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Small Satellite Probes of Spiral Galaxies

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Abstract.
Small, bound satellites of larger spiral galaxies are employed in the determination of the statistical presence of mass beyond the rotation disk of the largest (primary) galaxy. Optical and neutral hydrogen data are combined to develop mass estimates using the small bound groups. The resulting distribution of the internal/external mass ratios provides limits on halo mass models, and a glimpse at this mass estimation technique.

1. The Background

This technique, for estimating the masses of spiral galaxies beyond the most distant measurable diameter, is based on the ratio of the external (satellite orbit) mass to the internal (disk rotation) mass (van Moorsel 1982). The external mass comes from the projected orbital data, while the internal mass comes from a rotation curve. In bound pairs of galaxies a large mass difference improves the isolation from other systems.

Mass ratio values ($M_{\text{external}}/M_{\text{internal}} = X_m$) reflect influences from:

1. External halo mass
2. Orbital eccentricity - although only weakly
3. Friction (for some conditions)

Mass ratio (X_m) independent of separation and distance, and orbital parameters except for eccentricity

2. The Data

- The authors have assembled neutral (atomic) hydrogen (H I) and optical measurements of radial velocity and tangential separation between galaxy group pairs (primary and each satellite)
- Rotation curves required for primary (internal) mass estimates

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- Combined data from several observers indicates a consistent distribution of mass values, with important differences
- Projected separation values > 200 kpc and < 200 kpc tested separately to ensure radial independence

3. Concerns

- Selection of groups
- Isolation important for dominant central gravitational influence
- Dwarf features reviewed for isolation
- Consistency in selection criteria required for separate observations
    - Unbound pairs and/or contamination by chance projection can produce the same effects as large external (halo) mass
    - Orbital (eccentricity) effects are modeled to avoid complications
    - Observation radius (field of view) for small groups can influence distribution of mass ratios (X_m) if not carefully examined

4. Results

- Distribution of assembled X_m has important characteristics
- Small values observed to dominate data
- Large values observed in some groups
- Observations exhibit both features
- Models proposed that fit distribution of mass ratios must also contain both features
- Small X_m values require: Some low-mass halos. Circular orbits also produce small values but require unusual formation history for halo
- Large X_m values require: Some large halos. Highest X_m values found in Outer region of circular orbits Inner region of eccentric orbits
- Distribution of both features can be friction dependent

5. Models

Successful models proposed have:

- 400 kpc halo and satellite orbit maximum radius
- Velocity of rotation (at 15 kpc) is 240 $\mathrm{km\,s^{-1}}$

- Isothermal halo: Ratios of halo-to-disk (to 15 kpc) mass varied from 0.5 to 1000
- Mixed-eccentricity model : Highly eccentric mix with nearly-circular satellites orbits required to produce both of the distribution features ($e \approx 0.9 \pm 0.05$). Moderate eccentricity mixture does not produce distribution extremes for reasonable fit
- Mixed-mass model: Both large-halo systems low-mass systems (small or non existent halos) are required to produce both distribution features

6. Implications

Dark matter surrounding isolated spiral galaxies can be measured with gravitational probes, as with this technique. Although both large and small halos are required to model the data, implying both large and small halos for the observed spirals, a separate model can be fit using a more unlikely combination of extreme orbital eccentricities.

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