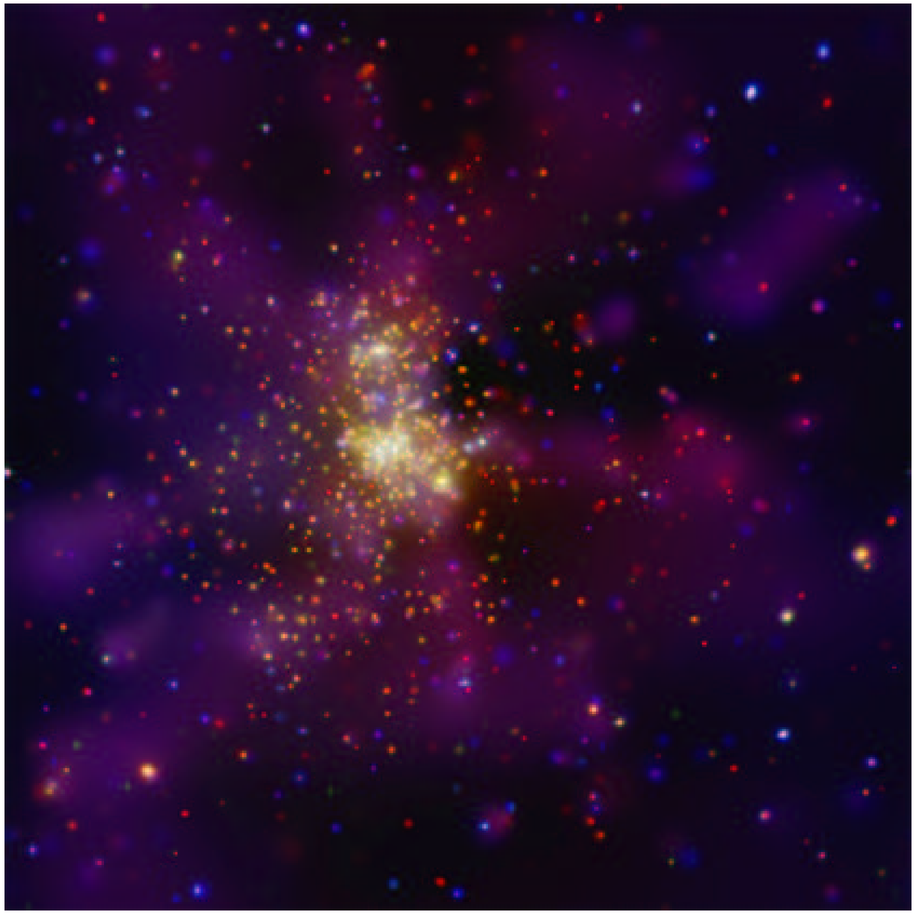
The X-Ray Universe

Potsdam University



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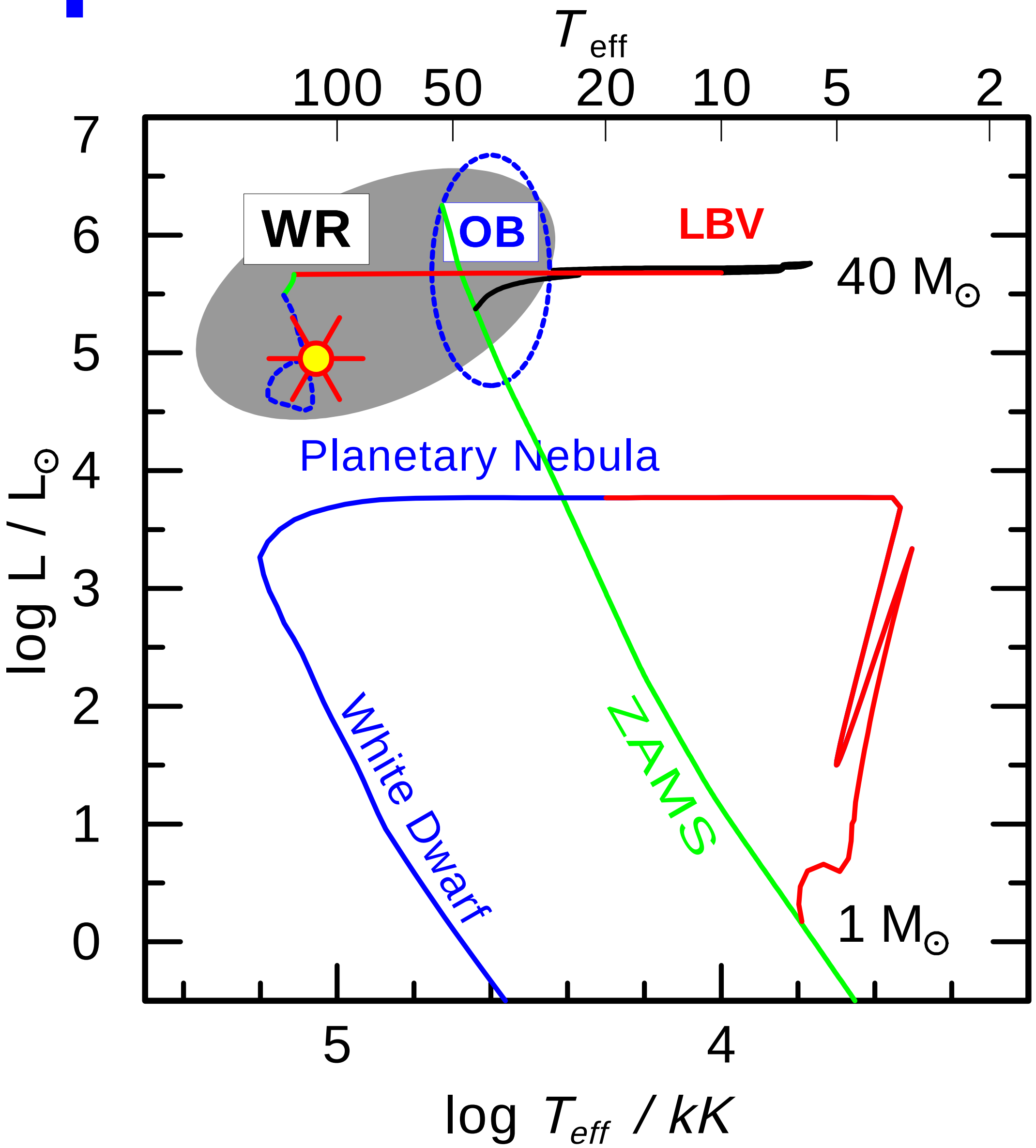
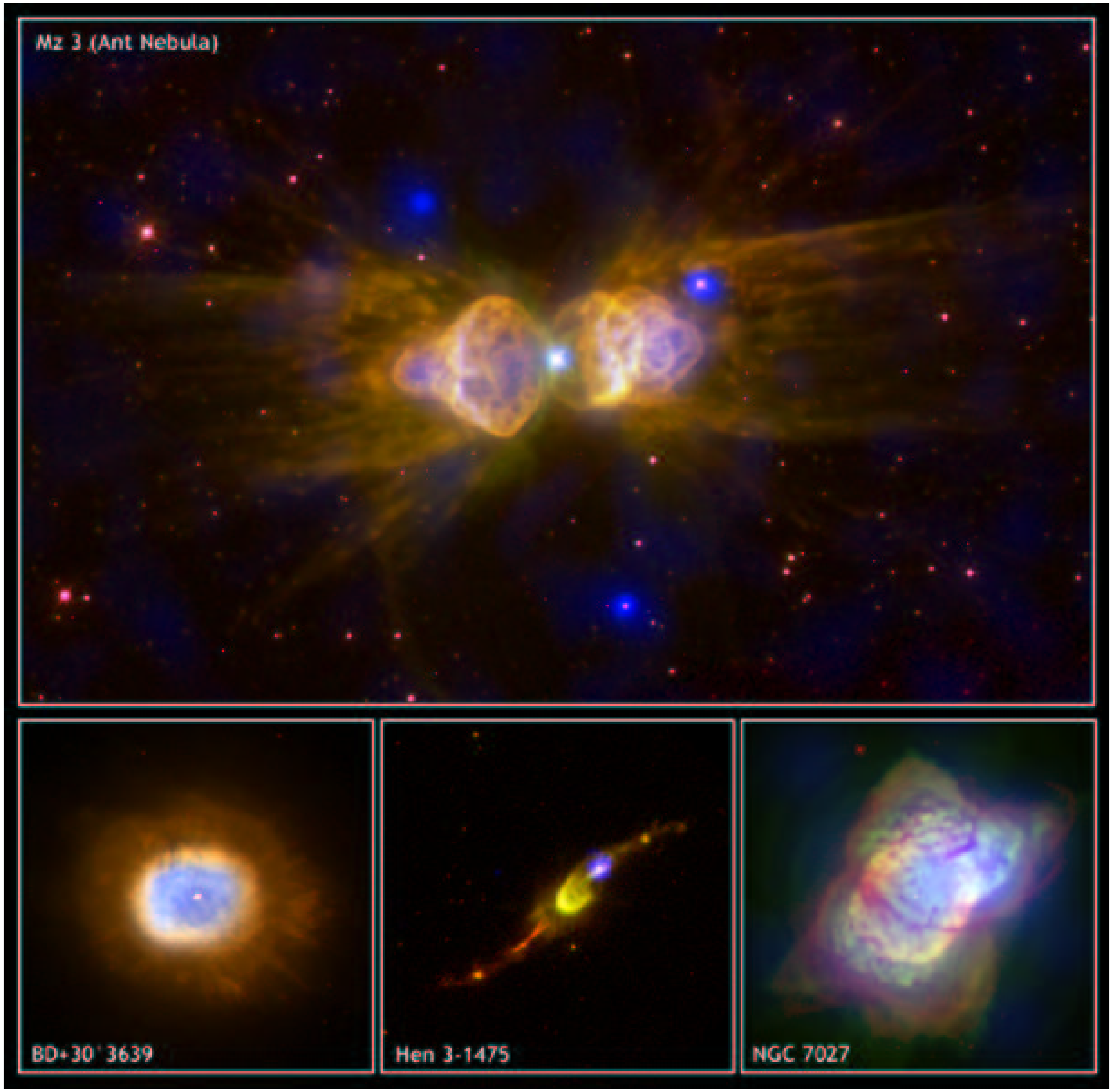
www.astro.physik.uni-potsdam.de/~lida/theormech.html

Chandra X-ray Observatory
Westerlund 2 - a young star cluster
d=2×10^4ly

VII. X-rays from Planetary Nebulae and Supernova Remnants



02 X-rays from PNe



Two possible mechanisms
→ hot gas in PNe

- Fast stellar wind is shocked when it rams in the AGB shell. The central cavity is filled with shocked gas.
- Fast collimated jets impinge on the AGB wind. Bow-shock structures.

X-rays are important to assess the action of stellar wind and test models of PNe shapes

03 Basic Structure of Supernova Remnants

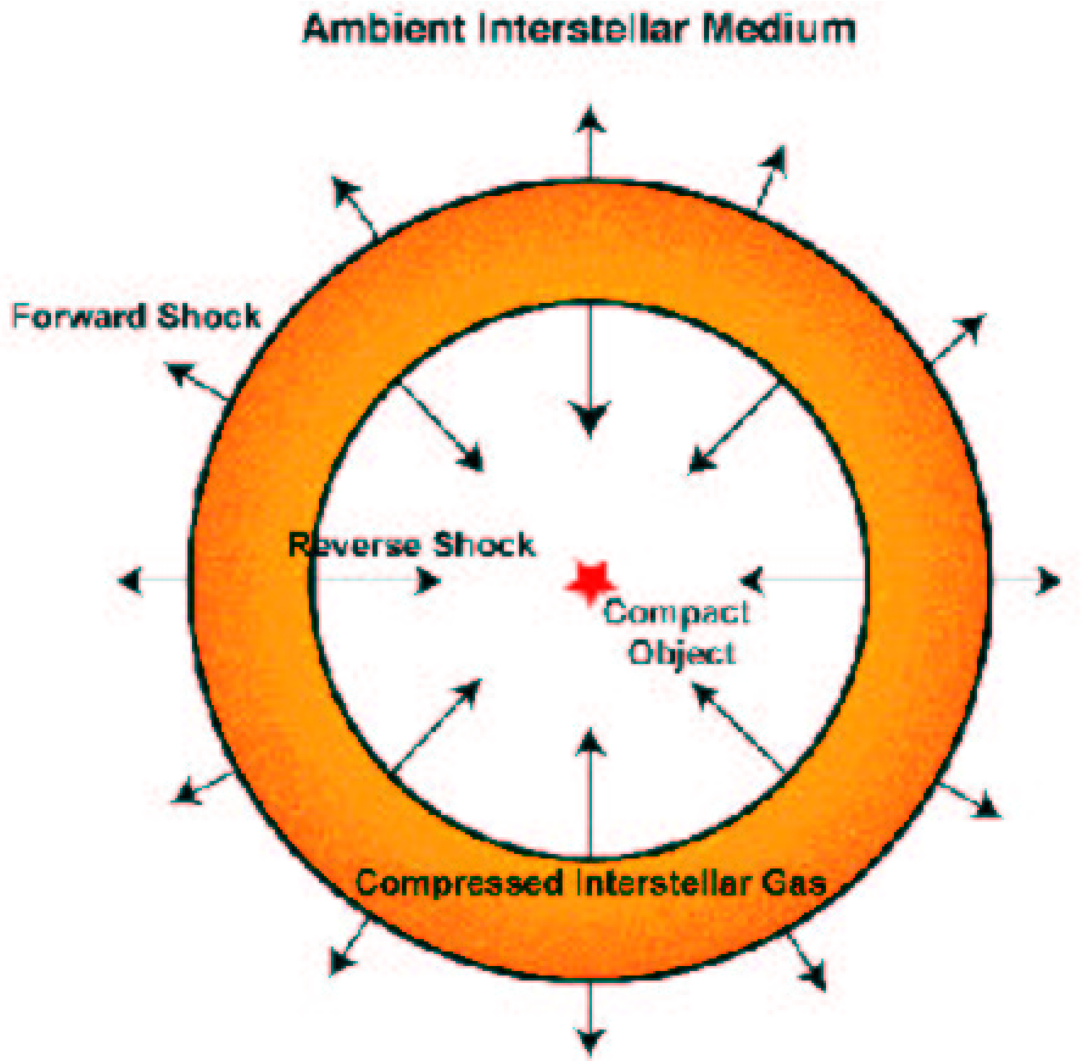
- Forward shock rams into the ISM or projenitor wind
- Reverse shock goes back into the unshocked ejecta.
- Contact discontinuity between shocked ISM and shocked ejecta

Thermal emission

- NEI, characterized by electron temperature, ionization timescale, element abundances
- primarily bremsstrahlung continuum
- collisionally excited emission lines

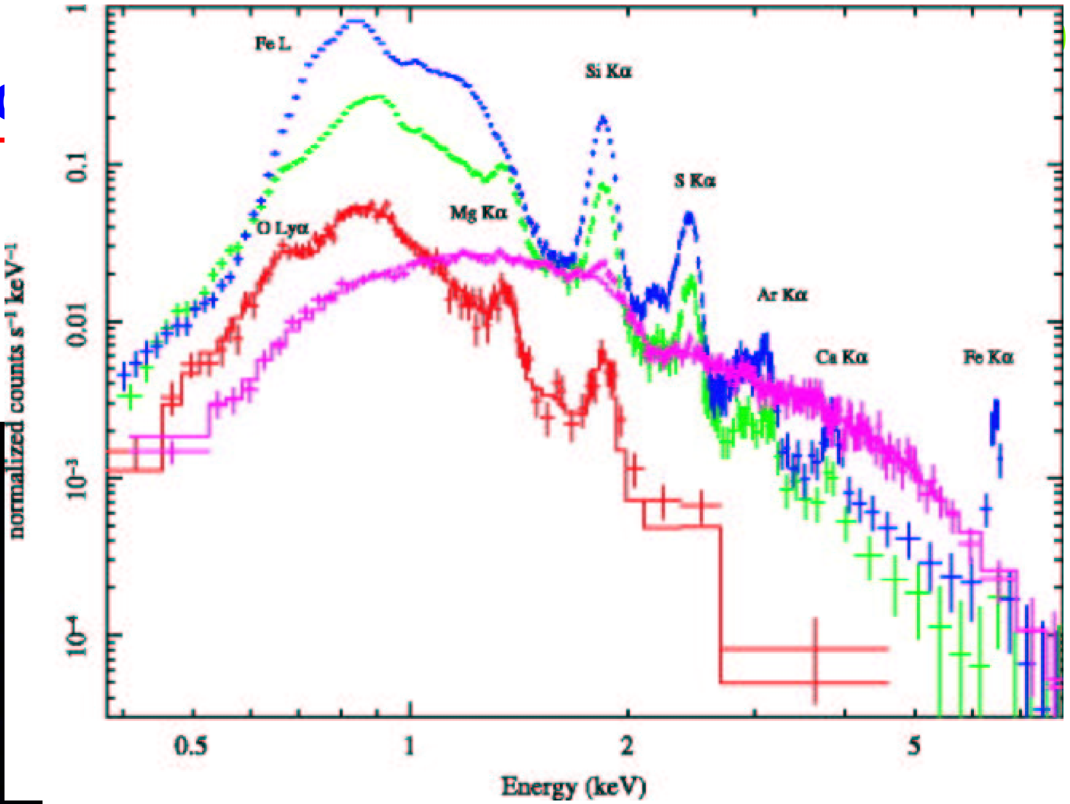
Nonthermal emission

- blackbody or power law from pulsar/neutron star if present (across electromagnetic spectrum)
- synchrotron emission from electrons accelerated at the shock (usually radio, sometimes up to X-rays)



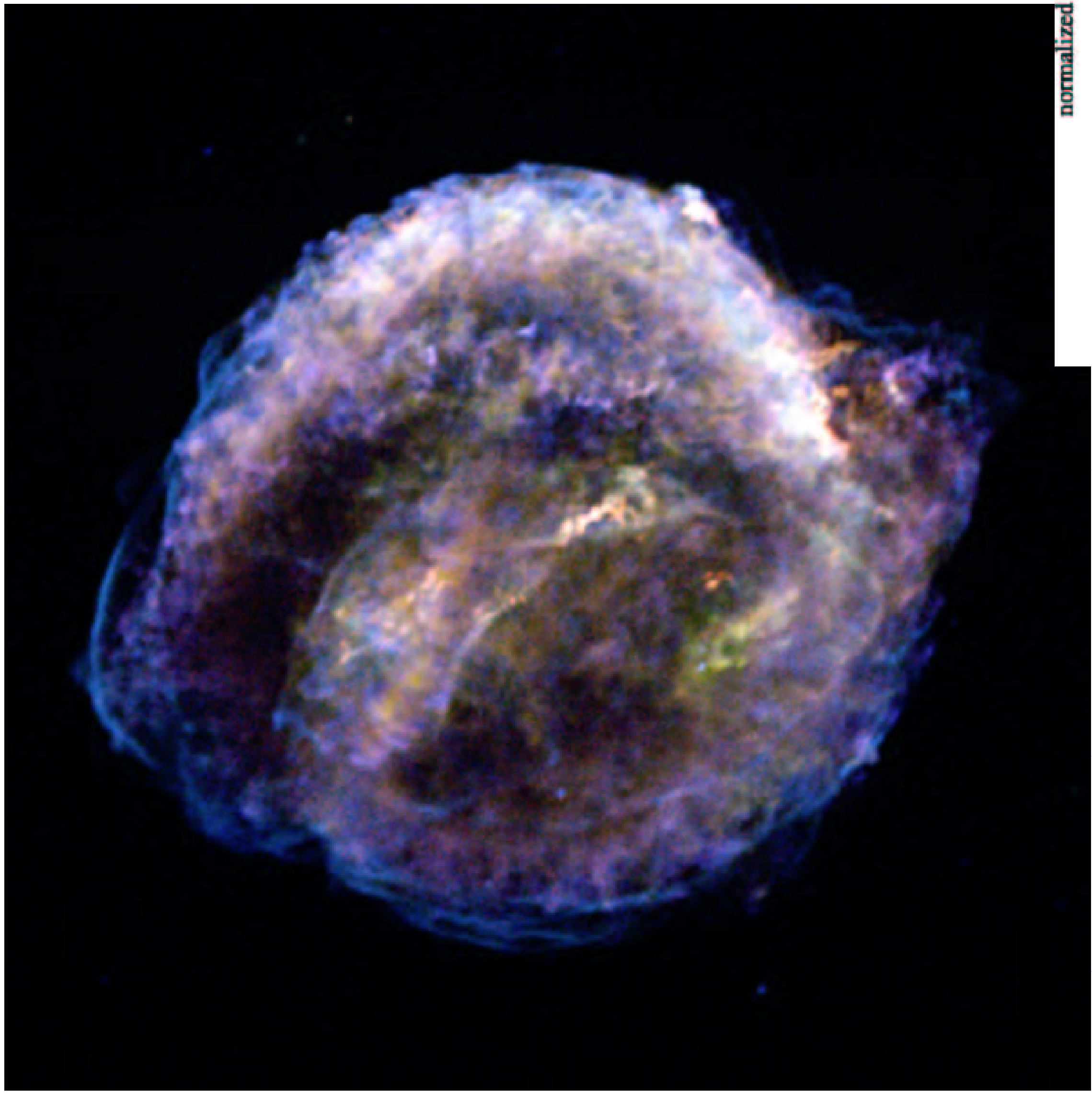
http://heasarc.gsfc.nasa.gov/docs/objects/snrs/c

03a Kepler SNR (Type is not kn



Reynolds etal. ApJ 668, L135

Interpreting Thermal SNR Spectra



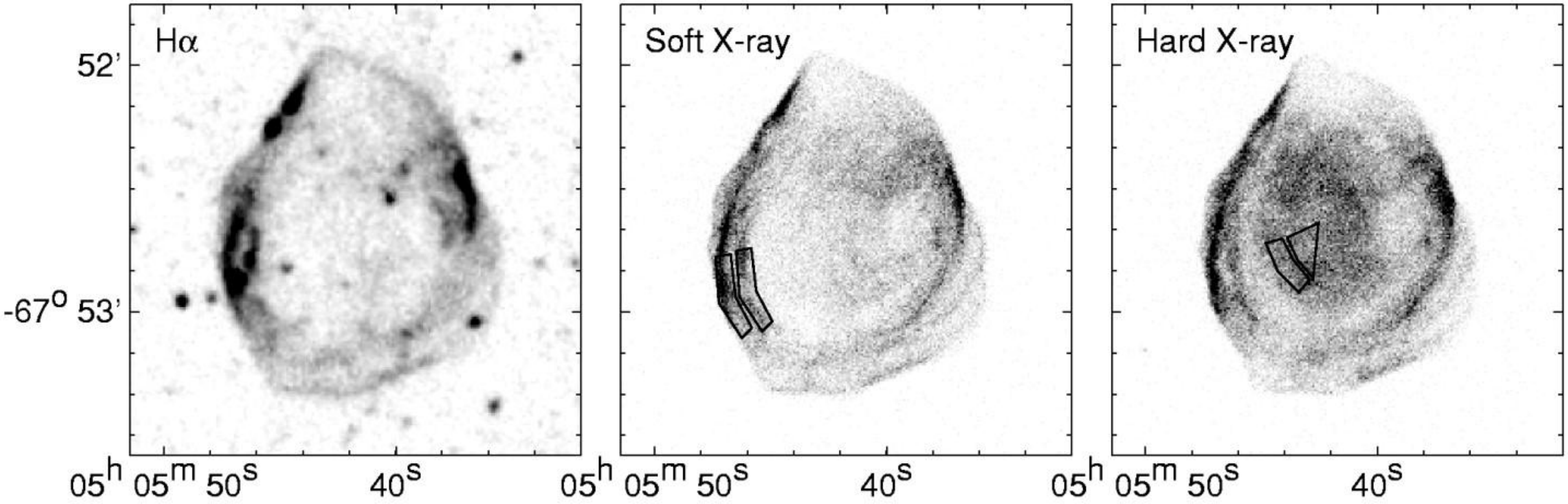
http://chandra.harvard.edu/photo/2007/kepler

low energy; medium energy; high energy

- Time evolution of ρ, P, and T. SNR expands, cooling by line emission and particle acceleration. Heating by collisions and radiation
- Atomic processes: collisional ionization and excitation followed by radiative decay
- Spectrum is affected: the denser gas is brighter ($EM=n^2V$), abundances, non-thermal continuum (e.g. synchrotron)

04 Identifying SNR

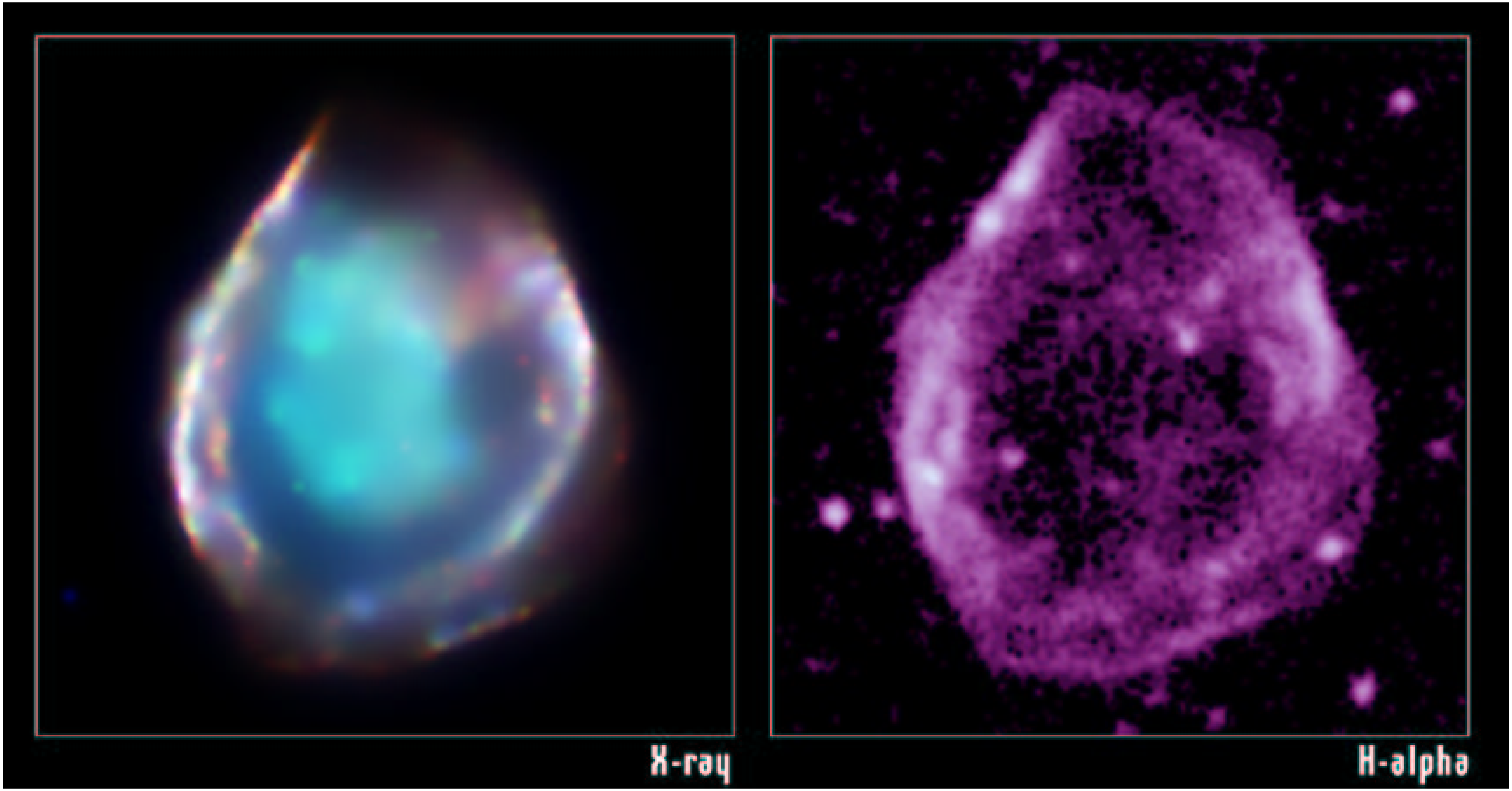
Chandra: DEM L71 SNR in the Large Magellanic Cloud



Hughes etal. 2003 ApJ 582, 95

- Clear double-shock morphology: an outer blast-wave shock surrounding a central bright region of reverse-shock--heated ejecta.
- The abundances of the outer shock are consistent with LMC values, while the ejecta region shows enhanced abundances of Si and Fe.
- A distinguishing characteristic of SNe Ia is the large amount of iron that is produced mainly through the decay of radioactive ^{56}Ni.
- Positions of the blast-wave shock and the CD using SNR evolutionary models → total mass 1.5 Msun, $0.8M_{sun}$ of Fe and 0.12 Si
- Type Ia supernova several thousand years after explosion.

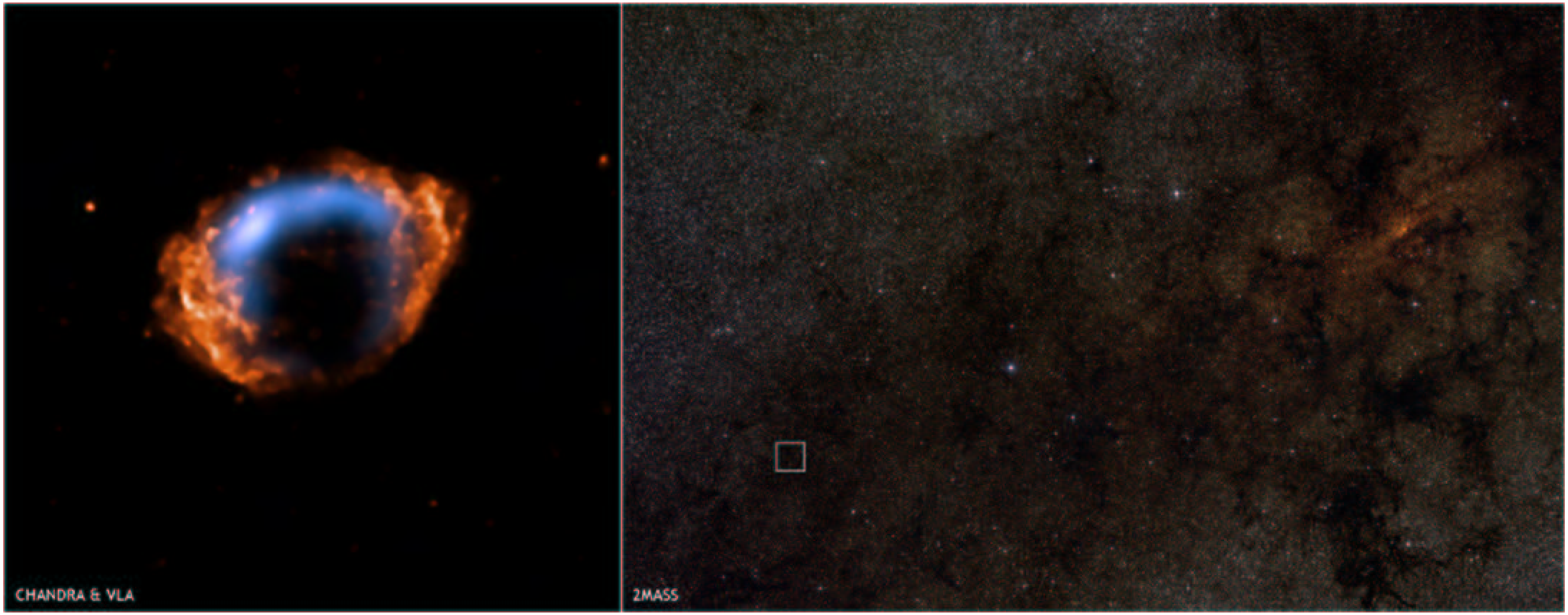
05 DEM L71 in the LMC



http://chandra.harvard.edu/photo/2003/deml71/

Hot inner cloud (aqua) of glowing Fe and Si surrounded by an outer blast wave.

06 Most Recent Supernova in Our Galaxy: G1.9+0.3



http://chandra.harvard.edu/photo/2008/g19/

2007: X-ray Chandra image is shown in orange

1985: radio NRAO’s Very Large Array (VLA) in blue

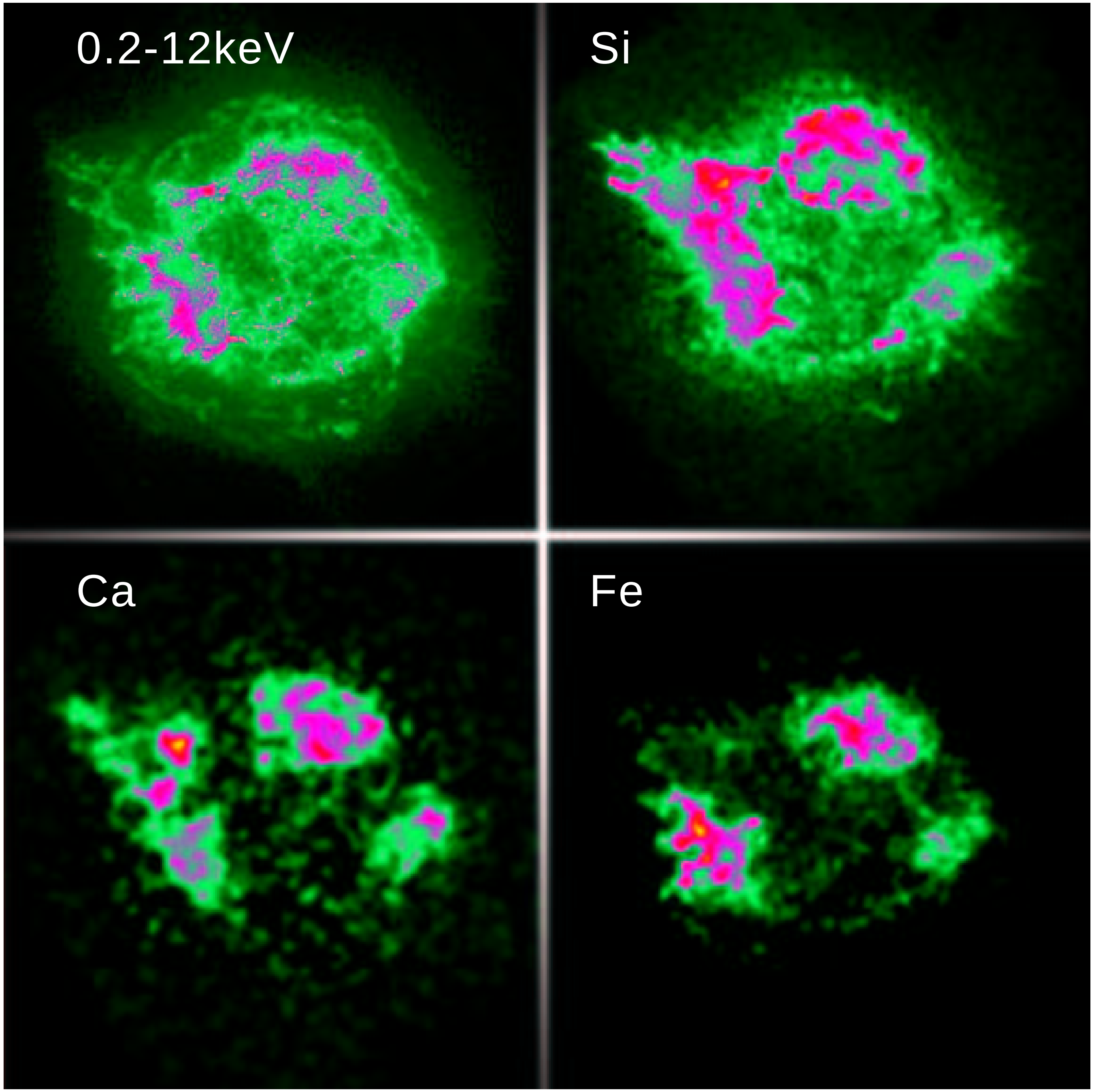
The youngest known SNR in the Galaxy 140 years old

Previously known Cassiopeia A was 330 years old

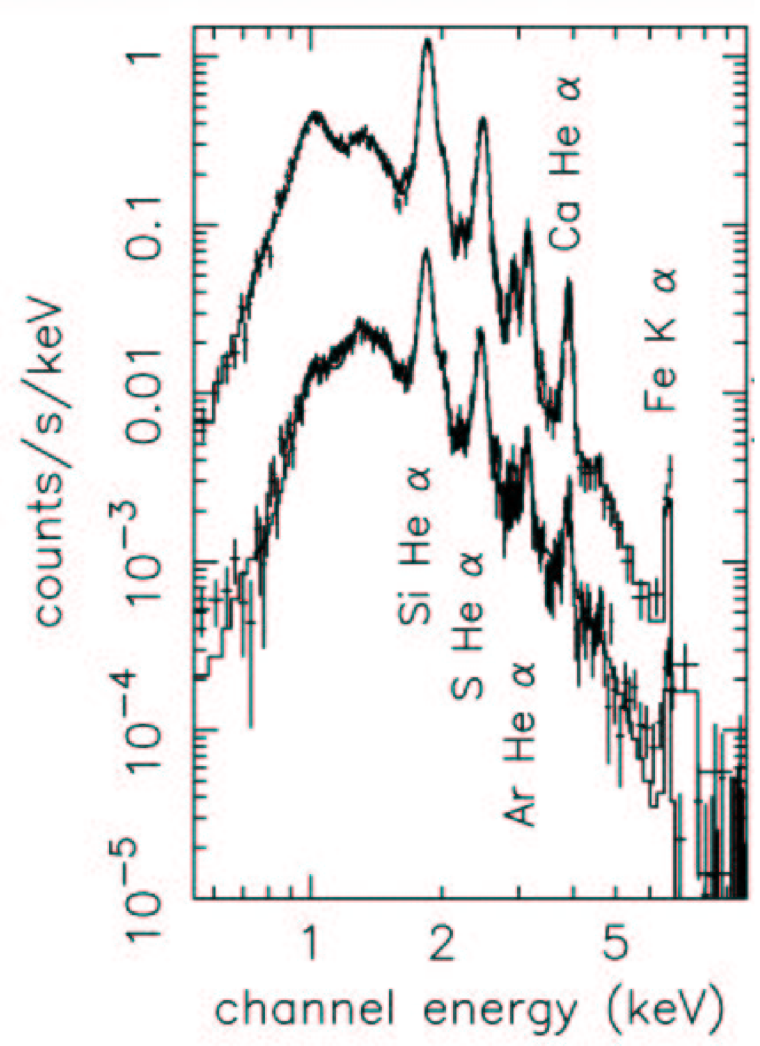
Both were not noticed.

G1.9 is visulally obscured, but why not Cas A??

07 Morphology of SNRs



http://chandra.harvard.edu/photo/2008/g19/



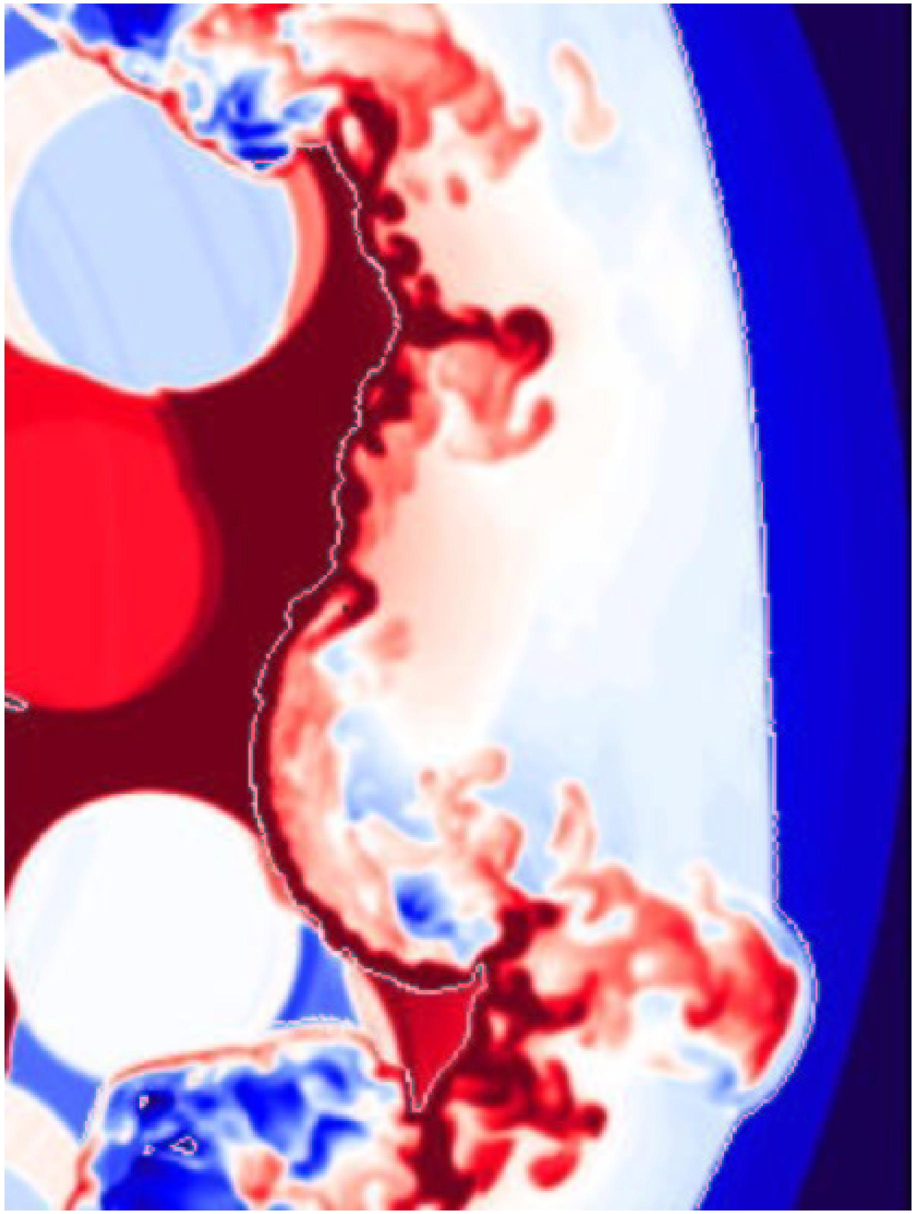
Hwang etal. 2004, ApJL 615, 117

Bipolar jets: Si

Compact source SNII

Inhomogeneous: Fe is the heaviest element, mixing before or during SN

08 Core collapse SNRs as Swiss Cheese



Blondin etal. 2001, ApJ, 557,782

- Freshly synthesized Ni
- Mixing is not complete
- Two-phase SN ejecta structure
- Low density Fe bubbles: from Ni decay
- High density matter around

3D Hydrodynamic simulations

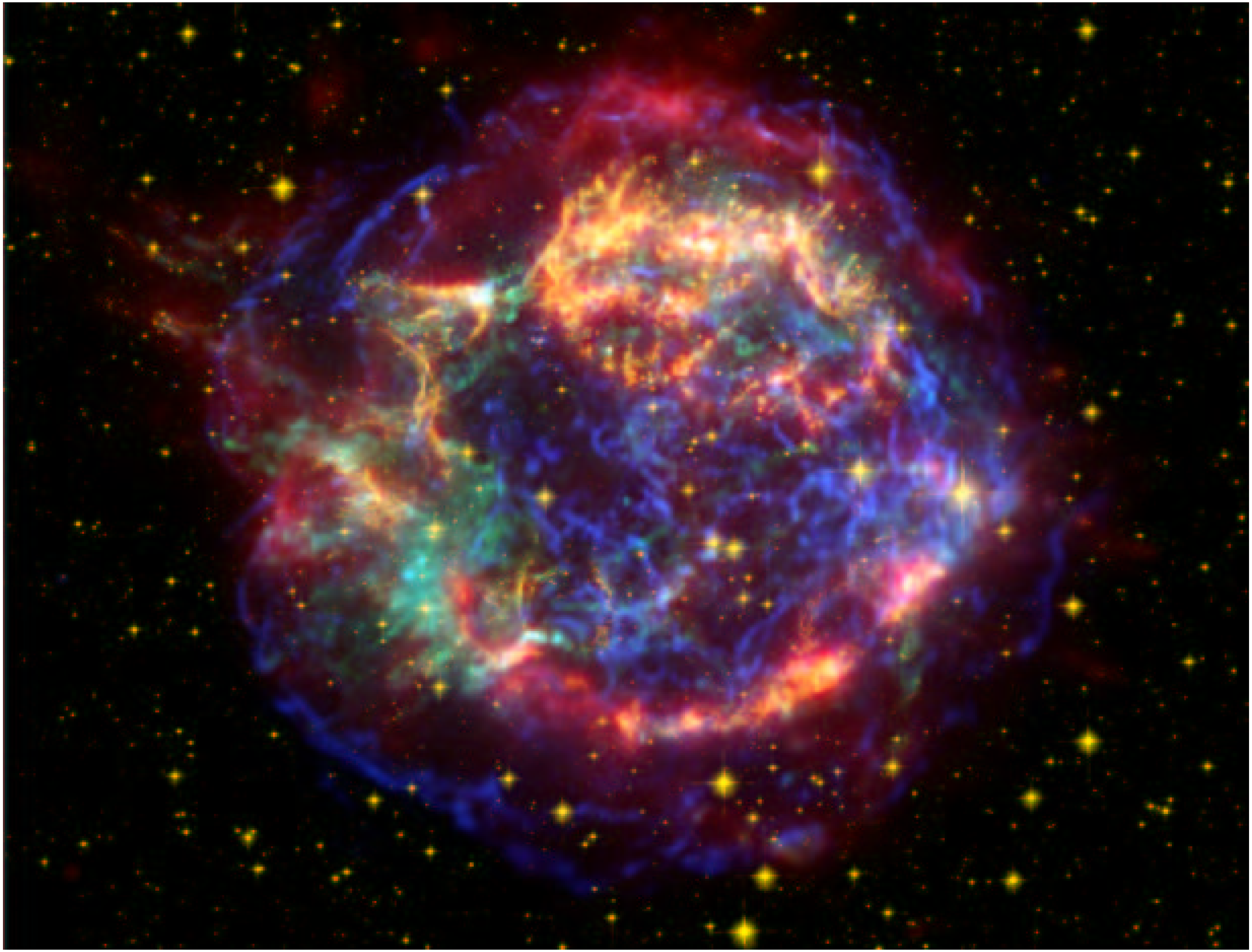
Fe bubbles → turbulence and mixing

fast narrow filaments and clumps

Red - high density

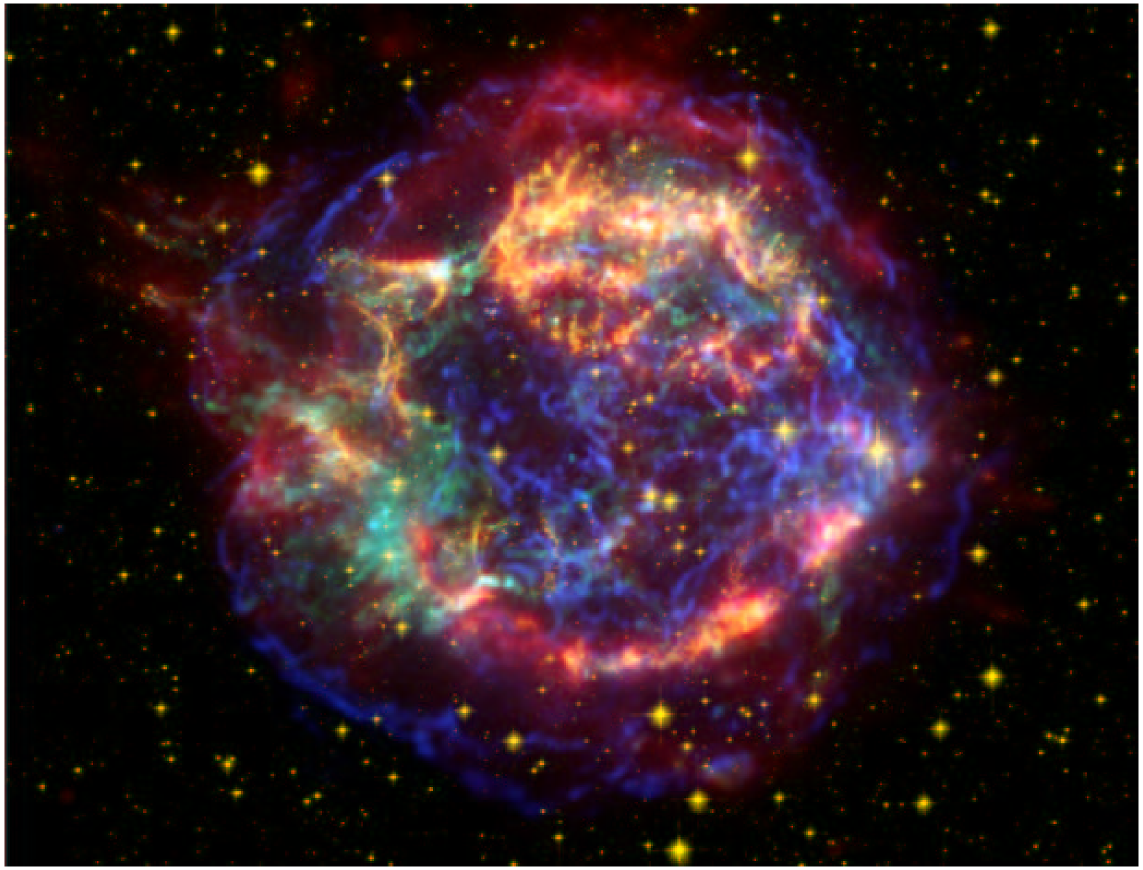
Blue -low density

09 Composite image of Cas A (Chandra, HST, Spitzer)



http://chandra.harvard.edu/photo

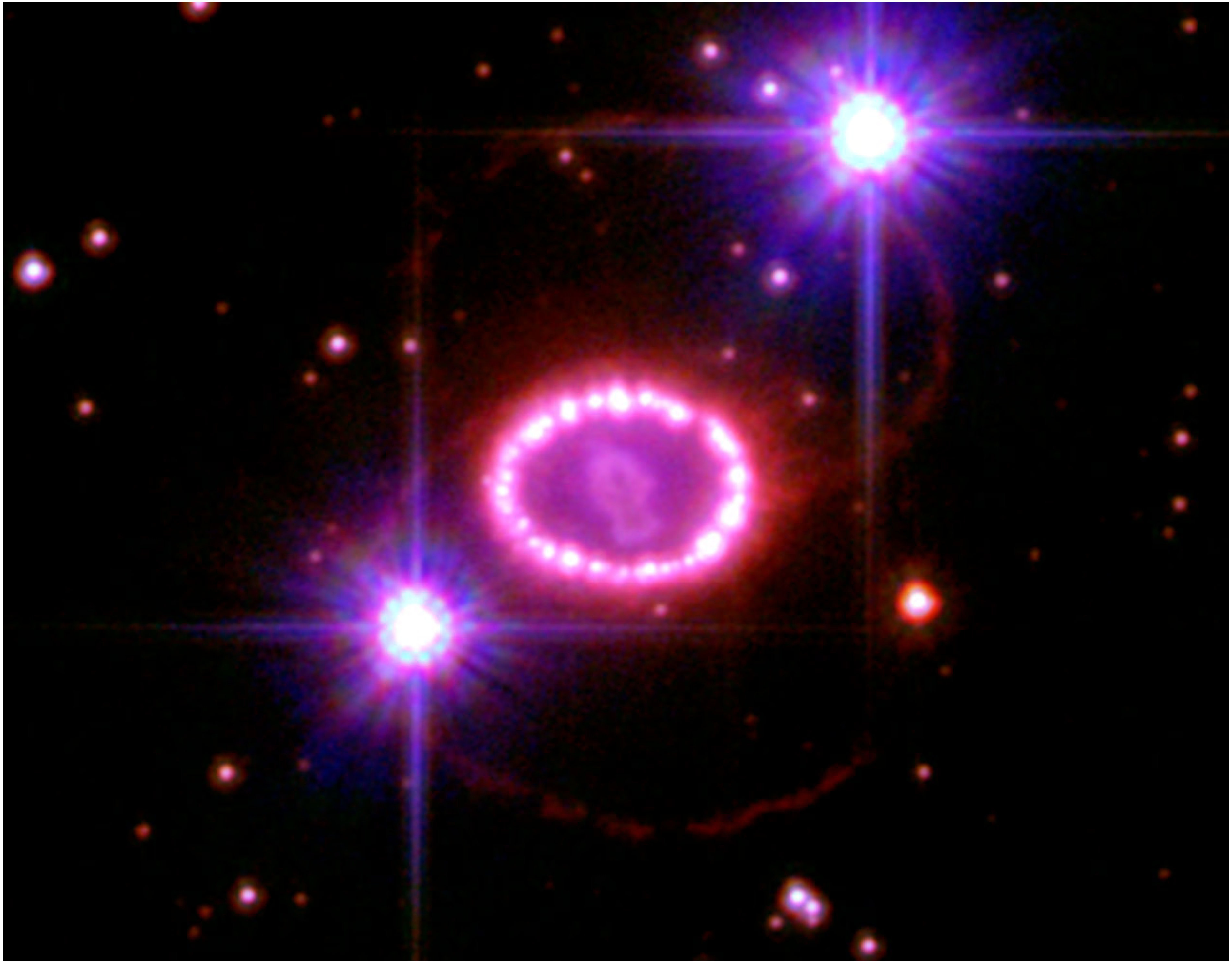
09a Composite image of Cas A (Chandra, HST, Spitzer)



http://chandra.harvard.edu/photo

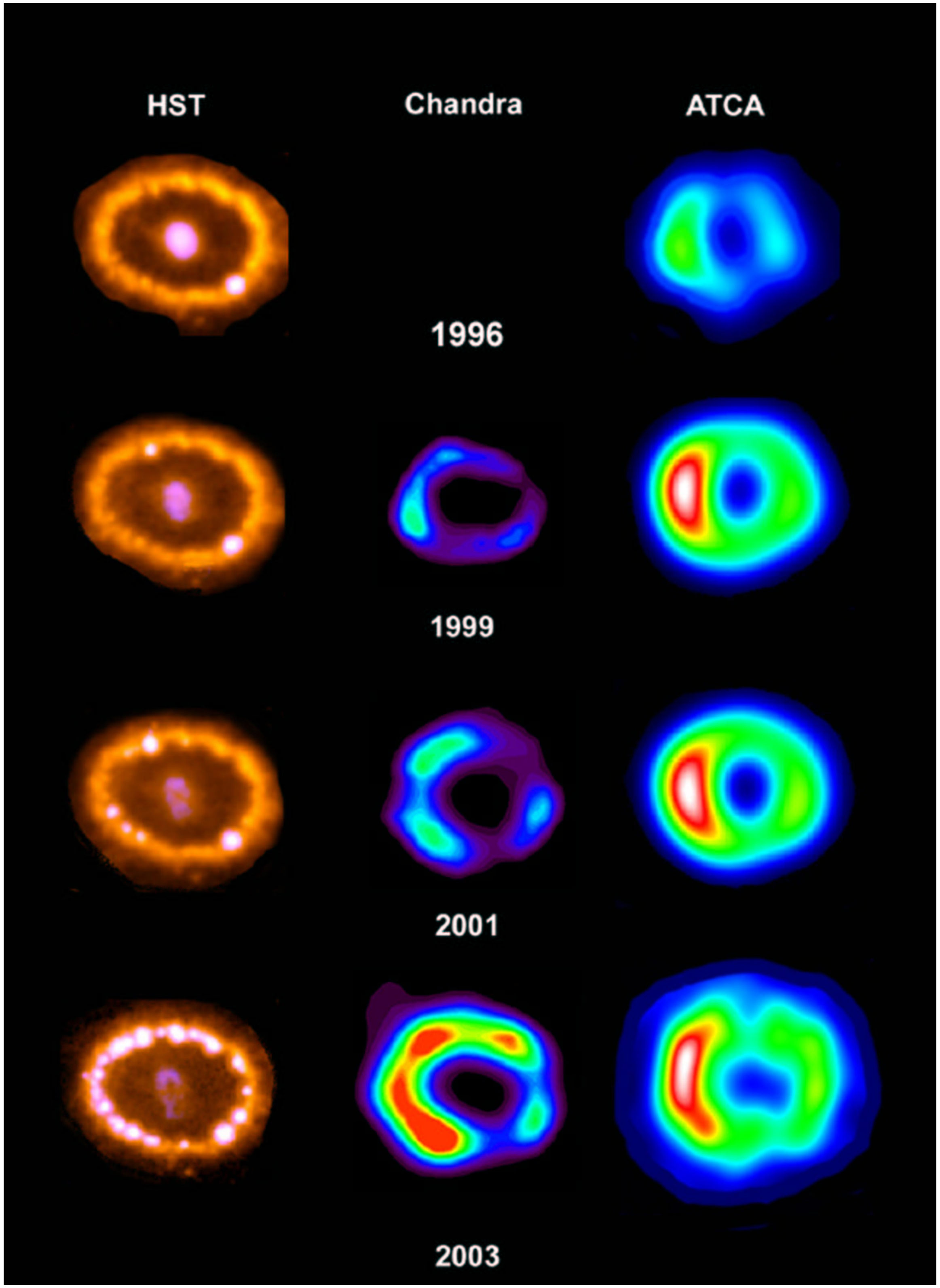
see images of galactic supernovae

10 Supernova 1987A



http://www.spacetelescope.org/images/html/heic0704a.htm December 2006

11 Optic, X-ray, & radio images

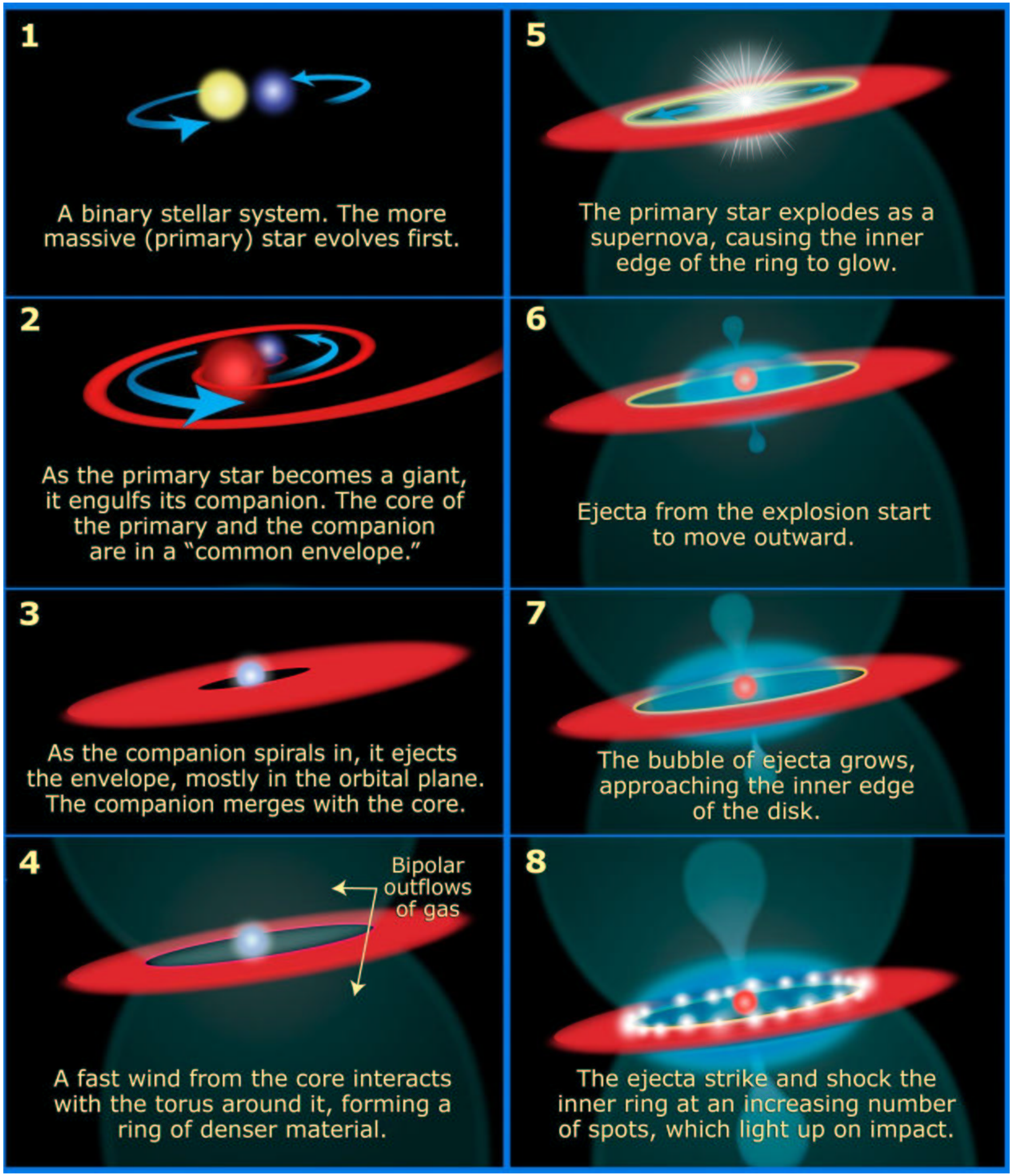


http://www.spacetelescope.org/images/html/opo0409r.html

Note correlation between brightness of the hot spots and the size of X-ray emitting region. Radio (synchrotron) is closely following X-rays.

Neutrino blast 3 hours before optical detection, unusual light curve, and identified BI type projenitor → core collaps SNII. Where is pulsar??
To understand the physical strucure of SNR we shall understand hystory of mass-loss.

12 Binary channel for observed structure



1 A binary stellar system. The more massive (primary) star evolves first.

2 As the primary star becomes a giant, it engulfs its companion. The core of the primary and the companion are in a "common envelope."

3 As the companion spirals in, it ejects the envelope, mostly in the orbital plane. The companion merges with the core.

4 A fast wind from the core interacts with the torus around it, forming a ring of denser material.

5 The primary star explodes as a supernova, causing the inner edge of the ring to glow.

6 Ejecta from the explosion start to move outward.

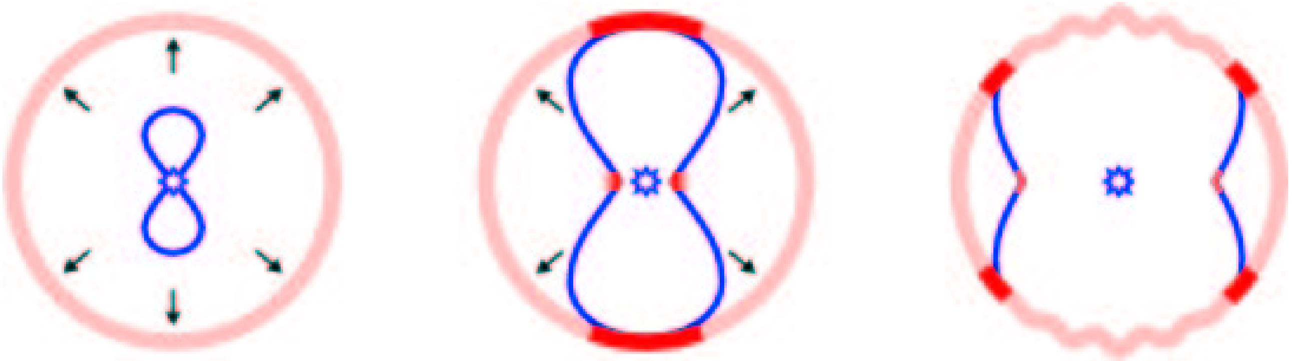
7 The bubble of ejecta grows, approaching the inner edge of the disk.

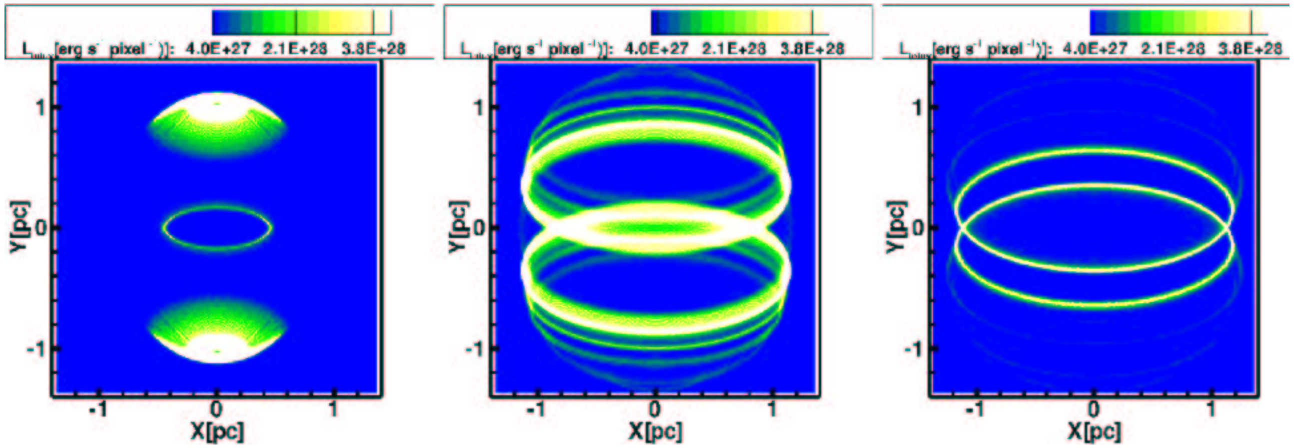
8 The ejecta strike and shock the inner ring at an increasing number of spots, which light up on impact.

http://www.spacetelescope.org/images/html

Orbital plane:
axisymmetry in the system

13 Single star channel





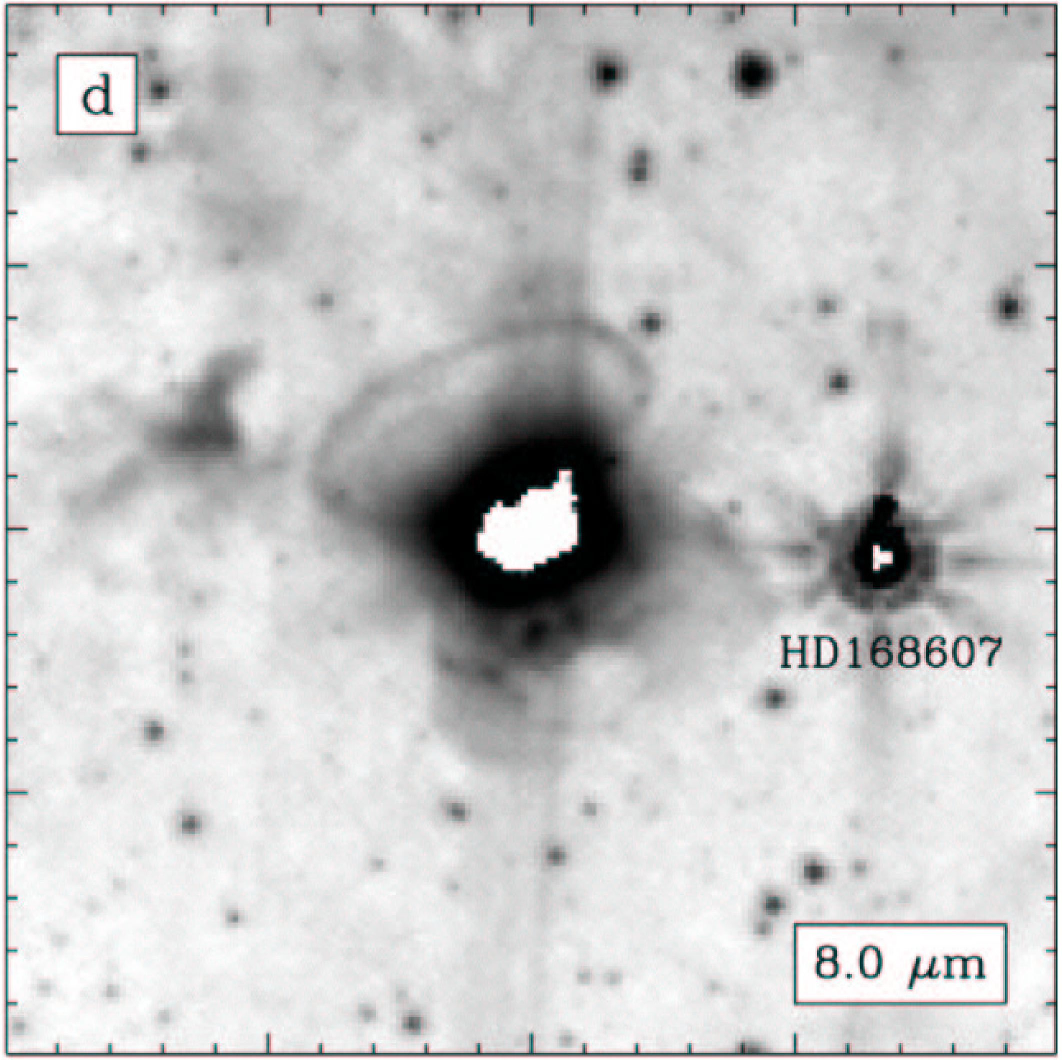
Chita et al. 2008, A&A 488, L37

Model of a rapidly rotating $12M_{sun}$ star RSG → BSG

- The slow RSG wind will be stalled by the high pressure of the previously created hot wind bubble → shell at the bubble pressure equals the RSG wind ram pressure
- Evovolving to BSG star contracts and speeds up to break-up velocity ejecting a dense equatorial disk.
- BSG wind sweeps up the preceding slow wind into an hourglass structure. Its collision with the previously formed spherical red supergiant wind shell forms a short-lived luminous nebula consisting of two polar caps and a central inner ring. With time, the polar caps evolve into mid-latitude rings which gradually move toward the equatorial plane while the central ring fades.

14 Howerglass nebulae around massive stars

Spitzer images of the nebula around HD 168625

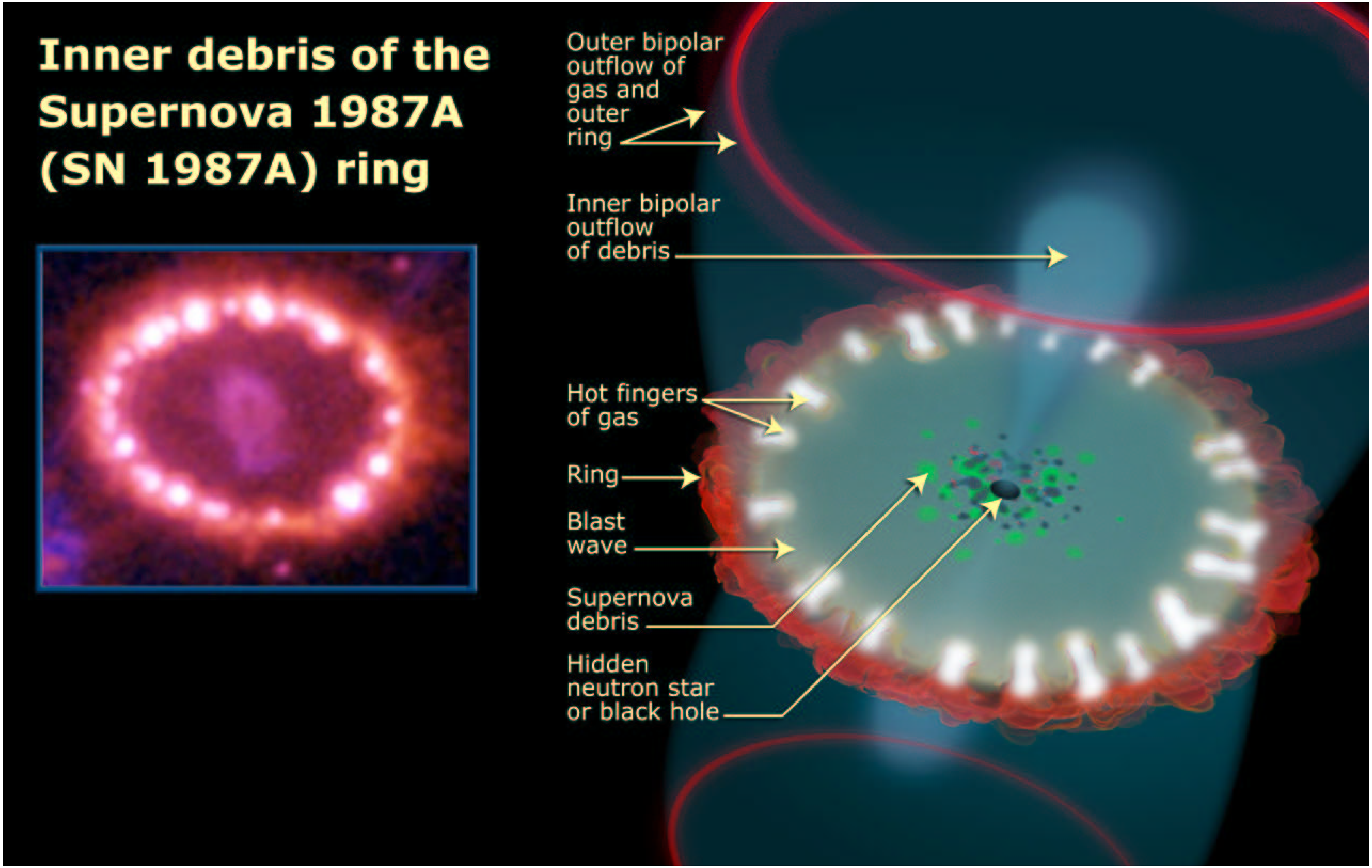


Smith ApJ, 2007, 133, 1034

There are examples of such nebuae around massive stars

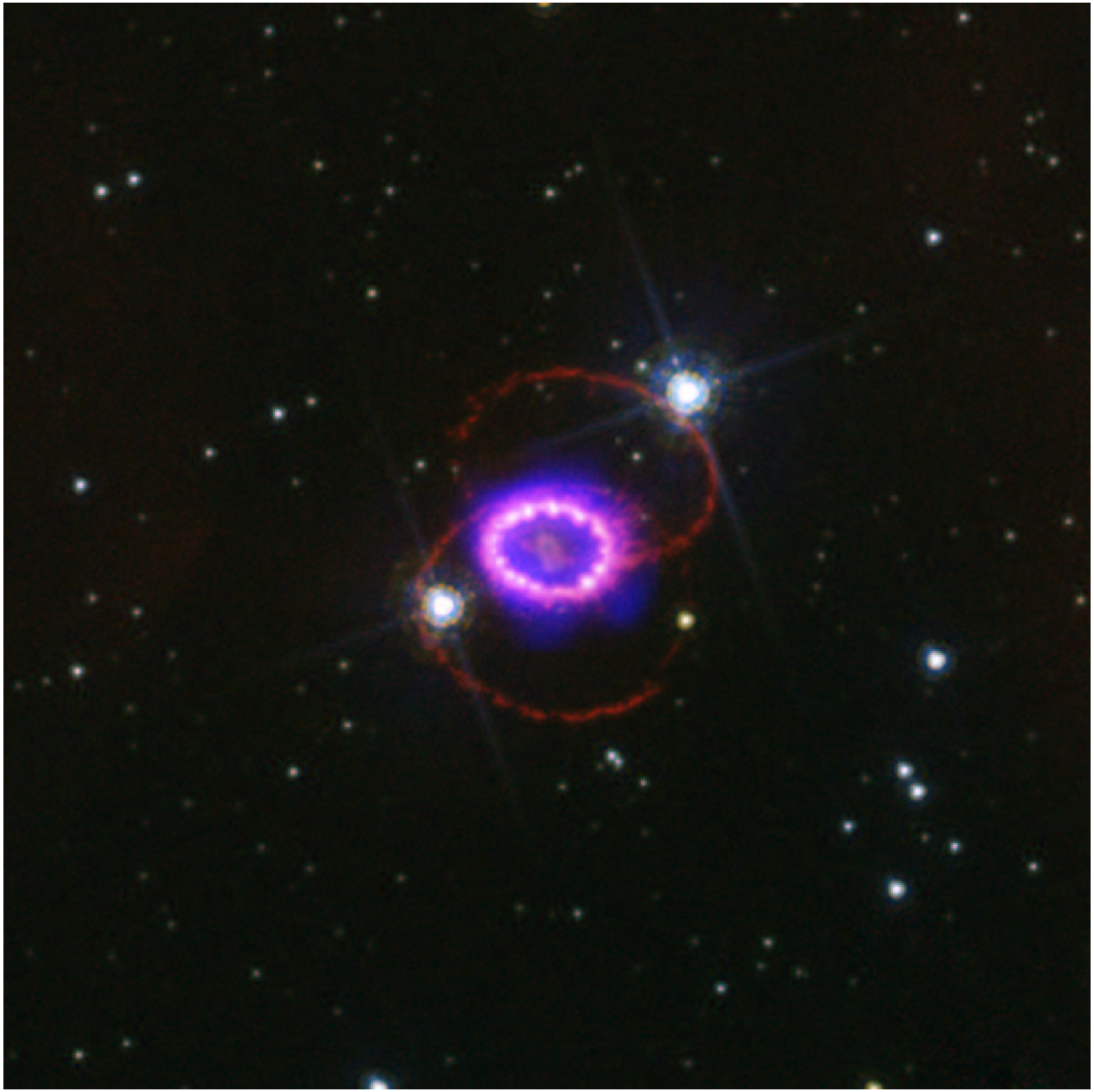
Collision of fast anisotropic wind with slow RSG wind: PNe connections?

15 Interaction of circumstellar matter with the blast wave



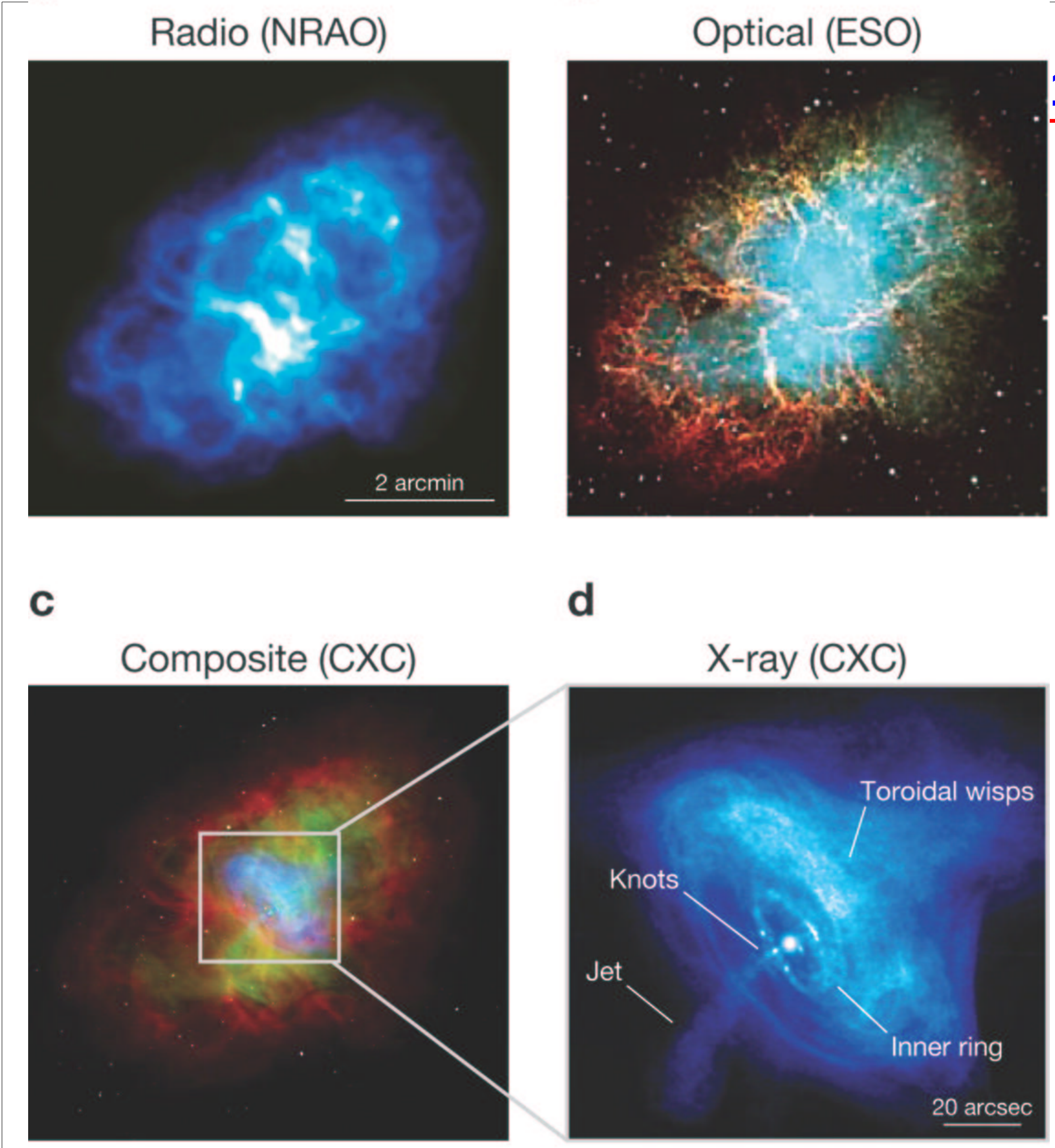
http://www.spacetelescope.org/images/html

16 X-ray emission correlates well with bright knots



http://chandra.harvard.edu/photo/2007/sn87a/ 2005

17 Neutron Stars in SNRs



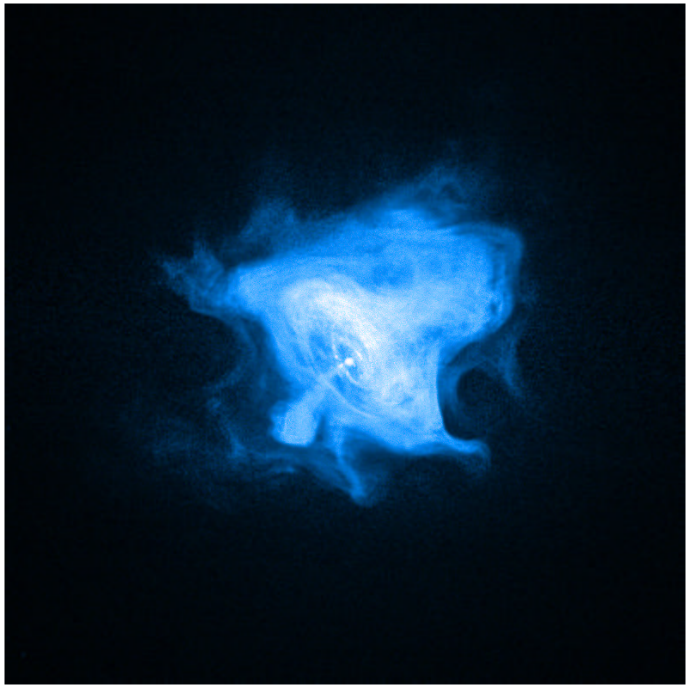
Gaensler BM, Slane PO. 2006.
Annu. Rev. Astron. Astrophys. 44:17–47

- 15 NS in SNRs are known. Crab is filled at all λ, Tycho's and Kepler's SNRs → shell morphology
- Pulsars have initial spin P 10..100 ms → $E_{kin}^{rot} \sim 10^{50}$ erg. Pulsars are spinning down, the released energy $\dot{E} = 4\pi^2 I\dot{P}/P^3 \propto 10^{35..39}$ erg/s. ($I=10^{45}$ g cm^{-2} moment of inertia, P- speen period)
- Most of the released energy → a relativistic magnetized particle wind. Particle wind interacts with the SNR → pulsar wind nebula (PWN) .

17a Standard model for Crab-like PWN

- In the earliest stages of evolution, a PWN is a quasi-spherical expanding wind bubble with a constant central energy source.
- Close to the pulsar (r<0.1pc) wind particles flow freely outward in all directions. This cold wind is not directly observable.
- About 0.1pc from the pulsar, this wind is confined by external pressure, and forms a termination shock. Par-ticles are accelerated at this shock up to ultrarelativistic energies
- Downstream of the termination shock, the flow further decelerates and the gyrating particles emit synchrotron emission, forming the observable PWN.
- In radio the extent of PWN is larger because the synchrotron lifetimes are longer than the age of PWN
- Magnetic filed strenght is ~μG

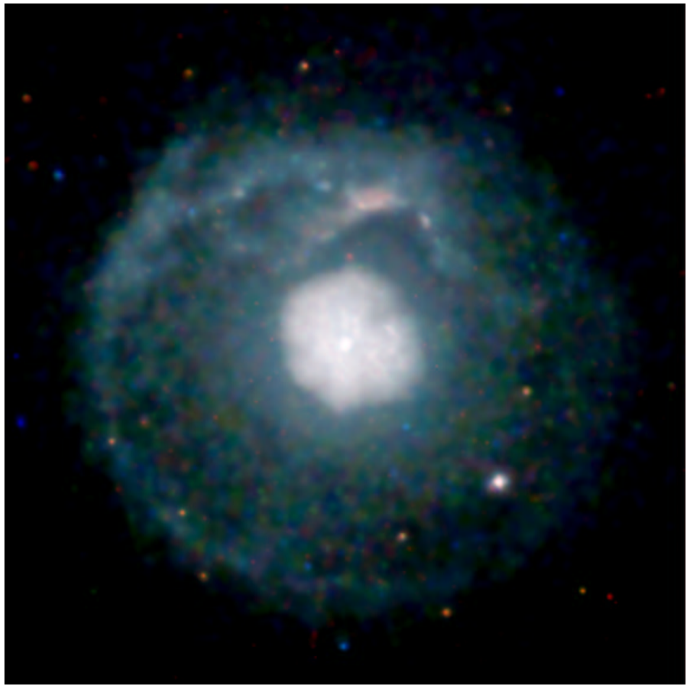
18 PWN properties



Crab

Young SNR (t<1kyr), $\dot{E} = \text{const}$

PWN expands into unshocked ejecta



LMC G21.5-0.9

Middle-aged

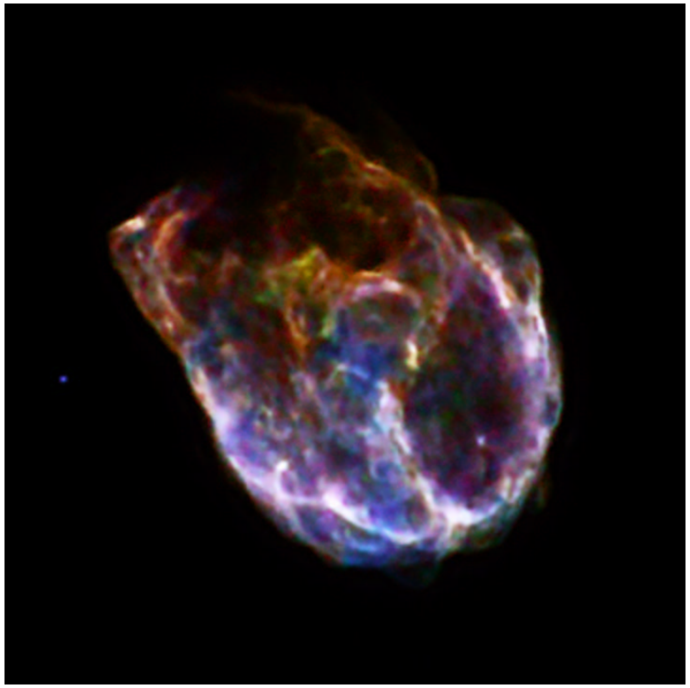
(t=10-50kyr),

Reverse and forward

shocks in SNR

Reverse shock

interacts with PWN



LMC N132D

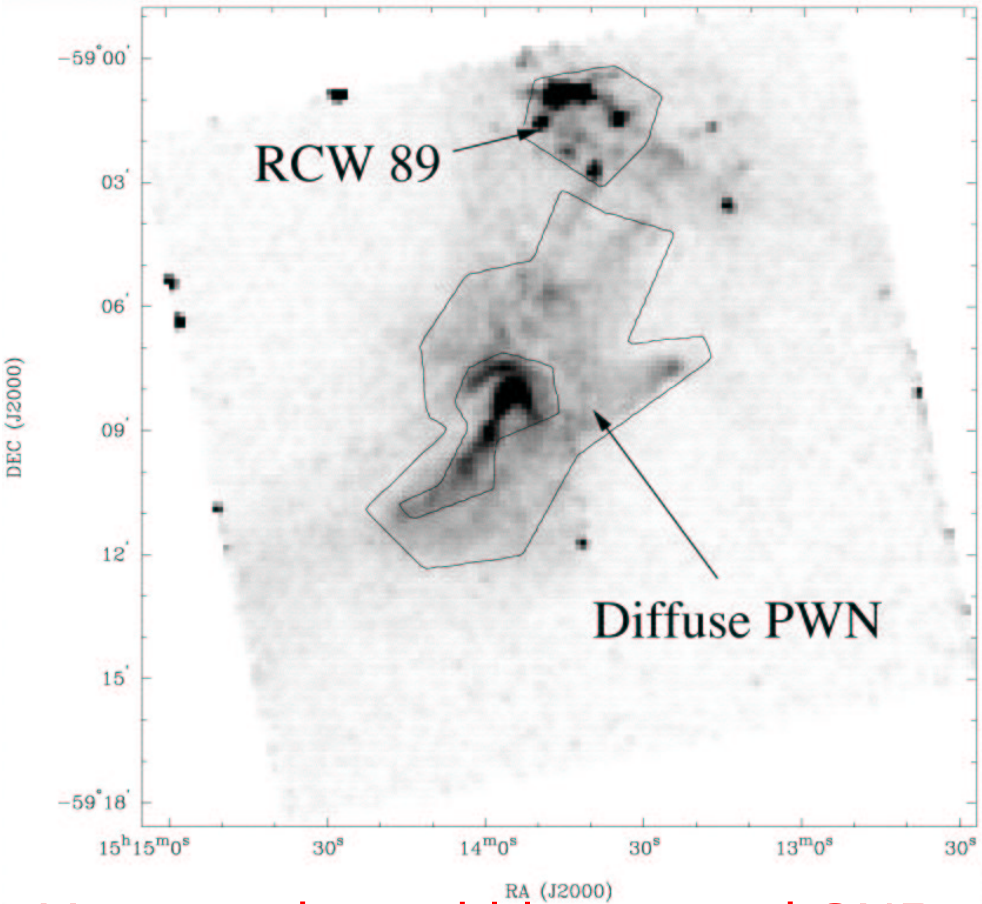
Old SNe (t>100kyr)

NS moved far from its birthplace

it will essentually escape SNR

pulsar wind drives bow shock, confined by ram pressure

19 Cir Pulsar Wind nebula



Young pulsar within unusual SNR

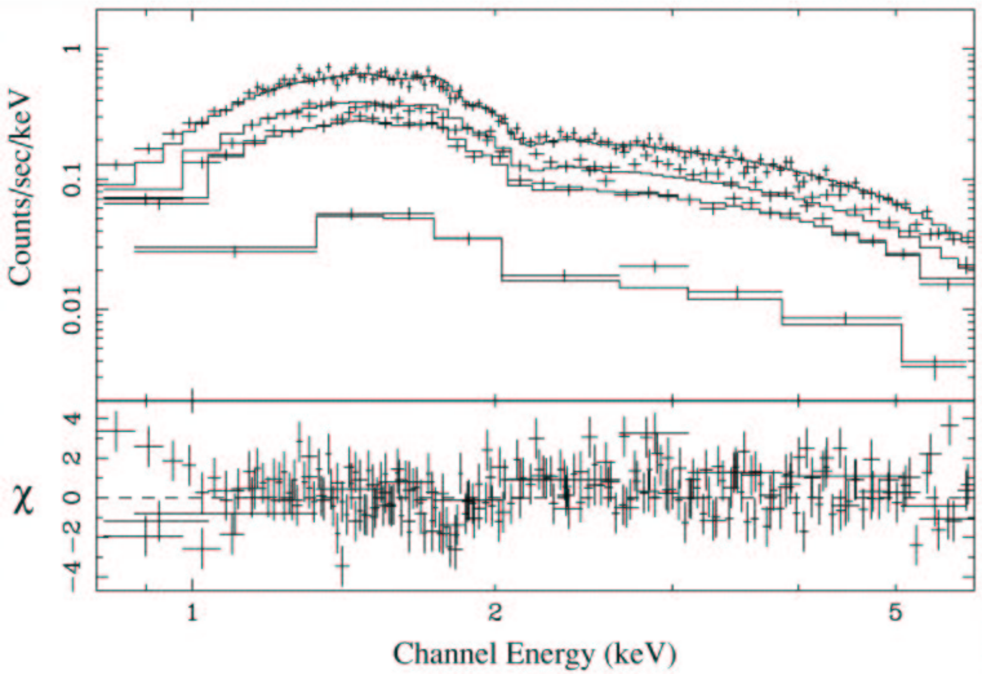
large elongated nonthermal nebula

a one-sided collimated outflow

emanating from the pulsar

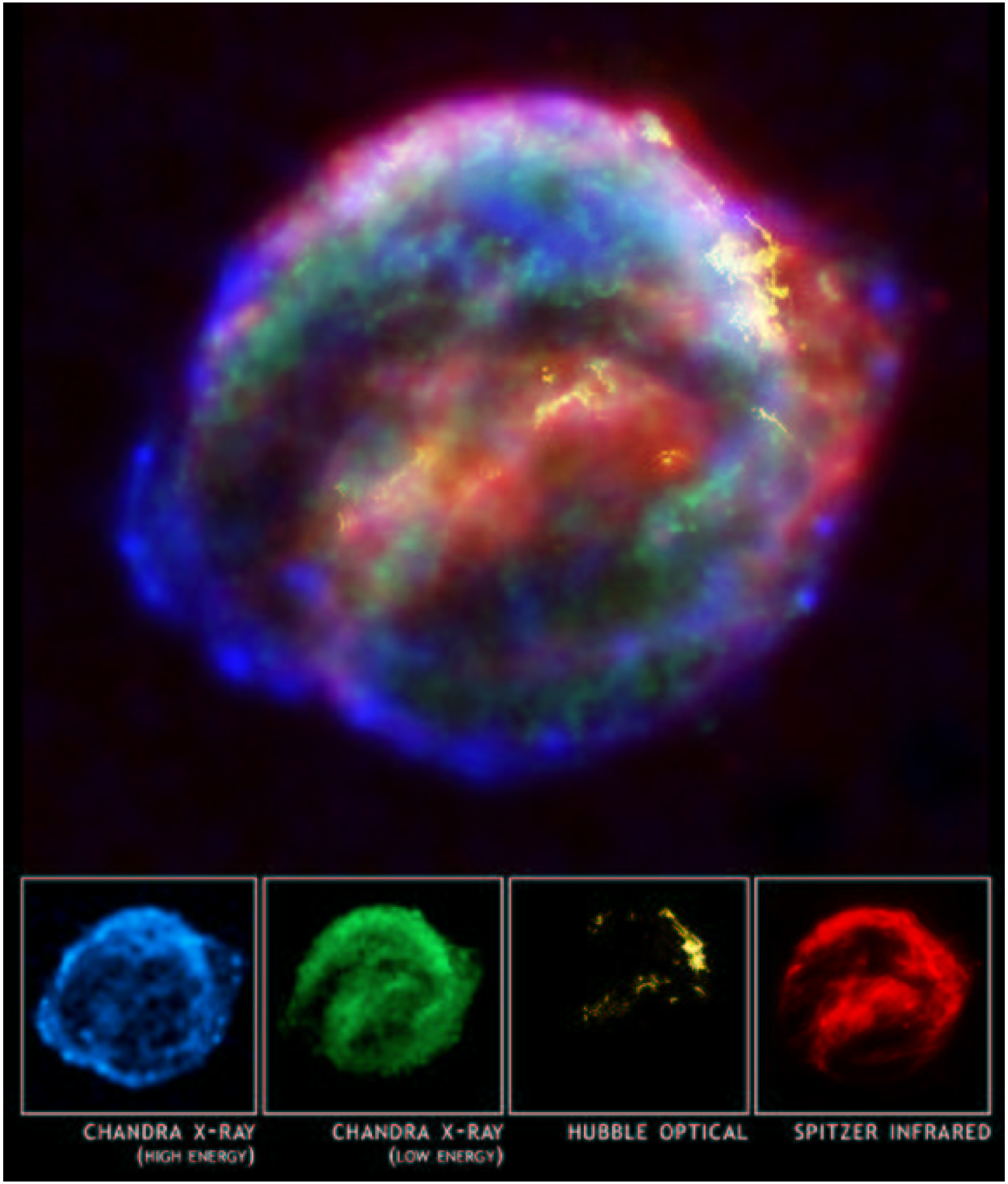
torus similar to seen in Crab

Gaensler et al. 2002, ApJ, 569, 878



Four curves correspond to four CCDs

Absorbed power law



20 SNR Summary

Interaction between SN ejecta
and projenitor wind or ISM

Thermal X-ray spectra
Non-equilibrium ionization (NEI)

Non-thermal X-ray spectra
synchrotron from PWN

Explosive nucleosynthesis

Clumpy -- seeds for dust formation
Important for chemical evolution

SN 1987A: single or binary?
parallels with PNe formation

Importance of magnetic field

Newtron stars and black holes