LITHIUM IN CHEMICALLY PECULIAR CP STARS WITH MAGNETIC FIELDS

N. S. Polosukhina\(^1\) and A. V. Shavrina\(^2\)

The problem of lithium in chemically peculiar Ap-CP stars has been the subject of debate for many years. The main reason for this is a lack of spectral observations of Ap stars in the neighborhood of the lithium resonance doublet Li I 6708 Å. An international cooperation project on "Lithium in cool CP stars with magnetic fields" was started in 1996. Systematic observations of CP stars in spectral regions of the 6708 Å and 6103 Å lines at the ZTSh (CrAO), CAT (ESO), Feros (ESO), and the 74" telescope of the Mount Stromlo Observatory (Australia) have been used to analyze spectra of several CP stars studied by the way the 6708 Å lithium line varies with the stars' rotational phase. Monitoring of the spectra of the oscillating CP stars (group I) HD 83368, HD 60435, and HD 3980, for which significant Doppler shifts of the Li I 6708 Å line are observed led to the discovery of "lithium spots" on the surface of these stars whose positions are related to the magnetic field structure. Models of the surfaces of these stars with the special program "ROTATE" based on the profiles of the Li I 6708 Å line are used to estimate the size of the spots, their positions on the stars' surface, and the lithium abundances in these spots. A detailed analysis and modelling of the spectra of slowly rotating oscillating CP stars with strong, invariant lithium 6708 Å emission, including blending with lines of the rare earth elements, reveals an enhanced lithium abundance, with the abundance determined from the lithium 6103 Å line being higher than that determined from the 6708 Å line for all the stars. This may indicate vertical stratification of lithium in the atmospheres of CP stars with an anomalous isotopic composition ($^{6}\text{Li}/^{7}\text{Li} = 0.2 - 0.5$). HD 101065, an ultraslow rotator ($v\sin i = 1.5$) visible from the poles and with powerful oscillations which cause pulsating line broadening in its spectrum, is unique among these stars. The amount of lithium in the atmosphere of HD 101065 $\log N(\text{Li}) = 3.1$ on a scale of $\log N(\text{H}) = 12.0$ and the isotope ratio $^{6}\text{Li}/^{7}\text{Li} = 0.3$. The high estimates of $^{6}\text{Li}/^{7}\text{Li}$ may be explained by the production of lithium in spallation reactions and the preservation of surface $^{6}\text{Li}$ and $^{7}\text{Li}$ by strong magnetic fields in the upper layers of the atmosphere near the magnetic poles.

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\(^1\) Scientific Research Institute Crimean Astrophysical Observatory, Ukraine; e-mail: polo@crao.crimea.ua
\(^2\) Main Astronomical Observatory, National Academy of Sciences, Ukraine; e-mail: shavrina@mao.kiev.ua

1. Introduction

Lithium is one of the few elements originating in the Big Bang. After hydrogen and helium it is one of the most abundant primary elements in the universe. Furthermore, it is one of the easily destroyed elements: at temperatures of about 2 million degrees, characteristic of stellar interiors, it undergoes thermonuclear burning. Because of convection and other mixing mechanisms, matter which is depleted in lithium is carried into the atmosphere of a star, so the atmospheres of young stars usually contain more of this element than old stars [1,2]. As a result, a large fraction of evolved stars, the late giants, have a relative deficit of lithium. But among the evolved stars there are some with anomalously high lithium abundances, and the spread in the amount of this element is up to 6 orders of magnitude. The high lithium abundance in older stars and the wide range of this excess abundance among physically similar stars is an intriguing puzzle [3].

Lithium overabundance content may be caused by physical processes that impede the mixing of stellar matter and preserve its originally high abundance in the atmosphere, perhaps through suppression of convection by magnetic fields. An alternative might be actual processes for production of lithium in stellar atmospheres, such as spallation reactions in which protons and alpha particles accelerated in the magnetic fields destroy heavier C, N, and O nuclei leading to the production of lithium. The fact that the lithium rich evolved stars include some for which the abundance of this element exceeds that of lithium in even the youngest T Tau stars [4-6] means that a single mechanism for the preservation of the initial high lithium abundance in stellar atmospheres is not enough, and an additional process, by which it is actually produced, is really necessary.

Wallerstein [4], and Lambert and Sawyer [5] suggested that, during their evolution, lithium rich giants had passed through a stage as chemically peculiar CP stars with high magnetic fields and a high lithium abundance. This circumstance stimulated an interest in studying lithium in these stars. There is a contrary opinion according to which peculiar CP stars have passed through a red giant stage and are evolving into white dwarfs. A diffusion theory is invoked to explain the anomalies in the elemental abundances in the atmospheres of both groups of stars, the CP stars and the white dwarfs.

Among many of variable stars, one group of chemically peculiar stars in spectral classes B8-F0 stands out, the so-called Ap-CP stars, whose line spectra have anomalous intensities for many chemical elements. On a Hertzsprung-Russell diagram these stars form a fairly compact group in the upper portion of the main sequence. It was discovered that some Ap-CP stars have variable magnetic fields of up to 30 kG [7]. The spectra of the most of magnetically variable stars are so unusual and so rich in lines which do not appear in the spectra of normal stars of the same spectral class, that astronomers constantly have problems identifying them. Even for well studied magnetically variable Ap-CP stars about a third of the lines are unidentified. Most of these stars are distinguished by the presence in their spectra of atomic lines corresponding to a lower temperature than that ascribed to a given star on the basis of its photometric and spectral characteristics.

Studies of the chemical composition of the atmospheres of magnetic Ap-CP stars are complicated by a number of problems. Doppler mapping of the surface of some Ap-CP stars made it possible to discover nonuniformities in the distributions of a number of chemical elements associated with their magnetic field structure [8]; thus, the chemical composition averaged over the surface does not reflect the actual picture of the atmosphere of these stars. The local chemical composition of individual portions of the surface of a star has a real physical significance. The observed