

Probing Cosmology with Gravitational-Wave and Euclid data

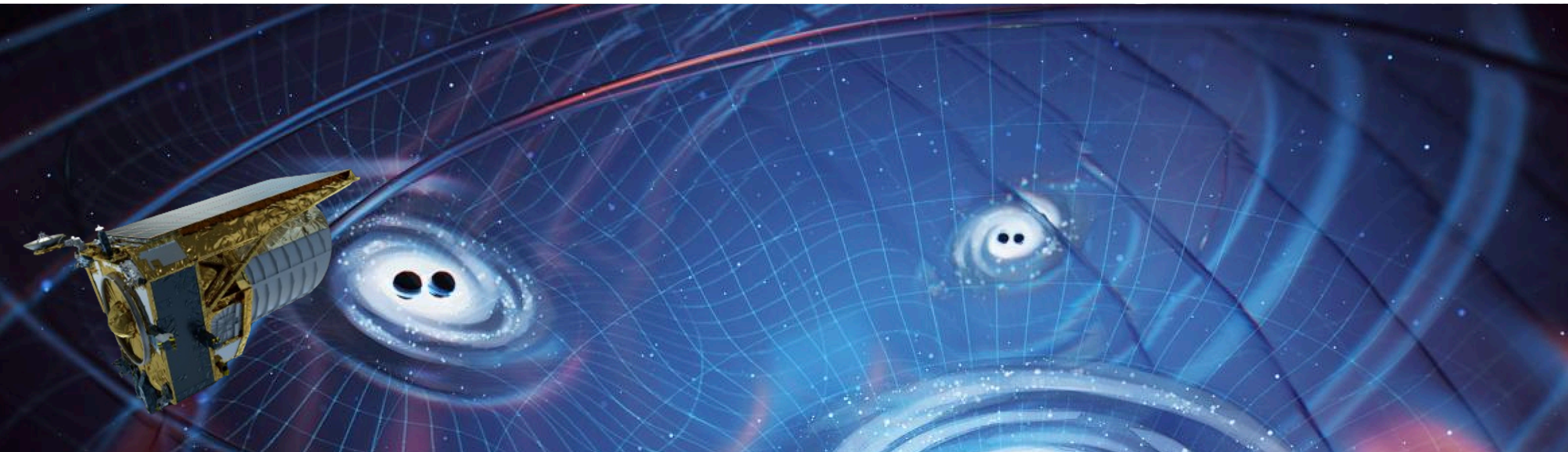
Sarah Ferraiuolo, GdR Ondes Gravitationnelles Lyon, 06/10/2026



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Outline

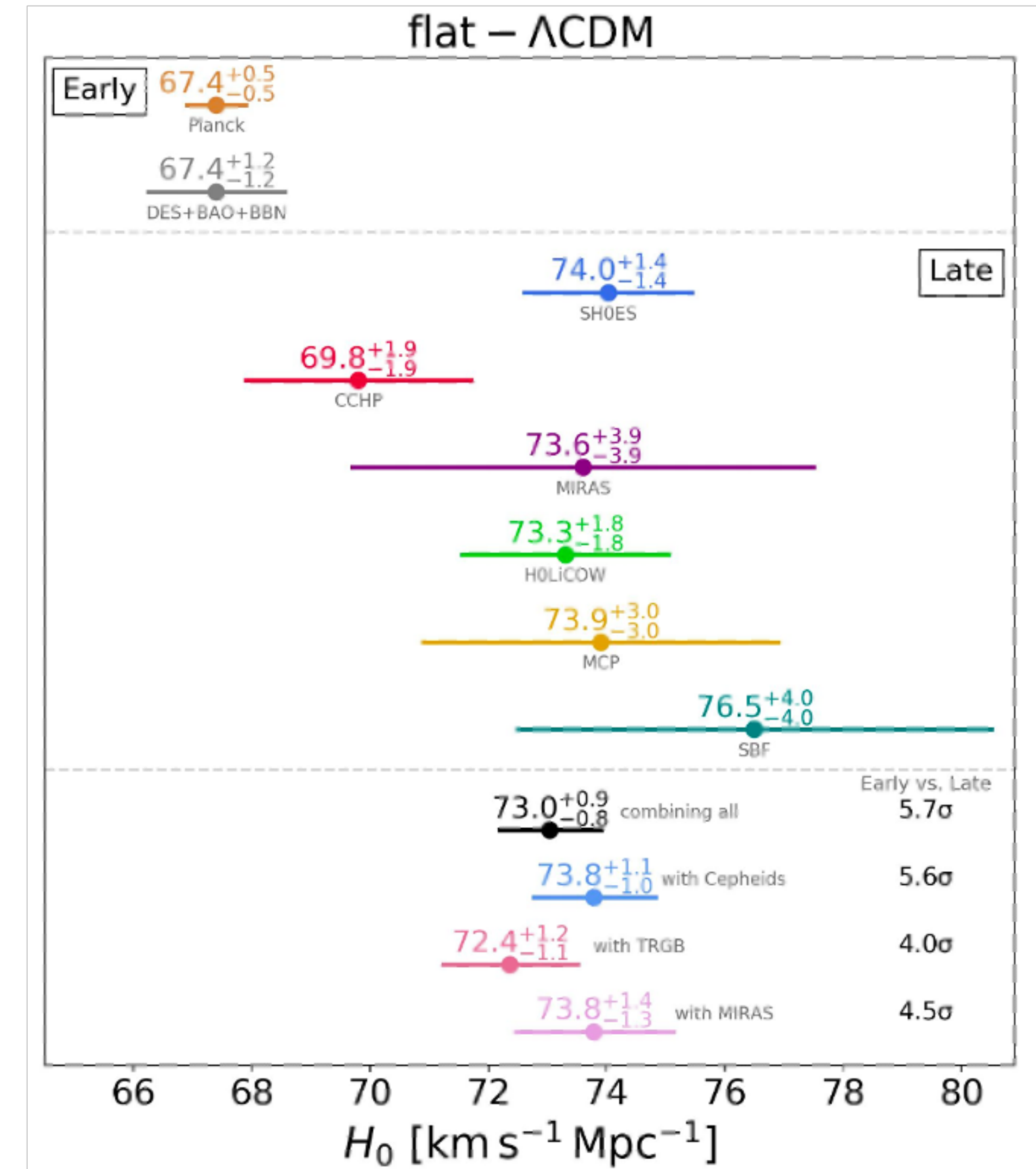
- The Hubble Tension and the Standard-Siren Approach
- Galaxy-Catalog Selection and Schechter Function Characterization
- Dark Sirens in the Euclid Footprint: Single-Event Results
- Population-Level Analysis and Comparison with Other Galaxy Catalogs
- Conclusions

The Hubble tension

- There is a tension between late-time and early-time measurements of the Hubble constant
- Although in-depth studies for hidden systematics the tension has not been yet alleviated
- We are required to directly measure the Universe expansion in all the observable Universe

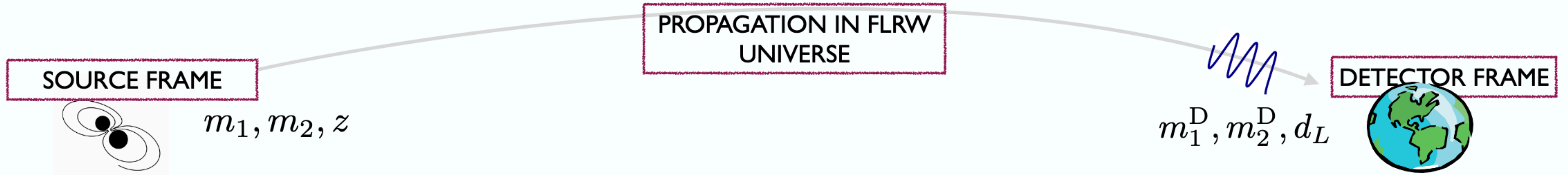


Gravitational Waves!



Verde, L., Treu, T. & Riess, A.G. Tensions between the early and late Universe. *Nat Astron* **3**, 891–895 (2019).

Standard Sirens with CBCs



Redshift: degenerate with mass in the GW signal.
Must be found through other methods

Hubble constant, redshift,
luminosity distance relationship:

$$d_L = \frac{c(1+z)}{H_0} \int_0^z \frac{dz'}{\sqrt{(1+z')^3 \Omega_m + \Omega_\Lambda}}$$

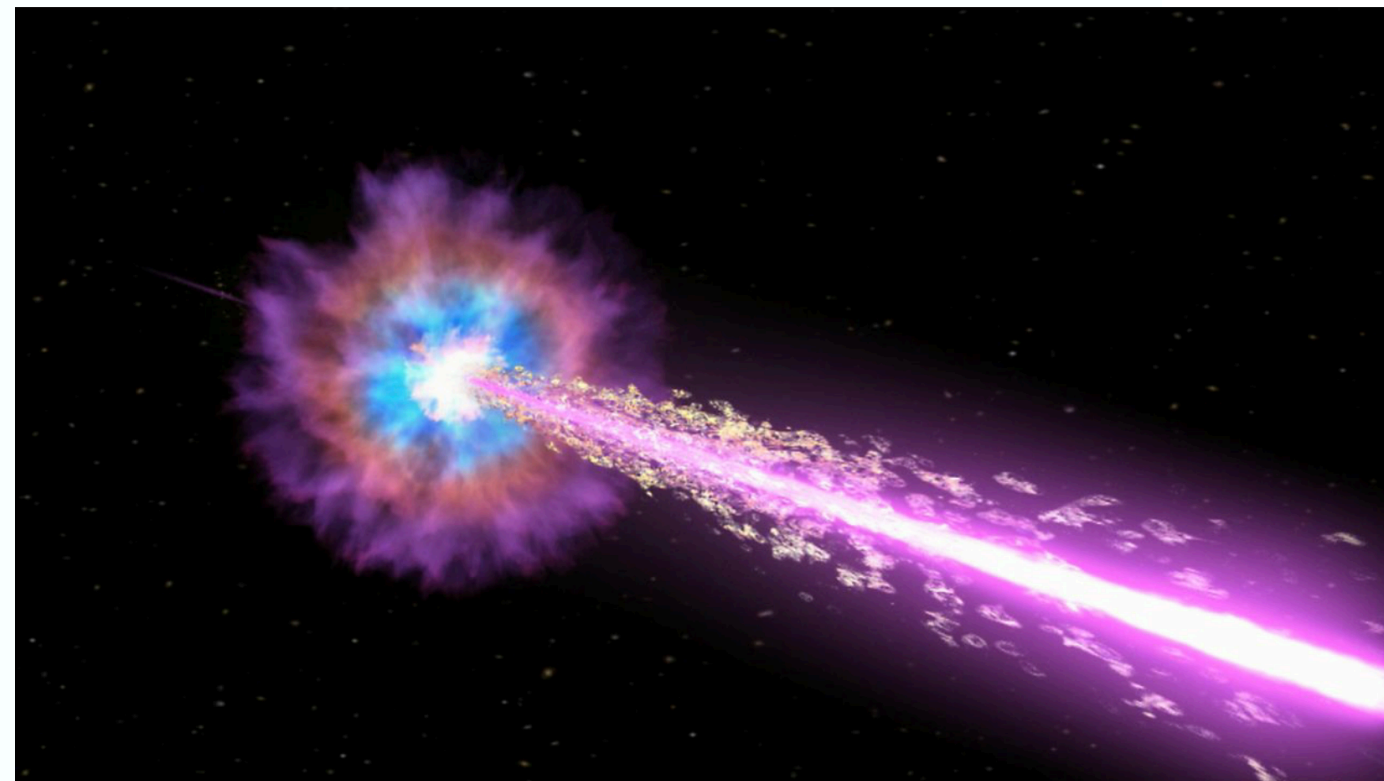
Standard Sirens

Standard Sirens with Compact Binary Coalescences

‘Sirens’ methods = associate redshift information to distance measurement

Bright Sirens

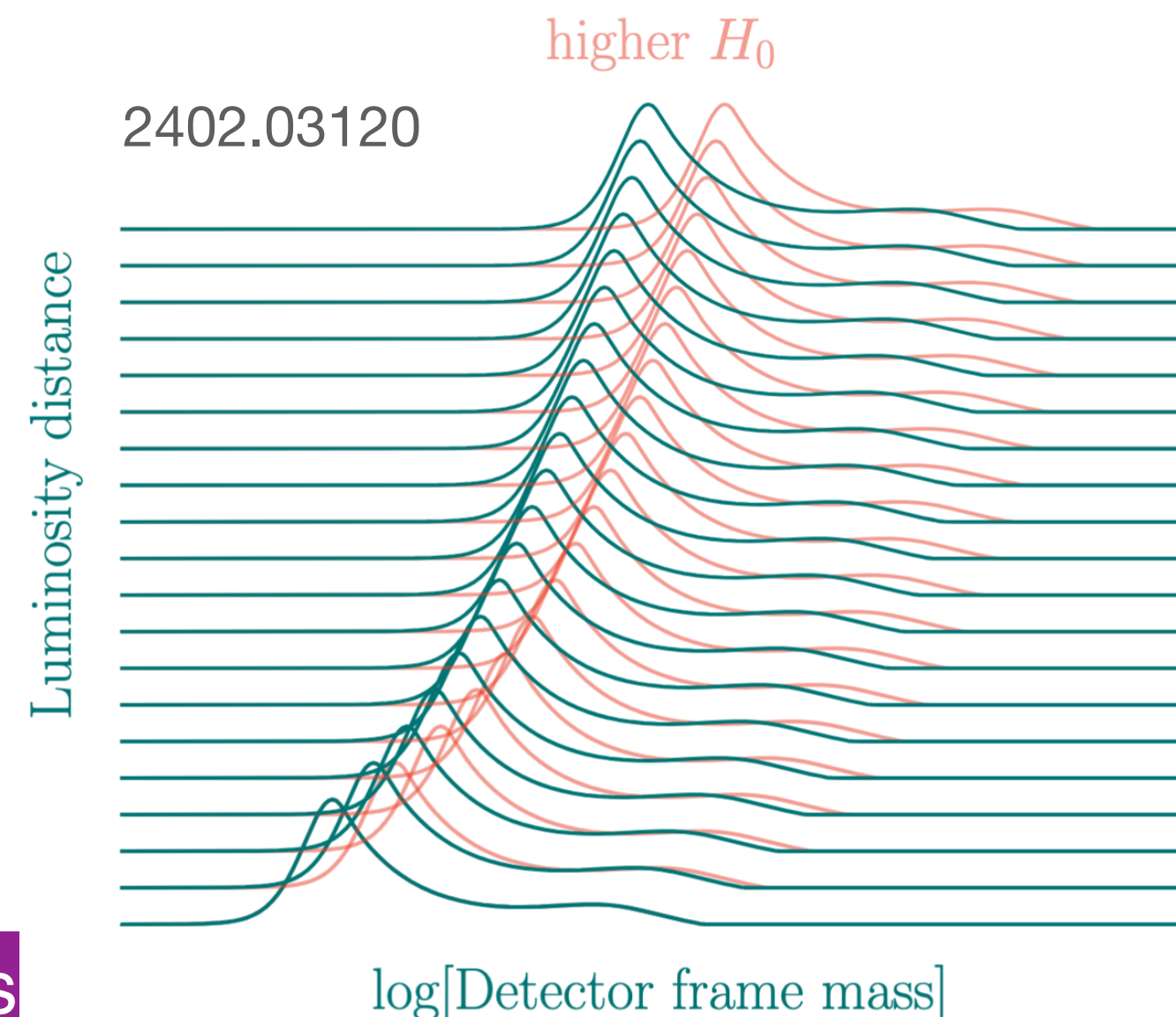
- An EM counterpart is observed and used to obtain the host galaxy's redshift
- E.g. GW170817 and NGC4993



Spectral Sirens

- Features in the mass distribution of the GW population break the mass-redshift degeneracy

$$m_{det} = m_{source}(1 + z)$$



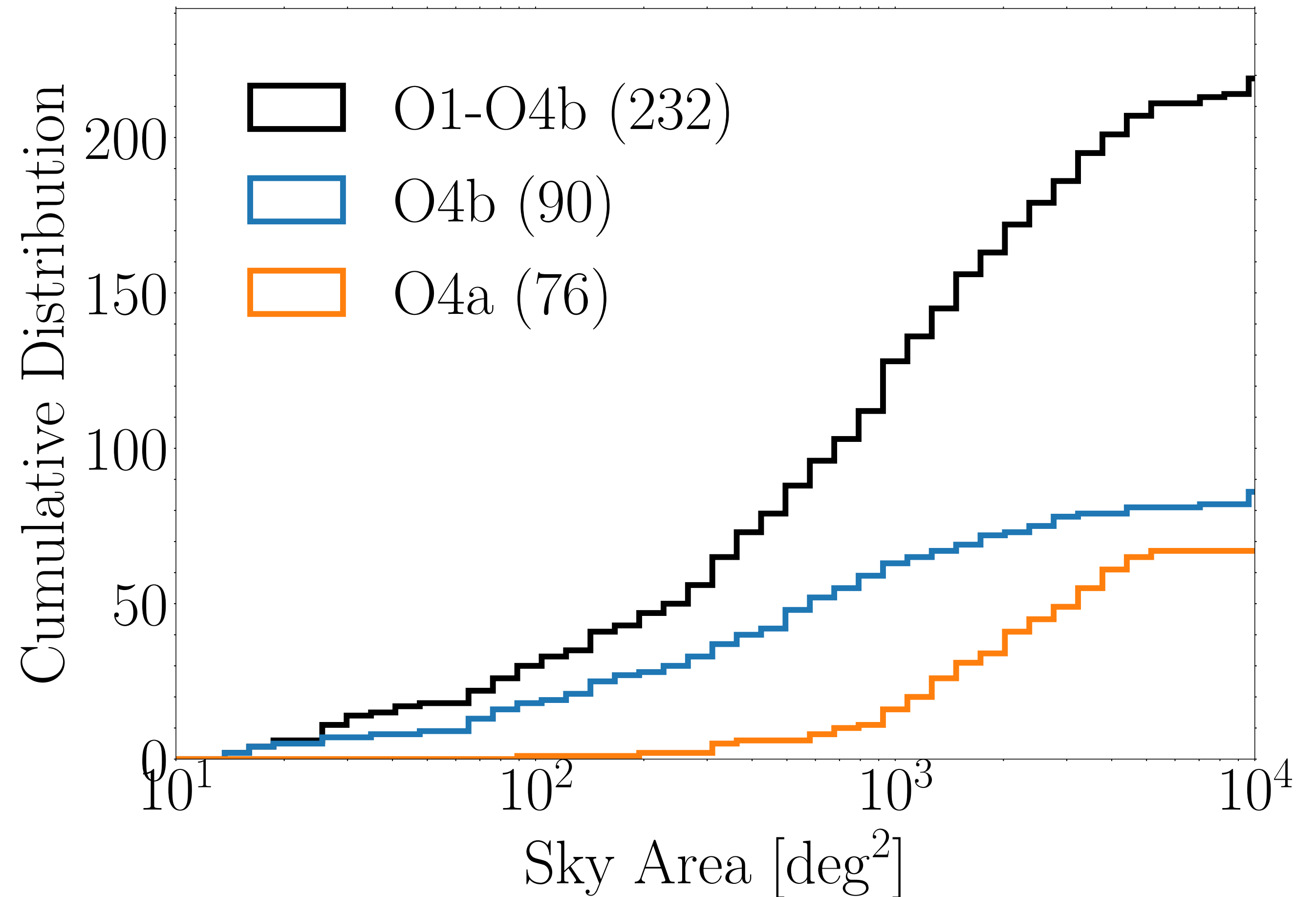
Dark Sirens

- Galaxy surveys are used to provide redshift estimates for potential host galaxies → **the galaxy catalog method**



Gravitational wave sources

- The GWTC-5 is the latest GW catalog released by the LVK collaboration
- 232 BBH+ 5 events with at least one NS (236 without EM counterparts + GW170817)
- Well localised events increased significantly due to the joint run with Virgo



Euclid DR1

Euclid Q1 (First Data Release)

Contains VIS and NIR imaging from one pass over the three Euclid Deep Fields (North, South, Fornax) and LDN1641 (Orion) ≈ 63 square degrees

Euclid TR1 (Internal Release)

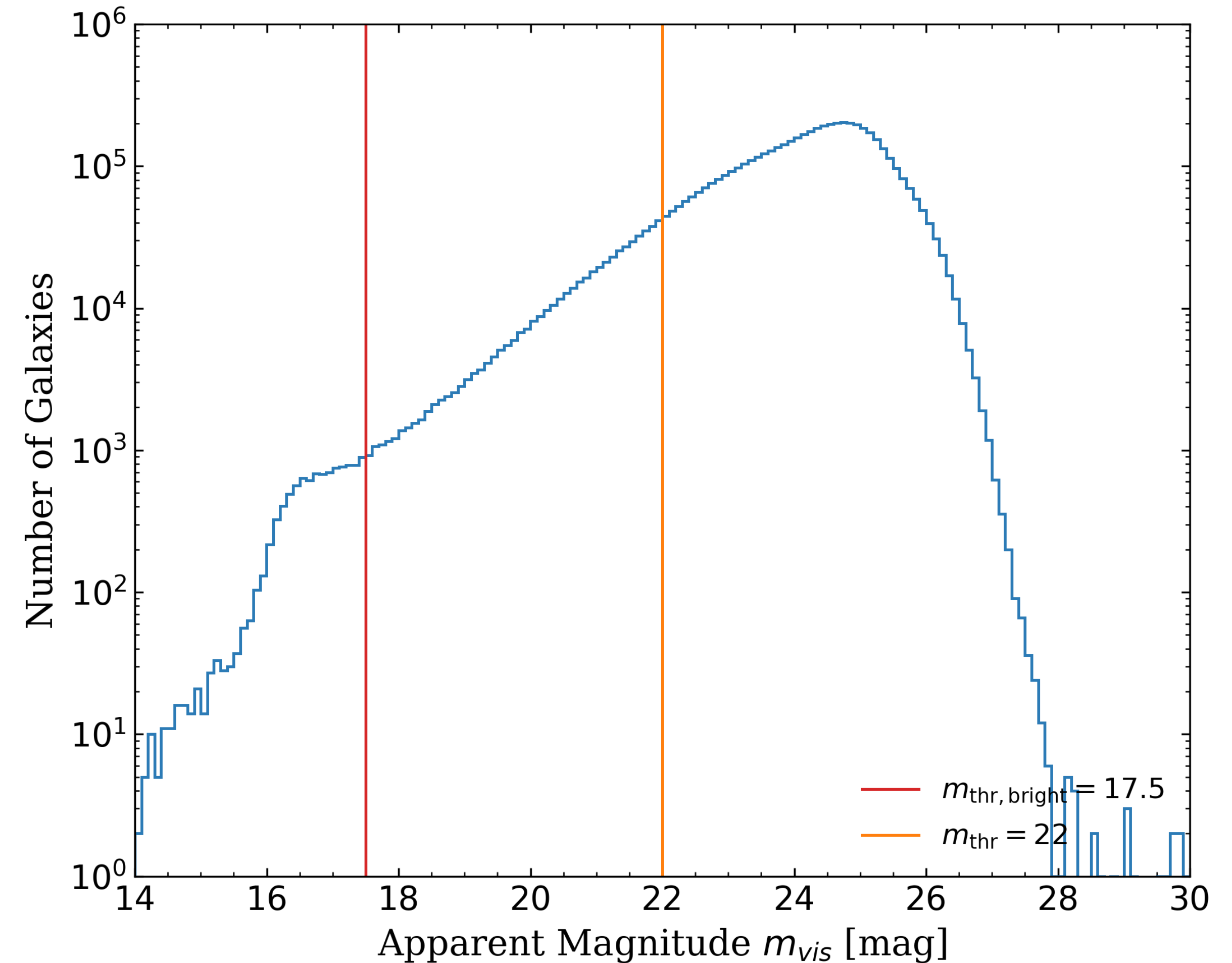
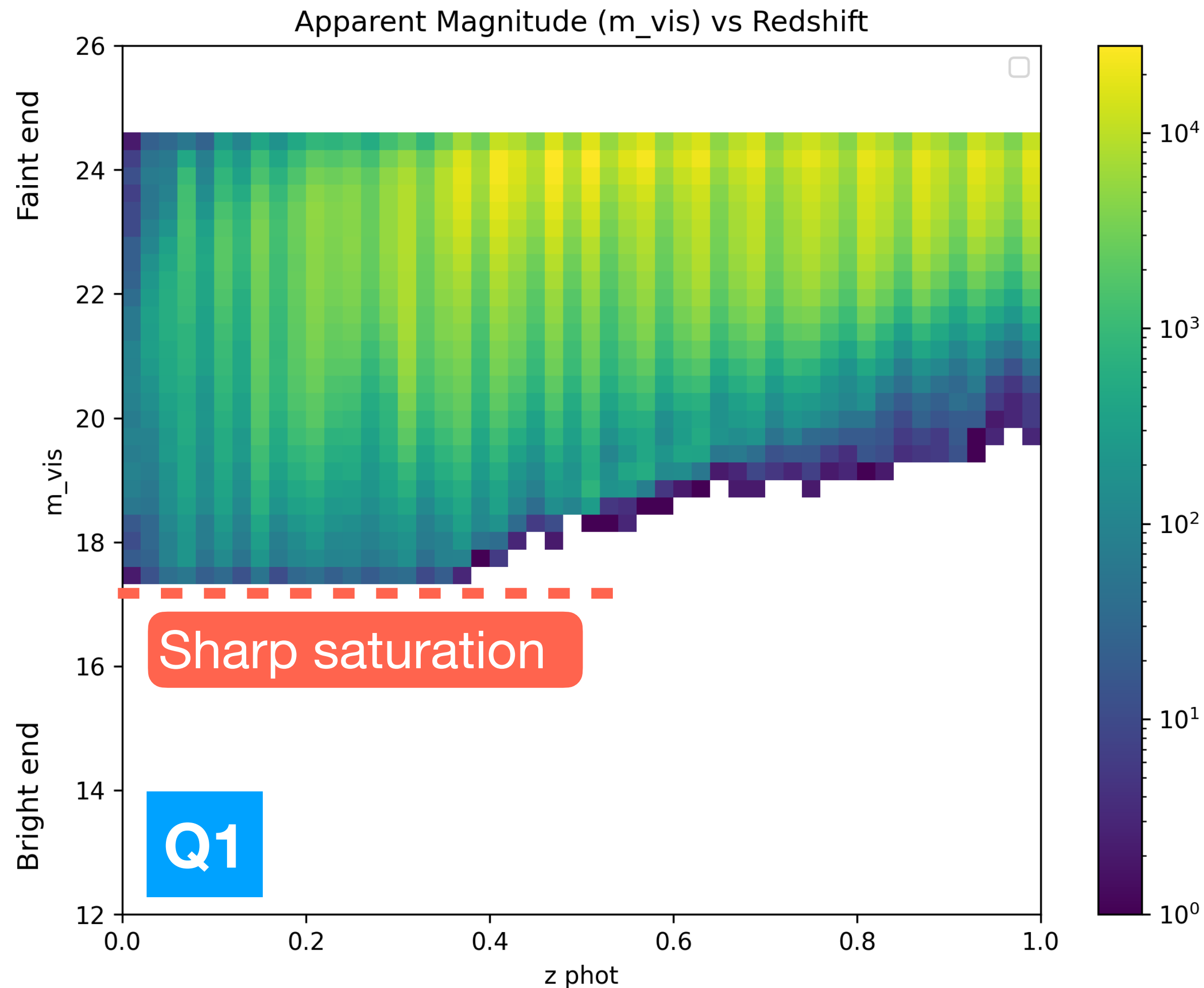
Internal validation dataset used to test analysis pipelines. Area is $\sim 30\%$ of DR1. Calibration and photometry expected to reach DR1 levels ≈ 600 square degrees

Euclid DR1 Mask

Defines the survey footprint: the specific sky area observed and used for scientific analysis in the first public data release ≈ 1900 square degrees

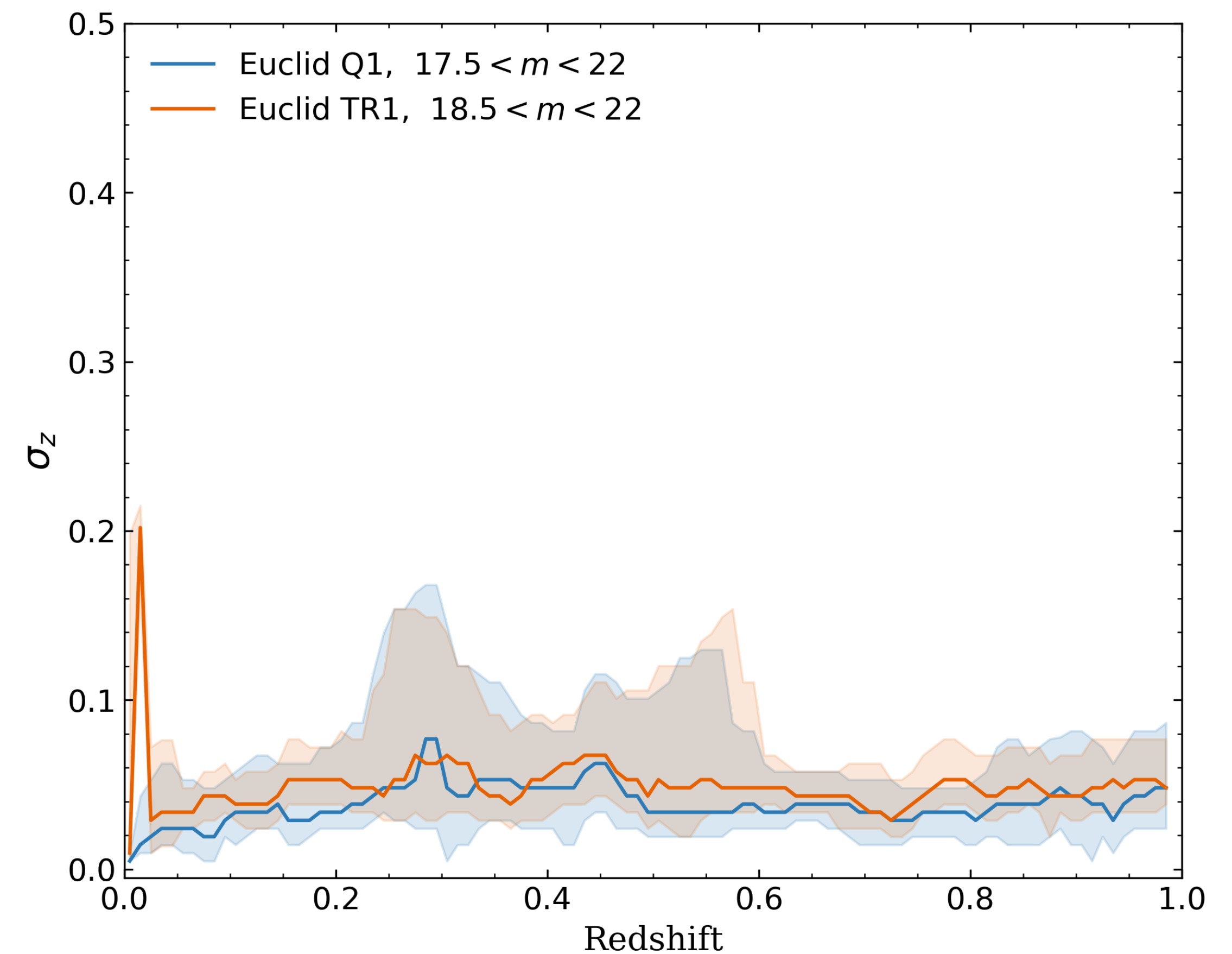
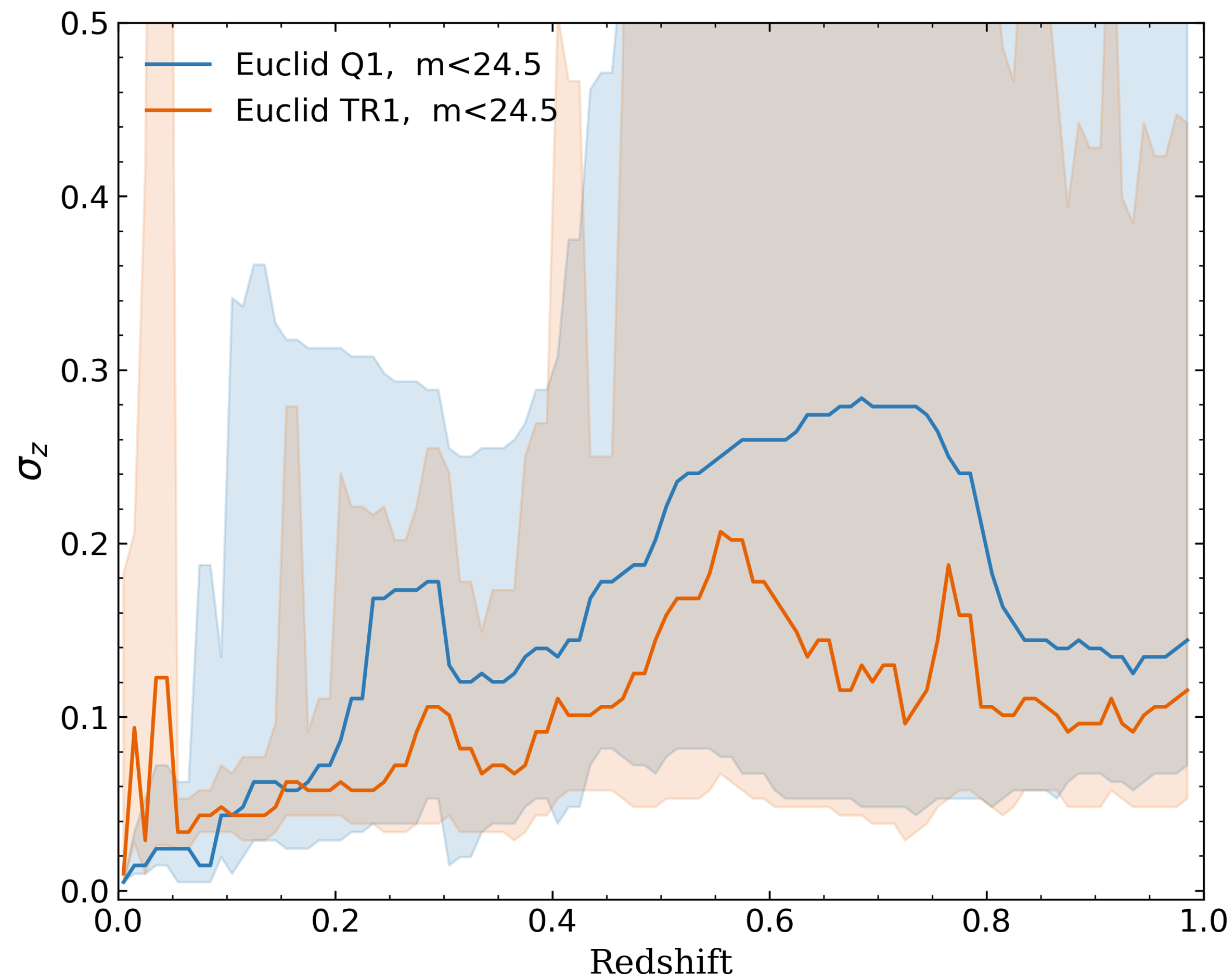
Data Selection – Bright-Magnitude Cut

There is a sharp selection cut in apparent magnitude from the data processing pipeline



Data Selection – Faint-Magnitude Cut

Restricting the sample to $m < 22$ leads to much smaller and more consistent redshift uncertainties. A magnitude cut is therefore important for a homogeneous galaxy sample and for the dark-siren analysis.



Completeness

$$C_{CBC} = 1 - I_{CBC}, \quad \text{Bright cut} \quad \text{Faint cut} \quad (64)$$

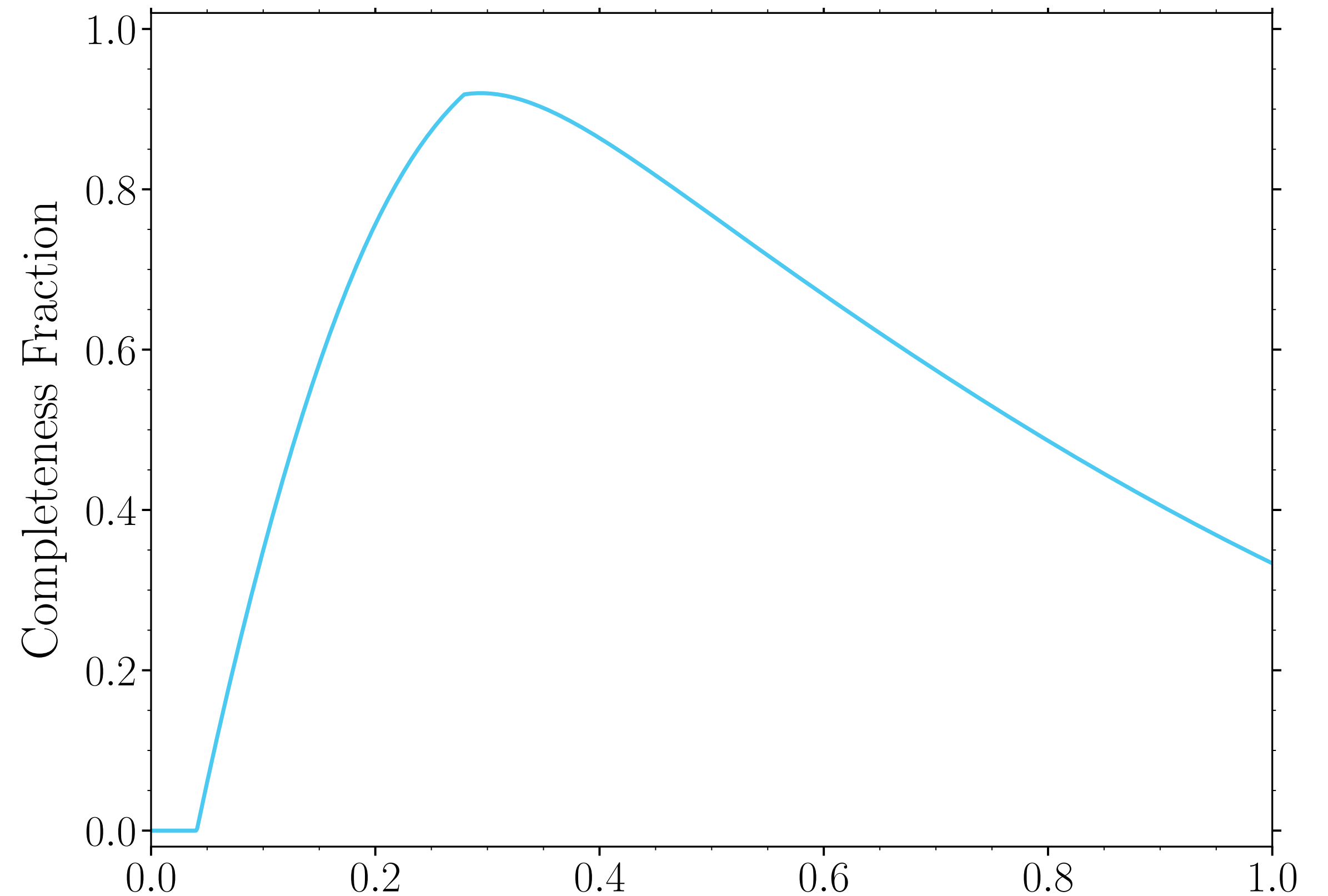
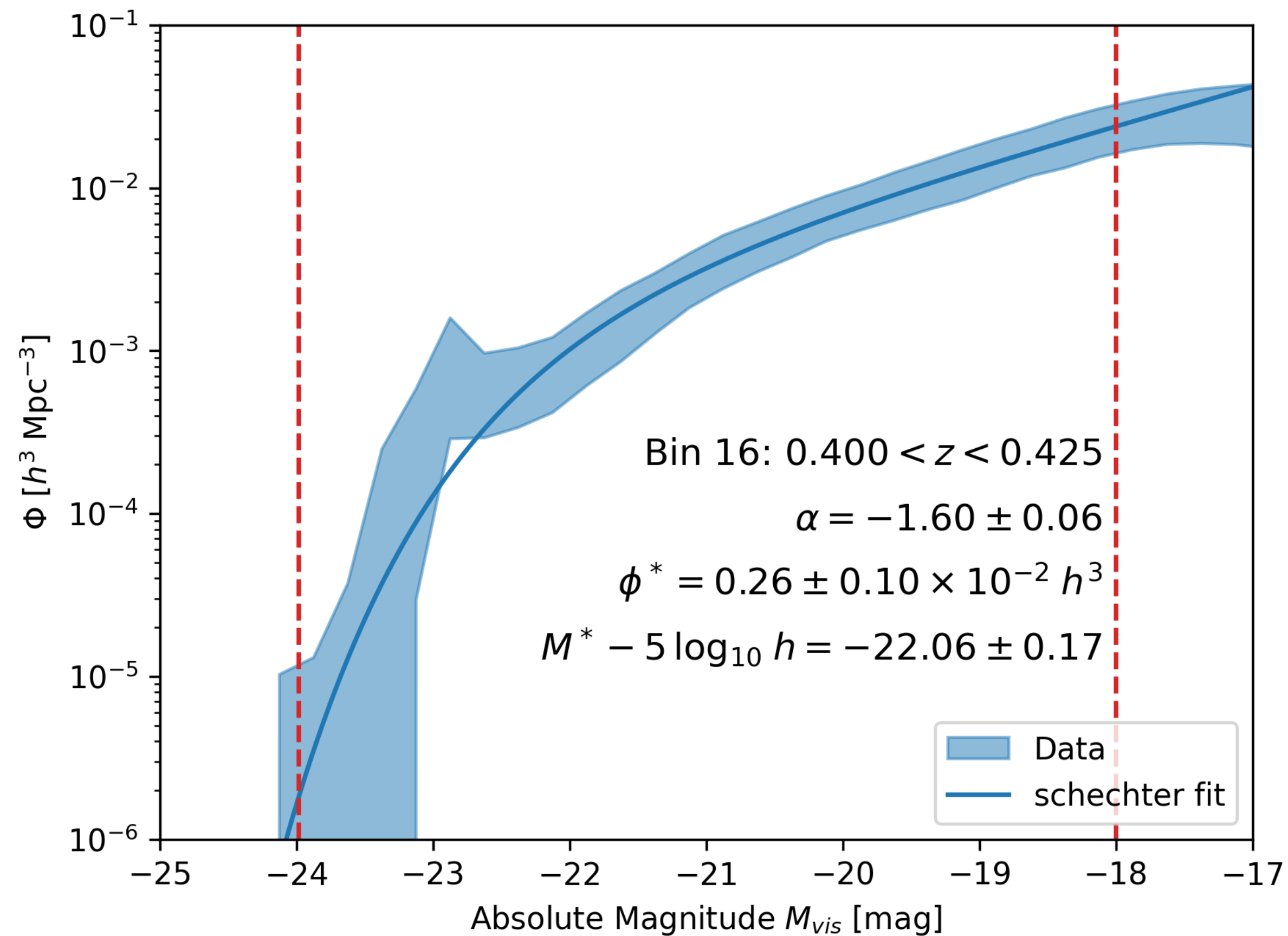
$$I_{CBC} = \frac{\int_{M_{\min}(H_0)}^{M_{\text{sat}}(H_0, m_{\text{sat}}(\Omega), z)} dM \text{Sch}(M, \alpha + \epsilon) \frac{dV_c}{dz d\Omega} + \int_{M_{\text{thr}}(H_0, m_{\text{thr}}(\Omega), z)}^{M_{\max}(H_0)} dM \text{Sch}(M, \alpha + \epsilon) \frac{dV_c}{dz d\Omega}}{\int_{M_{\min}(H_0)}^{M_{\max}(H_0)} dM \text{Sch}(M, \alpha + \epsilon) \frac{dV_c}{dz d\Omega}} \quad (65)$$

$$= \frac{\Gamma_{\text{inc}}(\alpha + \epsilon + 1, x_{\text{sat}}(\Omega, z), x_{\min}) + \Gamma_{\text{inc}}(\alpha + \epsilon + 1, x_{\max}, x_{\text{thr}}(\Omega, z))}{\Gamma_{\text{inc}}(\alpha + \epsilon + 1, x_{\max}, x_{\min})} \quad (66)$$

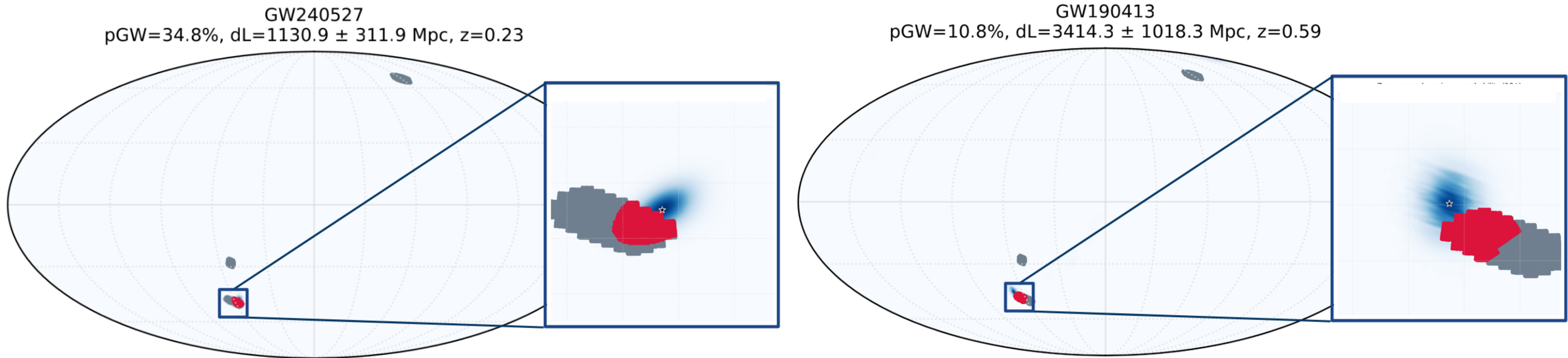
Luminosity Function in Q1 Catalog

VIS band example

Estimating the out-of-catalog part and completeness requires a distribution of galaxy luminosity in the Universe, usually given by the Schechter function



Euclid and GW events overlaps



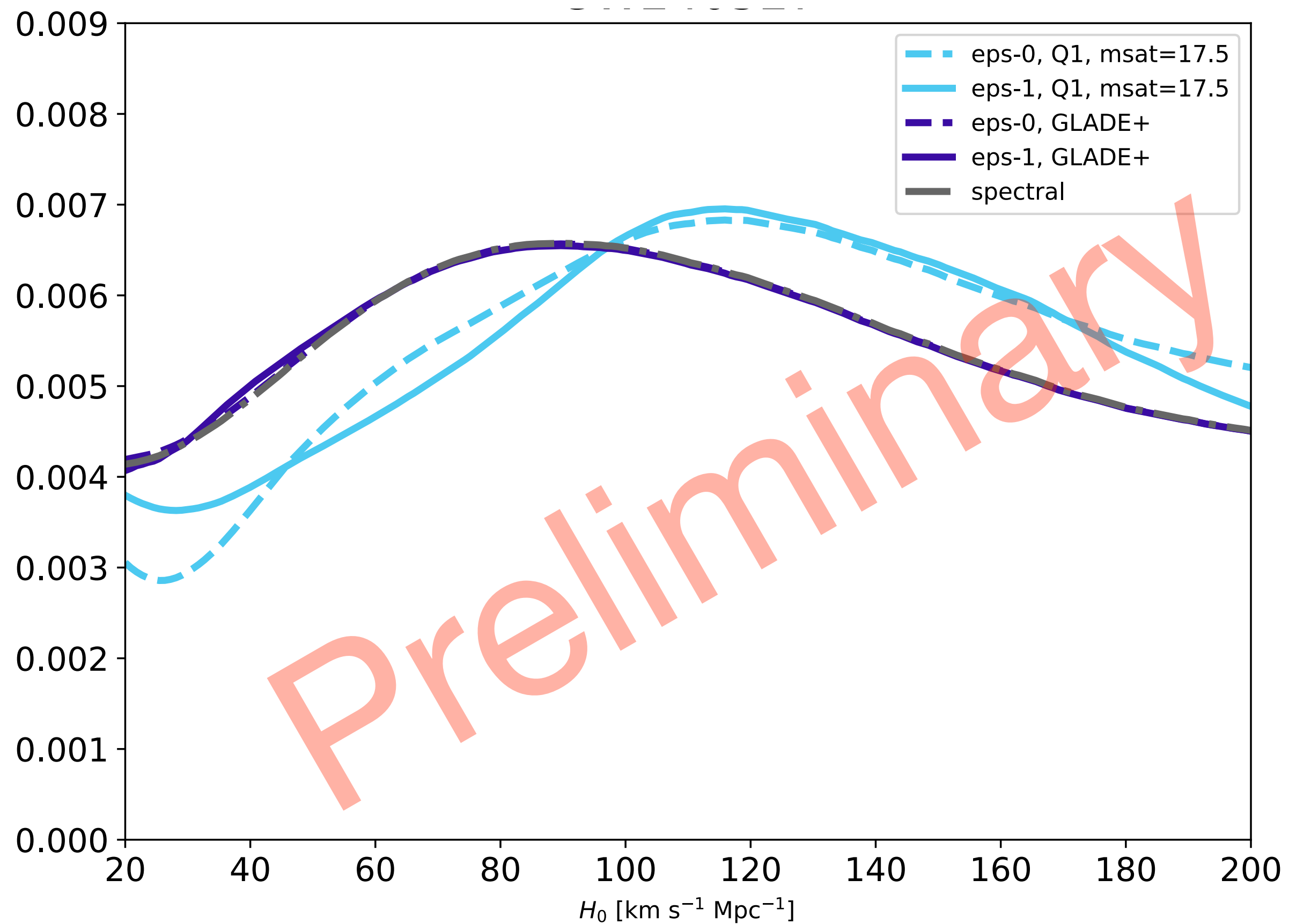
In total, we have **6 candidate** overlaps with **DR1**: **2** of which also intersect with **Q1**, and **4** intersect with **TR1**

ANALYSIS AND RESULT

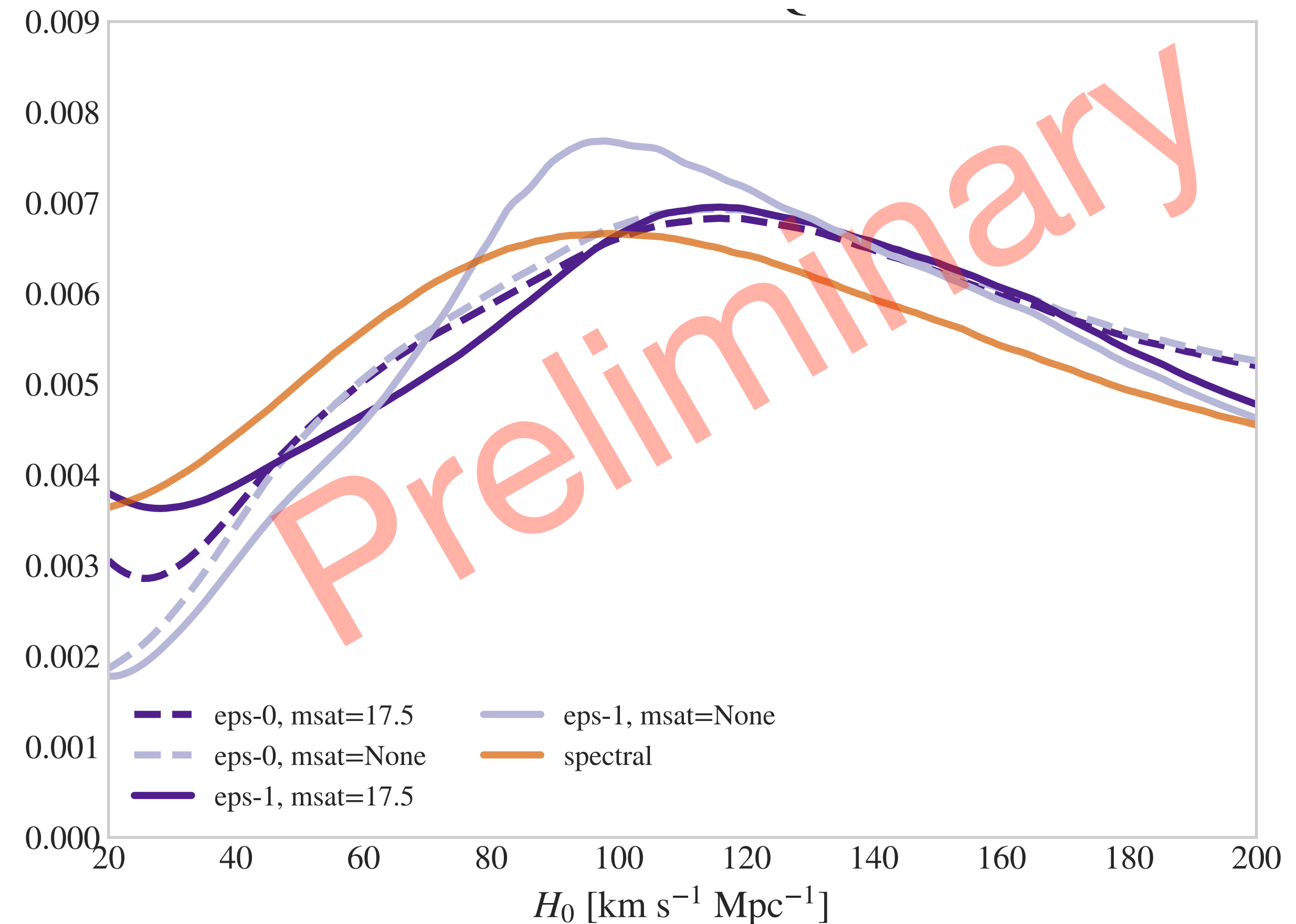
GW240527 analysis

Comparative analysis of H_0 posterior distributions and H_0 constraints across different catalog configurations.

H_0 posterior distributions

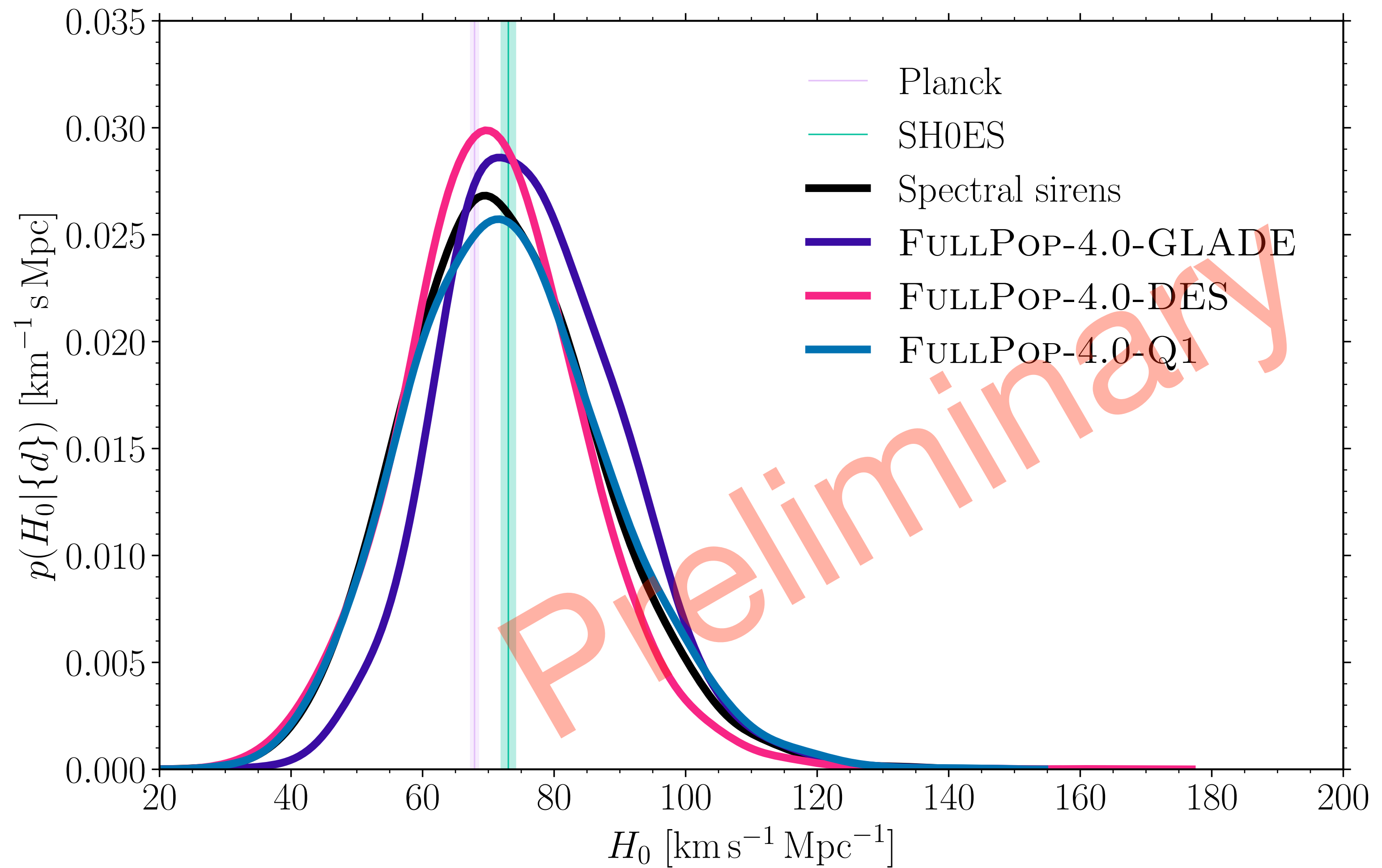


Systematics checks

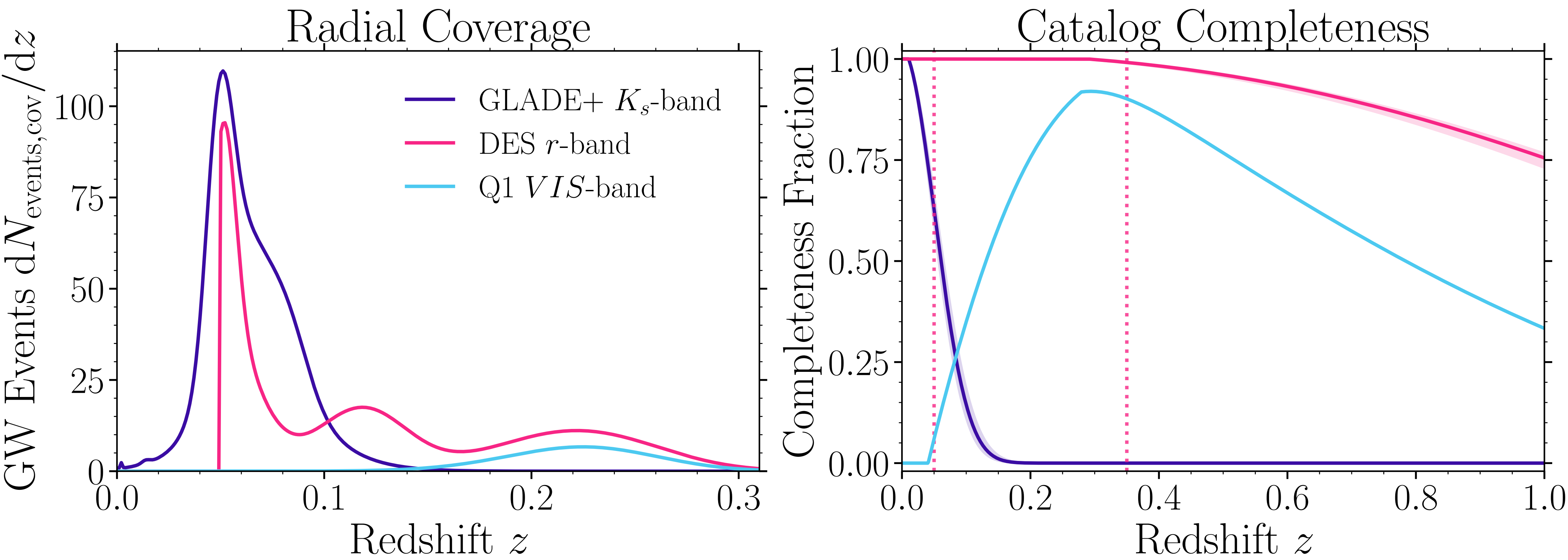


Full population analysis

- Q1 lower catalog completeness and larger photo-z uncertainties reduce the information from the galaxy distribution.
- The limited footprint strongly restricts the contribution of galaxy information.
- Most of the constraining power comes from spectral-siren information



Catalog comparisons



Galaxy Catalog	N_{gal}	sky coverage [deg] ²	z_{med}	$\sigma_z/(1 + z_{\text{med}})$
Euclid Q1	5.5×10^6	85.2	0.770	0.0869
Euclid TR1	2.0×10^7	585.2	0.630	0.0531
DES Y6	3.2×10^8	5181.2	0.816	0.0911
GladeP	9.9×10^5	37201.0	0.080	0.0140

Conclusions and future steps

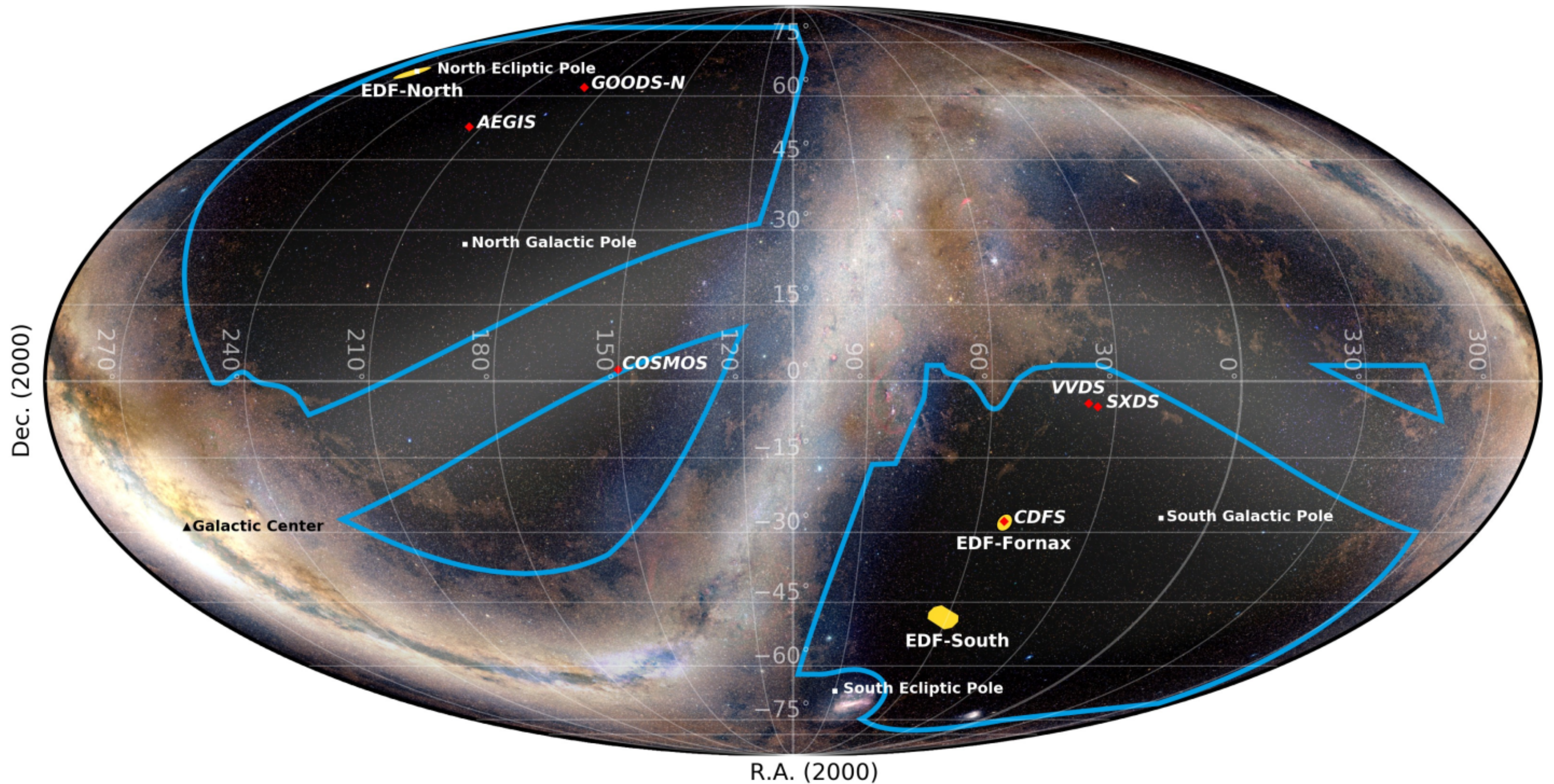
- Euclid galaxy catalogs are **promising** for dark-siren cosmology, but the current Q1 release has important **limitations**: completeness and limited sky coverage.
- **Full GWTC-5.0 constraints remain dominated by spectral sirens**, with no significant improvement from Q1 over the empty-catalog case.
- **DR1 is the key next step**: larger footprint + improved processing should increase the number of well-covered GW events.
- **Future work**: exploit Euclid multi-band information and improved luminosity functions to construct more informative catalogs.

Thank you for your attention!

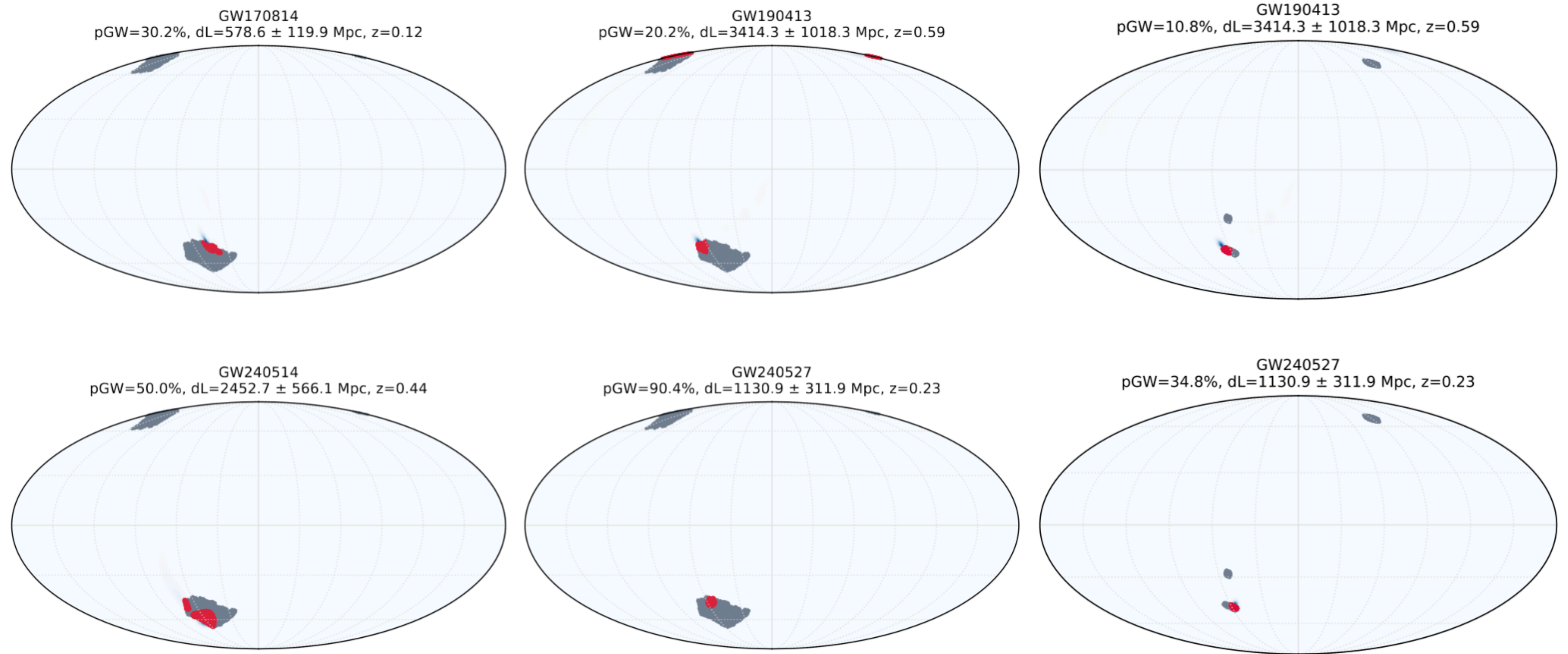


Backup slides

Euclid Region of Interest



Euclid and GW events overlaps



In total, we have **6 candidate** overlaps with **DR1**: **2** of which also intersect with **Q1**, and **4** intersect with **TR1**