# Miras and Janet Mattei

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**Abstract** Janet Mattei's name is on more than 70 papers concerning Mira variables or related classes of red variables. Janet also helped to start several observational programs concerning particular types of variables, and was involved with the planning and/or data analysis on space missions that observed these stars. In this review I put her contributions into a general context of work in this field.

## 1. Introduction

A quick search of the Astrophysics Data System (ADS) in October 2004 turned up 471 papers by "J. Mattei"; however, of these at least one is by "Jean-Luc Mattei" and so at most 470 were papers authored or co-authored by Janet. Of these, approximately 70 had to do with Miras, semiregular SR red variables, or symbiotic systems (with or without Mira components). That is a respectable publication record even without the other 400 papers on other types of stars. By May 2005 the total had risen to about 480 and there are at least several more papers in the works. At the end of this paper I have collected a list of those papers involving Janet that are most significant, as well as a few other papers that are cited to give the historical context.

## 2. The pre-Janet era

I will review the history by decade, to give a context for Janet's contributions (or, perhaps more accurately, the AAVSO's contributions during Janet's reign).

From 1903 to 1913 we have the decade of the founding of the AAVSO. During the next four decades—1913 to 1953—variable stars were a hot topic in astronomy, and many of the top names of the era published papers on variable stars, including Joy, Cannon, Merrill, Oort, Swope, van Maanen, Buscombe, Payne-Gaposchkin, Eddington, Sanford, Thackeray, Jeans, and Shapley. Palomar 200-inch telescope time was devoted to getting high-resolution spectra, published by Joy (1947a, 1947b, 1947c, 1952a, 1952b, 1954a, 1954b, 1959) and Merrill (1947, 1948, 1950, 1952a, 1952b, 1952c, 1953, 1956, 1959; Merrill and Greenstein 1958; Buscombe and Merrill 1951, 1952a, 1952b) in a series of detail-rich papers that are still valuable resources. (Joy also published a leaflet on "Some Early Variable Star Observers" (1937) and several obituaries for astronomers, including P. W. Merrill.)

From about 1953 to 1973, however, the field of variable stars, and particularly of red variables, involved only a few professional observers and almost no theoretical work. (George Wallerstein claims to have remarked, on reading my first paper in 1972, "There's a theorist working on Miras. He must be out of his mind!") There were probably two reasons for this: (a) a lot of very high quality data had been obtained, but the models to interpret them were not yet possible; and (b) some breakthroughs required observations beyond the visible window. This situation began to change in the 1970s.

**3. 1973–1983**

Janet joined the AAVSO around 1973, about the same time I joined the faculty at Iowa State, although I didn't meet her and the AAVSO until 1978, when I took advantage of a college reunion to come to Cambridge and copy light curves at AAVSO Headquarters on Concord Avenue.

From 1973 to 1983, there was theoretical work done on shocks in variable stars including Miras. Just before this decade, Steve Hill computed shocks for RR Lyrae stars and noticed that the shock amplitude satisfied the relation $\Delta v = gP$ (Hill 1972). Later, Hill and I collaborated on models for Mira shocks, determining from the shock amplitudes that these stars must be pulsating in the fundamental mode (Hill and Willson 1979; Willson and Hill 1979). In the 1960s Whitney and Skalafuris had published some systematic studies on shocks in a hydrogen-rich gas (Skalafuris and Whitney 1961; Skalafuris 1965, 1968, 1969; Whitney and Skalafuris 1963). Linear modeling and nonlinear modeling for Miras and their shock-riddled atmospheres were carried out by Ostlie and Cox (1986; Cox and Ostlie 1993) and Wood and Fox (Fox and Wood 1982, 1985; Wood 1974, 1979). Wood and Zarro (1981) did an analysis of the period-changing Miras R Hya and R Aql in terms of He shell flashes. Also in this decade, Ed Brugel and I carried out observations of MgII emission lines with IUE, a project that enriched the archives more than the literature as most of those results did not make it into refereed publications before Ed left astronomy. More importantly, though, ground-based observations of thermal CO in the radio established the correct center-of-mass radial velocity for these stars; this was needed because the visual lines shift erratically and do not give a good indication of the stellar velocity (Reid and Dickinson 1976). Additional important observations from this era include the monitoring of CO lines in the IR (Hinkle 1978; Hinkle and Barnes 1979 a, b), giving constraints on the shock amplitude that allowed us (Hill and Willson 1979; Willson and Hill 1979) to show that Miras must be pulsating in the fundamental mode. This triggered a debate that has lasted most of 25 years, and has finally been put to rest only in the last year, with the discovery of moderately opaque water vapor shells around Miras. These "molecular shells" are sufficiently opaque in the visible and near IR that the star appears bigger than it is, and the true size is entirely consistent with fundamental mode pulsation.

Why was the mode of pulsation not obvious? For most classes of variables, theoretical models give $Q = P\sqrt{\rho / \rho_\odot}$ values for each mode, usually with a slight residual dependence of Q on M and R, and determination of the mass M and the radius R then identifies the mode associated with each observed period. Or, if M is uncertain, usually determining R will be sufficient to determine the mode, and then theoretical Q may be used to refine the estimate for M. However, for the Miras, angular diameter measurements with best estimates for their distances have resulted in large and scattered values for R, mostly large enough to suggest overtone modes of pulsation. (A given period, for a given M, will correspond to fundamental mode for a smaller star and overtones for larger ones.) What we showed was that the observed shock amplitudes could not arise in such large, low gravity, objects. In the last year, interferometric measurements over several frequencies have unambiguously demonstrated that the star is small, but that it has a nearly opaque “molecular shell” at two stellar radii confounding the measurements (Weiner *et al.* 2003; Perrin *et al.* 2004). As far as I could tell, Janet never picked a side in this debate, a fact I always interpreted as reflecting her awareness that her opinion would be taken seriously and should not be given lightly. She kept a statesmanlike distance from any controversies, at least outside of her own specialty.

An interesting approach to the analysis of the evolutionary status of Miras was introduced by Wood and Cahn (1977). They plotted the evolution as mass versus log(luminosity); as L increases exponentially, log(L) is a proxy for time. They showed that whatever happens after the Mira stage must be very quick, because the Miras already have the maximum luminosity that they will achieve, while at the same time the masses of Miras could not be much smaller than their main sequence progenitor masses given their periods and luminosities.

In this decade, Janet Mattei and John Percy set up the AAVSO program to study small amplitude red variables. Also, Janet and I had our first fun paper: The 1978 eclipse of R Aqr, reported in the *Information Bulletin on Variable Stars* (Willson, Garnavich, and Mattei 1981). From infrared observations of R Aqr during and after the event we deduced that R Aqr had been eclipsed during 1978 by some semi-opaque collection of material around its companion, and from the historical light curve we were able to deduce an orbital period of 44 years, making R Aqr the eclipsing binary with the longest period. The next eclipse of the Mira by the companion and its circumbody material is due in 2022, if our model is right. Peter Garnavich, who was then working at headquarters, joined us on this paper.

## 4. 1983–1993

In the next decade, 1983–1993, the Infrared Astronomy Satellite (IRAS) kindled widespread interest in these highly evolved, cool stars. Also, the Hipparcos satellite provided a wealth of data on stars generally, and included study of some red variables and a few Miras.

Janet and the AAVSO were heavily involved in the Hipparcos project, before, during, and after the mission. In order to determine accurately the positions of the variable stars on the program, their magnitudes needed to be known in advance. Also, the AAVSO was involved in picking appropriate targets (Mattei 1989). A story

I remember from that era is that Grant Foster, AAVSO's superlative data analyst, brought Janet some light curves of small amplitude variables with a very interesting light curve fitted to the data. Janet was skeptical—as I would have been—that so much information was contained in the data. However, when the Hipparcos photometry was compared with Grant's analysis of the AAVSO data, they were a perfect match, proving again that visual observations can be very valuable.

One result of the Hipparcos involvement was a study Janet undertook with Marie-Odile Mennessier in France, to see whether the spectral type (M, S, or C) could be deduced from the appearance of the light curve. In a plot of amplitude versus period, the C stars generally show much lower amplitude at a given P, and a few S stars stand out as having unusually large amplitudes as well as being prevalent at longer periods, for example (Mennessier *et al.* 1997).

The Hipparcos mission yielded excellent parallaxes on many types of stars and stellar systems, but the results for Miras were not as good as, for example, period-luminosity relations from the LMC (Willson 2000, Figure 5). The reason is undoubtedly that the star's radius is about 1 AU, and its apparent radius in the visible generally more like 2 AU. Thus, when the parallax was large enough to measure, the star was also partially resolved; its image was spread across several elements in the Hipparcos detector. In addition, there is some evidence for departures from spherical symmetry in optical interferometry images (Karovska 1999), possibly due to patchy or cloudy opacity in the molecular shell, and any change in the position of such bright spots would contribute to or subtract from the measured parallax.

Between 1983 and 2003 Janet was involved in a number of complementary projects to clarify the nature of the SR variables (Cadmus *et al.* 1991; Cannizzo *et al.* 1990; Mennessier *et al.* 2000; Kiss *et al.* 1999). The smaller amplitude red variables are still quite puzzling. The traditional classification scheme (GCVS) is not very satisfying: Miras are very cool giants, with emission lines, visual amplitude greater than 2.5 magnitudes, and relatively regular variation. The SR classes each differ from Miras in a different one of these dimensions: SRa: smaller amplitude than Miras; SRb: less regular than Miras; SRc: supergiants, not just giants (higher mass and/or luminosity); SRd: warmer than Miras.

Also between 1983 and 1993 interest in mathematical chaos waxed high in a variety of areas including astronomy. Janet was involved with a couple of projects looking to see whether this was relevant for Miras. Cannizzo *et al.* (1990) concluded that there was no evidence for mathematical chaos in the light curves. Also, at Janet's and my instigation, R. Cadmus of Grinnell, IA, began a monitoring program for stars with alternating large and small amplitude states, to see whether they were switching mode or not when the amplitude changed. An early publication from this effort was Cadmus *et al.* 1991.

On the theoretical front, the modeling of Miras split into several camps during this decade, emphasizing different comparisons with observations. Our work with Bowen's models (Bowen 1988; Bowen and Willson 1991), including efficient approximations for non-LTE cooling, dust, shocks, and constraints on the amplitude of driving, produced a broad but clear picture of the Mira stages of evolution of stars like the Sun. However, because these models include the non-LTE cooling in a simple way, they are not easy to translate to radiative transfer calculations. Other groups have focused on either matching spectra with radiative transfer, necessarily with an LTE approach (e.g. Höfner 1999; Höfner *et al.* 2000, 2002, 2003), or on detailed chemical networks to follow carbon grain formation with mostly equilibrium properties for the gas otherwise (see review by Höfner *et al.* 1996).

## 5. 1993–2003

From 1993 to 2003 major astronomical milestones include the Hubble Space Telescope and the 2-MASS infrared survey. Also, the study of Miras benefited enormously from the "garbage heap" of data from the dark matter surveys, including MACHO and OGLE. Possibly the most cited diagram in this topic is the K magnitude versus logP plot for LMC red variables assembled by P. Wood in 2000 from this "garbage," showing several overtone sequences, the F mode Mira sequence, and some longer period sequences that represent red giants not on the AGB and/or binary systems that don't quite become symbiotics. Janet's contributions during this era include the study of symbiotic systems containing Miras, with M. Karovska, the subject of Margarita's paper presented at this symposium [Ed. note: the abstract is printed in this issue], and some work on multiple periods and changing periods in Miras from AAVSO data that Matthew Templeton and I are finishing now (Templeton *et al.* 2005).

In all her work on Miras Janet readily admitted that her contribution was really the contribution of hundreds of observers over the past century who made it possible to determine what many of these stars are doing. She ably served as an avenue of communication between the AAVSO community and the wider professional community. She gained stature and a solid reputation for herself and thereby also for AAVSO by participating at the highest levels in the astronomical community in planning missions, analyzing data, and publishing results. When we collaborated on a project, I always found her very careful, very concerned to be sure that the data were appropriately used, ready to be enthusiastic for a good idea, but also ready to slam on the brakes if the interpretation galloped ahead of the data. This, I am sure, also characterized her contributions concerning other classes of objects.

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