The most distant radio quasars at the highest resolution

Sándor Frey (FÖMI SGO, Hungary)
Zsolt Paragi (JIVE, The Netherlands)
Leonid I. Gurvits (JIVE, The Netherlands)
Krisztina Gabányi (FÖMI SGO, Hungary)
Dávid Cseh (CEA Saclay, France)

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The outline of the talk

- Quasars already formed as early as <1 Gyr after the Big Bang
- How many of the z~6 quasars are radio emitters?
- High-resolution radio interferometric imaging with the EVN:
  compact structures down to ~10 pc scales
- Are they similar to each other? Are they ”young”?
- The first blazars – or not?
Quasars at $z \sim 6$ became known quite recently (in the last decade or so)

First discoveries in the Sloan Digital Sky Survey (SDSS)

To date, there are $\sim 40$-50 quasars known at $z \sim 6$

Most of the observed properties (e.g. metallicity, emission line strength, BH mass) are very similar to those of quasars at low redshifts

But: hot-dust-free quasars (2 out of 21) found – they may represent the first generation

Apparently not all of the earliest quasars we see are completely evolved objects (lack of the dusty structures around the accretion disk)
Radio quasars at $z \sim 6$

Among the $z \sim 6$ quasars, only three are "strong" continuum radio sources. For comparison, ~8% of all SDSS quasars have FIRST radio counterparts. 

If the radio emission is compact, it should come from an AGN: synchrotron jet in the vicinity of the central SMBH. 

This can be tested with Very Long Baseline Interferometry (VLBI) imaging.

Ivezić et al. (2002)
J0836+0054

Fan et al. (2001)

FIRST (VLA, 1.4 GHz) radio image

Weak (~1 mJy) radio sources → VLBI imaging is challenging
SDSS J0836+0054: luminosity

\[ L_5 = 10^{25} \text{ W Hz}^{-1} \text{ sr}^{-1} \]

\[ z = 5.774 \]

example: Parkes Half-Jansky Flat-Spectrum Sample

Jarvis & McLure (2002)
1 mas angular size corresponds to ~6 pc linear size at around this redshift.

- **compact** but somewhat resolved structure
- radio emission is confined to the central **few tens of parsecs**
- steep radio spectrum ($\alpha = -0.8$), no indication of strong relativistic beaming

Frey et al. (2003, 2005)
J1427+3312

McGreer et al. (2006); Stern et al. (2007)

z=6.12

33 x 33 pixels extracted from FIRST image 14270+33097E

Brightest pixel is 1.25 mJy/beam at

$X, Y = 17, 17$ pixels

RA, Dec = 14 27 38.516 +33 12 41.63 (J2000)

RMS noise 0.202 mJy
J1427+3312

5 GHz

peak: 167 μJy/beam

1.6 GHz

peak: 460 μJy/beam

Frey et al. (2008); Momjian et al. (2008)
J1427+3312:

- **double structure** seen at the lower frequency
- again, compact but resolved (~10^6-10^7 K brightness temperatures)
- comparison with lower-resolution VLA & WRST data: no significant ”missing” flux density, the total radio emission is also detected with VLBI
- again, steep radio spectrum (\(\alpha = -0.6\))

The source is remarkably similar to the **Compact Symmetric Objects** (CSOs), known typically at \(z<1\)
Those are really **young** (up to \(~10^4\) yr) ”baby” radio AGNs
Their (kinematic) age is derived from the separation speed

**Is our \(z>6\) quasar a newborn radio AGN?** – could be verified with VLBI monitoring over the time scale of a decade
**J1429+5447**  

**Willott et al. (2010)**

**Preliminary images made from recent EVN data (EF022)**  

1.6 GHz (2010 Jun 8), 5 GHz (2010 May 27)
J1429+5447:

- strikingly **similar** compact double structure & steep spectrum for both known $z>6$ radio quasars

*Is it the "rule", or these are just accidental exceptions?*
Apparently at $z>4.5$, the blazar-type sources (with flat spectrum and high Doppler-boosted brightness temperatures) are the *minority*

Do we see mainly young GPS sources at early cosmological epochs?

Their turnover frequencies should be $\sim 500$ MHz (in the observer’s frame)

Falcke et al. (2004)

this $z>4.5$ quasar sample was not selected on flat radio spectrum

EF021 (Frey et al. 2010, A&A, in press)
Conclusions & future directions

- Among the known $z \sim 6$ quasars, <10% is radio-emitting
- The three imaged with high angular resolution show compact but resolved radio structures at ~10-100 pc linear scales
- Their radio spectra are steep
- Two of them (at $z > 6$) are doubles, and remind us to the CSOs (very young radio AGNs at low redshifts)
- The highest-redshift radio quasars are still very rare
- There must be a lot more, just waiting for discovery…
- Existing at around the end of the era of reionization, these radio sources could also serve as ”radio beacons” for sensitive HI absorption studies towards their lines of sight