Testing Modified Gravity with the DiskMass Survey

Garry W. Angus
VUB — FWO

TAUP 2015
Torino
8th September 2015

Spiral (disk) galaxies. Often gas rich => star formation.

Kinematically useful
Weak bars & bulges

Bar strength
Bulge strength
The inclination is important

We want to measure rotation speed of galaxy as function of radius, $V(R) \Rightarrow M(R)$
Known mass from stellar and gas distribution if it helps: \( V(R) \rightarrow M(R) \)

Take a nearly edge on galaxy and measure its rotation using neutral hydrogen emission (radio - 21cm)

**M31/Andromeda, i~77 deg**

**Dark Matter (DM)**

**30kpc**

1 light year ~ 0.3 parsec

\[ M_\star = L_\star \times \frac{M}{L_K} \]

Mass-to-light ratio K-band - NIR
Influence of $M/L_K$ on DM halo

DM halo abundance depends on mass of stars ($M/L_K$). Numerical stellar evolution models favour $M/L_K \approx 0.6$. Can we measure $M/L_K$ directly?
What if we had a 2nd (independent) measure of the dynamics?

Stellar Vertical VelDisp gives

$$\sigma_z^2 \propto \Sigma_{\text{total}} \times h_z \propto M/L_K \times h_z$$

Need galaxies with \( i \sim 15-40 \) deg to simultaneously measure \( V(R) \) and \( \sigma_z \)
The DiskMass Survey

Surface brightness
Rotation speed
stellar velocity dispersion

Bershady et al. 2010
Surface Brightness = Proj. Luminosity Density = Luminosity/Area

Azimuthally averaged proj. luminosity density of stars, $I_\star(R)$

Azimuthally averaged vertical velocity dispersion of stars, $\sigma_z(R)$

$M_\star = L_\star \times M/L_K$
$\Sigma_\star = I_\star \times M/L_K$

$\Sigma_{total} \approx \sigma_z^2/\pi \ G \ k \ h_z$

Combining all this info gives:
$\Sigma_\star = \Sigma_{total} - \Sigma_{atom} - \Sigma_{mol} (-\Sigma_{DM})$

$k$ is a parameter fixed by the vertical stellar distribution.
$G$ is Newton's constant.
$h_z$ is the exponential scale-height of the galaxy disk.
$\Sigma_\star$ is the stellar disk surface density.
$\Sigma_{total}$ is the total disk surface density.
$\Sigma_{atom}$ is the atomic gas (HI, He) surface density.
$\Sigma_{mol}$ is the molecular gas (H2) surface density.
Galaxy disks have been dieting

Result: Galaxy disks weigh 2x less than previously thought. More room for DM in central parts.
Modified Newtonian Dynamics (MOND)

\[ a_N >> a_0 \Rightarrow \text{Newtonian dynamics: } 1/r^2 \text{ (Milgrom 1983)} \]

\[ a_N << a_0 \Rightarrow \text{Modified force law: } a \sim \sqrt{a_N a_0} \sim 1/r \]

Angus, Diaferio, et al., 2015, MNRAS

Only 1 free parameter - \( M/L_K \) - for 2 datasets
Galaxy disks are significantly lighter than previously thought. Modified gravity theories are at odds with the DiskMass Survey data.

Conclusions
Using scaling relations to find scale-height, $h_z$ and inclination, $i$

Kregel et al. (2002)

After accounting for DM

Result: Almost half of all galaxy disks weigh nothing!?

Values from Evol models

Values from Martinsson et al. 2013a