The Circumstellar Environment of Evolved Stars as Revealed by Studies of Circumstellar Water Masers

by

Kevin Marvel

ISBN: 1-58112-061-3

DISSERTATION.COM

1999

ISBN: 1-58112-061-3

Published by
Dissertation.com
1999

www.dissertation.com/library/1120613a.htm

THE CIRCUMSTELLAR ENVIRONMENT OF EVOLVED STARS AS REVEALED BY STUDIES OF CIRCUMSTELLAR WATER MASERS

BY

KEVIN BOYD MARVEL, B.S., B.S., M.S.

A Dissertation submitted to the Graduate School

in partial fulfillment of the requirements

for the Degree

Doctor of Philosophy

Major Subject: Astronomy

Minor Subject: Physics

New Mexico State University

Las Cruces, New Mexico

December 1996

"The Circumstellar Environment of Evolved Stars as Revealed by Proper Motion Studies of Circumstellar Water Masers," a dissertation prepared by *Kevin Boyd Marvel* in partial fulfillment of the requirements for the degree, *Doctor of Philosophy*, has been approved and accepted by the following:

Timothy J. Pettibone
Dean of the Graduate School

Jack O. Burns
Chair of the Examining Committee

Date

Committee in charge:

Dr. Jack O. Burns

Dr. Reta Beebe

Dr. Phil Diamond

Dr. Paul Nachman

Dr. Rene A. Walterbos

ACKNOWLEDGMENTS

"That this book has its faults, no one can doubt,

Although the Author could not find them out.

The faults you find, good Reader, please to mend,

Your comments to the Author kindly send. "

Kitchiner's The Economy of the Eyes.—Part II.

When I first decided to become an astronomer, I gave up a promising career in marine biology. Of course, being only twelve years old at the time it wasn't such a great loss. I decided to pursue astronomy simply because my parents, June and Barry Marvel, purchased a cheap 1.5" refracting telescope and gave it to me for Christmas. I took it outside and pointed it towards the brightest object in the sky (Venus at the time) and found, to my amazement, that this little tube took a small, point-like image on the sky and displayed a small crescent shaped object in the eyepiece. I was just amazed. I had no idea what I was looking at, so I ran inside and managed to find an old *Zim's Field Guide to the Stars*, which explained that Venus went through phases and that this was a major piece of evidence for the Copernican model of the Solar System. Well, I was hooked. Since that time, no matter what crazy ideas I came up with (like getting up at 3:00 a.m. to see meteors, traveling through scary third-world countries to see an eclipse, or going to school for eleven years), my parents have

supported me completely. They provided me with an early exposure to all forms of human endeavor from art to construction, an absolute must for a scientist. To them I owe my college education at a world-renowned astronomical center, which formed the basis of my skills allowing the completion of this dissertation. To them I owe everything, and little else can be said except that I thank you both from the bottom of my heart for helping me fulfill one of my life's goals. I hope this makes up for setting the backyard on fire that one time.

Along the way, innumerable people have provided knowledge, experience or support. I would like to mention a few of those people who had a profound impact on my life and career. Ms. Rice, an early English teacher, taught me to read carefully and interpret things in my own way and not simply follow in the footprints of others. Mr. Richard Taylor, my first Physics instructor, who made not just me but the entire physics class take a test a day on the classic sliding box problem until everyone got it right. I can still solve those problems very quickly, by the way. My chemistry instructors, Mr. Homer Alexander and Ms. Nella Hewlett, introduced me to the "factor-label" method, aka unit analysis. Dr. Ron McPherson, who taught me statistics, computer science and the value of a good teacher, is still working at J.J. Pearce in Dallas doing what he does best. Mr. Jack Crowder taught me to read all the instructions on a test before taking it, and Ms. Sue Parrish let me memorize the names and properties of ten elements with high atomic numbers instead of ten with low atomic numbers (even though she

had to learn them as well so she could grade me). Perhaps the most influential early educator I had was Alison Morrison from St. Louis. She obtained special permission for me to take my study hall in the science lab building so I could read their stockpile of *Sky and Telescope* magazines as well as letting me write a report on shrews instead of wombats...I still thank her today for that decision.

When I finally got to college at the University of Arizona, I met a group of individuals with whom I lived, worked, played and learned. Luke Keller, Babar Ali and Tad Adair: You know who you are and what you did...thanks bunches. Tad helped out with some statistical analysis and figure creation for this dissertation. All the other science nerds, who prided themselves on *not* being astronomers, thanks to you as well for keeping my mind open to other approaches: Jen Ahearn, Keith Mulvihill, Jenny Vuturo, Heather Merbs, Teri Suzuki, Andy Young, Brett McDaniel, and anyone else I forgot, thank you for always being around...we sure had fun didn't we?

I would like to thank Dr. Miller Goss of NRAO for sponsoring me as a summer student in 1988 and for suggesting (despite my "classified misadventure") I take a summer position in Australia the following year. I hope the NRAO summer student program never dies despite funding cuts. The NRAO pre-doctoral program is one of the best ways of learning radio astronomy at a professional level; please don't let it wither. I also thank Dr. Richard Manchester, who found out the use of a hacksaw was not one of my better skills, and Dr. Andrew Lyne, who

had better still be juggling after the exciting first lesson I gave him at Parkes. Roc Cutri deserves a pat on the back for teaching me 'awk' which has made this dissertation possible in no small part. Thanks to Rex Saffer for teaching me to fit spectra and just how busy a graduate student could get.

At the University of Arizona, nearly all my astronomy classes were taught by one individual, Dr. Thomas Swihart. As an educator and advisor he was without equal. He knew the value of estimation and detail. I regret that he passed away prior to the completion of my doctorate, but I think he never had any doubts I could finish, even when I did. He gave sage advice to all his students, and I will never forget the first day of Astronomy 271 when he lectured for a whole hour on how difficult the class would be and that all the students should drop now. I think only a few did, but his point was that you should only attempt things if you want to work hard and struggle. Thank you, Dr. Swihart, and may you rest in peace.

I managed to get into graduate school because one man called me on the phone and wanted to know what was up with my GPA. After explaining my situation (I guess to his satisfaction), Dr. Jack Burns let me into his department as a trial experiment. Along with my eight classmates, I began in 1990 to learn more at a faster rate than I ever had before. I stumbled a few times along the way, but Jack was always willing to give me another chance to prove myself. I appreciate his guidance and knowledge... not to mention his often swift kicks in my rear-end. I

want to thank all my other instructors at NMSU, especially Dr. Reta Beebe, Dr. Rene Walterbos, Dr. Kurt Anderson, and Dr. Andrew McWilliam, who all gave of their time and knowledge and helped me achieve this degree. The postdocs are a hard-working bunch of folks, and I would like to thank Tom Harrison, Chris Loken, George Rhee and Mike Ledlow for their interest in the finer arts (e.g. beer drinking).

My fellow students provided help, fun, relaxation and competition and were an integral part of my education. I would like to especially mention Kurt Roettiger (Mr. WORK), Jason Kendall ("Krash!"), Nancy Chanover ("...here Roxy..."), Bryant Heikkila (Mr. HIKE!), Lyle Huber (who finally won the beard competition after all) and all the rest. A special word of thanks for the sanity of "The Lost Class". Keeping the computers up and running was always a tough job, but Shaun Cooper and his folks always made things possible.

I was lucky enough to be a roommate with two of the craziest astronomy graduate students in the whole world, Brian Kooiman and Jason Pinkney. Thanks guys for all you did and all you do. Jason, stop lining up your toothbrush and toothpaste! Brian, "you try you like"! I wish you both all the success in the world.

At NRAO, I managed to meet some of the best and most helpful people in the world of Radio Astronomy. I would just like to mention my gratitude for the following individuals, who helped in one way or another: Chris (pillar number

1), Julia, and Claire DePree, Bhindu and Dhruv Desai, Tim Roberts, Caroline Smith, Claire Chandler, John Conway, Tony Beasley, Michael Rupen, Leonid Kogan, Craig Walker, Joan Wrobel, José Navarro, Randi Petterson, Dave Boboltz ("Diamond-back" number 4), David and Cathi Moffett (congrats you guys!), Andrei Lobanov (you're *not* in Socorro now, are yah?), Gustaaf van Moorsel, Pat Palmer, Huib, Lisette and Phebe van Langevelde, Tim Bastian, Angelos and Racquel Vourlidas (SALSA!), Rob Olling (pillar number 2), Rick Perley, Jacqueline van Gorkom ("chile verde y picante"), Vivek Dhawan, Jon Romney, John Benson and all the correlator folks. I also want to thank all the people who make doing science at the AOC easy and fun: Terry Romero, Eileen Latasa, Theresa McBride, Jon Spargo, Ruth Milner, all the computer support staff and everyone else from accounting to shipping.

Special thanks is due to my advisor, Phil Diamond. As the third of the "Diamond-backs", I felt particularly honored to learn from one of the best in the field of spectral line VLBI. His advice and assistance proved invaluable. Thanks also goes to "Diamond-backs" numbers one and two, Athol Kemball and Ketan Desai. Their help in learning the technique was crucial. Thanks tons.

During my tenure as a graduate student I was lucky enough to be a supervisory T.A. for a young German student named Tamara Koch. She thought we gave her too much work, and maybe we did but, hey, she got a 103 % in the class, what more do you want? We didn't start dating until after the semester (contrary

to popular rumor), and only a few years later I find myself married to the best woman in the world. If I had everything to do over again, the only thing that would change would be completing this degree before the wedding, and Tamara would agree. As a companion she is without equal, as an editor she is unsurpassed, and as a person she is wonderful. Tamara is my best friend, my best supporter and my true love. I am honored to be her husband and hope I may find opportunity during our lives together to support and help her in the ways she has done during the past several years.

During my graduate school years, several individuals with whom I was quite close passed away. I would like to dedicate this dissertation to the memory of Stuart Marvel, Mark Taylor and Barry Rappaport. All died before their time with many jobs left undone and goals left unmet. I hope they are all at peace.

This research has made use of NASA's Astrophysics Data System Abstract and Article Services.

In this dissertation, I have used, and acknowledge with thanks, data from the AAVSO International Database, based on observations submitted to the AAVSO by variable star observers worldwide.

In this research, I have used, and acknowledge with thanks, data from the Hungarian Astronomical Association Variable Star Section.

This research has used, and I acknowledge with thanks, data from the Variable Star Observer's League in Japan.

This research has made use of the VSNET database and I graciously thank the dedicated services of variable star observers around the world.

This research used observations obtained by the NF/ Observatory of Silver City, NM. Special thanks to Dr. Bill Neely of Silver City, NM.

This research has also made use of the SIMBAD data base of the CDS.

VITA

September 29, 1967 – Born in Colorado Springs, Colorado

Summer 1988 – Summer Student National Radio Astronomy Observatory Very Large Array, Socorro, New Mexico

Summer 1989 – Summer Student Commonwealth Science and Industry Research Organisation Division of Radiophysics, Epping, New South Wales, Australia

May, 1990 – B.S. in Astronomy, B.S. in Physics. University of Arizona, Tucson, Arizona

1990 – 1994 Teaching and Research Assistant, New Mexico State University, Las Cruces, NM

May, 1993 – M.S. in Astronomy, New Mexico State Universiy, Las Cruces, New Mexico

1994 – 1996 Junior Research Associate, National Radio Astronomy Observatory, Array Operations Center, Socorro, New Mexico

PROFESSIONAL AND HONORARY SOCIETIES

American Astronomical Society

Sigma Zi

American Association of Variable Star Observers

MENSA

FIELDS OF STUDY

Major Field: Astronomy

Very Long Baseline Interferometry

Astrophysical Masers

AGB Stars

ABSTRACT

THE CIRCUMSTELLAR ENVIRONMENT OF EVOLVED STARS AS REVEALED BY STUDIES OF CIRCUMSTELLAR WATER MASERS

BY

KEVIN BOYD MARVEL, B.S.,B.S.,M.S.

Doctor of Philosophy in Astronomy

New Mexico State University

Las Cruces, New Mexico, 1996

Dr. Jack O. Burns, Chair

The dissertation presents the results of a multi-epoch very long baseline interferometric study of water masers located in the extended atmospheres of evolved stars. The research was performed using the Very Long Baseline Array and Very Large Array of the National Radio Astronomy Observatory. Optical monitoring of the stars was provided by the American Association of Variable Star Observers, the Variable Star Network and Dr. Bill Neely of the NF/ Observatory.

Water masers are found to exist in a region where a population inversion of

the rotational transition at 22 GHz can be maintained by collisional pumping. The masers are identified as individual pockets of gas, which have good velocity coherence and may be imaged using radio interferometry. Stellar winds are initiated in these sources by dust formation and acceleration of the gas through momentum coupling. The typical wind speeds in the region of the water masers are 10 to 20 km/s . The water masers are followed through several epochs of observation and exhibit proper motions consistent with the assumed source distance and the measured outflow velocity in the water maser region. Estimates of the distance to the sources using statistical approximation are in agreement with the currently accepted distances to the stars. A detailed kinematic model is used to describe the flow motions of the gas in the maser region. The regions are found to be complex and not well modeled by uniform radial outflow, radial outflow with rotation, or radial outflow with acceleration. The reasons for this are explored and include anisotropic velocity fields induced through non-uniform dust formation near the star and incomplete sampling of the outflow due to a lack of detected masers. Possibilities for future work in the subject are described and include more sophisticated modeling, more sensitive observations, and analysis of other maser species.

List of Tables

List of Figures