A New X-ray Σ–D Relation for SNR with Thermal Emission

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Abstract

Supernovae (SN) are the events that supply a huge amount of energy and heavy metal into the Galactic space. There are two types of SN: a type I and a type II. The amount of energy and heavy metal depends on the progenitor star mass. After the explosion, the SN leaves as supernova remnants (SNR). If the SN explosion leaves a compact source in its center, the compact source can be an energy source that affects the evolution of the ejecta like the Crab nebula. If there is nothing left in its center or a compact source does not become an energy source, the evolution of the SNR is divided into four phases and well studied.

The first is a free expansion phase where the ejecta expand into the interstellar medium without deceleration. When the swept-up matter exceeds the ejecta, the SNR enters into the Sedov phase. In this phase, the matter is compressed in the shell region where it shows high density and low temperature. The interior is occupied by a low density and high temperature plasma. The pressure at the center is about 0.3 times that of the shock front. Due to the relatively high density at the shock front, a radiation loss becomes important. Then it enters into the radiative phase in which the radiation loss becomes important only at the shock front region due to the relatively high density. The interior region still stays high temperature with low density. Finally the SNR becomes a resolving phase where the expansion velocity is comparable to the proper motion of the interstellar cloud. Even in this phase, a high temperature cavity is still left behind.

Both in the Sedov phase and in the radiative phase, the SNRs are enclosed by the shock front. If the SN explosion is occurred in the homogeneous medium, the shock front will be the highest density resulting a shell structure. The radio emission is mainly generated from the shell region, which makes a radio structure of the SNR to be a shell like structure. On the contrary, the X-ray structure does not always show a shell structure. If the SNR shows a shell structure in X-ray, the shock front contains high-density plasma leaving weak emission in its center. Therefore, the plasma filling factor becomes 0.25. There are two explanations for the center-filled structure in X-ray: a cloud evaporation model and a radiative shock model.

We analyzed the archival data for ROSAT and ASCA. Since we focused on the SNR showing thermal emission, we selected the SNRs imposing the below criteria: 1) the spectrum is well represented by a thin thermal emission, 2) the extent of the X-ray emission is measured, 3) the extent of the radio emission is measured. In many cases, the X-ray emitting volume is less than the volume enclosed by the radio shell. We assume that the interior of the SNR cavity does not lose energy through radiation nor conduction due to the low density. If there is no energy loss inside the SNR, the pressure is relatively uniform much better than other parameters: density, temperature. We measured the pressure in the X-ray emitting volume that is hardly affected whether or not the radiation loss becomes effective at the shell region. Using the volume enclosed by the radio shell, we calculate the thermal energy contained in the SNR when there is no radiation loss. We find that the thermal energy calculated in this way shows similar values for various SNRs: from young SNR to old SNR. We also show that we can estimate the distance to the SNR from the combination of the thermal energy of the X-ray emitting plasma and the volume enclosed by the radio shell.

CATEGORY: SUPERNOVAE, SUPERNOVA REMNANTS AND ISOLATED NEUTRON STARS