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Space dust and Earth's temperature

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Abstract

The increase of the space dust amount in the Solar system results in the total cooldown of the Earth. This may negatively tell on the evolutionary processes in the ecosystems.
We have calculated the decrease of the Earth's temperature versus different space dust concentrations in the Solar system.

1. Introduction

Based on the study of zodiacal light, it has been determined that the dust concentration near the Earth orbit is 10^{-15}–10^{-13} cm^{-3} [2].
The meteoroid matter average concentration in the near-Earth space is ~10^{-14} cm^{-3} [1], i.e. is close to the basic concentration of dust particles in the Earth orbit area.
The space dust concentration in the Solar system with its very slight long-term changes provides the invariableness of the solar constant and the heat balance of our planet [5, 6, 8].
Far more visible may prove to be the decrease of the Solar constant due to the absorption of the Solar emission by the interstellar dust, in case the Solar system enters a thick galactic dust cloud [3].

2. Absorption of solar emission by space dust

The planet temperature can normally be determined from the heat balance equation binding the flux of energy from the Sun to a planet and the flux of energy emitted be the latter (regardless of the energy coming from the planetary interior) [4, 7]:

$$\sigma T^4 = \frac{1}{4}(1-A)I = \frac{1}{4}(1-A)\frac{I_\oplus}{a^2} \qquad (1)$$

where I – the solar constant for a planet with the semi-major axis a. For the Earth $a_\oplus$=1 AU=15·10^7 km, the Solar constant $I_\oplus$=1370 W·m^{-2}. With the Earth's albedo A=0.30 and no greenhouse effect, the average global temperature of the Earth T=255K; in actual fact, subject to the greenhouse effect, T=288 K.
In case the Solar system enters a space dust cloud, the solar constant decreases and the Earth cools down.
Herein I in the context of the availability of the obscuring matter between the Earth and the Sun ($a_\oplus$=1 AU) is less than $I_\oplus$ and is determined from Bouguer's law:

$$I = I_\oplus \cdot e^{-k}, \qquad (2)$$

where k (AU)$^{-1}$ – the dust matter absorption coefficient in the optical spectrum range.
Thus, the Earth's temperature subject to the existence of the dust layer between itself and the Sun is determined as

$$T = \left(\frac{1-A}{4\sigma}\right)^{1/4} \cdot I_\oplus^{\frac{1}{4}} \cdot \exp\left(-\frac{1}{4}k\right). \qquad (3)$$

Figure 1 shows the Earth's temperature change ΔT for different Δk as a function of the absorption coefficient k. With low Δk it is insignificant. However, if the dust matter absorption coefficient is k=1 (AU)$^{-1}$ (Δk=1), the solar constant for the Earth will decrease e times, up to I=502.6 W/m^2, and the planet temperature will significantly go down: $T_e = 255 \cdot e^{-0.25}$≈198 K =-75 °C. Even with the greenhouse effect raising the average global temperature of the Earth by ΔT≈33°C, it will remain negative (T=-42°C). This drop of temperature may cause the ecocatastrophe and, probably, the vanishing of life.
In such a case, the Sun will get weaker only by one magnitude; its visual exo-atmospheric brightness will be

$$m = m_\odot + 2.5\log\frac{I_\odot}{I} = m_\odot + 2.5\log e = -25.7, \quad (4)$$

where $m_\odot$=-26.8 – its current visible exo-atmospheric brightness and will slightly go red (the color index B-V will increase by 0.7^m). And the man's eye will not note this change in the Sun's brightness.

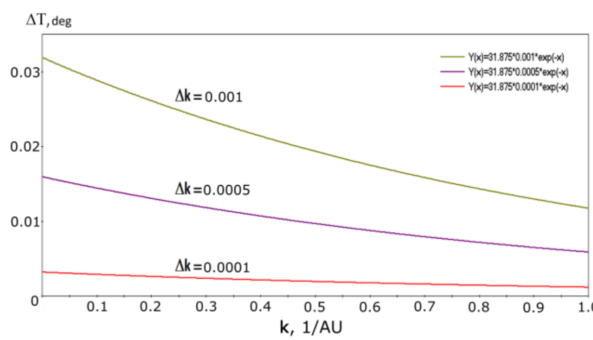

Figure 1: The change of the Earth' temperature with different space dust absorption coefficients

3. Space dust absorption coefficient

The interstellar extinction near the Sun approach in the galactic disc is 2^m per 1 kpc in the V band and varies with the wave length as $\lambda^{-1,3}$. For a star in the galactic disc which is 1 kpc away from us, the absorption in the U, B, and V bands will be $2{,}0^m$, $2{,}7^m$, and $3{,}5^m$, consequently, and the color indices (U–B) and (B–V) will increase by $0{,}8^m$ and $0{,}7^m$.

That means that with the congruence of stellar magnitudes characterizing the absorption, the concentration of particles in the Solar system is supposed to be $206265\cdot10^3$ times as high as in the Milky Way (herein 206265 – the number of astronomical units per parsec). For instance, with k=1 the extinction of light in the Solar system is Δm=1.1 mag/AU, and in the interstellar space – Δm≈20 mag/kpc, which conforms with the absorption in a thick dust cloud.

In the context of the interstellar absorption according to the Mie theory, they consider the case of particles with the 0.5 μ in radius which have the refraction coefficient of 1.33. For this, the coefficient of absorption k is related to the particle concentration n as

$$k = nm. \qquad (5)$$

For Δm=1 kpk^{-1}, the absorption coefficient per particle is $m=10^{-8}$ cm^{-2}, the volumetric coefficient – $\alpha=3\cdot10^{-22}$ cm^{-1}. Hence, $n_0=k/m=3\cdot10^{-14}$ cm^{-3}.

And the absorption coefficient in terms of 1 AU will be $k=4{,}5\cdot10^{-9}$ $(AU)^{-1}$. That is, with the current dust concentration in the Solar system, there is basically no absorption of the solar emission.

4. Solar Motion in Milky Way and Dust in Solar System

Very often we hear the ideas that while moving around the Milky Way centre the Sun enters thick clouds of space dust. This results in the temperature reduction consequently followed by the ice period advent and planet-scale vanishing of life [6, 8, 10]. They refer to glacial periods and the related origination rates of species during the past half billion years [2, 8].

Indeed, the galactic disc makes one revolution nearly during 230 million years. The spiral pattern – density wave – rotates like a rigid body, i.e. with a similar angular rate. Difference between these angular rates is the frequency of the Sun meeting spiral branches [7]. The point is that the spiral pattern rotation rate cannot to be determined directly from observations and is not yet know at present. There is a concept that the Sun is located in the area of the captured rotation of the disc and spiral pattern – "corotation" – and very rarely meets the spiral pattern [7].

5. Summary

Calculations show that even with the increase of dust concentration in the Solar system by five orders of magnitude will not lead to a considerable Earth temperature fall.

According to the current data the Sun can very unlikely enter a thick dust cloud while moving in the Milky Way.

6. References

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