Challenges remaining in the long-term modulation of cosmic rays in the heliosphere

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Main questions:

- Long-lived opinion on the situation about the study of long-term cosmic ray modulation in the heliosphere
- The most important unsolved (or "half-solved") problems.
- On the causes of the long-lived (but still false!) opinion
- Our assessment of the situation

50 years apart – two opinions on the study of cosmic ray solar modulation in the heliosphere

Prof. Eugene Parker
U. Chicago, USA
born 10.06.1927
90 !!!

Anonymous
Expert

1969: "Finally, may I remark that the time has come for those of us who work on questions of cosmic ray modulation to be looking to the time a few years hence when we can close out the field and move on to other things."

Rapporteur talk at 11th ICRC, Budapest

2016: "The questions connected with the modulation effects are mainly settled… The authors are dealing with the refining corrections."

The long-term modulation of cosmic rays in the heliosphere – Subjects and main areas of focus

- The main subject is the observation and understanding of the variations in CRs of galactic origin due to the heliospheric manifestation of variations in solar activity.
- The second subject is the study of the heliosphere itself by means of CR as they carry valuable information on heliosphere, unattainable in very scanty direct measurements.
- Theoretical and numerical studies of the theoretical basis and the methods for simulation of CR characteristics and for understanding the causes and mechanisms of these variations

The most important unsolved problems.
1. Observation of the GCR variations in heliosphere

1. Close to the Earth:

- T_n < ~500 MeV/n) since 1973, but not all the main species of CR ($e^{+/-}$, p^- etc.);
- T_n = 500-10000 MeV/n – since 1957, but only the secondary CRs in the Earth's stratosphere;
- T_n > 5000 MeV/n– since 1953, but only the secondary CRs on the ground.

High expectations - with PAMELA and AMS-2, better out of the magnetosphere.

2. The inner heliosphere (r < 5 AU):

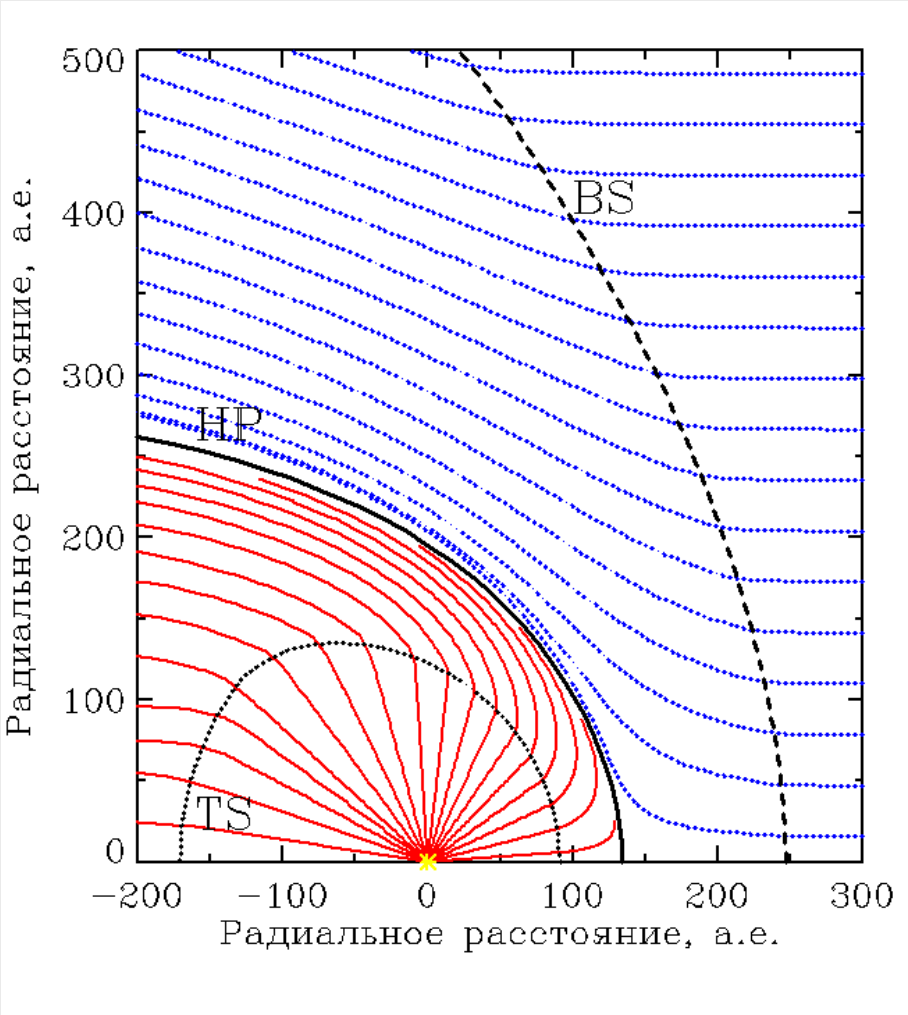
Only low energies: Helios 1, 2 in the 1970s, Ulysses in 1990-2009, STEREO A, B since 2006.

3. The outer heliosphere (r > 50 AU):

Only low energies: Pioneer 10, 11 in the 1970s-1990s, Voyager 1, 2.

Due to the large dimensions of the heliosphere the CR characteristics will remain unknown until new methods are devised for distant probing of CRs.

The most important unsolved problems.
2. The study of the heliosphere itself by means of CR



- Very simple models (Parker-type HMF,2D, seldom 3D)
- Still unknown how the HMF fluctuations generate and evolve in different parts of the heliosphere.
- Still unknown what exactly happens in the heliosphere during the HMF reversal
- Recently developed the MHD and kinetic models are still too complex to be used effectively for the purpose of GCR simulations.

The most important unsolved problems. 3. Theoretical and numerical studies of CR

Boundary value problem,
Fokker-Planck TPE for $f_0=J/p^2$

$$-\frac{\partial f}{\partial t} = \underbrace{-\nabla(K\nabla f)}_{\text{diffusion}} + \underbrace{\vec{V}^{sw}\nabla f - \frac{\nabla\vec{V}^{sw}}{3}p\frac{\partial f}{\partial p}}_{\text{convection+adiabatic loss}} + \underbrace{\vec{V}^{dr}\nabla f}_{\text{drift}} = 0$$

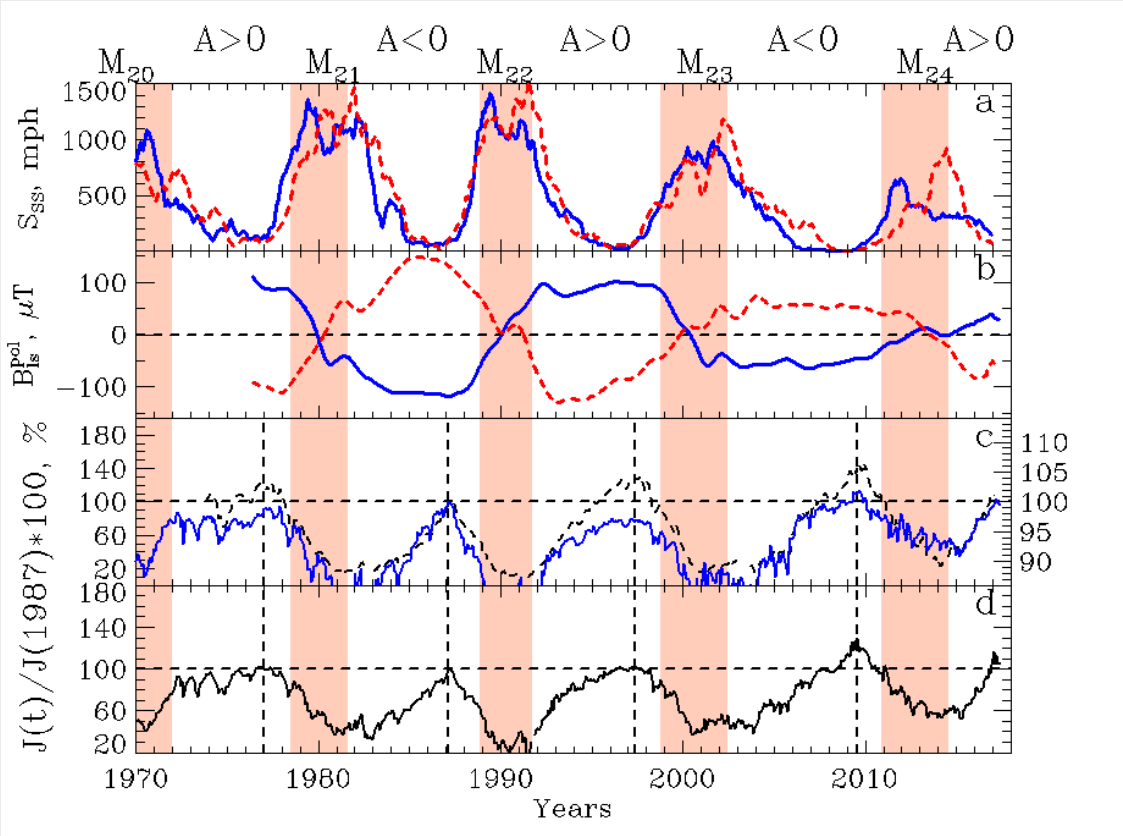
$$\left.\frac{\partial f}{\partial r}\right|_{r=r_{min}} = 0, \qquad f|_{r=r_{max}} = f_{nm}(p)$$

$$\left.\frac{\partial f}{\partial \vartheta}\right|_{\vartheta=0} = 0, \qquad \left.\frac{\partial f}{\partial \vartheta}\right|_{\vartheta=\pi} = 0$$

$$f|_{p=p_{max}} = f_{nm}(p_{max})$$

1. TPE with standard boundary and initial conditions is a theoretical base, but not all agree.
2. Mostly *ad hoc* TPE coefficients are used. A self-consistent *ab initio* approach is seldom applied.
3. Where the ACRs are accelerated and the mechanism of this acceleration.
4. The role of other mechanisms (such as magnetic helicity and reconnection, momentum diffusion) in the heliosheath.
5. What causes the CR variations and the relative importance of the different mechanisms.

Some specific and not fully understood CR effects

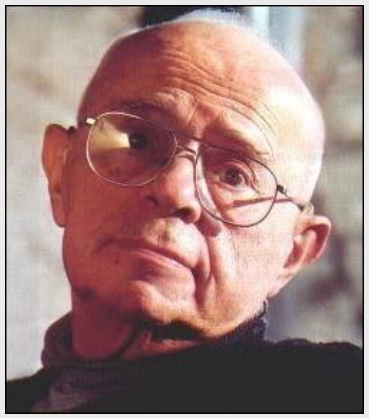


- The strange details of the CR behavior during some periods, e.g., the well-known mini-cycles in 1974-1975.
- The details of some steady 27-day variations.
- The GCR intensity's behavior during the five last HMF inversions.
- The energy dependence of the maximum GCR and ACR intensity in the anomalous solar minimum 23/24.
- What CR intensity will be in the next solar minimum 24/25 (2019-2020)

The main causes of the long-lived opinion that the main problems are solved

- Many researchers consider the observation and understanding of the long-term CR variation near the Earth as the main task of our science. Actually, we are interested in observing and understanding these variations in all parts of the heliosphere.
- The best of the models for the simulation of GCR variations demonstrate a very good description of observed data. So there is an opinion that the GCR variations are understood as they are reproduced theoretically. Actually, the above reproduction uses mostly ad hoc methods and the specially selected TPE coefficients. Besides, the reproduction of observations does not necessarily mean the understanding of the phenomenon.
- However, the main cause of the above opinion and the state of our science is more general: a general crisis in science due to limited resources.

General crisis in science due to limited resources: 1964



Stanislaw Lem
Writer, philosopher
1921-2006, Poland,
Summa technologiae, 1964

1964: **A**nticipated a crisis in science within a few decades due to limited resources, first of all the number of scientists. He considered the crisis as very dangerous for science as,

- regardless of the persons who decide which field of science should be advances at the cost of others, this decision can be mistaken, as the field where the main discovery could be made is fundamentally unpredictable
- the avalanche of the scientific information forces the scientists to slowly absorb it.

General crisis in science due to limited resources: Now

2017:

We are at the height of the crisis, mainly due to the shortage of funding. Actually, it is the cause

- of the competition between quite different projects and a tendency similar to commercials for advancing own projects at the cost of the other projects;
- of using the very unsophisticated methods for estimating the scientific activity of the individuals and organizations such as different publication and citation indices, forcing people to publish as much as possible in the journals of the highest impact factor, while the quality as well as the degree of the personal contribution of the individual researches are much less important.
- in Russia the shortage of funding is aggravated by the reforms in the systems of education, the Academy of Sciences and the main scientific funds.

Our assessment of the situation in solar modulation of the galactic cosmic rays

- Although the achievements in all fields of study of solar modulation of the GCR are significant, still much should be done to consider its main tasks as settled.
- The processes of the competition, estimation by the unsophisticated indices and reforms will continue and soon the studies will be made by the very limited number of researchers. Let us wish them good luck!
- However, it should be born in mind that the notion of all main problems in our science as almost solved is quite erroneous. What is left behind is some kind of the ignorance of the second order, when the main problems are posed but still not fully settled. Recall that Stanislaw Lem considered as the ignorance of the first order that of the Neaderthal man who not only knew nothing about the nature of the electron but also completely ignored its existence.