OSSERVATORIO ASTROFISICO DI TORINO

UNIVERSITÀ DI TORINO

Istituto Nazionale di Fisica Nucleare
SEZIONE DI TORINO

The EMU Cosmology Project

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INAF OATo

In collaboration with:
Chandra Shekhar Saraf (KASI), Kostas Tanidis (Nova Gorica), Albany Asher (Western Sydney), Giulia Piccirilli (INFN Rome), David Parkinson (KASI), Jacobo Asorey (Zaragoza), Stefano Camera (UniTO), Catherine Hale (ROE), Daniela Carollo (OATs) and members of the EMU collaboration

EMU
Evolutionary Map of the Universe

EMU

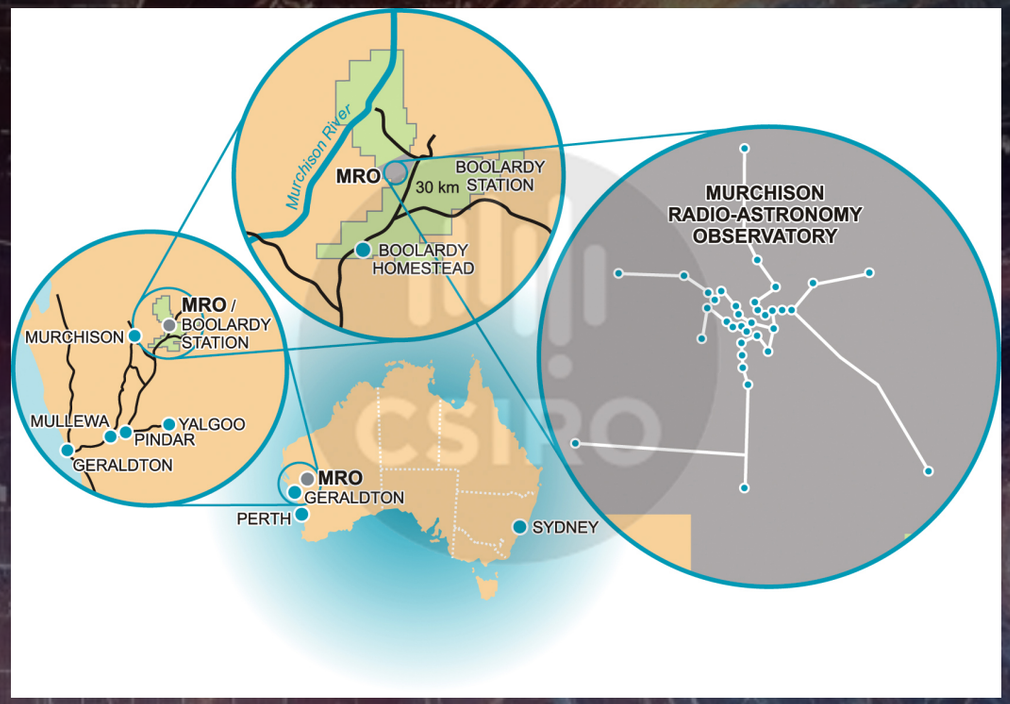


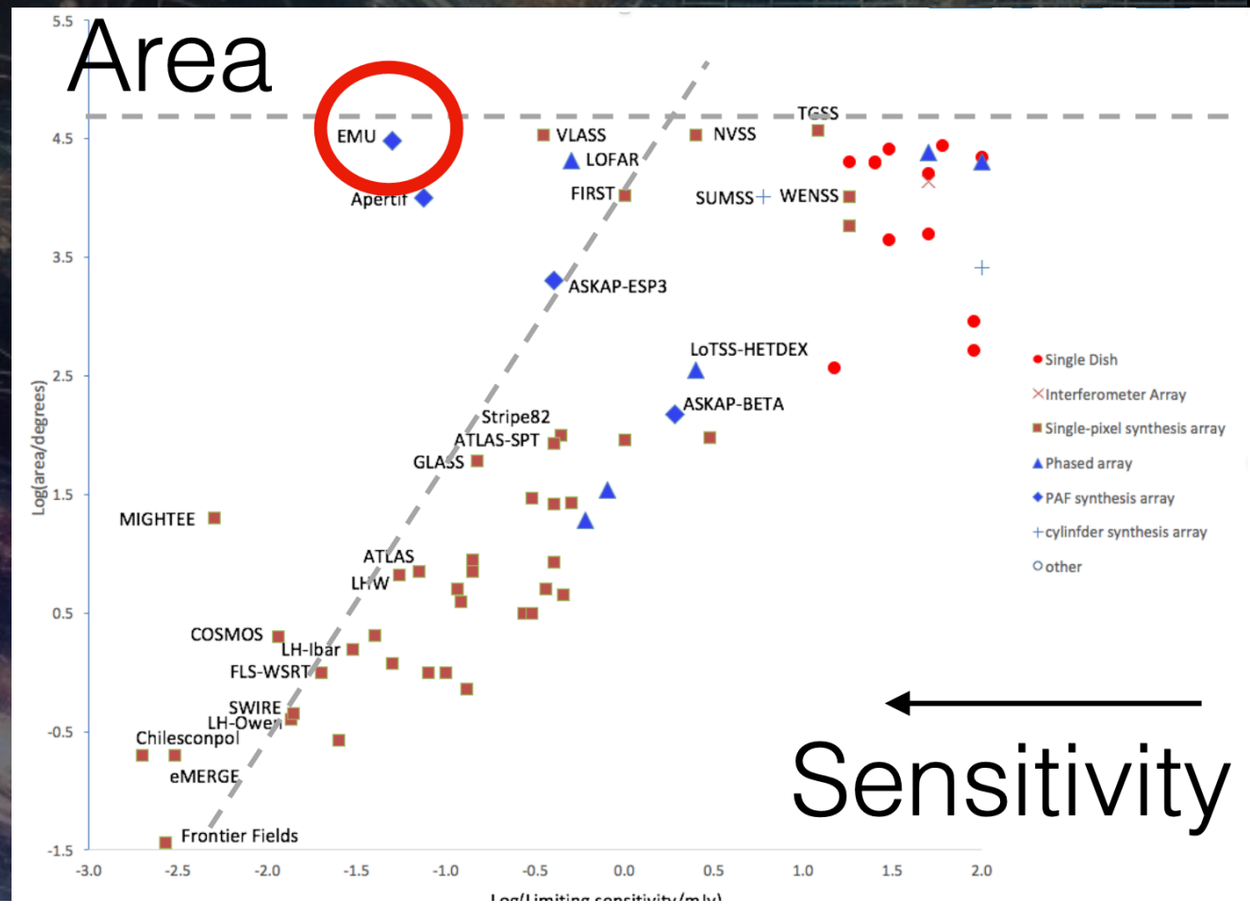

Image credit: CSIRO (Norris et al. 2011)

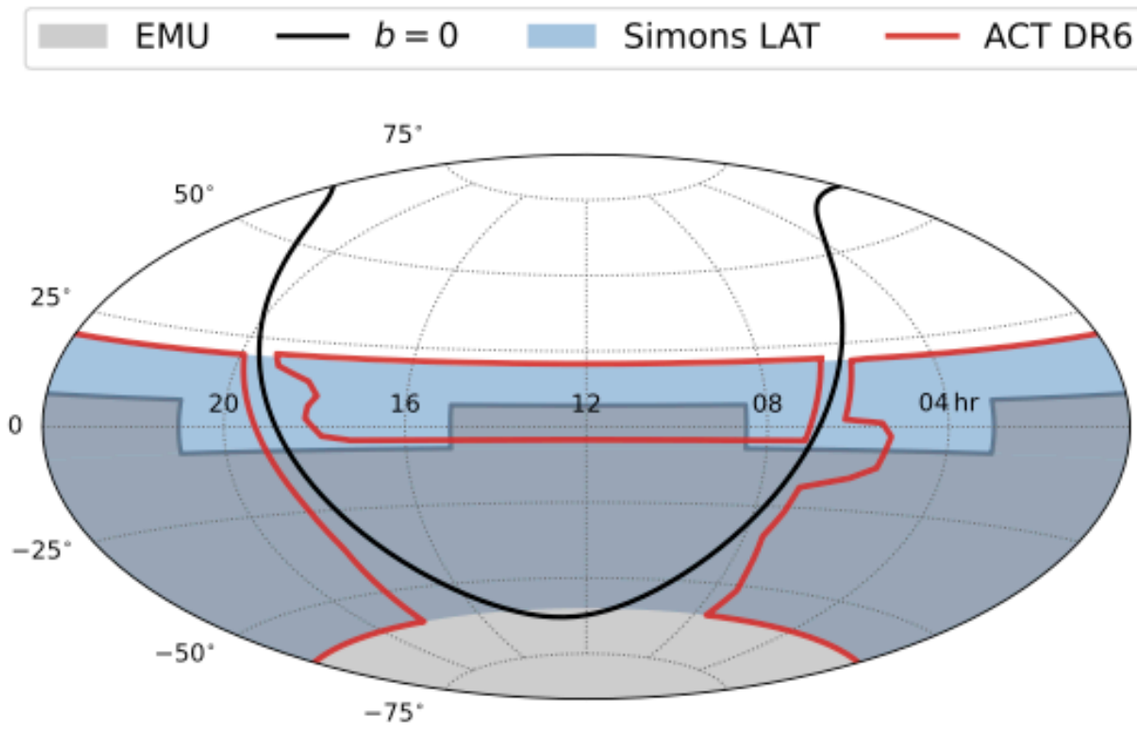
- Evolutionary Map of the Universe (EMU) is a wide-field radio continuum survey by the Australian SKA Pathfinder (ASKAP)
- ASKAP composed of 36 12m dishes at Inyarrimanha Ilgari Bundara, the CSIRO Murchison Radio-astronomy Observatory
- Started end of 2022 and will detect 20 million radio galaxies by 2028

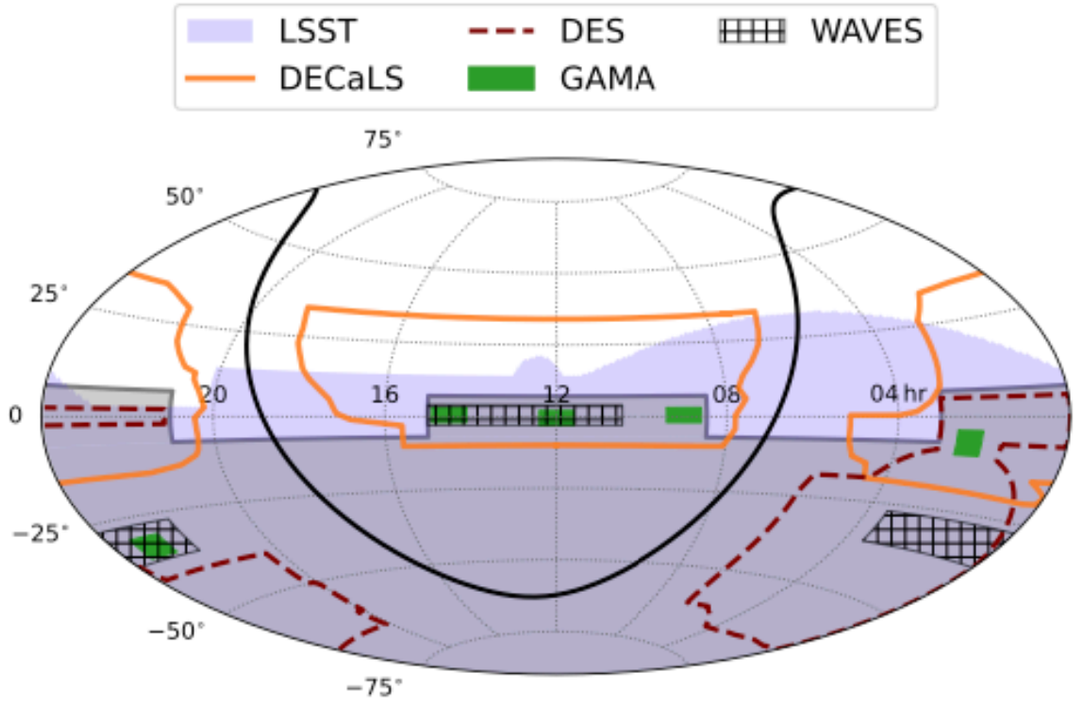
We acknowledge the Wajarri Yamatji people as the traditional owners of the Observatory site. Name of telescope site means 'sharing sky and stars' in the Wajarri language.

EMU

- Will cover entire Southern Sky (2 pi survey), ideal for ultra-large-scale cosmology (e.g. relativistic effects, primordial non-Gaussianity, cosmic dipole, …)
- Central Frequency 943 MHz
- bandwidth 288 MHz
- FoV 30deg
- RMS of 30 μJy/beam
- Resolution of ~15″ FWHM







Hopkins et al. 2025, PASA

EMU forecasts

10 μJy rms/beam, 2 Traces, 5 Redshift bins[a]					
	$f_{\rm NL}$	w_0	w_a	μ_0	γ_0
GC+ISW	3.9 (4.9)	0.49 (1.2)	1.4 (2.8)	0.31 (0.61)	0.71 (1.3)
GC+ISW+Planck*	2.9 (3.2)	0.19 (0.25)	0.48 (0.70)	0.12 (0.19)	0.29 (0.43)

[Bernal *et al.* 2019]

Caveats:

- Relies on being able to split into tracers and redshift bins
- Have to revisit assumptions on $n(z)$ and $b(z)$
- EMU got down-scoped to $f_{\rm sky} = 0.5$ rather than $f_{\rm sky} = 0.75$ (at least for first 5 years)
- Actual noise is 15 uJy rms/beam

Continuum Cosmology

1. Angular correlation function of radio galaxies
2. Cosmic Magnification of high-z radio galaxies by low-z optical foreground galaxies
3. Cosmic Magnification of CMB by radio galaxies
   - Cross-correlation between radio density and CMB on small scales
4. Integrated Sachs-Wolfe effect
   - Cross-correlation between radio density and CMB on large scales

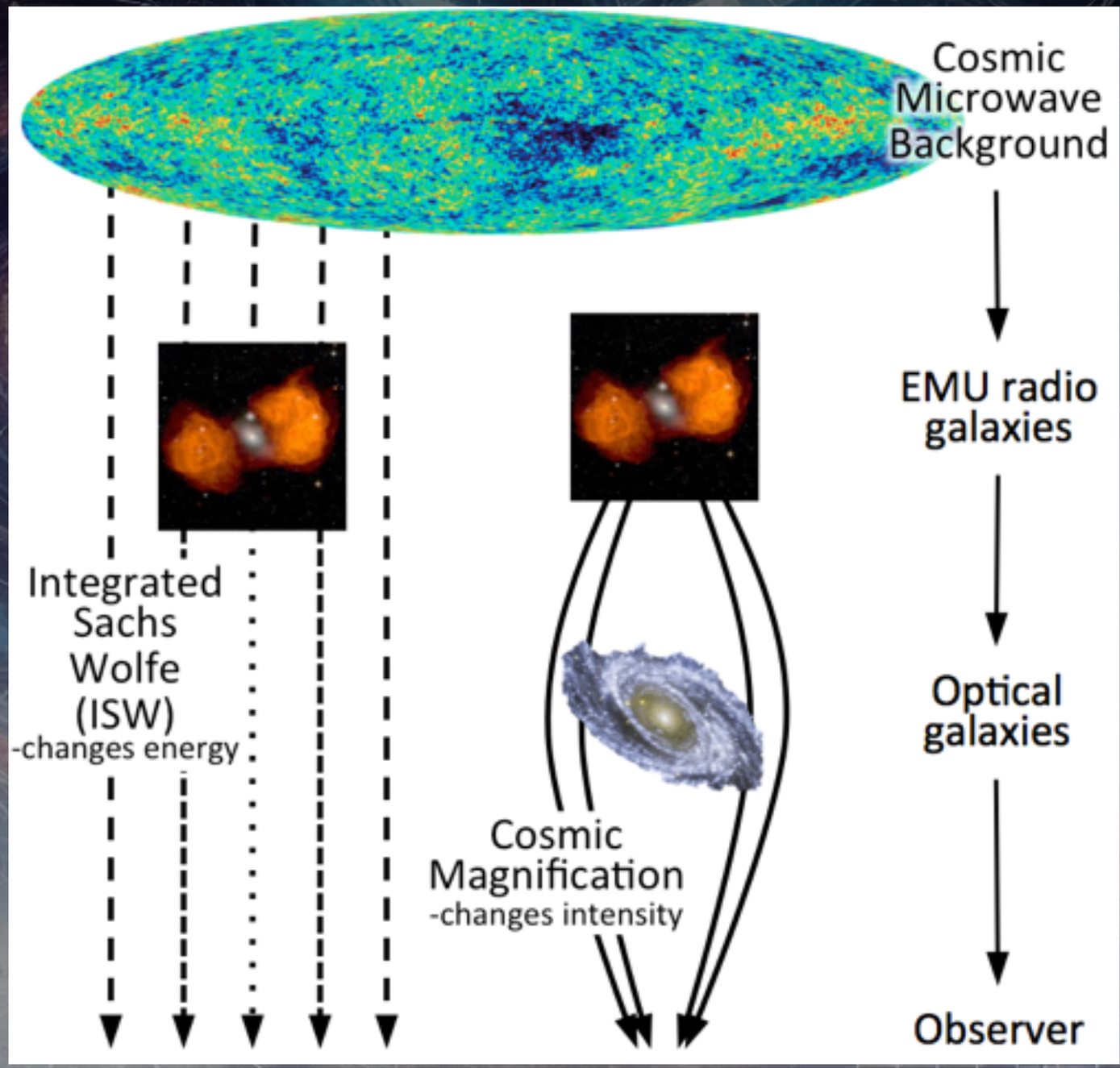


Image credit: Tamara Davis

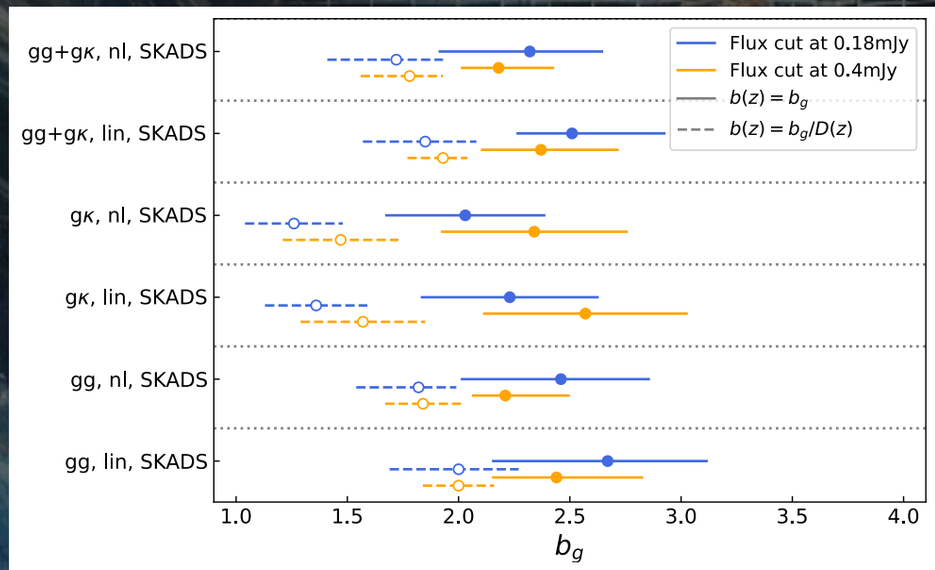
First Cosmology Results from EMU Pilot Survey

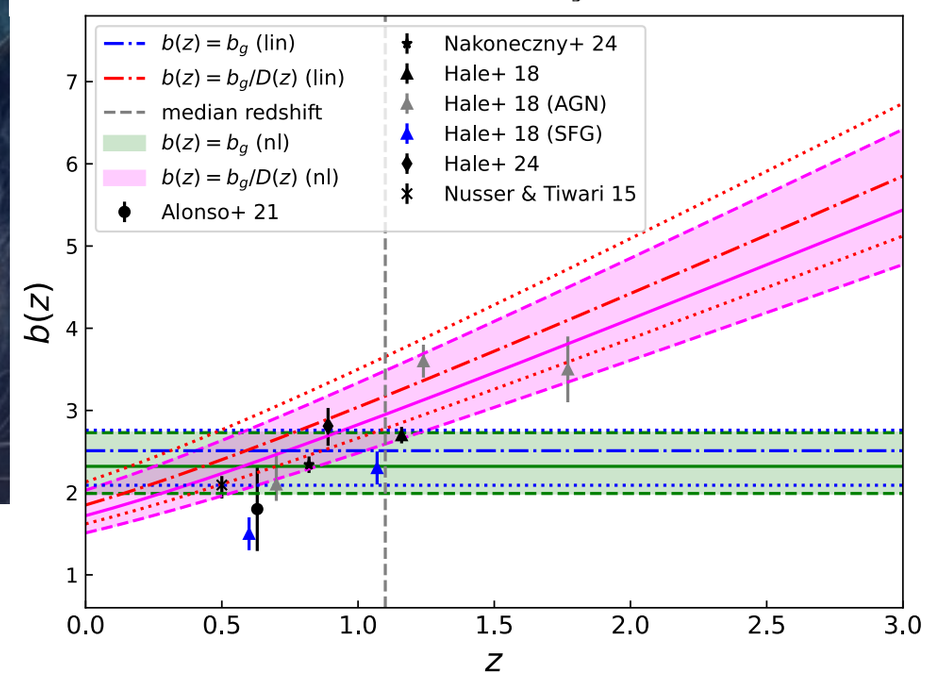
- X-correlation between density field from EMU PS1 ($300\mathrm{deg}^2$) and Planck PR4 lensing magnification:

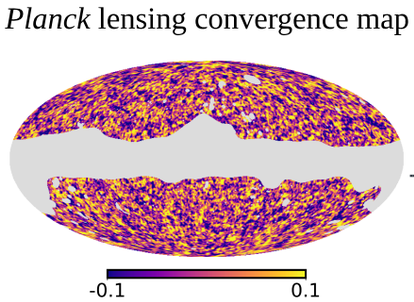
$$C_\ell^{XY} = \int_0^{\chi_h} \frac{\mathrm{d}\chi}{\chi^2} W^X(\ell,\chi)\, W^Y(\ell,\chi)\, P_m\left(k = \frac{\ell+\frac{1}{2}}{\chi}, \chi\right)$$

$$W^{\mathrm{g}}(\ell,\chi) = n(\chi)b(\chi),\ W^{\kappa}(\ell,\chi) = L(\ell)\frac{3\Omega_m H_0^2}{2c^2}[1+z(\chi)]\chi\frac{\chi_\star - \chi}{\chi_\star}$$

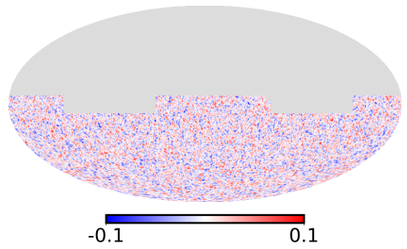
- Bias and σ_8 consistent with similar studies





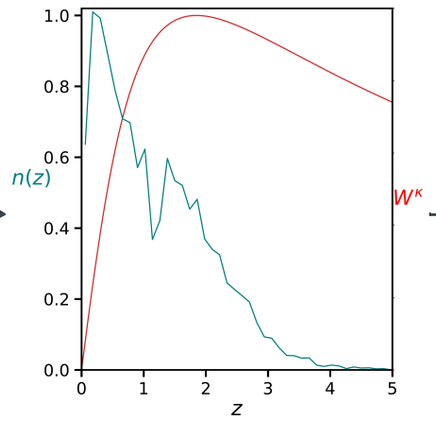


X

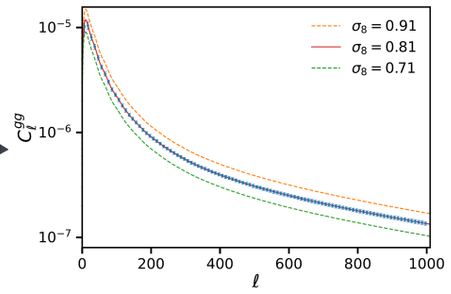


Planck lensing convergence map

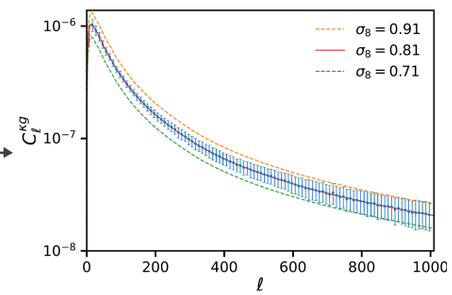
EMU galaxy density map

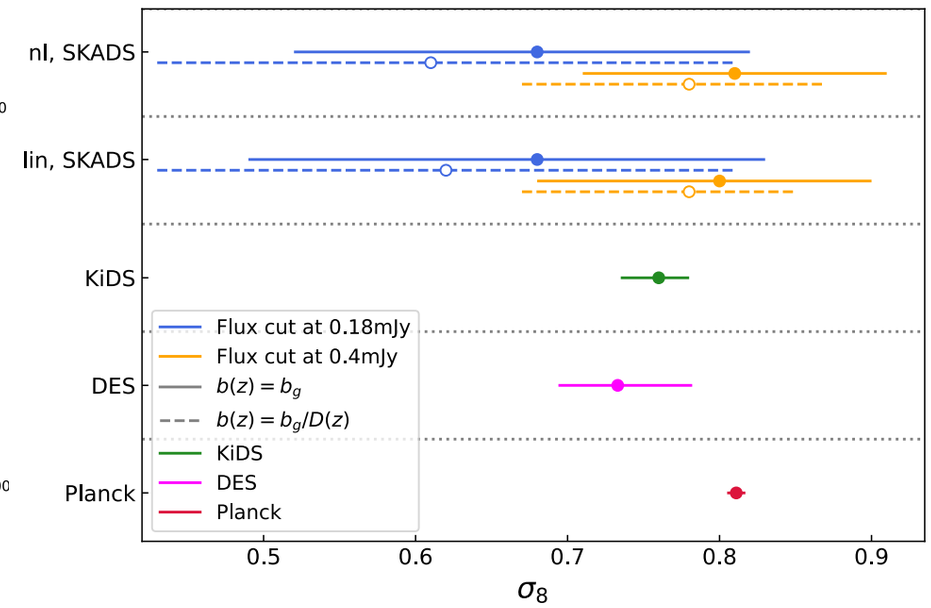


window functions



angular power spectra



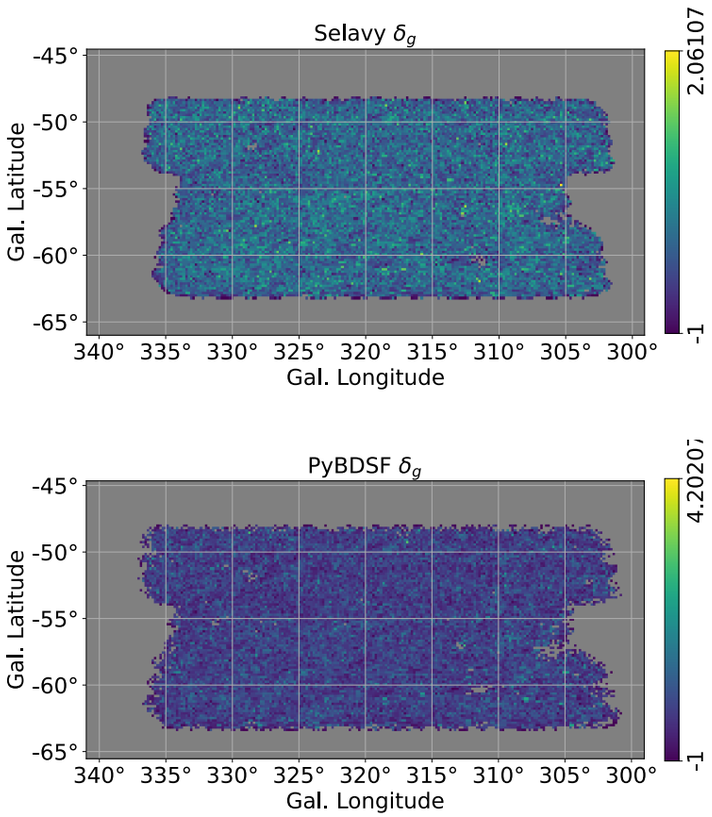


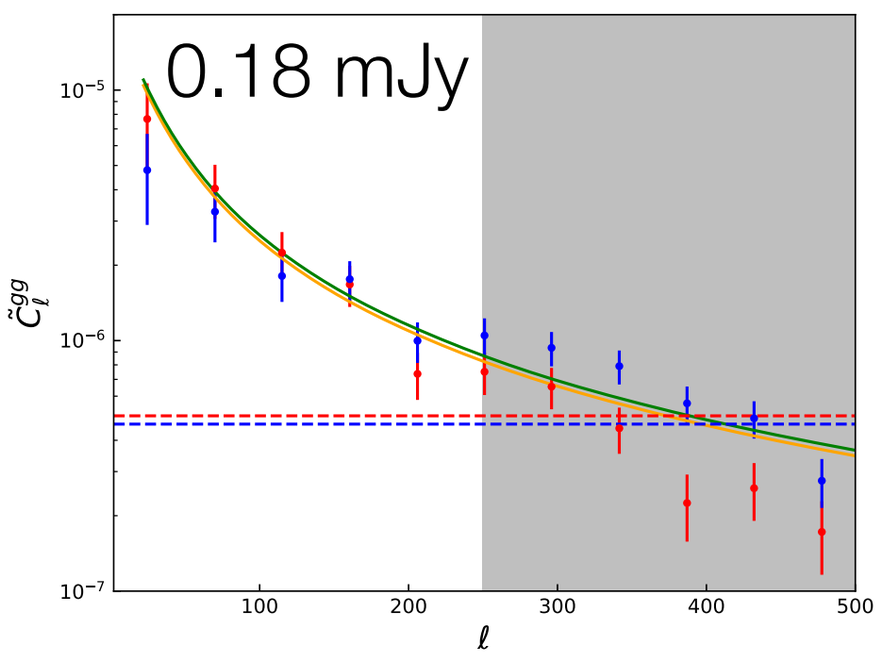
(a) (b) (c)

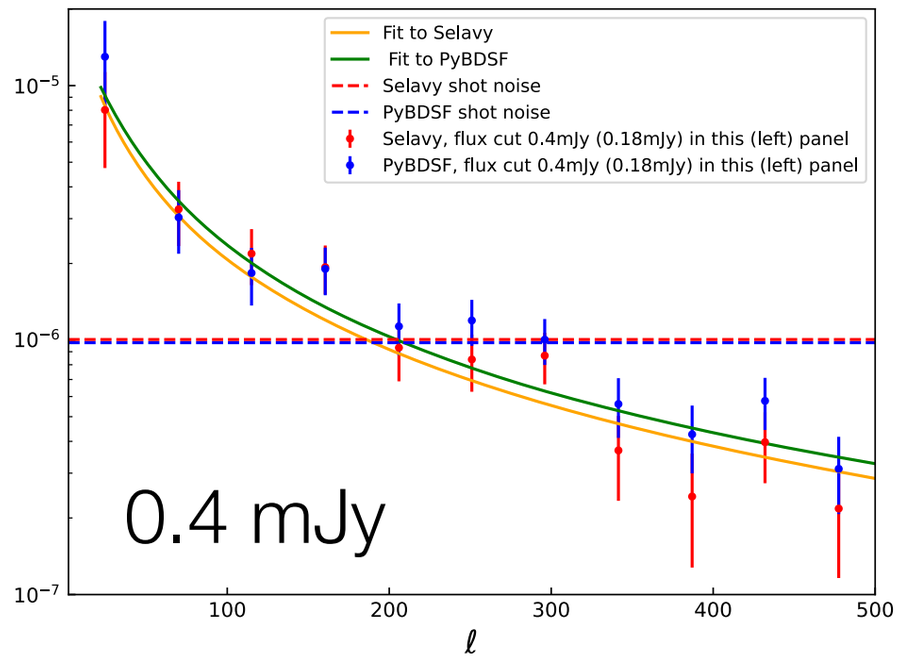
G.S. Saraf for [Hopkins+2025] [Tanidis+2025]

Issue I: Source Finder dependence

- Radio continuum sources difficult to define as they present multiple images (components)
- Considered 2 different source finders: Selavy [Whiting&Humpreys12] and PyBDSF [Mohan&Rafferty15]
- Source-finder dependent auto-power spectrum at small scales especially for faint flux cuts





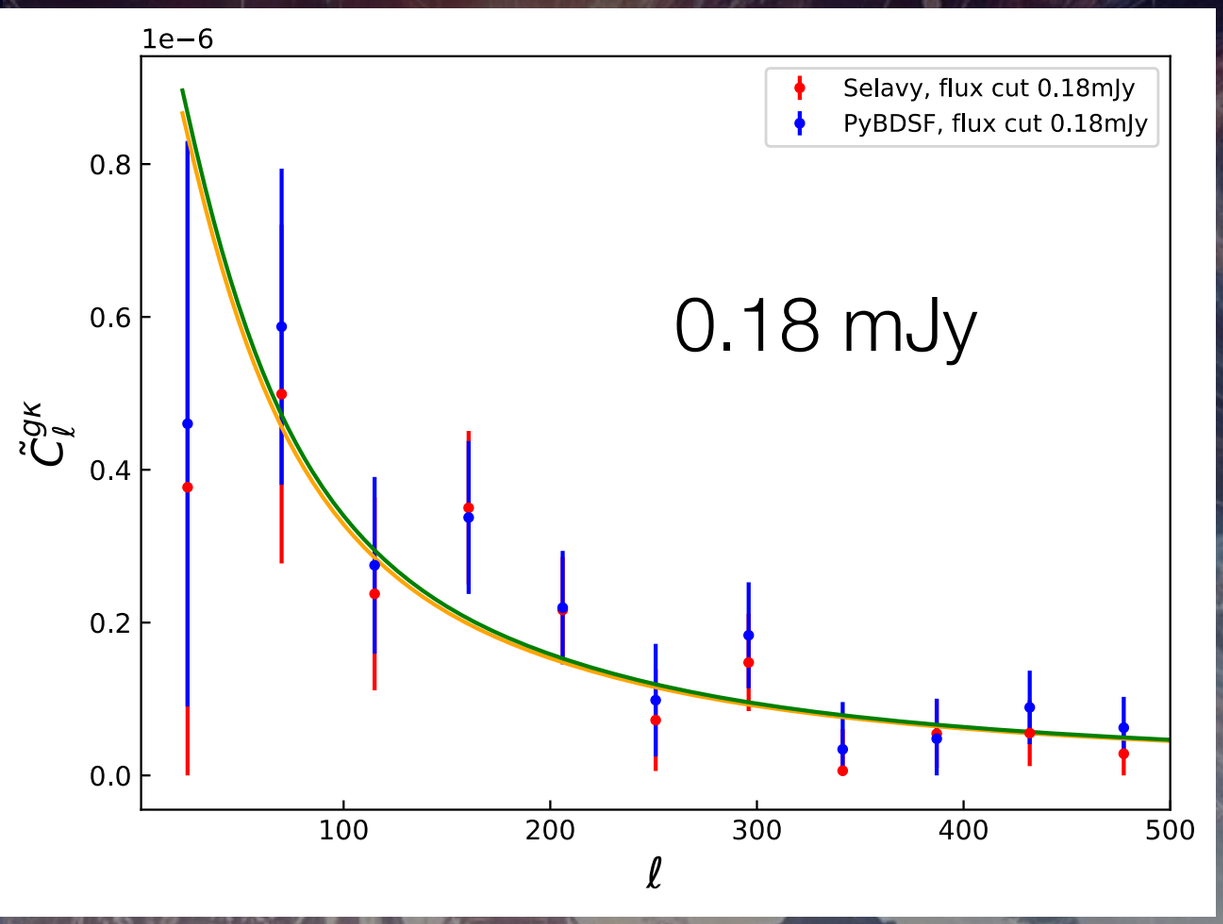


[Tanidis+2025]

Issue I: Source Finder dependence

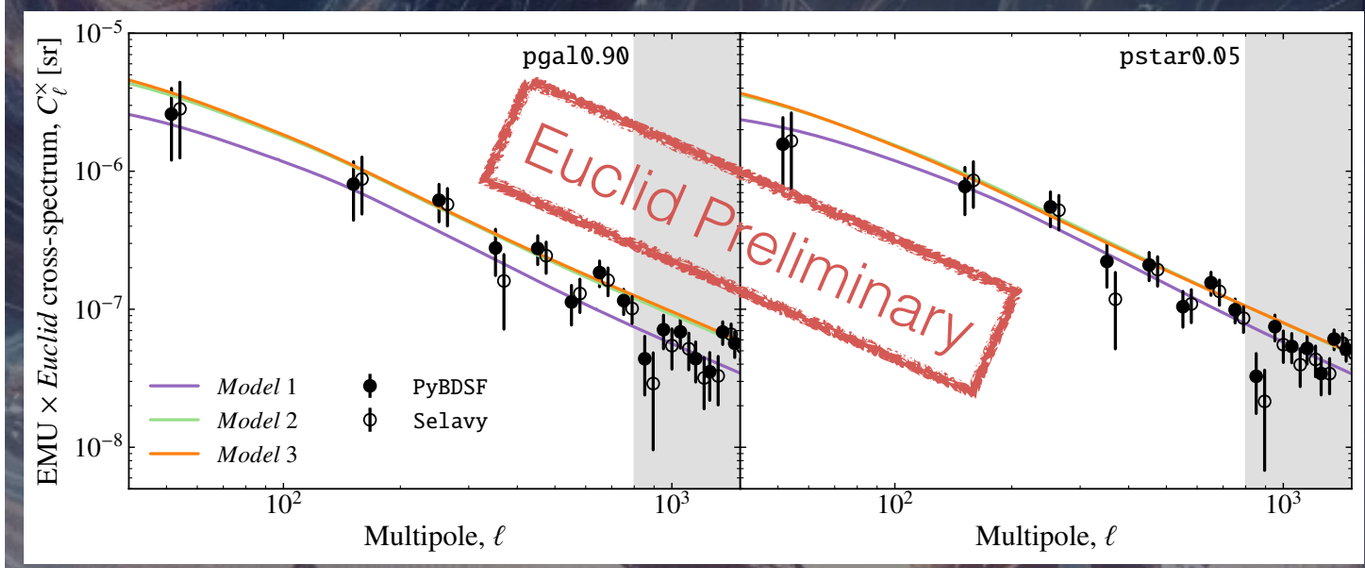
- Cross-correlations are safe:

EMU PS1 x Planck PR4 CMB lensing



[Tanidis+2025]

EMU MS x Euclid Q1 Deep Field South



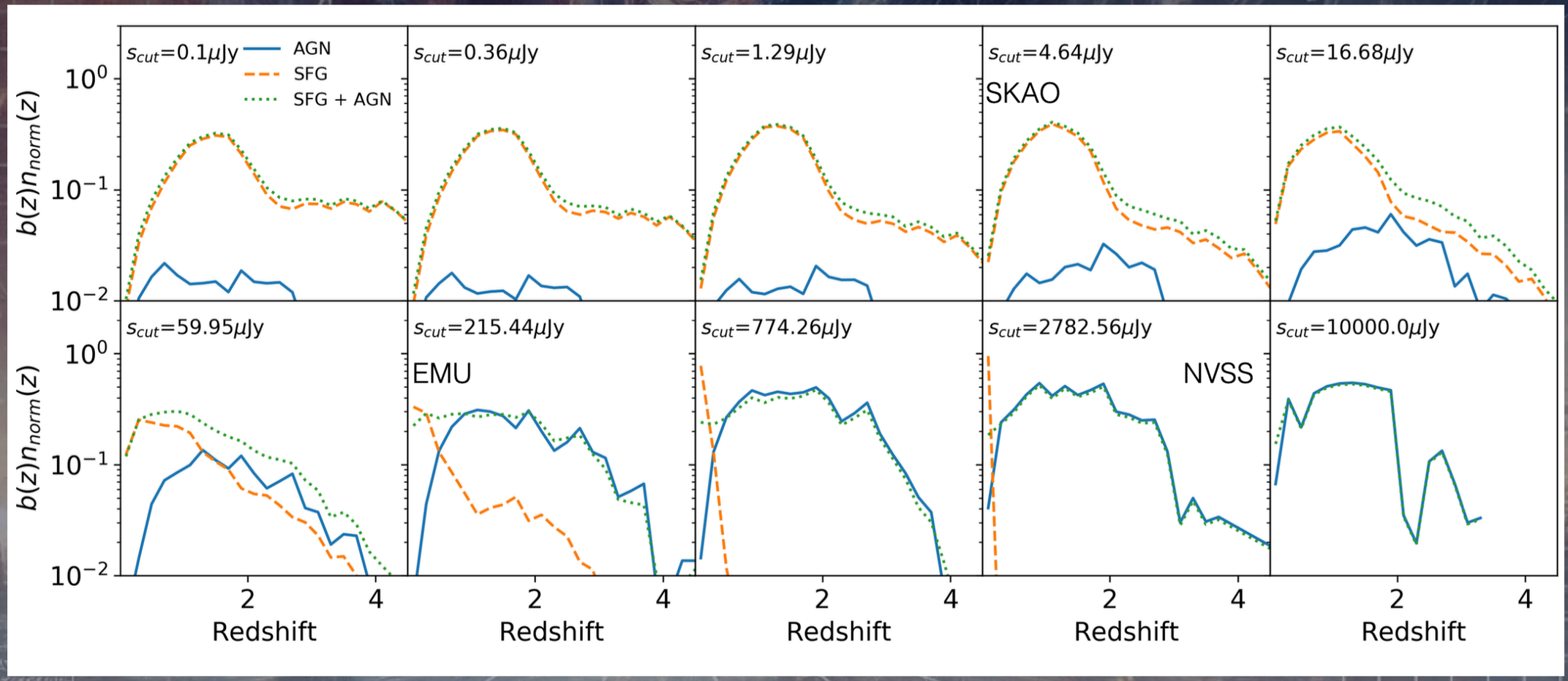
[Piccirilli+2025]

Issue II: N(z)/b(z)

- Angular clustering depends on the redshift distribution N(z) and the galaxy bias.
- N(z) is a mixture of SFG and AGN. For example, N(z) from T-RECS simulation (Bonaldi et al., 2016) and theoretical prescription for the bias.
- Angular power spectrum:

$$C_\ell^{ij} = \frac{2}{\pi} \int W_\ell^i(K) W_\ell^j(k) P(k) k^2 dk$$

$$W_\ell(k) = \int j_\ell(kr) b(z) \frac{dN(z)}{dz} dr$$



[Asorey & Parkinson 2021]

Issue II: N(z)/b(z)

- The uncertainty on the redshift distribution and bias of the radio populations is one of the main sources of uncertainty.
- Three main approaches:
  - Use N(z) from “radioized" simulations like T-RECS or SKADS
  - Cross-id matches with spectroscopic or photometric catalogs (e.g., LoTSS DR1 & DR2)
  - Clustering redshifts

$$C_\ell^{AB} = \frac{2}{\pi}\int dk\, k^2\, W_\ell^A(k)\, W_\ell^B(k)\, P_{mm}(k) \qquad W_\ell(k) = \int dz\, b(z)\, n(z)\, D(z) j_\ell[k\chi(z)] + W_\ell^\mu(k)$$

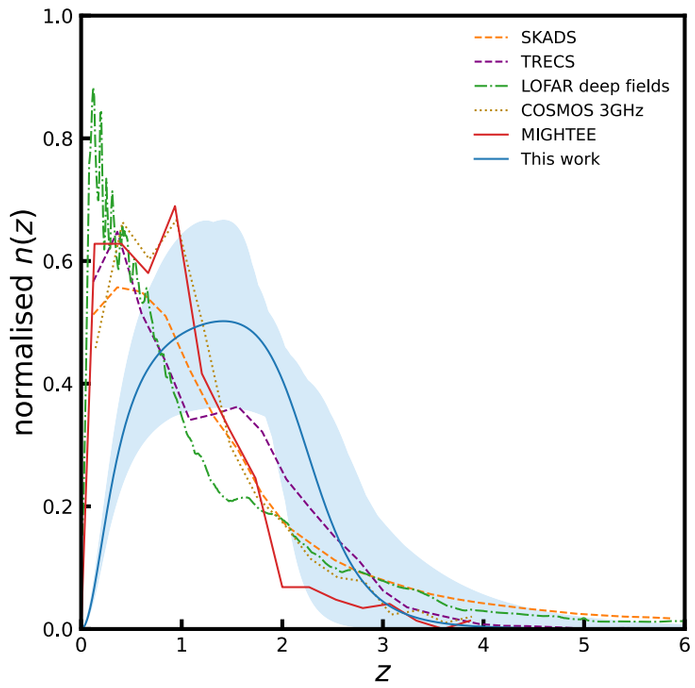
Use sample with “known redshifts”

Assume a functional form for b(z)n(z)

Example 1: LoTSS DR1 (Alonso et al. 2021) $n(z) \propto \frac{(z/z_0)^2}{1+(z/z_0)^2}\frac{1}{1+(z/z_{\rm tail})^\gamma}$

Example 2: LoTSS DR2 (Nakonieczny et al. 2024) $n(z) \propto \frac{z^2}{1+z}\left[\exp\left(-\frac{z}{z_0}\right)+\frac{r^2}{(1+z)^\alpha}\right]$

Results from EMU PS1 x DES MagLim:



C.S. Saraf, D. Parkinson, J.A, C.L. Hale, B. Bahr-Kalus et al. 2025, arXiv e-print: 2505.05821

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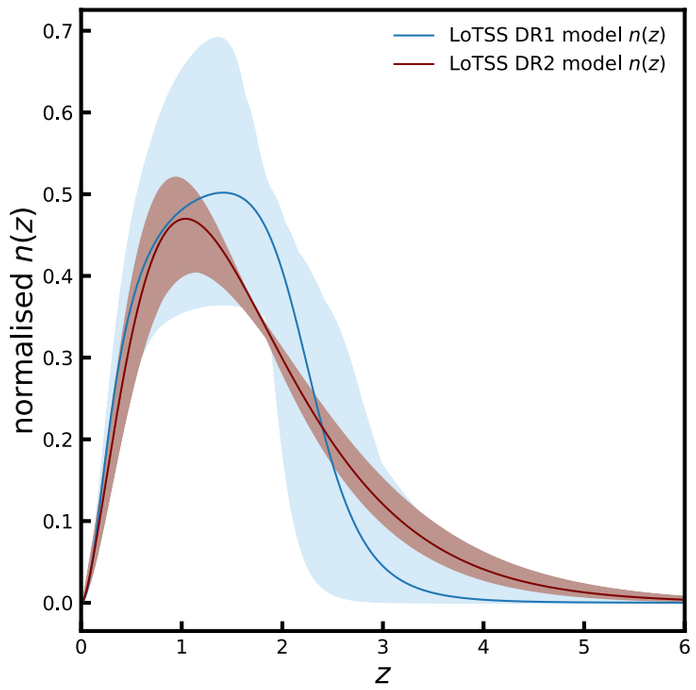
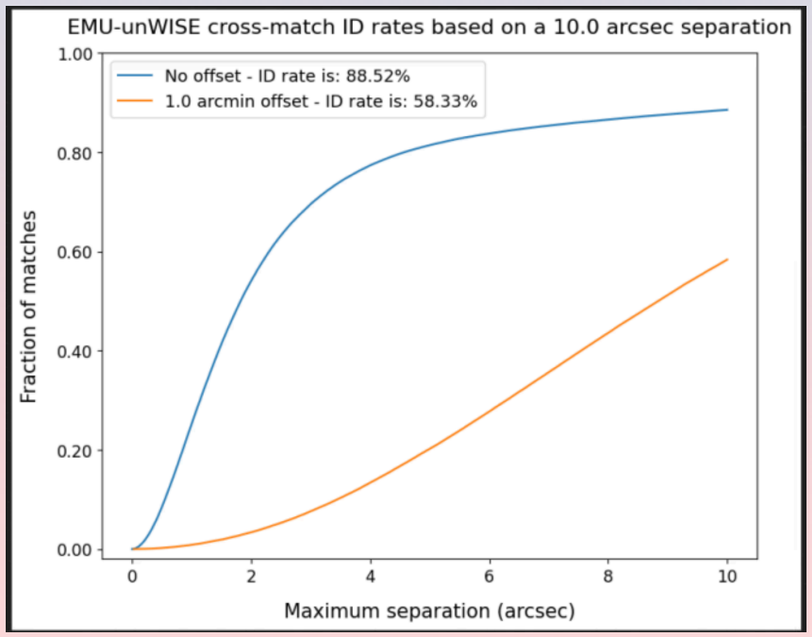


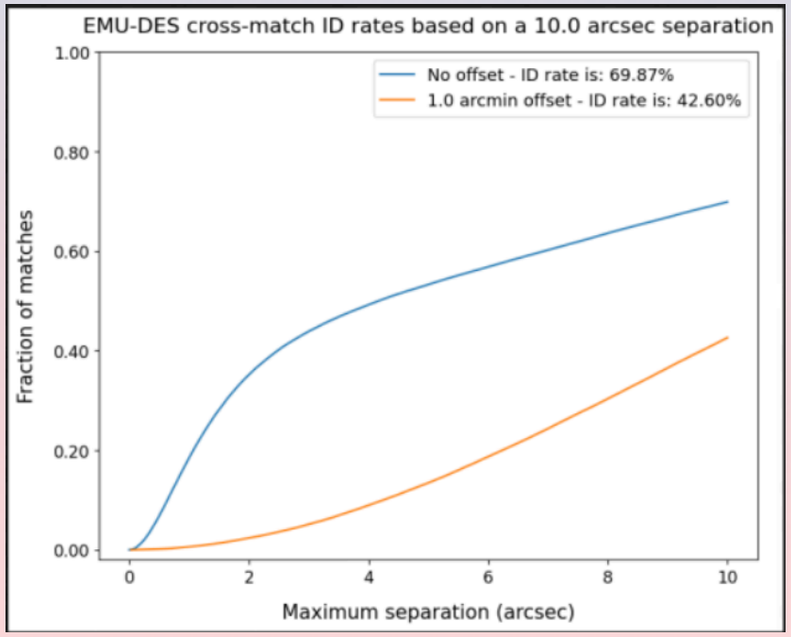
C.S. Saraf, D. Parkinson, J.A, C.L. Hale, B. Bahr-Kalus et al. 2025, arXiv e-print: 2505.05821

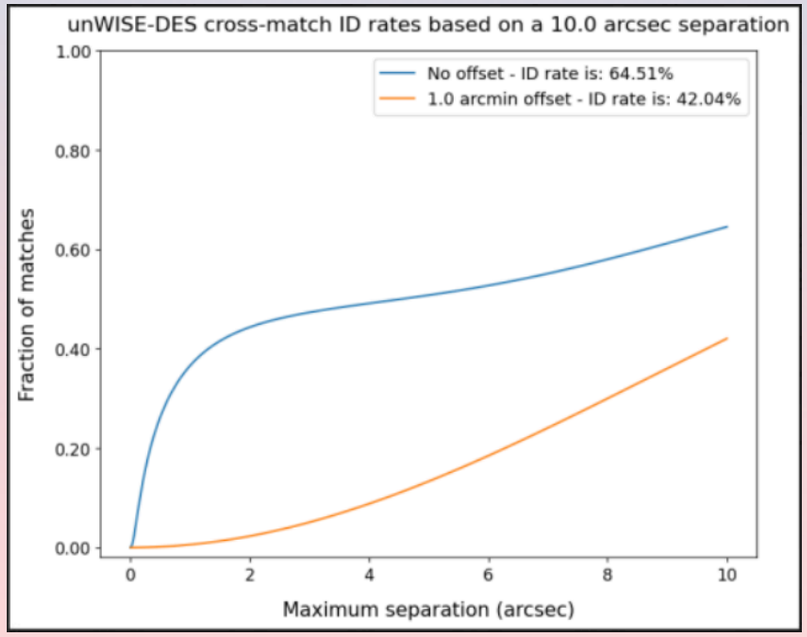
Asher et al., in prep:

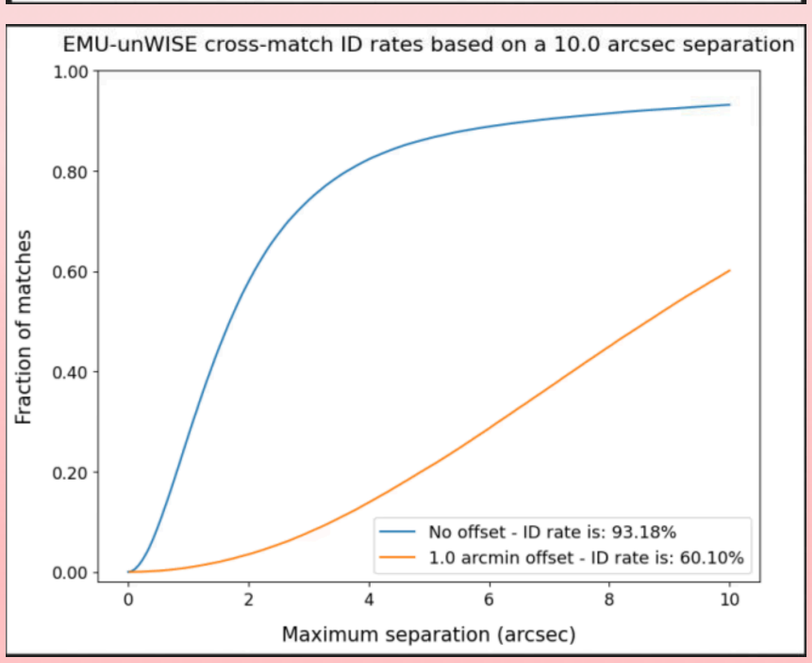
Top Row: cross-matching results where appropriate conditions are set for EMU, unWISE and DES DR2 catalogues

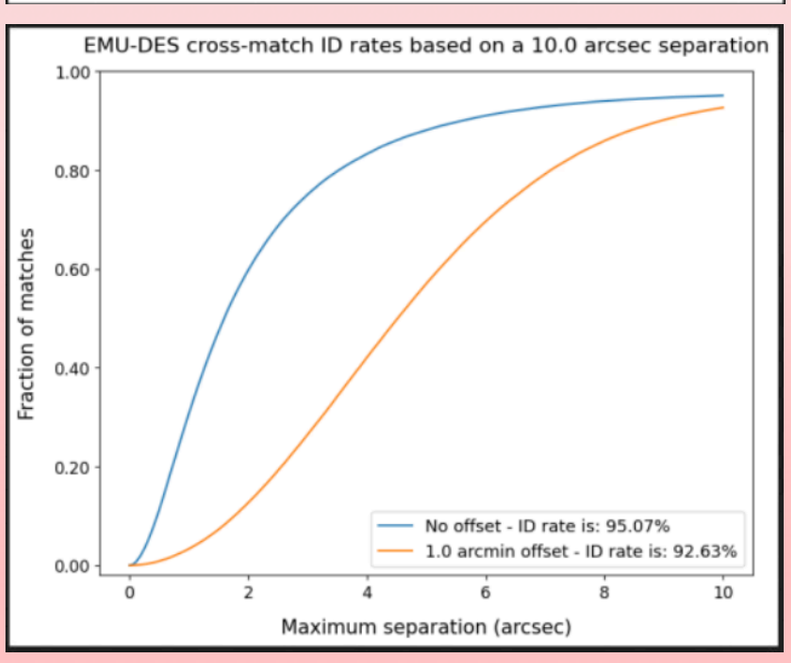
Bottom Row: cross-matching results when no conditions are set for unWISE or DES DR2 catalogues

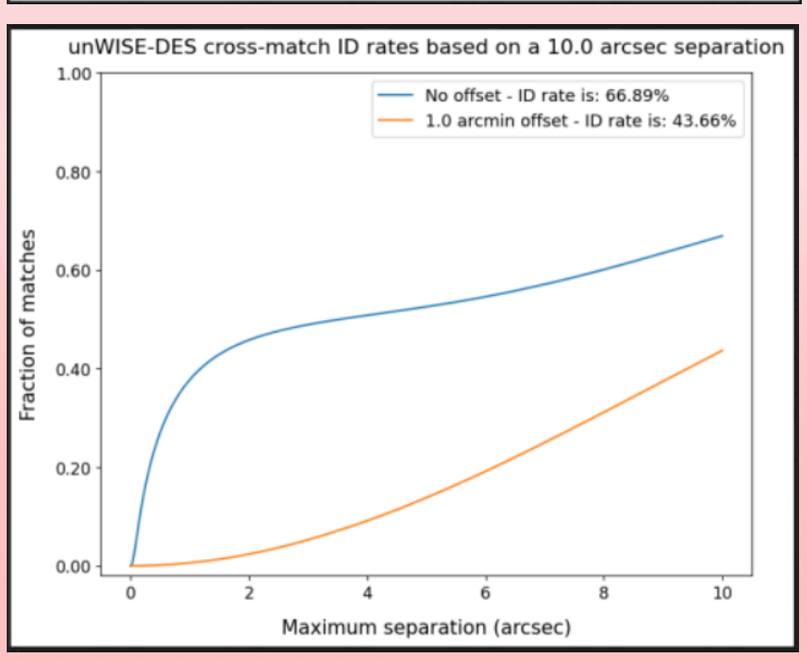








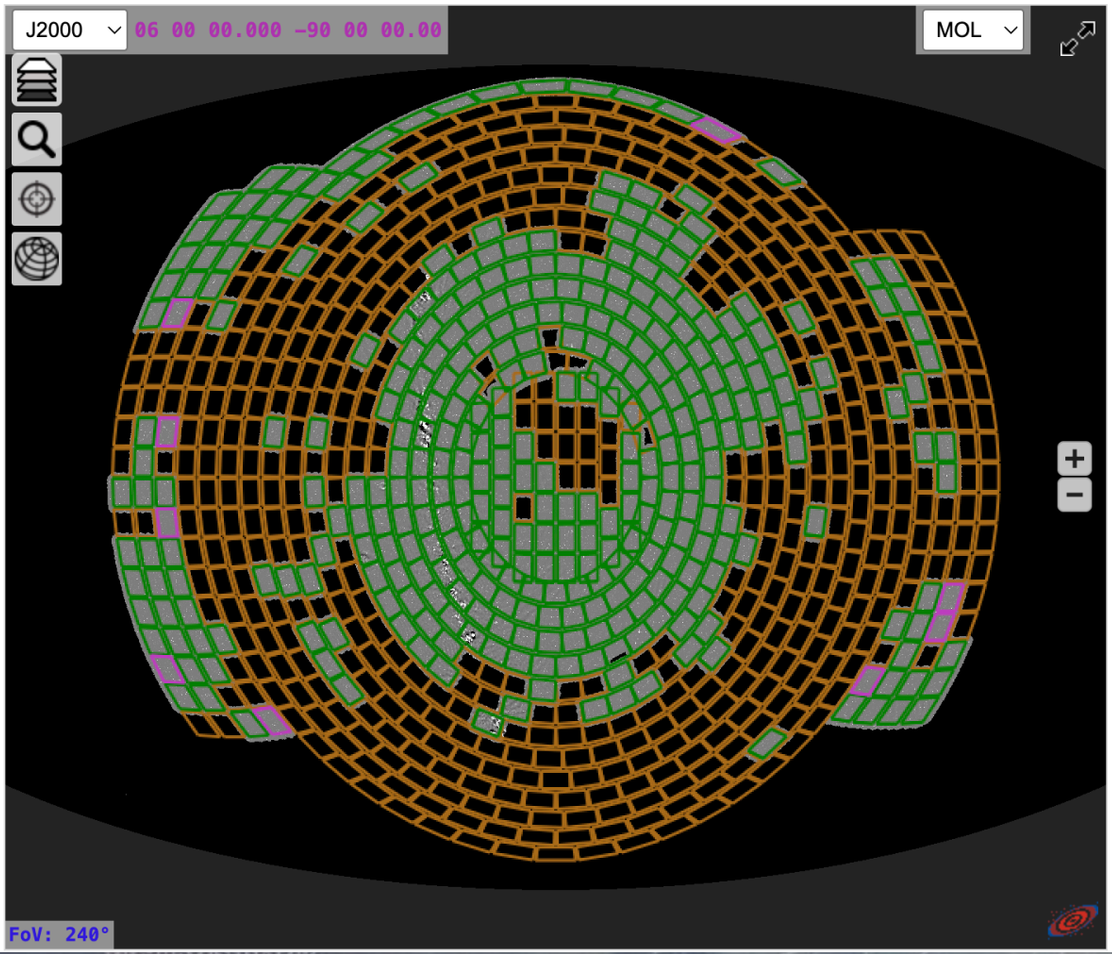




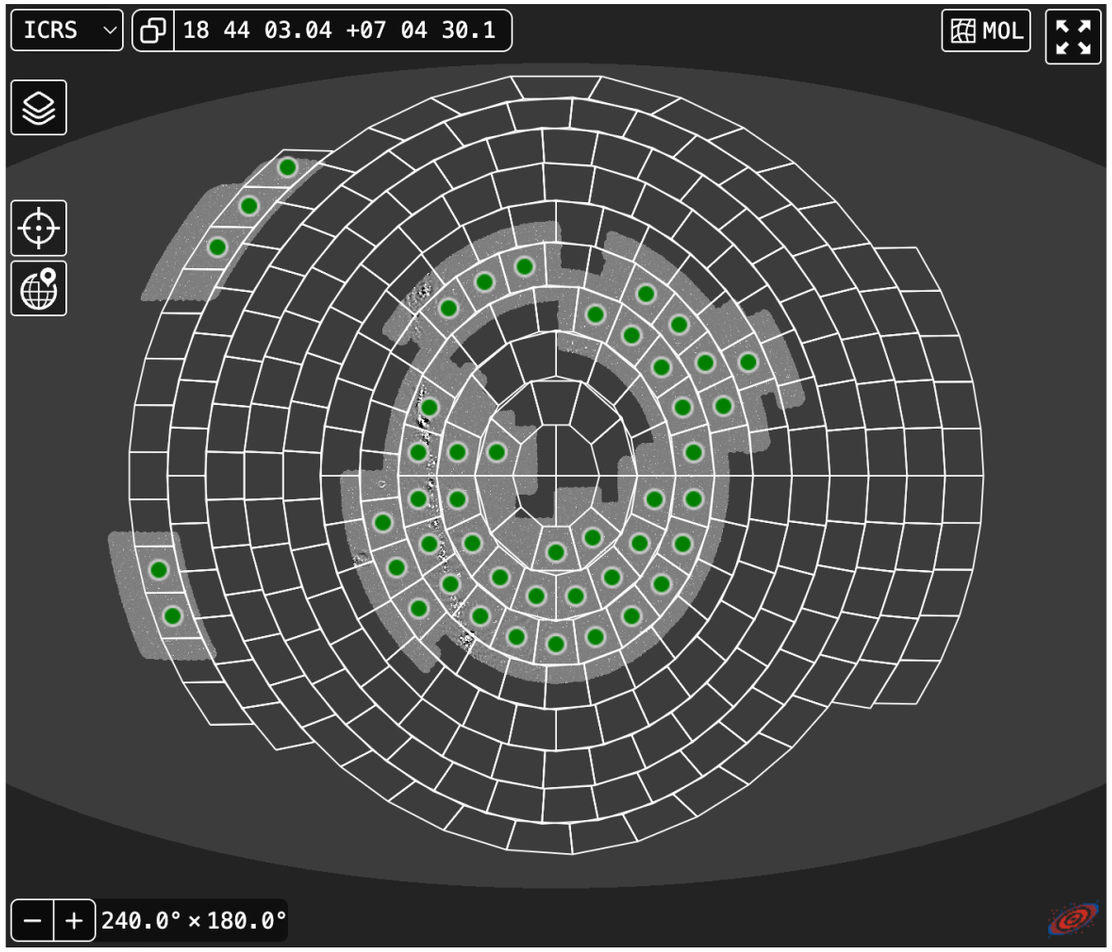
SPOZ

EMU 42.4% complete, 16.4% of EMUCAT regions supermosaicked (3220 sq.deg.), first cosmology analysis with EMU Main Survey in “South Polar Orbital Zone”

EMU Survey Progress and HiPS Image

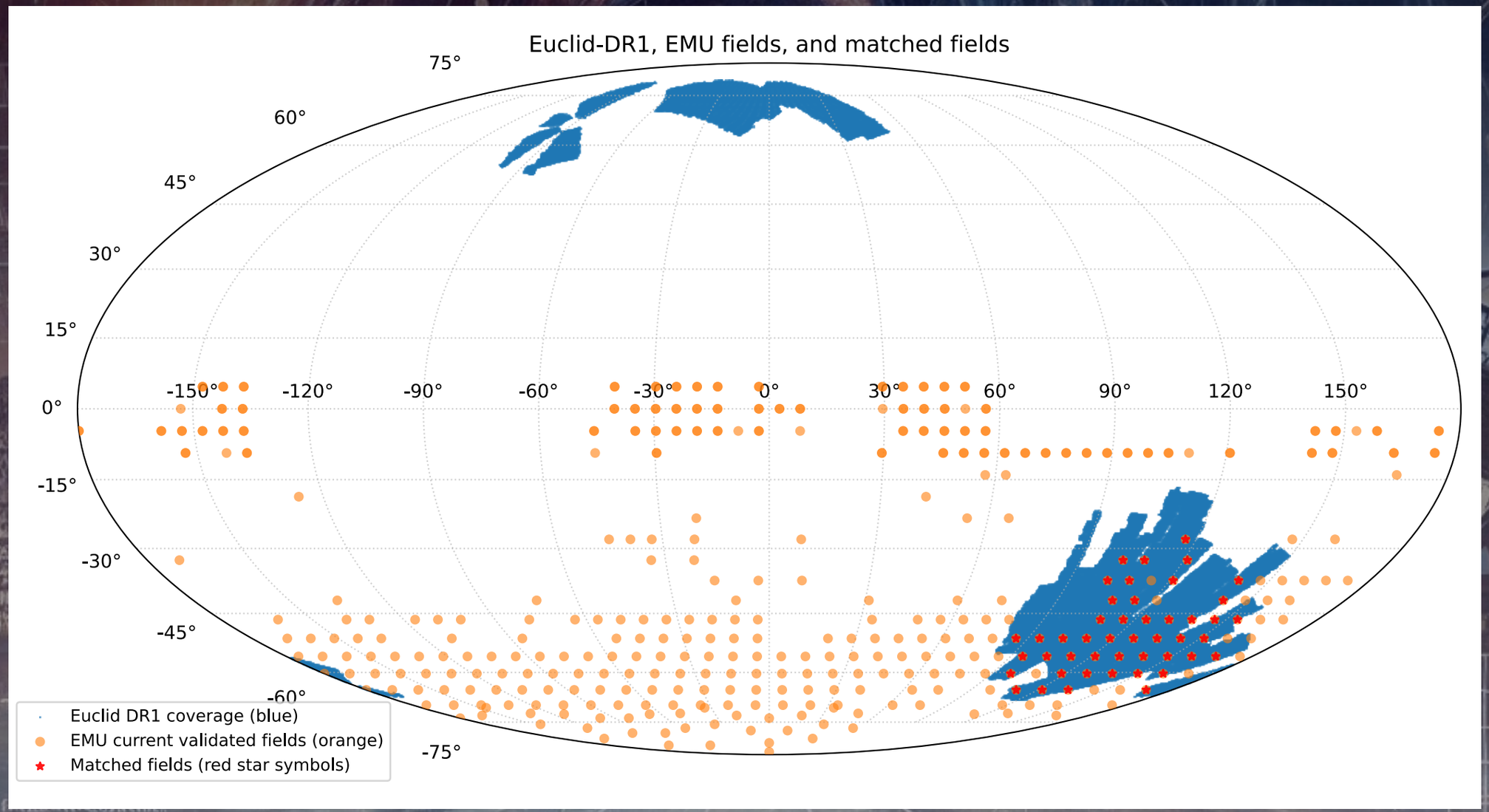


EMUCAT Progress and HiPS Image



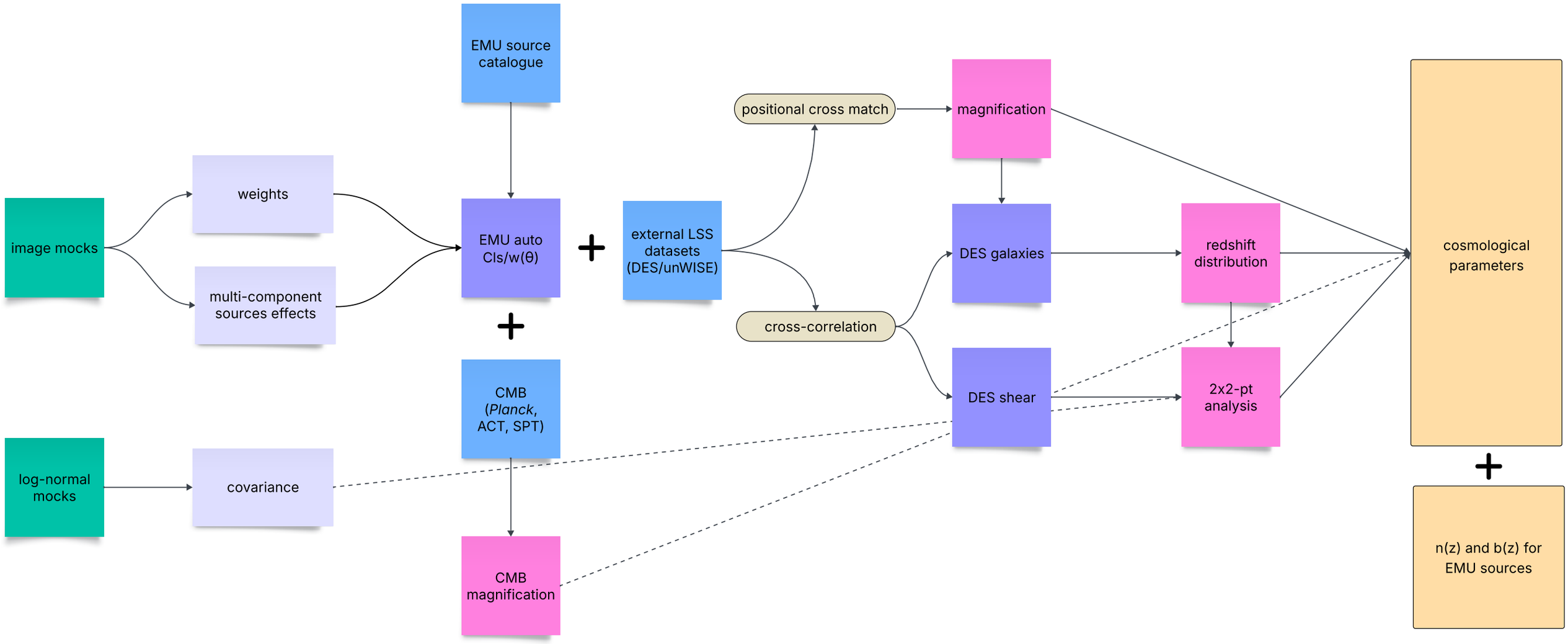
SPOZ

Also considerable overlap with Euclid DR1 (talk to Daniela Carollo daniela.carollo@inaf.it for joint Euclid-EMU projects)



6 SPOZ “Key Papers”

- Continuum Clustering (David Parkinson, Catherine Hale)
- EMU x CMB (Kostas Tanidis)
- EMU cross-matching and EMUxEMU magnification (Albany Asher)
- EMU x optical galaxy positions (Chandra Shekhar Saraf)
- EMU x DES lensing (Maciej Bilicki)
- Joint Cosmology Analysis (BKK, Chandra Shekhar Saraf)



The EMU Collaboration

- 400 scientists in 28 countries
- Open collaboration: Anyone can ask to join, if intending to contribute, and agreeing to follow publication policy
- Contact the EMU Management Team (Andrew Hopkins, Josh Marvil, Tessa Vernstrom, Anna Kapinska): O365-Group-EMU_Management@mq.edu.au
- EMU website: www.emu-survey.org
- EMU team wiki: askap.pbworks.org
- EMU team Slack workspace: emunetwork.slack.com

- Interested in EMU Cosmology? Also, contact me, the cosmology project co-ordinator (benedict.bahrkalus@inaf.it)