TMT
THIRTY METER TELESCOPE

Focus errors from tracking sodium layer altitude variations with laser guide star adaptive optics for the Thirty Meter Telescope

CfAO Fall Retreat, Nov. 2006, Yosemite CA

Glen Herriot[a], P. Hickson[b], S. Davis[b], R. Clare[f],
B. L. Ellerbroek[c], J.-P. Véran[a], C. Y. She[d], D. Looze[e]

[a]National Research Council Canada – Herzberg Institute of Astrophysics,
[b]UBC Canada, [c]TMT, [d]Colorado S.U., [e]U. Mass. [f]Keck Obs.

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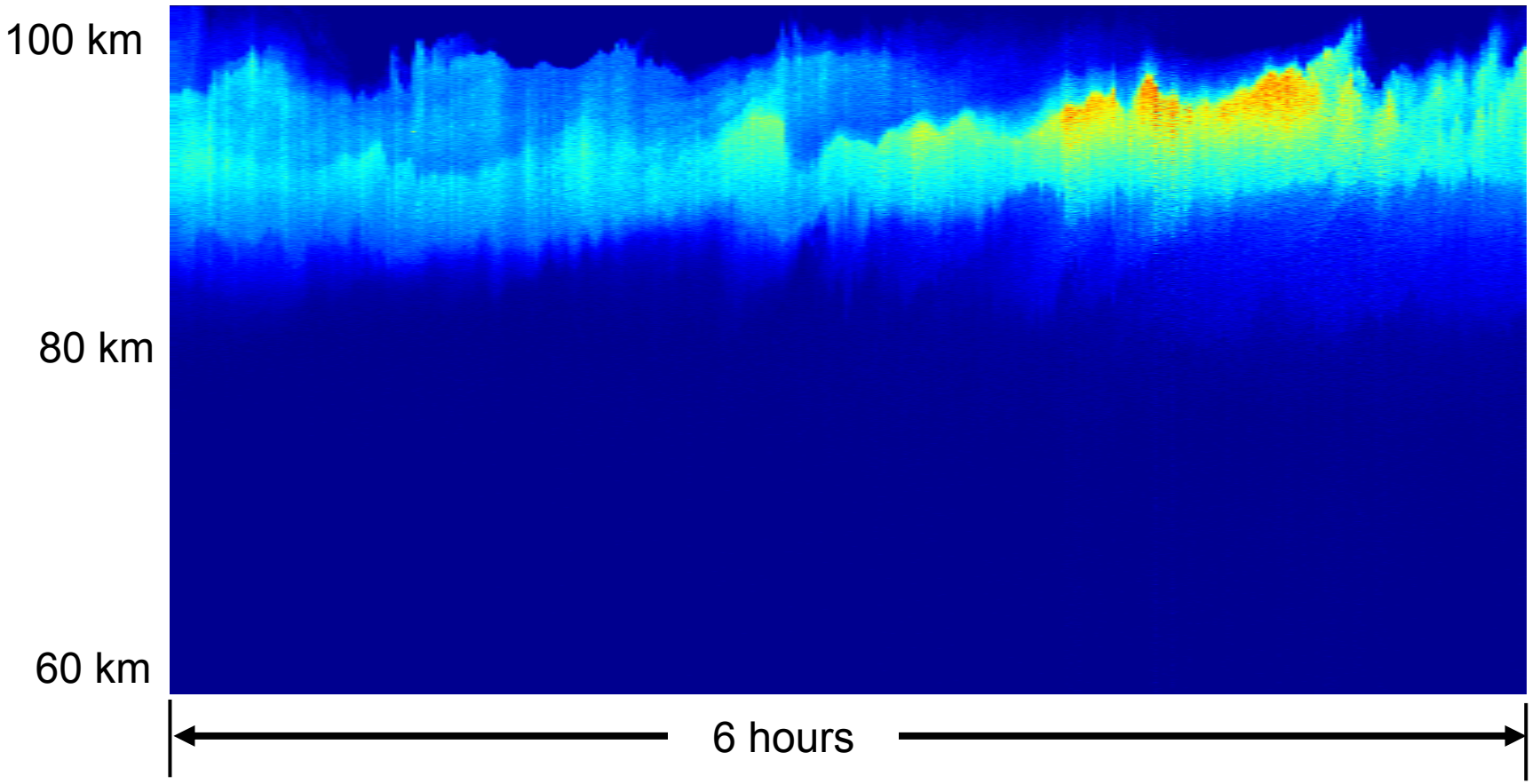
Motivation & Outline.

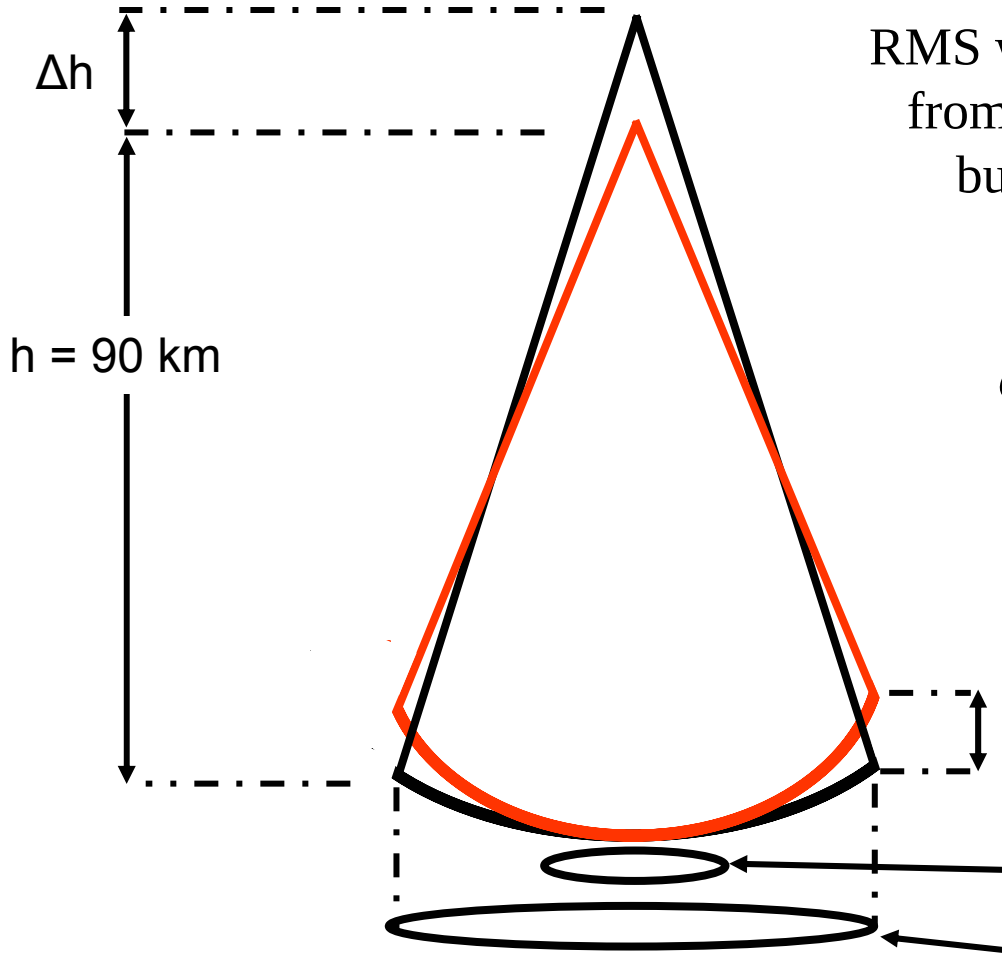
- Sodium altitude variation introduces defocus errors for LGS AO on TMT and other large aperture telescopes
- Sensitivity grows ~ D^2
- Focus sensing via natural guide stars, with good sky coverage, leaves residual servo errors
- Residual WFE = f(Natural Guide Star sky coverage)
- Na Layer thickness reduces signal vs noise on LGS WFS via spot elongation
- Pulsed lasers and novel CCD clocking scheme help both problems

Lidar measurements of Sodium Layer



- Purple Crow Lidar, University of Western Ontario

Defocus Wavefront error ~ D^2

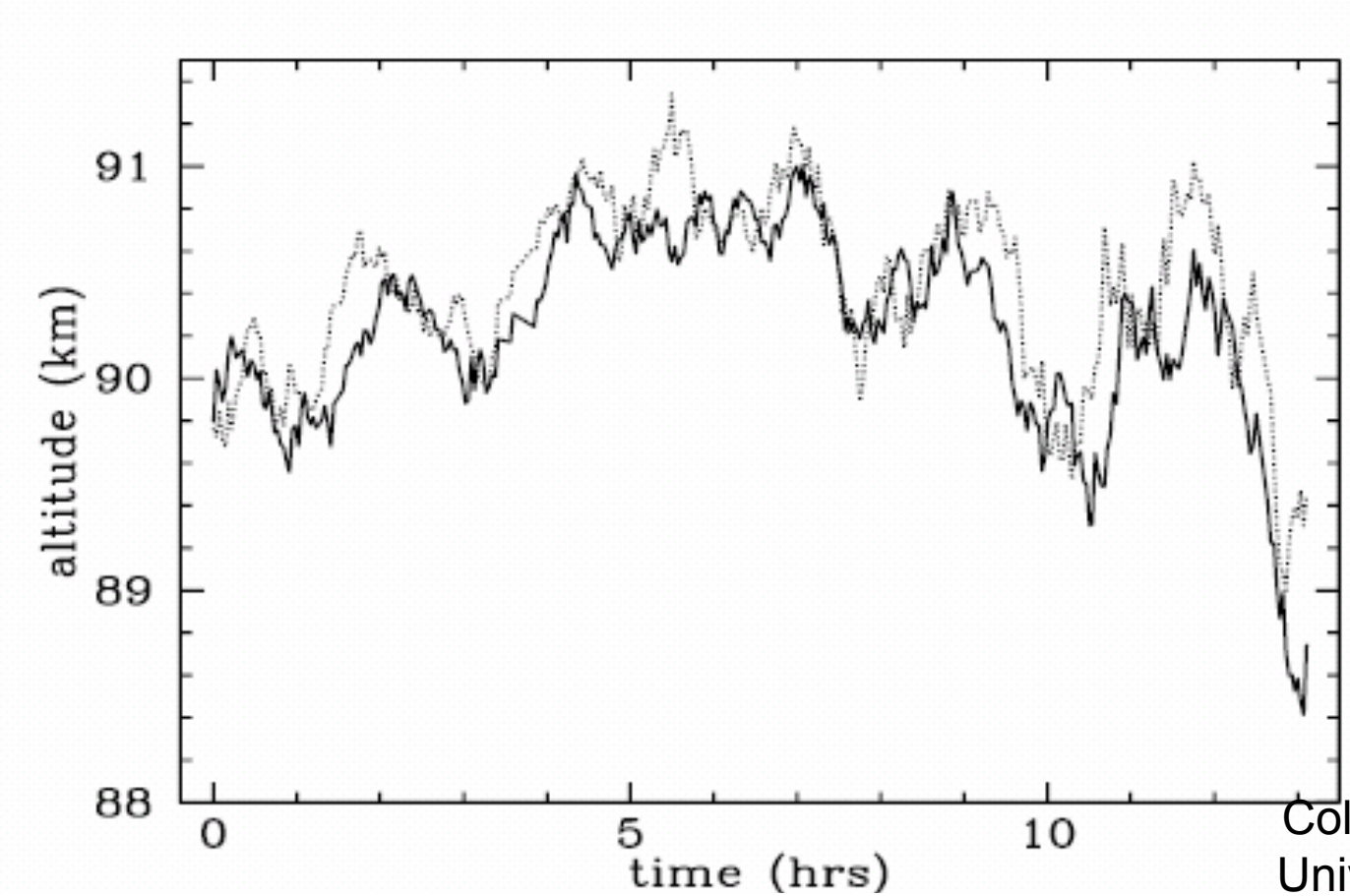


RMS wavefront focus error 120 nm from Δh =15 m defocus is entire budget for TMT NFIRAOS

$$\sigma = \frac{1}{8\sqrt{3}} \cdot \frac{D^2}{h^2} \Delta h$$

Sodium altitude time series

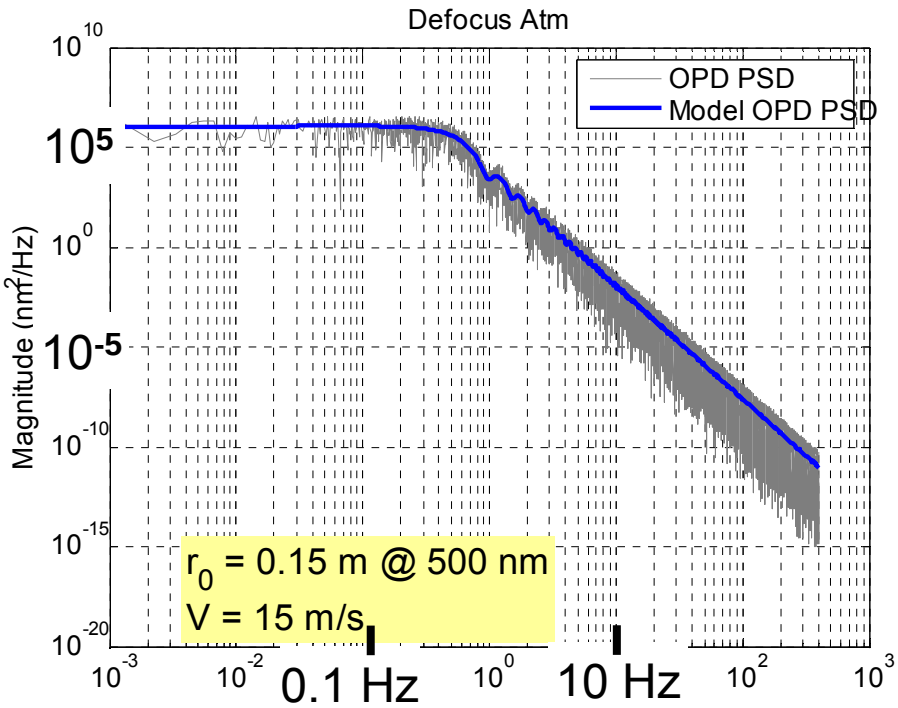
- One night, at zenith and 30 degrees off-zenith

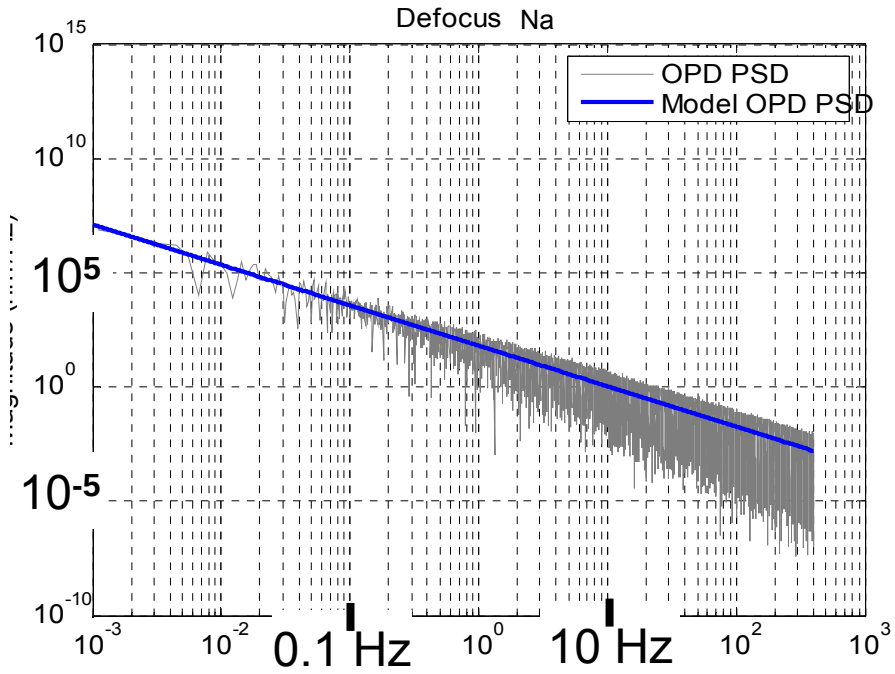


Colorado State University Lidar

Temporal frequencies overlap: turbulence focus and Na altitude defocus

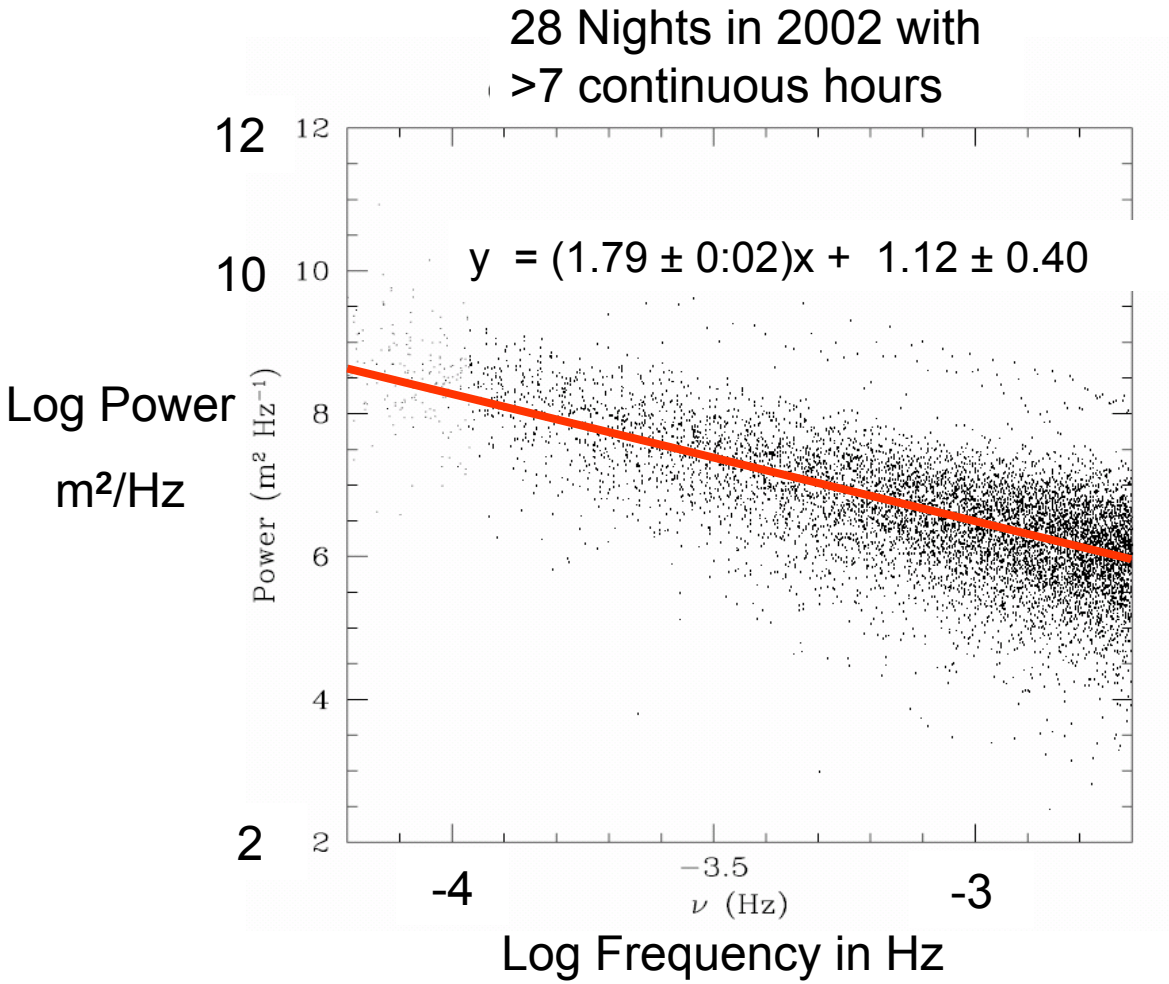
Atmospheric Focus
PSD nm²/Hz





Focus PSD nm²/Hz from Na altitude variations at 30-m telescope

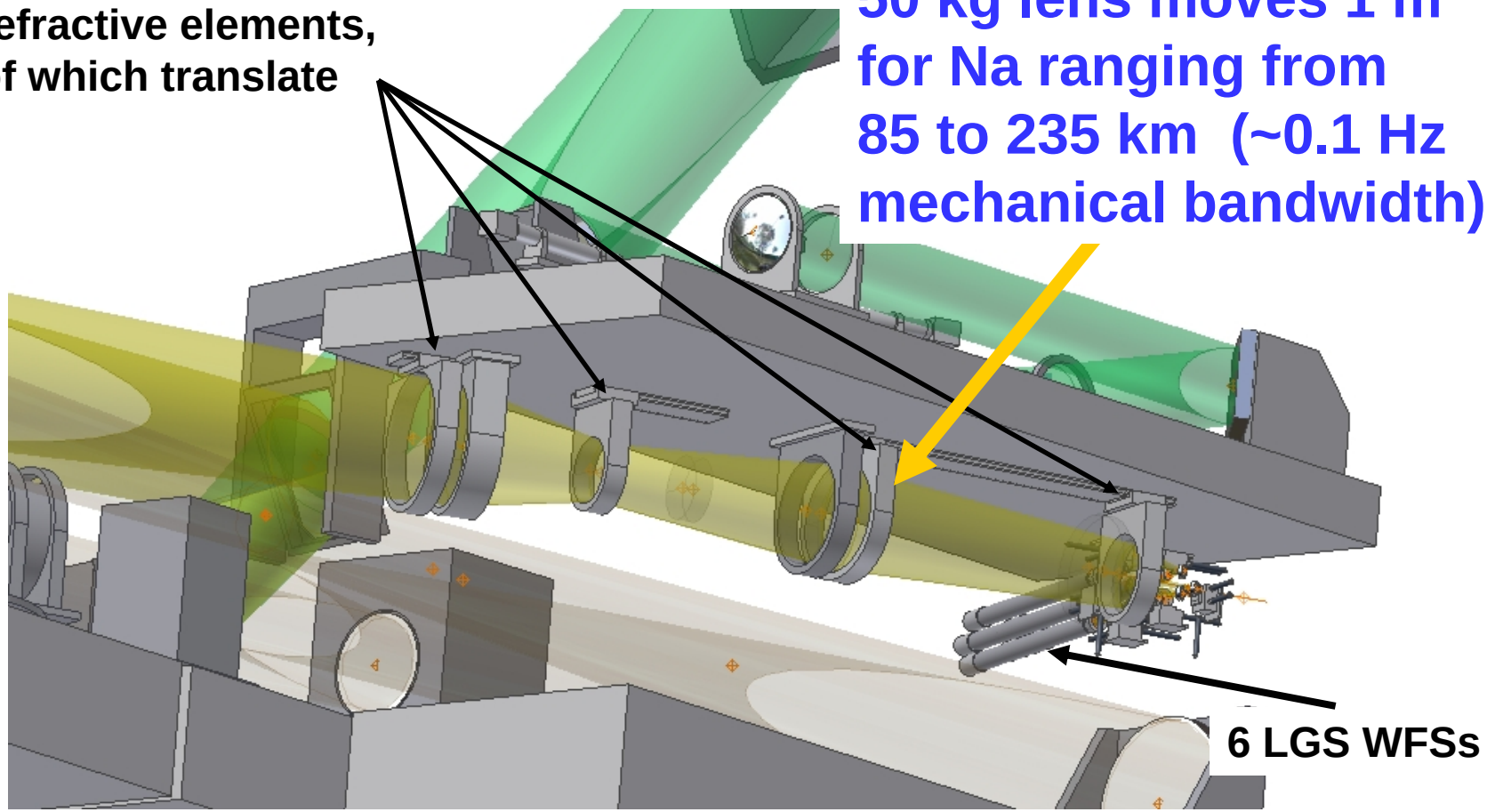
Power Spectrum of Na Altitude



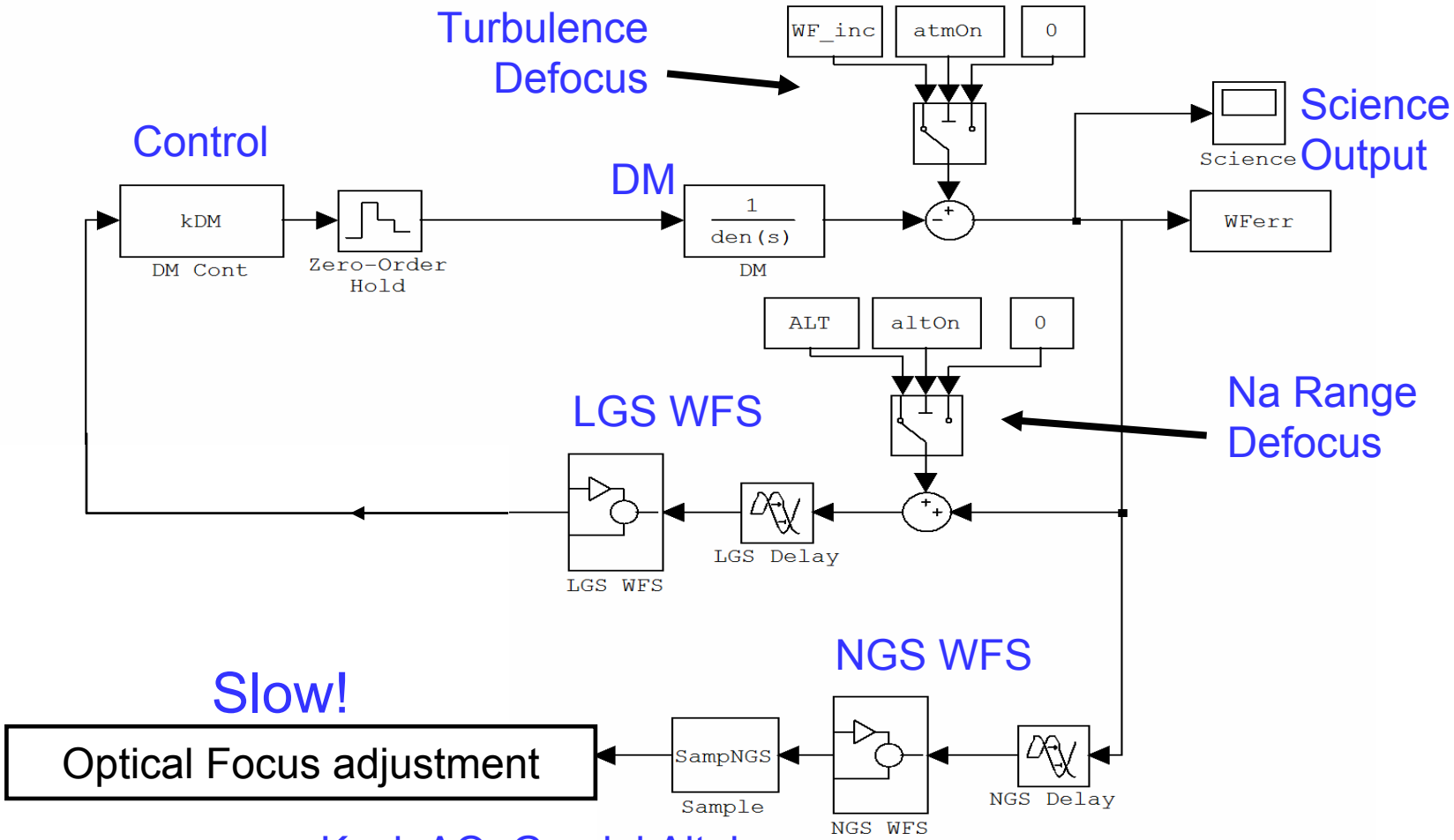
- Only longer data series (>7 hrs) included
- Long time → Narrower windowing function in Fourier domain
- ∴ Steeper PSD slope than we showed in Orlando.
- ∴ More benign high frequencies

Colorado State University Lidar

TMT NFIRAOS' Laser WFS Components

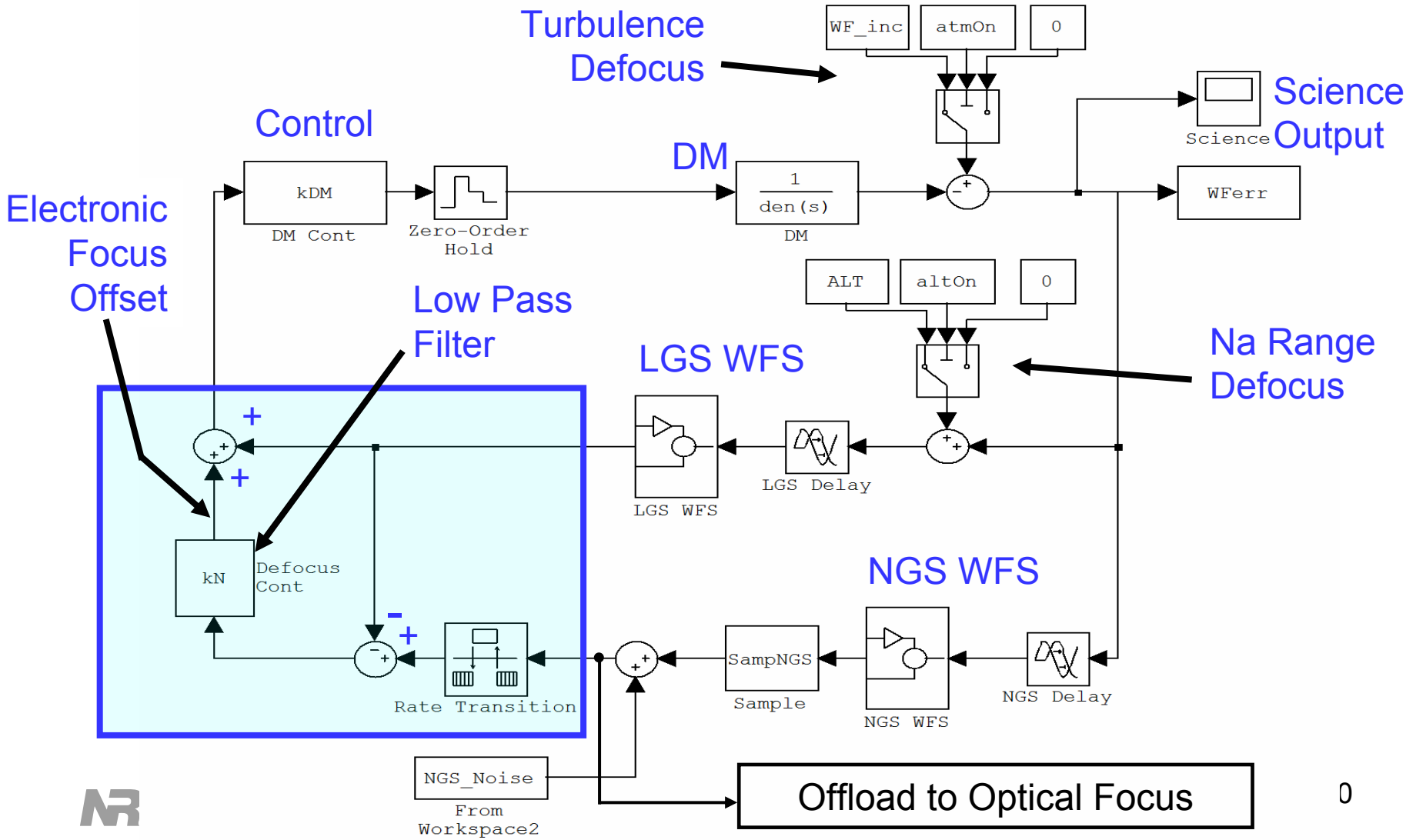


Simulink Model
8-m to 10-m Telescope Na Tracking

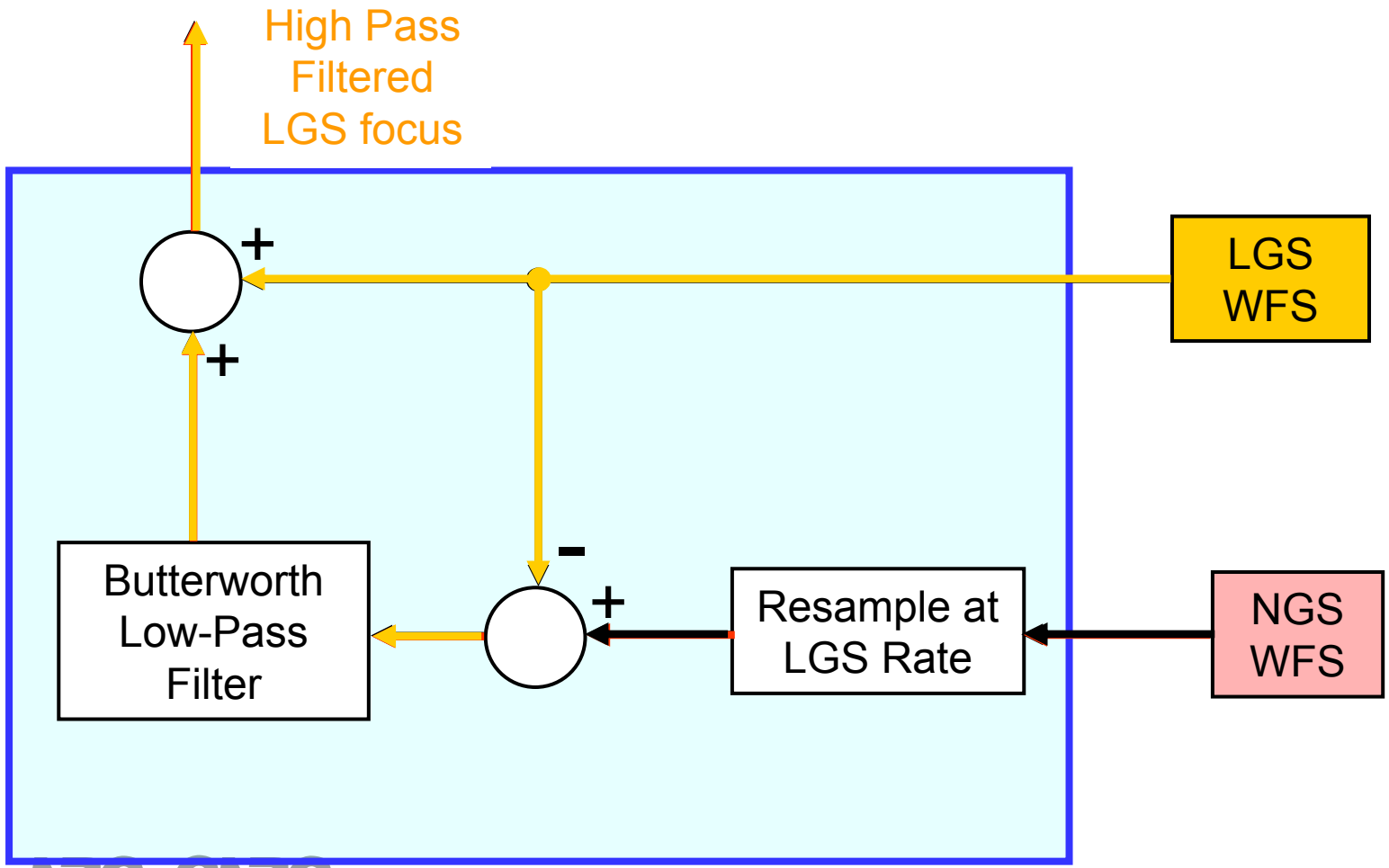


e.g. Keck AO, Gemini Altair,
Gemini South MCAO

Sodium Layer Electronic Focus Offset for 30-m Telescope

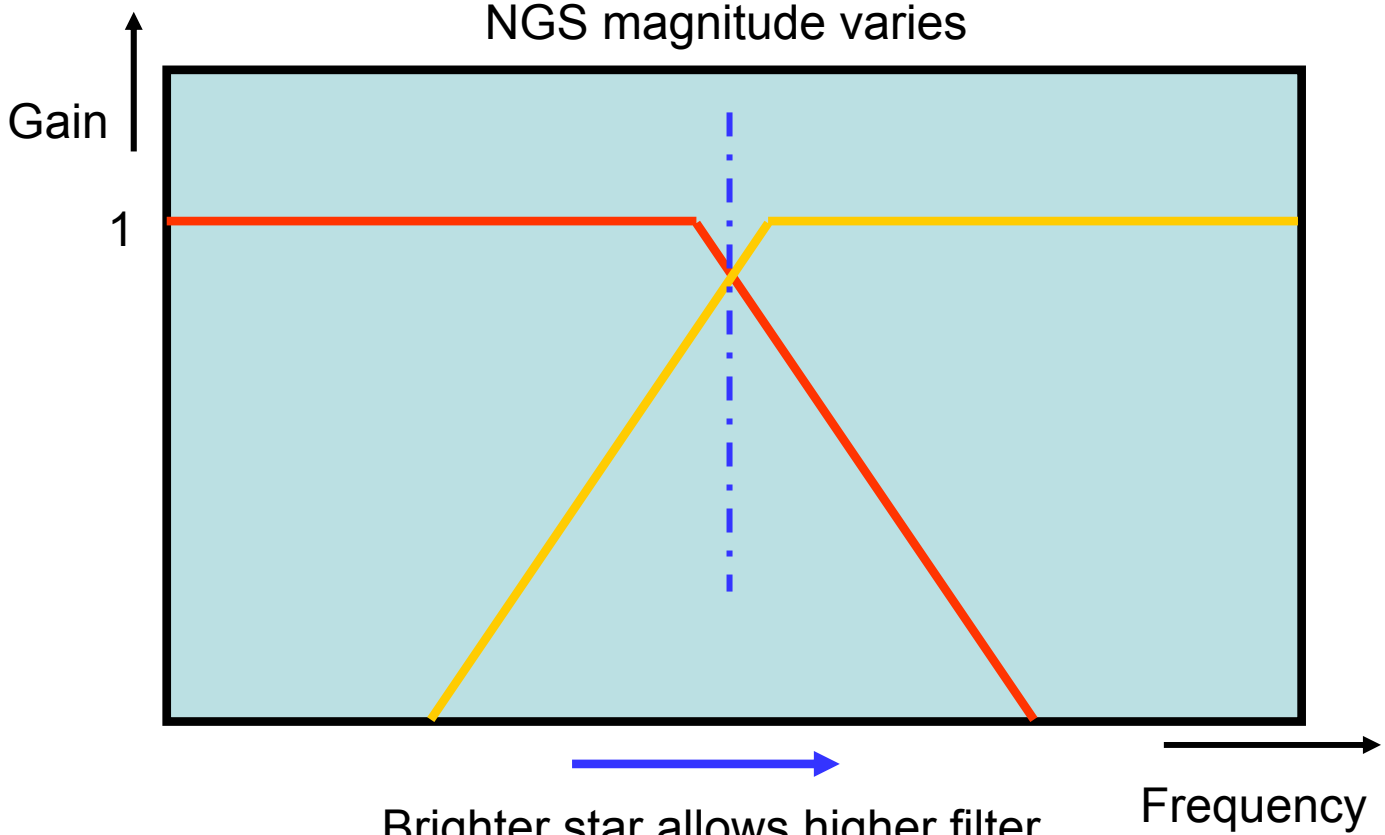


Electronic Focus Offset Detail

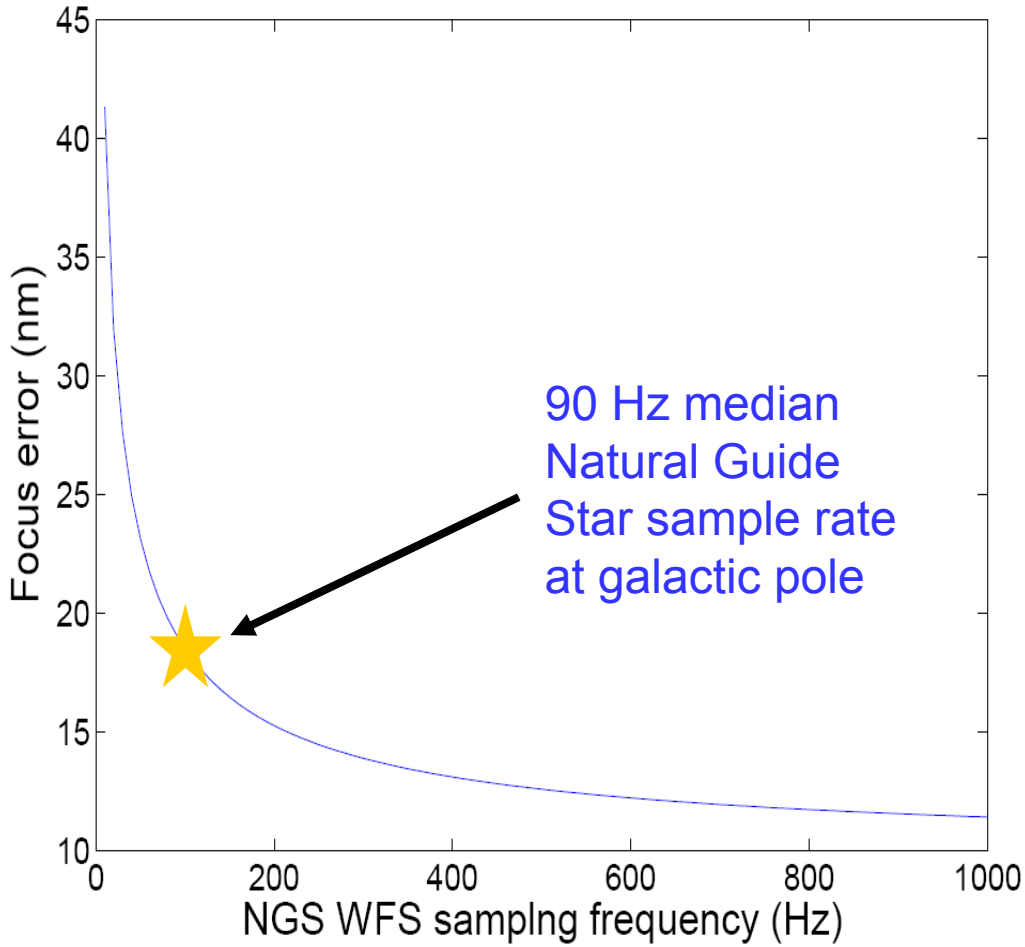


Why such an arcane scheme?

- NGS and LGS filters are exactly complementary
- Single parameter, Filter BW, adjusts blending as NGS magnitude varies

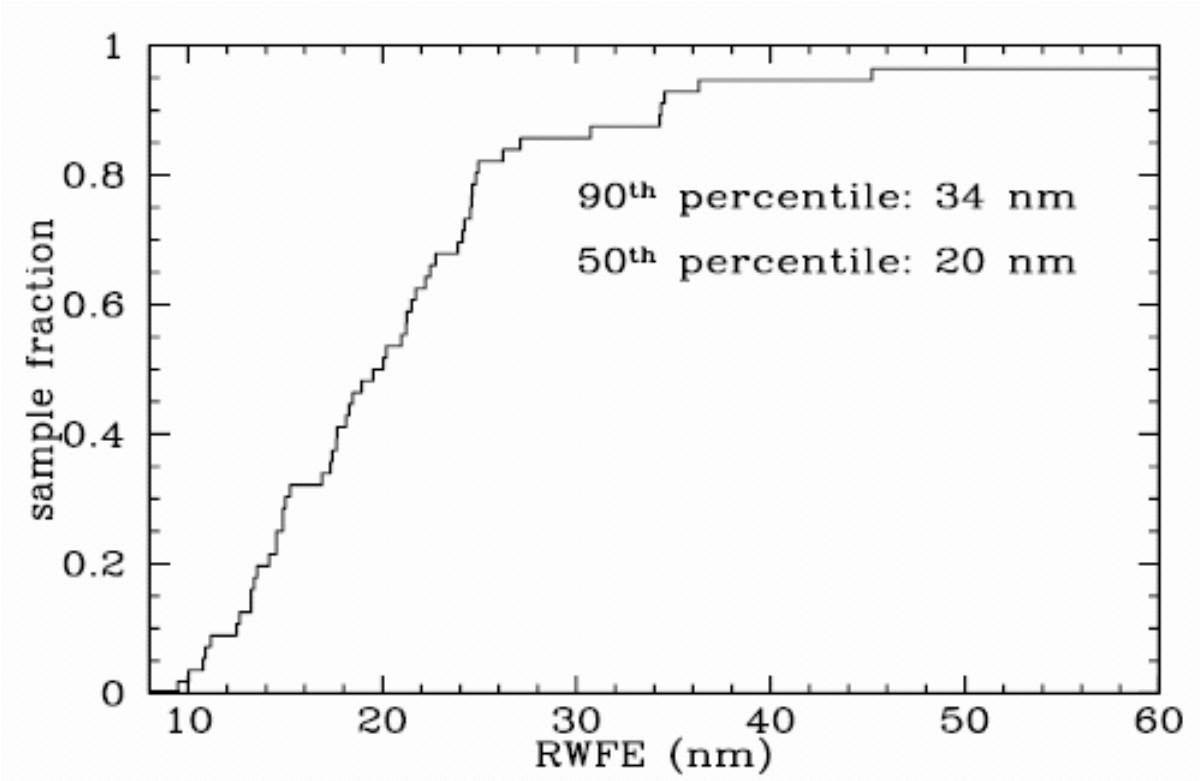


Na Defocus vs sample rate using WFS electronic focus offsets



- Based on Tip-Tilt error budget & Sky coverage models for TMT NFIRAOS
- Optimization of frame rate to balance servo lag, read and photon noise, measurement errors, anisoplanatism, and sodium tracking error
- R. Clare, TMT, SPIE Orlando, 6272-107

Residual error after electronically refocusing via NGS measurements



Latest results from the CSU Lidar

56 time series, each >7 hours duration

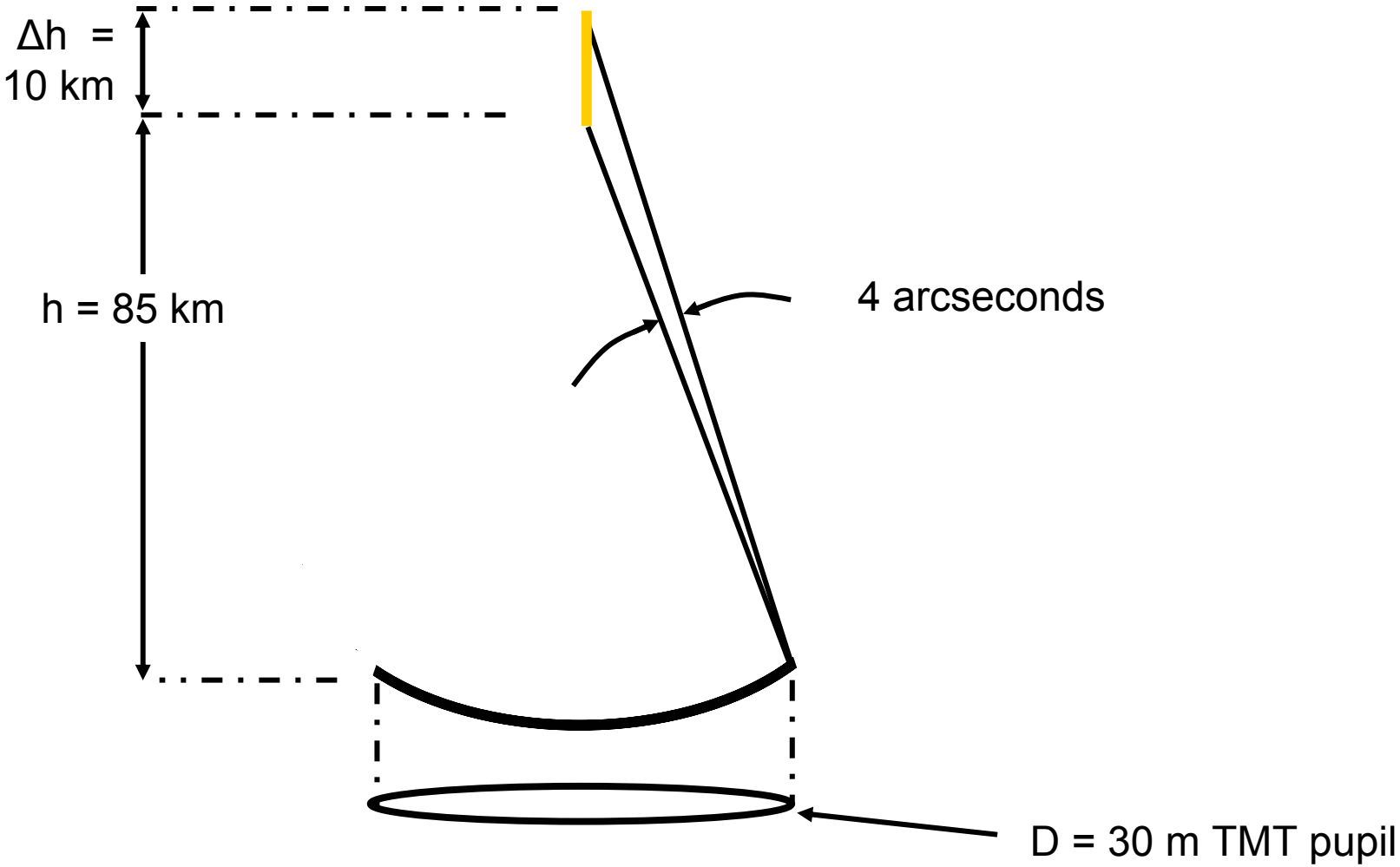
90 Hz electronic focus offsets applied to LGS WFSs

50% sky coverage at galactic pole.

Sodium layer altitude tracking

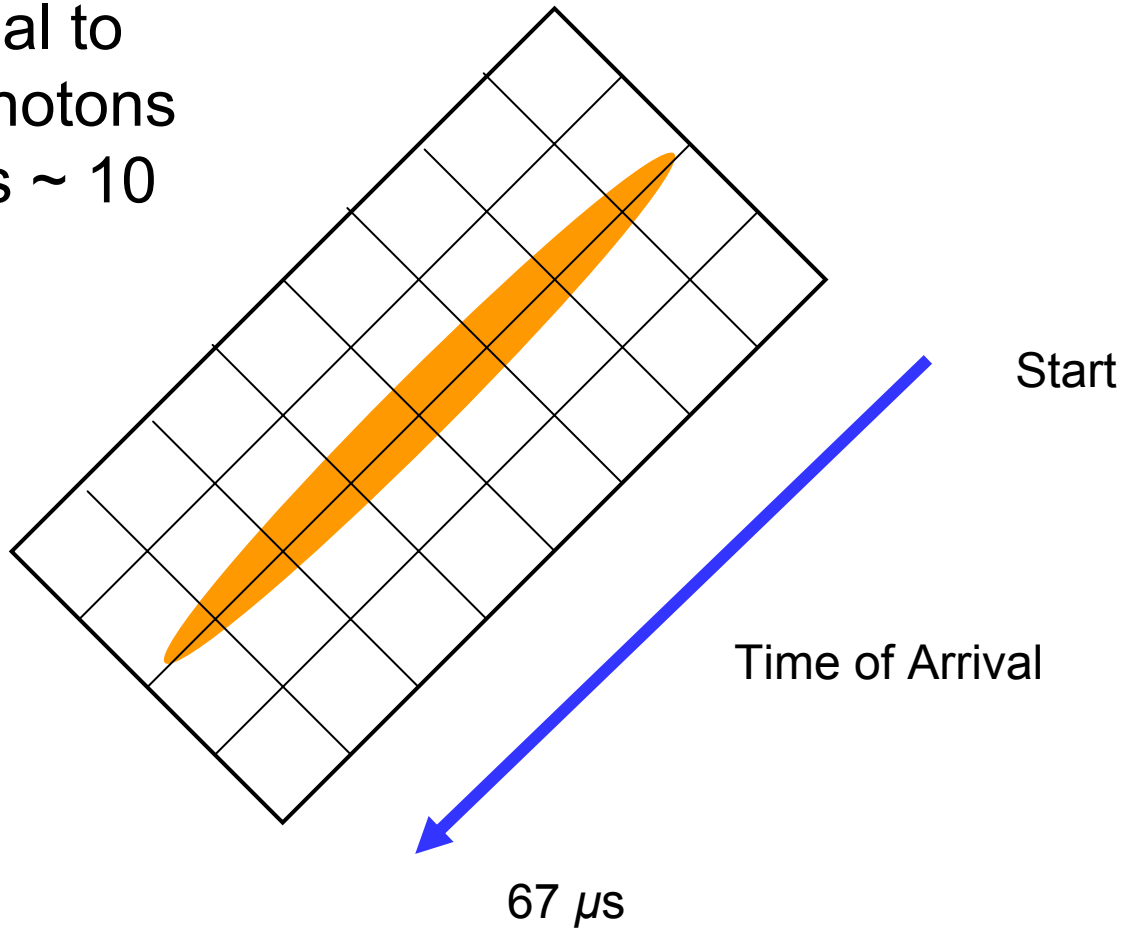
- LGS WFS confounds Na layer altitude change with turbulence
- Need to rely on moderate bandwidth NGS WFS for focus tracking
- On D=30m, 1 m of tracking error = 8 nm rms (D^2 effect)
- Lidar data available with temporal resolution of 2 min
- From each measurement, a PSD is derived and extrapolated
- Rejection transfer function is applied (90 Hz frame rate, electronic compensation)
- Residual is computed
- Caveat: 3 decades of temporal frequency extrapolation
  - Higher time-resolution data planned for further studies

WFS Spot elongation 4 arcseconds

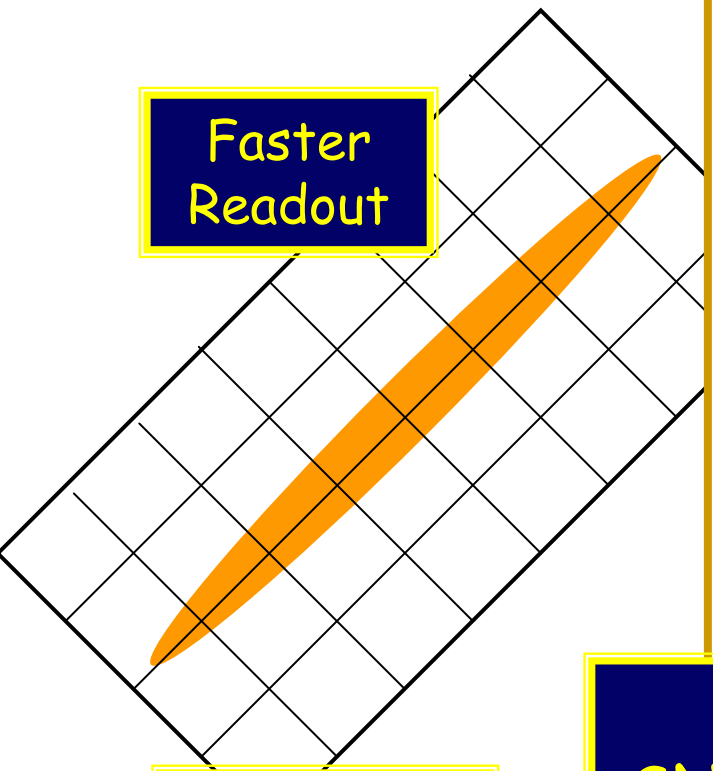


Elongated Pattern on CCD

- Reduced signal to noise since photons spread across ~ 10 pixels.

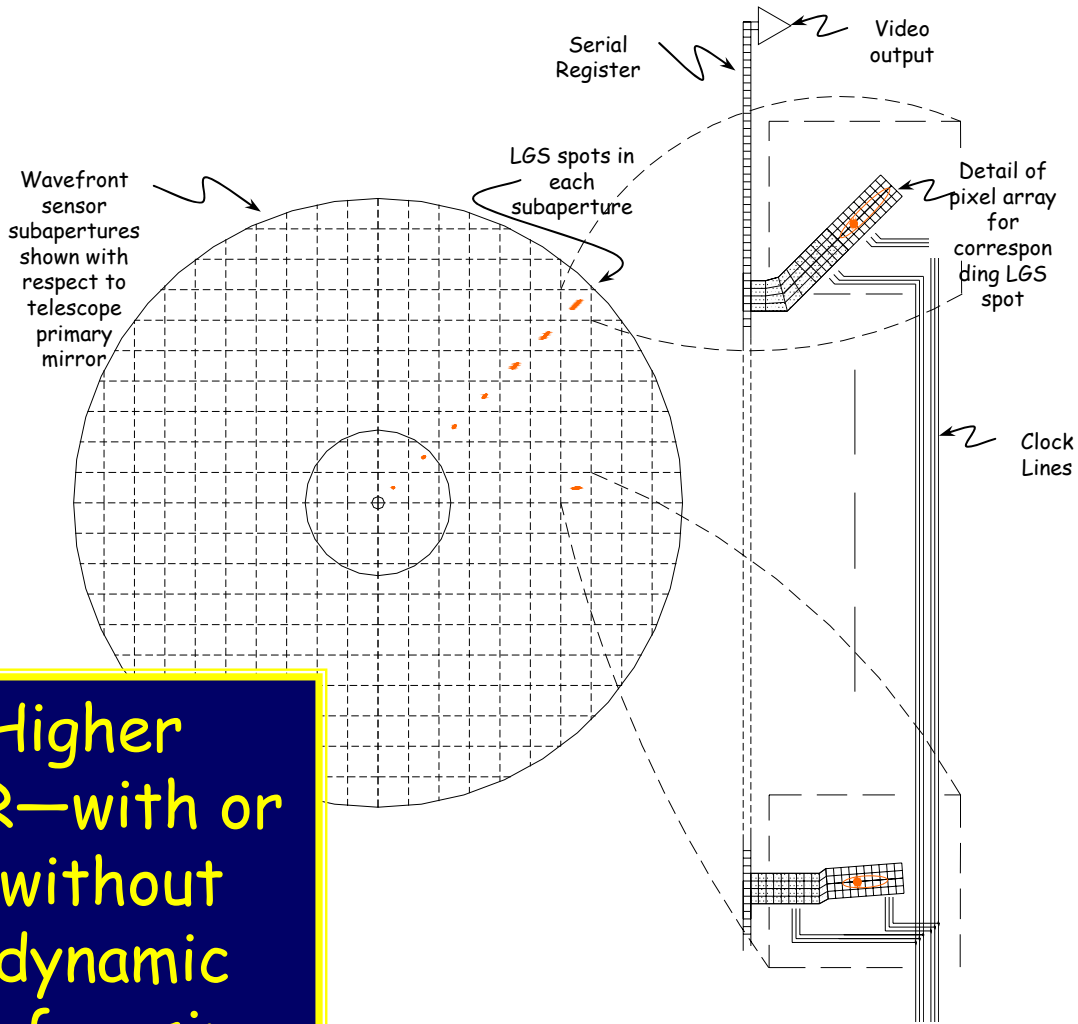


Polar coordinate CCD Pixel Geometry for Laser Guidestars



Faster Readout

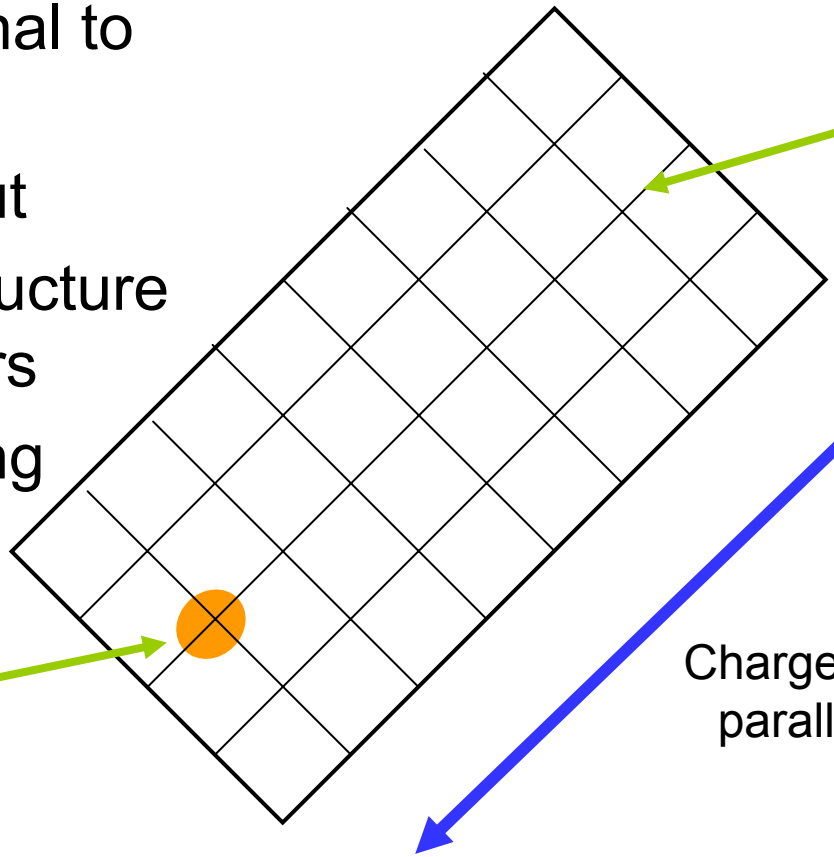
Lower Readout Noise



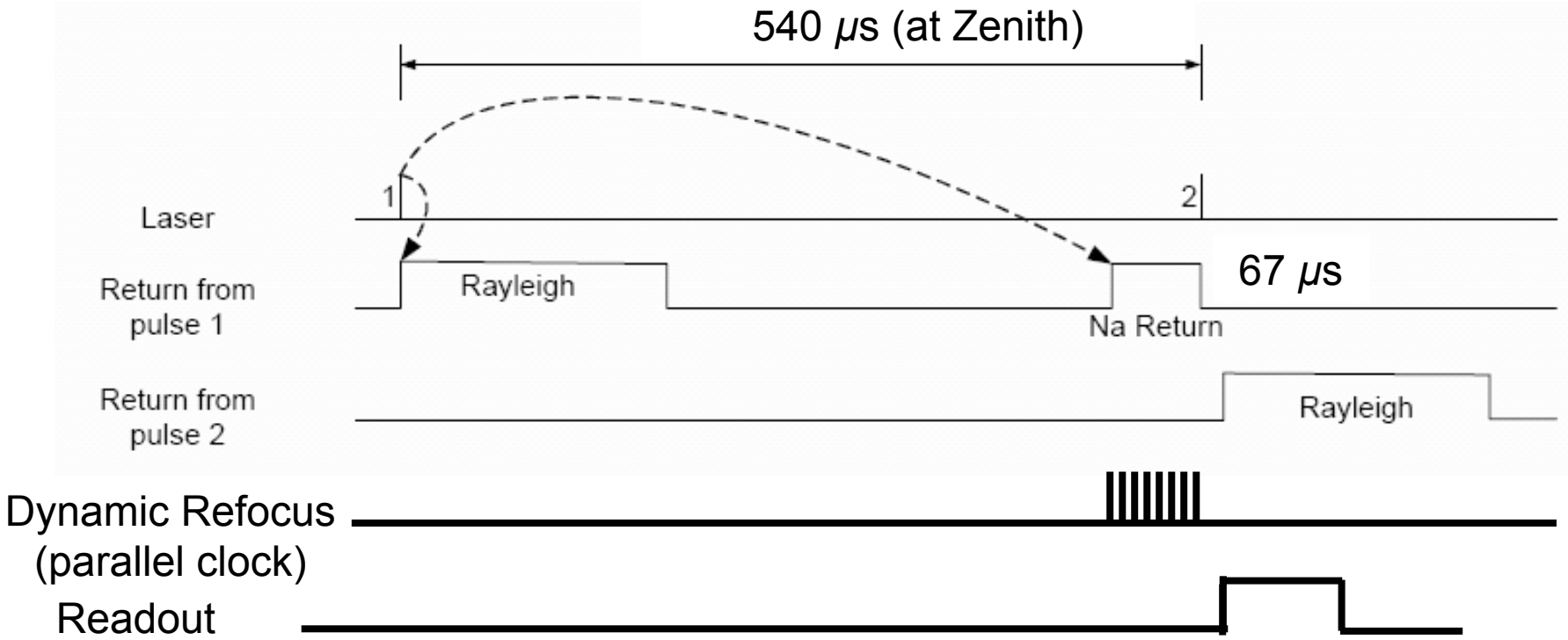
Higher SNR—with or without dynamic refocusing

Dynamic Refocusing on CCD

- Improved signal to noise
- Faster readout
- Avoids Na structure variation errors
- Avoids tracking errors

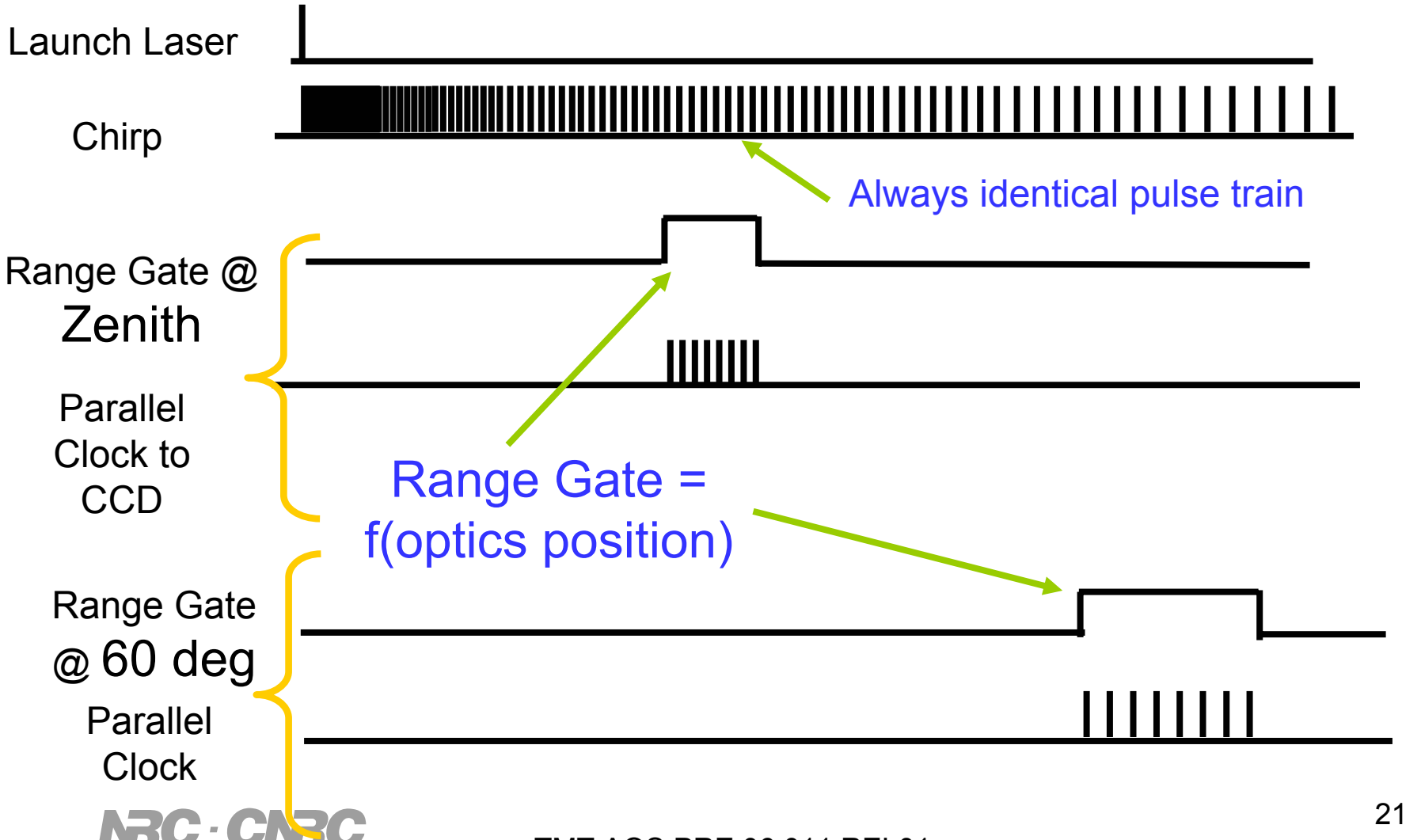


Pulsed Laser Timing at Zenith



- Sean Adkins

Chirped Clock

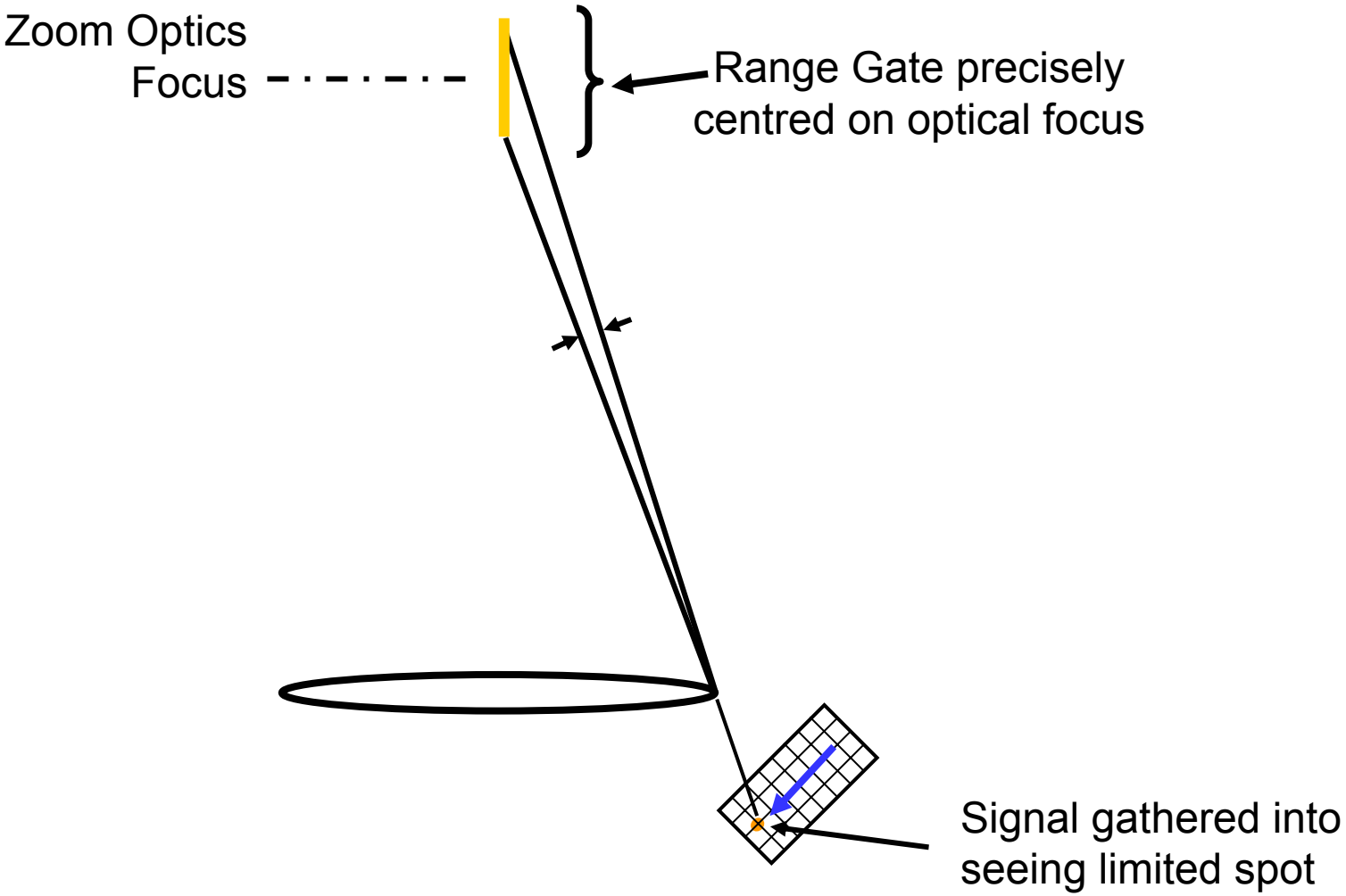


Why does chirp fix focus tracking error?

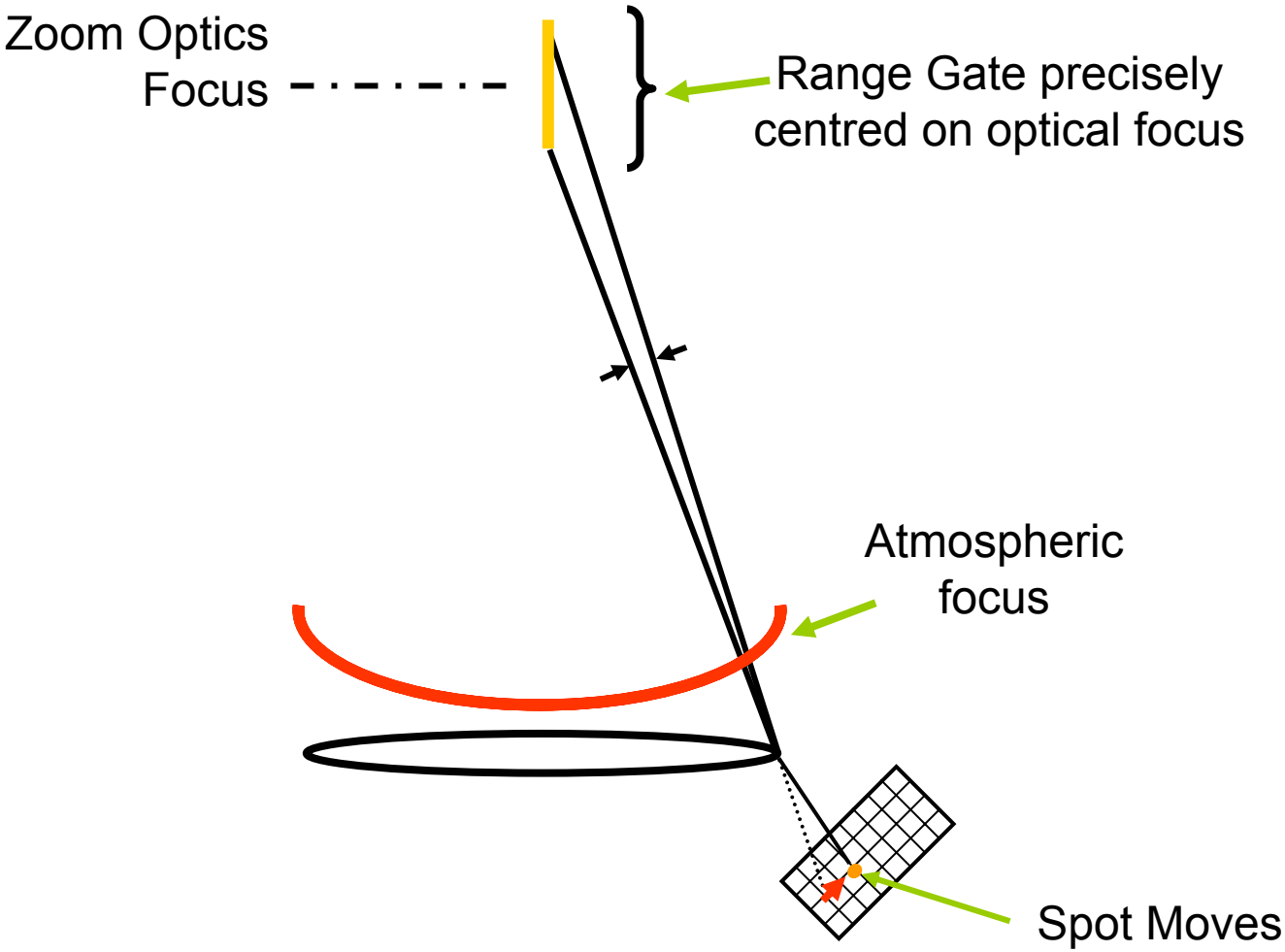
- Return from a given range, arrives at a known time and is collected correctly on CCD.

- Range Gating of chirp pulsed train onto CCD at time determined by current setting of zoom optics.
- Good calibration of mechanical position to range gate interval needed.
- Does not depend on accurate mechanical focusing of zoom optics to track sodium altitude.
- If zoom is severely wrong, flux lost, but no focus error.

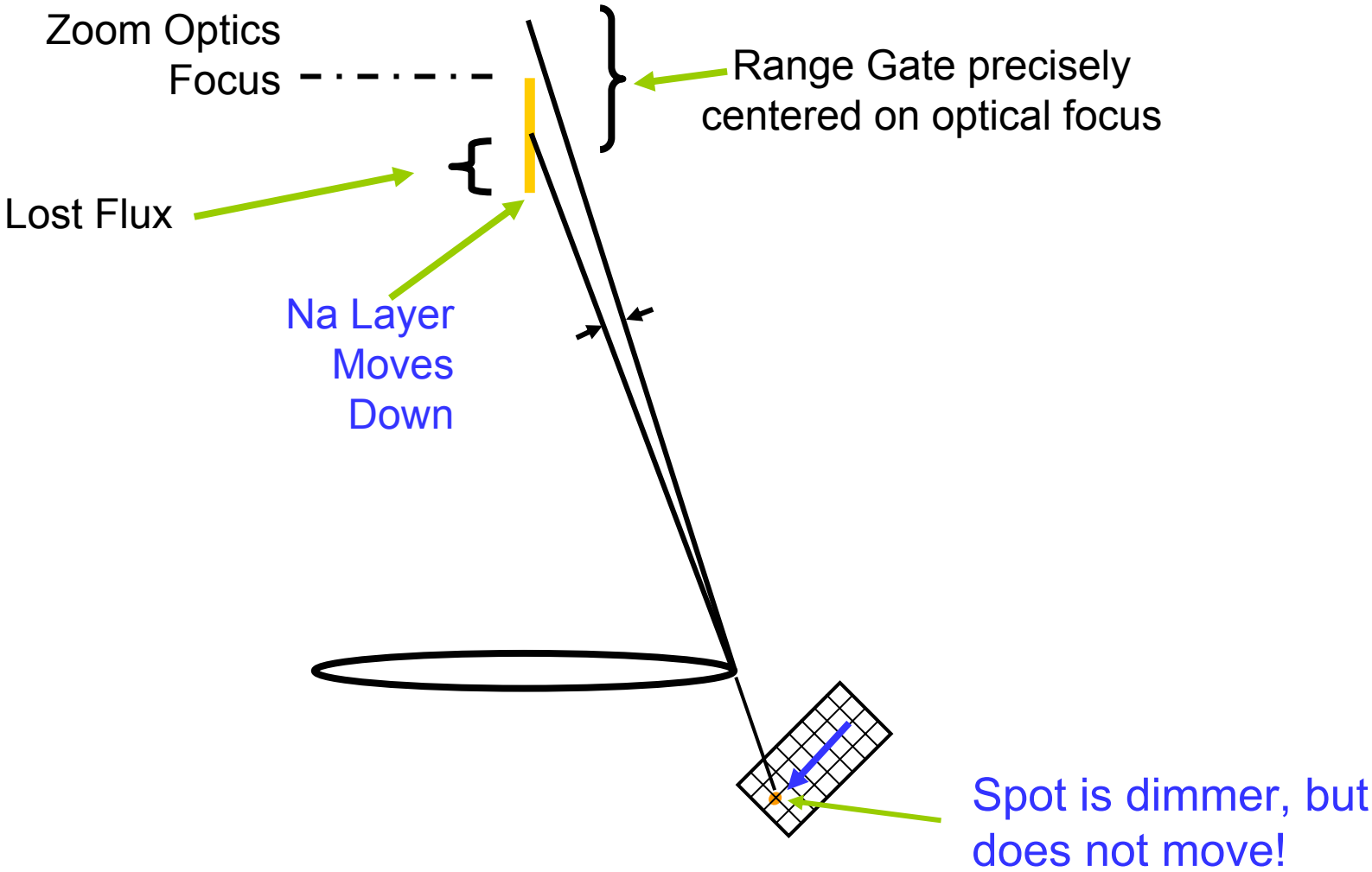
Range Gated Chirp -- ideal situation



Range Gated Chirp -- Turbulence



Chirp: Sodium Layer moves



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Summary

- Sodium Layer mean altitude and structure varies on short time scales, causing measurement errors.
- Spot elongation reduces signal to noise ratio.
- Range-gated chirp-clocked polar-coordinate CCD mitigates both these problems.
  - But depends on a pulsed (~ 3 μs) laser