than the rest (*14*). This again implies a mixture of stellar populations, consistent with more recent merging activity for the Andromeda Nebula than is implicated for the Milky Way.

State-of-the art ΛCDM simulations of galaxy formation (*15*) predict that a substantial fraction of each stellar component of a disk galaxy—even in the thin disk—consists of tidal debris from merged former companion galaxies. Thus, much substructure should be observed in kinematics and in chemical abundances. Spectroscopic surveys of large numbers of stars are required to determine the full chemical abundance and kinematic (radial velocity) distributions.

These data should become available from ongoing and future surveys. Computer simulations are limited by resolution and by the simplistic physics of star formation that are used to model galaxies associated with dark haloes. Both aspects should improve. Soon we should be able to say whether ΛCDM is an appropriate framework for understanding galaxies.

References and Notes

1. D. Spergel *et al.*, http://xxx.lanl.gov/abs/astro-ph/0302209.
2. B. Moore, http://xxx.lanl.gov/abs/astro-ph/0103100.
3. R. Wyse, *ASP Conf. Ser.* **230**, 71 (2001).
4. B. Yanny *et al.*, *Astrophys. J.* **540**, 825 (2000).
5. S. Majewski *et al.*, http://xxx.lanl.gov/abs/astro-ph/0304198.
6. R. Ibata, G. Gilmore, M. Irwin, *Nature* **370**, 194 (1994).
7. M. Odenkirchen *et al.*, http://xxx.lanl.gov/abs/astro-ph/0301086.
8. B. Yanny *et al.*, *Astrophys. J.* **588**, 824 (2003).
9. R. Ibata *et al.*, *Mon. Not. R. Astron. Soc.* **340**, 21 (2003).
10. G. Gilmore, R. Wyse, J. Norris, *Astrophys. J.* **574**, L39 (2002).
11. E. Tolstoy *et al.*, *Astron. J.* **125**, 707 (2003).
12. M. Unavane, R. Wyse, G. Gilmore, *Mon. Not. R. Astron. Soc.* **278**, 727 (1996).
13. A. Ferguson *et al.*, *Astron. J.* **124**, 1452 (2002).
14. T. M. Brown. *et al.*, http://xxx.lanl.gov/abs/astro-ph/0305318.
15. M. G. Abadi, J. F. Navarro, M. Steinmetz, V. R. Elke, http://xxx.lanl.gov/abs/astro-ph/0212282.
16. R. Wyse, G. Gilmore, M. Franx, *Annu. Rev. Astron. Astrophys.* **35**, 637 (1997).

17. We thank S. Majewski for preparing a high-resolution version of the second figure.

PHYSICS

Sensing Electrons on the Edge

Gerard H. Lander

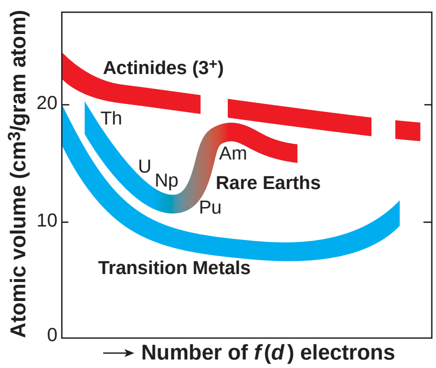
Plutonium (Pu) is one of the elements best known to the general public. Its notoriety stems from the element's nuclear properties: It emits alpha particles, leading to its radiotoxicity, and is able to undergo fission with thermal neutrons, leading to its use in nuclear weapons.

But plutonium has another, more benign, face. Its place in the periodic table imbues it with exceptional electronic properties that still defy a clear explanation, 60 years after they were first discovered. A recent theoretical report (*1*) and the experimental study by Wong *et al.* on page 1078 of this issue (*2*) elucidate the elementary transitions (the movement of atoms in the solid), an aspect of plutonium that has not been addressed before.

Plutonium is midway across the row called the actinides in which the 5*f* electron shell is progressively filled (see the figure). In the early part of the actinide series, the 5*f* electron states contribute to the bonding between atoms. Here, the atomic volume dependence on electron count resembles that of a transition metal series. In contrast, the heavier actinides [americium (Am) and beyond] have larger atomic volumes that depend little on the electron count. These properties signal a rare earth–like behavior; the 5*f* states are localized and do not participate in the bonding.

In plutonium, the 5*f* electrons are "on the edge," and it is this unique situation that gives rise to a plethora of unusual properties (*3*). Plutonium goes through six different phases before it melts, more than any other element. Here, we confine our attention to the simple face-centered cubic (fcc) phase, which is stable at high temperatures and may be stabilized at room temperature by adding a small amount (less than 1 weight percent) of gallium.

The author is at the European Commission's Joint Research Center (JRC) Institute for Transuranium Elements, 76125 Karlsruhe, Germany. E-mail: gerard.lander@cec.eu.int



Atomic volume as a function of electron count. The uniform parabolic dependence of the 3*d*, 4*d*, and 5*d* elements (the transition metals) indicates that all *d* electrons take part in the bonding of the atoms (they are "itinerant"). The 4*f* elements (rare earths, or lanthanides) are larger and show only a small volume reduction across the series. The 4*f* electrons do not contribute to the bonding; they are "localized." The 5*f* elements (the actinides) show an intermediate behavior, with a substantial change between Pu and Am.

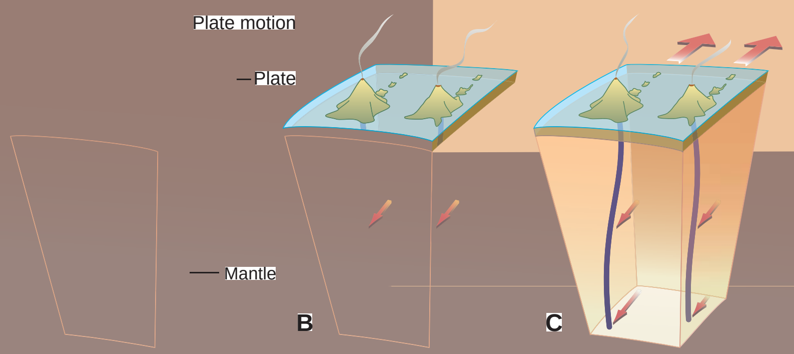
The fact that plutonium is radioactive is a great impediment to performing experiments on this element. Despite 60 years of effort, knowledge is limited. For example, the frequencies of its elementary excitations (or phonons) are poorly known. Many elastic and thermodynamic properties depend on the phonons. These properties are known for almost all other elements and many compounds, mainly from neutron inelastic scattering. For plutonium, however, neutrons are not the answer, because the technique requires relatively large single crystals (at least 100 mm^3). Furthermore, special isotopes must be used to avoid the high absorption of ^{239}Pu.

That the phonons in plutonium would be interesting is ensured both by its place in the periodic table and by renowned experiments performed 27 years ago (*4*). These measurements showed that the elastic properties of fcc plutonium are highly direction-dependent (anisotropic). Ever since, the field has waited to learn more of the properties of plutonium, particularly its elementary excitations at finite q (a parameter that is inversely proportional to the wavelength of the excitation).

Now, in the space of 2 months, we have been treated to two pioneering papers on the phonons in fcc plutonium. First, Dai *et al.* (*1*) made a theoretical prediction within a framework (the dynamical mean field theory, DMFT) that includes the electron correlations so important in plutonium. These calculations reproduce the large shear anisotropy of plutonium (*2*). The authors went on to explain some of the high-temperature phases of plutonium as a consequence of its large anharmonicity and the influence of the phonon entropy.

Wong *et al.* (*2*) present experimental results that complement the theoretical work of Dai *et al*. The authors use inelastic scattering of x-rays from a third-generation synchrotron facility (the European Synchrotron Radiation Facility in Grenoble, France) to determine the complete phonon dispersion curves of plutonium.

The agreement between theory and experiment is surprisingly good. However, a noticeable difference appears in the ⟨111⟩ direction, especially at short wavelengths. This feature probably arises from the electron-phonon interaction. A natural extension will be to follow such effects as a



Different views of hotspot plumes. (**A**) The plumes are stationary and vertical. As the plate moves over them, the only control on the hotspot tracks is the plate velocity. (**B**) The plume bases are fixed relative to one another, but the plumes are at an angle due to mantle flow, with the plate moving over them. Thus, there are two controls on the hotspot tracks: mantle flow and plate motion. (**C**) The hotspot tracks are due to the sum of three effects: relative motion between the two plume sources, change in geometry of the plume conduits due to mantle flow, and plate motions at the surface.