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NEW INFRA-RED DATA ON MIRA VARIABLES

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Abstract

The "IRC" catalog provides photometric data on 5562 objects; most of them are late type stars. Two current projects are described: (1) a search for variables among the IRC objects, (2) construction of infra-red light and color curves.

The Mira stars are known for their relatively long periods (typically, 200 to 500 days), their deep red color, and their large visual amplitudes, which often reach six magnitudes, or a factor of 250 in brightness. Their large amplitudes make these stars particularly easy to discover, so it is no accident that, among the 87 constellations listed in the <u>General Catalog of Variable Stars</u>, 61 have a Mira star designated "R", indicating that it was the first variable discovered in that constellation after the modern convention of naming was initiated.

But their large amplitude for the visual observer is somewhat deceptive. The bulk of their energy is known to be radiated in the infra-red, well beyond the sensitivity limit of the human eye, so the visual observer merely detects the blue "tail" of a much more extensive curve. It is not difficult to see that this tail will fluctuate more widely than the main body of the curve, if we assume that the cyclic fading of these stars is produced by a cyclic drop of surface temperature. Such a drop would have two consequences, both tending to amplify the visual variations of light. First, the radiation of the atmospheric layers would be shifted from the visual to the infra-red, and second, some of the atmospheric atoms would combine to form molecules (such as titanium oxide, TiO) which are particularly adept at absorbing visual light. (The cyclic variations of temperature are probably caused by pulsation, as is the case for Cepheids and RR Lyrae stars, but it is not yet clear why the Miras are so much more erratic.)

Theoretical studies of Miras can probably be counted on the fingers of one hand. Until recently, to start on such a project would have been a bit like undertaking to study an elephant by examining only its tail. But the situation is changing. New infra-red detectors have permitted photometry at selected wave lengths over the entire range of atmospheric radiation; radio telescopes have detected emissions from extended shells; and most recently, "speckle interferometry" has provided direct measures of the angular diameter of Mira and a handful of other bright red stars.

To supplement these detailed studies of individual stars, a number of astronomers have also studied -- and are continuing to study -- the statistical properties of Miras as a group, asking such questions as, "How do their properties, such as average temperature and pulsation amplitude, depend on pulsation period?", "How are these stars distributed in the galaxy?", "Will this distribution give a clue to their ages and their evolution?"

A valuable and unique source of statistical information was published in 1969 by G. Neugebauer and R. Leighton, of the California Institute of Technology. It is known informally as the "IRC" (Infra-Red Catalog) and it was the first stellar catalog based entirely on invisible radiation.

Neugebauer and Leighton carried out their observations at Mount Wilson, California, using a telescope with a 62-inch, f/1, mirror made of epoxy and coated with aluminum. They used two detectors: a silicon photovoltaic cell for radiation at 8000 angstroms and a lead sulfide cell for radiation at 22,000 angstroms. Their catalog lists 5562 objects brighter than the adopted cut-off limit, and correcting for the area of the sky covered in their survey this figure implies a total of 7800 objects on the entire sky. By comparing measured coordinates with those found in other star catalogs, the authors were able to identify the majority of the IRC stars with known red stars, and the list includes 1055 variables. A small fraction was identified with bright yellow stars. Later comparisons have brought the total number of variables to approximately 1446, including 395 Mira stars and 465 semiregular variables. Virtually all of the remaining objects have been identified with faint red stars on the Palomar Sky Survey.

Table 1 indicates the faintness reached by the IRC, for which the infra-red limit was K = 3.0. ("K" is the magnitude measured at 22,000 angstroms.) This limit can be converted to a visual limiting magnitude by using the (V-K) colors of stars of various spectral types. We see that the catalog barely reaches the naked-eye limit among stars of spectral type K0. But, for the very red stars of spectral type M9, whose radiation is concentrated in the infra-red, the catalog reaches nine magnitudes fainter, down to a limit that could represent a challenge to AAVSO observers.

These extremely red stars were virtually unknown before the IRC, and little is known about them today, except their location and their colors and spectral types. One thing appears certain: The fainter of these stars must be at great distances, perhaps halfway across the galaxy. Table 2 gives an estimate of the distances reached by the IRC for various spectral types, and it is based on known absolute magnitudes for the K0-M5 giants and guesses for the cooler stars. This table indicates that studies of such stars may offer a unique way of surveying the distant portions of our galaxy.

Two projects are underway at the Center for Astrophysics, and I will mention them briefly.

1. Sarah Hill is preparing finding charts for the faint red IRC stars and is examining Harvard photographs for signs of variability. Of the 200 stars examined thus far, she has found nearly one-third to be variable by more than one magnitude. We suppose that these are Mira stars -- perhaps the coolest known -- but the photographic data are fragmentary, and the light curves cannot be drawn without more observations. (I am looking into the possibility of adding some of these stars to the AAVSO list.)

2. Cecilia Payne-Gaposchkin and I are constructing infrared light and color curves from IRC data on known Miras, and we are attempting to map out the mean behavior of colors and magnitudes as functions of period. As suggested by early Mount Wilson studies of the brightest Miras, we find that the infra-red (K) amplitude is only 0.8 to 0.9 magnitudes as contrasted with a visual amplitude of nearly six magnitudes.

The K amplitudes appear to be nearly independent of period, and this fact will probably be a clue to the ultimate theoretical interpretation of these stars.

Earlier, I mentioned the recent measures of angular diameters for Mira and a few other bright red stars. The derived angles, typically 0.05 arcseconds, are equivalent to the apparent diameter of a golf ball at a distance of 100 kilometers, and they can presently be measured with a precision of about ten percent. We had hoped to use this information to derive reliable temperatures for these stars, but it now appears that such a hope was premature, because the new measures have presented a new problem in themselves. Mira, for example, is nearly fifty percent larger in blue light than in infra-red light, as though it were surrounded by an immense blue halo. Such a halo would defy a simple interpretation.

So, as is typical of many new observations, these are raising more questions than they answer. But we have the satisfaction of knowing that we are beginning to sense some of the true mysteries of the Mira variables. Or so it appears!

TABLE 1

Limiting V Magnitude of IRC Stars

Spectral Type	(V-K)	V_{limit} (K=3.0)
K0	2.3	5.3
M1	4.1	7.1
M5	6.0	9.0
M7	8.2	11.2
M9	11.8	14.8

TABLE 2

Limiting Distances of IRC Objects

Spectral Type	M_V	m-M	d(kpc)*
K0III	+1.0	4.3	0.07
M1III	-0.4	7.5	0.32
M5III	-0.8	9.8	0.91
M7III	-1	12.2	2.75
M9III	-1	15.8	14.4

*The sun's distance from the center of the Milky Way is approximately 8kpc.