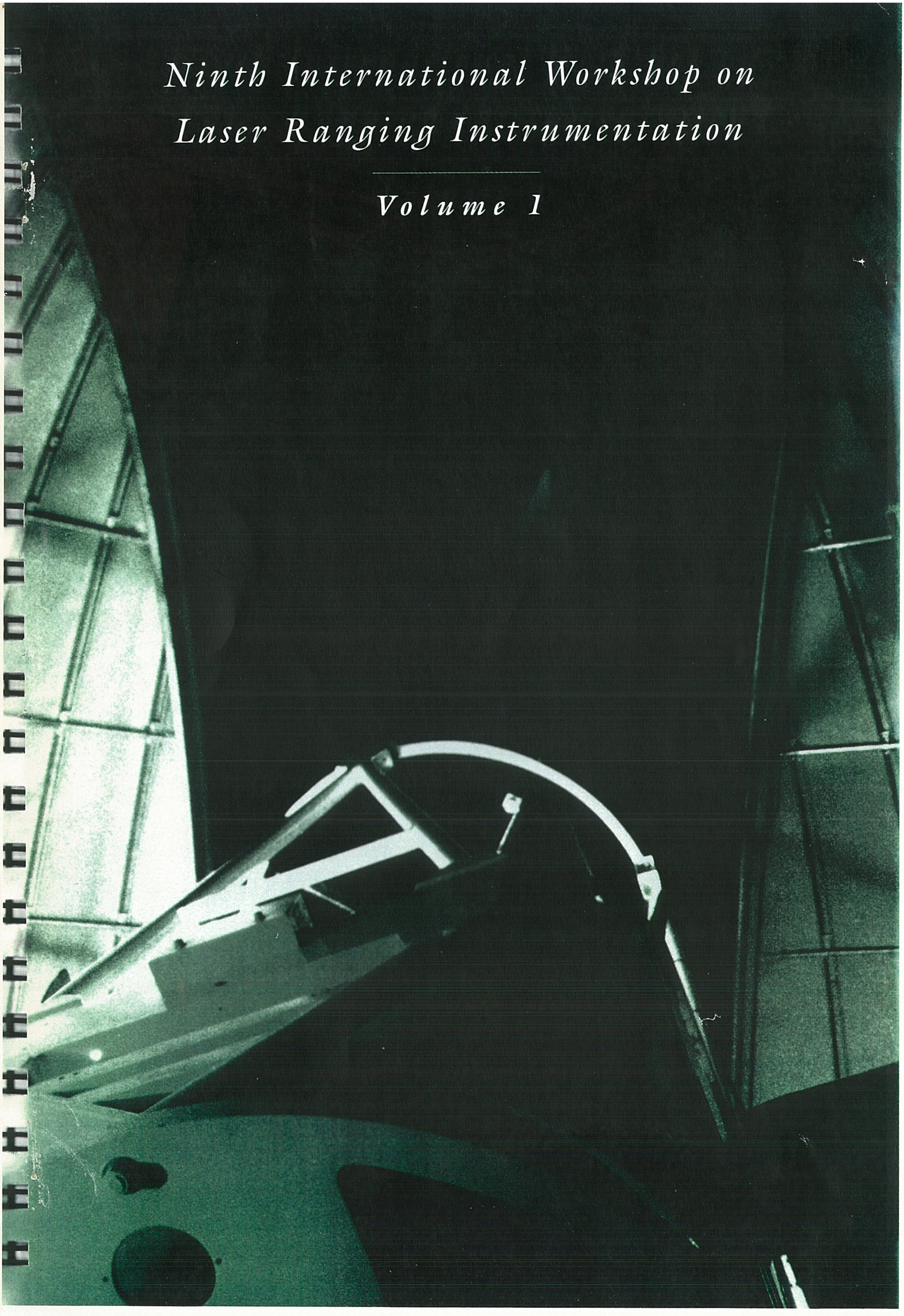
Ninth International Workshop on Laser Ranging Instrumentation

Volume 1



Ninth International Workshop
on
Laser Ranging Instrumentation

incorporating a

Symposium on Western Pacific Laser Ranging Network

WPLS '94

Canberra 1994

VOLUME 1

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with assistance from Georgina R. Luck, Mark J. Elphick, Robbie Horn

Australian Government Publishing Service
Canberra

ISBN 0 644 47424 6 (Vol. 1)
ISBN 0 644 47427 0 (Set)

The Ninth International Workshop on Laser Ranging Instrumentation, incorporating WPLS '94, was held at Becker House, Canberra, Australia, from 7 to 11 November 1994.

Workshop sponsors: Auslig, EOS, Qantas

Symposium sponsor: STA, Japan

Papers compiled and edited by:
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Canberra ACT, Australia

Cover photograph: Orroral Observatory, Australia
Photographer: Anthony Willing

Produced by the Australian Government Publishing Service

ADDENDUM

The following paper "ZIMLAT: The New Zimmerwald Laser and Astrographic Telescope" was inadvertently omitted from these Proceedings. I sincerely apologize to the authors for losing the original manuscript.

J McK Luck

John McK. Luck
Editor
1 February 1997

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ZIMLAT

The New Zimmerwald Laser and Astrographic Telescope

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Session: New Fixed Stations

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ABSTRACT

The nearly 20 years old Laser Telescope in Zimmerwald cannot respond anymore to all requirements of modern Satellite Geodesy. Daytime operation is impossible, ranging is limited to low orbiting satellites (Lageos), pass interleaving is slow, the accuracy is not sufficient.

During the last few years first developments and tests with astrographic tracking (CCD) of moving objects (comets, minor planets, geostationary and other satellites, space debris) have been performed on the same SLR telescope. However, neither its optical quality nor its tracking accuracy are sufficient to make use of the full potential of this method.

Since 1991 the Astronomical Institute has been evaluating a new telescope for both satellite laser ranging and astrographic tracking. In March 1994 the new instrument has been ordered from Télas, Cannes, a Joint Venture between the French companies Aérospatiale and Framatome. The new telescope will share the 1 m primary mirror and the secondary and tertiary mirrors between the satellite laser ranging and the astrographic tracking of moving objects. There are four camera ports, three of which are reserved for CCD cameras of different focal lengths and one for the TV guiding camera for SLR.

The telescope will allow either independent SLR or astrographic mode of operation or, with a slight reduction in imaging quality, even a simultaneous tracking mode. Switching between different tracks can be rapidly performed thanks to excellent angular velocities and accelerations of the mount.

The Laser system, the electronics equipment, the station computer, and the tracking software will be upgraded as well. The installation of the new system on site will start in July 1995. The system will be financed by the Federal Office of Topography, the Swiss National Science Foundation, the University of Bern and the Canton of Bern.

1. THE ZIMMMERWALD OBSERVATORY

1.1 The Schmidt/Cassegrain Telescope

The Zimmerwald observatory was built by the University of Berne in 1955/56 to provide the Astronomical Institute the possibility to perform optical observations far from the polluted air and the light of the city of Berne.

It consisted of a building with a dome for the instruments, a dark chamber and two office rooms, and a separate building with accommodation rooms for the observers.

The telescope contains in the same tube actually two parallel telescopes:

- a Schmidt camera (aperture 40 cm, mirror diameter 60 cm, focal length 104 cm, field of view 6.6°) to search for supernovae, minor planets and comets

- a Cassegrain telescope (aperture and primary mirror diameter of 60 cm, focal length 12.6 m, field of view 10'). It can be used for visual observations as well as for observations with various kinds of sensors (e.g. photometer, cameras)

Till now more than 50 supernovae, 100 minor planets, and 10 comets have been detected.

Between 1965 and 1974 the Schmidt telescope has also been used for optical (astrometric) observations of various satellites. The accuracy of a satellite position was found to be about ± 0.5". These activities marked the beginning of the research at our institute in the area of satellite geodesy.

In the years 1971 and 1972 first satellite Laser ranging tests were performed with a ruby laser using the Cassegrain as receiving telescope. The outcome was rather poor, mostly due to the inability of the telescope to track the satellites during their passes.

However, because of the promising prospects of the satellite laser ranging the Astronomical Institute decided to develop a specially designed telescope, in a separate dome, just for the purpose of SLR.

1.2 The Current SLR Telescope

The instrument, designed and built by the institute, consists of

- a Cassegrain telescope with a primary mirror of 52 cm diameter for signal reception and optical tracking (using a ISIT camera) and

- a separate Galilei telescope (diameter 15 cm, factor of 5) for signal transmission

Initially the axes were driven by step motors, eventually replaced by DC motors and angle encoders. The maximum slew rates are 7°/sec for the azimuth axis and 3.5° for the elevation axis. The tracking range goes from -270° to +270° in azimuth and 0° to 180° in elevation.

The Laser beam is guided to the transmitting telescope through a Coudé path, expanded by the telescope by a factor of five. The divergence of the beam can be adjusted by moving the concave lense of the telescope by remote control from the minimum few arc seconds to several arc minutes.

During the first few years a ruby laser (built in-house by the Institute for Applied Physics) was used. It was replaced 1984 by a Nd:YAG laser

The ranging system, consisting of a photomultiplier, a constant fraction discriminator, and a LeCroy time interval counter results in a single shot accuracy of about 0.4 ns.

The calibration is done in-pass (each 6. observation is a calibration measurement) by extracting a fraction of the transmitting pulse and properly attenuating it before inserting it into the receiving path.

The epoch timing is done by a counter based on an undisciplined, high-precision BVA quartz automatically controlled by a Loran-C receiver and by hourly TV comparison with the atomic clocks of the Federal Office of Metrology near Berne. The same frequency is also used by the time interval counter.

1.3 CCD Observations

Since 1990 a small group of people have been developing at our institute a CCD astrographic observation system designed to optically observe all kinds of moving objects like minor planets, comets, earth satellites, and especially space debris.

Eventually it will consist of a CCD camera, a camera computer, a telescope, a computer for image analysis and various programs to track objects, take images, process the images to precisely determine the positions of the objects relative to known positions of catalogued stars (including object recognition software) but also software for additional processing such as orbit determination, system transformations, orbit predictions (also in realtime).

Currently the SLR telescope is used for tests by temporarily replacing the TV camera by a CCD camera.

1.4 Permanent GPS Receiver

Since June 1992 the Federal Office of Topography has been operating a permanent GPS receiver (Trimble 4000SSE). It is part of the global network of the International GPS Service for Geodynamics IGS. The receiver also generates a 1 pps signal that is used to additionally control the SLR system clock.

2. System Limitations

The current system, designed in the early seventies, shows several limitations for up-to-date Satellite Laser Ranging:

- Due to unstable axes (the transmitted laser beam and the receiving telescope do not stay properly parallel) we have to allow for a pretty large field of view (about 2 arc minutes), which excludes any daytime observations. Also passes in the Earth's shadow are sometimes difficult to realize.

- The single-shot accuracy (0.4 ns = 6 cm) is not sufficient anymore
- Etalon, GPS and Glonass satellites are beyond the maximum range
- The current software system and the rather low maximum slew rate limit the possibilities for pass interleaving. We need about 90 seconds between the last observations of one pass and the first observations of the next pass
- Most of the optical components are coated for one frequency only, the receiving path could not easily be extended for a second sensor
- The Nd:YAG laser has been in operation for more than 10 years, it has practically reached it's service life
- The telescope optics show shortcomings in their precision
- The tracking accuracy of the telescope is insufficient for precise optical tracking
- As the old astronomical telescope (Cassegrain) cannot be used for object tracking (there are no motorized computer-controlled drives for the axes available nor possible to install) we are also in need for a suitable telescope for this application.
- The camera mounted on the SLR telescope has a derotated field of view with respect to elevation only but not e.g. with respect to star tracking
- The dome limits the observations to 30° minimum elevation

3. Requirements for a New Telescope

An analysis shows that an astrographic telescope can be used during less than 25 % of the time only (the sun has to be below ca. -12° elevation, no strong moonlight), weather conditions not taking into account.

So we can ask the question:

Can a telescope be designed that is suited for both Satellite Laser Ranging and astronomical (astrographic) observations?

In order to be able to perform an evaluation procedure to answer this question, we had to formulate a proper list of requirements for a new telescope:

3.1 Satellite Laser Ranging

- ranging from low orbiting satellites up to geostationary satellites
- accuracy: a few millimeters single shot

- night- and daytime operation

- pass interleaving, i.e. switching from one satellite to a next in less than half a minute

- fully automated operation, no operator interaction necessary under normal conditions

- prepared for two colors

- 10° to 20° minimum elevation

- visual tracking support with a rather large field of view (> 0.5°), sensitive enough to track low-magnitude satellites (at least mag. 15)

3.2 Astronomical Telescope

One of the traditional areas of activity at our observatory was the sky survey to look for supernovae which often lead to the detection of new objects in our solar system, such as minor planets and comets. Tracking and orbit determination of those objects was the logical consequence. The experiences gained with this optical tracking and the data processing lead to similar new activities in the optical tracking of satellites, first with photographic means in the sixties and now with CCD cameras and image processing.

A new telescope to be used for these activities should therefore allow for high-precision tracking of

- zero-velocity objects (geostationary satellites)

- slow-moving objects (minor planets)
  → tracking with 0° - 1'/sec velocity and exposure times of several minutes

- fast-moving objects (LEO)
  → tracking with 0° - 1°/sec velocity and exposure times of a few tenths of a second

- high image resolution: ca. 1" per CCD pixel

- optical tracking of small objects (of a few centimeters diameter)

- derotation of the field of view according to several scenarios

- fast switching from one experiment to another (i.e. several ready-to-use camera ports with individual focal reductors)

3.3 General Requirements

If only one telescope could be used for the two applications:

- any reductions in the performance (e.g. imaging qualities, laser cadence) have to be acceptably small
- and the switching from SLR mode to astrographic mode and vice versa has to be performed within a few seconds

Last but not least the telescope has to fit into the existing SLR building.

4. The New ZIMLAT Telescope

4.1 The Evaluation

In 1991 six telescope manufacturers were asked to verify if the detailed requirements could be met by one telescope only, to prepare a coarse design of such a combined telescope, and to submit a first cost estimate.

Four out of the six manufacturers submitted end of 1991 a concept study and a cost estimate, they all came to the conclusion that basically a dual-purpose telescope should be possible.

We decided to go on with G.I.E. Télas, France (a joint venture between the two French companies Aérospatiale and Framatome) and ordered a detailed design study to be realized during 1992.

In parallel we also evaluated

- a Laser system
- a station computer
- electronic equipment for the signal processing
- a new dome for minimum elevation of less than 20 degrees,

the evaluation to be finalized end of 1994.

In 1993 negotiations with and between various institutions for the financing of the whole system were performed. The following institutions finally agreed to support the new system:

- The Federal Office of Topography
- The University of Berne (Canton of Berne)
- The Department for Civil Engineering of the Canton of Berne
- The Swiss National Science Foundation

The telescope was ordered at Télas in March 1994 and the final Design Review already took place end of October 1994.

According to the detailed plans the installation of the telescope will start in July 1995.

4.2 The Telescope

The telescope will have a 1 m primary mirror and a 30 cm secondary mirror in a Richey-Chrétien configuration.

The optical part of the telescope will have a Nasmith path to 4 different positions for cameras, each with its own focal reductor:

Camera	Reductor	Field of view	Focal length
TV Camera	FR	45'	1.2 m
CCD Camera	CO1	13'	4 m
CCD Camera	CO2	40'	4 m
CCD Camera	CO3	13'	8 m

The cameras are radially mounted on motorized slides on a vertical instrument platform fixed at one end of the horizontal axis. The deflection mirror (DM) at the center of the platform selects the camera port to be used. The platform can be rotated around this axis for field of view derotation.

The requirement of fast switching between various satellites asked for rather high slew rates and accelerations. Technical reasons didn't allow a 180° range for the elevation axis (which would have allowed an even faster switching and an easier tracking at near zenith). This restriction could be compensated by a relatively high maximum velocity in azimuth:

- Azimuth $< 30°/s$; $10°/s^2$; $\pm 270°$
- Elevation $< 15°/s$; $5°/s^2$; $-2°$ to $+90°$

The tracking accuracies have been fixed to

- ± 2" absolute
- few 1/10" relative

The Laser beam will be expanded into a ring shape by means of an axicon (two conical lenses), guided into the telescope through a Coudé path and a beam splitter (DBS) mounted in the horizontal axis of the telescope, and leave the telescope concentrically around the secondary mirror (M2). The ring diameters will be about 35 cm (inner) and 50 cm (outer).

The receiving path will use the remaining area around the laser ring and it will be separated from the transmitted beam through a 45°-mirror with a center hole for the beam. This design does not need a rotating mirror as transmit/receive switch and the transmitted laser beam does not change its position within the telescope during the tracking. The latter fact should facilitate in-pass calibration and beam direction control through retroreflectors.

All the optical components are prepared for two-color ranging (beamsplitter, coudé mirrors).

4.3 The New Laser

Currently there are still two options open

1) A classical Nd:YAG laser with the two wavelengths $\lambda_1 = 532$ nm and $\lambda_2 = 1064$ nm

and

2) A Titanium Sapphire laser with the two wavelengths $\lambda_1 \approx 420$ nm and $\lambda_2 \approx 840$ nm

The decision will most certainly be in favor of a Titanium Sapphire laser because its two frequencies can directly be used for two-color ranging and because the best performance of avalanche diodes is in the area of 840 nm.

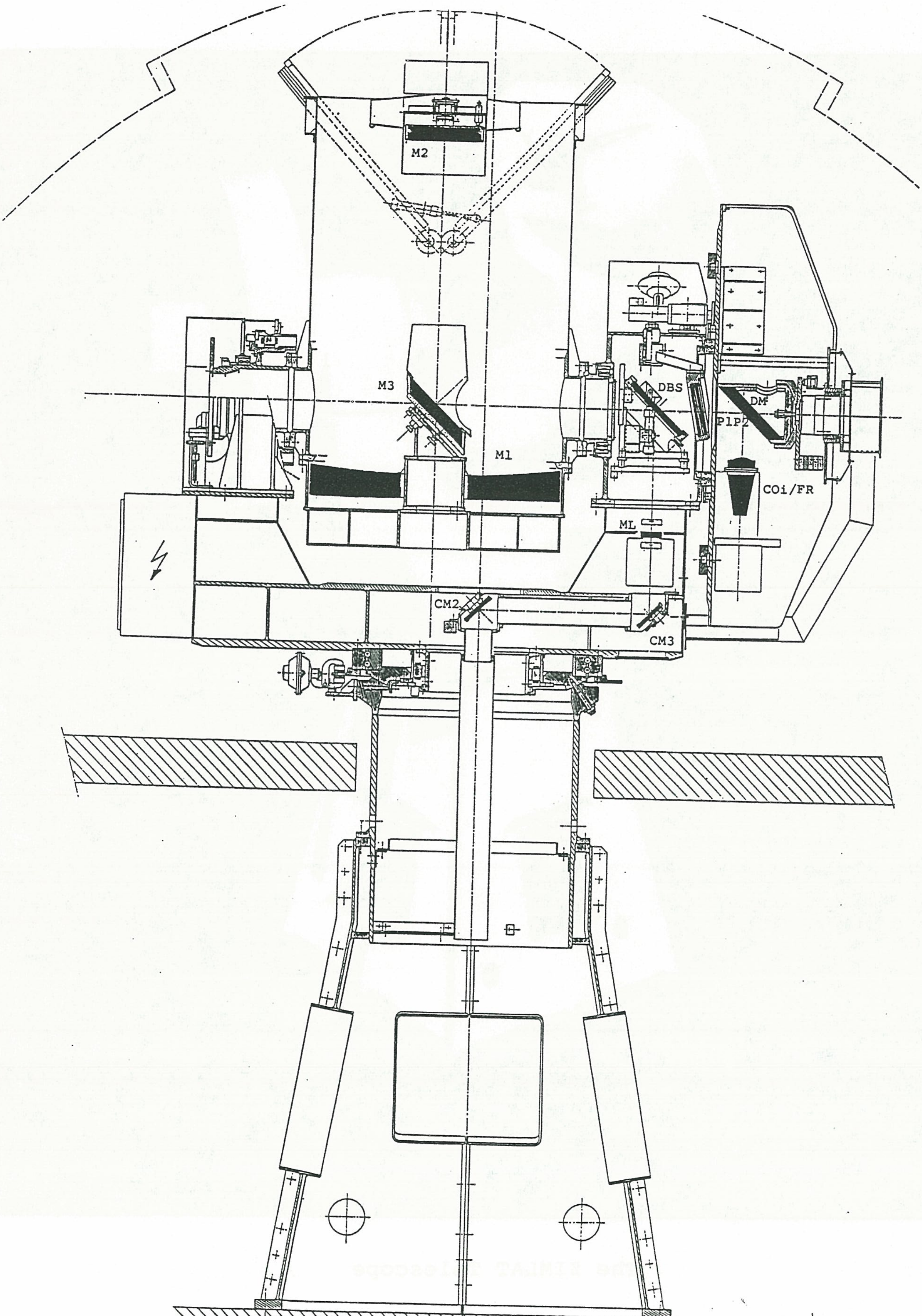
5. Implementation Plan / Operation

- The routine operation will be stopped in May 1995.
- In June 1995 the necessary modifications of the building (dome, wiring, telescope pedestal, ...) will be performed.
- The onsite installation starts on July 3rd.
- Three months are planned for installation, tests and acceptance procedures.
- Operation should resume not later than November 1st, 1995.

The operation procedures should be as follows:

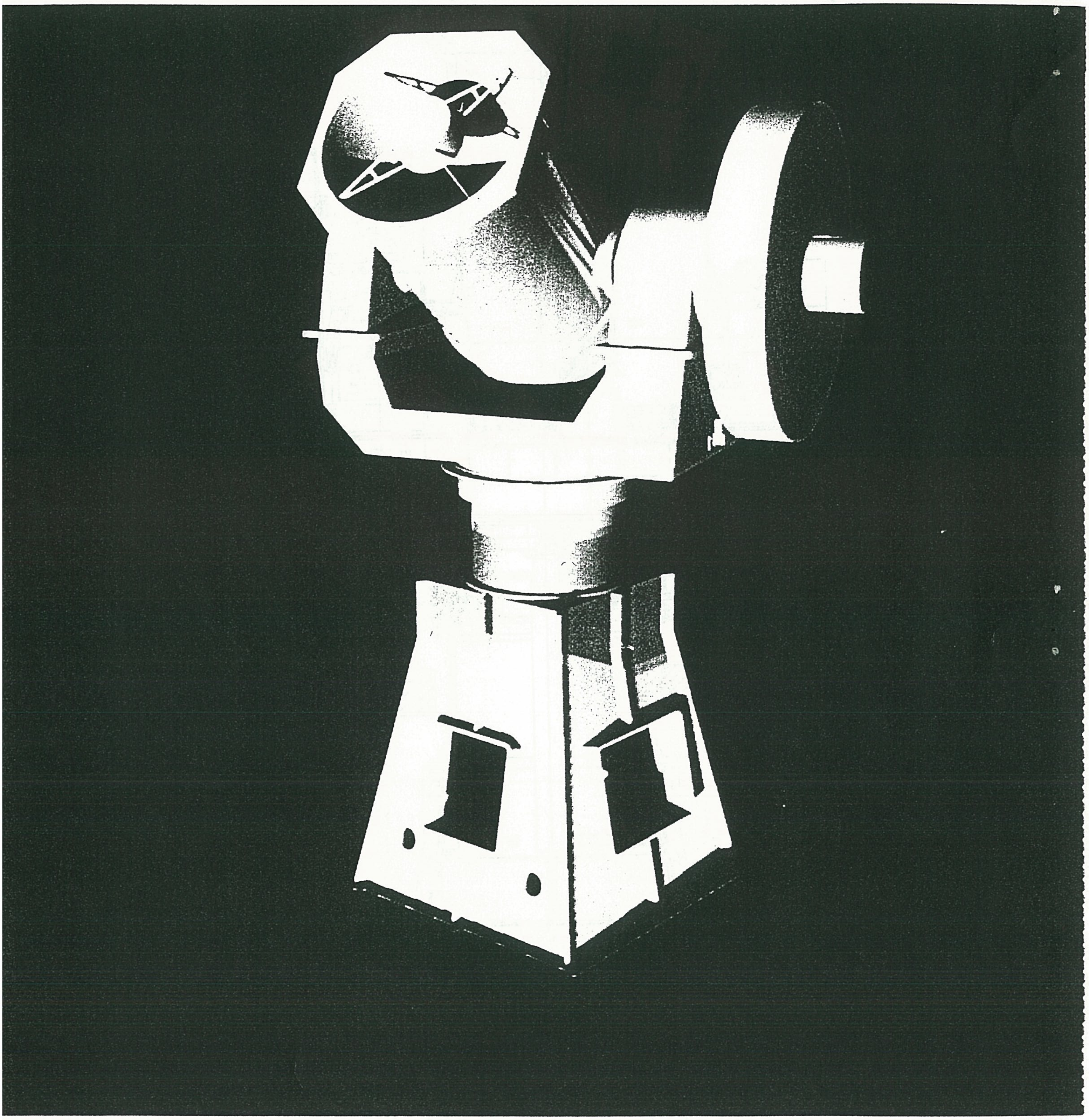
- The nighttime with no or few moonlight only will be reserved for optical (CCD) observations.
- The daytime, the nighttime with less favorable conditions and the time between CCD observations (for special experiments even simultaneously) will be used for SLR tracking.

The medium term goal will be to be capable of fully automated SLR operation for intervals of several hours. Onsite staff will then be needed for emergency conditions only.

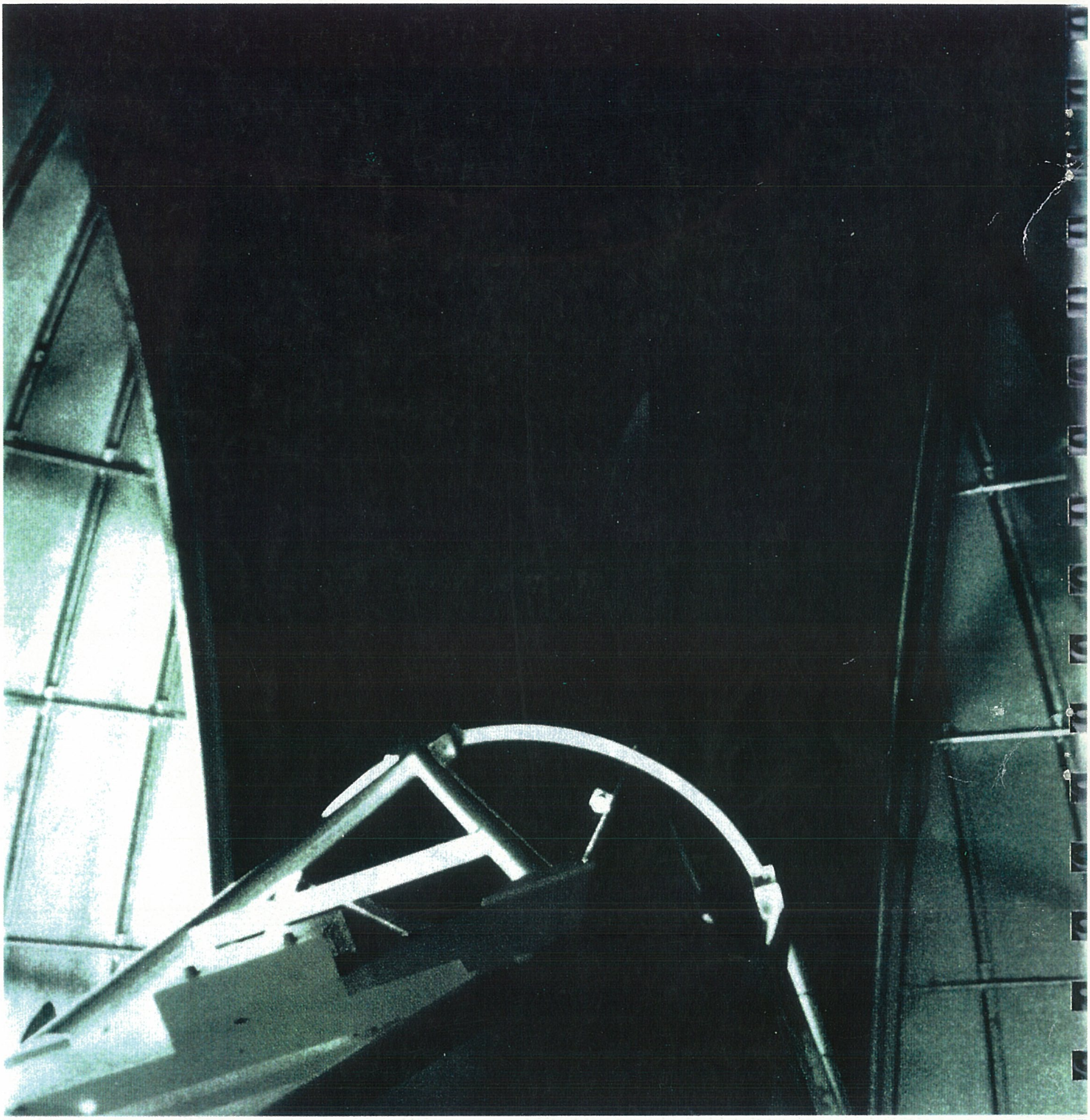


G.I.E. TELAS

TELESCOPE ZIMLAT



The ZIMLAT Telescope



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