Galactic encounters and ice ages in the earth's history

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The keys to understanding history of earth lie buried not only in our own planet, but in our planetary neighbours, in the sun and in the neighbouring galactic region.
– Lunine, J.
Earth – Evolution of a Habitable World

During earth's 4.5 billion years (b.y.) of evolution, there have been repeated spells of ice ages lasting for millions of years. In the Proterozoic era itself, between 2440 and 540 million years (m.y.) ago, earth had experienced at least five such spells. Among them, those that had occurred during Paleoproterozoic, 2 b.y. ago and in the Neoproterozoic, between 900 and 540 m.y. ago, are believed to have covered the entire earth for millions of years, a scenario aptly described as 'snowball earth'[1–3]. While these events of glacial spells are not doubted, the view that some of them had covered the entire earth including its oceans is disputed and it still remains a topic for debate among climatologists, geochemists and geologists[3].

The development of ice ages or glaciation events is attributed to a process known as ice-albedo feedback or the power of white ice to reflect back solar energy, thereby inducing progressive cooling of earth and ending up with ice formation. This is supposed to be more effective in earth's low-latitudes (< 30°) where the surface area per latitude is greater. In early earth times, this cooling must have happened more rapidly as our sun was at that time 25% less luminous and hence earth had received less solar radiation flux. Skeptics, however, doubted if this could have forced a runaway glaciation of global magnitude since under such conditions terrestrial warming induced by the greenhouse gases from early earth volcanoes, would have effectively prevented such a trend[4]. An alternate hypothesis[5,6] attributes earth's peculiar orientation in the Precambrian times when its obliquity or the tilt (the angle between its spin and orbital axes) was greater than 54° (presently this is 23.5°). Such a high tilt, it appears, was forced on earth ~ 4.5 b.y. ago, when it was impacted by the moon-producing massive bolide. Earth returned gradually to the present 23.5° over the subsequent geological periods, under the influence of dissipative core–mantle torques. As a result of this high obliquity, the low-latitude palaeo-equatorial region, where most of the continental landmasses were located in those geological periods, received less solar radiation making this belt the coldest region and promoting development of ice-cover.

Now a team of astrophysicists, atmosphere and space physicists has found galactic involvement for the repeated development of ice ages on earth[7]. According to their postulate, whenever the solar system while orbiting around the centre of our Milky Way galaxy, once in 250 million years, encounters giant molecular clouds (GMC), dramatic changes in climate could be triggered on earth. Several thousands of such cloud masses, mostly made up of atomic and molecular hydrogen and dusty carbonaceous particles and silicates are known to lie in its path (Figure 1). They can effectively shut-off solar radiation, enhance water vapour content of the middle atmosphere with attendant drop in temperature, form dense mesospheric ice-clouds and finally precipitate runaway ice-albedo feedback leading to global cooling[8]. A mere 5 to 10% reduction in the solar luminosity by the dust could decrease the amount of heat reaching earth and initiate sufficient cooling for the polar ice to spread slowly to low latitudes and even up to the equator.

The density prevailing outside these locations of GMC is so low (hardly 300 H atoms/cc) that earth and other planets get shielded by the sun's heliosphere (magnetic field of very low density of particles). However, when the solar system plunges through a dense GMC (cloud density ~ 2×10^3 at/cc), this shielding gets completely suppressed and the interstellar material gets swept into the upper atmosphere (ionosphere) of earth[6]. Since it takes over hundreds of thousands of years for the sun, with its planets in tow, to cross such clouds, enormous interstellar dust accumulate in the upper atmosphere. From there, they slowly gravitate to the stratosphere and then to the troposphere, within 30 km of the earth's surface and in the process they collide mutually and grow to submicron size and get distributed in the atmosphere in 10–15 years.

The authors conducted simulation studies using different environmental conditions involved in the development of global cooling. They varied the parameters like atmospheric circulation, sea-surface temperatures, solar luminosity (100–94% present levels), levels of CO_2 (420 ppm) and positions of landmasses in Proterozoic to derive the radiative forcings that would be required to trigger snowball conditions. Their studies revealed that with even 96% solar luminosity, an encounter with cloud density as small as ~ 1000 H at/cc could bring about ice cover up to 50° mid-latitudes. In their view, if the global mean surface temperature, just before the GMC encounter, was even similar to present temperature (288 K), it could trigger snowball conditions with GMC density of ~ 2200 H at/cc.

According to them, in the 4.5 billion years of earth's history, our solar system may have had ~ 4 GMC encounters which could have triggered snowball episodes and at least 15 moderate ice ages through encounters with less dense GMCs (~ 1000 H at/cc). These glacier conditions, they say, would have lasted till the CO_2 levels, accumulating from volcanic outgassing, reached about ~ 0.1 bar level (in about 10^7 yrs), to initiate greenhouse conditions to de-glaciate the planet[2]. The GMCs are concentrated in the spiral arms of the galaxy and the probability of the solar system, on an average, to encounter them will be once in ~ 140 million

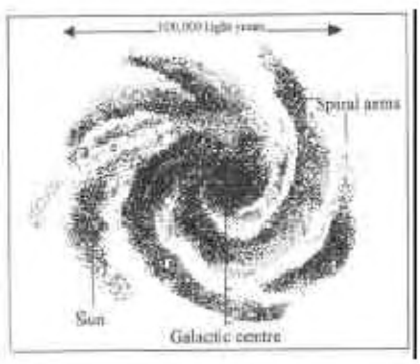

Figure 1. Milky Way Galaxy showing position of the solar system, lying about two thirds of the way from the galactic centre (about 25,000 light years away). In its orbit around the centre of the galaxy, once in 250 million years, the sun and its planets encounter dense molecular clouds of atomic and molecular hydrogen, carbonaceous and silicate dust particles which get swept into earth's atmosphere, and reduce solar radiation to its surface.

years. Interestingly, this agrees with the two well-known snowball episodes occurring at ~ 600 and ~ 750 m.y. ago.

The GMC connection for the development of snowball earth receives support from a recent report of excess amounts of iridium and a few other elements derived from interstellar dust accumulated in the glacial ice[9]. A group from the University of Vienna, Austria, and University of Witwatersrand in South Africa, has come across the Ir enrichment in drilled core samples of Neoproterozoic marine formations at the base of the cap carbonates (deposits formed after a prolonged glacial period) from the copper mines of Zambia and eastern Congo. The increase of iridium and platinum group elements as well as the ratios of Cr/Ir, Ni/Ir and Au/Ir observed in the samples were much higher than earth's crustal or mantle values. Their possible terrestrial origin from volcanoes or concentration by geochemical processes was ruled out, as neither of these agencies, they claim, can account for the observed abundance. The enrichment of Ir had obviously taken place when all the interstellar dust accumulated in the ice covering the earth during prolonged (millions of years) glacial cover sank with the onset of meltdown and settled as a single thin layer over the marine sediments. It is estimated that a staggering figure of $\sim 4 \times 10^{17}$ g of Ir could have been delivered in ~ 200,000 years, most of which get deposited over the already glaciated earth[7]. Their find of three sharp Ir spikes in the 635 and 710 m.y. old core samples correlates well with the two well-known glaciation spells during the Marinoan, about 635 m.y. ago and Sturtian times, about 710 m.y. ago[9]. They could even establish a correlation between the concentration of Ir and the duration of the snowball phase.

Although the find of excess Ir in the African samples clearly point to an extraterrestrial source, they do not prove that these materials were products from GMC encountered by the solar system. The proponents of the galactic encounter hypothesis have suggested that such involvement for earth's glacial events can be established with certainty only by examining the $^{235}U/^{238}U$ ratio in samples lying below the cap carbonates. This ratio, which is presently ~ 0.00725, would be closer to ~ 0.012–0.014 about 600–800 m.y. ago (Neoproterozoic times) due to difference in decay constants[7]. They explain that GMC materials invariably show larger ratio due to constant additions of enriched ^{235}U from supernovae explosions of massive stars, known to occur in such massive galactic clouds.

The recent findings by the two groups, no doubt, appear to support a galactic connection for the Neoproterozoic glaciation events. Answers are now awaited to what triggered the ice-albedo mechanism for the other ice age events during the Ordovician–Silurian (460–430 m.y. ago) or the Carboniferous–Permian (350–200 m.y. ago) or the geologically recent Pleistocene (3 m.y. ago) periods. In these periods, neither was our sun less luminous nor did earth have high obliquity, nor were its landmasses clustered near the poles. It is interesting to note the recurrence of these ice age events close to ~ 140 million year interval, an average period predicted for galactic cloud encounters[6], and now earth scientists will be keenly awaiting results from isotopes of U or other suitable elements combined with tell-tale geochemical noble metal tracers for possible GMC involvement for these glaciation events as well.

1. Kirschvink, J. L., in *The Proterozoic Biosphere* (eds Schopf, J. W. and Klein, C.), Cambridge University Press, New York, 1992.
2. Hoffman, P. H., Kaufman, A. J., Halverson, G. P. and Schrag, D. P., *Science*, 1998, **281**, 1342–1346.
3. Sankaran, A. V., *Curr. Sci.*, 2000, **79**, 274–277; 2003, **84**, 871–873.
4. Caldeira, K. and Kasting, J. F., *Nature*, 1992, **359**, 226–228.
5. Williams, G. E., *Earth Sci. Rev.*, 1993, **34**, 1–45.
6. Williams, D. M., Kasting, J. F. and Frakes, L. A., *Nature*, 1998, **396**, 453–455.
7. Pavlov, A. A., Toon, O. B., Pavlov, A. K. and Pollard, D., *Geophys. Res. Lett.*, 2005, **32**, L03705.
8. McKay, C. P. and Thomas, G. E., *Geophys. Res. Lett.*, 1978, **5**, 215–218.
9. Bodiselitsch, B., Koeberl, C., Master, S., and Reimold, W. V., *Science*, 2005, **308**, 239–242.

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