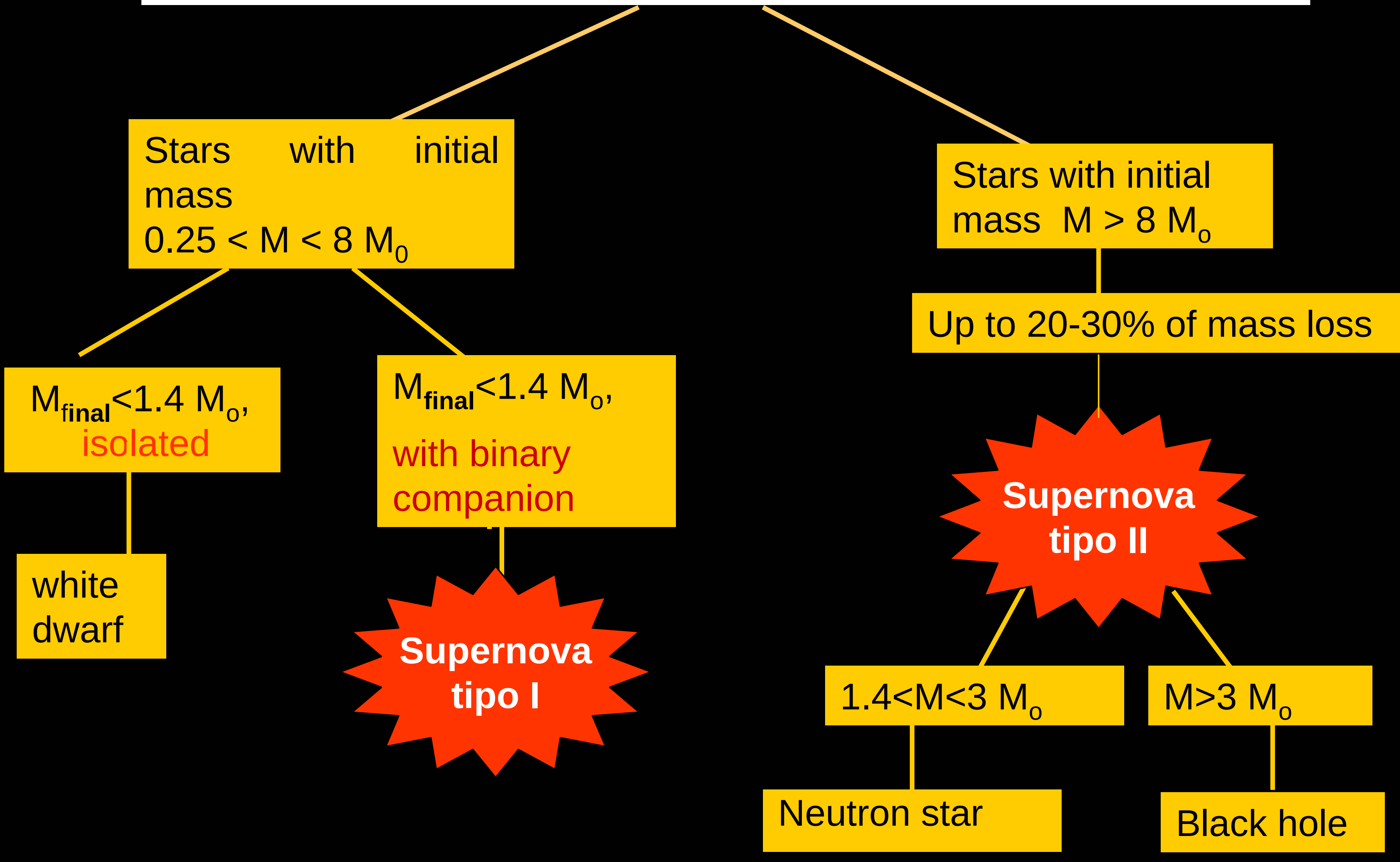
Fate of the stars



In the Universe there are approximately 8 new SNe exploding per second.

In the next hour there will be almost 30 thousand new SNe!!

A SN explosion means the sudden release of about 10^{53} ergs into the space

99 % is carried away by neutrinos

- 1% interacts with the ambient material
- After ~100 yrs the original 10^{51} ergs of mechanical energy are distributed over a cubic parsec.

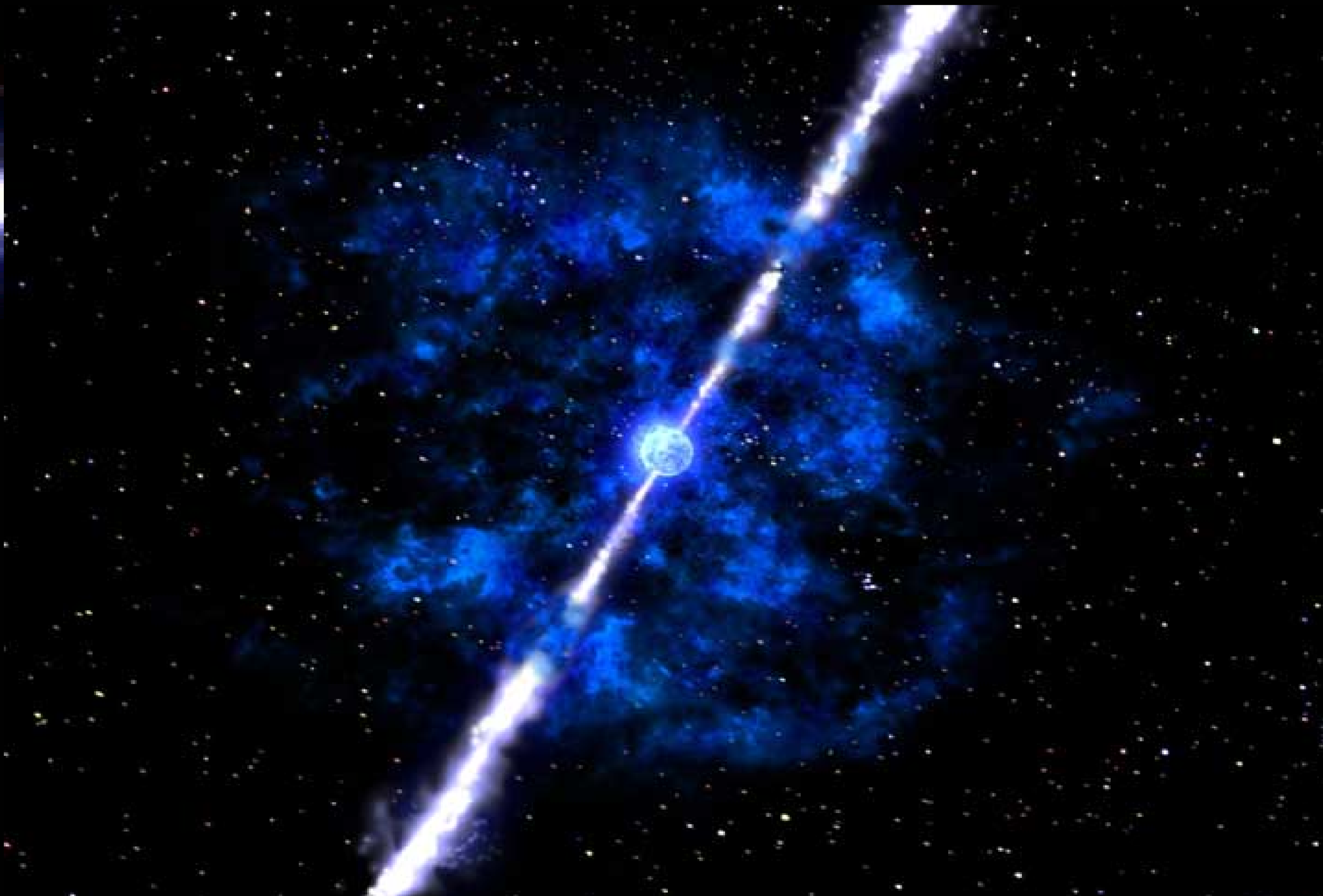
⇩

This means ~2 x 10^7 eV/cm^3 = <u>10^7 times larger</u> than the typical interstellar starlight and cosmic ray densities

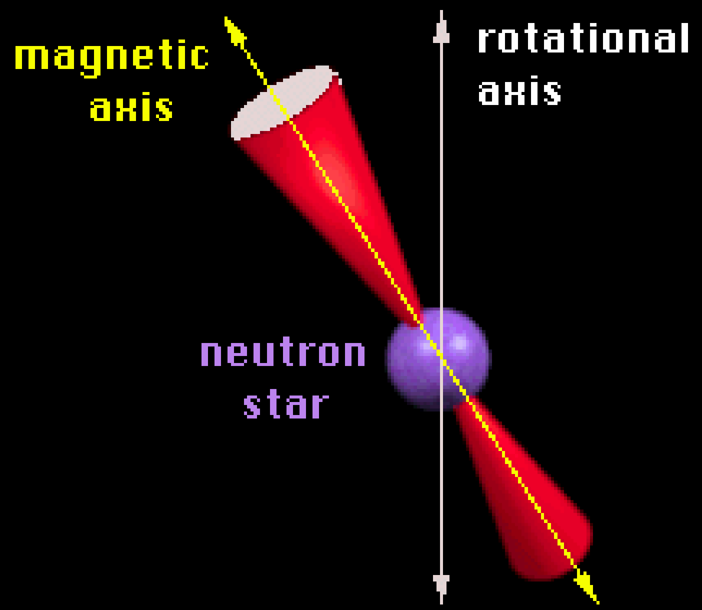
- Most of the matter (one to several solar masses) is ejected at speeds near 10^5 km/s

After the explosion of a SN it is expected to find:

- ejected stellar debris
- a shell of shocked ISM and swept-up material
- a central compact core (neutron star or black hole)
- a synchrotron nebula around the central neutron star
- thermal X-ray emission from the hot interior
- optical filaments from stellar ejecta and from interaction between the SN shock and the surrounding clouds

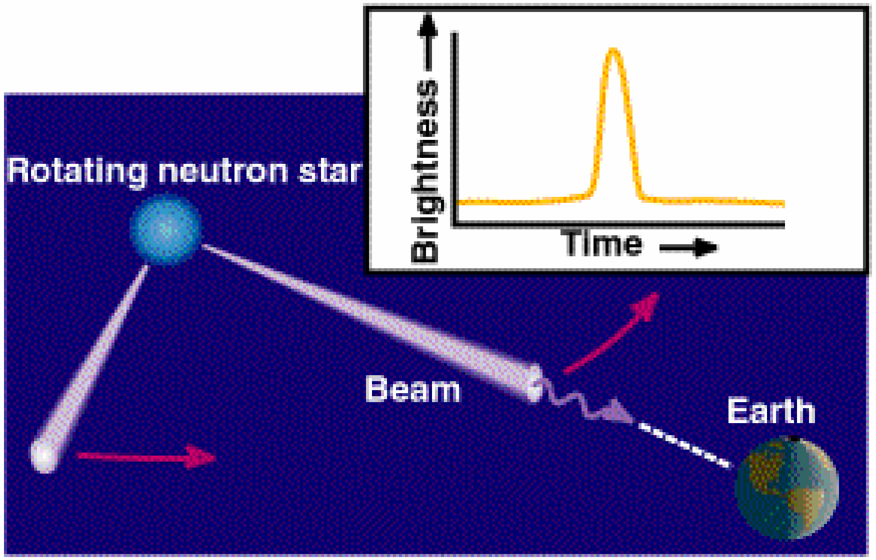


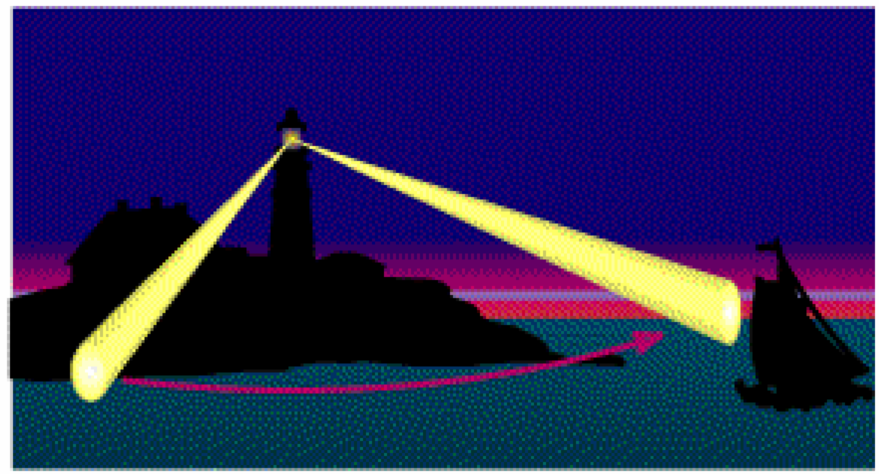
Rotating neutron star: pulsar



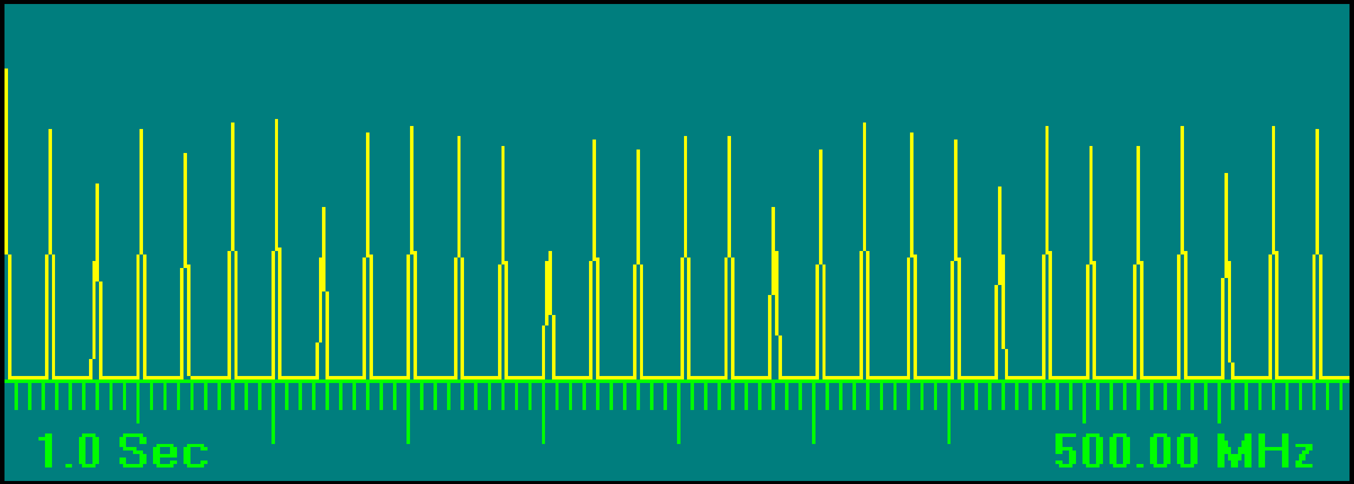
Pulsar Beaming

We see a pulse
when beam
points at Earth.

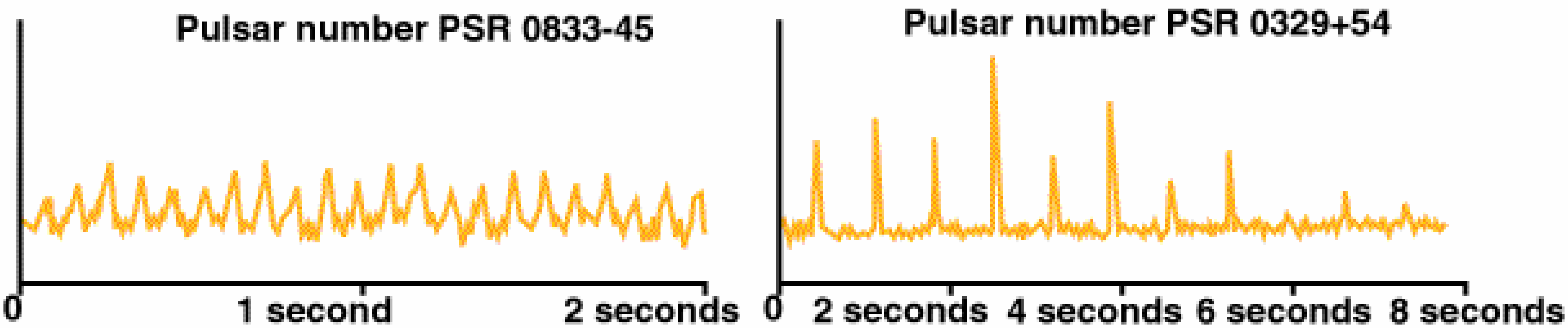


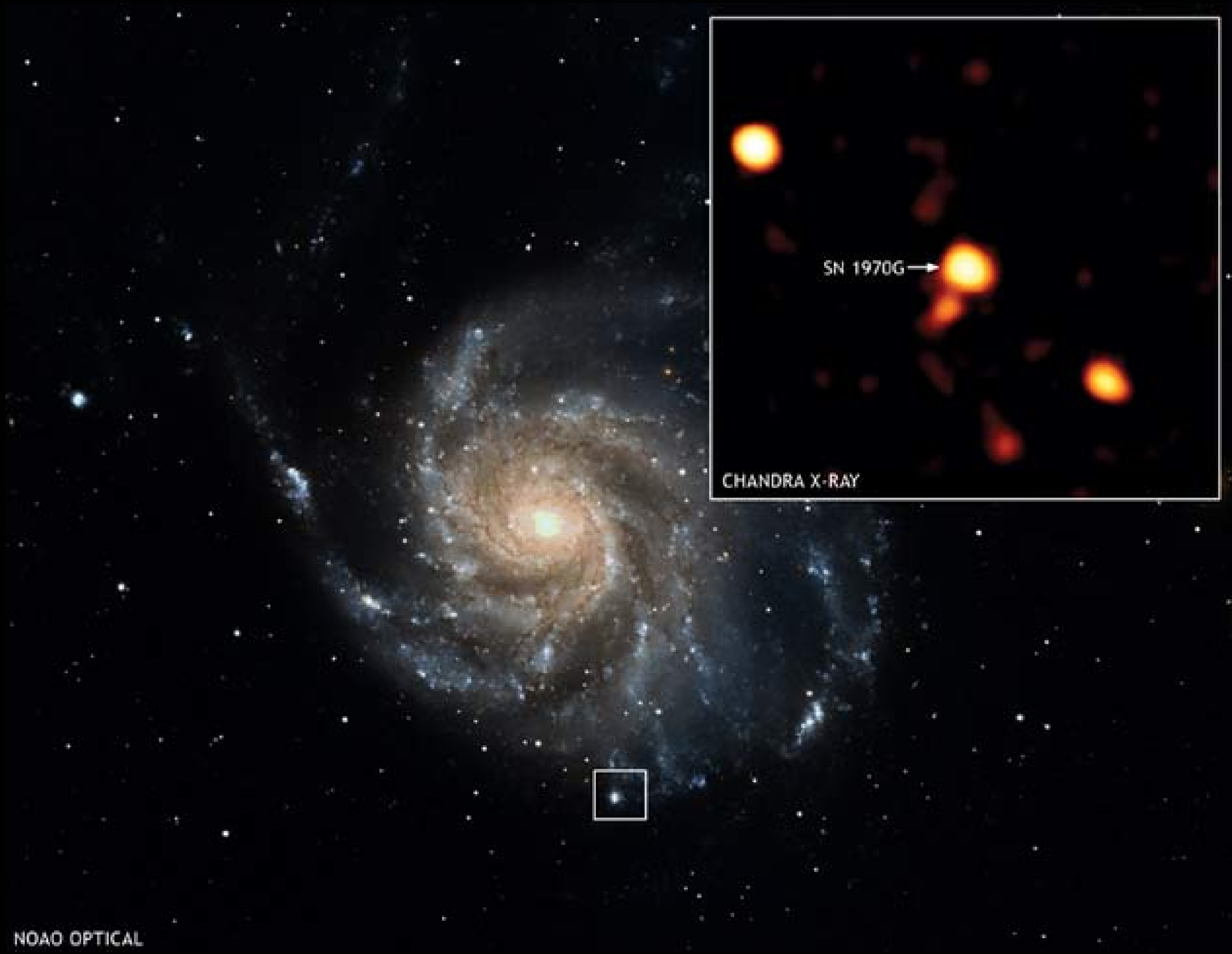


The Crab Pulsar



Graph of Pulsar Pulses

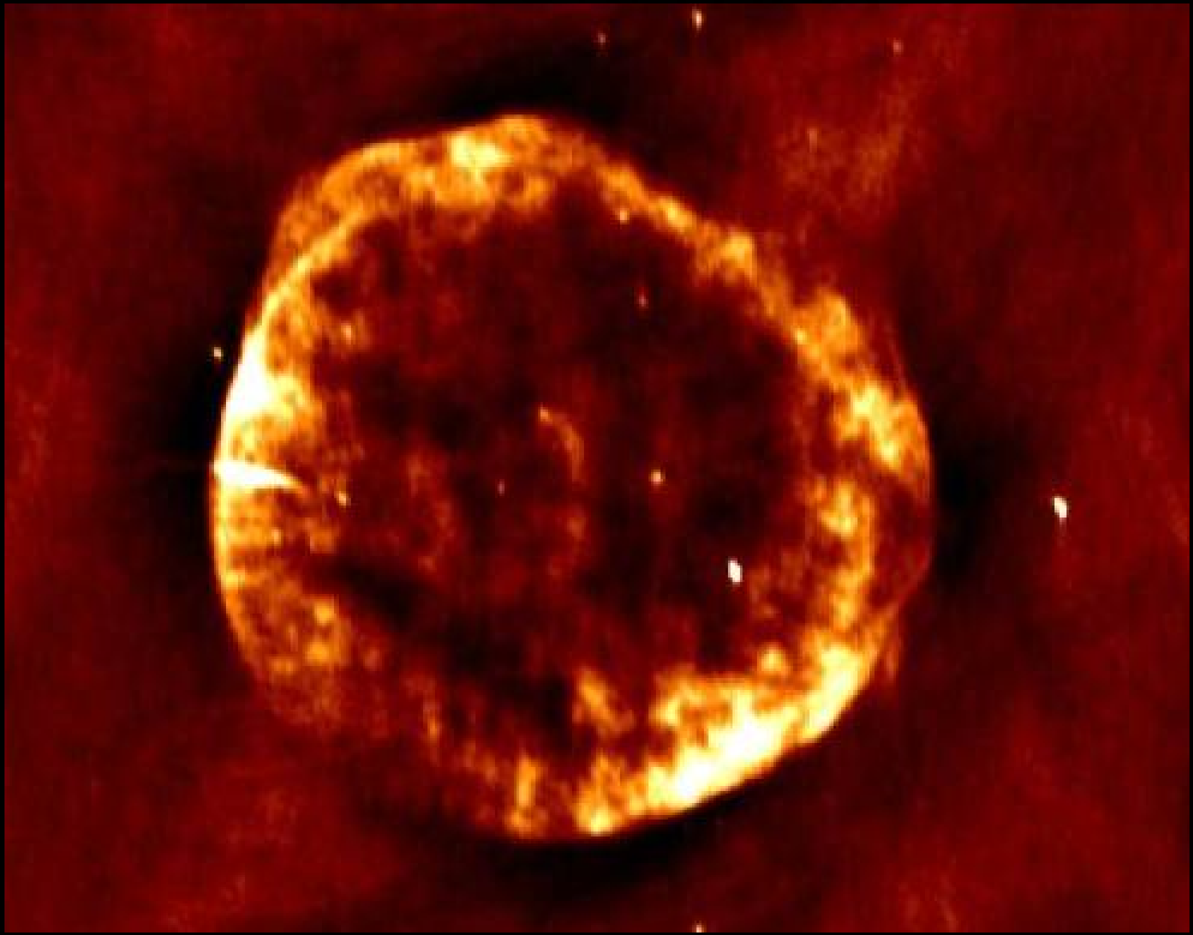




Immler & Kuntz, Ap. J.in press, 2005

Historical Supernovae

	year	duration
SN1006	1006	several yrs
Crab	1054	22 months
3C58	1181?	6 months
Tycho	1572	16 months
Kepler	1604	12 months
Cas A	~1658	



radio VLA image

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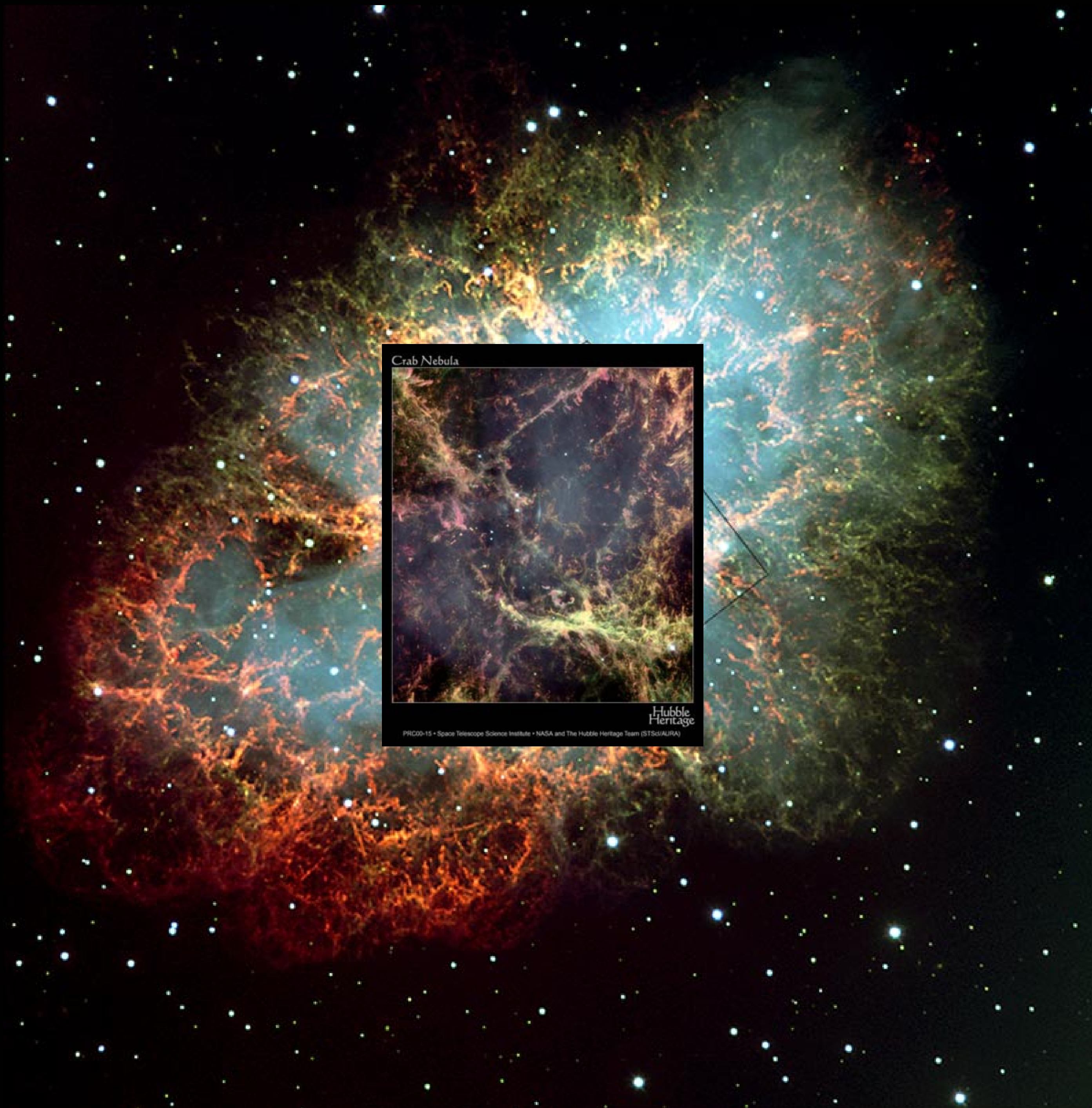
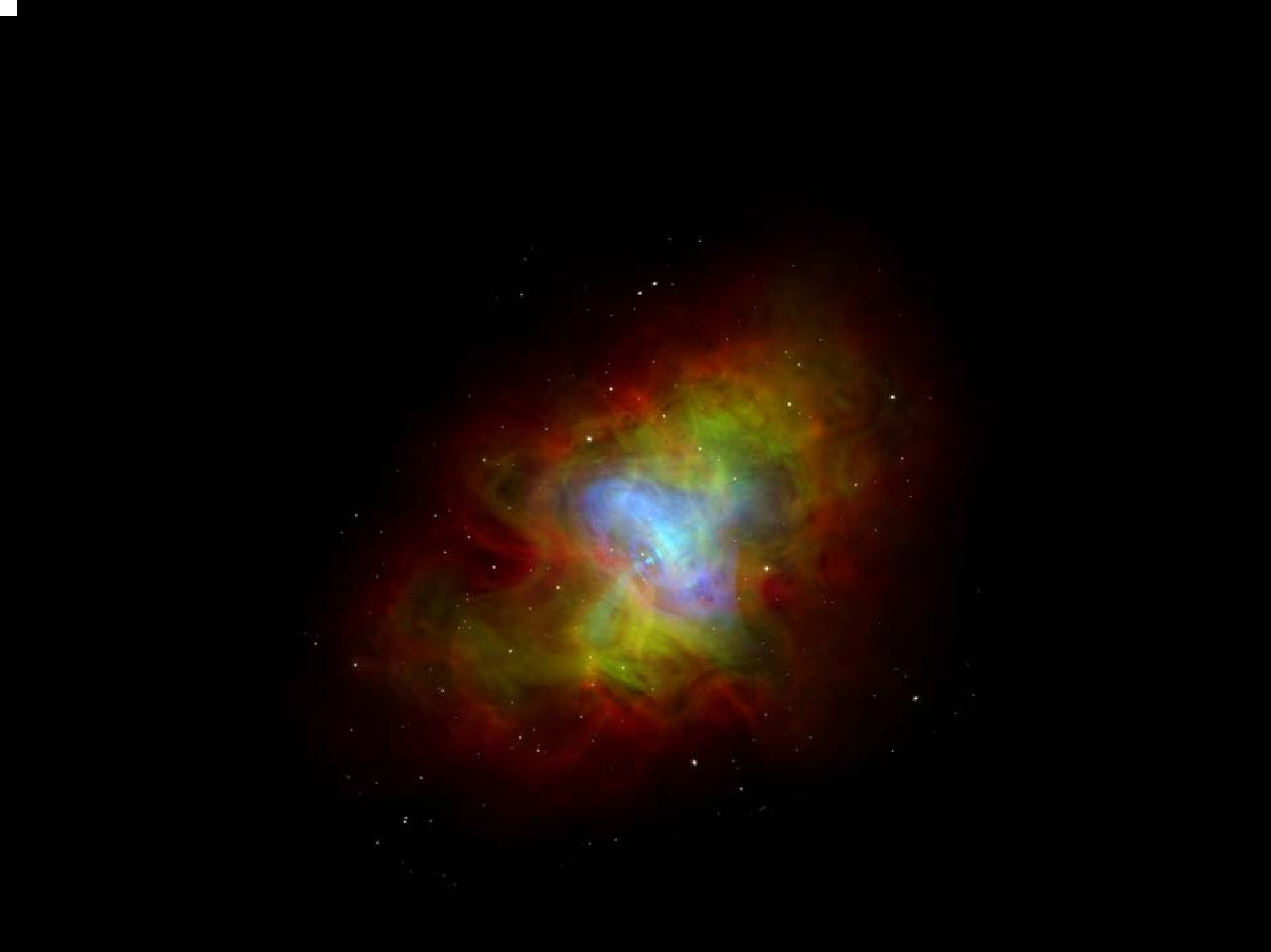
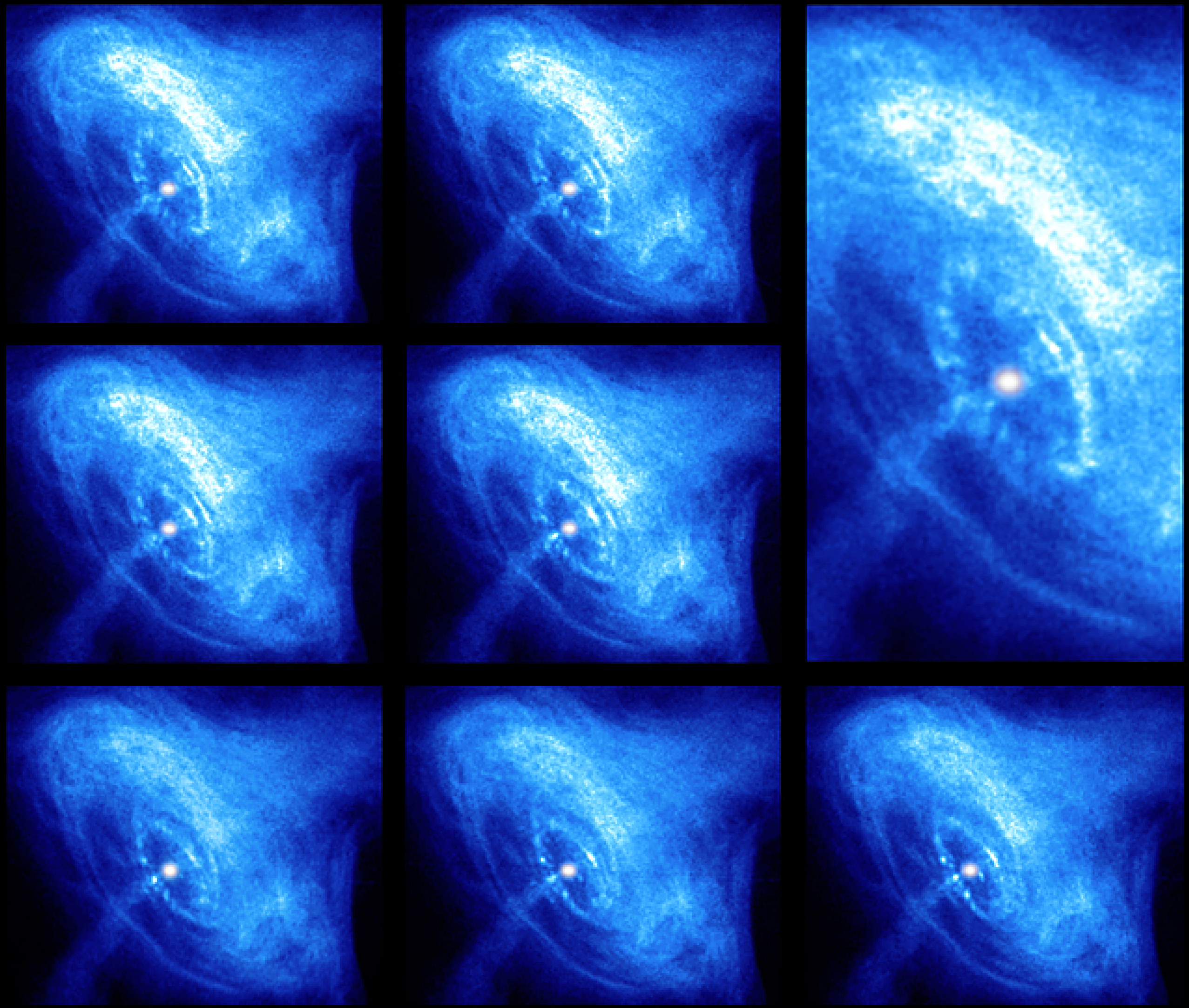
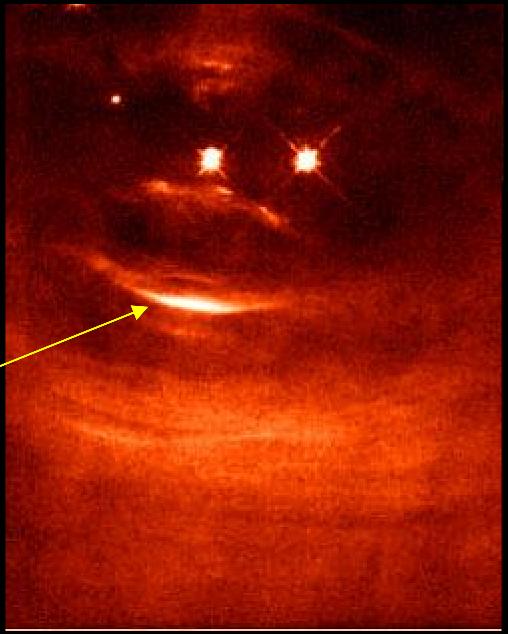

Crab Nebula
Hubble Heritage
PRC00-15 • Space Telescope Science Institute • NASA and The Hubble Heritage Team (STScI/AURA)







the bright spots
moves away at
~ 150.000 km/s

Crab Nebula Supernova Remnant Spitzer Space Telescope • IRAC • MIPS

NASA / JPL-Caltech / R. Gehrz (University of Minnesota) sig05-004

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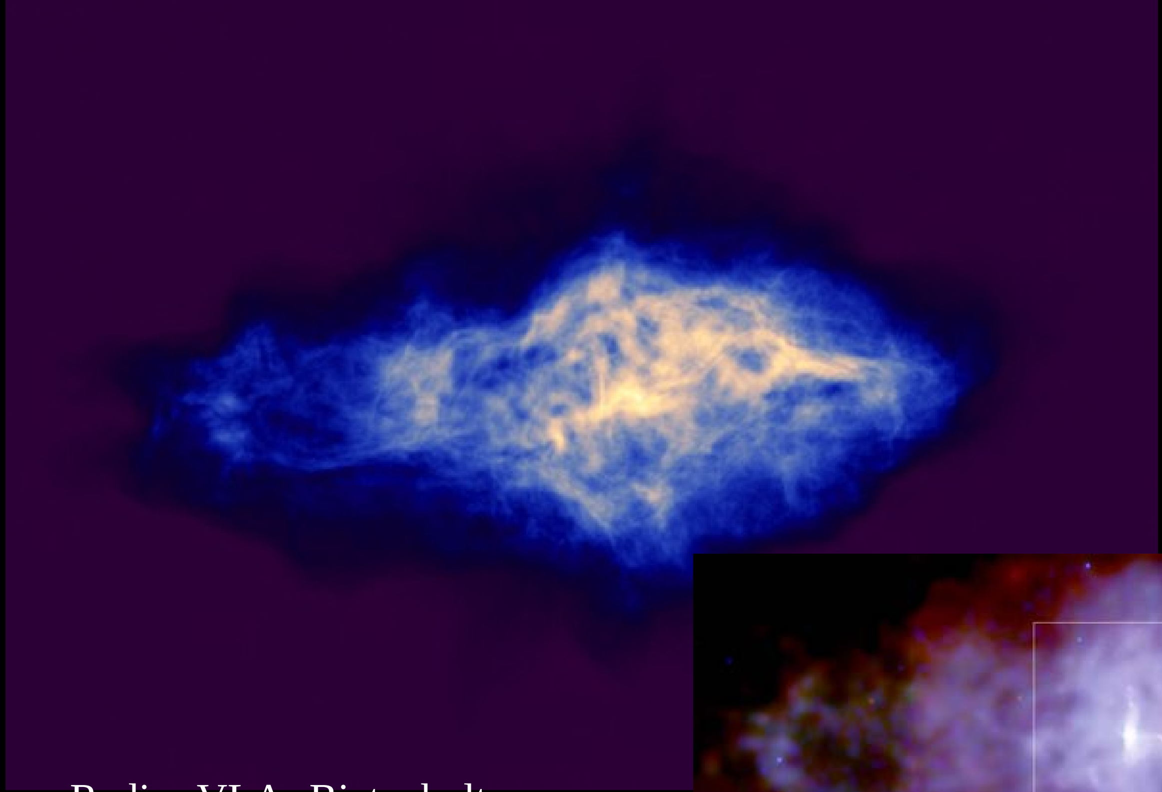
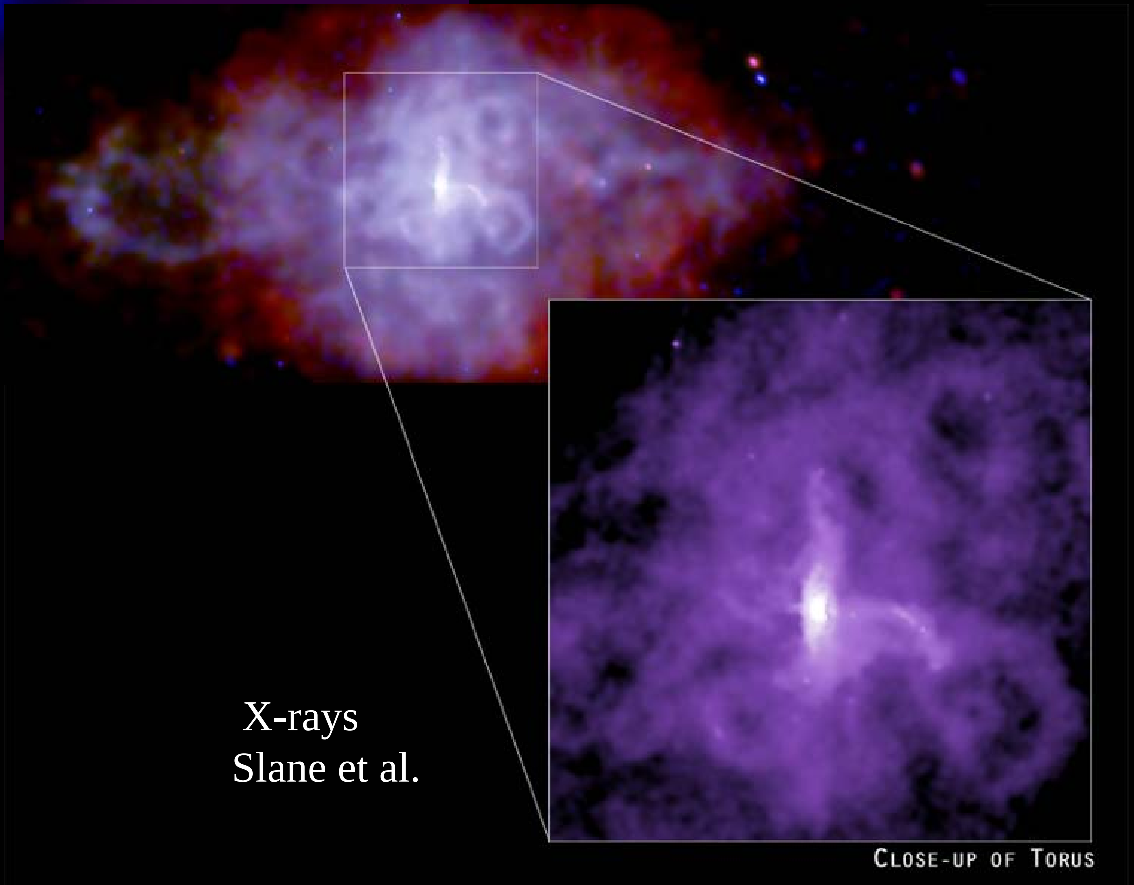
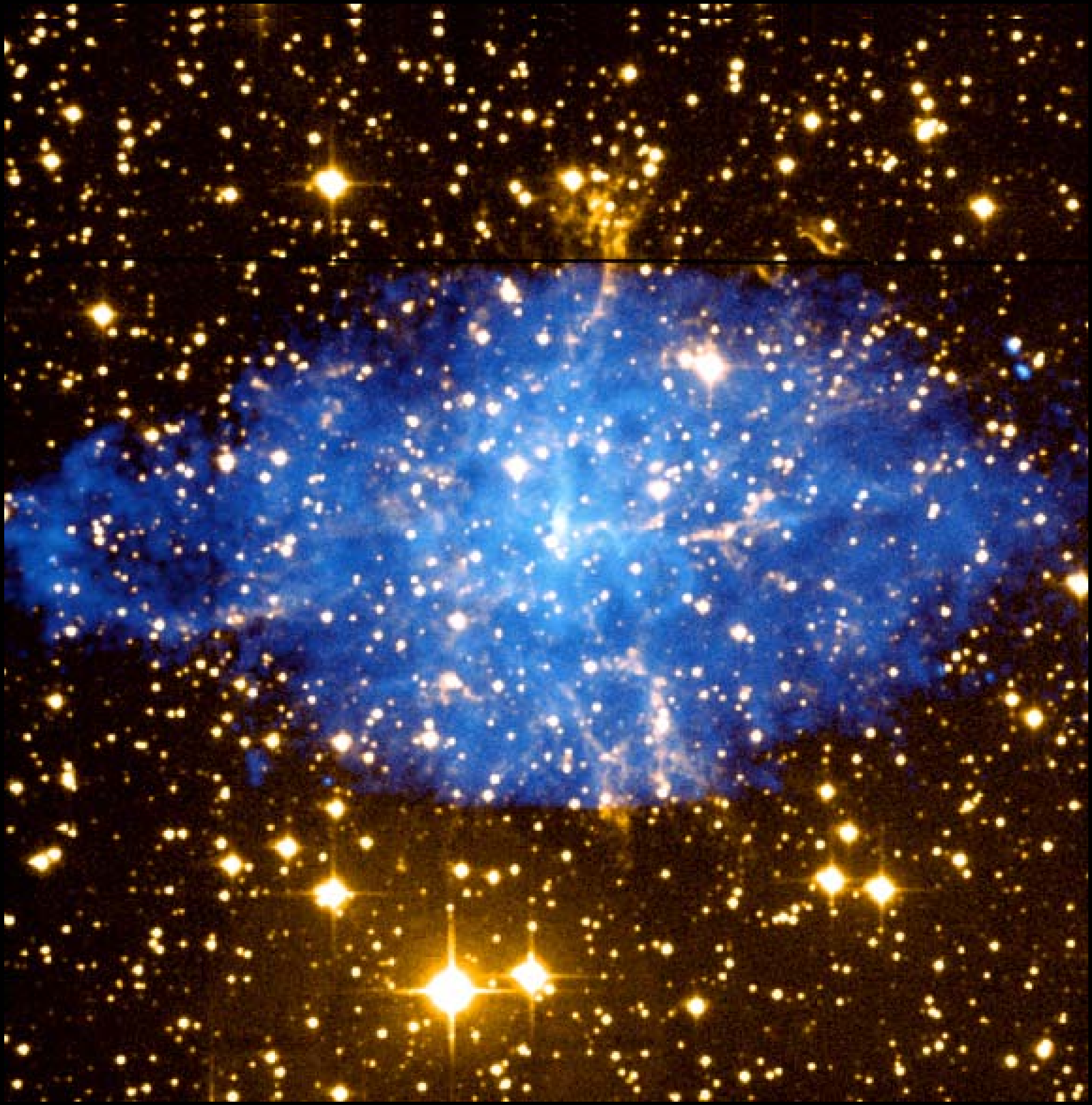


Radio- VLA- Bietenholtz



X-rays
Slane et al.



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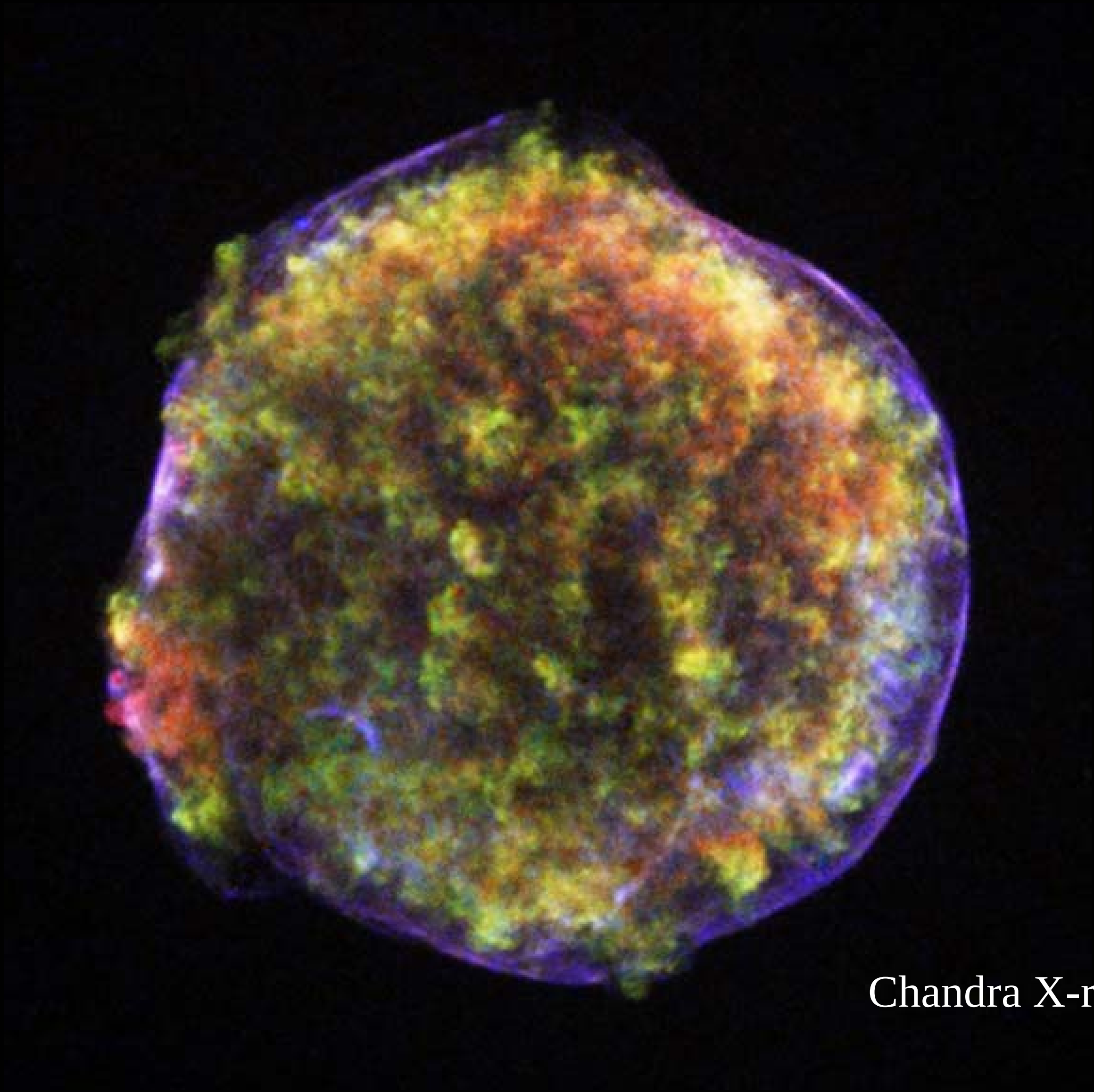
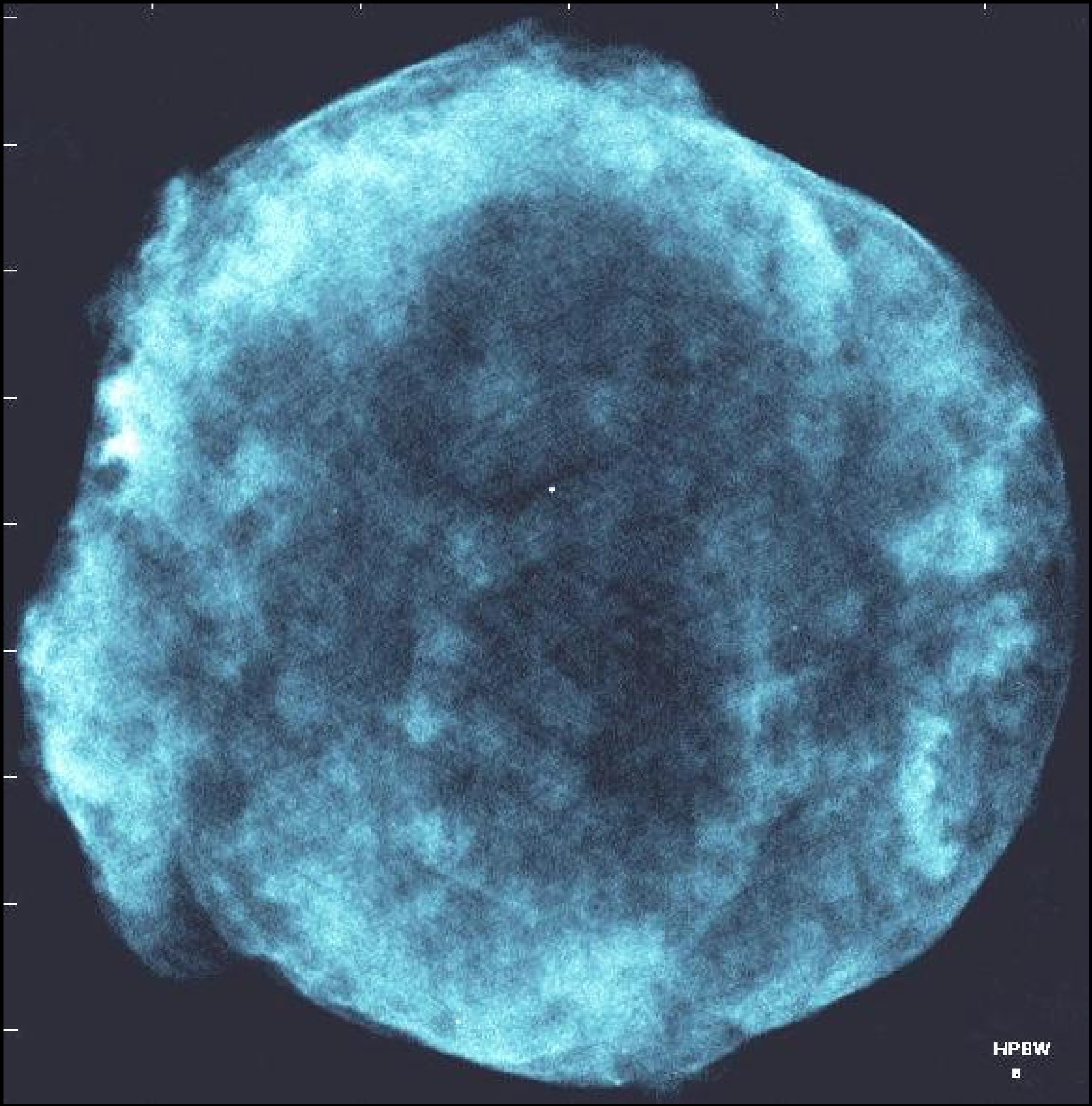
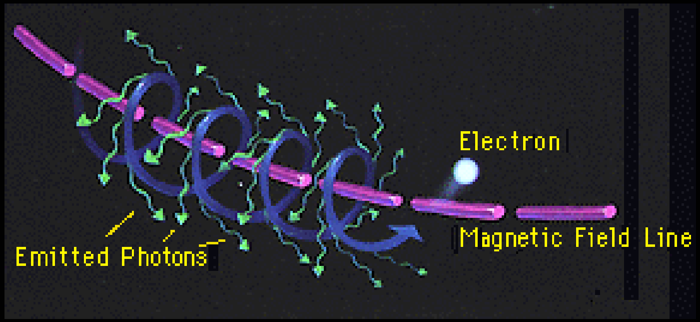

Chandra X-ray image

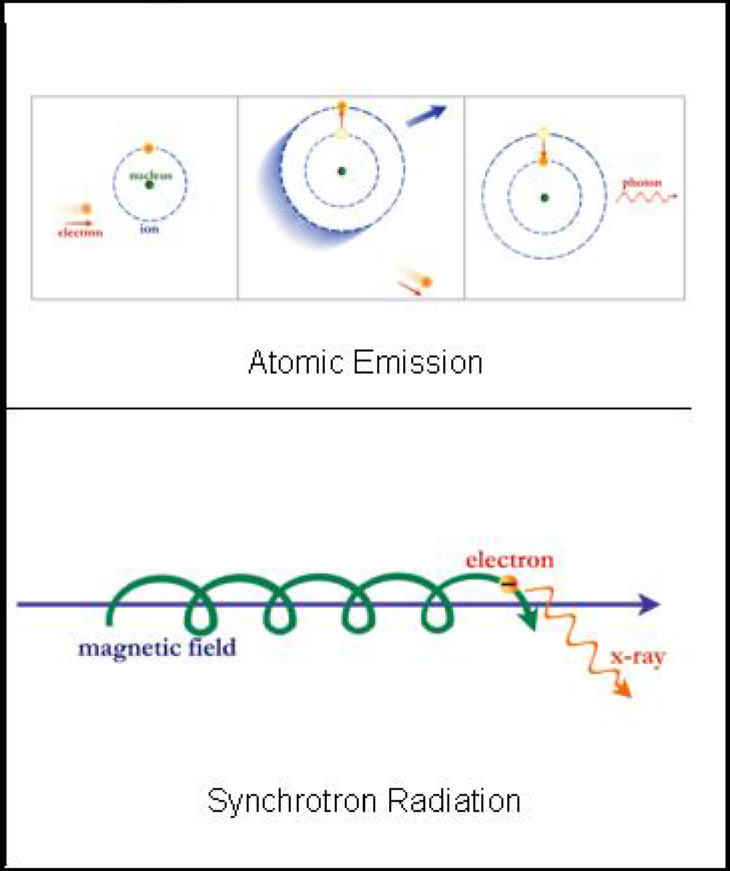


VLA radio image

Non-thermal radio emission



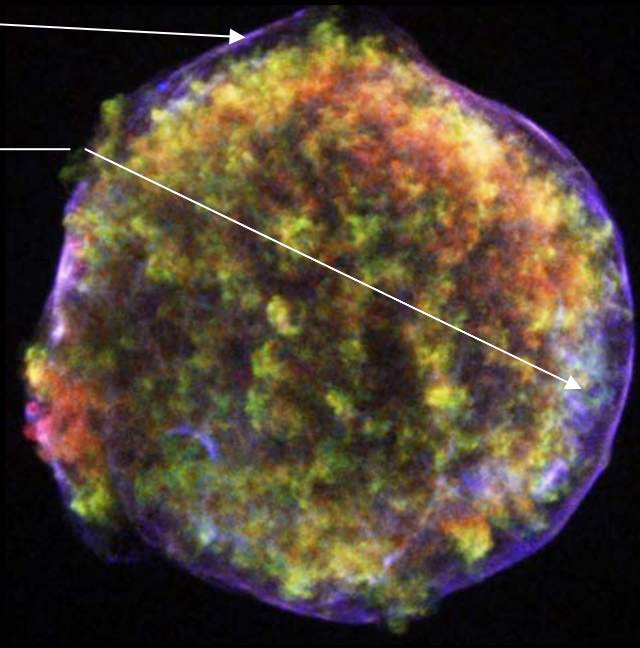
Thermal and non-thermal X-rays



The supersonic expansion of the stellar debris has created two X-ray emitting shock waves - one moving outward into the interstellar gas, and another moving back into the debris.

The small separation between them is thought that is because a large fraction of the energy of the outward-moving shock wave is going into the acceleration of atomic nuclei to speeds approaching the speed of light.

This finding is important for understanding the origin of cosmic rays,



Red 0.95-1.26 keV,
Green 1.63-2.26 keV,
Blue 4.1-6.1 keV

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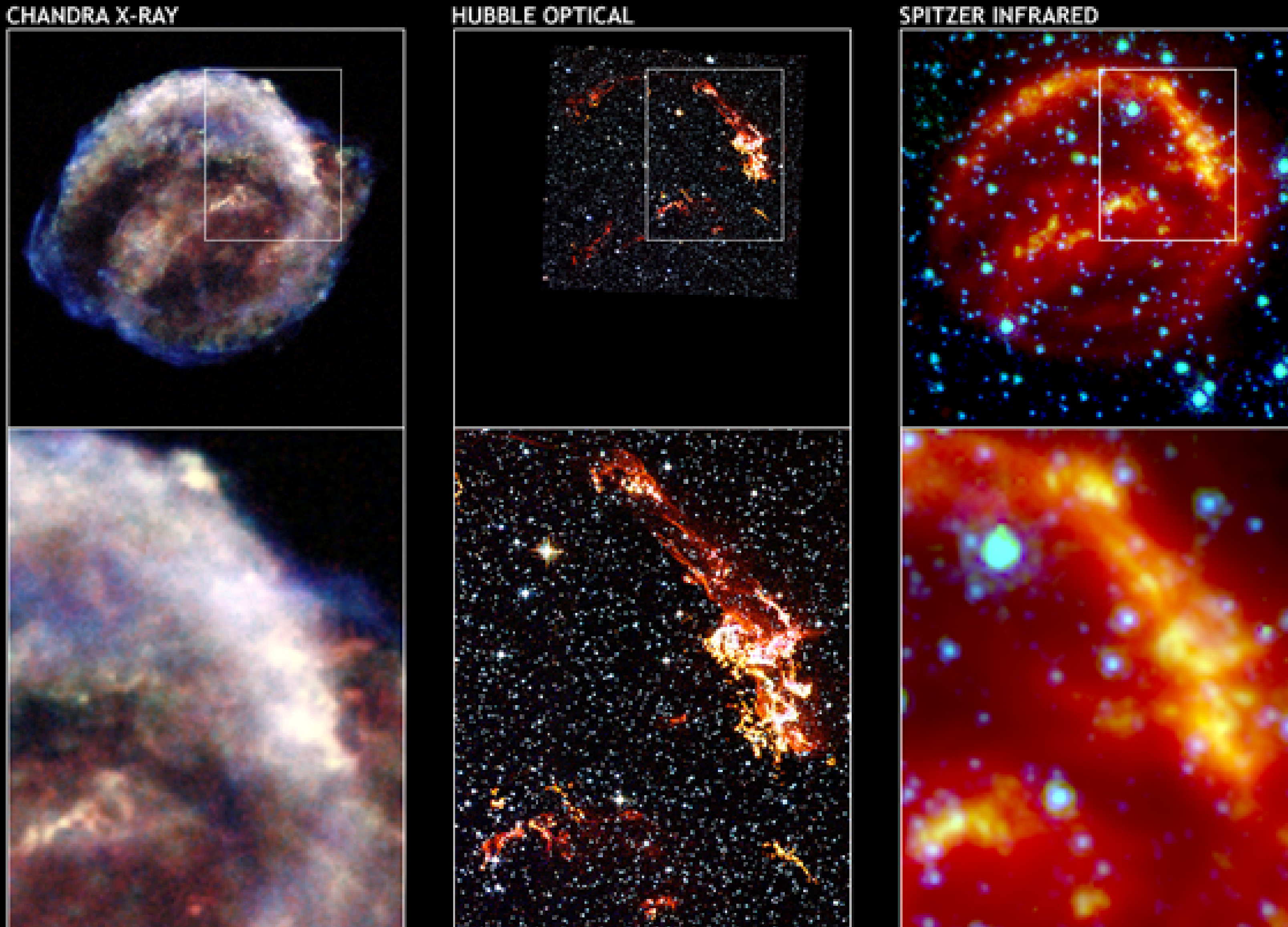
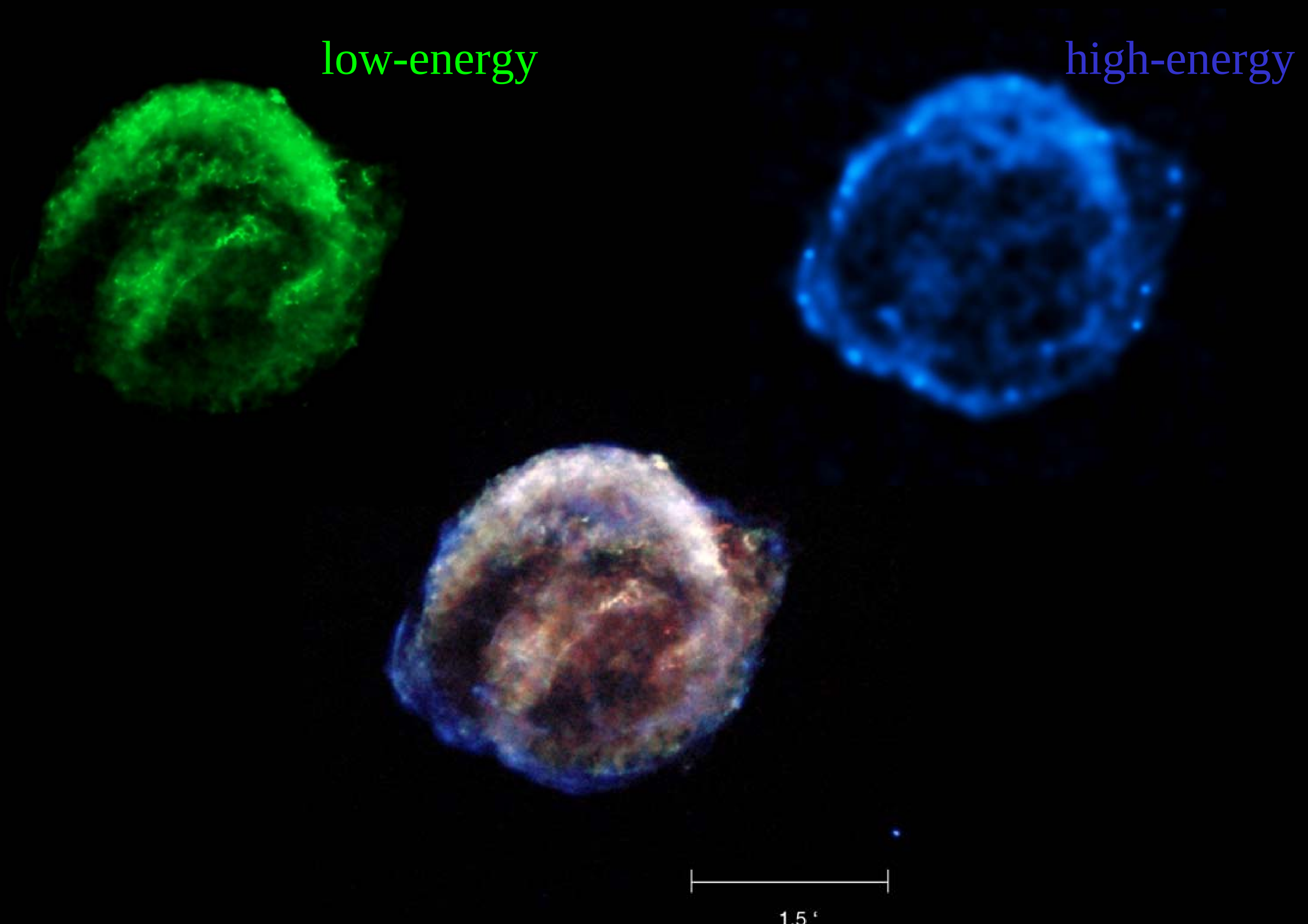

CHANDRA X-RAY
HUBBLE OPTICAL
SPITZER INFRARED

Chandra X-ray images of Kepler SNR



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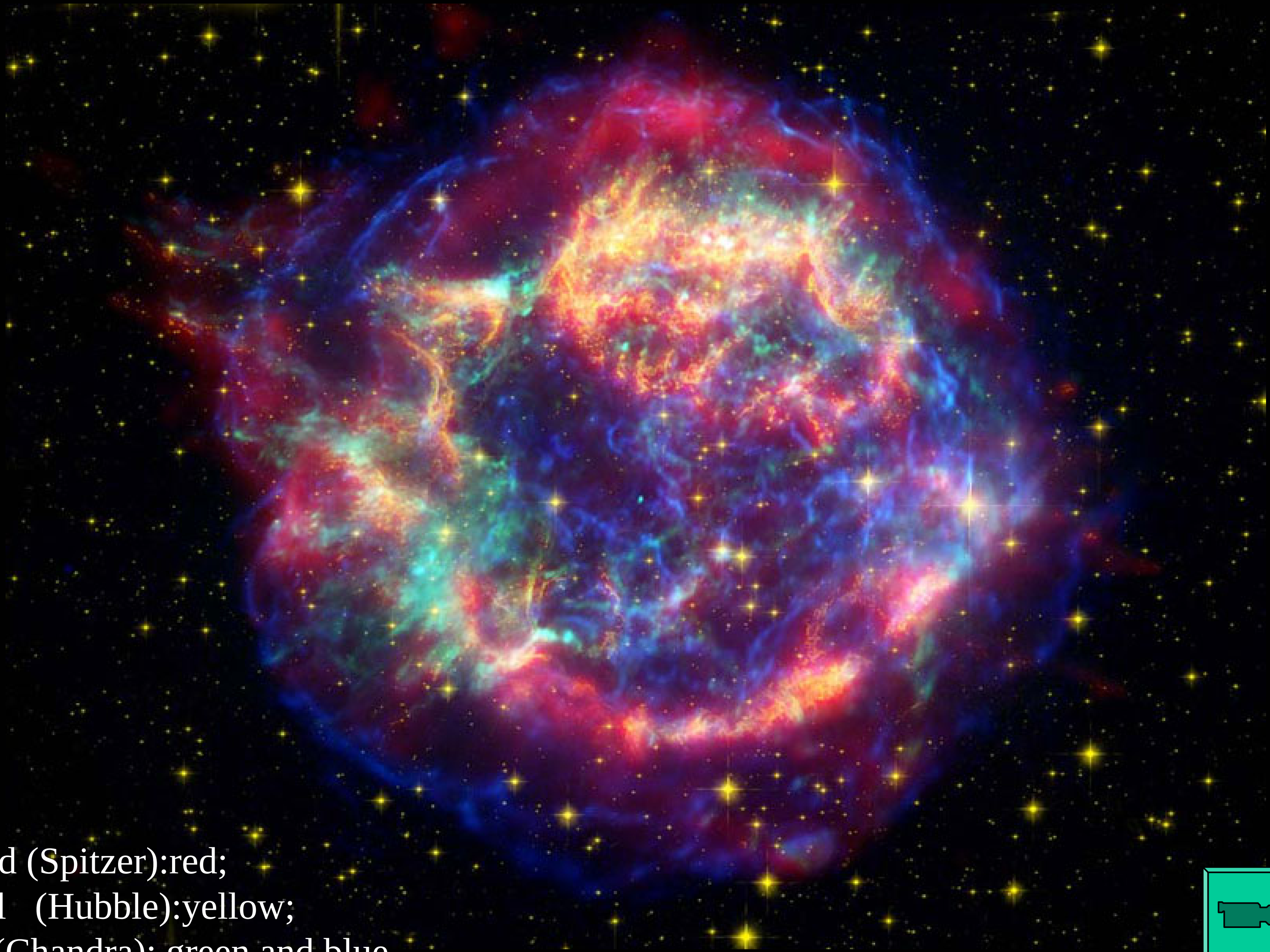
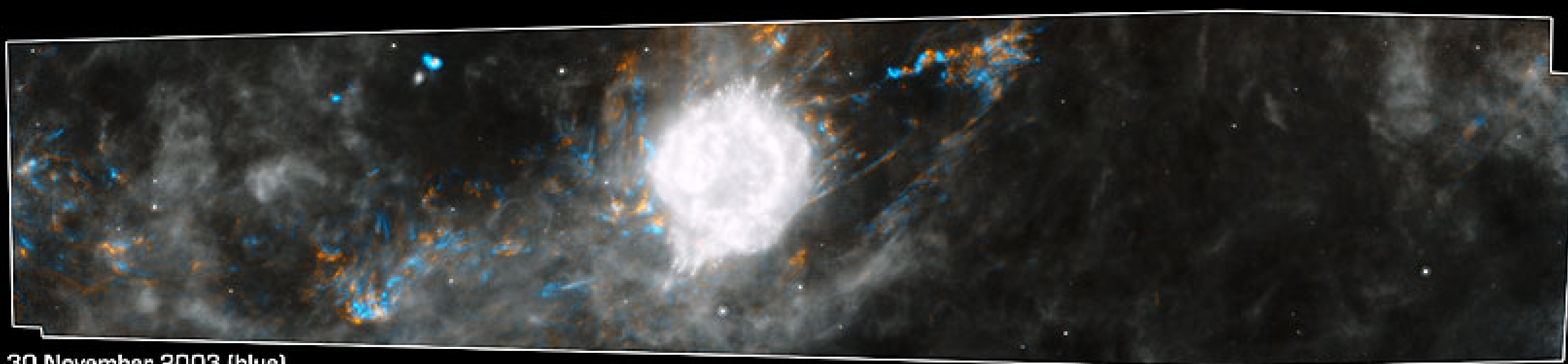


Infrared (Spitzer):red;
Optical (Hubble):yellow;
X-ray (Chandra): green and blue.

Infrared echoes trace the light waves blasted away from the SN (about 50 yrs ago). As the light waves move outward, they heat up clumps of surrounding dust, causing them to glow in infrared light.

The dust is not moving, but is being lit up by passing light.

Spitzer pictures revealed a blend of at least two light echoes around Cassiopeia A, one from its supernova explosion, and one from the activity that occurred around 1953 in the neutron



30 November 2003 (blue)
2 December 2004 (orange)

Cassiopeia A Supernova Remnant & Light Echo
NASA / JPL-Caltech / O. Krause (Steward Observatory)

Spitzer Space Telescope • MIPS
ssc2005-14b

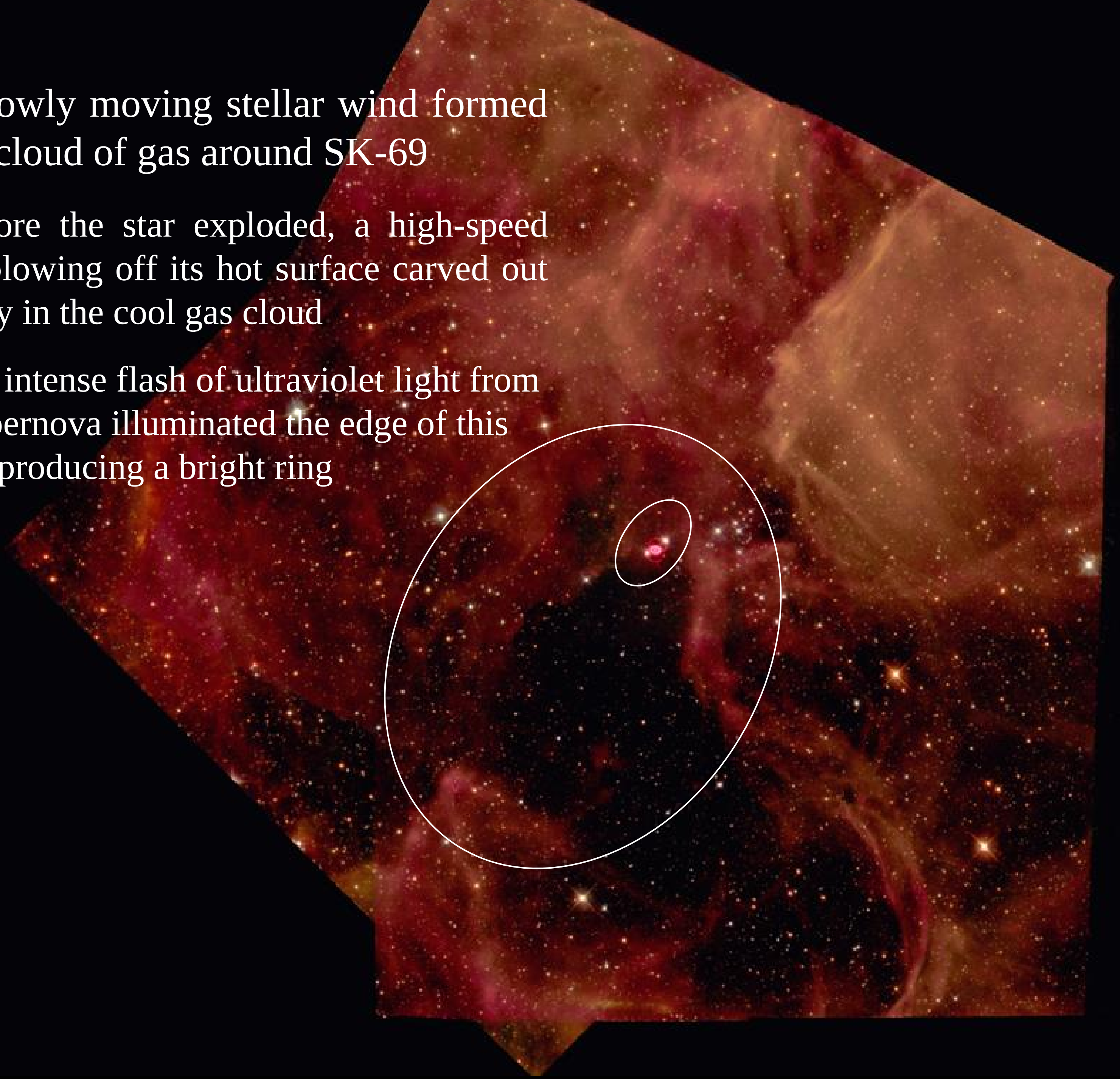
The explosion of a blue supergiant star called Sanduleak -69º 202 (SK -69) with a mass of ~ 20 M_o

It is the brightest and the best observed SN of modern astronomy

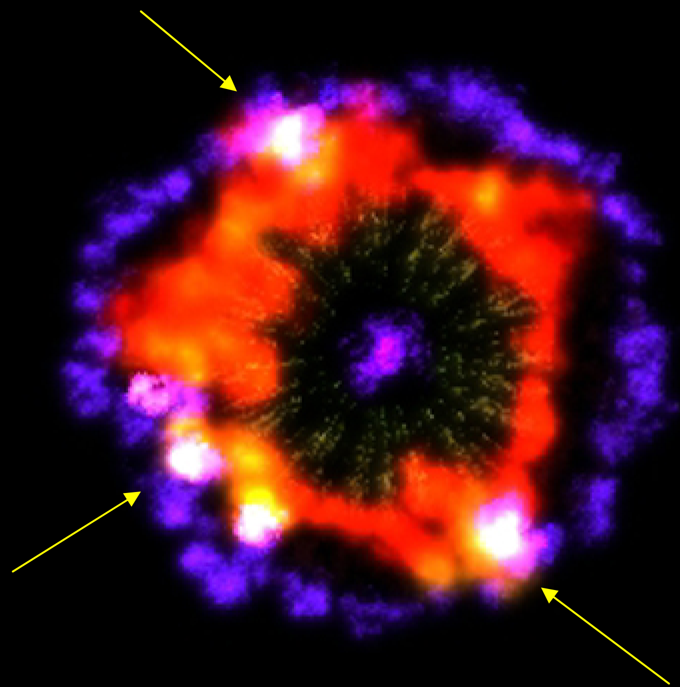
1) a slowly moving stellar wind formed a vast cloud of gas around SK-69

2) before the star exploded, a high-speed wind blowing off its hot surface carved out a cavity in the cool gas cloud

3) The intense flash of ultraviolet light from the supernova illuminated the edge of this cavity producing a bright ring



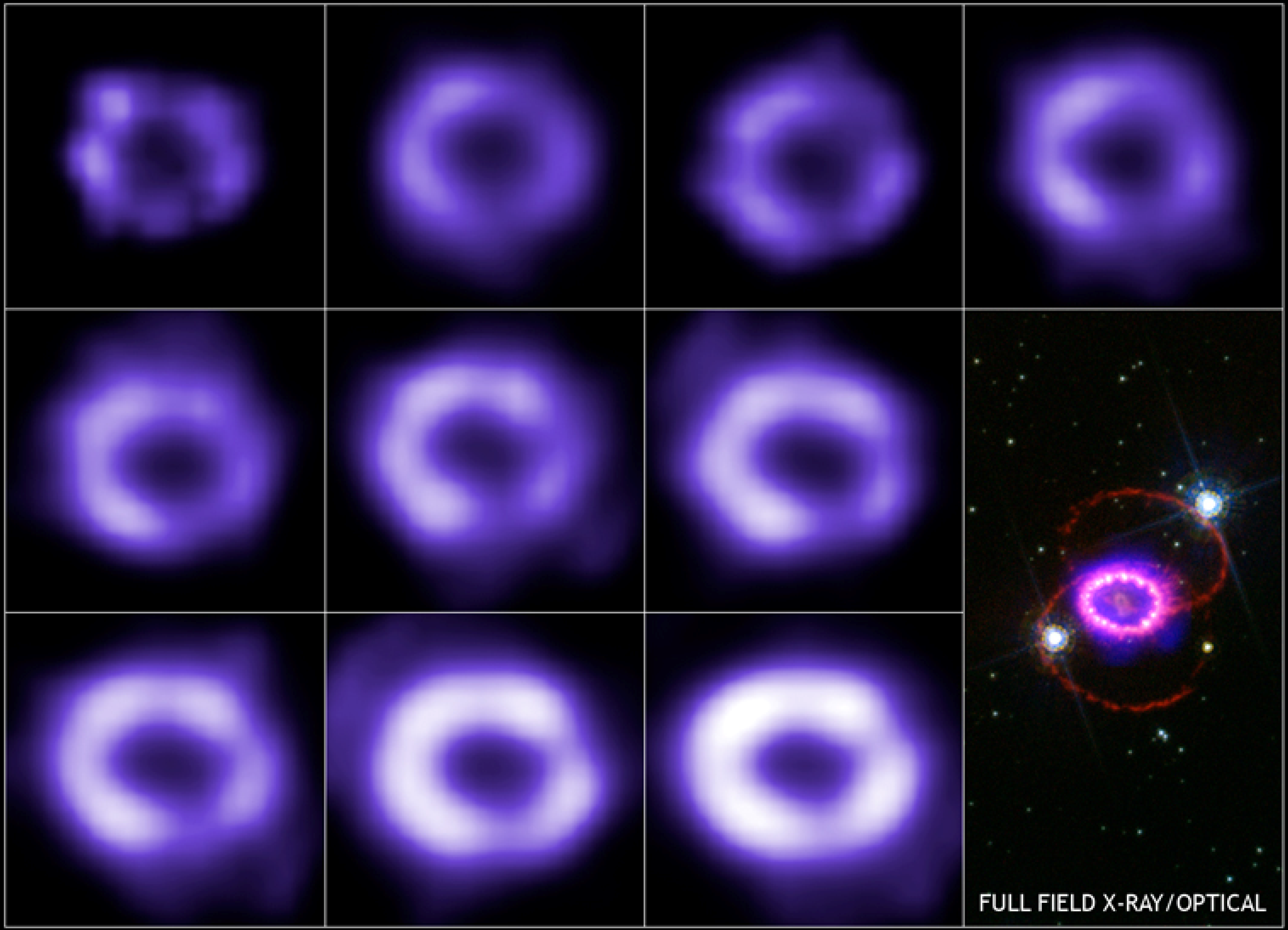
The blue ring is material ejected from the star thousands of years ago.
The expanding orange and yellow shell is multimillion degree, X-ray emitting gas produced by the explosion.
Portions of the blue ring light up when struck by the X-ray shell.

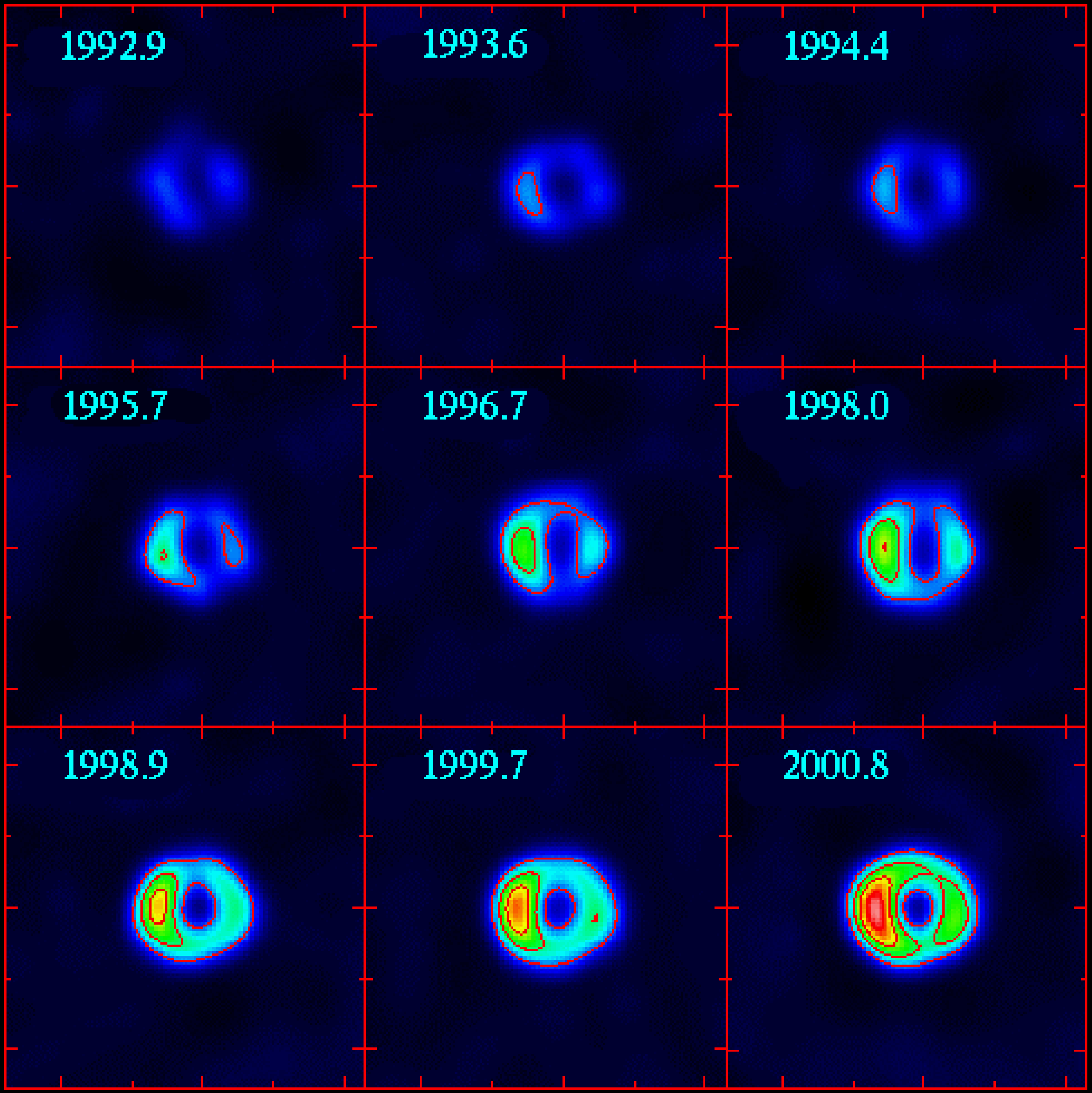


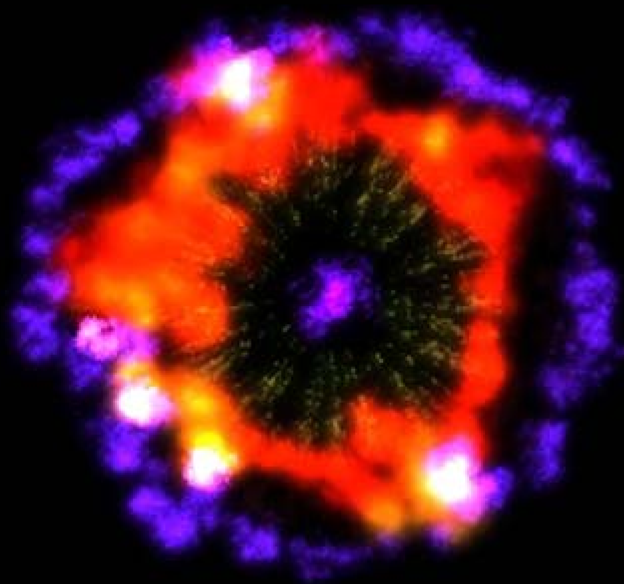
- The fingers protruding inward were produced by the interaction of the high-speed wind with the dense circumstellar cloud.

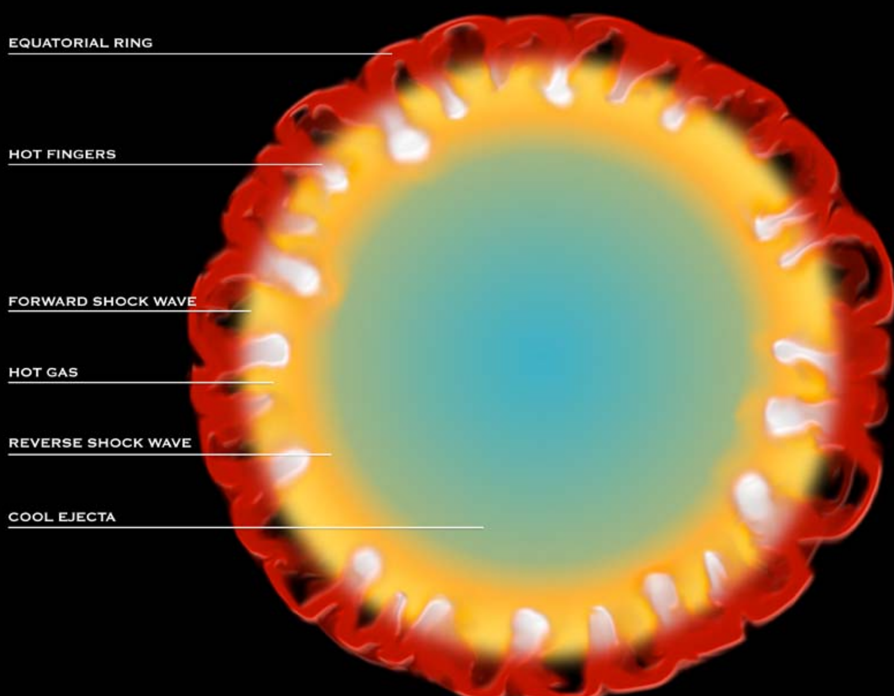
- The collision of the outward-moving supernova shock wave (yellow) with the dense fingers of cool gas produce bright spots (white) of optical and X-ray emission.

- The expanding debris (blue) of the exploded star lags behind the shock wave and, except for a thin shell around the outer edge (gold), is too cool to produce X-rays.


FULL FIELD X-RAY/OPTICAL


1992.9
1993.6
1994.4
1995.7
1996.7
1998.0
1998.9
1999.7
2000.8





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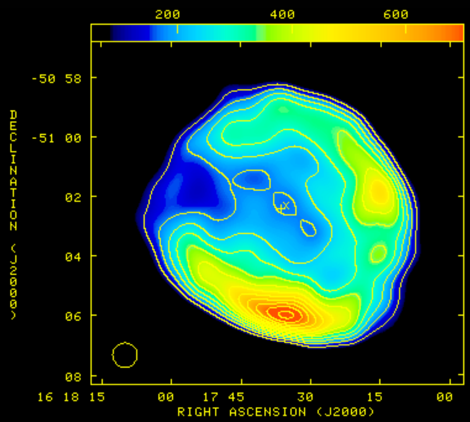
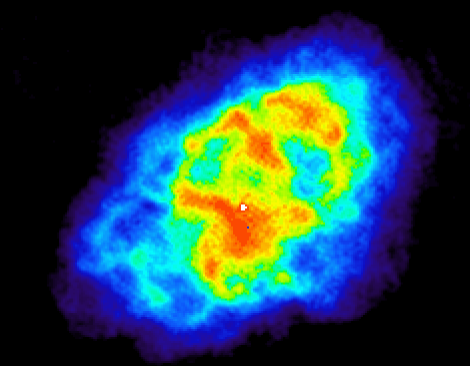
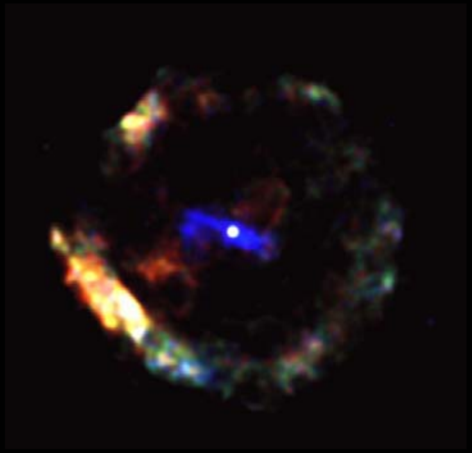
SNRs have been classically classified into three broad categories, according to their radio morphology:



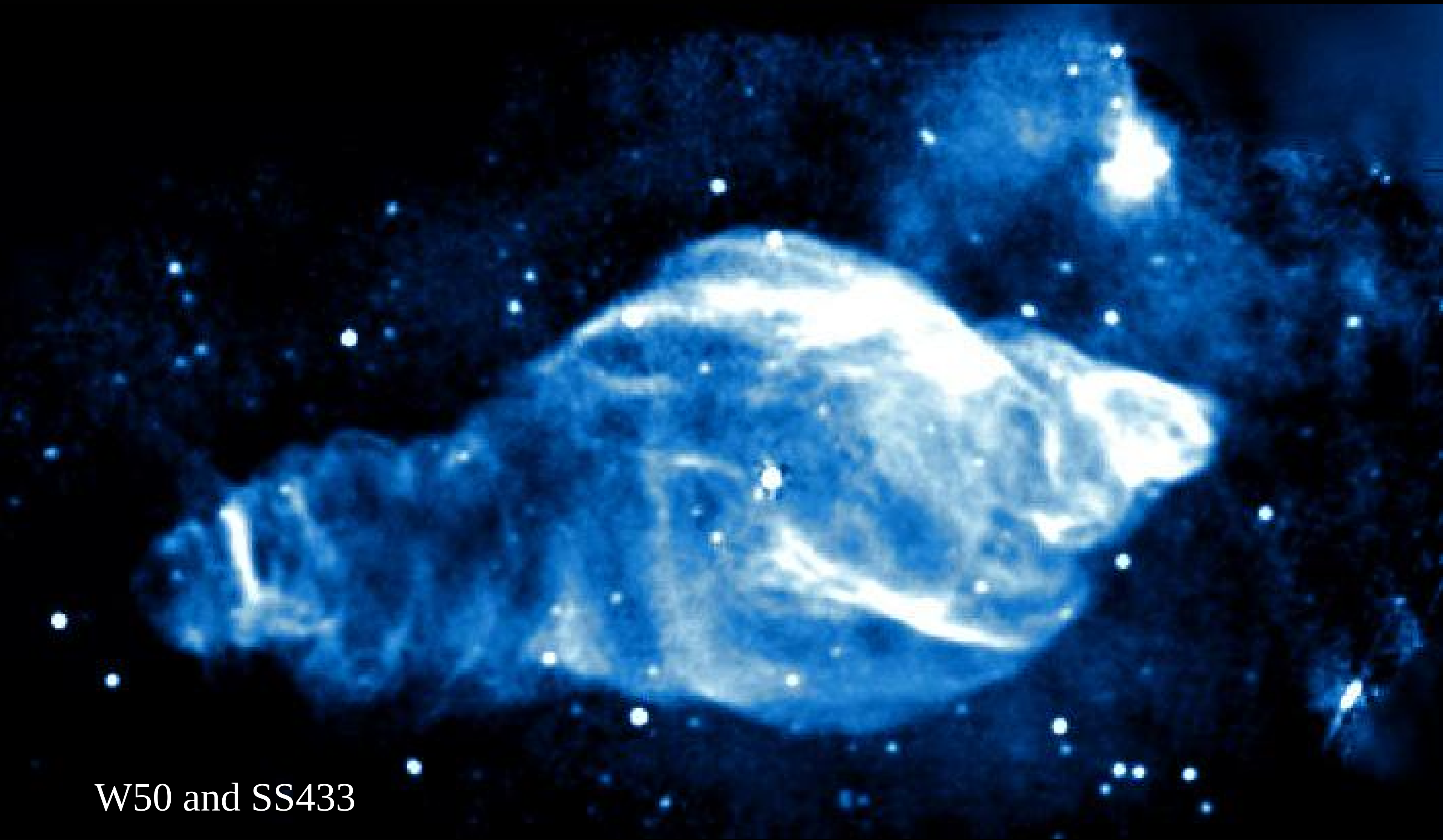
Shell - type: where electrons are accelerated at the shock front.

Crab-like or plerions: where the electrons are injected by a central neutron star

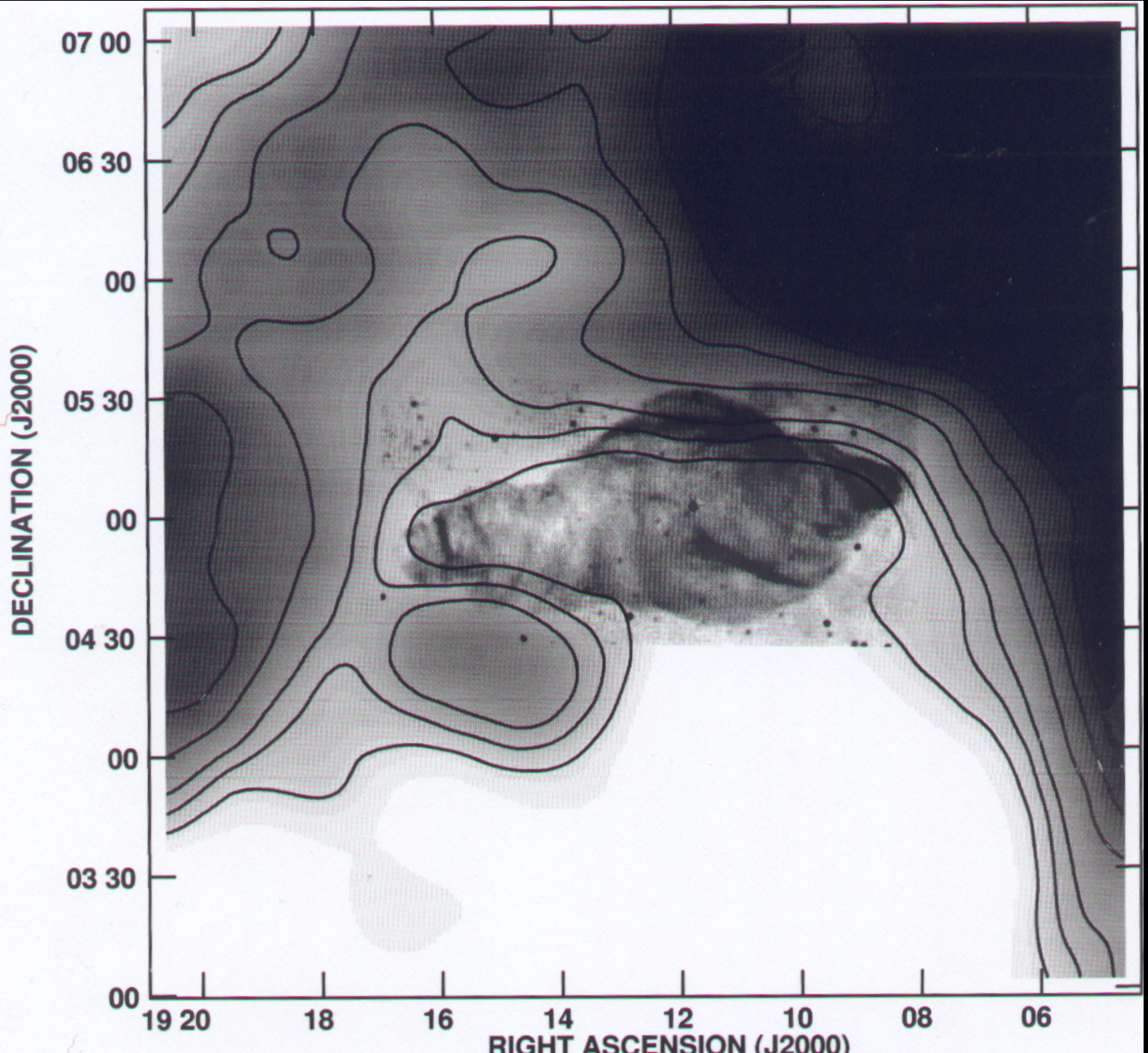




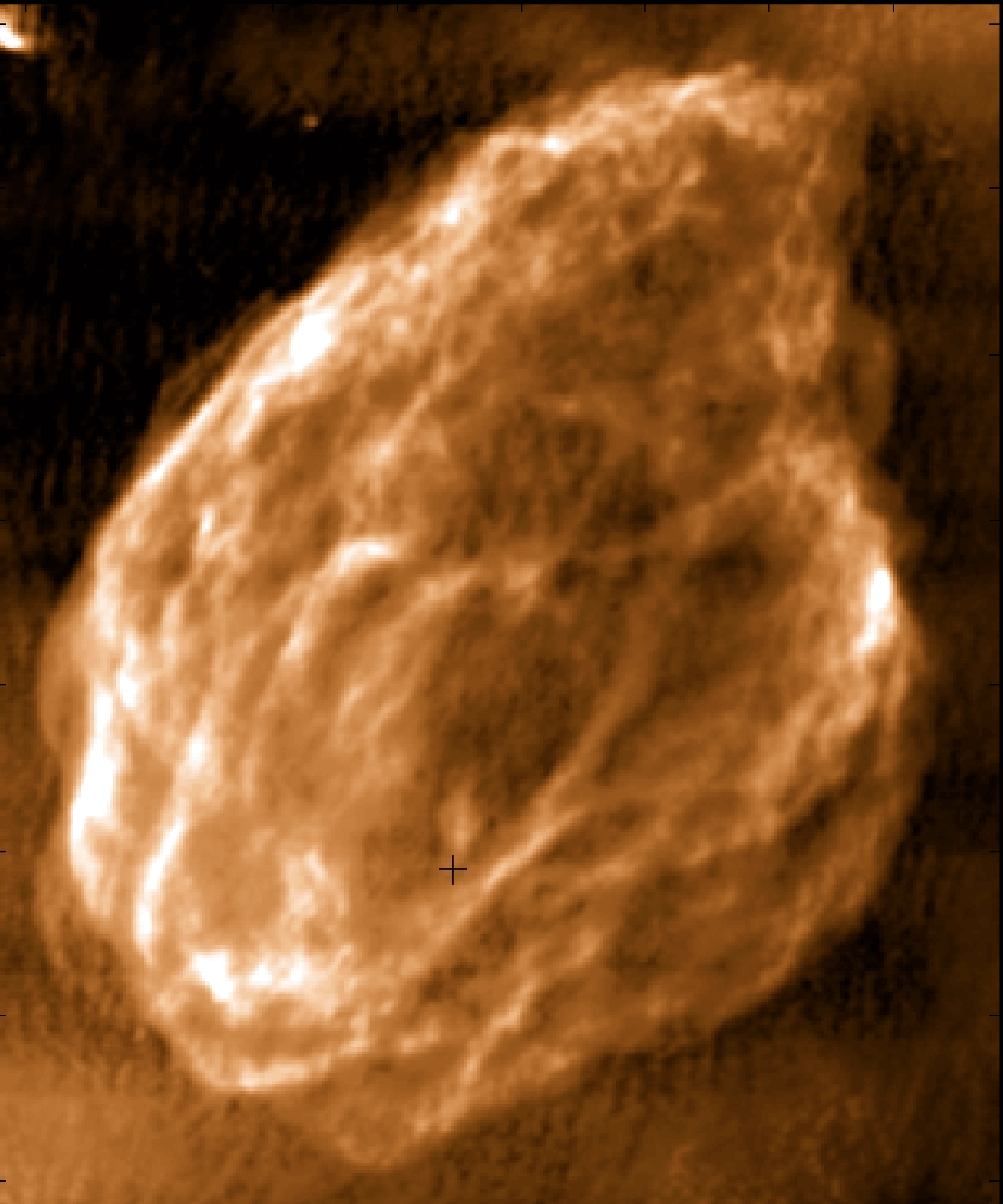
Composites: which include a shell plus a central component (in radio or X-rays)



W50 and SS433



07 00
06 30
00
05 30
00
04 30
00
03 30
00
DECLINATION (J2000)
19 20
18
16
14
12
10
08
06
RIGHT ASCENSION (J2000)



High resolution radio images of SNRs show **visual anisotropies** in shape and brightness.

shape

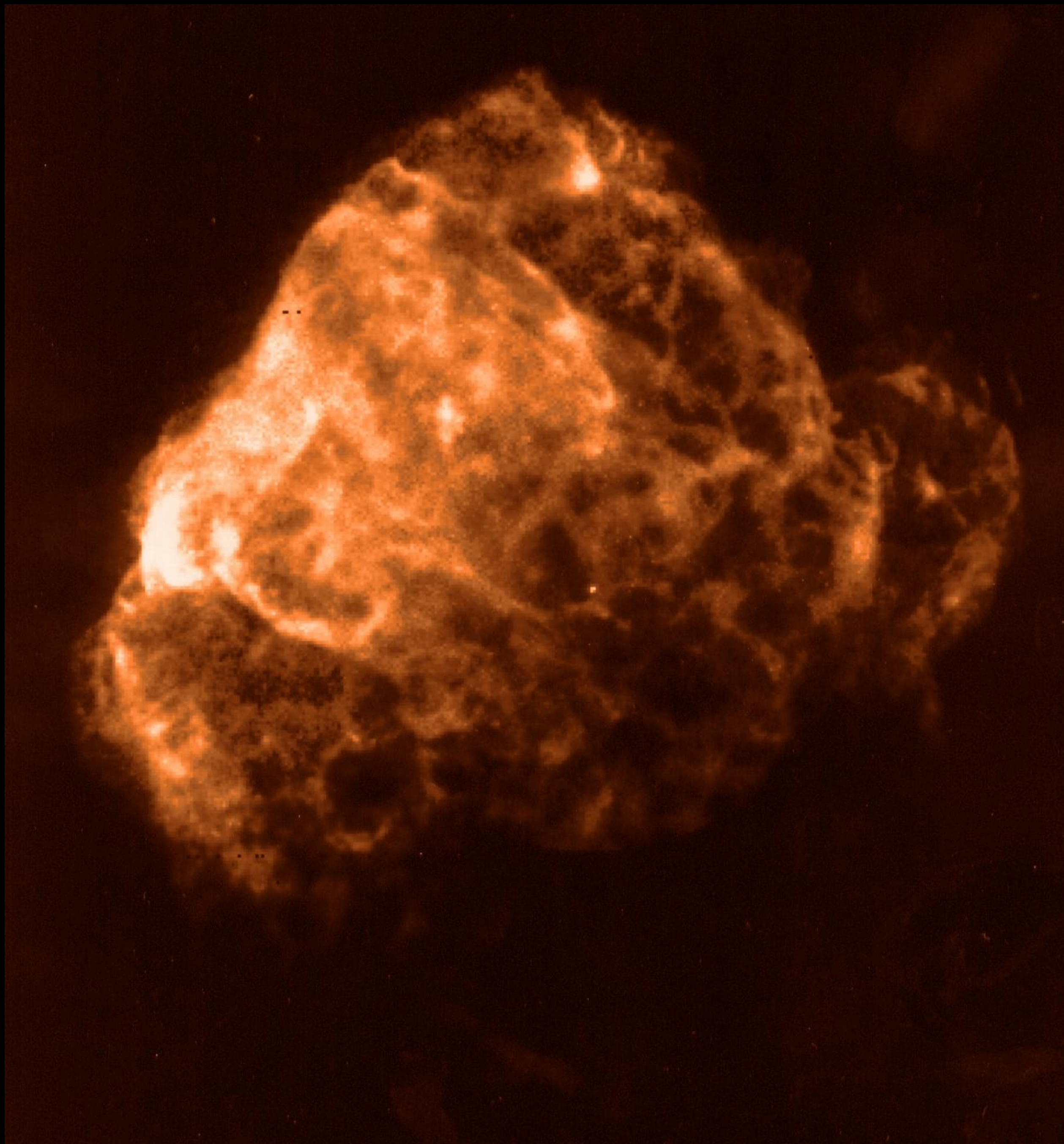
↓

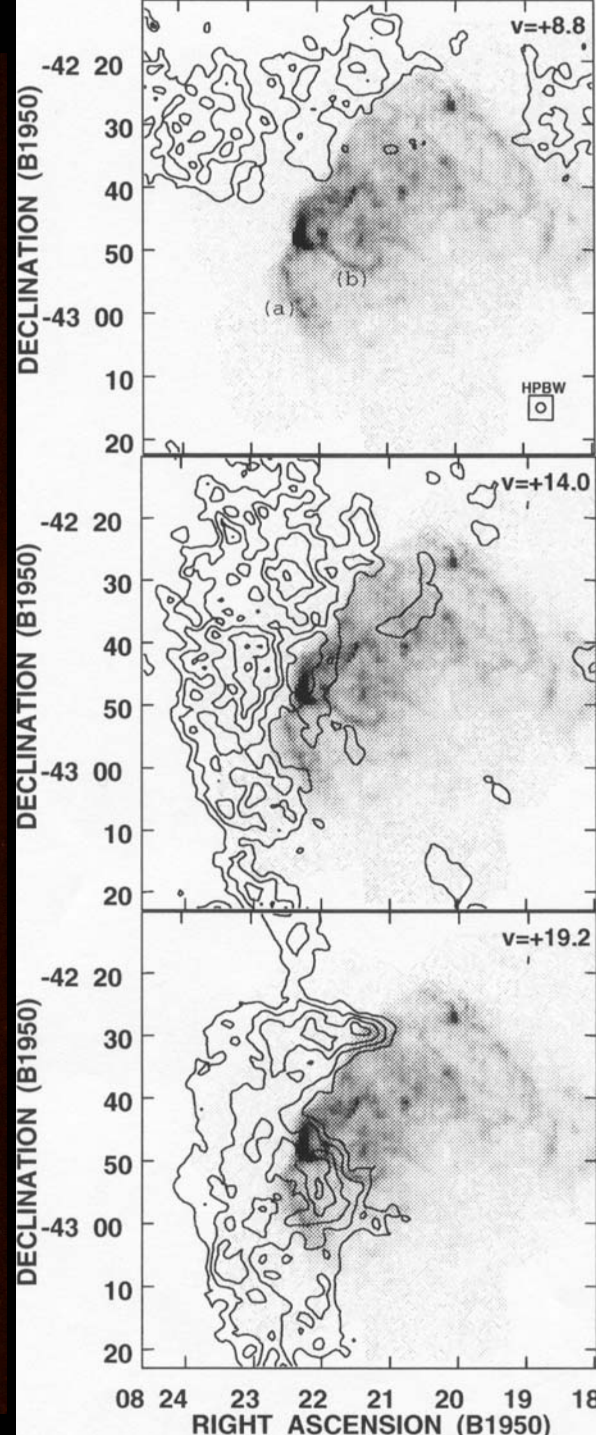
consequence of the shock wave dynamics

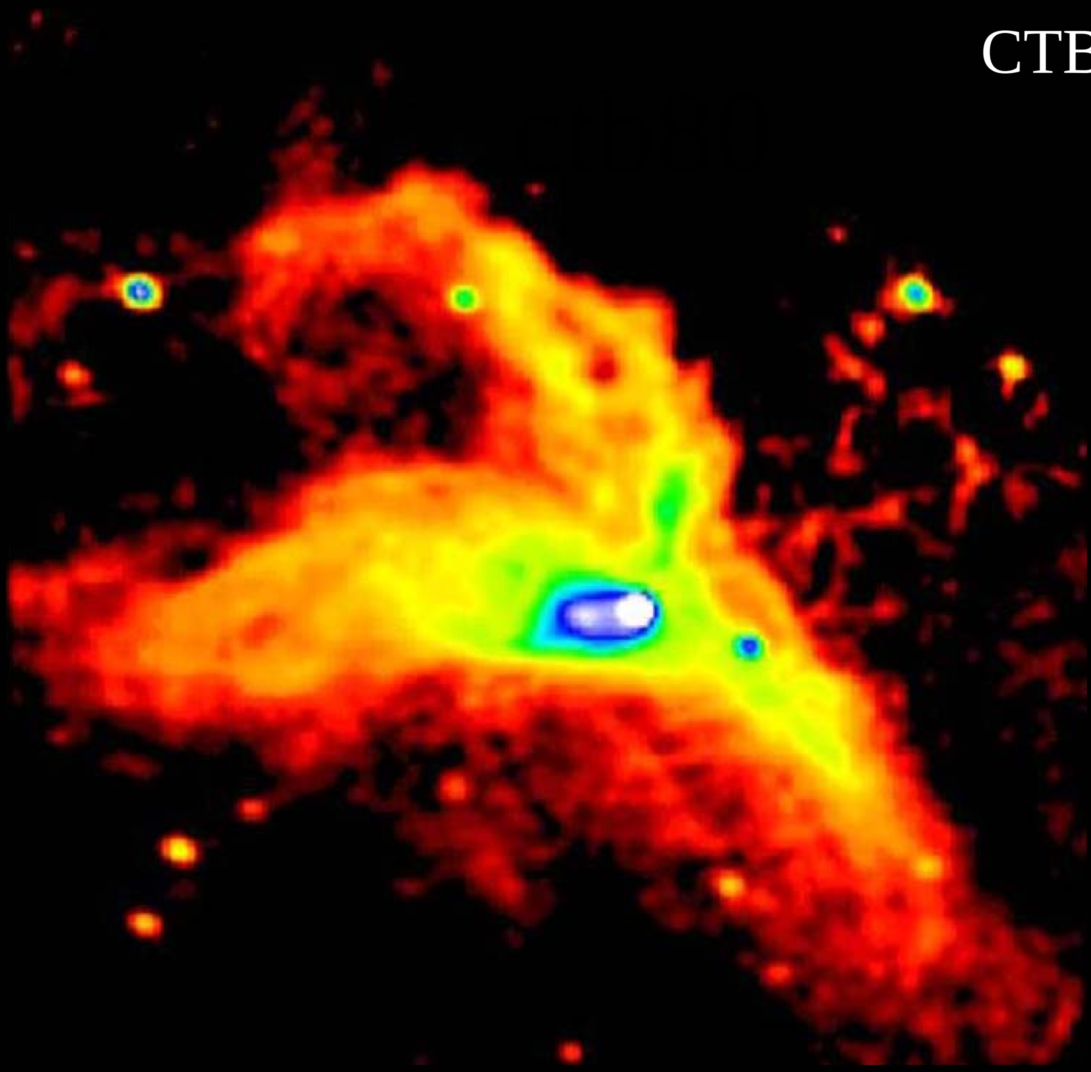
brightness

↓

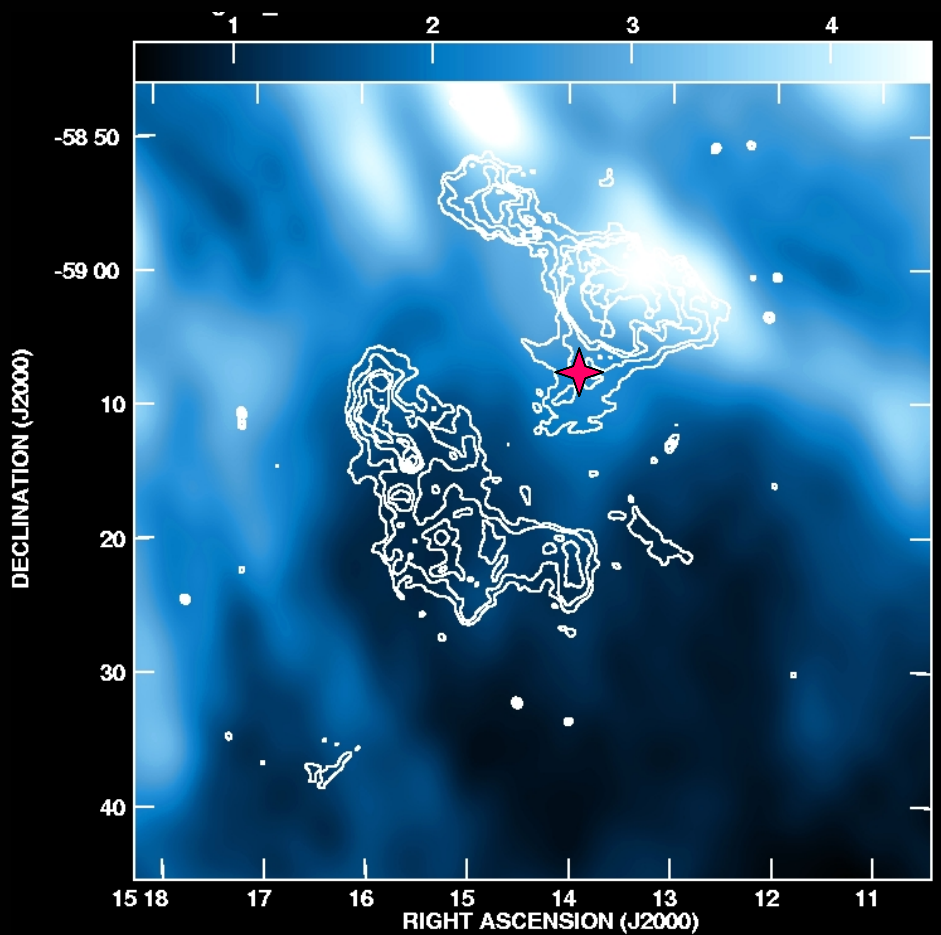
consequence of the state of the plasma inside the SNR



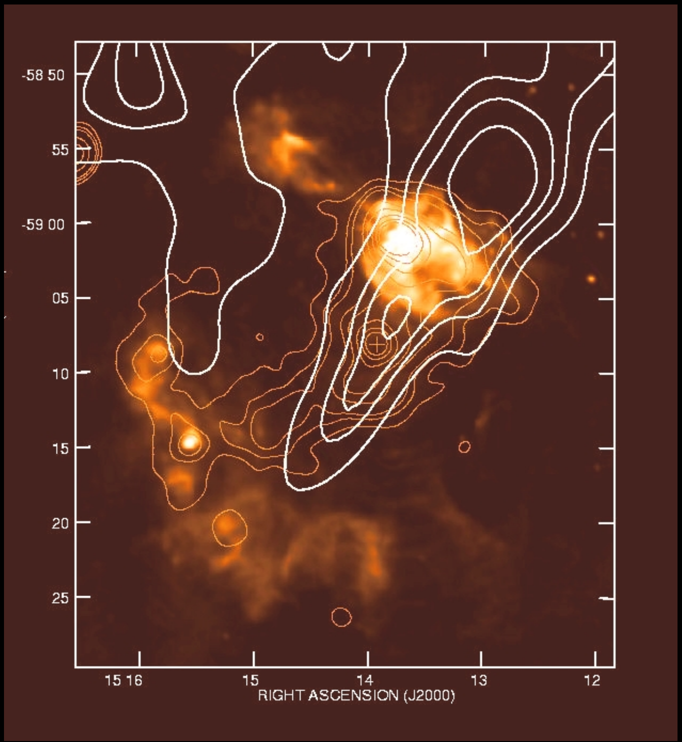

v=+8.8
v=+14.0
v=+19.2
(a)
(b)
HPBW
-42 20
30
40
50
-43 00
10
20
DECLINATION (B1950)
08 24
23
22
21
20
19
RIGHT ASCENSION (B1950)


CTB80

G320.4-1.2



1
2
3
4
-58 50
-59 00
10
20
30
40
DECLINATION (J2000)
15 18
17
16
15
14
13
12
11
RIGHT ASCENSION (J2000)



-58 50
55
-59 00
05
10
15
20
25
15 16
15
14
13
12
RIGHT ASCENSION (J2000)

The observed morphology of SNRs is :

a consequence of

- the properties of the progenitor star
- the mechanisms of explosion
- the density distribution of the CSM and of the ISM
- the presence of a compact remnant
- the strength and orientation of the ambient magnetic field

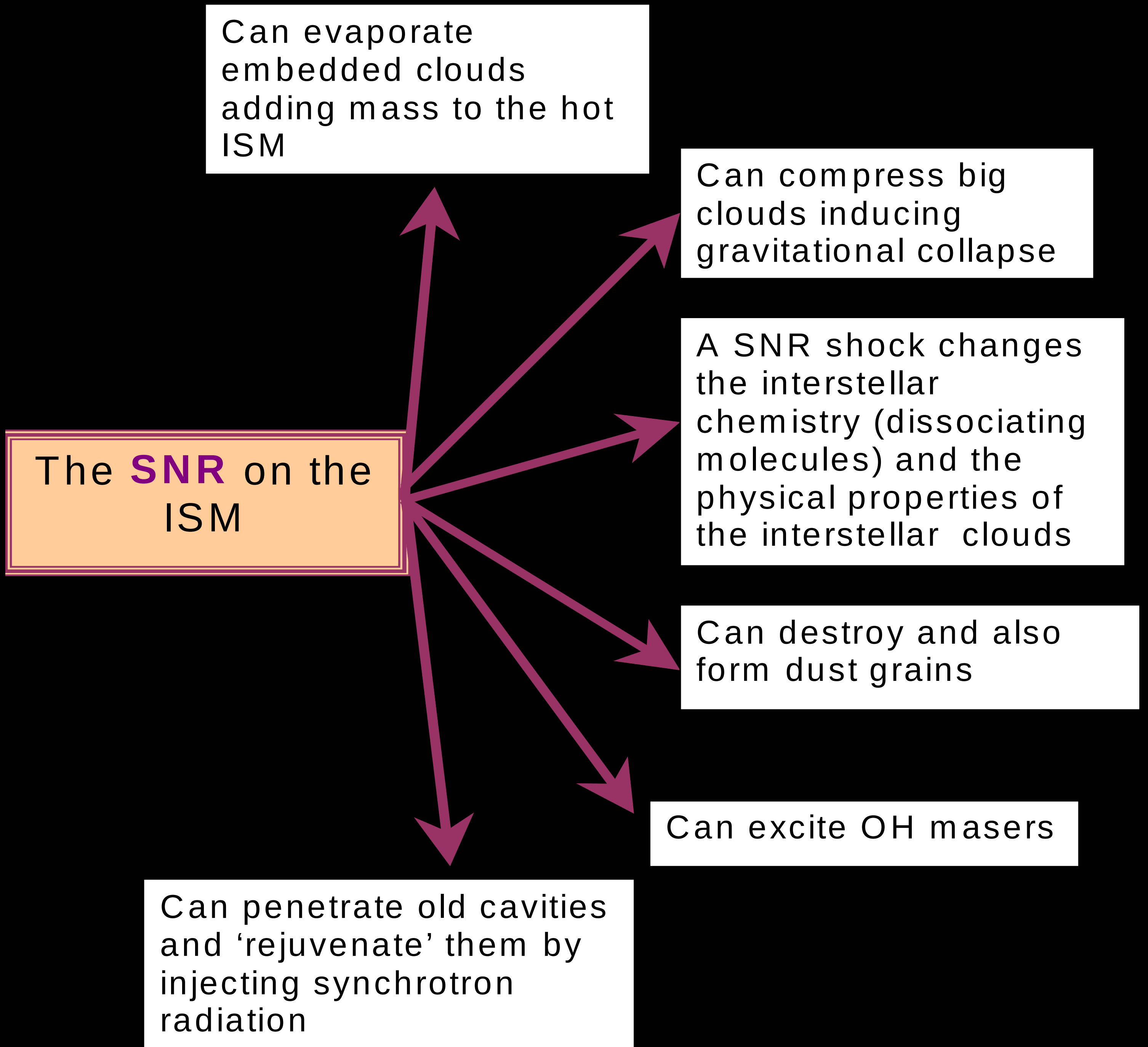
Interaction between SNRs and the ISM

The **ISM** on the SNR

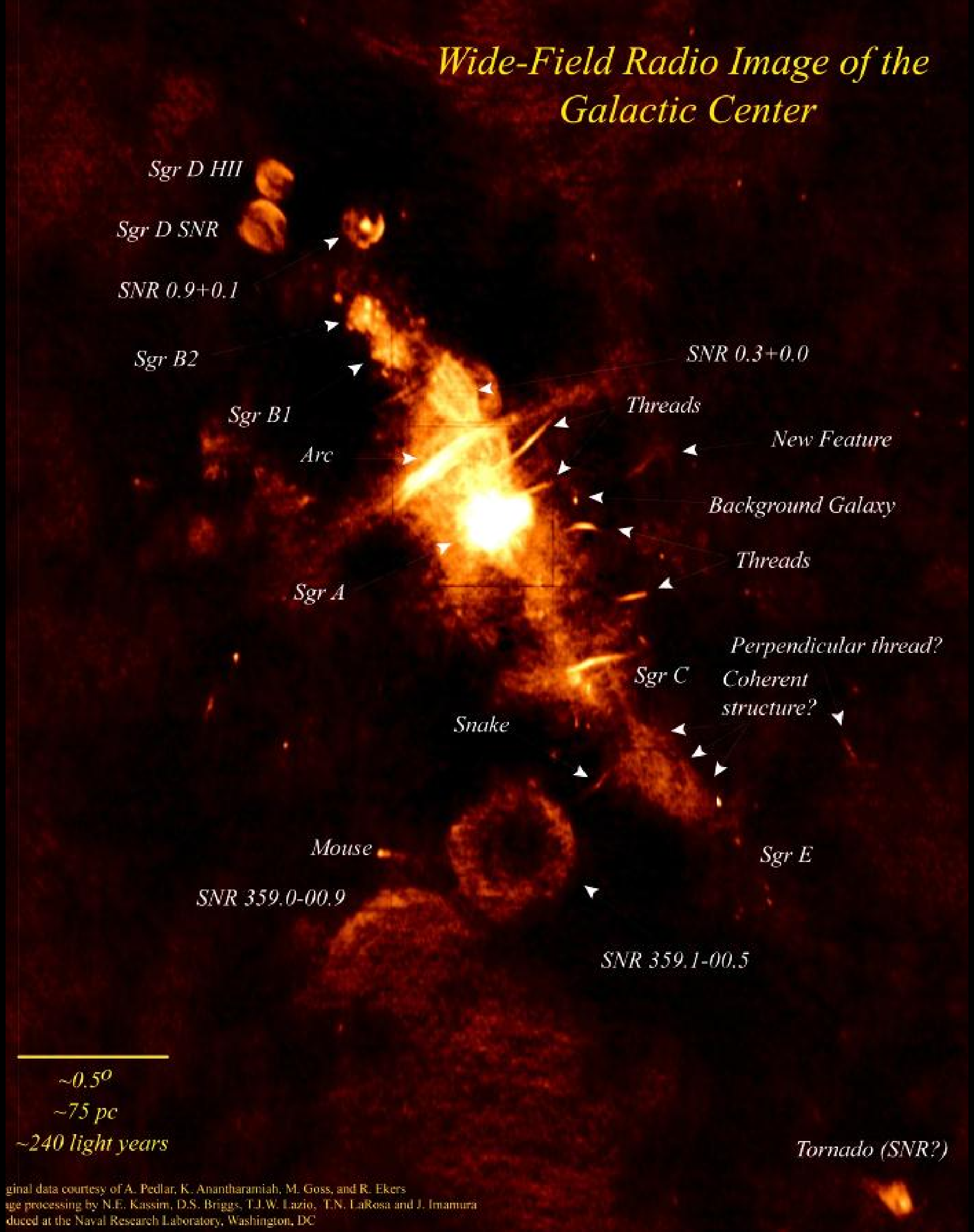
The inhomogeneous environment can determine the morphology of the remnant in the different spectral regimes

The interstellar clouds can locally modify the spectrum of the radio remnant

The characteristics of the surrounding ISM regulate the temporal evolution of the SNR



Can evaporate embedded clouds adding mass to the hot ISM
Can compress big clouds inducing gravitational collapse
A SNR shock changes the interstellar chemistry (dissociating molecules) and the physical properties of the interstellar clouds
The SNR on the ISM
Can destroy and also form dust grains
Can excite OH masers
Can penetrate old cavities and ‘rejuvenate’ them by injecting synchrotron radiation


Wide-Field Radio Image of the Galactic Center
Sgr D HII
Sgr D SNR
SNR 0.9+0.1
Sgr B2
Sgr B1
SNR 0.3+0.0
Threads
New Feature
Arc
Background Galaxy
Threads
Sgr A
Perpendicular thread?
Sgr C
Coherent structure?
Snake
Mouse
Sgr E
SNR 359.0-00.9
SNR 359.1-00.5
~0.5^o
~75 pc
~240 light years
Tornado (SNR?)
ginal data courtesy of A. Pedlar, K. Anantharamiah, M. Goss, and R. Ekers
age processing by N.E. Kassim, D.S. Briggs, T.J.W. Lazio, T.N. LaRosa and J. Imamura
duced at the Naval Research Laboratory, Washington, DC

Exotic central compact objects

- radio-quiet NS (RQNS)

- radio-silent NS

- anomalous X-ray pulsars (AXRP)

magnetars?

- soft gamma-ray repeaters (SGRS)


The End

Green's Catalogue of SNRs: http://www.mrao.cam.ac.uk/surveys/snrs

List of SN pages on the www: http://rsd-www.nral.navy.mil/7212/montes/sne.html

Bright supernova: http://www.ggw.org/asras/snimages

Pulsar catalog: http://www.atnf.csiro.au/research/pulsar/catalogue/psr_export.dat

Cosmic Catastrophes, J. C. Wheeler, Cambridge Univ. Press, 2000

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Supernovae, Ed. A. Petschek, Springer Verlag, 1990

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