 0.0 to 2.0 mag, with steps of 0.1 mag.

• For each aperture a χ^2-type method was used to find the best fit between observed and reddened theoretical SED. The function used to find the best fit was,

$$\chi^2 = \sum_i (\frac{\text{flux}_i^{\text{obs}} - \text{flux}_i^{\text{mdl}}}{\sigma_i^{\text{obs}}})^2 \,, \qquad (1)$$

where i= far-UV,..., H, K. σ_i^{obs} is the uncertainty of observed flux in the i band. The function χ^2 will have the lowest value (χ^2_{min}) for the best match. Currently, we are exploring another method to infer the stellar population properties and its errors.

A typical problem related with the determination of stellar parameters using SEDs of stellar population is the age-extinction-metallicity degeneracy (Worthey 1994). However there are several works pointing out that the use of data covering a wide wavelength interval is useful to overcome these problems (Bridzius et al. 2009).

We fitted the observed SEDs of all the 59 apertures with SSPs of different age and extinction. Because there are more than one SSP that reasonably fits an observed SED, we selected not only the best fit model, but also all those SSPs with $\chi^2 \leq 5\chi^2_{\text{min}}$, corresponding to fits at 95% confidence level. In Figures 2 and 3, we display the results for apertures 5 and 25 (see Figure 1). The black area corresponds to models at 95% confidence level. The SED produced by the stellar population inside the aperture 5 is best fitted with an SSP model of 300 Myr old, with a reddening of $E(B-V) = 0.4$, and the stellar population inside the aperture 25 is best fitted with an SSP model of 1.7 Myr old, with a reddening of $E(B-V) = 1.2$. The resulting model SEDs are displayed superposed on the observed data in Figures 4 and 5, respectively. Filled circles correspond to observed data, circles and continuous line to theoretical model of the best fit. Fluxes were normalized to the flux in the V band.

In order to illustrate that the derived age and extinction are not affected by degeneracy we have also overplotted the theoretical SED of an SSP for a young population (10 Myr) in Figure 4, and relatively older population (500 Myr) in Figure 5, in both cases SEDs being reddened with an absorption of $A_v = 1.0$, 3.0 and 5.0. It can be seen that in the case of a young population (e.g. region 25), the observed SED is not well fitted over the entire range of wavelengths with any less reddened model of an old population and the SED of an old population (e.g. region 5) is not fitted by a heavily reddened model of a young population.

Following the method just described, we have determined the age and extinction of the stellar population inside each aperture. Figure 6 shows the trend followed by the age as a function of the distance to the galactic center. It is easily noticeable that all the

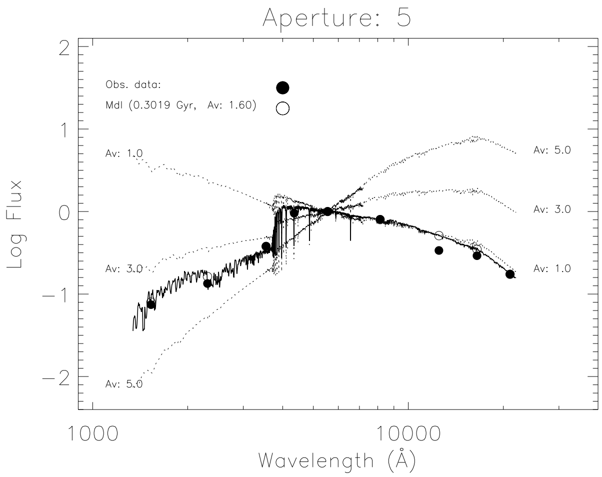

Fig. 4. The figure displays the fit between the observed spectral energy distribution of aperture 5 and the theoretical SED of an SSP model 300 Myr old, reddened with $A_v = 1.6$. A theoretical SED of 10 Myr, reddened with different values of A_v is overplotted (dotted lines) to show that the age-extinction degeneracy is broken with the use of a wide interval in wavelength.

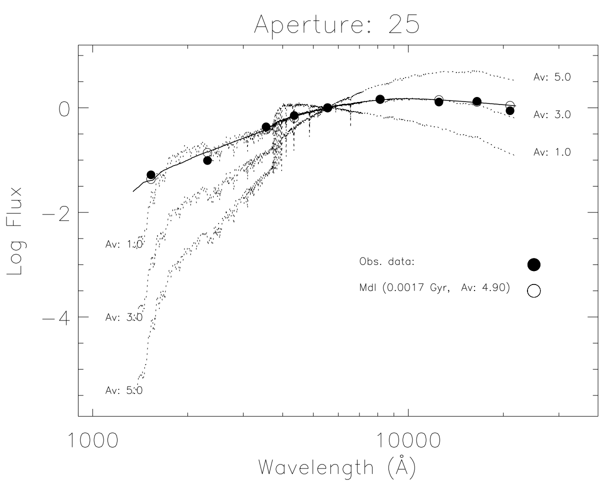

Fig. 5. The figure displays the fit between the observed spectral energy distribution of aperture 25 and the theoretical SED of an SSP model 1.7 Myr old, reddened with $A_v = 4.9$. A theoretical SED of 500 Myr, reddened with different values of A_v is overplotted (dotted lines).

populations younger than 60 Myr are located within a distance of 450 pc from the galactic center. Outside this zone stellar populations are older than 100 Myrs, with the oldest UV emitting populations having ages of around 400 Myrs. In the zone between 0.5–1.5 Kpc there is an evidence of an age gradient. Figure 7 displays the trend of the extinction with the galactocentric radius. In the nuclear area the A_v

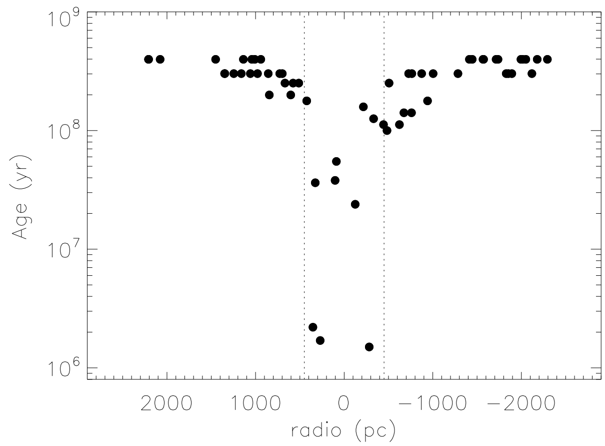

Fig. 6. The figure shows the age of the stellar population in function of the distance to the galactic center. Positive distances correspond to the north east (NE) and negative distances correspond to the south west (SW). Vertical dotted lines indicates the nuclear area.

reaches values of ~ 5.0 mag, decreasing smoothly at larger galactocentric distances.

It is important to stress that we are obtaining age and extinction for the stellar population within 59 apertures located in the disk and nuclear parts of M82 using only the photometric data. We were able of constrain the values of both the parameters within a small range. Our results are in agreement with the results obtained in previous works based on age and extinction sensitive spectroscopic features for the disk (Mayya et al. 2006) and nucleus (Förster Schreiber et al. 2001).

4. UV EMISSION BY STAR CLUSTERS

From the analysis of the previous section, it is clear that the UV flux observed by *GALEX* in the disk of M82 is contributed entirely from stars. In particular, in this galaxy it has been demonstrated that the disk contains rich population of compact star clusters (Mayya et al. 2008). So, one of the interesting questions is to investigate whether the observed UV emission comes from star clusters or field stars. In order to investigate this we have estimated the expected UV fluxes from all the clusters within apertures defined in this work. Typically, the disk apertures contain less than 10 clusters, whereas nuclear apertures contain more than 10, with the aperture 28 containing as much as 80 clusters. We calculated the SED of each cluster based on the mass, age, and extinction estimated for each stellar cluster. The UV flux in the two *GALEX* bands of these SEDs along with the positions of the stellar clusters were used to construct two images at the pixel scale

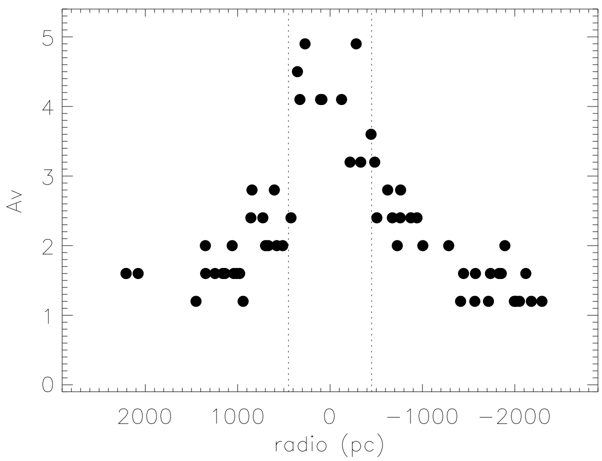

Fig. 7. The figure shows the extinction in function of the distance to the galactic center. The central part of the galaxy is more extincted. Positive distances correspond to NE and negative distances correspond to SW. Vertical dotted lines indicates the nuclear area.

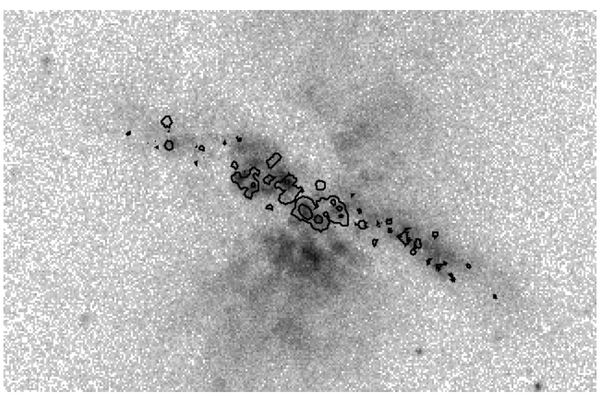

Fig. 8. This figure displays the far-UV image of M82 obtained by *GALEX*, contour lines overplotted correspond to the far-UV synthetic image. The theoretical image was produced with the physical properties of the stellar clusters and the simple stellar populations models.

of the *ACS* camera. The high resolution images were convolved with a Gaussian kernel of $\sim 5''$ of FWHM and rebined to match the image scale of the *GALEX* images.

Figure 8 displays the far-UV image obtained by *GALEX* in which we have overplotted in contours the synthesized image representing the UV contribution of the star clusters only. The simulated image in general reproduces the observed large-scale structure in the image. However, on the scale of a few parsecs especially in the disk, there are large differences between the two images, i.e. there are regions with bright observed emission with negligible contribution

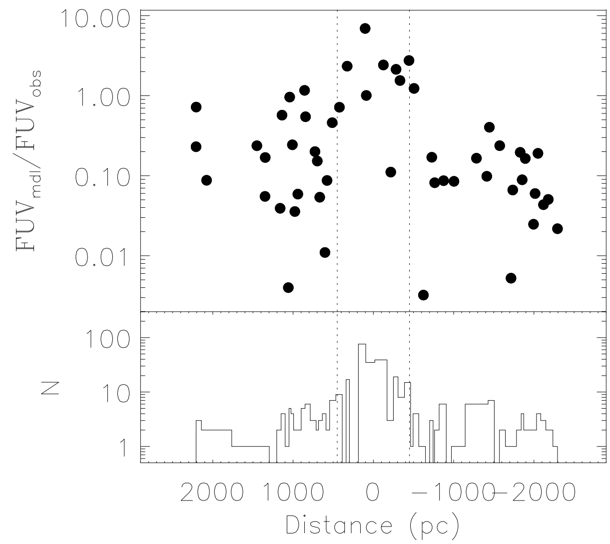

Fig. 9. The figure displays the comparison between modeled and observed far-UV fluxes as a function to the galactocentric distance. The upper plot shows the ratio between modeled to observed flux, each point corresponds to an aperture, and the lower plot shows the number of star cluster inside the aperture. Positive distances correspond to NE and negative distances correspond to SW. The vertical dotted lines mark the nuclear region.

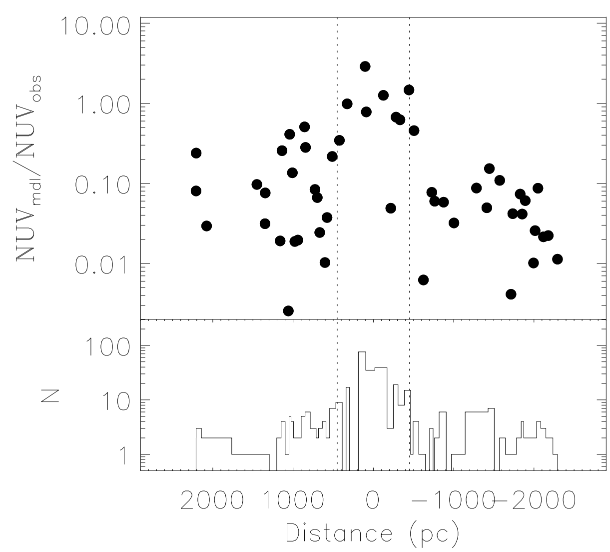

Fig. 10. Similar to Figure 9, but for the near-UV band.

from the clusters. Similar results were obtained for the image in the near-UV band. This could mean that in some regions of the galaxy the field stars are the most important sources of ultraviolet flux.

Since the modeled UV flux using only the star cluster properties, does not reproduce all the UV flux of the disk detected by *GALEX*, it is interesting to estimate the percentage of ultraviolet flux emitted by the clusters in all the 59 apertures. Figures 9 and 10 display in the upper plots the comparison between modeled and observed UV fluxes in the selected apertures. The lower plots show the number of star clusters inside each aperture. The two dotted-vertical lines enclose all the nuclear regions.

It can be seen that the observed UV flux of majority of the nuclear apertures can be completely reproduced by the star clusters, whereas typically only around 10% of the observed emission for the disk apertures can be attributed to the clusters. These results show that field stars, not clusters, are the principal contributers to the observed UV flux outside the nuclear area.

Meurer et al. (1995), working with the *HST* UV images of nine starburst galaxies with several bright star clusters, found that 20% of the total UV luminosity is emitted by the clusters. It may be noted that in our work we separate the UV contribution of stellar clusters based on their ages. This is uniquely possible in M82 because of the spacial segregation of extinguished young clusters from the not so reddened old clusters. Our result that the contribution to the observed UV emission from super star clusters (SSCs) is 100% when young and decreases to $\sim$10% when they are around 10^8 yrs may imply that the clusters in the sample of Meurer are on average of intermediate ages. This illustrates the danger of obtaining physical parameters for a sample of clusters with a wide distribution of ages.

5. CONCLUSIONS

We have carried out an analysis of the ultraviolet emission of the nucleus and the disk of M82. For this, we used the SEDs covering the far ultraviolet to the near infrared bands in 59 apertures of $5''$ diameter.

Using the physical parameters of the star clusters located in M82 and theoretical models of simple stellar population, we have estimated the contribution of the star clusters to the UV flux detected along the disk of the galaxy. We demonstrate that the star clusters located in the nuclear area produce almost all the UV flux, while in the disk the contribution of the star clusters is less than 10%. Given the fact that star clusters in the nuclear regions are young ($\sim$10 Myrs) and in the disk are relatively older, the observed differences in the relative contribution (100% in nucleus vs 1–10% in the disk) imply that the cluster contribution to the observed UV flux decreases with age. Most of the UV emission from the disk comes from intermediate age field stars and not clusters. The synthesized UV image obtained from the parameters of the disk clusters resembles the observed image on kiloparsec scales, but not on scales of less than 100 parsecs. This, along with the fact that the observed UV emission comes from the disk stars suggests that these stars were once part of the clusters, and are now dissolved.

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