Testing Star Formation Theory
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creation of beneficial new systems. It has its own ethos: decentralization to avoid social and technical bottlenecks, openness to the reuse of information in unexpected ways, and fairness. It uses powerful scientific and mathematical techniques from many disciplines to consider at once microscopic Web properties, macroscopic Web phenomena, and the relationships between them. Web science is about making powerful new tools for humanity, and doing it with our eyes open.

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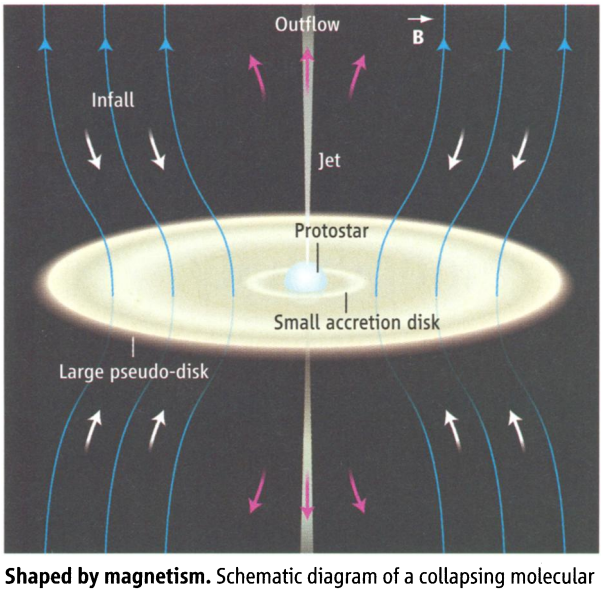
ASTRONOMY

Testing Star Formation Theory

Richard M. Crutcher

The importance of magnetic fields for the formation of stars, such as the Sun, is supported by measurements of polarized radio waves from dust particles near a newly forming star.

Understanding how stars form is one of the outstanding challenges of modern astrophysics. It has become clear that stars form from dense interstellar clouds of gas and dust, called molecular clouds because gas in such clouds is predominantly in molecular rather than atomic form. However, despite substantial progress in recent years, there remain fundamental unanswered questions about the basic physics of star formation. In particular, it remains unclear whether molecular clouds undergo rapid gravitational collapse as soon as sufficient matter accumulates to make the clouds gravitationally bound, or whether there is some mechanism resisting collapse that delays the process and introduces new star formation scenarios. The observational result reported on page 812 of this issue by Girart *et al.* (*1*) provides new data regarding this important scientific question.



Shaped by magnetism. Schematic diagram of a collapsing molecular cloud core with a strong magnetic field (**B**) showing the characteristic hourglass shape. [Adapted from (*4*)]

The "standard" model for the formation of low-mass stars such as our Sun has been that interstellar magnetic fields provide support against gravity in dense molecular clouds (*2*). In this picture, interstellar magnetic fields are "frozen" into interstellar matter by the small fraction of the gas and dust that is ionized. As material accumulates (due to the driving of flows by galactic spiral-arm shocks, supernovae explosions, the gravity of a galaxy, etc.), the magnetic field increases in strength as the gas density increases. After a molecular cloud accumulates sufficient mass to become self-gravitating, it will still not collapse and form stars because gravity is balanced by magnetic pressure.

If there were no other forces operating, molecular clouds would persist indefinitely and star formation would not occur. However, magnetic fields are frozen only into the ions of molecular clouds, not into the neutral gas and dust. The neutrals are therefore free to respond to gravity and collapse to form a much denser, gravitationally unstable core to the molecular cloud and eventually to form stars. However, as neutrals collapse through the ionized gas and dust, collisions with ions will occur. These collisions will greatly slow down the collapse rate, leading to molecular cloud lifetimes typically several orders of magnitude longer than the gravitational free-fall lifetime of a cloud.

In contrast to magnetically dominated star formation, the other extreme point of view is that magnetic fields are too weak to provide support against gravity. In this model, molecular clouds are intermittent phenomena, and the problem of cloud support for long time periods is irrelevant (*3*). Supersonic flows in the low-density turbulent interstellar medium produce regions of enhanced density. Star formation does not occur in every location where the gas is dense, but only in small volumes within clouds where sufficient mass accumulates to become self-gravitating. Collapse and star formation then proceed in that small fraction of the total cloud mass at a very rapid, free-fall rate.

In both models, the rate at which low-density interstellar gas is turned into stars is consistent with the observed star formation rate in the Milky Way Galaxy, about one solar mass per year. The strong magnetic field model achieves this result by setting the time scale for collapse of a dense molecular cloud much longer than the gravitational free-fall time. In the turbulent, intermittent model, only a small fraction of each molecular cloud actually becomes self-gravitating and forms stars. But the physical principles behind the two models are fundamentally different.

As a result, the two models make very different predictions that can be tested observationally. Simulations of molecular cloud formation and evolution carried out with weak magnetic fields show that the fields have a chaotic morphology, because the field lines are twisted by turbulence in the clouds. On the other hand, turbulence cannot twist field lines very much if the field strength is sufficiently strong. Magnetic field lines in dense, strongly magnetized clouds would then be roughly parallel. Collapse along the magnetic field is not impeded by the field, so cores are predicted to have a disk morphology. However, perpendi-

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cular to the magnetic field, the field impedes the collapse. As a dense cloud gradually collapses perpendicular to the field because of neutrals being driven toward the core by gravity, they will drag along the ions and the magnetic field. This will result in an hourglass structure to the magnetic field in a dense core (see the figure).

Interstellar magnetic fields can be observed because they produce polarization of the electromagnetic radiation emitted in or passing through the magnetized region. Irregular, spinning, paramagnetic interstellar dust particles will end up spinning about their short axis, and that short axis will be aligned with the magnetic field. An interstellar dust particle will therefore have a larger projected dimension perpendicular to the magnetic field than parallel to it. The dust will therefore radiate more strongly perpendicular to the magnetic field than parallel to it. By mapping the linear polarization of emission from dust particles in molecular clouds, it is possible to map the morphology of magnetic fields (projected onto the sky).

Such a map is what Girart *et al.* have produced for the low-mass star formation region NGC 1333 IRAS 4A. It is evident from the data that the magnetic field morphology is not chaotic, and it has the predicted hourglass shape. Their map shows gravitational collapse and future star formation caught in the act. The bent magnetic field lines have been drawn inward by the central gravity of the slowly collapsing molecular cloud. At the same time, the tension of the bent magnetic field lines resists gravity, slowing the collapse from the much faster free-fall rate. Moreover, they estimated the strength of the magnetic field and found that it was quite strong but just insufficient to prevent gravitational collapse, consistent with magnetically regulated star formation. This result strongly supports the strong magnetic field model of star formation, at least in this region, and provides important new data to astrophysicists working to understand how our Sun and the other stars form.

References and Notes

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MICROBIOLOGY

Breaking the Barrier Between Commensalism and Pathogenicity

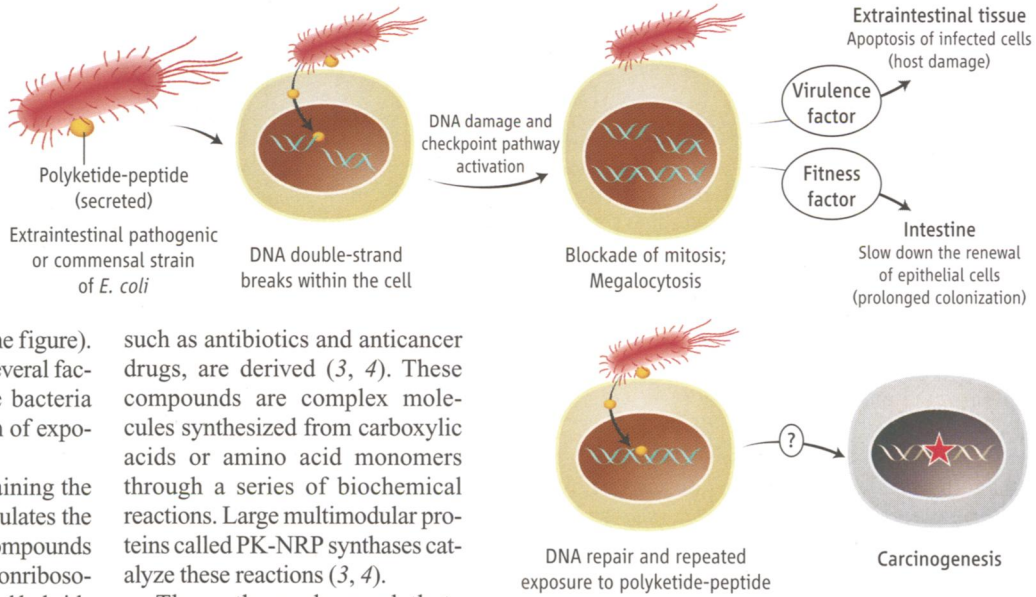
Harmless bacteria in the intestinal tract secrete a peptide that may enhance their survival. The same peptide causes disease when secreted by pathogenic bacteria outside the intestine.

Tetsuya Hayashi

Escherichia coli is a commensal bacterial inhabitant of the large intestine of humans and animals, but it also turns out to cause a wide range of diseases (*1*). On page 848 of this issue, Nougayrède *et al.* (*2*) report that certain *E. coli* strains harbor a set of genes that specify the biosynthesis of compounds that are either toxic to a host organism or can prolong bacterial survival and thus act as a fitness factor (see the figure). These opposing effects depend on several factors, including the location of the bacteria within a host organism and duration of exposure to the compound.

The large genomic region containing the gene set, called the "*pks* island," regulates the production of one or more hybrid compounds containing polyketides (PKs) and nonribosomal peptides (NRPs). PKs, NRPs, and hybrids of both are bioactive natural products that are widely produced in bacteria and fungi, from which many important therapeutic agents, such as antibiotics and anticancer drugs, are derived (*3*, *4*). These compounds are complex molecules synthesized from carboxylic acids or amino acid monomers through a series of biochemical reactions. Large multimodular proteins called PK-NRP synthases catalyze these reactions (*3*, *4*).

The authors observed that upon contact with cultured mammalian cells, certain *E. coli* strains induced megalocytosis, or gradual enlargement. They identified the *pks* genomic island as the underlying cause of the phenotype; inactivation of genes on the *pks* island prevented megalocyto-



Dual aspects of a bacterial toxin. A subset of *E. coli* strains, including both extraintestinal pathogenic and commensal strains, produce one or more polyketide–nonribosomal peptide hybrid compounds upon contact with a host eukaryotic cell. The compound damages DNA, which activates a pathway that leads to cell cycle arrest. Outside the intestine, the compound acts as a genotoxin; in the intestine, it functions as a fitness factor that enhances colonization. Long-term persistence of such strains in the colon may be involved in colorectal cancer development.

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