that may extend to intermediate filament proteins in other tissues. Two other intermediate filament proteins, K18 (a major keratin in secretory epithelia)[9] and vimentin (found in fibroblasts and endothelial cells, among others)[10], are known to bind to 14-3-3. Notably, mutation of K18 at the Ser 33 site that regulates 14-3-3 binding stops the movement of 14-3-3 from the nucleus during liver regeneration[9]. Given that increased expression of intermediate filaments is a protective response to injury in many tissues[3,6], such upregulation of these filaments, coupled to interaction with 14-3-3, may have similar 'healing' roles in other tissues. However, intermediate filament induction will probably have many roles that may or may not require 14-3-3, as well as being mechanical and non-mechanical in nature.

The 14-3-3 proteins are already implicated in wound healing, as they can facilitate migration of keratinocyte skin cells to close the wound by regulating the adhesion molecules that hold the cells together[11]. Presumably, this is a late event in wound healing, as K17 binding to 14-3-3 probably occurs earlier and regulates other 14-3-3 binding partners (for example, modulators of the mTOR pathway[4]) to allow increased protein synthesis and progression of wound repair (Fig. 1). The regulation, stoichiometry and precise timing of K17 binding to 14-3-3 after tissue injury remain to be determined. For instance, although Kim *et al.*[4] examined Thr 9 and Ser 44 in K17, it is not clear whether both of these need to be phosphorylated for 14-3-3 to bind. Developing genetic models[9], such as those in mice where K17–14-3-3 binding is blocked, and reagents (for example, antibodies specific for the phosphate tag) to track the precise timing of K17–14-3-3 binding, should further clarify this regulatory pathway.

The induction of K17 now becomes one of several established 'command posts' for the regulation of protein synthesis[4,7]. It may well be that K17 induction is part of a regulatory loop that can, depending on context, further enhance protein synthesis and promote cell growth.

Additional questions are raised by this work. For instance, what is the significance of nuclear 14-3-3 and its redistribution during wound healing? 14-3-3 is linked to the regulation of cell division, and can affect gene expression by binding to the histone proteins that are associated with chromosomes[8,12]. So are these processes involved in the injury response? Also, can some of the skin and nail disorders caused by mutations in the K17 gene[3] be explained by signalling effects mediated by 14-3-3 proteins? K17 is induced in several conditions, including psoriasis and some cancers[6], so what is its role in these disorders? Further areas for investigation include the possible interaction of K17 with 14-3-3 proteins other than the σ-isoform and involvement of K17–14-3-3 binding in other known functions of 14-3-3 (ref. 8). By linking the induction of keratin in response to skin damage with signalling through 14-3-3 proteins and the consequent effects on protein synthesis and cell growth, Kim *et al.* have made an exciting advance towards solving such problems. ■

M. Bishr Omary and Nam-On Ku are in the Department of Medicine, VA Palo Alto Health Care System and Stanford University School of Medicine, 3801 Miranda Avenue, Mail code 154J, Palo Alto, California 94304, USA.
e-mail: mbishr@stanford.edu

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PLASMA PHYSICS

Cool vibes

Thomas C. Killian

Ultracold plasmas blur the classical boundaries between the different states of matter. Newly observed electron-density waves could become useful probes of how electrons behave in this exotic regime.

The complex soups of ions and electrons known as plasmas are ubiquitous in nature, whether in a simple flame, the aurora borealis, the Sun or elsewhere. They are also crucial for technologies such as fluorescent lighting, or for plasma processing in microelectronics. Determining how properties such as temperature and density change inside a plasma is often challenging, but it is necessary for optimizing technological applications and also for understanding fundamental physical phenomena. Some of the most valuable probes developed to determine these properties are based on collective motions of the charged particles that are sensitive to conditions in a plasma. Writing in *Physical Review Letters*, Fletcher *et al.*[1] describe observations in an ultracold plasma of what seem to be oscillations in electron density known as Tonks–Dattner resonances. The history of these resonances reads like a good detective novel, and the results imply that they may become a powerful diagnostic tool.

Students taking a first course in plasma physics learn that, in an infinite, homogeneous plasma, the electron density oscillates naturally at a frequency, ω_{p}, that is proportional to the square root of the electron density. This 'electron plasma oscillation' has a simple physical description: if the electron density drops because electrons are, on average, moving away from the more massive and sluggish ions, strong electric fields develop that pull the electrons back. As there is little damping for electron motion, however, the electrons overshoot, and the local electron density tends to oscillate around its equilibrium value.

In plasmas with densities that vary over a length scale greater than that of the electron oscillations, the structure of these electron collective modes becomes richer. This fact was discovered in the 1950s, during experiments motivated by a prediction[2] that radio waves with a frequency of ω_{p} should reflect off plasma in the tail of a meteor. To general surprise, cylindrical plasmas designed to simulate meteor tails in fact scattered incident radio waves at multiple frequencies near ω_{p}, indicating the existence of additional collective modes besides the electron plasma oscillation expected from the theory of homogeneous plasmas.

The additional modes were later named Tonks–Dattner resonances, and their frequencies increased as the diameter of the plasma column decreased[3], in a manner reminiscent of the increase in pitch from a pipe organ as the pipe becomes shorter. A quantitatively accurate model of this resonance phenomenon[4] drew on the insight that the thermal motion of the electrons can transform the electron plasma oscillation into an extended density wave that propagates rather like a sound wave. In the experiment, the plasma density — and so ω_{p} — increased towards the central axis. The Tonks–Dattner modes were resonant density waves of various frequencies ω, each confined to a region at the outer edge of the plasma where their ω was greater than ω_{p} (Fig. 1). Farther in, at the inner radius at which $\omega = \omega_{\mathrm{p}}$, the Tonks–Dattner wave decayed abruptly (became 'evanescent'), because at this point the higher-density electrons were moving quickly enough to cancel, or screen, the oscillating electric field underlying the wave. Higher-frequency resonances represented shorter-wavelength 'standing waves', for which more wavelengths of the

EVOLUTION

Experiments in botany

Amborella trichopoda, a shrub from New Caledonia in the Pacific Ocean, is believed to be the last remnant of one of the most ancient lineages of angiosperms, or flowering plants. As William E. Friedman reports in this issue (*Nature* **441,** 337–340; 2006), its red fruits, shown here, contain a relic of what seems to have been a period of intense evolutionary experimentation in early angiosperm history.

In nearly all angiosperms, the female gametophyte — egg-producing structure — is a sac containing seven cells and eight nuclei (see Fig. 1 of the paper on page 337). Apart from the egg cell itself, which is fertilized to become the embryo, a so-called central cell is fertilized to become the supporting tissue or endosperm. These are the elements required for the phenomenon of double fertilization unique to angiosperms. Making up the numbers are three antipodal cells and two synergids — sterile cells that accompany the egg.

Amborella dares to be different, and has one extra synergid. This may seem a trifling matter, but it is akin to finding a fossil amphibian with an extra leg: the developmental ramifications are equally important, for Friedman's detailed examination of *Amborella* development shows that the egg cell is — uniquely — a lineal sister of a synergid, rather than a mitotic sister of one of the nuclei of the central cell.

These findings add to the oddities of other relics of early angiosperm evolution, such as water lilies (Nymphaeales) whose mature female gametophytes contain only four cells. The major lineages of angiosperms are believed to have become established in an interval of around 15 million years, 130 million years ago. *Amborella* and other living fossils offer an immensely valuable window into how the reproductive structures of flowering plants evolved.

T. LEMIEUX, UNIV. COLORADO

Henry Gee

density wave fitted between the edge of the plasma and the radius at which evanescence occurred. This explained the multiple reflections observed in the cylindrical-plasma experiment.

The experiments of Fletcher *et al.*[1] probed ultracold plasmas, which are formed from laser-cooled atoms by the ionizing action of an intense laser pulse. With electron temperatures ranging from 1 to 10^3 kelvin, and ion temperatures near 1 K, these plasmas push the envelope of neutral-plasma physics beyond the conventional range of between 10^3 K (for a flame) and 10^7 K or higher (for the solar core or a nuclear fusion reactor). At such very low temperatures, interactions between the particles can dominate the particles' random thermal motion, creating a 'strongly coupled' plasma that acts as a liquid or a solid rather than as a standard, gaseous plasma. Studying this strong coupling in the ultracold regime in a laboratory could illuminate the properties of systems that are strongly coupled as a result of their high density, for example the interiors of gas giant planets such as Jupiter, or the surfaces of neutron stars.

Ultracold plasmas are also notable for their well-defined density distribution, which drops off in a gaussian fashion in all directions radiating out from a central point, as well as their small characteristic size of about 1 mm or less. They are also formed far from their thermal equilibrium: electrons are confined in the plasma by electric attraction to the ions, and after plasma formation, the entire distribution expands into a surrounding vacuum and dissipates in about 100 microseconds.

To study electron oscillations, Fletcher *et al.*[1] applied radio waves to their ultracold plasma, just as in the meteor experiments. When the radio frequency matched the resonance of a collective mode, the applied radio field pumped energy into the electron cloud. This caused some electrons to boil out of the plasma and escape the pull of the ions, allowing them to be counted by a charged-particle detector. At low excitation intensity, only a single resonance, matching the electron plasma oscillation, was observed.

Fields of higher intensity, however, excited a series of higher-frequency modes. As the plasma expanded, the mode frequencies decreased in accordance with what would be expected for Tonks–Dattner modes. It might seem surprising that thermal electron motion — which is crucial to the formation of such modes — would be important in ultracold plasmas. But the small plasma size means that the resonant wavelength must be small, which increases the likelihood that resonant modes form.

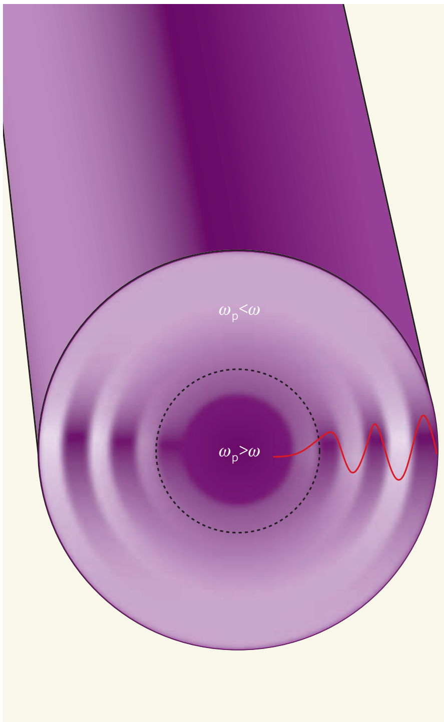

Figure 1 | All wave together. Cross-section of a Tonks–Dattner wave of frequency ω in a cylindrical plasma, such as a meteor tail. Darker colour indicates higher plasma density and the red line indicates a radial trace of the amplitude of the density variation associated with the wave. The wave is confined in the low-density region, where $\omega_p < \omega$. When $\omega_p > \omega$, electron screening quickly damps the oscillation. In ultracold plasmas, Tonks–Dattner waves are spherical, but are still confined to the outer region of low density.

One difference between the observed modes and the classic Tonks–Dattner picture is that the gaussian-shaped ultracold plasmas have no hard edge like that of the confined cylindrical plasmas of the earlier experiments. How exactly a standing wave forms in this open geometry still needs to be worked out. With that theoretical input, however, the resonance frequencies should provide an accurate measure of the electron temperature, a quantity that is essential for studying the approach towards thermal equilibrium of ultracold plasmas near, or in, the strongly coupled regime.

The approach towards equilibrium is a fundamentally challenging problem, as there are many competing processes that affect the electron temperature, such as cooling through adiabatic expansion of the plasma, or heating caused by the recombination of electrons and ions to form neutral atoms. The collective modes observed by Fletcher and colleagues[1] could prove to be the best probe for investigating it. ■

Thomas C. Killian is in the Department of Physics and Astronomy, Rice University, Houston, Texas 77251-1892, USA.
e-mail: killian@rice.edu

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