CXO2LYNX

X-ray Insights into the Earliest Stages of a Radio Source Evolution

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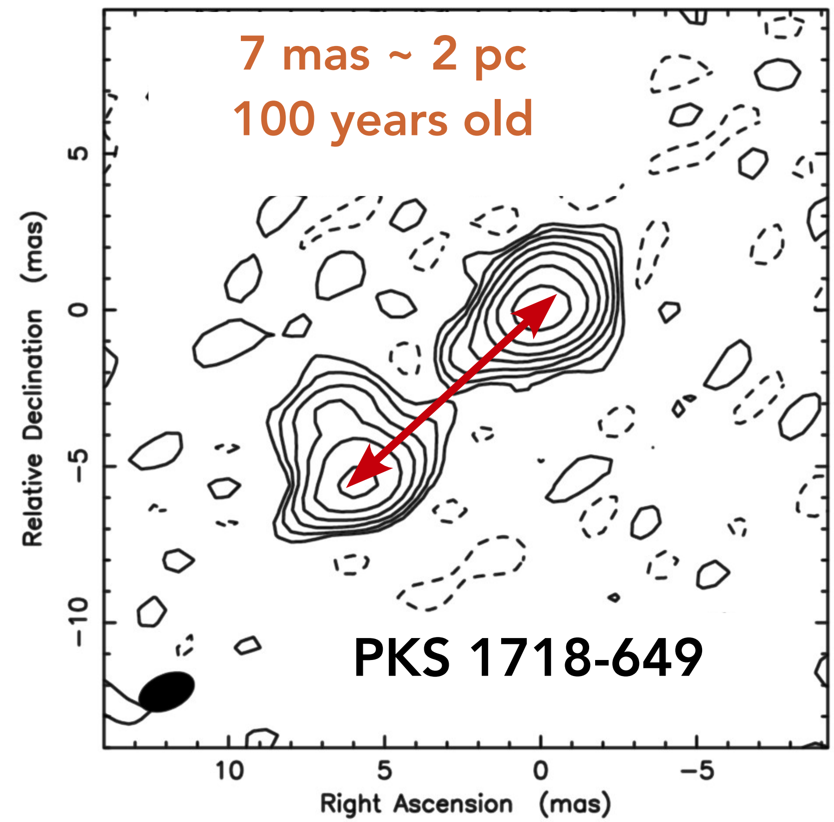
Giga-Hertz Peaked-Spectrum Radio Sources (GPS)

O'Dea 1998, Stanghellini 2003, Labiano et al. 2007, Edwards & Tingay 2017, Callingham et al. 2017

GPS sources

- radio spectral turnover frequency ~1 GHz
- < 1 kpc radio size

Tingay, de Kool (2003), 22 GHz VLBI radio imaging



GPS spectral classification

+ symmetric radio structure (two-sided, dominated by mini-lobes/hotspots)

= Compact Symmetric Objects (CSOs)

CSOs are seen **perpendicular** to the jet axis.

Early Stages of a Radio Jet Evolution – Motivation

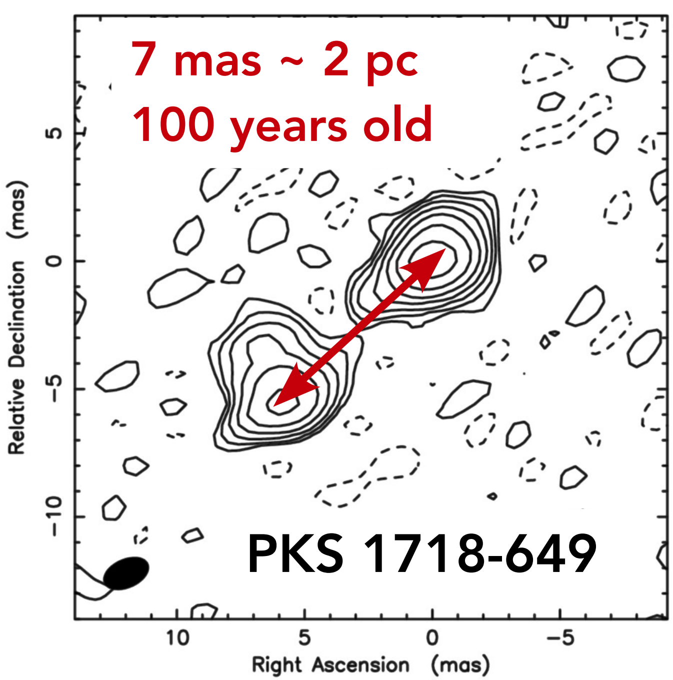
In CSOs with multi-epoch radio monitorings, kinematic methods indicate that CSO radio jets may be very young, **< 3000 years old** (An & Baan 2012).

Unique opportunity to study the AGN-galaxy feedback process:

- galactic conditions at the time of a radio jet launch and initial jet expansion,
- impact of the young expanding jet on its host galaxy.

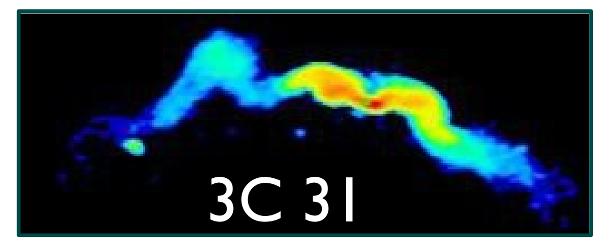
CSOs have been argued to be among the progenitors of large scale radio galaxies:

(e.g. O'Dea 1998, Snellen 2003)

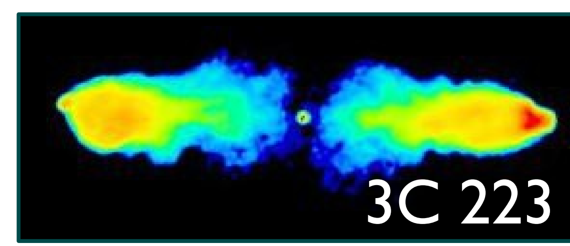


?

FRI



FRII



jets that never expand beyond the host galaxy

Current Status: X-ray Properties of CSOs

- **16 CSOs** with redshift z < 1, and measured kinematic ages of the radio structures ~2010; Chandra and XMM-Newton observations revealed that CSO form a **heterogeneous X-ray population** and expand into diverse environments.

- **100% CSO X-ray detection rate** with even short 2–5 ksec Chandra exposures, 2-10 keV X-ray fluxes 10^{-14} – 10^{-13} erg cm^{-2} s^{-1}.

- Deeper X-ray observations to discriminate among models of CSO X-ray emission (jet, radio lobes, X-ray corona, shocked ISM, etc.); **9 CSOs, 30–55 ksec.**

- Detection of OQ+208 **above 10 keV** with NuSTAR. The youngest and most compact source, PKS 1718-649, is a **gamma-ray emitter** (Fermi/LAT).

– Details –

Siemiginowska, Sobolewska, et al. 2016, ApJ, 823, 57.
Migliori, Siemiginowska, Sobolewska, et al. 2016, ApJL, 821, 31.
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- **X-ray unobscured vs. obscured CSOs.**
  Are the CSO jets **young,** or are they **confined** by their environment?
  (e.g. Phillips & Mutel 1982, van Breugel+1984, Kunert-Bajraszewska et al. 2010)

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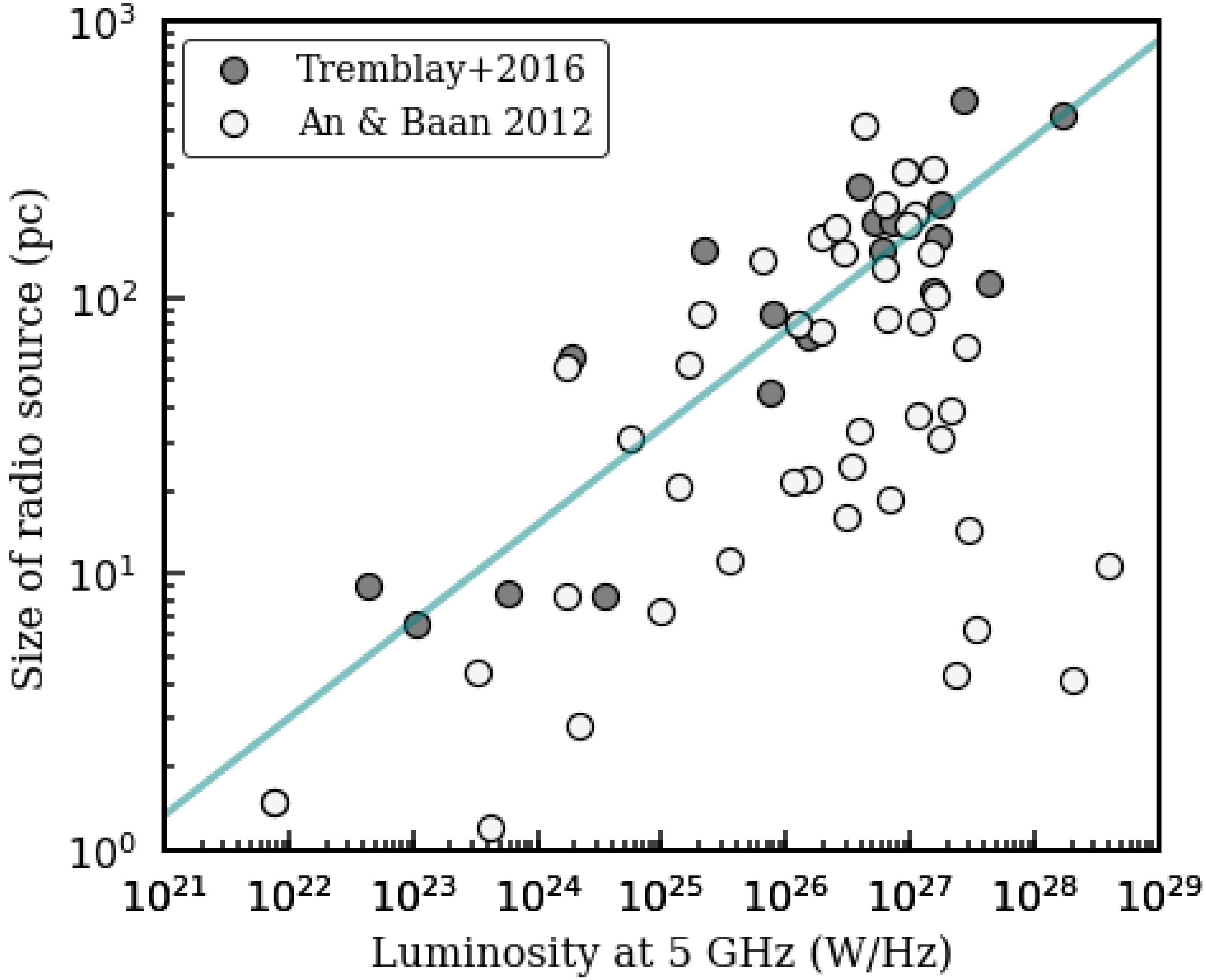
Radio Perspective: 5 GHz luminosity vs. size of CSOs

Tremblay: VLBA Imaging and Polarimetry Survey (VIPS)
An & Baan: literature



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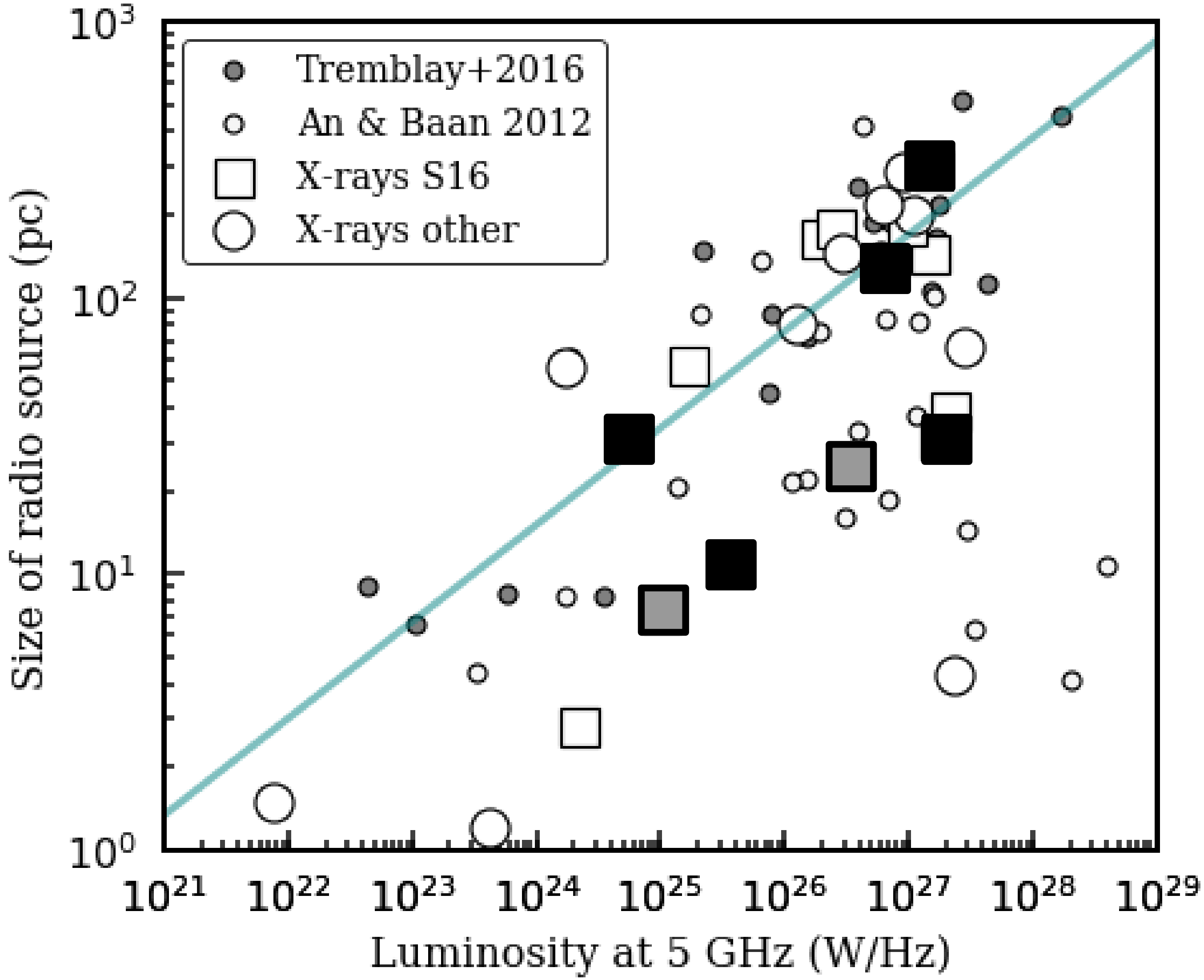


Black squares:

CSO with intrinsic $N_H > 5 \times 10^{23}$ cm^{-2}

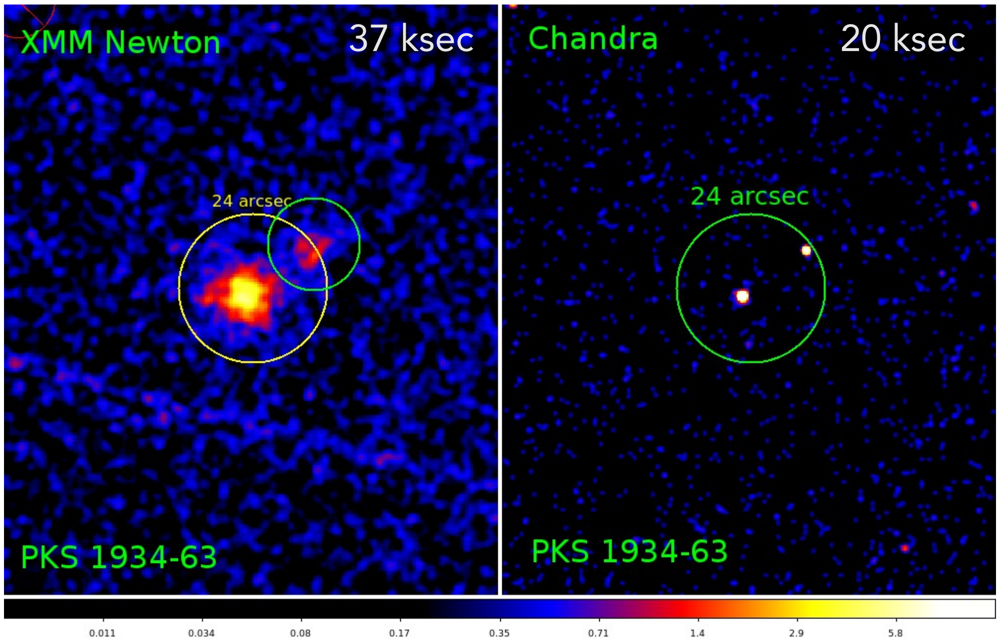
(XMM, Tengstrand et al. 2009, Vink et al. 2006 Guainazzi et al. 2004; Beppo-SAX, Risaliti et al. 2003)

Gray squares:

Compton Thick CSO candidates

(Chandra; Siemiginowska et al. 2016)

Chandra/XMM test of CSO X-ray absorption properties



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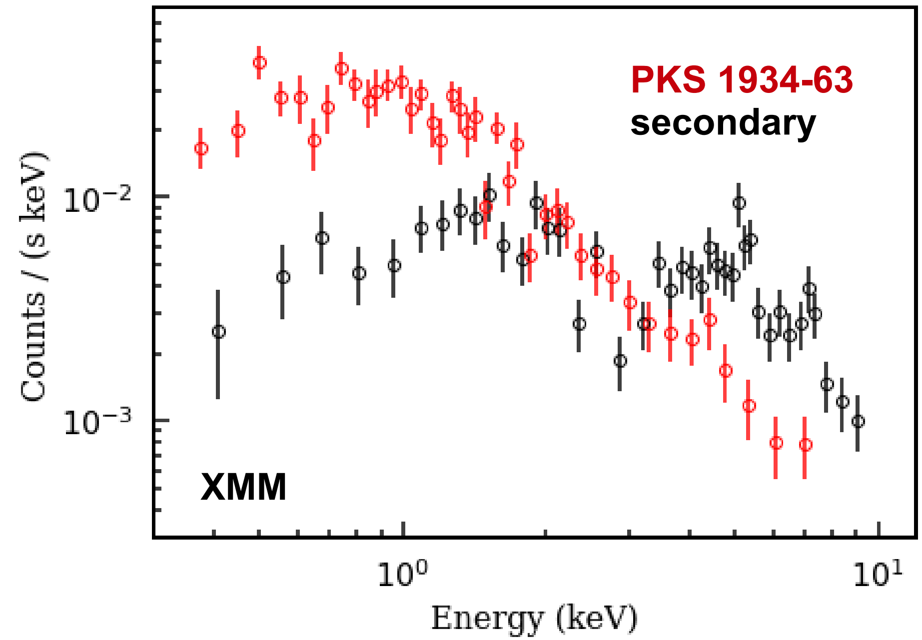
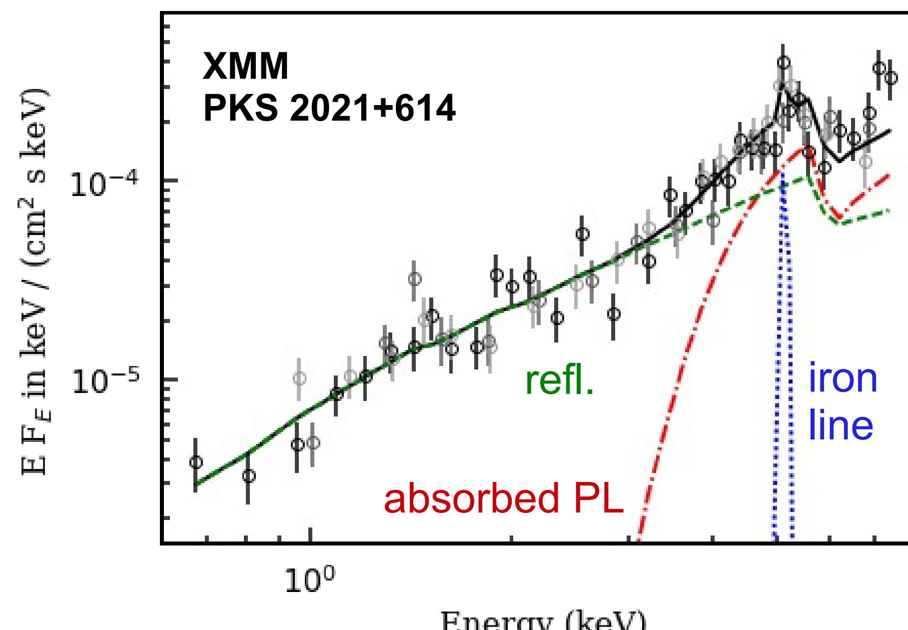




PKS 1934-63

- Serendipitous source seen in Chandra/XMM.
- Iron line emission comes from the position of the secondary source.
- CSO is **not** Compton Thick.

PKS 1946+708, 1607+26

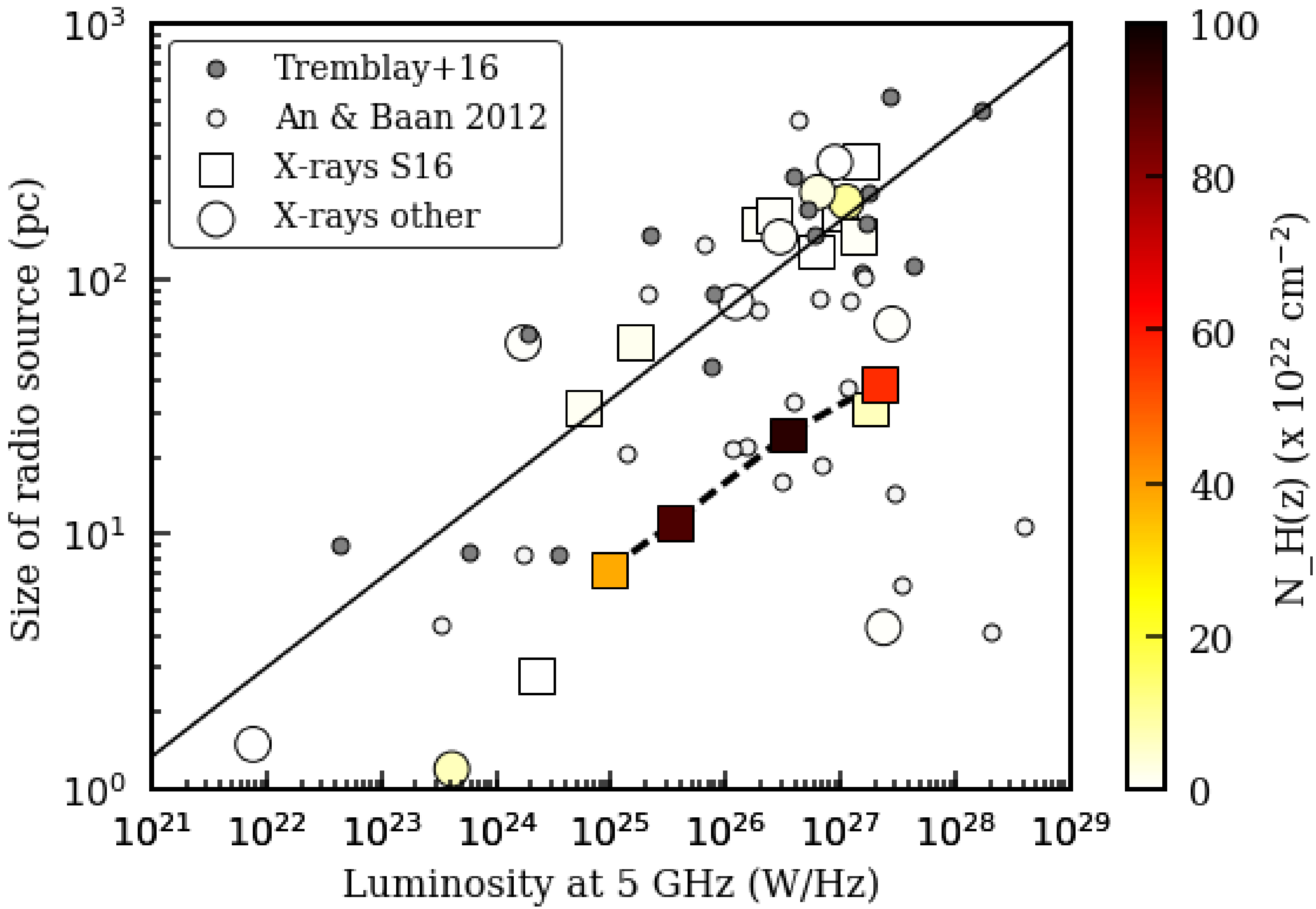
Chandra (XMM): **not** Compton Thick.

PKS 2021+614

XMM data confirm the source **is heavily absorbed**.

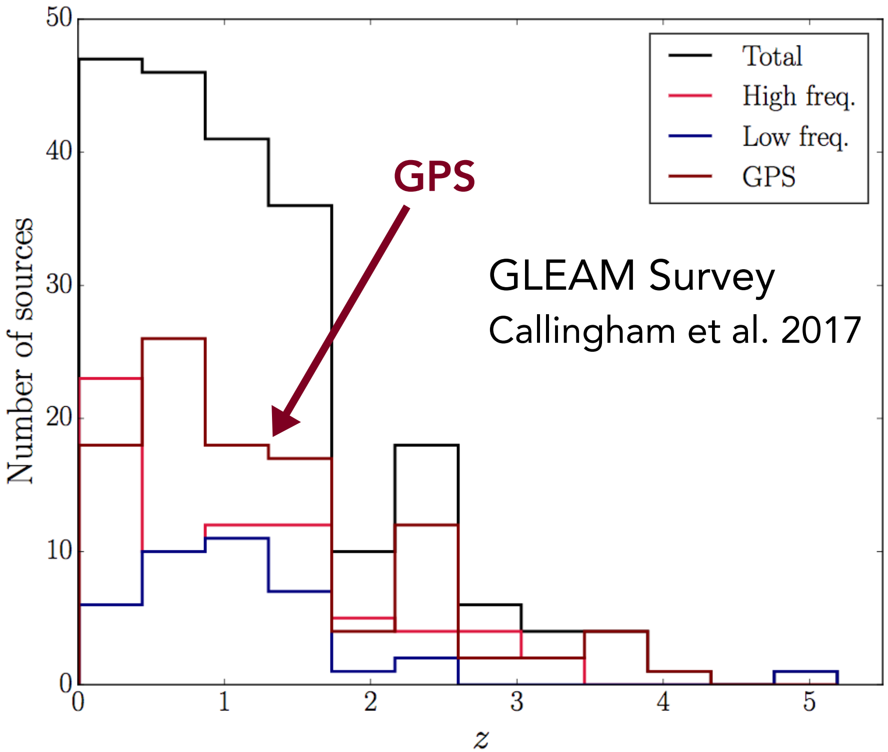
Radio/X: Environment may affect the initial jet expansion

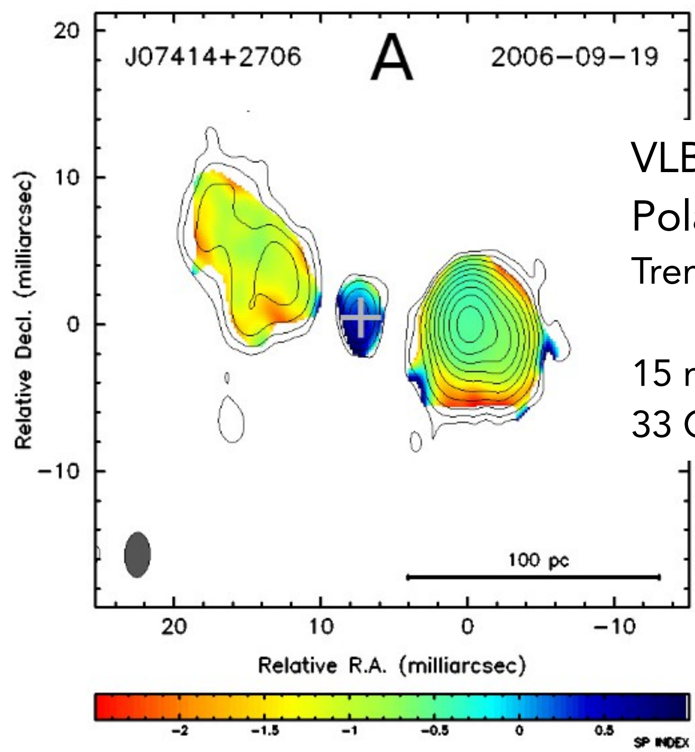
S16: Siemiginowska, Sobolewska et al. 2016; Sobolewska et al., in prep.



How are we going to push it forward?

- Ongoing and future radio surveys fundamental to the identification of the compact radio sources (Tremblay et al. 2016, Callingham et al. 2017)
- Multi-epoch radio monitorings needed to derive kinematic ages of the CSO radio jets.





VLBA Imaging and Polarimetry Survey
Tremblay et al. 2016

15 new CSOs and 33 CSO candidates

X-ray studies of the most compact radio jets and the environments into which they expand require **arcsec** spatial resolution, **high sensitivity**, and collective area at **soft energies**.

Near term science goals

- Expand the Chandra X-ray CSO sample, observe sources with recent radio CSO identification.
- Include more evolved, > 1kpc, symmetric radio sources to enable statistically robust evolutionary studies.
- Verify that some radio jets can be confined at a very early stage of their expansion (**young** jet vs. **confined** jet).
- Study radio/X-ray variability, and the NHI (radio) – NH (X-ray) correlation (Ostorero+17).
- In the nearest sources, resolve and study X-ray emission extended on arcsec scales.

- **Physics of Feedback**
  AGN/jet/galaxy interactions
- **Physics of Plasmas**
  acceleration of particles in a newly formed jet, emission of shocked ISM
- **Evolution of Structure and AGN populations**
  evolutionary paths leading to the large scale jet formation and FRI/FRII dichotomy
- **X-rays in the Multi-wavelength, Multi-Messenger Era**
  ongoing and future radio surveys identify the candidates, long term radio monitorings constrain age of the jets, broad-band SED needed to constrain model parameters