Big Astronomy in Chile: The Southern Observatories Come of Age

La Serena, Chile. The region around this isolated coastal town of 87,000 is at first glance an unlikely candidate for the astronomical center of the Southern Hemisphere. It is hard to get to, a 12-hour plane trip from the United States—over the hump of the Andes to Santiago—and then a 500-kilometer drive north. The location near the southern edge of the Atacama desert makes the countryside, outside of a few irrigated valleys, anything but a garden paradise. Chile's political upheavals have not enhanced the country's reputation as an idyllic place to visit or to live. Nonetheless, astronomers from the United States and Europe have been coming here for years, even at the height of the troubles, and the flow of visitors is increasing. The traffic this past year alone has amounted to nearly 200 investigators, enough that foreigners passing through Santiago customs with bulky, sealed boxes of photographic plates for hand luggage no longer attract any special attention.

The destination of the travelers is one of three major observatories located in the mountains near La Serena. They are the Cerro Tololo Interamerican Observatory (CTIO), a U.S. national observatory operated for the National Science Foundation by a group of universities; the European Southern Observatory (ESO), a collaborative venture of six European countries; and the Las Campanas Observatory, a private scientific facility financed by the Carnegie Institution of Washington, operated by the Hale Observatories and still known locally by its earlier name, the Carnegie Southern Observatory (CARSO). All three observatories are now putting into service large new telescopes ranging in size from 2.5 to 4.0 meters. In the process they are establishing the Norte Chico region of Chile as the foremost staging ground for efforts to open up the still poorly studied southern skies to modern optical and infrared astronomy.

These new southern outposts come at an auspicious time. Investigations of how galaxies evolve are increasingly moving to the fore as astronomers seek to understand these building blocks of the universe. Others are exploring the roles that such exotic objects as supernovas, black holes, and quasi-stellar sources (quasars) play in the formation and development of galaxies. Among the prime candidates for galactic evolution studies are the closest galaxies, visible only from the Southern Hemisphere—the Magellanic Clouds, already known to have followed an evolutionary pattern somewhat different from that of the Milky Way. The galactic center of the Milky Way, thought to harbor energetic processes of uncertain character, but cloaked in dust that renders most optical observations fruitless, passes directly overhead at La Serena, thus facilitating infrared observations that can see through the dust. The three new telescopes in Chile and another in Australia, the Anglo-Australian telescope, are the first large modern optical instruments in the Southern Hemisphere; they have already enabled quasar researchers to study numerous additional examples of this phenomenon and are facilitating investigation of a host of other astronomical problems as well. As the latest additions to the current generation of big telescopes, these new facilities have been able to incorporate advances in automated computer control into their designs more fully than many older instruments in the Northern Hemisphere.

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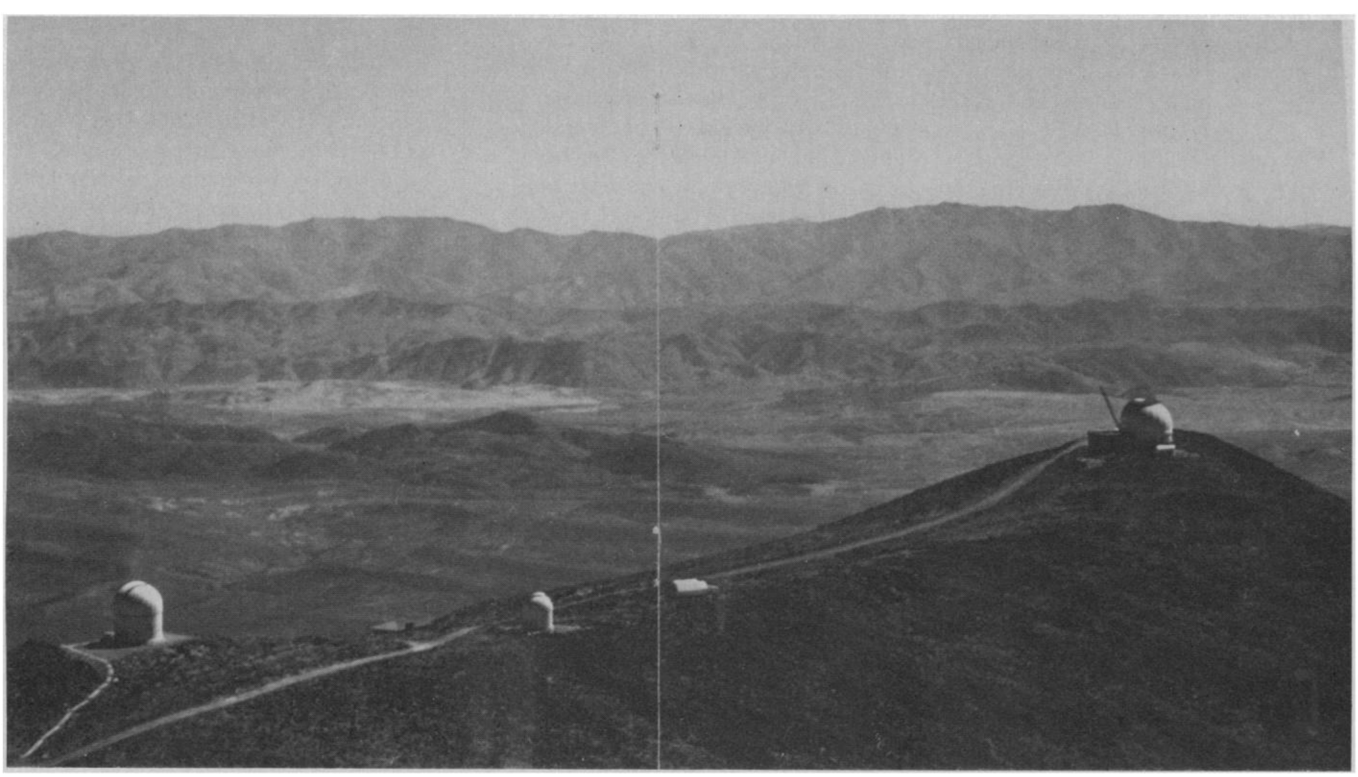
Operating an observatory in the remote regions of northern Chile is not without its problems—logistical, political, cultural. The attraction has been that good atmospheric conditions are of nearly surpassing importance to optical as-



Site of the Las Campanas Observatory in the Norte Chico region of Chile.

tronomers. It is more than a matter of clear weather; atmospheric distortion caused by moisture, dust, or turbulence is the limiting factor in the performance of most telescopes. The geography of Chile—akin to but more extreme than that of the West Coast of the United States, also prime astronomical territory—works to good effect. Huge mountains rise 5 or 6 kilometers on the eastern border, scarcely 200 kilometers inland. The north-south climatic gradient is steep; lush green hillsides south of Santiago give way first to brown, sparsely covered earth and then, just north of La Serena, to one of the driest, most barren deserts in the world. The arid climate is intensified by the cold Humboldt current that runs offshore, the sea so cold that only in the height of summer do Chileans venture in to swim. The prevailing winds are from the open Pacific; the air is so clear and dry, the weather generally so fair near La Serena, that atmospheric conditions at altitudes of about 2.5 kilometers on the foothills and lower ridges of the Andes are often nearly ideal for astronomy. Many astronomers regard the "seeing" here—measured by stellar images with a size as sharp as 0.5 second of arc or less on good nights—as superior to conditions at observatories anywhere else in the world.

The price tag for the superior seeing is high. An hour of observing time at Cerro Tololo, for example, costs almost twice as much as at CTIO's sister observatory at Kitt Peak, near Tucson, Arizona. Referring to the remoteness of the site, a Carnegie official compares the logistical difficulties to those of building an observatory on the moon, only partly in jest; it differs, he says, only in that in Chile "there is air and water, and not much of the latter." A defect in equipment shipped from the United States or Europe often cannot be remedied without shipping it back again, with a delay of months. The observatories are oases of sophisticated equipment located far from such conveniences as suppliers of spare parts and French or English language schools for the children of observatory personnel. Each is self-sufficient in heavy equipment and repair shops, generates its own power, and pumps water from wells often as far away as a dozen kilometers.

It has required "a substantial adjustment" to live and work in Chile as an astronomer, according to Barry Lasker of CTIO. The observatory staff is based in La Serena and includes about 25 U.S. nationals, including a dozen astronomers. It is a small, close-knit colony whose primary links to the United States are magazines, a radiotelephone hookup through Kitt Peak, and the steady flow of visiting astronomers who come for 4- or 7-night observing stands. The cultural isolation takes its toll, even for those who learn Spanish, and there is high turnover among technicians. The astronomers, mostly young, have stayed longer and integrated better; several have married Chileans. They have also had professional attractions to compensate for the isolation, including the 40 percent of telescope time reserved for the staff. One astronomer says of his motivations, "I have had a chance to help develop and shape a major observatory—something I would never get a chance to do in the States until I was much more senior—and I have gotten more observing time here in 7 years than I would have there in twice that time."

Building multimillion dollar observatories in Chile also involved a decision, as one astronomer puts it, "to take the good weather and gamble on the political stability." The observatories here were founded in the 1960's and in the past decade have had to deal with three Chilean regimes of quite different character—the Christian Democratic government of Edwardo Frei, the Socialist government of Salvador Allende, and the current military junta headed by Augusto Pinochet. The astronomers appear to have managed their diplomatic chores with success; they report good cooperation from all three governments and no real infringement of their ability to function, although there have been some tense moments at times.

Interest among astronomers in coming to Chile has not been visibly diminished by these shifts in the political wind or by the bad name that the current regime has acquired in international circles. Despite a nationwide curfew that remains techni-

CARSO

As a privately operated observatory, now part of the Hale Observatories, the Carnegie Southern Observatory (CARSO) has an institutional style distinct from that of its governmentally supported neighbors. CARSO is the smallest of the three southern observatories, with only three telescopes, including the new 2.5-meter instrument that is just coming into regular use. Its site, however, a long ridge known as Las Campanas, offers far more scope for future expansion than the crowded mountaintops of La Silla (ESO) and Cerro Tololo (CTIO). CARSO operates essentially as an observing station, without resident astronomers and with only a modest (Chilean) support staff. Observers commute from the United States.

The large CARSO telescope has an unusually large field of view for direct photography, 2.1 degrees of arc, and can take photographic plates as large as 50 centimeters on a side. It is thus useful as a survey instrument, a necessity now because CARSO plans no auxiliary survey telescope and possibly a boon in the future when even the largest earthbound telescopes will point the way for orbiting space telescopes. A novel feature of the telescope control system is that it is based not on a master computer but on a series of microprocessors, each operating a particular function or instrument independent of the others—an approach that Hale astronomers believe offers greater reliability and simplicity of use. The observatory has taken special pains in planning for high-resolution spectroscopy of the type useful for sorting out the chemical history of the Magellanic Clouds and other galaxies; its design for extracting light from the telescope and transmitting it to an adjacent (coudé) spectroscopic laboratory employs only three reflections rather than the normal five, thus reducing the losses that each reflection entails.

Despite CARSO's advantages of having a small and experienced group of users and relative freedom from red tape, some astronomers wonder how well the observatory will be able to compete with its larger and wealthier neighbors. Development of the coudé laboratory for the new telescope has been held up by lack of funds, for example, and one Hale astronomer describes CARSO as "a lean operation and getting leaner." Horace Babcock, director of the Hale Observatories, says that despite a limited budget "there has been no compromise in quality." He expects that a major emphasis in work at the observatory will be on the chemical and dynamical evolution of galaxies.—A.L.H.

cally in effect, things are calm in La Serena and much improved over conditions, such as shortages of food and other essentials, that complicated observatory life a few years ago. In any case, visiting astronomers at the observatories often do not encounter much of Chile during their stay. Although some U.S. astronomers visit Chilean friends or tour the country, most spend their time up on the mountain. They tend to be more interested in how to use the observatory computers or in such things as the huge Andean condors that put on spectacular flying demonstrations outside the cafeteria windows at Cerro Tololo than in Chile itself. But they encounter one aspect of the country's problems at their telescopes in the form of "a tragedy that works to our benefit," as one astronomer put it. The competence of Chilean night assistants who position the telescopes, run the data-acquisition computers, and sometimes develop plates for visitors has become a minor legend in the international astronomical community, and their skill has saved many an inexperienced observer from embarrassment. It is a highly sought-after job in La Serena; such has been the state of the universities here and the economy as a whole that the assistants are an unusually qualified group for the job, including some former university staff.

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Interest in using the southern observatories has increased since the completion of the large telescopes—a 2.5 meter at CARSO, a 3.6 meter at ESO, and a 4.0 meter at CTIO (see boxes). These dimensions, the diameter of the primary mirror, give little feel for the size and complexity of a modern large telescope; they are intricate assemblages of optical, mechanical, and electronic components weighing hundreds of tons and towering 20 meters or more. They are the essence of big science, and the astronomers who use them are rarely those who design and build them. Increasingly, in fact, observers have little direct contact with the telescope unless they are taking photographic plates. All three of the big telescopes here have control rooms where observers sit in comfort, communicating with the telescopes via computer (or via their night assistant who operates the computer), operating a variety of spectrographic and photometric instruments (also by computer), and monitoring sky position and the incoming data on television screens. Astronomy is rapidly becoming a science of numbers that reflect information about photons collected by a telescope; both the numbers and the telescope are mediated and manipulated electronically. Increasingly rare, at least with these large telescopes, is the old sense of "hands-on" astronomy, the requirement that the observer endure the physical rigors of a cramped perch on the telescope and the chill of the unheated dome to wrest knowledge from the sky.

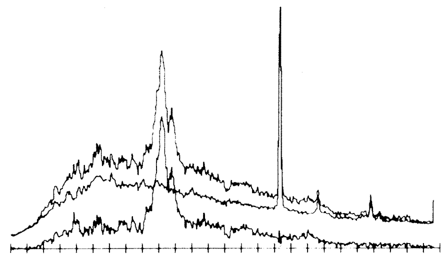


Fig. 1. Raw spectral data from quasar Q0002-422 obtained with the CTIO 4.0-meter telescope and a SIT vidicon detector. The uppermost trace is the total signal received. The next lower trace is the spectrum of the night sky (measured in the same exposure). The bottom trace is the difference of the upper two and is the net quasar signal. [Source: Patrick Osmer, CTIO]

Photographic plates are still the primary medium of record for astronomy, and the new telescopes will find some use in direct photography. All three incorporate modern optical designs that permit wide-field photography of objects nearly 1 degree of arc in size for the CTIO and ESO telescopes, more than twice that for the CARSO telescope. Wide-field photography is particularly useful for studying such things as clusters of galaxies or supernova remnants.

More frequently, however, the light collected by the big telescopes will be enhanced, analyzed, and recorded with the aid of electronic instruments whether the final result is a photographic plate, a spectroscopic analysis, or a photometric (photon-counting) determination. In fact the development of new instruments is what paces astronomical research today.

Modern instruments are increasingly based on electronic sensors ranging from television camera tubes to photosensitive solid-state diode arrays, and they are revolutionizing astronomical practice. The new electronic sensors not only are 10- to 20-fold more efficient in detecting photons than are photographic plates but also generate signals that vary linearly with the amount of incoming light and collect the data in digital form. This in turn permits more precise, quantitative

CTIO

The pioneer among the three southern observatories has been the Cerro Tololo Interamerican Observatory (CTIO). A U.S. national facility like its sister observatory at Kitt Peak, on which it depends in a major way for logistical and engineering support, CTIO is operated by the Association of Universities for Research in Astronomy. The observatory's seven telescopes include a new 4.0 meter that was the first of the large telescopes in Chile and has now been in use for about 2 years.

The observatory has the largest resident astronomical staff (currently 12, including two postdoctoral fellows) of the three and, although the facility exists in large part to serve visiting astronomers, it reserves 40 percent of the telescope time for its staff. CTIO is considered by many astronomers to have been the most productive of research of the three observatories, at least to date, a record for which visitors credit the observatory's bilingual director—Victor Blanco, a native of Puerto Rico—and the enthusiasm of the observatory's young staff.

The 4.0-meter telescope is a copy of the one at Kitt Peak, differing only in that CTIO "learned from our mistakes," as one Kitt Peak astronomer put it. The telescope has unusually good optics, concentrating 99.1 percent of the light collected from a star within 0.5 second of arc, and was one of the first large telescopes to be set up for computerized control and remote handling. The computer system is extremely flexible, with a spare minicomputer that can be put into use should the main one fail. Visitors, however, find that the computer system takes some getting used to—some of the programs were written at Kitt Peak, others at CTIO, so that observers initially had to use one computer language to converse with the telescope and another to run the spectrograph. No provision has been made for high-resolution spectroscopy of the classical (coudé) type, but the observatory expects to install a high-dispersion echelle instrument that will serve some of the same functions.—A.L.H.

observations and makes possible such techniques as sky subtraction—in which the unwanted "noise" of the night sky glow can be numerically subtracted from the spectrum of the object of interest. Without such techniques, for example, many faint optical sources would remain out of reach and infrared observations could not be made at all, since the heat of the night sky and of the telescope itself generates far stronger radiations in the infrared portion of the spectrum than the signal from a distant star.

The three observatories pursue different philosophies in developing new astronomical instruments. Those for CARSO take shape in the United States under the direct guidance of the astronomers who will use them. At the other extreme, ESO instruments are developed by an engineering group in Europe and only later turned over to the observatory's astronomers and visitors. CTIO occupies an intermediate position; although some instruments are built by Kitt Peak's engineers, others are developed in La Serena by the observatory's staff astronomers for their own research and then made available to visitors as well.

The strong link between instrumental development and research productivity is illustrated by recent work at CTIO in identifying and characterizing quasars, the intense but very distant (and hence very faint) objects that are now thought by many astronomers to be associated with the formative stages of galaxies.

Of particular interest to astronomers curious about when galaxies first began to form are the most distant and hence oldest quasars, many of which have been found by radio astronomers despite the fact that radio quasars are outnumbered by the optical or radio-quiet kind by about ten to one. In the early 1970's, however, CTIO director Victor Blanco designed a prism device that made it easier to identify optical sources whose light showed a marked shift to longer wavelengths—the high red shifts that are a characteristic of distant quasars. Malcolm Smith (then of CTIO) used the device to find a large number of quasar candidates.

To fully characterize the quasars, however, more sensitive spectroscopic detectors were needed than were then available at Cerro Tololo. To exploit this opportunity and other research problems with similar instrumental demands, CTIO staff headed by Barry Lasker undertook to build an instrument of a type pioneered at the Hale Observatories and known as a silicon-intensified-target (SIT) vidicon. Its sensitivity is such that it permits red shifts and other spectral information to be readily determined from signals as faint as a few hundred photons accumulated over a 30-minute exposure (Fig. 1). Using the instrument with the 4.0-meter telescope, Patrick Osmer of CTIO has been able this past year to study some 120 quasars with red shifts greater than 2.0 at the rate of 10 to 20 a night, a substantial addition to the roughly 150 high-red shift quasars previously reported. The CTIO finds include eight of the most distant quasars, those with red shifts greater than 3.0.

Even more sensitive spectroscopic detectors are on the way. One of the instruments being developed for the new CARSO telescope by Steven Shectman of the Hale Observatories is based on an array of silicon diodes known as a Reticon that detects photons with efficiencies as high as 85 percent at some wavelengths. The instrument will also employ several stages of intensification ahead of the Reticon so that the device will be able to detect incoming light nearly photon by photon—a capability that can be most productively utilized with Chile's good seeing.

Another development of particular interest to the southern observatories is the growing interest among astronomers in the infrared portion of the spectrum. The optical (visible) wavelengths occupy only a small portion of the spectrum compared to the infrared region, and a host of new and more sensitive infrared instruments are under development. Much of the incoming infrared radiation is absorbed by the atmosphere, but there are several wavelength "windows"

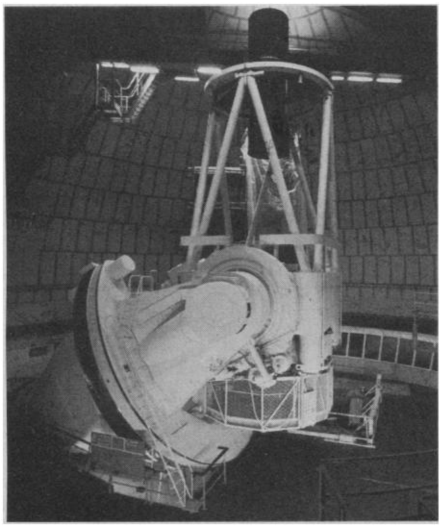
ESO

The European Southern Observatory (ESO) is a multinational facility modeled organizationally on CERN, the European high-energy physics collaboration. The multinational character entails a large administrative staff, departmental chairmanships that rotate among different countries, and a decidedly bureaucratic character. ESO is the largest of the three southern observatories, with nine telescopes, many of them owned and operated by individual European countries. The major joint facility is the new 3.6-meter telescope that has just gone through initial shakedown tests and is beginning to be used as a research tool.

ESO is oriented to serving visiting astronomers from member countries* and visitors use about two-thirds of the observatory's telescope time. Optical astronomy has been a neglected branch of the science in many European countries until recently, however, and ESO officials report that visiting astronomers are often inexperienced and require considerable help. A staff of resident astronomers devotes half of its time to assisting visitors, half to individual research. The permanent European personnel live in Santiago, where German and French schools and other cultural facilities are available, and work at the observatory in shifts, commuting in an ESO chartered plane.

The new large ESO telescope represents a major step up in size for European optical astronomers (although other comparable telescopes are now being built) and promises to stimulate new interest in research and in the development of instruments for use with the telescope. The telescope itself is designed to permit rapid change of focus or replacement of mirrors, observing cages, and instruments in anticipation that observers from a half-dozen countries will have quite different ideas about the configuration they want to use. ESO officials report that the telescope meets its design specifications and should prove a productive research device. Nearly all aspects of telescope operation are controlled by a single minicomputer; another will operate and collect data from instruments attached to the telescope. An auxiliary 1.5-meter telescope is housed in a separate building but will share a large coudé laboratory for high-resolution spectroscopy with the larger telescope. Despite the provisions for coudé work, ESO officials expect that the initial emphasis of research with the telescope will be on extragalactic astronomy, a field in which European optical astronomers have lagged far behind their U.S. colleagues in recent years and in which there is consequently considerable pressure to catch up.—A.L.H.

*ESO member countries are Belgium, Denmark, France, the Federal Republic of Germany, the Netherlands, and Sweden; European headquarters are located at Garching, near Munich.



The European Southern Observatory's new 3.6-meter telescope.

where stellar atomic emissions of interest to astronomers can be observed—neon and argon at 10 micrometers, for example. Because infrared light is absorbed on average only about one-tenth as much as visible light by interplanetary dust, astronomers hope to gain an additional handle on populations of stars (such as those in the galactic center) that were heretofore observable only with radio telescopes. And because water vapor in the atmosphere absorbs infrared light preferentially, the extreme dryness of the air above northern Chile makes it an ideal place for such work.

All three southern observatories are giving a high priority to infrared observations and instruments. The first research user of the new CARSO telescope, for example, was guest observer Charles Townes, of Berkeley, who is studying the motion of gas near the galactic center with infrared techniques. ESO has dedicated a 1.0-meter telescope to infrared work and equipped it with a computer-controlled drive system of sufficient accuracy that survey observations can be taken 24 hours a day (daytime work requires automated direction-finding because there are no visible stars to guide on). CTIO recently modified a 1.5-meter telescope to facilitate infrared studies. The modifications consisted primarily of a "chopping" secondary mirror which can be oscillated at frequencies up to 50 cycles per second so as to continually compare signals from two different portions of the sky.

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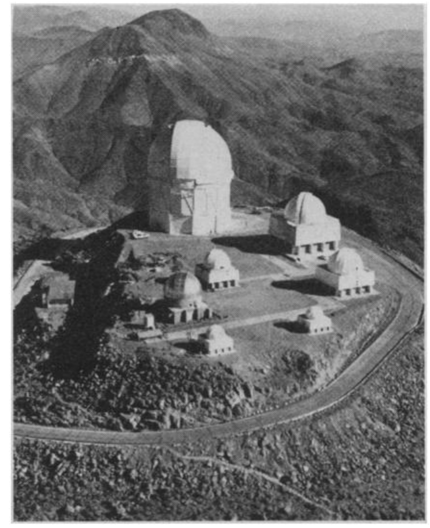
The southern skies played an important role in an earlier period of astronomy. Sixty years ago, observations of Cepheid variable stars in the Magellanic Clouds—where the stars are all at a comparable distance from the earth—showed that their brightness was related to their variable frequency in a predictable manner. This information proved to be the key to the establishment of an initial distance scale for the universe and the subsequent recognition of galaxies other than the Milky Way.

Now astronomical attention is again focused on the Clouds, because of interest in how galaxies evolve. The Clouds are the largest of several small companion galaxies to the Milky Way (which is about 1000 times their size). They are close enough that astronomical spectroscopists can now measure the relative abundances of elements in individual stars and thus study the chemical evolution of the galaxy in great detail. Such information as already exists indicates that star formation in the Clouds was initially delayed or occurred far more slowly than in the Milky Way but is now very active—a different evolutionary pattern. A variety of preliminary studies of the Clouds are now under way. At CARSO, for example, Eduardo Hardy—a Chilean astronomer now at Laval University in Quebec—is mapping the distribution of stars of different types to look for patterns in star formation and evolution.

In addition to work on the chemical evolution of galaxies, there has been a great deal of interest recently in how galaxies evolve dynamically. Theoreticians have proposed that large galaxies can have large effects on their neighbors, tidally disrupting smaller galaxies and perhaps stealing some of their stars. In what may be a related phenomenon, radio astronomers in Australia have discovered what is known as the Magellanic stream—a stream or jet of neutral hydrogen gas emitted from the Magellanic Clouds and containing many tiny nearby galaxies and other debris. Whether or not the Magellanic Clouds were tidally disrupted, the stream is a curious dynamic entity and presents what one astronomer calls "a particularly nice opportunity to study dynamical evolution." Several projects are under way at CTIO and elsewhere to look carefully at the fragments in the stream and at the structure of the Clouds themselves.

Most galaxies are so remote that astronomers have tended to consider them as relatively unchanging objects, at least for the purposes of discussing cosmological models of the universe. Now, however, there is considerable ferment among theoreticians over how the evolution of galaxies over billions of years affects such models, but so little information exists that one astronomer describes



Aerial view of the Cerro Tololo Inter-American Observatory.

galactic evolution as "*the* problem for the rest of the century." In any case, astronomers at all three of the southern observatories agree that the Magellanic Clouds will take up a great deal of telescope time in coming years.

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Galactic evolution is far from the only subject that has occupied the observatories so far, however. In the past few years, four hew comets have been discovered by Hans-Emil Schuster of ESO and others using ESO telescopes. ESO has also undertaken (in collaboration with Australian observers) to extend the widely used Palomar sky charts to the uncovered port ons of the southern sky and has already completed a "quick look" survey. At CTIO, staff astronomer John Graham has discovered optical filaments associated with one of the brightest radio sources in the sky, Centaurus A; the filaments are apparently gaseous material and may provide a clue to the otherwise mysterious radio "lobes" that extent far from the galaxy itself. Still other astronomers have visited CTIO seeking to identify the optical counterpart to a newly discovered x-ray or radio source.

The southern observatories in Chile face unique obstacles ranging from an earthquake-prone location to high costs to political instability. But they are also poised to make good use of three separate but converging opportunities: the unexploited richness of the southern skies, large new telescopes, and a new generation of electronic detectors. The combination would seem to augur an interesting future, both for the observatories and for astronomy as a whole.

—ALLEN L. HAMMOND