Gravitational Refractions

Galaxies can act as lenses, making multiple images of objects beyond them

By DIETRICK E. THOMSEN

The ability of gravitational fields to focus light is a consequence of the prediction contained in Einstein's general relativity theory that gravitational forces act on light and can bend the path of a light beam. The idea makes possible a gravitational lens. A strong gravitational field, possibly due to some very dense body, can form multiple images of a single celestial object.

The first example that astronomers generally accept as a gravitational lens, the double quasar 0957+561A, B, was discovered in 1979. At the time many more were expected to exist. As of now, five are known — the numbers are their coordinates in the sky — 0957+561, 1175+088, 2345+007, 2016+112, 1635+267. As Irwin I. Shapiro of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Mass., notes, the linear relationship—an average of one new gravitational lens per year—continues to hold. Discovery of two of the five, 2016+112 and 1635+267, was reported at the recent meeting in Las Vegas of the American Astronomical Society.

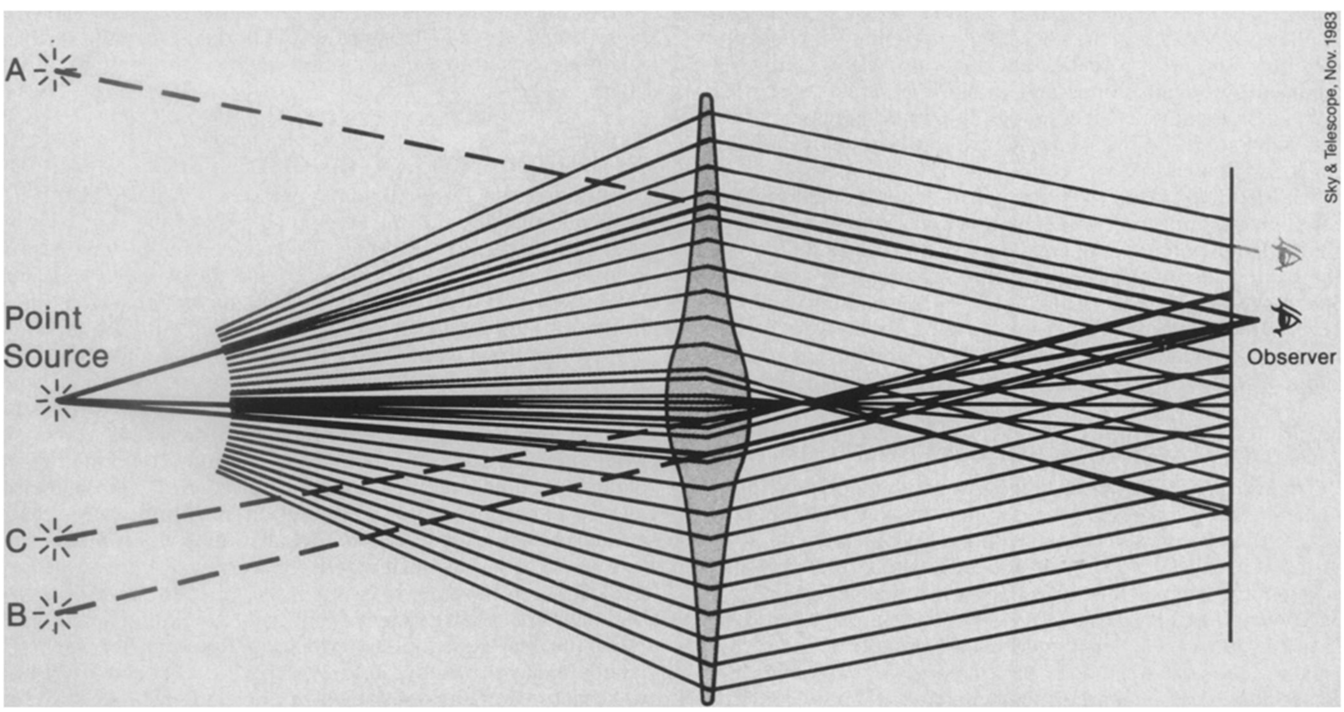
Discovery of 2016+112 is one result of a systematic search for previously unknown radio sources, the Massachusetts Institute of Technology-Green Bank survey (hereafter the MG survey). Charles L. Bennett of MIT told the meeting that the surveyors used the 300-foot-diameter radio telescope of the National Radio Astronomy Observatory at Green Bank, W. Va., to search a band of sky along the celestial equator (from declination $-0.5°$ to $+19.5°$ entirely around the sky) at a frequency of 5 gigahertz. They found 6,300 sources. The questions then to be faced were: What are they? What is the structure of the radio-emitting matter? Can they be identified visibly?

Bernard F. Burke of MIT related that 602 of the sources found in the MG survey were selected for more detailed observation with the Very Large Array radio telescopes located near Soccorro, N.M. The observers classified the sources morphologically — whether the sources appeared to be points or extended, whether they were single, double or multiple. Points were most common, but it was multiple sources that were most likely to have ready optical identifications.

Out of these came 2016+112, the one MG gravitational lens candidate so far. Charles Lawrence of California Institute of Technology in Pasadena described it as three objects, A, B and C, forming a right triangle with B at the right angle. The radio and optical spectra of A and B match, which is the criterion for calling them images of the same thing. C is part of the lens; B looks redder than A. The astronomers have not yet been able to get a spectrum of C, but its appearance is consistent with that of a giant elliptical galaxy. However, there has to be something yet unseen that contributes to the lensing. The redshift (which measures the distance) is quite large, 3.7233, and the object is the least luminous ever observed at such a distance.

Edwin Turner of the Princeton University Observatory in Princeton, N.J., presented some theory about 2016+112. A "realistic" model with two or more components, each having internal structural peculiarities, has too many loose ends ("free parameters") to analyze, he says. A simpler model has two simple components with fixed internal structure. It is a case of "ignorance hidden by assumptions," he says, but it yields a picture in which C is a galaxy, and a spherical cluster of galaxies is the other part of the lens. The object imaged is a quasar at a redshift of

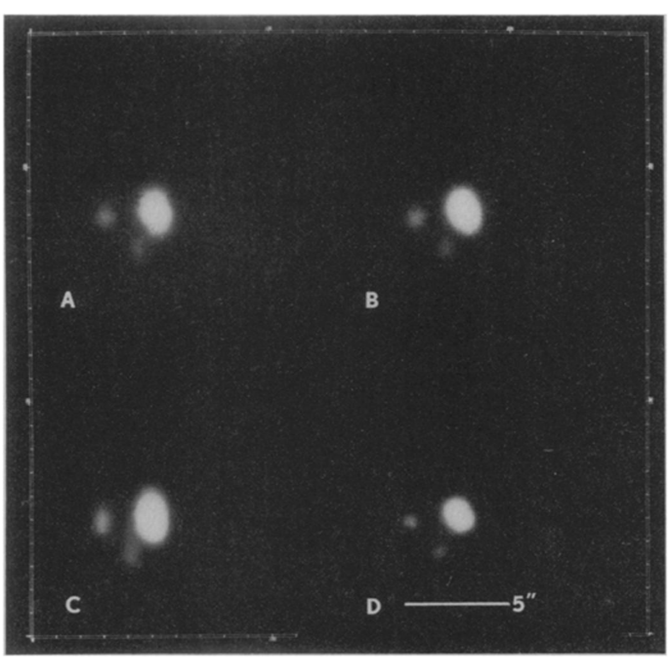
A galaxy's lens action can depend to some extent on the observer's location. A centrally located observer (dark eye) will see three images (A, B, C) of the point source. One somewhat offside (light eye) will see only A, displaced slightly upward. Drawing developed by Emilio Falco.



3.27. The model has yet to explain the image positions and the ratio of fluxes between the images.

Lawrence said that there are other candidates for gravitational lenses among the MG sources, but he would not say how many. The second new lens reported, however, came not from the MG survey, but from independent work by S. George Djorgovski and Hyron Spinrad of the University of California at Berkeley. Djorgovski described the object as a quasar pair, KP 1635+267, discovered in 1977. The discoverer thought this was two different quasars with slightly different redshifts. Djorgovski and Spinrad managed to get spectra of the two objects using telescopes at Kitt Peak National Observatory and the Lick Observatory. They found the spectra to be the same and to have the same redshift, and so concluded that this is another gravitational lens effect. However, they could find no evidence for a lens down to the very dim magnitude 23.5.

All five of these cases are supposed to arise because some object lying in the line of sight between us and a distant quasar bends the light to produce multiple images. Twenty years ago, shortly after qua-



Univ. of Ariz./Steward Obs.

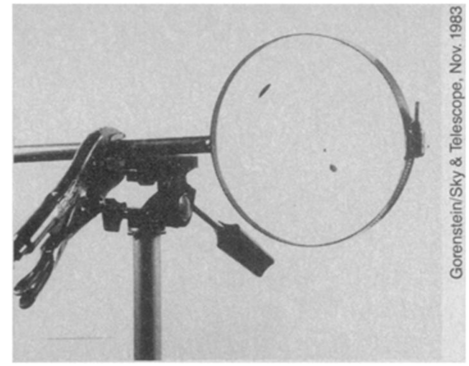
Two or more quasar images lying close together in the sky and seeming to be identical could be the result of gravitational lensing. This is one candidate for that phenomenon seen through four different color filters.

sars were first discovered, Jeno Barnothy, now retired, proposed that quasars were galaxies imaged and amplified by a gravitational lens process. At the time the idea attracted a great deal of derision. Years later after the discovery of the first gravitational lens the suggestion was remembered with more respect.

Barnothy was at this meeting to suggest a quite different kind of gravitational lensing. Barnothy proposes that the space-time of the universe has the shape of a four-dimensional hypersphere with pole and antipole analogous to the north and south poles of the earth. In such a universe the shape of space-time itself would image an object at the location antipodal to where the object actually was. This is rather like the business of digging down through the center of the earth and coming out in China. (If one started from the United States, however, one would more likely come out in Australia.) Barnothy believes there should be a lot of such antipodal ghost images around. Barnothy's ideas are not in the mainstream, as few cosmologists are attracted to a universe of that shape, but this time the audience listened politely.

Reviewing the conventional wisdom about gravitational lenses, Shapiro demonstrated with light beams and glass lenses the imaging properties of various possible cases. He was particularly concerned with lenses that are diffuse and transparent like galaxies and clusters rather than solid and opaque like black holes. The two instances of the five where a lensing object has been detected seem to be cases of this kind. Indeed W. Zheng and E. N. Hubbard of the University of California at San Diego presented a theoretical argument to show that disk galaxies seen by us edge on could serve most cases.

A major mystery is thereby encountered: A transparent lens should give an odd number of images—at least three. In



Gorenstein/Sky & Telescope, Nov. 1983

Marc Gorenstein developed glass lenses to mimic effects of gravitational ones. Here one of them makes three images of a single point of light.

none of the five known cases have more than two images been seen. Shapiro suggests that very long baseline interferometry (VLBI), in which correlated simultaneous observations by widely spaced radio telescopes are used to gain finely detailed information, might help.

VLBI has been done at least three times so far on 2016+112. Lawrence mentioned a "quickie" experiment using telescopes in Owens Valley, Calif., and Arecibo, P. R., in which components A and B were detected. Marc V. Gorenstein, representing a large group of astronomers, reported observations on Oct. 13, 1983, and Dec. 7, 1983, using a seven-telescope array that ranged from the VLA in New Mexico to an antenna at Effelsberg, West Germany. These also detected A and B. In no case was a third image detected. Now the astronomers want to go on to study the internal structure of the two components they can find.

Another large group, this time represented by N. L. "Chip" Cohen of the Harvard-Smithsonian Center for Astrophysics, did a more detailed VLBI survey of 0957+561, using twelve different baselines between telescopes and generating 900 data points. Although this too failed to find a third image, it discovered that, of the two known components, B seems like a magnified image of A. The two images have the structure of a core plus a jet.

Differences in the two cores lead the astronomers to suspect that in the two images they are seeing one and the same quasar at different epochs in time. Gravitational retardation of the light could cause such a difference. Not only does gravity bend light rays, it also slows the passage of the light. If the light represented by the two images took different paths through the gravitational field of the lens, it could be retarded by different amounts so that light forming one image takes longer to get to the image location than that forming the other and so represents an earlier epoch. Such a development could be interesting to those who study how quasars evolve over time.

Shapiro urges more detailed VLBI of known grativational lenses and a continuing search for unknown ones. □