Magnetic fields of spirals

Virginia Trimble

Our Galaxy had been known to have a large-scale magnetic field for about 20 years\(^1\) when Fritz Zwicky suggested as a hypothesis for its origin: ‘Diuitique Deus, fiat lux campaque magnetae’. Another 20 years later, studies of the face-on spiral galaxy M83 (ref. 5) and of other galaxies discussed at a recent meeting show that we still do not understand galactic magnetic properties well enough to test competing theories of their origin much better than Zwicky could. The competitors are a pre-galactic field, amplified by differential rotation, and dynamos.\(^2\) More of their implications have been noted immediately that each requires some primordial seed field, though a fairly weak one will do in the dynamo case.

What do real galactic magnetic fields look like? That depends on how you look. Polarization of scattered star light and of synchrotron emission reveal the orientation of the ordered field component, but only in the plane of the sky and to within 180°. Faraday rotation of the polarization (with some assumptions about electron density distribution) indicates the strength of ordered fields and the absolute orientation, but again only in the plane of the sky. Thus we probe the field in the disk for spiral galaxies seen face-on and the field perpendicular to the disk for edge-on galaxies.

Most face-on spirals have ordered magnetic fields of a few microgauss (\(\mu G\)) lined up roughly along their spiral arms, according to Marita Krause (Max Planck Inst. for Radioastronomy), Yoshiaki Sofue (Univ. Tokyo) and others. The randomly oriented component is of similar strength. Rainer Beck (Max Planck Inst. for Radioastronomy) noted that, at least in NGC6946, the field direction is definitely that of the spiral arms, not that of the circular gas motion. For two galaxies, M31 (the Andromeda Nebula) and IC342, Faraday rotation data show that the field points the same direction along the arms, a configuration called an axisymmetric spiral (ASS). In others (M81, M51 and possibly M33), the magnetic field lines change direction by about 180° between arms, forming a bisymmetric spiral (BSS).

In many face-on spirals, the intensity of the ordered field is largest between the arms, not in them. This sounds paradoxical, but seems to mean that the field in the arms has been tangled up by gas turbulence (caused by stellar winds and explosions) so that it is stronger than the inter-

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\(^1\) And God said, let there be light and magnetic field.

away from a rotation axis and cyclonic motions — loosely, turbulence with a net twist. And there has to be a bit of field (of almost any geometry) there to start with. The poloidal and toroidal components of the dominant field mode are both axisymmetric. Stars with convective envelopes (like the Sun) and terrestrial planets with metallic fluid cores (like the Earth) meet the required conditions, and their magnetic fields are generally attributed to dynamos.

The disk of a spiral galaxy has the requisite differential rotation, and turbulence is constantly fed in by stellar winds and supernova explosions. Two consequences suggest themselves if galactic fields are dynamo-produced. First, axisymmetric spiral morphology should be favoured, though the dominant mode can be suppressed in several ways, so that an $m = 1$ bisymmetric field is seen. Possible promoters of the BSS configuration include a nearby companion galaxy (Beck), a high ratio of turbulence to differential rotation (Friedrich Krause, Astrophysical Observatory, Potsdam), a relatively thick gas disk (Makoto Tosa and M. Chiba, Tohoku University) and other minor gas-dynamic effects (Alexander A. Ruzmaikin, IZMIRAN, Moscow; Yulia S. Krasheninnikova and Anvar M. Shukurov, Space Research Institute, Moscow).

Second, there ought to be some intimate connection between field morphology and the processes responsible for star formation, in and out of spiral density waves. Leon Mestel (Univ. Sussex), A. N. Nelson (Univ. Wales), Fujimoto, Tosa and Chiba all emphasized the synergistic relationship between density waves and dynamos, especially BSS ones.

Galaxies where star formation is primarily driven by density waves are supposed to be the ones with grand designs dominated by two main arms, whereas localized star formation processes give rise to multi-armed and flocculent spirals.12

Can we say that “all” BSS magnetic fields occur in grand design spirals? Yes, but “all” at the moment means two (M51, M81) or perhaps three (M33) examples. And both the ASS fields (M31 and IC342) occur in multi-armed spirals. But the Milky Way fits into neither category. It has several (perhaps four) major spiral arms and a number of subsidiary ones, but a magnetic field with several reversals. If the field lines follow the gas flow direction rather than the arms, then it is neither ASS nor BSS. Shukurov pointed out that a linear combination of several dynamo modes can produce such a ringlike (axisymmetric, but with reversals) field morphology. Kulsrud’s primordially derived field configuration would seem to be an equally good fit. He also noted that, where the random field component <B^2> is larger than the uniform component <B^2> as we find in the solar neighborhood, then the dynamo equations are not a good approximation anyway.

Perhaps we should not yet feel forced to accept Zwicky’s hypothesis, but it seems that at least we have an answer and, at the moment, asking quite the right questions about the nature and origin of galactic magnetic fields.

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BEHAVIOURAL GENETICS

Nature – nurture and intelligence

Matt McGue

Philosophers, poets and scientists have long been intrigued by the relative influence of nature and nurture on human behavioural variability. Plato flirted with eugenics in designing his ideal society, Shakespeare emphasized heredity in character development, Locke and Mill espoused radical environmentalism and Galton devoted much of his illustrious career to a controversy that became synonymous with his name. For the past 50 years the nature–nurture debate has set the research agenda in human behavioural genetics. And, while a balanced review of behavioural genetic research on intelligence leads to the conclusion that both genes and the environment play an essential role in the development of individual differences in intelligence, as measured by IQ, for some the debate lingers on. The carefully designed French adoption study reported by Capron and Duyne on page 552 of this issue1, by clearly showing that the IQ of children is influenced by both their biological background and the circumstances of their rearing, should help behavioural scientists move beyond tired controversies and begin to address the real issues surrounding the mechanisms of genetic and environmental influence.

Genetics provide the behavioural scientist with a powerful set of tools for unravelling the sources of individual differences. The simple elegance of the Capron and Duyne design, lost perhaps on those accustomed to precise experimental control, is rarely seen in non-experimental behavioural research. They have no need for the obfuscating statistical models and attendant unsupported assumptions that burden so much similar research. The effects Capron and Duyne report are strong and indisputable. Their study clearly illustrates the utility of behavioural genetic methods and highlights the issues that need to be addressed in future research. Four issues are relevant.

Environmental influence

Capron and Duyne report that the average IQ of French adoptees is some 12 points higher when they are reared by parents with high rather than low socio-economic status (SES). This is a sizable difference between the mean IQ of students admitted to US colleges and that of the general population. At first this may seem a trivial observation because high-SES parents have children who perform well on IQ tests. But it is not. By demonstrating a relationship between characteristics of adoptive parents and the test performance of their non-genetically related offspring, Capron and Duyne unnecessarily implicate an environmental effect. There have been numerous studies relating parental SES to the IQ of their offspring in intact biologically related families. These studies, however, identify the mechanism of that influence. Parental education and SES are ambiguous indicators of the intellectual environment of the child. Working class parents can provide their children with intellectually stimulating experiences and professional parents can neglect the intellectual needs of their children. It remains unclear whether the SES effect is related to access to quality education, the variety and complexity of intellectual stimulation in the home, the parents’ press for scholastic achievement, or some other factor that differentiates between high- and low-SES homes. At least one adoption study has