



**Column Editor:** Timothy F. Slater, Department of Physics, Montana State University, Bozeman, MT 59717-3840; tslater@physics.montana.edu

## A Desktop Universe for the Introductory Astronomy Laboratory

**Laurence A. Marschall, Glenn A. Snyder, and P. Richard Cooper,** Department of Physics, Gettysburg College, Gettysburg, PA 17325; clea@gettysburg.edu

“Clearly a simulated ‘experiment’ is the creation of the devil, and the temptation to use one must be stoutly resisted.”

— Robert H. Romer, *Am. J. Phys.* **61**, 135 (1993)

What is a well-intentioned astronomy instructor to do? There is no argument that experience with the real world is desirable in any astronomy course, especially the

introductory classes that fulfill the science distribution requirements at many colleges and universities. Though it is a simple matter to take students out of doors, show them the motions of the Sun, Moon, and stars, and have them squint for a few seconds at Saturn’s rings through a telescope, these activities represent only a small portion of the subject matter of modern astronomy. It is simply not possible, given the constraints of time, weather, and equipment at most schools, to have students determine

the photometric distance of a star cluster, measure the dispersion distance of a pulsar, or confirm Hubble’s redshift-distance relation for themselves.

Computer simulations, we have found, provide an effective solution to this problem. Most professional astronomers do their work today using computer-controlled telescopes, digital cameras, and computer-intensive data analysis. So even though the student only deals with a “virtual” telescope, she or he can access the same data, employ the same strategies, and experience the same uncertainties as a professional astronomer. Project CLEA (Contemporary Laboratory Experiences in Astronomy), based at Gettysburg College, has been developing software and curricular materials to implement such simulations since the early 1990s, with financial support from the National Science Foundation.

A typical CLEA exercise includes a computer program, a student workbook, and a technical guide for the instructor. The programs access selected data sets that illustrate specific research techniques, but they incorporate a large number of optional settings that can be set for whatever a particular class requires. Thus,

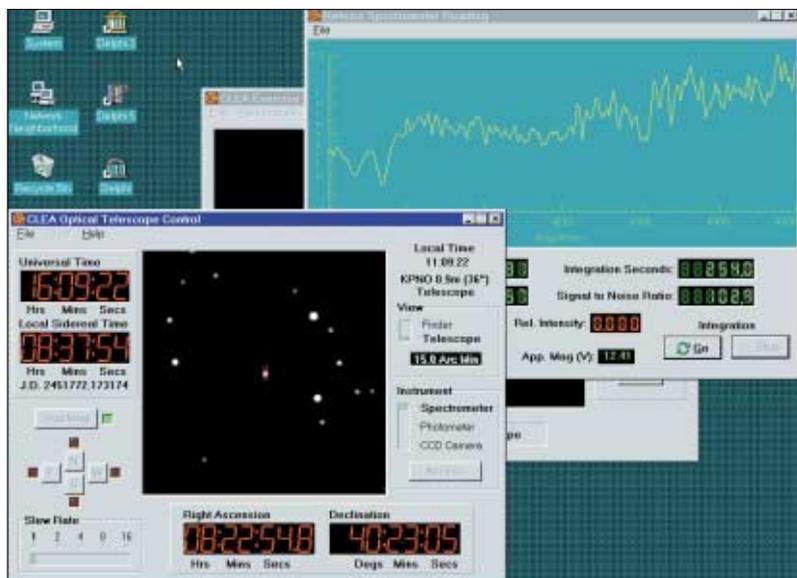


Fig. 1. Screen from CLEA’s “Object X” software, showing controls of the optical telescope and photon-counting spectrometer.

though intended primarily for introductory college courses, CLEA exercises are used at all levels from elementary schools to advanced college classes. Both the software and the manuals may be downloaded at no charge from the Web (<http://www.gettysburg.edu/academics/physics/clea/CLEAhome.html>). We frequently run CLEA training workshops on campus and at regional and national meetings of the American Association of Physics Teachers. As a result of our distribution effort, CLEA exercises are currently in use in all 50 states and over 60 countries worldwide; the student manuals have been translated into Spanish, Italian, Dutch, Polish, and Hebrew. (There may be others of which we are not yet aware.)

Currently, nine Project CLEA exercises are available:

- 1) *Revolution of the Moons of Jupiter*, in which students determine the mass of Jupiter using Kepler's third law by observing the period and distance of the Galilean satellites.
- 2) *Rotation of Mercury Using Doppler Radar*, in which students measure the equatorial velocity of Mercury using radar echoes from a simulated radio telescope.
- 3) *Flow of Energy out of the Sun*, in which students can experiment with how photons are randomly scattered in the interior and the atmosphere of a star.
- 4) *Classification of Stellar Spectra*, in which students use a simulated optical telescope with a photon-counting spectrometer to classify stars and determine their distances from Earth.
- 5) *Photoelectric Photometry of the Pleiades*, in which students use a photon-counting photometer to construct a Hertzsprung-Russell diagram of the Pleiades and determine the distance to the cluster.
- 6) *Hubble Redshift-Distance Relation*, in which students use a telescope and spectrometer to obtain spectra of galaxies in five galaxy clusters at various distances from the Milky Way, plot a velocity-distance graph, determine the Hubble constant, and calculate the expansion age of the universe.
- 7) *Large-Scale Structure of the Universe*, in which students use a telescope and spectrometer to measure the redshifts of a large sample of galaxies and then construct a diagram of the distribution of galaxies in a pie-shaped diagram of the universe.
- 8) *Radio Astronomy of Pulsars*, in which students use a simulated steerable radio telescope to investigate the intrinsic properties of pulsars and then determine the distance of pulsars from the dispersion in arrival times of pulses at different frequencies.
- 9) *Astrometry of Asteroids*, in which students use a specialized image-analysis program to "blink" pairs of images taken with a research telescope. They find asteroids in the star fields, measure their proper motions, and also determine the distance to asteroids using parallax determined by images taken simultaneously at sites in New York and Arizona.

A new CLEA exercise will be released in January 2001, tentatively titled "The Search for Object X" (see Fig. 1). Like the final lab in a chemistry course, the "Object X" lab involves the identification of an unknown object—only the celestial coordinates are given. Simulated radio and optical telescopes of various sizes are available, along with a simulated spectrometer, photometer, and CCD camera. The program includes data on over 15 million stars, tens of thousands of galaxies, more than 500 pulsars, and numerous other objects.

The development of this capstone lab opens up an exciting new possibility: a true virtual observatory that allows students and teachers to access the entire sky and conduct open-ended observational projects just as professional astronomers do. Interestingly, the idea of such a virtual observatory appeals not just to teachers nowadays. As more and more astronomical data become available online, professional astronomers speak of doing research by "mining" the large data sets from space missions and all-sky surveys without actually going to the telescope. See, for instance, the webpages on Virtual Observatories of the Future: <http://astro.caltech.edu/nyconf>. Teaching labs of the future, in other words, may use the same tools and the same databases as research astronomers. In just a few years, if this trend continues, the distinction between simulated observing and "real" research will be far less significant than it is today.