Astronomy

Nonradial pulsations of very hot dwarf stars

from Arthur N. Cox

IN this issue of *Nature* (p.781), there is a paper about the pulsations of a very hot dwarf star discovered in 1979. This very blue and very hot star allows us to look into the centre of a highly evolved star that was originally perhaps a few times larger than our Sun. During its evolution over billions of years, the outer layers have been shed by various poorly understood processes, and what now remains is the nuclear processed core laid bare. Of particular interest is the possibility that measurements of slow changes in the observed pulsation periods may be a direct test of our calculations for the cooling of this very hot dwarf star as it becomes a more common white dwarf.

The 14.5-magnitude star, known as PG 1159–035 (the two sets of numbers indicate the approximate right ascension and declination), was discovered in a search for very blue objects that could be quasars. The spectrum of the star reveals that it is in fact a very rare hot star with a surface gravity 10,000 or more times greater than that found on Earth. The spectrum obtained from observations using optical telescopes, the International Ultraviolet Explorer, the Einstein Observatory and the Voyager 1 and 2 spacecrafts shows no peak of intensity for the shortest available wavelength, suggesting a very high temperature, perhaps as high as 150,000K.

No hydrogen can be seen in the spectrum although it would be expected to be present even at these hot temperatures. Helium and carbon seem to be the most abundant elements, at least at the surface.

The most unusual aspect of this star is its luminosity variations which indicate pulsation with periods of about 460 and 540 seconds and with others not yet accurately determined. These periods and their possible changes allow a comparison of observations and stellar evolution theory.

Stellar evolution theory and some observations predict that for stars of mass up to 8 or so solar masses, the central 0.6–1.4 solar mass will be composed of carbon and oxygen at the end of its life. These elements are produced by thermonuclear burning of hydrogen to helium and subsequently to carbon and oxygen. This process involves combination of three helium atoms to form carbon which can be followed by another fusion of a helium atom with the carbon giving oxygen. Calculation of the relative amounts of carbon and oxygen using the latest radiative capture cross-sections gives a small amount of oxygen. But for the star to pulsate, more oxygen, with its cyclical ionization at temperatures above a million kelvin, is needed.

The observed helium signal in the spectrum must be from the outer layers which did not completely convert helium to the heavier elements. Although all hydrogen has been completely stripped off from the star, a very small amount of helium remains in the outer 10^{-12} – 10^{-13} of the stellar mass. Helium at greater depth would poison the pulsation driving force and make the star nonvariable.

Following the discovery of this very hot star, some theoretical calculations were done assuming a size of 0.6 solar masses at 5,151 solar luminosities and that the pulsations giving the luminosity variations were radial, that is, purely spherical. The success in predicting the two strongest observed periods and their instability was spoiled when further observations showed periods unaccounted for and broad spectral lines indicative of a very high surface gravity. It became clear that the star had a weaker luminosity (about 100 suns) and a smaller radius than assumed, not much larger than that of a common white dwarf star. For a star of this small radius — only a few per cent of the solar radius — the radial pulsation periods are very short, typically only 10 seconds. The observed longer periods therefore must be nonradial *g*-modes of high overtone whose motions are mostly caused by gravity at temperatures near a million kelvin. These details are given in *Astronomical Journal Letters* of 1 May.

An important issue is the amount of oxygen in the pulsation-driving regions buried under only 10^{-10} of the stellar mass. If the star is as hot as the Einstein and Voyager observations indicate, carbon will be completely ionized at this depth. In that case we need to rely on a significant abundance of incompletely ionized oxygen there to drive the pulsations, and that amount is much larger than stellar evolution theory predicts.

It is hoped that the predicted period changes of this star and the few similar ones recently discovered can give further insight into the evolution and perhaps even the composition of very hot dwarf stars. ☐

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Geophysics

Rare gas isotopes and the evolution of the Earth's mantle

from Grenville Turner

THE structure and major-element chemistry of the Earth's mantle are relatively well understood as a result of the combined evidence from seismology and from studies of the chemistry and petrology of mantle-derived rocks and xenoliths. The dynamics and the consequent evolution through time of the mantle are subject to greater uncertainties, and while geophysicists are united in their acceptance of the importance of convection there is considerable disagreement over the dominant pattern of convection. At their simplest, the arguments centre on whether the convection cells extend throughout the mantle, as a whole or are layered with separate systems for the upper and lower mantle. A paper published in this issue of *Nature* (p.795) now presents important new evidence from gas isotope ratios supporting a layered mantle.

Studies on isotope ratios have played an important part in imposing chemical constraints on allowed models of mantle evolution and convective mixing. The models depend on the existence of suitable pairs of isotopes of a given element, one a 'primordial' isotope present in the Earth since its formation, the other a 'radiogenic' daughter isotope produced by radioactive decay at a known rate throughout geological time. The isotopic composition of these isotope pairs in different terrestrial reservoirs, for example different regions of the mantle, the Earth's crust and, in the case of the rare gases, the atmosphere, are a function of the transport and mixing of parent and daughter elements between the different reservoirs. These principles have been applied with great success for the elements strontium, neodymium and lead, which are involved, along with the corresponding 'parent' elements rubidium, samarium and uranium, in the differentiation of the mantle to produce continental crust. They have led to a picture of a mantle containing regions (the upper mantle?) that are depleted in crust-forming elements and other regions (the lower mantle?) that are essentially undepleted.

At the same time, rare gas isotope pairs have been investigated in an attempt to place constraints on the evolution of the atmosphere as well as on the corresponding transport process in the mantle. The rare gas radiogenic/primordial isotope pairs are ^{4}He–^{3}He, ^{40}Ar–^{36}Ar, ^{129}Xe–^{130}Xe and ^{136}Xe–^{130}Xe. The radiogenic isotopes are produced respectively from α-decay of uranium and thorium, β-decay of ^{40}K, β-decay of ^{129}I and spontaneous fission of ^{244}Pu and ^{238}U. ^{129}I and ^{244}Pu are referred

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