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MT PEGASI (= HD 217813) — A YOUNG SUN WITH STARSPOTS

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Before its discovery as a variable star, MT Peg (HD 217813; G1V; $m_v = +6.65$ mag; $B-V = +0.62$) was used by us as a comparison star for multi-band photometry of 51 Peg. This photometry was carried out during the fall 1995 shortly after the announcement of a possible exosolar giant planet in orbit around 51 Peg by Mayor & Queloz (1995). The existence of this planet was subsequently confirmed by Marcy et al. (1997). The photometry was made primarily to investigate possible light variations of 51 Peg that could account for the 4.43 day, ~ 56 m/s radial velocity variations reported for this star (Mayor & Queloz 1995). After about two weeks of observations it became apparent that MT Peg was a variable star with small (~ 0.02 mag) light variations as noted by Guinan et al. (1995). Conversely, 51 Peg was found to be constant in brightness to less than a few millimags (Guinan et al. 1995), as later confirmed by Henry et al. (2000).

MT Peg has an assigned MK spectral type of G5V (Simbad). However, this spectral type is not in good agreement with the spectral class of $\sim$ G1V indicated from the UBV and Strömgren indices that appear in the Simbad database. The observed $B-V$ and $U-B$ values of $+0.62 \pm 0.01$ and $+0.10 \pm 0.01$ mag, respectively, and the Strömgren indices of MT Peg of $b-y = +0.39$, $m_1 = +0.202$, and $c_1 = +0.321$ indicate a G0-1 V star rather than a G5V (Simbad). In addition, the absolute visual magnitude of MT Peg of $M_v = +4.72 \pm 0.2$ mag (computed using the Hipparcos parallax of $d = 24.3$ pc and $\langle V \rangle = +6.65$ mag), is in better agreement with a near-ZAMS G1V star than a G5V star. It is possible that MT Peg has an unresolved blue companion that effects the color indices but this is unlikely. A new spectral classification of MT Peg would be useful to resolve this minor discrepancy.

$UBVRI$ photometry was conducted with the Four College Consortium (FCC) 0.8-m Automatic Photoelectric Telescope (APT) in the Patagonia Mountains located in southern Arizona. The observations were made on 14 nights from 14 October–12 November 1995. Differential photometry was made employing the usual observing sequence sky–comparison–variable–comparison–sky. The stars were observed for about 20–25 minutes per night with integration times of 10 seconds. Standard photometric reduction methods were utilized to reduce the data. The UT times were transformed to heliocentric Julian Day (HJD) and differential atmospheric extinction corrections were applied. The observations were converted to delta-magnitudes in the sense of variable minus comparison star. In the reductions, the role of the "variable" and "comparison" star were interchanged and 51 Peg served as the comparison star for the photometry of MT Peg. Because the angular separation of 51 Peg and MT Peg is small ($< 2°$), the corrections for differential

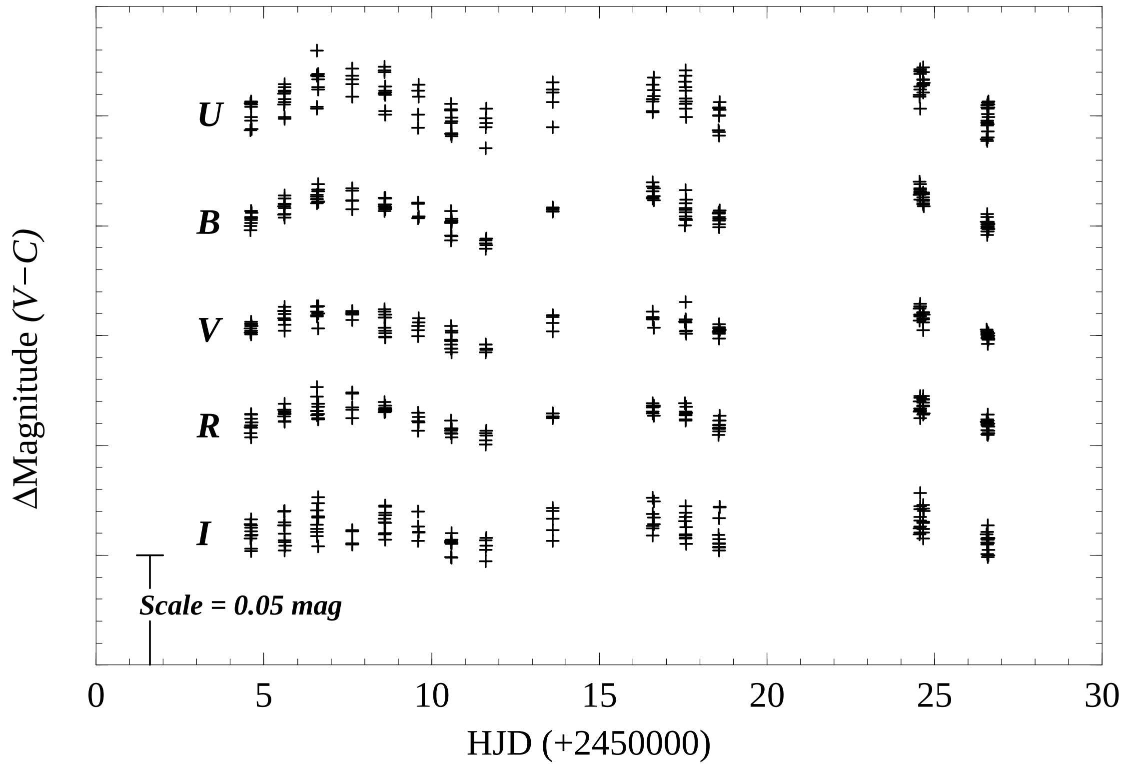

Figure 1. Light variations of MT Peg from photometry obtained during October–November 1995 are shown.

atmospheric extinction were negligible. To illustrate the light variations of MT Peg, the U, B, V, R, I observations are plotted in Figure 1 against Julian Day Number.

As shown in Fig. 1, MT Peg has periodic quasi-sinusoidal brightness variations with a period of several days. Also the light variations are wavelength dependent with the greater light amplitudes occurring at shorter wavelengths. From a power spectrum analysis (Scargle 1982), a broad, definite peak is found for a period of $P = 8.1 \pm 0.2$ days when all of the band-passes are used. Unfortunately, this observing run lasted less than a month so that the photometric period is not as well defined as it could be with additional data. The observations were combined and plotted against phase with this period. Representative light curves and a geometrical starspot model fit (discussed later) are presented in Fig. 2. As shown, the light variations are quasi-sinusoidal with light amplitudes that are small and a function of wavelength. The observed light ranges for each band-pass are: U (0.018 ± 0.003 mag), B (0.021 ± 0.002 mag), V (0.015 ± 0.003 mag), R (0.013 ± 0.002 mag), I (0.012 ± 0.003 mag).

The nature of the light variations and the wavelength dependence are similar to those reported for chromospherically-active, cool stars (BY Dra and RS CVn variables) in which the light variations arise from the presence of starspots. The starspot hypothesis for explaining the light variability of MT Peg is strongly supported by the discovery that MT Peg is a moderately strong coronal X-ray source with an X-ray luminosity of $L_x = 1.25 \times 10^{29}$ erg s^{-1} (Gaidos 1998). Moreover, the L_x observed for MT Peg is in excellent agreement with the value expected from $L_x - P_{\rm rot}$ relationship found by Güdel et al. (1997) for G0-5 V stars, with the adopted rotation period of $P_{\rm rot} = 8.1$ d. Also, because the rotation of a single, solar-type star is dependent on age, the "rotational" age of MT Peg is about 0.7 ± 0.2 Gyr from age $- P_{\rm rot}$ relation from Dorren et al. (1994). Although this

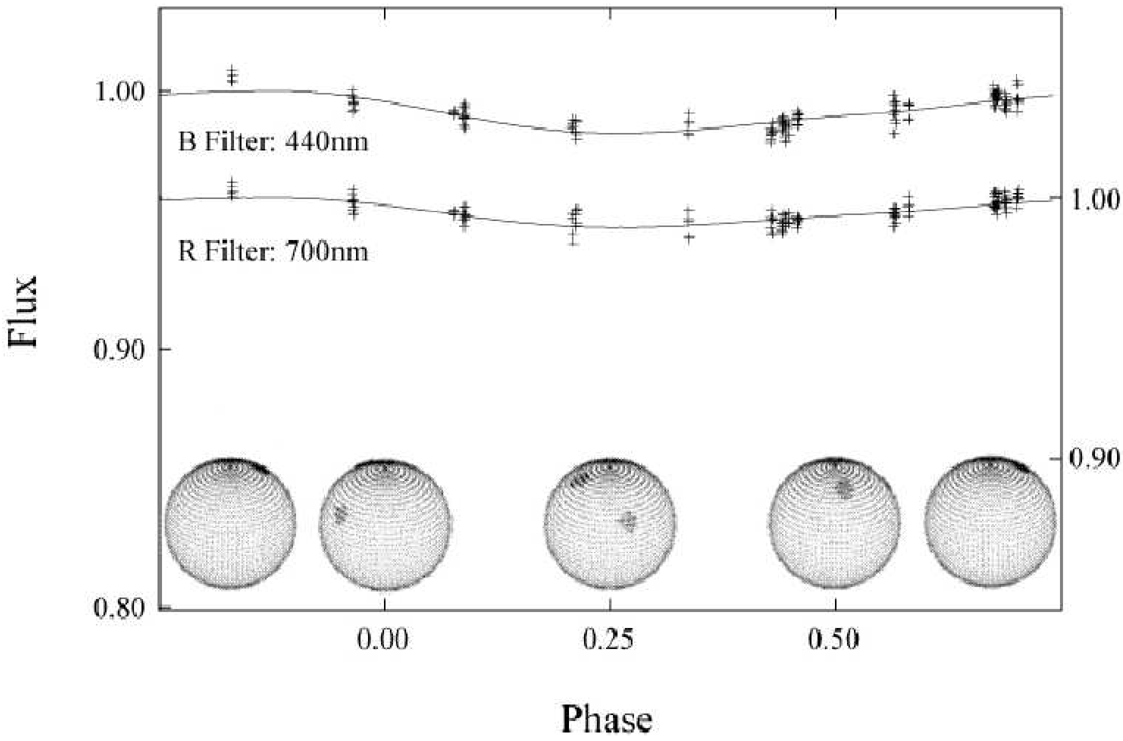

Figure 2. Starspot model fits to the B and R observations are shown in the lower part of the figure. Different rotational aspects of the star are shown. The observations are phased with a period of 8.1 days.

"spin-down" age for MT Peg is similar to the evolutionary age of Hyades stars, the (U, V, W) space motions of MT Peg of (+22.4, +11.2, +11.9) km s^{-1} are not consistent with membership in the Hyades Moving Group (−40, −18, −2) (Soderblom & Clements 1987). However, the space motions of MT Peg are similar to those of the Sirius Supercluster of (+11.1, +3.3, −8.2) km s^{-1}. A recent determination of the age of the Sirius Supercluster (which includes the Ursae Majoris Star Stream) is $\sim 0.49 \pm 0.13$ Gyr (Palouš & Hauck 1986).

The light curves were modeled using a simple starspot model included in the Binary Maker Program (Bradstreet 1993). In this case, the companion star was given a near zero mass and luminosity. The amplitudes and shapes of the light curves were fitted through manual iterations. We adopted a model with two cool, circular starspots. From the assumed spectral class of G1V, we also assumed a temperature of $T_{\rm eff} = 5800$ K for the immaculate regions of the star (Cox 2000). Because of the low amplitude light variations, there is little information contained in the light curves about the latitudes of the starspots on the star. The best fits were obtained when the spots were placed at latitudes of 30° and 60°. After about 50 iterations we obtained satisfactory fits to U, B, V, R, I light curves; the best fits were obtained with a total spot coverage (measured relative to the star's total surface area) of $\sim$ 2.2% or 4.4% if equatorial symmetry is assumed and the spots are located in both northern and southern hemispheres. From the iterative analysis, we found that the spots were separated in longitude by $\sim 90 \pm 25°$. Figure 2 shows the spot model fits to the B and R observations. The wavelength dependence of the light variations indicates a difference of temperature (photosphere − spot) of $\sim 500 \pm 150$ K. For the modeling, we assumed the rotational pole of the star is viewed at a nominal value

$i = 60°$ to our line-of-sight. When a precise value of the projected rotational velocity ($v \sin i$) is determined from spectroscopy, then the inclination of the star (i) can be found from its rotational period. Because of the small light variations and the lack of Doppler imaging, the latitudes of the star spots can not be accurately determined. However, they should be considered as representative of spot areas, distributions, and temperatures at the time of observations.

MT Peg is an important star for studying the magnetic evolution of our Sun. In particular, its estimated age of $\sim$ 0.5–0.7 Gyr makes it a suitable bright, nearby proxy for the Sun at an age when life was first developing on Earth some $\sim$ 4 Gyr ago. Additional photometry is needed to refine its period as well as to investigate possible differential rotation and a starspot activity cycle commonly found for other young solar-like stars. A modern determination of a MK spectral type would be very useful to confirm our adopted G1V spectral class. Also high dispersion spectra are needed as well to determine the star's projected rotational velocity ($v \sin i$) and to ascertain that it is a single star.

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