High Resolution Studies of 4C+43.15 with International LOFAR

Leah Morabito

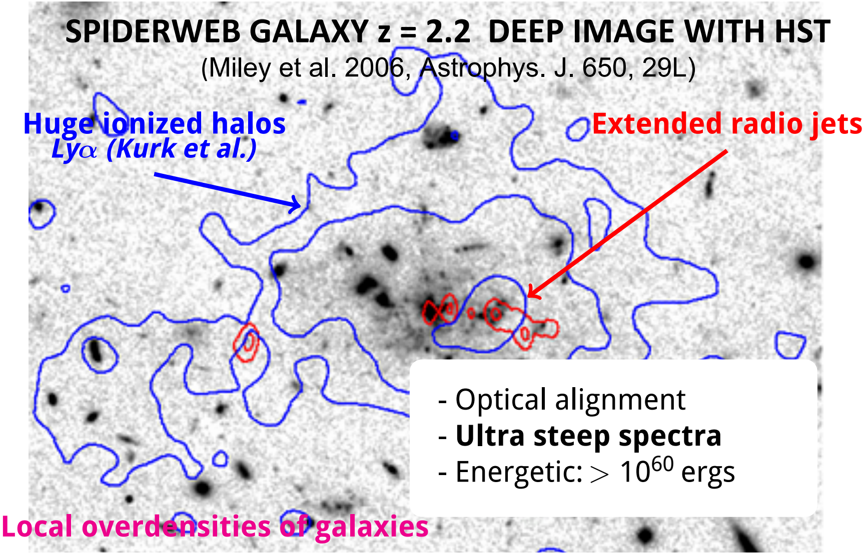
Adam Deller, Javier Moldon, George Miley, Huub Röttgering,
+ LB working group

Sterrewacht Leiden

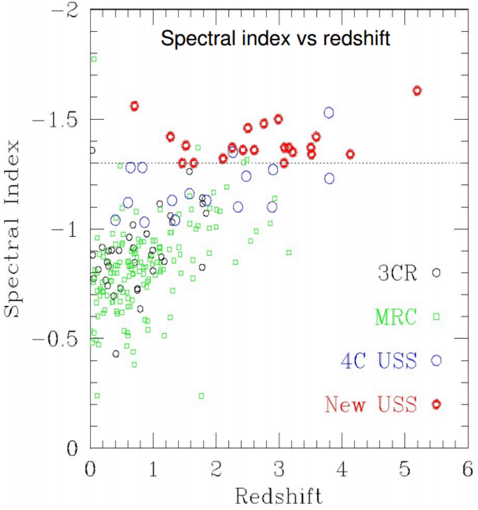
Leiden Observatory

LOFAR Science Workshop
6 April 2016

Characteristics of a high-z radio galaxy



Ultra Steep Spectra (USS)



De Breuck et al. (2000)

Ultra Steep Spectra (USS)

Why do high-z sources have USS?

* Concavity at lower frequencies + K-correction
  - Higher redshift → probe higher rest frequencies
    Afonso et al. (2011), Miley & De Breuck (2008), Klamer et al. (2006), Athreya et al. (1998)
* Higher ambient density
  - Reduce bulk velocity → steeper spectra
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* Luminosity–α relation + observational flux limits
  - Higher L → more powerful jets → steeper spectra
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External: environmental, observational

vs.

Internal: particle acceleration processes

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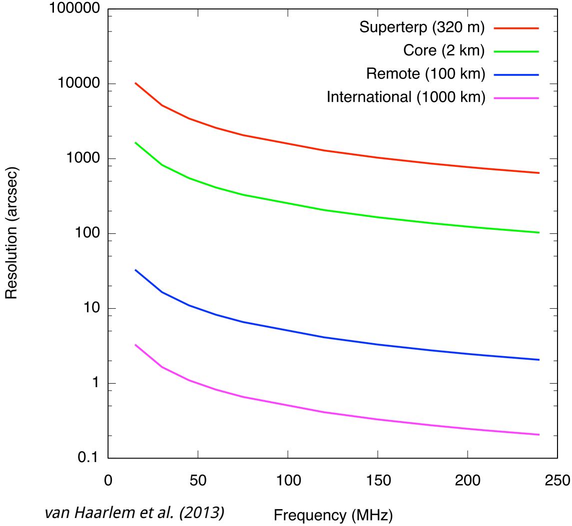
External: environmental, observational

vs.

Internal: particle acceleration processes

To resolve: need <u>low frequencies</u> & <u>high resolution</u>

USS Survey: Instruments



van Haarlem et al. (2013)

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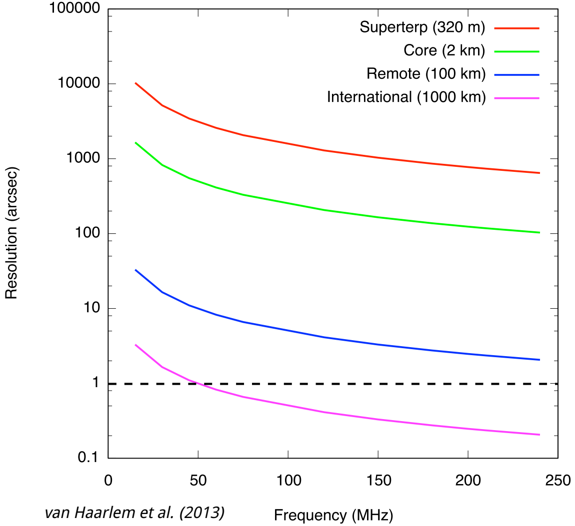

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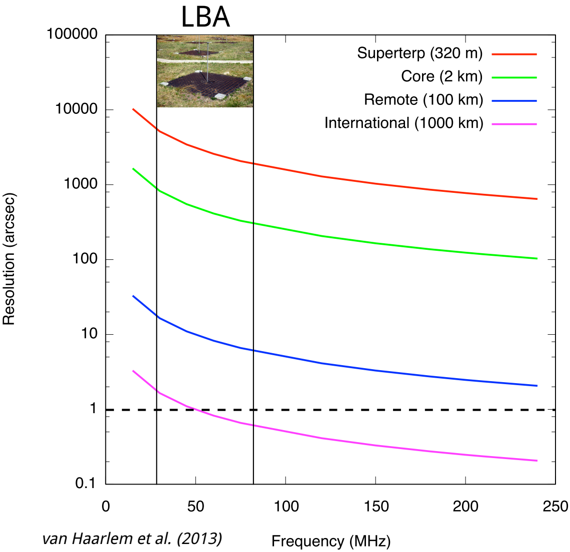

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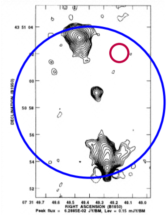

Carilli et al. (1997)

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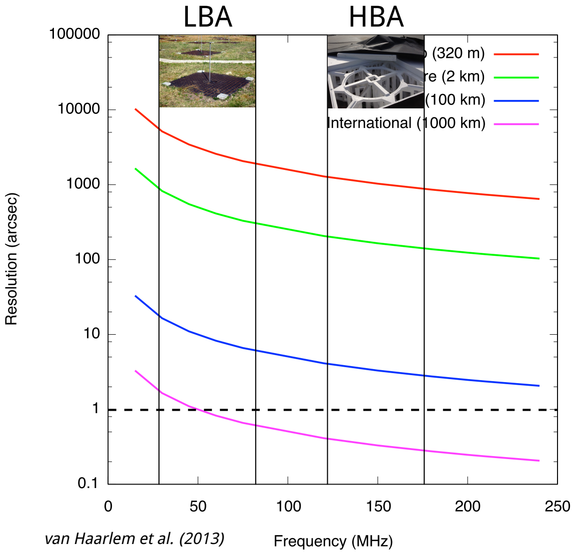

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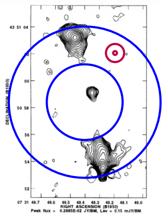

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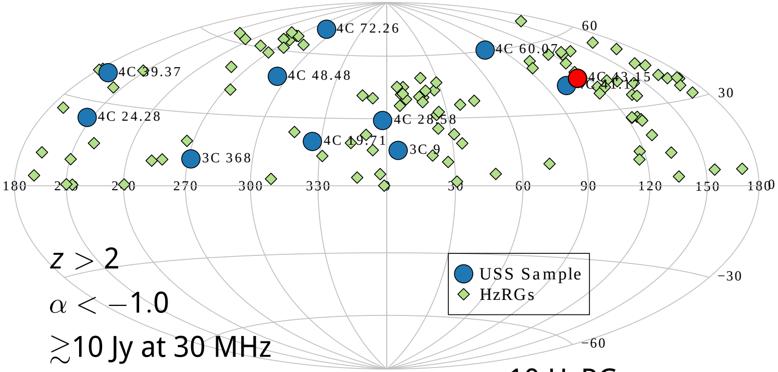


$z > 2$

$\alpha < -1.0$

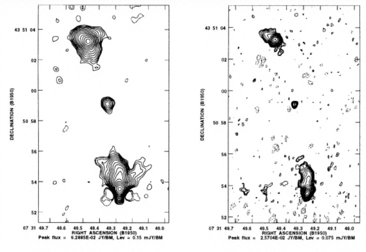
$\gtrsim$10 Jy at 30 MHz

LAS $> 5''$

10 HzRGs
+ 1 low-z analog

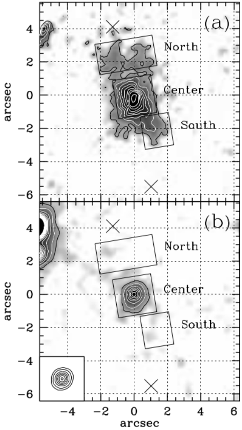
Introduction to 4C+43.15

higher radio frequencies



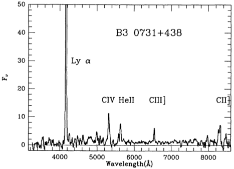
Carilli et al. (1997)

Hα-ionised cones



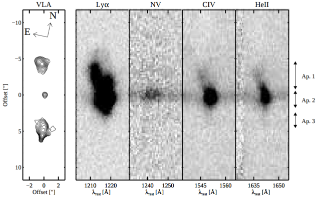
Motohara et al. (2000)

redshift 2.429



McCarthy (1991)

extended Ly-α



Villar-Martín et al. (2003)

Calibration Strategy

What are some of the issues?

Sensitivity	LBA has poor signal to noise
Clocks	All stations are connected, only CS are on the same clock
Correlator Model	Baselines up to 1300 km lead to geometric errors/delays
Ionosphere	Can be wildly varying, larger differential impact on long baselines
Calibrators	Need compact, bright sources at low-ν ... very few known

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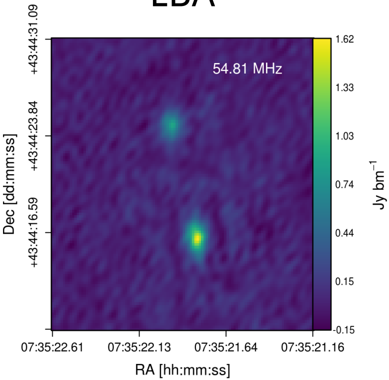
Particular attention must be given to:

- Signal to noise on individual baselines (phased up core)
- Frequency dependence (narrower $\Delta\nu$ – model $1/\nu$ behaviour)

Results

LBA



4.25 hrs, $\Delta\nu = 15.6\,$MHz

3C 147 Calibrator

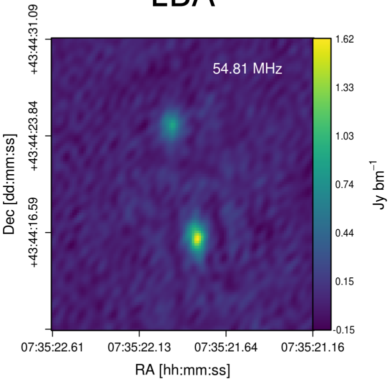
rms $\sim$ 40 mJy bm^{-1}

2.2 $\times$ theoretical noise!

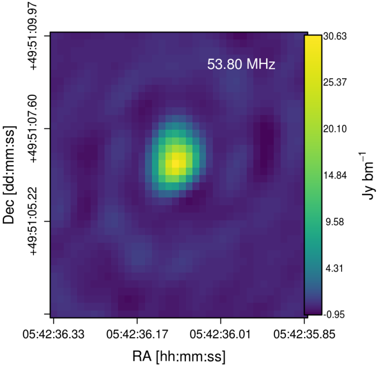
HBA

Results

LBA



3C 147



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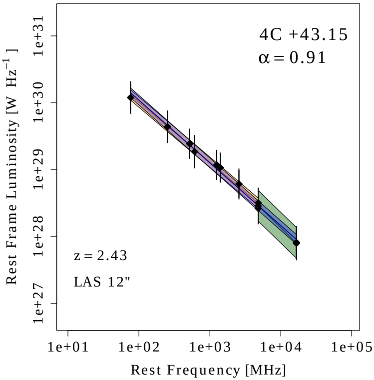
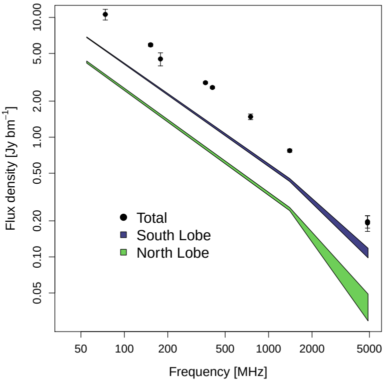
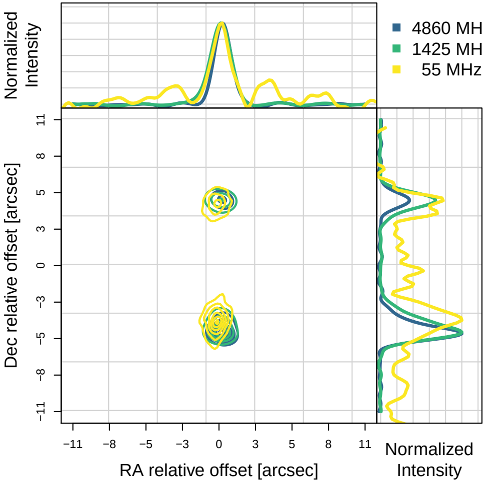
Results: Integrated spectra





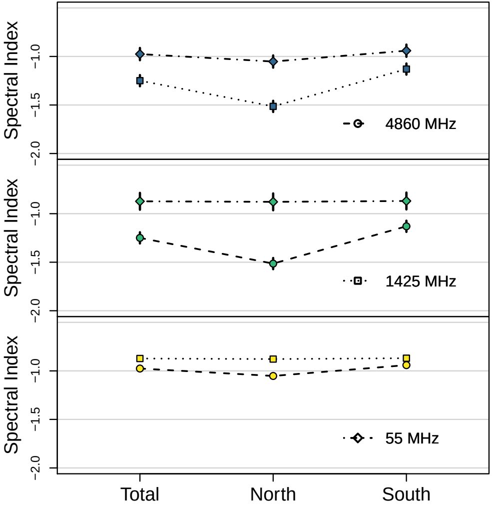
Overall behaviour of lobes qualitatively similar, indicating
an internal process drives the spectral index

Spatially Resolved



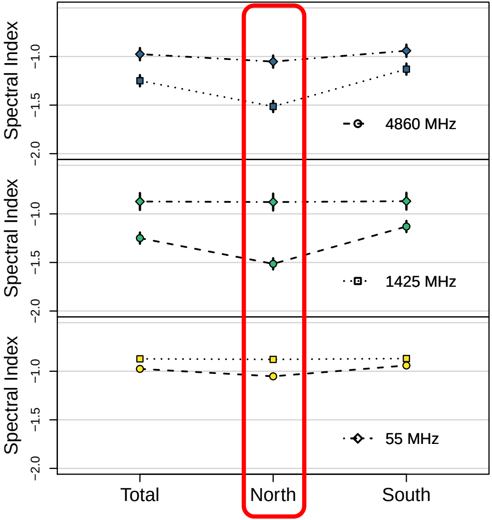
1. Morphology along jet axis evolves with frequency
   - lower frequencies closer to host galaxy
     Carilli et al. (1991)
2. Relative lobe ratio evolves with frequency

Spatially Resolved

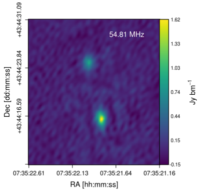


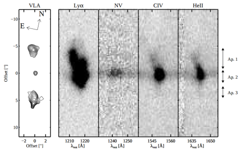
Spatially Resolved

Steeper α at high ν

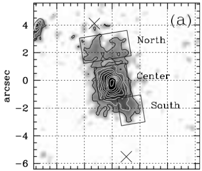


Interpretation





Villar-Martín et al. (2003)



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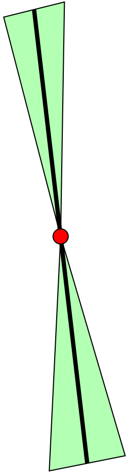

Northern Lobe

- More extended Lyα, Hα
- Dimmer radio lobe
- Steeper spectrum

Southern Lobe

- Higher relative Lyα
- Brighter radio lobe
- Flatter spectrum

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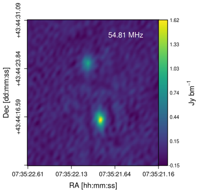

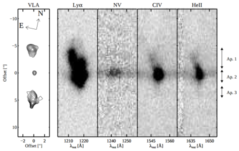

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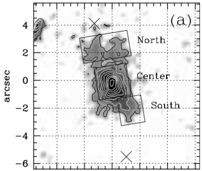

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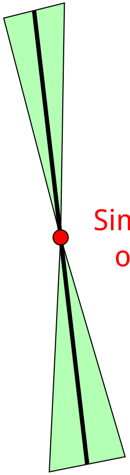

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Still To Do:
Simple modelling to estimate orientation / environment contributions

Southern Lobe

- Higher relative Lyα
- Brighter radio lobe
- Flatter spectrum

Summary

Low frequency spectral index of lobes is similar, which implies similar initial conditions for particle acceleration

1. Steepness of spectral index likely from internal cause

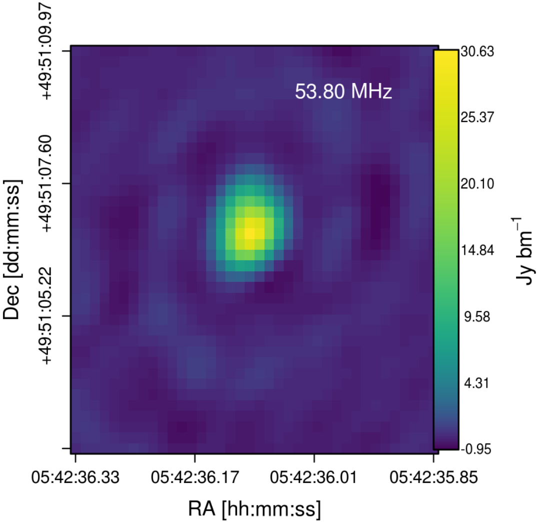
Integrated spectra of lobes show largest $\Delta\alpha$ between lobes at highest frequencies

2. Northern lobe/jet has more interaction with environment

Future work:
process more of USS survey to identify trends

Extra Slides

3C 147



53.80 MHz
+49:51:09.97
+49:51:07.60
+49:51:05.22
Dec [dd:mm:ss]
05:42:36.33
05:42:36.17
05:42:36.01
05:42:35.85
RA [hh:mm:ss]
30.63
25.37
20.10
14.84
9.58
4.31
-0.95
Jy bm^{-1}

USS Survey

Northern hemisphere, $z > 2$

Ultra steep spectra, $\alpha < -1.0$

Brighter than 10 Jy at 30 MHz

LAS $> 5''$, simple morphology

Source	z	S_{178} [Jy]	α_{178}^{1400}	S_{30} [Jy]	LAS
4C 41.17	3.792	2.7	-1.12	19.84	$13''$
3C 9	2.02	19.4	-1.06	128.09	$9.6''$
3C 368*	1.131	15	-1.2	127.07	$11''$
4C 39.37	3.221	5.3	-1.47	72.52	$8''$
4C 60.07	3.791	3.1	-1.45	40.72	$9''$
4C 72.26	3.537	3.2	-1.15	24.91	$15.4''$
4C 28.58	2.905	2.9	-1.17	23.11	$14.5''$
4C 24.28	2.889	4.8	-1.05	30.87	$6''$
4C 43.15*	2.429	4.5	-0.95	20.61	$10.8''$
4C 48.48	2.343	3	-1.02	18.44	$14''$
4C 19.71	3.592	2.5	-0.96	13.89	$8.9''$

Delays

Table 4. Approximate delay contributions at 140 MHz to a 700 km baseline.

Effect	Delay	Timescale
Non-dispersive		
Correlator model error	$\sim$75 ns	24 h (periodic)
Station clocks	$\sim$20 ns	$\sim$20 min
Source position offset (1.5″)	$\sim$ 15 ns	–
Dispersive		
Slowly varying ionosphere	$\sim$300 ns	$\sim$h
Rapidly varying ionosphere	$\gtrsim$10 ns	$\sim$10 min
Differential ionosphere (source elevation 60 deg)	5 ns/deg sep.	–

Moldon et al. (2015)