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.[1] 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 ($Z =$

10) and argon ($Z = 18$) is believed possible at Princeton without further modification of the accelerator; neon and argon acceleration is planned for this month.

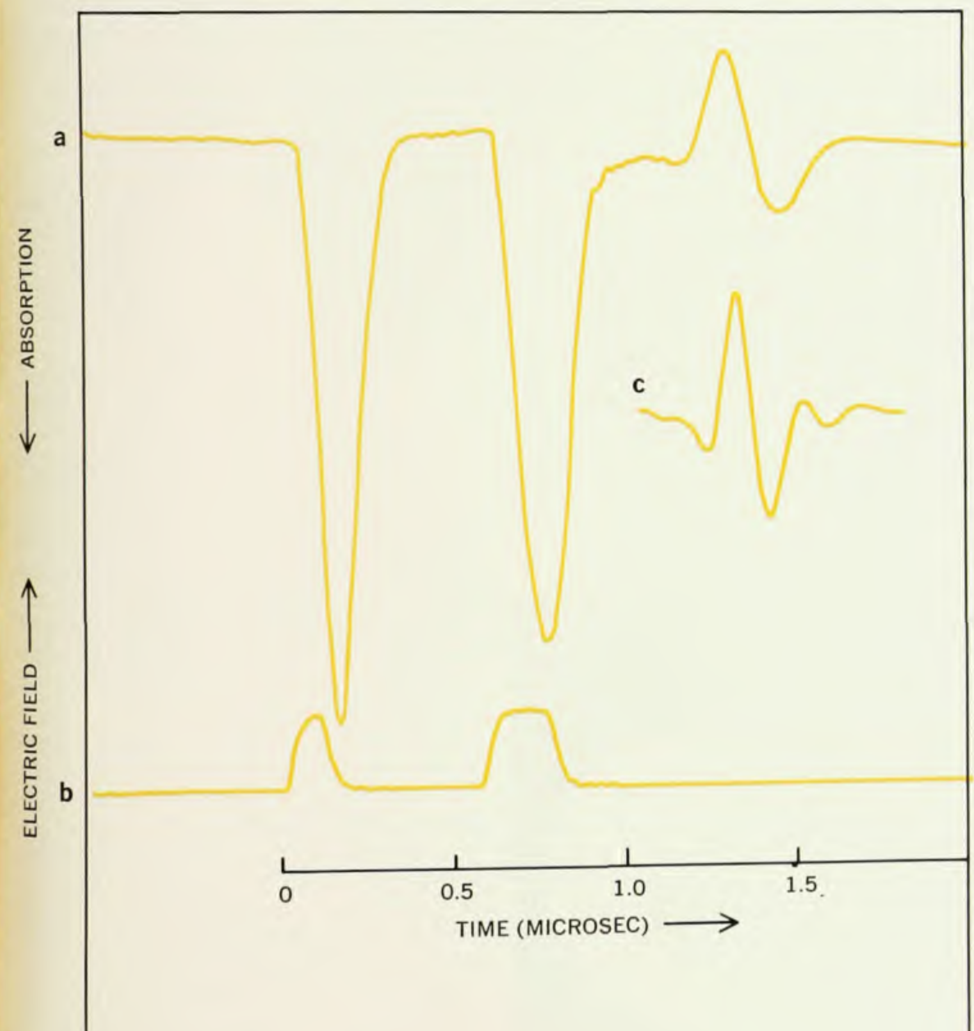
The AEC withdrew support of the laboratory this June, and private support runs out this month. PPA director Milton White, however, was confident at the start of November that either the National Cancer Institute or a combination of US agencies would assume support of PPA on a long-term basis.

A proposed modification at Berkeley might allow acceleration of ions up to krypton ($Z = 36$). The improvement would come from linking the Bevatron with LBL's HILAC (Heavy Ion Linear Accelerator), which is now being rebuilt as the "super-HILAC." The super-HILAC could be a copious source of fully stripped ions for the Bevatron, where they would be accelerated up to 2.7 GeV per nucleon; the combined accelerator is being referred to as "Bevalac." —MSR

Photon echoes *continued from page 17*

uel McCall in 1967. In their picture a pulse of light coherently excites a sample, and if the conditions of intensity and pulse duration meet certain requirements, the light pulse can propagate through the sample unattenuated—the medium becomes transparent.

Brewer says that it has been difficult to apply existing laser techniques to the study of these coherent transient phenomena (photon echoes, optical nutation and self-induced transparency), despite their potential usefulness in studying molecular or solid-state systems. He believes that the new technique, although limited to materials with an electric dipole moment, should provide new ways of studying the details of how these systems absorb and dissipate energy. —GBL



Photon echo in methyl fluoride at 5.2-millitorr pressure. (a) Optical response to $\pi/2$ and π pulses followed by the echo beat signal. (b) Corresponding electric pulses where the delay is 570 nanosec and the pulse widths are 90 and 180 nanosec. Pulse amplitude is 35 V/cm. (c) Echo signal for a pulse amplitude of 60 V/cm. The other conditions are the same as (a), but the beat frequency is about twice as large.

Theory of early universe explains particle production

If the early universe had a strongly time-dependent gravitational field, the field would have created pairs of particles, according to Ya. B. Zel'dovich (Institute of Applied Mathematics, USSR Academy of Sciences).[1] This mechanism might explain the existence of particles in the universe, and it offers the hope of understanding why the present ratio of photons to baryons in the universe is 10^8.

Zel'dovich assumes for simplicity that the early universe is expanding in two directions and contracting in the third; the Einstein equations fix the expansion rates. Such a model is called "Bianchi type I," and its solution is called the "Kasner solution."

In the beginning of the universe all energy is concentrated in a source-free gravitational field—that is, enormous curvatures of the vacuum space-time, which is exploding out of a singularity. Zel'dovich shows that because of the different expansion rate the energy is converted into pairs. In principle any kind of particle that exists in pairs is created because all the particles are coupled to gravity, presumably including photons. The process is analogous to the pulling of positron-electron pairs out of the vacuum in the presence of a very strong electric field. But a simple static strong gravitational field, by itself, may not be sufficient to create pairs; the irregularity in expansion rate is also necessary.

In the theory particles are primarily created when they are relativistic; so the mass is just a small correction and the rate, to a crude approximation does not depend on whether protons or electrons are being produced, for example.

Early work, by Leonard E. Parker (University of Wisconsin, Milwaukee and Princeton University)[2] and by Roman Sexl and Helmut Urbantke (Institute for Theoretical Physics, University of Vienna)[3] had studied particle creation in isotropic universes. Parker found a negligible rate of particle creation in the present universe, but concluded that in the early stages of the expansion it may well have been of great cosmological significance.

Zel'dovich's theory *a priori* suggests that equal numbers of particles and antiparticles are created. Whether or not the universe does, in fact, consist of equal amounts of matter and antimatter is of course unknown.

The particle-production process appears to be highly dissipative. This dissipation would help to explain why the universe, starting out with an irregular expansion, would have ended up with a regular expansion. Although particle creation is not the only pos-