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First Results of a Polychromatic Artificial Sodium Star for the Correction of Tilt

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With the present state of technology, the tilt component of a aberrated stellar wavefront which has been distorted by atmospheric turbulence cannot be ascertained by an artificial guide star. The absolute position of the artificial guide star cannot be determined since it wanders on the uplink portion of its propagation and there is no way, at least with a single receiving telescope, to distinguish an undetermined position of a guide star from tilt in the wavefront. In conventional adaptive optics systems, a natural star is needed to supply the tilt information in addition to the higher order corrections supplied by an artificial guide star. The probability of finding a suitably bright natural guide star for tilt correction is not significantly higher than for higher order correction despite the fact that the entire telescope area is used and both the tilt anisoplanatic angle and integration time are considerably larger. Since the tilt contributes $\approx 90\%$ of the phase variance, the accuracy in the tilt measurement has to be much greater than for higher order corrections¹. In particular at galactic latitudes above the galactic plane, or at visible wavelengths, the sky coverage for a tilt star becomes unacceptable for most applications.

A new concept has been proposed² which uses two wavelengths to optically pump the mesospheric sodium atoms to a higher level from which several lines are emitted. The two pump wavelengths, 589 nm and 569 nm are sufficiently close for dispersion to be negligible so that the optically pumped region is essentially the same volume as in the standard monochromatic guide star. However, the shower of lines all emanating from a single spatial position do suffer atmospheric dispersion and this effect can be used to measure the tilt aberration. In particular, the dispersion from one emission line at 330 nm is compared to the dispersion from the sodium D₁ line, chosen to eliminate interference with the pumping D₂ line, forms the basis of the technique.

Although the measurement scheme is on solid theoretical grounds, the difficulty lies in the measurement accuracy which is required and the subsequent need for high power lasers. For the two wavelengths chosen, the dispersion is only a few percent. This means that the centroids of the guide star viewed with 330 nm and 590 nm filters must each be resolved to an accuracy of a few milliarcseconds in order to resolve the differential motion. This measurement accuracy imposes a minimum on the signal to noise ratio in the centroid detector which requires high laser power. There are several innovations which can reduce the laser power requirement including better UV detectors. For the present, however, estimates were that about a hundred watts of average power in each of the two pumping wavelength are needed for this measurement. Previous (monochromatic) laser guide experiments at LLNL³ propagated over 1200 W at 589 nm and the capability does exist to split that power between the two pumping wavelengths.

As a first feasibility experiment, a joint experiment was carried out at LLNL during the first two weeks in January of 1996. Despite the usually poor weather in northern California during the winter season, 4 acceptable nights were encountered and this paper presents the results of that preliminary experiment. An optical system was designed, built and installed at the Cassegrain focus of a 50 cm telescope adjacent to the Atomic Vapor Laser Isotope Separation (AVLIS) building at LLNL. The optical system displayed both 330 nm and 590 nm guide stars in addition to a natural guide star for reference. The laser system was developed by the AVLIS program and was modified to deliver the two pumping

wavelengths with about 400 W -500 W of average power at system repetition rates of 4.3 kHz and 12.9 kHz and with a pulse duration of about 40 ns. The power split between the two lines was variable but generally equal. The laser beam was expanded to a rectangle of 40 mm x 80 mm and was projected out of an "elevation over azimuth" beam director 5 meters from the receiving telescope.

A schematic diagram of the optical system is shown in Figure 1. Three spectral channels are separated using dichroic beam splitters (3) and (5), for the 330 nm line, the sodium D₁ line, and a broader bandwidth for a superimposed natural star. In the laser line bandwidths, dispersion components are used to make the number of photons from the natural star lower than the photon noise in each laser line (see Fig. 1).

The three spectral channels produce three separated images of the same field on a Photometrics (Model CH250) CCD camera which uses a Texas Instruments CCD chip (TK512 MPP).

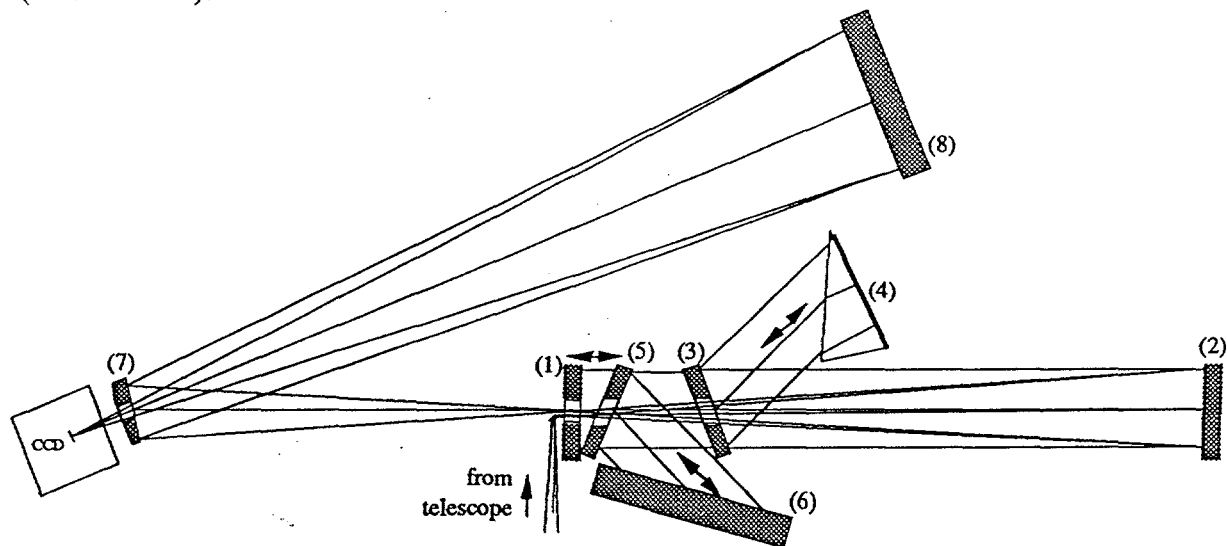


Figure 1. Simplified layout of the optics system. Two dichroic beam splitters isolate the UV (3) and the yellow (5) bandwidths. The broad band part is reflected on the flat (1). Dispersion elements are a prism (4) and an échelle grating (6).

The LLNL AVLIS laser system is a copper vapor laser pumped dye laser with full beam control including wavefront correction, wavelength stabilization and modulation, low bandwidth pointing and centering control and high bandwidth jitter control. A dye was chosen for the amplifiers which could provide gain for both wavelength in a co-propagation mode but the outputs of two separate dye oscillators were combined for this experiment. The modulation format for the 569 nm line was chosen to be single, 1 GHz wide format but two modulation formats were tried for the 589 nm line. The first was again a single, 1 GHz wide profile while the second was a double peaked, 3 GHz wide profile which was the format first used in the previous LLNL monochromatic guide star experiments³.

Observations of the radiative decay from the 4D5/2 energy level of mesospheric sodium atoms have been restricted to the 330nm and D₁ lines. The 569nm laser light was broadened to 1 GHz to fit with the Doppler profile in the mesosphere. The following laser parameters have been varied to attempt to maximize the returned flux in the D₁ line:

- the central wavelength of the D₂ line has been scanned from -2.1 to +1.8 GHz around the middle of the hyperfine structure with a 1 GHz FWHM profile. Fig. 2 shows the variation of the returned D₁ line. The curve peaks at -750 MHz. It is consistent with the convolution of the Doppler profile with the 1 GHz laser profile.

- the D₁ flux is roughly doubled when broadening D₂ from 1 to 3 GHz.
- the D₁ flux varies smoothly when tuning the central wavelength of the 569nm line.
- the balance between the D₂ and the 569nm lines has been varied from 30%-70% to 70%-30%, with little effect on the returned flux, as expected.
- the returned flux is slightly decreased when the repetition rate is increased from 4.3 to 12.9 kHz, which means that the sodium layer was not saturated.

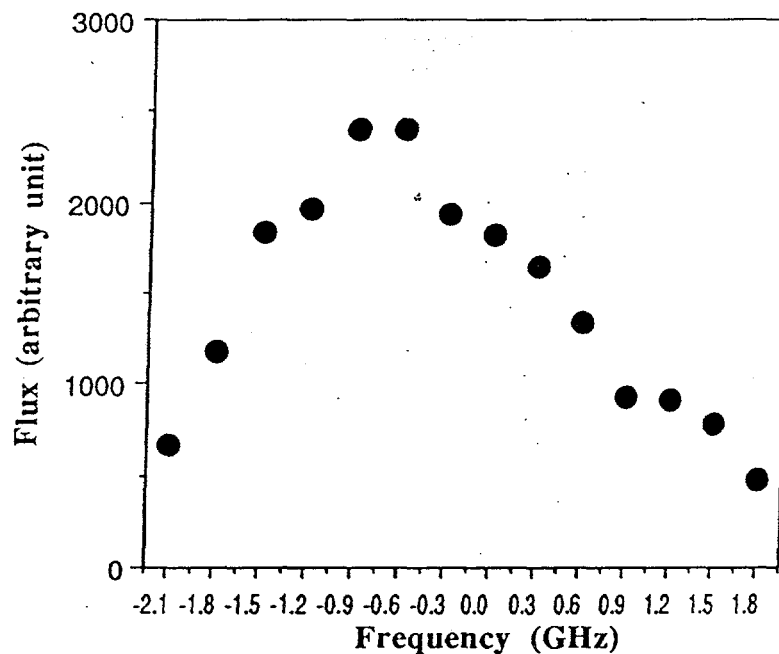


Figure 2. Returned flux in the D1 line versus shift of the central frequency of the D2 line beam.

With the optimized parameters (3 GHz wide D₂ line at -750MHz and a rep rate of 4.3 kHz), the returned flux in the 330nm line has been evaluated, using for the calibration the UV spectrum of the star SAO60855 observed simultaneously. Typically 16000 photons are detected per second with a seeing of $\approx 2.5-3''$, which is consistent with the flux requirement to sense the tilt at a good site.

The next step of the polychromatic artificial star concept will aim at tilt measurements. It will require to increase the sensitivity of the whole process, e.g.: by a factor of 3 using a CCD with a quantum efficiency of 70% in the UV, and by a factor of 1.3 using a polarized beam. In further steps, the polychromatic star should be observed through an adaptive optics to improve the accuracy in the tilt measurement and accordingly decrease the laser power.

Acknowledgements

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