Bulgarian Chemical Communications, Volume 47, Special Issue B (pp. 364–367) 2015

Extinction and massive stellar population in Andromeda galaxy

P. L. Nedialkov*

Department of Astronomy, Faculty of Physics, St. Kliment Ohridski University of Sofia, 5 James Bourchier Blvd., BG-1164 Sofia, Bulgaria

We probed to derive a new information on the massive star population and the extinction in the disc of Andormeda galaxy from a ground based *UBV* stellar photometry. Classical dereddening procedure was applied to evaluate both the extinction of starlight caused by the dust and the intrinsic properties (luminosity, color) of stars themselves. Thus, we were able draw conclusions about the spatial distribution of the dust, and – with the use of isocrones – to estimate the age of each successfully dereddened star. The last parameter allowed us to perform a search for sites of coherent star fomation on different time and size scales. We paid a special attention to the spiral arm S4 where we confirm that evidences exist in support to the density wave theory. Some hidden star formation may be detectable with the available catalog data along the lanes of highest concentration of dust and gas.

Key words: spiral galaxies, interstellar medium in external galaxies, stellar content and populations, spiral arms, stellar characteristics and properties

INTRODUCTION

Due to its large angular extend on the sky the spiral galaxy Andormeda (hereafter M31) is not an easy target for complete surveys and photometry of individual stars. Even nowadays when HST is equipped with the wide field WFPC3 and ACS detectors only 1/3 of disc will be covered by a survey like PHAT [2]. When it comes to ground based telescopes, *UBV* photometry is crucial for deriving the intertwined extinction and physical characteristics of massive stars. In this paper we used the *UBVRI* catalog of [1], containing about two hundred thousands of stars with that appropriate photometry.

DATA REDUCTION

We started with the construction of the classical two-color diagram in terms of $(U-B)$ vs. $(B-V)$ colors. Dereddening was performed by the means of constant slope κ of the reddening vector, equal to 0.72 and total-to-selective- extinction ratio $A_U/E_{B-V} = 4.85$ [3]. These commonly accepted parameters are typical for the diffuse component of the ISM of Milky way rather than for the dense clouds in which some newborn stars could be found. Adopting of the above values is only a first step approximation allowing us to acquire physically meaningful extinction, luminosity, true color and age to some of stars. On the other hand, the usage of these values simply means that we expect the extinction by the diffuse ISM to predominate the extinction by the dense ISM which is reasonable for a highly inclined system as M31 disk. All stars with normal Q-index earlier than B6V (AOIa) were slide backward to the zero reddening line for the main sequence stars and their true color and absolute magnitude were calculated.

Later on we put them of color magnitude-diagram to figure out whether they belong to the main sequence or they are blue supergiants candidates. The Hertzsprung-Russell diagram (see Fig. 1) was constructed using the synthetic *UBV* photometry from the Database of Geneva stellar evolution tracks and isochrones [4] based on the grids of 5 to 120 $M_\odot$ tracks of Geneva's stellar evolution models for solar initial composition and standard mass loss of $M_{dot} = 10^{-6} M_\odot/yr$ and corresponding 46 isochrones with ages in the range of 10^3 yr to 10^8 yr in time steps of $\Delta\log t = 0.05$ dex. We have excluded of further consideration both stars with negative extinction on two color diagram or bluer than the left end of the main sequence (zero age curve). Since the fraction of ground-based sources that turned out to be multiple sources in HST is qute high [2] we also put a conservative limit for the absolute magnitude $M_U > -10$ mag. The right end of the main sequence was defined as a curve that connects the turn off points of all the tracks within the studied mass range. The stars falling between these two curves and between the tracks of the most massive and the lowest mass star are actually the main sequence candidates which will be hereafter called dwarfs for simplicity. Finally we have $\sim 34\,000$ dwarf candidates and $\sim 45\,000$ blue supergiants candidates in total area of 8 170 $\Box'$ of the M31 disc.

* To whom all correspondence should be sent:
japet@phys.uni-sofia.bg

© 2015 Bulgarian Academy of Sciences, Union of Chemists in Bulgaria

Since [1] did not provide additional photometry useful for estimation of the foreground contamination we selected several fields with a total area of 522 $\square'$ in the outskirts of M31 disc well beyond the standard isophote at $\mu_B = 25^m/\square''$ and as far as possible – away from the major axis. Thus we compare a photometry of the same quality and origin but the contamination estimates should be taken as upper limits because some star formation could be presented even at these remote places. Taking into account the area correction the corresponding percentage of the expected foreground contamination is 2.5% for the dwarfs sample and 9.7 % for the blue supegians candidates sample.

Following error propagation technique we calculated the error of the derived physical quantities for each successfully dereddened star. In the case of extinction, luminosity and true color its application is straightforward. The acquried age is the mean of ages of all isochrones weighted by the inverse square of the ratio of two distances measured on HRD. The first one is the distance star-isochrone, and the second is 1σ radius of the ellipse of errors towards each isochrone. The error of the age is just the weighted standard deviation from the weighed mean.

RESULTS AND DISCUSSION

A preliminary analysis of the intial mass function (IMF) which is based on counts of stars between the evolutionary tracks like those on Fig. 1 showed that one could relay on sample of M31 massive dwarfs which is completed down to 20 $M_\odot$. Moreover, the obtained slope of the IMF $\Gamma = -1.5 \pm 0.1$ is close to the empirical Salpeter slope [5] and to the theoretical slope [6]. Practically, it coincides with the result of [7] where some high resolution HST data was also involved.

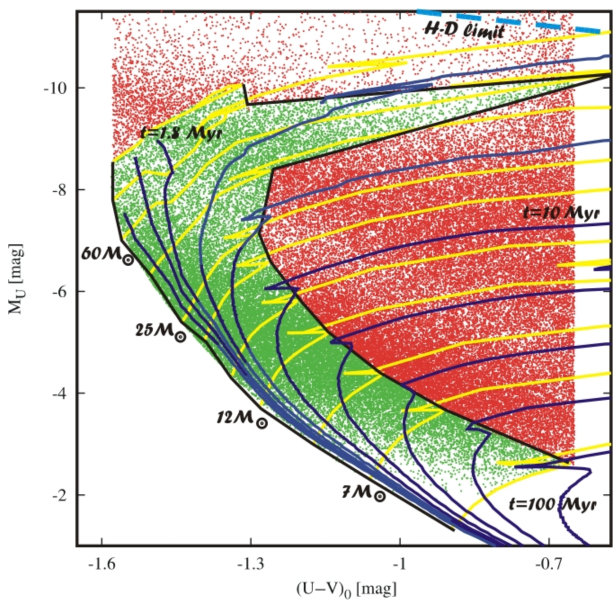

Fig. 1. Hertzsprung-Russell diagram for the massive stellar population in M31 galaxy. Stellar tracks of different initial masses (yellow solid lines) and isochrones (violet solid lines) of different ages are indicated on the plot. Stars between the two black solid lines and the stellar tracks of the most massive star and less massive star are Main sequence stars, which spent the bulk of their life burning hydrogen in their cores. The empirical edge where stars become unstable or Humphrey-Davidson limit is plotted (blue dashed line) on the right upper corner.

We consider the azymuthally averaged distribution of the mean extinction. It is expected in a magnitude limited sample as ours the Malquist bias to be

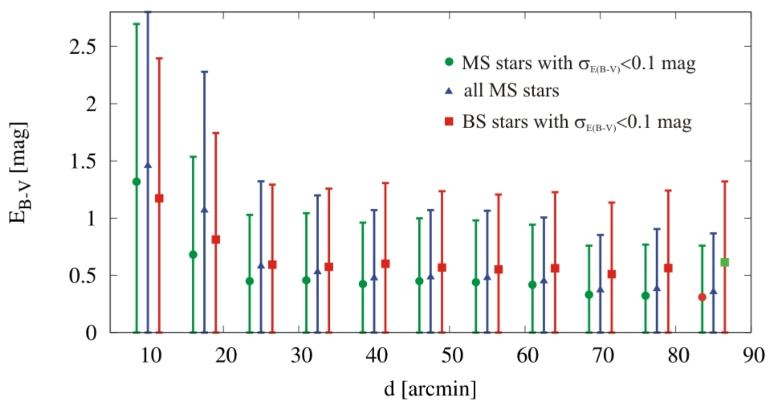

Fig. 2. Radial distribution of the mean extinction versus galactocentric distance as derived for all main sequence stars (blue triangles) and stars with individual extinctional error $\sigma_{E(B-V)} < 0.1$ mag, plotted with red circles (main sequence) and squares (blue supergians). The error bars represent the standard deviation of the mean.

presented. When a highly inclined disc and a large vertical optical thickness are combined the maximum extinction, including the mean, will depend on the absolute magnitude of the dereddened star. Surprisingly, that is not the case with the studied distribution which have been found almost independent from the imposed different absolute magnitude limits. As seen on Fig 2, there exists a constancy of of the mean extinction $E_{B-V} \simeq 0.5^m$ with the galactocentric distance which may indicate optically thick case, indeed. The standard deviation of the mean extinction is of the same order as the extinction itself which reflects the large variance rather than big errors of the derived quantity. Some information about the optical thickness of the disk may be locked in the distribution of E_{B-V} at a certain galactocentric distance or spiral arm fragment which demands Monte-Carlo simulations, analogous to those perfomed in [8].

In Fig. 3 we show the spatial distribution in the view plane of the NE part of M31 disc. The dereddened dwarfs were divided into three subsamples of different age: oldest stars: $\log t > 7.0$, intermediate age stars: $6.0 < \log t < 7.0$ and youngest stars: $\log t > 6.0$ (blue circles). By taking only stars with individual logarithmic age error $\sigma_{\log t} < 0.3$ in the first two samples we aimed at distinguishing them confidently. The idea here is to compare the clustering of the samples. We confirm the finding of [9] that the younger stars are being systematically more strongly clustered than the older, which are more dispersed. Most clearly it can be seen in the large complexes OB102 and OB54 [10], though there are 'clusters' like OB7 less populated by young stars. The faint stars in OB7 are real older stars rather than heavily obscured young stars which is proved here by the means of proper dereddening. The resolution of our data for certain goes down to size scales of few 10 pc, characteristic of unbound stellar aggregates and OB associations.

Finally, on Fig. 4 we superimposed the stars younger than 10^6 yr over all dereddened dwarfs to check for signs of density wave. It was done on the rectified plane the M31 which corresponds to a face on orientation of the disc. The only fragment of spiral arm where the youngest stars are located along its

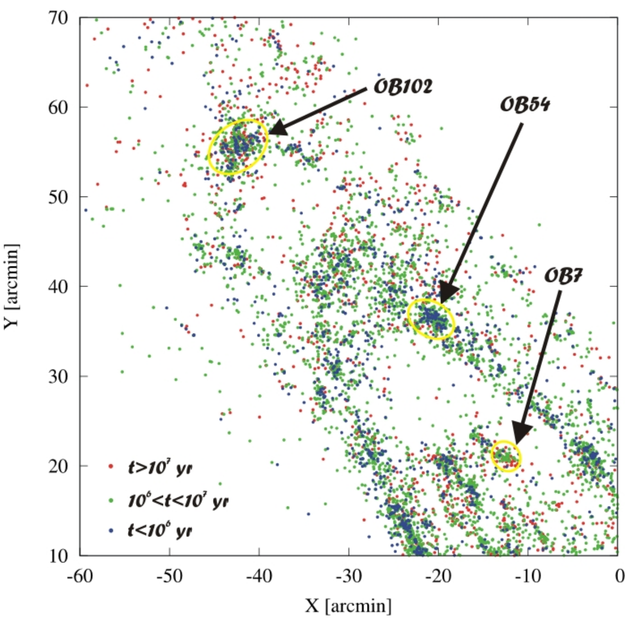

Fig. 3. Spatial distribution in the view plane of the NE part of M31 disc of three subsamples of main sequence stars wiith different age: oldest stars: $\log t > 7.0$ (red circles), intermediate age stars: $6.0 < \log t < 7.0$ (green circles) and youngest stars: $\log t > 6.0$ (blue circles). In order to distinguish between to first two samples only stars with individual logarithmic age error $\sigma_{\log t} < 0.3$ were considered. Note the blurring of the stars with the age hinting that the young groups do dissipate with time. The location of of 3 prominent van den Bergh's associations outlined by solid yellow line are shown as well.

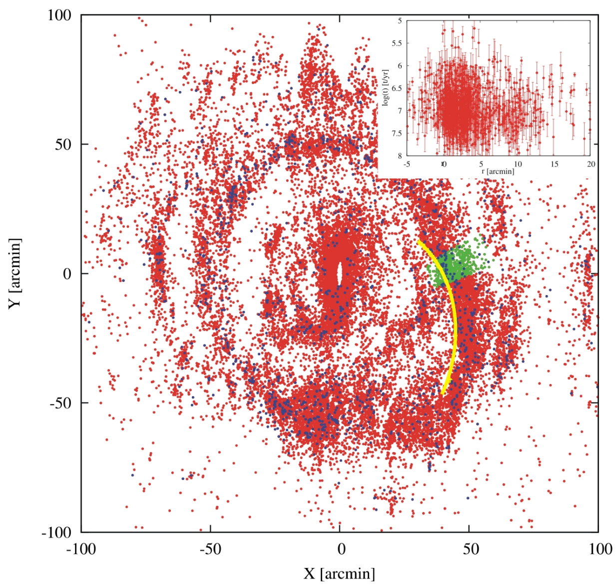

Fig. 4. Spatial distribution in the rectified plane the M31 disk of all main sequence stars with individual logarithmic age error $\sigma_{\log t} < 0.5$ (green circles for the fragment of spiral arm S4 in the area of association OB78 and red circles elsewhere) with a subsample containing only stars younger than $\log t = 6.0$ (blue circles) superimposed. The maxima of gas and dust emission were used to approximate the S4 fragment with a logarithmic spiral (yellow solid line). The age gradient across the spiral arm fragment is shown on the

inset in the upper right corner.
inner edge is S4. At the region of association OB78 the age gradient across the spiral arm fragment is most prominent.

CONCLUSIONS

By the means of a standard dereddening procedure we derive extinction estimates along ~ 80000 sightlines towards M31 galaxy and obtained meaningful physical characteristics (luminosity, color, age) of the same number of stars. Their masses varies form 5 to 120 $M_{\odot}$ with a completeness limit of $\sim 20 M_{\odot}$.

The azymuthally averaged mean extinction is nearly constant with the galactocetric distance indicating thick disk in the optical: $A_V \simeq 1.5^m$. We assign this to the high inclination of the M31 disc, but more sophisticated approach is needed to derive its true vertical thickness. Highly variable extinction from star to star even within the boundaries of one and the same stellar group is the main cause for the high dispersion of the mean extinction.

The younger the stars are, the stronger they are clustered pointing that the groups with mean size-scales like those of the OB associations ($\sim$80 pc) are gravitationally unbound and will be dissolved into disc background after a certain time.

Spiral arm S4 is still the only place where some new evidences can be raised in support to the density wave theory. They come from the age gradient of stars across the arm which is most prominent in the region of association OB78.

REFERENCES

[1] P. Massey, K. Olsen, P. Hodge, S. Strong, G. Jacoby, W. Schlingman and R. Smith *The Astronomical Journal* **131**, 2478–2496 (2006).

[2] L. Bianchi, Y. Kang, P. Hodge, J. Dalcanton and B. Williams *Advances in Space Research* **53**, 928–938 (2013).

[3] J. Cardelli, G. Clayton and J. Mathis *The Astrophysical Journal* **345**, 245–256 (1989).

[4] T. Lejeune and D. Schaerer *Astronomy & Astrophysics* **366**, 538–546 (2001).

[5] P. Kroupa *Science* **295**, 85–88 (2002).

[6] D. Weisz, M Fouesneau, D. Hogg; H.-W. Rix, A. Dolphin, J. Dalcanton, D. Foreman-Mackey, D. Lang, L. Johnson, L. Beerman, E. Bell, K. Gordon, D. Gouliermis, J. Kalirai, E. Skillman and B. Williams *The Astrophysical Journal* **762**, 123–144 (2013).

[7] T. Veltchev, P. Nedialkov and G. Borisov *Astronomy & Astrophysics* **426**, 495–501 (2004).

[8] P. Nedialkov and V. Ivanov *Astronomical & Astrophysical Transactions* **17**, 367–391 (1999).

[9] D. Gouliermis, L. Beerman, L. Bianchi, J. Dalcanton, A. Dolphin, M. Fouesneau, K. Gordon, P. Guhathakurta, J. Kalirai, D. Lang, A. Seth, E. Skillman, D. Weisz and B. Williams *(astro-ph.GA* **1407.0829**, 1–10 (2014).

[10] S. van den Bergh *The Astrophysical Journal Supplement* **9**, 65–80 (1964).

ЕКСТИНКЦИЯ И МАСИВНО ЗВЕЗДНО НАСЕЛЕНИЕ В ГАЛАКТИКАТА АНДРОМЕДА

П. Недялков

Катедра Астрономия, Софийски университет "Св. Климент Охридски", бул. "Дж. Баучер" №5, 1164 София, България

(Резюме)

Изследвахме потенциала на фотометрията от звездния каталог на галактиката M31 (Massey et al. 2006) да служи като източник на нова информация относно звездобразуването и екстинкцията в нейния диск. За целта разработихме процедура за освобождаване от почервеняване, причинено от праховата компонента на междузвездната среда. Тя позволява да бъдат направени изводи както за количеството и пространственото разпределение на праха, така и за физическите параметри (светимост, температура, възраст) на населението от масивни звезди. Потърсени са области на кохерентно звездообразуване на различни времеви скали и размери. Намерени са както доказателства в подкрепа на теорията на спиралната вълна на плътността за ръкава S4, така и свидетелства за скрито звездобразуване, близо до областите с най-висока концентрация на газ и прах.