News & views

Astronomy

Vibrations probe magnetic fields inside evolved stars

Lisa Bugnet

Oscillations in the light emanating from three Sun-like stars reveal the presence of strong magnetic fields deep in their interiors. The discovery could explain a quirk of stellar dynamics that has so far eluded understanding. **See p.43**

There's something curious about the cores of objects known as red giants, which are huge stars that are in a late phase of stellar evolution: they spin much more slowly than expected. Indeed, the cores of these stars rotate up to 100 times more slowly than is predicted by current models that contain the vast majority of our knowledge about stellar dynamics[1–3]. Magnetism is one of the most promising candidates to explain this difference, but magnetic fields are difficult to detect below the surface of stars. Now, on page 43, Li *et al.*[4] report the discovery of strong magnetic fields in the cores of three red giants — an observational feat that could prompt an update to models of stellar evolution.

The discrepancy between theory and observations suggests that there is at least one physical process missing from our understanding of what takes place inside the cores of stars that are similar to the Sun. This missing process could have a large impact on the way that chemicals mix inside stars, which in turn informs models of stellar evolution. It could thus result in inaccurate stellar dating and obscure our understanding of how galaxies are formed.

Magnetism is implicated in the slow-spin puzzle because the plasma inside stars freezes along magnetic field lines, and this results in rotation rates that show very little variation across the breadth of the star. But the internal plasma of a star cannot be observed, so probing the effects of magnetism on stellar dynamics is challenging. Examining the polarization of the light that stars radiate can offer information about their magnetism at the surface, but this approach cannot access internal magnetic fields. Instead, astronomers must turn to a technique known as asteroseismology.

Sun-like stars vibrate. Asteroseismology is the study of the modes, frequencies, amplitudes and lifetimes of these oscillations as they resonate inside the star. Every dynamic process that modifies the stellar interior is reflected in the properties of these oscillation modes and can therefore be unveiled by careful seismic analysis. For example, the discrepancy between the predicted and observed internal rotation rates of red giant stars was previously revealed by such analyses[1,2].

Having spent their central hydrogen reserves, red giant stars exist as a helium core and a hydrogen-burning shell (Fig. 1). The amplitude of the magnetic fields inside these stars has been predicted[5] to be around 100 kilogauss, which is roughly 2,000 times the strength of a typical fridge magnet. Theoretical studies suggest that this very strong internal magnetism produces asymmetries in the stars' oscillation patterns, and that these asymmetries differ depending on where they arise in the star[5–8]. Specifically, oscillation-frequency shifts that are induced by magnetism should be smaller for pressure-dominated modes (mostly found in the outer portion of the star) than they are for gravity-dominated modes (existing only in the zone at the centre known as the radiative interior).

These asymmetries are expected to produce measurable signatures in the asteroseismic data that were collected during NASA's Kepler mission. However, the detection of such internal magnetic fields is very challenging, because the data contain observational noise, and the asymmetries can be mixed up with signatures of the rotation of the cores, as well as with other second-order effects.

Li *et al.* surmounted these challenges to discover strong magnetic fields inside the cores of three red giants. The authors' asteroseismic detection method was based on the analysis of graphs known as stretched echelle

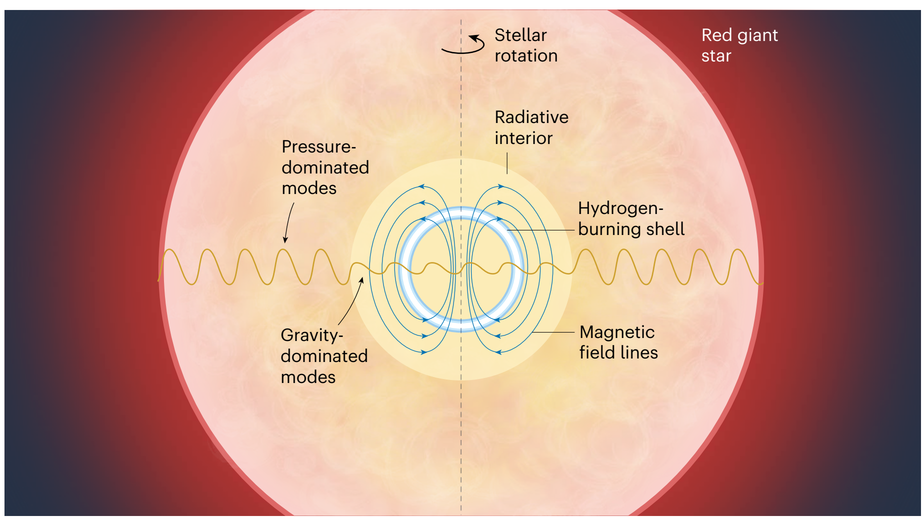

Figure 1 | Detection of magnetic fields inside a red giant star. Red giants are stars in a late phase of stellar evolution that have a helium core (not shown) and a hydrogen-burning shell. They vibrate, and the modes of their oscillations are gravity-dominated in the central part (known as the radiative interior) and pressure-dominated in the outer portion of their mass. Shifts in the modal frequencies can enable the detection of magnetic fields in the stellar interior, because magnetism induces shifts that are smaller for the pressure-dominated modes than they are for the gravity-dominated modes. Li *et al.*[4] used this method to detect magnetic fields at the location of the hydrogen-burning shell by analysing data collected by NASA's Kepler mission for three red giants. The configuration shown corresponds to a magnetic field aligned with the rotation axis of the star.

diagrams[2,5,9]. This approach can be used to measure the amplitudes of magnetic fields at the radius where the red giant burns hydrogen. For the three stars examined by Li and colleagues, these amplitudes were 102 kG, 98 kG and up to 41 kG, all of which are consistent with our understanding of how magnetic fields were generated inside the cores of these stars[5,10]. These findings strengthen support for theoretical studies proposing a scenario for how magnetic fields inside some stars relax after the star stops burning hydrogen in the core[11].

The discovery has opened the way for an extensive search for magnetism inside red giant stars[12], which it is hoped will lead to an understanding of the slow rotation rates observed in these evolved stars. A study reported earlier this year also detected magnetic fields near the core of a younger and more massive star than those analysed by Li and colleagues[13]. Both of these observational studies, together with theoretical developments in the past few years[7,14–16], demonstrate the promising future of asteroseismology for probing the magnetism of stars of all masses and ages.

Future studies might explore the spatial structure of magnetic fields inside red giants, because it is possible to constrain the topology of the field from oscillation-frequency spectra[7]. Such investigations would provide extremely valuable constraints on estimations of the transport of angular momentum inside evolved stars. This could then spark a large collaborative effort to develop stellar-evolution models that incorporate the effect of magnetic fields, based on observations, to provide better estimates of stellar ages in the Universe.

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The author declares no competing interests.

Marine biogeochemistry

Seasonal peak in Arctic Ocean acidity could shift

Victoria Qutuuq Buschman & Claudine Hauri

The acidity of the Arctic Ocean currently peaks in winter. A modelling study suggests that this peak could shift to the summer in the future — this is bad news for ecosystem functions, food webs and Indigenous communities. **See p.94**

The global ocean is gradually acidifying on multidecadal timescales. This acidification occurs when carbon dioxide generated by human activities is absorbed by the ocean, and produces conditions in which many marine organisms cannot thrive. On page 94, Orr *et al.*[1] present global simulations suggesting that future warming in the Arctic Ocean will cause CO_2 levels to peak seasonally in surface waters in the summer, implying that climate change will further accelerate ocean acidification. The resulting increase in acidification would double down on the already heat-stressed ecosystem, with effects that could creep up the food web — further challenging the food security, culture and well-being of Indigenous peoples in the Arctic.

Ocean acidification varies depending on local environmental conditions and processes. For example, acidification of Arctic waters is enhanced by the freshwater input from melting sea ice, precipitation and rivers[2]. The partial pressure of CO_2 (p_{CO_2}, which quantifies the pressure generated by CO_2 dissolved in seawater, but which can be used as a broad measure of how much CO_2 is dissolved) also varies naturally across days, seasons, years and even decades because it depends on a mixture of biological and physical processes.

For instance, when phytoplankton photosynthesize, these microscopic algae use light and CO_2 from their surroundings to produce organic matter and grow, thereby substantially decreasing p_{CO_2} in the surrounding waters. By contrast, high temperatures can have the opposite effect: dissolved molecules of CO_2 gain kinetic energy as the temperature rises, and interact less with surrounding water molecules than they do at cooler temperatures. The CO_2 molecules therefore become less soluble in seawater, and have a greater tendency to escape to the atmosphere (higher partial pressure). This is known as the thermal effect.

Historically, the effect of biological processes on summer CO_2 levels in the Arctic Ocean have dominated over the thermal effect — p_{CO_2} declines because phytoplankton blooms, even though Arctic waters warm in summer. By contrast, Orr and colleagues now suggest that future rapid summer warming of Arctic surface waters, attributable to early sea-ice retreat, will enhance the thermal effect on p_{CO_2} and eventually outweigh the biological effect.

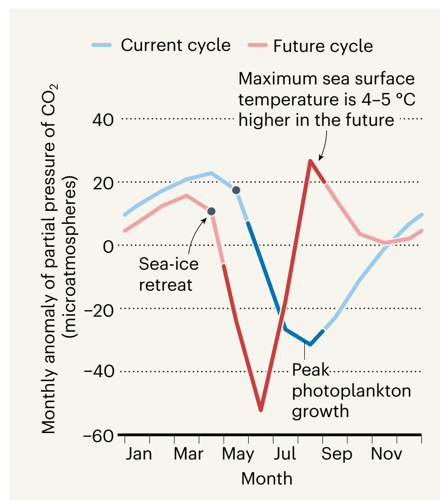

Figure 1 | Simulations of seasonal variation in acidity in the Arctic Ocean. Orr *et al.*[1] assessed the seasonal cycle of the partial pressure of CO_2 (p_{CO_2}, which correlates with seawater acidity) in the Arctic Ocean, using simulations from a set of Earth-system models. The simulated data are plotted as the monthly anomaly — the difference between average monthly p_{CO_2} and the annual average, measured in microatmospheres. Currently, p_{CO_2} peaks around April, but declines when sea ice melts, reaching a minimum in the summer months when marine phytoplankton consume dissolved CO_2 to grow; darker lines indicate periods of peak growth. Future global warming (simulated data are for 2091 to 2100) causes early melting of sea ice and blooming of phytoplankton, resulting in an earlier seasonal minimum of p_{CO_2}. However, p_{CO_2} then reaches a maximum in the summer months, as a consequence of the high summer ocean temperatures. The combination of high temperatures and high acidity in the summer could be devastating for marine ecosystems.