grouped data can be made fully available and disclosure poses no risk of loss of confidentiality for individual subjects).

Can findings such as these be applied in the clinic? Companies are already offering direct-to-consumer genetic testing for the risk of developing various diseases, using the same SNP chips as in the new studies[1–3]. The rationale claimed for determining risk in individuals is that it will encourage them to change their lifestyle and/or undergo screening so that disease can be detected earlier. In the case of smoking, however, there is a danger that such 'personalized' medical advice will weaken the public-health message that everyone should avoid smoking. Even if a subset of people are deemed 'resistant' to the effects of smoking on lung cancer development, it is unlikely that they will also be protected against the adverse effects of heart disease and obstructive pulmonary disease, disorders that are also associated with smoking. On the other hand, we may be able to evaluate smoking-cessation treatments informed by knowledge of a person's genetic predisposition to start smoking or to nicotine addiction, and thus add new weapons to the anti-smoking arsenal.

Follow-up studies should clear the smoke clouding the differing conclusions of these papers[1–3] and establish the biological rationale for the robust association of 15q24/15q25.1 with lung cancer. It is at least reassuring that all three groups point to the same region on chromosome 15. The sceptics have fretted that association studies would be riddled with false positive results; yet, because of the high standards that have been developed[6], the evidence for the association between some genetic loci and certain complex diseases is now unequivocal. For most diseases, more loci will surely be discovered, adding to the first wave of results that have been primarily related to disease causation. On the horizon we can see the crest of studies reporting on disease outcomes, but progress, both in understanding the basic causes and in estimating personal risks, will require environmental and lifestyle factors to be taken into account. To quote Winston Churchill, it is "perhaps the end of the beginning" in the battle to understand complex diseases. ■

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EXTRASOLAR PLANETS

With a coarse-tooth comb

Gordon Walker

The search for Earth-like planets outside our Solar System is bedevilled by the lack of an adequate frequency standard for calibrating starlight. Tweaking existing laser 'frequency combs' could be a way forward.

As we look for planets orbiting other suns, it is often tiny, periodic shifts in the spectrum of light coming from a star — a tell-tale 'Doppler wobble' — that reveals the presence of one or more smaller, unseen companions. But when it comes to finding Earth-like planets, this technique reaches a hurdle: the lack of a suitable frequency standard with which to measure the truly tiny spectral shifts caused by such very small planets. On page 610 of this issue, Li *et al.*[1] take this matter in hand, adapting the optical comb — a technology developed to measure very high frequencies — to the purposes of astronomical measurements.

The Austrian physicist and mathematician Christian Doppler first suggested in 1842 that the difference in colour observed between the two stars in some binary systems could be explained if the stars were moving in opposite directions along our line of sight. The wavelength of the light from the star moving towards us would be shifted to shorter, bluer wavelengths, and that of the star moving away from us to longer, redder wavelengths.

In this case, Doppler was wrong: such a shift is much too small for the naked eye to detect, and the different colours of binary stars actually correspond to different surface temperatures. But he was right in principle. We are well attuned to the effect now named after him when it involves sound waves from bodies moving towards and away from us: the speed of sound is a million times slower than that of light, allowing our senses to pick up the difference in their tones. And spectrographs allow us to measure the relative displacement of the spectral lines of binary stars (Fig. 1a). The difference between the stars' velocities can easily be calculated from this wavelength shift, and plotting how this relative velocity changes with time gives the period of revolution of the stars and, with a little additional information, their relative masses and the size of their mutual orbit.

When the Doppler technique is applied to the search for extrasolar planets, only a single spectrum is measured — that of the putative parent star. If an orbiting planet is present, its gravitational attraction will at times pull the star towards us, and at times pull it away from us. The result will be a slow, periodic oscillation in the star's velocity relative to us, and an accompanying shift in its spectrum. The effect is tiny: Jupiter, the giant of our Solar System, has only one-thousandth of the mass of the Sun, and its gravity changes the Sun's radial velocity by just ± 13 m s^{-1} in a cycle that takes almost 12 years, the period of Jupiter's orbit. Earth, which is closer to the Sun, but 300 times smaller than Jupiter, affects the Sun's velocity to the tune of just ± 10 cm s^{-1} over the course of a year.

Planet-searching astronomers need to measure, with confidence and over timescales of years, the truly minuscule wavelength (equivalently, frequency) shifts that accord with

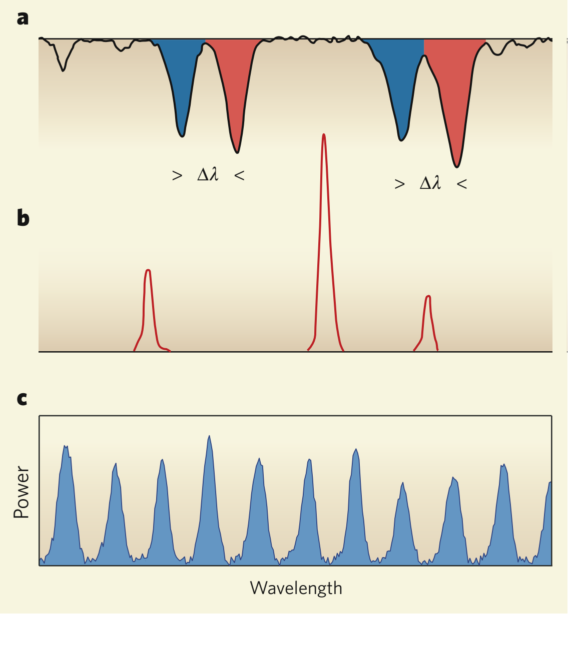

Figure 1 | Shifting stars. a, The motion of two stars in a binary system along our line of sight will shift the frequency of light observed by us: to longer, redder wavelengths if a star is moving away from us; to shorter, bluer wavelengths if the motion is towards us. **b,** Comparison with accurately calibrated reference lines (here from an iron arc) allows the degree of this wavelength shift, $\Delta\lambda$, to be measured. A similar measurement of the 'Doppler wobble' of a single star, induced by an unseen companion, is used in the search for extrasolar planets. **c,** Li *et al.*[1] provide a new reference standard based on a 'comb' of evenly spaced frequency lines that should allow these measurements to be made more accurately — perhaps opening up the possibility of spotting an Earth-like planet.

these velocity changes. So they need highly reliable local 'standards of rest' — standards of precisely known and completely stable wavelengths. Until now, discharge lamps and absorption spectra have served well. The first technique provides stabilized, reasonably well-distributed emission lines for elements such as thorium and argon (Fig. 1b); the second works by passing starlight through a cell containing a molecular vapour, usually iodine, so that the molecule's absorption lines are imposed on it. With further improvements such as the use of a highly stable, preferably evacuated, spectrograph, Doppler measurement precisions of about 1 m s^{-1} can be achieved using reference standards derived from either or both of these techniques.

The harvest from the radial-velocity method has been, at the time of writing, a crop of 261 giant planets. Some of these are rocky, and 25 of the solar systems involved have been found to have more than one planet[2]. The push is now on to find analogues of Earth — rocky planets within the habitable zone (the range of distances within which liquid water would be present) of their parent stars. The focus will be on stars that are both cooler and less massive than the Sun: in these solar systems the radius of the habitable zone is considerably smaller and closer to the star than it is in our own, and a planet of lower mass causes a larger velocity perturbation of the star over a shorter time.

Such cool stars are considerably brighter at infrared wavelengths than they are at optical wavelengths, and the intention is to build spectrographs specifically designed to cover this region. But therein lies a problem: at infrared wavelengths, there are no suitable extended emission or absorption spectra for use as a reference standard.

Enter the 'astro-comb'. Li and colleagues' brainchild[1] is an optically filtered comb of evenly spaced frequency references, all derived from a single frequency source — a pulsed laser. The idea is not new[3,4] (half of a Nobel Prize in Physics was awarded for the idea in 2005)[5], and nor is its application to astronomy[6]. But Li *et al.* are the first to realize the concept in a way suitable for astronomical practice, in what could be a breakthrough in the precision of astronomical spectroscopy.

The principal difficulty that the authors had to overcome was that, although the repetition rate of a fast pulsed laser generates a wide, stable comb of equally spaced sharp fringes, this spacing is much too fine to be resolved by the planet-search spectrographs currently in use or proposed. Li *et al.* use a Fabry–Perot optical filter to give a much sparser comb with teeth ideally spaced for optimum wavelength calibration (Fig. 1c). This might sound simple, but to cover the possible range of frequencies to be measured an effective astro-comb needs to provide at least a thousand teeth, each acting as a reference standard for a particular part of the spectrum, and each bright enough to be readily exploited in a short space of time. That makes great technical demands on the available equipment.

In theory, the astro-comb could lead to radial-velocity measurements with a precision of 1 cm s^{-1} — nearly a hundred times better than the current best, and comparable to the magnitude of Earth's influence on the Sun. But the advance is only a first, albeit essential, step when it comes to the detection of terrestrial planets. There are many factors that can confound accurate measurements of the true radial velocity of a star: if our own Sun serves as a benchmark, a star's surface is a maze of bright granules caused by hot gas boiling to the surface at velocities of around 1 km s^{-1}; dark sunspots, coupled with the star's rotation, severely distort the measured radial velocity; and rapid pulsations, a characteristic of most stars, further complicate matters. Extracting any signal corresponding to another Earth has substantial hurdles to overcome yet. ■

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GEOPHYSICS

Humming a different tune

Toshiro Tanimoto

Earth breathes in and out, murmuring gently to itself as it does so. The habit has been ascribed to the tickling effects of ocean waves — but a new-found twisting oscillation might reopen the search for the source.

Over the past decade, the word 'hum' has acquired a special meaning for seismologists. No longer just what they might do under the shower, it connotes for them a fundamental resonant oscillation of the Earth. A sequence of these oscillation modes, with periods of between around 2 and 5 minutes, was first identified[1–3] in 1998. These were all 'spheroidal' modes, representing perturbations of the planet's equilibrium surface, rather akin to the effect of waves on water. Writing in *Geophysical Research Letters*[4], Kurrle and Widmer-Schnidrig now introduce a further, entirely different mode — 'toroidal' hum, in which parts of Earth's surface twist around in the horizontal plane (Fig. 1, overleaf).

The existence of this low-frequency Earth hum is not the surprising thing. Seismic noise is ubiquitous, generated by various natural processes such as falling water (the impact of, say, the Niagara Falls is not confined to the surface) and even swaying trees, as well as all manner of human activities. It is the magnitude of the hum that is disconcerting[5,6]: its summed amplitude is equivalent to a continuous earthquake of magnitude 6. (Because the waves are at such a low frequency, we humans cannot sense them; as they represent no threat to our well-being, there has presumably never been a need to evolve such a capability.) An earthquake of this size occurs once every three days on average; clearly, seismic activity cannot sustain hum of such magnitude and continuity.

Since those first intriguing findings, the ocean has by general consensus been identified as the most likely source of Earth hum: the origin of the excitations seems to lie in oceanic areas at mid-latitudes, between about 30° and 60° north and south[7,8]. In addition, the amplitude of the effect has a periodicity of six months, with a maximum occurring in each hemisphere during its winter; satellite data show that ocean waves are particularly large at mid-latitudes during the winter months.

The proposal[9,10], which borrows an idea of some 60 years ago[11], is that so-called infragravity waves, which are known to have the same sort of periods as the hum[8,12], transmit this oceanic motion to the solid Earth. These waves are similar to tsunami waves — low-frequency, long-wavelength ocean waves that move the whole column of ocean waters, from surface to sea floor, as they propagate. The collision of such waves could produce large pressure variations[11], and thus excite the hum. A problem is that infragravity waves are mainly known to be a phenomenon of shallow water, although a mechanism for generating them in the deep ocean has recently been proposed[13].

Even so, a direct interaction between the atmosphere and the solid Earth has not been ruled out as a source of the hum. Atmospheric and oceanic effects are difficult to separate: when we see large-amplitude ocean waves, the cause is likely to be an atmospheric effect, namely strong winds. The observant frequent flyer from New York to Paris or Tokyo to San Francisco will note that, during winter in the Northern Hemisphere, flights are often diverted from the shortest geographical route, a great circle over the Arctic, to a more southerly route of near-constant mid-latitude. The