Is the Solar System expanding?

Heikki Sipilä
Physics Foundations Society, Vasamatie 25, 02630 Espoo, Finland

E-mail: heikki.sipilä@gmail.com

Abstract. It is argued in this article that observations undermine the *no-expansion hypothesis* of standard physics, where gravitationally bound systems do not expand along with the expansion of space, and support the contrary *expansion hypothesis* where the Solar System expands proportionally to the expansion of space. First, the no-expansion hypothesis yields the Faint Young Sun Paradox –the dilemma of explaining why there have been oceans on Mars and why the Earth has been warm 3.5 billion year ago, when luminosity of the Sun was 25% smaller than today– whereas the expansion hypothesis resolves the paradox. Second, the number of days in a year in the past cannot be explained with tidal friction alone, whereas the fusion of the tidal friction and the expansion hypothesis functions as a natural explanation. Third, the no-expansion hypothesis does not match the historical increase of the Earth-Moon distance, whereas the expansion hypothesis matches it perfectly. These three examples strongly indicate that the Solar System is expanding along with the expansion of space.

1. Introduction

According to the standard model of cosmology that is based on general relativity, gravitationally bound systems do not expand along with the expansion of space [1], whereas in Tuomo Suntola's [2] *Dynamic Universe* model the Solar System expands at the same rate as space. Both hypotheses cannot be true, and not even equally virtuous. Nature is the final arbiter of this disagreement. As we are dealing with phenomena that have taken place during several billion years, it is imperative to investigate empirical data which gives indications about long-term changes in the Solar System. Three kinds of data are studied, which strongly indicate that three respective phenomena have taken place.

In section 2, the Faint Young Sun paradox is investigated. It is evaluated how the expansion hypothesis and the no-expansion hypothesis cope with the dilemma of explaining why there have been oceans on Mars and why the Earth has been warm 3.5 billion year ago, when luminosity of the Sun was 25% smaller than today.

In section 3, coral fossil data is investigated, which testifies that the number of days in a year has varied rather significantly. It is evaluated how the expansion hypothesis and the no-expansion hypothesis cope with this variance.

In section 4, data gathered from sandstone layers is investigated. This data reflects tidal activity and the corresponding lunar-solar cycles. When analyzed with the no-expansion hypothesis, the data testifies that the Earth-Moon distance has been increasing at a smaller rate in the distant past than during the last 50 years when it has been monitored in the Lunar Laser Ranging program [3]. It is evaluated how the expansion hypothesis and the no-expansion hypothesis cope with the development of the rate at which the Earth-Moon distance has been increasing.

When considered real, each or these phenomena separately and all of them together make perfect sense in the context of the expansion hypothesis. In contrast, these phenomena cannot be fitted together with the no-expansion hypothesis, or at any rate, not without heavy parametrisation, i.e., not without adding hypothetical explanations to the no-expansion hypothesis.

2. The Faint Young Sun paradox

It is commonly accepted that radiation energy from the Sun will increase and has increased about 7% in a billion years. It follows that when life appeared on Earth 3.85 billion years ago the Sun had 25% lower luminosity. Despite this there were oceans on Earth and on Mars 3.85 billion years ago. Current distances of the planets from the Sun are presented on the left side of Table 1. The habitable zone is assumed to be 0.90-1.37 astronomical units. This is supposed to be the range allowing liquid water on a planet. Only the Earth is in the habitable zone. Venus is too hot and Mars is frozen.

It is interesting to consider the Faint Young Sun paradox if we assume that the Solar System is expanding at the same rate as the whole of space. When expansion of the Solar System is assumed to follow the current estimation of the Hubble's law, about 70 (km/s)/Mpc, the distances of the planets from the Sun at different times can be calculated. The right side of table 1 shows the distances of the planets from the Sun when life appeared on Earth 3.85 billion years ago.

Planet	Current distance	Distance 3.85 billion years ago
Mercury	58 Mkm = 0.37 AU	45 Mkm = 0.30 AU
Venus	108 Mkm = 0.72 AU	83 Mkm = 0.55 AU
Earth	150 Mkm = 1.00 AU	116 Mkm = 0.77 AU
Mars	230 Mkm = 1.53 AU	178 Mkm = 1.19 AU

Table 1. Distances of the planets from the Sun. Mkm: million kilometres. AU: astronomical unit.

Taking into account the weaker Solar luminosity 3.85 billion years ago, the habitable zone was 0.78-1.19 astronomical units. Back then both Earth and Mars were in the habitable zone, and oceans were possible on both planets. These calculations do not prove definitely that the expansion hypothesis explains away the Faint Young Sun paradox. However, the expansion hypothesis allows one to get rid of numerous other hypotheses. Different types of greenhouse effects or volcanos have been proposed, but these explanations have been found questionable, especially because they would have to be valid for both Earth and Mars. Moreover, the expansion hypothesis does not *add* complexity to cosmology or to physics in general, but makes it more uniform, for it merely *removes* the special convention that gravitationally bound systems do not expand, while the Universe as a whole does expand.

3. The number of days in a year

Coral fossil data testifies that millions of years ago there were more days in a year than now. When corals grow, they develop “daily layers”, similar to annual rings of trees. It is possible to calculate the number of their daily layers by microscopy. Years can be recognized because the layers are thinner when there is less light and when water has been colder. Eicher [4] p. 117 has calculated the number of days in a year accurately as a function of the age of the fossils.

The coral fossil data is illustrated by the black squares in figure 1. It shows how the number of days in a year has been increasing when going millions of years back from the present time. Also, the data indicates that there have not been any major jumps in tidal friction, i.e., the observed curve is smooth. Following the no-expansion hypothesis, the length of a year stays constant, and the explanation of the coral fossil data is based on a decrease in the rotational velocity of the Earth due to tidal friction. According to careful calculations by Mathews and Lambert [5], tidal friction causes slowing down of the day by 2.5ms/100y, illustrated by the blue curve in figure 1. Obviously, the coral fossil data and the prediction based on tidal friction do not fit together. However, when the effect of tidal friction on the

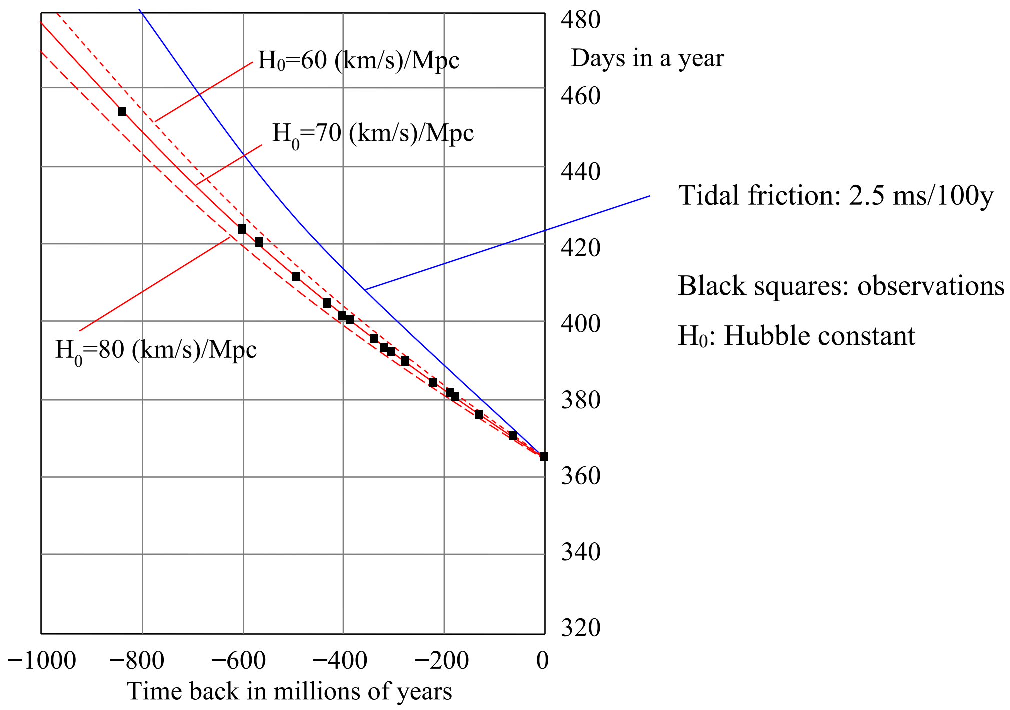

Figure 1. Variation of length of the day. The x-axis denotes time back in millions of years from the present time 0. The y-axis denotes the number of days in a year. Black squares denote number of days counted from coral fossils [4], [6-8]. The picture presents the prediction of the standard model based on tidal effects (blue curve), and the DU prediction (red curves) combining the tidal effects and the lengthening of a year due to the expansion of space, when the Hubble constant is 60 (km/s)/Mpc, 70 (km/s)/Mpc, and 80 (km/s)/Mpc. (Mpc is an abbreviation of a megaparsec, i.e., a million parsecs, where one parsec is approximately 31×10^{12} km.)

length of a day is combined with the effect of the expansion of the Solar System on the length of a year, a perfect match with the coral fossil data is obtained as indicated by the solid red curve in figure 1. The curve is based on the expansion of space corresponding to the currently accepted estimate of the Hubble constant H_0=70 (km/s)/Mpc. Vice versa, the match with the coral fossil data suggests the value H_0=70±2 (km/s)/Mpc for the Hubble constant as an estimate independent of cosmological observations. As illustrated in figure 1 by the dashed curves, predictions obtained with Hubble constant H_0=60 (km/s)/Mpc and H_0=80 (km/s)/Mpc deviate considerably from the coral fossil data.

4. Increase of the Earth-Moon distance

When the Moon orbits the Earth it creates tides. In some areas, tides create sand layers. Those layers can be found in favorable locations as layers in sandstone. The tides are stronger when the Moon and the Sun are aligned, and therefore also the corresponding layers are thicker. From these thicker layers we can count the number of the Moon's orbits around the Earth. The Moon's orbit is elliptical, which can be seen in layer thickness. Finally, it is possible to count how many times the Moon has orbited the Earth in one year, as the eccentricity of the Earth's orbit gives the annual signature and makes it possible to count the number of lunar cycles in a year. In Australia near Townsville there is a sandstone deposit which has been thus far the best for this purpose. There is a continuous 60-year footprint of lunar cycles. G. Williams [9] has studied this deposit thoroughly. In his publications he gives the age 620 million years for this deposit. Just recently, he informed me that a new dating gave the value 635 million years. There are other deposits in different countries which are also studied but the results are not so accurate.

The average Earth to Moon distance today is 384 400 km and the length of a sidereal month (rotation time of the Moon around the Earth with respect to the fixed stars) is 27.3 days corresponding to 13.38 sidereal months in a year. The distance of the Moon from the Earth is measured in the Lunar Laser Ranging program [3] using mirrors on the Moon set up by astronauts almost 50 years ago. Based on measurements throughout the years, the distance increases 3.82 cm/y.

In the 620 million-year-old tidalites, the observed number of months in a year was 14.1, corresponding to the sidereal month of 25.9 current days in a year (assuming that the length of a year has been unchanged), which is 0.944 times the present sidereal month. Accordingly, following Kepler's 3rd law, the distance to the Moon 620 million years ago was $0.944^{2/3}$ x 384 400 = 371 143 km, which means that the distance has increased 13 257 km in 620 million years, which gives the average change as 2.1 cm/y, which is substantially less than today's measured value 3.82 cm/y. Following today's cosmology and the no-expansion hypothesis, Williams assumed that the length of the year (in time units) has been constant.

In Suntola's Dynamic Universe model, all gravitationally bound systems expand in direct proportion to the expansion of space. This means 2.79 cm annual increase in the Earth to Moon distance due to the expansion of space, when the Hubble constant is assumed to be 70 (km/s)/Mpc. The increase of the Earth to Moon distance due to the expansion of space is not observable in the moths/year count in the tidalites, because the orbital radii of both the Moon and Earth increase in direct proportion to the increase of the 4-radius of space, which means that the length of the month increases in direct proportion to the increase of a year. The increase of the orbital radii with the expansion of space is associated with a decrease of the speed of light and the rate of physical processes like the ticking frequencies of atomic clocks [2] p. 183.

When Williams' calculations are repeated, observing the changes associated with the expansion of space (assuming the Hubble constant 70 (km/s)/Mpc), the sidereal year 635 million years ago has been 349 days and the length of the sidereal month 24.8 days. With these values, the Earth to Moon distance, based on Kepler's 3rd law, was 358 789 km corresponding to 3.85 cm/y average increase in the Earth to Moon distance, in a full agreement with the value 3.82 cm/y, measured in the Lunar Laser Ranging program. The 3.8 cm/year average increase calculated from the tidalite data comprises 2.75 cm/y increase due to the expansion of space and 1.1 cm/y increase due to tidal effects (both values are calculated as cm/current year). The modern value from tidal friction is 3.82−2.75 cm/y ≈ 1.1 cm/y according Suntola [2] p. 226.

5. Conclusions

This paper investigated experimental "theory-free" observations from the Solar System. These observations are not just congenial with Suntola's Dynamic Universe model, where the Solar System and gravitationally bound systems in general expand at the same rate as space, but also allow deriving the value 70 km/s/Mpc for the Hubble constant.

How should one react to this result? On one hand, I believe that most physicists accept that physics is natural science, that the history of the Solar System is literally carved in stones and fossils, and that the accepted theory should conform to this data and explain it. On the other hand, expansion of the Solar System is unacceptable in the context of standard physics, astronomy and cosmology. I believe that the current failure of standard physics in explaining the data is not interpreted as a real failure, but either silenced away or interpreted as something that will be fixed in the foreseeable future, practically by deploying new metaphysical parameters.

Acknowledgements

I thank Tuomo Suntola for helpful discussions, Avril Styrman for editing the article, and Jan Dabek for revising the language of the article.

I got interested in the Dynamic Universe in Suntola's presentation at the Finnish Society for Natural Philosophy in 1998. Since then I have tried to find phenomena to test the validity of this theory. Originally, I did not know whether expansion of the Solar System, as predicted by DU, explains e.g. the

Faint Early Sun paradox, but it turned out that it does. I have given presentations of my findings related to this article in meetings of the Finnish Society for Natural Philosophy on 6.3.2018, 20.5.2016 and 17.2.2015.

Commentary

Reviewer A. Comment 1.

Rondanelli and Lindzen [8] argue that Cirrus Clouds could after all explain away the Faint Young Sun paradox.

Reply.

The basic idea in the Cirrus Cloud explanation is to design an atmosphere that explains away the Faint Young Sun paradox, i.e., to invent just such atmosphere that does the job. Various versions of the Cirrus Cloud explanation have been given since the introduction of the Faint Young Sun paradox in the 1960's and 1970's. To start with, the Cirrus Cloud explanations are not derived as consequences of the standard model, but they are additional hypotheses, i.e., metaphysical assumptions that are added to the standard model in order to keep it standing. Like all additional hypotheses, they decrease unifying power of the standard model (see Styrman's article in section 2 of this volume). It has become standard practice to add metaphysics to the standard model to keep it standing. Additional metaphysics is not seen as something negative, for the standard model is practically considered as an empirical fact, and therefore anything that is needed to keep it standing is also considered as viable as an empirical fact. Within this tradition, the only requirements for the Cirrus Clouds seem to be (a) consistency with the standard model, (b) the capability of explaining away the Faint Young Sun Paradox, and (c) consistency with the available empirical data. Accordingly, the overall methodology of the Cirrus Cloud explanations is to invent some sorts of past atmospheric conditions that are not known to contradict empirical data at that time; later, if new data is acquired that violates these conditions, or if the conditions are seen otherwise implausible, new conditions are invented that are compatible with the new data, and that have not yet been proved implausible. The whole Cirrus Cloud edifice is thus a matter of inventing new additional metaphysical hypotheses or modifying old additional hypotheses, that are not derivable from the standard model. Therefore, and again, *whatsoever* Cirrus Cloud explanation decreases virtuousness of the standard model, even if it meets requirements (a-c).

Goldblatt and Zahnle [9] raised a number of issues concerning earlier suggestions in 2011, regarding the conditions on Earth. Rondanelli and Lindzen [8] argued in 2012 that some of Goldblatt and Zahnle's criticism is not warranted, also regarding the conditions on Earth. All this contemplation was prior to NASA research in 2015 which suggests that Mars had more water than Earth's Arctic Ocean some 3.5. billion years ago. In order to explain the temperature on Mars back then, one should come up with a very different atmosphere than on Earth. In other words, even if the conditions that were designed for Earth were viable on Earth, they would fail on Mars. This means that we need yet another metaphysical parameter for explaining the conditions on Mars.

In sum, the Cirrus Clouds explain very poorly the Faint Young Sun paradox on Earth and not even so well on Mars. Rondanelli and Lindzen's remarks do not bring any significant change to the case. In contrast, DU's basic structure explains the temperatures on Earth and Mars, without any additional hypotheses.

Reviewer B. Comment 1.

This article examines possible evidence for the spatial and temporal changes that can occur in the Solar System according to Suntola's theory of Dynamic Universe. In that theory, such changes occur in two ways – 1) because of the expansion of space and consequent increase in the distance between planetary bodies, and 2) the change in the rate of clocks with which duration is measured, correlated with the decrease in the speed of light.

One important point to be made about such exploration is that the main question asked here, whether the Solar System is expanding (with the universe), has physical relevance that is independent of any particular theory. It is an open problem even in standard cosmology because the common assumption that "gravitationally bound" systems, and interaction-bound systems in general, do not expand with the universe whereas "free space" between galaxies does is only an assumption open to observational tests. There is no proof of this assertion, starting from fundamental theories.

To be precise, what do we mean by gravitationally bound? It cannot be the binding energy that is relevant because the binding energy between two distant galaxies GM^2/R is much larger than the binding energy between the earth and sun or between other bodies in the solar system. Next, we can consider the binding force, GM^2/R^2. Between two galaxies that are separated by 100 Mpc, the gravitational force is comparable to that between the Earth and the Sun. Of course, the uniform distribution of galaxies will balance the forces from different directions, but I don't think this assertion that 'bound systems do not expand with the universe' is established either by theory or observations. Therefore, what Sipilä addresses is an important issue that need to be decided purely from observational evidence. If such an expansion is found observationally, it seems to be consistent with present cosmology with its hypothesis of expanding space that carries galaxies with it. In other words, if these observations can be definitely proved independent of any theory, it has enormous value within standard cosmology itself, because standard cosmology does not rule out local expansion of space; it just assumes that such expansion is not there. So, definite proofs stated independently of specific theories will be noticed with great interest.

Reply.
The no-expansion hypothesis in standard cosmology has been stated by de Sitter [1] as early as 1935. Its rejection in the context of standard physics, celestial mechanics and cosmology would have profound implications, and it is not certain that the edifice could stand after this. In Suntola's Dynamic Universe theory [2], the expansion of gravitationally bound systems is a direct consequence of the conservation of total energy in the buildup of local systems. The expansion of space is associated with a change in the velocity of light and the frequency of atomic clocks and physical processes in general. Observations of the number of days and the number of months in a year in coral fossils and tidalites offer independent observational evidence of the expansion of the Solar System. The expansion of gravitationally bound systems means also that large local systems like galaxies and quasars expand in direct proportion to the expansion of space. As a consequence, DU predicts that the angular diameter of distant galaxies and quasars is inversely proportional to the observed redshift, which means Euclidean appearance of galaxy space in a convincing agreement with observations as illustrated in figure 6 in Suntola's article in this volume.

Reviewer B. Comment 2.
Contemplation about the "faint sun paradox" is be at best circumstantial additional evidence because many details are unknown about the conditions on Earth and other planets several billion years ago.

Reply. I agree that this can be at best circumstantial additional evidence. However, before my calculations it was not evident what the result will be. It could have been in conflict with the hypothesis that the Solar System expands. As we can see, the result fits well with the expansion hypothesis, even though it is not a conclusive proof.

Reviewer B. Comment 3.
The most impressive is the evidence for the increase in the duration of the year, arrived by estimating the increase of number of days in a year, from coral growth in water, with samples dating back several hundred million years. The number of days in a year has been smaller than that estimated by considering only the slowing down of the Earth's rotation due to tidal friction. This discrepancy is attributed to a shorter duration of the year due to the smaller Earth-Sun distance in the past. This data and its analysis are discussed in Suntola's article as well. It is surprising to see the tight fit to a value of the Hubble

constant around 70 km/s/Mpc, with high precision. What seems to be established beyond doubt is the decrease in number of days in a year. However, what needs to be established beyond doubt now is whether the length of the year has increased or whether only the length of the day has decreased progressively, differently from what is assumed in tidal models. If the latter is true, the tidal theory needs revision. This is not addressed in the paper or the analysis.

Reply. Almost 20 years ago I collected data from the ancient number of days in a year from the literature based on coral fossils. There is discrepancy of this data between slowing down of the Earth rotation based on tidal friction. Tidal friction is studied widely e.g. by Mathews and Lambert [5], independently of work on coral fossil data. Suntola [2] pp. 66-7, 230-2 found that this discrepancy can be resolved by taking into account expansion of the Earth's orbit. He used the currently accepted estimate 70 (km/s)/Mpc of the Hubble constant. The fit is very good. For our workshop I found that by using the basic experimental data it is possible also to determine the value of the Hubble constant. Fig. 1 illustrates that the fitting curves suggest the 70 (km/s)/Mpc value between the curves based on values 60 (km/s)/Mpc and 80 (km/s)/Mpc.

Finally, you asked how can one be certain that the length of the year has increased, and why cannot it be so that only the length of the day has increased progressively (or decreased if counting back in time), differently from what is assumed in tidal models? In the context of the expansion hypothesis, which is the starting point of the present work, expansion of the Solar System increases the radius of Earth's orbit, and the orbit itself. Due to conservation of energy, the expansion of space is associated with a decrease of the rotational velocity of the Earth in proportion to the decrease of the velocity of light which increases the length of a day. Also, Earth's orbital velocity decreases, i.e., the orbital period is longer, i.e., length of the year has increased along with the expansion. Again, one may argue that there are no definite proofs of any of these claims. But there are no define proofs of the contrary claims either. Nature is the final arbiter. Which theory gives more accurate predictions? If two theories give equally accurate predictions, which one requires less additional hypotheses?

References

[1] de Sitter W 1931 Do the galaxies expand with the universe? B. A. N. **6** 146
[2] Suntola T 2018 *The Dynamic Universe: Toward a unified picture of physical reality,* fourth edition (Espoo: Physics Foundations Society. Helsinki: The Finnish Society for Natural Philosophy) https://physicsfoundations.org/data/documents/DU_EN_978-952-68101-3-3.pdf
[3] Dickey J O et.al. 1994 Lunar laser ranging: A continuing legacy of the Apollo Program, Science **265** 482-490
[4] Eicher D L 1976 *Geologic Time* (London: Prentice/Hall International Inc.) 2nd edition
[5] Mathews P M and Lambert S B 2009 Effect of mantle and ocean tides o the Earth's rotation rate, *Astronomy and Astrophysics* **493** 325-30
[6] Wells J W 1963 Coral growth and geochronometry, *Nature* **197** 948-50
[7] Wells J W 1970 Problems of the annual and daily growth rings in corals, *Paleogeophysics,* ed S K Runcorn (London: Academic Press) pp 1331-2
[8] Vanyo J P and Awramik S M 1985 Stromatolites and Earth–Sun–Moon dynamics, *Precambrian Research* **29** 121-42
[9] Williams G E 1997 Precambrian length of day and the validity of tidal rhythmite paleotidal values, *Geophysical research Letters* **24**.4 421-4
[10] Rondanelli R and Lindzen R S 2012 Comment on "Clouds and the Faint Young Sun Paradox" by Goldblatt and Zahnle, *Clim. Past* **8** 701-3. doi:10.5194/cp-8-701-2012
[11] Goldblatt C and Zahnle K J 2011 Clouds and the Faint Young Sun Paradox, *Clim. Past* **7** 203-20. doi:10.5194/cp-7-203-2011
[12] Coughenour C L, Archer A W and Lacovara K J 2013 Calculating Earth-Moon system parameters from sub-yearly tidal deposit records: An example from the carboniferous tradewater formation, Sedimentary Geology **295** 67-76