Lunar Laser Ranging

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A Computer-Controlled x-y Offset Guiding Stage for the MLRS

by

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ABSTRACT

The MLRS has experienced excellent success in its lunar and artificial satellite laser ranging operations during its many years of operation, in spite of its relatively small "receive" aperture. We continue to strive, however, for a greater volume of data, together with better accuracy and precision. We have just now completed the design, construction, and implementation of a computer controlled x-y offset guiding stage for the MLRS, analogous to the manual one that had been a part of the original 2.7-m lunar laser ranging system on Mt. Locke at McDonald Observatory. In the past we had been hampered by the lack of a satisfactory hardware design which could fit within the very cramped quarters of the MLRS telescope's tailpiece. Recently, with funding support from the U. S. Naval Observatory and the design and construction expertise of DFM Engineering, Inc., a satisfactory instrument has been specified, designed, built, and installed. This instrument will greatly expand MLRS observational opportunities by allowing the observing crews to actively guide on visible off-axis lunar surface features or background stars while the on-axis lunar surface retroreflector targets are in the dark. This paper describes this instrument and its present implementation at the MLRS.

Introduction

The McDonald Observatory Laser Ranging Station (MLRS) is a dual purpose installation (Shelus 1985) which was designed to obtain laser returns from both artificial satellite and lunar surface retroreflector targets. It was originally constructed to replace the NASA Apollo Lunar Ranging Experiment (LURE) system which had been installed on the McDonald Observatory 2.7-m telescope in the late 1960's (Silverberg 1973) and was used up until the mid 1980's. The MLRS is designed around a 0.76-m x-y mounted Cassegrain/Coudé reflecting telescope and a very short pulsed, frequency doubled, 532-nm wavelength, neodymium-YAG laser, with associated computer, electronic, meteorologic, and timing interfaces. The station was initially erected in the saddle between Mt. Locke and Mt. Fowlkes at McDonald Observatory, near Fort Davis, in far west Texas and first became operational in the summer of 1983. It was soon recognized that wind tunnelling effects in and around this saddle site had very serious effects on what astronomers call atmospheric seeing. A new telescope pad was constructed and the MLRS was moved to its present site atop Mt. Fowlkes in early 1988 (Fig. 1).

Since the mid-1980's, the MLRS observing emphasis has been shifting dramatically from the Moon to artificial satellite targets (Fig. 2) but the Moon has always continued to be an important part of its routine operations (Shelus 1987). Also, attesting to the splendid versatility of the MLRS, in a cooperative effort with the CERGA lunar laser ranging facility in France, we are using the Meteosat P-2 geostationary weather satellite in a laser ranging experiment to study the transfer of time at the sub-nanosecond level over intercontinental distances. Most of the MLRS observing systems are transparent to the observer and it is often the case that through the course of a single 8-hour observing shift an observing crew will routinely range to such diverse targets as Topex/Poseidon, ERS-1, Starlette, Ajisai, Lageos, Etalon-1, Etalon-2, MP-2, and the Moon. The

Figure 1

MLRS Laser Ranging Activity

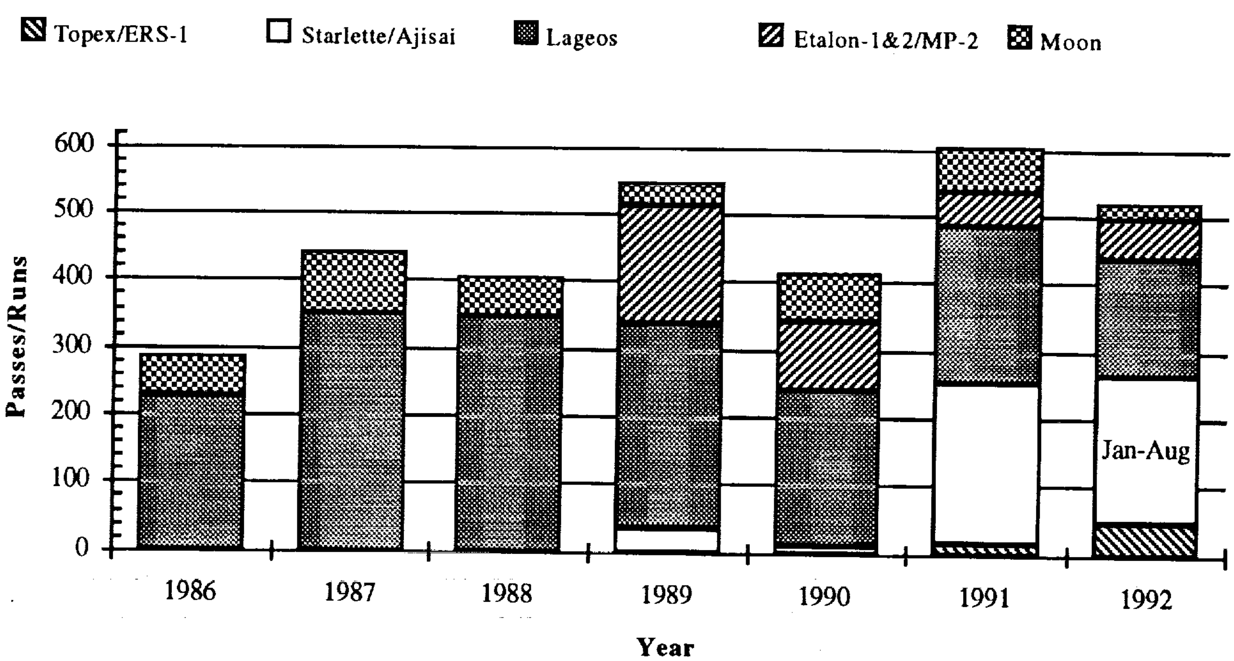

Figure 2

principal differences among all of these observations are the apparent angular speed of the target's motion across the sky and the return signal strength. Of course, low targets move quickly and high targets move slowly. Return signal strength is dictated primarily by the inverse-fourth-power nature of laser ranging. It is extremely important to realize that the return signal strength ratio, neglecting all parameters except the distance, for a near-Earth artificial satellite and the Moon is something like 3×10^{12}. That is to say, it is more than one trillion times more difficult to laser range to the Moon than it is to laser range to, say, Ajisai or Topex/Poseidon.

Increased Data Volume Requirements

In spite of these tremendous handicaps of low signal strength and small "receive" aperture, the MLRS has experienced remarkable success in its lunar laser ranging (LLR) measurements, and the resultant computation of lunar orbit and Earth orientation information therefrom (Whipple et al 1991). However, we are always striving for an even greater number of observations which will, in turn, naturally lead to better accuracy and finer precision. It is evident that we can increase MLRS LLR data volume in at least three ways:

1. spend more time on target;
2. transmit more energy;
3. increase "receive" aperture.

With support from a contract from the U. S. Naval Observatory we have found ourselves in a position to make a viable attempt at implementing the first technique, i.e., spending more time on target, via the design, construction, and implementation of an x-y offset guiding stage for the MLRS.

An Offset Guiding Stage

The concept of an offset guiding stage is one that is commonly used in observational Astronomy and it has surfaced many times during our deliberations about the logical up-grade of the MLRS during the past several years. It is merely the idea of installing an offset guiding stage on the MLRS, analogous to the one that had been in place and in use on the original 2.7-m LLR system at McDonald Observatory. An MLRS x-y offset guiding stage would allow us to routinely guide on a visible off-axis lunar surface feature (or, perhaps, even a star) while the on-axis retroreflector remains in the dark (i.e, it is on the "other" side of the lunar terminator). Not only would there be a much greater number of observing opportunities during the course of a lunation, perhaps, more importantly, ranging data to lunar surface retroreflectors in the dark would be virtually noise free. In our past plannings we had been hampered by the lack of a suitable hardware design which could fit within the very cramped quarters of the MLRS telescope's tail-piece, and the lack of money to actually construct and implement a design if a satisfactory one could be found. Recently, within our interactions with the U. S. Naval Observatory and DFM Engineering, Inc., support has been provided and a new concept has been formulated for just such an MLRS x-y offset guiding stage.

After a very successful series of bid and negotiating sessions, a contract was set up between the University of Texas at Austin and DFM Engineering, Inc. of Longmont, Colorado for design and construction of a x-y stage for the MLRS. Design drawings for the mechanical systems of the stage were received by us in February, 1992. These drawings were reviewed by McDonald Observatory Laser Operations personnel, with support from our McDonald Observatory mechanical engineering colleagues. In general, the overall design was found to be very well thought out and quite workable. A very small number of minor problems and several enhancements were identified during the review. These were conveyed to DFM, Inc. and were incorporated into the final design. Preliminary design drawings for the electrical systems of the stage were received from DFM, Inc. at the end of March. An internal electrical systems design review which was held at the MLRS during the first week in April. The results of that review were conveyed to DFM, Inc. for implementation. Machining and assembly of the mechanical structures were completed in May at DFM, Inc.. Delivery of the hardware to Austin took place in June and initial testing and shake-down, before its shipment to the MLRS for final installation and implementation, was performed. The instrument was transported to the MLRS at McDonald Observatory in July. After a number of adjustments and relatively minor modifications, installation on the telescope took place at the end of August.

The instrument is a two-axis translation stage (Fig. 3) which mounts directly to the MLRS telescope's back-plate. It provides for the simultaneous mounting of two electronic TV cameras with turning optics to direct the telescope's Cassegrain beam to either of the cameras. The cameras are selectable from within the MLRS operation's trailer via computer control or an auxiliary switch. Each axis is driven by a DC servo motor/encoder combination at speeds in a range 0-8 mm/sec and is directly encoded using digital linear encoders. Positioning of each stage is accurate and repeatable to 5 microns with a travel of more than 125 mm in each axis, centered on the optical axis of the MLRS telescope. The electronics control package includes a dedicated PC-type computer based on an Intel 80386SX processor, a motor controller board inside the PC, together with all of the necessary electronic/computer interfaces and controls. Software provides a closed servo loop between the encoders and the motors and communicates with the external MLRS control computer via a serial port. In addition to the source code, the software deliverable includes the development environment as well, so that future software changes, if necessary, can be accommodated without a need to return to the vendor.

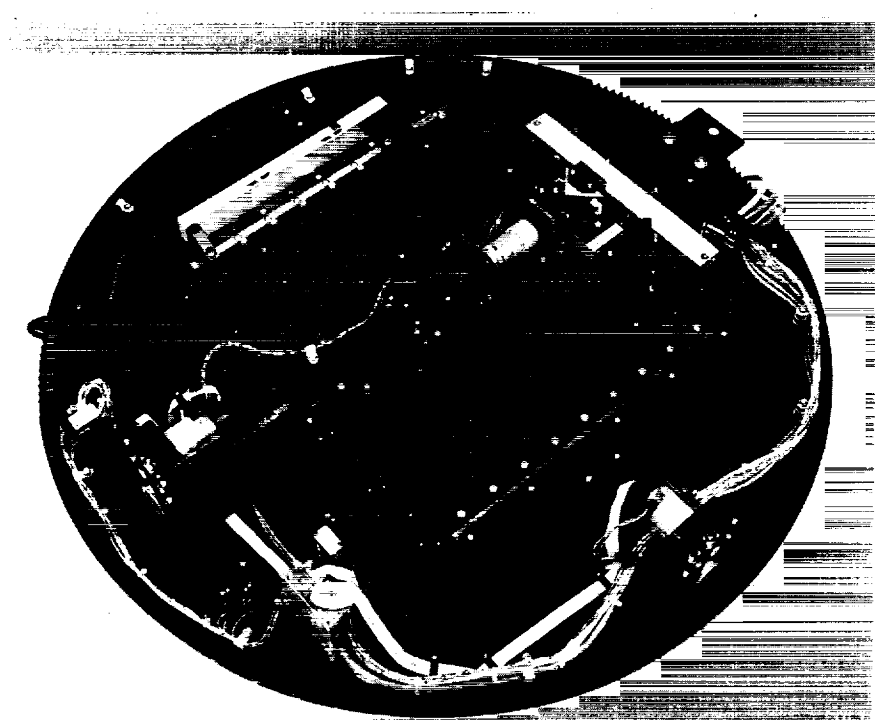

Figure 3

Conclusion

Once in operation, the completed x-y offset guider will have a very positive impact on the quality and quantity of lunar data acquisitions from the MLRS. Sufficient software currently exists to begin immediately the manual operation of the stage at the MLRS. In the coming months and years it is our plan that additional software and hardware will be secured for eventual sem-automatic and completely automatic operation of the stage.

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Lunar Laser Ranging Data Processing in a Unix / X Windows Environment

by

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In cooperation with the NASA Crustal Dynamics Project initiative placing workstation computers at each of its laser ranging stations to handle data filtering and normalpointing, MLRS personnel have developed a new generation of software to provide the same services for the lunar laser ranging data type. The Unix operating system and X-windows/Motif provides an environment for both batch and interactive filtering and normalpointing as well as prediction calculations. The goal is to provide a transportable and maintainable data reduction environment. This software and some sample displays are presented.

Introduction

The processes of reformatting, calibrating, filtering and normalpointing lunar ranging data has taken several shapes during the years of University of Texas McDonald Observatory participation in lunar laser ranging. During the days of the 2.7m ranging system, from 1969 to 1985, data was transferred on magnetic tape from the Observatory to Austin, where batch programs on the CDC Cyber computer systems were invoked on an entire month's data. After a good deal of interaction with line printer plots, listings, and punch cards, the data was finally processed and ready for mailing -- on punch cards or magnetic tape.

The part-time lunar ranging facilities on the 2.7m telescope were soon replaced by the dedicated lunar and artificial satellite ranging system MLRS (McDonald Laser Ranging System). From the first lunar observations in 1983 until mid-1990, data was processed interactively on Data General NOVA 4/X computers. There were restrictions as to the amount of computer memory and the speed of processing. Fortunately, the station contained 2 identical NOVAs sharing a hard disk, meaning that the lunar (or satellite) data could be processed on one computer while data was taken on the other. The reduction of the data was totally interactive and in no way automated. In addition, lunar predictions were produced on-site, another first in the effort to down-size historically mainframe-based applications. Extraction of earth rotation parameters was at one time attempted on site in near-realtime.

In 1988, the Crustal Dynamics Project SLR Computer Panel mandated the installation of Hewlett-Packard 9000/360 Unix workstations at each NASA-operated laser ranging station to relieve the aging controller computers of much of their data and communications handling responsibility and to provide on-site data filtering and normalpointing for a growing list of artificial satellite targets. This was seen by MLRS staff as an opportunity to provide a better lunar data processing environment as well.

A New Environment

One of the important goals of the computer panel was to provide a standard environment for data handling that would allow portable code to be written for a nonproprietary system. To this end Unix as well as X windows were chosen for the software environment. Both of these products can be found on workstations and mainframes from many different vendors. Although there are many "flavors" of Unix, there is enough of a common thread, especially with POSIX, SVID , and other standards to allow fairly portable code to be written. In addition there are many useful tools generally available with Unix, from text editors to file manipulation utilities and operating system shells. The availability of shell scripts to create batch jobs has also eased the task of system development.

X windows (along with OSF/Motif) provide a network-oriented interactive graphical user interface that is quite portable and has been implemented on several operating systems. X-windows is policy free, meaning that there is no implied style imposed on code being written for this interface. The Open Systems Foundation (OSF) Motif graphical user interface was adopted to give a common style to this and other programs written for the X-windows environment.

Lunar Tasks

The process of obtaining lunar data requires several pre- and post-acquisition steps, which are at the heart of this discussion:

1) range and point angle predictions,
2) data calibration and reformatting,
3) data filtering,
4) data normalpointing.

Much of the software for tasks 1), 2), and 4) was implemented in a FORTRAN 66 variant on the NOVA as well as in FORTRAN 77, after a joint port with the Australian National Mapping organization. While the data filtering code also existed on the NOVA, it was not in a form that was readily usable on the Hewlett-Packard workstation. Common to all these steps is the need for a flexible user interface which handles entry of parameters, plotting of data, and display of processing results.

Predictions

The first task of any ranging system is to provide point angle and range predictions. Lunar ranging is no exception. Most of the code required to produce lunar predictions is also required in the production of the filtered lunar data and normalpoints, making the maintenance of code relatively straightforward. This software can use either the MIT/UT PEP ephemeris or the JPL DE-303 ephemeris and its successors. Lunar and planetary predictions as well as lunar librations are included in both of these packages. Since no fit of lunar or solar system parameters is made in the on-site processing, no partial derivatives are needed. Earth rotation data is updated weekly to provide the most accurate predictions possible.

Parameters to run this software are set in the Lunar Data Editor program. The prediction software itself is run automatically on a daily basis from a Unix "cron" script. The program reads the date and time, recognizes whether predictions already exist and produces predictions as appropriate for the next day. The prediction program can also be run interactively from the command line of a terminal window as well as from XControl, the main user interface program, but that is never done in production. Lunar predictions are moved to the ranging system control computer over an RS-232 serial link in the same way as the artificial satellite predictions.

Batch Analysis

The reduction of the lunar ranging data after the moon is observed starts with the same suite of programs as do the artificial satellite reductions. Once the data has been transferred from the controller computer and preliminary reformatting and collating of data has been done a shell script is initated to calculate and apply geometric and electronic calibrations, to filter the data using Poisson filtering techniques, and to normalpoint the data. (See figure 1.) The results of processing are then displayed using the Lunar Data Editor program, giving the crew can get an objective view of the quality of the ranging data.

Interactive Analysis

During the time when lunar data was being entirely reduced on-site with NOVA software, there was manpower available to scrutinize data. We no longer have that luxury. The lunar data is electronically transferred to Austin (using batch uucp over a dedicated line) for final filtering and lunar-network-oriented quality control.

To better interact with the data, the Lunar Data Editor (LDE) was developed. It uses X windows and OSF Motif to provide a modern environment in which to examine and process the lunar data. Pull down menus, pop-up windows as well as both histogram and scatter plots of the data are available for operator use. Figures 2-7 show portions of the user interface through which the user has control over the scale of the plots, the parameters used in the Poisson filtering and normalpointing and the sequence of reduction operations. Also included in the interface are provisions to manage up to 10 sets of station coordinates, lunar ephemeris parameters, and control parameters as well as 5 sets of lunar reflector coordinates. This capability permits easy changes among ephemerides and stations as the situation dictates.

LDE is comprised of several programs with distinct responsibilities. LDE itself is a C language program that handles the user interface, including parameter input and data display. The entire X-windows/Motif interface resides here. It in turn uses the Unix "system" call to invoke the lunar calibration program (C), the Poisson filtering program (FORTRAN), and the normalpoint program (which can also be called to recompute data residuals) (FORTRAN). This has the advantage of breaking up what would otherwise be a huge program into more manageable units. It also provides a way to integrate existing FORTRAN and new C programs in a portable manner. Error codes and messages returned by the called programs are used by LDE to provide pop-up error dialog boxes as needed. Results from each program's execution are shown in the scrolling text box at the bottom of the screen, as can be seen in figure 7. Each of the called programs can also be run individually from the command line, as they are in the batch file.

Since LDE is an X windows program, it can be run across a network. The program itself is run on the HP workstation, but the user can either be at the system console or, as is often the case, running the eXodus X windows server on a Macintosh connected to the workstation over the departmental ethernet network. One can even run this program across internet from thousands of miles away (with some degradation in speed) and still have the advantages of the graphics, pull-down menus and so forth.

It should be noted that none of the above discussion touches on performing quality control by comparing multi-run or multi-station data or the computation of earth orientation parameters from the data. Due to the origins and complexity of that code, it will remain on an IBM mainframe for some time to come.

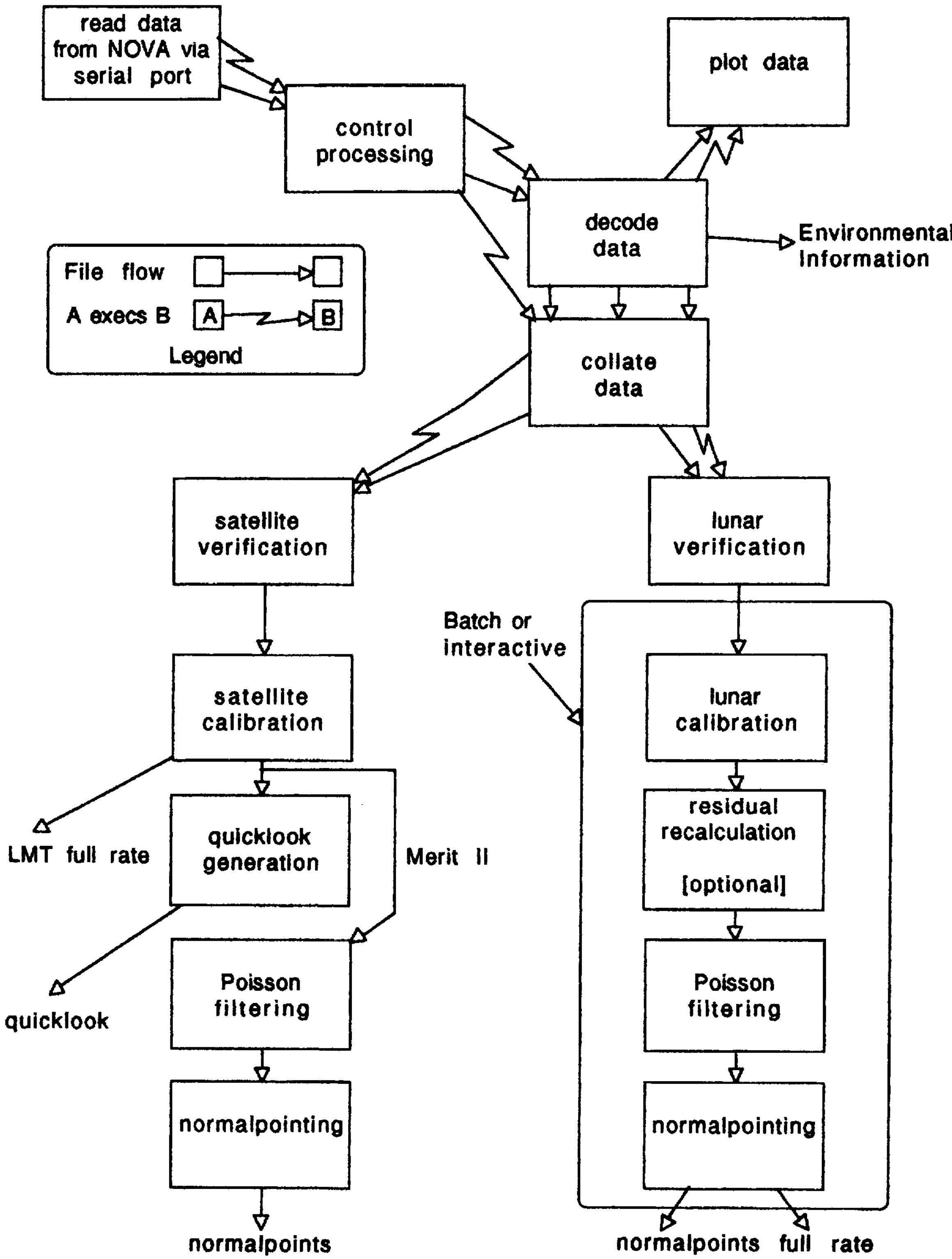

Figure 1 - MLRS Data Flow - HP Workstation

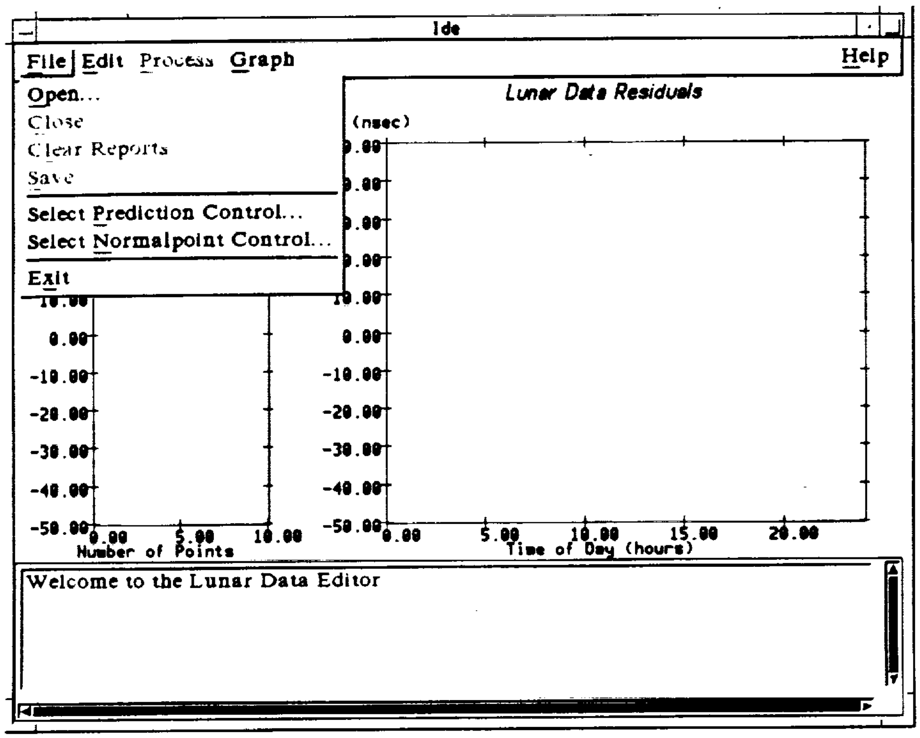

Figure 2 - Lunar Data Editor file menu

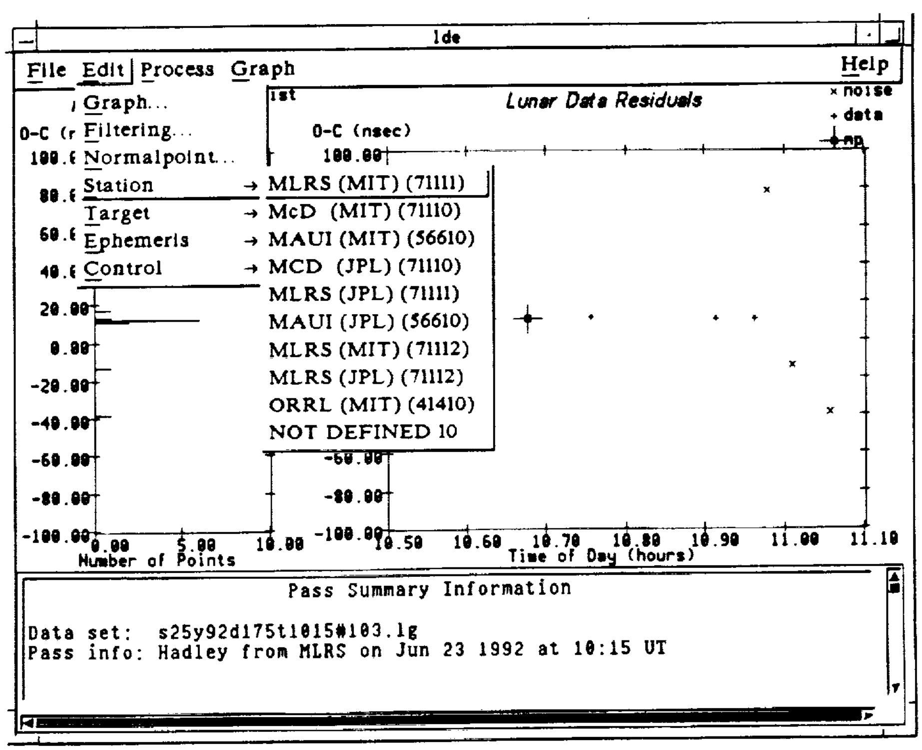

Figure 3 - Lunar Data Editor edit menu

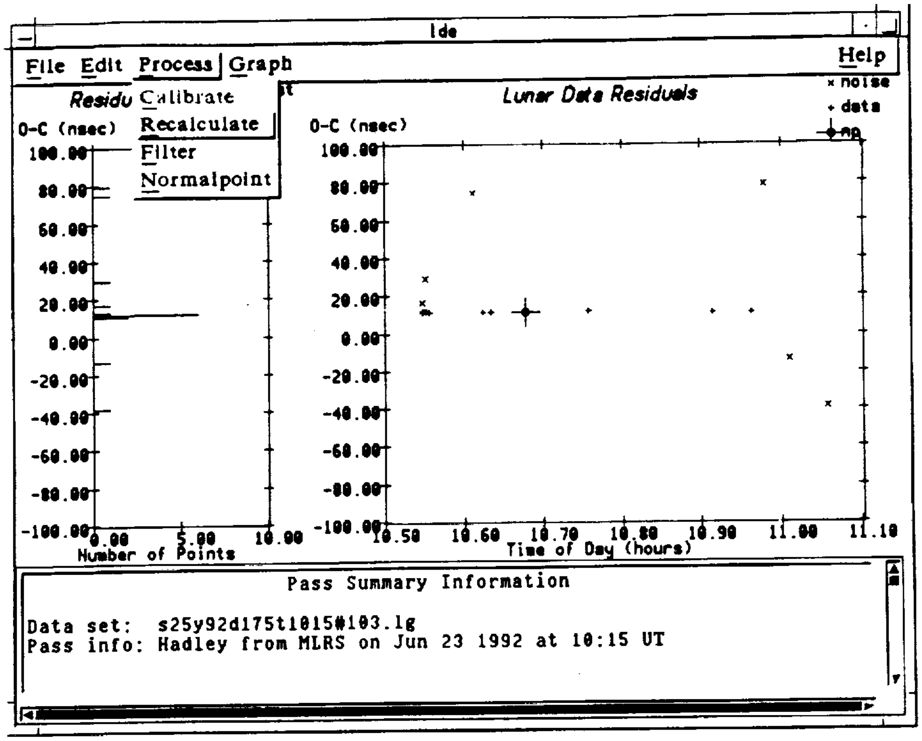

Figure 4 - Lunar Data Editor process menu

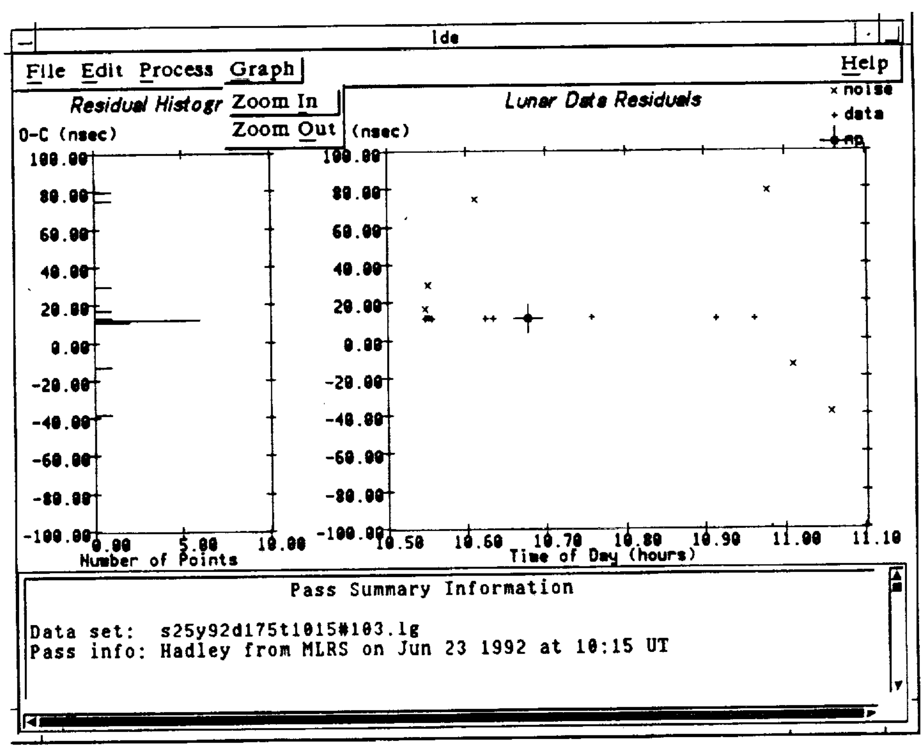

Figure 5 - Lunar Data Editor graph menu

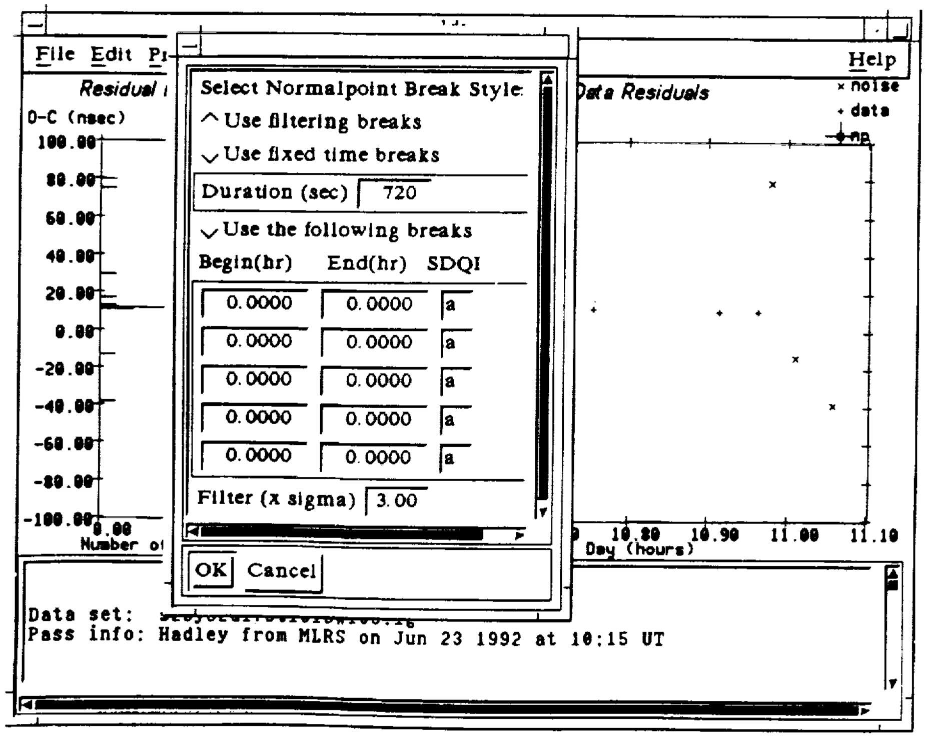

Figure 6 - Lunar Data Editor dialog box for normalpoint parameter edit

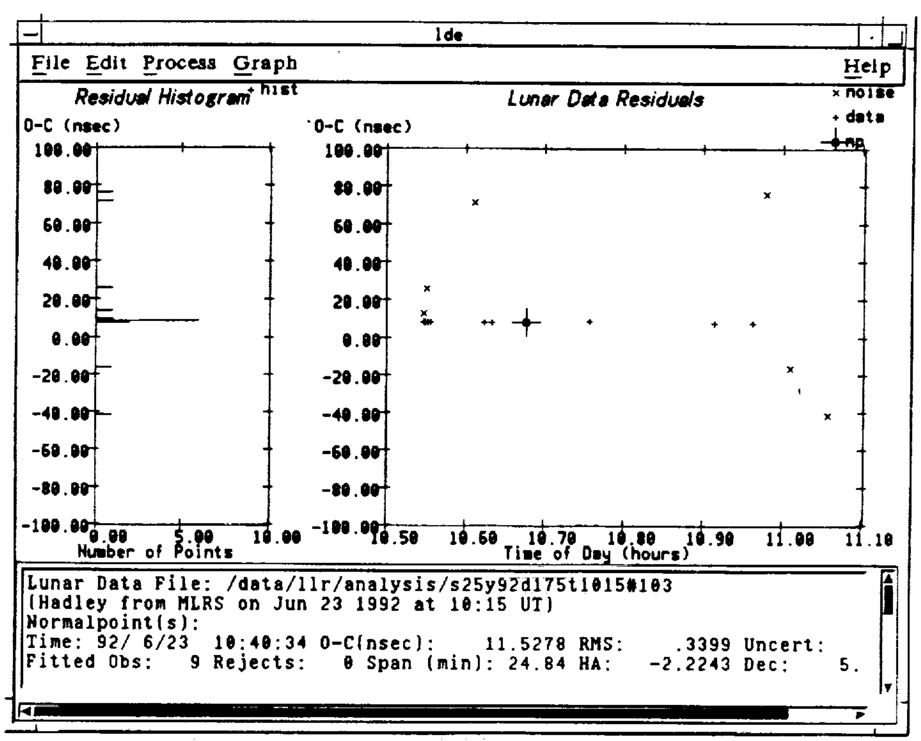

Figure 7 - Lunar Data Editor showing results of normalpointing

Conclusions

The lunar prediction and data analysis at McDonald Observatory have made several big transitions over the years, the latest being a successful move to a X windows/Motif graphical user interface and the Unix operating system. This move has proven to be worthwhile, producing more portable and flexible code and a network-based interactive data reduction environment.

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LLR- Activities in Wettzell

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Abstract

Following the idea of a fundamental station, the Wettzell Laser Ranging Station was designed to range to all types of satellites and to the moon [1]. After obtaining the first lunar echos in October 1990, the system's operation was improved. A short report of lunar ranging activities is given.

1 Ranging to the moon in Wettzell

The WLRS was put to routine operation in the beginning of 1991. It was taking over the task of the old Sylvania Ranging System (SRS). In the beginning it was ranging to LAGEOS and the two ETALON satellites. However, the design was such that it should also allow ranging to the moon. This was shown very early, when in February of 1990 the first ranges from Meteosat P2 were obtained. Unfortunately it took more than half a year to stabilize the operation of this part of the ranging realtime software. For the measurements to the moon a cooled PMT (RCA C 31034a) and a spectral Fabry- Perrot bandpass of 1.5 Å width around a centerwavelength of 532 *nm* is used. The laser energy was measured to be 180 *mJ* with a pulse duration of 200 *ps*. As the telescope aperture is only 75 *cm* and the location of the WLRS is on an altitude of only 600 *m*, there is a poor signal to noise ratio for these measurements. For these reasons the WLRS is usually employing a semipulsetrain for lunar ranging. The semitrain contains 5 individual pulses, the first 3 of them are contributing most to the energy budget. The semipulsetrain gives the additional advantage of producing a known pattern of lunar returns within the random noise from other sources. Ranging to the moon from Wettzell is challenging as the noise counts are usually hiding the lunar returns. This requires a complex post ranging examination procedure, carried out at the Technical University of Munich, to analyse the measurements. At Wettzell LLR has a very high ranging priority. However there were only very few nights during the last year permitting lunar ranging. In these nights hardly any passage of LAGEOS or ETALON was lost as it takes only a few minutes to switch the WLRS from lunar mode to satellite mode and the lunar ranging was interrupted for a short while.

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2 Echos from the moon

In figure 1 a successful measurement is shown. Clearly the pattern of the used semitrain can be seen. The high noise rate is also evident. There is a fixed spacing in time between the individual pulses in the semitrain. This separation is depending on the length of the laser cavity and can be measured independendly. For the WLRS laser the pulses are 6.902 ns apart. This relation can be used to fold the lunar returns from the second and the third pulse of the semitrain onto the main pulse to increase the number of returns in the normal point.

3 Status of the WLRS

The WLRS proofed it capability for lunar ranging. However, the ranging to the moon is very complicated and not very well supported by the ranging software, which only provides elementary features. At the present efforts are made to increase the signal to noise ratio and to support blind tracking. The goal is a more efficient use of the few useful observation nights per year in Wettzell.

We would like to thank the lunar ranging team in Grasse (France) for for their help.

References

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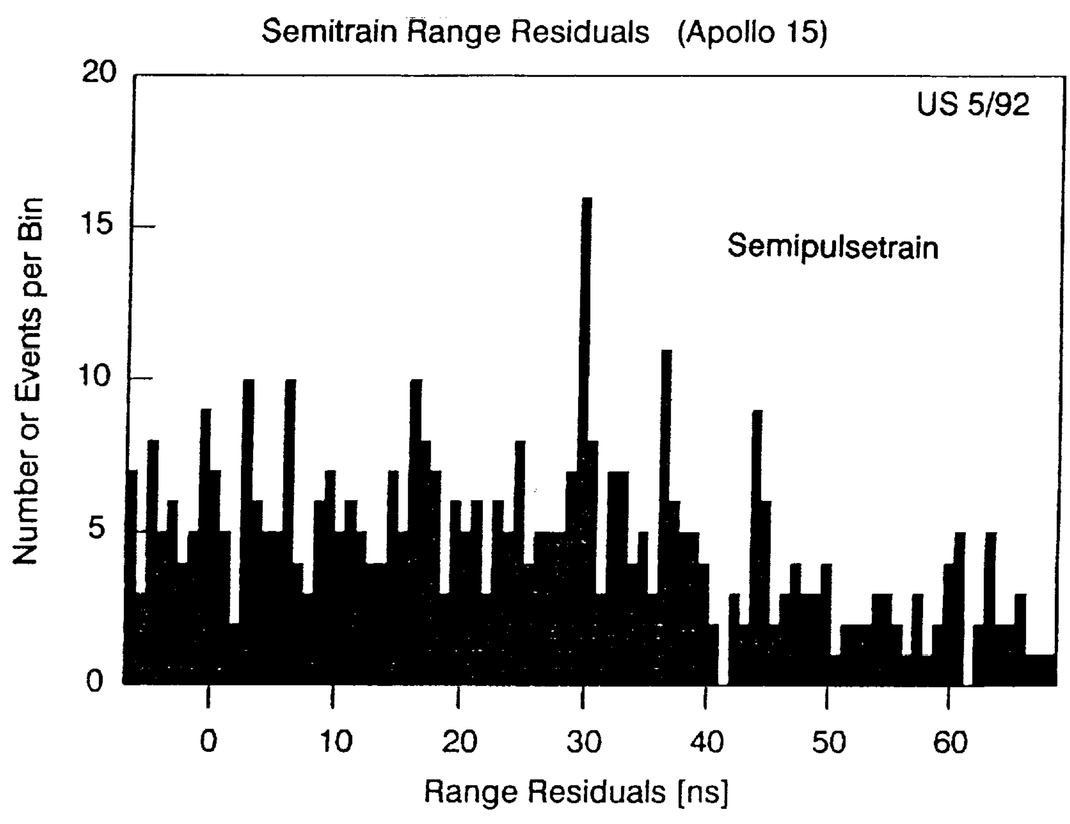

Figure 1: Histogram of the 'semitrain ranges' to APOLLO 15 during the night of Nov. 25th 1991. The session lasted 15 minutes