waves sweep up matter and magnetic fields even more efficiently[5]. Because the intensity of synchrotron radiation is proportional to the square of the magnetic field strength, a field which is spatially intermittent by virtue of having been swept into shells will yield higher synchrotron luminosity than the same amount of magnetic flux in smoothly distributed form, confounding measurements. Furthermore, extensive calculations[6] have borne out Parker and Ko's suggestion[7] that the turbulence associated with energy output by massive stars accelerates dynamo activity.

More generally, it appears that the morphology of galactic magnetic fields can tell us little about the fields' origin. When rotation is weak, dynamos of the so-called α^2 type may still operate, and these give rise to fields lacking a dominant azimuthal component, perhaps of the type observed in the Small Magellanic Cloud. Perhaps even more surprisingly, the bisymmetric spiral fields once thought to be conclusive evidence of primordial origin can perhaps be explained by dynamo theories[8].

How is the question of the origin of galactic magnetic fields to be resolved? Chi and Wolfendale's counterexamples undermining the assumption of energy equipartition are one element; they may also be telling us something about the mechanism of cosmic-ray acceleration. There are also other tantalizing observational clues. For example, whatever large-scale intergalactic field there is cannot be detected at present[9]. Also, Kronberg *et al.*[10] have found magnetism in a distant, dark object, possibly a developing protogalaxy. And the theories are challenged on their own turf as well: primordial field theories must still explain how the Universe came to be magnetized and dynamo theories must answer a host of difficult questions about the operation of turbulent resistivity in the interstellar medium. Perhaps as theorists and observers continue to close in from different directions we will be left with a single viable explanation for galactic magnetic fields. □

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OZONE DEPLETION

Satellite maps ozone destroyer

Martyn Chipperfield

OVER the past few years localized measurements of the chlorine monoxide radical in the lower stratosphere from ground-based instruments[1] and aircraft[2] have revealed that the large springtime loss of ozone over Antarctica is due to catalytic destruction involving this species. Although similar measurements detected comparable levels of ClO in the Arctic winter stratosphere[3], the differing meteorology between the two hemispheres has so far prevented the formation of an Arctic ozone hole. Now satellite measurements have revealed the extent of the winter increase in ClO in both polar regions. On page 597 of this issue[4], Waters *et al.* present the first measurements from the satellite-borne Microwave Limb Sounder, which provide a dramatic four-dimensional picture of the role of ClO in destroying Antarctic ozone and of the potential for similar ozone loss in the north.

More than 80 per cent of the current chlorine loading of the stratosphere (around 3.5 parts per billion by volume, p.p.b.v.) comes from anthropogenic sources such as chlorofluorocarbons. Once these relatively stable chlorine-containing source gases reach the stratosphere they are broken down by solar ultraviolet radiation and by reaction with electronically excited atomic oxygen. According to the known gas-phase chemical reactions, the chlorine thus released should be tied up in the relatively inert reservoir molecules such as HCl and $ClONO_2$. However, in the winter stratosphere, a strong westerly circulation is set up (the polar vortex) which leads to temperatures cold enough, below about 195 K, for polar stratospheric clouds (PSCs), composed of condensed water and nitric acid, to form.

Reactions can occur on the surface of PSCs to convert these reservoir chlorine species into more reactive forms, a process termed chlorine activation, which ultimately leads to ClO which can efficiently destroy ozone in catalytic cycles (involving Cl_2O_2 and BrO) when sunlight is present[5]. Therefore the requirements for polar ozone depletion are cold temperatures, for PSCs to activate the chlorine, and for this activated air to be exposed to sunlight. These conditions are always met in the Antarctic, but in the Arctic the winters are shorter and warmer, although there is a large amount of year-to-year variability.

Outside the polar regions a downward trend in ozone has been observed at all latitudes except the tropics, with a decrease in the lower stratosphere of 10 per cent per decade[6]. This unexplained downward trend may be caused by transport of ozone-poor air from the polar regions. Or it may be due to *in situ* ClO-catalysed ozone loss either by transport of ClO-rich air from the polar vortex or by chlorine activation on liquid sulphuric-acid aerosols. These aerosols are present throughout the lower stratosphere, and following the eruption of Mt Pinatubo in June 1991 their abundance was significantly increased.

The Microwave Limb Sounder (MLS), used by Waters *et al.*, is one of ten sensors on the NASA Upper Atmosphere Research Satellite (UARS) launched by the space shuttle on 12 September 1991. The satellite was designed to provide an integrated and coordinated study of the chemistry, dynamics and radiation of the Earth's atmosphere. The instruments onboard measure the energy input, winds and composition of the stratosphere, mesosphere and lower thermosphere. In addition to making the first global observations of ClO, MLS measures ozone and water vapour along with pressure and temperature. It is the first space-borne 'limb'-viewing instrument (looking tangentially through the atmosphere) to use the microwave frequency. The planned lifetime of the mission is three years, although problems with the satellite's power supply[7] might cut it short.

Waters *et al.* present meaurements of ClO and ozone from the Antarctic in 1991 and 1992 and from the Arctic in the winter of 1991–92. The Southern Hemisphere data show that the build up of ClO starts early in the season: MLS measured more than 1 p.p.b.v. of ClO in the Antarctic in early June 1992. The observed ozone depletion started in mid-August and later, in the austral spring when the ozone depletion was well underway, the data reveal the striking anticorrelation between high levels of ClO (up to 2.5 p.p.b.v. at 20 km) and low ozone inside the polar vortex. The authors argue that destruction may have started before August, but was hidden by descent of ozone-rich air in the polar vortex.

The Northern Hemisphere measurements show that comparable amounts of ClO were observed in the Northern Hemisphere in early January 1992. The location of the enhanced ClO is consistent with our understanding that chemical reactions on PSCs are responsible for the chlorine activation and the ClO was contained within the polar vortex. Although ozone destruction of 4 per cent was inferred from the ozone data from

1–13 January 1992, temperatures in the Arctic stratosphere rose above the PSC threshold later in the month, at which point the ClO levels decayed, by conversion to $ClONO_2$ (ref. 8), and large ozone loss was avoided.

An interesting feature of the MLS data is the magnitude of the measured ClO. In both polar regions, MLS measured ClO mixing ratios of up to 2.5 p.p.b.v. at around 20 km altitude. This is approaching the limit of the expected total amount of chlorine in the atmosphere. Indeed, as some chlorine is expected to be in the form of the dimer of ClO (which is in equilibrium with ClO and is not measured by MLS) these measurements may be hard to reconcile with the known photochemical data of the ClO/Cl_2O_2 system.

Although Arctic ozone loss was limited in the winter of 1991–92, the natural variability in the length of the Northern Hemisphere winter could prolong the occurrence of PSCs into late February or even March. In the winter just passed, PSCs did persist into late February giving greater opportunity for ozone loss. Waters *et al.* comment briefly on this period and note that they measured ClO higher than 1 p.p.b.v. until 4 March 1993. In late February, they observed ozone inside the polar vortex to decrease by 0.7 per cent per day. On the basis of the colder winter and prolonged period of high ClO, substantial ozone loss should be expected in the Arctic spring of 1993. Indeed, on the basis of satellite- and ground-based observations, the World Meteorological Organisation reported that over much of the Northern Hemisphere throughout February ozone levels were up to 20 per cent below normal. A quantitative study will be needed to see if such polar ozone loss can explain all of the ozone decrease seen by MLS or whether other processes, which may be causing the gradual ozone loss at mid-latitudes, are contributing. The global data provided by MLS along with the other instruments on UARS (to appear in a special issue of *Geophysical Research Letters*) will be an invaluable aid in trying to understand and quantify the evolution of stratospheric ozone. □

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PATTERN FORMATION

Instant patterns in thin films

Daniel K. Schwartz

WHAT do magnets and soap films have in common? The answer is spontaneous symmetry breaking. Physicists ascribe permanent magnetization of iron to a broken time-reversal symmetry. And on page 614 of this issue[1], Eckhardt *et al.* show that a thin film of soap-like organic molecules can separate into regions of different handedness, breaking the inherent mirror symmetry of the system.

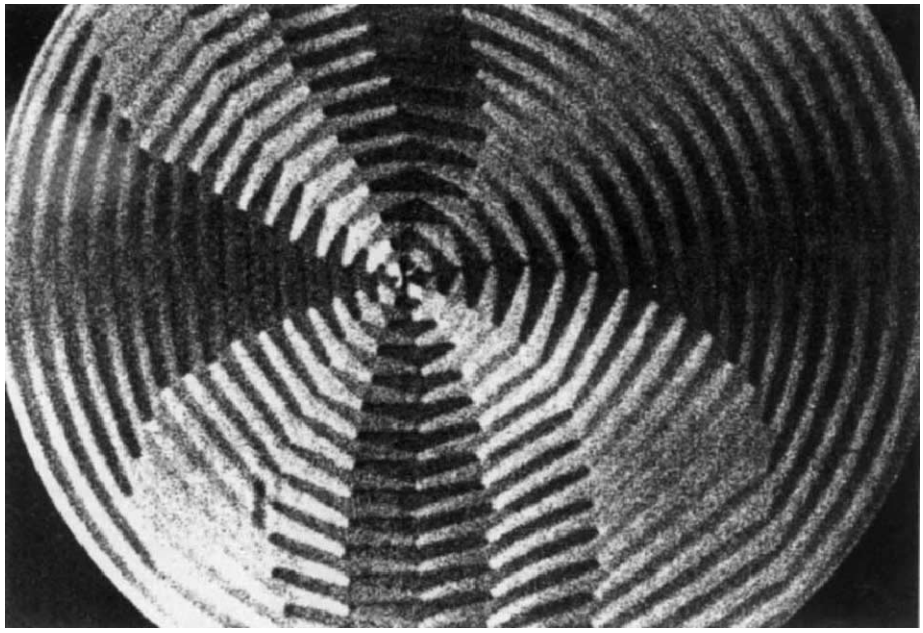

FIG. 1 A pattern on a thin, freely suspended liquid-crystal film observed through crossed-polarizers. The different shades of the stripes are due to the azimuthal tilt direction of the rod-like molecules. The soliton (sharp-edged) stripes predicted by theory[8] are arranged into a twelve-armed star. (From ref. 5.)

Although nature has a preference for symmetry, many physical systems adopt ground states that lack the full symmetry that they might, in principle, assume. The most familiar example of this spontaneous symmetry breaking is ferromagnetism. In the absence of an external magnetic field, the unpaired spin on each atom in a lump of iron can be either up or down with equal probability. But at low temperatures, spins within a macroscopic domain align to produce a finite magnetization, thus breaking the inherent up/down symmetry. This occurs even without the presence of an ordering magnetic field, hence the word spontaneous.

Another type of symmetry often found in physical systems is chiral, or mirror, symmetry. Pasteur's work on optical activity in sugars in the 1860s demonstrated that chiral effects in liquids are related to chirality at the molecular level. However, recent studies show that two-dimensional liquids composed of achiral units can spontaneously separate into right- and left-handed regions, thus breaking the natural mirror symmetry. This effect is related to ferroelectricity at interfaces.

Eckhardt *et al.* report the first direct observation of this phenomenon on molecular length scales. They have imaged the molecular lattice of an organic monolayer using atomic-force microscopy and find that, under certain conditions, a monolayer composed of equal numbers of right- and left-handed molecules (a racemic mixture) can separate into chiral regions.

Other studies have revealed remarkable patterns on scales 10^4 times larger (10 μm or more) in quasi-two-dimensional systems such as thin freely suspended liquid-crystal films and Langmuir monolayers (monolayers of amphiphilic molecules at the air/water interface). Striking chiral patterns such as spirals or pinwheels are found in systems composed of chiral molecules[2]. Clearly, the chiral nature of such patterns is the macroscopic manifestation of the underlying molecular chirality. And recently there have been reports of chiral domain shapes in racemic[3] and even achiral[4] systems. Striking patterns such as stripes, honeycombs and striped stars (Figs 1 and 2) have also been observed and attributed to spontaneous chiral separation in systems of achiral molecules[5,6]. The exciting possibility is that Eckhardt *et al.* have observed the