





How Do We Know That it Exists?

- Cosmological Parameters +
 Inventory of Luminous material
- Dynamics of galaxies
- Dynamics and gas properties of
 - galaxy clusters
- Gravitational Lensing







Hot Gas in Galaxy Clusters

- High mass required to keep the hot gas from leaving the cluster!
- If gas in hydrostatic equilibrium \rightarrow Luminosity and temperature profile \rightarrow mass profile

























Dark Halo Density Profiles III

But there are plenty of complications...

- Non-spherical dark matter halos?
- Central part dominated by dark baryons instead of CDM?
- Best target galaxies do not sit in typical dark halos?
- N-body simulations responsible for the predicted CDM halo profile prediction not reliable?

Dark Halo Substructure I The dark halos around galaxies form the merger of smaller halos, but many remnants of the smaller halos survive → The dark halos of galaxies are not perfectly smooth! ~10 % of the dark matter is in clumps (a.k.a. subhalos or halo substructure)





Naïve expectation Observed A factor of 10—100 too few satellite galaxies around the Milky Way!

Dark Halo Substructure III

The solution: Dark galaxies?

• Dark galaxy: A dark subhalo which either lacks baryons, or inside which the baryons form very few stars

 Possible detections exist of galaxies with very high mass-to-light ratios (M/L≥1000), but not yet in sufficient numbers to solve the problem





























Suggestion for literature Exercises: Alternative theories of gravity vs. Dark matter • Many examples (pick <u>one</u>): • MOND – Lots of work done. Fairly easy to

- MOND Lots of work done. Fairly easy to understand at an undergraduate level
- MOdified Gravity (MOG) Slightly more technical. Requires some understanding of tensors.
- Can GR explain rotation curves without dark matter?