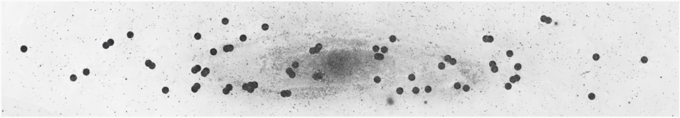
Disk Galaxy Rotation Curves and Dark Matter Halos



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Outline

Early Observations of Galaxy Rotation Curves

Outline

Method

- Observations of 67 *HII* regions in Andromeda
    - DTM image-tube spectrographs
- Observations of $[N\,II]\,\lambda 6583$ emission for the core
- Rotational speeds from the Dopplershift

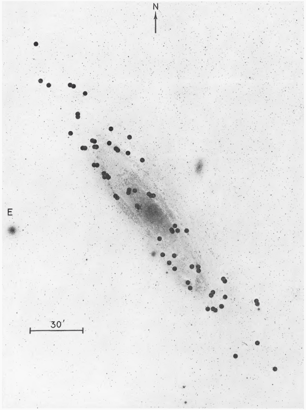

Figure 1: UV photograph of Andromeda with the observed HII regions marked with dark dots

Results

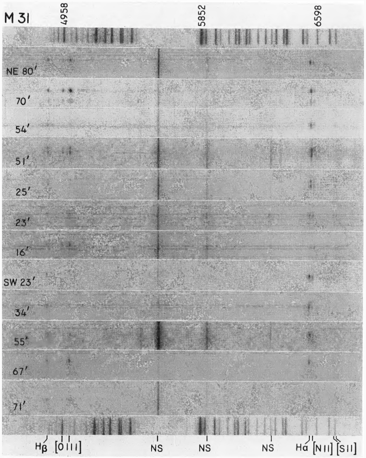

Figure 2: Representative spectra of emission arranged according to distance from center with a Ne + Fe comparison spectrum on top and bottom.

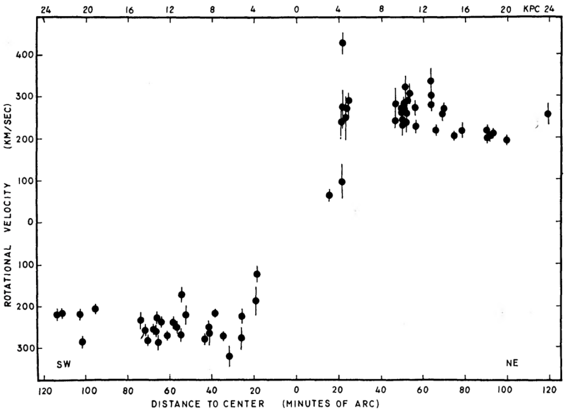

Figure 3: Rotational velocities for sixty-seven emission regions in M31, as a function of distance from the center. Error bars indicate average error of rotational velocities.

Results

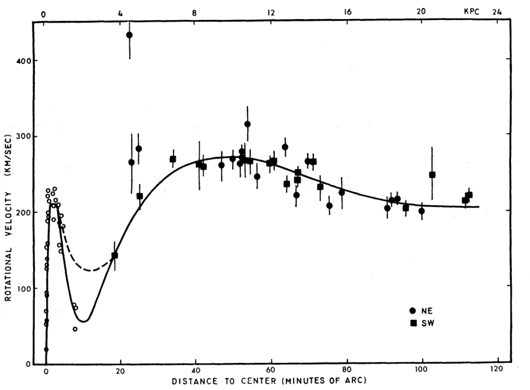

Figure 4: Rotational velocities for OB associations in M31, as a function of distance from the center. For R < 12', curve is fifthorder polynomial; for R > 12', curve is fourth-order polynomial required to remain approximately flat near R — 120'. Dashed curve near R = 10' is a second rotation curve with higher inner minimum.

Outline

Method

- Rotation curves for 21 Sc Galaxies
    - Kitt Peak 4m RC Spectrograph w. a Carnegie image tube
- again mostly *HII* regions and [*N II*] λ6583

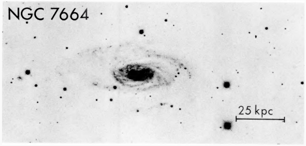

Figure 5: Image of NGC 7664, one of the observed Sc galaxies

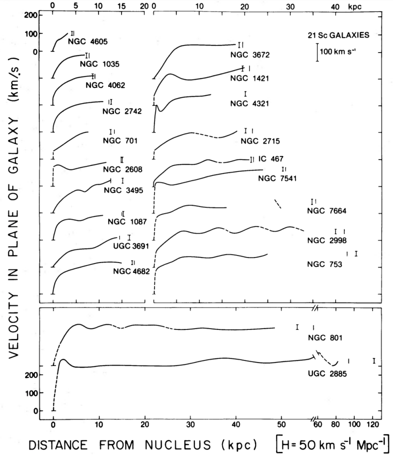

Figure 6: Mean velocities in the plane of the galaxy, as a function of linear distance from the nucleus for 21 Sc galaxies, arranged according to increasing linear radius.

Results

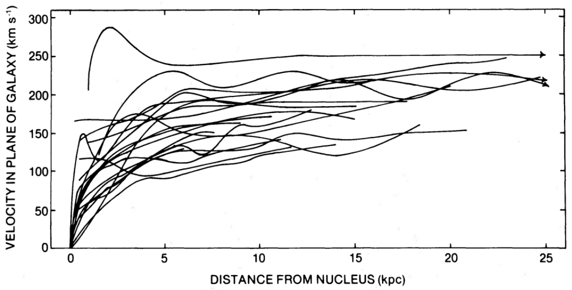

Figure 7: Superposition of all 21 Sc rotation curves

Results

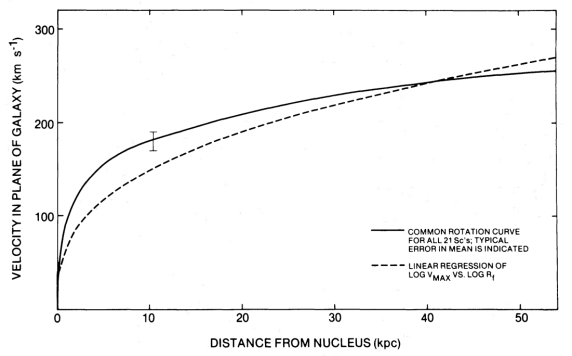

Figure 8: Rotational velocity as a function of radius for all 21 Sc galaxies.

Results

"This form for the rotation curves implies that the mass is not centrally condensed, but that significant mass is located at large R. The integral mass is increasing at least as fast as R. The mass is not converging to a limiting mass at the edge of the optical image. The conclusion is inescapable that non luminous matter exists beyond the optical galaxy."

Connecting Rotation Curves to the Distribution of Dark Matter in Halos

Outline

Method

- Large (1100) sample of rotation curves + photometry
  - But only 131 reliably sampled using optical spectrometry
  - Rest from co-adding different observations
- Statistical analysis of the data

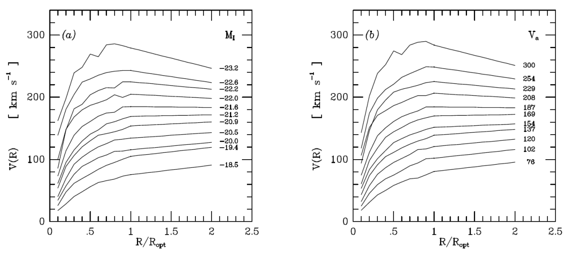

Figure 9: The Universal Rotation Curve of spiral galaxies. Radii are in units of R_{opt}.

Results

$$V_{URC}\left(\frac{R}{R_{opt}}\right) = V(R_{opt}) \left[\left(0.72 + 0.44 \log \frac{L}{L_*}\right) \frac{1.97\ x^{1.22}}{(x^2 + 0.78^2)^{1.43}} + 1.6\, e^{-0.4(L/L_*)} \frac{x^2}{x^2 + 1.5^2\, (\frac{L}{L_*})^{0.4}} \right]^{1/2} \quad \mathrm{km\ s^{-1}}$$

- Universal rotation curve describing the velocity distribution in a Galaxy
- Dependent only on the luminosity
- Can be used to estimate the LM/DM ratio

Outline

Method

- N-body simulations for SCDM & CDMΛ cosmological models

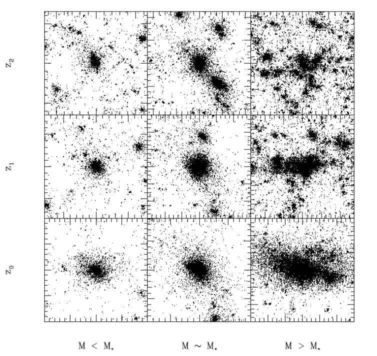

Figure 10: Particle plots illustrating the time evolution of halos of different mass

Results

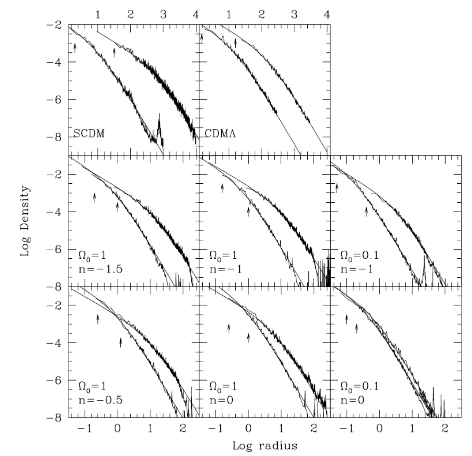

Figure 11: Density profiles of one of the most massive halos and one of the least massive halos in each series

Results

Navarro, Frenk & White DM density profile

$$\rho\,(r) = \frac{3H_o^1}{8\pi G}(1+z_o)^3\,\frac{\Omega_0}{\Omega(z_0)}\,\frac{\delta_c}{cx\,(1+cx)^2} \qquad (1)$$

$$\text{with: } \delta_c(M,z_0) \sim 3\times 10^3\Omega\,(z_0)\left(\frac{1+z_{coll}}{1+z_0}\right)^3$$

- Rotational curves generated from this profile fit the observations
- Consistent with the universal RC of Persic, Salucci & Stel

Dark Matter Candidates

Fuzzy Dark Matter

- Particles so light ($m < 10^{-22} eV$) that the wave properties can suppress cusps in DM halos

$$\lambda_{db} \approx 2kpc \left(\frac{10^{-22} eV/c^2}{m_a} \right) \left(\frac{10 km/s}{v} \right)$$

- non-thermally produced
- needed in large numbers

Primordial Black Holes

- Small black holes (10^{20}g $<$ M$_{PBH}$ $< 10^{27}$)
- Not produced astronomically
- Form during the QCD phase transition in the early Universe by cosmic string loops, bubble collisions or large density perturbations.
- About 10^{25} PBH needed to produce the MW DM halo
- Might be detected by gravitational wave detectors

Summary

Summary

- Rotation curves cannot be explained by the Keplerian motion of the luminous matter
- The extent of DM halos can be calculated using the NFW profile
- It is largely unknown what dark matter is but PBH and FDM are possible candidates to explain the observations

Appendix

References i

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