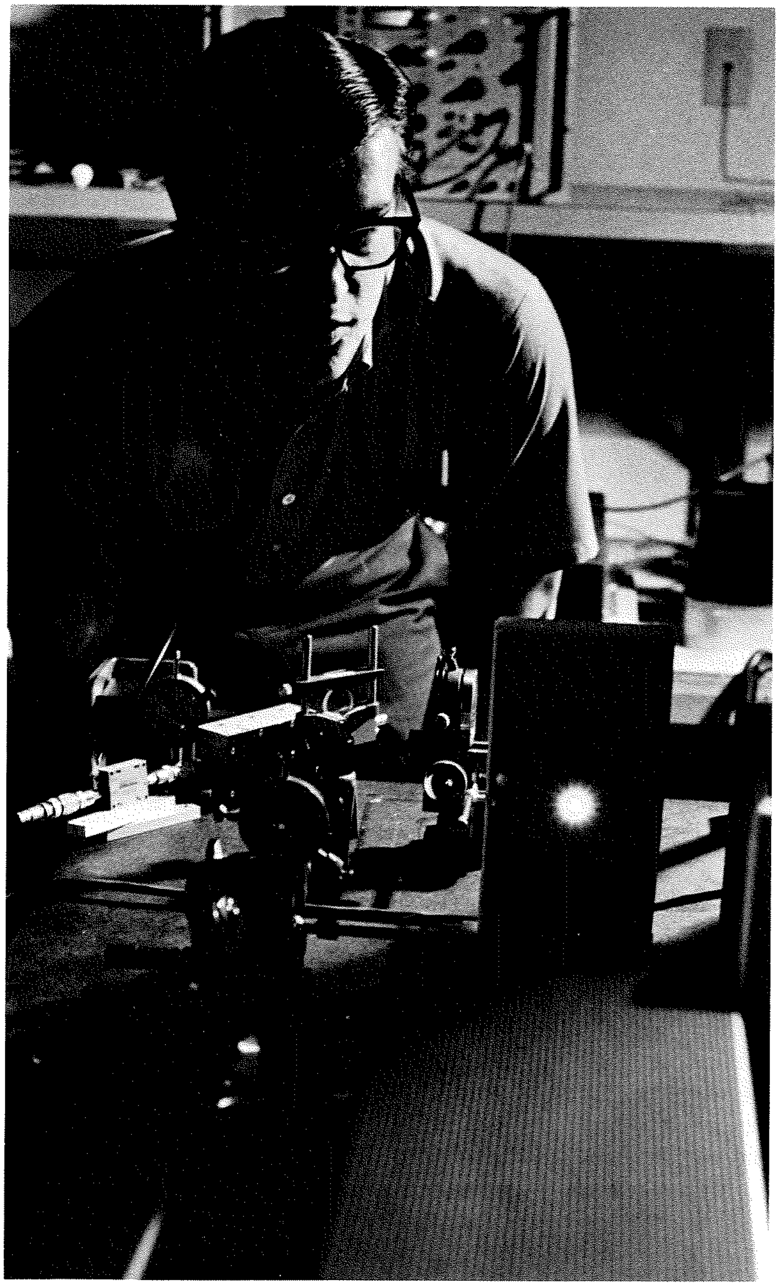
Research Notes



Research fellow Robert Menzies activates a high-powered carbon dioxide laser resembling the ones that will one day be used to detect pollution violators. The laser mechanism itself is contained in the long rectangular box at the lower right. The bright spot is the fire brick safety shield glowing white hot from the laser beam, which is invisible because it's in the infrared portion of the spectrum.

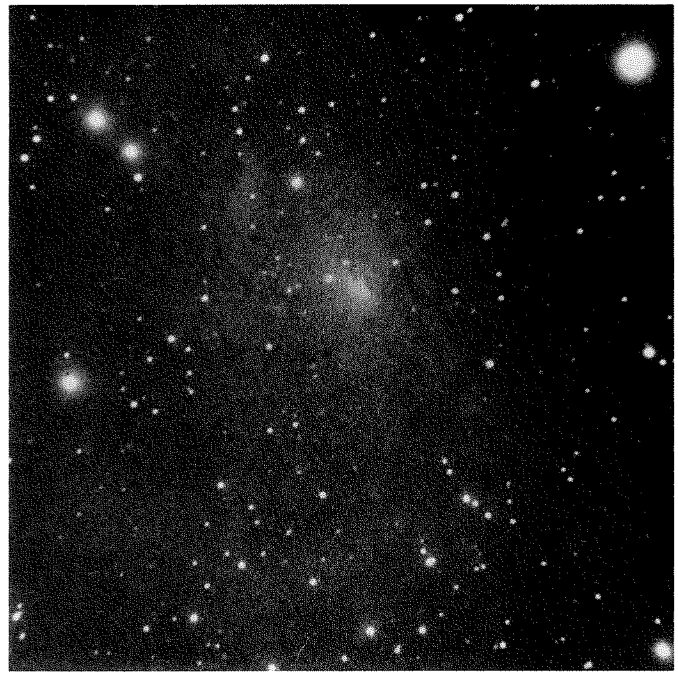
Laser Smog Detector

Robert Menzies, research fellow in electrical engineering, and Nicholas George, associate professor of electrical engineering, are currently developing infrared laser devices that can not only measure the presence of smog but can pinpoint the sources of it as well. The systems can detect pollutants over distances up to several kilometers, and may someday be used to spot air pollution violators in the way that traffic patrolmen use radar today.

The development of these devices has been concentrated on two general types of infrared laser systems for pollution detection and monitoring—a passive system and an active one. Both systems depend on the fact that molecules of the most important pollutants radiate in the infrared portion of the spectrum, and also that the emissions fall into identifiable spectral regions. Consequently, oxides of nitrogen—one of the major constituents of smog—as well as methane, ozone, carbon monoxide, and sulfur dioxide, all have spectral signatures that can readily be identified and measured.

The passive system employs a type of infrared radiometer known as a heterodyne receiver, which operates in roughly the same way as an ordinary radio. It uses a small laser as a local oscillator, together with a photosensitive device such as a crystal, to pick up pollutant infrared emissions from the atmosphere. Such emissions occur naturally, and since their amplitude increases with temperature, passive devices need to be calibrated with temperature measurements of the pollutants. These devices are directional: They can be pointed, like a radio telescope, to receive signals from a certain direction.

The active system—sometimes called a lidar (Light Detection And Ranging) system because of its similarity to radar—is also directional. It utilizes a telescope and a heterodyne receiver linked to a high-power pulsed laser. The laser emits radiation that is in turn absorbed by a particular type of pollutant molecule. For example, in experiments with locating and measuring sources of oxides of nitrogen, a beam from a carbon monoxide gas laser can be used, since part of its radiation coincides with the absorption frequencies of nitric oxide. When the laser beam encounters a pollutant molecule, the molecule absorbs



Maffei 1, left, photographed with the 200-inch telescope in infrared light, appears to have no structure except for some narrow dust lanes that probably belong to our Galaxy. Maffei 2 has a faint but visible spiral pattern that suggests it is structurally much like our own Galaxy.

infrared energy, becomes excited, and fluoresces, emitting radiation at its own characteristic wavelengths. The heterodyne receiver, which is sensitive to radiation at these wavelengths, is connected to the telescope, which scans along the direction of the laser beam and picks up the induced radiation from the pollutant molecules in the path of the beam.

Both the passive and the active systems have been used successfully in the laboratory in detecting three major components of smog—nitric oxide, nitrogen dioxide, and methane. In fact, George and Menzies, together with a group of Caltech doctoral students and faculty, are extending the technique to include other pollutants by matching their radiation absorption and emission characteristics with the radiation patterns of other laser beams. So far, matchups have been found—using carbon dioxide and carbon monoxide—with nitrogen oxides, carbon monoxide, and sulfur dioxide. Both of these gas lasers are capable of very high-power emissions and are suitable for active, or lidar, systems.

Although none of these devices have yet been tested in the field, preliminary laboratory measurements indicate that the passive system should be able to monitor atmospheric pollutant concentrations at distances up to a few kilometers. Since this type of system detects ambient radiation—the radiation that is already present— as opposed to induced radiation, it cannot be used to focus on a specific point in space. It measures the *average* concentrations over its total path length in whatever direction it happens to be pointing. However, by directing the receiver at a localized emission point such as a smoke stack, then shifting the view slightly to one side or the other and measuring the *difference* between the two radiation levels, it is possible to calculate pollutant concentrations at a specific point.

The more complex lidar system, using a high-power pulsed laser to induce radiation, is capable of "resolutions" of about 300 yards. By operating with a timer, it can focus on 300-yard increments along its path and measure the concentrations in each increment. The lidar system, then, should be suitable for monitoring atmospheric concentrations in short increments at distances up to about a kilometer. Because of the greater sensitivity of this type of system, one possible application might be to measure pollutants in auto exhausts. The use of high-powered lasers will require strict safety precautions, though: A 10-watt unit like the one Menzies is currently working with can inflict severe burns at distances up to about 20 meters.

Menzies first began thinking about using infrared lasers to detect air pollutants while he was a graduate student working with Nicholas George. After he received his PhD in physics in June 1970, Menzies went to work at JPL on a NASA project to develop a portable laser receiver for eventual use in tracking satellites. Today, in addition to the JPL project, he is continuing his work on pollutant detection as a part-time research fellow at Caltech.

New Neighbors

About two years ago a young Italian astronomer named Paolo Maffei reported finding two strange "objects" on infrared photos he made in the Laboratory of Astrophysics at Frascati, Italy. Maffei's brief research note, appearing in 1968 in the *Publications of the Astronomical Society of the Pacific*, sparked an investigation that culminated last month in the announcement by Caltech and U.C. Berkeley astronomers of two massive but previously unknown galaxies—right in our own stellar backyard.

The report on the galaxies, which appeared in the January 1971 issue of *The Astrophysical Journal,* was written by Wallace Sargent, J. B. Oke, and James Gunn, who are astronomers at Caltech and staff members of the Hale Observatories; Gerry Neugebauer, a physicist at Caltech and also a staff member of the Hale Observatories; Gordon Garmire, associate professor of physics at Caltech; Hyron Spinrad, Ivan King, and graduate student Robert Landau, of the astronomy department at U.C. Berkeley; and Nannielou Dieter of the Radio Astronomy Laboratory at Berkeley. Their statement, "Maffei 1: a New Massive Member of the Local Group?" enlarges the probable membership of what astronomers call the Local Group of galaxies —our Galaxy's nearest neighbors. Until now, astronomers have thought that the Local Group included only the Milky Way and the Andromeda Galaxy plus several smaller or satellite galaxies.

The new galaxies—named Maffei 1 and Maffei 2—appear to be about three million light years from earth (or about twice as far away as the Andromeda Galaxy). Maffei 1, the brighter of the two, may be larger than either the Andromeda or Milky Way galaxies, which would make it the largest member of the Local Group.

Overlooking objects of this size until now may seem incredible, but it really is not. The galaxies are located in a region that, for earthbound observers, is heavily obscured by interstellar dust. Discovery and confirmation of their existence was partly the result of intensive study by astronomers at Berkeley, Caltech, and the Hale Observatories, and partly the result of a lucky guess by a Berkeley graduate student.

Robert Landau, who is working toward his PhD in astronomy at Berkeley, read Maffei's research note in 1968 and was struck by the fact that the objects could be seen in a region so congested with dust that it is known as one of the "dirtiest" places in the sky. (Interstellar dust, believed to be mainly tiny grains of carbon and sand, is concentrated in many regions in the plane of the Milky Way Galaxy.) The dust is so dense in this particular vicinity—a spot in the northern sky between the constellations of Perseus and Cassiopeia—that it blocks all but about one percent of visible light and six percent of infrared light. Landau suspected that if the objects were actually shining through this heavy cloud, they might be much larger and brighter than they appeared to be.

Following his hunch, Landau and others at Berkeley made infrared photos with a 30-inch reflector telescope at the Leuschner Observatory at Lafayette, California. Spinrad and Gunn then photographed the objects with the 48-inch Schmidt telescope at Palomar. Both objects appeared fuzzy in the new photos but nevertheless showed unmistakable traces of the characteristics of large galaxies.

Infrared plates were obtained with the 48-inch Schmidt, and further infrared measurements were taken by Neugebauer and Garmire using the 200-inch Hale telescope at Palomar and the 100-inch, 60-inch, and 24-inch telescopes at Mount Wilson. Gunn, Oke, Sargent, and Spinrad used the 120-inch Lick telescope at Mount Hamilton, California, and the 200-inch Hale to study the light from the new objects; and Spinrad and Dieter used the facilities of the Hat Creek radio observatory in northern California to search for radio emission.

So far, the research findings strongly indicate that Maffei 1 is a "large, normal elliptical galaxy." Maffei 2, which is also large, appears to be a spiral rather than an elliptical galaxy, which means that it has pinwheel-like arms extending from a central nucleus to the periphery.

Light from Maffei 1 was found to be reddened by the effect of the dust in the Milky Way Galaxy—an indication that the light source is beyond the Milky Way. In addition, the spectrum properties of the Maffei 1 light clearly fit the pattern expected to match the chemical abundances of many large galaxies. The light energy characteristics measured across the core of Maffei 1 were shown to be similar to the energy distribution across the Andromeda Galaxy and other large, elliptical galaxies.

The distance calculations were hampered by the obscuring dust, but the astronomers applied several tests to arrive at their "reasonable estimate" of three million light years for Maffei 1. They were also guided by some basic assumptions—for one, most elliptical galaxies are not much larger than the Andromeda Galaxy. This leads, by means of brightness comparisons, to an estimated upper distance limit for Maffei 1 of 10 million light years. If the distance were smaller than about one million light years, individual stars could be distinguished in photographs of the galaxies, but this cannot be done. The estimated distance of three million light years was arrived at after careful study of gravitation and inferred motions in Maffei 1.

A weak radio signal can be detected from Maffei 2, but as yet there has been no radio detection of Maffei 1. More radio observations as well as a variety of other studies are being planned for the future.

The position of Maffei 1 and 2 in the sky is really a piece of bad luck for the astronomers. Moved only a few degrees to one side or the other, the new galaxies would miss the obscuring dust and be clearly visible to earthbound observers. Eventually, of course, Maffei 1 and 2 will swing into view as our solar system rotates with the Milky Way—in about 10 million years.

Young Galaxies?

For years astronomers have searched the universe in vain for a "young" galaxy. And now astronomers at the Hale Observatories have found two that appear to be a mere 10 million years old —one-thousandth the age that all galaxies are supposed to be, according to the "big bang" theory. This rather generally accepted theory says that 10 billion years ago all the material in the universe was in one location—and then exploded. The universe has been flying apart ever since in great chunks called galaxies, which are aggregates of stars, gas, and dust.

Astronomers are especially interested in finding a young galaxy because such an object would provide the first evidence that these, the largest collections of matter in the universe, evolve from infancy to old age. The discovery of a young galaxy would also prove that galaxies can be created subsequently to that original big bang.

The two astronomers searching for youth in the universe are Wallace L. W.

Sargent, associate professor of astronomy, and Leonard Searle, who with Sargent is a staff member of the Hale Observatories. In an article in the December issue of the *Astrophysical Journal* they point out that the two young galaxies are unusually rich in the star-making material hydrogen, and contain only one kind of star—short-lived, large blue ones. Older stars, which are reddish, small, and can live for billions of years, do not show up in these galaxies.

The newly discovered galaxies are very small—about 100 light years in diameter compared with 10 billion light years for our Milky Way Galaxy—and are irregular blobs instead of spirals, or sphericals, as are most galaxies. They are similar to the ionized hydrogen regions in the arms of dust and gas in spiral galaxies where new stars are being born, but this is the first time such regions have been found outside of galaxies in deep space. These particular little galaxies do not even reside in galactic clusters, as most galaxies do, but are "loners" in space.

Are these astronomical oddballs actually as young as their stars (10 million years), or are they the same age as other galaxies (10 billion years) and unable, for some reason, to harbor old stars? Sargent and Searle admit that they don't really know, but—paradoxically—they are inclined to believe the two oddballs are really old galaxies that are cosmic perpetual motion machines capable of manufacturing only short-lived young stars.

"One must assume that the hydrogen clouds from which these galaxies originated were formed 10 billion years ago," Searle says. "If the galaxies are only 10 million years old, the clouds must have existed only as clouds for some 9.99 billion years and then suddenly, only 10 million years ago, started manufacturing stars.

"That is more difficult to imagine than that the original clouds immediately started condensing into stars, as is believed to be true of conventional galaxies. In these two cases, however, the only stars that were manufactured were large blue ones that are short-lived. Such big stars matured quickly, then exploded, ejecting their material back into the galaxies to be recondensed into new young stars. This process could be repeated over and over, and the galaxies always would appear to be very young because all their stars always were young."

It is not known why a galaxy would limit its manufacture only to big blue stars. Some simple reason such as the density of hydrogen in the galaxy might account for it; some 50 percent of the material in these galaxies is hydrogen, compared with only 5 percent in our own galaxy.

Astronomers Leonard Searle and Wallace Sargent scan a sky map similar to the one on which they recently found two small galaxies that just might represent youth in the universe—or may be cosmic perpetual motion machines.

Appropriately, the two unusual galaxies have unusual names—I Zw 0930 plus 55 and II Zw 0553 plus 03. The Roman numerals refer to two catalogs in which they are listed. The Zw refers to Fritz Zwicky, professor emeritus of astrophysics at Caltech, who catalogued them along with some 2,000 other objects that he calls compact galaxies. The Arabic numbers refer to positions in the sky.

I Zw consists of two blobs very close together with a pair of faint, luminous patches nearby. II Zw consists of a bright core with very faint plumes extending from it. Both objects are a little more than 15th magnitude, which means they are invisible to all but powerful telescopes.

The tentative conclusion from the available evidence is that the two objects are dense intergalactic clouds of neutral hydrogen in which the formation of massive stars is proceeding vigorously while the formation of low mass stars is suppressed.

Taking the Pulse of the Gulf of California

Geologists are monitoring the Gulf of California's earthquake-prone floor to learn how its motions affect California's great San Andreas fault and how the continents appear to be drifting over the earth's surface.

The National Science Foundation has awarded a total of $132,600 to Caltech, U.C. San Diego, and the University of Mexico to establish a network of eight seismological stations around the gulf. Chief investigators in the international study are Clarence Allen, Caltech professor of geology and geophysics; James Brune, formerly of Caltech and now professor of geophysics at U.C. San Diego; Cinna Lomnitz, professor of geophysics at the University of Mexico, who received his PhD from Caltech in 1955; and Federico Mooser, chief geologist of the Mexican Federal Power Commission.

Understanding how the earth's crust is being deformed in the gulf is vital to understanding and predicting the future behavior of the San Andreas fault system —the source of most of California's large earthquakes. In fact, the San Andreas fault is an extension of the fault system within the gulf that is responsible for the northwest coast of Mexico splitting off and forming the gulf and the peninsula of Baja California. The split began about four million years ago and is still widening—by about one or two inches per year.

The system of faults involved in this separation intersects the North American continent near the Colorado River delta and continues northwest through California as the San Andreas fault, which goes out into the sea north of San Francisco in Mendocino County.

Crustal activity in the gulf results in many earthquakes there. Swarms of them shook the north end of the gulf beginning on March 20, 1969. During the ensuing week 196 earthquakes of magnitude 4 to 6 were recorded. In one six-hour period, there were 75 tremors of more than magnitude 4—the largest being magnitude 5¾.

Through the network of seismic stations, the researchers hope to pinpoint the origins of these earthquakes and eventually develop an accurate map of the fault lines in the gulf floor. They also want to find out whether the deep trenches in the gulf are the sites of earthquakes.

The other major objective of the project is to increase our understanding of the now generally accepted continental drift theory, which in essence holds that the earth's great land masses have been drifting apart since the time when they were all in one piece. Great plates that include entire continents, and the ocean floor as well, are moving over a plastic layer of rock. Some plates have drifted thousands of miles over the past millions of years.

This massive drifting is related to the upwelling of molten rock beneath the great mid-ocean ridges. The material moves up vertically, solidifies, and then spreads out to form the ocean floor, moving laterally away from the ridges as huge plates.

Where two plates meet head-on, one usually is driven under the other, forming mountains and deep oceanic trenches, and causing earthquakes and volcanoes. In some instances the edges of two plates slide horizontally against each other, which is what happens along the San Andreas fault. The fault and the Gulf of California separate two major plates—one extending eastward from the San Andreas to the middle of the Atlantic Ocean, the other extending westward from the San Andreas to the Asiatic shoreline.

The floor of the Gulf of California is a young "mid-ocean ridge," but one with a very complicated and little-understood pattern. The upwelling of molten rock along this ridge is believed to be associated with the widening of the gulf. This oblique widening movement is consistent with the movement of the Pacific plate to the northwest at a rate of about two inches a year in relation to the adjoining North American plate.

By studying the sea-floor spreading in the gulf, the scientists hope to be able to understand something about how the big plates are moving: They may be pushed, carried by convection cells in the mantle, or driven by gravity or by the forces related to the earth's rotation.

The international seismological team already is monitoring the gulf's pulse. After the first swarm of earthquakes there in 1969, Caltech rushed portable seismographs to the area. Back-pack instruments were set up, and subsequently more permanent stations were established at Rio Hardy, San Felipe, and El Golfo in Mexico's Colorado River delta.

Scientists now are looking for sites for the five other permanent stations. The sites must be located near the gulf, a minimum distance apart, built on bedrock, and near some community so they can be serviced. Probable locations for the five new stations are Caborca and Guayman, both in Sonora State; Los Mochis in Sinaloa; and Bahia de Los Angeles and La Paz, both in Baja California. The Mexican Federal Power Commission will service them all.

Initial installations will include a short-period seismograph, a photographic recorder, radio, clock, solar panels for power, and portable housing. The instruments are under construction at the Caltech Seismological Laboratory and eventually will become the property of the University of Mexico.