Social distancing between particles and objects in the Universe

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Accepted today. Received today; in original form today

ABSTRACT

The novel coronavirus, dubbed COVID-19, upended our lives maybe in irreversible ways during its initial spread throughout the world in March 2020. It forced us all, willingly or unwillingly, to keep social distance from each other to slow down the spread of COVID-19. As scientists, we started speculating what kind of separation is between the constitutes of different objects in the Universe. In this work, we study the “social” distance between elements inside various objects, no matter their size, mass, and nature. We consider things ranging from diamond, baseball to Saturn, asteroid belt or M87 Black Hole, to name a few. We show our results in the form of a fascinating mass/”social” distance plot, where a cool cartoon figure represents each object.

Key words: COVID19 – Social Distancing

1 INTRODUCTION

China reported a novel coronavirus (COVID-19) in Wuhan, Hubei Province, on December 31, 2019 (Gralinski & Menachery 2020). The COVID-19 pandemic is considered the greatest public health threat since the 1918 Influenza Pandemic that infected one-third of the world’s population and killed at least 50 million people. COVID-19 cases and fatalities were and are still growing exponentially and there is much uncertainty about its ultimate impacts globally (Greenstone & Nigam 2020). One of the key questions of public health epidemiology is how individual actions can help mitigate and manage the costs of such a pandemic (Reluga 2010).

Social distancing is an aspect of human behavior particularly important to epidemiology because of its universality; everybody can reduce their contact rates by changing their behaviors. Theoretical work on social distancing has been stimulated by studies that indicate that small changes in behavior can have large effects on transmission patterns during an epidemic (Del Valle et al. 2005).

Astronomers study, among other things, (most often large) objects and their meaningful properties. The bulk of the job is heavily based on research, as the focus is on understanding how the universe works, and on trying to discover things about the universe that would be considered scientific breakthroughs (CareerExplorer 2019). To help the world during these difficult times, we visualized the social distancing between particles and object in the Universe to get a better view on how far 1.5 meter actually is between two humans. The final result can be found in figure B1.

This paper is organized as follows. In Section 2 we describe the method and calculations describing how we find the values for the object mass and the social distancing property. In Section 3 we present our conclusion. Finally we list the physical constants in Appendix A and our figure in Appendix B.

2 METHODS

Below we describe how we determined the mass and distance between the objects.

| Mass (kg) | u | N | Distance (m) |
|-----------|---|---|-------------|
| Water     | 1 | 18.02 | 3.34E25 | 3.10E-10 |
| Uranium   | 19.05 | 238.03 | 4.82E25 | 2.75E-10 |
| Baseball  | 0.15 | 68.12 | 6.19E24 | 5.45E-10 |
| Diamond   | 0.00012 | 12.01 | 1.76E26 | 1.78E-10 |

Table 1. The table shows the mass in kilogram, molecular weight in u, amount of molecules in 1 dm³ and the distance between the molecules in m. For the baseball we took molecular weight of Polyisoprene (Jones & Harris 1992).

2.1 Objects on earth

We considered 5 different objects one can find on earth: water, uranium, a baseball and a diamond. For this objects we take the weight of 1 dm³, or in case of the baseball and diamond the average weight of the object. this gives us the values shown in table 1. To determine the molecular distance between the particles we find the number of molecules in 1 dm³ and use $D = \frac{1}{\sqrt{N}}$, where N is the number density. The distance between the molecules is given in table 1.

2.2 Humans

The average weight of an adult in Europe is 70.8 kg and Asia is 57.7 kg (data from 2005, Walpole et al. 2012), for the population in Sweden and COVID-restricted we use the European average weight and for the population in Hong Kong we’ll use the Asian average weight.

In table 2, one can see the population, surface area and average distance between inhabitants of Sweden and Hong Kong. For the distance we use $D = \frac{1}{\sqrt{N}}$, where N is the population density. Data is from World Bank (2021). In Switzerland a social distancing of 1.5 metres is maintained during COVID times (Federal Office of Public Health 2021).

1 0.6 carat

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we have \( M = \frac{32\pi G^3 (6.5 \times 10^9 M_\odot)^2 m_p}{3c^2} \) \( 1 \)

Supermassive Black hole with approximate mass \( M_{\text{Bh}} \approx 6.5 \times 10^9 M_\odot \) at the centre of Messier 87 or M87 elliptical Galaxy at a distance of around 54 million ly (Akiyama et al. 2019).

If we divide the solar radiation intensity \( I_\odot \), by the energy of solar photons \( E = h\nu / \lambda_\odot \), we get the number density flux. By further division by speed of light, we obtain number density

\[
n_\odot = \frac{\lambda_\odot}{4\pi h c^2 (1\text{AU})^2} = 1.2 \times 10^{13} \text{ m}^{-3}
\]

and therefore the interparticle distance can be achieved

\[
l_\odot \approx n_\odot^{-1/3} = 5 \times 10^{-5} \text{ m}.
\]

Although the photons are massless particles, we can assign a mass to them based on their energy as

\[
M_\odot^\gamma = \frac{h}{\lambda_\odot c} = 4 \times 10^{-36} \text{ kg}
\]

2.7 Nuclear star cluster

\( M = M_\odot \) & \( r = 0.03 \text{ pc} \)

Massive compact star cluster with high density and high luminosity found near the centre of most galaxies. Dwarf galaxies with no central supermassive black hole usually host nuclear star cluster at their centre.

If we have a nuclear star cluster with total mass of \( 10^6 M_\odot \) and effective radius of \( 3 \text{ pc} \) hence for \( M = M_\odot \) we have \( r = 0.03 \text{ pc} \).

2.8 Locust swarm

\( M = 0.002 \text{ Kg} \) & \( r = 0.13 \text{ m} \)

Swarm of short-horned grasshoppers, which are initially innocuous solitary beings later turned into swarmy winged gregarious insects under suitable conditions. In this later phase, they start destroying the agricultural entities. If we assume on an average mass of 2g per locust then for locust swarm density of 60 million per km\(^2\) we get \( r = 0.13 \text{ m} \).

2.9 Solar photons on Earth

\[
l_\odot = \int B(\lambda, T) \text{d}\lambda
\]

with \( T_\odot = 5777 \text{K} \)

\[
B(\lambda, T) = \frac{2\pi c^3}{\lambda^5} \left( \frac{1}{e^{\frac{\lambda k_B T}{\hbar c}} - 1} \right)
\]

Solar luminosity \( L_\odot = I_\odot (4\pi 1\text{AU})^2 \) \( \approx 4 \times 10^{26} \text{ W/s} \).

If we divide the solar radiation intensity \( I_\odot \) by the energy of solar photons \( E = h\nu / \lambda_\odot \), we get the number density flux. By further division by speed of light, we obtain number density

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\]

Although the photons are massless particles, we can assign a mass to them based on their energy as

\[
M_\odot^\gamma = \frac{h}{\lambda_\odot c} = 4 \times 10^{-36} \text{ kg}
\]
After plugging in the specific values, namely $T = T_{\text{CMB}} = 2.73$ K, we get $n_{\text{eq}} = 1.65 \cdot 10^6$ m$^{-3}$. From number density, it is easy to obtain the average social distance between specific photons

$$l_{\text{CMB}} = n_{\text{eq}}^{1/3} = 8 \cdot 10^{-3} \text{ m.}$$

(11)

Similar to the previous calculation, we can get the mass as

$$M_{\text{CMB}}^2 = \frac{\hbar}{\lambda_{\text{CMB}} c} = 1.1 \cdot 10^{-29} \text{ kg}$$

(12)

with $\lambda_{\text{CMB}} = 2$ mm.

2.11 Cold atoms

Here, we refer to the experiments with cold atoms in optical lattices. The social distance of cold atoms is given by the half-wavelength of laser generating periodic potential. We use data from Landig et al. (2016), where rubidium atoms of laser generating periodic potential. We use data from Landig et al. (2016), where rubidium atoms $87\text{Rb}$ were trapped in potential generated by laser with wavelength $\lambda = 785.3$ nm. So the cold atoms social distance is $\lambda/2 = 3.9 \cdot 10^{-7}$ m and the particle mass $m_{87\text{Rb}} = 87m_p = 1.4 \cdot 10^{-25}$ kg.

2.12 WIMP background

We assume that all the dark matter content of the Universe is made of standard WIMPs (weakly interacting massive particles) with mass 100 GeV. Using the Planck 2018 results (Planck Collaboration et al. (2021)), we take $\Omega_m = 0.315$, $\Omega_b = 0.049$. So $\Omega_{dm} = \rho_{dm} / \rho_c = \Omega_m - \Omega_b = 0.266$. With $\rho_c = \frac{3H^2}{8\pi G}$ and $H = 67.37$ km/s/Mpc, the mass density of WIMP background can be estimated as

$$\rho_{dm} = \Omega_{dm} \rho_c = 0.266 \times 9 \cdot 10^{-27} \text{kg/m}^3 = 2.4 \cdot 10^{-27} \text{kg/m}^3$$

and therefore number density $n_{\text{WIMP}} = 1.3 \cdot 10^{-2} \text{m}^{-3}$. As a result, the social distance between WIMP particles is $l_{\text{WIMP}} \approx 4.2 \text{ m}$.

2.13 Giant planets/Saturn (core)

We will pick Saturn as a representative of giant planets. According to Mankovich & Fuller (2021), the Saturn’s core extends as far as up to 60% of the planet’s radius. The cited study models the core density profile, reaching $\rho_{\text{core}} = 7$ g/cm$^3$ at the centre of the planet and decreasing with larger radii. For the sake of this approximation, we take an average core density to be $\rho_{\text{core,av}} = 3.5$ g/cm$^3$ (estimated from Fig.2b of Mankovich & Fuller (2021)), and assume the core composed mostly of iron. This gives a number density of $n = \rho_{\text{core,av}} / 56m_p = 3.7 \cdot 10^{22}$ cm$^{-3}$. Mean social distance can be then easily obtained and gives $l_{\text{core}} = 3.0 \cdot 10^{-10}$ m.

2.14 Oort cloud

The quantitative description of Oort cloud is still very challenging and there is many uncertainties in the physical details of the system. In our work, we adopt the properties of Oort cloud from Correa-Otto & Calandra (2019). We assume the Oort cloud to be a spherical system starting at approximately $r_0 = 32$ AU measured from the centre of Solar system, where 1AU = 1.5 $\cdot 10^{11}$ m and reaches as far as $R \sim 10^4$ AU. Further we assume, that the total number of particles it contains (planetesimals, comets, asteroids,...) is $N = 10^{31}$ and the total mass of the Oort cloud $M_{\text{total}} \sim 10M_\odot$. In agreement with Correa-Otto & Calandra (2019), we assume the density profile of Oort cloud scaling as $\rho \sim r^{-3.5}$. In the case of spherical symmetry, for the total number of objects holds

$$N = \rho_0 \int_0^R 4\pi r^2 dr = 6\pi \rho_0 \left[ \frac{1}{\sqrt{r_0}} - \frac{1}{\sqrt{R}} \right].$$

(14)

We as the Oort cloud size is significant and so is the density difference in the inner and outer edge, we will calculate the characteristic social distance in these two regions. For the inner region number density, one can write

$$n_{\text{in}} = \frac{\rho_0}{r_0^{3.5} M_{\text{OC}}},$$

(15)

where $M_{\text{OC}} = M_{\text{total}} / N$ is the average mass of the Oort cloud object. We assume that the average mass in the inner and outer region is similar. For social distance at $r = r_0$, we obtain

$$l_{\text{in}} = \frac{1}{n_{\text{in}}^{1/3}} = r_0 \left[ \frac{6\pi}{N} \right]^{1/3} \left[ 1 - \sqrt{\frac{r_0}{R}} \right].$$

(16)

Analogously, number density in the outer region can be expressed as

$$n_{\text{out}} = \frac{\rho_0}{R^{3.5} M_{\text{OC}}}$$

(17)

and the average social distance then follows

$$l_{\text{out}} = \frac{1}{n_{\text{out}}^{1/3}} = R \left[ \frac{6\pi}{N} \right]^{1/3} \left[ 1 - \frac{R}{r_0} \right].$$

(18)

Using the introduced values of Oort cloud properties, the social distances result into $l_{\text{in}} = 2.7 \cdot 10^3 \text{m} \sim 0.018 \text{AU}$ and $l_{\text{out}} = 2.2 \cdot 10^{12} \text{m} \sim 15 \text{AU}$. The average object mass $M_{\text{OC}} = 6 \cdot 10^{14}$ kg.

2.15 Global IGM

The global intergalactic medium (IGM) is the baryonic matter in the regions in between galaxies and galaxy clusters. It is made up mostly of ionized hydrogen (Meiksin 2009), so the average mass of its constituent particles can be estimated as approximately one proton mass $m_p$. Taking the most recent results from Planck (Planck Collaboration et al. 2021) for the density parameter of baryonic matter in the universe, $\Omega_b$0. Together with the critical density of the universe, $\rho_{\text{crit}}$, we can estimate the average density of the baryonic matter, $\rho_{b,0}$, in the IGM.

$$\rho_{b,0} = \rho_{\text{crit}} = \Omega_{b,0} = 0.0493 \pm 0.035$$

(19)

with

$$\rho_{\text{crit}} = \frac{3H_0^2}{8\pi G}$$

(20)

For the calculation of the critical density we will use the most recent result for the Hubble parameter from (Planck Collaboration et al. 2021).

$$H_0 = 67.36 \pm 0.54 \text{ km s}^{-1}\text{Mpc}^{-1}$$

(21)

and hence the baryonic matter density is estimated as

$$\rho_{b,0} \approx 4.2 \cdot 10^{-28} \text{ kg m}^{-3}$$

(22)
which, assuming only protons, translates to

\[ n_{b,0} = 2.5 \cdot 10^{-1} \text{ m}^{-3} \quad (23) \]

Assuming the IGM particles are distributed evenly in a cubic volume, their average inter-particle distance is therefore

\[ d_{\text{IGM}} \approx 1.6 \text{ m} \quad (24) \]

2.16 Intra-cluster IGM

The intra-cluster IGM is the baryonic matter that is in between galaxies in galaxy clusters. Similarly to the global IGM, it consists of mostly ionized hydrogen gas (Sarazin 1986), so we estimate the average particle mass to be one proton mass \( m_p \). The intra-cluster medium however is denser and hotter than the average global IGM as infalling material releases gravitational energy into the medium. Due to its high temperature, it emits strong X-ray radiation whose spectrum can be well explained by thermal bremsstrahlung (Felten et al. 1966; Mushotzky et al. 1978). Its average density can then be estimated from X-ray Luminosity measurements, which lead to a typical average intra-cluster IGM number density of approximately \( 10^{-3} \text{ cm}^{-3} \) (Felten et al. 1966; Sarazin 1986; Loewenstein 2003).

From the number density, it is straightforward to estimate the social distance in a cubic volume of the intra-cluster IGM as \( d_{\text{data}} \approx 0.1 \text{ m} \), which is an order of magnitude less than that of the one in the global IGM.

2.17 ISM

The interstellar medium is the baryonic matter that fills the space between the stars of the Milky Way galaxy. It has been studied thoroughly, and we direct the reader to a review on its properties by (Ferriere 2001) for a detailed summary. Weighted by mass, fifty percent of the ISM is in dense clouds of molecular gas, but these clouds only occupy one to two percent of its total volume. By volume, its main component is warm and mostly ionized hydrogen gas, so again we take the particle mass in the social setting of the ISM to be one proton mass. The average particle density can then be estimated by measuring the intensity of hydrogen Balmer emission lines that are produced after ionized hydrogen combines with a free electron to eventually transition from an excited state with \( n > 2 \) down to \( n = 2 \). These observations lead to an estimated average particle density of approximately \( 1 \text{ cm}^{-3} \). Thus, in a cubic volume, the average social distance in the ISM is estimated to be \( d_{\text{ISM}} \approx 10^{-2} \text{ m} \).

2.18 Dunlin swarm

Some bird species move about collectively and occasionally gather in large swarms in order to feed, mate or to gain safety in numbers. It is an interesting question to ask what is the average interbird distance in such a swarm, and how does this distance relative to the individual bird’s mass compare to the average “social” distance relative to the respective particle masses in the other systems treated in this paper. As a representative example, we estimate the social distance in a swarm of dunlins, which are small birds commonly found near shorelines of arctic and subarctic regions. A typical dunlin weighs \( m_{\text{dunlin}} \approx 50 \text{ g} \). Observations have shown that in a typical dunlin swarm of fifty birds, the average three-dimensional number density is approximately \( 4 \text{ m}^{-3} \) (Major & Dill 2004). This translates to an average interbird distance of \( d_{\text{dunlin}} \approx 0.6 \text{ m} \) in a cubic volume.

2.19 Asteroid belt

The asteroid belt is a torus-shaped region between Mars and Jupiter, ranging from 2AU to 3.4AU, that contains a large amount of solid bodies which cover a wide range of sizes starting at diameters comparable to that of a dust particle and ending at the most massive object, Ceres, with a diameter of 950km. The total amount of mass in the asteroid belt is estimated to be \( 2.39 \cdot 10^{21} \text{ kg} \) (Pitjeva & Pitjev 2018), of which \( 60\% \) are contributed from the four largest objects in it - Ceres, Vesta, Pallas, and Hygiea. Most of the rest of the mass is then found in smaller objects with diameters larger than 1km of which there are estimated to be between \( 7 \cdot 10^5 \) and \( 1.7 \cdot 10^6 \) (Tedesco & Desert 2002). Therefore, on average, their mass is:

\[ m_{\text{asteroid}} = 2.39 \cdot 10^{21} \text{ kg} \times 0.4/10^6 = 9.56 \cdot 10^{14} \text{ kg} \approx 5 \cdot 10^{-16} \text{ M}_\odot \quad (25) \]

Let us estimate the number density of these smaller objects in the asteroid belt by assuming they are equally distributed in an annulus between 2 and 3.4AU (In reality, the objects are neither equally distributed along the angles, nor do they share the same flat plane of orbits, but we believe our simplification suffices for an order of magnitude estimate of the social distance in the asteroid belt). The surface number density of objects is then:

\[ n = \frac{10^6}{\pi \left( (3.4 \text {AU})^2 - (2.0 \text {AU})^2 \right)} \approx 1.87 \cdot 10^{-18} \text{ m}^{-2} \quad (26) \]

From this, we estimate the average distance between the objects to be \( d_{\text{belt}} \approx 7.3 \cdot 10^8 \text{ m} \).

2.20 Air

Assuming a density of \( \rho = 10^{-3} \text{ g/cm}^3 \) and noting that the air consists mostly of Nitrogen molecules \( N_2 \), having a mass of \( 28m_p \), the average inter-particle distance yields:

\[ l = \frac{1}{\sqrt{4 \pi \frac{28m_p}{\rho}}} \approx 2 \cdot 10^{-7} \text{ cm} \]

The number density gives:

\[ n = \frac{\rho}{28m_p} \approx 2.1 \cdot 10^{19} \text{ cm}^{-3} \]

2.21 Lab vacuum

Assuming a vacuum of \( 10^{-6} \text{ mbar} \) (Isolating vacuum of the LHC CERN 2022) and applying the ideal gas equation the number density of molecules yields:

\[ n = P/k_B T = 2.4 \cdot 10^{12} \text{ cm}^{-3} \]

The inter-particle separation is:

\[ l = \frac{\sqrt{3}}{4 \pi n} \approx 2.15 \cdot 10^{-4} \text{ cm} \]

2.22 Rocky planet

Considering the most abundant elements in the earth, 32% Fe, 30% O, 15% Si and 14% Mg Morgan J W (1980), one arrives at a mean molecular weight of \( 33m_p \). The density of the earth is \( \rho = \frac{4 \pi r_e^2}{3 M_\oplus} = 5.5 \text{ g/cm}^3 \). The inter-particle distance follows:

\[ l = \sqrt{\frac{3}{4 \pi} \cdot \frac{33m_p}{\rho}} = 1.3 \cdot 10^{-8} \text{ cm} \]

and the particle density:

\[ n = \frac{\rho/(33m_p)}{= 9.9 \cdot 10^{23} \text{ cm}^{-3}} \]

3 CONCLUSIONS

As already argued, preserving sufficient interpersonal distance has been confirmed to be (among others) a very efficient precaution to
suppress the spread of COVID-19 disease. Thus, we (to significant extent (hopefully)) lived in a society with minimal “interparticle” (human) separation of ~ 1.5 meters. In this work, we took a challenge of bringing up objects from the Earth as well as from the neighbouring or distant Universe across wide variety of scales in terms of masses and “social” (interparticle) distances together and provided a reader with a comprehensive overview of how such “social” distances can be calculated. Moreover, we visualized the chosen objects (credits to Door van Flonkelaar) and created an illustrative figure from which particle masses and “social” distances can be easily read out. In terms of distancing, we range from neutron stars with neutron separations of order ~ $10^{-14}$ m to nuclear star clusters, in which stars are as far from each other as ~ $10^{14}$ m.

From Fig. B1 we can observe that COVID-restricted humans, together with other terrestrial objects, are interestingly very close to the middle of the figure in terms of separation scales (however, one might argue adding even more exotic objects into the plot could modify this observation). During COVID-19, a separation of 1.5 m has shown to be a good compromise (however, some countries may have used 2 meters). However, in case of more severe circumstances, like a possible future Omega - variant, we might be forced to keep larger mutual distances. If we assume the current population (7.9 billion) and the Earth surface area (5.101 million km$^2$), one can estimate a maximum interpersonal separation to be ~ 270 m (in case we could use 100% of the Earth’s surface). Whenever interpersonal distances of higher order of magnitude are needed, it’s hardly imaginable to achieve that on Earth.

However looking at Fig. B1, there is an optimism that, if need be in the future, there are systems in the Universe where such separations are feasible. We don’t even have to look far, within our own solar system we could already do an “Arc of Noah” type mission by giving everyone their own Asteroid to stand on (Politt et al. 2020).

Apart from that, this study does not provide any deeper arguments on how to approach a possibility of such a large “social” distancing or why such a review would practically help us in dealing with paradigm such as COVID-19, but it was fun.

ACKNOWLEDGEMENTS

The authors acknowledges Prof. Prasenjit Saha for insightful discussions and guidance. Furthermore we would like to thank ICS for the existence of the pool room where some of the exciting ideas could emerge.

REFERENCES

Akiyama K., et al., 2019, Astrophys. J. Lett., 875, L6
CERN 2022, A vacuum as empty as interstellar space
CareerExplorer 2019, What does an astronomer do?, https://www.careerexplorer.com/careers/astronomer/
Correa-Otto J. A., Calandra M. F., 2019, Monthly Notices of the Royal Astronomical Society, 490, 2495
Del Valle S., Hethcote H., Hyman J. M., Castillo-Chavez C., 2005, Mathematical biosciences, 195, 228
Federal Office of Public Health 2021, Coronavirus: Measures and ordinances
Feltin J. E., Gould R. J., Stein W. A., Woolf N. J., 1966, ApJ, 146, 955
Ferriere K. M., 2001, Rev. Mod. Phys., 73, 1031
Grainline L. E., Menachery V. D., 2020, Viruses, 12, 135
Greenstone M., Nigam V., 2020, ssnr
Jones F., Harris G., 1992, Journal of Research of the National Institute of Standards and Technology, 97, 335
Landig R., Hruby L., Dogra N., Landini M., Mottl R., Donner T., Esslinger T., 2016, Nature, 532, 476–479
Loewenstein M., 2003, in Carnegie Observatories Centennial Symposium. 4. Origin and Evolution of the Elements. (arXiv:astro-ph/0310557)
Major P. F., Dill L. M., 2004, Behavioral Ecology and Sociobiology, 4, 111
Mankovich C. R., Fuller J., 2021, Nature Astronomy, 5, 1103
Melikog A. S., 2009, Rev. Mod. Phys., 81, 1405
Morgan J W E. A., 1980, Proceedings of the National Academy of Sciences of the United States of America
Mushotzky R. F., Serlemitsos P. J., Smith B. W., Boldt E. A., Holt S. S., 1978, ApJ, 225, 21
Pitjeva E. V., Pitjev N. P., 2018, Astronomy Letters, 44, 554
Planck Collaboration et al., 2021, A&A, 652, C4
Politt A. T., et al., 2020, in 51st Annual Lunar and Planetary Science Conference. Lunar and Planetary Science Conference. p. 2430
Reluga T. C., 2010, PLos computational biology, 6, e1000793
Sarazin C. L., 1986, Reviews of Modern Physics, 58, 1
Tedesco E. F., Desert F.-X., 2002, The Astronomical Journal, 123, 2070
Walpole S. C., Prieto-Merino D., Edwards P., Cleland J., Stevens G., Roberts I., 2012, BMC Public Health, 12, 439
World Bank 2021, World Bank Open Data

APPENDIX A: PHYSICAL CONSTANTS

\[ G = 6.67430(15) \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2} \] (Gravitational Constant)
\[ c = 299792458 \text{ m s}^{-1} \] (Speed of light in vacuum)
\[ k_B = 1.380649 \times 10^{-23} \text{ m}^2 \text{ kg s}^{-2} \text{ K}^{-1} \] (Boltzmann constant)
\[ h = 6.6260715 \times 10^{-34} \text{ m}^2 \text{ kg s}^{-1} \] (Planck’s constant)
\[ N_A = 6.02214076 \times 10^{23} \text{ mol}^{-1} \] (Avogadro constant)
\[ m_e = 9.1093837015(28) \times 10^{-31} \text{ Kg} \] (Mass of electron)
\[ m_p = 1.67262192369(51) \times 10^{-27} \text{ Kg} \] (Mass of proton)
\[ m_n = 1.67492749804(95) \times 10^{-27} \text{ Kg} \] (Mass of neutron)
\[ M_\odot = 1.989847(7) \times 10^{30} \text{ Kg} \] (Solar mass)
\[ M_{\odot} = 5.9726(7) \times 10^{24} \text{ Kg} \] (Earth mass)
\[ H_0 = 67.36(54) \times \frac{10^5}{3.086 \times 10^{24}} \text{ s}^{-1} \] (Hubble constant)
\[ 1ly = 9.4607 \times 10^{15} \text{ m} \] (lightyear)
\[ 1au = 1.495978707 \times 10^{11} \text{ m} \] (astronomical unit)
\[ 1pc = 3.0857 \times 10^{16} \text{ m} \] (parsec)

APPENDIX B: FIGURE

This paper has been typeset from a Ti\TeX\LaTeX\ file prepared by the author.
1: Nuclear star cluster
2: Outer Oort cloud
3: Inner Oort cloud
4: Asteroid belt
5: Humans in Sweden
Figure B1. An illustration of different mass and social (interparticle) distance scales in a selection of terrestrial, astrophysical and cosmological objects or media.