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A couple of recent developments in the structure of the outer disk of the Milky Way

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Abstract. In this contribution we summarize recent achievements by our group on the understanding of the structure of the outer Galactic disk, with particular emphasis to the outer disk *extent*, and the spiral structure beyond the solar circle.

1. Spiral structure in the outer Galactic disk

The spiral structure of the Milky Way beyond the solar ring has traditionally been overlooked. HI surveys mostly concentrated in the inner disk, where the HI density is larger and detections easier. Despite many years of accumulating data, the debate on how many arms the Galaxy has, and their nature, shape and pitch angles, is still lively (Turner 2013).

The situation in the outer disk improved significantly in the last 10 years, especially in the southern Milky Way. One of the most remarkable results is the detection of the fourth quadrant distant arm by McClure-Griffiths et al. (2004) in HI. A whole sky HI map was presented by Levine, Blitz, & Heiles (2006) which covers also the outer disk. Vázquez et al. (2008) presented additional radio data using the CO molecules in the outer disk, in the third quadrant. Together with CO, Vázquez et al. (2008) also presented optical data from a large sample of young open clusters and young associations located behind these clusters. This wealth of data allows one to describe the outer disk spiral structure in some details. Interestingly enough, the outcome is different from the GLIMPSE description of the MW spiral arm, popularized by Churchwell et al. (2009, their Fig 15).

This study is based on counting Red Giant clump stars all over the Milky Way. Red Giant clump stars span ages from 0.5 to 10 Gyrs, so they virtually trace several different stellar populations. If they do trace spiral structure, this would imply that spiral arms are long-lived structure, something that simulations do not confirm. Carraro (2013) discuss in details the nature of these stars, concluding that they are not ideal spiral m tracers. Looking in fact at external galaxies, spiral arms possess plenty of gas and blue, hence extremely young, stars. According to Churchwell et al. (2009) the

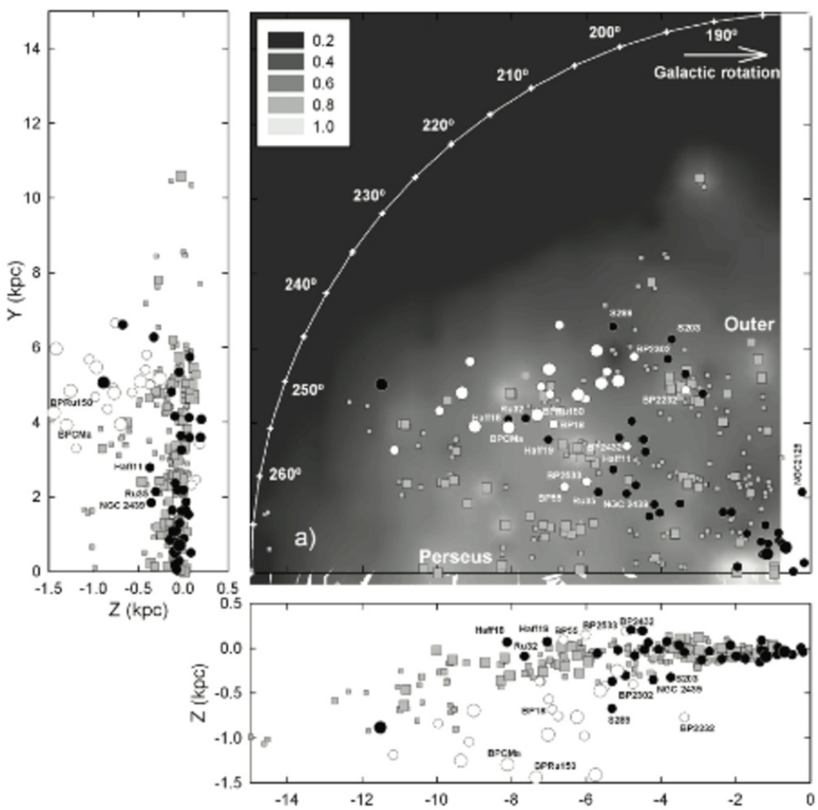

Figure 1. The spiral structure of the Galactic disk in the third quadrant from Vázquez et al. (2008). Solid dots indicate open clusters, while white dots indicate associations of young stars in the background of open star clusters. Finally, squares are for CO clouds. Notice the clear indication of the thin disk warp in the bottom panel.

Galaxy has two majors arms, Perseus and Scutum Crux, and two additional minor arms, Carina-Sagittarius and Norma Cygnus. The conclusion is then that the Milky Way is a two-arms spiral.

At odds with Churchwell et al. (2009), surveys like those of Levine et al. (2006) and Vázquez et al. (2008) show that Sagittarius is more prominent than Scutum Crux, and that Perseus is negligible compared to Norma Cygnus. This confirms the tradition that tracing spiral arms in our own Galaxy is challenging and complicated. And that the outcome still depends on the adopted tracers.

However, if we have to believe to what we see outside the Milky Way, the evidences from optical and radio surveys (HI, HII, CO) should be preferred. The picture emerging from these surveys (see Fig 1 and Levine et al. (2006) Fig. 4A,B) is that the Norma-Cygnus arm (also called outer arm) is prominent in the third quadrant, and its ideal prolongation encounters the distant arm detected by McClure-Griffiths et al. (2004) in the fourth quadrant. Besides, there are very minor indications of a Perseus arm in the third quadrant, and virtually none in the fourth. What is prominent in the third quadrant is a feature which resembles an extension of the local arm, visible both in optical (Vázquez et al. 2008) and in HI (Levine et al. 2006). The nature of this structure is unclear. Available observations show that it is most probably an inter-arm feature, a bridge, and not a proper arm. Its origin is not understood, but Purcell during the conference showed that it can have a tidal origin.

The spiral structure in the third quadrant is referred to as an excess of star formation (Benjamin, this conference) that artist's conception cannot reproduce. We believe this is not the case, but, simpler, it is so because we are looking at a privileged direction, where extinction has been traditionally known to be low (Fitzgerald 1968; Janes 1991; Moitinho 2001), thus permitting to see very far from the Sun.

2. The outer disk: density break, cut-off, truncation?

During the conference several speakers mentioned the fact that almost all disk galaxies show density breaks in the form of a change of slope in the disk surface brightness profile. According to GLIMPSE data (Churchwell et al. 2009; Benjamin & GLIMPSE360 Team 2013) this occurs also in our Milky Way, at a distance of about 13-14 kpc from the Galactic center. This distance coincides with the cut-off radius of the disk adopted in Galactic models like Besançon (Robin et al. 1992), and is referred to as the edge of the stellar disk (Minniti et al. 2011).

Star clusters, associations and gas are routinely found well beyond this distance (Carraro et al. 2010; Zasowski et al. 2013), and therefore naming this distance as *edge* or *truncation* of the disk is highly inappropriate. The cut-off, edge or truncation used in Galactic models is caused by not taking into account the disk warp and flare (Lopez-Corredoira et al. 2012), while claims like the ones in Minniti et al. (2011) are simply based on the incapability to detect correctly red clump stars below some magnitude limit, due to confusion and photometric errors.

The actual difficulties of Galactic models to reproduce star counts in the outer disk is shown in Fig 2 (Perren 2013), where star counts is several Galactic anti-center directions are compared with predictions from Besançon and TRILEGAL (Girardi et al. 2005) models. It is evident how much work is still needed on the model side.

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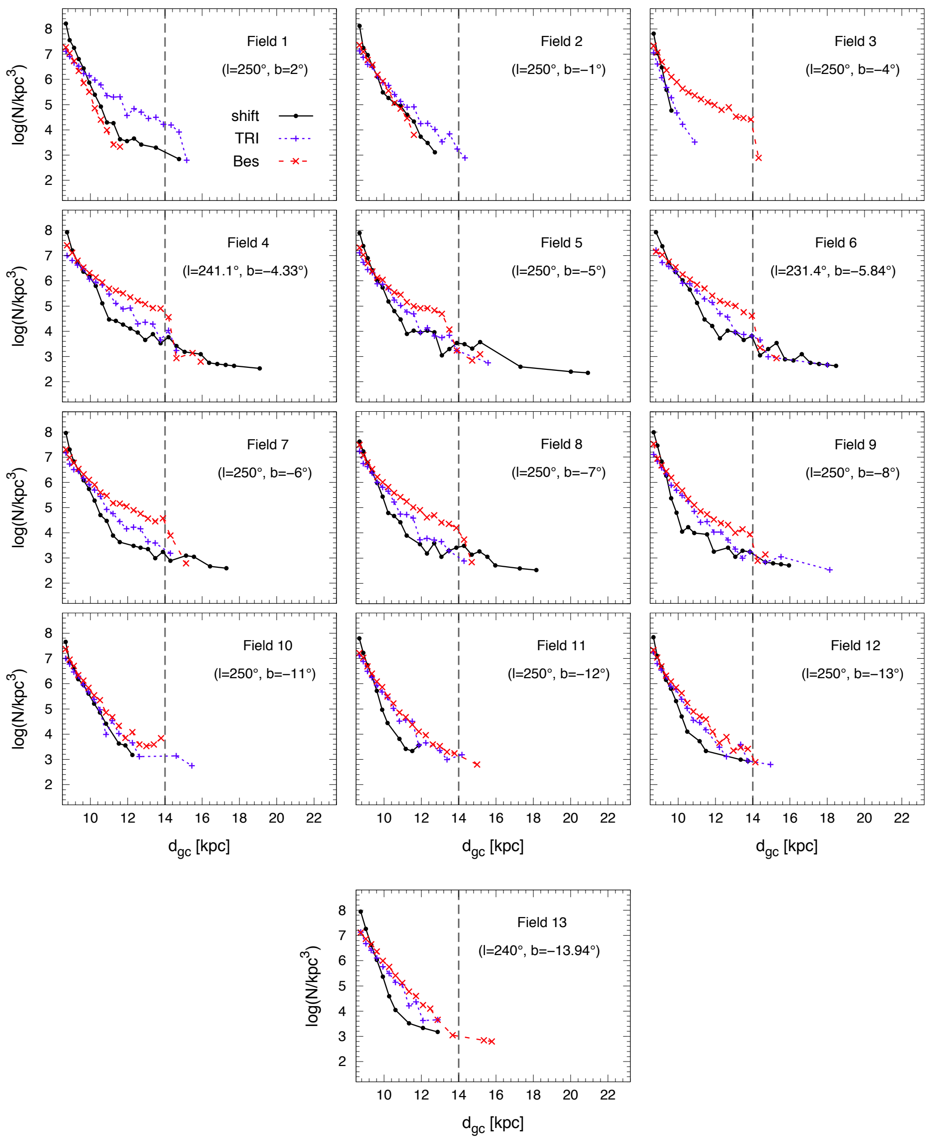

Figure 2. Star counts along several directions in the third Galactic quadrant (solid black lines). Red and blue lines indicate the expectation from Besancon and Trilegal models, respectively.

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