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November 22, 2010

Attention: Astronomy Fellowships Committee
Department of Terrestrial Magnetism
Carnegie Institution of Washington
5241 Broad Branch Road, NW
Washington, DC 20015-1305

Dear Astronomy Fellowships Committee:

I am writing as a candidate for the Postdoctoral Research Fellowship in Astronomy at the Carnegie Institution's Department of Terrestrial Magnetism. I am a graduate student at the University of Virginia and expect to complete my thesis this summer. My dissertation project is a study of the chemical composition of rapidly rotating field giant stars to test whether planet accretion is the mechanism responsible for these stars' unusually large rotational velocities.

As a fellow at the Carnegie Institution of Washington, I plan to continue my research in the observational study of exoplanets around evolved host stars. I intend to perform the first comprehensive abundance comparison of giant stars with and without planetary companions. I will also expand my search for giant stars that have accreted planets to include stars in open clusters. The facilities at Las Campanas Observatory will be ideal for collecting data, and my proposed project will make use of both the du Pont and Magellan telescopes.

I am a strong candidate for this position both because of my research interests and because of my past work with a wide range of data sets and techniques. As demonstrated by my thesis project and research plan, my primary interest is in understanding the relationship between exoplanets and their evolved host stars—an interest in line with this fellowship's targeted field of the "origin and evolution of stars, planets, and life." My skills include extensive experience acquiring spectroscopic data, from which I have measured chemical abundances and both radial and projected rotational velocities. As a graduate student, I have also modeled the angular momentum evolution of exoplanet host stars, simulated binary star observations for the APOGEE project, and searched for Galactic structures using the all-sky distribution of M giants. I look forward to the interdisciplinary opportunities afforded by the Carnegie Institution and, if possible, would like to become involved in exoplanet detection in collaboration with Dr. Paul Butler or Dr. Allan Boss.

As requested, I have enclosed my curriculum vitae, publications list, and a brief research proposal. I will be attending the 217th AAS meeting if you would like to meet to discuss this position and my research interests. I will present my dissertation talk on Wednesday, January 12, 2011. Thank you for your consideration, and I look forward to hearing from you.

Sincerely,

Joleen K. Carlberg

Abundances of Evolved Stars: Clues to the Birth and Death of Planets

Joleen K. Carlberg

Background

Although stars and their planets form from the same original clouds of material, the relative abundances of individual elements can vary widely from one stellar system body to the next. The Sun, for example, differs considerably from the chemically-diverse terrestrial, gas giant, and ice giant planets in the Solar System. These differences can be used to study the formation and evolution of exoplanetary systems. Evolved giant stars with planets, which have largely been overlooked by chemical studies thus far, have much to add to our understanding of planetary systems. They are ideal for interpreting unexpected chemical abundance enhancements that, in main sequence (MS) stars, could be explained by either (1) planets preferentially forming around stars with the identified enhancement, or (2) pollution of the stellar envelope with metal-rich planet formation debris. The deep convection zones in giant stars rule out the latter interpretation.

Giant stars are also well-suited for studying planet *destruction* because they are more chemically distinct from their planets in light elements (e.g., Li, B, and Be). These elements are steadily depleted in stars throughout their lifetimes. The accretion of a planet has long been proposed as a possible mechanism for replenishing Li in the "Li-rich" giant stars (Alexander 1967). However, my thesis work has shown that finding planet accretion signatures in field giant stars is complicated by difficulties in constraining the ages, masses, and evolutionary stages of the stars in question. Open clusters provide a more ideal laboratory for investigating abundance variations. Not only does the known distance to a cluster allow an accurate determination of stellar masses and evolutionary stages, but the expected chemical homogeneity of the cluster stars also makes any chemical variation more significant. Therefore, studying open clusters allows one to make compelling cases for the detection of planet accretion signatures in individual stars.

By measuring abundances in evolved stars, I will explore two specific questions about the intrinsic and post-planet-accretion abundances of evolved stars. First, are evolved planet-hosting (PH) stars chemically different from non-PH stars? Second, do the red giant stars in open clusters show evidence of planet accretion in the form of rapid rotation and unusual elemental abundances?

Part 1: Elemental Abundances in Evolved Planet-Hosting Stars

Elemental abundance studies of MS stars have shown that PH stars frequently differ from non-PH stars. For example, Smith et al. (2001) found that refractory (i.e., non-volatile) elements are relatively enhanced in some PH stars compared to non-PH stars. Others have found differences in abundances of Na, Mg, Al (Gonzalez et al. 2001), Si, and Ni (Robinson et al. 2006). However, almost no comprehensive studies of individual elements exist for PH giants. The one exception is in overall stellar metallicity, as traced by [Fe/H]. This measurement in PH giant stars led to the unexpected result that the increased likelihood of finding planets around metal-rich stars, well-established in MS stars (Fischer & Valenti 2005), may not hold for giants (Pasquini et al. 2007; Takeda et al. 2008).

I plan to conduct a composition study comparing PH and non-PH giant stars, which will require high-resolution spectra at a high signal-to-noise ratio (S/N $=$ 100). I have already obtained these spectra for ten giant PH stars, and I will observe $\sim$ 25 more. I will also compile and observe a sample of non-PH stars, chosen from the same radial velocity surveys that found the planets.

From the spectra, I will derive effective temperatures, surface gravities, and abundances of ~ 20 individual elements. The stellar parameters, i.e., $T_{\rm eff}$, $\log g$, and [Fe/H], of each star will be derived from the spectra using Fe I and Fe II lines. By measuring the equivalent widths, or relative strengths, of these iron lines, I will find the single model atmosphere for which all of the lines give the same stellar iron abundance. For my thesis work, I have developed codes to automate the solution search, and these codes exploit the fact that Fe I lines are more sensitive to changes in temperature, while Fe II lines are more sensitive to the surface gravity. Once I have determined the stellar parameters, I will interpolate a model atmosphere from grids of MARCS atmosphere models (Gustafsson et al. 2008) to match each star. Individual abundances of many elements will be measured from the equivalent widths of optical absorption lines. I will input the equivalent widths and stellar atmosphere models to the MOOG stellar line analysis program (Sneden 1973), yielding elemental abundances.

I will look for relative enhancements or depletions in element groups (e.g., volatiles vs. refractories) and individual elements (Na, Mg, etc.). Because these giant stars are bright, spectra of S/N $= 100$ can be obtained in 10 minutes for even the faintest stars using the du Pont 2.5-m telescope at Las Campanas Observatory. The publicly-available Kitt Peak 4-m and echelle will provide access to targets too far north to be observed at Las Campanas.

Part 2: Open Cluster Survey for Planet Accretors

I plan to study the rotational velocities and chemical abundances of giant stars in open clusters in order to explore planet accretion in these stars. The project has two phases: rapid rotator (RR) identification and follow-up characterization. The first phase requires high resolution and moderate S/N spectra of red giant stars in selected open clusters. Table 1 lists two potential clusters in the Southern Hemisphere and gives each cluster's right ascension, declination, number of red giants with verified cluster membership, expected number of RRs, age, metallicity, and distance modulus. The expected number of RRs is estimated from the field red giant population, in which 1–5% of red giants are rapidly rotating, because the fraction is not documented for open clusters. However, rapidly rotating open cluster giants are known to exist. At least one of the 30 stars (3%) in Yong et al. (2005) is rapidly rotating (also note that this star is metal poor with [Fe/H]$= -0.8$), and Sestito et al. (2008) shows the spectrum of a RR in Melotte 66.

Once the RRs have been identified, control stars will be chosen to closely match the evolutionary stage (and hence mass) of each of the RRs. These control stars will establish a baseline of "normal" chemical abundances in that cluster at that evolutionary stage. The RRs and control stars then form a new sample that will be re-observed at much higher S/N as part of phase two. These new spectroscopic data will allow for the precise measurement of many elemental abundances. Because the cluster target stars are much fainter than the PH stars in the previous section, they will require the Magellan 6.5-m telescope with echelle spectrograph, MIKE. Throughout this second phase, RRs and control stars that have not had binary companions ruled out will have their radial velocities (RVs) monitored with moderate-S/N, multi-epoch spectroscopy for that purpose.

As already stated, planet accretion may replenish abundances stellar atmospheres with elements that have been destroyed earlier in the stellar evolution. In giant stars, Li is severely depleted and the carbon isotope ratio (^{12}C/^{13}C) is reduced, particularly during the first dredge-up mixing episode on the early red giant branch. The left panel of Figure 1 illustrates how both the Li abundance, A(Li)=$\log(N_{\rm Li}/N_{\rm H})+12$, and ^{12}C/^{13}C are predicted to change during the stellar life-time. Time follows the arrows from the zero-age main sequence (ZAMS) through the MS turn-off to the RGB tip. Note that the 3 $M_\odot$ star depletes Li by a factor of about 100, while the 1.2 $M_\odot$ star depletes Li over 1,000-fold. Therefore, a planet can contribute a significant amount of Li to the stellar envelope. For example, consider a star with a 0.8 $M_\odot$ convective envelope and a measured A(Li) that is 1.0 dex larger than that of stars of similar mass and age. This degree of Li enrichment requires the accretion of a planet of only 4 $M_{\rm Jup}$. Similar estimates can be made for ^{12}C/^{13}C enhancements. After first dredge-up, giant stars have ^{12}C/^{13}C$\sim 20-30$, whereas planets are expected to have the primordial value of ^{12}C/^{13}C~ 90. The right panel of Figure 1 shows the expected post-planet accretion ^{12}C/^{13}C as a function of accreted planet mass for a star originally having ^{12}C/^{13}C~ 20. To be detectable, this chemical signature requires a much more massive accreted planet. The 4 $M_{\rm Jup}$ planet from the Li enrichment example would create a detectable signal only if $M_{\rm env} < 0.2 M_\odot$.

Stars that have accreted planets may also demonstrate enhancements in refractory elements. In the core accretion model, rocky cores of at least $\sim 10 M_\oplus$ build up before an atmosphere is accreted onto the planet, and Baraffe et al. (2008) noted that the radii of some transiting planets imply cores that are $\sim 200 M_\oplus$. These planet cores could preferentially enhance the refractory elemental abundances in a stellar envelope if the planet were accreted. Stars that accreted planets, such as RRs, would show relative enhancements in elements that have higher condensation temperatures compared to control stars. The enhancement of refractory elements in stellar atmospheres is optimally detectable in open cluster stars because these stars should have minimal star-to-star abundance variations that come from other astrophysical processes (i.e., supernova enrichment).

Summary

As an Astronomy Fellow at Carnegie DTM, I will continue using my research of chemical abundances to probe the formation and fate of exoplanets. The "formation" study will be accomplished with a comparative chemical composition analysis of planet-hosting and non-planet-hosting giant stars. The "fate" study will search for planet accretion signatures in open cluster red giants. These two observational programs will make extensive use of the Las Campanas Observatory resources available through this fellowship.

Table 1. Cluster Properties[a]

Cluster Name	α	δ	$N_{\rm RGB}$	$N_{\rm Rapid}$	$\log t$[b]	[Fe/H]	m-M
NGC 6253	16 59 05	−52 42 30	45	0-2	9.70	+0.36	11.51
Melotte 66	07 26 23	−47 40 00	245	2-12	9.445	−0.35	13.62

[a]Data from the WEBDA database, operated at the Institute for Astronomy of the University of Vienna. www.univie.ac.at/webda/

[b]t is the cluster age in years.

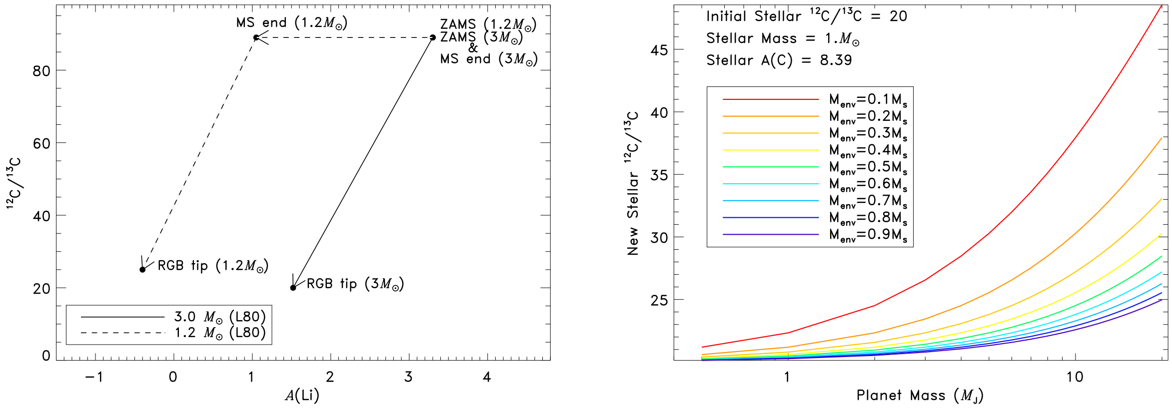

Fig. 1.— *Left:* The expected evolution of A(Li) and ^{12}C/^{13}C for stars of 1.2 and 3 $M_\odot$, adapted from Lambert et al. (1980). For both models, the lines begin at the main sequence and follow the stellar evolution to the end of the red giant branch. *Right:* Expected increase in ^{12}C/^{13}C as a function of accreted planet mass for a solar mass and metallicity red giant star. The different lines show different fractions of the stellar mass in the convective envelope, ranging from 10% (top) to 90% (bottom).

References

Alexander J. B., 1967, The Observatory, 87, 238

Baraffe I., Chabrier G., Barman T., 2008, A&A, 482, 315

Fischer D. A., Valenti J., 2005, ApJ, 622, 1102

Gonzalez G., Laws C., Tyagi S., Reddy B. E., 2001, AJ, 121, 432

Gustafsson B., Edvardsson B., Eriksson K., Jørgensen U. G., Nordlund Å., Plez B., 2008, A&A, 486, 951

Lambert D. L., Dominy J. F., Sivertsen S., 1980, ApJ, 235, 114

Pasquini L., Döllinger M. P., Weiss A., et al., 2007, A&A, 473, 979

Robinson S. E., Laughlin G., Bodenheimer P., Fischer D., 2006, ApJ, 643, 484

Sestito P., Bragaglia A., Randich S., Pallavicini R., Andrievsky S. M., Korotin S. A., 2008, A&A, 488, 943

Smith V. V., Cunha K., Lazzaro D., 2001, AJ, 121, 3207

Sneden C. A., 1973, Carbon and Nitrogen Abundances in Metal-Poor Stars., Ph.D. thesis, The University of Texas at Austin

Takeda Y., Sato B., Murata D., 2008, PASJ, 60, 781

Yong D., Carney B. W., Teixera de Almeida M. L., 2005, AJ, 130, 597

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Education

- **University of Virginia, Charlottesville, VA**
  Ph.D. in Astronomy — expected 2011
  M.S. in Astronomy — 2006
- **Villanova University, Villanova, PA**
  B.S. in Astronomy & Astrophysics — 2004
  Minor in Physics
  Summa Cum Laude

Research

- **Graduate Research Assistant** — 2004–2011
  University of Virginia, Advisor: Dr. Steven Majewski

  Studying detailed chemical composition of rapidly rotating red giant stars to determine whether planets ingested during the stars' evolution causes their rapid rotation.

  Simulating the effects of binary companions on the radial velocity measurments of giant stars for the APOGEE project.

  Looking for structures, i.e., star streams or dwarf galaxies, associated with the Milky Way using M giant stars from the 2MASS database as tracers.

- **NASA Academy Summer Intern** — 2004
  Goddard Space Flight Center, Advisor: Dr. James Thieman

  Wrote software to import Radio Jove (an amateur radio telescope kit) data into IDL for scientific analysis, allowing the study of radio outbursts from Jupiter.

  Science team member, educational outreach leader, and webmaster for the group project, *Design the Next Mars Scout Mission: Mars Subsurface Chemical Life Explorer*.

- **Research Experience for Undergraduates (REU) Summer Intern** — 2003
  Smithsonian Astrophysical Observatory, Advisor: Dr. Peter Nisenson

  Precisely measured the radial velocity offsets between the stellar "reference spectra" of exoplanet candidate host stars taken before and after a physical upgrade of the AFOE spectrograph so that the pre- and post-upgrade data could be shifted to the same velocity zero-point.

- **Undergraduate Research Assistant** — 2002–2004
  Villanova University, Advisor: Dr. Edward Sion

  Modeled the ultraviolet spectra of symbiotic variable star systems to study their physical properties, specifically to look for the presence and nature of associated accretion disks.

Teaching & Professional Development

- **Dark Skies, Bright Kids** Sep. 2009–present
  Univ. of Virginia & Southern Albemarle Cty. VA

  Volunteer for Astronomy after-school programs at local elementary schools.
  Aid in lesson-plan development.
  Lead author of bilingual Astronomy art book for children.

- **Teaching Astro 101 Workshop** Jan. 2010
  Center for Astronomy Education

  Attended a workshop on teaching introductory astronomy for non-science majors.

- **"Astronomy Tutorial" Mentor** Spring 2010
  University of Virginia

  Mentored undergraduate student in an introduction to independent research course.
  Developed both general and project-specific course materials.

- **Summer Session Instructor** June 2008
  University of Virginia

  Taught a three-credit undergraduate Astronomy course entitled *Life Beyond Earth*.

- **Tomorrow's Professor Today** Sep. 2007–Apr. 2009
  University of Virginia

  Completed two-year professional development program for graduate students.

- **Teaching Assistant** 2004–2008
  University of Virginia

  Introductory astronomy courses: night lab TA, head night lab TA, revised laboratory manual, constellation quiz TA, telescope observing TA, held day lab office hours.

  Life Beyond Earth: support TA and substitute lecturer.

- **Private Tutor with "Math Advantage"** 2004–2007
  Charlottesville, VA

  Worked as a one-on-one tutor in math with two middle school students.

Awards & Professional Membership

- NASA Earth and Space Science Fellowship 2008–present
- Virginia Space Grant Consortium Graduate Fellowship 2008–present
- First prize oral presentation at Huskey Graduate Research Exhibition 2007
- NSF Graduate Research Fellowship, Honorable Mention 2004
- Barry M. Goldwater Fellow 2003
- American Astronomical Society Junior Member 2003–present

Outreach and Service

- Poster Judge for AAS Chambliss Astronomy Achievement Student Award Jan. 2010

- Fan Mountain Public Night 2004–present

  Tour Guide for biannual Fan Mountain Observatory open house.
  Lecturer for the "FOBOS" spectrograph part of tour.

- McCormick Observatory Public Night 2004–present

  Operate the historic 6-in. refractor and 10-in. Meade telescopes for public.

- NASA Academy Scoring Committee 2007

  Evaluated written applications for the 2007 NASA Academy Program.

Publications

Joleen K. Carlberg

Refereed Journal Articles

- **Carlberg, J. K.**, Majewski, S. R., Patterson, R. J., Bizyaev, D., Smith, V. V., & Cunha, K., "The Frequency of Rapid Rotation Among K Giant Stars," submitted to *ApJ*

- **Carlberg, J. K.**, Smith, V. V., Cunha, K., Majewski, S. R., & Rood, R. T., 2010, *ApJL*, **723**, 103 "The Super Lithium-Rich Red Giant Rapid Rotator G0928+73.2600: A Case for Planet Accretion?"

- Sharma, S., Johnston, K. V., Majewski, S. R., Muñoz, R. R., **Carlberg, J. K.**, & Bullock, J., 2010, *ApJ*, **722**, 750 "Group Finding in the Stellar Halo Using M-giants in the Two Micron All Sky Survey: An Extended View of the Pisces Overdensity?"

- **Carlberg, J. K.**, Majewski, S. R., & Arras, P., 2009, *ApJ*, **700**, 832, "The Role of Planet Accretion in Creating the Next Generation of Red Giant Rapid Rotators"

- Kolb, K., **Miller, J. K.**, Sion, E. M., & Mikołajewska, J., 2004, *AJ*, **128**, 1790 "Synthetic Spectral Analysis of the Hot Component in the S-Type Symbiotic Variable EG Andromedae"

Published Conference Proceedings

- **Carlberg, J. K.**, Majewski, S. R., Smith, V. V., Cunha, K., & Bizyaev, D., "The Fate of Exoplanets and the Red Giant Rapid Rotator Connection," to appear in American Institute of Physics Conference Proceedings, Planetary Systems Beyond the Main Sequence, ed. S. Schuh, H. Drechsel, & U. Heber

- **Carlberg, J. K.**, Majewski, S. R., Smith, V. V., Cunha, K., Patterson, R. J., Bizyaev, D., Arras, P, & Rood, R. T., 2009, "A New Spin on Red Giant Branch Rapid Rotators: Evidence for Chemical Exchange Between Planets and Evolved Stars," in IAU Symposium Vol. 265, Chemical Abundances in the Universe: Connecting First Stars to Planets, ed. K. Cunha, M. Spite, & B. Barbuy, 408