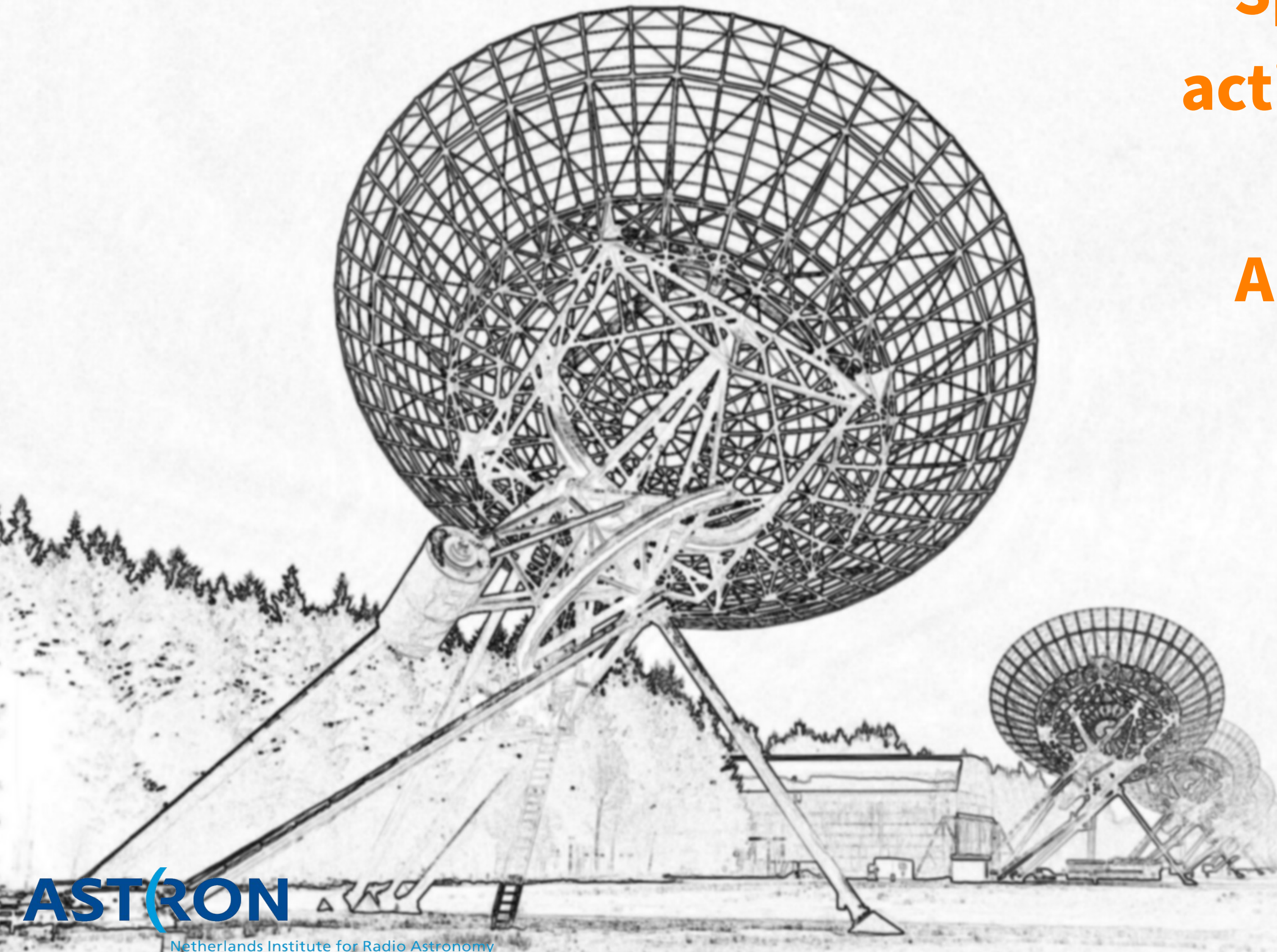

Spectral indices in active galactic nuclei probed by Apertif and LOFAR

Alexander Kutkin

Apertif imaging team

LOFAR Family Meeting
22-26 Sep 2025
Paris

ASTRON
Netherlands Institute for Radio Astronomy

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Spectral indices of radio sources

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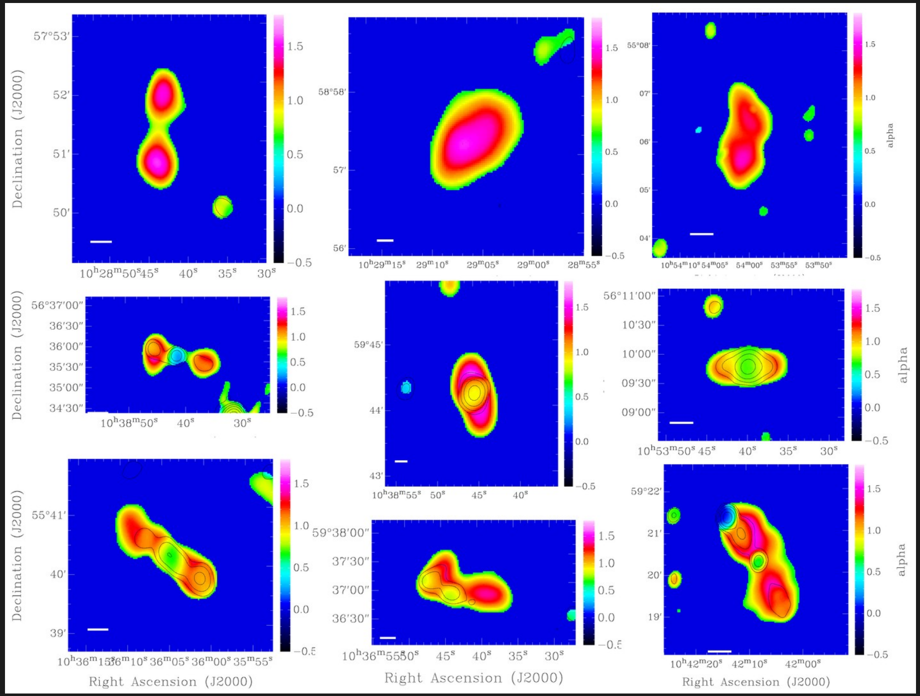
$S_\nu \propto \nu^\alpha$

Spectral index α characterizes radio emission:

- emission mechanisms
- source ages
- environments

In large samples median α ~ -0.75

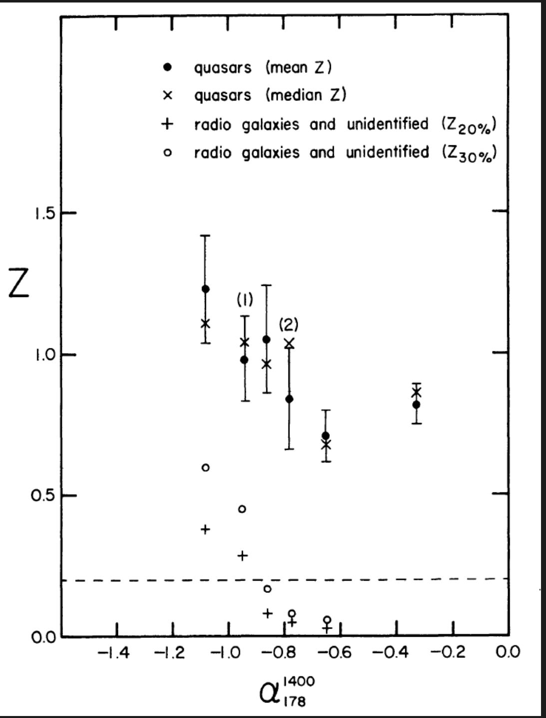


Morganti et al 2021

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

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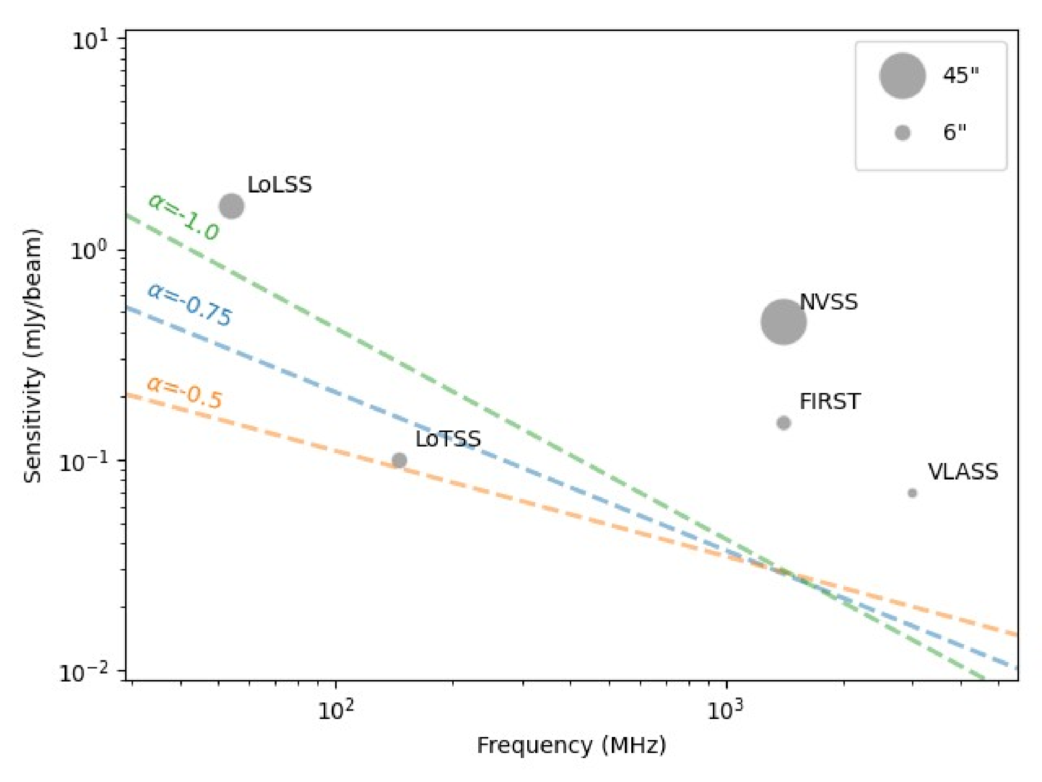
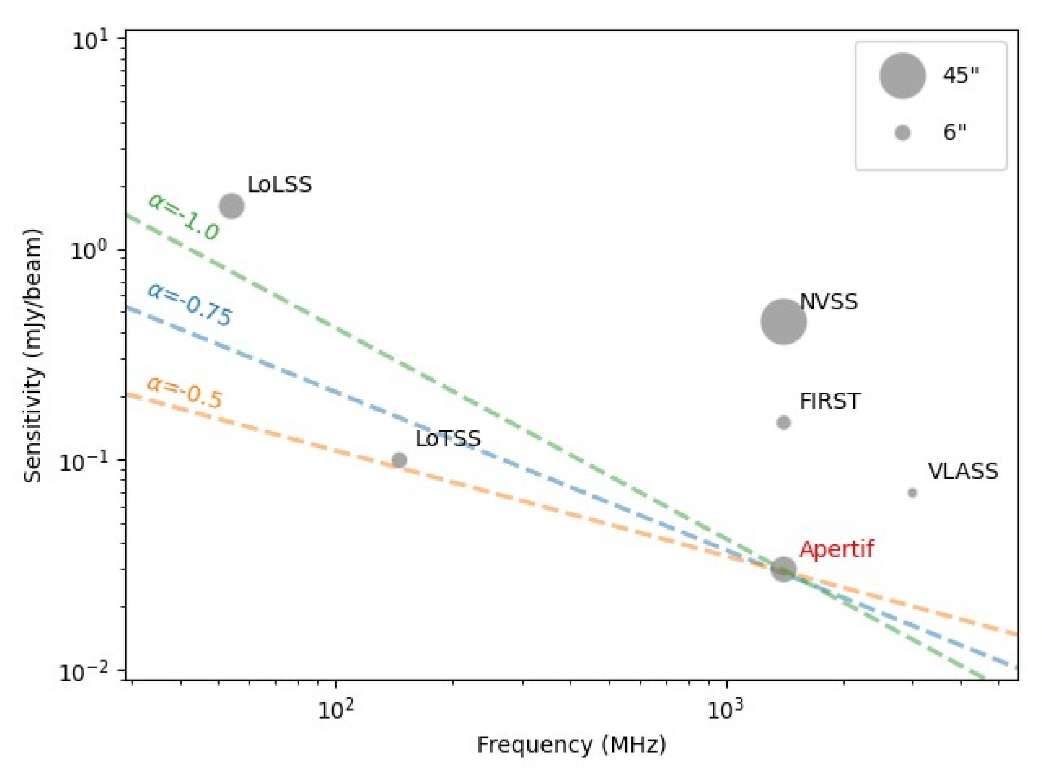
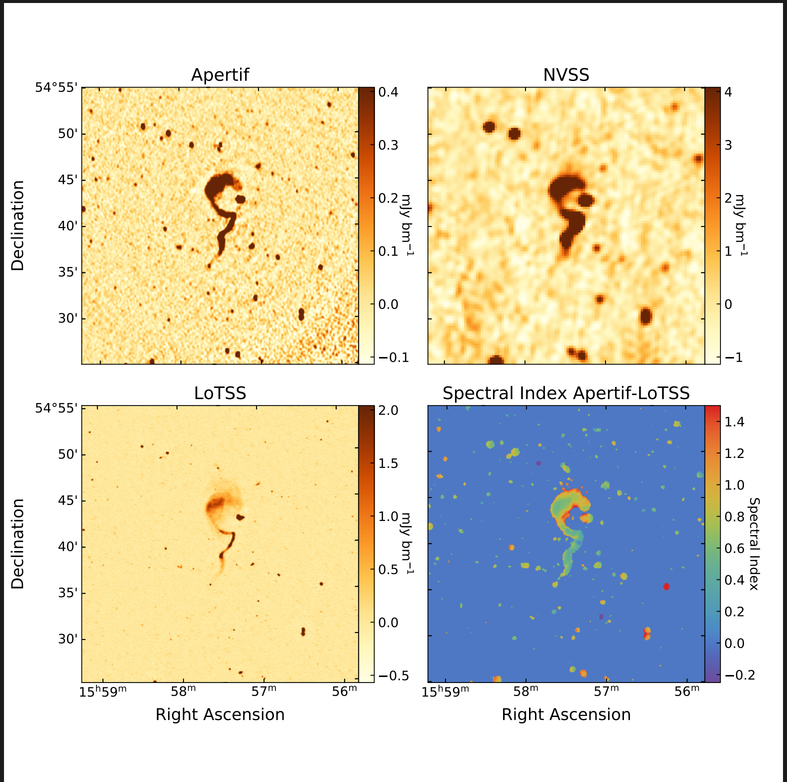


Apertif!





Adams et al. 2022

Apertif results

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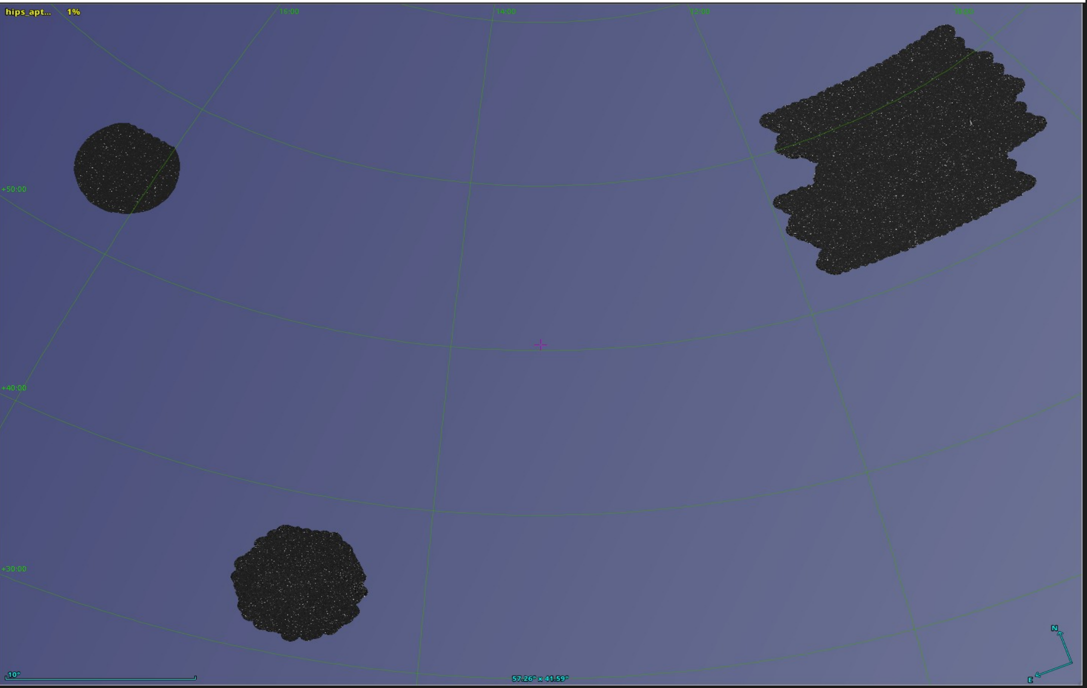
Field name	RA	DEC	Area [sq. deg.]	Resolution ″	Image noise [μJy beam^{-1}]	N sources
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Boötes	14:31:53	+34:27:44	27	23×11	40	8994
Elais North	16:10:20	+54:38:13	24	18×11	37	8526
Lockman Hole	10:57:40	+57:02:36	136	15×13	27	55166



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

Kutkin et al. 2023, 2025

LOFAR data

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Value added LOFAR catalogs with redshifts

(Kondapally+ 2021, Duncan+ 2021)

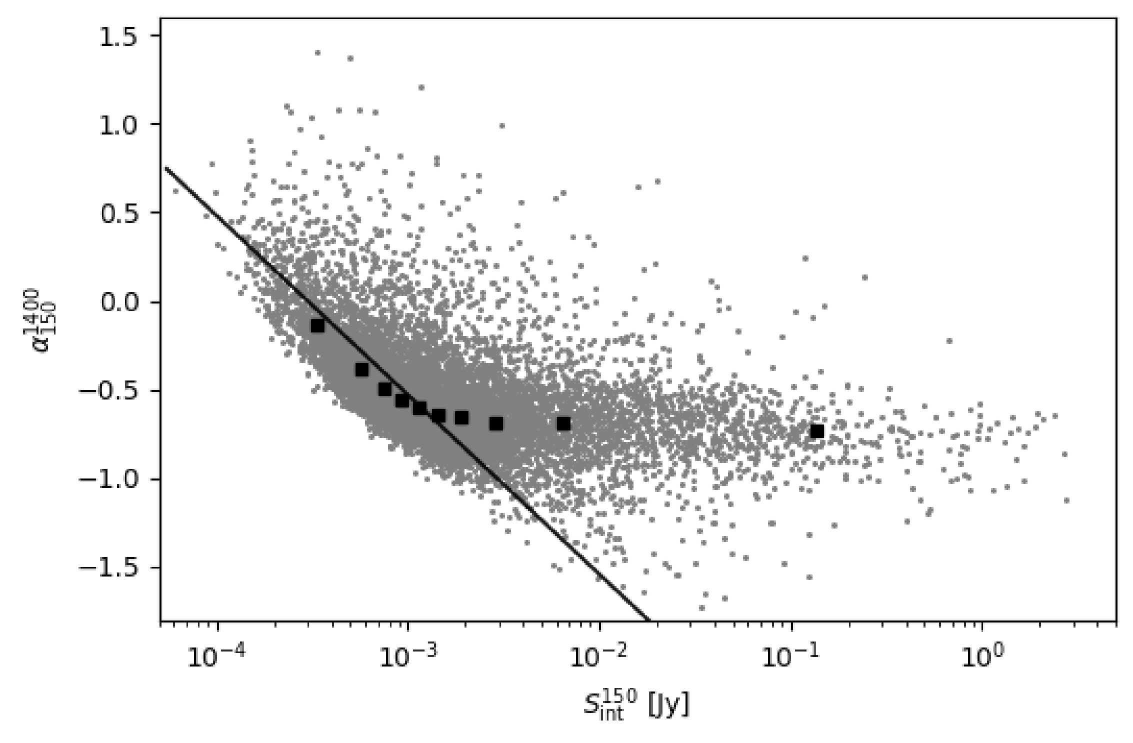
https://lofar-surveys.org/deepfields.html

=> ~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

Kutkin et al. 2025

Spectral index and sensitivity



Spectral index and sensitivity

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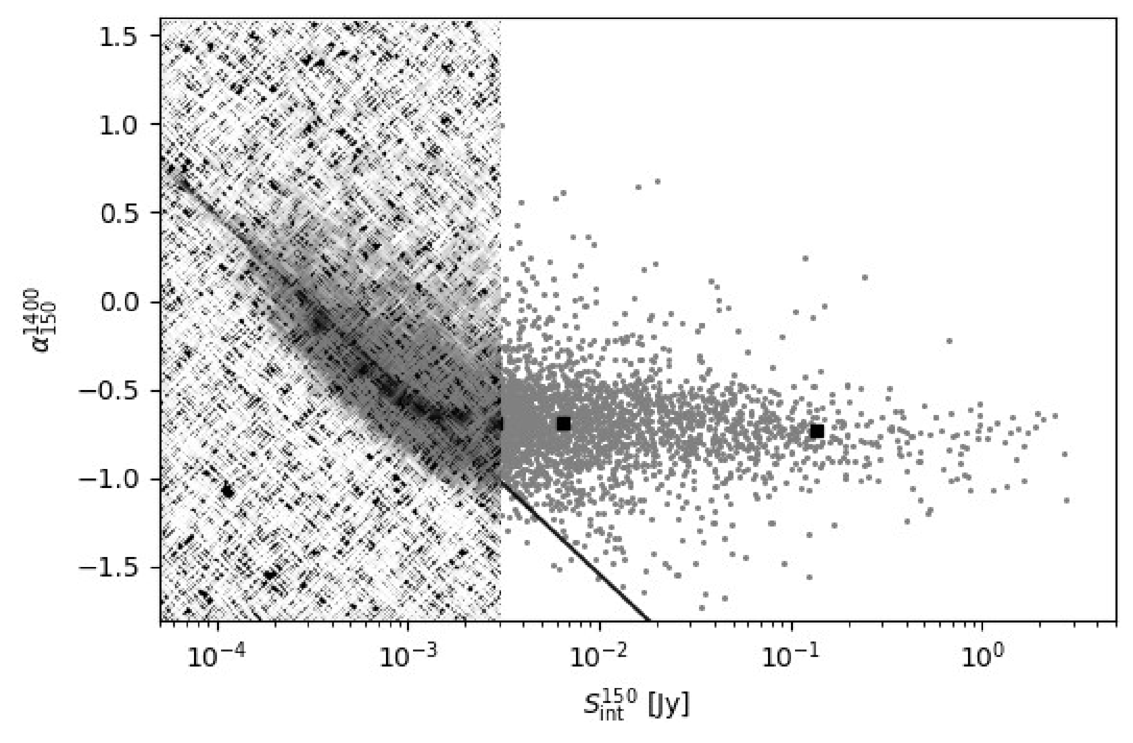

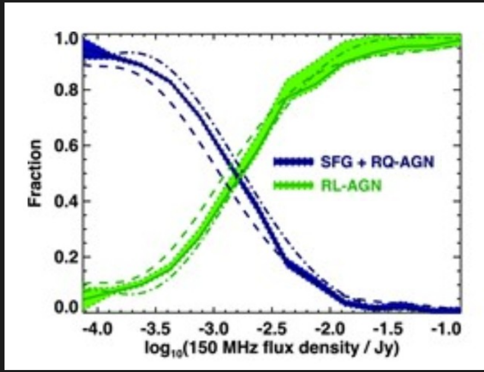

Best+ 2023

S^{150}_{int} > 3 mJy => Main sample (>2000 sources with redshifts, AGN)

Malmquist bias

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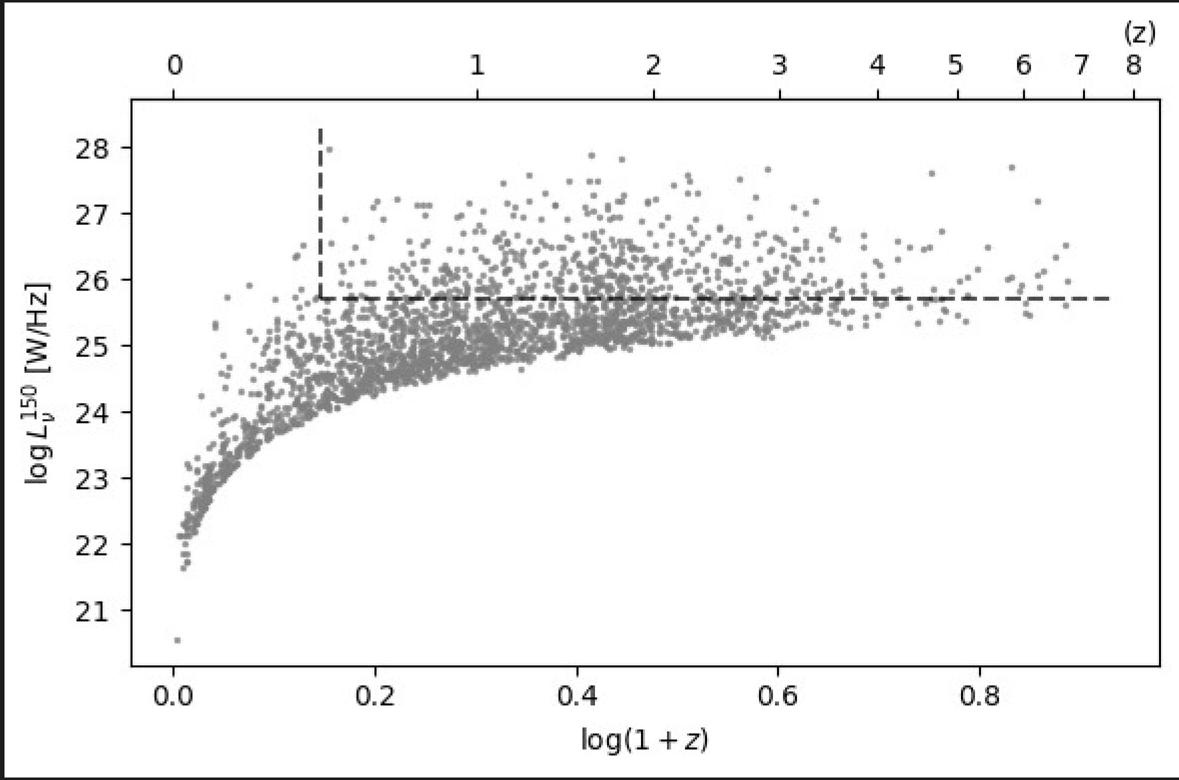

Malmquist bias

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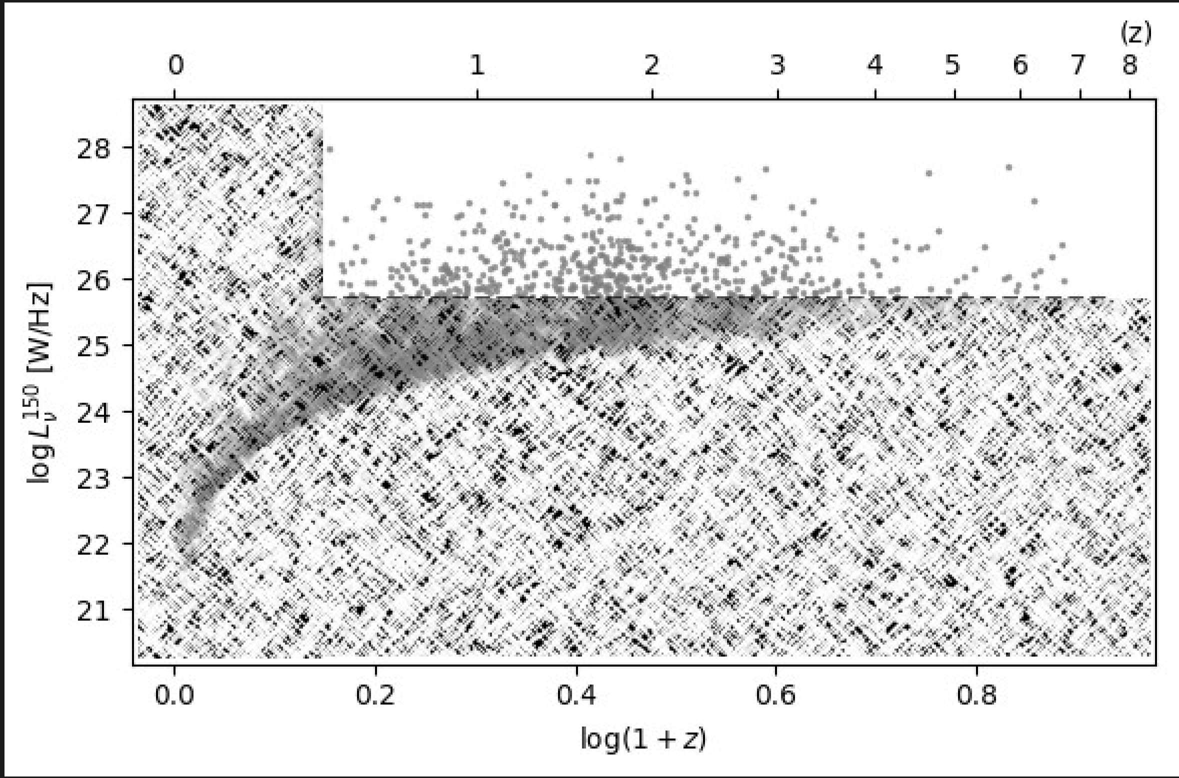
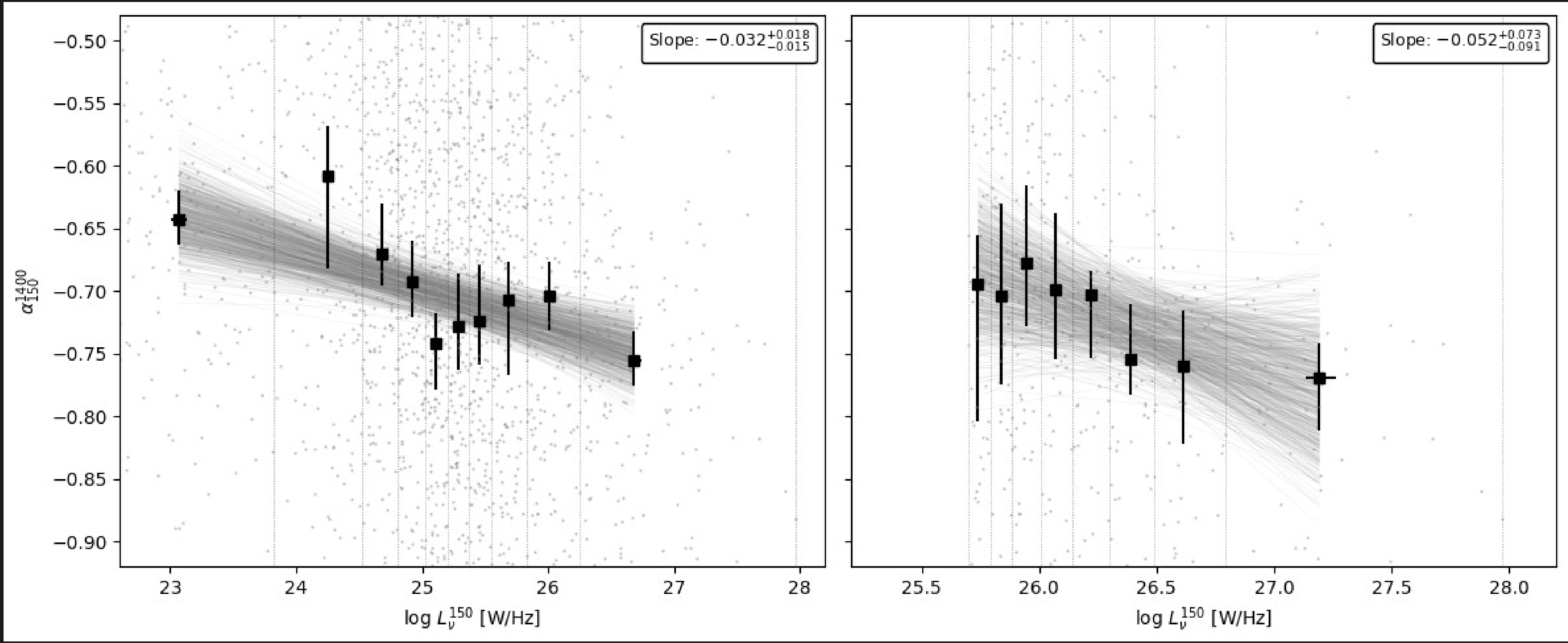


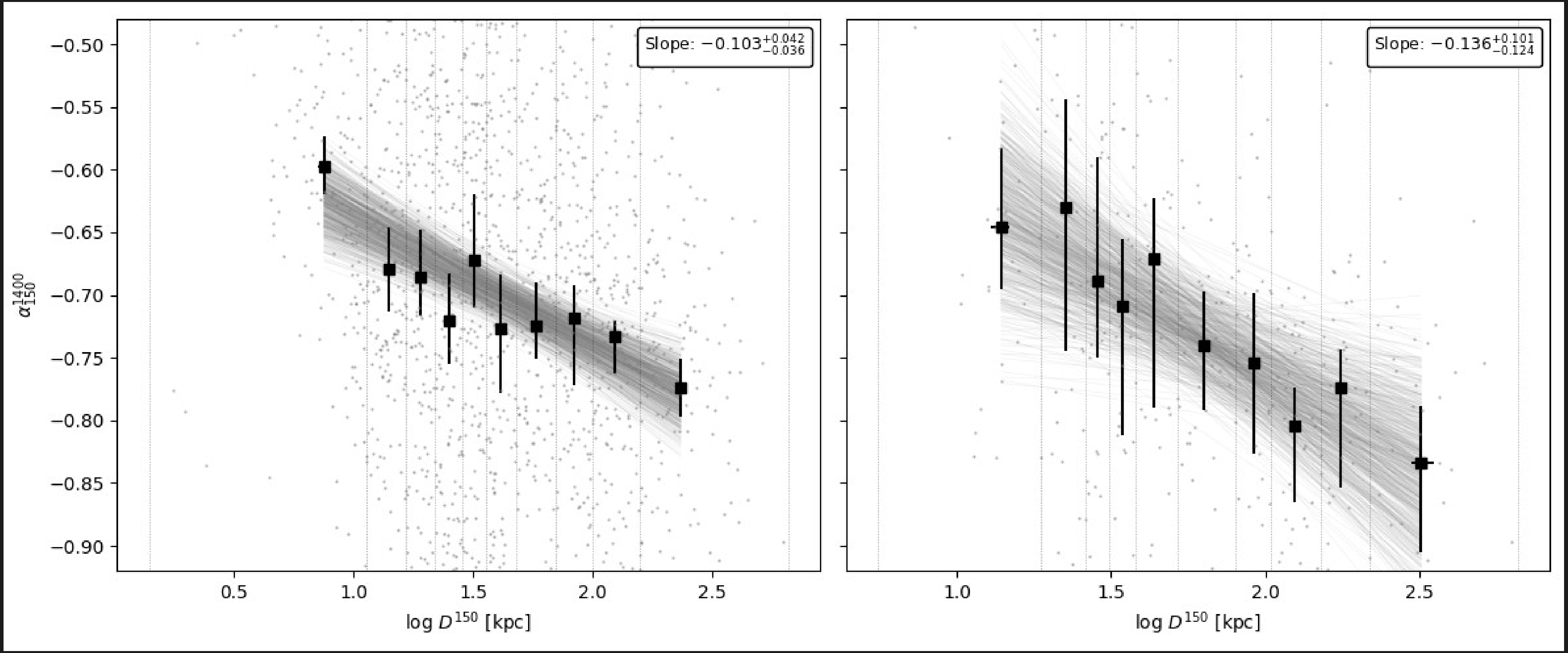
z>0.4 & L^{150}_{ν}>5·10^{25} W/Hz => Malmquist bias free subsample (>500 sources)

Spectral index and luminosity



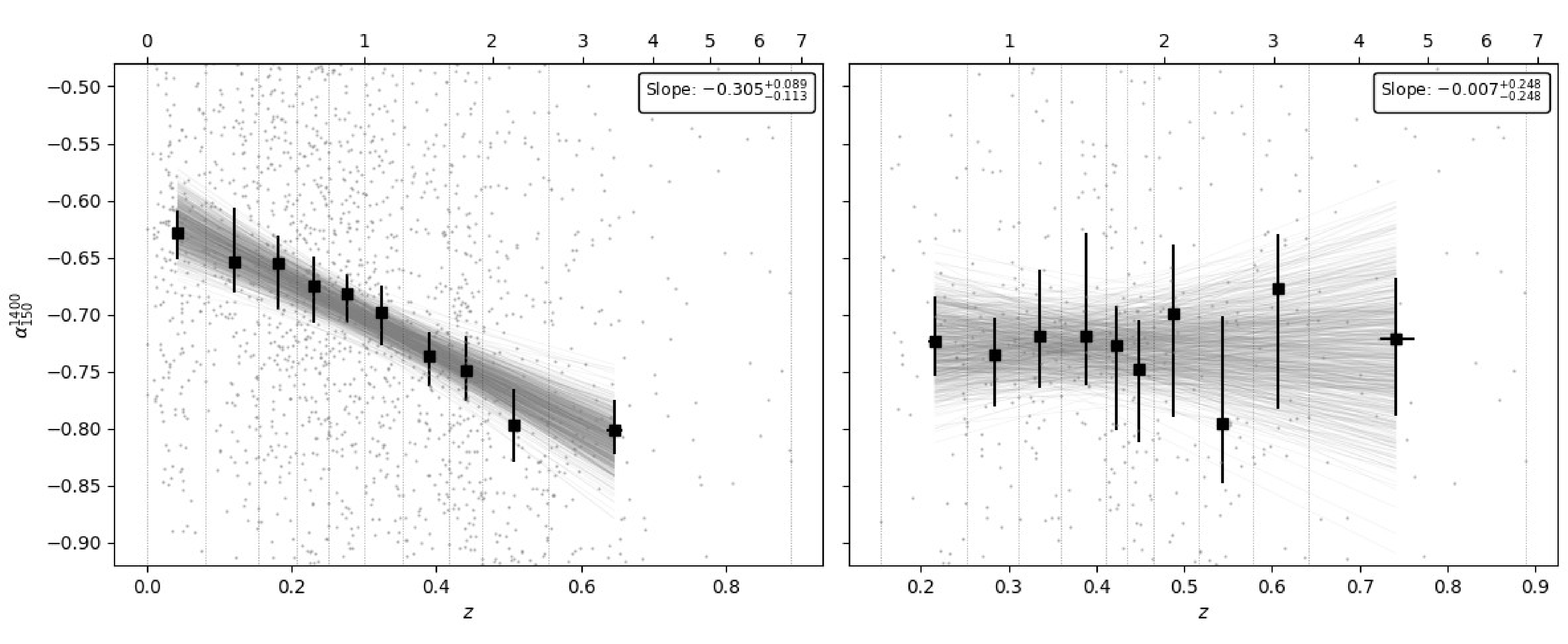
Kutkin et al. 2025

Spectral index and linear size



Kutkin et al. 2025

Spectral index and redshift



Kutkin et al. 2025

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 α(z) is driven by the Malmquist bias and α(L)
- See also Pinjarkar+ 2025
- …

Summary (2)

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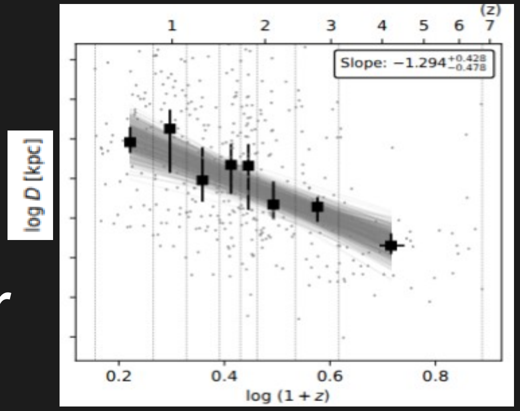
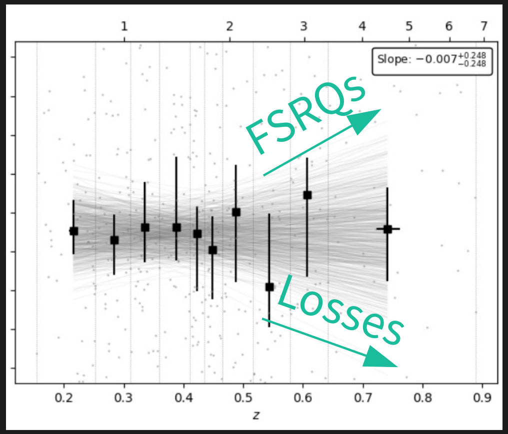
- …
- $\alpha \propto D^{-0.1}$ & $D \propto (1+z)^{-1.3}$ with $\alpha \propto (1+z)^{0}$ =>
- A mechanism for steeper spectra at higher redshifts not related to $\alpha(L,D)$, e.g. more efficient inverse Compton losses
- Two mechanisms: IC-losses vs a population of compact flat spectrum sources arising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





Second data release this year

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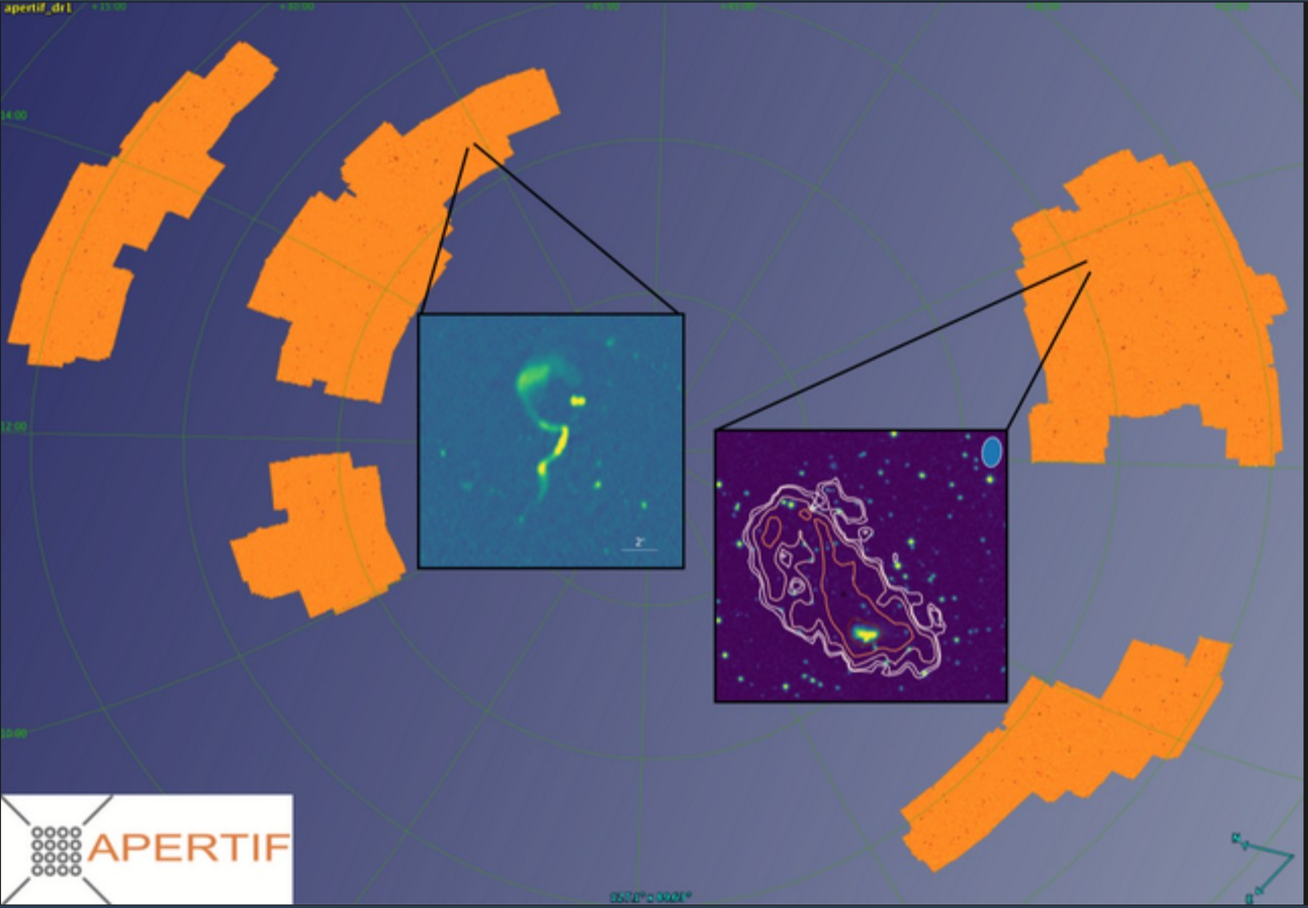

- **All products!**
- **~ 350 fields**
- **> 25000 images**
- **~ 2300 square degrees**
- **Processed with DI-pipeline**
- **Validated**
- **+ HETDEX field with DD-processing**

Stay tuned and approach me for collaboration

Apertif – phased array feed for WSRT

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40 beams with FoV ~ 3°x3°

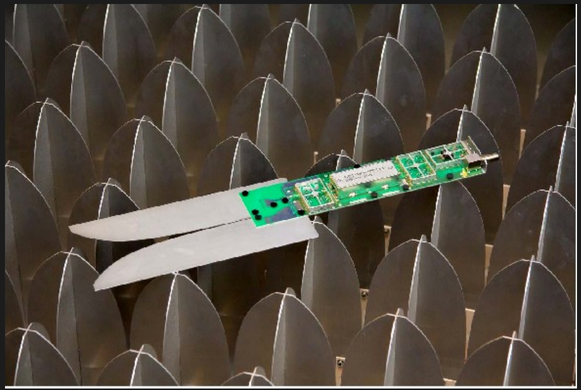
L-Band 1130--1430 MHz
(z<0.26 for HI)

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

Angular resolution ~11"x11"/sin(δ)

Two linear polarizations

+ time-domain backend



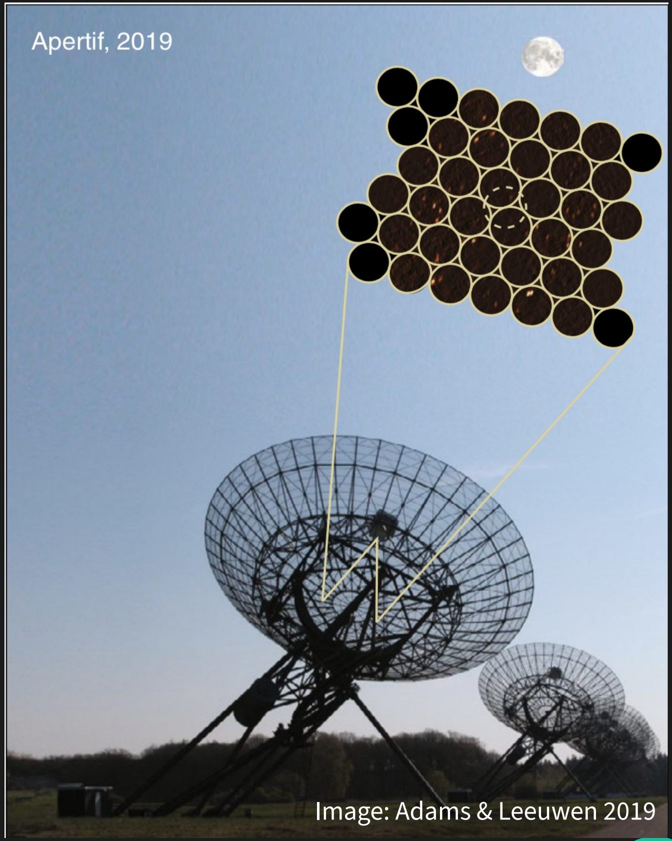
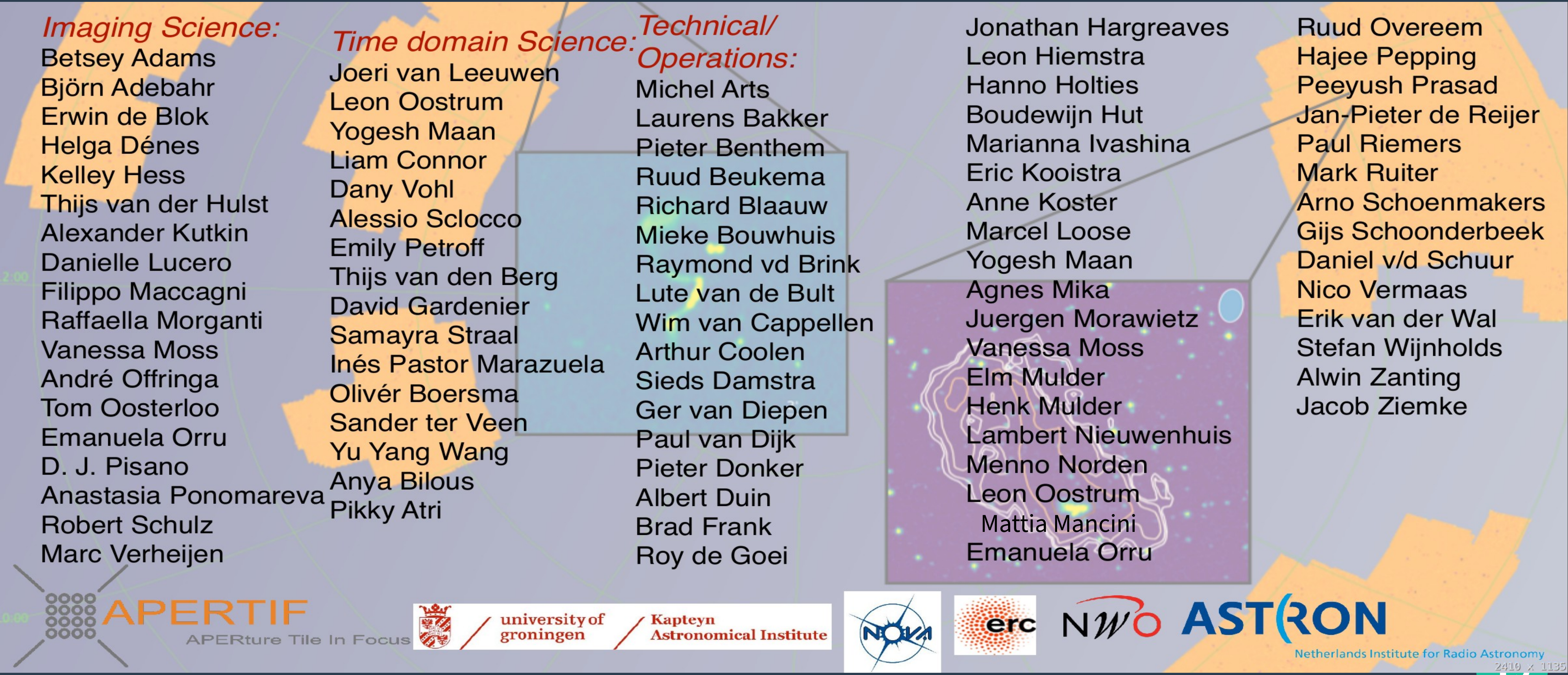


Image: Adams & Leeuwen 2019

Apertif team



Lockman Hole mosaic

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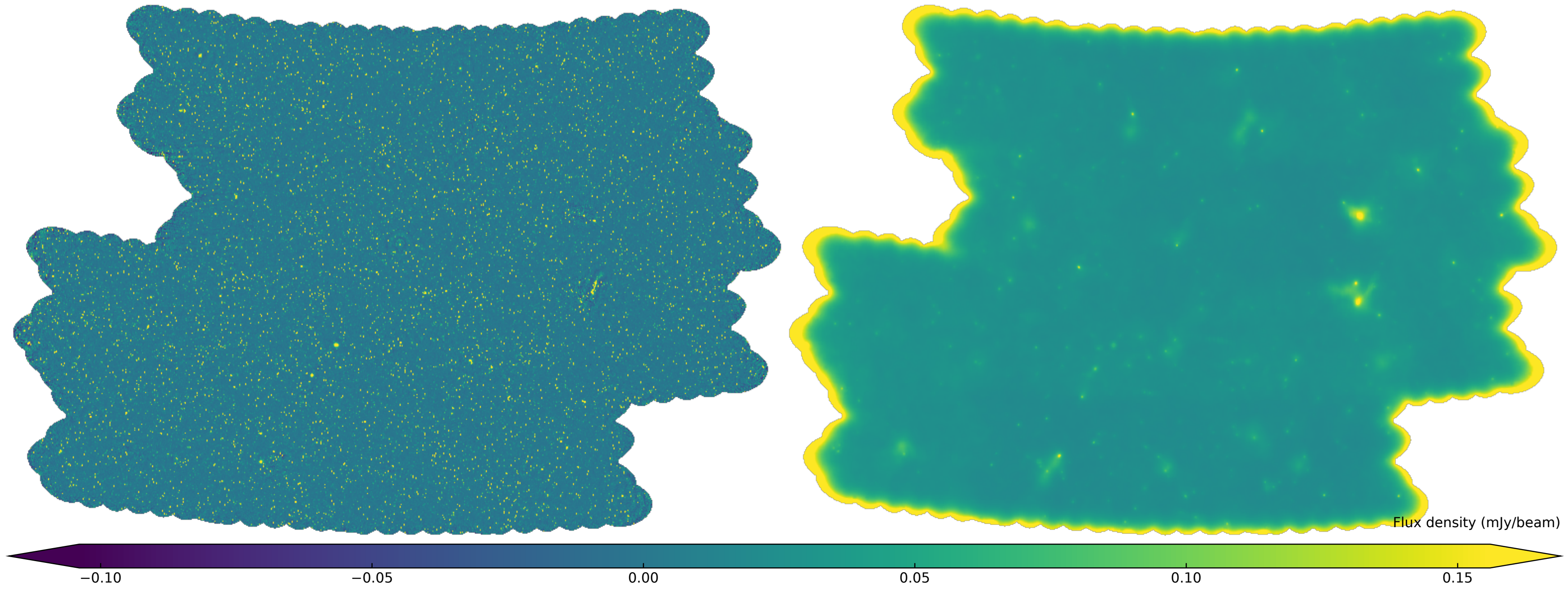

Reliability and completeness

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Source finding on the inverted images to estimate the false positives

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