相対論的現象で探る宇宙の進化IV
3/23@Okinawa

RIKEN's Programs for Junior Scientists

THE UNIVERSITY OF TOKYO RESEARCH CENTER FOR THE EARLY UNIVERSE RESCEU

Summary of SNR 1181 and a White Dwarf in its center

Takatoshi Ko (RESCEU)

Coworkers ;

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(In alphabetical order)

arXiv: 2304.14669
arXiv: 2401.12487

Self-Introduction

- PhD student in University of Tokyo
- JRA fellow in RIKEN

- Interests
  - Type Iax SNR 1181 (Today's topic)
  - interaction-powered SN

https://sites.google.com/view/**takatoshi-ko**/home

Many historical SNR are identified

Name	Historical Record	SN Remnant	SN Type	Note
SN 185	後漢書 巻十二 (Book of Later Han vol 12) “中平二年十月癸亥，客星 (guest star) 出南門中，大如半筵，五色喜怒稍小，至後年六月消”	RCW 86	Ia?	
SN 393	宋書 巻二十五(Song Shu vol 25) “太元十八年二月、有客星在尾中、至九月乃滅”	RX J1713.7-3946	II or Ib	
SN 1006	Sources in China, Japan, Iraq, Egypt, Europe	SN 1006	Ia	
SN 1054	明月記 (also in Chinese record 宋史) “後冷泉院・天喜二年四月中旬以後の丑の時、客星觜参の度に出づ。東方に見わる。”	Crab nebula	II	Made the Crab pulsar
SN 1181	吾妻鏡 “治承五年六月廿五日（1181年8月7日）庚午。戌尅。客星見艮方。”	?	?	
SN 1572	“De nova stella” by Tycho Brahe...	Tycho’s SNR	Ia	Rebuttal of the Aristotelianism concept of unchanging sky
SN 1604	In European, Chinese, Korean, Arabic sources	Kepler’s SNR	Ia	
SN 1987A		SNR 1987A	II	At LMC. First detection of SN ν

The newest un-identified SNR 1181

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SN 1572				Rebuttal of the Aristotelianism concept of unchanging sky
SN 1604				
SN 1987A		SNR 1987A	II	At LMC. First detection of SN ν

the newest un-identified SNR

- It occurred in the direction of Cassiopeia
- It is as luminous as Saturn
- It lasted for 180 days

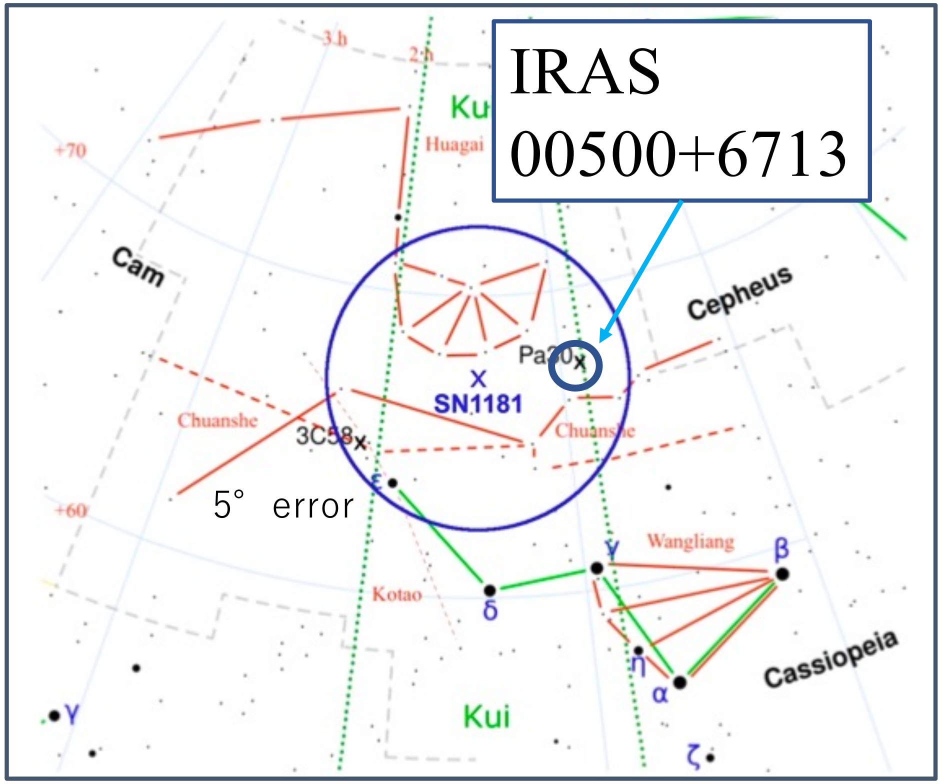
A leading candidate of SNR 1181
IRAS 00500+6713

distance ~ 2.3 kpc (Gaia DR3)

- The on-sky location fits historical reports of SN 1181
- Radius and velocity of the remnant
  → SN happened ~1000 yr ago

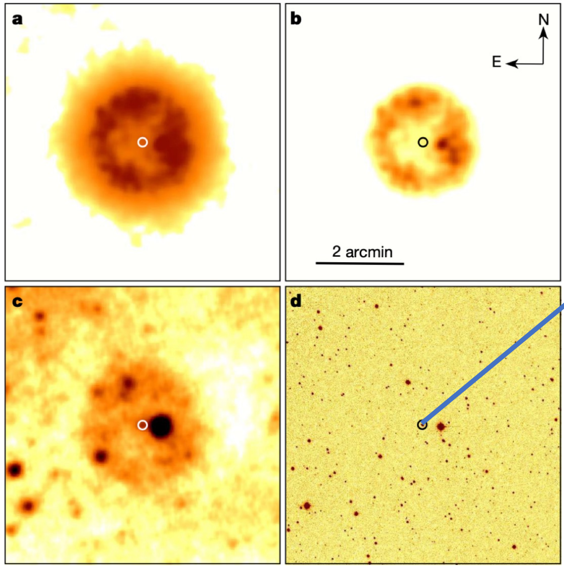
⬇

- IRAS 00500+6713 has been a leading candidate of SN 1181 remnant!
- I will report the properties of this object

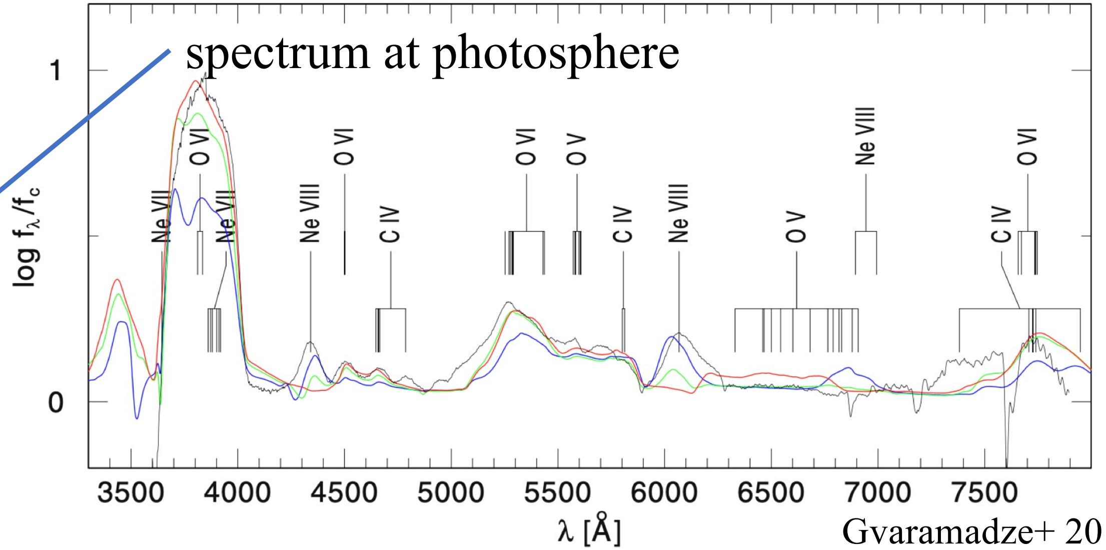


Ritter+ 2021

Mid-Infrared/Optical Observation



distance ~ 2.3 kpc (Gaia DR3)



Gvaramadze+ 2019

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

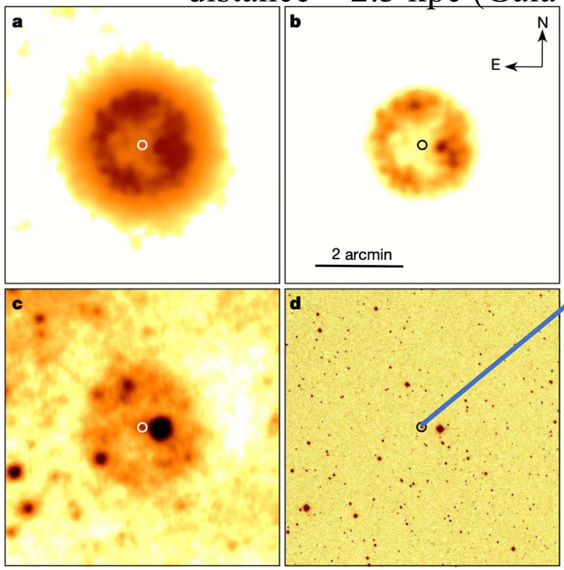
$v_\infty = 16{,}000 \pm 1{,}000\, \mathrm{km\, s^{-1}}$

magnetohydro model → mass$\sim 1.1 - 1.3 M_\odot$

Kashiyama+ 2019

Massive White Dwarf : WD J005311

distance ~ 2.3 kpc (Gaia DR3)



IRAS 00500+6713

Table 1 | Stellar parameters and surface abundances of J005311

Parameter	Value
$\log(L_*/L_\odot)$	4.60 ± 0.14
T_* (K)	$211{,}000^{+40{,}000}_{-23{,}000}$
R_* ($R_\odot$)	0.15 ± 0.04
$\dot{M}$ ($M_\odot$ yr^{-1})	$(3.5 \pm 0.6) \times 10^{-6}$
D	10
v_∞ (km s^{-1})	$16{,}000 \pm 1{,}000$
β	1.0
d (kpc)	$3.07^{+0.34}_{-0.28}$
$E(B-V)$ (mag)	0.835 ± 0.035
R_V	3.1
He mass fraction	<0.1
C mass fraction	0.2 ± 0.1
O mass fraction	0.8 ± 0.1
Ne mass fraction	0.01
Fe group mass fraction	1.6×10^{-3}

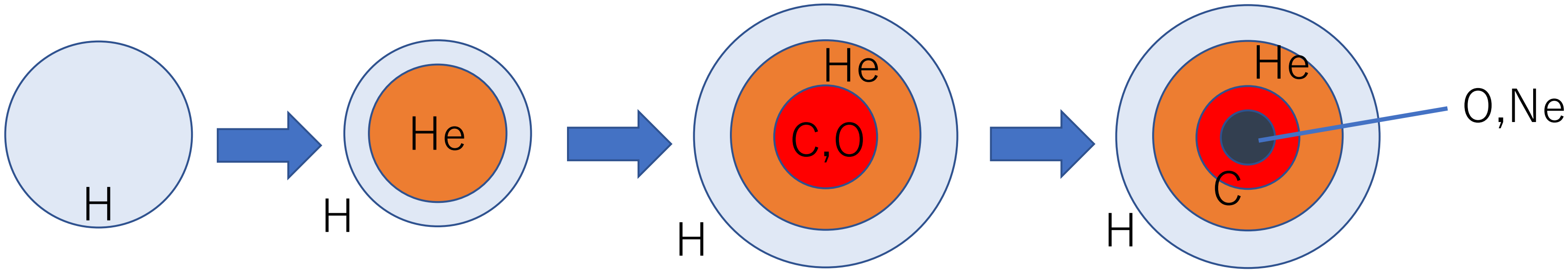
The given uncertainties are an indicator of the obtained fit quality as a function of stellar parameters, on the basis of the criteria described in Methods. Owing to the nature of this analysis they do not represent statistical error distributions. Parameters without error estimates were adopted in the model. D, wind clumping factor; β, acceleration parameter; d, distance to J005311; R_V, total-to-selective absorption ratio.

Gvaramadze+ 2019

$M \sim 1 M_\odot$ (Kashiyama+ 2019, Lykou+2023)
$v_{esc} \sim v_{wind} = 1.5\times10^9$ cm/s

$r_{WD} \sim 10^8$ cm

White Dwarf



When the fuel runs out

$r \sim 10^9$ cm

single star origin
WD with low spin
rotation period~1d

$r \sim 10^8$ cm

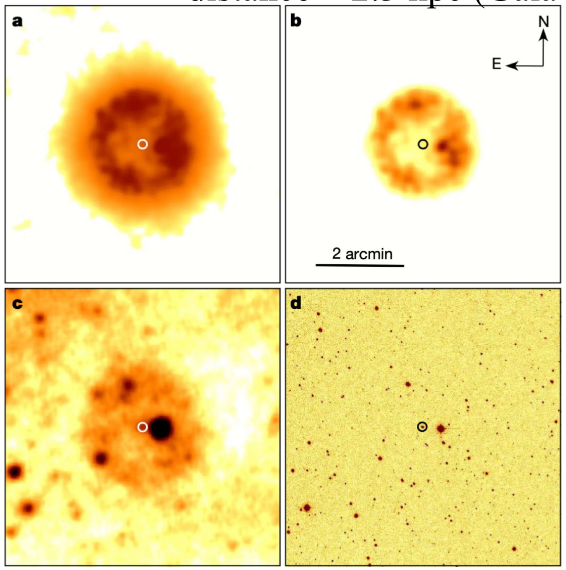
CO WD
$M < 1.0\ M_\odot$

ONe WD
$M \sim 1.1\ M_\odot$

Binary origin WD
sometimes with high spin
sometimes larger than $1.1\ M_\odot$

Massive White Dwarf : WD J005311

distance ~ 2.3 kpc (Gaia DR3)



IRAS 00500+6713

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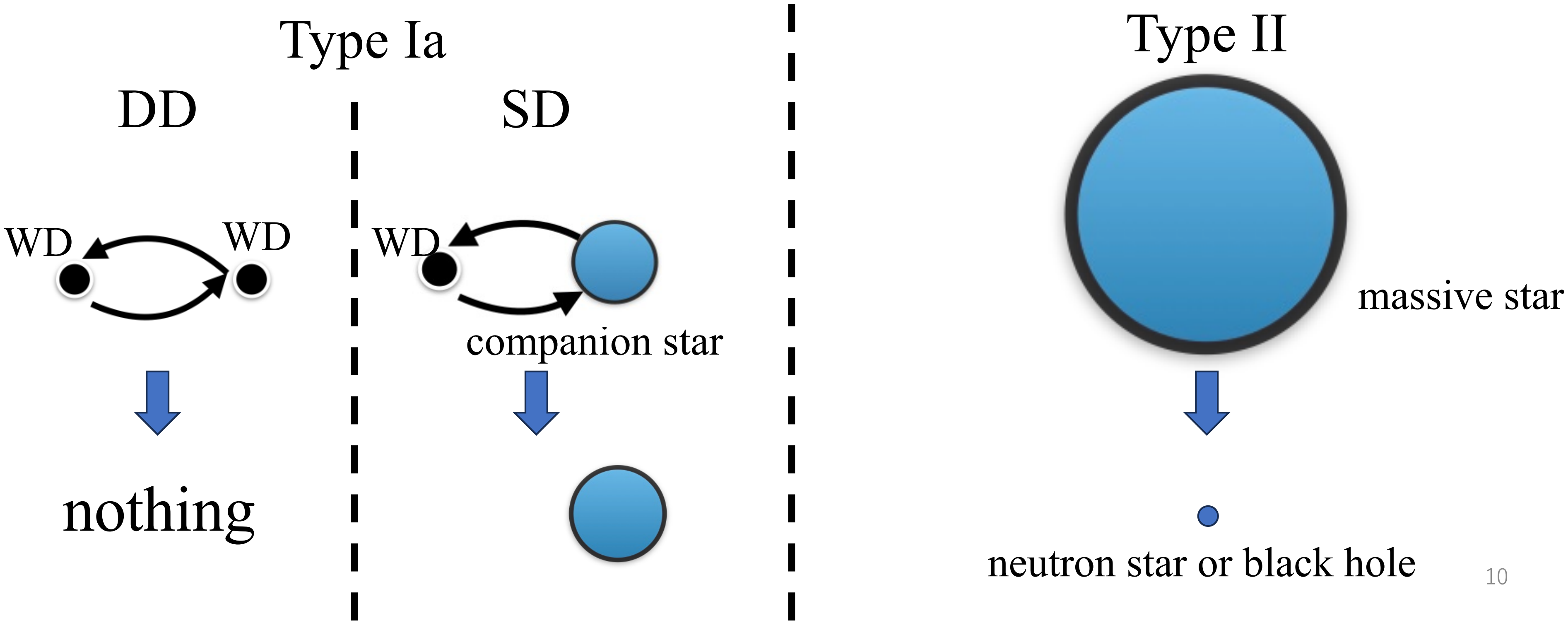
Gvaramadze+ 2019

WD mass$\sim 1.1 - 1.3 M_\odot$
$\Omega \sim 0.2 - 0.5$ /s

→

Merger origin WD in SNR

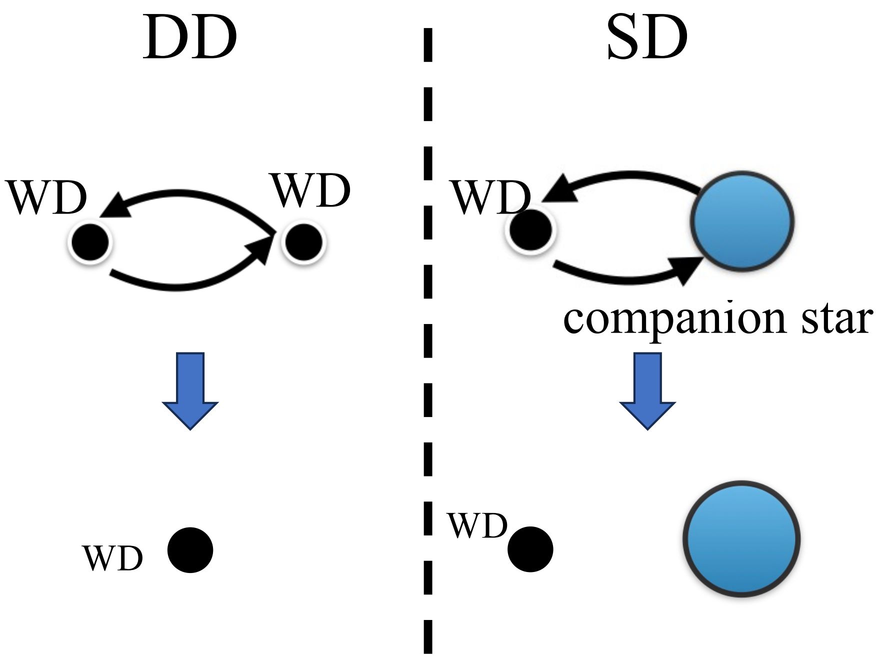
Peculiar properties of SNR 1181



Peculiar properties of SNR 1181

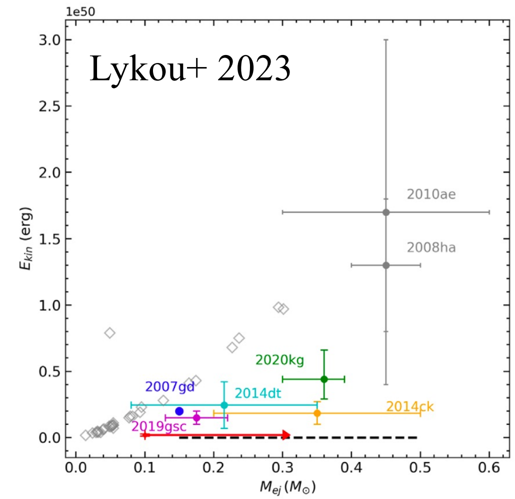
IRAS 00500+6713 includes a white dwarf → SN 1181 may be a SN Iax?

Type Iax



SN 1181 is a type Iax SN?

SN Iax is thought to leave a WD as its remnant.



Features of SN Iax

- Type Iax SN → sub-luminous Type Ia SN
- thought to leave a white dwarf as a remnant
- typical ejecta mass ~ 0.5 solar mass
- rate → ~10% of SN Ia rate
- progenitor → If DD : ONe WD + CO WD with super-Chandrasekhar ?

Our work

- We assume this nebula is SNR 1181.
- We analyze the X-ray emission from the SNR .
- We calculate the time evolution of the SNR.

arXiv: 2304.14669

→ We estimate the ejecta mass, explosion energy of SN 1181

→ consistent with SN Iax? with every observation?

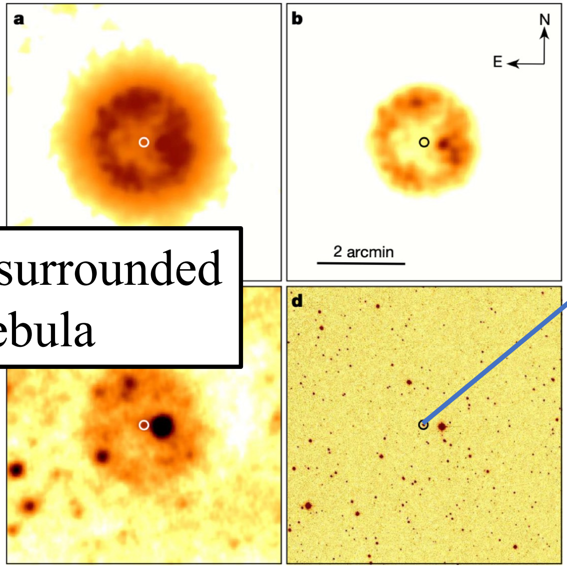
→ If so, our work supports this nebula is a type Iax SNR 1181

→ If not, this nebula should not be SNR 1181

arXiv: 2401.12487

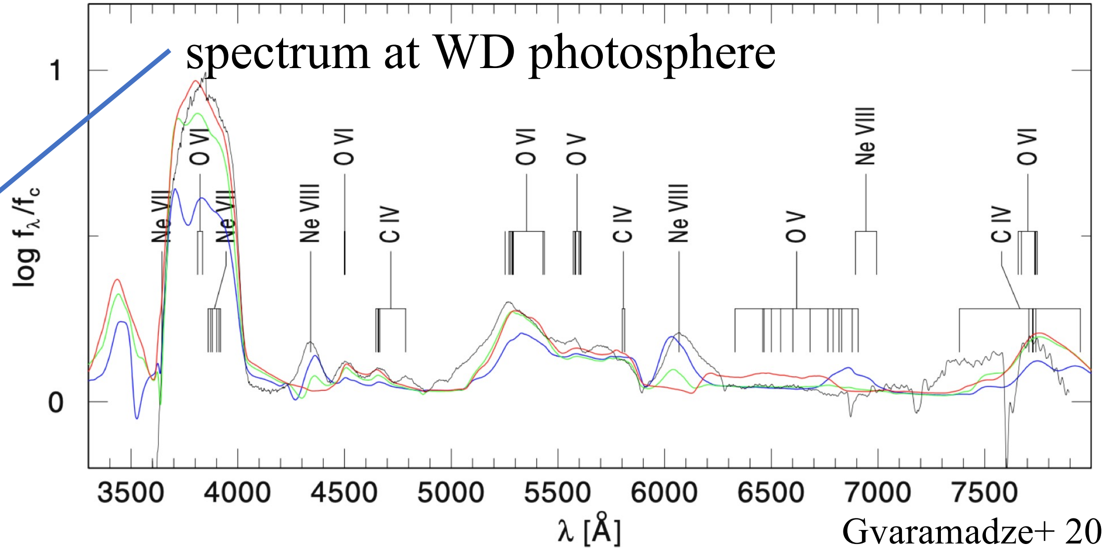
- If this nebula is SNR 1181, there might be a radio source
- We estimate the radio source and search the radio archive data.

Mid-Infrared Observation



WD surrounded by nebula

distance ~ 2.3 kpc (Gaia DR3)



Gvaramadze+ 2019

The width & height of the wind line spectrum

$$\dot{M} = (3.5 \pm 0.6) \times 10^{-6}\, M_\odot\, \mathrm{yr}^{-1}$$

$$v_\infty = 16,000 \pm 1,000\, \mathrm{km\, s}^{-1}$$

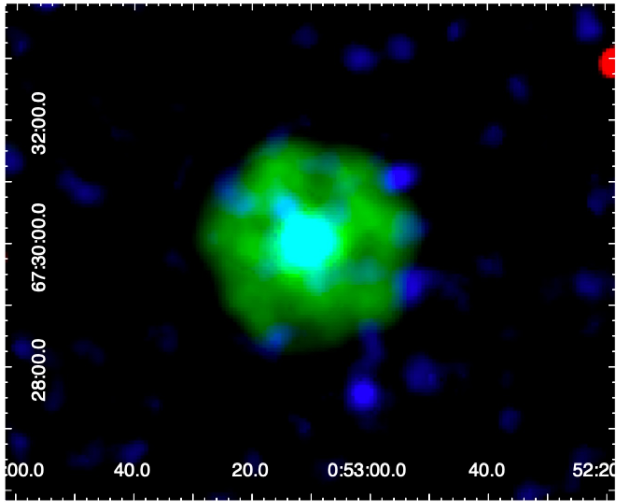
magnetohydro model

Kashiyama+ 2019

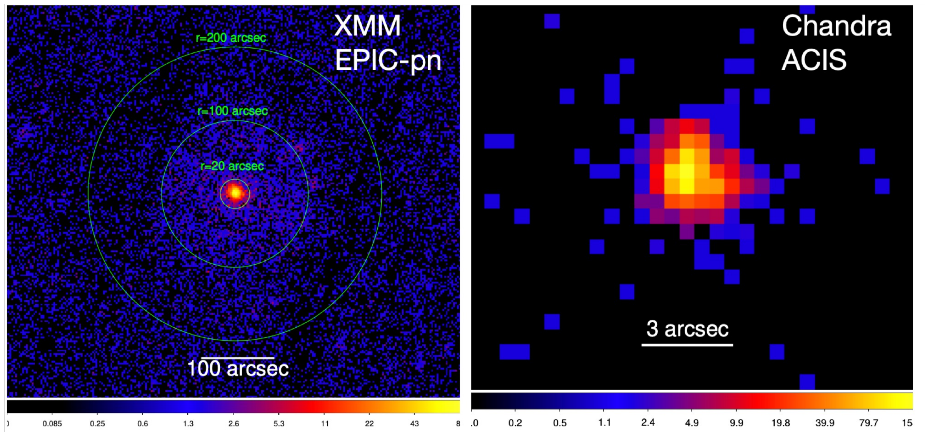
WD mass $\sim 1.1 - 1.3 M_\odot$

X-ray observation

Oskinova+ 2020



Ko+ 2023



distance ~ 2.3 kpc (Gaia DR3)

$R_d \sim 131$ arcsec

$R_c \sim 1.5$ arcsec

XMM Observation
→ diffuse source & central source

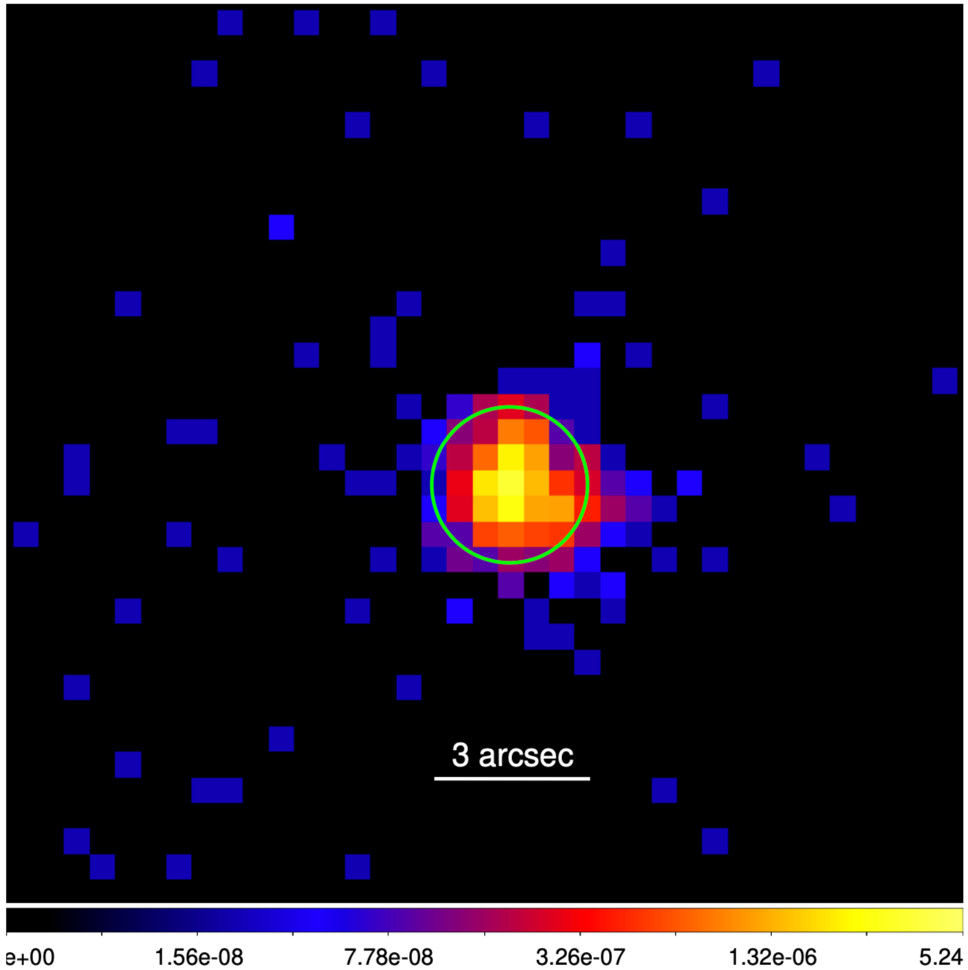
Chandra observation

r = 0.77–1.60 arcsec
→ 0.0087 – 0.018 pc

comparing with
photosphere radius ~10^{10} cm
This region is certainly spread

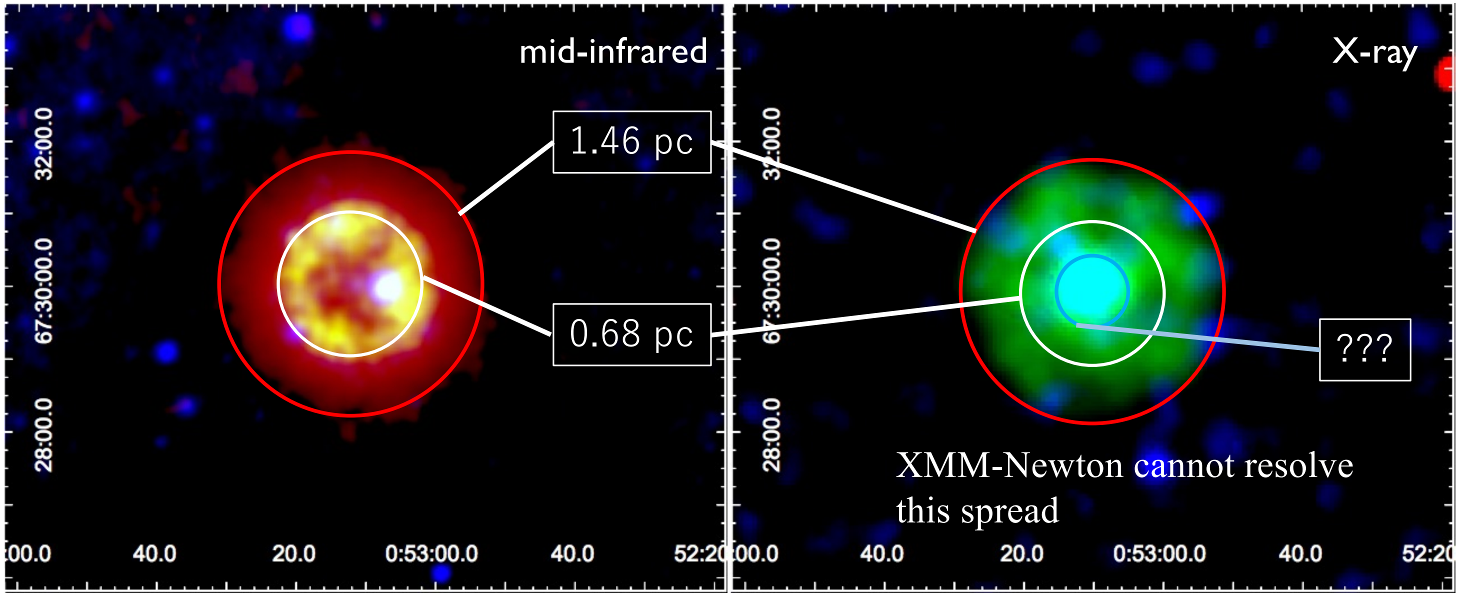
→inner X-ray region is not
WD origin

Ko+ 2023



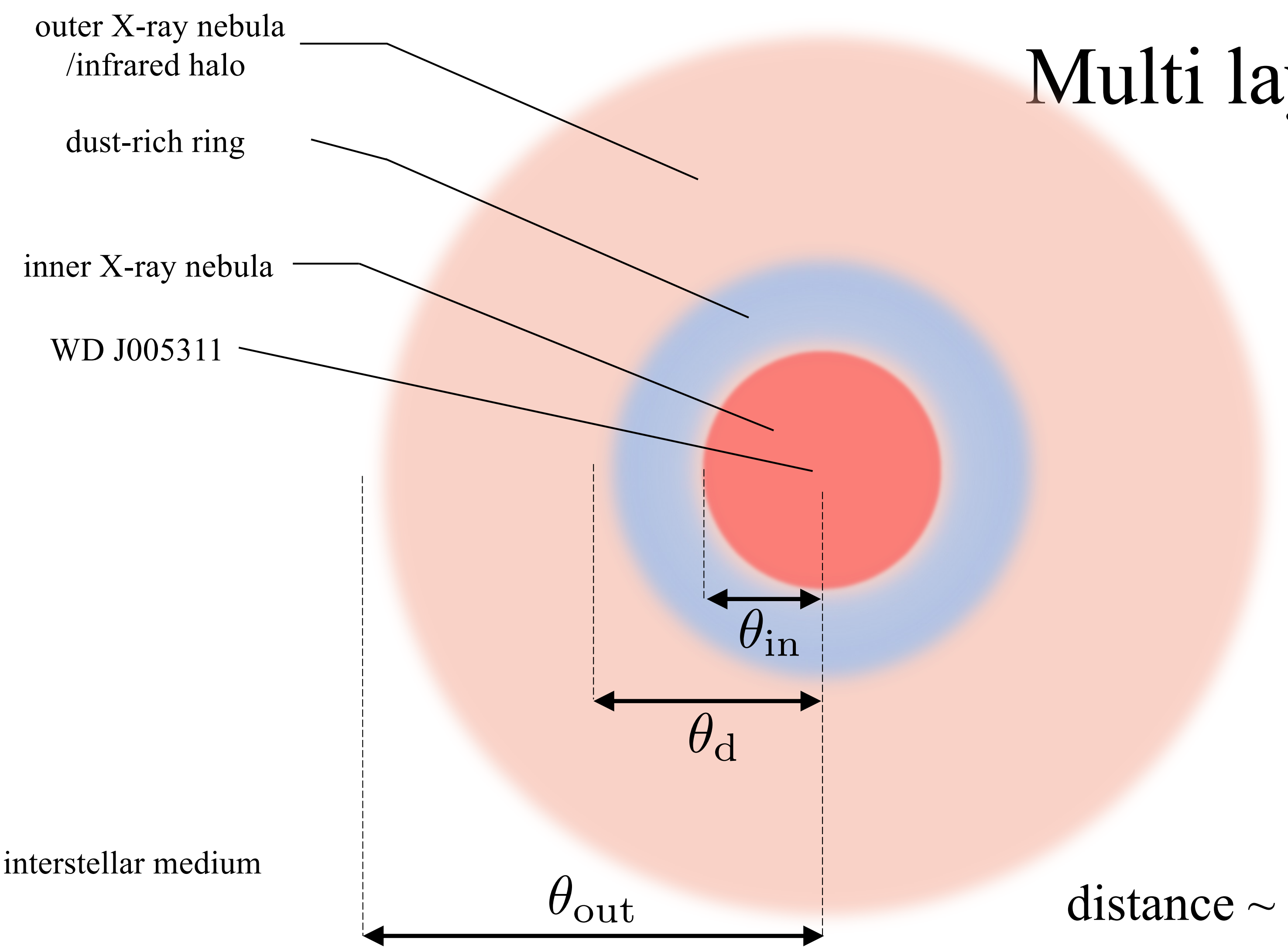
SNR consists of Multi layers

Oskinova+ 2020



Multi layers!

Multi layer structure



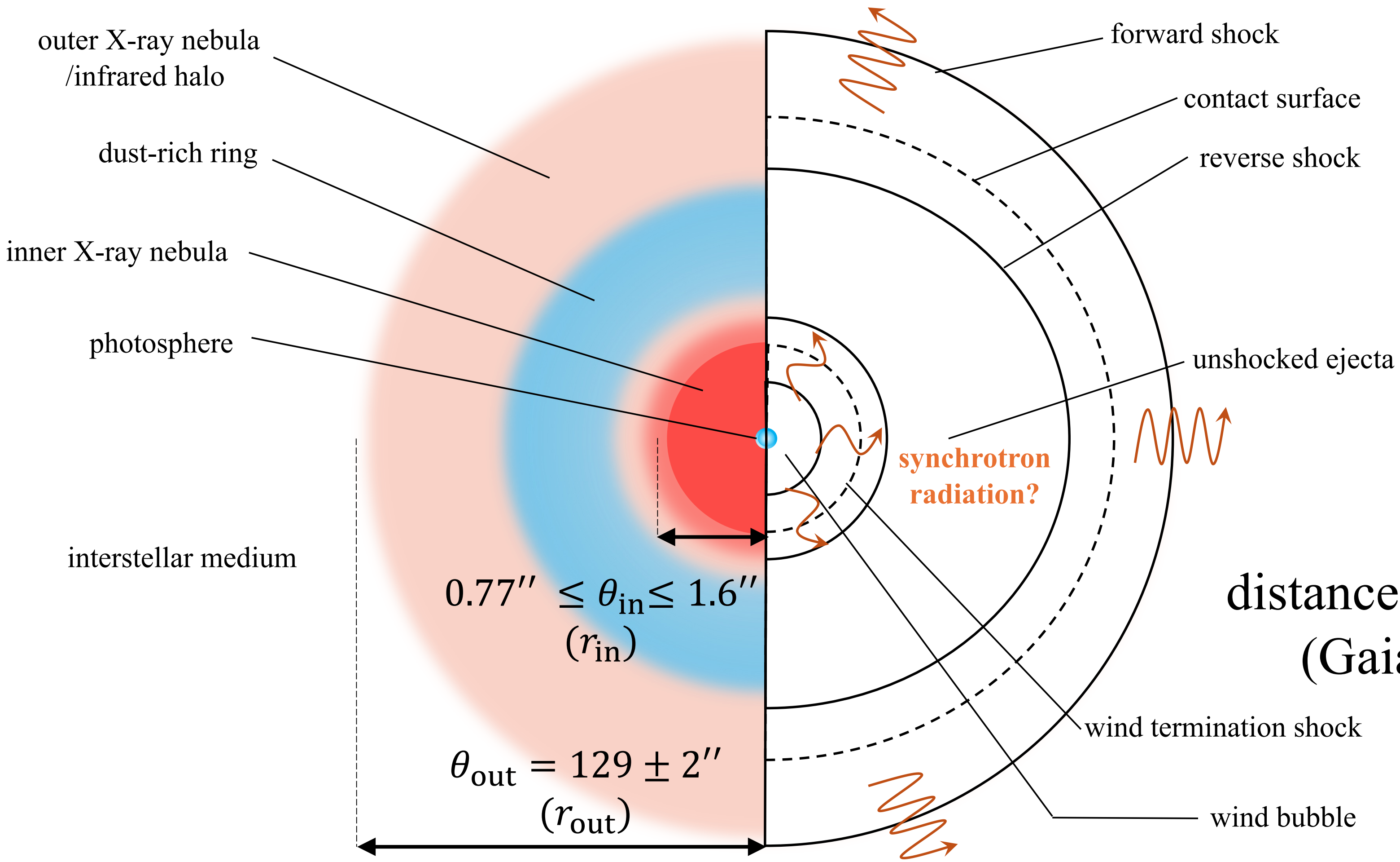
$\theta_{\rm in} \sim 1.5$ arcsec

$\theta_{\rm d} \sim 60$ arcsec

$\theta_{\rm out} \sim 130$ arcsec

distance ~ 2.3 kpc (Gaia DR3)

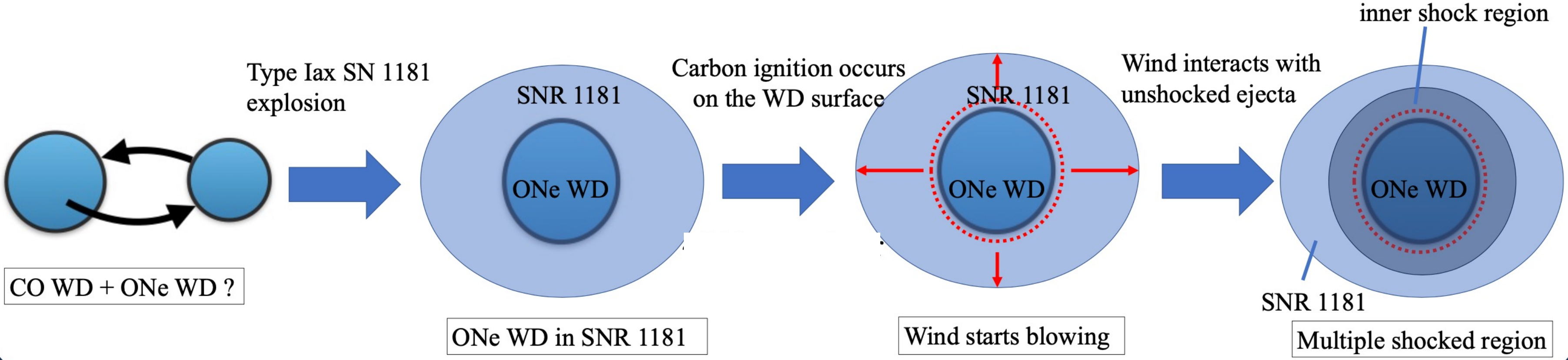
Multi layer structure



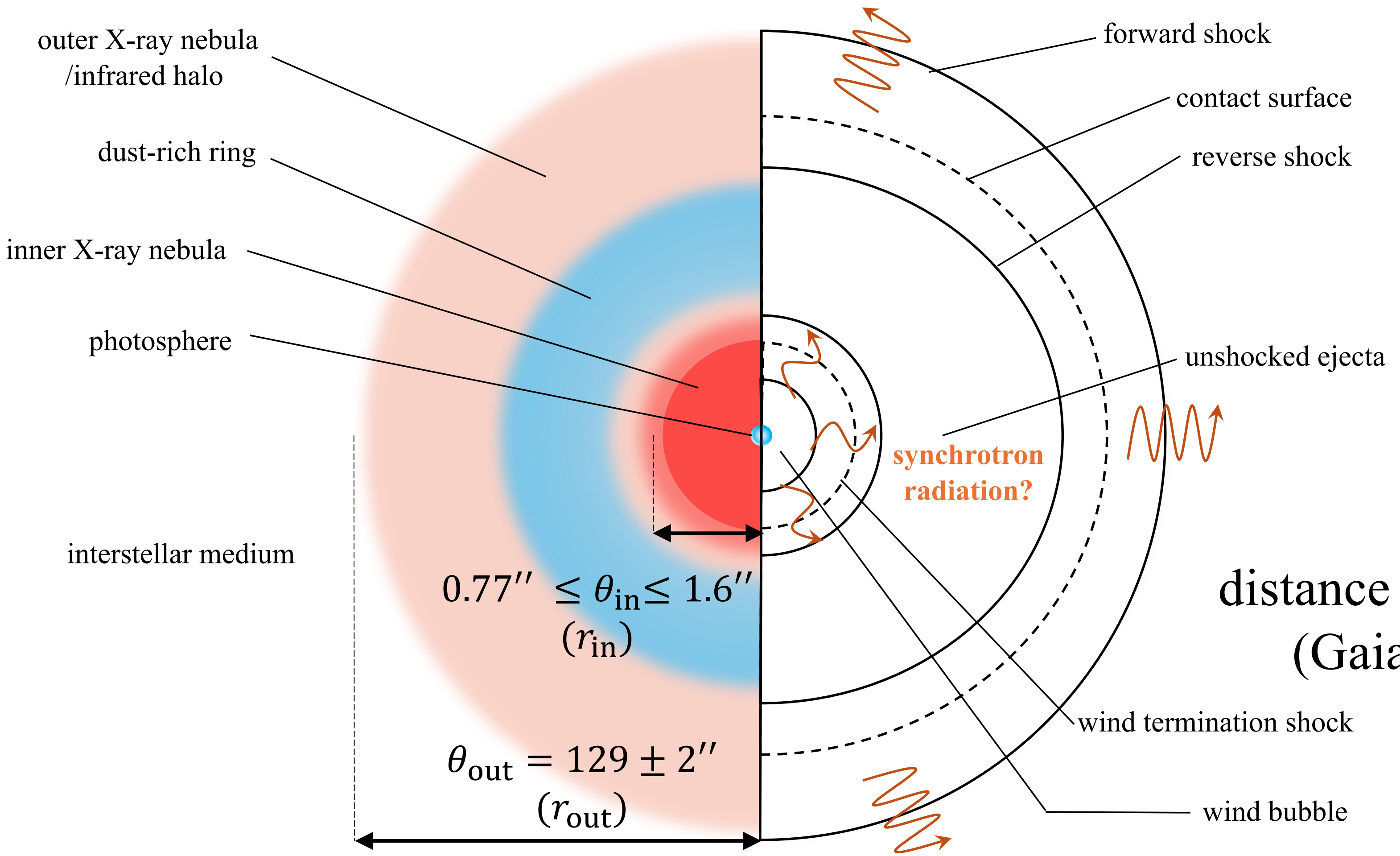
distance ~ 2.3 kpc
(Gaia DR3)

Ko+ 2024

The time evolution of SNR 1181 from the explosion



Multi layer structure

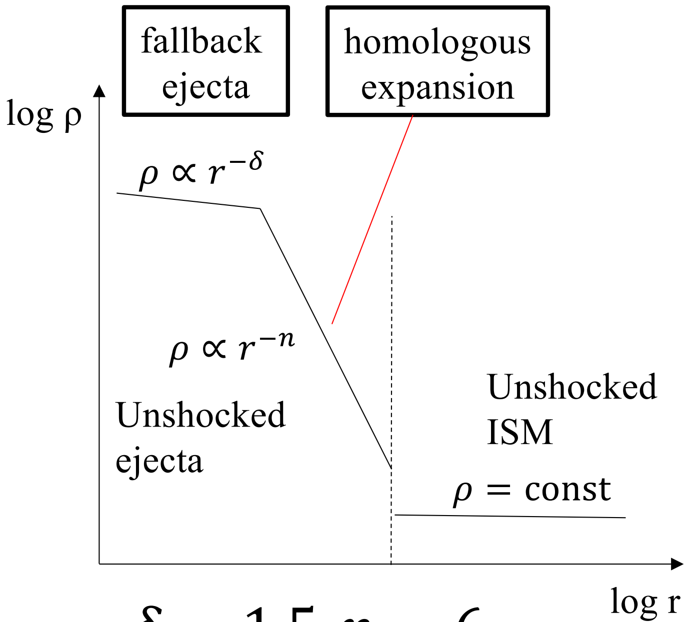


distance ~ 2.3 kpc
(Gaia DR3)

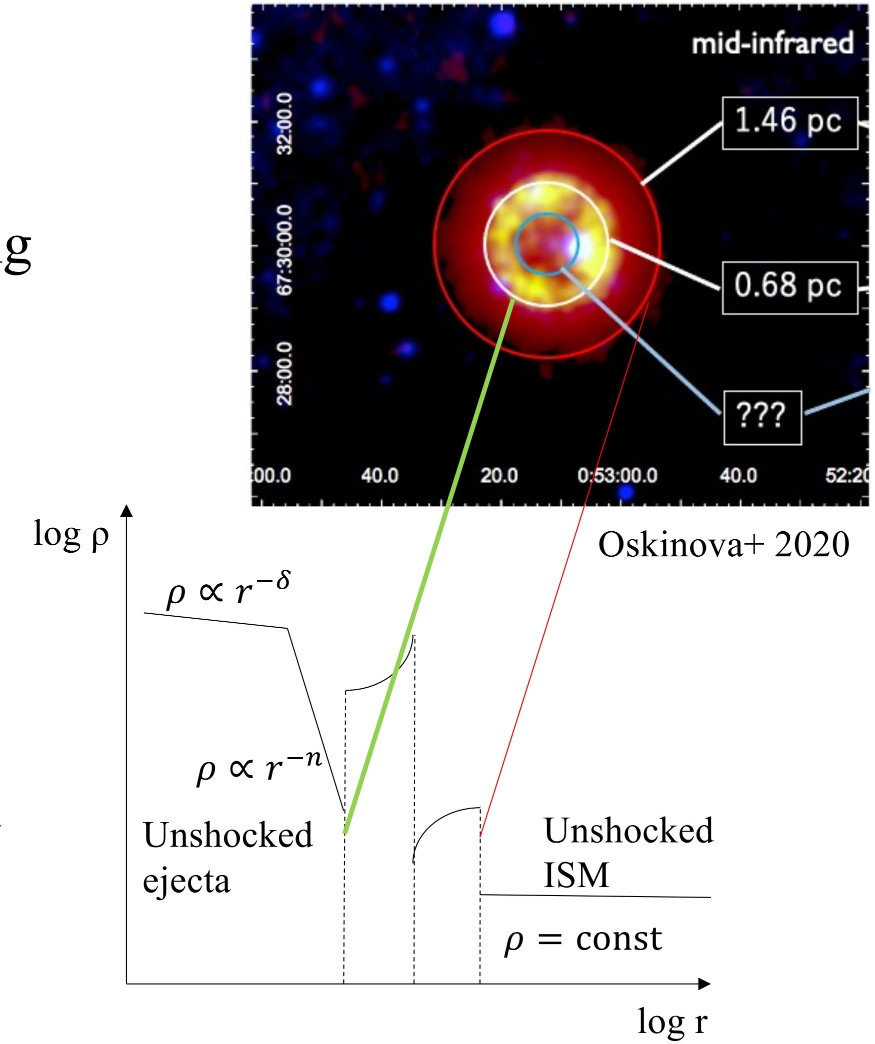
Ko+ 2024

Outer region modeling

- We calculate the shock evolution using solution by Chevalier 82



$\delta = 1.5, n = 6$



Outer region modeling

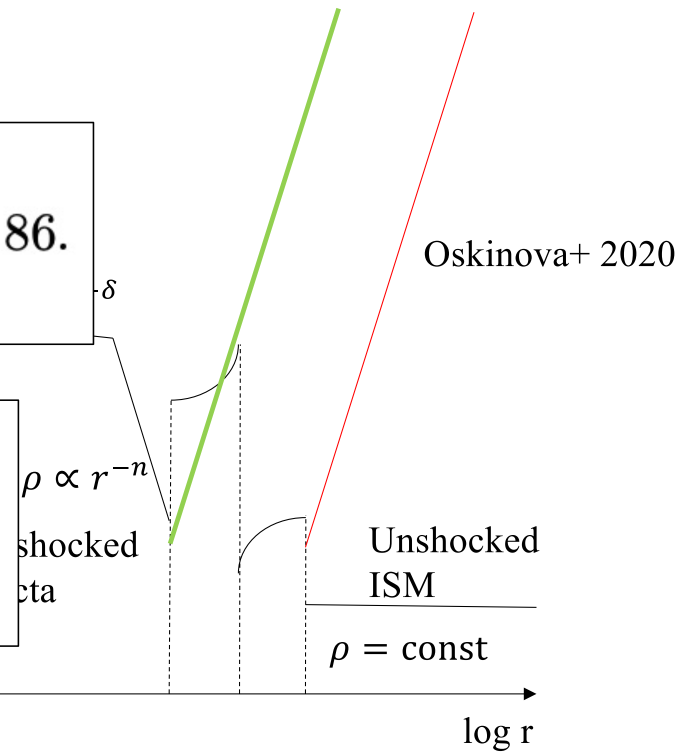
- We calculate the shock evolution using solution by Chevalier+82

$$\left(\frac{E_{\rm ej}}{10^{48}\ {\rm erg}}\right)^{-1/2}\left(\frac{M_{\rm ej}}{0.5\ M_\odot}\right)^{1/6}\left(\frac{\mu_{\rm ISM} n_{\rm ISM}}{0.1\ {\rm cm}^{-3}}\right)^{1/3} = 0.86.$$

$$n_{\rm ISM} = 0.11\ {\rm cm}^{-3}\left(\frac{{\rm EM}_{\rm out}}{3.7\times 10^{54}\ {\rm cm}^{-3}}\right)^{1/2}.$$

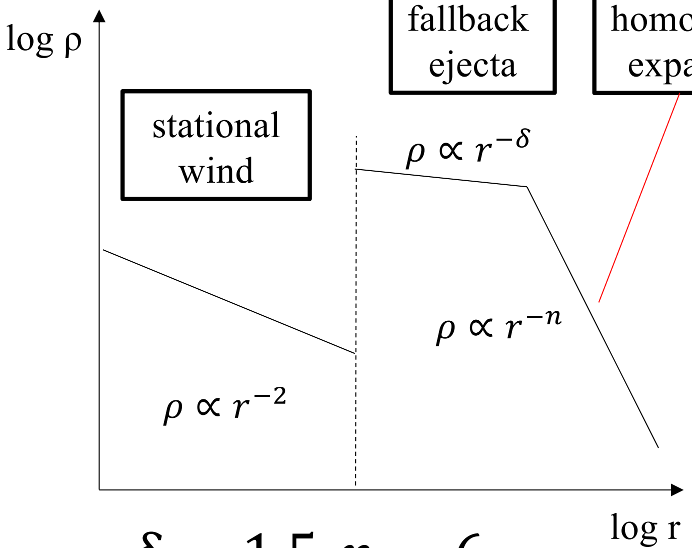
$\delta = 1.5, n = 6$

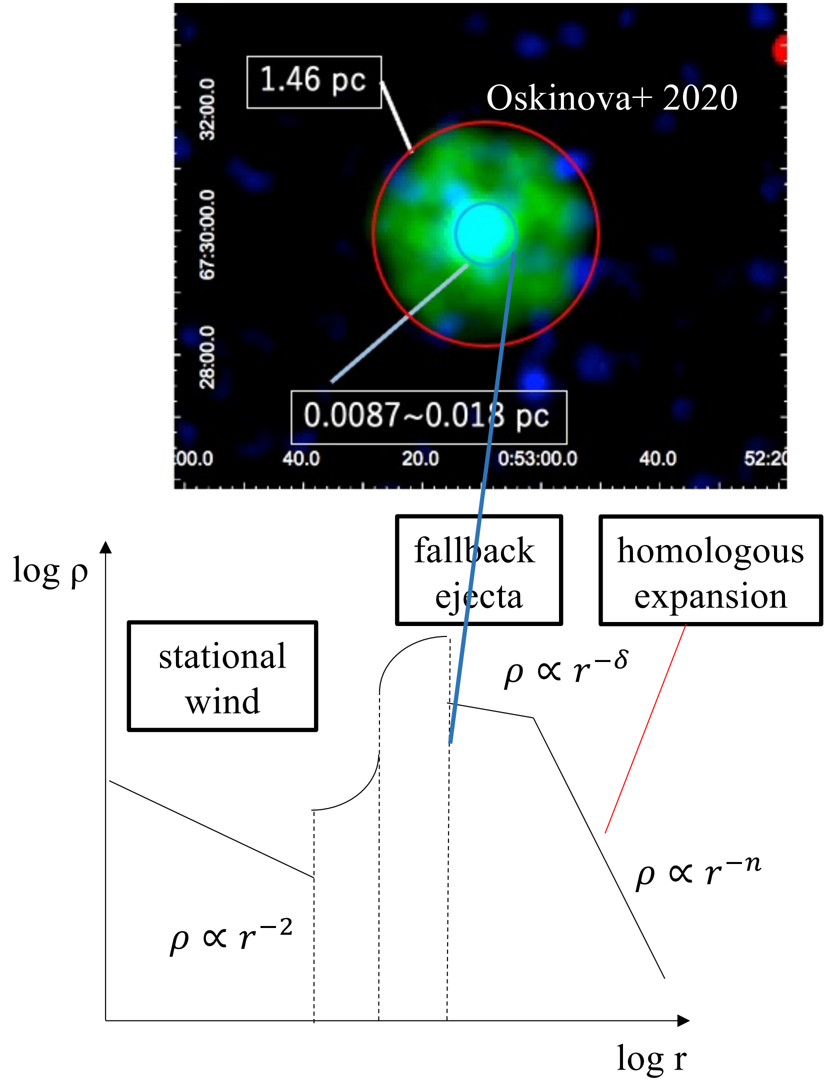
log r



Inner modeling

- We use thin shell approximation.





$$\delta = 1.5, n = 6$$

Inner modeling

- We use thin shell approximation.
- EOM + energy conservation of the shell

$$\frac{d}{dt}M_{\rm sh,in} = \dot{M}_{\rm w} + 4\pi r_{\rm sh}^2 \rho_{\rm ej}(r_{\rm sh}) \left(v_{\rm sh} + \sqrt{\frac{2GM_*}{r_{\rm sh}}} \right).$$

$$M_{\rm sh,in}\frac{dv_{\rm sh}}{dt} = 4\pi r_{\rm sh}^2 \left[p_{\rm sh} - \rho_{\rm ej}(r_{\rm sh}) \left(v_{\rm sh} + \sqrt{\frac{2GM_*}{r_{\rm sh}}} \right)^2 \right] - \frac{GM_{\rm sh,in}M_*}{r_{\rm sh}^2},$$

$$\frac{d}{dt}\left[\frac{4\pi r_{\rm sh}^3}{3} \frac{p_{\rm sh}}{\gamma - 1} \right] = L_{\rm w} - p_{\rm sh} \times 4\pi r_{\rm sh}^2 v_{\rm sh},$$

- If the observed wind is released steadily from the time of merger (1181 AD)

→ r_inner >> 0.018 pc （constraint from X-ray analysis）

Wind started blowing recently?

- Wind is produced by the surface burning of the massive WD

- Wind launching timescale can be estimated by Kelvin-Helmholtz timescale

$$t_{KH} = \frac{GM^2}{RL} \sim 1000 \text{ years}$$

Schwab+ 2016

- We consider the wind started blowing recently → free parameter

Parameters of our model

	parameters estimated from observations	
distance	d [kpc]	$2.3^{+0.1}_{-0.1}$
wind mass loss rate	$\dot{M}_{\rm w}$ [$M_\odot\,{\rm yr}^{-1}$]	(7.5–40) $\times 10^{-7}$
wind mechanical luminosity	$L_{\rm w}$ [${\rm erg\,s^{-1}}$]	(0.53–2.8) $\times 10^{38}$
angular radius	$\theta_{\rm in}$ [arcsec]	0.77 – 1.6
	$\theta_{\rm out}$ [arcsec]	129^{+3}_{-3}
	$\theta_{\rm d}$ [arcsec]	60^{+12}_{-12}
expansion velocity	$v_{\rm SII}$ [${\rm km\,s^{-1}}$]	1100^{+100}_{-100}
emission measure	${\rm EM_{in}}$ [$10^{52}\,{\rm cm^{-3}}$]	180±40 (near-solar)
		6.3±1.1 (pure metal)
	${\rm EM_{out}}$ [$10^{52}\,{\rm cm^{-3}}$]	370±100 (near-solar)
		3.6±0.8 (pure metal)
	parameters estimated from our model	
power-law index of the SN ejecta density profile	n	6 (fixed)
	δ	1.5 (fixed)
number density of ISM	$n_{\rm ISM}$ [${\rm cm^{-3}}$]	?
ejecta kinetic energy	$E_{\rm ej}$ [10^{48} erg]	
ejecta mass	$M_{\rm ej}$ [$M_\odot$]	
wind launching time	$t_{\rm w}$ [yr]	

Ko+2023

What we want to obtain

Parameters of our model

Outer analysis gives

$$\left(\frac{E_{\rm ej}}{10^{48}\,{\rm erg}}\right)^{-1/2}\left(\frac{M_{\rm ej}}{0.5\ M_\odot}\right)^{1/6}\left(\frac{\mu_{\rm ISM}n_{\rm ISM}}{0.1\ {\rm cm}^{-3}}\right)^{1/3}=0.86.$$

$$n_{\rm ISM}=0.11\ {\rm cm}^{-3}\left(\frac{{\rm EM}_{\rm out}}{3.7\times10^{54}\ {\rm cm}^{-3}}\right)^{1/2}.$$

We solve the inner region with each parameter sets: $M_{\rm ej}, t_{\rm wind}$

Inner region calculations

We solve these equations with each parameter sets: M_{ej}, t_{wind}

compared with

Constraints :

- $5.0 \times 10^{52}\,\mathrm{cm}^{-3} < \mathrm{EM_{wind}} < 7.6 \times 10^{52}\,\mathrm{cm}^{-3}$. at 2021
- 0.0087 < r < 0.018 pc at 2021
- t_{wind} < 828 yr

$$\frac{d}{dt}M_{\rm sh,in} = \dot{M}_{\rm w} + 4\pi r_{\rm sh}^2 \rho_{\rm ej}(r_{\rm sh})\left(v_{\rm sh} + \sqrt{\frac{2GM_*}{r_{\rm sh}}}\right).$$

$$M_{\rm sh,in}\frac{dv_{\rm sh}}{dt} = 4\pi r_{\rm sh}^2\left[p_{\rm sh} - \rho_{\rm ej}(r_{\rm sh})\left(v_{\rm sh} + \sqrt{\frac{2GM_*}{r_{\rm sh}}}\right)^2\right] - \frac{GM_{\rm sh,in}M_*}{r_{\rm sh}^2},$$

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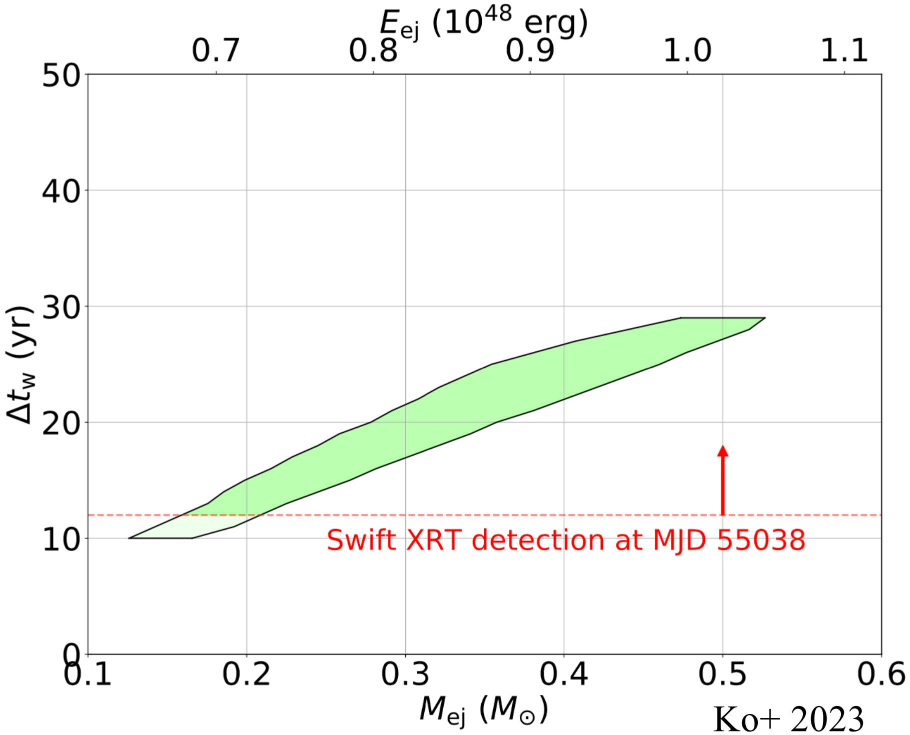
Results



Ko+ 2023

$$12\ \mathrm{yr} < \Delta t_w < 30\ \mathrm{yr}$$
$$0.18 M_\odot < M_{\mathrm{ej}} < 0.53 M_\odot$$
$$0.77\times 10^{48}\ \mathrm{erg} < E_{\mathrm{ej}} < 1.1\times 10^{48}\ \mathrm{erg}$$

Progenitor mass

- progenitor binary mass = remnant mass +ejecta mass

$1.1 < M_{WD} < 1.3M_{\odot}$ (Kashiyama +2019)
$0.18M_{\odot} < M_{\rm ej} < 0.53M_{\odot}$ (This work)

- progenitor binary mass : $1.3 - 1.8\ M_{\odot}$

→ ONe WD + CO WD? as Kashyap+2018 reported.

What is SN Iax?

- Type Iax SN → sub-luminous Type Ia SN
- thought to leave a white dwarf as a remnant
- typical ejecta mass ~ 0.5 solar mass
- rate → ~10% of SN Ia rate

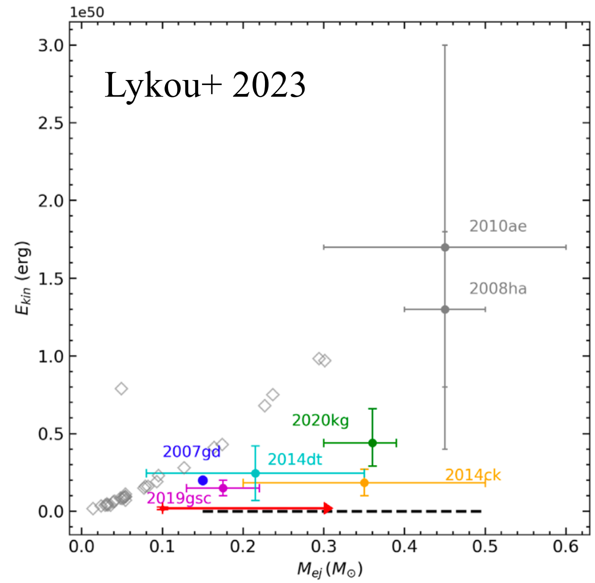
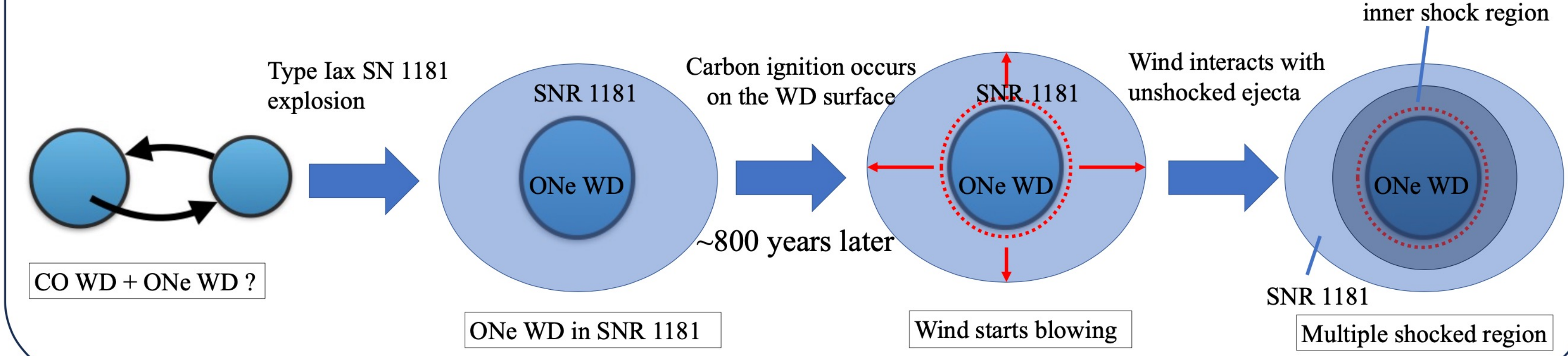


Figure 13. Comparison of the ejecta mass against kinetic energy released by Type Iax SNe. Pa 30/SN 1181 is marked in red. Lach et al. (2022) models are also shown (open diamonds), while the range of expected values for Iax by Foley et al. (2013) is shown in black (dashed). A few examples of known extragalactic Iax are also shown: 2008ha and 2010ae data by Stritzinger et al. (2014), 2007gd by McClelland et al. (2010), 2014ck by Tomasella et al. (2016), 2019gsc by Srivastav et al. (2020), and 2020kg by Srivastav et al. (2022).

Physical quantities of SN 1181 estimated by our work are almost consistent with SN Iax
→ our model strongly suggests IRAS 00500+6713 is Type Iax SN 1181 remnant !

The time evolution of SNR 1181 from the explosion



Conclusion of the first paper

- IRAS 00500+6713 has been a leading candidate of SNR 1181
- Type Iax SN 1181 remnant has a multiple layer and includes a massive ONe WD
- We follow the time evolution of the SNR 1181 and obtain
  - ejecta from SN 1181 : $0.18 M_{\odot} < M_{\rm ej} < 0.53 M_{\odot}$
  - SN 1181 energy : 0.77×10^{48} erg $< E_{\rm ej} < 1.1\times10^{48}$ erg
- These values are consistent with the assumption that type Iax SN occurred at 1181

→ strongly supports that IRAS 00500+6713 is a SN 1181 remnant

- Fast wind started blowing recently! 12 yr $< \ \Delta t_w \ < 30$ yr
- WD J005311 was formed by ONe WD + CO WD

  and mass of the binary system is $1.3 - 1.8\ M_{\odot}$

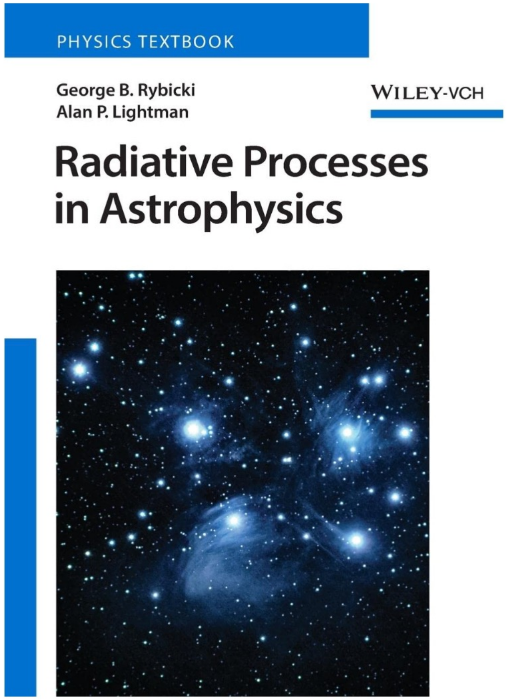
Wind started blowing recently?

- The KH timescale ~ 1000 yr → The wind can start blowing recently
- By checking this, we can justify our theoretical model.

→ Precise spread and the expansion velocity is required.

- Radio observation → from next slides
  - Better spatial resolution
  - Magneto structure
- XRISM observation → future work (the deadline of the proposal is Feb. 22nd) 😢
  - Better energetic resolution → We may be able to obtain the expansion velocity from the spectral
  - Precise composition

Synchrotron Emission



$$P_{\mathrm{syn},i}(\omega) = \frac{\sqrt{3}e^3 C B_i \sin\alpha}{2\pi m_e c^2 (p+1)} f(p) \left(\frac{m_e c \omega}{3 e B_i \sin\alpha} \right)^{-(p-1)/2}$$

$$N(E) \propto E^{-p}$$

$p \sim 2.5, 3$ in SNR context

$$\int E N(E) dE = \epsilon_e \rho v^2 .$$

Electron acceleration efficiency

$10^{-4} < \epsilon_e < 10^{-2}$

for historical SNR, young SN

Magnetic field

$$\frac{B_i^2}{8\pi} = \epsilon_B \rho_i v_i^2$$

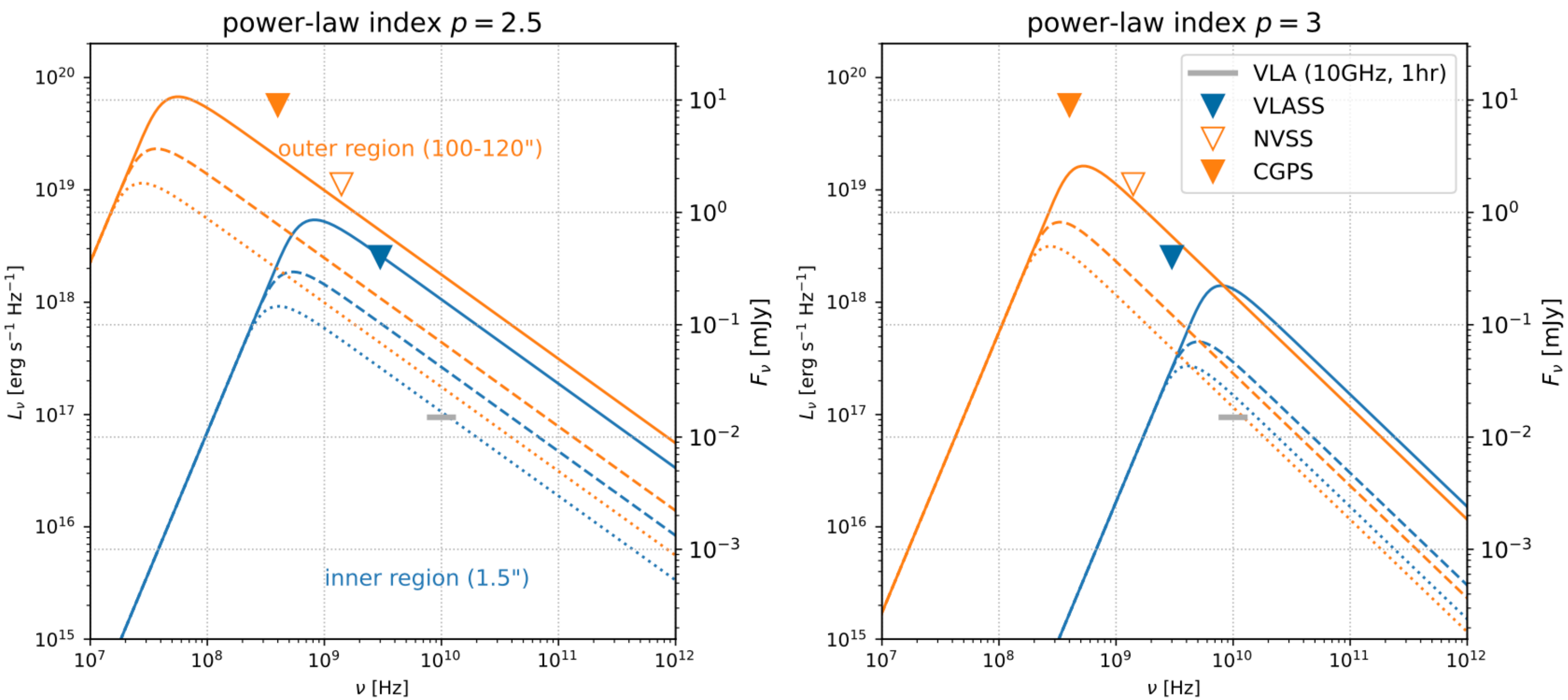
Magnetic-field amplification efficiency

$$B_{\rm in} \approx 0.70 \ {\rm mG} \left(\frac{\epsilon_B}{0.01}\right)^{1/2}, \ B_{\rm out} \approx 32 \ \mu{\rm G} \left(\frac{\epsilon_B}{0.01}\right)^{1/2}.$$

Synchrotron Emission

$s = 2.5$	
Optimistic	$\epsilon_e = 1 \times 10^{-3}$
Fiducial	$\epsilon_e = 3 \times 10^{-4}$
Pessimistic	$\epsilon_e = 1 \times 10^{-4}$
$s = 3$	
Optimistic	$\epsilon_e = 2 \times 10^{-2}$
Fiducial	$\epsilon_e = 5 \times 10^{-3}$
Pessimistic	$\epsilon_e = 1 \times 10^{-3}$

Ko+ 2024

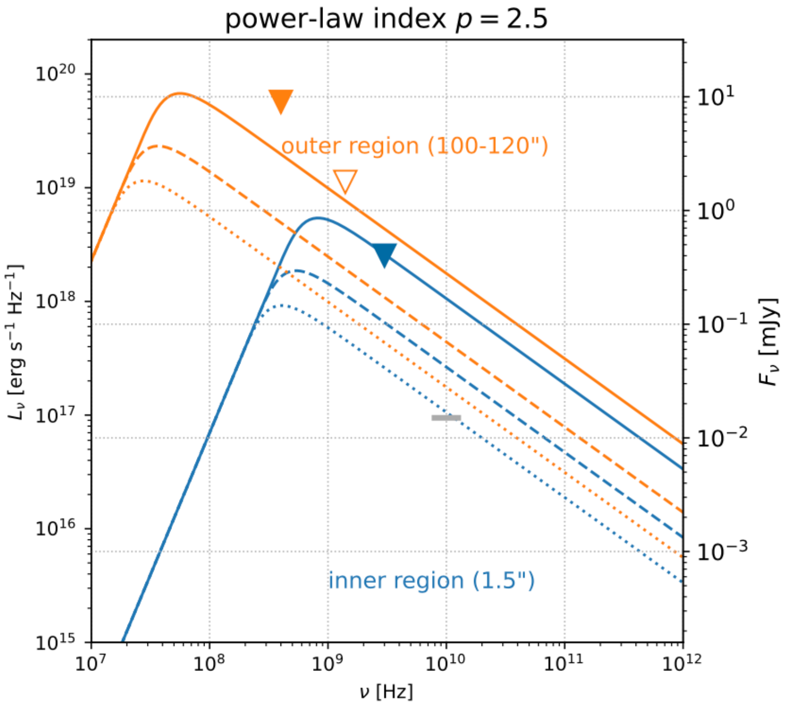


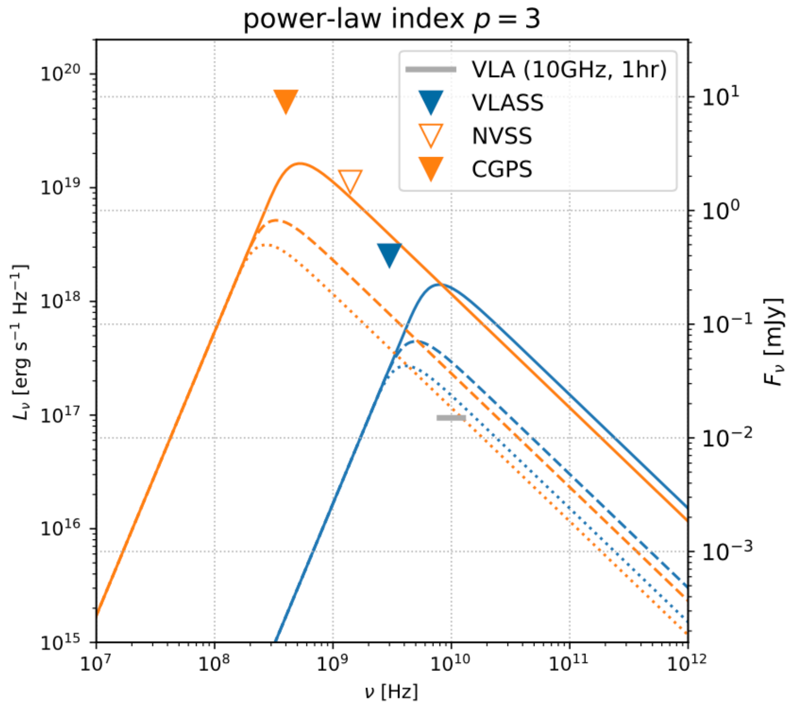
Radio archive data

No detection by VLASS, NVSS, CGPS (3 sigma)

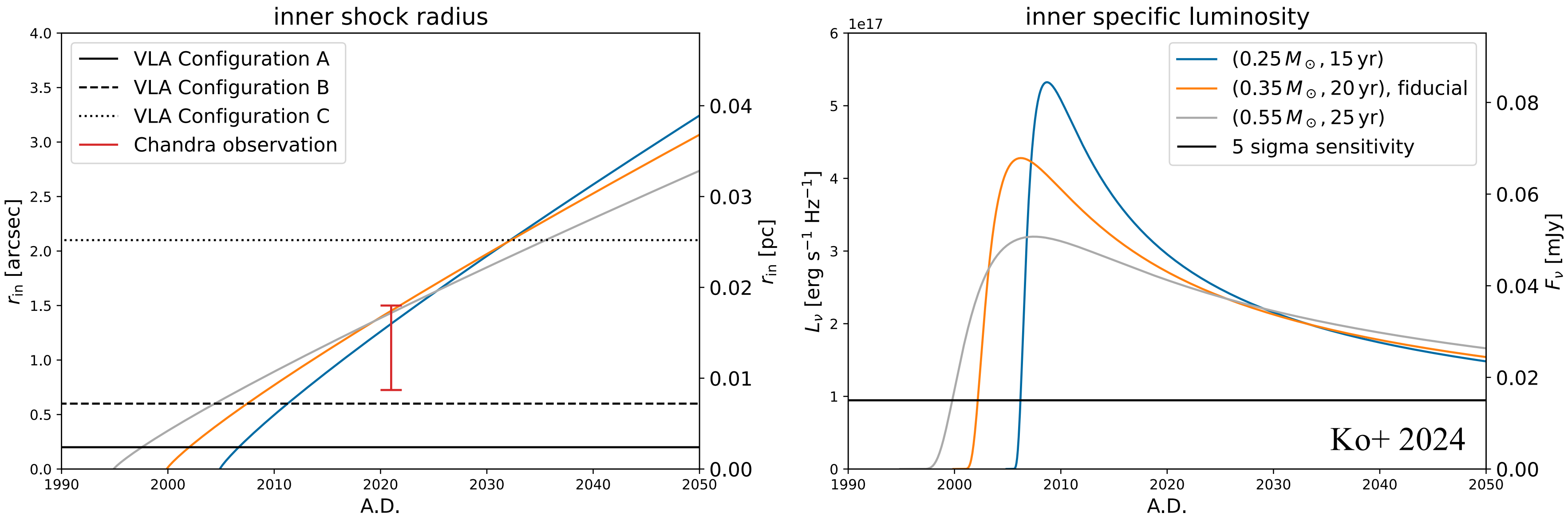
$s = 2.5$	
Optimistic	$\epsilon_e = 1 \times 10^{-3}$
Fiducial	$\epsilon_e = 3 \times 10^{-4}$
Pessimistic	$\epsilon_e = 1 \times 10^{-4}$
$s = 3$	
Optimistic	$\epsilon_e = 2 \times 10^{-2}$
Fiducial	$\epsilon_e = 5 \times 10^{-3}$
Pessimistic	$\epsilon_e = 1 \times 10^{-3}$

Ko+ 2024



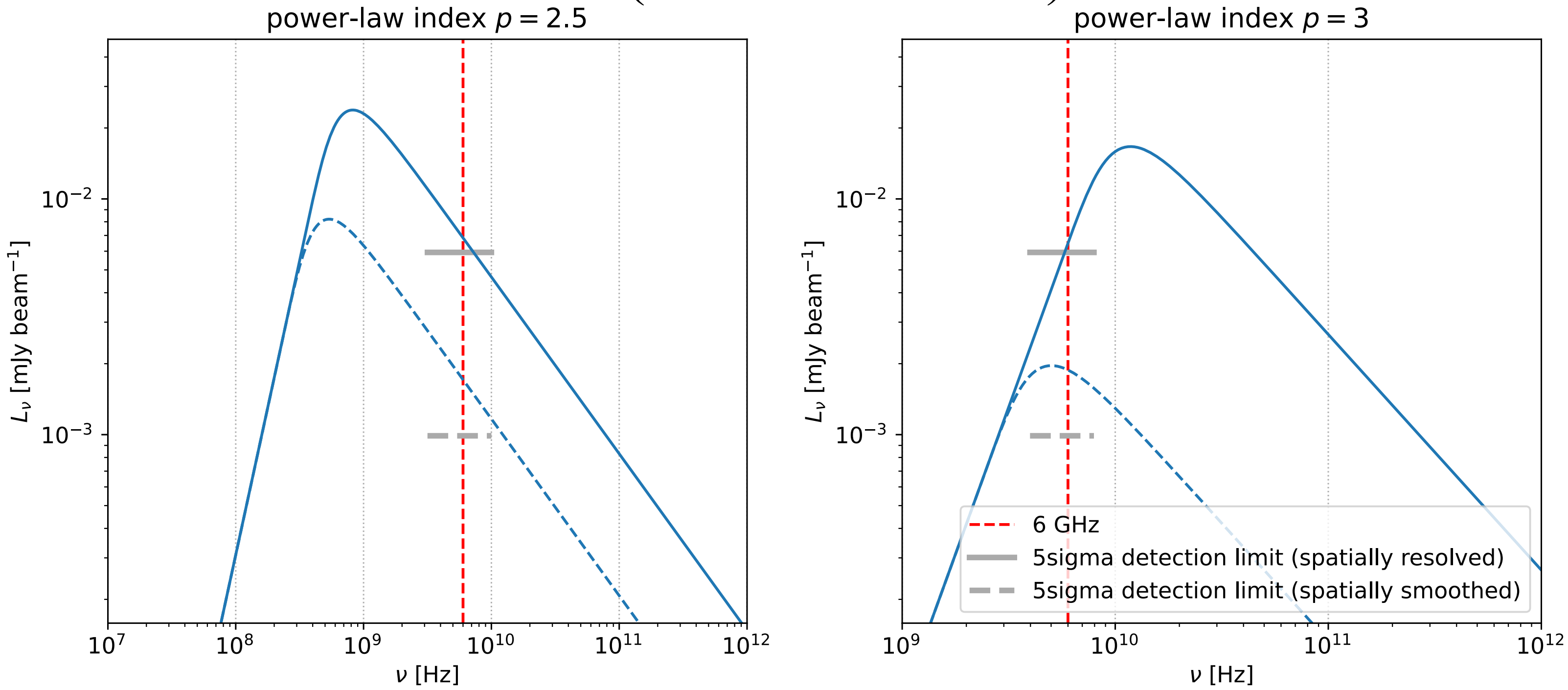


Radio future observation



Proposal for VLA

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



Future work

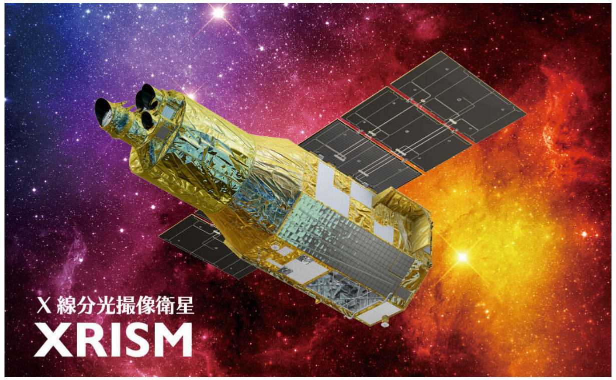
• Radio observation

→ spatial information

proposal to VLA (submitted)

• XRISM observation → spectral information

(deadline 2/22)



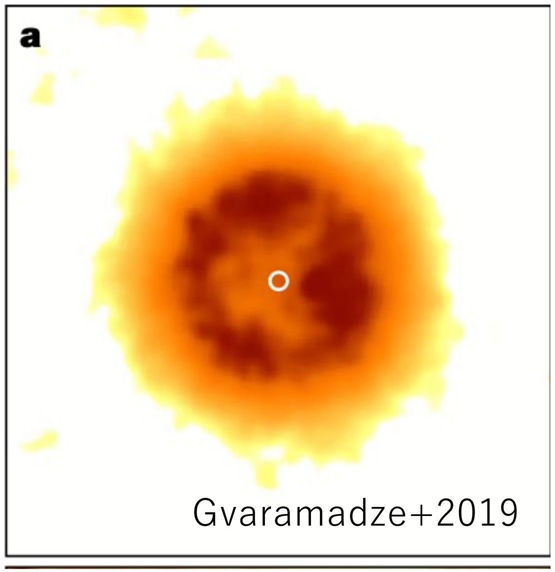
• Why wind started blowing recently?

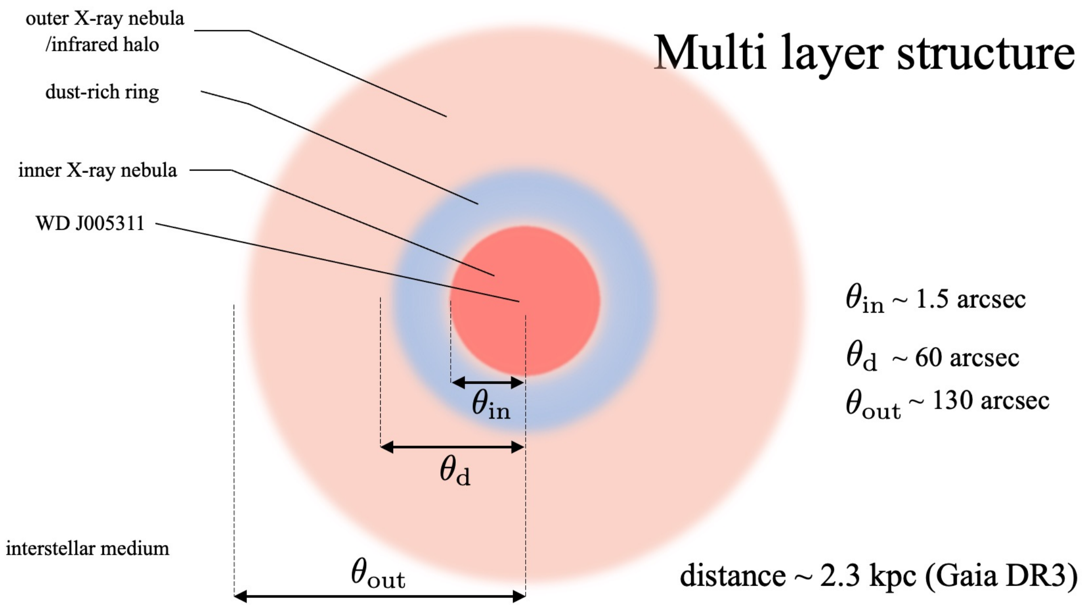
→ theoretical modeling (carbon accretion on ONe WD)

Other interesting Features

Dust Features

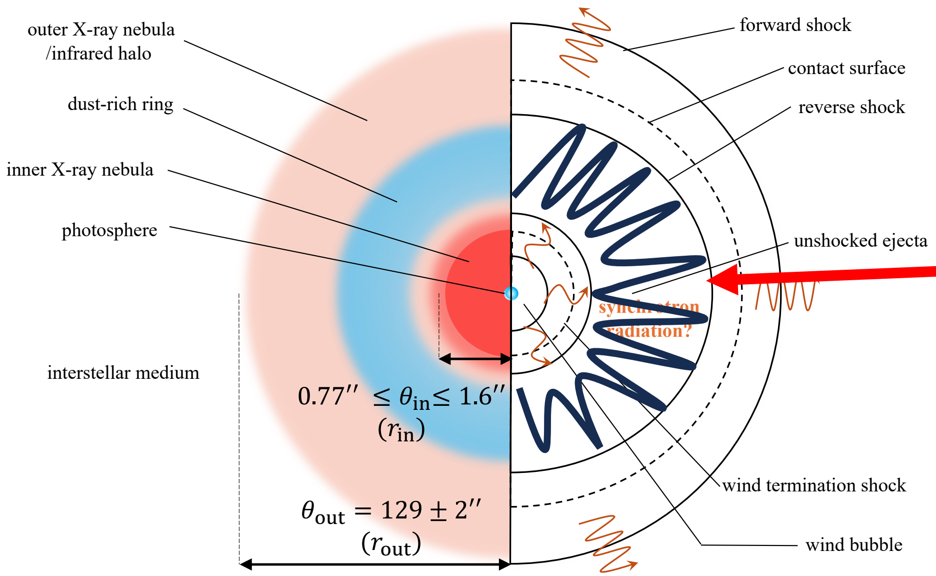
- We cannot explain the dust formation and extinction.
- Only a few SN Ia(x) remnant with dust inside the remnant.

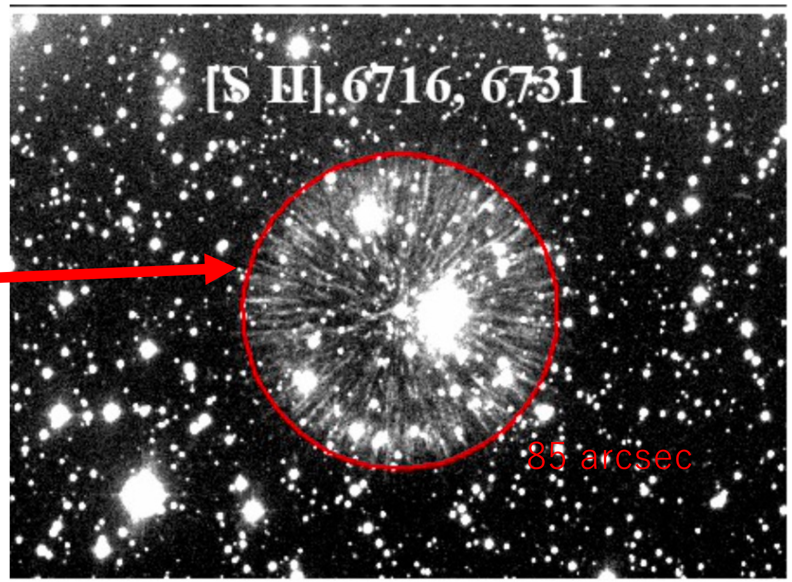




Filaments Structure

- long filament structure (Fesen+2023)



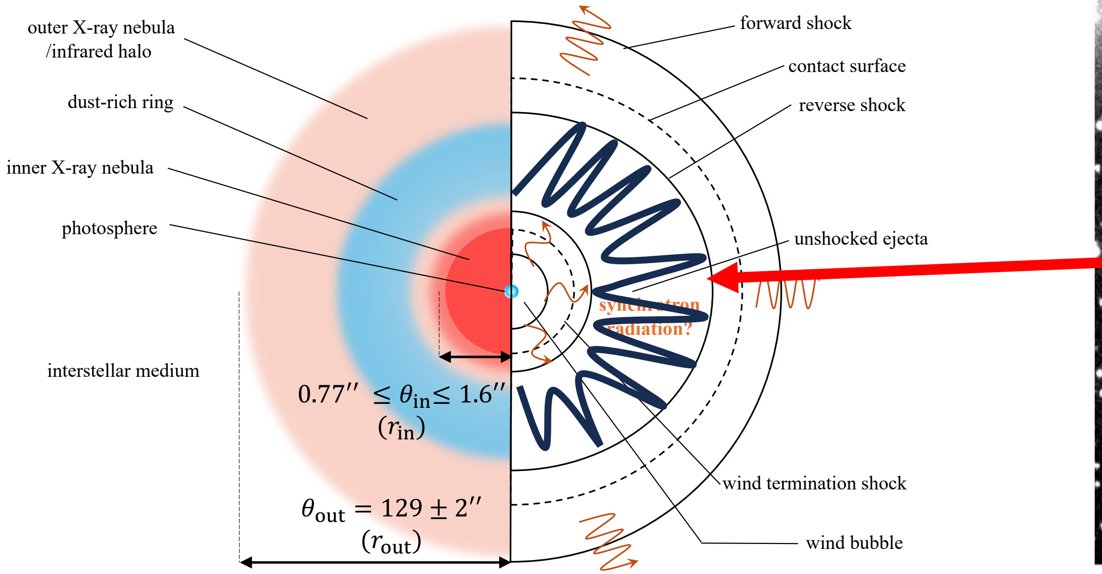


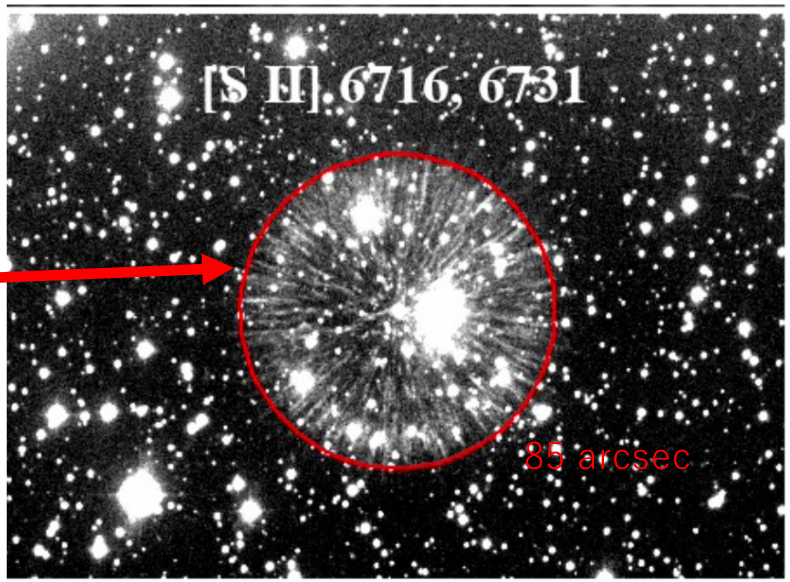
Fesen+2023

To Reveal the Filament Structure

- Are there such filament structures in outer shocked ISM/ejecta ?

→ Subaru narrow band imaging (Hα)





Fesen+2023

Hα line in the outer shocked ISM

Virginia Tech "Hα" Spectral-line Survey (VTSS; Dennison et al. 1998)

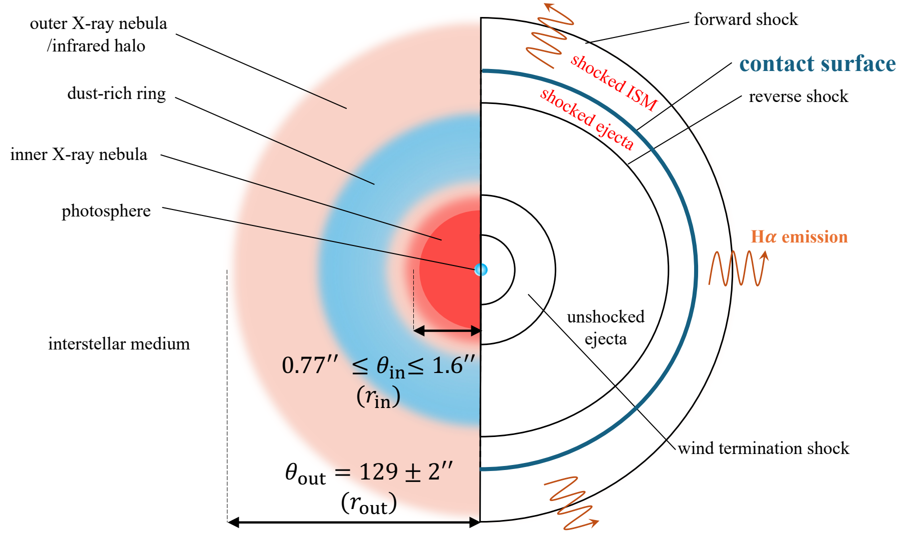
→ tentatively detected (~ 200 uJy or ~ 18 mag)

→ proposal for Subaru (~1 mins)

→ Where is the contact surface?

ISM number density?

Are there filament structure?



Proposal Deadline : April 2nd

w/ K. Maeda, K. Uno, K. Taguchi,

T. Shigeyama, Y. Shiraishi

Dust Features (ongoing with Hotoke-san)

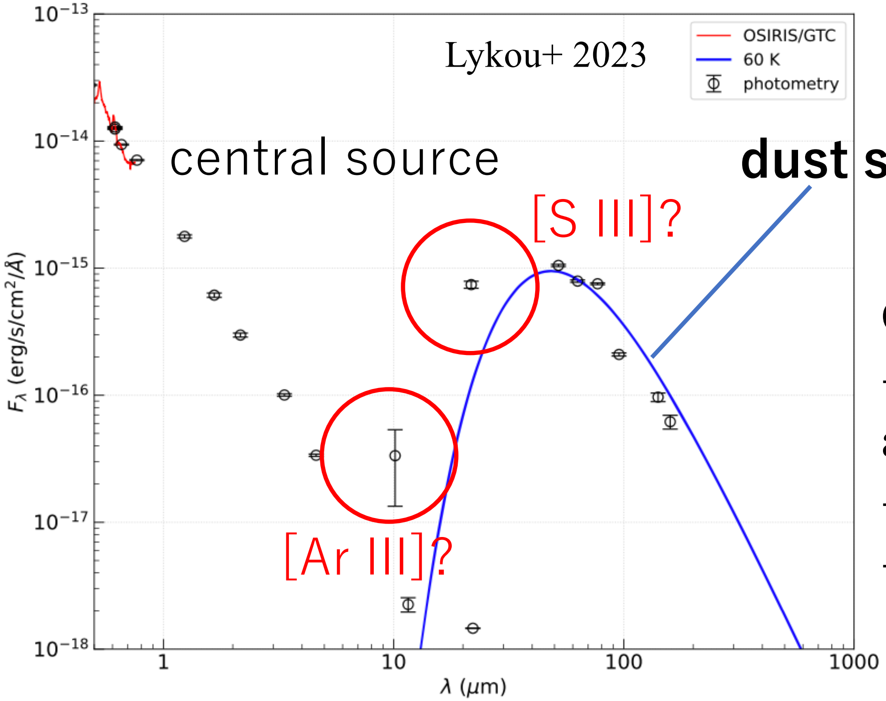


Figure 12. Infrared SED of Pa 30, including the new photometry in Section 5.2 (60 K blackbody; blue) and the OSIRIS/GTC spectrum (red). There is no IR excess below 10 μm. The photometry below 3 μm and spectrum have been dereddened using extinction from Paper I.

Optical observation
→ Only [S II] λ6716, 6731 and [Ar III] λ7136 are detected in the unshocked ejecta.
→ [S II] 20um and [Ar III] 9um are expected
→ Something like that from the photometry data!

↓

unshocked ejecta properties
(electron temperature, number density...)

Searching for the companions

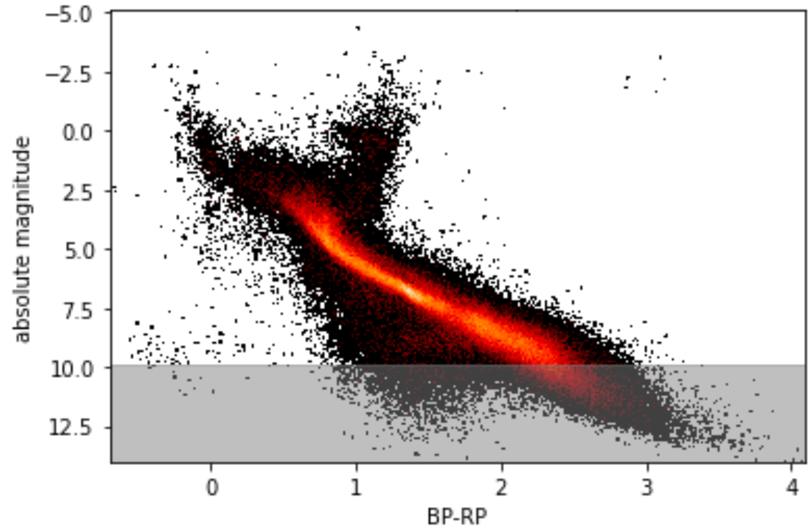
- SD vs DD
- If SD, companion must survive
- If DD, no companion

- If exists, can we find it by Subaru?

→ No.

Because the binary would not break…

Since a WD is left…

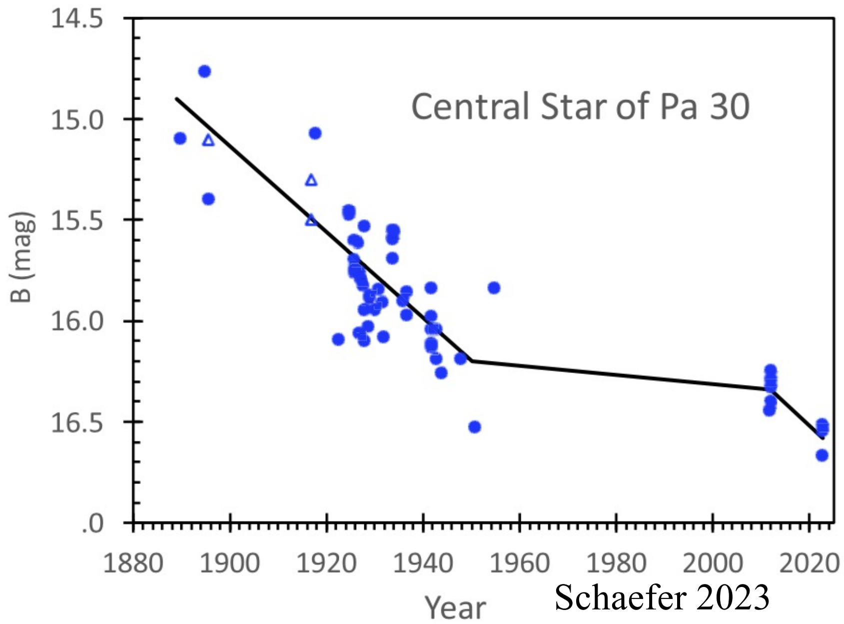


Created by Shiraishi-kun based on Gaia data

Features our model cannot explain

- Schaefer 2023 examined approximately 100 years of the object's luminosity and found that the luminosity has been fading.

- We guess this might relate to the wind starting blowing recently

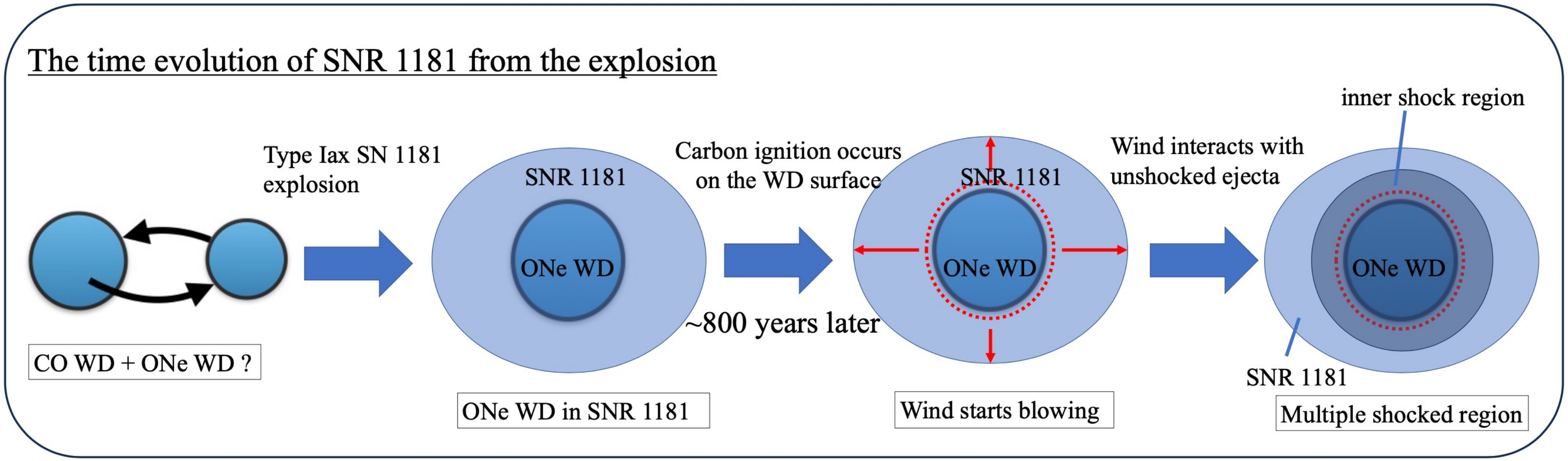


Schaefer 2023

Figure 7. The central star is fading fast from 1889 to 2022. This light curve is from Table 2, with typical error bars of 0.10–0.15 mag before 1960, and ±0.03 for the last two decades. All data sets have the observed scatter around the mean light curve being substantially larger than the measurement errors, so the scatter is dominated by the intrinsic night-to-night variability of order 0.2 mag. The primary point of this figure is to test my prediction that a surviving stellar remnant of an 842-year-old supernova might still be fast fading over the past century. To test this prediction, it is vital that all the *B* magnitudes be calibrated into an identical photometric system, and this renders useless the large amounts of post-1950 photometry. The result of this test is that the stellar remnant is certainly fading at a fast rate, with a drop of 1.68 mag in the last 105 yr.

Please remember

- There is a recently-identified historical SNR 1181 with a massive WD in its center.
- There may be several such SNRs (or WDs) in our universe.



Sculpting the Morphology of Supernova Remnant Pa 30 via Efficient Ejecta Cooling

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ABSTRACT

We demonstrate in a proof-of-concept numerical hydrodynamics calculation that the narrow radial filamentary structures seen in Pa 30 could be generated through highly efficient cooling (e.g. via line emission) in the ejecta. Efficient cooling in the ejecta causes a drop of pressure support in Rayleigh-Taylor fingers, leading them to be compressed, and suppressing the growth of Kelvin-Helmholtz instability. Following this result, we make three predictions that could determine whether this is the mechanism responsible for shaping Pa 30: First, we predict very strong emission lines, strong enough to cool a significant fraction of the shock energy in an expansion time. Secondly, we predict that the forward shock should be highly corrugated on small scales, with the shock front closely following the structure of the filaments. Third, we predict that these filaments should be nearly ballistic, with velocities around 90% of the free-expansion velocity ($v \approx 0.9\ r/t$). These predictions should be falsifiable in follow-up observations of this remnant.

Keywords: supernovae, shocks, supernova remnants, hydrodynamics

Figure 1. Passive scalar X denoting composition (ejecta vs. CSM) at $t = T_{\rm sweep}$. Upper half employs cooling and lower half included no cooling.