by Wolfgang Kundt
wkundt@astro.uni-bonn.de – DOI: 10.1051/epn/2015306

Cosmic Rays, Clouds and Climate

I much enjoyed Henrik Svensmark's contribution "Cosmic Rays, Clouds and Climate" in number 2 of volume 46. Indeed, we desperately try to quantify manmade climate changes, without understanding much larger climate changes in our past, *not* manmade, with 'ice ages', and possibly also with 'desert ages'.

In other words, we do not yet fully understand all the different heating and cooling mechanisms of our planet. Svensmark mentions heating by infalling 'cosmic rays' and 'gamma-rays', from both our Sun and our Galaxy. (The cosmic-ray energy spectrum extends from thermal energies, of order eV/particle, up to extreme values of $10^{20.5}$ eV, with its dominant share below 1GeV). He also mentions observed fluctuations thereof, on timescales between hours, and hundreds of Megayears.

Ideally, we should like to know the power spectra of their fluctuations, between years and Megayears, and the precise screening mechanisms of our atmosphere against them, via aerosols and clouds. Svensmark mentions 'Forbush decreases', during hours, and oceans as calorimeters, on timescales of kyr, via varying isotopic-rate distributions, and measured (varying) supernova rates.

So which of all the aforementioned inputs into our terrestrial temperature balance are the dominant ones? Starlight, supernova explosions, cosmic rays, and/or active galactic nuclei and their twin-jets? I have never seen a curve like Svensmark's Fig.2 drawn for all the above inputs, on timescales of yrs to kyrs. It could be useful to try and draw such curves.

A problem for this may be our as yet poor understanding. For instance, main- stream knowledge talks of "Galactic cosmic rays" and "cosmic rays", meaning that the highest-energy CRs came from beyond our Galaxy – an energetically unfeasible task, among others because of propagation losses – or of their "shock-wave acceleration" in SN remnants – a violation of the Second Law (*cf.* "*Physikalische Mythen auf dem Pruefstand*" by W. Kundt & O. Marggraf, Springer, 2014).

Many of our astrophysical insights are as yet preliminary, because they are untested. So there remains a lot to be explored by the next generation. ■

The author responds

There is certainly a need to understand the natural processes responsible climate variations over the Earth's history. The main surprise as stated in my contribution "Cosmic Rays, Clouds and Climate" is that variations in cosmic rays flux seem to be a common factor on time scales ranging from days to 10^8 years. Very close (< 10 pc) super nova will be quite rare, as would jets from active galactic nuclei. Finally starlight will be too feeble compared to solar irradiance, which leaves cosmic ray flux as the dominating omnipresent candidate for a cause. If the link is to clouds in the lower atmosphere, then the main effect is from cosmic rays with median energy of about 10 GeV accelerated in super nova remnants.

There is actually additional evidence for a link between cosmic rays and climate on time scales not discussed in the article, for example a ~30 Myr oscillation associated with the solar systems movement in and out of the galactic plane as it travel around the galactic center [1,2] and the agreement between cosmic rays and climate can be extended to the whole history of the Earth (the last ~4 billion years) [3]. Although there is a remarkable correlation seen on nearly all time scales, it does not exclude other influences. One example is the Milankovitch theory of ~40 and ~100 kyr iceages caused by collective effects in the Earths movement. Further on the long timescales it is speculated that there will be a positive feedback from biological processes. For example if the temperature is increasing it will result in less biological activity, fewer trace-gasses and thereby fewer cloud condensation nuclei, which would in the end lead to even fewer and thinner clouds.

Here DTU Space intense experimental work is currently performed with the aim of adding to the understanding of the microphysical link between cosmic ray ionization and cloud formation. All inspired by remarkable agreement between star formation/SN/cosmic rays on the one side and climate/life on the other. The hope is that this field will receive further attention in the future. ■

[1] H. Svensmark, Imprint of Galactic Dynamics on Earth's Climate, *Astron. Nach.* **327**, 866 (2006)

[2] N. Shaviv, A. Prokoph and J. Veizer, Is the Solar System's Galactic Motion Imprinted in the Phanerozoic Climate?, *Sci. Rep.* **4**, 21 (2014)

[3] H. Svensmark, Cosmic Rays and the Biosphere over 4 Billion Years, *Astron. Nach.* **327**, 871 (2006).