News & views

Astronomy

A glimpse inside δ Scuti stars

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Patterns in the vibrations of stars produce a sort of natural music that offers clues to the stars' internal structure. Astronomers have identified such patterns for some δ Scuti stars, a group for which this music had been elusive. **See p.147**

Our knowledge of the stars is based almost exclusively on the study of their light. But the light that reaches us originates from their upper layers – we can't see inside. There is, however, a tool we can use to look into the interior of the stars: asteroseismology. On page 147, Bedding *et al.*[1] report that a subgroup of the enigmatic δ Scuti stars exhibits regular pulsations that will finally enable the stars to be probed using this tool.

Inside a star, gravity and gas pressure compete with each other. If the two are in balance, the star is in equilibrium, but if one increases more than the other, the star contracts or expands. Hot gas spheres such as stars can show characteristic periodic oscillations in which the star pulsates in this way. These characteristic oscillations, called eigenmodes, are standing waves, like the standing sound waves responsible for the sounds of musical instruments such as violins and oboes. The eigenmodes are determined by the physics of the oscillating system.

Asteroseismology is the study of these stellar oscillations[2]. The idea is similar to that of seismology, in which the interior structure of our planet is inferred from earthquakes. Each star can have different – and often very large numbers of – eigenmodes, depending on its internal structure. Oscillations that have different periods or frequencies are sensitive to physical conditions in different regions inside the stars. The more eigenmodes that can be determined from observations, the more detailed will be our map of the internal structure.

Oscillations produce brighter and darker areas (corresponding to higher and lower pressures and temperatures; Fig. 1) on the star's surface[2]. However, we cannot resolve the surfaces of stars, apart from that of our Sun and a few other special cases (see ref. 3 and references therein, for example). Only their total brightness can be measured. The complicated distribution and variation of surface brightness results in an equally complex temporal variation in the total brightness. By measuring the brightness of a star, a photometric time series known as the light curve is obtained.

For asteroseismology, then, we need the following steps. To obtain the surface-brightness distribution from the measured light curves, the frequency of the brightness variations must be determined. Next, we must work out how these frequencies correspond to the eigenmodes expected from theoretical models, a process called mode identification. If the mode identification is successful, actual asteroseismology can begin by determining key physical parameters such as stellar mass and age. Then the ultimate goal of asteroseismology can follow: obtaining the total seismic inversion, which means the detailed determination of stratifications of the pressure, temperature and chemical composition inside the star.

For decades, researchers have made tremendous efforts to obtain valuable asteroseismic data sets. Extensive observation campaigns were carried out using ground-based telescopes, but inevitable variations in detectors and weather conditions affected the data. Space missions (such as CoRoT, Kepler and TESS) delivered the real breakthrough. Thanks to the missions' long, homogeneous and evenly sampled light curves, and the precision of the collected data, asteroseismology has now been successfully applied to thousands of stars across several stellar types that have different internal structures[4–6].

But the abundant star type known as δ Scuti (ref. 7), named after a star in the constellation Scutum, has remained one of the exceptions. Stars of this type have a slightly larger mass

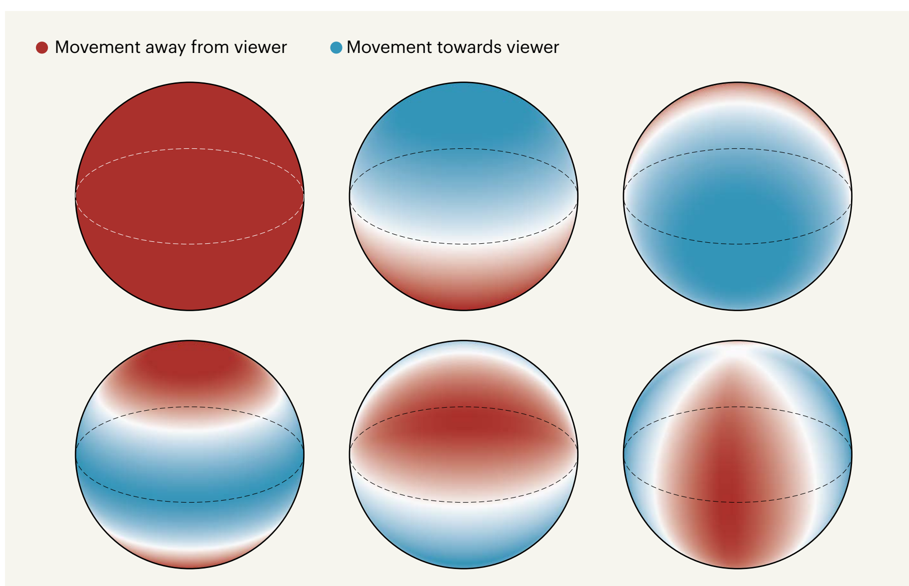

Figure 1 | Simple modes of stellar oscillations. Pressure oscillations in stars occur in many different combinations of characteristic patterns and frequencies, such as the simple examples shown here. These oscillations change the brightness of stars, and offer clues about the physical conditions inside them. The oscillatory modes of an important family of stars known as δ Scuti stars have been difficult to identify. Bedding *et al.*[1] have identified a group of δ Scuti stars that pulsate at a high rate and with regular patterns of frequency that agree with theoretical predictions. This allowed the oscillation modes to be identified.

than that of our Sun, but their inner structure is very different. They have long been known to have complicated, low-amplitude light curves[7]. One might think that the large number of detected frequencies would make these stars ideal targets for asteroseismology.

The theoretical models of δ Scuti stars predict many possible excited eigenmodes and corresponding frequencies. In fact, there are many more such frequencies in models than have been observed[8], and usually we do not know which of the possible modes are seen. If there were some regular structure to the frequencies (such as frequencies with comb-like regular differences), we would have a better chance of identifying them. But the theoretical models generally do not predict regular frequency structure for these stars.

Bedding *et al.* have identified a special subgroup of δ Scuti stars that pulsate at higher frequencies than do most such stars. For this subgroup, both theory and observations suggest the existence of regular frequency structures. Other researchers have previously found regular structures in observed data for some δ Scuti stars (see refs 9–14, for example), but did not identify the oscillating modes conclusively, if at all. Bedding *et al.* provide unambiguous mode identification for a uniform and relatively large sample of these stars.

A key factor in the authors' success is that many of the stars in the subgroup rotate more slowly than do other δ Scuti stars. (Alternatively, it could be that some of the stars are observed almost pole-on, resulting in apparently small rotation velocities.) Theoretical models predict that the frequency spectra of stars that have low rotation velocities are less complicated than those with higher rotation speeds[14], which makes it easier to recognize their regular frequency structures. Bedding *et al.* not only identified these structures, but also associated the frequencies with the corresponding eigenmodes.

Sky surveys now and in the near future will target many thousands of δ Scuti stars, including many that are similar to those described by Bedding and co-workers. This is not merely an opportunity to understand the physics of a special group of δ Scuti stars better. The authors show that these are young stars, which means that they can be used as tracers to estimate the age of open star clusters or of young stellar associations in our Galaxy. In this way, we might learn more about the evolution of the Milky Way. Bedding and colleagues' study is therefore not the last word on δ Scuti stars. Rather, it opens up avenues of investigation for this important stellar group.

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Immunology

Brain–spleen connection aids antibody production

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Elucidating how the brain controls peripheral organs in the fight against infection is crucial for our understanding of brain–body interactions. A study in mice reveals one such pathway worthy of further investigation. **See p.204**

Interactions between the mind and the body have sparked the interest of scientists and philosophers for centuries. In ancient Greece, the physician Galen described the spleen as being the source of black bile, which was thought to cause melancholy when secreted in excess. Today, research is uncovering complex ways in which the brain and body interact to affect diverse aspects of health, from mood to immune function. The spleen aids immune defences by functioning as part of the lymphatic system; the organ is a major hub of activities needed to initiate responses in the adaptive branch of the immune system, which handles defences that are tailored to a specific disease-causing agent.

The spleen is a target of top-down control from the brain[1]. Zhang *et al.*[2] have taken our understanding of brain–spleen connections to the next level by revealing on page 204 an aspect of top-down control that regulates the adaptive immune system.

The spleen's contribution to immune responses occurs mainly in its white-pulp region, where immune cells that have arrived from elsewhere in the body present peptide fragments called antigens to immune cells called T cells. If a T cell binds to and recognizes such an antigen, which might indicate the presence of an abnormal cell or a foreign invader, this activates the T cell, which in turn activates immune cells called B cells. B cells differentiate to form plasma cells (Fig. 1) that secrete antibodies specific for the antigen presented, and these antibodies are released into the bloodstream to fight infection[3].

Spleen activity is controlled by the autonomic nervous system — a part of the nervous system that regulates organs. More specifically, the spleen is controlled mainly by the sympathetic branch of the autonomic nervous system, which is associated with the 'fight-or-flight' response[4]. However, little was known previously about possible upstream brain regions that might connect to the autonomic nervous system in the spleen to control it and, by extension, adaptive immunity. An earlier study in mice[5] revealed that stimulation of a brain region called the ventral tegmental area, a part of the brain's reward circuit, boosts immune responses and protection against harmful bacteria.

Zhang and colleagues developed a surgical technique to remove nerves from the spleen in mice. This mainly removed inputs from the autonomic nervous system and prevented top-down control from the brain to the spleen. After surgery, the animals were injected with an antigen. Plasma cells that made antibodies targeting that antigen arose in abundance in control mice that had undergone a 'sham' operation that did not remove nerves. Such an increase did not occur in the denervated mice, indicating that splenic-nerve activity regulates the formation of plasma cells and thus adaptive immunity.

The authors investigated which molecular mechanisms might be needed for plasma-cell formation in this context. They studied the expression of various types of receptor that can bind the neurotransmitter molecule acetylcholine, which is a key signalling component of the autonomic nervous system. Zhang *et al.* report that B cells express a type of acetylcholine receptor called a nicotinic receptor, and the authors pinpointed protein subunits