赤方偏移天体(z=0.89)におけるフッ素化合物のアルマ電波観測

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ALMA observations of fluorine-bearing molecules at redshift z=0.89 toward the quasar PKS 1830-211

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ALMA 電波望遠鏡を用いた赤方偏移天体方向（準星 PKS 1830-211, z(Δλ/λ)=0.89 周波数は 1/1.89 になる）での HF, CF^+の検出、H_2F^+の探査について報告する。観測により得られた分子の存在量からフッ素化合物の化学過程,存在量比[CF^+]/[HF], [H_2F^+]/[CF^+]について考察した。また本観測では H_2Cl^+のオルソ遷移が観測でき、存在量比[H_2F^+]/[H_2Cl^+]＜1/16 が F と Cl の宇宙存在度比 1/6 から異なっているのは主に生成反応の違いによるとした。

Among fluorine containing molecules, HF is chemically stable and is found to be ubiquitous in interstellar space by Herschel observations. CF^+ was first detected in 2005 and later recognized as a significant molecule in diffuse molecular clouds. However, the ion has not been detected in extragalactic sources. Pure rotational transitions of H_2F^+ were searched in Galactic clouds, but not detected.[1] The present paper reports detections of pure rotational transitions of HF J=1-0, CF^+ J=2-1 and search for H_2F^+ 1_{10}-1_{01} at a red-shifted cloud (z=Δλ/λ=0.89) toward the quasar PKS 1830-211 with the Atacama Large Millimeter/submillimeter Array (ALMA). The transition frequencies of HF (1232 GHz) and H_2F^+ (782 GHz) are not observable from ground based telescopes because of atmospheric absorption. So we observed the highly red-shifted cloud, where the original frequency becomes 1/1.89, and the object has the radial velocity of 0.56 times the speed of light estimated from the relativistic Doppler formula. So far many molecules have been detected in the cloud toward PKS 1830-211, as reported by Muller et al.[2]

ALMA observations were carried out on 2014 Aug. and 2015 May. HF and CF^+ were detected as shown in Figs. 1 and 2. The abundances (column densities) of HF and CF^+ have been determined to be $>3.4 \times 10^{14}$ cm^{-2} and 5.5×10^{12} cm^{-2}, respectively, where the lower limit is given for HF from the saturated line shape. H_2F^+ has not been detected, so we estimated the upper limit abundance of the ion to be $<8.8\text{x}10^{11}$ cm^{-2}.

The ionization energies of F atom and HF are higher than that of H, so these species are not ionized in (diffuse) clouds. The reaction of F and H_2 produces HF, which is subjected to two main decay channels in the cloud, (1) reaction with C^+ to produce CF^+ (2) reaction with H_3^+ to produce H_2F^+. By considering the production and decay (recombination reaction with electron) processes, the abundance ratio of H_2F^+ and CF^+ is given in steady state as follows,

$$\frac{[\mathrm{H_2F^+}]}{[\mathrm{CF^+}]} = \frac{k_f(\mathrm{H_2F^+})k_e(\mathrm{CF^+})[\mathrm{H_3^+}]}{k_f(\mathrm{CF^+})k_e(\mathrm{H_2F^+})[\mathrm{C^+}]} = 1.7\frac{k_e(\mathrm{CF^+})[\mathrm{H_3^+}]}{k_e(\mathrm{H_2F^+})[\mathrm{C^+}]} = 1.6\frac{[\mathrm{H_3^+}]}{[\mathrm{C^+}]}$$

where the k_f and k_e are the formation and the recombination rate constant with electron, and electron density is assumed to be equal to carbon. The H_3^+ ion has not been observed in the present source, so the abundance was estimated by using the cosmic ray ionization rate of $\zeta=2\times10^{-16}$ s^{-1}. Thus H_2F^+ abundance was estimated to be 3.5 % of CF^+, that is, 1.9×10^{11} cm^{-2} which is about 1/4 of the present upper limit.

In the present observation, H_2Cl^+ ortho line was also detected, giving the column density of 9.1×10^{12} cm^{-2} and $[H_2F^+]/[H_2Cl^+]$ = 1/16. Since the cosmic abundance ratio of of F and Cl is 1/6, the observed smaller abundance is thought to be due to difference in the formation mechanisms of two ions. In the case of H_2Cl^+, there are two kinds of formation routes, (i) $Cl^+ + H_2 \rightarrow HCl^+ + H$, $HCl^+ + H_2 \rightarrow H_2Cl^+ + H$, (ii) $HCl + H_3^+ \rightarrow H_2Cl^+ + H$

(i) is due to the fact that ionization energies of Cl and HCl are smaller than that of H. The present result indicates that major formation route for H_2Cl^+ is through HCl^+. In fact the HCl^+ ion has been detected in diffuse clouds.

[1]K. Kawaguchi et al. Mol. Spectrosc. Symposium, 2014, Tokyo, and ApJ in press, 2016
[2]S. Muller et al. A&A, 535, 103 (2011)

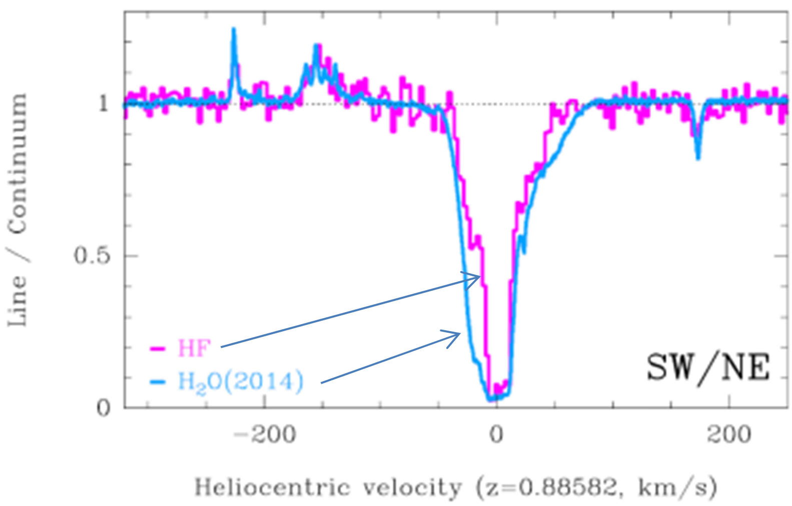

Fig. 1 Observed absorption of HF and H_2O toward PKS 1830-211. The SW image has been divided by that toward the NE image

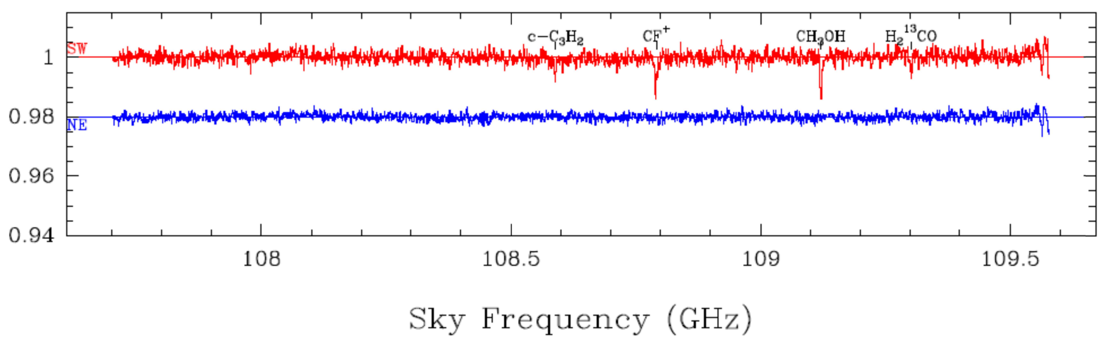

Fig. 2 A part of observed ALMA spectra toward PKS 1830-211 SW (upper) and NE (lower) cloud