The vertical force in the solar neighbourhood

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Friday 28 April 2017
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The force-equation

- We explore the vertical force-equation:

\[- \frac{d \Phi}{dz} \equiv F_z = \frac{\sigma_z^2}{\nu} \frac{d \nu}{dz} + \frac{d \sigma_z^2}{dz} + \frac{\text{cov}(v_R, v_z)}{R} \left[ 1 - \gamma_{\nu, R} - \gamma_{\text{cov}(v_R, v_z), R} \right] \]

where:

\[\gamma_{Q(x),x} = - \frac{x}{Q(x)} \frac{dQ(x)}{dx}\]

- The surface mass density is approximated by:

\[\Sigma(z) \approx \frac{|F_z(z)|}{2\pi G}\]
The vertical force equation & dark matter

- Near the mid-plane, the baryonic surface density is expected to be dominant over a possible DM surface density.

- Therefore, to constrain a DM density we need to probe up to sufficiently large galactic heights.
Data

• TGASxRAVE = 6D phase-space information for about 200,000 stars!

• Selection Criteria:
  parallax > 0
  parallax_error / parallax < 0.2

• Parallaxes are either taken from TGAS or from RAVE DR5: the measurement with the best relative error on the parallax is used.

  • RAVE radial velocities if:
    eHRV < 8 km/s
    CorrelationCoeff > 10

  • RAVE distances only if:
    ALGO_CONV != 1
    SNR > 20
The effect of the maximum relative parallax errors on the sample

- We choose a maximum of 20% relative distance error
Distribution of stars in our sample

20% parallax error sample: ~110000 stars
30% parallax error sample: ~175000 stars

Sun at R = 8.3 kpc & z=+14 pc
vLSR = 228.5 km/s
(U,V,W) = (11.1, 12.24, 7.25) km/s
\[
\frac{-d\Phi}{dz} \equiv F_z = \frac{\sigma_z^2}{\nu} \frac{d\nu}{dz} + \frac{d\sigma_z^2}{dz} + \frac{\text{cov}(v_R, v_z)}{R} \left[ 1 - \gamma_{\nu, R} - \gamma_{\text{cov}(v_R, v_z), R} \right]
\]
Vertical velocity dispersion at the solar radius.
The vertical dispersion profile

\[-\frac{d\Phi}{dz} \equiv F_z = \frac{\sigma_z^2}{\nu} \frac{d\nu}{dz} + \frac{d\sigma_z^2}{dz} + \frac{\text{cov}(v_R, v_z)}{R} \left[ 1 - \gamma_{\nu,R} - \gamma_{\text{cov}(v_R,v_z),R} \right]\]
Contribution of the individual terms

\[- \frac{d\Phi}{dz} \equiv F_z = \frac{\sigma_z^2}{\nu} \frac{d\nu}{dz} + \frac{d\sigma_z^2}{dz} + \frac{\text{cov}(v_R, v_z)}{R} \left[ 1 - \gamma_{\nu,R} - \gamma_{\text{cov}(v_R,v_z),R} \right] \]
The implied surface mass density

\[ \Sigma(z) \approx \frac{|F(z)|}{2\pi G} \]
Mass model

• We model the stellar contribution in the solar neighbourhood by a single disk:

\[ M_{\text{disk}} = 4.5 \times 10^{10} M_\odot \]
\[ h_R = 2.5 \text{ kpc} \]
\[ h_z = 0.3 \text{ kpc} \]

• We allow for a dark matter component by assuming a constant dark matter density.
Mass models

\[ \rho_{DM}(R = R_\odot, z = 0) = 0.010 \, M_\odot/\text{pc}^3 \]

\[ \text{error}(\rho_{DM,R_\odot}) = 0.003 \, M_\odot/\text{pc}^3 \]
Mass models

\[ \rho_{DM}(R = R_\odot, z = 0) = 0.007 \, M_\odot/\text{pc}^3 \]

\[ \text{error}(\rho_{DM,R_\odot}) = 0.003 \, M_\odot/\text{pc}^3 \]
Mass models

\[
\rho_{DM}(R = R_\odot, z = 0) = 0.009 \, M_\odot/pc^3
\]

\[
\text{error}(\rho_{DM, R_\odot}) = 0.005 \, M_\odot/pc^3
\]
\[ \rho_{DM}(R = R_\odot, z = 0) = 0.018 \, M_\odot/\text{pc}^3 \]

\[ \text{error}(\rho_{DM,R_\odot}) = 0.005 \, M_\odot/\text{pc}^3 \]
Varying $h_z$
Varying \((h_R, h_z)\)

fits from \(z=0.3\) kpc
30% parallax error sample

- Left graph: Comparison of 20% and 30% parallax error samples. The blue line represents the 20% sample, and the red line represents the 30% sample. Error bars are present for each data point.

- Right graph: Data points with error bars, along with a fitted curve represented by a purple line. The coordinates (a, b) and their associated errors ε(a, b) are indicated as (1008, 340.4) and (33.61, 1.825) respectively.

- Bottom graph: A plot showing the sum of mass density (Σ [M/pc^2]) against the radial distance (z [kpc]), with error bars for each data point.
Mass models

\[ \rho_{DM}(R = R_\odot, z = 0) = 0.017 \, M_\odot/\text{pc}^3 \]

\[ \text{error}(\rho_{DM, R_\odot}) = 0.005 \, M_\odot/\text{pc}^3 \]
Mass models

\[ \rho_{DM}(R = R_\odot, z = 0) = 0.027 \, M_\odot/pc^3 \]

\[ \text{error}(\rho_{DM, R_\odot}) = 0.005 \, M_\odot/pc^3 \]
Varying $h_z$

The graph shows the variation of $\Sigma(Z)$, the surface density of mass per area ($M_\odot \text{ pc}^{-2}$), with $Z$, the distance in kiloparsecs, for different values of $h_z$. The legend indicates:

- $h_z=350$ pc (red line)
- $h_z=300$ pc (green line)
- $h_z=250$ pc (blue line)

The graph illustrates how the surface density changes with $Z$ for each value of $h_z$. The error bars show the uncertainty in the measurements.
Varying \((h_R, h_z)\), 30% sample

fits from \(z=0.7 \text{ kpc}\)
Summary

• We attempted to model the DM density by a single disk component.

• We obtain large errors and are looking at the data, to see why we obtain different results.

• Errors on disk parameters can have a significant influence on the implied dark matter density at the solar position.

• Gaia DR2: more & accurate proper motions, distances and radial velocities.
Questions