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Evidence of outflow from the Galactic bulge imprinted in stellar elemental abundances

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Abstract. We explore the elemental abundance features of metal-rich disk stars, highlighting the comparisons made with those of the recently revealed Galactic bulge stars. A similarity between two of the comparisons leads to a new theoretical picture of the bulge-disk connection in the Galaxy, where a supermassive black hole resides at the center. We postulate that a metal-rich outflow, triggered by feedback from a black hole, was generated and quenched the star formation, which had lasted several billion years in the bulge. The expelled gas cooled down in the Galactic halo without escaping from the gravitational potential of the Galaxy. The gas gradually started to accrete to the disk around five billion years ago, corresponding to the time of sun's birth, and replaced a low-metallicity halo gas that had been accreting over nearly ten billion years. The metal-rich infalling gas, whose elemental abundance reflects that of metal-rich bulge stars, mixed with the interstellar gas already present in the disk. Stars formed from the mixture compose the metal-rich stellar disk.

1. Introduction

Feedback from supermassive black holes at the innermost regions of galaxies has a crucial influence on the evolution of their host galaxies (Silk & Rees 1998). While the growth of black holes through gas accretion is regulated by its associated feedback, the feedback also influences the host on a large scale through energy input into the gas surrounding the black holes, which halts star formation and induces a powerful outflow (Springel *et al.* 2005). It is evident that the Galaxy possesses a supermassive black hole, with a mass of $\sim 3 \times 10^6 M_\odot$ at the Galaxy center (Genzel *et al.* 1997, Schödel *et al.* 2003). Because of the short distance, the Galaxy is the best-suited laboratory to probe the past of other galaxies hosting supermassive black holes and that have been affected by their feedback. Now is the time to pursue this subject using a powerful tool to trace the mechanisms of galaxy formation, e.g., elemental abundances of stars, especially since we have obtained detailed elemental abundances of individual stars in the Galaxy, including member stars belonging to the bulge (Fulbright *et al.* 2007).

2. Abundance Trends of Metal-Rich Disk Stars

We will examine the abundance trends of metal-rich disk stars with [Fe/H] $\gtrsim 0$ in a framework that considers the tight link to the activity and formation of the Galactic bulge. Figure 1 shows the comparison between abundance features in the [X/Fe] vs. [Fe/H] diagram for six elements of disk stars and metal-rich bulge stars. The characteristic feature of α-elements, such as Mg, Si, Ca, and Ti, in comparison with Fe for metal-rich disk stars, is the upturn with an increase in [Fe/H]. Two upper panels give a sample of $X =$ Mg and Si, demonstrating that this feature is surely observed in $0 \lesssim$ [Fe/H] $\lesssim +0.4$. Although the origin of these upturn has been a totally open question, superposition of the observed data for metal-rich bulge stars on those of the disk stars leads to a

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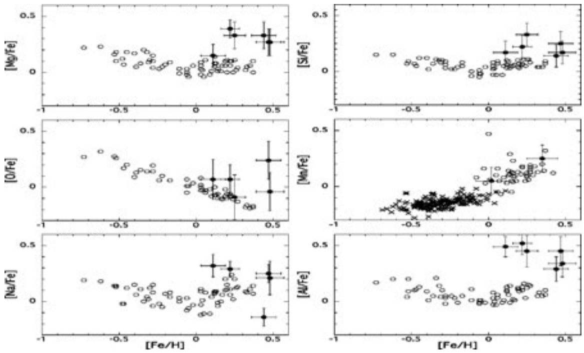

Figure 1. Correlations of [X/Fe] with [Fe/H] for disk stars (open circles and crosses) together with metal-rich ([Fe/H] > 0) bulge stars (filled circles). Except for Mn, filled and open circles represent data from Fulbright *et al.* (2007) and Bensby *et al.* (2005), respectively. The Mn abundances are taken from McWilliam *et al.* (2003) (filled circles), Feltzing & Gustafsson (1998) (open circles), and Reddy *et al.* (2003) (crosses).

possible indication for solving the puzzling upturn. Our proposed view of abundance trends between two different populations is that the [Mg (Si)/Fe] ratio of disk stars gradually *approaches* that of the metal-rich bulge stars in relation to the increase in [Fe/H]. This interpretation also holds true in the cases of [O/Fe] and [Mn/Fe], where the abundance trend in a metal-rich regime inherits that for [Fe/H] $\lesssim 0$ (middle panels). In addition, odd elements such as Na and Al, which show an upturn in their ratios to Fe like the case of α-elements, also have enhanced ratios of bulge stars ahead in the direction of their upturn trends (lower panels).

However, this poses the question of which theoretical scheme can be applied to the potential bulge-disk connection to understand their stellar elemental relationship. A possible answer is that metal-rich disk stars are formed from a mixture of an infalling metal-rich gas originally ejected from the bulge and the remaining gas of a star formation in the disk. In this case, their abundance pattern is determined by the combination of heavy elements ejected from the bulge at the end of star formation, along with those elements that are already present in the interstellar gas of the disk. In accordance with an accumulation of infall with time, the source of heavy elements in stellar abundances is gradually dominated by those in a metal-rich infalling gas. This results in an abundance trend directed to the elemental ratios of metal-rich bulge stars. Furthermore, an iron contained in a metal-rich infalling gas will promote an increase in the [Fe/H] of stars, which results in an extended metal-rich tail of stellar abundance distribution function as observed. Detailed discussion can be found in Tsujimoto (2007).

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