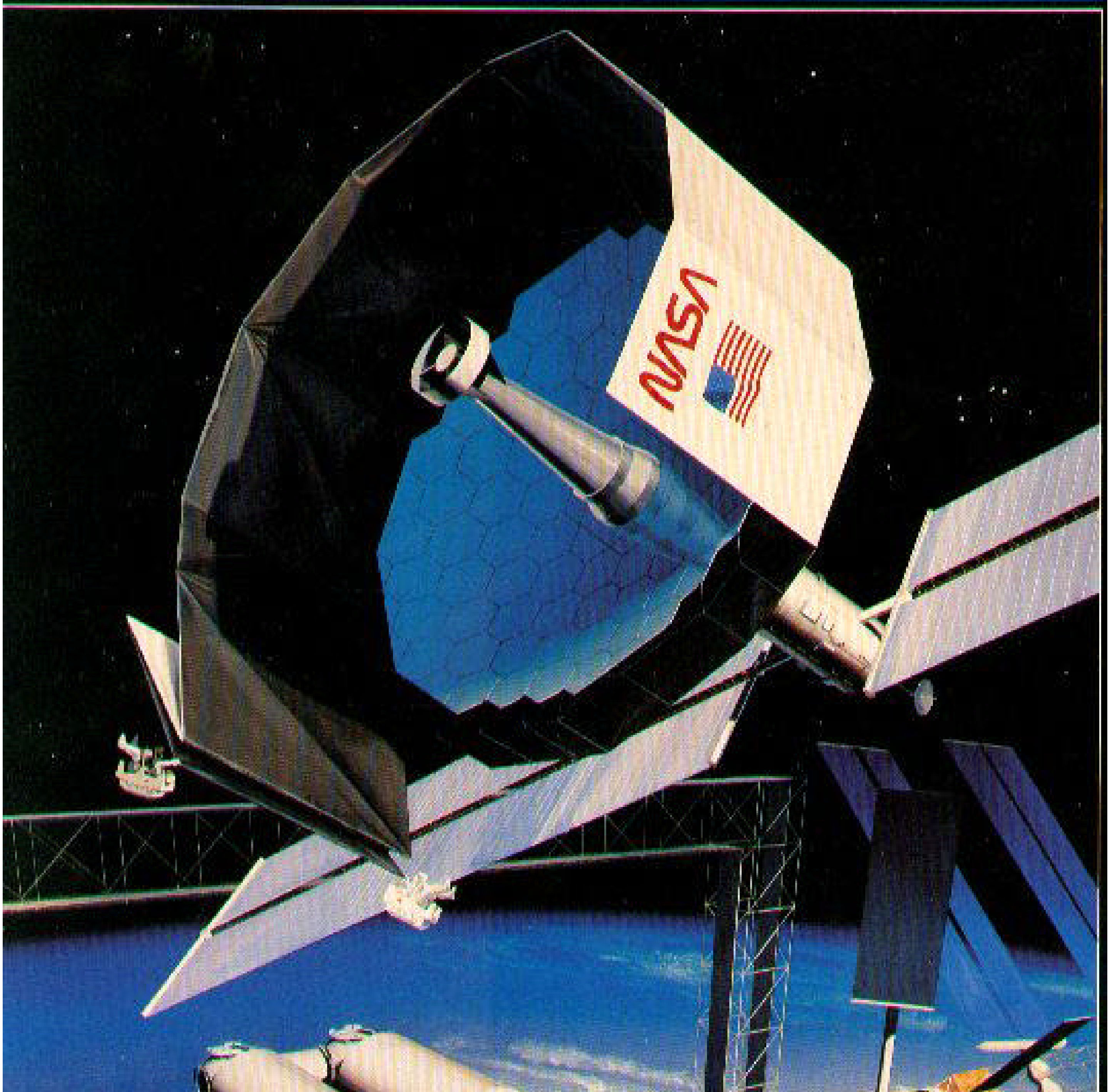
THE LARGE DEPLOYABLE REFLECTOR

LDR

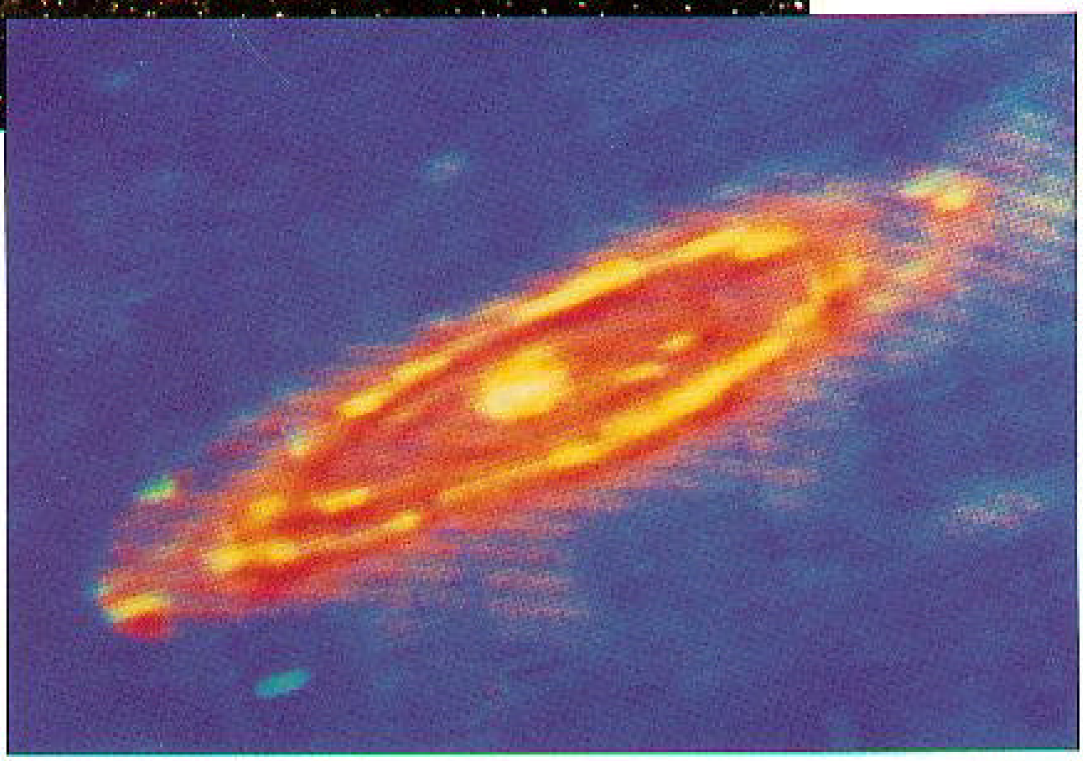
To Lift the Far-Infrared Veil Of the Cosmos



LDR

To Lift the Far-Infrared Veil Of the Cosmos

by Donald Goldsmith and David Hollenbach



Andromeda galaxy viewed in visible light (above) and infrared radiation (right)

Seeking to Lift the Veil

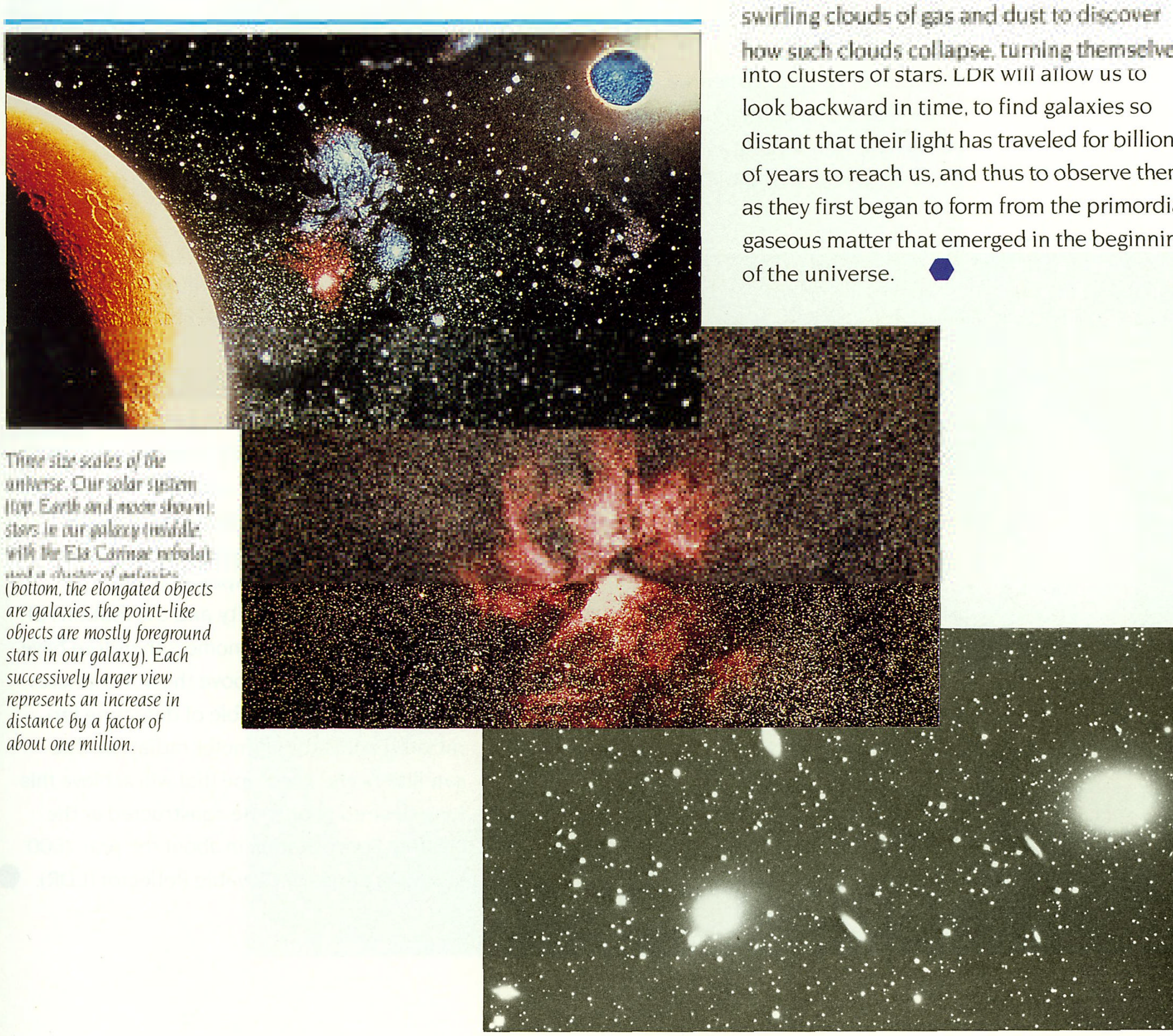
Imagine a planet continuously shrouded in a veil of clouds, so dense, so efficient at absorbing light waves that its inhabitants could never observe the cosmos around them. For untold generations, scientists on this planet could only guess at the astronomical objects that might be sending light in their direction. The light emitted from these objects traveled trillions upon trillions of kilometers, only to be swallowed up at the very end of its journey by the planet's impenetrable atmosphere.

That planet is Earth. When we seek to study the cosmos, not in familiar light, but in a kind of "light" our eyes cannot sense—far-infrared and submillimeter radiation—Earth's atmosphere forms an opaque veil. So long as we observe the universe from within the confines of our atmospheric shroud, we remain unable to detect this kind of radiation from extraterrestrial objects.

As if to compensate, however, the far-infrared and submillimeter radiation, so completely absorbed by Earth's atmosphere, easily penetrates another cosmic veil: that of the dusty interstellar clouds within which new stars and their planets are being born. The birth of stars and planets is almost completely hidden from our view—unless we analyze the far-infrared and submillimeter radiation they emit. By analyzing this radiation, we can determine the composition, the temperature, the density, and the motions of star-forming gas. Astronomers therefore have long sought to place above the atmosphere a large telescope capable of detecting far-infrared and submillimeter radiation. The satellite-borne telescope that will achieve this long-desired goal, to be constructed at the orbiting Space Station in about the year 2000, is NASA's Large Deployable Reflector (LDR).

Observing Cosmic Evolution

Until now, our observations of the universe have been mainly of the finished products of cosmic evolution that we can see: planets, stars, and the stellar component of galaxies. Because we have limited means to observe the universe in far-infrared and submillimeter radiation, we have been unable to obtain a clear understanding of the large part of the universe that is still gas and dust, the raw material from which all the visible objects in the universe have formed. The LDR will have the capacity to follow the motions of this diffuse matter as it clumps together to form galaxies, stars, and planets. LDR will allow us to see which of the sun's neighbors are surrounded by disks of material that may form planets, and which stars have already formed their planets. With LDR we can penetrate the swirling clouds of gas and dust to discover how such clouds collapse, turning themselves into clusters of stars. LDR will allow us to look backward in time, to find galaxies so distant that their light has traveled for billions of years to reach us, and thus to observe them as they first began to form from the primordial gaseous matter that emerged in the beginning of the universe.



Three size scales of the universe. Our solar system (top, Earth and moon shown); stars in our galaxy (middle, with the Eta Carinae nebula); and a cluster of galaxies (bottom, the elongated objects are galaxies, the point-like objects are mostly foreground stars in our galaxy). Each successively larger view represents an increase in distance by a factor of about one million.

What is LDR?

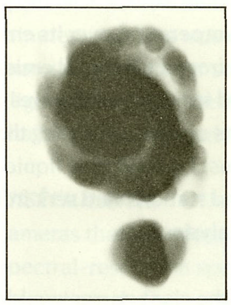
LDR will use a mirror 20 meters (65 feet) in diameter to collect and to focus radiation from faraway cosmic objects. The mirror's large size is the key to LDR's abilities: only by using a large mirror can astronomers obtain a clear, detailed view of the universe in far-infrared and submillimeter radiation, which is inherently more difficult to focus than visible light. To build a mirror this large—too large to be sent fully deployed into orbit—poses a difficult challenge. Working under microgravity conditions in airless space, astronauts must construct the telescope while based at NASA's planned Space Station. This requirement poses major technical problems for the engineers who must design and fabricate easy-to-assemble LDR components.

LDR, with 20-meter mirror and sunshade, during assembly at the Space Station facility.

The Next Step: LDR

The LDR satellite will complement the abilities of SIRTF in two critical ways: greatly improved spatial resolution and enhanced spectral resolution.

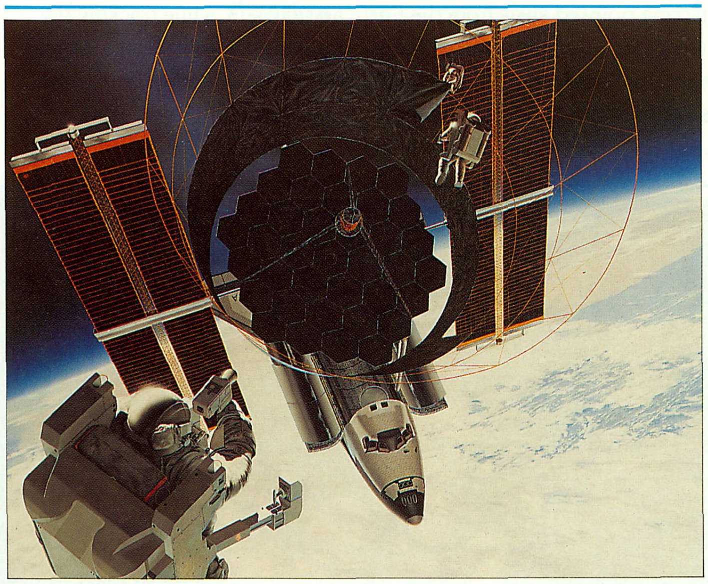
Spatial resolution refers to the ability of any collector of electromagnetic radiation to "resolve" or separate nearby sources of emission. Greater spatial resolution means that more detail appears in the observation, so that the pictures we obtain are sharp and relatively free of distortion. For a given wavelength, any reflecting telescope's spatial resolution increases in proportion to its mirror diameter. For a given mirror diameter, a telescope's spatial resolution *decreases* with increasing wavelength. LDR, with a reflector 24 times as large as SIRTF's, will have 24 times the spatial resolution of SIRTF in the far infrared, and will be able to distinguish sources of far-infrared radiation spaced no more than 1 second of arc apart—equivalent to the angular size of a dime seen from 3 miles away! Because LDR will generally observe very long wavelength far-infrared and submillimeter radiation, its huge diameter simply allows LDR to obtain as accurate a view at these wavelengths as SIRTF and optical telescopes achieve at near-infrared and optical wavelengths.



Spiral galaxy M51 *with* SIRTF *spatial resolution in far-infrared.*

M51 *with* LDR *spatial resolution in far-infrared.*

Spectral resolution describes how well the detector can distinguish the "colors" of the radiation it observes. Our own eyes give us the impression of more than 200 different shades of color, that is, of different wavelengths of visible light. LDR will be able to observe *millions* of different colors of far-infrared and submillimeter radiation. To make accurate observations of the chemical composition and the patterns of motion in star-forming regions—that is, to see *how* stars are born—we need a spectrometer, an instrument that can discriminate accurately among the colors of far-infrared and submillimeter radiation. Such a spectrometer requires much more power and a greater size than have been previously available. What is needed is a new type of space observatory—the LDR—with 500 times the collecting area and with spectrometers having 1,000 times the spectral resolution of those on SIRTF.



LDR's *large main mirror must be assembled in space from smaller panels.*

How Will LDR Work?

The LDR satellite will be assembled at the Space Station and will then be launched into its own Earth orbit. The satellite will orbit the Earth at altitudes of a few hundred miles; it will be visited by the Space Station-based Orbital Maneuvering Vehicle at 1- or 2-year intervals to upgrade the instruments, replace the liquid helium used for cooling the instruments, and repair any malfunctions.

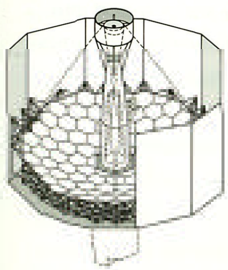
The heart of the LDR will be its giant mirror, made of hexagonal panels about 2 meters on a side, linked together to form a parabololic surface. To build such a 20-meter reflector in space is no easy task. In addition, since all warm objects emit infrared radiation, the mirror itself will emit millions of times more infrared radiation than arrives from the sources LDR seeks to detect. Hence the mirror must maintain a *constant* temperature over its entire surface, in order that its own emission may be accurately subtracted from the infrared emissions that astronomers want to observe. The 20-meter mirror will reflect and focus infrared waves, via a series of smaller mirrors, onto the detectors in the various instruments used for analyzing the radiation. To achieve maximum sensitivity, most of these instruments must be cooled by liquid helium. The data from the instruments will be telemetered to Earth ground stations, and sent from there to universities, NASA centers, and other scientific institutes for analysis.

Infrared radiation from the sun and Earth striking the giant mirror would warp it to an unacceptable degree and would produce uneven infrared emission from the mirror surface that would confuse LDR's infrared detectors. Therefore the LDR must never point in the direction of the sun or the Earth, and it will have a large sunshade to keep this radiation from reaching its mirror. Keeping the telescope pointed away from the Earth and the sun, while tracking the source under observation, requires a complex process of pointing the LDR as it swings around the Earth once every 100 minutes. With modern computers, however, the LDR can continuously reorient itself to fulfill these requirements, and can observe without regard to Earth's day and night.

Technological Challenges Posed by LDR

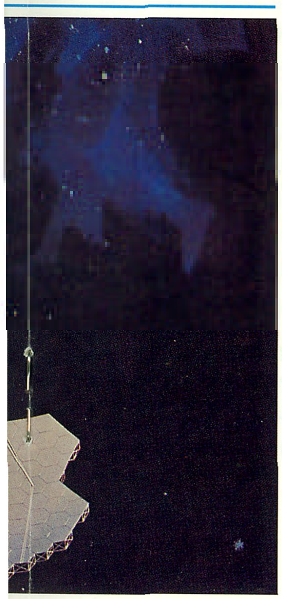
In order to build the LDR, scientists and engineers must overcome a series of technological obstacles. Among the most complex of these are the following:

The Mirror To minimize the weight of the mirror, and thus the number of Shuttle flights required to carry the LDR components into space, the panels that form it must be made from extremely lightweight materials. Dozens of these panels, each about 2 meters on a side, must fit together, and stay together, with a variation no greater than 1 micrometer—0.00004 inch! This accuracy must be maintained even though the enormous mirror will change direction in space at a rate of 90° in 10 minutes time, then remain pointed at a given source for about 20 minutes, and then move across the sky for another 10 minutes, and so continue indefinitely to examine source after source. The difficulty of fabricating the mirror and keeping its surface in alignment despite the disturbances caused by such motions represents one of the greatest challenges posed by the LDR design.



Instruments The heart of the instrument package will be its imaging arrays, electronic cameras that take detailed pictures in far-infrared and submillimeter radiation, and its high-spectral-resolution spectrometers, capable of measuring wavelengths to one part in a million throughout the prime spectral range available to the LDR. The development of such arrays and spectrometers is still in the initial stages and will pose a challenge during the decade of preparation for LDR construction.

Cooling For successful operation of LDR, the detectors must be cooled to −440°F, close to absolute zero. Successful deployment of LDR will require the development of either long-lived cooling fluids that can hold temperatures near absolute zero and evaporate only slowly, or a new generation of refrigerators capable of cooling components close to absoute zero with minimal power requirements. On Earth, we use coolants when we fill an ice chest with dry ice, frozen carbon dioxide. Once the dry ice evaporates, the chest grows steadily warmer. The best cooling fluid for LDR is liquid helium, which must periodically be replaced as it evaporates.



Pointing To take full advantage of the high spatial resolution offered by the LDR, the telescope must be capable of remaining pointed toward a given position on the sky with an accuracy of a tenth of a second of arc. The LDR must embody the technology needed to guide a 20-meter reflector with this precision, avoiding vibration that would destroy the pointing accuracy.

Assembly and Deployment The LDR will be assembled in space and then moved into a higher orbit, the first time that this sequence of assembly has been attempted. NASA there-

that will allow the LDR to be constructed high above the Earth's surface by astronauts working in the space environment.