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HALO-DISK VS. SHRINKING SCENARIOS

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RESUMEN

Discutimos la posibilidad de que las estructuras extensas sin estrellas jóvenes que habitualmente se encuentran en las galaxias enanas irregulares (eIrr), sean consecuencia de un encogimiento progresivo de la región de formación estelar. Sería una alternativa a la posible estructura halo-disco de las eIrr. En ausencia de datos cinemáticos adecuados, presentamos dos aproximaciones alternativas al estudio de estas estructuras extensas en eIrr. En la primera, se ha aplicado a DDO 165 (eIrr situada a unos 5 Mpc de la Vía Láctea) la distribución radial de poblaciones junto con síntesis de poblaciones basada en fluctuaciones de brillo superficial (FBS). Los resultados muestran que la población jóven, resuelta, está más concentrada que la población de edad vieja-intermedia, no resuelta. Esta última es, en promedio, de 7 Ga, y tiene una metalicidad muy baja ($\sim Z = 0.0007$). Esto indica que, junto con una población estelar realmente vieja, existe una población importante de edad intermedia en la zona externa de la galaxia. En nuestra segunda aproximación, se ha usado diagramas color magnitud (DCM) profundos basados en observaciones del Telescopio Espacial Hubble (TEH) para analizar las poblaciones estelares internas y externas de la galaxia enana de Phoenix. Los resultados muestran que junto con una población estelar vieja, el campo externo contiene también una población de edad intermedia. Estos resultados son compatibles con un escenario donde la región de formación estelar mengua con el tiempo (el escenario menguante). Parece más difícil sostener el escenario halo-disco que requiere estructuras extensas pobladas exclusivamente por estrellas viejas.

ABSTRACT

We discuss the possibility that the extended structures, lacking young stars, routinely found in dwarf irregular galaxies (dIrr) are a consequence of a progressive shrinking of the star forming region. This would be an alternative scenario to the possible halo-disk structure of dIrr. Although the final answer must wait until kinematical data of some accuracy become available, we present two alternative approaches to the study of the extended structures in dIrrs. In the first one, the radial distribution of stellar populations together with population synthesis, based on surface brightness fluctuations (SBF), has been applied to DDO 165. This is a dIrr about 5 Mpc away from the Milky Way. Results show that the resolved, young population is more concentrated than the intermediate-old, unresolved population. The later is 7 Gyr old, in average, and has a very low metallicity (about $Z = 0.0007$). This indicates that, together with a truly old stellar population, an important intermediate-age population is present in the outer region of the galaxy. In our second approach, deep color–magnitude diagrams (CMDs), based on Hubble Space Telescope (HST) observations and reaching the oldest turn-offs, are used to analyze the inner and outer stellar populations of the Phoenix dwarf galaxy. Results show that, together with an old stellar population, the outer field contains also an intermediate-age population. These results are compatible with a scenario in which star forming regions are shrinking with time (the shrinking scenario). It seems more difficult to support a halo-disk scenario, which would require extended structures populated only by really old stars.

Key Words: **GALAXIES: DWARF — GALAXIES: STELLAR CONTENT — GALAXIES: STRUCTURE**

1. INTRODUCTION

An usual prediction for cold dark matter dominated universes is the hierarchical scenario for galaxy formation (White & Rees 1978, Blumenthal et al. 1984), in which dwarf galaxies arising from 1σ fluctuations in the density distribution of the primeval Universe are the first structures to form. On the other hand, the fact that dwarf ellipticals (dEs) are usually found in denser parts of the Universe than dwarf irregulars (dIrrs) suggests that an evolutionary connection could exist between both types, dEs being in a more evolved stage and in the process of being soon incorporated into bigger neighboring galaxies. However, according with Dekel & Silk (1986), the driving winds of supernovae (SNe) of the first stellar generation should have swept out most of the gas. Galaxies retaining some of it would eventually be able to produce new stellar generations, resulting in dIrrs. If this is the case, dIrrs should still bear the traces of their first stellar generation, which would

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be seen today as extended structures populated by very old, low metallicity stars.

Extended low surface brightness structures have been routinely discovered in dwarf galaxies like WLM (Minniti & Zijlstra 1996), Antlia (Aparicio et al. 1997), NGC 3109 (Minniti, Zijlstra, & Alonso 1999), Phoenix (Martínez-Delgado, Gallart, & Aparicio 1999), DDO 187 (Aparicio, Tikhonov, & Karachentsev 2000), and DDO 190 (Aparicio & Tikhonov 2000). However, the existence of these extended structures lacking young stars is not enough to conclude that the Dekel & Silk (1986) scenario is at work. The latter would imply that such a structure is populated only (or mostly) by really old, low-metallicity, kinematically differentiated stars and hence, that a halo-disk scenario is appropriate.

The important point is to ascertain whether this is the case or whether the extended structure is the superposition of successive old and intermediate-age populations (that we have called the shrinking scenario) just lacking young stars. In the halo-disk scenario gas removal produced by first generation of SNe would be followed by an era in which no gas was available or cold enough to host star formation. Subsequently, star formation would start again once the galaxy had reorganized. The shrinking scenario could be the result of a progressive shrinking of the star formation region of the galaxy, possibly produced by the gas progressively thinning out in the outermost regions.

The definitive pieces of evidence would be kinematics and accurate enough estimates of the stellar population age. A kinematical study requires measuring velocity dispersions for individual stars in the extended components, which is still out of reach for most dIrrs, although it is now becoming possible for the nearest dwarf galaxies a few hundred kpc away from the Milky Way (MW).

In the following, we present two approaches that shed light on the problem. In the first one, morphological distributions of young and intermediate-old stars of the dIrr DDO 165 plus surface brightness fluctuations (SBF) population synthesis is used. In the second, deep color–magnitude diagrams (CMDs) based on Hubble Space Telescope (HST) observations and reaching the oldest turn-offs, are used to analyze the inner and outer stellar populations of the Phoenix dwarf galaxy.

2. TESTING THE SCENARIOS IN DDO 165

Lacking kinematical data and age information from the turn-off analysis, indications can still be obtained about the scenario preferable by combining several pieces of information, which include morphology, metallicity, and age estimates. We have obtained average ages and metallicities of the stellar populations of the extended structure of DDO 165, situated at ~ 5 Mpc from the MW. The study uses B and R photometry from which are derived: (i) radial stellar populations of the resolved blue stars; (ii) surface brightness profiles for the unresolved stars, and (iii) SBF originating in the unresolved population. The remaining population (i.e. all but the very young) is sampled by the unresolved stars.

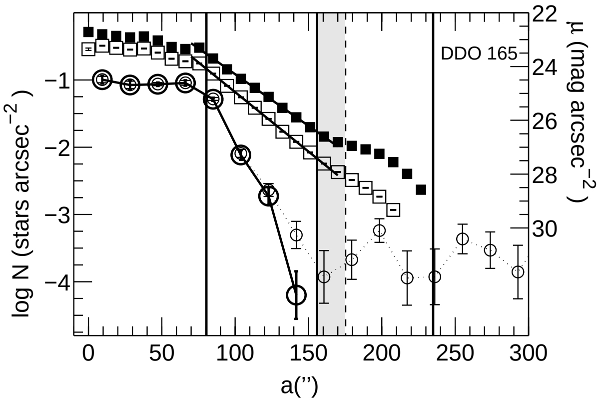

Fig. 1. Resolved stellar density profiles and surface brightness profiles of DDO 165. Logarithm of number density of stars (the left-hand vertical axis) before subtraction (thin open circles, dotted line) and after subtraction (thick open circles, solid line) of foreground/background objects are given for young stars. Radial surface brightness (the right-hand vertical axis) in R (filled squares) and B (open squares) are also given. The solid vertical lines correspond to different regions of the galaxy, from left to the right: the core radius, the region were the stellar density profile drops (where the exponential laws have been fitted), the region where no resolved stars belonging to the galaxy are present, and finally, the region where the sky brightness and foreground/background object contamination are evaluated. The shaded region has been used to derive the SBF of the unresolved stellar population.

The extended structure of DDO 165 is shown in Figure 1. It shows the profiles of the radial distribution of the resolved and unresolved populations. Exponential laws have been fitted to the profiles. The scale lengths are $26.4 \pm 0\farcs2$ and $8.8 \pm 1\farcs2$ for the old and young population, respectively. It can be seen that the resolved population is more concentrated than the unresolved population. The latter also extends farther out.

The SBF technique (Tonry & Schneider 1988) has been applied to the shaded region of Fig. 1), where the young population no longer exists, but

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the unresolved population is still present. The results obtained show that the stellar population of the extended structure of DDO 165 is on average older than 7 Gyr and has a metallicity lower than $Z = 0.0007$. This indicates that truly old (older than $\sim$ 10 Gyr) and very metal poor stellar populations are probably an important component in the extended structure of DDO 165. But it also allows an important intermediate-age population.

This latter possibility requires further confirmation. But, if it is right, it would imply that the extended structures in dwarf galaxies host both an old and an intermediate-age stellar population, hence favoring the shrinking scenario, rather than the halo-disk one.

3. THE EXTENDED STRUCTURE OF PHOENIX REVEALED BY HST

We show preliminary results arising from two WFPC2 fields on Phoenix, a dwarf galaxy situated at about 450 kpc from the MW. One of them is at the Phoenix center and coincides with the Holtzman, Smith, & Grillmair (2000) one. The other is about 4′(450 pc) from the center of the galaxy.

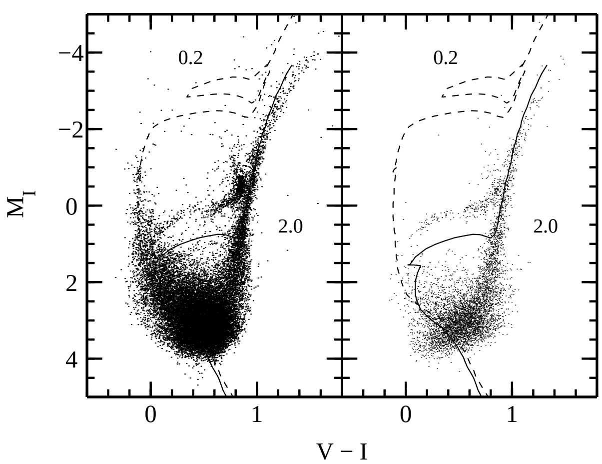

Fig. 2. CMD of the inner (left) and outer (right) region of Phoenix. Isochrones with the age in Gyr are also plotted. Solid and dashed lines are for metallicities $Z = 0.001$ and $Z = 0.004$, respectively. The CMD of the outermost region shows the presence of old stars (the well populated horizontal branch), but also, the presence of an intermediate age population of 2 Gyr, evidenced by the less developed, but still clear, main sequence.

Figure 2 shows preliminary CMDs for two fields of Phoenix. The fields show signatures of old stellar populations (the well populated horizontal branches, mainly). As expected (Martínez-Delgado et al. 1999), the inner field shows also a conspicuous main sequence young population. But, very interestingly, together with the old stellar population, the outer field contains also an intermediate age population, evidenced by the less developed, but still clear, main sequence. This points to the shrinking scenario, but a detailed analysis is required to confirm this.

4. CONCLUSIONS

- Extended low brightness structures, lacking young stars, are routinely found in dIrrs.
- The stellar population in these structures seems a mixture of old and intermediate-age stars.
- According to this, the idea that these structures are old, “true” halo components is not clear.
- We suggest the possibility that the star forming region in dIrrs continuously shrinks with time as a result of gas progressively being consumed.

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