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Modelling the Milky Way with Gaia - TGAS

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The recent first data release from the European Space Agency's Gaia mission gives us a new window on the Solar neighbourhood. Gaia DR1 contains the Tycho-Gaia Astrometric Solution, a catalogue of ~2x10^6 stars in common between Gaia and Tycho-2, with positions on the sky, parallaxes and proper motions. We use this new data to make a measurement of $V_\odot$ and R_0 in Section 1 using a novel method (Hunt, Bovy & Carlberg, 2017, ApJL, 832, L25, and then attempt to constrain the nature of the Perseus Spiral arm in Section 2 (Hunt, Kawata, Monari, Grand, Famaey & Siebert, 2017, MNRASL, 467, L21).

1a. The data

- We can cross match the TGAS data with data from the Radial Velocity Experiment (RAVE), giving us ~200,000 stars with six dimensional phase space information.
- We can then do a simple coordinate transform to get (U,V,W) (km s^{-1}) for the sample.
- Fig. 1 shows the resulting tangential velocity distribution, which exhibits a 'dip' around -240 km s^{-1}.

1b. The explanation?

- Carlberg & Innanen (1987, AJ, 94, 666) predicted this feature:
- Stars with close to zero angular momentum should plunge towards the Galactic center and be scattered onto chaotic orbits but the strong nuclear potential.
- We performed simulations of this effect by injecting test particles into a Milky Way like potential.
- Fig. 2 shows three example orbits. The top panel shows the orbit of a star with V=0 km s^{-1} which exhibits chaotic behavior. The two lower panels show orbits with V=10 and V=-10 km s^{-1}, which remain on regular orbits.

1c. Modelling the feature

- We calculate the percentage of orbits which are not scattered to higher chaotic orbits and thus remain close to the disc plane for a variety of different values of $V_\odot$.
- The top panel of Fig. 3 shows the effect for different values of $V_\odot$. It shows the shape of the feature remains unaffected.
- The lower two panels show the effect on the shape of the feature for different definitions of 'remain close to the disc plane'. The shape of the feature is similar for 50 pc and 300 pc, so we use 300 pc.

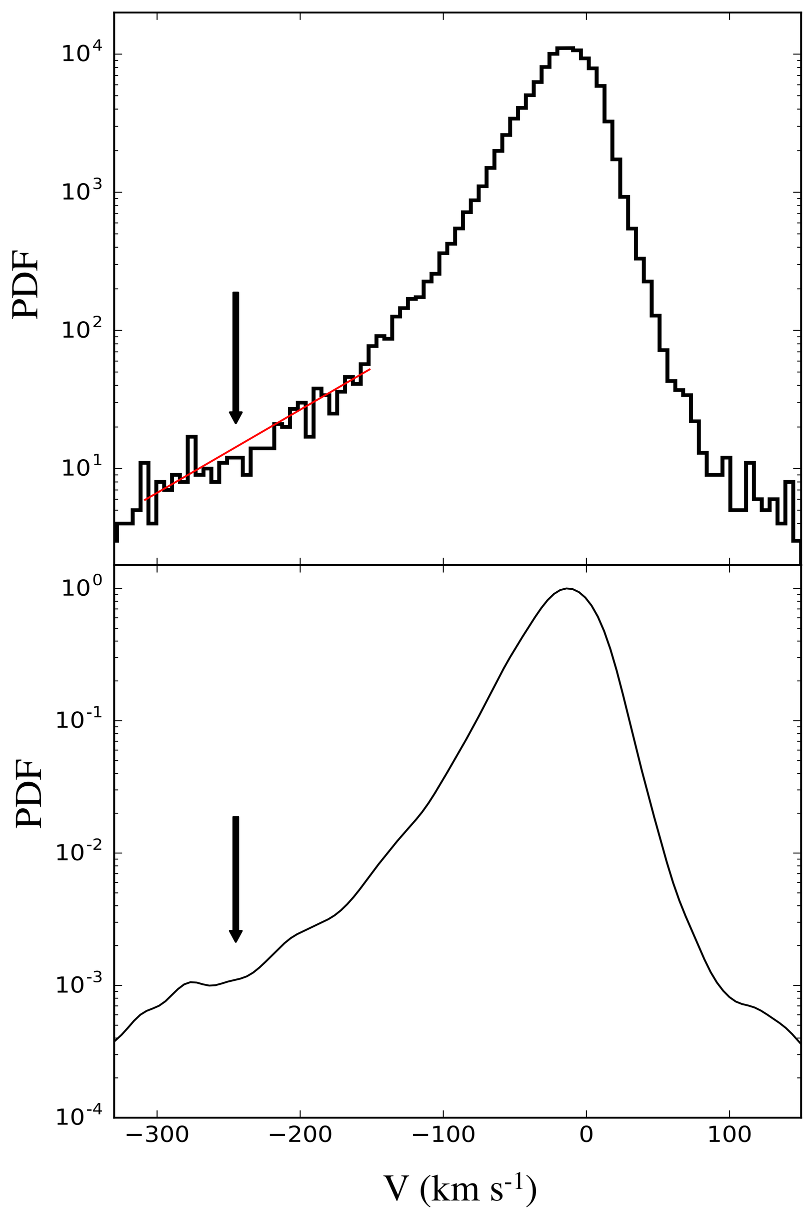

Figure 1: Tangential velocity distribution V (km s^{-1}) for cross matched TGAS and RAVE.

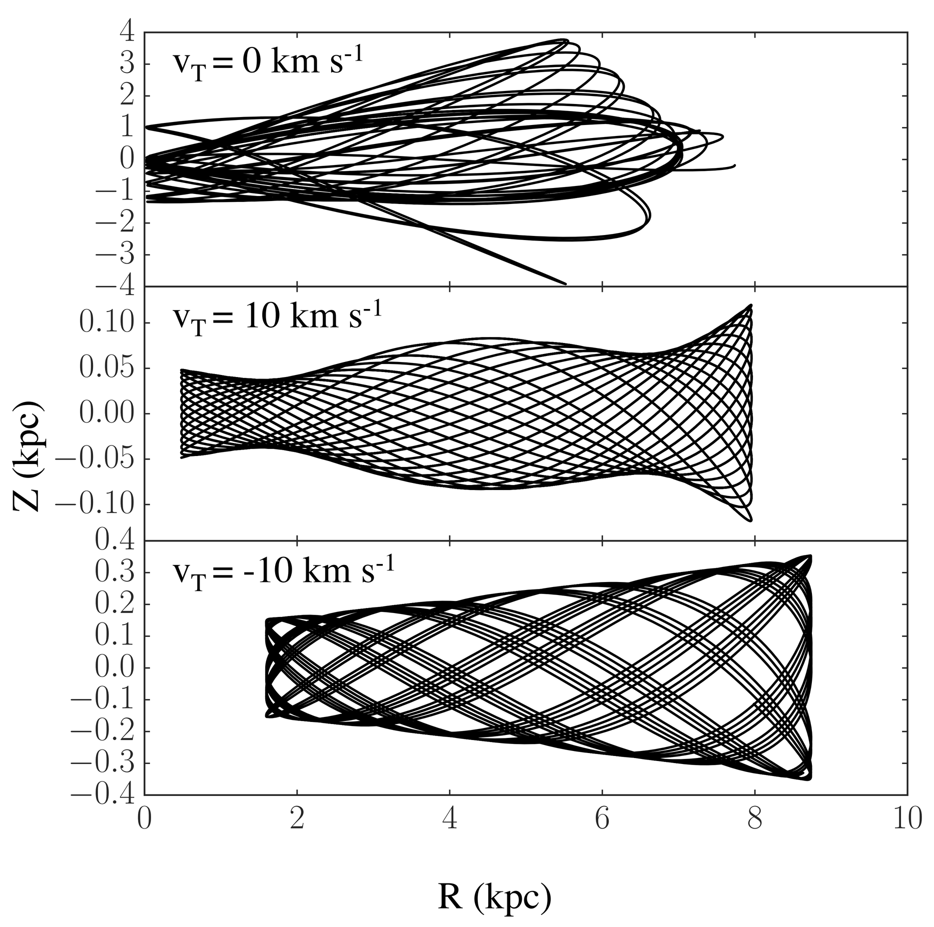

Figure 2: Orbits, chaotic (upper panel) and regular (central and lower panels)

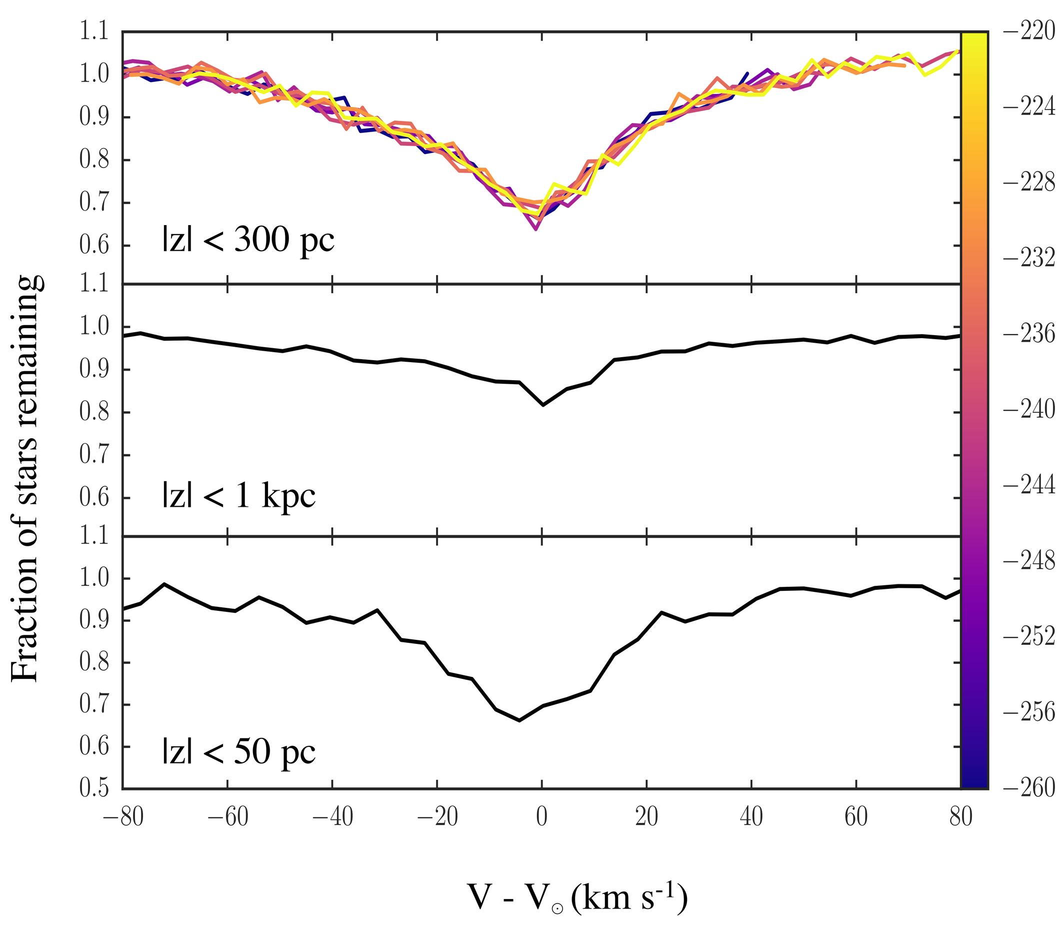

Figure 3: Fraction of stars remaining on stable orbits for |z|<300 pc (upper), 1 kpc (middle) and 50 pc (lower).

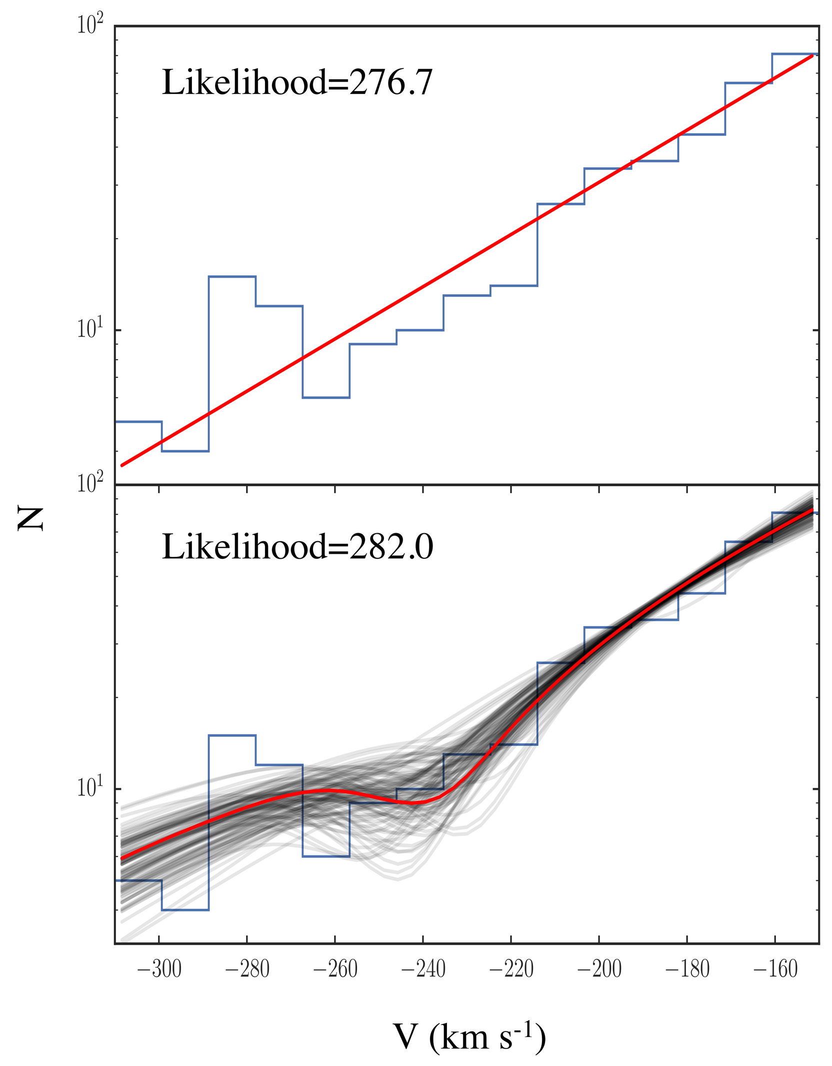

Figure 4: An exponential (upper) and the 'dip function' (lower) fit to the tail of the tangential velocity distribution.

1d. Fitting the data & resulting measurement of $V_\odot$ and R_0

- We create a function from the distribution in Fig. 3, combine it with an exponential and fit it to the data. We also fit a pure exponential for comparison. We find that the data prefers a 'dip' centered on -239 km s^{-1} over the flat exponential at a significance of ~2.7σ. We run MCMC to calculate uncertainties giving us a measurement of $V_\odot$=239±9 km s^{-1} and R_0=7.9±0.3 kpc when combined with the proper motion of Sagittarius A*. If the feature is real, the next Gaia data release will allow us to repeat the measurement at a precision of ~1 km s^{-1} at which point systematics will become extremely important.

2a. Spiral arms in TGAS?

- We cannot see far enough in the TGAS data to observe the Perseus arm directly, but we can examine the kinematics of stars on the near trailing side of the spiral arm.
- The top panel of Fig. 5 (Kawata et al. 2014, EAS, 67, 247) shows that the Galactocentric rotation velocity distribution is very different on the trailing near side (red), and the leading far side (blue) of a N-body spiral arm, with a lot of structure in the distribution.
- In contrast, the lower panel of Fig. 5 shows a very similar smooth distribution on the near and far side of a density wave like spiral arm.
- We do not have enough stars in TGAS+LAMOST to calculate v_{rot}, but we can use TGAS proper motions alone, v_l at (l,b)=(180,0) deg is analogous to Galactocentric rotation velocity.

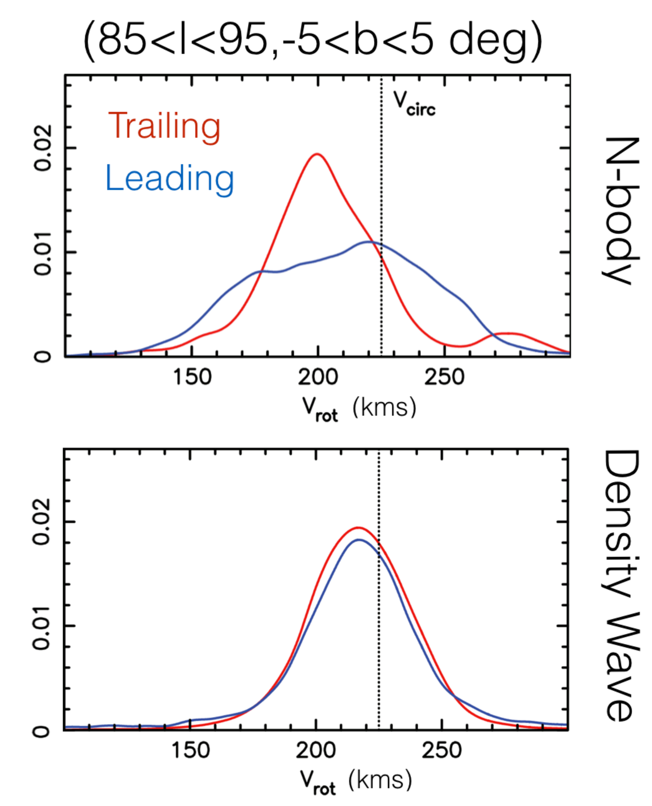

Figure 5: V_{rot} distribution for a N-body model (upper) and a density wave model (lower) at (l,b)=(90,0)±5 deg (Kawata et al 2014).

2b. Comparison with simulation

- Fig. 6 shows the distribution of v_l (km s^{-1}) at (l,b)=(180,0)±5 deg (red) overlaid with predictions from a N-body model with a strong spiral arm (left), an N-body model with a weak spiral arm (centre) and a test particle model with density wave like arms (right).
- The left and right panels of Fig. 6 shows the strong arm model and the density wave model are not a good fit to the data. The centre panel is closer, but the high velocity bump caused by the corotation of the N-body arm is still too strong compared with the data.
- We propose that a still weaker arm may reproduce the data nicely, as the strength of the arm effects the acceleration of the stars in the high velocity tail.
- Alternatively, the bump may be a resonance feature of a density wave like arm. Future Gaia data should enable us to better distinguish between the models.

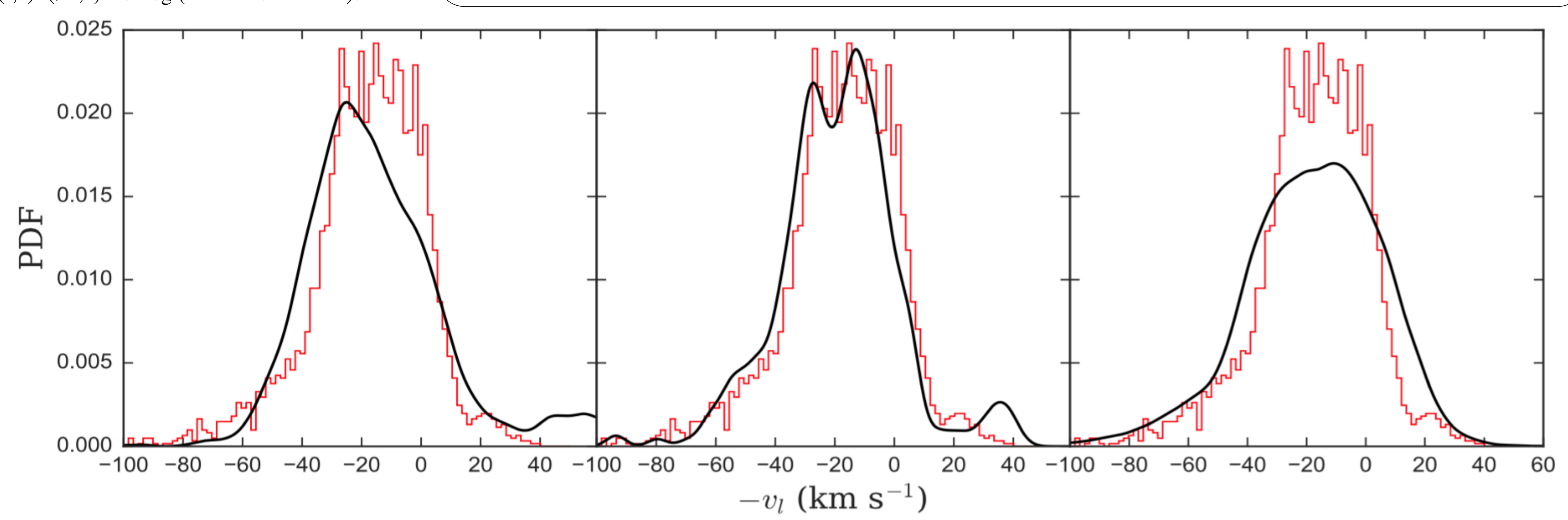

Figure 6: Distribution of v_l (km s^{-1}) at (l,b)=(180,0)±5 deg (red) overlaid with the prediction of a N-body model with a strong arm (left), a weak arm (centre) and a test particle model with density wave like spiral arms (right). (Hunt et al. 2017)