



## Hyperspectral Sun Photometer for Atmospheric Characterization and Vicarious Calibrations

Data acquired by such devices are used in atmospheric, pollution, and solar energy studies.

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A hyperspectral sun photometer and associated methods have been developed and demonstrated. Sun photometers are used to measure total (global), direct, and diffuse at-surface solar irradiance. The data acquired by sun photometers are used in atmospheric, pollution, and solar energy studies. In addition, the data acquired by sun photometers are used for radiometric vicarious calibration of optical remote-sensing systems. Sun photometer measurements at various wavelengths can be analyzed to estimate molecular scattering, aerosol extinction, and columnar concentrations of water vapor, ozone, and trace gases in the atmosphere.

Accurate sun photometer calibration is critical to properly measure the solar irradiance and characterize the atmosphere. Traditional sun photometer calibration requires solar observations over several hours. This approach can be impractical and inadequate, particularly in places where the atmosphere is harsh and/or its optical characteristics are variable. In contrast, the procedures for operating this photometer entail less data acquisition time and embody a more direct approach to calibration. The scientific value of the measurement data produced by this instrument is not adversely affected by at-

mospheric instability. In addition, this instrument yields hyperspectral data covering a large spectral range (350–2,500 nm) not available from most traditional sun photometers.

The hyperspectral sun photometer components include (1) a commercially available spectroradiometer that has been calibrated in a laboratory according to standards traceable to the National Institute of Standards and Technology and (2) a commercially available reflectance standard panel that exhibits nearly Lambertian 99-percent reflectance. The spectroradiometer is positioned above, and aimed downward at, the panel. The procedure for operating this instrument calls for a series of measurements: one in which the panel is fully illuminated by the sun, one in which a shade is positioned between the panel and the sun, and two in which the shade is positioned to cast a shadow to either side of the panel. The total sequence of measurements can be performed in less than a minute.

From these measurements, the total radiance, the diffuse radiance, and the direct solar radiance are calculated. The direct solar irradiance is calculated from the direct solar radiance and the known reflectance factor of the panel as a func-

tion of the solar zenith angle. Atmospheric characteristics are estimated from the optical depth at various wavelengths calculated from (1) the direct solar irradiance obtained as described above, (2) the air mass along a column from the measurement position to the Sun, and (3) the top-of-atmosphere solar irradiance.

The instrumentation used to implement the sun photometer is the same as that used to characterize targets used in radiometric vicarious calibrations. Utilizing this type of sun photometer thus reduces the amount of instrumentation and labor required to perform these studies.

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## Dynamic Stability and Gravitational Balancing of Multiple Extended Bodies

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Feasibility of a non-invasive compensation scheme was analyzed for precise positioning of a massive extended body in free fall using gravitational forces influenced by surrounding source masses in close proximity. The  $N$ -body problem of classical mechanics is a paradigm used to gain insight into the physics of the equivalent  $N$ -body problem subject to control forces.

The analysis addressed how a number of control masses move around the proof mass so that the proof mass position can be accurately and remotely compensated when exogenous disturbances are acting on it, while its sensitivity to gravitational waves remains unaffected. Past methods to correct the dynamics of the proof mass have considered active electrostatic or capacitive methods, but the possibility of

stray capacitances on the surfaces of the proof mass have prompted the investigation of other alternatives, such as the method presented in this paper.

While more rigorous analyses of the problem should be carried out, the data show that, by means of a combined feedback and feed-forward control approach, the control masses succeeded in driving the proof mass along the speci-