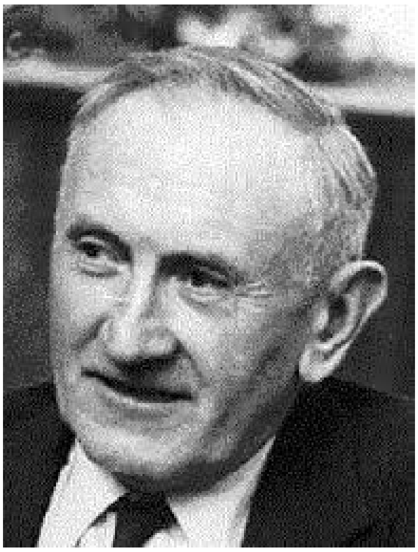
THE TWO FACES OF GRAVITY

Gravity, the mysterious force that makes an apple fall from a tree and keeps our Moon in orbit around the Earth, is under scrutiny again. Cosmic inconsistencies require a fudging component to account for observed anomalies in galaxies and clusters of galaxies: **Objects at the edge of a gravitational system are moving too fast to be held captive by the visible mass of the system alone.** This has been known for almost 80 years, ever since **Fritz Zwicky** in 1933 noticed the anomaly in the Coma clusters of galaxies. While examining the cluster Zwicky proposed the existence of *dunkle Materie* (dark matter). He calculated the gravitational mass needed to keep the galaxies within the cluster and obtained a value 400 times greater than expected from their luminosity. Today's calculations do show a greater value for the mass of luminous material, but by far the greater majority still appears to be invisible.



Fritz Zwicky (1898 – 1974) was a Swiss astronomer who worked at the California Institute of Technology, where he made many important contributions in theoretical and observational astronomy

Either Gravity works differently over cosmological distances to the way it works in the Solar System, or there is more mass in galaxies than what the eye can see. The solution to the first suggestion is a proposal called 'Mond' (modified Newton dynamics), and the second is a hypothetical new invisible kind of material, called Dark Matter. Both, at this stage, have none standard properties to account for the gravitational discrepancies.

Gravity was first scientifically investigated in 1687 when the English mathematician **Sir Isaac Newton** published his Principia, in which he followed up on the work of **Galileo** and hypothesized the inverse-square law of universal gravitation. In his own words, "I deduced that the forces which keep the planets in their orbs must be reciprocally as the squares of their distances from the centres about which they revolve: and thereby compared the force requisite to keep the Moon in her Orb with the force of gravity at the surface of the Earth; and found them answer pretty closely."

The equation is the following:

$$F = G\frac{m_1 m_2}{r^2}$$

where F is the force, m1 and m2 are the masses of the objects interacting, r is the distance between the centres of the masses and G is a gravitational constant, approximately $6.67384 \times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$. This constant is still being refined today, and refined to such a degree that a small, 5.9 year cyclic variation has been detected.

Sir Isaac Newton (1642 – 1726/7) was an English physicist and a "natural philosopher" widely recognised as a key figure in the scientific revolution

Newton's theory enjoyed its greatest success when it was used to predict the existence of Neptune based on motions of Uranus that could not be accounted for by the actions of the other planets. Calculations by both **John Couch Adams** and **Urbain Le Verrier** predicted the general position of the planet, and Le Verrier's calculations are what led **Johann Gottfried Galle** on 23 September 1846 to the discovery of Neptune. A discrepancy in Mercury's orbit pointed out shortcomings of Newton's theory and the issue was only resolved in 1915 with **Albert Einstein's** General Theory of Relativity. But for most modern non-relativistic gravitational calculations Newton's theory has been perfectly adequate and, because it is simpler to work with and it gives sufficiently accurate results for most applications, it is still universally used in Solar System applications.

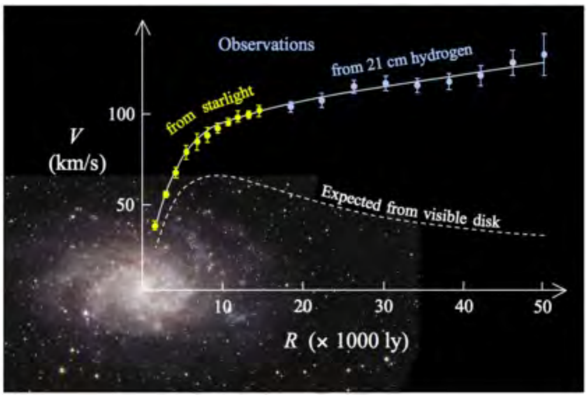
Modified Newtonian Dynamics (MOND) is a theory that proposes a modification of Newton's laws to account for the otherwise unexplained observed properties of galaxies. Created in 1983 by Israeli physicist **Mordehai Milgrom**, the theory's original motivation was to explain the fact that the velocities of stars in the outer regions of galaxies were observed to be larger than expected based on Newtonian mechanics. Milgrom is a professor in the department of Particle Physics and Astrophysics at the Weizmann Institute in Rehovot, Israel. He is best known for his proposal in 1981 of Modified

Mordehai Milgrom (born 1946 in Rumania) is an Israeli Astrophysics at the Weizmann Institute in Israel.

Newtonian dynamics (MOND) as an alternative to the dark matter and galaxy rotation curve problems. He noted that the discrepancy could be resolved if the gravitational force came to vary inversely with radius (as opposed to the inverse square of the radius, as in Newton's Law of Gravity). In MOND, violation of Newton's Laws occurs at extremely small accelerations, far below anything encountered in the Solar System or on Earth. MOND's dependence of the internal dynamics of a system and on its external environment (in principle, the rest of the universe) is strongly reminiscent of **Mach's Principle**, and may hint towards a more fundamental structure underlying Milgrom's law. **A very general statement of Mach's principle is "Local physical laws are determined by the large-scale structure of the universe."** This may turn out to be the most fundamental implication of MOND, beyond its implied modification of Newtonian dynamics and General Relativity, and beyond the elimination of dark matter. The concept was a guiding factor in Einstein's development of the General Theory of Relativity when he realized that the overall distribution of matter would determine the metric tensor, telling you which frame is rotationally stationary. Frame dragging and conservation of gravitational angular momentum makes this into a true statement in certain solutions. However, as yet no full theory has been constructed, manifesting these connections in a natural way.

Ernst Mach (1838 – 1916) was an Austrian physicist and philosopher, with contributions such as the Mach number and the study of shock waves. He was a major influence on Einstein's General Theory of Relativity.

So, what is gravity? Is it a constant, universal force, or does it react to matter differently in different locations and circumstances. Do we need dark matter, a substance with peculiar and as yet hard to define properties, to make the sums come out right? Why does gravity work so well within the Solar System and yet fail miserably at galactic dimensions? **Are there more fundamental properties of gravity not yet sufficiently explored?** The MOND theory seems to suggest that gravity over galactic distances no longer decreases at the square of radius, but in line with radius. This could explain to some extent the difference between the observed and the calculated rotational curves on the Andromeda Galaxy. →



Milgrom (in the MOND theory) invokes Mach's principle of "Local physical Laws are determined by the large-scale structure of the universe". **That of course begs the question, what are the limits of the so-called large-scale structure?** The local galaxy, the cluster of galaxies, the supercluster? Is this again a fudge factor that can be manipulated to suit the specific requirements?

I would like to propose another solution to the dilemma: Picking up Milgrom's idea of the gravitational force to vary inversely with radius instead of Newton's inverse square of the radius, what would happen if the gravitational effect of mass is in fact made up from the combined effect of two forces, each acting differently in the space surrounding it:

- The gravity of matter, mediated by the Higgs Boson
- The gravity of energy, mediated by the hypothetical massless spin-2 particle Graviton

Both contribute to the general effect we know as gravity, the Higgs Boson at the inverse square of the Higgs Field radius, and the Graviton at the linear radius of the sphere. The strength of the resulting field in a given sphere will be dominated by the inverse square law close to the source, and then at greater distances after the cross-over point, by the inverse of the radius of the sphere.

In our local system, where the matter content of an object is the dominant mass constituent, the inverse square law dominates, but in cosmic assemblies like galaxies, clusters and black holes, the mass contributed by energy far outweighs the matter contribution, and the inverse of radius gravity will dominate. An extreme example is the case of a so-called Black Hole, where most of its mass is actually contributed by the energy of matter compression due to gravitational contraction. **Beyond a certain matter density, gravitational contraction pressure is creating more and more gravitational mass in a runaway collapse to a black hole!**

While-ever Dark Matter remains the ubiquitous substance that needs to be given all sort of unique attributes to solve the missing mass problem (right up to creating complex parallel worlds), I prefer to look for a solution to the problem with known quantities and known laws.

AK from Wikipedia notes