GEOPHYSICS

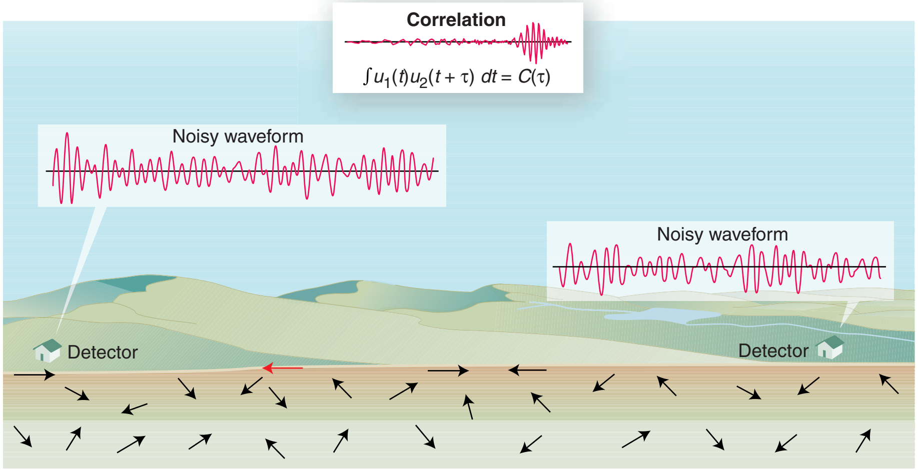
# Information from Seismic Noise

**Richard L. Weaver**

It is commonly supposed that noise obscures, but does not contain, useful information. Intuition suggests that multiple scattering of waves garbles them into illegibility. Yet insights arising out of a branch of physics called "mesoscopic physics" are challenging this assumption. Theory shows that, regardless of scattering, linear waves preserve a residual coherence. This coherence leads to behaviors that confound intuition, such as Anderson localization in which a multiply scattered wave field is confined to a finite volume and unable to diffuse.

Such residual coherences can also be useful in seismology, as shown by Shapiro *et al.* on page 1615 of this issue (*1*). The authors have analyzed seismic noise to obtain new information on the structure of Earth's crust. By correlating the data from a month of ambient noise [due in part to wave-wave interactions in the ocean (*2*)] detected by 62 long-period seismograph stations in southern California, they determined the seismic response that they would have obtained from Earth's crust if they had applied forces at each of their stations. In particular, they measured the times that it took for seismic surface waves to propagate between every pair of stations. They then used tomographic techniques to create a map of seismic wave velocity with an unprecedented horizontal resolution of 75 to 100 km. The map is consistent with presumed geologic structures to a depth of 20 km. As new high-density seismograph networks come online, such results can be extended throughout the United States.

Correlation of seismic noise is a new and intriguing tool with numerous possible applications. Examples include oil exploration without explosives or thumper trucks, seismic wave profiling and deep Earth tomography from arbitrary positions without waiting for an earthquake, and the extraordinary pleasure of using and interpreting a wealth of data that were previously considered worthless.



**Using noise in seismology.** When a diffuse wave field is generated by distant sources and/or by multiple scattering, detectors report random signals. Occasionally a ray (for example, the one shown in red) passes through both detectors. As a result, the signals are weakly correlated.

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The term "mesoscopic" is taken from low-temperature electronics, where electrons remain quantum mechanically coherent over the almost macroscopic intervals needed for electronic transport in modern small devices. Constructive and destructive interferences of the electron wave lead to a wealth of fascinating phenomena. For example, mesoscopic fluctuations of electronic conductance affect the electronic properties of the devices. The behaviors are not confined to quantum mechanical systems, but are a consequence of linearity and of the constancy in time of the structures. Related phenomena have been observed for acoustic, seismic, and optical waves (*3*).

A transient seismic source such as an earthquake often causes two different sets of seismic waves: a main wave that propagates directly from the source, and a long-duration noisy "coda" consisting of waves (or rays) that have been scattered or reflected at least once. The variations in the intensity of the seismic coda with time have long been known to be characteristic of a region, but independent of the earthquake (*4*). Recently, Hennino *et al.* found that, at least for a region in Mexico, the seismic coda has an additional property: Its energy is distributed in a characteristic way (equipartitioned) among the various types of seismic waves (*5*). Such partitioning is a consequence of multiple scattering. The observation thus indicates that coda waves have been scattered several times.

In the case of multiply scattered electrons and visual light, residual coherences are generally manifested in intensity correlations. At the lower frequencies of microwaves, acoustics, and seismology, we can measure fields as well as intensities. This permits observation of additional effects of residual coherence. For example, time-reversal imaging (*6*) depends on the coherence between an acoustic process and its time-reversed form, even if multiply scattered. It has applications in medical ultrasound, ocean acoustics, and nondestructive evaluation of engineering structures. Another example is coda wave interferometry (*7*), which investigates changes in codas. Details of a coda waveform cannot be interpreted, but changes in a coda can correspond to changes in a medium or to the movement of scatterers within it. This method has been used to measure temperature and regularity in a body's shape (*8*), detect the growth of cracks in materials, and monitor changing environments in a volcano, mines, and a fishtank.

A third example is weak Anderson localization of seismic waves. It corresponds to an enhancement of a diffuse field's intensity at the position of its source long after the source has ceased to act. The phenom-

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enon was first observed in electronics and optics, but has recently been seen with seismic waves (*9*). It is sensitive to the mean free time for a typical ray to scatter, and thus measures the elastic heterogeneity of a region.

The work by Shapiro *et al.* (*1*) arises out of helio-seismology (*10*) and ultrasonics (*11*), where it was noted that equipartitioned wave fields must have correlation functions equal to the signals that one would obtain following a concentrated impulsive force. Such correlations therefore passively reveal information about a structure that is normally obtained only by actively launching waves and detecting responses. A perfectly diffuse equipartitioned field is provided by thermal fluctuations. Correlations of thermal noise in an ultrasonic receiver circuit reveal the conventional ultrasonic waveform (*11*).

As with thermal noise, a diffuse field generated by distant active sources also permits retrieval of the response function. It is not difficult to understand how propagation times might be revealed. A ray that is part of an isotropic diffuse field and that passes by one receiver will pass by another receiver slightly later, with its phase undisturbed except by the propagation time. Thus, the signals, although noisy, are correlated (see the figure).

Shapiro *et al.* have now demonstrated the utility of these ideas in seismology. High-resolution maps of surface wave velocity are to be expected in the near future. The prospects for other seismic applications are also good, although not yet fully proven. These and other mesoscopic phenomena may find applications in other fields of acoustics, such as ocean acoustics (*12*), room acoustics, structural acoustics and vibration, and ultrasonic nondestructive evaluation.

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PLANT SCIENCES

# Plant Genes on Steroids

**Robert Sablowski and Nicholas P. Harberd**

Plants, like animals, use steroid hormones to regulate their development through changes in the expression of target genes. However, the molecules used by plant cells to perceive and respond to the steroid signal are different from those used by animals. In animal cells, nuclear receptors generally bind to steroid hormones and directly regulate target gene expression. By contrast, in plants the steroid hormone is bound by a receptor at the cell surface. The resultant signal is then transmitted through a chain of events that include dephosphorylation of regulatory proteins and their accumulation in the nucleus. Exactly how these events are translated into changes in gene expression was, until recently, unknown. The link in the plant steroid signaling chain now is revealed by He and colleagues on page 1634 of this issue (*1*) and by Yin and coworkers in a recent issue of *Cell* (*2*).

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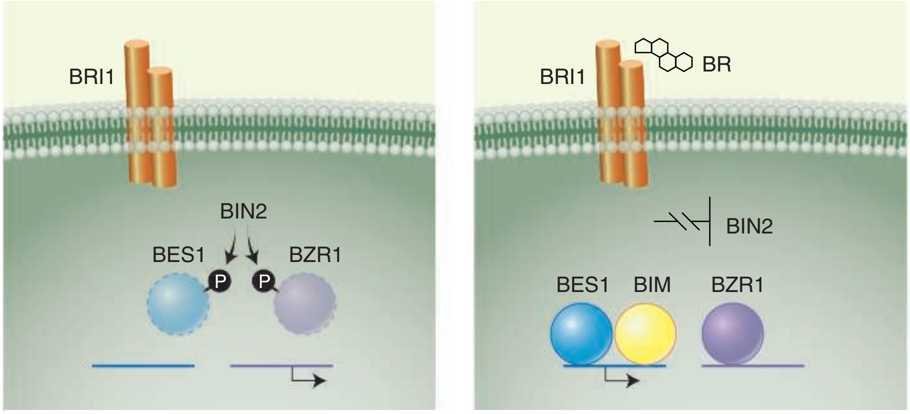
The steroid hormone found in plants is brassinosteroid (BR). BR controls multiple processes, including cell expansion, light-induced differentiation, seed germination, and vascular development (*3*). This steroid hormone is detected by BRI1, a leucine-rich repeat receptor kinase that spans the outer membrane of plant cells (see the figure). In response to BR, BRI1 inhibits BIN2, a protein that normally attaches phosphate groups to the nuclear proteins BES1 and BZR1. These phosphate groups tag BES1 and BZR1 for rapid destruction in the proteasome, the cellular organelle that degrades unwanted proteins. Thus, inhibition of BIN2 activity promotes the accumulation of BES1 and BZR1 in the nucleus. BES1 and BZR1 then activate selected BR-responsive genes (for example, genes encoding enzymes that relax the cell walls, thus permitting cell expansion) and repress the activity of others (such as *CPD*, which encodes CPD, a key enzyme in the BR biosynthesis pathway).

The two new studies demonstrate that BZR1 and BES1 are members of a new family of transcription factors. He *et al.* (*1*) found that BZR1 binds directly to specific sequences within the *CPD* gene and thus represses transcription (that is, the production of mRNA that subsequently directs synthesis of CPD). In addition, they identified a subset of BR-regulated genes that are probably direct targets of BZR1 and contain the BZR1 binding sequence. Yin *et al.* (*2*) showed that BES1 also binds



**Steroid signaling in plants. (Left)** In the absence of steroid, the BIN2 protein phosphorylates BES1 and BZR1, which are then degraded. Genes activated by BES1 (blue line) remain inactive, whereas genes repressed by BZR1 (purple line) are active. **(Right)** When steroid hormone is bound by the BRI1 receptor at the plant cell surface, this leads to inhibition of BIN2 and stabilization of BZR1 and BES1. BZR1 binds to target genes directly in order to turn them off, whereas BES1 acts together with BIM proteins to bind and to activate the expression of target genes.

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