Laser Beacon Spot Elongation

Jerry Nelson

2002 March 22

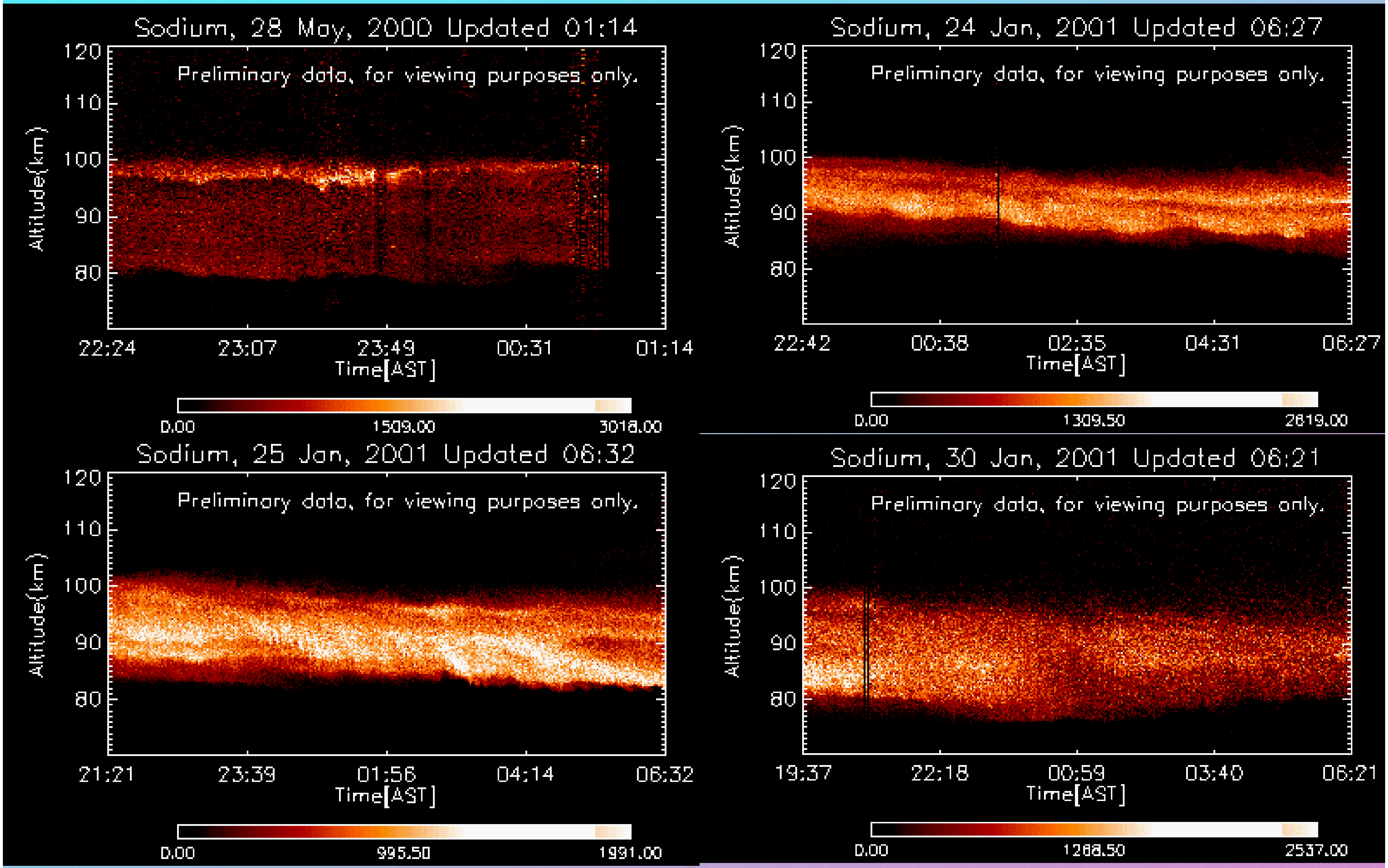
CfAO Proposal Retreat

Contents

- Characteristics of Na layer
- Spot geometry
- Elongation
- Elongation effects
- Possible solutions
- Key issues
- Crossed spots (if we have time)

Characteristics of Na layer

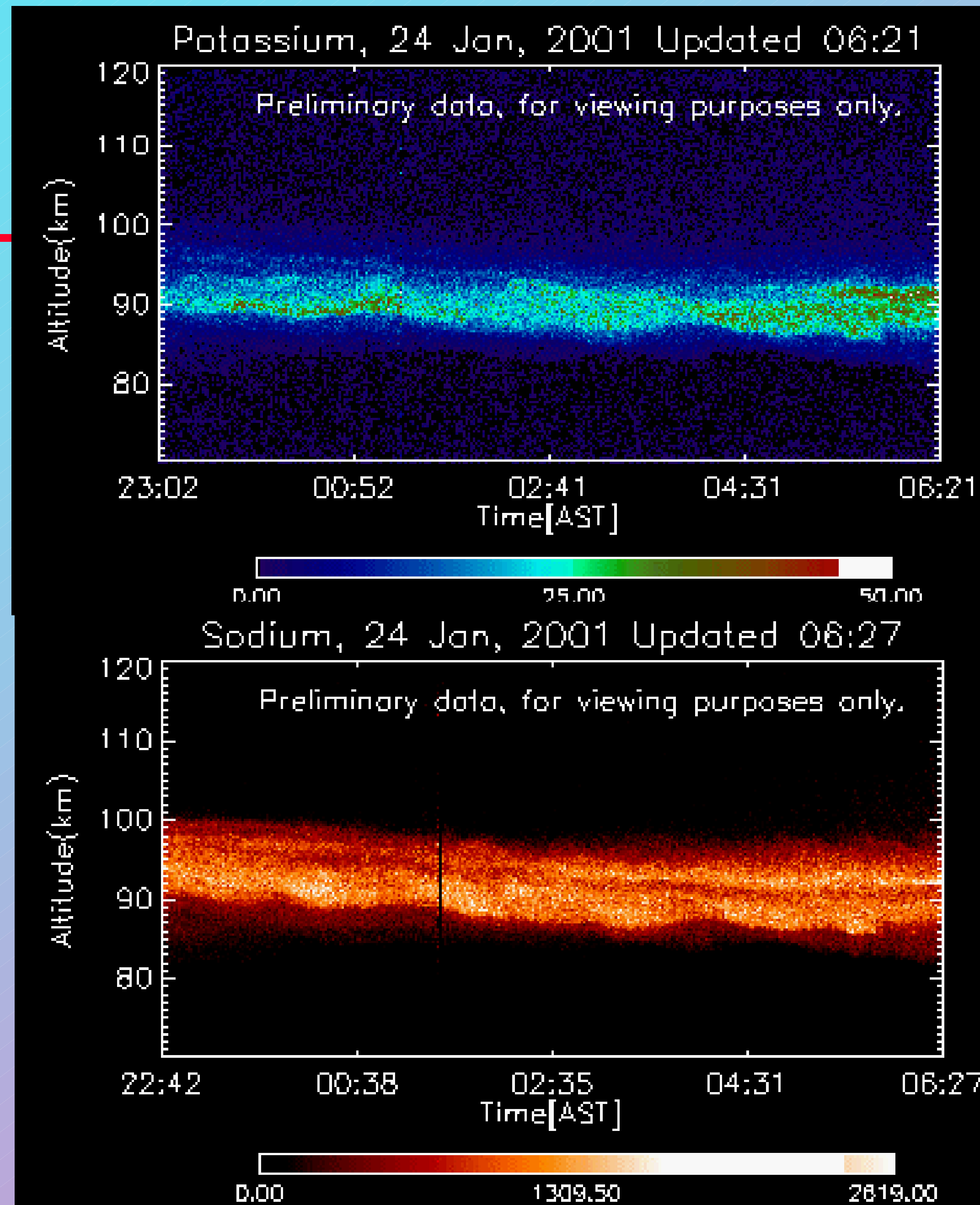
- **Height**
  - Average height is about 90 km
  - Height is variable, but in the range 85-95 km
- **Thickness**
  - Average thickness is about 10 km (equivalent width, not σ)
  - Thickness is quite variable in time 5-20 km
  - Density is non uniform (see pictures)
- **Column density**
  - Density averages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



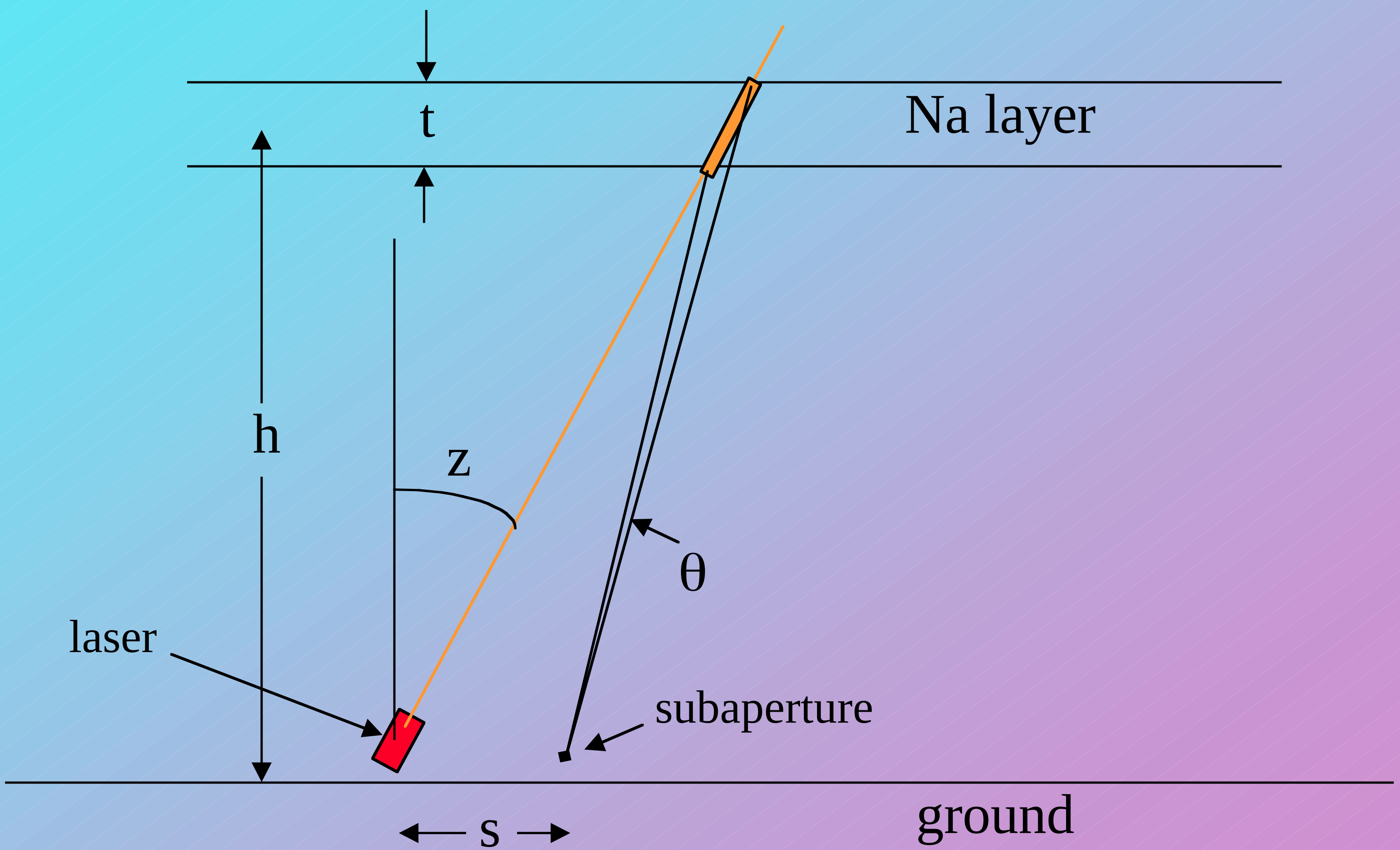
Pictures courtesy of Jonathan Friedman, jonathan@naic.edu, Craig Tepley, craig@naic.edu, Shikha Raizada, shikha@naic.edu, Arecibo

Potassium and Sodium seem to have the same distribution

Data from J. Friedman



Geometry



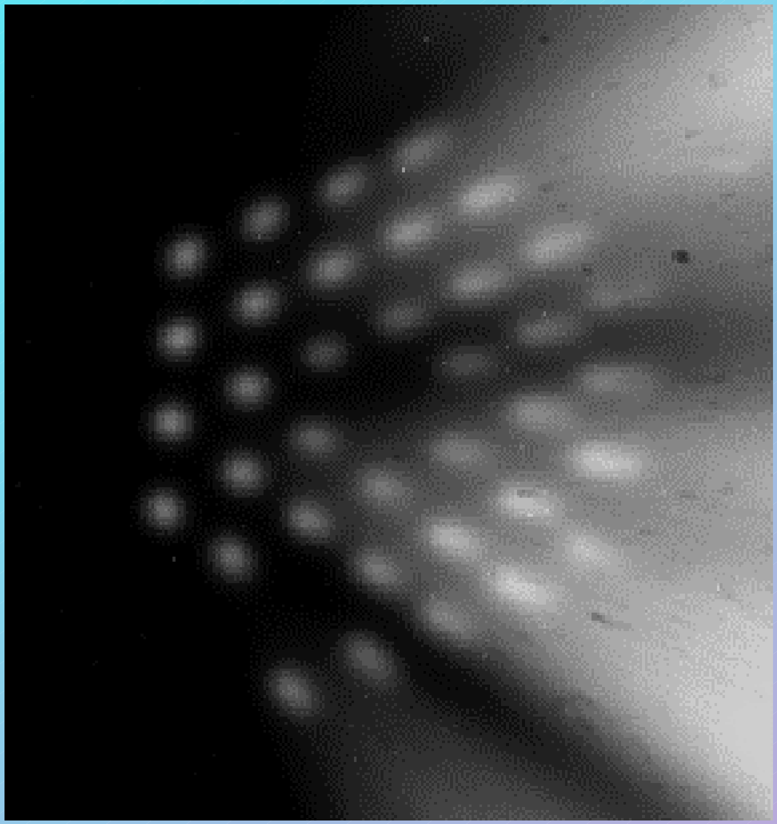
The Elongation problem

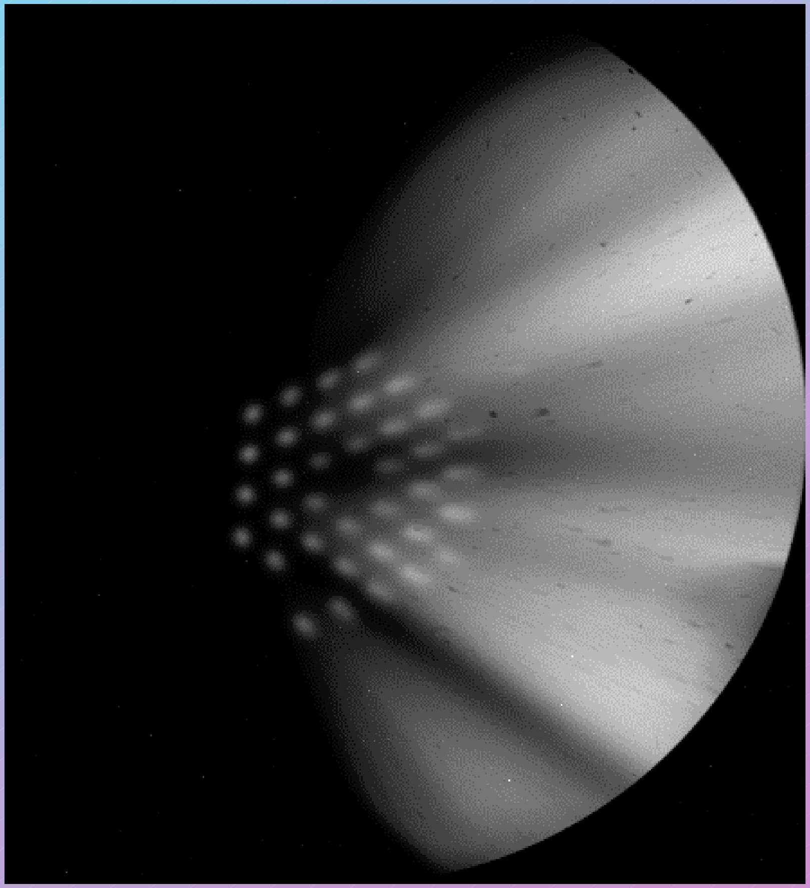
- **The luminous column through the Na layer appears as a circular spot when viewed from the laser launch telescope itself**
- **When viewed obliquely, the spot appears elongated**
- **Elongation**

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

- **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

Spot elongation at Keck





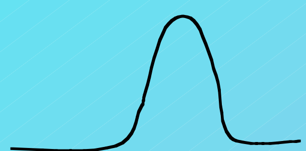
Spots are from tilted segments

Importance of elongation to atmospheric reconstruction

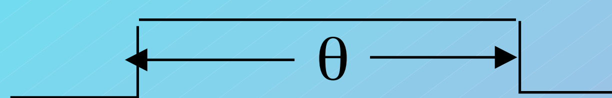
- **Elongated spot means that centroid location in one direction is very poor**
  - At 15m separation, the image rms is degraded by $3.8/(12)^{0.5}$ arcsecond vs 0.2 arcsecond (factor of 5.5)
  - Systematic effects a large concern (eg non uniform, variable layer)
  - Statistically, to achieve same centroid error needs 30 x photons
- **Elongated spots mean that the detector size may 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 ~ 100x6/0.2 ~ 3000 x 3000

Models for degradation of spot centroid

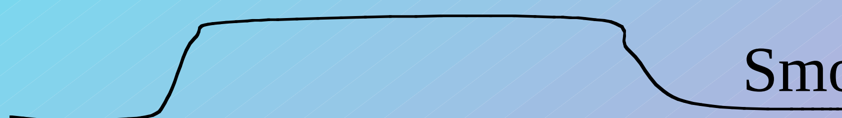
•



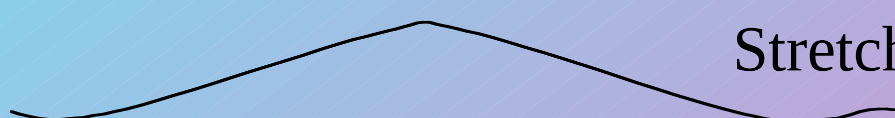
Simple gaussian $$\delta = \frac{\sigma}{\sqrt{N}}$$



Top hat $$\delta = \frac{\theta}{N}$$



Smoothed top hat $$\delta = \sqrt{\frac{\theta\sigma}{N}} = \sqrt{\frac{\theta}{\sigma}}\frac{\sigma}{\sqrt{N}}$$



Stretched gaussian $$\delta = \frac{\theta}{\sqrt{N}}$$

Effects of elongation

- **Elongated spot implies a larger transverse probe of turbulence**
  - A spot length of θ arcseconds implies the light entering a subaperture from each end of the spot has arrived from a different direction than the center of the spot. This is angular anisoplanatism
  - At 3.8 arcseconds, anisoplanatism effects are for 1.9 arcseconds, probably small effect on the average centroid
- **Unless data is thoughtfully generated and collected, elongated spots will lead to poor estimates of the wavefront errors**
  - For tomography, systematically incomplete information from each Na location probably leads to poor knowledge of atmospheric turbulence (we haven't worked this out in detail)

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 ~ 3µs pulse width (~ 1km)]
- 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

Method comparison

Method	detector	Laser pulse format	Total Laser power	Computing	Technical complexity
1 nothing	big	any	Very high	normal	normal
2 cross correlate	big	any	high	hard	normal
3 high speed images	Big, fast	Narrow pulses	normal	hard	high
4. dynamic focus	small	Narrow pulses	normal	normal	high
5 custom charge shifting	Exotic shape, big	Narrow pulses	normal	normal	high
6 many lasers/stitching	many	any	Very high	hard	high
7 crossed spots	big	any	2x normal	3x normal	3x normal

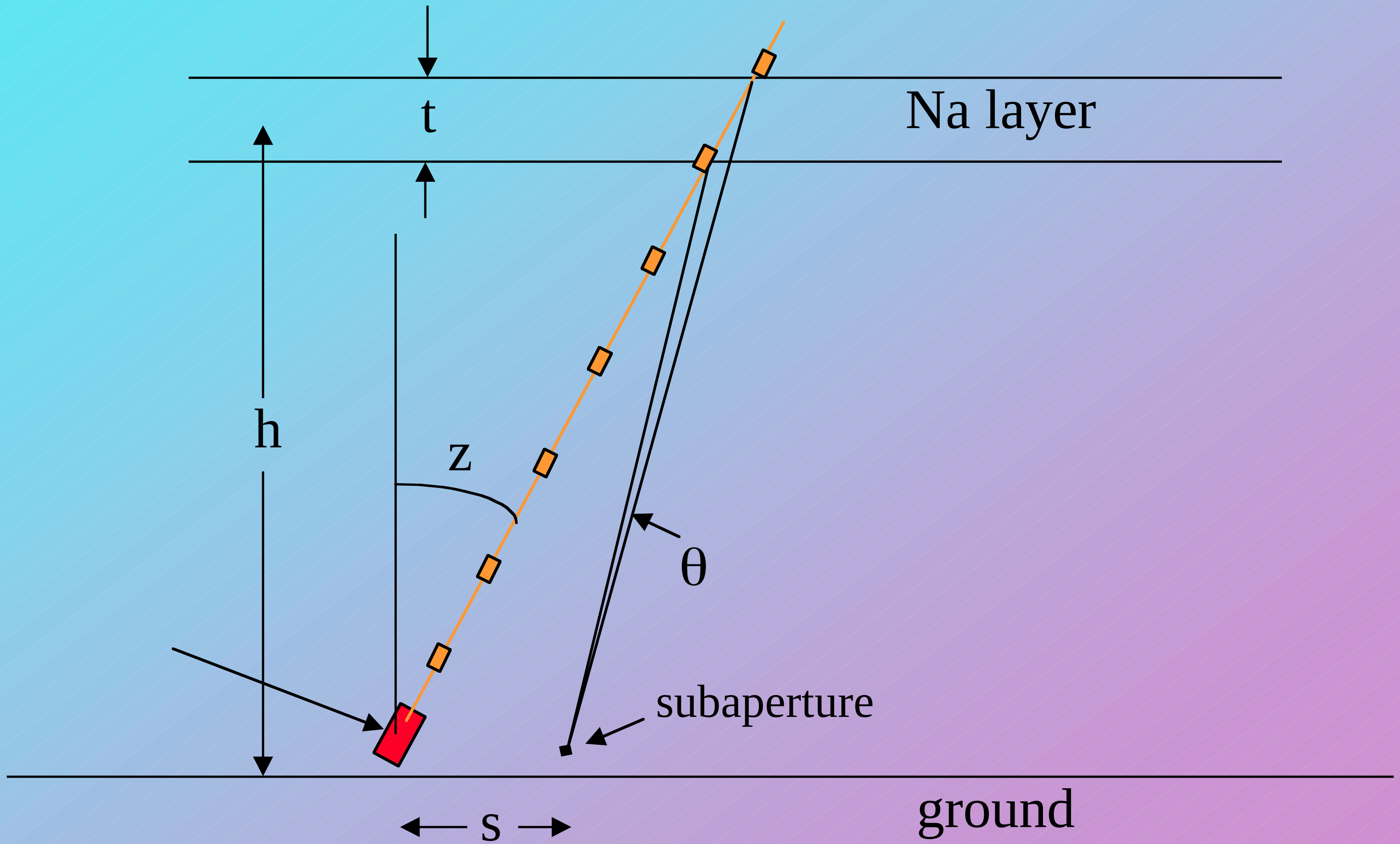
Key Issues

- **How hard is it to make narrow pulse lasers**
  - < 3 μs pulse width (small broadening)
  - ~ 3-15 kHz pulse rate (only 1 pulse in Na layer)
- **How hard is a dynamic focus mechanism**
  - Depends on wavefront difference top of layer- bottom of layer

$$\Delta z = \frac{a^2}{2h^2}\Delta h \cos z \sim 140\mu m$$

  - Resonanant piston of lens (U of A testing)
  - Stack of birefringent lenses (polarized light, fast polarization switches to insert birefingent lenses- discrete approx to continuous focus- Beckers)
- **How do we deal with laser fratricide (Rayleigh vs Na)**
- **How hard are custom shaped CCD's**
- **Need to quantify the impact on wavefront error**

Pulsed laser format



Illuminating a Na location