Revealing the Unique Multi-Structural Features of a Historical Type Iax Supernova Remnant with a White Dwarf Through Multi-Wavelength Observations†

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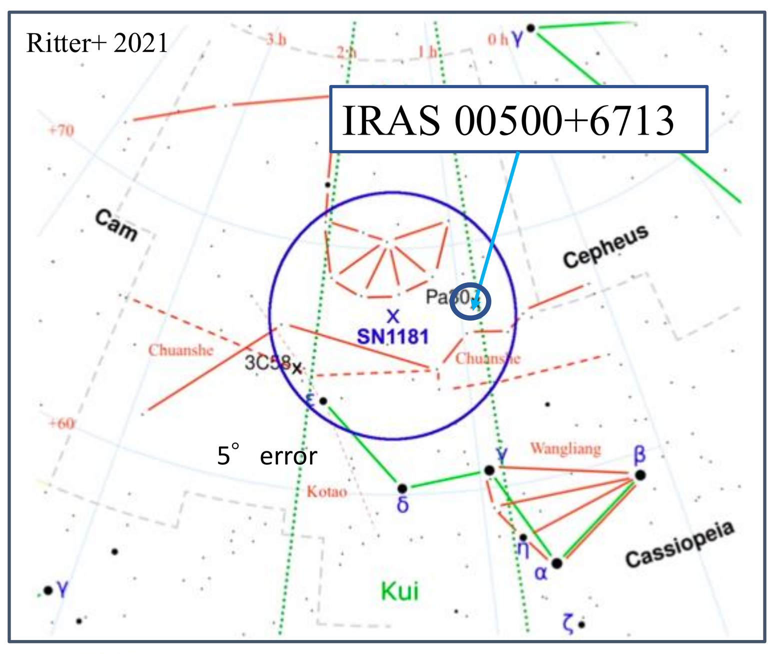
Mass accretion on PhD student

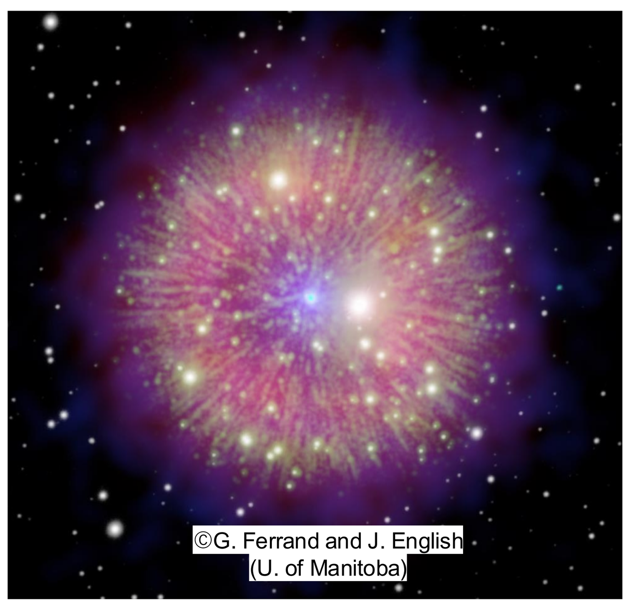
Abstract

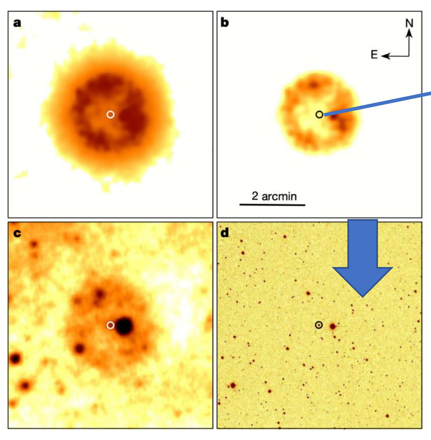
The historical supernova SN 1181 remained unidentified for decades. In 2021, a strong candidate for its remnant was finally discovered, revealing several unique properties not seen in other supernova remnants (SNRs). Most notably, the SNR contains a white dward (WD) and the central WD is currently emitting a fast stellar wind at 15,000 km/s. This high-velocity wind is likely colliding with the ejecta of SN 1181, forming a termination shock. Consequently, the remnant exhibits a multi-layered X-ray structure: thermal X-ray emission is observed from both the shocked SNR and an inner emission region, as revealed by XMM-Newton. We analyzed Chandra X-ray data of this central emission and developed a theoretical model that reproduces the observed X-ray structure. Our analysis suggests that the fast wind from the WD began relatively recently, around 1990. To investigate this delayed wind onset, we performed WD evolution calculations using the stellar evolution code MESA, demonstrating that a delay of approximately 1,000 years is feasible. Furthermore, our calculations constrain the properties of the central WD, allowing us to constrain the progenitor system of SN 1181, which remains poorly understood. Additionally, we have conducted VLA observations targeting the termination shock region, which are expected to provide further constraints on the interaction between the fast wind and the surrounding medium. In this presentation, we will discuss our Chandra/VLA data analysis, theoretical modeling, and the potential implications of our findings for understanding SN 1181 and its central WD.

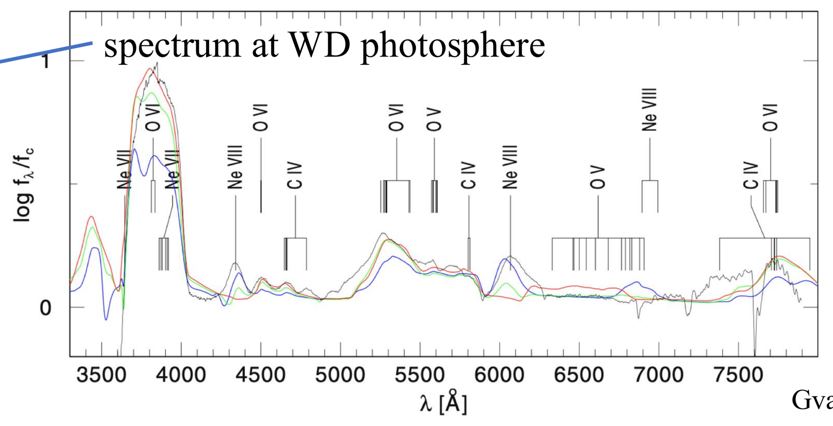
A leading candidate of SNR 1181

distance ~ 2.3 kpc (Gaia DR3)







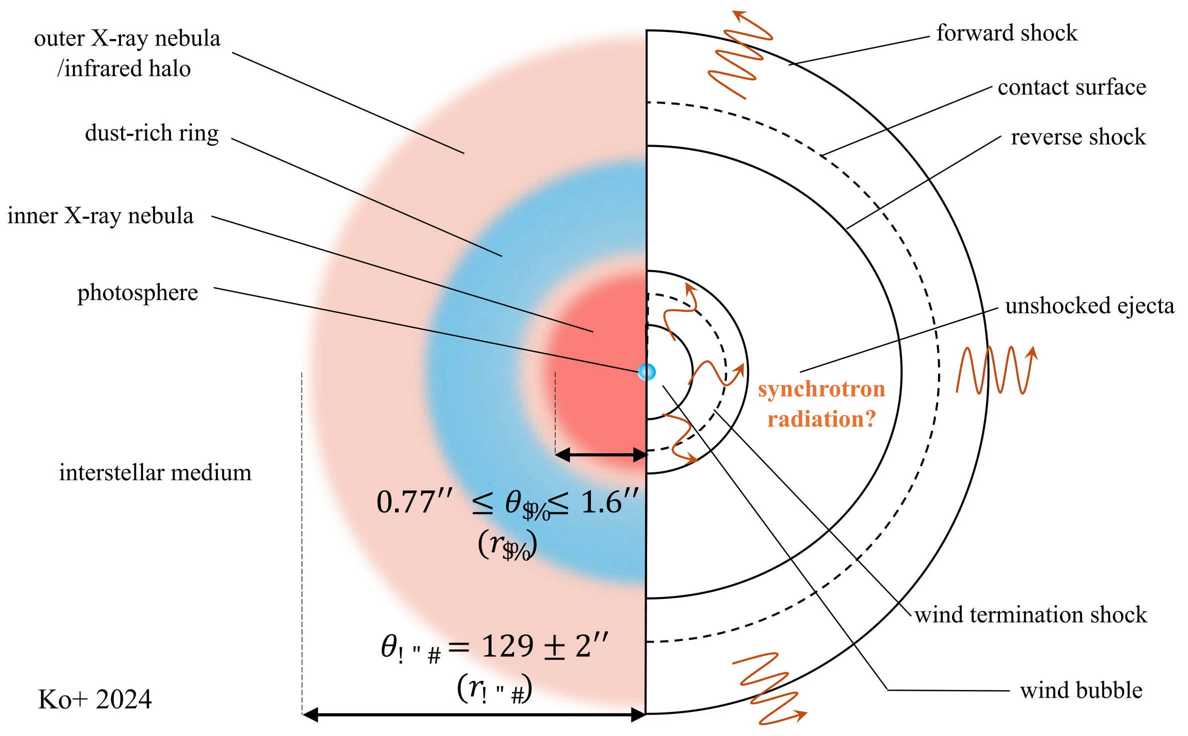


The width & height of the wind line spectrum ⇒ $\dot{M} = (3.5 \pm 0.6) \times 10^{-6}\, M_\odot\, \mathrm{yr}^{-1}$, $v_\infty = 16{,}000 \pm 1{,}000\, \mathrm{km\, s^{-1}}$

magnetohydro model ⇒ WD mass $\sim 1.1 - 1.3 M_\odot$ Kashiyama+ 2019

Features of IRAS 00500+6713/ Pa30/ SN 1181

- ✓ The newest identified historical SN (SN 1181)
- ✓ SNR with a white dwarf in the center → SN Iax?
- ✓ Fast wind (~15,000 km/s) from WD started blowing recently
- ✓ Multi-layer structure of SNR 1181
- ✓ Long filament structure
- ✓ Dust formation in SNR



Theoretical modeling of SNR 1181

- We calculate the outer shock evolution using self-similar solution by Chevalier+82
  - We search for a parameter M_{ej} and E_{ej}, which can reproduce the spread of the shock region and the EM.
  - X-ray analysis → $EM = n_e n_{ion} V = 3.7 \times 10^{54}$ /cm^3
  - We obtain the following relation:
- We calculate the inner shock evolution using thin-shell approximation
- If we assume the wind started blowing soon after SN1181, we cannot reproduce the spread of the region.
- The wind must start blowing recently
- We calculate the evolution of the thin shell and estimate the spread and EM of the inner region for each parameter set of M_{ej} and Δt_w (Δt_w refers to how many years ago the wind started blowing from now.).
- We compare these values with the observation and constrain the parameters (M_{ej}, E_{ej}, Δt_w)

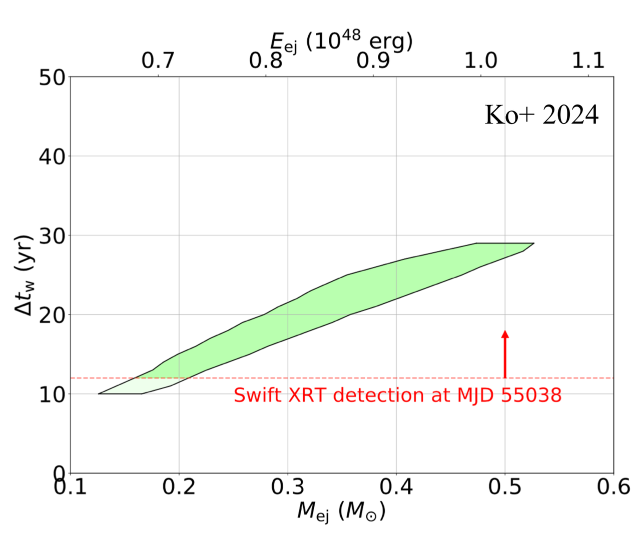
$12\,\mathrm{yr} < \Delta t_w < 30\,\mathrm{yr}$

$0.18 M_\odot < M_{ej} < 0.53 M_\odot$

$0.77 \times 10^{48}\,\mathrm{erg} < E_{ej} < 1.1 \times 10^{48}\,\mathrm{erg}$

↓

consistent with SN Iax features

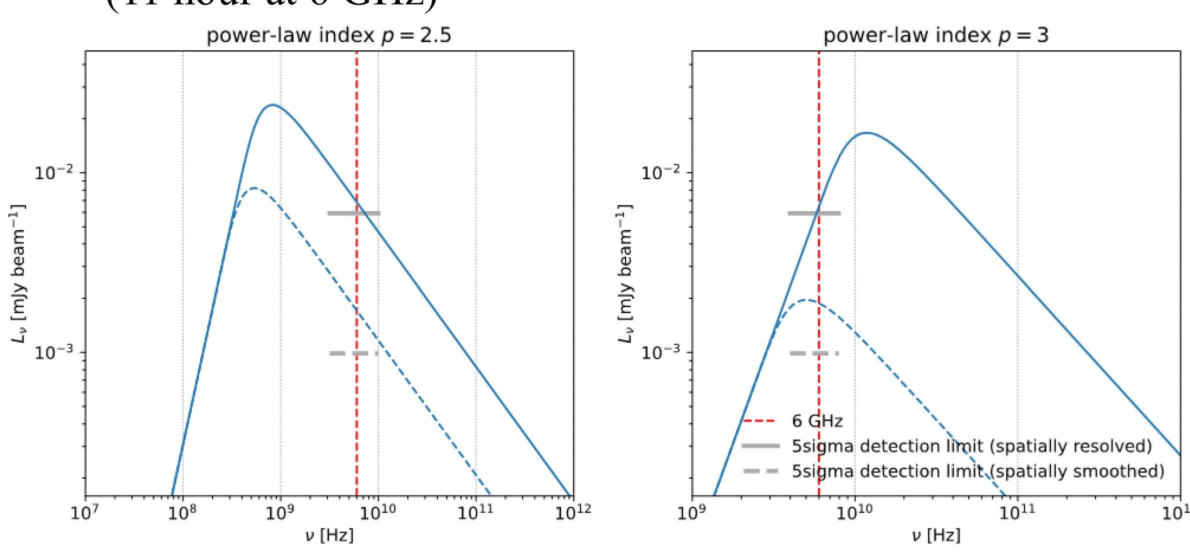


Radio Emission

- Radio Emission is can be detected from the shock regions
- By detecting the termination shock, the wind launch time can be estimated
  → We conducted VLA observation

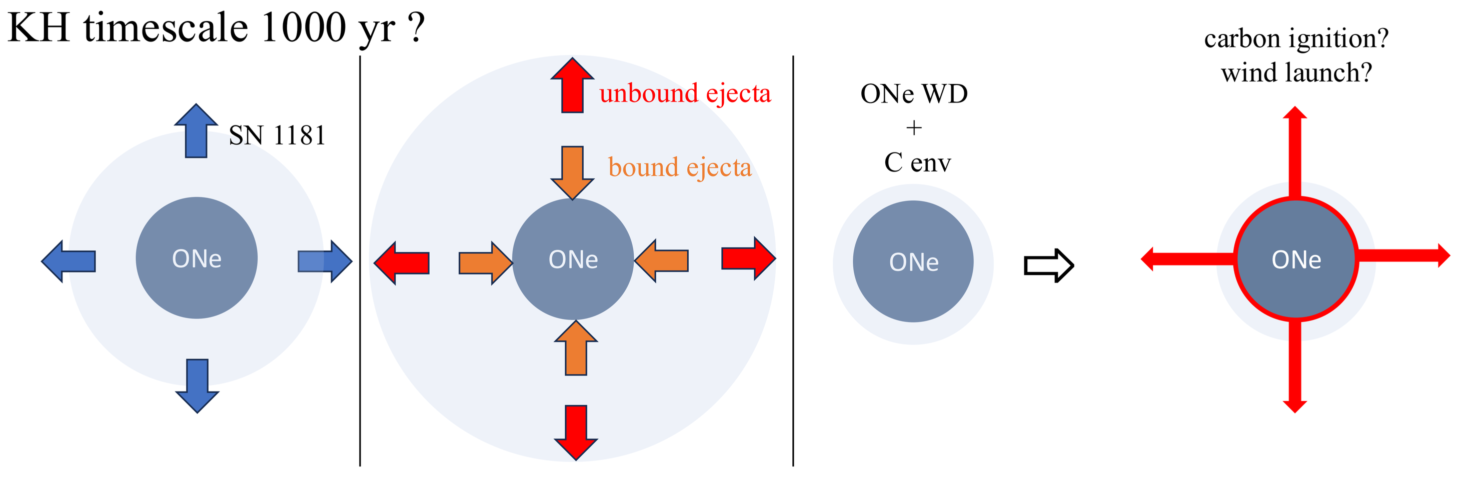
beam number = 36, beam size = 0.488 arcsec (11 hour at 6 GHz)

We now have 5 hours observation data and nothing was detected



Wind Launch timescale

- Wind launch may be due to the carbon ignition on WD surface
- Wind launch delay may be due to the ignition delay
- Ignition timescale depends on the KH time scale of the central WD
- Is the KH timescale 1000 yr ?

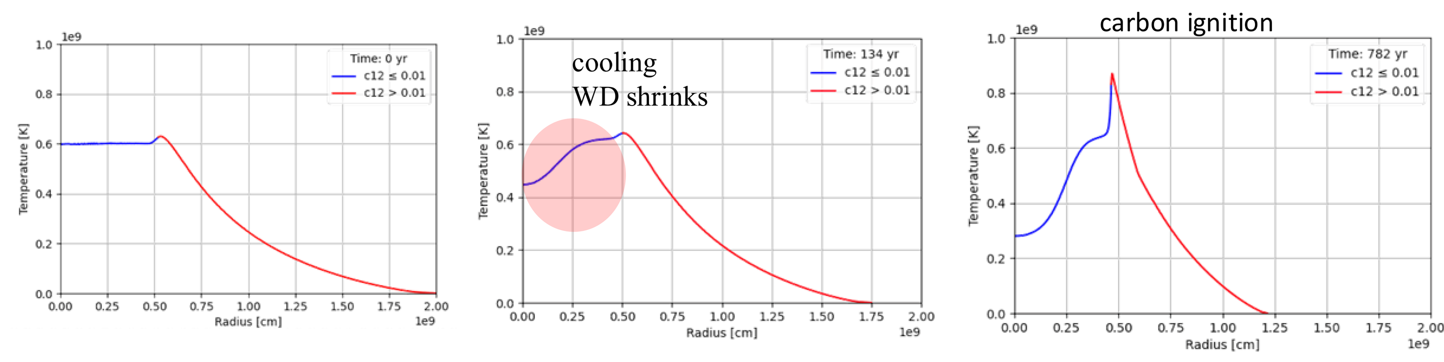


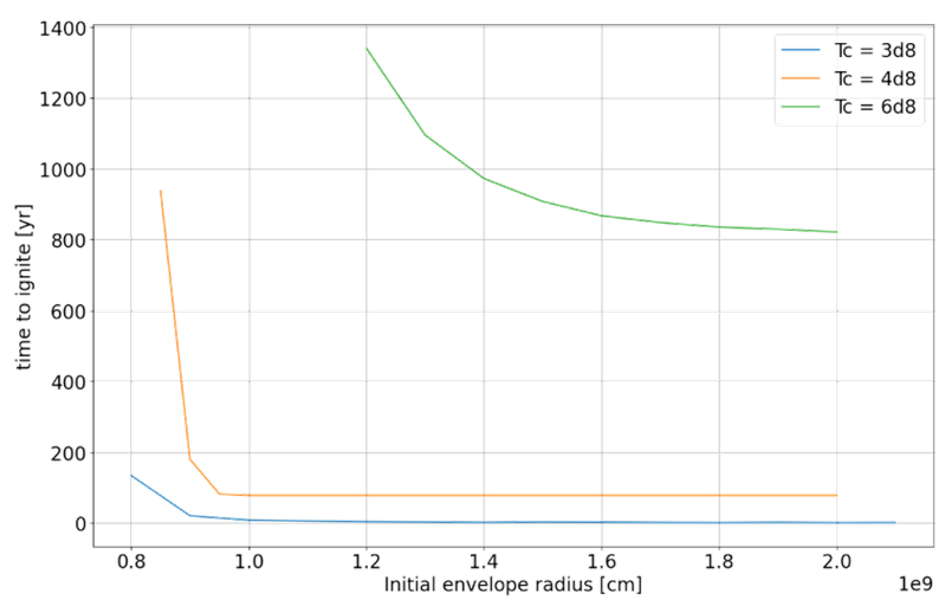
We constructed models of ONe WD with C envelope by MESA

1.1 solar mass ONe WD (O:Ne = 1:1)

0.5 solar mass carbon envelope

→ WD temperature (T_c) and Envelope Radius (R_{env}) are parameters





Larger R_{env} : t → KH timescale = const

Smaller R_{env} : t → infinity

When R_{env} is small, the bottom of the envelope is more susceptible to cooling.

The ONe WD central temperature must not be cooled down to explain ignition delay ~ 1000 yr.

↓

As SN 1181 progenitor system

ONe WD + CO WD scenario can be ruled out (In this case T_c is low)

CO WD + He star? (e.g., Fink+2014)

In this case, C deflagration occurs in the WD, leading to the formation of ONe WD

→ T_c is higher

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The time evolution of SNR 1181 from the explosion