# Weighing our Dark Halo

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# Overview

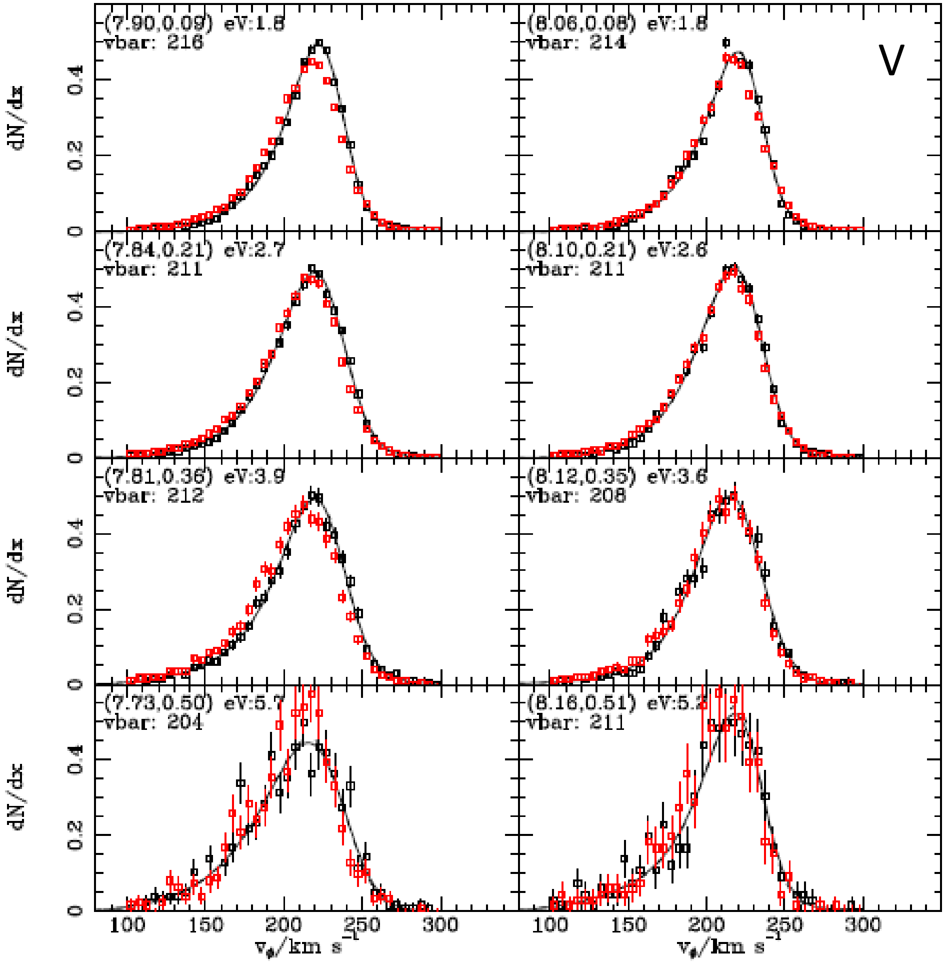
- 5 papers
  - Binney, Burnett & the RAVE collaboration 2014
  - Piffl, Binney & the RAVE collaboration 2014
  - Piffl Penoyre & Binney 2015
  - Binney & Piffl 2016
  - Cole & Binney 2016

# The physical idea

- We fit an analytic f(J) to the kinematics of RAVE stars
- The kinematics essentially fixes the dependence of f on $J_r$ and $J_z$
- From $V_c(R)$ we know how much mass is need inside R
- If all this mass is put into the disc, the stellar disc is too thin
- We decant mass from the disc to a dark halo until the disc has the observed thickness
- The leading uncertainty is the flattening of the halo
    - A flatter halo creates more $K_R$ and $K_z$ with the same mass so requires a less massive disc

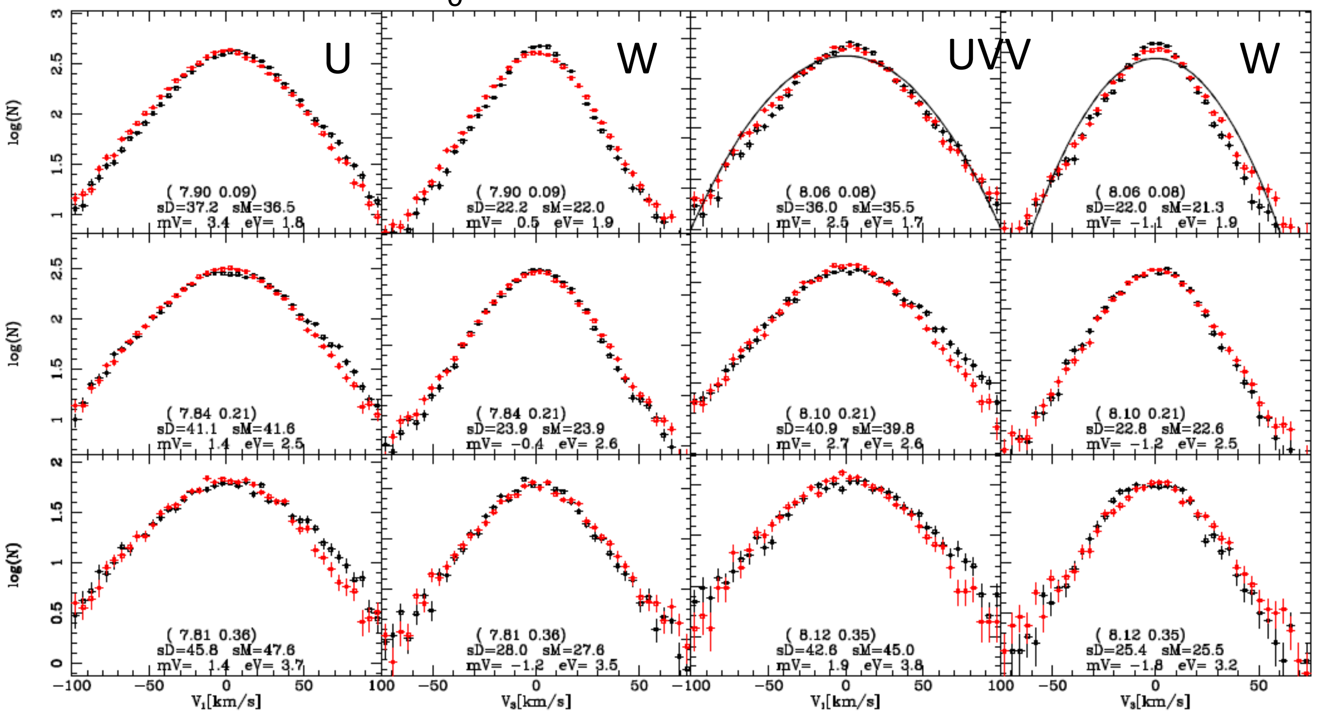
# Binney + 2014

- Using newly introduced Staeckel Fudge Binney (2012) fitted f(J) to GCS data (s <~ 0.1 kpc)
- Binney + (2014) tested its *predictions* for kinematics of RAVE stars in 8 volumes with s <~ 2 kpc




Cool dwarfs

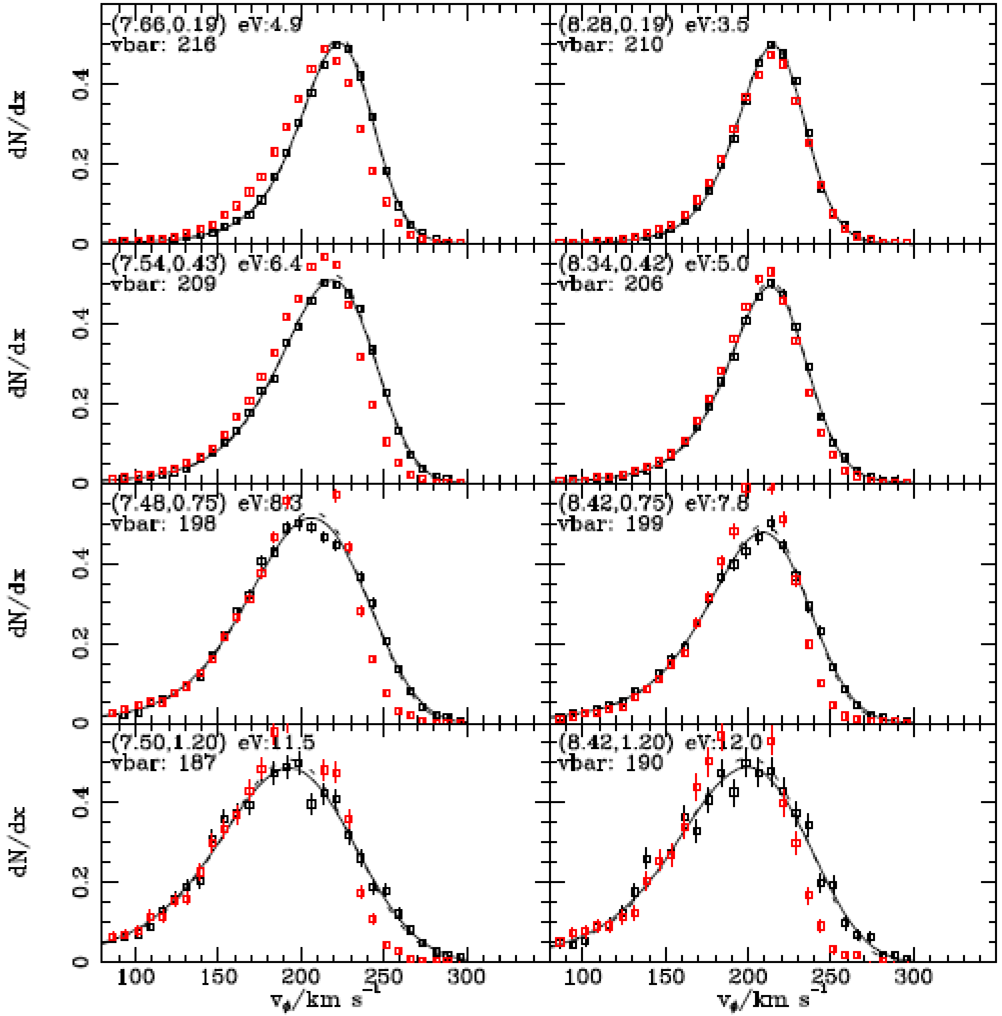
R < $R_0$      R > $R_0$

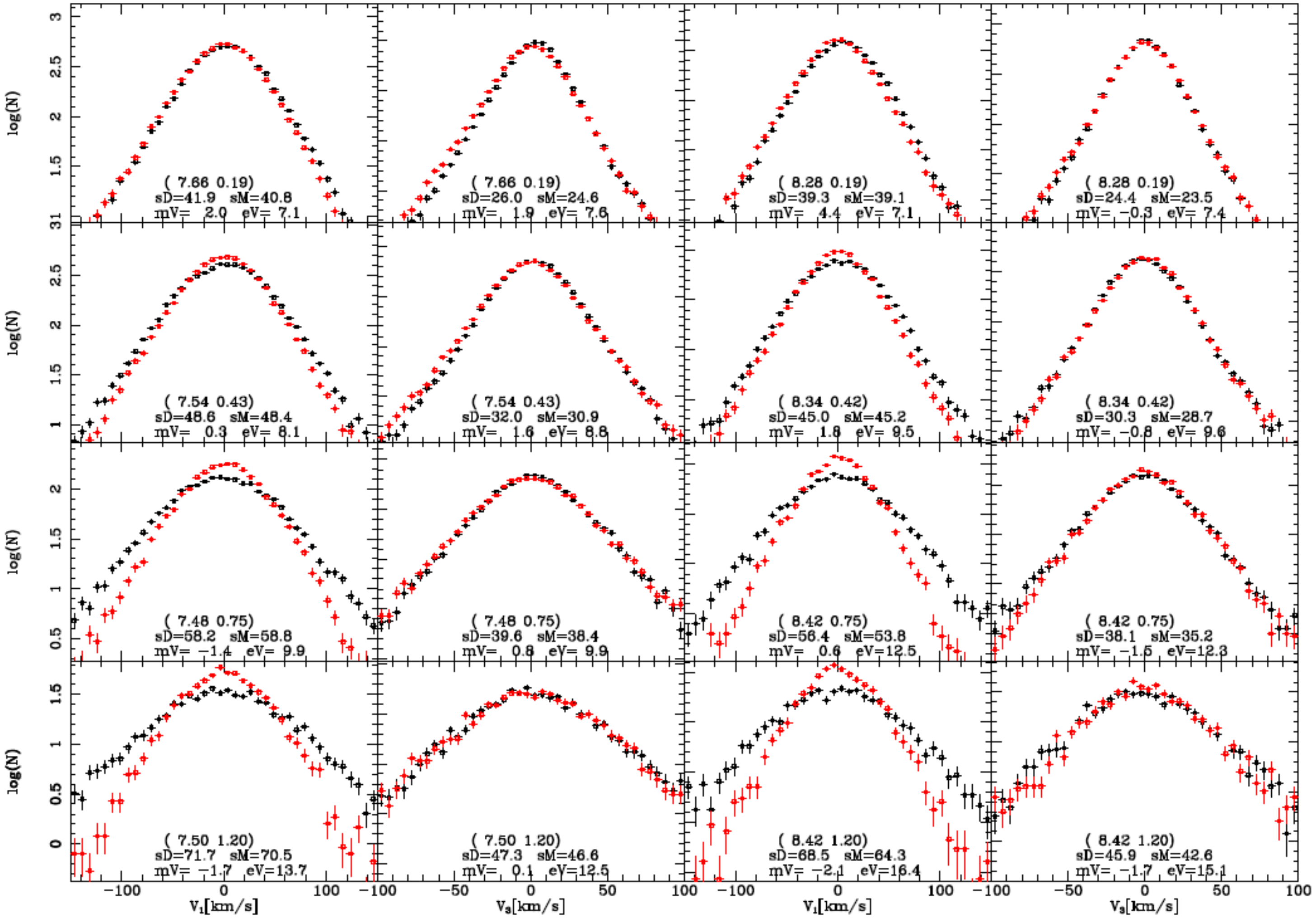


# Binney + 2014 (cont)

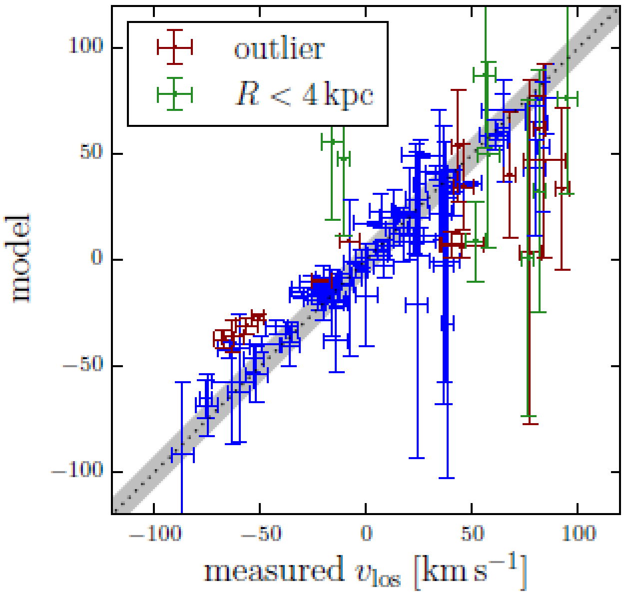
giants

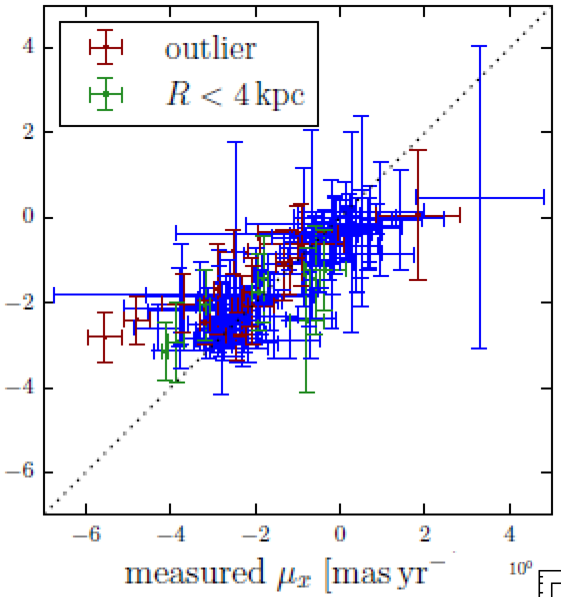
R < $R_0$ R > $R_0$

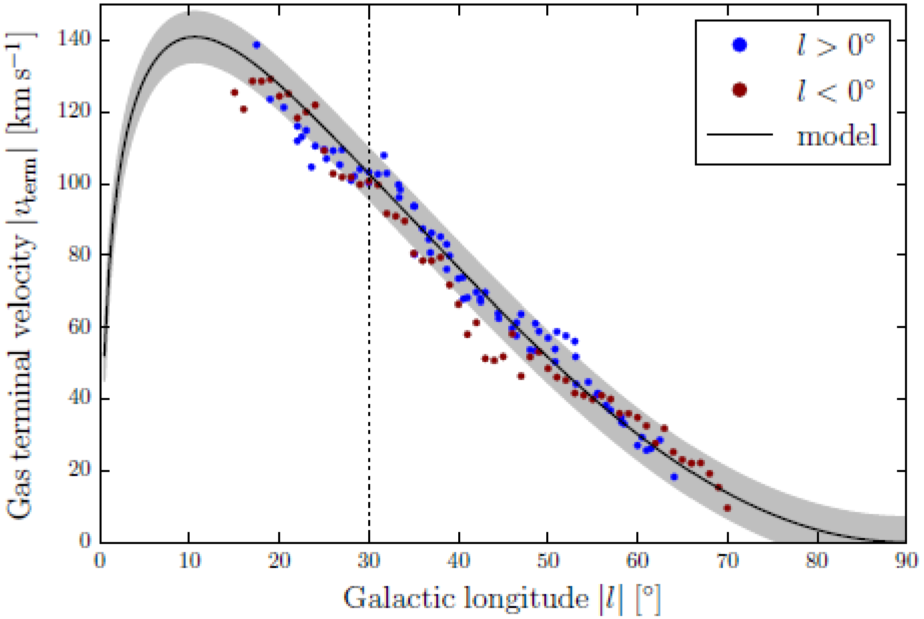


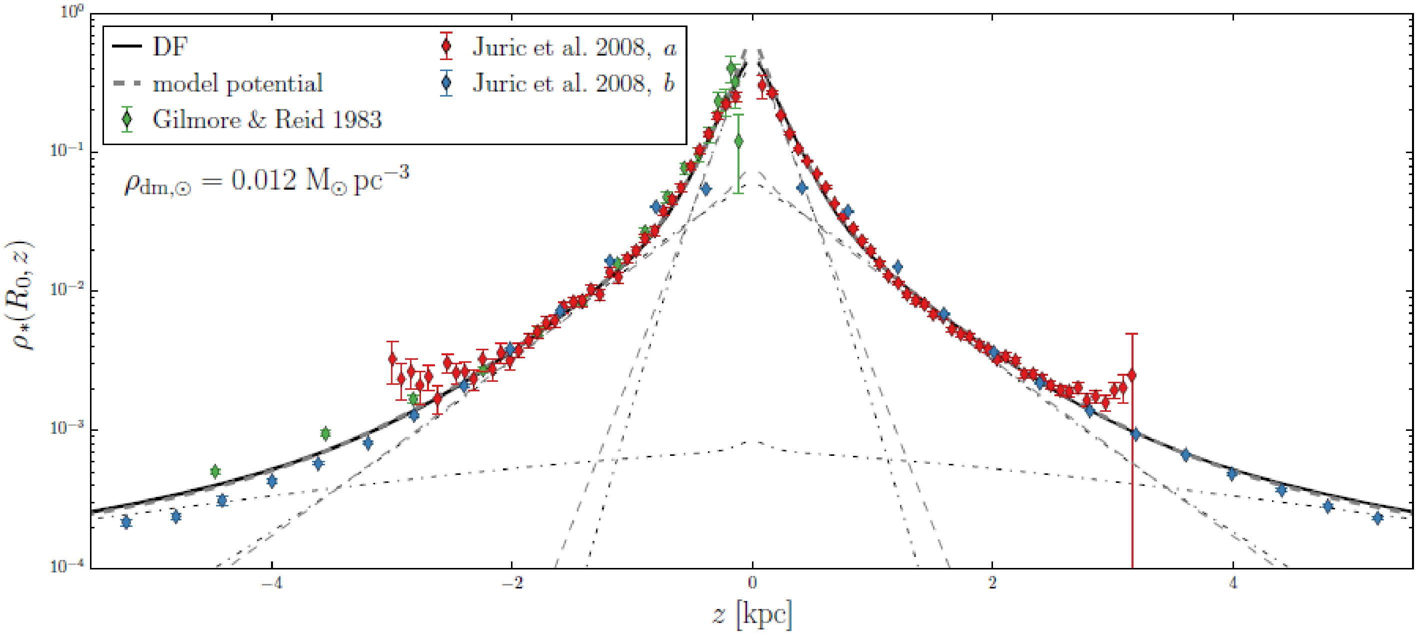



# Piffl + 2014 (data)

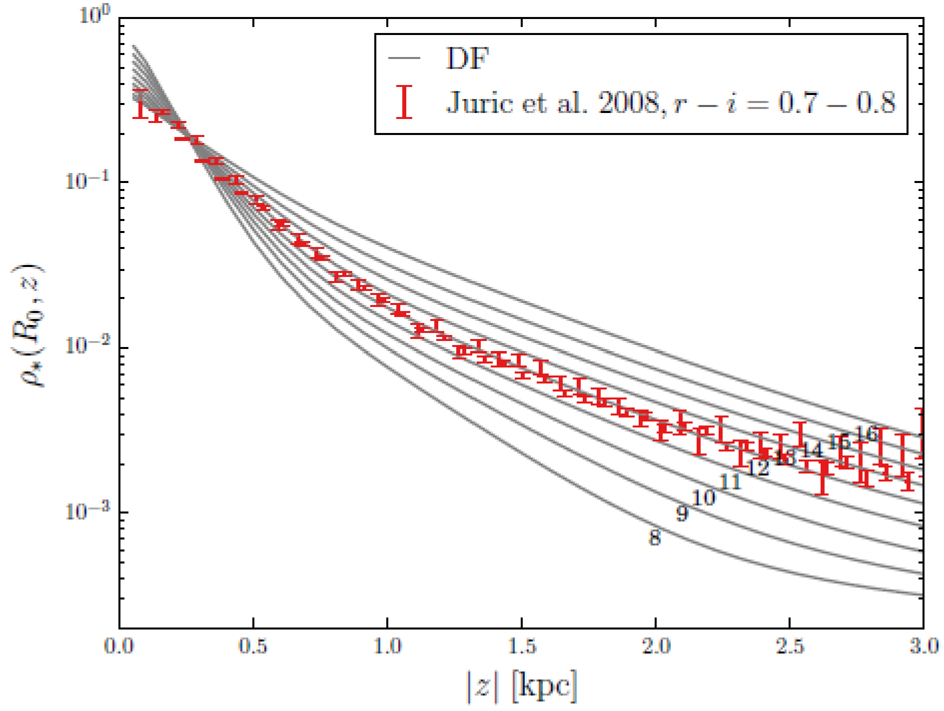


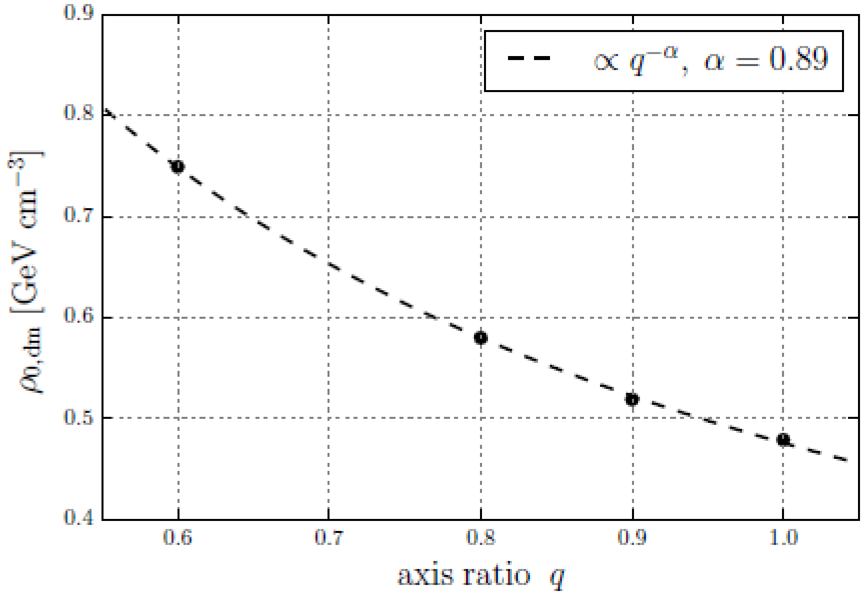



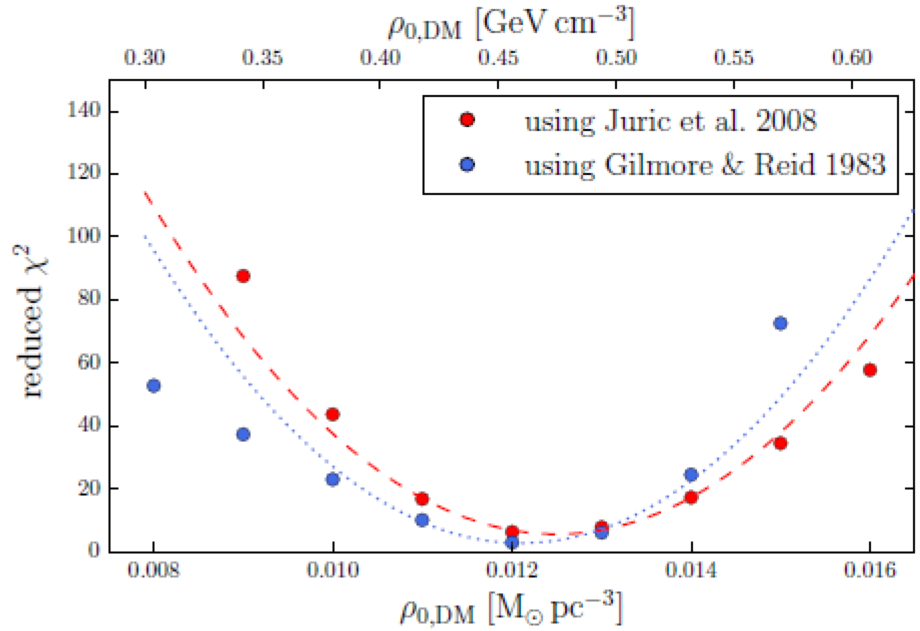



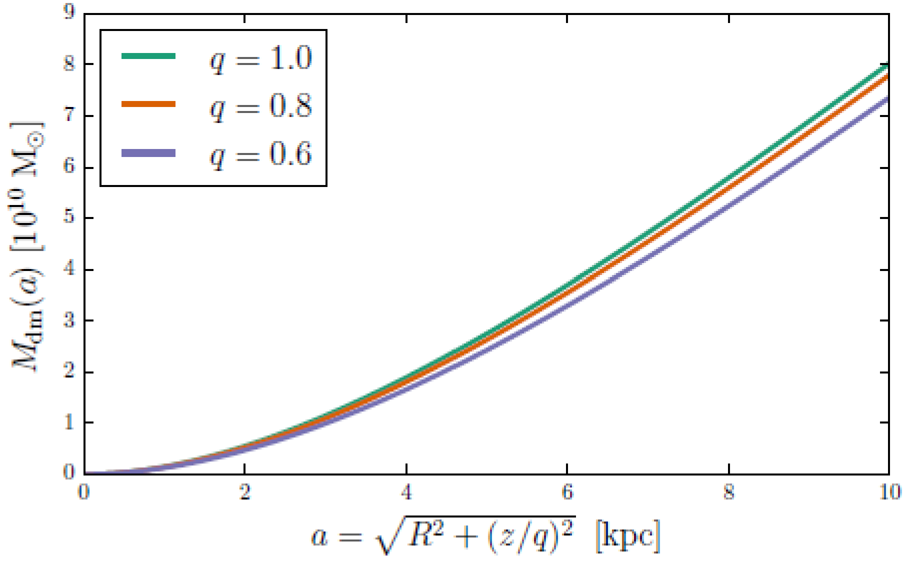



# Piffl + 2014 (fits)



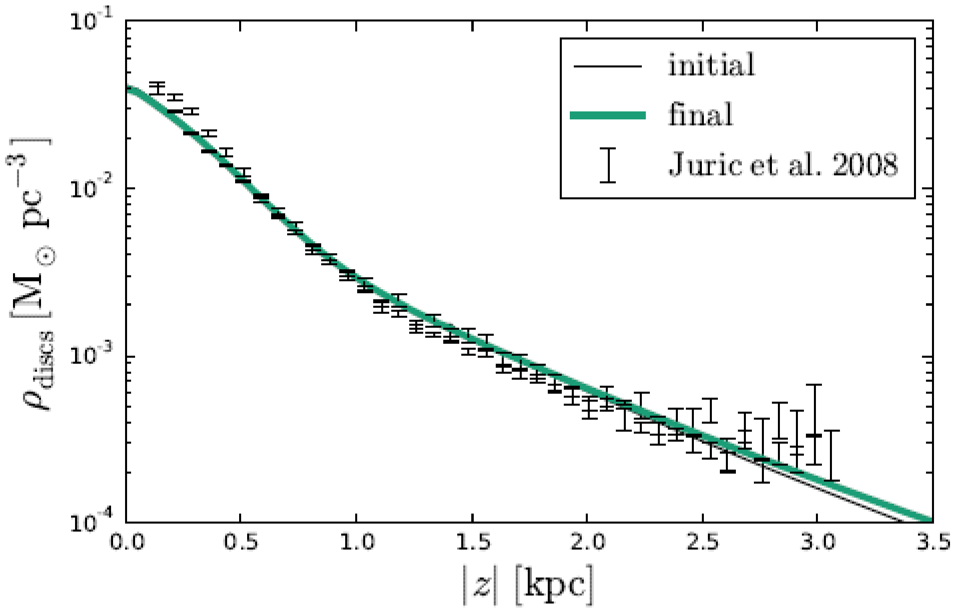



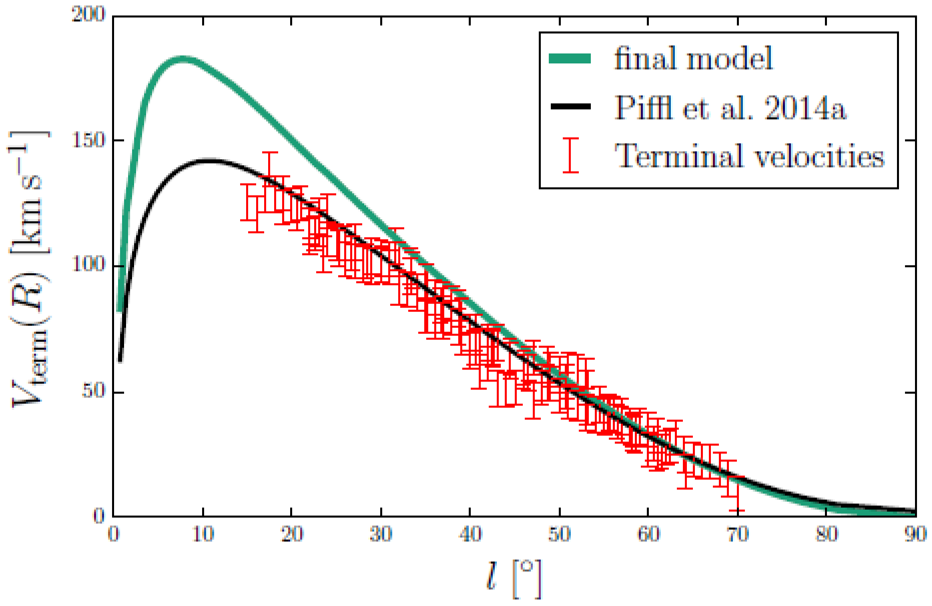



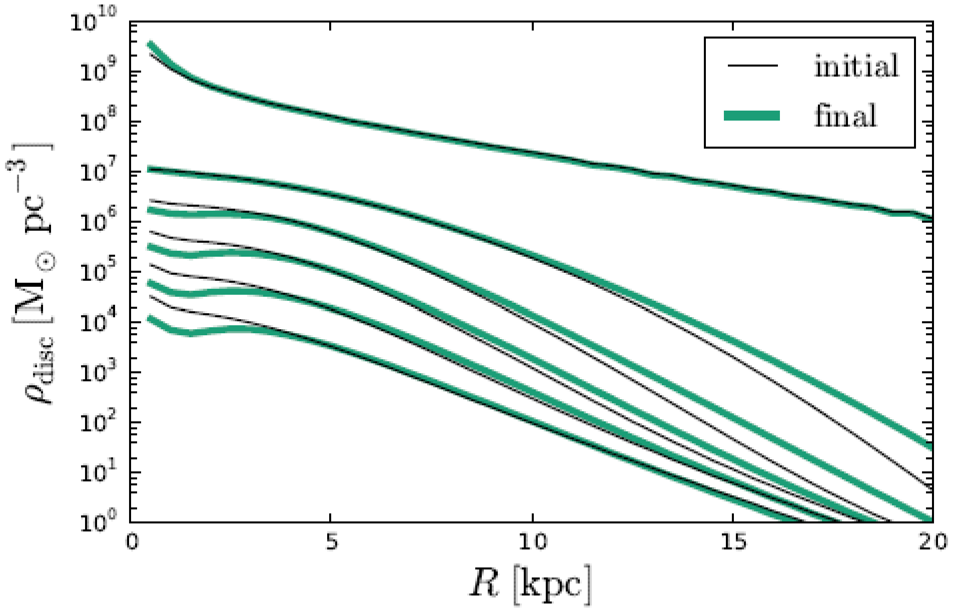



# Piffl Penoyre & Binney 2015

- Adopt
  - For disc f(J) found by Piffl + 2014
  - For dark halo f(J) that in isolation self-consistently generates NFW found by Piffl + 2014
- Solve for self-consistent Phi(x) and examine model
- disc only moderately affected by change in halo
- But compression of halo makes Galaxy too centrally concentrated

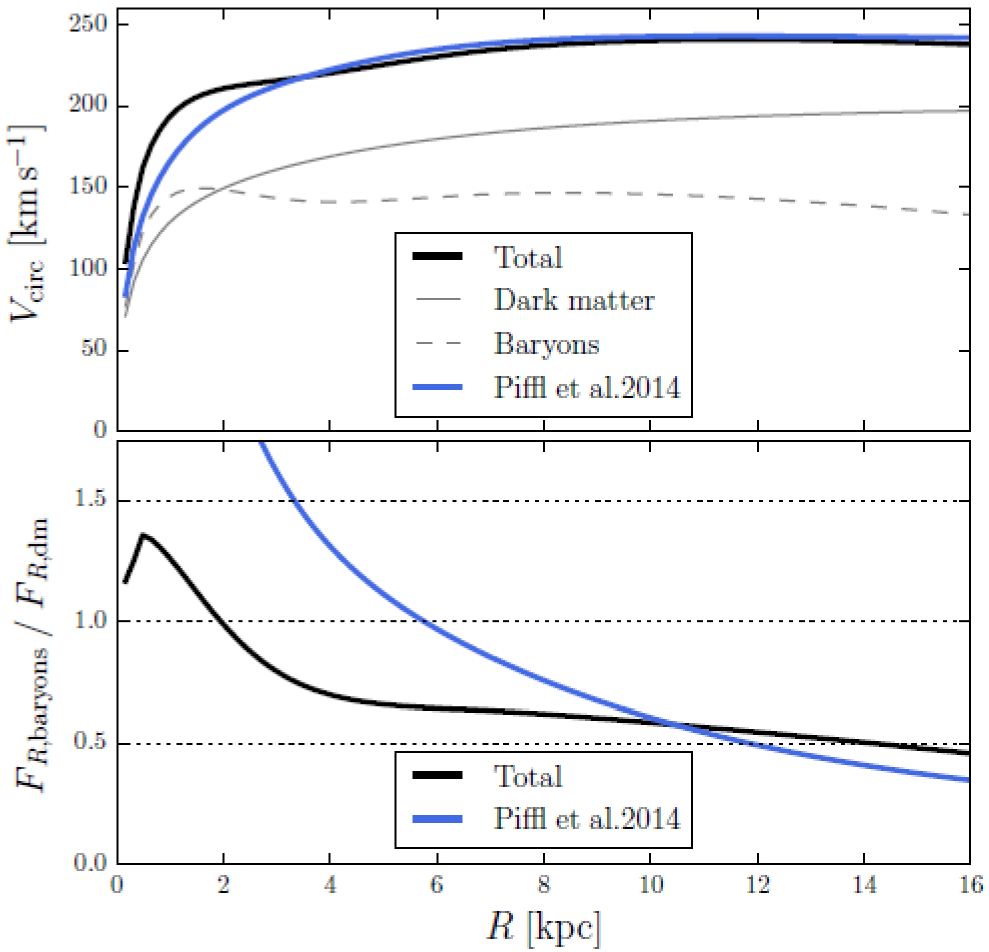


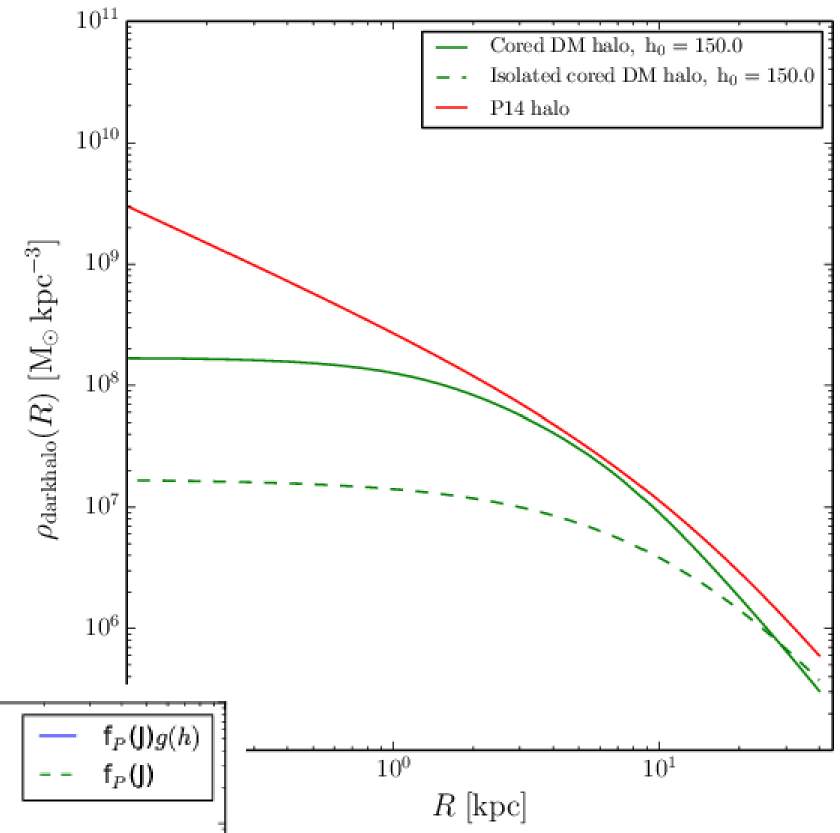
# Binney & Piffl (2015)

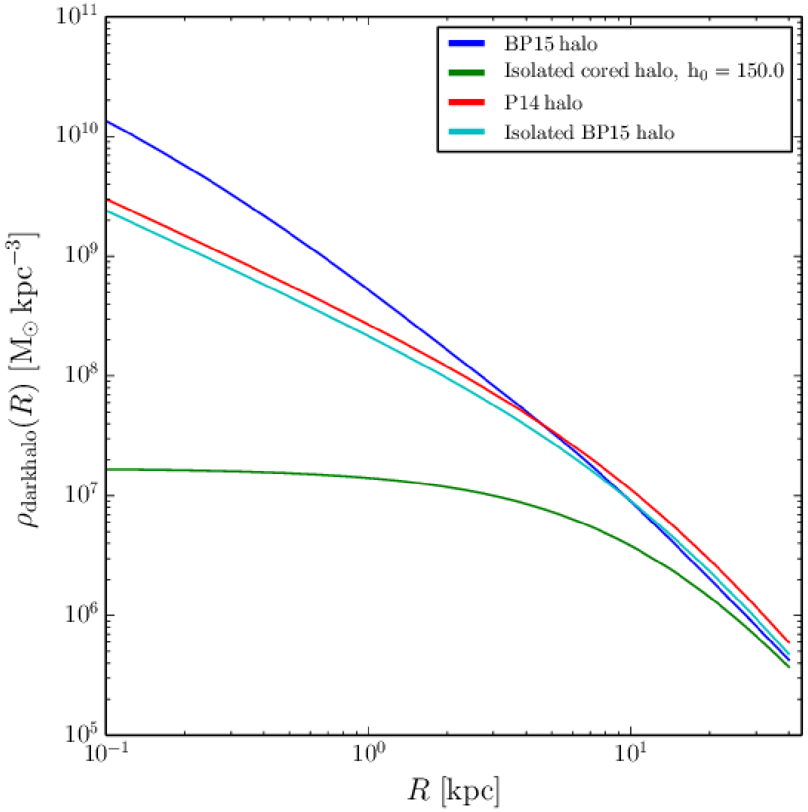
- *Search model space* for a disc f(J) and a NFW f(J) that's consistent with the data used by Piffl + (2014)
- Model found but its centre is very DM dominated making it inconsistent with microlensing data
- Conclude: our Galaxy is inconsistent with an adiabatically compressed NFW halo
- Either halo was never NFW (interacting DM etc) or significant upscattering of DM by baryons

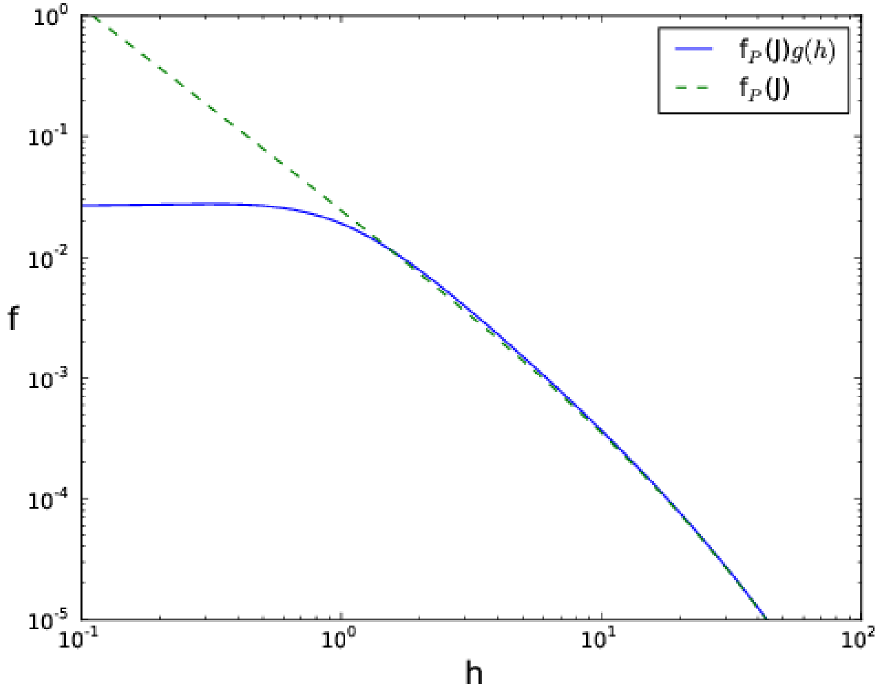


# Cole & Binney (2016)

- Modify NFW f(J)
- Multiply by g(J) $= \left[\frac{h_0^2}{h^2} - \beta\frac{h_0}{h} + 1\right]^{-5/6}$

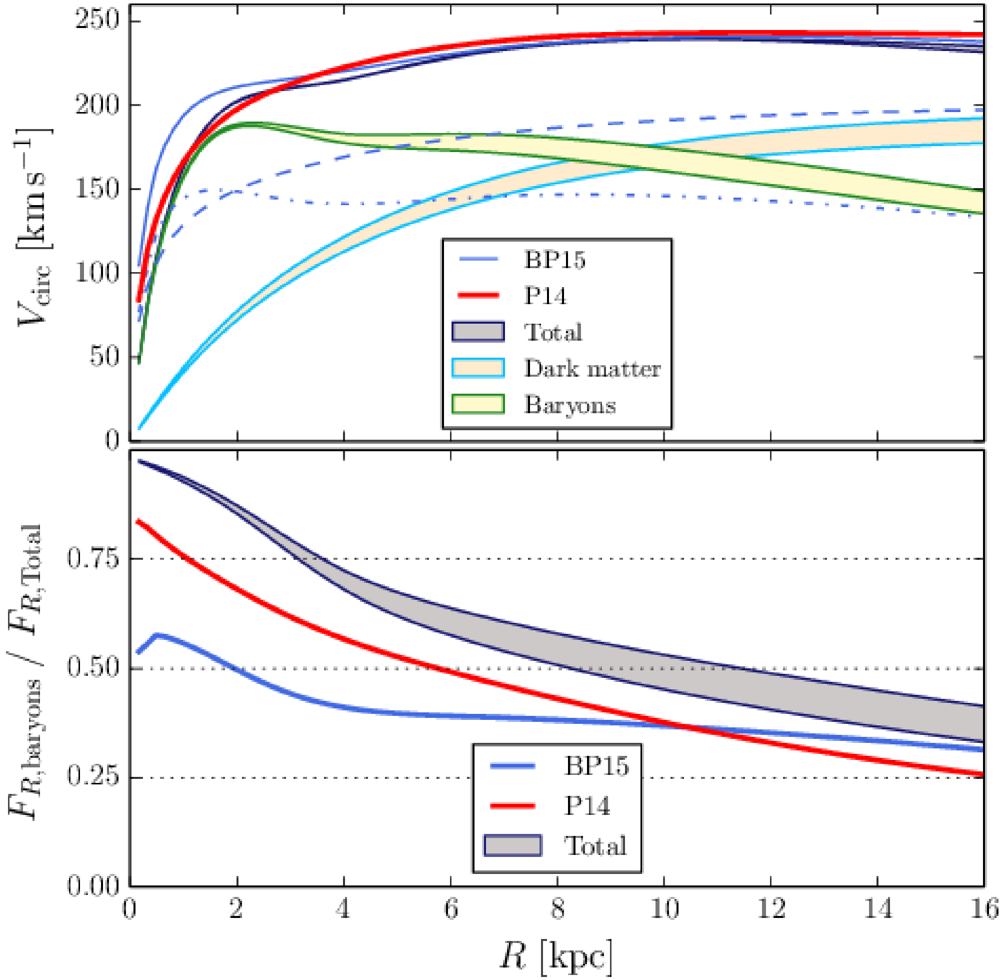


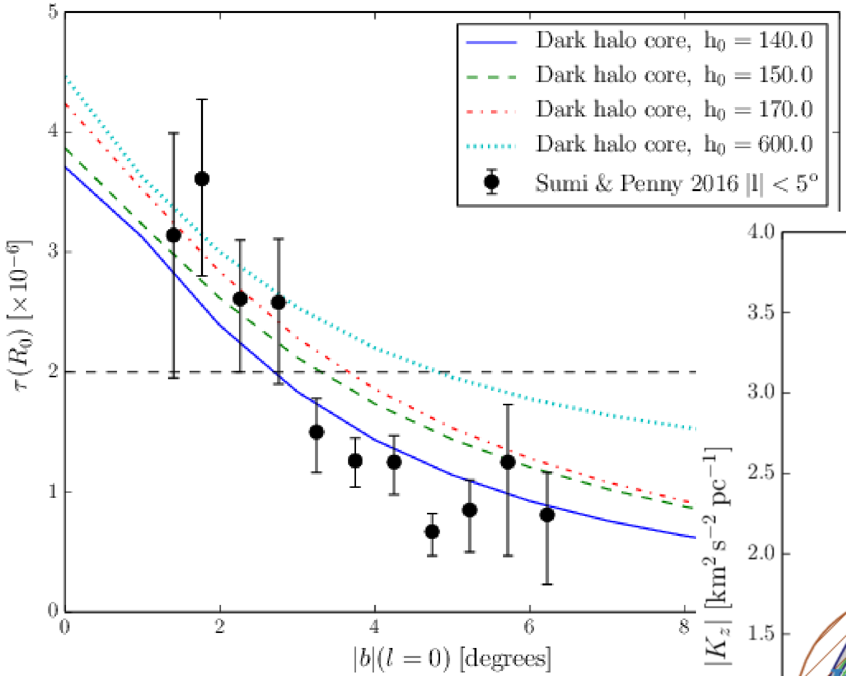



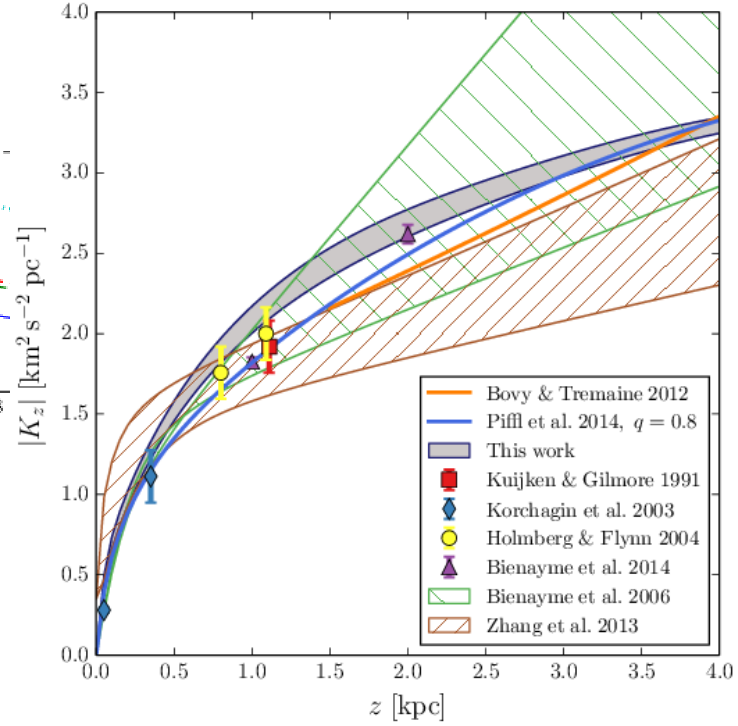



# Cole & Binney (2016)

- Use BP15 algorithm to search for models consistent with *all* data




| | $h_0$ / kpc km s$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|
| Parameter | 140 | 150 | 160 | 170 | 180 | 190 | 600 |
| $\beta$ | 0.37 | 0.38 | 0.39 | 0.398 | 0.41 | 0.415 | 0.66 |
| $N/10^{11}\,{\rm M}_\odot$ | 12.0 | 12.6 | 12.9 | 12.0 | 13.5 | 12.5 | 18.1 |
| $M_{200}^{\rm DM}/10^{11}\,{\rm M}_\odot$ | 7.51 | 7.97 | 8.20 | 7.54 | 8.67 | 7.95 | 12.7 |
| $R_{200}$/ kpc | 183 | 186 | 188 | 183 | 191 | 186 | 217 |
| $R_{\rho_{1/2}}$/ kpc | 1.90 | 1.97 | 2.03 | 2.11 | 2.15 | 2.18 | 3.59 |
| $\rho({\rm R}_0, 0)$/ ${\rm M}_\odot\,{\rm pc}^{-3}$ | 0.0126 | 0.0131 | 0.0133 | 0.0120 | 0.0139 | 0.0124 | 0.0109 |
| $\rho({\rm R}_0, 0)$/ GeV/c$^2$ cm$^{-3}$ | 0.477 | 0.497 | 0.504 | 0.456 | 0.527 | 0.472 | 0.415 |

# Conclusions

- F(J) modelling is an extremely powerful tool
- Local DM density is 0.0126 $q^{-0.86}$ $M_\odot$ $pc^{-3}$
- The DM mass profile M(R) is securely established for $R<R_0$
  - $M(<R_0)$ fixed to few percent
- Either the dark halo never had an NFW profile, or it has not been adiabatically compressed
- All this work should be repeated
  - With a proper selection of stars from model for comparison with RAVE
  - With Tgas kinematics
- Multi-component modelling is the future of galactic (chemo)dynamics
  - f(J) modelling is clearly the way to go
  - The essential tools are already online