Le projet international du télescope à miroir liquide de 4m (The International 4m Liquid Mirror Telescope, ILMT)

Cours 8 + 5,
Astro./Tech. Spat.
+ Master Sc. Sp.
18/11/2011

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The International 4m LMT project (J. Surdej):

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- International…
- Vous avez dit : « miroir liquide » ?
- Du miroir liquide au télescope...
- Les télescopes à miroir liquide dans le monde
- Avantages et désavantages des TMLs
- Le ILMT et la science...
- Le site idéal
- Actuellement
- Conclusions

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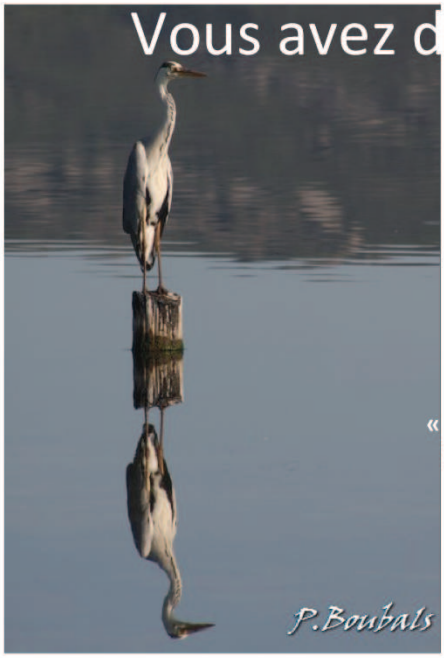
The International 4m LMT project (J. Surdej):

International…

I.P.: Prof. J. Surdej (ULg)
Chefs du projet: Prof. S. Habraken & Prof. J.-P. Swings (ULg)
En collaboration avec:
- AMOS (Adv. Mech. Opt. Syst.) & CSL (Centre Spatial de Liège)
- ROB (Royal Observatory of Belgium),
- Canada (Laval Univ., Montreal Univ., Toronto Univ., Yorke Univ.)
- ARIES (Aryabhatta Research Institute of Observational Sciences, India)

Vous avez dit miroir liquide ?



« L'œil ne se voit pas lui-même ;
il lui faut son reflet dans quelque autre chose ».

William SHAKESPEARE

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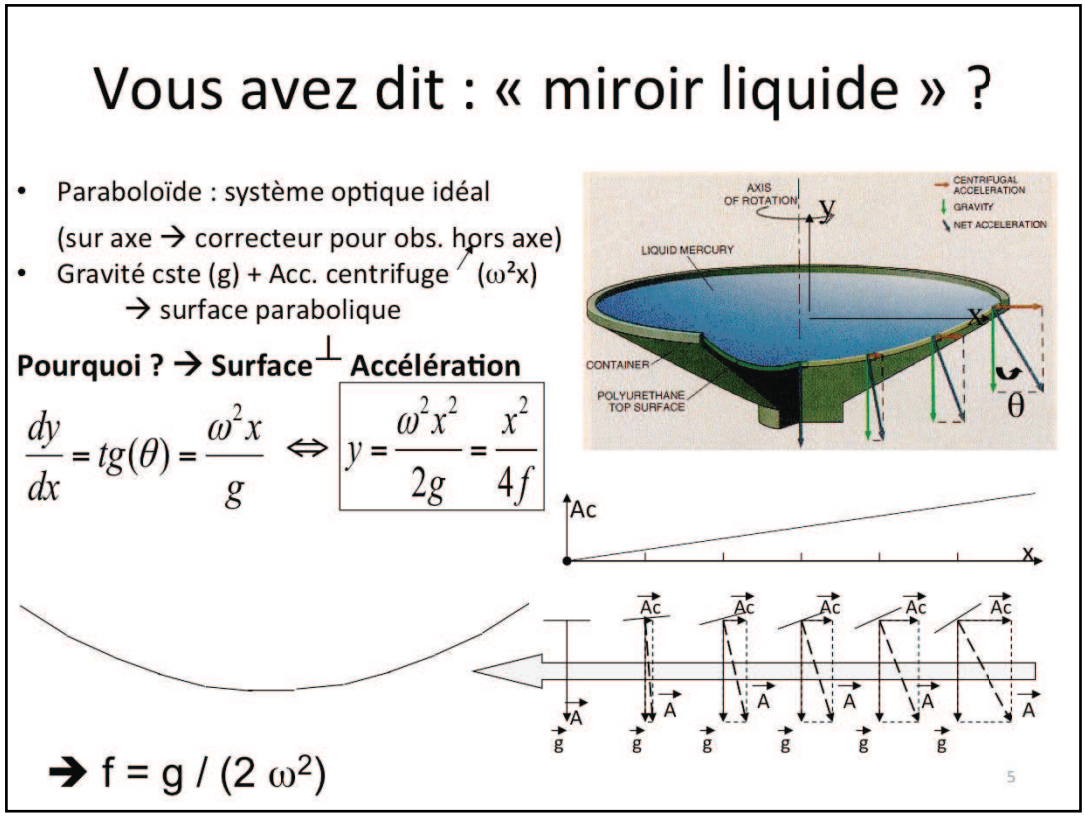


The International 4m LMT project (J. Surdej): What is a liquid mirror?

As we all know, a perfect parabola represents the ideal contour for an optical device that focuses parallel rays of light into a single point.

It is therefore of the greatest importance to have realized that a rotating liquid surface takes the shape of a parabola under the constant pull of gravity and a centrifugal acceleration, which grows stronger at distances further from the central axis (E. Cappoci, 1850). The parabolic curve occurs because a liquid surface must always be perpendicular to the net acceleration it experiences, which in this case becomes increasingly steep with distance from the central axis. Indeed, inspection of the above figure clearly shows that

$dy/dx = tg(\theta) = \omega^2 x / g$, (1)

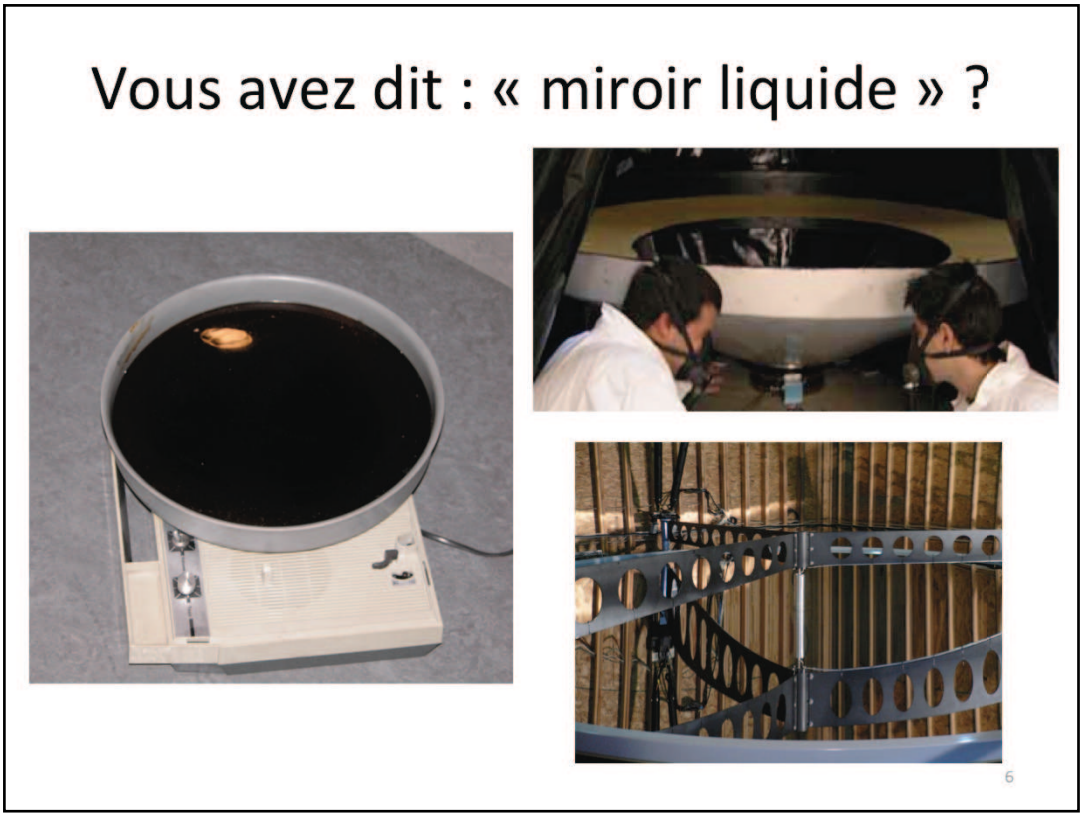
where $\omega^2 x$ and g represent the centrifugal force and gravity acting on a mass unit. Integration of the above differential equation leads to the solution

$y = \omega^2 x^2 / (2g) = x^2 / (4f)$, (2)

which is the equation of a parabola with a focal length

$f = g / (2\omega^2)$, (3)

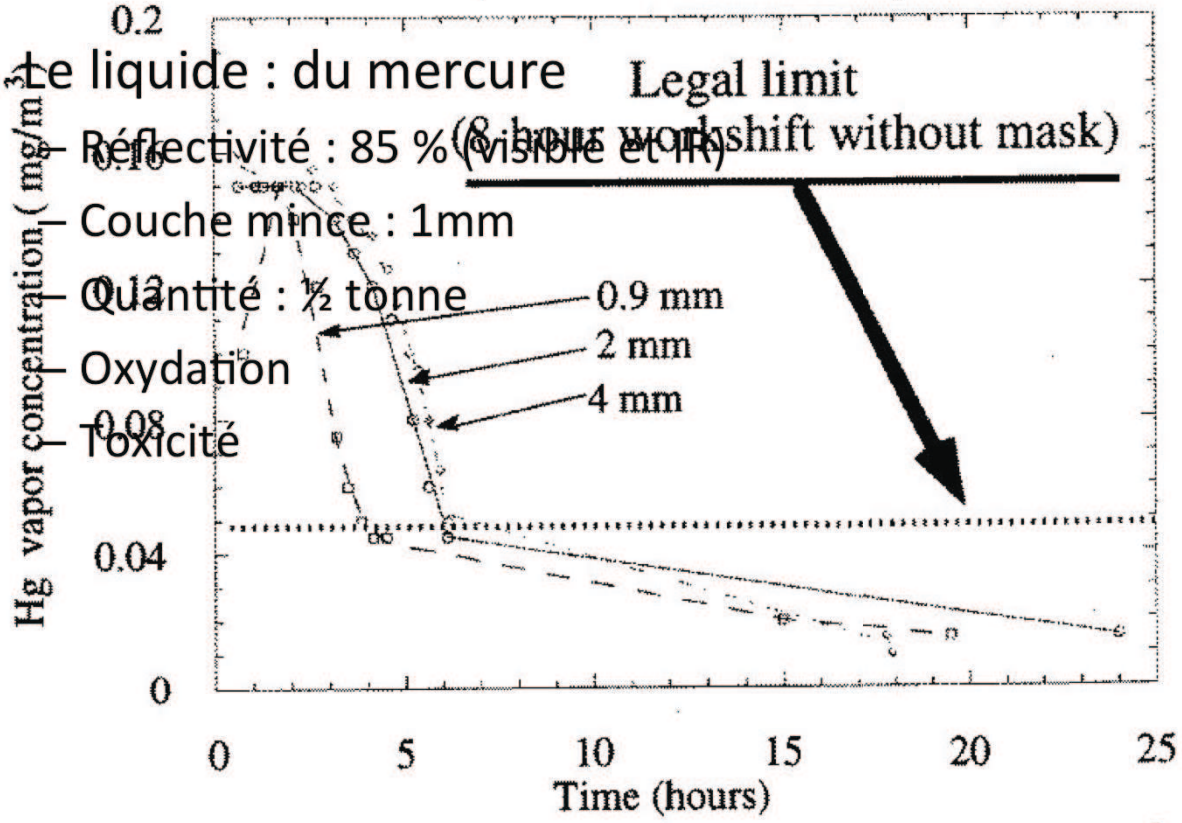
such that a focal length of approximately 40 cm is obtained for a value of the angular velocity of 33 turns per minute. A gramophone with a turntable of 20 cm in diameter may thus provide us with a liquid mirror characterized by a focal ratio f/D ~ 2, a very acceptable value for an astronomical mirror (see the proposed experiment). For large mirrors of practical interest, the periods of rotation are of the order of several seconds and the linear velocities at the rims of the mirrors range between 2 and 10 km/h.



The International 4m LMT project (J. Surdej); Examples and didactical experiment: On the left, an old phonogram was transformed in a small demonstration liquid mirror. A container has been adapted and filled with motor oil. This small mirror has been shown during the lesson to illustrate the liquid mirror principle.
On the top right, two Ph.D. students are seen working on the 2m Liquid Mirror Telescope of the CSL (Liège Space Center). This telescope was first aimed at demonstrating the feasibility of the concept. It has also been used to train with liquid mirror manipulation and to test the acquisition software.
On the bottom right, the Large Zenithal Telescope (LZT) primary mirror located near Vancouver.

Du miroir liquide au télescope...

- Le liquide : du mercure
  - Réflectivité : 85 % (visible et IR)
  - Couche mince : 1mm
  - Quantité : ½ tonne
  - Oxydation
  - Toxicité



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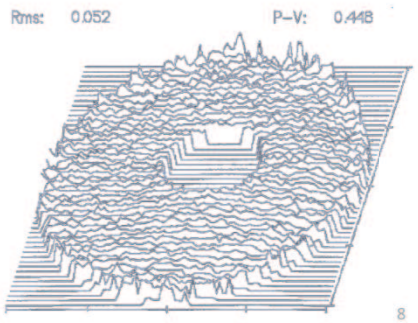
The International 4m LMT project (J. Surdej); Description of a LMT:
The above figure illustrates the mercury vapor concentration as a function of time for different thicknesses of the mercury layers.

Miroir liquide: qualité optique

- Théorie
  - Paraboloïde parfait
- Littérature
  - Test interférometrique : Parabole à λ/20 (Borra 1992)
  - Images limitées par le seeing: qualité scientifique (Hickson 2007)



Perturbations des miroirs liquides 1/2

- Courbure de la terre
- Désalignement de l'axe de rotation
- Rotation de la terre

➔ Changement de distance focale

+ autre effets

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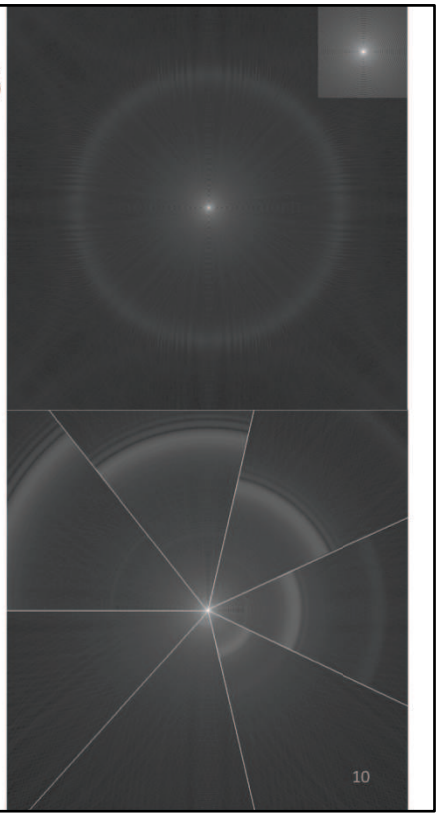
Perturbations des miroirs

- Ondes concentriques
  - Source: vibrations
  - Longueur d'onde ~ 1 - 2 cm
- Ondes spirales
  - Source: vent de rotation
  - Longueur d'onde ~ 3 - 5 cm
- Amplitudes : ~ µm

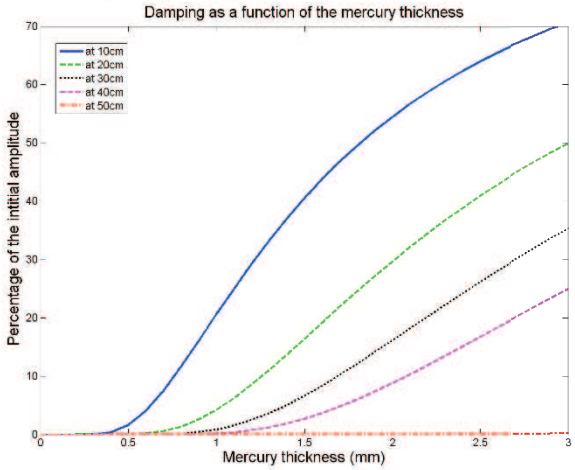


Solutions

Ondes concentriques → Stabilité

Onde spirales → Protection (Mylar)

Epaisseur de mercure



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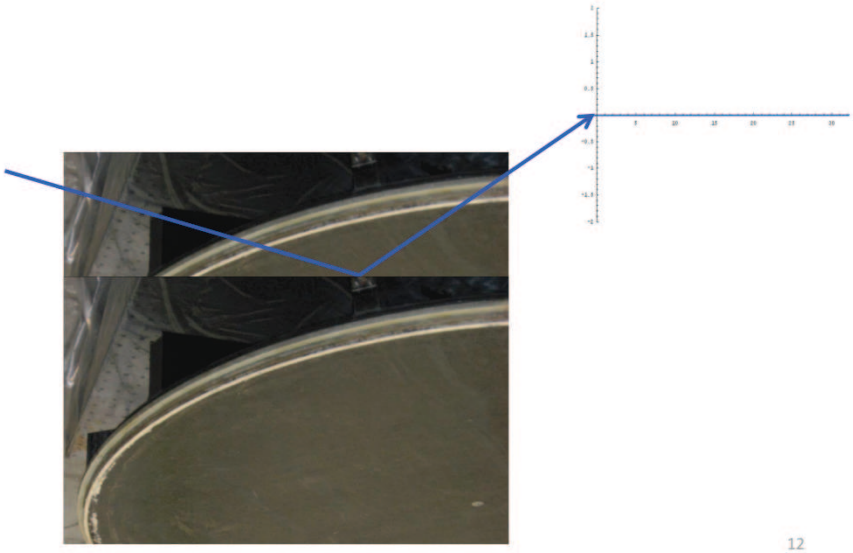
Ondes sur le miroir: détection

- Ne pas utiliser d'éléments mobiles



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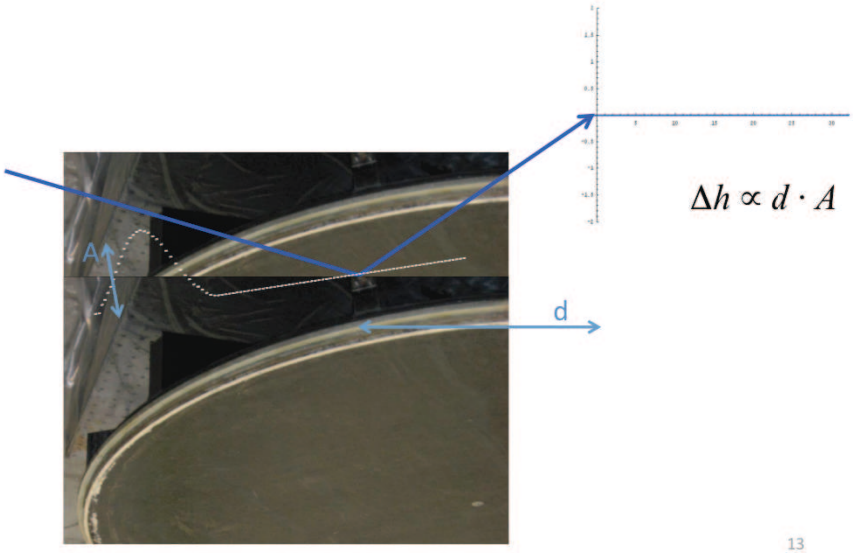
Waves on the mirror: detection

- Ne pas utiliser d'éléments mobiles



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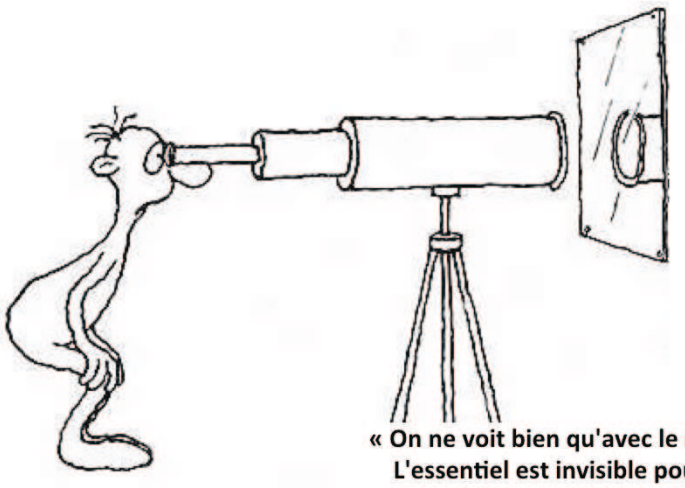
Du miroir au télescope



« On ne voit bien qu'avec le cœur.
L'essentiel est invisible pour les yeux ».

Antoine de Saint-Exupéry

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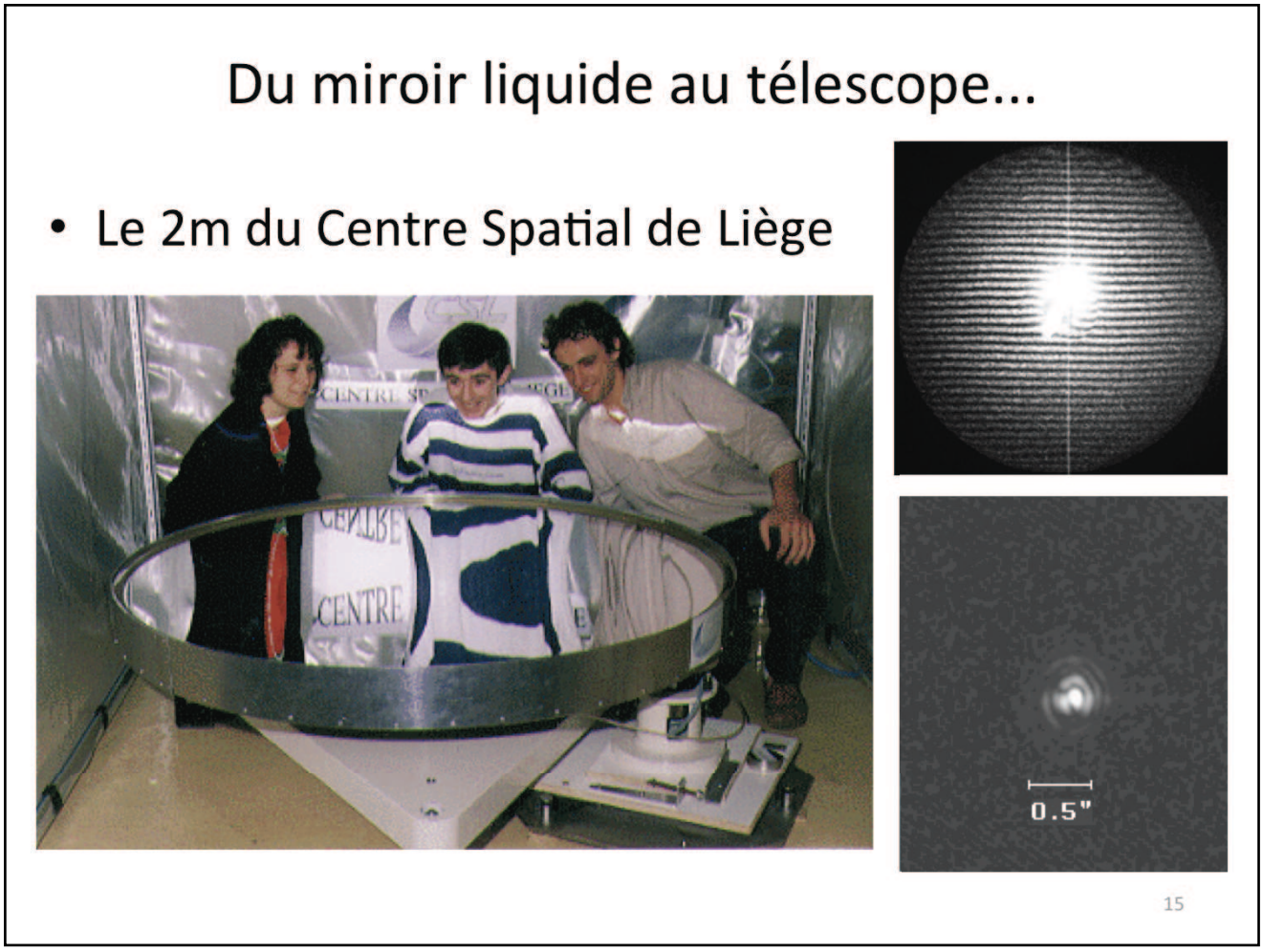
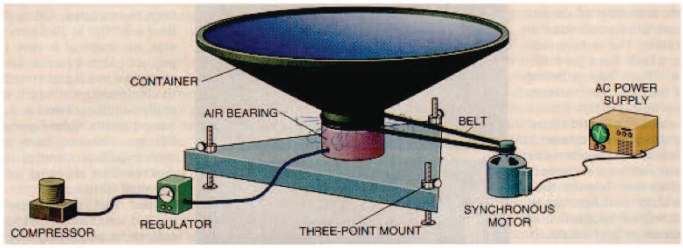
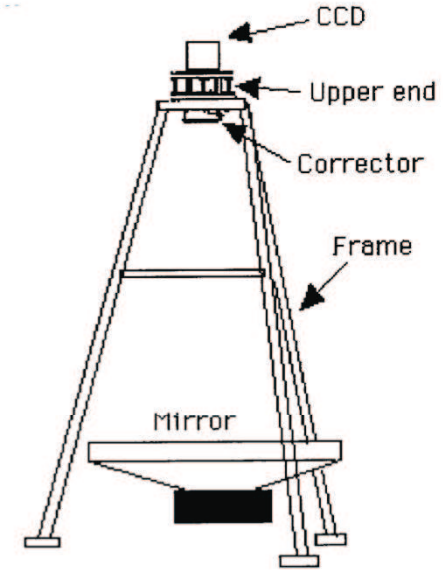


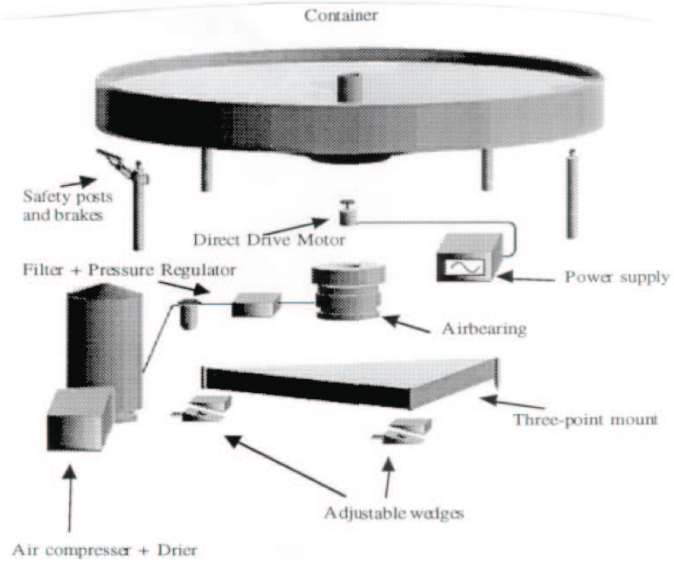
The International 4m LMT project (J. Surdej); Description of a LMT:
After presenting the LM experiment, slides of real (mercury) LMs (1.4, 2.5 and 3.7m) will be shown! We will say a few words about the optical shop tests (interferometry, airy disk point spread function, etc.) carried out for the 1.4 and 2.5m mirrors. We will then give a general description of the LMT systems and say a few words about the behaviour of the mercury vapour concentration with time ("Famous mad hatters"). We will describe a little bit the properties of (classical and new; cf. Borra, Moretto and Wang) correctors to be used at the prime focus.

Telescope technical description: The instrument has been developed taking into account two requirements: low cost and optimal optical performance. The next figures show views of the entire telescope system and of the basic mirror set-up. 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. The turn-table is a commercial air bearing that is driven by a synchronous motor which is controlled by a variable-frequency AC power supply stabilised with a crystal oscillator. The container is a very important component of the system. It must be light and rigid. It is made with Kevlar laminated over a foam core (Hickson, Gibson and Hogg 1993). A thin layer (0.5 mm to 1 mm) of mercury is then spread on the container. The reflectivity of mercury is approximately 85% and it is easy to clean it with a filter. 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 in a focusing system and a detector. There is some saving in the upper end structure since it does not have to be tilted. The largest cost savings obviously come from the mount which consists of a simple tripod.

Du miroir liquide au télescope...

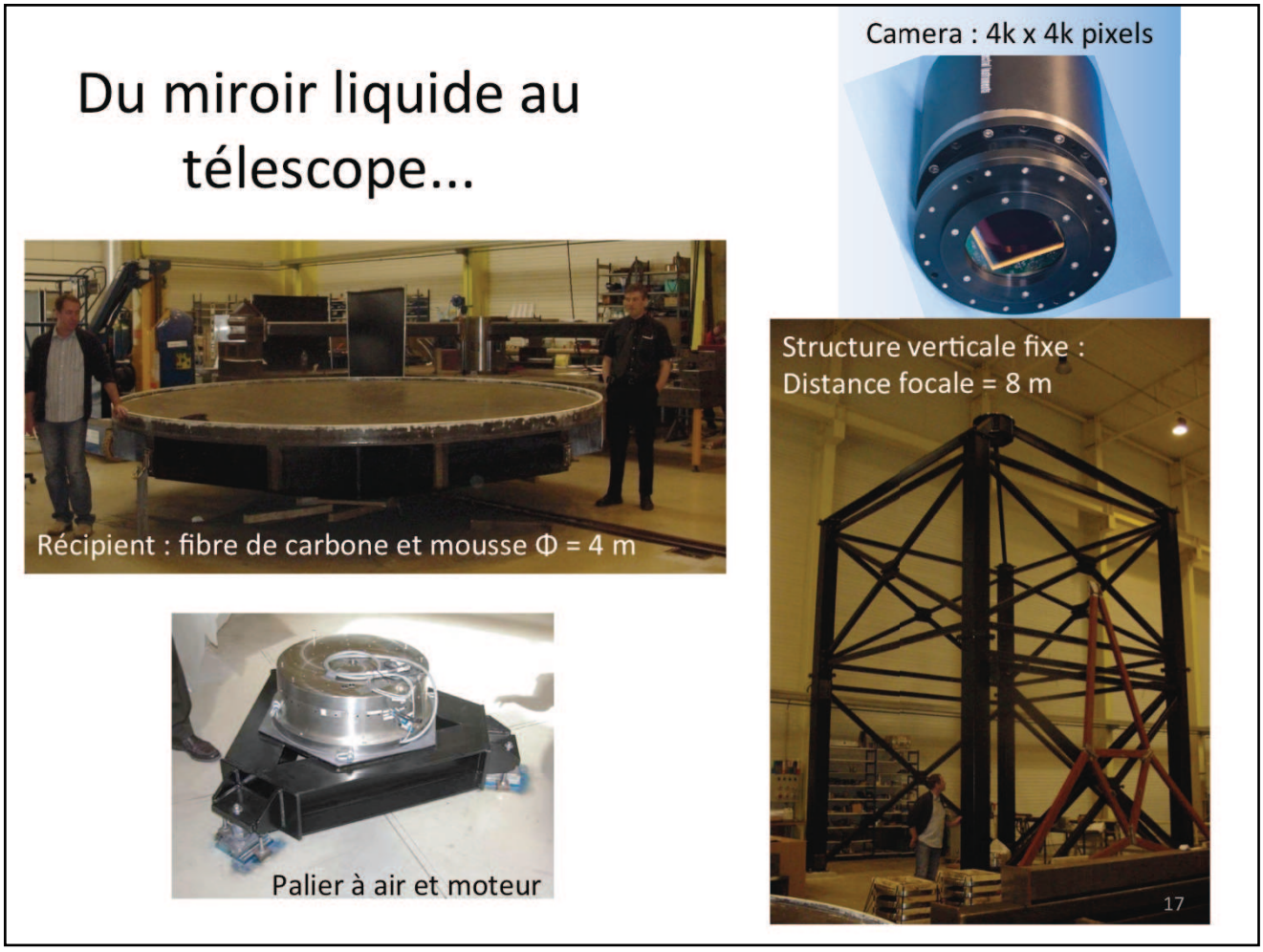






The International 4m LMT project (J. Surdej); Description of a LMT:

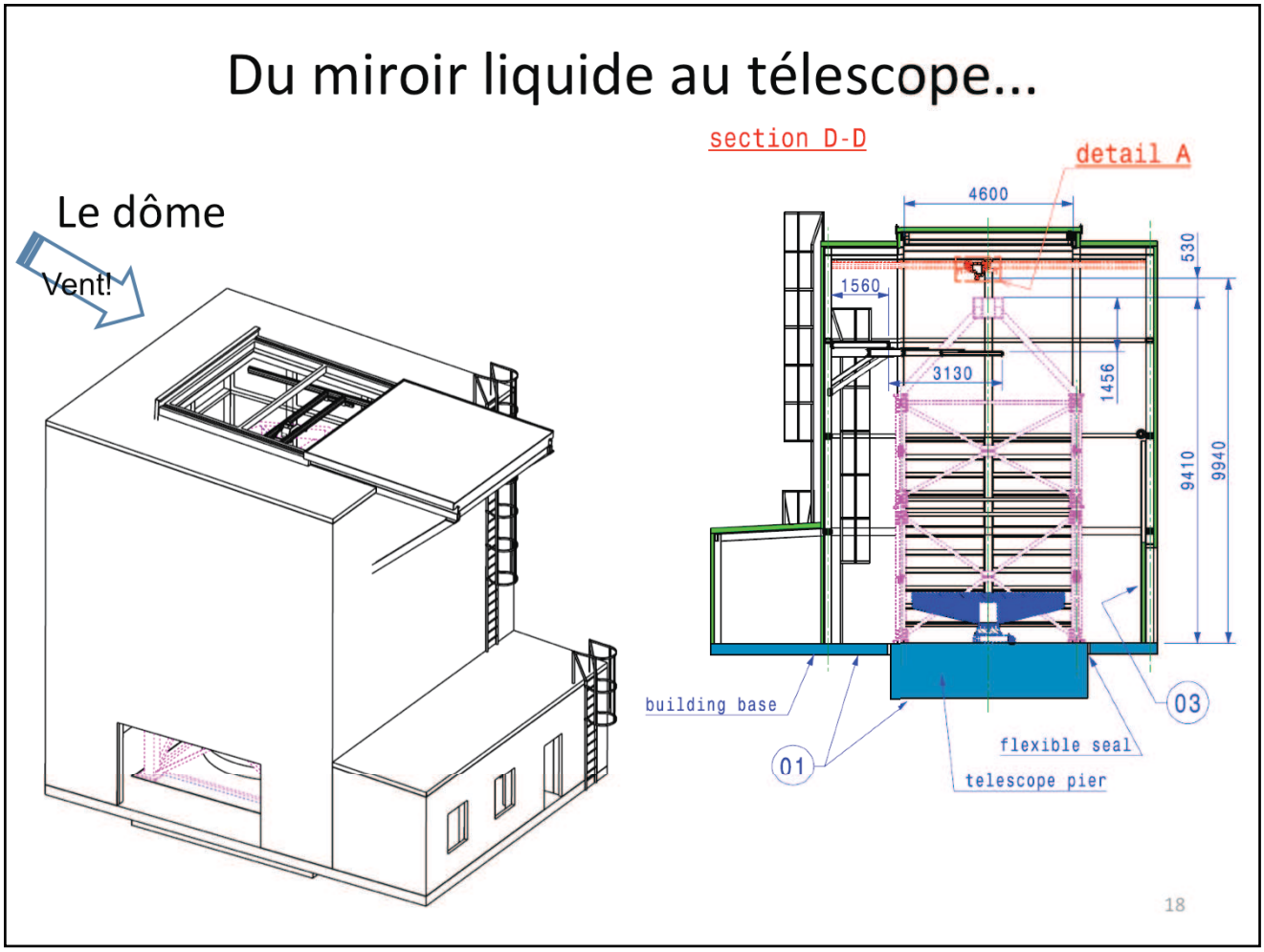
The mirror size will be 4m diameter considering that it is a low-risk undertaking. It is a small extrapolation from the 3-m NASA LMT and the 2.5m Laval LMT and for these sizes the same technology can be used. The tracking will be done with the TDI technique (Borra has pointed out in 1982 that modern technology had given us tracking techniques, known as time delay integration -TDI- or drift scan, that render LMs useful to astronomy). This restricts us to direct imagery. Obviously, low-resolution spectroscopy can be carried out with interference filters. With a dichroic beam splitter, two CCDs and two different filters, the observations can be done at different wavelengths. A semi-classical on-axis glass corrector capable of about ½ 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).



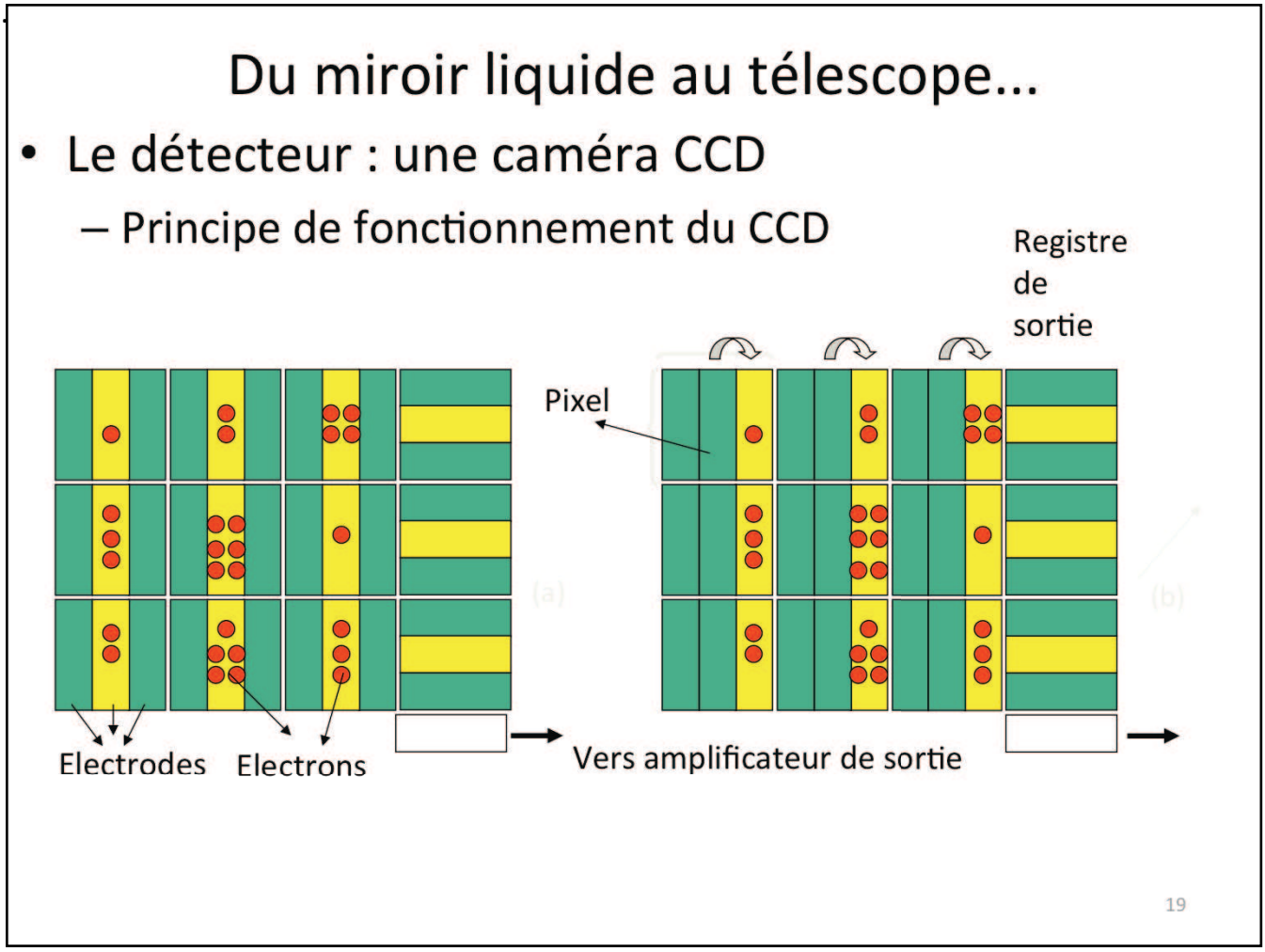
The International 4m LMT project (J. Surdej); Description of a LMT:

On the lower right: the 8m high ILMT structure. This structure is quite simple as it does not need to be mobile since the primary mirror cannot be tilted.

On the left, the 4m carbon-fiber container of the ILMT before the spincasting with the polyurethane. The spincasting consists in covering the container with liquid polyurethane while it is rotating, so that when the PU solidifies it already presents the expected parabolic shape of the final mirror. This allows to use a very thin layer of mercury, which is mandatory to limit the wave at the surface of the mirror. At the bottom left corner is a picture of the motor and air bearing supported by a tree points mount to adjust the rotation axis of the whole table with the vertical. A CCD camera is seen at the upper right.



The International 4m LMT project (J. Surdej); Description of a LMT:
The above figure shows a layout of observatory for a 4-m telescope. The structure is much more simple than the dome of a conventional telescope. The roof and the folding platform needed to service the upper end are the only movable parts.



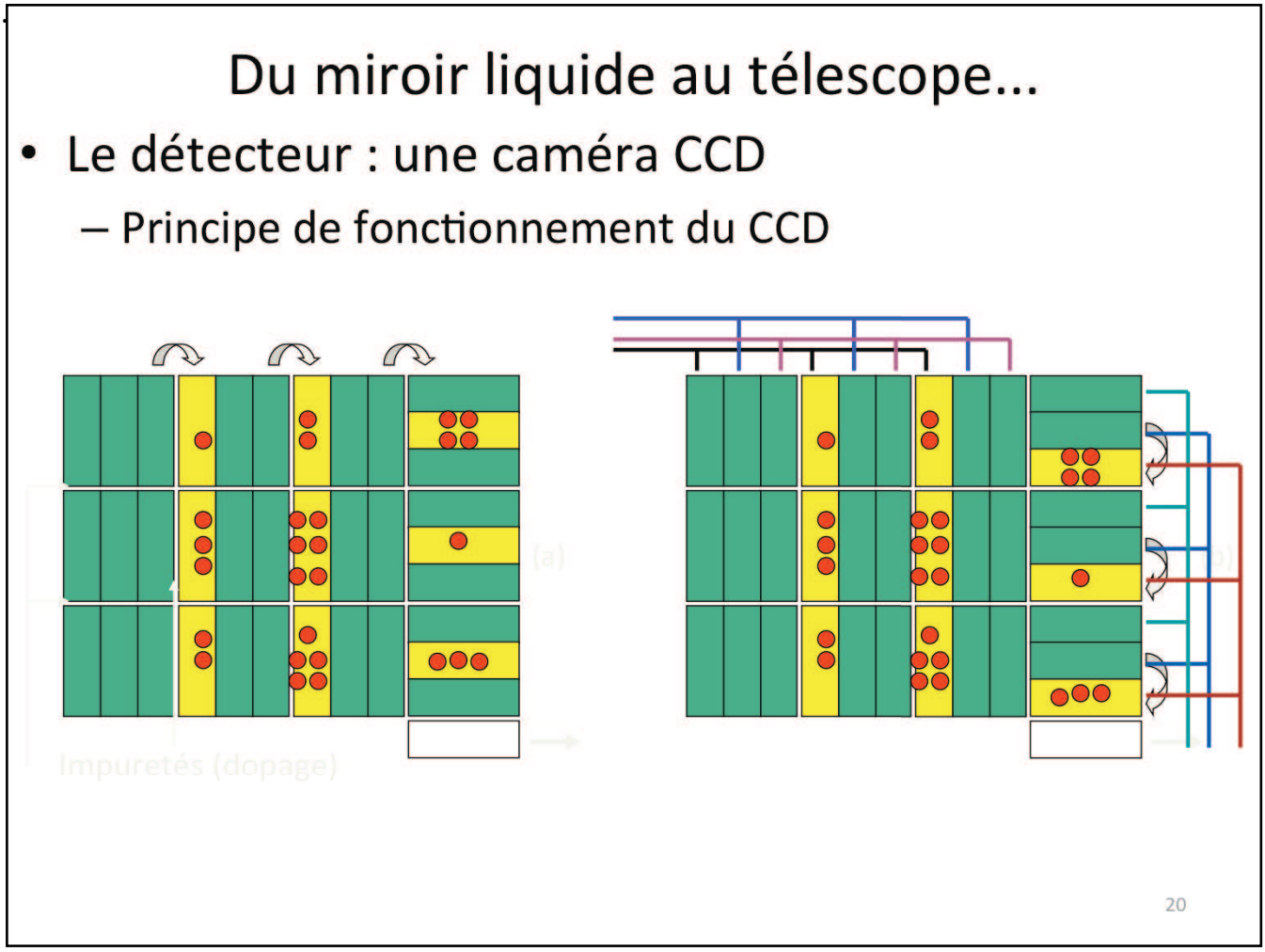
Le détecteur CCD (les notes ci-dessous sont reprises du cours sur les CCD)

12.3 Fonctionnement simplifié d'un CCD

En vue de produire une image, un CCD doit réaliser quatre fonctions:

- 1) générer des photoélectrons (cf. la pluie),
- 2) collecter les électrons (cf. les seaux),
- 3) transférer les charges collectées (cf. les tapis roulants),
- 4) lire ces charges (cf. station de mesure).

La premère fonction est basée sur l'effet photo-électrique. L'absorption de lumière dans le réseau de silicium du CCD génére ces photoélectrons, proportionnels en nombre aux photons incidents. Ceux-ci sont immédiatement collectés dans des sites bien définis, les plus proches. Ces sites (cf. les seaux) sont appelés pixels (de l'anglais "picture elements"). Ces pixels sont définis au moyen d'un réseau d'électrodes disposées à la surface du CCD. Les électrodes forment de véritables puits de potentiel, pour empêcher que les charges collectées ne s'échappent. Lorsque la pose est terminée, le transfert des charges (cf. déplacement des seaux sur les tapis roulants) est assuré en changeant de façon coordonnée les potentiels aux bornes de chaque triplet d'électrodes de telle façon que les électrons puissent se déplacer horizontalement d' un pixel à l'autre. A la fin de chaque rangée de pixels se trouve le registre de sortie (cf. tapis roulant vertical),

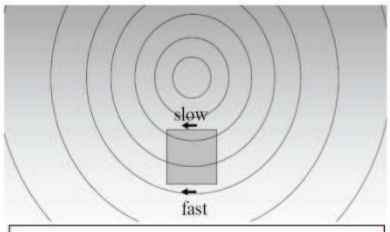


12 Le détecteur CCD

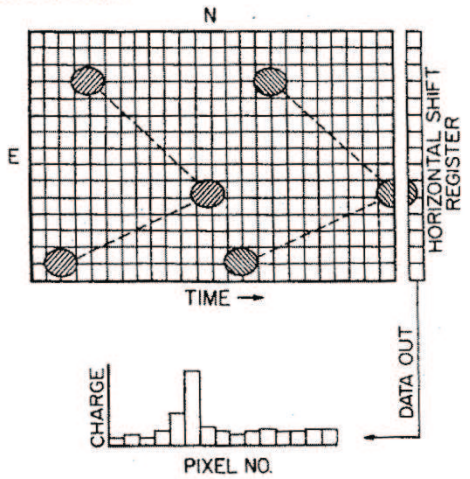
rangée d'électrodes extérieure à la région photosensible du CCD et disposée à angle droit avec celle-ci. Ce registre transmet un à un les paquets de charges vers un amplificateur de sortie où, à la fin de cette chaîne d'opérations, les charges sont mesurées et converties en une suite de chiffres enregistrés sur le disque d'un ordinateur. Le signal enregistré peut ensuite être traîté, calibré et analysé. On peut restituer sous forme d'une image numérique la distribution de brillance de l'astre observé (cf. distribution spatiale des précipitations sur le champ).

Du miroir liquide au télescope...

- Le détecteur : une caméra CCD en mode TDI
  - Technique TDI (Time Delay Integration)
    - Suivi du ciel par déplacement des charges sur le CCD
    - En imagerie directe
    - Distorsion TDI
      - Trajectoires incurvées
      - Vitesse de transit variable (N-S)



→ **Correcteur spécifique**



- Intégration : 2 min
- Co-addition : augmentation de la magnitude limite (m_l = 22,5 +1 mag / 6 scans)

The International 4m LMT project (J. Surdej); Description of a LMT:

The above figure illustrates the Time Delay Integration (TDI or drift scan) technique. A characteristic time for a star to cross the CCD field is approximately 90 seconds. It is possible to obtain longer integration times by co-adding the CCD frames recorded on different nights.

Du miroir liquide au télescope...

- Magnitudes limites

Filtres	Nombres de scans	$M_{lim}(5\sigma)$
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

- Co-addition

Nbre de scans :	3	6	12	60	240
Δm :	0.6	1.0	1.35	2.22	2.98

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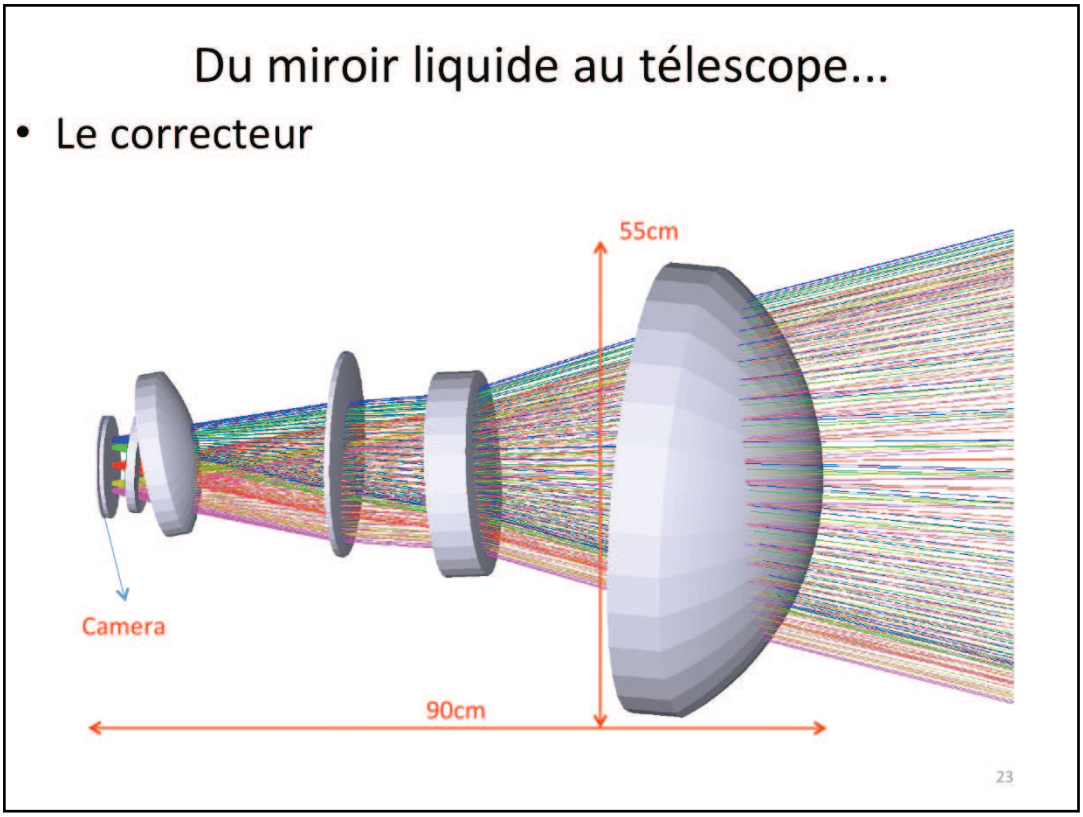
The International 4m LMT project (J. Surdej):
- Limiting magnitudes (for a 5σ detection of point-like sources under median seeing conditions of 0.7"):

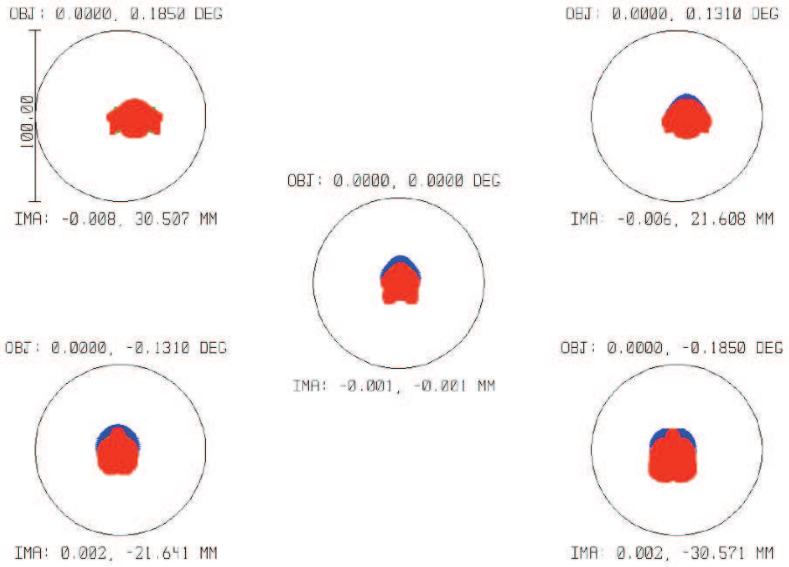
Filters	Number of scans	M_{lim}
U	15	24.5
B	3	24.5
V	6	24.5
R	4	23.5
I	6	23.5
Gunn-z	2	22.3

Co-adding data leads to improved limiting magnitudes by 0.6 mag. after 3 nights, 1 mag. after 6 nights, 1.35 mag. after 12 nights, 2.22 mag. after 60 nights (typically one year of operation) and 2.98 mag. after 240 nights (typically 4 years of operation).



The International 4m LMT project (J. Surdej); Description of a LMT:
The figure above illustrates the TDI corrector to be implemented on the ILMT. The lenses are made of classical glass. They are tilted to correct for the TDI distortion.

Diagramme de points



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Les TMLs dans le monde
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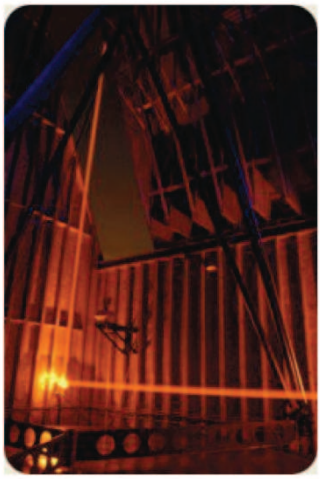
Les télescopes à miroir liquide dans le monde

- Sciences atmosphériques

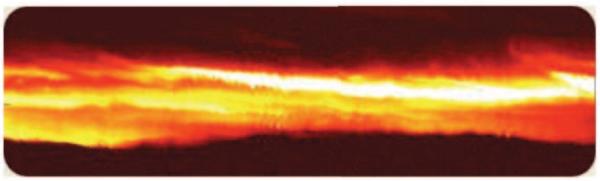
Univ. of Western Ontario
2.7m LIDAR

→ étude de l'atmosphère



Univ. of British Columbia
6m LZT LIDAR

→ optimisation O.A.



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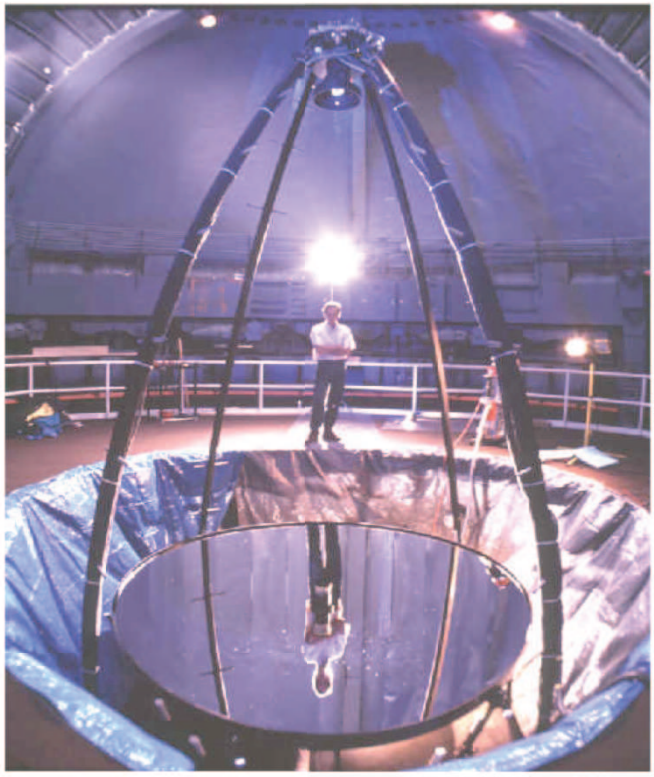
The International 4m LMT project (J. Surdej); - LMTs in the world:

• Atmospheric Sciences (UWO 2.7m LIDAR Observatory in London, ONT and UCLA 2.7m LIDAR): a LIDAR is a Light Detection and Ranging System to study with great accuracy the rapid variations in the density and temperature structure of the atmosphere at heights between 30 and 110 km (excitation of atmospheric molecules and analysis of the light emitted by these molecules and collected by the LMT). These two facilities constitute the best LIDARs in present operation in the world.

Les télescopes à miroir liquide dans le monde

- Environnement Spatial

3m NASA Orbital Debris observatory



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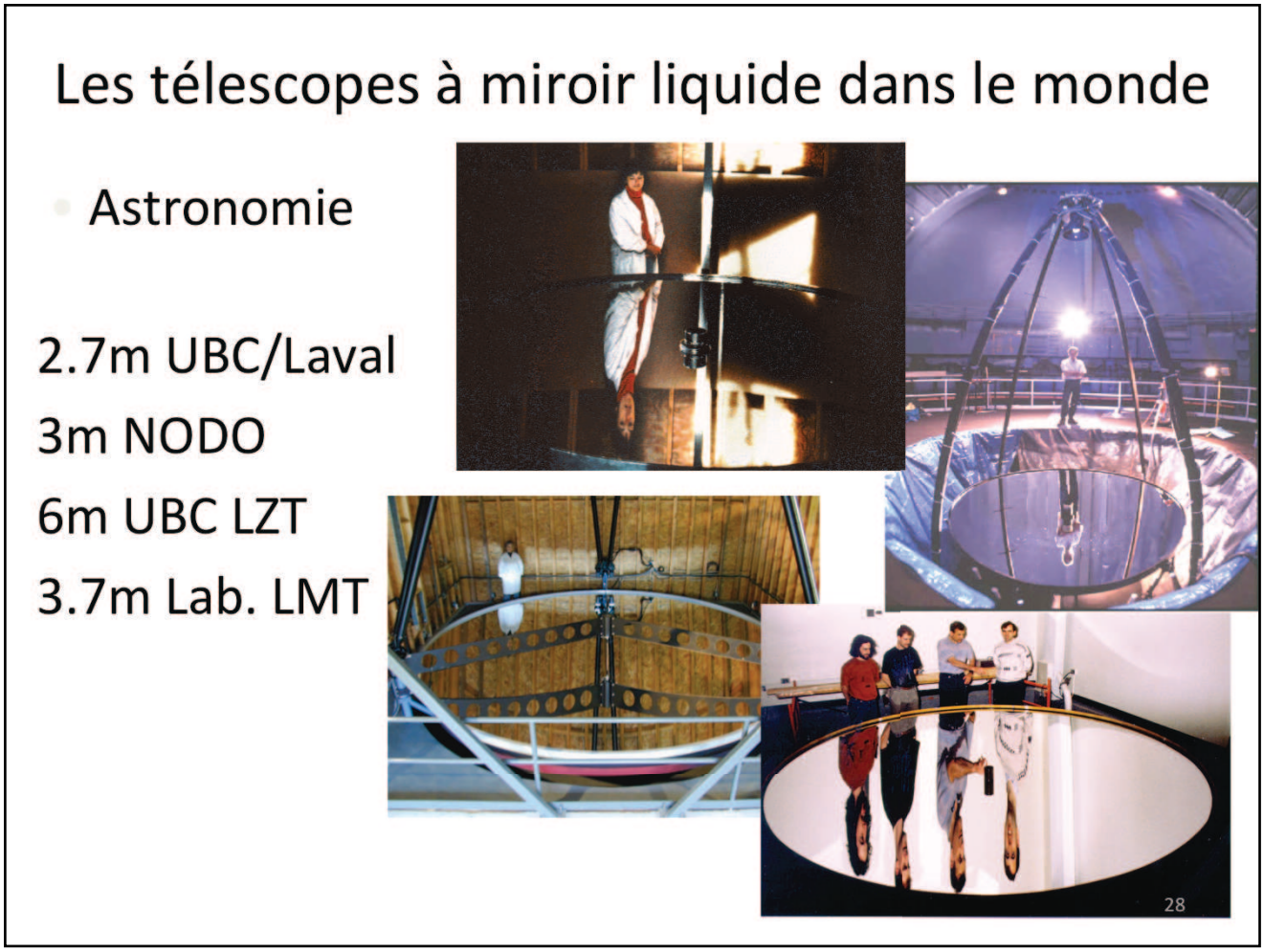
The International 4m LMT project (J. Surdej); - LMTs in the world:

- Space Sciences (3m LM Orbital Debris Observatory, NASA, NM)



The International 4m LMT project (J. Surdej):

- LMTs in the world:

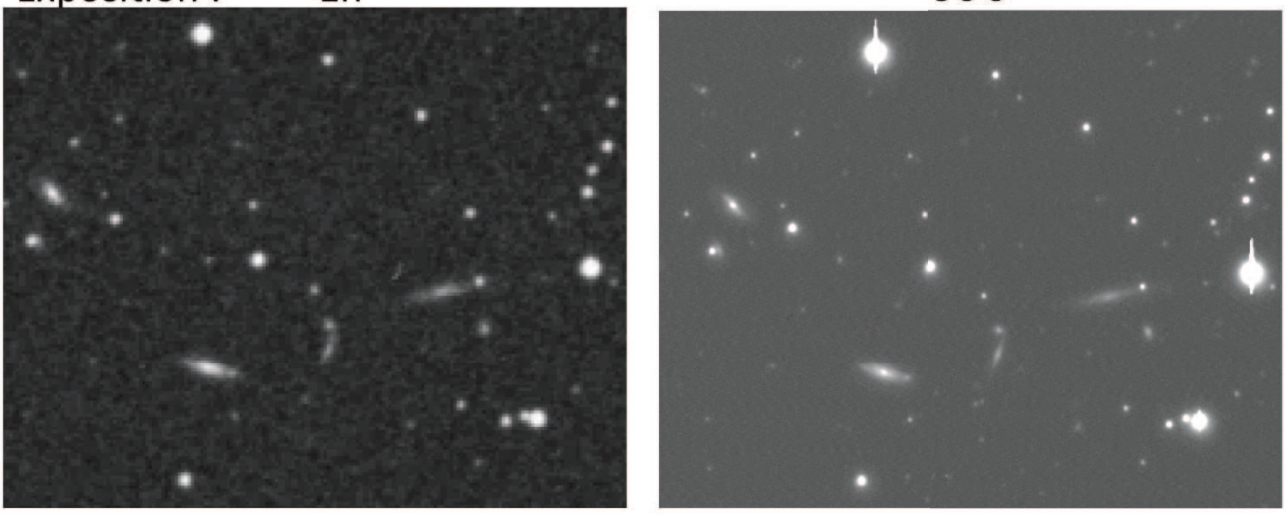
• Astronomy (3m NASA LMT Observatory in operation, 6m Observatory in Vancouver (BC) in construction, 4m LMT project?): 35 observing nights have been carried out by Hickson and Mulrooney (1998) in direct imaging through 10 narrow bands. HR and color-color diagrams of stars as well as a comparison of the observed number counts of stars as a function of magnitude, galactic latitude with predictions from Bahcall and Soneira have led to nice confirmatory results. The 3m NASA LMT Observatory is also being used with a fast reading CCD camera to detect space debris, at dusk and/or at dawn.

Les télescopes à miroir liquide dans le monde

- Observations astronomiques avec le NODO

Palomar Schmidt Telescope (1.2m) NODO (3m)

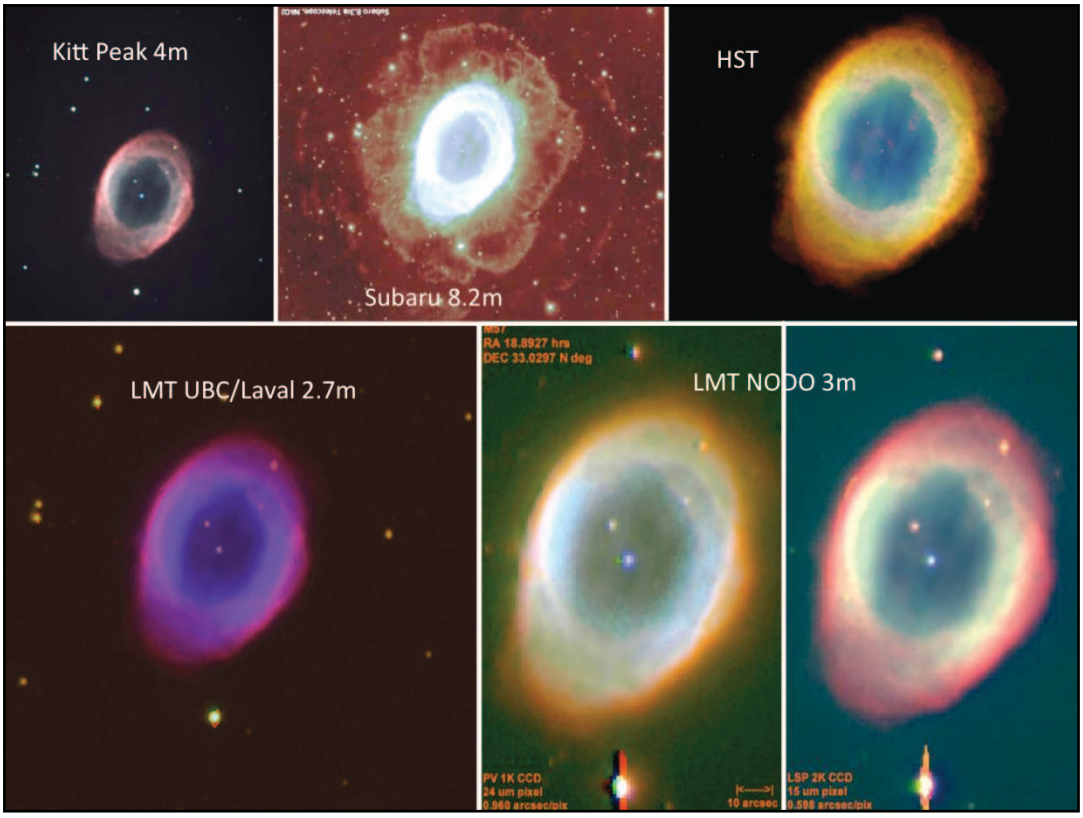
Exposition : 1h 90 s



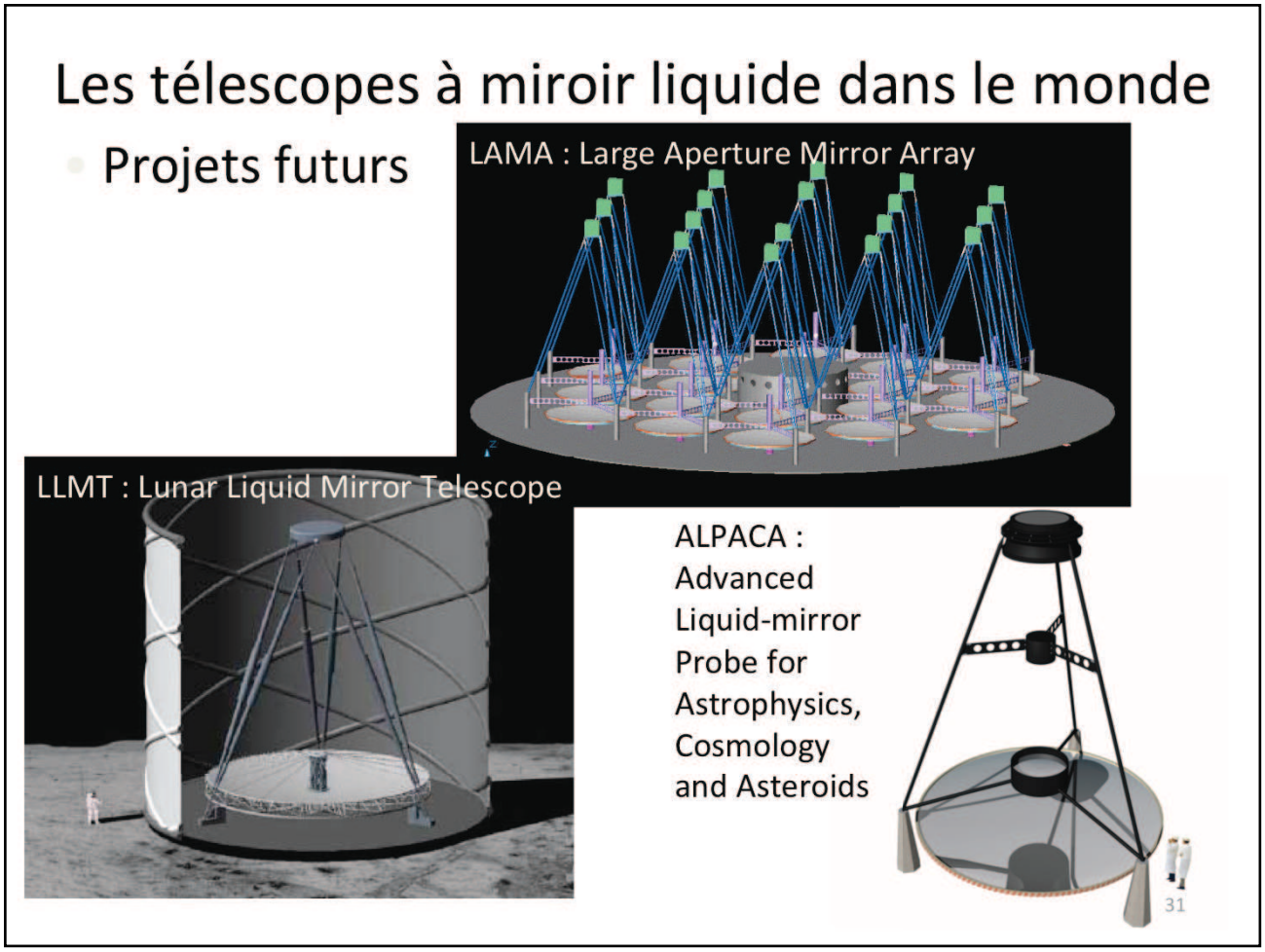
The International 4m LMT project (J. Surdej):
- LMTs in the world:

The above figures illustrate some of the observations made with the Palomar Schmidt telescope (photographic plate exposed during one hour) and the 3m NASA LMT (CCD, approximate exposure of 90 sec.). They represent a small field at high galactic latitude.

… before addressing the scientific justifications for the construction of a 4m LMT, let us have a look, in a very broad sense, at the main advantages and disadvantages of LMTs over conventional telescopes.



The International 4m LMT project (J. Surdej):
The planetary nebula of the Lyra seen by different classical telescopes (top row) and by liquid mirror telescopes (bottom row). The image quality is comparable.



The International 4m LMT project (J. Surdej):

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Avantages et inconvénients des TMLs

1) Avantages:

- La technologie actuelle permet de construire de grands (6m) TMLs peu coûteux (1/50)
- Dédiés à des projets astronomiques spécifiques
- Très grande efficacité
- Seeing et transparence optimaux au zénith
- Excellente calibration des images CCD

2) Désavantages

- Observation limitée au zénith
- Temps d'intégration court (90 sec.)
- Enorme volume de données (~ 15 Gbytes de données / nuit).

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The International 4m LMT project (J. Surdej):

- Advantages and disadvantages of LMTs:

1) Advantages:

• Large inexpensive telescopes may be constructed based upon existing technology (prices of LMTs are 50 - 100 less than those of conventional telescopes)

• LMTs can be used for dedicated astronomical projects (surveys, see science goals!)

• Efficiency is very high: observing each night a same strip of sky, no slewing, no field acquisition, no lost readout times, etc. No OPC! (difficulty to get more than a few nights per year)

• The seeing and transparency conditions are optimal at zenith

• Flat fielding and defringing are much more accurate since the images are actually formed by averaging over entire CCD columns (in the direction of the scan).

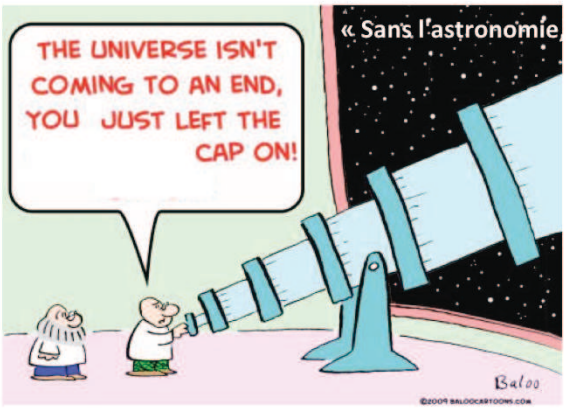
2) Disadvantages:

• Can only observe at zenith a strip of constant declination. At a latitude of 29°30', a band of 1/2° covers 156 square degrees, with 88 square degrees being at high galactic latitude

• Short nighly integration times set by the CCD: t (sec.) = 1.33 10^{-2} n(pixel) w(μm) / (f(m) cos(δ)) ~ 90 sec. (in Devasthal - India, f = 8m, w = 15μm); … but can coadd to get longer integration times

• Large volume of data. The time spent on one pixel is t(sec.)/n_{row}. In one second, the flow of data is given by (ncol / (t(sec)/nrow)) 16 bits x 2 CCDs x 8 hours / 8 (bits/bytes) ~ 15 Gbytes of data per night.

Objectifs scientifiques



« Sans l'astronomie, l'homme ignore la place qu'il occupe ».

Aristote

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Le ILMT et la science...

Workshop de Marseille 1997 : "Science with LMTs",

Le télescope à miroir liquide est un instrument unique qui permet d'effectuer un survey profond d'un bande de ciel.

→ Etude de variabilité (photométrique / astrométrique)

→ Une importante variété d'objets peut être étudiée.

1) **Recherche et suivi de supernovae (cosmologie)**
2) **Etude de mirages gravitationnels (cosmologie, lentille,…)**
3) **Recherche de quasars,**
4) **Etude d'objets variables, (RR Lyrae, AGN,…)**
5) **Détection de naines blanches, brunes,… (parallaxes)**
6) **Recherche de cibles pour les grands télescopes (VLT, ELTs, …)**
7) **…**

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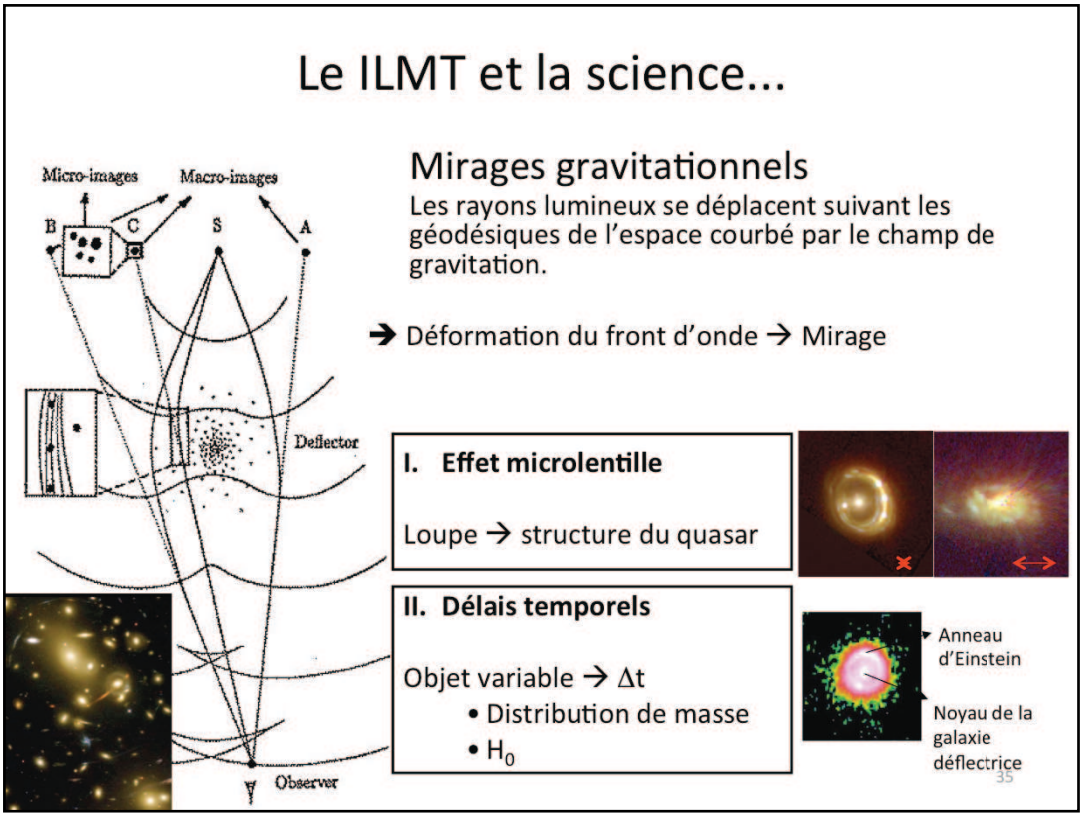
The International 4m LMT project (J. Surdej):

- Science with a 4m LMT:

Given the multiple 'playdoyers' made by several of us, inluding Sjur Refsdal, to have a dedicated telescope for the monitoring of gravitational lenses, Ermanno Borra has contacted us in march 1995, for us to consider the possible adequacy of an LMT for the photometric monitoring of gravitational lenses. Given the very restricted field of view of an LMT, the probability to be able to observe with such a telescope, even only one of the 25 known (at that time) multiply imaged quasars -almost randomly distributed over the sky- was of course virtually null. It was not until march 1997 that one of us recontacted Borra to let him know about another possible strategy to observe gravitational lenses. Borra informed us about the organisation of the Marseille Workshop to be held on 14-15 April 1997, "Science with LMTs", and invited us to participate. A paper entitled 'Gravitational lens studies with a LMT' was presented by Surdej and Claeskens (1997). A total of approximately 20 scientific contributions may be found in the proceedings of that workshop. Among the main science drivers that could justify the operation of a 4m LMT, all survey projects based upon photometric and/or astrometric variabilities are essentially good ones. These include:

1) a search for supernovae at high z,
2) QSOs surveys based upon colour selection and photometric variability,
3) detection of distant RR Lyrae stars in the galactic halo,
4) detection of white, brown, etc. dwarfs based upon their proper motions or trigonometric parallaxes,
5) studies of DM in very low surface brightness galaxies,
6) targets for the VLT, ELTs, etc.

In the remainder, I shall describe our project: 'GL studies with a LMT'.

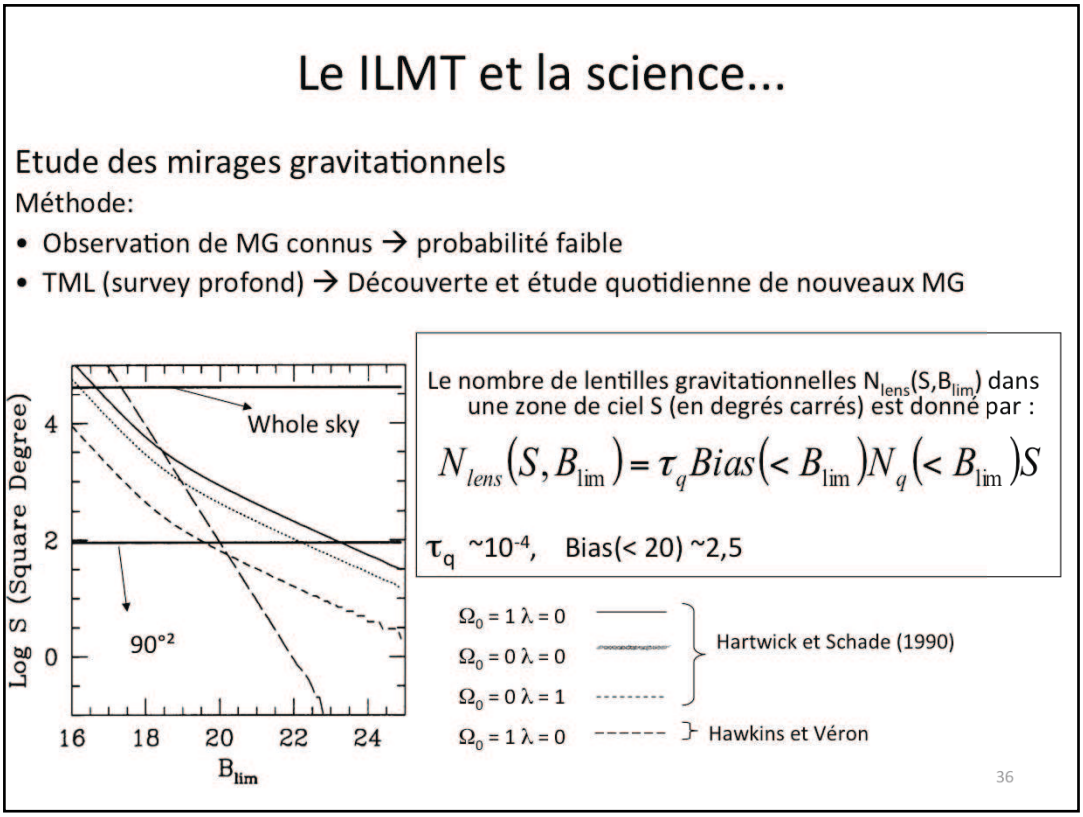


The International 4m LMT project (J. Surdej):
Introduction on gravitational lensing

A gravitational lens is an optical phenomenon involving a distant source (quasar) a deflector (galaxy) and an observer. In case all tree components meet alignment and distance requirements, the observer will see several images of the source. This is due to the deflector galaxy which curves the space around it. As it is known from relativity theory, the rays of light follow the geodesics of the curved space. The wavefront leaving the source is spherical, when it reaches the deflector galaxy, it is slowed down depending on the mass density it encounters. It happens that the wavefront folds until it self intersect. The observer can thus see several parts of the same wavefront, which correspond to several images.

It is interesting to note that a gravitational lens act as a huge free natural telescope as it increases the amount of light received from the source. Moreover, being able to model the deflector galaxy, it is possible to reconstruct the source from the multiple images, which increase the angular resolution. The GL can thus be used to study the background source

Another interesting application of gravitational lensing is related to the intrinsic variability of the source. Indeed, as the optical paths are different for the different images, if the source varies, the images will vary at different times. This time delay between the images is related to the Hubble constant (H_0) and to the lens (galaxy) model. Knowing one of them and measuring the time delay, it becomes possible to determine the other parameter.

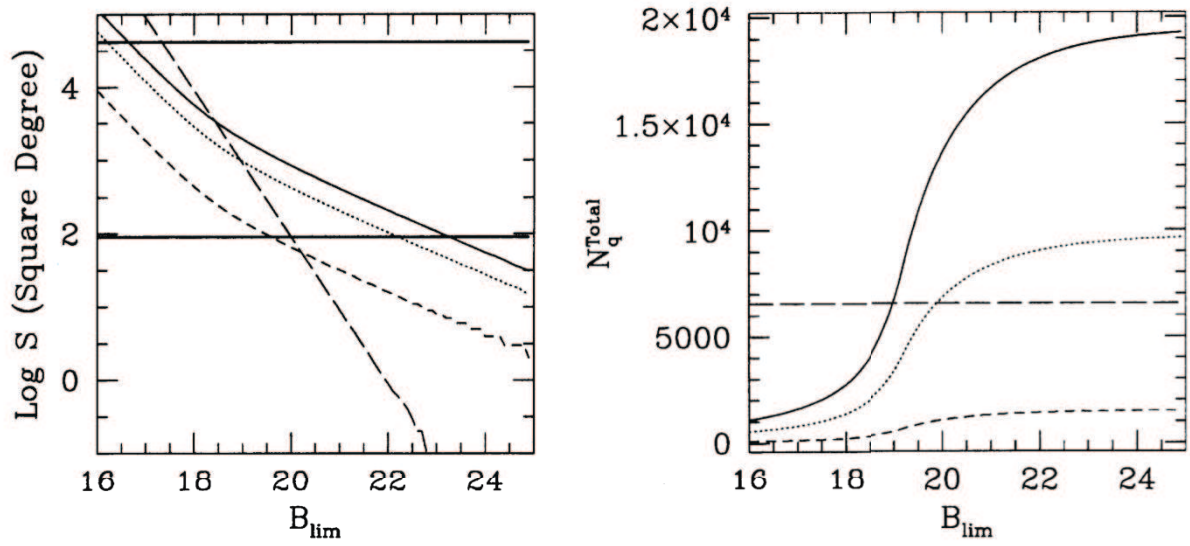


The International 4m LMT project (J. Surdej): Requirements for a GL imaging LMT survey:
From previously published statistical GL studies (Surdej et al. 1993), it is easy to derive the observational requirements to identify within a LMT direct imagery survey a large number (e.g. 50) of multiply imaged quasars. Given a flux limited sample of quasars down to the limiting magnitude B_{lim}, the expected number of multiply imaged quasars $N(S,B_{lim})$ over a sky area S (expressed in square degree) is easily found to be a function of the macro-lensing optical depth τ_q for galaxies to produce multiples images, of the magnification bias, of the number counts of quasars $N_q(B_{lim})$ and of the surveyed area S. Imposing $N(S,B_{lim}) = 50$ and adopting, for sake of simplicity, a representative value for the quasar redshift $z_q = 2$, we have illustrated in the next Figure the resulting sky area S to be surveyed as a function of B_{lim}. Also shown in this figure are the results for the values of the cosmological parameters $\Omega_0 = 0$, $\lambda_0 = 0$ and $\Omega_0 = 0$, $\lambda_0 = 1$ and, finally, the results expected for $\Omega_0 = 1$, $\lambda_0 = 0$, assuming that the number counts of quasars at faint magnitudes does not flatten out, as suggested by Hawkins and Véron (1995). Similarly, we have illustrated in the second next Figure the total number of quasars N_q^{Total} expected in the surveyed sky area S over which 50 new cases of GL ought to be identified.

We conclude that, even under the most unfavourable conditions (i.e. $\Omega_0 = 1$, $\lambda_0 = 0$), a realistic sky area S to be surveyed in order to identify 50 new lenses down to limiting magnitudes $B_{lim} < 24$ can be easily probed with a 4m LMT (typically S < 60 square degrees at high galactic latitude). In this case, a total of approximately 20,000 quasars will also be identified. From the observed numbers of detected lenses and quasars in such a deep and complete survey, we should be able to independently infer the most realistic values for the cosmological parameters Ω_0 and λ_0, as well as precisely characterize the luminosity function and number counts of quasars as a function of redshift and magnitude, respectively.

The International 4m LMT project

- Science with the 4m ILMT



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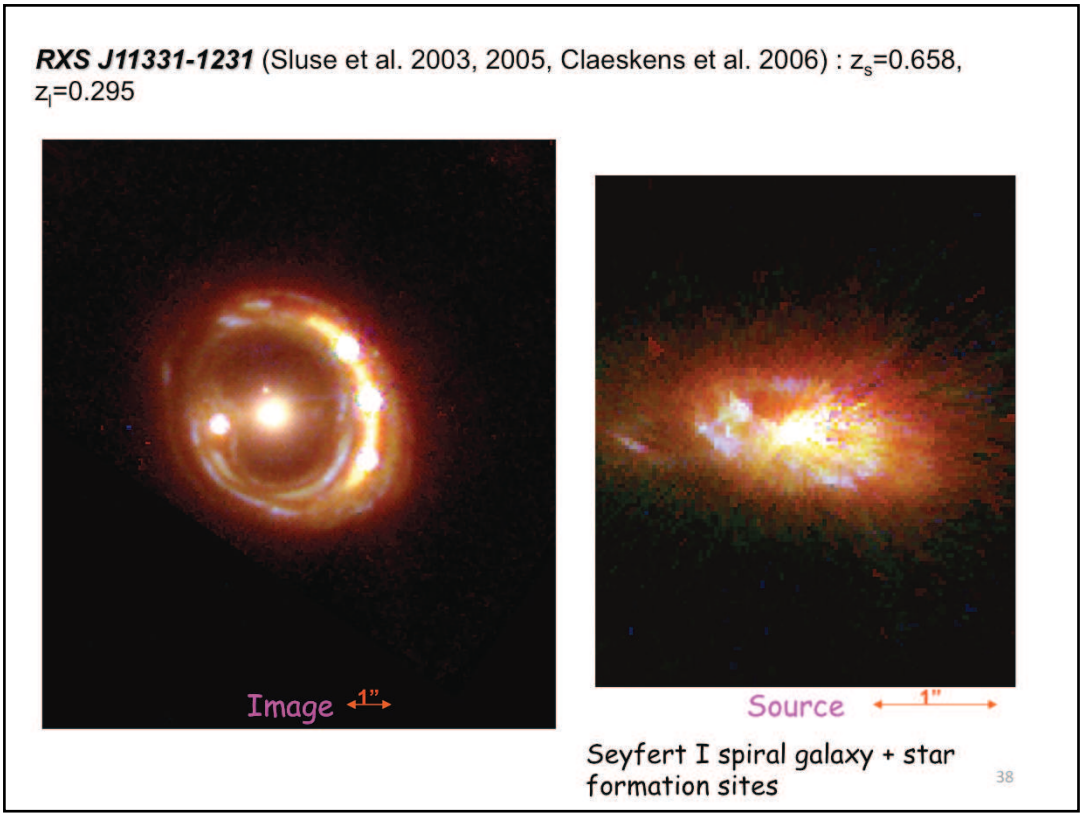
The International 4m LMT project (J. Surdej):

Note that observational searches for multiply imaged quasars among highly luminous ones have prevented in the past to use a complete QSO reference sample and introduced many other ill-defined biases in the statistical estimates of the various physical (cf. the efficiency for galaxies to produce multiply imaged quasars) and cosmological parameters (Ω_0, λ_0).

Left figure: Sky area S to be surveyed as a function of the limiting magnitude B_{lim} to identify 50 multiply imaged quasars. The two horizontal lines refer to limits set by the whole sky area and a field of 90 square degrees (see text). For simplicity, a representative value of $z_q = 2$ was adopted for the quasar redshift and, unless stated otherwise, the number counts of quasars are taken from Hartwick and Schade (1990). The different curves refer to $\Omega_0 = 1$, $\lambda_0 = 0$ (full), $\Omega_0 = 0$, $\lambda_0 = 0$ (dotted), $\Omega_0 = 0$, $\lambda_0 = 1$ (dashed) and, finally, $\Omega_0 = 1$, $\lambda_0 = 0$ (long-dashed) with the number counts of quasars from Hawkins and Véron (1995). Note that for $B_{lim} > 22$ (resp. $B_{lim} > 21$), these curves are extrapolations from the Hartwick and Schade (resp. Hawkins and Véron) number counts of QSOs. Conversely, the LMT survey will help in defining more precisely the number counts of quasars at very faint magnitudes, resulting in a better defined and complete sample of QSOs.

Right figure: Total number of quasars (N_q^{Total}) versus the limiting magnitude B_{lim}, expected in the surveyed sky area S over which 50 new cases of GL ought to be identified. Unless stated otherwise, the number counts of quasars are taken from Hartwick and Schade (1990). The different curves refer to $\Omega_0 = 1$, $\lambda_0 = 0$ (full), $\Omega_0 = 0$, $\lambda_0 = 0$ (dotted), $\Omega_0 = 0$, $\lambda_0 = 1$ (dashed) and, finally, $\Omega_0 = 1$, $\lambda_0 = 0$ (long-dashed) with the number counts of quasars from Hawkins and Véron (1995).

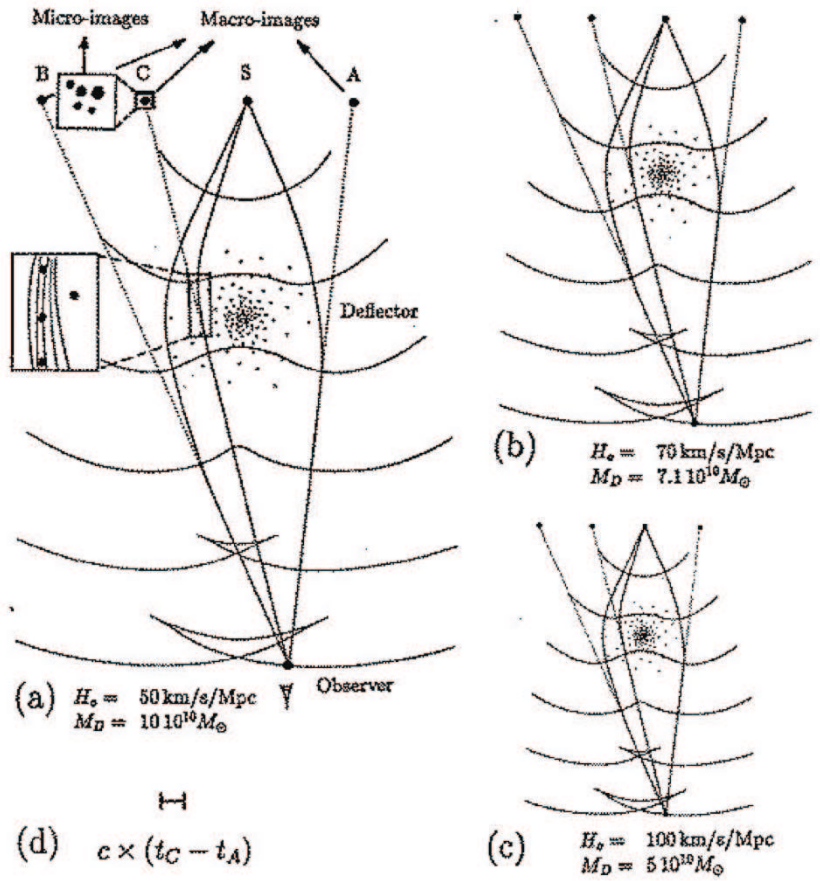


•Zs = 0.66 = 6.5 Gly
•Zl = 0.3 = 3.5 Gly
• The position of the images gives the astronomer information about the mass distribution and quantity in the lens. This allows to reconstruct the source as it would have appeared without the presence of the lens, with a much improved angular resolution.

Astrophysical and cosmological applications of gravitational lensing:
When a foreground galaxy (the macro-lens) produces multiple images of a background quasar, it is expected that time delays will become measurable between the light travel times of photometric variations of the quasar along the different trajectories. Such measurements offer a unique opportunity of deriving the value of the Hubble parameter H_0 which is inversely proportional to the observed time delays (Refsdal 1964; see the above figures representing a gravitational lens system with identical angular separations between the lensed images as seen by an observer, assuming different values for the Hubble parameter H_0). In addition, those macro-images are most of the time seen through rather dense parts of the galaxy and there is a good chance that one or several macro-images are affected by micro-lensing (Chang and Refsdal 1979). The micro-lens is a star (or several stars) of the galaxy, acting as a magnifying lens with a very small ''field of view'' (typically of the order of one micro-arcsec), which produces a more or less intricated network of micro-caustics. When the light beams coming from different regions of the source cross this network, they get differently amplified, according to their sizes and locations. There will thus result a differential amplification of the different components of the quasar. For instance, in the spectrum of a micro-lensed quasar image, the optical continuum will be more amplified than the Broad Line Region (BLR) which has a larger extension.

Délais temporels

- Constante de Hubble (H_0)
- Distribution de masse



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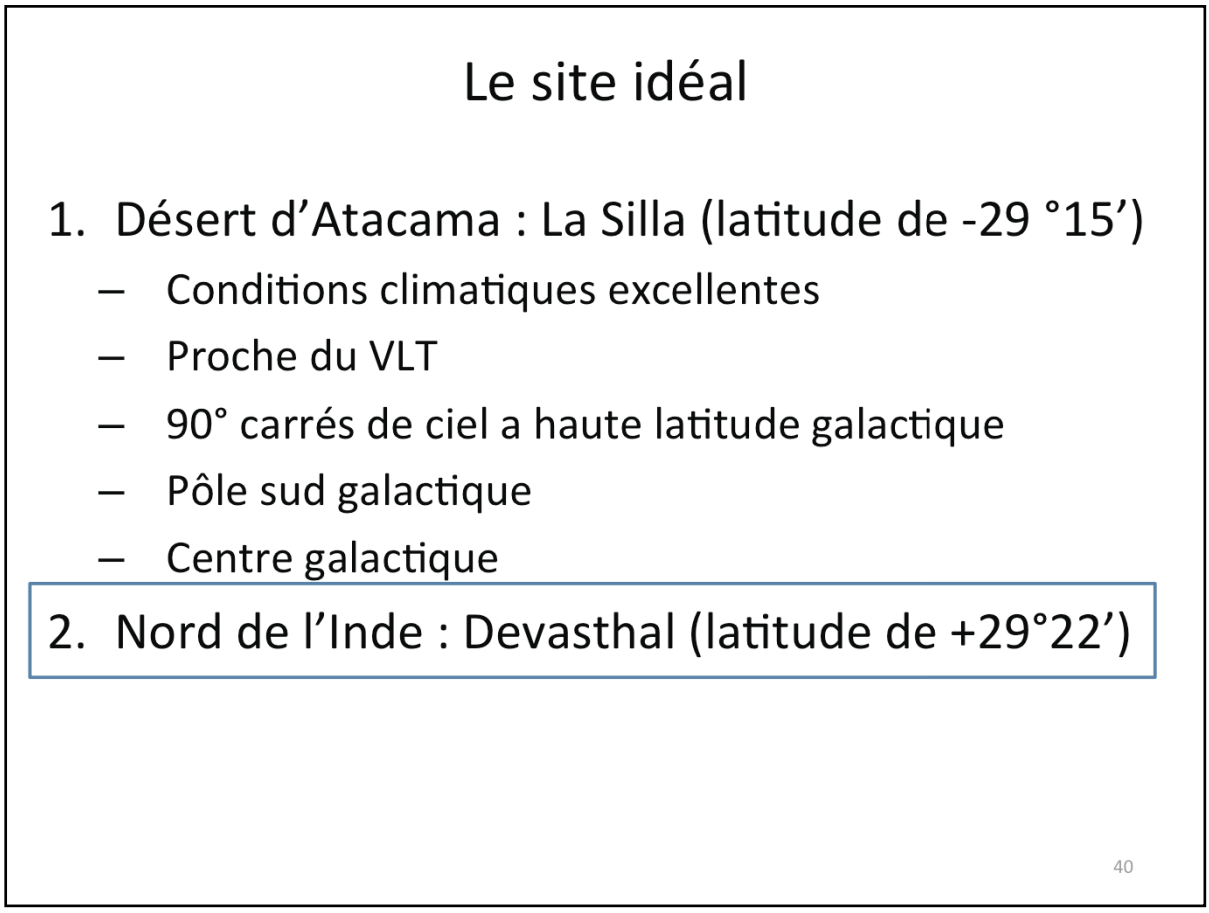
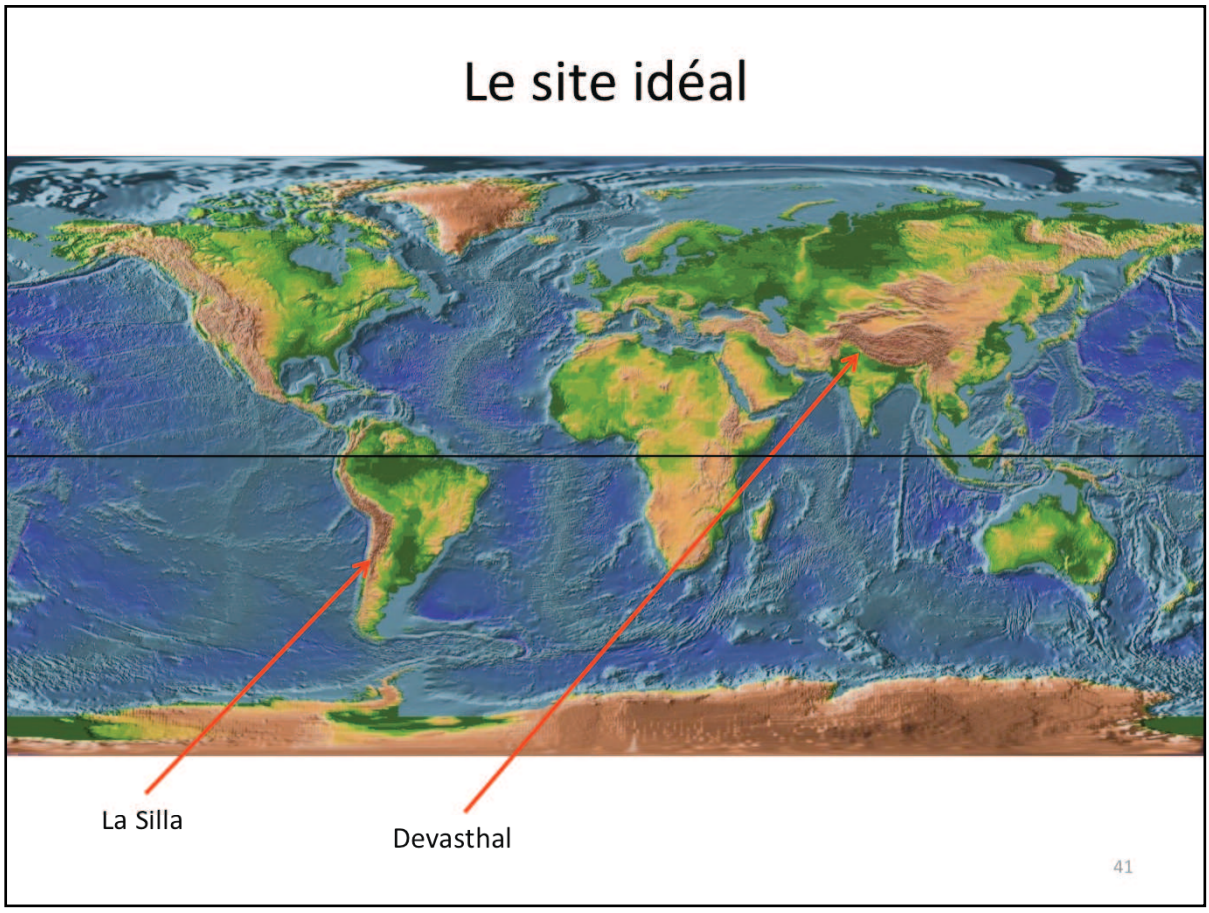
Due to relative proper motions, this phenomenon varies on a time scale of a few months or years and produces characteristic light curves (and very likely variable spectroscopic line profiles for the broad emission-lines). Of course, the shape of these curves depends on the size of the source. A spectroscopic monitoring of such micro-lensed QSO images, first identified on the basis of a LMT imaging survey, with VLT-like telescopes will thus allow to probe the structure and size of the continuum source, as well as the distribution in size (with an angular resolution of the order of 10^{-6}") and velocity of the BLR clouds. In addition, high resolution spectroscopy of the multiple (2-4) lensed images of a background quasar should also allow one to set interesting constraints on the size and structure of the Ly-α and/or heavy absorbing element clouds located along their lines-of-sight (cf. Smette et al. 1992, 1995). It should even be possible from such observations to set constraints on the value of the deceleration parameter q_0 of the Universe. We therefore conclude that gravitational lens systems, consisting of several variable macro-lensed images and of a deflector with angular separations of the order of one arcsecond, constitute unique laboratories to probe very important astrophysical and cosmological parameters. As shown earlier, a large number of interesting gravitational lenses ought to be identified within a LMT survey.

We also expect that a significant number of these macro-lensed images will reveal photometric signs caused by micro-lensing effects. Photometric and VLT spectroscopic observations of these candidates should lead to interesting constraints on the size and structure of the various QSO emitting regions. High resolution spectroscopy of selected gravitational lens systems with the VLT will also lead to interesting estimates of the size and shape of intervening intergalactic absorbing clouds. Other astrophysical and cosmological applications relying on the studies of the LMT lenses include tracing the luminous and dark matter in the Universe, setting limits on the cosmological density of compact



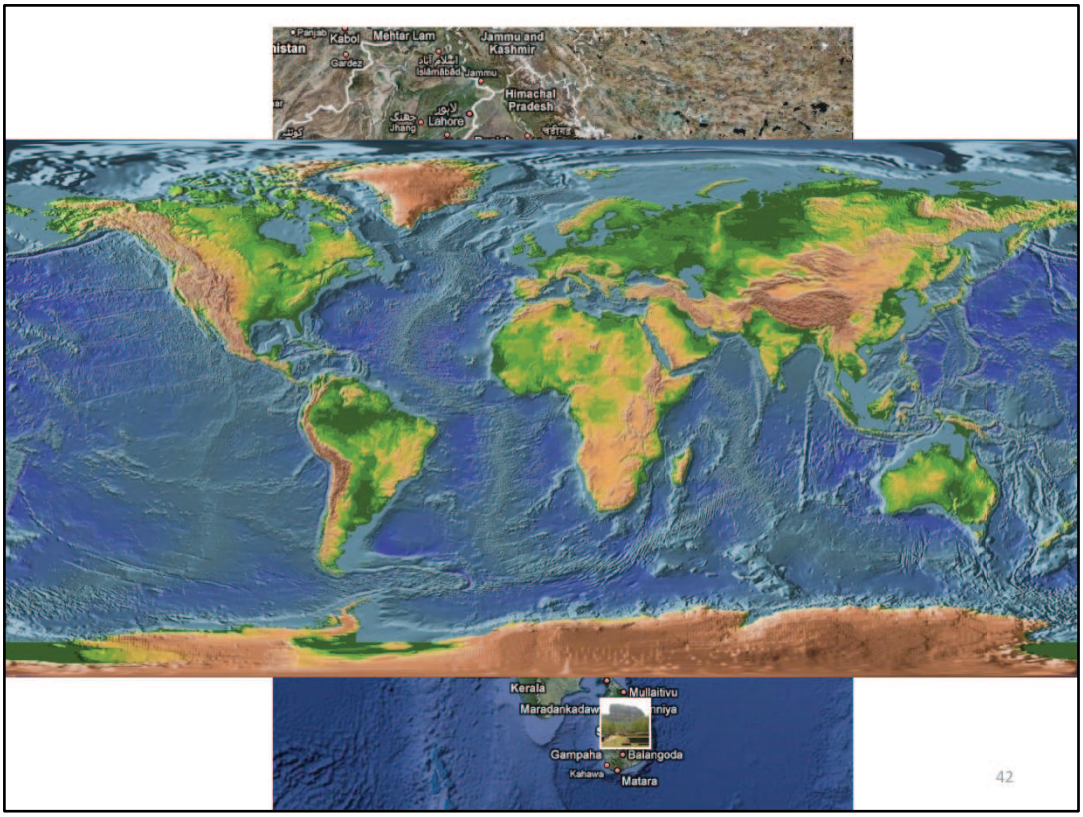
objects with mass ~ $10^{10}\,M_{\odot}$, probing the extinction law of external galaxies responsible for differential reddening between multiple macrolensed QSO images. In addition, such an extragalactic LMT survey will lead to the discovery of interesting variable stars (cf. distant RR Lyrae to trace the limits on the stellar component of the halo), supernovae, galaxies, clusters at high redshift and to a large sample of approximately 20,000 quasars down to B ~ 24 which will provide a unique grid of light probes to study the morphology, structure and size of large scale structures (heavy elements and hydrogen ones) in the Universe at scales ranging from several Mpc up to hundreds of Mpc.

-**Science with a 4m LMT; Additional interesting results and conclusions:** A good site to carry out a GL direct imagery LMT survey 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 interesting faint targets. For instance, operation of a LMT (field of view ~ 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 ($|b| > 30°$), 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. As far as GL is concerned, the proposed multi-color and variable photometric survey would lead to the detection of ~ 50 new multiply imaged quasars for which nearly daily photometric information will become available. Of course, the lenses can first be directly selected from those quasar candidates revealing a peculiar image morphology. From the statistical identification and study of these lenses, it will be possible to independently infer



the most likely values for the cosmological parameters Ω_0 and λ_0 and to precise the relation for the number counts of quasars at faint magnitudes. From the photometric monitoring of a selected sample of multiply imaged quasars, we shall derive in a statistical sense the value of the Hubble parameter H_0 from the measurement of the time delay between their multiple lensed images.

The site chosen for the operation of the ILMT is finally in India, at Devasthal (29°22'N) where new observing facilities are currently under construction. It presents almost the same advantages as La Silla except for the monsoon which takes place between July and September when the galactic plane crosses the field of the ILMT which is of poor interest as far as ILMT is concerned since we are mostly interested in the extragalactic sky.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Mehtar Lam
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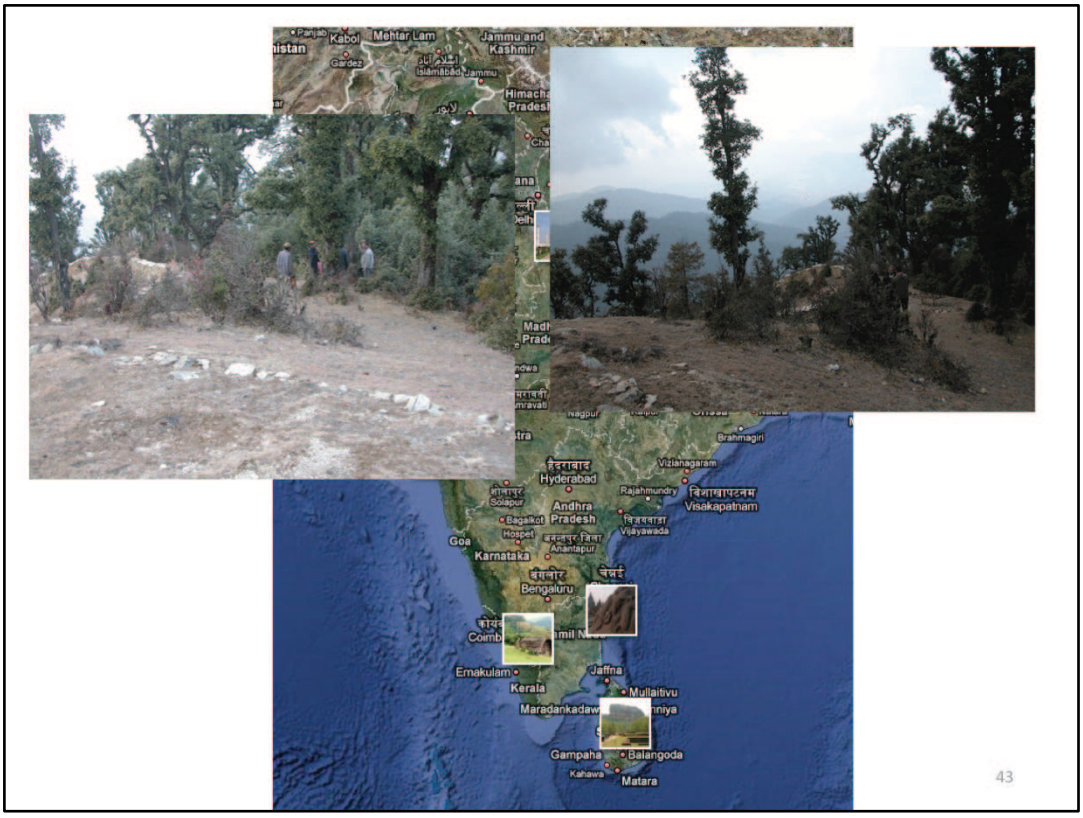
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Andhra Pradesh
Bagalkot
Vijayawada
Goa
Hospet
Anantapur
Karnataka
Bengaluru
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Etat du projet

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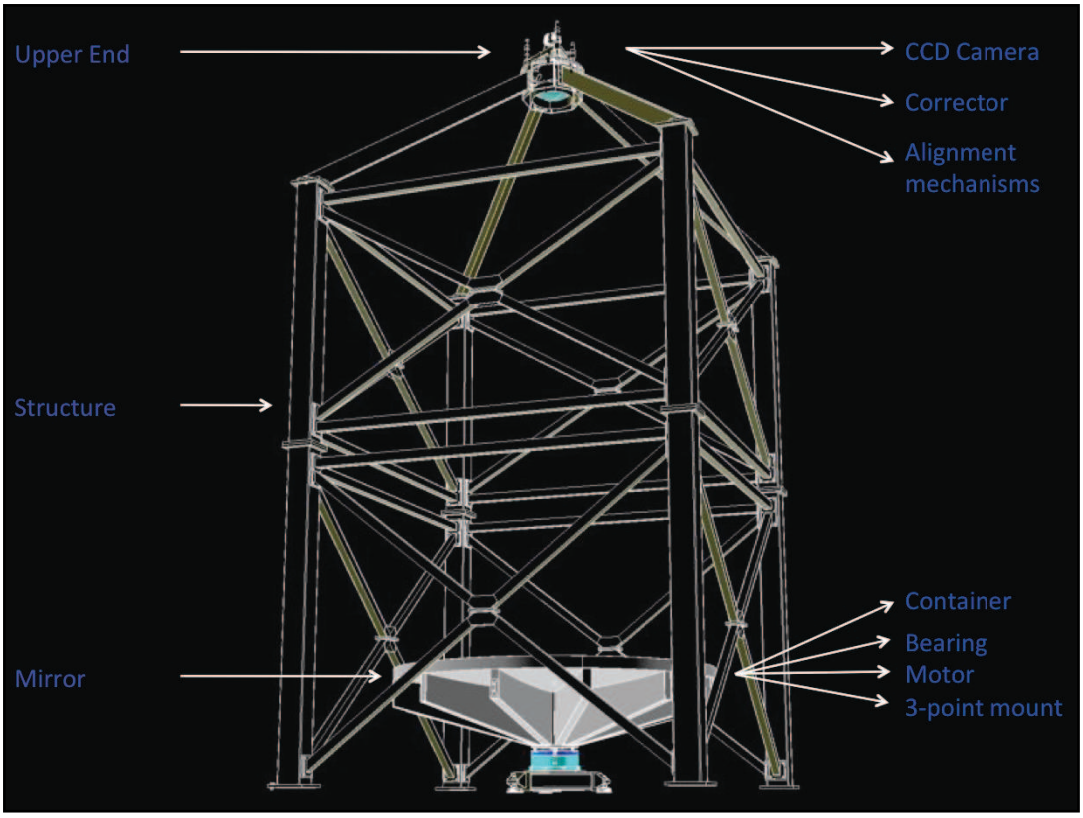


The International 4m LMT project (J. Surdej):

- Present status of the 4m LMT project:

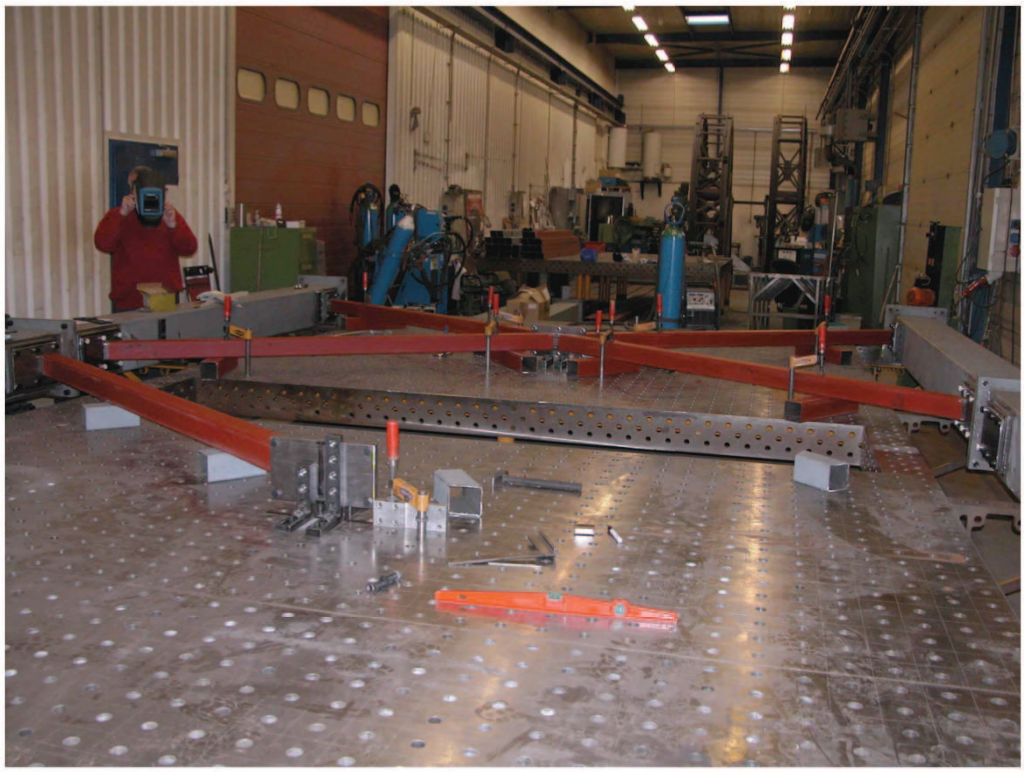
• At the moment, institutes participating to the international LMT project are: Liège (AMOS, CSL and IAGL, construction of the mirror and one of the sites for data analysis, dome, corrector and upper end), ROB (CCDs), … Universidad de La Serena (Chile) or Aryabhatta Research Institute of Observational Sciences (ARIES, India) for the image analysis and operation of the LMT.

• An executive summary of the project has been submitted to ESO and has been approved by the DG; alternate observing sites exist!

• Granting agencies have been identified and applications have been submitted.

Actuellement

Janvier 2007



The International 4m LMT project (J. Surdej):

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Actuellement

Janvier 2007

The International 4m LMT project (J. Surdej):

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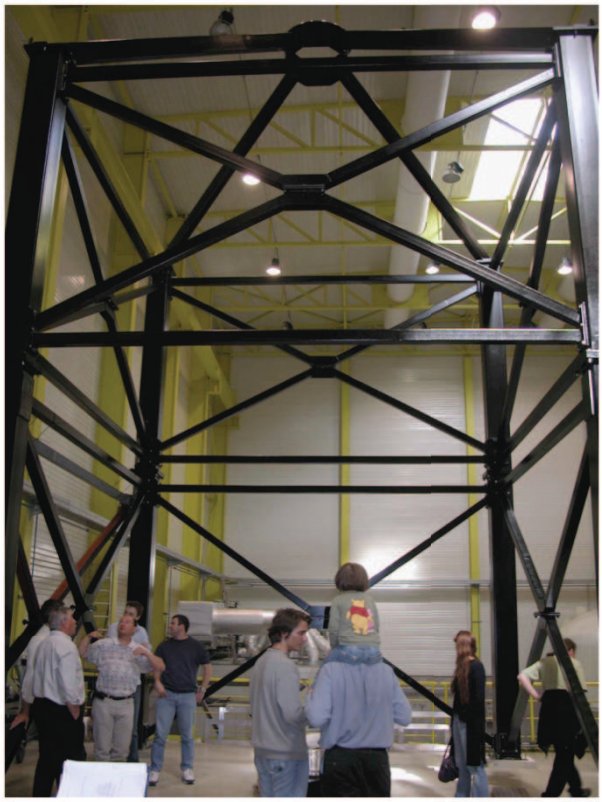

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The International 4m LMT project (J. Surdej):

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Juin 2007

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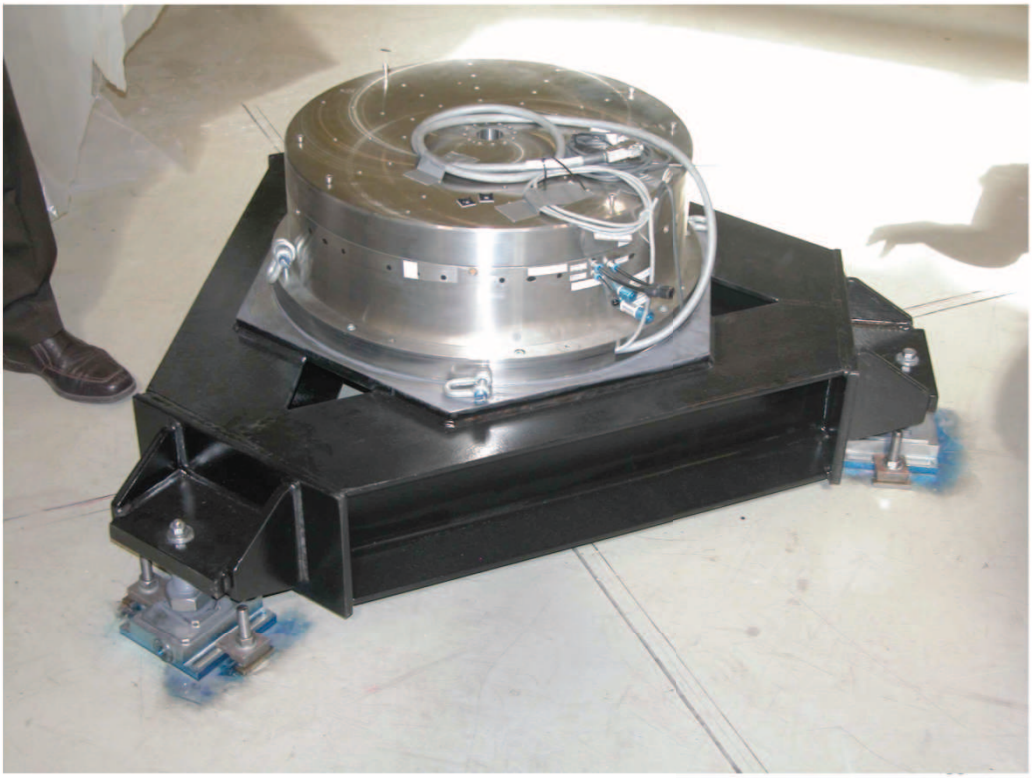

The International 4m LMT project (J. Surdej):

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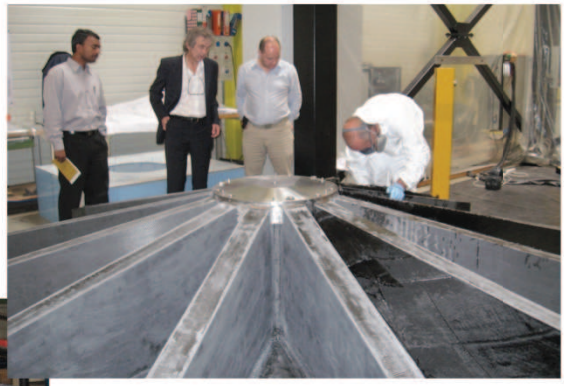
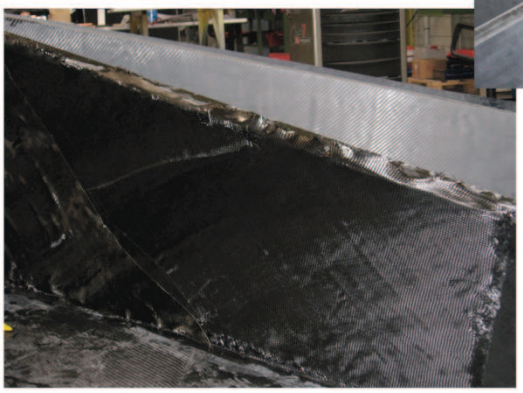
Rigidification

Juin 2009





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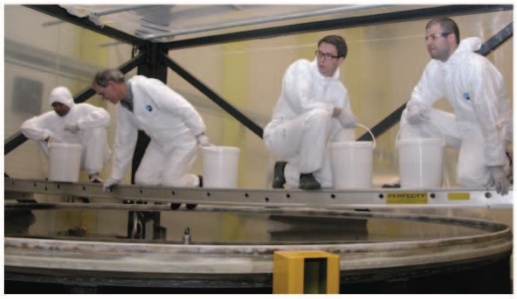
Spin-Casting



Septembre 2009

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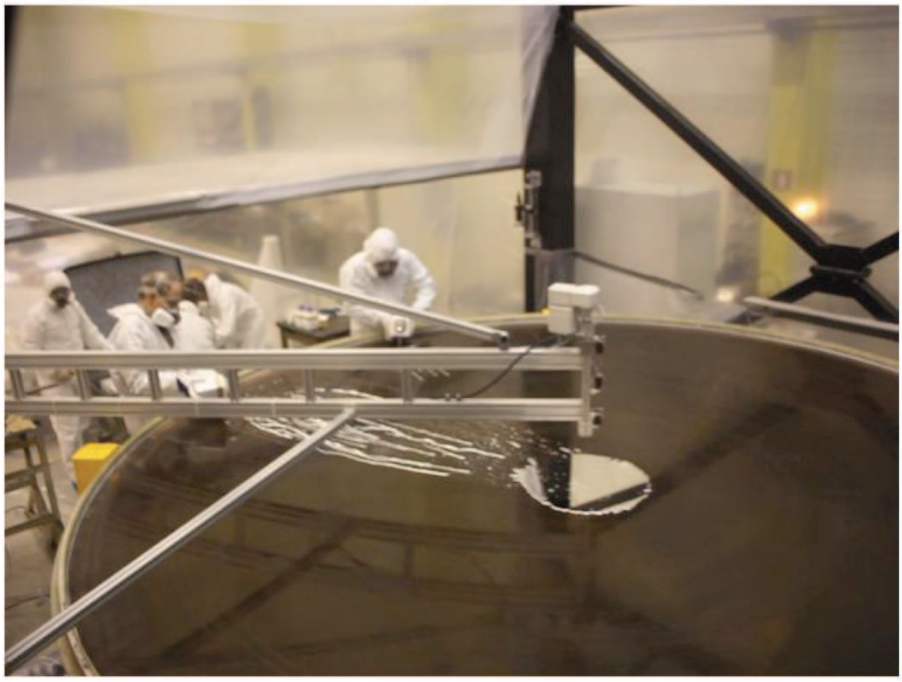
First tests with mercury (15-1-2011)



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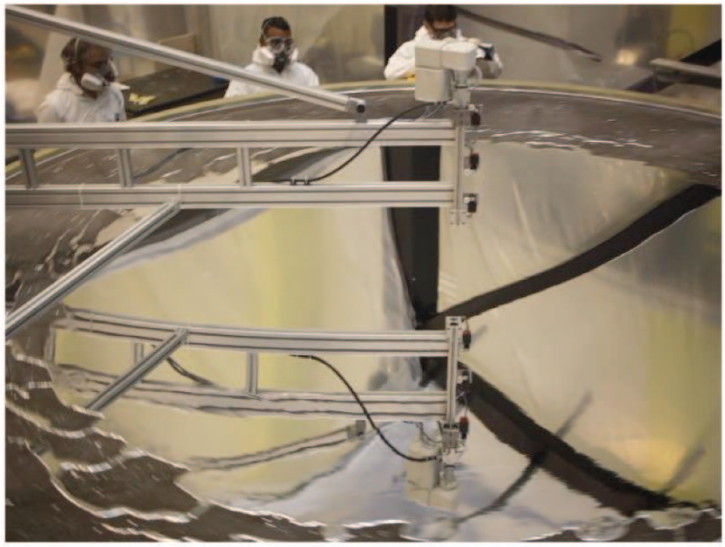

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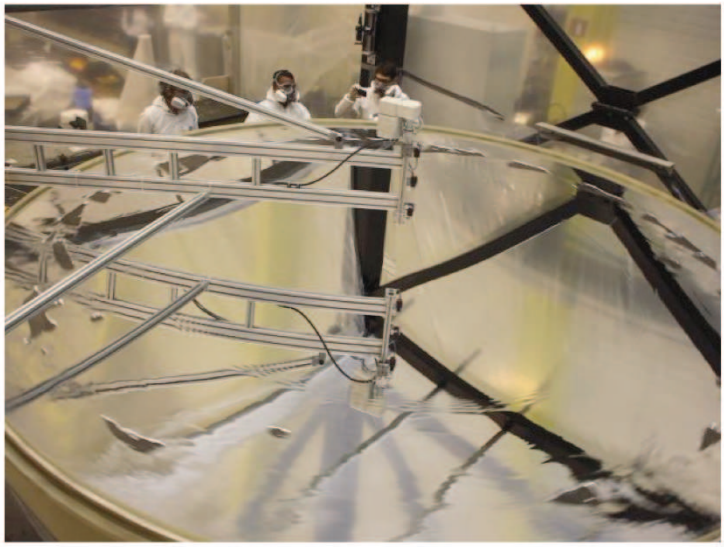

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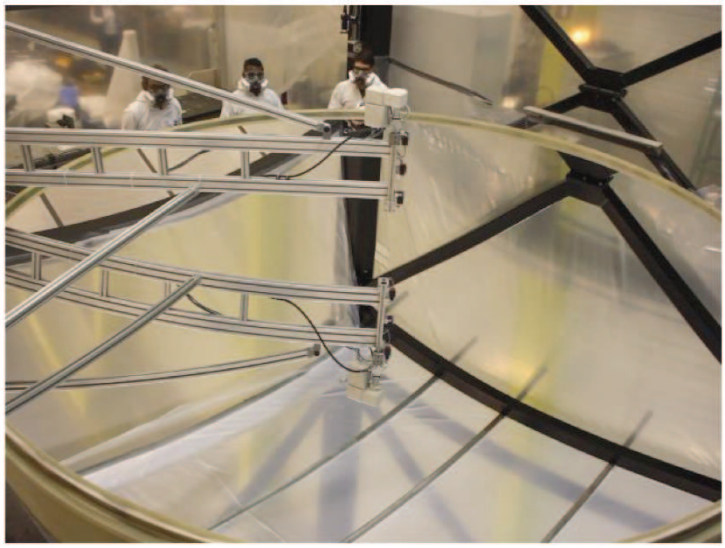
First tests with mercury (15-1-2011)



59

First tests with mercury (15-1-2011)

60

First tests with mercury (15-1-2011)

61

First tests with mercury (15-1-2011)

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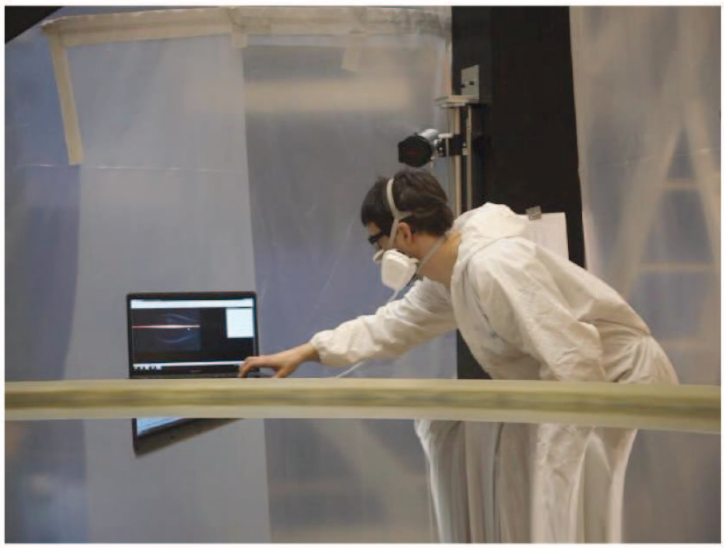
First tests with mercury (15-1-2011)



63

First tests with mercury (15-1-2011)

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Conclusions

- **Le télescope à miroir liquide est un instrument unique permettant un survey dédié à des projets scientifiques très intéressants**
- Haute qualité optique
- Faible coût
- La technologie : ILMT 4m ok
- Diverses institutions sont activement impliquées dans le projet
- L'ILMT de 4m est un pas important pour la préparation de projets de grande envergure impliquant des TMLs

Références : http://www.aeos.ulg.ac.be/LMT

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The International 4m LMT project (J. Surdej): - Conclusions:
In few words, the ideas briefly developed in this document are:
- dedicated and very interesting science have been identified for 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.
- LMs have excellent optical qualities (extensive interferometric tests show diffraction limited optics)
- LMTs are inexpensive
- Novel correctors promise to give access to large regions of sky
- The 4m LMT is a test before constructing larger LMTs.
- see La Recherche, February 1998, "L'avenir bon marché des télescopes à miroir liquide"

References: See the WWW bibliography available at the URL:
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