A Tale of Two Supernova Remnants

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Compton Lecture #1

October 4, 2008

Outline

- Organizational notes
- What this series is about
- A Tale of SN 1006
- A Tale of IC 443
- A Tale of Two Supernova Remnants
- Summary and conclusion

Organizational Notes

- Lecture notes in the back of the room
- Lectures and notes will be posted at

  http://kicp.uchicago.edu/~humensky/ComptonLectures.htm

  (starting later today)
- No lectures the dates of
  - Oct 18th
  - Nov 29th
  - Dec 6th (Physics Department's Holiday Lecture and Open House)
- Questionnaire

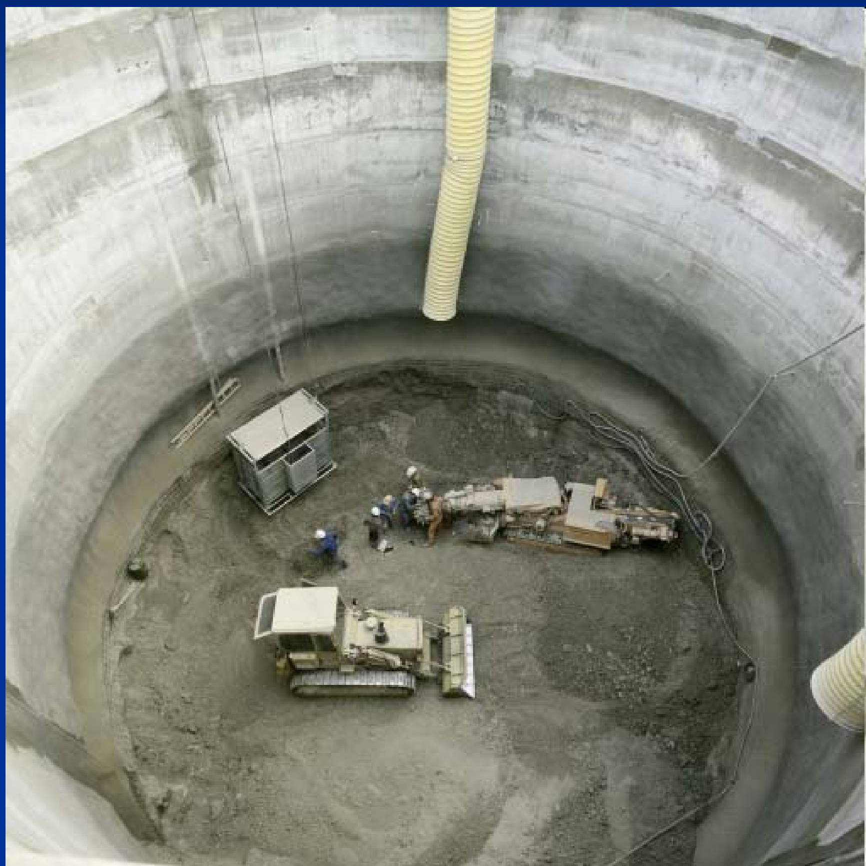
What are these lectures about?

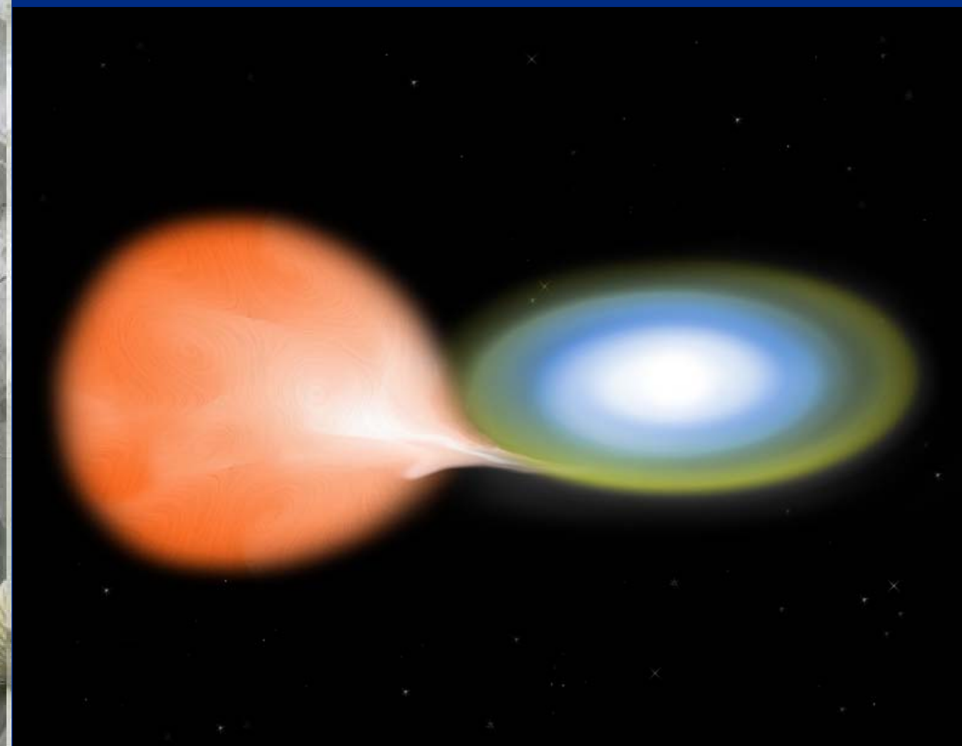
Stanford Linear Accelerator Center

Crab Nebula

- Particle accelerators are pretty amazing, no matter who builds them

How does Nature build particle accelerators?





Digging an access shaft at CERN for the LEP (later LHC) accelerator

Accreting mass onto a white dwarf to create a supernova

My Day Job: VERITAS

- Ground-based gamma-ray observatory at Whipple on Mount Hopkins in southern Arizona
  - Detects gamma rays with energies > 100 GeV
  - Built to study cosmic particle accelerators

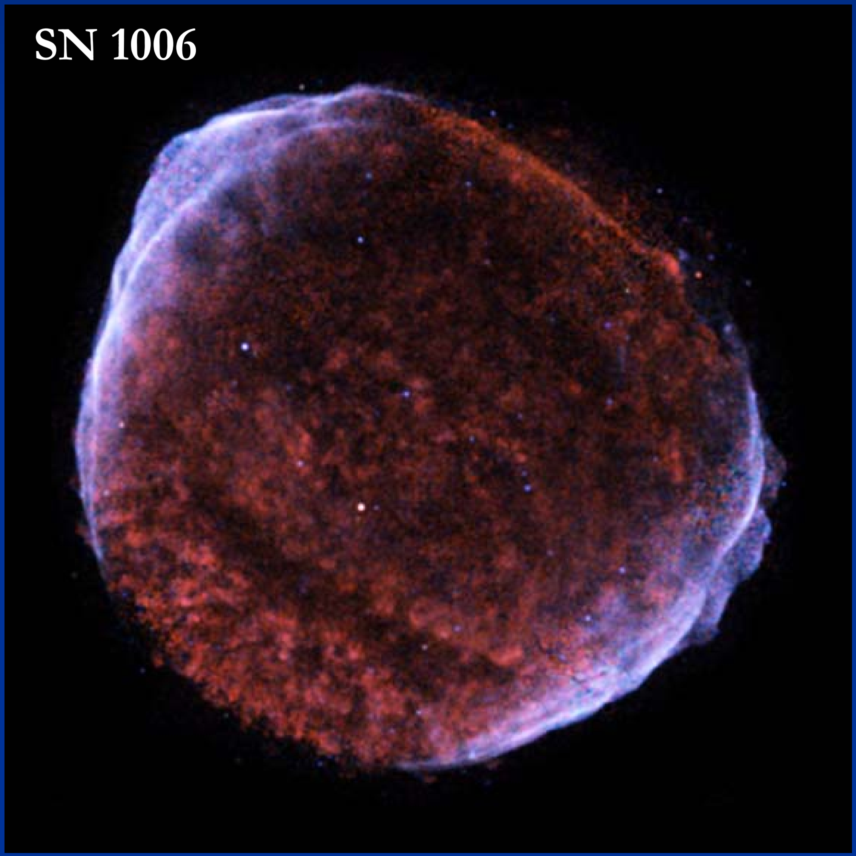
Some themes for the series

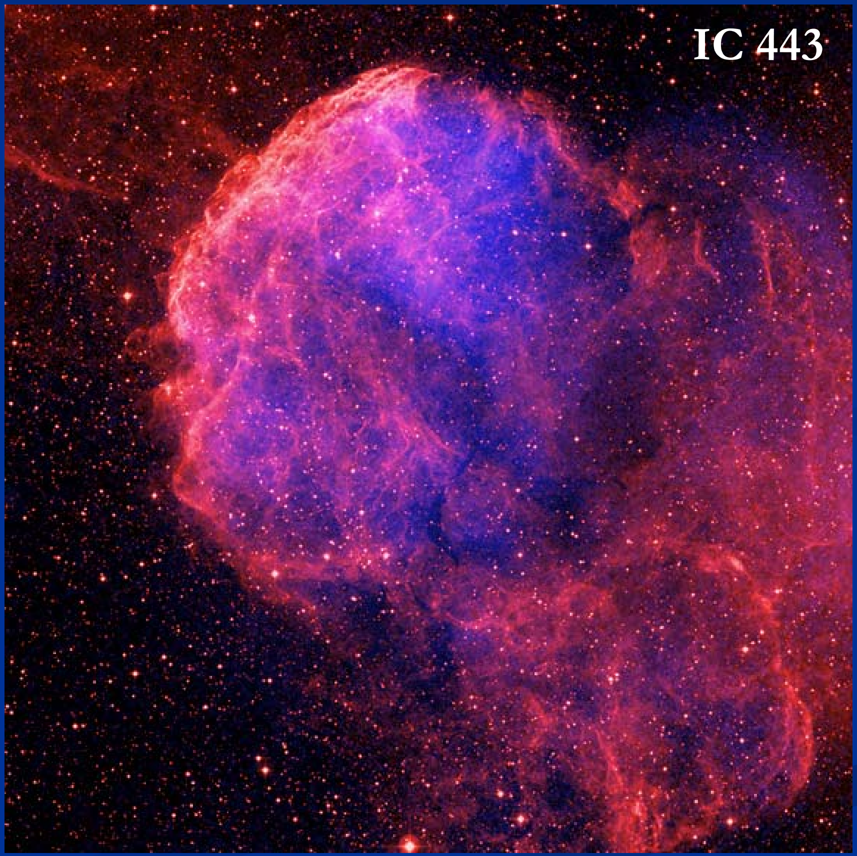
- What determines how a star evolves? In particular, how does the environment in which a star evolves influence its fate?
- What final states can a star evolve into?
- How does a star influence its own environment and affect its neighbors?
- What kinds of nonthermal radiation can stars produce, and why are they interesting?

An example: Supernova Remnants

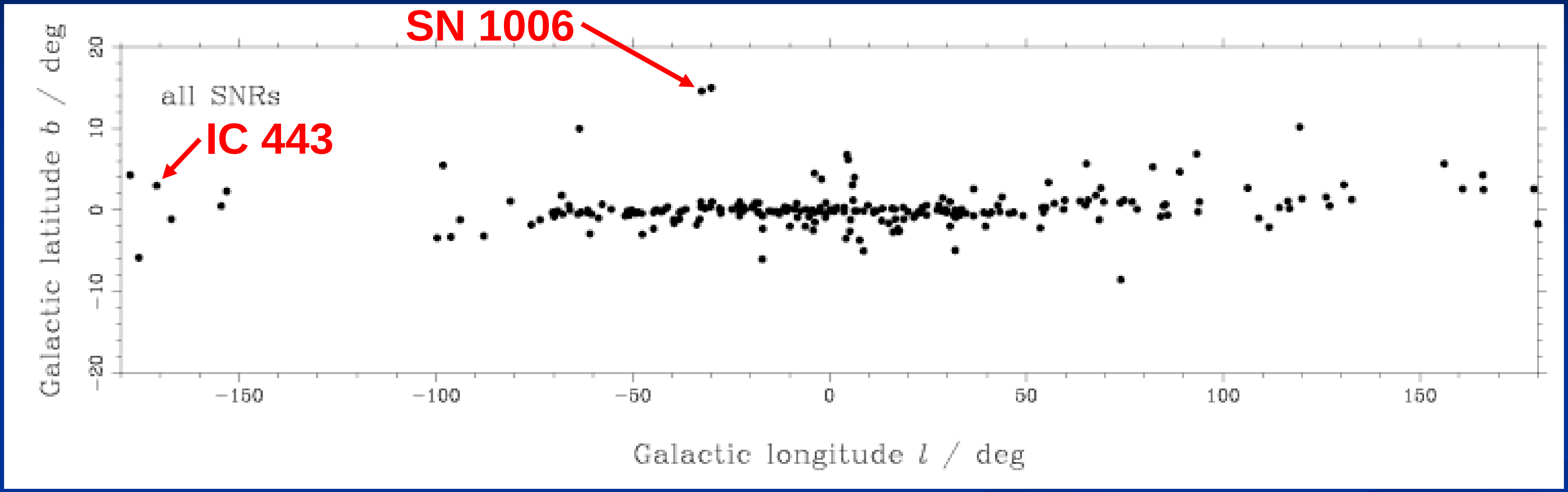
- Supernova Remnants (SNRs) are made of the expanding shell of matter thrown off by a supernova, along with the interstellar matter swept up by that shell
  - Distinct from the stellar remnant – the compact remains of the star: white dwarf, neutron star, black hole, or nothing

Two very different particle accelerators of the same kind





Where are SN 1006 and IC 443?



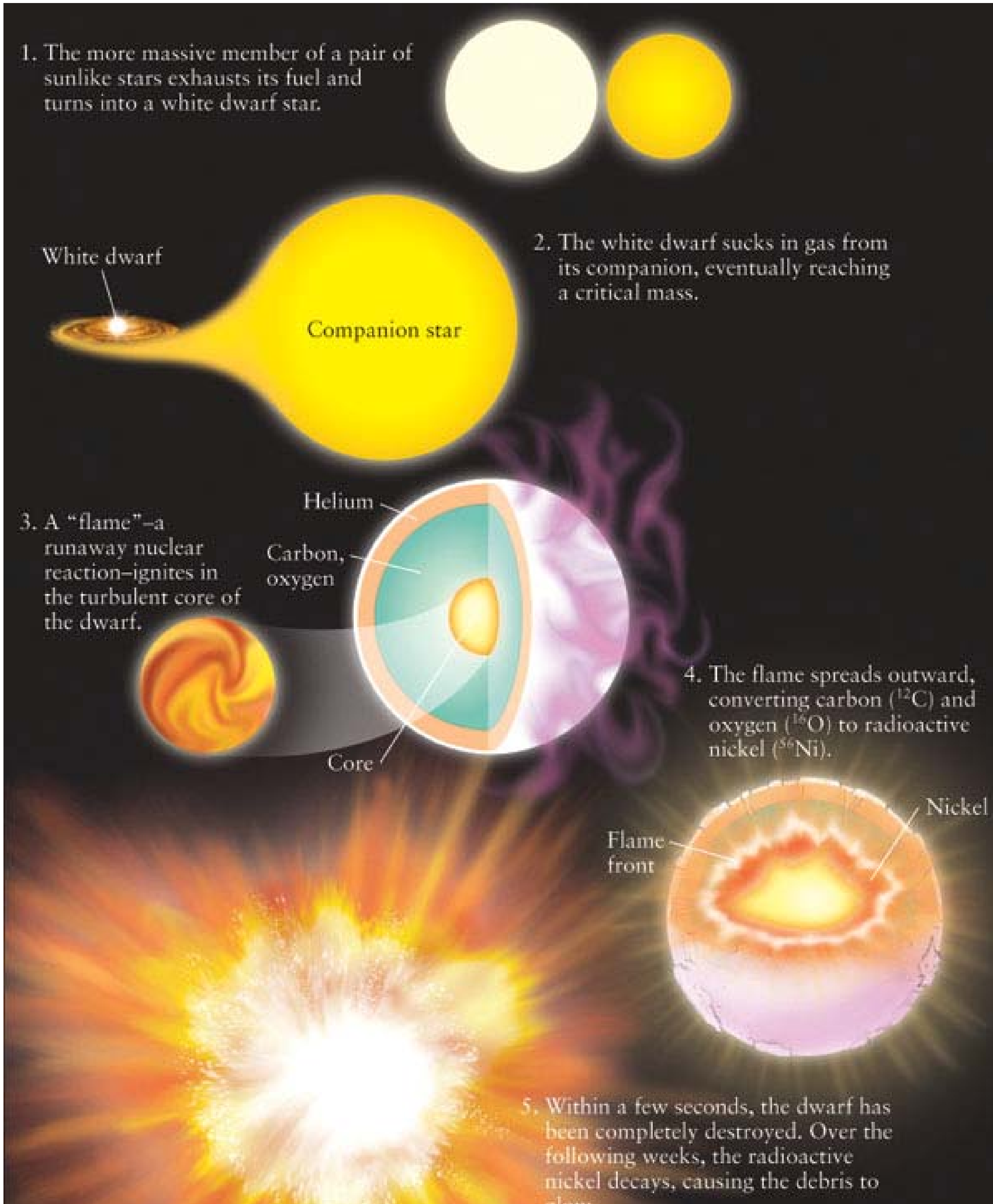
- Supernova remnants tend to cluster along the galactic plane.
  - figure from Green, D. A. Mem. S.A.It. Vol. 76, 534 (2005)

Why do SN 1006 and IC 443 differ?

- Very different environments.
- Progenitor stars of very different types.
- In response, the supernova remnants are evolving quite differently.

A Tale of SN 1006

- Appeared in the sky Apr 30 / May 1, 1006
  - recorded in Japan, China, Arab World, and Europe
- Result of a Type Ia supernova explosion



Universe, 8th ed.

Type Ia Supernovae

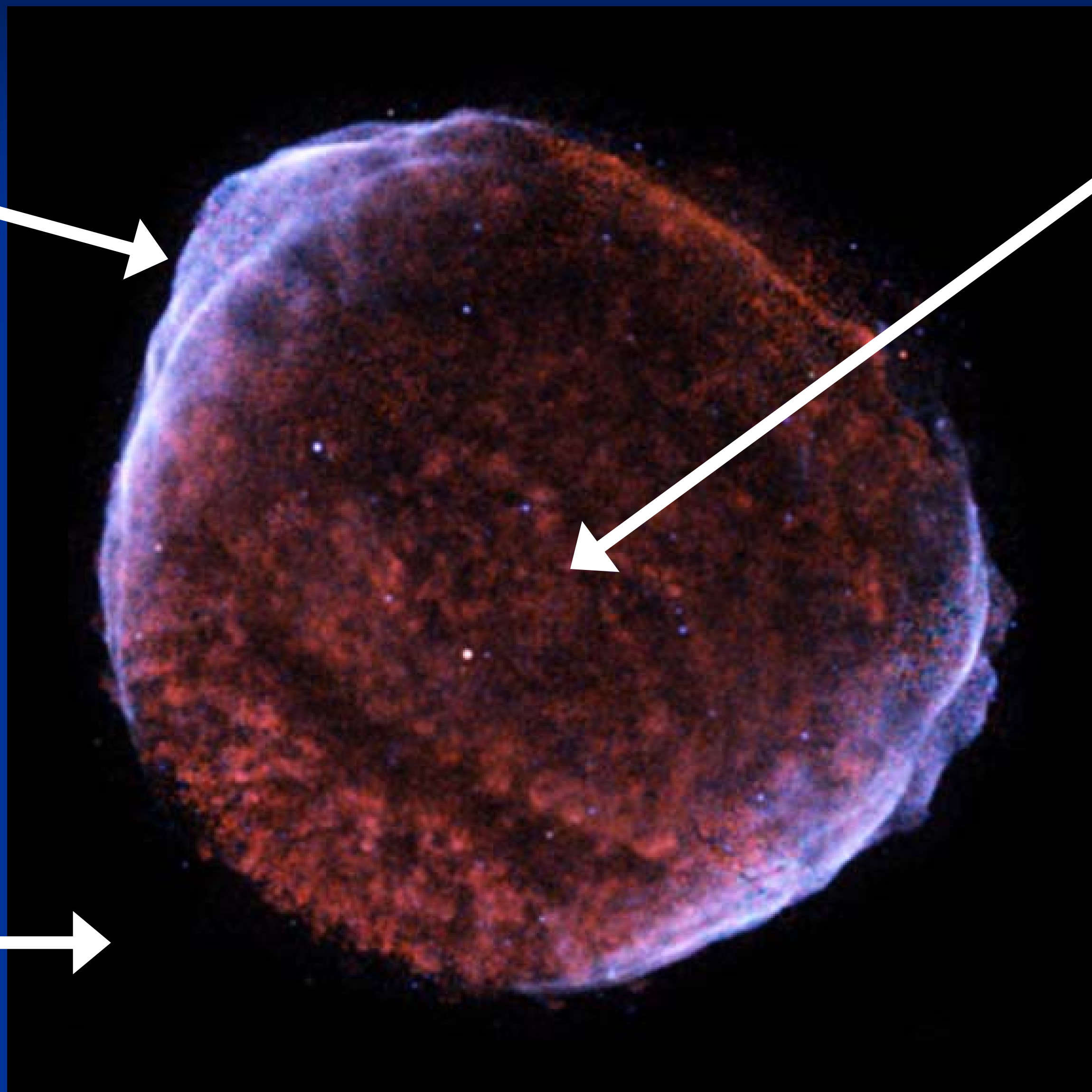
- Binary system
- More massive star becomes a white dwarf first
- White dwarf sucks in gas from companion
- When it reaches a critical mass, a runaway nuclear reaction ignites in the core
- White dwarf is completely destroyed

A Tale of SN 1006

- Appeared in the sky Apr 30 / May 1, 1006
  - recorded in Japan, China, Arab World, and Europe
- Result of a Type Ia supernova explosion
- White dwarf exploded in a high-speed shell of matter, sweeping up matter
- 1,002 years later, the shell is 0.5° in diameter, ~60 light years across
- Remnant not seen by modern astronomers till 1960's and 70's – very faint!

SN 1006 Today: X-rays

Rims: synchrotron radiation from electrons accelerated by the shock front

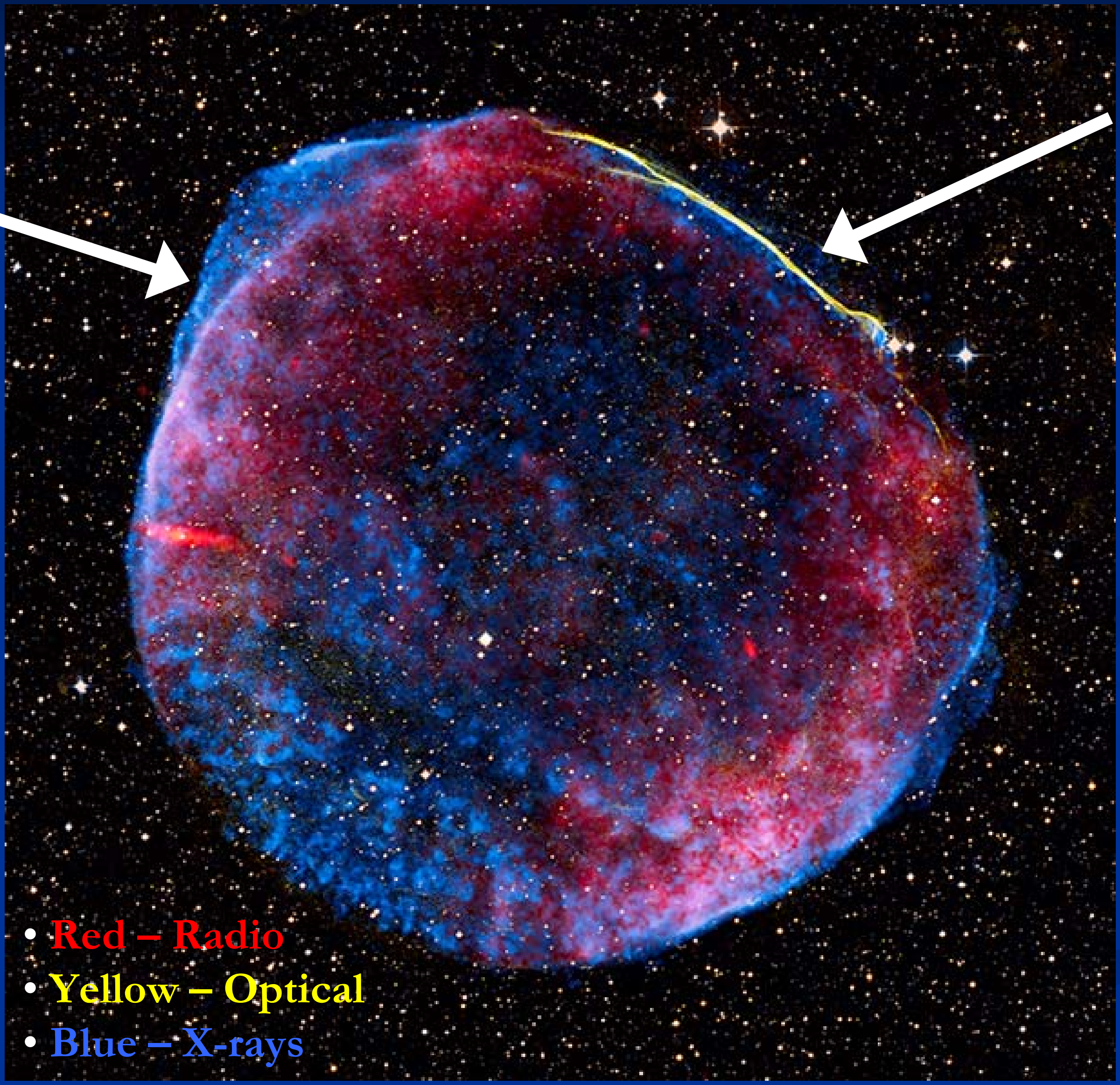


Interior: filled with hot gas - multimillion degrees

Exterior: low-density interstellar medium

SN 1006 Composite Image

X-rays show thin, sharp filaments in contrast to "fuzzy" radio intensity – related to electron energy



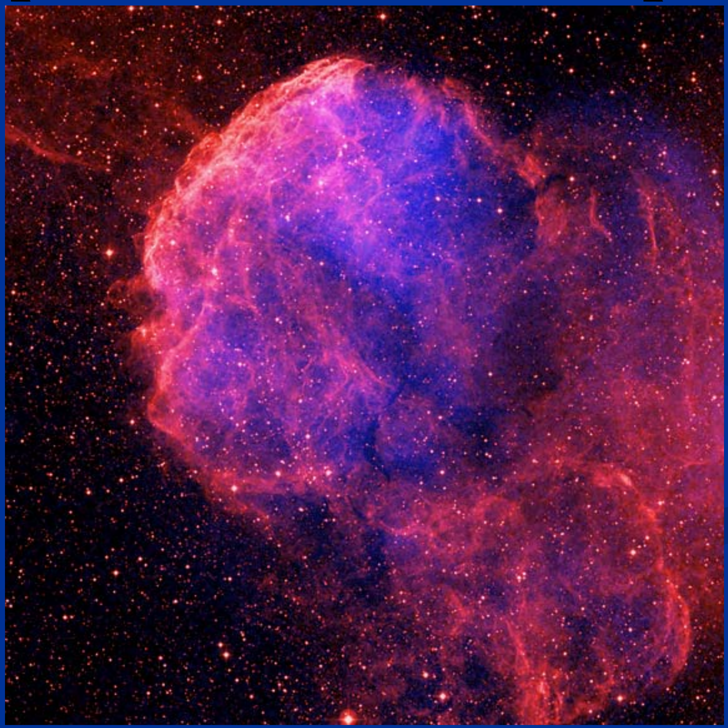
shock front encountering a higher-density region (~0.2 cm^{-3}) and slowing down

SN 1006: Key Facts

- Young – only 1002 years
- Type Ia
  - thermonuclear explosion of a white dwarf
  - leaves behind no black hole or neutron star
- Low-density environment
  - still expanding rapidly
- Nearly uniform environment (except northwest)
  - symmetrical development

A Tale of IC 443

- Middle-aged remnant, probably a few thousand years old
- Most likely a Type Ib supernova, core-collapse of a massive star



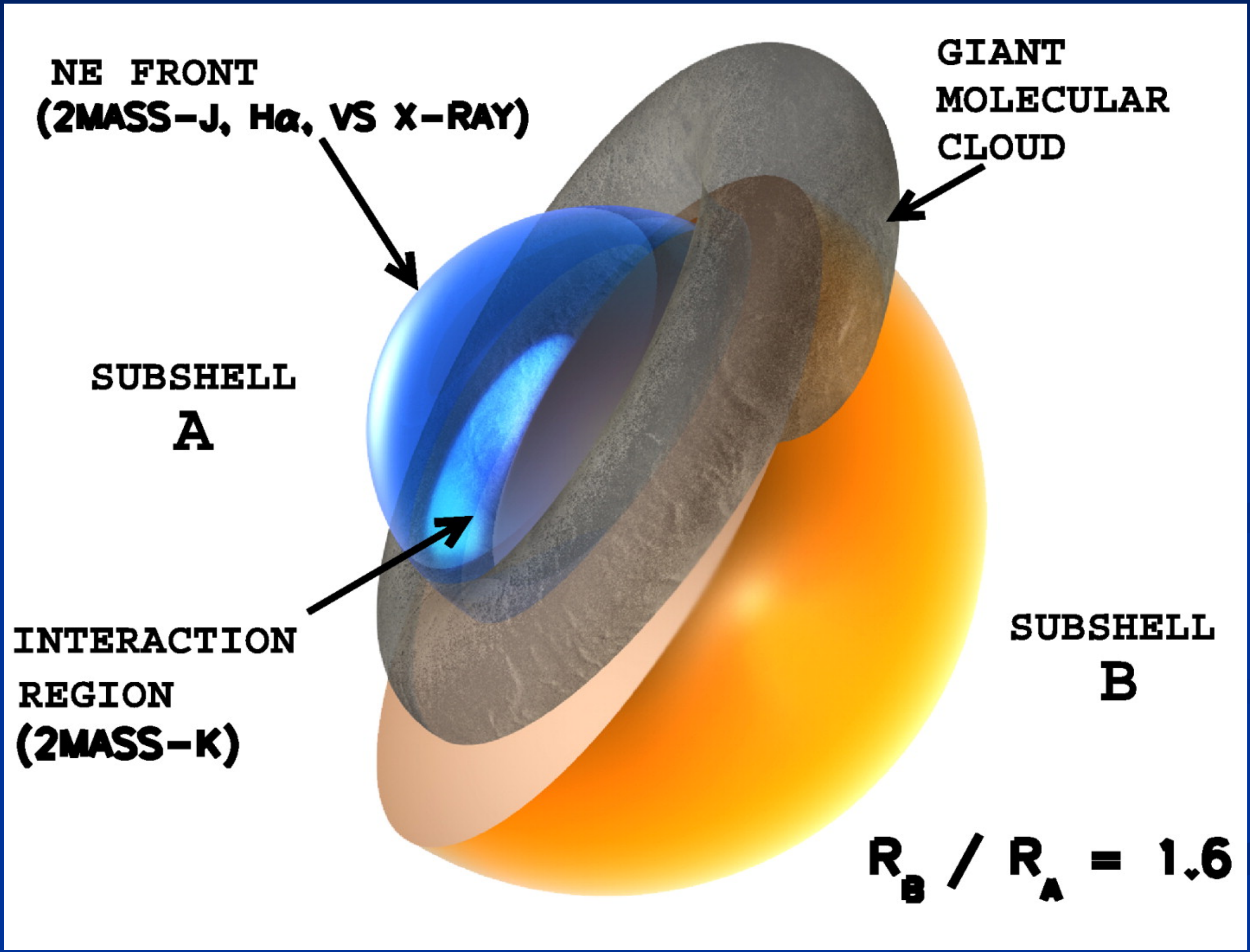
Core-collapse supernovae

- Massive star runs out of fuel and collapses, unable to support itself against gravity any longer
- Core collapses to nuclear density in < 1 second
- Infalling material bounces off the core, generating an outward-going shock wave → star explodes
- Core remains as a neutron star (or black hole)

A Tale of IC 443

- Middle-aged remnant, probably a few thousand years old
- Most likely a Type Ib supernova, core-collapse of a massive star
- Developing in a complex environment, surrounded by dense clouds of material
  - 100 – 10,000 x denser than SN 1006's environment

Schematic View

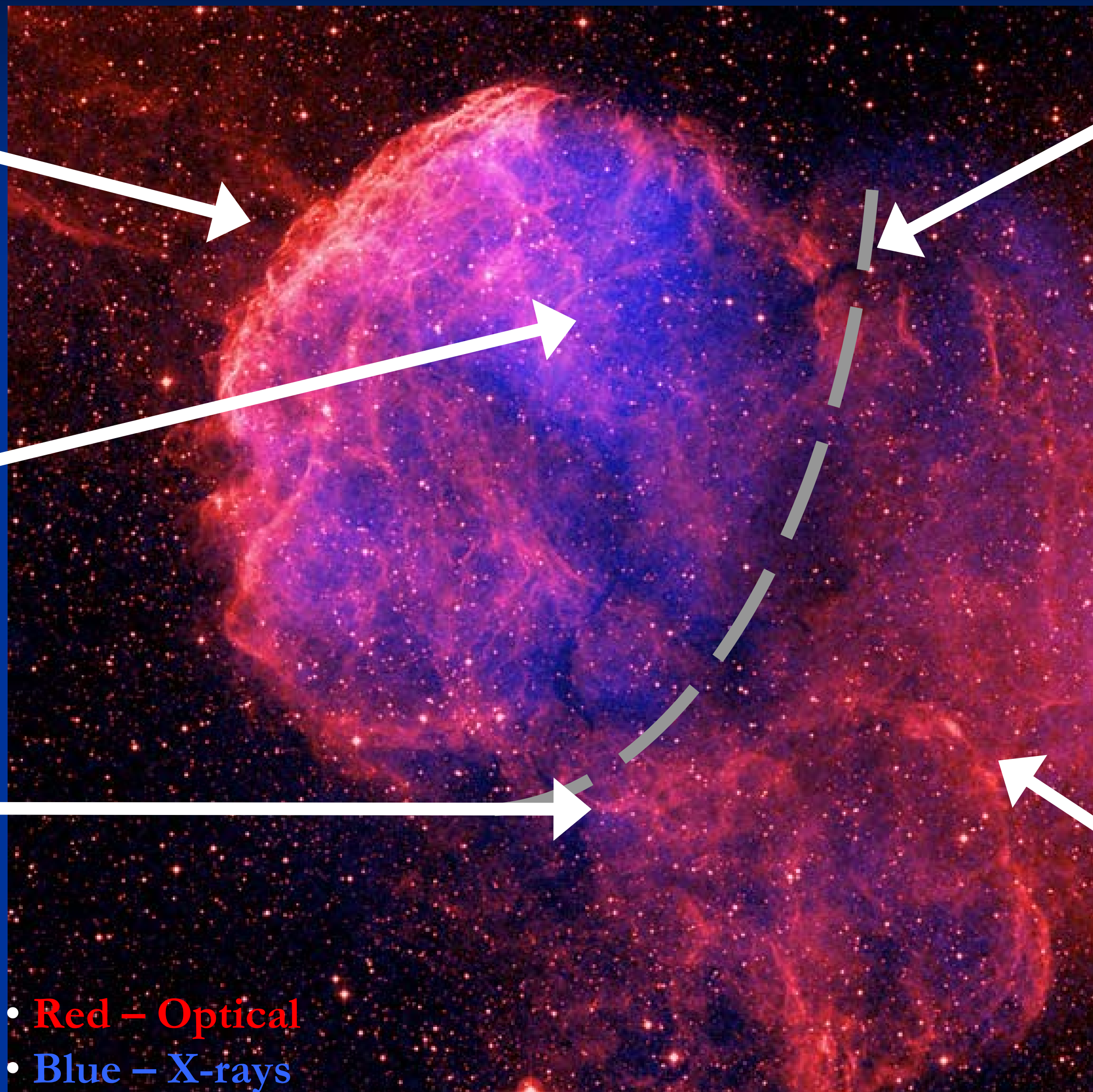


IC 443 in Optical and X-rays

expanding shell impacting a cloud of atomic hydrogen

hot gas fills the interior

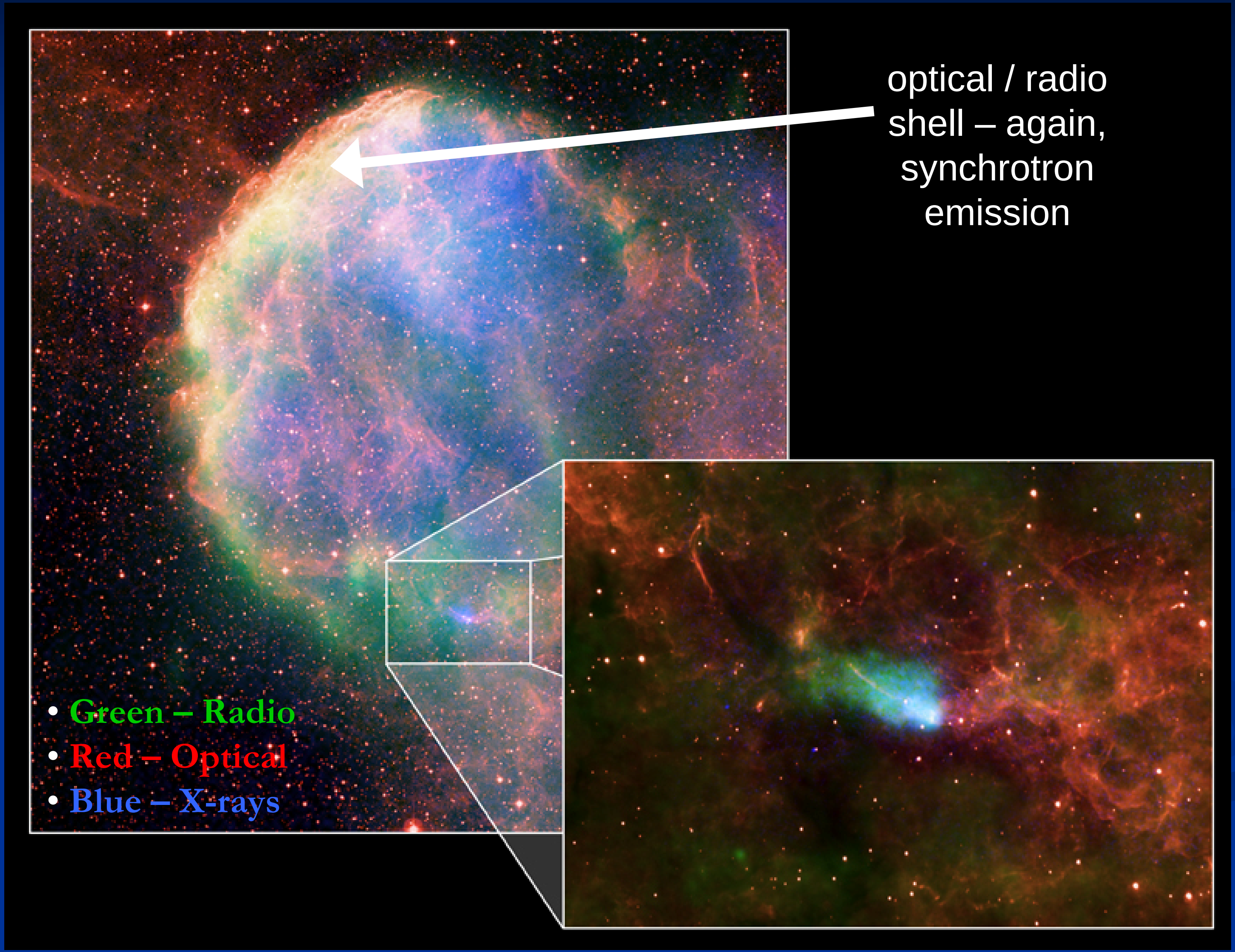
pulsar wind nebula



giant molecular cloud

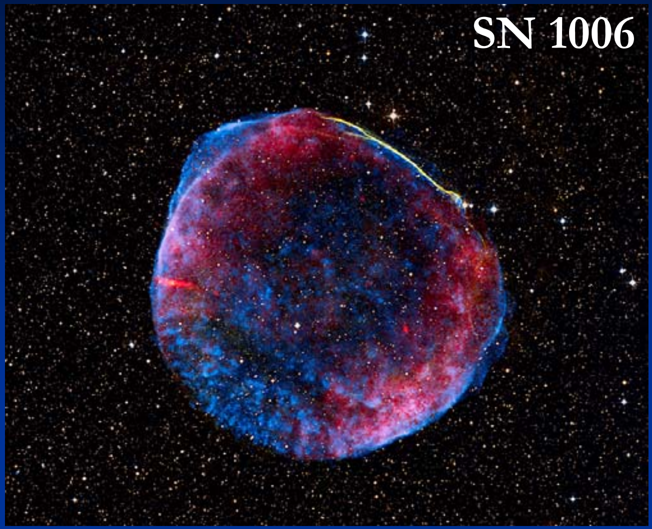
breakout into lower-density region

Where's the remains of the star?



A Tale of Two Supernova Remnants

	SN 1006	IC 443
Progenitor	White dwarf in a binary system	Massive star
Environment	Nearly uniform, low density (0.05 – 0.2 cm^{-3})	Atomic and molecular clouds (10 - 1000 cm^{-3})
Expansion	~4500-5000 km/s (but NW ~2900 km/s)	Varies; few 100 km/s or less
Stellar Remains	None known	Neutron star (probably)
Effect on Environment	Rapid expansion and CR acceleration	Shocking, heating, and compressing clouds



Summary and Reminders

- Why did I pick these two SNRs – SN 1006 and IC 443 – to talk about today?
  - They're about as different as can be and cover the range of features supernova remnants can have
  - We'll see them both again when we discuss SNRs and cosmic rays in detail
- There's a lot more variety yet to explore amongst the denizens of the stellar afterlife
- Next week we'll see how stars form and evolve

IC 443: The Movie