Young extragalactic radio jets probed with X-rays

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- with -

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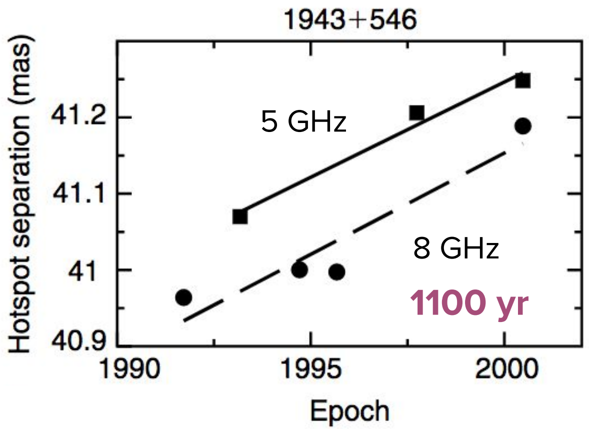
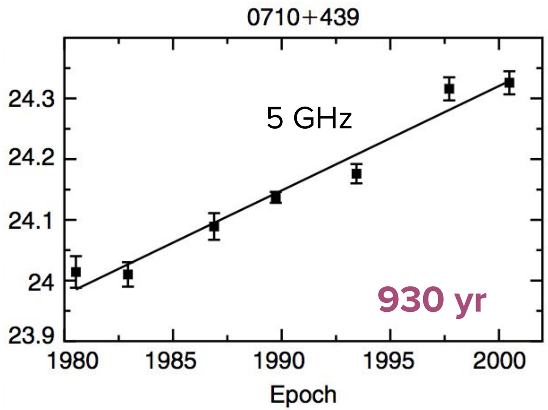
Outline

1. Observations of compact (young) extragalactic jets
2. Motivation: why compact jets are important?
3. Results
   - X-ray environment of compact radio jets
   - Compact radio sources across redshift range ($z < 1$ and $z > 4$ samples)
   - Broadband radio-to-X/gamma-ray spectra of young radio sources
   - First constraints on the origin of X-ray emission of young radio sources
4. Summary and future work (see also poster P84)

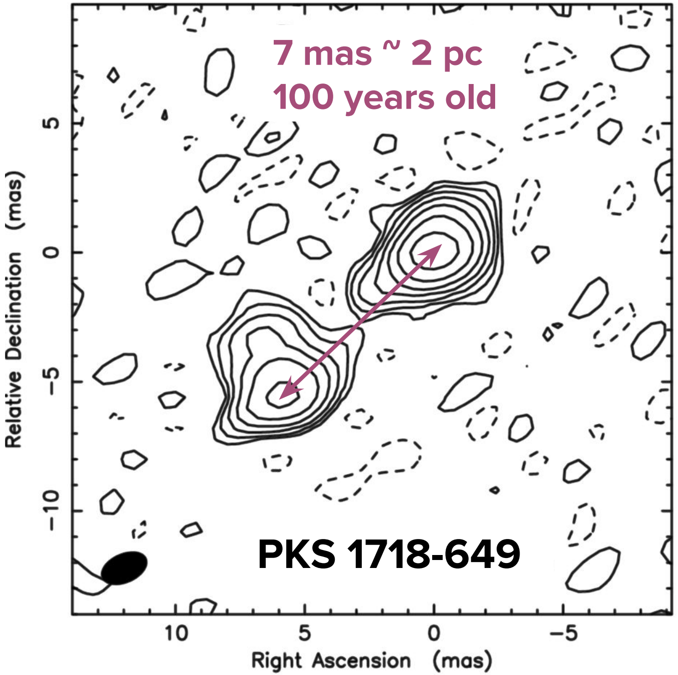
Radio identifications of compact extragalactic jets

Compact Symmetric Objects (CSO)





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



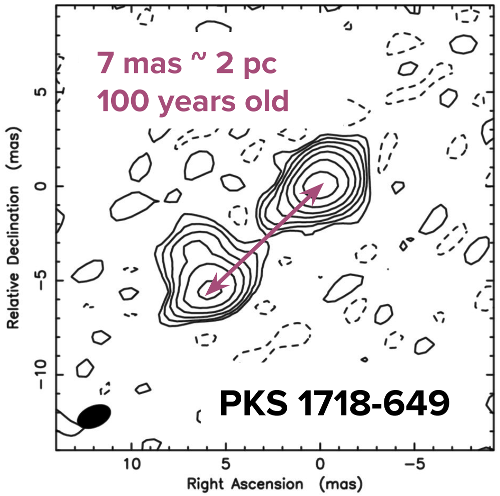
O'Dea 1998, Owsianik et al. 1998, Stanghellini 2003, Polatidis & Conway 2003, Labiano et al. 2007, An & Baan 2012, Edwards & Tingay 2017, Callingham et al. 2017

Why do we study compact radio jets?

Kinematic methods suggest that jets in CSOs may be very young < 3000 years old (e.g. An & Baan 2012)

Unique opportunity to study an interesting aspect of the AGN / galaxy feedback process

- conditions in a galactic center at the time of a radio jet launch and initial jet expansion
- impact of a young expanding jet on the innermost regions of its hosts galaxy

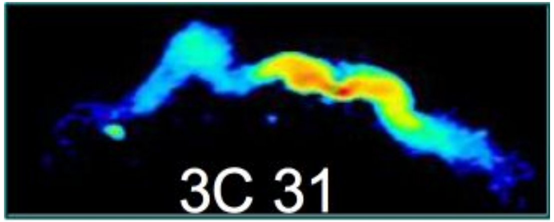


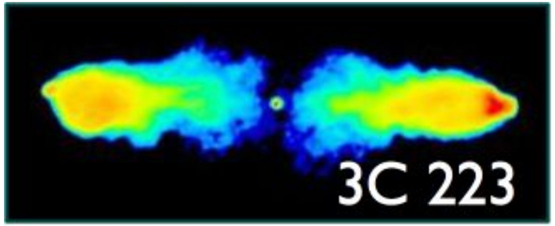
CSOs, progenitors of
the large scale radio galaxies

→ FRI

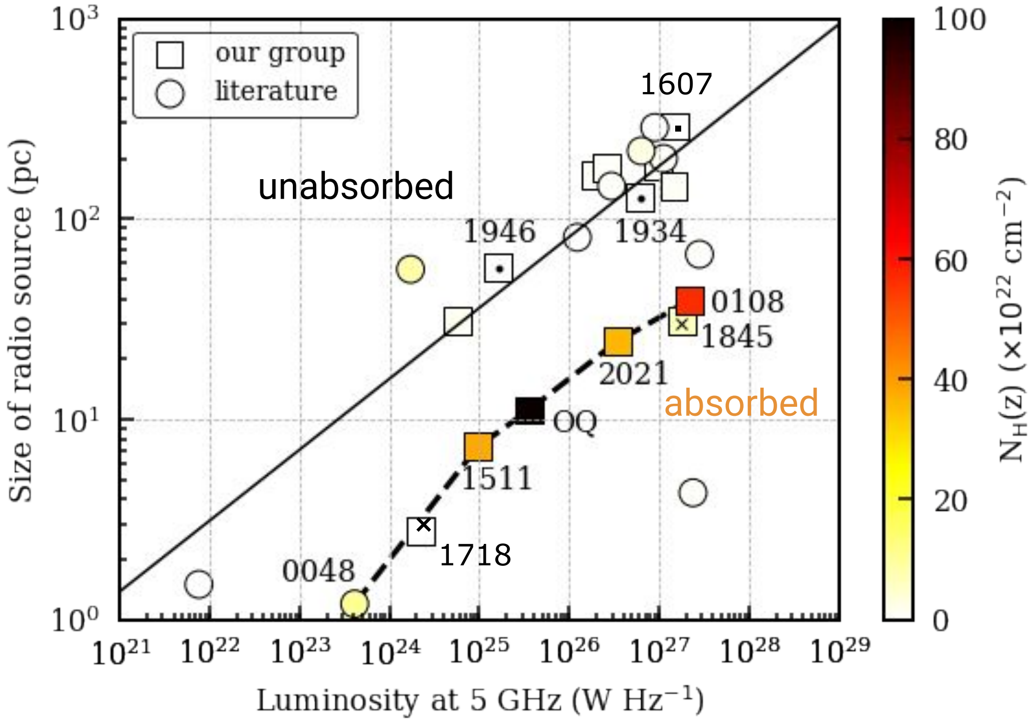
→ FRII

→ never expand
beyond the host galaxy





CSO sample. X-ray absorption properties

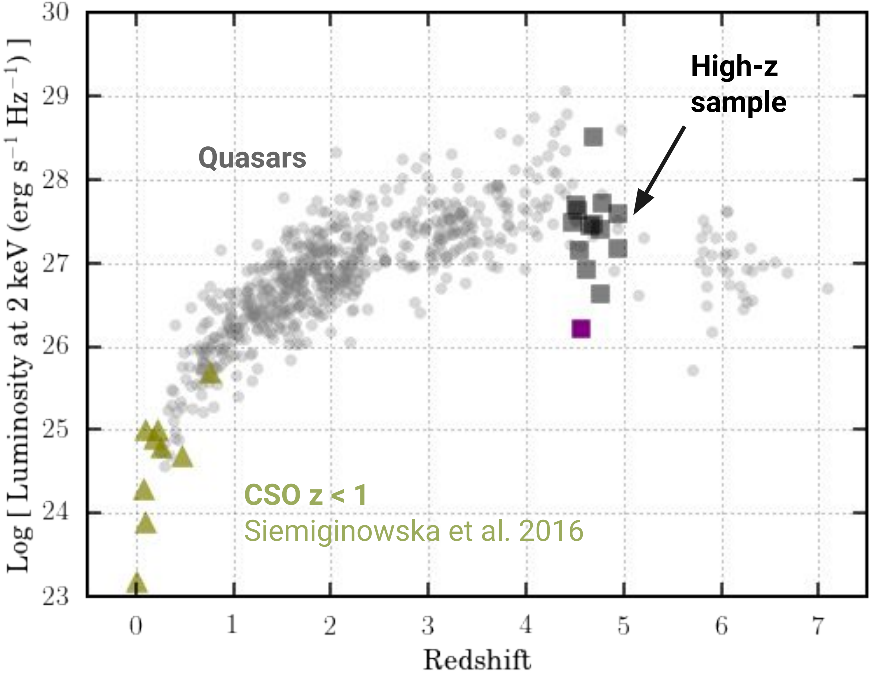


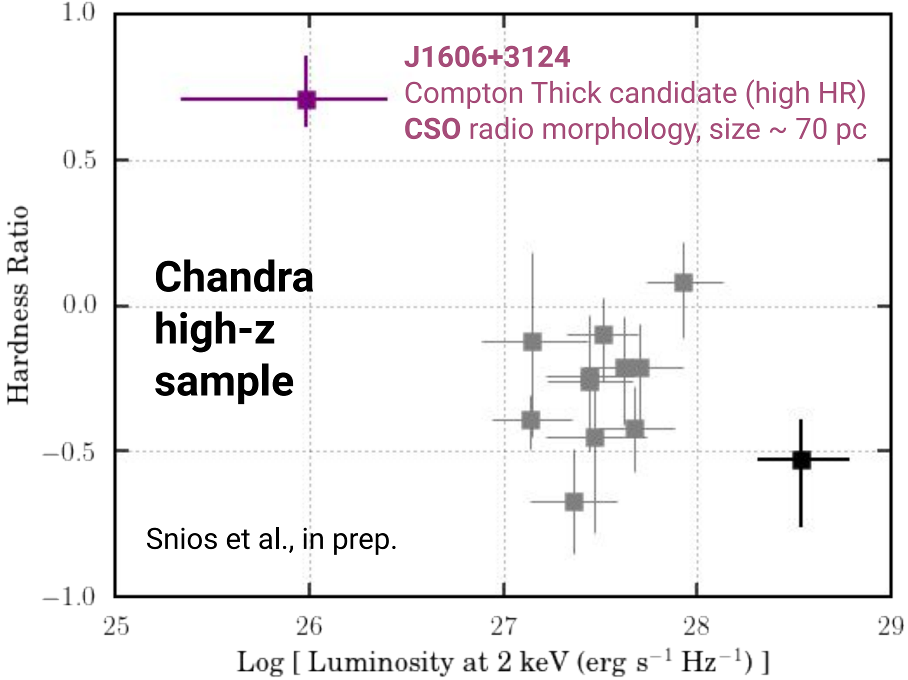
Sobolewska et al., 2019, *ApJ*, 871, 71
Sobolewska et al. 2019, *ApJ*, 884, 166
Siemiginowska, Sobolewska et al. 2016, *ApJ*, 823, 57

- **X-ray absorbed sources have**
  - **smaller radio size** than X-ray unabsorbed sources with the same radio power, OR
  - **larger radio power** than X-ray unabsorbed sources with the same radio size

- **So far, no detection of $N_H(z) > 10^{23}$ cm^{-2} in CSO sources with radio size exceeding ~ 40 pc.**
  Implications:
  - Size of the region responsible for the X-ray obscuration?
  - Torus destruction by an expanding jet?
  - X-rays from radio lobes that expanded beyond the compact X-ray obscurer?

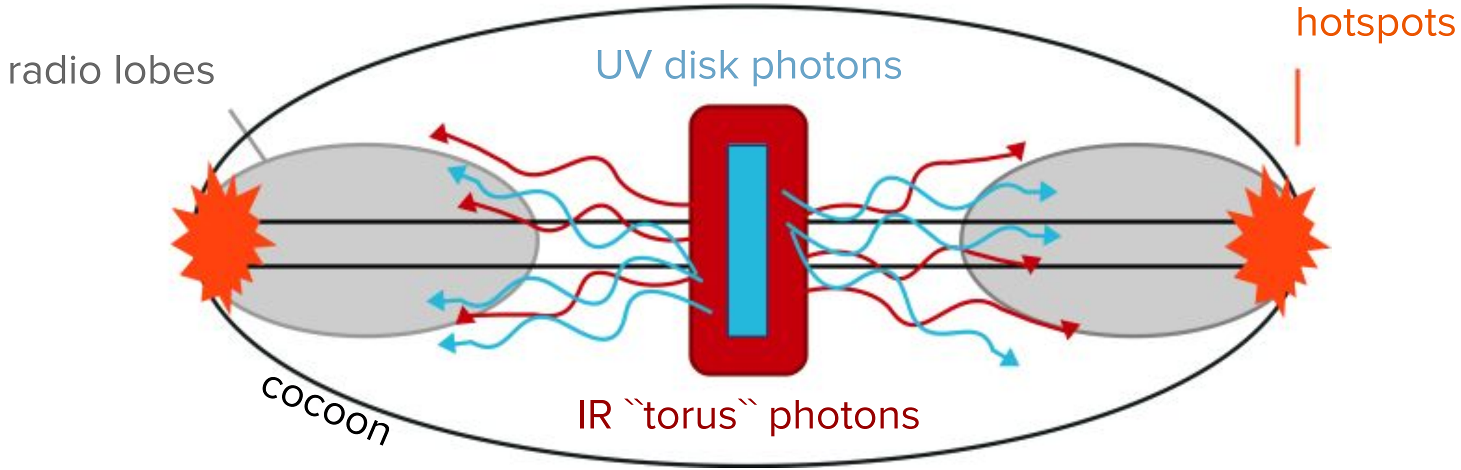
Compact radio sources across redshift range





Quasars: Shemmer+ 2006, Just+ 2007, Lusso+ 2016, Martocchia+ 2017, Nanni+ 2017, Zhu+ 2018, Vito+ 2019

Outstanding question. The site of X/γ-ray production?

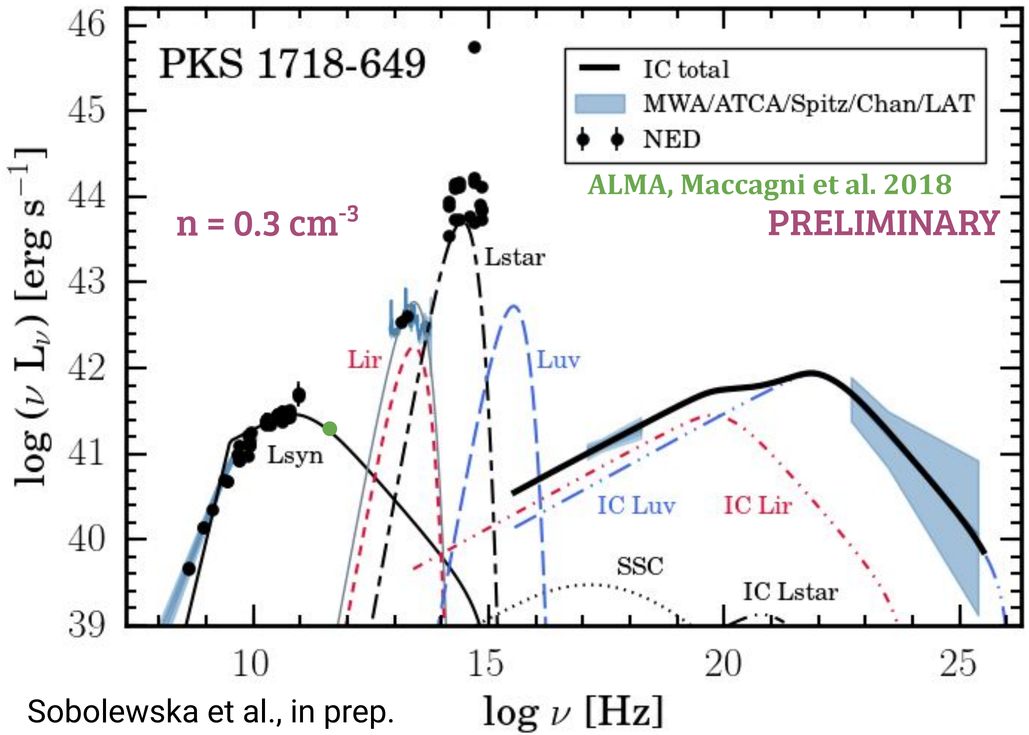


Expanding radio lobes model framework (Begelman & Cioffi 1989; Stawarz et al. 2008; Ostorero et al. 2010)

- Follow the evolution of ultrarelativistic electrons injected from terminal jet hot spots to the expanding lobes
- Account for appropriate adiabatic and radiative energy losses
- Electrons Inverse Compton up-scatter the soft photon fields

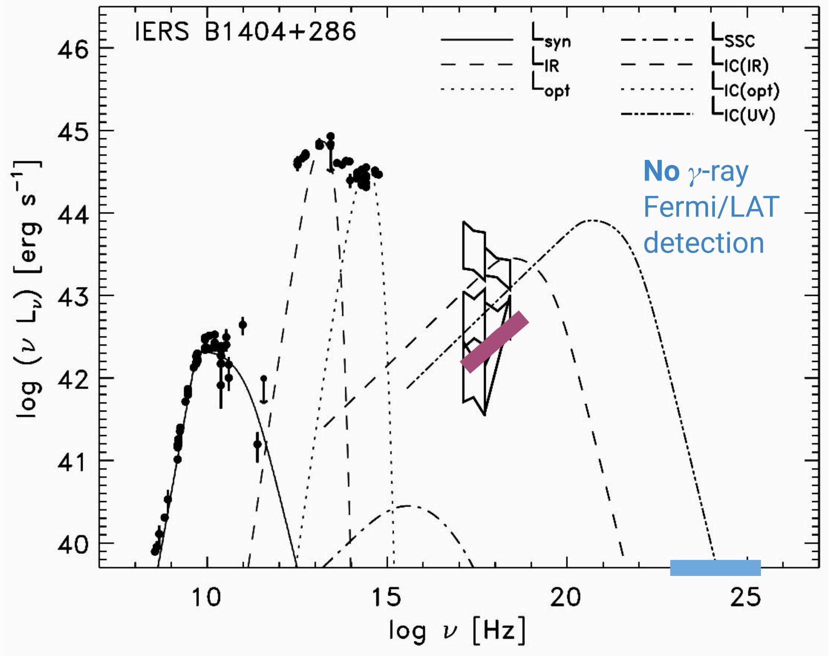
Broadband modeling. Radio to X/γ-ray SED

MWA/ATCA, Tingay et al. 2015; Spitzer, Willett et al. 2010; Fermi/LAT, Migliori et al. 2016



Sobolewska et al., in prep.

Ostorero et al. 2010; Migliori et al. 2014



Chandra + NuSTAR + XMM (Sobolewska et al. 2019)

Summary and future work

- Combining the low-z and high-z samples allows us to study compact radio sources across a wide range of intrinsic X-ray luminosity.
- High-energy CSO emission **not due to IC processes** in radio lobes? Or magnetic pressure dominates over electron pressure.
- First hard X-ray detections of CSOs (NuSTAR). To date, only PKS 1718-649 has been detected with Fermi/LAT.
- X-ray absorbed/unabsorbed CSO dichotomy:
    - difference in radio size for the same radio luminosity at 5 GHz **(confinement?)**
    - difference in radio luminosity for the same radio size (**density of the environment**? **jet power**?)
- Ongoing Chandra, XMM and NuSTAR observing programs
- New CSO candidates identified in the radio band; Callingham et al. 2017; Tremblay et al. 2016), ~10 with sizes 5 - 50 pc. X-ray follow-ups imperative