32. A Survey of Intergalactic Warm Molecular Gas with PRIMA

Hiroyuki Kaneko (Niigata University, Japan)

Not only within a galaxy, but also in the intergalactic space of nearby galaxy groups and interacting galaxies, there is warm molecular hydrogen gas at temperatures of about 1000 K. The warm molecular gas is thought to be ejected from the galaxies and compressed by galaxy interactions. These results suggest that the warm molecular gas in intergalactic space may be gas ejected from galaxies and compressed by intergalactic interactions. However, there are a few examples of spatially resolved observations of warm molecular gas in intergalactic space. As a result, our understanding of its physical environment, including its mass, temperature, and distribution, is poor. Many questions remain unanswered, such as how it coexists with the high-temperature plasma in intergalactic space and by what mechanism it is heated.

By taking advantage of the wide field and high sensitivity slit spectroscopy of PRIMA /FIRESS Band 1 to image and observe H_2(0-0)S(0) emission lines (rest wavelength: 28.2 μm) in different environments in the local Universe at z<0.15, we will quantitatively understand how warm molecular gas affects galaxy evolution.

Science Justification

Galaxy clusters are known to be filled with high-temperature gas plasma. High-temperature intergalactic gas prevents the selective stripping of HI gas and the accretion of cold gas, thereby suppressing star formation in clusters compared to field galaxies. These differences in galaxy environments are also reflected in the morphology of galaxies, which has long been known to evolve in high-density environments such as clusters and groups, leading to an increase in the number of elliptical galaxies with low gas content in the number of elliptical galaxies with low gas content (Dressler 1980). This suggests that intergalactic gas plays an important role in the evolution of clusters and galaxies.

X-ray observations have shown that the intergalactic high-temperature gas contains oxygen, nitrogen, and iron. This suggests that elements synthesized by supernova explosions in the galaxy have been ejected into intergalactic space. Possible mechanisms for the supply of such gas include outflows from galaxies, AGN jets, and galactic collisions. In fact, cold and hot gas associated with such structures has been observed.

On the other hand, the photoionization regions formed in starbursts, which are also the driving force behind these phenomena, shocks associated with galaxy collisions, or high-temperature environments can excite molecular hydrogen. Although molecular hydrogen is the most abundant molecule in the Universe, it is usually not directly observable at low temperatures due to its lack of a permanent dipole moment. However, in these extreme environments, pure rotational transitions of molecular hydrogen can be observed in the form of thermal or fluorescence emission; using PRIMA/FIRESS, the rotational emission line H_2(0-0)S(0) (28.2 µm, excitation temperature of 510K) can be observed from sources at z=0–0.175.

The first observations of H_2 rotation emission lines for galaxies were detected from NGC 6946 using ISO/SWS (Valentijnet al. 1996). After this, most observations continued to come from single-point observations of galaxies (Ogle et al. 2007; Egami et al. 2006; Ogle et al. 2012), with imaging observations coming from Stephan's Quintet (compact galaxy group: Appleton et al. 2017) and NGC 4258 (Seyfert galaxy: Ogle et al. 2014), Taffy I (colliding galaxies: Peterson et al. 2012), and few others.

These observations show that warm H_2 molecules are indeed present in intergalactic regions, along with outflows, AGN jets, galaxy collisions, and other galactic activity. In addition, these warm H_2 gas coexist with low-temperature molecular gas and star-forming regions. The physics that makes this coexistence possible, and the quantitative study of how much of the gas in galaxies is ejected into intergalactic space, providing high-temperature gas and plasma, are still poorly understood.

We propose to use PRIMA/FIRESS Band 1 to perform spatially resolved spectroscopic imaging of rotationally excited emission lines of warm H_2 molecules, which have been rarely observed in the past, for various environments ranging from galaxy clusters to galaxy groups to explore the spatial distribution of their physical states and their relation to galaxy morphology and star formation. Galaxy activity, such as AGN jets and galaxy collisions, also depends on the galaxy environment. For example, in high-density environments such as compact galaxy groups, the effects of galaxy collisions are expected to be stronger. On the other hand, in a galaxy cluster, the effect of the suppression of star formation activity in the environment due to the stripping away of cold HI gas by ram pressure is stronger than the increase in star formation activity due to frequent galaxy collisions. Understanding whether warm H_2 molecules exist in such different environments, and if so, how they affect their surroundings, is intrinsically important in understanding galaxy evolution.

The amount and distribution of warm H_2 gas in galaxies and intergalactic space, for which only a limited sample exists, can be spatially resolved by observations with PRIMA/FIRESS at realistic times. In combination with JWST/MIRI imaging observations of highly excited warm H_2 emission lines, the heating mechanism (temperature and velocity of shocks) can be identified, although model-dependent, since H_2 emission lines have a very short cooling time and require in situ heating. Further analysis of similar observations in different high-density regions (galaxy clusters and groups) could provide insight into the evolution of warm intergalactic material in intergalactic space and thus into the evolution of galaxies.

Instruments and Modes Used

This proposed observation will be performed by using the FIRESS spectrometer, in the low-resolution mapping mode. The typical size of targets (galaxy groups and clusters at z<0.175) is 5’ x 5’.

Approximate Integration Time

For observing H_2(0-0)S(0) emission (rest wavelength of 28.2 μm), we select low-resolution mapping mode with FIRESS Band 1. Assuming a survey area of 25 arcmin^2 and a mapping sensitivity of 8 x 10^{-19} (W/m^2, 5σ), the required observation time is 28 hours per source based on PRIMA ETC.

Special Capabilities Needed

None

Synergies with Other Facilities

This proposal aims to clarify the heating mechanism of molecular gas in intergalactic space by taking advantage of PRIMA's imaging capabilities to map warm H_2. However, synergies with other facilities can provide a comprehensive understanding of the physics of the multi-phase interstellar/intergalactic medium.

The distribution of warm molecular gas, cold molecular gas, and cold atomic gas will be investigated by HI observations (SKA/ngVLA) and multi-J CO observations (ALMA). We can compare the results with models such as CLOUDY and MAPPING III, as well as other models. It will greatly improve our understanding of shocks and energetics in mergers, galaxy groups, and galaxy clusters.

Description of Observations

We propose low-resolution mapping observations with FIRESS Band 1 of H_2(0-0)S(0) emission lines in intergalactic space from relatively nearby to around z = 0.15, especially for galaxy clusters to galaxy clusters in medium to high density environments. Nearby galaxy clusters typically have a size of 5 arcmin x 5 arcmin. Since the source is spread out, the observational limit is determined solely by the areal luminosity sensitivity: according to Appleton et al. (2017), the H_2(0-0)S(0) emission line intensity at Stephan's Quintet is >8 x 10^{-19} (W/m^2) per 7.4” x 7.4”. Assuming a survey area of 25 arcmin^2 and a mapping sensitivity of 8 x 10^{-19} (W/m^2, 5σ), the required observation time is 28 hours per source. For example, if we set the total observing time limit to 1000 hours, 35 galaxy groups can be observed with this setting, which can be discussed in terms of the statistical features of warm H_2 gas in galaxy groups.

References

Dressler, A. 1980, ApJ, 236, 351

Valentijn, E. , van der Werf, P., de Graauw, T. & de Jong, T. 1996, A&A, 315, 145

Ogle, P., Antonucci, R., Appleton, P., Whysong, D. 2007, ApJ, 668, 699

Egami, E., Rieke, G., Fadda, D., Hines, D. 2006, ApJ, 652, 21

Ogle, P., Davies, J., Appleton, P., Bertincourt, B., et al. 2012, ApJ, 751, 13

Appleton P., Guillard, P., Togi, A., et al. 2017, ApJ, 836, 76

Ogle, P., Lanz, L., Appleton, P. 2014, ApJ, 788, 33

Peterson, B., Appleton, P., Helou, G., et al. 2012, ApJ, 751, 11