Near-infrared [PII] and [Fe II] Emission-line Study of Supernova Remnants in the Magellanic Clouds

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Abstract

We report findings from near-infrared imaging observations of 17 young and middle-aged supernova remnants (SNRs) in the Magellanic Clouds to examine the impact of SNR shocks on dust destruction and the possible detection of supernova ejecta. We have analyzed [P II] (1.189 μm) and [Fe II] (1.257 and 1.644 μm) narrowband images obtained with the InfraRed Survey Facility 1.4 m telescope at the South African Astronomical Observatory. We calculate the P/Fe abundance ratio, X(P/Fe), using the [P II]/[Fe II] line ratio, which provides valuable information on dust content and/or processing in the interstellar medium (ISM) because P is not depleted while Fe is a refractory species. Only 6 of 17 SNRs show emission features in both [P II] and [Fe II]. Among these, N49, N63A, and N206 exhibit X(P/Fe) ratios between 1.2 and 3.0 $X_\odot$(P/Fe), which are many times smaller than the general ISM ratio (e.g., Orion Bar ~15 $X_\odot$(P/Fe)), suggesting significant destruction of dust grains by the shocks. In contrast, the remnants of SN 1987A, N157B, N158A, and the clump studied in N206 have P/Fe abundance ratios that are comparable to or higher than the general ISM. For SN 1987A, the high X(P/Fe) ratio may result from the lack of Fe in the gas phase, although the flux densities fluctuate constantly due to shocks. For N157B, N158A, and the clump in N206, many interpretations are being explored, including Fe atoms bound primarily to dust grains, material from supernova ejecta, and photoionization from nearby H II regions.

1 Introduction

Supernova(SN):

Involved in dust formation/destruction through generating shock waves, heat, accelerate the gas etc.

⇒Play an important role in the physical/chemical evolution of the ISM

Deriving the destruction efficiency for each Supernova remnant (SNR) is important

Approaches to investigate the influence on dust destruction by shock waves:

① Derive the abundances of refractory elements in shocked gas and compare them to those of the general ISM

② Derive the dust-to-gas ratio of shocked gas and compare it to that of the general ISM

This study: Adopt ① approach to derive destruction efficiency of SNR in Large Magellanic Cloud(LMC) and Small Magellanic Cloud(SMC) with **P/Fe abundance ratio measured by [PII] and [FeII]1.257μm** emission line

Advantages of P/Fe:

- Good indications of dust content and/or dust processing
- Possible to be used to study SN ejecta and their interaction

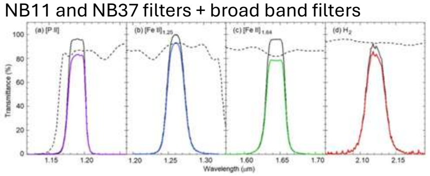
2.Observation & data reduction

2.1 Observation

Execute Near-IR imaging observation for 17 SNR in LMC/SMC with SIRIUS/SAAO(South Africa)

①Broad band image with J, H, Ks band filters

②Narrow band image for [PII], [FeII]1.257, 1.64μm and H_2 lines with NB11 and NB37 filters + broad band filters



Transmittance of narrow band image(solid: narrow band only, dotted: broad band only)

2.2 Flux measurement

① Execute PSF photometry to subtract radiation from bright stars

② Derive total flux from the radiation field of SNR

③ Correct extinction with Av measured by X-ray studies

④ Subtract the contribution of continuum emission

1. Estimate the strength of non-thermal synchrotron radiation with radio observation data(1GHz)
2. Measure the continuum with NIR continuum filters (more reliable than 1.)

(We can determine only upper limit of [PII]/[FeII] with ④-1.)

2.3 SNR with [FeII] and/or [PII] emission features

Search [PII] or [FeII] 1.64μm associated with SNR

1. Look for a structure like a shell and a filament on narrow band image
2. Judge the detection by comparing the narrow band image with other multiwavelength observation

⇒Both [PII] and [FeII] are detected in 8 SNRs (LMC), 0(SMC)

2 SNRs have emission features well beyond the SNR

⇒Excluded from the samples(association is not likely)

2.4 P/Fe abundance ratio from the [PII]/[FeII] ratio

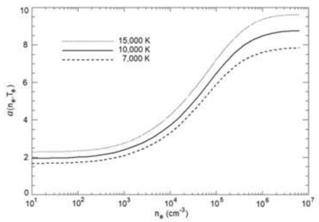
Derive P/Fe abundance ratio with [PII]/[FeII]1.64μm

$$\frac{F_{[PII]1.188}}{F_{[FeII]1.257}} = 2.87\,\frac{f_{^1D_2,PII}}{f_{a^4D_{7/2},FeII}}\,\frac{f_{PII}}{f_{FeII}}\,X(P/Fe)$$

Flux ratio; Ratio of Einstein A coefficients and the wavelength; Level-population ratio; Fractional ionization of each element; Abundance ratio

- $a(n_e, T_e) = 2.87\,\frac{f_{^1D_2,PII}}{f_{a^4D_{7/2},FeII}}$
- $\frac{f_{PII}}{f_{FeII}}$~1**([PII] and [FeII] are emitted from the same region)**

$$\frac{F_{[PII]1.188}}{F_{[FeII]1.257}} = a(n_e, T_e)X(P/Fe)$$



Value of $a(n_e, T_e)$

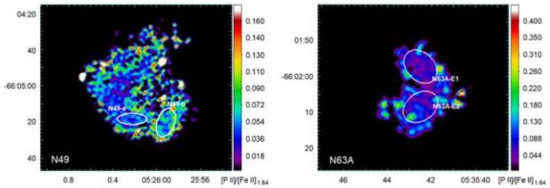
- [FeII]1.257μm intensity: derived with theoretical ratio [FeII] 1.257/1.64μm = 1.36
- Electron density: derived from [SII]6716Å/6731Å
- Electron temperature: assume 10000K(α is nearly independent of T_e)

Derive abundance ratio of the entire SNRs and unique region (show higher/lower [PII]/[FeII] than the other)

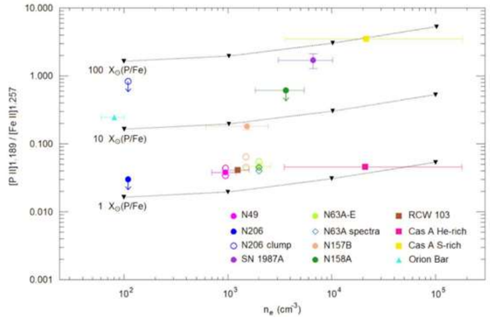
3 Result & Discussion

3.1 SNR with small P/Fe

3 SNRs(N49, N63A, N206(upper limit)) shows low X(P/Fe) close to cosmic abundance



[PII]/[FeII] line ratio of N49(left) and N63A(right)



n_e-[PII]/[FeII] relation in samples, SNRs in MW and theoretical line ratio(black)

Estimate destruction efficiency (Orion Bar=typical ISM):

N49: 53±14%, N63A: 46±13%

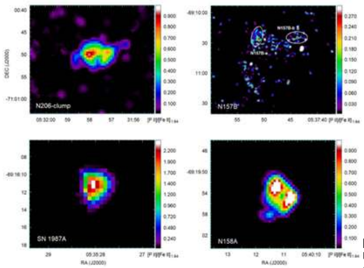
Theoretical destruction efficiency for graphite/silicate grains (use measured shock velocity and preshock density):

N49: more than 50%, N63A: 9~25%

Destruction efficiency should vary with density of ISM, strength of magnetic field(by 30-50%) and model description (we assume the uniform temperature and density, but the ISM has significant substructure in reality).

We should improve modelling of ISM

3.2 SNR with large P/Fe



[PII]/[FeII] line ratio of N206(upper left), N157B(upper right), SN 1987A(lower left), N158A(lower right)

Discuss the scenarios to explain large P/Fe

①SN 1987A

- Matsuura et al.(2011) described a large dust mass in the center of the SNR
- SN ejecta and circumstellar equatorial ring emit both [PII] and [FeII]
- Since the ejecta is O rich, Fe might be partially locked by Fe_3O_4(Kozasa et al.1989)
- **The grains were formed from material ejected from the SN, and have not beem affected by shocks**

②N206-Clump

- Shows higher P/Fe than the other region
- [PII]/[FeII] vary widely
- Dust grains in the clump might have been partially destroyed by slow shock, but other scenarios are considerable

③N157B

- Only in small regions(N157B-a, b) show high P/Fe
- N157B-a and b show similar P/Fe
- N157B is currently interacting with a molecular cloud
- The environmental scenario seems very complex

④N158A

- O-rich ejecta and Pulsar wind nebula are found
- Only in the small nebula at the center of SNR emits [PII] and [FeII], and the peak of them are slightly offset from the center
- [PII] and [FeII] show different morphology from that by [OIII, [SII] and [ArIII](reflect origins in different nuclear burning zone?)
- There are 2 regions(high ISM density & slow shock, low ISM density & fast shock) in N158A
- We can explain high P/Fe with partially destroying by only slow shock

5 Summary

1. We detect both [PII] and [FeII]1.64μm from 6 SNRs in LMC
2. Derive [PII] and [FeII] flux with narrow band imaging and calculate P/Fe abundance ratio
3. There are two types of SNRs, with ①low P/Fe, ②high P/Fe.
4. We calculated destruction efficiency in SNRs with low P/Fe. That of N49 is matched with theoretical prediction, but N63A is mismatched(we should improve model description of dust destruction)
5. We discuss the scenarios for SNRs with high P/Fe, but most of them are hard to find out a reliable scenario (we proposed some hypothesis, like ①Fe still trapped in dust grains,② in situ production of P in SN ejecta, or ③ contamination from nearby H II regions).

We'll continue the discussion of these LMC SNRs using optical spectroscopic observations, in 2nd paper