Searching for LOFAR-selected optical/NIR-dark galaxies in the EDF-N

A new population of high-z starburst/AGN systems?

Marika Giulietti (IRA-INAF)

In collaboration with: I. Prandoni, L. Bisigello, G. Rodighiero, M.Bondi, M. Talia, F. Gentile, G. Girardi, L Wang, A. La Marca, P. A. C. Cunha, R. Scaramella, A. Lapi, H. J. A. Rottgering and many more…

LOFAR Family Meeting - Paris, Sept.2025

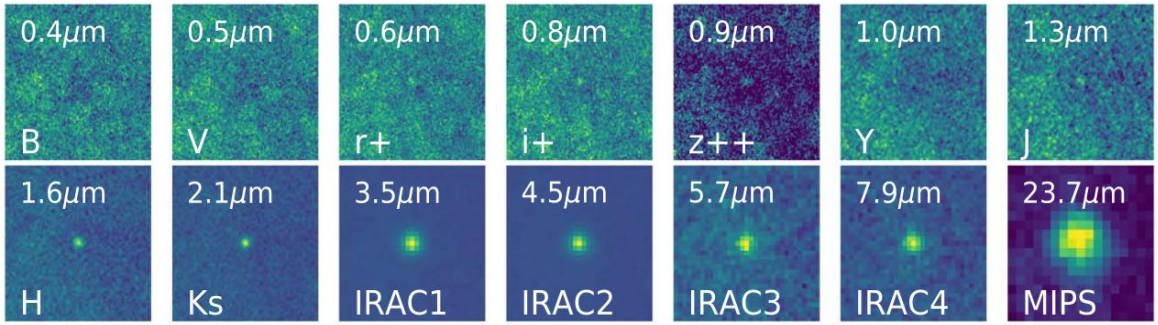
Credit: ESA/Euclid/Euclid Consortium/NASA

Introduction

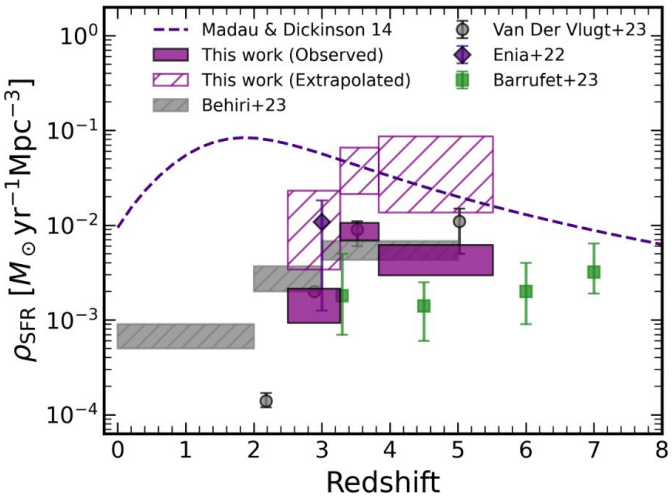
Radio continuum emission is an **unbiased tracer of star-formation:** synchrotron emission (supernovae remnants) + free-free emission (HII regions).

Radio selection effectively identifies populations of dusty star-forming galaxies up to high-redshifts ($z \lesssim 6$; e.g. Talia et al. 2021, Enia+2022, Behiri+2023, Van der Vlugt+2023, Gentile+2024a, 2025)

Optical/NIR dark (or faint) galaxies **significantly contribute to the cosmic SFRD** (e.g. Simpson+2014, Wang+2019, Gruppioni+2020, Franco+2018; Williams+2024).



Talia+2021



Gentile+2025

Large area and high-sensitivity needed

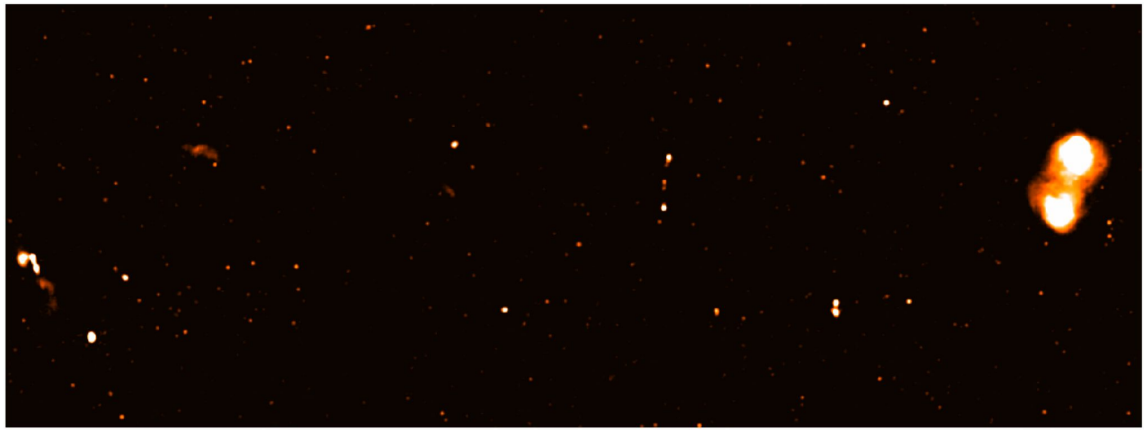
Studies of Rs-NIR dark galaxies so far limited to high radio frequencies (e.g. 3 GHz)

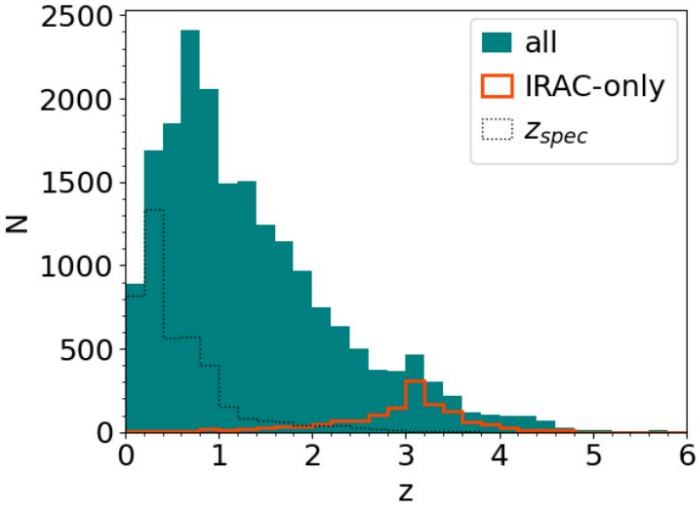
→ LOFAR + Euclid

LOFAR EDF-N observations and multi-band catalogue

Bondi+2024:

- 72h LOFAR HBA 144 MHz observations covering 10 deg^2:
- θ= 6”
- σ = 32 μJy $beam^{-1}$
- 23 309 sources peak S/N > 5





Bisigello+2025:

- Optical/MIR counterpart association:

  HEROES (UV/opt) catalogue
  IRAC (MIR) maps (Euclid collaboration: Moneti+2022)
  \+ *Herschel* (FIR) cross-match

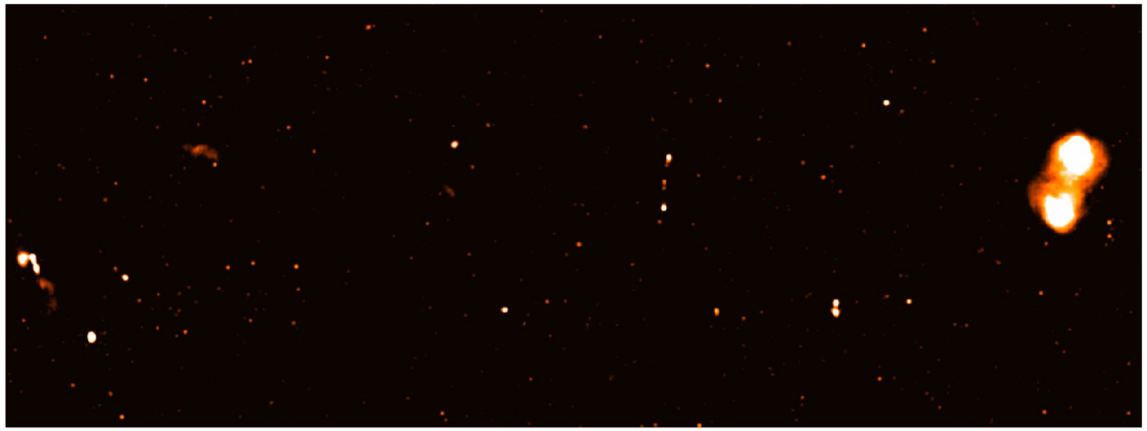
- Improved positional accuracy with 2.5x2.5 deg^2 image obtained with ILT at θ= 1.5” and σ =36 μJy $beam^{-1}$

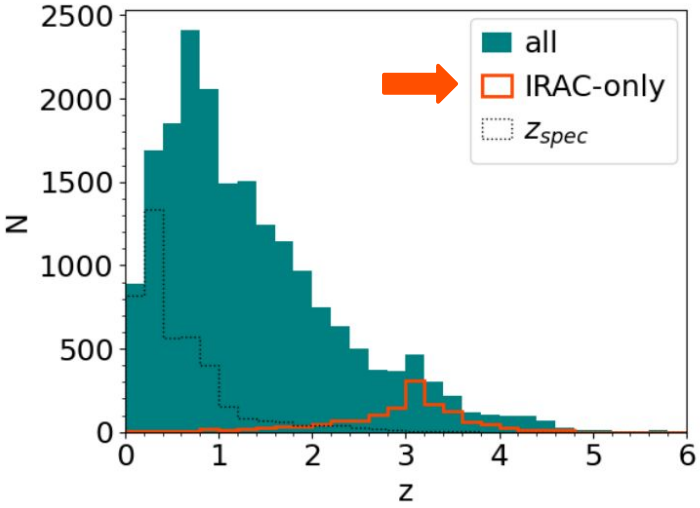
Robust identification strategy: Likelihood Ratio (LR) method + targeted visual inspection -> **99.2% identification rate**

LOFAR EDF-N observations and multi-band catalogue

Bondi+2024:

- 72h LOFAR HBA 144 MHz observations covering 10 deg^2:
- θ= 6”
- σ = 32 μJy beam^{-1}
- 23 309 sources peak S/N > 5





Bisigello+2025:

- Optical/MIR counterpart association:

  HEROES (UV/opt) catalogue
  IRAC (MIR) maps (Euclid collaboration: Moneti+2022)
  \+ *Herschel* (FIR) cross-match

- Improved positional accuracy with 2.5x2.5 deg^2 image obtained with ILT at θ= 1.5” and σ =36 μJy beam^{-1}

Robust identification strategy: Likelihood Ratio (LR) method + targeted visual inspection -> **99.2% identification rate**

Searching for Radio Selected Dark Galaxies in Euclid

Removal of sources with 5σ NIR emission contained within 5σ radio/MIR emission

Sample: 1363 IRAC-Only sources (B25)

Visual inspection

311 candidate "dark" sources

Cross-match with EUCLID-MER catalogue (0".9) + visual check

166 "dark" sources

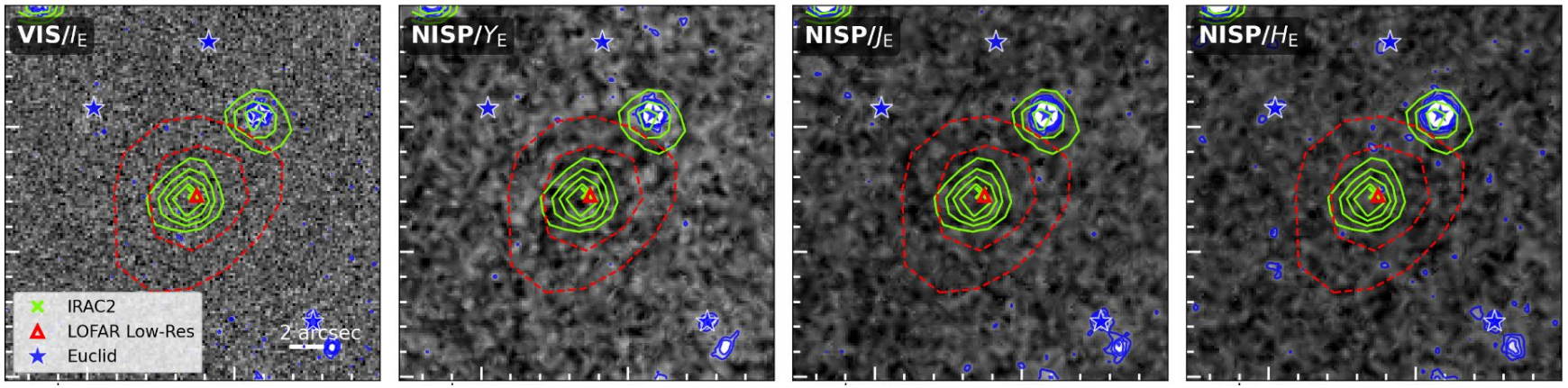
Isolated source?*

Isolated sample: 88 sources

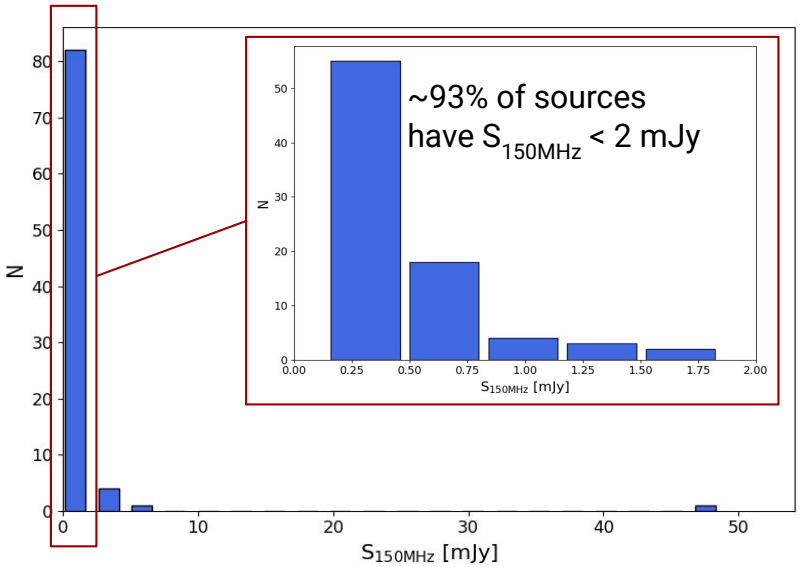
Removal of FLAG_SPURIOUS=1, object nearby bright local sources/star spikes

*no overlap between 3σ MIR emission of the target and 3σ MIR/NIR emission of nearby objects

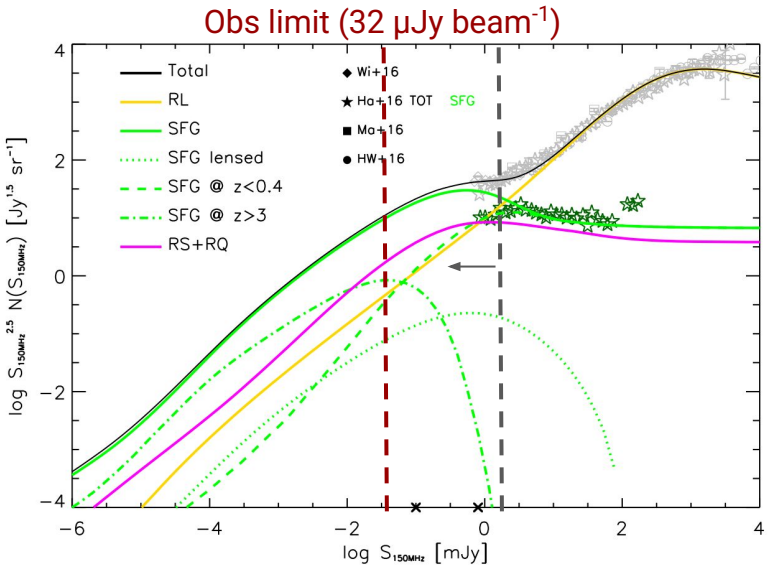
Example of an isolated source:



Isolated sample (88 sources)



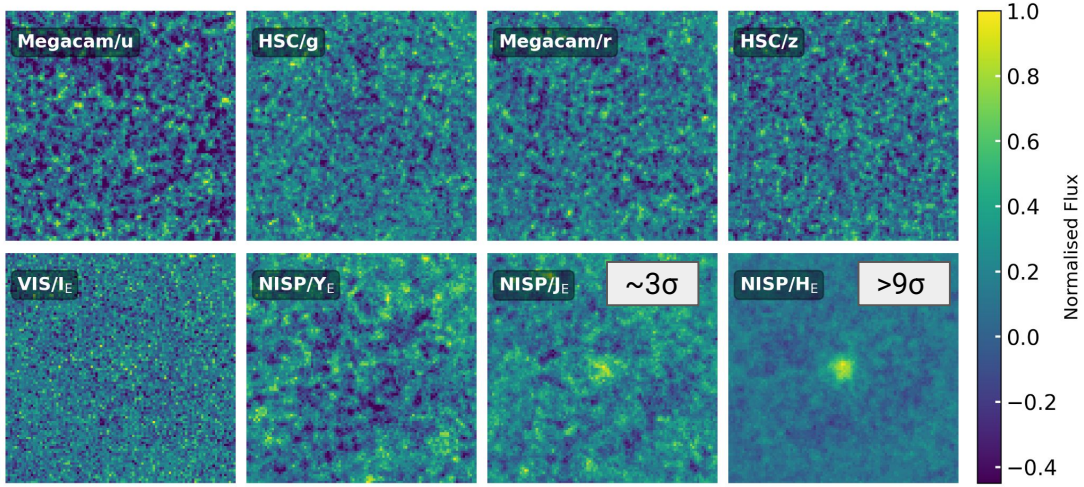
Multi-band data



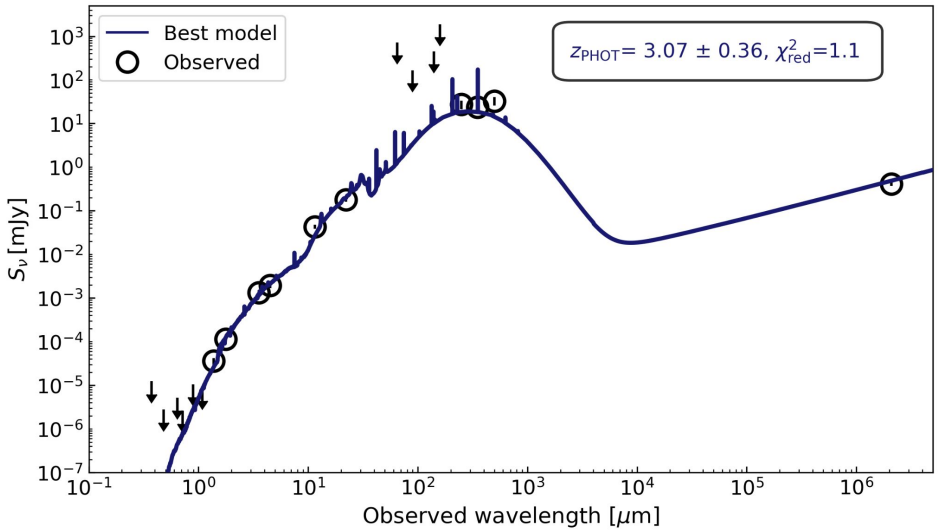
Mancuso+2017

Band	λ_{eff} [μm]	Depth	FWHM [arcsec]
CFHT/MegaCam *u*	0.372	24.2 mag	0.89
HSC *g*	0.480	25.7 mag	0.90
CFHT/MegaCam *r*	0.640	24.8 mag	0.71
Euclid VIS/I_E	0.715	25.45 mag	0.16
HSC *z*	0.891	24.1 mag	0.71
Euclid NISP/Y_E	1080.9	24.6 mag	0.3
Euclid NISP/J_E	1367.3	24.1 mag	0.3
Euclid NISP/H_E	1771.4	23.9 mag	0.3
Spitzer/IRAC1	3.550	24.8 mag	1.66–1.95
Spitzer/IRAC2	4.493	24.8 mag	1.72–2.02
Spitzer/IRAC3	5.696	20.8 mag	1.88
Spitzer/IRAC4	7.799	21.9 mag	1.98
WISE *W3*	12.082	19.1 mag	8.5
WISE *W4*	22.194	17.2 mag	17
AKARI/FIS65	65	3.2 Jy	37
AKARI/FIS90	90	0.55 Jy	39
AKARI/FIS140	140	3.8 Jy	58
AKARI/FIS160	160	7.5 Jy	61
Herschel/SPIRE250	250	0.045 Jy	18.2
Herschel/SPIRE350	350	0.037 Jy	24.9
Herschel/SPIRE500	500	0.054 Jy	36.3

Median stacking of the Primary Sample:



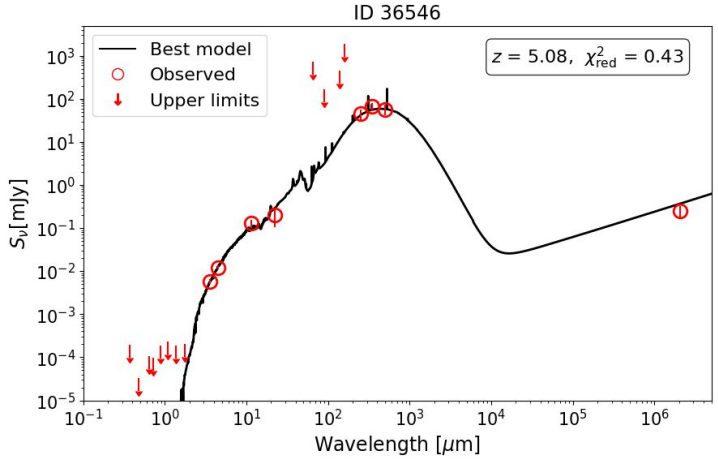
Median SED

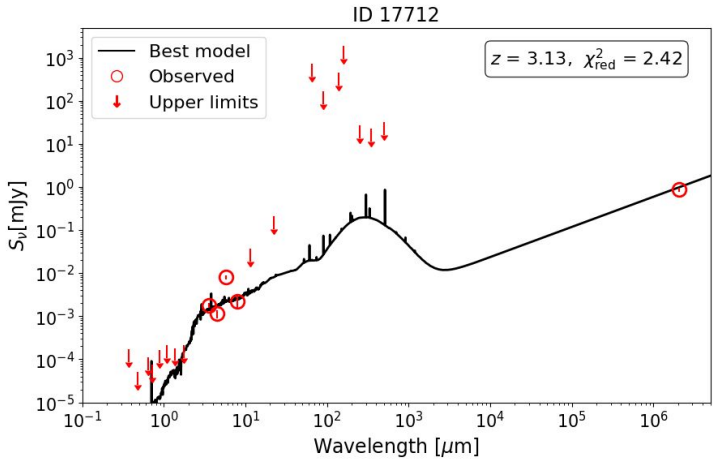


Median SED-fitting results	
z_{ph}	3.07 ± 0.36
$\log_{10}(M_\star/M_\odot)$	11.00 ± 0.16
$A_{V,ISM}$	4.9±0.3
$\log_{10}(L_{dust}/L_\odot)$	12.91 ± 0.18
$\log_{10}[SFR/(M_\odot\ yr^{-1})]$	2.93 ± 0.23
f_{AGN}	0.23 ± 0.05
$\log_{10}[L_{1.4\,GHz,AGN}/(W\,Hz^{-1})]$	24.48 ± 0.23
R_{AGN}	[1.0]
$\log_{10}(L_{IR}/L_\odot)$	12.81 ± 0.04
$\log_{10}[L_{1.4\,GHz,SF}/(W\,Hz^{-1})]$	24.29 ± 0.36
$\log_{10}[SFR_{radio}/(M_\odot\,yr^{-1})]$	2.89 ± 0.36
q_{IR}	2.06 ± 0.09

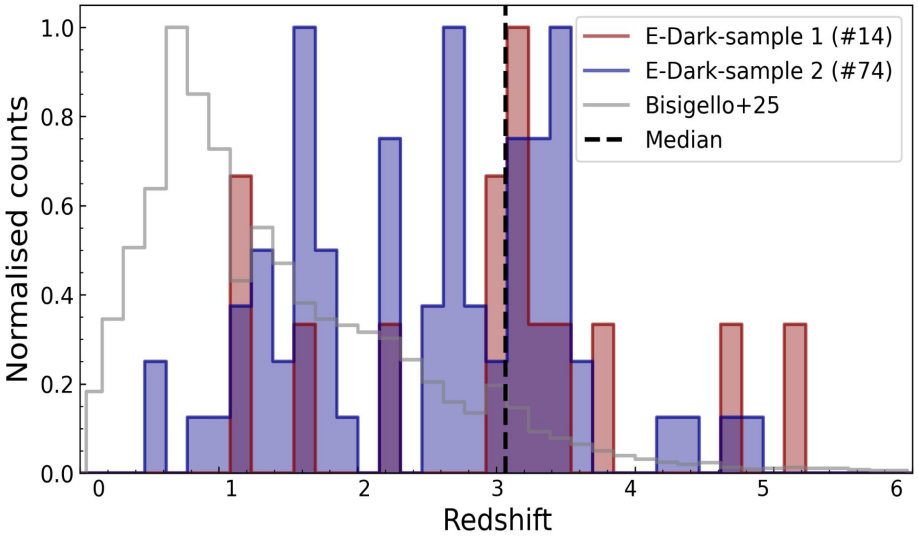
Single objects analysis

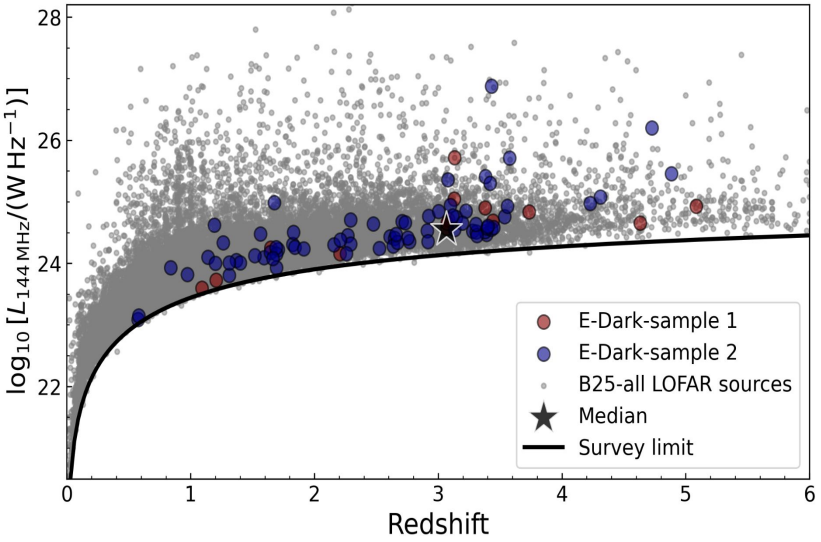
<u>Sample 1:</u> 14 objects with at least a detection at λ>4.6μm
<u>Sample 2:</u> 74 remaining objects with 3 photometric detections



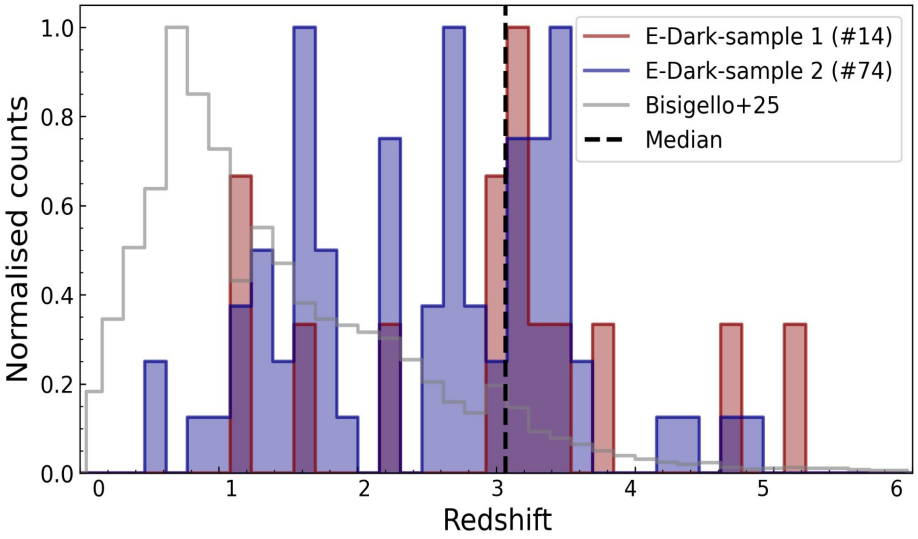


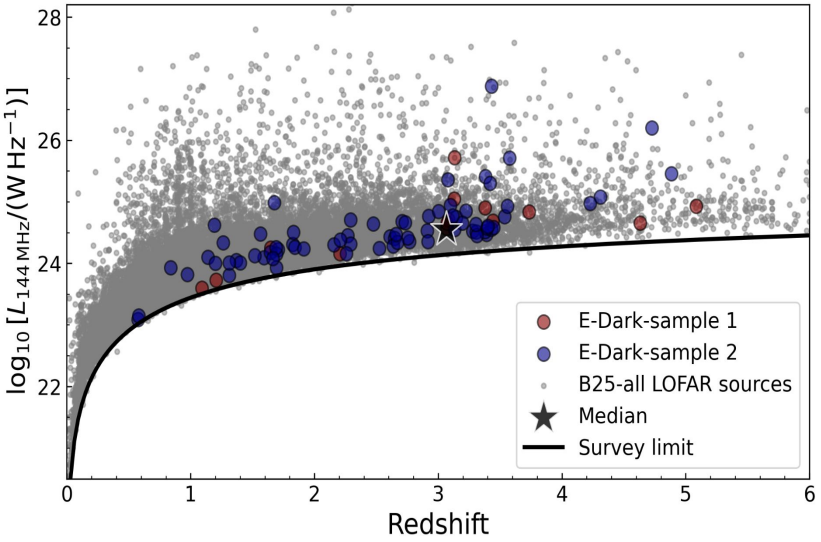
Results

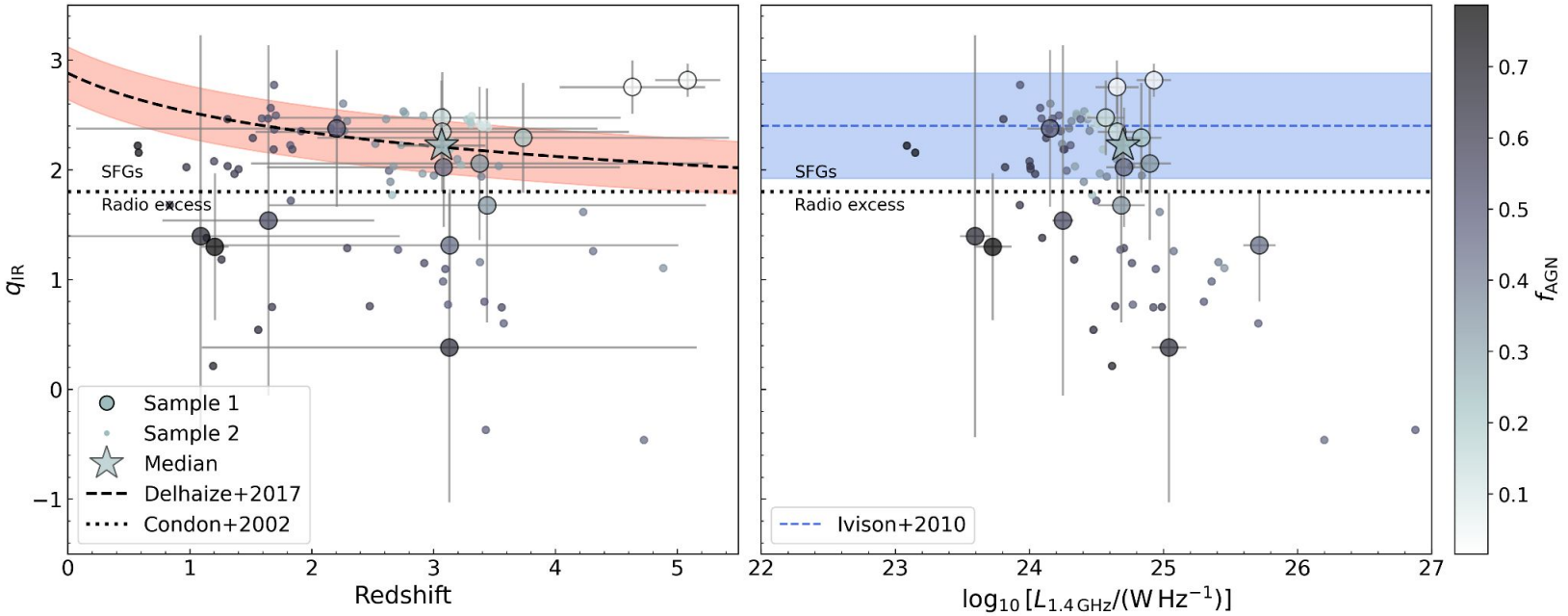

E-Dark-sample 1 (#14)
E-Dark-sample 2 (#74)
Bisigello+25
Median
Normalised counts
Redshift


E-Dark-sample 1
E-Dark-sample 2
B25-all LOFAR sources
Median
Survey limit
$\log_{10}[L_{144\,\mathrm{MHz}}/(\mathrm{W\,Hz^{-1}})]$
Redshift

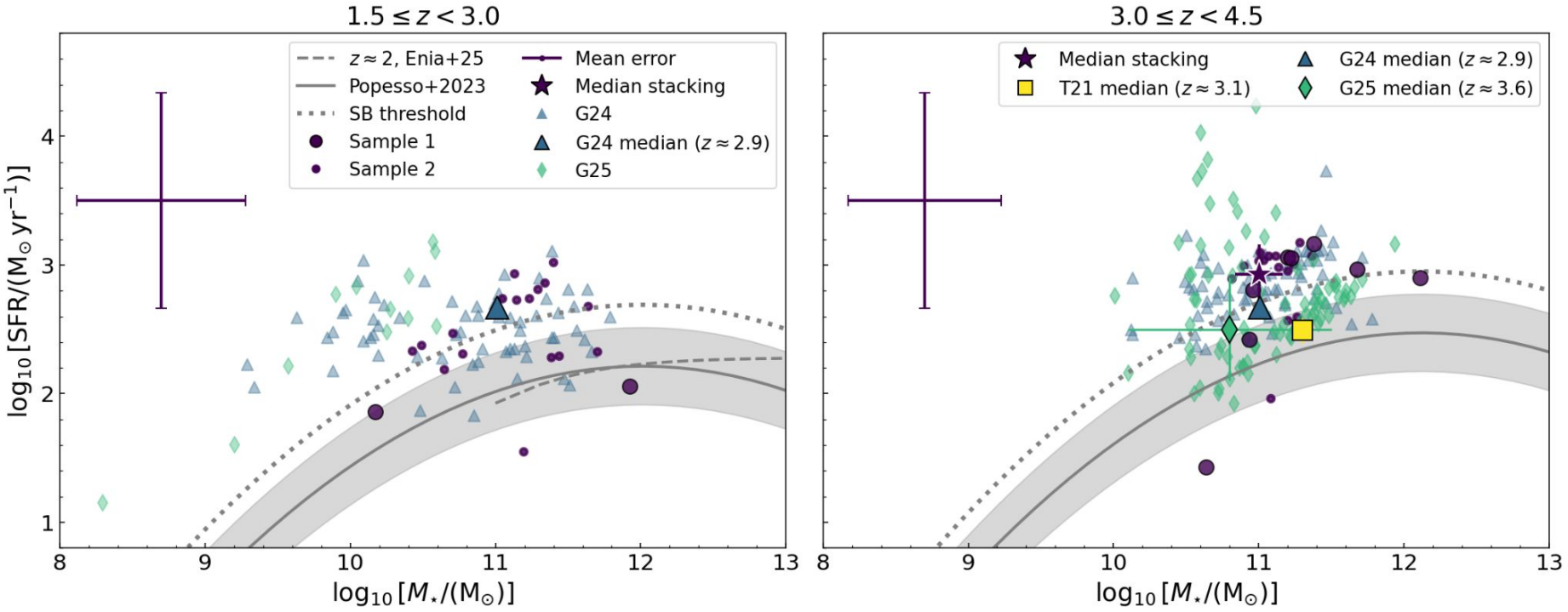
Results


E-Dark-sample 1 (#14)
E-Dark-sample 2 (#74)
Bisigello+25
Median
Normalised counts
Redshift


E-Dark-sample 1
E-Dark-sample 2
B25-all LOFAR sources
Median
Survey limit
Redshift


SFGs
Radio excess
Sample 1
Sample 2
Median
Delhaize+2017
Condon+2002
Redshift
SFGs
Radio excess
Ivison+2010

Results



Higher stellar masses & SFRs with respect to previous Rs-NIR dark samples (Δlog SFR ≈ 0.3-0.4 dex, Talia+2021, Gentile+2024a, Gentile+2025)

Compatible with a population where AGN and strong star-formation phases co-exist.

Summary and conclusions

-By exploiting sensitive LOFAR 150 MHz observations of the EDF-N (~10 deg^2) we selected a sample of 166 Rs-Euclid dark sources.

-The analysis of the median stacked and individual sample of 88 sources revealed a population of high-z (z_{med}~3), massive (M_{med}~10^{11} $M_\odot$) star-forming (SFR_{med}~850 $M_\odot yr^{-1}$) galaxies with a non-negligible AGN component.

-Significant fraction of our sources compatible with RQ AGNs, better sampled by larger areas.

-Large area + shallower coverage wrt previous selections→ selection of galaxies in which AGN and SF activity co-exists.

Next steps:

-Improving photometry.
-Waiting for Euclid DR1.
-Expanding to other large fields (e.g. EDF-S).