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CIRCUMSTELLAR INFRARED EMISSION FROM COOL STARS

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ABSTRACT

From a recalibration of published spectra of cool stars in the wavelength region 3–14 μ, it is shown that most of the emission from 10 to 14 μ is circumstellar rather than photospheric. Broad-band photometry shows the emission in giants later than M5 and in M2 supergiants but not in some cool carbon stars. The spectrum of the emission resembles that predicted from mineral grains. The carbon star R Leporis has an emission feature in its spectrum unlike that of the M stars.

An 11.5-μ broad-band stellar photometer is in use on the 30-inch telescope at the O'Brien Observatory (Ney and Stein 1968). The photometric system will be described by Woolf and Ney (1969). As a result of using this system, it has been found that there is circumstellar emission from cool stars. This Letter is a preliminary announcement of this result.

Spectra of cool stars in the wavelength region 3–14 μ have been published by Gillett, Low, and Stein (1968), but doubts about the relative calibration of the regions 3–5 μ and 8–14 μ made it uncertain whether the cooler stars showed an absorption band from 7.5 to 9.5 μ or an emission band from 9.5 to 14 μ. The new 11.5-μ broad-band photometry fortunately has its response entirely in one of these regions. Therefore, the broad-band photometry could be used to calibrate the long-wavelength region of the stellar spectra.

Absolute calibration of the broad-band photometry was done by the method of observing objects whose extraterrestrial flux could be predicted. These objects were the planet Mercury at superior conjunction, a G dwarf star, and (with less confidence in the prediction), an A0 star. The calibrations agree to within ± 10 per cent. For more details see Woolf and Ney (1969).

The broad-band photometry was used to normalize individually the 8–14-μ region of the spectra of o Cet, χ Cyg, α Ori, and μ Cep. The absolute levels had to be raised in all spectra, but by varying amounts. After renormalization, the continuum near 7.5–8 μ fell close to a blackbody curve through the 3 μ region for all the stars. The region from 9.5 to 14 μ appeared as an emission feature, almost five times as bright as the continuum in μ Cep, with smaller factors in the other stars. Figure 1 shows the modified spectrum of μ Cep. Figure 2 shows the result of subtracting a blackbody spectrum from the long-wavelength continuum in each star. The results are least accurate for χ Cyg. However, it is clear that the spectral distributions of the excess emission are similar in all the stars, although possibly not identical. It can be argued that no known mechanism could produce this feature as chromospheric emission and thus that it must be circumstellar. Likely abundant circumstellar molecules do not seem to have strong emission bands in this spectral region. Therefore, it is suspected that the emission is by circumstellar solid particles. The emission is far more sharply peaked than a blackbody. Therefore, the wavelength dependence of the emission probably closely mimics the wavelength dependence of the opacity of the material.

Gaustad (1963) has estimated the opacity of mineral grains under the assumption that they are mainly $MgSiO_3$, with some Fe_2O_3 and SiO_2. Figure 3 shows the wavelength dependence of the opacity of these grains and also of olivine, $(Mg,Fe)_2SiO_4$. It is seen that in these materials the wavelength dependence of the opacity resembles that of the material responsible for the circumstellar emission. Spread in particle size, impurities, and imperfect crystal structure will all smear out features in the band and broaden it, making precise identification difficult.

Solid materials expected to condense in cool atmospheres are discussed in the following Letter (Gilman 1969). For details of the oxygen-rich case see also Larimer (1967). Aluminum silicate will be rare because of the low cosmic abundance of aluminum, so that olivine and orthopyroxenes such as $MgSiO_3$ should be the first abundant solids to condense in oxygen-rich atmospheres like those of the M stars. Olivine and orthopyroxene are the major minerals of the stony meteorites.

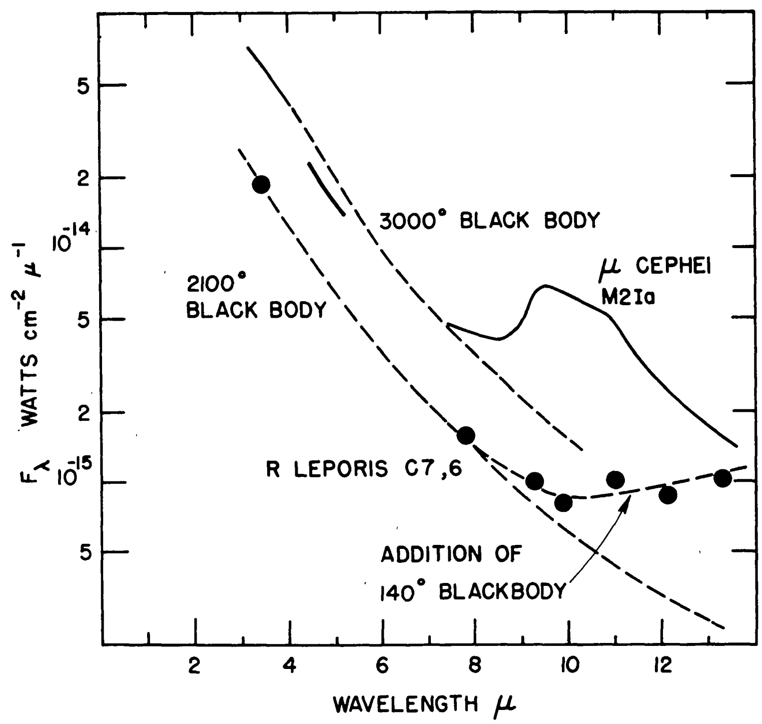

FIG. 1.—Observed spectrum of μ Cep (*solid lines*), with the region 7.5–13.5 μ normalized to the results of broad-band photometry. Points are observations of R Lep. Point at 3.5 μ is an unpublished broad-band observation by D. Strecker, and the points from 7.5 to 13.5 μ were obtained with a spectrometer with 1 per cent resolution at Lick Observatory. Dashed lines are theoretical curves for blackbodies. The 140° curve for R Lep assumes an optically thin gray body.

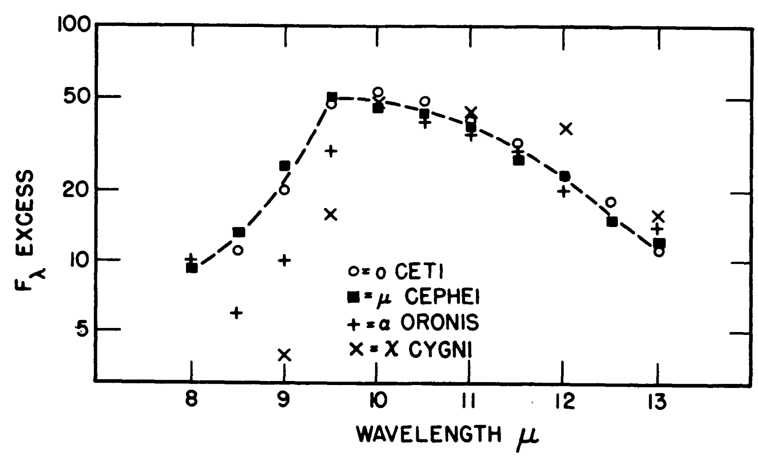

FIG. 2.—Excess radiation over a hot blackbody spectrum for four stars from Gillett, Low, and Stein (1968). Dashed curve is an empirical attempt to fit the observations of μ Cep.

Carbon is expected to condense in carbon-rich atmospheres, and this has probably been observed for R CrB (Stein *et al.* 1969). By use of a color-color plot, broad-band photometry of cool stars can be used to distinguish those in which circumstellar emission occurs. It does not occur in the two carbon stars TX Psc C6,2 and DS Peg C6,3, even though these are cooler than M stars such as g Her (M6 III), which shows the emission, or α Her (M5 II), in which it is beginning to be present.

Observations of intrinsic polarization for the carbon star R Lep C7,6 (Serkowski 1966) suggested that it might have circumstellar emission, and preliminary spectroscopic observations of this star were made at Lick Observatory (Fig. 1). It is seen that there is an emission feature visible at the longest wavelengths but that this does not

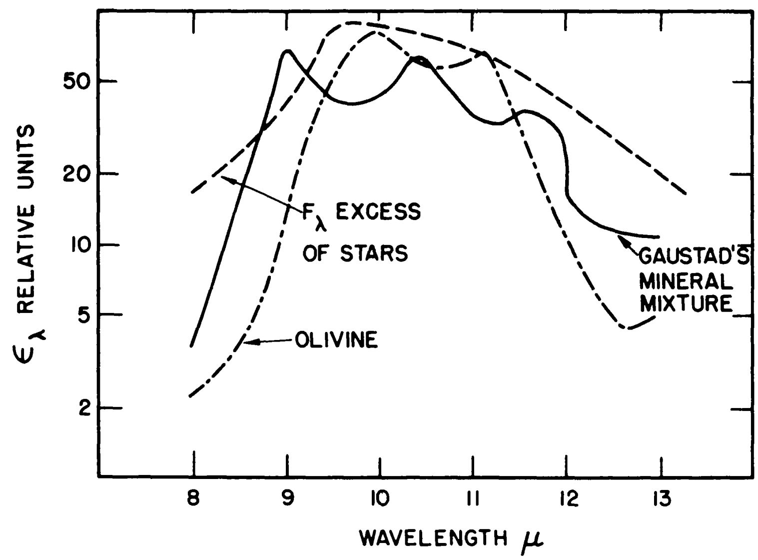

FIG. 3.—Comparison of wavelength dependence of emissivity for two kinds of mineral grains with the excess radiation from cool stars. Gaustad's mineral mixture is 80 per cent pyroxene $MgSiO_3$, the remainder being SiO_2 and Fe_2O_3. The olivine $(Mg,Fe)_2SiO_4$ is a terrestrial rock sample of unspecified Mg:Fe ratio. For details and references see Gaustad (1963).

resemble the feature in the M stars. It could be the short-wavelength end of a cool black-body spectrum, $T \sim 140°$ K.

The temperature of the mineral grains around the M stars is not yet known. Observations place an upper limit to the angular size of the emitting envelope around α Ori of about 5″ diameter. The corresponding peak brightness temperature of the emission is $\sim$140° K. The black-sphere temperature at this radius is $\sim$200° K, and the grains are probably hotter than this. Some indications of the grain temperature are perhaps being obtained from R Aqr (Stein *et al.* 1969), in which the circumstellar peak is flattened as though it had become optically thick. If so, in this case, the temperature of the grains is $\sim$300° K.

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