vision, not only weather and weapons simulations but also business computing tasks, such as accounting and supply-chain logistics, can be accommodated in the "grid." Peer-to-peer file- and music-sharing schemes (*8*) have demonstrated that enormous storage reserves also exist at the "edge of the network," and that these can be tapped to meet a shared interest.

Synchronizing all this computation to allow extracting the state of the computation at a particular time is a well-known problem. SETI@home emphasizes that a participant whose screen saver announces that aliens have left a message should under no circumstances call the press. The real information content of the data from that part of the sky and time period will not be completely assessed until all relevant work units are returned, which may take weeks. SETI@home is willing to wait weeks to assemble all the data because interesting events are very rare. In other cases, such as weather prediction, such delays are unacceptable, and synchronization becomes crucial.

Korniss *et al*. consider a simple model of synchronization in which no processing element proceeds to the next time step until it has checked that it is in sync with its neighbors. To expose the worst case, they consider a one-dimensional array of processing elements, each with only two neighbors. The temporal dispersion that emerges is enormous.

One might question whether simulations of two-dimensional (2D) (such as, the temperatures in all European cities) or three-dimensional phenomena (such as, the weather) exhibit such a dramatic temporal roughening. The figure exhibits the result of Korniss *et al.*'s local synchronization model for a 2D array of 1000 × 1000 processing elements. Asynchronously, in arbitrary order, each processing element has attempted to take a time step ahead, first checking with its four neighbors. On average, each processor has made 1600 attempts. Roughly one-third of them are successful, and already the time steps completed are scattered over a range of at least 30 time steps. Data over this temporal range must be stored for subsequent combination with data from distant points in the simulation.

Korniss *et al*. show that the roughening satisfies equations developed to explain crystal growth. These equations predict that the temporal width continues to grow over time until it is limited by the size of the simulation. The challenge it poses will thus continue to grow as problem sizes increase. The physical analogy to roughening also implies that long-range interactions will eliminate or drastically reduce the interface width.

There are trade-offs between computing and communication costs that can be made in exploiting this insight. One can eliminate temporal roughening by requiring each processing element to check for synchronization with a randomly chosen (and probably distant) other element before starting some small fraction of its time steps. Alternatively, one can ask the same small fraction of the processing elements to synchronize with a single distant partner before every time step. Both of these approaches result in essentially the same smoothing. Which solution is preferred will depend on the cost of the fewer links to distant sites required versus the imbalance in the workload of the elements on which falls the extra demand of participating in the small world far away from them.

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ATMOSPHERIC SCIENCE

Deciphering the Energetics of Lightning

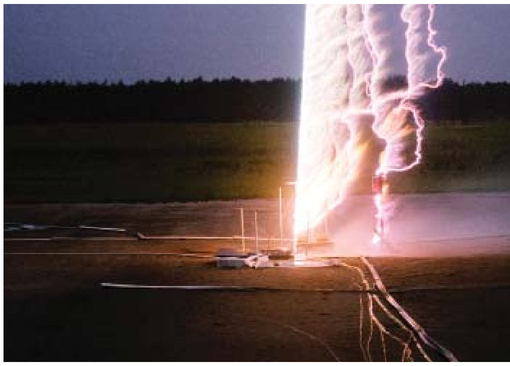
Philip E. Krider

On page 694 of this issue, Dwyer *et al.* (*1*) report the first observations of energetic radiation—x-rays, gamma rays, and/or relativistic electrons—during rocket-triggered lightning. Using an instrument designed to operate in the highly disturbed environment near a lightning strike (see the figure), the authors detected intense bursts of radiation (much more than 10 keV) just before 84% of the return strokes that they were able to trigger. The radiation began while dart leaders were propagating downward—before they contacted ground and initiated return strokes, intense pulses of current that begin at the ground and propagate upward at close to the speed of light (*2*).

Their sensor, a NaI(Tl) scintillation counter operating in conjunction with a control detector, was placed within 25 m of the rocket launcher at a triggering site in central Florida, the International Center for Lightning Research and Testing (ICLRT). In all cases, energetic radiation began when the dart leader was close to the ground and before it initiated an upward-propagating return stroke. The radiation appeared to cease at, or a few microseconds after, the onset of the stroke current. Although the observed bursts of radiation were short and started at most 160 μs before the onset of the current, the total energy deposited in the detector was large, typically many tens of MeV per stroke.

The dart leader/return stroke sequences in triggered lightning are similar to the return strokes that come after the first stroke in natural cloud-to-ground lightning (*2*). Because Dwyer *et al.* detected high-energy radiation during 31 out of 37 triggered strokes, they suggest that such radiation is probably present in all cloud-to-ground flashes. This hypothesis is consistent with a recent report of energetic radiation during the final stages of the stepped-leaders that initiated three natural flashes to a mountain in New Mexico (*3*). The fact that energetic radiation has been observed in Florida near sea level (1 atm pressure) adds credence to other observations and models of energetic radiation at higher altitudes, where such radiation can be more easily produced.

The search for radiation from thunderstorms and lightning has a long history, dat-



Lightning strikes. A rocket-triggered lightning flash striking on or near a short rod at the ICLRT.

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ing back to the 1920s, with successful and unsuccessful detections occurring with approximately equal frequency, probably because of the observational difficulties in making such measurements (*4*). Serious concerns have been raised about the validity of many of the early results, which may have been affected by RF noise in the local environment, power line transients, and/or increases in background radiation due to the washout of radon daughter products in rainfall.

Another problem has been the difficulty of obtaining repeated observations, given the unpredictable occurrence of thunderstorms and lightning. Because of atmospheric absorption, any sources of energetic x-rays or gamma rays must be within a few hundred meters of the detector, and the sources of energetic electrons must be within a few meters. Even in geographic regions that have a high lightning frequency, such as central Florida, it can take many months or even years before a natural cloud-to-ground flash will strike in close proximity to a detector.

For this reason, rocket-triggered lightning experiments are very attractive, allowing repeated measurements at close range in a partially controlled environment. The spatial scale of triggered flashes is about 1000 times larger than the largest discharges that can be made in a laboratory. Because Florida has many thunderstorms that can be used to create rocket-triggered lightning, and because the ICLRT has an installed base of supporting instrumentation, this site is ideal for further experiments to determine the specific types of radiation and the associated energy spectra.

Most models of high-voltage breakdown in nonuniform electric fields at high pressures (*5–7*) do not include (or predict) the production of energetic electrons or x-rays in large (meter scale) sparks or lightning. Therefore, the physics of the breakdown processes may need to be revisited. At present, the only viable mechanism for producing energetic radiation involves the production of runaway electrons. Runaway electrons occur when the energy gained by the free electrons between collisions, as they are accelerated by the high electric field, exceeds the energy that is lost by collisions with the background gas.

Models of electron runaway can be loosely divided into two categories. In cold electron models, extremely large electric fields (many times larger than the breakdown field) accelerate low-energy electrons to relativistic energies, and produce x-rays via "bremsstrahlung" (*8*, *9*). Avalanche models require much lower fields (~300 kV/m) and the presence of energetic seed electrons (*10*, *11*). In both cases, the secondary electrons are further accelerated by the field, producing avalanches of energetic electrons and photons, and, ultimately, a beam of energetic radiation. It is not yet clear whether either of these models can be applied to lightning.

Given the high electric fields and length scales in lightning, measurements like those of Dwyer *et al.* (*1*) can help to determine whether runaway electrons are present and test the validity of breakdown models. Further experiments on rocket-triggered discharges can also enhance our understanding of other types of atmospheric discharge phenomena, such as sprites (*12*), and perhaps the processes that produce bursts of terrestrial gamma rays (*13*).

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GENETICS

Where Do Male Genes Live?

Christian Schlötterer

There are obvious physical differences between males and females, such as the antlers of a male deer and the elaborate tail of a male peacock. Despite pronounced phenotypic differences between the sexes, they still share virtually all of the same genetic information apart from that encoded by the Y chromosome, which is found only in males. A simple assumption is that all male-specific genes responsible for male characteristics should reside on the Y chromosome. But this is not the case; in fact, the Y chromosome contains very few functional genes. It turns out that the phenotypic differences between males and females reflect the differential expression of genes between the sexes. Differential gene expression can be studied by comparing expression in sex-specific tissues such as the ovary and testis. Genes expressed more strongly in the testis are considered to be male-biased, whereas those preferentially expressed in the ovary are considered to be female-biased. Comparing the gene expression patterns of these two tissues has led to the isolation of many sex-specific genes. On page 697 of this issue, Parisi *et al.* (*1*) take a big step forward with their genome-wide microarray analysis of sex-specific gene expression in the fruit fly *Drosophila melanogaster.*

First, Parisi and colleagues ensured that dosage compensation (increased transcription of male-biased genes in *Drosophila*) did not bias the gene expression patterns they obtained. The authors then mapped all expressed genes onto one X chromosome and two nonsex chromosomes (autosomes) of fruit flies. They found that female-biased genes were almost evenly distributed among all three chromosomes. In contrast, male-biased genes were significantly underrepresented on the X chromosome (see the figure).

To investigate the cause of the smaller number of male-biased genes on the *Drosophila* X chromosome, Parisi *et al.* took advantage of the recently completed genome of the mosquito *Anopheles gambiae* (*2*). They discovered that many X-linked fruit fly genes were also found on the X chromosome of *A. gambiae*. However, X-linked fruit fly genes with a strong male bias were poorly conserved in *A. gambiae*, <5% being found on the mosquito X chromosome. In contrast, male-biased fruit fly genes on autosomes were better conserved, >40% also being found on *A. gambiae* autosomes. Female-biased genes and genes expressed in both sexes at a similar level did not show such an extreme difference between the two species, suggesting that this phenomenon is specific for male-biased genes.

Parisi and co-workers coined the phrase "demasculinization of the X chromosome" to describe the underrepresentation of male-biased genes on the X chromosome and the poor conservation of X-linked, male-biased genes among species. Three different evolutionary processes could explain the demasculinization of the X chromosome: (i) preferential emergence of male-biased genes on the autosomes, (ii)

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