

# How Dark Matter Came to Matter[1]

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## 1 Stem of Thought

Two problematic observations:

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

Conclude: unexpected large galaxy masses

## 2 The Two Anomalies

### 2.A DM? Mass discrepancy in Clusters of Galaxies

- Problem: Average mass density deduced from velocity dispersion  $>$  observed visible matter
- Explanation: velocity dispersion high  $\Rightarrow$  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  $\times$ )
  - (c) Others: regions of ionized hydrogen, large density of gravitational radiation, changes to the law of gravity, presence of massive neutrinos, etc.

## 2.B Flat Galactic Rotation Curves

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

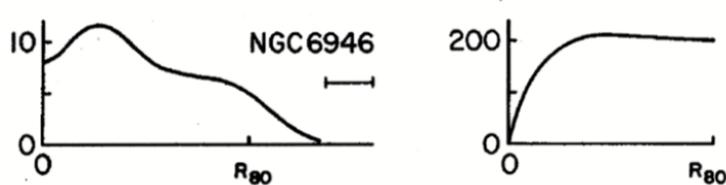


Figure 1: observed from galaxy NGC6946. Left: hydrogen surface density vs. radius. Right: RC- rotation velocity vs. radius.

## 3 The Rise of Cosmology $\Rightarrow$ DM

### 3.A 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.B 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,  $\rho$ .
- Approach: visible mass density of galaxies ( $\rho$ )  $\geq$  critical density ( $\rho_c$ )  
 $\rightarrow \Omega \geq 1$  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  $\geq 10$

Ultimate question: ”why certain observations were eventually conceived as ‘evidence’ as anything”.

## References

- [1] J. G. de Swart, G. Bertone, and J. van Dongen, “How dark matter came to matter,” *Nature Astronomy*, vol. 1, no. 3, 2017.