[Fe II]-Bright Supernova Remnants in Our Galaxy and Nearby Galaxies

Ho-Gyu Lee,[1] Takashi Onaka,[1] Bon-Chul Koo,[2] and Jae-Joon Lee[3]

[1] *Department of Astronomy, The University of Tokyo, Japan*
[2] *Astronomy Program, Seoul National University, Korea*
[3] *Korea Astronomy and Space Science Institute (KASI), Korea*

ABSTRACT

We have performed extensive near-infrared [Fe II] line observations of supernova remnants (SNRs) in our Galaxy and nearby galaxies using various instruments and telescopes. Here, we introduce our recent results from our unbiased [Fe II] imaging survey of the Galactic plane, near-infrared high-resolution imaging and spectroscopy of SNRs, and [Fe II] imaging observations of nearby galaxies. The corresponding strong line and continuum emissions at mid-infrared wavelength can be explored by sensitive instruments on *SPICA*.

1. INTRODUCTION

Massive stars evolve fast. Thus, these relatively young stars are mainly distributed close to the Galactic plane, where most of high-mass star-forming clouds are located, and there they end their lives. As a result, the remains of stars, supernova remnants (SNRs), are frequently seen toward cloudy regions of the Milky way. This gives difficulties in observational studies of SNRs, because they often suffer strong extinction and confusion effects. A good method is to make observations in infrared wavelength, where extinction is less severe than optical and confusion can be suppressed due to advent of new imaging and spectroscopic instruments. Especially, infrared [Fe II] line emission is useful to trace shock-heated gas of SNR. Enhanced iron released either from destruction of dust grains, containing highly depleted elements, in shocked layer or from metal-rich ejecta of the progenitor star can be an origin of the emission. In addition, well-developed partially ionized zone behind the shock front can supply sufficient amount of iron in the singly excited state. In the near-infrared wavelength, model calculations of fast radiative shocks expect strong [Fe II] 1.26 and 1.64 μm lines (e.g. Hollenbach & McKee 1989; Koo 2013).

The strong [Fe II] emissions were detected at several SNRs using circular variable filter (CVF) after the development of astronomical infrared detectors. Low-resolution near-infrared spectra using coarse resolution apertures were obtained at MSH 15–52 (Seward et al. 1983), IC 443 (Graham et al. 1987), Kepler, RCW 103, and three SNRs (N 63A, N 49, and N 103B) in Large Magellanic Cloud (LMC) (Oliva et al. 1989), and Crab (Graham et al. 1990). Later, more sensitive spectroscopic observations were done for two very bright historical SNRs Cas A and Kepler (Gerardy & Fesen 2001). There are recent near-infrared observations using modern instruments, including our works. Some examples are 3C 391 (Reach et al. 2002), W 28, and W 44 (Reach et al. 2005), W 49B (Keohane et al. 2007), G11.2–0.3 (Koo et al. 2007; Moon et al. 2009; Lee et al. 2013a), 3C 396 (Lee et al. 2009), and IC 443 (Kokusho et al. 2013). Here, we introduce our near-infrared [Fe II] observations of SNRs in our Galaxy and nearby galaxies.

2. [FE II]-BRIGHT SNRS IN OUR GALAXY

For the last two years, we have performed an unbiased Galactic plane imaging survey, covering $10° \lesssim l \lesssim 60°$ and $|b| \lesssim 1°$, using [Fe II] 1.64 μm narrow band filter on the UKIRT telescope (Koo 2013). In the survey images, there are several interesting objects such as young stellar objects, H II regions, evolved stars, planetary nebulae, and SNRs. SNRs are one of the most remarkable objects in the [Fe II] 1.64 μm line images, due to their relatively large sizes and brightnesses. Numbers of SNRs, including known [Fe II]-emitting SNRs, are identified in the survey area (Lee et al. 2013b). In general, SNRs which have high mean-surface-brightnesses are bright at the [Fe II] 1.64 μm line images, when we define the mean-surface-brightness as the 1 GHz flux divided by its square size in the Green's catalog (Green 2009). It suggests that [Fe II] line emission can be a tracer for SNRs in the complicated interstellar medium. Many of them are SNRs detected by the mid-infrared search of SNRs within the *Spitzer* IRAC Galactic plane survey field (Lee 2005; Reach et al. 2006). Therefore, near-infrared and mid-infrared observations of SNRs are tightly correlated each other, mostly due to strong radiatively lines at those wavelengths (e.g. Koo 2013). The similar region of the Galactic plane is surveyed by near-infrared H_2 2.12 μm line (Froebrich et al. 2011). In many cases, [Fe II]-emitting SNR shows H_2 line emission as well. In our previous study of 3C 396, we found interesting morphological characteristics of the near-infrared [Fe II] 1.64 μm and H_2 μm line images (Lee et al. 2009). The less-dense, atomic [Fe II] region is located inside the recombined molecular region, indicating that the distributions cannot be interpreted by a single shock. Instead, the observed morphological characteristics may be due to the pre-supernova structures generated by the mass-loss of the progenitor and related surrounding molecular cloud. On the other hand, we have observed a handful of [Fe II]-emitting SNRs on the southern hemisphere using the AAT telescope. Figure 1 shows two bright SNRs on the northern and southern hemispheres. The young core-collapse SNR G11.2–0.3

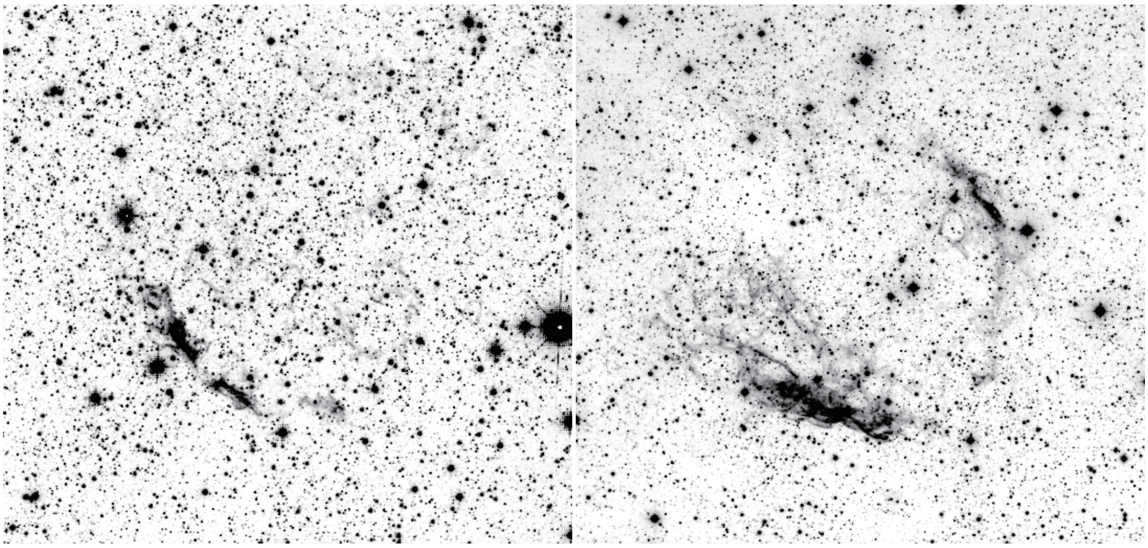

Figure 1. Near-infrared [Fe II] 1.64 μm narrow band images of two bright core-collapse SNRs. *Left:* G11.2–0.3 on the northern hemisphere taken by UKIRT telescope. *Right:* RCW 103 on the southern hemisphere taken by AAT telescope.

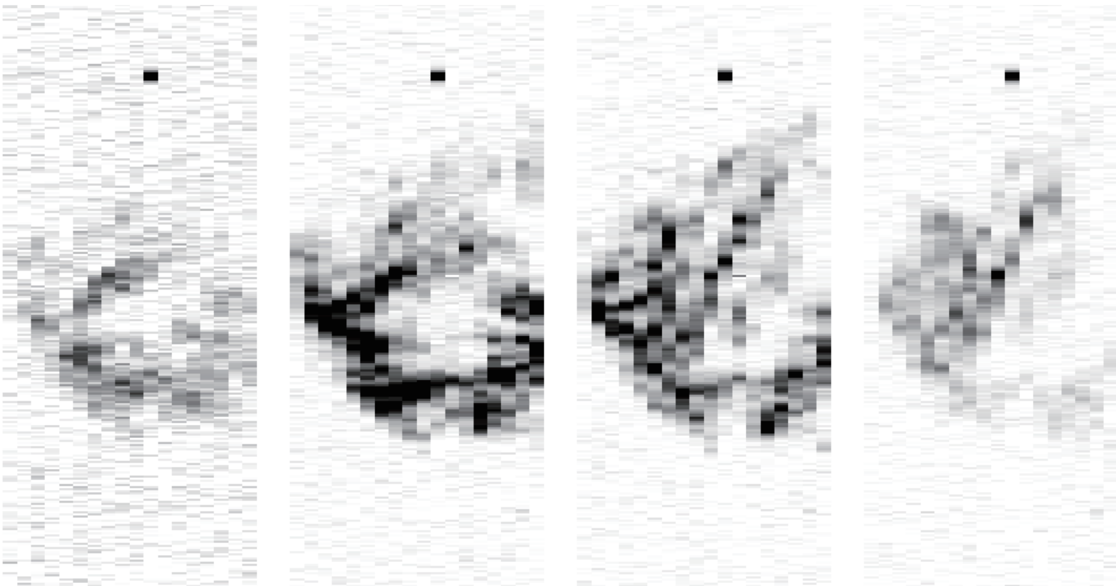

Figure 2. Near-infrared [Fe II] 1.64 μm line velocity channel maps of N 49 in LMC. The channel velocities cover $\sim$ 100–500 km s^{-1}. The bright infrared star on the north has the H-band magnitude of 10.6.

is one of the brightest [Fe II]-emitting SNRs in our Galaxy (Koo et al. 2007; Moon et al. 2009; Lee et al. 2013a). The bright [Fe II] emission originates mainly from the swept-up circumstellar material heated by shocks. Besides, there are faint [Fe II] emission from the fast-moving knots of the dense iron ejecta. The other young core-collapse SNR RCW 103 on the southern hemisphere has comparable brightness to G11.2–0.3. The two bright [Fe II] filaments distribute opposite (NW-SE) direction. Presently, we are working on near-infrared spectra toward positions of [Fe II] filaments to understand the origin and dynamics of the [Fe II]-emitting dense gas in RCW 103.

3. [FE II]-BRIGHT SNRS IN NEARBY GALAXIES

We have performed near-infrared imaging and spectroscopic observations of SNRs in the nearest galaxy LMC using the AAT telescope. For two bright SNRs (N 49 and N 63A), we made spectral mapping observations. The [Fe II] line luminosity of N 49 is much higher than those of Galactic SNRs. Figure 2 shows velocity channel maps of N 49 constructed from the [Fe II] 1.64 μm line spectra. Some bright structures are resolved over the velocity range of $\sim$ 100–500 km s^{-1}, although the observed sensitivity and spectral resolution is not enough to see faint, detailed structures. The different morphologies at different channel maps indicate that the surroundings of N 49 are not simple. Whether such surroundings can make the strong [Fe II] emission is uncertain. Very recently, we have carried out near-infrared [Fe II] 1.64 μm narrow band imaging observations of nearby galaxies: M 31, M 33, M 51, M 74, M 83, M 101, NGC 247, NGC 4214, and NGC 4449 using the UKIRT telescope. The [Fe II] imaging observations successfully distinguish bright SNRs from H II regions and stellar components. For example, the [Fe II]-bright SNR G98-28 in M 33 is clearly isolated from the nearby giant H II region and other ionized gas clouds, which is unclear in Hα images. Moreover, the SNR also shows bright mid-infrared emission in the *Spitzer* IRAC and MIPS images. Because it is hard to explain bright emission over the broad infrared bands by pure line emission only, more sensitive high-resolution imaging and spectroscopic observations are necessary to understand the origin of the infrared emission detected at this [Fe II]-bright SNR in the nearby galaxy M 33.

4. *SPICA* OBSERVATIONS

We are working on infrared studies of SNRs in our Galaxy and nearby galaxies using various methods presently available. In addition to individual study of well-known SNRs, there will be large area surveys of our Galaxy and nearby galaxies using *SPICA*. We expect that SNRs can easily be identified in such surveys. Our efforts are essential to prepare studies of supernova explosion, evolution of SNR, dust formation in ejecta, SNR interaction with environment, and SNR shock physics using infrared instruments on *SPICA*.

This work is supported by a Grant-in-Aid for Japan Society of Promotion of Science (JSPS) fellows (No. 23·01322) and K-GMT Science Program Galaxy Ecology and Massive Stars at z=0 (GEMS0).

REFERENCES

Froebrich, D., Davis, C. J., Ioannidis, G., et al. 2011, MNRAS, 413, 480
Gerardy, C. L., & Fesen, R. A. 2001, AJ, 121, 2781
Graham, J. R., Wright, G. S., & Longmore, A. J. 1987, ApJ, 313, 847
— 1990, ApJ, 352, 172
Green, D. A. 2009, Bulletin of the Astronomical Society of India, 37, 45
Hollenbach, D., & McKee, C. F. 1989, ApJ, 342, 306
Keohane, J. W., Reach, W. T., Rho, J., & Jarrett, T. H. 2007, ApJ, 654, 938
Kokusho, T., Nagayama, T., Kaneda, H., et al. 2013, ApJ, 768, L8
Koo, B.-C. 2013, in Supernova environmental impacts, edited by A. Ray (Cambridge: Cambridge University Press), vol. 296 of IAU Symp., 8
Koo, B.-C., Moon, D.-S., Lee, H.-G., et al. 2007, ApJ, 657, 308
Lee, H.-G. 2005, JKAS, 38, 385
Lee, H.-G., Moon, D.-S., Koo, B.-C., et al. 2009, ApJ, 691, 1042
— 2013, ApJ, 770, 143
Lee, Y.-H., Koo, B.-C., & Lee, J.-J. 2013, in Supernova environmental impacts, edited by A. Ray (Cambridge: Cambridge University Press), vol. 296 of IAU Symp., 2
Moon, D.-S., Koo, B.-C., Lee, H.-G., et al. 2009, ApJ, 703, L81
Oliva, E., Moorwood, A. F. M., & Danziger, I. J. 1989, A&A, 214, 307
Reach, W. T., Rho, J., & Jarrett, T. H. 2005, ApJ, 618, 297
Reach, W. T., Rho, J., Jarrett, T. H., & Lagage, P. O. 2002, ApJ, 564, 302
Reach, W. T., Rho, J., Tappe, A., et al. 2006, AJ, 131, 1479
Seward, F. D., Harnden, F. R. J., Murdin, P., & Clark, D. H. 1983, ApJ, 267, 698