Astronomical seeing conditions at Matjiesfontein as determined by optical and turbulence methods.

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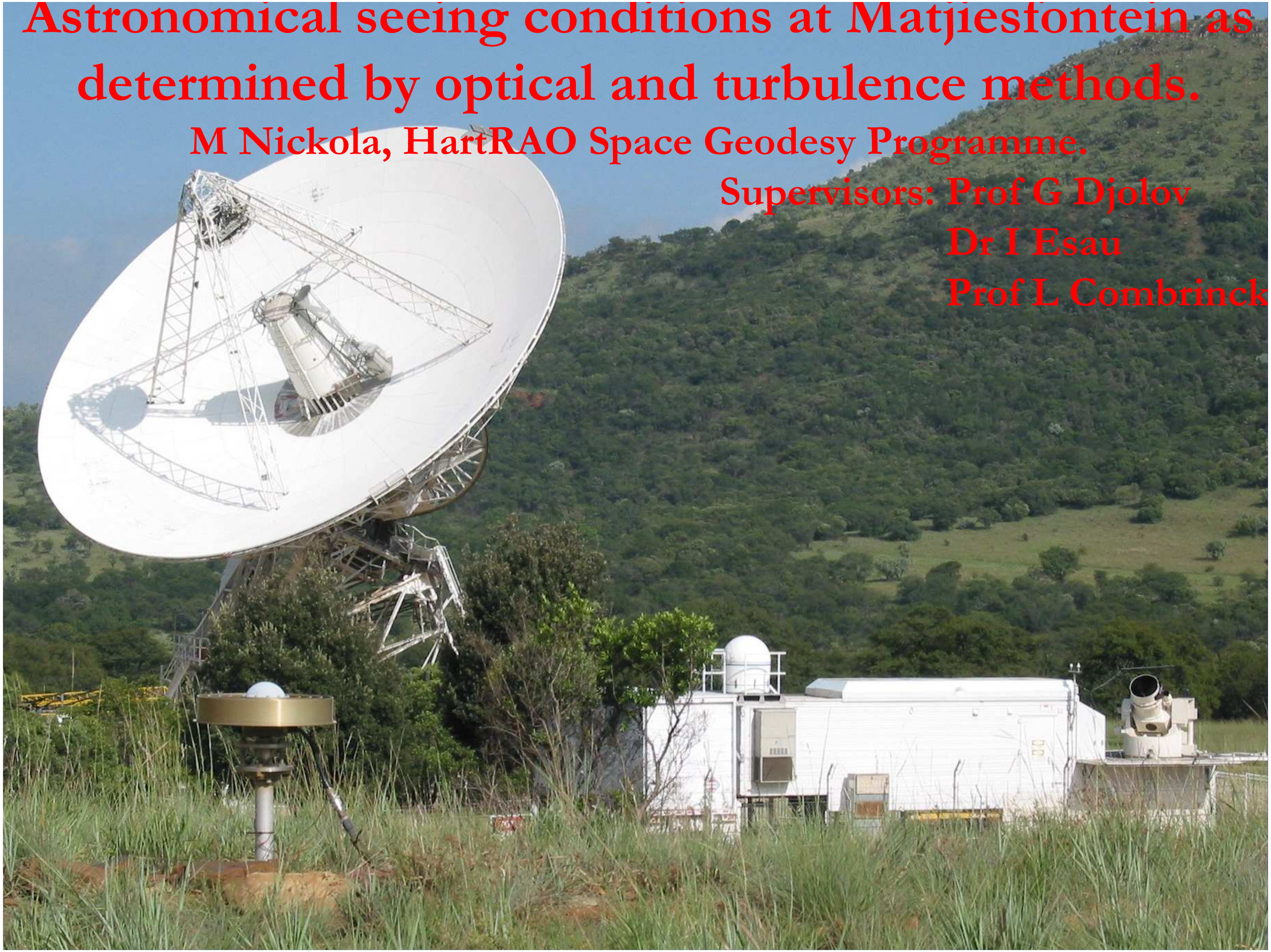
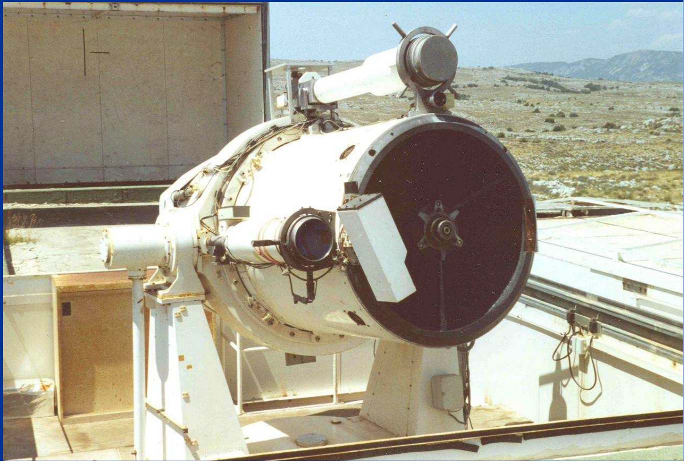


Need for new fundamental space geodetic station at Matjiesfontein

- At HartRAO - pollution, cloud cover, RFI, obsolete instrumentation
- Require location for optimal scientific output – infrastructure, stable ground, reduced RFI, benign atmosphere, low horizon
- All 4 major space geodetic techniques - VLBI, GNSS, Doris and S/LLR - co-located on-site

Lunar laser ranging at Matjiesfontein

- One of the first major projects at Matjiesfontein – LLR
- First LLR in southern hemisphere
- Current LLR observatories: APOLLO, McDonald, OCA
- OCA donated 1m optical telescope towards development of LLR

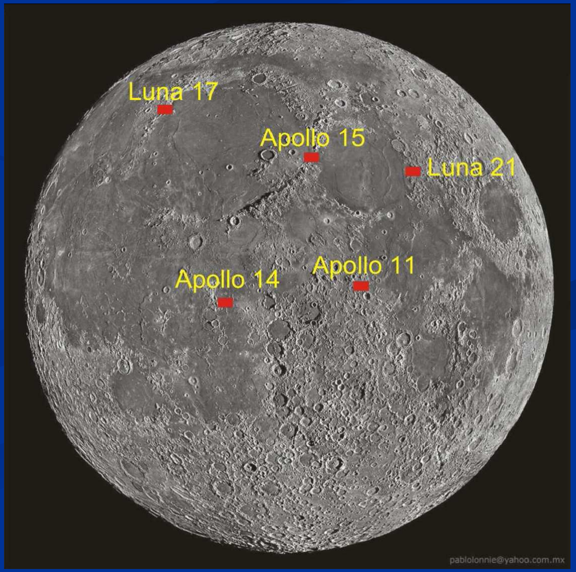


How does LLR work and why LLR?

- Laser pulses transmitted from
  Earth station to retro-reflector on Moon

- Round-trip time-of-flight measured

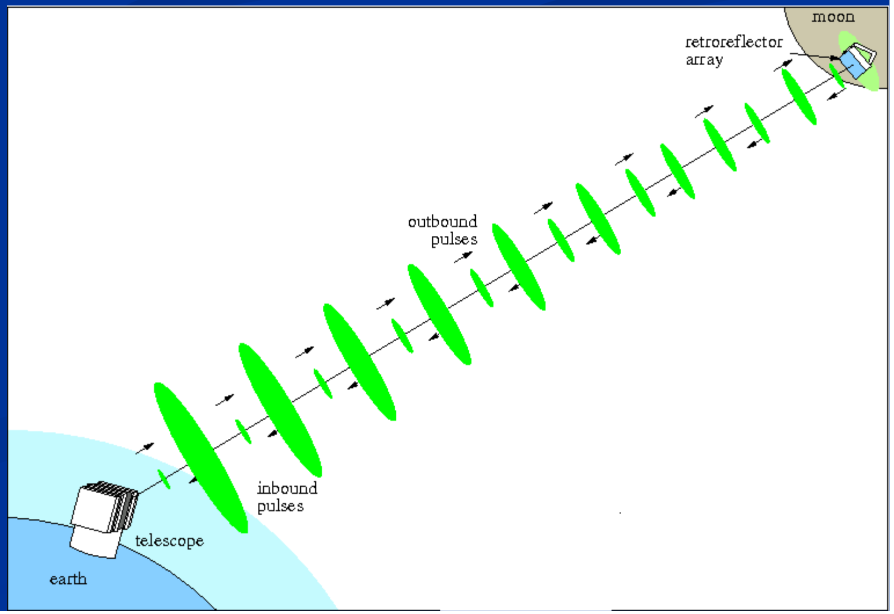
- Earth-Moon distance determined



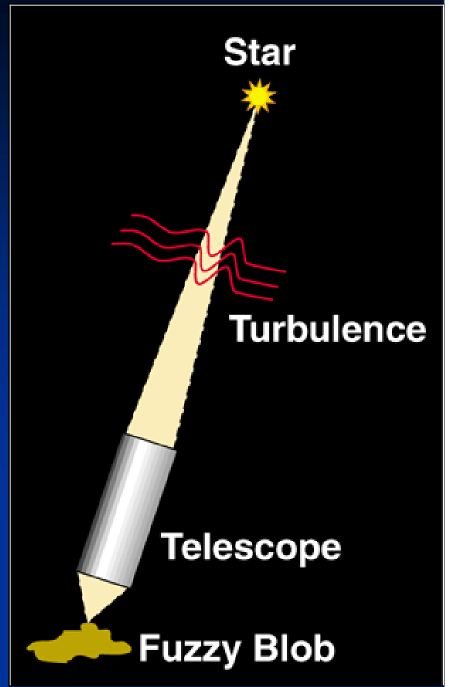
- Earth's, Moon's structure, dynamics;
  Equivalence principle of GR

Turbulence and seeing

- Turbulence causes laser beam to diverge
- Turbulence adversely affects data quantity and quality
- LLR single-photon returns require excellent seeing (< 1")
- Atmospheric turbulence occurs in surface layer, ABL, free atmosphere

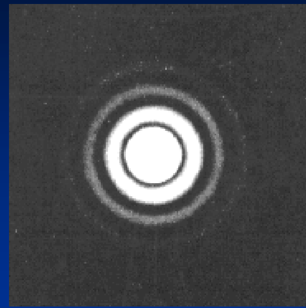


Turbulence & seeing cont.

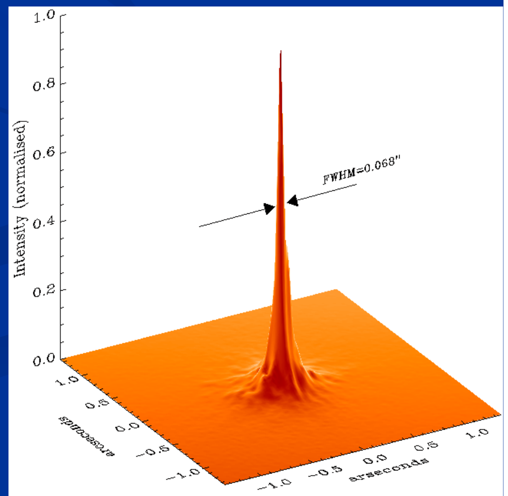


- Turbulence degrades astronomical seeing
- Stars not point sources but blurred, moving images
- Eddies - unstable air masses acting as lenses
- Velocity fluctuations cause temperature variations that cause index of refraction variations

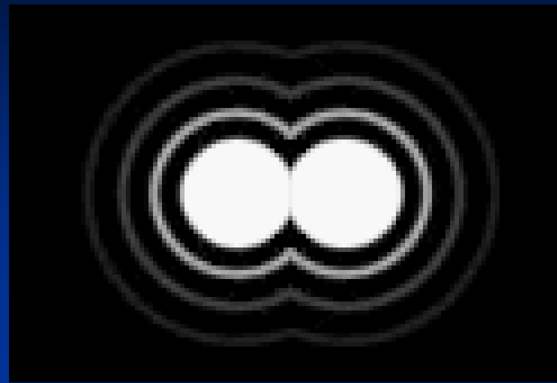
Seeing measurements – optical method



- Seeing monitor to consist of telescope, CCD camera, control/processing PC
- Observe stars at varying positions on sky, capture frames of varying exposure times
- Images stacked to obtain average output image – PSF
- PSF depicts where photons from star have fallen
- PSF characterises imaging under non-ideal conditions – atmospheric turbulence, imperfect instrument
- PSF broadened by bad seeing
- Fit Gaussian profile to PSF



Seeing measurements – optical method cont.



- Determine FWHM
- Compare statistical analysis of captured images with theoretical Airy function
- Airy function – describes image of point source under ideal conditions – no atmosphere, perfect instrument
- FWHM corresponds to σ from normal distribution –
  $$FWHM = 2\sqrt{2\ln 2}\,\sigma \approx 2.355\sigma$$
- Related to Fried parameter by – $$FWHM = 0.98\frac{\lambda}{r_0}$$
- Observe close binaries for calibration, verification purposes

Seeing from turbulence method

- Kolmogorov model attempts to describe perturbations to wavefront caused by variations in index of refraction

- Turbulent field described by structure function –

$$D\phi_a(\rho) = \left\langle \left| \phi(r) - \phi(r+\rho) \right|^2 \right\rangle$$

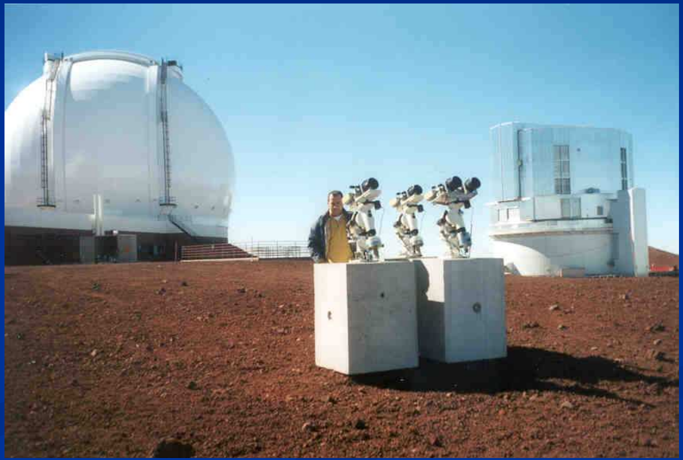
- Phase structure function at telescope – $D\phi_a(\rho) = 6.88\left(\frac{|\rho|}{r_0}\right)^{5/3}$ where r_0 Fried parameter to characterise seeing

- C_N^2 profile measured and r_0 determined –

$$r_0 = \left(16.7\,\lambda^{-2}\,\frac{1}{\cos\gamma}\int_0^{\infty} dh\, C_{N^2}(h)\right)^{-3/5}$$

Seeing from turbulence method cont.

- Large eddy simulation (LESNIC) – large eddies resolved, small eddies modelled
- Seeing monitor and weather station to collect on-site observational data



- Meteorological data fed to LESNIC model to provide structure functions
- Calculate C_N^2 distribution - sodar, lidar, radar data used to determine C_N^2 profile
- Compare data from seeing monitor with model results

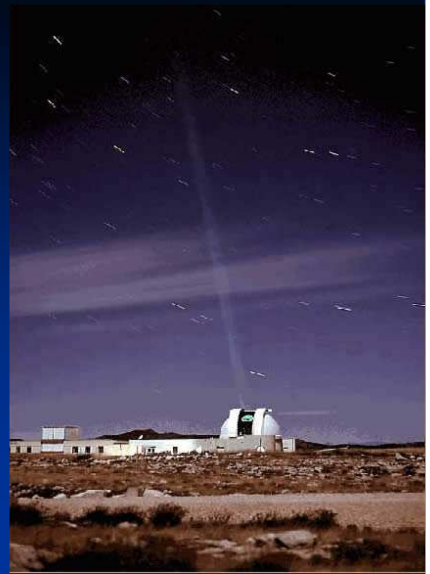
Outcomes

- Measure astronomical seeing and meteorological conditions at Matjiesfontein to determine whether it is an optimal location for LLR in this respect.

- Obtain quantitative measure of seeing –
  - develop & implement automated seeing monitor
  - deploy meteorological instruments
  - use data from observations
  - employ LESNIC model

- Determine suitability of LESNIC for modelling seeing conditions

Outcomes cont.



- Determine relationship between seeing quality and meteorological conditions
- May be used for future seeing forecasts
- Enhanced data quantity and quality

Thank you for your time