X-ray view of pulsar-wind nebulae: What we can learn with Athena?

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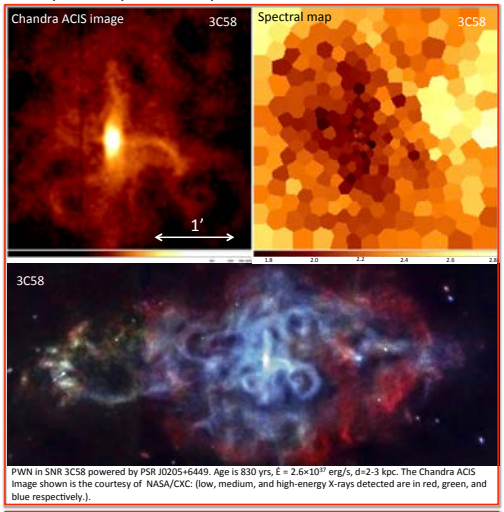
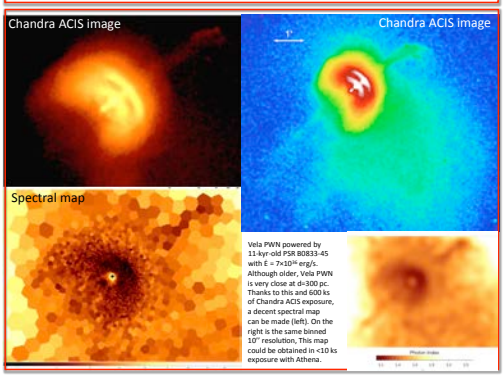
Athena shall observe the structures of several sufficiently extended and bright PWNe of different morphological types and ages. The sensitive spatially-resolved spectroscopy enabled by Athena will constrain transport and particle acceleration mechanisms, particle numbers, magnetization and energetics of ultra-relativistic plasma in pulsar winds and allow us to study the evolution of these properties both in time and with the distance from the pulsar.

Objective #1: Spatially-resolved spectroscopy of large bright PWNe:

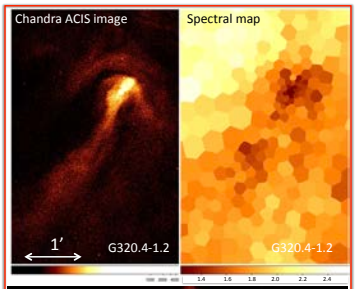
Examples of spectral maps for PWNe suitable for Athena studies:



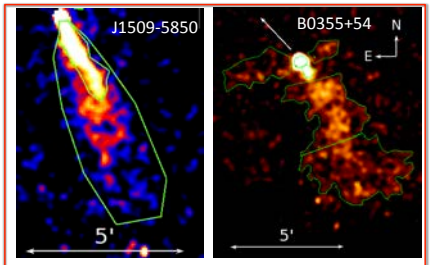
PWN in SNR 3C58 powered by PSR J0205+6449. Age is 830 yrs, $\dot{E} = 2.6\times10^{37}$ erg/s, d=2-3 kpc. The Chandra ACIS Image shown is the courtesy of NASA/CXC: (low, medium, and high-energy X-rays detected are in red, green, and blue respectively.).



Vela PWN powered by 11-kyr-old PSR B0833-45 with $\dot{E} = 7\times10^{36}$ erg/s. Although older, Vela PWN is very close at d=300 pc. Thanks to this and 600 ks of Chandra ACIS exposure, a decent spectral map can be made (left). On the right is the same binned 10″ resolution, This map could be obtained in <10 ks exposure with Athena.



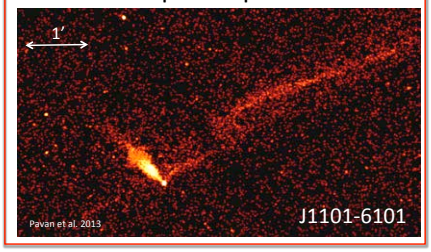
PWN G320.4-1.2 is powered by 1.7-kyr-old PSR B1509-5 with $\dot{E} = 1.8\times10^{37}$ erg/s at the distance of about 5 kpc. The color-coded Chandra ACIS image shows low and high-energy X-rays in red and blue respectively (courtesy of NASA/CXC). The PWN exhibits puzzling structure with multiple "prongs" in addition to the rings and jets often seen in other PWNe. The soft X-ray emission (red) comes from RCW 89 gas complex that may be heated by the pulsar wind.



Region	Γ (fit to Absorbed Power-Law)
Pulsar	1.91 ± 0.12
Jets	1.80 ± 0.13
Tail	1.88 ± 0.06
Brightening	2.11 ± 0.07
Tail (excl. bright.)	1.78 ± 0.09

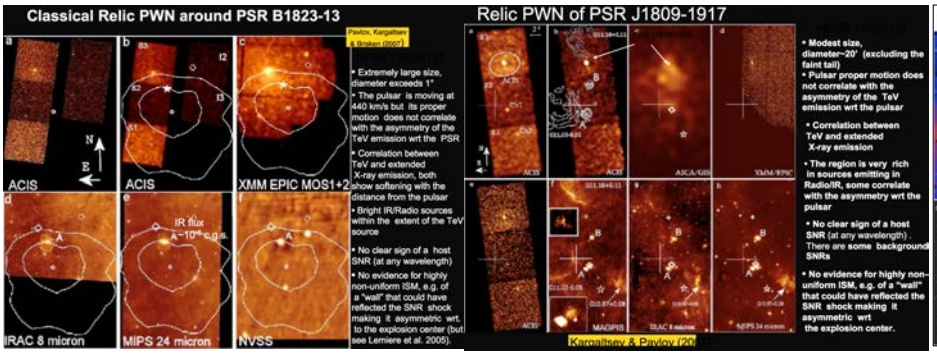
Region	Γ (Absorbed Power-Law)
Pulsar	1.80 ± 0.10
CN	1.54 ± 0.05
Whiskers	1.6 ± 0.3
Stem	1.73 ± 0.17
Tail (Entire)	1.74 ± 0.08
Tail (Near)	1.72 ± 0.10
Tail (Far)	1.77 ± 0.11

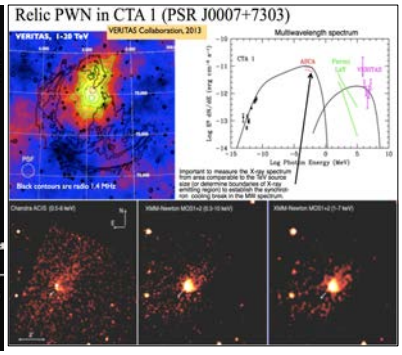
Pulsar tails and sideways extensions: These remarkable extended structures are very faint. **Athena's sensitivity is required to produce spectral maps.**



Science Goal: understand the behavior of magnetic field, flow velocity, and plasma energy content in pulsar tails, PWNe with prominent equatorial outflows and jets, and the properties collimated relativistic outflows in general.

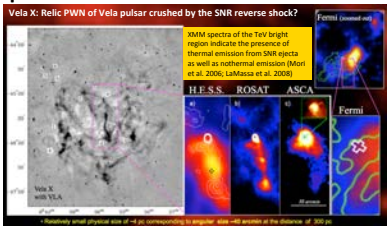
Objective #2: Mesure the spectrum of the faint X-ray emission from relic PWNe seen in TeV:





Science Goal: enable informative modeling of MW spectra of relic PWNe to constrain transport mechanisms, the numbers of particles produced by pulsars (multiplicity parameter), magnetization of pulsar winds, and fraction of relativistic hadrons in pulsar winds; enable identification of new VHE sources associated with relic PWNe

Objective #3: Observe and spectrally map interaction between the pulsar wind and dense SNR ejecta, reverse SNR shock, or SNR shell:



Science Goal: understand the evolution of magnetic field, flow velocity, and plasma energy content in pulsar tails, PWNe with prominent equatorial outflows and jets, and collimated relativistic outflows in general.