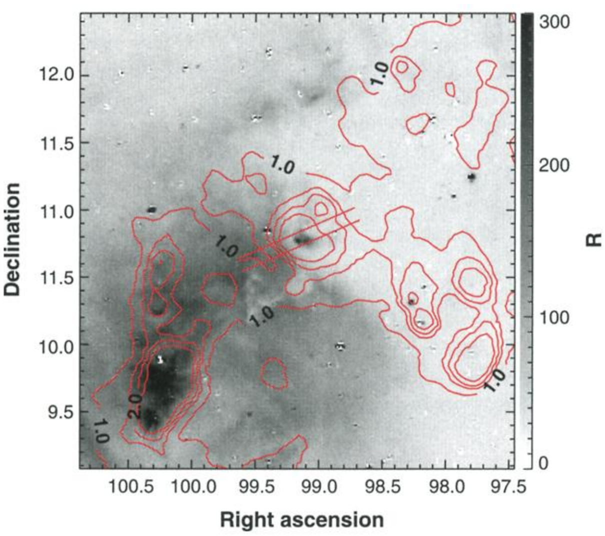
ularities. In this mechanism, random torques caused by photoelectric emission, photon absorption or emission, and H_2 molecule formation force the angular momentum of the grains to grow, eventually pushing rotational frequencies to values well above 10 GHz.

In 1994, Ferrara and Dettmar (*6*) rejuvenated the earlier work (*2*, *3*) and calculated emission spectra for radio-emitting dust from the free electron layer of galaxies (a thick, uniform, ionized gas layer in which stars are embedded in many nearby galaxies). The calculated spectrum was shown to peak at 10 to 30 GHz, depending on grain size distribution and the efficiency of the radiative damping of the rotation. More importantly, the predicted intensity of the radio emission was larger than that of free-free radiation (*7*) from the ionized layer and had a different spectral dependence. Hence, it should be detectable with experimental methodologies available at the time of the study.

The first observations rapidly followed, revealing (*8*, *9*) a substantial excess emission—the "mystery component" (*10*)—toward the North Celestial Pole at 14.5 and 32 GHz. Calculations with state-of-the-art grain models and physical properties of the interstellar medium (*11*, *12*) confirmed that the excess radio emissions could not be completely attributed to free-free radiation and were probably caused by cosmic dust.

In a very recent study (*1*), the observations were extended to lower frequencies (5, 8, and 10 GHz), providing insights into the overall spectral shape of the emission. Equally important, the authors were able to study a limited number of discrete sources, namely dark or infrared-selected interstellar clouds and HII regions. One of these sources, an HII region (see the figure), unambiguously showed the expected intensity and rising spectrum signatures of the "mystery" radio emission from spinning grains. A second candidate, a dark cloud, was also inconsistent with pure free-free emission, albeit at a lower confidence level.

These radio emissions from dust grains provide an important new tool for studies of the interstellar medium in galaxies. Future investigations with ground-based telescopes and satellites as PLANCK and MAP should be able to constrain the abundance of small grains, their spatial variations, and the degree to which they are aligned. The "mystery" emission could also represent yet another important foreground to be subtracted in experiments aimed at measuring the angular structure of the cosmic microwave background.



Evidence for spinning grains. This composite image of the HII region LPH 201.663+1.643 shows evidence for radio emission from spinning grains. The gray scale is the image centered at the wavelength of the hydrogen H_α emission [rayleigh (R) units on the bar; 1 R = 10^6 photons cm^{-2} s^{-1}]. Contours are dust extinction levels. The region scanned during the study (*1*) is also shown.

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PERSPECTIVES: ECOLOGY

Darwin and the First Ecological Experiment

Andy Hector and Rowan Hooper

The disappearance of species from Earth has been likened to the loss of rivets from an airplane (*1*). This vivid analogy has inspired ecologists to think about how changes in biodiversity affect the way that ecosystems operate. We tend to view this research, which is currently one of the most active areas in ecology, as relatively new, but as with many things in biology, Darwin got there first (*2–4*). In *The Origin of Species* (*3*) Darwin says, "It has been experimentally proved that if a plot of ground be sown with one species of grass, and a similar plot be sown with several distinct genera of grasses, a greater number of plants and a greater weight of dry herbage can thus be raised."

Darwin clearly identifies that ecological differences between species can make communities both more diverse and more productive. But which experiment was he referring to? Unfortunately, *The Origin of Species* does not contain references as it was intended only as an abstract for an unfinished longer work, *Natural Selection*, which was put to one side after Wallace independently conceived the same theory of evolution. An edited version of *Natural Selection* based on Darwin's writings was eventually published in 1975 complete with references (*5*). The work Darwin refers to comes from an 1826 article by the Duke of Bedford's head gardener, George Sinclair (*6*). In his article, Sinclair describes experiments conducted at Woburn Abbey in Bedfordshire, England, at the start of the 19th century. The results of these experiments were originally published in *Hortus Gramineus Woburnensis* (*HGW*) (*7*).

The first edition of this book, published in 1816, describes an experimental garden designed to compare the performance of different species and various mixtures of grasses and herbs on different types of soil (see the figure). A plan of the experimental garden lists the plant mixtures grown in 242 plots, each 4 square feet, enclosed by boards set in cast-iron

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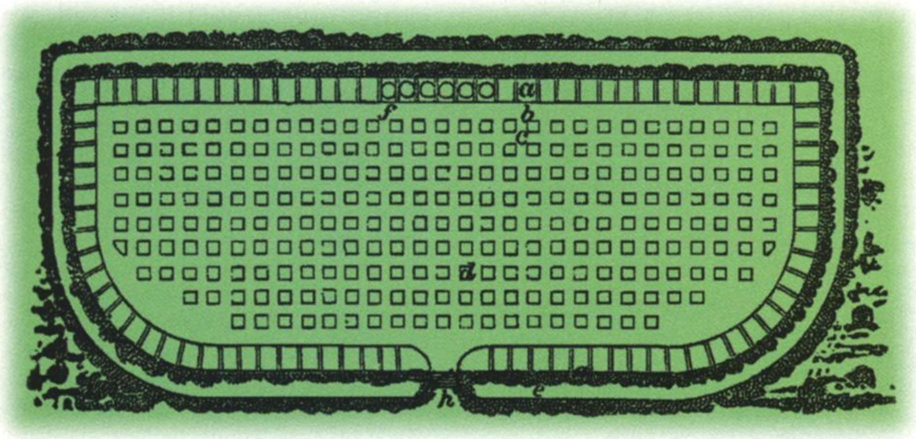

In an English country garden. Plan of the *Hortus Gramineus*, or grass garden, at Woburn Abbey in 1817. The plan shows the 242 experimental plots and 85 beds with the original legend: "***a***, represents a border for the herbage plants, as clover, trefoil, lucern, saintfoin etc; likewise for new or dubious varieties of grasses, and for experiments and trials generally. ***b***, A path or walk of sand or gravel. ***c***, Paths between the different grasses. ***d***, Spaces inclosed by iron or timber borders, for the perennial and known annual grasses, or such species as live in water. ***g***, Hedge of hornbeam, holly, box, or privet, to inclose the grass-garden, or compartment, from the rest of the surrounding garden or grounds. ***h***, Entrance to the grass-garden." Plan of the garden is reproduced from (*6*), and has been annotated with additional information from the map in the first edition of *Hortus Gramineus Woburnensis* (*7*).

frames, with leaded tanks for aquatic species. The plots were filled with selected soils or custom-made mixtures to compare the performance of the plant communities on different substrates in terms of their numbers, sizes, and reproduction. These measurements of individuals and populations were accompanied by some of the earliest chemical analysis of plants and soils under the guidance of the chemist Sir Humphry Davy (*8*).

To the manor born. An 1828 engraving of Woburn Abbey in Bedfordshire, England.

The third edition of *HGW* reported that diverse transplanted turf communities were more productive than less species-rich communities established from seed (see supplementary Web table) (*9*), which prompted Darwin's statement that more diverse communities are more productive. Although the results clearly convinced Sinclair and Darwin, inevitably there are several caveats. First, the work conducted around 1820 is so early that it predates modern methods of experimental design and statistical analysis. For example, differences in diversity are confounded by differences in methodology: The communities with higher productivity and diversity were transplanted turfs, whereas those with lower productivity and diversity were established from seed. Second, in the absence of supporting data, we have to take Sinclair's assurance that "the weight of produce in herbage and in hay increased in proportion" to the number of plants (*6*), although we know that the number of individuals is often uncoupled from total yield. For monocultures, productivity generally increases with density only at low numbers of individuals. The modular nature of plants and the fact that individuals can vary hugely in size leads to a law of "constant final yield" (*10*) in which a wide range of low- and high-density mixtures reach the same end point. Despite these limitations, the experiment is impressive even by today's standards. Indeed, several recent biodiversity experiments have used a similar approach (*11*).

The work also influenced the development of Darwin's "principle of divergence," one of the building blocks for his theory of evolution by natural selection (*12*, *13*). According to the principle of divergence, selection leads to new varieties arising in the same location. Although Darwin's main interest was how natural selection drives the evolution of differences between species, we argue that by explicitly linking diversity with productivity and decomposition, Darwin also recognized the consequences for ecosystems of the "ecological division of labor" (*5*). As Darwin states in *Natural Selection* (*5*), "A greater absolute amount of life can be supported...when life is developed under many and widely different forms,...the fairest measure of the amount of life being probably the amount of chemical composition and decomposition within a given period."

In addition to its historical importance as the source of the intellectual link between biodiversity and ecosystem biology first made by Darwin, the research from the forgotten grass garden at Woburn Abbey predates all other ecological experiments that we know of. Although "ecology" was not coined by Haeckel until 1866 (*14*), we think that the work at Woburn may be seen retrospectively as the world's first ecological experiment.

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15. We thank A. Minns, J. Browne, S. Ratcliffe, A. Mitchell, K. Pickard, the editors of the Darwin Correspondence Project, A. Wilby, B. Schmid, M. Loreau, C. Godfray, and J. Lawton for help in locating this work and for comments on the manuscript.