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New VIRAC proper motion maps show signature of galactic boxy/peanut bulge

Jonathan P. Clarke[1], Christopher Wegg[2], Ortwin Gerhard[1], Leigh C. Smith[3,4], Phil W. Lucas[4] and Shola M. Wylie[1]

[1]MPI für Extraterrestrische Physik, Gießenbachstraße, D-85748 Garching, Germany
email: jclarke@mpe.mpg.de

[2]Laboratoire Lagrange, Université Côte d' Azur, Observatoire de la Côte d' Azur, CNRS, Bd de l'Observatoire, 06304 Nice, France

[3]Institute of Astronomy, University of Cambridge, Madingley Rd, Cambridge, CB3 0HA, UK

[4]School of Physics, Astronomy and Mathematics, University of Hertfordshire, College Lane, Hatfield AL10 9AB, UK

Abstract. We have derived absolute proper motions of stars in the Galactic bulge region combining the VVV InfraRed Astrometric Catalogue (VIRAC) and *Gaia*. We use the proper motions to study the kinematic structure of the bulge both integrated along the line-of-sight and in magnitude intervals using red clump stars as standard candles. In parallel we compare to a made-to-measure barred dynamical model, folding in the VIRAC selection function, to understand and interpret the structures that we observe. The barred dynamical model, which contains a boxy/peanut bulge, and has a pattern speed of 37.5 $\mathrm{km\,s^{-1}\,kpc^{-1}}$, is able to reproduce all structures impressively well.

Keywords. Galaxy: bulge, Galaxy: kinematics and dynamics, Galaxy: structure

1. Introduction

There are still a number of open questions relating to the structure of the Milky Way's (MW) barred bulge. Does there exist a secondary classical bulge component in the central parts of the bulge (e.g. Shen *et al.* 2010)? Is the split red clump (e.g. Nataf *et al.* 2010) the result of a funnel shaped component in the bulge, now commonly referred to as an X-shape, or due to a population effect combined with the superposition of multiple bulge components (e.g. Lee *et al.* 2015)?

The VVV InfraRed Astrometric Catalogue (VIRAC) (Smith *et al.* 2018) provided $\approx 1.75 \times 10^8$ proper motion measurements in the $(-10 < l\ (\mathrm{deg}) < 10, -10 < b\ (\mathrm{deg}) < 5)$ Galactic bulge region. Combined with data from *Gaia* (Gaia Collaboration 2018) to work in an absolute reference frame, these data present unprecedented opportunities for studying the MW bulge. Dynamical models are an essential tool when interpreting the vast data quantity provided by current stellar surveys. We use a barred fiducial model, with pattern speed $\Omega = 37.5\ \mathrm{km\,s^{-1}\,kpc^{-1}}$ (Portail *et al.* 2017), to predict the VIRAC proper motions.

Here we focus on the comparison between the integrated kinematic maps. A more extended description of the work described here is given in Clarke *et al.* (2019).

2. Integrated Kinematics of the Milky Way barred bulge

Figure 1 shows the comparison between the VIRAC data, top row, and the fiducial model, bottom row, for the integrated kinematics. In general we see excellent agreement

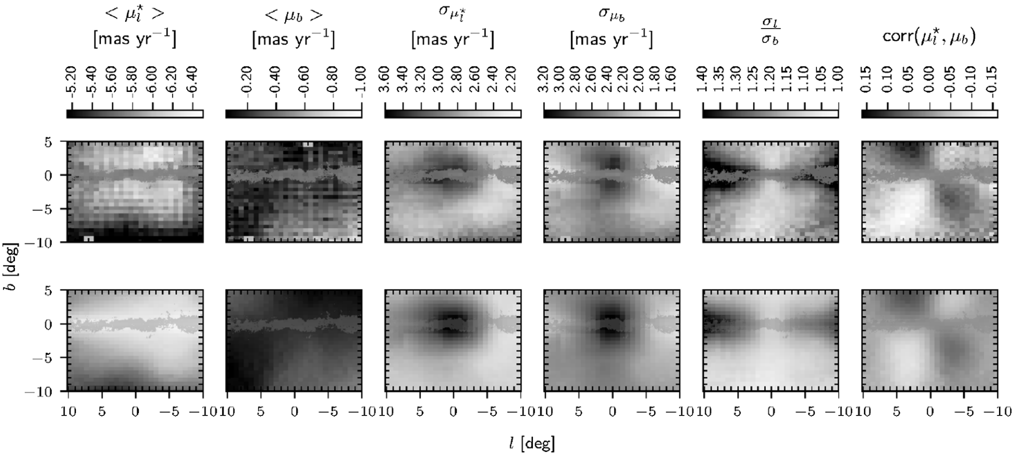

Figure 1. Integrated kinematic maps of the on-sky Milky Way bulge for the VIRAC data Smith *et al.* (2018) (top row) and the fiducial bar model Portail *et al.* (2017) (bottom row). The columns show, from left to right, the mean longitudinal and latitudinal proper motions, the corresponding dispersions, the dispersion ratio, and the proper motion correlation. The kinematics were integrated over the magnitude interval $11.8 < K_{s0}$ (mag) < 13.6. The mask at $b \approx 0°$ covers regions of high extinction, $A_K > 1.0$ mag, where the VIRAC data is less trustworthy. Adapted from Clarke *et al.* (2019).

between the structures seen in the data and those reproduced by the fiducial model. The model reproduces the lobed structure seen in the mean longitudinal proper motion data which is caused by the viewing angle of the bar, 28° relative to the sun-GC line (Wegg & Gerhard 2013; Portail *et al.* 2017), combined with the boxy/peanut bulge structure. The mean latitudinal proper motion map shows a clear quadrupole signature which, while offset from axisymmetry due to the effect of the solar motion, is caused by the bar pattern rotation. Both dispersion maps exhibit a high dispersion region around the Galactic centre (GC) caused by stars falling into the deep gravitational potential well. Away from the GC both dispersions also show significant structures, e.g. the b-symmetrical lobe of lower dispersion at negative l caused by bar orientation. The correlation maps also show excellent agreement between the model and the VIRAC data. The magnitude sliced analysis shows there are correlated proper motions at all magnitude intervals through the bulge (Clarke *et al.* 2019). The maps shown in figure 1 and the further analysis presented in Clarke *et al.* (2019) demonstrate the impressive agreement between the predictions of the fiducial model and the VIRAC data. We see no discrepancy that might be attributed to the presence of a secondary classical bulge component. Furthermore the X-shaped boxy/peanut bulge in the model provides an excellent match to the structures seen in the VIRAC data providing strong evidence for that scenario.

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