Cosmological expansion in the Solar System

L. A. King[1,a)] and H. Sipilä[2,b)]
[1]*27 Ivar Gardens, Basingstoke, RG24 8YD, United Kingdom*
[2]*Physics Foundation Society, Vasamatie 25, 02630 Espoo, Finland*

(Received 3 February 2022; accepted 17 March 2022; published online 21 April 2022)

Abstract: In accepted theory, Hubble expansion only operates at the largest scales, i.e., the intergalactic level. However, this is a theoretical conclusion, which can be rebutted with other theoretical considerations. More significantly, increasing observational data and other evidence, particularly within the Solar System, point to universal expansion operating on all scales where gravitation, as opposed to electronic interaction, is the dominant force. Local Hubble flow has implications for current theories of tidal drag as well as both the early evolution of the Solar System and its long-term future. Expansion is also expected to operate on the structure of galaxies, but it is unclear whether this has any impact on the dark matter problem.
 [http://dx.doi.org/10.4006/0836-1398-35.2.139]

Résumé: Dans la théorie acceptée, l'expansion de Hubble ne fonctionne qu'aux plus grandes échelles, c'est-à-dire au niveau intergalactique. Cependant, il s'agit d'une conclusion théorique, qui peut être réfutée par d'autres considérations théoriques. Plus, important encore, l'augmentation des données d'observation et d'autres preuves, en particulier au sein du système solaire, indiquent une expansion universelle opérant à toutes les échelles où la gravitation, par opposition à l'interaction électronique, est la force dominante. Le flux local de Hubble a des implications pour les théories actuelles de la traînée des marées ainsi que pour l'évolution précoce du système solaire et son avenir à long terme. On s'attend également à ce que l'expansion agisse sur la structure des galaxies, mais on ne sait pas si cela a un impact sur le problème de la matière noire.

Key words: Hubble Flow; Recession; Planets and Satellites; Solar Expansion; Tidal Drag; Gravitation.

I. INTRODUCTION

The expansion of the Universe, based on the red-shift in light from distant galaxies, is described by the velocity-distance relationship ($v = H_0 r$), where H_0 is the Hubble parameter. Although there is continuing uncertainty[1] regarding the best value of H_0, here it will be taken as $H_0 = 70$ (km/s)/Mpc. The question is often asked whether all objects in the universe participate in this expansion. This in turn is related to the question whether space itself is scale invariant. However, it is not suggested that such expansion occurs in condensed matter bound by electronic interactions; there is no evidence that the fundamental constants, which define the size and structure of matter at the atomic scale, such as the fine-structure constant[2] (α) or the Rydberg constant (R_∞), whose value[3] is known to a relative uncertainty of 1.9×10^{-12}, undergo secular changes at least on the time-scale of the Solar System's evolution.

In this paper, we show first that objections to local expansion are often based on little more than assumptions. In contrast, there is increasing observational support for cosmological expansion within the Solar System as well as a number of anomalies, which might also be resolved by invoking local expansion. This has led to renewed interest in the question. For example, a conference[4] was organized by the Czech Academy of Sciences to discuss "Cosmology on Small Scales," while Sipilä[5] provided data to support the expansion of the Solar System. Much of the published work in this area has appeared in the past 20 years and, to a certain extent, reflects our increasing knowledge of the dynamics of the planets and their satellites brought about by data from unmanned probes. A number of theoretical descriptions of local expansion have been proposed, and some of which invoke an all-pervading dark-energy field.

II. OBJECTIONS TO LOCAL EXPANSION

In standard theories of the universe, expansion operates only on the largest scales. This assumption has its origins in early relativistic cosmological models. Thus, the Friedmann–Lemaitre–Robertson–Walker (FLRW) metric, which assumes isotropy and homogeneity, describes an expanding Universe.[6] Since local systems, such as the planets and their satellites in the Solar System are neither isotropic nor homogeneous, then it is often stated that these cannot, therefore, take part in the overall expansion. However, a more logical conclusion is that they are beyond the scope of the FLRW metric, and no deduction can be made about their dynamics.

The second argument used to deny local effects is that the Hubble flow is unable to overcome the force of gravity. It is often suggested that intergalactic gravitational effects are far less than those experienced by, for example, the planets and satellites in the Solar System and can therefore be ignored. This is another false argument. If a typical galaxy

a)les@king.myzen.co.uk
b)hjsipila@gmail.com

has a mass M_g and is separated from its neighbor by distance r_g, then the relative gravitational potential experienced at r_g compared with the gravitational potential experienced by the Earth due to the Sun is given by $(M_g\, r_o)/(M_o\, r_g)$, where M_o is the mass of the Sun and r_o is the Earth–Sun separation. If $M_g = 2 \times 10^{12}\ M_o$, $r_g = 2 \times 10^{18}$ km, and $r_o = 1.5 \times 10^8$ km, then the above expression shows that this ratio is over 100. In other words, some intergalactic gravitational potentials may be far greater than those in the Solar System, and the gravitational potential caused by the mass of the entire universe will be even greater.

A final objection to local Hubble flow is that any expansion of "closed" systems would violate both the conservation of energy (E) and orbital angular momentum (L). However, the changes implied in E and L are of the order of 1 part in 10^{11} per annum and beyond the present experimental confirmation of such conservation "laws." Dumin[7] has discussed other reasons for rejecting the claimed absence of Hubble flow in local systems.

III. OBSERVATIONAL EVIDENCE FOR LOCAL EXPANSION IN THE SOLAR SYSTEM

A. Recession of the Moon from Earth

1. Direct measurement

The Lunar Laser Ranging Program (LLRP) was set up during the Apollo Moon landings. Measurements[8] give a rate of recession of 3.82 cm yr^{-1}. From the velocity-distance relationship using a mean separation distance of 3.83×10^5 km, then the expected rate of recession of the Moon is 2.8 cm yr^{-1}. This apparent coincidence, which has been recognized for over 50 years, suggests that tidal drag represents only part of the expansion of the Moon's orbit.

2. Paleotidal data and the Moon's orbit

The analysis[9] of sedimentary cyclic rhythmites of tidal origin as stored in sandstone, siltstone, and mudstone in South Australia leads to a conclusion that around 620×10^6 years ago there were 13.1 +/− 0.1 lunar months yr^{-1}, 400 +/− 7 solar days yr^{-1} and a day length of 21.9 +/− 0.4 hr. These data are then consistent with a mean rate of lunar recession since that time of 2.17 +/− 0.31 cm yr^{-1}. Since, as discussed above, the known rate of recession of the Moon is 3.82 cm yr^{-1}, then tidal drag only accounts for around half of this. Bearing in mind the uncertainties involved, this is entirely consistent with the above results from the LLRP.

B. Recession of the Earth from the Sun

1. The Faint Young Sun Paradox

Although the basic features of stellar evolution have been known for a considerable time, the paradox of the "Faint Young Sun" seems not to have been discussed in any detail until around fifty years ago when Sagan and Mullen[10] described the evolution of atmospheres and surface temperatures on Earth and Mars. The paradox arises because there is a contradiction between observations of liquid water early in Earth's history and the astrophysical expectation that the Sun's output would be only 70% as intense around $3\text{–}4 \times 10^9$ years (3–4 Gyr) ago as it is now.[11] Apart from the geophysical evidence, it is also apparent from paleontological data that conditions on Earth were suitable for life to evolve around 3–4 Gyr ago.[12] In addition, there is strong evidence for the presence of liquid water on the surface of Mars in the distant past.[13] Many explanations have been suggested for this paradox including denser cloud cover or greenhouse gas effects, yet none is satisfactory nor widely accepted.

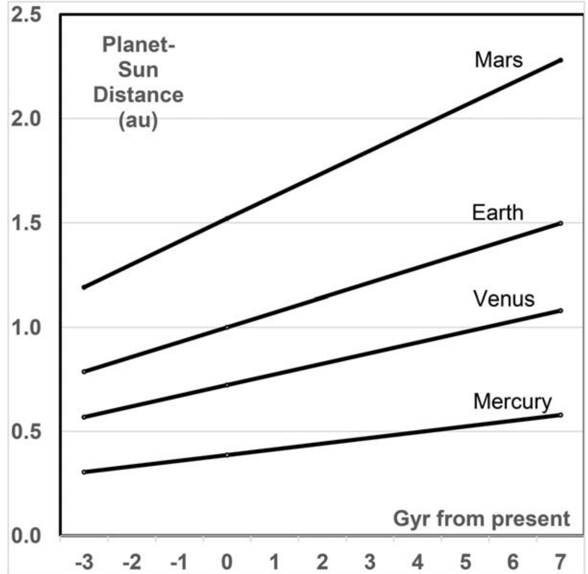

FIG. 1. The Planet-Sun distances (au) in the period from 3 Gyr before present to 7 Gyr in the future.

However, if we assume that the Earth and all other planets have followed the cosmological expansion then the paradox is readily solved. Figure 1 shows the current distances (r) of the terrestrial planets from the Sun with those estimated several Gyr ago as well as their distances in the future. This is based on $H_0 = 70$ (km/s)/Mpc which, in more useful units, can be converted to $H_0 = 0.071$ au per Gyr per au where au = astronomical unit (1.496×10^8 km). For simplicity, it is assumed that H_0 is constant over this period. The solar radiation experienced by a distant body is proportional to $1/r^2$, Thus, if the current radiation experienced by Earth is taken as unity, then the value at 3–4 Gyr ago is given by $(0.7)/(0.787)^2 = 1.13$. Thus, despite the Sun producing only around 70% of its current intensity in that earlier epoch, the radiation reaching the Earth and the other planets would have been slightly greater than now. However, some caution is needed in interpreting these data since the planets are predicted to have been much closer in the distant past. Thus, there may have been significant planet-planet interactions such as in those theories[c),d)] that describe the origin of the Moon as a result of major disturbances in the inner Solar System.

[c)] https://en.wikipedia.org/wiki/Formation_and_evolution_of_the_Solar_System
[d)] https://en.wikipedia.org/wiki/Origin_of_the_Moon

2. Fossil corals and days in a year

By measuring the annual growth rings in coral fossils, which date back several hundred million years, it can be shown that the number of days in the year has been decreasing. Tidal effects from the Moon would have led to a much steeper decline in days per year, but the effect of an increasing orbital period for the Earth causes the annual number of days to increase. The effect of these two opposing trends in the number of days per year provides an independent estimate of the Hubble parameter close to the currently accepted value.[5]

3. Direct measurement

Given $H_0 = 70$ (km/sec)/Mpc, then the Earth–Sun distance is expected to increase by 11 m yr^{-1}. However, Křižek and Somer[14] have pointed out that direct measurement of such a change in the astronomical unit is fraught with uncertainties. One of the many problems is that the center of gravity of the Solar System moves about 1000 km each day. Using radiometric measurements of the distances between the Earth and the major planets, Krasinsky and Brumberg[15] estimated that the Earth–Sun recession was as low as 15 +/− 4 m cyr^{-1}. However, there are problems with this result. First, it was based on 62 astronomical parameters each of which is subject to some uncertainty. Second, and more importantly, is the theory-bound interpretation of the observations. Thus, Krasinsky and Brumberg[15] state that a model of the observables was developed in the frame of the relativistic background of the uniform isotropic Universe even though, as discussed earlier, the Solar System is neither uniform nor isotropic. Those authors then invoke the "Einstein effect," namely, the dependence of the observer's clock on the gravitational field. Křižek and Somer[14] considered the estimate by Krasinsky and Brumberg[15] as unreliable.

C. Recession of Saturn's moons

Titan is known to recede from Saturn at a rate of 11 cm yr^{-1}. Lainey *et al.*[16] have described this orbital expansion in terms of tidal effects leading to resonance locking. Using $H_0 = 70$ (km/s)/Mpc and a mean separation distance of 1.2×10^6 km, then the cosmological rate of recession of Titan is 8.6 cm yr^{-1}. Part of the observed recession is undoubtedly caused by tidal friction, but it suggests that Hubble flow accounts for around 75% of the orbital expansion.

No data are available on the recessional velocity of the other moons of Saturn. However, the dynamics of that system are known to lead to a number of problems particularly in respect of conflicting evidence for determining their origin and age.[17,18] Thus, the crater distribution on many of their surfaces suggests that the moons formed several Gyr ago, but the expansion of their orbits thought to be due to tides raised by the moons on Saturn points to much more recent formation. Just as with Titan, where the rate of recession is much higher than expected from tidal theory,[16] cosmological expansion of the Saturnian system rather than tidal effects could explain those anomalies.

D. Expansion of the Sun

Current theories of stellar evolution show that the Sun will eventually deplete its hydrogen fuel and become a red giant; they predict[e)] that the radius of the Sun will double in 7 Gyr. If Hubble expansion applies to the Sun, then in 7 Gyr its radius will have increased by 50%. It follows that cosmological expansion accounts, at least in part, for the enlargement of the ageing Sun and other stars. It is normally predicted that once the Sun becomes a red giant, it will overwhelm the terrestrial planets. However, the orbits of those planets are also predicted to increase. Thus, in 7 Gyr, the orbit of the Earth will also have expanded by 50% to reach the current orbital distance of Mars. This has implications for the suggested destruction of the inner planets at that time.

E. Other paradoxes in the Solar System

Křižek and Somer[14] have presented a number of anomalies in the Solar System that could be resolved by local expansion. However, these lack quantitative evaluation, and only a brief mention is provided here.

1. The origin of Neptune

It is an open problem how Neptune could have formed so far from the Sun (r = 30 au) when the original protoplanetary disc was sparsely populated at that distance. By extending the data shown in Fig. 1, local expansion indicates that at 4.5 Gyr ago, Neptune would have been about 20 au distant from the Sun.

2. The absence of moons orbiting Mercury and Venus

Again, by extending the data shown in Fig. 1, both planets would have been much closer to the Sun and the orbits of any moons that did form could have been disrupted by solar tidal forces.

3. Slow rotation of Mercury

Tidal forces are inversely related to the cube of the orbital radius. The closeness of Mercury during its formation around 4.5 Gyr ago would have resulted in much higher tidal forces than today, leading to its now slow rotational period (59 days).

4. Fast satellites

It is suggested that there are 19 satellites in the Solar System, which can be regarded as "fast," that is to say their orbital period is less than their rate of rotation. According to Křižek and Somer,[14] these observations suggest that it is local expansion that has prevented these satellites from crashing into their respective planets.

IV. THEORETICAL APPROACHES TO LOCAL EXPANSION

A number of earlier theoretical investigations were summarized by Bonnor.[19] Suntola[20] has provided a novel

[e)]https://en.wikipedia.org/wiki/Sun

explanation of why gravitationally bound systems should follow the overall expansion of space. This is based on the concept of the zero-energy balance of motion and gravitation. Other authors describe local expansion in terms of dark-energy, a mysterious field that pervades the universe and opposes the attractive force of gravity.[f)] In some respects, dark-energy is a manifestation of Einstein's cosmological constant Λ.[g)]

Since it can be argued that dark-energy pervades the entire Universe and not just the space between galaxies, it provides a possible origin for local effects. In this way, Dumin[21] has described the expansion of the lunar orbit as a dark-energy effect while Křižek *et al.*[22] discuss its effect on the orbit of Titan. However, it is unclear why dark-energy, as a repulsive force, should have a similar magnitude to that of the overall expansion of the Universe since the latter has always been considered a manifestation of the Big Bang. This paradox would be solved if the Hubble expansion is itself a consequence of dark-energy.

More speculative suggestions for the origin of expansion include secular variation in the Newtonian gravitational constant (G). However, G has not been determined to the required level of accuracy and is unlikely to be in the near future. Furthermore, Mould and Uddin[23] have argued that, under the assumption that the physics of type Ia supernovae are universal, analysis of observations of 580 of them has shown that the gravitational constant has varied by less than one part in ten billion per year over the last 9 Gyr.

V. CONCLUSIONS

Despite the wealth of evidence supporting local Hubble flow, the prevailing paradigm in astrophysics is that this does not and cannot occur. It may be predicted that continued exploration of the Solar System will eventually provide yet further evidence to support the hypothesis of local effects. But the history of scientific revolutions[24] provides many examples where paradigm shifts not only take years or even decades to gain traction, but they may only occur when data become overwhelming and current theories become untenable. In this respect, it can be claimed that the evidence described above can have other explanations and that scientific opinions will only shift when unique observations of local expansion arise without any satisfactory alternative interpretation.

Although it is beyond the scope of the present essay, local expansion would also be expected to operate on the overall structure of galaxies. The measured rotation rate of a galaxy is then a vector sum of the true rotational velocity and the outward radial velocity. It is unclear whether this might have any impact on the dark matter problem. As noted by Dumin,[7] the pattern of galaxy evolution is complicated by the formation of stars and their proper motions; and the question of cosmological effects at the scale of galaxies remains completely unexplored.

[1] L. Knox and M. Millea, Phys. Rev. D **101**, 043533 (2019).
[2] H. Sipilä and A. Lehto, "Fundamental constants in time from the Big-Bang," preprint 10.20944/preprints202007.0239.v1.
[3] See https://physics.nist.gov/cgi-bin/cuu/Value?ryd for National Institute of Standards and Technology, The NIST Reference on Constants, Units and Uncertainty.
[4] *Cosmology on Small Scales 2016, Local Hubble Expansion and Selected Controversies in Cosmology*, edited by M. Křížek and Y. V. Dumin (Institute of Mathematics, Czech Academy of Sciences, Prague, 2016).
[5] H. Sipilä, J. Phys: Conf. Ser. **1466**, 012004 (2020).
[6] M. Lachieze-Rey and J.-P. Luminet, Phys. Rep. **254**, 135 (1995).
[7] Y. V. Dumin, "Local Hubble expansion: Current state of the problem," in *Cosmology on Small Scales 2016, Local Hubble Expansion and Selected Controversies in Cosmology* (Institute of Mathematics, Czech Academy of Sciences, Prague, 2016).
[8] J. O. Dickey, P. L. Bender, J. E. Faller, X. X. Newhall, R. L. Ricklefs, J. G. Ries, P. J. Shelus, C. Veillet, A. L. Whipple, J. R. Wiant, J. G. Williams and C. F. Yoder, Science **265**, 482 (1994).
[9] G. E. Williams, Rev. Geophys. **38**, 37 (2000).
[10] C. Sagan and G. Mullen, Science **177**, 52 (1972).
[11] G. Feulner, Rev. Geophys. **50**, 2011RG000375 (2012).
[12] B. K. D. Pearce, A. S. Tupper, R. E. Pudritz, and P. G. Higgs, Astrobiology **18**, 343 (2018).
[13] S. W. Squyres, Icarus **79**, 229 (1989).
[14] M. Křižek and L. Somer, "Anthropic principle and the local Hubble expansion," in *Cosmology on Small Scales 2016, Local Hubble Expansion and Selected Controversies in Cosmology* (Institute of Mathematics, Czech Academy of Sciences, Prague, 2016).
[15] G. A. Krasinsky and V. A. Brumberg, Celestial Mech. Dyn. Astron. **90**, 267 (2004).
[16] V. Lainey, L. G. Casajus, J. Fuller, M. Zannoni, P. Tortora, N. Cooper, C. Murray, D. Modenini, R. S. Park, V. Robert, and Q. Zhang, Nat. Astron. **4**, 1053 (2020).
[17] M. Ćuk, L. Dones, and D Nesvorný, Astrophys. J. **820**, 97 (2016).
[18] M. Neveu and A. R. Rhoden, Nat. Astron. **3**, 543 (2019).
[19] W. B. Bonnor, Mon. Not. R. Astron. Soc. **282**, 1467 (1996).
[20] T. Suntola, Phys. Essays **34**, 486 (2021).
[21] Y. V. Dumin, "Testing the dark-energy-dominated cosmology by the solar-system experiments," e-print https://arxiv.org/abs/0808.1302v1
[22] M. Krizek, V. G. Gueorguiev, and A. Maeder, "An alternative explanation of the rapid orbital expansion of Titan," preprint https://www.preprints.org/manuscript/202109.0200/v1
[23] J. Mould, and S. A. Uddin, Pub. Astron. Soc. Australia **31**, e015 (2014).
[24] T. S. Kuhn, *The Structure of Scientific Revolutions*, 2nd ed. (The University of Chicago Press, Chicago, 1970).

[f)] https://en.wikipedia.org/wiki/Dark_energy
[g)] https://en.wikipedia.org/wiki/Cosmological_constant