Stellar subsystems of edge-on disk galaxies

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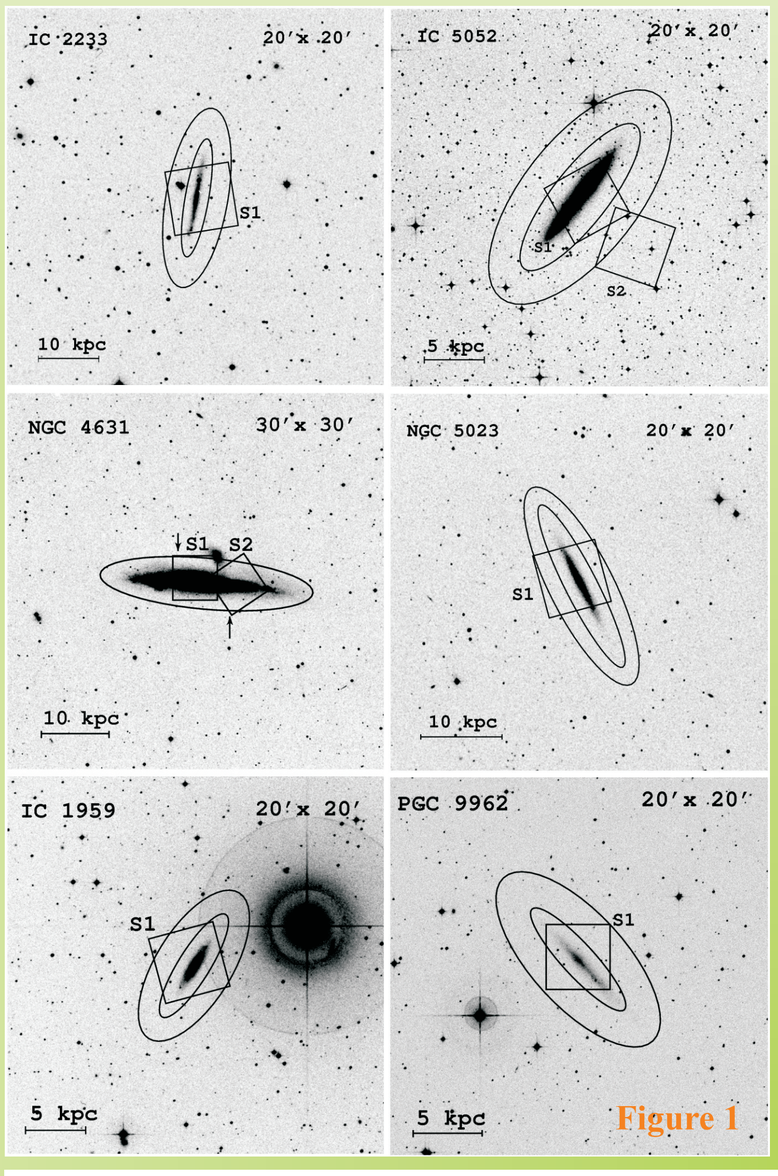

Figure 1

Introduction

Understanding the structure of the stellar component of disk galaxies is an important step for unraveling their formation and evolution. The extraplanar stellar content around galaxies is a potentially important probe of the most ancient stellar populations, as well as of the role that different external and internal processes play in the evolution of modern galaxies, such as: merging of neighbour galaxies, accretion of metal-poor gas, disk heating or the ejection of gas from the underlying disk. The stellar outskirts around some large spiral galaxies have been extensively studied over the last years and revealed faint stellar envelopes in many of them. We selected six edge-on spiral galaxies (Fig.1) for a study of their stellar structure. The choice of high-inclination galaxies ensures minimal contamination by stars belonging to the dominant galactic disk component and provides a more robust separation of the thick disk and halo stellar populations.

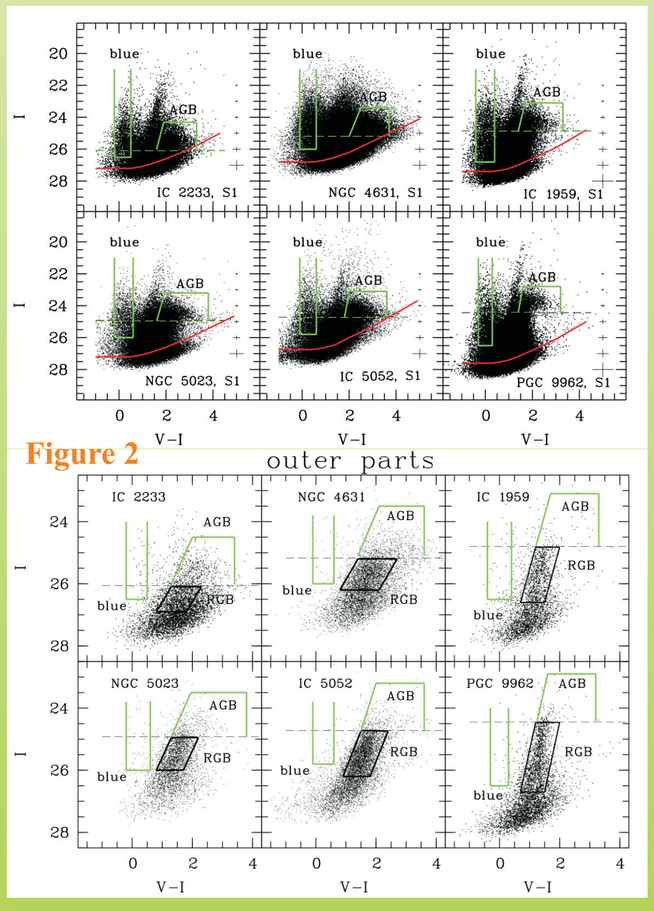

Figure 2

Stellar photometry

To study the resolved stellar population of galaxies, we obtained ACS/WFC images available in the HST archive. Stellar photometry was carried out with DAOPHOT II in MIDAS (Stetson, 1994). The results of stellar photometry in the galaxies are presented as colour-magnitude diagrams (CMD) in Fig.2. On these CMDs we can see the branches of blue and red supergiants, of intermediate age stars (AGB) and a branch of red giants. We correct all the photometry results for Galactic extinction (Schlegel, 1998) and assume that internal extinction in all galaxies is negligible in their outer parts. For our spatial structure analysis we used only stars with magnitudes above the 50 % completeness level that occurs at about $I = 27^{m}.5$ in these diagrams. In order to estimate distances, we have used the TRGB method of Lee et al. (1994).

Stellar spatial distributions

Using CMDs, we separate different stellar populations and analyze their spatial distribution. The measurements of the stellar number density perpendicular to the galaxy plane and search for the truncation radius (edge) of the thin and thick disks allow us to trace farther a presence of stellar halo.

The surface number density profiles such as the ones presented in Fig. 3 show that distribution of different stellar populations has quite different scale-lengths and truncation radii. The distribution of the faint stars shows a decline toward the galaxy planes due to the increase of stellar crowding and bright background. The majority of young stars of thin disks are bright enough to be detected even near the mid-plane of a galaxies and, therefore, they do not show the same drop-out as less luminous stars (AGB and RGB).

Farther above the thick disks, a density of the RGB stars declines with a shallower slope. By fitting the exponential law, we extrapolated stellar halos out to Z = 5-15 kpc. Unless there is an additional outermost stellar component not covered by the ACS/WFC field, the relatively small extent of the stellar halo in comparison with apparent large axis length (planar extent) indicates that stellar halo might be represented by oblate ellipsoid.

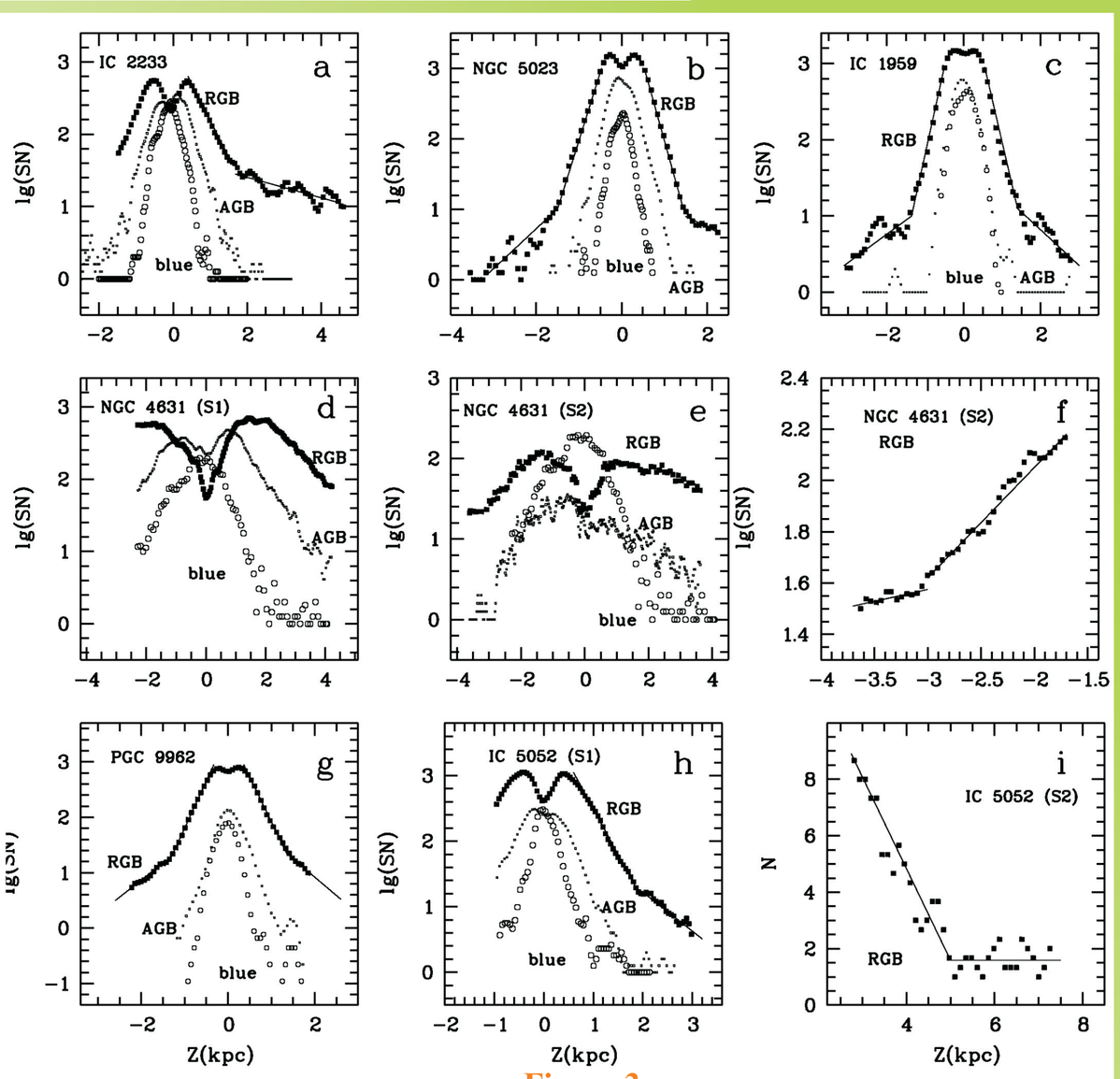

Figure 3

HI envelopes

It is generally assumed that the size of the neutral hydrogen envelopes of the disk galaxies is several times larger than the stellar envelopes. In some cases it is valuable to compare the extraplanar size of the outermost stellar and gaseous structures of galaxies.

In galaxy IC 2233, the extraplanar height of the HI envelope is Z = 6.1 kpc (Wilcots, 2004). We detected the edge of the IC 2233 thick disk at extraplanar distance of 3.8 kpc, while its stellar halo is traced as far as 9.6 kpc. In galaxy IC 5052, old RGB stars reveal break in their number density at Z = 1.9 kpc but extend farther with smaller surface density gradient tracing a stellar halo up to 4.0 kpc. In the presented contours (Ryan, 2003), the IC 5052 vertical structure HI halo is seen until Z = 3.2 kpc, but there is also an indication of more extended hydrogen filaments. The peculiar distribution of the evolved AGB and RGB stars can be explained by interaction between NGC 4631 and NGC 4627. We estimated the outermost vertical extension of the NGC 4631 stellar halo as 8 - 10 kpc. From the spectroscopic observations Martin (2001) has detected the extraplanar emission line gas around NGC 4631 out to Z = 7 kps. In galaxy NGC 5023 the HI envelope is seen until Z = 1.8 kpc (Swaters et al., 2002), while the thick disk and halo are traced until Z = 1.6 and 3.2 kpc respectively. The size of HI halo of galaxy ESO115-G121 is 3.4 kpc (Brien et al., 2010) while the stellar halo is seen more then Z = 3 kpc. One can see that in all cases the HI envelopes do not exceed the stellar halos.

Model of the stellar structures of a disk galaxy

Comparing the inferred parameters for the thin and thick disk and halo with our and other published results, we compose a scale 3-D model of the stellar structures of a typical disk galaxy (Fig. 4). This model relies on the star number counts in edge-on and face-on spiral galaxies. We would like to note that massive irregular galaxies such as IC 10 and M 82 show all kinds of stellar structures, including thick disk and halo. The spatial distribution of stars along and perpendicular to a disk galaxy plane are alike. Young stars are mostly confined to the thin disk of the galaxy, while older stars are more spread out with oldest stars being traced outermost.

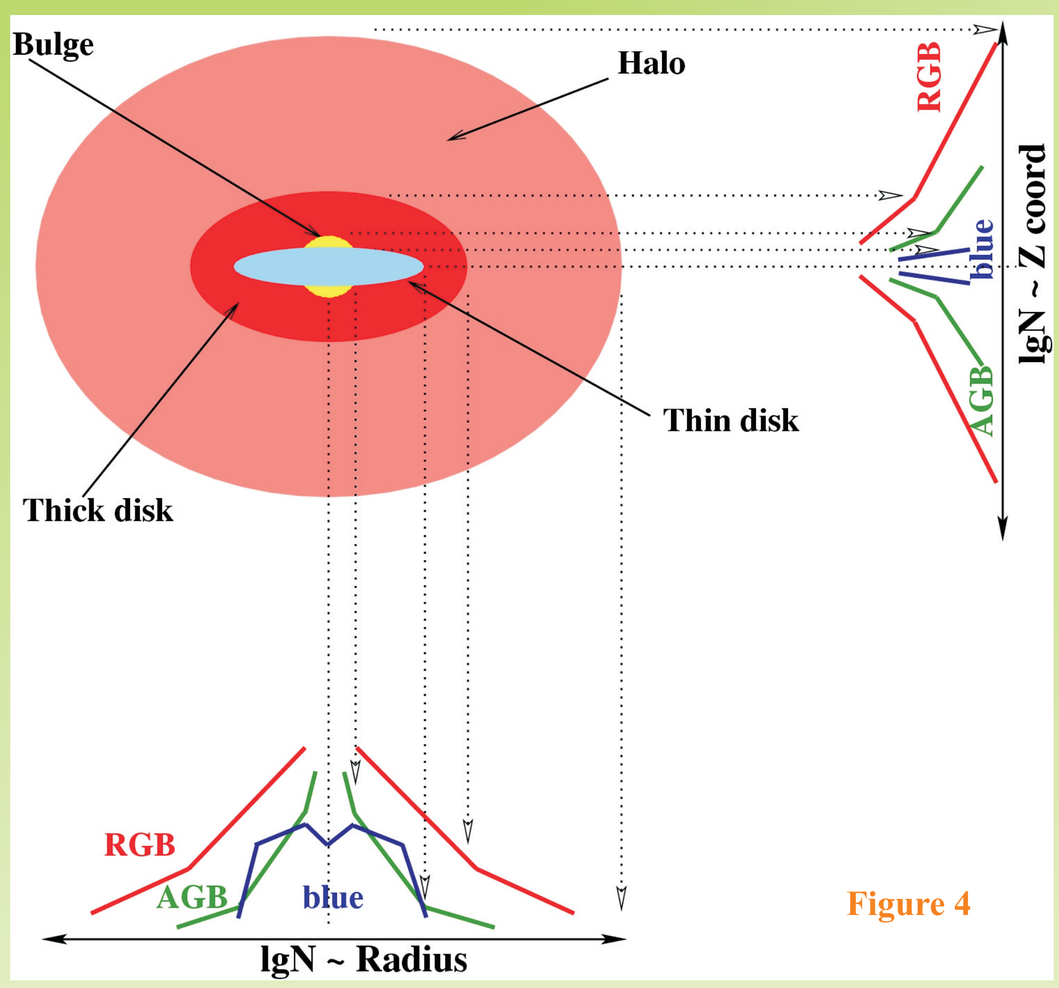

Figure 4

Discussion

Relying on the star number counts in the six edge-on disk galaxies, we examine the extraplanar spatial distribution of young and evolved stars in their disks and halos. All galaxies show the similar morphological properties, thin and thick disks and halos, but relative sizes of these structures are different in each galaxy. Combining this work with results obtained for other galaxies we suggest that most of the massive disk galaxies have not only a thick disk but also an extended halo, consisting mainly of evolved stars. The ratio of the halo-to-thick disk size is relatively constant, $\mathbf{R_{halo}/R_{thick\ disk} = 2.5}$. It might reflect the overall rotation of the galaxy, including flatten stellar halo.

Stellar populations of bulge, thin and thick disks and halo have likely formed by different mechanisms, especially considering the differences in ages and metallicities. The thick disk and halo may cast light on the most ancient structure formation, and are therefore extremely important for the understanding of early history of galaxy formation and evolution. Additional results from photometry of more evolved stars (Horizontal Branch and old Main-Sequence Turn-Off stars) as well as from kinematic and chemistry of resolved stars are required to refine various scenarios of galaxies formation.

Summary

On the basis of the stars count method, we have analyzed extraplanar stellar structures in six large high-inclination galaxies. Main results can be summarized as follows:

- **The extended stellar thick disks and halos have been detected in all galaxies**
- **There are clear differences between surface density gradients of evolved stellar populations assigned to the thick disks and halos, which allowed us to detect the edge of the thick disk.**
- **The spacial distribution of stellar populations of these six galaxies provide more confidence for the unified model of three-dimensional structure of large disk galaxies and motivate follow-up spectroscopic study to constrain the kinematic characteristics of the stellar components.**

References

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