

# Mitigation of Spot Elongation Effects

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## ABSTRACT

It is possible to reduce significantly spot elongation in adaptive optics systems, if the laser creating the artificial beacon is broken up into many weak independent lasers, sent from scattered locations up to the periphery of a large telescope.

**Keywords** : adaptive optics, laser guide stars, artificial beacons.

## 1. INTRODUCTION

We face a problem which will be significant when larger telescopes, on the 25-100 m scale, will come into service. Most of these dishes will be corrected by active and adaptive optics, to remedy slow and fast variations of the optics and of the atmosphere.

In order to measure the quality of the optics, the current solution is the usage of laser guide stars. These beacons serve as reference optical sources at elevations of 30-100 km, in addition to the few weak natural stars in the telescope field of view.

Essentially all laser beams to create guide stars are launched through a simple telescope, located on the telescope mount, either next to the telescope or above its secondary mirror.

The diameter necessary to send this beam up is approximately 0.5 m, allowing focusing down to a 0.75-1.5 m spot at 15-100 km. The larger beam diameter is set by the turbulence distorting the beam going up. Most systems use the light scattered from dust below 30 km or from sodium at the elevation of 87-95 km. The light return is very low, and the power of today's lasers is barely sufficient for this purpose.

When the telescope is small, it essentially looks at the scattered light along its direction of propagation. If the telescope diameter is large, then even for 8 m telescopes and side-mounted laser launcher, the opposite side of the aperture perceives elongation of the spot. This reduces significantly the performance of the popular Hartmann-Shack and curvature wave front sensors, as well as others. Future telescopes in diameters larger than 10-15 m will run into this difficulty for all parts of the aperture distant from the launch beam by a few metres.

Some solutions to the beam elongation problem are<sup>4,1</sup>:

- Time-gating, where the detector is active only during a short time interval, or length, of the scattered beam, thus losing the rest of the light<sup>5,2</sup>.
- Flexible focusing, where the detecting telescope keeps focusing on the scattered light as it travels up the sky<sup>6,3</sup>.
- Two crossed beams measure consecutively both directions normal to their elongation<sup>7,4</sup>.
- Height imaging, relating each section along the beam on a different pixel of the detector and using it as a separate beacon<sup>8,5</sup>.

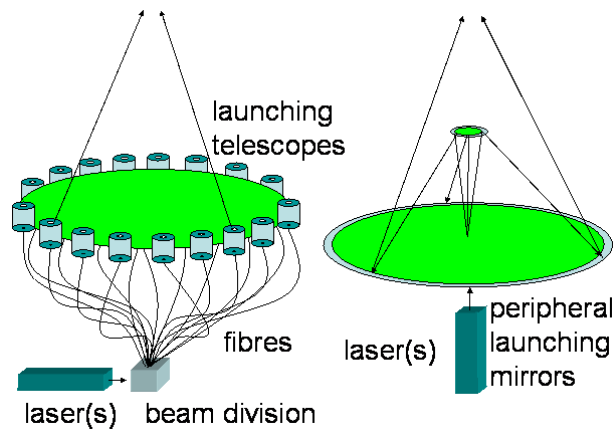
The solution we propose<sup>1,6</sup> relies more on the launching optics than on the detection scheme:

- Multiple weak laser beams launched from a large number of launch telescopes. All beams focus and combine at 25 to 93 km.

## 2. DETAILS

Each beam is fed by a fiber leading from a central laser or a number of weak lasers. The launch diameter does not have to be much larger than  $r_0$ .

The launch telescopes can also be planted between panels of the primary. Another option is to have separate mirrors around the edges of the secondary and primary, focused at the right elevation.



**Figure 1:** Mounting the launch optics around the rim of the telescope allows for better focusing of the laser spot. Left: fibre feed from a single or many weak lasers with separate telescopes. The projection optics can ring the telescope primary or its secondary. Right: mirrors around the edges of the mirrors are focused at the required position.

## 3. SPOT SIZE

We examine the incoherent addition of all projected beams at the required altitude. These beams overlap within a volume of two cones, whose angular width is  $\theta/d$ , where  $\theta \sim 500$  nm. Since turbulence is the limiting factor, the diameter of the launch telescopes is  $d \sim r_0$ . The actual width of the spot at altitude  $H$  is

$$w = \theta H / d$$

If the distance between launching telescopes is  $L$ , then the height of the spot is

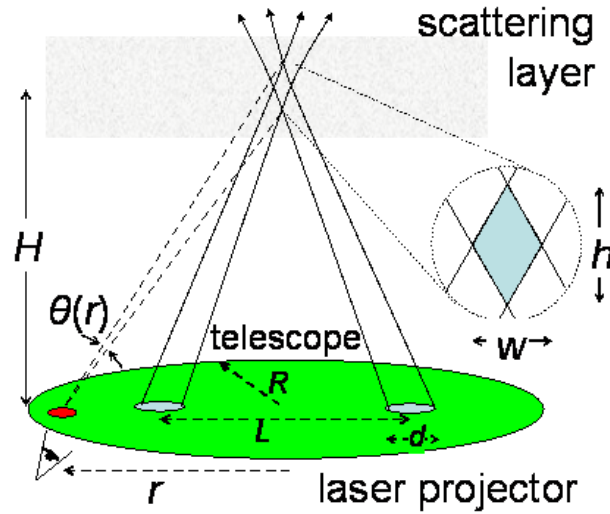
$$h = 2 \theta H^2 / d L$$

This is much larger than its width  $w$ , and it limits the spot size as seen from the ground. At a distance  $r$  from the centre, the subtended angle is

$$\theta(r) = h r / H^2 = 2 \theta r / d L$$

If the launch telescopes are around the periphery of the primary,  $L = 2r = 2R$ , and the spot size is  $\theta/d$  or smaller as we approach the centre of the telescope. Even if they are around the periphery of the secondary,  $L = R/2$ , the worst spot elongation will be only  $4\theta/d$ .

For comparison, the single-beam spot elongation is also  $hr/H^2$ , where  $h$  is now the layer thickness. For a 100 m telescope and secondary circumference projection it is 9 times longer for the Rayleigh case, 35 times for sodium.



**Figure 2:** The geometry of projected beams. The angular extent of the spot subtends the two-cone overlap area of all side beams. In case of coherent addition, the width of the central section of this volume drops by  $dL$ .

#### 4. SIMULATION

We show a spot as created by incoherent addition from a projection circle of 13 apertures, which can be on periphery of either the primary or the secondary. More scattered lasers will create a more uniform spot. To remove low scattering, gating was applied for the lower 50% of the optical path (sodium spot), 90% and 92.5% (Rayleigh and Rayleigh gated in Fig. 3). Single layer turbulence was included<sup>1</sup>.

#### 5. SUMMARY

Comparing the single bright beacon with the multiple-weak-lasers, some issues are:

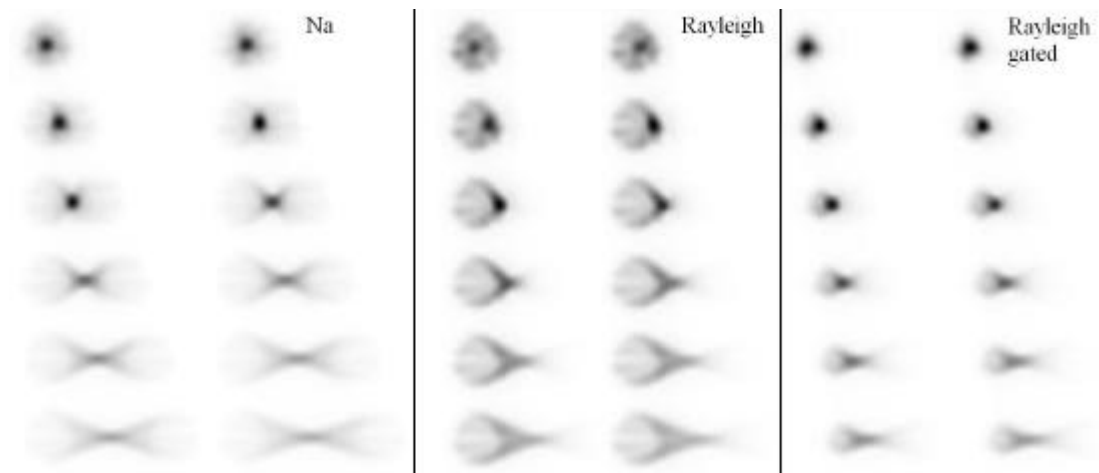
Disadvantages:

- Complex housekeeping: the separate lasers and fibres need power lines and fibres to connect to the telescopes.
- Telescope point-spread-function depends on the shape of the aperture. If some central panels are missing for the sake of laser launchers, they might scatter more light near a stellar image.
- Variable spot shape might occur when observing from different parts of the telescope aperture, and can reach up to about twice the bore-sight spot size.
- Gating still required: in some instances, the scattering from lower altitudes cannot be blocked by the telescope secondary, and so has to be gated away.

Advantages:

- Reduced spot elongation: from most locations on the aperture, the spot is slightly larger than the diffraction limit.

- Reduction of tip-tilt problem: averaging of multiple lasers reduces the collinearity of the ascending and descending beams.
- Simpler lasers: since the beams do not have to be coherent, they can be sent from weaker lasers, instead of one bright one.
- Simpler Optics: weaker beams can be sent through fibres without worry for non-linear effects. They can all be in a central location or near the launch telescopes.



**Figure 3:** Appearance of a spot created by incoherent addition from a projection circle of 13 apertures, for  $D/r_0 \sim 200$  and  $D/d=64$ . We begin to discern spot elongation as we step out from the telescope centre (left to right, top to bottom), and cross the circle of apertures (5<sup>th</sup> image and on). The spots were gated to show scattering only from the sodium layer (left). The central sequence shows Rayleigh scattering, gated for the last 10% of the optical path, and for the last 7.5% (right).

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## 6. REFERENCES

1. J M Beckers, "Overcoming perspective elongation effects in laser-guide-star-aided adaptive optics", *Applied Optics*. **31**, 6592-4, 1992.
2. J M Beckers, "Detailed compensation of atmospheric seeing using multiconjugate adaptive optics", *SPIE* **1114**, 215-7, 1989.
3. M Lloyd-Hart, J R P Angel and N M Milton, "MCAO for a new generation of giant telescopes", *SPIE* **4840-02**, 2002.
4. J. Nelson, private communication, 2002.
5. R Ragazzoni, E Diolaiti, M Tordi and D Kirkman, , "Z-invariant wavefront sensor: sensing a Rayleigh beacon without gating", in *Beyond Conventional Adaptive Optics*, Venice, E Vernet, R Ragazzoni, S Esposito, N Hubin, Eds, *European Southern Observatory Proceedings* **58**, 417-20, 2001.
6. E N Ribak and R Ragazzoni, "Reduction of laser spot elongation in adaptive optics", *Optics Letters*, accepted (2003).