

search & discovery

Simple technique produces photon echoes and optical nutation

A simple way to generate and study photon echoes, optical nutation, and other coherent optical effects has been developed by Richard G. Brewer and Richard L. Shoemaker (IBM Research Laboratory, San Jose). The work was reported by Brewer at the Esfahan (Iran) Symposium on Fundamental and Applied Laser Physics in September, and appears in *Physical Review Letters* (27, 631, 1971).

A photon echo is a spontaneous pulse of light from a sample that has been irradiated with two intense, coherent pulses of light from a laser. It was first observed in 1964 at Columbia University by Sven Hartmann, Isaac Abella and Norman Kurnit and is the optical analog of spin echo, a nuclear magnetic resonance effect discovered by Erwin Hahn in 1950. The Columbia experiments used a pulsed ruby-laser source.

In Brewer and Shoemaker's experiments the laser operates cw, and a pulsed electric field provides molecular level splitting. The molecules absorbing the laser light are tuned to the laser frequency by subjecting them to this pulsed field. The electric field acts on the electric dipole moment of the molecules to split their vibrational energy levels, and this tunes the molecules to the fixed laser frequency. Brewer and Shoemaker feel that this is a much simpler technique than the previous approach, which involved generating short, very precisely timed optical pulses from the laser.

To produce a photon echo, the sample is switched into optical resonance twice by means of two electric pulses. Then the photon echo follows. The first pulse produces an induced electric dipole moment in the sample. When this pulse terminates, the induced molecular dipoles begin to get out of phase with one another (because of a spread in transition frequencies caused by the pulse widths and the Doppler broadening), and the radiation produced by the dipoles undergoes destructive interference. A second pulse, lasting twice as long as the first, now reverses the dipole direction and causes them to get into phase again in just the amount of time that elapsed between the first two pulses. At this point the dipoles inter-

fere constructively, and the sample spontaneously emits a pulse of light—the photon echo.

The related effect of optical nutation can also be observed by this technique, using a single electric pulse of long duration. Molecules that are switched into resonance are coherently excited so as to alternately absorb and emit radiation. This optical ringing or nutation effect appears as a damped oscillation in the transmitted laser light. It is the optical analog of transient nutation in nuclear magnetic resonance found by H. C. Torrey.

Using a continuously operating car-

bon-dioxide laser at 10 microns, Brewer and Shoemaker readily observed photon echoes and optical nutation in methyl fluoride and deuterated ammonia. From the dependence of echo amplitude on pulse intervals, the experimenters were able to examine the importance of various collisional mechanisms (rotational energy transfer, velocity-changing collisions, and so on).

Brewer and Shoemaker believe that their technique can also be used to study other optical analogs of nmr as well as self-induced transparency, an effect first observed by Hahn and Sam-

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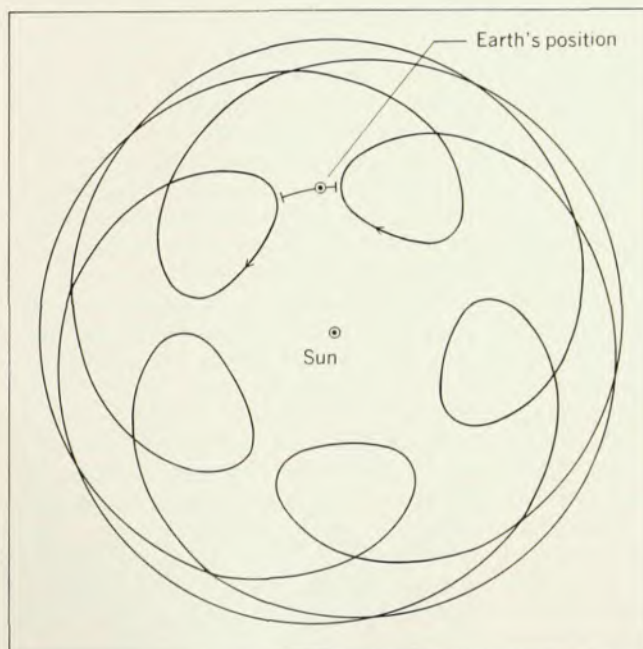
Toro makes a threesome with Earth and Moon

A small asteroid named Toro forms a triplet system with the Earth and the Moon, according to Hannes Alfvén (University of California, La Jolla and Royal Institute of Technology, Stockholm). The discovery, which was made by Lars Danielsson (Royal Institute of Technology) and W. H. Ip (La Jolla), is the first indication that another celestial body is part of the Earth-Moon

system.

Whether this triplet system is permanent and was formed at the time when the solar system was born is still not known, Alfvén told us. "If it is, Toro will be of decisive importance for the understanding of how the Earth-Moon system has developed."

For the past two years Alfvén and Gustaf Arrhenius (Scripps Institution



Path of Toro from a coordinate system centered on the Sun rotating with the Earth. Loop shown is produced during eight years around the year 2020.

of Oceanography, La Jolla) have been advocating a space mission to an asteroid.¹ Toro might be a candidate for such a mission, Alfvén says.

At the Nobel symposium called "From Plasma to Planet" held in Stockholm in September, Danielsson and Ip reported that they had performed a computer integration of the perturbed Toro orbit for 200 years backwards and forwards for a total of 400 years and found that Toro forms a quasiresonance. They include the perturbations caused by Venus, Earth, Mars, Jupiter and Saturn, using the method developed by Philip Cowell.

Although Toro's orbit is only known since 1964, when it was discovered by Samuel Herrick (UCLA), Alfvén says that the data are sufficient to extrapolate the orbit with very high accuracy. After 100 years, which requires 1000 integration steps, the relative error is about 10^{-8} .

Toro has a period of 1.6 years, which means that it makes five turns around the Sun in exactly the same time as the Earth makes eight turns. Toro passes very close to the Earth in January of one year and again two years later, in August. On one of these occasions Toro passes before the Earth and on the other, behind the Earth. If you look at Toro from a coordinate system centered on the Sun rotating with the Earth, its path is as shown in the figure. The loop shown is produced during eight years around the year 2020. It is not exactly closed; instead it oscillates around the Sun with an amplitude of 9 deg and a period of 164 years. This is shown in the figure by letting the Earth oscillate along an 18-deg arc.

Danielsson and Ip caution that Toro might get out of coupling with the Earth. One way is through secular variations bringing Toro to the "wrong side" of the Earth. Alternatively, when Venus moves away from Earth it could capture Toro or perturb it out of resonance.

At its closest approach Toro comes within 0.13 AU of the Earth. It is not the asteroid to come closest; Icarus came much closer to Earth in June 1968.

Toro, unlike most of the asteroids, which are in the so-called "main belt" between Mars and Jupiter, is in a Mars-crossing orbit (its perihelion is inside the orbit of Mars). Such Mars-crossing asteroids are the closest neighbors in space of the Earth-Moon system; one of them would be a good target for landing (first unmanned and in the future, Alfvén hopes, manned), as the next logical step after the lunar landings, Alfvén and Arrhenius have argued. NASA has responded by setting up a panel to study missions to comets and asteroids. Originally Alfvén and Arrhenius had thought the asteroid Eros would be the

best candidate for the first mission. Now Toro is also a likely contender, but the choice requires more detailed study, Alfvén says.

Both asteroids are small—Eros is 20 km in diameter and Toro is about 5 km.

In a talk at the Asteroid Symposium held in Tucson in March, Alfvén and Arrhenius said, "There is *a priori* no reason why a small body like an asteroid should be less interesting than a body as big as a planet. On the contrary, the small bodies probably have recorded and preserved more information about the early history of the solar system than the planets and satellites, which actively destroy their own record."

Many believe that the asteroidal belt

represents an intermediate state in the formation of planets. So, exploration of asteroids should help to explain how the planets built up from interplanetary grains, they say. Furthermore, the asteroids could clarify the history of the Earth-Moon system and of the Moon itself, they suggest.

The Earth and Moon undergo volcanism and radial differentiation; so you can't make many conclusions about their bulk chemical composition from studies of samples from their surfaces. Because the asteroids are so very much smaller, they state, "we will approach the primordial state much further."

—GBL

Reference

1. H. Alfvén, G. Arrhenius, *Science* **167**, 139 (1970).

Two accelerators switch to nitrogen ions

Experiments with high-energy nitrogen ions have now been done at two accelerators that were formerly devoted only to elementary-particle physics. At the Princeton Particle Accelerator (PPA) a 3.9-GeV nitrogen beam was achieved on 15 July, and the Bevatron at the Lawrence Berkeley Laboratory (LBL) produced its 36-GeV beam on 17 August. Both laboratories can now produce beams of sufficient intensity (at least 10^5 particles per sec) to carry out experiments, and the broad range of scientists eager to use the energetic heavy ions includes biologists, nuclear chemists, astrophysicists, solid-state physicists and high-energy physicists.

Biologists and others interested in medical research want to study the effects of the very densely ionizing radiation on cancerous tissue. For these experiments, the unique feature of the new beams is the penetrating power their high energy gives them; 4-GeV nitrogen ions can pass through 20 cm of tissue before they are stopped, so that they can be used for deep-lying tumors. And nitrogen has an ionization loss at the well-defined Bragg peak of about 200 keV per micron, which gives the ions a biological effectiveness six times that of x rays; this is the maximum so far observed for any deeply penetrating ionizing radiation.

Just as important, nitrogen ions are believed to be intrinsically superior to x rays and neutrons for killing tumors. X rays are only one-third as effective in killing oxygen-deficient cells as they are in killing normally oxygenated cells; because tumors are thought to contain clusters of oxygen-deficient cells, x-ray dosages high enough to kill tumor cells can damage the surrounding healthy tissue severely. Heavy ions, on the other hand, are apparently free of this oxygen effect.

Production of superheavy elements is the goal of another kind of experiment. If the high-energy nuclei hit a heavy target, such as uranium, large fragments might come out of the target nuclei with sufficient energy to combine with a uranium nucleus, forming a superheavy nucleus.

The nitrogen-ion energies reached at PPA and LBL are as high as the energies of cosmic-ray nuclei, so that the beams offer opportunities to astrophysics and space biology. Studying spallation cross sections of nitrogen ions on various target nuclei, for example, could help explain the origin and nature of the heavy-ion cosmic rays. Determining the effects of the ions on different kinds of tissue, on plant life and on solid materials could be very helpful for planning space flights. One already announced result is that the flashes of light reported by the astronauts have been traced to heavy ions passing through the retina. Edwin McMillan, LBL's director, was one of the "human detectors" who volunteered for this experiment.

New information about elementary particles might also be gained with fast, heavy ions. One proposed high-energy physics experiment would use the collisions of a fast nitrogen ion with a heavy nucleus to study the collective behavior of nucleons as revealed in the resulting elementary-particle spectrum. Another would look for copious production of mesons resulting from the collisions.

PPA is continuing experiments with nitrogen ions and, as of the beginning of November, had produced beam energies as high as 7.4 GeV, with a maximum intensity of 10^6 particles per second at 4 GeV. Some of the planned studies need ions heavier than nitrogen ($Z = 7$), and acceleration of neon ($Z =$