Young Sun, galactic processes and origin of life

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- The problem of the young Sun is part of the great problem of the Sun-Earth interaction. If the Earth were a passive object, then until today the energy of the Sun would not be enough to provide the required temperature. Moreover, the situation is even worse if, we consider the albedo of the frozen Earth. At the same time, there is no doubt that the Earth's temperature was higher than today. This follows from the analysis of the evolution of proteins, and geological data. All external physical mechanisms that could resolve this paradox are either ineffective or have a short duration.

SEE summary slide

Name: Solar Evolution and Extrema (SEE)

Goals and Objectives: 1) To reproduce magnetic activity as observed in the Sunspot and cosmogenic records in dynamo simulations, 2) To amalgamate the best current models and observations for solar spectral and wind output over the Earth's history, and 3) To determine the size and expected frequency of extreme solar events such as flares and coronal mass ejections (CMEs).

Questions: 1) Are we at the verge of a new grand minimum? If not, what is the expectation for cycle 25? 2**) Does our current best understanding of the evolution of solar irradiance and mass loss resolve the "Faint Young Sun" problem? What are the alternative solutions?** 3) For the next few decades, what can we expect in terms of extreme solar flares and storms, and also absence of activity? Another Carrington event? What is the largest solar eruption/flare possible? What is the expectation for periods with absence of activity?

Data/Theory Model: Dynamo models, stellar evolution calculations including mass loss and rotation, early solar wind simulations, observations of solar□type stars, observations of very large events on stars, statistical analysis of event distributions.

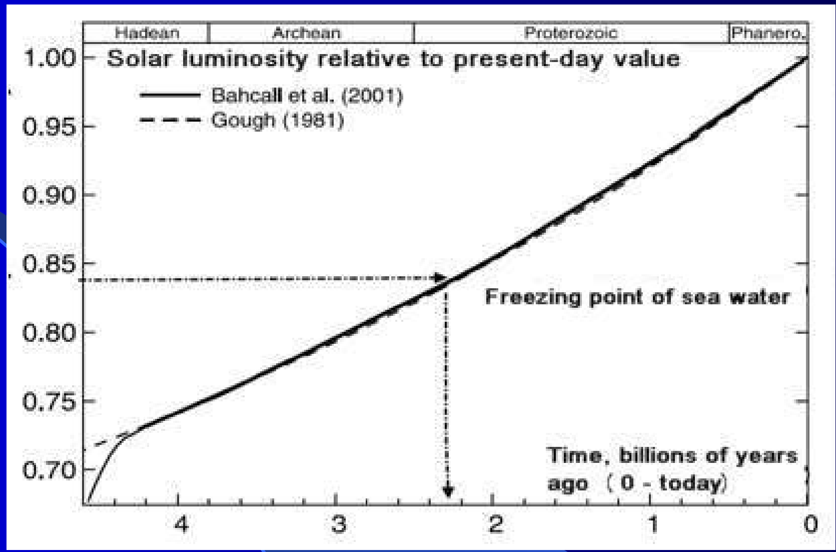
Key Members: Piet Martens, Vladimir Obridko, Dibyendu Nandi

EARLY SUN. Luminosity - 70% of the present value

The standard solar model (SSM) is the result of calculating the evolution of a star of mass equal to 1 Sun provided that at the age of 4.6 billion years the luminosity and radius of the star are equal to the respective present-day solar values.
Calibration - fitting of 2 parameters: the helium content (which is not determined from observations) and parameter a of the convection theory.

+ Simplifications: full spherical symmetry of the problem, no accretion and loss of mass, no mixing outside the convection regions, etc.

The age of the Sun is determined by the age of the oldest meteoric matter as 4.6 billion years.

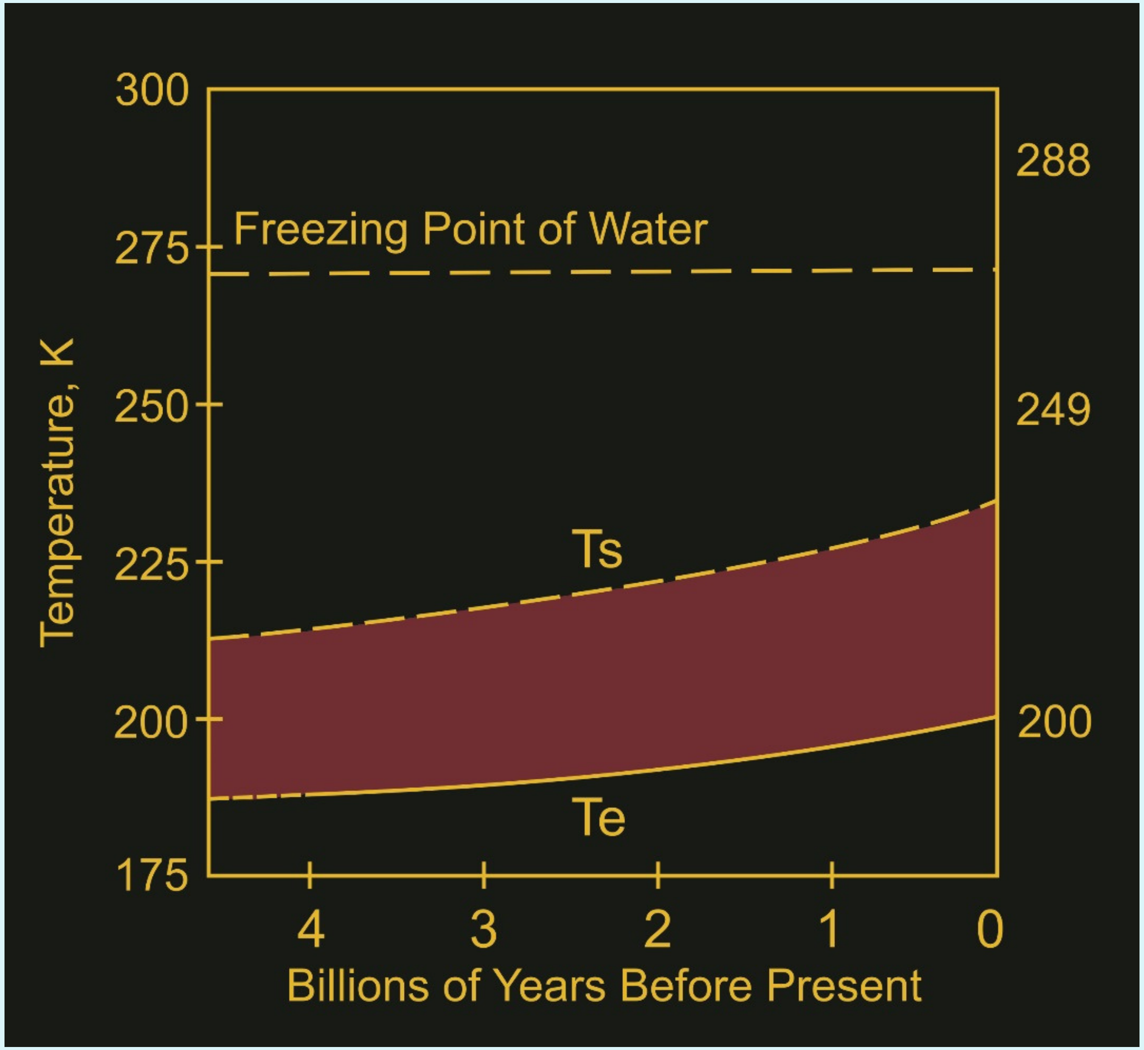


Evolutionary track of the standard luminosity model of the Sun at the stage of the main sequence.

Luminosity of the early Sun – 70% of the present value

Freezing point of the see water corresponds to the luminosity 0, 843 of the present value (half lifetime of the Earth)

Earth temperature with albedo



The effective temperature is calculated for an albedo of 70%.

nature

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LETTERS

Palaeotemperature trend for Precambrian life inferred from resurrected proteins

Eric A. Gaucher[1], Sridhar Govindarajan[2] & Omjoy K. Ganesh[3]

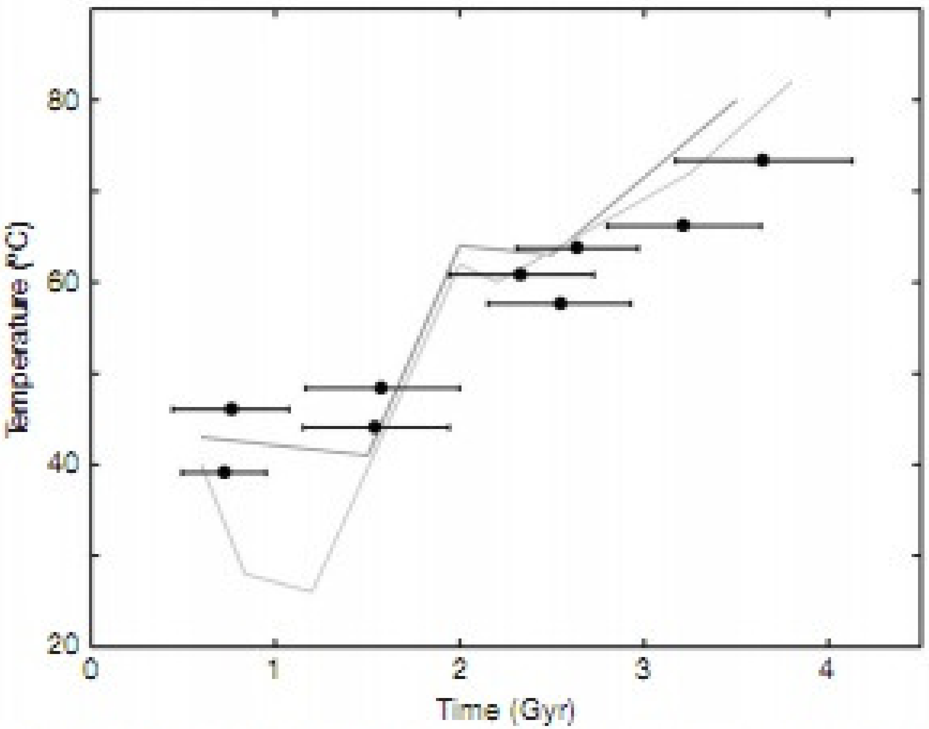
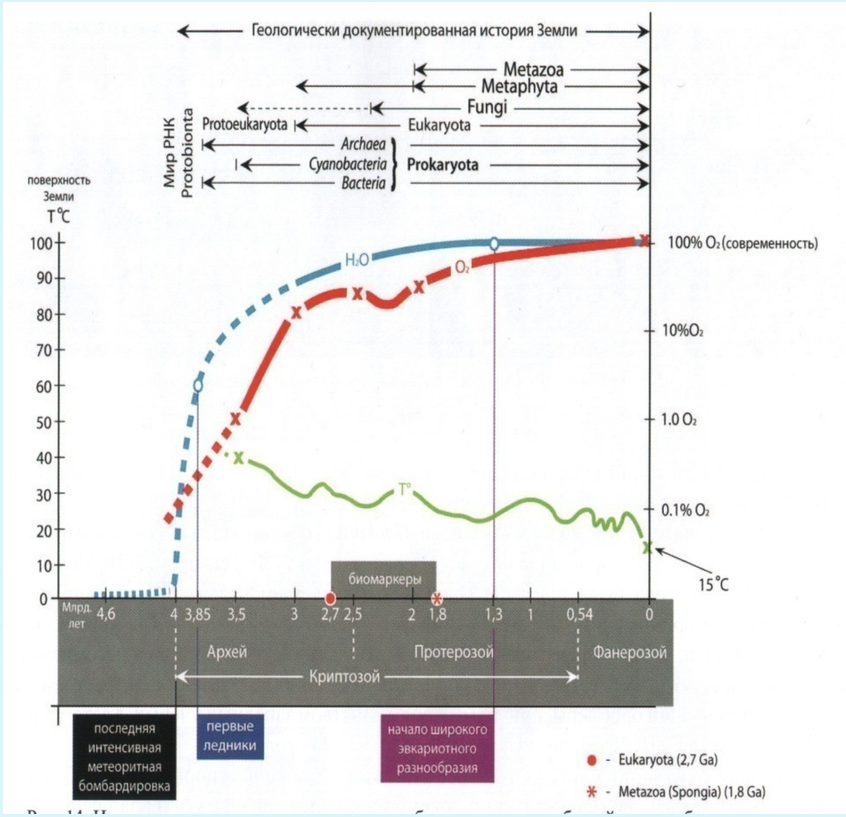


Figure 3 | Plot of ancestral EF melting temperatures against geological time. Molecular clock estimates are shown with their confidence intervals (horizontal bars) from ref. 16, using a 2.3-Ga minimum constraint for the Great Oxidation Event. Solid lines are temperature curves of the ancient ocean inferred from maximum $\delta^{18}O$ (light grey[3,4], dark grey[5]). Although not shown, an analogous trend is seen with $\delta^{30}Si$ isotopes[5].

Pre-biological chemical evolution on the Earth

Organic matter and water are needed. (Water on Earth appeared about 4 billion years ago). Comets. According to Bradley et al. (2014), cosmic dust could be a source of water. Water bubbles are found in IDP particles. They are formed by the action of the solar wind (the interaction with silicates yields free oxygen, which immediately reacts with hydrogen ions H +, forming water molecules).



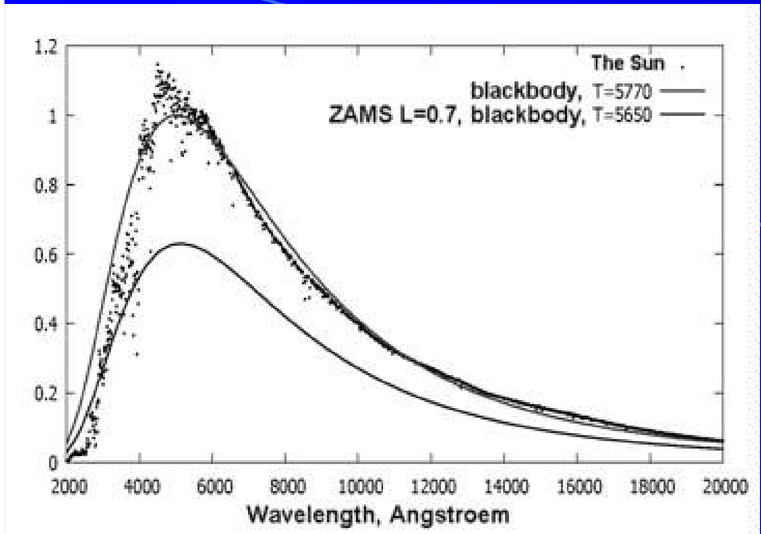
C.Sagan, G.Mullen, July 1972
"Earth and Mars: Evolution of Atmospheres and Surface Temperatures"

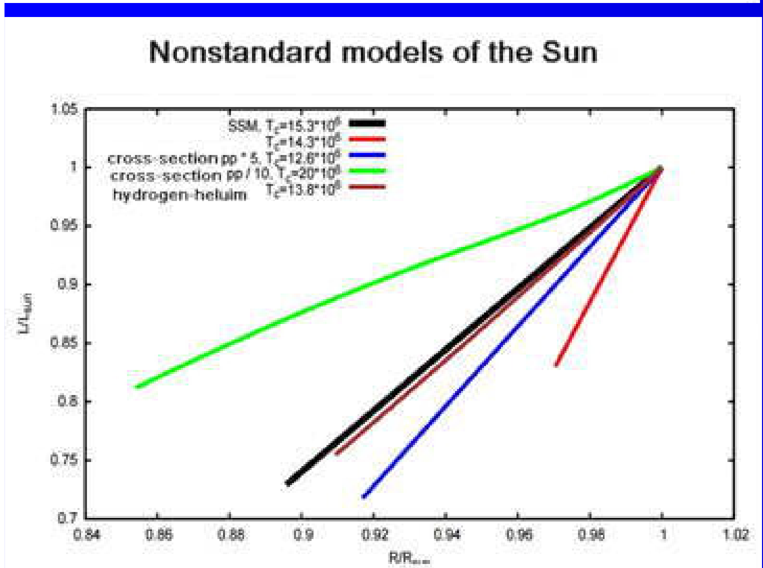
Heat balance for the planet:

$$1/4\,S = (1 - A) = e\,\sigma T^4$$

A - albedo, e - radiant emittance in IR range, S - solar constant,
T - Earth surface temperature.

If
1) A and e are constant during the Earth lifetime
2) S varies in accordance with the luminosity,
then
2.3 billion years ago the oacens had to freeze





Possible solutions:

Different Sun, different Earth, different mutual position

1. Different distance from the Sun to the Earth:

A) Was the mass of the young Sun by 7 % more? (3% for the present).

B) Different positions of the Earth and planets in the Solar system

C) Different gravitation constant

No!

2. Young Sun – did the luminosity change little?

Nonstandard models of the Sun

No!

3. Early Earth – different albedo and heat radiation:

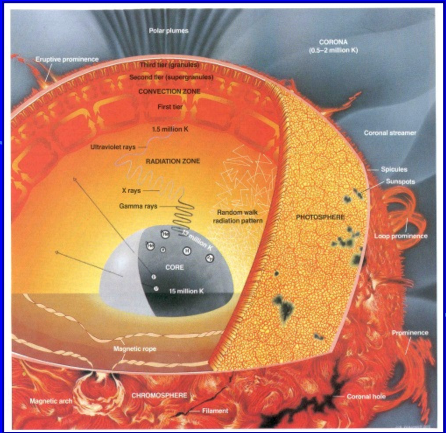
A) Greenhouse gases

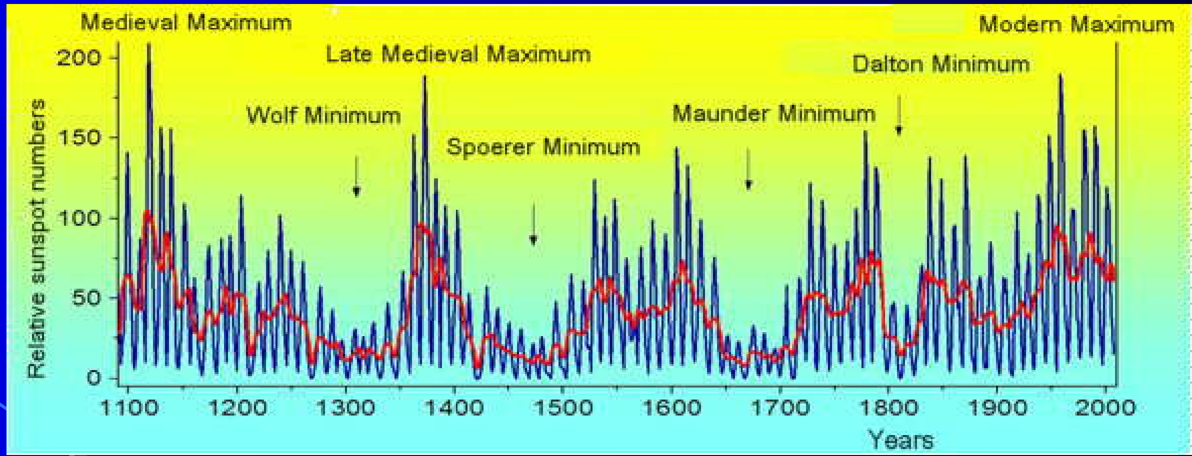
Most probably !

Б) Geothermal super-activity

B) Biogenic factors

Contemporary Sun – rotation period 27-29 days; 11-year cycle of solar activity (SA)





Young Sun = contemporary Sun? NO!

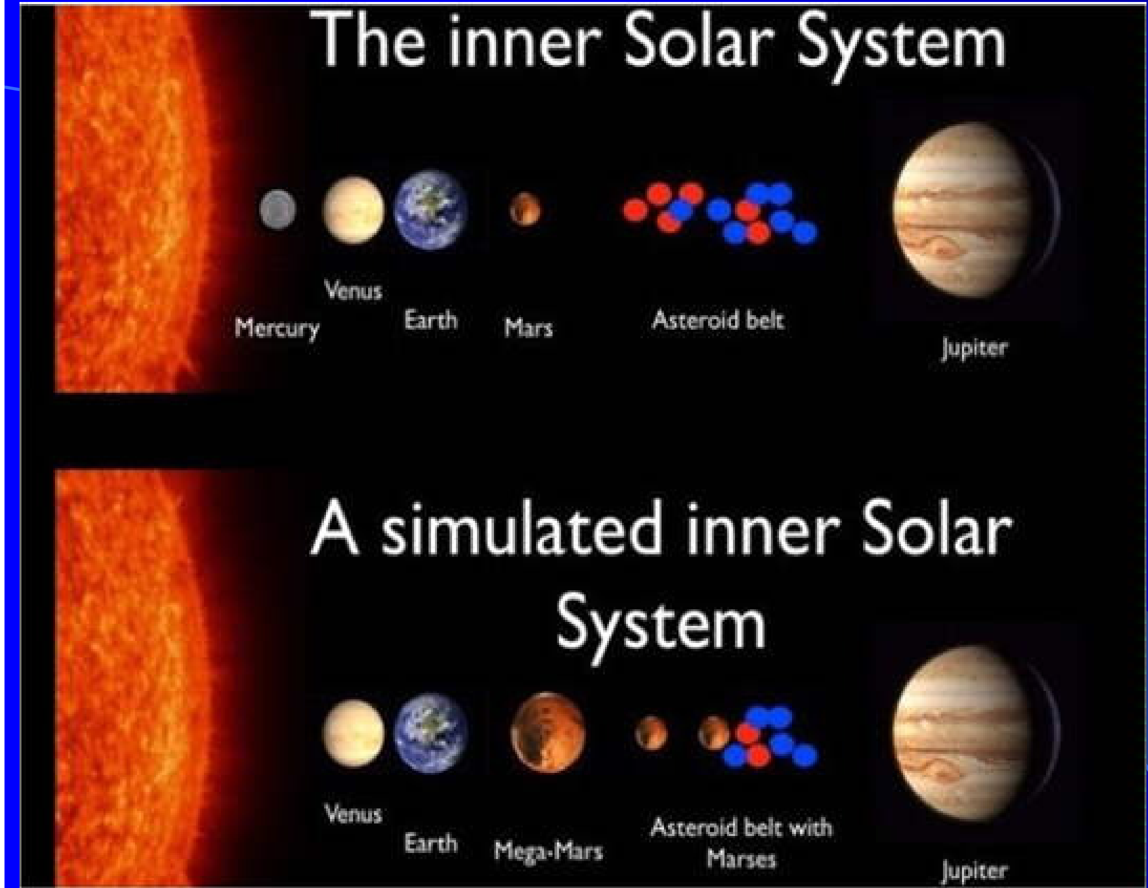
Young Sun

1. Rotation period– 6-8 days, mass up to 103%
2. Activity – unstable and irregular
3. Intensity of radiation - 100-1000 times higher than today, particularly in X-ray and UV ranges (M.Katsova et al., 2018)
4. It is possible that regular cycles were not established immediately, but about 2-2.5 billion of years ago, when the rotation period was 15 days and intensity 5-10 times higher than today (V.V.Pipin, 2015)

Some conclusions

- Most likely, the young Sun is close to the typical stars type BY Dra. Fast braking is then followed by a slower, that should be considered when analyzing the loss of angular momentum and the evolution of solar-type activity.
- Although the luminosity of the young Sun is only 20% less than it is now, the nature of the activity in all the atmosphere height s was significantly different: the spots area is larger 10 times or more,
- Soft X-rays was 2 - 3 orders of magnitude greater.
- The mass loss of the young Sun 2 orders of magnitude more than the present value .
- Analysis of activity of the young Sun shows that in this period there were a strong perturbations of the Earth magnetic field. Fluxes of accelerated partiles (protons with energies of tens of MeV) from longtime flares and CMEs are likely to have been extremely high.

Formation of the Solar system – Migration of Jupiter and Saturn



Early migration of Jupiter towards the Sun and the reverse drift occurred during the first tens of millions of years. This cannot resolve the paradox of the faint Sun.

LETTER

doi:10.1038/nature10201

A low mass for Mars from Jupiter's early gas-driven migration

Kevin J. Walsh[1,2], Alessandro Morbidelli[1], Sean N. Raymond[3,4], David P. O'Brien[5] & Avi M. Mandell[6]

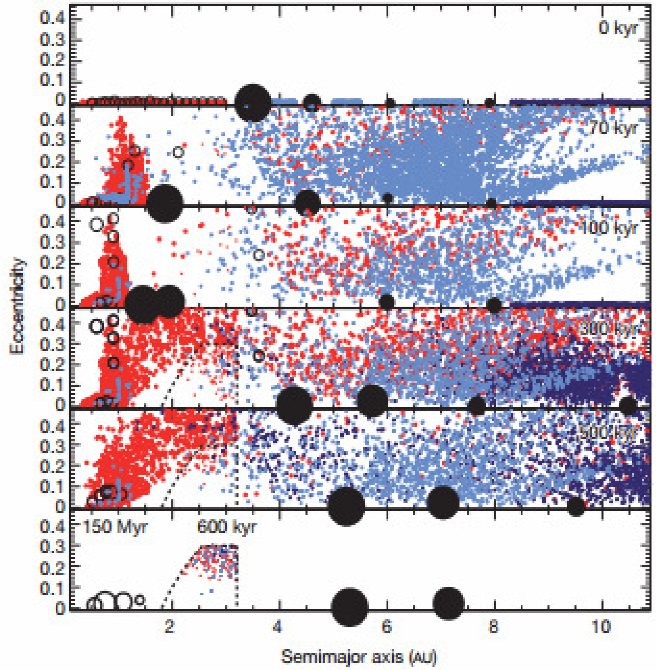
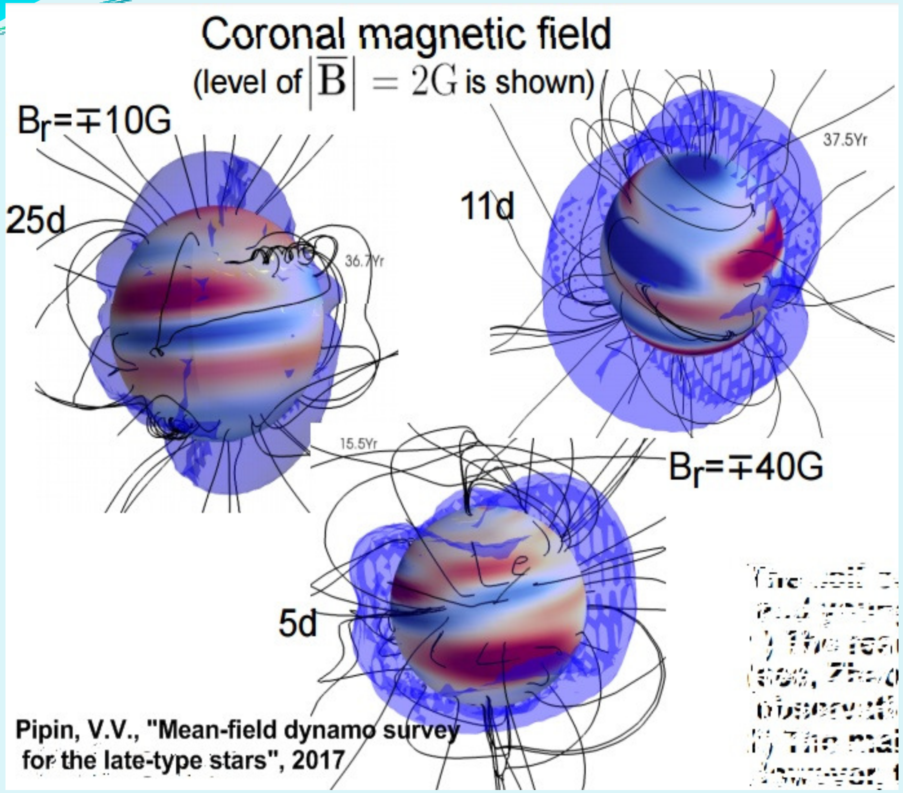


Figure 2 | The evolution of the small-body populations during the growth and migration of the giant planets, as described in Fig. 1. Jupiter, Saturn, Uranus and Neptune are represented by large black filled circles with evident inward-then-outward migration, and evident growth of Saturn, Uranus and Neptune. S-type planetesimals are represented by red dots, initially located between 0.3 and 3.0 AU. Planetary embryos are represented by large open circles scaled by $M^{1/3}$ (but not in scale relative to the giant planets), where M is mass. The C-type planetesimals starting between the giant planets are shown as light blue dots, and the outer-disk planetesimals as dark blue dots, initially between 8.0 and 13.0 AU. For all planetesimals, filled dots are used if they are inside the main asteroid belt and smaller open dots otherwise. The approximate boundaries of the main belt are drawn with dashed curves. The bottom panel combines the end state of the giant planet migration simulation (including only those planetesimals that finish in the asteroid belt) with the results of simulations of inner disk material (semimajor axis $a < 2$) evolved for 150 Myr (see Fig. 4), reproducing successful terrestrial planet simulations[8].

(Martens, 2017)

It has been demonstrated that the torque required to slow down the young Sun from a rotation period of the order of five days to its current rotation rate requires a sustained (~3 Gyr) massive solar wind, or an unrealistically large lever arm for the Alfven surface, well beyond the orbit of Venus

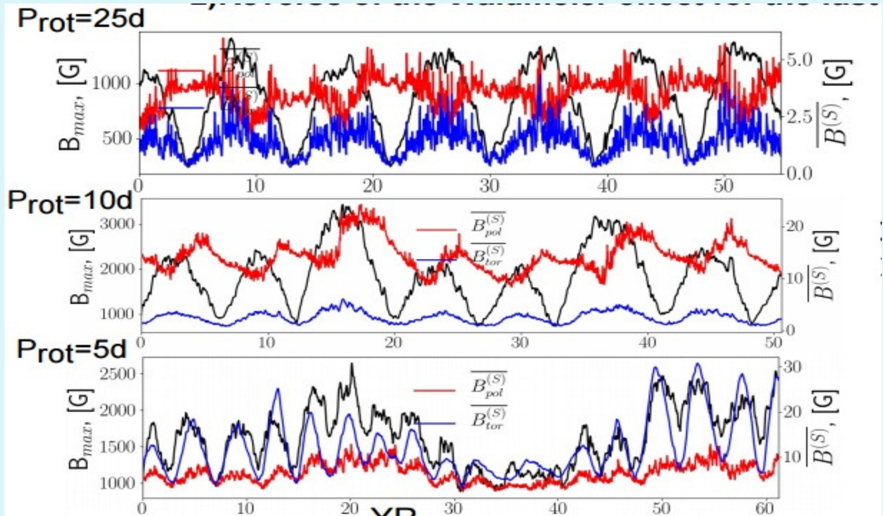
Young Sun, modeling



The paper (Pipin V., 2017) the self-consistent nonlinear model is applied to study the large-scale dynamo on the modern and young solar analogs. Revealed:

1) The toroidal magnetic field dominates the poloidal one on the young Sun, rotating with period of 5 days (left). The coronal activity shifts to equator at the same time. This means that angular momentum loss on the young Sun were considerable larger than on the modern Sun.

2) The main period of magnetic cycle decreases with the decrease of the rotational period. However, the strong cycles on the young Suns have the longer duration than the weak cycles. This is opposite to the Waldemeier effect on the modern Sun.



Random modulation of magnetic cycle by emergence of the non-axisymmetric magnetic field (young and modern Sun). The increase impact of the surface activity with decrease of rotational period (Pipin, V.V., 2017, MNRAS, 466, 3007)

ENHANCED GREENHOUSE EFFECT

Enhanced greenhouse effect arguably still seems the most likely solution to the faint young Sun problem. A final assessment of greenhouse gas warming in the early atmosphere, however, is complicated by uncertainties in the radiative transfer functions and the lack of spatially resolved and fully coupled climate models for the early Earth comprising the full range of feedbacks in the Earth system. Finally, other climatic factors like changes in cloud cover could in principle at least have contributed to a warming of the Archean Earth.

Hypothesis:

Abiogenic synthesis led to the appearance of a pelliculus on the water (film coating)

Liquid ocean beneath the surface of Pluto

- An international team of planetologists from Japan and the United States found that there could be a liquid ocean beneath the surface of Pluto, protected from freezing by an insulating layer.
- The scientists analyzed what could retain heat in sea water, maintaining the inner surface of the ice shell uneven. Computer modeling showed that under the frozen layer, there should exist a layer of gas hydrates, i.e., crystalline solids formed from gas and water. They are very viscous, have low thermal conductivity and therefore have insulating properties.
- Without an insulating layer, the subsurface ocean would freeze hundreds of millions of years ago. The most likely gas component is methane emitted by Pluto's rocky core. Similar gas hydrate layers can ensure the existence of liquid water on other planets outside the Solar system.

- ***This means that water could have been preserved in the same form on Earth***

- So, how did life appear on Earth and what role did the space environment play in its appearance ?
- What factors determined some important properties of life on Earth?
- What is the relation between the main types of energy?

The main criteria for the existence of the biosphere of terrestrial type:

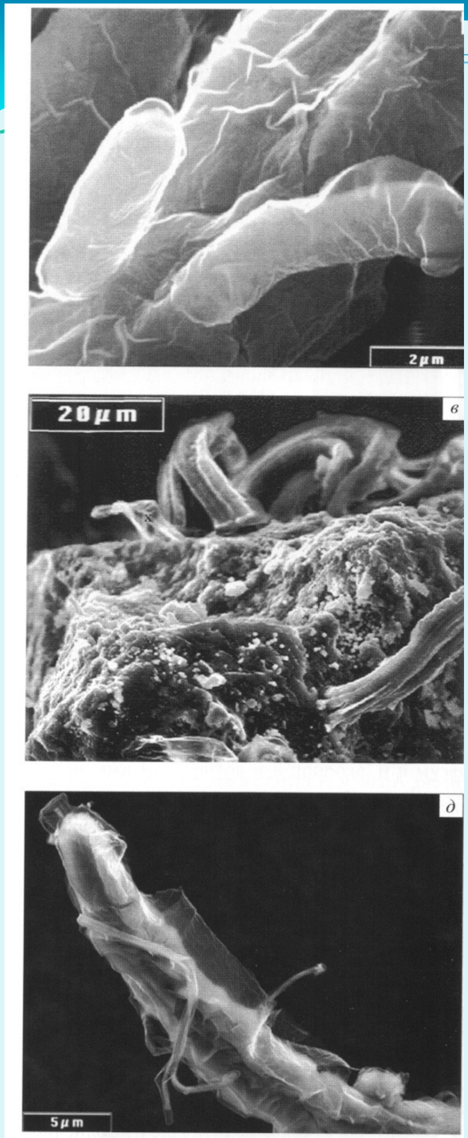
1. A large variety of the organic compounds;
2. The availability of energy sources necessary for the maintenance of biochemical processes, including chemical energy;
3. The presence of liquid water over a long geological period;
4. The presence of protective shells, providing a gradient of matter and energy

- So, how did life appear on Earth and how did suitable living conditions arise? Most likely, life did not originate on Earth. There is plenty of evidence of the existence of life germs in space. It is precisely the cosmic origin that probably explains one of the most mysterious properties of life on the Earth — homochirality. After life appeared on Earth, there still remained the problem of survival.

**

Pseudomorphs are only discovered in carbonaceous chondrites. Their age is 4.5 – 4.56 billion years, while the age of the fossils is even more, which suggests that these organisms existed <u>before the formation of the Earth.</u>

This is evidence of extraterrestrial origin of life. Life could have arisen on an earth-like planet, where there was water and suitable temperature and atmospheric conditions. And the RNA world should be even more ancient.



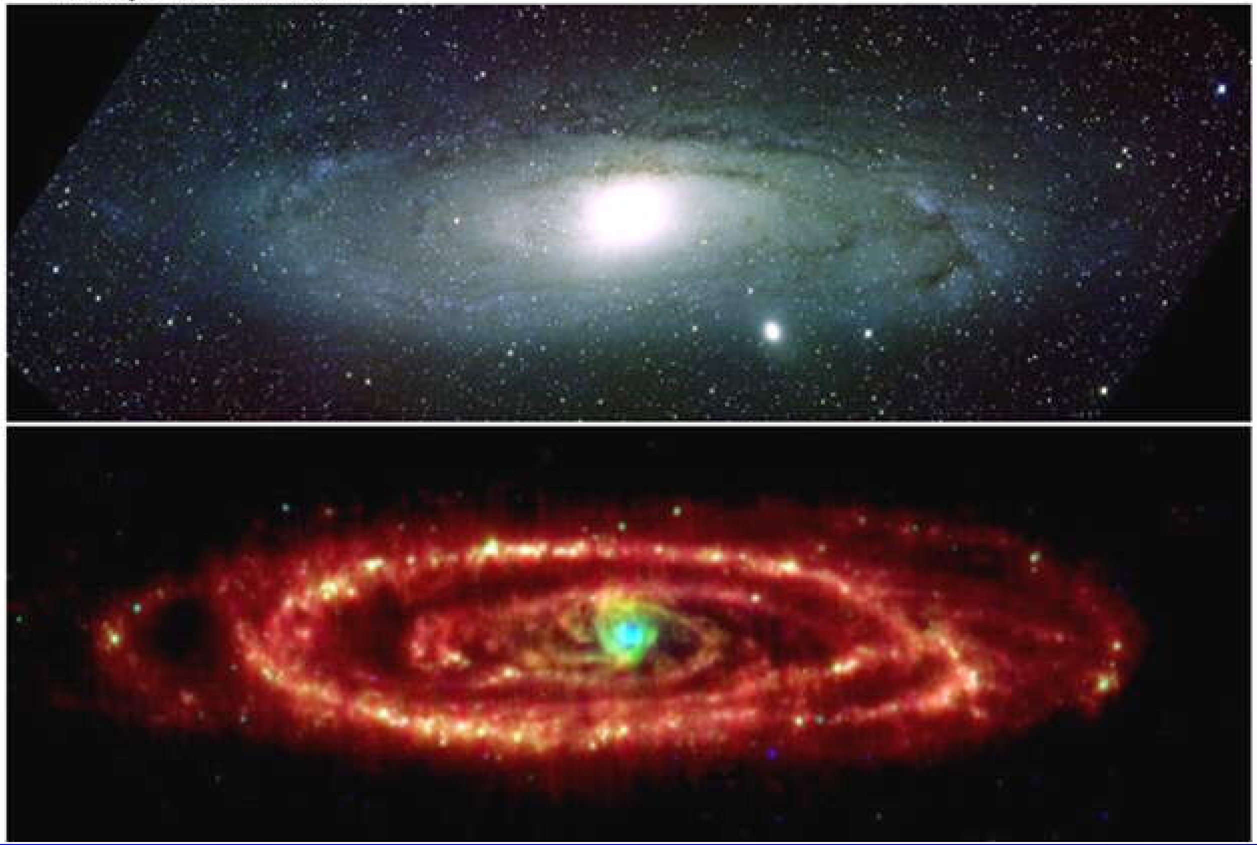
Bacterial bodies in the Orgey meteorite.

Roz_1/12

Pre-biological synthesis of organic matters in molecular and protoplanet clouds

Molecular clouds

- Mass - up to $6 \cdot 10^6 M_\odot$
- Size - tens of pc
- Temperature - 10-50 K
- Density - more than 200 cm $^{-3}$



Life could originate already at the stage of formation of star clusters from molecular clouds.

The data on chemical composition of molecular clouds in interstellar space suggest the existence of an active pre-biological synthesis of complex organic matters.

List of known interstellar and circumstellar molecules
(http://astrochymist.org/)

Molecules of two atoms

AlF AlCl C_2 CH CH^+ CN CO CO^+ CP CS SiC HCl H_2 KCl NH NO NS NaCl OH PN SO SO^+ SiN SiO SiS HF SH SH^+ O_2 HCl^+ OH^+ CN^- AlO HCl^+ NO^+

Molecules of three atoms

C_3 C_2H C_2O C_2S CH_2 HCN HCO HCO^+ HCS^+ HOC^+ H_2O H_2S HNC HNO MgCN MgNC N_2H^+ N_2O NaCN OCS SO_2 c-SiC_2 CO_2 NH_2 H_3^+ SiCN FeCN KCN H_2Cl^+ H_2O^+ AlOH HO_2 SiCSi

Molecules of four atoms

c-C_3H l-C_3H C_3N C_3O C_3S C_2H_2 HCCN $HCNH^+$ HNCO HNCS $HOCO^+$ H_2CO H_2CN H_2CS H_3O^+ NH_3 SiC_3 H_2O_2 HSCN PH_3 l-C_3H^+ NCCP MgCCH HCCO

Molecules of five atoms

C_5 C_4H C_4Si l-C_3H_2 c-C_3H_2 CH_2CN CH_4 HC_3N HC_2NC HCOOH H_2CHN H_2C_2O H_2NCN HNC_3 SiH_4 H_2COH^+ CH_3O HNCNH $NCCNH^+$

Molecules of six atoms

C_5H C_5O C_2H_4 CH_3CN CH_3NC CH_3OH CH_3SH HC_3NH+ HC_2CHO $HCONH_2$ l-H_2C_4 C_5N C_5N^- E-HNCHCN C_5S SiH_3CN

Molecules of seven atoms

C_6H CH_2CHCN CH_3C_2H HC_5N $HCOCH_3$ NH_2CH_3 c-C_2H_4O CH_2CHOH C_7^-(?) CH_3NCO

Molecules of eight atoms

CH_3C_3N $HCOOCH_3$ CH_3COOH C_7H H_2C_6 CH_2OHCHO NH_2CH_2CN CH_3CHNH

Molecules of nine atoms

CH_3C_4H CH_3CH_2CN $(CH_3)_2O$ CH_3CH_2OH HC_7N C_8H

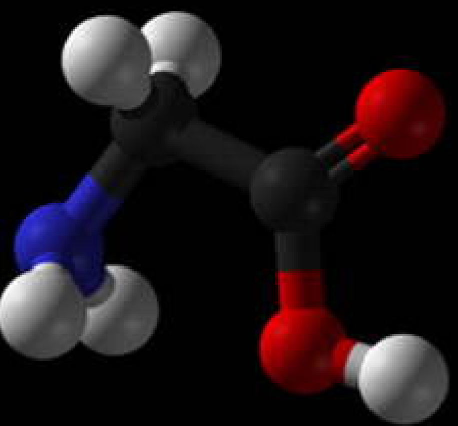
Molecules of ten atoms

CH_3C_5N? $(CH_3)_2CO$ NH_2CH_2COOH? $HOCH_2CH_2OH$ CH_3CHCH_2O

Molecules of eleven atoms HC_9N C_2H_5OCHO

Molecules of twelve atoms $CH_3OC_2H_5$ C_3H_7CN

Molecules of thirteen atoms $HC_{11}N$?



There are several other factors that can affect the Earth and determine terrestrial types of life .

UV radiation as a selective factor:

1. Selection of UV-resistant nitrogenous bases
2. Selection of nucleotides in complementary pairs
3. Selection of longer and more stable RNA molecules
4. Selection of homochiral nucleotides (the mixture is less resistant to UV radiation

Trajectory of the Sun around the Galaxy

Passage of galaxy arms

Interstellar gas

in the immediate vicinity of the Sun (but outside the heliosphere) has a temperature of about 8000K. Its density is a few tenths of a particle in a cubic centimeter, the degree of ionization is about 50%. However, in the next five thousand years, the Solar System may move to a denser area. This may cause compression of the heliosphere and bombardment of the inner planets with asteroids from the Oort cloud.

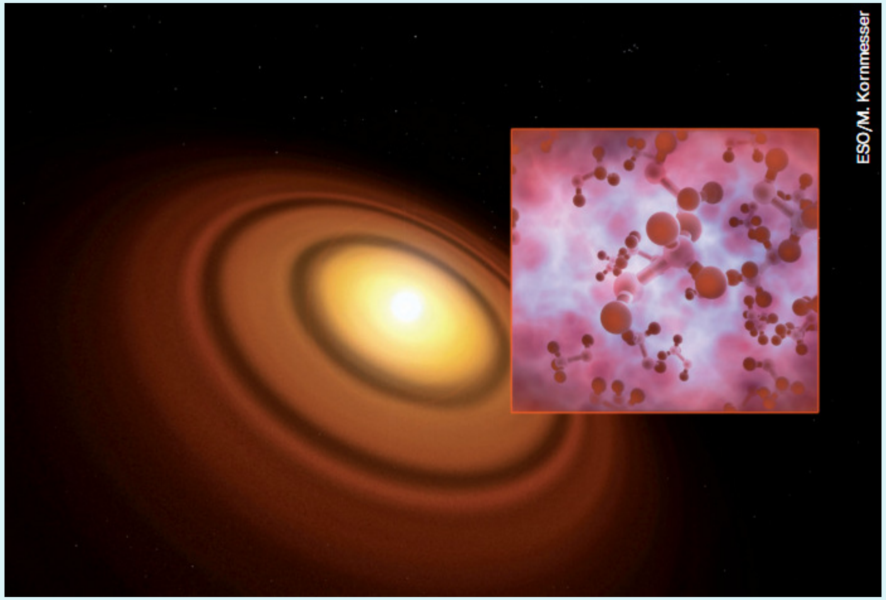
During 4.5 billion years, the Sun passed about 130 times through inter-stellar clouds with a density n> 100 particles (i.e., 7–8 times per galactic year) and approximately 16 times through clouds with n>1000 cm^{-3}. The number of anomalous sub-relativistic cosmic rays increased hundreds of times, which could affect the evolution of the biosphere.

(N.G.Bochkarev)

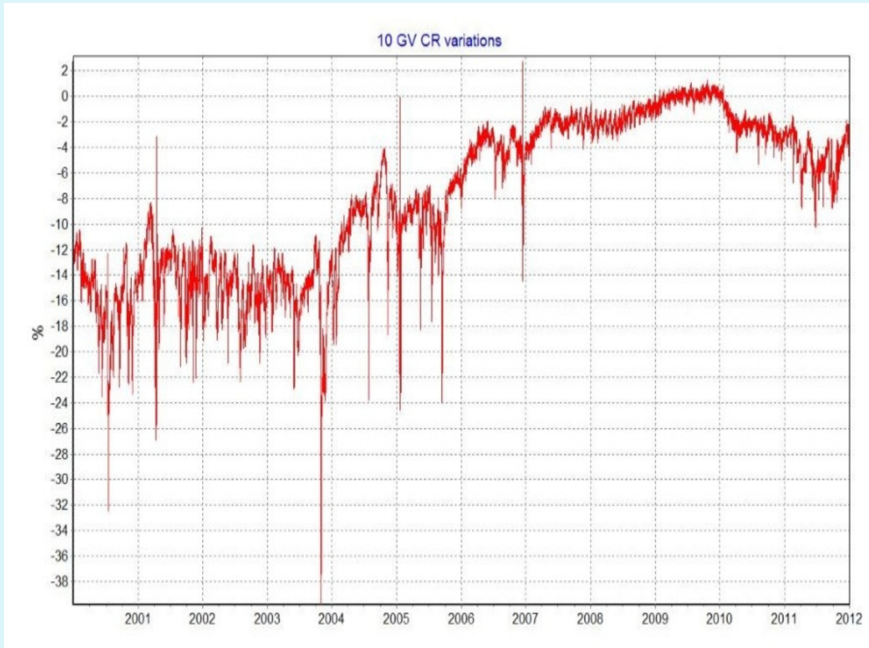
Galactic cosmic rays and cosmic dust

1. The key role in interstellar molecular chemistry belongs to ion-neutral (or ion-molecular) reactions involving cosmic dust. In the process of formation of organic matter in molecular clouds, the primary ionization is provided by cosmic rays.

2. Precipitation of cosmic dust (up to 100 000 tons per year) and variations in its amount (as the Solar System is moving through the Galaxy) significantly affect the Earth's climate.



Organic molecules in protoplanet disc of TW South Hydrae

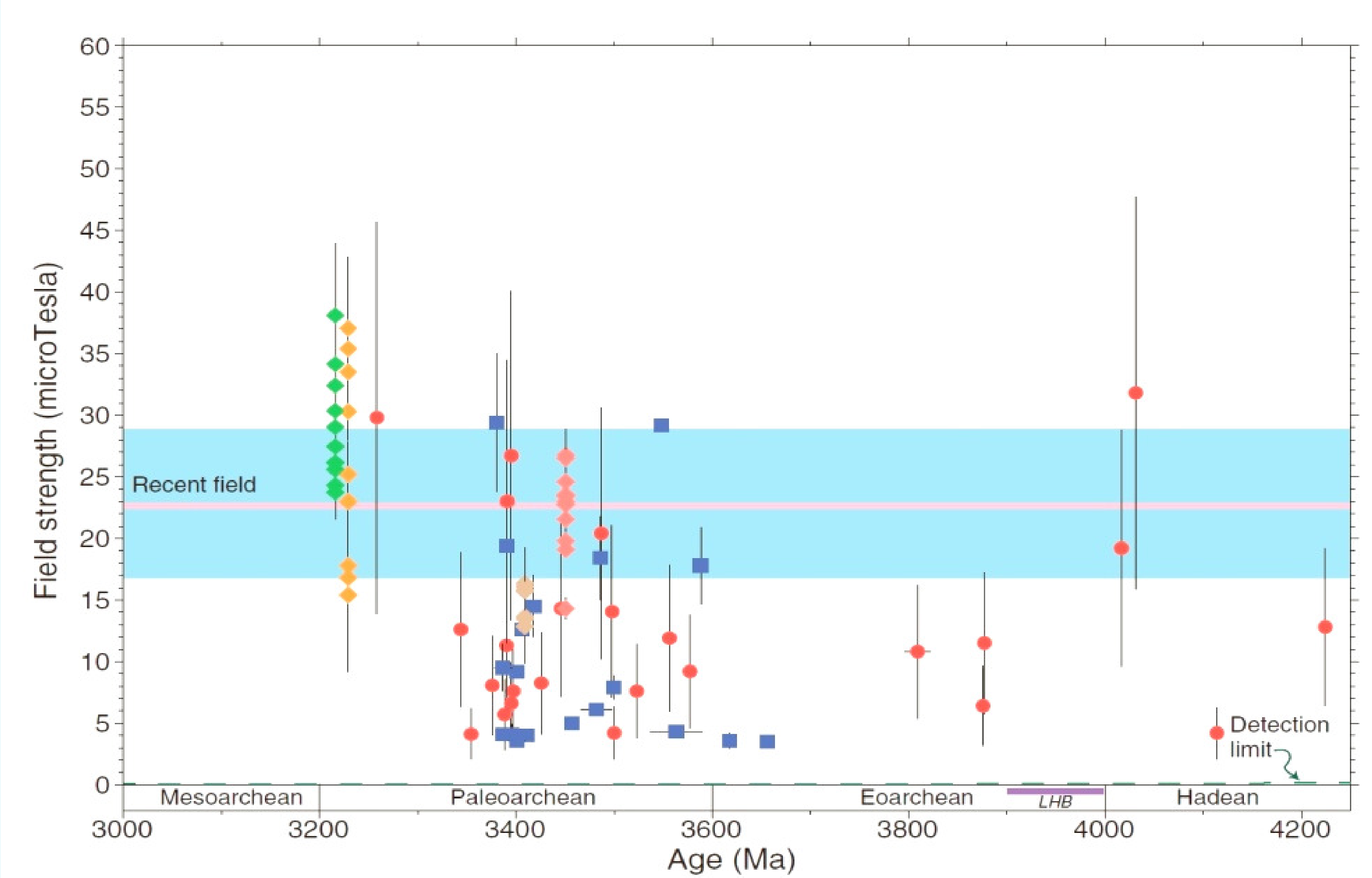


Ground-level GCR dynamics of in 2000-2012

Geomagnetic paradox, isotope paradox

Paleomagnetic data – magnetic field 4.2 billion years ago comparable with the present-day field

Dynamo theory: solid nucleus and composition convection 1-2 billion years ago



Tarduno et al, 2015

Earth-Moon system

1. Stabilization of the Earth orbit

2. Tidal interaction:

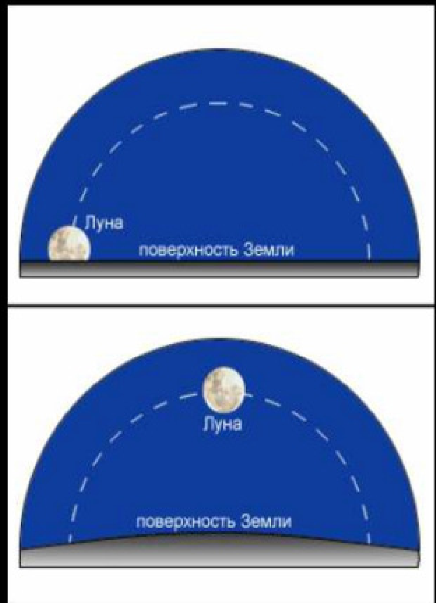
A) Deceleration of the Earth (primarily a day had 6-8 hours)

Б) Recession. Initial distance was 25 – 30 thousand km, now it is 357 – 406 thousand km

3. Same isotopic composition, chemical composition similar to that of the Earth mantle.

But the Moon is depleted in sulfur, sodium, lead, chlorine, and iron

Theory of mega-impact in 30-50 million years



- **Thus, the evolution of life in contact with cosmic factors passed through several stages.**

- Stage 1. Assembling of organic matter, chirality, and RNA in outer space (***before the appearance of the Earth)***
- Stage 2. Selection of a common genetic code of our biosphere and ways of obtaining energy by living organisms in the course of adapting to terrestrial conditions and radiation of the young Sun. Energy balance of the biosphere is controlled by endogenous factors. The characteristics of the biosphere are influenced by the solar activity and cosmic rays. (***the first 2-2.5 billion years***).
- Stage 3. ***Biosphere as a planetary factor .*** At present, the biosphere assimilates 30 times more solar radiation than the heat energy from the Earth interior spent on all tectonic processes. This quantity is comparable with the total amount of heat emitted by the Earth interior. (***Biosphere 26,8 10^{-5} W/m^2, tectonics 1,0 10^{-5} W/m^2***)

Development of new models of the magnetic field dynamics and the heliosphere of the young Sun is necessary to understand the processes of origin of life and evolution of the biosphere. The question of the intensity of galactic cosmic rays in the early Solar System remains open.

- Thus, the paradox of the young Sun is part of a much more general problem requiring the participation of biologists, geologists, astronomers of all directions (cosmology, stellar astronomy, physics of the interstellar medium, celestial mechanics). Often, seeming solutions that remove this problem in one respect are unacceptable in another.


Thank you for attention!