



Universiteit
Leiden

THE MILKY WAY TOMOGRAPHY

The Milky Way Tomography with Sloan Digital Sky Survey. V. Mapping the Dark Matter Halo: Loebman et al. (2014)

Milky Way Mass with K Giants and BHB Stars Using LAMOST, SDSS/SEGUE, and Gaia: 3D Spherical Jeans Equation and Tracer Mass Estimator: Bird et al.(2022)

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Galaxies: Structure, Dynamics and Evolution April 2026

Introduction

Loebman et al. (2014)

- Dark matter is an important constituent of galaxies
- It is poorly described in the Milky Way
- How can we study its effects?
- Where is it distributed?

Methodology

$$-\frac{\partial \Phi}{\partial R} = a_R = \sigma_{RR}^2 \frac{1}{v} \frac{\partial v}{\partial R} + \frac{\partial \sigma_{RR}^2}{\partial R} + \sigma_{RZ}^2 \frac{1}{v} \frac{\partial v}{\partial Z} + \frac{\partial \sigma_{RZ}^2}{\partial Z} + \frac{\sigma_{RR}^2}{R} - \frac{\sigma_{\phi\phi}^2}{R} - \frac{v_\phi^2}{R},$$

$$-\frac{\partial \Phi}{\partial Z} = a_Z = \sigma_{RZ}^2 \frac{1}{v} \frac{\partial v}{\partial R} + \frac{\partial \sigma_{RZ}^2}{\partial R} + \sigma_{ZZ}^2 \frac{1}{v} \frac{\partial v}{\partial Z} + \frac{\partial \sigma_{ZZ}^2}{\partial Z} + \frac{\sigma_{RZ}^2}{R}.$$

Gradients of gravitational potential

$$v(R, Z, \phi) = v_D(R, Z) + v_H(R, Z).$$

Juric+2008

$$\sigma_{RR}^2 = \sigma_{rr}^2 \cos(\alpha)^2 + \sigma_{\theta\theta}^2 \sin(\alpha)^2,$$

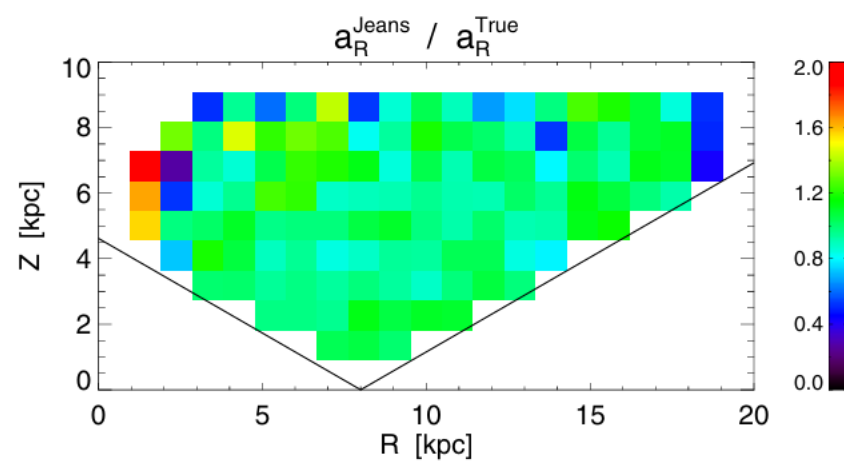
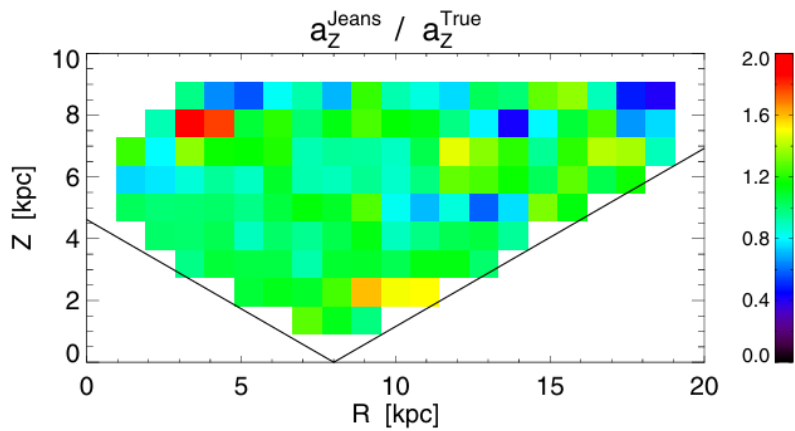
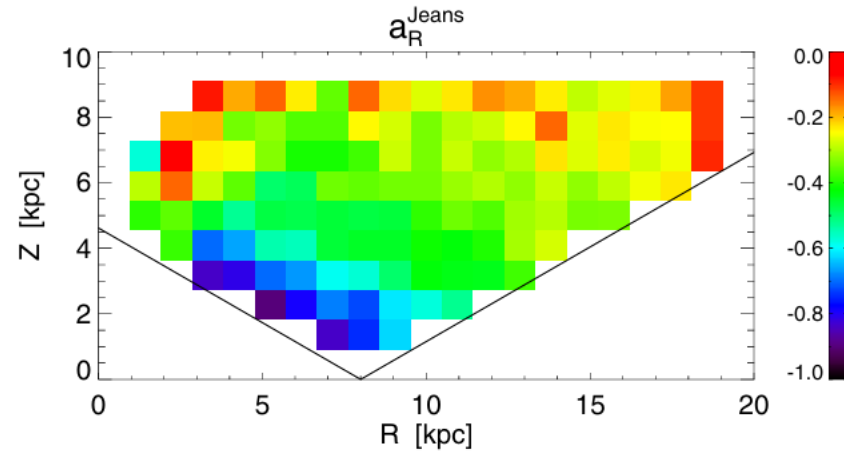
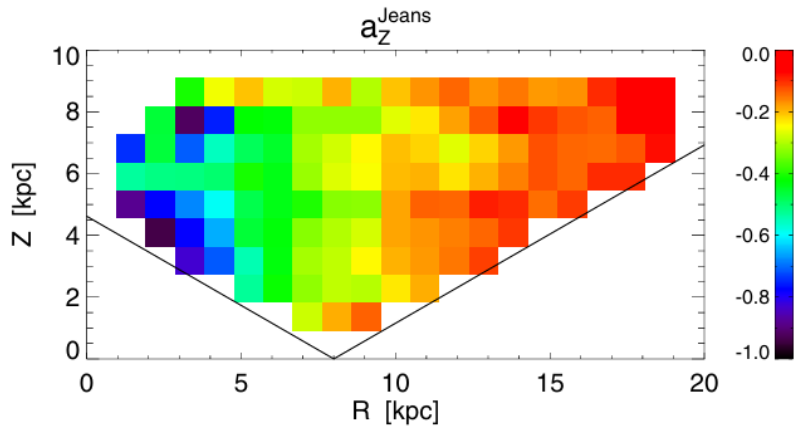
$$\sigma_{ZZ}^2 = \sigma_{rr}^2 \sin(\alpha)^2 + \sigma_{\theta\theta}^2 \cos(\alpha)^2,$$

$$\sigma_{RZ}^2 = (\sigma_{rr}^2 - \sigma_{\theta\theta}^2) \sin(\alpha) \cos(\alpha),$$

Bond+2010

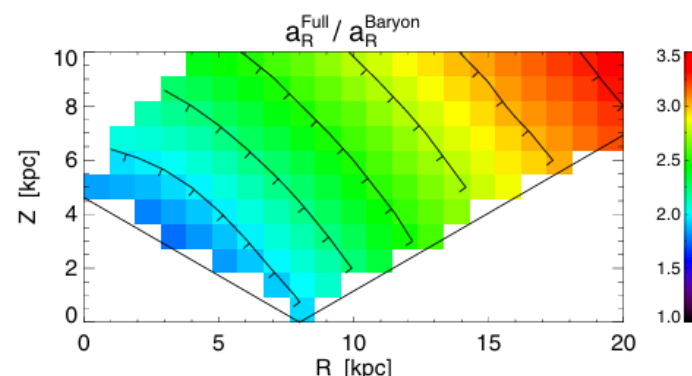
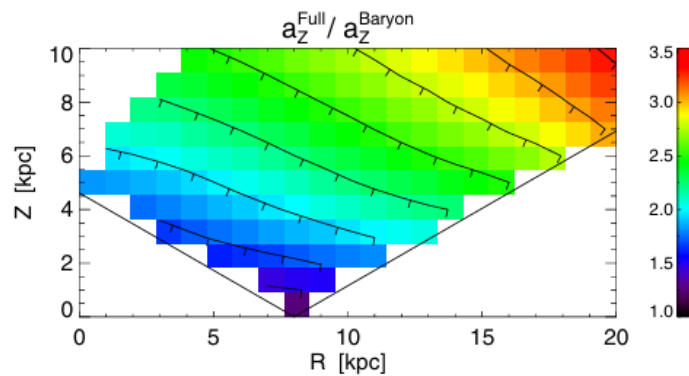
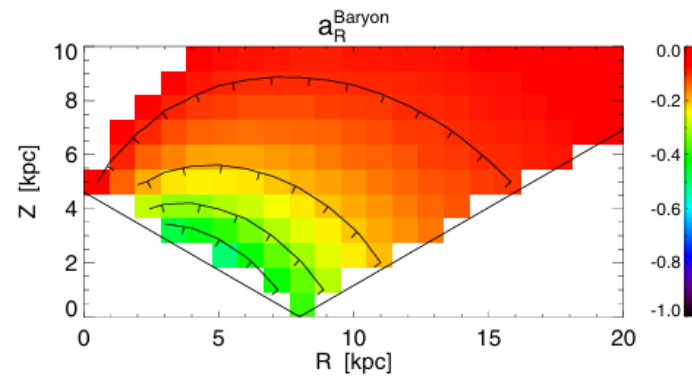
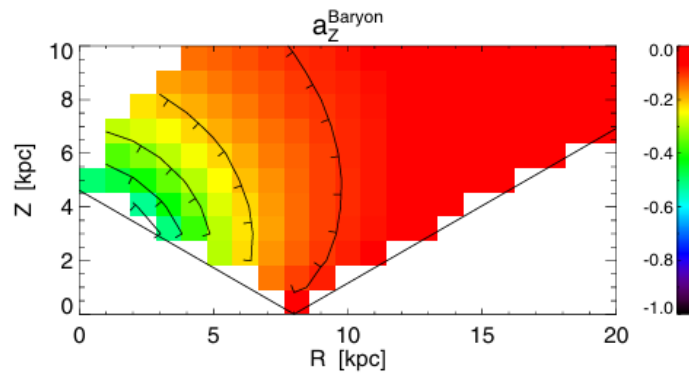
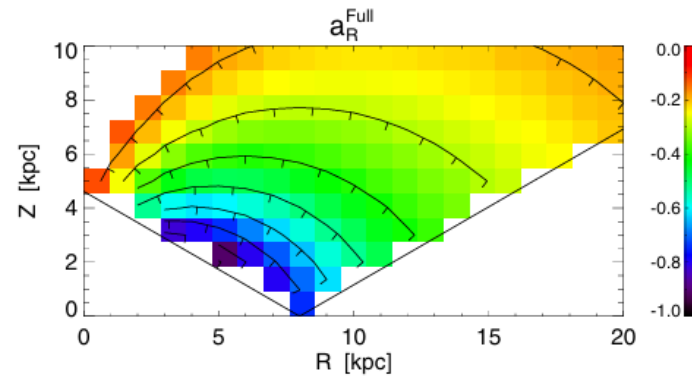
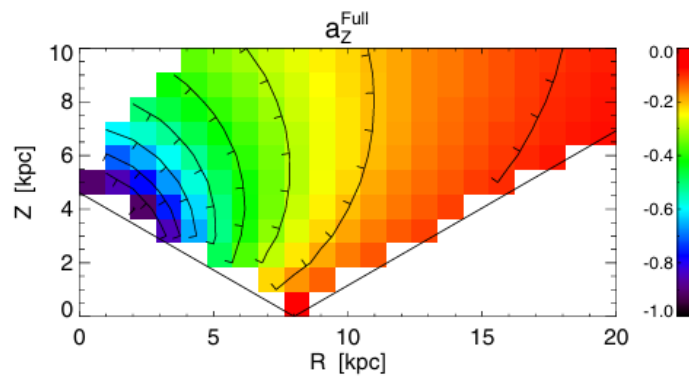
- Test the validity of the Jeans equations using a N-body & SPH simulation + apply the Jeans Equations to stars from SDSS catalogue

Discussion



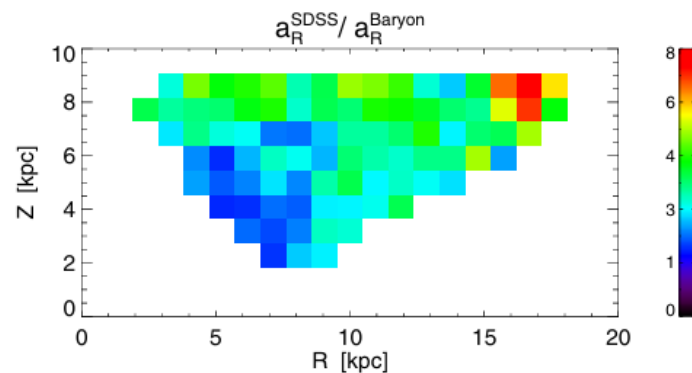
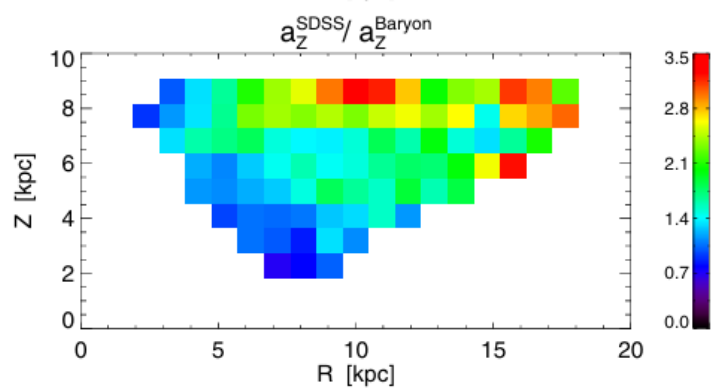
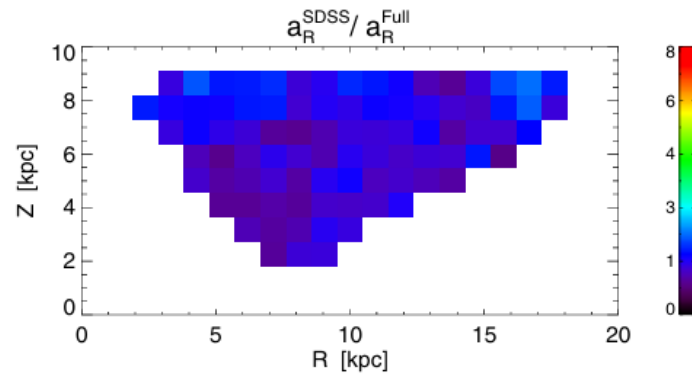
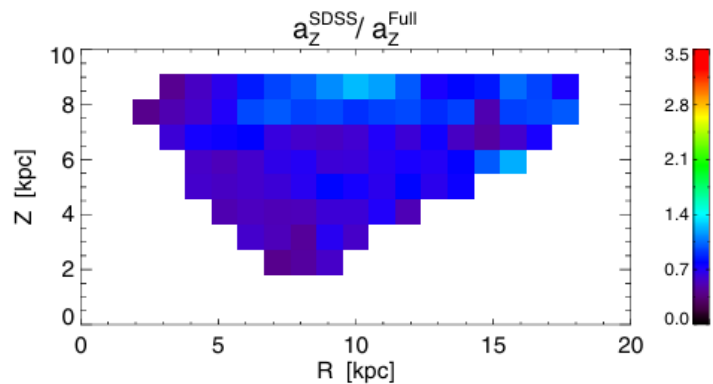
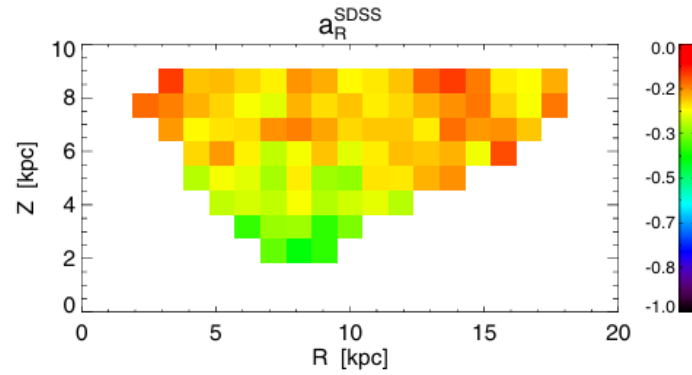
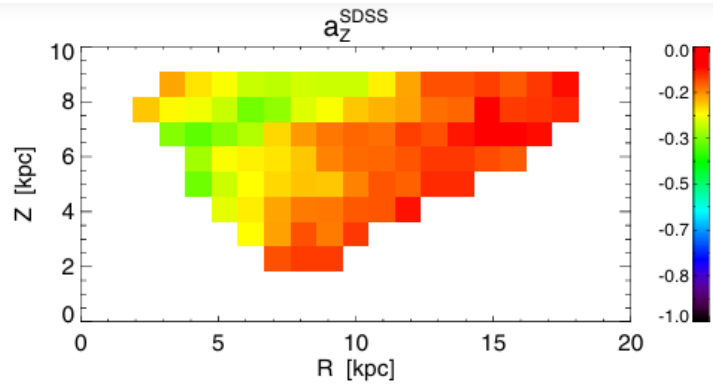
- The magnitude of the acceleration decreases with radius
- Mean ratio=1.02 & 1.05
- $\sigma \sim 0.13$ & 0.18
- Jeans equation recover very well the accelerations
- Safe to apply to SDSS data!

Discussion



- At large distances, N-body simulation accelerations are ~ 3 times higher when DM is taken into account!

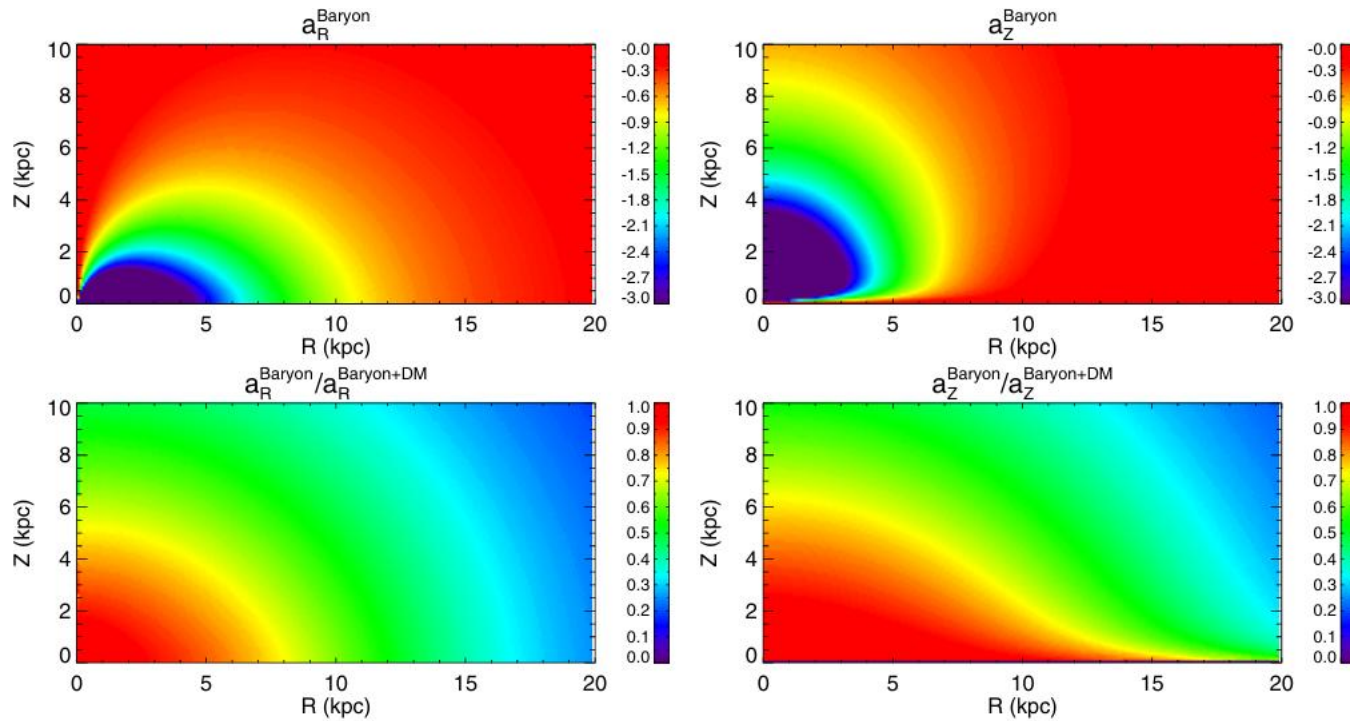
Discussion



- Same correlations than before

Discussion

- It is important to measure how much visible matter and DM contributes to acceleration individually



Bovy&Riv (2023)

$$\Phi(R, Z) = f_{BR} \Phi_{\text{bar}}(R, Z) + \Phi_{\text{DM}}(R, Z),$$

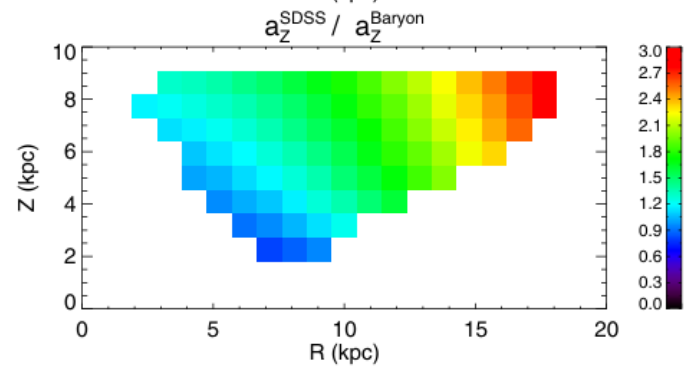
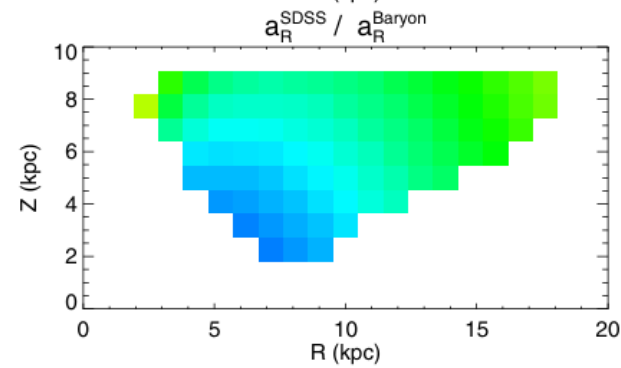
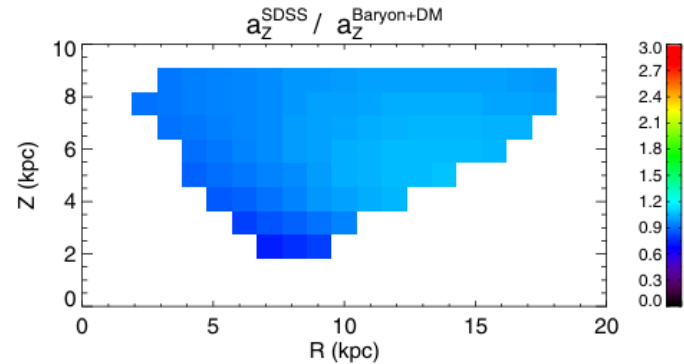
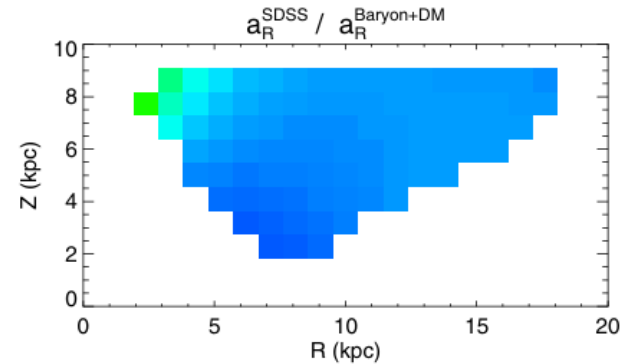
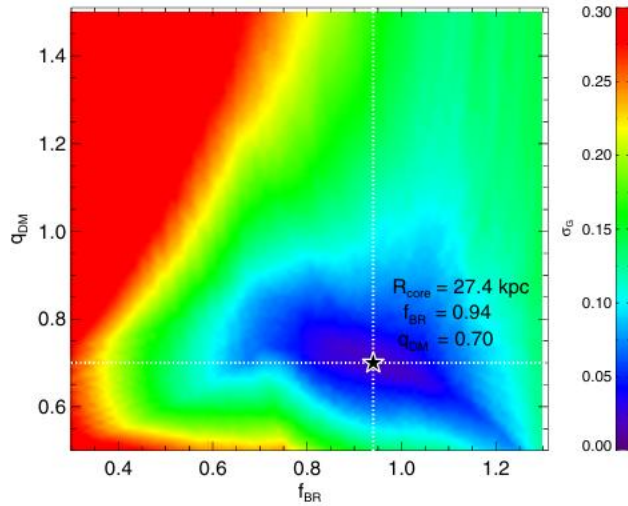
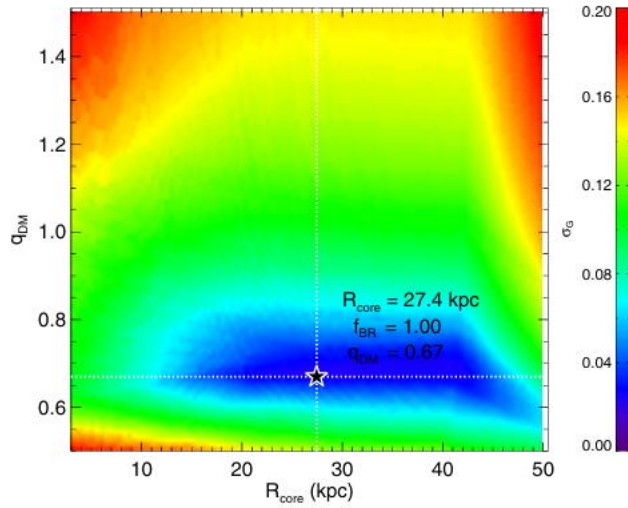
$$\Phi_{\text{DM}}(R, Z) = \frac{1}{2} v_o^2 \ln \left(\frac{R^2 + (Z/q_{\text{DM}})^2 + R_{\text{core}}^2}{R_{\odot}^2} \right)$$

Binney&Tremaine (1987)

How well does the spherically symmetric DM halo fit the SDSS-based results?

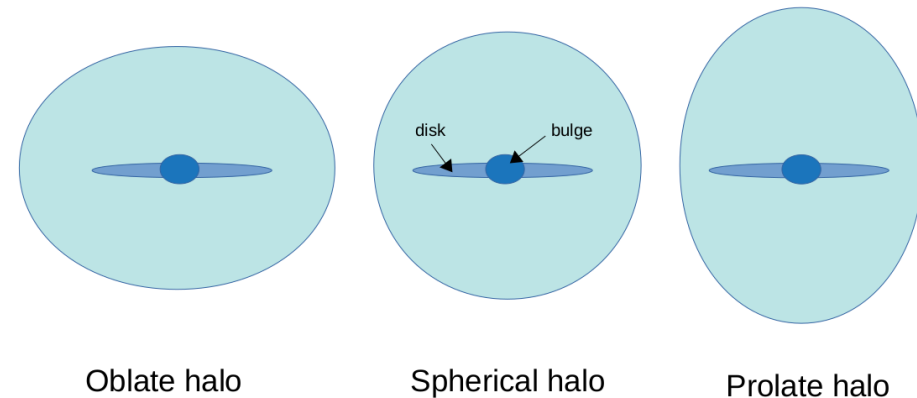
Discussion

- DM halo is not spherical!



Conclusion Loebman et al. (2014)

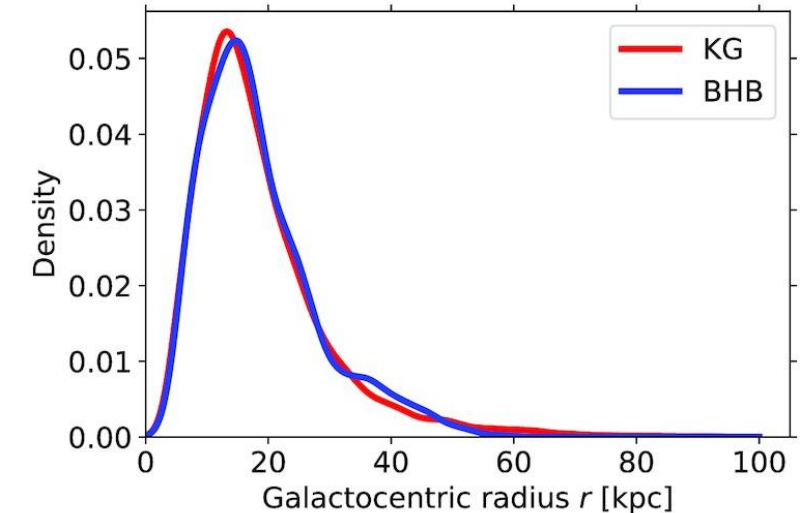
- Stellar kinematics from SDSS → acceleration maps of the Milky Way
- Acceleration cannot be explained by baryonic matter
- Evidence for dark matter halo
- Shape of halo: oblate



Kumar+2021

Bird et al. (2022)

- Milky Way mass with K giants and BHB stars using LAMOST, SDSS/SEGUE, and Gaia : 3D spherical Jeans equation and tracer mass estimator
- Methods:
 - Spherical Jeans equation (similar to Loebman et al.)
 - Tracer mass estimator



Assuming a particle is on a circular orbit at radius r , there is a relationship between the circular velocity v_c and $\frac{d\Phi}{dr}$

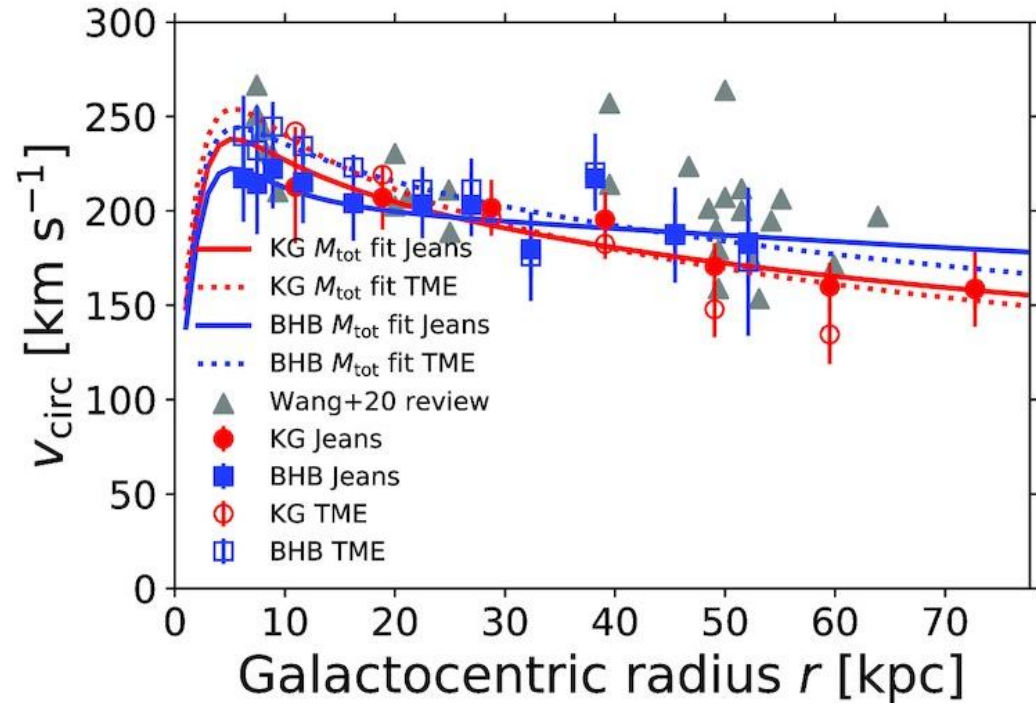
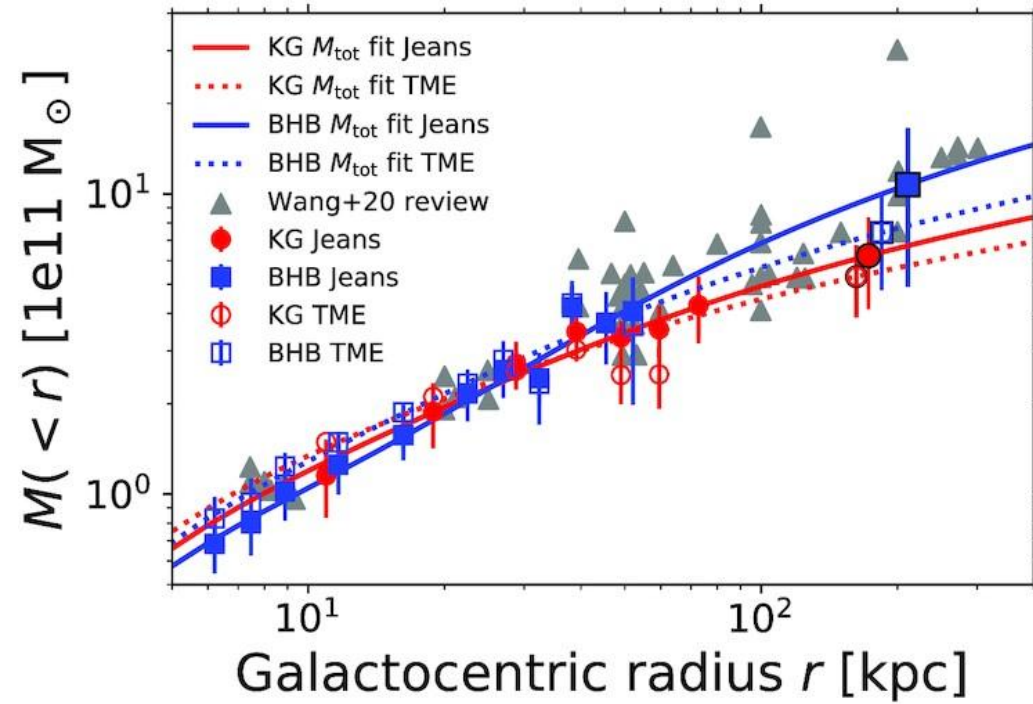
$$\frac{d\Phi}{dr} = \frac{GM(<r)}{r^2} = \frac{v_c^2}{r}$$

Using this relation, the Jeans Equation can be written as

$$v_c^2 = \frac{GM(<r)}{r} = -\bar{v}_r^2 \left(\frac{d \ln \nu}{d \ln r} + \frac{d \ln \bar{v}_r^2}{d \ln r} + 2\beta \right)$$

$$M(<r) \approx \frac{r^{0.5}(\gamma - \alpha - 2\beta)}{GN} \sum_{i=1}^N r_i^{0.5} (V_{r,i} - \langle V_r \rangle)^2.$$

Bird et al. (2022)



Conclusion

- Loebman+2014: Local acceleration fields
- Bird+2022: Halo tracers
- Consistent results
- Complementary constraints on MW halo and enclosed mass