HG-WELS: Hungry Giants: WISE Excesses and Lithium Study—
Using WISE Data to Search for IR Excesses around Li-rich K giants

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ABSTRACT

As stars evolve from the main-sequence (MS) to the red giant branch (RGB), they experience several changes. Specifically, the outer layers expand and cool, the convective zone deepens, and a series of shell-burning and core-burning phases begin to take place. A number of RGB K-type stars, however, have been found to contain unusual characteristics such as a high lithium abundance that is inconsistent with standard stellar evolution models. Stellar objects with high Li abundances (*A*(Li)) are often also rotating more rapidly than standard evolutionary models predict (Carlberg et al. 2012). Additionally, many Li-abundant RGBs have infrared (IR) excesses, suggestive of a circumstellar shell or disk (de la Reza et al. 1997; Drake et al. 2002). Several hypotheses have been put forth as to the origin of the Li in these stars along with their increased rotation rates and IR excesses. These include engulfing nearby planets or a newly triggered nuclear fusion stage that could eject a dusty shell. Prior investigators looking for correlations between Li and IR excesses (e.g., de la Reza et al 1997 and references therein) used Infrared Astronomy Satellite (IRAS) data both to select targets and assess whether or not there is an IR excess. Our goal is to investigate the original targets with higher spatial resolution data from the Widefield infrared Survey Explorer (WISE) to see if the IR excess is really associated with the star, but also to look for WISE IR excesses in a much larger sample of RGB K-type giants, assembled without regard to IR brightness (Carlberg et al. 2012). We hope to determine or at least constrain the empirical relationship between *A*(Li), rapid rotation, and IR excess in these K giants.

1. BACKGROUND

Accurate Li studies of stars are thus crucial for continuing to understand and test stellar evolution models (Uttenhaler et al. 2012). Unlike heavier elements, which are formed within the cores of stars, Li is easily destroyed at temperatures $T>3\times10^6$ K. Abundances measured in stars (via spectroscopy) are by definition the surface abundances; convection in the outer layers can carry surface material down inside the star to high enough temperatures that the Li is destroyed, and/or mixes the surface material with Li-poor material from deep inside the star (where the Li has already been destroyed), resulting in a net dilution of surface Li abundance. For young low mass stars, lithium abundance [*A*(Li)] is indicative of age – Li can be found in higher abundances in younger stars, whereas older stars have had more time to destroy/dilute it. In Red Giant Branch (RGB) stars, it is an indicator of mixing. Convection forces surface elements (including Li) deep into hotter layers of the star, where it mixes with Li-poor material and returned to the surface, leading to a steady decrease in surface Li content over the lifetime of a star. Solar-abundance stars initially contain a surface Li abundance, or *A*(Li), of ~3.3 (where $A(Li) = \log\left(\frac{n(Lithium)}{n(Hydrogen)}\right) + 12$, and *n* is the number density of atoms – Ruchti et al. 2011). As a star exhausts the hydrogen fuel in its core, and evolves from the main-sequence (MS) to the RGB, several processes take place. The star's (radiative) core contracts, and its temperature increases, causing the outer (convective) layers to expand and cool. The expansion of the stellar envelope leads to a decrease in the (surface) stellar rotation rate in accordance with the law of conservation of angular momentum. Meanwhile, a deepening of the convection zone leads to the first dredge-up (FDU). During FDU, matter from the interior of the star circulates outward, mixing with surface material that in turn circulates inward, changing the abundances of surface elements. At hotter temperatures, ^7Li is burned into ^4He nuclei ($p + {}^7Li \Rightarrow {}^4He + {}^4He$). Convection mixes the Li-rich surface material to be mixed with the Li-poor interior material, causing the *A*(Li) to drop over time to ~1.5 (Adamow et al. 2012).

Some evolved stars have been found to contain *A*(Li)>1.5 following FDU, using Li absorption lines detected at 6708 Å and 6104 Å. De la Reza et al. (1996) discovered about 20 such RGB stars of spectral class K in 1995 (K giants). A study of the red giant BD+48 740 by Adamow et al. (2012) determined an *A*(Li)=2.33 ± 0.4; this object also has a planetary companion with a highly eccentric orbit. Both of these observations are unusual in evolved stellar systems (Adamow et al. 2012). Drake et al. (2002) found that approximately 50% of Li-rich K giants have a higher rotation rate than normal (where the rotation rate is determined from the widths of spectral lines, and is the rotation velocity projected onto the line of sight, v sin i, and thus is, like abundances, reflecting stellar surface properties, rather than properties throughout the star). In comparing a group of approximately 70 slow rotating K giants with 15 rapid rotators, Carlberg et al. (2012) found that the mean *A*(Li) was 0.99 dex greater in the rapid rotator group (a factor of $10^{0.99}$; dex(x) = 10^x). A small sample of slowly rotating red giants known to have planets was also included in the sample, and these red giants also showed a lower *A*(Li) than the rapid rotators.

Drake et al. (2002) and De la Reza et al. (1996; 1997) determined that many of their Li-rich K giants not only show a correlation between *A*(Li) and rotation, but also contain an IR excess, meaning more energy is detected in the IR than would be expected from a star alone. Such an IR excess may be indicative of a circumstellar (CS) shell or disk of gas and dust (as shown in Figure 2), which may be left over from a protostellar disk or nebula, mass loss during planetary ingestion/dissolution, or simply material that has been ejected from the envelope due to changes in internal pressure.

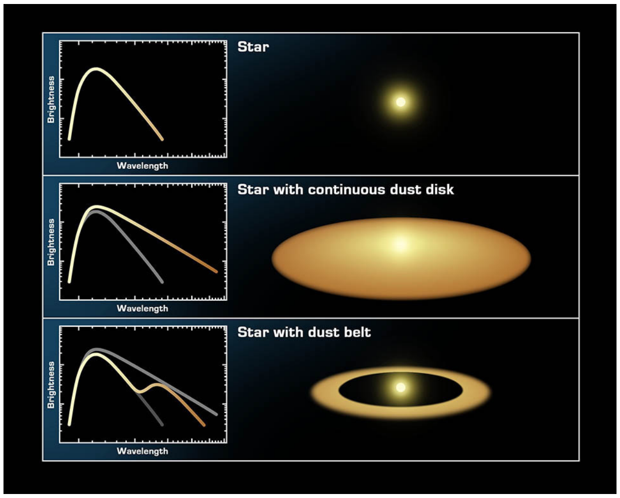

Figure 1 : Cartoon version of the spectral energy distributions (SED) for three example systems. As a circumstellar disk or shell surrounding a star is heated, energy is re-emitted at IR wavelengths. Since more IR energy is emitted than is expected from a stellar photosphere, this is called an "IR excess". Dusty disks and shells both result in similar SEDs. Credit: NASA/JPL-Caltech/T. Pyle (SSC); SSC press release sig05-026, 2005.

To explain the relationship between IR excesses, rotation rate, and Li abundances in these giants, De la Reza et al (1997) initially proposed a "dredge up mechanism" in which ^{3}He can be used to synthesize ^{7}Li at the base of the convection zone, which then is mixed and brought up to the surface via convection, leading to an increase in surface *A*(Li). According to Sackmann & Boothroyd (1992), if some additional mixing took place that transported material from the bottom of the convection zone to deeper in the star where H-burning is taking place and then back, Li enrichment could be seen. However, the $^{12}C/^{13}C$ ratio in the star would also change because the model requires a 'dredge-up' material from near the H-burning shell, and H-burning changes the 12C/13C ratio. This has not been observed (Carlberg et al. 2012). This model also assumes that the mechanism responsible for the production of the fresh ^{7}Li is accompanied by a sudden mass loss and ejection of a CS shell or disk. These events would result in the star having an IR excess and a *A*(Li) increase at the surface that will later be depleted as the convection zone continues to mix the Li down where it can be destroyed. De la Reza does not give details of a mechanism that would provide the energy necessary for the ejection of the CS, nor the rapid rotation found in many Li-abundant K giants; however, three additional mechanisms were proposed by De la Reza et al. (1997). These include (a) starting from a large pre-MS abundance and maintaining a base amount of Li during the RGB phase, (b) ^{7}Li production by a nearby nova, or (c) engulfing orbiting planets. As seen in Figure 3, we now know of many so-called "hot Jupiters" (high mass, gaseous planets orbiting close to their host star); stars entering the giant phase will expand to engulf such planets. If the engulfed planet is massive enough – such as hot Jupiters and/or brown dwarfs – they will change the surface abundances. (Terrestrial planets are not thought to provide enough material to change the abundance patterns.) While ^{7}Li preservation by the star or ^{7}Li production by a nearby nova could explain a *A*(Li) excess, planetary engulfment is the only known mechanism to explain the simultaneous presence of rapid rotation, IR excesses, and high ^{7}Li . in the case of BD+48 740, a nearby planet with an eccentric orbit (Adamow et al. 2012; Carlberg et al. 2012; Siess & Livio 1999) suggests that interactions between the expanding giant star and its planets may indeed be likely. A combination of planetary engulfment and other mechanisms is also a possibility (Drake et al. 2002; De la Reza et al. 1997).

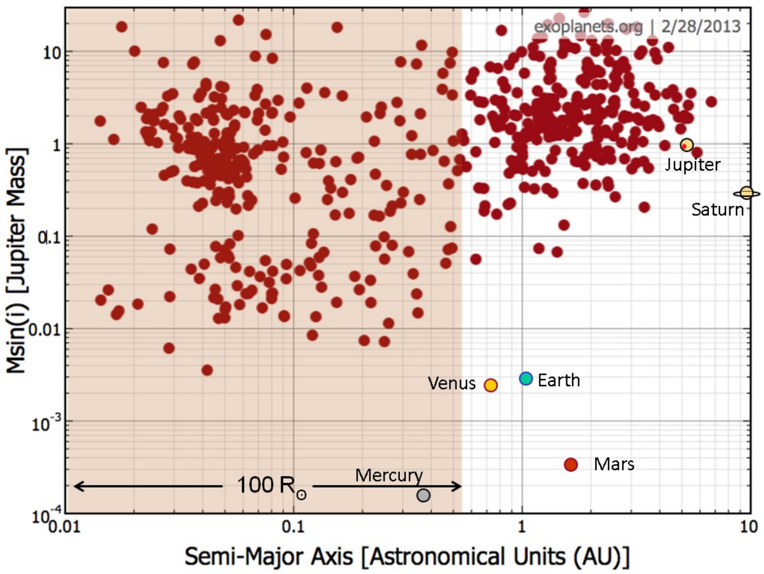

Figure 2: Many exoplanets discovered thus far have been "hot Jupiters," or large planets in close proximity to their parent stars (<1AU). When evolving stars expand to 100 times the radius of the Sun, denoted here by the shaded region, most of these hot Jupiters could be engulfed. The deposition of the matter from these planets into the outer convective regions of these giant stars could affect the abundances of the stars in a measurable way, and could result in the ejection of a dusty CS shell or disk (note that this figure was made on 2/28/2013 and doesn't include recent Kepler discoveries). Figure provided by Carlberg, private communication, 2014.

2. SCIENTIFIC GOAL AND EXPECTED OUTCOMES

In this work, we are looking for IR excesses around a sample of K giants, since the literature suggests a correlation between rotation rate, lithium, and IR excesses. We have two goals: (a) assess the correlation presented in the literature using more recent data, and (b) look for any correlation using a larger, less biased sample.

Although de la Reza et al. detected IR excesses in their sample, their sample was assembled by selecting objects using IRAS, the Infrared Astronomy Satellite, which conducted the first IR survey of the sky in 1983. The IRAS data are low spatial resolution (~1-3 arcmin) and shallow, meaning that the catalog consists only of the brightest objects in IR; this sample is therefore highly biased towards the brightest objects in the IR, and objects identified as having an IR excess may instead be normal giants with an apparent IR excess coming from another object nearby in projected location on the sky. Newer IR data is available from the Wide-field Infrared Survey Explorer (WISE; Wright et al. 2010), which has a higher spatial resolution of 6-12 arcsec. However, the WISE data are at shorter wavelengths – IRAS's longest wavelength was 100 microns, and WISE's longest wavelength is 22 microns. Our first goal is thus to examine the targets in de la Reza et al.'s original list in WISE and see if we can replicate their findings. This will be done in two parts. First, we will determine if the IR excess seen by IRAS is indeed due to the giant star, or instead due to another source – this is called source confusion. By using WISE data, we have the potential to identify any source confusion present in the IRAS data. However, by using WISE, we are using shorter wavelengths and thus sensitive to warmer dust than the original IRAS data. Thus, secondly, we will compare the WISE measurements with the original IRAS measurements and determine if there is a measurable IR excess at WISE bands, and not just IRAS bands, for these targets.

Our second goal is to look for new IR excesses, but in a much less biased sample of K giants, and a sample for which rotation rates and Li abundances are already available. We will study sources identified by Carlberg et al. (2012), supplemented by other Li-rich K giants from the literature in a catalog compiled by Carlberg (private communication). The sample of giants from Carlberg et al. (2012) was assembled without regard to the IR properties of the objects, and so is a much less biased sample. It includes K giants with a range of rotation rates and Li abundances (and carbon isotope ratios, $^{12}C/^{13}C$, which could be indicative of mixing, as discussed above).

Our overall goal is to determine if there is a correlation between IR excess and *A*(Li) in either of these samples. We also hope to better understand the correlation between *A*(Li), rotation and IR excess specifically in the sample studied by Carlberg et al. (2012). Right now, the different models for explaining Li rich giants do not make clear-cut predictions for what the relationship between *A*(Li), IR excess, and rotation (or what $^{12}C/^{13}C$ should be). We are in the position to discover and characterize those relationships, and these observations will hopefully drive better models for explaining what we see. If a correlation is not found, this could indicate that an alternative mechanism or a combination of mechanisms is responsible for the observed trends between Li and rotation rate.

3. ANALYSIS PLAN

Our sample consists of 196 K-type giants that have been identified as having high Li abundances (and in some cases rapid rotation) by de la Reza et al. (1996, 1997), Carlberg et al. (2012), and other Li-rich K giants from the literature in a catalog compiled by Carlberg (private communication). We will keep track of which star comes from which sample, e.g., if a given object was selected via de la Reza's IRAS-based approach, or from the substantially less biased Carlberg catalog. The rotational velocities, *A*(Li), and $^{12}C/^{13}C$ ratios we will use come from de la Reza et al. (1996) and Carlberg et al (2012).

Our goals for this project mean that we need to measure whether or not IR excesses are present for these objects (since IR excesses can indicate a CS likely resulting from planetary ingestion). We need to assemble the IR data for these giants from a variety of surveys. Preliminary investigations using the IRSA catalog search (powered by Gator) suggest that WISE photometry is available for 83% of these sources, and K_s-band data from the Two Micron All Sky Survey (2MASS) is available for 88% of our sources. Although there is sky coverage in both WISE and 2MASS for all of our targets, we may not be able to find WISE or 2MASS counterparts for either of two reasons. First, some targets in our catalog may not have good enough sky positions for our initial foray into catalog searching to find a match; we will need to investigate each source by hand, which we were planning to do in the context of source confusion anyway. Secondly, some of our targets are very bright, and unfortunately the brightest targets may not be available in WISE and 2MASS. We may need to supplement our WISE data with those from other missions, particularly for brighter sources. Similar preliminary investigations suggest that AKARI (a Japanese IR mission from 2006) photometric data is available for 66% of our sources, and MSX (a USAF IR mission from 1996) photometric data is available for 9% of our sources. Additional catalogs we can mine for photometric data include the Deep Near Infrared Survey of the Southern sky (DENIS) (K band data available for just over half of our sources) and the Spitzer Enhanced Imaging Products (SEIP) source list, though somewhat surprisingly, only ~5% of our sources appear in the SEIP(!).

Typically, to assess whether or not an IR excess is present, one needs to compare a relatively short IR wavelength to the longest IR wavelength available for each object. The relatively short wavelength samples the photosphere, and the long wavelength samples any dust that is present. This has been done frequently in the past by comparing K_s (2.2 microns) and 24 micron IR bands (from Spitzer/MIPS), and more recently comparing WISE's 3.4 and 22 micron bands (see, e.g., Mizusawa et al. 2012; Curie 2008). In many cases, the IR excess may be small (but real), or small but not real, e.g., a result of measurement uncertainty. In order to compare the broadband IR measurements and assess whether or not IR excesses are truly present, the uncertainties (σ) on the measurements in the short and long IR bands (Ks, [3.4], [22], and/or [24], where the bracket notation indicates a measurement at that band in magnitudes) must be accounted for.

Mizusawa et al. (2012) identified IR excesses by calculating the significance of the excess as follows:

$\chi_{24} = \frac{(K_S-[24])_{observed}-(K_S-[24])_{predicted}}{\sigma(K_S-[24])}$ for K_s and [24], and

$\chi_{22} = \frac{([3.4]-[22])_{observed}-([3.4]-[22])_{predicted}}{\sigma([3.4]-[22])}$ for [3.4] and [22].

Where the predicted IR color for any dust-free star is 0. Conventionally, an object is taken to have an IR excess if χ > 3. If all four measurements (K_s, [3.4], [22], and [24]) are available for any given object, they can be combined as

$$\chi_{best} = \frac{\chi_{22}\sigma(K_s - [24]) + \chi_{24}\sigma([3.4] - [22])}{\sqrt{\sigma^2_{([3.4]-[22])} + \sigma^2_{(K_S-[24])}}}$$

If only one pair of measurements is available, only one χ can be calculated. If both pairs of measurements are available, then they are two completely independent assessments of the presence of IR excess; by combining them into a χ_{best} as above, an object for which χ is close to but < 3 independently in both 22 and 24 microns can be identified as having an IR excess because $\chi_{best} > 3$.

We plan to follow this same basic approach, where we will be primarily relying upon χ as calculated from WISE data alone, but in cases where we have additional data (from, e.g., Akari, DENIS, Spitzer, etc.), we can choose to include these additional data.

We will use Microsoft Excel to assemble, organize and analyze the data, keep track of the survey origin of each target and its data, converting between flux density and magnitudes as needed, calculating χ, constructing plots, and doing statistical analysis such as correlation coefficients (e.g., between IR excess and A(Li)).

4. EDUCATION PLAN

We will adopt two approaches to our education plans for this program. We will coordinate across teams to assess educational impact, and we will also work individually at each school.

To assess educational impact across teams, we will develop a questionnaire to determine the attitudes of students regarding astronomy/STEM careers based on their NITARP experience. This questionnaire will be administered to them (and, ideally, to a group of control students in each high school; permission is being secured) at the beginning of their NITARP training in March 2014, just prior to their trip to Caltech in mid-July, at the end of their stay at Caltech, and after completion of their poster in December. The control group students will be tested in March and October. The test will contain a series of 7-point Likert-style scales (e.g. strongly agree, agree, neutral, disagree…) with spaces for comments. Altogether there will be approximately 16-20 participating students (the test group) and 12 to 16 control students.

All of the test results will be compiled into an Excel spreadsheet and analyzed statistically to see if the NITARP training and experiences have impacted student knowledge and attitudes concerning STEM careers in general and astronomy specifically.

This questionnaire will be written as a PDF document that can be printed out by the teachers in our group, or made available on an online source such as Survey Monkey or Schoology. We may also want to administer the test a fifth time after the students go to Seattle in mid-January, 2015.

4.1 INDIVIDUAL EDUCATOR PLANS

David Black's team will consist of students from a broad range of classes: physics, chemistry, astrobiology, 3D animation, and other science and math classes. They will meet weekly after school to keep up with the work. Background material will be taught in the Spring, and meetings will continue through the Summer. There will be a science research class in the Fall to help prepare the poster and investigate possibilities for independent science fair projects.

Elin Deeb intends to present the results of the project to the public through Fiske Planetarium's "Colorado Skies" series (where she has access to the technology as a former employee), as well as to viewers during public astronomy nights sponsored by colleague Jennifer Jones at Arapahoe Community College. Education workshops will be provided to other 9th grade Earth Science teachers in relation to the astronomy unit, which emphasizes stellar evolution. One to two AP physics students will have the opportunity to work with Elin Deeb during an off period (as "TA's") analyzing data, and potentially attending the 2015 AAS conference. Detailed plans for student involvement will be developed as her job situation solidifies.

John Gibbs' team at Glencoe High School currently has ten students who have expressed interest in participating in the HG-WELS research. This team of students will meet weekly after school for 60-90 minutes to read and discuss selections from the literature referenced in this proposal. In addition, students will work on background for this research by doing activities involving the use of Excel to manipulate and analyze data, log-log graphs, angular momentum, spectroscopy, stellar evolution and photometry. Students will work in teams during the data analysis and discuss each team's work to check each other for accuracy. In addition, to presenting the HG-WELS research at the 2015 AAS meeting, students will present this work to the Glencoe High School staff and the Hillsboro School District school board.

Estefania Larsen's team at Millard South High School will work with Ms. Larsen and her coworker Michael Edmundson during an after-school club held every Wednesday. All students are invited to attend and join in learning about the HG-WELS project. Currently, approximately 15 students attend weekly. The purpose of the club is to provide students an opportunity into academic scientific research in astronomy. Ms. Larsen and Mr. Edmundson will begin in the Spring of 2014 by working with the students to learn the necessary background information, such as stellar evolution and electromagnetic radiation. Students will be expected to present their results at the AAS meeting as well as to the math and science club, staff members, and other venues.

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