Dark Halo Shapes and Rotation Curves

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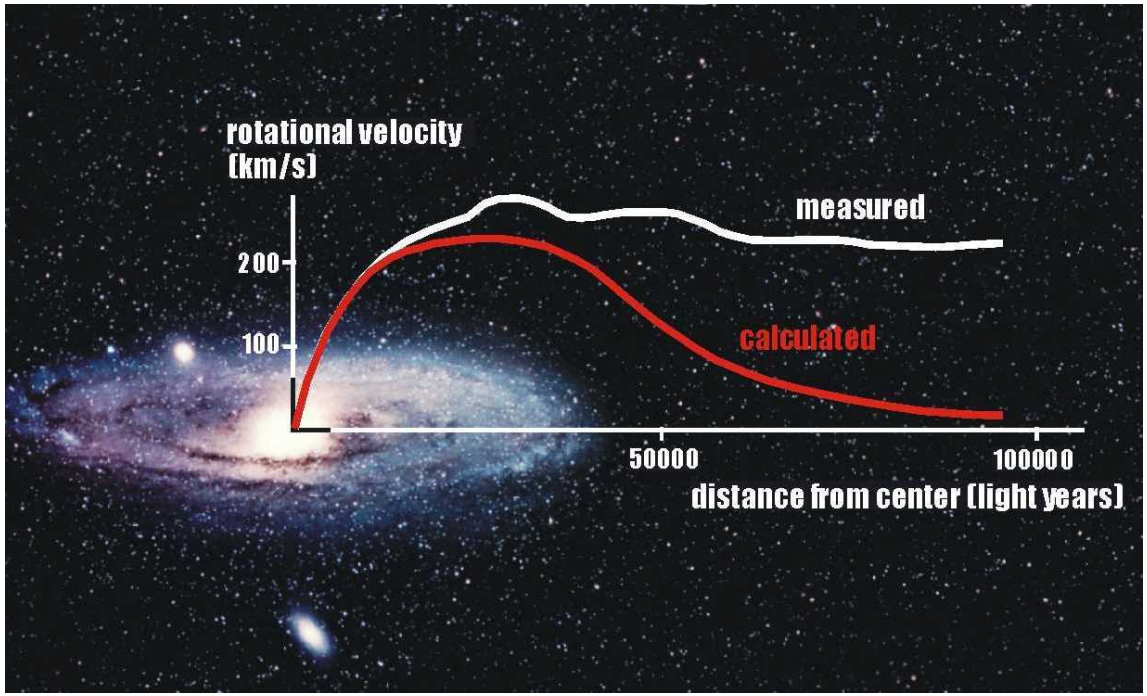
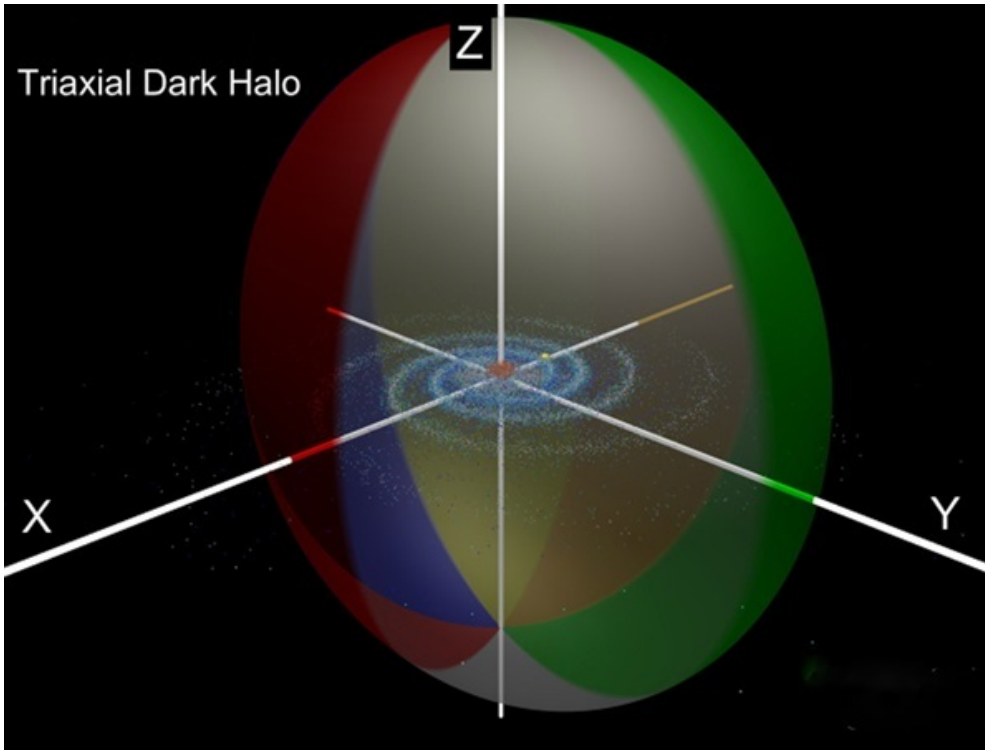
Dark Matter

- Around 85% of matter in the Universe is comprised of unknown substance
- Key piece of evidence: "flattened" galaxy rotation curves $\Rightarrow$ effective log–potential at large distances
- Proposed solutions: specific DM profiles, modified Newtonian dynamics (MOND)



- Simple geometric idea from electrostatics: infinite charged line/cylinder yields log–potential
- Strongly prolate dark halos produce flattened curves
- The halos are actually prolate in CDM simulations (Dubinski, Carlberg, 1991)
- But: MOND only mimics near–spherical halos, and self–interacting DM (SiDM) favors rounded shapes $\Rightarrow$ halo morphology can allow to discriminate!



- Commonly used density profiles: NFW and Burkert

$$\rho_{NFW} = \frac{\rho_0 r_0^3}{r(r+r_0)^2}\ ,\ \rho_B = \frac{\rho_0 r_0^3}{(r+r_0)(r^2+r_0^2)} \tag{1}$$

- Deformation $r^2 \to x^2 + y^2 + q^2 z^2$ with $q < 1$ results in steeper rises and shallower declines

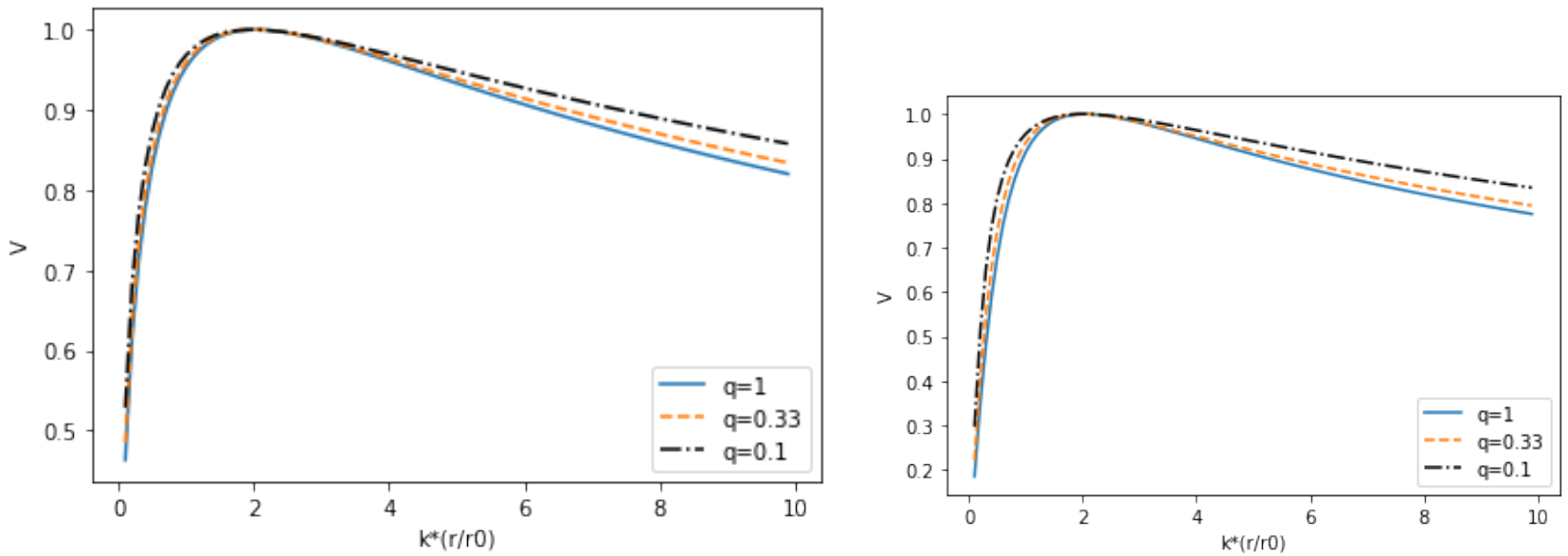


Figure 1: Rotation curve velocities, rescaled to have peak at 2 and normalized to unity (left: NFW, right: Burkert)

Galaxy fits

We fitted 69 galaxies from the SPARC database (Lelli, McGaugh, Schombert, 2016), and found that about 22 of them prefer prolate shapes for the NFW anzatz, and about 29 for Burkert.

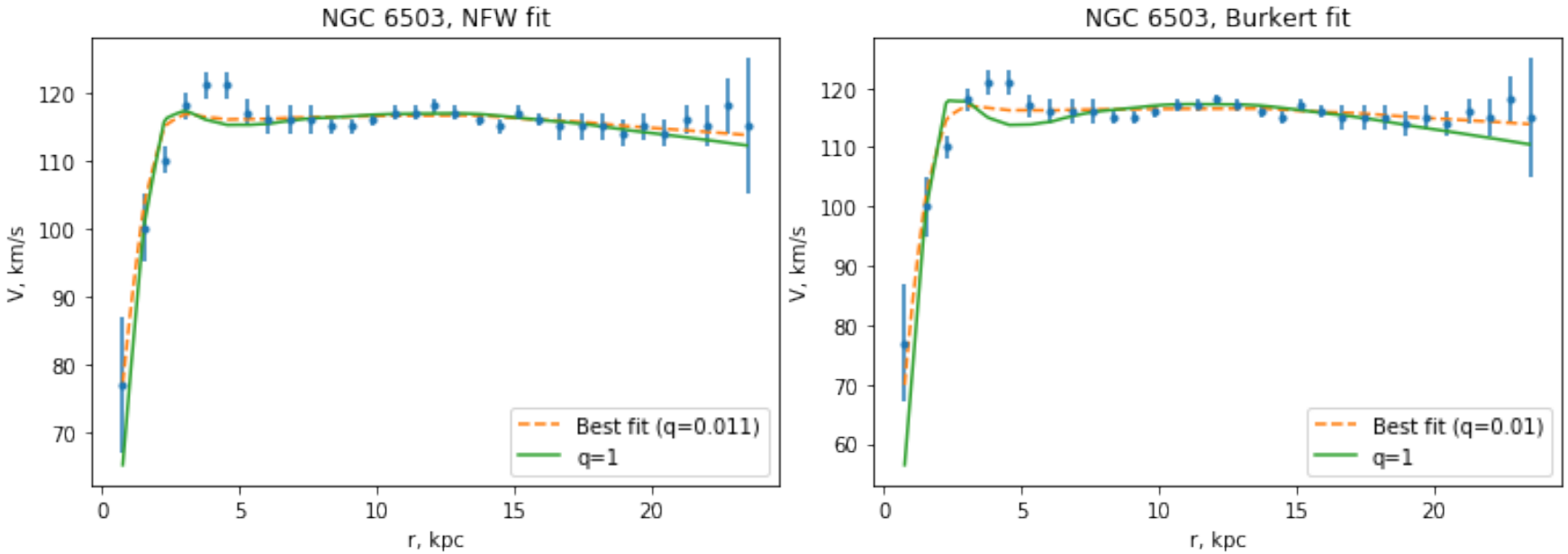


Figure 2: Rotation curve fits for galaxy NGC 6503; the value q=0.01 shows considerable improvement compared to q=1 (left: NFW, right: Burkert)

But: best fit is often with unphysical values of q (< 0.1), and physically plausible values like 0.5 or 0.33 give only marginal improvement. Could it be that instead of elongated halo, we have a string–like object at the center?

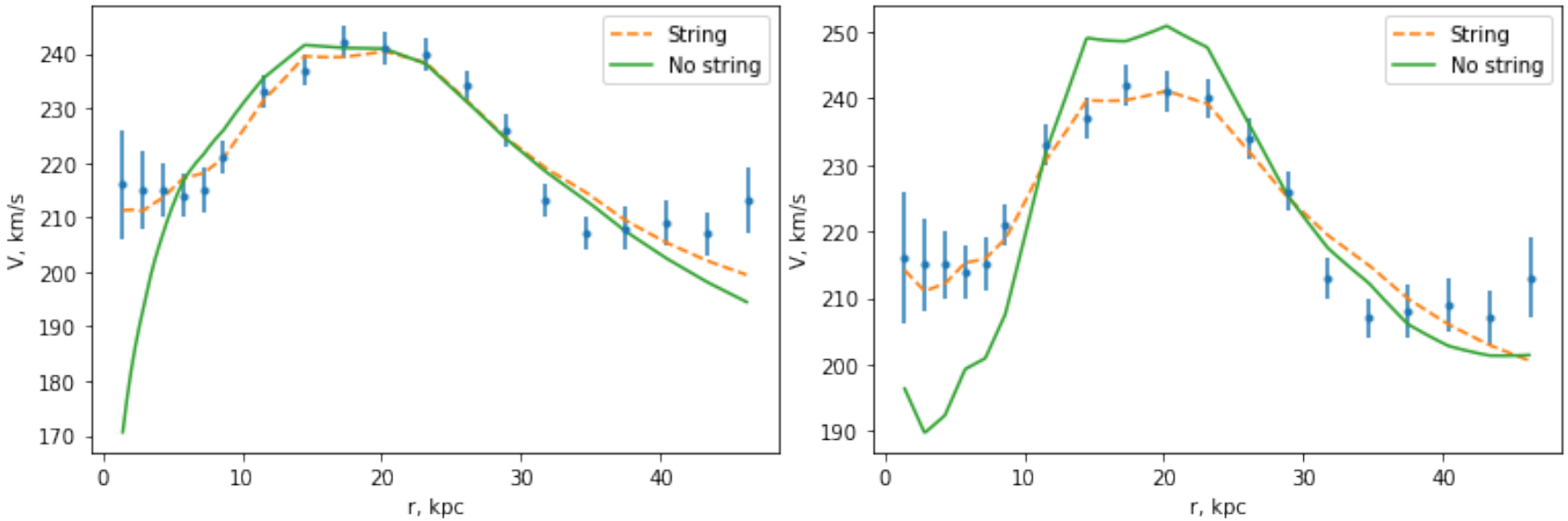


Figure 3: Rotation curve fits for galaxy NGC 5371; addition of a string–type filament yields considerable improvement for both NFW (left) and Burkert (right)

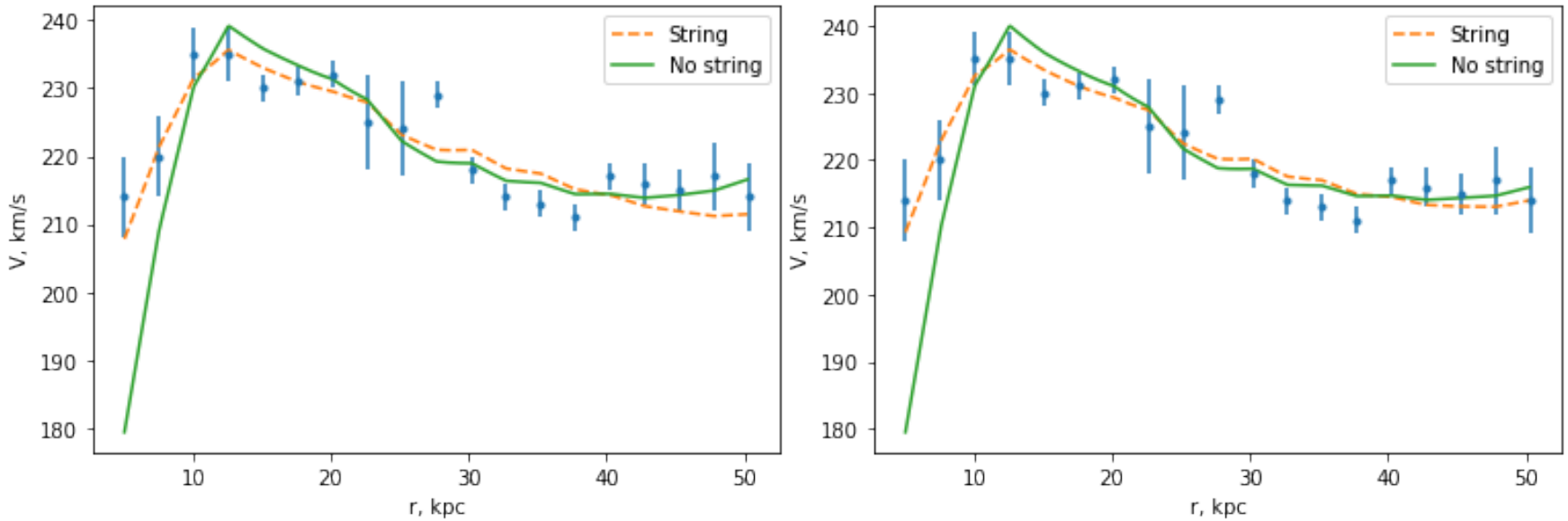


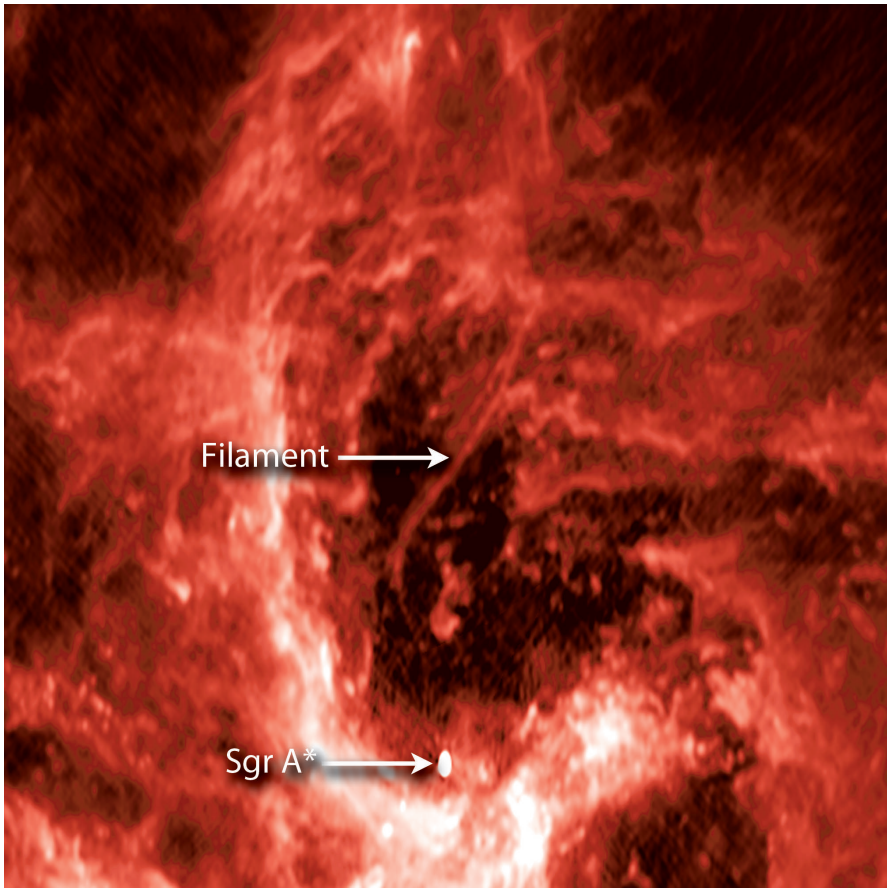
Figure 4: Rotation curve fits for galaxy NGC 5907; addition of a string–type filament yields considerable improvement for both NFW (left) and Burkert (right)

What could these objects be?

- Tidal streams? NGC 5907 (“knife-edge galaxy“) has an extended stucture of this type
- Black–hole jets made of baryonic and/or dark matter?
- But: BH jets are rarely aligned with the rotation axis of the galaxy

Cosmic strings?

- Morris, Zhao, and Goss (2017): a mysterious radio filament connected to the black hole at the center of Milky Way
- Vilenkin, Levin, Gruzinov (2018): cosmic strings can attach themselves to PBHs in the early Universe and form networks
- Pulsar observations of NANOGRAV interpreted as GW signal from cosmic strings (Blazi, Brdar, Schmitz, 2020)
- Filament tensions in our fits are below the upper bound from Planck ($7.8 * 10^{-7}$)



Conclusions

- Performing the same analysis for different profiles proves to be a powerful method for making model–independent conclusions about whether or not a certain feature is present.
- Gravitational lensing observations from EUCLID will tell us more about halo shapes and other structures.

Thanks for your attention!