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A New Technique for Measuring Aerosols with Moonlight Observations and a Sky Background Model

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There have been an ample number of studies on aerosols in urban, daylight conditions, but few for remote, nocturnal aerosols. We have developed a new technique for investigating such aerosols using our sky background model and astronomical observations. With dedicated observations we have successfully tested this technique for nocturnal, remote aerosol studies.

This technique relies on three requirements: (a) sky background model, (b) observations taken with scattered moonlight, and (c) spectrophotometric standard star observations for flux calibrations.

The underlying assumption is that all components, other than the atmospheric conditions (specifically aerosols and airglow), can be calculated with the model for the given observing parameters. By comparing the scattered moonlight taken at various angles and wavelengths along with the extinction curve from the standard stars, we can find the optimal aerosol size distribution for the time of observation.

We had dedicated observations at the Very Large Telescope (European Southern Observatory) at Cerro Paranal in the Atacama desert, Chile with the instrument X-Shooter to use as a case study for this method. X-Shooter is a medium resolution, echelle spectrograph which covers the wavelengths from 0.3 to 2.5 micrometers. We observed plain sky at six different distances (7, 13, 20, 45, 90, and 110 degrees) to the Moon for three different Moon phases (between full and half). This is an ideal data set for testing this technique.

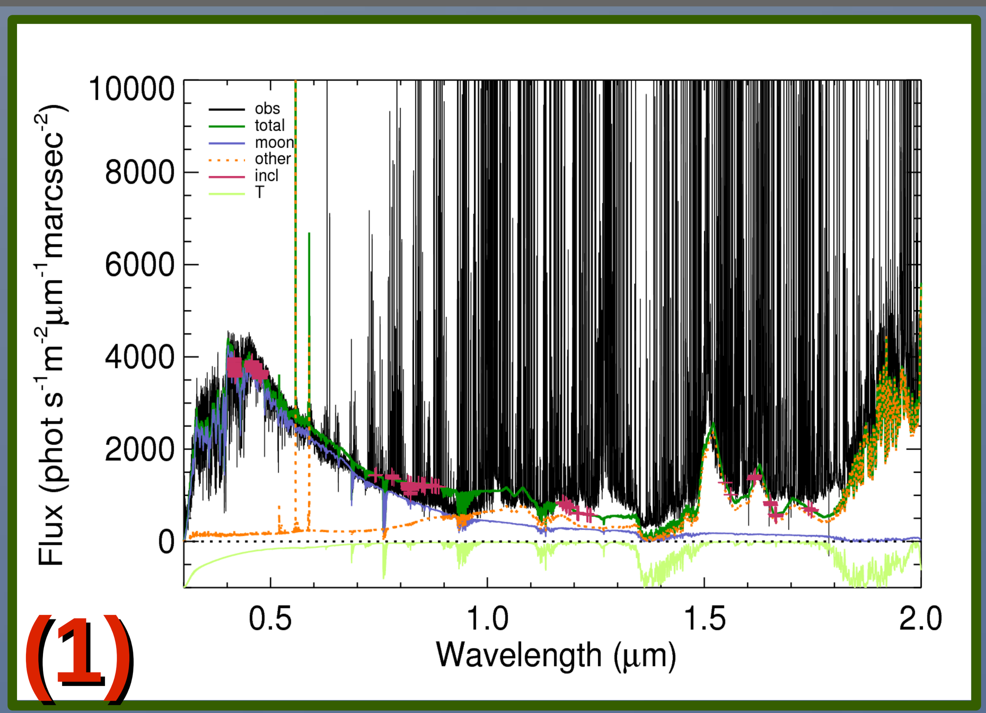
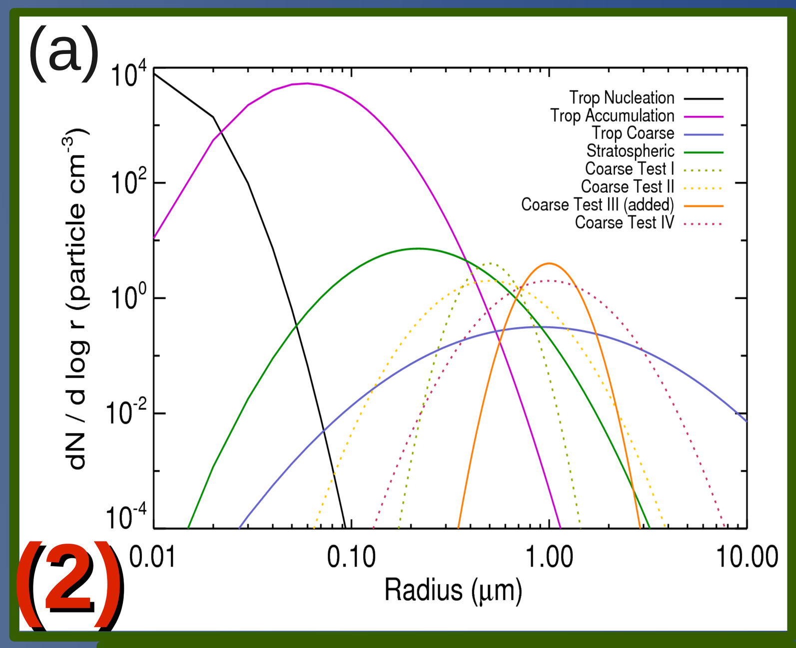
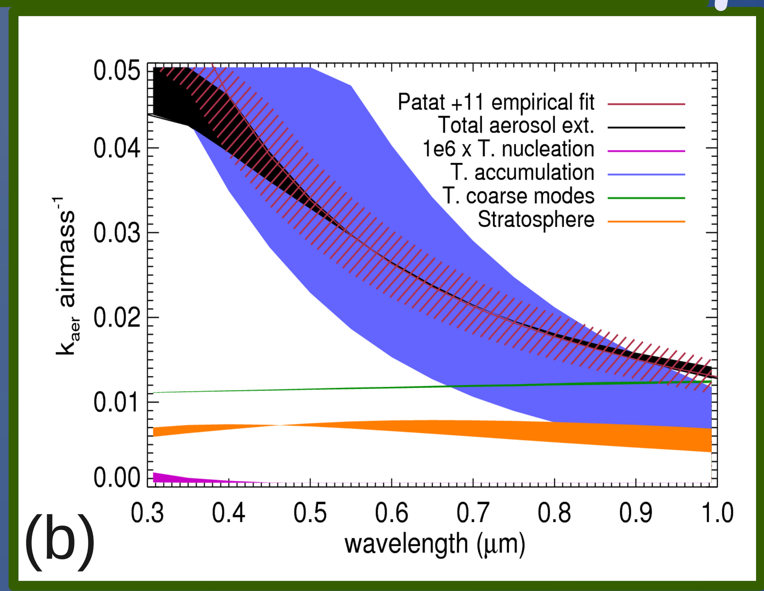


Fig 1. An example X-Shooter spectrum from our dedicated observing run taken 45 degrees from the Moon (black). Our total sky background model (green) without sky lines [1], the scattered moonlight model (blue) [2], and the rest of the sky model components (orange) are overlaid. The inclusion regions used for the analysis (pink) and the transmission curve T (light green) are also shown.





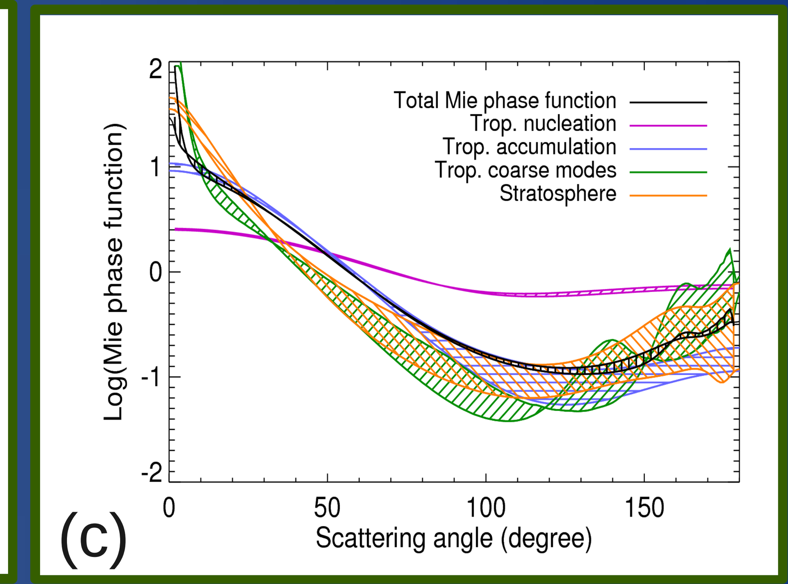


Fig 2. Within the sky background model, the mixture of aerosols can be varied. Previously, [3] had empirically measured an aerosol extinction curve in the optical for Cerro Paranal. We used the aerosol size distributions for remote continental aerosols [4] (Fig 2a). We scaled the number density for each mode by various amounts and the refractive index (Fig 2b), and used a Mie scattering code based on [5] (Fig 2c). We also added a second coarse mode in attempt to reproduce the extra flux seen in observations close to the Moon. The coarse modes we tried are also shown in Fig 2a, including coarse test III, which is the added coarse mode for the analysis.

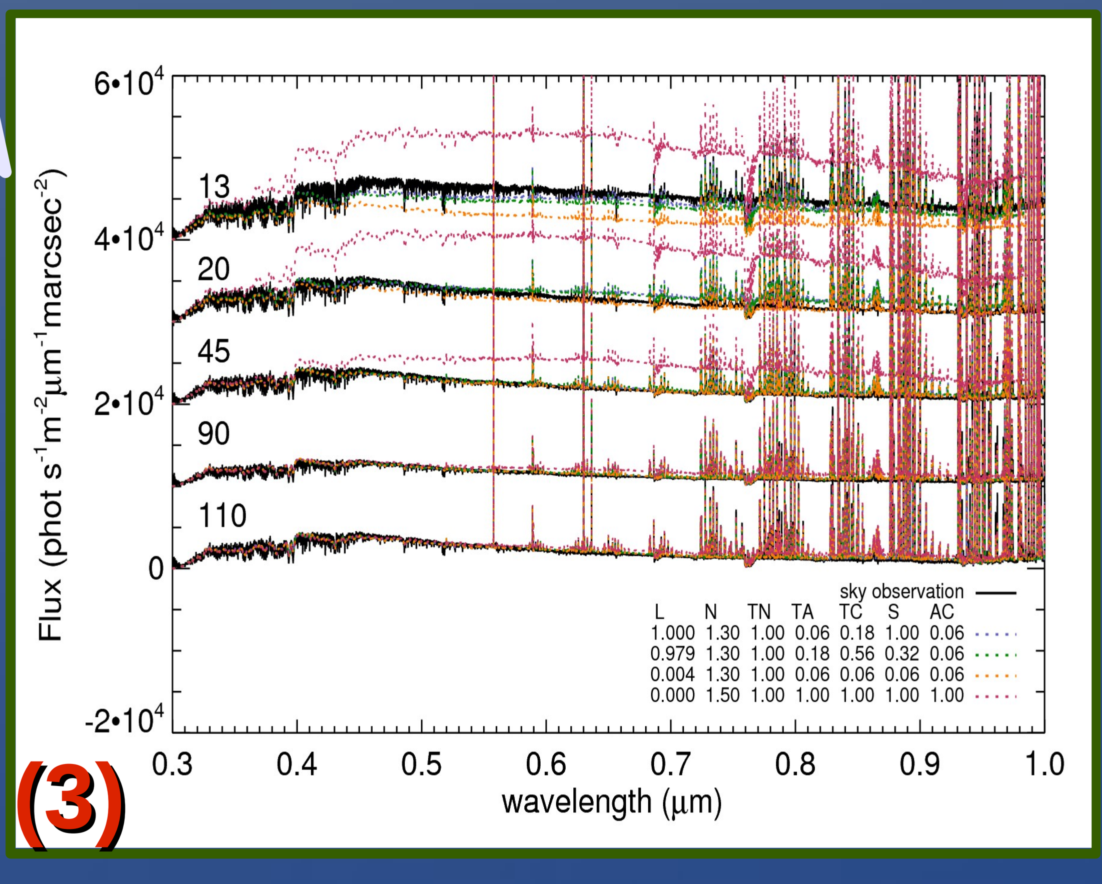


Fig 3. The observed spectra at the different lunar distances (black) and offset in flux. Overlaid are the sky background models with various aerosols distributions (colors). The likelihood L as well as the refractive index N and the fractions of the number density of the tropospheric nucleation TN, accumulation TA, coarse TC, stratospheric S, and the added coarse mode AC of the models shown are given in the legend. The 7 (not shown) and 13 deg spectra seem to have extra flux. The possibility of contamination from moonlight coming into the dome and hitting the detector cannot be excluded. The 20 and 45 deg spectra are sensitive to aerosol scattering, whereas the 90 and 110 deg are not, as expected.

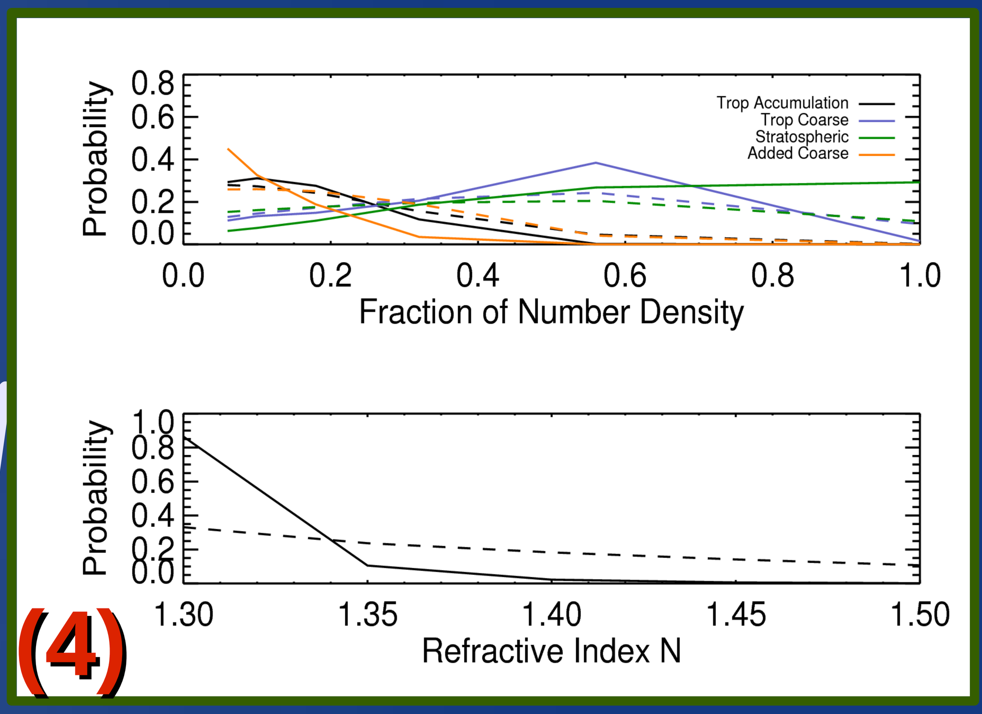


Fig 4. The top panel shows the probability depending on the fraction of the number density for each aerosol mode. The bottom panel is the probability as a function of the refractive index N. The probabilities were calculated with two different methods (solid and dashed lines), since some of the errors are unknown. The stratospheric mode is mostly degenerate, but the other modes and N have some constraints. This was done for one night of observations, which seems to have a lower optical depth than the average.

This technique for studying aerosol properties looks promising. We will continue exploring this method with the other two nights from the dedicated X-Shooter observations. Then, we will apply it to the X-Shooter archival data to explore trends in the nocturnal background aerosols at Cerro Paranal.

References:
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