SNR 101

3rd X-ray Astronomy school
Wallops Island May 12-16 May

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(USRA/NASA/GSFC)

Many thanks to:

Pat Slane (Center for Astrophysics)

CXC website for their marvelous animations

Chandra SNR catalogue on-line (aka Fred Seward's catalogue)

What are SNRs ?

SNRs: SuperNova Remnants are the tracers of explosions from stars reaching the end of their lifes. SNRs also enrich the ISM by dispersing material produced both during the star's life and at the moment of the SN event.

How frequent? Estimates varies according to SN types, environment (Galaxy type), …: About 2 per century for Milky Way (all types)

Why should we (you) care?

SNRs are probes both of their progenitor star (and of their pre-supernova life) and of the ISM.

They are also cosmic accelerators (cosmic rays).

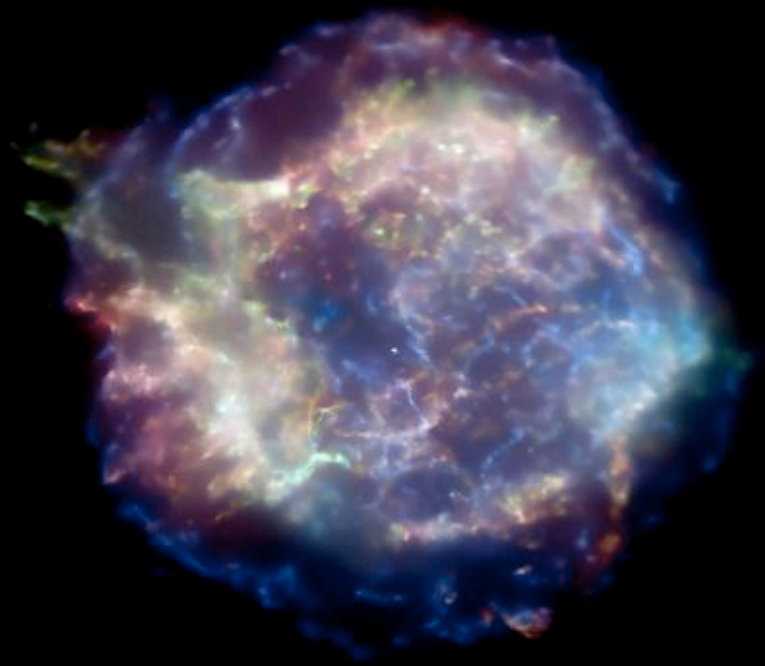
Birth places of neutron stars and stellar mass black holes.

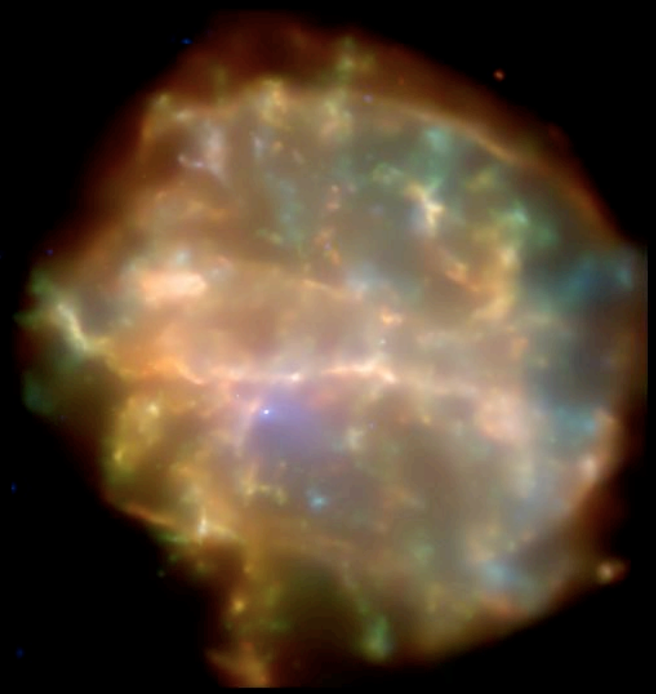
They can also be space laboratories for study of high magnetic fields, shock physics, jets, winds, (PWNe)…

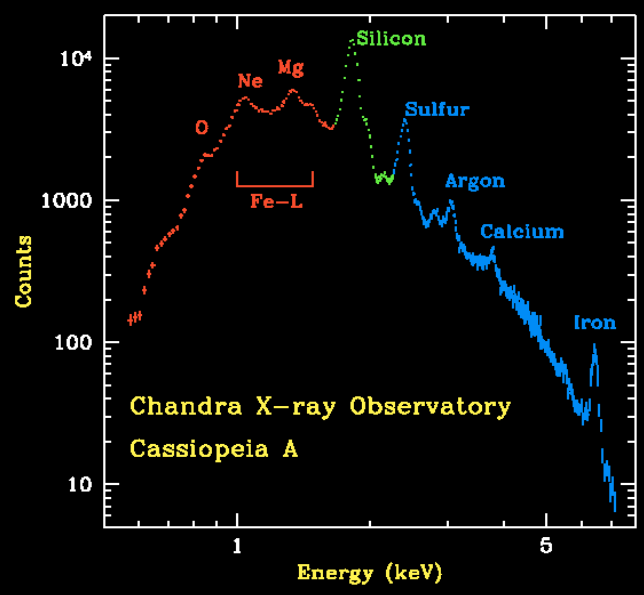
Now the real story….

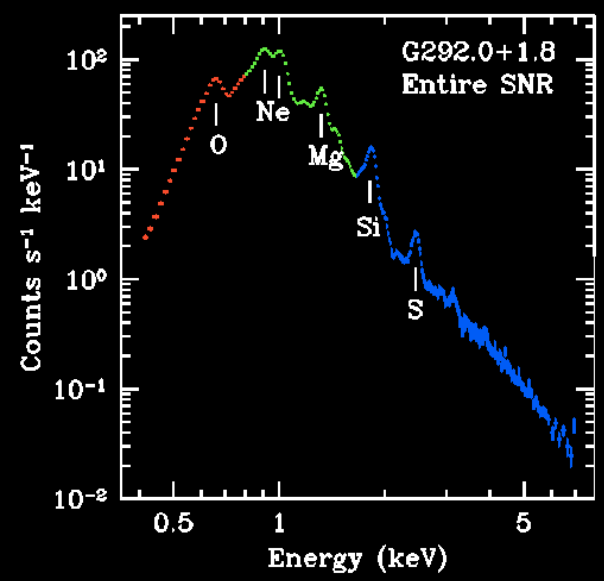
is a lot darker….

- Morphology classification is a zoo
- Spectral classification is a royal mess



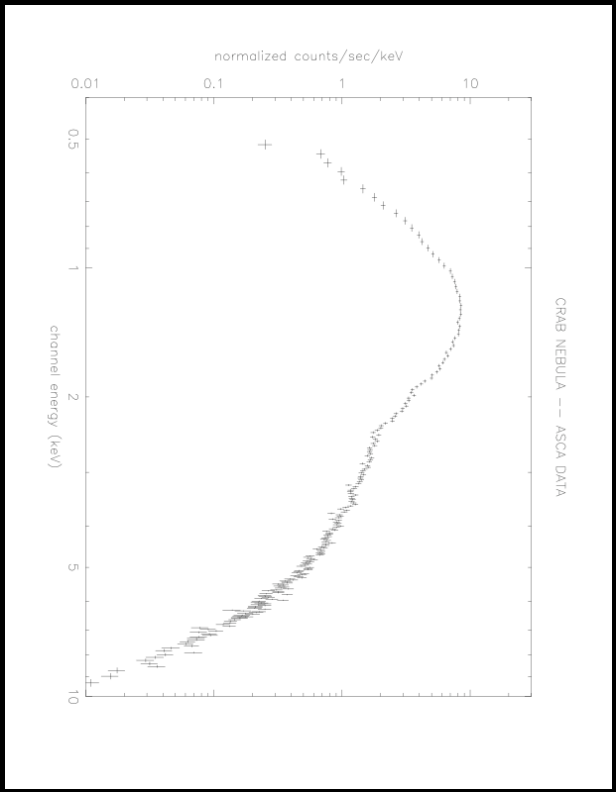


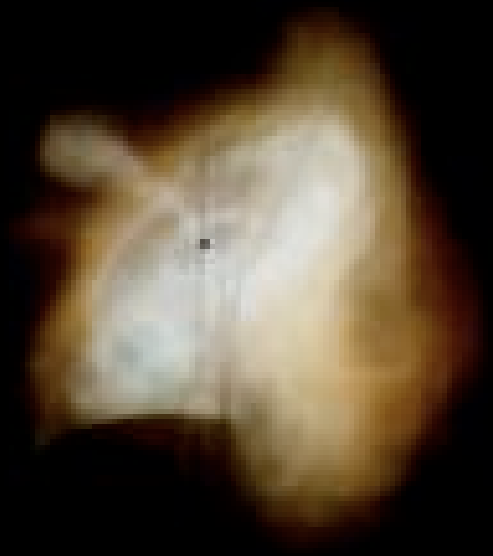


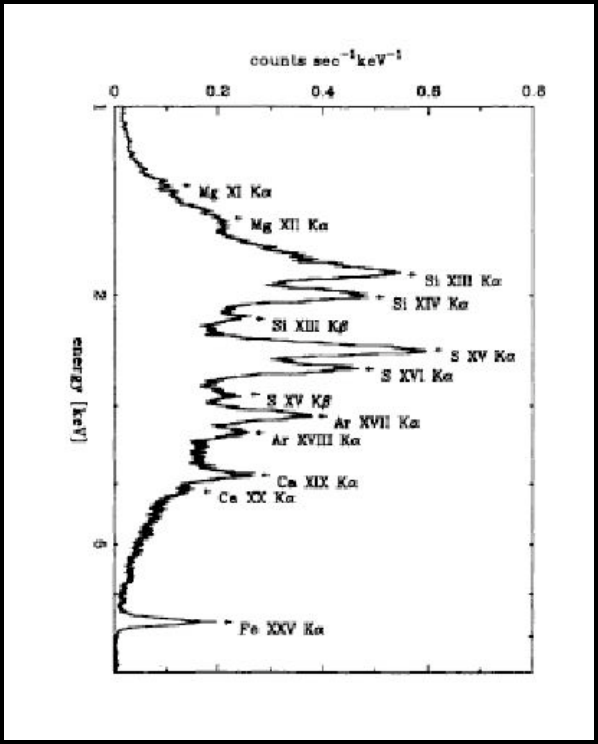


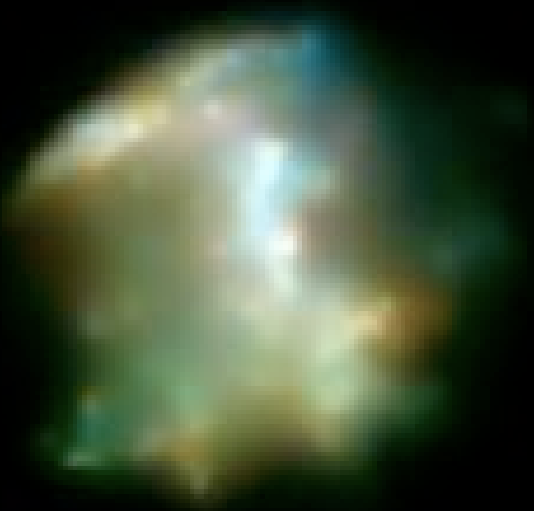
Hughes et al. 2000, ApJ, 528, L109

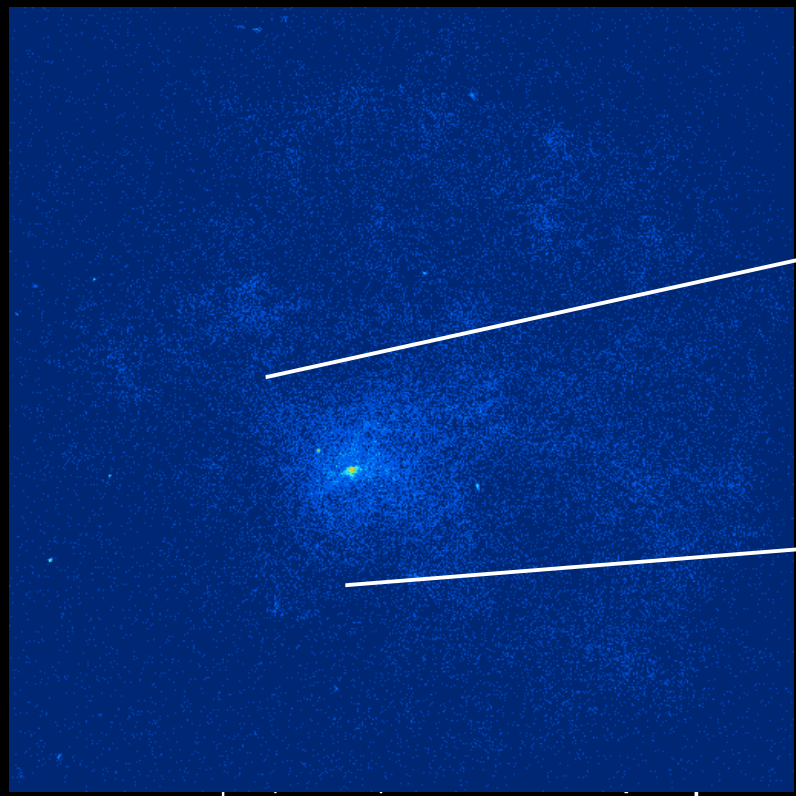
Park et al. 2002, ApJ, 564, L39

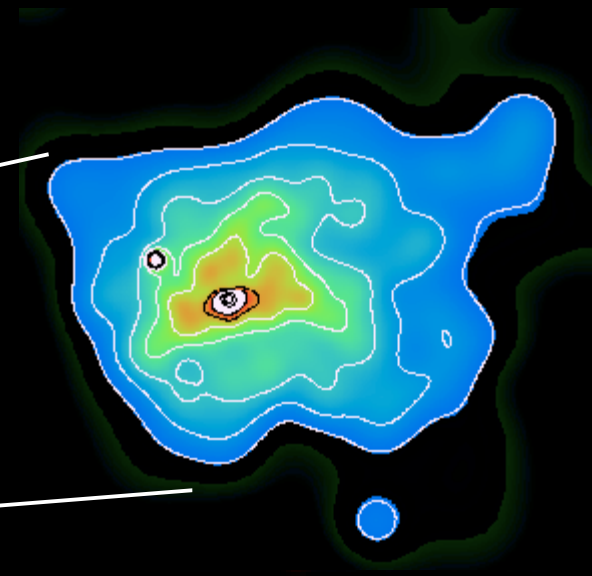

normalized counts/sec/keV
0.01
0.1
1
10
channel energy (keV)
0.5
1
2
5
10
CRAB NEBULA -- ASCA DATA

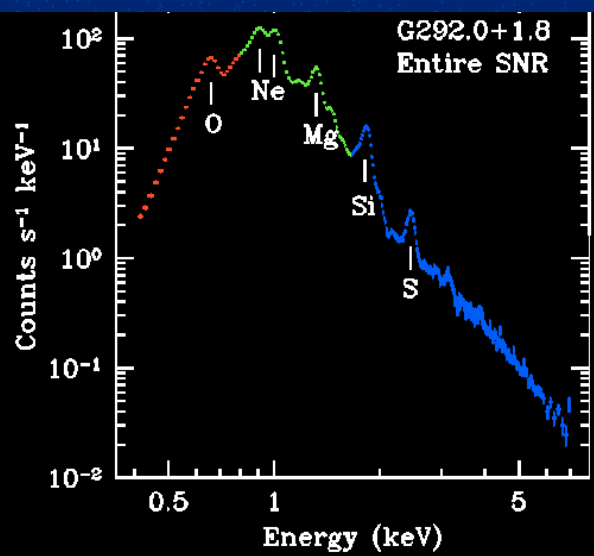



counts sec^{-1}keV^{-1}
0
0.2
0.4
0.6
0.8
energy [keV]
1
2
6
Mg XI Kα
Mg XII Kα
Si XIII Kα
Si XIV Kα
Si XIII Kβ
S XV Kα
S XVI Kα
S XV Kβ
Ar XVII Kα
Ar XVIII Kα
Ca XIX Kα
Ca XX Kα
Fe XXV Kα



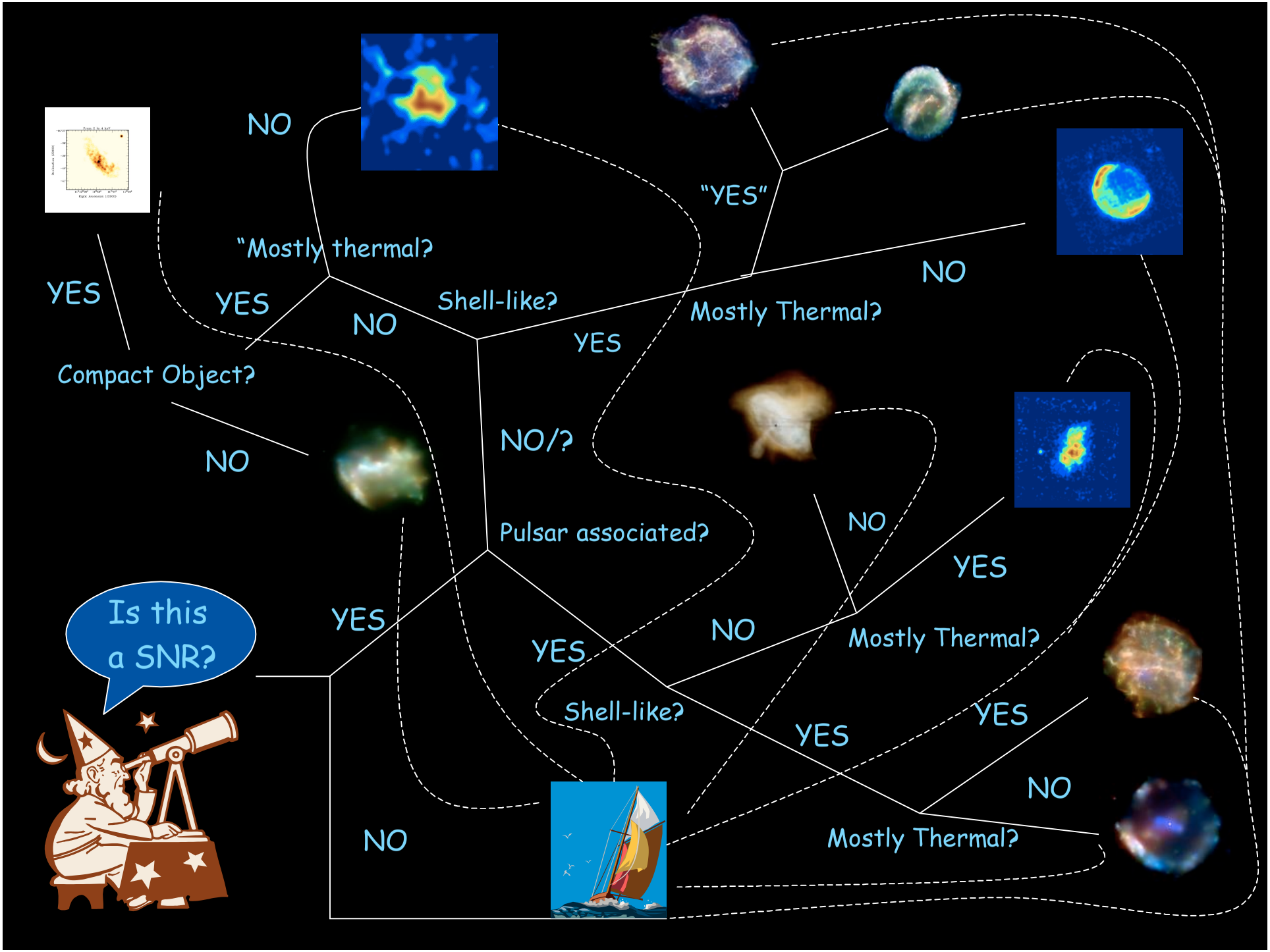






Park et al. 2002, ApJ, 564, L39

Hughes & Slane 2003, ApJ (submitted)


Is this a SNR?
Compact Object?
YES
NO
"Mostly thermal?
YES
NO
Shell-like?
YES
NO/?
Pulsar associated?
YES
NO
Shell-like?
YES
NO
"YES"
Mostly Thermal?
NO
YES
NO
Mostly Thermal?
YES
YES
NO
Mostly Thermal?

Why is this such a mess??

SNR evolution (and their appearance now) depends on many factors:

- Its age
- Its environment (density)
- The total energy of the explosion

and … its progenitor star (mass, type of SN associated..)

3 phases in SNR's life.

- Free expansion (less than 200-300 years)
- Adiabatic or "Taylor-Sedov" phase (about 20,000 years)
- Radiative or Snow-plow phase (up to 500,000 years)

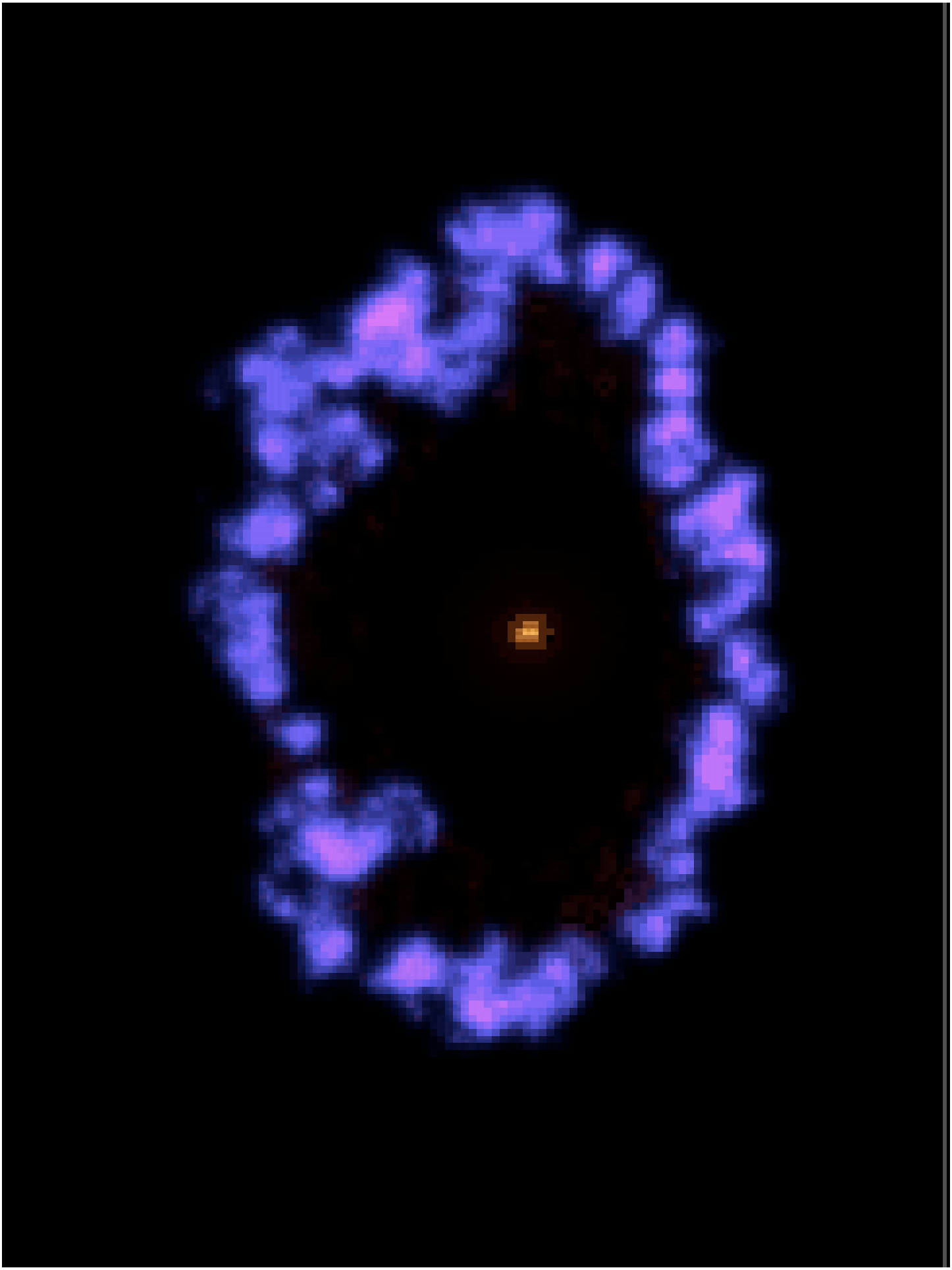
and then … Merge with the ISM

Free expansion phase

- Independent of the nature of the SN explosion
- No deceleration
- Evolution only depends on E_o the initial energy.
- Velocity of ejected shell varies between (7-12) 10^3 km s^{-1}
- Mass swept-up negligible until $M_{su} \sim M_{eje} \sim 1\ M_\odot$

===> $Rs = 250\ \text{yrs}\ M_{eje}^{5/6}\ n_1^{-1/3}\ E_{51}^{-1/2}$

SNR enters then its Adiabatic Phase



Sedov-Taylor phase

The key word here is SELF SIMILAR *(solutions can be scaled from solutions elsewhere)*

===> $f(r, t)$ becomes $f(r/r_{ref}) * f(r_{ref})$

(skipping the equations) … Et voilà!

$$R_s = 12.4 \text{ pc } (KE_{51}/n_1)^{1/5} \, t_4^{\,2/5}$$

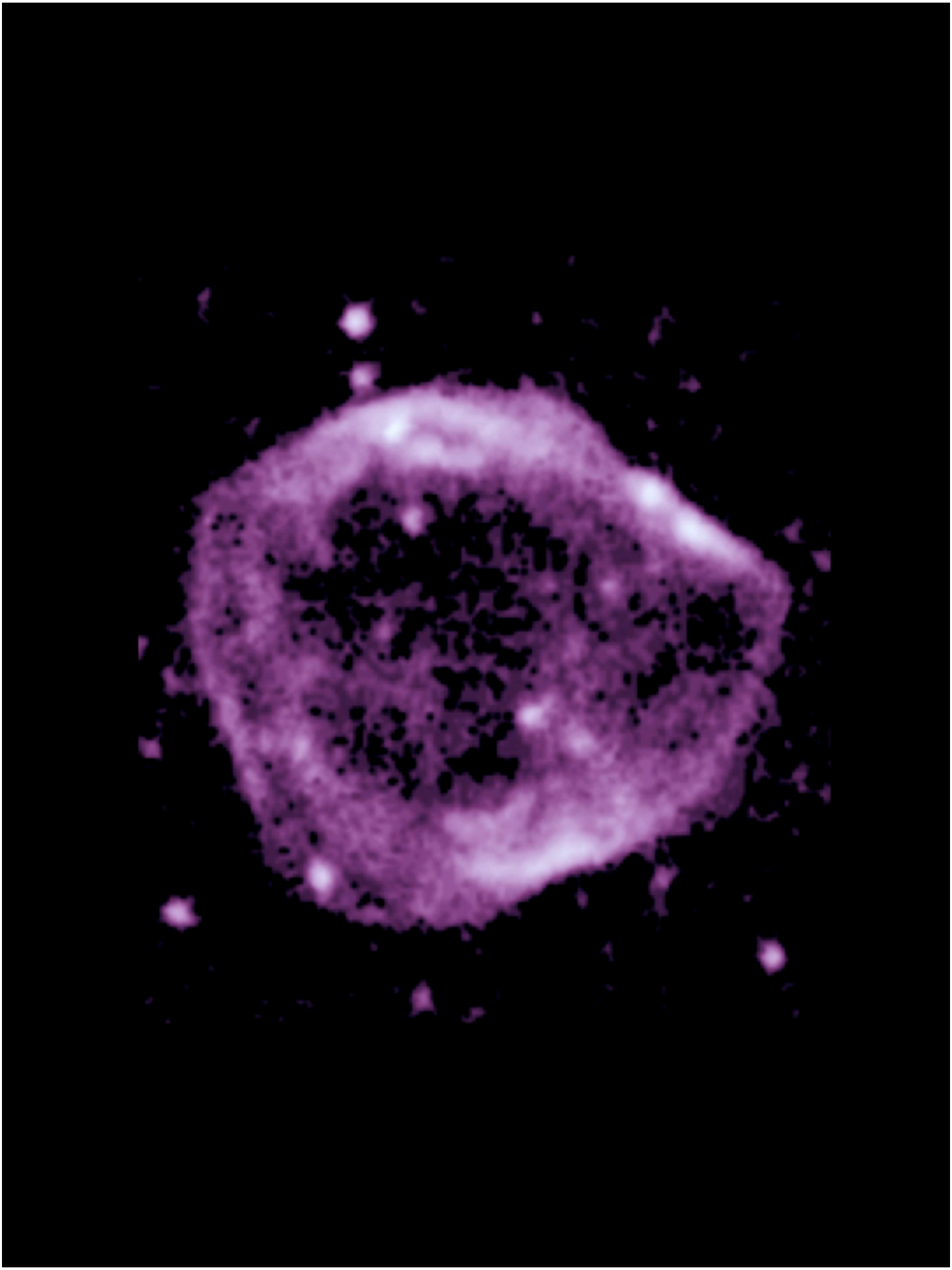
$$t == 390 \text{ yr } R_s \, T_{meas}^{-1/2}$$

Sedov-Taylor phase

The Sedov-Taylor phase is one the most often used in papers about SNRs (that's because one can get actual physical quantities from measurements).

In Sedov-Taylor model one expects thermal emission coming from a thin shell behind the blast wave. As the shock expends the pressure drops between the shock wave and the material ejected.

At one point, "reverse" shock starts propagating ===> will eventually heat the ejecta (also thermal emission).



Radiative phase

T drops as a steep function of radius

===> at some point, T is below $T_{recomb} \sim 1$ keV

Age of SNR when this happens depends on models for cooling functions, explosion energy and density.

Between 17,000 and 25,000 years (assuming standard E_o and n_1)

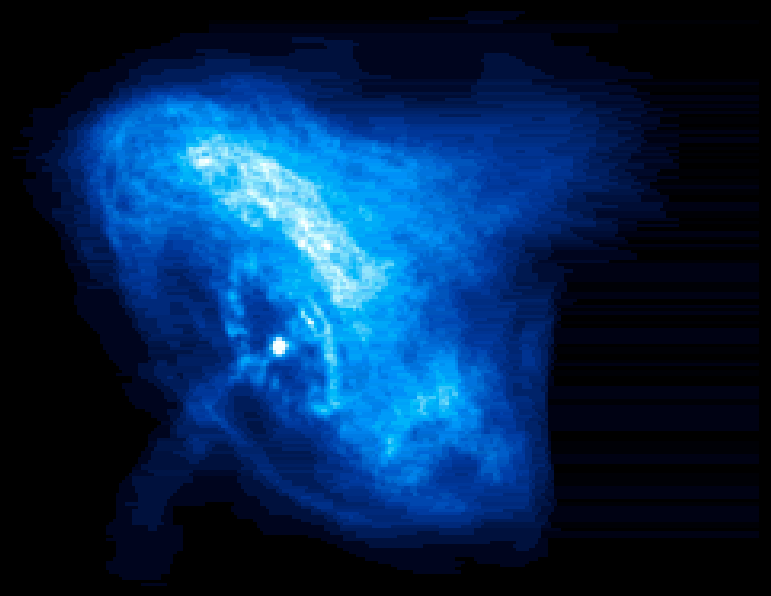
Then: THE END… SNR merges with surrounding medium

Why so complicated then??

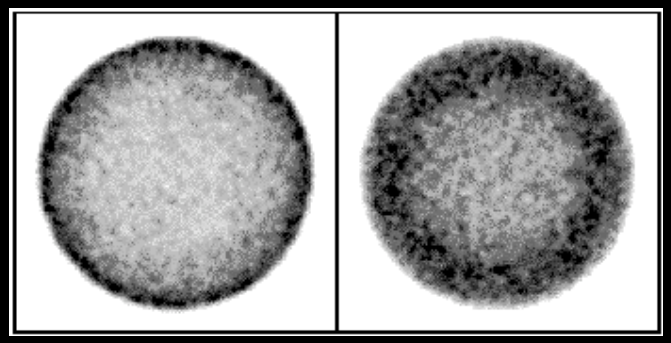
- Different explosion energy, age, …
- Different angle of visions
- Amount of material along line of sight is not uniform
- ISM is not homogenous
- Different progenitor histories
- …..

First the simplest:

- Different angle of view:



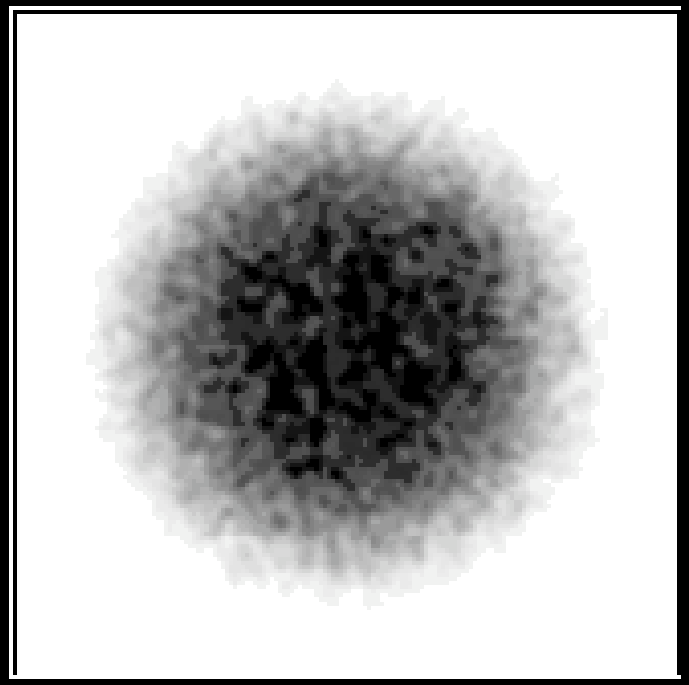
  - Then we may see the SNR "through" a lot more of absorption.



ISM not homogenous

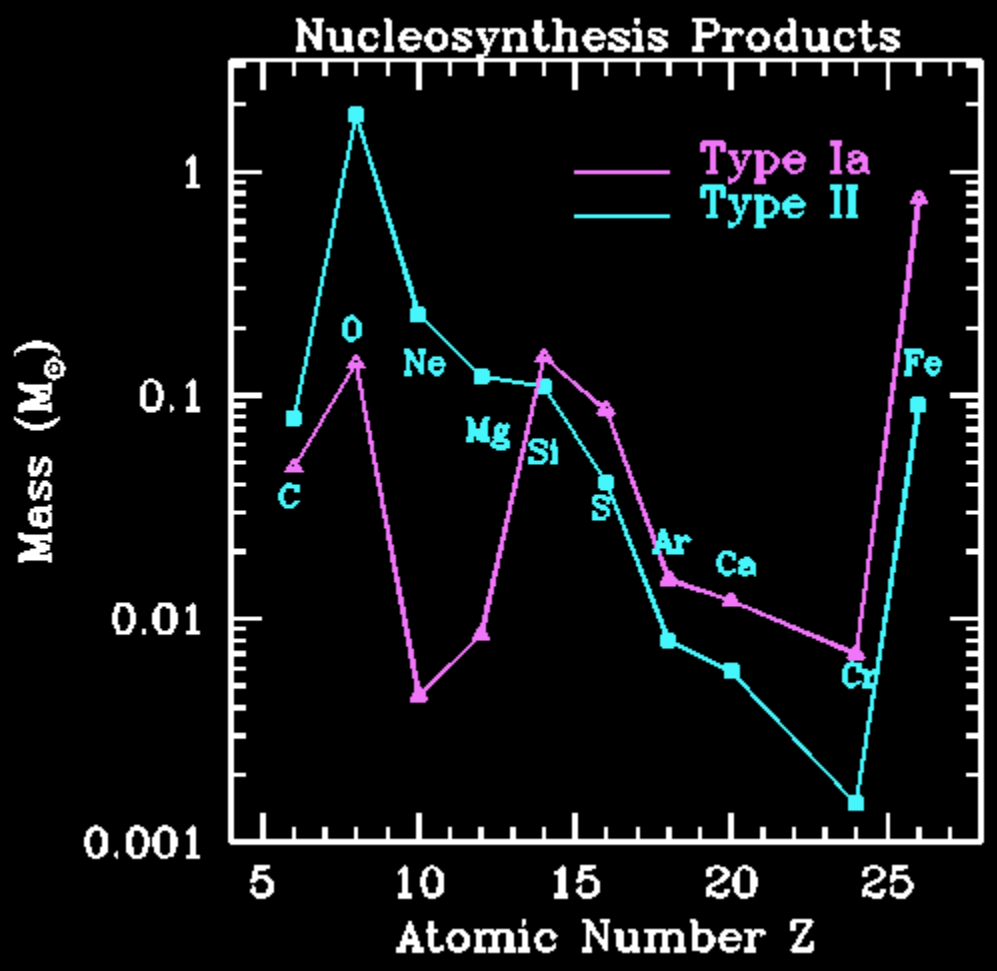
Several models to explain differences with Sedov-Taylor "shell-like" predictions.

"Several" clouds evaporating "slowly" behind shock wave
(White & Long, 1991)



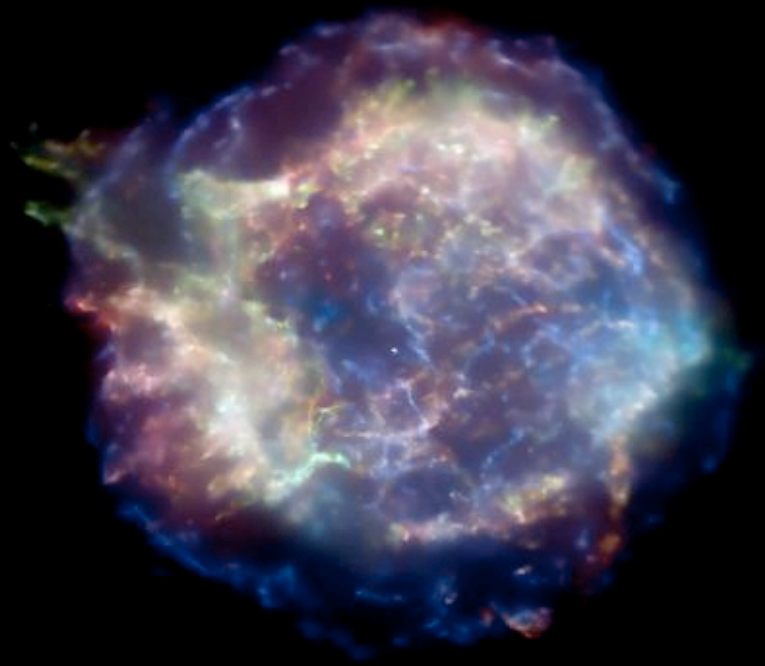
Several problems with this type of models.

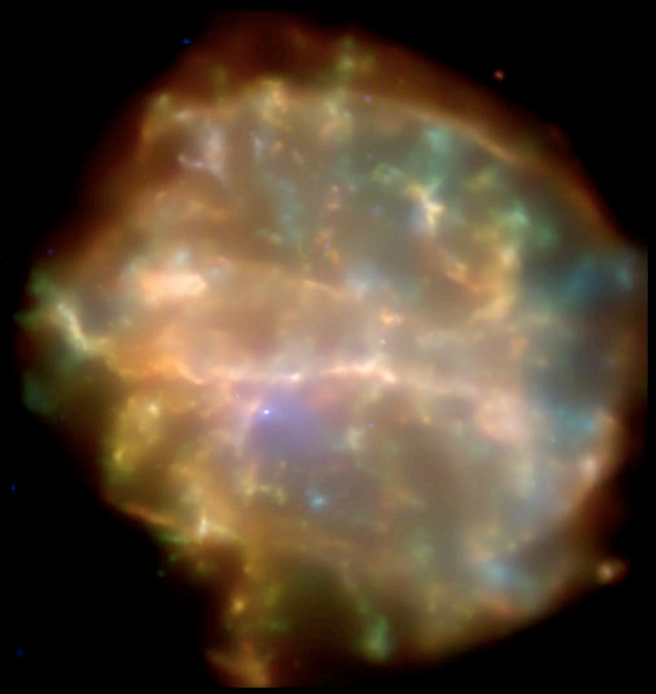
Different progenitors

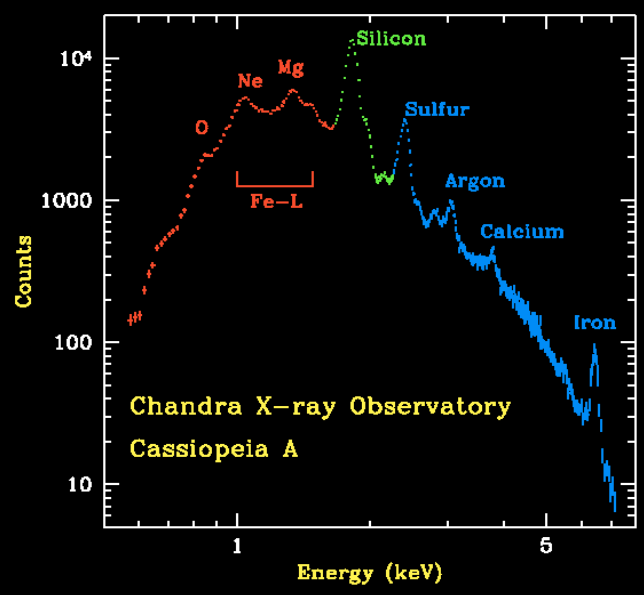


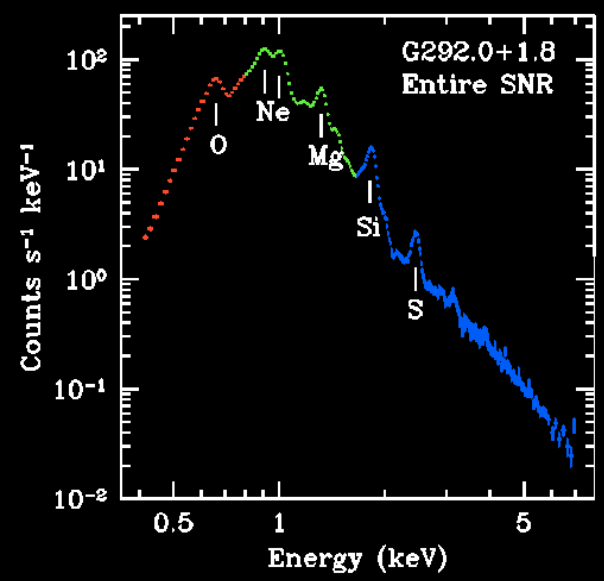
Type Ia: thermo-nuclear destruction of an accreting white dwarf. Low O/Fe ratio.

Type II: Core collapse of massive star. High O/Fe ratio.









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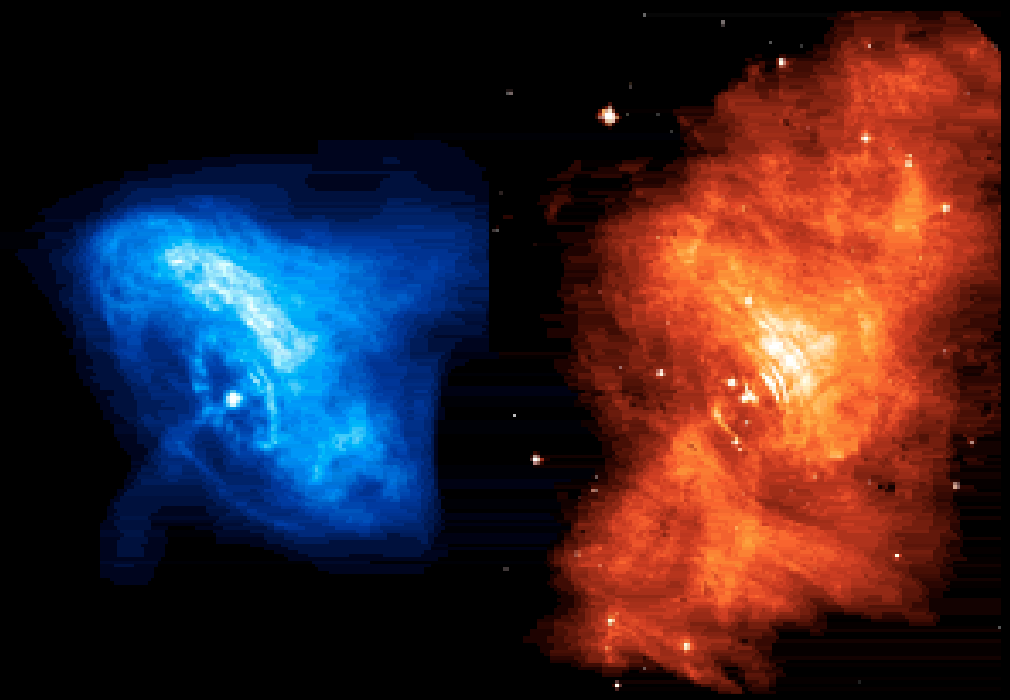
Pulsar Wind Nebulae (in SNRs)

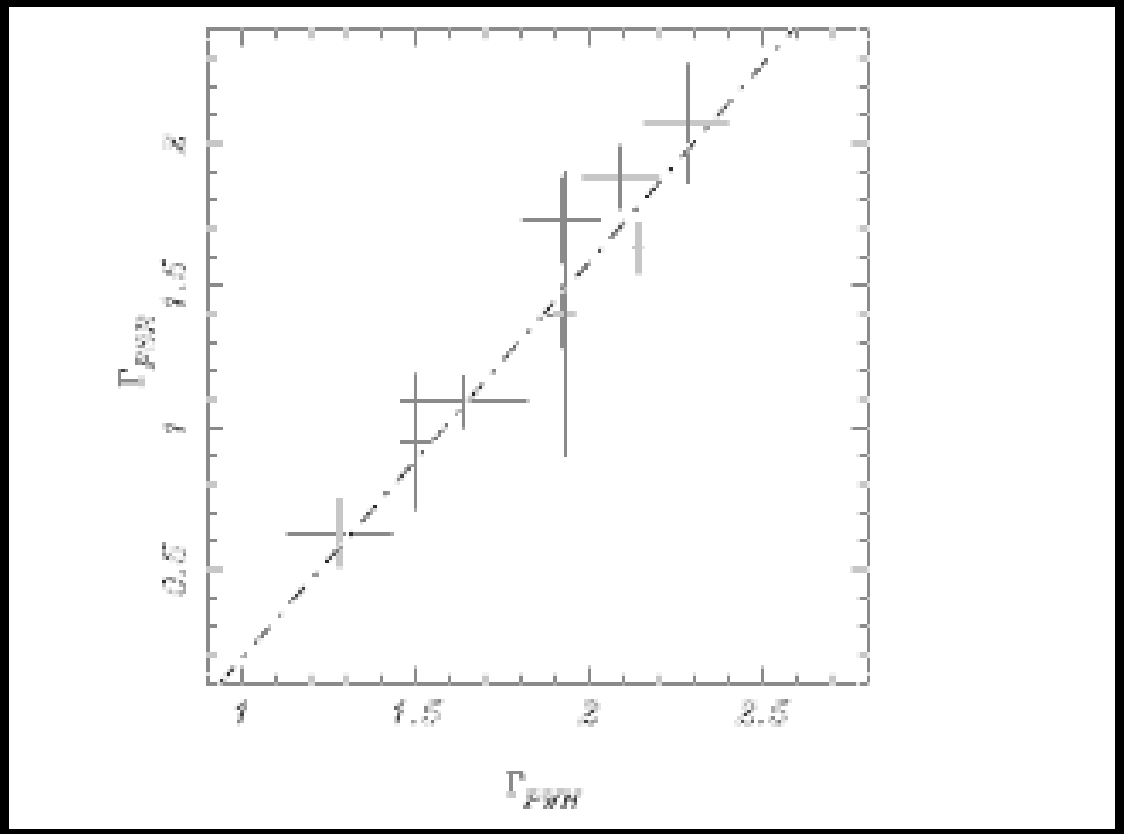
- Recent developments (using Chandra) of PWNe studies (particle acceleration, magnetic fields, jets, winds, …)



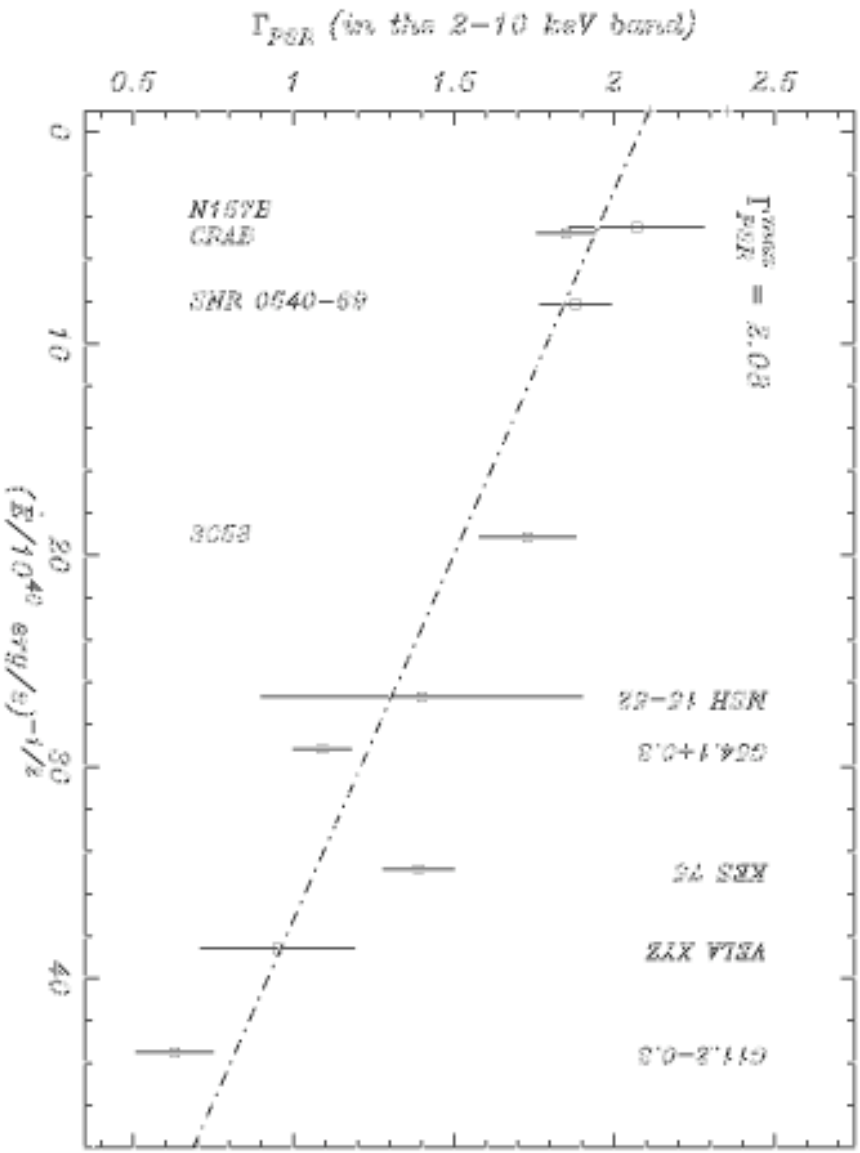
Pulsar Wind Nebulae

Studies of PWN can yield information on magnetic fields, ….

With the new data increase from Chandra (and the spatial resolution), it is now possible to start doing statistical analysis.



Gotthelf 2003


Γ_{PSR} (in the 2–10 keV band)
0.5
1
1.5
2
2.5
0
10
20
30
40
$(\dot{E}/10^{46}$ erg/s$)^{-1/2}$
N157B
CRAB
SNR 0540–69
3C58
MSH 15–52
G24.7+0.3
KES 75
VELA XYZ
G11.2–0.3
$\Gamma_{PSR} = 2.03$

What was not mentioned here:

- Non-equilibrium ionization effects
- Non-thermal emission at the shock wave (SN 1006)
- Accuracy of the spectral diagnostics
- Association of PSR/SNR
- …

For more information on SNRs:

Books and proceedings:

- "Supernovae and Stellar Wind in the ISM" T. Lozinskaya
- " Supernovae and supernova remnants" K. Weiler
- "Neutrons stars in supernova remnants" (proc)-- Slane and Gaenlser (Eds.)
- "Exploring the X-ray Universe" Charles & Seward

Articles:

- Trimble -- Rev. Mod. Phys.1982 Vol 54, No 4

- McKee -- ApJ 1974188 355
- Chevalier -- ApJ 1974 188 501
- Hamilton, Sarazin & Chevalier 1983 ApJ Supp, 51 115

Conclusions

SNRs (and PWNe) are a complicated but important field of study.

Thanks to Chandra (its spatial resolution and its ability to allow for spatially resolved spectroscopy) and XMM-Newton (its large effective area and its ability to collect many more photons.)

===>large rethinking of the field is happening now

Any questions?