

Physics 681: Solar Physics and Instrumentation – Lecture 6

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Tools for Solar Observations

- Limitations
 - General difficulties
 - Seeing: description and definition
 - Seeing: How to live with it
 - Adaptive Optics
 - Image Restoration
- High-Resolution Telescopes
- Spectrographs and spectrometers
- Filter and Monochromators
- Polarimetry
- Special-Purpose Instruments

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Limitations

- ❑ The Sun is the only star, where we can resolve surface details!
- ❑ Instrument
- ❑ Earth's turbulent atmosphere
- ❑ Solar observations can be photon starved! \Rightarrow larger apertures, more efficient instruments, longer exposure times
- ❑ Atmospheric extinction
- ❑ Space missions: Ulysses, Yohkoh, SoHO, TRACE, RHESSI
- ❑ Ground-based projects: FASR, ATST, GREGOR, and NST



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Seeing

- ❑ Degradation of image quality: image motion, differential image motion, and blurring
- ❑ Boundary layer seeing vs. high-altitude seeing (jet-stream)
- ❑ Site selection is critical
- ❑ Refractive index fluctuations (pressure equilibrium but temperature fluctuations)

$$n - 1 = 2.79 \times 10^{-4} \frac{P/P_0}{T/T_0}$$

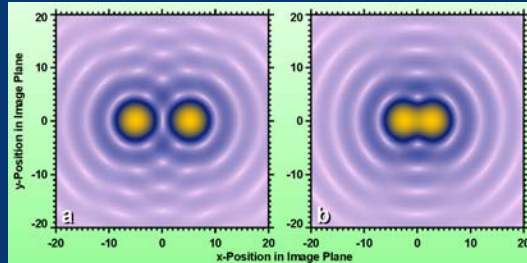
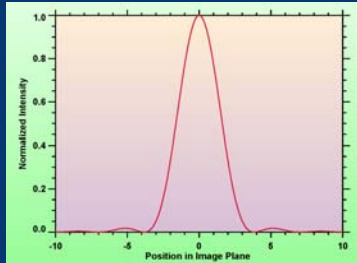
- ❑ Thermal convection in the entire troposphere
- ❑ Correlation time scale ≈ 40 ms (day) and ≈ 160 ms (night) \Rightarrow short-exposure times \Leftarrow spectroscopy becomes difficult
- ❑ Isoplanatic patch size ≈ 5 – 10 arcsec
- ❑ Spatial resolution under good seeing conditions ≈ 1 arcsec \Rightarrow Fried parameter $r_0 \approx 10$ cm
- ❑ Adaptive optics and/or post-facto image reconstruction



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Point-Spread Function (PSF)



$$I(x, y) = \int \int_{-\infty}^{\infty} I_0(\xi, \eta) \text{PSF}(x, y; \xi, \eta) d\xi d\eta$$

$$\text{PSF}_D(r) = \frac{1}{\pi} \left[\frac{J_1(br)}{r^2} \right]$$

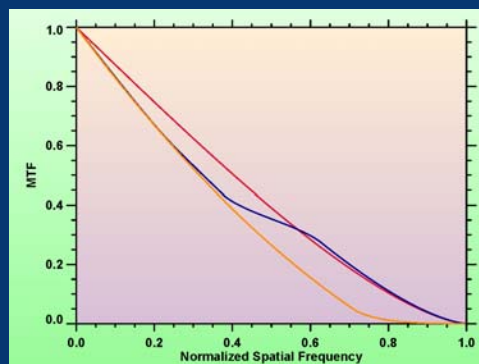
$$\alpha = 1.22\lambda / D \quad (\text{Rayleigh criterion})$$



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Modulation Transfer Function



$$S(\vec{q}) = \int \int_{-\infty}^{\infty} \text{PSF}(x, y) \exp[-2\pi i(q_x x - q_y y)] dx dy$$

$$\text{MTF}(q) = 2\pi \int_0^{\infty} r \text{PSF}(r) J_0(2\pi qr) dr \quad \text{with } q = (q_x^2 + q_y^2)^{1/2}$$

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Image Reconstruction

- Spectral ratio:

$$\varepsilon(\vec{q}) = \frac{\langle |F_i(\vec{q})|^2 \rangle}{\langle |F_0(\vec{q})|^2 \rangle} = \frac{\langle |S_i(\vec{q})|^2 \rangle}{\langle |S_0(\vec{q})|^2 \rangle}$$

- Power spectrum:

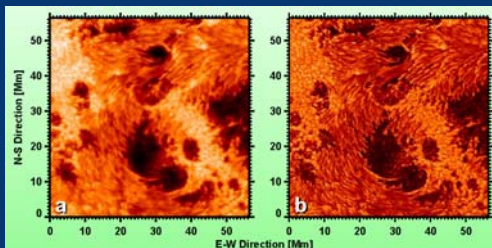
$$|F_0(\vec{q})|^2 = \frac{\langle |F_i(\vec{q})|^2 \rangle}{\langle |S_i(\vec{q})|^2 \rangle}$$

- Cross spectrum (Knox-Thompson):

$$\langle F_i(\vec{q}) F_i^*(\vec{q} + \Delta\vec{q}) \rangle = F_0(\vec{q}) F_0^*(\vec{q} + \Delta\vec{q}) \cdot \langle S_i(\vec{q}) S_i^*(\vec{q} + \Delta\vec{q}) \rangle$$

- Bispectrum:

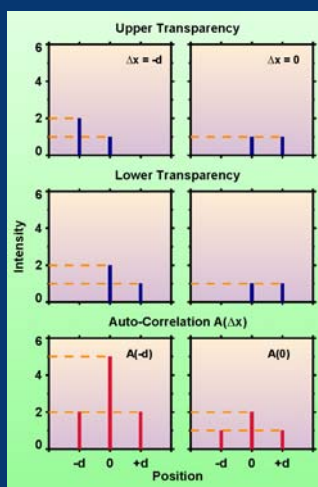
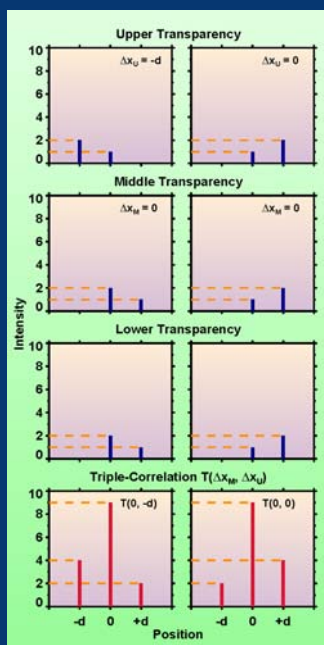
$$\langle F_i(\vec{q}) F_i(\vec{p}) F_i^*(\vec{q} + \vec{p}) \rangle$$



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Speckle Masking

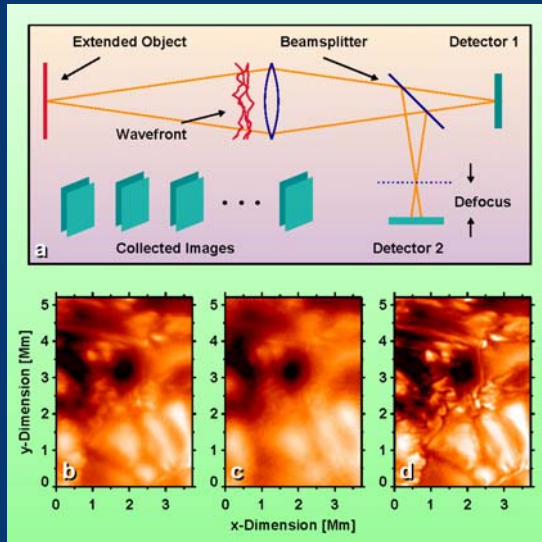


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Phase Diversity

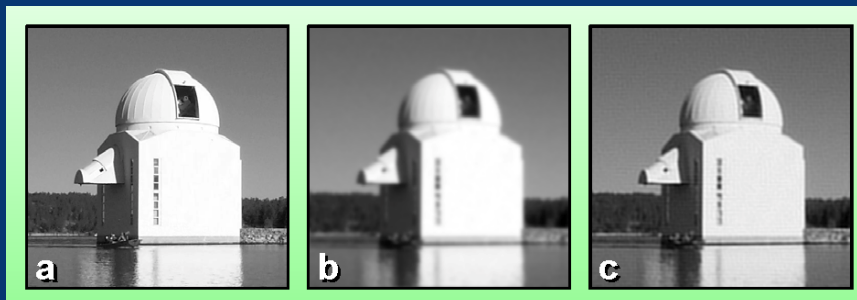


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Wiener Filter



$$\hat{F} = D/S = F$$

$$\hat{F} = D/S = F + N/S$$

$$\hat{F} = \frac{D}{S} W$$

$$W = \frac{|F \cdot S|^2}{|F \cdot S|^2 + |N|^2} = \frac{P_d}{P_d + P_n}$$

$$W = \frac{P_d}{P_d + P_n} \sim \frac{\text{SNR}}{\text{SNR} + 1}$$

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