Questioning the Observational Evidence for the Cosmological Standard Model

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Abstract: The majority of physicists agrees upon that cosmological data are best described by the Friedmann-Lemaitre model with the currently accepted ΛCDM -paradigm. From a methodological point of view, the concepts of dark matter and dark energy are however free parameters added to the underlying theories of general relativity and Newtonian gravity. Moreover, an increasing number of results still does not fit into the model, in particular in the weak-acceleration regime of cH_0, such as the prominent Pioneer anomaly. The results in this regime are particularly unsettling because nothing else but the tremendous success of general relativity in solar system tests can justify the huge extrapolation we perform when considering galactic and cosmological scales. It seems thus worthwhile to examine the direct evidence for conventional theories of gravity without assuming its validity a priori. It turns out that for a wide range of masses and distances, the weak accelerations are poorly tested. A related discussion is given in gr-qc/0702009.

1 Introduction

Using satellite-based telescopes and digital image processing mankind collected astronomical data of unique precision, while the theoretical ΛCDM -Model is accepted for about ten years. This quite fast digestion of data is accompanied by an increasing number of free parameters. Progress in cosmology however cannot consist of precise measurements only but must answer the question as to what the related quantities 'dark matter' and 'dark energy' do really mean. It is dangerous to interpret new data assuming a model we should not forget to test. In this context, the following comment in a textbook of galactic astronomy ([1], p. 635), is remarkable:

> 'In fact, there is little or no direct evidence that conventional theories of gravity are correct on scales much larger than a parsec or so. Newtonian gravity works extremely well on scales of $\sim 10^{14}$ cm (the solar system). (...) It is principally the elegance of general relativity and its success in solar system tests that lead us to the bold extrapolation that the gravitational interaction has the form GM/r^2 on the scales 10^{21}-10^{26} cm...'

While GR is an extremely successful correction for *strong* fields, the actually unexplained phenomena like galaxy rotation curves (dark matter), the Pioneer anomaly etc. seem to occur in *weak* fields where GR does not distinguish from the Newtonian limit. We will focus in the following on observations that put in evidence the gaps where our knowledge on gravity is not well tested. This holds in particular for the regime of weak accelerations in the order of cH_0. More extensive reviews are given in [2, 3, 4, 5, 6].

2 Crucial tests of gravity

'Theories crumble, but good observations never fade' (H. Shapley)

2.1 The gravitational constant *G*

Interestingly, all mass estimates up to the cosmological scale rely on G. The most precise measurements yet are based on the 200 year old torsion balance, and for decades G was believed to have an uncertainty of only 0.013 % [7]. Then [8] published a much higher value which led to a lot of new measurements and astonishing discrepancies pushed the uncertainty to 0.15 %. Recent precision measurements [9, 10, 11] are still slightly discrepant though the controversy seems to be settled. On the geophysical scale, a discrepancy from Newton's law was found for a mine hole [12, 13] (for a review see also [14]), which coincides with a measurement in in the Greenland ice cap [15], but both did not yield unambiguous evidence against Newton's law. To summarize, the very discrepant measurements of G in the 1990s (see a review [16]) seem to converge to a commonly accepted value of $G = 6.674 \cdot 10^{-11}\ m^3\ s^{-2}\ kg^{-1}$ Going into the details, there is much variation in the single measurements which is believed to be of statistical nature. The completely different issue of a possible time variation is reviewed in [17]. Less prominent riddles are the increase of the astronomic unit reported by [18, 19, 20, 2] and an anomalous slowdown of the earth' rotation derived from ancient solar and lunar eclipses [21].

2.2 Spacecraft anomalies

The Pioneer anomaly

The anomaly consists of an unmodelled acceleration a_p= 8.74 ±1.33 $\cdot 10^{-10}$ ms^{-2} directed towards the sun, or equivalently, an anomalous blue shift drift (2.92±0.44)$\cdot 10^{-18}$ s^{-1} of the radio tracking signal [22, 23, 24, 25]. Besides the constant acceleration, there are anomalous daily and annual signals, too. In the meantime, an enormous effort has been conducted to model possible influences. Two explanations favoured by group members were: (1) some effect related to the heat produced by the spacecrafts energy source (2) gas leaks that lead to an acceleration. Both hypotheses became more and more unlikely, because (1) the decreasing heat production should have translated into a decreased force that has not been observed (2) gas leaks would require an astonishing constancy and the unlikely coincidence to be aligned with motion for all spacecrafts. Particularly mysterious remains the numerical coincidence of a_p with cH_0. A review of theoretical speculations explaining the Pioneer anomaly is given in [23]. Probably most of these proposals are going to be ruled out by orbital data of the outer planets, which have shown to be incompatible with an extra acceleration of the amount a_p [26]. Considerations on comets and minor planets [27] give hope that in the near future it can be tested if a_p influences highly elliptic orbits. While new missions are proposed to test the anomaly [28, 29], the analysis of newly recovered data [30] will be extremely interesting.

The flyby anomaly

The swing-by technique for satellites is used to change the direction and heliocentric velocity of spacecraft [31]. In various occasions, after a swing-by process at the earth, satellites showed an unexplained velocity increase . Until now, it has been observed three times independently (Galileo, NEAR, Rosetta, see [31]) under very different conditions. While the existence of the effect is quite accepted, further data will help to understand. The hyperbolic trajectory of all occurrences seems to be the main difference to many other well-tested satellite orbits. Such a possibility could be revealed by the analysis of old data on the Pioneer effect, whose onset was suspected to take place at the time of the last flyby [31].

2.3 Dark Matter

Galactic rotation curves

of about 1000 Galaxies [32] provide the strongest evidence for the disagreement of 'dynamical' and visible mass. Assuming that all mass of a spiral galaxy is contained within its optical radius, Kepler's law suggests a dependency $v \sim r^{-\frac{1}{2}}$ in the velocity profile of orbiting clouds. Interestingly, up to multiples of the optical radius practically all galaxies show quite constant ('flat') velocities with a curious systematics [33]. While the deviation is already visible within the optical radius, in the outer regions ratios of dark and luminous matter up to 1000 are required [33]. Low surface brightness dwarf galaxies (LSBD) show the same anomaly but require an even higher relative amount of dark matter; the anomaly itself is beyond any experimental doubt (see overviews [34, 35, 36, 37, 38]), but detailed investigations show new riddles [39, 40, 41, 42, 43, 44]. The form of the galactic rotation curves seem to depend just on the size of the galaxy [33, 45], a fact which is hard to explain by the properties of any dark matter candidate. The most extended velocity profile of NGC 3741 is in clear conflict with the standard model [46]. LSBD contradict DM models as well [47, 48], as it is addressed in detail in [49]. The same holds for tidal dwarf galaxies [50, 51]. The Tully-Fischer (TF) relation [52] (see also [53]), the L_{bulge}-σ and Faber-Jackson-relation [54], as well as the M_{BH}-σ relation [55, 56] still miss a compelling theoretical explanation.

Globular cluster distribution and the local group

Rotation curves could be explained with dark matter located in the disc, but there is clear evidence that the gravitational potential obeys radial symmetry. The spatial distribution and velocities of globular clusters makes a dark matter concentration in the disk extremely unlikely, besides other evidences like the magellanic stream [34]. The Milky Way and Andromeda (M31), the biggest galaxies in the local group, are approaching each other much faster than can be explained by gravitational attraction of the visible mass. The extra (dark) matter required exceeds the visible one by a factor of about 70 [57]. In this context, the recent discovery of very distant halo stars in Andromeda [58] is surprising, too. Recent HST measurements [59, 60] suggest either a fly by of the Magellanic Clouds at the Milky Way or a conflict with common mass estimates.

Galaxy clusters

gave the first hint that observed and expected velocities did not match. This was discovered as early as 1933 by Zwicky [61] and called the 'missing mass problem'. Recent measurements are [62]. Hot gas in galaxy clusters is a further, independent confirmation of the 'dark matter' phenomenon. X-ray emission allows to determine the temperature of intergalactic gas. Assuming that hot gas being bound to the galaxy cluster much more mass than the visible amount is needed to explain the gravitational potential that keeps it. Structure formation simulated by numerical models requires large amounts of 'dark matter', though thousands of unobserved dwarf galaxies in the vicinity of large spirals like the milky way are predicted.

Galaxy rotation curves and MOND

Since many observational facts can hardly be explained by *any* 'dark matter' theory [63], galactic rotation curves can suggest a modification of Newton's law. This does not make sense at a fixed distance [34]. Modified Newtonian Dynamics (MOND) however considered at a fixed *dynamical* scale in the order of 10^{-10} ms^{-2}. The proposal of an effective acceleration

$$g = \sqrt{a_0 \frac{GM}{r^2}} \tag{1}$$

with the parameter $a_0 = 1.1 \cdot 10^{-10}$ ms^{-2} indeed matches most of the galactic rotation curves with a astonishing accuracy [64, 65]. As in the case of the Pioneer anomaly, the same order of magnitude of a_0 and cH_0 attracted attention. Few people think that MOND could become a complete gravitational theory, but it's indisputable merit is to have attracted attention to the fact that Newton's law is poorly tested for accelerations below 10^{-10} ms^{-2}. The approximate agreement of a_0 with cH_0 is either a coincidence invented by nature to fool astronomers or a proof that we do not understand gravity yet.

Globular cluster anomaly

Though a statistical measure, velocity dispersion curves provide information analogous to rotation curves. [66, 67, 68] investigated such distributions for , *M* 15, *NGC* 6171, *NGC* 6341 and *NGC* 7099. Instead of an expected falloff, the curves show a flattening of the velocity profile at the same acceleration a_0. This has been confirmed at the low-concentration cluster *NGC* 288 [69]. Since globulars can contain only very few dark matter, this anomaly can turn out very unsettling for the ΛCDM paradigm.

2.4 Dark Energy

High-redshift supernovae

Cosmology faced a long controversy on the Hubble constant (see the recent review [70]) until in 1998 [71, 72, 73] and [74] independently announced that relatively too faint high-redshift supernovae should be interpreted as an accelerated expansion of the universe. This is commonly explained by postulating a new form of matter called 'dark energy' (DE) that acts repulsively. While the data clearly exclude a universe of ordinary matter, the question as to what 'dark energy' consists of is completely open. Solar system [75, 76] and laboratory tests could not give evidence for it yet [77] and there are still discrepant observations from X-ray data [78, 79]. A detailed look at the data [80] however shows that some surprising interpretation is not yet excluded; the data is even compatible with an 'empty' universe Ω=0.

Cosmic Microwave Background data

of the WMAP satellite are used to fix the corresponding amount fo DE to Ω_{DM} to about 0.7 [81], as part of the central result $\Omega \approx 1$. A multipole analysis is in agreement so far with the common paradigm, though the quadrupole-anomaly [82, 2] is yet mysterious.

2.5 Overview

The failure of gravity at low accelerations

In the last section a variety of anomalies was discussed. The most puzzling fact is that accelerations of the order 10^{-10} ms^{-2} occur in several completely different circumstances. If we try to give an order of strength of evidence, this involves (1) Galactic rotation curves, (2) The Pioneer anomaly, (3) Globular cluster data.

Moreover, all the other unexpected phenomena consistently occur below that acceleration regime. The enigmatic coincidence with cH_0 is an additional strong hint that the discrepancies have a common origin and lead to a general failure of Newton's law in the weak-acceleration regime.

'Cosmologists are often in error, but never in doubt' (L.D. Landau).

Extrapolation over the gaps

It is often forgotten that all absolute G measurements occur on small scales of a few *kg* and *m* which are separated by a considerable gap from the well-tested regime of celestial mechanics with 10^{30} kg and 10^{12} m. Our belief in Newtonian gravity and GR relies there, but strictly speaking these are tests of Kepler's law rather than Newton's. The spacecraft anomalies however menace the picture of perfect agreement of the solar system dynamics with the accepted theories of gravity.

Gravity tests from the galactic to the cosmologic scale are much less direct. None of them yields undoubtable evidence for the validity of Newton's law, i.e. i must be backed by additional assumptions like DM or DE. Usually few reflection is done with respect to the huge extrapolation from the celestial mechanics regime to cosmological scales of 10^{53} kg and 10^{26} m. To rely on such a assumption seems hazardous but is customary.

'There is certainly not a lack of chutzpah in extragalactic astronomy' - Margret Geller

3 The cornerstones of standard cosmology

Dark matter

There is overwhelming evidence that the 'dark matter' *phenomenon* exists on various scales. While the DM hypothesis explains galactic rotation curves at a first glance, maintaining it in the light of more recent results seems to rely on the absence of detailed knowledge. Moreover, the absence of any decline suggests that the dark halos continue to regions not accessible by current technology. Cosmologists should be prepared that the 'fraction of DM' turns out to be just a measure of telescope resolution. phenomena satisfactory. Details of what has been proposed as candidates for DM cannot be addressed here. Massive compact halo objects (MACHOS), such as brown dwarfs, would have been detected by microlensing if they existed in the required amount. While the question of hot (fast, relativistic particles) or cold dark matter seems to be answered in favour of the latter, no reasonable candidate particle has been found in the laboratories yet. To some people, postulating neutralinos (or elsewhere, photinos and axinos) still gives hope for a possible explanation, since Italian language will hardly run out of diminutives. Dark matter at least remains an urgent need for the codes that simulate cosmic structure formation. The fluctuations in the CMB were by far insufficient to explain the clumping that corresponds to the concentration of galaxies. Dark matter instead clumps so easily as long as we do know about its properties. Isn't that a nice proof of its existence ? Or should we admit that we do not understand structure formation ? It is time to put into question the obvious idea of explaining deviations from Newton's law with gravitationally interacting matter not yet detected.

Dark energy

Even when appreciating the surprising discovery of dark energy, one should not forget that such a repair was urgently needed to resolve the conflict of the Hubble constant with the minimum age of the universe measured by globular clusters. The SNIa data now show an *accelerated* expansion of the universe (while before only how much it was decelerated). Though since Newton attraction is quite a characteristic property of matter, many physicists do not have problems to assume a repulsive interaction to DE, while others admit that 'dark energy' might be just a name for something we do not understand. Frequently, the relation to Λ is invoked. To justify his favoured steady-state-model, Einstein introduced the cosmological constant Λ, but after having realized that Hubble's data supported an expansion of the universe, he later called Λ the 'biggest blunder' of his life. The high-redshift supernovae, indicating an accelerated expansion, led to a renaissance of Λ, now called 'dark energy'. Einstein however was ready to introduce a mathematical complication in order to save a physically simple model, because of his deep-rooted conviction that laws of nature must be simple in a physical sense. Today's dark energy instead is just an additional free parameter used to adjust a more and more complicated observational situation [83, 84]. I think that Einstein had preferred to admit a blunder rather than being a chief witness for Λ.

The coincidence problem

Though the age problem was eliminated by DE, it re-entered cosmology at the back door. While during the first billions of years conventional matter dominates the expansion by decelerating, the accelerated expansion by dark energy becomes dominant at a certain epoch. But isn't it strange that the inverse current expansion rate coincides with the time past since the big bang ? Let p be the probability that the evolution of intelligent life takes place in *such* a period, and q the probability that our actual understanding of cosmic evolution is quite complete, it's up to the reader to decide whether $pq>(1-p)(1-q)$ holds.

The Flatness the Horizon problems

Measurements of the density parameter Ω, in particular from the recent WMAP data, yield a value very close to 1. However, evolution models of the universe would predict a strong drift of this value, once there is a minute deviation from 1. Therefore the question arises how this fine-tuning of a measuring value occurred, or if there is a theoretical reason beyond. The finite speed of light implies that we are not able to see parts of the universe further away than the distance light could travel since the big bang. This implies that, at the time being emitted, CMB photons at different positions (separated by more than 1deg) in the sky could not 'know from each other', i.e. there was no causal contact. The question arises how a common mechanism suggested by the highly uniform temperature, could occur.

Inflation

is called that the hypothesis that the universe expanded by a factor 10^{40} at the period around 10^{-34} s after the big bang. Indeed, it provides an explanation for the horizon and flatness problem, though such arguments, from the point of view of thermodynamics, appear superficial [85]. A more serious problem is falsifiability. How to observe 10^{-34} s after the big bang, which is still 380000 years before the last scattering surface of the CMB ? Inflation does not have a problem with explaining phenomena, it has the problem that it explains almost everything. It is frequently claimed that inflation 'predicted' a flat universe, but we cannot act as if $K=0$ were a measuring value like other numbers. The observed flatness seems to be a very deep, cogent feature of the universe, for which an inherent theoretical reason should exist, not just an ad-hoc, qualitative mechanism. The flatness and the horizon problem arise, because we believe in Friedmann-Lemaitre cosmology. At a constant expansion rate, more distant objects have a greater relative 'velocity' (Hubble's law) and the distance that corresponds to c is called horizon. If the expansion is slowed down by gravity, new objects drop into the horizon. If there was no gravity acting, there is no slowdown, no horizon increase and no problem. Instead of believing in a theory relying on the constancy of c, then running into problems, and resolving these problems by postulating an expansion $v>c$, isn't it just more honest to say that standard cosmology is incompatible with observation and we do not understand yet cosmic evolution ? Though extensions like inflation are not yet full-fledged members of the standard model, they usually gain creeping acceptance if there are no better ideas around. Let us conclude with Richard Feynman:

> *'correct theories of physics are perfect things, and a replacement theory must be a new perfect thing, not an imperfection added onto an old perfect thing. This is the essence of "revolution", the replacement of the old with a new, not the adding of more crap on to the old.'*

4 Do we understand gravity ?

4.1 General observational problems

Linearity and superposition

A mass dependence of the gravitational acceleration for galactic scales of a $\sim\sqrt{M}$ has been suspected by MOND [86]. Usually, $a\sim M$ is taken for granted, but a deviation for large masses would not necessarily violate the EP, at least within its experimental constraints which mostly apply to test masses. It is not that common to wonder about such a dependence because it is completely out of our theoretical expectations. For instance, mass distributions with spherical symmetry could not be replaced by point masses any more since the linear method of mass integration as such would break down. We are used to the nonlinearities arising in GR, and automatically infer that gravity must be linear in the Newtonian limit, that is, the superposition principle holds. The claim that any physical theory must be linear in the weak-field-limit reflects some of our experience but cannot be rigorously proven. Strictly speaking, we perform an extrapolation of our simple mathematical methods which must be tested. A possible field mass dependence of Newton's law can hardly be detected by satellite trajectories, since independent mass determinations by densities lead to crude estimates only.

Radial and tangential velocities

The data of solar system observations consists of precise orbital data in three dimensions. The situation is very different on larger scales. While radial velocity measurements can easily performed by Doppler methods on galactic and cosmological distances, measuring velocities perpendicular to the line of sight is usually impossible. The very few occurrences where VLBI and HST detected secular shifts of galactic objects on the microarcsecond level led often to surprising results [59, 60]. At the galaxy scale and beyond our knowledge is a snapshot of tens of years - we do not really know the secular dynamics and the common picture of stable and virialized systems is an extrapolation of accepted theories of gravity.

Hyperbolic and Elliptic orbits

Another case where the available data are exceptionally biased regards the elliptic and hyperbolic orbits. For a long time, the precision of celestial mechanics masked the fact that all these tests rely on elliptic orbits. Who had ever suspected that the solution could depend on the test particle's energy ? In view of the fact that almost all precisely measured hyperbolic trajectories led to anomalies like Pioneer and flyby, we must be prepared to an essential failure of some basic assumptions underlying our theories of gravitation.

4.2 General theoretical problems

Rather than postulating new quantities without meaning, advance in theoretical physics has often been achieved by a better understanding of quantities one was already familiar with. There are still some points left where our knowledge must be scrutinized.

Time

Barbour [87] has presented a very deep reflection on the nature of time. Analogously to the concept of space which does not make sense without matter, he claimed that the concept of a time as an invisible river that runs without relation to matter is senseless. If instead the evolution of the universe and the periodic processes in there define time, profound consequences for the laws of nature must be expected. Barrow commented [88]:

> „The question if there is a unique absolute standard of time which globally is defined by the inner geometry of the universe, is a big unresolved problem of cosmology."

Energy

The concepts of potential and kinetic energy were born when physicists described Galileo's free fall experiments with the time-independent quantity $mgh + \frac{1}{2} mv^2 = const.$ Newton's potential $-GM/r$ and all the other forms of energy found in the following were based on the same idea of finding time-independent laws of nature. In quantum mechanics, this is reflected by the fact that only stationary states of the wave function have a well-defined energy. While the concept of energy conservation is extremely successful in describing local effects, its application to cosmology remains questionable. The observations of the evolution of the universe, for instance the CMB, the galaxy distribution and star formation processes tell us that the wave function of the universe is anything but stationary. Thus the notions of kinetic and potential energy may be inadequate.

Mass

may be another concept to be reflected. Einstein's famous $E= mc^2$, applied to gravitational energy $\frac{GMm}{r}$, tells us that mass can be proportional to a product of masses. This remains a very puzzling fact and could indicate that G is an artefact that can be calculated from parameters of the universe.

The equivalence principle,

the fact that a kinematical property measured by accelerations, mass, at the same time should be a 'charge' for a certain interaction, is very deep and amazing. 'I was ultimately astonished by its validity', Einstein said

[89]. The (weak) equivalence principle guarantees a special role for gravity among the fundamental interactions.

Planck scale vs. Mach's Principle

It is common folklore that gravity needs to be unified with quantum mechanics, and this should occur at the Planck level $l_p = \approx \sqrt{\frac{Gh}{c^3}} = 10^{-35}$ m, which protects comfortably from being falsified by experiment. However l_p is deduced from G and relies on the correctness of conventional theories of gravity. Ernst Mach suggested that the gravitational interaction had its origin in the distribution of matter in the universe. A theory that puts into practice Mach's principle could construct a relation of G to the mass distribution of the universe and therefore reveal the Planck level as an artefact. Most of the modern theories would lose then even a hypothetical contact to experiment.

Dirac's large number hypothesis,

like Mach's principle, is another example of profound thoughts standing quite isolated in the current fashion of theories. Dirac [90] observed that the number of protons in the universe is about the square of the ratio of electric and gravitational forces (10^{40}) , and moreover, that the Hubble time 13.4 *Gyr* is about 10^{40} times the time light needs to pass the proton radius. These are two independent coincidences which remained an enigma to this day. Though Dirac postulated a time-dependence of the gravitational constant $\dot{G}/G$ which is above the current observational constraints [17], these deep ideas should not be discarded completely [91].

5 Outlook - not too bad, homo sapiens

How science works

> *'The great tragedy of Science–the slaying of a beautiful hypothesis by an ugly fact.' (Thomas H. Huxley)*

This is an ironic version of Popper's criterion of falsifiability, indeed a good attribute for testing whether a theory is scientific or not. For the development of science however it tells only how things *should* work. In practice, established theories which frequently are considered 'beautiful', do not die suddenly when confronted with ugly facts, they rather affiliate them by becoming extended 'models'. This process was described by the philosopher Kuhn [92] as 'normal science', which tries to understand the observations within an accepted framework. When the anomalies pile up to an obviously too complicated scheme, a paradigm shift takes place that may lead to a 'scientific revolution'. What is 'obvious' and whether the crisis has begun or not is not easy to decide. The last occurrence in history, the Copernican paradigm shift, tells us in retrospect only that scientists may be blind for a long time.

> *'They defend the old theories by complicating things to the point of incomprehensibility.' - Fred Hoyle*

Too scary to contemplate

Frequently it is stated that precision tests described by PPN parameters do not allow deviations from standard gravity. It is well-known that the Ptolemaic model gave an accurate description of planetary orbits, that means the 'post-Ptolemaic-parameters' were close to zero. But it is also well-known that the Copernican revolution did not take place in a small 'volume' of such a parameter space - actually Newtonian gravity was something fundamentally deeper, not an extension of an existing model. In his excellent book on the worrying situation of theoretical physics [93], Lee Smolin gives an example of the mechanism that leads to such a narrowing of our view: 'The [...] possibility - that we are wrong about Newton's laws, and by extension general relativity - is too scary to contemplate.' (p.15).

After the darkness of the Ptolemaic model Newton's celestial mechanics was an ingenious big leap for science which at that time required an amount of mathematical abstraction and new physical concepts we hardly can imagine today. This holds even more for the refinement revealed by the general theory of relativity. Since those theoretical developments our knowledge of the universe has increased drastically, in a relatively short span of time: the discovery of galaxies, the Hubble redshift, the cosmic microwave background. I fear however that the hierarchy of structures earth - solar system - galaxy - cosmos does not stop at laws found for the solar system but requires a corresponding hierarchy of theories which may be similarly hard to imagine like Newton's theory in 1600. Introducing new parameters, data fitting and numerical simulations will not do the job; rather this seems to be a modern version of the epicycles of Ptolemy. It is not only the complication of our current theories that merits a warning from history, but also the amount of extrapolation we perform. Though the range of the universe we know about has increased dramatically, we extrapolate conventional theories of gravity to those scales. The extrapolation of classical mechanics over 10 orders of magnitude to the atomic level was a quite childish attempt. The amount of research in cosmology which is done nowadays on the base of an untested extrapolation over 14 orders of magnitude is a quite remarkable phenomenon. It is remarkable as well that the majority of homo sapiens believes that after 13 billion years after the big bang, the definitive description of our universe was found in 1998. The stars cannot laugh but will give us an answer.

References

[1] J. Binney and S. Tremaine. *Galactic Dynamics*. Princeton, 1994.
[2] C. Lämmerzahl, O. Preuss, and H. Dittus. Is the physics within the solar system really understood ? *arXiv*, gr-qc/0604052.
[3] O. Bertolami et al. General theory of relativity: Will it survive the next decade? *arXiv*, gr-qc/0602016, 2006.
[4] C.M. Will. Was Einstein right? Testing relativity at the centenary. *arXiv*, gr-qc/0504086, 2005.
[5] Clifford M. Will. The confrontation between general relativity and experiment. *Living Reviews in Relativity*, 9(3), 2006.
[6] A. Unzicker. *ArXiv: gr-qc/0702009*, February 2007.
[7] G. G. Luther and W. R. Towler.. *Physical Review Letters*, 48:121–123, January 1982.
[8] W. Michaelis, H. Haars, and R. Augustin. *Metrologia*, 32:267–276, 1995.
[9] J. Gundlach and M. Merkowitz. *arXiv*, gr-qc/0006043, 2000.
[10] T. Quinn et al. A new determination of G using two methods. *Physical Review Letters*, 87(11):111101, 2001.
[11] St. Schlamminger, E. Holzschuh, and W. Kündig. *Physical Review Letters*, 89(16):161–102–2, 2002.
[12] S.T. Holding et al. Gravity in mines - an investigation of Newton's law. *Physical Review D*, 33:3487–3494, 1986.
[13] E. Fischbach and C. Talmadge. *American Journal of Physics*, 59:200–200, 1991.
[14] F.D. Stacey et. al. Geophysics and the law of gravity. *Reviews of modern physics*, 59(1):157–174, 1987.
[15] M.E. Ander et. al. *Physical Review Letters*, 62(6):985–988, 1989.
[16] G. T. Gillies. *Measurement Science and Technology*, 10:421–425, June 1999.
[17] J.-P. Uzan. The fundamental constants and their variation, hep-ph/0205340. *Reviews of modern physics*, 75:403–455, 2003.
[18] Krasinsky and Blumberg. *Celestical Mechanics and dynamical Astronomy*, 90:267–288, 2004.
[19] E. V. Pitjeva. In D. W. Kurtz, editor, *IAU Colloq. 196: Transits of Venus: New Views of the Solar System and Galaxy*, pages 230–241, April 2005.
[20] E. M. Standish. In D. W. Kurtz, editor, *see ref.[19], p. 163-169.*
[21] F.R. Stephenson. Historical eclipses and earth's rotation. *Astronomy and Geophysics*, 44:2.22–2.27, 2003.
[22] J. D. Anderson et al. *Physical Review Letters*, 81:2858–2861, October 1998, gr-qc/9808081.
[23] J. D. Anderson et al. *Physical Review D*, 65(8):082004–+, April 2002, gr-qc/0104064.
[24] S. G. Turyshev, N. N. Nieto, and J. D. Anderson. The Pioneer anomaly and its implications. *arXiv*, gr-qc/0510081, 2005.
[25] M. M. Nieto and S. G. Turyshev. Finding the origin of the Pioneer anomaly. *arXiv*, gr-qc/030817, 2003.
[26] L. Iorio. Can the Pioneer Anomaly be of Gravitational Origin? *Foundations of Physics*, 37:897–918, 2007,gr-qc/0610050.
[27] J. F. Wallin et al. Testing Gravity in the Outer Solar System: Results from Trans-Neptunian Objects. *ArXiv:0705.3408*, 2007.
[28] M. M. Nieto and S. G. Turyshev. The Pioneer anomaly: The data, its meaning, and a future test. *arXiv*, gr-qc/0411077, 2004.
[29] M.N. Nieto. New horizons and the onset of the Pioneer anomaly, 2007, arXiv.org:0710.5135.
[30] V.G. Toth and S. G. Turyshev. The Pioneer anomaly: seeking an explanation in newly recovered data. *arXiv*, gr-qc/0603016.
[31] J.D. Anderson, J.K. Campbell, and M.M. Nieto. The energy transfer process in planetary flybys. *arXiv*, astro-ph/0608087, 2006.
[32] M. Persic and P. Salucci. Rotation curves of 967 spiral galaxies. *arXiv*, astro-ph/9502091, 1995.
[33] M. Persic, P. Salucci, and F. Stel. The universal rotation curve of spiral galaxies. *MNRAS.*, 281:27–47, 1996, astro-ph/9506004.
[34] A. Aguirre et al. Astrophysical constraints on modifying gravity at large distances. *CQG*, 18:223, 12/ 2001, hep-ph/0105083.
[35] A. Bosma. Dark Matter in Disc Galaxies. *ArXiv Astrophysics e-prints*, astro-ph/9812013 1998.
[36] Y. Sofue and V. Rubin. *Annual Review of Astronomy and Astrophysics*, 39:137–174, 2001, astro-ph/0010594.
[37] A. Bosma. Dark matter in galaxies: Observational overview. *arXiv*, astro-ph/0312154, 2003.
[38] A. Bosma. In G. Contopoulos and N. Voglis, editors, *LNP Vol. 626: Galaxies and Chaos*, pages 271–278, 2003.
[39] N. W. Evans. In N. J. C. Spooner and V. Kudryavtsev, editors, *Identification of Dark Matter*, pages 85, 2001, astro-ph/0102082.
[40] J. A. Sellwood and A. Wilkinson. *Reports of Progress in Physics*, 56:173–256, February 1993, arXiv:astro-ph/0608665.
[41] A. Tasitsiomi. *International Journal of Modern Physics D*, 12:1157–1196, astro–ph/0205464, 2003.
[42] P. Salucci and A. Borriello. Cold Dark Matter Halos Must Burn, astro-ph/0106251.
[43] P. Salucci and A. Borriello. The Intriguing Distribution of Dark Matter in Galaxies, astro-ph/0203457.
[44] T. Wong et al. A Search for Kinematic Evidence of Radial Gas Flows in Spiral Galaxies. *AJ*, 605:183–204, astro-ph/0401187.
[45] P. Salucci et al. The Universal ... II The Dark Matter Distribution out to the Virial Radius. *ArXiv: astro-ph/0703115*, 2007.
[46] G. Gentile et al.. NGC 3741: the dark halo profile... . *MNRAS.*, 375:199–212, 2007, arXiv:astro-ph/0611355.
[47] E. de Blok, S. McGaugh, and V. Rubin. *ArXiv: astro-ph/0107366*, 2001.
[48] W. J. G. de Blok and A. Bosma. *Astronomy and Astrophysics*, 385:816–846, 2002, astro-ph/0201276.
[49] A. Tasitsiomi. *International Journal of Modern Physics D*, 12:1157–1196, astro–ph/0205464, 2003.
[50] F. Bournaud et al. Missing mass in collisional debris from galaxies. *Science*, 316:1166, 2007, arxiv:0705.1356.
[51] G. Gentile et al. Tidal dwarf galaxies as a test of fundamental physics. *ArXiv: 0706.1976*, 2007.
[52] R. B. Tully and J.R. Fisher. A new method of determining distances to galaxies. *A&A*, pages 661–673, 1977.
[53] I.A. Yegorova and Paolo Salucci. The radial Tully-Fisher relation for spiral galaxies i. *arXiv*, astro-ph/0612434, 2006.
[54] S. M. Faber and R. E. Jackson. *Astrophysical Journal*, 204:668–683, March 1976.
[55] Tremaine et. al. *Astrophysical Journal*, 574:740–753, 2002, arXiv:astro-ph/0203468.

[56] Robertson et. al. The evolution of the *MBH*–σ-relation. *Astrophysical Journal*, 641(arXiv:astro-ph/0506038):99–102, 2005.
[57] Schneider. *Extragalactic Astronomy and Cosmology (German)*. Springer, 2006.
[58] A. Sarajedini. The "Super-Halo" of M31 and M33. *ArXiv: astro-ph/0610632*, page 10632, October 2006.
[59] N. Kallivayalil et al. The Proper Motion of the Large Magellanic Cloud Using HST.*ApJ*, 638:772–785, 2006 astro-ph/0606240.
[60] G. Besla et al.Are the Magellanic Clouds on Their First Passage about the Milky Way?*ApJ*, 668:949, 2007,astro-ph/0703196.
[61] F. Zwicky. Die Rotverschiebung von extragalaktischen Nebeln. *Helvetica Physica Acta*, 6:110–127, 1933.
[62] R.W. Schmidt and S.W. Allen. The dark matter halos of massive, relaxed galaxy clusters. *arXiv*, astro-ph/0610038.
[63] J. A. Sellwood and A. Kosowsky. Does Dark Matter Exist? astro–ph/0009074, 2001.
[64] J. Bekenstein and M. Milgrom. *Astrophysical Journal*, 286:7–14, November 1984.
[65] M. Milgrom. The modified dynamics - a status review. *arXiv*, astro-ph/9810302, 1998.
[66] R. Scarpa et al. Globular clusters as a test for gravity in the weak acceleration regime. *arXiv*, astro-ph/0601581, 2006.
[67] R. Scarpa et al. Using globular clusters to test gravity in the weak acceleration regime: NGC 7099. *arXiv*, astro-ph/0611504.
[68] G. A. Drukier et. al. The Global Kinematics of the Globular Cluster M92. *AJ*, 133:1041–1057, 2007, astro-ph/0611246.
[69] R. Scarpa et al. Using globular clusters to test gravity in the weak acceleration regime, arXiv:0707.2459.
[70] Neal Jackson. The Hubble Constant. *LIVING REVIEWS IN RELATIVITY*, 10:4, 2007, arxiv: 0709.3924.
[71] S. Perlmutter et al. Discovery of a supernova at half the age of the universe. *arXiv*, astro-ph/9712212, 1997.
[72] Perlmutter et. al. *Astrophysical Journal*, 517:565, 1999.
[73] Perlmutter et. al. *Nature*, 391:51, 1998.
[74] A. G. Riess et al. *arXiv*, astro-ph/9805201, 1998.
[75] M. Sereno and P. Jetzer. *Physical Review D*, 73(6):063004–+, 2006, arXiv: astro-ph/0602438.
[76] P. Jetzer and M. Sereno. Solar system tests of the cosmological constant, 2007, arXiv:0711.3723.
[77] D. J. Kapner et al. *Physical Review Letters*, 98(2):021101–+, January 2007.
[78] S. C. Vauclair et al. The XMM-Omega project. *Astronomy and Astrophysics*, 412:L37–L41, 2003, astro-ph/0311381.
[79] D. H. Lumb et. el. The XMM-NEWTON Ω project. *Astronomy and Astrophysics*, 420:853–872, 2004, astro-ph/0311344.
[80] Riess et. al. *Astrophysical Journal*, 607:665–687, 2004, astro-ph/0402512.
[81] C. L. Bennett et. al. *arXiv*, astro-ph/0302207, 2003.
[82] M. Tegmark et al. *Physical Review D*, 68(12):123523–+, December 2003, arXiv:astro-ph/0302496.
[83] Michael S. Turner. Making sense of the new cosmology, 2002, astro-ph/0202008.
[84] L. M. Krauss. *ArXiv: astro-ph/0406673*, 2004.
[85] Roger Penrose. *The Road to Reality: A Complete Guide to the Laws of the Universe*. Jonathan Cape, 2004.
[86] A. Aguirre. Alternatives to dark matter ? *arxiv*, astro-ph/0320572, 2003.
[87] J. Barbour. *The End of Time*. Oxford University Press, 2000.
[88] J. Barrow. *The world within the world*. Oxford university Press, 1988.
[89] A. Einstein. *Mein Weltbild*. Piper, 1930.
[90] P. A. M. Dirac. A new basis for cosmology. *Proc. Roy. Soc. London*, A 165:199–208, 1938.
[91] A. Unzicker. A Look at the Abandoned Contributions to Cosmology of Dirac, Sciama and Dicke. *ArXiv: 0708.3518*, 2007.
[92] T.S. Kuhn. *The Structure of Scientific Revolutions*. University of Chicago Press, Chicago, 1962.
[93] L. Smolin. *The Trouble with Physics*. Houghton Mifflin Company, New York, 2006.