Prospects for Indirect Detection of Dark Matter in 'Classical' Dwarf Galaxies

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Dark matter profiles and annihilation in dwarf spheroidal galaxies: prospectives for present and future γ-ray observatories
I. The classical dSphs

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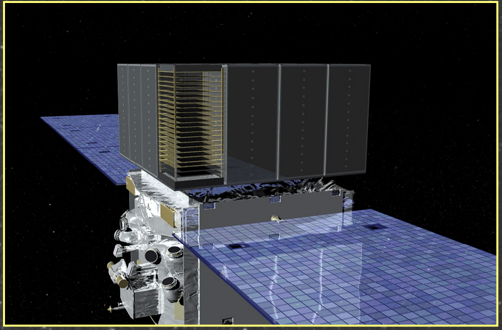

DARK MATTER IN THE CLASSICAL DWARF SPHEROIDAL GALAXIES: A ROBUST CONSTRAINT ON THE ASTROPHYSICAL FACTOR FOR γ-RAY FLUX CALCULATIONS

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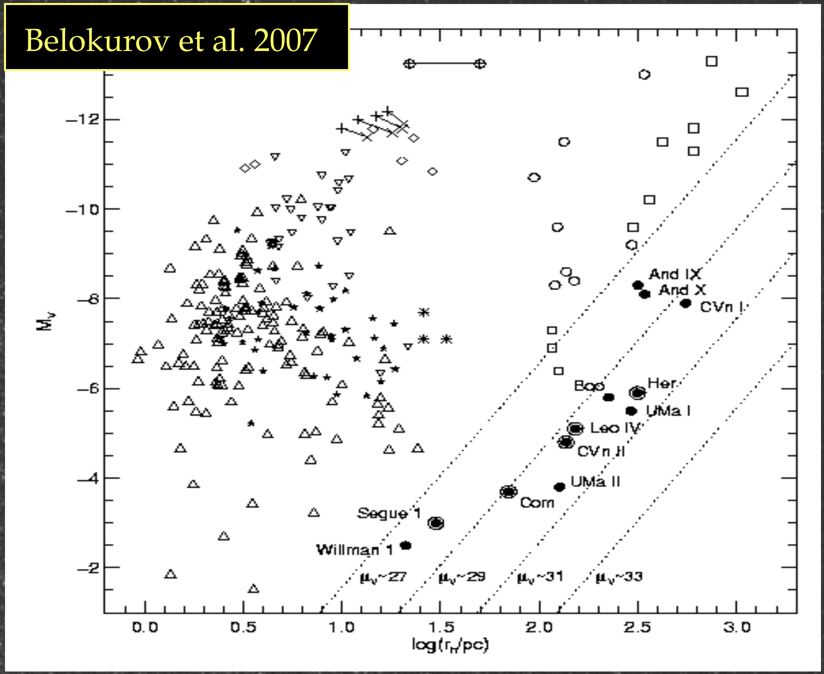
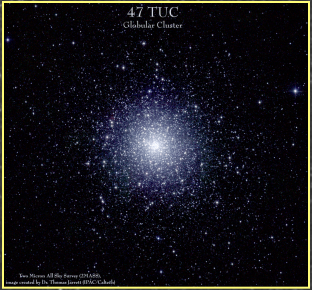
TeVPA, Stockholm

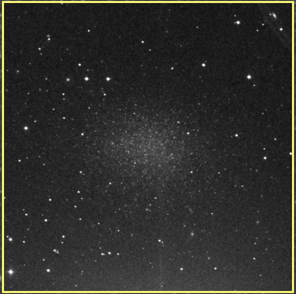
Milky Way Satellites: Star Clusters vs. Galaxies

- Globular Clusters
  - Pressure supported
  - 10^{3-6} L_sun
  - No gas
  - <v> ~ 5-15 km/s
  - ~Single age
  - R_{half} ~ 10 pc
  - No Dark Matter
- dSph galaxies
  - Pressure supported
  - 10^{3-7} L_sun
  - No gas
  - <v> ~ 5-15 km/s
  - Extended Star formation
  - R_{half} ~ 100 pc
  - Dark Matter

$$M \sim \frac{\bar{v}^2 R}{G}$$

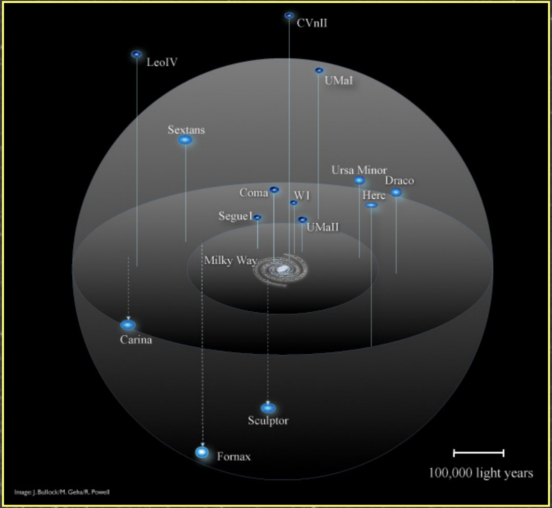






Dwarf Spheroidal (dSph) Galaxies

- Lower limit of galaxy formation
  - Smallest: $r \sim 10^{1\text{-}3}$pc
  - Faintest: $L \sim 10^{3\text{-}7}\ L_{sun}$
  - Darkest: $M/L \sim 10^{1\text{-}3}$ solar
  - Nearest: $D \sim 10^{1\text{-}3}$ kpc
  - Most(?) Metal-Poor
- Tests of Cold Dark Matter
  - Halo mass function
  - Mass Profiles
- Indirect Detection?



Springel etal (2008); see also Diemand etal (2008)

Astro-particle Physics

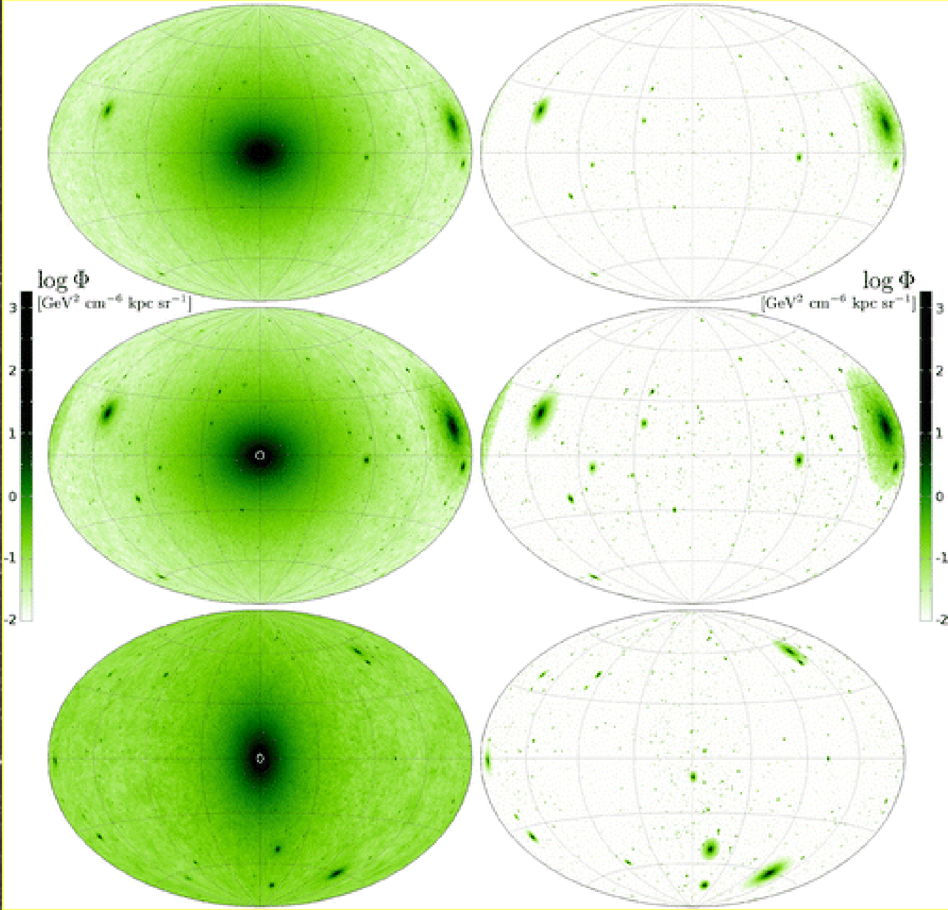
$$\frac{\mathrm{d}\Phi_\gamma}{\mathrm{d}E_\gamma}(E_\gamma, \Delta\Omega) = \Phi^{\mathrm{PP}}(E_\gamma) \times J(\Delta\Omega)$$

$$\Phi^{\mathrm{PP}}(E_\gamma) \equiv \frac{\mathrm{d}\Phi_\gamma}{\mathrm{d}E_\gamma} = \frac{1}{4\pi}\frac{\langle\sigma_{\mathrm{ann}} v\rangle}{2m_\chi^2} \times \frac{dN_\gamma}{dE_\gamma}$$

$$J = \int_{\Delta\Omega}\int \rho_{\mathrm{DM}}^2(l,\Omega)\, dl d\Omega.$$

Pervious dSph calculations: see, e.g., Bergstrom & Hooper 2006, Sanchez-Conde etal 2007, Bringmann etal 2009, Pieri etal 2009, Kuhlen 2010, Strigari etal 2007, Martinez etal 2009, ...

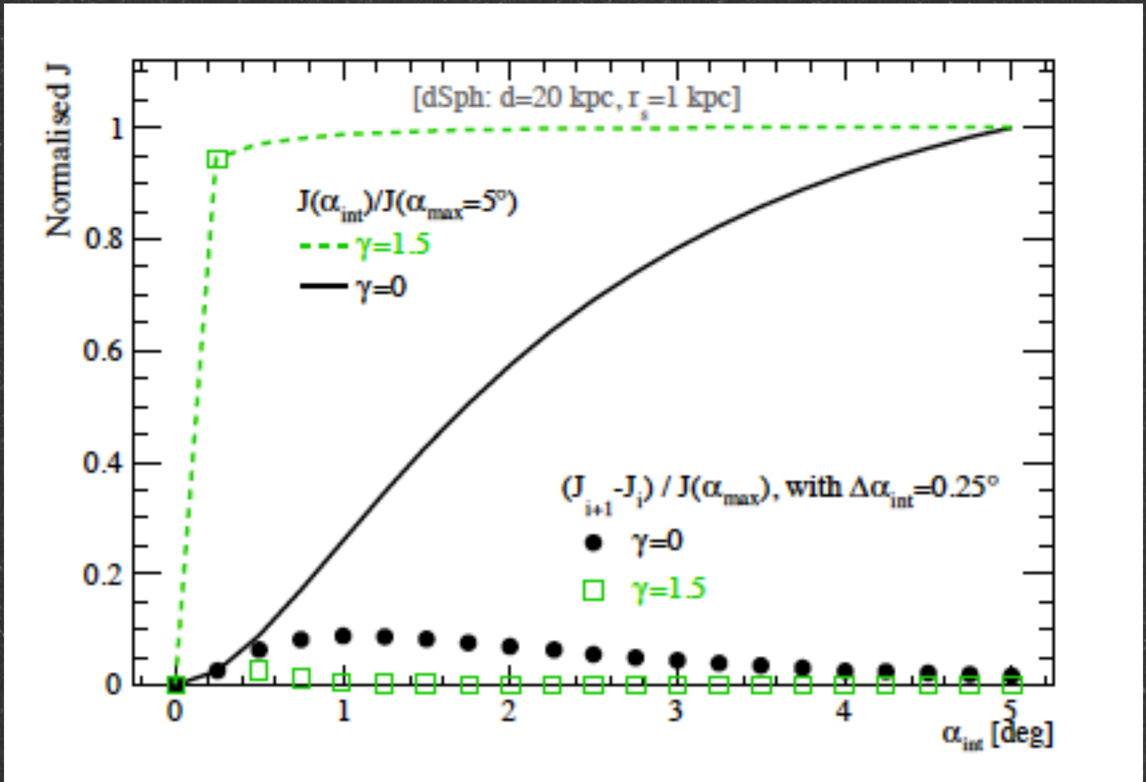
Expected DM Flux from LCDM



Predictions from *Via Lactea* simulation (Kuhlen et al. 2008; see also Springel etal 2008)

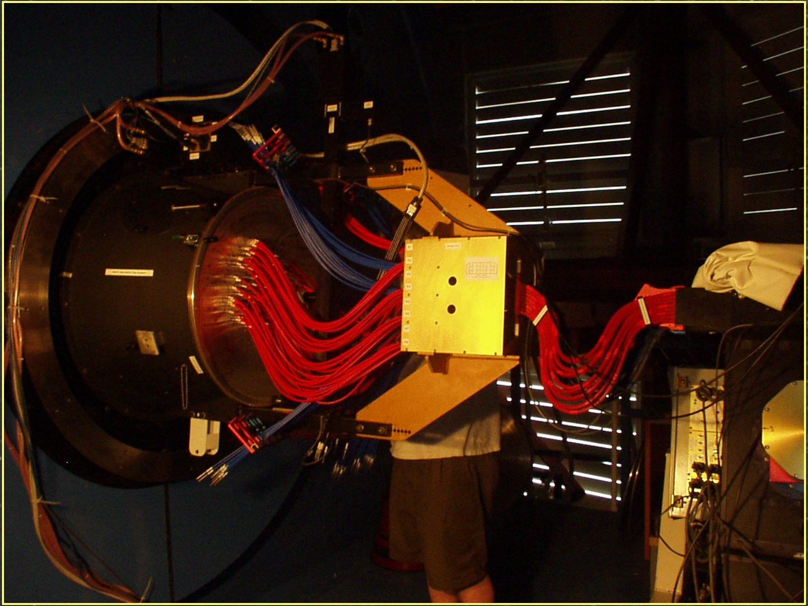
Relevance of cores vs cusps

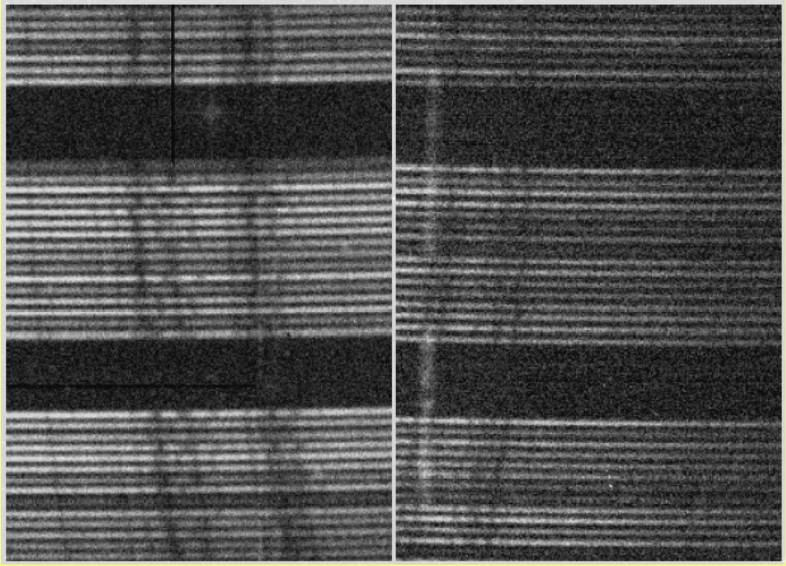
$$J = \int_{\Delta\Omega} \int \rho^2_{\rm DM}(l,\Omega)\, dl d\Omega.$$



Charbonnier etal. Arxiv:1104.0412

Observations: Spectroscopy of "Classical" dSphs

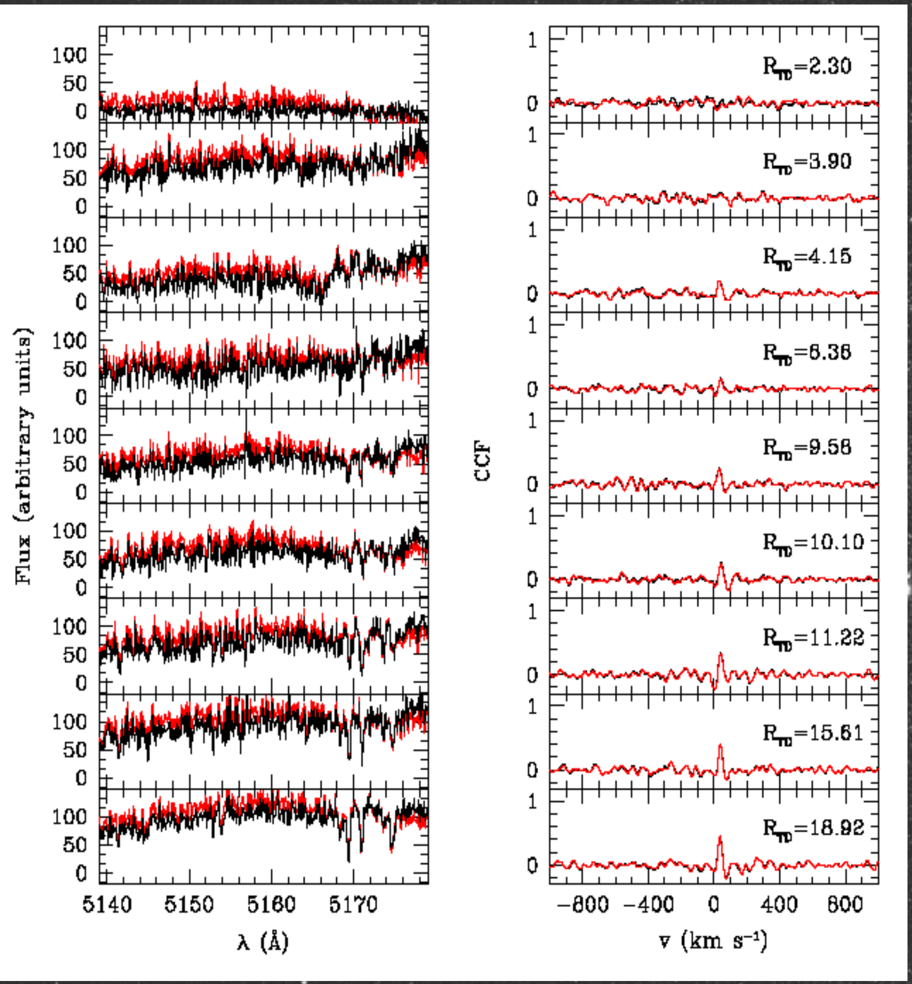


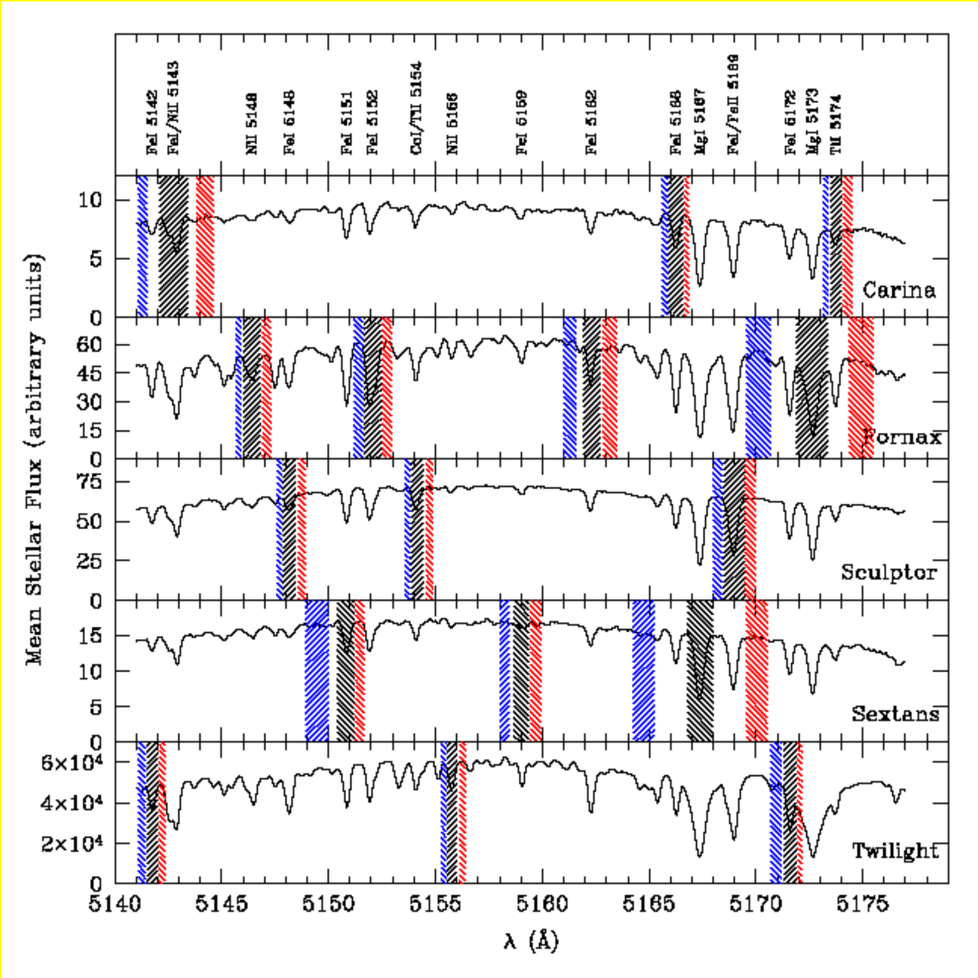


Observations: Spectroscopy of “Classical” dSphs

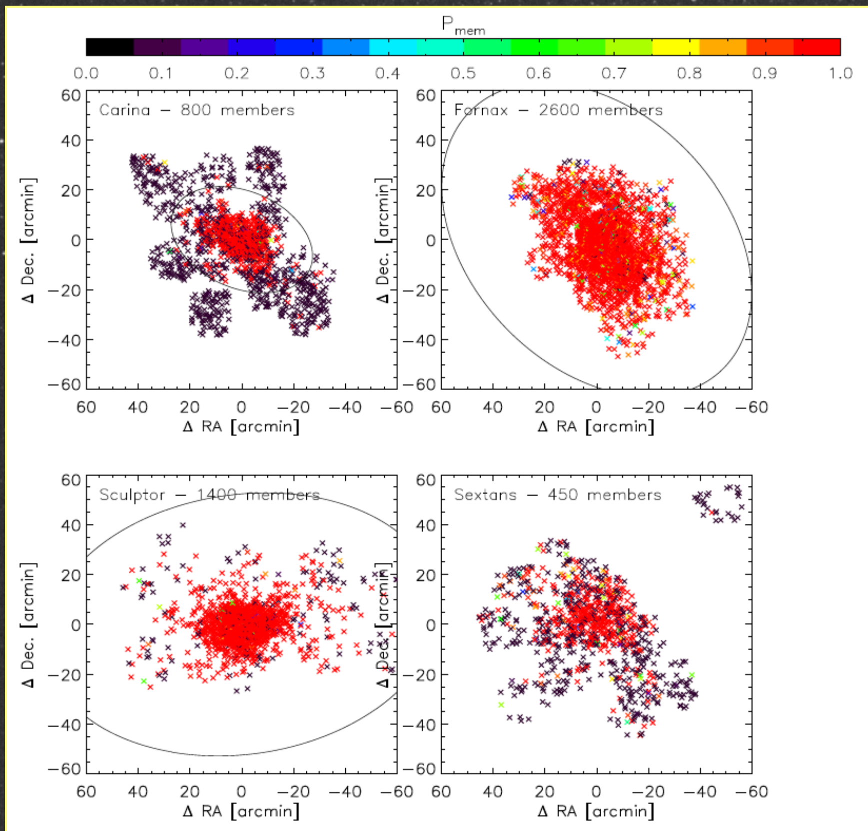
$$CCF(v) = \int S(v)[T(v) - v]\, dv$$

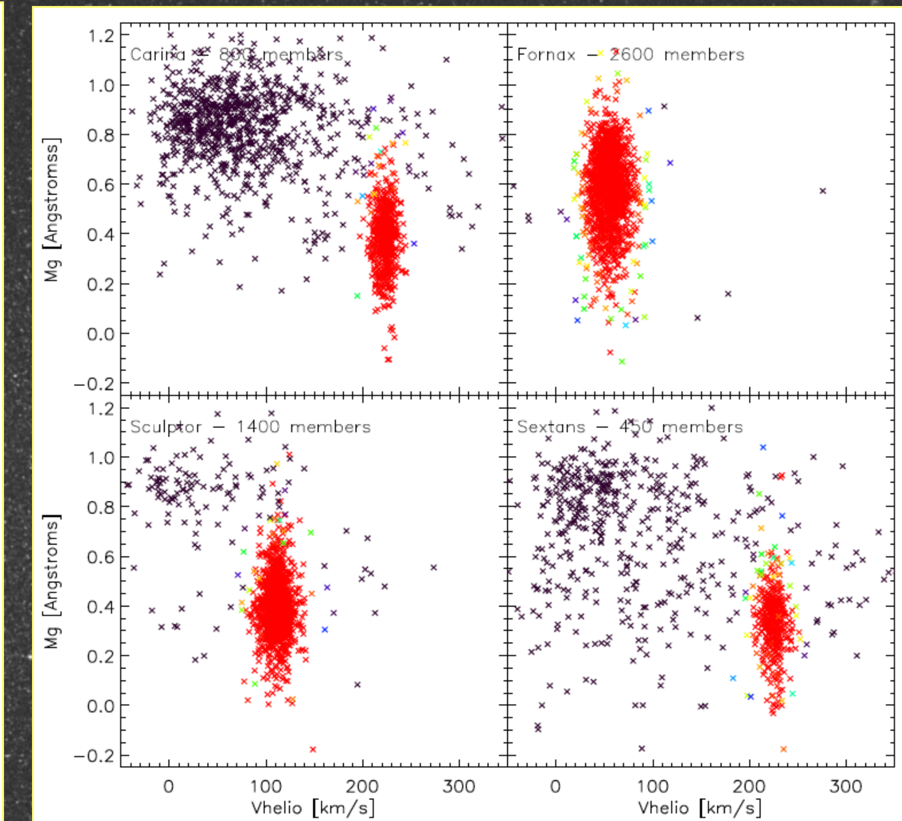
$$W = \int_{\lambda 1}^{\lambda_2} [1 - S(\lambda)/C(\lambda)]\, d\lambda$$





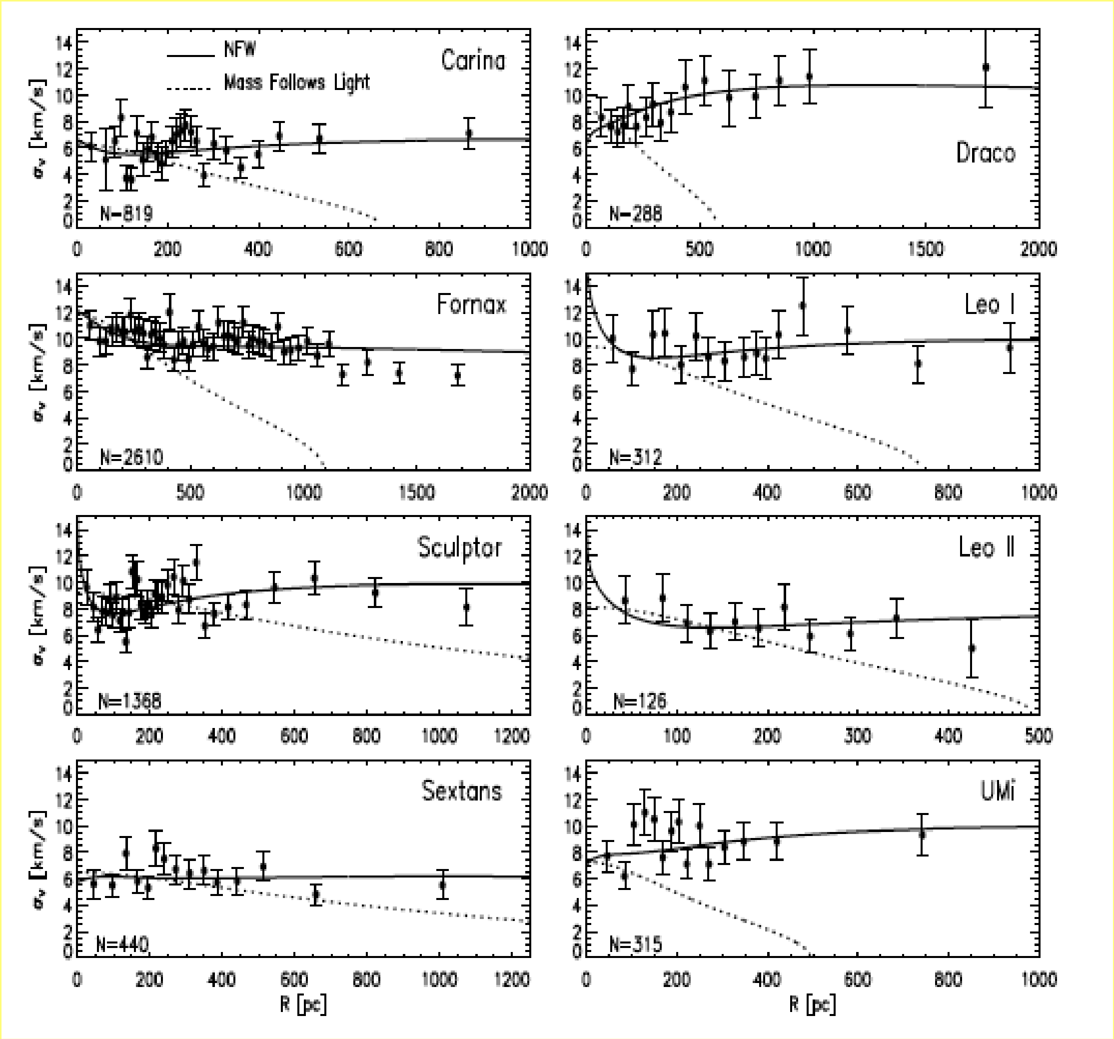
Observations: Spectroscopy of “Classical” dSphs

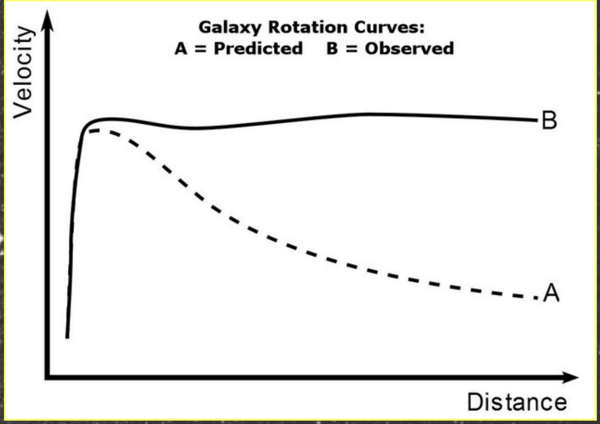




MW etal (2009)

Observations: Spectroscopy of "Classical" dSphs





MW etal. 2009

Kinematics with the Jeans Equation

Assumptions: Spherical symmetry, Dynamical equilibrium, negligible binary motions

1) Collisionless Boltzmann Eq.

$$\frac{\partial f}{\partial t} + \mathbf{v}.\frac{\partial f}{\partial \mathbf{r}} - \nabla\Phi.\frac{\partial f}{\partial \mathbf{v}} = 0$$

2) Jeans Eq. (spherical)

$$\frac{1}{\nu}\frac{d}{dr}(\nu \bar{v_r^2}) + 2\frac{\beta \bar{v_r^2}}{r} = -\frac{GM(r)}{r^2}$$

3) Solution in terms of observables

$$\sigma_p^2(R) = \frac{2}{I(R)}\int_R^\infty \left(1 - \beta\frac{R^2}{r^2}\right)\frac{\nu(r)\bar{v_r^2} r}{\sqrt{r^2 - R^2}}dr$$

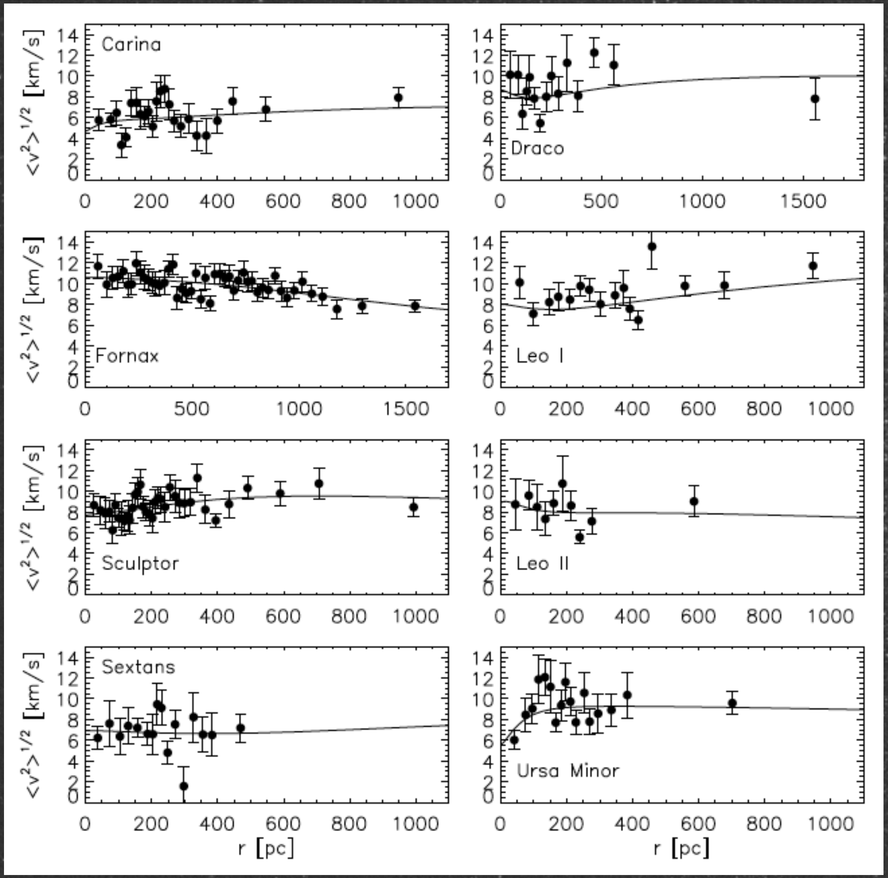
4) Adopt Halo Model

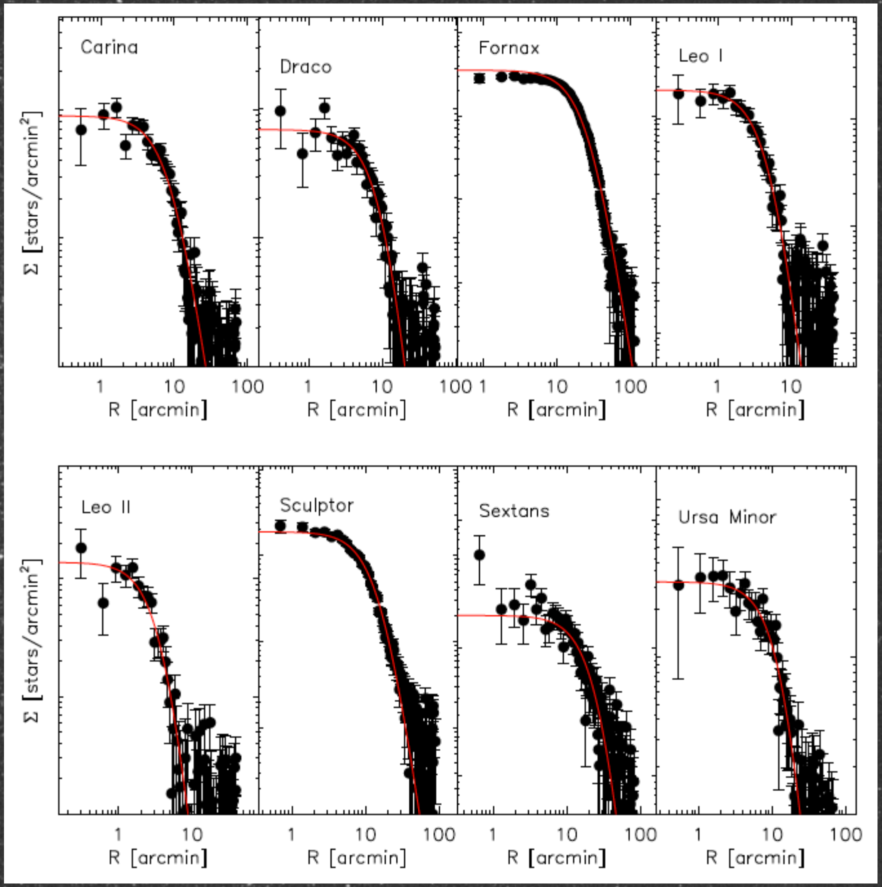
$$\rho(r) = \rho_0\left(\frac{r}{r_0}\right)^{-\gamma}\left[1 + \left(\frac{r}{r_0}\right)^\alpha\right]^{\frac{\gamma-\eta}{\alpha}}$$

$$J = \int_{\Delta\Omega}\int \rho_{\rm DM}^2(l,\Omega)\, dl d\Omega.$$

Kinematics with the Jeans Equation: Fits to Data

$$\sigma_p^2(R) = \frac{2}{I(R)} \int_R^{\infty} \left(1 - \beta \frac{R^2}{r^2}\right) \frac{\nu(r)\bar{v_r^2} r}{\sqrt{r^2 - R^2}} dr$$

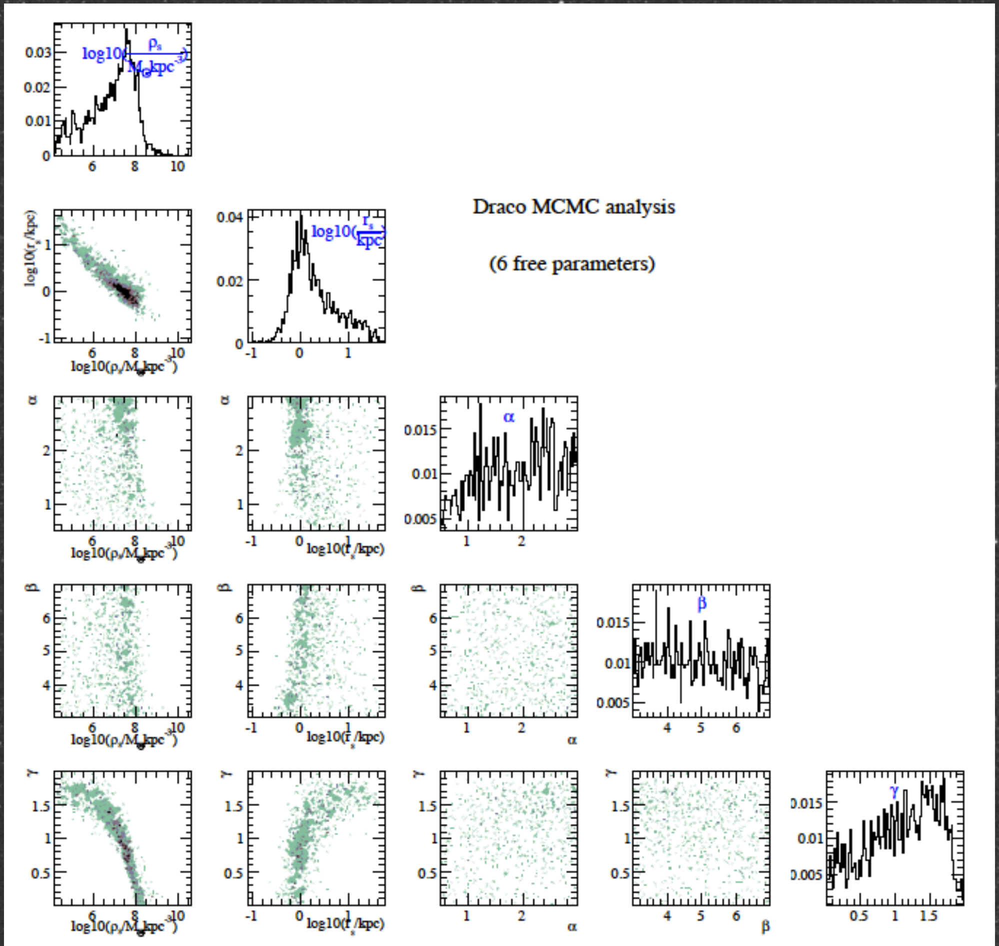




Kinematics with the Jeans Equation: MCMC

$$\rho(r) = \rho_0 \left(\frac{r}{r_0}\right)^{-\gamma} \left[1 + \left(\frac{r}{r_0}\right)^{\alpha}\right]^{\frac{\gamma-\eta}{\alpha}}$$

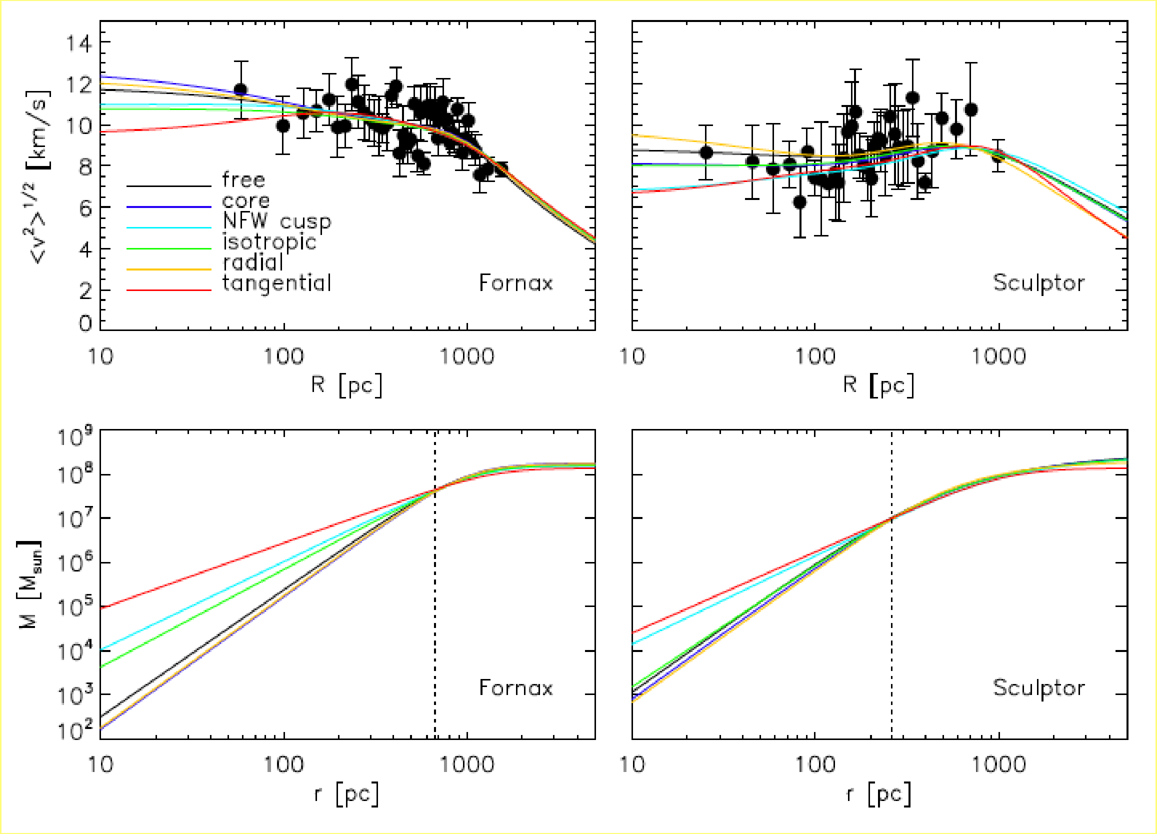
$$\sigma_p^2(R) = \frac{2}{I(R)} \int_R^{\infty} \left(1 - \beta \frac{R^2}{r^2}\right) \frac{\nu(r)\bar{v_r^2} r}{\sqrt{r^2 - R^2}} dr$$



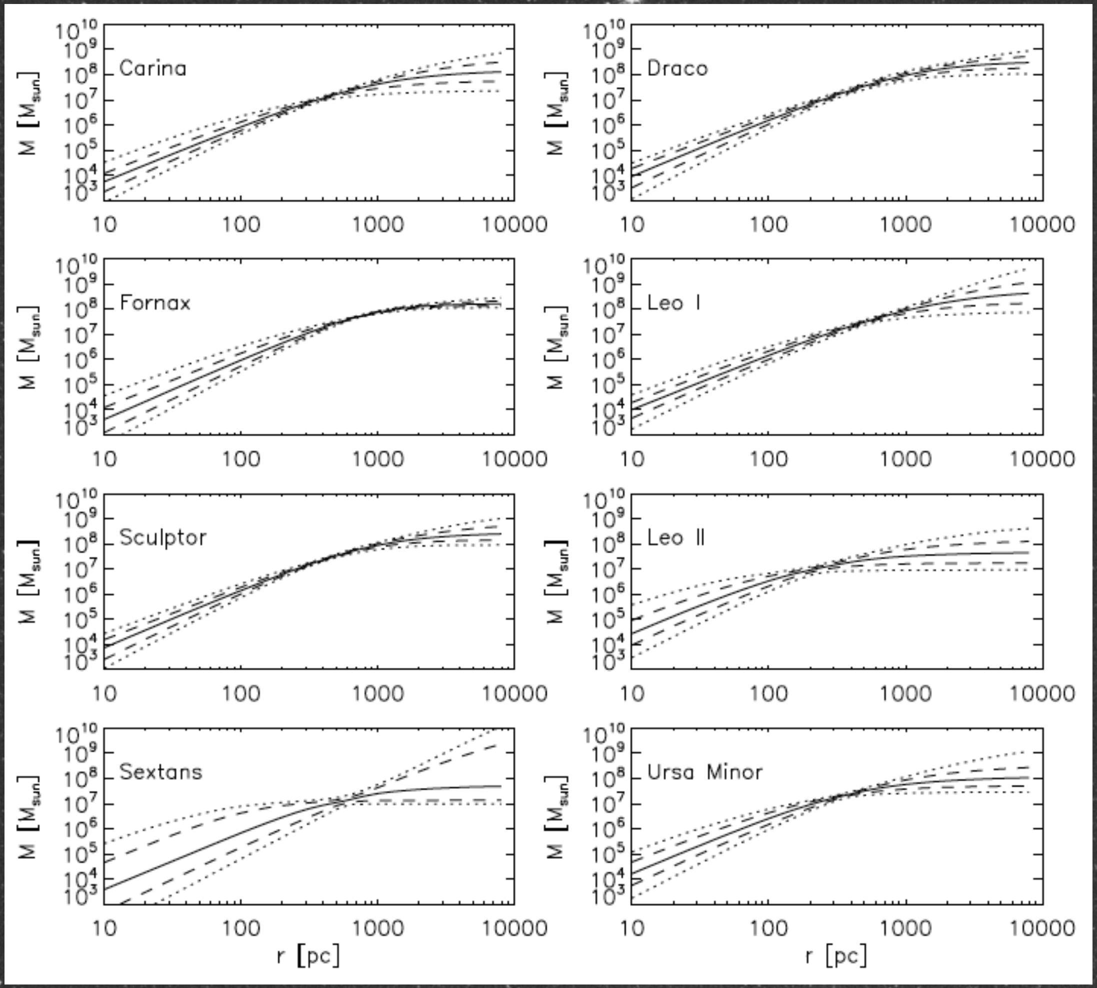
Charbonnier etal. Arxiv:1104.0412

Kinematics with the Jeans Equation: Degeneracy

$$\frac{1}{\nu}\frac{d}{dr}(\nu \bar{v_r^2}) + 2\frac{\beta \bar{v_r^2}}{r} = -\frac{GM(r)}{r^2}$$



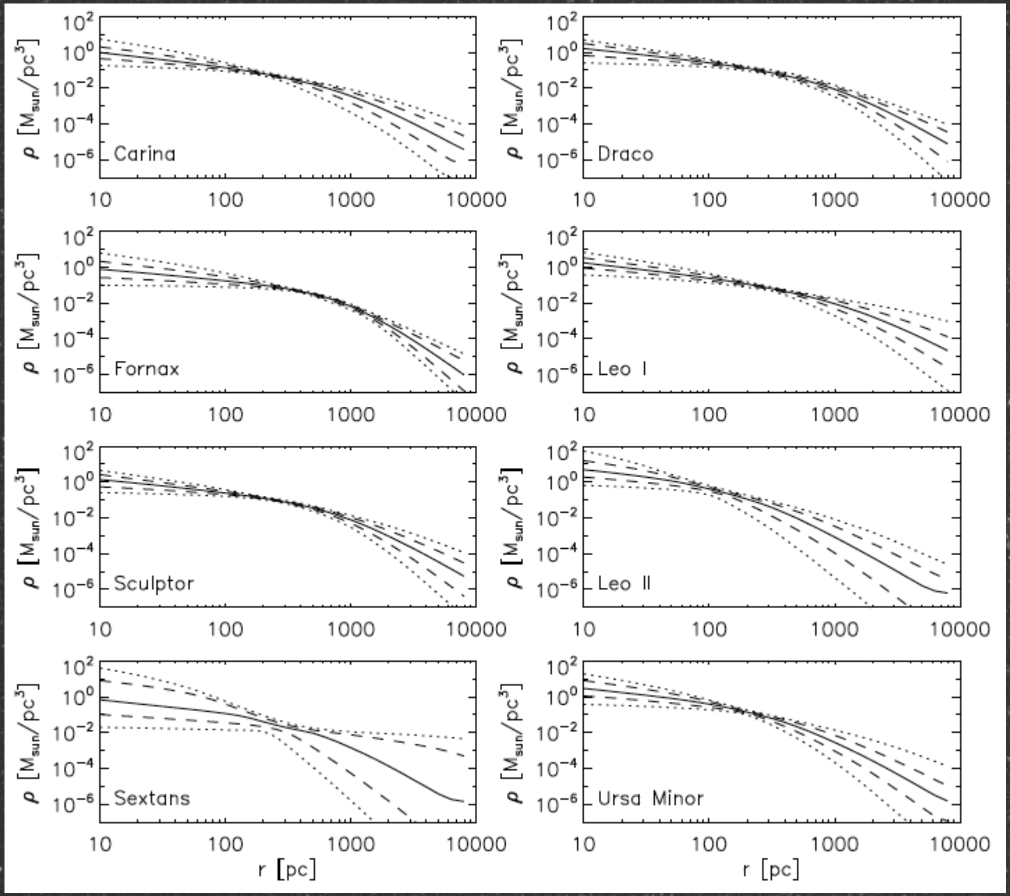
Kinematics with the Jeans Equation: Enclosed Mass Profiles



Kinematics with the Jeans Equation: Density Profiles

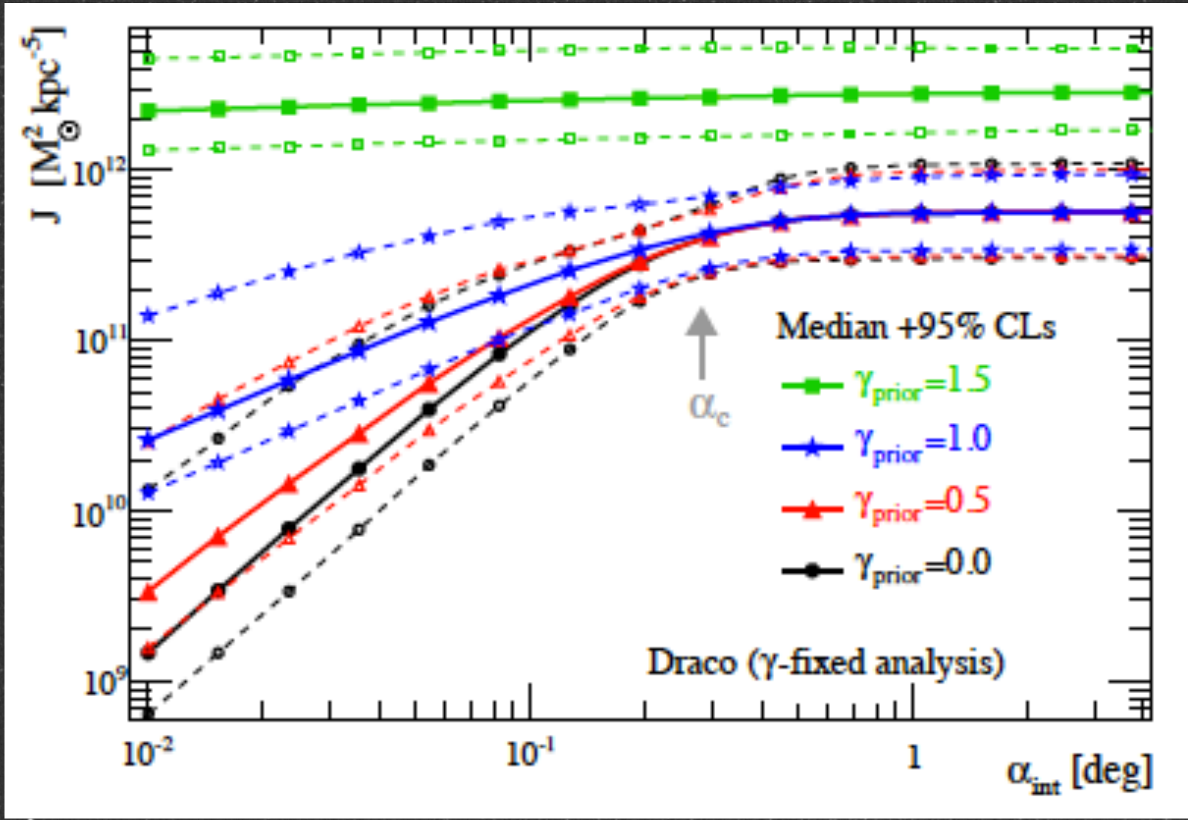
$$\rho(r) = \rho_0 \left(\frac{r}{r_0}\right)^{-\gamma} \left[1 + \left(\frac{r}{r_0}\right)^{\alpha}\right]^{\frac{\gamma-\eta}{\alpha}}$$

$$J = \int_{\Delta\Omega} \int \rho_{\rm DM}^2(l, \Omega)\, dl d\Omega.$$



Constraints on J

$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma, \Delta\Omega) = \Phi^{PP}(E_\gamma) \times J(\Delta\Omega)$$



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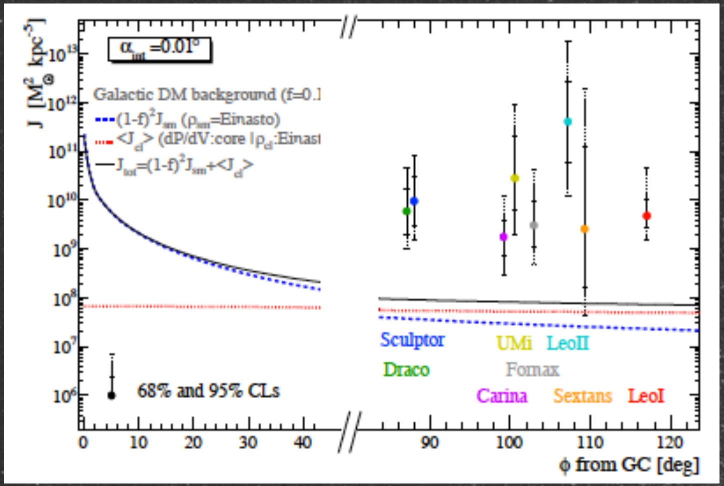
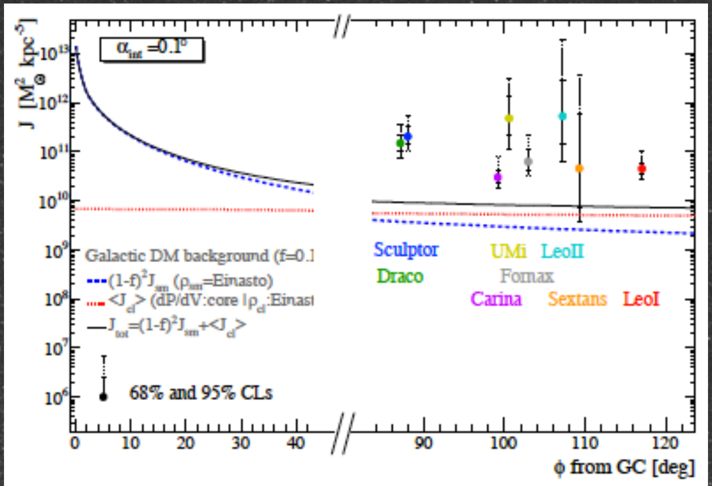
Background and integration angle





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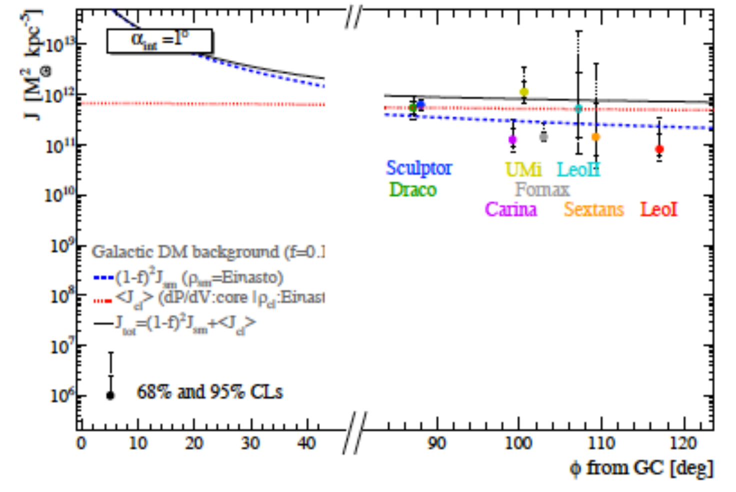
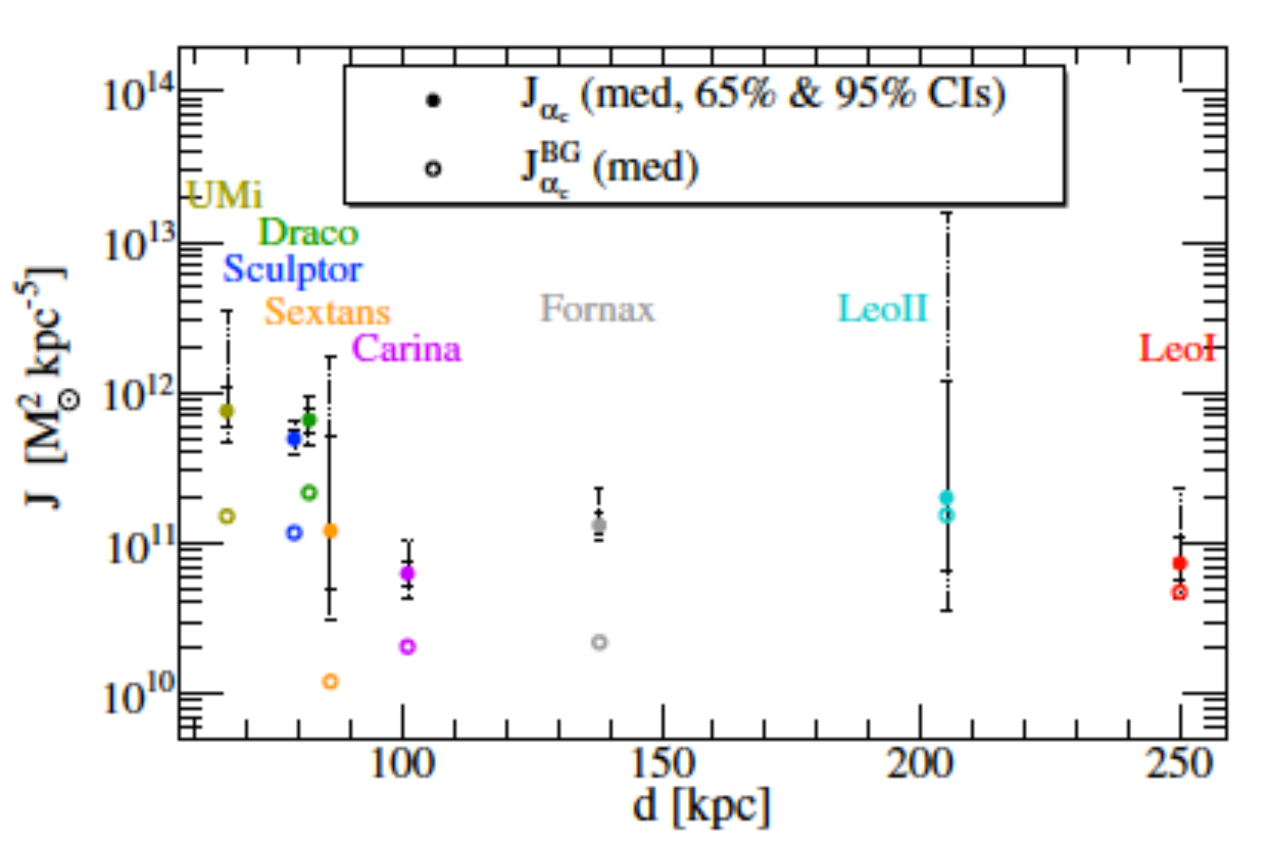


J comparisons for classical dSphs



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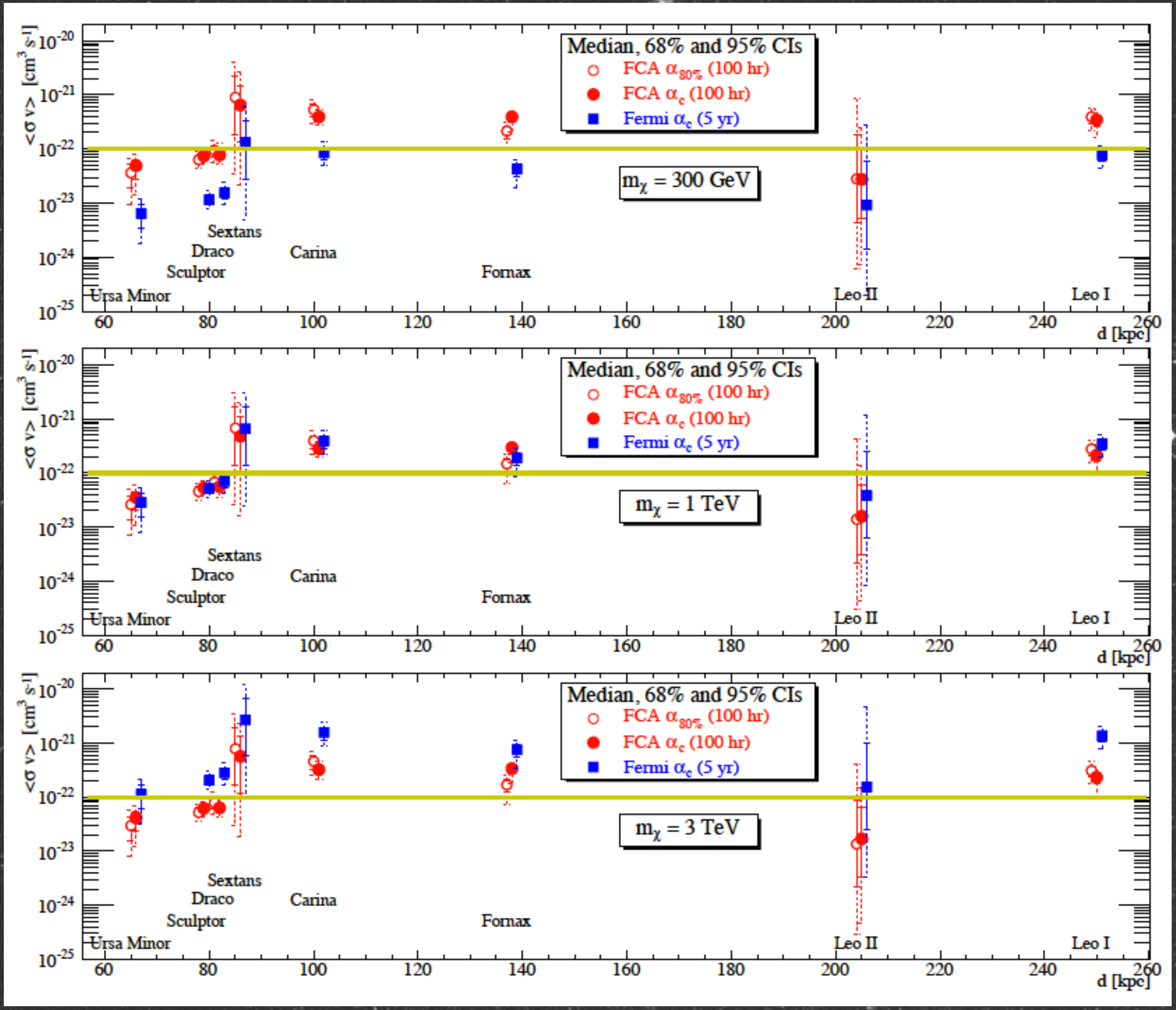
corresponding limits on cross section



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Summary

- For indirect detection, particle physics constraints only as good as astronomical constraints.
- We have no empirical evidence for DM cusps in dSph galaxies. Core/cusp uncertainty is relevant for indirect detection experiments.
- Given astrophysical uncertainties, we get most robust constraints on J if integration angle is ~ $2r_{half}$/distance.
- These constraints indicate smaller annihilation fluxes than obtained from CDM assumptions, several orders of mag fainter than Galactic center (but remember to consider backgrounds!), too faint to detect WIMPs?