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Multiple quasar may indicate another gravitational lens

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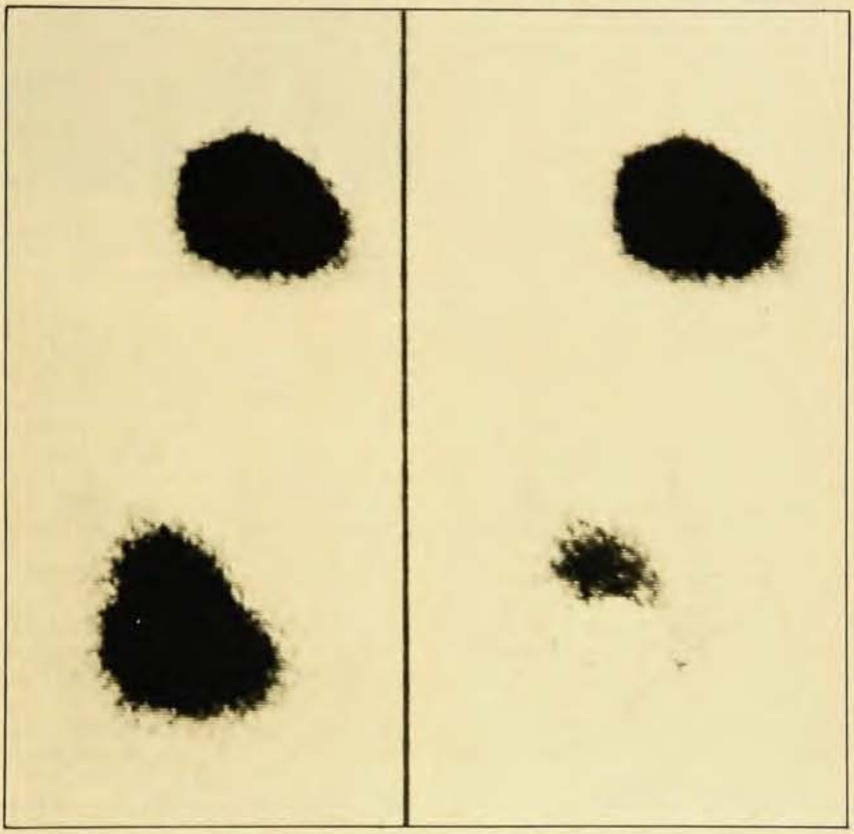
Multiple quasar may indicate another gravitational lens

Early last year a pair of quasars—0957 +561 A and B—was found whose spectra were almost identical. By now it is generally believed that these twin quasars are in fact a single quasar that is multiply imaged by a gravitational lens. Recent observations and model calculations suggest that this gravitational lens effect is produced primarily by the brightest member, G1, of a cluster of galaxies, with the other members collectively producing an important effect.

This spring a group using both the Multiple Mirror Telescope and the 2.3-meter Steward telescope found what many believe is a second gravitational lens effect—the triple quasar 1115 +080. More recently, a group using the 200-inch Palomar telescope confirmed the earlier result and hypothesized that the gravitational lens image of 1115 +080 may be quintuple.

So far the gravitational lens effect has been observed only with quasars, in part because they are very bright objects, and in part because they are sufficiently distant from the observer that an intervening galaxy might have a significant probability of being near the line of sight.

As one astronomer mused, in the past, astronomy has been biased toward luminosity. Now we have a window biased toward mass; with these multiple quasar images, one can probe the mass distribution in the foreground.



Gravitational lens effect in 0957 + 561. In left panel is a digital superposition of five one-minute exposures, which shows the A (upper) and B (lower) components of the quasar. The extension of the images to the lower right in both images is due to a misalignment of the telescope optics. The right panel shows the same superposition, but the A component has been scaled to the same brightness as B and then subtracted from it, thus showing the gravitational lens galaxy more clearly. Photo by Alan Stockton, Inst. of Astronomy, U.of Hawaii.

In March 1979, Dennis Walsh (Jodrell Bank), Robert F. Carswell (Cambridge University) and Ray J. Weymann (Steward Observatory, University of Arizona) found that both the A and B images of 0957 +561, which are 6 arc sec apart, had almost identical spectra—key emission and absorption lines in both spectra had similar intensities and widths, and the red shifts ($z = 1.4$) inferred from the emission spectra agreed within a few hundred km/sec (PHYSICS TODAY, November 1979, page 19); those from the absorption spectra agreed somewhat better.

Gravitational bending is independent of wavelength. So the flux ratio between two images should be constant as the observing wavelength is varied. Such a constant flux ratio has been verified in the radio, infrared, ultraviolet and visible region.

Because the A and B images were nearly equal in intensity, many astronomers believed that the gravitational lens was a compact object halfway between A and B. Radio studies of 0957 + 561, done last year, particularly those by David Roberts, Perry Greenfield and Bernard Burke (MIT), with the Very Large Array, showed radio sources to the north and east of A, but did not seem to have corresponding images near B, casting some doubt on this model of a gravitational lens.

Lens finding. But late last November, Peter Young and James E. Gunn (Palomar Observatory), Jerome Kristian (Mount Wilson and Las Campanas Observatories), J. B. Oke and James A. Westphal (Palomar) used a Charge Coupled Device on the 200-inch Palomar telescope to look at 0957 +561; the CCD gave them large dynamic range so that a faint object would be visible near a bright object. Their photograph[1] was consistent with the existence of a point source at B and an elliptical galaxy (G1) slightly offset from B. This galaxy appeared to be the brightest member of a cluster.

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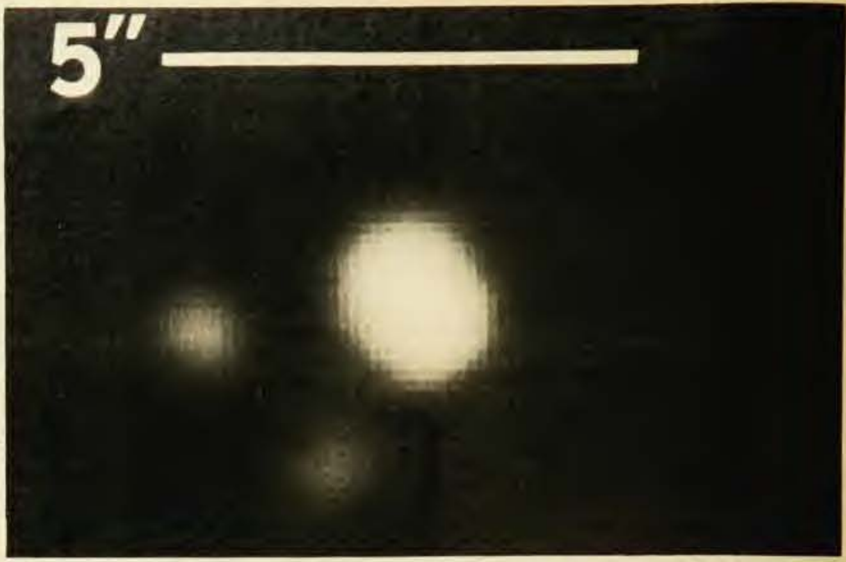
Meanwhile, Alan Stockton (Institute of Astronomy, University of Hawaii) independently observed[2] 0957+561, using an image tube on the 88-inch Mauna Kea telescope, at a time of extremely good seeing. After Stockton noticed that the B component looked fuzzy, he took shorter exposure plates. Basically, he looked at the average of many images, threw out the images where the seeing was poor, and corrected for blurring introduced by image wandering. Subtracting the A image from the B image of his composite photograph, Stockton obtained a clear picture of the nucleus of the G1 galaxy, which was just north of the B component.

Young and his collaborators developed a model using all the available radio and optical data, including information on the entire cluster of galaxies. They treated G1 and the rest of the cluster as a transparent lens for which there can only be an odd number of images.[3] (A point mass lens yields two images.) Kristian explained to us, imagine an observer, an isolated galaxy acting as a lens, and a quasar, nearly in a line. Two images would be formed on either side of the lens and a third one would be formed near the center of the galaxy because the bending for central rays will be small. Such a model, with the main part of the lens located near B, can account for the appearance of only one image of the radio sources observed to the north and east of A. More recently, Greenfield, Burke and Roberts obtained[4] a better map with the VLA that distinguished a faint source that appears to coincide with the center of the G1 galaxy found optically by the Hawaii and Palomar observers. Based on their model, Young and his collaborators propose that this faint radio source is the third image.

Maps of the region with sufficiently good resolution, say a milliarcsec or less, should disclose the structure of the quasar images. The relationship between the images will put constraints on the model of a gravitational lens. From the ground, only Very Long Baseline Interferometry appears capable of achieving such high resolution, but observing the structure is very difficult because of the weak ratio emission from 0957+561. Marc Gorenstein, Irwin Shapiro and Brian Corey (MIT) and Richard Porcas (Max Planck Institute for Radio Astronomy at Effelsberg, West Germany) used the new Mark III VLBI system in an attempt to map these quasar images. From observations made in February with the 64-meter-diameter JPL antenna at Goldstone, California and the 100-meter-diameter antenna of the Max Planck Institute, the group find that the images show definite structure, although reliable maps have not yet been obtained. From these observations, they also determined[5] the separation of the A and B images with an unprecedentedly small uncertainty of 50 microarcsec; Shapiro noted that this is equivalent to the angle subtended by Lincoln's nose on a penny in San Francisco, as viewed from Boston.



Gravitational lens in 1115 + 080. This red-light image, obtained by a group from the Steward Observatory using the Multiple Mirror Telescope, was obtained while the seeing was 6 arcsec. Three separated images of the quasar are seen; note that the brightest is elongated (ref. 9).

Variability. More recent optical observations, by the group working at Palomar and by a group working at the Lick Observatory, indicate that the flux from 0957 + 561 is varying. The original observations, done in Arizona in March 1979, and the Palomar observations done last November, showed that in the red wavelength range, the luminosity ratio of B to A was 1. But in the blue, the luminosity ratio was about 0.7. Part of the luminosity in the red is attributable to contamination from the lensing galaxy. Joseph Miller, William Keel and Robert Antonucci (Lick), using the Crossley reflector, found this May and June that the ratio in the blue wavelength range had increased so that both A and B had equal luminosity. In January, the Palomar group had found that since November the A component retained the same brightness, but the B component had brightened by 0.3 magnitude, becoming as bright as A. They found the spectrum remained the same.

If a gravitational lens is indeed causing the multiple images, a change in A should after some appropriate time delay be visible in B. One model of Young and his collaborators predicts a time delay of five years between variations in the A and B images. Such a time delay is proportional to the inverse of the Hubble constant, H_0, thus offering the possibility of another way[6] to measure H_0. Young, Gunn, Kristian, Oke and Westphal note[7] that with 0957 + 561, because G1 and the rest of the cluster are acting as a combined lens, one would need at least three images and two time delays "to have any hope of measuring H_0." Kristian says it's not clear whether or not the geometry of 0957 + 561 is favorable for measuring the Hubble constant this way at all, let alone how accurately. Meanwhile the Palomar group is measuring 0957 + 561 every month, monitoring its variability.

The second gravitational lens—1115 + 080—was reported[8] this June, by Weymann, Roger Angel, Richard F. Green, James Liebert, David Turnshek and Diane Turnshek (Steward), David Latham (Smithsonian Astrophysical Observatory) and J. Anthony Tyson (Bell Labs). While the group was doing an image-tube spectroscopic survey at high resolution with the 2.3-meter telescope, they found what looked like a triangular image. On closer observation, they decided they were seeing a close triplet. The brightest member, the A component, has a visual magnitude of 15.9, and the other members (B and C), each within 3 arcsec of A, have magnitudes of 19 and 18.6, respectively. Weymann and his collaborators with the MMT and Steward telescopes found that all three objects had nearly identical spectra and a redshift of about 1.7. They believe that 1115 + 080 is also an example of a gravitational lens. However, they noted, because of the closer separation of the images and the large flux ratio of A/C and A/B, the possibility of contamination by A of the spectra of C and especially B (which is closer to A), is serious. To combat contamination, the group tried to block out the light from A when measuring the spectra of B and C and examined ratios of spectra B/A and C/A.

Further observations in June made under conditions of excellent seeing at the MMT by Keith Hege (Steward), Angel, Weymann and Eugene Hubbard (Steward) yielded[9] an image showing clearly the three separated images of the quasar, but also that the brightest component is not a single point object, but is elongated, indicating further gravitational splitting in the image.

Soon after the observations in June by Weymann and his collaborators, Young, Robert S. Deverill (Palomar), Gunn, Westphal and Kristian also obtained separate spectra of the A, B and C components of 1115 + 080 and confirmed that they are equal. Unfortunately, 1115 + 080, like about 95% of quasars, is radio quiet (at least down to the 1.5-millijansky flux level obtainable with the Very Large Array); so radio observations have not helped clarify what's going on.

No lens galaxy has been found optically either. Kristian told us there was no trace of such a galaxy down to 29th magnitude per $(\mathrm{arcsec})^2$. After doing another model calculation, the Palomar collaborators speculate that the lens is a massive spiral galaxy with both a disc and spheroidal component. Such a lens could produce five images. One set of models predicts that the brightest image is really two close images, and the Palomar CCD data show also an elongation of the A component in the predicted direction, presumably the fourth image. And presumably a fifth image is present, too, but so faint or so close to one of the others that it can't be seen with a ground-based optical telescope. —GBL

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Voltaic cells use photosynthesis

Photosynthesis in green plants is a quite remarkable solar-energy storage system, which one would dearly love to mimic. But after two centuries of investigation we still have only a very incomplete picture of how plants harness photons in the visible spectrum to perform the trick of knocking out of water molecules the electrons that ultimately serve to reduce carbon dioxide to energy-rich carbohydrates.

Photosynthetic bacteria make similar use of light to generate chemical energy, but by a somewhat more primitive process that may well have been an evolutionary precursor of green-plant photosynthesis. The greater simplicity of bacterial photosynthesis makes it attractive as a stepping stone to the ultimate understanding of the process in green plants, whose successful imitation could be enormously useful.

Mordechay Schönfeld, Maurice Montal and George Feher, biophysicists at the University of California, La Jolla, have recently succeeded in obtaining electric currents directly from photosynthesis,[1] by constructing a photovoltaic cell out of intact reaction centers taken from photosynthetic bacteria and imbedded in a synthetic membrane. When illuminated, these reaction centers generate transient and steady-state voltages and currents, whose characteristics the La Jolla group hopes will elucidate the physical and biochemical processes of photosynthesis in the living bacterium.

More recently, Nigel Packham and his colleagues at the University of Pennsylvania have reported very similar results[2] with a photosynthetic voltaic cell illuminated by repeated laser and flash-tube pulses. The Penn group sought to clarify electron-transport mechanisms by noting differences in photoinduced currents between consecutive flashes a few milliseconds apart.

Photosynthetic reaction centers are the minimal units capable of performing the photosynthetic process in plant and bacterial cells. In a bacterium each reaction center is a highly organized chlorophyll–protein charge-transfer complex about 60 Å long, imbedded in the plasma membrane. It consists basically of three peptide chains, with four bacteriochlorophyll molecules, two pheophytin and two quinone molecules attached. Although Roderick Clayton at Cornell had isolated bacterial reaction centers in the 1960's, it was not until techniques became available to incorporate them into planar synthetic lipid bilayers that the La Jolla group was able to demonstrate the direct photosynthetic transduction of light energy to electric currents by intact reaction centers.

Photoinduced potentials had been observed in 1976 by V. P. Skulachev and his colleagues at Moscow State University, with reaction centers imbedded in lipid vesicles fused to a thick film. But in this complex geometry one could not control or even know the topology of the reaction center's local environment. Reaction centers have not yet been cleanly isolated from the more highly organized green-plant cells, where they are confined in organelles called chloroplasts. But Elisabeth Gross and her colleagues at Ohio State have observed small photovoltaic potentials with chloroplast substructures imbedded in plastic filters.

A number of groups had previously studied the photogeneration of potentials in chlorophyll alone, not bound in a reaction center. But that doesn't tell one much about photosynthesis, Feher argues, because this pigment in isolation is insufficient to perform the characterisic photosynthetic processes. One can in fact get photovoltaic activity by illuminating any number of pigments.

Bacterial photosynthesis does not involve the photoinduced breakup of water and the consequent liberation of oxygen. Because bacteria must depend on other hydrogen donors, such as H_2S, organic compounds or hydrogen gas, and on more complex carbon sources than CO_2, they present a less attractive model for our emulation than do plants, which use the cheapest ingredients imaginable—water and carbon dioxide.

Photosynthesis in both plants and bacteria bears some resemblance to the operation of a semiconductor photocell. Photons induce a spatial separation of positive and negative charges, producing a potential difference that can do work. In a living photosynthetic system this light-induced potential gradient across a membrane is used to drive endothermic reactions for the chemical sotrage of energy, but the La Jolla group uses this voltage directly to produce external currents. They expect that the time dependence of the transient components and the steady-state levels of the photoinduced voltages and currents will serve to clarify the kinetics of the various stages of electron transfer in photosynthesis.

The photosynthetic process in bacteria begins with the absorption of a photon