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Step Towards the Development of Lunar Liquid Mirror Telescope

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ABSTRACT : Desolate, airless and with no people around for hundreds of thousands of kilometers, the Moon is a great place for astronomers. Sky watchers have an enduring hope of one day building a lunar observatory, where gleaming from the earliest stars can be snared without the curse of man-made light pollution and Earth's atmospheric distortion. But making telescopic mirrors is eye-wateringly expensive, for it requires grinding and polishing glass to an accuracy of a few tens of billionths of a meter and after making a mirror, there's the risk of breaking it when you haul it to the Moon. So, the scientists brought the idea to use a liquid mirror telescope on the surface of the moon, to be known as the lunar liquid mirror telescope (LLMT), that could be hundreds of times more sensitive than the Hubble Space Telescope. The potential of a return of human presence to the Moon raises the possibility of significant lunar infrastructure and with it the possibility of astronomical installations which can make use of the lunar surface as a stable platform and take advantage of the lack of atmosphere. A study is being conducted to determine the feasibility of constructing a lunar liquid mirror telescope, or LLMT, by NASA Institute for Advanced Concepts (NIAC) and the Canadian Space Agency.

Keyword : Lunar Liquid Mirror Telescope (LLMT), Hubble Space Telescope, NASA Institute for Advanced Concepts (NIAC), Canadian Space Agency.

I. INTRODUCTION

Given that detector technology and optical technology can achieve near 100% efficiency for the transmission and detection of photons, the primary means of obtaining higher sensitivity astronomical observations is via larger apertures. For point source sensitivity, large apertures provide both larger collecting area and better angular resolution - assuming they are limited by diffraction. This is why the worldwide astronomical community is currently extensively studying the implementation of large (>20 m) telescopes. A key element of these proposed ground-based telescopes is adaptive optics systems which correct for the effects of atmospheric seeing (blurring) and provide improved point source sensitivity [1]. Liquid mirror telescopes (LMT's) have been built on Earth, the Large Zenith Telescope is a 6-meter LMT in British Columbia is the third largest telescope in North America. LMT experts plan to build a 100-meter mirror, which would collect 1,736 times more light than the Hubble. Even a 20-meter instrument, which is more likely in the near term, would be 70 times more sensitive than the Hubble and could detect objects 100 times fainter than those that will be seen with the James Webb Space Telescope, a next-generation orbiting observatory scheduled for launch in 2013 [2].

Liquid mirror telescopes are telescopes made with a reflective liquid in place of the conventional glass lens. The most common liquid used is mercury (Hg), but other liquids will work as well (for example, low melting alloys of gallium). The container for the liquid is rotating so that the liquid assumes a paraboloidal shape. A paraboloidal shape is precisely the shape needed for the primary mirror of a telescope. The rotating liquid assumes the paraboloidal shape regardless of the container's shape. To reduce the amount of liquid metal needed, and thus weight, a rotating mercury mirror uses a container that is as close to the necessary parabolic shape as possible. Liquid mirrors can be a low cost alternative to conventional large telescopes. Compared to a solid glass mirror that must be cast, ground, and polished, a rotating liquid metal mirror is much less expensive to manufacture.

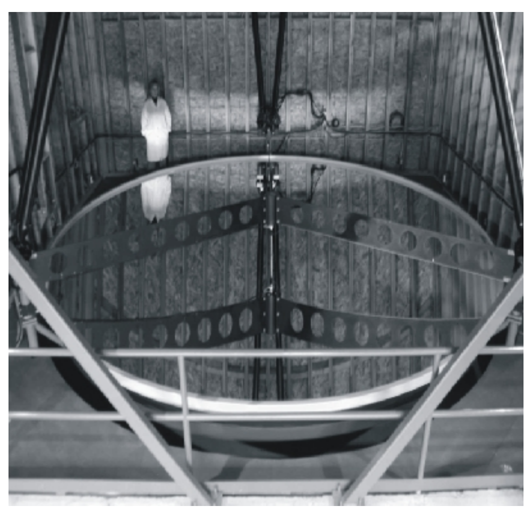

Fig. 1. The Large Zenith Telescope in British Columbia has a 6-meter primary liquid mirror (Photo: Courtesy of Dr. Paul Hickson)

II. INSTALLATION OF THE LLMT

Although the final cost of the project is yet to be determined, a 20-meter lunar LMT ought to be a bargain in comparison to the James Webb Space Telescope, which is expected to carry a $4.5 billion price tag. It would also make the JWST look like a child's spyglass [2]. The greatest advantage of a liquid mirror telescopic is its small cost, about 1% of a conventional mirror. This cuts down the cost of the entire telescope at least 95%. The University of British Columbia's 6 meter Large Zenith Telescope cost about a fiftieth as much as a conventional telescope with a glass mirror [3]. Liquid telescopes cost 10 to 20 times less to build than polished aluminum mirrors of similar size, in part because they needn't be engineered to the same tolerances. And even the largest liquid mirrors don't require the sophisticated support structures that are needed to prevent solid ones from sagging under their own weight. All the parts of the LLMT will have to be shipped by rocket to the moon and assembled there. The primary mirror because it's liquid, will simply be carried in a jug and stored until the telescope infrastructure is ready. Then an astronaut will pour the liquid into the dish to form the primary mirror. The truss system used to support the dish and mirror could be prebuilt and deployed robotically, its framework unfolding like an umbrella being opened.

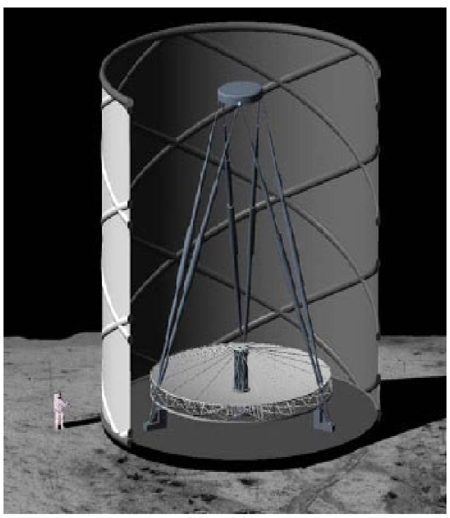

Fig. 2. A NASA rendering of a lunar liquid mirror telescope. (Image courtesy of NASA)

One disadvantage of a liquid telescope is that it cannot be pointed in an arbitrary direction, but rather looks toward the zenith. On the other hand, eliminating steering capabilities simplifies the engineering design and reduces the weight. Such a telescope is best suited for cosmological studies of large redshift objects. For such studies, many of the interesting objects are in the IR. A location near the lunar polar region may be a good choice for looking at a small region of the sky.

Table 1 summarizes the design parameters. The 2 m precursor telescope would test the new technologies that will have to be developed and will also carry out a competitive research program. The 20 m LLMT, hopefully to be followed by a gigantic 100 m telescope, would be the first competitive instrument. We consider the optical design of a three mirror f /15-f /20 system diffraction-limited at 1 m wavelength. The focal ratio of f/15 was chosen so that the 15° field of view can be critically sampled (Nyquist sampling) at 1.6 m wavelength with current technology arrays with 18 m pixels. A multi-object spectroscopic instrument is also essential to meet our scientific requirement. Working in the infrared requires a very cold environment and sets stringent technical requirements on the telescope and instrumentation. For example, the liquid mirror must operate at a very low temperature (about 100 K) that is above its freezing point, setting strict requirements for the liquid substrate [9].

Table 1 : Parameter of LLMT Designs.

Parameters	*2 m Telescope*	*20 m Telescope*	*100 m Telescope*
Mirror area (m^2)	3	300	7600
Mirror density (kg mA 2)	15	3.3	5Y10
Primary mass (tons)	0.05	1	50
Total mass (tons)	0.5	3	100
Field	3.1 annulus	150	30
Diffraction limit at 1 m (arcsec)	0.1	0.01	0.002
Pixels at 2 m (Nyquist)	18000	45000	45000

III. LIQUID SUITABLE FOR THE LLMT

The basic requirements of the liquid to be used in the LLMT are:

* High Reflectivity.
* Should retain its liquid state in the lunar environment.
* Low vapor pressure required to prevent evaporation in the lunar vacuum.

A. Mercury

The first candidate is mercury (Hg) which is being utilized in the large zenith LMT's on Earth. But mercury won't work in the harsh environment of moon because its freezing point is –101.966° F (–74.43° C). The low temperature on the moon can reach –243° F (–153° C), so mercury would solidify, making it an unacceptable choice for the primary mirror. Moreover it is very dense and thus heavy to launch, it is very expensive, and would evaporate quickly when exposed to the lunar vacuum [4].

B. Ionic Liquids

Recently, scientists have discovered a class of liquids that might make an LLMT possible. They are known as ionic liquids, and they have properties such as:

* They are liquid at temperatures below –212° F (–136° C).
* They are composed entirely of ions.
* They possess no vapor pressure at room temperature or below, which means they won't evaporate.
* They are highly viscous.

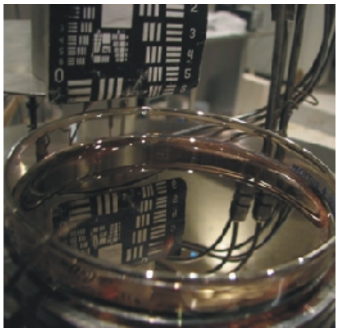

Fig. 3. Five centimeter diameter flat liquid mirror. It is made of an ionic liquid coated with a thin layer of silver. A reflection of a resolution chart is visible in the liquid.

Although not highly reflective themselves, ionic liquids can be coated with materials that give them high reflectivity. For example, a spinning mirror of an ionic liquid can be coated with an ultrathin layer of silver about 50 to 100 nanometers just as if it were a solid mirror. In the vacuum of space, a liquid mirror coated with a thin solid layer of silver would neither evaporate nor tarnish [5].

One ionic fluid showing promise is

1-ethyl-3-methyli-midazolium ethylsulphate

Commercially known as **ECOENG 212.**

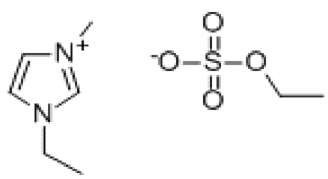

Fig. 4. Chemical Structure of ECOENG 212.

ECOENG 212 can be coated in silver by Physical Vapor Deposition (PVD) under high vacuum, and shows good reflectivity properties while remaining liquid down to 175 K. An approximately 10 nm thick Chromium diffusion-stop layer previously deposited before the Silver further improves reflectivity. Both the Silver and the Chromium exist as a colloidal dispersion in the ionic liquid, rather than as a continuous solid layer [5]. Unfortunately, this substance only remains liquid to temperatures of 175 K, below which it freezes. A liquid with an operating temperature of 130 K or below is desired.

C. Metal Ammonia Solutions

Liquid metals created by dissolving alkali metals in ammonia have been known for over 130 years [6]. They have been extensively studied with a large number of techniques over many years. Of greatest interest for a liquid lunar telescope is the saturated solution of lithium in ammonia, $Li(NH_3)_4$. In these solutions, the outermost electron of the lithium dissociates from the metal, resulting in one nearly free electron for each lithium atom dissolved. Li(NH3)4 is a good liquid metal, with an electrical conductivity higher than liquid mercury. Importantly, it remains a liquid down to a temperature of 89 K [7].

$Li(NH_3)_4$ is not very suitable for earth-based telescopes. It has a high vapor pressure (~ 0.8 bar) at room temperature. In addition, the mixtures react with air, harming the surface quality. However, these difficulties would not be present at low temperature under vacuum. Li(NH3)4 has other valuable properties for a liquid telescope. A simple mixing of the constituents suffices to create the solution. It is also a very low density (~ 0.5 g cm^{-3}) liquid. The low density minimizes the weight of liquid required for a given size telescope. For instance, a 50 m diameter telescope with a 2 mm thick liquid mirror would require about 2 metric tons of liquid. For comparison, a liquid mercury mirror of the same diameter and thickness would need a mass of about 54 metric tons. The low mass of the liquid reduces the demands on the support structure as well as transport costs [7].

IV. CONCLUSION

Lithium ammonia has several advantages over the proposed ionic liquids. First, its density is lower by a factor of 2-3. In addition, there is no need for coating the liquid on site. This eliminates the weight of the coating equipment as well as the silver needed for the coating. Perhaps more importantly, it eliminates another step in the assembly procedure. Moreover, there is enough amount of research going on the synthesis of ionic liquids and given that there are millions of ionic liquids, scientists feel confident that they will find another candidate with a better freezing-point profile. So, the liquid to be employed for the primary mirror of the LLMT is still not confirmed.

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