astro-ph seminar 2024.07.03 (Ryou Ohsawa)

The broken-exponential radial structure and larger size of the Milky Way galaxy

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Abstract

The radial structure of a galaxy is a fundamental property that reflects its growth and assembly history. Although it is straightforward to measure that of external galaxies, it is challenging for the Milky Way because of our inside perspective. Traditionally, the radial structure of the Milky Way has been assumed to be characterized by a single-exponential disk and a central bulge component. Here we report (1) a measurement of the age-resolved Galactic surface brightness profile in a wide radial range from $R = 0$ to 17 kpc and (2) the corresponding size of the Milky Way in terms of a half-light radius. We find a broken surface brightness profile with a nearly flat distribution between 3.5 and 7.5 kpc, in contrast to a canonical single-exponential disk. This broken profile results in a half-light radius of 5.75 ± 0.38 kpc, significantly larger than that inferred from a single-exponential disk profile but consistent with that of local disk galaxies of similar mass. We also confirm that the size growth history of the Milky Way is broadly consistent with high-redshift galaxies but with systematically smaller size. Our results suggest that the Milky Way has a more complex radial structure and larger size than previously expected.

Background

The size of a disk galaxiy is usually evaluated in terms of the half-light radius (R_{50}), which encloses the half of the total luminosities.

The R_{50} of Milky Way was previously evaluated about 3.12 kpc, which is much smaller than a typical size for nearby Milky-Way counterparts.

Is Milky Way a peculiar galaxy? The authors suspected that the Milky Way size was underestimated due to a simplified Galactic model.

The authors devised a method to estimate the radial profile of the surface brightness without assuming a specific Galactic structure.

Data and Methods

The authors used high-resolution (R ~ 22,500) spectroscopic data from APOGEE DR17 (225,790 stars, see, Supplementary Figure 1).

The selected sources are distributed within the galactocentric radius R < 18 kpc (25,667 stars in the bulge and 5528 stars at R < 1 kpc).

The surface gravities, effective temperatures, and metallicities ([Fe/H] & [Mg/Fe]) were derived from the APOGEE spectra.

The ages and distances were evaluated by an astroNN deep-lerning code using APOKASC asteroseismology data and Gaia DR3 parallaxes as anchillary data.

First, the authors compiled mono-abundance populations. The sources were categorized by Galactic positions, [Fe/H], and [Mg/H].

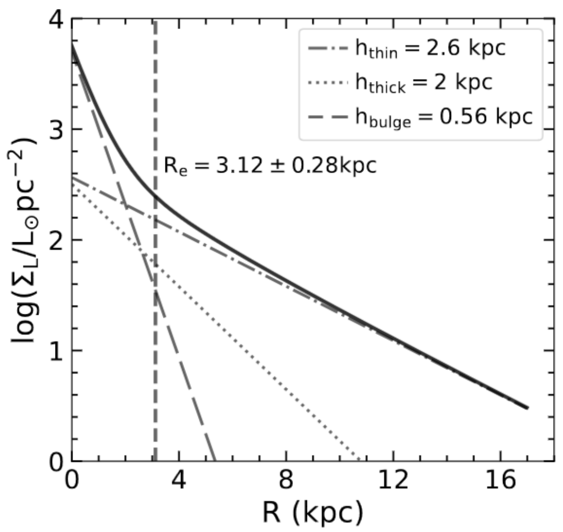
The probability that a source was observed in the APOGEE survey was evaluated, leading to the intrinsic number densities of the populations.

The authors sampled stars from the stellar isochrone defined by the stellar age, [Fe/H], and [Mg/H] (= mono-abundance populations).

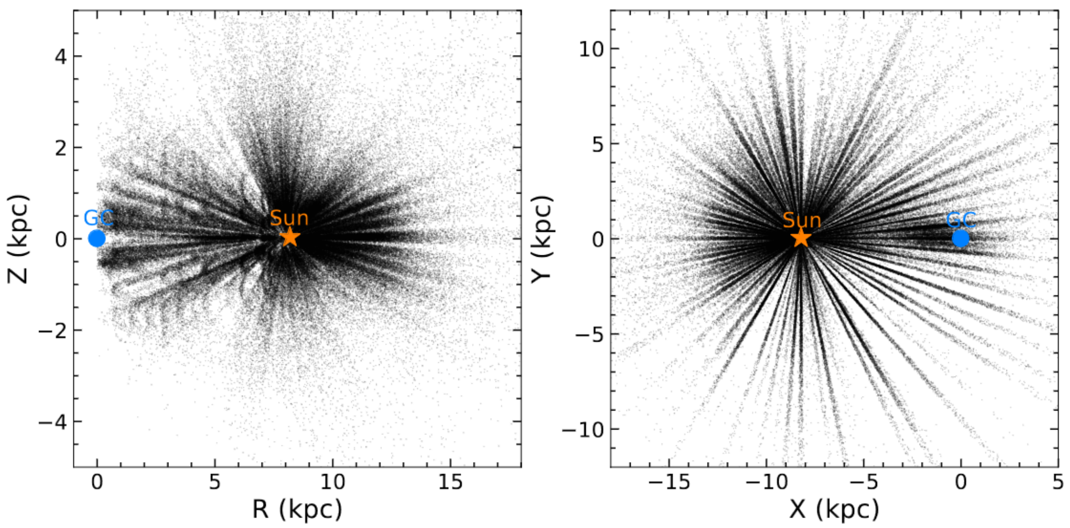
The mono-abundance populations are recompiled into mono-age populations with a bin width of 2 Gyrs.

The lumonosity densities were integrated along with the galactic Z direction, and the surface brightness profiles of the mono-age populations were obtained.

Supl. Figure 2 (panel 4)



Supl. Figure 1



Results and Discussion

Figure 1

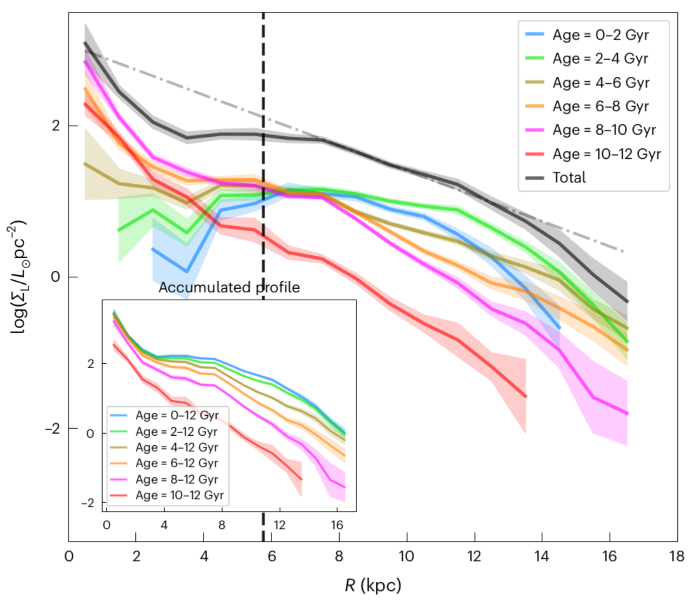


Figure 2 (panel 1)

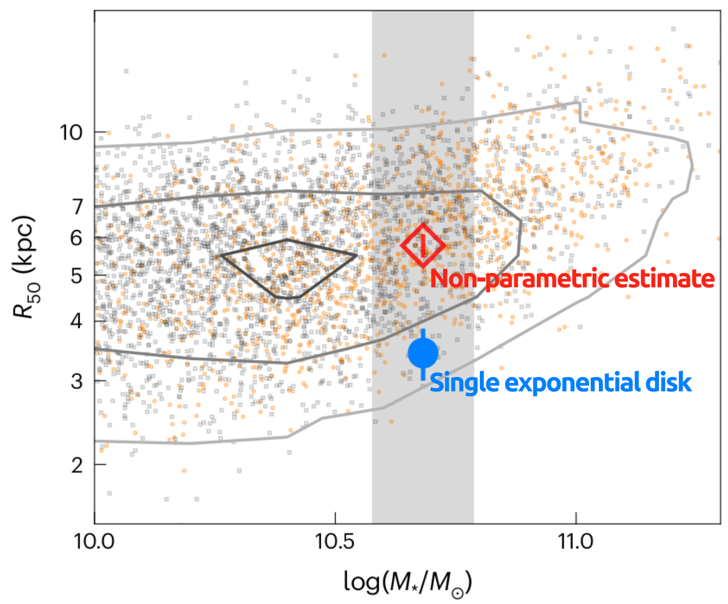


Figure 3

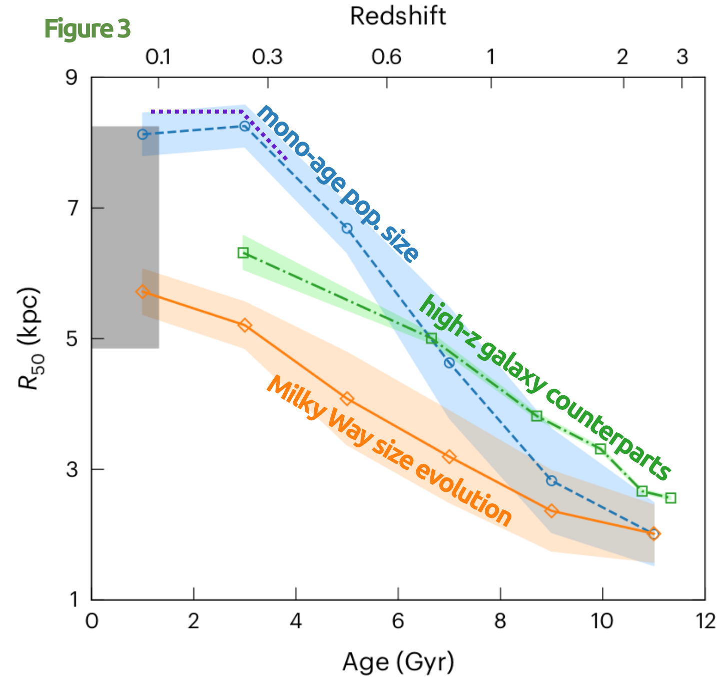


Figure 1 illustrates the surface brightness profiles of the mono-age populations.

The brightness profile is flat from 3.5 to 8 kpc, suggesting that a single-exponential disk is unappropriate.

The oldest population monotonically decreases with the galactocentric distance.

The young populations show flatter profiles and posotive slopes in the inner region (R < 5 kpc).

The R_{50} of Milky Way was estimated to be 5.75±0.38 kpc (including systematic errors).

Figure 2 compares the estimated Milky Way size with those of local star-forming disk galaxies (from SDSS).

The non-parametric estimate (**Red**) is comparative to other galaxies in the same mass range.

The present analysis shows that Milky Way is a typical galaxy in size but has an extremely steep metallicity gradient.

The sizes of the mono-age populations strongly support the inside-out growth of Milky Way.

The R_{50} radii of the mono-age populations are illustrated in Figure 3.

Younger populations are preferentially formed in the outer region of Milky Way.

The growth of the mono-age R_{50} stalled about 2 Gyr ago, the end of the inside-out formation.

The R_{50} raii of the cumulative-age populations indicate the growth rate of Milky Way.

The growth rate of Milky Way is similar to those of high-z counterparts, while Milky Way is smaller than the counterparts.

Summary

To summarize, we recovered the nonparametric surface brightness profile of the Milky Way, from the Galactic bulge to the outer disk, and directly measured its half-light radius. We found a rather complex radial density structure for the Milky Way, with a broken disk profile that flattens between 3.5 and 7.5 kpc. The deviation of the disk structure from a single-exponential profile may substantially change our understanding of the Milky Way's structure and estimate of the Milky Way's fundamental global properties, which have generally been based on an assumption of a single-exponential disk profile. Owing to the flattened inner disk density profile, we obtained a significantly larger 'size' (defined as the half-light radius) for the Milky Way than that expected from a single-exponential disk profile, pushing the Milky Way from an outlier in the similar-mass disk galaxy population to a typical one. The half-light radii of the mono-age populations increase monotonically from the oldest stars until an age of 2 Gyr, consistent with an inside-out formation of the Milky Way that possibly ended in the last few gigayears. In comparison with high-redshift galaxies, the Milky Way appears to have experienced a similar size growth history but at a systematically smaller size.