POT1 (ref. 8). POT1 is related to well-known proteins that bind single-stranded telomeric DNA in ciliates and budding yeast[9,10], and it itself binds to single-stranded telomeric substrates *in vitro*[8]. Loayza and de Lange show that, consistent with this biochemical property, POT1 is present at the tips of human chromosomes, and that this association is reduced when the length of the G-rich single-stranded overhang is decreased. But POT1 does not rely solely on its nucleic-acid-binding properties to bring it to telomeres. It is also found in a complex with the duplex-binding protein TRF1 (along with other TRF1-associated proteins, collectively referred to as the TRF1 complex). So, POT1 interacts with two different sites on telomeres: the extreme terminus, and along the duplex region.

What happens if POT1 loses its ability to interact with one of these two sites? Loayza and de Lange tested this by removing the DNA-binding portion of the protein, creating a derivative called POT1(ΔOB). This derivative still associated with the TRF1 complex, and hence with duplex telomeric DNA. But it could not interact with the single-stranded telomeric ends, and this resulted in a profound disruption of telomere length, with telomeres becoming rapidly and extensively elongated. These observations establish that POT1, like TRF1, is a negative regulator of telomere length. More significantly, because POT1 can interact with both the site of telomerase action and the duplex portion of the chromosome, it could be the missing link in the telomere-repeat-counting model.

Loayza and de Lange therefore propose that information about telomere length, which is measured by TRF1 through its ability to bind duplex telomeric repeats, is transferred to the tip of the telomere through the interaction between POT1 and TRF1. This interaction presumably affects the amount of POT1 that is loaded onto single-strand overhangs: the more telomeric repeats there are, the more POT1 is transferred to the telomere tip, and the greater is the reduction in telomerase activity (Fig. 1). The next question is how POT1 relays information to telomerase. It might act as a negative regulator by directly binding to the enzyme complex and inhibiting its catalytic activity. Alternatively, through its DNA-binding activity, POT1 might sequester telomeric DNA and thereby block access of telomerase to its substrate.

The picture is also far from complete in other respects. For instance, POT1 might not function solely as a negative regulator: Colgin *et al.*[2] propose that it also positively controls telomerase-mediated telomere elongation. The idea that a protein that binds single-stranded telomeric DNA can serve as both a positive and a negative regulator of telomere length has also been established in studies of the yeast Cdc13 protein[5,11]. Meanwhile, TRF2, like TRF1, binds duplex telomeric DNA and similarly contributes to the feedback mechanism that monitors telomere length[7] — yet it does not interact with POT1 (ref. 1). This implies that TRF2 must have a different partner that transmits its signal to the chromosome terminus.

A separate question about POT1 centres on its postulated role in protecting chromosome ends (as opposed to maintaining telomere length) in human cells. Fission yeast lacking POT1 have a severe defect in end protection[8] — will the same be true in humans? These open questions suggest that the intense focus on telomere biology is unlikely to abate anytime soon. ■

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Atmospheric physics

Electric jets

Victor P. Pasko

Powerful electric currents have been detected in discharges between thunderclouds and the upper atmosphere. Carried by gigantic jets, they are a new factor in the model of the Earth's electrical and chemical environment.

Although cloud-to-ground lightning is a familiar disruption in the modern electronic world, lightning formed above the clouds is also an important factor in what is known as the global circuit of atmospheric electricity. Radio atmospherics are natural electromagnetic emissions from lightning discharges and can propagate thousands of kilometres through the 'waveguide' formed by the Earth's surface and the ionized region of the upper atmosphere, known as the ionosphere. In 1925, the physicist C. T. R. Wilson wrote[1]: "The discharges above the cloud would doubtless give rise to atmospherics. If, as has been maintained, atmospherics frequently originate in regions of rain unaccompanied by thunder, they may in such cases be due to discharges of this nature."

Wilson was right: on page 974 of this issue[2], Su and colleagues report their observations of several large-scale discharges, branching upwards to an altitude of about 90 km from the top of thunderclouds in the South China Sea; no associated lightning discharges were detected in the underlying thunderstorm. Radio atmospherics recorded at remote locations in Japan and Antarctica, however, showed that there was a significant flow of current that moved several tens of coulombs of negative charge upwards from the thundercloud to the lower ionosphere.

Although eyewitness reports of events such as these — known as 'transient luminous events', or TLEs — have been recorded for more than a century, the first image of one was captured[3] only in 1989, serendipitously during a test of a low-light television camera. Since then, several different types of TLEs above thunderclouds have been documented and classified[4–6] (Fig. 1, overleaf). They seem to be fairly common in most regions of the globe, appearing over North, Central and South America, Europe, Australia, Japan and China. TLEs are known to be associated with large volumes of ionization, creating electrical paths through the atmosphere[7] and causing significant perturbations of long-range communication signals[8]. But the effects of this ionization and its associated currents on the Earth's electrical and chemical environment are not fully understood.

In a simplified picture of the global electrical circuit, the Earth's surface and the conducting atmosphere above it can be imagined as plates of a giant spherical capacitor, with a potential difference of about 300,000 volts between them[9]. There are many components contributing to the balance of potential between the plates, but two are critical: thunderstorms, of which there are about 2,000 globally at any given time and which act as batteries charging the capacitor; and fair-weather regions, in which the capacitor can discharge continuously through the weakly conducting atmosphere, with a global leakage current of about 1 kiloampere.

The upper plate of the capacitor is not confined to a single level, but rather is distributed through the atmosphere, reflecting changes in atmospheric conductivity and the fair-weather electric field (so that the density of the leakage current in fair-weather regions remains roughly constant with altitude). In fact, most of the 300,000-volt potential drop between the capacitor plates happens within

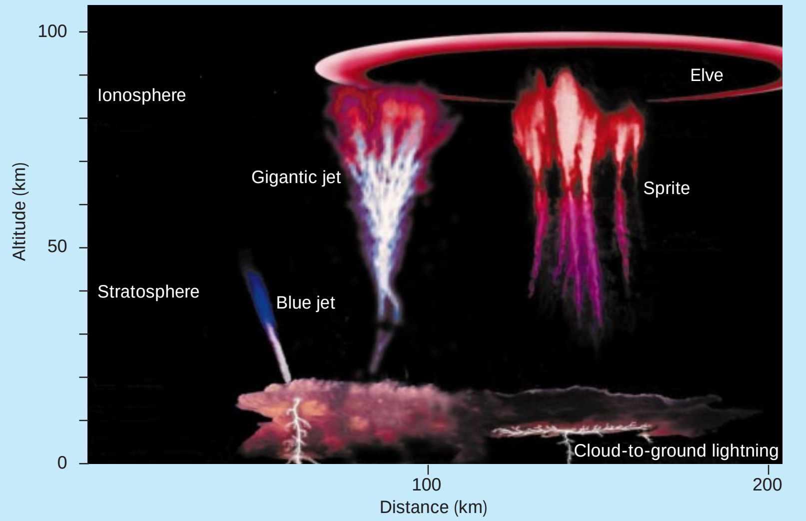

Figure 1 **Lightning-related transient luminous events (TLEs). Several types of TLEs are known, and some examples are shown here: relatively slow-moving fountains of blue light, known as 'blue jets', that emanate from the top of thunderclouds up to an altitude of about 40 km; 'sprites' that develop at the base of the ionosphere and move rapidly downwards at speeds of up to 10,000 km s^{-1}; and 'elves', which are lightning-induced flashes that can spread over 300 km laterally. Su and colleagues[2] now report their observations of several gigantic jets, which propagated upwards from thunderclouds to altitudes of about 90 km. The strong emission of electromagnetic radiation from these events, detected as radio atmospherics thousands of kilometres away, indicates that several tens of coulombs of negative charge were transferred from the thundercloud to the lower ionosphere. (Graphic adapted from ref. 15, with the permission of the American Geophysical Union.)**

a few tens of kilometres of the Earth's surface. For instance, 'blue jets' — TLEs that terminate at altitudes of around 40 km (Fig. 1) — probably move some charge to the upper plate of the capacitor. But no associated radio atmospherics have been detected for these events, probably because they take much longer to develop than the more impulsive jets reported by Su and colleagues.

Atmospherics of the strength recorded by Su *et al.* have previously been observed only in conjunction with the most powerful cloud-to-ground lightning discharges and the TLEs triggered by them, known as 'sprites'[10]. The authors admit that there may be a slight chance that the atmospherics they detected were associated with cloud-to-ground lightning discharges in the underlying thunderstorm — but then these discharges must have been repeatedly missed by the local lightning detection network, which is unlikely. However, it is clear that the events observed by Su *et al.* are very different from sprites, which typically start at altitudes of about 70 km and propagate downwards: the gigantic jets seen by Su and colleagues branch upwards from thunderclouds, spreading to a diameter of about 40 km at an altitude of 85–90 km (Fig. 1).

The ionization created by a gigantic jet is likely to have a significant chemical effect on that volume of atmosphere. In fact, the occurrence and dynamics of many TLEs, including those observed by Su *et al.*, closely resemble the behaviour of 'streamers' — miniature needle-shaped filaments of ionization, commonly observed when an electric field is applied to a small volume of relatively un-ionized ambient air at ground pressure. Streamer discharges can lead to significant power losses on high-voltage transmission lines and can damage insulating materials; a streamer plasma of hot electrons embedded in cooler air is a good source of highly reactive species for use in the chemical treatment of hazardous and toxic pollutants[11]. Because streamer filaments have high electric fields around their tips, streamer plasmas can easily generate electrons with sufficient energies to dissociate atmospheric oxygen molecules. The dissociation initiates a chain of reactions that leads to the formation of ozone in air (this process has been used for industrial ozone production for more than a century[11]).

As atmospheric pressure is much lower at ionospheric altitudes than at the Earth's surface, streamers that would have diameters of a fraction of a millimetre at ground level instead appear as channels of glowing plasma that are many kilometres long and a hundred metres in diameter — easily observable above thunderclouds by low-light imaging systems deployed hundreds of kilometres away[12]. High-altitude streamers also have the ability to produce highly active chemical species and can effectively 'treat' thousands of cubic kilometres of atmosphere. The branching observed in atmospheric TLE discharges, including those documented by Su and

NATURE

100 YEARS AGO

The cleanliness of electric lighting has always been urged as one of the great claims in its favour, and it has been justly pointed out that the saving effected in redecoration partly balances its extra cost. Although this is true, electric light cannot be regarded as perfectly clean; it has long been noticed that there is a marked tendency for dust to accumulate on electric light fittings and wires, and on the walls and ceilings in their immediate neighbourhood. This is partly, no doubt, due to the air currents produced by the local heating, but it is also partly an electrical phenomenon. The dust particles floating in the air are presumably at air potential, and are consequently attracted to the conductors on the non-earthed side of an earthed system; they either stick to these permanently, or remain on them until charged, when they are projected on to and stick to the walls… If switches are always put, as they should be, in the non-earthed wire, the deposition of dust will only occur during the time the lamps are alight, and will be minimised. Mr. D. S. Munro, writing in the *Electrical Review*, points out that a still further improvement can be effected by using concentric flexible conductors instead of the ordinary twisted cord, the outer conductor being connected to the earthed side of the system.

From *Nature* 25 June 1903.

50 YEARS AGO

During the course of an ecological investigation of the polychaete annelid *Pygospio elegans* Clap., a remarkable mode of asexual reproduction was noticed… The bodies of the adults, both males and females, divide into pieces consisting of varying numbers of segments, generally about three or four, sometimes up to seven; several times fragments consisting of one segment only have been observed. Fission takes place in any part of the body. When just separated, the single fragment looks as if it had been cut off with a knife… Every single fragment is able to form a new individual exclusively from its own tissue. The rate of regeneration is very high, and at 20 °C. the regeneration of a new animal was completed in eight days; then the asexually formed individual will start a new division process.

From *Nature* 27 June 1953.

colleagues, is also known in ground-level streamers (and is recognized as an important parameter for effective chemical treatment of large gas volumes[13]). So the known chemical impact of streamers may be a good indication that TLEs noticeably affect the chemistry of the atmosphere.

This field is in its infancy, and it remains to be seen how important the electrical and chemical effects of the gigantic jets and other TLEs are for our planet. The large quantities of negative charge transported by these jets, discharging the atmospheric capacitor, may have a strong influence on the voltages and currents in the global electric circuit. The events seen by Su *et al.*[2] seem to be a property of oceanic thunderstorms, and a global survey of these and other types of TLEs is planned, using Earth-orbiting sensors[6,14]. Knowing how frequently these events occur will help us to understand their contribution to the global electrical circuit. ■

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Evolution

The battle between the sexes

Tom Tregenza

Male–female conflict over mating rate can drive rapid evolution and lead to female refusal to mate with males from other populations, so implicating sexual conflict in the generation of biodiversity.

Sexual conflict is a pervasive feature of the living world. Although the sexes need one another, they rarely have exactly the same priorities. Males can often increase their reproductive success — the number of offspring they sire — simply by mating with as many females as possible. Females, on the other hand, are limited by their ability to produce offspring, and unnecessary matings may be costly. This difference sets the stage for an evolutionary arms race in which males are continually evolving new adaptations to get females to mate with them rather than with other males, and females are striving to resist this manipulation.

On page 979 of this issue[1], Martin and Hosken provide evidence that sexual conflict can indeed drive very rapid evolution of female willingness to mate and of male traits that promote matings. They show that this process can lead to females being less ready to mate with males from other populations. This type of reduction in matings between populations could eventually lead to a complete lack of interbreeding, at which point the two groups would have become separate species.

Martin and Hosken took the dung fly *Sepsis cynipsea*, males of which can be seen harassing females on cowpats throughout Europe, and set up three types of laboratory populations. Monogamous populations had females kept with only one male, eliminating conflicts of interest altogether. 'Conflict' populations had either 50 or 500 flies in the same-sized plastic box, with equal numbers of males and females. Flies kept at higher densities mate more frequently, and the females lay fewer eggs, presumably because they are continually having to fend off amorous males. After two-and-a-half years and 35 generations, females were tested for their willingness to mate, both with males from their own population and with males from an independent population of the same type. As predicted, females from monogamous populations (having been under no selection for avoiding males) were the most willing to mate. Females from conflict populations were not only generally less willing to mate, they were also even more reluctant to mate with males from a different population than they were with males from their own population.

There were also differences between the two types of conflict population. At the larger population size, females evolved even greater discrimination against males from populations other than their own. This is particularly interesting because it is exactly the opposite of what is predicted by theories of speciation that are based on the idea that smaller populations diverge rapidly. When populations are small, the frequency of different genes can change very rapidly — each type of gene is found only in a few individuals and so the prevalence of particular genes is strongly affected by chance events that happen to their carriers. The faster progress towards speciation in the larger populations seen in Martin and Hosken's study is, however, exactly what is predicted by speciation theories based on selection that include sexual conflict[2]. In large populations, selection will be more effective at finding genes in females that can counteract manipulative genes in males, because there will be more genetic variation available and because selection is not swamped by chance events.

But there is an alternative explanation for the pattern seen. The important thing might not be the fact that some populations were larger, but that they were at higher density, and hence experienced greater levels of conflict. This will have increased the pressure on females to be more reluctant to mate, which could have similar effects — evolution is faster because selection is stronger, while in the previous case evolution is faster because there is more variability for it to work with.

The study of the evolutionary role of sexual conflict is still in its infancy and, as might be expected, Martin and Hosken's study raises as many questions as it answers. In particular, the finding that females are more resistant to males from populations other than their own runs counter to several studies[3] that have found females with lower resistance to foreign males. These previous results have been taken as support for the idea that sexual conflict is characterized by males continually evolving new ways to manipulate females, who in turn evolve new methods of resistance[4] — that is, females are poor at resisting male tactics they have not evolved with. Perhaps the explanation for Martin and Hosken's different results is that by artificially increasing the level of conflict, they have created a situation where, instead of following male adaptations, females are leading the evolutionary dance, evolving new criteria that males must meet in order to be granted a mating. Hence, males that have been able to adapt to the preferences of females from their own population are at an advantage over foreign males.

This view has similarities to the type of argument used in models that examine the potential for differences in female mate preferences to drive speciation[5], and highlights a second issue. Although there is clearly a lot of sexual conflict in Martin and Hosken's system, it is possible that there is also sexual selection of the more familiar type in which females are choosing the 'best' males. The laboratory is very different from the wild, and females might simply be picking males better at dealing with this new environment, with chance differences between populations in the male traits that females use for mate choice.

This study shows that simply changing