Young Radio Sources across cosmic time: 20 years of Chandra study

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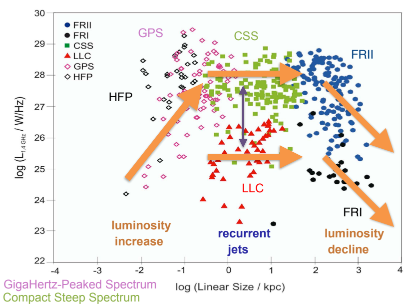
ABSTRACT:
Giga-Hertz Peaked Spectrum (GPS) and Compact Steep Spectrum (CSS) radio sources comprise a population of compact objects with radio emission fully contained within the innermost regions of the host galaxy (< a few kpc). Spectral and kinematic age measurements indicate their young age (typically < thousands years, and in some cases less a few hundred years). These sources provide the important insights to the initial phase of the jet formation, radio source growth, source evolution, and the jet impact on the ISM in the very central regions of the host galaxy. Over the last two decades we used Chandra to study the X-ray properties of these sources. Because these sources are relatively faint in X-rays only a few sources have been detected by other X-ray missions before Chandra. We have obtained Chandra and XMM-Newton observations for a large sample of these radio sources over several observing cycles. Our most recent Chandra observations targeted Compact Symmetric Objects (CSO) associated with the nuclear regions of nearby galaxies, and a small sample of MHz-peaked sources constituting the first X-ray sample of young radio sources at high redshift.

Building X-ray Sample of Young Radio Sources

- 48 GPS/CSS radio sources at z < 1
- 13 Quasars and 35 Galaxies
- 17 CSO with known kinematic age from the expansion of the radio hot spots (<3000 years old)
- 15 young radio source candidates at z > 4.5

Study:
- Radio Source Evolution
- Nature of the high energy emission
- Environment of compact radio sources

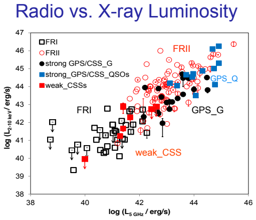
Evolution of Radio Sources



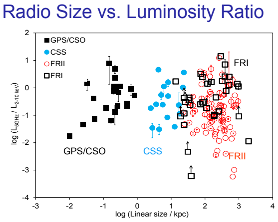
GPS - GigaHertz-Peaked Spectrum
CSS - Compact Steep Spectrum
LLC - Low Power CSS
HFP - High Frequency Peaked

Kunert-Bajraszewska et al (2010, 2014)

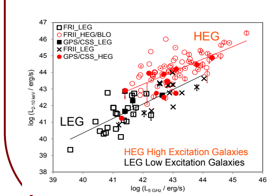
Radio vs. X-ray Luminosity



Radio Size vs. Luminosity Ratio



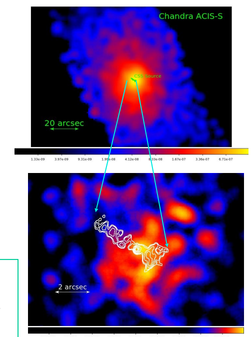
FR I objects have on average higher radio/X-ray luminosity ratio than the FR II objects suggesting a greater decrease in X-ray luminosity with radio power in FR I than in FR II objects. This is in agreement with the X-ray emission in FR I originating from the base of a relativistic jet while in FR II in an accretion flow. This may apply to GPS and CSS sources. At some radio power level, the compact GPS and CSS sources start to resemble FR I objects



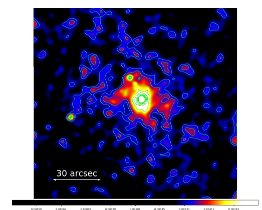
The HEG and LEG sources occupy a distinct locus in the radio/X-ray luminosity plane, notwithstanding their evolutionary stage. This is in agreement with the postulated different origin of the X-ray emission in low- and high-ionization objects. Compact sources can be found in within both excitation modes.

The Environment

- Two CSS sources were found to reside in the center of a bright X-ray clusters:
  - a powerful quasar with FRII type morphology (S10)
  - a low power symmetric radio source, with no hot spots or jets, with FRI morphology [on the right] (KB13)
- Interactions between the radio sources and the ICM in different regimes: the powerful jets in the CSS radio quasar, 3C186, and a 'coasting' CSS radio source 1321+045 in declining radio luminosity phase.



Upper image shows the smoothed Chandra image of the cooling core cluster surrounding a LLC radio source, 1321+045.
Lower panel zooms into the center showing the radio source contours overlayed on the smoothed Chandra image.
New deep Chandra observations have been approved for the current Cycle 21.

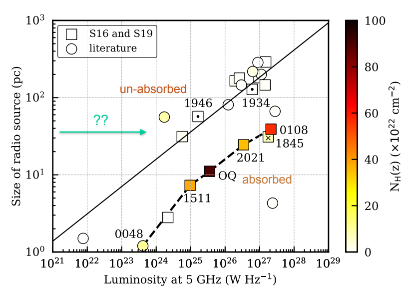


A smoothed Chandra ACIS-S image of PKS1718-649 displaying the hot ISM of the host galaxy. The radio source has the size of 2 parsecs and it is contained within the unresolved central 1 arcsec region.

- Hot diffuse X-ray emission is detected in a few nearby sources. The Chandra image of PKS 1718-649 on the far right shows a large scale X-ray thermal emission of the ISM in the host galaxy.
- In compact radio sources the hot medium of the host galaxy can contribute to the X-ray emission if the intrinsic AGN emission is weak or absorbed.

X-ray Absorption in Young Compact Symmetric Objects

Sobolewska et al (2019)

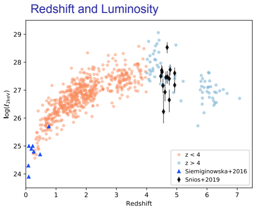


Luminosity at 5 GHz vs. radio source size for CSOs observed with Chandra and/or XMM-Newton. Squares mark sources with kinematic age measurements studied in X-rays by S16 and S19. Circles mark new CSO or candidates with X-ray information from the literature. Color coding represents the intrinsic equivalent hydrogen column density measured from the X-ray spectra. Solid line marks the relation fitted to the CSO data of Tremblay et al. (2016). Dashed line connects CSOs with intrinsic $N_H > 10^{23}$ cm^{-2} (labeled).

- X-ray obscured and unobscured CSOs appear to occupy separate regions in the ($L_{5\,GHz}$, LS, N_H) parameter space.
- Thus X-ray absorbed CSOs have smaller radio sizes than X-ray unabsorbed CSOs. Alternatively, X-ray absorbed CSOs could be more radio luminous than X-ray unabsorbed CSOs with the same radio size.
- In both cases the high density environment plays the key role: (1) High density ISM could prevent the radio source from expanding freely. (2) Radio source born in a dense environment would appear more radio luminous than a source born in a low density environment, as a high density environment is able to sustain a higher mass accretion rate onto a black hole than a low density environment. Consequently, jet power and hence radio luminosity increase with increasing mass accretion rate.
- If X-ray emission originates in radio lobes, then these results place an upper limit on the distance of the high column density clouds from the center as we did not detect high intrinsic X-ray obscuration in CSOs with LS exceeding a few tens of parsecs.

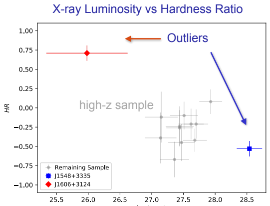
High Redshift Chandra Sample

Redshift and Luminosity



The high-z sample shown in comparison to the other quasar samples and low-z CSO sample

X-ray Luminosity vs Hardness Ratio



Extreme high HR and low X-ray luminosity may indicate a Compton Thick source (red). Extreme high X-ray luminosity may be due to contribution from an Fe-line (blue point). The AO19 XMM-Newton observation for this source has been approved for 2020.

Snios et al (2019)

Summary

- Chandra has opened studies of high energy emission in compact young radio sources. These sources represent early stages of the radio source growth.
- Our X-ray sample of GPS/CSS sources covers a range of luminosities typical to FRII galaxies, while a small sub-sample of weak CSS is consistent with FRI-type luminosities.
- Our pilot Chandra study contained mainly short X-ray exposures. The next step is to obtain high quality spectra and deep images.
- Future X-ray missions will be able to provide the highest quality X-ray data and compile homogenous samples necessary for the evolutionary studies of the radio sources.

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Acknowledgments

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