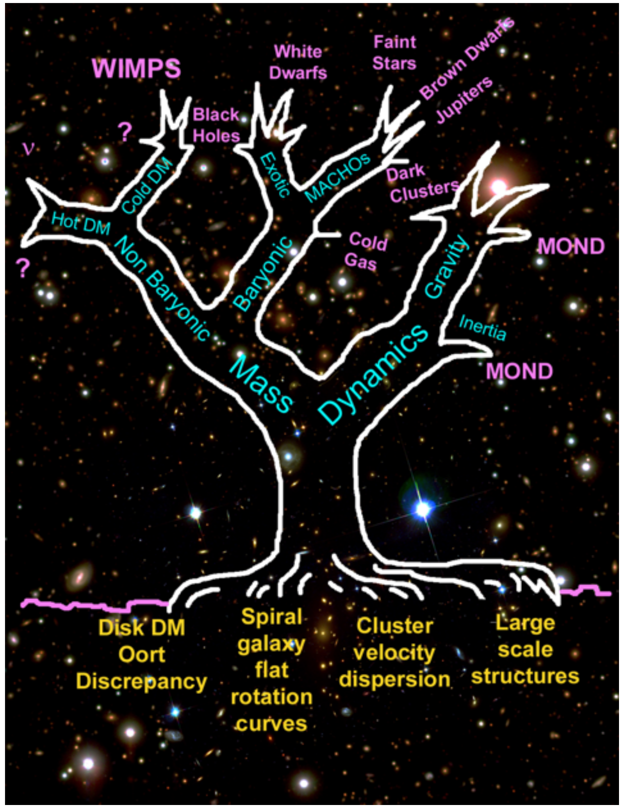
Cosmic duologue

Federico Lelli & Azadeh Fattahi-Savadjani

Dark Matter vs. Modified Newtonian Dynamics



Stacy McGaugh

See also: 2010 Dark Matter debate between Pavel Kroupa and Simon White (Bethe Kolloqium @ Bonn University):
http://astroweb.case.edu/ssm/mond/20101125_BE_DarkMatter.mp4

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Zwicky 1933:

The redshift of extragalactic nebulae

(1242 ADS citations as of 24/04/2020)

Die Rotverschiebung von extragalaktischen Nebeln

von F. Zwicky.

(16. II. 33.)

Inhaltsangabe. Diese Arbeit gibt eine Darstellung der wesentlichsten Merkmale extragalaktischer Nebel, sowie der Methoden, welche zur Erforschung derselben gedient haben. Insbesondere wird die sog. Rotverschiebung extragalaktischer Nebel eingehend diskutiert. Verschiedene Theorien, welche zur Erklärung dieses wichtigen Phänomens aufgestellt worden sind, werden kurz besprochen. Schliesslich wird angedeutet, inwiefern die Rotverschiebung für das Studium der durchdringenden Strahlung von Wichtigkeit zu werden verspricht.

§ 5. Bemerkungen zur Streuung der Geschwindigkeiten im Coma-Nebelhaufen.

Wie aus der Zusammenstellung in § 3 hervorgeht, existieren im Comahaufen scheinbare Geschwindigkeitsunterschiede von mindestens 1500 bis 2000 km/sek. Im Zusammenhang mit dieser enormen Streuung der Geschwindigkeiten kann man folgende Überlegungen anstellen.

1. Setzt man voraus, dass das Comasystem mechanisch einen stationären Zustand erreicht hat, so folgt aus dem Virialsatz

$$\bar{\varepsilon}_k = -\tfrac{1}{2}\,\bar{\varepsilon}_p, \qquad (4)$$

wobei $\bar{\varepsilon}_k$ und $\bar{\varepsilon}_p$ mittlere kinetische und potentielle Energien, z. B. der Masseneinheit im System bedeuten. Zum Zwecke der Abschätzung nehmen wir an, dass die Materie im Haufen gleichförmig über den Raum verteilt ist. Der Haufen besitzt einen Radius R von ca. einer Million Lichtjahren (gleich 10^{24} cm) und enthält 800 individuelle Nebel von je einer Masse entsprechend 10^9 Sonnenmassen. Die Gesamtmasse M des Systems ist deshalb

$$M \sim 800 \times 10^9 \times 2 \times 10^{33} = 1.6 \times 10^{45}\ \text{gr.} \qquad (5)$$

Daraus folgt für die totale potentielle Energie Ω:

$$\Omega = -\frac{3}{5}\,\Gamma\,\frac{M^2}{R} \qquad (6)$$

Γ = Gravitationskonstante

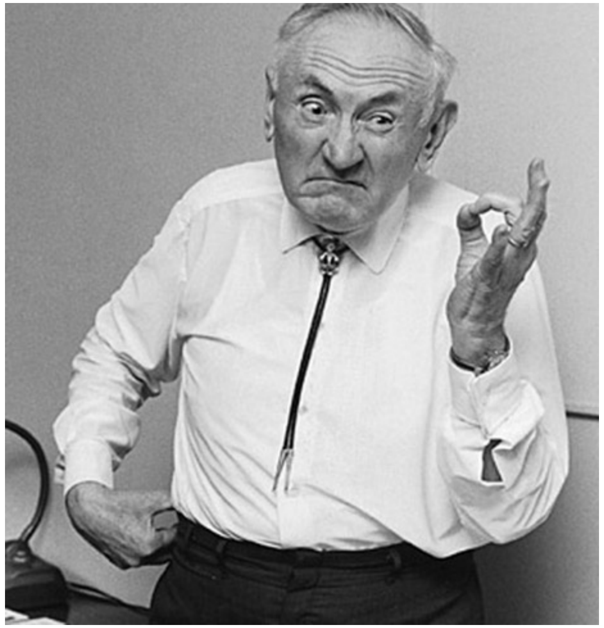
oder

$$\bar{\varepsilon}_p = \Omega/M \sim -64 \times 10^{12}\ \text{cm}^2\,\text{sek}^{-2} \qquad (7)$$

und weiter

$$\bar{\varepsilon}_k = \overline{v^2}/2 = -\varepsilon_p/2 = 32 \times 10^{12}\ \text{cm}^2\,\text{sek}^{-2}$$
$$(\overline{v^2})^{1/2} = 80\ \text{km/sek}\,. \qquad (8)$$

Um, wie beobachtet, einen mittleren Dopplereffekt von 1000 km/sek oder mehr zu erhalten, müsste also die mittlere Dichte im Comasystem mindestens 400 mal grösser sein als die auf Grund von Beobachtungen an leuchtender Materie abgeleitete[1]). Falls sich dies bewahrheiten sollte, würde sich also das überraschende Resultat ergeben, dass dunkle Materie in sehr viel grösserer Dichte vorhanden ist als leuchtende Materie.



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Rubin, V. et al. (1980):

(960 ADS citations)

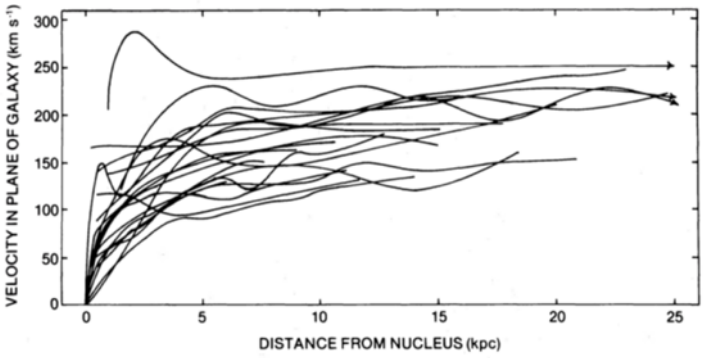

FIG. 6.—Superposition of all 21 Sc rotation curves. General form of rotation curves for small galaxies is similar to initial part of rotation curve for large galaxies, except that small galaxies often have shallower nuclear velocity gradient and tend to cover the low velocity range within the scatter at any *R*.

THE ASTROPHYSICAL JOURNAL, **238**:471–487, 1980 June 1

ROTATIONAL PROPERTIES OF 21 Sc GALAXIES WITH A LARGE RANGE OF LUMINOSITIES AND RADII, FROM NGC 4605 ($R = 4$ kpc) TO UGC 2885 ($R = 122$ kpc)

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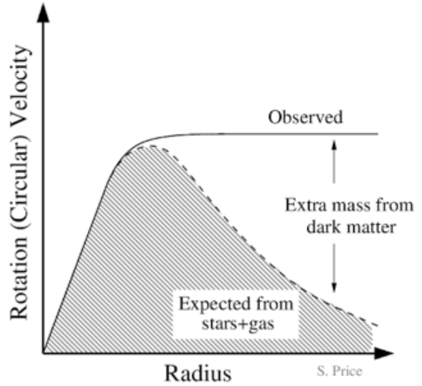

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Milgrom (1983):
(1974 ADS citations)

THE ASTROPHYSICAL JOURNAL, 270:365–370, 1983 July 15

A MODIFICATION OF THE NEWTONIAN DYNAMICS AS A POSSIBLE ALTERNATIVE TO THE HIDDEN MASS HYPOTHESIS[1]

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Received 1982 February 4; accepted 1982 December 28

ABSTRACT

I consider the possibility that there is not, in fact, much hidden mass in galaxies and galaxy systems. If a certain modified version of the Newtonian dynamics is used to describe the motion of bodies in a gravitational field (of a galaxy, say), the observational results are reproduced with no need to assume hidden mass in appreciable quantities. Various characteristics of galaxies result with no further assumptions.

In the basis of the modification is the assumption that in the limit of small acceleration $a \ll a_0$, the acceleration of a particle at distance r from a mass M satisfies approximately $a^2/a_0 \approx MGr^{-2}$, where a_0 is a constant of the dimensions of an acceleration.

A success of this modified dynamics in explaining the data may be interpreted as implying a need to change the law of inertia in the limit of small accelerations or a more limited change of gravity alone.

I discuss various observational constraints on possible theories for the modified dynamics from data which exist already and suggest other systems which may provide useful constraints.

A MODIFICATION OF THE NEWTONIAN DYNAMICS: IMPLICATIONS FOR GALAXIES[1]

M. MILGROM
Department of Physics, Weizmann Institute, Rehovot, Israel; and The Institute for Advanced Study
Received 1982 February 4; accepted 1982 December 28

ABSTRACT

I use a modified form of the Newtonian dynamics (inertia and/or gravity) to describe the motion of bodies in the gravitational fields of galaxies, *assuming that galaxies contain no hidden mass*, with the following main results.

1. The Keplerian, circular velocity around a finite galaxy becomes independent of r at large radii, thus resulting in asymptotically flat velocity curves.
2. The asymptotic circular velocity (V_∞) is determined only by the total mass of the galaxy (M): $V_\infty^4 = a_0GM$, where a_0 is an acceleration constant appearing in the modified dynamics. This relation is consistent with the observed Tully-Fisher relation if one uses a luminosity parameter which is proportional to the observable mass.
3. The discrepancy between the dynamically determined Oort density in the solar neighborhood and the density of observed matter disappears.
4. The rotation curve of a galaxy can remain flat down to very small radii, as observed, only if the galaxy's average surface density Σ falls in some narrow range of values which agrees with the Fish and Freeman laws. For smaller values of Σ, the velocity rises more slowly to the asymptotic value.
5. The value of the acceleration constant, a_0, determined in a few independent ways is approximately $2\times10^{-8}(H_0/50\text{ km s}^{-1}\text{ Mpc}^{-1})^2\text{ cm s}^{-2}$, which is of the order of $CH_0 = 5\times10^{-8}(H_0/50\text{ km s}^{-1}\text{ Mpc}^{-1})\text{ cm s}^{-2}$.

The main predictions are:

1. Rotation curves calculated on the basis of the *observed* mass distribution and the modified dynamics should agree with the observed velocity curves.
2. The $V_\infty^4 = a_0GM$ relation should hold exactly.
3. An analog of the Oort discrepancy should exist in all galaxies and become more severe with increasing r in a predictable way.

Subject headings: galaxies: internal motions — galaxies: stellar content — galaxies: structure — stars: stellar dynamics

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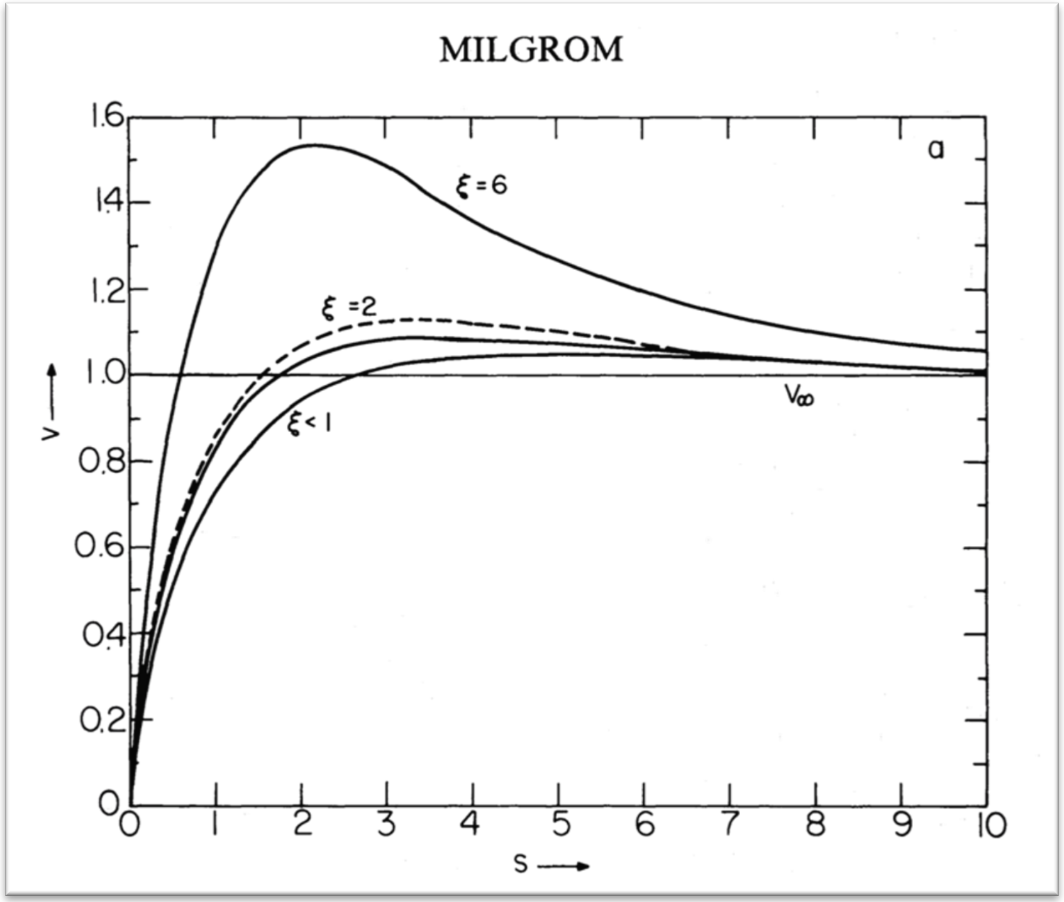

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