Very Large Space Telescopes

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The largest optical telescopes have mirrors about 10 metres in diameter (Keck, and Gran Telescopio Canarias). The main obstacles to building larger telescopes are the Earth's gravity that deforms the massive glass reflectors, and turbulence in the Earth's atmosphere that distorts the images captured by terrestrial telescopes and that requires complex machinery to make compensatory distortions to the telescope's mirrors. Furthermore, the Earth's atmosphere blocks many light wavelenghs of interest to astronomers.

Space telescopes face none of these problems, but the astronomical cost of getting payload into orbit (currently about US$25,000 per kg for a geostationary orbit) has so far limited the mass, and hence diameter, of space telescopes. The Hubble Space Telescope (HST) is currently the largest with a 2.4 metre diameter mirror. Hubble's orbit is about 560 km above the Earth's surface. Warmed by sunlight and heat from the Earth, and stabalised by internal heaters, its main mirror operates at 15°C, which prevents it from capturing deep infra-red images. The James Webb Space Telescope will have a 6 metre primary mirror, and will be located at the Sun-Earth L2 Lagrangian point so that it is permanently in the Earth's shadow. It will operate at a much lower temperature that the Hubble Space Telescope, collecting deep infra-red light from close to the time that the universe was formed.

Space Elevators

The idea of using space elevators to get payloads into space cheaply and conveniently has been around for a long time. For example, a counterweight some 100,000km above the Earth's surface is attached to a point on the equator by a long tether and turns with the Earth, completing one revolution per sidereal day. Since the counterweight is far higher than a geostationary orbit, its angular momentum or “centrifugal force” is far greater than the force of the Earth's gravity acting upon it, so it pulls against the tether. Elevators carrying payloads can then climb up the tether and release their cargoes into space. About 1 million joules of energy would be required to lift one kilogram 100km above the Earth's surface, the amount of power used by a 100 watt incandescent light bulb in three hours. The cost would be minuscule compared to current payload launch costs.

So far we have not found any material strong and light enough to act as the tether in a space elevator, the weight of the tether itself being a limiting factor. In 2000 NASA published a study by Bradley C. Edwards, “The Space Elevator”, in which he found that a space elevator could be built if material with a tensile strength of 130GPa, some 200 times stronger than steel, could be used for the tether, which would need to be about 10cm wide by 1 micron thick. At that time it had been calculated that carbon nanotubes would be strong enough, if they could be grown in sufficient length. Progress in growing longer nanotubes has been slow, but progress in growing graphene, the substance from which carbon nanotubes is formed, has been quite rapid. Sheets one centimetre square have been fabricated thus far.

If space elevators become viable in the future then much larger space telescopes will become affordable. The mirrors of modern large telescopes are built in hexagonal sections, each section between one and two metres wide, and then assembled in a supporting steel structure to form a large mirror. Multiple sections like these could be hoisted by space elevator into orbit and assembled into a very large space telescope. The problems posed by gravity and atmospheric absorption and turbulence on the Earth's surface would be avoided by such telescopes.

Liquid Mirror Telescopes

While we contemplate these possibilities, we can also think of alternatives to the glass telescope mirrors used today. They have to be built with astonishing precision. The Hubble Space Telescope's main mirror was meant to deviate by no more than 10 nanometres from the required shape. Once deployed in orbit, it was found that the mirror did not conform to this exacting standard, and corrective optics had to be built and installed on the telescope to fix the problem.

There is a much simpler and cheaper way of obtaining a rotated parabolic shaped reflector, the shape that a telescope mirror should ideally have. If a bowl of liquid is spun in a uniform gravitational field then it naturally assumes a rotated parabolic shape. Its focal length depends upon how rapidly it is spun. The Earth-based Large Zenith Telescope in British Columbia, is a working example of such a telescope. Its 6 metres diameter rotating mirror is supported on a specially designed large air bearing. As with glass mirrors on Earth, weight is a limiting factor. But if a liquid telescope mirror was assembled in space then weight wouldn't be a limitation. That's the good news. The bad news is, the liquid wouldn't assume a parabolic shape when spun in a zero gravity field. Some gravity, or other form of uniform acceleration, is required.

We also need to note that liquid mirror telescopes must always point upwards, away from the gravitational force that shapes them. This greatly limits the range of targets available to them. But the universe is believed to be isotropic and homogeneous in the large scale, and if this is true then it shouldn't make much difference which way the telescope is pointed, it should see much the same sort of stuff. This sounds like crazy talk, but for deep field surveys it's true enough. Some of the most interesting images captured by the Hubble Space Telescope to date, the Hubble Deep Field images, were obtained by pointing the telescope to an apparently empty and boring piece of sky. Fascinating images of distant galaxies in very early stages of formation were recorded.

Large Liquid Mirror Lunar Telescope

One possibility that is currently being explored is to locate a large liquid mirror telescope on the Moon, see “Deposition of metal films on an ionic liquid as a basis for a lunar telescope” by Ermanno F. Borra et al, or this public NASA article. The Moon has no atmosphere to distort the image, and its surface gravity is only 16% that of Earth's, so weight problems are much reduced. Borra et al investigated the use of the ionic fluid ECOENG 212 which has a low freezing point and a density of only 1.24 g/cc. Once they had formed a spinning mirror with this fluid in a vacuum chamber, they were able to coat it with a layer of evaporated silver. They obtained even better results (80% reflectivity) by evaporating a layer of chromium onto the fluid before the layer of silver, and hope to improve further upon this.

But building a very large telescope the Moon presents some challenges, even if one assumes the existence of a space elevator to do the heavy lifting off Earth. Lowering the components of a massive telescope gently to the Moon's surface would consume a lot of rocket fuel, and there is no atmosphere to use as a brake. Perhaps one day we will be able to mine the Moon for the materials required to build a large telescope, but that day is still a long way off.

Geostationary Liquid Mirror Space Telescope

In this paper we suggest another possibility, which is to use the gravitational well that surrounds the Earth to help shape the surface of the telescope mirror. Suppose the components of a very large liquid mirror space telescope, a large counterweight of equal mass, and a 25,000km tether made of graphene, were lifted by space elevator to a geostationary orbit. The telescope and the counterweight would be attached to opposite ends of the tether, and then set free. They are then moved to their respective orbits using a similar approach to the one proposed by Bradley C.

Edwards for the deployment of the space elevator tether. Rockets attached to the telescope would gradually move it downwards closer to the Earth, and reduce its orbital velocity so that it continues to orbit the Earth once per sidereal day. Rockets attached to the counterweight would move it further from the Earth and increase its orbital velocity so that it too continues to orbit the Earth once per sidereal day. The tether linking them would be initially coiled, and gradually released as the two bodies moved further apart. The two bodies would be steered so that at all times they were above the same point of the Earth's surface, the counterweight vertically above the telescope. The telescope would have insufficient orbital velocity to maintain its reduced altitude, and would exert a downward tug on the tether. Conversely, the counterweight would have excess angular momentum, and would tug upwards on the tether. With care, the upward and downward tugs could be kept equal and opposite, and made to cancel one another.

Once the scope was 9,000km below geostationary orbit, it would experience a downward force of 0.186 newtons per kg, about 2% of Earth's surface gravity. If the counterweight is 15,500km above geostationary orbit, it would experience an upward force of 0.187 newtons per kg, and with a little more fine tuning the two forces could be made to cancel one another, resulting in a stable configuration, although tidal perturbations caused by the Sun and the Moon would require some orbital maintenance from time to time. At this stage, the telescope could be assembled from its parts and commissioned. The telescope mirror would point up to the counterweight some 24,500km distant. A long, slender counterweight would interfere less with the images captured by the telescope.

The Liquid Mirror Space Telescope's Attributes

A wide variety of configurations are possible for the liquid mirror space telescope. Just by way of example, the telescope could have the following attributes:

- A primary mirror diameter of 60 metres,
- with a focal length of 60 metres (an “f1” objective),
- a radius of curvature of 120 meters,
- and a liquid mirror depth of 1cm.

This would result in a mirror with an area of 2,827 square meters. The volume of mirror liquid required would be 28 cubic metres. The density of ECOENG 212 is 1.24 g/cc, so the liquid required would be about 35 tons in mass, but would weigh only about 700kg (i.e. exert a force of about 7,000 newtons) in the reduced gravity field in which it operates.

The primary mirror should probably be divided into a number of adjacent hexagonal pans, each say 6 metres across, requiring about 100 cells to complete the mirror. There is a lot of space junk orbiting the Earth, and if a chunk of this hits and punctures the primary mirror container then one would not want to lose the entire mirror to one accident. The supporting structure would also be far easier to build and manage if broken into a number of independent pans of moderate size. Each pan would contain about 350 kg mass of liquid, with an apparent weight of just 7kg. The containing pans could be supported by graphene threads of about 100 microns diameter that attach to their corners and run to a collar at the centre of curvature of the primary mirror. The collar would rotate freely about a mounting tube on magnetic bearings. The hexagonal pans that contain the mirror liquid should be made from a substance that is sufficiently strong to support the liquid content without deforming more than about 1mm from the required shape. It should be chosen so that the surface tension between the mirror liquid and its container is minimal, to reduce the curvature of the liquid at the edges of the pan. Pipes would run from the centre of each pan to the centres of its six immediate neighbours so that the liquid could find its natural level across all of the pans. But these connecting pipes would have valves that could be activated to cut off the flow from neighbouring pans should any cell become punctured.

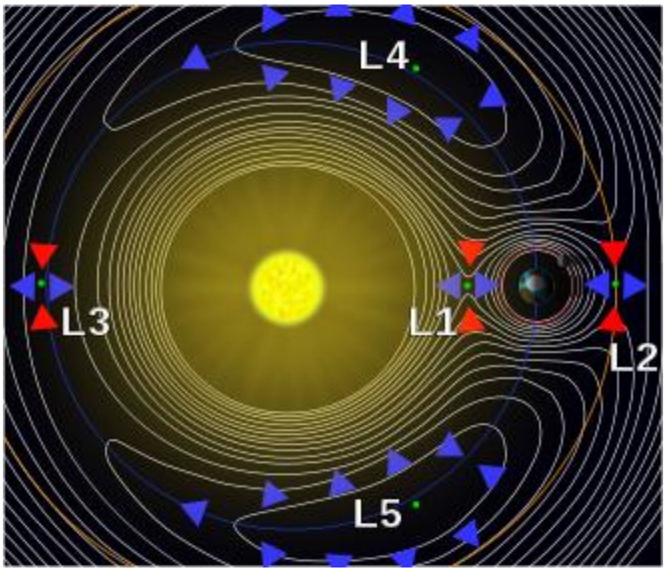
Other Earth Orbits

A geostationary liquid mirror space telescope would rotate through 360° every sidereal day. The image recording element would have to be mounted on a counterbalanced platform that could track sideways, extending the amount of time that light from a particular target is captured. Small tracking errors could be corrected by a computer program once the exposure is completed. Even so, long exposures would not be possible. An obvious option would be to raise the telescope and its counterweight to a higher altitude, where they would orbit the Earth with longer period. The effective gravitational force acting on the telescope's main mirror would then be reduced, unless the length of the tether is extended.

A large space telescope in a geostationary orbit would track the Earth's equator, passing through the shadow of the Earth once a day. It would be exposed to alternate sunshine and darkness, and experience large temperature shifts. Its large size would make it difficult to shield from the Sun's warmth. A space telescope could be put into a high altitude polar orbit, where it would pass through the Earth's shadow and experience temperature instability only during certain seasons of the year.

Lagrangian Point Liquid Mirror Telescope

A liquid mirror space telescope could be positioned at any of the five Lagrangian points of the Earth's orbit, although the gravitational gradients at L3, L4 and L5 would be too small to be useful. At L1 the telescope would have to point either directly towards the Sun or the Earth, limiting its utility, so the L2 location, some 1.5 million km from the Earth, would be the best choice, with the telescope located closer to the Earth than the L2 point, pointing outwards, and the counterweight located further from the Earth than the L2 point. Here the telescope would rotate 360° per annum, allowing for very long exposure times for each target selected.



Lagrangian points, courtesy Wikipedia

Alternatively, a liquid mirror space telescope could be positioned at the Earth-Moon L2 point, some 61,500km beyond the Moon. Here it would rotate with the Moon about the Earth, completing a rotation every 28 days or so. This would lead to conveniently long but not excessively long exposure times. The Moon would always be between the space telescope and the Earth, so a relay station would be needed to allow communication between the telescope and its control centre on Earth.