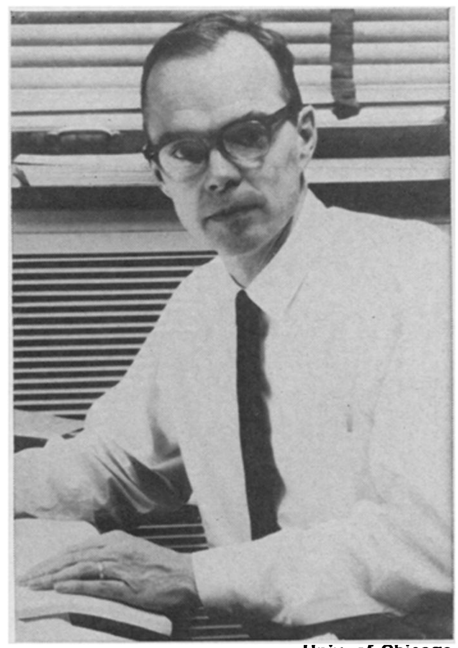
Washburn Observatory

The Milky Way, as seen from the Southern Hemisphere: The disk of gas is flatter than the disk of stars.

COSMIC MAGNETISM

Exploring the nature of galactic fields

Galactic magnetic fields appear to have a dynamic rather than primordial origin



Univ. of Chicago

Parker: System like a leaky balloon.

by Dietrick E. Thomsen

Magnetic fields are a common characteristic of astronomical bodies. The earth possesses one. So do other planets, the sun and other stars. A very weak field, a few microgauss or about a thousandth of the earth's, pervades the Milky Way galaxy, and a galactic magnetic field also appears to pervade the Magellanic Clouds (SN: 5/16, p. 477).

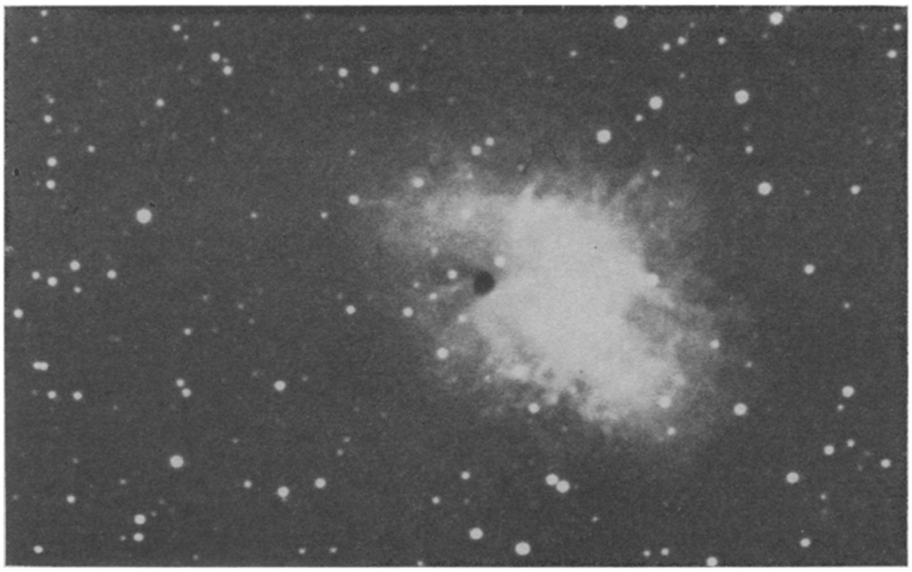
Geophysicists have long believed that the earth's field is generated by circular motions of an electrically conducting fluid in the core. Astronomers, when asked about the galactic field, have usually replied that it was probably primordial, a remnant of magnetism generated at the beginning of the galaxy's history.

Recent observations have determined the direction of the Milky Way's magnetic field. This supplied Dr. Eugene Parker of the University of Chicago with the basis for a suggestion that it may not be primordial but continually generated by motions of the interstellar gas. Thus, he says, the galactic field could be produced in a manner similar to the way the earth's field is generated.

Furthermore, Dr. Parker believes that the magnetic field plays an important part in the constitution of the interstellar medium. The cosmic rays and the interstellar gas, he says, are all bound together by the forces they exert on each other in a system that he describes as "like a leaky balloon, into which air is continually being pumped."

In shape the Milky Way galaxy is a very flat disk. The disk of gas is in fact somewhat flatter than the disk of stars. The gas is about 1,000 light years thick and 100,000 light years long. The disk of stars is about 15,000 light years thick at the center and slopes more or less to a point at the edges.

The magnetic field lies within the disk of gas, and the recent measurements have shown it to be directed in curved

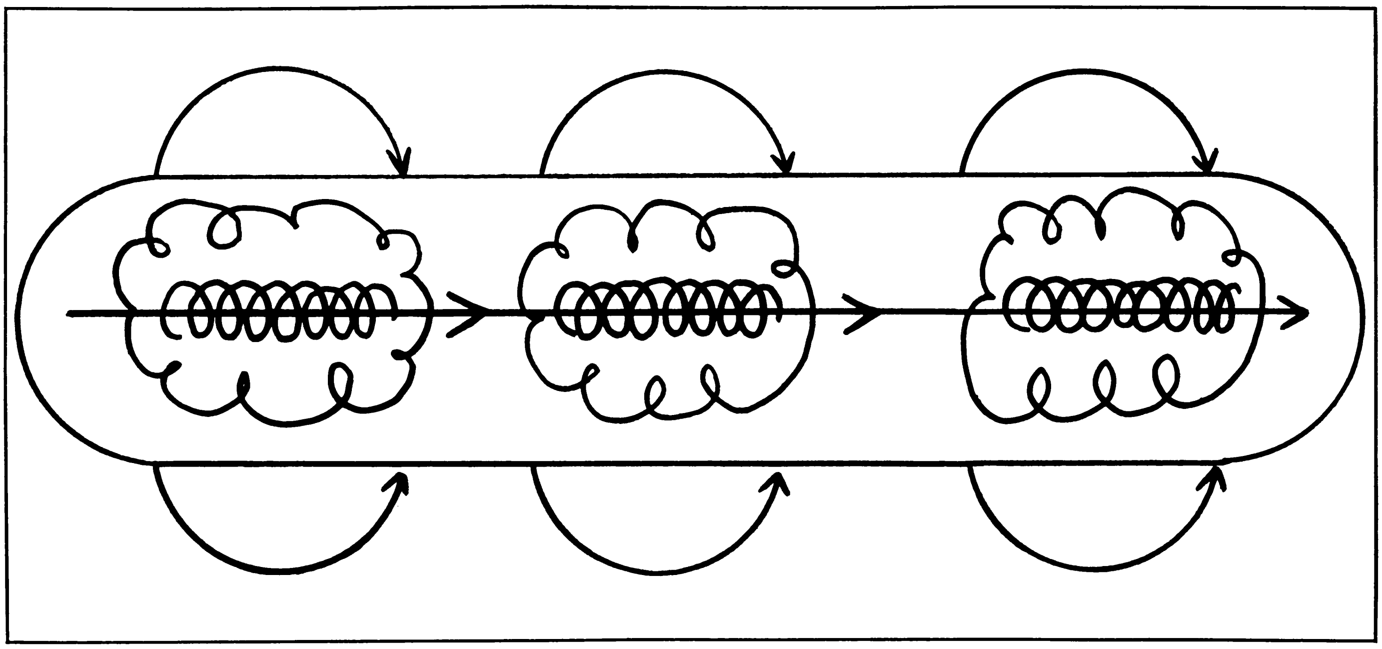


Naval Observatory

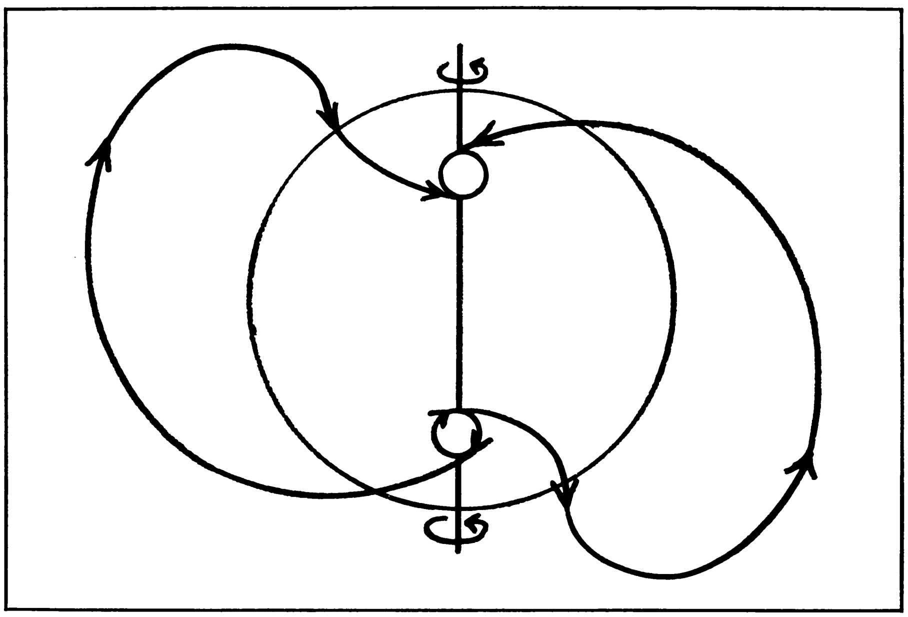
lines that follow the shape of the disk.

The direction was determined by measuring the polarization of starlight that had been reflected by interstellar dust. The dust grains have a slight electric charge and because of this are oriented by the magnetic field. When starlight is reflected off their faces, it is polarized. That is, the electric waves in the light all vibrate in one direction and the magnetic waves all vibrate in a direction perpendicular to the electric waves. In ordinary light the waves vibrate in random directions. The direction of polarization tells the orientation of the dust grains and that tells the direction of the field.

A field formed in curves of this kind, says Dr. Parker, is what geophysicists envision in the center of the earth. The liquid core of the earth does not rotate



Robert Trotter



Supernova and pulsar in the Crab (top) both make it prime cosmic-ray source. Spiral cosmic-ray paths (center) follow galactic magnetic field lines. Eddies in the earth's core (right) generate its magnetic field.

uniformly; parts of it go faster than others. This difference in speed produces convection cells or giant eddies. These eddies generate looping magnetic fields, and some of the loops escape from the core to form the curved lines of force that run from the North Pole to the South Pole.

Conditions in the galaxy are analogous to those in the earth, says Dr. Parker. The interstellar gas is an electrically conducting fluid since much of it is ionized, and its motions therefore form electric currents. The gas rotates with the galaxy and at different distances from the center of the galaxy it rotates at different speeds. This difference produces eddies, and these circular currents generate the galactic magnetic field.

The distribution of the interstellar gas is not uniform. It is found in clumps or clouds. Between these clouds loops of field lines rise above the surface of the galaxy, says Dr. Parker. But instead of having only one entrance and one exit, like the earth's North and South Poles, the galactic field has many and the pattern of loops is quite complicated.

Since the cosmic rays are electrically charged, they and the magnetic field should exert forces on each other. The question for both theoretical and observational calculation and determination is whether the forces are large or small; the mutual influence negligible or considerable. Dr. Parker believes that the mutual influence is considerable, and there is some observational evidence in support of that view.

Dr. J. A. Earl of the University of Maryland reports that studies of the numbers of cosmic-ray electrons that arrive at the earth with different amounts of energy lead to the conclusion that the electrons at least are constrained to move in spiral paths around the magnetic field lines and that they drift back and forth through the galaxy in such spirals. If the electrons are so bound then it is likely that the protons and atomic nuclei in the cosmic rays are similarly affected.

There is also a terrestrial analogy to the magnetic binding of the cosmic rays. The Van Allen belts are regions near the earth where the terrestrial magnetic field traps particles coming from the cosmic rays and the solar wind. These particles also move in spirals around the field lines.

Dr. Parker sees the gas, the field and the cosmic rays as bound together in a self-regulating, unstable balance. The field, he says, tends to expand as any magnetic field will do if it can. In any magnetic field the lines of force will move as far apart from each other as possible. The cohesion of the source of the field sets a limit to this expansion. In a bar magnet it is the strength of the metal; in the galactic case it is the gravitational forces between the gas molecules.

The field and the gas thus exist in a balance. If the field could somehow come loose from the gas, it would expand indefinitely. If there were no field, gravity would collapse the gas into a very small volume.

To this balance, says Dr. Parker, the cosmic rays add a disturbing and regulating element. The cosmic rays abet the expansive tendencies of the field. When they are more numerous, the disk will be larger; when they are less numerous, the disk will be smaller.

Since cosmic rays can both leave and enter the system, the size of the disk is not stable, and Dr. Parker expresses this instability with his image of a leaky balloon being constantly pumped.

The field lines that loop out of the galactic disk are the leaks. Cosmic rays may spiral along these lines, and once they get outside of the disk they can get lost there. Dr. Parker says there is observational evidence for cosmic rays at large distances from the disk, and these are presumably escapees from the disk.

To maintain a relatively uniform size for the disk, cosmic rays must be added to replace those lost by escape and by absorption by other matter in the galaxy. It is now generally agreed that the sources of nearly all cosmic rays are within the galaxy. Dr. Parker says observational evidence shows there are not enough particles in intergalactic space to account for a large intergalactic exchange of cosmic rays.

The prime candidates for cosmic-ray sources are supernova explosions and pulsars, but proving that they are the sources is difficult. The supposed sources are "discrete events in space and time," says Dr. Reuven Ramaty of the Goddard Spaceflight Center in Greenbelt, Md., but the way in which the cosmic rays drift along the magnetic field smooths them out. Among those that arrive at the earth, no one has yet found evidence of origin in bursts.

Dr. Ramaty is looking for such evidence among the lowest energy cosmic rays. Since cosmic rays lose energy as they travel, those that start with low energy will not last as long as those that start out with high energy. Among the lowest energy cosmic rays recorded at the earth, Dr. Ramaty reasons, should be some from fairly near sources. These may not have been drifting long enough to be completely smoothed out. If Dr. Ramaty can find evidence of bursts among them, he will have identified the pumps that, in Dr. Parker's hypothesis, keep the galactic balloon in shape. □