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Laser guide star absolute tilt recovery using a single auxiliary telescope

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ABSTRACT

It is shown that, using a pulsed laser to generate a laser guide star (LGS), a frame transfer technique at the focal plane of an auxiliary telescope can be used to retrieve the bidimensional tilt of such an LGS. We discuss how this approach can be used to reduce from two to one the number of auxiliary telescopes in the NGS-based perspective technique proposed in the literature. A discussion of the requirements for the laser pulse format is given.

Key words: instrumentation: miscellaneous – methods: observational.

1 INTRODUCTION

Absolute tip–tilt determination using laser guide stars (LGSs) (Rigaut & Gendron 1992; Olivier et al. 1993) is a central problem in the area of whole-sky diffraction-limited imaging for ground based telescopes. Several techniques have been devised for this purpose (Esposito 1998; Ragazzoni 1999). Focusing our attention on the auxiliary telescopes technique (Ragazzoni, Esposito & Marchetti 1995, hereafter REM95), we worked out a way to reduce the impact of the practical requirements of the cited technique. Amongst other requirements, ground occupation (Marchetti & Ragazzoni 1997) and the need for two independent auxiliary telescopes are the most relevant ones. We spent some effort in finding out ways to reduce substantially the first of these (Esposito, Riccardi & Ragazzoni 1998).

In this paper we point out how, using a pulsed LGS, a single auxiliary telescope, rather than two, can be used.

2 THE BASIC CONCEPT

Using a pulsed LGS one can project the LGS pulses on to a charge-coupled device (CCD) arranged in a frame transfer configuration. When the frame transfer rate corrects for the apparent motion of the beacon that propagates into the sodium layer, a *frozen* image of the pulse can be recovered. In multiple-port CCDs the Natural Guide Star (NGS) used to provide the absolute tilt reference can be located within a portion of the CCD not affected by the frame transfer technique. Provided some proper geometrical assumptions are satisfied, as described in the following section, one will obtain images of the NGS and LGS in which the latter is no longer elongated. A bidimensional displacement measurement of the LGS image can be obtained. The tilt component orthogonal to the pulse propagation is unaffected by the described technique. The tilt component along the direction of pulse propagation (the one undetectable in the original REM95 technique, leading to the need for two separate auxiliary telescopes and NGSs) can be estimated, providing that enough accuracy in synchronization between LGS pulses and frame transfer operation is accomplished.

The pulse format will be characterized by two typical times: the pulses repetition time t_{R} and the duration of a single pulse t_{P}. In some lasers, a single pulse is obtained as a train of very small pulses. This pulse train is referred in the laser literature as a *macro-pulse*. In this latter case we still refer to such a macro-pulse by the term *pulse*. Moreover, almost all of the non-continuous wave lasers useful for adaptive optics operation are characterized by $t_{\mathrm{R}} \gg t_{\mathrm{P}}$, an assumption that we will use throughout the paper.

Typical values (Milonni & Telle 1997) for t_{R} range from 33 μs to 1.2 ms, while those for t_{P} range from 32 ns to 150 μs, with a ratio $t_{\mathrm{R}}/t_{\mathrm{P}}$ ranging from 8 to 1.2×10^3.

In the following discussion we consider, as a baseline, the Keck II LGS system, characterized by $t_{\mathrm{P}} = 150\,\mathrm{ns}$ and $t_{\mathrm{R}} = 33\,\mu\mathrm{s}$ (Friedman et al. 1997).

In Fig. 1 a sketch of the geometry involved in the concept is outlined. The LGS will form within the sodium layer, characterized by an altitude $H \approx 90\,\mathrm{km}$ and a thickness $\tau \approx 10\,\mathrm{km}$ (Happer et al. 1994).

Two successive LGSs pulses should show up in the auxiliary telescope at the same time, when $ct_{\mathrm{R}} < \tau$. A minimum $t_{\mathrm{R}} \approx 33\,\mu\mathrm{s}$ is obtained. Almost all of the lasers considered for this type of application will not exhibit multiple LGS pulses, other than, marginally, the Keck II system. When such a multiple (actually double) laser spot occurs, we can define a minimum distance d_0 for the auxiliary telescope, so that two successive pulses no longer appear superimposed in such a telescope. Denoting the light speed by c and the transverse size of the LGS spot at the sodium layer by s, one obtains

$$d_0 \approx \frac{Hs}{ct_{\mathrm{R}}}, \qquad (1)$$

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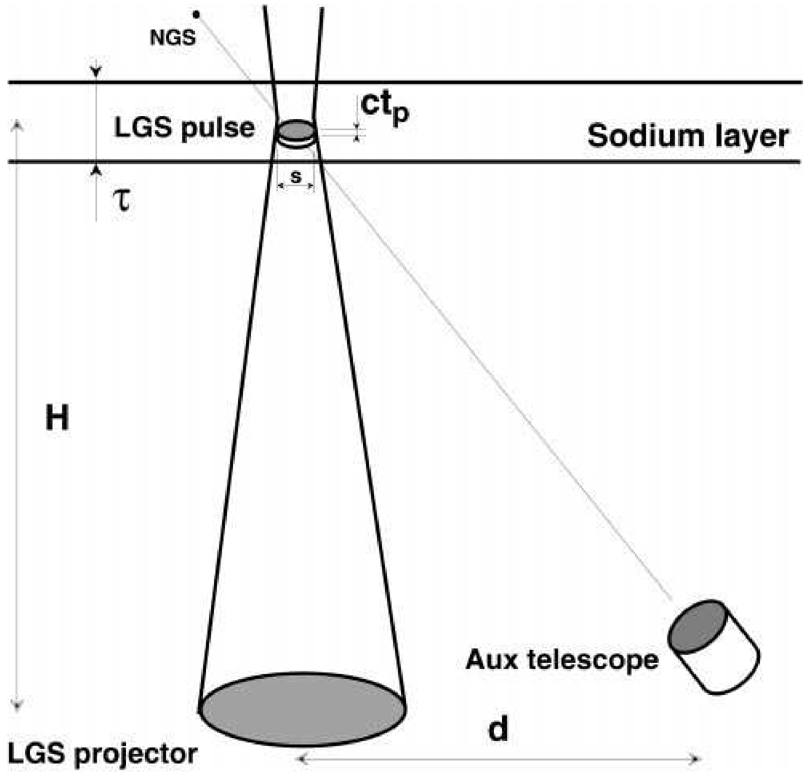

Figure 1. Geometry of the arrangement described in the text.

and, correspondingly, a *blind* zone, characterized by an angular radius θ_B, in which the REM95 technique with the modification proposed here cannot be achieved:

$$\theta_B \approx \frac{d_0}{H} = \frac{s}{ct_R}. \tag{2}$$

For the Keck II case (the only relevant one for this problem), assuming a reasonable $s = 0.4$ m we obtain $d_0 \approx 36$ m and $\theta_B \approx 8$ arcsec. The assumed s value corresponds to about 1 arcsec; it should be noted that the smallest width achieved for an LGS spot is roughly 0.8 arcsec (Lloyd-Hart et al. 1995).

As θ_B is of the same order as the isoplanatic patch size, one can conclude that the effect of this blind zone is irrelevant because a tracking star within θ_B can be observed from the main telescope, to measure the absolute tilt directly.

In order to ensure that the apparent elongation of a frozen spot will not be larger than its transverse dimension, one should avoid positioning the telescope at a distance greater than d_1, defined by

$$d_1 \approx \frac{sH}{ct_P}, \tag{3}$$

corresponding to an angular displacement of the tracking NGS from the science target given by θ_1:

$$\theta_1 \approx \frac{s}{ct_P}. \tag{4}$$

Under the conditions discussed above, typically $d_1 \approx 800$ m and $\theta_1 \approx 0.5°$. These numbers are to be compared with typical distances found, for instance, in Marchetti & Ragazzoni (1997), leading to the conclusion that in the practical range the suggested modification will not exhibit a spot size along the propagation path substantially larger than the orthogonal one. This means that errors no larger than that induced by the transverse size should be experienced.

3 TIMING REQUIREMENTS

An LGS spot will travel along the sodium layer and will appear as a moving object on the auxiliary telescope. A displacement of Δz along the LGS propagation direction will translate into an angular displacement $\Delta\theta$ given by

$$\Delta\theta \approx \frac{d\Delta z}{H^2}, \tag{5}$$

where d is the current auxiliary telescope distance from the LGS projector. The apparent speed of propagation as seen from the ground of the LGS spot is just $c/2$ (because of the round trip of the light) so that an angular speed (see also Fig. 2)

$$\frac{\partial\theta}{\partial t} \approx \frac{cd}{2H^2} \tag{6}$$

will be measured at the focal plane of the auxiliary telescope.

In order to freeze such an angular displacement, a CCD characterized by a given pixel size px, expressed in arcsec, has to be operated in a frame transfer mode with a frequency f_{ck} given by

$$f_{ck} \approx 206265 \times \frac{cd}{2H^2(px)}. \tag{7}$$

A typical figure of $f_{ck} \approx 400$ kHz, when $px = 1$ arcsec, is obtained. Such a value is not a demanding one (Levine, Janesick & Shelton 1994). It is to be pointed out, in fact, that the CCD is read *after* the end of the frame transfer operation, in a much slower manner.

During the read-out phase, a small number of pixels are read.

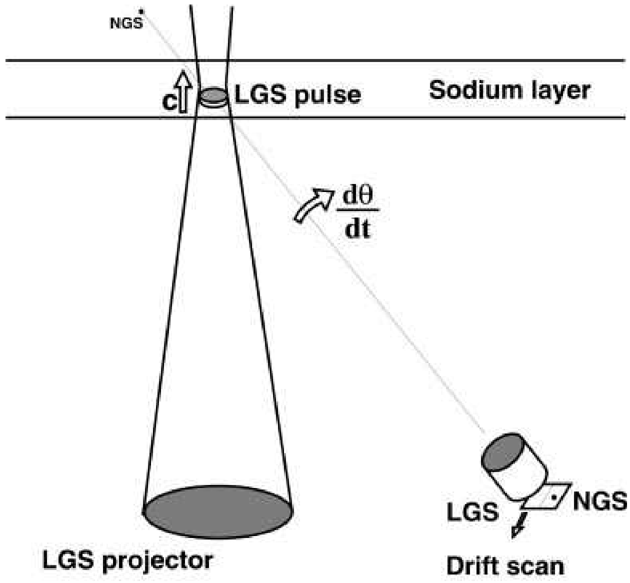

Figure 2. The apparent motion of the LGS pulse as seen from the auxiliary telescope is compensated for by operating the proper CCD half in drift scan mode, while the other CCD half images the NGS in a conventional manner.

Assuming a 4×4 pixel box and a 0.5-μs per pixel read-out time, $\approx$10 μs is lost for this operation. Such a time is still lower than t_P, allowing for a full coverage of successive LGS spots (or, in other words, no LGS photons are lost during the read-out).

However, accurate synchronization between pulse firing and the start of frame transfer operation is required. In fact, it is easy to show that a timing error Δt leading to an angular indetermination of the LGS spot position of the order of λ/D is expressed by the following relationship:

$$\Delta t \approx \frac{2\lambda H^2}{cdD}. \qquad (8)$$

For the Keck II LGS system, we have $\Delta t \approx 34$ ns, attainable by standard electronic equipment. It should be noted that only a synchronization between the two periodic processes involved in the considered technique (the LGS pulse and the CCD drift scan) is required, irrespective of any initial time delay.

4 CONCLUSIONS

We have outlined the requirements on the pulse format that allow us to use a single auxiliary telescope in the framework of the REM95 approach. With all the variety of pulsed LGSs available in the current literature, the proposed variation is feasible. The advantages of removing the need for the second auxiliary telescope are not limited to the half-reduction of auxiliary equipment. As only a single NGS has to be found around the science target, the required ground occupation is also significantly smaller (roughly by a factor of 2, assuming a homogeneous density of suitable NGSs in the sky area around the line of sight).

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REFERENCES

Esposito S., 1998, Proc. SPIE, 3353, 468
Esposito S., Riccardi R., Ragazzoni R., 1998, MNRAS, 294, 489
Friedman H. W., Erbert G. V., Kuklo T., Thompson G. R., Wong N. J., Gavel D. T., Salmon J. T., Feldman M., 1997, Proc. ESO, 55, 138
Happer W., MacDonald G. J., Max C. E., Dyson F. J., 1994, JOSA A, 11, 263
Levine B. M., Janesick J. R., Shelton C. J., 1994, Proc. SPIE, 2201, 596
Lloyd-Hart M. et al., 1995, ApJ, 493, 950
Marchetti E., Ragazzoni R., 1997, A&AS, 125, 551
Milonni P. W., Telle J. M., 1997, Proc. ESO, 55, 114
Olivier S., Max C., Gavel D. T., Brase M. J., 1993, ApJ, 407, 428
Ragazzoni R., Esposito S., Marchetti E., 1995, MNRAS, 276, L76 (REM95)
Ragazzoni R., 1999, NATO ASI Series C: Mathematical and Physical Sciences, Laser Guide Star Adaptive Optics in Astronomy, 1997, in press
Rigaut F., Gendron E., 1992, A&A, 261, 677

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