Discovery of a jet-like structure with overionized plasma in the SNR IC 443

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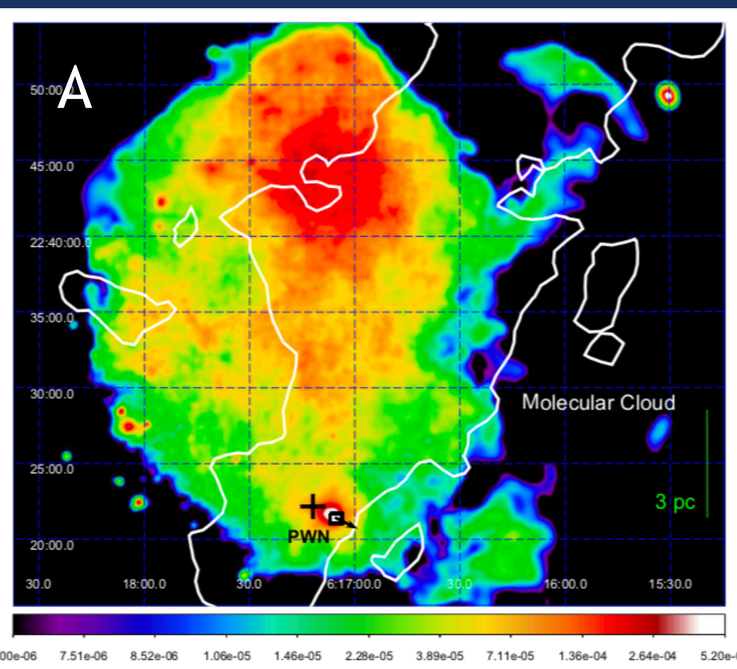
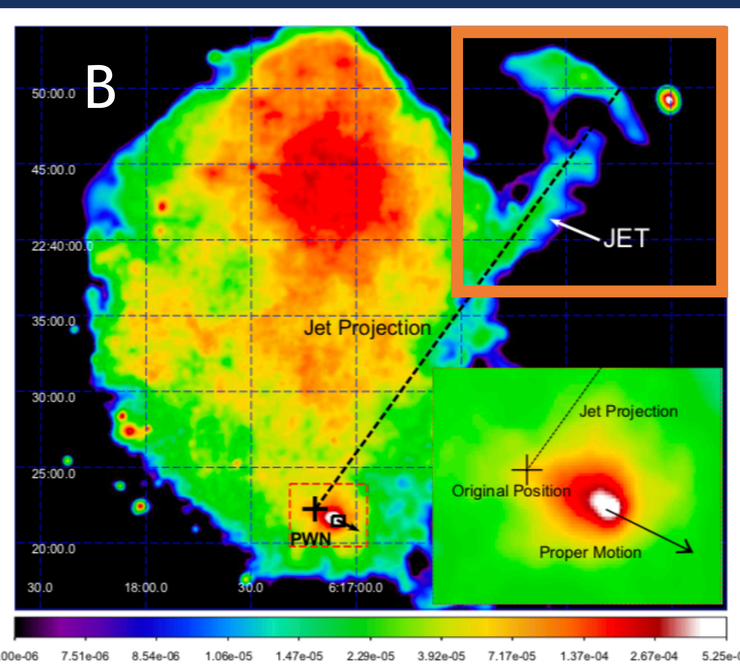
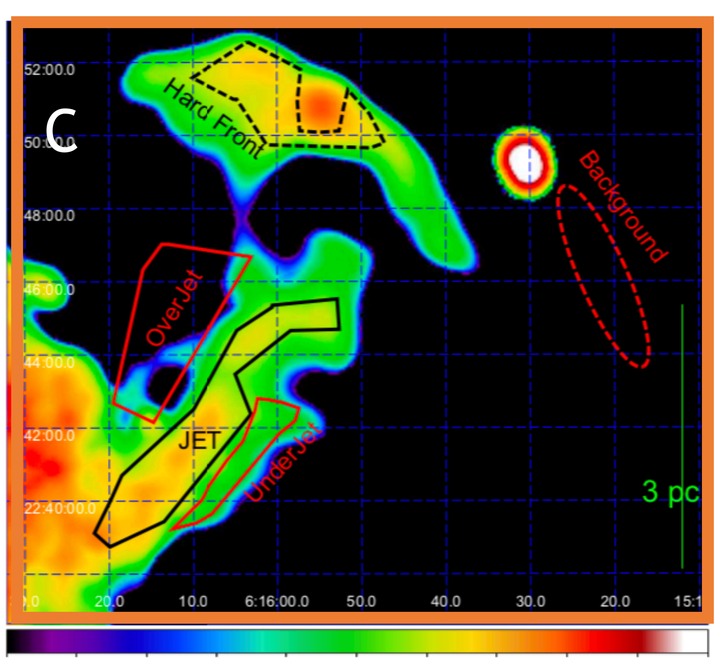
Rationale

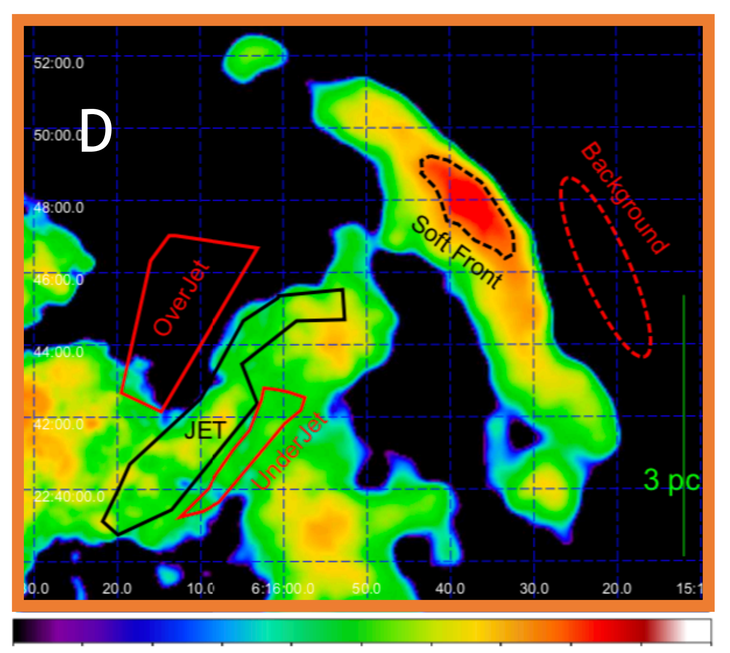
IC443 is a Supernova Remnant (SNR) which interacts with nearby clouds. Because of its peculiar position and proper motion, it is not clear if the pulsar wind nebula (PWN) within the remnant is the relic of the IC443 progenitor star or just a rambling one seen in projection on the remnant. We analyzed two **XMM-Newton** performing both image analysis and spatially resolved spectral analysis of the X-ray emission, to identify ejecta structures in the remnant and investigate its association with the PWN.

XMM-Newton Image Analysis







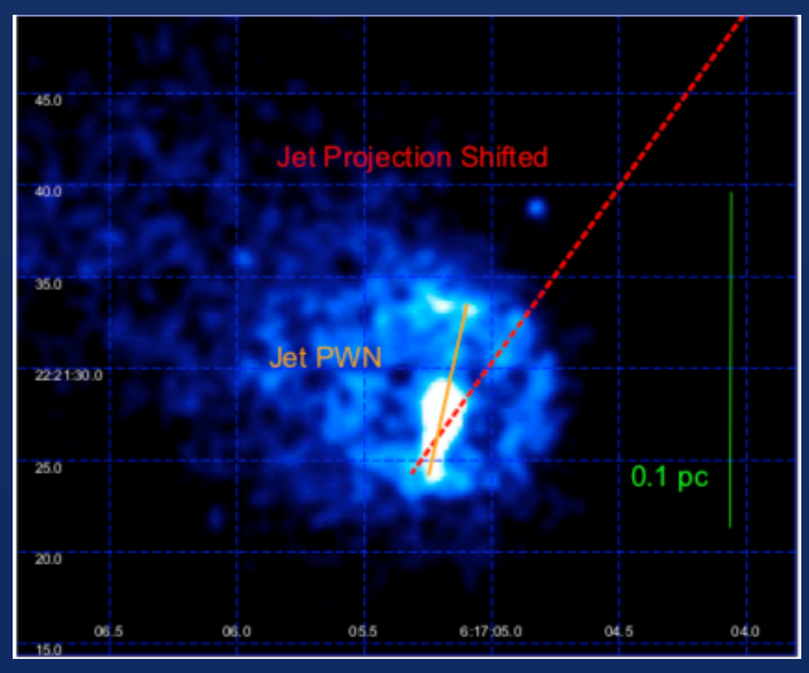


A) The molecular cloud (white contours, Su et al. 2014) is interacting with IC 443 (Denoyer 1979) and the PWN CXOU J061705.3+222127 (hereafter PWN J06) is far away from the geometric center of the remnant.

B) We detected a **collimated x-ray emitting jet-like structure**, visible within the orange box. The projection of the jet (dashed line) matches the position of PWN J06 at the time of the explosion (~ 4 kyr ago).

C) Morphology of the jet in the band 1.4-5 keV.

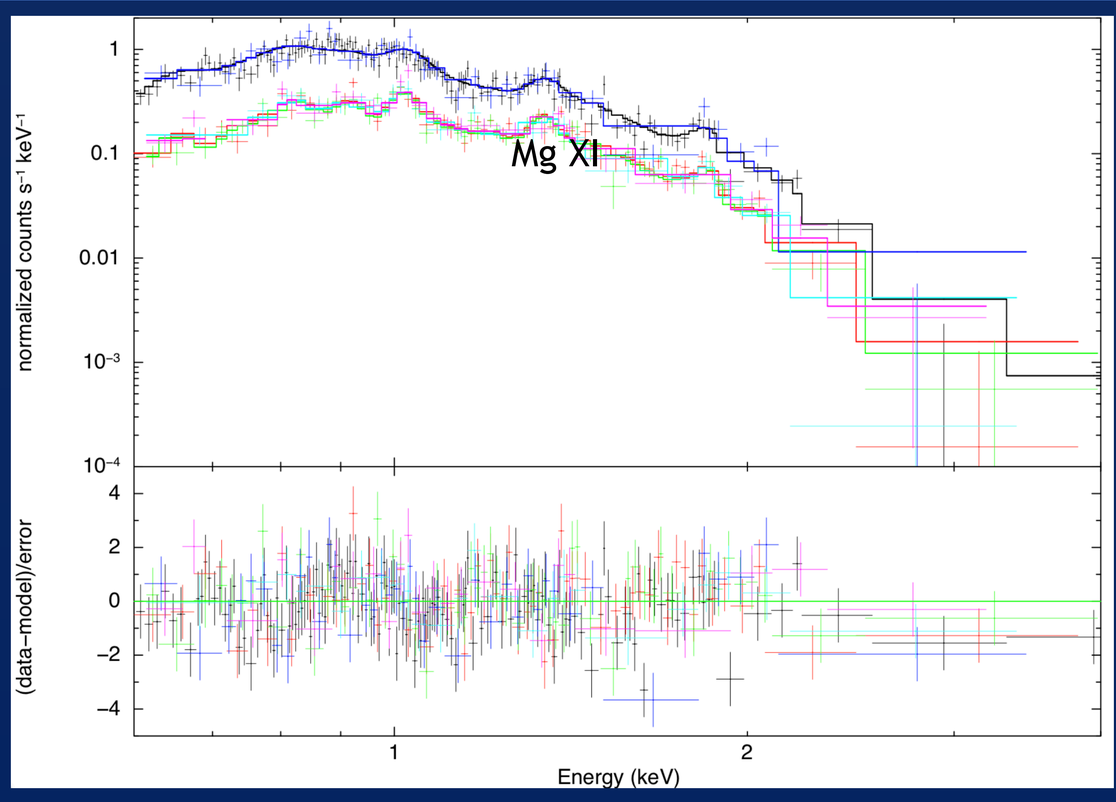
D) Morphology of the jet in the band 0.5-1.4 keV.



CHANDRA image of PWN J06: the jets of the PWN and of IC443 are somehow aligned. This may be suggestive of a physical connection between each other

Spatially Resolved Spectral Analysis

We found that in the whole jet area there is a superimposition of ISM at T~0.4 keV (VAPEC component) and **overionized Mg-rich ejecta** at T~0.2 keV (VRNEI component)



Jet		
Parameter	Model	
	VAPEC+VAPEC	VAPEC+VRNEI
nH (10^{22} cm^{-2})	0.57 ± 0.03	$0.60^{+0.03}_{-0.01}$
kT (keV)	0.44	0.38
$n^2 l^a$ (10^{18} cm^{-5})	5 ± 1	4 ± 3
kT_{init} (keV)	–	5 (frozen)
kT (keV)	$0.76^{+0.08}_{-0.05}$	$0.21^{+0.04}_{-0.03}$
O	11^{+7}_{-5}	1 (*frozen*)
Ne	4^{+2}_{-3}	11^{+8}_{-5}
Mg	4^{+1}_{-2}	13^{+11}_{-7}
Si	$0.8^{+0.4}_{-0.6}$	1^{+2}_{-1}
Fe	0.8 ± 0.3	10^{+10}_{-6}
Tau (s cm^{-3})	–	$3^{+2}_{-1} \times 10^{11}$
$n^2 l^a$ (10^{18} cm^{-5})	0.6 ± 0.2	$4.2^{+0.9}_{-1.2}$
χ^2 (d.o.f.)	613.77 (506)	575.05 (506)
Counts	20 000	

Results and conclusions

We detected an elongated jet-like structure whose emission is mainly due to overionized ejecta. The jet is distorted due to the interaction with the cloud. The jet projection towards the remnant crosses the position of the PWN J06 at the time of the explosion, strongly indicating that it **belongs to IC 443** and that the collimated jet has been produced by the explosion. The **cause of overionization is most likely the adiabatic expansion**, analogously to what described by Zhou et al. 2011 for W49B. We estimated mass and kinetic energy associated with the Jet. We obtained M ≈ 0.03 M_{sun} and K ≈ 4 10^{48} erg which are **intermediate values between those found by** Willingale et al. (2003) and Orlando et al. (2016) **for the Si-rich jet in Cas A and those found** by García et al. (2017) **for the Si-rich collimated shrapnel in Vela SNR.**

See Greco et al. 2018, 615, A517 for further details