tic) medium and have found a home in a variety of astrophysical models (*7–10*). One fascinating possibility is that GWs in the intergalactic medium may explain the observed dimming of supernovae at high redshift. Astronomers use measurements of the brightness and redshift of distant objects to determine how quickly the universe is expanding. Observational evidence of the apparent luminosities of supernovae at high redshift (*11*, *12*) have been taken to suggest an accelerated expansion of the universe, driven by "dark energy"—a concept that has recently revolutionized cosmology.

However, there are a number of potential explanations for these observations that would remove the need for "dark energy," among them models that explain supernova dimming through particles in intergalactic space that absorb or scatter light (*9*, *10*). Graphite whiskers are an ideal candidate for this material for two reasons: These grains change the spectrum of incident light very little, consistent with the apparent colors of the high redshift supernovae, and they are very efficient absorbers, so they could be preferentially ejected from the formation sites within galaxies by radiation pressure. Although early models (*9*) are difficult to reconcile with more recent supernova data (*13*), new, more detailed models (*10*) are compatible with current data.

With the potential to study extraterrestrial GWs in the lab, Fries and Steele have shown that analysis of meteorites can provide "ground truth" data for the models discussed above. Before the current study, only one other form of mineral needle or whisker had been discovered in extraterrestrial materials: enstatite, a magnesium silicate (*13*). It was suggested, based on the unusual crystal morphology and microstructure of the enstatite needles, that they were vapor-phase condensates and that they might have formed either in the solar nebula or in a presolar environment (*13*). Similarly, Fries and Steele note that all known GW synthesis methods involve deposition from a vapor at high temperature. GWs appear to be commonly associated with CAIs (*2*); thus, Fries and Steele propose that, because CAIs are thought to form close to the young Sun, and GWs are condensing there, GWs could easily have been launched into interstellar space from the disk by bipolar outflows, a common feature of protoplanetary disks (see the figure).

Bringing the discussion closer to home, what are the implications for our understanding of processes occurring in the early solar system? GWs are observed in three settings: within a chondrule, inside several CAIs (and also at the CAI/matrix boundary), and associated with a rim around a piece of altered matrix-like material. Many CAIs show evidence for formation by condensation, so it is not unexpected to find evidence for another condensed phase there. More surprising are the GWs associated with the fragment of matrix-like material, which, with associated minerals, suggests high-temperature formation of these fragments at asteroidal distances.

The GWs described by Fries and Steele clearly have a solar system origin. The abundance of presolar GWs may be very low compared with other presolar grains found in meteorites, but if Fries and Steele are correct, then bona fide presolar GWs should also be there. Although bipolar outflows are a reasonable mechanism by which to launch GWs into interstellar space, it is clearly a priority now to confirm whether GWs are indeed a component of the interstellar medium. Meteorite analysis can answer that question. CV chondrites—the type of meteorite studied here (2)—are arguably the least primitive of all the carbonaceous chondrites. Therefore, a necessary next step would be to extend the search to fine-grained materials in the most primitive meteorites, cosmic dust, and cometary samples to identify graphite whiskers that exhibit the type of isotopic anomalies characteristic of formation in the atmosphere of stars other than the Sun.

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MUSIC THEORY

Creating Musical Variation

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Inspiration for composition may come from natural sounds, chance, and methods based on chaos theory.

In the 21 letters that Mozart wrote to his friend Michael Puchberg between 1788 and 1791, there exist at least 24 variants of the supplication "Brother, can you spare a dime?" Mozart ornaments his language to cajole, flatter, and play on Puchberg's sympathies (*1*, *2*). He varies his theme of "cash needed now" in much the same way an 18th-century composer might dress a melody in new attire by weaving additional notes around its thematic tones in order to create a variation. Such ornamentation could enliven and elaborate one or more musical entities, as can be heard in the Haydn F Minor Variations (1793) (*3*). The Haydn represents one of the most popular forms of the 18th and 19th centuries—variations on original or borrowed themes. Yet myriad variation techniques existed besides ornamentation, including permutation and combination, as advocated by a number of 18th-century treatises. More recently, fields such as chaos theory have allowed composers to create new kinds of variations, some of which are reminiscent of earlier combinatorial techniques.

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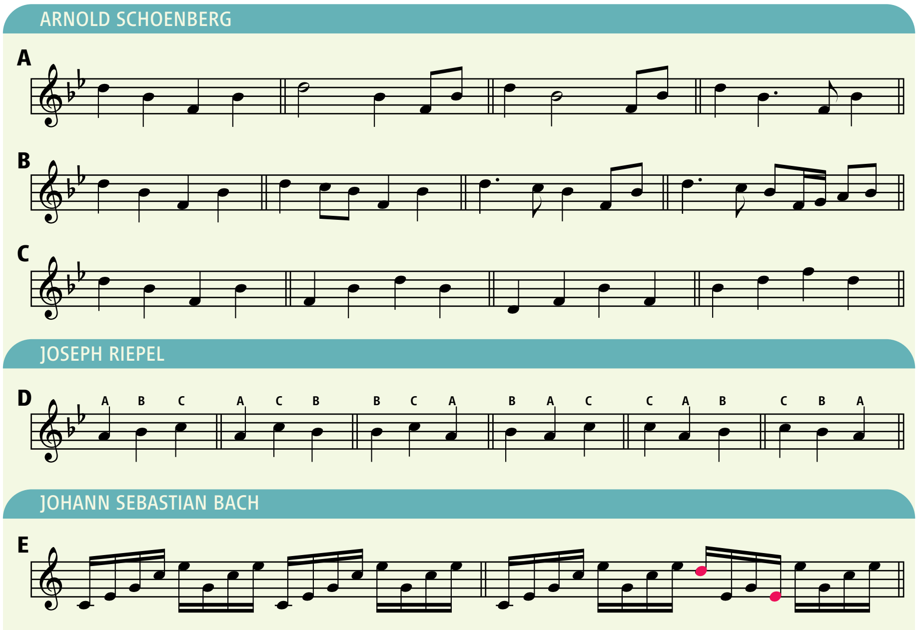
In a broad context, variation refers to the technique of altering musical material to create something related, yet new. Recognizing its importance to composers, the 20th-century composer and teacher Arnold Schoenberg defined variation as "repetition in which some features are changed and the rest preserved" (*4*). He wrote numerous examples showing how a group of four notes, each having the same duration, can be varied by making rhythmic alterations, adding neighboring notes, changing the order of the notes, and so on (see the figure, panels A to C) (*5*). Changing the order of the notes reflects the 18th-century practice of *ars combinatoria*. Joseph Riepel advocated a similar approach (see the figure, panel D) (*6*). How might a composer use such ordering techniques?



Idea and variations. Variation techniques illustrated by Schoenberg, Riepel, and a chaotic mapping example. Schoenberg offers numerous ways to vary a given four-note group, shown in the first measure of each line. (**A**) Rhythmic changes. (**B**) Addition of neighboring notes. (**C**) Changing the original order. (**D**) One of many examples given by Riepel of *ars permutatoria*, a branch of *ars combinatoria*, where six permutations of the notes A B C are given (*15*). Note that Riepel writes above the staff the German musical spelling of the notes so that "B" translates to B-flat. (**E**) The first measure of a Bach prelude (pitches only) followed by the first measure of a variation generated by the chaotic mapping.

Igor Stravinsky offers one of many possible examples in his *Variations: Aldous Huxley in Memoriam* for Orchestra (1964): "My Variations were composed on the following pitch series, a succession of notes that came to my mind as a melody: D C A B E A# G# C# D# G F# F. After writing it out, I gradually discovered the possibilities in it as material for variations. … Veränderungen—alterations or mutations, Bach's word for *The 'Goldberg' Variations*—could be used to describe my Variations as well, except that I have altered or diversified a series, instead of a theme or subject…" (*7*).

Stravinsky derived additional material from his array of notes to produce 12 variations by, for instance, taking his original series and reversing the order to generate a second row of notes: F F# G D# C# G# A# E B A C D. He then rotated this row to create five more rows by placing the first note at the end to generate a second row. To construct the third row, he rotated the second, and so on. Clearly Stravinsky built a 6 × 12 matrix of notes. He then exploited the rows and columns to construct his variations of the original series by, for example, deriving the opening chords of his *Variations* from the first six columns of the matrix (*8*).

Yet an array of material does not have to consist of single notes, as demonstrated by Pierre Henri in his 48-minute *Variations pour une porte et un soupir* ("Variations for a Door and a Sigh," 1963). Using recordings of a breathed sigh, the sung sigh of a musical saw, and a squeaking door, Henri created his variations by mixing, then transforming these sounds in their entirety and in fragments, while varying rhythm and intensity (*9*).

Flash forward to 1987 when DJ Lil' Louis, using much more sophisticated analog equipment, produced *French Kiss*, the first house music hit to sell a million copies in Europe and North America. House music typically features a sampled audio clip that undergoes successive transformations, engineered through electronic effects and instruments. Louis started with a simple repetitive array of rhythms heard on kick drum, synthesizer, and hi-hat, which he gradually varied by adding shakers, electronic brass instruments, hand claps, and more (*10*, *11*).

John Cage broke with tradition by leaving the elemental material of the array and its order unspecified. The "score" for his *Variations IV* consists of handwritten instructions providing a schematic that enables chance not only to decide the musical material but also to determine its order. Cage allows "any number of players, any sounds or combinations of sounds produced by any means, with or without other activities" (*12*). Cage's piece will drastically change from performance to performance—much more so than, say, Stravinsky's *Variations*—by virtue of the chance and randomness he deliberately inserts into his score.

However, if a composer wants to vary an entire work from one hearing to the next, and even from performance to performance, without Cage's randomness, a different kind of variation technique has been helpful—one that uses a chaotic mapping to make musical variations of the entire work (*13*). Such a technique harnesses a natural mechanism for variability found in the science of chaos—that is, the sensitivity of chaotic trajectories to initial conditions. Two chaotic trajectories map the pitch sequence of a musical score into a variation where the same set (or subset) of pitches appear, but in modified order (see the figure, panel E). Virtually infinite in number, these variations can be close to the original, diverge from it substantially, or achieve degrees of variability between these two extremes. Unlike the above methods, the technique offers a postcompositional process in which a composer can go on a journey to someplace new or unimagined with an already completed piece (*14*).

The several music files available online (*3*, *11*, *14*) are intended to serve as only a sampling of the richness of musical variations. Just opening one's ears makes it possible to hear the variations that pervade our musical lives, from jazz improvisations on popular songs to the tinkling pitches caused by rain on a tin roof.

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