

## *Overview of the MLRO Project (History and Status)*

G. Bianco, Agenzia Spaziale Italiana

M. Selden, T. Oldham, M. Bieneman, D. McClure, R. Sala, C. Steggerda, R. Stringfellow, M. Heinick, C. Clarke, J. Hundertmark, Honeywell Technology Solutions Inc.

The MLRO program, dreamed of and discussed in the 1980s, finally began in the last few days of 1993. The objective was to develop a no-compromise multi photoelectron system that could accommodate a two-color upgrade and be designed to allow for enhanced automation. The goal of the ASI and the engineers was a 2mm RMS system with a high satellite echo return rate. The actual system performs between 0.8mm and 1.2 mm RMS and has achieved return rates from LAGEOS approaching 100%. The MLRO has been a collaborative effort and could not have succeeded without the contribution of many people in both Italy and the US.

The following is a narrative description of the history of the program. It highlights the basic system design features but not in great detail since this has already been discussed in previous congresses.

The MLRO system development has undergone essentially six basic phases. These are:

1. Design Phase
2. Hardware Technology and Software Infrastructure Development Phase
3. System Integration / Software Application Development Phase (at GGAO)
4. GGAO Single-Color Testing Phase
5. Two-Color Upgrade Development
6. Matera Deployment and Testing Phase (which has had several sub-phases).

A diagram showing the approximate phase timeframes is shown in figure 1.

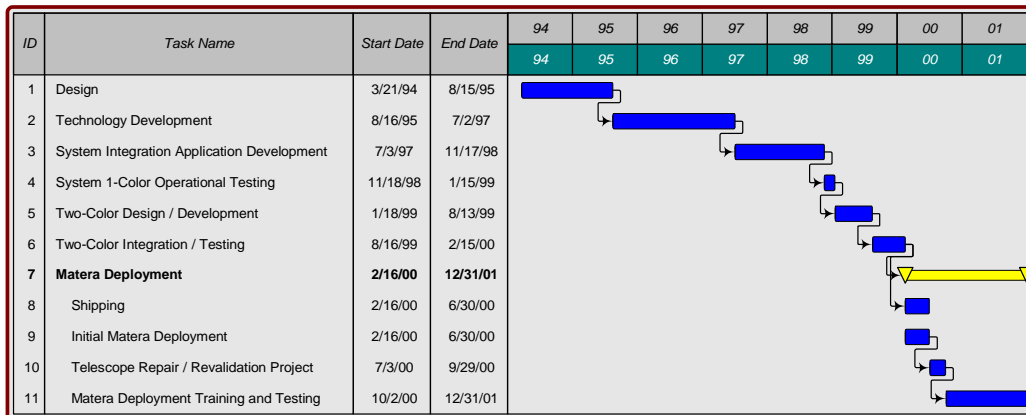


Figure 1: Timeline for the MLRO Program

**Design Phase (1/1994 – 6/1995)**

The initial design phase lasted 18-months and culminated in almost 20 volumes of fairly detailed design information. These were examined, criticised, and approved using three critical design reviews (CDR). The CDR documentation would also become the foundation for the system documentation. The design phase was done partially in parallel with the development of the telescope and of the MLRO laser subsystem.

**Technology Development Phase (6/1995 – 4/1997)**

Most of these development activities have been more-fully described in prior workshop proceedings, but are summarized here.

The MLRO design relied upon development of several new electronic instruments, and also electronic subassemblies that would be integrated within commercial instruments to improve their performance. The main three instruments developed were the event timer, range gate generator / simulator, and the peak amplitude measurement instrument. Each of these primary instruments went through a breadboard / brass-board phase and each instrument has since been replicated for other SLR systems in addition to the MLRO.

The MLRO T/R Optics subsystem also required a significant investment of development time as it is highly automated and made of very high-quality optical components. The entire mechanical structure was modeled in the ProEngineer® system. Additionally custom improvements were made to the telescope subsystem to improve automation and diagnostics.

A newer MCP-PMT was developed to support the MLRO ranging requirements. This MCP-PMT was based on an existing design, but the anode structure shape was modified to provide the pulse characteristics desired for improved ranging.

The MLRO software system is divided into three basic parts: the real-time control and data acquisition subsystem, the non-real-time data processing and analysis subsystem, and the X-Windows Graphical User Interface subsystem.

An entirely new object-oriented subsystem was developed for the real-time software. This was composed of class libraries and real-time infrastructure designs to allow for improved long-term maintenance.

The Non-real-time software system was based on the NASA data processing software, but reworked and tightly bound with an Oracle database table system for improved system flexibility and to allow for processing of multiple systems, assuming that the MLRO would be a part of a network. The MLRO incorporates an automated scheduling system, also tied into the Oracle structures and a Geodyne analysis capability. An infrastructure application was added to allow for monitoring of the NRT subsystem status.

All of the MLRO applications are controlled through the X-Windows interfaces and the system is constructed in a way to allow for a fully-automated upgrade, if so desired. The X-Windows interface is primarily built on a set of custom object tools developed for the MLRO program. These make X-Windows application development easier, more stable and the process and behavior repeatable.

### **System Integration and Software Application Development (4/1997 – 9/1998)**

The system integration began soon after the GGAO facility became ready in the spring of 1997. The skeleton of the system was quickly integrated and the first data results acquired in time for the 1997 WEGENER meeting in Maratea Italy, although there still remained a lot of integration and development to be done. At first the system used the breadboard versions of the developed instruments and rudimentary versions of the software with command-line entry control of the system. The system integration continued throughout 1997 and well into 1998. In the fall of 1998, the system was in its final data measurement configuration and the system underwent a successful formal collocation with MOBLAS-7. Preliminary results were presented half way through the collocation at the 1998 Workshop on Laser Ranging in Deggendorf, Germany. At that time a proposal for the two-color upgrade had been submitted to the ASI for consideration. In December 1998 this was approved.

During 1998 the MLRO facility also took its first form. The building was constructed with the help of the Basilicata regional government and the dome was procured from Jackson Mississippi by the ASI. Construction began in late 1998 and continued through most of 1999.

### **Two-Color Upgrade Phase (Jan to Nov, 1999)**

The two-color upgrade phase was like a not-so-mini system development. A design phase culminated in a Critical Design Review and went forward into a technology development phase through much of 1999. The two-color upgrade added an entirely separate optical and receiver subsystem for two-color versus one color (i.e. two green paths and one ultraviolet path). The two color subsystem included both dual MCP ranging and a separate streak camera ranging path, all highly automated and including significant diagnostics. The streak camera was made in Japan and a new special two-color T/R switch prism assembly was designed and made in the US.

A significant upgrade of the software system was also done, which dramatically increased the system capability but changed the software enough to introduce new instabilities that would need to be worked-out later. The two-color system was integrated at GGAO, but the configuration of the STALAS building did not allow for full testing of the upgrade and so after preliminary two-color testing was completed, the system was shipped to Italy, where the building would support the final testing of this upgrade. This need to move the system to its final facility for full testing extended the time needed in Italy, but resulted in an overall better program success.

### **Matera Deployment**

The Matera deployment has been divided into four fundamental sub-phases. These are: 1) Shipping, 2) Initial (single-color) Deployment and testing, 3) Telescope Repair Project, 4) Deployment finalization: Two-Color set-up and Testing, Training, and Validation Testing.

#### **Shipping**

The first phase of the deployment did not go well. The shipping was routed differently than promised by the shipping agent, which resulted in excessive handling of the telescope which may have been the cause of its damage. After a delay in Italian customs, the team began to install the system at Matera. Almost immediately it was noticed that there was a problem with the telescope: three of the primary support radial counterbalances (all on the same side) had become

detached from the primary mirror, that is the epoxy bonds had been broken. The team (HTSI, ASI, and telescope manufacturer) considered the options available at the time and elected to continue with the installation until the damage would no longer support the operational testing – first ensuring that no additional damage could occur from this.

#### Initial Installation and Testing

The initial installation, with the exception of the telescope, was relatively smooth and before long the system was able to range to ground targets and to satellites. Software instability that had been introduced during the two-color upgrade were gradually isolated and fixed. Before very long the system was able to range. Pointing instability caused by the telescope damage did not permit the system to perform ranging requiring precise pointing (Lunar Ranging). An initial data set was sent to the CSR for data confirmation and the results indicated that the system data measurement was working as before. By the end of June 2000, it was apparent from the pointing problem that further testing would require that the telescope be repaired.

#### Telescope Repair Project

At the time that the telescope damage was discovered a plan was developed to repair the damage. First, a set of criteria were established to determine which path the repair should take: If the mirror itself were damaged then the primary mirror cell would be removed and returned to Pittsburgh for replacement, if not it would be repaired in place. Special tools were manufactured to allow the repair and the strain gauges that are an integral part of the telescope would allow the system to be returned to factory specification.

In August / September 2000, a team arrived in Matera to repair the telescope damage. First the telescope was inspected to ensure that there was no damage to the glass surfaces, or any undiscovered cracks within the structure. After the repair a series of star calibrations, lunar tracking, and other tests confirmed that the telescope performance had been returned to its original specification.

#### Training, Two-Color Testing, Validation Testing

After the telescope repair the team returned to its work of installation, training, and testing. The software gradually returned to collocation timeframe stability and the system actually performs better now than during collocation both from an operational perspective and a data perspective. Due to the strain on the HTSI team from the first phases of deployment, the completion of the installation process has

been focused into intense four-to-six week trips with a break between these to allow team members to be with their families. Two-color streak images were received in the spring of 2001 and since that time the team has been completing the operational documentation, performing the validation tests as weather permits and finalizing the training. The ASI team has been operating the system on a non-interference basis and are achieving very results.

### **Summary**

The MLRO program has actually been a collection of many projects, first a set of technology development projects, then a system integration project, followed by another development (two-color) project, with another system integration and testing project and a delivery and training program. Couple with these have been the coordinated efforts between ASI and HTSI personnel to orchestrate the overall flow of funding and the diverse technical efforts in both the US and Italy. It has been a successful collaborative effort between people from ASI, Telespazio, and Honeywell on a rather long and difficult journey, but all have benefited from and enjoyed the process.