ANALOG
SCIENCE FICTION AND FACT

LSST: The Dark Matter Telescope

There's a new astronomical telescope project in the works, the Large-aperture Synoptic Survey Telescope or LSST, sometimes called the Dark Matter Telescope. The LSST is a most unusual telescope, both in its design and in its goals. It is designed to provide fast electronic images of a very wide swath of the sky. It is designed to investigate some of the most intriguing questions in astronomy and astrophysics, including issues relating to dark matter, dark energy, supernovas, gamma ray bursts, objects in the far reaches of the solar system, and dangerous asteroids that cross the Earth's orbit and could produce catastrophic collisions. I'll start by considering these LSST goals, one at a time, and then focus on the design and funding of the project.

Dark Matter–Recent astrophysical results tell us that normal matter, the stuff of which galaxies, stars, planets, and people are made, accounts for only about 4.4% of the mass-energy in our Universe. The rest of the Universe's mass-energy is 23% dark matter (ghost particles of some unknown kind) and 73% dark energy (energy stored in the vacuum itself). One of the main missions of the LSST is to gather images that tell us more about the dark matter. It seems strange that a telescope would be designed to look at dark matter, stuff that emits no light and is known to us only because of its gravitational effects. But those gravitational effects carry their own signature–the gravitational lensing of distant galaxies. In a previous column, "The Rainbows of Gravity," (*Analog*, November 1988) I described the way that gravity bends light to produce "Einstein rings" and related streak-images–highly distorted ring-like images of background stars and galaxies. Gravitational lensing tends to stretch and distort the image and can produce the illusion of luminous objects that appear to be millions of light-years in length. Such distortions can be systematically used to get at the underlying mass that produced them.

However, rather than looking at individual distorted images (called "strong lensing"), the LSST plans to use multi-wavelength deep imaging to measure the overall "shear" or stretching of all the images viewed by the telescope in a given region ("weak lensing"), and to use these data to produce a "tomographic" three-dimensional mass map of all the dark matter in the Universe. Using the relative distortion of background galaxies at different distances (obtained with long-exposure multi-color images) one can solve for the most likely space-time distance and size of the lensing mass. With 3-D mass tomography of the Universe, the LSST will detect hundreds of thousands of mass concentrations of dark matter distributed over look-back times of one to eight billion years. In this way, we expect to learn much more about the nature of dark matter.

Dark Energy–In two previous columns (*Analog*, May 1999 and January 2001), I described the evidence from supernova and cosmic microwave background data indicating that about 73% of the mass-energy in our Universe is in the form of some mysterious "dark energy" present in the vacuum itself. Dark energy produces a negative-pressure antigravity effect that causes the expansion of the Universe to accelerate. Dark energy has two distinct effects on the Universe: accelerated expansion and the growth of mass structure. The weak-lensing effects probed by LSST will provide a direct measurement of the growth of mass structure. This view of dark energy should be completely independent of other information we have, i.e., data from Type Ia supernovas and cosmic microwave background, and should constrain the properties of dark energy in an important new way.

Short-Duration Astronomical Events–The task of the LSST is gathering light with an 8.4-meter mirror and recording a high-resolution image of a fairly large patch of the sky with an electronic camera. The LSST is designed to make, in a 10-second exposure, an image of objects of the 24th magnitude (6.3 x 10-10 times dimmer than the brightest 1st magnitude stars in the sky), covering seven square degrees of the sky. It is expected that this unique capability will reveal much of the brief "fireworks" in the sky that we might normally miss, for example the flash of blue light from red-shifted bursts of ultraviolet light produced by the most distant supernovae.

But the real payoff of the LSST should come from totally unexpected phenomena. No other telescope system is equipped to watch the sky for such dim short-timescale phenomena. It’s an excellent bet that we will see things that no one has thought of or predicted. And the results should be available immediately. The LSST designers plan to have an automated system that would release data from such sources over the Internet as they occur, to be used by the astrophysics community for correlation with satellite observations at high energy and for follow-up studies with other telescopes.

I**nvestigation of the Outer Solar System–**The solar system is fairly well mapped out to the orbit of Neptune, but beyond that boundary, little is known. There has been some recent progress in identifying large objects in our solar system in the Kuiper Belt beyond Neptune’s orbit, but there could be large bodies, perhaps even of planetary size, of which we know nothing. It requires a detailed understanding of the link between our solar system and those being discovered around other stars. In other star systems, there is evidence for extensive material at large distances from the central star, in some cases extending to 1,100 AU from the star. No one knows if our own solar system follows this pattern.

The LSST system, highlighting objects that move or change intensity with respect to the background stars, should greatly improve the study of the outer solar system, and should shed light on its formation. It should also provide information on how star formation in general proceeds.

The objects in the outer solar system are the most pristine material left over by the original protoplanetary cloud. The orbiting material out there may contain up to thirty trillion objects. We need a sample of at least 10,000 such objects to definitively sample both the spatial distribution and mass distribution of the cloud. The large telescope aperture and field-of-view of the LSST cannot be traded for longer exposure time on a smaller telescope because the objects of interest are faint and move rapidly. In fact, most solar system objects that are discovered are subsequently lost because they are not monitored long enough to get a sufficiently precise orbit.

And of course, there is the potential for totally unexpected discoveries in the outer solar system. Not only may we find new planets the size of Pluto or larger, we very likely will find objects with physical characteristics quite unlike those of the currently better known classes of solar system bodies.

Near-Earth Objects–In a previous column (*Analog*, January 1992), I discussed the surprisingly high probability that one might be killed by an asteroid impact on the Earth. Asteroids are surprisingly dangerous. If a big one hit the Earth at the wrong place, it could kill many people. And a sufficiently big one could kill everyone.

As it turns out, the odds are about 2.4 times greater that you might be killed by a asteroid or comet impact than by an air crash or a tornado, both taken together. The probability of death-by-asteroid is so large, of course, because the calculated odds are the product of the chances of an asteroid strike (small) and the number of deaths predicted to result from it (very large in some cases). We are coming to the realization that both as individuals and as the human species as a whole, we are running a significant risk of extinction. All of our eggs are in one pretty blue basket, and the solar system has the unpleasant habit of throwing large rocks at that basket.

But how many such rocks are out there? There are tens of thousands of uncharted Near-Earth Objects of significant size. Alan Harris of JPL has shown that the sky must be surveyed several times per month at a sensitivity 100 times greater than that used in current searches for Near-Earth Objects to find objects down to a 300 meter diameter. The LSST, together with a wide-field camera and a fast computer, could do this job very well.

The discovery of Near-Earth Asteroids is time-critical and coverage-dependent. Today, smaller asteroids are detected only when they get close to the Earth and show a large apparent motion against the background stars. The LSST, because of its sensitivity, can catch such asteroids farther out, when their apparent motion is smaller, making it easier to "connect the dots" and catch them with automated software. The LSST could also sample a larger volume of space for them and so catch a greater number with each look. Both throughput and telescope aperture are important for a complete systematic survey.

The 300-meter asteroid size mentioned above corresponds to a limiting magnitude of 24. Detection in short exposures is needed, since the asteroids smear very quickly for exposures of more than 20 seconds, making large aperture important. The utility of such a survey would be diminished if it could not cover the entire visible sky several times per month, since there would be no other telescopes that could cover the holes or even follow its discoveries. Present systematic surveys like Spacewatch have difficulty even in finding all of the 21st-magnitude Near-Earth Asteroids. With its capability to detect objects as faint as 24th magnitude in 10 seconds, the LSST should be able to find all of the significant Near-Earth Objects down to 300 meters in size.

So that’s the menu for the LSST, everything from fundamental cosmology to asteroid safety. The remaining questions are those of design and funding.

Design–The LSST design calls for an 8.4-m aperture using three mirrors and covering 3 degrees of field diameter. The design takes advantage of advances in optical fabrication and detectors to obtain high-quality imaging capability. Its "etendue," the product of collecting area and field of view, would be ten times greater than any other existing or planned telescope. Its focal surface would be equipped with circular mosaics of imaging detectors 55 cm in diameter, using CCDs for wavelengths 0.3—1 mm. These would record the three-degree field imaged at f/1.25. Interference filters 60 cm in diameter would be used to select wavelength bands as narrow as 3%.

The LSST telescope structure is centrally balanced and very compact, only slightly longer than the primary mirror diameter, and would need an enclosure much smaller and less expensive than standard 8-meter telescope designs. In a run of three to four clear nights, the fast-slewing telescope could survey the entire visible sky (20,000 square degrees) to a limiting magnitude (5 sigma) of V=24, I=23. Alternatively, in 50 hours of observation, an 8-color composite image of a single 7-degree square degree field could be made to 5 sigma limiting magnitudes U = 26.7, B=27.8, V=27.9, R=27.6, I=26.8. (Here, U, B, V, R, and I characterize the magnitudes of objects visible in standard astronomical wavelength bands ranging from U=ultraviolet to I=infrared.)

Funding–The price tag for the LSST is around $150 million–quite small for a space project, but fairly large for a ground-based telescope. Since the LSST would be built on the ground, with no involvement of the shuttle or space station, the NASA science policy makers have decided they are not interested. This means the funding would have to come from other sources, probably some combination of private sources and the National Science Foundation. The LSST proponents are now in the process of securing such funding, and the prospects for finding all the money needed are good.

Watch this column for further developments in this cutting-edge science project.

AV Columns On-line: Electronic reprints of over 110 "The Alternate View" columns by John G. Cramer, previously published in *Analog*, are available on-line at: http://www.npl.washington.edu/av.

References: ***The LSST Project***

"Large Synoptic Survey Telescope: Overview," J. Anthony Tyson and the LSST Collaboration, available at http://www.dmtelescope.org/Project/docs/tyson4836-04.pdf

See also the LSST Observatory Home Page at http://www.dmtelescope.org/lsst_home.html and the links contained there.
