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Elemental Abundances in Supernova Remnant W49B as Clues to Its Progenitor

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ABSTRACT

We apply the Smoothed Particle Inference (SPI) technique to analyze the X-ray emission from SNR W49B. In X-rays, it is visible as a centrally-filled SNR, and was recently recognized as one of the first remnants to have plasma that is overionized. Using SPI we infer the density structure and derive the mass of individual elements in the plasma over the entire remnant. We have compared the abundances inferred with SPI to those obtained from a wide range of supernova explosion models, including both Type Ia and core-collapse, as well as energetic and off-center variants. Type Ia models that incorporate some form of detonation are found to be the most compatible, while pure deflagration models, and all core-collapse models, are found to be incompatible.

Keywords: X-rays: individual (W49B) — supernovae: individual (W49B) — nuclear reactions, nucleosynthesis, abundances — ISM: supernova remnants — X-rays: ISM — circumstellar matter

1. INTRODUCTION

After first being identified as a supernova remnant (SNR) in radio (Mezger et al. 1967), W49B has been observed over the entire wavelength range. In X-rays, W49B is a centrally-filled SNR with enhancements along the central-bar, as well as the eastern and western edges. Using *ASCA*, Hwang et al. (2000) characterized the emitting plasma and suggested that the remnant had a Type Ia progenitor, due to the relative abundances. Analysis of *XMM-Newton* and *Chandra* data led Lopez et al. (2009) to propose that the morphology and abundances of W49B were suggestive of a bi-polar core-collapse progenitor. More recently, Zhou & Vink (2018) concluded that the abundance pattern was more compatible with a Type Ia origin.

Here we report on our application of the Smoothed Particle Inference (SPI) technique to *XMM-Newton* observations of W49B. SPI models the plasma as a collection of independent smoothed particles, or blobs, of plasma (Peterson et al. 2007). Each blob has its own spectral and spatial model, and both position and size are treated as free-parameters. This allows SPI to model the entire remnant and offers considerable flexibility in the analysis process. Details of the SPI process, combined with a first demonstration of its unique capabilities are provided in two earlier papers, where it was used to study the morphology, structure and abundance distribution of the SNR DEM L71 (Frank et al. 2019; Siegel et al. 2020). We have applied SPI to the XMM EPIC observation 0724270101 of W49B from April 2014. For each blob, we use the `vmekal` model of a thermal plasma in collisional ionisation, coupled with the `phabs` absorption model, to fit the SNR emission. The X-ray background emission is modelled with several component.

Our aim is to thoroughly investigate the abundances and compare them to a wide range of SN explosion models available in the literature, in order to gain clues to the progenitor of W49B.

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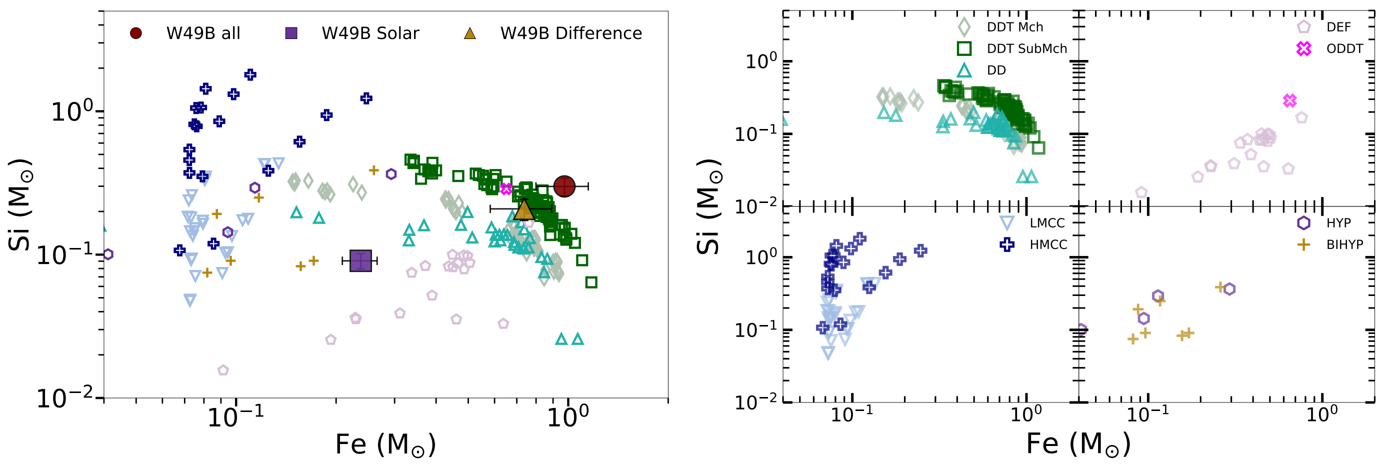

Figure 1. *Left Panel*: The overall mass of Si and Fe derived using SPI abundances (red circle) and solar abundances (purple square), as well as the difference between the two (gold triangle) in comparison to the yields of SN explosion models. The models are broken into 9 families, and each family is displayed in a different shape and color. *Right Panel*: The Si and Fe yields for each model family. For ease of comparison, the model families are displayed in the same shape and color as the left panel.

2. RESULTS

Following the procedure outlined in Siegel et al. (2020), we calculate the density and mass of each blob with two different approaches.

In the first case, we assume that all the material has a solar composition. This allows us to estimate the density of the gas under the scenario where it is solely composed of swept-up local Galactic material. In the second approach, the abundance of each element is taken from the SPI fit. In both cases, the total mass is found by summing over all the blobs and the mass of each individual species is inferred by using the composition of the material to find the element's mass fraction

If we assume the only source of extra-solar values to be the SN ejecta, then the difference between the two values is approximately the mass ejected in the SN explosion.

We next use these estimates to investigate the progenitor of W49B by comparing the inferred abundances with a wide selection of SN models. Since prior studies have suggested Type Ia, core-collapse, and hypernova progenitors, we consider a large model suite that includes all of these mechanisms. In order to facilitate comparison, we have divided the models into 9 families:

- DDT M_{CH}: Chandrasekhar-mass Deflagration-to-Detonation Transition (Bravo et al. 2019)
- DDT SubM_{CH}: Sub-Chandrasekhar Mass DDT (Bravo et al. 2019)
- DD: Double-Detonation (Leung & Nomoto 2020)
- DEF: Pure-Deflagration (Maeda et al. 2010; Fink et al. 2014; Leung & Nomoto 2018)
- ODDT: Off-Center DDT (Maeda et al. 2010)
- LMCC: Low-Mass ($\lesssim 40 M_\odot$) Core-Collapse (Wanajo et al. 2009; Sukhbold et al. 2016)
- HMCC: High-Mass ($\gtrsim 40 M_\odot$) Core-Collapse (Sukhbold et al. 2016; Limongi & Chieffi 2018)
- HYP: Hypernova (Nomoto et al. 2006)
- BIHYP: Bi-Polar Hypernova (Maeda & Nomoto 2003)

In Figure 1, we present the Si and Fe masses inferred using SPI measured abundances, solar abundances, and the difference between the two, as well as the predicted yields from each SN model. We find a clear stratification between the Type Ia and core-collapse models with respect to Fe, and an additional stratification between the LMCC and HMCC models with respect to Si. Of the Type Ia models, we note that the families that incorporate some form of detonation all show considerable overlap, while the DEF family shows lower Si and Fe values. As seen in Figure 1, we find that none of the core-collapse models can match the inferred Fe abundance, while all the Type Ia models, excluding the pure-deflagration family, provide the best match with the inferred masses.

Our results therefore lean towards a Type Ia origin for W49B. It is difficult to provide a definite conclusion since some morphological characteristics of W49B are susceptible to multiple interpretations. Finally we note that these results are preliminary, and our investigation of W49B's morphology and abundances is ongoing.

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Facilities: XMM(EPIC)

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