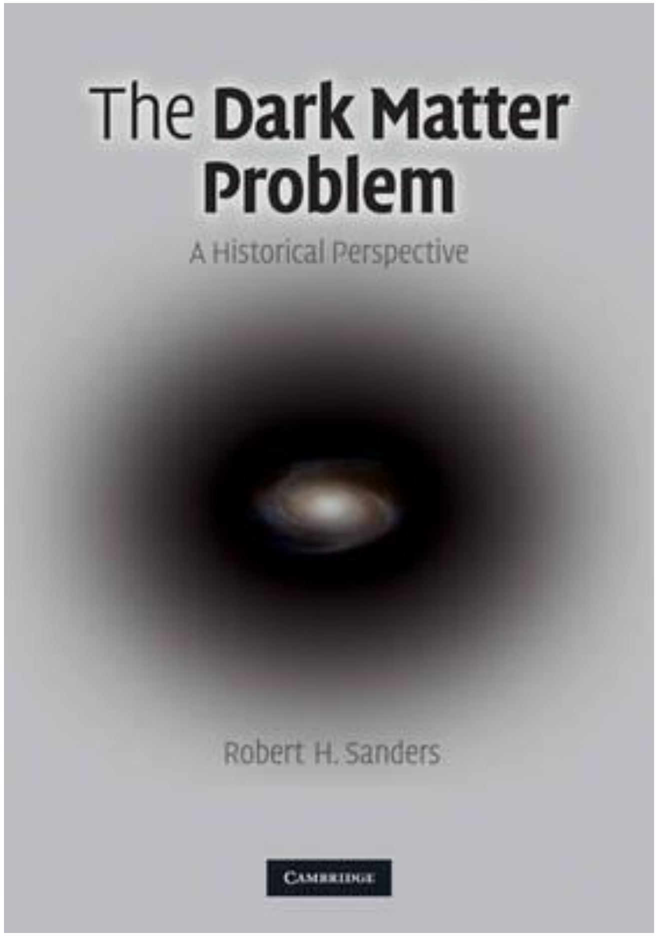
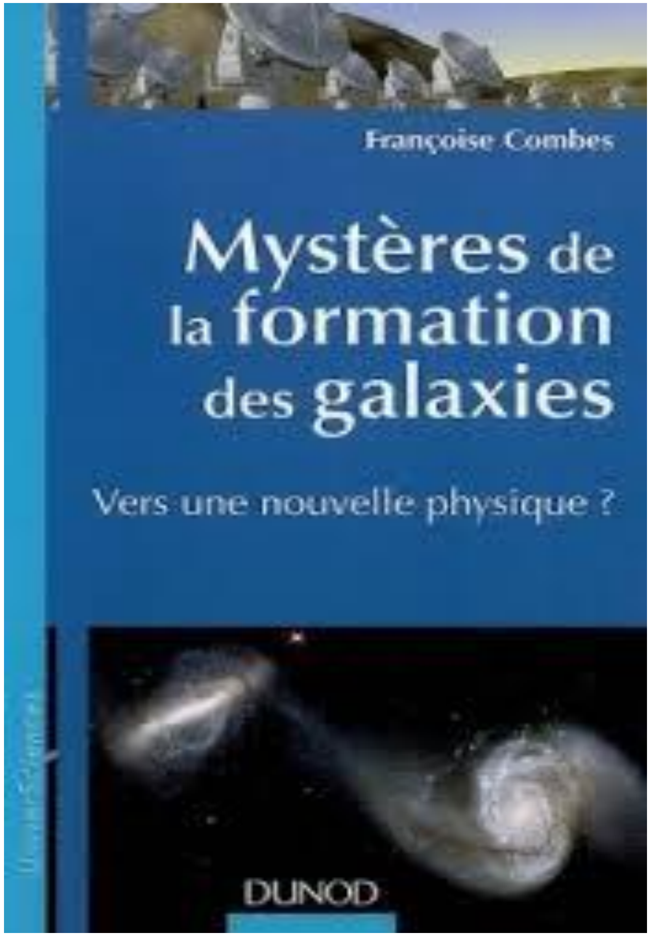
Matière noire : histoire et problèmes

Jérôme Perez – Lab. Math. Appl. ENSTA Paristech

Deux références avec toutes les références…





La préhistoire

Matière noire : contenu matériel de l'univers se justifiant par des effets gravitationnels.

- ***Les sphères d'Eudoxe …?***
- ***Neptune, puis Vulcain***

Une mauvaise habitude ?

- ***Phlogistique (XVII^{e}), calorique (XVIII^{e}), …***
- ***Ether(XIX^{e})***

Le visionnaire…

Fritz Zwicky

Rotverschiebung verursacht interpretiert. Unter Voraussetzung der obigen Masse M hätte man für die relative Änderung der Wellenlänge λ

$$\Delta\lambda/\lambda = -\varepsilon_p/c^2 = 3{,}5 \times 10^{-8}, \qquad (10)$$

was einer Geschwindigkeit von nur 10 m/sek entspricht. Um also auf diese Weise zu einer Erklärung für die grossen Streugeschwindigkeiten zu kommen, müsste man noch eine sehr viel grössere Dichte dunkler Materie zulassen als unter 1. oder 2.

[1]) Dies wäre grössenordnungsmässig in Übereinstimmung mit der in § 4 besprochenen Auffassung von Einstein und de Sitter.

Le décalage vers le rouge des nébuleuses galactiques

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.

Act. Helv. Phys., 6, 110-127, **1933**

Amas de la chevelure de Bérénice (Coma) - HST

Loi de Hubble ➔ Distance ➔ Taille de l'amas Coma : R ≈ 1Mpc

Vitesse connue pour 8 galaxies (sur 1000) : v ≈ 1000 km/s

Théorème du viriel : $2E_c+E_p = 0$

➔ $M = Rv^2/G$

AN: $M \approx (10^6 \times 3.10^{16}).(10^6)^2 / 6{,}7.10^{-11}$
$\approx 5.10^{44}$ kg $\approx 10^{14}\ M_\odot$

On dénombre 1000 galaxies contenant chacune environ 1 milliard d'étoiles…

« dunkler materie » , $M/L = 400\ M_\odot/L_\odot$

3 ans plus tard…

ApJ., 83, 23-30, **1936**

THE MASS OF THE VIRGO CLUSTER*

SINCLAIR SMITH

ABSTRACT

The lists of radial velocities now include results for thirty-two members of the Virgo Cluster, thus giving for the first time sufficient data to determine some of the physical characteristics of a cluster of nebulae.

A comparison of the velocities of fainter members of the cluster with those of brighter members shows that the line-of-sight velocity of a nebula has no dependence on its magnitude; hence, equipartition apparently does not hold in the cluster. The distribution of the velocities in right ascension and declination shows that the cluster is not in rotation and that there is no central concentration of high velocities. This result is taken to mean that the cluster is neither condensing nor breaking up, but is a fairly stable assemblage, more or less held together by its gravitational field.

From the observed distribution function for radial velocity is derived the distribution function for space velocity. For an assumed distance of 2×10^6 parsecs this function leads to 2×10^{47} g or $10^{14}\odot$ as a value of the mass of the cluster. On the basis of 500 nebulae in the cluster, the mass per nebula is $2\times10^{11}\odot$.

Although far larger than Hubble's value of $10^9\odot$ for the mass of an average nebula, other evidence lends support to the high value obtained from the Virgo Cluster. It is possible that both figures are correct and that the difference represents a great mass of internebular material within the cluster.

…

move in circular orbits with a speed of 1500 km/sec. Hence we can write either

$$m=\frac{v^2r}{2G} \quad \text{or} \quad \frac{v^2r}{G},$$

the difference being of small importance.

Taking the circular orbit form, and assuming for radius of the cluster 2×10^5 parsecs (i.e., 0.1 times its distance), we find for the mass

$$2\times10^{47}\ \text{grams} \quad \text{or} \quad 10^{14}\odot.$$

Assuming 500 nebulae in the cluster and no internebular material, we find for the mean mass of a single nebula

$$4\times10^{44}\ \text{grams} \quad \text{or} \quad 2\times10^{11}\odot.$$

This value is some two hundred times Hubble's[3] estimate of $10^9\odot$ for the mass of an average nebula. The cause of the discrepancy is not clear. In the determination of the mass of the cluster, the only

…

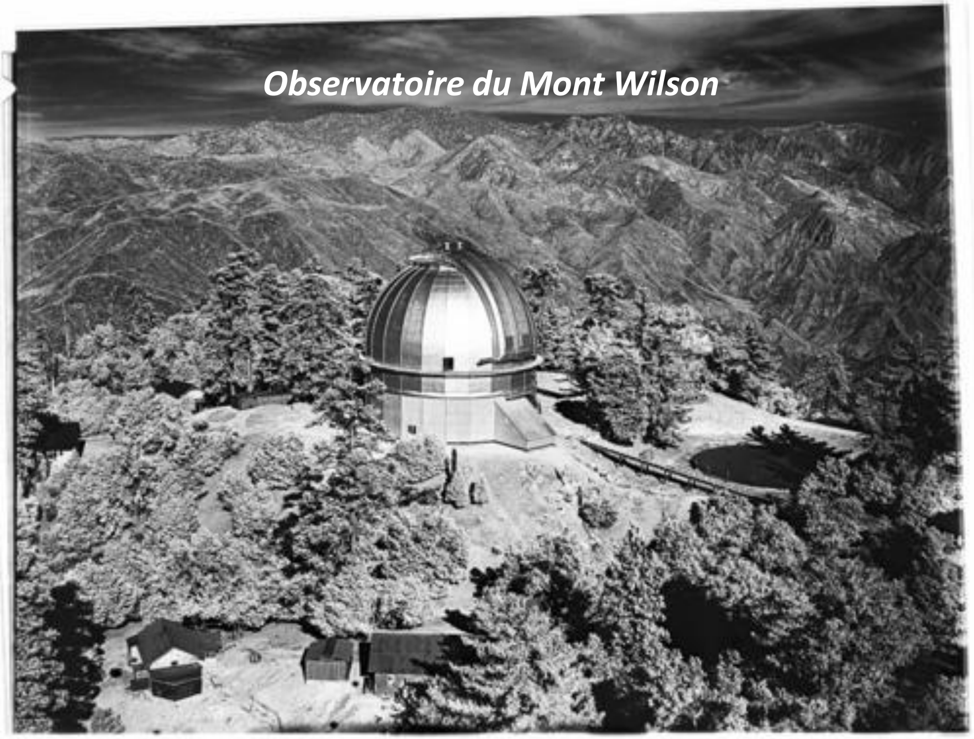
CARNEGIE INSTITUTION OF WASHINGTON
MOUNT WILSON OBSERVATORY
September 1935

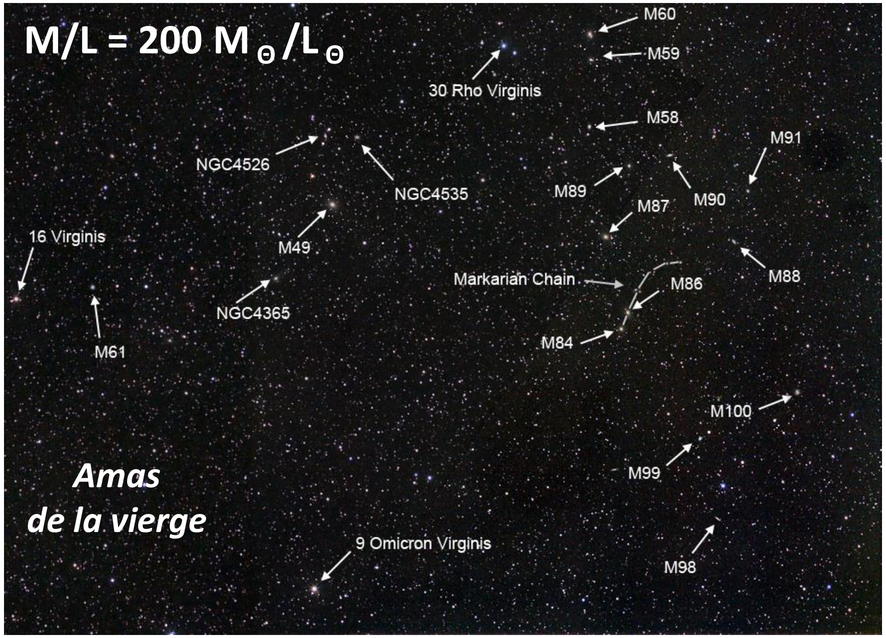
[4] *Mt. W. Comm.*, No. 105; *Proc. Nat. Acad.*, **15**, 168, 1929.

[5] I am indebted to Dr. Hubble for suggesting this point.

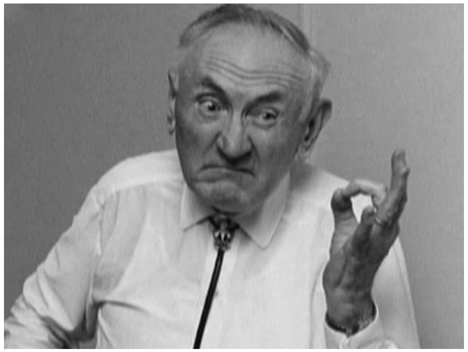
[6] F. Zwicky has pointed out (*Helv. Phys. Acta*, **6**, No. 2, p. 110, 1933) that the velocity range in the Coma Cluster indicates non-luminous matter which is some four hundred times the amount of the observed luminous material.

[7] Stebbins, *Mt. W. Comm.*, No. 113; *Nat. Acad. Proc.*, **20**, 93, 1934.





Conclusion provisoire



THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME 86 OCTOBER 1937 NUMBER 3

ON THE MASSES OF NEBULAE AND OF CLUSTERS OF NEBULAE

F. ZWICKY

- Soit, chaque galaxie est bien plus massive que ce que l’on croit : la matière noire est concentrée dans les galaxies ;
- Soit, il y a de la masse invisible entre les galaxies ;
- Soit, la force de gravitation n’est peut-être pas en $1/r^2$ …

… en tous cas $\Upsilon \approx$ de 200 à 500 $\Upsilon_{\odot}$ dans les Amas

Du coté des spirales

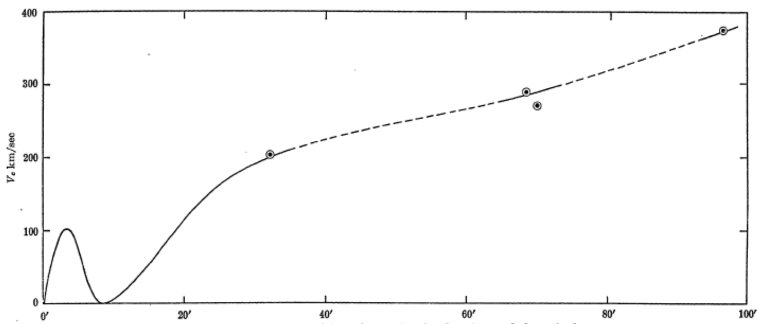


Fig. 4. Mean velocities of rotation in the plane of the spiral.

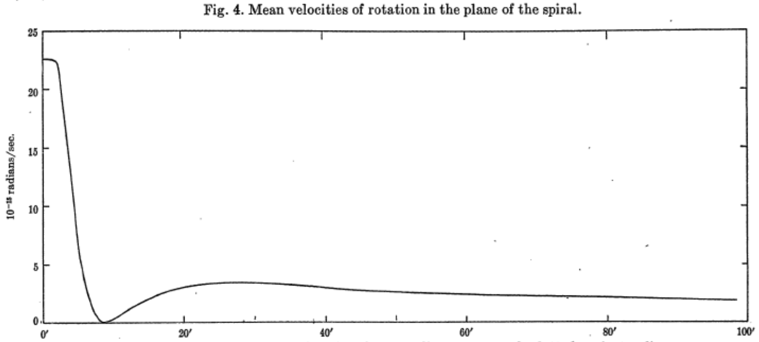


Fig. 5. Angular velocity, ω, in units of 10^{-15} radians per second, plotted against radius.

UNIVERSITY OF CALIFORNIA PUBLICATIONS
ASTRONOMY

LICK OBSERVATORY BULLETIN

NUMBER 498

THE ROTATION OF THE ANDROMEDA NEBULA*

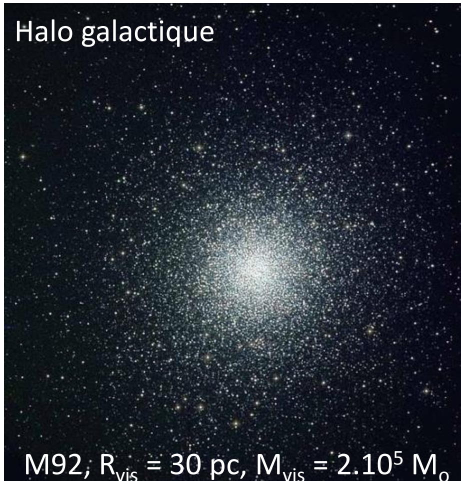
BY

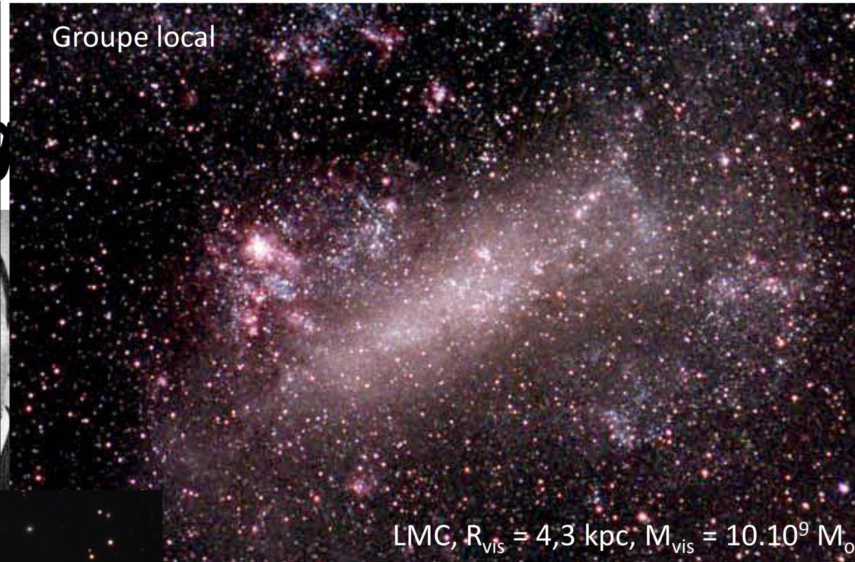
HORACE W. BABCOCK

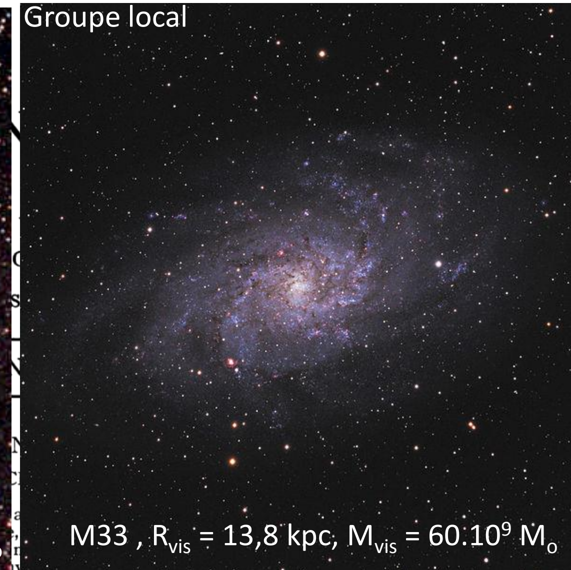
The Andromeda Nebula and the Galaxy have many well-known features in common, but one outstanding discrepancy between the two systems has hitherto been in their diameters. The spiral arms of M31 can hardly be traced to a radius of more than 1°6 or 6 kiloparsecs. Beyond this radius, no stars, comparable to the brighter stars in the vicinity of the sun, have been reported, although Hubble has discovered some outlying globular clusters[10] which lead him to suggest that the radius of the nebula, as outlined by these objects, may possibly be as great as 3½°. This large figure is supported by the photo-electric measurements of Stebbins and Whitford,[19] and by the micro-photometric measures of Shapley,[20] both of which indicate the existence of a widespread, faint, diffuse luminosity.

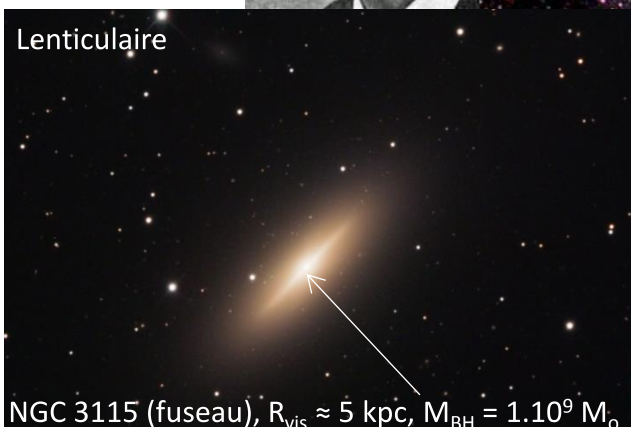
A new discrepancy is now directly apparent when the rotations of the two systems are compared, for the nearly constant angular velocity of the outer parts of M31 is the opposite of the "planetary" type of rotation believed to obtain in the outer parts of the Galaxy.

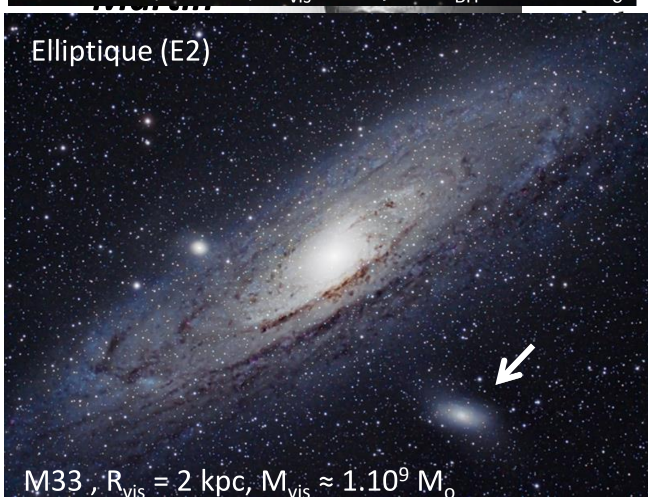
MOUNT HAMILTON, CALIFORNIA,
MARCH 31, 1939.
Issued October 30, 1939.











a mass-luminosity ratio much larger than that of pure population I systems. The Andromeda nebula is found to have an intermediate mass-luminosity ratio, suggesting that the body of the Andromeda nebula may consist of a mixture of population II and old population I stars.

TABLE VII. SUMMARY OF MASS-LUMINOSITY RATIOS

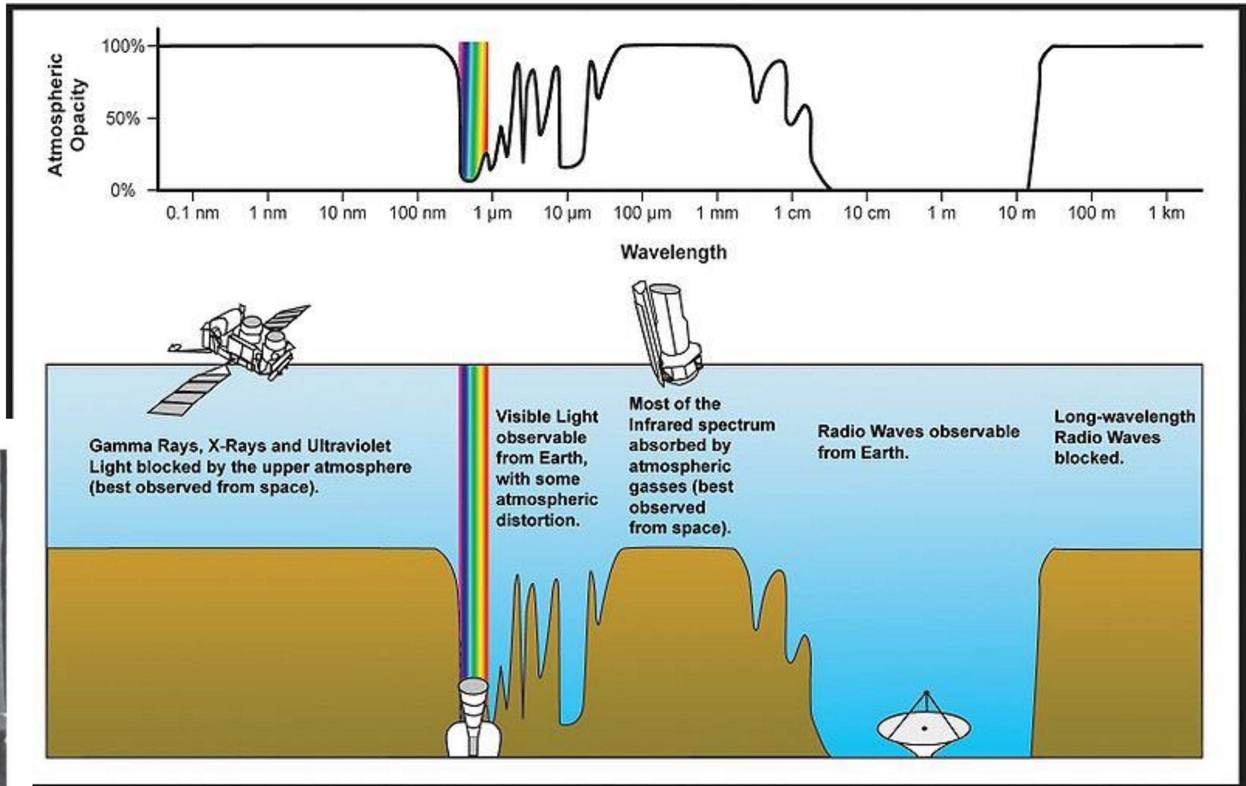
Objects	Distance (in kpc)	Luminosity (in sol. lum.)	Mass (in sol. mass)	Mass/Lum. f
Neighborhood	—	—	—	4
ngulum Nebula, M33	480	1.4×10^9	5×10^9	4
e Magellanic Cloud	44	1.2×10^9	2×10^9	2
meda Nebula	460	9×10^9	1.4×10^{11}	16
lar Cluster, M92	11	1.7×10^5	$<8 \times 10^5$	<5
cal Galaxy, NGC 3115	2100	9×10^8	9×10^{10}	100
cal Galaxy, M32	460	1.1×10^8	2.5×10^{10}	200
ge S in Double Gal.	—	1.3×10^9	7×10^{10}	50
ge E in Double Gal.	—	8×10^8	2.6×10^{11}	300
ge in Coma Cluster	25000	5×10^8	4×10^{11}	800

ϒ dépend des objets considérés

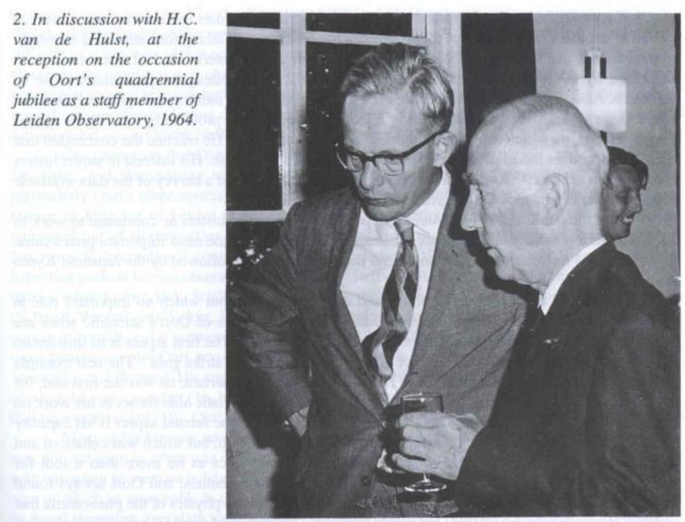
Familles d'objets ⇔ Valeurs de ϒ

La raie à 21 cm

Le «trou» radio est découvert par Janski
dans les années 30



La raie à λ = 21 cm
est découverte par Oort et Van de Hulst en
1940, dans le spectre de l'hydrogène neutre
(transition hyperfine spin up->down à 1420,4 MHz)



2. In discussion with H.C. van de Hulst, at the reception on the occasion of Oort's quadrennial jubilee as a staff member of Leiden Observatory, 1964.

Les nuages interstellaires sont essentiellement constitués d'hydrogène neutre…

BULLETIN OF THE ASTRONOMICAL INSTITUTES OF THE NETHERLANDS

1957 NOVEMBER 9 VOLUME XIV NUMBER 480

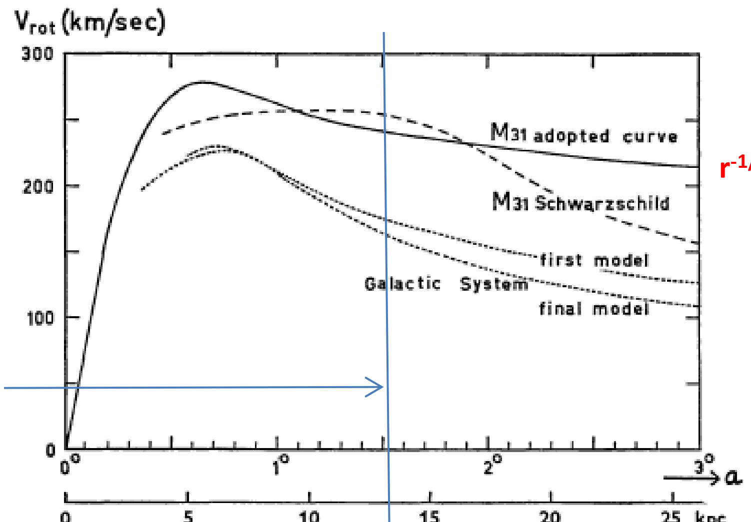
COMMUNICATIONS FROM THE NETHERLANDS FOUNDATION FOR RADIO ASTRONOMY AND THE OBSERVATORY AT LEIDEN

ROTATION AND DENSITY DISTRIBUTION OF THE ANDROMEDA NEBULA DERIVED FROM OBSERVATIONS OF THE 21-cm LINE

BY H. C. VAN DE HULST, E. RAIMOND AND H. VAN WOERDEN

Bull. Astron. Inst. Neth. , 14, 1-16, **1957**

FIGURE 11



Rotation laws of M31 and the Galactic System.

$r^{-1/4}$ au lieu de $r^{-1/2}$

Rayon apparent : 1,5 °

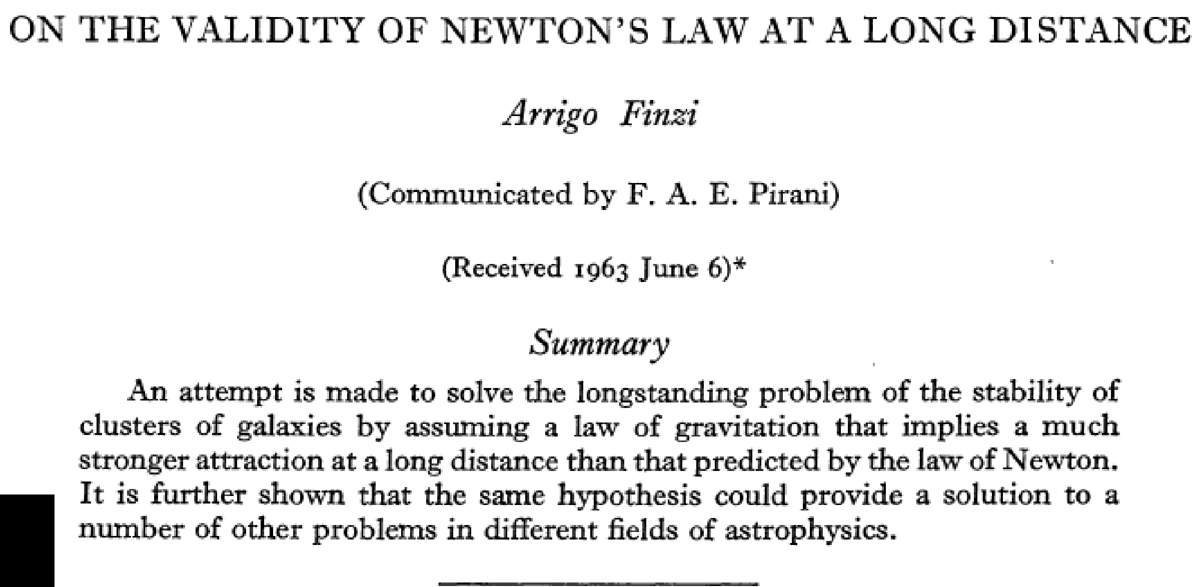
Diamètre apparent d'Andromède : 3,18°

Visible optique

Visible 21 cm

Quand on commence à se poser des questions…

MNRAS , 127, 21-30, **1963**



ON THE VALIDITY OF NEWTON'S LAW AT A LONG DISTANCE

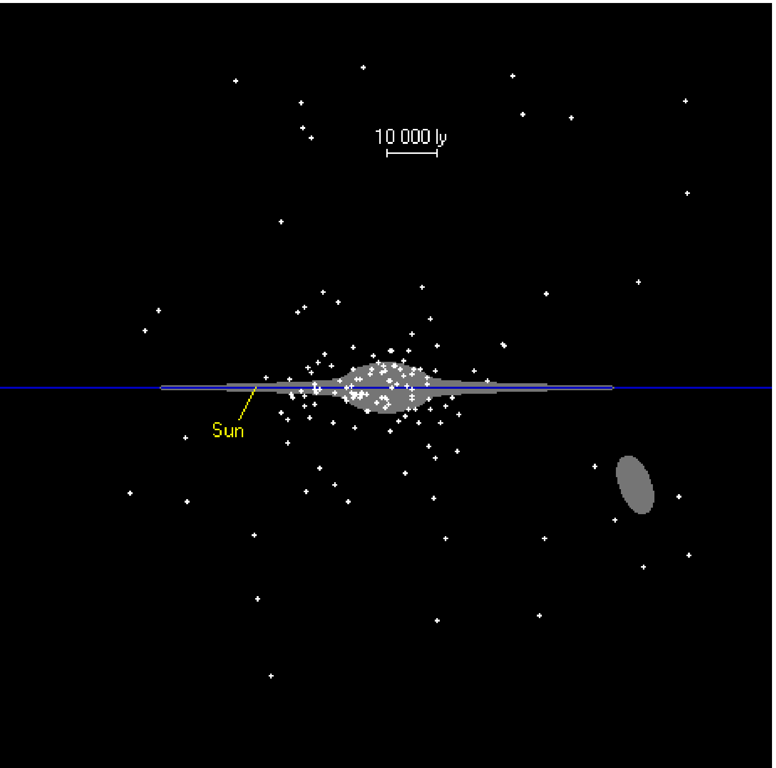
Arrigo Finzi

(Communicated by F. A. E. Pirani)

(Received 1963 June 6)*

Summary

An attempt is made to solve the longstanding problem of the stability of clusters of galaxies by assuming a law of gravitation that implies a much stronger attraction at a long distance than that predicted by the law of Newton. It is further shown that the same hypothesis could provide a solution to a number of other problems in different fields of astrophysics.



… en se basant sur le mouvement des amas globulaires autour de notre galaxie, il calcule pour sa masse une valeur 3 fois plus grande que celle provenant des mesures de rotation de la partie centrale. Il propose une modification de la loi de Newton à grande distance ($r^{-2} \rightarrow r^{-1,5}$)

Les premières simulation numériques

THE ASTROPHYSICAL JOURNAL, 168:343–359, 1971 September 15

NUMERICAL EXPERIMENTS WITH A DISK OF STARS

FRANK HOHL
NASA, Langley Research Center, Hampton, Virginia
Received 1971 March 10; revised 1971 April 28

ABSTRACT

The evolution of an initially balanced rotating disk of stars with an initial velocity dispersion given by Toomre's local criterion is investigated by means of a computer model for isolated disks of stars. It is found that the disk is unstable against very large-scale modes. After about two rotations the central portion of the disk tends to assume a bar-shaped structure. A stable axisymmetric disk with a velocity dispersion much larger than that given by Toomre's criterion is generated. The final mass distribution for the disk gives a high-density central core and a disk population of stars that is closely approximated by an exponential variation.

100 000 particules dans un disque en rotation et en équilibre (gravité/centrifuge)

… une spirale se forme mais elle disparait rapidement !

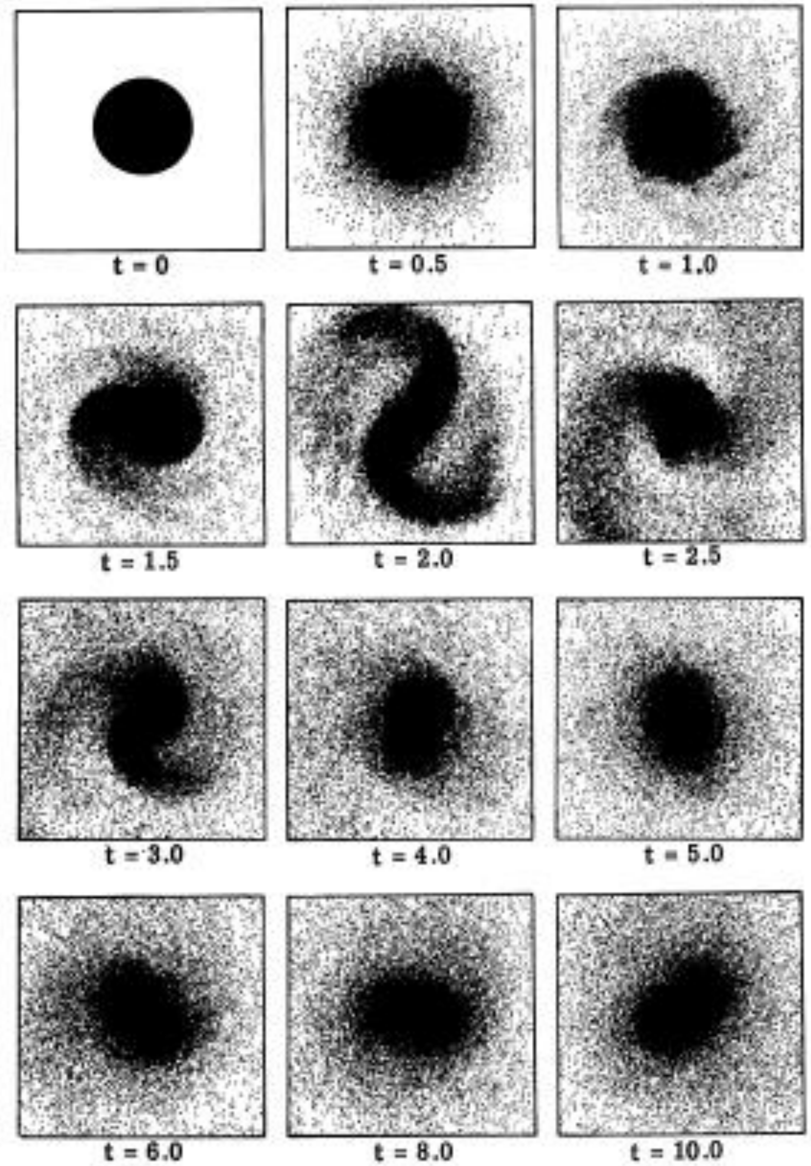
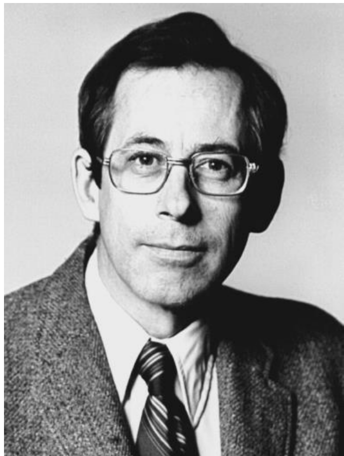


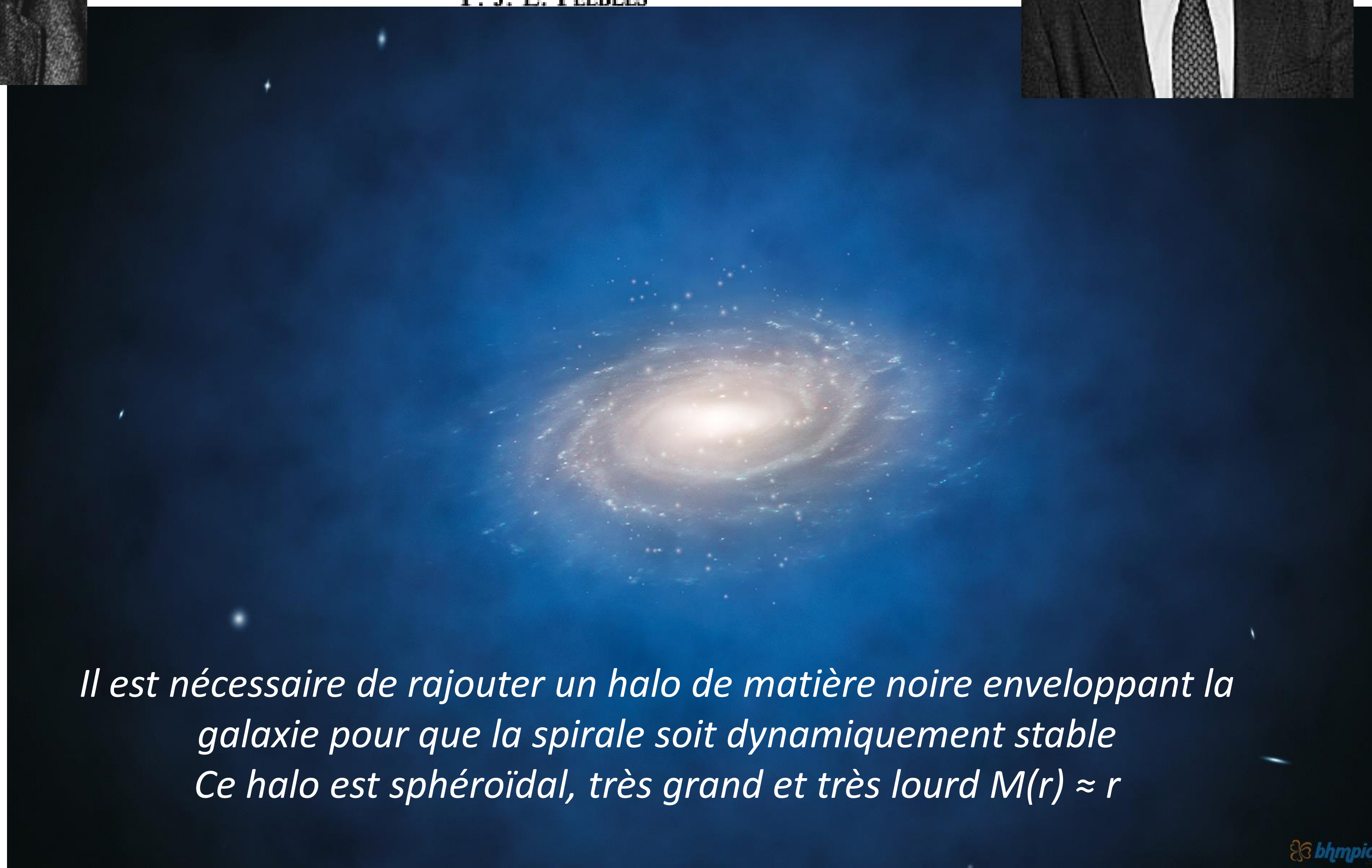
FIG. 4.—Unconstrained evolution of the initially balanced uniformly rotating disk of 100000 stars. The stars have an initial velocity dispersion given by Toomre's criterion.

THE ASTROPHYSICAL JOURNAL, 186:467–480, 1973 December 1



A NUMERICAL STUDY OF THE STABILITY OF FLATTENED GALAXIES: OR, CAN COLD GALAXIES SURVIVE?*

J. P. OSTRIKER
Princeton University Observatory
AND
P. J. E. PEEBLES



Il est nécessaire de rajouter un halo de matière noire enveloppant la galaxie pour que la spirale soit dynamiquement stable
Ce halo est sphéroïdal, très grand et très lourd M(r) ≈ r

Matière Noire
à l'échelle galactique

Astron. Astrophys. 223, 47–60 (1989)

ASTRONOMY AND ASTROPHYSICS

H I rotation curves of spiral galaxies

I. NGC 3198

K.G. Begeman

Kapteyn Astronomical Institute, Groningen University, Postbus 800, NL-9700 AV Groningen, The Netherlands

Received December 14, 1988; accepted April 3, 1989

THE ROTATION CURVES OF GALAXIES

IAU Symposium 1975

M. S. ROBERTS

National Radio Astronomy Observatory, Green Bank, W. Va., U.S.A.*

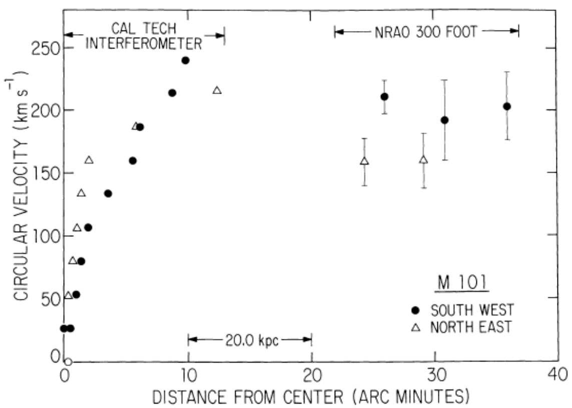


Fig. 3. The rotation curve for M101. All data points are based on 21-cm observations. The inner 12′ are from interferometer measurements by Rogstad and Shostak (1971) and are for major axis values in their Figure 4. The outer points are from recent measurements made with the 300-ft telescope.

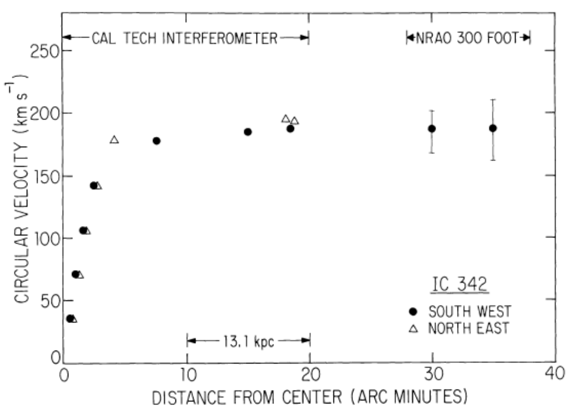
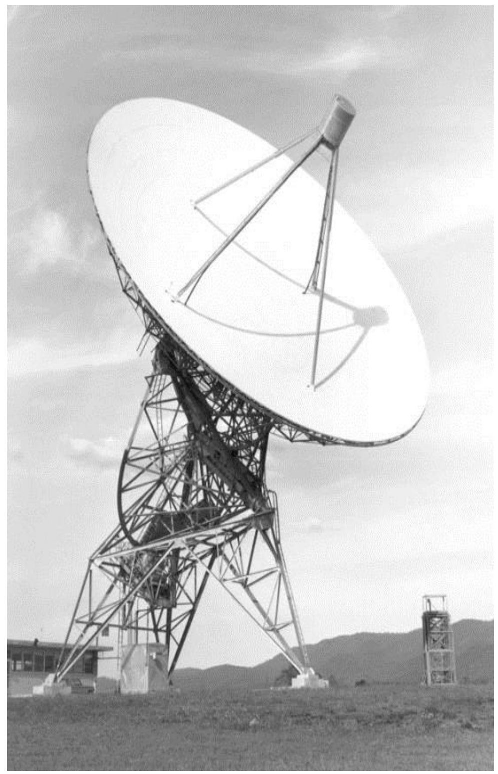


Fig. 4. The rotation curve for IC 342. All data points are based on 21-cm observations. The inner 19′ are from interferometer measurements by Rogstad *et al.* (1973) and are for major axis values in their Figure 5. The outer points are from recent measurements made with the 300-ft telescope.



Radio-Observatoire de Green Bank
Virginie Occidentale (26m)
(GBI : x 3)
Effondrement en 1988

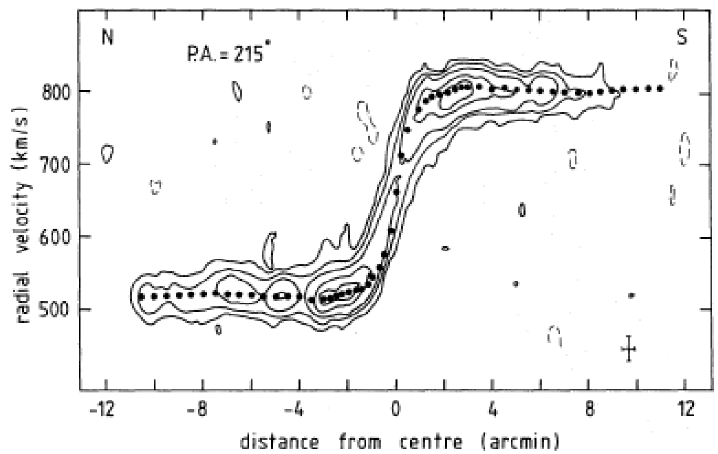


Fig. 9. The mean rotation curve for northern and southern half projected on a position-velocity map at a position angle of 215°. Contour levels are −1, 1, 3, 6, 13, 19 K. This map has not been corrected for primary beam attenuation

Le « double horn »

Les spirales et LSB

Astron. Astrophys. 54, 661—673 (1977)

ASTRONOMY AND ASTROPHYSICS

La relation de Tully-Fischer

A New Method of Determining Distances to Gala

R. Brent Tully[1*] and J. Richard Fisher[2]

[1] Observatoire de Marseille, France

[2] National Radio Astronomy Observatory**, P.O. Box 2, Green Bank, W. Va. 24

Received July 15, 1975, revised April 26, 1976

La luminosité absolue des galaxies spirales est corrélée à la vitesse tangentielle des étoiles dans le disque

(partie plate de la courbe de rotation)

V_{rot} et L varient dans le même sens

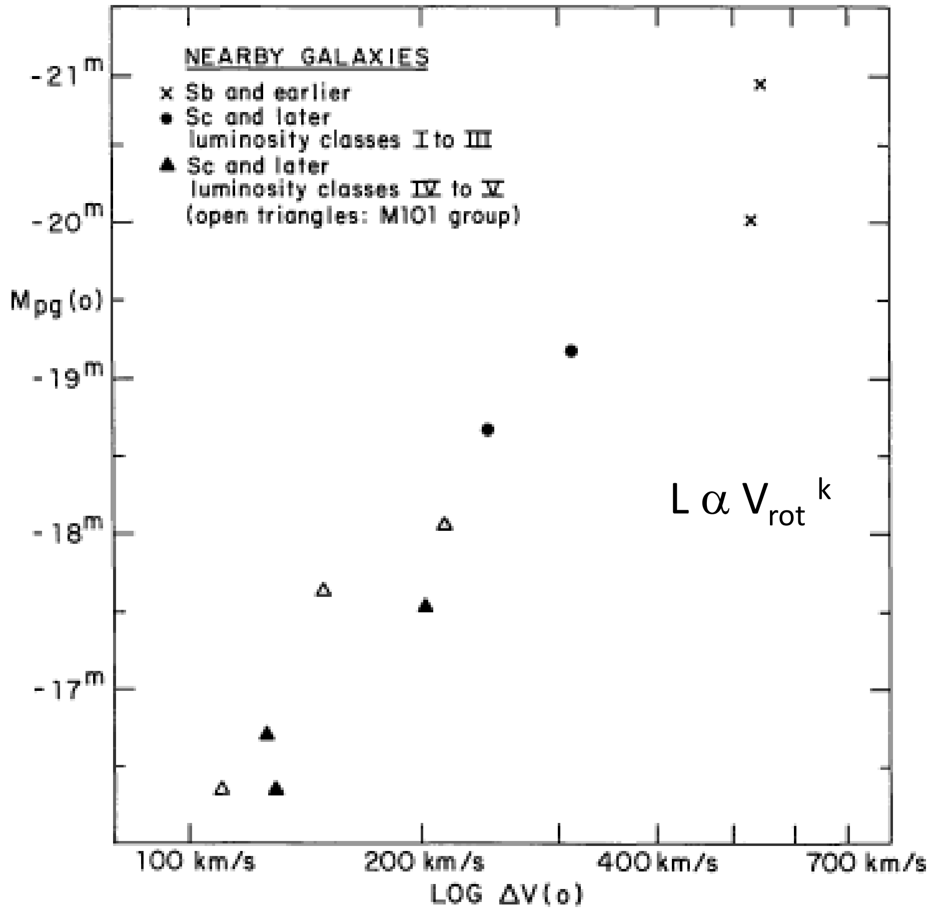


Fig. 1. Absolute magnitude – global profile width relation for nearby galaxies with previously well-determined distances. Crosses are M31 and M81, dots are M33 and NGC 2403, filled triangles are smaller systems in the M81 group and open triangles are smaller systems in the M101 group

THE ASTROPHYSICAL JOURNAL, 477:L1–L4, 1997 March 1

Devient un solide indicateur de distance

THE TULLY-FISHER RELATION AND H_0

RICCARDO GIOVANELLI AND MARTHA P. HAYNES
Center for Radiophysics and Space Research and National Astronomy and Ionosphere Center,[1] Cornell University, Ithaca, NY 14953
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Space Telescope-European Coordinating Facility and European Southern Observatory, Karl Schwarzschild Str. 2, D-85748 Garching b. München, Germ
JOHN J. SALZER
Department of Astronomy, Wesleyan University, Middletown, CT 06457
AND
GARY WEGNER
Department of Physics and Astronomy, Dartmouth College, Hanover, NH 03755
Received 1996 November 5; accepted 1996 December 19

ABSTRACT

The use of the Tully-Fisher (TF) relation for the determination of H_0 relies on the availability of an adequate template TF relation and of reliable primary distances. Here we use a TF template relation with the best available kinematical zero point, obtained from a sample of 24 clusters of galaxies extending to $cz \sim 9000$ km s^{-1}, and the most recent set of Cepheid distances for galaxies fit for TF use. The combination of these two ingredients yields $H_0 = 69 \pm 5$ km s^{-1} Mpc^{-1}. The approach is significantly more accurate than the more common application with single cluster (e.g., Virgo, Coma) samples.

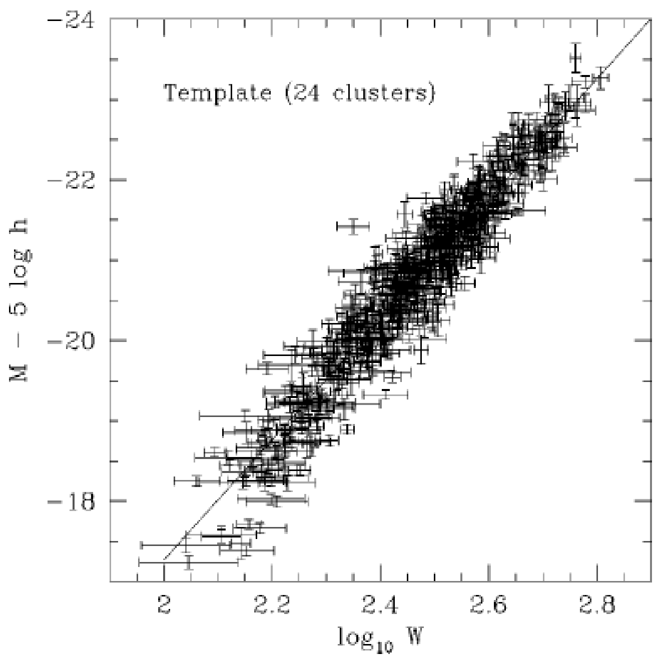
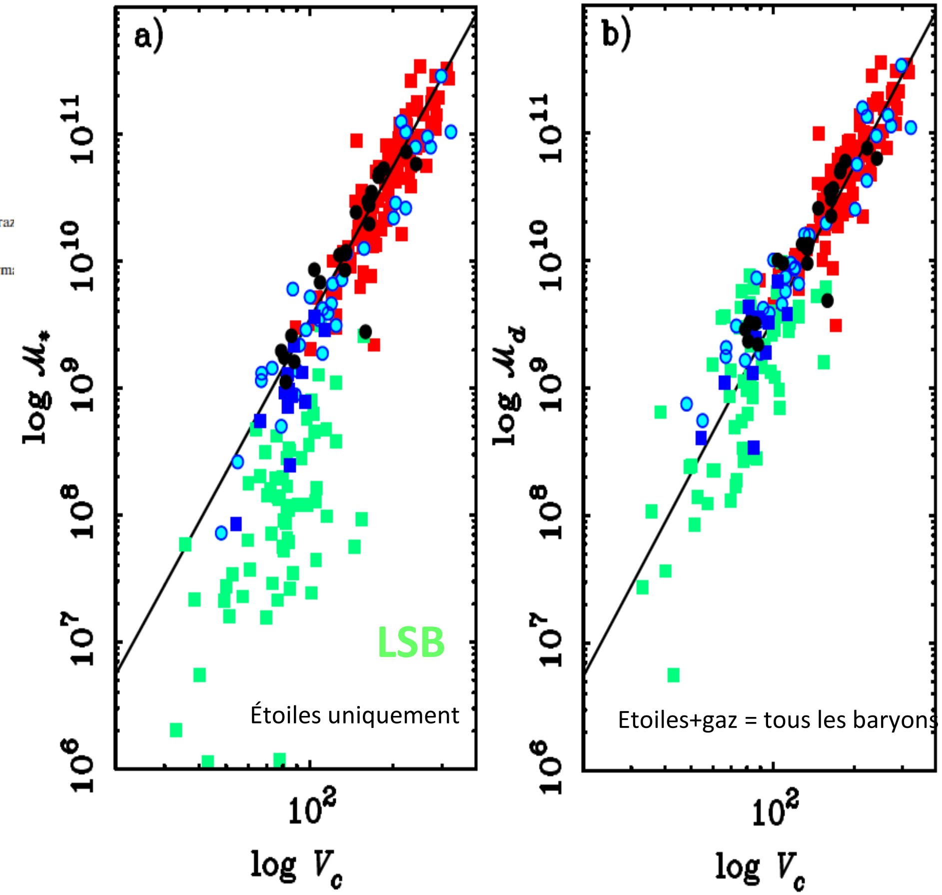


FIG. 1.—Template relation based on 555 galaxies in 24 clusters. The fit is $-21.00 \pm 0.02 - 7.68 \pm 0.13\ (\log W - 2.5)$.



THE ASTROPHYSICAL JOURNAL, 533:L99–L102, 2000 April 20

THE BARYONIC TULLY-FISHER RELATION

S. S. MCGAUGH,[1] J. M. SCHOMBERT,[2] G. D. BOTHUN,[2] AND W. J. G. DE BLOK[3,4]
Received 1999 December 14; accepted 2000 March 1; published 2000 March 21

ABSTRACT

We explore the Tully-Fisher relation over five decades in stellar mass in galaxies with circular velocities ranging over $30 \lesssim V_c \lesssim 300$ km s^{-1}. We find a clear break in the optical Tully-Fisher relation: field galaxies with $V_c \lesssim 90$ km s^{-1} fall below the relation defined by brighter galaxies. These faint galaxies, however, are very rich in gas; adding in the gas mass and plotting the baryonic disk mass $M_d = M_* + M_{gas}$ in place of luminosity restores the single linear relation. The Tully-Fisher relation thus appears fundamentally to be a relation between rotation velocity and total baryonic mass of the form $M_d \propto V_c^4$.

Puis, indicateur de M/L

Pour les objets triaxaux : le plan fondamental

3 paramètres :
- **R : la taille**
- **L : la luminosité**
- **σ : la dispersion de vitesse**

Amas globulaires

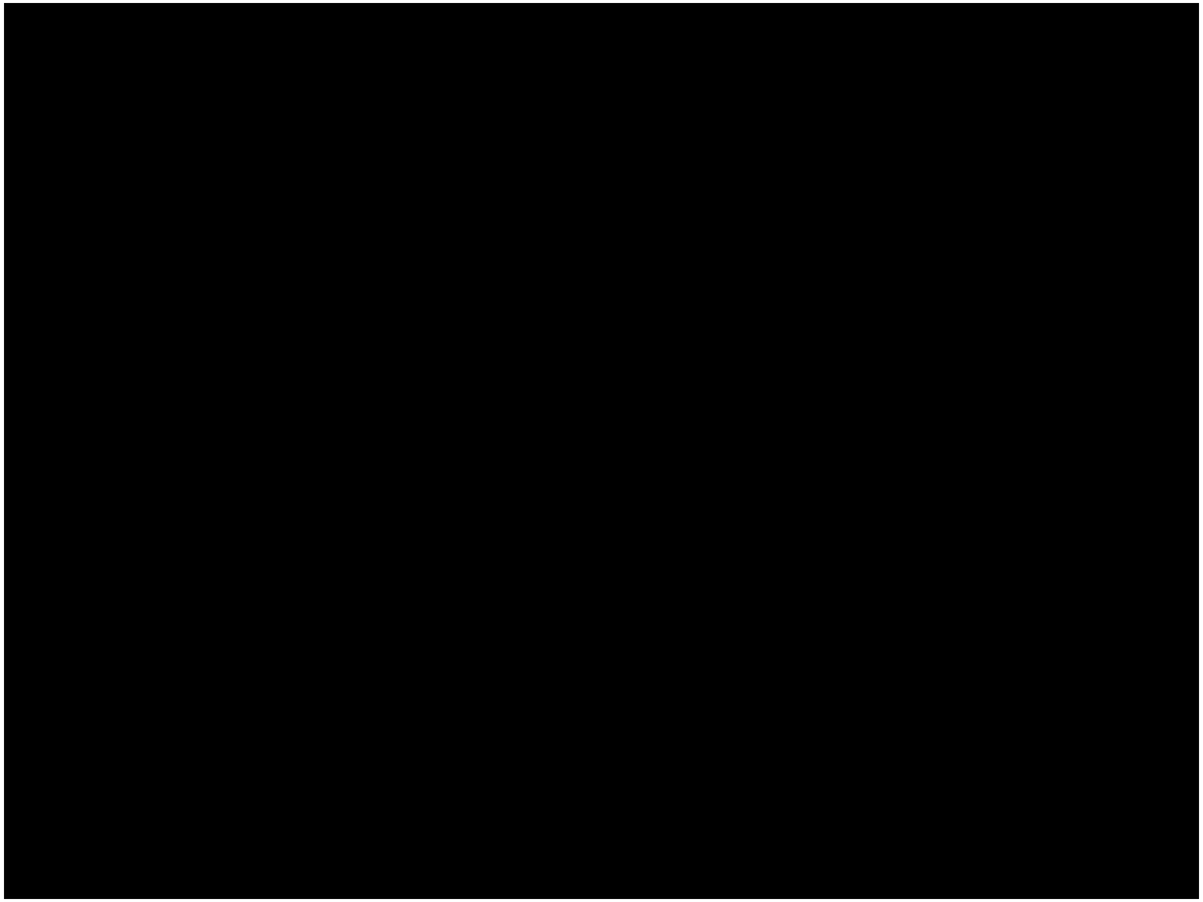
Ultra-compactes naines

Sphéroïdales naines

Elliptiques naines

Elliptiques

Amas de galaxies



Tollerud E. J., Bullock J. S., Graves G. J., Wolf J., [2011, ApJ, 726, 108]

Bilan à l’échelle galactique

Galaxies à faible brillance de surface (LSB)

(peut être 90% des galaxies)

Beaucoup plus de gaz (H neutre) que d’étoiles

Isolées et ayant peu interagit

$\Upsilon \approx 1000\ \Upsilon_{\odot}$ (courbes de rotation)

Galaxie naine de la machine pneumatique

Galaxie de l’œil noir (M64 ou NGC4826)

Galaxies spirales

1 bulbe, 1 disque et un Halo de matière noire

Souvent de faible masse «bleues» et isolées

Masse du Halo : au mois 2 fois celle visible

Naines

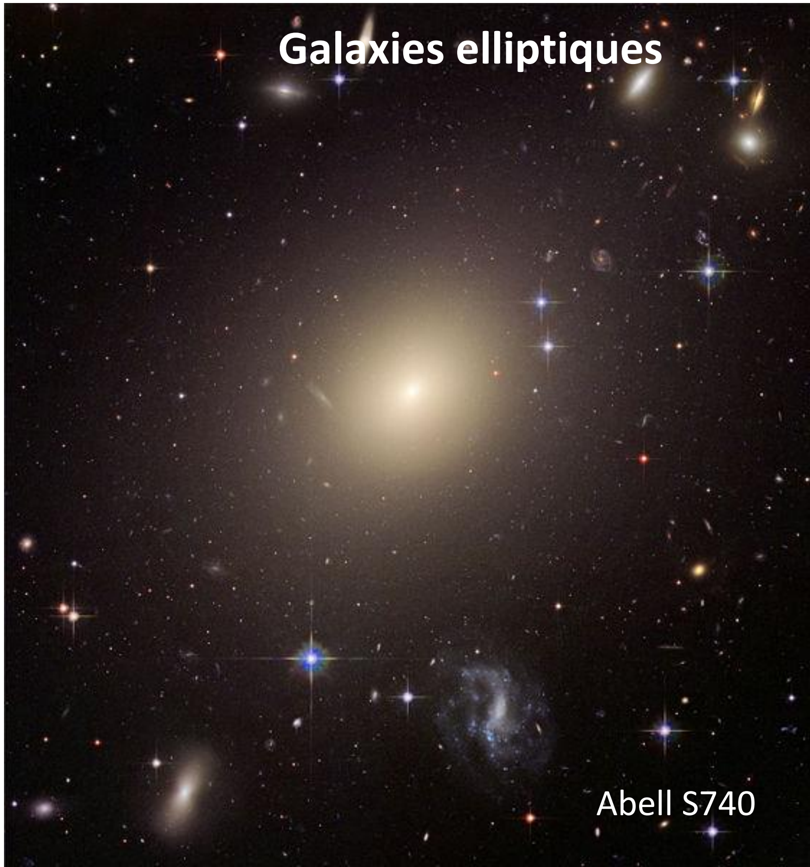
Géantes

Peu de gaz

Pas de halo ?

Matière noire et répartition ?

Quelques pistes avec les lentilles

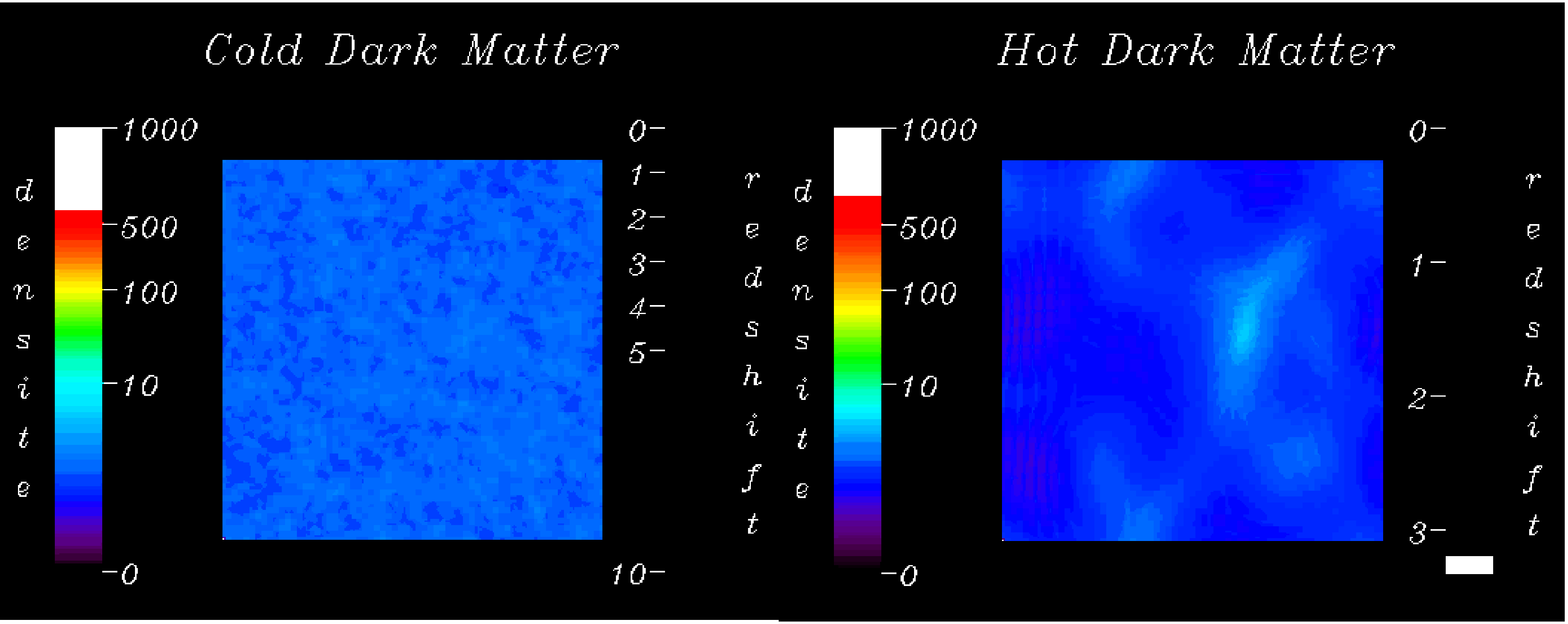


Galaxies elliptiques

Abell S740

Les simulations cosmologiques

dans les années 80-90



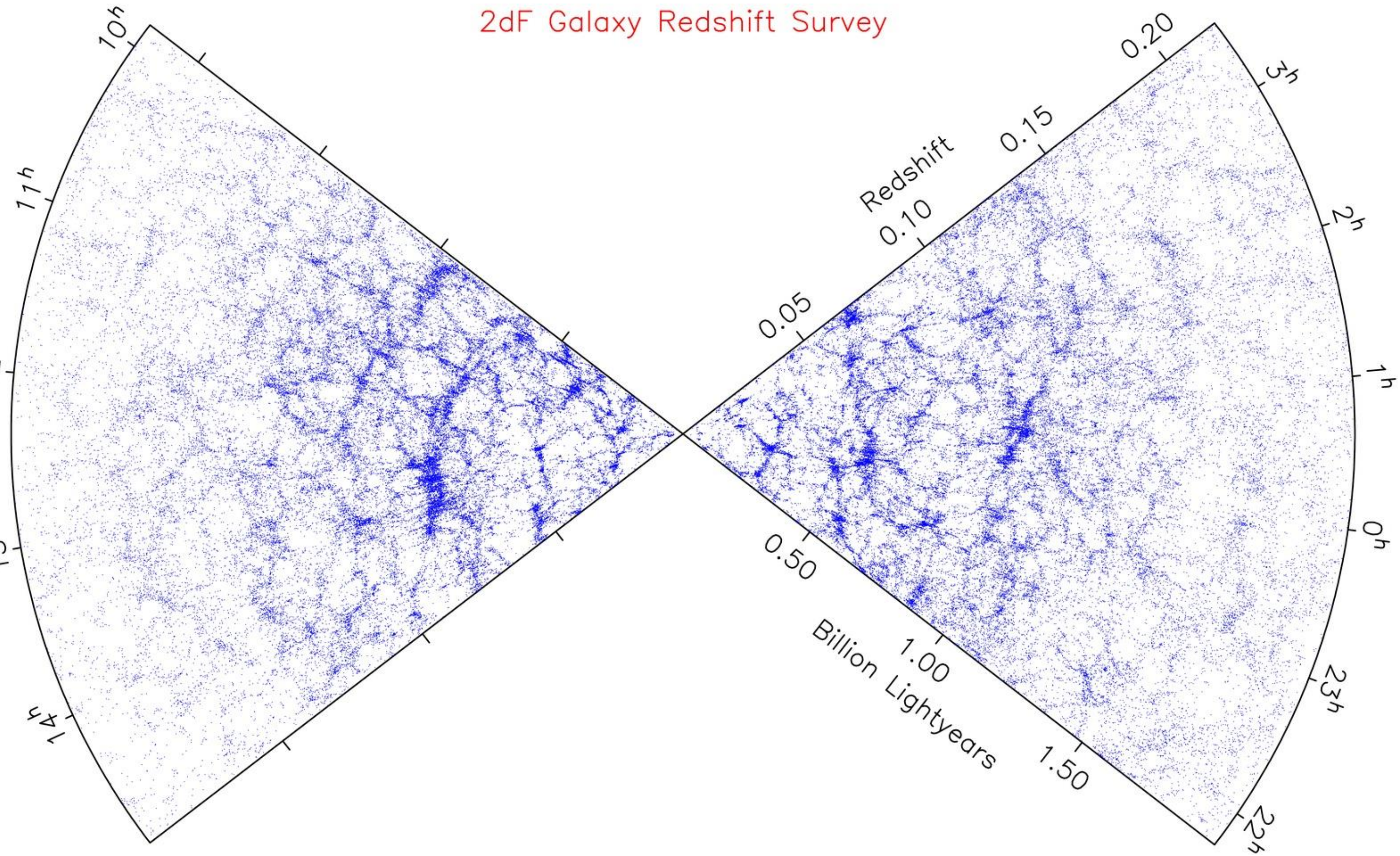
Formation des structures

Bottom → Up

Top → Down

La matière noire ne peut pas être chaude !

(non relativiste au moment du CMB)



Les neutrinos ne peuvent pas représenter plus de 2% de la matière noire.

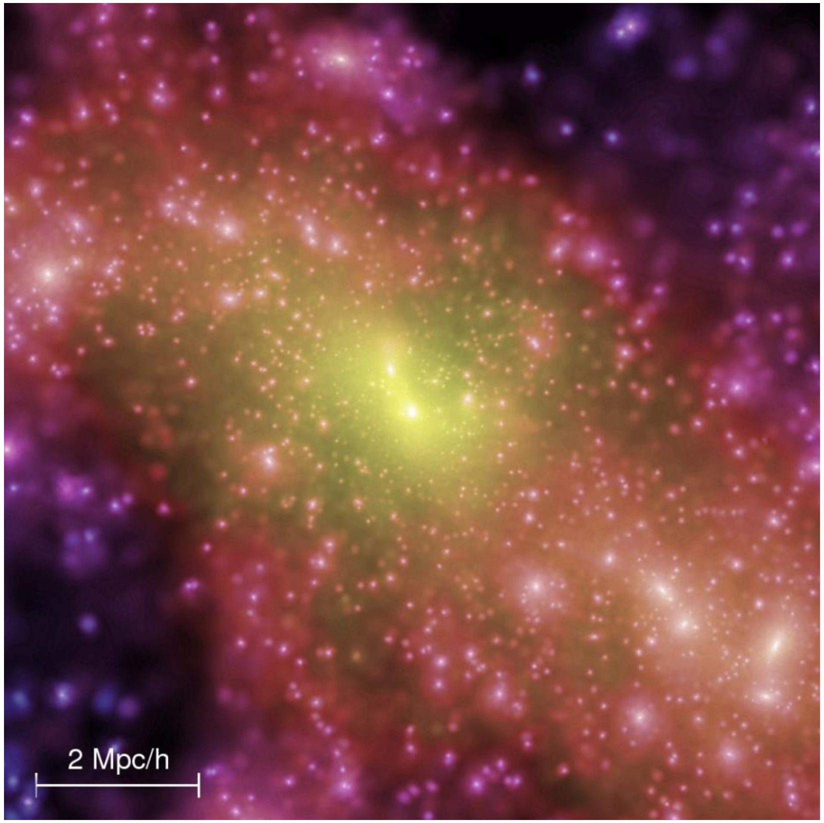
On commence à penser aux particules SUSY

Supersymmetric relics from the big bang - John Ellis et al.

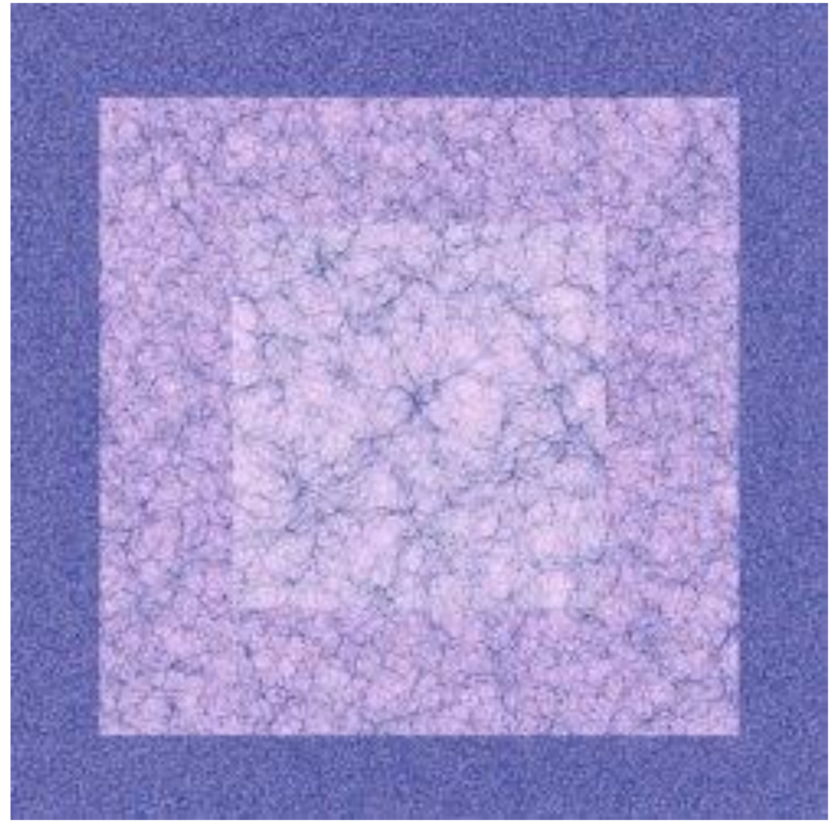
Nuclear Physics B

Volume 238, Issue 2, 11 June 1984, Pages 453–476

La répartition de la matière noire dans les simulations



The Aquarius Project, MPA Garching, 2008
Code Gadget 2



Projet Horizon, Collaboration Française, 2007
Code Ramses

Pas mal de succès mais…
au moins 2 gros problèmes …

Le problème du « cusp »

Les LSB (qui sont faites de MN)
ont un profil de densité isotherme (Cœur-Halo)

THE ASTROPHYSICAL JOURNAL, 552:L23–L26, 2001 May 1

MASS DENSITY PROFILES OF LOW SURFACE BRIGHTNESS GALAXIES

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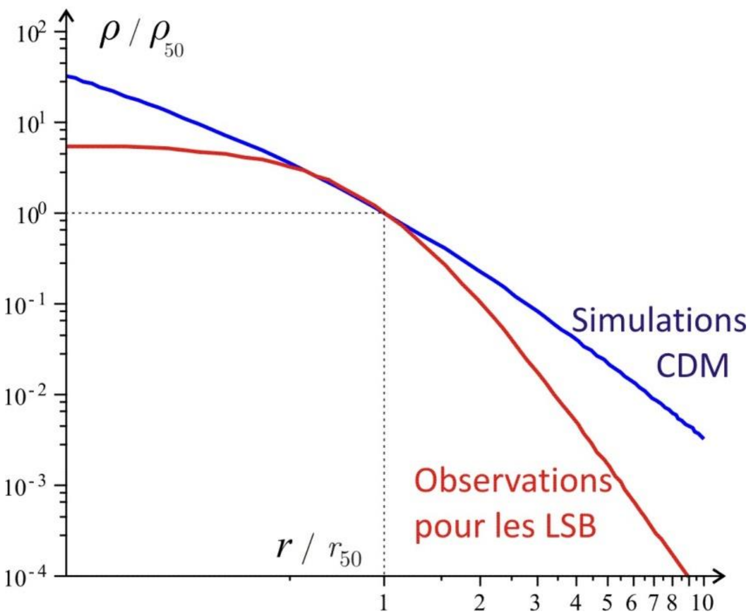
Received 2001 February 6; accepted 2001 March 15; published 2001 April 18

ABSTRACT

We derive the mass density profiles of dark matter halos that are implied by high spatial resolution rotation curves of low surface brightness galaxies. We find that, at small radii, the mass density distribution is dominated by a nearly constant density core with a core radius of a few kiloparsecs. For $\rho(r) \sim r^{\alpha}$, the distribution of inner slopes α is strongly peaked around $\alpha = -0.2$. This is significantly shallower than the cuspy $\alpha \leq -1$ halos found in cold dark matter simulations. While the observed distribution of α does have a tail toward such extreme values, the derived value of α is found to depend on the spatial resolution of the rotation curves: $\alpha \approx -1$ is found only for the least well resolved galaxies. Even for these galaxies, our data are also consistent with constant-density cores ($\alpha = 0$) of modest (~1 kpc) core radius, which can give the illusion of steep cusps when insufficiently resolved. Consequently, there is no clear evidence for a cuspy halo in any of the low surface brightness galaxies observed.



Les simulations CDM montrent des
structures avec Cusp aux échelles galactiques
(NFW)

THE ASTROPHYSICAL JOURNAL, 462:563–575, 1996 May 10

THE STRUCTURE OF COLD DARK MATTER HALOS

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Received 1995 August 1; accepted 1995 December 4

ABSTRACT

We use *N*-body simulations to investigate the structure of dark halos in the standard cold dark matter cosmogony. Halos are excised from simulations of cosmologically representative regions and are resimulated individually at high resolution. We study objects with masses ranging from those of dwarf galaxy halos to those of rich galaxy clusters. The spherically averaged density profiles of all our halos can be fitted over two decades in radius by scaling a simple "universal" profile. The characteristic overdensity of a halo, or equivalently its concentration, correlates strongly with halo mass in a way that reflects the mass dependence of the epoch of halo formation. Halo profiles are approximately isothermal over a large range in radii but are significantly shallower than r^{-2} near the center and steeper than r^{-2} near the virial radius. Matching the observed rotation curves of disk galaxies requires disk mass-to-light ratios to increase systematically with luminosity. Further, it suggests that the halos of bright galaxies depend only weakly on galaxy luminosity and have circular velocities significantly lower than the disk rotation speed. This may explain why luminosity and dynamics are uncorrelated in observed samples of binary galaxies and of satellite/spiral systems. For galaxy clusters, our halo models are consistent both with the presence of giant arcs and with the observed structure of the intracluster medium, and they suggest a simple explanation for the disparate estimates of cluster core radii found by previous authors. Our results also highlight two shortcomings of the CDM model. CDM halos are too concentrated to be consistent with the halo parameters inferred for dwarf irregulars, and the predicted abundance of galaxy halos is larger than the observed abundance of galaxies. The first problem may imply that the core structure of dwarf galaxies was altered by the galaxy formation process, and the second problem may imply that galaxies failed to form (or remain undetected) in many dark halos.

Le problème des sous-structures

THE ASTROPHYSICAL JOURNAL, 524:L19–L22, 1999 October 10

DARK MATTER SUBSTRUCTURE WITHIN GALACTIC HALOS

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Received 1999 April 16; accepted 1999 August 2; published 1999 September 13

ABSTRACT

We use numerical simulations to examine the substructure within galactic and cluster mass halos that form within a hierarchical universe. Clusters are easily reproduced with a steep mass spectrum of thousands of substructure clumps that closely matches the observations. However, the survival of dark matter substructure also occurs on galactic scales, leading to the remarkable result that galaxy halos appear as scaled versions of galaxy clusters. The model predicts that the virialized extent of the Milky Way's halo should contain about 500 satellites with circular velocities larger than the Draco and Ursa Minor systems, i.e., bound masses $\gtrsim 10^8\ M_\odot$ and tidally limited sizes $\gtrsim 1$ kpc. The substructure clumps are on orbits that take a large fraction of them through the stellar disk, leading to significant resonant and impulsive heating. Their abundance and singular density profiles have important implications for the existence of old thin disks, cold stellar streams, gravitational lensing, and indirect/direct detection experiments.

Les simulations sont auto-similaires !

La voie lactée devrait être entourée d'environ 500 galaxies satellites alors que l'on en observe une douzaine !

S'il en avait autant notre disque serait beaucoup plus chaud à cause des fréquentes collisions…

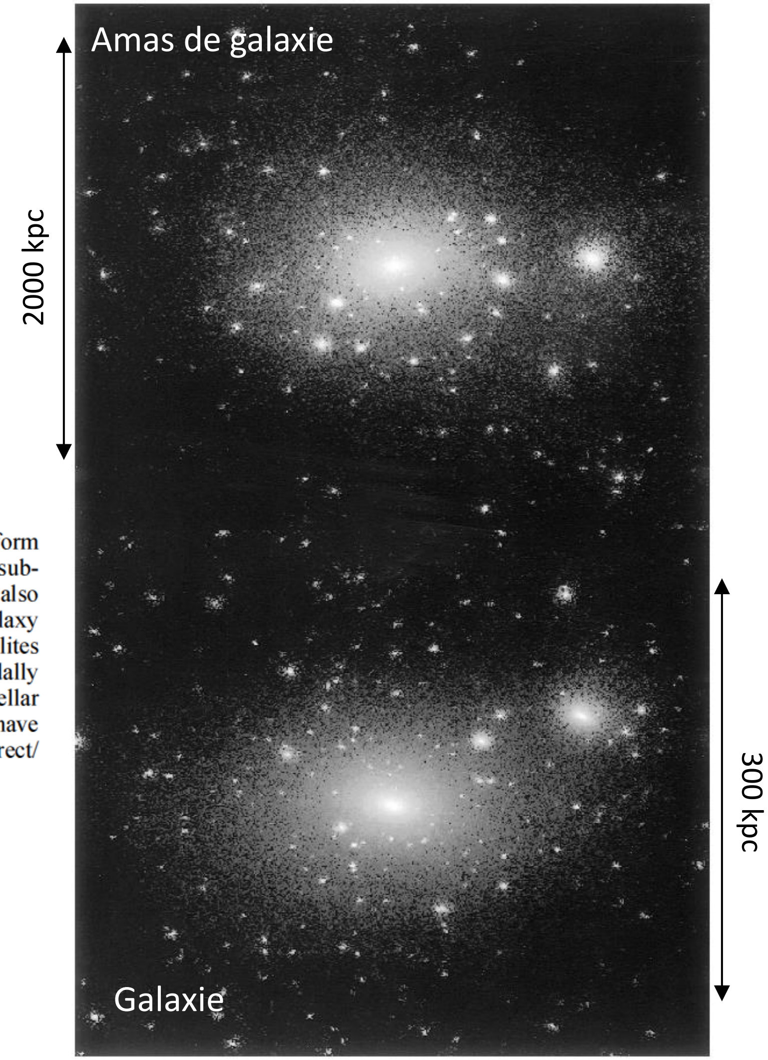

FIG. 1.—Density of dark matter within a cluster halo of mass $5 \times 10^{14}\ M_\odot$ (*top*) and a galaxy halo of mass $2 \times 10^{12}\ M_\odot$ (*bottom*). The edge of the box is the virial radius, 300 kpc for the galaxy and 2000 kpc for the cluster (with peak circular velocities of 200 and 1100 km s^{-1}, respectively).

Tout n'est pas perdu… dans les amas de galaxie

THE ASTROPHYSICAL JOURNAL, 504:636–660, 1998 September 10

WEAK LENSING ANALYSIS OF Cl 1358+62 USING *HUBBLE SPACE TELESCOPE* OBSERVATIO

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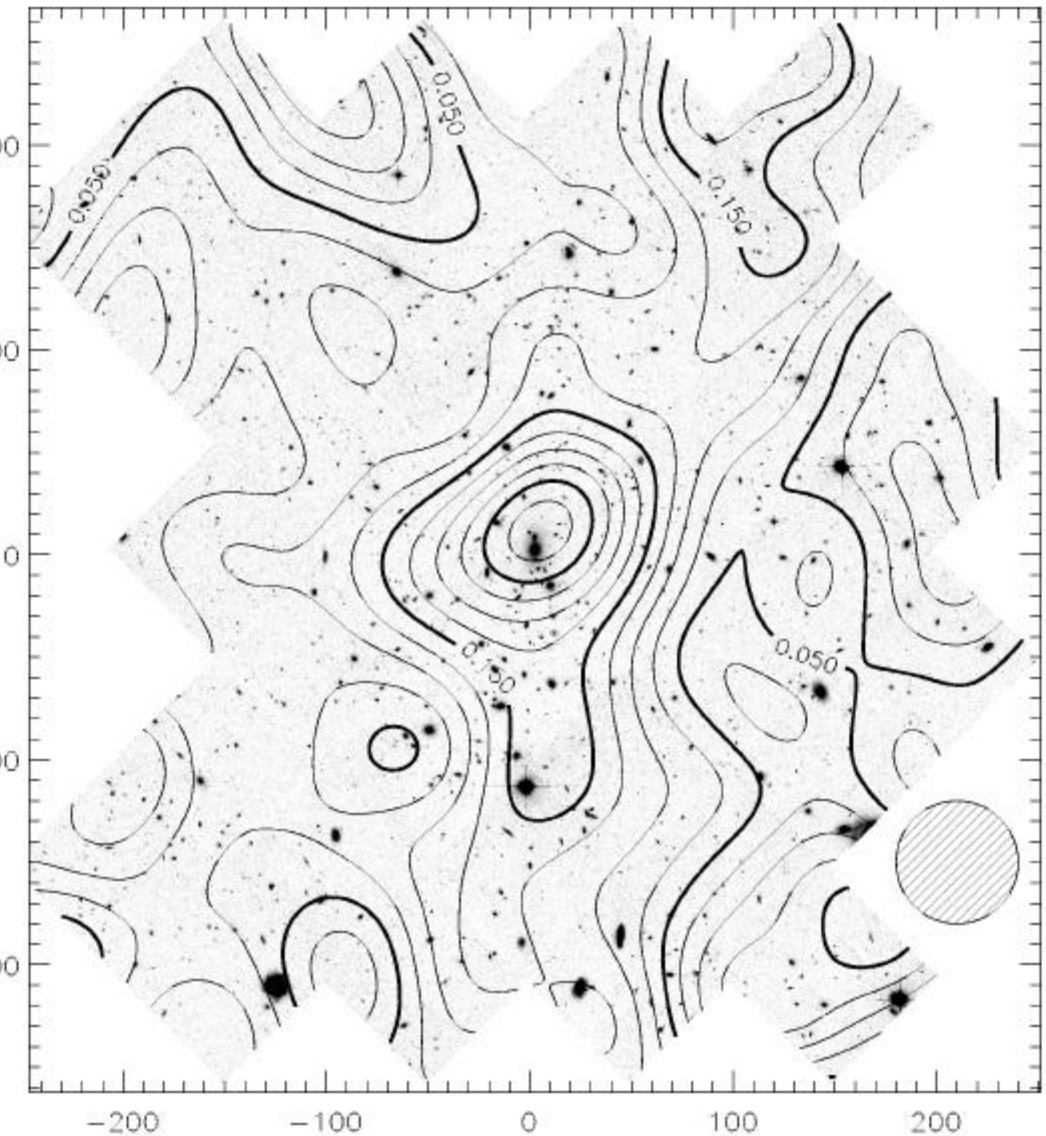
ABSTRACT

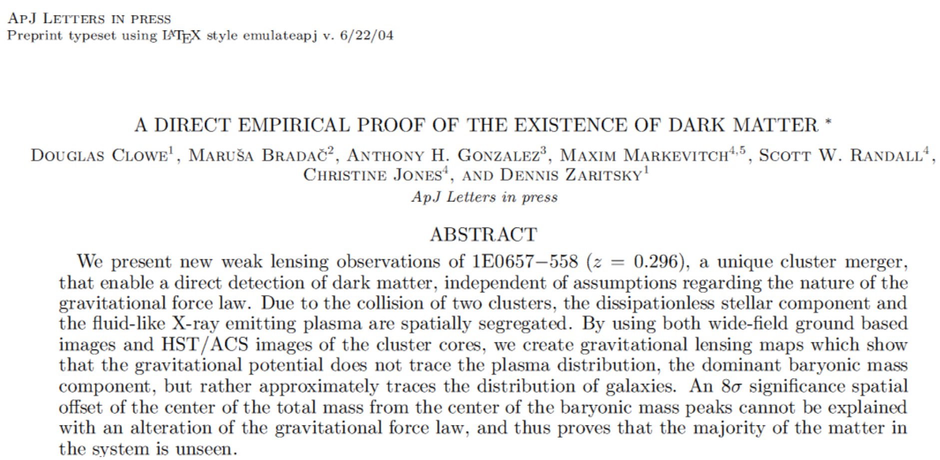
We report on the detection of weak gravitational lensing of faint, distant background objects by Cl 1358+62, a rich cluster of galaxies at a redshift of $z = 0.33$. The observations consist of a large, multicolor mosaic of *Hubble Space Telescope* WFPC2 images. The number density of approximately 50 background objects arcmin^{-2} allows us to do a detailed weak lensing analysis of this cluster. We detect a weak lensing signal out to ~ 1.5 Mpc from the cluster center. The observed distortion is consistent with a singular isothermal sphere model with a velocity dispersion of 780 ± 50 km s^{-1}. The total projected mass within a radius of 1 Mpc corresponding to this model is $(4.4 \pm 0.6) \times 10^{14}\ M_{\odot}$. The errors given here represent the random error due to the ellipticities of the background galaxies. The uncertainty in the redshift distribution introduces an additional systematic error of $\sim 10\%$ in the weak lensing mass. The weak lensing mass is slightly lower than dynamical estimates and agrees well with X-ray mass estimates. The mass distribution is elongated in a similar way as the light. The axis ratio of 0.30 ± 0.15 and position angle of $-21° \pm 7°$ were measured directly from the observations and agree very well with a previous strong lensing determination. A two-dimensional reconstruction of the cluster mass surface density shows that the peak of the mass distribution coincides with the peak of the light distribution. We find a value of $(90 \pm 13)h_{50}\ M_{\odot}\ L_{V\odot}^{-1}$ for the mass-to-light ratio, consistent with being constant with radius. The point-spread function of *HST* is highly anisotropic at the edges of the individual chips. This systematically perturbs the shapes of objects, and we present a method for applying the appropriate correction.



Les effets de lentille gravitationnelle permettent dans certains cas de tracer des cartes de la répartition de la matière noire dans les amas de galaxie

…et d'atteindre le viriel …

Le boulet fait du X



ApJ Letters in press
Preprint typeset using LaTeX style emulateapj v. 6/22/04

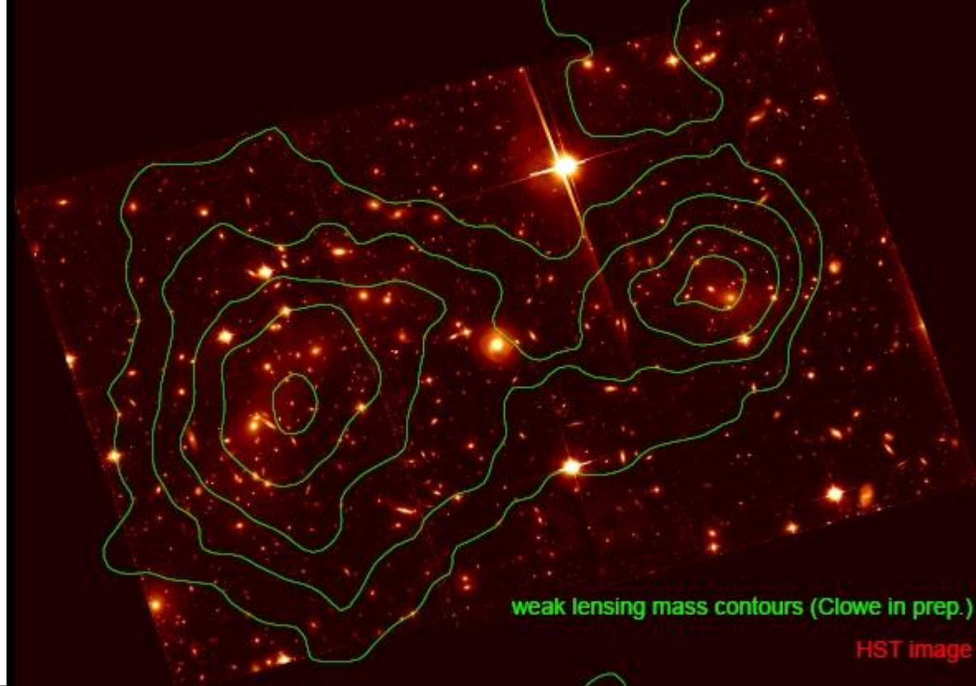
A DIRECT EMPIRICAL PROOF OF THE EXISTENCE OF DARK MATTER *

Douglas Clowe[1], Maruša Bradač[2], Anthony H. Gonzalez[3], Maxim Markevitch[4,5], Scott W. Randall[4], Christine Jones[4], and Dennis Zaritsky[1]

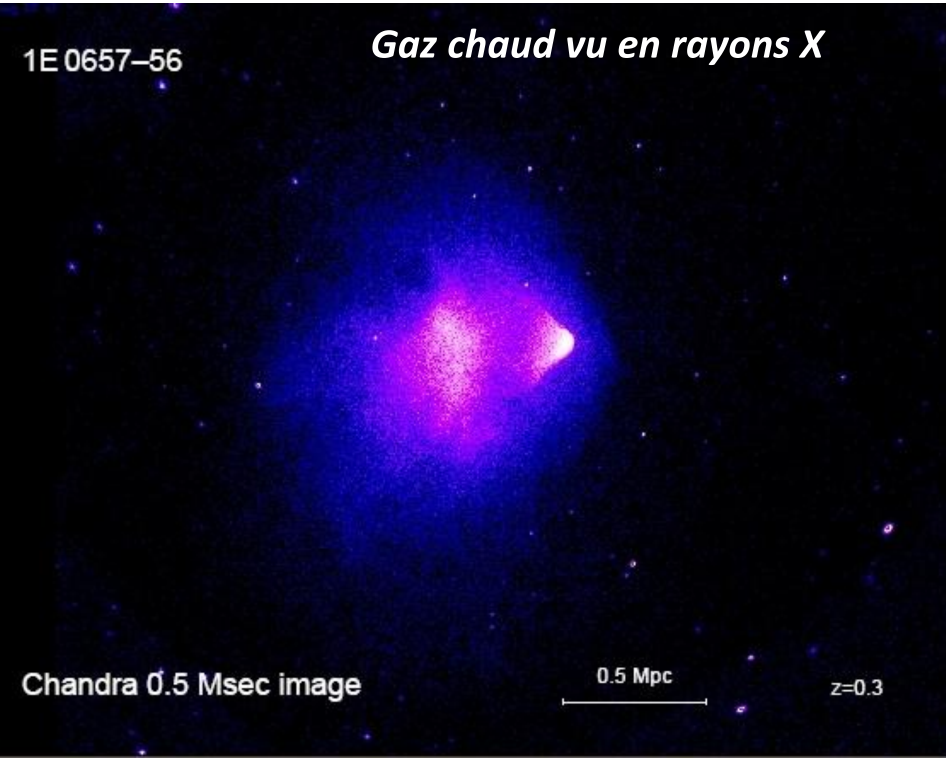
ApJ Letters in press

ABSTRACT

We present new weak lensing observations of 1E0657−558 (z = 0.296), a unique cluster merger, that enable a direct detection of dark matter, independent of assumptions regarding the nature of the gravitational force law. Due to the collision of two clusters, the dissipationless stellar component and the fluid-like X-ray emitting plasma are spatially segregated. By using both wide-field ground based images and HST/ACS images of the cluster cores, we create gravitational lensing maps which show that the gravitational potential does not trace the plasma distribution, the dominant baryonic mass component, but rather approximately traces the distribution of galaxies. An 8σ significance spatial offset of the center of the total mass from the center of the baryonic mass peaks cannot be explained with an alteration of the gravitational force law, and thus proves that the majority of the matter in the system is unseen.



Masse visible et contour de masse vu par effet de lentille



La collision de deux amas de galaxies a réchauffé la matière noire (qui se trouvait être du gaz…)

On la voit rayonner en X …

Une alternative
***MO**dified **N**ewtonian **D**ynamics*

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.

Régime des fortes accélérations

Si $a \gg a_0$ $\quad F_g = -\dfrac{GMm}{r^2}$

Régime des faibles accélérations

Si $a \ll a_0$ $\quad F_g = -\dfrac{GMm}{r\, r_0}$

Exit la matière noire, un seul paramètre $a_0 \approx 10^{-10}$ m.s^{-2} car $r_0 = r_0(a_0) \approx 10$ kpc

Effet sur la courbe de rotation

Force centrale
mouvement plan

$$\vec{r} = r\ \widehat{e_r}$$

$$\vec{v} = \dot{r}\ \widehat{e_r} + r\dot{\theta}\ \widehat{e_\theta}$$

$$\vec{a} = \left(2\dot{r}\dot{\theta} + r\ddot{\theta}\right)\ \widehat{e_\theta} + \left(\ddot{r} - r\dot{\theta}^2\right)\widehat{e_r}$$

Mouvement circulaire

$r_c = \text{cste}$

$$\vec{v}_c = r_c\,\dot{\theta}\ \widehat{e_\theta}$$

$$\vec{a}_c = r_c\,\ddot{\theta}\ \widehat{e_\theta} - r_c\,\dot{\theta}^2\,\widehat{e_r} = \dot{v}_c\widehat{e_\theta} - \frac{v_c^2}{r}\widehat{e_r}$$

Régime d'accélération
faible

$$\vec{F}_{gm} = -\frac{GMm}{r\ r_0}\widehat{e_r}$$

$$m\vec{a}_c = \vec{F}_{gm} \implies v_c = \sqrt{\frac{GM}{r_0}} = \text{cste}$$

Pas de matière noire

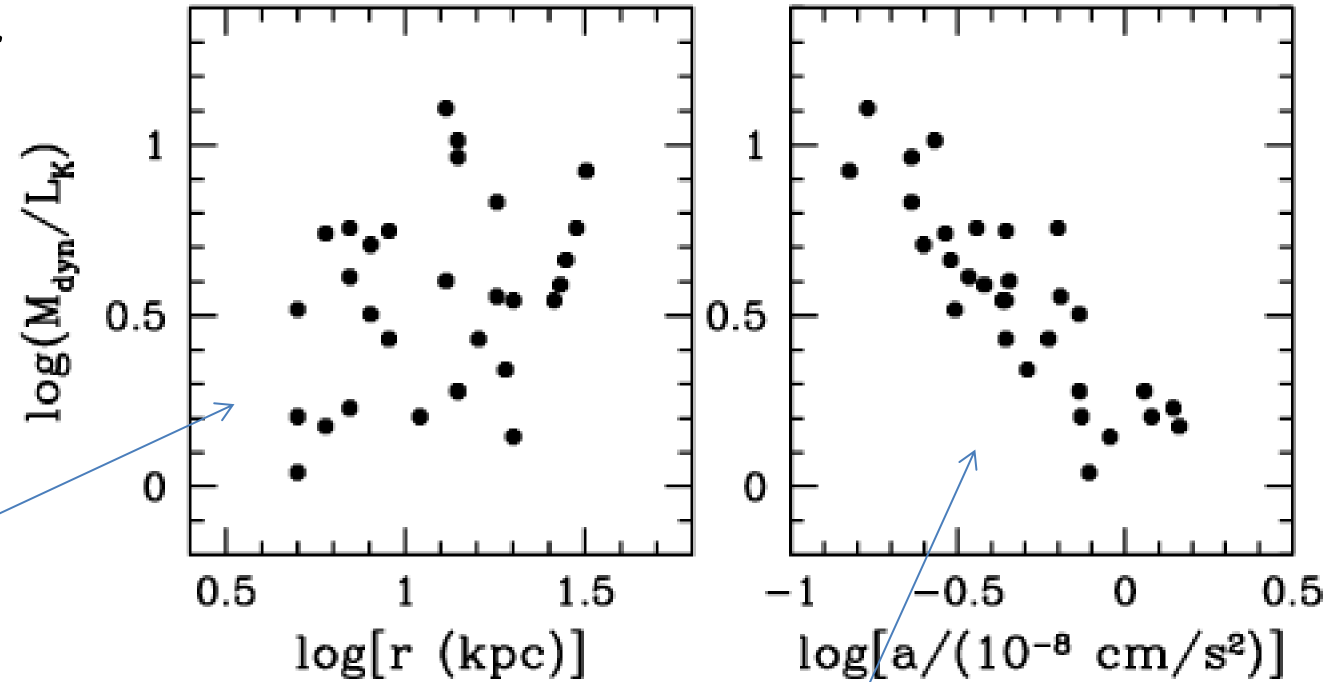
$$\left[r_0 = \frac{v_c^2}{a_0} \implies M = \frac{1}{Ga_0}v_c^4 \quad \left[\frac{M}{L} = \frac{M_\odot}{L_\odot}\right] \quad L = \frac{L_\odot}{M_\odot G a_0}v_c^4\right|$$

$a_0 \approx 10^{-10}$ m.s^{-2}

Tully-Fischer

Un véritable succès

Sur un échantillon de galaxies, le rapport M/L semble être différent de la valeur 1 Indépendamment de la taille de la galaxie,



Par contre il s'écarte de 1 dans le régime des faibles accélérations !

… dès que a < 10 $^{-10}$ m.s^{-2} !!!

MODIFIED NEWTONIAN DYNAMICS AS AN ALTERNATIVE TO DARK MATTER

Robert H. Sanders[1] *& Stacy S. McGaugh*[2]

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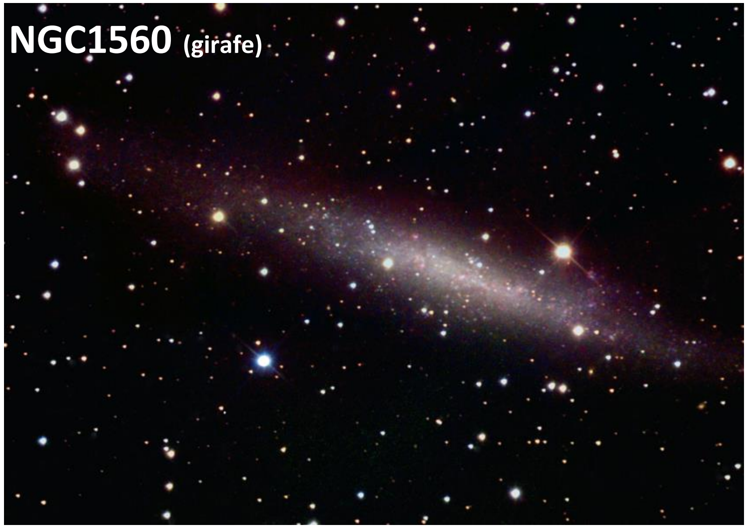
KEYWORDS: dark matter, galaxy dynamics, gravitational theory, cosmology

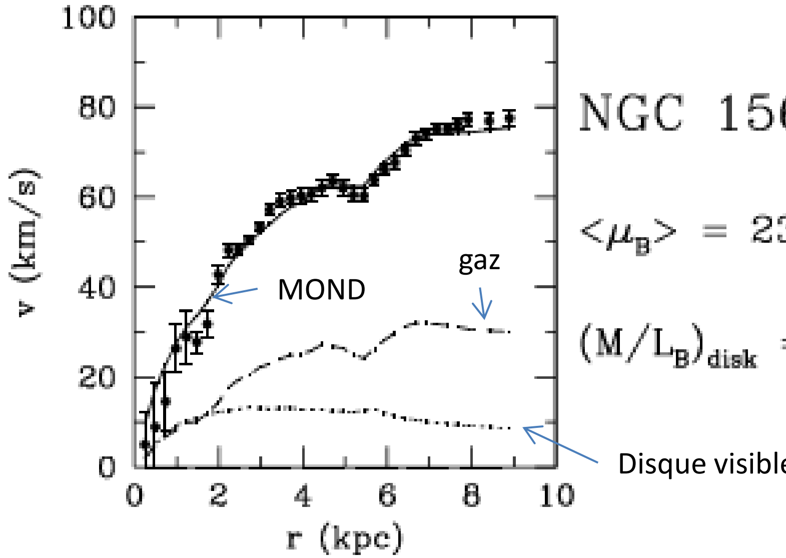
ABSTRACT:
Modified Newtonian dynamics (MOND) is an empirically motivated modification of Newtonian gravity or inertia suggested by Milgrom as an alternative to cosmic dark matter. The basic idea is that at accelerations below $a_o \approx 10^{-8}$ cm/s^2 $\approx cH_o/6$ the effective gravitational attraction approaches $\sqrt{g_n a_o}$ where g_n is the usual Newtonian acceleration. This simple algorithm yields flat rotation curves for spiral galaxies and a mass-rotation velocity relation of the form $M \propto V^4$ that forms the basis for the observed luminosity-rotation velocity relation– the Tully-Fisher law. We review the phenomenological success of MOND on scales ranging from dwarf spheroidal galaxies to superclusters, and demonstrate that the evidence for dark matter can be equally well interpreted as evidence for MOND. We discuss the possible physical basis for an acceleration-based modification of Newtonian dynamics as well as the extension of MOND to cosmology and structure formation.

Echantillon utilisé :
Les spirales de la grande ourse

Annual Review of Astronomy and Astrophysics, Vol. 40, p. 263-317 (2002)



Dans le même article

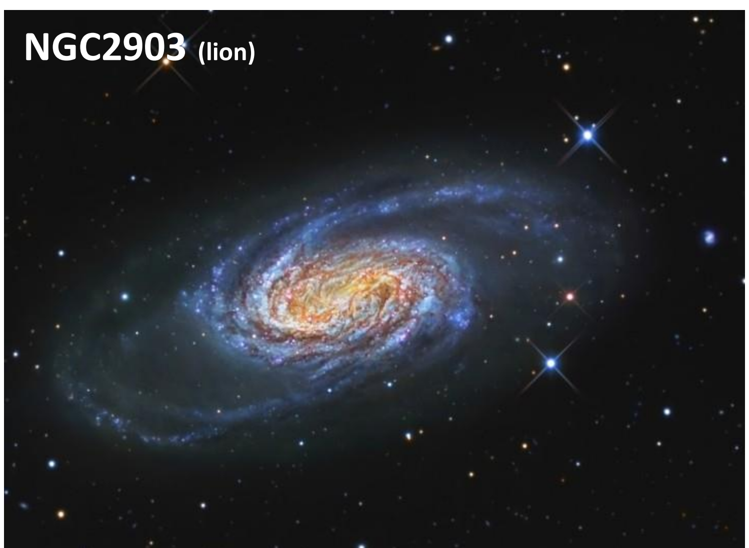


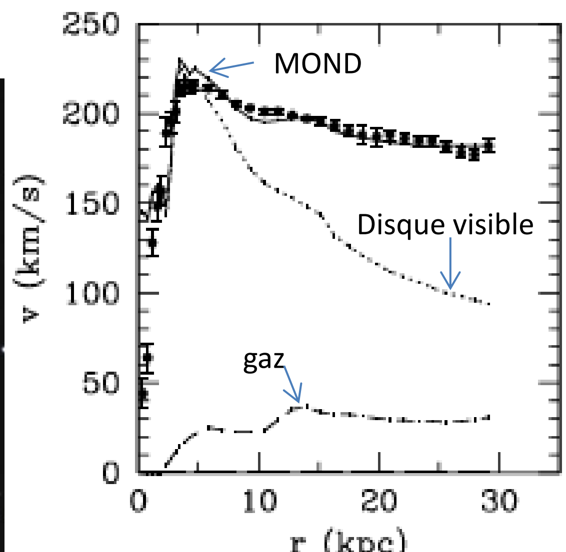
NGC 1560 **(LSB)**

$\langle \mu_B \rangle = 23.2$ mag/arcsec^2

$(M/L_B)_{disk} = 0.4$

Le modèle fonctionne pour tous les types de galaxies spirales

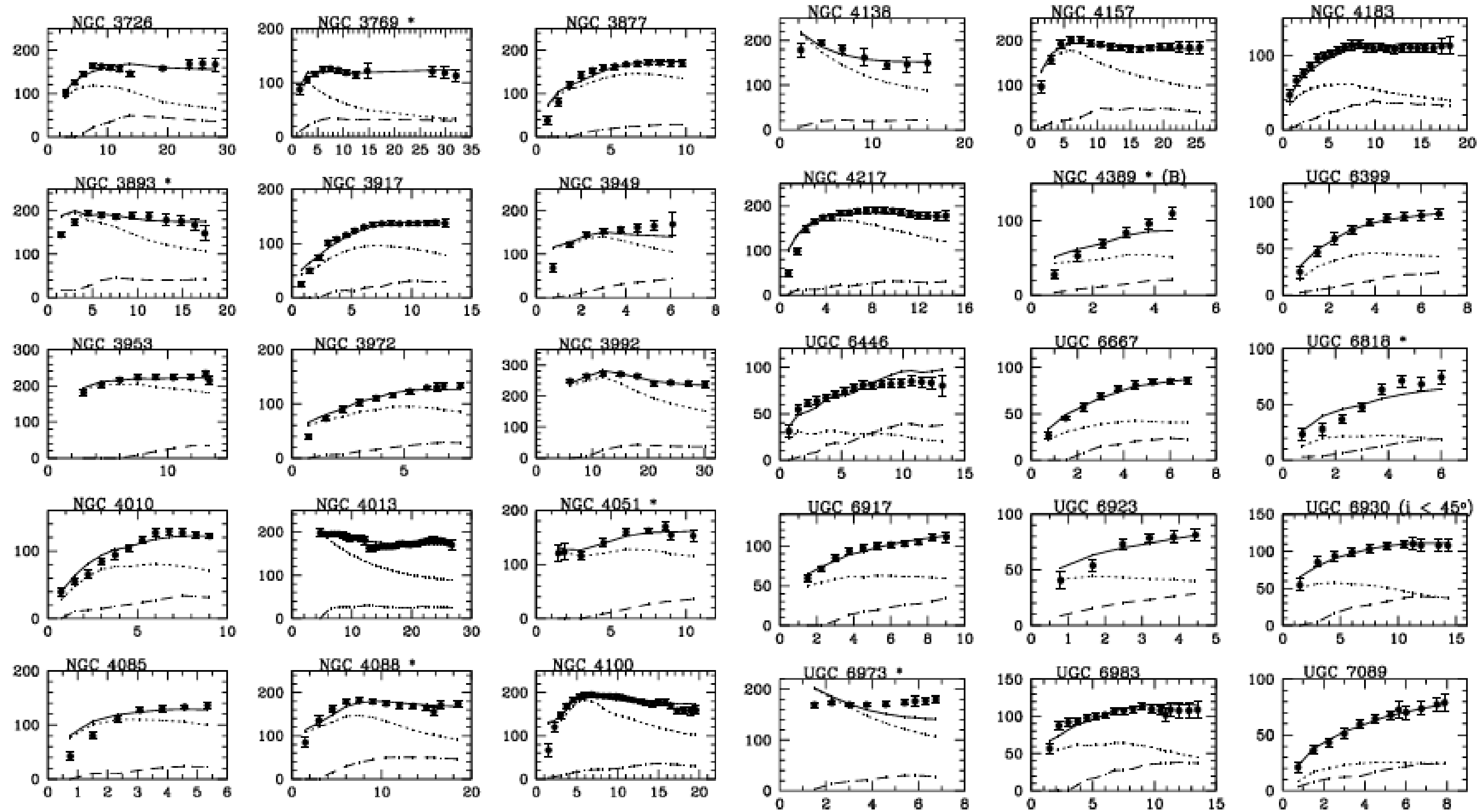




NGC 2903 **(HSB)**

$\langle \mu_B \rangle = 20.5$ mag/arcsec^2

$(M/L_B)_{disk} = 1.9$



Dans tous les cas particuliers (spirales de la grande ourse)

Pour les amas de galaxies, MOND arrange les choses…
… mais ne règle pas le problème !

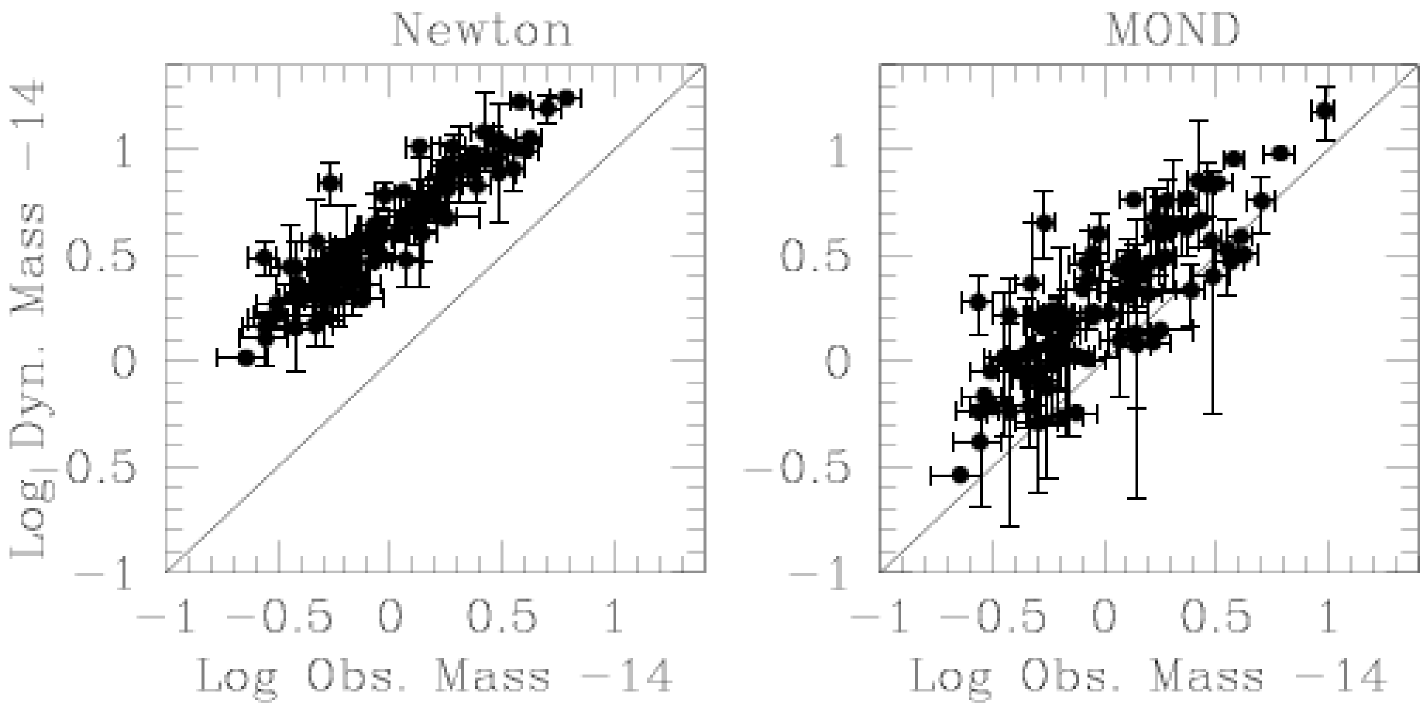


Figure 10: (*Left*) the Newtonian dynamical mass of clusters of galaxies within an observed cutoff radius (r_{out}) vs. the total observable mass in 93 X-ray emitting clusters of galaxies (White et al. 1997). The solid line corresponds to $M_{dyn} = M_{obs}$ (no discrepancy). (*Right*) the MOND dynamical mass within r_{out} vs. the total observable mass for the same X-ray emitting clusters. From Sanders (1999).

MOND crée moins de petites structures que CDM

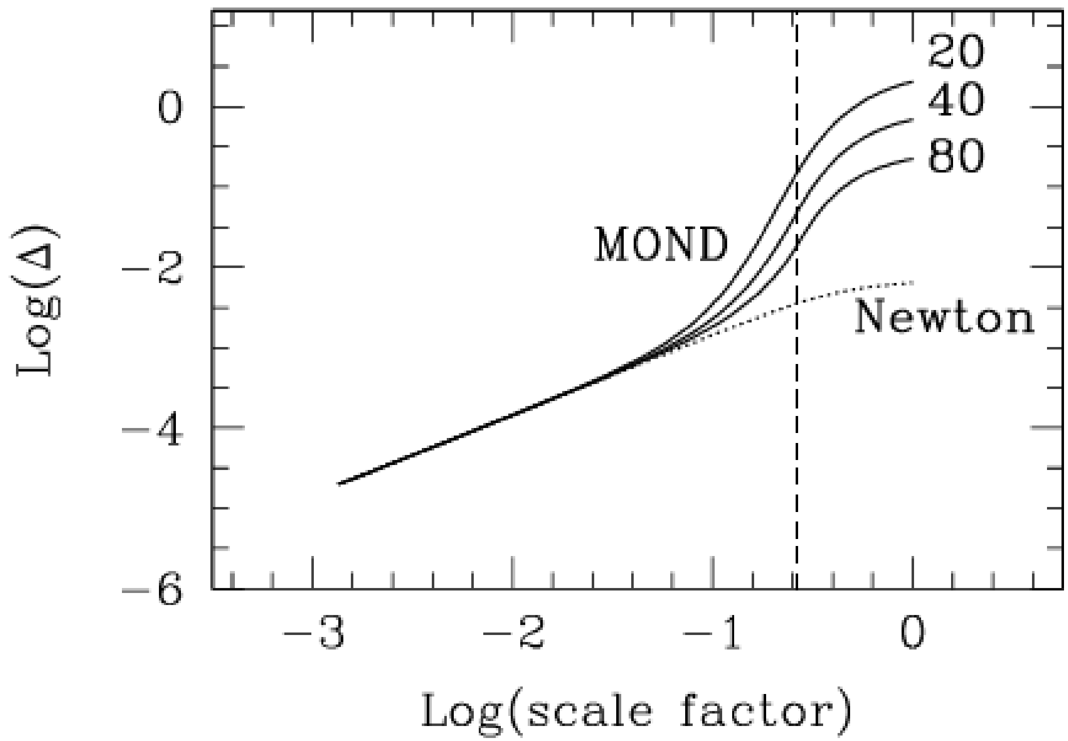
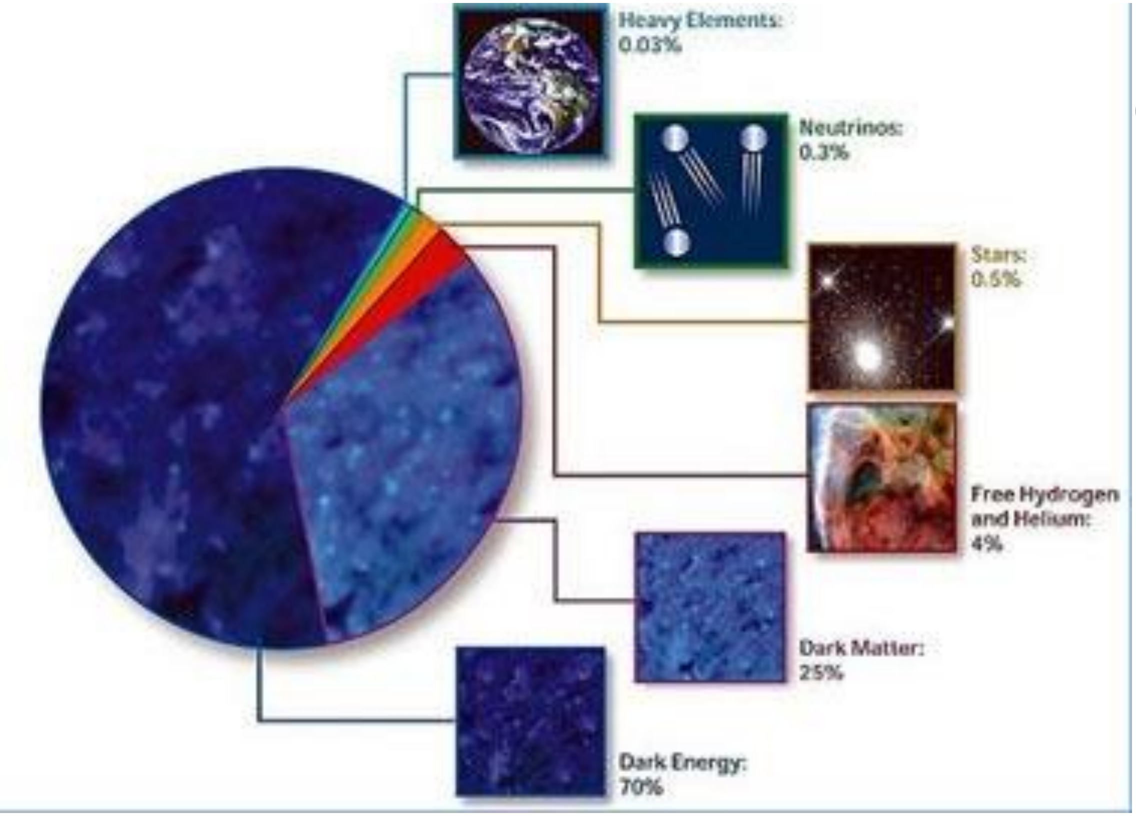
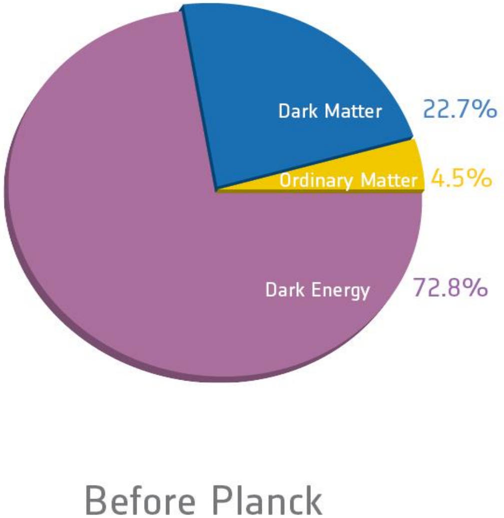


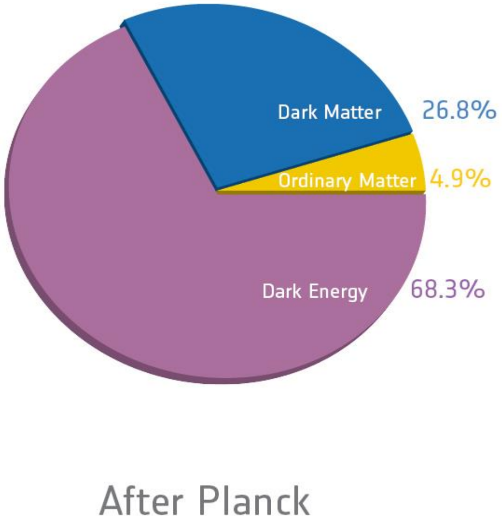
Figure 12: The growth of spherically symmetric over-densities in a low-density baryonic universe as a function of scale factor in the context of a two-field Lagrangian theory of MOND. The solid curves correspond to regions with comoving radii of 20, 40, and 80 Mpc. The dotted line is the corresponding Newtonian growth. With MOND smaller regions enter the low-acceleration regime sooner and grow to larger final amplitude. The vertical dashed line indicates the epoch at which the cosmological constant begins to dominate the Hubble expansion.

CDM → Λ CDM

modèle de concordance depuis 1998…







Phys. Rev. D **70** (8), 2004

Relativistic gravitation theory for the MOND paradigm

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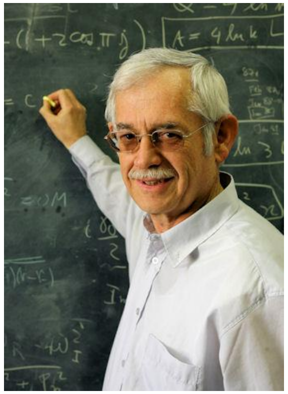
(Dated: February 2, 2008)



The modified newtonian dynamics (MOND) paradigm of Milgrom can boast of a number of successful predictions regarding galactic dynamics; these are made without the assumption that dark matter plays a significant role. MOND requires gravitation to depart from Newtonian theory in the extragalactic regime where dynamical accelerations are small. So far relativistic gravitation theories proposed to underpin MOND have either clashed with the post-Newtonian tests of general relativity, or failed to provide significant gravitational lensing, or violated hallowed principles by exhibiting superluminal scalar waves or an *a priori* vector field. We develop a relativistic MOND inspired theory which resolves these problems. In it gravitation is mediated by metric, a scalar field and a 4-vector field, all three dynamical. For a simple choice of its free function, the theory has a Newtonian limit for nonrelativistic dynamics with significant acceleration, but a MOND limit when accelerations are small. We calculate the β and γ PPN coefficients showing them to agree with solar system measurements. The gravitational light deflection by nonrelativistic systems is governed by the same potential responsible for dynamics of particles. To the extent that MOND successfully describes dynamics of a system, the new theory's predictions for lensing by that system's visible matter will agree as well with observations as general relativity's predictions made with a dynamically successful dark halo model. Cosmological models based on the theory are quite similar to those based on general relativity; they predict slow evolution of the scalar field. For a range of initial conditions, this last result makes it easy to rule out superluminal propagation of metric, scalar and vector waves.

MOND

Symétrie sphérique

$$\mathcal{L} = -\frac{\mathfrak{a}_0^2}{8\pi G} f\left(\frac{|\nabla\Phi|^2}{\mathfrak{a}_0^2}\right) - \rho\Phi.$$

$$f(y) \longrightarrow \begin{cases} y & y \gg 1; \\ \frac{2}{3}y^{3/2} & y \ll 1. \end{cases}$$

AQUAdratic Lagrangian

Formulation de MOND en théorie des champs classiques

Champ faible

$$S = S_g + S_s + S_v + S_m$$

TeVeS

Géométrie $$S_g = (16\pi G)^{-1} \int g^{\alpha\beta} R_{\alpha\beta} (-g)^{1/2} d^4x.$$

Scalaire $$S_s = -\frac{1}{2} \int \left[\sigma^2 h^{\alpha\beta} \phi_{,\alpha}\phi_{,\beta} + \frac{1}{2} G\ell^{-2}\sigma^4 F(kG\sigma^2)\right] (-g)^{1/2} d^4x,$$

Vecteur $$S_v = -\frac{K}{32\pi G} \int \left[g^{\alpha\beta} g^{\mu\nu} \mathfrak{U}_{[\alpha,\mu]} \mathfrak{U}_{[\beta,\nu]} - 2(\lambda/K)(g^{\mu\nu}\mathfrak{U}_\mu \mathfrak{U}_\nu + 1)\right] (-g)^{1/2} d^4x,$$

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Large Scale Structure in Bekenstein's theory of relativistic Modified Newtonian Dynamics

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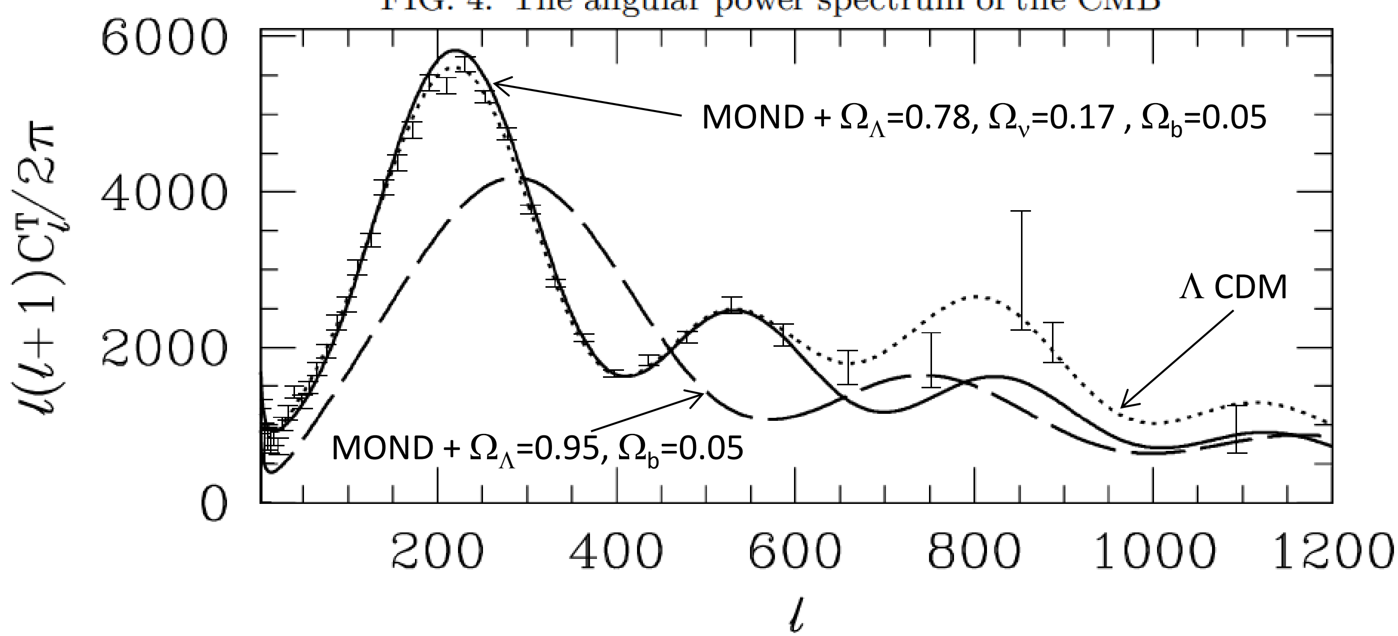
Ca peut marcher !

En attendant Planck…

A relativistic theory of modified gravity has been recently proposed by Bekenstein. The tensor field in Einstein's theory of gravity is replaced by a scalar, a vector, and a tensor field which interact in such a way to give Modified Newtonian Dynamics (MOND) in the weak-field non-relativistic limit. We study the evolution of the universe in such a theory, identifying its key properties and comparing it with the standard cosmology obtained in Einstein gravity. The evolution of the scalar field is akin to that of tracker quintessence fields. We expand the theory to linear order to find the evolution of perturbations on large scales. The impact on galaxy distributions and the cosmic microwave background is calculated in detail. We show that it may be possible to reproduce observations of the cosmic microwave background and galaxy distributions with Bekenstein's theory of MOND.

FIG. 4: The angular power spectrum of the CMB



Conclusion ?

- A l’échelle galactique on a besoin de la matière noire ?
- A l’échelle des amas on peut éventuellement s’en passer ?
- MOND ne guérit sans doute pas tout !
- Il y a plusieurs formes de matière noire

Baryonique	/	Non baryonique
Gaz		Neutrinos, etc
Trous noirs, Jupiter		?

On compte sur vous …

La matière noire : mangez-en !