How DM Came to Matter Summary (Nature)

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1 Stem of Thought

Two problematic observations:

1. High velocity dispersions in clusters ⇒ Mass Discrepancy
2. Flat rotation curves, instead of "declining"

Conclude: unexpected large galaxy masses

2 The Two Anomalies

2.1 DM? Mass discrepancy in Clusters of Galaxies

- Problem: Average mass density deduced from velocity dispersion > observed visible matter
- Explanation: velocity dispersion high ⇒ need higher mass density for galaxy system to be stable
- Proposed solutions:
  (a) Additional Matter
  (b) Absence of "dynamical equilibrium"- instability (Implication: galaxy lifetime< 10-1000 million yrs ×)
  (c) Others: regions of ionized hydrogen, large density of gravitational radiation, changes to the law of gravity, presence of massive neutrinos, etc.

2.2 Flat Galactic Rotation Curves

- Rotation curves (RC): Orbital velocity (gas, stars) vs. Distance to galactic center
- Problem of flatness: flat RC ⇒ more gravity
  Explanation: velocity expected to decline beyond "interior mass" (Keplerian)
- Solution: it's a "matter of taste"

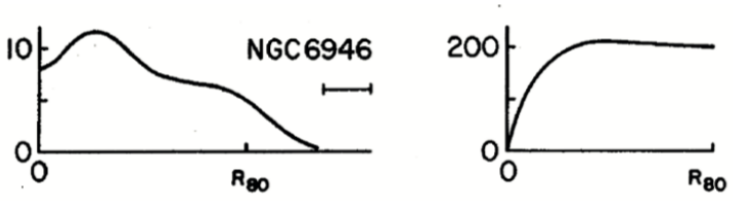

Figure 1: observed from galaxy NGC6946. Left: hydrogen surface density vs. radius. Right: RC- rotation velocity vs. radius.

3 The Rise of Cosmology ⇒ DM

3.1 Larger scales and higher energies, breakthroughs:

- Identification of quasars, cosmic microwave background: demise of steady state theory of the Universe)
- Universe very different in the past and today
- Distances based via the appearances of galaxies: unreliable
- Aggregation of mass: neutron stars

3.2 DM! Closed Universe

- Motivation: A desire for a **closed universe**
  - A universe could be open (infinte), closed (finite), or flat.

  - Distinction: Balancing cosmic expansion and gravitational attraction– Universe collapse or expand forever?
  - Why attractive? Closed Universe agrees with Mach's principle.

- The deceleration parameter relate to mass density of the Universe, ρ.
- Approach: visible mass density of galaxies (ρ) $\geq$ critical density (ρ_c) $\rightarrow \Omega \geq 1$ for closed U.
- DM! Observation: $\Omega \sim 0.01 \rightarrow$ need extra mass!

4 To Conclude..

- 1974- The two anomalies came together as one problem: DM
- Mass of galaxies underestimated by a factor ≥ 10

Ultimate question: "why certain observations were eventually conceived as 'evidence' as anything".