PARALLAX YOU CAN SEE

By Laurence A. Marschall, Steven J. Ratcliff, and Thomas J. Balonek

How amateurs can get a fix on near-space objects.

Parallax. I never exactly understood.
James Joyce, *Ulysses*

PEEK in the door of an introductory astronomy class and you may see a roomful of people, arms outstretched, squinting through one eye at their thumbs. What you are witnessing is a lesson on parallax. "Your right eye is the Earth in June," the instructor is saying. "Your nose is the Sun, your thumb is a nearby star, and the blackboard is the background of more distant stars.

"Now change to your left eye, the one representing the Earth six months later. See how your thumb seems to jump sideways against the background? The shorter your arm, the larger the change. That's how we measure distances to nearby stars — using the diameter of Earth's orbit as a baseline, just as you're using the distance between your eyes as a baseline to observe the apparent shift of your thumb. It's all very simple."

Measuring astronomical parallax may be simple in principle, but it is exceedingly difficult in practice. Even the nearest star, Alpha Centauri C (often called Proxima) shifts back and forth by only 1½ arc sec-

onds, too small a motion to detect easily with most telescopes. Although parallax is a cornerstone of the cosmic distance scale, measuring it requires such extraordinary precision that most astronomers regard it as tedious stuff, best left to a few patient

Above: **The 16-inch telescope of Middlebury College Observatory in Vermont, with Wesleyan University student Anastasia Alexov at the controls. This modern instrument was equipped with a CCD camera for the asteroid-parallax project described here, but much humbler equipment can also do the job. Photograph by Erik Borg.**

experts called astrometrists. Astronomy classes do not go out and measure parallax, as a rule, on anything much more distant than a thumb.

However, they could. Between the thumb and the stars are many objects that offer attractive targets for demonstrating how this phenomenon works.

FINDING THE MOON'S PARALLAX

One such target is the Moon. Viewed merely from opposite sides of our own Earth, the Moon shows a very substantial parallax shift of about 2°.

Lunar parallax, however, does not exactly overwhelm the observer. The Moon's fast orbital motion around the Earth (about 12° per day) tends to camouflage the effect. To eliminate this problem observers at two sites can look at exactly the same time. Even so, the Moon's precise position is hard to tell because its brilliant glare hides background stars.

In December, however, there's a fine opportunity to beat this problem too. The Moon will be totally eclipsed on the 9th, appearing greatly darkened in a rich star field of the Taurus Milky Way. The eclipsed Moon will be visible in early evening for observers in most of eastern North America, as described on page 670. The Earth's shadow on the Moon is expected to be unusually dark for this event, so photographers should be able to take long, guided exposures through a telescope to record many faint stars right next to the lunar limb.

Measuring the Moon's parallax on simultaneous photographs could make an unusual class or club project. Widely separated observers can open and close their camera shutters in synchronization by using the telephone. The farther apart they are the better — ideally several hundred miles at least. Use fast film. A wide range of simultaneous exposures, from several seconds to more than a minute, may be needed to ensure that the lunar limb and the star field are both properly exposed.

The Moon will be in the eastern sky, so a north-south baseline is preferred (though this is not essential as described in the box at right). In comparing your images, measure how far the Moon shifts to the north as seen from the southern site (or to the east as seen from a western site). To determine the scale of your photographs, measure the Moon's diameter in millimeters. This corresponds to about 1,930 arc seconds at the time of the eclipse.

Observers only a few dozen miles apart should see shifts of several arc seconds. Those as far apart as Chicago and Miami should see the Moon displaced by more than half its own diameter.

ASTEROID PARALLAXES

Asteroids are in many ways more suitable than the Moon for a parallax project.
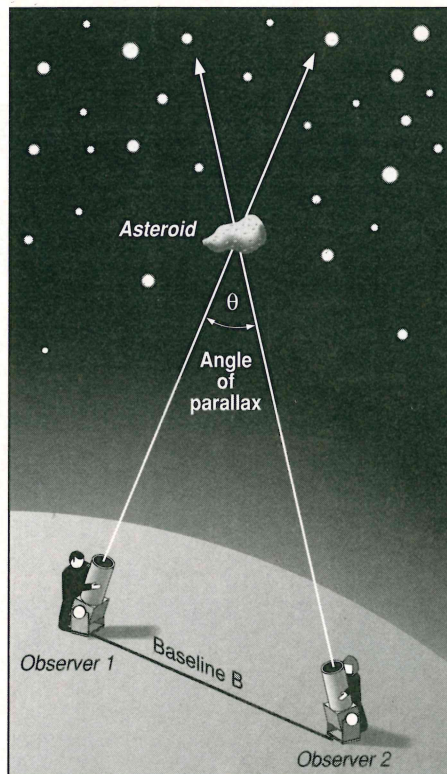
The principle of parallax. When two people in different places look at the same object, they gaze in different directions. The angle between these directions gives the object's distance, via the simplified formula in the box below.

They appear starlike, they move more slowly, and their positions can be measured with relative ease, though the parallaxes are much smaller. For instance, an asteroid 1 astronomical unit (93 million miles; 150 million kilometers) from Earth shows a parallax of about 7 arc seconds when viewed near the meridian from opposite coasts of the United States.

This is pretty tiny on the scale of photographs taken with most amateur telescopes. But the closer the asteroid the greater the effect, and here again December brings a special opportunity. Around midmonth the asteroid 4179 Toutatis will pass exceedingly close to the Earth, flying within 2.2 million miles (0.024 a.u.) of us on December 8th. A week later, when the asteroid will be better situated for observing, it will still be nearby as it brightens to magnitude 11. Details and finder charts begin on page 673.

Toutatis passes so close that sites 1,000 miles apart will see a parallax of up to 90 arc seconds. Even late in the month when it is fading into the distance, observers just a few hundred miles apart should be able to note a measurable shift.

The trick will be to get a pair of simultaneous images showing the asteroid against a good background of stars. Photographs made with 8-inch or larger telescopes should be adequate, but plan on experimenting with exposure times. Modern CCD cameras, increasingly available to amateurs and schools, make the task much easier since they can produce fine images with short exposures. It is also easier to measure precise positions on digital images. Another advantage: the same phone line you use to synchronize the exposures can be used to transfer the images from one site to another, so they can be compared in short order.

HOW WE DID IT

We have carried out several asteroid-parallax projects ourselves and have had a grand time doing so. Carl Pennypacker of the Space Sciences Laboratory at Berkeley first suggested this project as an ideal one for small colleges. Those of us participating all have 16- to 20-inch telescopes with CCD cameras. With so much power at hand we targeted newly discovered near-Earth asteroids, since these should show big parallaxes. They were all much fainter than Toutatis will be.

On June 8, 1991, Tom Balonek at Col-

Crunching the Numbers

THE FORMULA for finding distance by parallax, as shown in the illustration above, is

$$D = 0.00222 \, B/\theta,$$

where D is the distance in astronomical units, B is the "projected baseline" between the observers in miles, and θ is the parallax in arc seconds. This simplified formula is good enough for astronomical parallax angles, which are always far narrower than illustrated above.

The "projected baseline" is the separation of the observers on a plane at right angles to the object's direction. This is the same as the actual baseline if, for instance, the object is due east and the observers are spaced north-south. In other cases, finding it takes more spherical trigonometry than there's room for here. However, we have written a Basic program to do the job. Computer users with a modem can obtain it from CompuServe or a bulletin board.

From CompuServe: At any ! prompt, type GO ASTROFORUM. Choose Library 12 and download BASELI.BAS.

From SpaceMet Physics Forum (science teachers' bulletin board): Dial 413-545-1959, follow the registration instructions, go to the Main Menu, choose (F)ile areas, then (A)rea change to 20, then (D)ownload BASELINE.BAS.
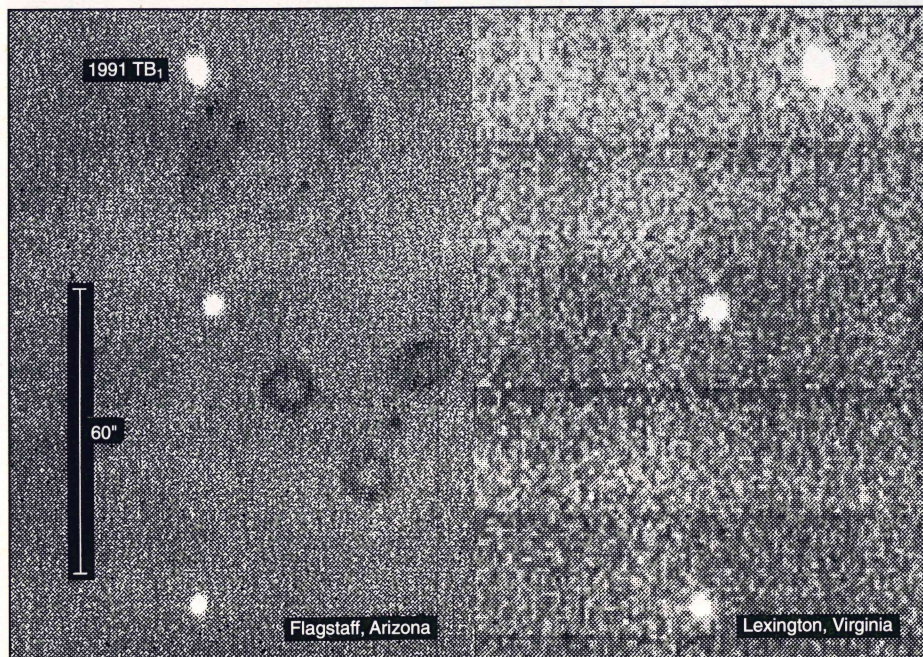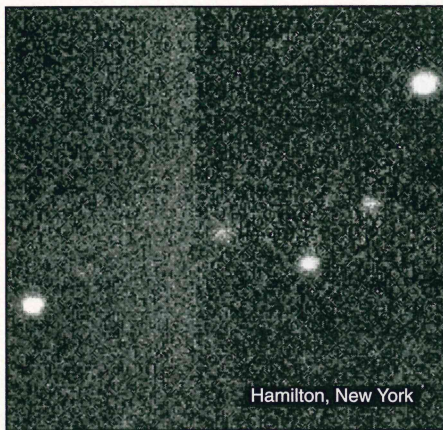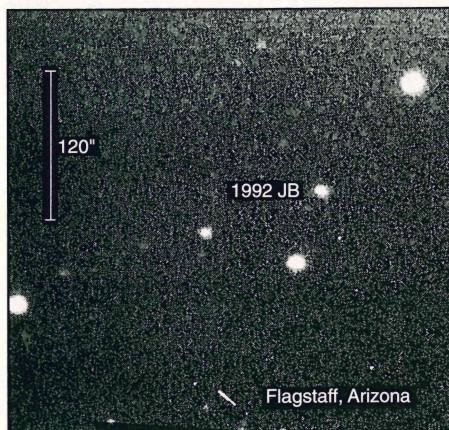
Above: These images of the 14th-magnitude asteroid 1991 TB$_1$ (top object) were taken simultaneously 1,800 miles apart while the observers conferred by phone. *Courtesy American Journal of Physics. Top:* Newly discovered 1992 JB betrays its presence by the parallax it shows against a star field in these simultaneous views taken from opposite sides of the United States. CCD images courtesy Laurence Marschall.

gate University's Foggy Bottom Observatory in Hamilton, New York, telephoned Steve Ratcliff at Middlebury College Observatory in Vermont about 140 miles northeast. Together they orchestrated 11 pairs of simultaneous images of an object called 1991 JX. This asteroid, discovered only a month earlier, was just 0.038 a.u. or 3.5 million miles from the Earth at the time. The images from Middlebury clearly showed the expected offset, about 8 arc seconds, from the Colgate images.

A month later, on July 17th, the Colgate-Middlebury team obtained even better images of asteroid 1982 BB, which was 0.224 a.u. (21 million miles) distant. They determined a parallax of slightly less than 2 arc seconds.

That's pretty small. But if you choose closer asteroids and sites farther apart, the parallaxes jump right out at you. Last March Larry Marschall and Biao Zhang of

Gettysburg College scheduled five nights of observing at the National Undergraduate Research Observatory (NURO), which operates a 32-inch telescope near Flagstaff, Arizona. We chose asteroid 1991 TB$_1$, which would be a mere 0.14 a.u. (13 million miles) away. Balonek at Colgate and Dave DuPuy at the Virginia Military Institute provided sites on the opposite coast. If all went as expected, the observers in Arizona should see 1991 TB$_1$ almost 30 arc seconds east of where those in New York and Virginia would record it.

We doubted at first that we would even be able to find the 14th-magnitude asteroid. Its orbit was very poorly known, so we expected to have to hunt around for it in the bright moonlight. But luck was with us. On March 14th, while the Gettysburg astronomers were on an airliner for Arizona, DuPuy recorded the telltale streak of an asteroid about ¼° south of the predicted

position. That evening he and Balonek managed to get two pairs of simultaneous images before clouds rolled in.

Once we had accurate positions, the rest was easy. On March 15th and 17th we collected six more pairs of simultaneous images. Coordinating the work was exciting. The asteroid moved rapidly, crossing the entire field of view of the CCDs in less than an hour. On the phone we would describe the background star patterns to one another, taking pictures when the asteroid passed through a particularly rich group.

"Here in Arizona it's going due north of two 14th-magnitude stars," one observer would say.

"We see the two stars," the eastern observer would reply, "but the asteroid is northwest of them." Parallax measurement never before involved so much live action.

In May we followed up this success with a series of images of 1992 JB taken from NURO and Colgate. Though 1992 JB was farther and fainter, the nights were clearer and darker and our results of generally higher quality.

We intend to use these images mainly in laboratory exercises for our introductory classes. Although students can't share in the excitement of making the observations, they can easily measure the parallax shift, and hence the asteroids' distances, to an accuracy of a few percent. We have moved beyond the thumb!

Scientifically speaking, this project doesn't tell us much we don't already know. If an asteroid's orbit is well established by a long series of accurate position measurements, we can calculate its distance in astronomical units. By measuring the parallax, therefore, we are basically determining the number of miles in an astronomical unit, the distance from the Earth to the Sun. Until fairly recently, in fact, asteroid parallaxes provided the best way to calibrate this fundamental yardstick of the solar system. They have been superseded only by radar observations and spacecraft tracking.

This project has been instructive and great fun. We plan further campaigns whenever we can, searching for better images against richer backgrounds of reference stars. We welcome others to join this effort — the close approach of Toutatis is a good place to start — and we'll be happy to offer advice and hear how you make out. Write to Larry Marschall, Dept. of Physics, Gettysburg College, Gettysburg, Pa. 17325.

Larry Marschall is a professor of physics at Gettysburg College; his research interests include spectroscopic binary stars, open clusters, and supernovae. Steve Ratcliff, an assistant physics professor at Middlebury College, works with CCD spectroscopy and variable star photometry. Tom Balonek, associate professor of physics and astronomy at Colgate University, studies supernovae and quasar variability.