A down-to-earth guide to high-resolution solar observations

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AURA

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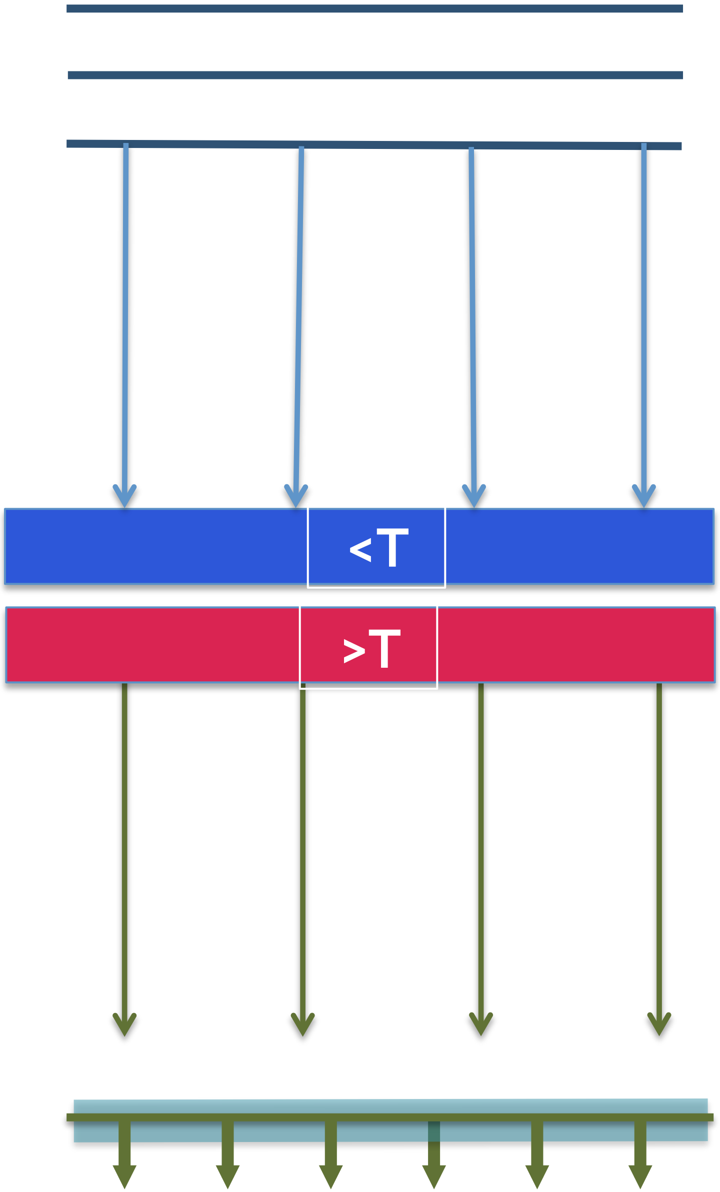
DKIST
DANIEL K. INOUYE SOLAR TELESCOPE

Terminology and Concepts

- Seeing
- Adaptive Optics
- Image Reconstruction
- Atmospheric Effects
- Spectral Lines
- Calibration Considerations

Atmospheric Turbulence



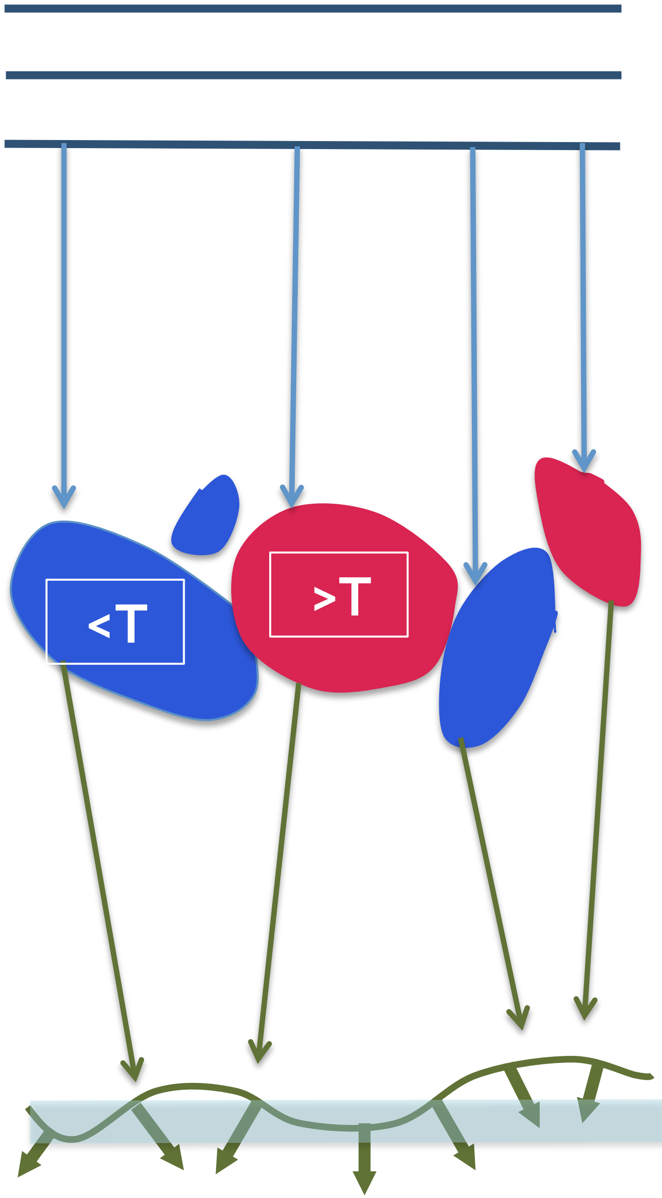
Plane Wave

Stratified (non-turbulent) atmosphere

Unperturbed Wavefront

Telescope Aperture

Atmospheric Turbulence



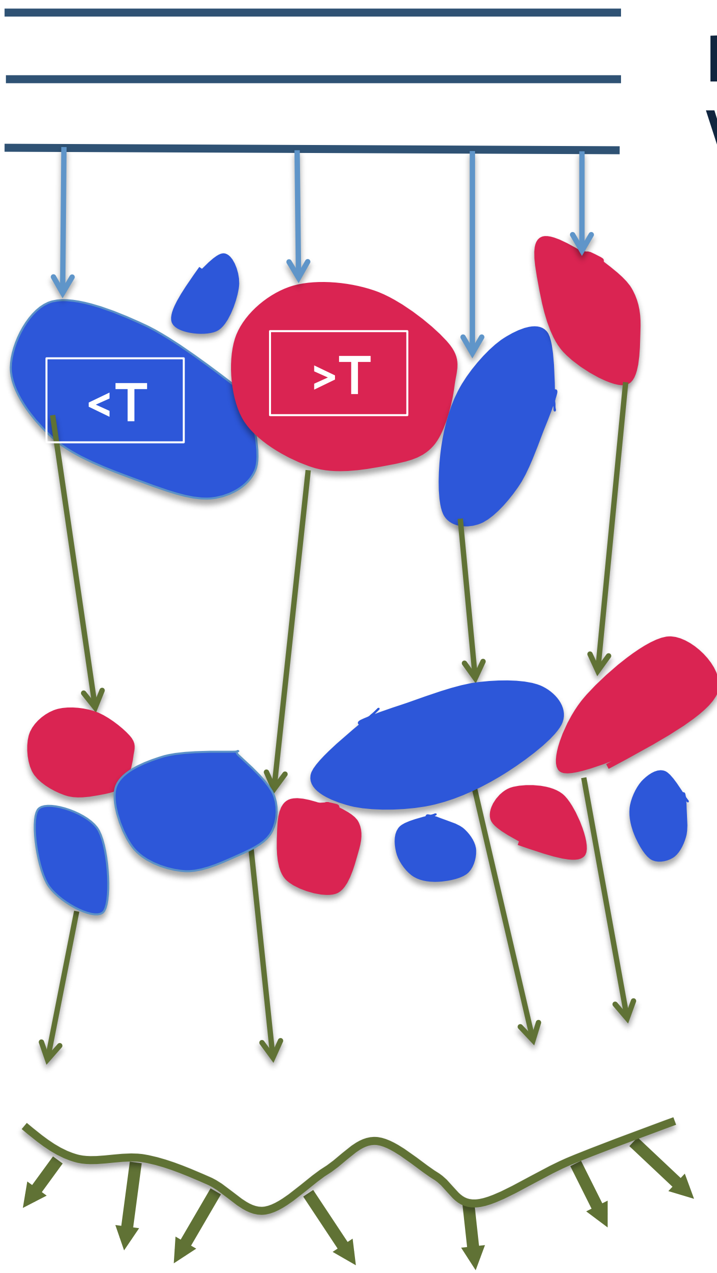
Plane Wave

Index of refraction variations

Distorted Wavefront

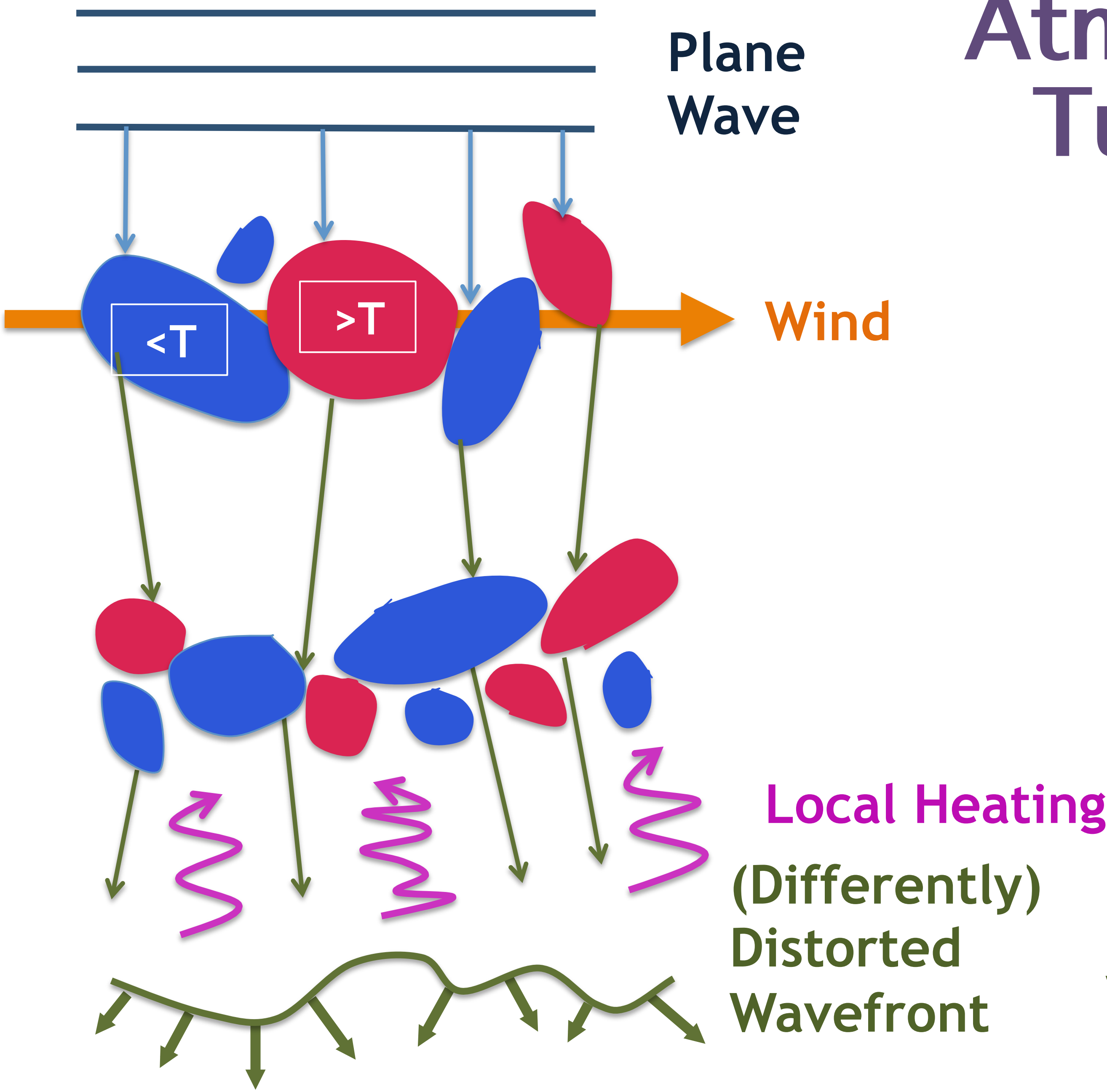
Telescope Aperture

Atmospheric Turbulence



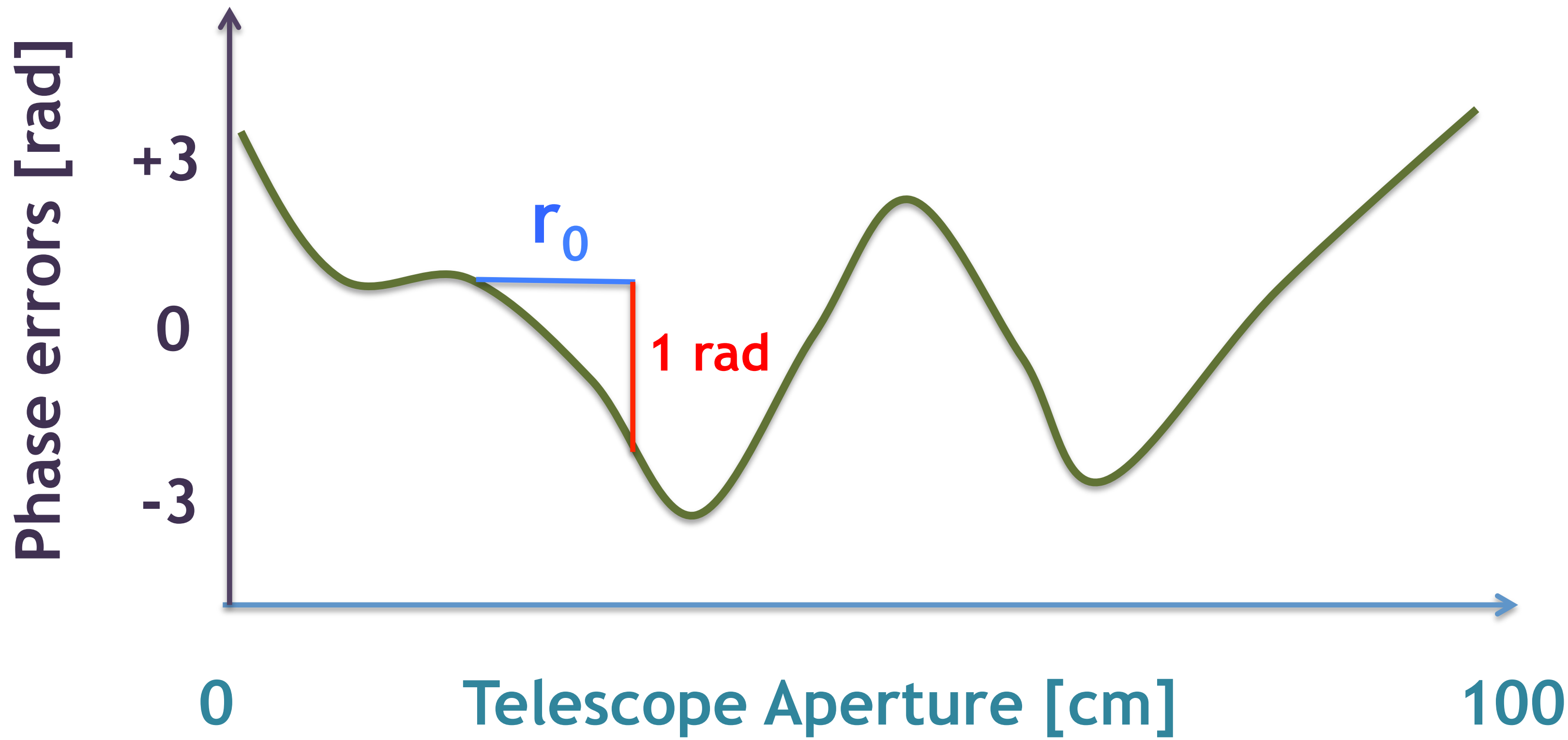
at time t_0

Atmospheric Turbulence



at time $t_0 + \Delta t$
where Δt of order 10 msec

Atmospheric Turbulence

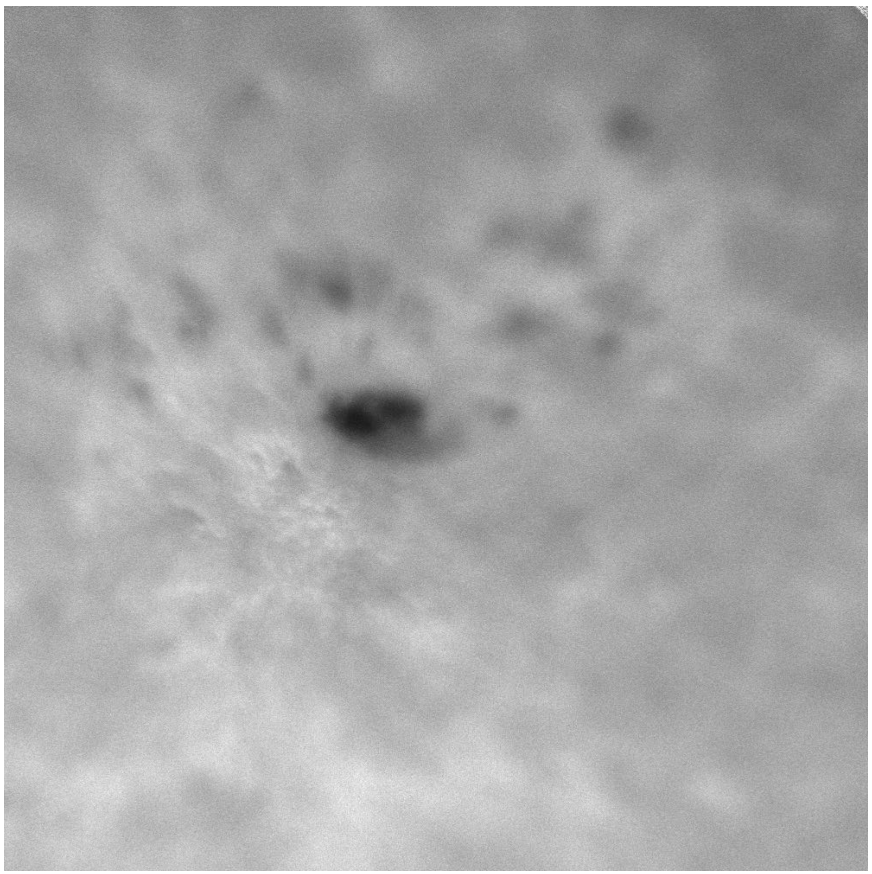


Key term: r_0

average distance over which rms wavefront errors are approximately 1 radian – measure of seeing quality (bigger is better)

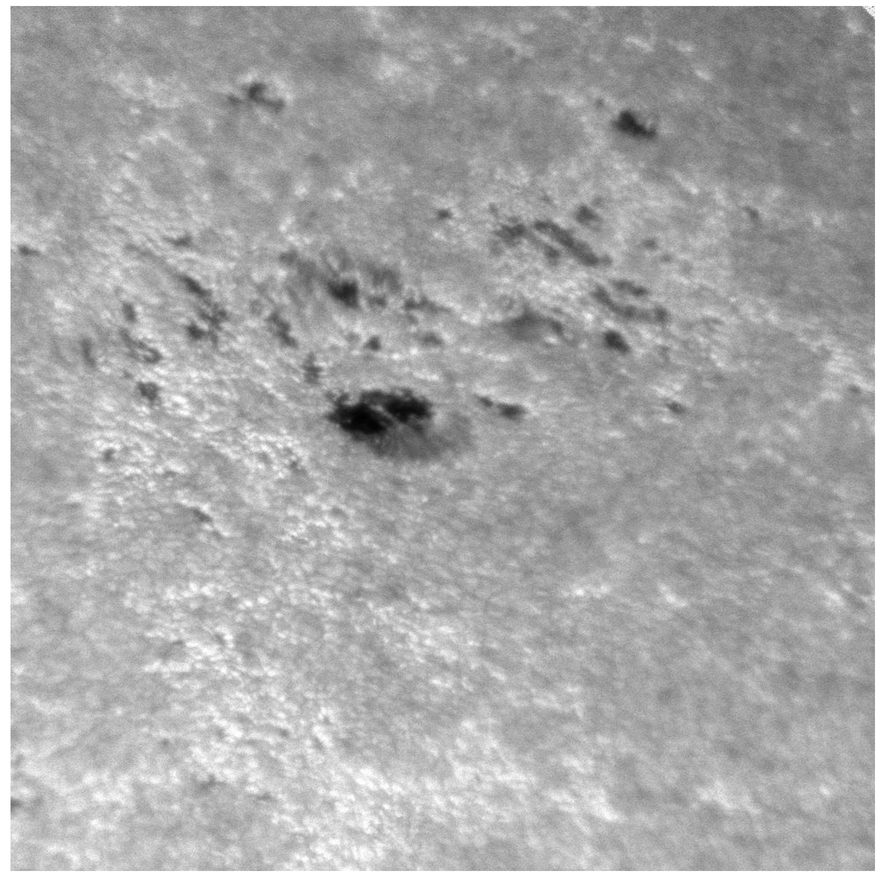
Seeing Quality

low r_0 ; <5 cm

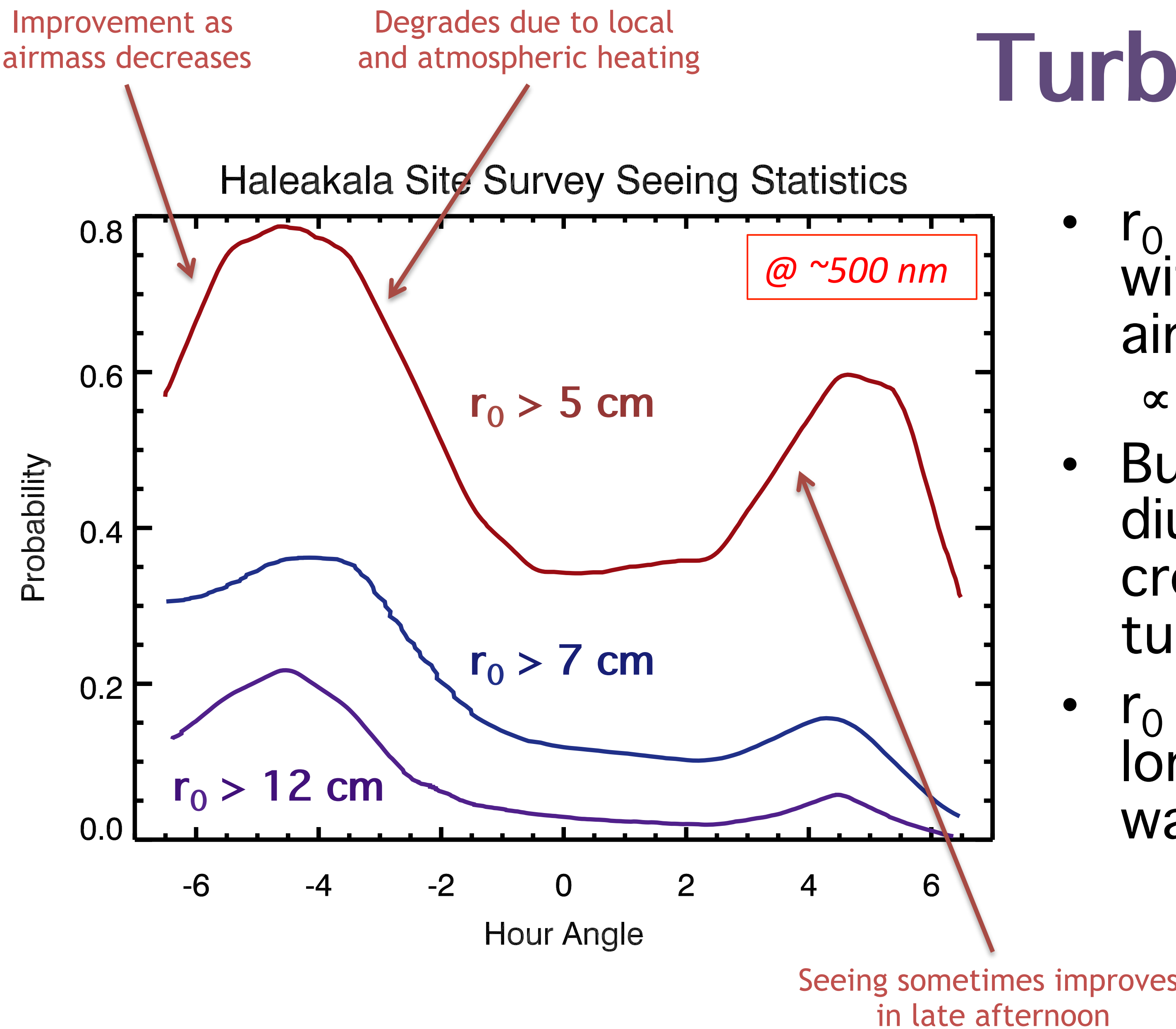


95 arcseconds

high r_0 ; >10 cm



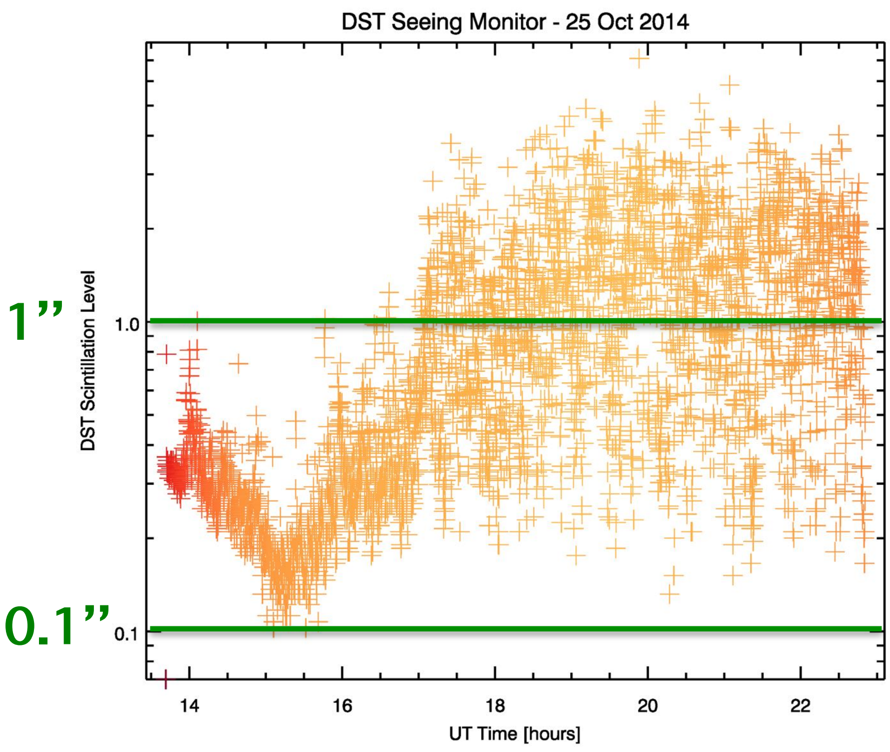
Atmospheric Turbulence



- r_0 decreases with increasing airmass
  $\propto (\cos z)^{3/5}$
- But local/ diurnal heating creates turbulence
- r_0 increases at longer wavelengths
  $\propto \lambda^{6/5}$

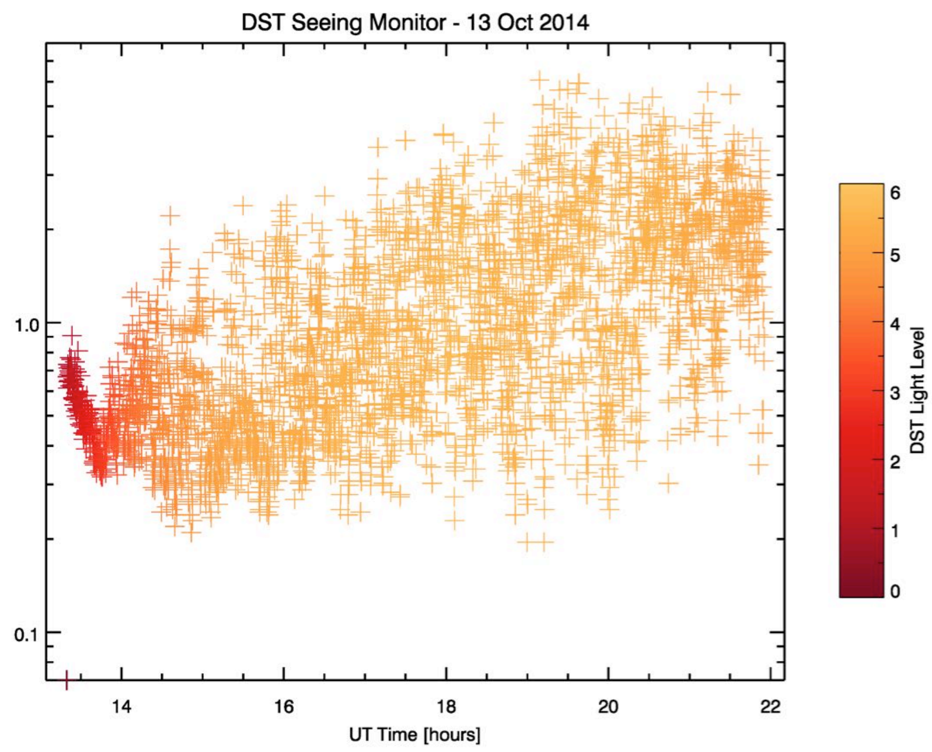
Seeing Variability

"good" seeing



Seeing conditions improve during morning and slowly degrade

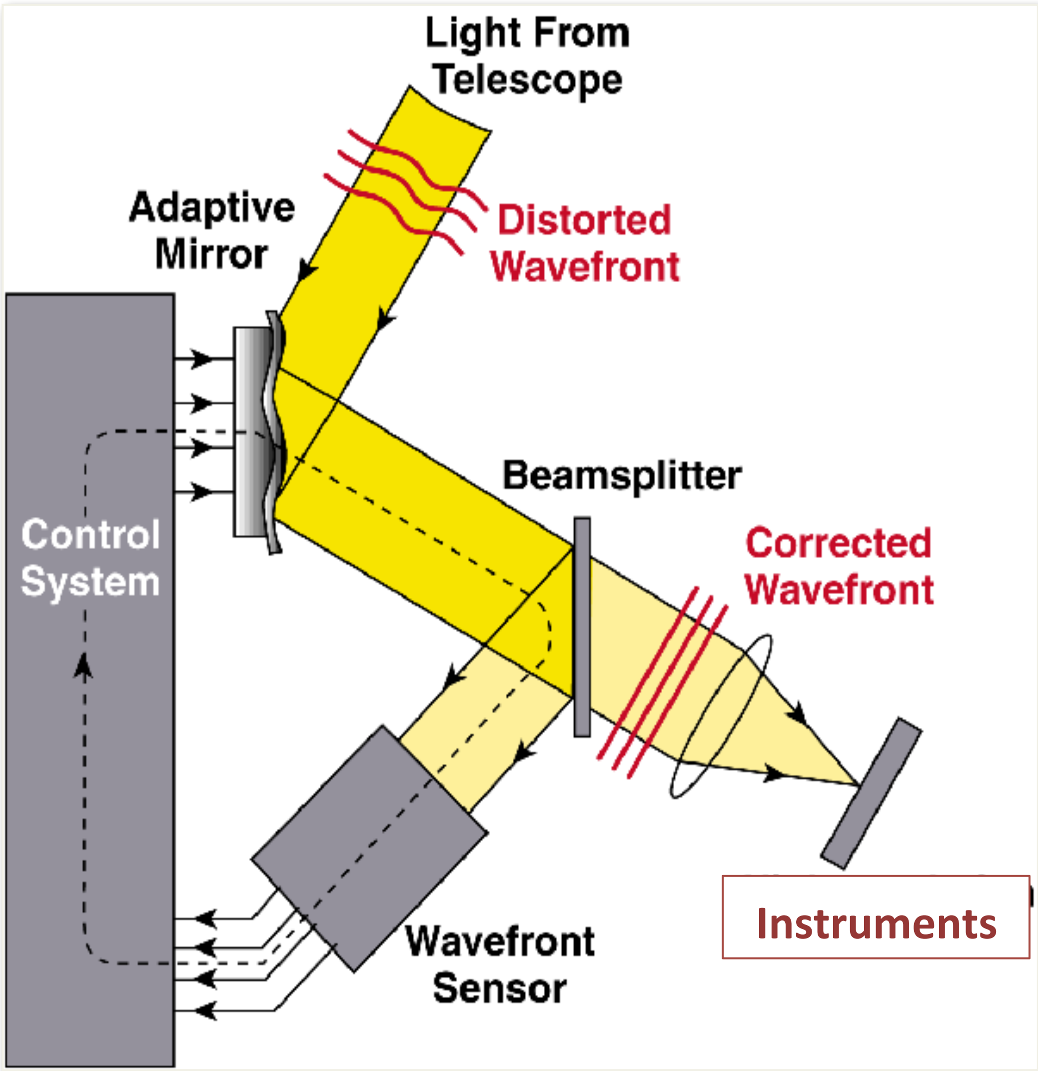
"poor" seeing



Conditions improve slightly as Sun rises, but quickly degrades

In both cases, seeing quality can vary significantly on short timescales

Adaptive Optics

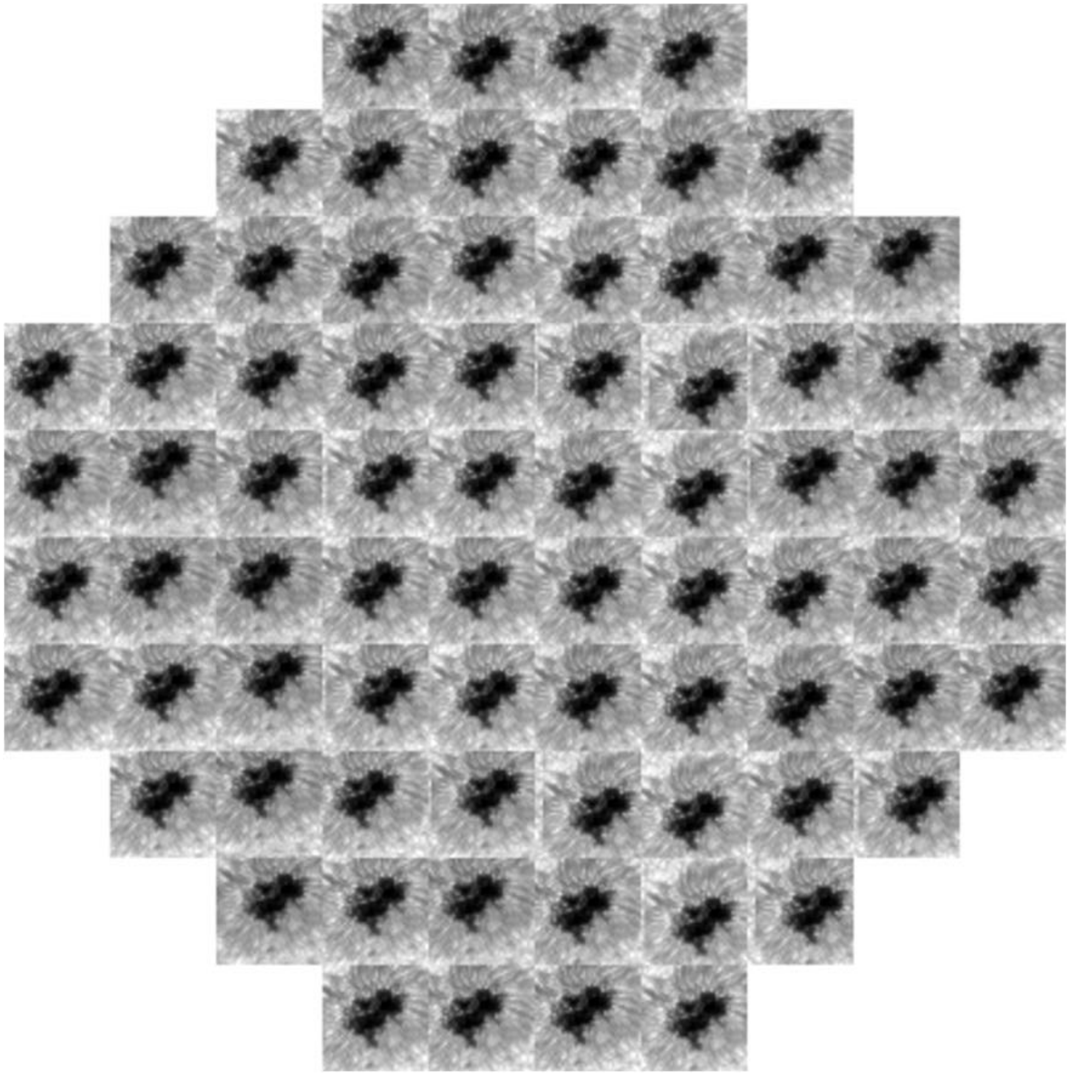


- Measure and correct wavefront errors
- Correction must be done at 1000-2000 Hz
- Pupil is subdivided into subapertures
- Correction is not perfect, depends on r_0

Key term: **lock point**

the position in the field of view where the AO system is measuring and correcting

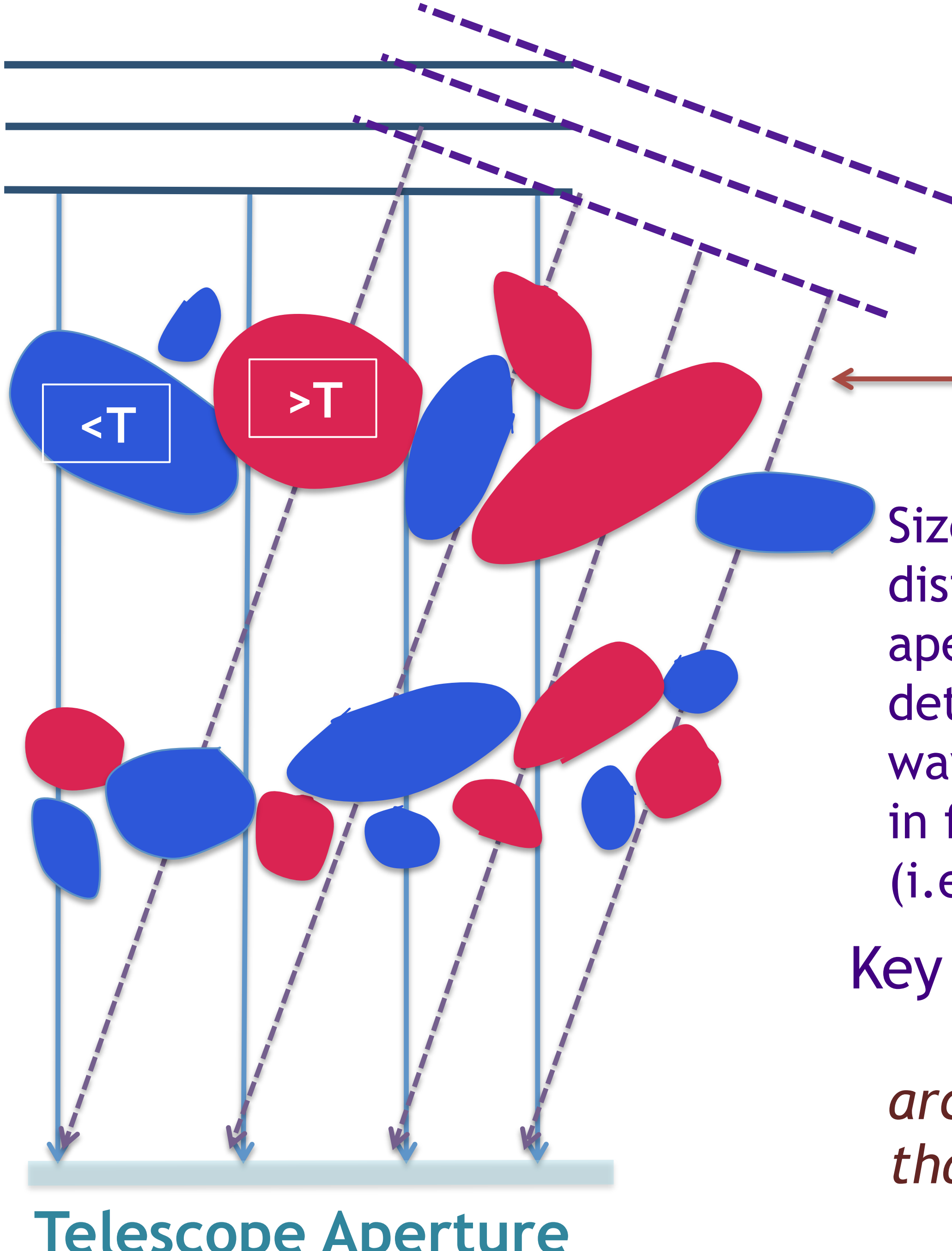
Adaptive Optics



Marino, 2012, *Opt. Eng.*, **51**

- DST – 76 subapertures
- DKIST – 1429 subapertures
- Some structure is required to work
  - won't work in bad seeing, off-disk (*)
  - Higher contrast features are better
  - less efficient at limb
- DKIST AO measures and corrects wavefront at ~500 nm

Atmospheric Turbulence



Other portions of the field of view traverse different paths through the atmosphere

Size scale, magnitude, and distance from telescope aperture of turbulent layers determine correlation of wavefront (seeing) at positions in field away from AO lock point (i.e center of field of view)

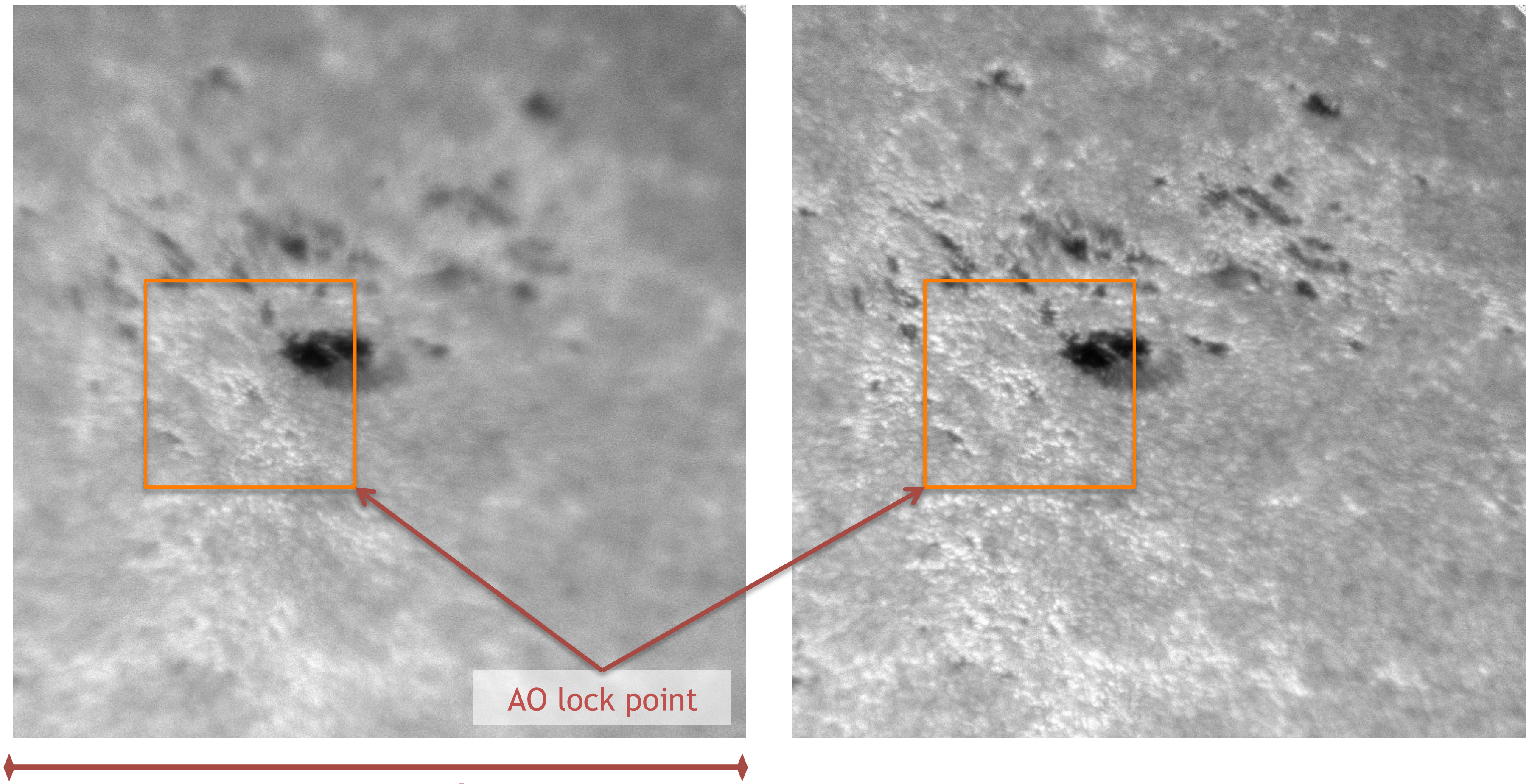
Key term: **isoplanatic patch**

Approximate size (in arcseconds) of field of view that is well-corrected by AO

Isoplanatic Patch

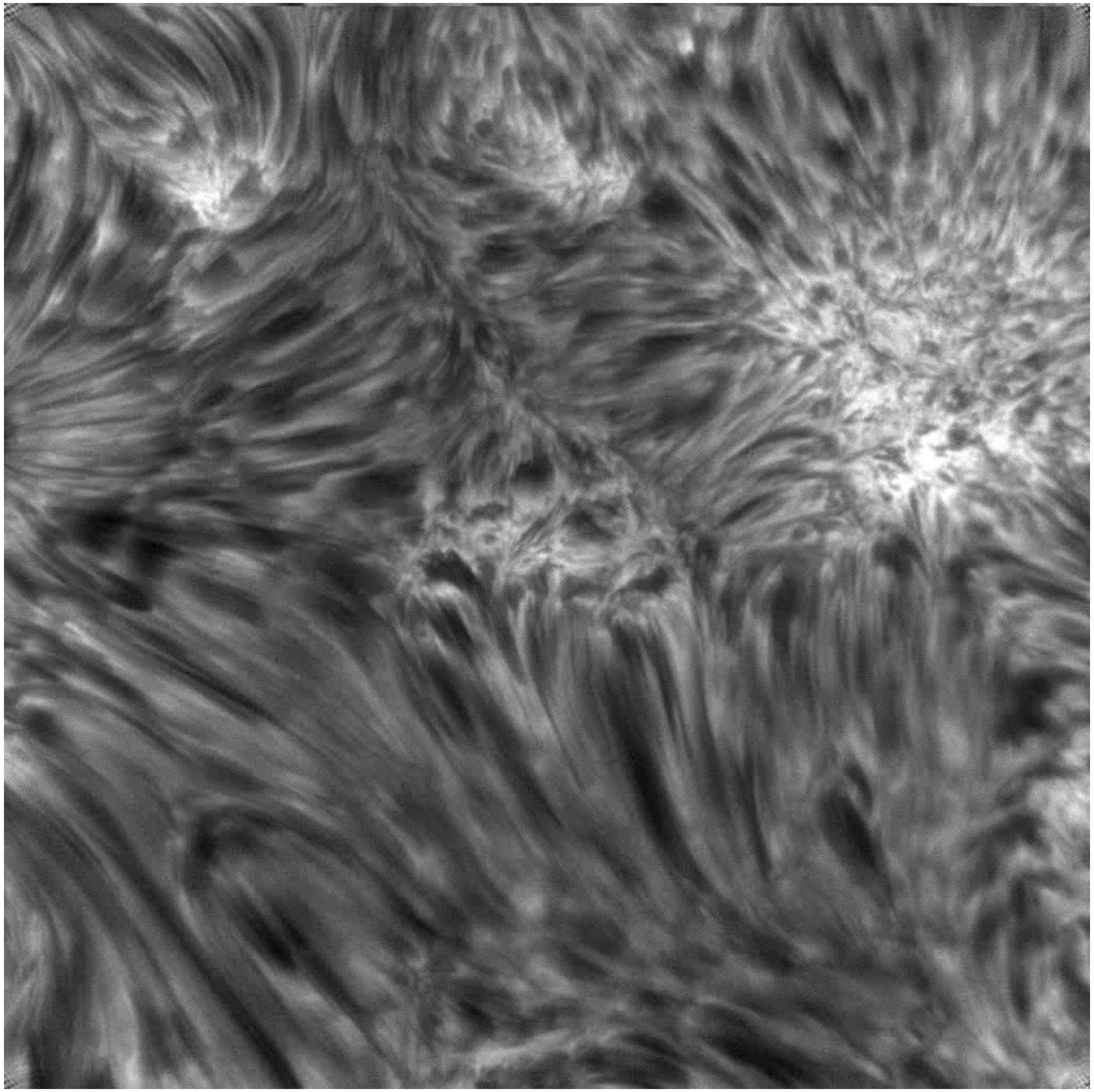
small isoplanatic patch

large isoplanatic patch



Data Impacts

Raw Hα image sequence



In addition to “blurring” seeing can cause:

- Image motion (tip-tilt)
- Field-dependent distortions
- Spectrograph slit jitter
- Photometric errors

even after adaptive optics correction

Image Reconstruction

- Separate constant <Object> (solar scene) from time varying, spatially dependent PSF.
- Most techniques require short exposures to “freeze” seeing – i.e. preserve high-spatial-frequency components
- Combination of multiple images to improve final SNR while preserving spatial information
- Operate on subfields over which PSF is mostly constant – *optimal subfield size depends on isoplanatic patch*
- Requires an image (generally)
- Speckle Reconstruction – Statistical analysis of turbulence profile
- Blind Deconvolution – optimization technique to find PSF

Image Reconstruction

Raw images

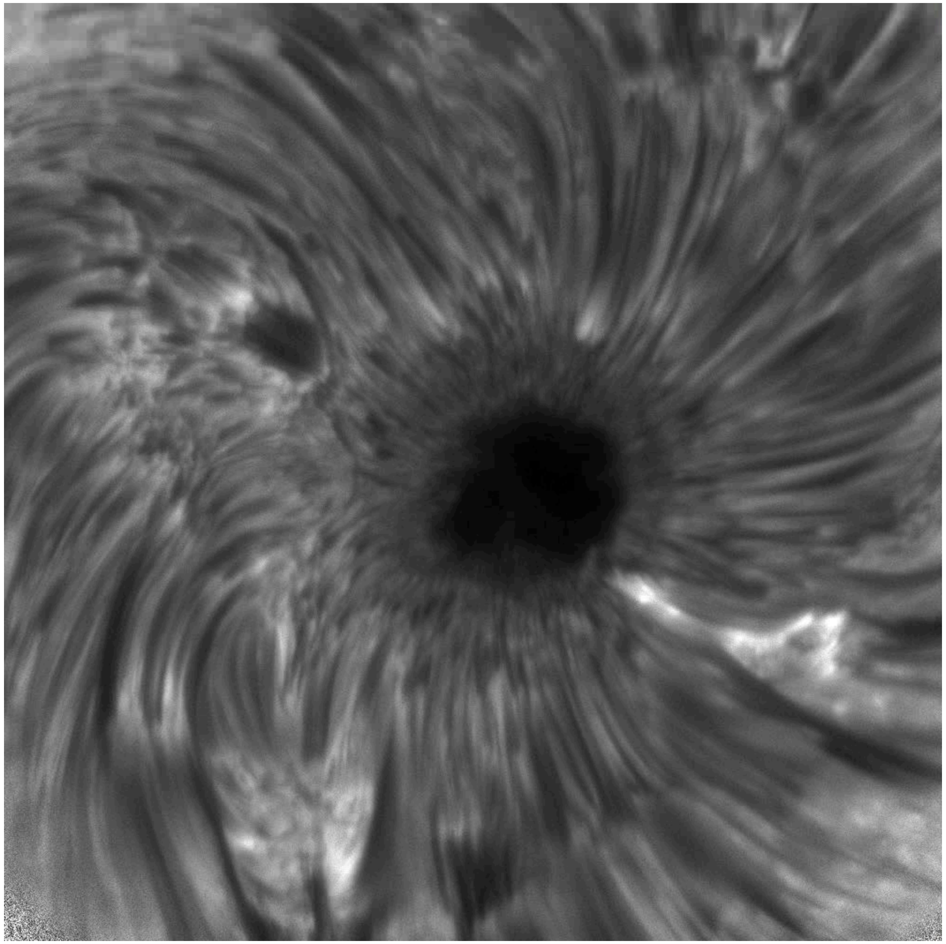
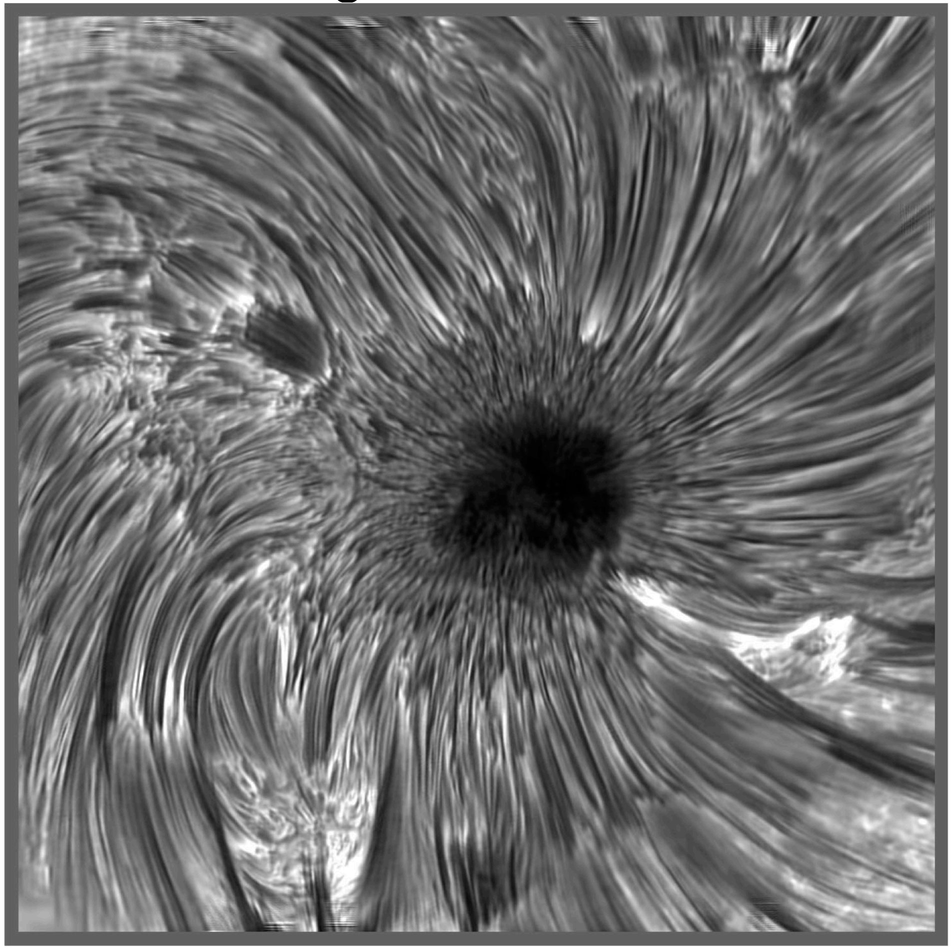
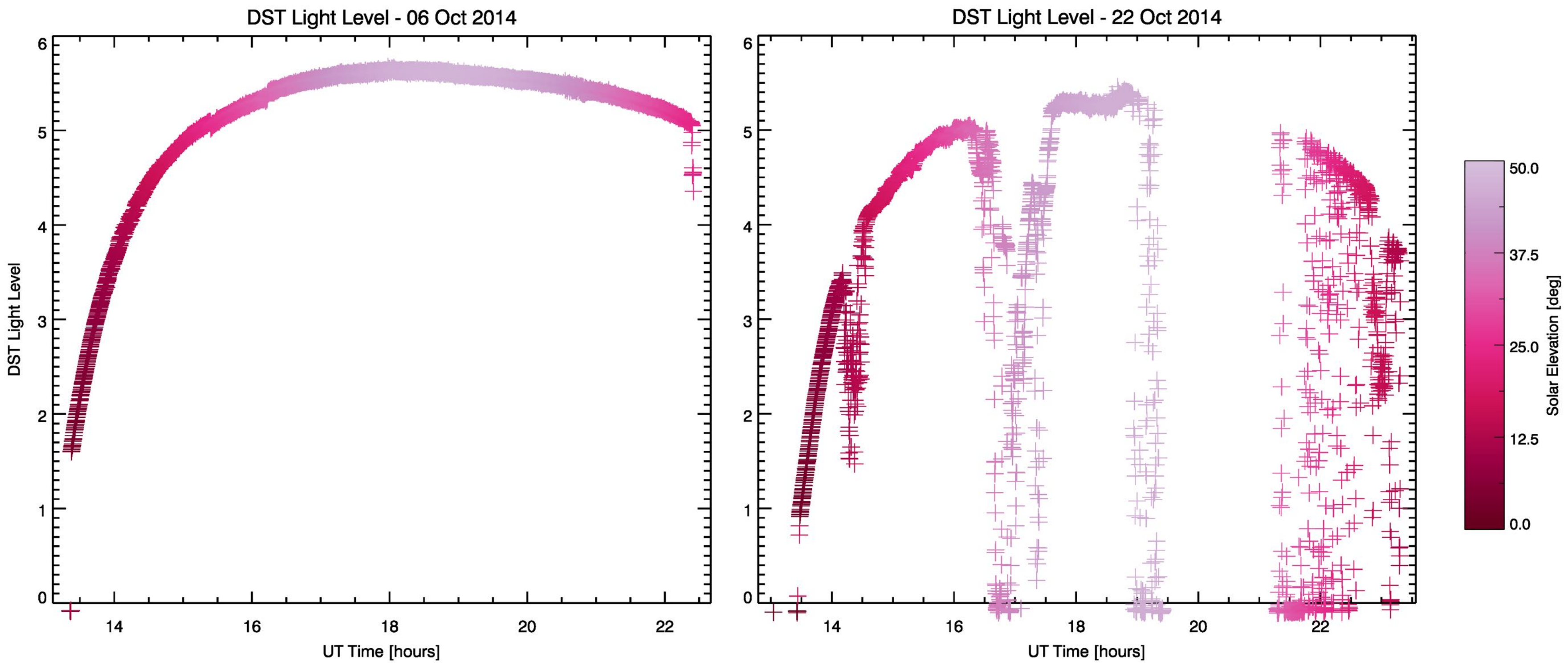


Image reconstruction



Atmospheric Effects

- Diurnal variations
  - Airmass – changes photon flux (SNR considerations)
  - Scattered light (coronal sky background)
  - Clouds!



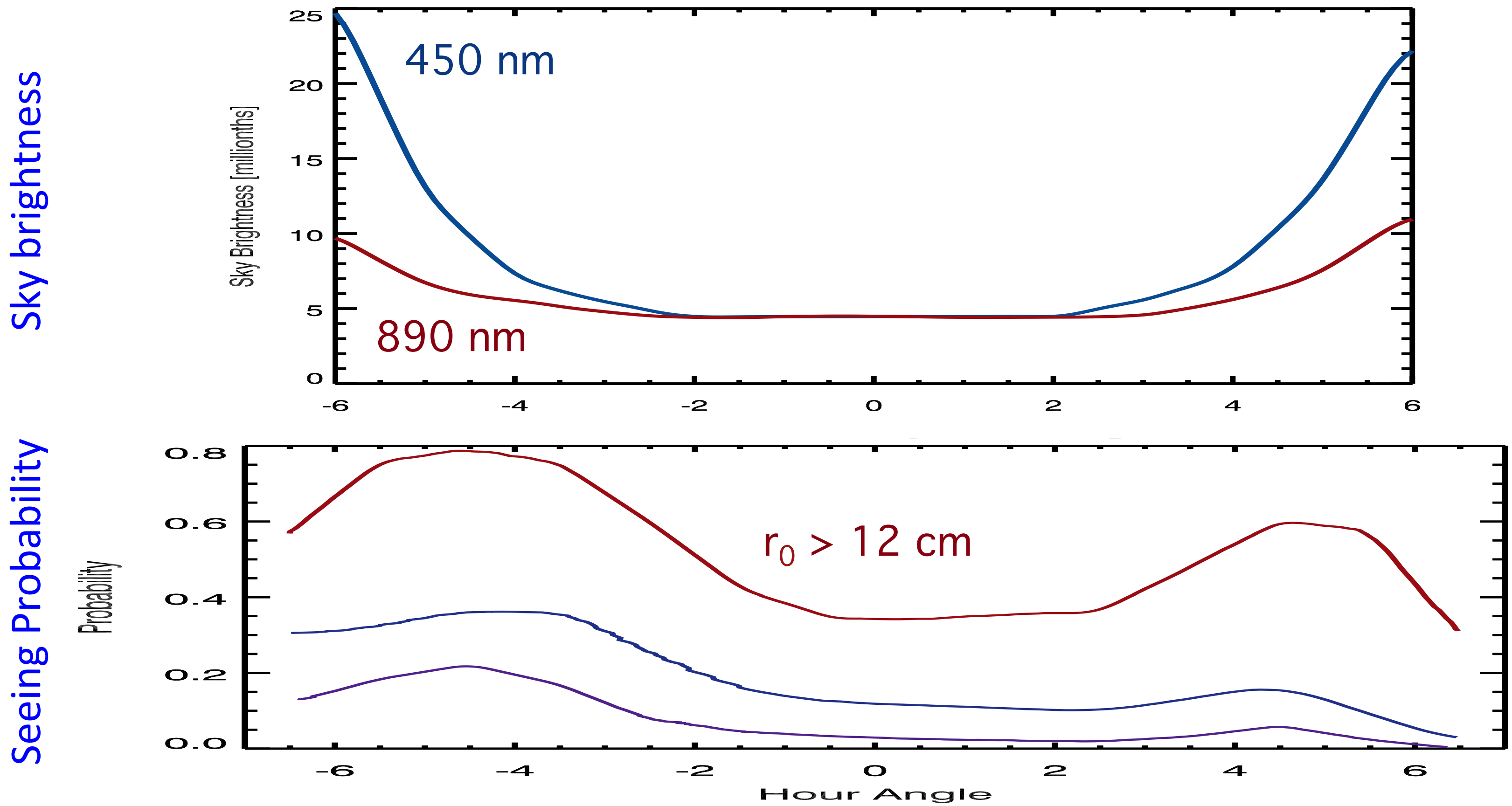
Atmospheric Effects

Seeing is best in the morning

Sky brightness is lowest when Sun is highest

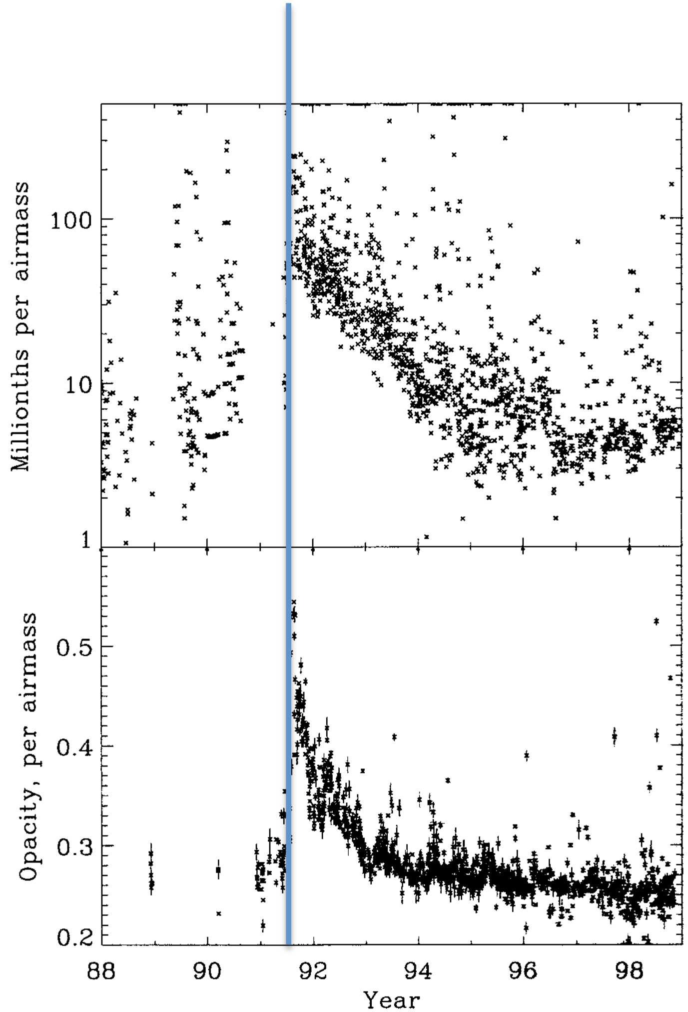
— hence —

High-resolution and coronal observations are naturally complementary



Episodic Events

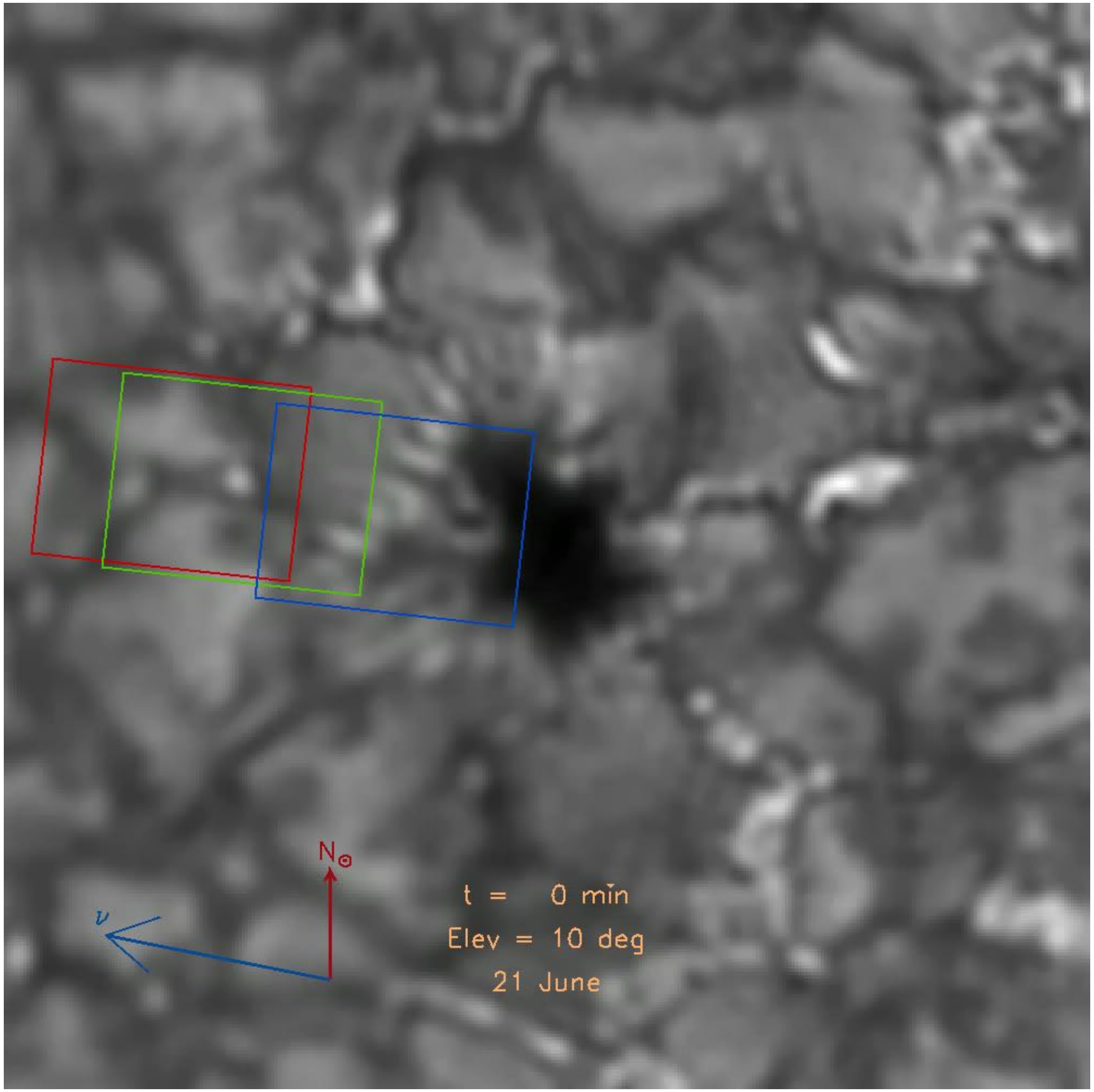
Mt. Pinatubo Eruption



Labonte, 2003, Solar Physics

Haleakalā sky brightness and transparency changes following eruption of Mt. Pinatubo in 1991

Atmospheric Dispersion



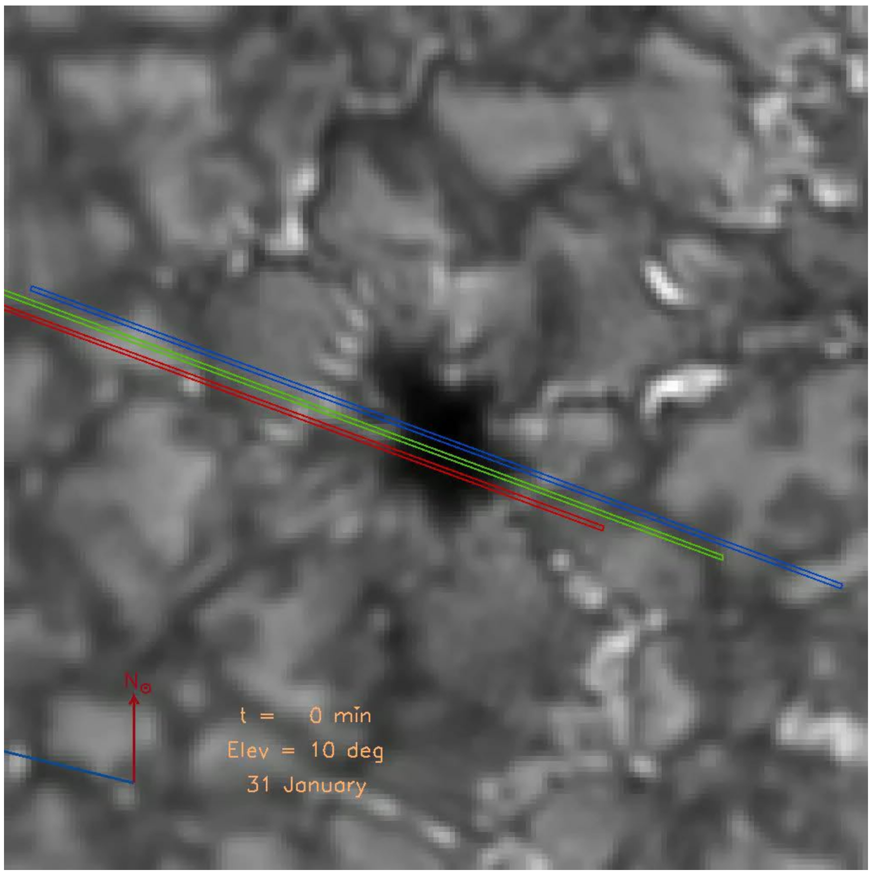
DL-NIRSP
high-resolution field
1.8″ x 2.4″

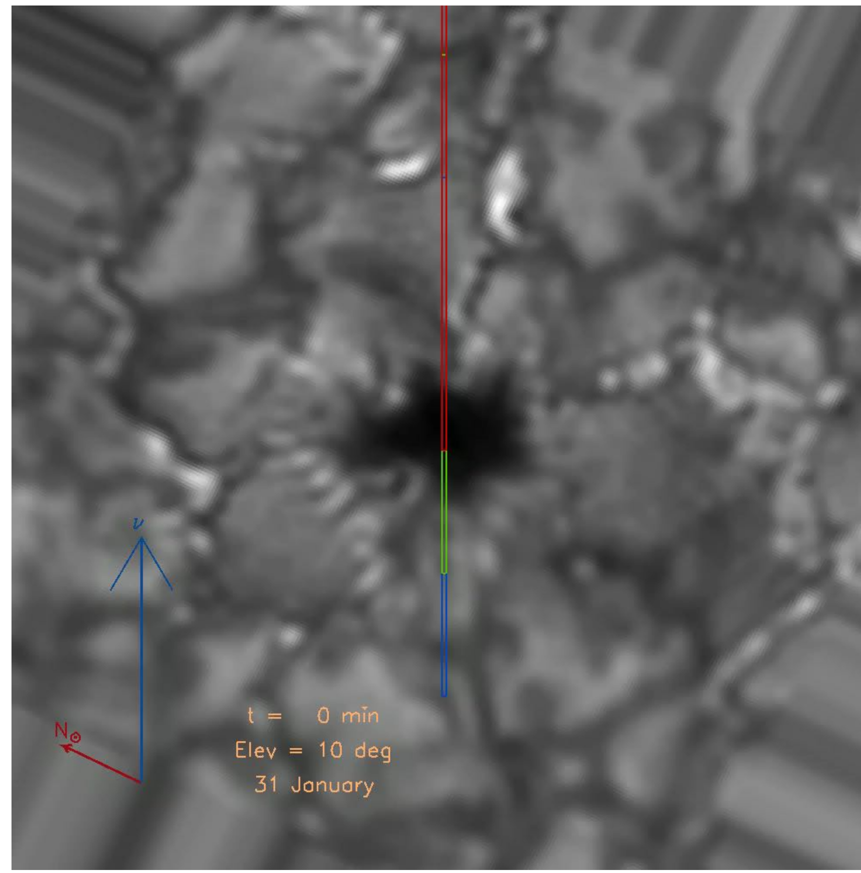
channels:
8542 Å
10830 Å
15000 Å

ν = dispersion vector
N⊙ = solar north

ViSP – 0.05″ slit
channels:
5250 Å
6300 Å
8542 Å

Atmospheric Dispersion





Spectral Diagnostics

- Chromospheric lines
  - Hα – 6563 Å – VBI, VISP, VTF
  - Hβ – 4861Å – VBI, VISP
  - Ca II H & K – 3968, 3933 Å – VISP, VBI
  - Ca II infrared triplet – 8542 Å – VTF, VISP, DL-NIRSP
  - He I – 10830 Å – DL-NIRSP, Cryo-NIRSP
  - He I D_3 – 5876 Å – VISP, DL-NIRSP
  - CO – 2.2, 4.6 μ – Cryo-NIRSP

- Photospheric lines
  - magnetic vs. non-magnetic
  - wavelength dependence of splitting

- Coronal lines
  - Temperature sensitivity

Calibration Considerations

- Optical "setup" may change from day to day
  - moving optics, detectors, fiber bundles, etc.
  - some level of stability is the goal, but changes may occur

- Calibrations may be time dependent
  - sensitivity of detector and component electronics
  - fringes, polarization modulation
  - dust accumulation

Some calibration frequency may be hourly to daily