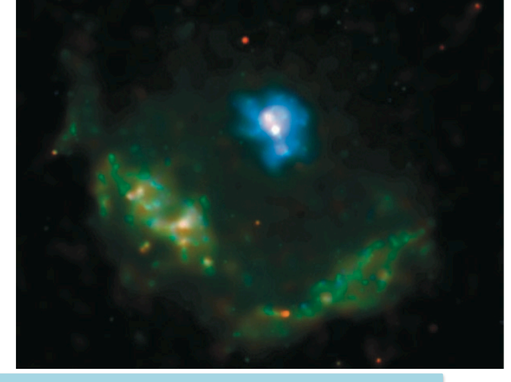
XMM-Newton and NuSTAR Observations of the SNR Kes 75 and its PWN

Samar Safi-Harb (U. of Manitoba), Eric V. Gotthelf (Columbia U.)
Joseph D. Gelfand and Samayra M. Straal (NYU, Abu Dhabi)



The Kes75/PSR J1846-0258 System

- The SNR Kes 75 is one of the youngest known SNRs in our Galaxy, powered by PSR J1846-0258.
- PSR J1846-0258 is a young, highly energetic, high-magnetic field (B), 325 ms X-ray pulsar (*Gotthelf+2000*):
  - Edot = 8.3E36 erg/s
  - P/2Pdot ~ 723 yr
  - B ~ 5E13 G
- The high B is likely responsible for the flare and burst activity seen in 2006, revealing the PSR's possible transition between a rotation-powered and a magnetar state (*Gavriil+2008; Kumar & Safi-Harb 2008*).
- We present overlapping *XMM-Newton* and *NuSTAR* observations, acquired 2017.08.17-20, to address the nature of its broadband emission and the SN explosion properties.

The New X-ray Observations

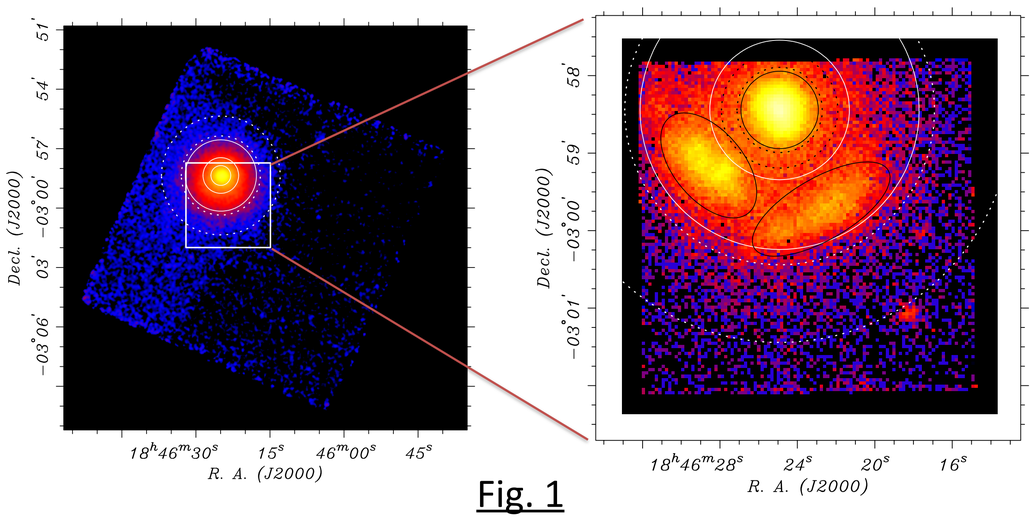
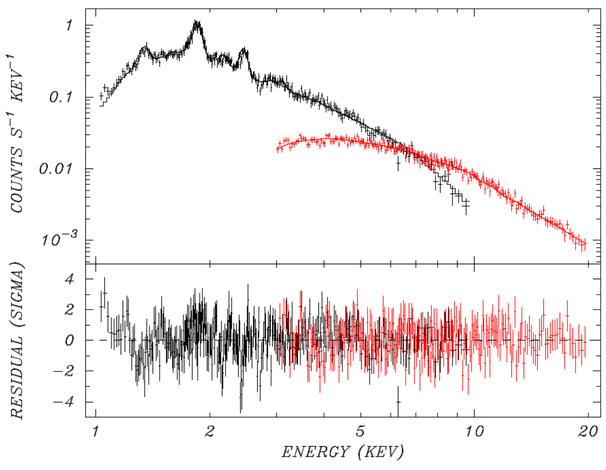


Fig. 1

NuSTAR, 100 ks *XMM-Newton*, 51.4 ks

We also use archival *Chandra* data for joint spatially-ressolved spectroscopy.

The SNR: Global and Spatially Resolved Broadband Spectroscopy



Discovery of hard non-thermal X-rays

NEI (variable abundances)**+power-law** model; using the TBabs absorption model with the *wilm* Solar abundances (Wilms+2000) and the *vern* photoionization cross-section. The thermal model parameter values are notably different from those reported in earlier *Chandra* studies (e.g. *Temim+12*). This is attributed (partly) to the updated ISM model used here, and the difference in the extraction regions (Fig. 1).

	Southeast	Southwest	Sector[a]
Region R.A. (J2000)	18:46:22.764	18:46:28.574	18:46:24.893
Region Decl. (J2000)	−02:59:43.33	−02:59:09.53	−02:58:28.31
Ellipse radii, P.A.	1′.0 × 0′.4, 300°	0′.8 × 0′.45, 40°	
Annulus radii			0′.9 × 1′.8
$N_{\rm H}$ (10^{22} cm^{-2})	$4.11^{+0.11}_{-0.10}$	$4.27^{+0.23}_{-0.31}$	$4.14^{+0.11}_{-0.09}$
kT (keV)	$1.01^{+0.17}_{-0.10}$	$1.18^{+0.24}_{-0.20}$	$0.87^{+0.05}_{-0.06}$
τ (10^{10} s cm^{-3})	8.5	4.2	$10.0^{+2.2}_{-1.6}$
Mg	$0.89^{+0.09}_{-0.11}$	$0.76^{+0.20}_{-0.16}$	0.81 ± 0.08
Si	$1.26^{+0.15}_{-0.13}$	$1.21^{+0.46}_{-0.28}$	1.27 ± 0.09
S	$0.98^{+0.17}_{-0.14}$	$1.0^{+0.53}_{-0.27}$	1.15 ± 0.11
Photon Index Γ	$1.73^{+0.33}_{-0.63}$	$2.02^{+0.37}_{-0.92}$	$2.02^{+0.04}_{-0.05}$
Flux (10^{-11})[b]	4.7	2.9	8.8
$\chi^2_\nu(DoF)$	1.459 (452)	1.369 (363)	1.369 (896)

See Figure 1 for the SNR clump regions. Quoted uncertainties for 90% C.L. for the parameter of interest.
[a]Joint fit to *XMM-Newton* EPIC pn, *Chandra* and *NuSTAR* spectra, with independent normalizations.
[b]Unabsorbed *XMM-Newton* EPIC pn flux measured in the 0.5−10 keV band in units of erg s^{-1} cm^{-2}. The first two columns correspond to the clumps fits using the *XMM-Newton* and *Chandra* dataset.

We acknowledge the support of NSERC and NASA grant 80NSSC17K0636

The PSR: Broadband Spectroscopy and Evolution

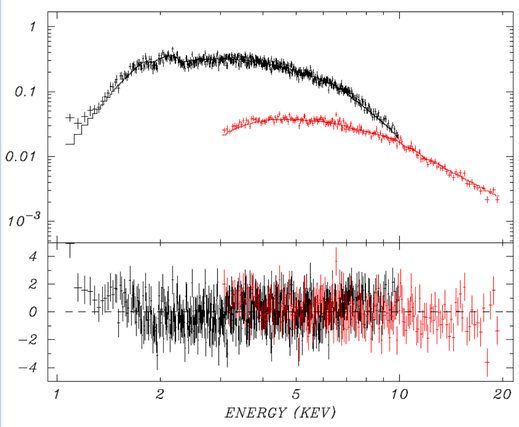
Reference	$N_{\rm H}$ (10^{22} cm^{-2})	Γ	Flux[a] [$\times 10^{-12}$]
	Chandra 2000 data set		
Helfand et al. 2003	3.96 (fixed)	1.39 ± 0.04	9.5
Ng et al. 2008	4.0 (fixed)	1.1 ± 0.01	6.1 ± 0.03
Gavriil et al. 2008	...	$1.17(-0.12, 0.15)$	...
Kumar et al. 2008	3.96 (fixed)	$1.32(-0.09, 0.08)$	4.3 ± 0.2
	Chandra 2006 data set		
Ng et al. 2008	4.0 (fixed)	1.86 ± 0.02	37 ± 01.0
Gavriil et al. 2008	...	$1.89(-0.06, 0.04)$	...
Kumar et al. 2008	$4.15(-0.12, 0.09)$	$1.97(-0.07, 0.05)$	$27(-2, +1)$
	Chandra 2016 dataset		
This Work	3.96 (fixed)	1.10 ± 0.07	2.6 ± 0.1
	XMM-Newton & *NuSTAR* 2017 data sets		
This Work	3.96 (fixed)	1.29 ± 0.08	3.28 ± 0.35

Column density is derived using the built-in `XSPEC wabs` interstellar absorption model in all cases for comparison purpose. Quoted uncertainties for 90% C.L. for one interesting parameter.
[a]Unabsorbed 2−10 keV flux, in erg cm^{-2} s^{-1}.

The PWN: Broadband Spectroscopy

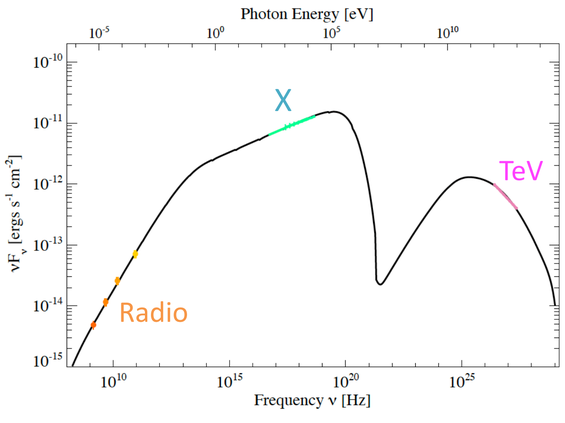
Parameter	*XMM-Newton*	*NuSTAR*	*XMM-Newton* + *NuSTAR*
$N_{\rm H}$ (10^{22} cm^{-2})	5.39 ± 0.18	5.0 ± 1.5	5.86 ± 0.14
Photon Index Γ	1.72 ± 0.05	1.91 ± 0.06	1.86 ± 0.03
Flux $F[\times 10^{-11}]^a$	1.29 ± 0.01	1.84 ± 0.02	1.24 ± 0.01 1.80 ± 0.02
Luminosity $L_{\rm x}^b$	1.1×10^{35}	1.1×10^{35}	7.2×10^{34} 1.1×10^{35}
$\chi^2_\nu(DoF)$	1.06(491)	1.03(186)	1.15(679)

Quoted uncertainties for 90% C.L. for two interesting parameter.
[a]Absorbed 2−10 keV flux, in erg cm^{-2} s^{-1}.
[b]Unabsorbed 2−10 luminosity, in erg s^{-1}, for $d = 6$ kpc.



PWN Modelling: SN explosion properties

The SN explosion and PSR birth properties are obtained by (1) fitting the SED of the PWN — using the radio, X-ray (current work) and TeV data (*H.E.S.S. collaboration 2018*) — and assuming a PWN expansion rate (*Reynolds+18)* inferred using *Chandra* data, and (2) with a model that accounts for its dynamical and radiative evolution (*Gelfand+2009*)



SED model fitting to the PWN in Kes 75

- Kinetic Energy of SN ejecta = 1.02x10^{50} ergs
- Mass of SN ejecta = 0.43 Solar Masses
- Density of surrounding ISM = 0.25 cm^{-3}
- Magnetization of pulsar wind = 0.0435
- Braking Index p = 2.65
- Spin-down Timescale = 405 years
- Age of Kes 75 = 476 years
- Initial Spin Down Luminosity = 4.51E37 erg/s
- Distance = 5.8 kpc

Some Conclusions

- We presented new and archival X-ray observations of Kes 75 to study the broadband spectrum of the pulsar, PWN and SNR for the first time, and to address its SN explosion properties.
- We find the first evidence of hard, non-thermal, X-ray emission from the SNR (photon index~2).
- We find that the pulsar's spectrum (2017) is back to its 2000 (pre-2006-magnetar-burst) level.
- The 1-20 keV spectrum of the PWN is well-characterized by an absorbed power-law model with a photon index of 1.86 +/- 0.03.
- Our broadband and modelling study suggests that Kes 75 results from a low-energy (~1E50 ergs), low-mass (<1 solar mass) ejecta, SN explosion.