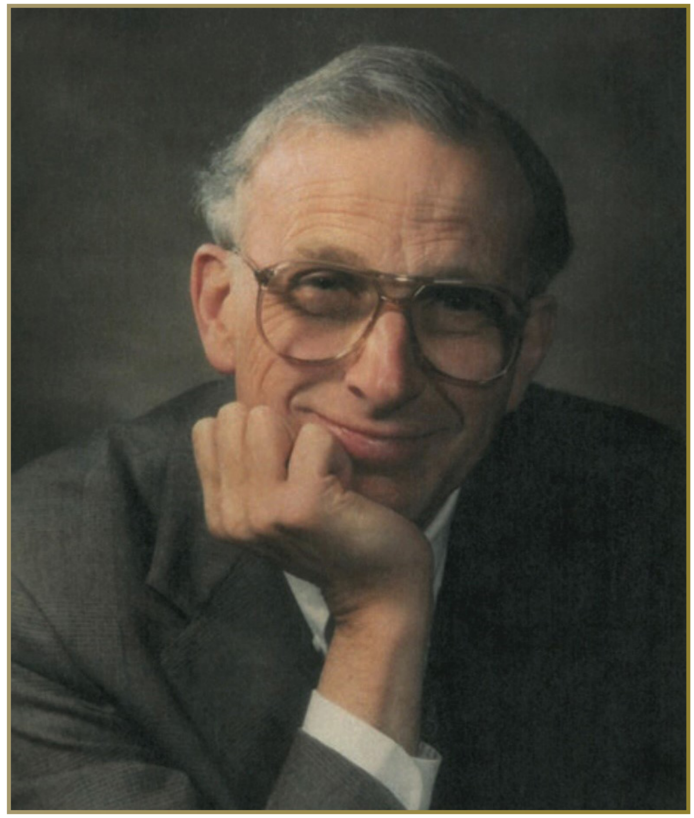
George Brooks Field

October 25, 1929–July 31, 2024
Elected to the NAS, 1989

A Biographical Memoir by Eric Blackman, Eric Keto, and Christopher McKee



George B. Field. *Photo reproduced from Field, G. B. 2014. Wondering about things.* Annu. Rev. Astron. Astrophys. *52:1–42 with permission granted by* Annual Reviews.

George Field was an outstanding scientist who left his mark on several branches of astrophysics. He was an important leader in astronomy and astrophysics in the latter part of the twentieth century and a mentor to many excellent astrophysicists. He stood out for his incisive pursuit of physical principles in astronomy, his unfading broad scientific curiosity, and his warm, welcoming demeanor in scientific discourse that engaged both students and senior collaborators. When asked, "Well, Professor, how do you explain that?" he responded with delighted laughter before tackling the problem, and in due course did so successfully.

Early Life, Education, and Academic Career

George Brooks Field was born on October 25, 1929, (the week of the stock market crash) to Winthrop Field and Pauline Woodworth in Edgewood, Rhode Island. His parents were both highly educated: his father graduated from Harvard University with a degree in mathematics, and his mother graduated from Radcliffe College with a degree in classics. George's father operated a sheep farm for a time and then worked for a company that gave financial advice to farmers, running its Providence office. George attended public schools in Cranston, Rhode Island. As Field recalled in his autobiography, his family were all voracious readers, and he first sparked his love of astrophysics through books he found at his local library.[1]

Field entered the Massachusetts Institute of Technology in 1947 and graduated in 1951. The following year, he embarked upon graduate studies at Princeton University, where he studied under Lyman Spitzer, who in turn had been a student of Henry Norris Russell. As he was completing his Ph.D. in 1955, Field was invited to apply as a Junior fellow at Harvard University. There, he met and married his first wife, Sylvia, and had his first child, Christopher. In 1957, he returned to Princeton as an assistant professor and was subsequently promoted to associate professor. During that time, he and Sylvia had their second child, Natasha.

In 1965, Field moved to the University of California, Berkeley as a professor of astronomy and later became the department chair. In 1972, he was named director of both the Harvard College Observatory and the Smithsonian Astrophysical Observatory, combining the two institutions into the Harvard-Smithsonian Center for Astrophysics, headquartered in Cambridge, Massachusetts. He remained the director until 1982, stepping down to resume his career in research and teaching as a professor of astronomy at Harvard. Field divorced Sylvia in 1978 and in 1981 married his second wife, Susan DiMeo. He retired in 1999 but continued to conduct research until his passing.

Scientific Contributions

From the beginning of his career, Field's research was motivated by scientific questions rather than technique or method. Whereas some researchers learn a technique, for example numerical modeling or observing, and then search for questions that require the technique, Field seems to have started with the question and then learned the necessary techniques for its solution. Although he studied plasma oscillations for his Ph.D. thesis at Princeton under Lyman Spitzer, he became interested in the new topic of interstellar matter that had recently been motivated by the first observations of interstellar HI (neutral hydrogen). As a Junior Fellow at Harvard, and without any background in observational astronomy, Field decided to search for intergalactic HI, as yet unobserved. The presence of intergalactic matter bears on questions such as whether the Universe is gravitationally bound or equivalently "cosmologically closed" as well as how galaxies form. Galaxies now occupy about one-millionth of the volume of the Universe, whereas shortly after the Big Bang, matter was more uniformly distributed. Is the space between galaxies now really empty?

The quantitative interpretation of any detection of HI requires the determination of the spin temperature, or excitation, of the HI atom, which was uncertain at the time. In 1952, Siegfried Wouthuysen proposed that the HI and the radiation field would be in thermodynamic equilibrium at the same temperature.[2] But the question remained of how quickly the HI spin temperature would evolve to equal the kinetic temperature. The time scale for the HI spin-flip transition is quite long, about 10 million years. This line of research resulted in a series of papers on the excitation of HI,[3,4] and a paper on the failure to detect intergalactic HI that provided an upper limit on its surface density.[5]

An incident during Field's observational experience cemented his decision to focus on theoretical astrophysics. He was in the habit of using the weight of the *Astronomical Almanac* to disable the limit switch on the elevation drive of the Harvard telescope at Agassiz Station that prevented the dish from descending too close to the ground. Predictably perhaps, one night this resulted in a collision with a supporting element of the telescope. Serious damage was averted by a secondary limit switch responding to vibrations of the telescope. Field said that he interpreted this as a "message from God" encouraging him toward theoretical research.[6] He did not explain how he, a confirmed atheist, arrived at this interpretation, nor why he put off the supernatural advice long enough to complete an observational program with the larger, more sensitive 85-foot antenna at the National Radio Astronomy Observatory (NRAO) in Green Bank, WV. This resulted in his improving the upper limit on the intergalactic HI surface density by a factor of three.[7] We now know that most of the intergalactic matter is in an ionized rather than an atomic state.

Field's interest in HI led him toward what he described as his most important contribution to astronomy, the explanation of the thermal instability and a two-phase model for the interstellar medium.[8,9,10] Carl Heiles, Field's graduate student at Princeton, was mapping HI in the Galaxy with NRAO's 300-foot antenna. The derived densities and temperatures indicated that the thermal energy of the HI clouds was larger than their gravitational energy, implying that the clouds should be expanding in the absence of another force. Field postulated that the HI clouds at a temperature of about 100 K could be in equilibrium with the pressure of surrounding warm (about 10,000 K) HI. Detailed study of the cooling and heating processes in each phase showed that each phase is itself stable at the same constant pressure. This two-phase model of the HI in the interstellar medium (ISM) has withstood the tests of time, with the exception that his suggestion that cosmic rays are the primary source heating the HI phases has been replaced by the understanding that dust-gas coupling is the primary source, with the dust heated by pervasive UV emission from stars. Field also participated in the discovery of a third phase of the ISM, hot X-ray-emitting plasma.[11] Our current understanding of the multiphase ISM now includes a fourth component—cold, often self-gravitating molecular gas revealed by the detection of the (1-0) rotational transition of CO. The concept of a multiphase interstellar medium pioneered by Field is now central to our understanding of gas in galaxies.

In an important but under-appreciated 1966 paper, Field, George Herbig, and John Hitchcock argued that the excitation of the 2.6 mm rotational lines of CN (cyanogen) resulted from the absorption of the then recently discovered cosmic microwave background radiation.[12] The paper was significant because at the time this was the shortest wavelength with evidence for the cosmic microwave background radiation. This wavelength was near the peak emission (Wien's law) of the blackbody curve at 2.7 K, providing evidence that the cosmic microwave background radiation had the expected distribution of a Planck function. With only the single wavelength of the discovery observation, the radiation could have been either on the Rayleigh-Jeans side of the black-body curve or possibly from another source.

In his 2014 remembrance, Field said that he had thought about CN excitation before 1965, after reading that observations of the first rotational state of CN had an excitation temperature of about 3 K.[13] Unless the Einstein B coefficient of this transition was unrealistically small, the molecule had to be radiatively rather than collisionally excited. But lacking an estimate of the dipole moment of the molecule necessary to calculate the B coefficient, both he and Lyman Spitzer decided that the result was too speculative to publish. This might have provided the first evidence, although not unambiguous, of pervasive 3K radiation in the Universe. By 1966, an estimate of the dipole moment was available, and the significance of the CN observations with respect to the cosmic microwave background was understood.

Field's extraordinary research on the interstellar medium was somewhat curtailed when he moved from Berkeley to Harvard in 1972 and assumed the directorships of both the Harvard College Observatory and the Smithsonian Astrophysical Observatory, combining them to create the Center for Astrophysics. Nonetheless, he continued to publish influential papers, including an *Annual Reviews* article on intergalactic matter and an interpretation of O VI emission in the context of a "galactic fountain," now a ubiquitous concept in galaxy evolution.[14,15]

When Field stepped down from the directorship of the CfA in 1982, he returned to his first interests in astronomy, plasma astrophysics, and magnetohydrodynamics (MHD). He pursued the development of a Lagrangian formalism for deriving the equations of MHD, which led him to focus on relevant Lorentz invariants. One of them, the dot product of electric and magnetic fields integrated over volume, caught his attention. This was equal to the 4-divergence of a so-called magnetic helicity 4-vector. The time component is the true magnetic helicity, a measure of twist and linkage of magnetic field lines in the chosen volume, and the 3-vector part measures the flux of twist and linkage through the boundary. The time-derivative of magnetic helicity was known to be zero in ideal MHD (zero resistivity) for a closed volume and generally better conserved than magnetic energy in non-ideal MHD, but the magnetic helicity is not gauge invariant when boundary terms are present. In considering how to characterize the twist and linkage of field lines in the solar corona for example, Field and his student, Mitch Berger, took the opportunity to develop the influential concept of "relative magnetic helicity," the difference between the magnetic helicity in a given volume and that of a potential field within that volume. This removed the boundary dependence and represents a gauge invariant version of the ideal MHD invariant.[16]

Magnetic structures and the analogy to the solar corona also featured in Field's effort to understand active galactic nuclei (AGN). Always paying close attention to new observations across astrophysics, he knew that X-ray observations of AGN were revealing power-law photon spectra modified by the presence of cold gas. It was known that any emission from accretion disks around black holes required matter to lose angular momentum and fall deeper into the gravitational potential, thereby releasing energy in the form of radiation. Field and Robert Rogers developed one of the early MHD models that combined disk angular momentum transport with a predicted coronal x-ray radiation spectrum.[17] In the model, differential rotation in the disk produces large-scale coronal loops. Footpoint twisting of these loops destabilizes them to dissipate their energy much like a solar flare, in which magnetic energy is converted to high energy electrons. These electrons inverse Compton scatter thermal disk photons to produce the observed X-ray spectra. An offshoot of this work was the first paper on highly relativistic magnetic reconnection because the plasma at the tops of the loops was pair plasma.[18]

Field next returned to hisinterest in magnetic helicity and pondered the role of the four-divergence of the magnetic helicity four-vector and its absence in the standard Lagrangian for electrodynamics. Because it is a boundary term it does not affect the dynamical equations unless coupled to a separate dynamical field. Such a term is a Chern-Simons term which has a long history in particle physics. With his student Sean Carroll he investigated the Lorentz-invariance violating consequences of this term and possible signatures for such from astrophysical polarization measurements.[19,20]

Field's investigations of large-scale magnetic structures in coronae, the topological invariant of magnetic helicity, and the increasing awareness that turbulence is ubiquitous in astrophysical plasmas came together in his work on magnetic dynamo theory with his student Eric Blackman. Mechanisms for the exponential growth of large-scale field generation in turbulent rotators had a long history from the 1950s on, but a predictive nonlinear saturation theory of the field strength was still absent at the turn of the twenty-first century. They sought to understand the implications for dynamo theory of magnetic helicity conservation, which was missing from standard textbook theories.

They realized that in a closed volume, the build-up of magnetic helicity for the highly conducting flows of astrophysical rotators would threaten the dynamo growth of large-scale fields.[21] They then derived the equations for a helical dynamo from first principles, with a turbulent closure, solving the generalized time evolution for a simple large-scale dynamo to show how magnetic helicity conservation determined saturation.[22] This work has influenced community thinking on large-scale dynamo saturation in a range of astrophysical contexts.

After his retirement, Field also turned his attention back to the galactic interstellar medium, particularly molecular clouds in the context of the new appreciation of the molecular ISM as fully turbulent. This research was undertaken with Blackman and his CfA colleague Eric Keto. Although turbulence in general would seem to preclude any equilibrium, their research indicated that interstellar turbulence is a significant perturbation to an average pressure and dynamical equilibrium in the molecular phase of the interstellar medium.[23,24] Before his death, he was able to read the results of Eric Keto's study with strong observational evidence for pressure equilibrium within turbulent molecular clouds, suggesting that his vision from forty years earlier remained essentially correct.[25]

Mentorship and Leadership

Field was an important leader in astronomy and astrophysics in the latter half of the twentieth century. In addition to his role as the founding director of the Center for Astrophysics, Field made major contributions to national science policy. In preparation for the 1970s, the National Academy of Sciences commissioned decadal surveys in both astronomy, led by Jesse Greenstein, and physics, led by Ralph Bromley. As a member of both committees, Field set up a panel on astrophysics and relativity with leading figures that included Maarten Schmidt and Steven Weinberg. His primary success was the promotion of the Large Space Telescope, first proposed by Spitzer about twenty years earlier and now known as the Hubble Space Telescope (HST). Building upon technology developments in the 1970s and construction techniques in the 1980s, the HST became one of the most successful of NASA's many astronomical missions.

Field chaired the decadal survey for the 1980s and established a pattern that was very influential in subsequent surveys. He was largely responsible for selecting members of the committee after extensive consultation with members of the community. The cost of the recommended program was to be limited to the amounts recommended by previous surveys after allowing for inflation. Each subfield of astronomy was covered by a separate panel, with the result that a significant number of astronomers from around the country had input into the final survey report. The recommendations of the panels were prioritized by the survey committee. The 1980 committee also gave the HST high priority, which was important in keeping the program alive in the face of budget concerns in Congress. The HST program has been enormously beneficial to the astronomical community through the large amount of funding distributed for data analysis, for the creation of the Space Telescope Science Institute, and for the NASA Hubble Fellowship Program.

Field's other major leadership contribution was the creation of the Harvard-Smithsonian Center for Astrophysics. He was offered the directorship of the Harvard College Observatory (HCO) in 1972, when the former director, Leo Goldberg, resigned in order to become director of Kitt Peak National Observatory. HCO was relatively small, but it was in the same location as the Smithsonian Astrophysical Observatory (SAO), which had been built up into a much larger organization by Fred Whipple, with scientists directly supported as federal employees and scientists indirectly supported through NASA contracts. Field realized that if he could use some of the federal positions to attract tenured scientists, he could build an organization to address the exciting opportunities in astronomy opened up by discoveries such as the cosmic microwave background, pulsars, quasars, and binary X-ray sources. He therefore decided to accept the position as director of HCO only if he were appointed director of SAO as well. His proposal was accepted, and the Center for Astrophysics (later the Harvard-Smithsonian Center for Astrophysics) was born. One of his first acts was to bring Riccardo Giaconni (who subsequently won the Nobel Prize) and his group into SAO; they developed the Einstein Observatory satellite, which flew from 1978-81. The new entity was rapidly recognized as one of the leading astronomical research institutions in the world.

His students include Susan Ames, Eric Blackman, Sean Carroll, Dan Garretson, John Girash, Carl Heiles, Richard Henry, John Hutchins, Chun Ming Leung, Phillis Lugger, Christopher McKee, Peter Meszaros, Telemachos Mouschovias, William Saslaw, Paul Shapiro, Boqi Wang, Ira Wasserman, and Hongsong Zhou

Awards and Honors

Field was first elected to the National Academy of Sciences (NAS) in the 1970s, but he declined over discomfort with the organization's role during the Vietnam War. He was elected again in 1989 and accepted (according to his wife, Susan, after she said "Hey, why not? It's like being invited to join pals playing baseball and refusing"). He was made a Fellow of the American Physical Society in 1970 and was elected to the American Academy of Arts and Sciences in 1972. He received the NASA Distinguished Public Service Medal in 1977 and the Joseph Henry Medal of the Smithsonian Institution in 1982. In 2014, he was awarded the Henry Norris Russell Lectureship by the American Astronomical Society, which is chosen "on the basis of a lifetime of eminence in astronomical research." He is survived by his son and daughter, Christopher and Natasha Field, and his wife, Susan.

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