Diagnosing the explosion mechanism of Type-Ia SN remnants: the case of Tycho's SNR

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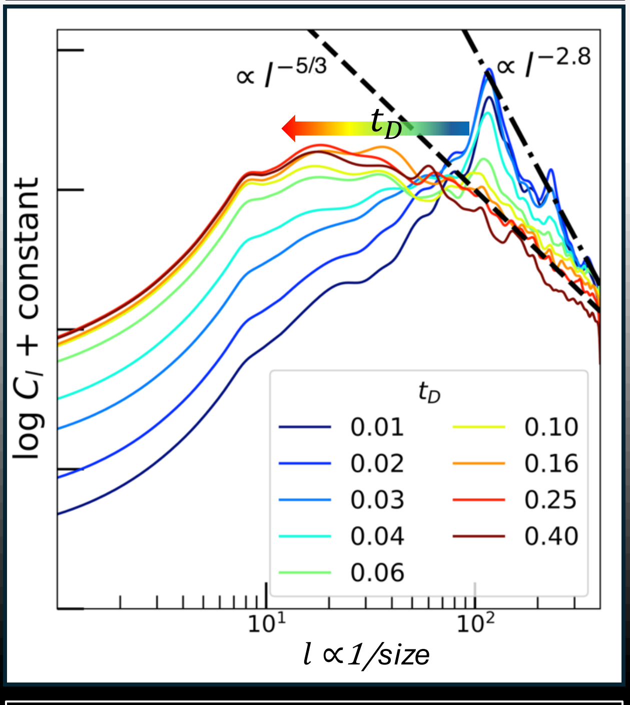
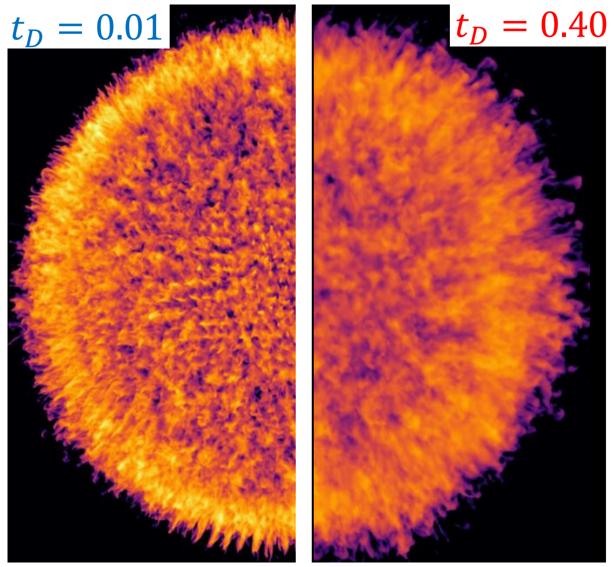
Small-scale substructures are formed in Supernova Remnants (SNRs) due to hydrodynamic instabilities. Here we present a novel approach to identify explosion mechanisms of Type-Ia SNRs (remnants of thermonuclear explosion of white dwarfs (WDs), by analyzing their Si/S-dominated and Fe-dominated turbulent substructures. Our three-dimensional hydrodynamical models show that substructures in an SNR dominated by iron-group elements (IGEs) may have a typical size different from substructures dominated by intermediate mass elements (IMES; e.g., Si, S) in the same SNR. This size difference is governed by the explosion mechanism in Type-Ia SNRs. Applying this approach to Tycho's SNR, we find that its observed structure is most consistent with the explosion of a sub-Chandrasekhar mass WD via the double-detonation mechanism.

1. SNR substructures grow with time...

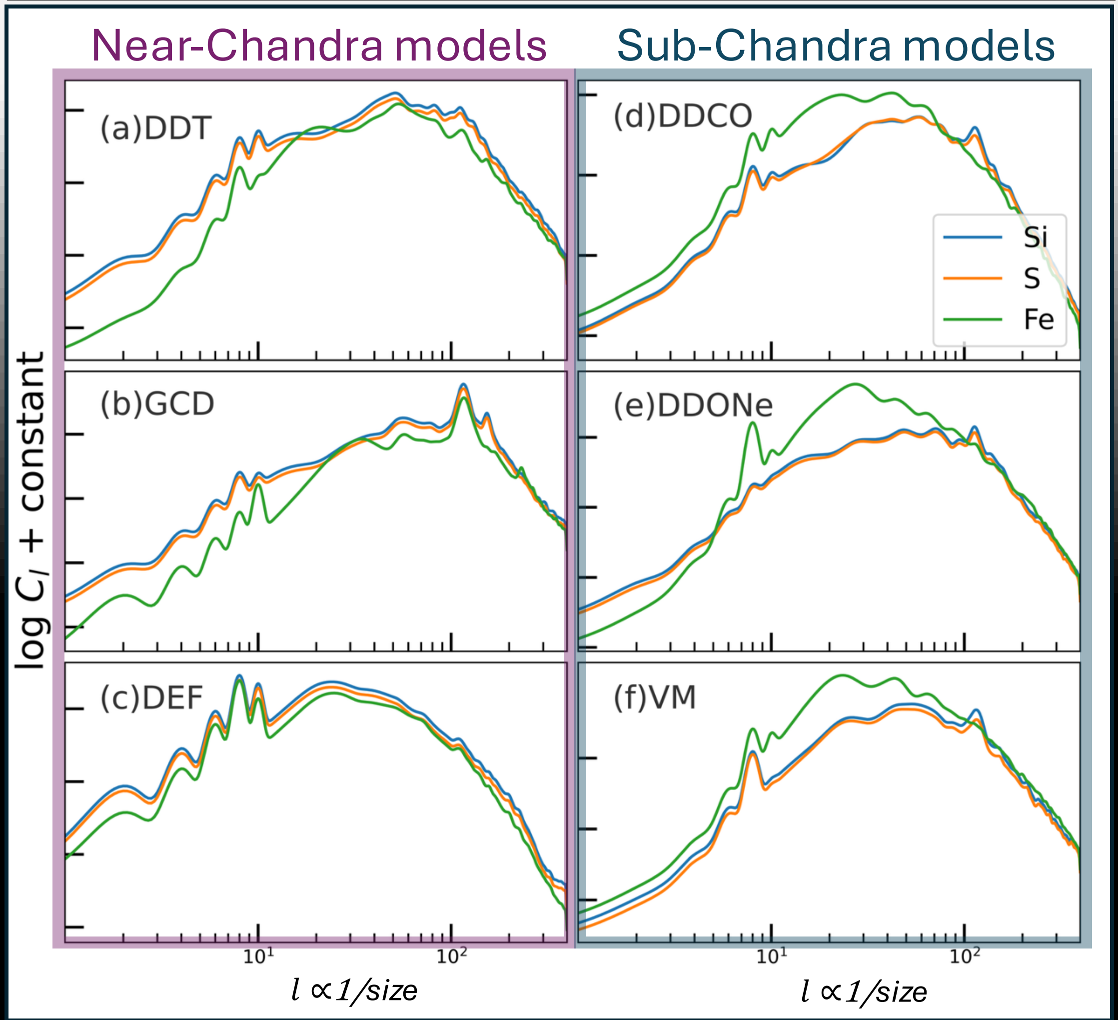


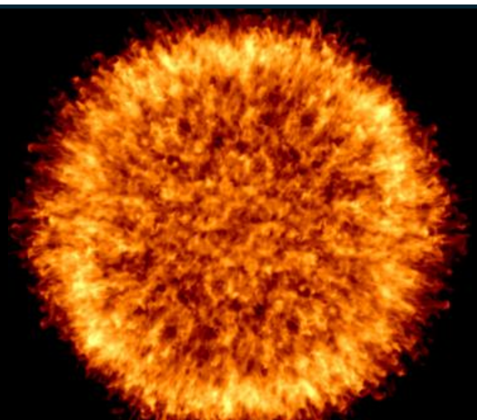
...and are excellent indicators of the SNR's dynamical age!



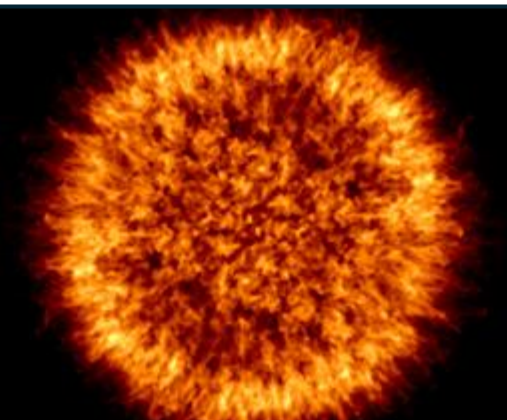
Typical SNR substructures are as big as the density scale height of the outermost ejecta (Mandal et al. 2024), and both grow with time.

2. At any given instant of time, Fe-dominated substructures *are larger than* Si-dominated substructures for sub-Chandra models



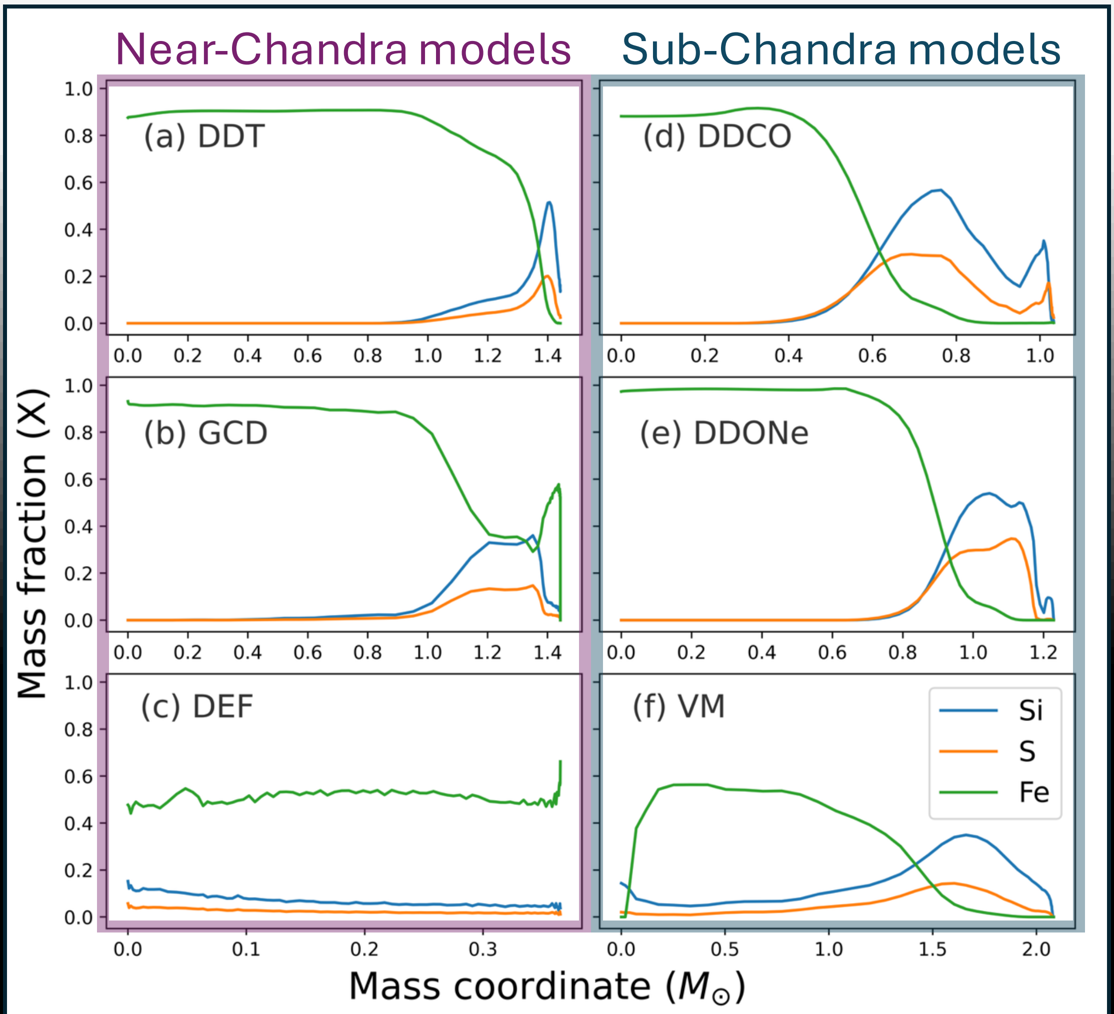


DDCO model, Si emission map



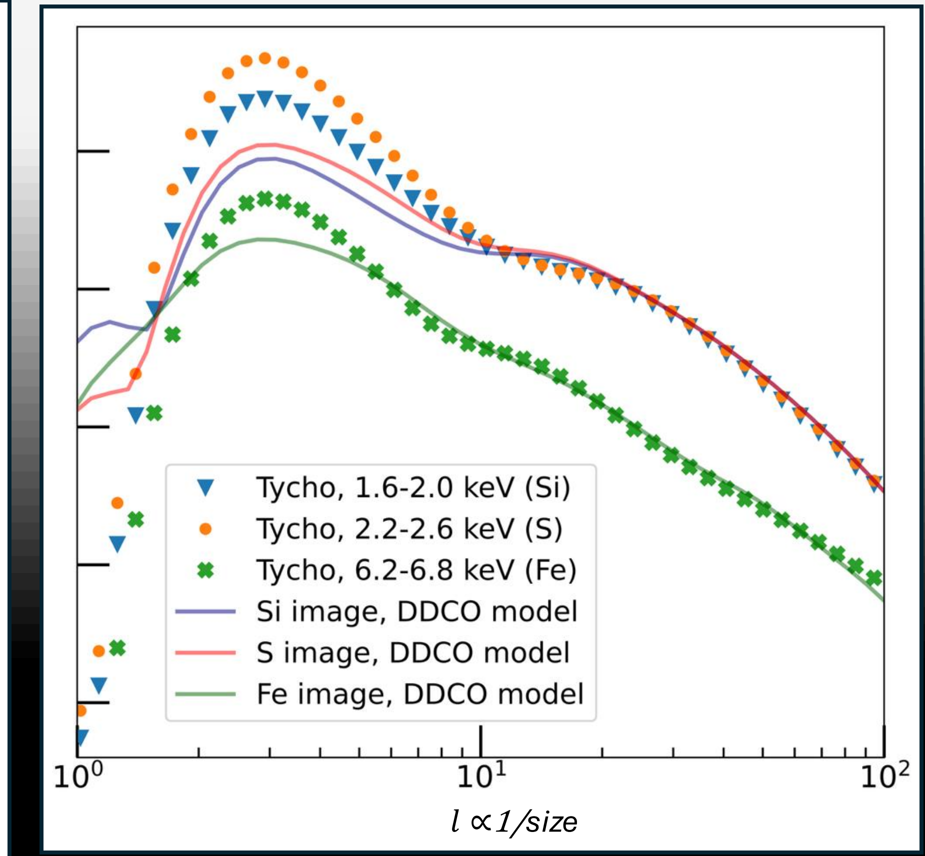
DDCO model, Fe emission map

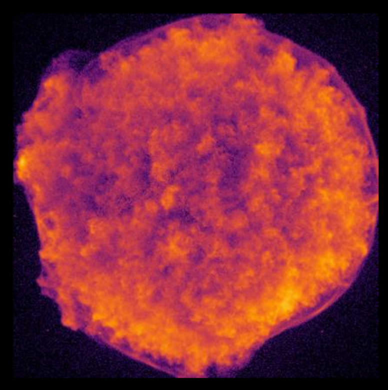
3. Why do sub-Chandra models show this disparity, but near-Chandra models don't?



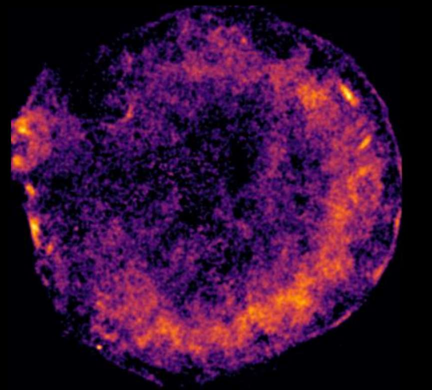
- Sub-Chandra models are more deficient in IGEs near the surface, compared to near-Chandra models.
- In a sub-Chandra WD ejecta, substructures formed early on are IME-rich but IGE-poor.
- The earlier-formed substructures are also smaller, on account of steeper density profile of the outermost ejecta (and hence smaller density scale height) at early times.
- IGEs start dominating substructures later in sub-Chandra SNRs, when the density scale height has increased significantly.
- Hence, IGE-dominated substructures are larger compared to IME-dominated substructures in sub-Chandra SNRs.
- In contrast, IMEs and IGEs are more evenly mixed in near-Chandra SNRs, leading to similarly-sized substructures.

4. Do **Tycho's** Si and Fe substructures differ in size?





Tycho, Si emission (1.6-2.1 keV)



Tycho, Fe emission (6.2-6.8 keV)

Glossary:
DDT: Deflagration to Detonation Transition
GCD: Gravitationally Confined Detonation
DEF: Deflagration
DDCO: Double Detonation of Carbon Oxygen WD
DDONe: Double Detonation of Oxygen-Neon WD
VM: Violent merger of two WDs

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