Existe Realmente la Materia Obscura?

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"We habitually act upon hypotheses, but not precisely as we act upon what we consider certainties; for when we act upon an hypothesis we keep our eyes open for fresh evidence"
-Bertrand Russel-

“The difficulty lies not
in the new ideas, but
in escaping from the
old ones”

-John Maynard Keynes-

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Spiral Rotation Curves

Surface density mass distribution follows $\Sigma(r) = \Sigma_0 e^{-R}$,

with $R = r/r_s$.

Integral Mass distribution hence given by: $M_D(< R) = M_D \left[1 - e^{-R}(R+1)\right]$

Mass converges rapidly, over 90% within $R = 4$ yet, rotation curves remain flat always at $V(R) = V_{\rm inf}$, out to last measured point, sometimes $R > 25$.

No Kepplerian fall off has ever been measured! end up with $M_{Tot} \sim 20 M_D$

$V_{\rm inf}$ and r_s range from 10-300 km/s and 0.2-5 kpc.

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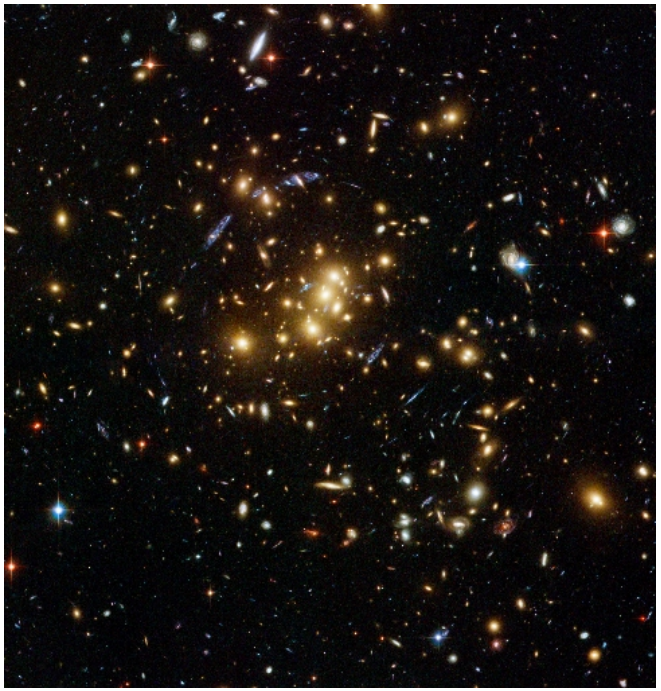
Galaxy cluster dynamics



Radial Velocity of each individual galaxy measured, giving a velocity dispersion for the cluster, σ

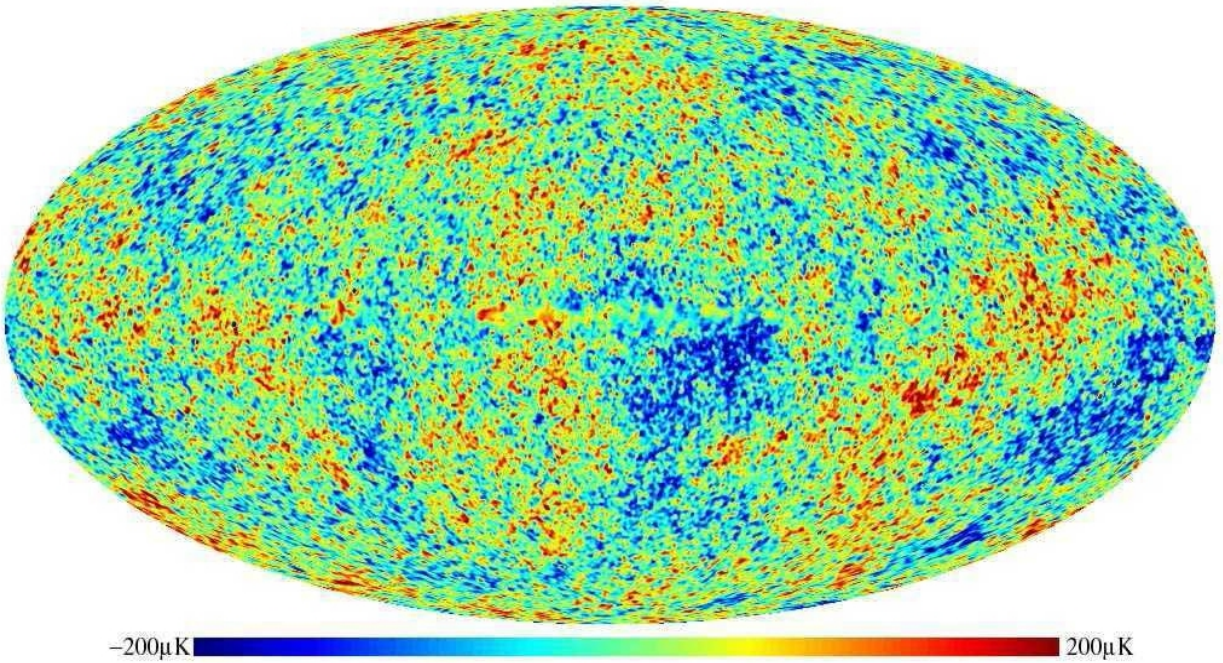
Total size (or half-light radius, R_{hl}), hence yields total cluster mass M_C from virial equilibrium, $2T + W = 0$:

$$M_C \sigma^2 = \frac{GM_C^2}{0.5 R_{hl}}$$

End up again with $M_{Tot} \sim 20 M_{Vis}$

.

Structure Formation



Linearised expansion law, fluctuations grow as $\delta\rho \propto (1+z)^{-1}$

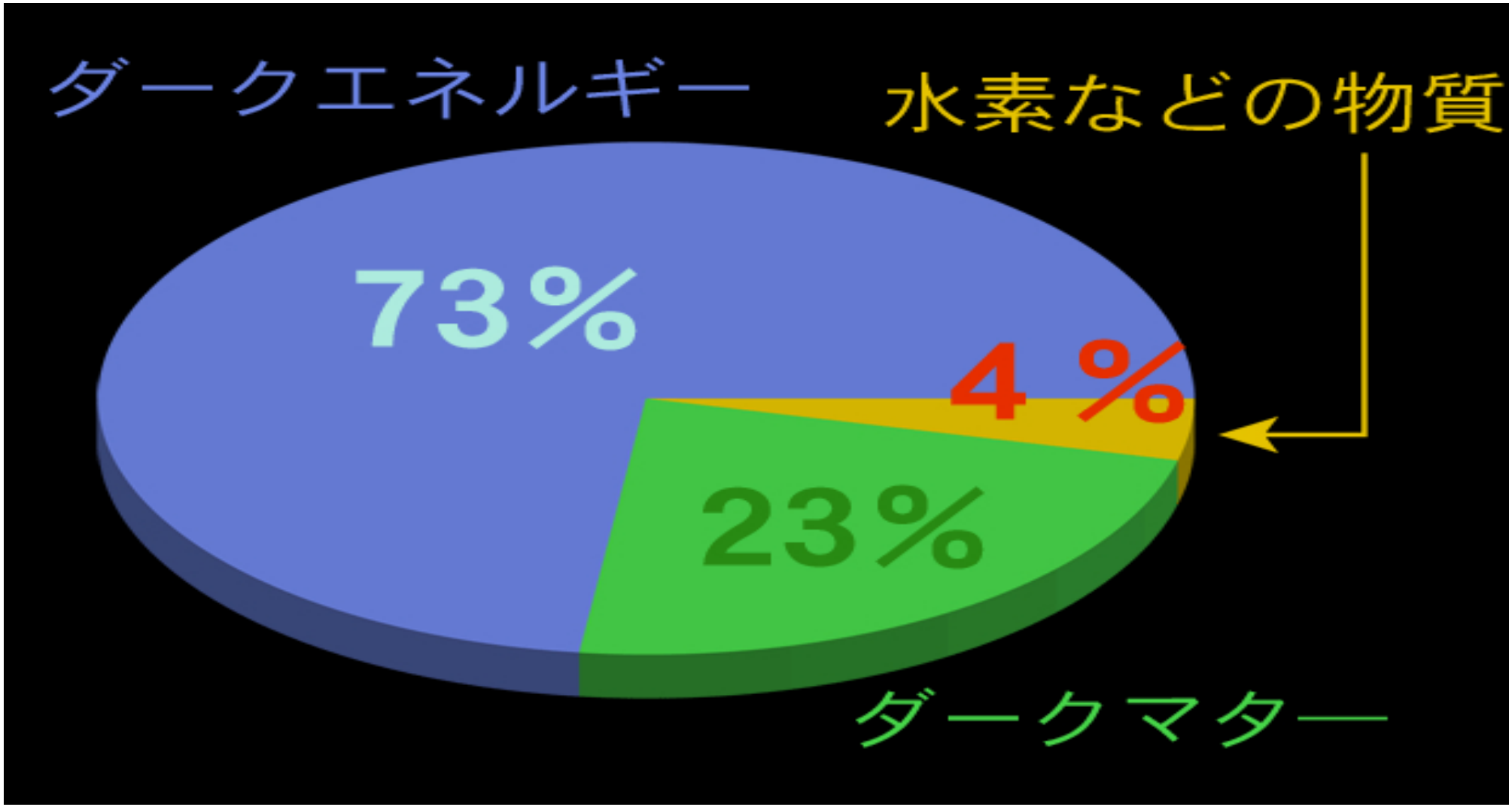
Since γ field energy density scales with $\rho_\gamma \propto (1+z)^4$ and ρ_γ scales with T_γ^4, Temperature scales with (1+z)

Therefore, present temperature of 2.7K and 13.6 ev H ionisation potential $\Rightarrow$ CMB emitted at z=1000.

Since δT (and hence $\delta\rho$) only of 1 part in 10^{4-5}, we should still be in the linear regime!

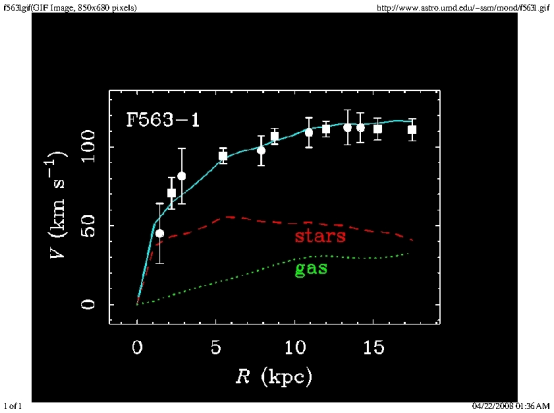
Need to boost gravity effect again, e.g. $M_{Tot} \sim 20 M_{Vis}$

Entonces de que esta hecho el Universo?

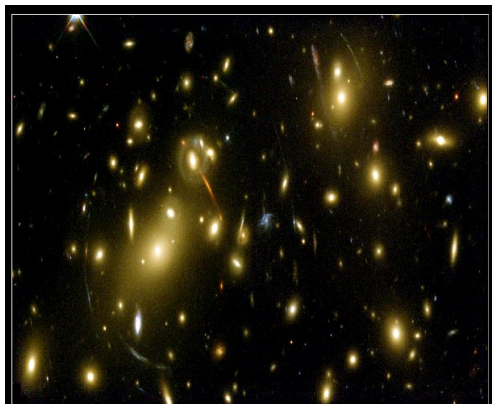


Indirect evidence for Dark Matter?

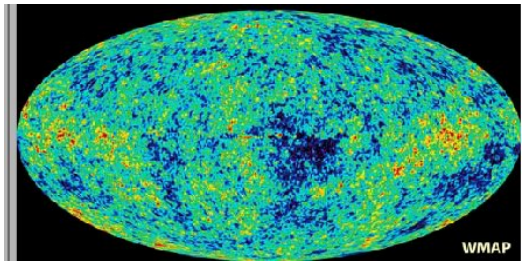
Rotation Curves of Large Spirals
(1-10 kpc)



Dynamics and Lensing of Galaxy Clusters
(1-5 Mpc)



Cosmological Matter Determinations
($>$ 50 Mpc)



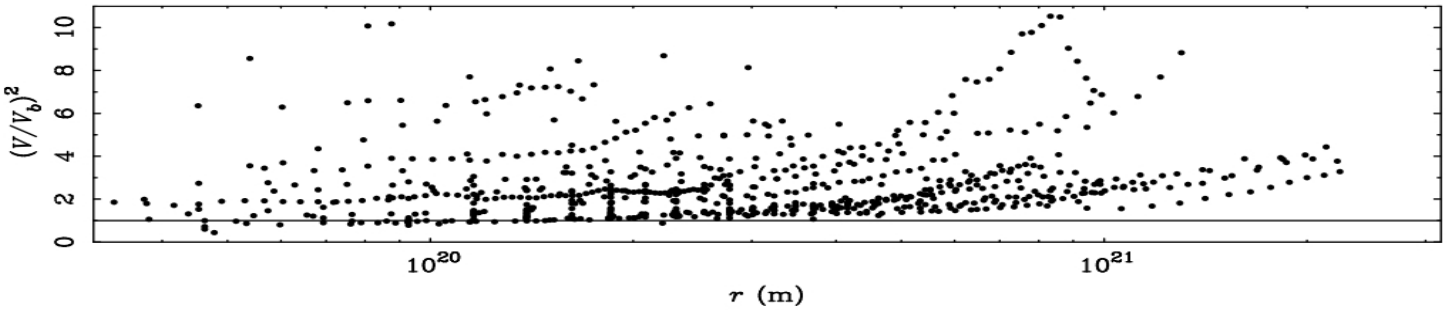
...or direct evidence for the failure of standard Gravity at large scales?

-Direct proof of the law of Gravity exists only for $R < 0.001pc$

-Direct proof of the existence of Dark Matter is still missing

Detailed Dynamics of Disk Galaxies

"Dark matter fraction" does not show any clear correlation with integral or differential Galactic properties.



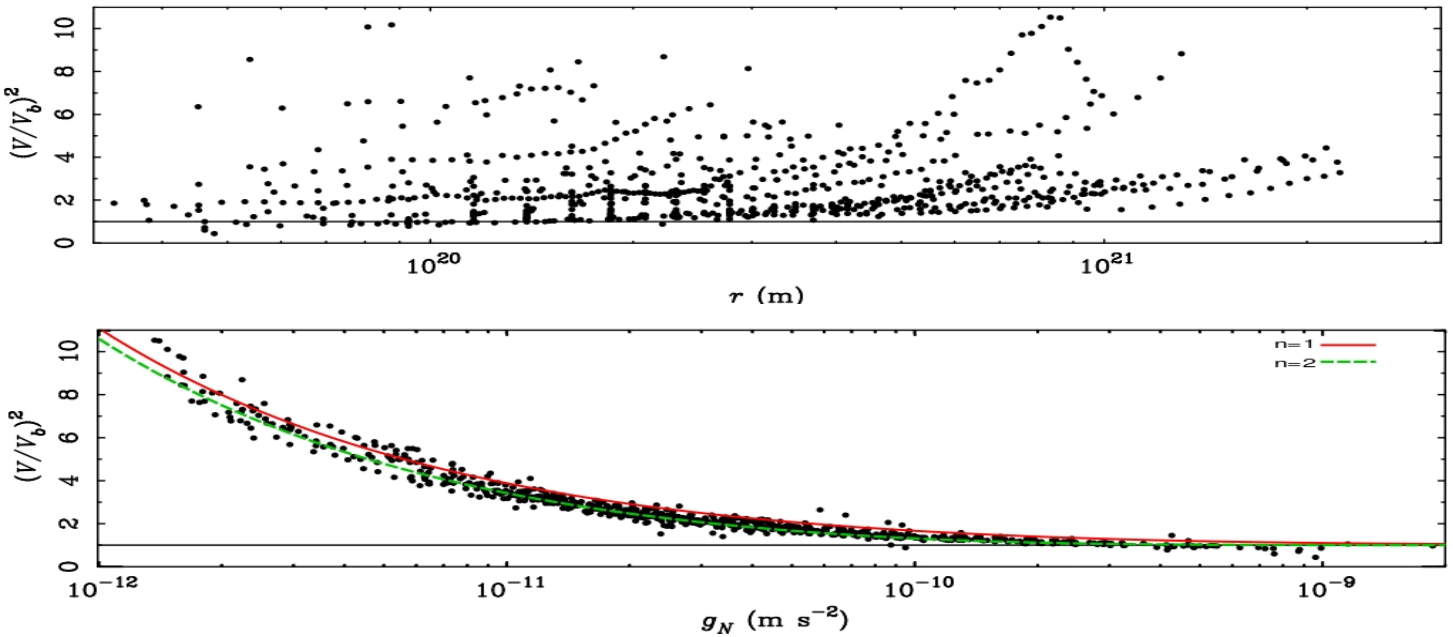
Famaey & McGaugh (2012), Living Rev. Relativity, 15, 10

Detailed Dynamics of Disk Galaxies

"Dark matter fraction" does not show any clear correlation with integral or differential Galactic properties.

However, mass discrepancy tightly correlates with acceleration,

at all radii, for all galactic types.



Distribution of baryonic mass uniquely determines total rotation!

Famaey & McGaugh (2012), Living Rev. Relativity, 15, 10

What would Newton have done?

Since $F = ma$, and for centrifugal equilibrium orbits $a = V^2/r$,

Given the Solar System rotation curve $V = \left(\frac{GM}{r}\right)^{1/2}$,

Gravitational force per unit mass is inferred to be: $\frac{GM}{r^2}$.

Take now the empirical rotation curves of galaxies, $V = (GMa_0)^{1/4}$,

Gravitational force per unit mass is inferred to be: $\frac{(GMa_0)^{1/2}}{r}$.

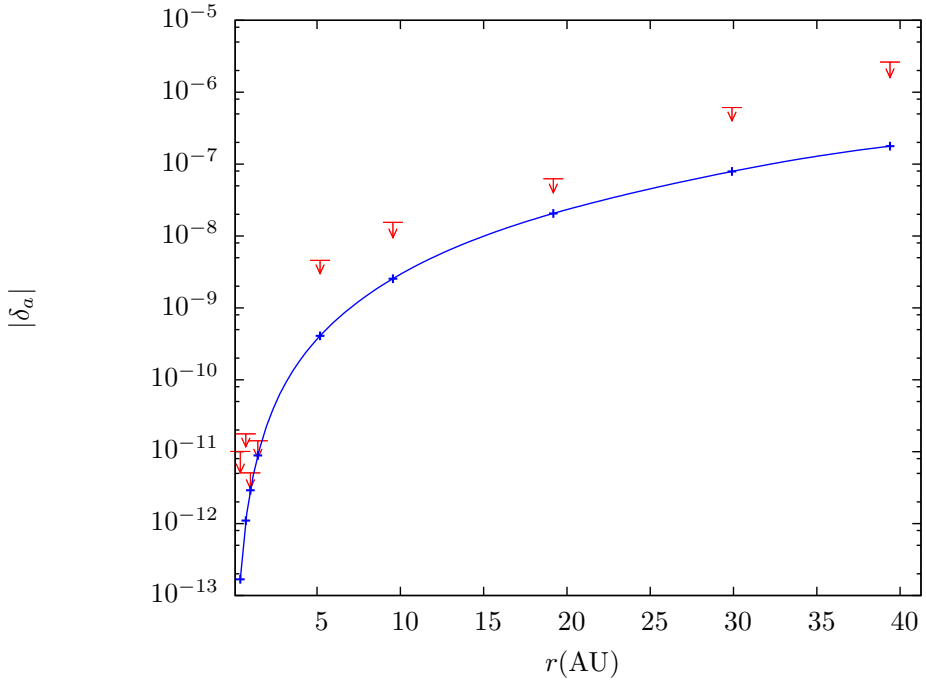
We can therefore write the dimensionless force per unit mass F/a_0 as:

$\frac{F_N}{a_0} = \left(\frac{GM}{a_0}\right)\frac{1}{r^2}$ $\qquad$ $\frac{F_M}{a_0} = \left(\frac{GM}{a_0}\right)^{1/2}\frac{1}{r}$

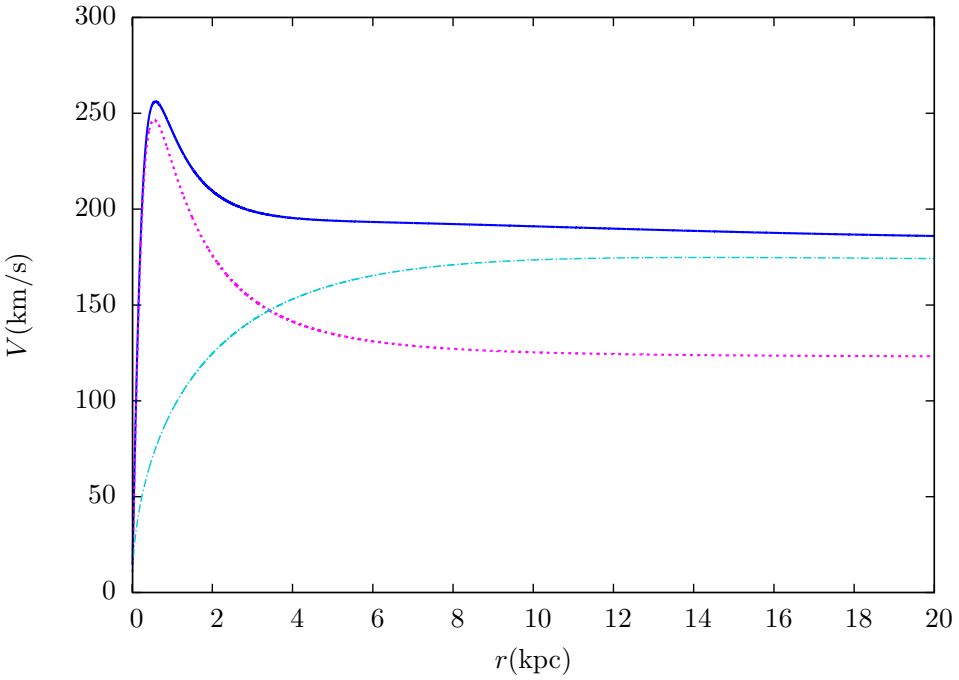
choosing $x = \left(\frac{GM}{a_0}\right)^{1/2}\frac{1}{r}$ gives:

$\frac{F_N}{a_0} = x^2$ $\qquad$ $\frac{F_M}{a_0} = x$ $\qquad$ Perhaps $\frac{F}{a_0} = ... + x^2 + x + ...$?

Self-consistency across astrophysical scales



Solar System.



Milky Way.

X. Hernandez, S. Mendoza, T. Suarez & T. Bernal (2010), A&A 514, A101
S. Mendoza, X. Hernandez, J.C. Hidalgo & T. Bernal (2011), MNRAS 411, 226
T. Bernal, S. Capozziello, J.C. Hidalgo, S. Mendoza (2011), EPJC 71, 1794

Generic modified gravity predictions

1) All $a > a_0$ systems in the low velocity regime should appear as purely Newtonian, without requiring any dark matter.
-Indeed, no counterexamples to this prediction exist.

2) All $a < a_0$ systems in the low velocity regime should appear as purely "MONDian", requiring substantial dark matter if interpreted under Newtonian Gravity.
-All known "dark matter" presenting systems neatly fall into this category.
-A definitive prediction appears for the outskirts of globular clusters and wide binaries

3) In the $a < a_0$ regime, equilibrium velocities become flat, with systems exhibiting a "Tully-Fisher" relation for $V_{MG}^2 \propto (MGa_0)^{1/2}$

X. Hernandez (2012), Entropy, 14, 484

Wide binaries as a critical experiment for gravity

A test particle orbiting a $1M_{\odot}$ star in a circular orbit of radius s,
will have an acceleration that falls below $a_0 = 1.2 \times 10^{-10} m/s$ for:
$s > 7000AU \; = \; 3.4 \times 10^{-2} pc$.

Therefore, relative velocities of binaries wider than $7000AU$ are
predicted to be qualitatively and quantitatively very different
under Newtonian Gravity and generically under modified gravity theories.

Which scaling will wide binaries show?

$$\Delta V_N = 2\left(\frac{GM}{s}\right)^{1/2} \quad or \quad \Delta V_{MG} = 2(Ga_0M)^{1/4} \; ?$$

A large survey of relative proper motions and separations for wide binaries should yield a conclusive answer.

X. Hernandez, M. A. Jimenez & C. Allen (2012) EPJC, 72, 1884

Newtonian prediction for wide binary samples

Predicted projected RMS 1D ΔV vs. s relation.

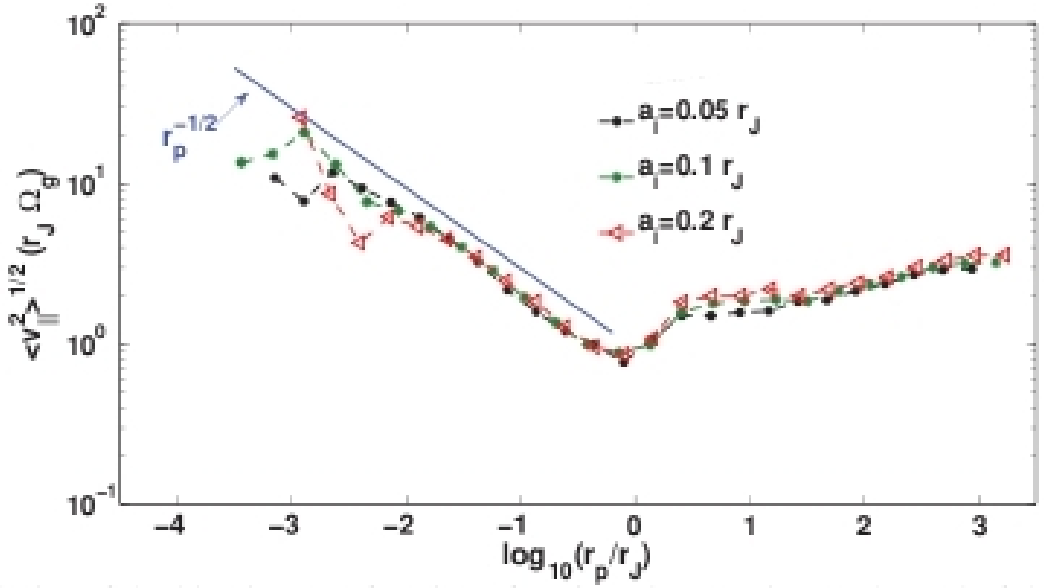


Figure 7. RMS line-of-sight relative velocity of the binaries as a function of projected separation, at the end of the simulations. The horizonta projected separation normal to a randomly chosen line of sight, while the vertical axis is the rms line-of-sight relative velocity in each separ Keplerian motion we expect $\langle v_{||}^2 \rangle^{1/2} \propto r_p^{-1/2}$, shown by the straight line. The relation between the line-of-sight relative velocity and the projecte deviates from the Keplerian relation for $r_p \gtrsim r_J$.

- Below $s = r_J = 1.7pc$, curve closely follows Kepler's law.

- Mostly, disruption occurs for $s > r_J$, the tidal radius of the problem.

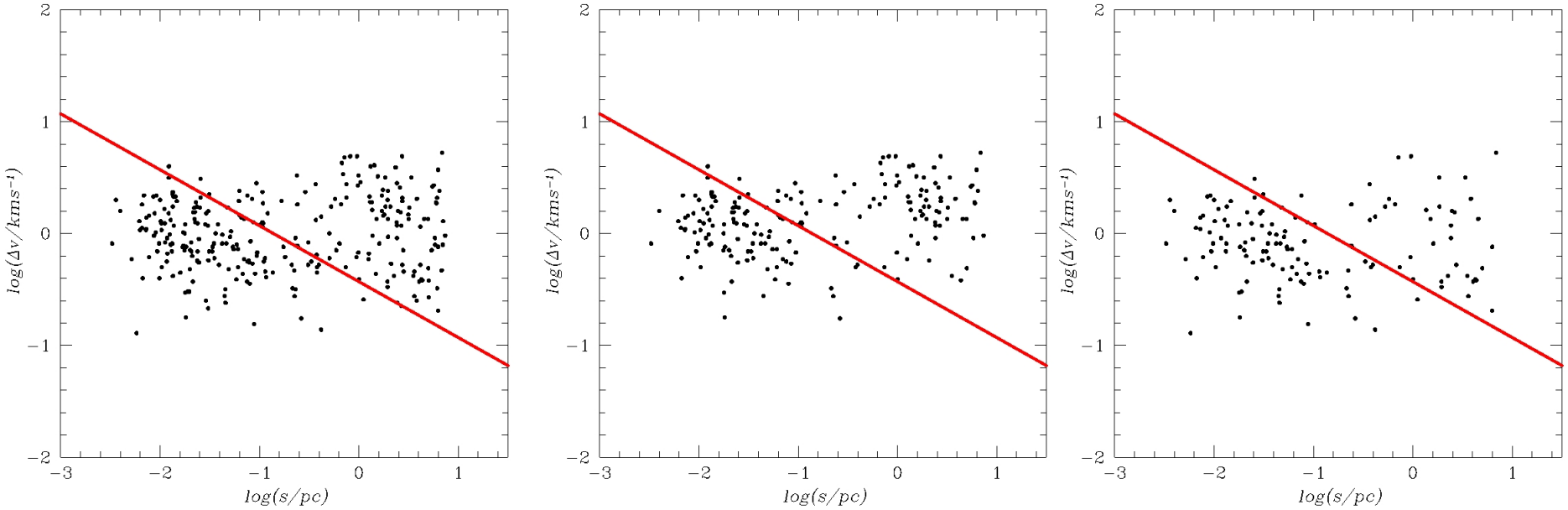
$\Rightarrow$ a definitive feature expected at $s = r_J = 1.7pc$

- Unbound stars continue to drift along very similar orbits and will show up in observational samples.

Y. Jiang & S. Tremaine (2010), MNRAS 401, 977

Wide binary catalogues -2) *Hipparcos*

From a catalogue of ~ 280 carefully selected wide binaries we obtain relative velocities on the plane of the sky and projected separations, average S/N=2.0.



- The upper envelope clearly defines a horizontal line, showing the "flat rotation curve" of modified gravity, and not the Kepplerian decline of Newtonian gravity.

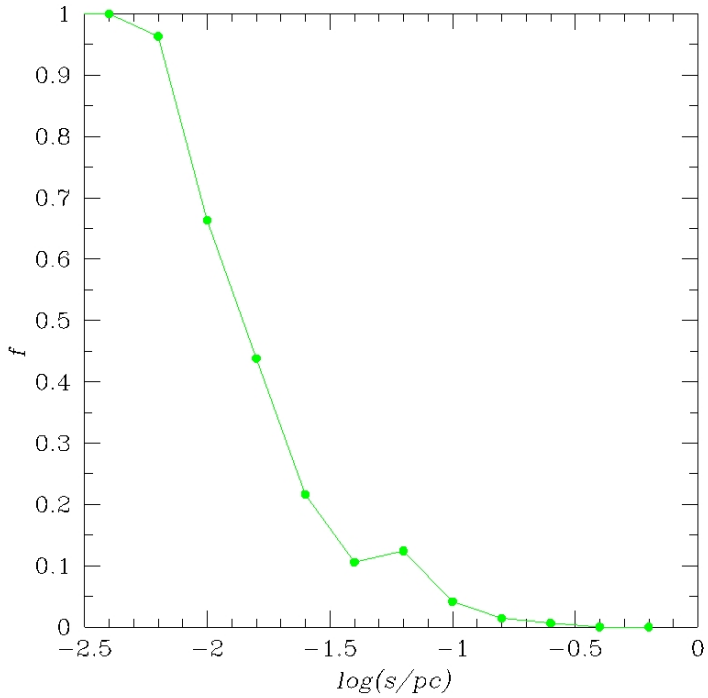
- It can be shown that results are not driven by errors or catalogue selection cuts.

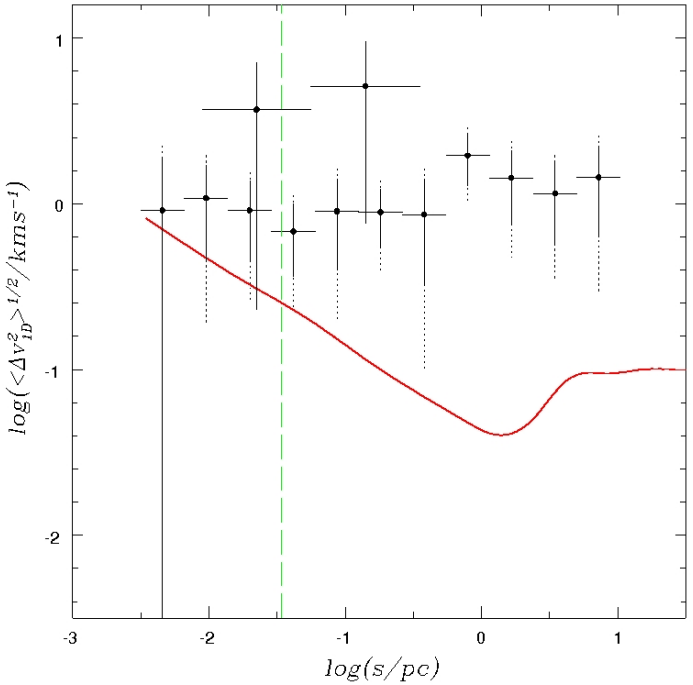
-The data show no feature of any kind on crossing the Newtonian tidal radius at 1.7pc.

E. J. Shaya & R. P. Olling (2011), ApJS, 192, 2

Wide Binary conclusions

Quantitative comparison with full Newtonian prediction:





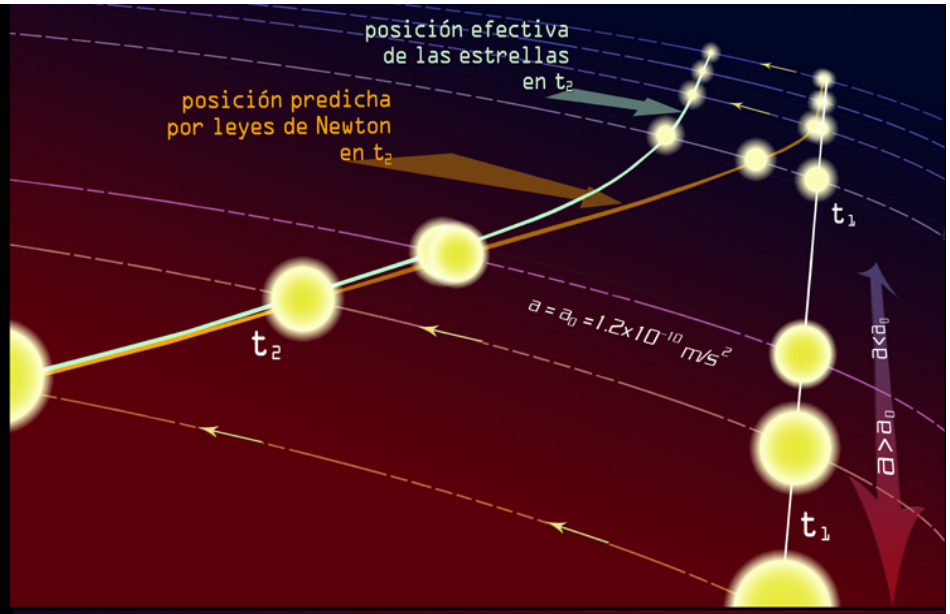
- The trends shown by the data are clearly defining the modified gravity phenomenology, Newtonian Gravity is only consistent with the data with a probability $< 3 \times 10^{-5}$.

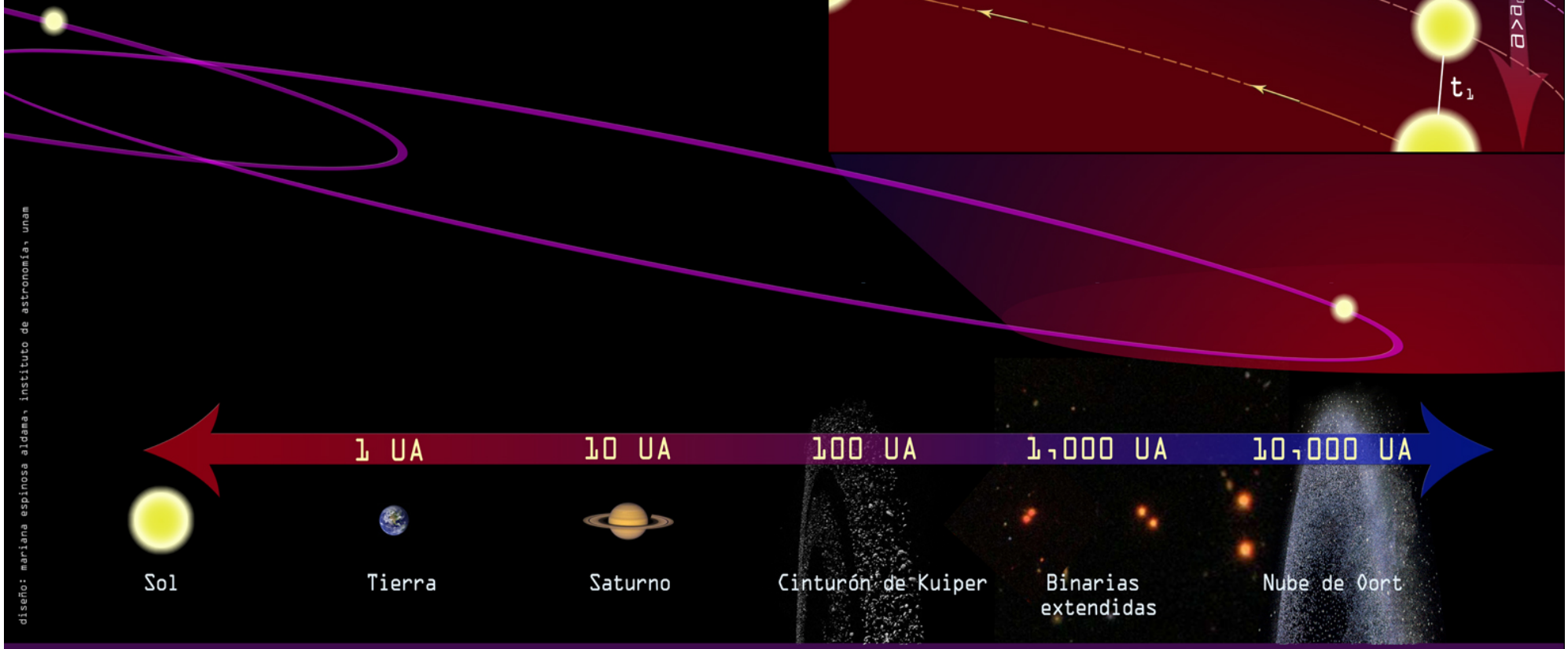
- The two completely independent catalogues yield fully consistent results.

- The data rule out the Newtonian model at a 4σ level.

X. Hernandez, M. A. Jimenez & C. Allen (2012) EPJC, 72, 1884

movimiento de las estrellas binarias extendidas

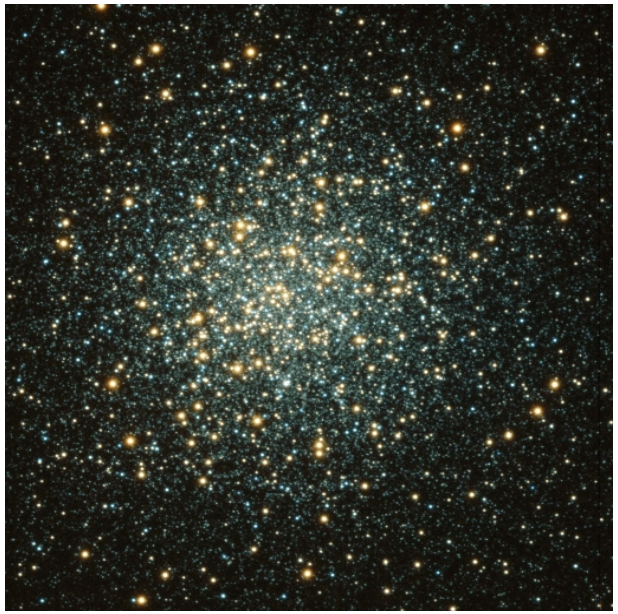


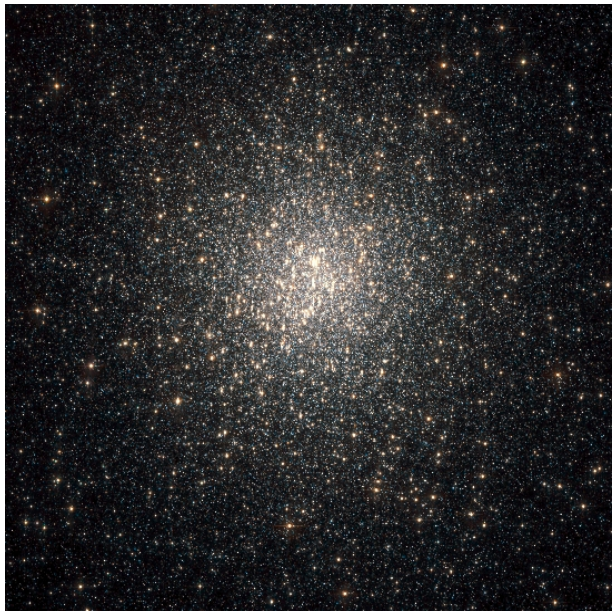


diseño: mariana espinosa aldama, instituto de astronomía, unam

El desplazamiento de las estrellas binarias separadas por más de 1000 UA no coincide con el predicho por la Ley Universal de Gravitación de Newton. La discrepancia se observa a partir del punto en que la aceleración sufrida por las estrellas es menor a la aceleración de Milgrom (a_0). La velocidad orbital de las binarias extendidas se vuelve constante a partir de a_0. La fuerza deja de ser inversamente proporcional a r^2 y comienza a ser inversamente proporcional a r, confirmando la predicción de la teoría de Gravitación Extendida.

Surprising New GC Results:





Total masses $\sim 10^5 - 10^6 M_\odot$

Half mass radii $\sim 20pc$

Up to now, with stellar velocity dispersion profiles measured towards the core regions, well modelled as purely Newtonian equilibrium strictures, without any Dark Matter.

The outskirts of GCs

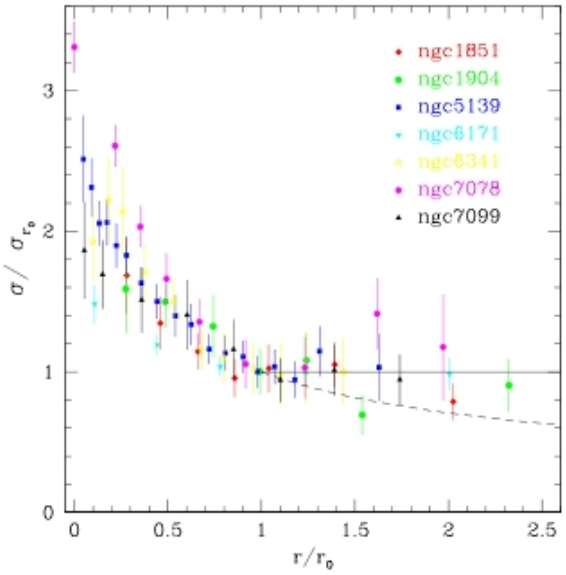
Astronomy & Astrophysics manuscript no. ms˙revised2
August 23, 2010

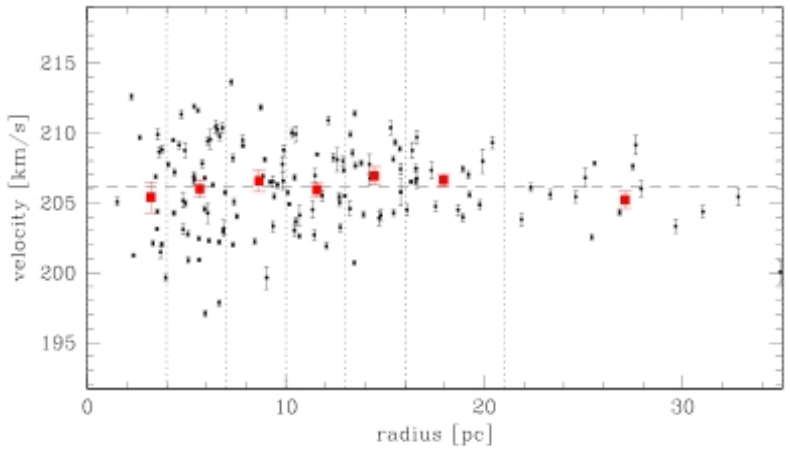
Testing Newtonian gravity with distant globular clusters: NGC1851 and NGC1904⋆

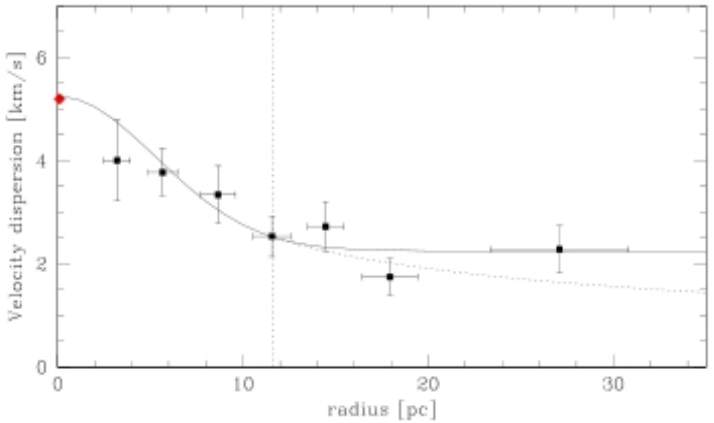
R. Scarpa[1], G. Marconi[2], G. Carraro[2], R. Falomo[3], and S. Villanova[4]

[1] Instituto de Astrofísica de Canarias, Spain
[2] European Southern Observatory, Chile
[3] Osservatorio Astonomico di Padova, Italy
[4] Universidad de Concepcion, Departamento de Astronomia, Concepcion, Chile

August 23, 2010







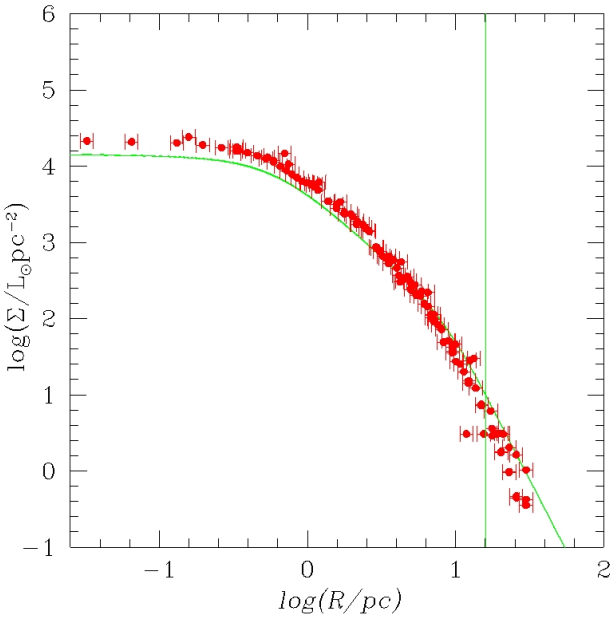
The outskirts of GCs

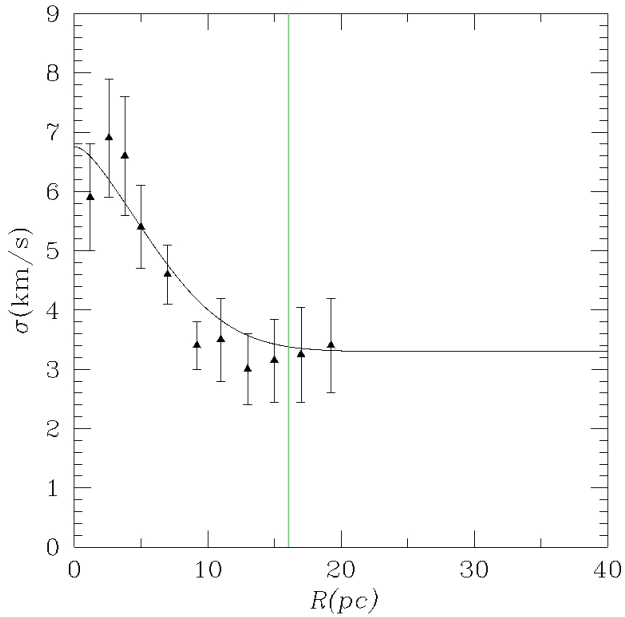
Using the modified force model, we solve equation:

$$\sigma(r)\frac{d\sigma(r)}{dr} + \sigma(r)^2\left[\left(\frac{\mathrm{d}M}{\mathrm{d}r}\right)^{-1}\frac{d^2M}{dr^2} - \frac{2}{r}\right] = F\left(GM(r)/a_0r^2\right)$$

with $F(X) = X\left(\frac{1-X^{10}}{1-X^9}\right)$

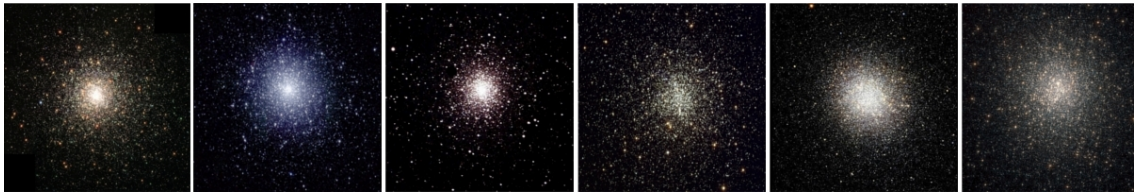
Constrained to give measured total mass, half mass radius, central stellar volume density and observed projected velocity dispersion and brightness profiles. Model for NGC 6341.

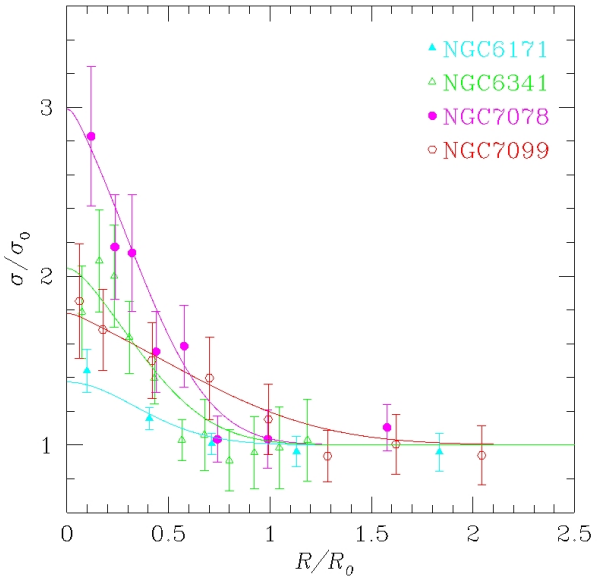




All observational parameters are fitted simultaneously. Vertical line gives point at which $X = 1$

GC conclusions

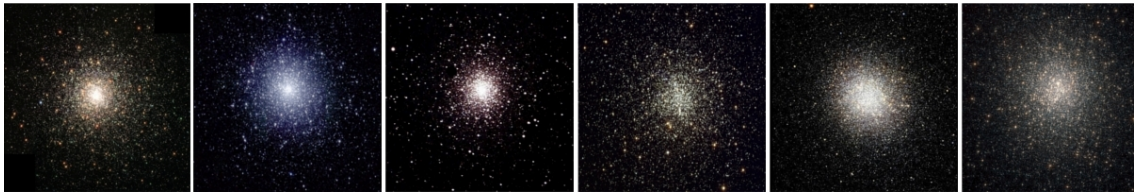


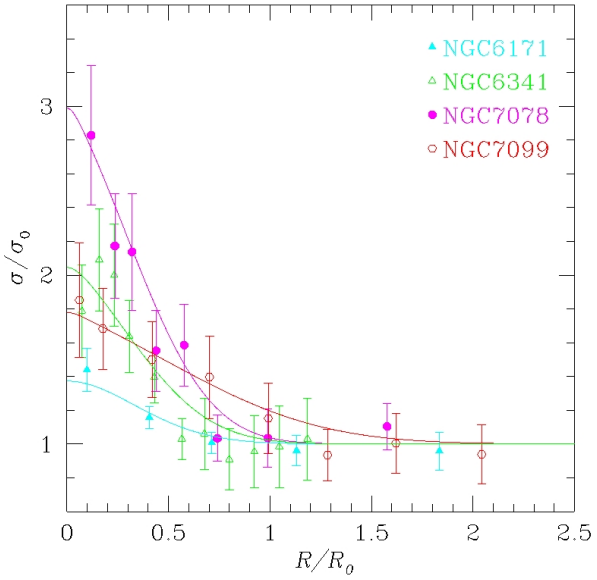


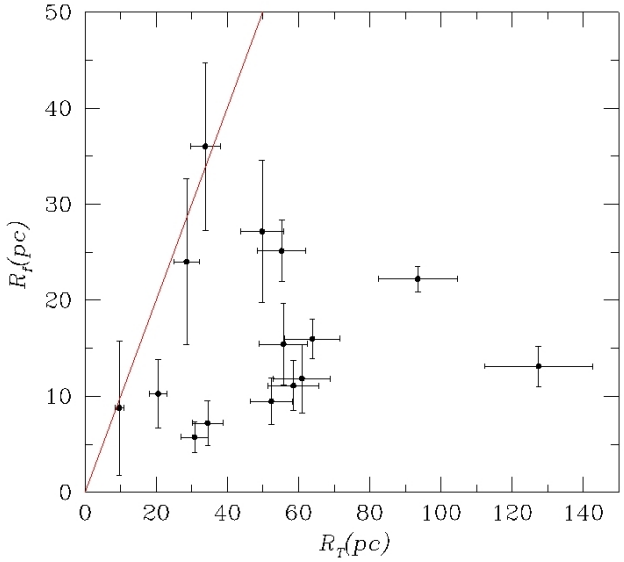
Flattening of the velocity dispersion profile closely coincides with $a = a_0$ threshold

X. Hernandez & M. A. Jimenez (2012), ApJ, 750, 9
X. Hernandez, M. A. Jmenez & C. Allen (2013), MNRAS, 428, 3196

GC conclusions







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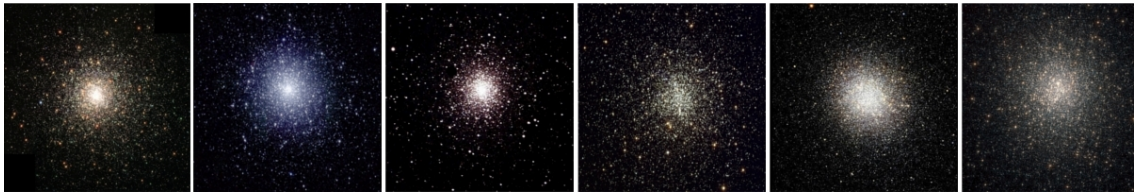
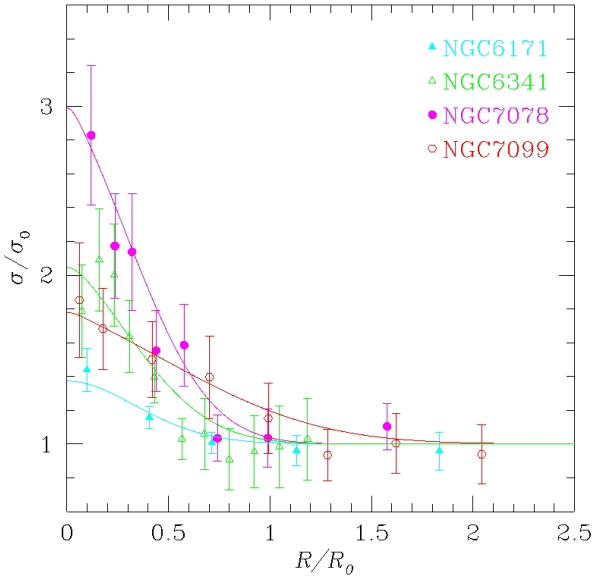
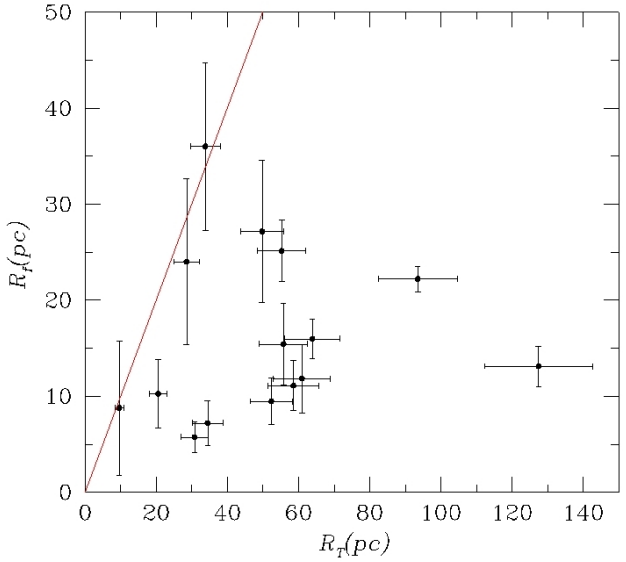
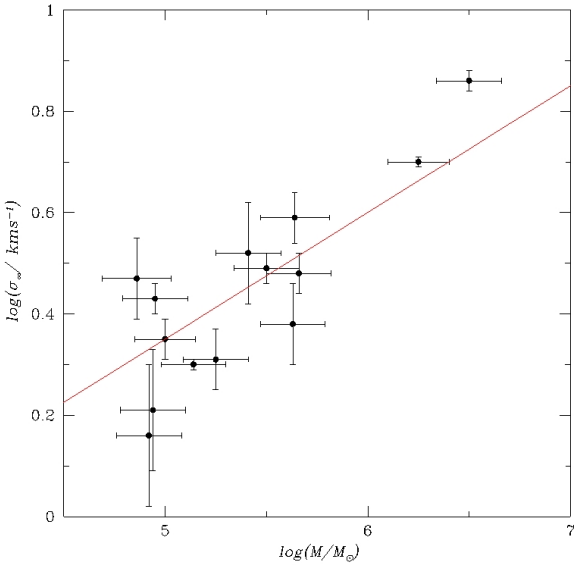








Flattening of the velocity dispersion profile closely coincides with $a = a_0$ threshold

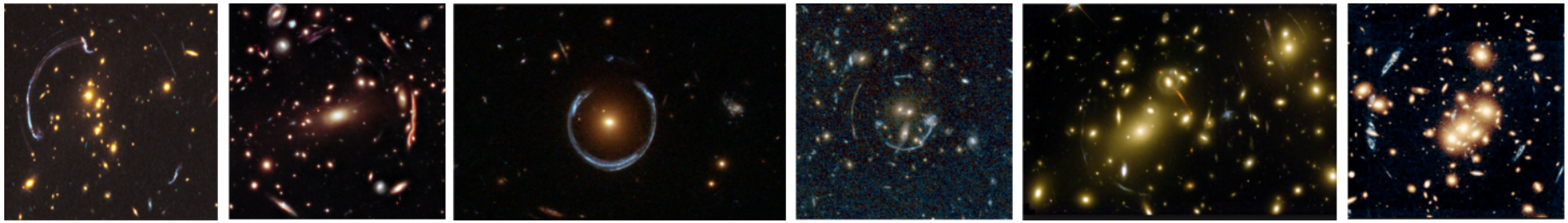
Using total masses from detailed stellar population modelling tuned to each individual GC, Even at perigalacticon, all the GC in the sample are smaller than their Newtonian tidal radii.

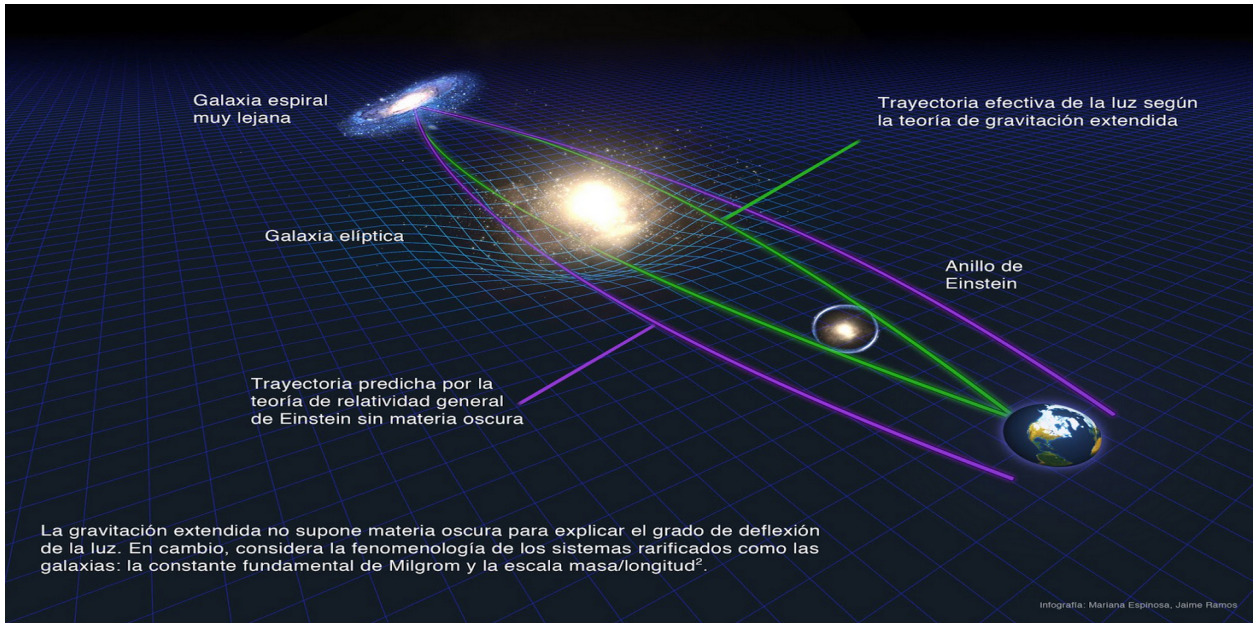
Fractional fall in σ correlates with fraction of the GC within $a < a_0$.

σ vs. Mass relation compatible with expected "Tully-Fisher" a_0 relation.

X. Hernandez & M. A. Jimenez (2012), ApJ, 750, 9
X. Hernandez, M. A. Jmenez & C. Allen (2013), MNRAS, 428, 3196

Lentes Gravitacionales como Experimento Crítico





-Mientras que las órbitas de partículas con masa (e.g. estrellas) dependen solo de las distorsiones en el paso del tiempo como función de la posición, las trayectorias de rayos de luz dependen tambien de las distorsiones en la medida del espacio como función de la posición.
-Presentamos la única teoría a la fecha de gravedad modificada que explica tanto los movimientos estelares como la deflección de la luz, sin requerir nada de materia obscura.

S. Mendoza, T. Bernal, X. Hernandez, J.C. Hidalgo & L. A. Torres (2013) MNRAS 433, 1802
http://www.comunicacion.amc.edu.mx/comunicados/plantean-inexistencia-de-materia-y-energia-oscuras/

What about the bullet cluster?

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Originally touted as a proof of the existence of dark matter

What does it really show?

X-ray/Optical Composite of 1E 0657-56

...merely that the gas has been subject to classical hydrodynamical effects, showing the encounter to have been strongly supersonic, and that the gravitational signal is centred not on the diffuse gas, but on the 'point like" baryonic galaxies...

.

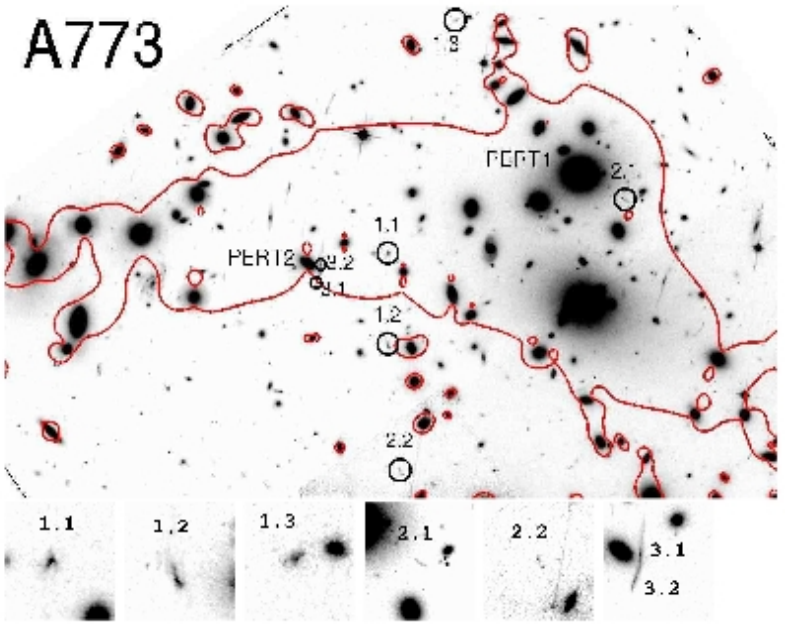
What about the bullet cluster?

.

Originally touted as proof of the existence of dark matter

What does it really show?

X-ray/Optical Composite of 1E 0657-56



...as would be expected in any normal or modified gravity model.

To first order, the observation is compatible under both points of view, ...only to first order!

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What about the bullet cluster?

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Detailed hydrodynamical modelling has shown the encounter velocity to have been $> 3500 km/s$, significantly larger that the escape velocity of the cluster!

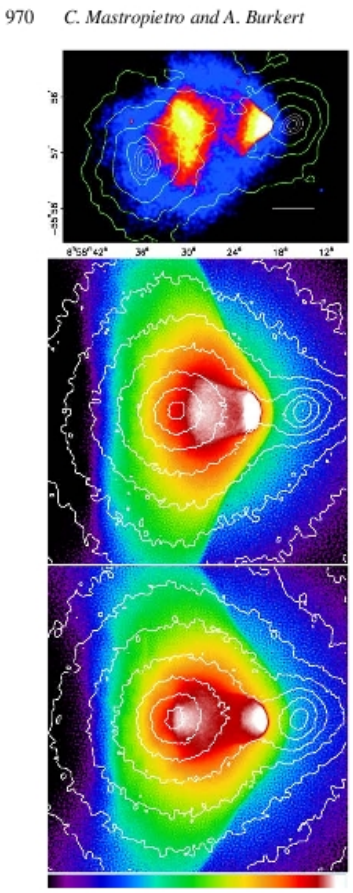

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Figure 1. Upper panel: 500-ks *Chandra* image of the system with weak lensing k reconstruction shown in green (courtesy of D. Clowe and reproduced by permission of the AAS). Central and bottom panels: 0.8–4 keV surface brightness maps of runs 6:vb0 and 6:v3000b0. Logarithmic colour scaling is indicated by the key at the bottom of the figure with violet corresponding to 10^{38} erg s^{-1} kpc^{-2} and white to 2×10^{41} erg s^{-1} kpc^{-2}. White contours trace the total surface mass density of the system within 2.3×10^3 and 2.3×10^8 M$_\odot$ kpc^{-2}. The box size is 1800 kpc.

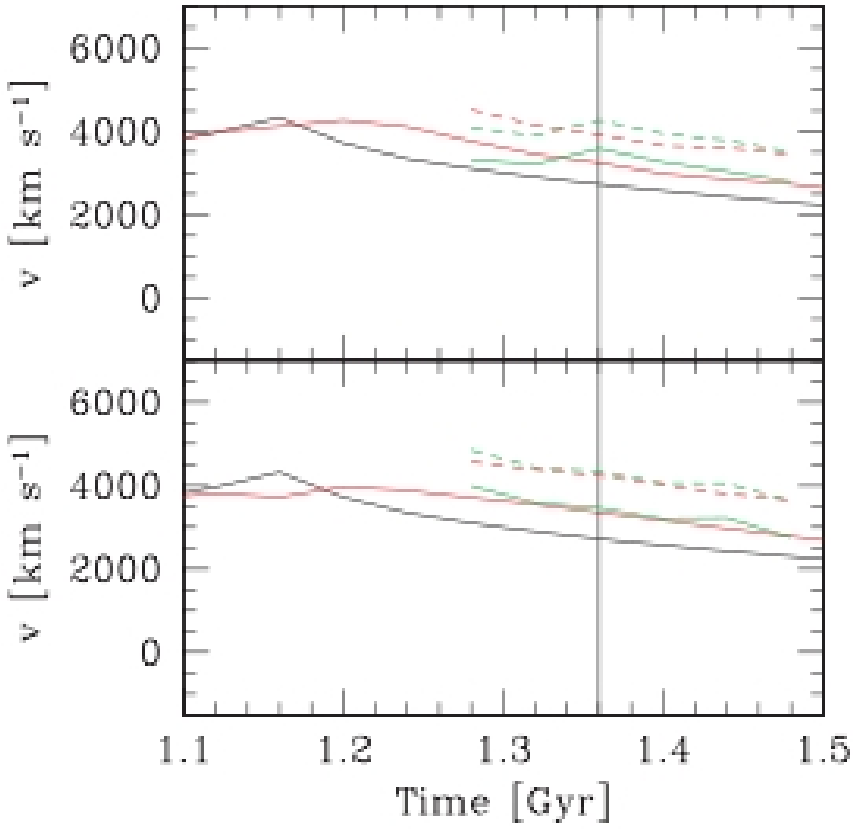


Figure 16. Run 10:1vb0c2 (top panel) and 10:1vb0c2nfw (bottom panel). Same as in Fig. 14.

This essentially rules out Classical gravity at this scale!

Mastropietro & Burkert (2008), MNRAS, 389, 976

What about the bullet cluster?

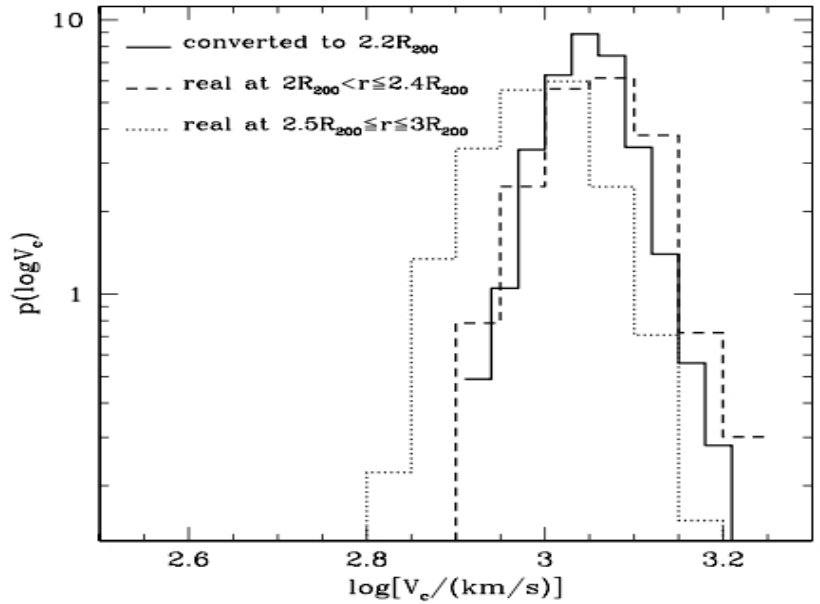


Figure 6. Testing Equation (1). The dashed line shows the distribution of log V_c in $2 \leqslant r/R_{200} \leqslant 2.4$ measured from the simulation, while the solid line shows the distribution of log V_c at $r_{\rm in} = 2.2R_{200}$ calculated from the measured distribution in $2.5 \leqslant r_{\rm out}/R_{200} \leqslant 3$ (dotted line) and Equation (1).

also has to be excluded because it cannot reproduce the observed X-ray brightness ratio of the main and subcluster or the X-ray morphology of the main cluster.

In this paper, we have shown that such a high velocity at 5 Mpc, which is about two times R_{200} of the main cluster, is incompatible with the prediction of a ΛCDM model. Using the results at $z = 0$ and $M_{\rm main} \geqslant 0.7 \times 10^{15}\,h^{-1}\,M_\odot$, ΛCDM is excluded by more than 99.91% confidence level (none of the 1135 subclusters have $V_c \geqslant 2000$ km s^{-1} in $2 \leqslant r/R_{200} \leqslant 3$). For a lower minimum main cluster mass, $M_{\rm main} \geqslant 0.5 \times 10^{15}\,h^{-1}\,M_\odot$, ΛCDM is excluded by more than 99.95% confidence level (none of the 2189 subclusters have $V_c \geqslant 2000$ km s^{-1} in $2 \leqslant r/R_{200} \leqslant 3$).

Encounter velocity necessary to obtain hydrodynamical signature is incompatible with classical gravity.

Lee & Komatsu (2010), ApJ, 718, 60

A recent independent confirmation

Detailed cosmological modelling has shown the encounter velocity to be outright incompatible with standard ΛCDM structure formation scenarios.

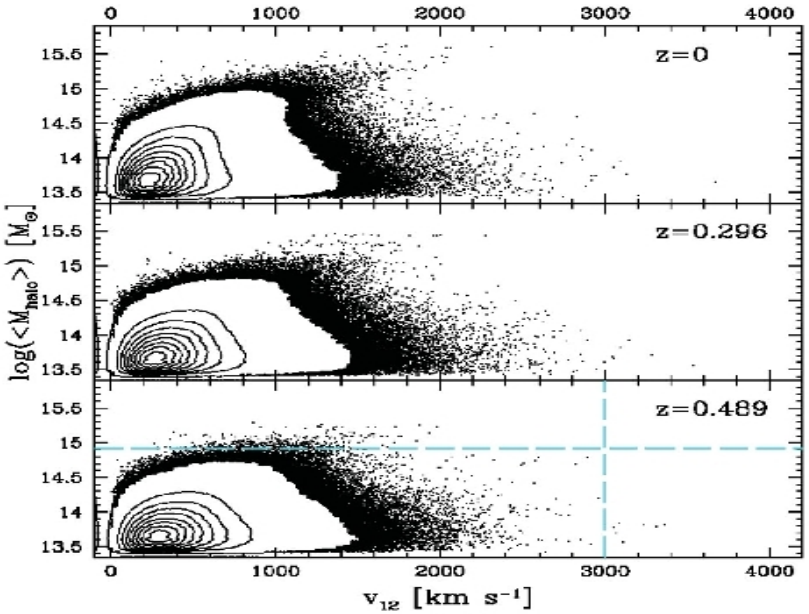


Figure 13. Average mass of halo pairs versus their pairwise velocity for the L2016N1008 run at $z = 0.0$, 0.296 and 0.489. In the bottom panel ($z = 0.489$), the horizontal dashed line represents an average pair mass of $8.25 \times 10^{14}\,M_\odot$ for 1E 0657−56, and the vertical dashed line represents a pairwise velocity of $3000\,km\,s^{-1}$ suggested by Mastropietro & Burkert (2008).

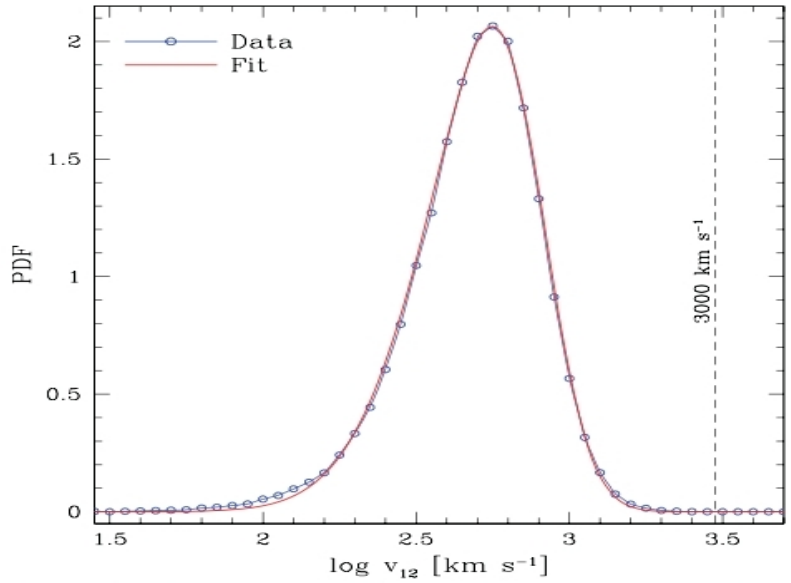


Figure 15. Pairwise velocity PDF for halo pairs with masses above $10^{14}\,M_\odot$ in our L2016N1008 run. The blue circles represent v_{12} binned PDF data, the blue curve is the linearly interpolated values, and the red curve is the best-fitting skew normal distribution (Azzalini & Capitanio 2010). Integrating the fit from $v_{12} = 3000\,km\,s^{-1}$ to infinity gives $P(>3000\,km\,s^{-1}) = 2.8 \times 10^{-8}$. This very low probability suggests that it is very difficult to produce a halo pair with high mass and high v_{12} as the observed 1E 0657−56.

This essentially rules out Classical gravity at this scale!

Thompson & Nagamine (2012), MNRAS 419, 3560

Understanding the impossibility of the bullet cluster under standard gravity

The sound speed for a gas in equilibrium with a dark halo having DM velocity dispersion σ is: $c = \sigma$.

The rotation velocity of this halo will be $V_R = 2^{1/2}\sigma$.
The escape velocity will therefore be $V_e = 2^{1/2}V_R = 2c$.
Releasing the "bullet" from infinity will therefore yield a maximum Mach number for the collision of $V_e/c \Rightarrow$ $M_{max} = 2$

From looking at the picture it is evident the collision resulted in a strong shock with $M_{obs} \approx 3$ or above.

Within a cosmological scenario, one has to start by overcoming the (accelerated!) expansion, which results in maximum Mach numbers even smaller than 2.

No amount on DM helps, as adding DM increases both V_e and c in the same proportion.

Under standard gravity it is impossible to produce Mach numbers as required to obtain the observed hydrodynamical signal, which explains the results of Lee & Komatsu (2010) and Thompson & Nagamine (2012).

Understanding the bullet cluster under extended gravity

We can get the collision velocity to first order from:

$$F = \frac{(GMa_0)^{1/2}}{r} = \frac{dV}{dt} = \frac{dV}{dr}V$$

$$VdV = (GMa_0)^{1/2} ln(r)$$

releasing the "bullet" from rest at a distance r_0, we see that V impact at r=5 Mpc implies:

$$\frac{V^2}{2} = (GMa_0)^{1/2} ln(r_0/5Mpc)$$

for a total baryonic mass of 3×10^{14}, obtaining V impact= 3,000 km/s requires:

$$3000 = 0.5(3 \times 10^{14})^{1/4} \, [ln(r_0/5Mpc)]^{1/2}$$

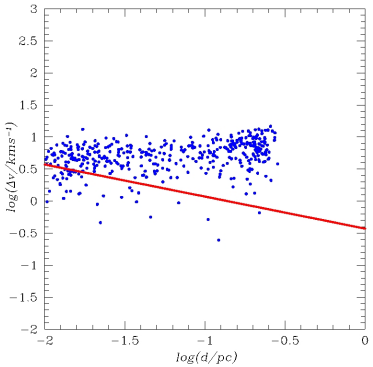
which yields, $r_0 = 8.33 \times 5Mpc.$

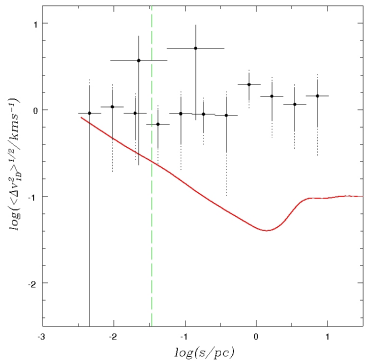
By comparison, the Newtonian escape velocity of the system,
including hypothetical DM, at 5 Mpc is of only $\sim$ 1,000 km/s.

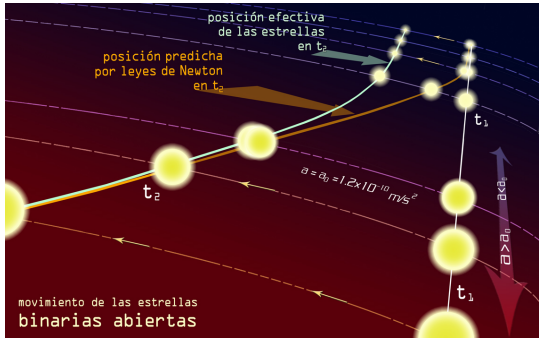
Under extended gravity schemes, starting from merely $\sim$ 10 times the observed size of the system, one can easily obtain impact velocities as required to obtain the observed hydrodynamical signal.

e.g. Moffat & Toth (2010), arXiv:1005.2685

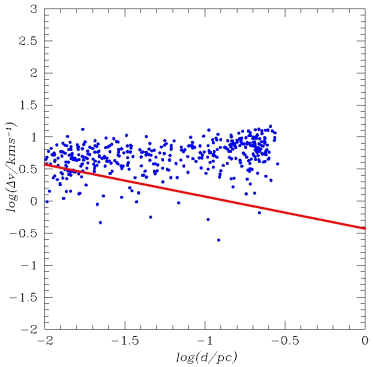
The relative velocities of observed Wide binaries are inconsistent with Newtonian Gravity and GR

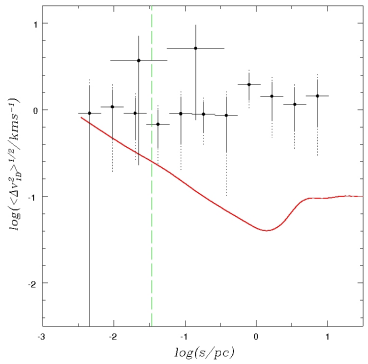


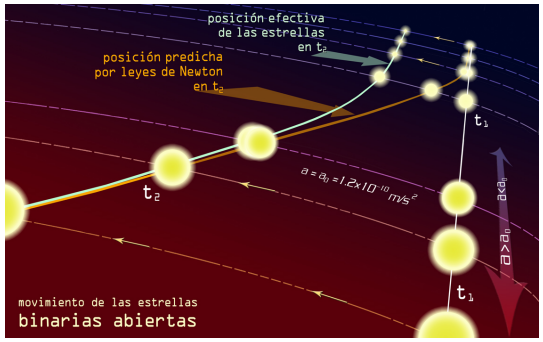




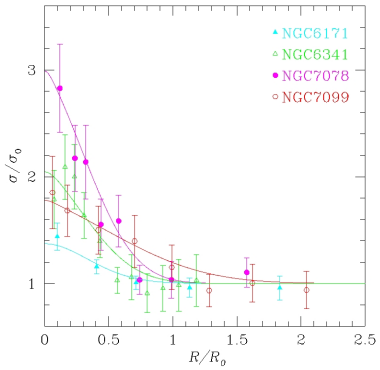
The relative velocities of observed Wide binaries are inconsistent with Newtonian Gravity and GR

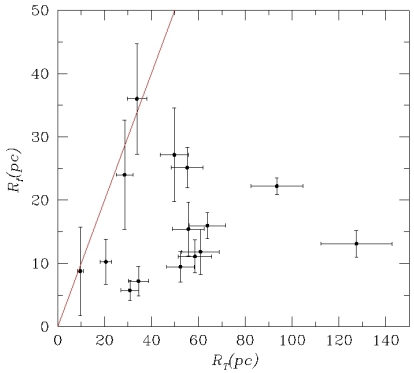


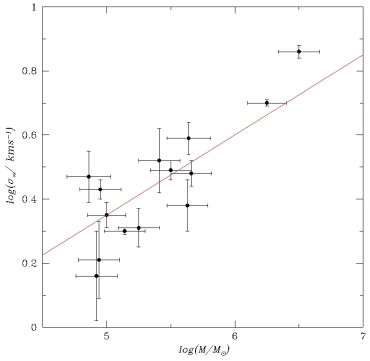




Outer velocity dispersions of globular clusters become flat and show the same galactic $\sigma \propto M^{1/4}$ TF scaling







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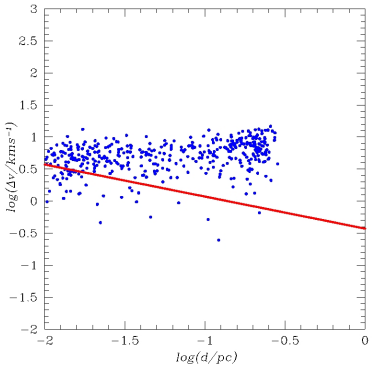
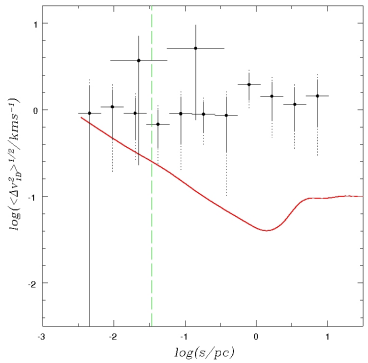
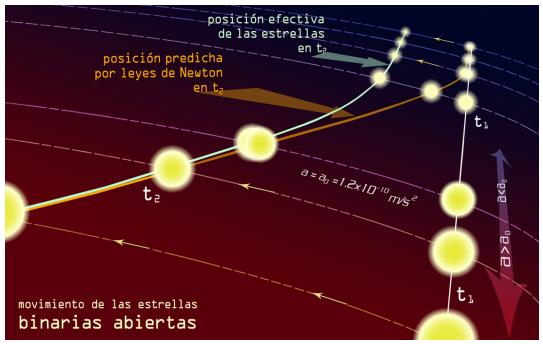
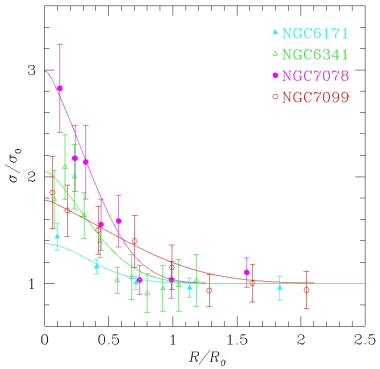
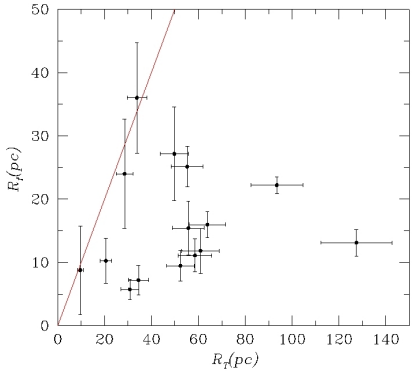


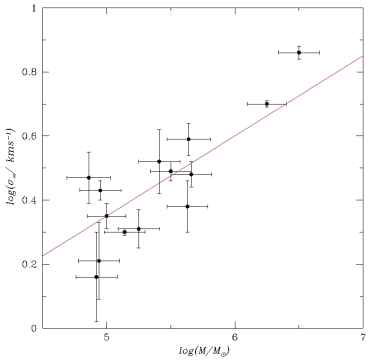




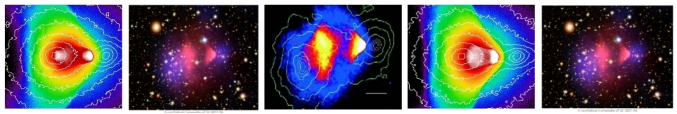
Outer velocity dispersions of globular clusters become flat and show the same galactic $\sigma \propto M^{1/4}$ TF scaling

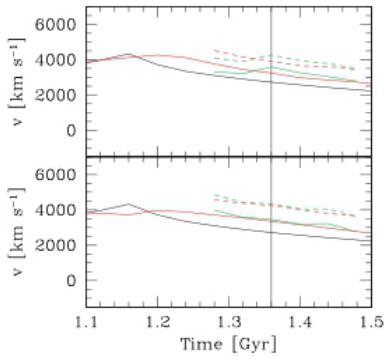


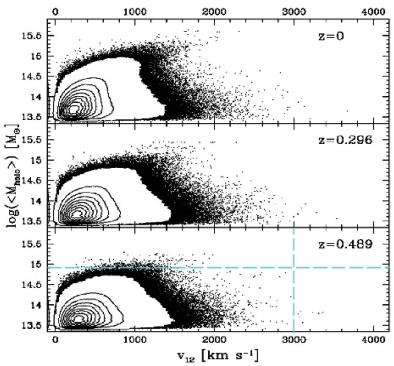


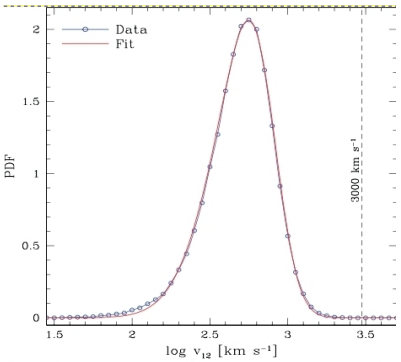


Infall velocity of the Bullet Cluster is larger than escape velocity, and hence incompatible with classical gravity

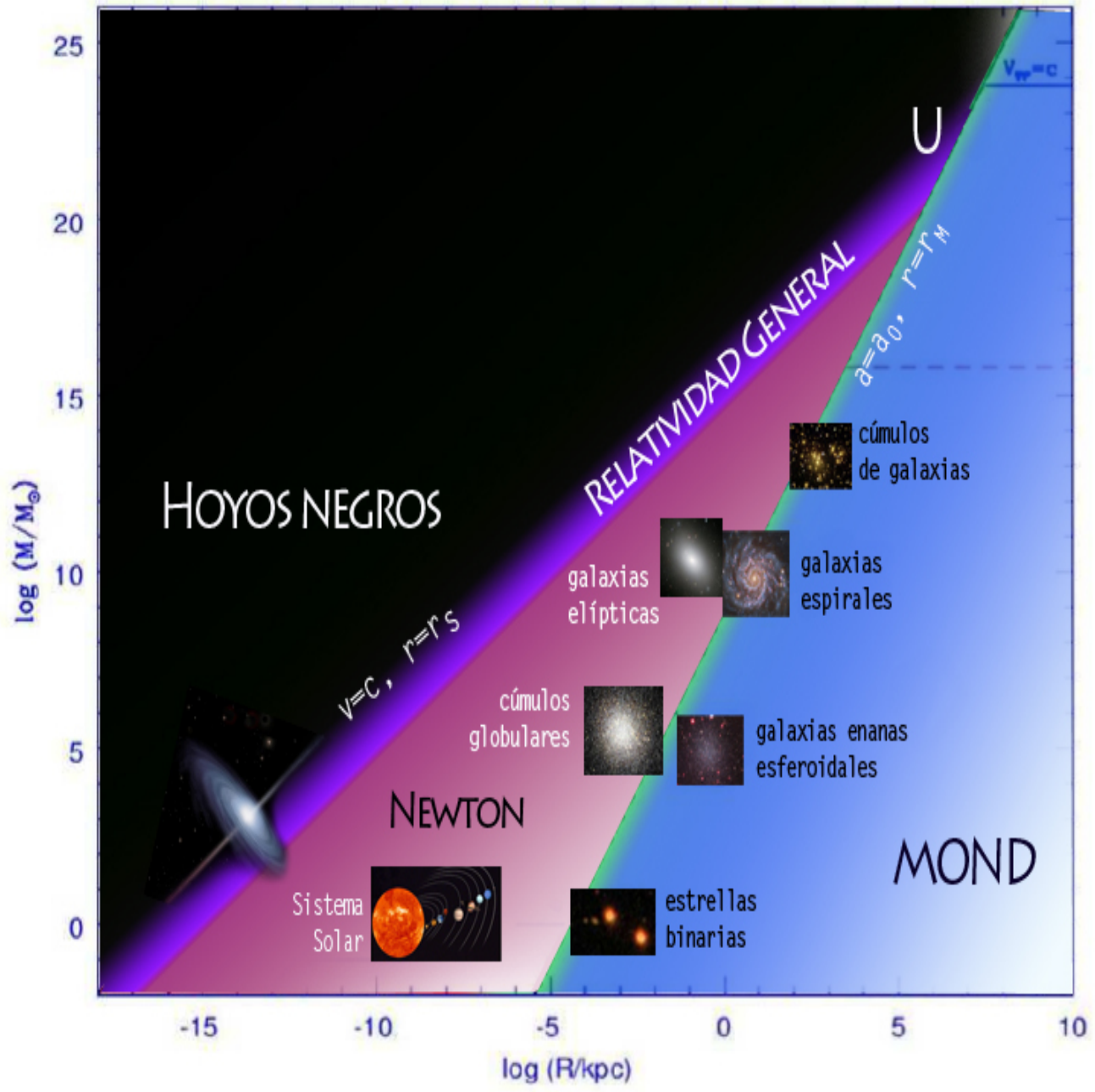








Overall scalings:



Conclusion:

The end of the validity regime
for Newtonian gravity and GR
has now been observed in a variety
of low acceleration astrophysical systems.

ariſe from the particular natures of thoſe bodies. But whence it is that bodies derive thoſe natures they don't tell us; and therefore they tell us nothing. And being entirely employed in giving names to things, and not in ſearching into things themſelves, we may ſay that they have invented a philoſophical way of ſpeaking, but not that they have made known to us true philoſophy.

Others therefore by laying aſide that uſeleſs heap of words, thought to employ their pains to better purpoſe. Theſe ſuppoſed all matter homogeneous, and that the variety of forms which is ſeen in bodies ariſes from ſome very plain and ſimple affections of the component particles. And by going on from ſimple things to thoſe which are more compounded they certainly proceed right; if they attribute no other properties to thoſe primary affections of the particles than Nature has done. But when they take a liberty of imagining at pleaſure unknown figures and magnitudes, and uncertain ſituations and motions of the parts; and moreover of ſuppoſing occult fluids, freely pervading the pores of bodies, endued with an all-performing ſubtilty, and agitated with occult motions; they now run out into dreams and chimera's, and neglect the true conſtitution of things; which certainly is not to be expected from fallacious conjectures, when we can ſcarce reach it by the moſt certain obſervations. Thoſe who fetch from hypotheſes the foundation on which they build their ſpeculations, may form indeed an ingenious romance, but a romance it will ſtill be.

There is left then the third claſs, which profeſs experimental philoſophy. Theſe indeed derive the cauſes of all things from the moſt ſimple principles poſſible;

Mr. COTES's PREFACE.

poſſible; but then they aſſume nothing as a principle, that is not proved by phænomena. They frame no hypotheſes, nor receive them into philoſophy otherwiſe than as queſtions whoſe truth may be diſputed. They proceed therefore in a twofold method, ſynthetical and analytical. From ſome ſelect phænomena they deduce by analyſis the forces of nature, and the more ſimple laws of forces; and from thence by ſyntheſis ſhew the conſtitution of the reſt. This is that incomparably beſt way of philoſophizing, which our renowned author moſt juſtly embraced before the reſt; and thought alone worthy to be cultivated and adorned by his excellent labours. Of this he has given us a moſt illuſtrious example, by the explication of the Syſtem of the
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