VLBI studies of radio-loud high redshift quasars

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High redshift radio-loud quasars (HzRLQs)

HzRLQ are associated with the most massive SMBHs (>$10^9 M_{sun}$)
When did the first SMBH form ?

First torch in the Universe (EoR)

How did they grow so quickly in the early Universe ?
Did jets play a role in black hole growth ?

The interplay between SMBH and host galaxies

Are they similar with their lower-redshift cousins ?
The physical environment of the early host galaxies

Nature of HzRLQs

Cosmological evolution of radio quasars – luminosity function
The link between HzRLQ and high energy background
HzRLQs as standard rod – cosmological parameters

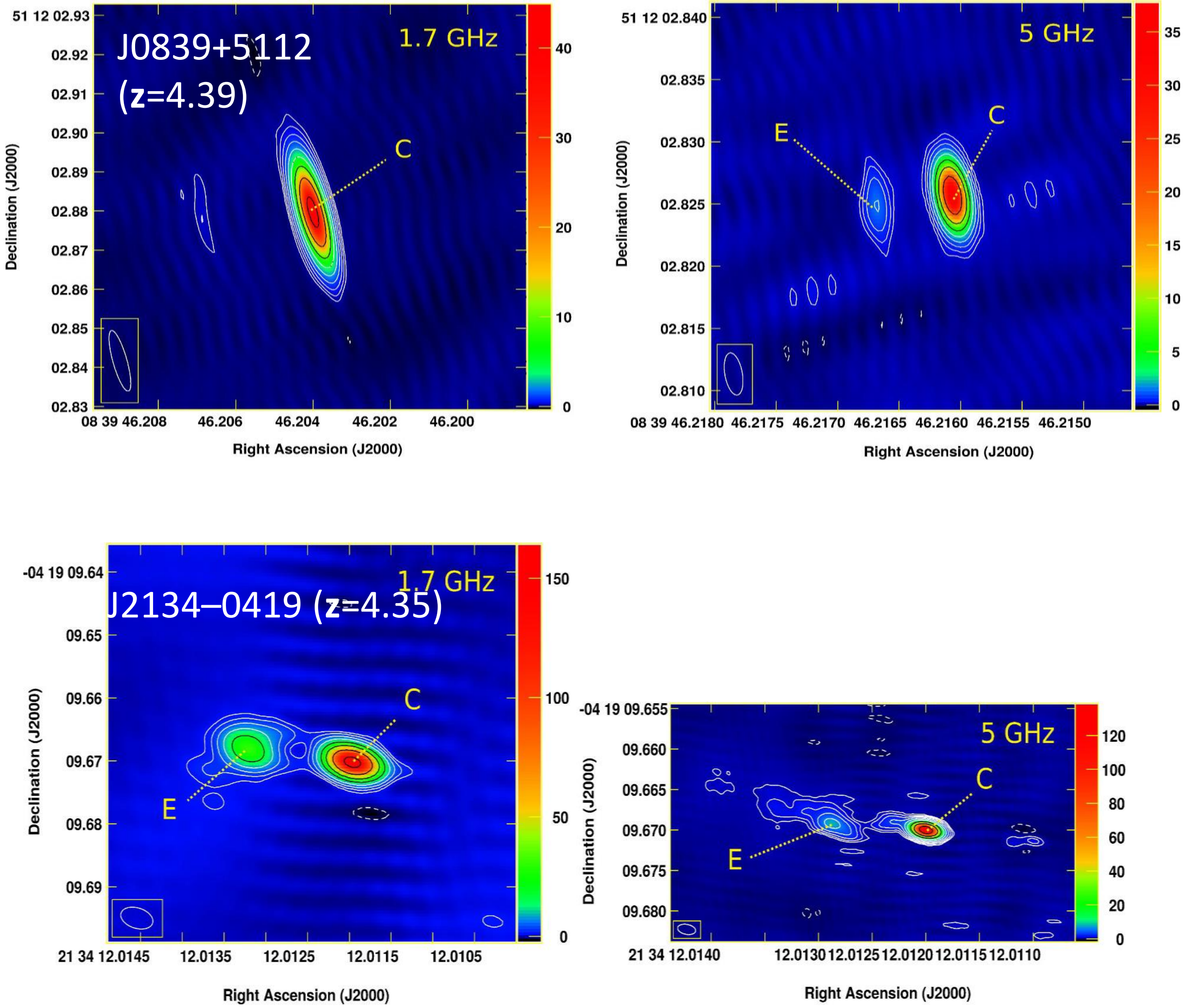
Tool of cosmology study

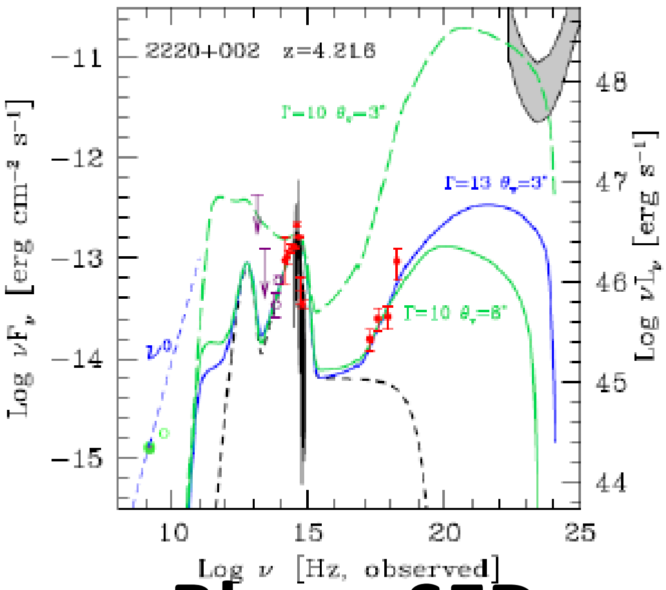
- VLBI a unique tool offering mas resolution, offering direct and model-independent evidence of blazar due to its high brightness temperature
- radio wave is transparent to dust-rich early galaxies, at (1+z)*v, probe the optically thin part of the inner jet
- HzRLQs are distant and weak – need extremely high sensitivity
- Time dilation – need a long time span to determine proper motion

Only recently, the jet kinematics study become feasible.

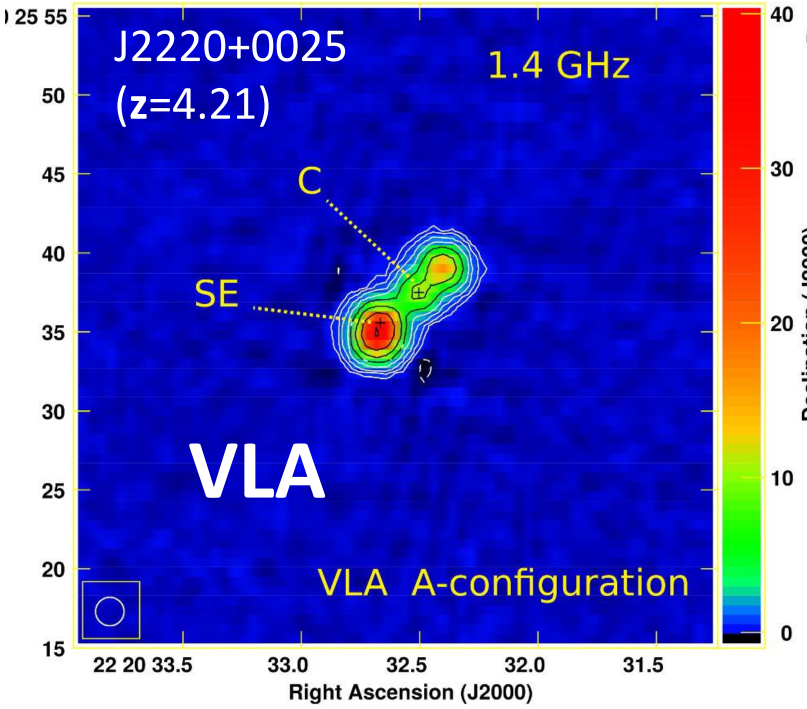
Very Long baseline Interferometry

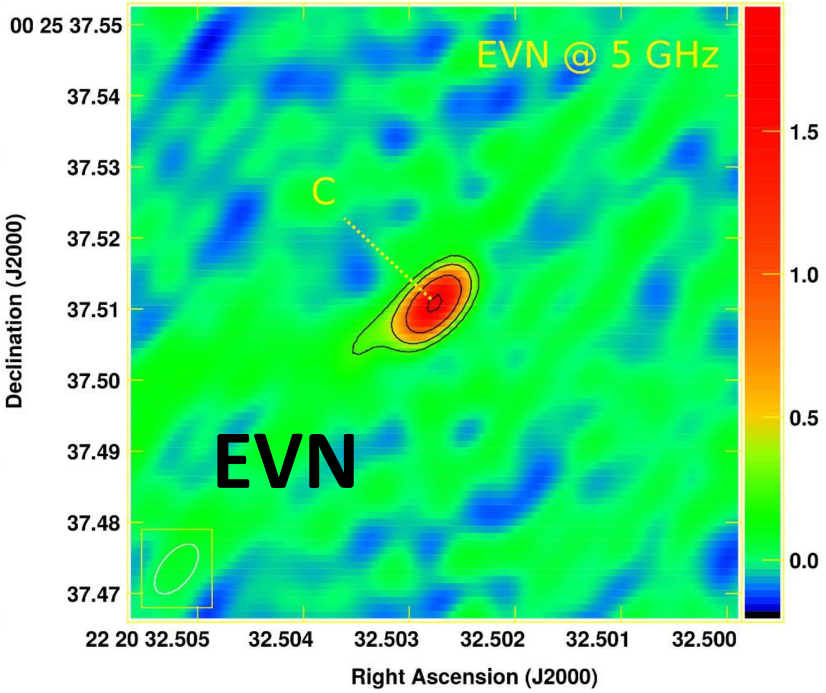
High-z blazars VLBI observations





Blazar SED

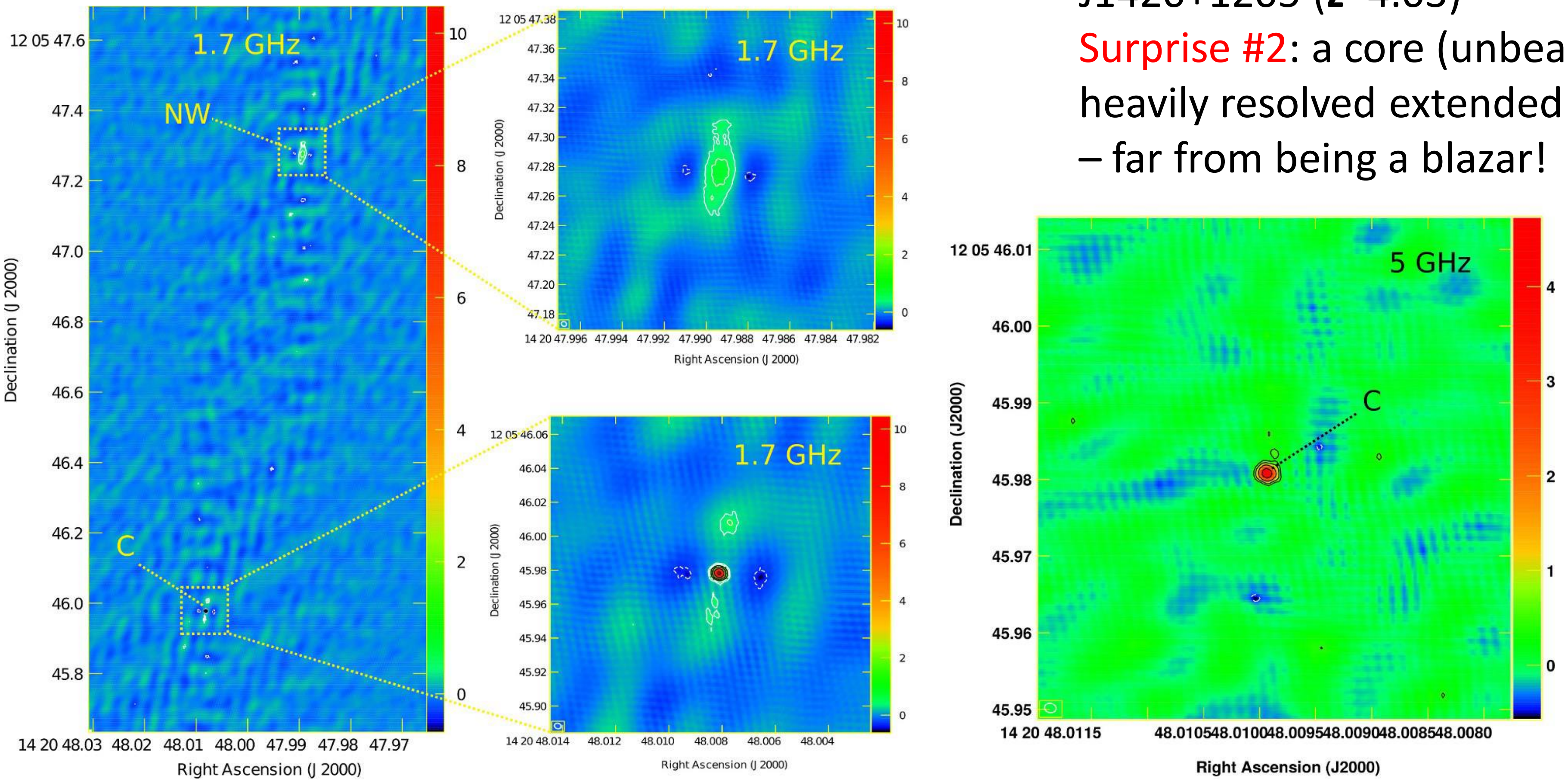




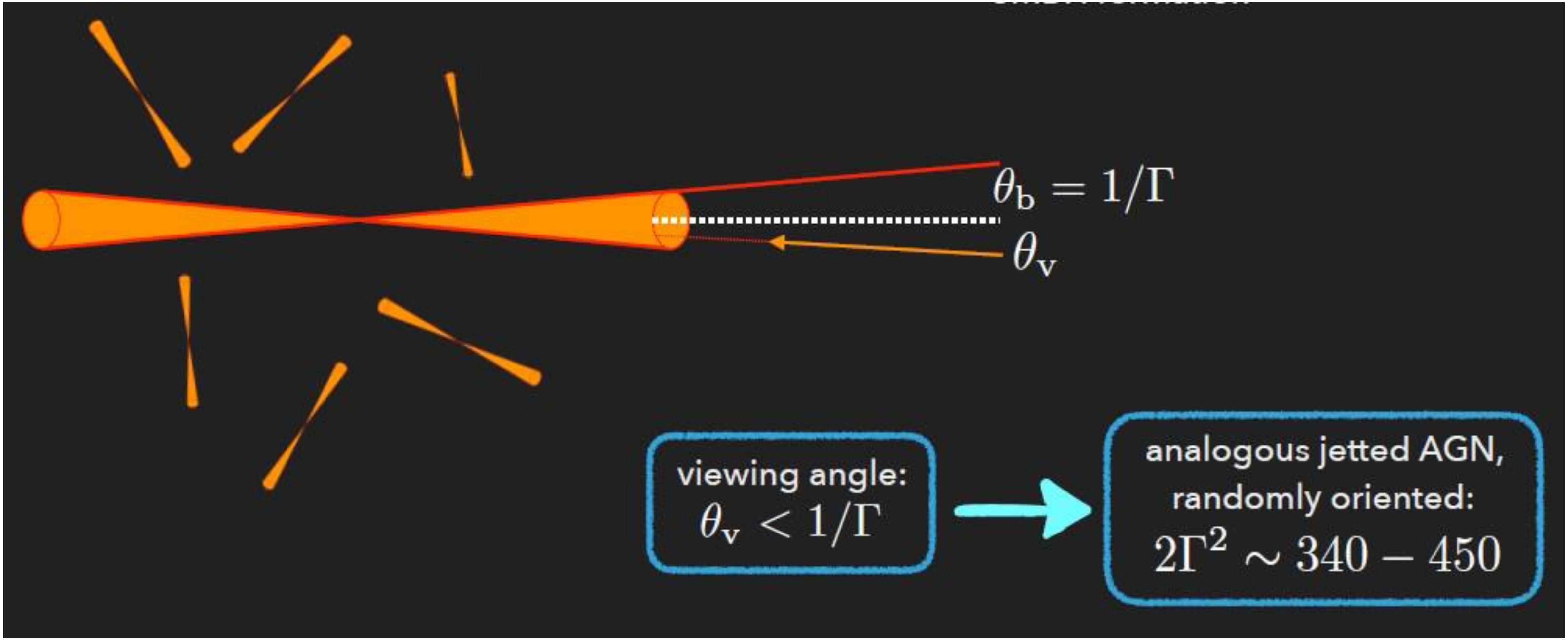
Surprise #1: one of the best candidates with blazar SED turns out to be a double-lobed radio source with unbeamed inner jet and a large viewing angle!

C also coincides with the SDSS optical position of the quasar

J1420+1205 (**z**=4.03)
Surprise #2: a core (unbeamed) and a heavily resolved extended lobe to NW – far from being a blazar!



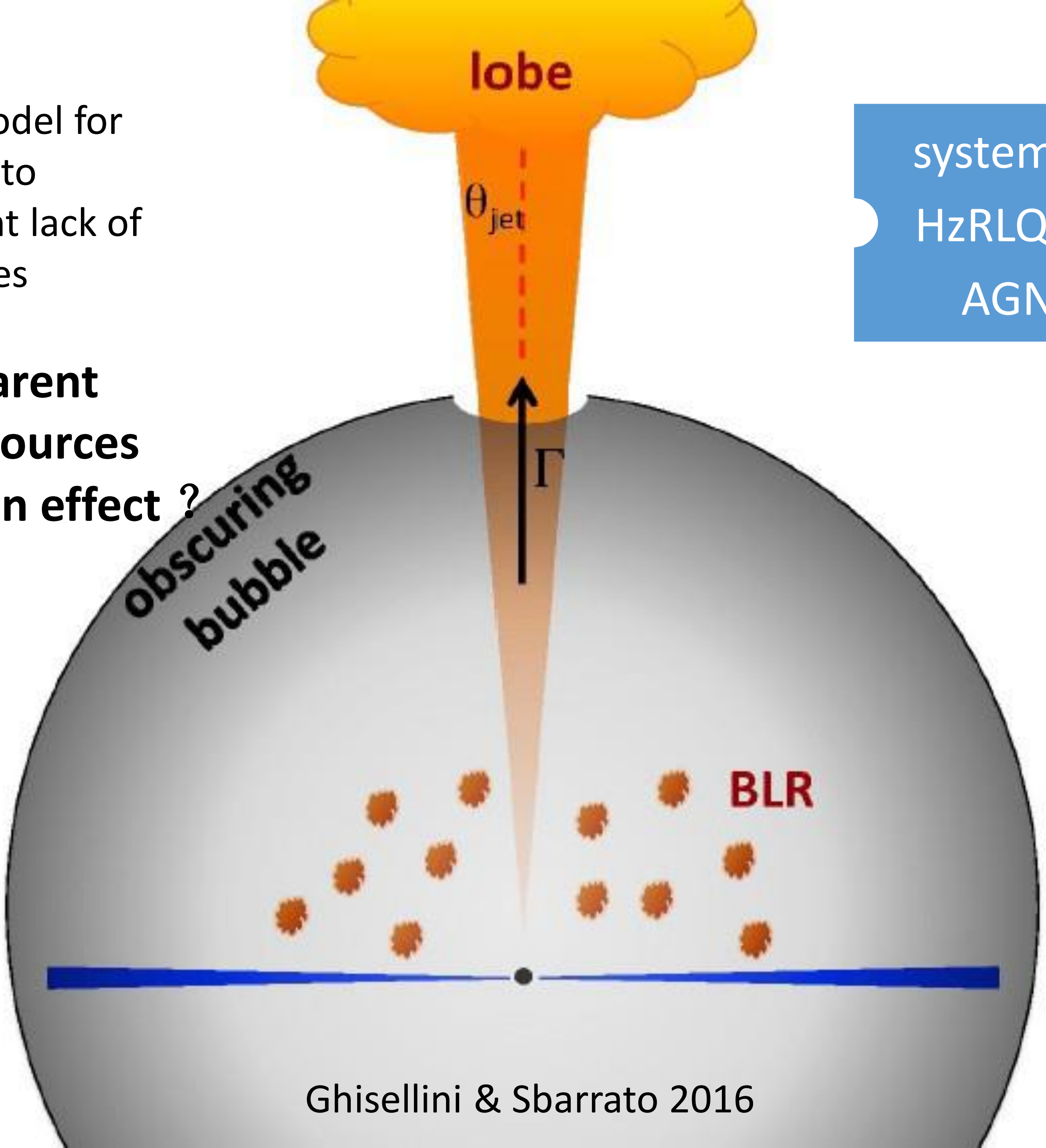
Also this finding questions the X-ray identification of high-z blazars



Blazars are sub-class of AGN, dominate the flux density limited survey
Correct understanding of the parent population of unbeamsed source
The current observations suggest that blazars are over-abundant, or unbeamed sources are less than expected

An obscuring bubble model for high-z AGN is proposed to account for the apparent lack of unbeamed jetted sources

But how is the apparent lack of unbeamed sources affected by selection effect？

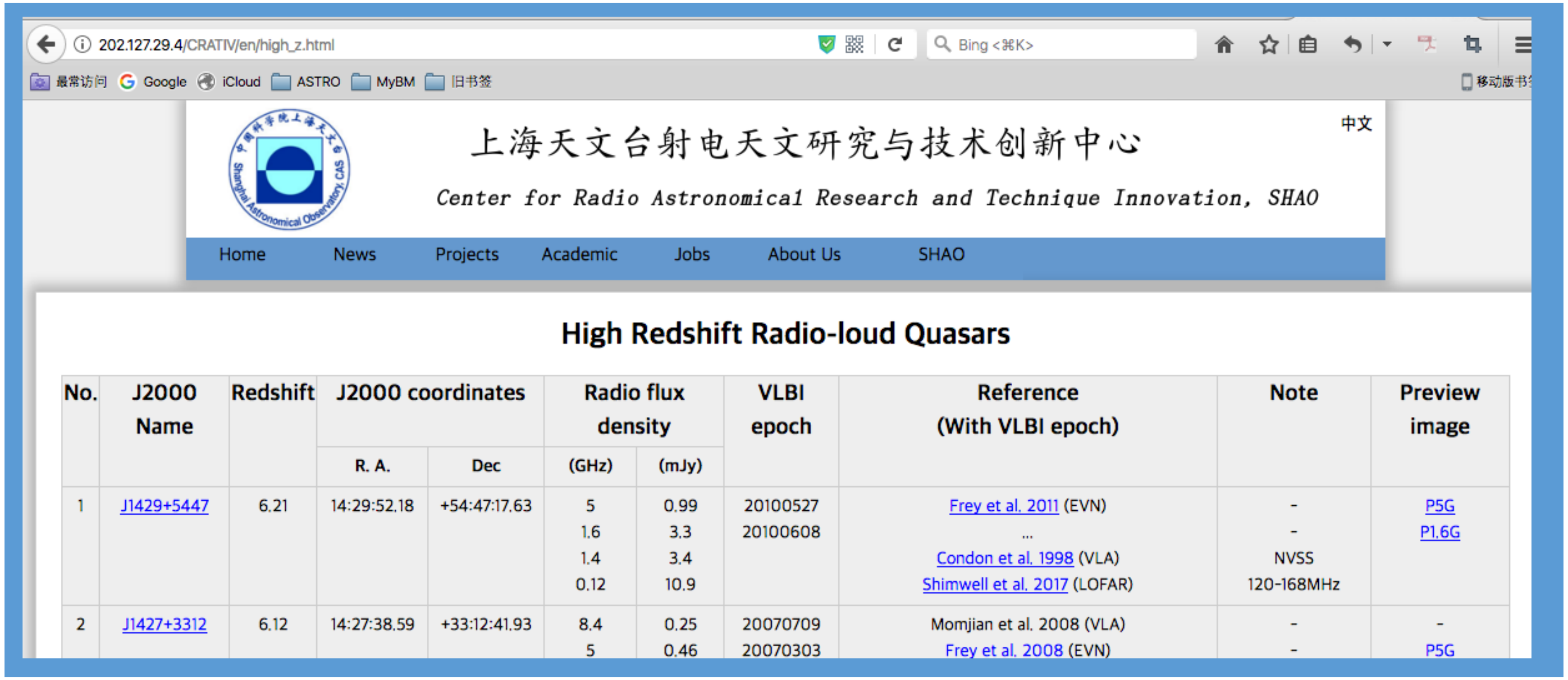


Ghisellini & Sbarrato 2016

systematic search of HzRLQs (blazar-type AGN) is needed

From case study to sample statistics

HzRLQs (z>4) catalog



202.127.29.4/CRATIV/en/high_z.html

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High Redshift Radio-loud Quasars

No.	J2000 Name	Redshift	J2000 coordinates		Radio flux density		VLBI epoch	Reference (With VLBI epoch)	Note	Preview image
			R. A.	Dec	(GHz)	(mJy)				
1	J1429+5447	6.21	14:29:52.18	+54:47:17.63	5 1.6 1.4 0.12	0.99 3.3 3.4 10.9	20100527 20100608	Frey et al. 2011 (EVN) ... Condon et al. 1998 (VLA) Shimwell et al. 2017 (LOFAR)	- - NVSS 120-168MHz	P5G P1.6G
2	J1427+3312	6.12	14:27:38.59	+33:12:41.93	8.4 5	0.25 0.46	20070709 20070303	Momjian et al. 2008 (VLA) Frey et al. 2008 (EVN)	- -	- P5G

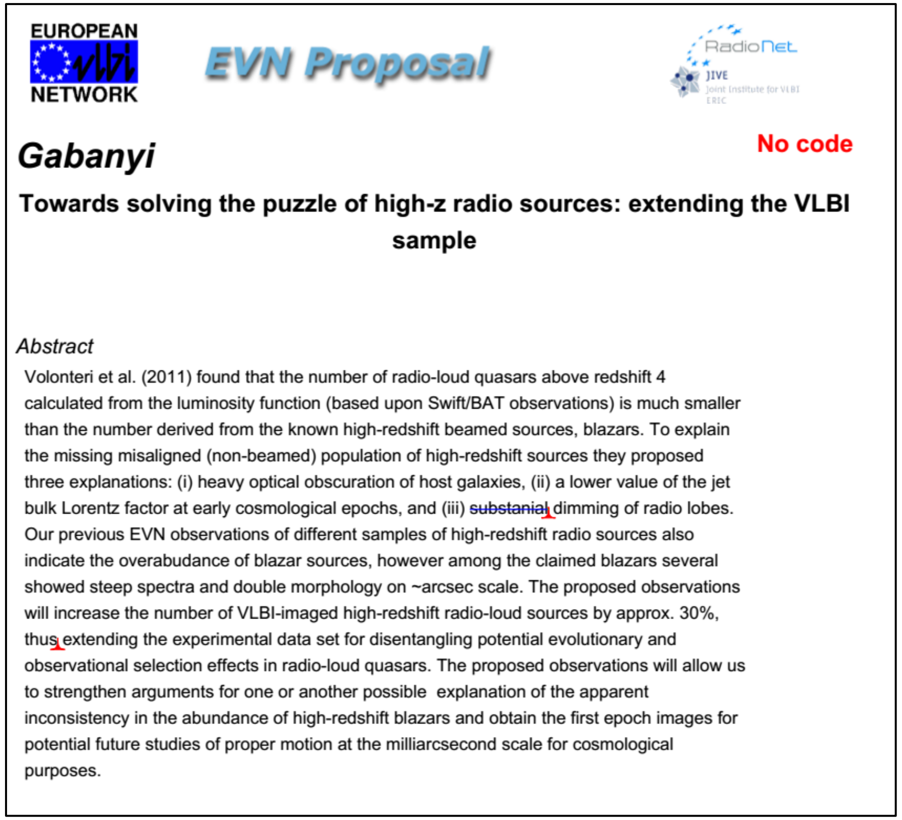
68 z>4 radio loud quasars, among which 35 have VLBI images

http://202.127.29.4/CRATIV/en/high_z.html

Contact: T. An, Y.-K. Zhang

Increase sample size

- Need a large sample to derive statistically meaningful results
- Need increase VLBI data of HzRLQs at z>4



EUROPEAN VLBI NETWORK

EVN Proposal

RadioNet
JIVE

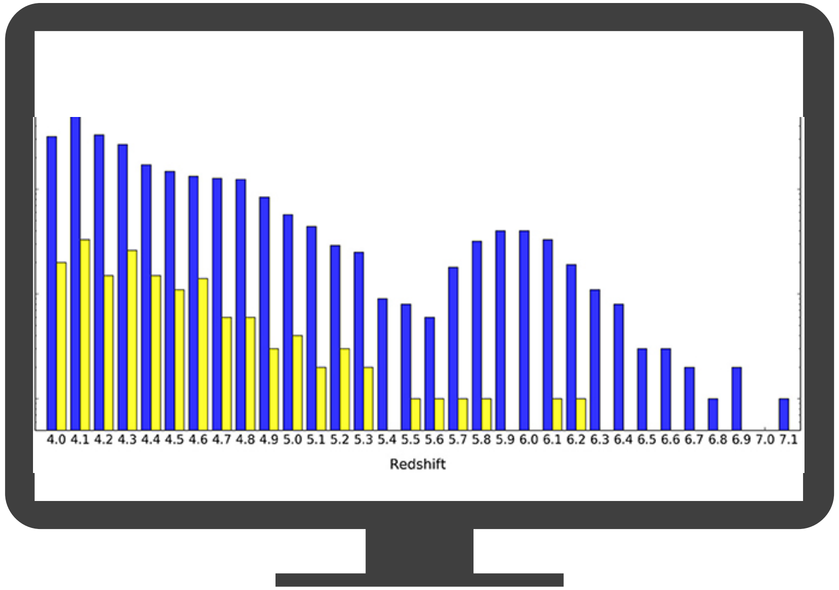
No code

Gabanyi

Towards solving the puzzle of high-z radio sources: extending the VLBI sample

Abstract

Volonteri et al. (2011) found that the number of radio-loud quasars above redshift 4 calculated from the luminosity function (based upon Swift/BAT observations) is much smaller than the number derived from the known high-redshift beamed sources, blazars. To explain the missing misaligned (non-beamed) population of high-redshift sources they proposed three explanations: (i) heavy optical obscuration of host galaxies, (ii) a lower value of the jet bulk Lorentz factor at early cosmological epochs, and (iii) substanial dimming of radio lobes. Our previous EVN observations of different samples of high-redshift radio sources also indicate the overabundance of blazar sources, however among the claimed blazars several showed steep spectra and double morphology on ~arcsec scale. The proposed observations will increase the number of VLBI-imaged high-redshift radio-loud sources by approx. 30%, thus extending the experimental data set for disentangling potential evolutionary and observational selection effects in radio-loud quasars. The proposed observations will allow us to strengthen arguments for one or another possible explanation of the apparent inconsistency in the abundance of high-redshift blazars and obtain the first epoch images for potential future studies of proper motion at the milliarcsecond scale for cosmological purposes.



Cross-matching FIRST/NVSS & SDSS

170 z>4 radio-detection

Contact: Sandor Frey, Krisztina Perger

HzRLQs - cosmology

1) Angular size – redshift relation

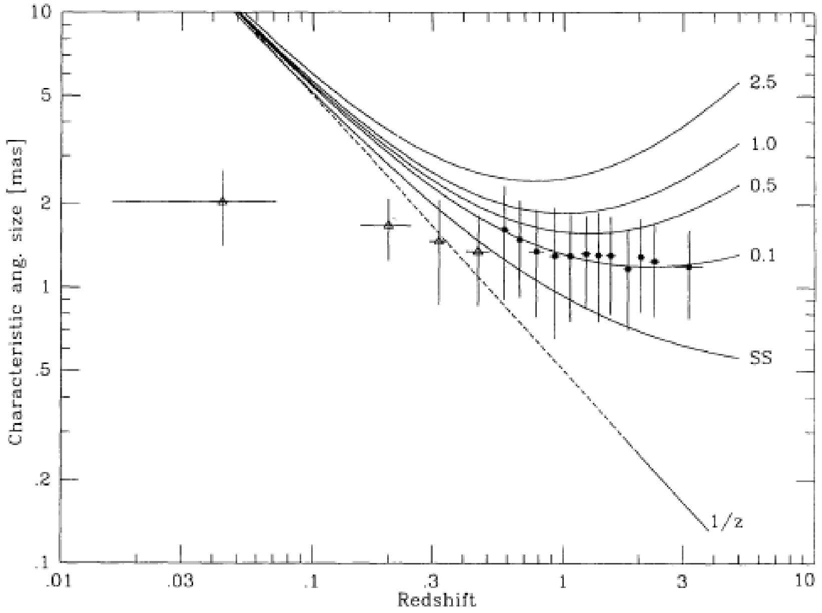


FIG. 5.—Characteristic angular size versus redshift. Open triangles corre-
spond … correspond to sources
with … viation values for a
group … resent cosmological
mode … r curves), the steady
state

Kellermann 1993, Nature

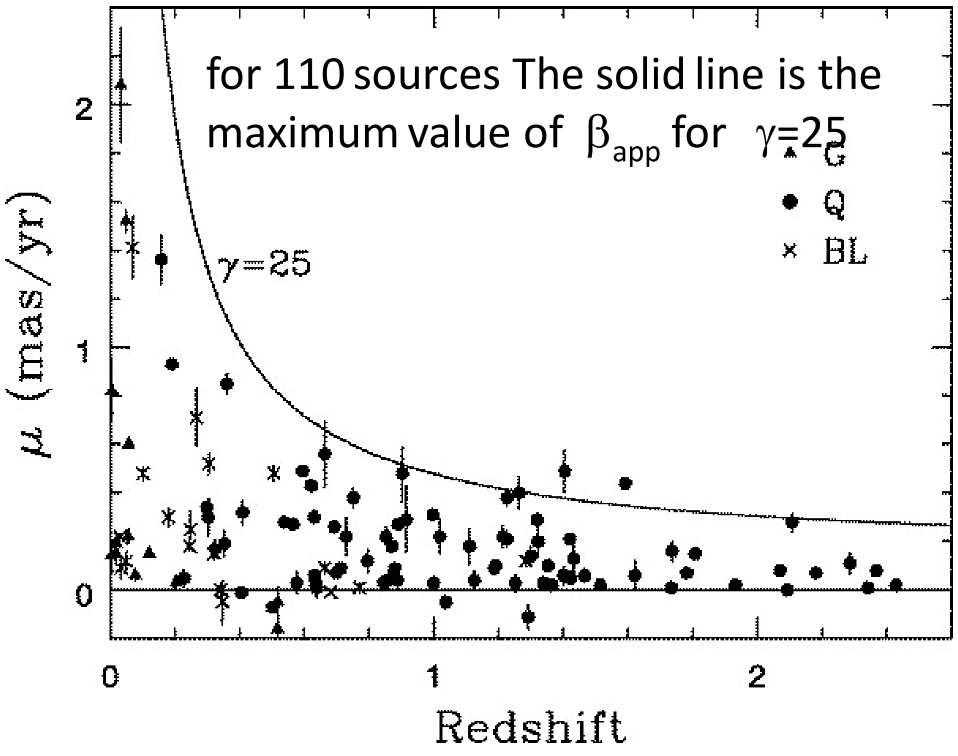
Guivits et al. (1994), *ApJ*

2) μ–z diagram

Kellermann et al. (2004),

ApJ **609**, 539

for 110 sources The solid line is the maximum value of β_{app} for γ=25



The first proper motion in HzRLQ

Over >7 years, component motions could be revealed (0.09 – 0.11 mas/yr)

Apparent superluminal speeds (11 – 14*c*)

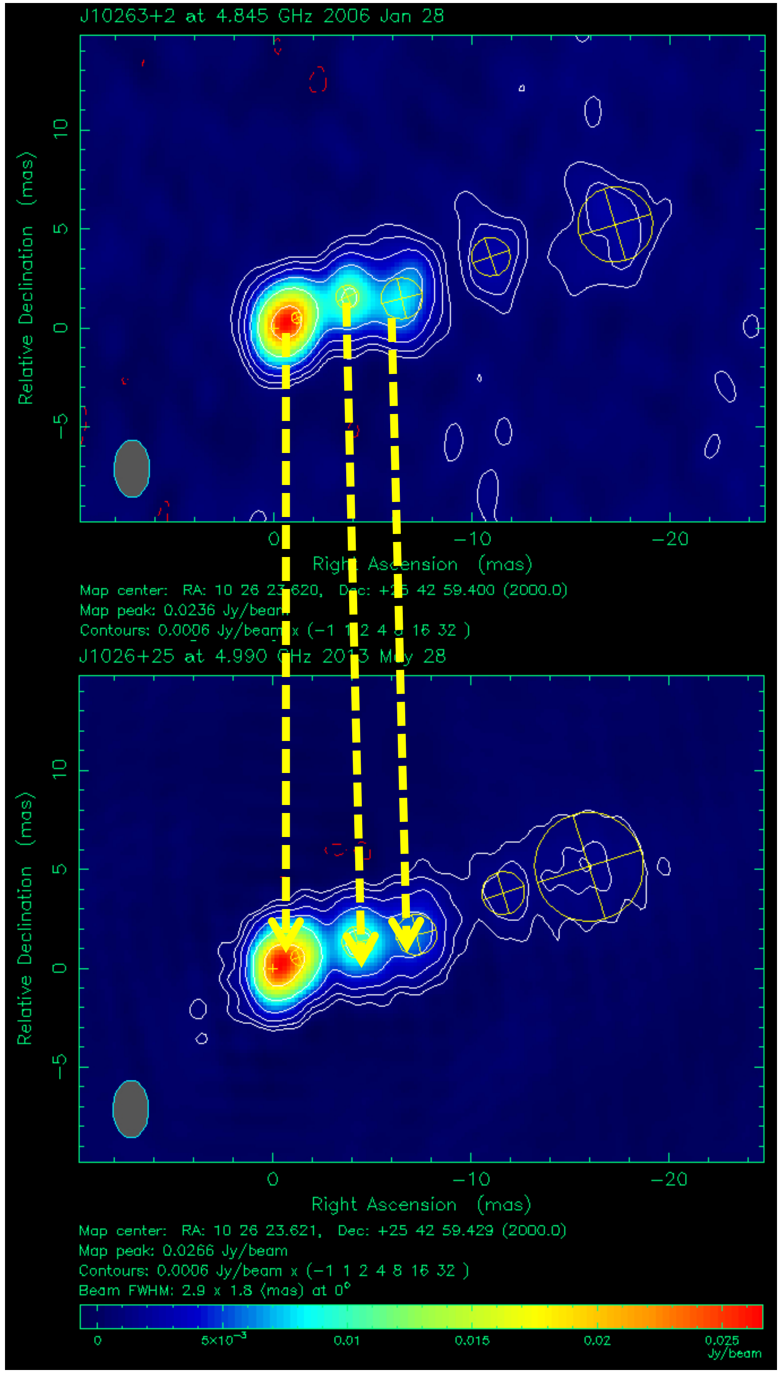
The moderate component proper motions are consistent with the cosmological interpretation of redshifts

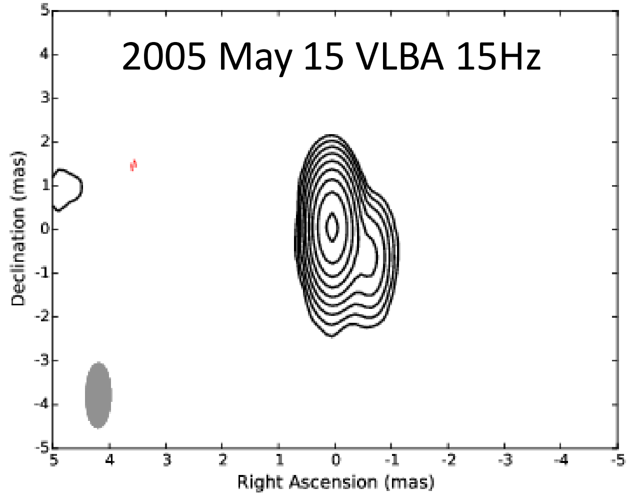
VLBA, 2006 Jan 28

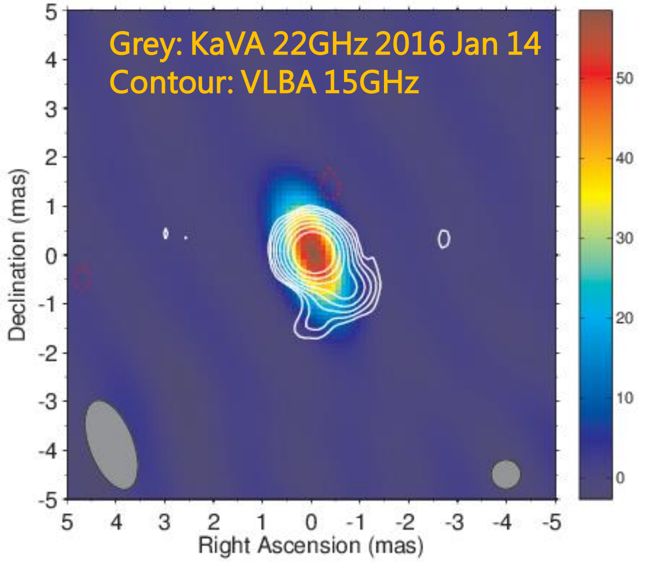
Helmboldt et al. 2007

The second most distant one is **J1026+2542** at z=5.266

EVN, 2013 May 28
Frey et al. 2015







- Morphology: core+jet at early epochs (2004–2005).
- Brightness temperature: $T_B = (0.12 - 2.6) \times 10^{11}$ K; low tail end of blazars T_B ($\sim 10^{12}$ K); Doppler factor: $\delta = T_B / T_{B,int.} \sim 4$.
- Spectrum:
  - $\alpha_{1.4-8.4\ GHz} = 0.2$ (core), $\alpha_{15-43\ GHz} = -1.0$ (jet).
  - Turnover $\sim$ 10 GHz = 64.7 GHz in source frame.
  - Projected size $\sim$ 5 pc, morphology, turnover consistent with high frequency peakers.
  - Possible young AGN in early universe.
- Compact beamed morphology with flat core: blazar.
- Variability:
  - 15 GHz OVRO based light curve from 2009 - 2016: $\Delta t \sim 4.3$ yr; compact variable region size $\Delta r \sim c\Delta t = 1.3$ pc.
  - Δt_{kpc}: radiation pressure balancing large scale accretion $\sim$ 260 kpc.
  - Δt_{pc}: low energy broad distribution of electrons injected into jet.

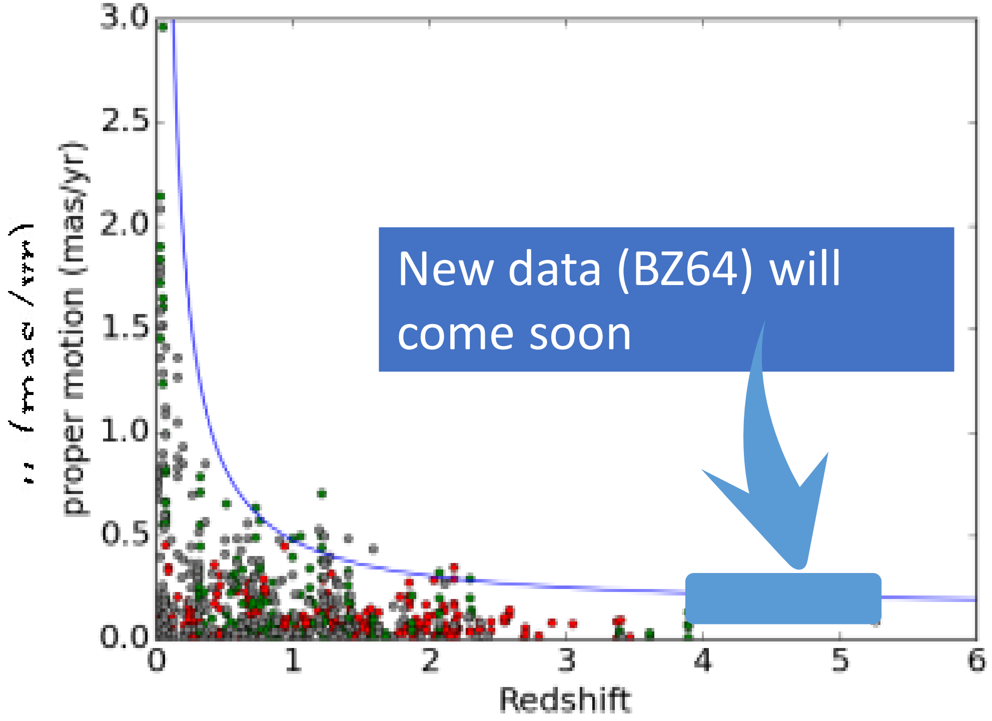
0906+6930 – the brightest blazar at z>5

- EAVN with higher sensitivity and better uv coverage is desirable
- the best target to determine Jet proper motion at z>5 – VLBA proposal (submitted)

Proper motion of HzRLQs

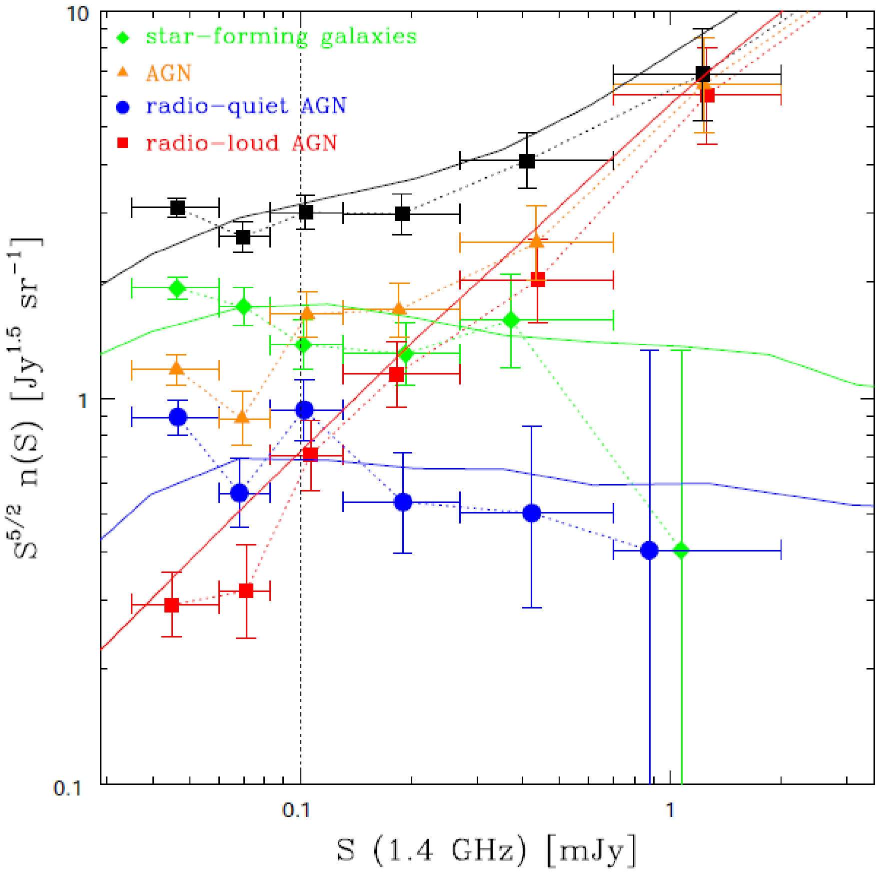
Are these jets different from blazar jets in local Universe?

Can be used to test cosmology model



Redshift

3) Luminosity function



log N - log S test (e.g. Ajello et al. 2009, Padovani 2016)

1. Distribution of source counts above an increasing flux density.
2. Generally modelled as a power law:
$N = A\, S_v^{-beta}$ so that
$\log N = \log A - beta \log S_v$.

Advantages of high redshift sample (z ~ 4 - 6) in the context of estimating the radio luminosity function (RLF):

- Growing statistical sample with future additions.
- Comparison with modelled source counts distribution: constrain parameters of RLF and its evolution.
- RLF shape: pure luminosity evolution or luminosity dependent density evolution: merger and accretion, black hole mass function and growth.

- Conclusion
  - Some of the claimed high-z blazar candidates are not blazars
    - Large influence on the inferred parent radio AGN population and models
    - SED modelling based on X-ray data : need to think again
  - Need a larger sample to confirm the blazar nature
  - We don’t fully understand selection effect of HzRLQ yet
    - Because known highly-beamed sources seem over-abundant
    - unbiased search of evolved HzRLQs in LOFAR and MWA bands

Prespective of EAVN/EATING in HzRLQ study

- KaVA -> EAVN : an increase of sensitivity, resolution, and uv coverage
- Phase-reference EAVN enables observe weak sources
- Adding FAST to EAVN/EATING (2.3, 5, 8.4GHz) opens a new window of AGN study, esp. the distant radio-loud AGN (with extended emission)

THANK YOU