The X-Ray Universe

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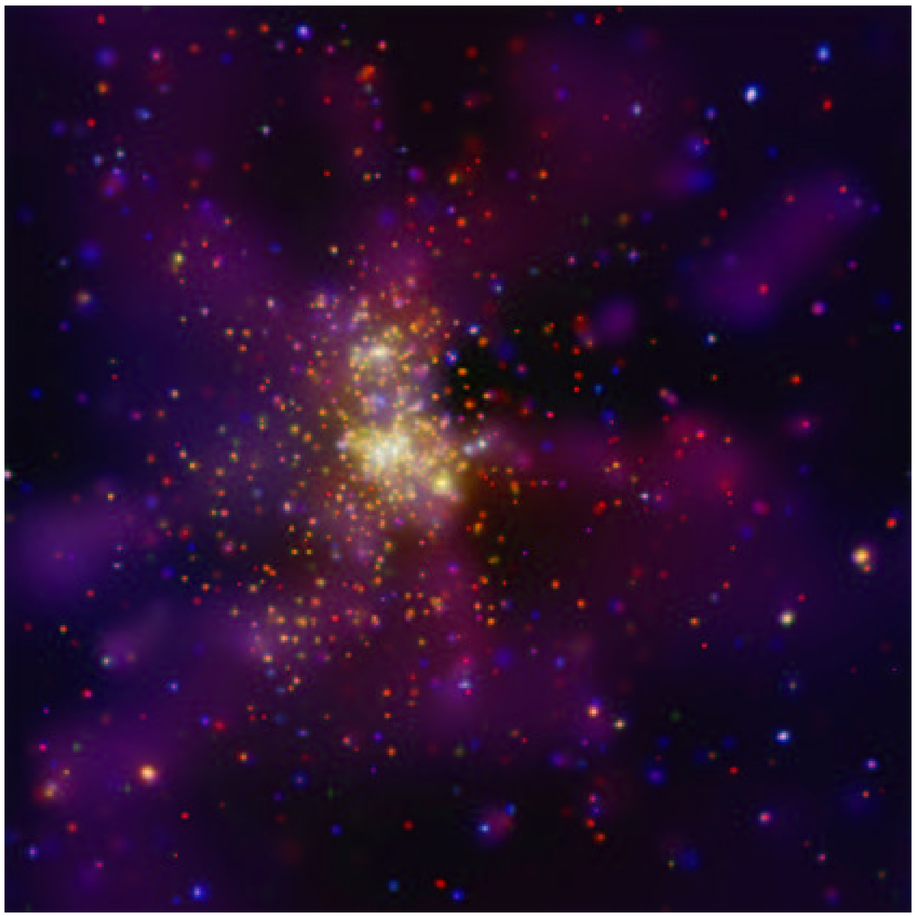
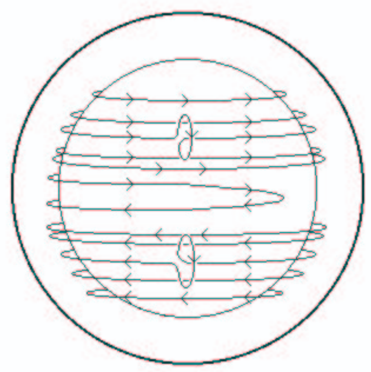
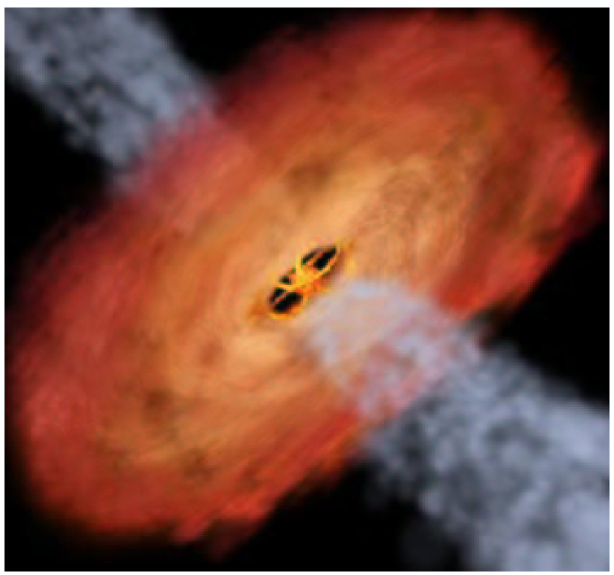


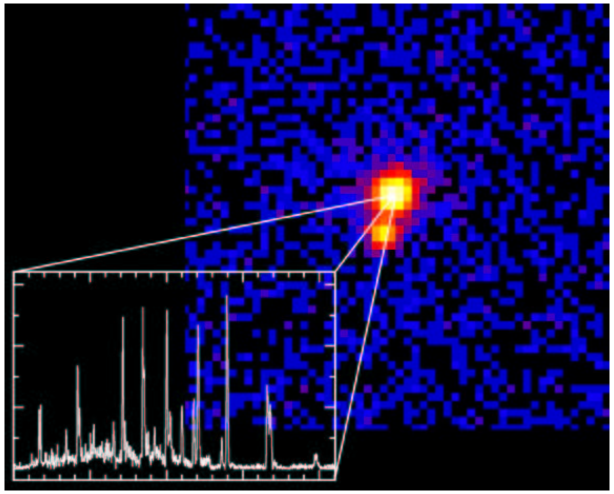
Chandra X-ray Observatory
Westerlund 2 - a young star cluster
d= 2×10^4 ly

VI. X-rays from stars: Overview



The α-effect





Low- and solar type stars

Rotation and convection → dynamo

Dynamo → B-field generation

B-field stress → flares: non-thermal X-rays!

Nanoflares → stable coronae: thermal X-rays!

Young stellar objects: T Tau stars

Accretion disks and streams

Coronae

Importans for planet formation

L_X-age correlation

Massive stars

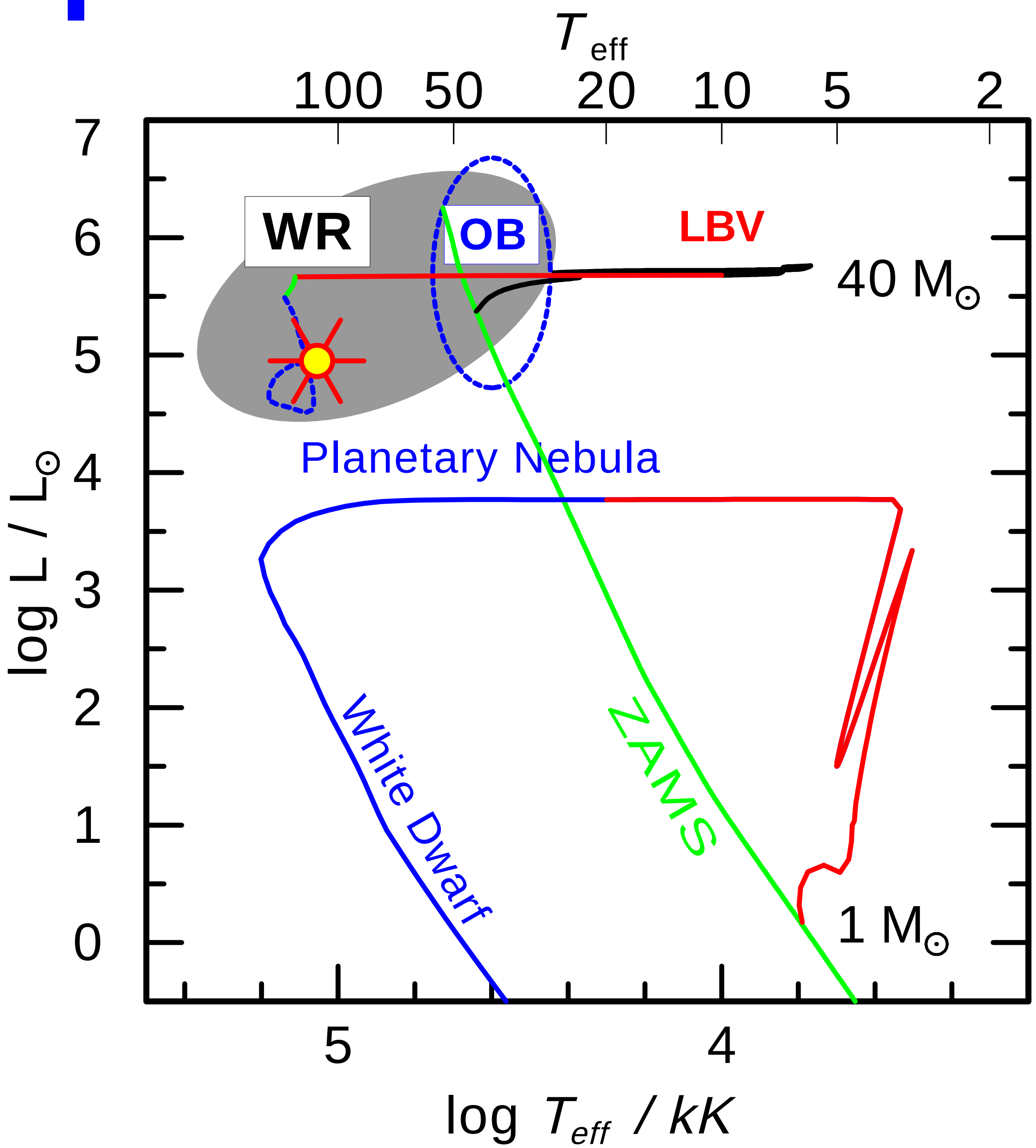
No outer convection zone → no dynamo

Strong stellar winds

Stellar wind instability→ shocks

Hot plasma is permeated in the wind

VII. X-rays from Planetary Nebulae and Supernova Remnants



03 Planetary Nebula shapes

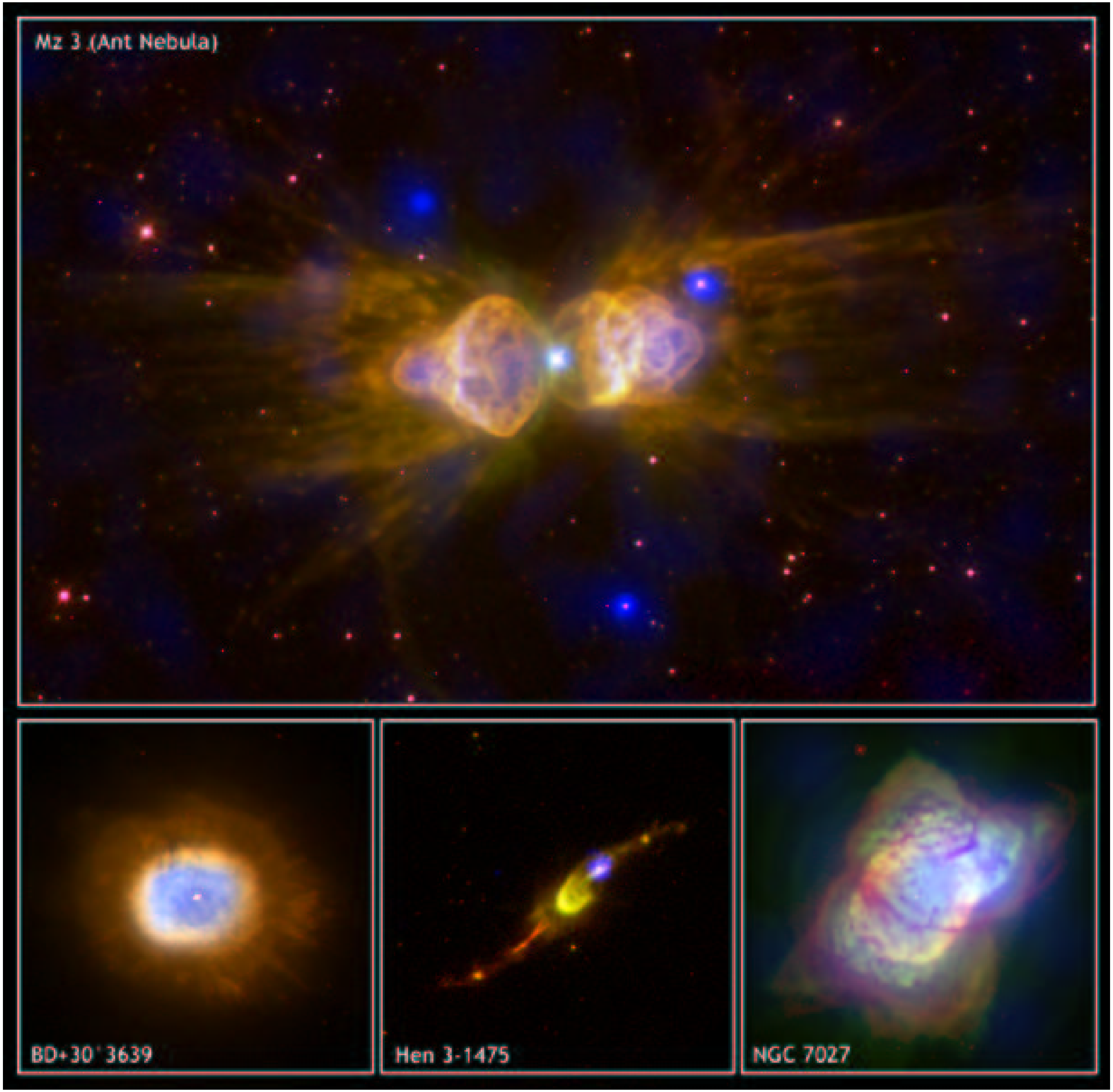
04 X-rays from PNe

http://www.iaa.csic.es/xpn/

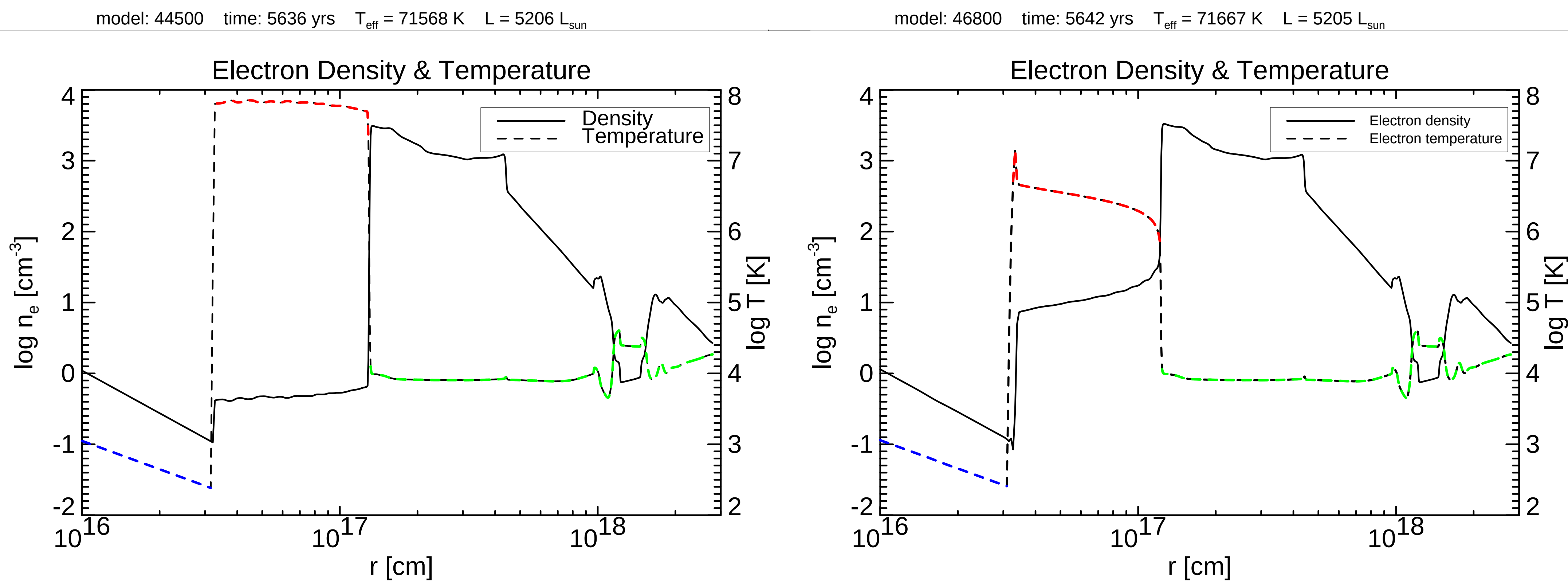
Two different mechanisms
→ hot gas in PNe

- The central cavity is filled with shocked gas, X-ray limb brightened morphology
- Extended cavities are filled with shocked gas.

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


Mz 3 (Ant Nebula)
BD+30˚ 3639
Hen 3-1475
NGC 7027

06 Models of X-rays from PNe



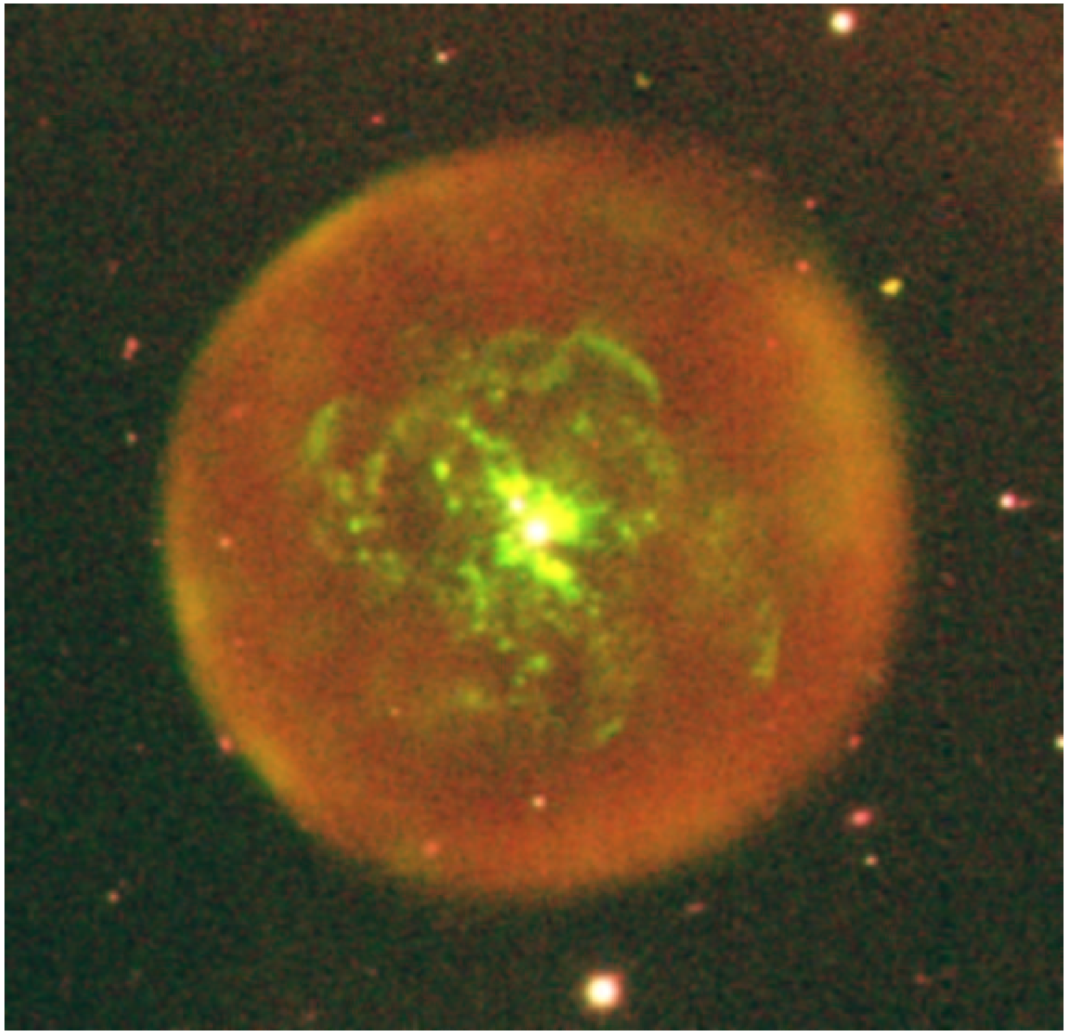
Hydromodels: predict a “hot bubble”

$T_X = 10^8$ K and low density

Not consistent with

the X-ray observations.

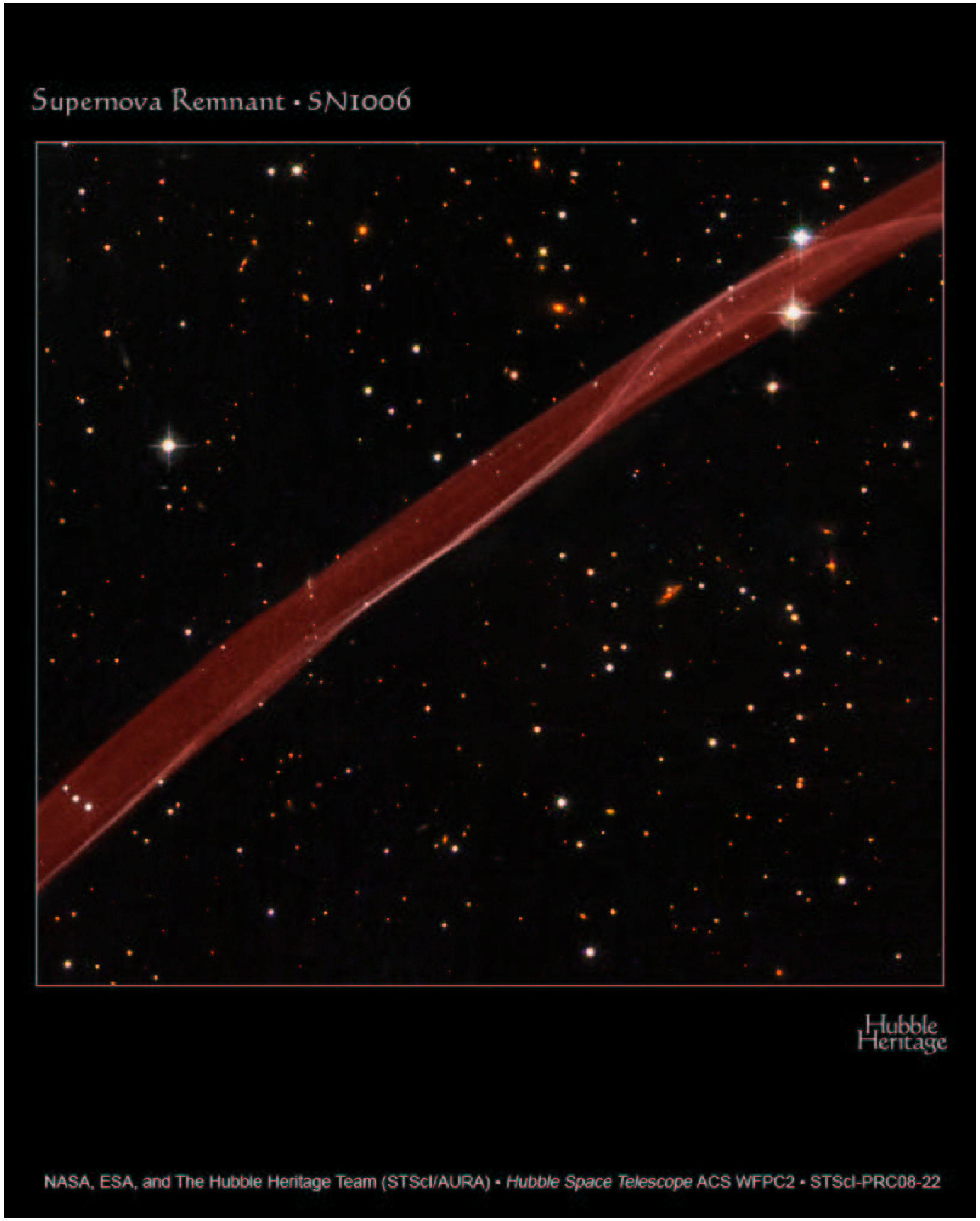
07 New observations of Abell 30 with XMM-Newton



from B. Blair homepage, KPNO

Abell 30 is a PN with [WC] cenral star, we will check chemical composition and whether the observations can be described by the mode

09 Supernova Remnants



http://heritage.stsci.edu/2008/22

Supernovae and their progenitors provide most of the heavy elements in the Universe and deposit kinetic energy (10^{51} erg each) into the interstellar medium

10 Supernova Classification

LMC SN 1987A

Supernovae:

powered mostly by radioactive decay:

^{56}Ni, ^{56}Co, ^{56}Fe

T~ 5000 K

characteristic emission is optical and IR, timescale ~ year

Ia Thermonuclear Runaway

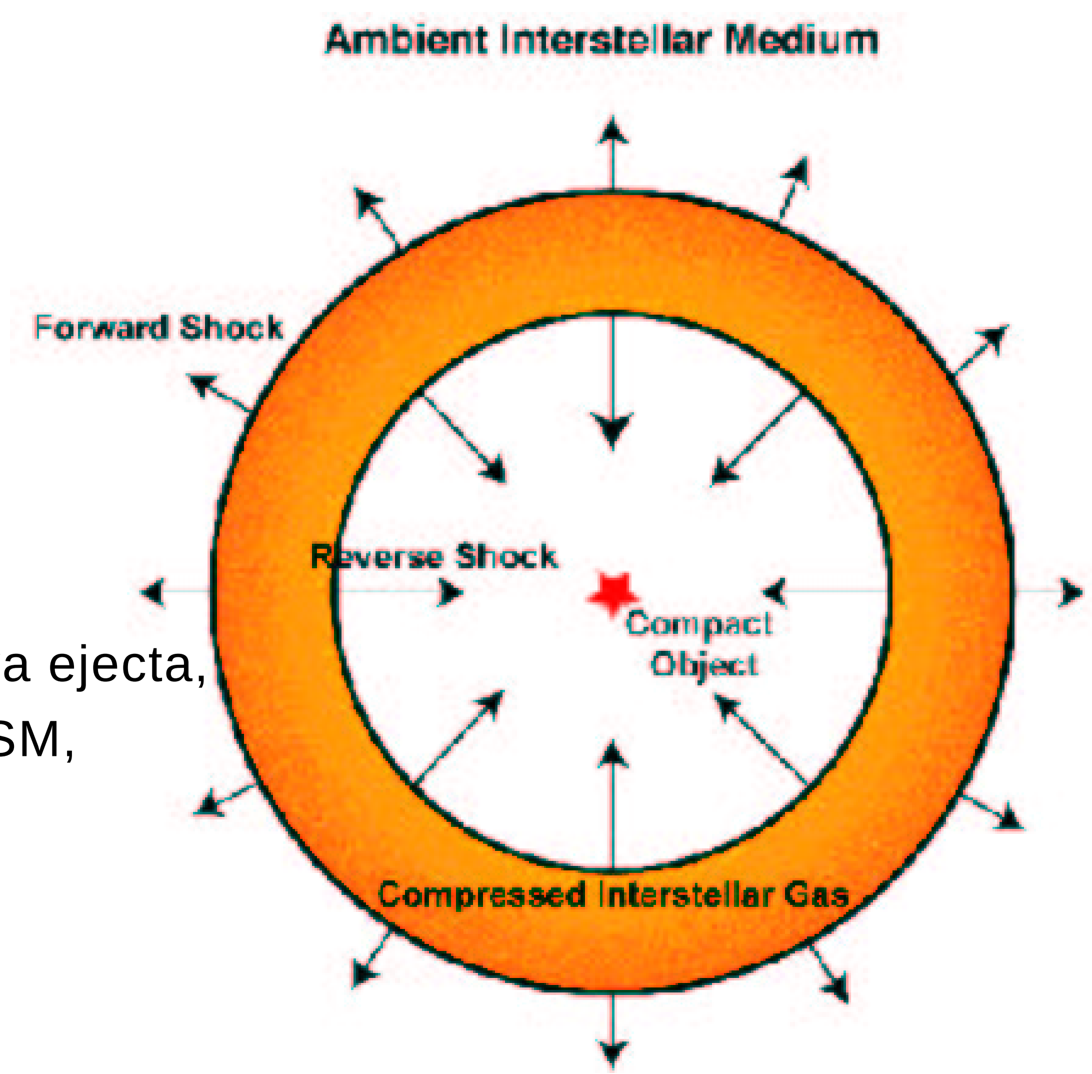
- Accreting CO WD reaches → Chandrasekhar mass limit → thermonuclea runaway. Total disruption of progenitor.
- Explosive synthesis of Fe-group plus some intermediate mass elements
- Uncertain mechanism and progenitor, but standard candles

II/Ib/Ic Core-Collapse of Massive Star

- Progenitor core neutron star or black hole
- Explosive nucleosynthesis products near core (Si and Fe) + hydrostatically formed outer layers (O, Ne) are expelled
- Most of the explosion energy is carried away by neutrinos
- Uncertain mechanism, GRB connections

11 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



- Powered by expansion energy of supernova ejecta,
- dissipated as the debris collides with the ISM,
- generating shocks T ~ 10^{6-7} K
- characteristic thermal emission is X-rays
- timescale ~100-1000 years

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

11a Why Study Supernova Remnants?

- **Supernova explosion:** How is mass and energy distributed in the ejecta? What was the mechanism of the supernova explosion? What elements were formed in the explosion, and how? What are the characteristics of the compact stellar remnant?

- **Shock physics:** How is energy distributed between electrons, ions, and cosmic rays in the shock? How do electrons and ions share energy behind the shock?

- **Interstellar medium:** What is the structure of the interstellar medium and circumstellar, and how does the shock interact with that structure?

12 Phases of remnant evolution

* Free Expansion. without deceleration r~t.
* Adiabatic (Sedov phase, or atomic bomb). Ejecta are decelerated by a roughly equal mass of ISM $r \sim t^{2/5}$. Energy is conserved: internal → kinetic. Temperature increases inward, pressure decreases to zero
* Snowplough. Remnant forms a thin, very dense shell which cools rapidly. Interior may remain hot. Energy loss via radiative cooling. Shell moves with constant momentum.
* Merging phase. Speed of expansion << a. SNR

13 Collisionless shocks

* SNR shocks move through ISM with ρ(ISM)=1cm $^{-3}$.

* Coulomb interactions occur on time-scale $\tau \approx 10T^{3/2}/\ln\Lambda$. For T=10^8, τ=12000yr > SNR age. Nevertheless there are X-rays, plasma must be heated somehow → collective plasma wave effects.

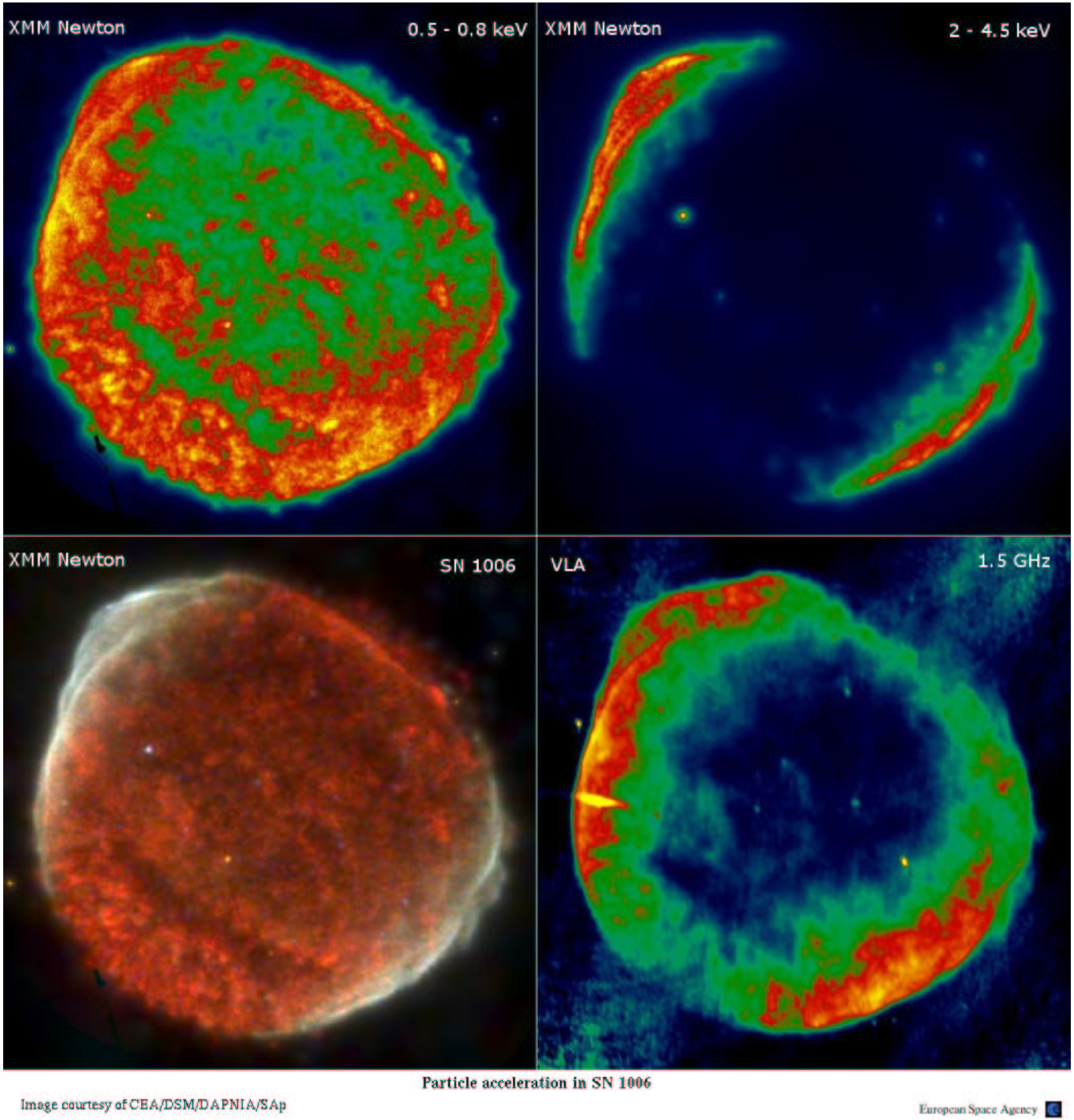
* Temperatures of different species are different. When particles i interact only among themsleves: $kT_\mathrm{i} = 3/16 m_\mathrm{i} v_\mathrm{s}^2$, v_s is shock velocity.

* Ionization time scale = n_et, t is time since impulsive shock heating, for n_e in ISM, n_e=10^4 yr.

* NEI Non-equilibrium ionization: temperature infered from line ratios and continuum is different.

That is neglecting energy loss for cosmic ray acceleation.

14 SN1066:
Particle acceleration



Particle acceleration in SN 1006

* Soft X-rays:
* thermal gas OVII Heα line
* Hard X-rays:
* synchrotron radiation
* Radio:
* cyclotron emissin

RGS spectra

v=4000 km/s

Young SNR

NEI

Particle accelartion

First order Fermi porcess

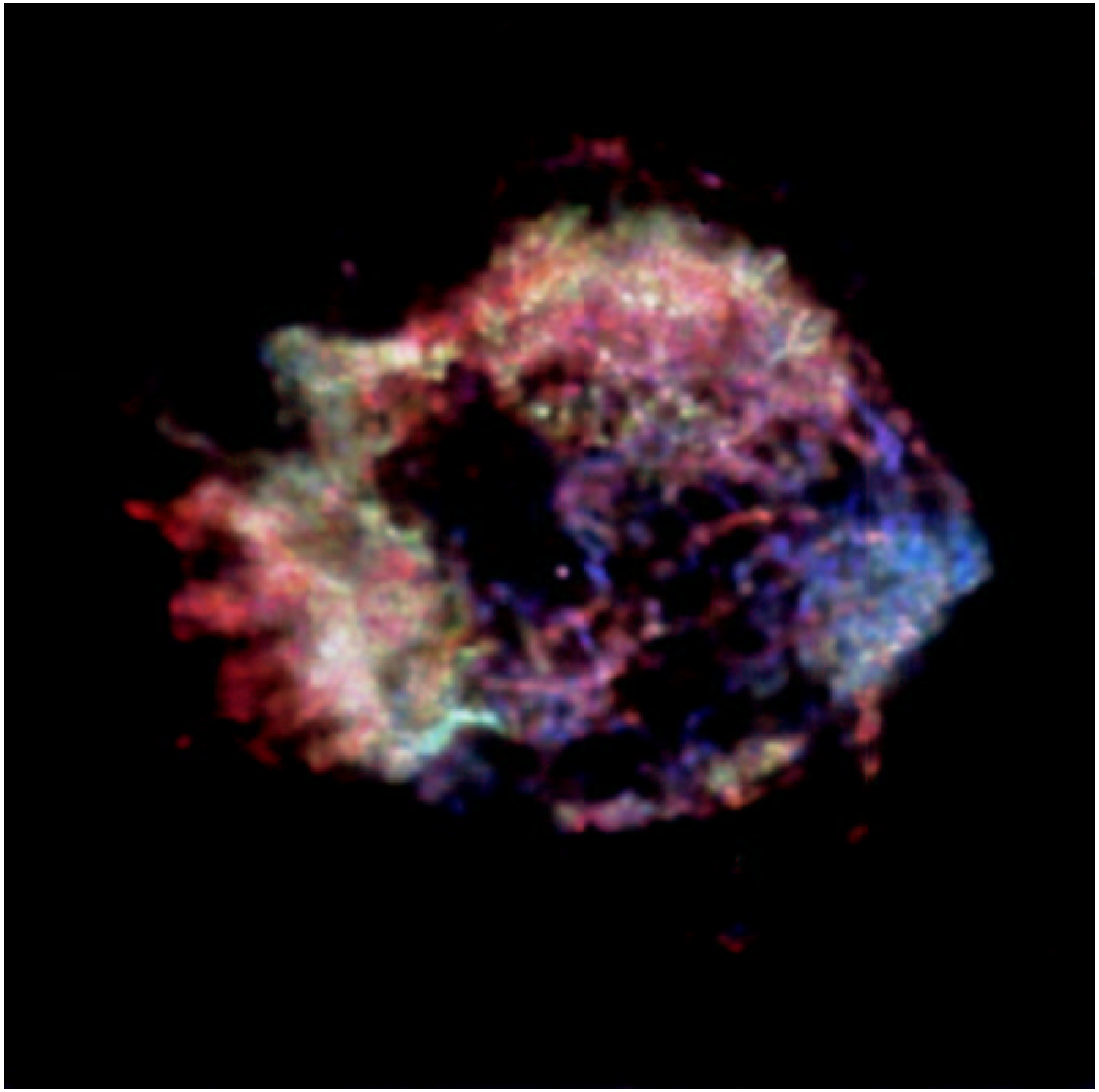
Diffusion in shocks B

Cosmic rays: ions

Synchrotron: **e**

15 Explosive Nucleosynthesis

Cassiopeia A



Hughes et al. ApJ 528, L109

Nuclear processing as the supernova shock wave propagates through the star

* C → O, Ne, Mg:T ~ 2 x 10^9 K
* Ne → O, Mg: T ~ 2.3 x 10^9 K
* O → Si, S, Ar, Ca: T ~ 3.5 x 10^9
* Si → Fe, Si, S, Ca: T ~ 5 x 10^9 K

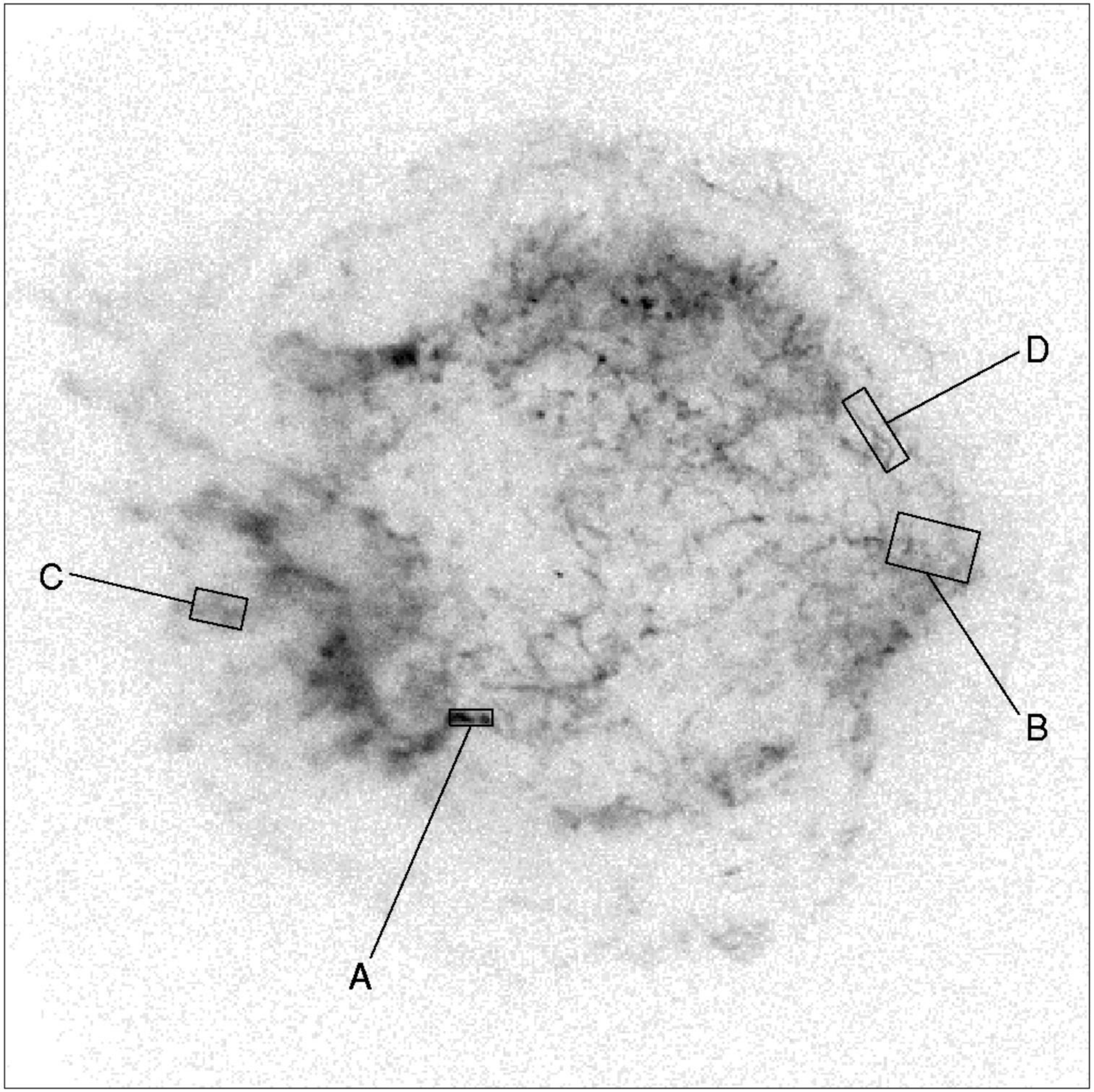
0.6-1.65 keV

1.65-2.25 keV

2.25--7.50 keV

16 Explosive Nucleosynthesis

Cassiopeia A



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O-burning

Incomplete Si

.. plus Fe

Featurless