AGE-RELATED ABUNDANCE ANOMALIES OF COOL OPEN CLUSTER DWARFS

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INTRODUCTION

Open star clusters and their dynamically dispersed cousins moving groups are unique astronomical laboratories populated with stars that share a common age and initial chemical composition. Aside from possible evolutionary-related changes in the abundances of the light elements H, He, and B, cluster members are expected to be chemically homogeneous. This makes open cluster and moving group stars valuable targets for studies of stellar physics and Galactic chemical evolution, among others. Starting with M34 (NGC 1713), we initiated an observational program to map the metal abundances of solar-type dwarfs in open clusters, but contrary to expectations, the derived abundances of some elements of stars cooler than ~5400 K were found to deviate from those of the warmer cluster members. There are two apparent effects observed in the cooler dwarfs: 1) Overexcitation- abundances derived from high-excitation lines increase with decreasing stellar T_eff and 2) Overionization- the difference in abundances derived from singly ionized Fe lines compared to neutral Fe lines increases with decreasing T_eff. Similar abundance anomalies have been found for cool dwarfs in the Pleiades, Hyades, and IC 4665, as well as the Ursa Major moving group and possibly the HR 1614 moving group. Here we present an overview of the abundances of cool dwarfs in open clusters and moving groups and discuss possible sources of the observed abundance anomalies.

OVEREXCITATION

The most dramatic example of overexcitation among cool cluster dwarfs is observed for [O i] 6300 Å transitions derived from the high-excitation (λ6300 Å ~ 9.15 eV) O i triplet at 7774 Å. A dramatic increase in derived O abundances with decreasing T_eff has been seen in the Pleiades, Hyades, IC 4665, and in the Ursa Major moving group. To the left, O abundances derived from the high-excitation triplet relative to similarly derived solar O abundances are shown as a function of T_eff for the Hyades. The figure has been taken and modified from Schuler et al. (2006a).

OVERIONIZATION

Abundances derived from spectral lines arising from neutral and ionized atoms of a given species should be equal. However, similar to abundances derived from high-excitation lines of neutral atoms, Fe abundances derived from Fe i lines relative to those derived from Fe ii lines show a dramatic increase in stars with decreasing T_eff. Here are the [Fe i/Fe ii] and [Fe ii/Fe i] abundances as a function of T_eff for dwarfs in the Pleiades open cluster. For the warmest two dwarfs in the sample, the difference is 0 within the typical uncertainties; the difference grows steeply for dwarfs with T_eff < 5500 K.

[O/H] abundances derived from the O i triplet are plotted versus the difference in [Fe ii/Fe i] abundances as derived from Fe i and Fe ii for the Pleiades, M34, Ursa Major, and the Hyades. A clear correlation is seen for each stellar group. The data shown here strongly suggest that the observed overexcitation and overionization effects are the result of the same mechanism.

AGED RELATED ANOMALIES?

Just as intercluster comparisons of stellar abundances revealed the overexcitation and overionization effects, intercluster comparisons can be used to understand the nature of these abundance anomalies. Here [O i/H] abundances derived from the O i triplet for dwarfs in the Pleiades, Ursa Major, Hyades, and HR 1614 groups are plotted versus T_eff. The [O i/H] abundance trend of the Pleiades, the youngest cluster shown, is steeper than that of the other clusters. The trends of Ursa Major and the Hyades, stellar aggregates of similar ages but of different metallicities, seem to track each other, whereas the trend of HR 1614, the oldest group shown, appears to be diminished compared to the other clusters. These comparisons suggest an age-related diminution of the O i triplet abundance trends.

Takeda (1995) showed that chromospheric activity may affect the O i triplet line formation in the solar spectrum. Chromospheric activity is expected to decrease with age, and a potential connection to the possible diminishing of O i triplet abundance trends in open clusters is intriguing. To the left, Pleiades [O i/H] abundance residuals (observed - fit) are plotted versus T_eff and Ca i triplet chromospheric emission (Soderblom et al. 1993; Soderblom et al. 2001) residuals, and Hyades [O i/H] abundance residuals are plotted versus T_eff. All Ca i emission indicators (Paulson et al. 2002) and residuals. No correlations are seen. We note, however, that the O abundances and chromospheric emission measurements are not contemporaneous.

THE CLUSTERS

Our stellar sample consists of stars from the Pleiades, Hyades, and M34 open clusters and the Ursa Major and HR 1614 moving groups. All abundances have been derived via analyses of high-S/N (70 - 300) high-resolution (R ~ 5000 - 45000 - 60000) spectra obtained with the 9.2-m Hobby-Eberly Telescope (Pleiades), the 10-m Keck telescope (M34), the 2.7-m Harlan J. Smith telescope at the McDonald Observatory (Ursa Major & Hyades), the 4.0-m Mayall telescope at Kitt Peak National Observatory (Hyades), and the 4.0-m Anglo-Australian Telescope (HR 1614).

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Age (Myr)</th>
<th>[Fe/H]</th>
<th>Distance (pc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pleiades</td>
<td>100</td>
<td>+0.07</td>
<td>130</td>
</tr>
<tr>
<td>M34</td>
<td>250</td>
<td>+0.17</td>
<td>475</td>
</tr>
<tr>
<td>Ursa Major</td>
<td>500</td>
<td>-0.09</td>
<td>-</td>
</tr>
<tr>
<td>Hyades</td>
<td>650</td>
<td>+0.13</td>
<td>45</td>
</tr>
<tr>
<td>HR 1614</td>
<td>2000</td>
<td>+0.25</td>
<td>-</td>
</tr>
</tbody>
</table>

DISCUSSION

The comparison of the [O i/H] abundances derived from the O i triplet of dwarfs in open clusters and moving groups of different ages and metallicities points to an age-related diminution of the overexcitation effects observed among the cool dwarfs. There is no evidence of a connection between the O i triplet abundances of Pleiades and Hyades dwarfs and chromospheric emission indicators; however, Shen et al. (2007) suggest such a connection exists for open cluster IC 4665.

We have investigated the possibility that photometric activity- hot and cool spots- could produce the abundance anomalies observed among the cool dwarfs (Schuler et al. 2006a). We utilized simplified “toy” atmospheric models consisting of flux contributions from hot and cool spots, as well as from the quiescent spot, to synthesize the O i triplet of three Hyades dwarfs with 4573 Å λ T_eff of 4988 assuming an O abundance equal to that of the solar T_eff dwarfs. The conservation of total luminosity was enforced by using a Stefan-Boltzmann relation weighted by areal coverages for each of the three temperature regions. Assuming reasonable areal coverages and temperatures, the toy models were able to reproduce the observed O i triplet strengths for all three stars. While this exercise is not conclusive, it does demonstrate that photometric temperature inhomogeneities are a plausible source of the observed cool dwarf abundance anomalies.

The results presented here portend that the abundances of dwarfs with T_eff ~ 5500 K should be viewed with caution.

References:

*Takeda, Y. 1986, PASJ, 47, 463

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