Miras and Janet Mattei

Lee Anne Willson
Department of Physics and Astronomy, Iowa State University, Ames IA 50014

Presented at a memorial symposium in honor of Dr. Janet A. Mattei, Brandeis University, Waltham, MA, October 29, 2004; received June 6, 2005; revised June 28, 2005; accepted June 28, 2005

Abstract Janet Mattei appears among the authors on over 70 papers concerning Mira variables or related classes of red variables. She contributed to the planning or execution of some of the research in this area, but more often appeared as representative for the thousands of AAVSO observers world wide. 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, and the AAVSO's contributions while she was Director, into a general context of work in this field.

1. Introduction

As AAVSO Director, Janet Matter worked to ensure that AAVSO data were correctly used by researchers, and that the thousands of AAVSO observers whose voluntary efforts had generated the data were acknowledged and represented. Thus, she enforced the AAVSO Council policy of having the Director or Director's representative be a co-author on those research papers based primarily on AAVSO data. The Director's responsibility included guaranteeing data quality and appropriate interpretation of the data, whether or not she was otherwise involved for her scientific expertise.

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 $\Delta v = g P$ (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 $Q = P\sqrt{\rho / \rho}$ 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 *et al.* 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; Kholopov *et al.* 1985) 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 either on 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, an inherently non-equilibrium process, 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.

6. References

6.1. Significant Miras/semiregulars papers where J. Mattei is an author

Alvarez, R., Mennessier, M. O., Barthes, D., Luri, X., and Mattei, J. A. 1997, "Oxygen-rich Mira Variables: Near-Infrared Luminosity Calibrations. Populations and Period-Luminosity Relations," *Astron. Astrophys.*, **327**, 656.

Barthes, D., Mennessier, M. O., Vidal, J. L., and Mattei, J. A. 1998, "Are Low-Order Resonances Observed in Mira Pulsation?", *Astron. Astrophys.*, **334**, L1.

Barthes, D., Mennessier, M. O., Vidal, J. L., and Mattei, J. A. 1998, "Erratum: Are Low-Order Resonances Observed in Mira Pulsation?", *Astron. Astrophys.*, **337**, 650.

Barthes, D., Tuchman, Y., Mennessier, M. O., and Mattei, J. A. 1993, "Theoretical Modes Fitting on Mira's Light Curves," *Astrophys. Space Sci.*, **210**, 139.

Cadmus, R. R., Willson, L. A., Sneden, C., and Mattei, J. A. 1991, "Observation of Possible Mode Switching in Three Semiregular Variable Stars," *Astron. J.*, **101**, 1043.

Cannizzo, J. K., Goodings, D. A., and Mattei, J. A. 1990, "A Search for Chaotic Behavior in the Light Curves of Three Long-Period Variables," *Astrophys. J.*, **357**, 235.

de Laverny, P., Mennessier, M. O., Mignard, F., and Mattei, J. A. 1998, "Detection of Short-Term Variations in Mira-type Variables from HIPPARCOS Photometry," *Astron. Astrophys.*, **330**, 169.

Hawkins, G., Mattei, J. A., and Foster, G. 2000, "R Centauri: An Unusual Mira Variable in a He-shell Flash," *J. Amer. Assoc. Var. Star Obs.*, **29**, 56.

Hawkins, G., Mattei, J. A., and Foster, G. 2001, "R Centauri: An Unusual Mira Variable in a He-Shell Flash," *Publ. Astron. Soc. Pacific*, **113**, 501.

Hazen, M. L., and Mattei, J. A. 2002, "Period Changes in the Mira Variable TY Cas," *J. Amer. Assoc. Var. Star Obs.*, **31**, 21.

Kiss, L. L., Szatmáry, K., Cadmus, R. R., and Mattei, J. A. 1999, "Multiperiodicity in Semiregular Variables. I. General Properties," *Astron. Astrophys.*, **346**, 542.

Kiss, L. L., Szatmáry, K., Szabó, G., and Mattei, J. A. 2000, "Multiperiodicity in Semiregular Variables. II. Systematic Amplitude Variations," *Astron. Astrophys. Suppl. Ser.*, **145**, 283.

Knapp, G. R., Dobrovolsky, S. I., Ivezić; , Z., Young, K., Crosas, M., Mattei, J. A., and Rupen, M. P. 1999, "The Light Curve and Evolutionary Status of the Carbon Star V Hya," *Astron. Astrophys.*, **351**, 97.

Kowalsky, P. A., Percy, J. R., Mattei, J. A., and Waagen, E. O. 1986, "AAVSO Observations of Long Period Variable Stars 1900–1975: Maximum and Minimum Magnitudes and O–C Diagrams," *J. Amer. Assoc. Var. Star Obs.*, **15**, 236.

Lopez, B., Danchi, W. C., Bester, M., Hale, D. D. S., Lipman, E. A., Monnier, J. D., Tuthill, P. G., Townes, C. H., Degiacomi, C. G., Geballe, T. R., Greenhill, L. J., Cruzalebes, P., Lefevre, J., Mekarina, D., Mattei, J. A., Nishimoto, D., and Kervin, P. W. 1997, "Nonspherical Structures and Temporal Variations in the Dust Shell of O Ceti Observed with a Long Baseline Interferometer at 11 Microns," *Astrophys. J.*, **488**, 807.

Mattei, J. A. 1989, "Report on Meetings with HIPPARCOS Input Catalogue Team on AAVSO Data Support of HIPPARCOS Observations of Long Period Variable Stars," *J. Amer. Assoc. Var. Star Obs.*, **18**, 70.

Mattei, J. A., and Allen, J. 1979, "Variable Star Notes (R Aquarii-A Unique Long-Period Variable)," *J. Roy. Astron. Soc. Canada*, **73**, 173.

Mattei, J. A., and Foster, G. 2000, "Trend analysis of 51 carbon long-period variables," in *The Carbon Star Phenomenon*, ed. R. F. Wing, IAU Symposium 177, Kluwer, Dordrecht, The Netherlands, 155.

Mennessier, M. O., Boughaleb, H., and Mattei, J. A. 1997, "Mean light curves of long-period variables and discrimination between carbon- and oxygen-rich stars," *Astron. Astrophys. Supp. Ser.*, **124**, 143.

Mennessier, M., Boughaleb, H., and Mattei, J. A. 2000, "Comparison of Mean Light Curve Parameters of M, S and C Mira and Semi-Regular Variable Stars Using 75 Years of AAVSO Data," in *The Carbon Star Phenomenon*, ed. R. F. Wing, IAU Symposium 177, Kluwer, Dordrecht, The Netherlands, 165.

Percy, J. R., and Mattei, J. A. 1993, "The AAVSO database of variable star observations," *Astrophys. Space Sci.*, **210**, 137.

Percy, J. R., Campbell, E. C., Sloan, W. B., Landis, H. J., and Mattei, J. A. 1988, "Studies of Red Variable Stars," *J. Roy. Astron. Soc. Canada*, **82**, 282.

Templeton, M. R., Mattei, J. A., and Price, A. 2003, "LX Cygni: a Mira Variable with a Drastic Period Increase," *Inf. Bull. Var. Stars*, No. 5367, 1.

Templeton, M. R., Mattei, J. A., and Willson, L. A. 2005, "Secular Evolution in Mira Variable Pulsations," *Astron. J.*, **130**, 776.

Wallerstein, G., Hinkle, K. H., Dominy, J. F., Mattei, J. A., Smith, V. V., and Oke, J. B. 1985, "The Spectrum of R-Cygni during its Exceptionally Low Maximum of 1983," *Mon. Not. Roy. Astron. Soc.*, **215**, 67.

Willson, L. A., Garnavich, P., and Mattei, J. A. 1981, "1978 Eclipse of R Aquarii," *Inf. Bull. Var. Stars*, No. 1961, 1.

Zijlstra, A. A., Bedding, T. R., and Mattei, J. A. 2002, "The evolution of the Mira variable R Hydrae," *Mon. Not. Roy. Astron. Soc.*, **334**, 498.

Zijlstra, A. A., Bedding, T. R., Markwick, A. J., Loidl-Gautschy, R., Tabur, V., Alexander, K. D., Jacob, A. P., Kiss, L. L., Price, A., Matsuura, M., and Mattei, J. A. 2004, "Period and chemical evolution of SC stars," *Mon. Not. Roy. Astron. Soc.*, **352**, 325.

6.2. Other papers cited in the text

6.2.1. Early papers involving Merrill and Joy

Buscombe, W., and Merrill, P. W. 1951, "Relative Intensities of Lines of Various Metals in Spectra of Classes ME and Se," *Publ. Astron. Soc. Pacific*, **63**, 235.

Buscombe, W., and Merrill, P. W. 1952a, "Intensities of Atomic Absorption Lines in the Spectra of Long-Period Variable Stars," *Astrophys. J.*, **116**, 525.

Buscombe, W., and Merrill, P. W. 1952b, "Variation of intensities of atomic absorption lines in the spectrum of Mira Cet," *Astron. J.*, **57**, 8.

Joy, A. H. 1937, "Some Early Variable Star Observers," *Astron. Soc. Pacific Leaflet*, No. 2, 193.

Joy, A. H. 1947a, "The absorption lines within the hydrogen emission of Mira Ceti," *Contrib. Mt. Wilson Obs.*, No. 737, 1.

Joy, A. H. 1947b, "The Absorption Lines Within the Hydrogen Emission of Mira Ceti," *Astrophys. J.*, **106**, 288.

Joy, A. H. 1947c, "The Absorption Lines Within the Hydrogen Emission of Mira Ceti," not published, 37.

Joy, A. H. 1952a, "Recent Radial Velocity Measures of Mira," *Astron. J.*, **57**, 16.

Joy, A. H. 1952b, "The Semiregular Variable Stars of the RV Tauri and Related Classes," *Astrophys. J.*, **115**, 25.

Joy, A. H. 1954a, "Abstract: Spectroscopic Observations of Mira Ceti, 1934–1952," *Astrophys. J.*, **119**, 468.

Joy, A. H. 1954b, "Spectroscopic Observations of Mira Ceti, 1934–1952," Astrophys. *J. Suppl. Ser.*, **1**, 39.

Joy, A. H. 1959, "Mira Ceti," *Astron. Soc. Pacific Leaflet*, No. 8, 57.

Merrill, P. W. 1947, "The Postmaximum Spectrum of Chi Cygni," *Astrophys. J.*, **106**, 274.

Merrill, P. W. 1948, "Wave Lengths of Atomic Absorption Lines in the Spectra of Long-Period Variable Stars," *Astrophys. J.*, **107**, 303.

Merrill, P. W. 1950, "The Spectrum of R Aquarii, 1936–1949," *Astrophys. J.*, **112**, 514.

Merrill, P. W. 1952a, "Measurements in the Spectra of Four Long-Period Variable Stars of Class Me," *Astrophys. J.*, **116**, 344.

Merrill, P. W. 1952b, "The Postminimum Spectrum of R Hydrae," *Astrophys. J.*, **116**, 18.

Merrill, P. W. 1952c, "The Preminimum Spectrum of R Leonis," *Astrophys. J.*, **116**, 337.

Merrill, P. W. 1953, "The Spectrum of Chi Cygni Near Minimum Light," *Astrophys. J.*, **118**, 453.

Merrill, P. W. 1956, "Companions to Long-Period Variable Stars," *Publ. Astron. Soc. Pacific*, **68**, 162.

Merrill, P. W. 1959, "Wave Lengths of Absorption Lines in the Spectrum of Omicron Ceti," *Astrophys. J.*, **130**, 123.

Merrill, P. W., and Greenstein, J. L. 1958, "Double Absorption Lines in the Spectrum of R Andromedae," *Publ. Astron. Soc. Pacific*, **70**, 98.

6.2.2. Other cited papers

Bowen, G. H. 1988, "Dynamical Modeling of Long-Period Variable Star Atmospheres," *Astrophys. J.*, **329**, 299.

Bowen, G. H., and Willson, L. A. 1991, "From Wind to Superwind—The Evolution of Mass-Loss Rates for Mira Models," *Astrophys. J., Lett. Ed.*, **375**, L53.

Cox, A. N., and Ostlie, D. A. 1993, "A Linear and Nonlinear Study of Mira," *Astrophys. Space Sci.*, **210**, 311.

Fox, M. W., and Wood, P. R. 1982, "Theoretical Growth Rates, Periods, and Pulsation Constants for Long-Period Variables," *Astrophys. J.*, **259**, 198.

Fox, M. W., and Wood, P. R. 1985, "Shock Waves in Mira Variables. II—Theoretical Models," *Astrophys. J.*, **297**, 455.

Hill, S. J. 1972, "Hydrodynamic and Radiative-Transfer Effects on an RR Lyrae Atmosphere," *Astrophys. J.*, **178**, 793.

Hill, S. J., and Willson, L. A. 1979, "Theoretical Velocity Structure of Long-Period Variable Star Photospheres," *Astrophys. J.*, **229**, 1029.

Hinkle, K. H. 1978, "Infrared Spectroscopy of Mira Variables. I—R Leonis: The CO and OH Vibration-Rotation Overtone Bands," *Astrophys. J.*, **220**, 210.

Hinkle, K. H., and Barnes, T. G. 1979a, "Infrared spectroscopy of Mira variables. II—R Leonis, the H_2O Vibration-Rotation Bands," *Astrophys. J.*, **227**, 923.

Hinkle, K. H., and Barnes, T. G. 1979b, "Infrared Spectroscopy of Mira Variables. III—R Leonis, the Atomic Lines," *Astrophys. J.*, **234**, 548.

Höfner, S. 1999, "A New Generation of Dynamic Model Atmospheres for AGB Stars: First Results," *Astron. Astrophys.*, **346**, L9.

Höfner, S., Fleischer, A. J., Gauger, A., Feuchtinger, M. U., Dorfi, E. A., Winters, J. M., and Sedlmayr, E. 1996, "Dynamical Models of Atmospheres of Long-Period Variables: A Comparative Study," *Astron. Astrophys.*, **314**, 204.

Höfner, S., Gautschy-Loidl, R., Aringer, B., and Jørgensen, U. G. 2003, "Dynamic Model Atmospheres of AGB stars. III. Effects of Frequency-Dependent Radiative Transfer," *Astron. Astrophys.*, **399**, 589.

Höfner, S., Loidl, R., Aringer, B., and Jørgensen, U. G. 2002, "Dynamical Atmospheres and Mass Loss of Pulsating AGB Stars," in *Radial and Nonradial Pulsationsn as Probes of Stellar Physics*, ed. C. Aerts, T. R. Bedding, J. Chistensen-Dalsgaard, ASP Conf. Ser. 259 (IAU Colloq. 185), Astron. Soc. Pacific, San Francisco, 534.

Höfner, S., Loidl, R., Aringer, B., Jørgensen, U. G., and Hron, J. 2000, "A New Generation of Model Atmospheres for AGB Stars Inspired by ISO," in *ISO beyond the peaks: The 2nd ISO workshop on analytical spectroscopy*, eds. A. Salama, M. F. Kessler, K. Leech, and B. Schulz, ESA-SP 456, 299.

Karovska, M. 1999, "Fifteen Years of High Angular Resolution Studies of Mira's Atmosphere," in *Asymptotic Giant Branch Stars*, IAU Symposium 191, eds. T. Le Bertre, A. Lebre, and C. Waelkens, *Astron. Soc. Pacific*, San Francisco, 139.

Kholopov, P. N., *et al.* 1985, *General Catalogue of Variable Stars*, 4th ed., Moscow.

Ostlie, D. A., and Cox, A. N. 1986, "A Linear Survey of the Mira Variable Star Instability Region of the Hertzsprung-Russell Diagram," *Astrophys. J.*, **311**, 864.

Perrin, G., Ridgway, S. T., Mennesson, B., Cotton, W. D., Woillez, J., Verhoelst, T., Schuller, P., Coudé du Foresto, V., Traub, W. A., Millan-Gabet, R., and Lacasse, M. G. 2004, "Unveiling Mira Stars Behind the Molecules. Confirmation of the Molecular Layer Model With Narrow Band Near-Infrared Interferometry," *Astron. Astrophys.*, **426**, 279.

Reid, M. J., and Dickinson, D. F. 1976, "The Stellar Velocity of Long-Period Variables," *Astrophys. J.*, **209**, 505.

Skalafuris, A., and Whitney, C. A. 1961, "Radiative Cooling Behind Shock Fronts in Stellar Atmospheres," *Ann. Astrophys.*, **24**, 420.

Skalafuris, A. J. 1965, "The Structure of a Shock Front in Atomic Hydrogen. II. The Region of Internal Relaxation," *Astrophys. J.*, **142**, 351.

Skalafuris, A. J. 1968, "The Structure of a Shock Front in Atomic Hydrogen. III: The Radiative Relaxation Region," *Astrophys. Space Sci.*, **2**, 258.

Skalafuris, A. J. 1969, "The Structure of a Shock Front in Atomic Hydrogen. IV: Stability Dissipation, and Propagation," *Astrophys. Space Sci.*, **3**, 234.

Weiner, J., Hale, D. D. S., and Townes, C. H. 2003, "Asymptotic Giant Branch and Supergiant Stellar Diameters in the Mid-Infrared," *Astrophys. J.*, **589**, 976.

Whitney, C. A., and Skalafuris, A. J. 1963, "The Structure of a Shock Front in Atomic Hydrogen. I. The Effects of Precursor Radiation in the Lyman Continuum," *Astrophys. J.*, **138**, 200.

Willson, L. A. 2000, "Mass Loss From Cool Stars: Impact on the Evolution of Stars and Stellar Populations," *Ann. Rev. Astron. Astrophys.*, **38**, 573.

Willson, L. A., and Hill, S. J. 1979, "Shock wave Interpretation of Emission Lines in Long Period Variable Stars. II—Periodicity and Mass Loss," *Astrophys. J.*, **228**, 854.

Wood, P. R. 2000, "Variable Red Giants in the LMC: Pulsating Stars and Binaries?", *Publ. Astron. Soc. Australia*, **17**, 18.

Wood, P. R. 1974, "Models of Asymptotic-Giant Stars," *Astrophys. J.*, **190**, 609.

Wood, P. R. 1979, "Pulsation and Mass Loss in Mira Variables," *Astrophys. J.*, **227**, 220.

Wood, P. R., and Cahn, J. H. 1977, "Mira Variables, Mass Loss, and the Fate of Red Giant Stars," *Astrophys. J.*, **211**, 499.

Wood, P. R., and Zarro, D. M. 1981, "Helium-Shell Flashing in Low-Mass Stars and Period Changes in Mira Variables," *Astrophys. J.*, **247**, 247.