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DEVELOPMENT OF A LIDAR SYSTEM AT THE STARFIRE OPTICAL RANGE

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INTRODUCTION

Adaptive-optics systems using laser guide stars have been developed for the 1.5 meter telescope operated by the Phillips Laboratory at the Starfire Optical Range (SOR) at Kirtland Air Force Base, New Mexico[1]. In applications where photometric measurements are of interest, it is necessary to be aware of variations in the extinction of light as it passes through the atmosphere. At visible wavelengths, such variations are primarily due to changes in the concentration of particulates, which are easy to monitor by lidar techniques. The main problems are patchy subvisual cirrus clouds and, to a lesser extent, changes in boundary layer aerosols.

The laser guide star at SOR is formed by propagating the beam from a copper vapor laser (CVL) through a 1.5 m telescope on elevation-over-azimuth gimbals and focussing at a 10 km range. During the summer of 1992, we developed a prototype lidar system which used the CVL guide star as a transmitter and a 14-inch Schmidt-Cassegrainian telescope as a receiver. The receiver was mounted on the side of the 1.5 m telescope, so that the lidar would always be aimed in the direction the telescope was pointing. However, some problems were experienced with the prototype receiver. An operational system was later developed, and the specific engineering measures which addressed the problems in the prototype are described in this paper. An example of subvisual cirrus cloud measurements is also presented.

The specifications of the CVL guide star (see Table 1) are unusual for lidar. The 5 kHz pulse repetition frequency imposes a range limit of 30 km, and it also exceeds the speed of some data systems, in which case not all laser pulses can be used by the lidar. The CVL also has two output wavelengths with roughly equal power. In addition, beams from other lasers such as Nd:YAG, doubled Nd:YAG, ruby, and a sum-frequency laser at 0.589 microns are sometimes transmitted in the same manner as the CVL, and lidar measurements are also needed with these lasers. These were important considerations for the receiver design.

Table 1. Specifications of CVL Guide Star

Wavelengths:	0.5106 and 0.5782 microns
Power transmitted:	70 Watts (typical)
Pulse repetition rate:	5 kHz
Energy per pulse:	14 mJ (typical)
Pulse width:	50 ns
Beam geometry:	1.5 m diameter leaving the telescope, focussed at 10 km range.

THE PROTOTYPE LIDAR RECEIVER

The prototype lidar was designed to monitor atmospheric particulates, including both boundary layer aerosols and cirrus clouds. This necessitated two receiver channels, referred to here as long range and short range, in order to have sufficient dynamic range and also to avoid defocus problems with the 14-inch telescope, which had a focal length of 154 inches. Specifications of the receiver are listed in Table 2. A standard two-channel data system based on CAMAC architecture was used with the prototype. This system included software for acquiring, storing, and analyzing data[2]. It was normally operated with 2048 range bins and a digitization rate of 10 Mhz, which yields 15 m range resolution and a maximum range of 30.72 km.

Table 2. Specifications of Lidar Receiver

	Long Range	Short Range
Aperture	14 inches	2 inches
Field of View	0.8 mr	11 mr
PMT	S-20	S-20
Optical filter		
center wavelength	0.511, 0.578μm	0.511μm
bandpass	1 nm	1 nm
peak transmittance	60%	60%

The prototype receiver was initially mounted outdoors on a tripod, aimed at the zenith. The CVL beam was brought out to a turning mirror on an adjustable mount and aligned so that the crossover distance was roughly the same as it would be later when the receiver was mounted on the 1.5 m telescope. A cardboard mask was used to reduce the receiver area of the long-range channel by a factor of three, because lidar returns from clouds tended to saturate the PMT.

Observations of subvisual cirrus with the long-range receiver are shown in Fig. 1. The lidar profiles were recorded during a 45 minute period at 30-second intervals with 3000 pulse averaging. Each profile was multiplied by range squared and smoothed to an altitude resolution of 45 m. Two small clouds are apparent in the data, at altitudes of about 8 and 10 km. These clouds were not visible to rooftop observers, even though the sky was illuminated by bright moonlight.

After this check-out, the prototype receiver was mounted on the 1.5 meter telescope and aligned. This required inverting the 1.5 m telescope to gain access to the receiver. Serious alignment errors occurred in the long-range channel when the telescope was returned to its normal position. This problem was traced to flexing of components inside the 14-inch telescope. The optical deflection was larger than the long-range receiver field of view, and efforts to stiffen the telescope were not successful. In addition, several other problems related to the ease of operation were encountered. All of these problems were addressed in the design of the operational system.

THE OPERATIONAL SYSTEM

A schematic diagram of the operational system is shown in Fig. 2. The two-channel feature has been retained, with a two-inch diameter short range telescope (based on the prototype) and a six-inch diameter long range telescope. The area of the six-inch telescope is approximately equal to that which was used during initial measurements with the prototype. Adjustable folding mirrors are provided in front of both telescopes for alignment, and all adjustments are made with knobs on the mirror mounts (no tools are required). Access ports are equipped with fasteners which require no tools and have no loose parts. The amount of light entering the telescopes is adjustable, with an iris diaphragm on the short range telescope and a sliding shutter in front of the long range telescope. Stray light is controlled by several levels of baffling. The left side of the receiver as shown in Fig. 2 is in a light-tight box. Gaskets are provided for both telescopes where they protrude through the box wall. Threaded and blackened aluminum

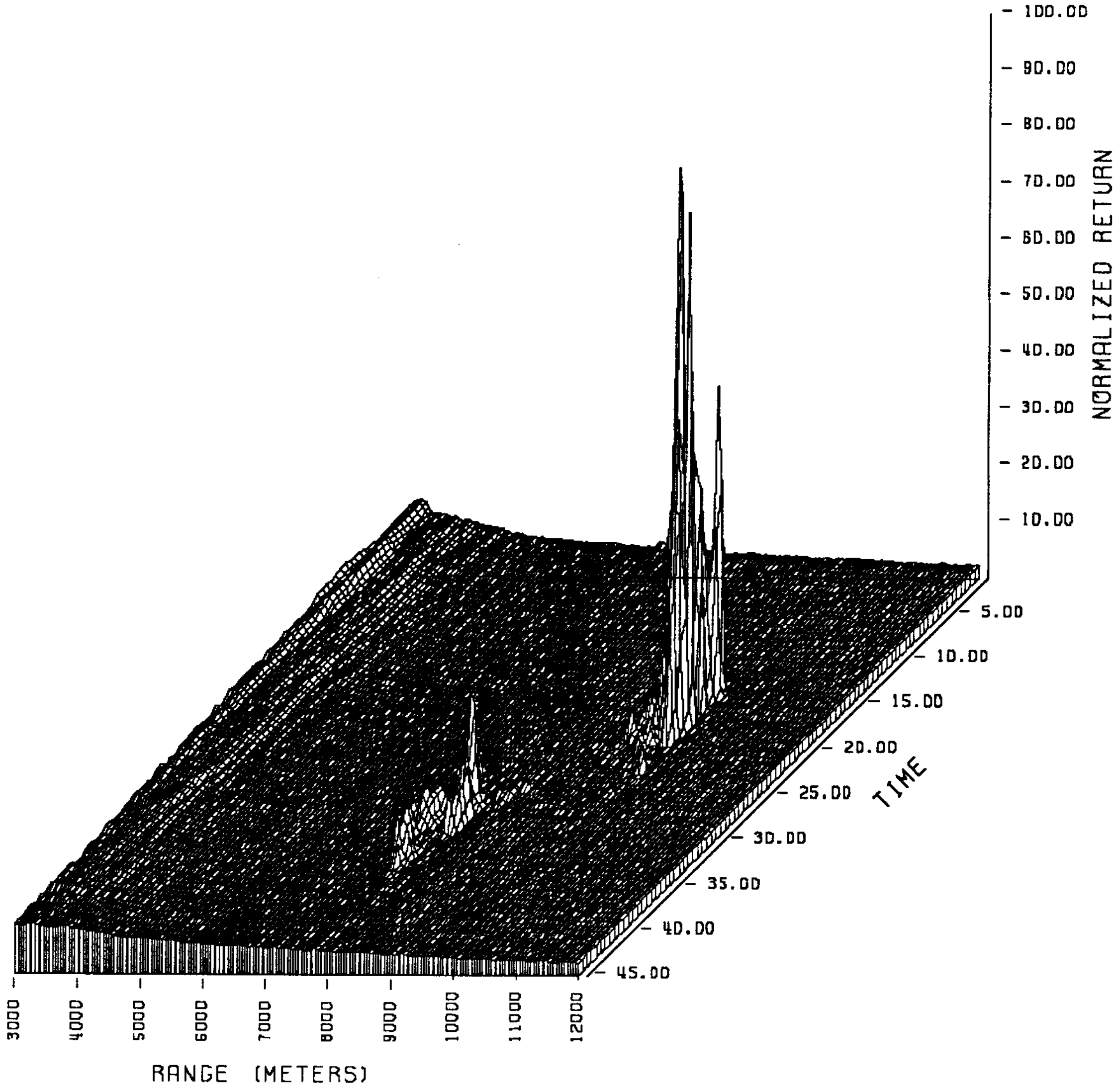

Figure 1. Normalized lidar profiles recorded at SOR on August 18, 1992. Two subvisual cirrus clouds were observed: the lower one had a base height of 7.7 km and thickness of 400 m; the higher one had a base height of 9.4 km and a thickness of 500 m. Changes in the boundary layer aerosol can also be seen during the 45-minute measurement period.

tubes are provided between the telescopes and the field stops, and black cloth tubes with drawstrings are used between the telescopes and the PMTs to avoid cross-talk. The inside of the light-tight box is painted black.

A great deal of design effort was expended in making the long range receiver rigid. Metal flexures were used for all angular adjustments. Leaf flexures were used on mirror mounts. The long-range receiver's secondary mirror was bonded to its mount with two-component RTV silicone rubber, with a thickness controlled to .0001 inch by shims behind the mirror, in order to minimize thermally induced tilts. The spider holding the secondary has four sets of double-legs made from stainless steel. The long range telescope is held to the baseplate by two "tripod" mounts that wrap around the telescope tube. The bottom of each mount has three raised pads forming a triangle with

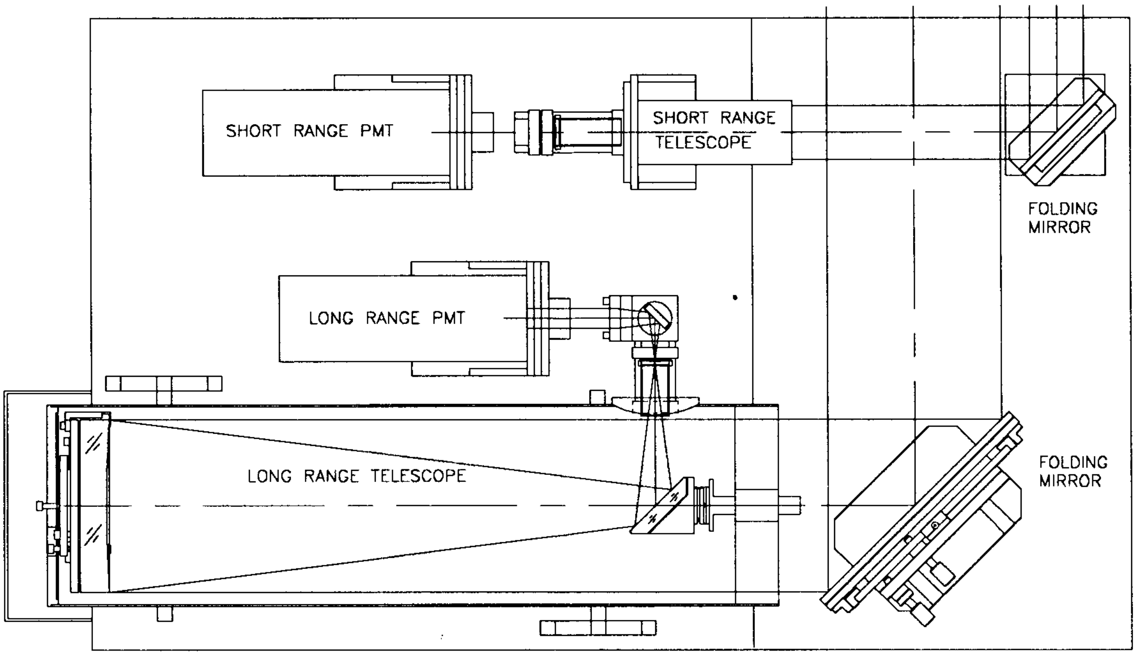

Figure 2. Schematic diagram of the operational SOR lidar receiver.

mounting bolt holes through the pads, to ensure that the mounts will not rock on their bolts, and that the stiffness gained by bolting the baseplate to the 1.5 meter telescope is passed on to the long-range receiver.

The operational lidar receiver was installed during the summer of 1993 and tested to assess the amount of flexure. A lidar data set was recorded with the 1.5 m telescope at 45 degrees elevation and the lidar receiver on top (the normal position), then the telescope was inverted and rotated in azimuth so that the lidar was underneath but pointed at the same point in the sky, and another data set was recorded immediately. The difference in the two data sets was taken as a measure of the flexure in the receiver caused by changing the direction of gravitational forces. The data from the flexure test were reduced by noting the range at which initial crossover occurred. The optic axis of the receiver was assumed to be coplanar with the optic axis of the laser beam, and the amount of flexure was estimated by a geometrical analysis. The deflection of the receiver optic axis when operating in the normal range of zenith angles was determined to be 170 microradians. This is larger than the design goal of 100 microradians, but it is not large enough to cause major difficulties.

CONCLUSIONS

The work described here resulted in an operational lidar system at SOR which is easy to use and very adaptable. The data in Fig. 1 show that the lidar can easily monitor subvisual cirrus clouds on a time scale of seconds. The system is in routine use with the CVL guide star, and it has also been configured for both ruby laser and doubled-Nd:YAG laser wavelengths.

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