

Spectral indices in active galactic nuclei probed by Apertif and LOFAR

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Apertif imaging team

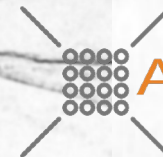
LOFAR Family Meeting

22-26 Sep 2025

Paris

ASTRON

Netherlands Institute for Radio Astronomy



APERTIF

APERTure Tile In Focus

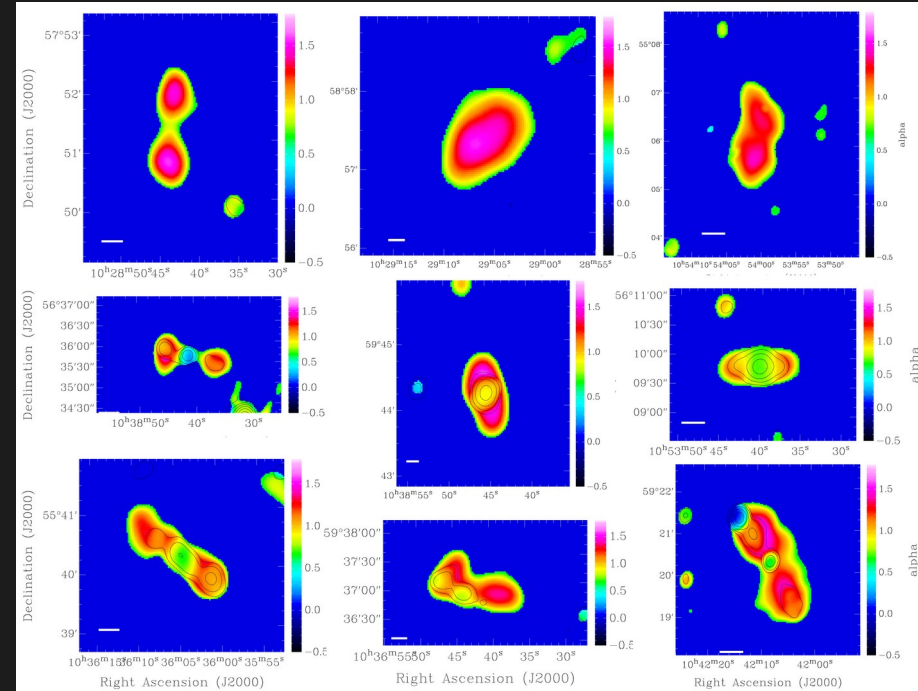
Spectral indices of radio sources

$$S_\nu \propto \nu^\alpha$$

Spectral index α characterizes radio emission:

- emission mechanisms
- source ages
- environments

In large samples median $\alpha \sim -0.75$

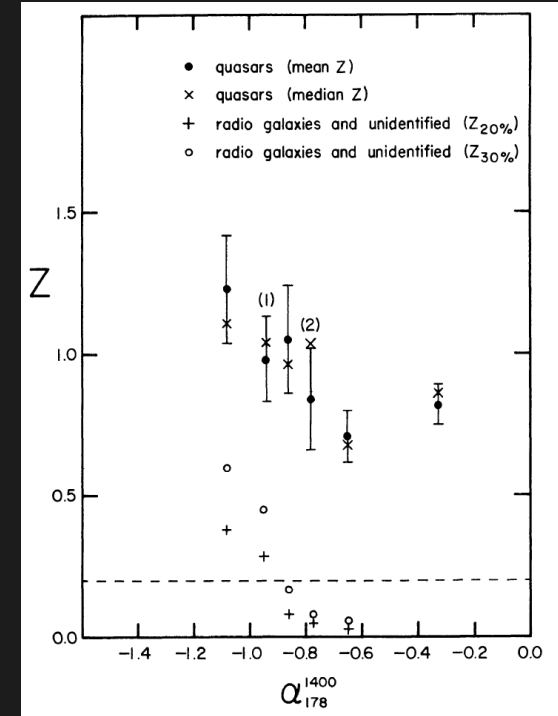


Morganti et al 2021

Spectral indices of AGN

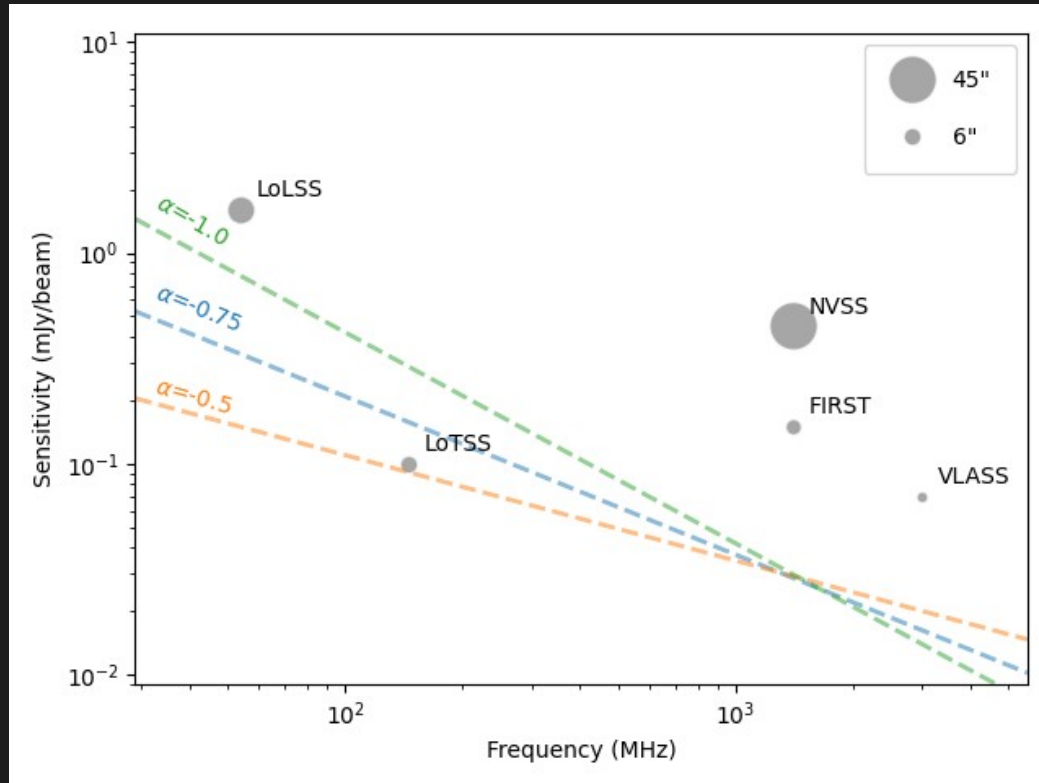
Higher redshift AGN tend to have steeper spectra

- What drives the observed correlation?
 - Environment?
 - IC-losses?
 - Intrinsic α -L relation?
 - ...
- How reliable is this for identifying HzRG?
- How do spectral index, luminosity, and source size relate in different samples?

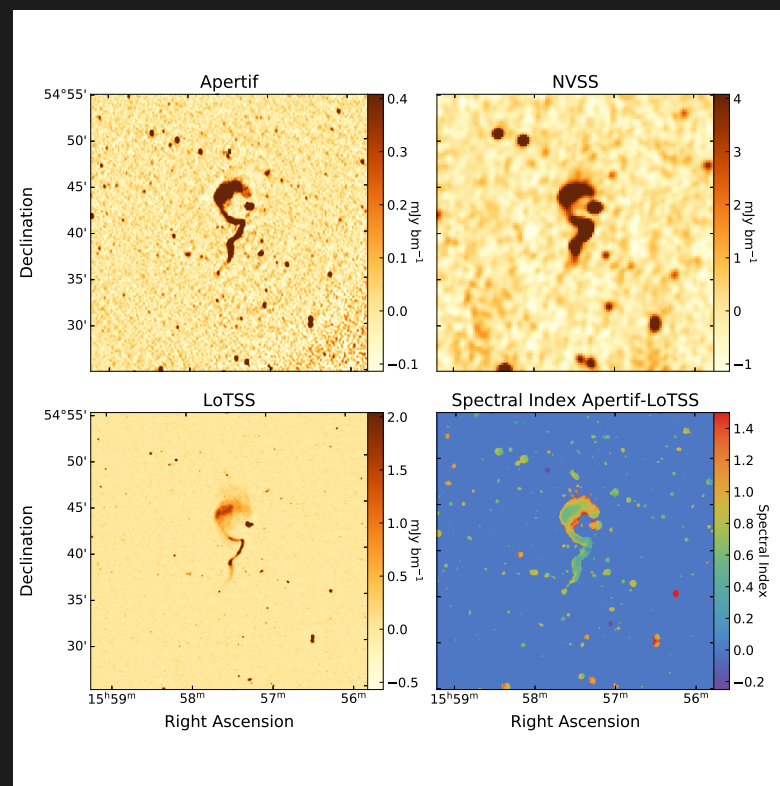
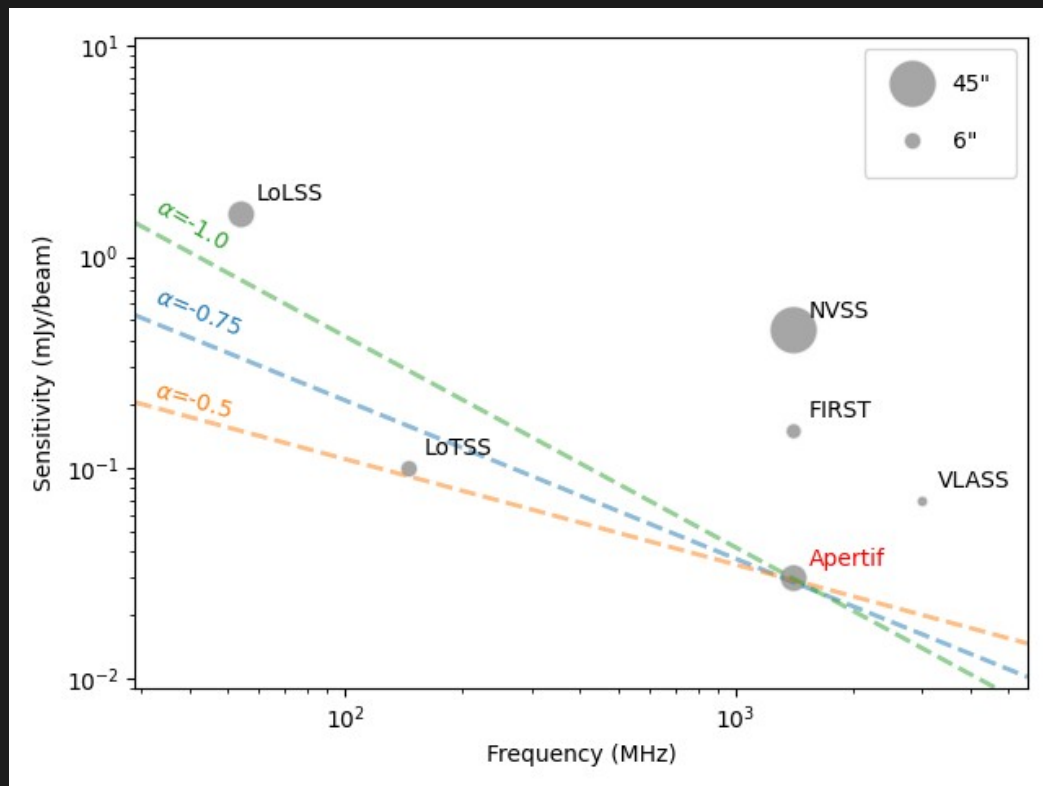


Bluementhal & Miley 1979

Northern sky surveys

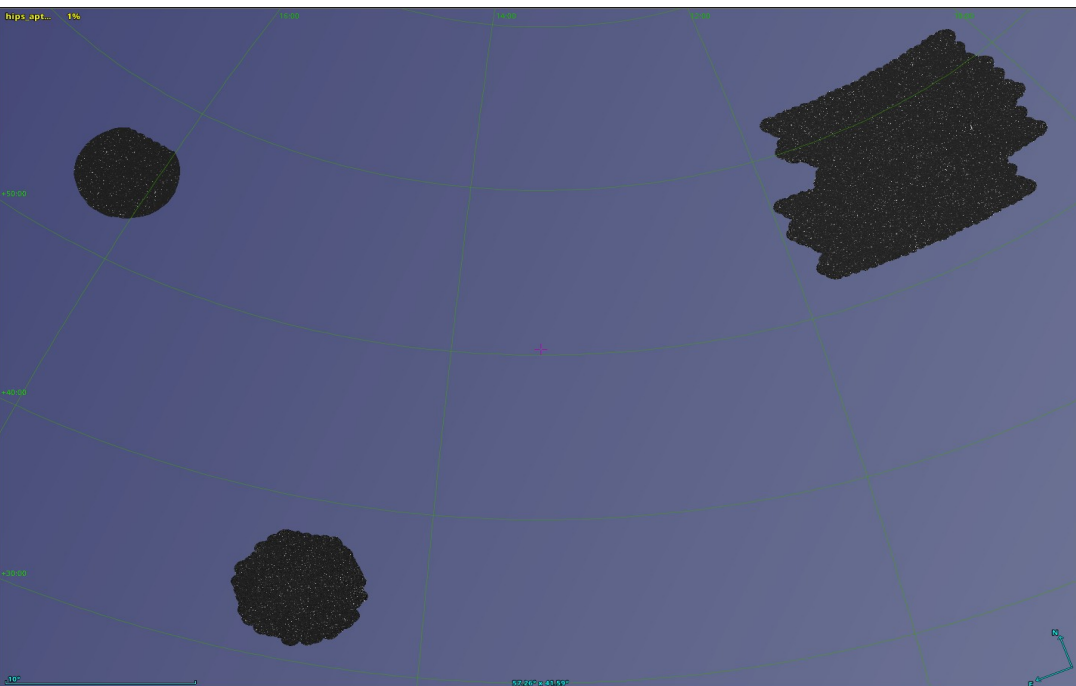


Apertif!



Apertif results

Field name	RA	DEC	Area [sq. deg.]	Resolution "	Image noise [$\mu\text{Jy beam}^{-1}$]	N sources
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Boötes	14:31:53	+34:27:44	27	23×11	40	8994
Elais North	16:10:20	+54:38:13	24	18×11	37	8526
Lockman Hole	10:57:40	+57:02:36	136	15×13	27	55166



Three continuum images
made with
direction-dependent calibration
+ catalogs
matching the LOFAR deep fields

False detections < 2%
Completeness ~ 0.3 mJy

Explore at
<https://vo.astron.nl>

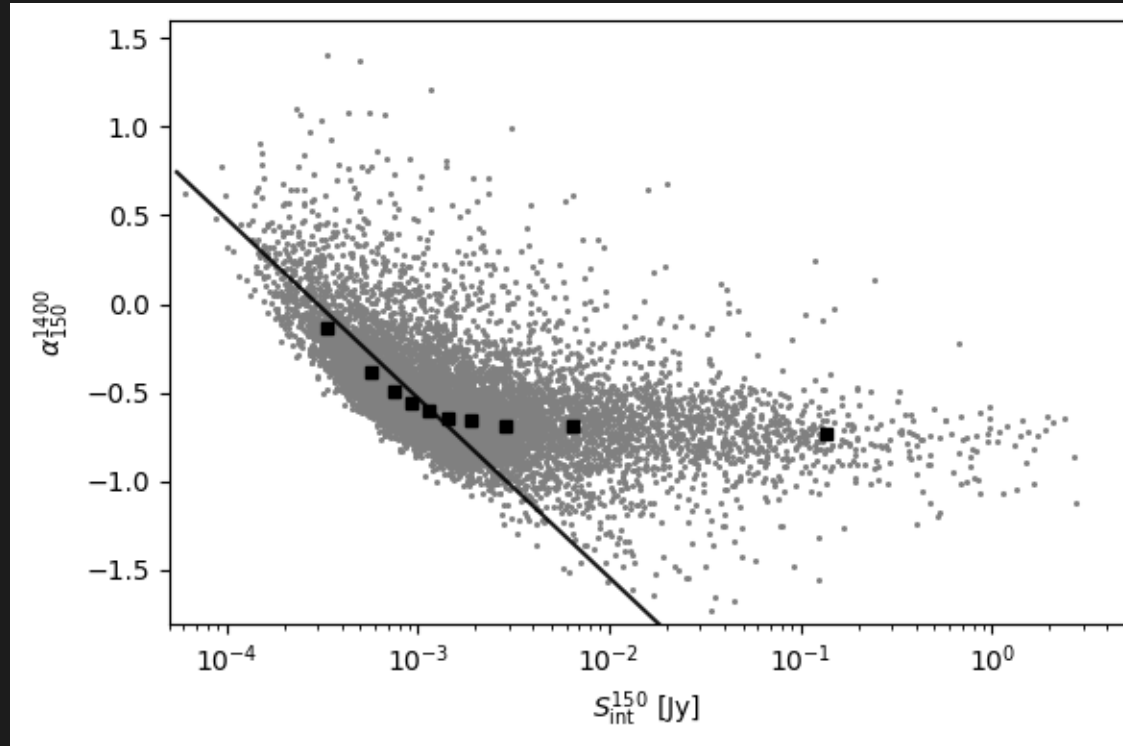
Value added LOFAR catalogs with redshifts
(Kondapally+ 2021, Duncan+ 2021)

<https://lofar-surveys.org/deepfields.html>

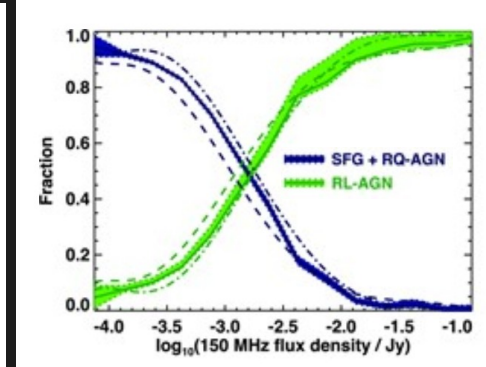
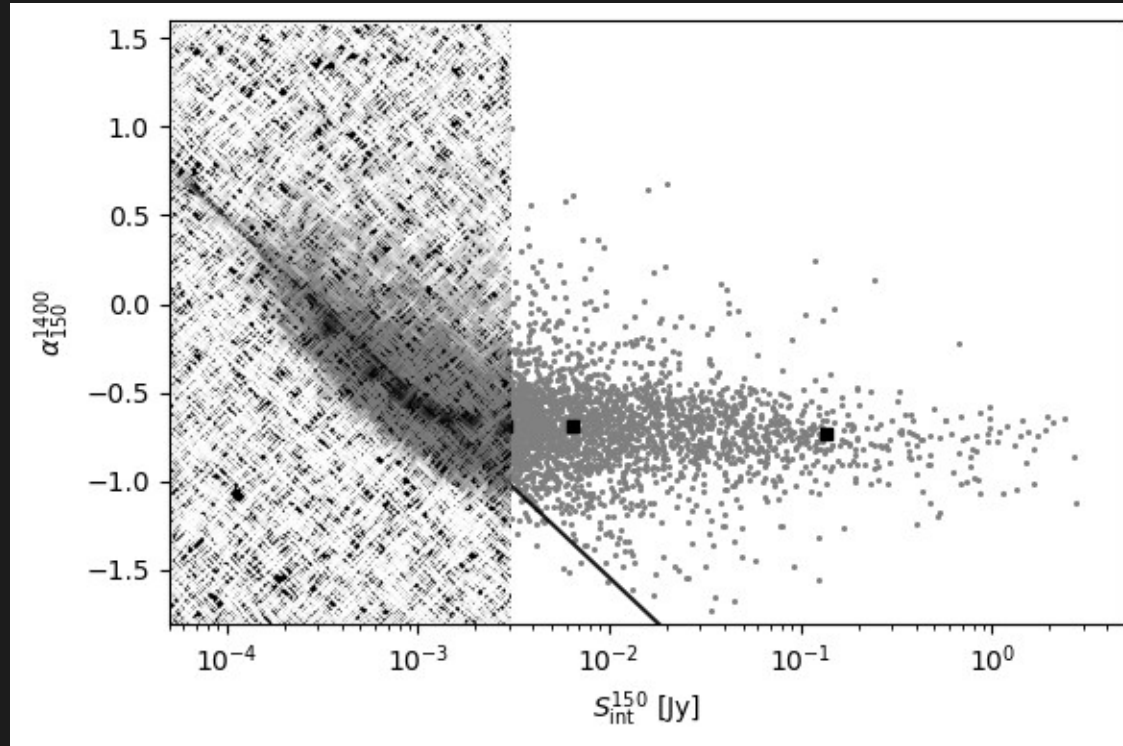
=> ~10 000 common Apertif-LOFAR radio sources (!)

Apertif name	LOFAR name	α_{150}^{1400}	σ_{α}	z	$\log L_{\nu}^{150}$ [W Hz ⁻¹]	D^{150} [kpc]
(1)	(2)	(3)	(4)	(5)	(6)	(7)
APTF_J143808+334640	ILTJ143808.71+334641.2	-0.60	0.13	1.30	24.3	23.53
APTF_J143812+343414	ILTJ143811.96+343416.4	-0.15	0.16	1.55	24.2	0.00
APTF_J143812+344012	ILTJ143812.31+344012.3	-0.65	0.07	0.13	22.8	2.60
APTF_J143814+352808	ILTJ143814.81+352808.2	-0.86	0.02	1.53	26.2	94.98
APTF_J143811+343104	ILTJ143811.18+343104.6	-0.43	0.11	0.68	23.8	0.00
APTF_J143811+343338	ILTJ143811.26+343341.3	-0.92	0.12	3.83	25.0	0.00

Spectral index and sensitivity



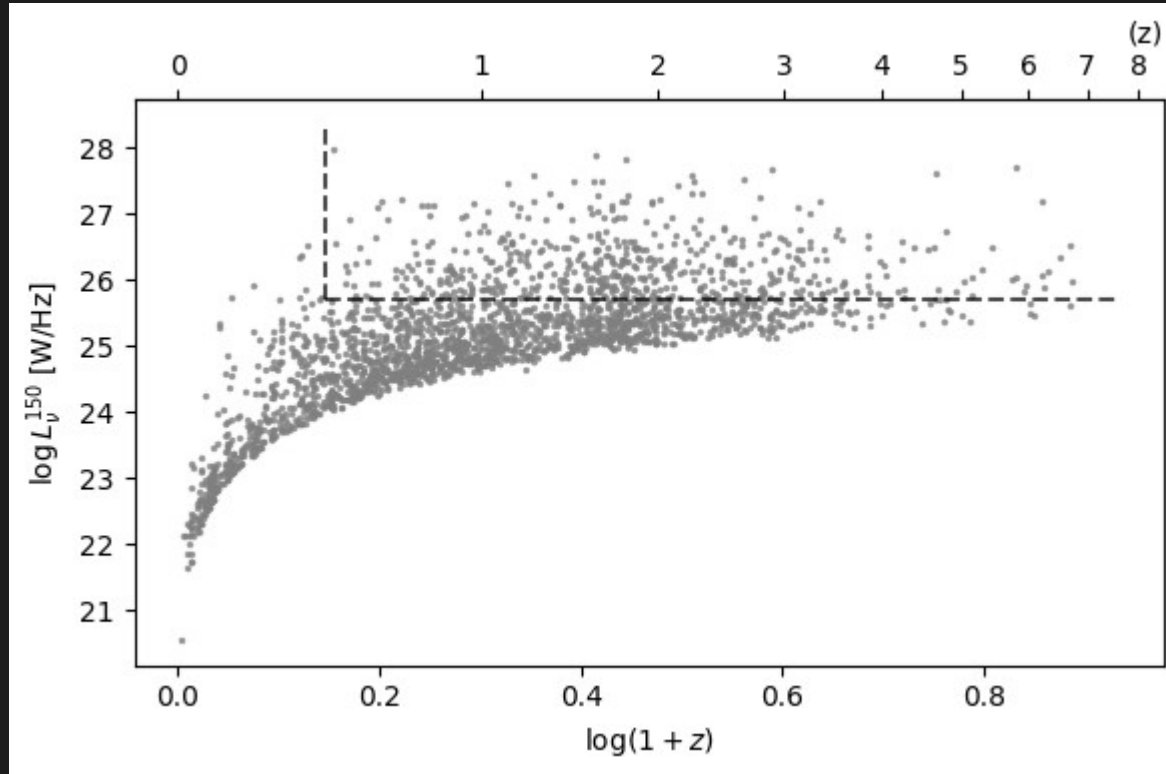
Spectral index and sensitivity



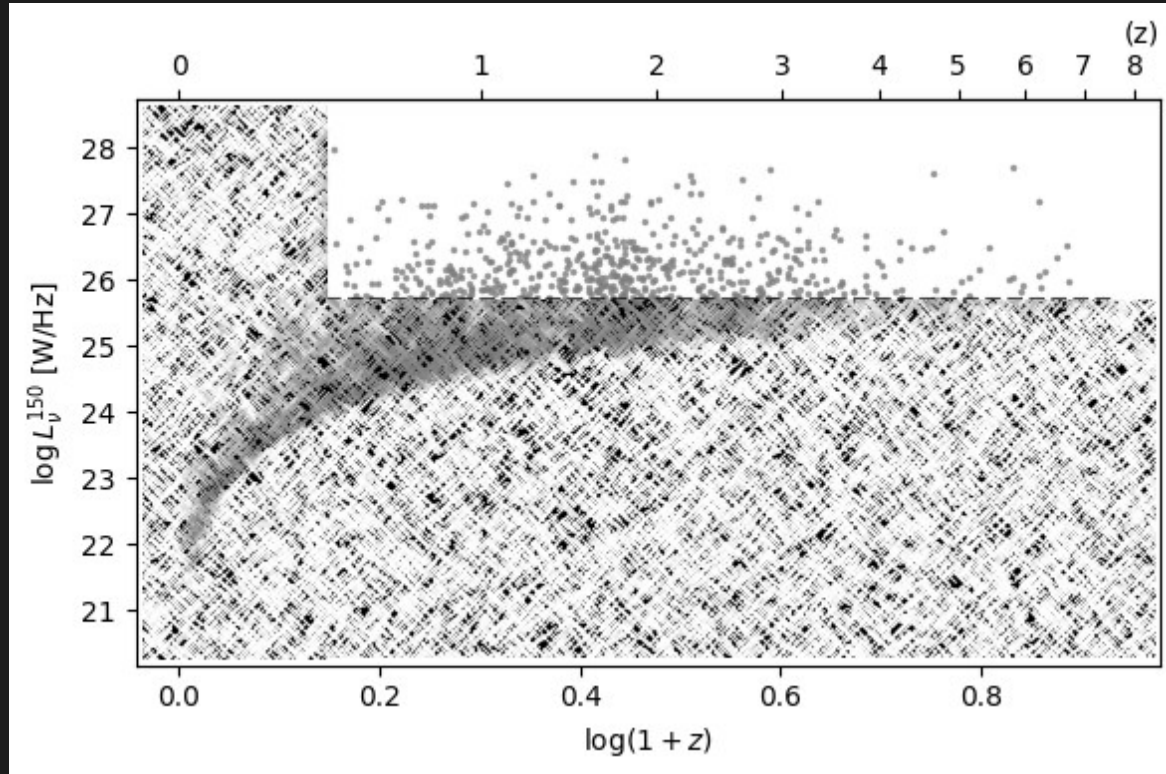
Best+ 2023

$S_{\text{int}}^{150} > 3 \text{ mJy} \Rightarrow$ Main sample (>2000 sources with redshifts, AGN)

Malmquist bias

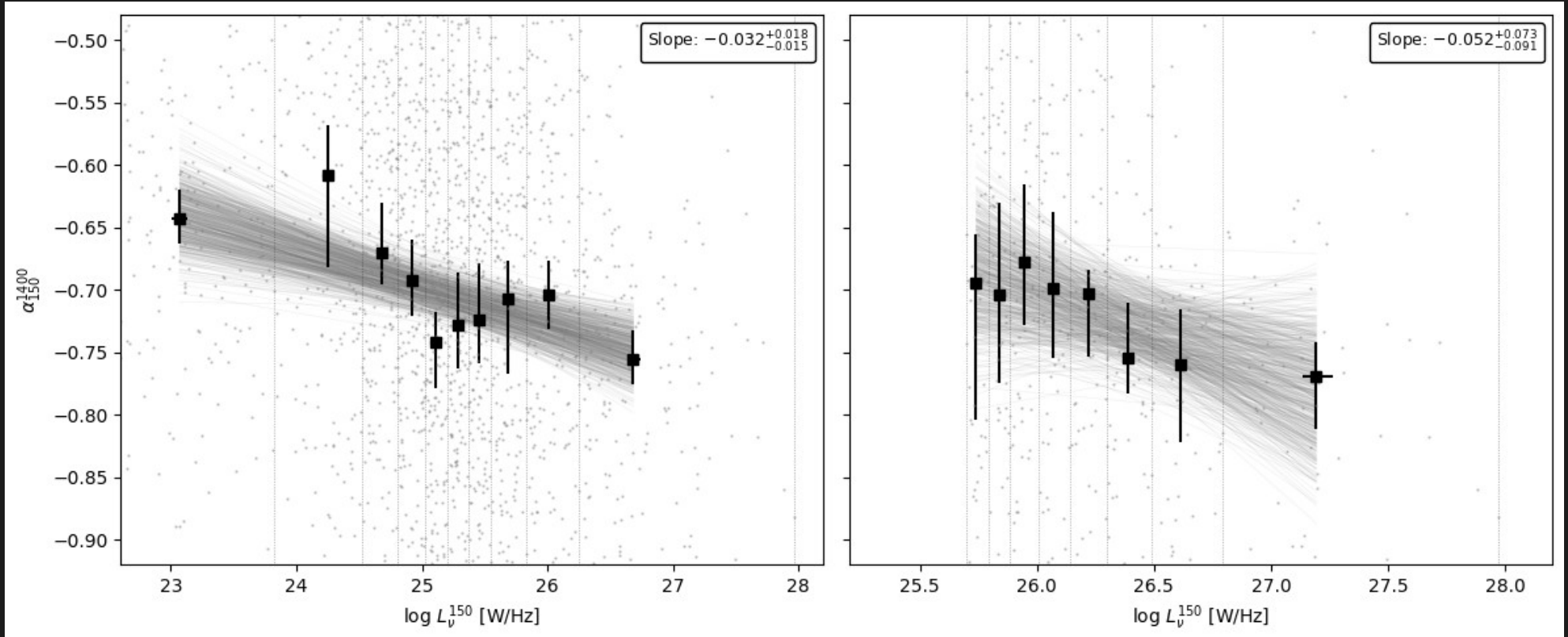


Malmquist bias

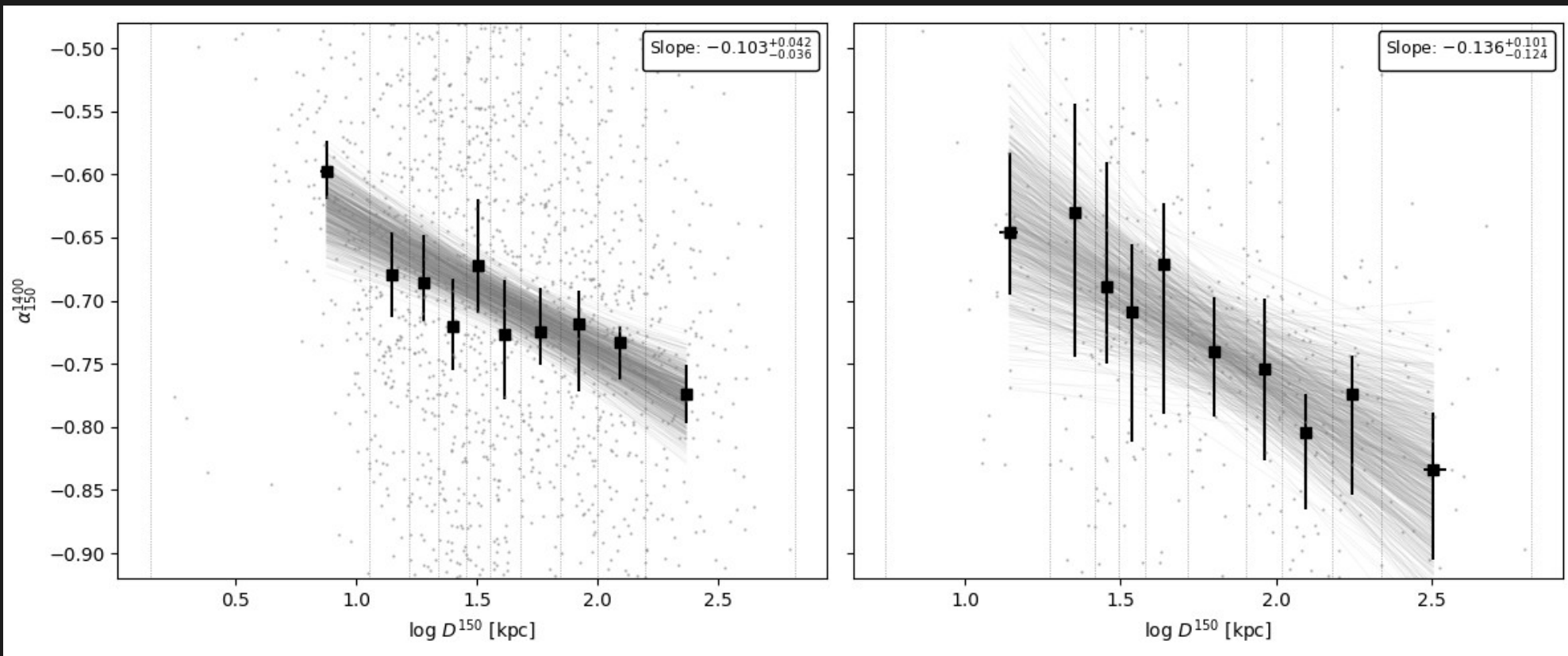


$z > 0.4$ & $L_v^{150} > 5 \cdot 10^{25}$ W/Hz $\Rightarrow$ Malmquist bias free subsample (>500 sources)

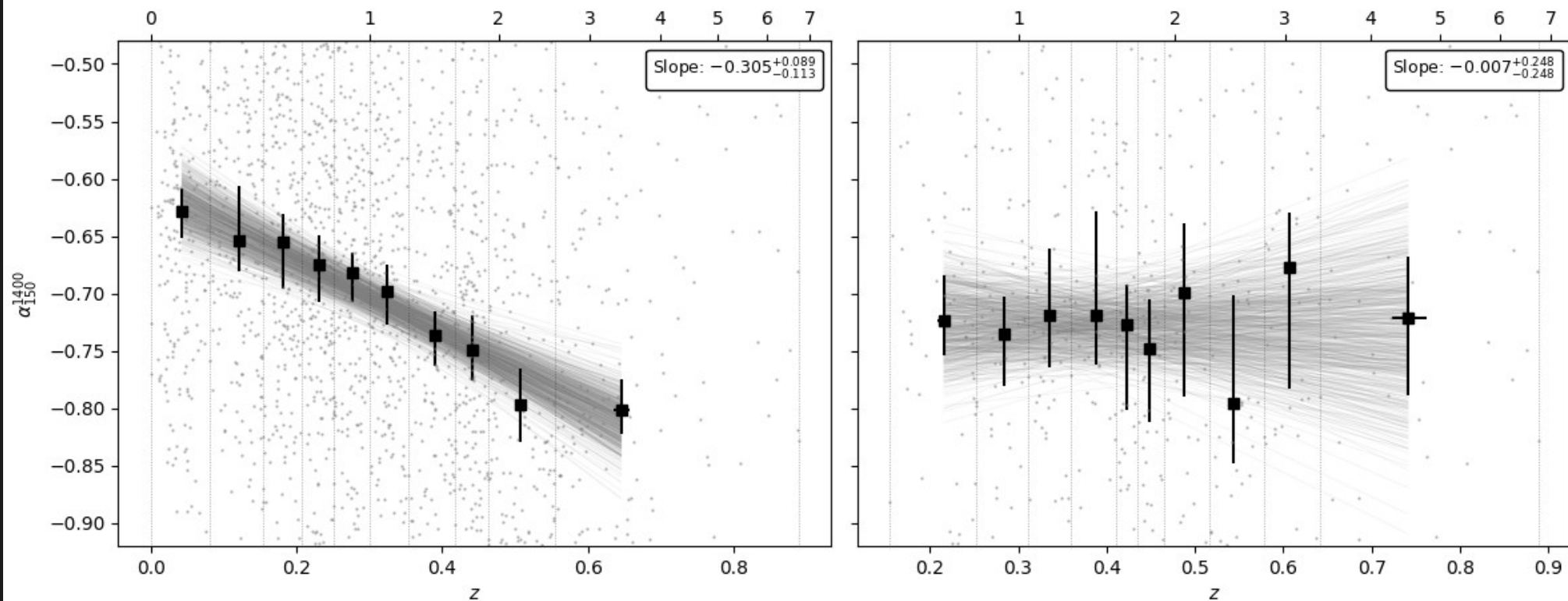
Spectral index and luminosity



Spectral index and linear size



Spectral index and redshift



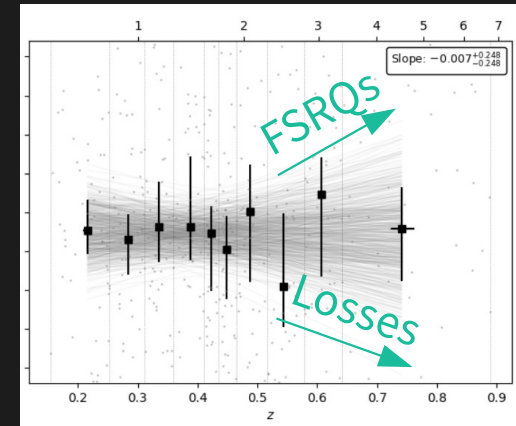
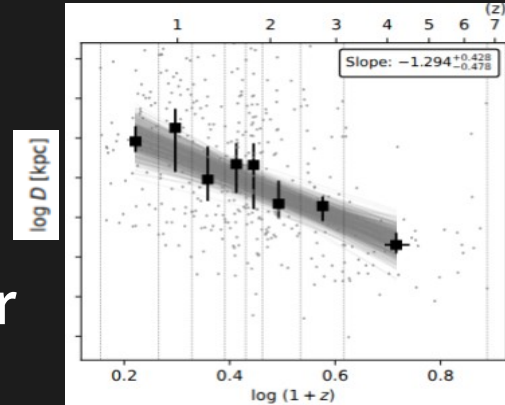
Summary



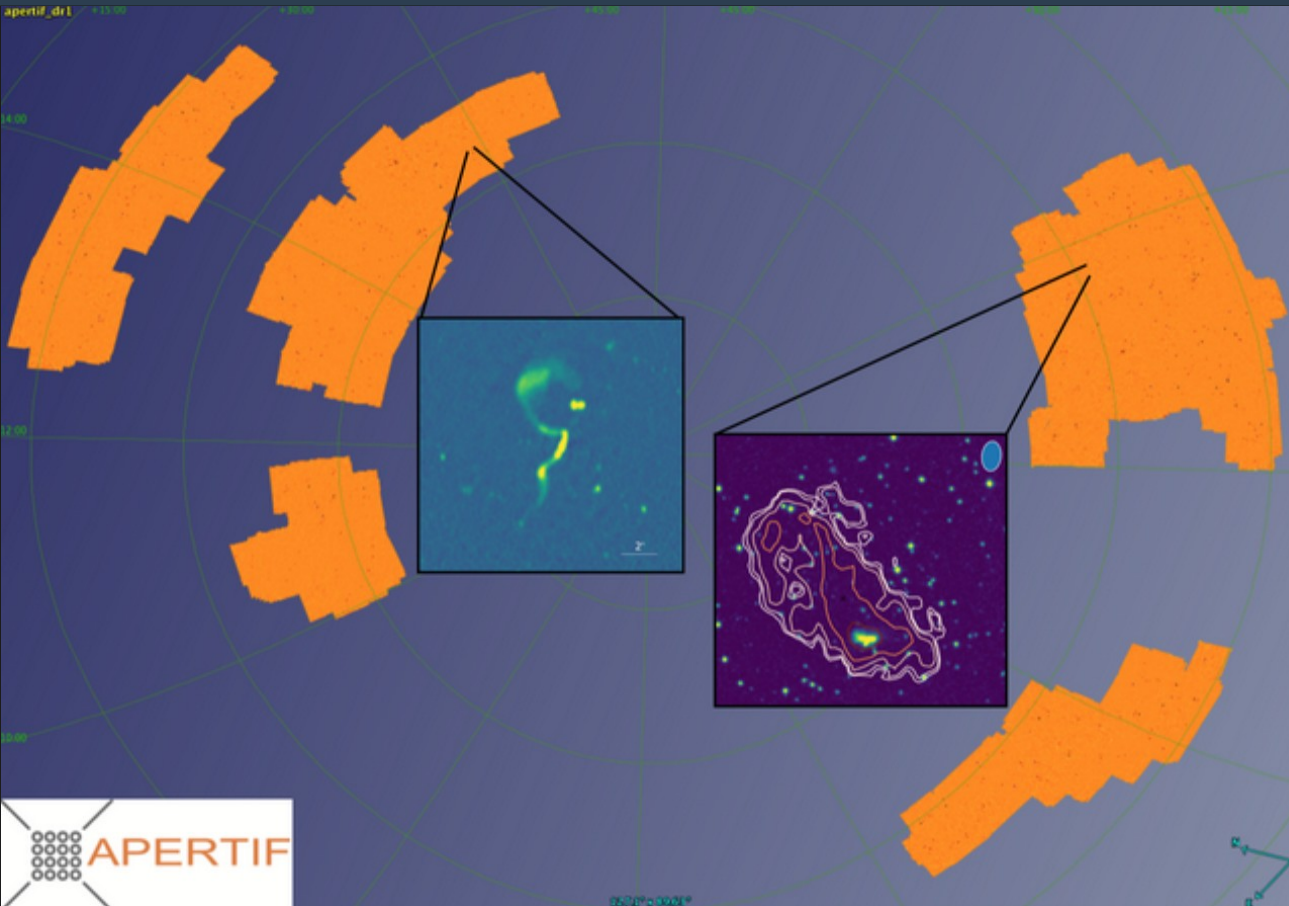
- New release of high quality Apertif images of famous fields
- One of the largest source samples with α estimates
- $\alpha \sim L^{-0.03}$
- $\alpha \sim D^{-0.1}$
- Observed $\alpha(z)$ is driven by the Malmquist bias and $\alpha(L)$
- See also Pinjarkar+ 2025
- ...

Summary (2)

- ...
- $\alpha \propto D^{-0.1}$ & $D \propto (1+z)^{-1.3}$ with $\alpha \propto (1+z)^0 \Rightarrow$
- A mechanism for steeper spectra at higher redshifts not related to $\alpha(L,D)$, e.g. more efficient inverse Compton losses
- Two mechanisms: IC-losses vs a population of compact flat spectrum sources arising at higher redshifts



Second data release this year



- **All products!**
- **~ 350 fields**
- **> 25000 images**
- **~ 2300 square degrees**
- **Processed with DI-pipeline**
- **Validated**
- **+ HETDEX field with DD-processing**

**Stay tuned and approach
me for collaboration**

Apertif – phased array feed for WSRT



40 beams with FoV $\sim 3^\circ \times 3^\circ$

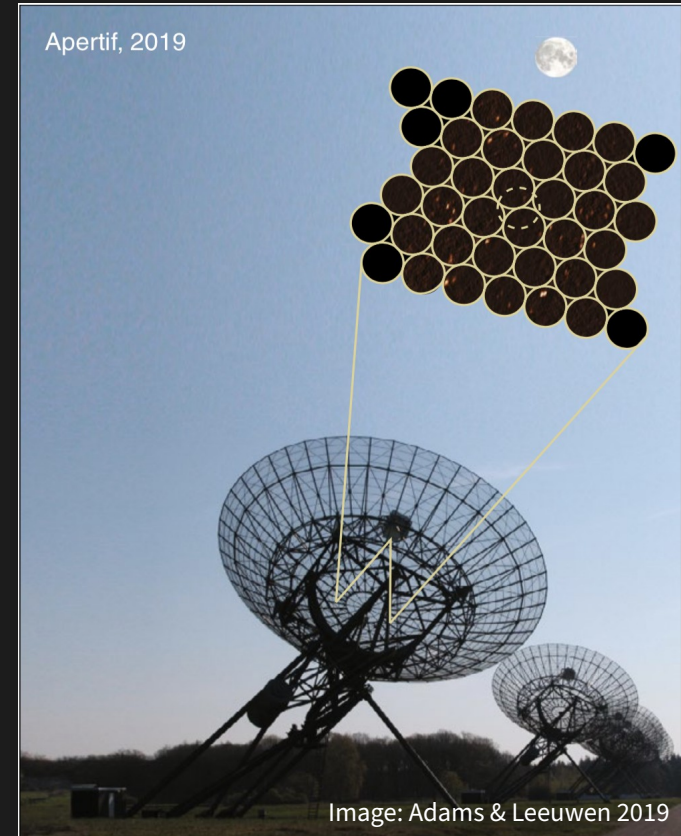
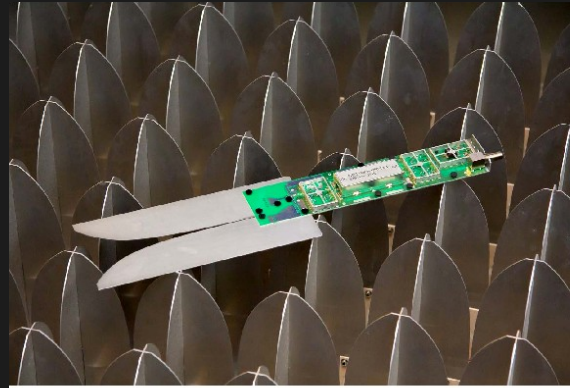
L-Band 1130--1430 MHz
($z < 0.26$ for HI)

12.2 kHz channels
(2.6-3.2 km/s for HI)

Angular resolution $\sim 11'' \times 11'' / \sin(\delta)$

Two linear polarizations

+ *time-domain backend*



Apertif team



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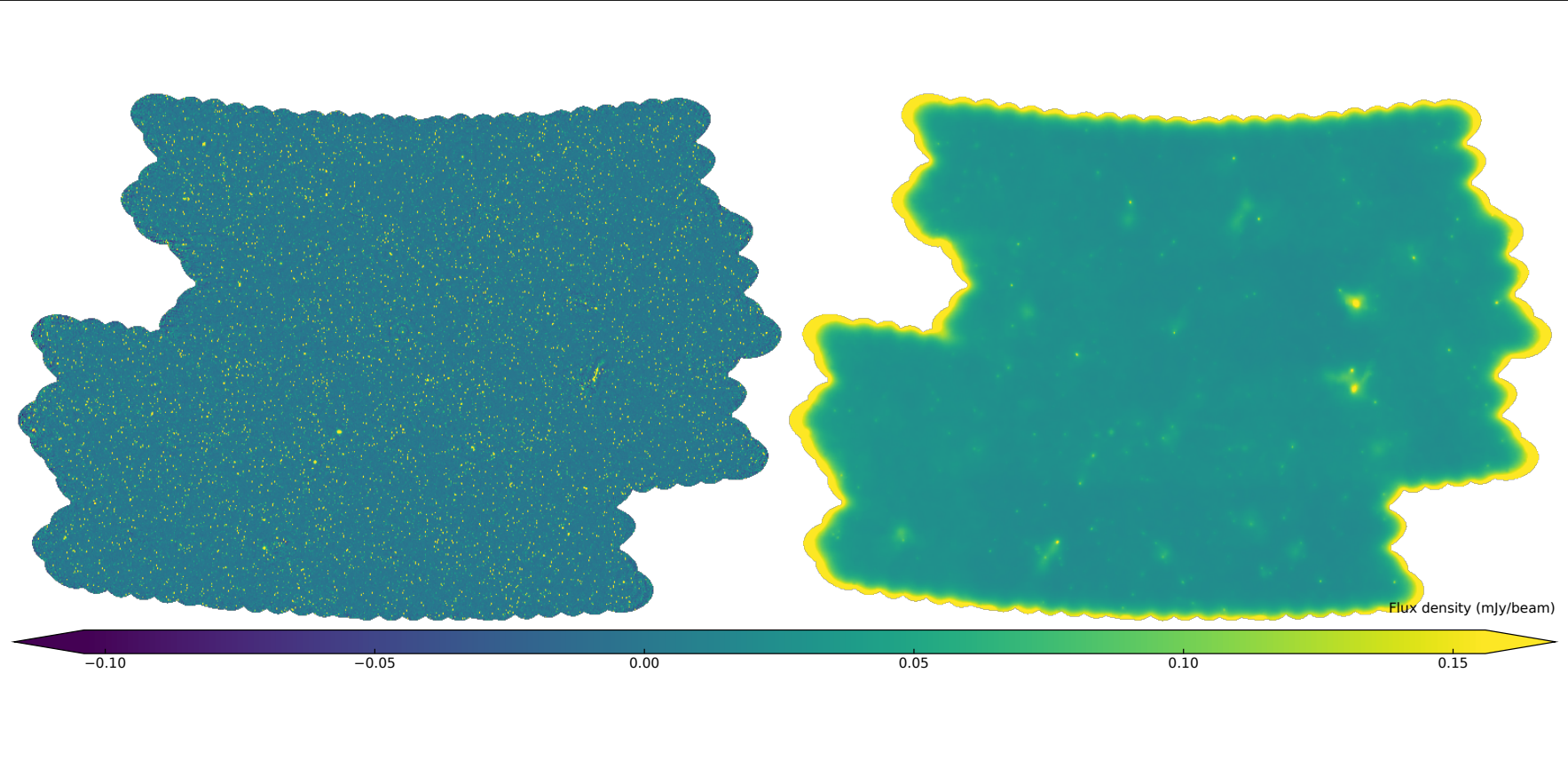
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Nico Vermaas
Erik van der Wal
Stefan Wijnholds
Alwin Zanting
Jacob Ziemke

Lockman Hole mosaic



Reliability and completeness

Source finding on the inverted images to estimate the false positives

Compare differential source counts with Matthews+ 2021 to estimate the completeness

