# 256. The edge of our star-forming disk

MAPPING THE DETAILED morphology and kinematics of our Galaxy's disk, and the dynamical processes that are shaping them, are important for a better understanding of the formation of our own Milky Way Galaxy, and placing it in a cosmological context.

Amongst its notable details are resonant motions due to the central bar and its spiral arms, the large-scale warp, various dynamical perturbations such as the phase-space spiral, and the discovery and characterisation of some hundred or more halo streams.

Understanding the outer parts of our Galaxy's disk has been another great challenge, and one with certain cosmological implications which I will look at here.

EARLY STUDIES, using photographic plates, found that the light profiles of disk galaxies terminate reasonably sharply, with a rather well-defined 'edge' to the stellar disk (e.g. van der Kruit, 1987). Later CCD photometry showed that, rather than being sharply truncated, disks are generally better described by a double-exponential model, with an exponential profile up to some 'break' radius, and an outer profile with a different scale length, which may be flatter or steeper (Pohlen et al., 2002).

A larger SDSS study of 90 face-on late-type (Sb–Sdm) spiral galaxies by Pohlen & Trujillo (2006) showed that the profiles can be broadly characterised either by a single exponential without a break (Type I); by a downward bend in the light profile beyond the break (Type II); or by an upward bend (Type III). Further studies from HST–ACS imaging at intermediate redshifts, $z \lesssim 1$ (e.g. Bakos et al., 2008; Borlaff et al., 2018), and more recently with JWST at larger redshifts, $1 < z < 3$ (Xu & Yu, 2024), demonstrate that Type II disks comprise roughly 50% of disk galaxies in both the local and early Universe.

A physical explanation for the observed break remains uncertain. Already, van der Kruit (1987) suggested that it is a consequence of the galaxy formation process, with the breaks being remnants from the early collapse phase. Bakos et al. (2008) suggested that the break in Type II galaxies is more likely due to a change in stellar population than to a drop off in the mass distribution.

ATTEMPTS TO EXPLAIN the breaks as radial thresholds in the star-formation process (e.g. Kennicutt, 1989; Schaye, 2004; Martín-Navarro et al., 2012), are in tension with the evidence for star-formation in the outer regions of spiral galaxies, well beyond the break in exponential structure (e.g. Thilker et al., 2005; Gil de Paz et al., 2005; Kennicutt & Evans, 2012; Yadav et al., 2026).

The cosmological implications become more evident when examining the disk profile dependency on morphological type. For example, Xu & Yu (2024) showed that, across a broad redshift range, galaxies that are more massive, or more centrally concentrated, tend to show more breaks of Type III, i.e. with an *upturn* in their surface brightness beyond the break radius.

The same study showed that, in barred galaxies, the ratio of the Type II disk break radius to the bar radius peaks at ~2.25. Attributing this to bar-induced radial migration at higher redshifts appears to be implausible because of the long timescale required for such secular evolution. Instead, they propose that violent disk instabilities may be responsible, in which spiral arms and other torques fling out the material, leading to the formation of outer exponential disks.

As part of a more extensive classification of galaxy morphology over the redshift range $1.5 < z < 8$ with JWST, these studies are demonstrating that most stars in the Universe were likely formed in disk galaxies, that the fraction of spiral types is well predicted by cosmological simulations, and that the 'Hubble sequence' was already in place a billion years after the Big Bang (e.g. Ferreira et al., 2023; Kartaltepe et al., 2023; Ormerod et al., 2024).

THE CURRENT VIEW is that Type II profiles originate from a combination of a cut-off in star formation, coupled with radial migration driven by bars or transient spiral arms (e.g. Debattista et al., 2006; Roškar et al., 2008a; Minchev et al., 2011; Roškar et al., 2012). Detailed simulations of such migration find that this leads to an increasing mean stellar age beyond the break radius and, in turn, to a characteristic 'U-shaped' mean stellar age profile (Roškar et al., 2008b).

Our Galaxy is, of course, the nearest to us and therefore in principle the most amenable to study. But our own location in the Galactic plane, far from its centre and plagued by interstellar extinction, greatly complicates the understanding of many of its most basic features such as its spiral arms and its disk warp.

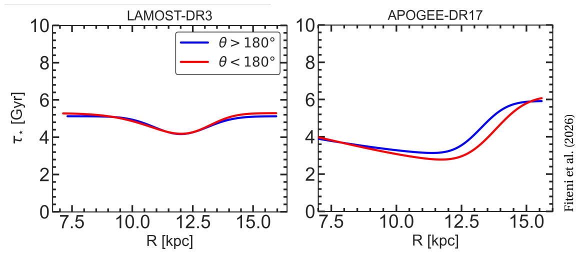
Whether the Milky Way has such a broken light profile remains an open question. Early studies based on star counts in the anti-centre direction, including from DENIS and COBE, suggested a break at 12–15 kpc (Robin et al., 1992; Ruphy et al., 1996; Freudenreich, 1998). Red clump giants in the near-infrared gave $13.9 \pm 0.5$ kpc along various lines-of-sight (Minniti et al., 2011), with similar results from 40 000 young A-type stars from the INT–WFC survey (Sale et al., 2010). A broken stellar density profile in the low-$\alpha$, low-[Fe/H] disk at 10–13 kpc is also supported by data from APOGEE (Bovy et al., 2016; Mackereth et al., 2017; Lian et al., 2022b).

Meanwhile, observations have demonstrated that Type II disk galaxies indeed exhibit U-shaped colour and age profiles as a result of net migration (Bakos et al., 2008; Radburn-Smith et al., 2012; Yoachim et al., 2012). But whether an upturn in the stellar age profile is present in the Milky Way's outer disk has also remained uncertain. Hints of an upturn have come from 640 000 red giant branch stars from LAMOST–DR4 (Wu et al., 2019), and a trend towards older ages beyond 13 kpc from APOGEE–DR16 (Lian et al., 2022a).

Gaia distances and space motions are contributing to a substantial advance in understanding of these related phenomena. In their recent study, Fiteni et al. (2026) considered two samples: spectroscopic data from LAMOST–DR3 combined with Gaia astrometry from Gaia DR2, and APOGEE–DR17 data combined with Gaia astrometry from Gaia EDR3. Essentially, the spectroscopic data provides good coverage of the outer disk, along with ages, $\tau$, effective temperatures, $T_{\rm eff}$, surface gravities, $\log g$; and metallicities [Fe/H].

The Gaia data is used to provide accurate distances, and to select only those stars moving on nearly circular orbits. The latter, in turn, identifies stars that have undergone true migration (or 'radial churning', presumably at the co-rotation resonance of transient spiral arms, or of the central Galactic bar), as opposed to orbital heating (or 'radial blurring, as a result of gravitational interaction with giant molecular clouds or massive clusters, through which the orbits become more eccentric). Churning permanently changes the star's angular momentum (and its guiding radius), but without heating its orbit.

The final LAMOST–DR3 sample comprised 66 615 kinematically cool giants, with an average age uncertainty of 1.32 Gyr. The final APOGEE–DR17 sample comprised 35 507 giants, with an average age uncertainty of 1.12 Gyr.




The analysis by Fiteni et al. (2026) reveals the edge of the Milky Way star-forming disk, by demonstrating a positive age gradient at larger radii (see figure above). This results from stars driven there by radial migration.

They also compared the observations with three numerical (N-body + SPH) models to investigate the radial age profiles of such populations. The models were evolved for 10 Gyr using `Gasoline2` (Wadsley et al., 2017), and simulated both an isolated disk, as well as conditions following a single early merger along the lines of the major Gaia Sausage–Enceladus (GSE) event.

While the stellar age profiles obtained from the models show distinct shapes, reflecting their varied evolutionary paths, the values for the location of the age minimum, $R_{\rm min}$, are all in the range 9.5–14.0 kpc, and comparable with those from their empirical samples.

Several conclusions follow. First, their findings indicate that the outer Milky Way disk is predominantly kinematically cold. Their cut on orbital circularity from the LAMOST–DR3 and APOGEE–DR17 samples close to the mid-plane ($|z| < 0.3$ kpc) removes less than 10% of disk stars in the outer disk ($R > 11.5$ kpc), as well as successfully excluding halo stars.

They find that the Galaxy has a U-shaped stellar age profile, with both samples showing consistent age dependencies: a negative age gradient from 7–10 kpc, a relatively flat plateau-like region from 10–12 kpc, and a clear positive age gradient beyond 12 kpc. The location of the age minimum, $R_{\rm min}$, is at $11.28 \pm 0.58$ kpc and $12.15 \pm 0.62$ kpc for the two samples.

Their simulations demonstrate that $R_{\rm min}$ corresponds to the edge of the star-forming disk, where there is a sharp drop in star-formation rate. While they were unable to distinguish between mechanisms responsible for this drop (such as the bar's outer Lindblad resonance, the Galactic warp, or extragalactic ionising fields), they conclude that the combination of a drop in star formation at $R_{\rm min}$, and outward stellar migration beyond this radius, drives the observed U-shaped age profile.

In turn, they argue that the presence of such a profile indicates that our Galaxy has a Type II (down-bending) stellar density profile, with the break in the density profile coinciding with $R_{\rm min}$. Their estimates of $R_{\rm min}$ are also consistent with the break radii reported for low-$\alpha$ populations in the Milky Way disk.