period decreased by 4.5 microsec. Hercules X-1 differs from the radio pulsars, whose periods increase. So far attempts to observe Hercules X-1 in the radio have not succeeded. Tananbaum believes the energy source of the pulsars is different. For the radio pulsars, he says, it is generally believed that the energy comes from conversion of rotational energy to electromagnetic energy. But for Hercules X-1, because it is a binary system, he thinks that the energy comes from matter accreting onto the neutron star from the bigger object.

The Bahcalls made their optical identification of HZ Herculis last summer at the Wise Observatory near Tel Aviv. It is difficult to make convincing optical identifications of x-ray sources because so many optical objects exist within the x-ray error boxes. But the Bahcalls found that the optical intensity of the star HZ Herculis was varying with the same 1.7-day period (to three significant figures) as Hercules X-1 was showing as an orbital period in the x rays. Within three days William Liller at Harvard University confirmed the optical identification but improved it to six significant figures, by using plates from the Harvard collection that date back to the 1940's. Using the Harvard collection plus data from the Soviet astronomer, N. E. Kurochkin, Liller has found that since 1900 every once in a while the optical source turned off and stayed at a minimum for periods of years before turning on again. John Bahcall remarks that the x rays probably also turned off at the same time.

Because Hercules X-1 is a binary system, it is possible to determine directly the mass of the neutron star, although so far not very accurately. In her talk Neta Bahcall gave a range of values for its mass, between 0.3 and 1.0 solar masses, depending on the method of calculation. Probably the simplest way, but not necessarily the most reliable, is by studying the spectrum of the faint side of HZ Herculis (when the x-ray source is behind it). From the spectrum you can obtain its absolute luminosity and its mass, if one assumes it's a normal star. Then from the x-ray data, which give the period and the velocity of the orbit, you can get essentially the ratio of the mass of the x-ray source to the mass of the optical source; hence you can calculate the neutron-star mass.

Another way to find the mass is to estimate the size of HZ Herculis by saying that if it were bigger the atmosphere would be gravitationally unbound in the field of the second star and if it were smaller it wouldn't be losing mass and you wouldn't be seeing x rays. Both the upper and lower limits are about the same size. Then the mass ratio can be calculated from the dynamics and one can use the x-ray data.

A third way is to use the optical velocity measurement of D. Crampton and J. B. Hutchings (Dominion Astrophysical Observatory), who determined the velocity of HZ Herculis in its orbit around the x-ray source. Then you can find the neutron-star mass just as you can determine the mass of a planet as it moves around the sun—from its velocity in the orbit.

Tananbaum estimates the mass of the neutron star to be between 0.7 and 1.2 solar masses by assuming that the Roche lobe (half of the figure eight described by the equipotential lines for a two-body system) is the same size as the occulting region. Then if you further assume that from optical data you know the inclination of the optical star, you can calculate the mass.

John Bahcall says there will be great interest this spring and summer, during the new optical observing season, to further refine the neutron-star mass determination. Last season about 15 groups looked at HZ Herculis; this season Bahcall expects 25 groups to be observing the star.

When the Bahcalls announced the identification of the 1.7-day period, they of course also knew what the phase was. But they were so surprised to find the optical and x-ray signals were in phase that they waited another week before announcing that the phase was the same. John Bahcall explained to us that if the neutron star moving in front of a big normal star had any effect at all, you would think it would make the optical source slightly fainter.

The opposite is the case. The explanation the Bahcalls offer is that the optical star and the neutron star have a symbiotic relationship, in which the big star feeds the small star and the small star feeds the big star. Matter somehow accretes onto the neutron star, which emits x rays and possibly other particles; this emission causes a hot spot on the side of HZ Herculis that faces the neutron star. When the neutron star is between HZ Herculis and the observer he sees maximum light because the neutron star is not being eclipsed by HZ Herculis and the hot spot is facing the observer. On the other hand, when the positions of the two sources are reversed, the observer sees minimum light because the neutron star is eclipsed by HZ Herculis and its hot spot is facing away from the observer.

There are two observable x-ray effects of the 1.7-day orbital period. The x-ray intensity undergoes regular eclipses with the source in eclipse for about one-quarter of a day every 1.7 days. The other effect observed in the x rays is the Doppler shift of the 1.24-sec pulse period in phase with the 1.7-day orbital period. To see this, it is helpful to think of the neutron star having a little clock that ticks every 1.2 sec. When the neutron star is at its maximum distance from us (behind HZ Herculis) the tick is delayed by the light travel time across the orbit. Similarly the tick comes early when the neutron star is closest to us. If you plot the time at which the tick reaches us minus the expected time if the neutron star were always in the same position, you get a sine function whose period is 1.7 days.

While the orbital period has remained constant, the 35-day periodic variation in brightness has not. When Tananbaum and his collaborators first started observing, they found that the source was on for 10 or 11 days and then for about 25 days it was below the threshold of the detectors. The turn-on time was localized to within an hour's accuracy in an interval of 35.7 days. Since then, over a 14-month period they find considerably more scatter to the period; the period now averages 34.9 days plus or minus one or two days. Tananbaum jokes: "It seems there's some sort of underlying clock; it just doesn't keep very good time." —GBL

5-km radiotelescope completed at Cambridge

One of the major problems that radioastronomers have faced is the lack of a radiotelescope with resolution as good as that obtained with optical telescopes. Now, with the inauguration of the 5-km radiotelescope at the Mullard Radio Astronomy Observatory at Cambridge, England, they will be able to study radio sources with a resolution of up to one arc sec.

The telescope is the latest in a series of multiple-element radiotelescopes that have been built at Cambridge that use the technique of aperture synthesis. This process, which is common by now in radioastronomy, makes use of the signals received by a number of antenna pairs to synthesize a receiver with an aperture close in size to the distance between the two most widely separated dishes. The telescope was built, and is operated under the direction of Sir Martin Ryle of the Mullard Observatory.

As of this writing, the radiotelescope has been calibrated and has made observations at 5 GHz with a resolution of 2 arc sec. It is intended to be used for research on the structure of radio sources, especially galaxies and quasars, and it will also be pointed at supernova remnants and H II regions—areas containing clouds of ionized hydrogen that are thought to be the sites of star formation.

The telescope itself consists of eight 13-m dish antennas standing in an east–west line 4.6 km long. Four of the antennas are fixed and four are mounted on tracks that were built specially for the telescope on what used to be a stretch of the Cambridge–Bedford railway. The fixed antennas are spaced 1.2 km apart and the tracks are

1.2 km long. Combining the signals from each of the fixed antennas with those from each of the movable antennas gives 16 antenna pairs for an observation at any one time. If the movable antennas are repositioned to a number of other viewing stations, a total of 128 pairs becomes available. Additional cable is switched in and out of the circuits that receive and transmit the radio signals, so that when different antennas are used there is no timing error caused by their positions. This design will produce a map about 5 arc min across at a wavelength of 6 cm.

The design of the dish antennas is based on a design used for communication-satellite station antennas. The surfaces are finished to provide accurate operation from 3 to 21 cm, with an angular resolution of from 1 to 7.5 arc sec.

Directional control of the antennas, switching of the compensating transmission lines, rotation of the antenna feed horns (for polarization measurements) and sampling of the signals being received during observation are all controlled by an on-line computer, a Marconi Myriad II. The same computer also performs all data processing on a timesharing basis and can draw maps on a graph plotter.

The Cambridge 5-km radiotelescope will remain the highest resolution instrument for making radio maps until the Very Large Array is completed in New Mexico in the late 1970's.

Proposals requested for Large Space Telescope

The deadline for submission of proposals for participation in the definition and preliminary design of the scientific instruments to be carried on the Large Space Telescope is 23 February. The 3-meter LST, which will have diffraction-limited performance, is being planned for launch into earth orbit by NASA in the early 1980's.

Those researchers whose proposals are selected will work on instrument definition teams under contract to NASA and will prepare the specifications of the instruments to be carried on the LST. The teams will play a large part in determining what information the LST will gather.

The telescope will have a Ritchey–Chretien optical system that will give a wide field of view at the focal plane where the image of a point source will be about 0.04 arc sec. Since the telescope is large and will be outside the earth's atmosphere, it will be able to image details about 10 times finer and to detect point sources about 100 times fainter than is now possible, according to C. R. O'Dell, project scientist, and Nancy Roman, program scientist.

The telescope is expected to open up a new class of astronomical problems and to provide greater capabilities in areas of current research, both in ultraviolet astronomy and in diffraction-limited imagery. In the area of faint-object investigation, for example spectroscopy, photography and photometry of stars and galaxies, the small image size and dark sky will permit investigation of objects up to five magnitudes fainter than presently possible. The high angular resolution of the telescope will permit the study of the structure of astronomical sources with much greater detail than from the ground.

The main instruments planned for inclusion in the LST program, and the ones that will be of greatest concern to the instrument definition teams, are a diffraction-limited camera, a low-dispersion spectrograph and a high-dispersion spectrograph. Other instruments will also be included.

The diffraction-limited camera will be a camera that reads out a small field matched to the resolution of the telescope optics. The camera will include means to enlarge the image from the principal focus to a scale compatible with the image detector finally adopted. Integration times of many hours should be possible, with limiting magnitudes as faint as +28.

The low-dispersion spectrograph is an optical ultraviolet instrument with wavelength resolution of about $\lambda/\Delta\lambda$ = 1000 capable of quantitative spectroscopy down to 1000 Å. It will be constructed to operate over a wide range of light levels including those from the faintest sources. Those working on definition of this instrument will also have to propose techniques for signal acquisition and recording.

The other main instrument to be carried on the LST is the high-dispersion spectrograph. It will also operate in the optical ultraviolet, but will have wavelength resolution of about $\lambda/\Delta\lambda$ = 30 000. The major design areas that will have to be studied are the type of spectral dispersion element to be employed, problems of object acquisition and also signal recording.

Other instruments that may be proposed for the telescope are not yet completely determined and will depend in part on what proposals are submitted. Those that NASA has suggested as compatible with the spacecraft and the scientific mission of the LST are photometers, polarimeters, astrometric instruments, infrared instruments and very-high-dispersion spectrographs. The instruments eventually sent on the LST will be chosen from those defined at this stage.

Each instrument definition team will meet monthly between April and March 1974, and the members will work closely with NASA personnel from either George C. Marshall Space Flight Center, which is the center responsible for overall LST project management or Goddard Space Flight Center, which is the center responsible for the scientific instruments, data management and orbital operations. An initial instrument definition will be due on 1 November and a final definition will be expected on 1 March 1974.

Large Space Telescope with 3-m optical telescope is planned for earth orbit in the early 1980's. NASA seeks proposals for the definition and preliminary design stage.

When the detailed design study is over in late 1974, NASA will request applications for participation in the construction and operational phases of each instrument for inclusion in the final payload. This is, of course, contingent on further funding of the LST program, which has so far been funded only through 1974.

A series of briefings for those who want to propose participation in instrument definition was held during January covering the design of the LST and the financial constraints of the program as well as information about submitting proposals. According to O'Dell, proposals should include a conceptual definition of the instrument, a statement of the proposed scientific goals of the instrument, and the role that the proposer would like to take in the instrument definition team—that is, his special interests and level of effort and an estimated budget.

Anyone interested in submitting a proposal for participation in the LST instrument definition should contact C. R. O'Dell, George C. Marshall Space Flight Center, Alabama 35812, attn: PD-LST, or phone (205) 453-0162. □