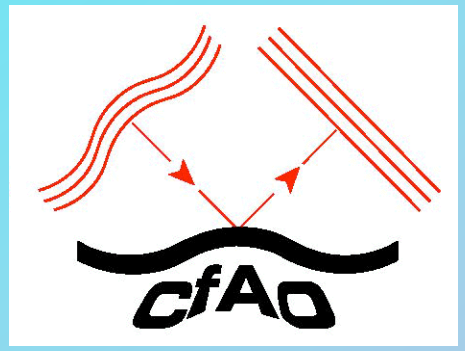
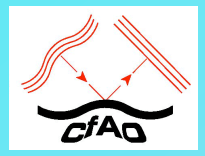



# Laser Beacon Spot Elongation and pulse format

**Jerry Nelson**

**2004 November 13**

**CfAO retreat**

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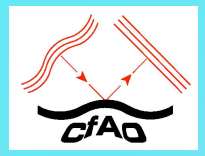
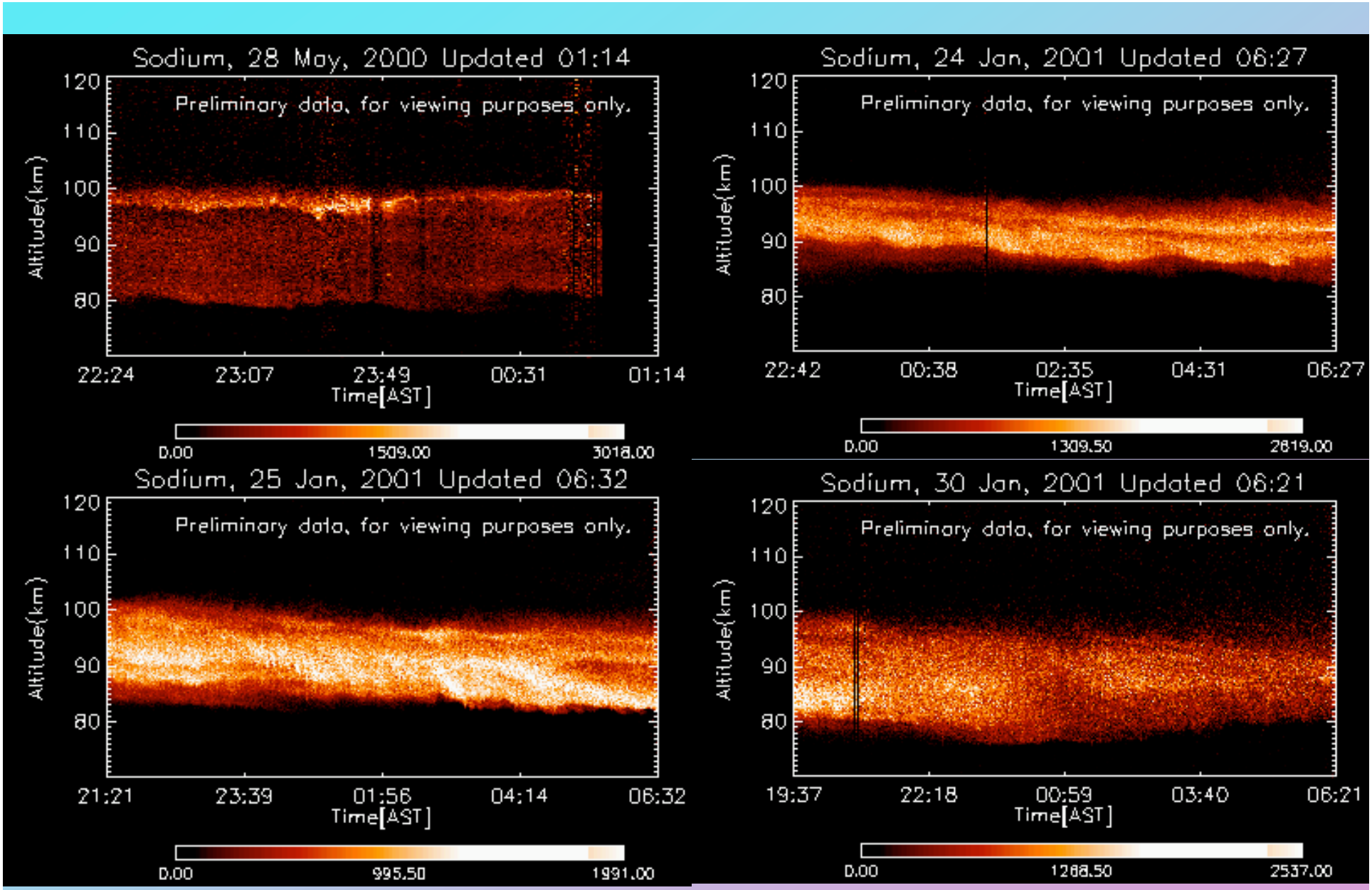


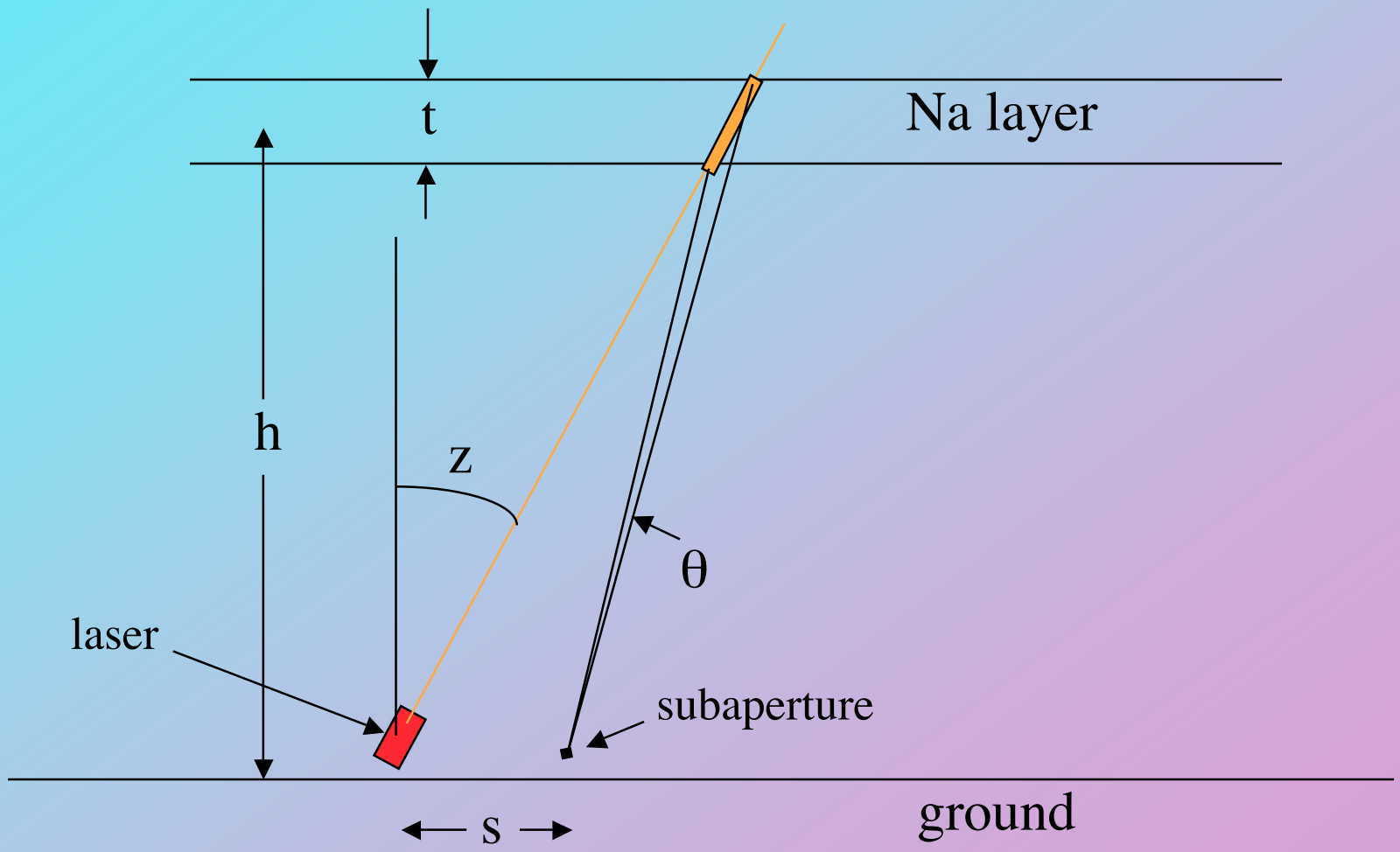

# Characteristics of Na layer

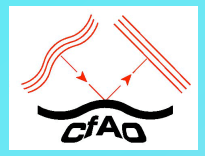
- **Height**
  - Average height is about 90 km
  - Height is variable, but in the range 85-95 km
- **Thickness**
  - Average thickness is about 10 km (equivalent width, not σ)
  - Thickness is quite variable in time 5-20 km
  - Density is non uniform (see pictures)
- **Column density**
  - Density averages $3 \times 10^9$ Na atoms/cm$^2$
  - Density range is about 1-5 x $10^9$ atoms/cm$^2$




Pictures courtesy of Jonathan Friedman, jonathan@naic.edu, Craig Tepley, craig@naic.edu, Shikha Raizada, shikha@naic.edu, Arecibo

# Geometry



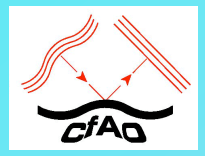



# The Elongation problem

- **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**

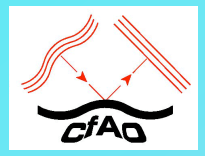
$$\theta = \frac{st \cos z}{h^2}$$

- **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°)
  - θ = 3.82 arc seconds




# Importance of elongation to atmospheric reconstruction

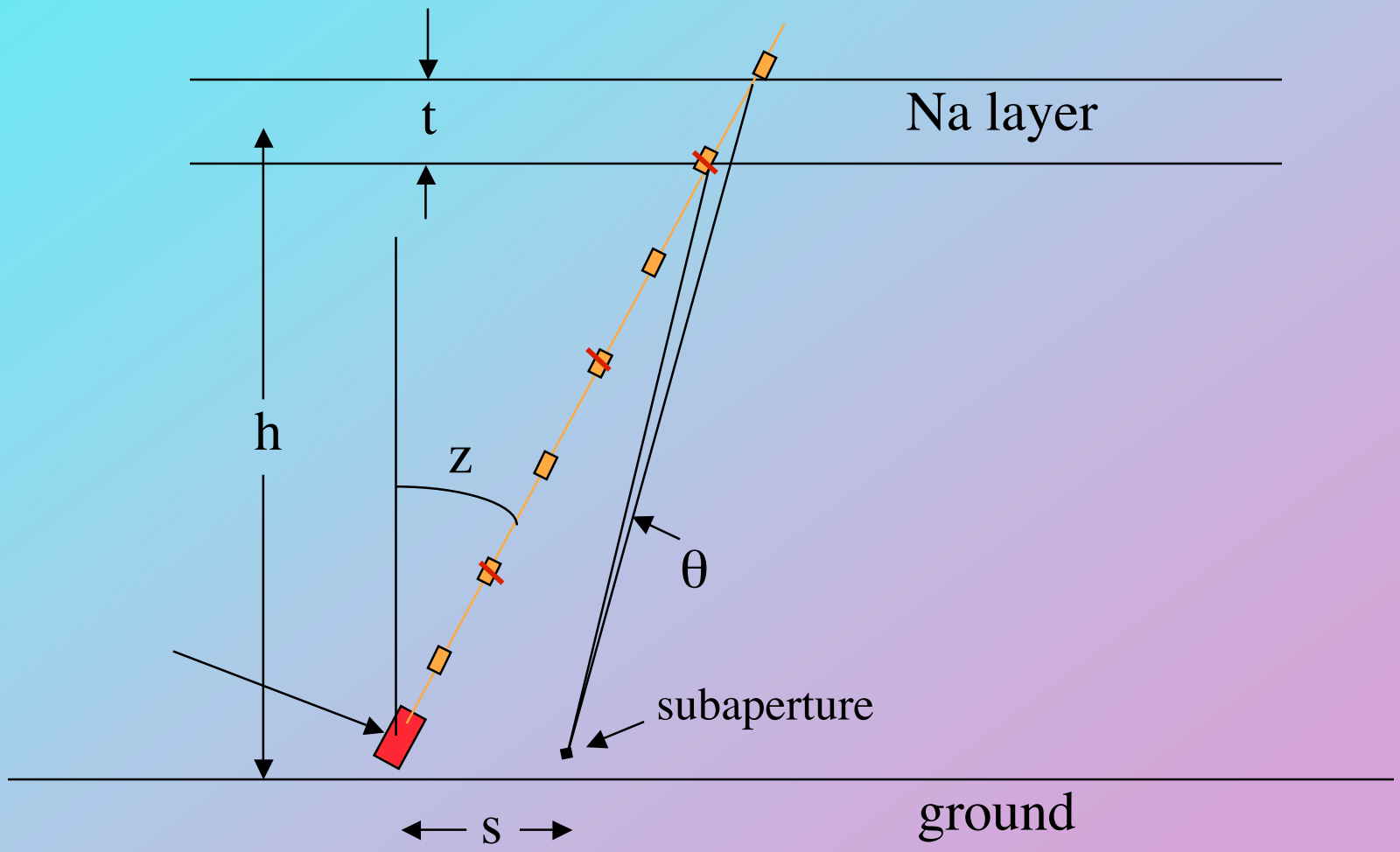
- **Elongated spot means that centroid location in one direction is very poor**
  - Reconstructing wavefront will be noisier, particularly for predominantly radial modes
  - Efforts should be made to minimize this effect: put laser behind secondary
  - Will need more laser power to achieve same reconstruction 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 ~ $(100 \times 6/0.2)^2$ ~ 3000 x 3000
  - Or custom detector: $(2/.2) \times (6/.2)/2 \times 100 \times 100 = 1{,}500{,}000$ (~1024x1024 pixels) and use polar coordinate layout around laser

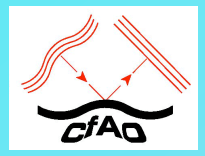



# Possible approaches to resolve this

- 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 ~ 5$\mu$s 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






# Pulsed lasers

- **Need to consider both intrinsic pulse width (w) and detector integration time (Δt)**
- **Apparent width of spot**

$$\theta = (w + \Delta t)\frac{sc}{2h^2}\cos^2 z$$

  - For s=15m
    c=3x10$^8$ m/s
    h=90km
    w+Δt=8.7$\mu$s
    z=0
    Get θ = 0.5 arcsec

# Key laser times

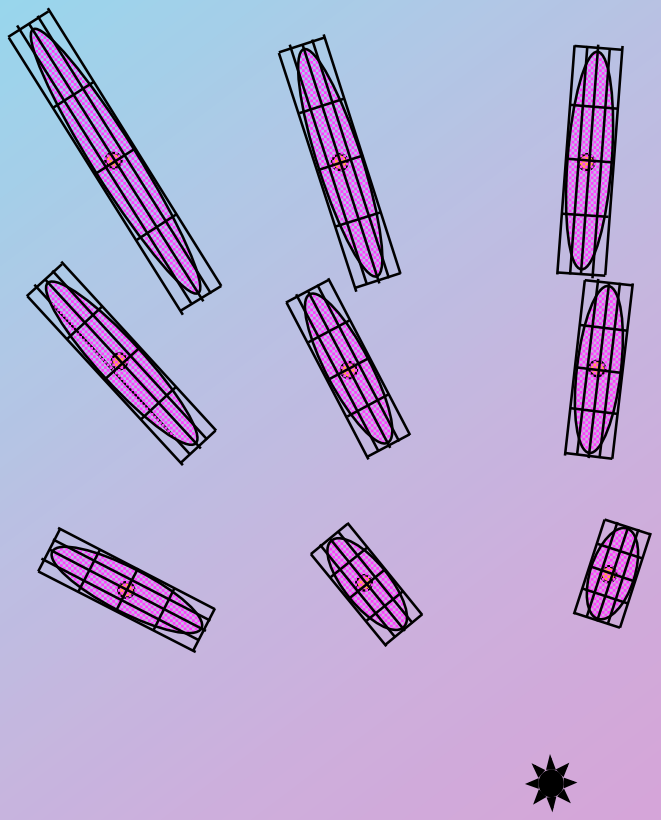
- **Time to Na layer** $300\mu s*(h/90km)/cosz$
- **Round trip** $600\mu s*(h/90km)/cosz$
- **Time through Na** $33\mu s*(t/10km)/cosz$
- **Pulse separation for single pulse in Na layer**

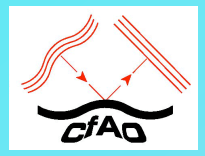
  $66\mu s*(t/10km)/cosz$
- **Max pulse frequency** $15Khz*(10km/t)*cosz$
- **Pulse duration + integration time**

  $< 8.7\mu s*(blur/0.5\ arcsec)/(s/15m)/cos^2z$

# 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- whats the impact on wavefront error**
  - See Ellerbroek talk
- **How dense must we sample the SH spot (cant 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