Supernovae Remnants with Astrosat

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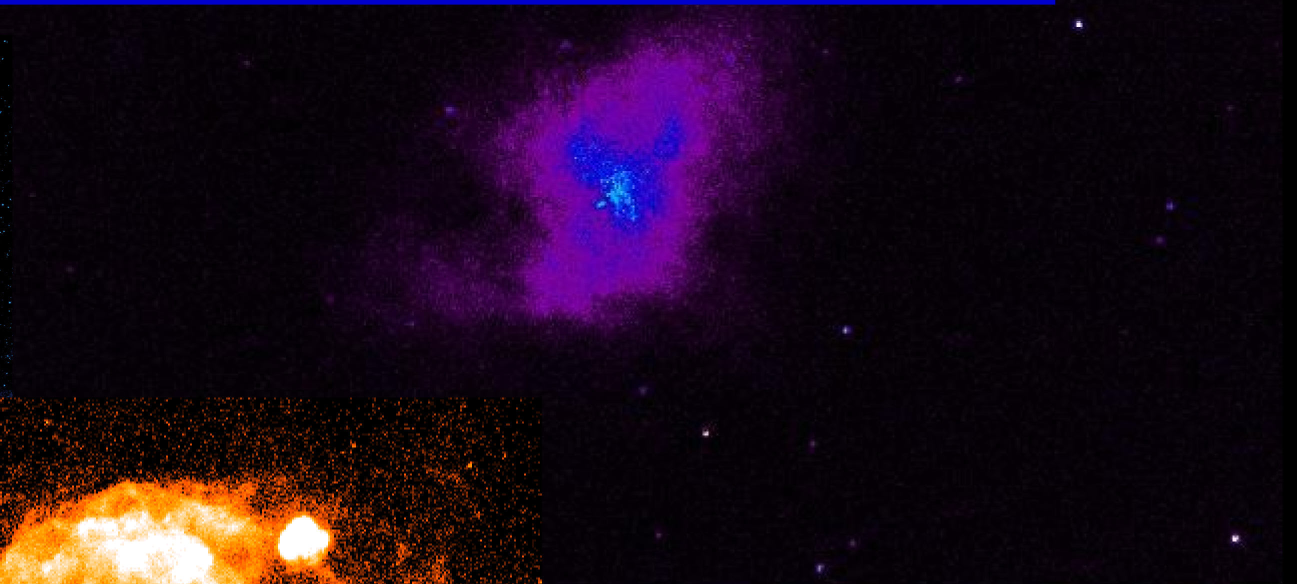
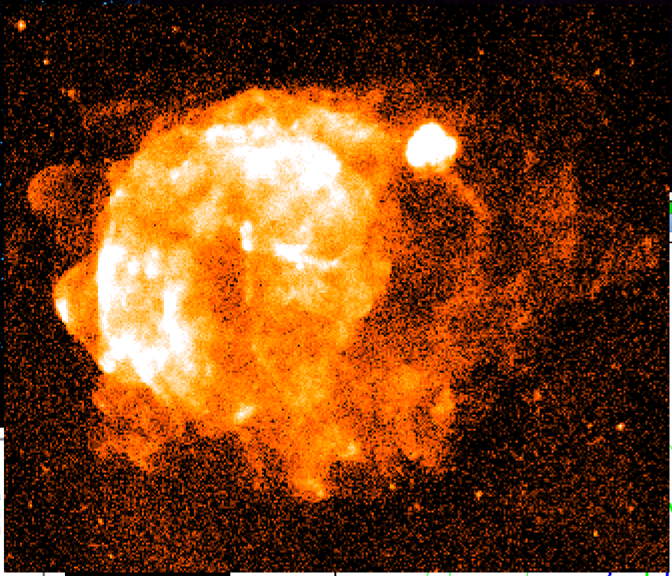
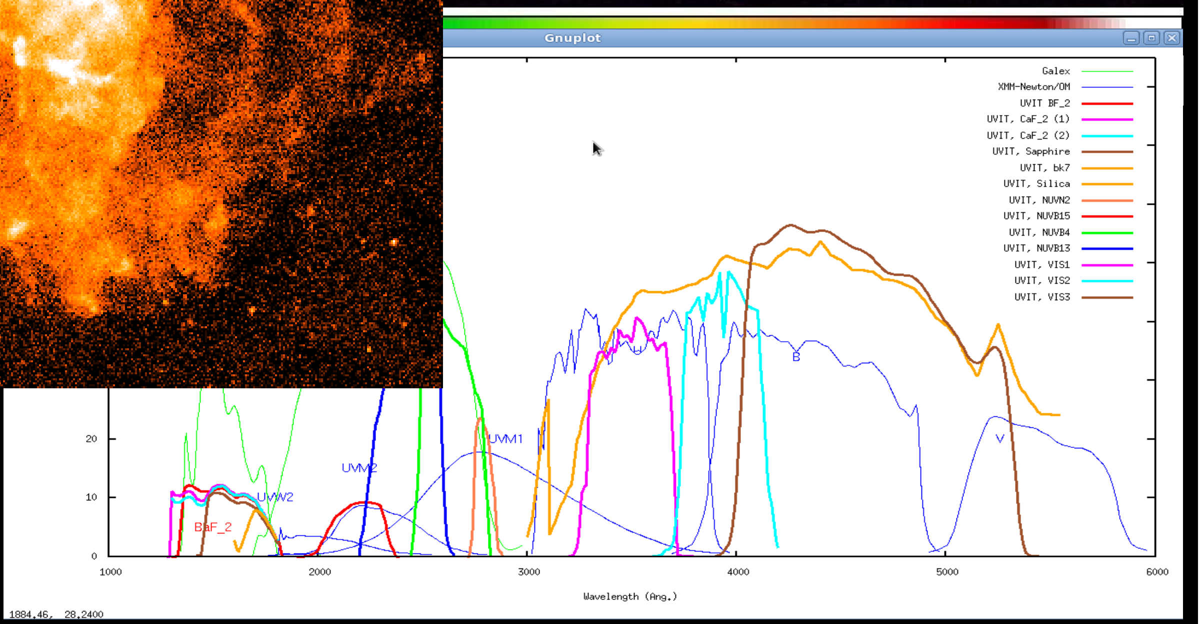
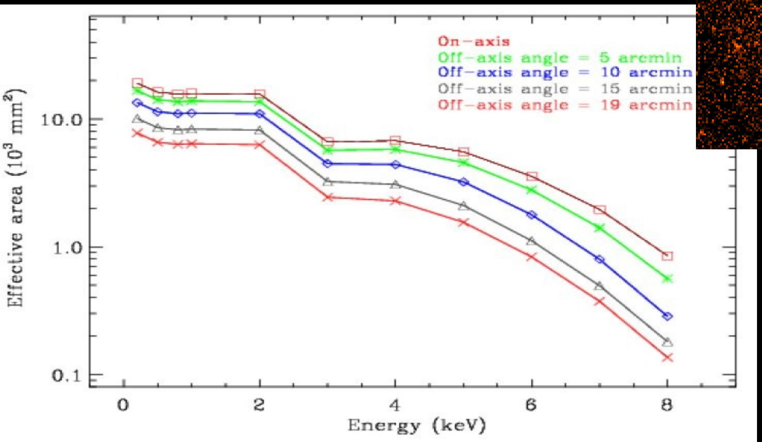








Why study SNRs? Because they are there!

(SNRs) play a vital role in many area of astrophysics.

- Enrich the ISM with newly nucleaosynthesised material from SNe.
- Responsible for the dynamics and kinematics of gas in the ISM, leading to star formation, formation of super bubbles, galactic outflows..
- May be sites for Galactic, ultra-high energy cosmic rays ($E \simeq 10^{14}$ eV), via diffusive shock acceleration in the forward shock.
- Constrain models of late time shock - ISM interaction,
- Provides an insight in to the evolutionary state of the pre-SN progenitor and its CSM.
- Deep (up to Msec) Chandra x-ray imaging of several SNRs highlighted several complex phenomena, both resolving and raising questions about the nature (clumpy, gaseous, or dusty) and the physical properties of the ISM.
- For SNRs that are both optical and X-ray bright, it is important to complement the high temperature (10^{6-7}K) phenomena with UV imaging, sampling regions of 10^{4-5} **K** gas both in filaments and other interacting medium.

A blast wave that lights up the past

- Core rebound initiates shock wave through progenitor envelope.
- Blast wave propagates out, sweeps up CSM / ISM material in front it.
- Free Expansion phase (10^2 to 10^3 yr):
  Supersonic, adiabatic expansion/cooling, $r_{shock} \propto t^{-3}$
- Reverse shock forms at $M_{CSM} \simeq M_{ejecta.;}$
  moves inwards,
  expansion slows,
  reheating
- Sedov-Taylor expansion (10^4 yr):
  Adiabatic cooling dominates.
- Snow plow phase: 10^6-10^9 yr
  Radiative cooling dominates.
- Mixing of ISM and ejecta

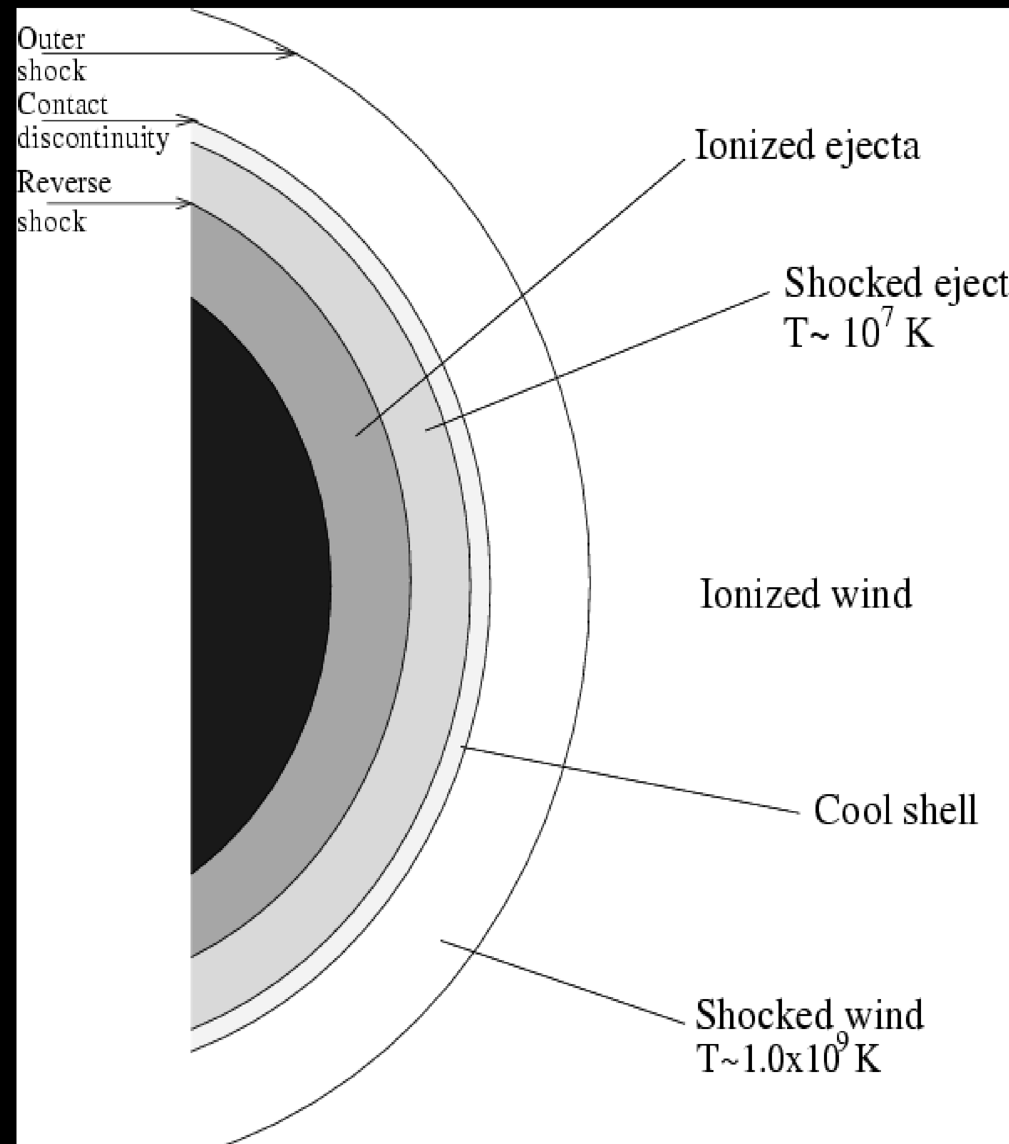


Image credit: Nymark, Fransson & Kozma, 2006, A &A

Revisiting well studied SNRs with Astrosat

Age range: 18000± 9000 yr (Vela) ;
5000-8000 yr (Cygnus loop) ;
1000 yr (Crab).

- Temporal evolution of SNRs from different classes of SNe, in a varying range of environments.

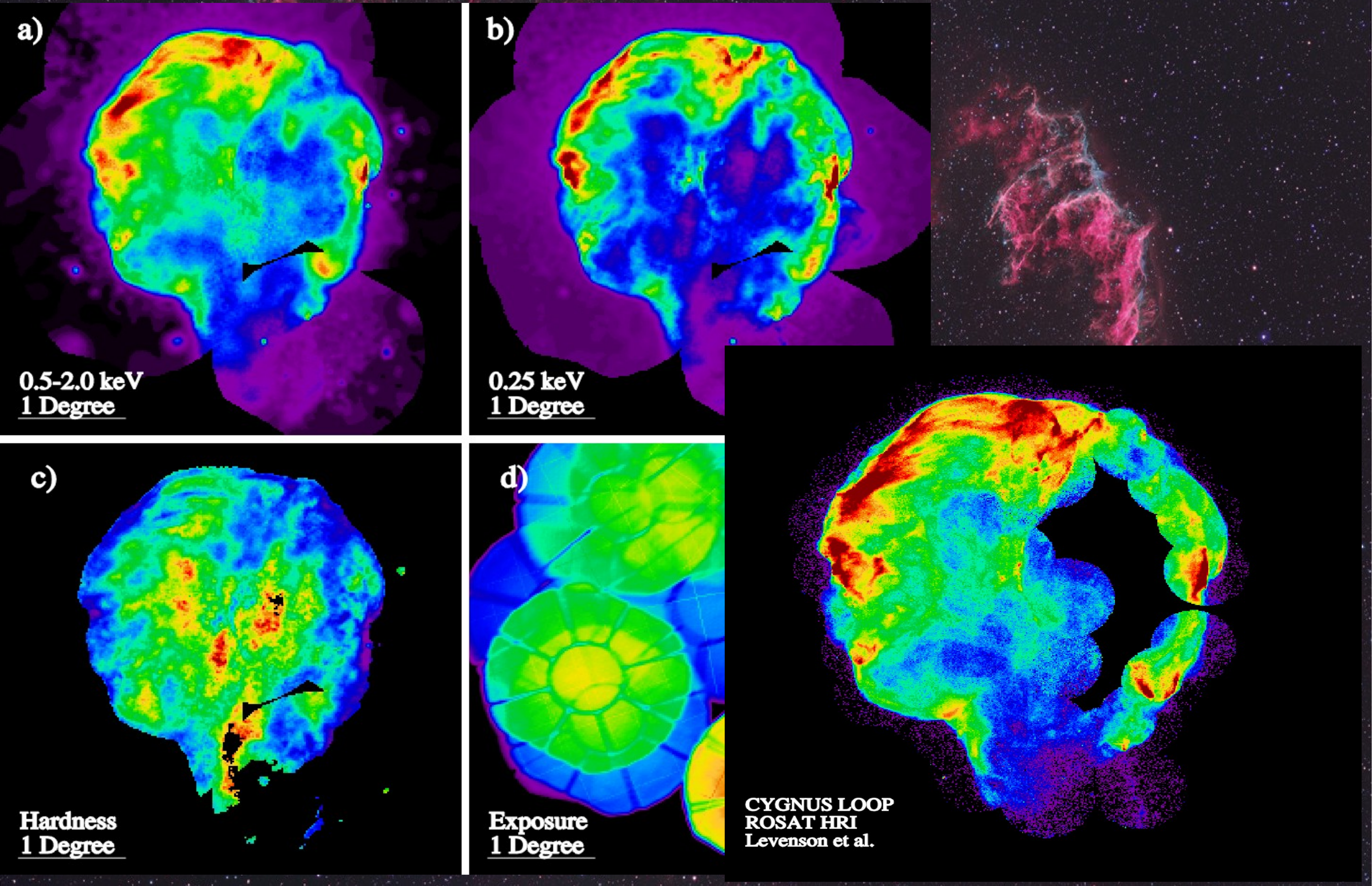
- Narrow band FUV + NUV imaging of hot (10^{4-5} K) and intermediate (5000- 8000 K) regions via emission lines of C IV (1550 Ang.), He II (1640 Ang.), and Mg II lines (2800 A),

- All are X-ray and optical bright. Filamentary structure seen in the optical, although Crab has centre filled geometry (PWN driven).

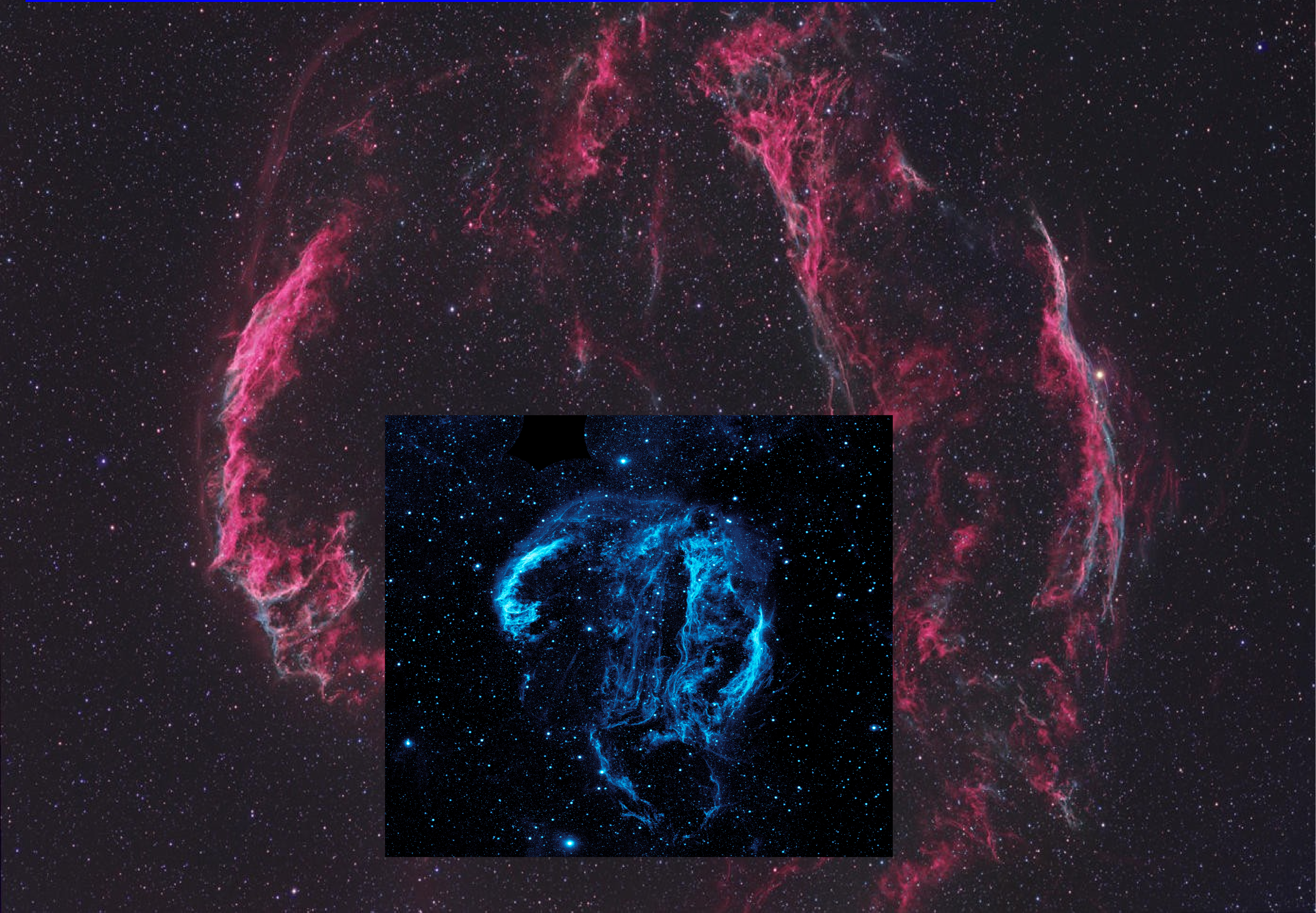
- Bridging the gap between x-ray bright (10^{6-7} K) and cool, optical regions.

- Nebular X-ray emission mainly soft, thermal. May be resolved in to multi temperature components.
- Multiple SNRs in Vela, and Cygnus(?)

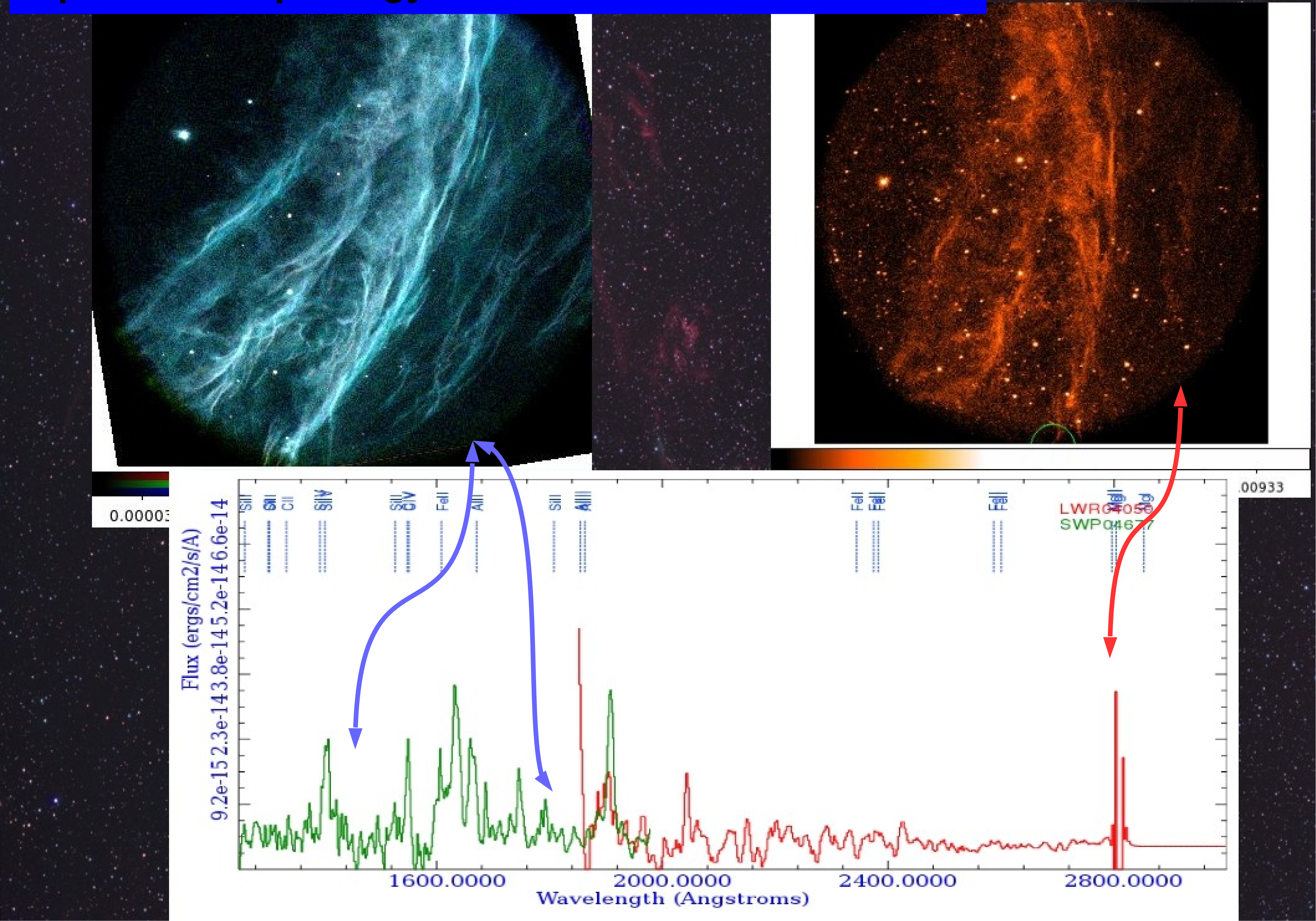
Cygnus loop – ROSAT PSPC + HRI



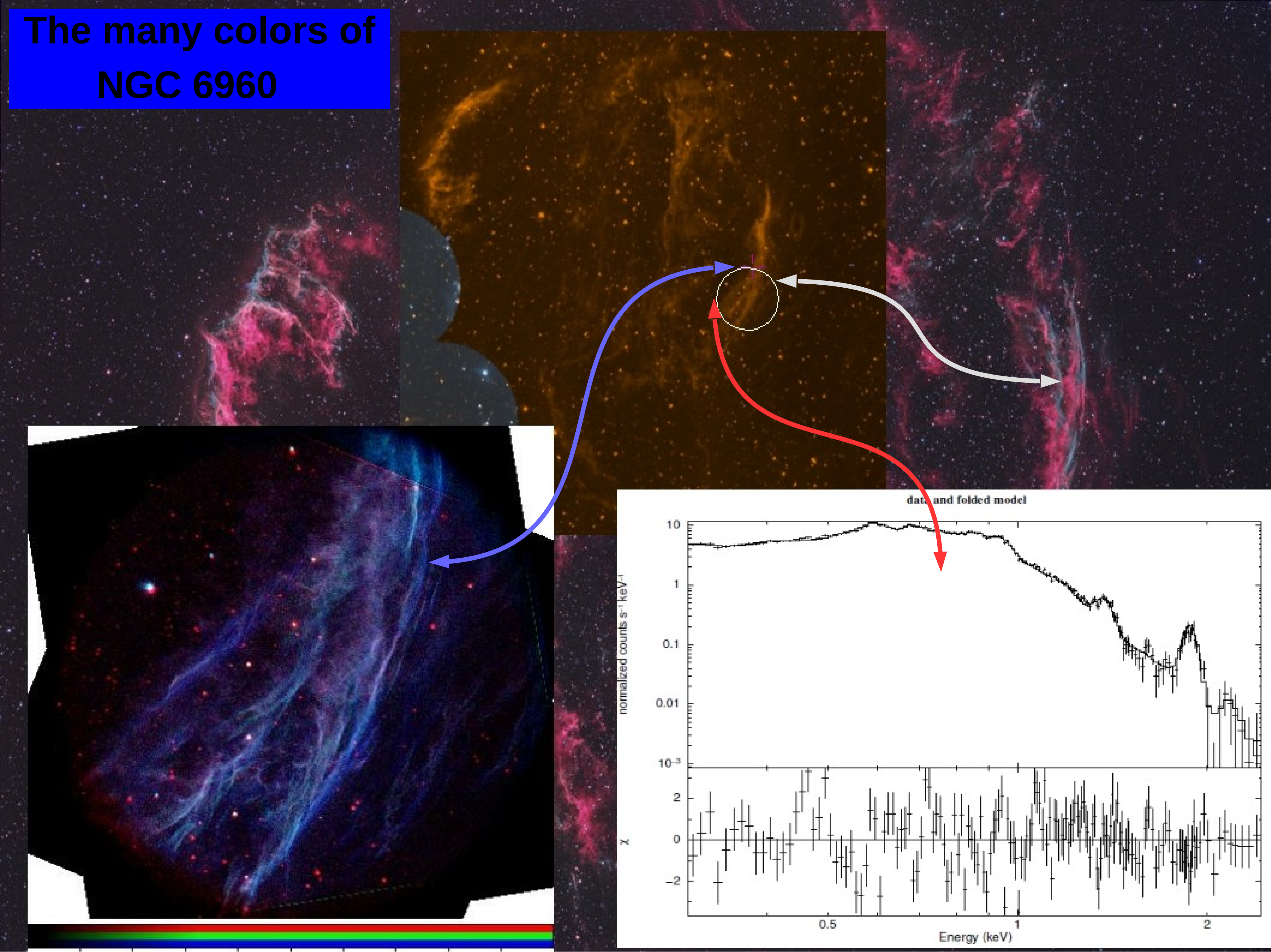
The Cygnus loop in H-a, RGB, and Galex UV



Spectral morphology of NGC 6960 – IUE & UVIT



The many colors of NGC 6960

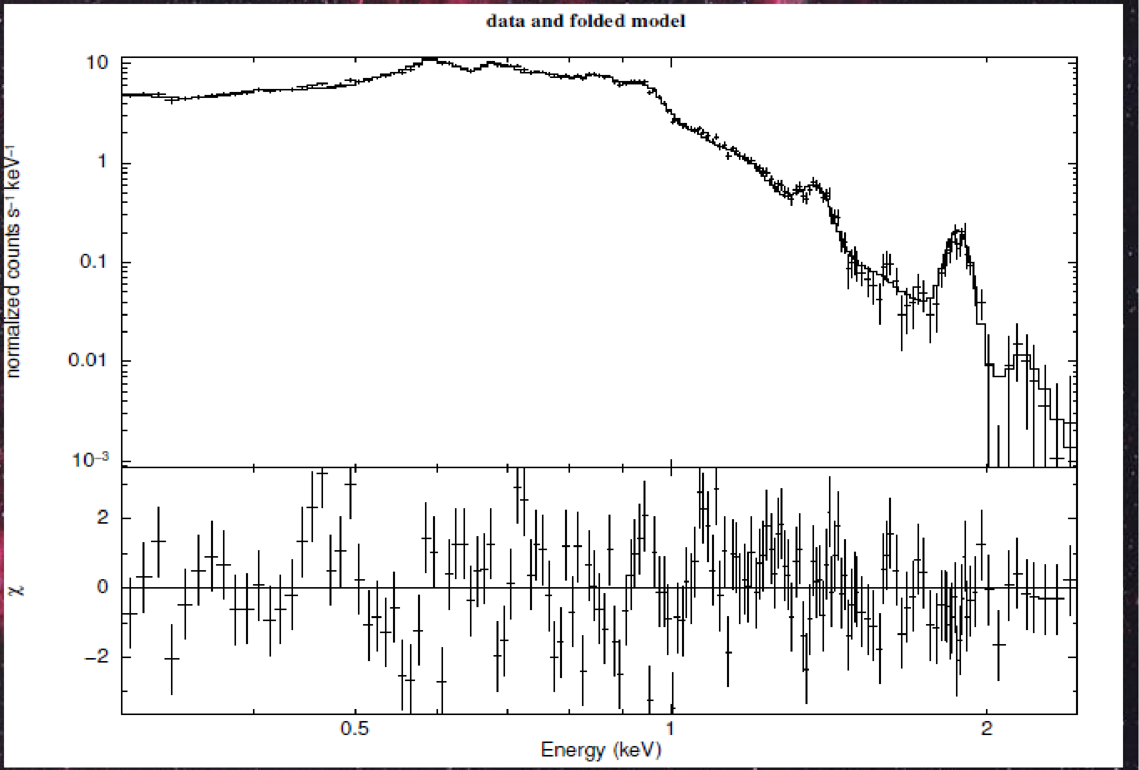


NGC 6960 in Soft X-ray (SXT band)

Two thermal component X-ray plasma model with variable abundances, with T_1= 0.194 ± 0.002 keV and T_2=0.75 ± 0.01 keV.

Mg dominates in the low temp component,

High temp should be dominated by C and He.

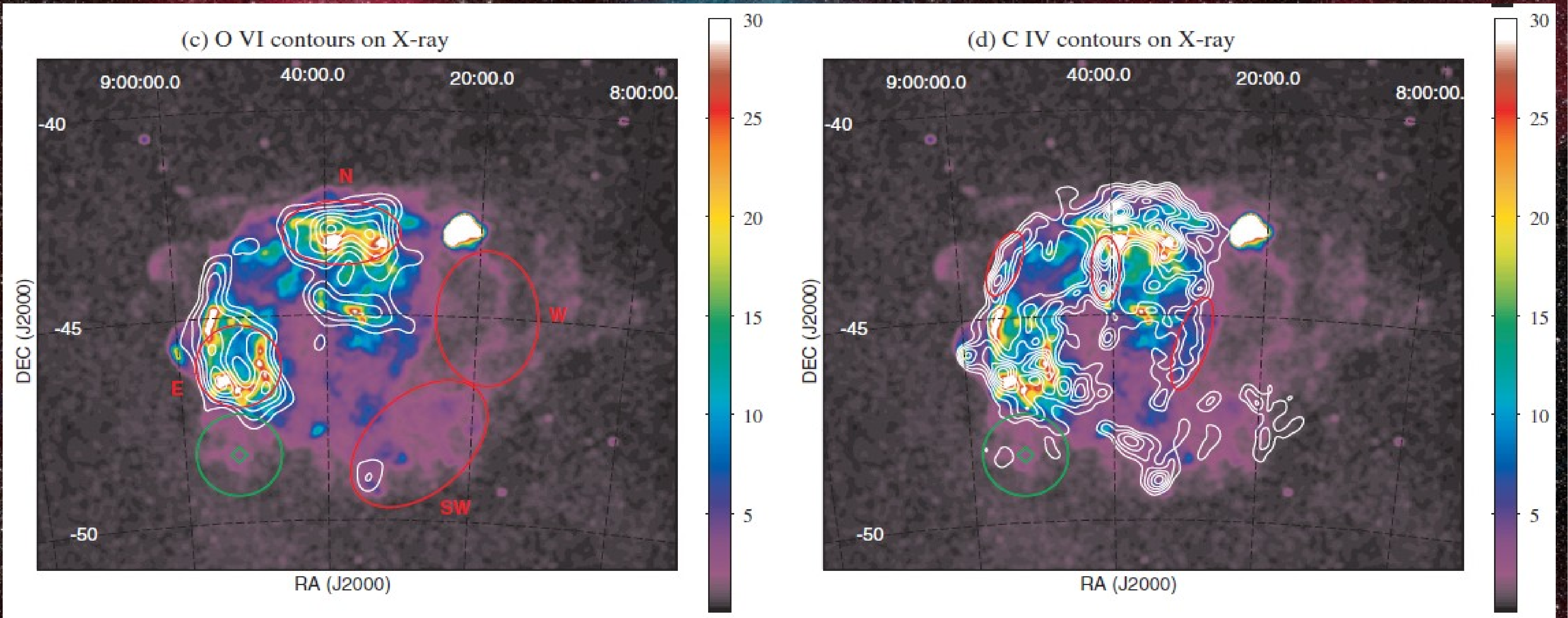


UVIT Image credits: Sutaria, Rahna, Ray, Singh, Ray, Murthy, Rao and Tandon.

Spectrum credit: K. P. Singh, Sutaria et al.

Vela: The residue of a very active galactic star forming region

SPEAR/FIMS data, Il-Joong Kim et al, 2012, ApJ.



FUV Line Luminosities and Comparisons with the Cygnus Loop

Species	N	E	SW	W	Whole	Cygnus Loop
C III λ977	2.07 ± 0.10	1.41 ± 0.10	2.19 ± 0.16	0.69 ± 0.08	21.84 ± 0.49	8.82[b]
N III λ991	0.23 ± 0.04	0.27 ± 0.05	0.42 ± 0.10	0.23 ± 0.06	3.01 ± 0.33	...
O VI λλ1032, 1038	2.12 ± 0.09	1.79 ± 0.10	0.42 ± 0.12	0.20 ± 0.07	14.81 ± 0.45	15.0[b]
Si IV λλ1394, 1403	0.16 ± 0.02	0.07 ± 0.02	...	...	...	0.66 ± 0.06[b]
O IV] λ1404	0.57 ± 0.03	0.41 ± 0.03	0.44 ± 0.05	0.28 ± 0.03	6.13 ± 0.17	
N IV] λ1486	0.11 ± 0.01	0.09 ± 0.01	0.06 ± 0.02	...	1.47 ± 0.07	...
C IV λλ1548, 1551	1.88 ± 0.02	1.38 ± 0.02	1.56 ± 0.03	0.76 ± 0.02	20.28 ± 0.12	4.47 ± 0.14[b]
He II λ1640.5	0.28 ± 0.01	0.14 ± 0.02	0.23 ± 0.03	0.07 ± 0.02	2.75 ± 0.10	0.68 ± 0.06[b]
O III] λλ1661, 1666	0.39 ± 0.02	0.20 ± 0.02	0.33 ± 0.03	0.10 ± 0.02	3.56 ± 0.12	0.65 ± 0.08[b]
X-ray	...	...	...	...	3.0[a]	3.59[b]

Vela: The residue of a very active galactic star forming region

Image credit: Marc Lorenzi

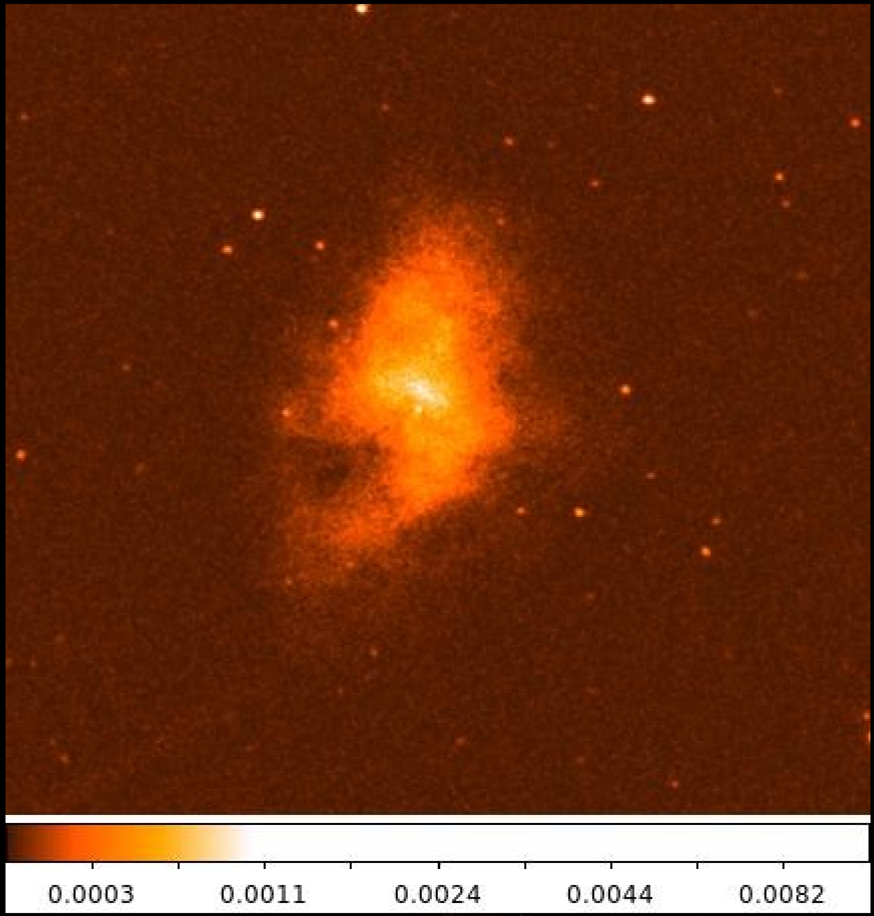
Crab

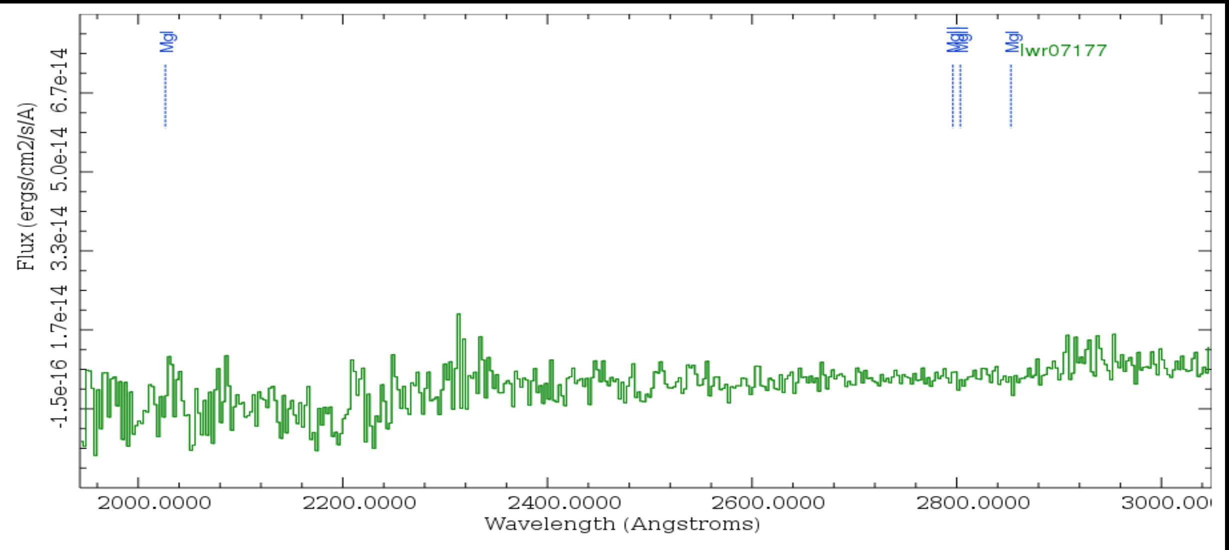
UVIT NUV-B13 (~2480 A) image ▶
of Crab Nebula.

Some faint emission is seen along the external filmanetary structure.

The PWN is clearly visible.

Emission is most likely continuum dominated.





Core collapse Supernovae from Radio to X-ray --

Reconstructing the progenitor from multi waveband properties

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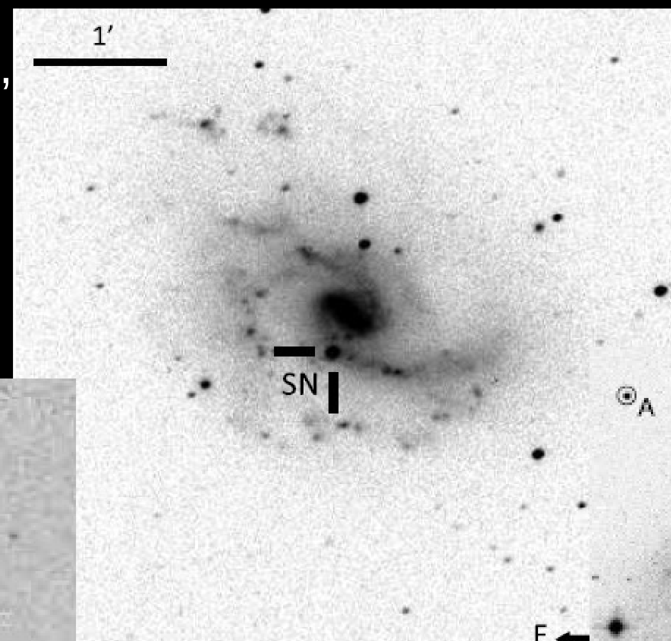
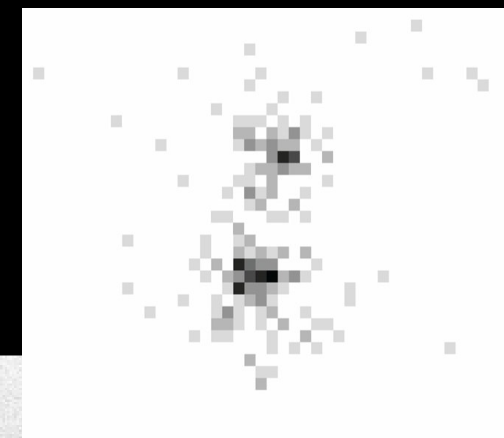
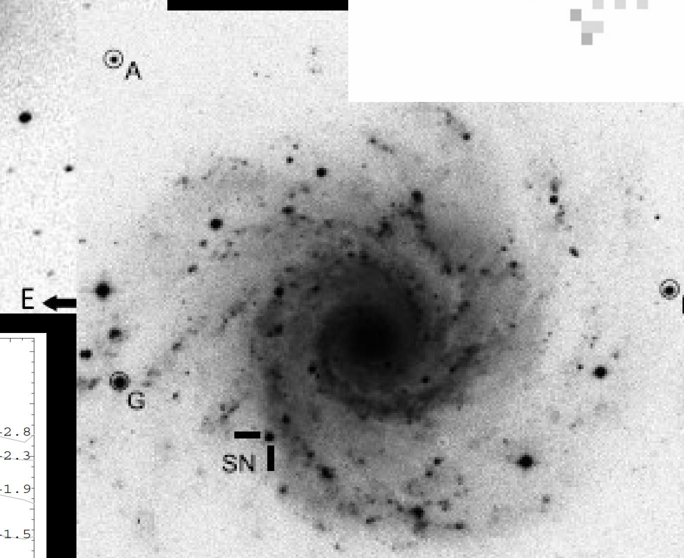
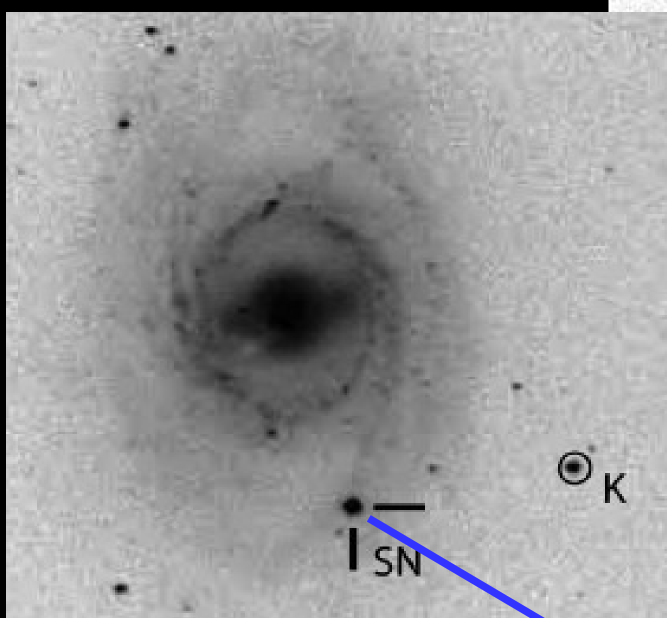
SN2013ab in NGC 5669 (V), (104 cm ARIES/ST). ▶



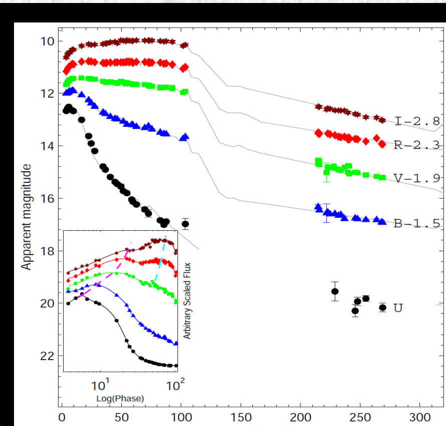


SN2011ja (Chandra ACIS-I) ▲

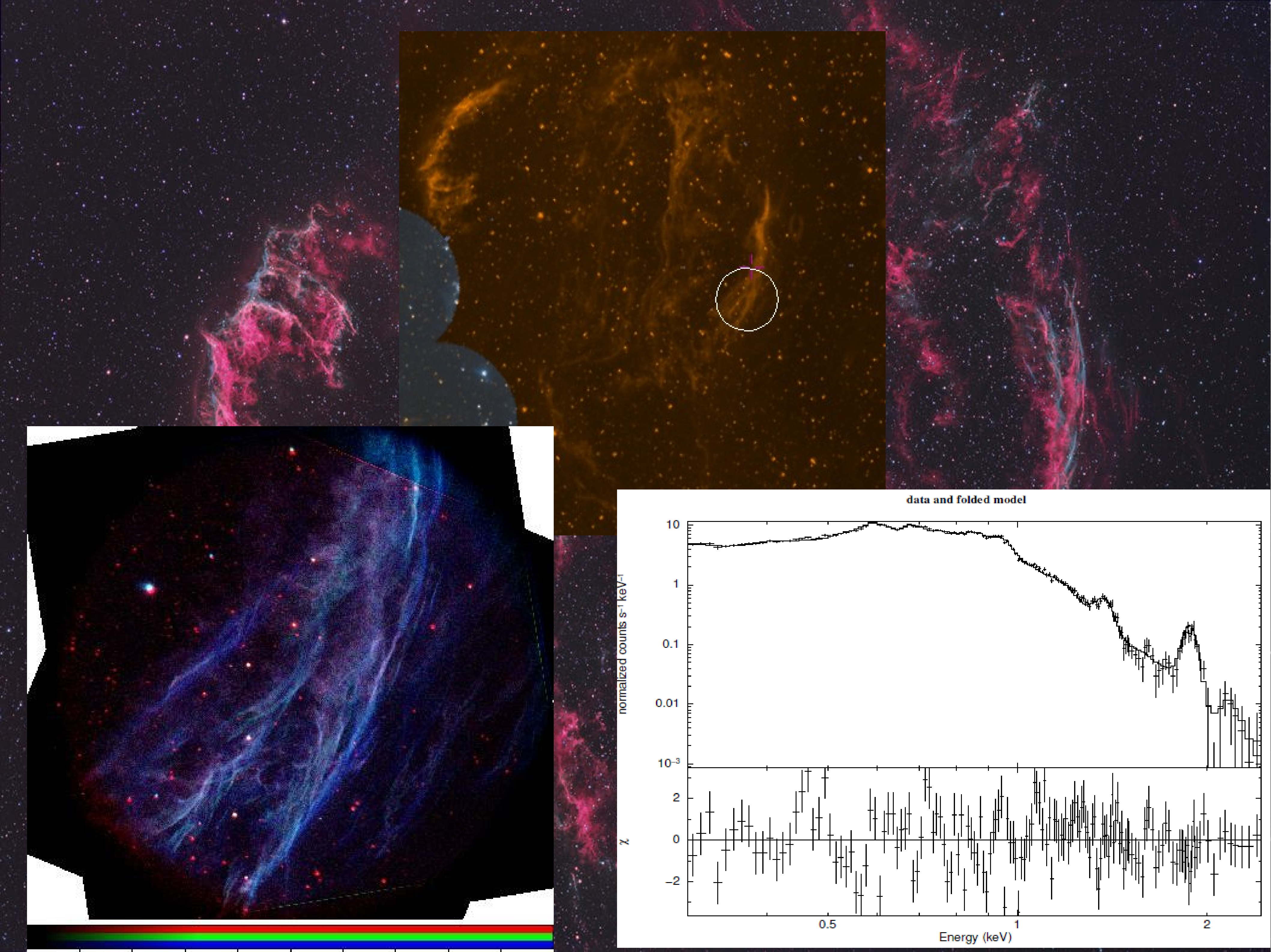


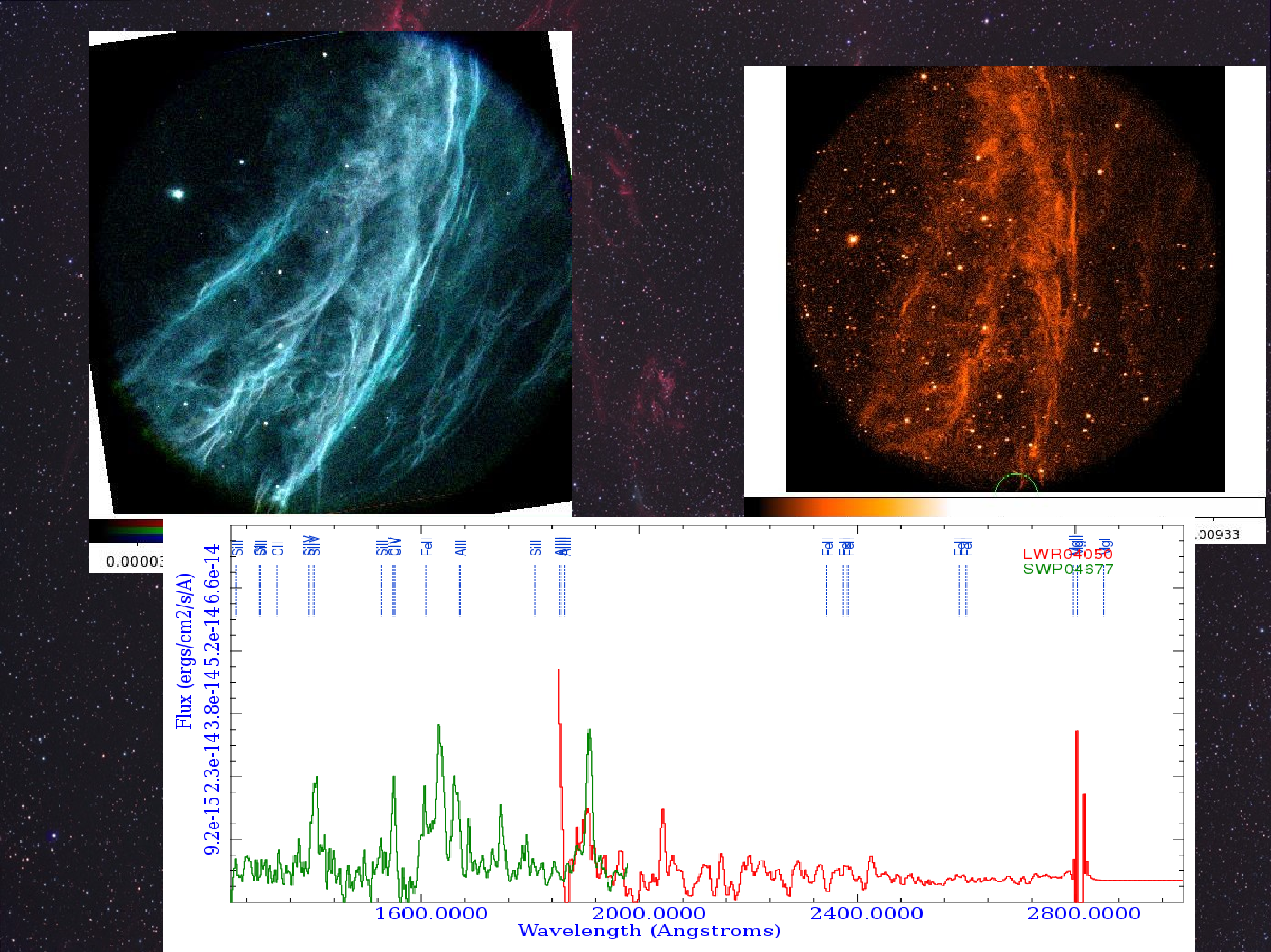


▲ SN2012aw in NGC 3551 (V), (104 cm ARIES/ST).



SN2013ej in NGC0628 (BR band; Composite). (104cm ARIES/ST).


data and folded model
normalized counts s⁻¹ keV⁻¹
χ
Energy (keV)


0.00003
.00933
SiII
SiII
CII
SiIV
SiII
CIV
FeII
AlII
SiII
AlIII
FeII
FeII
FeII
MgII
MgI
LWR04050
SWP04677
Flux (ergs/cm2/s/A)
9.2e-15
2.3e-14
3.8e-14
5.2e-14
6.6e-14
1600.0000
2000.0000
2400.0000
2800.0000
Wavelength (Angstroms)