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The Chemical Enrichment of the Diffuse Gas in the Outer Galaxy and the Abundance Gradient of the Milky Way

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Abstract. Using data from HST/STIS (*Hubble Space Telescope / Space Telescope Imaging Spectrograph*) and FUSE (*Far Ultraviolet Spectroscopic Explorer*) toward two QSOs, H1821+643 and HS0624+6907, we find that the overall metallicity of the Galactic "Outer Arm" is $Z = 0.3 - 0.5 Z_{\odot}$ with underabundant nitrogen and little depletion by dust. The results are consistent with those based on H II region measurements in the outer galaxy and provide additional constrains on models of the Galactic abundance gradient and Milky Way (MW) chemical evolution. The lower metallicity observed in the outer galaxy is consistent with abundance patterns observed in higher redshift damped Lyα absorbers (DLAs) extrapolated to z=0. The slow metallicity evolution of DLAs could be due to the larger cross sections of the outer regions of galaxies combined with the observed metallicity gradients.

Keywords. abundance gradient, metallicity

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1. Introduction

Measurements of abundances at large Galactic radii are relatively limited and crucial for determining the Galactic abundance gradient and testing theoretical models of Galactic chemical evolution.

The Outer Arm of the Galaxy is a large, contiguous neutral hydrogen complex located at $49° \leqq l \leqq 161°$ and $4° \leqq b \leqq 31°$. It is estimated to lie at a distance of $\sim 15kpc$ away from the Galactic center (Haud 1992). The origin of the Outer Arm is not clear yet. It could be a warped part of spiral arms or a byproduct together with Complex C due to the interaction between a satellite galaxy and the MW.

2. Observations

We use the high-resolution spectra of two quasars observed with STIS and FUSE to study the physical conditions of the gaseous structures in the outermost regions of the MW. The sight lines to the QSOs, HS0624+6907 ($l = 94°.00, b = 27°.42$) and H1821+643 ($l = 145°.71, b = 23°.35$) both pass through the Outer Arm region. We measure column densities of various species with the apparent optical depth (AOD) method (Savage & Sembach 1991) and a Voigt-profile fitting program (Fitzpatrick & Spitzer 1997).

The HI column densities of the high-velocity components associated with the Outer Arm along these two sight lines are $N(HI) = (3.3 \pm 0.5) \times 10^{18}\ cm^{-2}$ for H1821+643 and $N(HI) = (19.8 \pm 1.8) \times 10^{18}\ cm^{-2}$ for HS0624+6907 (Wakker *et al.* 2001).

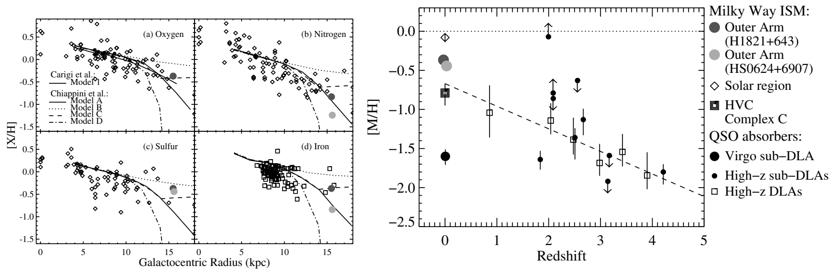

Figure 1. Left: Radial gradients in the MW for four species. The diamonds and black dots are H II region measurements. The squares represent the abundances in open clusters. The green and yellow dots are our results. Lines are model predictions (Chiappini, Matteucci & Romano 2001). **Right:** Comparison of abundances measured in sub-DLAs (Dessauges-Zavadsky *et al.* 2003) and DLAs (Prochaska *et al.* 2003) at various redshifts to abundances measured near the Sun, in the Outer Arm, and in HVC Complex C.

3. Photoionization and Abundances

We apply CLOUDY photoionization models (v94.0, Ferland *et al.* 1998) to correct our abundance measurements for ionization effects and dust depletion. The best fits of our measurements to the models give metallicity around $Z = 0.43Z_\odot$ for H1821+643 and $Z = 0.36Z_\odot$ for HS0624+6907, respectively. In both cases, Nitrogen is underabundant. The mild discrepancies between model predictions and our measurements for Fe II, Si II, and Al II indicate the existence of small amounts of dust.

4. Discussion

Our abundance measurements are consistent with those using H II regions at large Galactic radii (Fig.1 left) and indicate the outer Galaxy only contains small amounts of dust. It can put better constrains on models of abundance gradients and formation of the Galaxy (Fig.1 left).

Metallicity of the Outer Arm is about $Z = 0.3 - 0.5Z_\odot$, but nitrogen may be underabundant. It can better represent the metallicity of the MW when compared with measurements for high-redshift DLA samples, and it follows the metallicity evolution trend (Fig1. right).

The apparent column density profiles of various low-ion lines are well aligned, while the high-ion profiles show different line centroids and line widths compared with the low-ion profiles. Such comparison suggests the outer Galaxy gas is multiphase.

References

Chiappini, C., Matteucci, F. & Romano, D. 2001, *ApJ* 554, 1044

Dessauges-Zavadsky, M., Proux, C., Kim, T.-S., D'Odorico, S. & McMahon, R. G. 2003, *MNRAS* 345, 447

Ferland, G. J., Korista, K. T., Verner, D. A., Ferguson, J. W., Kingdon, J. B. & Verner, E. M. 1998, *PASP* 110, 761

Fitzpatrick, E. L. & Spitzer, L. Jr. 1997, *ApJ* 475, 623

Haud, U. 1992, *MNRAS* 257, 707

Prochaska, J. X., Gawiser, E., Wolfe, A. M., Castro, S.& Djorgovski, S. G. 2003, *ApJ* 595, 9

Savage, B. D.& Sembach, K. R. 1991, *ApJ* 379, 245

Wakker, B. P., Kalberla, P. M. W., van Woerden, H., de Boer, K. S. & Putman, M. E. 2001, *ApJS* 136, 537

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