Surveys with a 4-m Liquid Mirror Telescope

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Abstract: Liquid Mirror technology was developed a few years ago by E. Borra and collaborators at Laval University, Canada. A liquid mirror consists in a thin layer of a reflecting liquid (e.g. mercury) which rotates around a vertical axis. The surface of the liquid then takes the shape of a paraboloid which is the ideal surface for the primary mirror of an astronomical telescope. Obviously, the telescope cannot be tilted and can only observe the zenith. Consequently, pointing and tracking are impossible. Nevertheless, its main advantage is its low cost, almost 30 times less than a glass mirror telescope for the same diameter and, therefore, it can be fully dedicated to a project, like a survey for example. Several Liquid Mirror Telescopes (LMTs), such as the NASA 3-m LMT and the University of British Columbia - Laval 2.7-m LMT, have already been built and gave excellent scientific results.

LMTs are particularly well suited for the search and study of gravitational lenses, type Ia supernovae, faint nearby red, brown and white dwarfs, halo stars with high proper motions and, more generally, all variable phenomena like quasars, variable stars, micro-lensing effects, etc.

The construction and operation of such a 4-m LMT in the southern hemisphere is planned for the near future.

1 Introduction

The surface of a spinning liquid takes the shape of a paraboloid that can be used as the primary mirror of a telescope. Following the suggestion that modern technology (Borra 1982) gives us tracking techniques that render liquid mirrors useful to astronomy, research and development programs were begun to assess the feasibility of the concept. Mirrors up to 2.5 m diameter were extensively tested and showed the high surface quality of such mirrors (Borra & al. 1992; Borra, Content & Girard, 1993; Ninane & Jamar, 1996; Girard & Borra, 1997). Liquid mirror telescopes cannot be tilted and hence cannot track like conventional telescopes do. In order to track images through narrow- and wide-band filters or slitless spectroscopy, one can use a technique called time delayed integration (TDI), also known as drift scan, in which the CCD detector tracks the charges by electronically stepping its pixels. The information is stored on disk and the night observations can be coadded with a computer to give long integration times. The technique has been demonstrated with a 2.7 m diameter liquid mirror telescope (Hickson & al. 1994).

Why are we interested in liquid mirror telescopes, considering their limitations? The main reason comes from the size and cost advantages. The low cost (2 orders of magnitude less than an equivalent classical telescope) makes it possible for a small team of astronomers to have their own large telescope working full-time on a specific project. This is in practice not realistic with expensive classical telescopes. Some research projects (e.g. time consuming surveys, long term photometric monitoring programs) simply cannot be envisioned with classical telescopes but are possible with LMTs. This is particularly true for the type of research where the region of sky observed is not particularly important (e.g. cosmology).

2 Telescope technical description

The surface of a reflecting rotating liquid takes the shape of a paraboloid which is the ideal surface for the primary mirror of an astronomical telescope. The focal length F of the mirror is related to the gravity g and the angular velocity of the turntable ω by

$$F = \frac{g}{2\omega^2}$$

The container and the bearing rest on a three-point mount that aligns the axis of rotation parallel to the gravitational field of the Earth (Figure 1). The container must be light and rigid. A thin layer (0.5 mm to 1 mm) of mercury is then spread on the container.

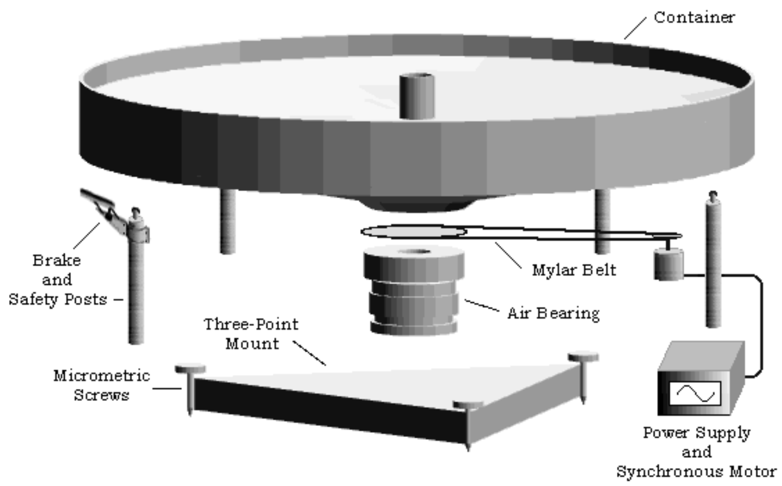

Figure 1: Exploded view of the basic mirror setup. [From Université Laval (Canada) web site: http://wood.phy.ulaval.ca/lmt/home.html]

Figure 2 shows the entire telescope system. Comparing the LMT to a conventional telescope, we see that they are similar with the exception of the mount. The top parts are identical, consisting of a focusing system and a detector. There is some cost saving in the upper end structure since it does not have to be tilted. The largest cost savings obviously come from the mount which consist of a simple tripod.

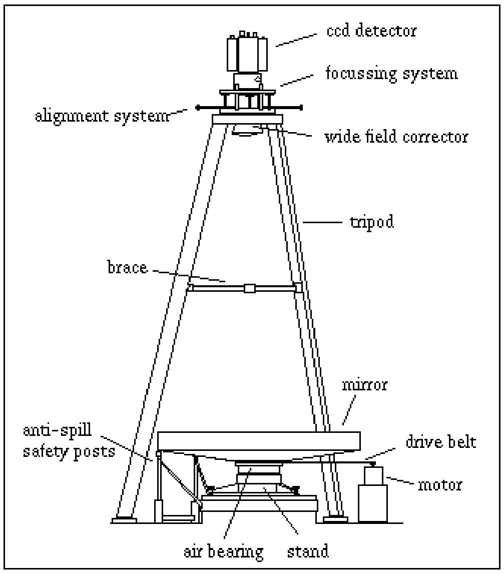

Figure 2: Entire telescope system. [From University of British Columbia (Canada) web site: http://www.astro.ubc.ca/LMT/lmt.html]

The tracking will be done with the TDI technique. Obviously, low-resolution spectroscopy can be carried out with interference filters. With a dichroic beam splitter and two CCDs, the observations can be done simultaneously in two different wavebands.

A semi-classical on-axis glass corrector capable of about 1-degree field will be used. It will remove the TDI distortion. With a classical corrector, the TDI technique degrades the images. This comes from the fact that the TDI technique moves the pixels on the CCD at a constant speed on a straight line while the images in the sky move at different speeds on curved trajectories. The deformation depends on the latitude of the observatory (it is zero at the equator and increases with latitude).

3 Science with a LMT

3.1 Introduction

Thanks to its very low cost ($\sim$ 1 million US$), a LMT can be entirely dedicated to a scientific project and, in spite of its relatively restricted field of view ($\sim$ 1 degree), several scientific drivers could be carried out like statistical determination of the cosmological parameters H_0 and q_0 based upon surveys for supernovae and gravitational lenses, search for low surface brightness and star-forming galaxies, observational studies of quasars and large scale structures, detection of high stellar proper motions, trigonometric parallaxes, a wide range of photometric variability studies (photometry of micro-lensing effects and of variable AGN over day to year time scales) and also a unique database for follow-up studies with the VLT. Among them, we present here only one example of those scientific projects: gravitational lensing studies.

3.2 Gravitational lensing studies with a LMT

Given the very small number ($\sim$ 25) of presently known multiply imaged quasars, almost randomly distributed over the sky, the probability to observe even only one of these within the $\sim$ 30' zenithal field of view of a LMT is virtually zero. Therefore, the observational strategy for studies of gravitational lensing effects with a LMT rather consists in first surveying a sky area as deep (B $\sim$ 24) and as wide as possible for interesting targets (e.g. quasar candidates using color and variability criteria) and then select gravitational lens candidates among them. The extent of the field of view is of course primarily dictated by the number (at least two) and/or the size (e.g. 2000$\times$4500) of the thin CCDs placed at the LMT prime focus. For the case of multiply imaged quasars, we find that direct imagery with a 4-m LMT would lead, after less than six weeks of effective operation, to the detection of approximatively 50 new gravitational lens systems ($\Omega_0 = 1, \lambda_0 = 0$). The natural possibility to photometrically monitor these at daily intervals offers a unique opportunity to define a sub-sample of interesting lenses with reliable geometrical parameters, time delay measurements and/or micro-lensing signatures for further astrophysical and cosmological applications (Surdej and Claeskens 1997).

3.3 Requirements for a gravitational lensing imaging LMT survey

Assuming that the observations would be carried out using a 4-m LMT in the drift-scan mode (single integrations of 90 sec), which will ensure excellent flat-fields, the expected magnitude limits M_{lim} for point sources with a seeing of 0.7 arcsec, a 5σ photometric accuracy and combining a number of N repeated scans, are listed in Table 1 for various broad band filters. Typically, in less than six weeks of effective observing time, a deep multi-color LMT survey would provide us with the necessary data to achieve the scientific goals previously exposed.

Filter	Number of scans	M_{lim}
U	15	24.5
B	3	24.5
V	6	24.5
R	4	23.5
I	6	23.5
Gunn-z	2	22.3

Table 1: Broad band filter, requested number of scans and corresponding limiting magnitude achievable for the detection of point-like sources with a 5σ photometric accuracy.

3.4 A site location for a LMT

A good site from where to carry out a LMT survey and photometric monitoring of gravitational lens systems should be characterized by excellent weather conditions (image and photometric quality) and allow access to sky areas at high galactic latitudes, the latter ones being also accessible to large telescopes such as the VLT to permit follow-up observations of faint interesting targets.

For instance, operation of a LMT (field of view $\sim$ 30') from La Silla (latitude of 29 degrees 15 minutes South) would enable to cover approximately 90 square degrees of sky at high galactic latitude ($|b| > 30^\circ$), passing very near to the south galactic pole. At the same time, such a LMT survey would probe regions near the galactic center, offering unique data for studies of the galactic structure, stellar populations, including accurate measurements of stellar proper motions (cf. red, white, brown dwarfs, faint halo stars, etc.), trigonometric parallaxes and detection of stellar microlensing effects caused by bulge stars, dark compact objects, etc.

4 Interested institutions

The institutions actively interested by the project, the technical development they could take on and the scientific interests they find in the project are summarized in Table 2.

Institutions interested by the LMT project and people (*) who can be contacted	*Technical developments they could take on*	*Scientific interests*
University LAVAL (Ca) Dr E. Borra* Dr R. Cabanac	- project supervisor - building	- QSO surveys - large scale structures
Observatoire de Marseille (Fr) Dr G. Lemaître* Dr G. Comte* Dr A. Bosma	- corrector and upper end	- low surface brightness galaxies - faint active star-forming galaxies
Royal Observatory of Edinburgh (UK) Dr M. Hawkins* Dr A. Russel*	- CCDs	- QSO surveys (variability)
University of Santiago (Chile) Dr L. Campusano Dr J. Maza*	- data acquisition - data storage - telescope operation - supervision of the building on the site	- QSO surveys - search for supernovae
Institut d'Astrophysique de Liège / Centre Spatial de Liège (Be) Dr J. Surdej* Dr N. Ninane* Dr C. Jamar Dr J.-P. Swings Ch. Jean	- mirror - project scientist	- QSO surveys - gravitational lenses - supernovae
ESO	- site - administrative help - technical help on the site	- large scale structures - surveys
University Mc Gill (Ca) Dr D. Hanna Dr K. Ragan	- data analysis software	

Table 2: Institutions interested by the LMT project

5 Conclusions

With few words, the ideas briefly developed in this document may be summarized as follows:

- dedicated and very interesting science can be done with a zenithal telescope,
- the technology is ready to develop a 4-m class liquid mirror telescope at very low cost,
- institutions are actively interested by the project.

Now, we want to officially set up a consortium and apply for grants.

6 References

See the WWW bibliography available at the URL:
http://wood.phy.ulaval.ca/lmt/home.html
http://vela.astro.ulg.ac.be/grav_lens/grav_lens.html

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