NuSTAR Upper Limits of ^{44}Ti Decay Emission in Four Nearby Thermonuclear Supernova Remnants

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^{44}Ti in Supernovae

Now it is generally accepted that no single progenitor system or explosion mechanism could account for the whole **thermonuclear supernova family**.

Unlike the element abundances revealed by thermal X-ray spectra, which are dependent on the accurate diagnostics of various plasma parameters, the **decay radiation** of **^{44}Ti** provides straightforward insights into its abundance and the corresponding **nucleosynthesis**. ^{44}Ti is mainly produced by two channels: explosive silicon burning and explosive He burning. We classified the models based on their ^{44}Ti production.

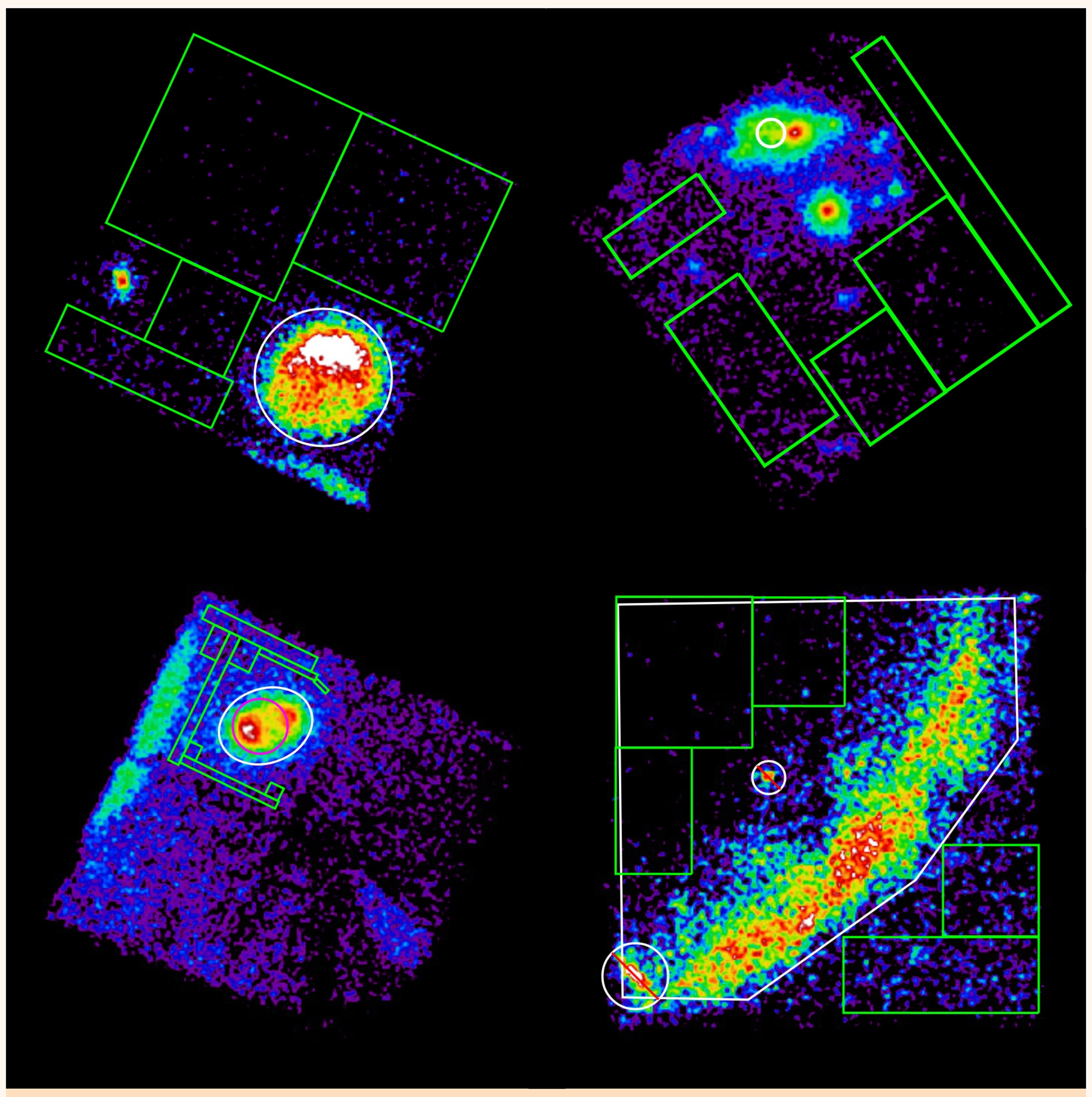
Model	Subgroup
Ca-rich transient	WD thick He shell detonation HeCO WD-CO WD merger
HeCO WD explosion	violent merger double detonation
CO/ONe WD explosion	near-M_{Ch} PD/DDT/GCD sub-M_{Ch} detonation/violent merger Iax

The supernova models used to compare with the derived ^{44}Ti mass limits of the targets.

To identify progenitors and investigate evidence of He burning, we searched for ^{44}Ti decay lines in four young nearby thermonuclear supernova remnants: **Kepler**, **SN 1885**, **G1.9+0.3** and **SN 1006**.

Fit the Decay Lines

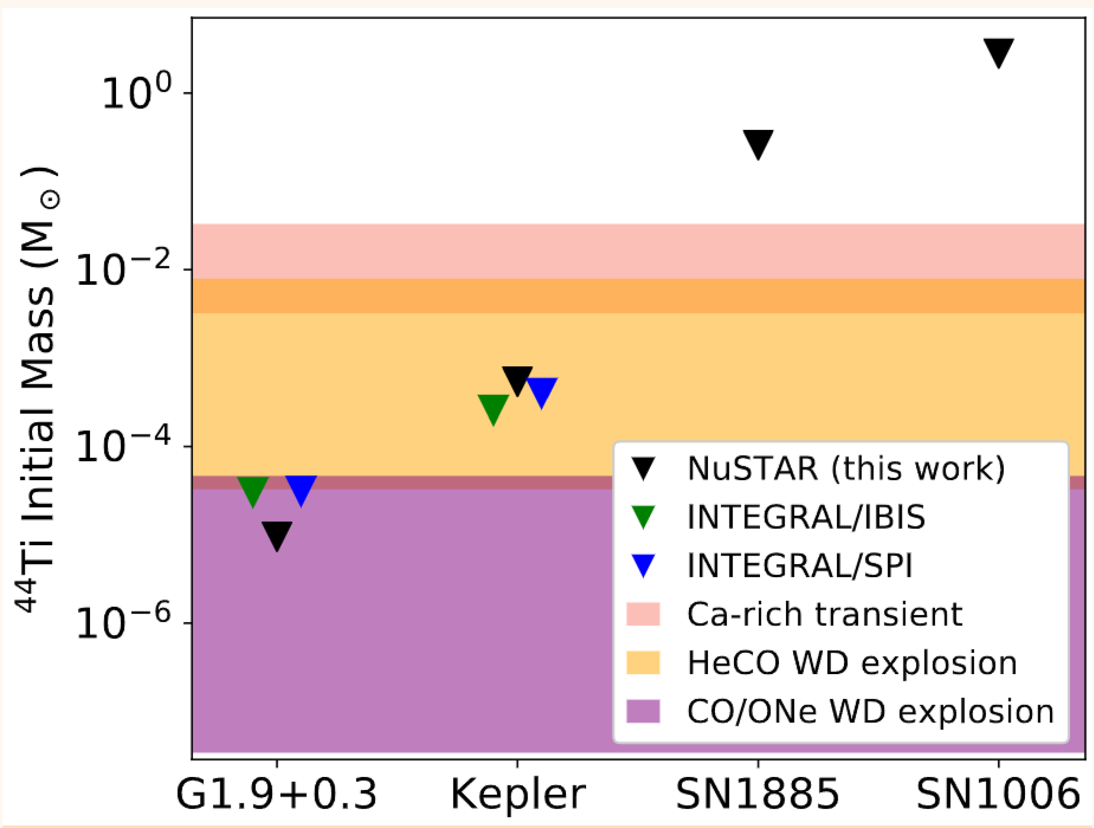
We analysed the up-to-date **NuSTAR** archival data and fitted the spectra with a power law model plus two velocity-shifted Gaussian lines (the centroids fixed at **67.87** and **78.32 keV**), which describes the underlying source continuum and the ^{44}Ti decay lines. Another heavily absorbed power law model with custom-built response was added for the intervening absorbed stray light.



An example of images (3 – 20 keV NuSTAR/FPMB) of the remnants (Kepler, SN 1885, G1.9+0.3 and SN 1006, from left to right, from up to bottom) and the extraction regions of source (white) and background (green).

No ^{44}Ti Detection

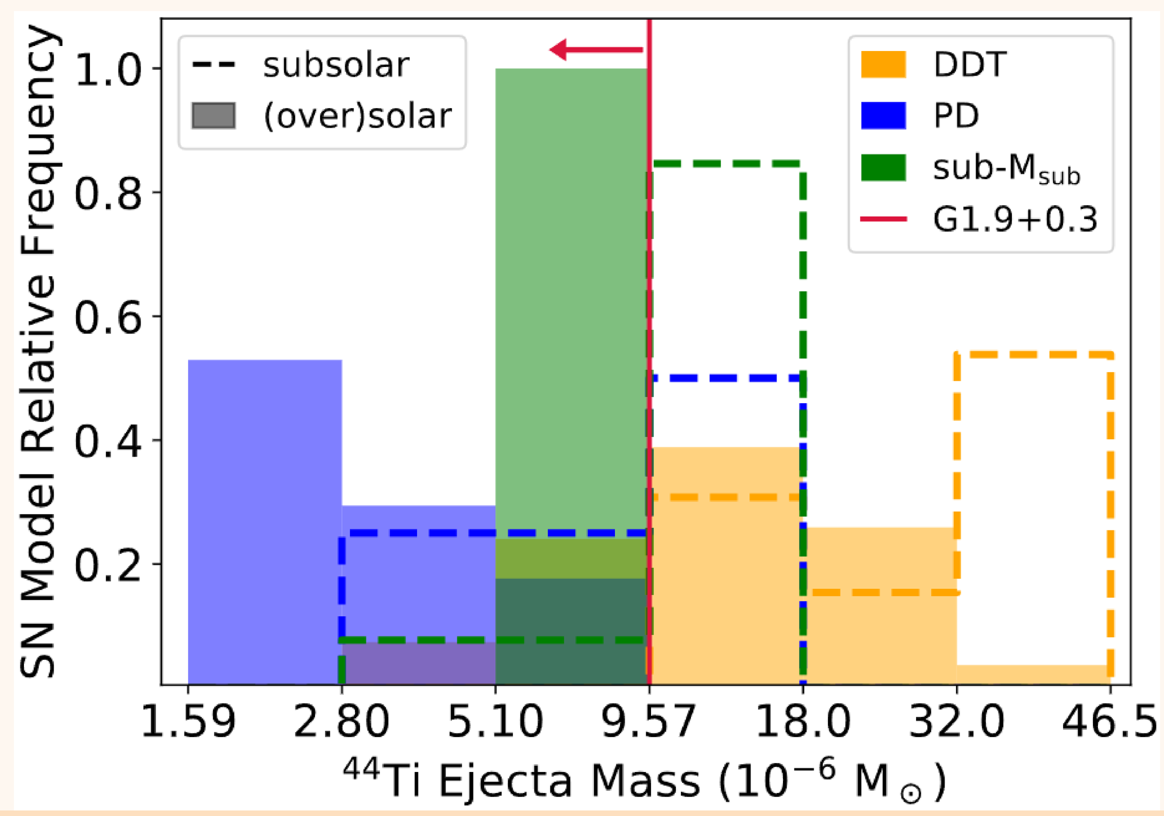
We did not detect well-defined ^{44}Ti lines. The translated mass upper limits from flux limits were compared with nucleosynthesis models. A **Ca-rich transient** origin cannot be excluded for **SN 1885** and current limits cannot provide physical constraints for SN 1006 due to its extent and old age.



The 2σ upper limits of ^{44}Ti initial mass of the remnants compared with theoretical supernova model yields. Previous results from other instruments are also depicted.

G1.9+0.3

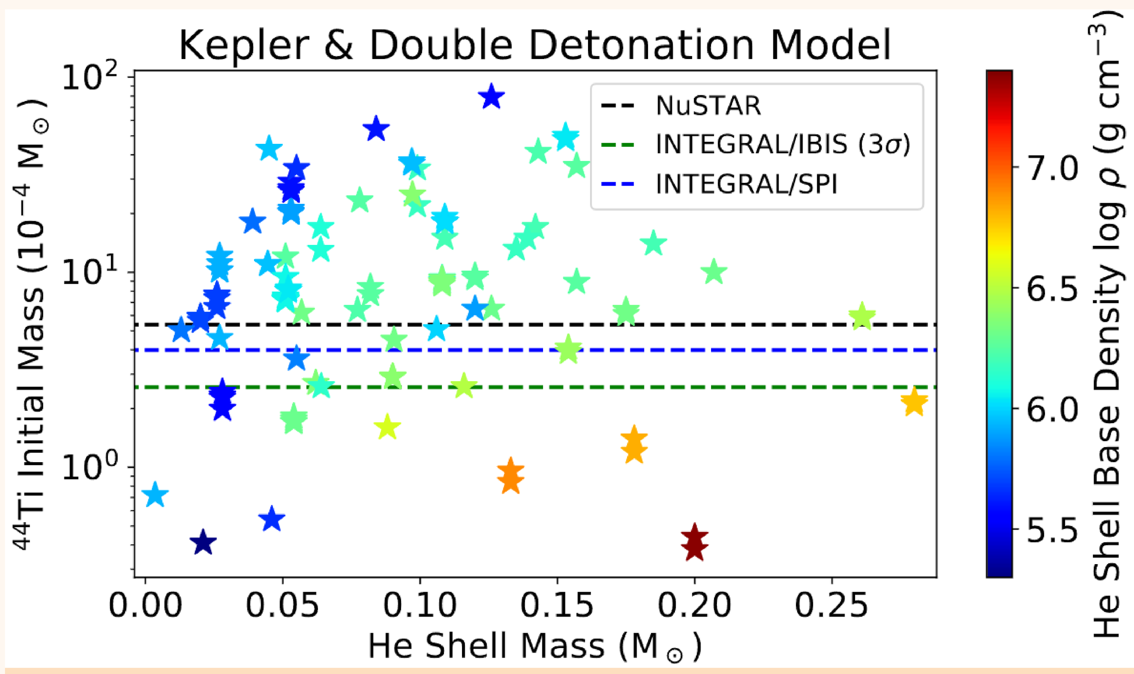
All pure deflagration and sub-M_{Ch} models with solar metallicity fall within the upper limit for G1.9+0.3 while **subsolar delayed detonation** models all produce **more** ^{44}Ti than the limit.



The relative frequency of "CO/ONe WD explosion" SN models versus their ^{44}Ti output. Different subgroups (colours) and metallicities (shaded bars and dashed lines) are depicted separately.

Kepler

The derived ^{44}Ti mass limit for Kepler **rejects** double-detonation models with a **thick He layer under low density**.



^{44}Ti yields of the double detonation models (stars) with various He shell masses and shell base densities, being compared with the mass upper limits of Kepler。

Takeaways

- The ^{44}Ti decay emission upper limit for **Kepler** excludes the Ca-rich transient, but cannot rule out the hybrid white dwarf explosion if the **He shell** is **thin or under high density**.
- The **Ca-rich transient** models remain **possible** for **SN 1885**.
- The updated upper limit for **G1.9+0.3** confirms a **He-poor** origin and **favours** a progenitor with **(over)solar metallicity** and a **less dominant detonation** phase.

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