PRECISION IR AND VISIBLE SOLAR PHOTOMETRY

I. Photospheric Network

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Abstract. A precision Solar Photometric Telescope (SPT) was constructed to study the large-scale thermal structure of the solar photosphere. This instrument does full-disk, broad-band (10 nm FWHM), two-color (500 and 650 nm) imaging of the solar photosphere. Data obtained by the SPT reveals network structures correlated with the supergranulation velocity field, and the CaK network of the chromosphere. Infrared array photometry extends these measurements to 1.6 and 2.2 micron. The observed correlation of the network brightness signal with the CaK network is positive at visible wavelengths. The correlation between the network at the opacity minimum (1.6 micron) and in the higher photosphere (2.2 micron) is positive also. The root-mean-square (r.m.s.) amplitude of the contrast at disk center is \((2.34 \pm 0.38) \times 10^{-3}\), \((1.83 \pm 0.51) \times 10^{-3}\), \((1.02 \pm 0.21) \times 10^{-3}\), and \((1.11 \pm 0.21) \times 10^{-3}\) for the green, red, \(H\), and \(K\) band, respectively. It is consistent with a brightness temperature modulation of 2.9 K. The r.m.s. amplitude of the contrast of active region network shows a large increase toward the limb, and the quiet region network shows little center-to-limb variation (CLV). Power-spectrum analysis shows that the bright facular points in the active regions appear in the form of enhanced network.

1. Introduction

The ACRIM experiment on board SMM (Wilson and Hudson, 1988) revealed that the Sun is a variable star. The correlation of the total solar irradiance variation with the 11-year sunspot cycle suggested that the mechanism that is modulating the solar radiative output is related to the magnetic activity on the Sun, however the details remain unsolved. The integrated-light observations of the SMM do not provide us information on how the Sun modulates its radiative output, nor does it tell us if it is the total luminosity that is changing. The limb brightness measurement (Kuhn, Libbrecht, and Dicke, 1988) provides some evidence of variable total luminosity. In this experiment, Kuhn, Libbrecht, and Dicke showed evidence of a variable limb brightness temperature excess at active latitudes with an amplitude of 3 K, correlated with the SMM measurements. Integrated over the full disk, it reproduced the luminosity variation observed by SMM. Foukal and Lean (1988) compared the data from ACRIM and Nimbus 7 with the He 10830 index, and CaK plage data to show the need of a third component, the ‘active network’ contribution to the total solar irradiance in addition to the sunspots and faculae, to account for the observed total solar irradiance variation. Since these observations are spatially unresolved, they do not provide a clear picture of what is causing the total irradiance variation. Thus, precise, spatially resolved, full-disk photometric measurements are important. A system similar to the one described in this paper was developed by Nishikawa (1990a, b). It successfully reproduced the daily solar luminosity variation measured by SMM over a 90-day period. The author did not address the
issue of large-scale surface brightness variations with his instrument. This paper describes a system designed to obtain full-disk photometry of the Sun with a large-scale photometric accuracy of $10^{-3}$ per pixel. We present here the results of measurements of the brightness temperature of the photospheric network at wavelengths between 0.5 and 2.2 micron.

The photospheric network is known to outline the supergranulation seen in photospheric velocity maps, and the photospheric magnetic network (Frazier, 1970; Muller, 1983). High-resolution observations show that it consists of isolated bright points, with contrast of 1.2 to 1.4, and size of 0.2", imbedded in intergranular lanes, and was considered to be the same as the facular bright points (Muller and Keil, 1983, and references therein). The observation of Nishikawa and Hirayama (1990), which showed that the center-to-limb variation of the facular, two-color contrast in the quiet network and active regions are the same, supported this finding, but different views exist.

The measurements of the photospheric network contrast in the continuum is important for measuring the network contribution to the total solar irradiance. However, no reliable photometric measurement of the network contrast in the continuum is available to date, due to its small magnitude. Becker (1968) obtained $\approx 0.3\%$ with broad-band continuum images centered at 4850 Å. Frazier (1970) found 1% contrast at 4850 Å. Liu (1974) used time-averaging techniques on white-light images to obtain images of the network near disk center, but the contrast was not measured. Infrared observations (Worden, 1975) at 1.6 micron showed temperature structure weakly correlated with chromospheric network. Other monochromatic studies found 0.29% at 5265 Å (Skumanich, Smythe, and Frazier, 1975), 0.1% at 5256 Å (Foukal and Fowler, 1984).

Since the network is found both in active- and quiet-Sun regions, it will be instructive to study the differences of the characteristics in these two regions. This study should yield information on how the network is formed, and its relation to the supergranulation.

2. The Instruments

2.1. The Solar Photometric Telescope

The sensitivity required to resolve a temperature variation of amplitude $\delta T$ from a black body at temperature $T$ at wavelength $\lambda$ is

$$\frac{\delta I}{I} = \frac{hc}{\lambda kT} \frac{\delta T}{T} \exp \left( -\frac{hc}{\lambda kT} \right) - 1$$

where $k$ is the Boltzmann constant, $h$ is the Planck constant, and $c$ is the speed of light. At the red bandpass of $\lambda_c = 6500$ Å, $\delta I/I = 6.5 \times 10^{-4}$ for $\delta T = 1$ K, and $T = 6000$ K. In the infrared at $\lambda_c = 16000$ Å, $\delta I/I = 3.3 \times 10^{-4}$ for the same magnitude temperature variation.