COSMIC INFLUENCES ON THE EARTH

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Contents

Summary

The Sun is the cause of the main cosmic influence on the Earth. Its influence relates mainly to the energy balance on the Earth, in which solar radiation plays the dominant role. A further question concerns possible changes in the level and character of the solar radiation, i.e. short- and long-term variations in the Sun's energy output. The luminosity of the Sun would not have to change very much in either direction for the Earth to be unable to support its present flora and fauna and density of human population. Although there are speculations about possible variations in solar irradiance even during the recent millennium, there exists no direct evidence to support them. There are certain indications that changes in the Earth's atmosphere related to human activity may cause radiation forcing (the greenhouse effect) and result in a serious threat to living conditions for mankind. Other important Sun-related circumstances that must be taken into account are the permanent and especially the sudden arrivals of solar high-energy particles and radiation, as well as solar wind-generated effects on and interactions with the protective layers of the Earth's atmosphere.

Impacts of near Earth interplanetary objects (asteroids and comets) upon our planet are rare events with enormous consequences; they can eliminate a large fraction of species over a short time scale (a few months to a few years). Our knowledge and current research efforts indicate that at least part of the hazard can be eliminated within a few

decades, when an inventory of large (> 1 km) near Earth asteroids and description of their physical properties achieves 90% completeness. The hazard presented by smaller asteroids and comets requires further investigation but is also potentially serious. Specifically, even smaller environmental disturbances caused by a small asteroid impact may severely affect our fragile civilization.

Strong disturbances of the geomagnetic field, i.e. the geomagnetic storms initiated from interplanetary space, along with the related enhanced energetic particle emissions, have many consequences for activities both in space and on the ground, where, for example, geomagnetically induced currents can disturb pipelines. Cosmic rays at their low-energy part, along with other charged energetic particles in space (e.g. those accelerated in solar flares, in the interplanetary medium and within the magnetospheres), may in some cases present hazards for astronauts, cause damage to spacecraft and aircraft electronics, produce changes in navigation and radio communication due to variations of the ionization in the ionosphere, and probably contribute to the atmospheric ozone depletion. The geomagnetic field and the atmosphere protect us from being exposed to low-energy cosmic rays. Possible relations of cosmic rays to the climate are currently much discussed. Indirectly, the anisotropy of cosmic rays (measured at the Earth) along with the interplanetary solar wind plasma and magnetic field (continuously monitored by satellites outside the magnetosphere) may serve as one potential indicator of "space weather" effects.

1. Influences of the Sun

Without the Sun there would be no Earth as we know it. No one can doubt that the Sun and, in particular, the quality and quantity of its radiation is the chief driving force for our terrestrial climate and therefore for conditions favorable for a sustainable life. The annual march of the seasons as the Earth's axis of rotation tilts toward or away from the Sun's direction is sufficient proof of that influence. The presence of periodicities in glacial deposits matching those of known orbital variations has revealed the apparent sensitivity of the global terrestrial climate to relatively small changes in the distribution of sunlight. What has remained debatable and controversial, however, is the question of whether or not variations in the Sun's radiative and plasma emissions occur that are capable of influencing the weather and climate at the Earth's surface. The luminosity of the Sun would not have to change very much in either direction for the Earth to be unable to support its present flora and fauna and density of human population. The main influence of the Sun on the Earth is through its emissions in the optical and neighboring regions of the electromagnetic spectrum. There is an additional effect produced by corpuscular emission from the Sun. This term refers to both the permanent solar wind and the occasional input of high-energy protons and interplanetary shock waves, which may reach the Earth and hit its protective layers after very strong solar flares or coronal mass ejections. (For a more detailed description of solar activity phenomena and solar variability effects, including their possible consequences for the Earth, see "History of Sun"). It is important to obtain a full understanding of the manner in which the Sun influences the Earth, particularly as fluctuations in the strength of the solar wind lead to magnetic storms which interfere with radio communication on the Earth. Magnetic storms occur when enhanced solar activity increases the strength of solar corpuscular emission. The increased arrival of solar corpusculae compresses the magnetosphere and raises the strength of the magnetic field at the Earth's surface. At the time of a magnetic storm, the number of charged particles trapped in the Earth's magnetic field increases. Particles moving out of the radiation belts towards the Earth's surface interact with the neutral atmosphere and produce auroras observed in polar latitudes.

There is no doubt that even the weather on the Earth is almost entirely determined by the interaction of solar radiation with the outer layers of the Earth. The fact that the weather is as complicated and unpredictable as it is results from a variety of factors, such as the ellipticity of the Earth's orbit, the Earth's rotation, the inclination of its rotation axis to its orbital plane, the division of the Earth's surface between sea and land, and the existence of mountain ranges as well as large-scale streams in the oceans.

2. Near Earth Objects

2.1. Sources of near Earth Objects

There are two broad categories of objects whose orbits bring them close to the Earth: asteroids and comets. They are distinguished on the basis of their telescopic appearance. If the object is star-like in appearance, it is termed an asteroid. If it has a visible atmosphere or tail, we call it a comet.

Asteroids accreted in the region between Mars and Jupiter during the planets' formation. The accumulation was more rapid in the region of Jupiter, which therefore grew much faster than the asteroids. Once Jupiter was formed, its increased gravitational effect prevented the further accretion of asteroids into larger bodies, by increasing their relative encounter velocities to about 5 km/s so that their collisions were disruptive rather than accumulative from then on. Ever since, asteroids fragment when colliding. The orbits of the asteroids are perturbed by the gravitational forces of the major planets and some asteroids are transferred to eccentric orbits which bring them into the near Earth region.

According to Kuiper's hypothesis, generally accepted nowadays, the asteroids and terrestrial planets condensed within the inner regions of the primeval solar nebula. More volatile materials condensed mostly in the external part. **Comets** formed from icy planetesimals in the region of Uranus and Neptune. The observed differences between asteroids and comets are due to their different compositions caused by their different places of formation. Although the comets initially have long orbital periods, they can be captured into short-period orbits by gravitational forces of the planets (particularly Jupiter).

The greater fraction of fragmented asteroid and cometary material was lost either by ejection from the Solar System due to planetary gravitational effects or in collisions with major planets or the Sun. These processes continue to act at present. Before being lost in these ways, some of the objects reach orbits approaching that of the Earth. These objects are referred to as near Earth objects (**NEOs**). Due to the processes mentioned above, the lifetimes of NEOs are in order of 10 to 100 million years. Sources of a new supply of NEOs are the asteroid main belt and comet populations, the latter either from the distant reservoir known as the Oort cloud or from the transneptunian disk called the Kuiper belt, which have both preserved unprocessed (unheated) cometary material.

2.2.Population and Properties of near Earth Objects

In the evolution of asteroids in the main belt, a major role was played by collisions between asteroids, together with their internal heating and radioactivity. These effects altered the structure and composition of asteroids so that most of them no longer closely resemble the original material from which they formed. The collisions are also responsible for the cratered surfaces of asteroids, mostly covered with a layer of regolith. Most larger asteroids lack a monolithic interior, instead being gravitationally bound aggregates (so called "rubble piles"), deeply shattered by collisions.

The groups of NEAs	Number
Amor (1.017AU < q < 1.3AU)	432
Apollo (q < 1.017AU, a ≥ 1AU)	448
Aten (Q > 0.983AU, a < 1AU)	71
Total NEAs	951

Table 1. The number of known near Earth asteroids, broken down by groups, valid on March 20 2000 (http://cfa-www.harvard.edu/iau/lists/Unusual.html)

The physical properties of near Earth asteroids and comets are mostly studied with telescopic observational techniques. NEOs are generally faint and can be studied only during short windows of visibility in the vicinity of the Earth.

Sizes. The known NEAs have diameters mostly greater than 0.5 km. The true population, however, increases rapidly in number with decreasing size. The best current estimate of the total number of NEAs greater than 1 km is about 900 (with an error of a few hundred); the cumulative number of NEAs increases with decreasing diameter according to a power law with the slope near 1.8. The number of NEAs with D>0.1 km is estimated to be in order of 60 thousand.

Orbits. Near Earth asteroids revolve around the Sun in elliptical orbits in the same direction as the major planets. The inclinations of their orbital planes to the ecliptic plane are mostly low. Their dynamical lifetimes, due to the gravitational forces of the planets, are in the order of 10 to 100 million years. Short-period comets are in planet-crossing orbits, occasionally making close approaches to the planets which result in major changes in their orbital elements. Lifetimes of the comets are shorter than those of the asteroids.

Shapes. Near Earth asteroids are generally more irregular than the larger main-belt asteroids; their shapes are mostly consistent with their derivation as collisional fragments. At least some of the near Earth asteroids are binary; that is, they are gravitationally bound pairs of bodies orbiting one another. Among theories of the creation of the binary near Earth asteroids, the most probable is that they are formed by tidal disruptions of larger parent bodies (assumed to be weak, gravitationally bound aggregates) during their close encounters with the Earth.

Densities. The densities of near Earth objects are not well known but they are thought to be similar to rocky material with voids. The densities of recovered meteorites are greater, from 3.6 g.cm-3 (chondrites) to 7.9 g.cm-3 (iron meteorite); the bulk densities of most NEOs must be less than those of meteorites, since only the densest fragments of asteroids are able to survive the impact with the Earth's atmosphere. The densities of comets have not been measured but are thought to be around or less than 1 g.cm-3.

Taxonomic classification of the asteroids. The chemical/mineral composition of asteroids can be derived from a spectral analysis of their light, but a lot of information is also provided by additional observational techniques, such as visual photometry, thermal infrared photometry, polarimetry, and radar. The measurements allow a classification of asteroids into several groups with distinct properties, called taxonomic classes (types). The classes can be linked (albeit sometimes not uniquely) to specific mineralogical compositions.

C -type	- carbonaceous objects with low albedos
D and P -type	- silicate objects with the addition of carbon or organic compounds, possibly containing volatiles
S -type	- stony (chondrite-like) objects, stony-iron objects, or a combination of both; have a moderate albedo
M -type	- iron, nickel
E -type	- enstatite, pyroxene or other non-iron silicate material
A -type	- olivine
V and R -type	- pyroxene + olivine + minor compounds

The composition of comets is a mixture of water ice and other volatiles, together with solid particles. In general, the physical structure of comets is even more poorly understood than that of near Earth asteroids. Comets often split into two or more bodies, under even rather modest tidal or thermal forces.

Albedos and colors. The surfaces of asteroids have albedos ranging from values perhaps as low as 0.02 (very dark) up to more than 0.4 (light material). The colors of asteroid surfaces range from reddish (for taxonomic types S, Q, R, V, A, and D) to neutral (C). Although the early expectations were that cometary nuclei would have high albedos, it is now recognized that most nuclei appear to be very dark objects. This is thought to be caused by a deposit of very dark carbonaceous material on the comet nucleus surface.

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Bibliography

Bottke W. F. and Melosh H. J. (1996). Formation of asteroid satellites and doublet craters by planetary tidal forces. *Nature* 281, 51-53. [This paper offers a theory of the formation of binary near Earth asteroids.]

Bottke W. F., Jedicke R., Morbidelli A., Petit, J.-M. and Gladman B. Understanding the Distribution of Near-Earth Asteroids. *Science* 288, 2190-2194. [This paper presents estimates of the numbers and sizes of near-Earth asteroids.]

Gehrels T., ed. (1994). *Hazards due to comets and asteroids.* Tucson: University of Arizona Press. [This book gives a comprehensive summary of hazards due to near Earth objects.]

Gosling J.T., McComas D.J., Philips J.L., and Bame J.S. (1991). Geomagnetic Activity Associated With Earth Passage of Interplanetary Shock Disturbances and Coronal Mass Ejections. *Journal of Geophysical Research* 96, No A5, 7831-7839.

Lang K.R. (1995). *Sun, Earth and Sky*, 282 pp. Berlin-Heidelberg-New York: Springer Verlag.

McFadden L. A., Tholen D. J., and Veeder G. J. (1989). Physical properties of Aten, Apollo and Amor asteroids. In *Asteroids II* (eds. R. P. Binzel, T. Gehrels, M. S. Matthews), 1258pp. Tucson: University of Arizona Press, p.442. [This paper gives an overview of the properties of near Earth asteroids.]

Morrison D., et al. (1992). *The Spaceguard Survey: Report of the NASA International Near Earth Object Detection Workshop*, 1-52, http://impact.arc.nasa.gov/reports/spaceguard/index.html. [This report summarizes knowledge and addresses issues in the search for near Earth objects.]

Reid G. C. (1995). U.S. National Report to IUGG, 1991-1994. *Reviews of Geophysics* Vol. 33 (Supplement), American Geophysical Union.

Suess S.T. and Tsurutani B.T., eds. (1998). *From the Sun: Auroras, Magnetic Storms, Solar Flares, Cosmic Rays* (papers by individual authors include: Jokipii J.R., 123-132; Joselyn J.A., 67-72; Lin R.P., 91-101; Goldstein B.E., 73-80; Mewaldt R.A. et al, 133-142). American Geophysical Union. [Important papers]

Editorial note: see articles 1.1.3. "History of Sun" and relevant parts of topic essay "Universe as the Earth´s Environment". Few sciences undergo such rapid evoution as astronomy - the upgraded information can be found on the web pages as follows:

The Spaceguard Foundation home page, http://spaceguard.ias.rm.cnr.it/SGF/ [This page contains a collection of links to many World Wide Web resources on near Earth objects.]

NEO search stations (as of May 2000):

Spacewatch Telescope, http://www.lpl.arizona.edu/spacewatch/

NEAT (Near Earth Asteroid Tracking), http://huey.jpl.nasa.gov/~spravdo/neat.html

LONEOS (Lowell Observatory Near-Earth Object Search),

http://www.lowell.edu/users/elgb/loneos_disc.html

Catalina Sky Survey, http://www.lpl.arizona.edu/css/

LINEAR (Lincoln Near Earth Asteroid Research), http://www.ll.mit.edu/LINEAR/

NEAR Shoemaker Spacecraft, http://near.jhuapl.edu [This web page gives information on the results of the first spacecraft mission in the orbit of a near Earth asteroid.]

http://www.physics.adelaide.edu.au/astrophysics

http://www.srl.caltech.edu/personnel/dick/cos_encyc.html

http://www.sciam.com/0197issue/0197swordybox2.html

http://helios.gsfc.nasa.gov/acr.html

http://web.ngdc.noaa.gov/stp/SOLAR/COSMIC_RAYS

Biographical Sketches

Petr Pravec, born in 1967, obtained PhD at the Charles University Prague in 1996. Since 1994 working at the Astronomical Institute of the Academy of Sciences of the Czech Republic in Ondřejov. Professional interest in the physics of near-Earth objects and their optical studies utilizing CCDs. PI and Co-PI on projects of studies of NEOs using optical telescopes. Concentrates on study of NEA rotations, shapes and structure. Recent results involve a finding of binaries among NEAs and a finding of the size boundary between small asteroids of monolithic structure and larger, rubble pile asteroids. Collaborates with several NEO research groups in the world with an aim to interpret puzzling rotations of some NEAs. Discoverer of several tens of asteroids. Member of the International Astronomical Union.

Pavel Kotrč, born in 1948, graduated from the Faculty of Sciences, Masaryk University at Brno (Mathematics and Physics) in 1972. Since then he has been working as a staff member at the Solar Department of the Astronomical Institute of the Academy of Sciences of the Czech Republic in Ondřejov. In 1980 he obtained his PhD in astrophysics - solar physics. Several longer missions abroad: ISZF Irkutsk, Russia; Hvar Observatory, Croatia; Crimean Observatory, Ukraine; National Solar Observatory Sacramento Peak, USA; Observatoire de Paris, Meudon, France. Research topics: Solar atmosphere, flares, surges, prominences, coronal loops, spectral observation and analysis, diagnostics of the solar activity phenomena, instrumentation. PI, Co-PI or Co-I on several solar physics projects. Since 1992 external lecturer on spectroscopy at the Charles University at Prague, since 2000 external lecturer on solar physics at the Masaryk University et Brno, supervisor of student diploma theses. Member of the International Astronomical Union and alternative representative of the Czech Republic in JOSO. Author and co-author of about 90 papers.

Karel Kudela, born in 1946, finished study at Faculty of Nuclear Physics and Engineering, Czech Technical University, Prague in 1969. Since 1971 until now working at the Institute of Experimental Physics, Slovak Academy of Sciences in Kosice, Slovakia. Subjects: energetic particle dynamics within magnetosphere and near its boundary regions, cosmic ray data analysis from ground based measurements. PI, Co-PI or Co-I on several energetic particle measurements on low and high apogee satellites. PI of neutron monitor at Lomnicky stit in High Tatras mountains. Recently working in two directions: a. dynamics of fluxes of medium energy particles (29 keV - 1 MeV) in the region upstream of the Earth s bow shock, within the magnetosheath and in outer magnetosphere, b. possible relevance of neutron monitor measurements for space weather studies. Lectures at Technical University Kosice.