Introduction to Our Research on SN1987A

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N3AS-ASPIRE Meeting 2024, RIKEN Wako Presentation Date: 18/Jun/2024.

Image: M44, Credit: NAOJ

Massive Stars Explode as Supernovae

Massive Stars ≡ Stars with mass of (10–25) M_s.

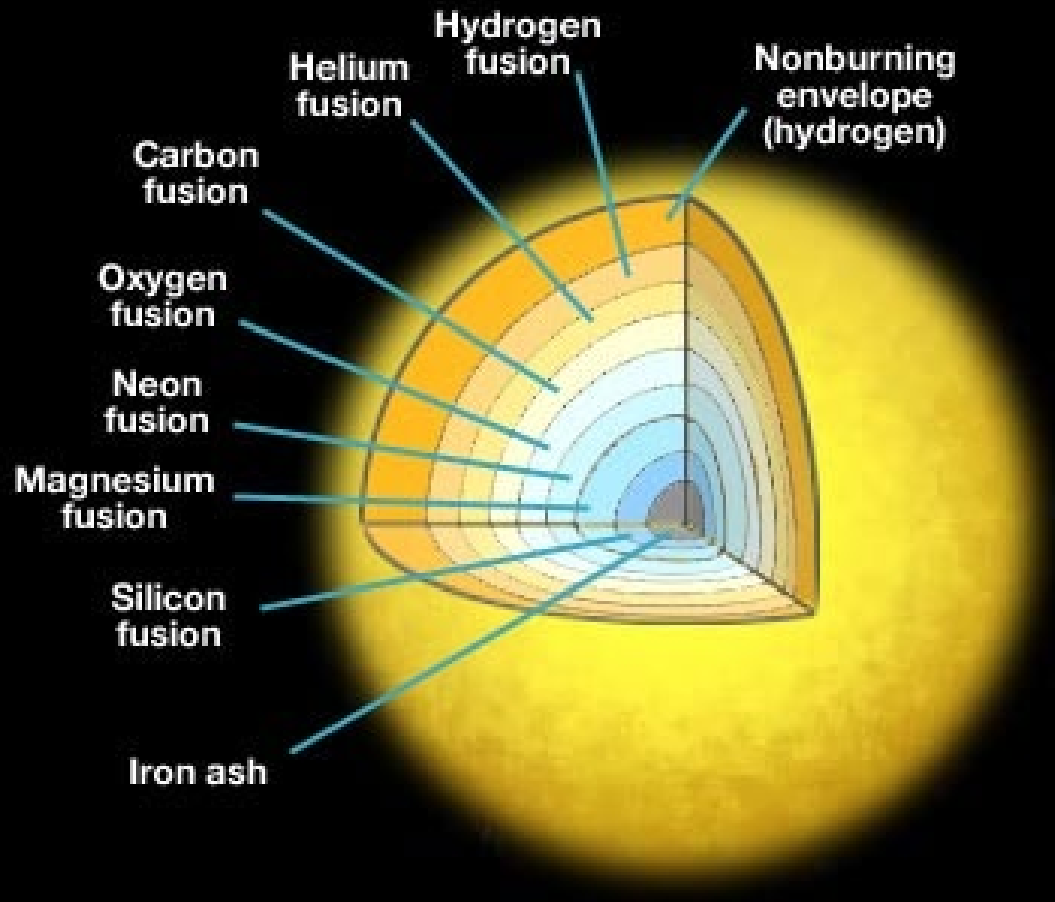
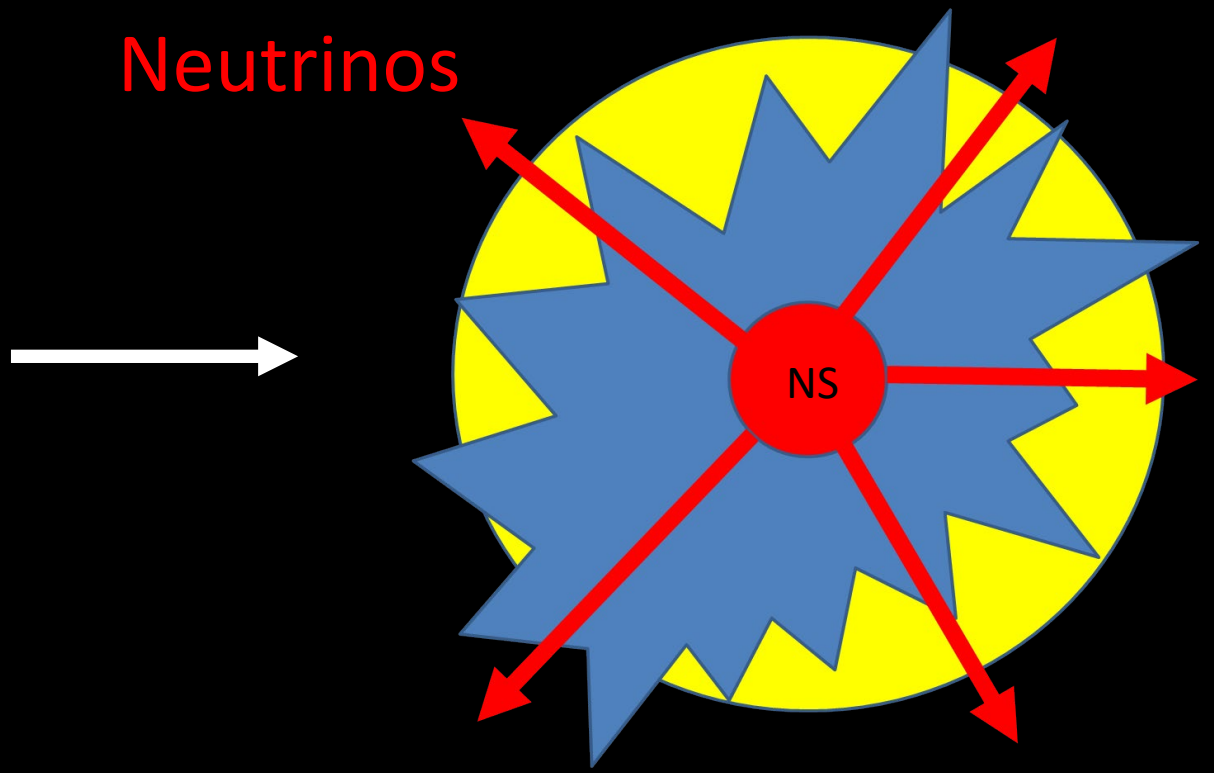
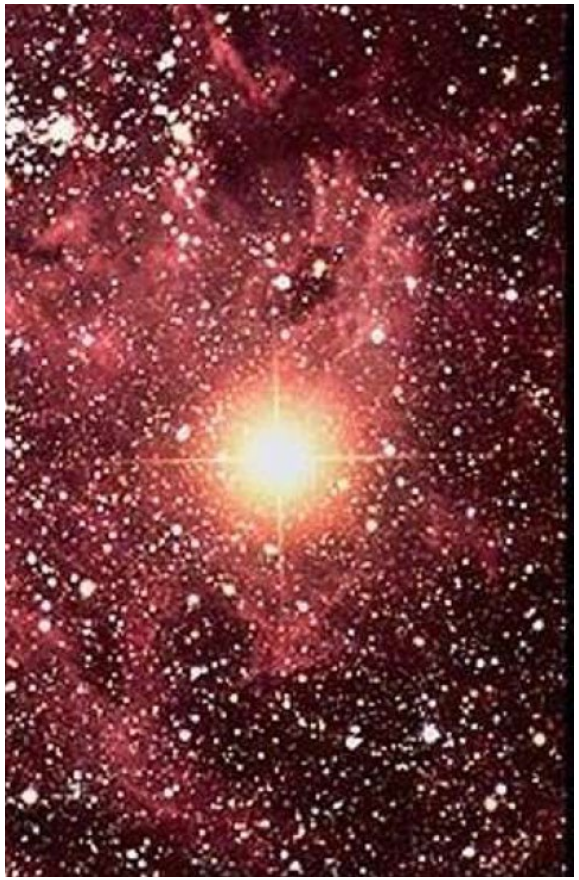


Image Credit: Penn State Astronomy & Astrophysics



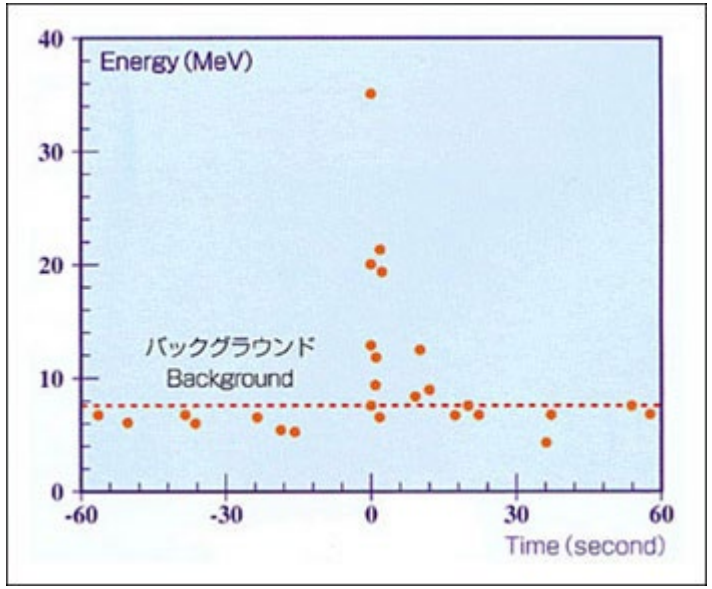
Iron Core Collapses and Neutron Star (NS) is formed at the Center.
The stiff NS makes an out-going shock wave and neutrinos from the NS heat the shock wave, which results in a supernova (e.g. Bethe & Wilson 1985).

SN1987A : Detections of Supernova Neutrinos

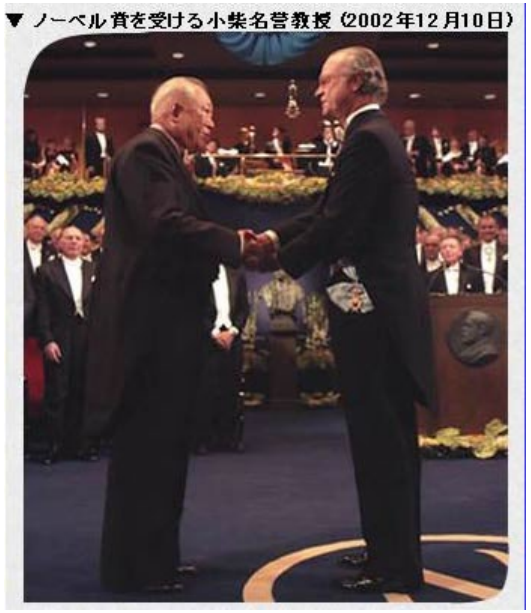


Sanduleak -69° 202, the Progenitor Star of SN1987A.
Blue-Super Giant.
$\sim 20\ M_s$.

SN1987A happened in Large Magellanic Clouds on 23 Feb. 1987.
The visible SN by naked eyes, about 350yrs after the last one (Cassiopeia A).

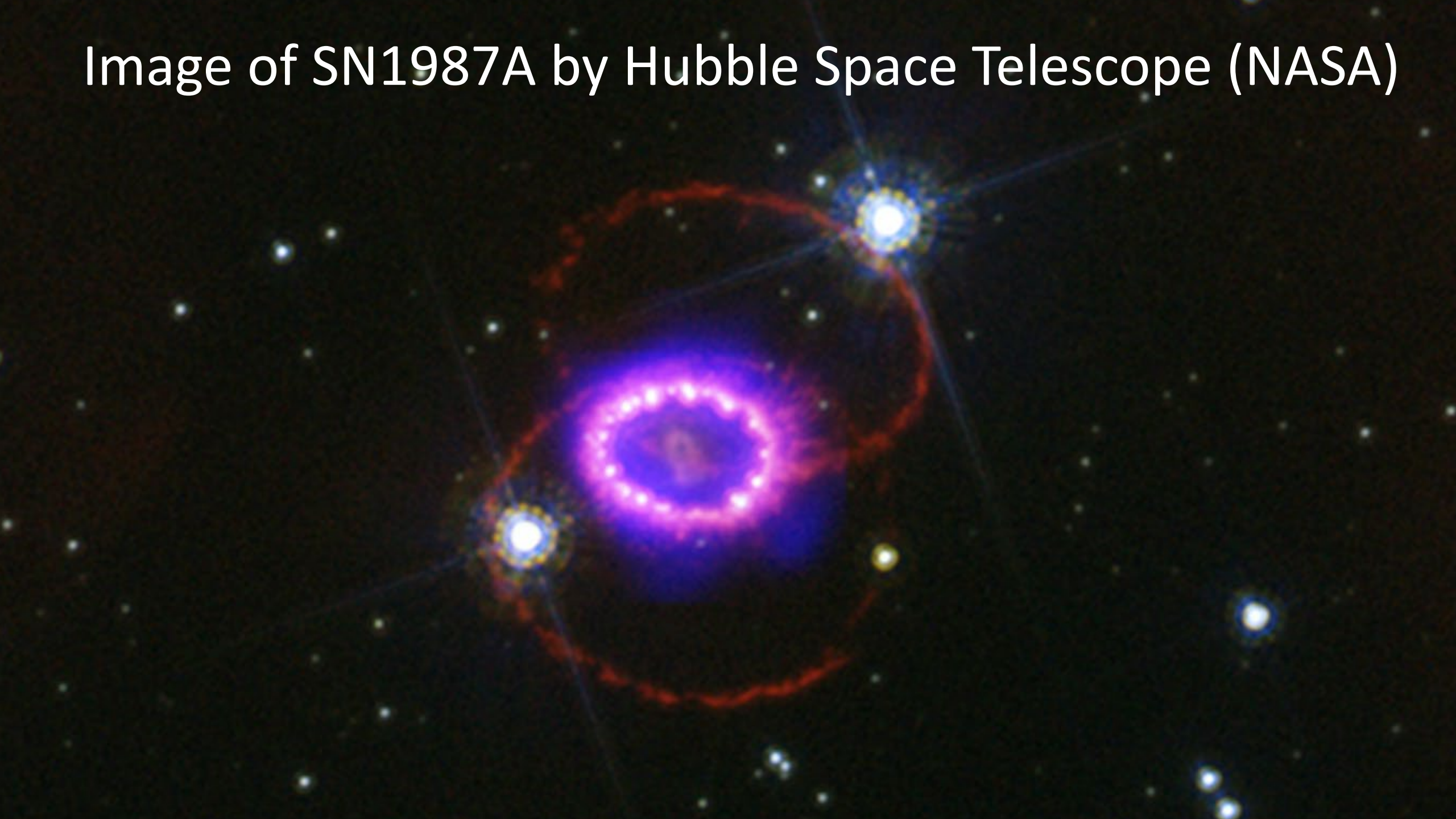


The 11 events of neutrinos from SN1987A, detected by Kamiokande.



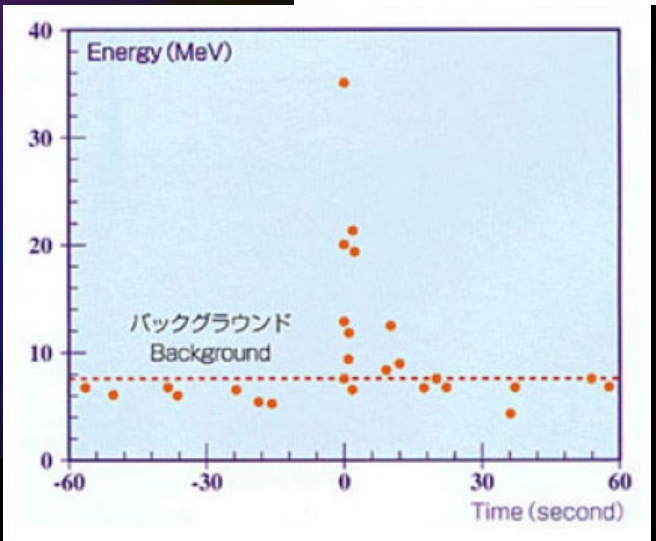
Masatoshi Koshiba
Nobel Prize in Physics 2002
for the detection of cosmic neutrinos.

Image of SN1987A by Hubble Space Telescope (NASA)

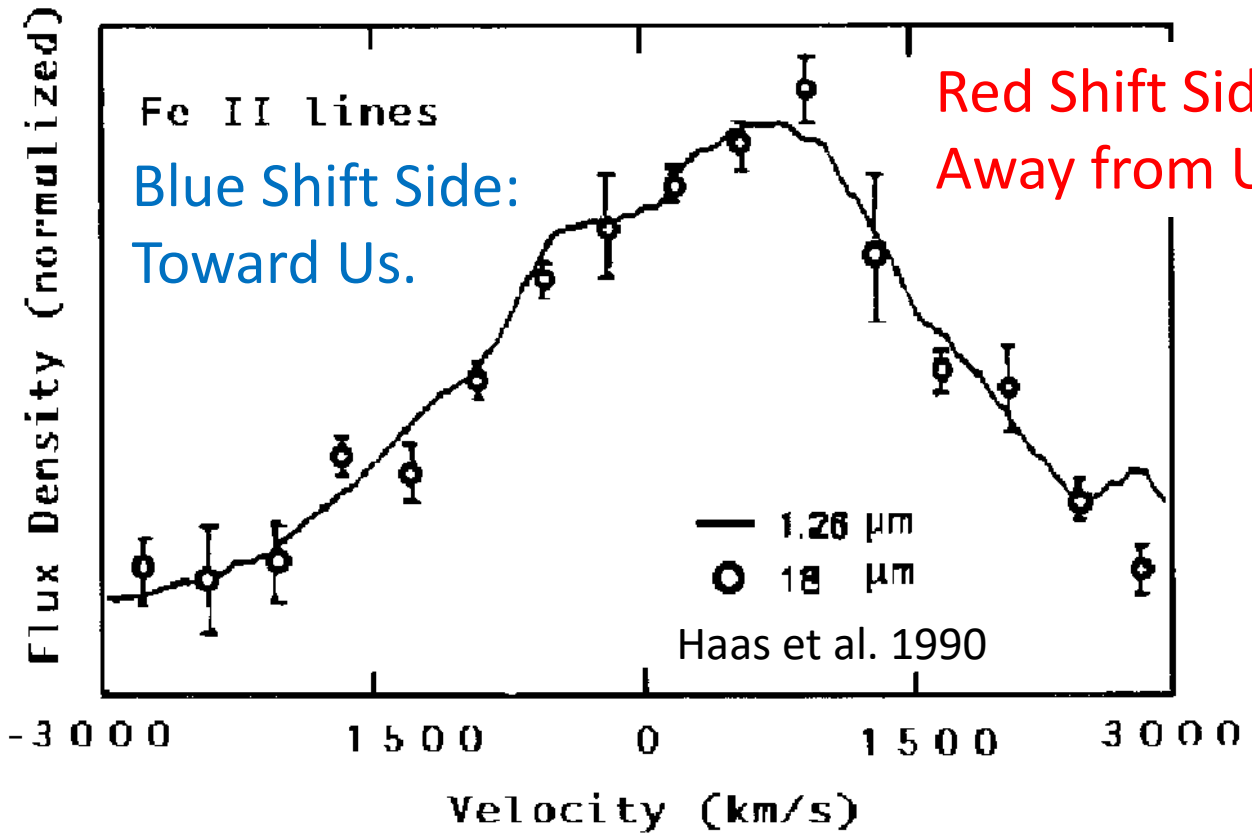


Where is the Neutron Star in SN1987A Now?

Prof. Koshiba



The Iron Emission Lines from SN1987A Changed My Life.



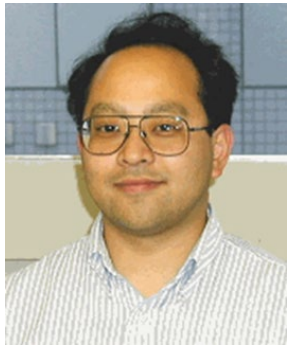
From this line profile, we concluded in 1997-2000 that

- **SN1987A was a Bi-Polar like explosion.**
- **Explosion was stronger in Red Shift Side and weaker in Blue Shift Side.**
- **The Neutron Star of SN1987A should be moving toward Blue Shift Side.**

S. Nagataki

K. Sato

M. Hashimoto



S. Yamada

Nagataki, Hashimoto, Sato, Yamada 1997
Nagataki, Shimizu, Sato 1998
Nagataki 2000

I got my Ph.D. degree in 1998, and I became an assistant professor in 2002.
Thesis Title: “Effects of Jet-Like Explosions in Collapse-Driven Supernovae”

Bi-Polar Explosion was Confirmed.

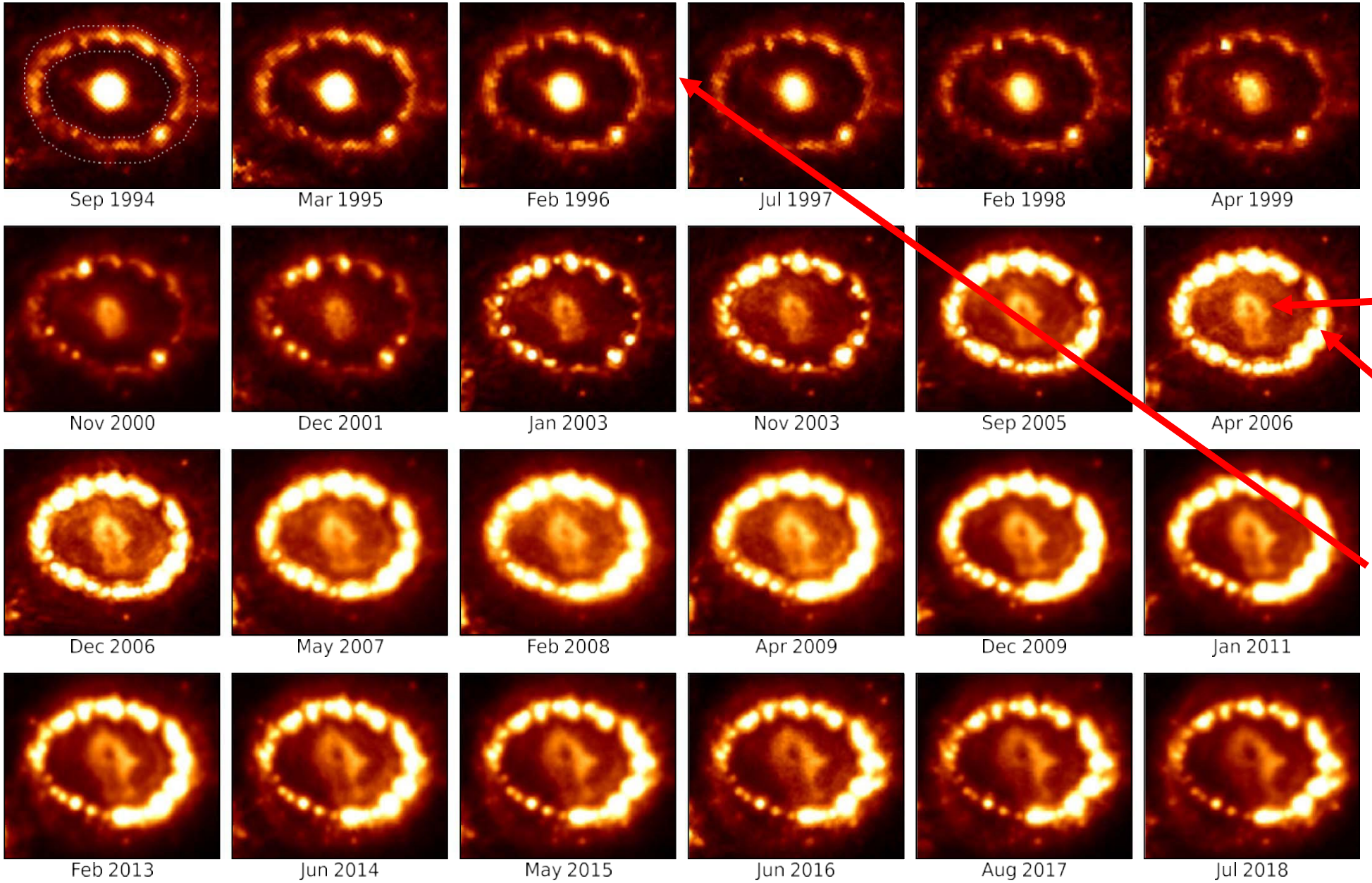


Image of 87A by Hubble Space Telescope

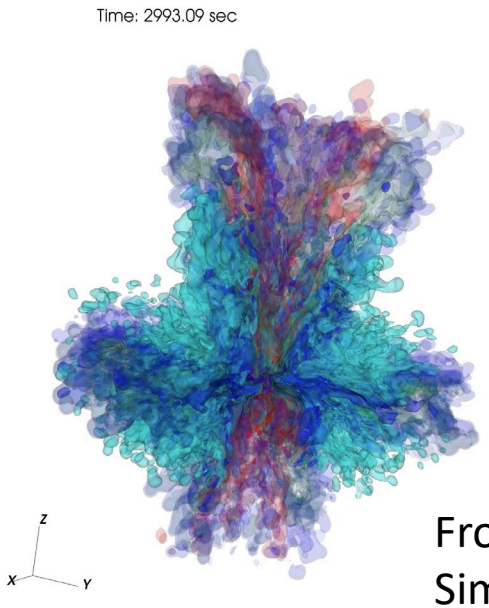
Figure from Larsson et al. (2019).

Supernova Ejecta

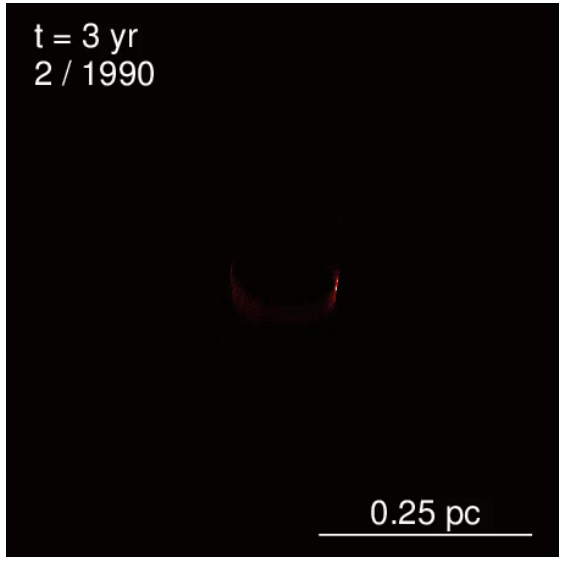
Ring was formed BEFORE the Supernova.

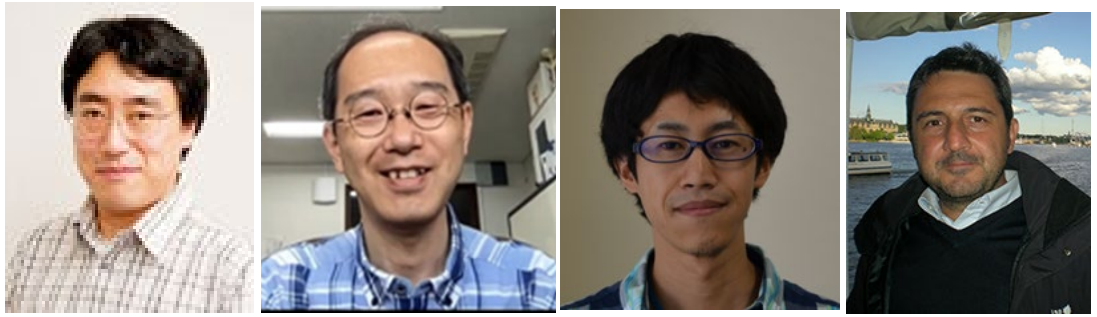
Our 1st paper was Submitted (21 Feb. 1997) and Accepted (21 Apr. 1997) Here.

Our Recent SN1987A Simulation from Progenitor Star



From SN to SNR Simulation.

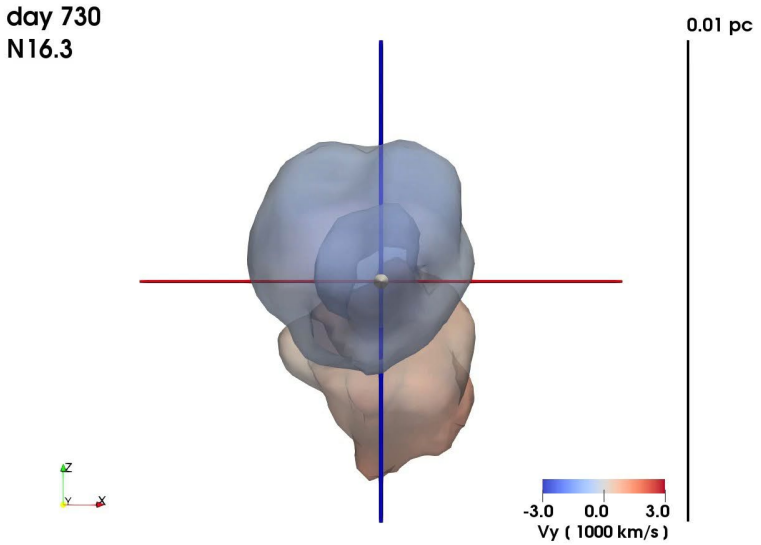


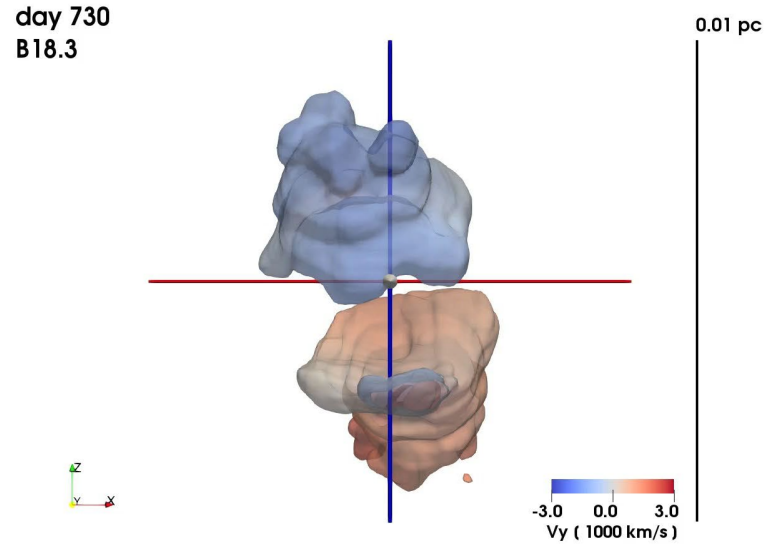


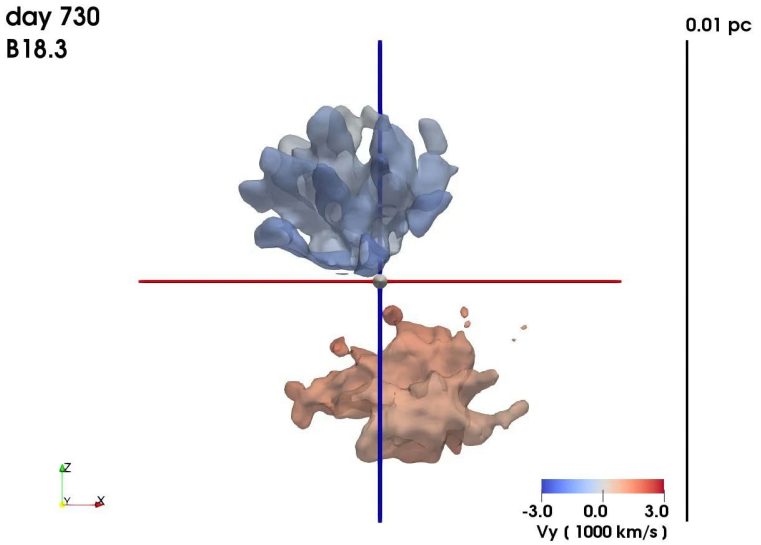
H. Umeda T. Yoshida M. Ono S. Orlando

Ono+2020, Orlando+2020.

We found that Bi-polar like explosions of a binary Progenitor star model explain many observations of 87A.
The best model showed a pulsar kick with -300km/s (blue shift).







Evidence of Bi-Polar Explosion!
Evidence of Stronger Explosion in Red-Shift Side (South-West Side)!

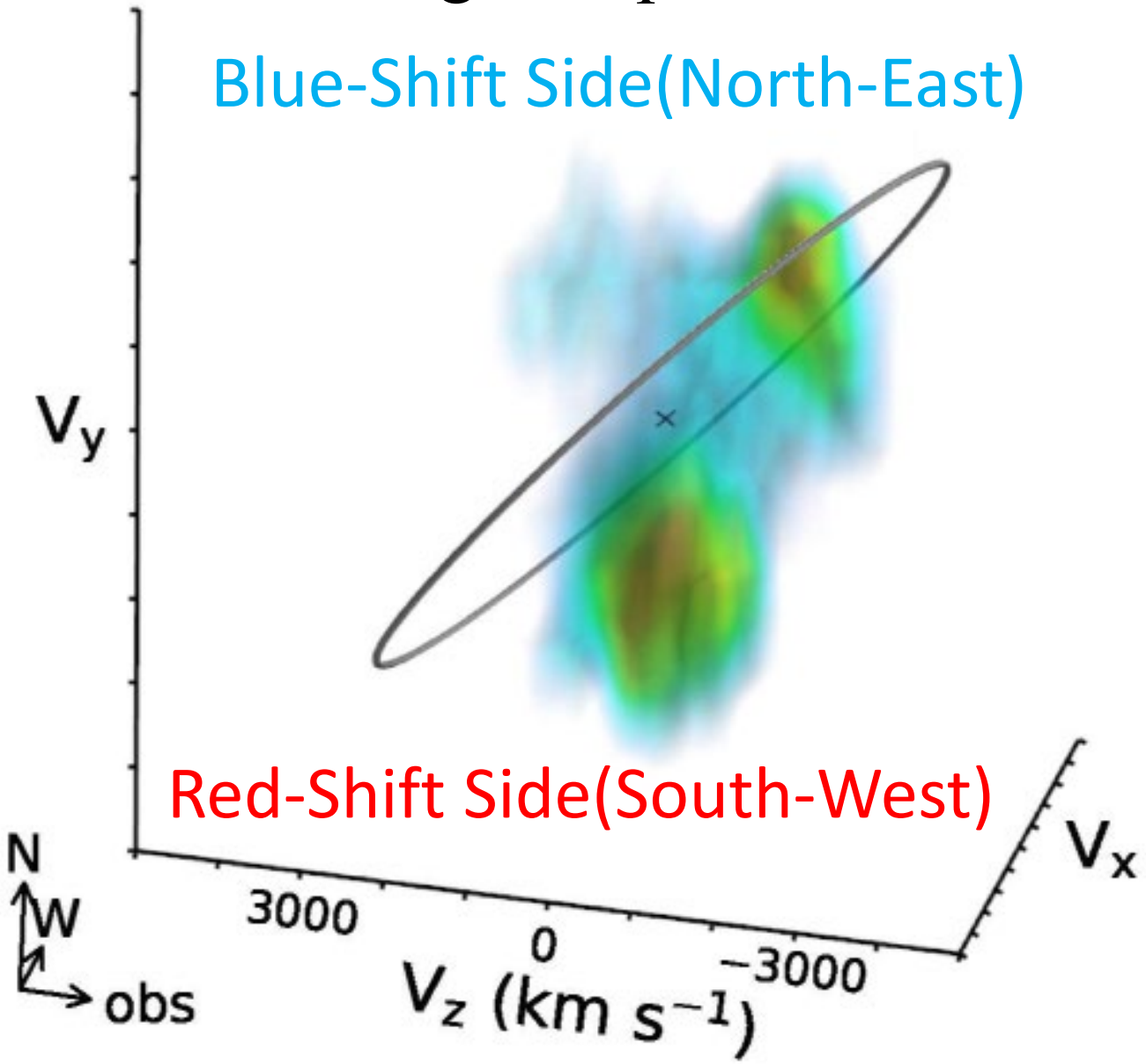
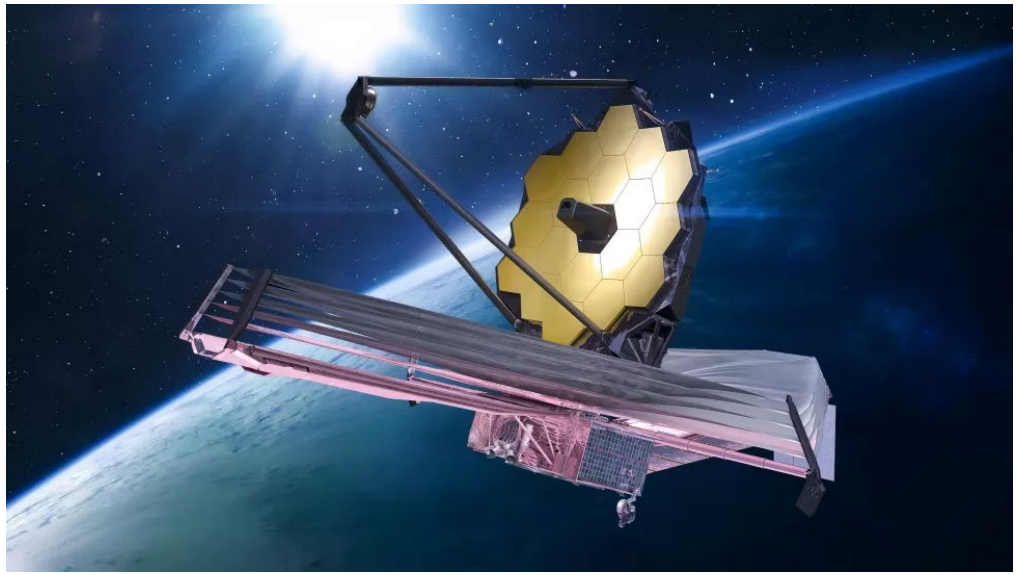
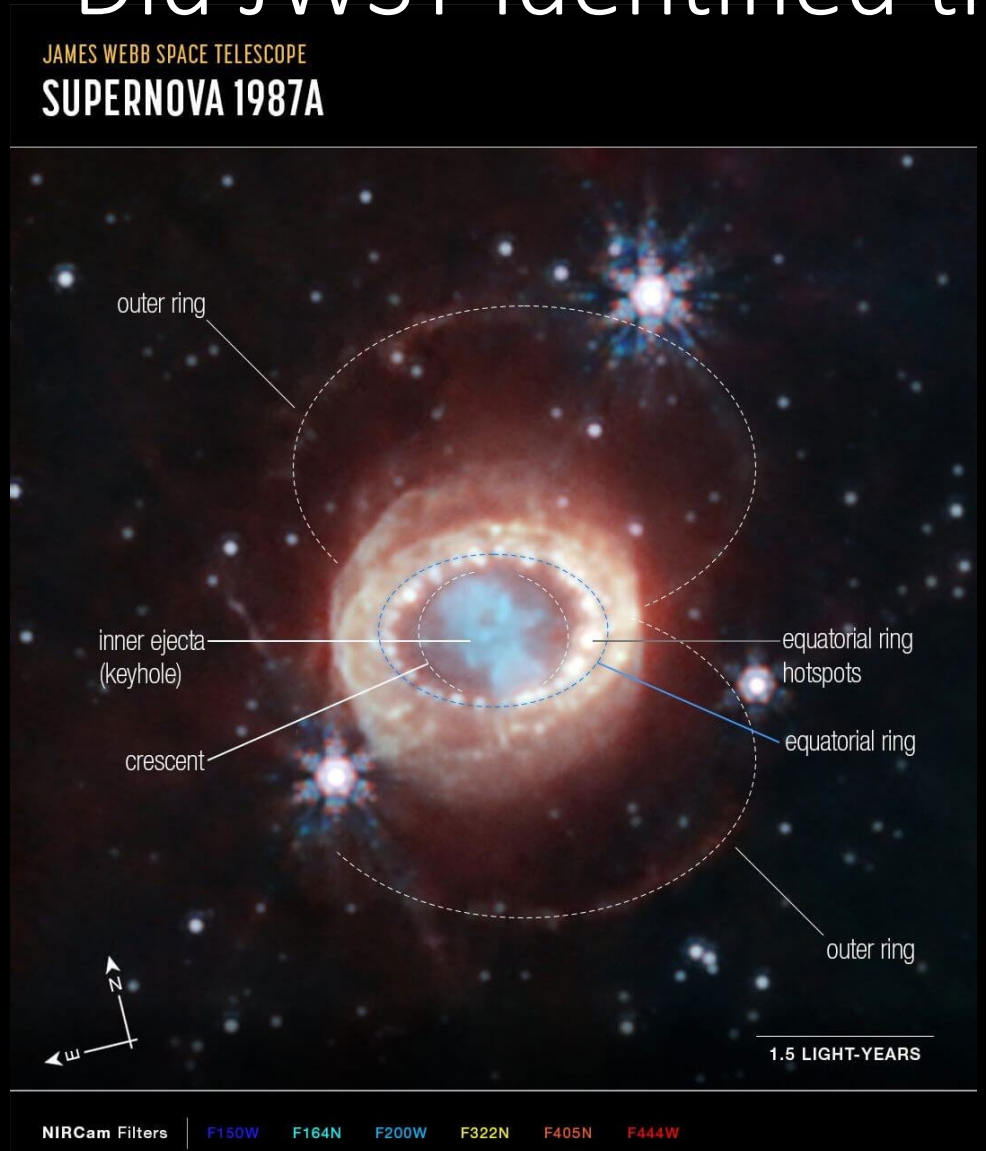


Image of [Fe I] 1.443μm line by JWST.
Larsson et al. (2023)



The James Webb Space Telescope
(JWST, 2021-)

Did JWST Identified the NS in the Blue-Shift Side?



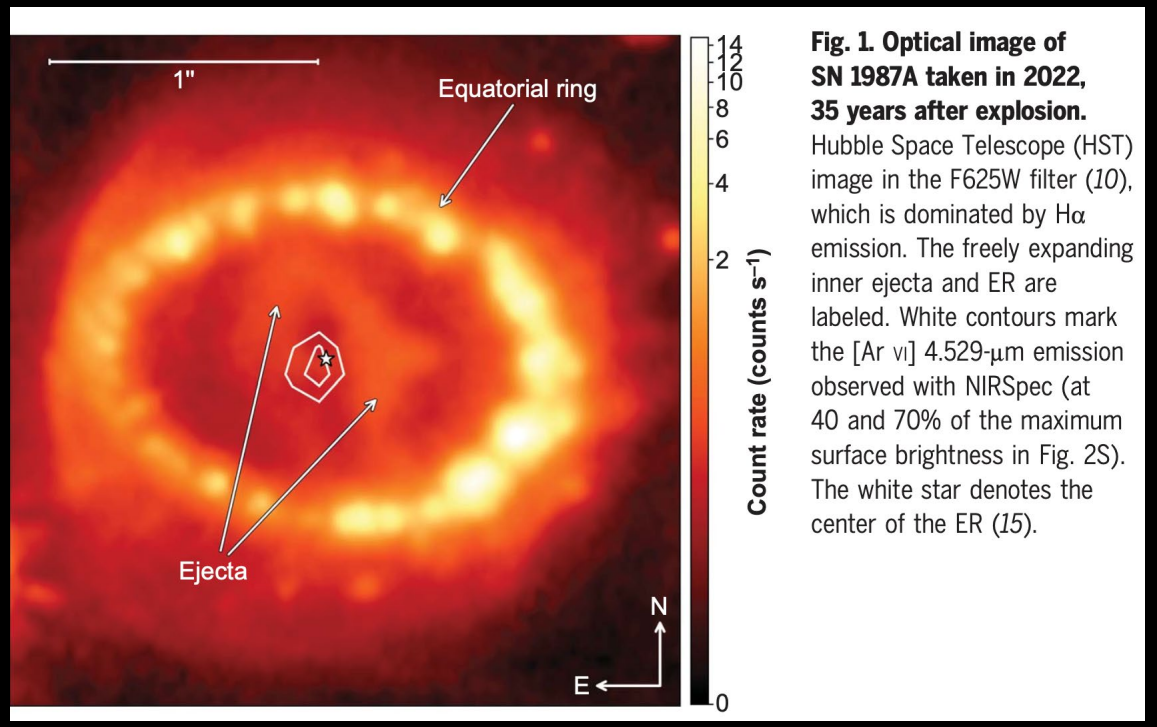


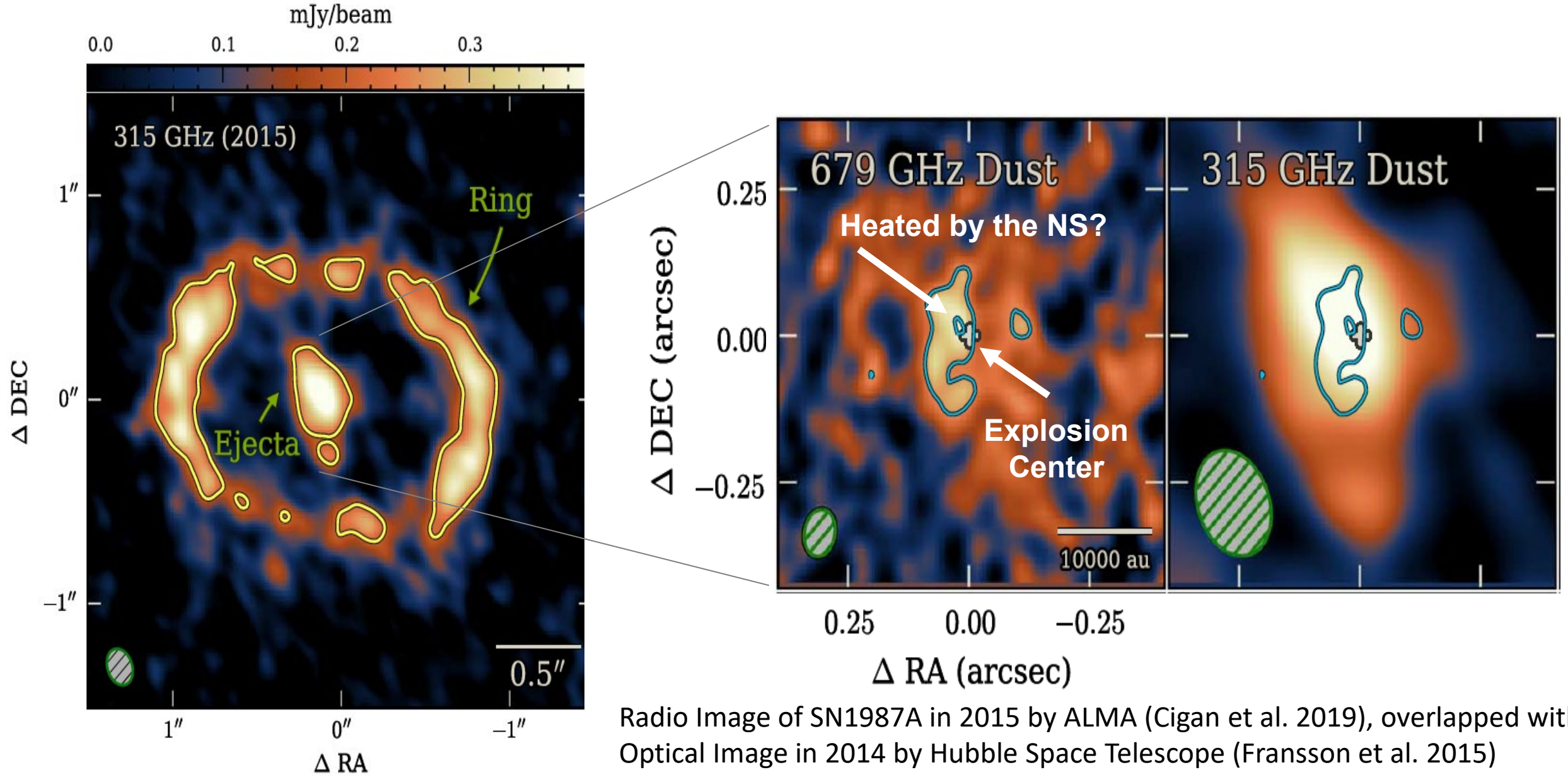
Fig. 1. Optical image of SN 1987A taken in 2022, 35 years after explosion. Hubble Space Telescope (HST) image in the F625W filter (*10*), which is dominated by Hα emission. The freely expanding inner ejecta and ER are labeled. White contours mark the [Ar VI] 4.529-μm emission observed with NIRSpec (at 40 and 70% of the maximum surface brightness in Fig. 2S). The white star denotes the center of the ER (*15*).

Fransson et al. Science (2024).
The detected [Ar VI] line showed blue shift of ～ -269km/s.

c.f. ～-300km/s in Ono+ 2020

Credit: NASA, ESA, CSA, M. Matsuura (Cardiff University), R. Arendt (NASA's Goddard Spaceflight Center & University of Maryland, Baltimore County), C. Fransson (Stockholm University), J. Larsson (KTH Royal Institute of Technology), A. Pagan (STScI)）

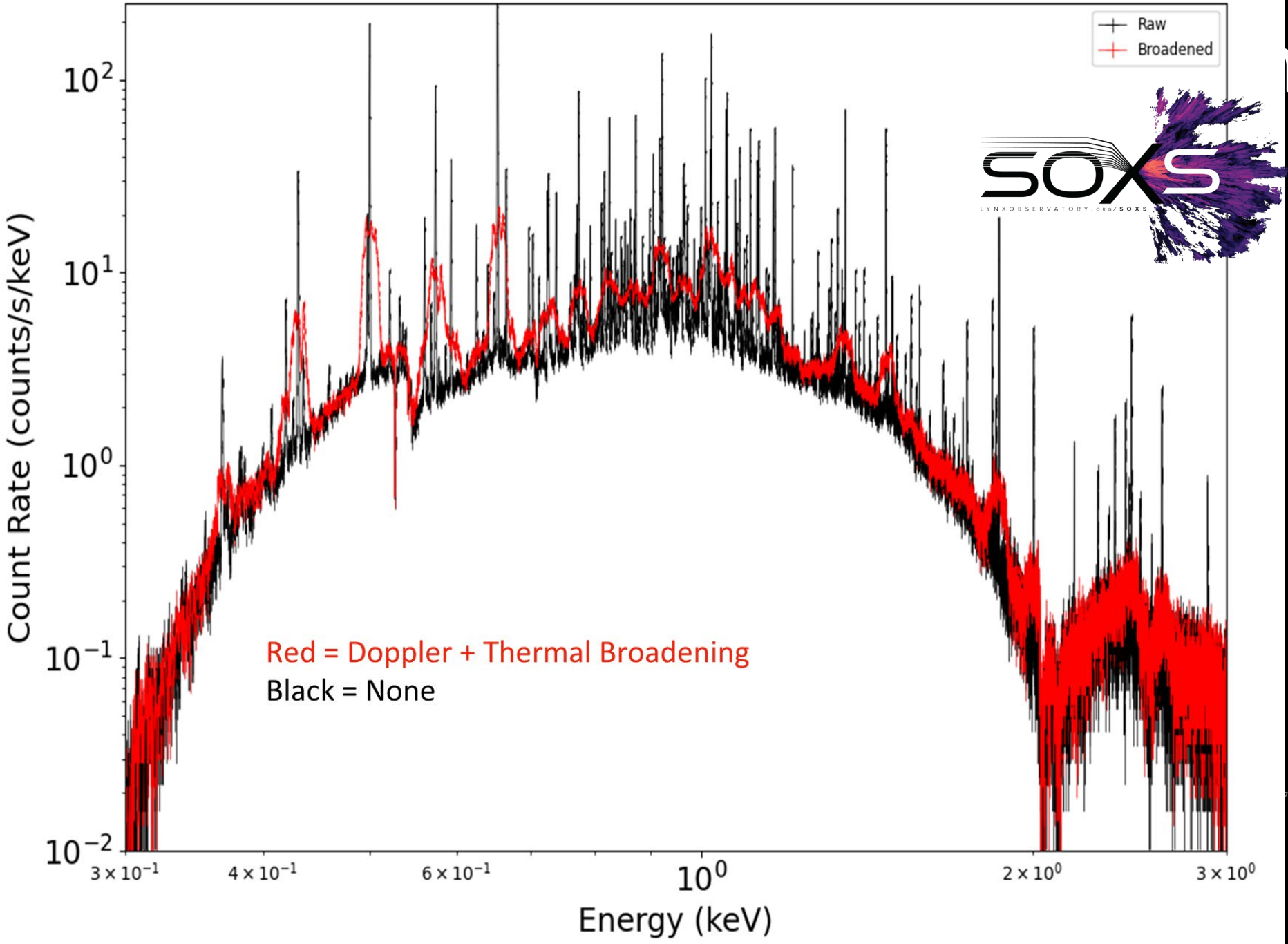
Evidence of the NS running toward the North-East?



Radio Image of SN1987A in 2015 by ALMA (Cigan et al. 2019), overlapped with Optical Image in 2014 by Hubble Space Telescope (Fransson et al. 2015)

T… NEI

Par…
Equ…
regi…



Shiu-Hang Lee (Herman)

Lee et al. (2024) in prep.

Note: s…

XRISM was Launched Last Year.

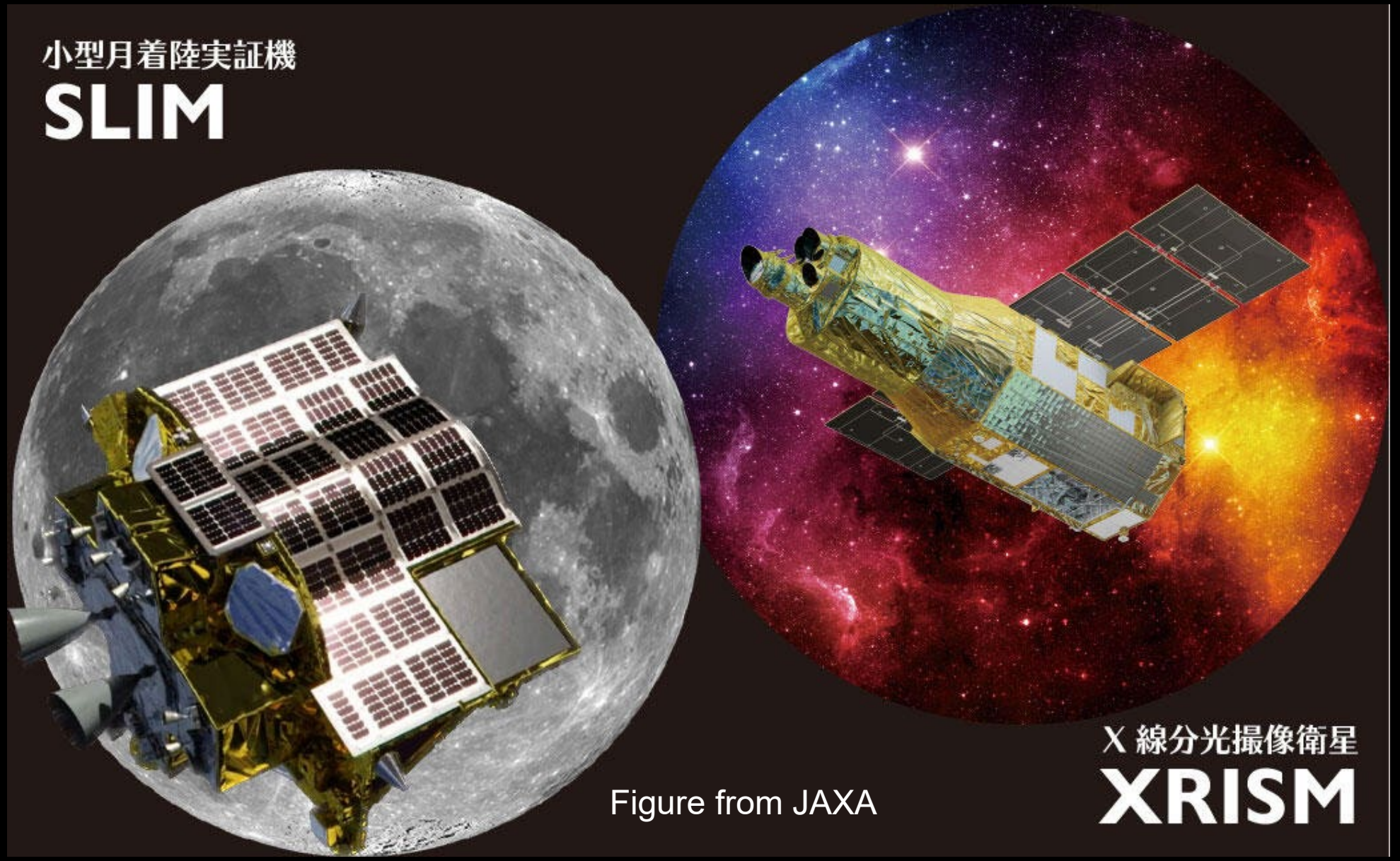
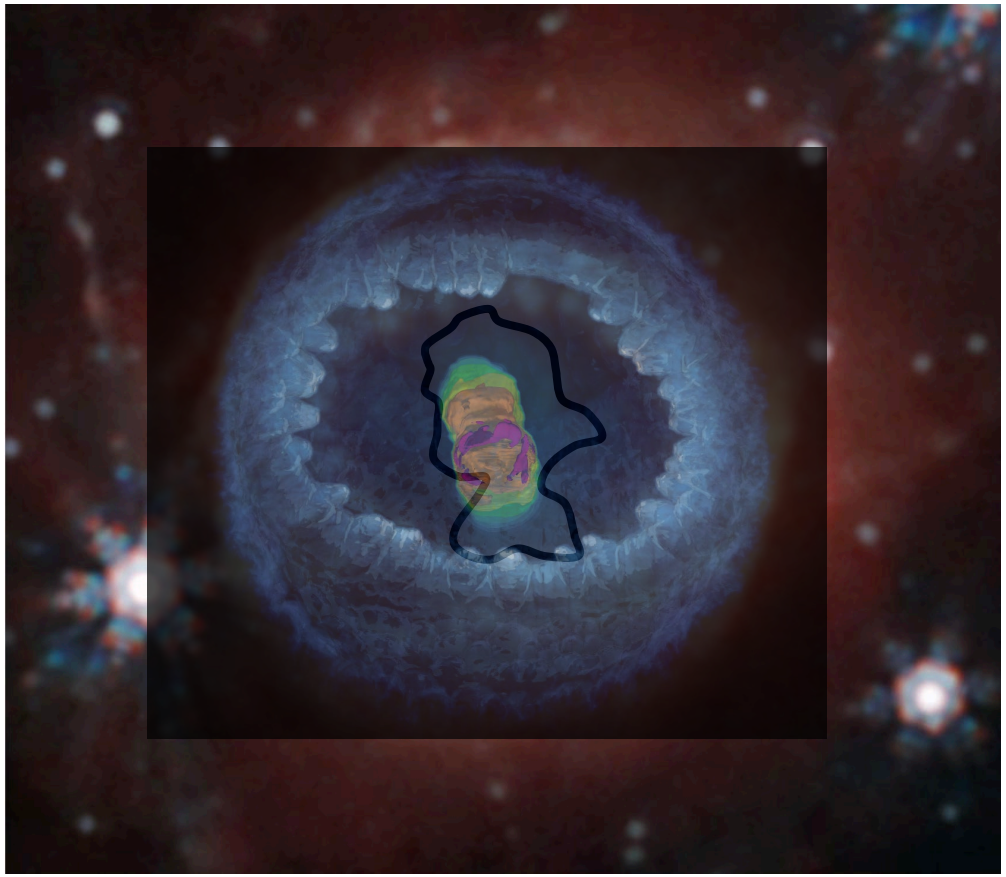
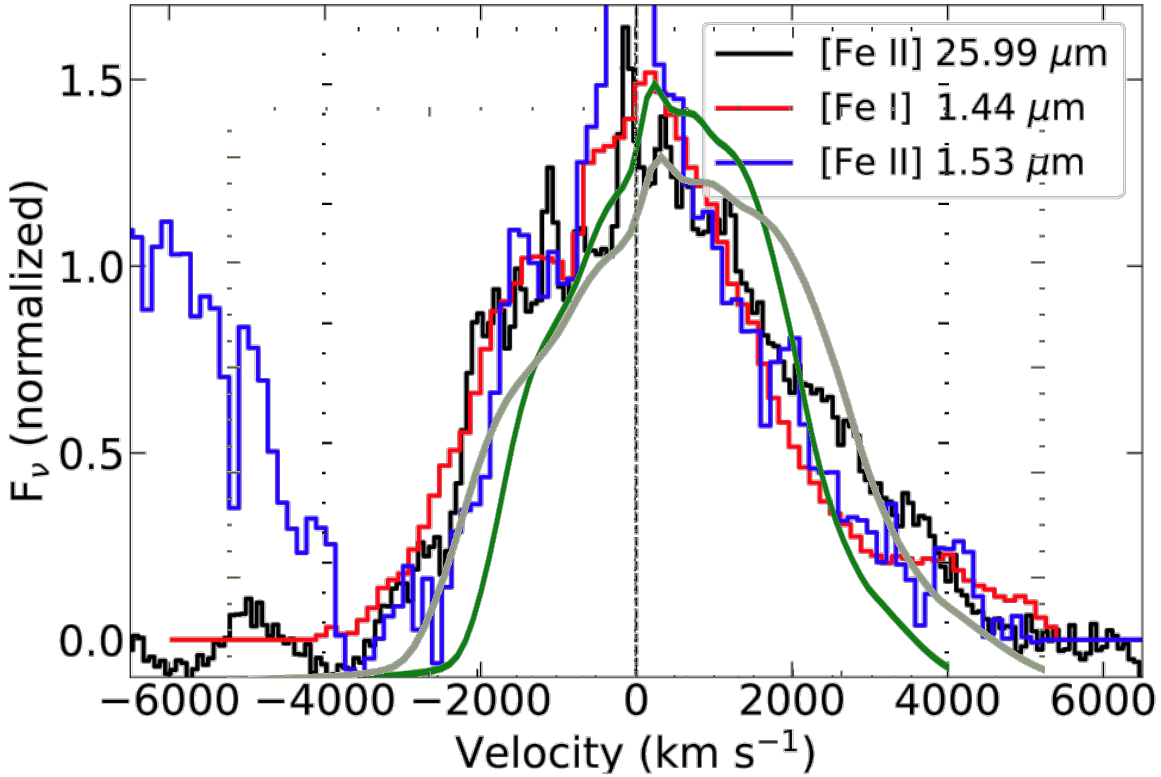


Figure from JAXA

The JWST Observations Suggest More Highly Jet-like Explosion

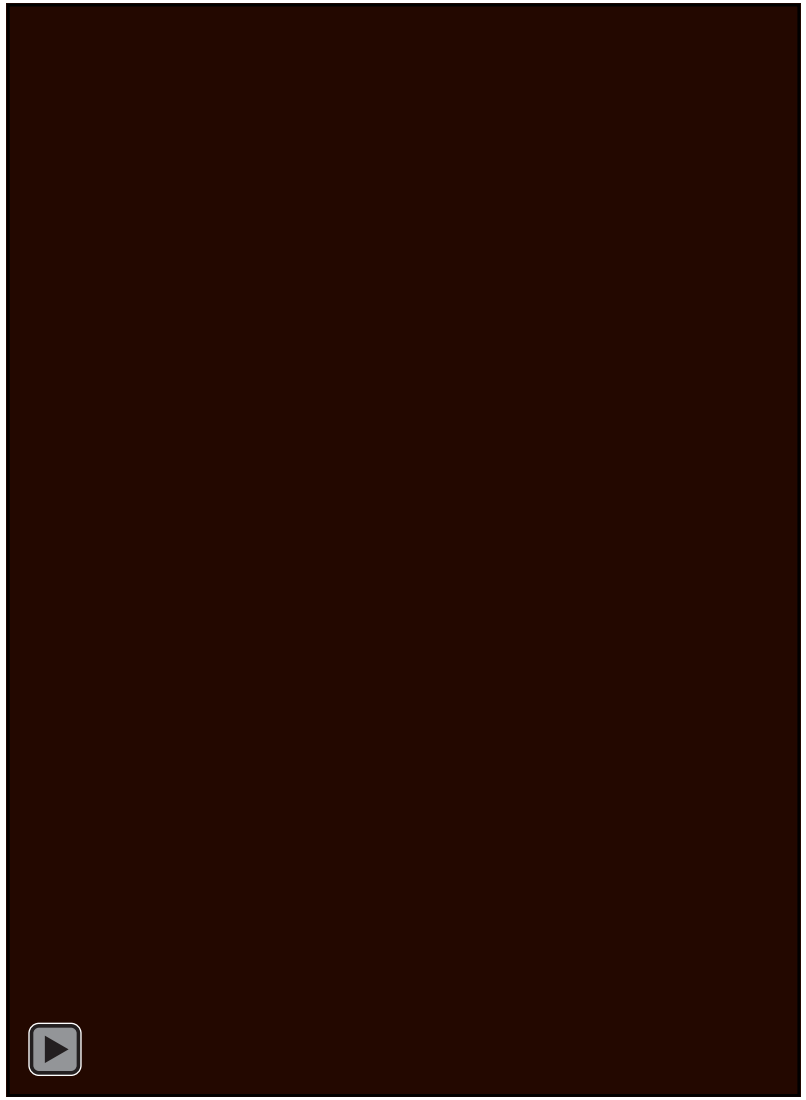


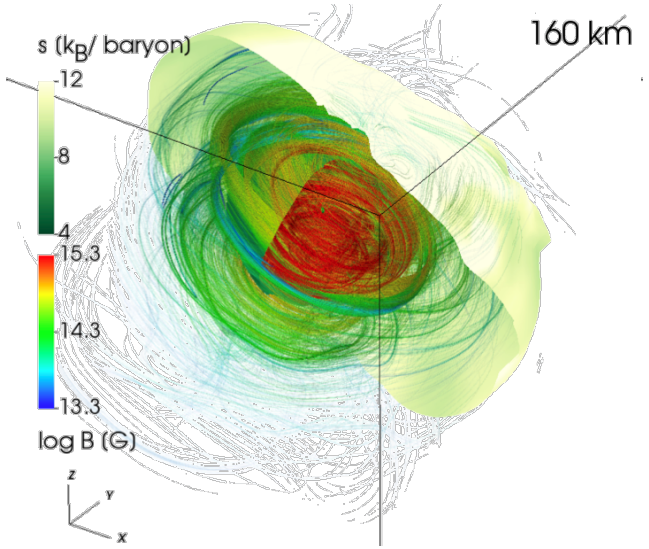


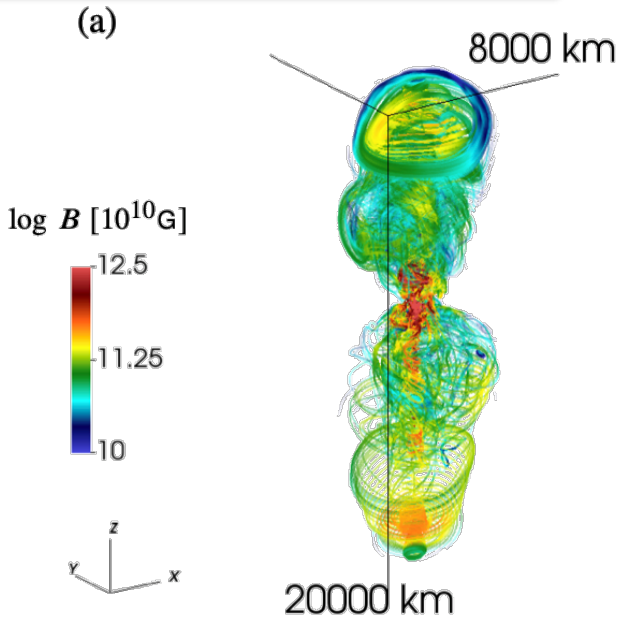
(Jones+ 2023)

JWST DATA:
NASA/ESA/CSA/M.Matsuura et al. 2023

A Missing Piece: What Happened at the Center of 87A?





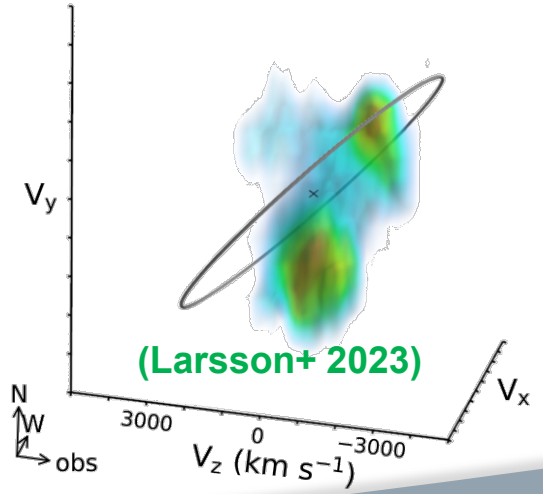


Obergaulinger & Aloy 2021

Fast rotating, magnetized core

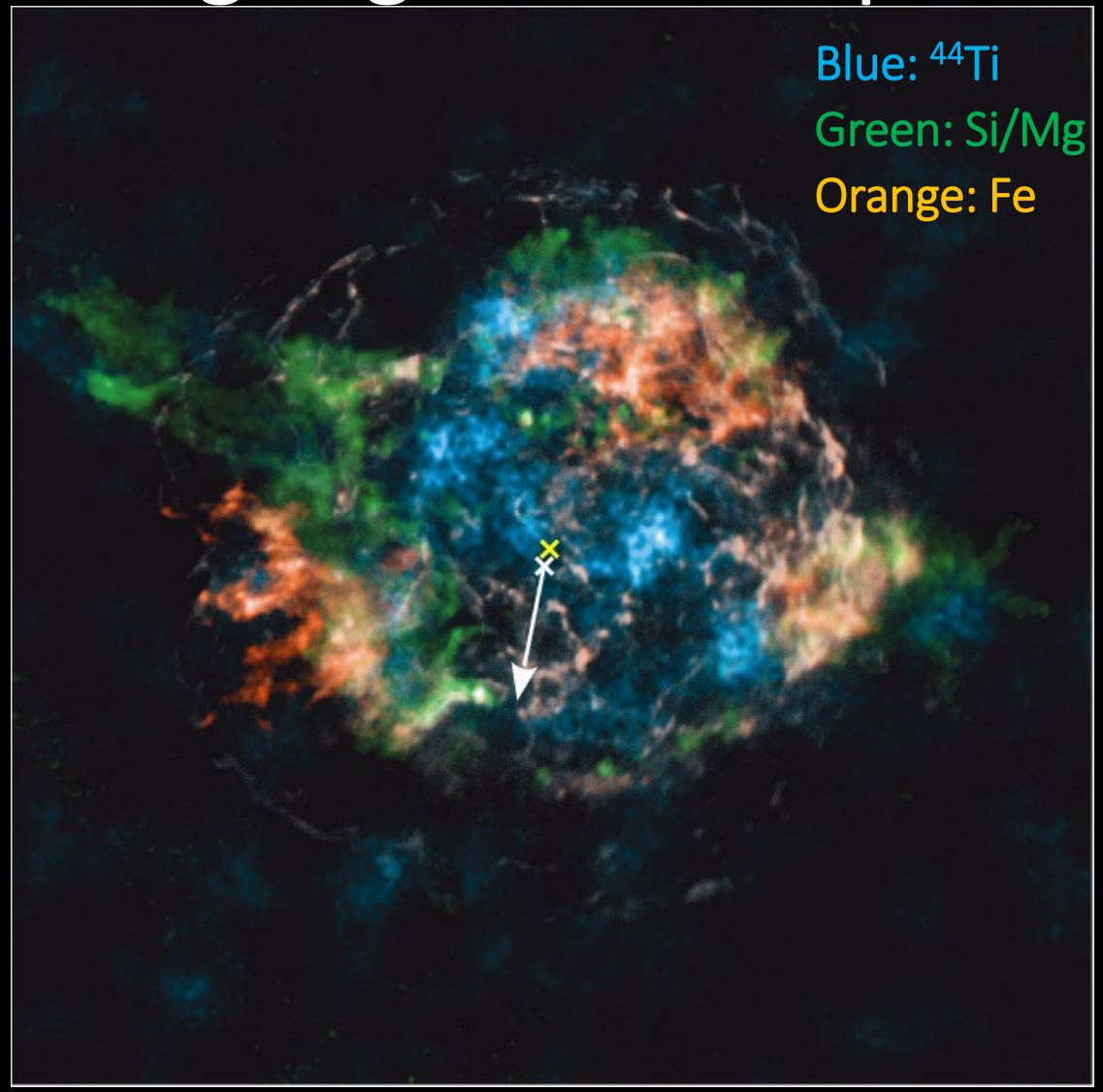
However, such rapid rotating SN should be rare…

Other mechanisms?



(Larsson+ 2023)

Hunting Legacies of Supernova Explosion in Cassiopeia A

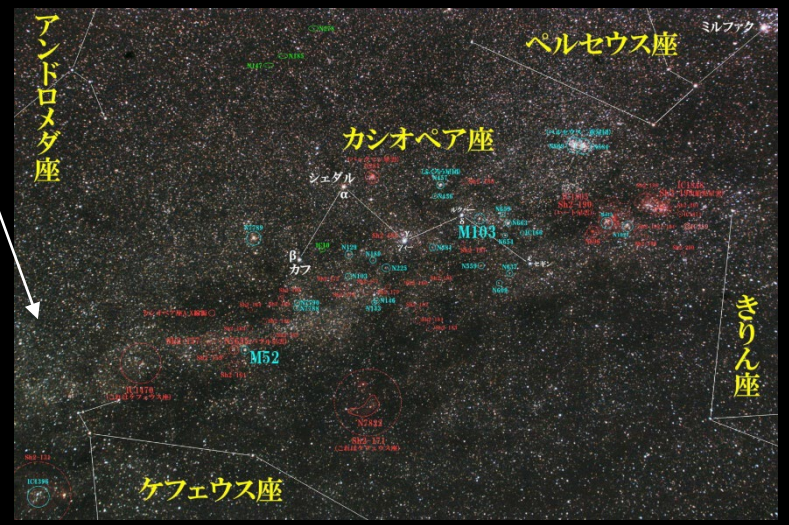


Grefenstette et al. 2017 (Blue:NuATAR, Red, Yellow, Green:Chandra)

Observed image of Cassiopeia A.
AGE～350 yrs old.

Iron exists at the rim of the remnant.
Yellow Cross: Geometrical Center of Cas A.
White Cross: Position of the Neutron Star.
White Arrow: Kick Velocity of the NS.

Here is Cassiopeia A.



From 天体写真ナビ

Our SN-SNR Project solved the Long-Lasting Mystery of Cas A.

Blue: ^{44}Ti
Green: Si/Mg
Red: Fe

Grefenstette et al. 2014
Copyright: Macmillan Publishers Ltd

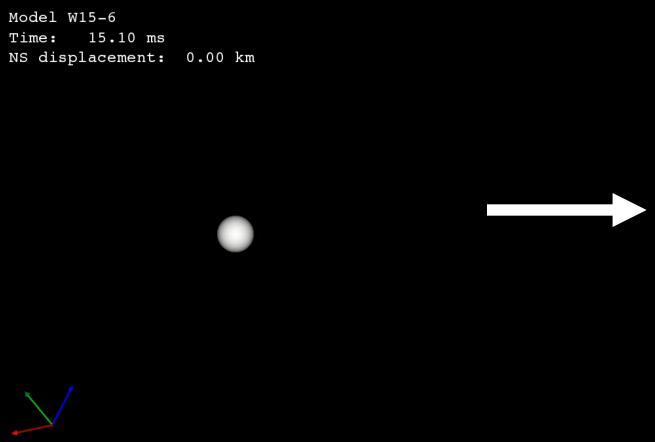
We could explain:
1. The inversion of Fe and Si.
2. Kick Velocity of the NS.
3. Distribution of Fe.

by the supernova remnant simulation from supernova phase.

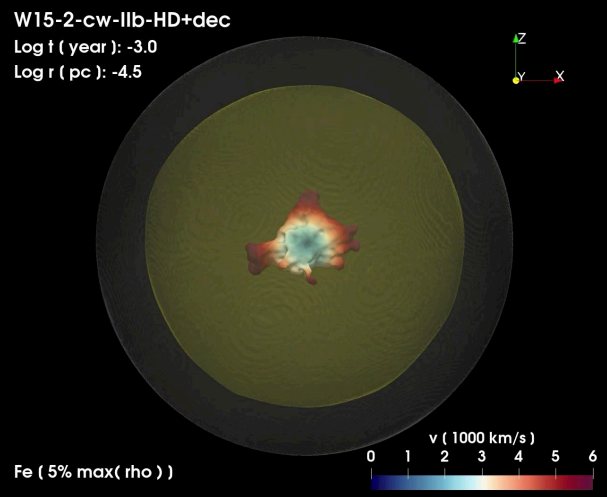
A. Wongwathanarat

S. Orlando

T. Janka



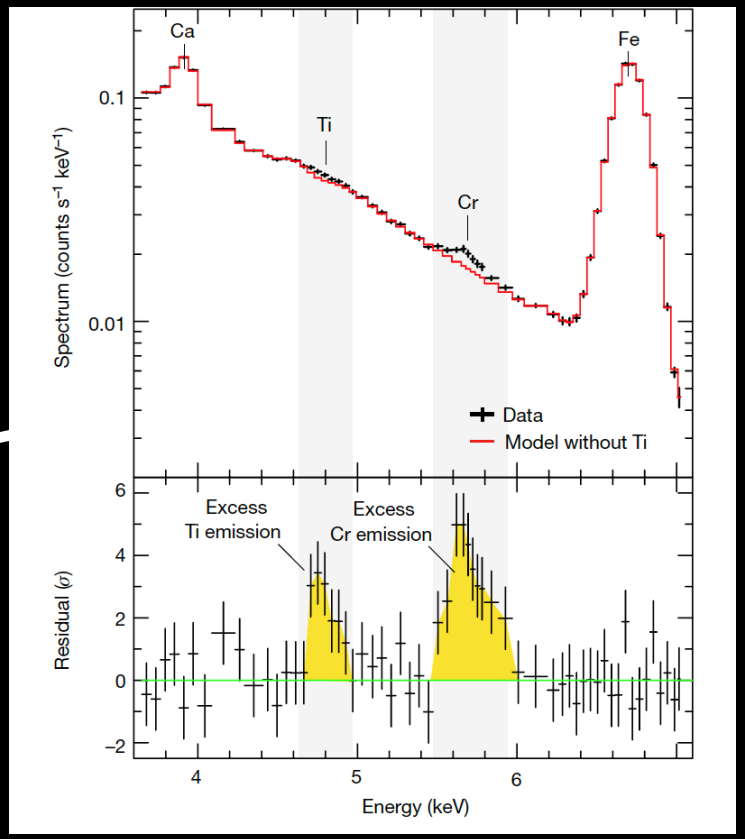
SN Phase (～1sec)



SNR Phase (～350 years)

Orlando+ A&A (2022)

We proved that the Iron Blob was ejected by Neutrino-Driven Winds from the NS



By the detailed analysis, we found
Not only Fe, but also Ti and Cr.

Sato+ Nature (2021)

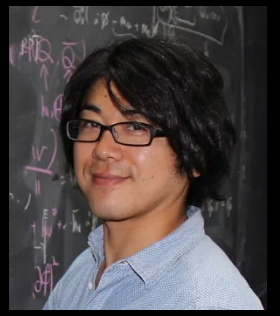
Our study was introduced on the
Cover page of Nature Vol. 592, Apr.2021

Tight Collaboration w/
the Atom Group of r-EMU.


Toshiki Sato


Takashi Yoshida


H. Umeda


K. Maeda

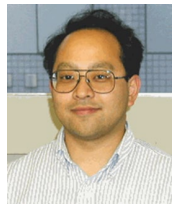

J. Hughes

Summary

- Our Project of Hunting Legacies of Supernova Explosion in Supernova Remnants is Going Well!
- Further Investigation is necessary to Understand What Really Happened in SN1987A and Cassiopeia A.
- We are Waiting for Self-Consistent, Successful Supernova Simulations.
- Highly Jet-like Supernova Models are Especially Welcome!


Hiro

Sato

Hashimoto

Yamada.

Ono.

Salvo.

Herman.

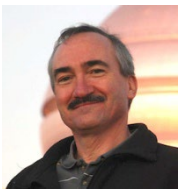
Umeda.

Yoshida.

Annop.

Thomas.

Sato.

Maeda.

Jack.