New orbital model details comet gas effects

Each time a periodic comet revisits the inner solar system, it can experience the gentle effects of dust-bearing gas jets erupting on its sun-warmed surface. These so-called nongravitational forces can advance or retard a comet's date of return by hours or years. For example, Comet Swift-Tuttle confounded most predictions when it returned last year, indicating a shift of as much as 11 years from the orbit it would have followed if guided solely by the gravitational pull of the sun and planets (SN: 10/10/92, p.230).

In most cases, astronomers can estimate these nongravitational orbital shifts with fair accuracy, although the detailed physical explanation for the outgassings that cause them remains controversial. Now, an astronomer has devised a detailed mathematical description, or model, that explains when, where, and how gas jets blossom on comets and produce the orbital changes that sometimes surprise Earth-bound astronomers.

Zdenek Sekanina of the Jet Propulsion Laboratory in Pasadena, Calif., emphasizes that his model is not suited for predicting cometary orbits. Instead, it allows astronomers to propose possible locations on a given comet where rocket-like discharges of sun-warmed gas and dust would have to erupt in order to produce the orbital changes observed from Earth. These gas jets can either retard or advance the comet's date of return.

Sekanina's model also offers a novel explanation of why the nongravitational forces on a comet can change, sometimes dramatically, from one orbit to another. "I am absolutely convinced now that these discontinuities [in comet periods] are due to either new active areas igniting on [a comet's] surface, or that previous active areas are suddenly terminated," he says. Sekanina reports his findings in the February ASTRONOMICAL JOURNAL.

The new model, a series of mathematical statements describing the motions of periodic comets through the solar system, explains how streams of material from discrete active areas on a comet's crust can create the observed nongravitational shifts. The effect these forces have on a comet depends on the orientation of the comet's spin axis, where on the comet's surface the various active areas lie, and whether the comet is most active before or after perihelion — the point in its orbit closest to the sun.

In 1986, several robot spacecraft photographed Comet Halley up close, showing that only about 10 percent of the comet's surface was active at that time, Sekanina explains. This strongly confirmed what astronomers had already deduced from ground-based observations. Sekanina's model is the first to give the physical locations of these discrete outgassing sites a central role in determining the nongravitational forces that act on comets, he says.

Sekanina checked his theory against nongravitational shifts observed in the orbits of 43 comets. For each one, he assumed reasonable values for unknown parameters such as density, location of active areas, and orientation of the spin axis — values that would, according to his model, produce the observed nongravitational effects. In every case, the forces proved "totally explainable in terms of this model," he says.

This picking and choosing of unknown parameters remains the Achilles heel of comet modeling, suggests Karen J. Meech of the University of Hawaii in Honolulu. Meech, who routinely makes precise observations of gas production and other aspects of comets, says that models of comet outgassing are not well constrained and allow one to come up with many different theoretical explanations that fit the observations.

Aware of this pitfall, Sekanina made sure he tested his model on Encke and Temple II, comets about which astronomers actually know certain important parameters. For example, after plugging into his equations the known values for Temple II, Sekanina found he could account for the nongravitational shifts by adjusting the density of the comet nucleus to a value he considers quite plausible, given what astronomers know about the composition of comets.

Astronomer Brian G. Marsden of the Smithsonian Astrophysical Observatory in Cambridge, Mass., says that Sekanina's model is valuable, despite its intrinsic limitations.

"The fact that he can [explain the nongravitational forces] and get something that looks plausible is a plus," says Marsden, who originated the mathematics astronomers now use to account for nongravitational effects on cometary orbits. "This whole process is so complicated that anything you can do like that is important." *— D. Pendick*

Packing electrons into an artificial atom

Over the years, researchers have prodded, stretched, squeezed, illuminated, and even smashed atoms into yielding their quantum secrets. Now they can create and tailor "artificial atoms" to study the behavior of individual electrons confined to spaces much larger than atomic dimensions.

Such novel structures allow researchers to investigate certain quantum effects under conditions not possible in ordinary atoms. "There's a continuum of physics to study as you vary the size," says Raymond C. Ashoori of the Massachusetts Institute of Technology.

Ashoori described the fabrication of an artificial atom and the result of adding electrons to it one by one this week in Boston at a meeting of the American Association for the Advancement of Science.

An ordinary atom stays together because of the attraction between its nucleus and orbiting electrons. An artificial atom is more like a tiny box whose walls keep electrons confined. Nonetheless, in both types of confinement, electrons can have only certain well-defined energies.

Ashoori and his collaborators at AT&T Bell Laboratories in Murray Hill, N.J., create an artificial atom by sandwiching a thin layer of gallium arsenide between two layers of aluminum gallium arsenide. The artificial atom itself corresponds to a location — a few hundred angstroms wide — in the gallium arsenide crystal that can be completely emptied of electrons, then gradually refilled.

"By observing how much energy it takes to add each successive electron, we can directly learn how the electrons interact with one another," Ashoori says.

To detect and measure the energy needed to add successive electrons, the researchers use a new, remarkably sensitive technique known as single-electron capacitance spectroscopy (SN: 4/4/92, p.222). "We can count them [electrons] one by one as they go in," Ashoori says.

Ashoori and his colleagues can also study how much the repulsion between electrons contributes to an electronic energy level. By applying an external magnetic field, they can squeeze an artificial atom; this squeezing makes it easier to distinguish between effects caused by electron repulsion and those attributed to electron motion.

Observing changes in energy level while increasing the magnetic field allows an unprecedented measurement of how much electrons interact with each other, Ashoori says.

Indeed, attempting an equivalent measurement in a helium atom would require a magnetic field of 400,000 teslas — far larger than the 2 teslas that Ashoori and his colleagues need to see this electron-electron interaction in a two-electron artificial atom.

For three electrons, the interactions among electrons become exceedingly complicated, and the corresponding energy measurements are difficult to interpret. But when more than 10 electrons are packed into an artificial atom, their behavior begins to resemble that of electrons in a metal. *— I. Peterson*