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Fluorine Abundances in the LMC and the Galaxy

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Abstract

To date, fluorine abundances have only been measured in a sample of asymptotic giant branch stars and in a few K- and M-giants with near-solar metallicities in our Galaxy. The behavior of fluorine versus metallicity has yet to be probed. In this work we discuss the first results for fluorine abundances measured outside of the Milky Way and in stars with metallicities significantly lower than solar. The sample consists of 9 red giants from the Large Magellanic Cloud and 2 red giants from the Galactic globular cluster ω Centauri. The fluorine abundances are derived from vibration-rotation transitions of HF using infrared spectra obtained with the Phoenix spectrograph on the Gemini South 8.1m telescope. The behavior of fluorine abundances with metallicity may suggest that Wolf-Rayet stars are an important source of fluorine production.

1.1 Introduction

The origins of fluorine have remained somewhat obscure up to the present time. The only stable isotope of fluorine, ^{19}F, is not easy to produce as it is readily destroyed by either proton or α captures during many phases of stellar evolution. From an observational point-of-view, fluorine is difficult to detect spectroscopically. The only atomic lines that might be studied are the ground-state lines of F I, falling in the far ultraviolet (UV) near 950Å. Molecular lines from HF are readily detectable in the infrared near wavelengths of $\sim$2.3 μm. These observational difficulties have led to a small number of fluorine abundance determinations. These abundances come from the study by Jorissen, Smith & Lambert (1992) who measured fluorine in Galactic s-process rich and carbon-rich AGB stars of spectral types MS, S and C, as well as a small number of giants of type K or M with near-solar metallicities.

There are three possible sources for fluorine production: 1) synthesis of fluorine on the asymptotic giant branch (Jorissen et al. 1992), 2) its production in Wolf-Rayet stars at the beginning of their He-burning phase (Meynet & Arnould 2000) and 3) production of fluorine via the ν-process in type II supernovae (Woosley et al. 1990). Observations are needed in order to decide whether one, or all of these three sources play a major role in Galactic fluorine production.

1.2 Fluorine Abundances

In this study we probe the chemical evolution of fluorine towards lower metallicities and derive fluorine abundances in a sample of 9 red-giants of the Large Magellanic Cloud, as well as two red giants in the Galactic globular cluster ω Centauri. The observational data are high resolution (R=50,000) IR spectra obtained on the 8.1m Gemini South telescope with the NOAO Phoenix spectrometer. The spectra were analyzed for HF and were centered near a wavelength of 23400 Å. The adopted effective temperatures and surface gravities for the sample stars were the same as previously published by Smith et al. (2000, for the ω Cen targets) and Smith et al. (2002, for the LMC targets). Fluorine abundances were derived from spectrum synthesis of the HF(1–0) R9 line. The final fluorine abundances, A(F), for the LMC and ω Cen giants are presented in the top panel of Figure 1 (represented filled circles and open triangles, respectively).

1.3 The Behavior of Fluorine with Metallicity

The three proposed sites for fluorine production: the ν-process resulting from core-collapse in SN II, operation of a neutron source during He-burning thermal-pulses in AGB stars, or mass loss from WR stars during their phase of He-burning, predict somewhat different behaviors of fluorine as a function of metallicity, yet to be probed.

Our primary interest is to investigate the behavior of the fluorine abundance with metallicity. Figure 1 shows the relation of [F/O] versus A(O), where oxygen is used as the metallicity indicator. The use of oxygen, instead of iron as a measure of metallicity, removes SN Ia as a contributing source to ^{19}F chemical evolution, as neither fluorine nor oxygen have significant production in SN Ia, unlike Fe. All the fluorine abundances known to date for giant stars are gathered in the top panel of Figure 1: the behavior of [F/O] versus oxygen is quite flat and scatters about [F/O]$\sim$ 0.0 for almost all stars, except the ones belonging to the globular cluster ω Cen that have quite low F/O abundance ratios. In fact, an average of all stars, except the ones in ω Cen, is [F/O]= +0.02$\pm$0.18 (this sigma is of the order of the estimated uncertainties in the analysis). Taken together, this indicates that [F/O] is flat down to metallicities of 0.15 solar (in oxygen), suggesting a primary origin for fluorine with respect to oxygen. This picture does not address the issue of the low values of [F/O] in the ω Cen giants. In this context, the lowest values of [F/O] found in two of the LMC stars perhaps are not just scatter, but part of a trend in which [F/O] is approximately flat at high metallicities, but then rapidly declines at some critical threshold metallicity.

In the following we discuss the expected behavior of fluorine versus oxygen for each proposed site for fluorine production in comparison with the abundance results:

1) **SN II:** with ^{19}F arising from ^{20}Ne losing a proton due to neutrino spallation, the expectation would be that fluorine would behave nearly as a primary element with respect to oxygen, as the abundances of neon and oxygen will track each other closely in SN II. This is roughly the behavior seen down to a certain metallicity. We note however, the lower values of fluorine for the ω Cen giants. The model predictions of Timmes et al. (1995) for fluorine production in the ν-induced process are shown as a solid line in the bottom panel of Figure 1. This indicates a slow decline of fluorine with oxygen. A comparison of the observations/ abundances in the top panel of the figure with the model predictions from ν-induced production would suggest that these do not fit the observed data at the lower metallicities, indicating that the ν-process is probably not the major source for fluorine at these metallicities. Inclusion of the ω Cen abundances argues against even the naive prediction of the ν-process that [F/O]$\sim$ 0.0.

2) **AGB Stars:** Although Jorissen et al. (1992) could explain the enhanced fluorine abundances they observed in the s-process enriched and carbon-enriched AGB stars, they did not

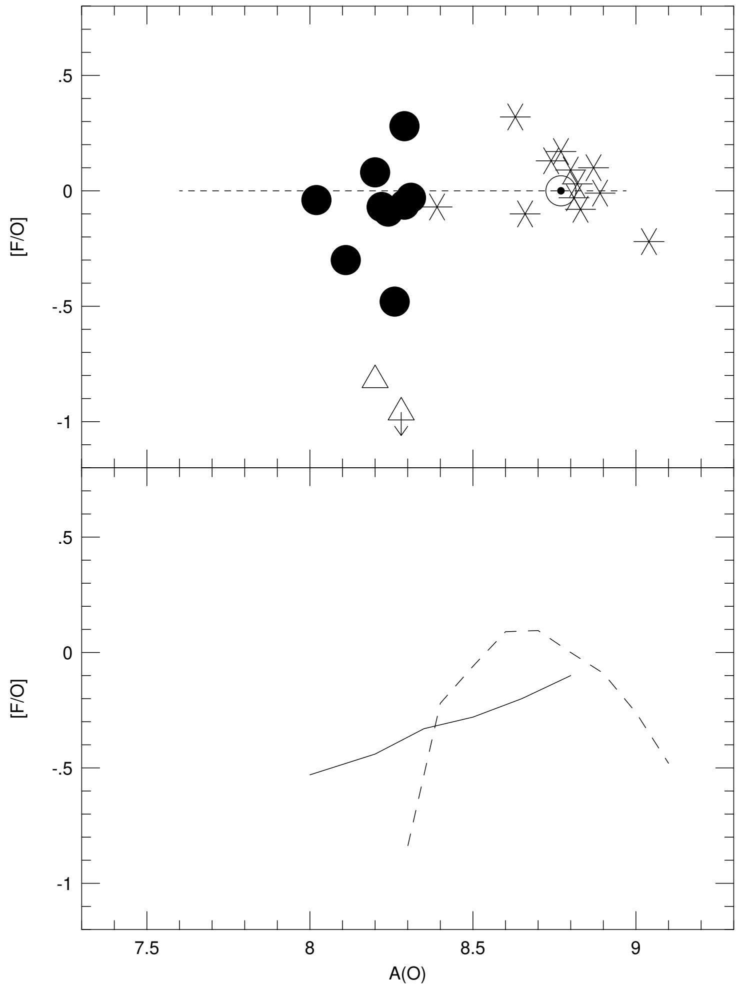

Fig. 1.1. The top panel shows [F/O] versus the oxygen abundance for the sample stars and field giants from the literature. Asteriks are the K and M giants from Jorissen et al. (1992), while filled circles are our LMC results and the open triangles are the ω Cen giants. Overall, the behavior of fluorine tracks the oxygen abundance, with [F/O] scattering $\sim$ 0.0 down to A(O)=8.2. The bottom panel displays two model predictions: one for the neutrino process by Timmes et al. (1995, solid line) and the other calculated from yields for Wolf-Rayet stars (Meynet & Arnould 2000, dashed line). The observed metallicity dependence of the fluorine abundance may favor its production in WR stars based on the few low values of [F/O] seen in the lower metallicity LMC and ω Cen stars.

make detailed predictions about the chemical evolution of fluorine. They did suggest that AGB stars would produce both secondary and primary (with metallicity) components, but that the relative amounts of either component would be difficult to calculate. The ω Cen giants, in this case, enter the picture as potentially crucial points, due to the large s-process abundances found in many of the ω Cen members: a result usually interpreted as showing an especially large degree of AGB enrichment contributing to the chemical evolution within ω Cen. In such a picture, the ω Cen giants should exhibit enhanced fluorine abundances, but show completely opposite behavior. Therefore, if the s-process enrichment observed in the ω Cen giants are the result of AGB contribution, and if the AGB stars are also major producers of fluorine, one would expect that these giants would also show fluorine enhancements and this is not the case.

WR Stars: Meynet & Arnould (2000) investigated the role that WR stars may play in the chemical evolution of fluorine. The crucial point emphasized in their study is that any fluorine produced must be removed from the stellar interior via extensive mass loss before it is destroyed. The WR mass loss is very metallicity dependent, thus Meynet & Arnould (2000) predict that fluorine yields from WR stars will exhibit a strong dependence on metallicity: a very small, to negligible yields at low metallicity, with increasing ^{19}F yields towards solar-like metallicities. In the bottom panel of Figure 1, the dashed curve attempts to reproduce the expected behavior of [F/O] versus A(O) calculated from Meynet & Arnould (2000) mass yields of ^{19}F versus stellar mass for three different metallicities. (We used a mass function with exponent -2.2 to convert their mass yields per star to mass yields per stellar mass interval.) The resulting curves of mass yields were then integrated across stellar mass to give total yields of fluorine at each of their three metallicities. Comparison of the behavior sketched by the dashed curve with the abundance results in the top panel of Figure 1, suggests that the general observationaltrend is reproduced.

Based on the abundance results shown here, and the predictions from WR stars, we conclude that it may be worth pursuing WR stars as serious candidates of fluorine production in stellar populations.

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