conceptual outline that describes the key steps in L–R patterning — from the initial breaking of symmetry at the node, through a cascade of signals that culminates in the direct induction of asymmetrically biased morphogenetic events[12]. As we continue to fill in the details of this outline, we will discover further how spatial orientation is controlled during the assembly of an embryo and, judging by the extraordinary pace at which this story has unfolded over the past few years, we should not have long to wait. □

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Astrophysics

Stress drives gas into a black hole

Kartik Sheth and Peter J. Teuben

On page 324 of this issue, Beck *et al.*[1] present new measurements of interstellar magnetic fields in the bar region of the galaxy NGC1097 (Fig. 1). From this, they infer the direction of gas flow in the galaxy and the location of regions of gas compression, where the gas traces visible dust lanes. It is suspected that gas flows inward along these lanes to fuel bursts of star formation in a ring of dense molecular gas known as the circumnuclear ring. Or, the gas may reach the very centre of the galaxy and provide fuel for an 'active galactic nucleus' — the extremely bright core where enormous amounts of energy are generated by the accretion disk around a supermassive black hole. This is the first time that the relationship between magnetic fields and gas flow in barred spiral galaxies has been investigated. The features of the magnetic field in the nuclear region lead Beck *et al.* to suggest that magnetic stress might be an efficient mechanism for fuelling the central black holes of active galactic nuclei.

Perhaps as many as two-thirds of spiral galaxies have a bright, central bar of stars. Indeed, our own Milky Way appears to have a bar[2]. These bars can extend over most of the optical disk and contain a large fraction of the stellar mass, as in NGC1097; or they may be confined to the nuclear region or form slight oval distortions to the disk, which are only evident at infrared wavelengths. A bar can have a dramatic influence on the evolution of the galaxy. Its gravitational pull induces large-scale non-circular motions in the stars and the interstellar gas. Although the resulting stellar orbits intersect, stars do not collide because of their small collision cross-sections. In the interstellar gas, on the other hand, there are many collisions between particles and considerable dissipation of energy; as a consequence, the gas can lose angular momentum and fall inwards.

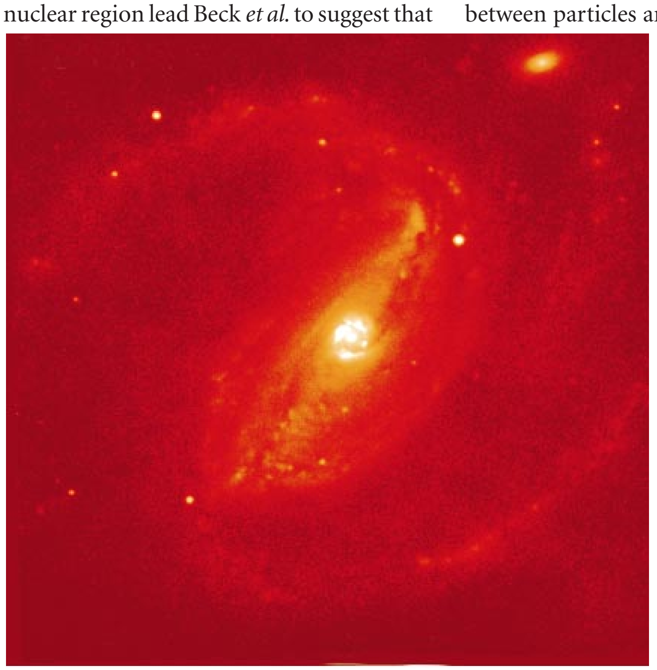

Figure 1 **Optical image[11] of spiral galaxy NGC1097 studied by Beck *et al.*[1]. The bar region is the elongated feature in the centre of the galaxy with two prominent straight dust lanes along the leading edge. Trailing spiral arms can be seen emerging from the ends of the bar.**

The infall of gas can produce major changes in a galaxy. It can trigger a nuclear starburst (a relatively short period of intense star-forming activity in the nucleus), or the inflow may lead to formation of a new bulge of young stars at the centre of the galactic disk[3]. The mechanisms and timescales for bulge (and disk) formation are crucial for understanding the evolution of galaxies. If the gas falls deep enough into the centre of the galaxy, it may fuel the supermassive black hole thought to exist in the active nucleus of many galaxies[4]. The large-scale mixing of the gas due to the bar can also change the overall chemical abundance in a galaxy[5], which bears upon our understanding of the history of star formation and predictions of its future activity. Finally, one of the most dramatic effects of the gas infall is the destruction of the bar itself when sufficient mass accumulates in the centre[3]. The bar can be its own worst enemy.

So gas inflow in barred galaxies has many effects, but there is disagreement about its exact nature. Although all models of the process predict inflow, they differ in how the gas reaches the centre. In one set of models, which simulate the interstellar dust as a collection of distinct clouds, the gas experiences occasional collisions and slowly spirals inwards[6]. In another set of simulations[7,8] in which the gas is modelled as an ideal fluid, experiencing hydrodynamic forces, the gas undergoes a compression, or shock, at the leading edge of the bar and flows directly into the centre. Some of these latter models show gas flowing close to the nucleus, but the bars required for this type of behaviour are not usually observed. The hydrodynamic models of gas inflow that best imitate observations show the gas stalling in a ring around the centre of the galaxy and not reaching the nucleus. These models successfully predict the dust lane morphology[8] and gas velocities[9] observed in bars.

Beck *et al.*[1] measure polarized radio synchrotron emission in the bar region of the galaxy NGC1097. From the intensity and direction of the radio emission, they determine the direction of the magnetic field in the bar and conclude that the field vectors are consistent with the gas flow vectors predicted by hydrodynamic models (as long as one makes the usual assumption that the magnetic field is frozen into the fluid). They observe a strip of zero polarization, which appears to be offset from the bar dust lane, about 800 parsecs (2,600 light years) in the upstream direction. Beck *et al.* interpret this strip to be the location of the hydrodynamic shock, in contrast with previous observations and models which concluded that the shock loci are in the dust lane itself. The strip may be an artefact produced by a varying field strength or gradually changing gas flow pattern. But, if the interpretation offered by these authors is correct, then the physics of the hydrodynamic models may need to be revisited.

A notable aspect of this work is that the authors have been able to study gas flow in galaxies where the usual (spectroscopic) observations of gas kinematics are not possible. For instance, when a galaxy is tilted so that the inflowing gas moves tangentially to the line of sight — making spectroscopic measurements difficult — this new method would allow one to study the gas flow and calculate inflow rates.

Beck *et al.* observe a change in pitch angle of the magnetic field lines in the central region of the galaxy where the dust lanes end at the circumnuclear ring. They suggest that this configuration is optimal for further inflow of gas as a result of magnetic stress. The manner of the inflow from the ring to the nucleus is of great interest to astronomers, because it may be another method of feeding a central black hole to power the active nucleus. However, the new observations do not have sufficient resolution to convincingly demonstrate the inflow. Other systems that could deliver fuel to a black hole are nuclear or nested bars and trailing nuclear spiral arms[4,10]. Although bars are extremely efficient at transporting gas from the disk to the central region of the galaxy (less than a kiloparsec or 3,000 light years from the middle), the central black hole is much smaller (only a few light minutes in diameter). How the gas loses additional angular momentum and travels to the centre of the galaxy remains a mystery. □

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Atmospheric chemistry

Bromine explosion

Paul Wennberg

Bromine free radicals are emerging as important players in the photochemistry of the lower atmosphere, at least on local scales. Earlier this month, Hebestreit *et al.*[1] described the discovery of air laden with bromine monoxide (BrO) wafting off the salt pans near the Dead Sea. And on page 338 of this issue[2], McElroy and colleagues report observations of BrO, obtained by remote measurements in the Arctic, that suggest bromine is present between the tropopause (at about 8 km height) and the top of the planetary boundary layer (~1 km). The planetary boundary layer is unlike the free troposphere that lies above it because the turbulence mixing timescale is very fast, and so exchange of gases with the surface occurs quickly (less than 1 day).

The data concerned come from April 1997, when a spectrometer on NASA's ER-2 high-altitude aircraft recorded the presence of tropospheric BrO by its effect on sunlight reflected off the ice below — so much BrO, argue McElroy *et al.*, that it must be present throughout the troposphere. The surprise here is that although bromine is known to figure in the marine boundary layer at high latitudes during springtime, and in the stratosphere throughout the year, there has been very limited evidence for BrO in the free troposphere (see for example ref. 3).

In addition to its well-known role in depleting stratospheric ozone[4], BrO is potentially an important catalyst in the troposphere; at a mixing ratio of tens of parts per trillion, it can completely eliminate all local ozone in a few days. It has been speculated that, at the Earth's surface, heterogeneous processes occurring with either the snowpack and sea ice, or marine aerosols, can autocatalytically convert sea-salt bromide to gas-phase molecular bromine (Br_2) (refs 5–7). Once in the gas phase, Br_2 is photolysed, yielding free bromine atoms that react with ozone to form BrO. In turn, BrO can react with itself, regenerating bromine atoms and thereby completing a cycle that destroys ozone while preserving the bromine radicals. In the Arctic springtime, a 'bromine explosion' occurs as the sunlight returns and sharply increases the rate of Br_2 photolysis[8]. Extremely high concentrations of bromine and the resulting depressed ozone levels have been observed in the boundary layer[8,9], and their geographical extent (latitude and longitude) determined from satellite observations[10,11].

Figure 1 **Flying high over the Beaufort Sea (see map on page 339), a spectrometer on NASA's ER-2 aircraft recorded the presence of large amounts of BrO in the Arctic troposphere. McElroy *et al.*[2] propose that convection occurring near cracks (leads) in the ice pack, such as those shown here, ventilates bromine produced at the surface into the free troposphere. This picture, taken from ER-2 through a fisheye lens, has a footprint at the surface of about 100 km.**

McElroy *et al.*[2] measure the amount of BrO that reflected sunlight passes through before arriving at their airborne spectrometer, but cannot directly determine where this bromine resides. Their argument that much of it is in the free troposphere hinges on the concentration of BrO in the planetary boundary layer below the aircraft — BrO concentrations in the boundary layer, as previously measured at the ground[9], are a factor of two or three too small to explain the aircraft data. Although it is conceivable that the BrO in the boundary layer could at times be higher than previously measured at the ground, McElroy and colleagues' conclusion is probably correct. Another piece of evidence supporting their view is the geographical distribution of the observed BrO, in that high values were measured hundreds of kilometres inland from the Beaufort Sea in a region separated from the ocean by Alaska's Brooks Range. It seems inconceivable that this bromine remained in the boundary layer as it was transported inland.

How does the BrO get to the free troposphere? McElroy *et al.* argue that bromine-laden air is ventilated through the boundary layer to the free troposphere by convection occurring at cracks in the ice pack (leads). Leads of sufficient size to promote convection were indeed documented on the ER-2 flight, in digital images taken by McElroy's group of the scene below the aircraft (see Fig. 1 and ref. 12). Once in the free troposphere, the impact of the bromine on ozone will depend on how long the BrO survives. Bromine radicals are lost to HBr through their reaction with formaldehyde and other compounds. Provided that bromine concentrations remain high, however, HBr will be recycled back to radical form by heterogeneous chemistry[13]. McElroy *et al.* suggest that the surfaces required for such reactions might be ice crystals borne aloft with the bromine. Although that is possible, it isn't necessary: laboratory work[14] has shown that these recycling reactions occur very efficiently on the background sulphate aerosol known to be present in the troposphere.

Despite the high concentrations of BrO described by McElroy *et al.*, and others, it is