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A new cosmic coincidence in conjunction with the cosmic expansion.

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Abstract

The discovery of the cosmic acceleration (Perlmutter & Riess, 1999; Perlmutter et al., 1999; Riess et al., 1998) along with the presence of dark matter is one of the most intriguing puzzles in modern physics and cosmology. Up to now, only 5% percent of the energy density in the universe can be explained by the physics that we know of. The other 95% are split up into 25% dark matter and 70% dark energy. For both energy densities there is still no reasonable physical explanation for their occurrence, only observational evidence.
Another vividly discussed topic is the requirement for the occurrence of life in our galaxy and in the universe. There are studies by von Bloh et al. (2003) and Franck et al. (2007) trying to investigate the early spreading of life, especially by panspermia effects, throughout the Milky Way galaxy. In order to derive their results, they determine the number of stellar systems containing habitable planets as a function of time.
Combining the results by Perlmutter & Riess (1999); Perlmutter et al. (1999), Riess et al. (1998) and von Bloh et al. (2003), Franck et al. (2007), there appears to be temporal correlation between the onset of cosmic acceleration and the formation of stellar systems containing habitable planets.The question is: is this just a mere coincidence, or is there a causal connection by a yet to be discovered physical mechanism?

1. Introduction

Cosmic acceleration is one of the most striking and yet unexplained discovery of the new millennium. Contrary to the expectation from simple Newtonian gravity, the relative velocities between galaxy clusters are increasing, not decreasing. In fact, measurements of the baryonic acoustic oscillations (BAO) and supernova surveys, indicate that ordinary matter can only account for about 5% of the energy density of the universe. Dark energy, presently being thought of as the reason for the acceleration of the universe, accounts for about 70% and the dark matter for about 25% of the energy density of the universe.
A variety of theories have been developed and discussed to explain the expansion. However, each of the theories suffer from various inconsistencies to describe the overall behavior of the acceleration. One of the problems is described by the coincidence problem, i.e. why has the transition of a decelerating to an accelerating universe happened so recently. Some authors try to address this issue (Caldwell & Kamionkowski, 2009) but the employed theories have to suggest an underlying physical mechanism that not only explains the expansion of the universe, but also why this has happened so recently. Presently none of the current models is able to answer this question adequately. Therefore, the scientific community is seeking new ideas or even physical mechanisms that are capable of explaining the onset of cosmic expansion. What is the mechanism that causes the universe to undergo the transition from deceleration to acceleration so recently or is it just a coincidence? This issue remains unanswered, and it becomes particularly intriguing when we take a closer look at the temporal development of stellar systems containing habitable planets within the Milky Way galaxy.

2. Data

2.1 Cosmic expansion

In the 90s two teams studying Type Ia supernovae presented independent evidence that the expansion of the Universe is speeding up (Perlmutter & Riess, 1999; Perlmutter et al., 1999; Riess et al., 1998). The data used for the discovery of the expansion

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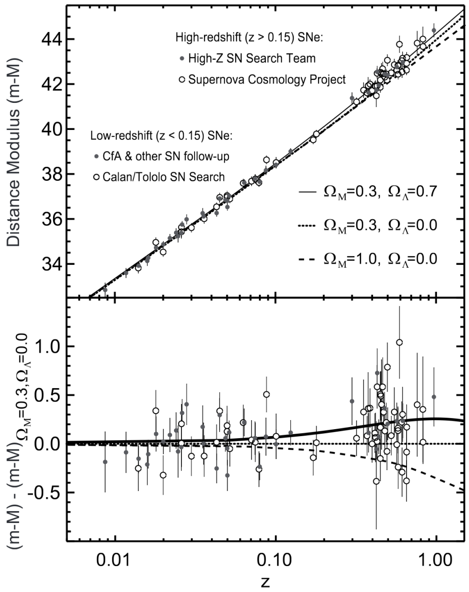

Figure 1: Figure adapted from Perlmutter & Schmidt (2003). The top panel shows the Hubble diagram of SNe Ia measured by the Supernova Cosmology Project and the High-z Supernova Team. The lines represent cosmic models with different sets of parameters for the energy density of matter, Ω_m and dark energy density, Ω_Λ. The lower bottom shows residuals in distance modulus relative to an open universe ($\Omega_{\rm M} = 0.3$, $\Omega_\Lambda = 0.0$).

of the universe is shown in Fig. 1. The solid curve shows the best fit to the data indicating a closure parameter of $\Omega_{\rm M} = 0.3$ for ordinary matter and $\Omega_\Lambda = 0.7$ for the cosmological constant or another yet unknown type of energy called dark energy. By removing the Hubble slope in the upper panel, the trends with cosmological redshift z become clearer. This is shown in the lower plot which plots the residuals in distance modulus relative to an open, non-accelerating universe ($\Omega_{\rm M} = 0.3$, $\Omega_\Lambda = 0.0$). The part of the curve with a positive slope indicates a phase of acceleration and the part with a downward slope corresponds to a deceleration phase of the universe (Perkins, 2005). While at high redshifts the curve with a downward slope dominates, it shows an upward slope for recent redshifts. Therefore, both teams found that low-z SNe are dimmer than they would be in a decelerating universe, indicating that the expansion has been speeding up for the last 5 Gyrs (Perlmutter et al., 1999; Riess et al., 1998). This discovery of the recent cosmic acceleration is arguably one of the most important findings in modern cosmology.

2.2 Formation of habitable stellar systems

The research done by von Bloh et al. (2003) and Franck et al. (2007) raises even more questions about the recent occurrence of the expanding phase of the universe. In principle, they investigate the probability of panspermia, i.e. the transport of life within stellar systems (interplanetary panspermia) or even between different stellar systems (interstellar panspermia). A first hypothesis about panspermia was already formulated by Arrhenius & Borns (1908) over a century ago and proposes that life originated on a different planet and was transported to earth through the interplanetary or even interstellar space. Now, besides the ongoing discussion if simple forms of life can survive the harsh conditions, i.e. high vacuum, extreme temperatures or radiation, the main factor for the probability of interstellar panspermia is the average density of stellar systems containing habitable planets. For the calculation of this density, it is necessary to adopt a definition for habitability. In contrast to previous investigations, where only the presence of liquid water is required, von Bloh et al. (2003) and Franck et al. (2007) define the habitable zone (HZ) as the region around a central star within which an Earth-like planet has a non-vanishing biological productivity. Thus, habitability does not just depend on the parameters of the central star, but also on the properties of the planet itself. The habitable zone is therefore strongly influenced by the CO_2 concentration and the photosynthetic activity of the planet and hence by the planetary geodynamics. This introduces further spatial and temporal evolution of the habitable zone as it becomes narrower with time due to the persistent loss of the atmospheric CO_2 concentration. This consideration together with the dynamical evolution of the HZ in a stellar system yields the probability, $p_{\rm hab}$, that a stellar system hosts a habitable Earth-like planet.
Furthermore, for the determination of the absolute number of stellar systems containing habitable planets in the Milky Way, $N_{\rm hab}(t)$, the planet formation rate (PFR) and the star formation rate (SFR), yielding the evolution of the metallicity μ, need to be determined beforehand. Then, the absolute number of stellar system containing habitable planets as a function of time is a convolution integral

$$N_{\rm hab}(t) = \int_0^t PFR(t') \cdot p_{\rm hab}(t - t') \mathrm{d}t' ,$$

where $p_{\rm hab}$ is the probability that a stellar system hosts a habitable Earth-like planet at time Δt after

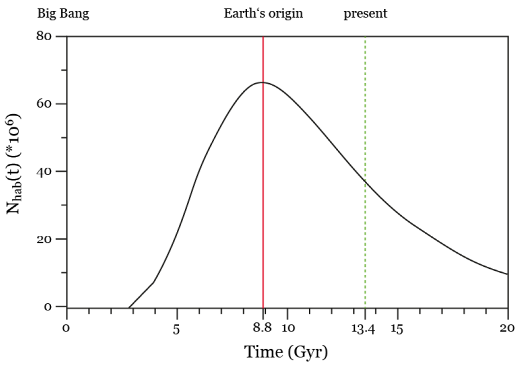

Figure 2: Figure adapted from von Bloh et al. (2003) and Franck et al. (2007). The number of stellar systems containing habitable planets, $N_{\rm hab}$, plotted as a function of cosmological time for the Milky Way.

its formation. Fig. 2 shows the temporal evolution of the number of stellar systems within the Milky Way that contain habitable planets as a function of cosmological time. The curve peaks at a distinct maximum at around 8.5 Gyr. This vast number of stellar systems that should contain planets in the HZ and hence life, supports the idea (mediocrity principle) that there is nothing special about the Earth which is also formed at the peak around 8.5 Gyr.

3. Is there a connection between the formation of habitable planets and the onset of cosmic expansion?

For the further discussion one can assume that the physics is the same everywhere in the universe and that the SFR and PFR are similar for all other spiral galaxies. Thus, the result shown in Fig. 2 should apply at least for all spiral galaxies throughout the universe.

With the mentioned data in Sect. 2 the question about the cosmological coincidence problem is even more intriguing if we plot the curve for the evidence for the expansion of the universe in the same plot as the number of stellar systems containing habitable planets, both as a function of cosmological time. This is shown in Fig. 3.

At around 6 Gyrs the curve for luminosity differences shows a prominent maximum, indicating the transition from a decelerating universe to a phase of acceleration. This can also be clearly seen in Fig. 4 where residuals in distance modulus and the first derivative and second derivative are plotted

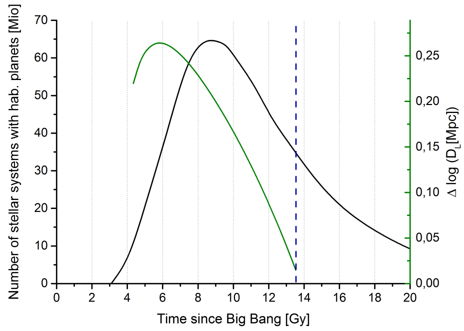

Figure 3: The curves of Fig. 1 and Fig. 2 shown in the same plot as a function of cosmological time, t. Black curve/left ordinate: Number of stellar systems containing habitable planets, $N_{\rm hab}$ in our Milky Way galaxy. Green curve/right ordinate: residuals in distance modulus relative to an open universe, now as a function of time after the Big Bang. The vertical line represents the present time on the time axis.

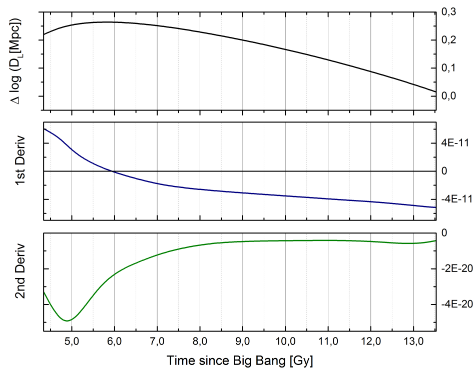

Figure 4: Top panel: best fit curve for residuals in distance modulus relative to an open universe as a function of time, see Fig.1. Middle panel: first derivative of the curve of residuals indicating decelerating/accelerating phases of the universe. Bottom panel: second derivative indicating the strength of the change in deceleration/acceleration.

as a function of cosmological time. The sign of the derivative determines the deceleration and the acceleration of the universe. As the curve is plotted as a function of cosmological time, t, instead of cosmological redshift-z, as shown in Fig. 1, the acceleration and deceleration switch sign in the derivative, i.e. a positive sign corresponds to a decelerating universe while a negative derivative indicates an accelerating expansion.

From the first derivative it is obvious that the

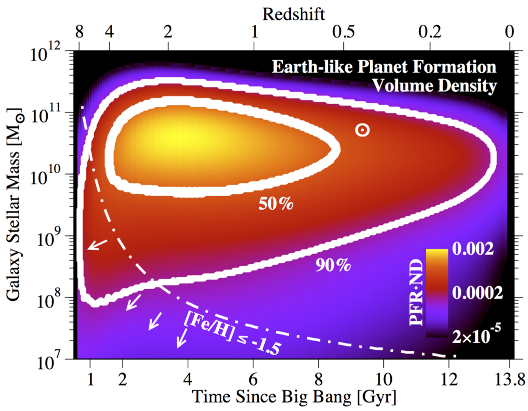

Figure 5: Figure and text adopted from Behroozi & Peeples (2015). Earth-like planet formation rate multiplied by galaxy number density as a function of stellar mass and cosmic time, i.e., the volume density of planet formation (in planets/yr/comoving Mpc^3/dex). Contours indicate where 50% and 90% of all planet formation has taken place. The symbol indicates the Milky Way's stellar mass and age at the formation of the Solar System.

transition from deceleration to acceleration occurs where the derivative changes sign, i.e. around 6 Gyrs. However, the influence of any physical mechanism on the dynamics of the universe has already occurred earlier by slowing down the deceleration. This can be detected by the investigation of the second derivative that shows the rate of change of the first derivative and hence the changes in the cosmic dynamics. The influence on the change of the deceleration has already started well before 4.5 Gyrs and coincides with the formation of first habitable stellar systems. The change of the cosmic dynamics is largest around 5 Gyrs and corresponds to the largest formation rate of habitable stellar systems as can be seen in Fig. 5 from Behroozi & Peeples (2015), which shows a newly determined planet formation rate of Earth-like planets in dependence of galaxy mass and cosmic time. They define Earth-like (i.e., habitable zones) with respect to planets that possess an Earth-like atmosphere and can support stable surface reservoirs of liquid water. This includes objects whose radii and orbital periods are within a factor of e of those of the Earth.
If the acceleration/deceleration of the cosmos, indicated by the first derivative in Fig. 4, is influenced by the absolute number of habitable stellar systems, as shown in Fig. 2, then the formation rate of Earth-like planets would influence the rate of change of the acceleration/deceleration, indicated by the second derivative. The PFR determined by Behroozi & Peeples (2015) shows a burst of newly formed Earth-like planets between 2 Gyrs and 8 Gyrs. This period of time accounts for about 50% of all planet that have been formed. As is shown in Fig. 4, this corresponds very well with the strong change in dynamics of the cosmic expansion going from a phase of deceleration to acceleration.

4. Conclusion

To the knowledge of the author, the above mentioned correlation has never been discussed before and raises the question if it is just a mere coincidence or if this is pointing to undiscovered physical effects and processes connected to the complex chemistry appearing on habitable planets such as the formation of complex organic compounds that are the building blocks of life? Maybe the coincidence can help to distinguish between the many theories, e.g. theoretical models of coupled quintessence, trying to explain the nature of the dark energy?
These questions can not be answered up to date, nonetheless, an interpretation of the coincidence needs to be carried out in order to investigate if this is just a mere coincidence or if there might be observational evidence of presently unknown physical mechanisms. This investigation will be carried out in a subsequent paper.

References

Arrhenius, S. A. and Borns, H. 1908.

Behroozi, P. and Peeples, M. S. 2015, Monthly Notices of the RAS, 454, 1811–1817.

Caldwell, R. R. and Kamionkowski, M. 2009, Annual Review of Nuclear and Particle Science, 59, 397–429.

Franck, S., von Bloh, W., and Bounama, C. 2007, International Journal of Astrobiology, 6, 153–157.

Perkins, B. 2005. Oxford University Press.

Perlmutter, S., Aldering, G., Goldhaber, G., Knop, R. A., Nugent, P., Castro, P. G., Deustua, S., Fabbro, S., Goobar, A., Groom, D. E., Hook, I. M., Kim, A. G., Kim, M. Y., Lee, J. C., Nunes, N. J., Pain, R., Pennypacker, C. R., Quimby, R., Lidman, C., Ellis, R. S., Irwin, M., McMahon, R. G., Ruiz-Lapuente, P., Walton, N., Schaefer, B., Boyle, B. J., Filippenko, A. V., Matheson, T., Fruchter, A. S., Panagia, N., Newberg, H. J. M., Couch, W. J., and Project, T. S. C. 1999, Astrophysical Journal, 517, 565–586.

Perlmutter, S. and Riess, A. 1999, In Caldwell, D. O., editor, COSMO-98, volume 478 of American Institute of Physics Conference Series, pages 129–142.

Perlmutter, S. and Schmidt, B. P. 2003, In Weiler, K., editor, Supernovae and Gamma-Ray Bursters, volume 598 of Lecture Notes in Physics, Berlin Springer Verlag, pages 195–217.

Riess, A. G., Filippenko, A. V., Challis, P., Clocchiatti, A., Diercks, A., Garnavich, P. M., Gilliland, R. L., Hogan, C. J., Jha, S., Kirshner, R. P., Leibundgut, B., Phillips, M. M., Reiss, D., Schmidt, B. P., Schommer, R. A., Smith, R. C., Spyromilio, J., Stubbs, C., Suntzeff, N. B., and Tonry, J. 1998, The Astronomical Journal, 116(3), 1009.

von Bloh, W., Franck, S., Bounama, C., and Schellnhuber, H.-J. 2003, Origins of Life and Evolution of the Biosphere, 33, 219–231.