**Eugene N. Parker (1927 – 2022)**

By Kanaris Tsinganos


The unquestioned founder and a legendary figure in the field of Heliophysics and Plasma Astrophysics, the S. Chandrasekhar Distinguished Service Professor Emeritus at the Depts. of Physics and Astronomy & Astrophysics and the Enrico Fermi Institute of the University of Chicago, namesake of the NASA solar probe, the theoretical solar physicist and astrophysicist Eugene Parker, died on March 15 in Chicago IL, at the venerable age of 94. He is survived by his wife of 67 years, Niesje, their two children, Eric and Joyce, three grandsons and two great-grandchildren.

Eugene Newman Parker was born in Houghton, Michigan, on June 10, 1927. He received a BS in physics from Michigan State University (1948) and a PhD in physics from the California Institute of Technology (1951), supervised by Howard P. Robertson. Subsequently, Parker was an Instructor in the Department of Mathematics of the University of Utah (1951-1953) and then a research associate with Walter M. Elsasser in the Department of Physics. Then, Parker moved to the University of Chicago in June 1955 as a research associate with Professor John A. Simpson. In 1957, Parker was appointed an assistant professor in the Department of Physics and the Enrico Fermi Institute, and professor in 1962. He was also appointed professor in the Department of Astronomy and Astrophysics (1967). He was elected to the National Academy of Sciences in 1967. Parker retired from the University of Chicago in 1995, but continued to publish books and articles.

Parker received numerous scientific awards over the years, beginning with the Space Science Award from the American Institute of Aeronautics and Astronautics (1964) and including among others the Henrijk Arctowski Medal of the National Academy of Science (1967), the Hale Award of the American Astronomical Society (1978), the United States National Medal of Science (1989), the William Bowie Medal of the American Geophysical Union (1990), the Gold Medal of the Royal Astronomical Society (1992) and the Bruce Medal of the Astronomical Society of the Pacific (1997). Parker was the recipient of the 2003 Kyoto Prize in Basic Science and also he received the 2020 Crafoord Prize in Astronomy, which is awarded every three years by the Royal Swedish Academy of Science and consists of a gold medal and a sum of six million Swedish krona, i.e., about $600,000. The Academy recognized Gene Parker for his pioneering and fundamental studies of the solar wind and magnetic fields from stellar to galactic scales.

NASA honored E.N. Parker's scientific contributions in 2018 by naming a spacecraft after him, the first time NASA had named a spacecraft after a living person. The Parker Solar Probe's successful launch, which Gene Parker attended at age 91, has since provided unprecedented views of the sun. During the COSPAR General Assembly in Athens (July 2022), Parker was leading the SOC of the session I organize on "Exploring the cradle of the solar wind with Parker Solar Probe/Solar Orbiter/Proba-3: what do we really know about the inner solar corona?" His last publication was entitled *Exploring the innermost solar atmosphere (*Nature Astronomy, *2020).*

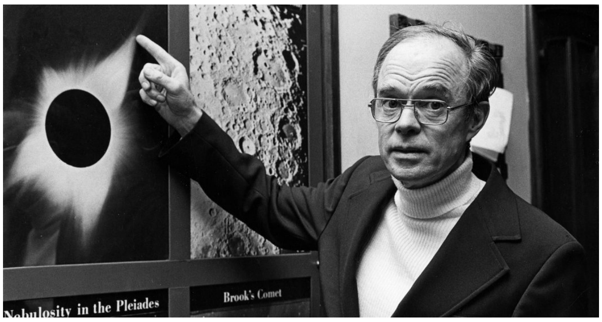
In addition to over 400 scientific papers in journals, Parker published 4 books, which have become landmarks in the fields of the Solar Wind (Interplanetary Dynamical Process, 1963, Interscience Division, John Wiley and Sons, New York), the basic theory of magnetic fields in Astrophysics (Cosmical Magnetic Fields: Their Origin and their Activity, 1979, Clarendon Press, Oxford), the heating of solar and stellar coronae (Spontaneous Current Sheets in Magnetic Fields, with Application to Stellar X-rays, 1994, Oxford University Press, New York) and the dynamic electromagnetism of the Cosmos, that is, the vast magnetic fields that are carried bodily in the swirling ionized gases of stars and galaxies and throughout intergalactic space (Conversations on Electric and Magnetic Fields in the Cosmos, 2007, Princeton University Press).

Plasma confinement in stable equilibrium states constitutes a fundamental and still unresolved question in plasma astrophysics and thermonuclear fusion research. In 1972 Parker focused on the topology of the lines of the magnetic force, and in particular on the non-equilibrium of non-invariant fields along some large scale direction. In the so-called *Parker theorem*, he proposed that if an equilibrium magnetic field is subjected to an arbitrary, small perturbation, then, under ideal plasma dynamics, the resulting magnetic field will in general not relax towards a smooth equilibrium, but rather, towards a state containing tangential discontinuities. And, as such a singular state is approached, dissipation must eventually become important, leading to the onset of rapid magnetic reconnection and energy dissipation. In other words, the formal theory of the spontaneous formation of tangential discontinuities leads to the result that magnetic fields subject to continuous deformation at very large magnetic or Lundquist numbers tend toward internal surfaces of tangential discontinuitires, across which rapid reconnection continues until the field topology is reduced to such simple form that discontinuities are no longer an essential part of the static equilibrium. In the presence of continuing shuffling of the footpoints of the field, the reconnection never ceases. This principle seems to be the essential effect providing the dissipation of magnetic free energy that creates the X-ray corona of the Sun and similar stars. That is to say, it looks as though the spontaneous discontinuities are the basis for much of X-ray astronomy.

This topological dissipation mechanism remains a key ingredient in the *nanoflare* model for coronal heating. Hence, Parker proposed (1987) that the solar corona might be heated by a myriad of tiny *nanoflares*, miniature brightenings resembling solar flares that would occur all over the surface of the Sun. Thus, Parker's theory became a leading candidate to explain the coronal heating problem.

In a long series of papers entitled *Sunspots and the physics of magnetic flux tubes* (1979, with myself contributing two papers) Parker studied the basic properties and interactions of isolated twisted magnetic flux tubes, proposing that sunspots are a conglameration of isolated flux tubes wherein hydrodynamic effects suggest that the separate flux tubes beneath the sunspots exert significant attractive forces on each other.

The generation and nature of magnetic fields in turbulent fluids, including the hydromagnetic *dynamo* problem, in planetary, solar, stellar and galactic environments were studied by Parker already in 1955.
The first theoretical framework of *magnetic reconnection* was established by Peter Sweet and Eugene Parker in 1956.
In 1961, Parker correctly predicted that the solar wind would create a large bubble around the sun, the heliosphere. In 2012, Voyager 1 finally left this bubble first predicted by Parker, entering interstellar space.
The propagation of charged particles in the heliosphere is generally described by *a transport equation* which is a special case of the general Fokker–Planck equation and it was derived by Parker in 1965.
Parker (1966) emphasized the importance of the magnetic buoyancy instability in the Galactic disk, including the effects of cosmic-ray and pressure, which explains the formation of interstellar cloud complexes. This so-called *Parker instability* of a galactic gas layer with a horizontal magnetic field supported against gravity by magnetic fields and cosmic rays, wherein the plasma falls down along bending magnetic field lines is thought to be dynamically important for galaxy evolution, possibly promoting molecular cloud formation and the galactic dynamo.




The most stringent, mass-independent upper limit on the flux of magnetic monopoles is based upon the survival of the galactic magnetic fields, the so-called *Parker limit* (1987), wherein it was explained that magnetic monopoles would short-circuit the galactic magnetic field, just as electrons short-out electric fields in the frame of any conducting matter.

Parker studied the physics of large-scale magnetic fields in fluids of high electrical conductivity, with emphasis on their generation in astronomical bodies and their interaction with those bodies. He described the role and nature of cosmic magnetic fields and developed solutions to the basic magnetohydrodynamic equations. He discussed the problem of magnetic equilibrium and the propagation of disturbances in a magnetic fluid.

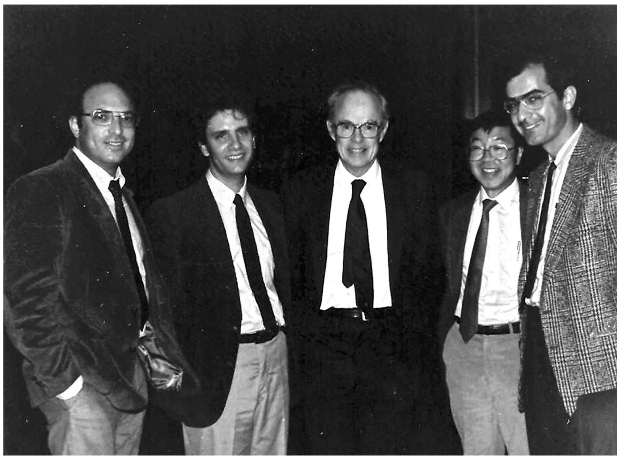
At the dawn of the Space Age in the late fifties, a conceptual revolution in astronomy was the prediction by Eugene Parker that an extremely hot solar corona cannot be confined by solar gravity, but expands supersonically into interplanetary space to fill the whole solar system and affect all planets. By using the basic equations of magnetohydrodynamics, Parker submitted for publication a seminal paper (1958) concluding that the hot solar corona should expand producing a supersonic flow of particles. Parker's theory of the solar wind remains even today one of the most beautiful chapters of modern astrophysics, both for its simplicity and for the plausible and wonderful way of explaining a not-so-simple natural phenomenon. Additionally, he correctly predicted the twisted shape that the rotating sun's magnetic field would take as the solar wind carried it to the outer solar system, which is now called the *Parker spiral*.
However, it is remarkable that his theory was largely ignored until 1962, when Mariner 2 became the first probe to travel beyond Earth's magnetic field. The spacecraft observed the supersonic solar wind and Parker was vindicated. The observational verification of the solar wind theory (1958) is a unique example in astrophysics, due to its immediate and brief confirmation by observations (1962). However, before that his conclusion was roundly criticized. This is in accordance to Parker's saying:

"*If you do something new or innovative, expect trouble*".

More on that, Parker himself told me the following story of what happened behind the scenes for the initial rejection of his classical solar wind paper. As he was pleased with the outcome of his MHD theory for the expansion of the solar corona in the interplanetary space, he wrote it up for publication in The Astrophysical Journal, of which, fortunately, Prof. S. Chandrasekhar was editor at that time. The referee's report came back in a few months with the suggestion that the author should spend some time in the library to familiarize himself with the solar corpuscular radiation, before attempting to write a scientific paper on the subject. There was no specific criticism of the mathematics or of the interpretation of the observations. Then, Chandra sent the paper to a second *eminent* referee, with essentially the same result. Parker emphasized to Chandra that these two referees, for all their hostility, could find no scientific error. Then, one day Chandra came to Parker's office and said, "Now see here, Parker, do you really want to publish this paper? I have sent it to two eminent referees, and they both say the paper is wrong." Parker replied that the referees had no scientific criticism. Chandra thought for a moment and then said, "Alright, I will publish it." Some years later he told Parker that he himself had been skeptical about the paper, but without objective criticism, he felt obliged to publish it. To his regret Parker failed to save the two referee reports to be framed and displayed on the wall of his office! This was another lesson in the sociology of science, demonstrating the importance of editors who do not fear to contradict eminent referees.

By the end of the 20th century, modern observations including those recently with the Hubble Space Telescope, have revealed that the Universe is replete with analogous outflows from all kinds of objects, ranging from the rich varieties of stars to the galaxies. Parker initiated the use of the magnetohydrodynamic (MHD) approach to describe all such cosmical phenomena. Since then, MHD is increasingly used in several key problems of solar plasmas, such as, magnetoconvection and magnetic field generation, sunspots and prominences, MHD equilibria in plasma loops and arcades, magnetic nonequilibrium and coronal heating, coronal mass ejections and the acceleration of the solar wind.
On the other hand, the same MHD approach has also increasingly been used in several central and puzzling aspects of more distant astrophysical plasmas, such as, stellar winds across the main sequence, the dynamics of the interstellar medium and the galactic center, collimated outflows from young stellar objects and accretion disks, molecular outflows and planetary nebulae, jets associated with enigmatic binaries and symbiotic stars, relativistic flows associated with superluminal micro quasars in our own galaxy, astrophysical jets from nearby galaxies, or far away active galactic nuclei and quasars probably fueled by supermassive black holes. However, although the underlying similarities in the physics of these phenomena are rather striking, nevertheless quite often researchers in one field are unaware of the methods employed in the study of the other. To emphasize the similarities of astrophysical outflows, as they are described via Parker's MHD theory, we organized an Advanced Study Institute on *Solar and Astrophysical Magnetohydrodynamic Flows* in June 11 - 23, 1995 at Fodele, the birth place of the Cretan painter D. Theotokopoulos (El Greco), in Crete, Greece. This conference was dedicated to Prof. Parker who has been the inspiration for many of us to study the role of magnetism in the Cosmos. Hundreds of researchers, experts in MHD and participants from 25 countries gathered to honour Eugene Parker on the occassion of his retirement from the University of Chicago, after more than 50 years in solar physics and astrophysics. What attracted them was also the scientific program which was naturally dedicated to Eugene Parker's interests. Thus, appropriately, special reviews were presented on topics Parker has immensely contributed, such as, new developments in the Parker instability in the interstellar medium, the spontaneous formation of electric current sheets in magnetized plasmas,

magnetic reconnection, sunspot modelling, coronal heating, stellar winds and also a generalisation of his model of the solar wind by our group via exact self-similar solutions of the MHD equations.
The presentations during this conference included a discussion of the generation, storage and eruption of magnetic fields in our Sun deep in its convective layers, as prototypes of the fields of other stars, galaxies and accretion disks. The erupted through the photosphere magnetic field forms intense flux tubes and sunspots and thus siphon flows and Alfven waves along such magnetic flux tubes. The impressive high resolution pictures of the Sun in X-rays by modern satellites were reviewed and indeed show a solar atmosphere constituted of many steady and transient magnetic loops like those expected to emerge from deep within the solar convective zone. The X-ray data also show clear evidence of intense heating due to magnetic reconnection. Thus, Parker's spontaneous formation of current sheets in astrophysical magnetic fields and the various MHD processes in the solar corona (flares, coronal mass ejections, etc) are today observed everywhere. Parker's ideas have been tested by numerical simulations of solar and astrophysical MHD flows (magnetic loops, flares, solar X-ray jets as well as the nonlinear evolution of the Parker instability and magnetically accelerated astrophysical jets). Observational data from the south and north solar polar pass of the Ulysses spacecraft are showing, for example, that the solar wind is indeed a rather meridionally anisotropic outflow with the proton speed at large heliolatitudes almost twice its equatorial value. Stellar winds from solar- as well as non solar-type stars were also reviewed in the conference and a discussion of some general implications of solar and stellar activity, such as the profound effects of the variation of solar brightness to the terrestrial climate.



Parker's name is littered across astrophysics and it is almost impossible to describe here all his scientific contributions. The scientific community is indebted to E.N. Parker for his life-long work on cosmical magnetic fields. His work, has revealed many basic mechanisms, opened many roads and possibilities for investigation and understanding, at the same time stirring up ways of thinking by pointing out inconsistencies and throwing new ideas into the field.

In conclusion, although Gene Parker is no longer with us, his revolutionary discoveries and legacy will live forever, because his main contributions on Plasma Astrophysics and Heliophysics can be discovered only once.

I had the privilege of completing my PhD thesis under the supervision of Gene Parker (1977-1980), while my office was in between the offices of Parker and Chandrasekhar. Words are poor to describe these two legendary scientists. Like

Chandra, Gene was not only a great physicist but at the same time he remained humble and approachable: till today I recall that whenever I was anxiously knocking his door to report on my research results, Gene would willingly interrupt his work to chat with me. His favorite advise was: *when your math becomes complicated stop and think again about your physics*.

I can only repeat what Alexander the Great said more that 2000 years ago about his teacher: *I owe to my father my life, but to my teacher Aristotle the dignity of my life.* In the picture above, Gene Parker (center) is surrounded by his former PhD students (from left to right) Eugene Levy, Tom Bogdan, Boon Chye Low and myself, during Parker's 60th birthday (1987).