Laser Beacon Spot Elongation and pulse format

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Characteristics of Na layer

- **Height**
  - Average height is about 90 km
  - Height is variable, but in the range 85-95 km

- **Thickness**
  - Average thickness is about 10 km (equivalent width, not $\sigma$)
  - Thickness is quite variable in time 5-20 km
  - Density is non uniform (see pictures)

- **Column density**
  - Density averages $3 \times 10^9$ Na atoms/cm$^2$
  - Density range is about $1 - 5 \times 10^9$ atoms/cm$^2$
Pictures courtesy of Jonathan Friedman, jonathan@naic.edu, Craig Tepley, craig@naic.edu, Shikha Raizada, shikha@naic.edu, Arecibo
Geometry

Na layer

h

z

θ

subaperture

laser

s

ground

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The Elongation problem

• The luminous column through the Na layer appears as a circular spot when viewed from the laser launch telescope itself

• When viewed obliquely, the spot appears elongated

• Elongation

\[ \theta = \frac{st \cos z}{h^2} \]

• Where

– s separation between laser launch location and subaperture (15 m)
– t is the Na layer thickness (~ 10 km)
– h is the height to the Na layer (~ 90 km)
– z is the zenith angle of the observation (0°)
– \( \theta = 3.82 \) arc seconds
Importance of elongation to atmospheric reconstruction

• Elongated spot means that centroid location in one direction is very poor
  – Reconstructing wavefront will be noisier, particularly for predominantly radial modes
  – Efforts should be made to minimize this effect: put laser behind secondary
  – Will need more laser power to achieve same reconstruction error

• Elongated spots mean that the detector size will need to be larger
  – Must resolve narrow direction: implies ~ 0.2 arcsecond pixels
  – Need enough space for 3-6 arcsecond lengths
  – For ELT might need ~ 30m/30cm ~ 100 subapertures in diameter
  – Size of detector ~ \((100 \times 6 / 0.2)^2 \approx 3000 \times 3000\)
  – Or custom detector: \((2/0.2) \times (6/0.2)/2 \times 100 \times 100 = 1,500,000\)
    (~1024x1024 pixels) and use polar coordinate layout around laser
Possible approaches to resolve this

– 1. Ignore the problem
– 2. Cross correlate the image shape with template (and rely on high spatial frequency structure in the layer/spot to improve resolution)
– 3. High speed images to freeze pulse within the Na layer (produces small, faint spots, need many frames)
– 4. High speed optical focus to give a sharp image for all positions in the Na layer. Focus must track pulse
– 5. High speed special CCD’s to shift the detected charge synchronous with pulse propagation through the layer
  • [methods 3,4,5 need ~ 5μs pulse width (~ 1.5km)]
– 6. Many lasers, each makes its own Na location, each has separate wavefront camera, views sub pupil (~ stitching)
– 7. Generate additional spots from different laser launch telescopes and mathematically combine the centroid information. Use custom shaped CCD to record image
Pulsed laser format

Na layer

h

z

θ

subaperture

ground

s

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Pulsed lasers

- Need to consider both intrinsic pulse width (w) and detector integration time ($\Delta t$)

- Apparent width of spot

\[ \theta = (w + \Delta t) \left( \frac{sc}{2h^2} \right) \cos^2 z \]

- For $s=15m$
  - $c=3\times10^8 \text{ m/s}$
  - $h=90\text{ km}$
  - $w+\Delta t=8.7\mu s$
  - $z=0$
- Get $\theta = 0.5 \text{ arcsec}$
Key laser times

- Time to Na layer: $300\mu s \times (h/90\text{km})/\cos z$
- Round trip: $600\mu s \times (h/90\text{km})/\cos z$
- Time through Na: $33\mu s \times (t/10\text{km})/\cos z$
- Pulse separation for single pulse in Na layer: $66\mu s \times (t/10\text{km})/\cos z$
- Max pulse frequency: $15\text{Khz} \times (10\text{km}/t) \times \cos z$
- Pulse duration + integration time: $< 8.7\mu s \times (\text{blur}/0.5\text{ arcsec})/(s/15\text{m})/\cos^2 z$
Custom CCD’s

- It appears practical to make custom CCD’s
  - Spot to spot separation is independent of the Na layer source on the CCD (set by lenslets on pupil)
  - Each lenslet image is sampled by “local” CCD. Example of a 4x4 pixel array covering each lenslet on the pupil is shown
  - Each array is custom to the direction and distance to the launch telescope
  - Beletic funded by the AODP Program to develop these CCD’s
Key Issues

- **How bad is the problem - what's the impact on wavefront error**
  - See Ellerbroek talk

- **How dense must we sample the SH spot (can't use quad cell)**
  - Poyneer talk?

- **How hard is it to make narrow pulse lasers**
  - < 5 $\mu$s pulse width (small broadening)
  - ~ 5-15 kHz pulse rate (only 1 pulse in Na layer)
  - See Pennington talk

- **How do we deal with laser fratricide (Rayleigh vs Na)**

- **How hard are custom shaped CCD's**
  - See Beletic talk