SEVENTH
INTERNATIONAL WORKSHOP
ON
LASER RANGING
INSTRUMENTATION

Matera, Italy

2-8 October 1989

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Cover : laser beam from Grasse LLR to the Moon over OCA/Calern observatory
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INTRODUCTION

The book you are reading contents most of the communications presented at the Seventh International Workshop on Laser Ranging Instrumentation, held in Matera on October 2 - 8, 1989.

If you have been attempting the meeting, you will see that the program has been rearranged in order to make the information easier to find in the proceedings. You will also note that some papers are missing, as this book is a compromise between a quick publication and an exhaustive work.

Ten chapters cover most of the topics of the meeting in the following order :
- Scientific results, requirements and goals
- International cooperation
- Station status and developments (USA, Eastern Europe, Asia, Western Europe)
- Laser technology
- Detection
- Multiple wavelength ranging
- Epoch and event timing
- Calibration
- Mobile systems technology
- Recent software developments

The conclusion summarizes the discussions held in the last technical session of the Workshop.

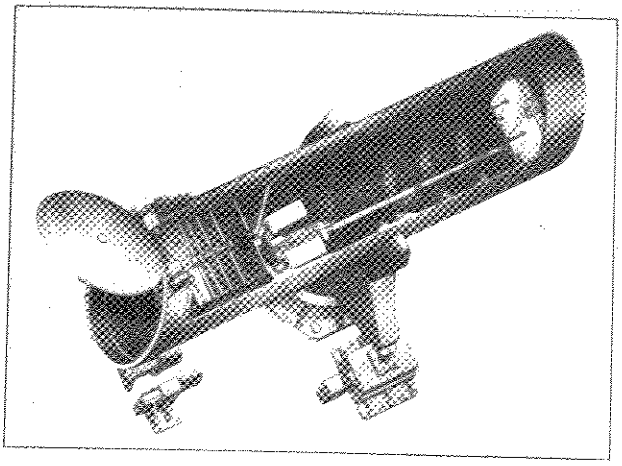
The Seventh International Workshop wouldn't have been held in Matera without the help of many organisations. It is not possible to list all of them, but the participants are very grateful to each of them for their contribution.

The publication of these proceedings has been sponsored by AERITALIA Space Systems Group, and OFFICINE GALILEO Optics and Space Division. Both these companies permitted to reduce the cost of this book.

Thanks to M. Glentzlin and the members of the Lunar Laser Ranging station staff at OCA/CERGA for making a readable book from the received papers ...

Ch. Veillet - March 1990

OFFICINE GALILEO



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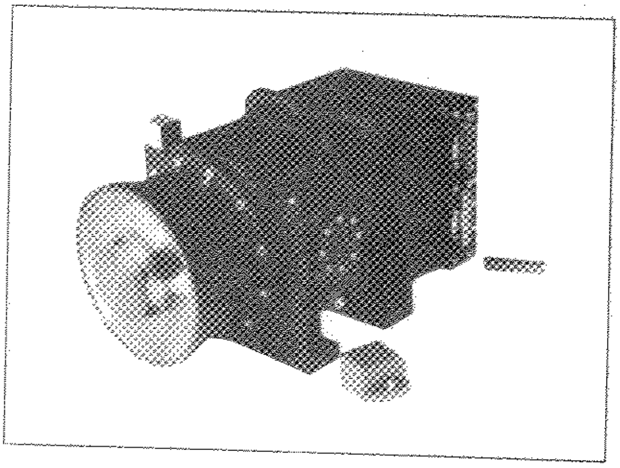

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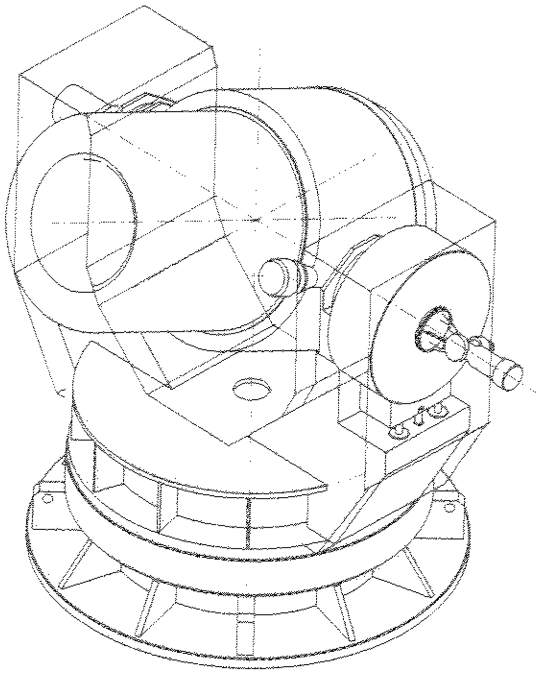

LASER TELESCOPE
FOR MOBILE
STATION OF MATERA

Officine Galileo, leader in Europe for the attitude measurement sensors (Infrared Earth Sensor, Sun Sensor, Star Sensor, CCD Cameras), has started since several years to develop a new line of electro-optical instruments for applications in the scientific research and the remote sensing fields.

To date the main instruments studied are:

- Image spectrometers for remote sensing
- Infrared radiometer for methereology
- Interferometric sounders for athmospheric study
- U.V. spectrometer for astrophisic research
- Instrument for optical diagnostic in microgravity experiments

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GRUPPO EFIM
FINANZIARIA E. BREDA

RESOLUTION 1

The 7th International Workshop on Laser Ranging Instrumentation meeting at Matera, Italy,

EXPRESSES great appreciation to the Italian Space Agency, to the Matera Center for Space Geodesy, and the government of matera for sponsoring and organizing this most succesful meeting.

RESOLUTION 2

The 7th International Workshop on Laser Ranging Instrumentation meeting at Matera, Italy,

RECOGNIZING the requirement for tracking of multiple low satellites in support of ongoing or imminent satellite missions, and the need for improved operational efficiency,

RECOMMENDS that immediate efforts be made to improve the prediction capability and to define new hardware and procedures for implementing multi-satellite tracking capibility.

RESOLUTION 3

The 7th International Workshop on Laser Ranging Instrumentation meeting at Matera, Italy,

RECOGNIZING the need for a balanced global distribution of laser ranging observations and the inadequate number of facilities in the Southern Hemisphere,

RECOMMENDS that national agencies operating laser ranging systems cooperate in joint effort to install, operate, and maintain laser ranging facilities in the Southern Hemisphere.

RESOLUTION 4

The 7th International Workshop on Laser Ranging Instrumentation meeting at Matera, Italy,

RECOGNIZING the scientific need for 1 mm accuracy in satellite and lunar laser ranging and that this capability appears feasible in view of the technological discussions at this meeting,

RECOMMENDS that financial resources be allocated to the technical realization of these requirements.

RESOLUTION 5

The 7th International Workshop on Laser Ranging Instrumentation meeting at Matera, Italy,

WHEREAS, the SLR community is concerned with implementation of quick-look normal points and with the proliferation of formats,

REITERATES the acceptance of the Herstmonceux normal point algorithm, and

RESOLVES

THAT a format as close as possible to the Merit-II be adopted consistent with telex constraints,

THAT range measurements should include only instruments delay (no center of mass or atmospheric correction)

THAT epoch of laser firing be recorded

THAT time tags from time system utilize BIPM, USNO, GPS, other

THAT alt/az data and redundant information be removed

THAT the format be finalized between representatives of RGO, NASA, and Univ . of Texas within 45 days and

THAT field implementation as a replacement for quick-look data for orbit prediction and rapid data analysis take place at the earliest possible date.

Scientific results,
requirements
and goals

FIRST RESULTS FROM LASER RANGING DATA TO METEOSAT P2

INTEREST FOR COGEOS PROJECT

by

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ABSTRACT

At the end of 1988, the Lunar Laser Ranging (LLR) station at Grasse has recorded the first laser ranging measurements to a geosynchronous satellite. Because of the 1 : 1 resonance between the orbital period of the satellite and the rotation period of the Earth, the perturbation effects of some tesseral harmonics of the gravity field of the Earth (mostly the J_{22} term; $J^2{}_{22} = C^2{}_{22} + S^2{}_{22}$) do accumulate with time. As a result, the satellite's semimajor axis and longitude exhibit long period variations. Our preliminary analysis of the data shows that a slight change in the S_{22} coefficient, with respect to its value as determined within the GEM-T1 model, agrees better with the observation data. The combined analysis of laser ranging data and optical observations of geosynchronous satellites collected within the international project COGEOS would greatly improve the results.

1. INTRODUCTION

The orbit of a near geostationary satellite exhibits a strong resonance with the C_{22}, S_{22} harmonics of the gravity field of the Earth. The satellite undergoes a significant acceleration in longitude with a corresponding longitude displacement. As an example, Figure 1 shows the longitude variation of Meteosat-P2 obtained by a numerical integration of the motion of the satellite. The earth gravity field used is GEMT1, truncated to 10 x 10. The initial conditions given by ESA/ESOC - Orbital determination Center Darmstadt -(a $\simeq$ 42165km, e $\simeq 10^{-4}$, i $\simeq 1°$, on September 28, 1988) are propagated over 55 days. The satellite longitude being close to the initial nominal value of $\simeq -1°.0$ shows a displacement of about 2 degrees for the 55 days period.

For the same case, the variation of the semimajor axis exhibits a clear secular drift of about 45 meters per day on which strong variations of several kilometers are superimposed (see Figure 2). The lunisolar gravitational perturbations, the solar radiation pressure effect, the Earth flattening effect, are the main origins of these short periodic variations while the C_{22}, S_{22} coefficients produce a great part of the secular drift. Of course, the acceleration in longitude and the secular drift of the semimajor axis strongly depends on the mean longitude. An example, the variation of the acceleration in longitude for given orbital elements (semimajor axis, eccentricity, inclination) is show in Figure 3 (Cot, 1984).

In point of fact, the more complete is the coverage of satellites observations at various longitudes, the more accurate will be the determination of the resonant coefficients (some of them do also require observations of satellites at non-zero inclination). This was actually the case that originated Project COGEOS (Nobili, 1987). Optical observations have the advantage that they do not require the satellite to be equipped with laser retroreflectors. Furthermore, while it is true that they are less accurate, it has to be taken into account that the observational geometry of a geosynchronous satellite is very poor: the longest baseline between two stations on the ground is seen from the satellite within an angle of about 8°.5. Hence, the uncertainty in the latitude and longitude of the satellite is about 10 times bigger than the range uncertainty (Milani and Nobili, 1980). Last, but far from the least, the uncertainty in the modelling of long term effects of solar radiation pressure on geosynchronous satellites is larger than the current accuracy of laser ranging stations thus making optical observations of 1 to 2 arcsec accuracy very useful (Milani, Nobili and Farinella, 1987).

2. THE ROLE OF LASER TELEMETRY TRACKING

METEOSAT P2, which was launched by ESA in June 1988, is the first geosynchronous satellite equipped with laser retroreflectors. The first laser range observations of METEOSAT P2 have been performed with the lunar laser facilities in Grasse (Veillet, 1989). In August 1989, only the LLR station in Grasse was getting returns (now Graz station is tracking the satellite too).

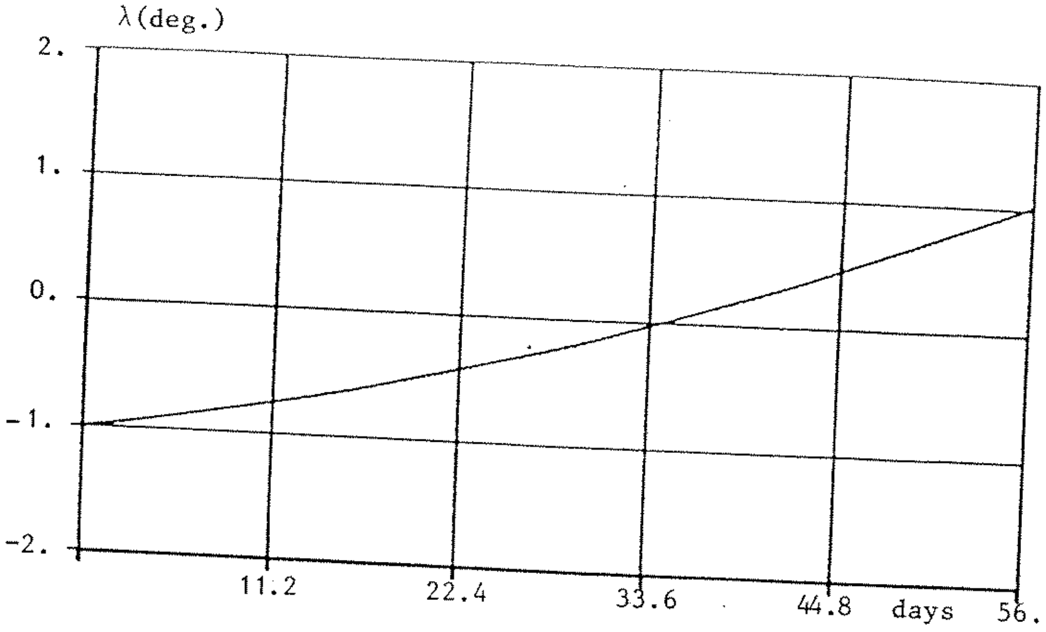

Fig. 1 : longitude evolution of Meteosat-P2 ($\lambda = \omega + \Omega + M - \Theta$)

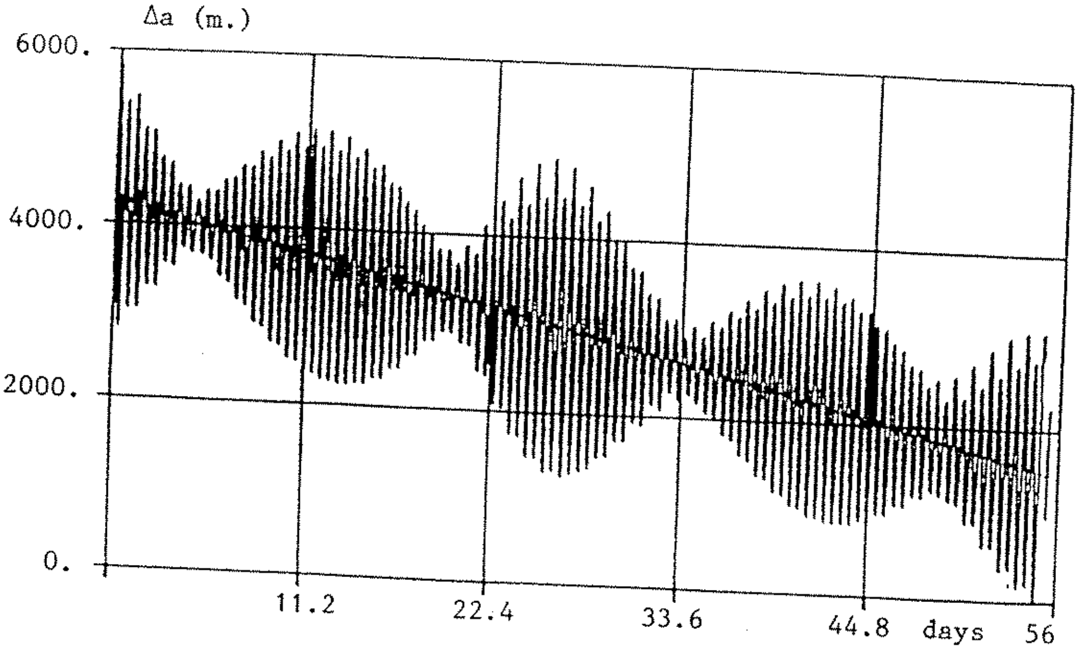

Fig. 2 : Variation of the semimajor axis of Meteosat-P2

This change could be significant in spite of the disagreement with the GEMT1, GEMT2 values, taking into account their relative uncertainties. However, the length of arcs are probably not long enough to yield very precise determination with one station and only distance measurement. Moreover, the satellite was partly in the shadow in the very beginning of the arc making the trajectory more difficult to be precisely determined. Other data are required to confirm such a result to be specific, angular optical positions could be extremely useful to decorrelate properly all the different parameters as well as other laser telemetry data.

4. CONCLUSION

Although these results need to be confirmed by the analysis of future tracking data, they seem quite encouraging. Further laser data will be particularly useful if another station -besides Grasse- will be able to get returns from METEOSAT P2, as it is now the case with the laser station at Graz (Austria). Optical (angular) observations collected within the COGEOS observation campaign, of METEOSAT P2 as well as of other synchronous satellites, will be most useful in the determination of several resonant coefficients. Therefore a fruitful collaboration between the laser stations that track METEOSATP2 and the scientists involved in COGEOS is worthwhile. Optical observations by the laser stations themselves would also be worth the effort.

RÉFÉRENCES

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Since METEOSAT P2 has no outside despun antenna it is of interest to note that only short periodic effects are to be expected from the solar radiation pressure (Anselmo et al, 1983). These effects have been computed neglecting satellite eclipses as well as the indirect effects of the Earth's albedo. Also, the angle between the Sun-Earth and the Sun-satellite conjunction lines has been neglected. The amplitude of solar radiation effects is of several meters. All other perturbations listed above give rise to effects of amplitude from several centimeters to several tens of centimeters.

The result of analytical substraction of the short period perturbations from the semimajor axis for the global arc is shown in Figure 5. A clear periodic effect is still present, but it can be removed with a numerical filtering using a fast Fourier transform. Now, the evolution of the semimajor axis may be well represented by a parabolic function. The coefficients of this parabol correspond to the GEMT1 model, but the quadratic term is less sensible to the model than the linear one.

According to the coverage of observations we divide the global arc into several sub-arcs (Figure 4). The same treatment as indicated above is applied to each sub-arc to determine the mean semimajor axis corresponding to the middle time of this sub-arc. The values obtained are plotted in Figure 6. When the quadratic term calculated for the global arc is substracted from these values, a line can be fitted so as to obtain the observed drift corresponding to the date Oct.4, 1990.

$$\frac{da}{dt}\ (\text{GEMT1}) = -\ 47.18\ \text{m/d} \qquad (1)$$

$$\frac{da}{dt}\ (\text{Observed term}) = -\ 47.45\ \text{m/d} \pm 0.10\ \text{m/d (rms)} \qquad (2)$$

Of all resonant coefficients C_{22}, S_{22} are the most important because of the low degree l. For a satellite close to zero longitude, the effective resonant coefficients are the S because the along track acceleration is proportional to $C_{lm}\sin(m\lambda)+S_{lm}\cos(m\lambda)$. The S_{22} coefficient is actually responsible for 80% of the linear drift in semimajor axis of METEOSAT P2. Therefore, we make the assumption that the discrepancy between the observed and the predicted drift be due to an error in the value of the S_{22} coefficient. The discrepancy between (1) and (2) would correspond to an error $\delta\ S_{22}$:

$$\delta\ S_{22} = (4.2 \pm 2)\ 10^{-3}\ S_{22}$$

In the present case, the results can be confirmed directly by changing slightly S_{22} to get the minimum rms of observation for the long arc (Figure 7).

In this case we found

$$\delta\ S_{22} = 6\ 10^{-3}\ S_{22}$$

This second solution is in a reasonable agreement with the first one. When we use one of these values for the global arc, the rms is reduced by about a factor of 2.

Because of the necessity to observe in nightime, and in good weather conditions, the orbit coverage was limited to arcs of several hours (Figure 4). However, as shown by Cenci et al (1989) reasonably good orbital elements can be determined if some of them (e.g. the eccentricity or the argument of perigee, the inclination or the right ascension of the node) are assumed to be known from radio tracking data (provided by ESA/ESOC, Darmstadt). Although less accurate (ten meters) the radio tracking data have the advantages that they can be obtained in daytime as well as in nightime and also that they are not affected by weather conditions. Of course the present results can be affected by some biases but as it can be shown not sufficiently to deteriorate the validity of the results aiming at exhibiting the interest of the method and pushing for future observations. In the future, it will be of great interest to add angular positions to compensate the insufficient coverage with one laser station.

3. RESULTS

An orbit determination programme based on numerical integration with differential correction technique has been used (GIN programme at GRGS/Toulouse under the responsibility of R. Biancale). The Earth's gravity field model is the GEMT1 model truncated to 10x10. The lunisolar gravitational perturbation and the direct solar radiation pressure effects are taken into account. An empirical coefficient for the solar radiation pressure and initial conditions of the state vector have been ajusted for the different arcs chosen around the data as shown in Figure 4. However the initial values of the argument of perigee and the right ascension of the ascending node have been fixed at the ESA/ESOC values.

Then the problem to be solved is the determination of the longitude acceleration or equivalently the secular drift of the mean semimajor axis. In this study we have chosen to analyse the latter. But to realize this, analytical theories have been adopted to eliminate the short periodic perturbations from the semimajor axis. The following short periodic perturbations have been taken into account :

- lunisolar gravitational perturbations
- solar radiation pressure effects
- short periodic perturbations generated by zonal harmonic J_2 of the geopotential
- effects of Earth tides
- short period effects in semimajor axis deriving from the secular and long period changes in the satellite longitude (caused by the Earth as well as by the Sun and the Moon)

Lunisolar perturbations are the biggest, with amplitudes of $\simeq$ 1.5 km. They have been subtracted using Kozai's method (Kozai, 1973) where terms up to $P_6(\sin \Psi)$ for the Moon and to P_3 $(\sin \Psi)$ for the Sun have been retained (Ψ is the angle between the direction to the satellite and the direction to the perturbating body - Wytrzyszczak 1989).

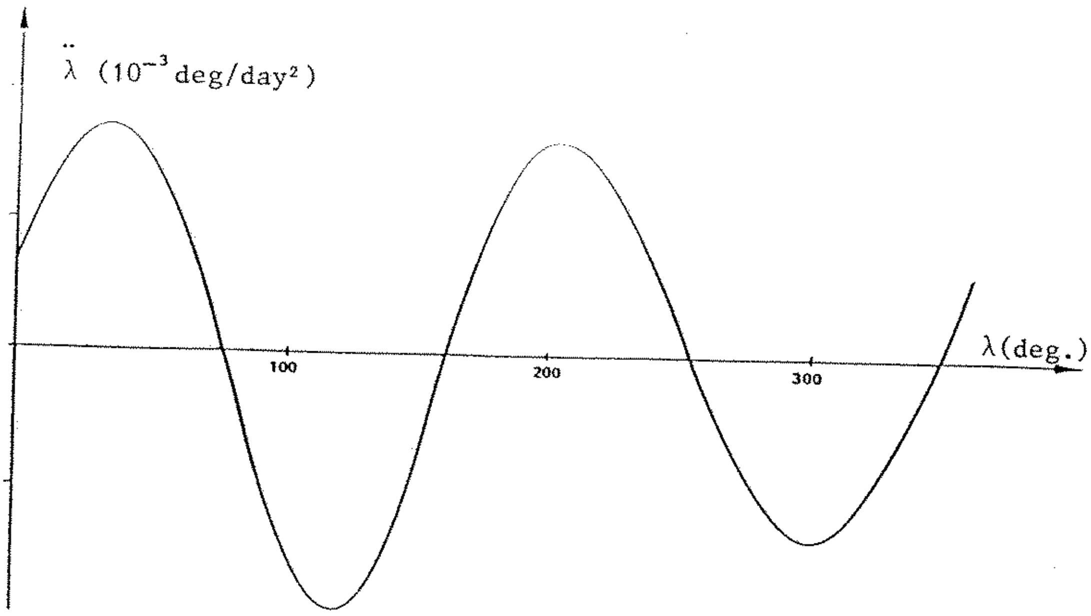

Fig 3: exemple of theorical longitude acceleration for Symphonie B ($a \simeq 42165$ km; $i \simeq 10^{-3}$; $e \simeq 10^{-3}$)

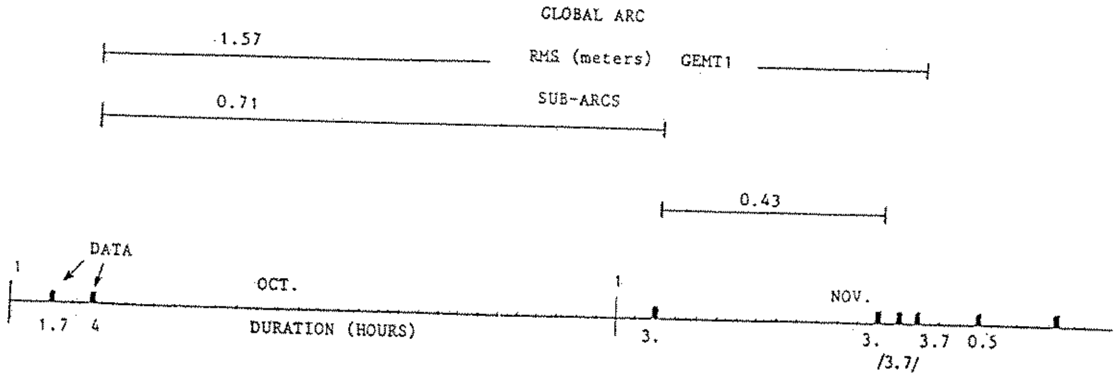

Fig. 4: data and arcs distribution

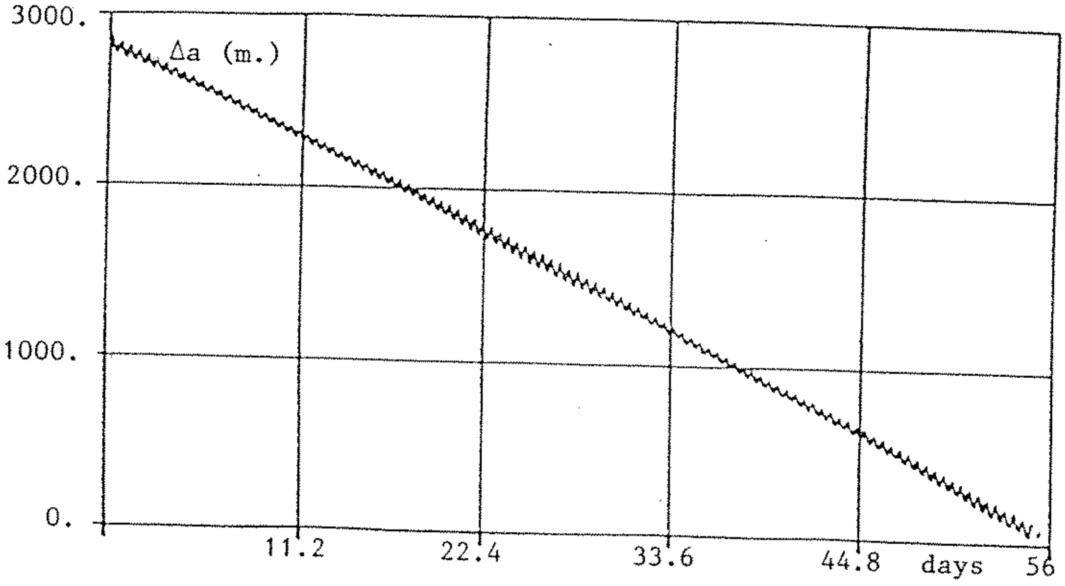

Fig. 5: Variation of the semimajor axis after analytical elimination of short period perturbations

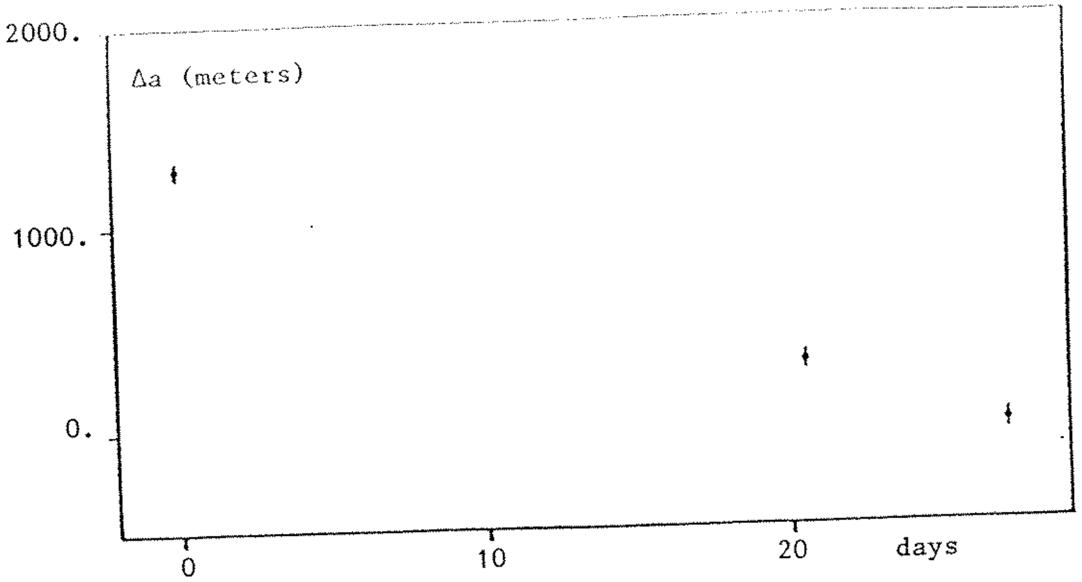

Fig. 6: Variation of the mean semimajor axis obtained for each subarc. Error bars represent the standard deviations magnified by 200.

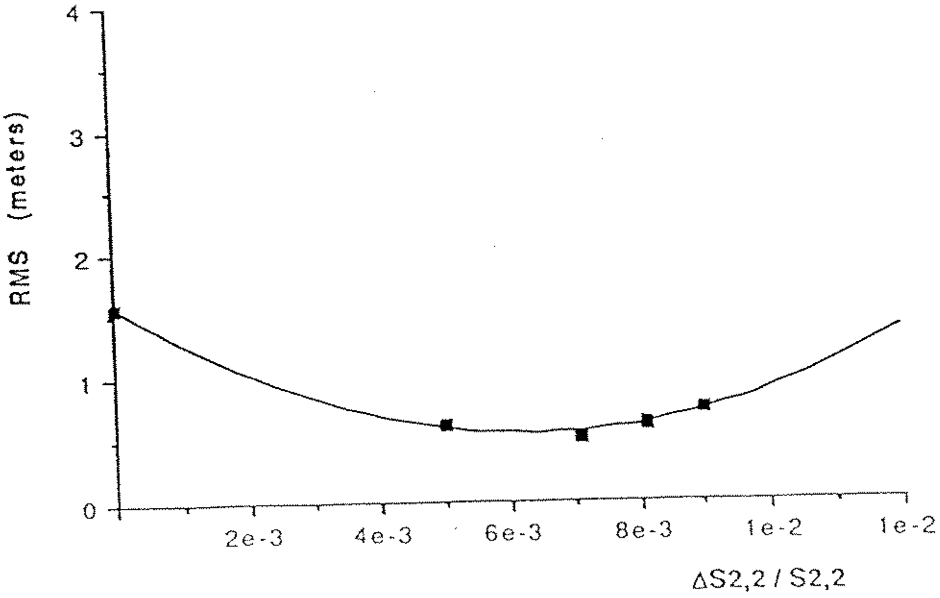

Fig.7: RMS for the global arc after orbit fitting changing S_{22}

PRECISE GEOSTATIONARY ORBIT DETERMINATION USING SLR: AN APPLICATION WITH METEOSAT-P2

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Marco Fermi
Cecilia Sciarretta

Telespazio S.p.A. - Rome

ABSTRACT. The ESA Meteosat-P2 satellite launched in 1988 is equipped with a retroreflector array to allow Laser ranging measurements.
This equipment, together with other dedicated payloads, is devoted to the LASSO (LAser Syncronization from Stationary Orbit) experiment. Besides this major application the availability on board of laser retroreflectors allows interesting studies on precise orbit determination for a geostationary spacecraft by means of SLR (Satellite Laser Ranging) technique.
Unfortunately most of the SLR stations which were planned to partecipate to the experiment have not been able to track this satellite up to now. Because of this the tracking geometry was poor. In spite of that the orbit recovery was possible even although with relatively high uncertainty for some recovered parameter. Preliminary results indicate that precise orbite determination of geostationary satellite can be easily achieved at a level of few tens of centimeters in the orbit residuals RMS. Significant improvements of these results are expected if better observation statistics and geometry will be available.

INTRODUCTION

Meteosat-P2 is the first ESA satellite equipped with laser retroreflectors. This equipment, together with other dedicated payloads, is devoted to the LASSO (LAser Syncronization from Stationary Orbit) which is an experiment to syncronize clocks at the nanosecond level on an intercontinental basis. Besides this major application the availability on board of laser retroreflectors allows interesting studies on precise orbit determination for a geostationary spacecraft by means of SLR (Satellite Laser Ranging) technique. A general improvement of our knowledge of force field acting on geostationary s/c is expected from Precise Orbit Determination and in particular low order and degree geopotential coefficients together with their secular variations could be investigated. In this paper we report on a preliminary analysis attempted using Laser Ranging Data to precisely determine orbit of Meteosat-P2.

1. OVERALL STATISTICS AND DATA PROCESSING.

Table 1. summarizes the entire data set available collected by the Lunar Laser Ranging system in Grasse. No other stations were able to track Meteosat up to the beginning of August. Looking at the table the poor statistics available is evident but the avail-

ability of ranging data from one station only introduces a further important limitation in initial state vector recovery. In fact, because of the poor geometry due to the geostationary configuration, it is impossible to recover the entire state vector (Soup. 1980). For this reason, in the input set up of GEODYN presented in table 2, the NASA-GSFC program we use to analyse laser ranging data, we decided to fix two of the six orbital parameters of the initial state vector, eccentricity and inclination, to introduce some constrains to reliably recover state vector.Furthemore because of the impossibility to model maneuvers into GEODYN we decided to divide the entire data set available into subsets called arcs following two main criteria: 1) each arc must be the longest as possible without any maneuvers in it, 2)each arc must have enough data to allow GEODYN convergence. The different arcs analysed are listed in table 3.

2. ANALYSIS RESULTS

Because of the poor geometry and statistics the main objectives of this analysis were the following: 1) to verify the possibility of precise orbit determination; 2) to quantify the expected accuracy of the orbital parameters.

In the following we will discuss the main results obtained.

Fig. 1 shows the orbit residuals RMS evolutions iteration by iteration of the four arcs analysed. The results are very promising, the final fit RMSs are in all the cases of the order of few tens of centimeters and for two arcs the orbit residuals RMSs are better than ten cm. Looking at the evolution iteration by iteration of the RMSs in more details the evolution toward the final convergence is clear. In some case GEODYN does not need all the iterations to find convergence, for example in the FEB89MP2 arc at the fifth iteration GEODYN find convergence and jumps directly to the end of convergence process without passing through all the planned iterations. The same happens for JAN89MP2 arc which finds convergence at the seventh iteration or JUN89MP2 arc at the sixth iteration.

In table 4 the RMSs in position and velocity of the recovered initial state vectors for all the analysed arcs are summarised. The RMSs obtained, of the order of few m in position and less than .001 m/s in velocity, are, in spite of the poor statistics and geometry very interesting results which indicate the possibility of achieving orbit determination recovery on Meteosat satellite at a satisfactory level.

All the results presented up to now give information about the precision with which orbit determination is achievable but what about the accuracy? To try to evaluate the accuracy in orbital elements recovery a dedicated experiment was performed.

3. ON THE ACCURACY OF ORBITAL PARAMETERS RECOVERY.

To match the second goal of the analysis a dedicated experiment was performed on the JAN89MP2 arc. It is a fourty days arc length starting from the beginning of 1989 up to the tenth of february. The experiment was organized in the following way; we divided the

JAN89MP2 arc into two subsets: the first from the beginning of the year up to the 27th of january and the second from the 26th of january up to the tenth of february. These two data set were analysed, using the same GEODYN setup, to recover the same initial state vector at the beginning of the year. In this way three independent estimation of the same initial state vector were available, one obtained from the JAN89MP2 solution, the entire data set and two other solution from the first part of the JAN89MP2 arc called JAN89A and from the second part of the same data set called JAN89B. The comparison of the different estimates of non singular elements are given in table 6 While in table 5 is given their definition with respect to the keplerian orbital elements. To quantify the differences between the three solutions we focus our attention on the semimajor axis and MWN elements. The agreement in the semimajor axes is within a few meters but things change if we look at MWN which shows differences of the order of hundreds of m.

This result gives an evaluation of the accuracy of our solutions which is less optimistic as appear from the RMSs of orbit residuals. This relatively high uncertainty in the state vector recovery are due to the poor geometry which is not able to constrain enough the solution. Furthermore the difference between the JAN89A solution and the JAN89MP2 is five times less than the difference between the JAN89B solution and the JAN89MP2. This is probably due two mismodelling in orbit propagation in fact JAN89B solution recovers the state vector far from the epoch in which it has data. A detailed analysis of the orbit residuals shows the presence of clear signature in the residuals themselves. Two examples are given in figs 2 and 3, fig 2 shows all the residuals of the JAN89MP2 arc while fig 3 shows the residuals of a little part of them.

CONCLUSIONS

In this preliminary analysis of Meteosat-P2 data the poor data statistics and tracking geometry strongly limited the recovered orbit accuracy, but, inspite of that, orbit residuals of the order of tens of cm RMS have been obtained. These results are very promising and significant improvments are espected if more than one station will track the satellite providing a more uniform, dense and strong data set from the geometric point of view.

REFERENCE:

Soop, M - Geostationary Orbit Determination by single Ground Station Tracking. ESA Journal 1980, Vol. 4

AKNOWLEDGEMENT

THIS WORK HAS BEEN SUPPORTED BY 'AGENZIA SPAZIALE ITALIANA'.

TABLE 1.

DATA SET AVAILABLE

yymmdd hhmm	yymmdd hhmm	nobs
890103 2244	890104 0426	488
890112 2122	890112 2139	30
890126 2152	890126 2213	76
890201 2321	890202 0345	604
890210 1940	890210 1946	17
MANEUVER		
890309 1916	890309 2226	533
MANEUVER		
890607 2208	890608 0008	371
MANEUVER		
890614 2253	890615 0243	251
890615 2246	890616 0104	135
MANEUVER		
890801 2119	890802 0334	897
890803 2205	890803 2314	269

TABLE 2

GEODYN SETUP FOR THE METEOSAT-P2 ORBIT DETERMINATION

<u>Kinematical model</u>

Precession	IAU 1976
Nutation	IAU 1980
Lunar and Planetary Ephemeris	JPL DE118
Reference System	1950.0
Earth semi major axis	6378144.11 m
Flattening	1/298.255

<u>Dynamical model</u>

Gravity field	GEM-T1 (8x8)
h2,12	0.6000 , 0.0750
Gm	3.98600440*10**14 m**3/s**2
Gravity from Sun and Moon	applied

<u>Method of Analysis</u>

Single-arc with variable length

<u>Common parameters estimated in the solution</u>

No common parameters estimated in the solution

<u>Arc parameters estimated in the solution</u>

- four Keplerian elements, <u>Eccentricity and Inclination fixed at the apriori values.</u>
- solar radiation coefficent (not in all cases)

<u>Preprocessing Options</u>

- laser wavelength dependent Marini and Murray tropospheric correction.

TABLE 3

ARCS ANALYSED

First Arc:	JAN89MP2	NOBS = 1185	From 890101 to 890210
Second Arc:	FEB89MP2	NOBS = 667	From 890126 to 890210
Third Arc:	JUN89MP2	NOBS = 386	From 890608 to 890616
Fourth Arc:	AUG89MP2	NOBS = 1166	From 890726 to 890803

TABLE 4

CONVERGENCE COMPARISON

	JAN89	FEB89	JUN89	AUG89
RMS POSITION (m)	4.406	21.773	8.889	5.419
RMS VELOCITY (m/s)	.00025	.00158	.0006	.00037

TABLE 5 - NON SINGULAR ELEMENT DEFINITION.

$A = A$

$ECWN = e * \cos(w + \Omega)$

$ESWN = e * \sin(w + \Omega)$

$SISN = \sin i/2 * \sin \Omega$

$SICN = \sin i/2 * \cos \Omega$

$MWN = \Omega + w + M$

A= semimajor axis, e=eccentricity

i = inclination, Ω = Node

w = perigee, M= mean anomaly

TABLE 6 - NON SINGULAR ELEMENT COMPARISON.

	JAN89ALL	JAN89A - JAN89ALL	JAN89B - JAN89ALL
AXIS (m)	42167214.262	- 1.598	1.639
ECWN	0.000136658	0.000000043	0.000000659
ESWN	-0.000048468	0.000000123	-0.000001819
SISN	-0.007548946	0.000000029	-0.000003838
SICN	-0.000473627	-0.000000459	0.000006158
MWN (Degree)	99.98046861	-0.0002333	0.0010938

FIGURE 1

Convergence Comparison

RMS evolution of orbit residuals

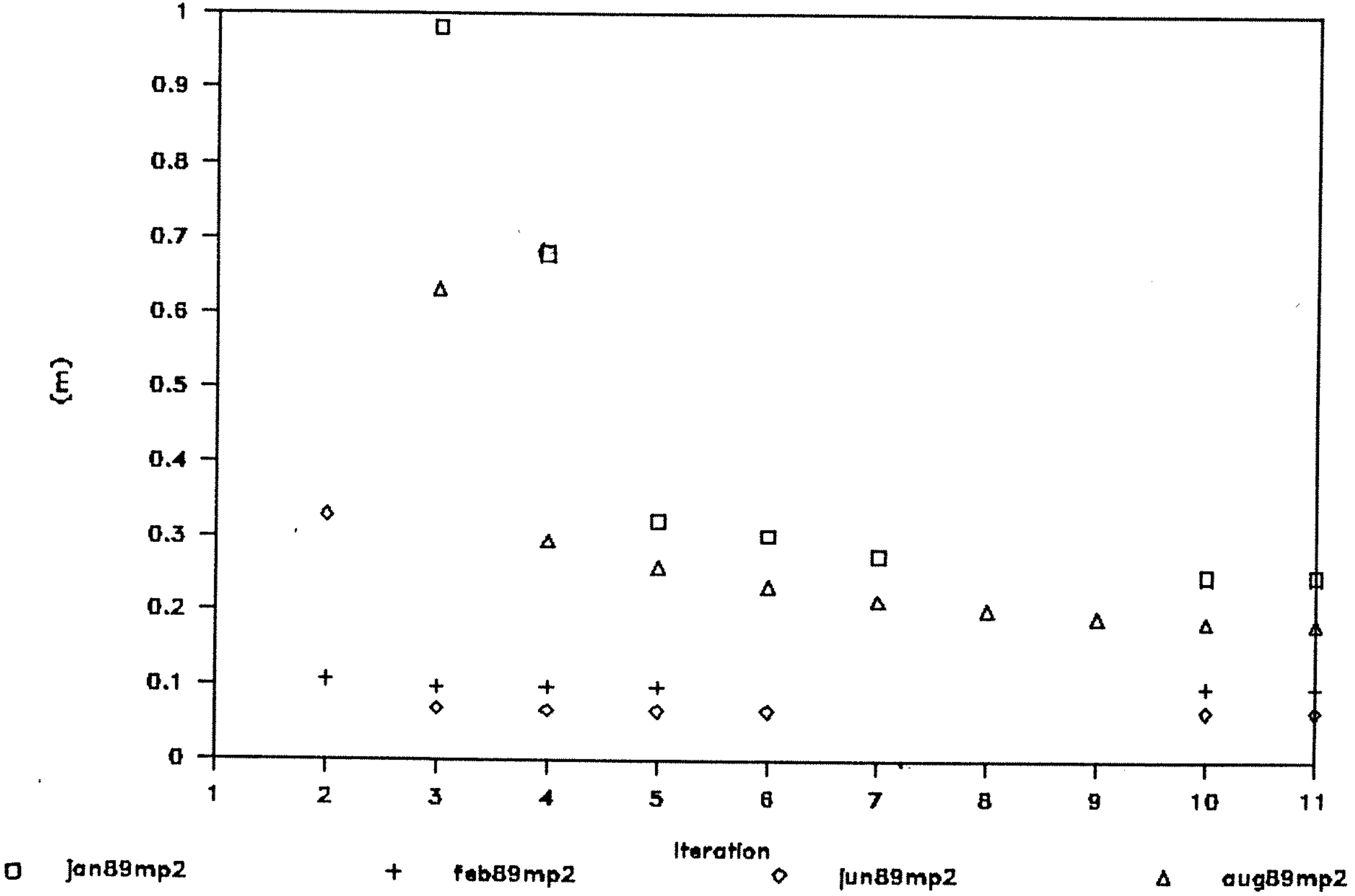


FIGURE 2

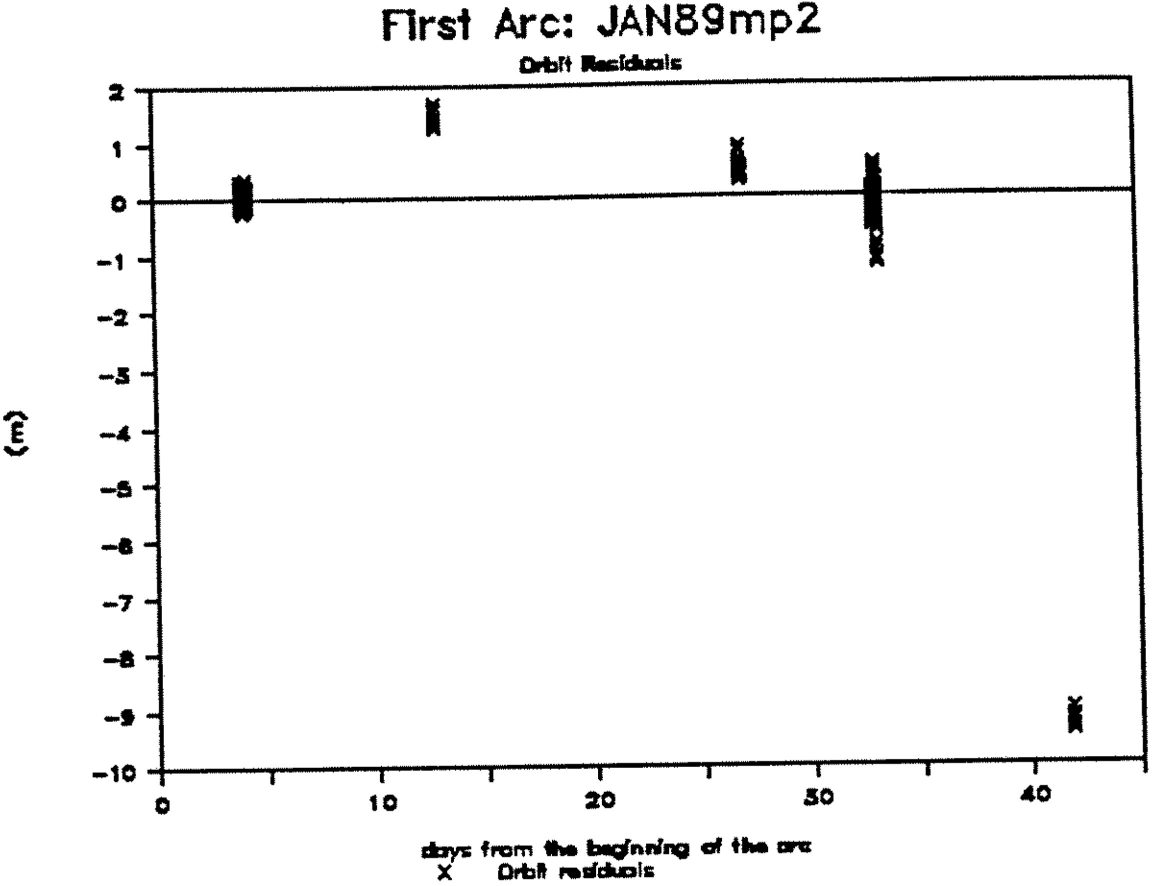
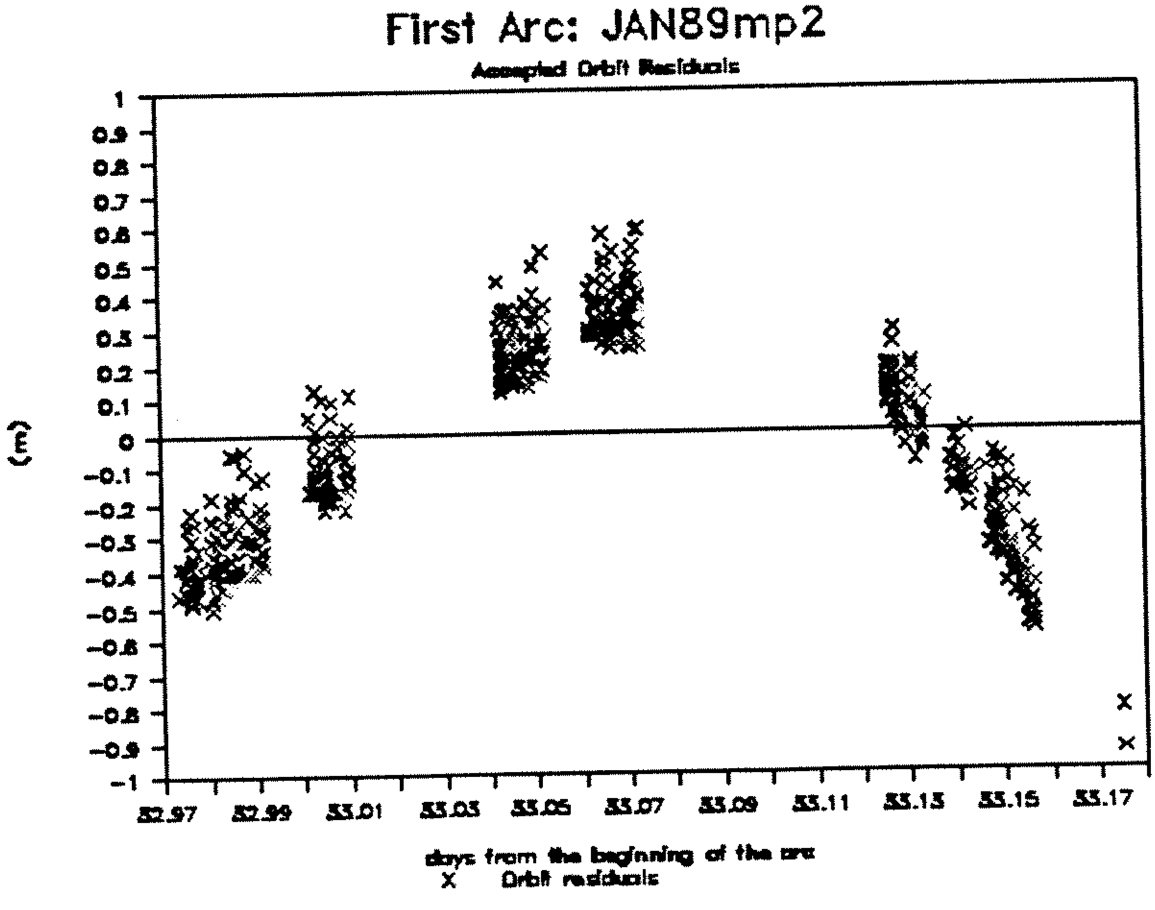


FIGURE 3



International

cooperation

LASSO

the European Phase

Aug. 88 – Sept. 89

Ch. Veillet
CERGA/OCA
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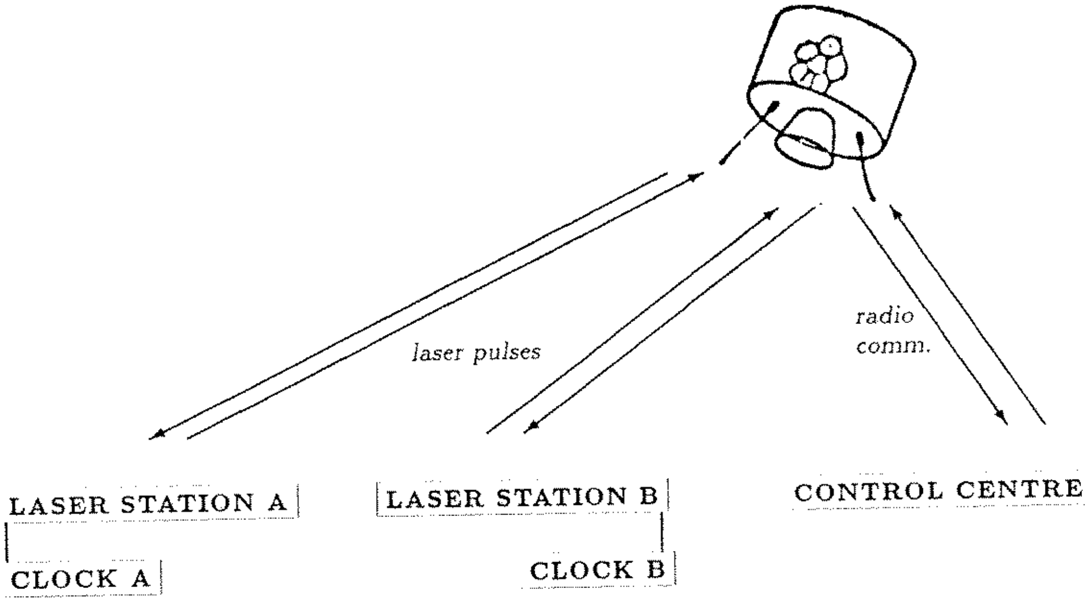
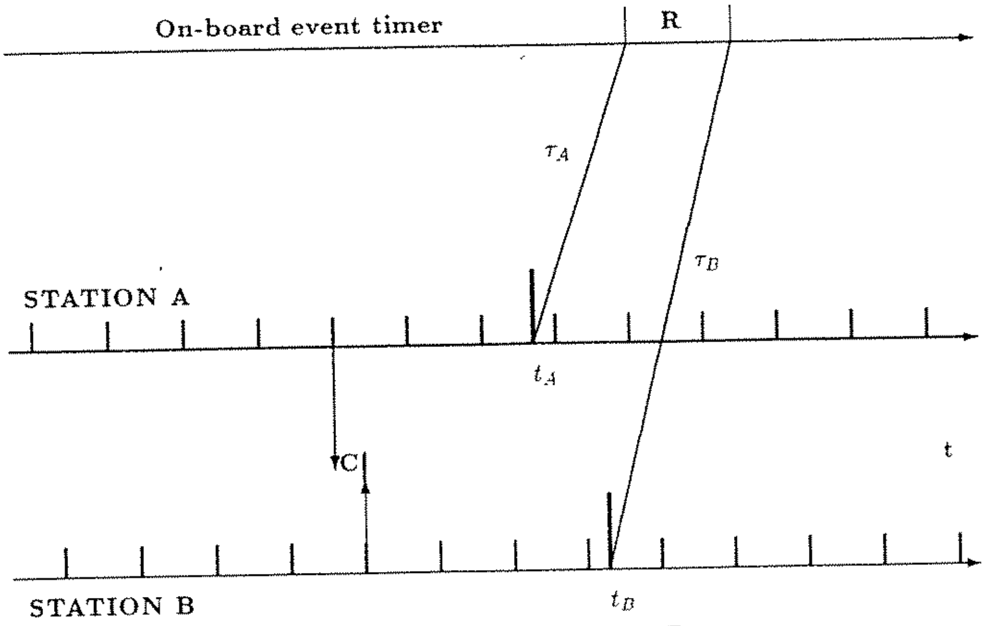
The LASSO experiment (a time comparison through laser pulses), carried on the European geosynchronous satellite Meteosat P2, started in August 1988. Some problems encountered for the first months were solved before the end of 1988, and many stations tried to range the satellite, or to be seen by the LASSO package, up to October 1989. Only two stations achieved laser ranging (Graz and Grasse LLR), and none of the other numerous participating SLR stations were able to be seen by LASSO. As the satellite left in October 89 for -50 degrees in longitude (far from Europe ...), the European phase of LASSO had unfortunately to stop more earlier than previously thought, and no time comparison has been achieved. An extensive range measurements data set has been obtained anyway, and is used for a geodynamical study of the low harmonics of the Earth's gravity field.

1 - The LASSO experiment

LASSO (LAser Synchronization from a Stationary Orbit) is an experiment for comparing time at two or more distant sites. An active package on board of a geosynchronous satellite (Meteosat P2) is able to detect a laser pulse and to date it. Retroreflectors close to the detectors can send back part of the laser beam. To achieve a time comparison, two laser stations fire to LASSO so that the two beams arrive on board very close in time (a few milliseconds is fine). The on-board oscillator provides the interval between the arrival times of each of the laser pulses, and every station (supposed to be able to range) records the round-trip time of its laser pulse from the station to the satellite and back to the station. By processing these time measurements, it is possible to compare the time scales at the various stations,as shown below.





$$c = t_A - t_B + \tau_A - \tau_B + R$$

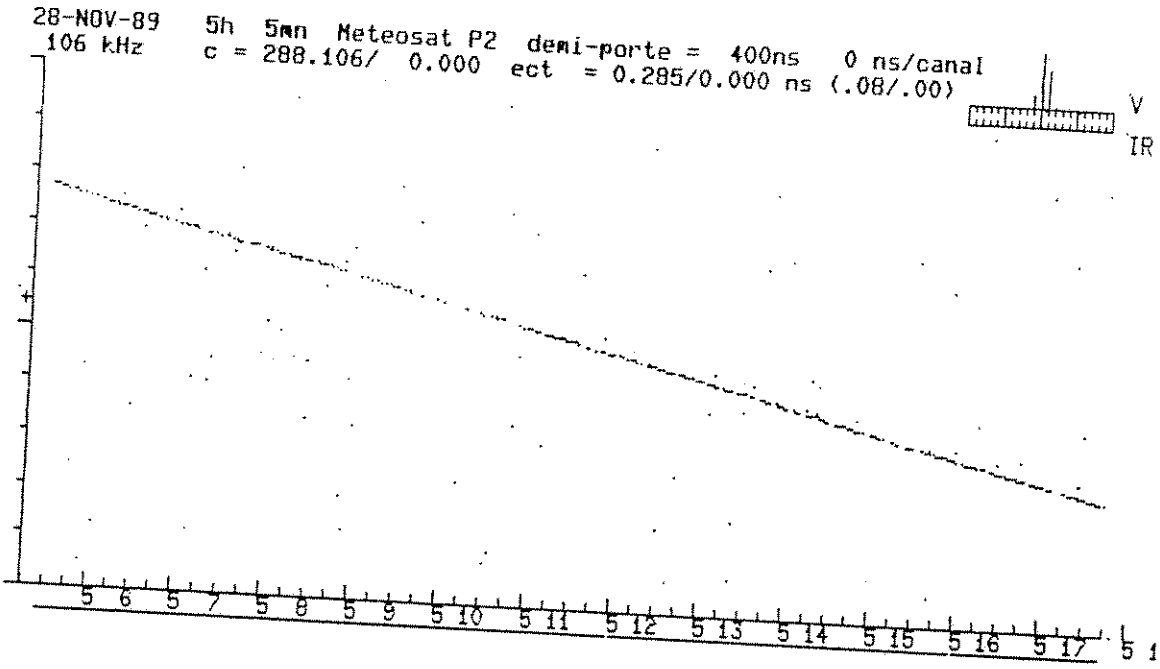


Figure .1: *A twelve minutes ranging of Meteosat P2. Time and date as written at the top of the figure and on the horizontal axis. Every dot is a photon detected by the equipment, noise or echo (the echoes are aligned). The vertical axis is centered on the predicted range, and 800 ns full scale.*

If at least two ranging stations are needed to achieve a time comparison, a one-way station (able to be seen by the LASSO detectors, but unable to detect the echoes from the satellite retroreflectors) can be used assuming that there is one more ranging station to compensate the deficiency in round-trip time.

The on-board oscillator is stable enough for determining the interval between two close pulses within 50 ps (the resolution of the event-timer). Taking into account the various error sources, an accuracy better than 1 ns can be achieved from the experiment.

2 - First shots, first problems ...

Meteosat P2, with LASSO, has been launched in mid-June 1988, and LASSO has been switched on at the beginning of September. No on-board dates of laser pulse arrival have been obtained for the first weeks of the LASSO cammpaign. In fact, range measurements came first on the third of October (88) at the CERGA Lunar Laser Ranging station. Many other echoes have been received for October and November, but no evidence for good dates was found in the LASSO data.

Using the raw data as received by Telespazio from the satellite in correlation with the laser firing times from CERGA LLR allowed us to find that the LASSO data were not encoded as they should have been. The new code was not too difficult to find, and the good behaviour of the receiving/timing package was clearly proved before the end of 1988.

It is important to send a pulse which will hit the LASSO package when arriving on the satellite. As Meteosat P2 is spinning very fast (600 ms per rotation), it is not a trivial point ! You need to know in advance the distance of the satellite, and also the phase of its rotation, if you want to be sure that your pulse arrives at the proper time ...If the distance and the rotation rate are not very difficult to predict, the phase is a more serious problem. The first predictions were off by half a rotation, and after some adjustments which occured in 1989, it was still off by 10 to 80 degrees (the angle of view

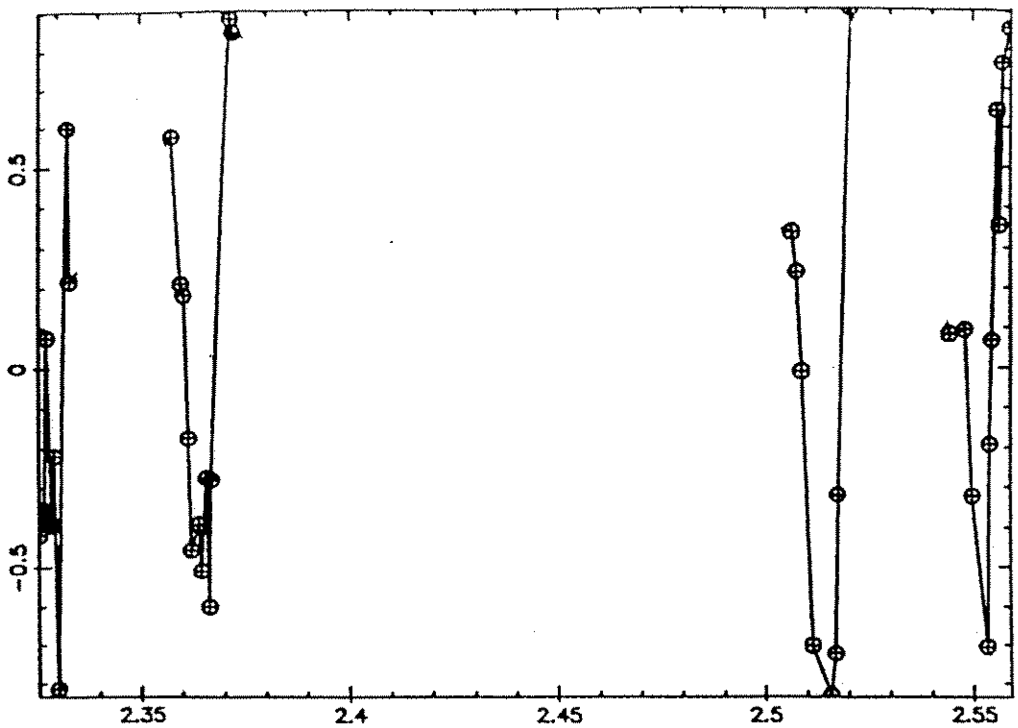


Figure .2: *A plot of residuals on the range of the LASSO retroreflectors using a firing period close to the Meteosat P2 spinning period. The satellite seems to rotate very slowly (stroboscopic effect) and the echoes arrive by packets. Every packet exhibits a shape, part of a sinusoidal curve which amplitude is the radius of the satellite. From such a behaviour, it is very easy to extract the rotation period and phase of the LASSO package. Unit on the horizontal axis is 1000 seconds, and on the vertical axis 1 ns (15 cm on the distance).*

of LASSO is roughly 50 degrees).

By using a ranging station with a high number of echoes, it is in fact very easy to determine the phase of the satellite. Assuming that you range at a constant rate (let say 10 Hz), and that you know the period of the satellite (nominally 604 ms), every shot which gives an echo is *in phase* within the angle of view of the retroreflectors. Looking to the distribution of these shots over a few minutes yields to a more accurate determination of the phase. Finally, a more sophisticated process can be done by looking to the range residuals over a few minutes. A spectral analysis of these values will give both the phase and the period, as they exhibit a periodic signature due to the large radius of the satellite (1 m). This process is shown in details on the Figure 2 and 3.

3 - Many stations, but few results ...

Forgetting for some time the CERGA LLR station, which ranges the Moon on a routine basis and for which Meteosat P2 is a very close target, it is clear that LASSO is not an easy satellite to observe. Due to its distance, six times larger than for Lageos, the energy coming back is roughly one thousandth of what a Satellite Laser Ranging equipment gets from Lageos, with two more difficulties to face : the prediction in position is much worse (the error can reach 6 minutes of arc), and if you are not working in phase for some reason (technical impossibility or phase prediction unuseful because wrong). If you want to hit LASSO, you need to increase the divergence of the laser beam, killing the return rate, or to see it, which is quite difficult with a small telescope as its magnitude is 13-14 ...

These statements, added to the fact that the detectors on board are probably not as sensitive as they should be, explain the results of this first European phase. Among the SLR community, only the Austrian station in Graz, able to see the satellite and equipped with a ruby laser (providing more energy) especially for this experiment, succeeded in getting echoes and obtaining pulse timing on board of Meteosat P2. Unfortunately, due to the wrong predictions of the phase and the poor positions provided, and also to hardware failures and a very bad weather during Spring and Summer, Graz obtained results too late to achieve any time comparison before the unexpected move of Meteosat to the East. The other stations, Borowiec, Cagliari, Grasse SLR, Katzively, Matera and Simeis, didn't give any detection on the LASSO package.

4 - The future ...

The European phase of LASSO ended in October 1989 with the move of Meteosat P2 at 50 degrees East. It was very sad for most of the European stations participating in LASSO, but it opened the transatlantic phase of the time comparison experiment. What is next ? Two stations, Mc Donald SLR and LLR (Texas) and Maryland 48 " (GSFC), will try to work on LASSO. There is a lot of work to be done in order to meet the requirements of the experiment. From Europe, Grasse LLR will be the only one ranging station, and Grasse SLR (and later San Fernando) could be one-way sites.

The first European phase proved that the LASSO package is working properly on Meteosat P2, and two stations obtained echoes. We have now to prove that the time comparison can really be achieved ...

Note added to the paper presented in Matera - January 1989

Afer the move of Meteosat P2, a LASSO meeting has been held at Redondo Beach (Cal. USA) in order to organize the transatlantic phase. Many actions started in order to make the US stations able to work for LASSO as soon as possible.
C. Veillet and F. Baumont visited the Mc Donald stations. Sensitivity tests have been made in order to determine the faintest magnitude observable with the LLR telescope. Many discussions permitted to express cler ideas for solving the various hardware and software problems linked to the LASSO experimental mode.
A big amount of work has been done at the Maryland station by the Alley's team, and some pointing and ranging attempts were possible at the beginning of 1990.

Late in December, Meteosat P2 started a journey back to Europe, due to some problems on the European meteorological satellite. This move made all these efforts (and most of the actions decided at Redondo Beach) useless at least for the near future. In spite of the desesperate efforts of the Maryland people during the move (until the time where MP2 was really too low from the East Coast), nothing has been done in this very short (!) transatlantic phase, and the LASSO payload hasn't been activated.

MP2 will spend at least four months at 0 deg. in longitude, probably waiting for a new launch of a European meteorological satellite. It means that we will have time for a new European phase before a possible new transatlantic phase later (it is too early now for assessing any long term plan).

MP2 will be available before the end of January. Most of the European stations able to participate efficiently to LASSO have been contacted.
Herstmonceux and Zimmerwald agree to provide optical positions of the satellite in order to make easier accurate predictions for the laser stations participating to LASSO.

Graz has been informed about the new European phase a few days before the removal of the ruby laser used for LASSO. They are now studying their participation as a two-way station and should take a decision before the end of January.
Borowiecz will participate as a one-way station.
The soviet stations has been informed, and we are waiting for an answer.
Grasse LLR will of course participate as a two-way station.

Contacts are re-established between Telespazio and CERGA for solving the phase prediction problem. Sessions will probably be organized for checking the accuracy of the predictions, and for finding the source of the errors.
The best from LASSO is still to come ...

STATUS REPORT ON THE EUREF-GPS OBSERVATION CAMPAIGN

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For future applications of the Global Positioning System (GPS) an accurate uniform geodetic reference network based on simultaneous GPS-observations employing dual frequnecy receivers is required. Based on such a geodetic network covering Western-Europe transformation parameters can be derived between the national geodetic networks and the European Datum in order to convert digital mapping data into an uniform frame on European scale.

In 1988 the EUREF-commission has been set up for the establishment of a new European Reference System which will be based on precise modern space techniques as

- SLR Satellite Laser Ranging
- VLBI (Very Long Baseline Interferometry)
- GPS (Global Positioning System)

With support of CERGO (Comite Europeen des Responsables de la Cartographie Officielle) and within the frame of EUREF first steps have been performed to realize such a network:

- GPS observations have been organized and carried out as a joint effort of the responsible national survey and research agencies on 93 sites all over Europe employing 69 dual frequency receivers.
- VLBI observations are carried out at 7 sites in the period from June to October 89 in order to densify the field of fiducial points in north and north-west Europe.

1. The EUREF-GPS-campaign

During the Crustal Dynamics Meeting held in October 88 in Munich a Steering Commitee for the establishment of a European GPS-network has been set up to study the feasibility, to design the network and to perform the total task. A small working group investigated the number of dual-frequency receivers which are available and the requirements of the participating nations to such a network.

Based on these results and on of the proposed support of all cooperating agencies (table 1) by making available receivers, observers, staff, cars, transportation etc. a detailed plan has been developed.

In the period from May 16 to May 28 alltogether 93 sites covering Western Europe (figure 1) have been observed within two phases A and B. Simultaneous observations have been performed on

61 sites during phase A from May 16 to May 21

Typeset by $\mathcal{A}\mathcal{M}\mathcal{S}$-TEX

and on

55 sites during phase B from May 23 to May 28.

Within both phases

23 sites have been occupied which include all the

- SLR-sites (Satellite Laser Ranging) and the
- VLBI-sites (Very Long Baseline Interferometry)

in Europe as well as additional overlapping stations to tie both phases together.

Spare receivers have been placed in different parts of Europe in order to be prepared for unforeseen events.

2. Site selection, Network design

To investigate the national interests of the different countries a circular letter has been sent to the national survey agencies in order to obtain national proposals on site selection. The national proposals then have been included in the network design.

In order to use them as reference stations all the available and future SLR- (Satellite Laser Ranging) and VLBI-sites (Very Long - Baseline Interferometry) have been equipped with receivers for the whole campaign. These sites will be finally used as fiducial stations to define the European Reference frame. Moreover to tie the two phases A and B together a well distributed number of overlapping stations had to be selected where observations were made during both phases.

3. Observations

Four types of dual-frequency receivers have been operated:

- TI4100 (Texas Instruments),
- MINIMAC 2816 (Aero Service Ltd.),
- WM102 (Wild Magnavox),
- Trimble 4000 SLD (Trimble).

In order to produce a data set observed with different receivers on short base-lines, which then has been used to test newly developed software for transforming the different receiver outputs into a standard data format and to calibrate the antenna reference points of the different receivers, a calibration-test has been performed at the Fundamentalstation Wettzell by operating 2 receivers of each type.

The antennas have been set up on well determined survey markers of the Wettzell reference network. The results have been published /W. Gurtner, et.al. 1989/. No obvious problems concerning data reduction have been detected and the phase centers of all antennas agreed within less than 0.5cm.

Special observation guidelines have been distributed to the field teams in order to collect all required site information (documentation, survey, meteorological data etc.) and to guarantee a common mode of observation for each receiver type.

During phase A respectively B six days of observations have been scheduled in order to collect a sufficient amount of data and to ensure - even in case of problems with the receiver on one or two days - that the observations will allow precise positioning.

In phase A the observation window was set between 11:00 and 16:00 UT and in phase B between 10:00 and 15:00 UT.

During this window the Satellites 3, 6, 8, 9, 11, 12 and 13 could be observed.

Several receivers failed during the campaign but they all have been replaced quickly enough to get enough data. All the sites which were planned have been observed successfully.

4. Data Processing

The data processing will be carried out in two steps:

1. Preprocessing,
2. Processing.

11 preprocessing centers (table 2) have been established to screen the data, to convert the data into a receiver independent exchange format (RINEX) and to provide the data onto a magnetic tape. The data tapes from the preprocessing centers will be sent to the University of Bern, which supports the preprocessing by making available software for data conversion and which will distribute all data to the other processing centers.

The final data reduction will be carried out by several processing centers which still are under discussion.

REFERENCES

W. Gurtner, G. Beutler, M. Rothacher, *Combination of GPS Observations made with different receiver types. Paper presented at the 5th International Geodetic Symposium on Satellite Positioning Las Cruces, 1989.*.

Figure 1

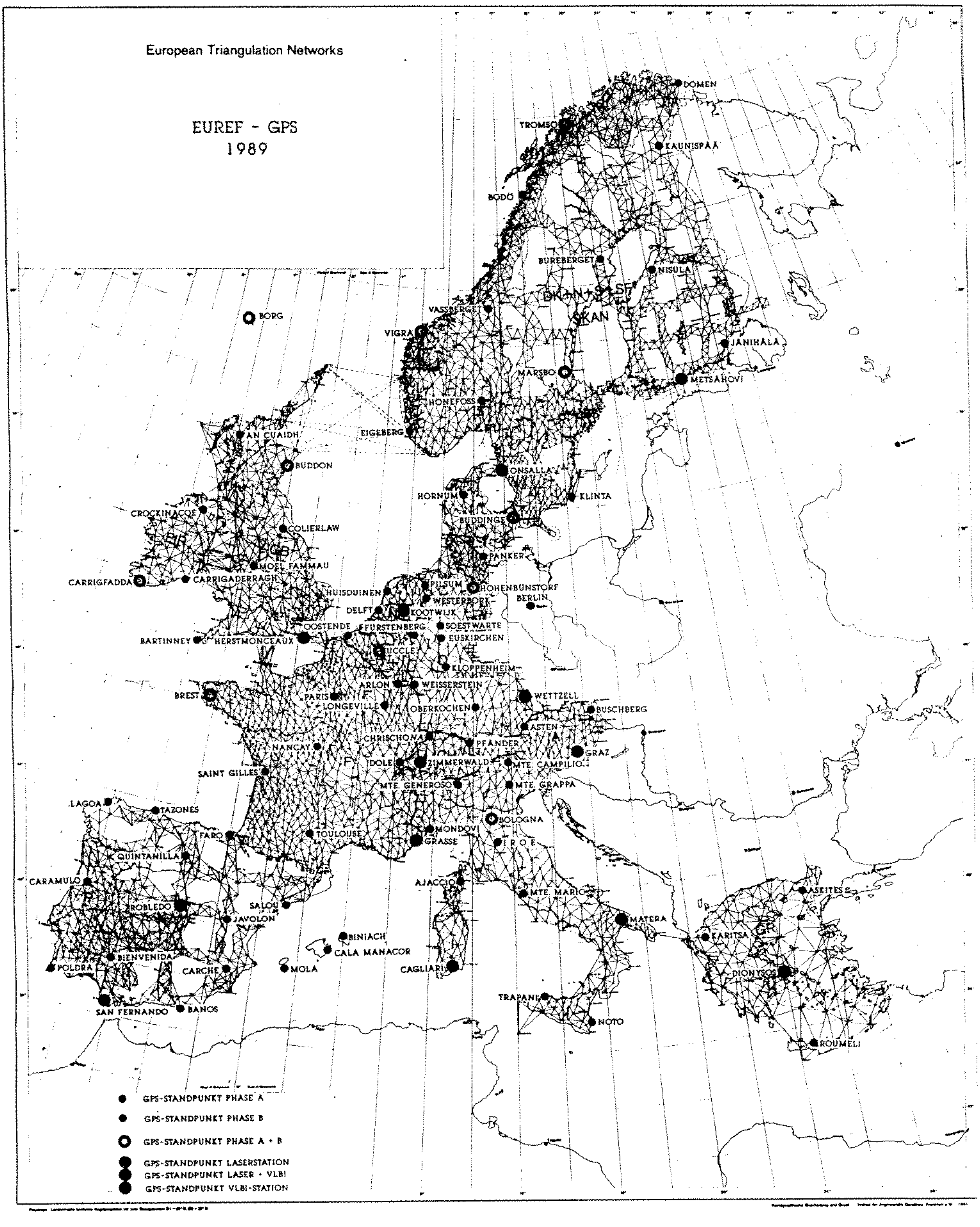
European Triangulation Networks
EUREF - GPS
1989
DOMEN
TROMSO
KAUNISPÄÄ
BODÖ
BUREBERGET
NISULA
DK+N+S+SF
SKAN
VASSBERGET
BORG
VIGRA
JANIHALA
MARSBO
METSAHOVI
HONEFOSS
EIGEBERG
AN CUAIDH
BUDDON
ONSALLA
HORNUM
KLINTA
CROCKINACOE
BUDDINGE
COLIERLAW
EIR
GB
MOEL FAMMAU
PANKER
CARRIGFADDA
CARRIGADERRAGH
PILSUM
HOHENBÜNSTORF
HUISDUINEN
WESTERBORK
BERLIN
DELFT
KOOTWIJK
OOSTENDE
FÜRSTENBERG
SOESTWARTE
BARTINNEY
HERSTMONCEAUX
EUSKIRCHEN
UCCLE
KLOPPENHEIM
BREST
ARLON
WEISSERSTEIN
WETTZELL
PARIS
LONGEVILLE
OBERKOCHEN
BUSCHBERG
ASTEN
CHRISCHONA
PFÄNDER
NANCAY
GRAZ
F
DOLE
ZIMMERWALD
MTE. CAMPILIO
SAINT GILLES
MTE. GENEROSO
MTE. GRAPPA
LAGOA
TAZONES
BOLOGNA
FARO
TOULOUSE
MONDOVI
GRASSE
I R O E
QUINTANILLA
CARAMULO
AJACCIO
MTE. MARIO
ASKITES
ROBLEDO
SALOU
JAVOLON
MATERA
BINIACH
KARITSA
GR
CALA MANACOR
BIENVENIDA
POLDRA
CARCHE
MOLA
CAGLIARI
DIONYSOS
TRAPANI
SAN FERNANDO
BANOS
NOTO
ROUMELI
● GPS-STANDPUNKT PHASE A
● GPS-STANDPUNKT PHASE B
○ GPS-STANDPUNKT PHASE A + B
● GPS-STANDPUNKT LASERSTATION
● GPS-STANDPUNKT LASER + VLBI
● GPS-STANDPUNKT VLBI-STATION

Table 1 Summary of cooperating agencies

Nation	Agency	Support with	
		receivers	observers
A	Institut für Weltraumforschung, Graz	1 TI 4100	1 team
	Techn. Universität Wien	1 WM 102	1 team
B	Observ. Royal de Belgique, Brussels	2 Trimble 4000 SLD	---
	National Geographical Institute, Brussels		2 teams
CH	Bundesamt für Landestopographie, Wabern	4 Trimble 4000 SLD	4 teams
	Institut für Geodäsie und Photogrammetrie, Zürich	3 WM 102	1 team
D	Institut für Angewandte Geodäsie, Frankfurt	5 TI 4100 3 MiniMac	9 teams
	Institut für Astronom. und Physikal. Geodäsie, München	2 TI 4100	2 teams
	Univ. Bundeswehr, München	2 TI 4100	4 teams
	Institut f. Erdmessung d. Univ. Hannover, Hannover	2 WM 102 2 TI 4100	2 teams
	Geod. Institut, Techn. Universität Berlin	2 WM 102	2 teams
	Alfred Wegener Institut, Bremerhaven	1 TI 4100	---
	Mil. Geogr. Amt, Euskirchen	---	2 teams
	Geod. Institut d. Univ. Stuttgart	2 WM 102	1 team
	Nds. Landesverwaltung, Landesvermessung, Hannover	4 Trimble 4000 SLD	4 teams
	Landesvermessungsamt Nordrhein-Westfalen, Bonn	1 MiniMaC	1 team
DK	Geodetic Institute, Copenhagen	2 TI 4100	2 teams
E	Instituto Geografico Nacional, Madrid	4 Trimble 4000 SLD	4 teams
	Servicio Geografico de Ejercito, Madrid	2 Trimble 4000 SLD	2 teams
	Real Observatorio de la Marina, San Fernando	2 Trimble 4000 SLD	2 teams
EIR	Ordnance Survey, Dublin	---	supporting 2 teams
F	Institut Geographic National, Paris	---	supporting 5 teams
GB	Ordnance Survey, Southampton	4 Trimble 4000 SLD	6 teams
	Univ. Nottingham, Nottingham	2 Trimble 4000 SLD	---
GR	National Technical Univers., Athens	---	supporting 3 teams
I	Facolta Ingeneria dell Universita, Rom	2 Trimble 4000 SLD	2 teams
	Istituto Geogr. Militare, Florence	2 WM 102	2 teams
N	Statens Kartverk, Hönefoss	6 TI 4100	6 teams
NL	Netherlands Triangulation Department, Apeldoorn	2 Trimble 4000 SLD	2 teams
P	Observ. Astronomico Monte de Virgens, Villa Nova	1 Trimble 4000 SLD	---
	Instituto Geografico e Cadastral, Lisboa	---	1 team
S	National Landsurvey, Gävle	3 WM 102	3 teams
SF	Finish Geodetic Institute, Helsinki	---	supporting 3 teams

Table 2 Summary of Preprocessing Centers

Agency	preprocessing for	Agency	preprocessing for
Institut für Geodäsie Universität der Budneswehr Munich, D	TI 4100 (CESAR)	Bundesamt für Landestopografie Wabern, CH	Trimble (CH)
Institut für Angewandte Geodäsie Frankfurt, D	MINIMAC 2816	Observatoire Royal de Belgique Brussels, B	Trimble (B, I, NL)
Institut für Angewandte Geodäsie Wettzell, D	TI 4100 (CIGNET)	Instituto Geografico Nacional Madrid, E	Trimble (E, P)
Institut für Erdmessung Univ. Hannover, D	TI 4100 (PROM)	National Land Survey Gävle, S	WM 102 (S, CH)
Ordnance Survey Southampton, UK	Trimble (UK)	Geodätisches Institut Technische Universität Berlin, D	WM 102 (D, I)
Niedersächsisches Landesverwaltungsamt, Landesvermessung Hannover, D	Trimble (D)		

Station status and developments

A REPORT ON THE COOLFONT MEETING

NASA SOLID EARTH SCIENCES (SES) PROGRAM

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Telex: 921428 SATELLITE CAM

In 1992, the Crustal Dynamics Project at NASA draws to an end, and activities are now underway to organize an even broader program for the following decade. The new Program, Solid Earth Sciences, will encompass the disciplines currently included in the Geodynamics Program including: crustal dynamics, geopotential fields, earth structure and dynamics, with those of the present Geology Program: volcanism, landforms, and paleoclimates. This synergy of the metric measurements from Geodynamics and the remote sensing from Geology, coupled with the combination of analysis capability within each of these areas, will give us a far better basis for understanding the complex processes within the earth system.

To begin the formulation of this new program, a workshop on long term planning for the Solid Earth Sciences Program was held at Coolfont, a resort near Berkeley, West Virginia, during July 22 -28, 1989. The major theme of the meeting was: "The relationship of the solid earth to its atmosphere, oceans and climate, and the concept of the earth as a system". The attendees included about 100 representatives from universities, institutions, government agencies, and foreign countries. International participation was a fundamental concept throughout the meeting in the recognition that any program of this scale would be intertwined with related programs from other nations and pre-existing international activities.

The meeting was organized into scientific panels, each with the charter to address the objectives and requirements in a particular scientific area. In addition there were panels on measurement and programmatic topics. The panels included:

- Technical Panels:
  - Volcanology
  - Land Surface: Process of Change
  - Structure and Evolution of the Lithosphere
  - Plate Motion and Deformation
  - Earth Structure and Dynamics
  - Earth Rotation and Reference Frames
  - Geopotential Fields
  - Measurement Technique Development and Analysis
- Interagency and International Panels
- Program Panel and Executive Committee

The objectives of the SES program were formulated at the meeting. In order of decreasing earth radius they are:

To improve our understanding of:

1. The interaction of the earth's surface with the oceans and atmosphere on time scales of hours to millions of years.
2. The evolving landscape as a record of tectonics, volcanism, and climate change during the last two million years.
3. The motions and deformations of the lithosphere within the plates and across plate boundries.
4. The evolution of the continents and the structure of the lithosphere.
5. The dynamics of the mantle including the driving mechanism of plate motion.
6. The dynamics of the core and the origin of the magnetic field.

The Panels developed their measurements requirements: those of most interest to the Laser Workshop include:

- Volcanology:

Deformation studies around volcanoes (GPS and Geodynamics Laser Ranging System - GLRS)

° Plate Motion and Deformation:

Global strain and fiducial networks of mixed space geodetic systems with average spacing of 1000 km, including the ocean floor.

Continuation of present plate tectonic, regional deformation, and associated earth rotation measurements, but with improved measurement capability to the 1 mm level.

Investigation of time dependent deformation to understand the earthquake process.

° Earth Structure and Dynamics:

Continued monitoring of global plate motions and earth rotation parameters, with an improvement in precision of measurement to the 1 mm level.

Measure both regional deformation and post glacial rebound.

Repeated measurements at high accuracy of the long wavelength portion of the earth's gravity field for temporal change.

° Earth Rotation and Reference Frames:

Continue and extend the quantity and quality of LLR, SLR, and VLBI data including intercomparison measurements to maintain a reference frame that ties the inertial and terrestrial coordinate systems at the 1 mm level.

Continue and expand the present plate motion measurements to at least three sites per major plate with auxillary data such as surface gravity at key sites.

° Geopotential Fields:

Oceanographic altimeter data with track spacing of 10 km at the equator.

Series of gravity missions or dedicated satellites in specialized orbits to measure the time-varying field.

To address these measurement needs, the particiants sought a global concept for monitoring geophysical activity. Not all requirements as presented by each panel could be addressed fully, but as seen from above, there was considerable overlap in measurement needs. To encompass these measurements needs, a concept of Global Geophysical Networks (GGNs) was developed. Two geodetic networks were defined:

1. Fiducial Links for an International Network of Geophysical Nodes - FLINN

   This would include:

   - Globally distributed SLR/VLBI stations with
     - At least one on each plate for crustal motion measurements
     - More dense distribution in certain areas of interest such as the Mediterranean, Pacific, etc.
     - Global distribution for orbit coverage (altimeter, gravity missions, etc.)
     - Measurement of relative motion to 1 cm/day and 1 mm/3 mos.
   - Locating GPS receivers at SLR/VLBI stations and elsewhere with
     - Roughly 1000 km spacing.
     - Measurement of relative position to 1 cm/day and 1 mm/3 mos.

2. Networks of Densely Spaced Geodetic Systems (DSGS)

   This would include:

   - Mobile and permanent GPS networks of short baselines.
   - Densely spaced networks of reflectors for the Geodynamics Laser Ranging System.
   - Placed in areas of high seismicity.
   - Tied to the global fiducial network (FLINN).

The Measurement and Analysis Technique Development (MATD) Panel provided an assessment of the current SLR performance and projections of future capability. At the moment, laser stations with ranging precisions of about 1 cm are providing measurement of station position to an accuracy of about 2 cm with about 60 passes of Lageos data. This set of data currently requires 4 - 6 weeks for acquisition on the single Lageos satellite. Station position degrades with fewer passes and does not improve significantly with more. Stations with poorer ranging precision, provide poorer station position quality, but only slightly. The conclusion is that computation of station position at the moment is being limited by the geodetic models and the satellite geometry. However, model development is an iterative process, itself depending upon measurement quality.

The MATD Panel saw dramatic improvements coming to SLR over the next 3 - 5 years. These include:

1. Additional high satellites such as Lageos II, Etalon I & II, and possibly Lageos III and ACRE, which will improve sky geometry and reduce data aquisition time. It is anticipated that the larger complex of satellites will reduce data acquisition times to about 7 days of good weather.
2. Additional SLR stations now in construction or under design.
3. Ranging hardware upgrades including: shorter pulse lasers, newer less expensive detectors, faster electronics, real-time calibration, etc.
4. Improved refraction correction through better modelling techniques and multiple frequency ranging.
5. Improved spacecraft center-of-mass correction through detailed laboratory tests.
6. Much more automation to reduce manpower requirements and to perform more tasks on site.
7. Improved geodetic and orbital modelling through more accurate data and data from future altimeter and gravity field (such as ARISTOTELES, GP-B, and Mini-Lageos).
8. Improved site operations and efficiency including on-site performance evaluation, normal point generation, and multisatellite tasking and interleaving.

Lasers should remain a key measurement technique in the areas of:

- Plate motion
- Regional motions over long baselines (>1000 km)
- Gravity field (long wavelength and secular variations)
- Precision tracking for altimeter and gravity field satellites
- Reference frames and earth rotation
- System intercomparison and validation

The role of SLR in the SES and other programs will depend however on how well and how fast the global network can adopt the above improvements.

A REPORT ON THE TOPEX/POSEIDON MISSION

NASA SOLID EARTH SCIENCES (SES) PROGRAM

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Topex/Poseidon will carry two radar altimeters to measure global sea level. Sea level data contains information on both the earth's geoid and on the dynamics of the oceans, which can be separated and interpreted by monitoring temporal and spacial variations and through models containing other geophysical data.

The satellite is currently planned for launch in June 1992, and will use laser ranging from the global SLR network for precise positioning required for proper interpretation of the altimeter data.

The main goals of the Program are oceanographic:

1. Measure sea level to study ocean dynamics, including the circulation and tides.
2. Process, verify, and distribute the data in a timely manner, together with other geophysical data, to science investigators.
3. Lay the foundation for a continuing program to provide long-term observations of the oceanic circulation and its variability.

The measurement objectives for ocean surface topography are:

- Precision: 2 cm.
- Spacial resolution: 20 km. along track, 300 km. across track
- Temporal resolution: 10 days
- Accuracy (including orbit and altimetry errors): 14 cm.

The sensors aboard Topex/Poseidon include:

- Dual frequency altimeter (corrects for propagation errors due to the ionosphere)
- Experimental solid state altimeter (provided by CNES)
- Microwave radiometer (corrects for propagation errors due to atmospheric water vapor)

For tracking purposes, the spacecraft will have:

- Laser retroreflector ring
- Doris transmitter
- GPS demonstration receiver

The laser retroreflector array will be two concentric rings of quartz cube corners mounted around the altimeter dish. The cubes will be tilted outward to enhance the optical cross-section at low elevation angles.

The mission is scheduled to last a nominal period of 3 years with an additional 2 year extension if all goes well. The approximate mission orbit parameters are:

- Semi-major axis: 7714 km. (altitude 1335 km.)
- Eccentricity: 0
- Inclination: 66 deg.

Longitude of the ascending node and argument of perigee will be adjusted to give 10 day repeat orbits with frequent overflights of calibration areas at Lampedusa and Point Conception off the west coast of the U.S.

The fundamental network of SLR stations identified by the Project for adequate global coverage and coverage of the calibration areas include:

Monument Peak, CA (MOB-4)
Yarradadee, Australia (MOB-5)
Mazatlan, Mex. (MOB-6)
Greenbelt, MD (MOB-7)
Quincy, CA (MOB-8)
Huahine, Tahiti (TLRS-2)
Easter Island (TLRS-2)

Arequipa, Peru (TLRS-3)
Cerro Tololo, Chile (TLRS-3)
Fort Davis, TX (MLRS)
Mt Haleakala, HI (HOLLAS)
Bar Giyyora, Israel (MOB-2)
Matera, Italy (SAO-1)
Wettzell, FRG
Herstmonceux, GB
Shanghai, PRC
Simosato, Japan
Orroral Valley, Australia

Other stations identified by the CDP for support:

Grasse, France
Graz, Austria
Metsahovi, Finland
Helwan, Egypt
any other operating lasers

The Project has an overall requirement for the "best possible orbit as soon as possible". To addresss this requirement within the framework of their measurement accuracy objectives, they are requesting the following:

- Laser Data Precision: 2 cm.
- Systematic Errors: < 2cm
- Tracking Horizon: 20 deg.
- Station Quick-look Data within 1 day.
- Station Generated Normal Points within 3 days.
- Full Rate Data within 30 days.

The pass pattern over the SLR stations will be in 10 day cycles with up to 5 passes per day depending upon station location and day within the cycle. All passes are important but priority tracks will be identified and station tradeoffs will be made within geographical areas to spread out the tracking burden.

The Project requirements for normal point computation are:

- 15 second aggregates of data
- Uncorrected for refraction and s/c center of mass
- Reasonable confidence (deletion of questionable, sparse data)

GSFC (CDP) will be the coordinating center for SLR. It will rely on regional supporting centers to provide the global participation.

There is still one important issue regarding SLR that must be addressed. The retroreflector array has been been designed to provide very large return signal strength (as much as 10 times that of Ajisai). This will permit ranging at very low elevation angles and during marginal weather conditions. This will mean, however, that SLR stations will see a large dynamic range in signal strength both during a pass and between passes of Topex and higher satellites such as Lageos or Etalon. This could become critical in those systems that are using detectors with limited dynamic range, such as the microchannel plate tube, where at a minimum there is strong likilihood of aliasing the measurements, but also the risk of destroying the detector itself. To protect the equipment and the data quality, these systems will be required to adjust optical return signal strength, probably with neutral density filters, between passes and possibly during Topex passes. As the tracking schedule becomes more crowded and satellite passes are interleaved for more efficient data acquisition, it will be necessary to make this signal strength adjustment and the corresponding calibrations in a dynamic manner (combination of programmed adjustment of optical filters and real-time internal calibration).

The Third-Generation SLR System
Made By NCRIEO

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Chen Daonan, Guan Zhenhua
North China Research Institute of Electro-Optics
P.O.Box 8511,Beijing
Tel: 472731 Telex: 211169 NCRI

A third-generation SLR system has been completed by North China Research Institute of Electro-Optics (NCRIEO), passed acceptance testing and sent to Fangshan Satellite Observation Station of Research Institute of Surveying and Mapping Science,November, 1988. It is under alignment.

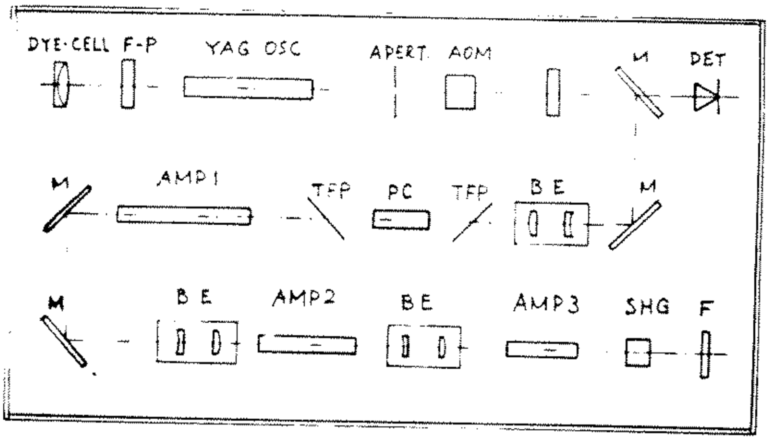
The system has been financed by National Commission of Science and Technology, PRC.

The Specifications of the SLR System are as follows:

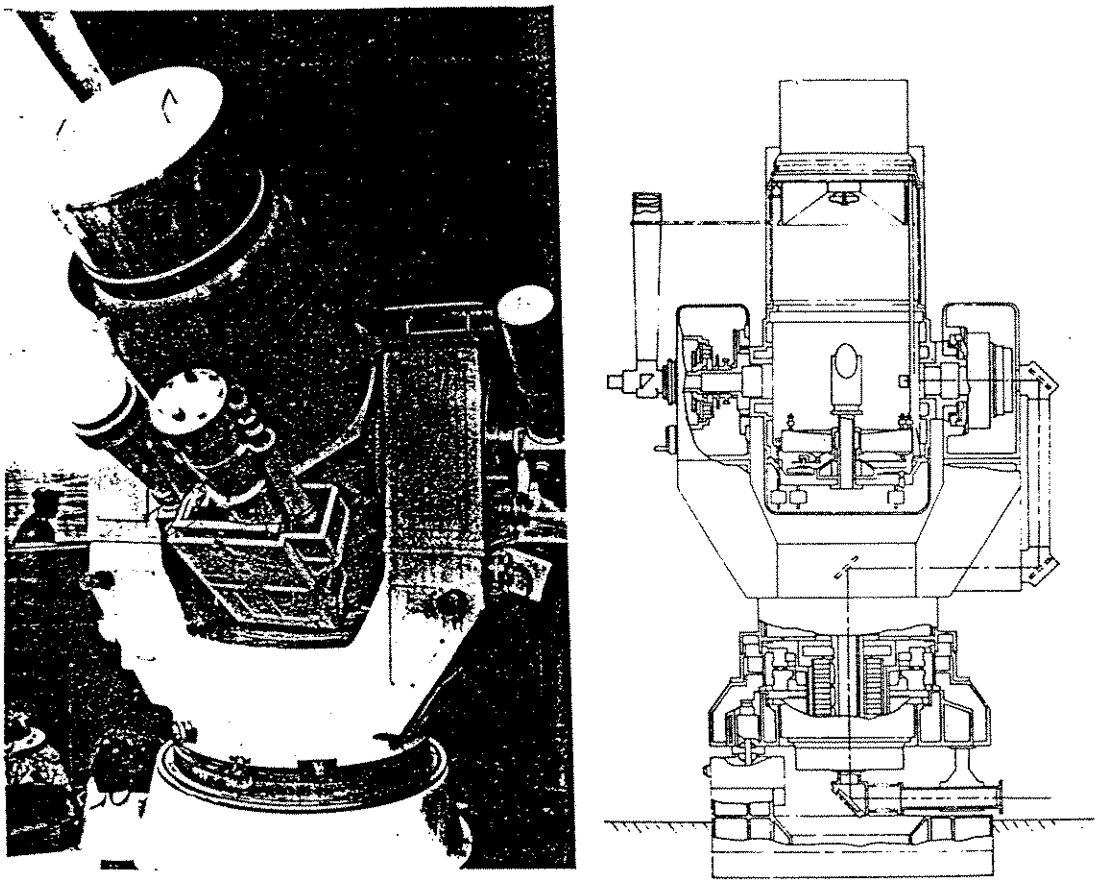
General	
Range	3 Km ~9000 Km
Data recovery rate	1 ~ 5 ranges/sec.
Operating staff	2 persons
Mount	
Axes	2
Configuration	alt-az. with Coude
Angular travel-elevation	±95°
-azimuth	±530 °
Orthogonality of axes	± 2″
Wobble on each axis	± 1″
Tracking velocity in elevation	0.001 °/s ~ 1°/s
in azimuth	0.001 °/s ~ 5°/s
Acceleration in elevation travel	$0.1^\circ/s^2$
in azimuth travel	$0.5^\circ/s^2$
Static pointing accuracy	better than 6″
Shaft encoder	21 bit

Transmitting Optics	
Configuration	Gallilean
Magnification	4x
Input diameter	40 mm
Output diameter	160 mm
Divergence	0.1 ~1.5 mrad variable continuously
Receiving Optics	
Contiguration	Catadioptric Cassegrain
Aperture diameter	600 mm
Focal length	5500 mm
Correction wavelength	532 nm
Field of view	0.15 ~1.5 mrad variable, step-by-step
Laser	
Oscillator	active-passive mode-locked Nd:YAG
Amplifier	3 stages
Frequency doubler	β- BBO
Output wavelength	0.532 μm
Output energy	160 mJ per pulse
Output stability	±3%
Pulse width	200 ps
Repetition rate	1~ 5 pps on external or internal command
Beam divergence	0.75 mrad
Beam diameter	9 mm
Receiver	
Detector	RCA 8850
Filter	bandwidth 1.0nm, multilayer dielectric film
Constant ratio discriminator	jitter < 100 ps, while signal dynamic range of 100 times
Range counter	JLJ-2, resolution 66 ps

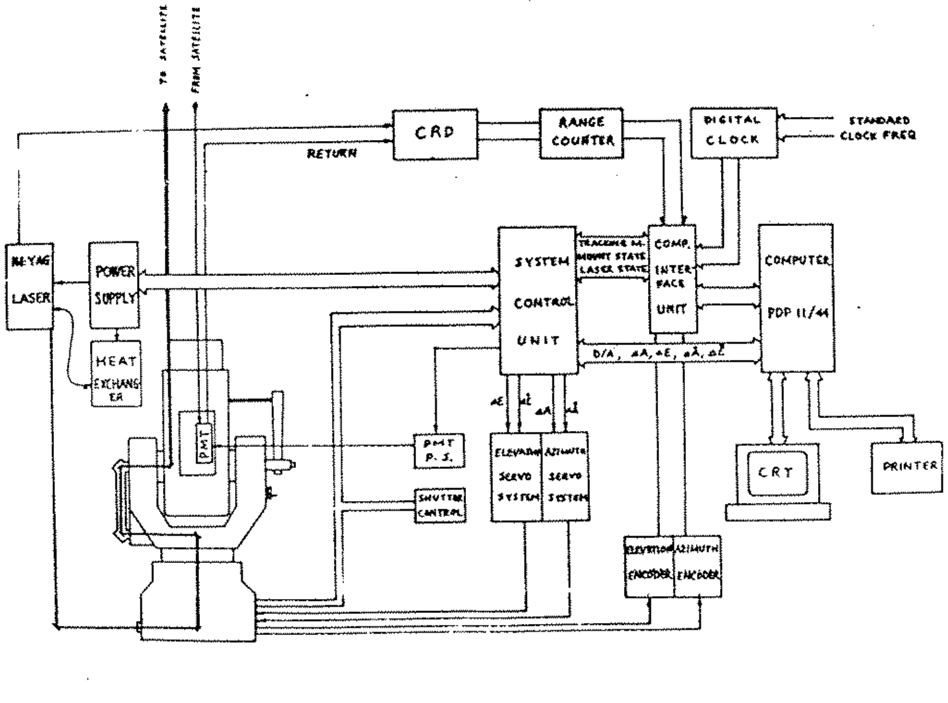
TV camera	
Type	ISIT
Sensitivity	10^{-5} lux
Aperture of the optics	180 mm
Computer and software	
CPU	PDP-11/44
Software	
Satellite prediction program	
Mount testing and star tracking program	
Mount calibration program	
Laser ranging program	

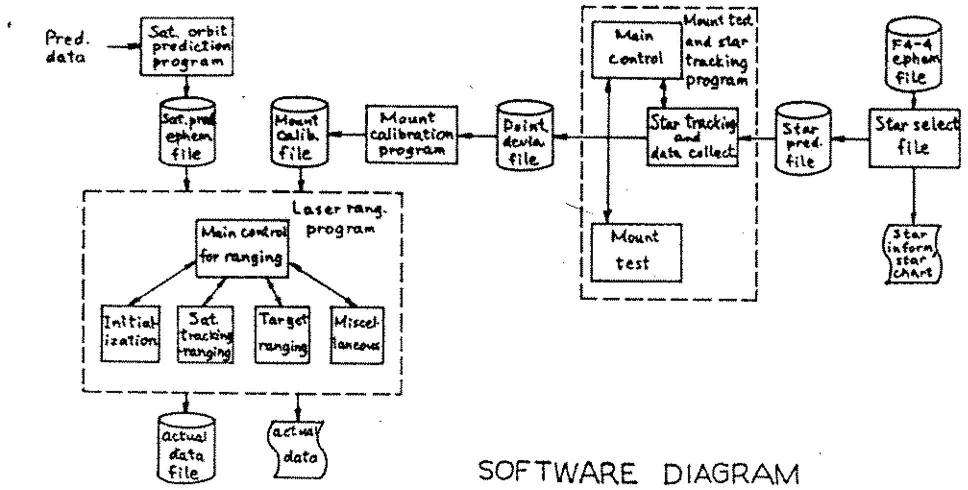


BLOCK DIAGRAM OF THE ND-YAG LASER

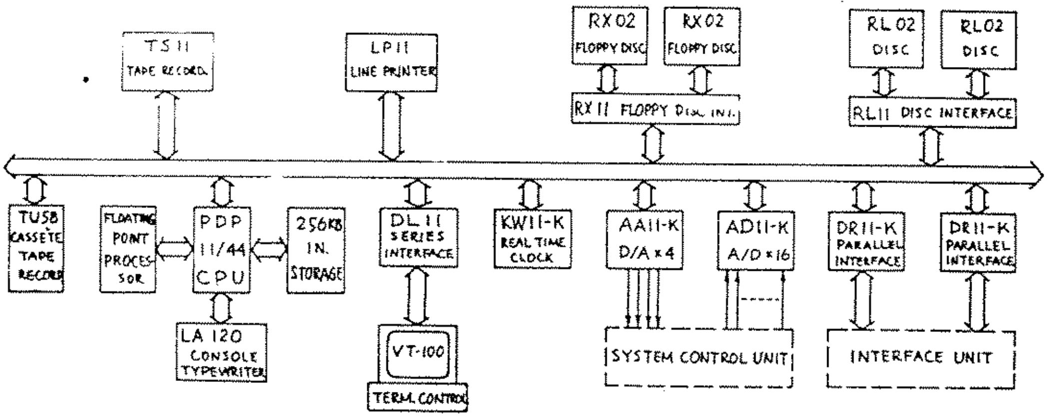


HIGH PRECISION SATELLITE LASER RANGING SYSTEM





SOFTWARE DIAGRAM



COMPUTER HARDWARE DIAGRAM

Upgrading of Shanghai SLR Station

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Abstract

It is shown in this paper that several improvements and tests at the satellite laser ranging station, Shanghai Observatory have been done since the sixth workshop.

1. The computer control system

To replace the old computer system (Z-80 CPU), a new control system based on an IBM/XT computer has been installed this summer. It consists of CPU (Intel 80286), co-processor (Intel 80287), 16 bits, 640KB memory, a 20MB hard disk, a 360KB floppy disk, CRT and printer.

Under the computer control are laser fire command, epoch timing, calculation of satellite positions and interpolations, range gate command, real time tracking, acquisition of ranging data and pointing angles of the mount, real time display O-C in azimuth, elevation and range respectively, offsets of along-track error of satellite prediction and the pointing angles of the mount, etc. After passes, can be done on-site with the same computer the ranging system calibration, preprocessing of ranging data, noise rejection, accuracy estimate, generation quick-look format and so on.

2. Internal calibration test

By means of the internal feedback calibration, the measurements of the system delay in different azimuths and/or elevations have been done. It has been shown that the variation of calibrations of our system at different pointing angles of the mount is about 3mm (rms). Having compared the internal calibration with the ground target calibration, we obtain the difference between the two calibations is about 1.3 cm.

3. Receiver

A HP5370B time interval counter has been adopted to replace the computing counter made by our group ten years ago. We have being assembled and tested a Hamamatsu MCP-PMT and a narrow band filter for better ranging accuracy and daytime ranging. The internal calibration test with the new MCP-PMT have shown that the ranging accuracy can reach 2-3 cm.

4. Softwares

Some improvements on prediction of satellites, real time control software of the mount, star position calculation and tracking, model of mount parameters have been completed.

5. Laser

A third-stage amplifier was installed in late 1986. After some improvements in recent two years, the laser system runs pretty good. The total output of the laser is 80-100 mj ($0.532\ \mu$) and the width of pulse is 180 psec. The repetition rate of the laser is 5 pps, but up to now only 1 pps is adopted for our routine operation to avoid damage of optical components.

6. TV Camera

In order to monitor the prediction error of satellites, a TV camera which was made in Nanjing, China was installed in 1987. The diameter of the cathode is 40 mm. The sensitivity of the cathode is 1×10^{-3} Lux. The TV camera is of help for improving pointing and obtaining echoes quickly.

The attached map (Fig. 6) is the chinese SLR network.

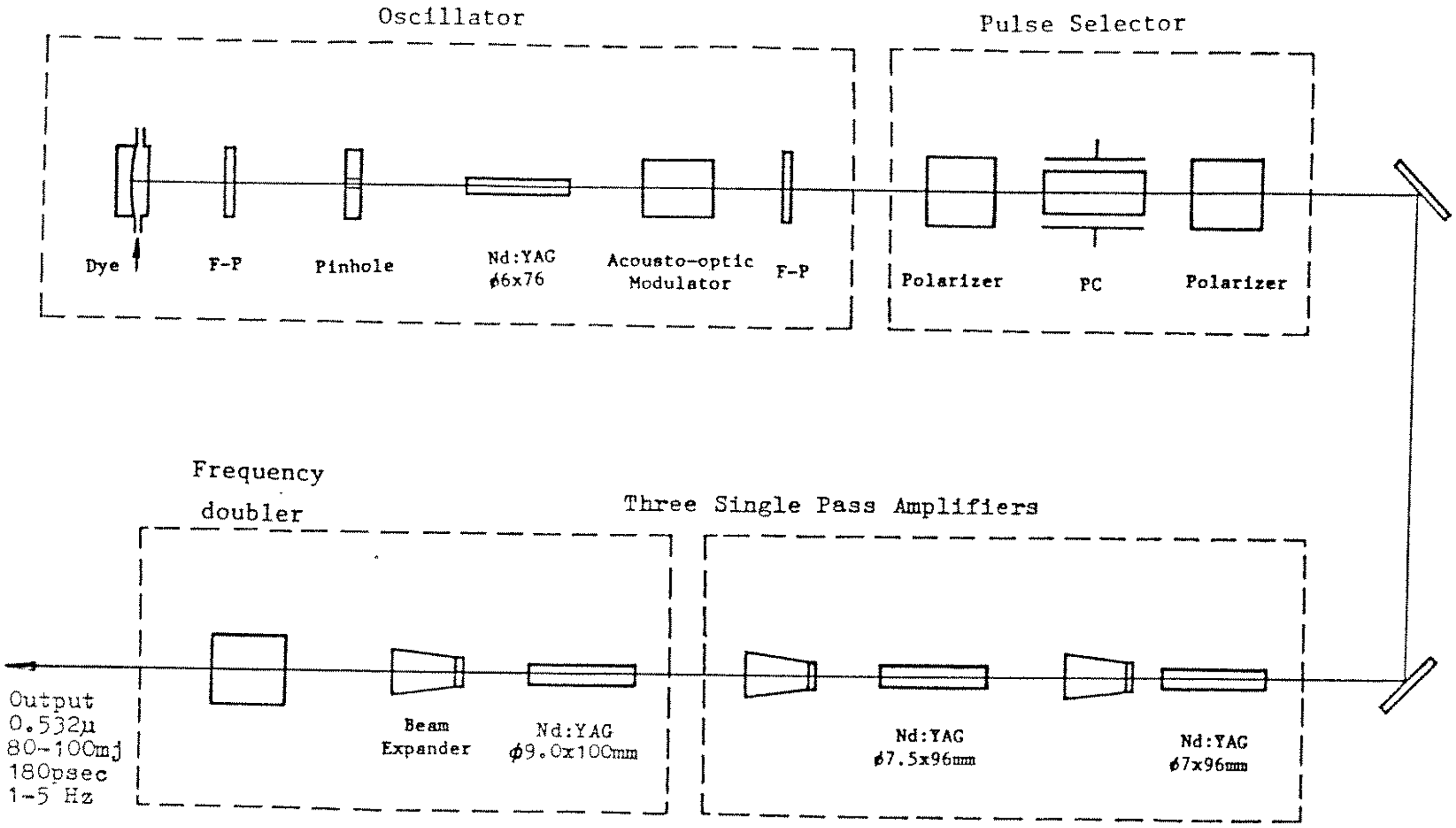


Fig.1 The Block Diagram of Nd:YAG Frequency-Doubled Mode-Locked Laser System

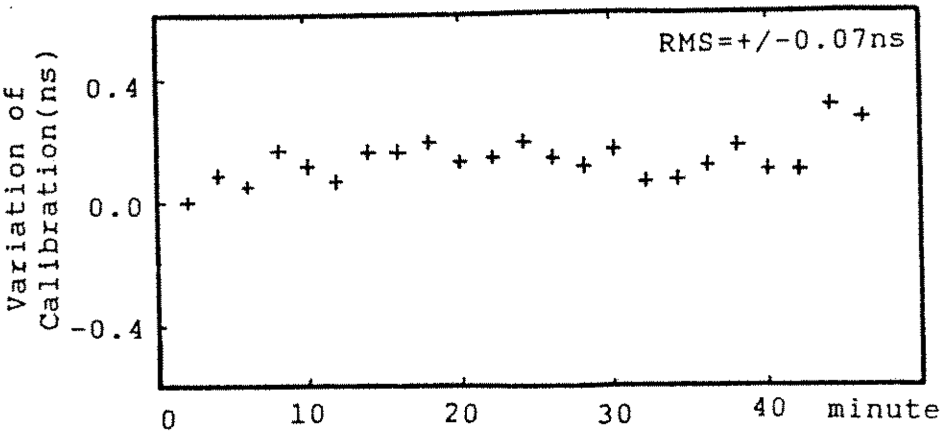


Fig 2. Stability Test

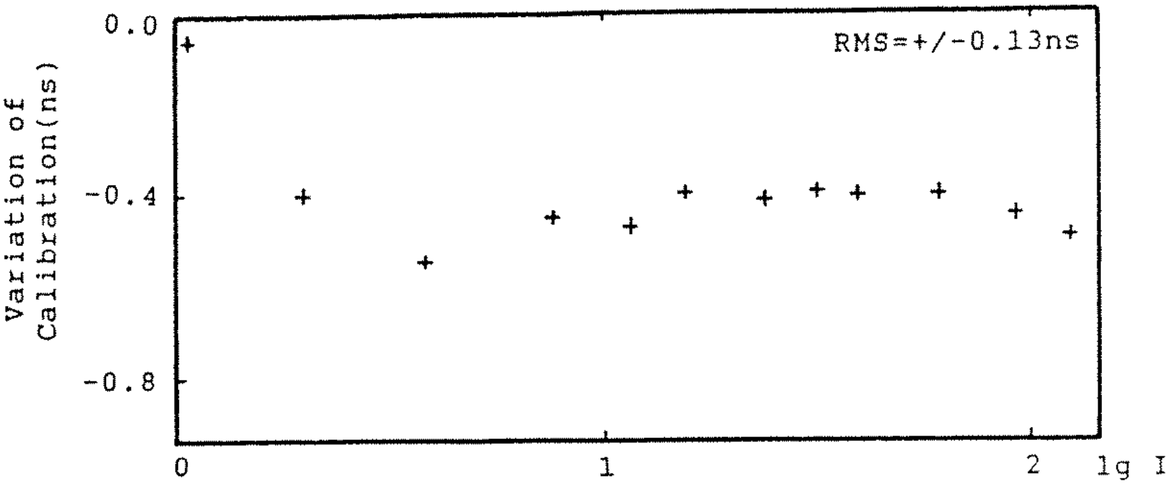
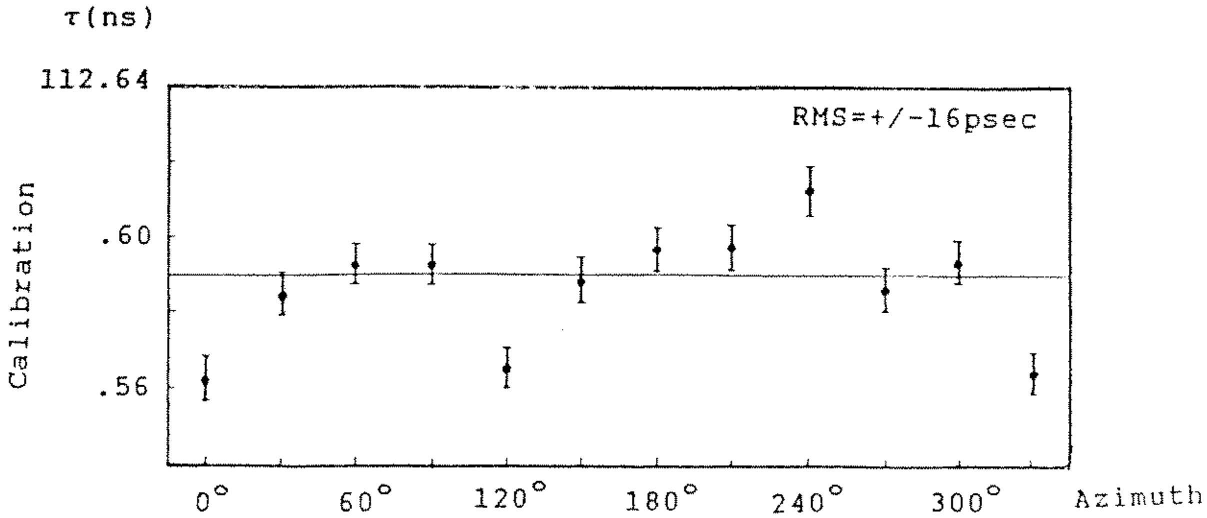
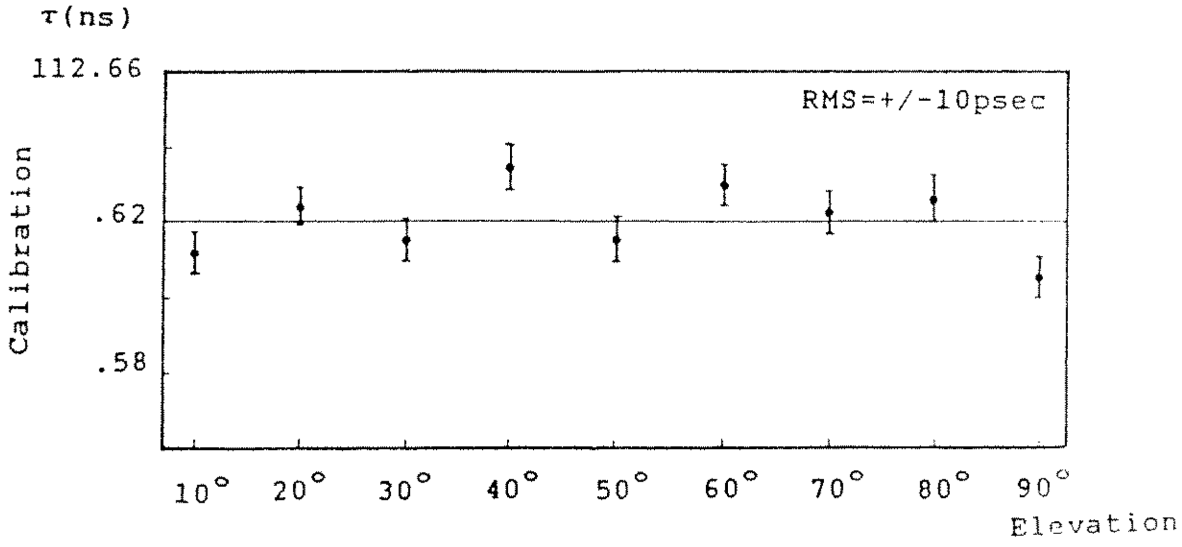


Fig 3. Return Signal Strength



Internal Calibration vs. Azimuth



Internal calibration vs. Elevation

Fig 4.

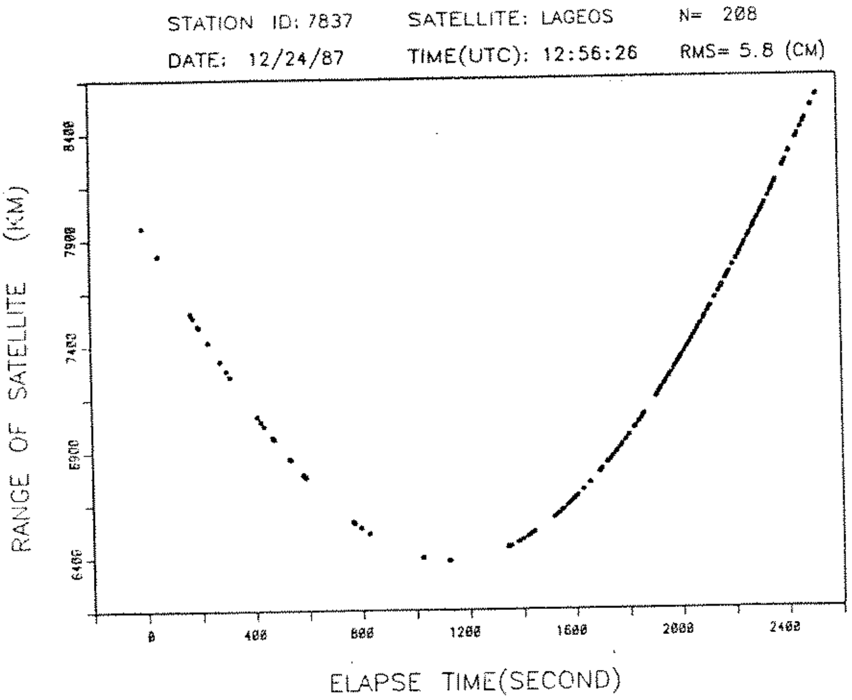

STATION ID: 7837
SATELLITE: LAGEOS
N= 208
DATE: 12/24/87
TIME(UTC): 12:56:26
RMS= 5.8 (CM)
RANGE OF SATELLITE (KM)
8400
7900
7400
6900
6400
0
400
800
1200
1600
2000
2400
ELAPSE TIME(SECOND)

Fig.5a

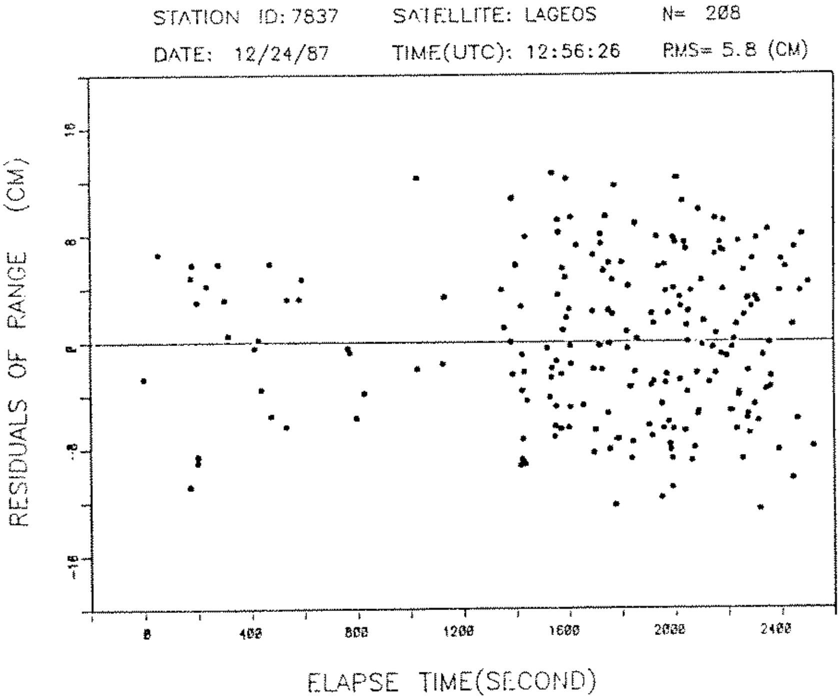

STATION ID: 7837
SATELLITE: LAGEOS
N= 208
DATE: 12/24/87
TIME(UTC): 12:56:26
RMS= 5.8 (CM)
RESIDUALS OF RANGE (CM)
16
8
0
-8
-16
0
400
800
1200
1600
2000
2400
ELAPSE TIME(SECOND)

Fig.5b

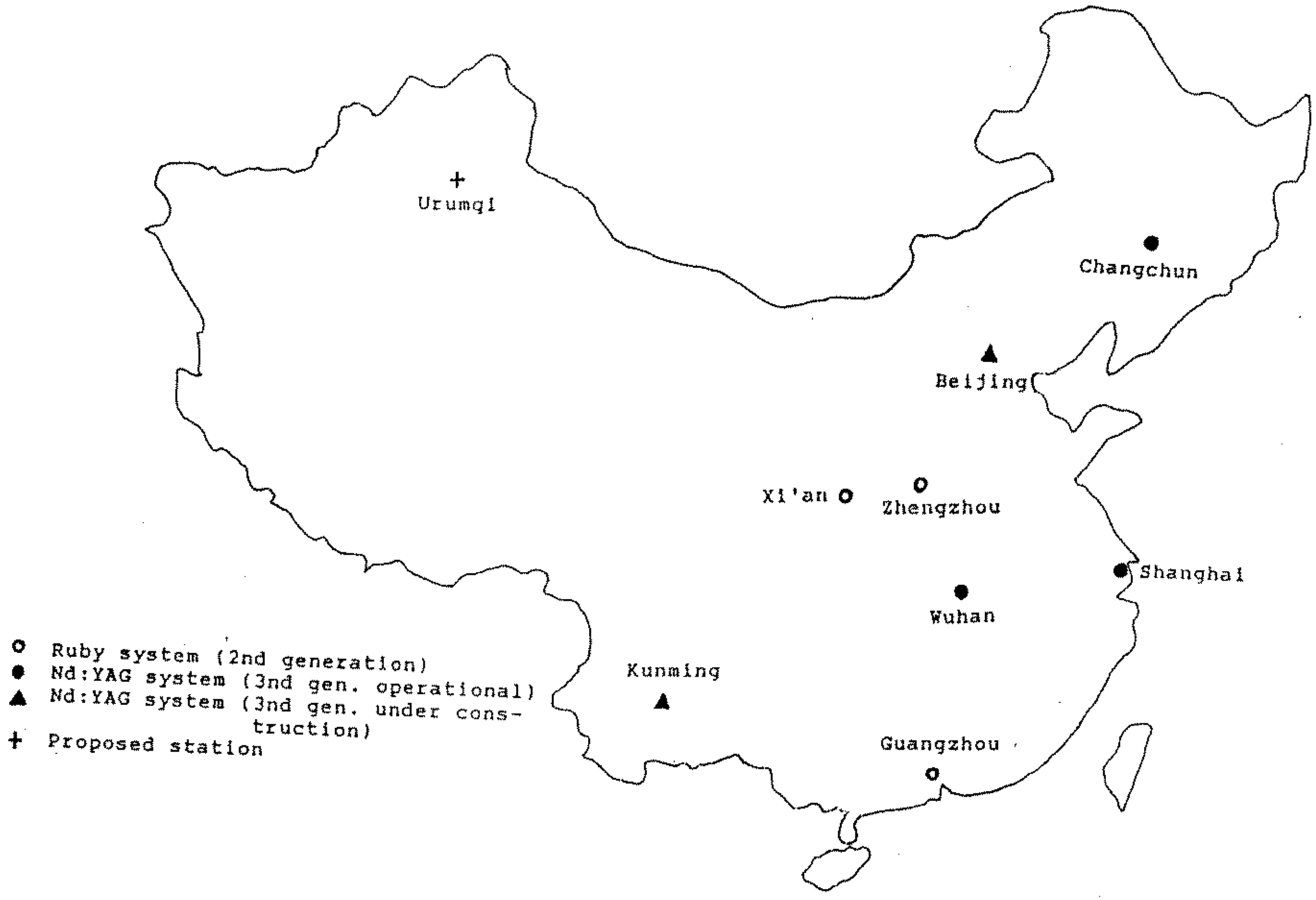


Fig.6 Chinese SLR Network

Interkosmos Satellite Laser Station Helwan Version Single Pulse / Semitrain

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Abstract

The Interkosmos SLR Station built in 1980 [1] located in Helwan, Egypt, operating since 1982 in the mode locked train version [2] [3],was switched in 1987 into the single pulse version and in 1989 into the semitrain version [P2].

Station upgrading:

1987 new laser transmitter / single pulse 17 psec
Coude pass reconstruction

1988 PMT /amplifiers / discriminator / optimizing
IBM PC implementation for data handling
data transmission via modem

1989 semitrain laser modification
data analysis procedures
Microprocessor based control slaved to IBM PC

To implement the single/semitrain version, the laser has been rebuilt [P3]. The oscillator is passively mode locked and passively Q switched generating 20 psec pulses. The semitrain version allows fully to exploit the stored energy of the active medium and to take the advantage of the short pulse, as well.

The length of the pulse was adjusted at 20 psec as an optimum from the point of view of

⋆ the existing laser technology (simplicity, reliability etc.),
⋆ the existing detectors for single photon operation [P4],
⋆ the atmospheric dispersion and consequent pulse broadening.

The single photon detection is desirable for compact mobile stations and even for the more powerful ones to range high satellites (Etalon, stationary) and for lunar ranging, obligatory. The laser pulse duration was chosen to be 20 psec, actually, the natural pulse length for most of the existing lasers for ranging based on NdYag / NdYap crystals. Any farther shortening leads to a complexity of the pulse compression and to pulse distortions mainly due to the atmospheric dispersion. Considering any photodiode detection, farther shortening does not considerably influence the overall rms budget. Using the streak camera for ranging [P5] we verified experimentally [P6] the theoretical range difference error 1.2 psec for 20 psec pulse duration. The safety hazards is considerably lower for single photon detection and laser transmitter is less complex, as well. To retrieve all information, applying the semitrain concept, we modified [P7] data analysis procedures. However, the laser station may be operated in single pulse version, if desired. The new laser radar electronics is based on IBM pc computer [P8].

Ranging low satellites having relatively low quality of predictions may be accomplished through the fast access to corrections during the pass and through two stage visual tracking, when the 30cm Newtonian telescope may be equipped by sit/iccd camera.

The results of SLR using the semitrain concept are shown in Fig.1. The histogram shows the distribution of echoes from different pulses of the semitrain. The envelope represents, in fact, approximately the transmitted burst (multiple pulse, semitrain) of pulses.

The concept of the receiver based either on a diode or a streak camera may allow in future to provide multicolor ranging [P9].

References

[1] K.Hamal, H.Jelínková, A.Novotný, I.Procházka, M.Čech: *Interkosmos Second Generation Satellite Laser Radar.* In: Proceedings of the Fourth International Workshop on Laser Ranging Instrumentation, Austin, USA, 1981

[2] K.Hamal, H.Jelínková, A.Novotný, I.Procházka: *Interkosmos Laser Radar, Version Mode Locked Train.* In: Fifth International Workshop on Laser Ranging Instrumentation, Volume I., Herstmonceux Castle, UK, 1984, pp. 214–218.

[3] K.Hamal,M.Čech, H.Jelínková, A.Novotný, I.Procházka, B.B.Baghos, M.Y.Tawadros, Y.E.Helali: *Interkosmos Laser Radar, Version Mode Locked Train.* In: Sixth International Workshop on Laser Ranging Instrumentation, Antibes, France, 1986, pp. 69–71.

In this Proceeding

Semitrain laser ranging
Lageos satellite ; 7000 km distance
October 15,1989 UT 2:15

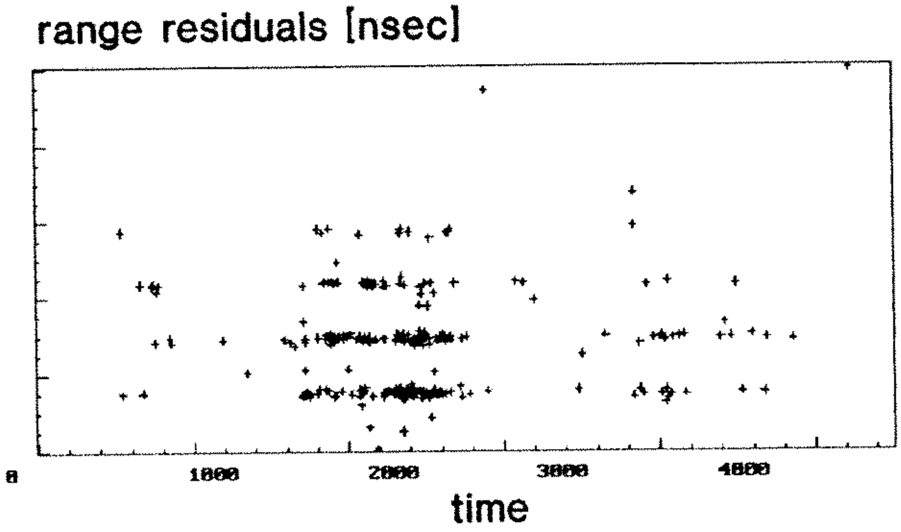

Fig. 1.b

Semitrain laser ranging
Lageos satellite, 7000 km distance
range residuals [nsec] 260 echoes

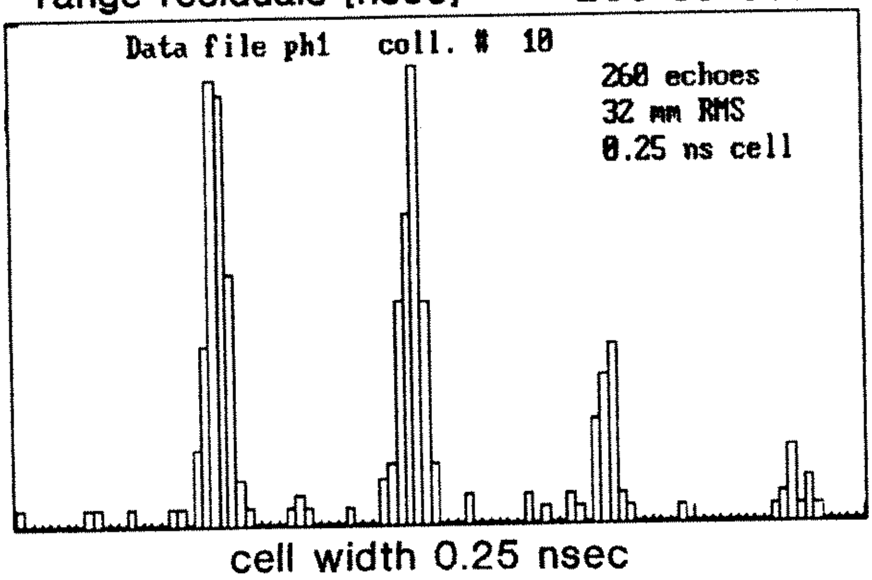

Fig. 1.a

System main parameters

Mount	configuration	Az-Alt, laser in Coude
	drivers	step motors, open loop
	control	dedicated uP, cont. track.
Laser	type	Nd YAG, passiv. mode locked
	configuration	osc/selector/3ampl/2 HG
	output energy	30 mJ / 1 pulse /0.53um
		80 mJ /semitrain/0.53um
	pulse length	17 psec HAFW
	rep. rate	2.5 or 5 Hz
Receiver #1	configuration	refractor, D : 30 cm
	FOV/filter	2 mrad, 1nm
	detector	RCA C31034A , gated, cooled
	discriminator	EG&G Ortec 473
Receiver #2	configuration	Newtonian, D : 30 cm
	purpose	experimental
Guiding		SIT Vidicon , FOV : 5 deg
Counter		HP5370B, 20 psec
Start	detector	optoswitch
Time gate	resolution	100 nsec delay/window
Epoch	resolution	100 nsec
	reference	Loran C, Mediter. chain
Control	hardware	uP based control system
		slaved to IBM PC AT
	software	prediciton / control
		data analysis
		prediction improvement

Fig. 2

System characterisation

(M.R.Pearlman,1984)

RANGING MACHINE ERRORS	1987	1989
Temporal stability	1.6 cm	0.4 cm
Wavefront distorsion (17psec HAFW)	(0.1 cm	(0.1 cm
Signal strength dependence (1PE only)	0.0 cm	0.0 cm
Cal. path survey (about 1 m length)	0.5 cm	0.2 cm
Mount/coude eccentricities	(1.0 cm	(0.2 cm
Calib. path meteo. conditions	0.0 cm	0.0 cm
r.s.s.	2.0 cm	0.5 cm
TIMING ERRORS (usec)		
Clock set	10usec	10usec
Broadcast monitoring (Loran C)	2usec	2usec
r.s.s.	11usec	11usec
MODELLING ENVIROMENTAL ERRORS		
Atmosphere propagation model	0.5 cm	0.5 cm
Atmospheric meteo. data	0.5 cm	0.5 cm
Spacecraft center of mass	0.2 cm	0.2 cm
r.s.s.	0.7 cm	0.7 cm

Fig. 3

New technologies R & D for subcentimeter ranging

Prague Calib.Center / Helwan SLR / Graz SLR

SUBJECT	GOALS
Laser	short pulses short/long term stability oscillator configuration semitrain multiple wavelength harm.generation walkoff
Photodiode	single photon detection low jitter at 0.53/1.06um aperture / noise relation temporal stability
Discriminator	inhouse built,Tennelec like matched to Hamamatsu MCP subcentimeter calibration
Streak camera	modular design circular/linear option dedicated for SLR
Electronics	uP based control system
Software/computer	IBM PC versions of prediction/control/ data analysis/prediction improvement

Fig. 4

Detectors performance summary, status 1989

SINGLE PHOTON		
PMT dynode chain	calibration	170 psec
	satellite	170 psec
PMT microchannel	calibration	120 psec
photodiode	calibration	60 psec
	satellite *	80 psec

* performed at Satellite Laser Station Graz,Austria

MULTIPHOTON		
PMT dynode chain	calibration	150 psec
	satellite	150 psec
PMT microchannel	calibration	60 psec
Streak cammera		
circular	calibration	6 psec
linear	calibration	20 psec
MULTIPHOTON TWO WAVELENGTH		
Streak cam.circular	calibration	6 psec
linear	calibration	420 fsec

Fig. 5

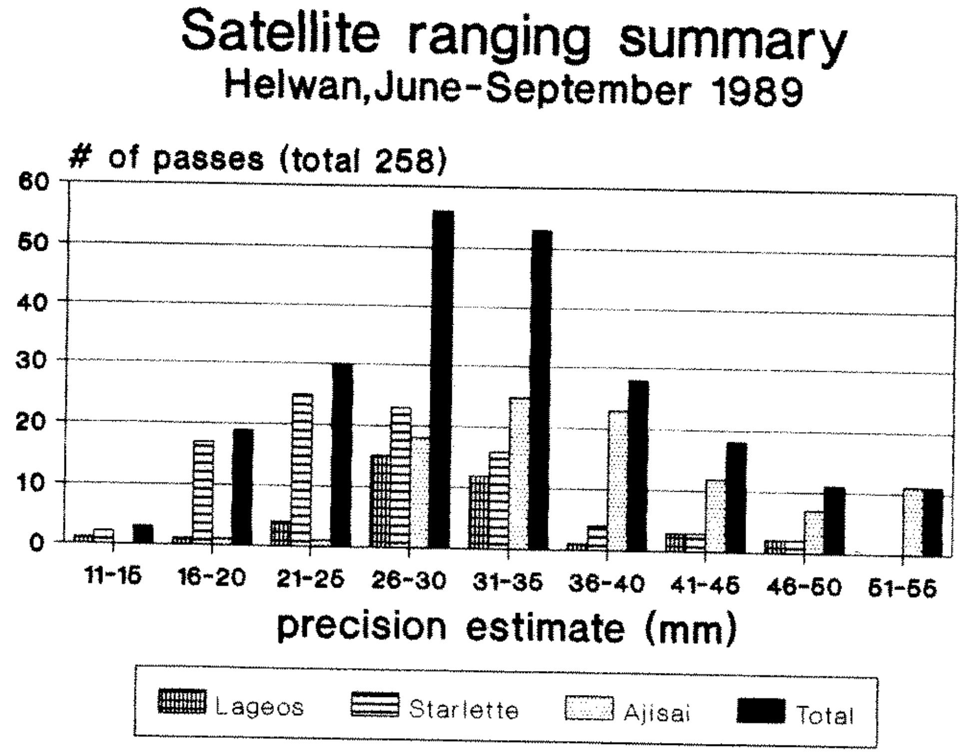
Satellite ranging summary
Helwan,June-September 1989
# of passes (total 258)
60
50
40
30
20
10
0
11-15
16-20
21-25
26-30
31-35
36-40
41-45
46-50
51-55
precision estimate (mm)
Lageos
Starlette
Ajisai
Total

Fig. 6

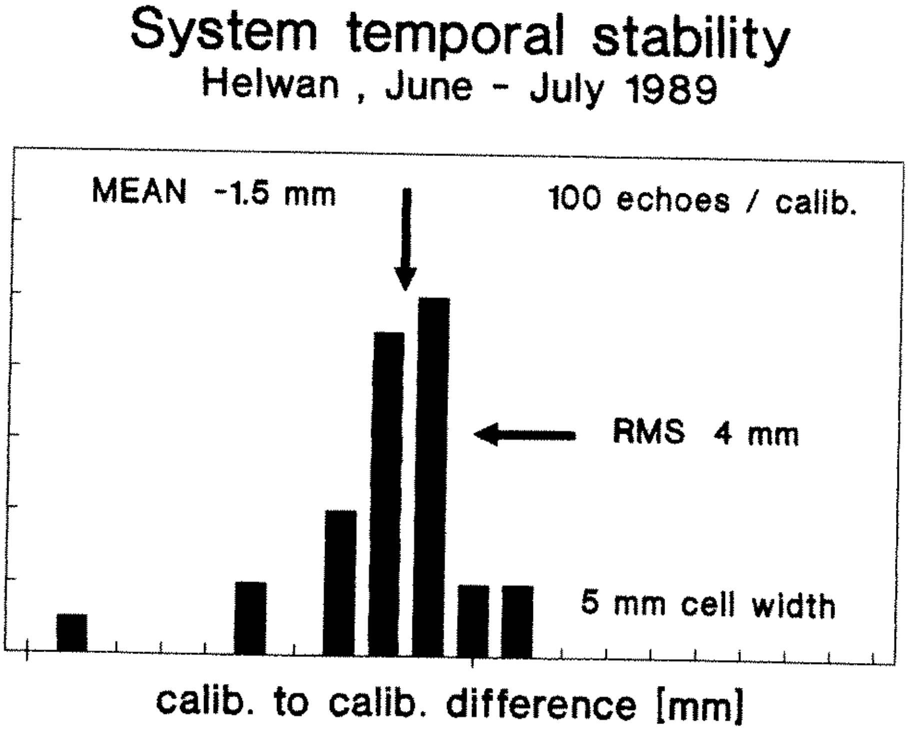
System temporal stability
Helwan , June - July 1989
MEAN -1.5 mm
100 echoes / calib.
RMS 4 mm
5 mm cell width
calib. to calib. difference [mm]

Fig. 7

STATUS AND PERFORMANCE OF THE SBG LASER RADAR STATIONS POTSDAM AND SANTIAGO DE CUBA

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Telex: 61254 cmict cu

Abstract

A short description of the 2nd generation systems of stations 1181 Potsdam and 1953 Santiago de Cuba , based on former photographic tracking cameras, is given. They are capable of LAGEOS blind tracking with the help of a star calibration method and can also range to the high-orbiting ETALON satellites.
Both stations contribute regularly to the IERS.

The laser radar stations 1181 Potsdam and 1953 Santiago de Cuba are based on the former photographic tracking camera SBG, a Maksutov-Schmidt-system with 32 cm effective diameter of the receiver optics on a 4-axis mount. Several modifications allow its use as laser ranging systems with 2nd generation performance. A short overview of the main principles is given here.

Receiver optics

The optical scheme of the receiver system is shown in Fig.1. Because of the optical-mechanical layout of the SBG mount it is impossible to install a Coude focus. So all the receiver optics had to be placed behind the main mirror. The former photographic unit was replaced by a secondary Cassegrain mirror and a central hole was drilled into the main mirror. The use of a dichroic beamsplitter for separating the signal photons allows the use of the main telescope for tracking purposes. This is especially helpful in the case of high orbiting, very faint objects as LAGEOS and ETALON.

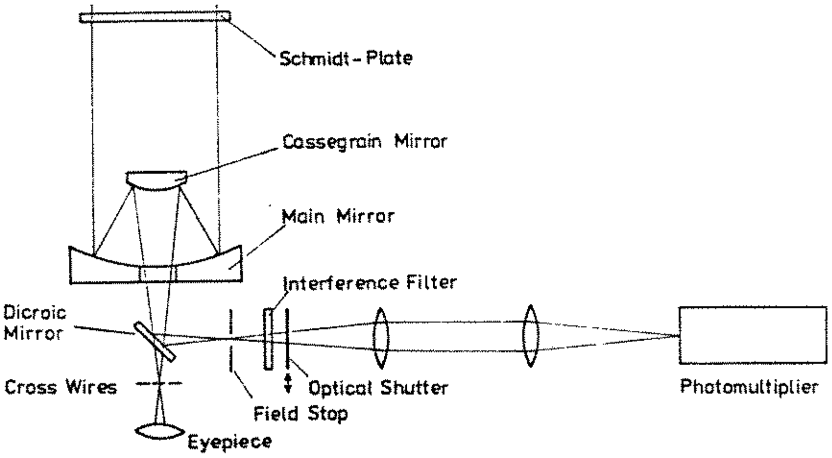

Fig.1: Optical scheme of SBG laser radar telescope (not true to scale !)

Mount

The original pointing accuracy of +/- 0.1° was improved by hardware modifications and error modelling to about 1 minute of arc.

For the use of narrow beams (20") a pointing accuracy of about +/- 10" is obtained by observing the positions of some stars brighter than 7th magnitude along the track of the satellite and finding the true position of the axes by matching the observed and the catalog positions via the station computer. In combination with the use of long-term predictions of the LAGEOS position (edited by the University of Texas), this procedure allows fully blind tracking of LAGEOS, but the need of deriving true setting angles for each individual pass via star observations prior to tracking limits this possibility to night and twilight passes.

Laser

The principal scheme of the laser transmitters of Potsdam and Santiago sites is shown in Fig.2. A simple passive Q-switch ruby oscillator with short cavity length (about 20cm) and high internal amplification produces TEM_{00} pulses of about 3 ns pulsewidth, amplified by the preamplifier R2 (mounted together with the oscillator rod R1 inside the same pumping cavity) and the external main amplifier rod R3. Transmission with variable divergence is done by the Galileian telescope L2/L3. In the Potsdam version, only a single pass through the preamplifier is used. Due to the mount construction, the laser has to be moved together with the main telescope.

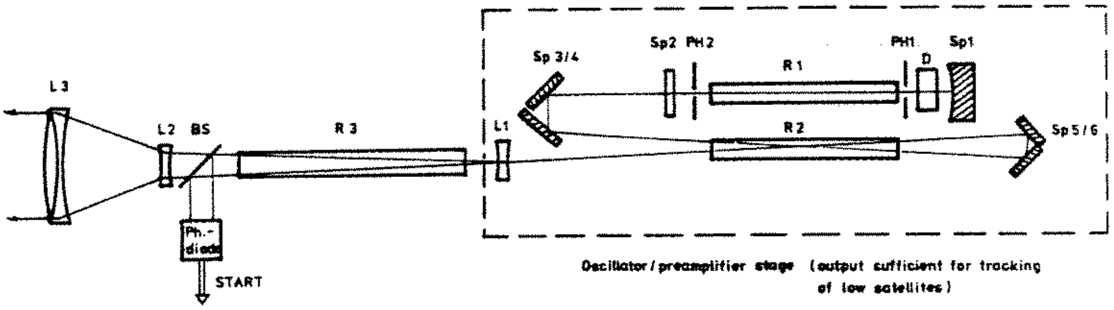

Fig.2: Optical scheme of the laser transmitter
D: dye cell; Sp1: 99% mirror (r=51m); Sp2: two-plate etalon; Sp3...6: flat dielectric mirrors (99%)
PH1,2: pinholes of 0.8 and 2mm diameter, resp.
ruby rod dimensions: R1,2: (6 x 120)mm
R3 :(10 x 150)mm

Control system

On-line computer control of the mount (3rd and 4th axis), related electronics as laser firing, digital range gate and readout of time-of-flight and epoch counters is achieved by an IEC 625 type interface with a desktop computer of 24 kByte operational memory (Santiago de Cuba: 8k + 16 k external RAM) as a controller. A complete program system for ephemeris prediction, tracking and data reduction as well as auxiliary programs for mount orientation and I/O routines are available.
An overview of the technical parameters of both stations can be found in Table 1. Station 1181 Potsdam is operated since 1974 (until 1981 with 20ns laser), station 1953 Santiago de Cuba since 1985. Both are contributing regularly to the International Earth Rotation Service since January 1988. Potsdam station has been taking part since 1980 in all MERIT and Post-MERIT activities. Examples of the data production of both stations are given in Table 2.

Table 1: Technical parameters of stations 1181 and 1953

	1181 Potsdam	1953 Santiago de Cuba
Transmitter		
Type	Ruby, passive Q-switch (TEM$_{oo}$)	
Pulsewidth	3...5 ns	
Max. output energy	250 mJ	800 mJ
Min. divergence	20"	
Receiver		
PMT type	RCA C 31034A	FEU 79
Quant. eff. (694 nm)	5...10%	3 %
Control system		
Bus controller	HP 9825 S	EMG 666 B
Operational memory	24 kByte	8 kByte (+16 kByte RAM)
Time base	BIH Cs-clock	USNO Rb-clock/TV + LORAN-C

Table 2: Ranging results of stations 1181 and 1953

	1181 Potsdam	1953 Santiago de Cuba
Period	1.1. - 31.8. 1989	1.1. - 31.12.1988
Passes of		
-LAGEOS	66	72
-low satellites	64	65
-ETALON-1	13	3 (1989)

THE NETWORK OF LASER RANGING STATIONS "CRIMEA"

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ABSTRACT

Since 1983 crimean team of the Lebedev Physical Institute creates the network "Crimea" containing 2 stationary and 3 transportable stations for laser ranging of the Moon and satellites. At the present time 3 stations are operationable and are used for the regular observations of the satellites Lageos and Etalons. Here is given the description of the station "Crimea-1" and the status of the network.

Crimean scientific station of the Lebedev Physical institute of the Academy of Sciences of the USSR works on laser ranging of the Moon since 1983. At first the 2.6 m telescope of Crimean Astrophysical observatory was used for observations. In the beginning of eighties due to reduction of observation time in the telescope schedule to 20 nigths per year the works were ceased. That was the reason for crimean team of the Lebedev Physical institute to suggest the creation of ranging network "Crimea" that should be consist of 2 stationary and 3 transportable laser ranging stations (LRS), supplied by proper telescope and intended for ranging the Moon and the satellites. Realisation th this project was started in 1982 and now it is nearly completed. A number of industrial and scientific organizations took part in this elaboration and now 5 main observatories of the country are dealing with the exploitation of the "Crimea" network.

NAME	ORGAN. of EXPLOITATION	PLACE of LOCATION
CRIMEA-1	LEBEDEV PHYS. INSTITUTE	KATZIVELY,CRIMEA
CRIMEA-2	LATVIAN STATE UNIVERSITY	RIGA,LSSR
CRIMEA-3	MAIN ASTRON. OBSERVATORY Acad. of SC., UKRAINNIAN SSR	KITTAB
CRIMEA-4	ASTRONOMICAL COUNCEL. Acad. of SC., USSR	MONGOLIA OR
CRIMEA-5	MAIN ASTRON. OBSERVATORY, Acad. of SC., USSR	BLAGOVESHCHENSK

Tab.1. STATUS AND PLANNED DISPOSITIONS OF "CRIMEA" NETWORK STATIONS

At present time only 2 stations are exploited in the planned places - these are the stationary stations"Crimea-1" (Katzively) and "Crimea-2" (Riga). The other stations are arranged in the base observatories : "Crimea-3" - in Kiev, "Crimea-4" - in Simeiz, "Crimea-5" - in Pulkovo. As far as they will be put into operation, the stations will be moved to the points shown in Tab.1.

All stations of the network consist of nearly identical equipments being distinguished by internal arrangement. As an example we give a description of LRS "Crimea-1". All systems of this station are mounted in the building with the rotating dome.

Telescope

The optical diagram of the station is shown on Fig.1 The same telescope is emploied for transmitting and receiving of light pulses. The telescope has an altazimuth mount system.

DIAMETER OF THE MAIN MIRROR	1 m
FOCAL LENGTH	11.6 m
ANGULAR RESOLUTION	1"
FIELD OF VIEW	40"
ACCURACY OF POINTING	0.2"
TRACKING RATE IN BOTH ANGLES	0.7"/sec
DIMENSIONS	1.5 x 1.8 x 1.9 m
WEIGTH	650 kg

Tab. 2. SPECIFICATIONS OF THE TELESCOPE

A particulary property of the telescope is the sphericity of both the main and secondary mirrors. For compensation of spherical aberrations the secondary mirror is constructed as doubleconcaved lens with the alluminiun coating of the back surface. This is the way of compensation of spherical aberrations for a number of discrete wave lengths, as in our case for λ=5320A, λ=6973A, λ=10600A.
Both in a stationary stations and in mobile ones the telescopes are placed on the concrete bases. Fig.2 shows the telescope of LRS "Crimea-1" mounted under the dome.

Laser transmitters

In the Lrs "Crimea-1" three different modications of Nd:YAG lasers are used. The optical diagrams of the lasers are shown in Fig.3, 4, 5.
The second and third modications of laser are used only in the station "Crimea-1" for ranging the Moon (TL-2) and the satellites (TL-3). All other sation of the network are equiped with the laser of the TL-1 type intended only for satellite ranging. Thus the LRS "Crimea-1" is the unique station of the network equiped with the laser of 3-rd generation.

PARAMETERS	TL-1	TL-22	TL-3
OUTPUT ENERGY (joules)	0.01-0.05	0.05-0.25	0.02-0.1
PULSE WIDTH (nanoseconds)	2.5-3.5	1.5-2.5	0.5
BEAM DIVERGENCY (arcminutes)	10	3 - 4	2
EFF. OF FREQ. DOUBLING	0.20	0.35	0.25
REPETITION RATE (Hz)	1-10	1-10	1

Tab.3. Nd: YAG LASERS SPECIFICATIONS

In all three lasers there are used the oscillators with unstable resonators formed by spherical mirrors. Laser of the 2-nd type contains one 4-passed amplifier with phase conjugation cell used for compensation of distortion of laser beam in the amplifier crystal. In the laser of the 3-rd type the effect of phase conjugation is used for time compression of the pulse.

Photoreceives

In the LRS "Crimea-1" 2 types of photoreceivers are used. As a receiver for satellites ranging it is used the microchannel PMT "FEU-165". In this case the accuracy of the timing electronics reaches 120 ps. But this receiver has low quantum efficiency (3 %) and therefore it is not used for ranging of the Moon. In the lunar configuration of the equipement the PMT "FEU-79" is used. The resulution reached with this PMT is lower (250 ps) but quantum efficiency with the enchancement prizim on the photocathode is equal to 15 %. In the receiver of this type it is used a holographic filter with spectral width 1.5A and the transparency 20 %. Fig. 6 shows the optical diagram of the photoreceiver with holographic filter.

Timing electronics and controlling equipment

For measuring the time delays and controlling the experiment it is used the chronographic system "PICAP" which consists of the event timer and computer. Tab. 3 shows the major specifications of timing system.

TYPE	CHRONOGRAPHIC
NUMBER OF CHANNELS	4 (1 START AND 3 STOP)
GATE POSITION	32 MSC - 6.7 SEC
GATE WIDTH	0.2 μsec - 3.2 msec
RESOLUTION	$<$70 psec

Tab. 3 EVEN TIMER SPECIFICATIONS

Lower limit of gate position depends on the time span that is needed for the computation of the ephemeris that has to be done between two successive pulses of the laser. In the case of ranging the satellites with low orbits the diminish the lower limit of the gate position.

In the controlling system the computer MERA-60 (64 KB) made in Poland is used. This system provides the realization of the following functions :

- registration of the epoch time,

- chronography of the events,
- computation of delays,
- time gate control,
- repetition rate control,
- control of the pointing and guiding the telescope,
- preprocessing the date, plotting the histograms of resuduals.

Calibration

For calibration it is used an internal target (screen) placed on the mirror M (Fig. 1). A part of the beam path from the screen to the primary mirror of the telescope

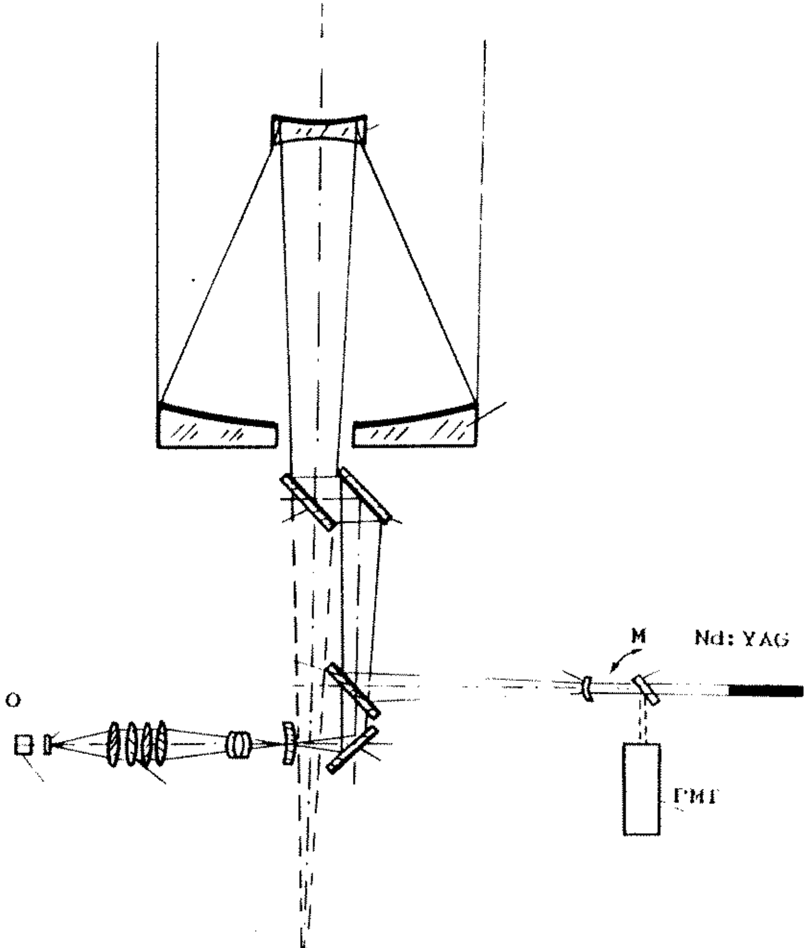

FIG. 1 OPTICAL DIAGRAM OF THE "CRIMEA" STATION

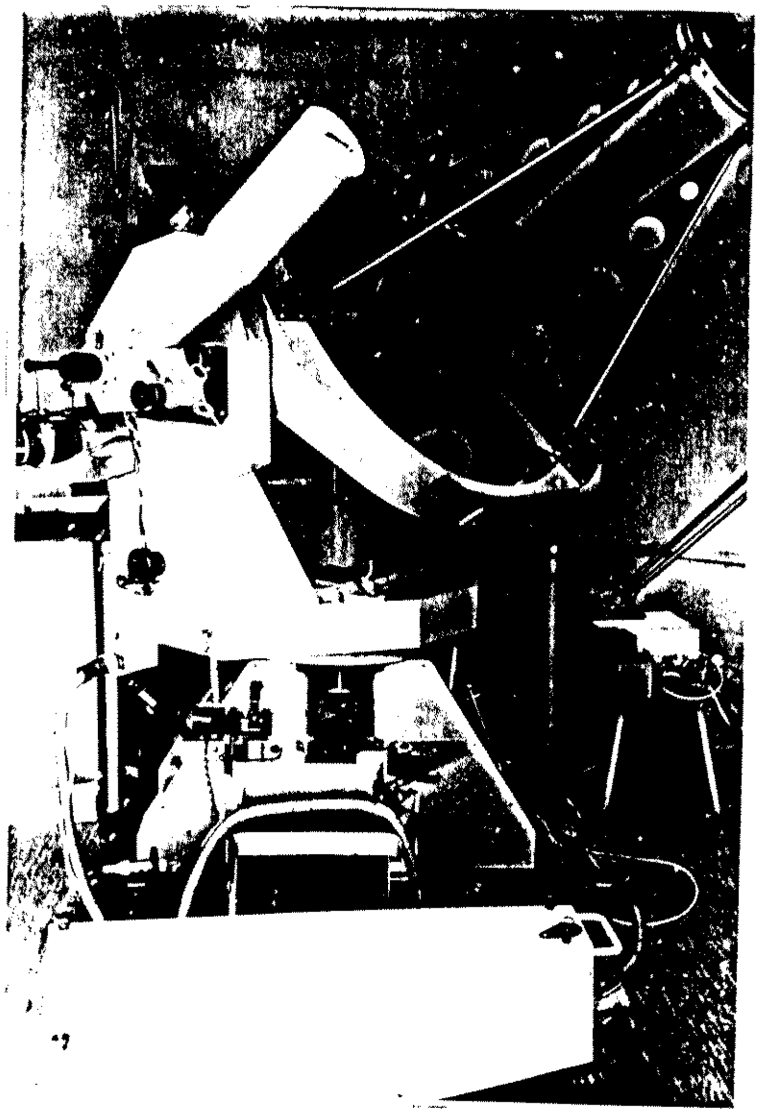

FIG. 2. TELESCOPE

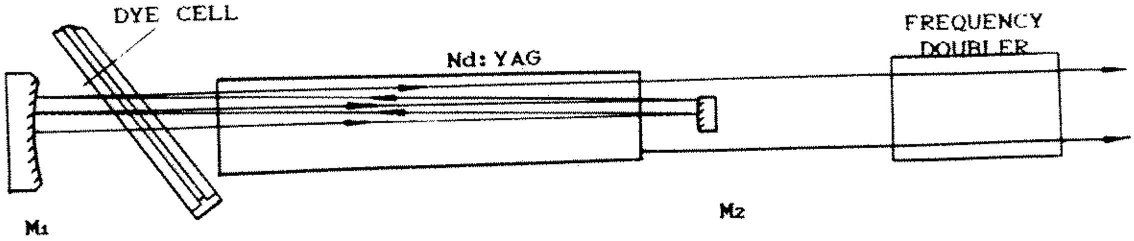

FIG. 3 OPTICAL DIAGRAM OF THE LASER TRANSMITTER LT-1

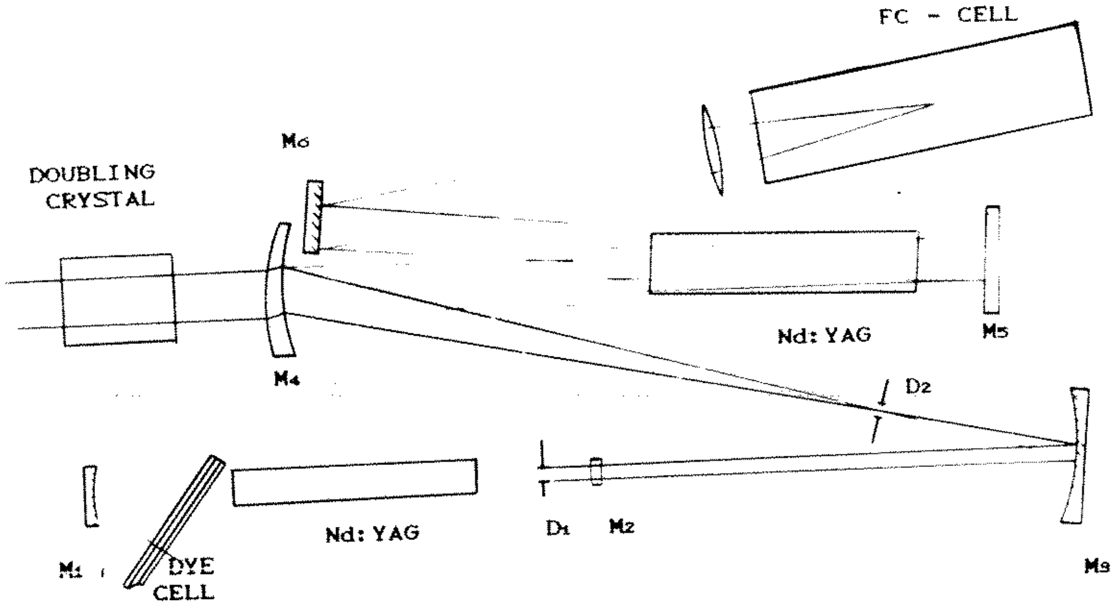

FIG. 4 OPTICAL DIAGRAM OF THE LASER TRANSMITTER LT-2

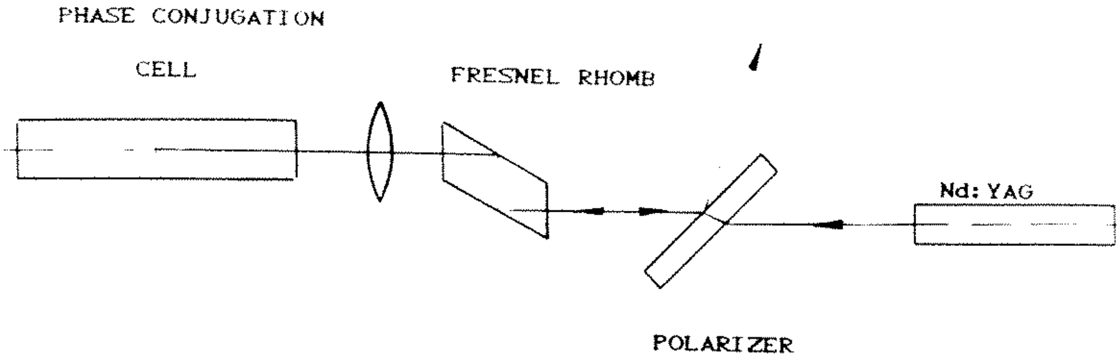

FIG. 5 OPTICAL DIAGRAM OF THE LASER TRANSMITTER LT-3
(WITH PC-COMPRESSION)

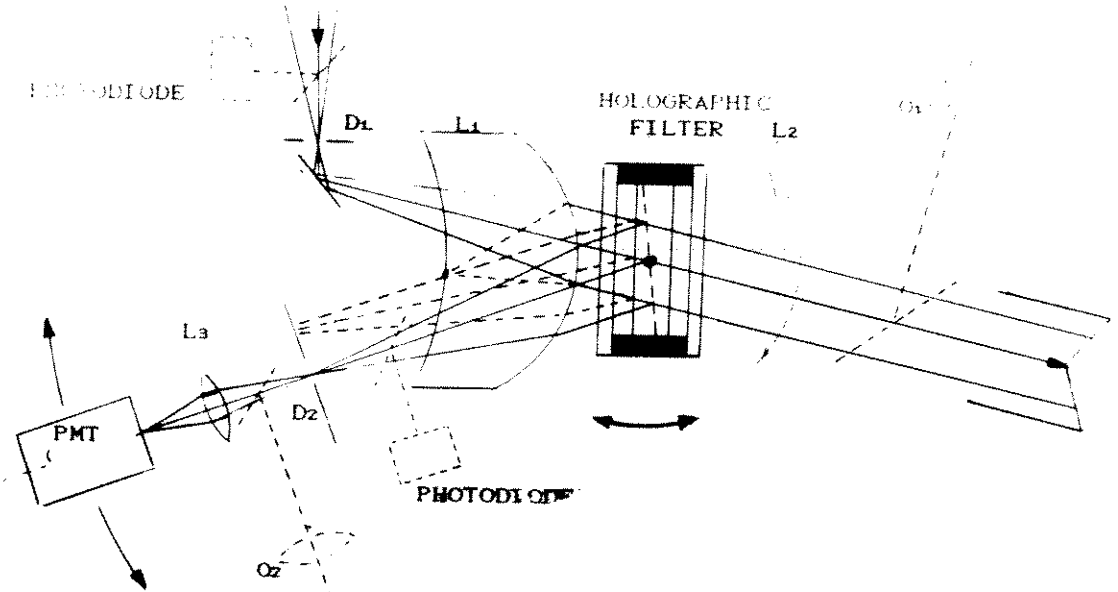

FIG. 6 OPTICAL DIAGRAM OF THE PHOTORECEIVER
WITH HOLOGRAPHIC FILTER

```
                      SATELLITE LASER RANGING

            LRS CRIMEA-1 (1893)           SAT. LAGEOS (7603901)

     1989-05-31              320 OBSERVATIONS           19:33:39-19:54:09

              HISTOGRAM OF RESIDUALS AFTER POLYNOMIAL FITTING

  POL. DEG.: 6      MIN. RES.: -1.37 NS.     MAX. RES.: 1.41 NS.     RMS = 0.423 NS.
```

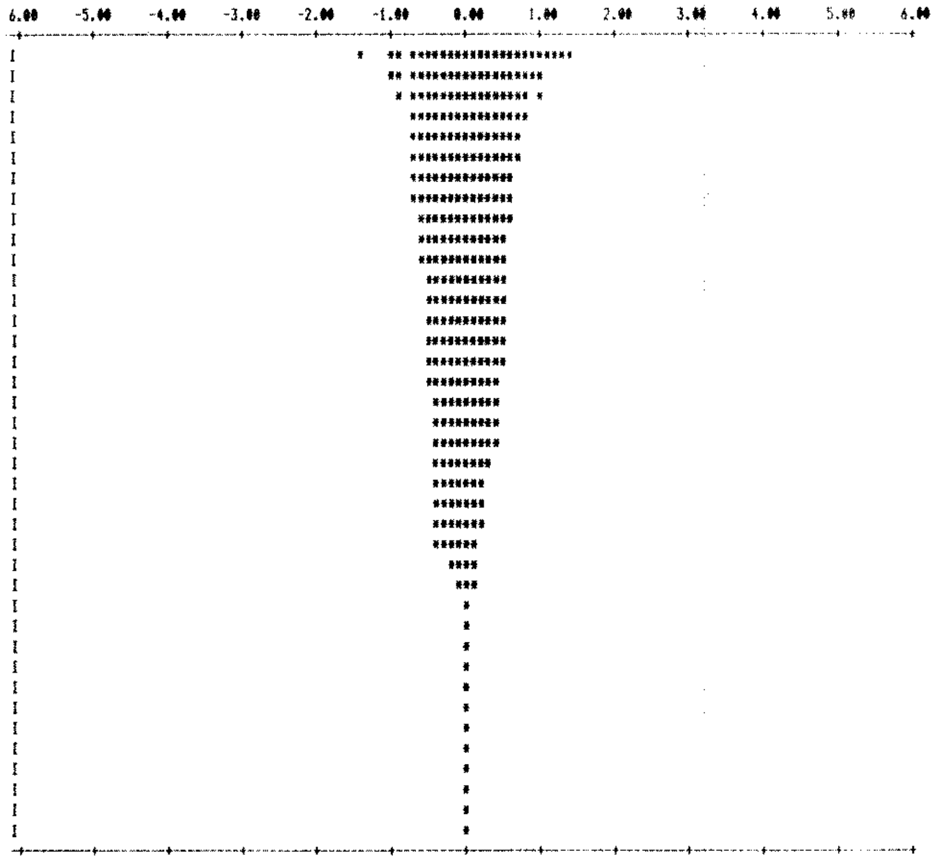

Fig. 7.

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                      SATELLITE LASER RANGING

            LRS CRIMEA-1 (1893)           SAT. ETALON (8900103)

     1989-08-23              357 OBSERVATIONS           20:04:00-20:19:02

              HISTOGRAM OF RESIDUALS AFTER POLYNOMIAL FITTING

  POL. DEG.: 6      MIN. RES.: -1.93 NS.     MAX. RES.: 1.93 NS.     RMS = 0.599 NS.
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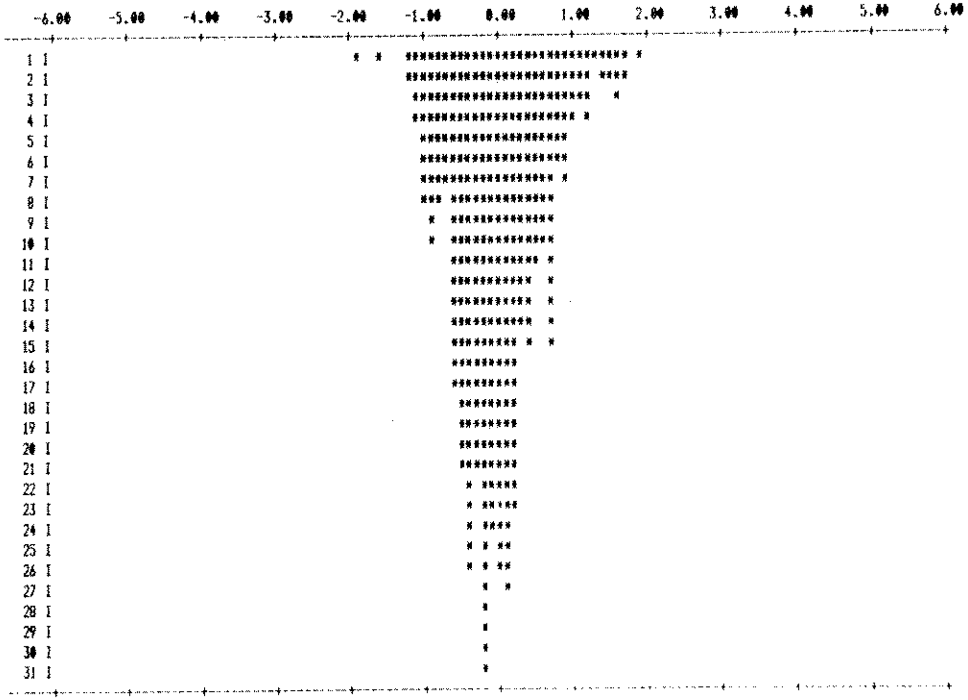

Fig. 8.

STATUS OF THE CAGLIARI SLR STATION AND THE LASSO EXPERIMENT

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In 1975 the Astronomic Station in Cagliari bought a ruby laser and acquired a Contraves cinethedolite and so we were able to start building the SLR station.

Only from 1987 it was possible to work for its completion and in the second half of 1989 the laser station started working.

It was very difficult to operate properly our old laser, in fact the flashlamps were not to be found anywhere and the calibration was hard.

As regards the telescope the original electromechanic and electronic assemblies were substituted so that the instrument we have at our disposal now is enough versatile and precise:

via serial port RS232 it is possible to send it controls both velocity (from 10 arcs to 17 degrees per second) and absolute positioning (with the precision of 0.1 mrad).

Once solved the most important problems, starting from 19th of September our attention was been addressed to the LASSO Experiment.

In fact our station belongs to LASSO USERS as so called "one way" system, it means that we send synchronized laser pulses to Meteosat 3 without receiving echoes.

Table 3 shows the first sessions of the LASSO EXPERIMENT.

Just something worked not well: the fire trigger is not right, we are looking for a better one and beam divergence is too large.

At the moment we are trying to improve our system and we are planning to substitute our obsolete laser with a new one: NEODYMIO or TWO COLOURS system.

Our research activity also concerns the collaboration and the supply facilities to the groups of mobile lasers and GPS.

Within the limits of the Earth Motion research, the Astronomic Station in Cagliari implements the SLR observations with those made by classical instrumentation (Danjion Astrolabe, Photographic Zenithal Telescope).

TAB. 1 - STATION FEATURES

STATION NUMBER	7543 (PUNTA SA MENTA)
LATITUDE	39°.13739 N
LONGITUDE	8°.977306 E
CLOCK ACCURACY	1 μsec
T.I.C. RESOLUTION	20 psec
T.I.C. PRECISION	100 psec
MAIN MIRROR	50 cm
EQUIVALENT FOCAL LENGTH	5 m

TAB. 2 - LASER SYSTEM SPECIFICATION

Oscillator rod	1x7.5 cm AR coated ruby
Amplifier	1.3x15 cm AR coated ruby
Q-Switch	1 cm clear aperture KD*P Pockels Cell
Cavity configuration	Flat-Flat, pulse-on switching
Wavelength	694.3 nm
Line width	0.3 Å FWHM typical
Output energy	1 Joule in 5 ns pulse width
Beam divergence	3 mrad
Repetition rate	60 per minute maximum

TAB. 3 - LASSO EXPERIMENT PERFORMANCES
AT CAGLIARI OBSERVATORY

EPOCH	LASER FIRES	FIRING PERIOD	NOTES
Sept 19	371	0.603	WARMING UP THE SYSTEM (TOO HIGH FREQUENCY)
Sept 21	-	-	FLASHLAMP BROKEN
Sept 22	644	1.960	AVAILABLE ONLY THE INTERNAL TRIGGER
Sept 25	303	1.960	AVAILABLE ONLY THE INTERNAL TRIGGER
Sept 26	-	-	BAD WEATHER
Sept 27	-	-	ACQUISITION SYSTEM FAILURE
Sept 29	360	1.960	AVAILABLE ONLY THE INTERNAL TRIGGER

REFERENCES

A. Banni, V. Capoccia - THE NEW SATELLITE RANGING SYSTEM AT CAGLIARI OBSERVATORY - 6th Inter. Workshop on Laser Ranging Intr.- Antibes 1987

A. Banni, V. Capoccia - HARDWARE AND SOFTWARE FEATURES OF THE ACQUISITION-CONTROL MICROCOMPUTER OF CAGLIARI SLR SYSTEM - Nota Tecnica Stazione Astronomica - Cagliari 1986

Status Report of the Modular, Transportable Laser Ranging System MTLRS#1

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Abstract. In this paper a report is given on the performance characteristics of the German Modular, Transportable Laser Ranging System MTLRS#1. Tracking results of the last years are summarized and plans are presented for future activities into the early 1990's. The technical status of the system is described and plans are given for a system upgrade.

1. Introduction

Since 1984 the Modular Transportable Laser Ranging System MTLRS#1 has supplied the international network with laser ranging data from 15 sites in Europe, Asia and North America. Despite the fact that tracking time is lost during transport between sites, the system has a demonstrated capability of tracking nearly 300 Lageos passes per year with a single shot accuracy of 4-5 cm. Even so, some degradation occurs, e.g. as a result of the atmospheric and vibrational influences encountered in the mobile environment, and the technical reliability can only be maintained with an increasing effort on the part of the crew. Apart from this though, an upgrade is necessary to improve the ranging accuracy to current standards, i.e. a single shot r.m.s. of 1 cm or better.

2. System Results Over the Past Year and Campaign Perspectives into the 1990's

2.1. Brief Remarks on System Performance 1984 - 1988

Table 1 gives an overall picture of MTLRS#1 tracking since delivery of the system in June 1984. Due to the testing of the system the number of passes obtained in 1984/85 was rather low. Both Starlette and Ajisai were tracked during the early years, but from the outset, Lageos tracking has received priority and the most significant results to date have been obtained with a single satellite. As a result of a long occupation at Richmond, Florida and the long transportation times between sites in Florida, Colorado and Caifornia, only three sites were occupied in the U.S.A. in 1988. In normal years, with nominal travel times of 3 to 7 days between sites the system has tracked between 250 and 300 passes (the 1000th Lageos pass was tracked this year in Yozgat).

2.2. WEGENER-MEDLAS Campaign 1989

During the current year the system has been operating in the Central and Eastern Mediterranean. The tracking schedule foresaw operations at five sites, viz. Lampedusa Island (Italy), Karitsa (Greece), Yozgat (Turkey), Diyarbakir (Turkey) and Kattavia (Rhodos, Greece) in the sequence.

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A map of the area showing the sites and the occupation times is given in Fig. 1. A period of annual maintenance preceded the campaign (January to mid March 1989) and a similar activity will follow the completion of this year's field activities after the system returns to Wettzell at the end of December.

Fig. 2 shows the weekly tracking for 1989 until end of september. With good weather the system has tracked about 4 passes per day, irrespective of whether the satellite was available during daytime or night. The average over the year to that date is 10.2 passes per week with 7.5 passes during daytime and 2.7 passes at night. This means that on the average a site occupation lasts about 5 weeks in order to obtain the required 50 passes. Under the best conditions, with excellent weather, no technical defects and a crew working 7 days per week, MTLRS#1 has a demonstrated capability of completing a site occupation in 14 days.

In this best case, the system has been able to track 95 % of all available Lageos passes exceeding 40 degrees (see Fig. 3). Due however to weather and system down time, the yearly average is only 43.1 % (with 42.3 % of daylight passes and 45.5 % at night). These numbers are only averaged over the time spent on-site.

A further important statistic addresses the number of normal points derived for a single Lageos pass. Here there is a significant difference between daylight (average 8.44 normal points; this good result is influenced by the abnormal high amount of normal points per pass in Diyarbakir) and night-time (average 10.3 normal points) passes. For this year an overall average of 8.93 normal points per pass has been obtained.

2.3. Perspectives into the 1990's

In setting up the WEGENER-MEDLAS Project an agreement with NASA was reached which foresees the deployment of MTLRS#1 in the U.S.A. in alternate years. In exchange for this a TLRS is operated in Europe during the WEGENER-MEDLAS field campaigns. The agreement currently covers the period up to the end of the Crustal Dynamics Project in 1991, but tentative agreement has been reached between the IfAG and NASA to extend the arrangement into the years beyond and present plans visualise the following schedules:

- December 1989 through March 1990: annual maintenance addressing primarily the exchange of damaged optical components and electronic repairs in Wettzell;
- April to December 1990: re-occupation of three sites (Flagstaff, Platteville and Owens Valley) in the Western U.S. as part of the ongoing observations in the NASA Crustal Dynamics Project;
- January to December 1991: system upgrade designed to improve ranging accuracy and operational hardware reliability;
- second half of 1991: co-location with SLR systems, probably at two sites in the U.S.S.R. (Simeiz and Riga);
- 1992: participation in the WEGENER-MEDLAS Project and in the TOPEX-Poseidon Project in the Mediterranean area.

3. The Technical Status of MTLRS#1 before and after Upgrade

The following is a summary of the hardware status of MTLRS#1;

- The total system has been operational since 1984 without major maintenance. The only significant technical change covered the replacement of the HP 1000 Model 5 by the HP A600 in 1987. The system has full daylight ranging capability and delivers ranging data with a single shot accuracy of 4-5 cm. The system averages 400 - 500 returns per Lageos pass and operates at the single photo-electron level. Following the upgrade the single shot r.m.s. should be about 1 cm and the return rate should increase. System reliability will be improved, and due to Software changes, data acquisition within the pass will be speeded up and the efficiency of pass scheduling will be matched to the increased compliment of satellites requiring to be tracked.
- The optical components of the emitting system (Nd:YAP laser with 370 psec pulse duration and 8 mJ output energy) are in good condition. Even so, laser failures resulting from the harsh environmental operating conditions have increased over the last years. During the upgrade the current laser will be exchanged for a new system with 30 psec pulse duration and 30 mJ output energy. This will lead to improved ranging accuracy. An independent cooling system will be introduced and calibrated control monitors in the optical path will facilitate remote control adjustment of the optical elements.
- The telescope is in good condition, though some problems are emerging as a consequence of dust in the optical path and damage to the coatings of some optical elements. These factors must be taken into account in the course of the next years and some maintenance may be necessary.
- To improve the single shot r.m.s., the photo-multiplier tube and the constant fraction discriminator in the current receiver package, (the present PMT has a rise time of 3 nsec) needs to be changed for a micro-channel plate with fast rise time (300 psec) and high quantum efficiency (10 - 15 %) and a matching constant fraction discriminator. A received energy detector will be introduced and used to exclude the influences of multi-photo-electron returns on the data occuracy.
- To meet future requirements some changes in system tracking software will be necessary. These include the facility for programming the sequential tracking of high (Lageos 1,2,3, Etalon 1,2, ...) and low (Starlette, Ajisai, Stella, ERS-1, TOPEX-Poseidon, ...) satellites along with the software to read out and record the output of the received energy detector. Furthermore, software will be incorporated for generating normal points in the field.
- Some additional sub-systems should be added to improve the handling of the system and overall data accuracy. These include:

  - A high accuracy meteorological recording system with automated read-out for pressure, temperature and humidity during tracking.

  - A CCD camera to assist in the determination of system orientation (star observations) and the Coude alignment of the telescope. The exact adjustment of the system will result in a significant increase in the return rate as well as facilitating more automation in the tracking proceduress

  - Improvements have already been made to the communications system (incorporation of INMARSAT) which have influenced system reliability and speeded up data distribution. Only minor changes will be necessary in future (data link to the IfAG computers in Wettzell and Frankfurt; Telefax, etc.).

4. Summary and Conclusion

The Modular, Transportable Laser Ranging System MTLRS#1 is an important contributor to the international satellite laser ranging network. Currently the system is leading the productivity of the mobile systems, but the single shot ranging accuracy (4-5 cm), performance and reliability of the system, due to its age, are no longer "state of the art". It is our hope and expectation that by mid-year 1991 MTLRS#1 will again be one of the most advanced SLR systems.

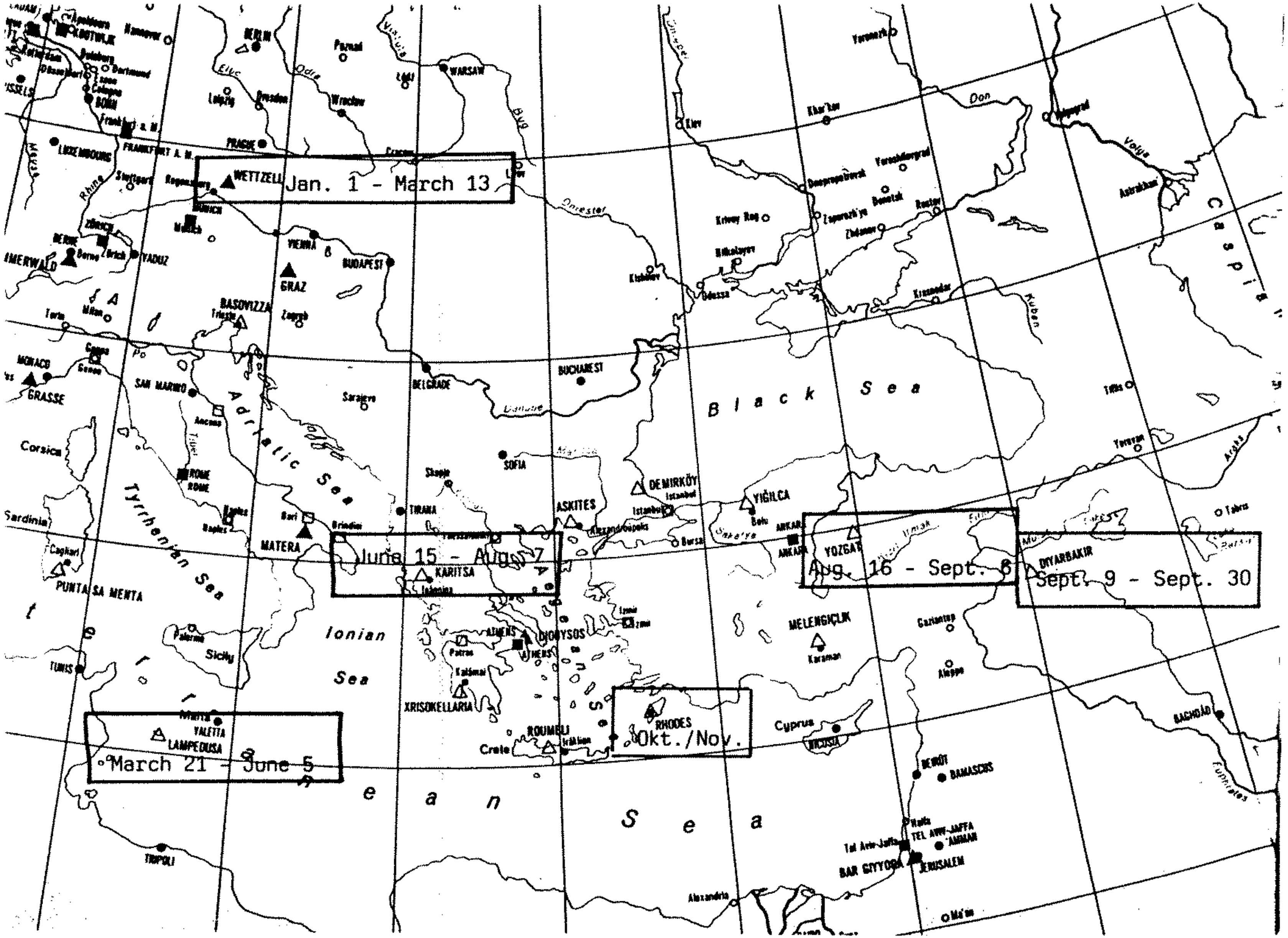

Fig. 1: Occupations of MTLRS#1 during the 1989 Wegener Medlas Campaign

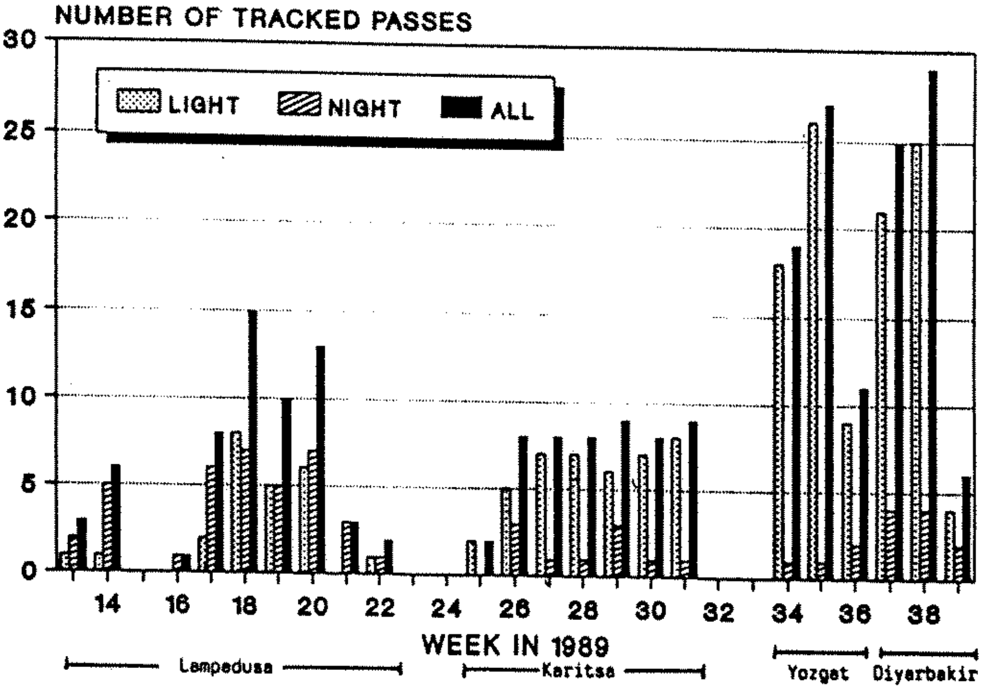

Fig. 2: Number of tracked Lageos Passes per week for MTLRS#1

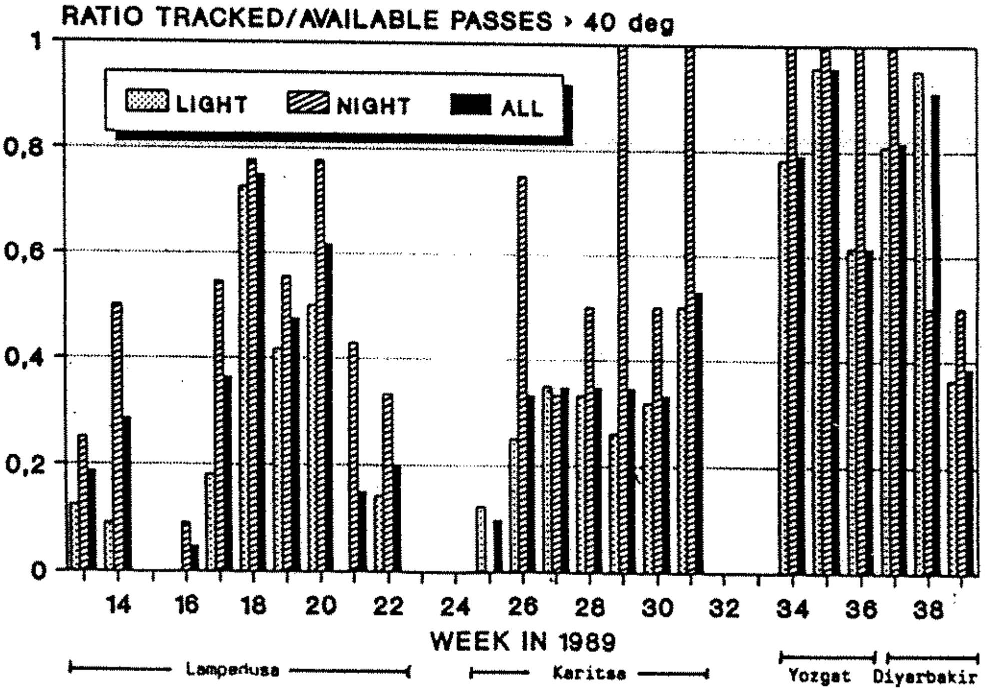

Fig. 3: Ratio of tracked/available Passes with maximum elevation greater 40 degrees

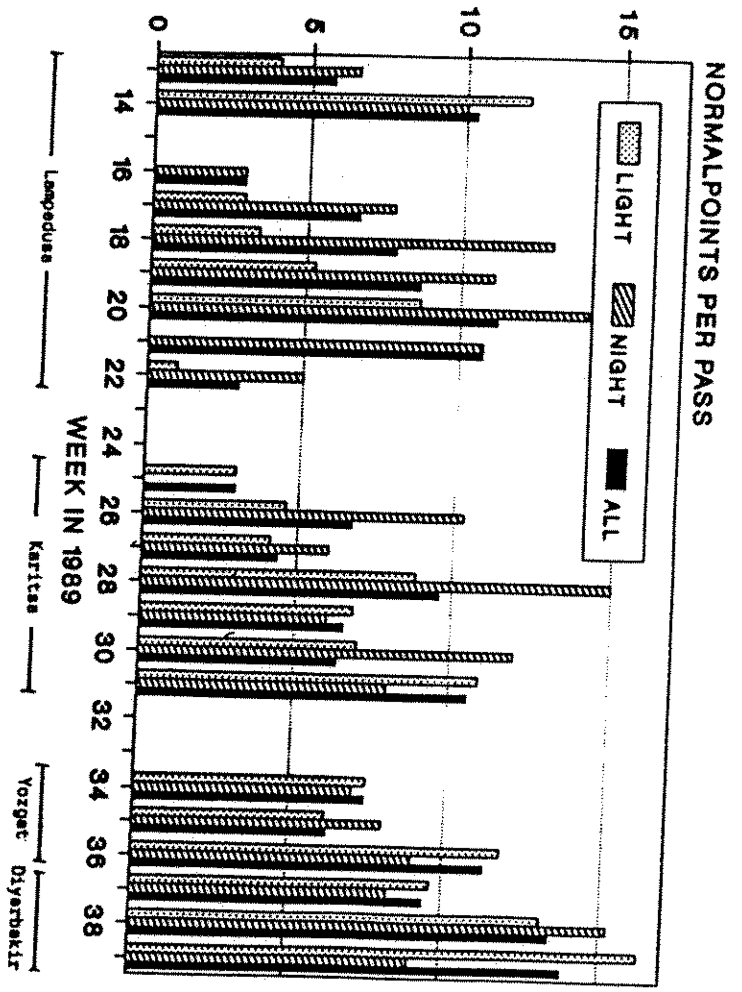

Fig. 4: Normalpoints per Lageos Pass for MTLRS#1 in 1989

Pass Summary MTLRS#1

	Lageos	Starlette	Ajisai
1984	36	7	-
1985	89	28	-
1986	266	10	-
1987	283	1	2
Richmond 1988 Platteville 1988 Owens Valley 1988	55 73 61	- - -	- - -
Lampedusa 1989 Karitsa 1989 Yozgat 1989 Dijarbakir 1989 Rhodes 1989	61 52 58	- - - - -	- - - - -

Table 1: MTLRS#1 Pass Summary

STATUS OF THE SATELLITE LASER RANGING SYSTEM AT METSÄHOVI

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Abstract. The partially upgraded Metsähovi satellite laser ranging system is briefly described. The ruby laser transmitter produces pulses with 100 mJ energy and 4.5 ns duration at a rate of 1/8 Hz. The range noise to the close satellites and the marginally reachable Lageos is 15-35 cm.

1. INTRODUCTION

This report looks briefly at the status of the partially upgraded Metsähovi satellite laser ranging system (7805). The system become operational in 1978 and used 25 ns long Q-switched ruby laser pulses. The range noise to various satellites, including Lageos, was 0.3-1.5 m. As these figures were becoming outdated, a programme to upgrade the system was started in 1985. The most obviuos constraining factor, the pulse duration, was shortened externally by an electro-optical shutter to 4.5 ns, a value typical for second-generation devices.

2. EQUIPMENT

The ranging equipment is basically the same as that reported earlier /1-3/. The major changes so far have been a new laser head, an electro-optical pulse shutter, faster electronics to handle 5 ns pulses, an image intensifier coupled to the guiding telescope and a new station computer. The main specifications are given in Table 1.

Table 1. Specifications of the Metsähovi satellite laser ranging system

Laser	Ruby, 694.3 nm, Q-switched, external pulse shuttering mode normally used
Pulse duration	4.5 ns (shutter mode) 20 ns (Q-switched)
Pulse energy	100 mJ (") 700 mJ(")
Repetition rate	1/8 Hz
Beam divergence	1 mrad (after collimating telescope)
Interference filter	3 nm
Receiving optics	630 mm diameter parabolic mirror
Photomultiplier	RCA C 31034, quantum efficiency 10%
Time interval counter	Nanofast 536B, 0.15 ns resolution
Timing processor	Nanofast M/2 half-maximum unit
Range gate	Computer controlled, 2 µs resolution
Telescope mount	Equatorial, sidereally driven, offsetting with stepper motors (one step equal to 6 arcsec), computer controlled
Tracking	Automatic, point-to-point, speed 1.5 degrees/s maximum
Computer	16 bits, 32 kWords (DCC 116, similar to Data General Nova 1200)
Station timing	Quartz oscillator HP 105B, phase-locked to Loran-C, time comparison with GPS time possible
Calibration	External, flat target at a distance of 333.32 m
Range capability	7700 km to Lageos (shutter mode) 20 000 km to Etalon-1 (Q-switched)
Range noise	15-35 cm to close Earth satellites 20-35 cm to Lageos (50-100 cm, Q-switched)

The original Korad K1 laser head was replaced with a new laboratory-made laser head, which uses two 10 mm diameter, 100 mm long linear flashlamps in series, a close-coupled ceramic pumping reflector and a ruby rod 9.52 mm in diameter and 101.6 mm long. The pumping energy dissipated at the operating level is 1250 J. The laser is situated on top of the telescope.

To shorten the laser pulse, a high speed electro-optical shutter was installed between the laser and the collimating telescope. The constructed shutter (or slicer) /4/ consists of a double crystal Pockels cell, parallel thin film polarizers, a special single chain avalanche transistor circuit (22 transistors, 6.2 kV operating voltage) and the trigger circuit. The shutter is able to cut a 4.5 ns long pulse from the mother Q-switched laser pulse. A slight residual leakage (pedestal), less than 5%, remains outside the main pulse. This leakage creates some additional scatter in the calibration and satellite range measurements. 100 mJ energy is obtained from 500 mJ Q-switched energy. Increasing the Q-switched energy does not increase the shuttered energy because of the intrinsic delay in the shutter electronics and the diminishing pulse duration.

The performance of the M/2 half-maximum time discriminator has deteriorated somewhat. The results of a recent test are shown in Fig. 1.; the original threshold was about 0.2 V /3/. An available Tennelec TC 454 constant fraction discriminator has a much better measured time walk, being not more than 0.1 ns within 0.1-4 V input. However, it is not very suitable for use with the current ruby laser pulses because of leakage energy. In fact the results of test measurements, especially in calibration measurements, have been inferior to those with the half-maximum detector, as predicted theoretically /5/. Some modifications to external circuits might improve performance. Additionally the saturation of the amplifier limits the dynamic range of the receiving electronics to 5 V. Over this value a gradual time walk towards shorter delays will take place /6/.

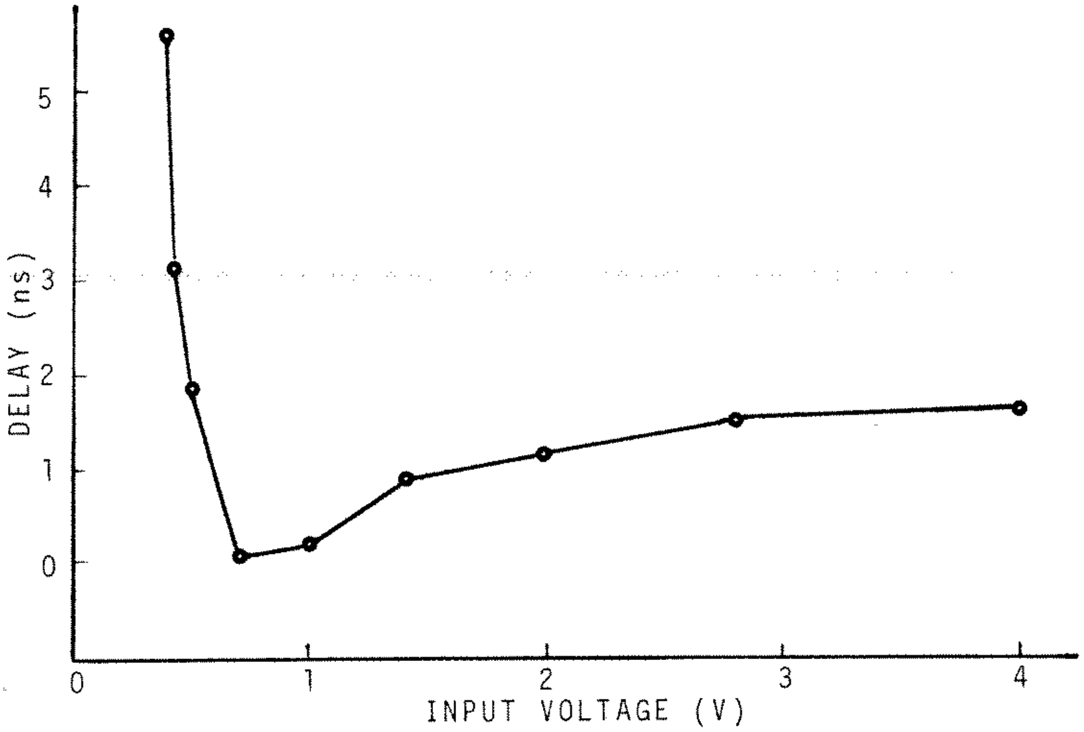

Fig. 1. Time walk of the Nanofast M/2 half-maximum timing discriminator.

A second-generation image intensifier was coupled to the 20 cm Celestron-8 guiding telescope. All sun-lit satellites, also Lageos and Etalon-1 and Etalon-2, can be seen at night, which has been a great help in finding the correct pointing angles.

The station time can now be controlled to 1 μs accuracy by comparing the Loran-C controlled quartz clock with GPS time through cable connection to the neighbouring Radio Research Station of the Helsinki University of Technology.

The laser station has got a powerful new computer, a Data General Eclipse MV/2000DC. This computer produces the satellite predictions using SAO elements and the QIKAIM orbit program. The predictions are transferred through a slow line to the old tracking computer, which can take only 170 points in one run. The range measurements are screened with the station computer using a Kepler orbit or observed minus predicted range differences and polynomial fitting. A sophisticated satellite prediction program, ORBIT, developed at the Royal Greenwich Observatory, Herstmonceaux, UK, has also been installed and used for comparisons. The program employs accurate long-term Lageos predictions distributed by the University of Texas.

3. SATELLITE RANGING RESULTS

The first ranging measurements to Lageos using the short pulse were made in March 1986. Because of the small return energy, the single photoelectron (photon counting) method was used. Owing to the diminished energy, the return rate was dropped to 5-25 pulses per pass, compared with about 50-100 returns per pass when the full Q-switched pulse was used. However, the single shot precision improved to 20-35 cm. The system has not been very productive in ranging to Lageos. Ranging to another distant satellite, Etalon-1, which is at 20 000 km distance, has been found marginally possible using the Q-switched pulse. Because of the small number of data points, data screening of Lageos observations has been somewhat critical. Inclusion of one deviating point may spoil the whole set. A test /7/ showed that use of the least sum criterion (L1-norm) in orbit fitting permitted more reliable detection of a wild point than use of the least squares method (L2-norm).

Ajisai is a suitable target for ranging from Metsähovi because of its orbit height, 1500 km, its inclination, 1500 km, and its high reflecting power. About 80% of all observations since 1986 (about 3500) has been obtained from Ajisai. The success rate within a pass has been over 75% down to 15 degrees elevation. Oscilloscope monitoring has shown that the return energy may in fact be too high. Further, the distribution of the residuals is often unbalanced towards shorter ranges, which obviously means that pulses from the photomultiplier and the amplifier are saturated. A pulse height monitoring system will be constructed later. The measured precision has generally been 15-35 cm for Ajisai and Starlette passes. An example of orbit preprocessing of a Starlette pass using a polynomial fit to the observed minus predicted range differencesis shown in Fig.2.

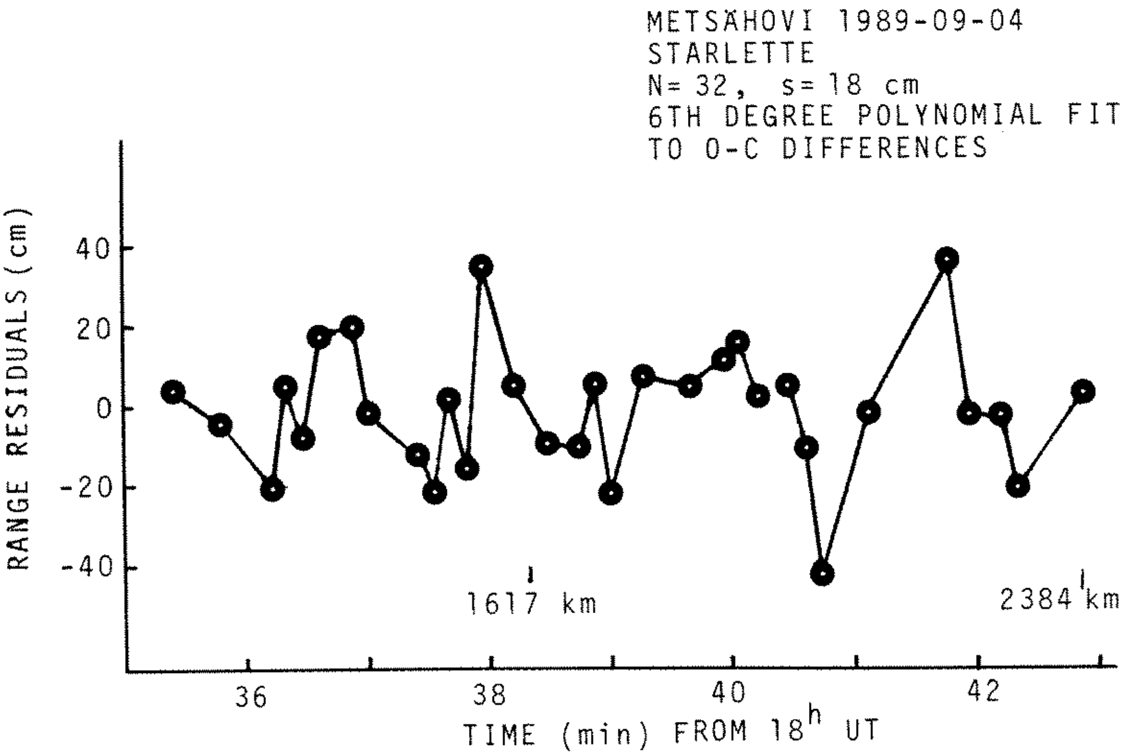

Fig. 2. Range residuals of a Starlette pass obtained by fitting a polynomial to observed minus predicted (O-C) range differences.

4. DEVELOPMENT WORK

The start-stop tracking method with the slow computer program still in use reduces the laser repetition rate to close satellites to about eight pulses per minute. The number of predicted points per run is limited to 170. Development of continuous tracking system using servo motors, high-resolution position encoding with resolvers and resolver-to-digital converters has recently started. The tracking operation will be controlled by a slave processor (a computer card using a Harris RTX 2000 processor) installed in an AT-type PC. This computer will also manage the ranging operations. The existing HP 5370B time interval counter and Tennelec TC 454 timing discriminator will be used. Connection to the station computer will be via an Ethernet cable. To correct pointing errors in the mount, a computer program similar to /8/ is under testing.

The improved tracking system allows a laser with a higher repetition rate to be used. The natural choice is a Nd:YAG laser, and so after discussions /9/ a Nd:YAG laser with a positive branch unstable resonator was selected. The optical scheme of the constructed laboratory model is almost similar to the laser used at the Katsiveli laser station, the Crimea /10/. The telescopic resonator uses a concave mirror with a radius of 500 mm and a convex mirror with a radius of -140 mm and a diameter of 2.6 mm. A saturable absorber using colour centers in a LiF crystal (LiF:F_2^-) was used as the Q-switch /11/. The Nd:YAG rod is 9.52 mm in diameter and 115 mm in length. When the initial transmission of the Q-switch was 11%, a pulse with about 300 mJ energy and 2.8 ns duration (FWHM) was obtained /12/. The repetition rate was 1 Hz. The beam divergence was less than 1 mrad. Conversion to the second harmonic wavelength (532 nm) is satisfactory, the measured value being at least 35% with a KD*P crystal. The measured pulse duration was 2.2 ns. A Galilean telescope with a designed magnification of 15 is available for beam collimation. Thus the transmitted beam divergence could perhaps be under 0.1 mrad at a minimum. This promises at least 100 times higher radiance than that now available, thus greatly improving the ranging possibilities to Lageos and the Etalons. The new Nd:YAG laser will be installed on the existing laser mounting.

A Nd:YAG laser with 2 ns pulses is only an interim solution, taking into account the general status of laser ranging to satellites. Development of a mode-locked laser has been going on as a background project for several years. In 1987 a mode-locked Nd:YAG laser oscillator with a self-filtering unstable resonator concept was tested /13/. Later a cavity dumper was installed and a single pulse with 10-15 mJ energy was obtained /14/. In the near future, a double pass amplifier will be added. This should produce about 200 mJ output energy, which could be converted to 100 mJ in green. The laser components fit on a table measuring 300 mm by 1700 mm, which is clearly too large for mounting on top of the telescope. Plans to acquire a new altitude-azimuth mount with a Coudé path were recently abandoned. In principle a Coudé path could be installed into the existing mount.

The geodetic ties of the laser station to the other space geodetic systems will be improved. A DORIS orbit determination beacon is situated at a 2.5 km distance of the laser. A transportable VLBI station MV-3 from the National Geodetic Survey, US, visited the DORIS site in 1989. The coordinates of the same site have also been determined in a European GPS campaign.

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