Future of Radio Continuum Clustering Cosmology Surveys

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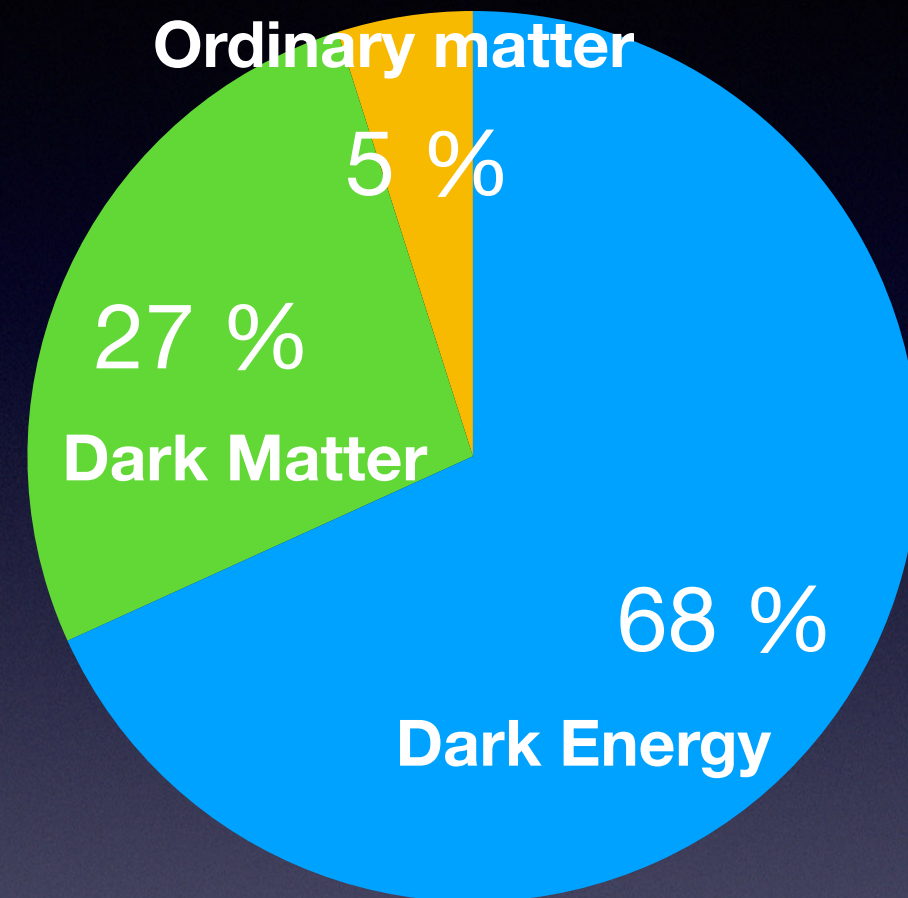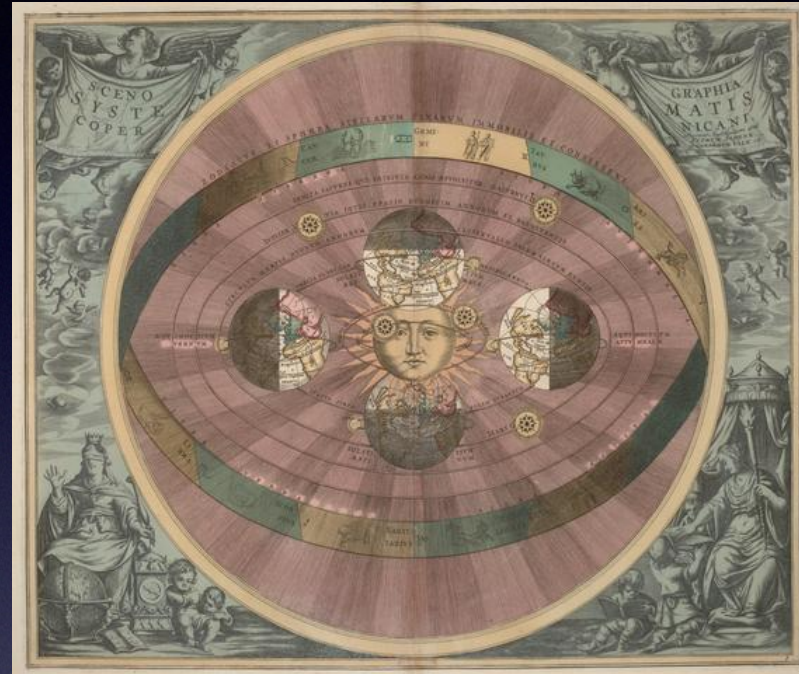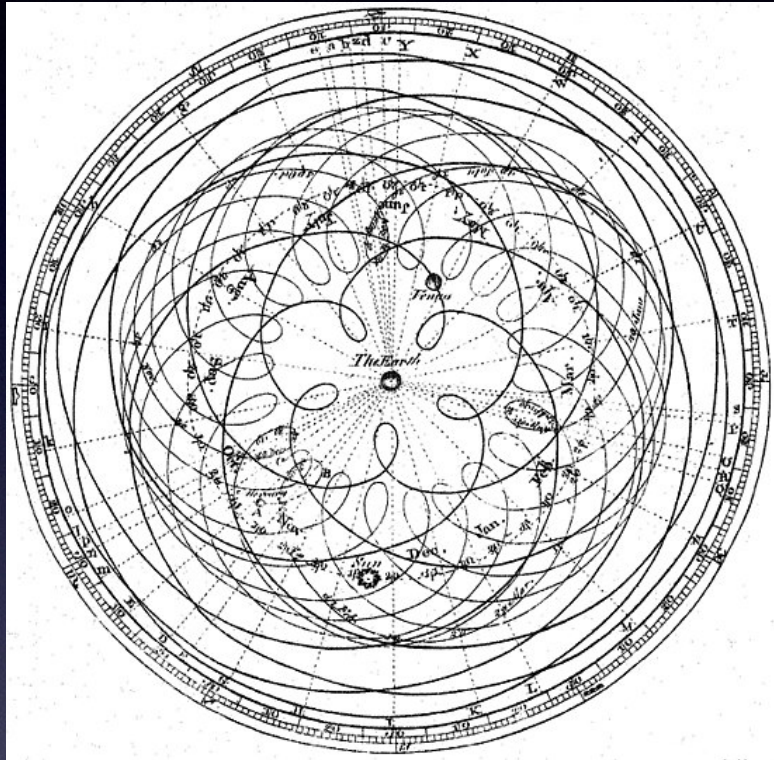
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Cosmology from Home, 2021 Edition

Introduction

Ordinary matter

5 %

27 %

Dark Matter

68 %

Dark Energy
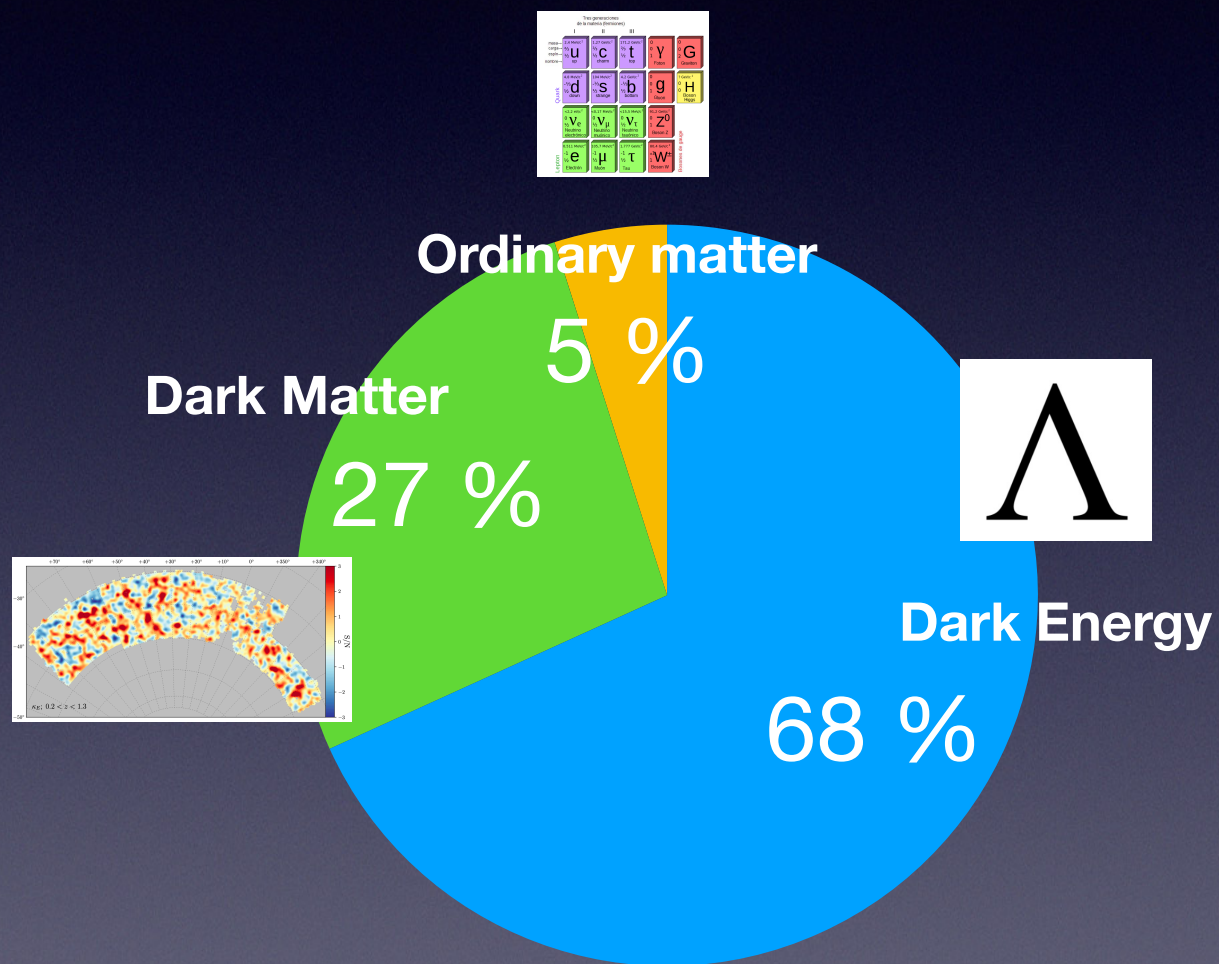
We have been capable of building a data-driven cosmological theoretical model based on the homogeneity and isotropy of the Universe.
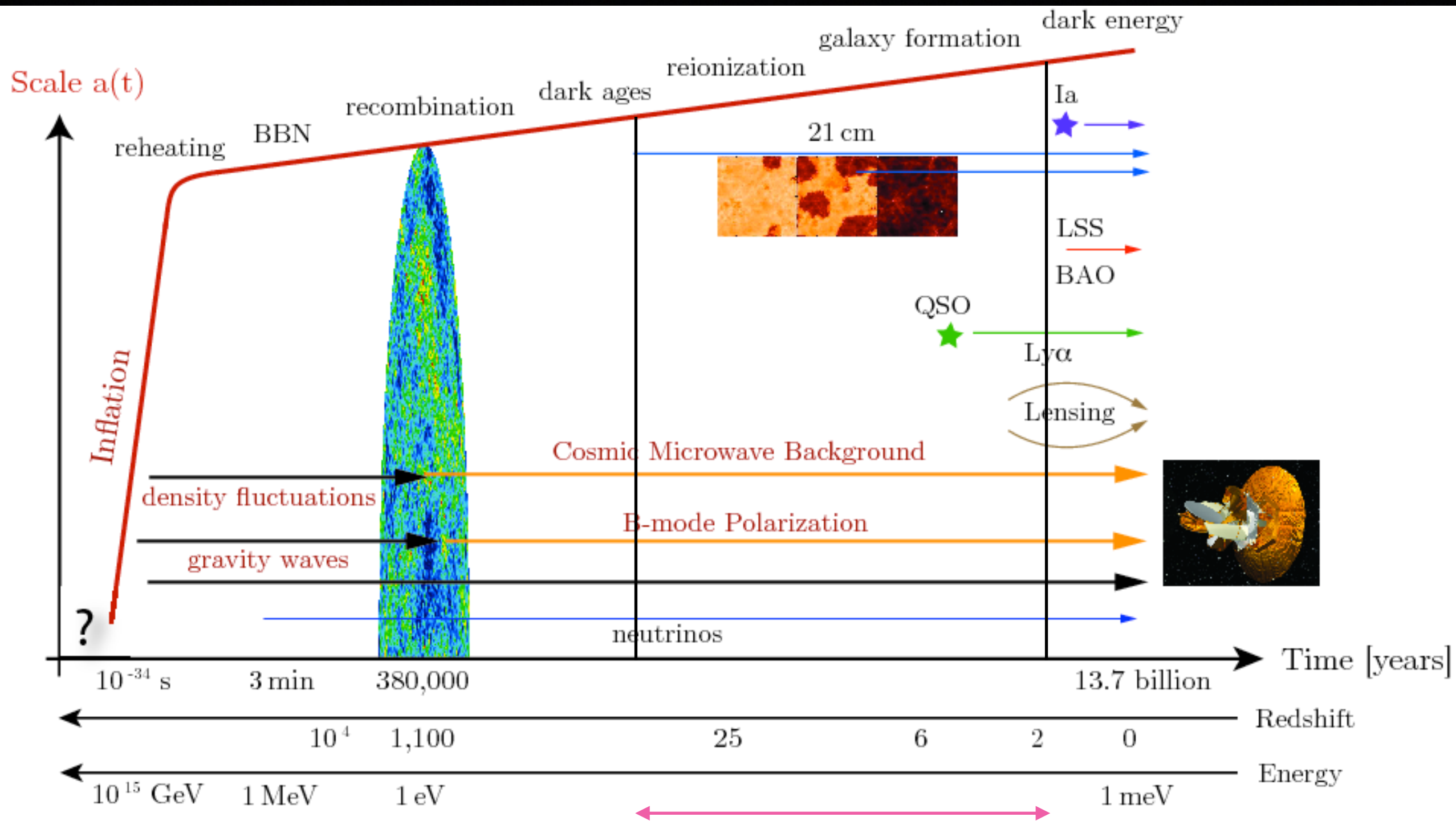
Cosmological standard model

But there are still some remaining open questions:

- Λ or not Λ?
- What is DM?
- What are the initial conditions?

Redshift desert

Large-scale structure

- Universe filled with density fluctuations

- Structure only only visible through galaxies (distribution) and photons (weak lensing)

- Galaxies and photons here are functioning as test particles - tracing out the gravitational field

- Most low-redshift surveys have measured the transfer function.

- Need very large volumes to measure primordial power spectrum and determine initial conditions (independently from CMB)
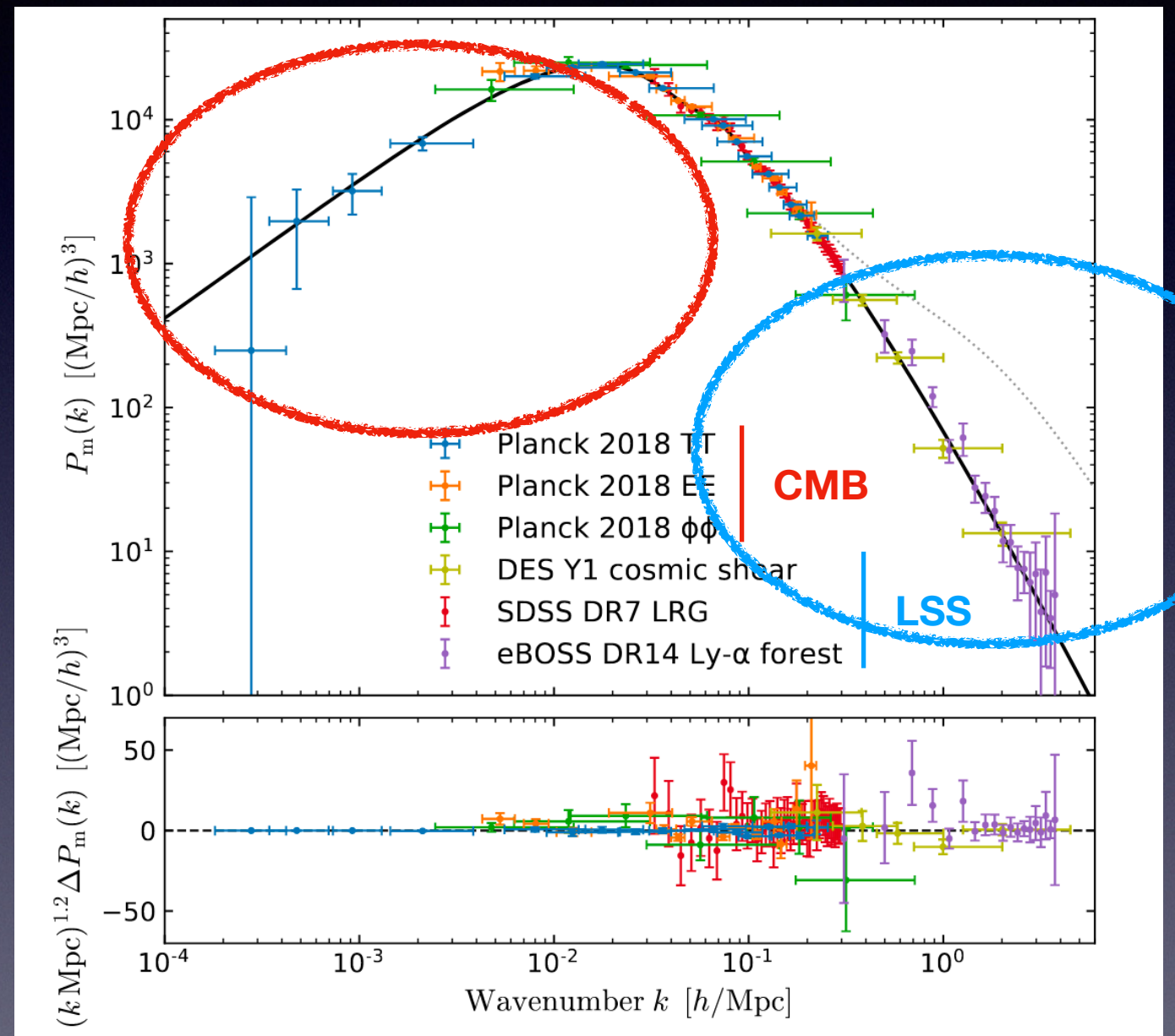
Sampling the redshift desert

- In the near future, we will sample the "redshift desert" with different missions and surveys.
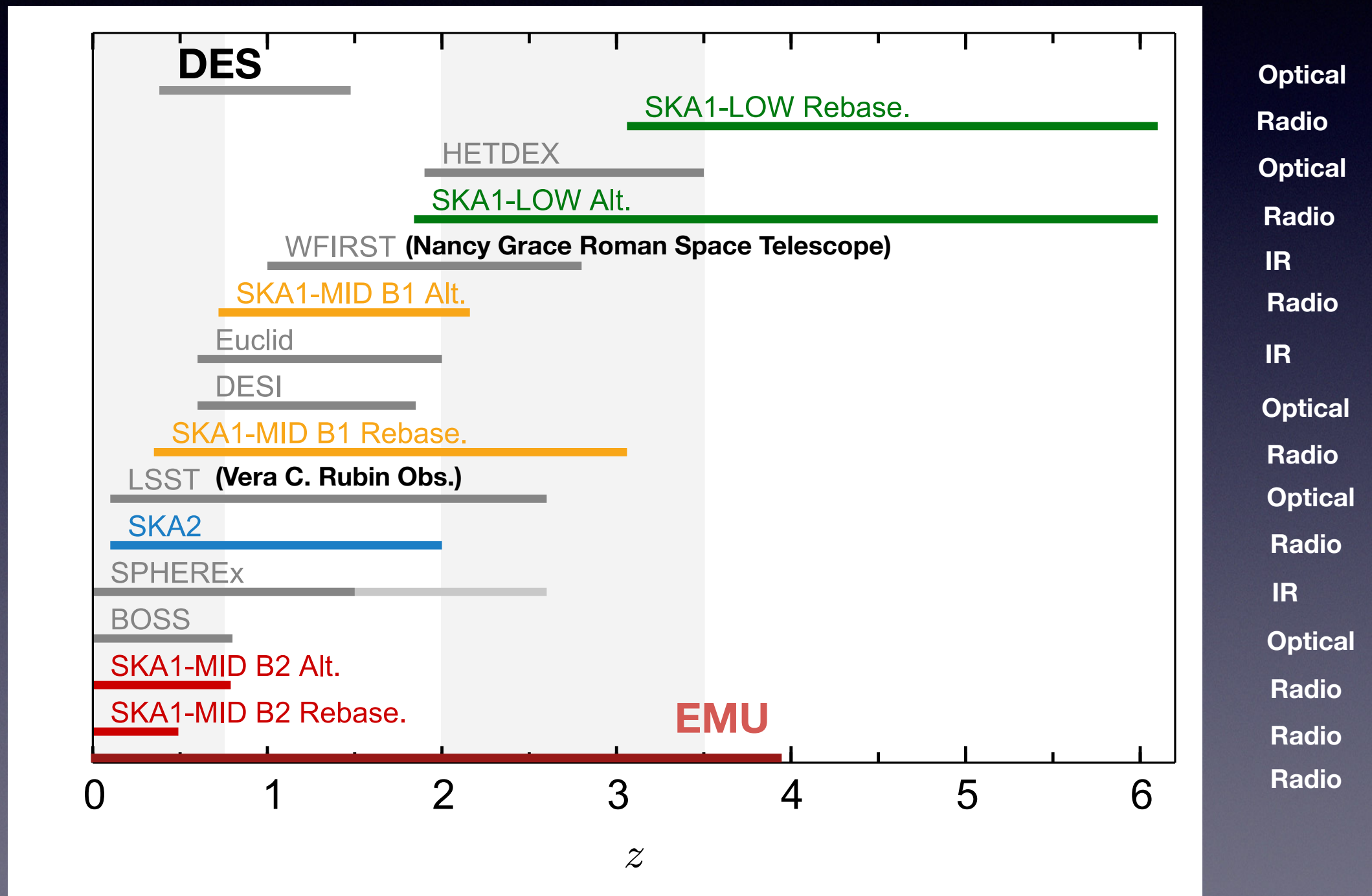
Radio cosmology

HI galaxy
(like spectroscopic surveys)
[e.g., HIPASS, ALFALFA]

Continuum galaxy
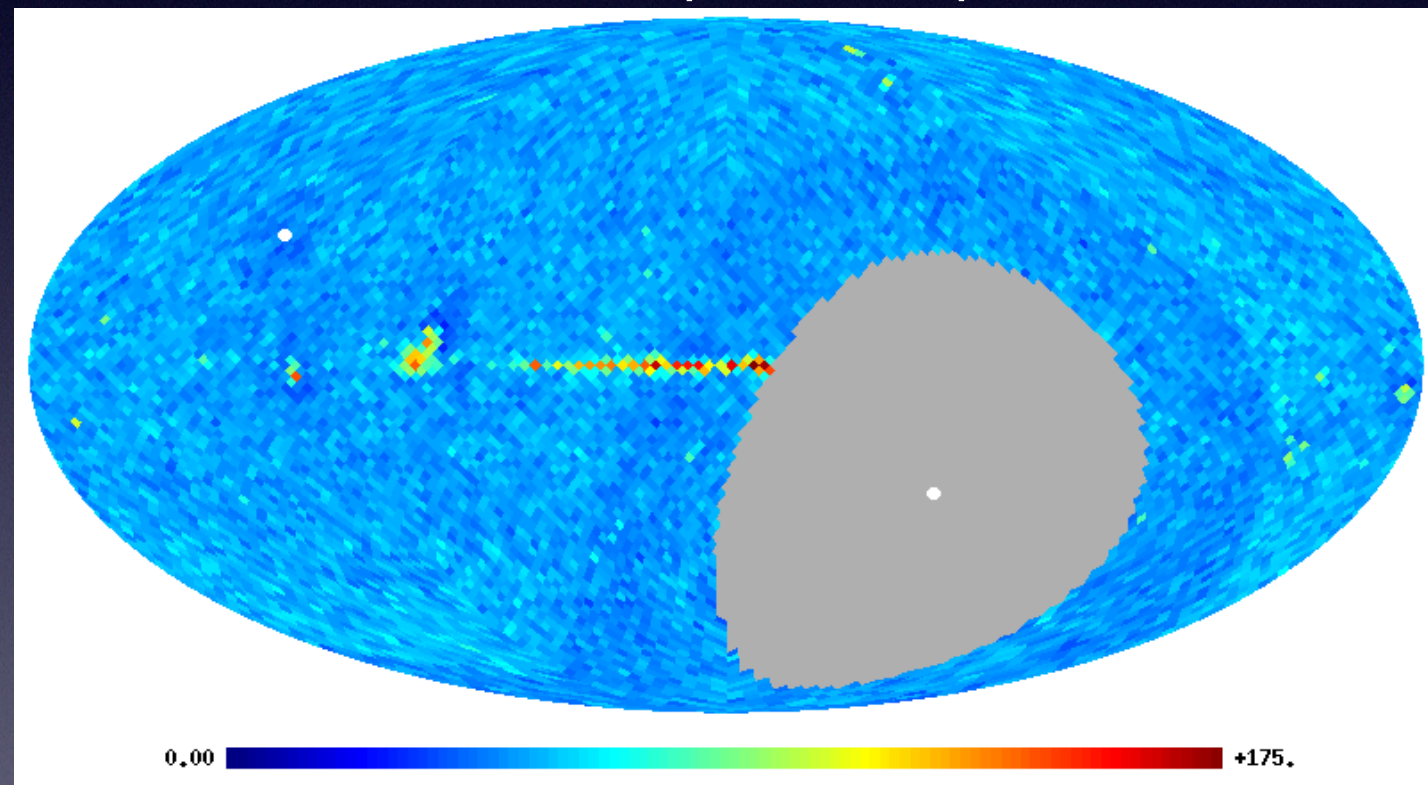(like photometric) surveys)
[e.g., ASKAP-EMU]

HI intensity mapping
(like 3D CMB)
[e.g., CHIME, TIANLAI]

Radio Continuum Surveys

- Continuum surveys measure intensity of total radio emission, across waveband

- Emission dominated by synchrotron, so spectrum (almost) featureless

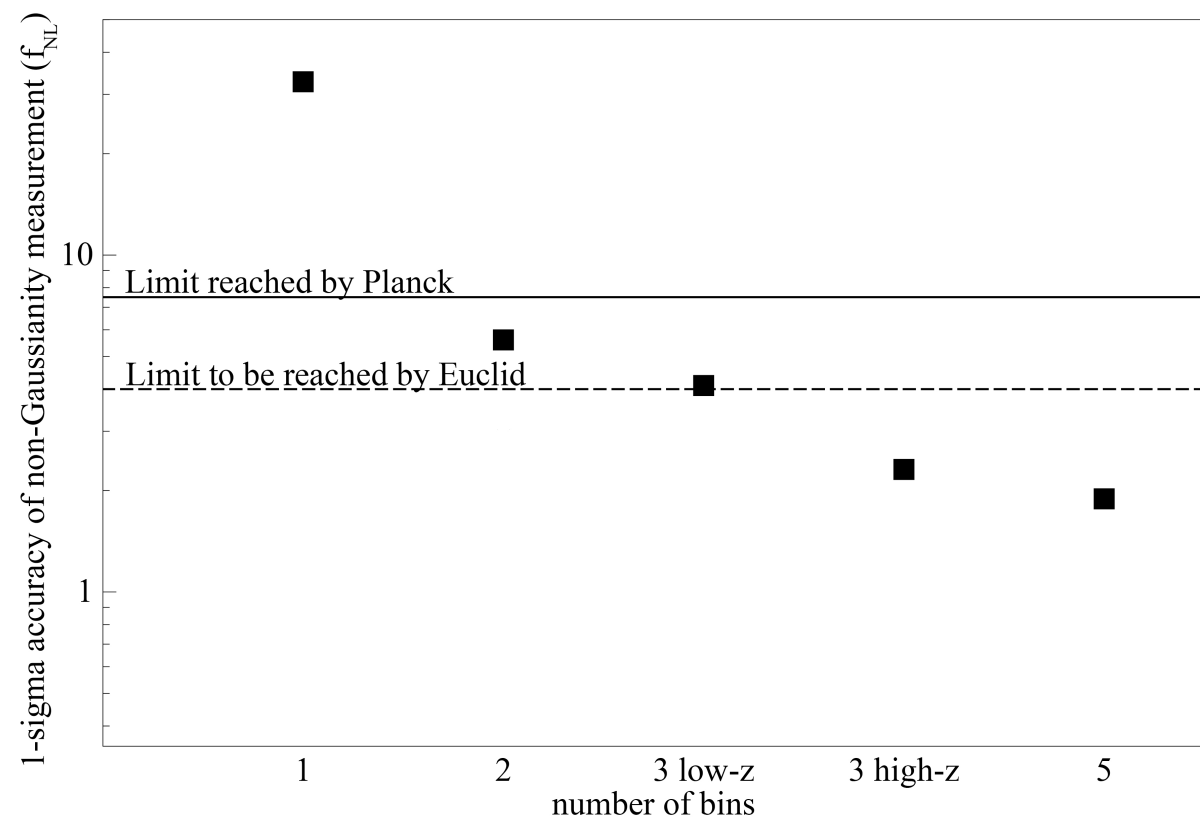- Measure RA and Dec of sources, but need other information for redshift
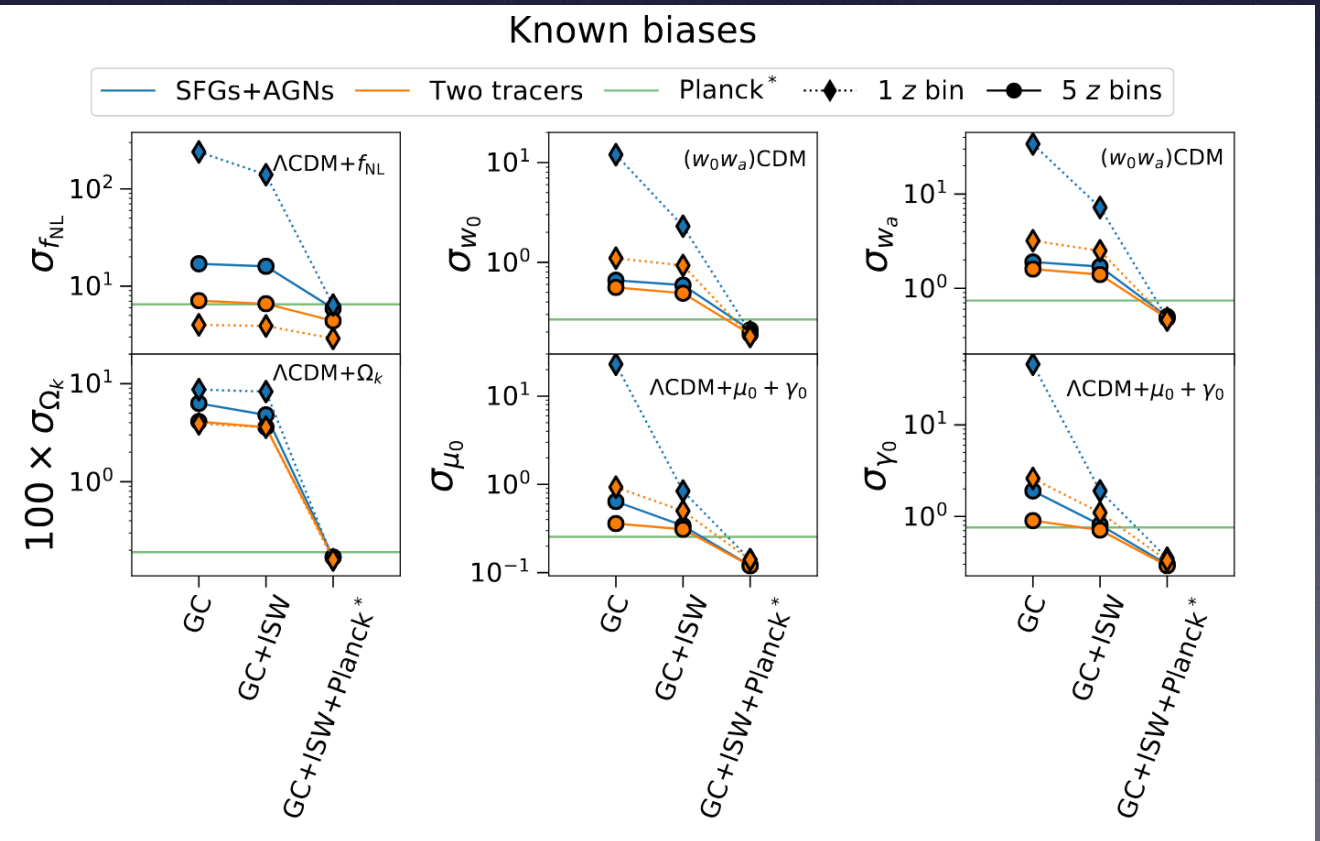
NVSS Healpix map

Chen & Schwartz (2016)

Forecasts on Continuum surveys

- Continuum surveys forecasts show we can enhance the constraints on cosmological parameters if we can divide our sample in redshift bins or if we can reduce the sample variance using the multi-tracer technique.

Racanelli et al. (2014)

Bernal et al. (2019)

Limits for continuum clustering cosmology surveys

- Clustering limits:
  - Redshift binning
  - Multi-tracer sampling

- On-sky radio survey limits:
  - Foregrounds
  - Confusion noise
  - Bright sources masking

Clustering statistics

- The error depends on the sample variance and on the shot noise.
- Angular clustering depends on the redshift distribution N(z) and the galaxy bias.
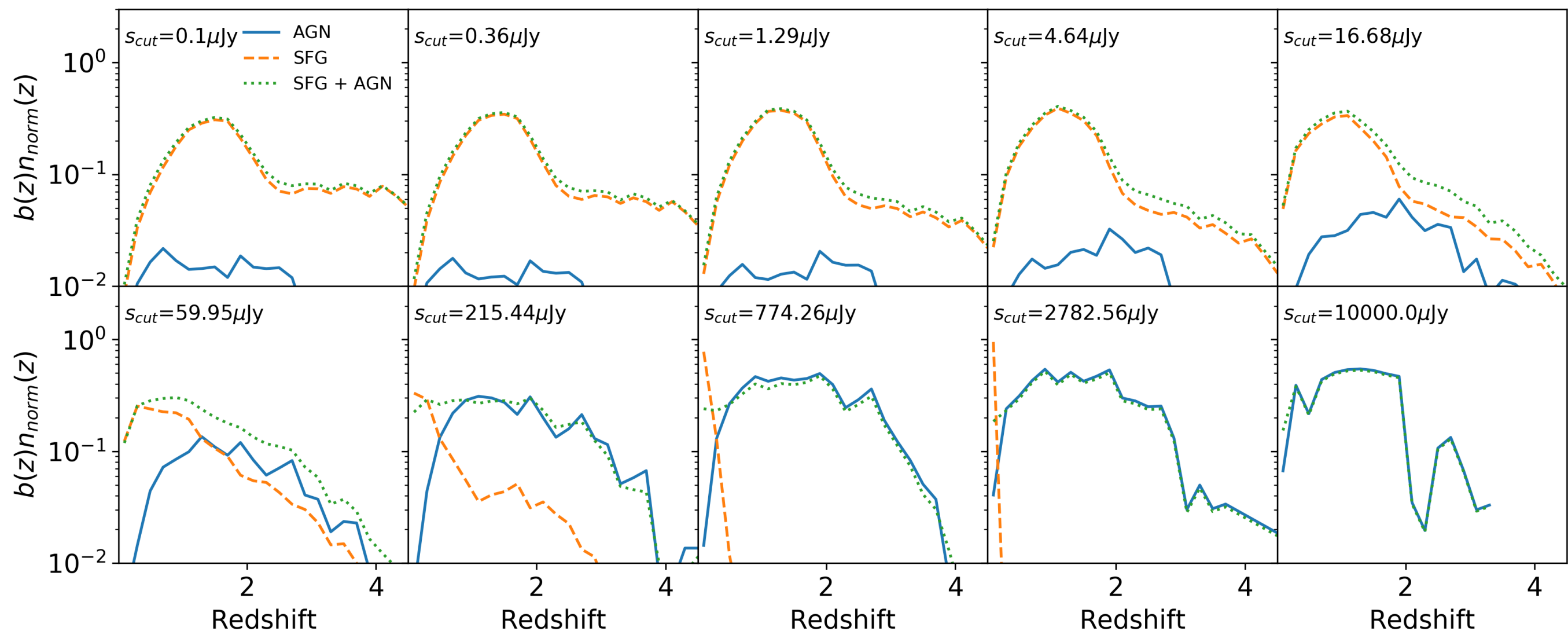- N(z) from T-RECS simulation (Bonaldi et al., 2016) and theoretical prescription for the bias.

Angular power spectrum:

$$C_\ell = 4\pi \int \frac{dk}{k} \Delta^2(k) \left[W_\ell^g(k) \right]^2 ,$$

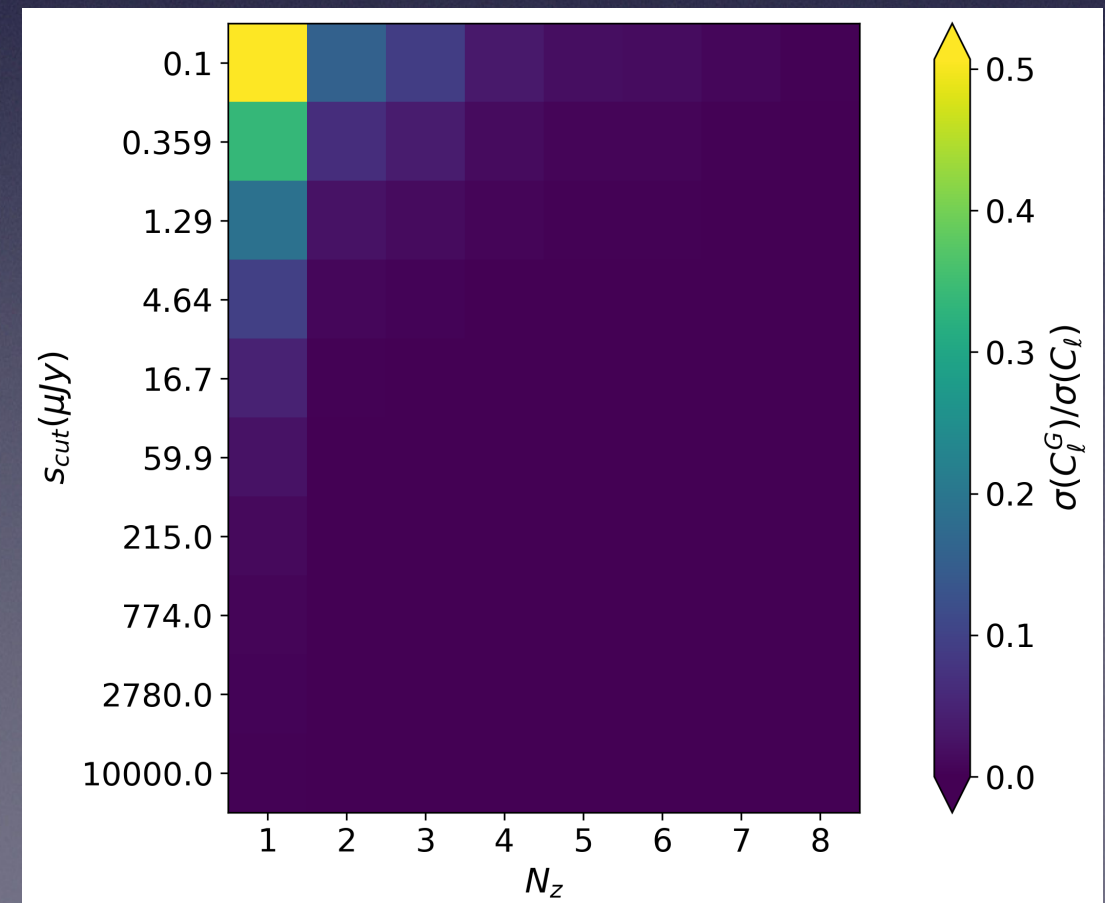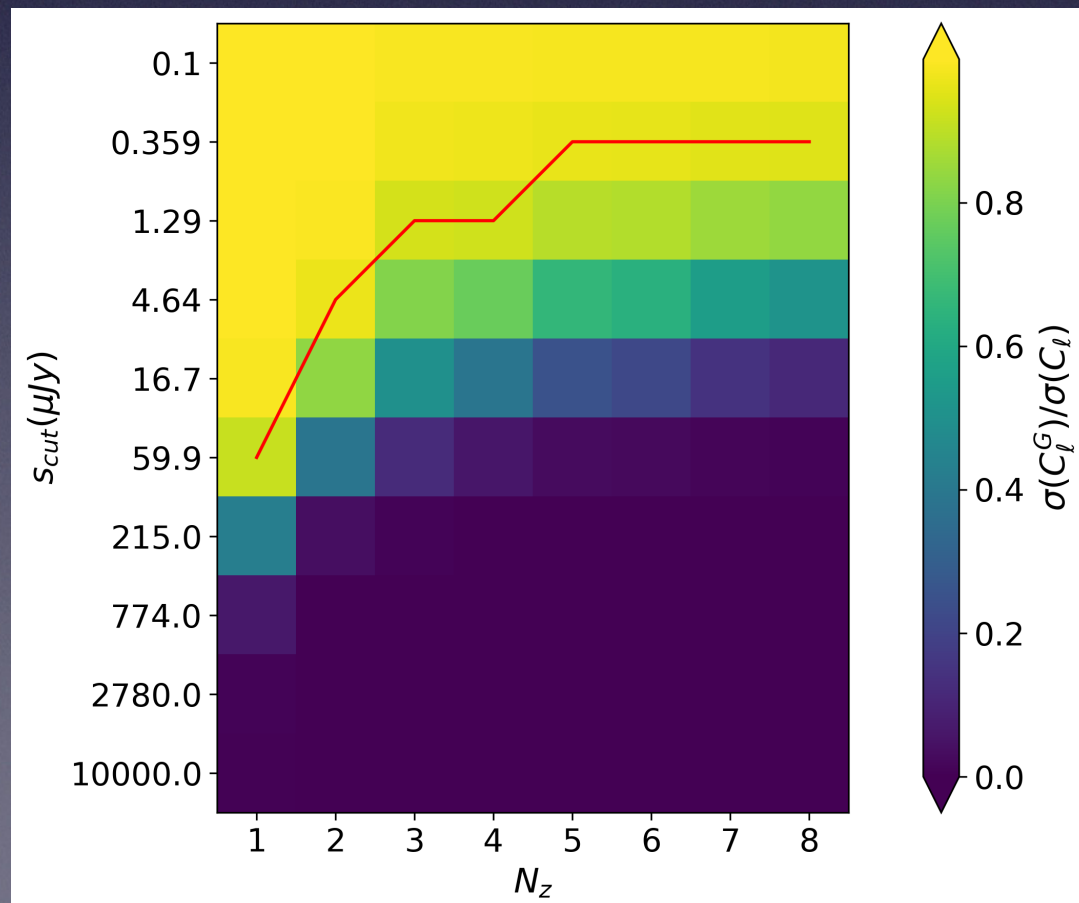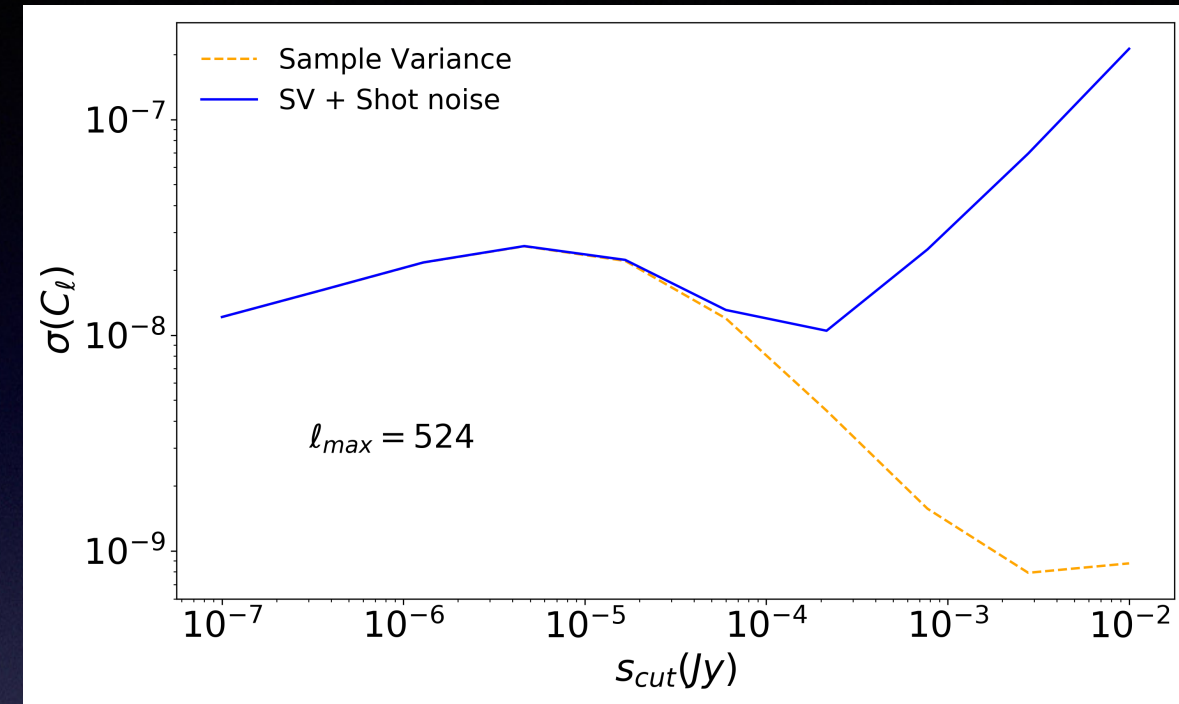$$W_\ell(k) = \int \frac{dN(\chi)}{d\chi} b(z) D(z) j_\ell[k\chi] d\chi .$$

Covariance of the power spectrum:

$$\mathrm{Cov}(C_\ell) = \frac{2(C_\ell + 1/\bar{n})^2}{N(\ell)} ,$$

Clustering limits

- Two effects increase the shot noise:
    - The redshift binning
    - The flux cut

- For future planned surveys, maximum binning range from 2-4 z-bins for µJy cuts.

- Multi-tracer sampling is limited by the amount of AGNs.

Foregrounds

- Sources are identify as having an emission larger than the rms produced by the diffuse emission from thermal telescope emission and sky diffuse emission.

- To reach the µJy that allows us to subdivide our sample in redshift bins, we need an integration time of at least 2 hours for a 50K detector.
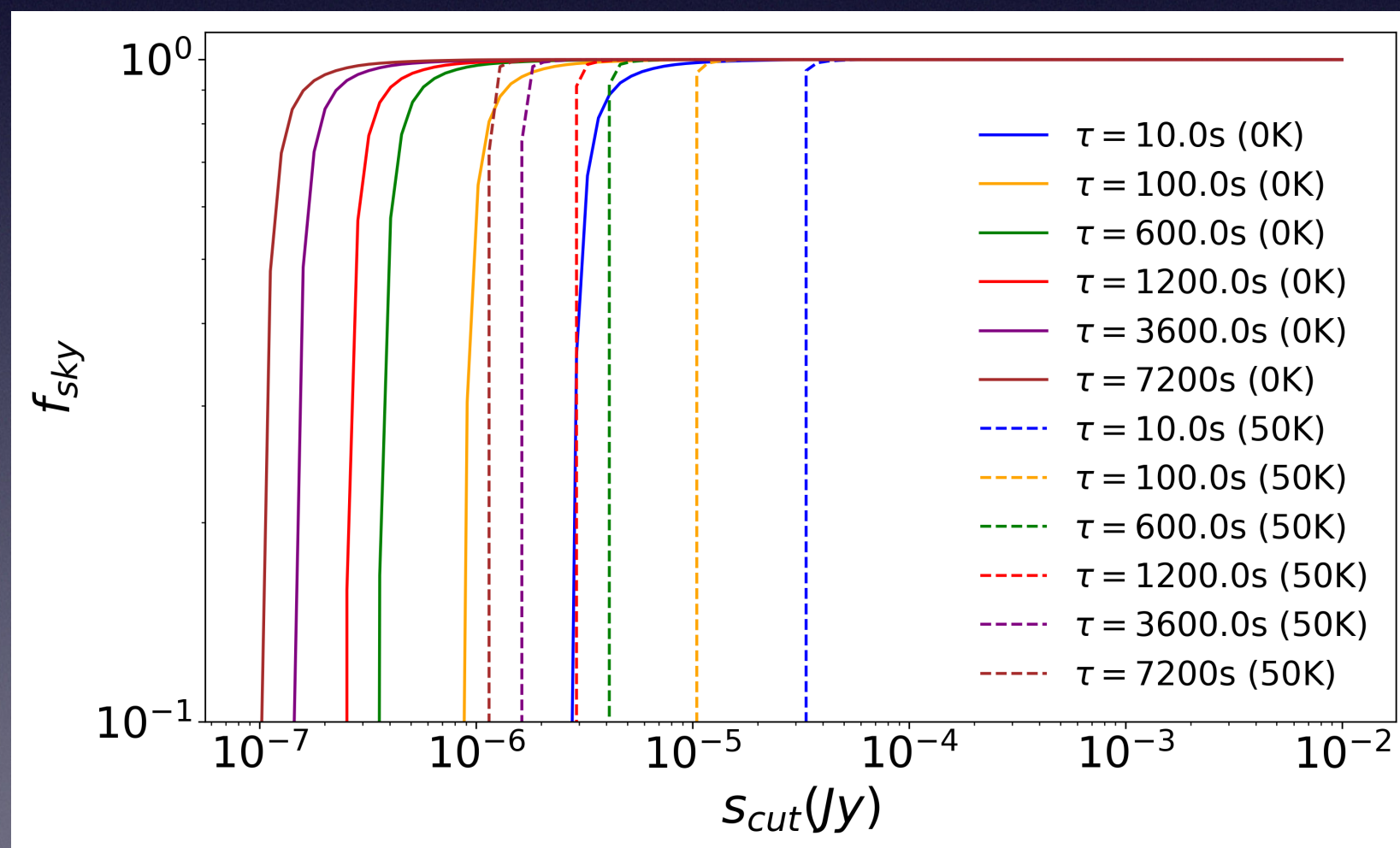
Confusion noise

- Even with infinite integration time, there is a natural limit in which faint sources create confusion noise.
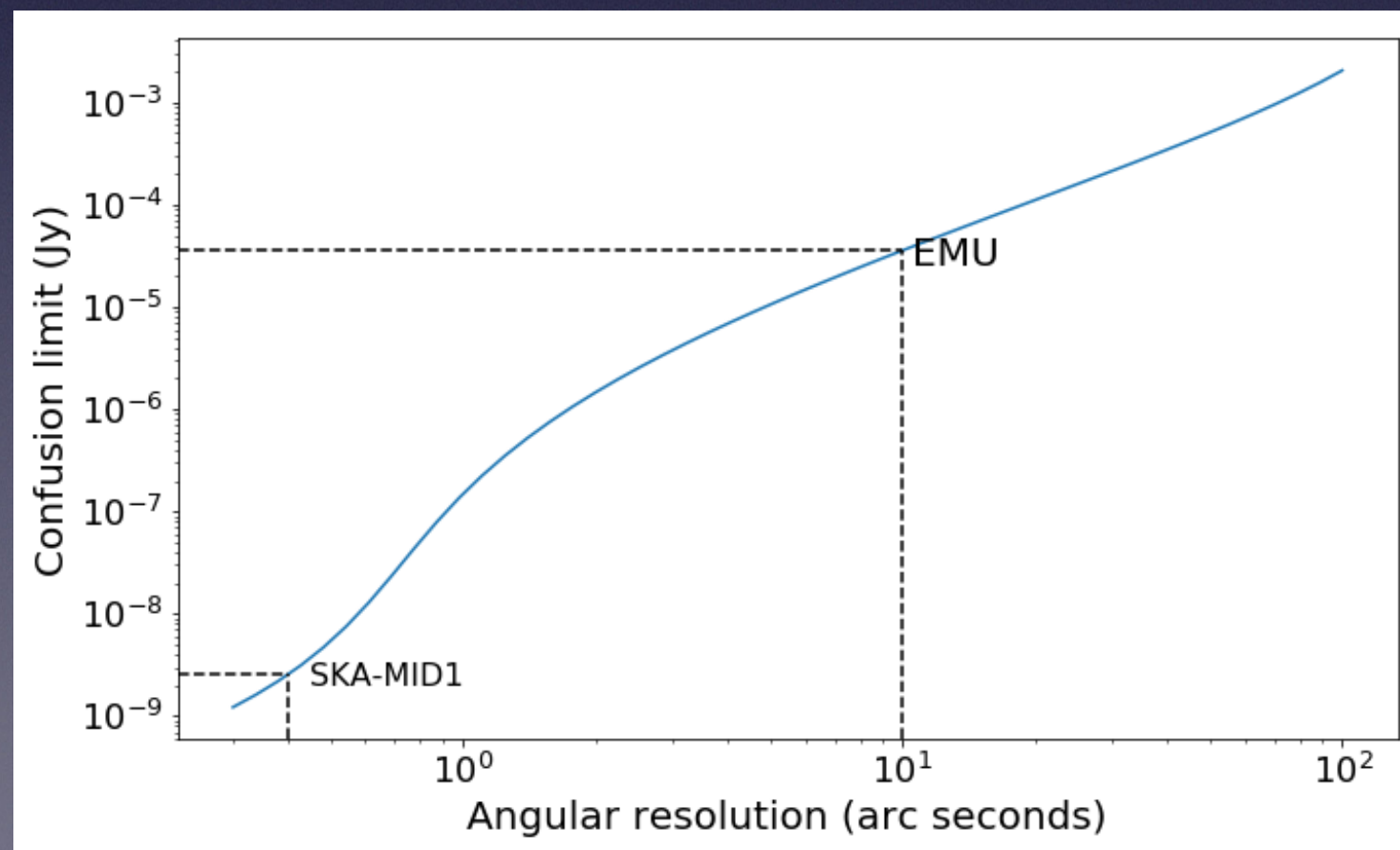
Number of sources above flux cut:

$$N(> S_0) \int_{S_0}^{\infty} n(S)dS.$$

Solid angle for a particular beam:

$$\Omega_{\text{beam}} = \frac{\pi\theta^2}{4\ln(2)},$$

Confusion noise limit:

$$\beta = [N(> S_0)\Omega_{\text{beam}}]^{-1},$$
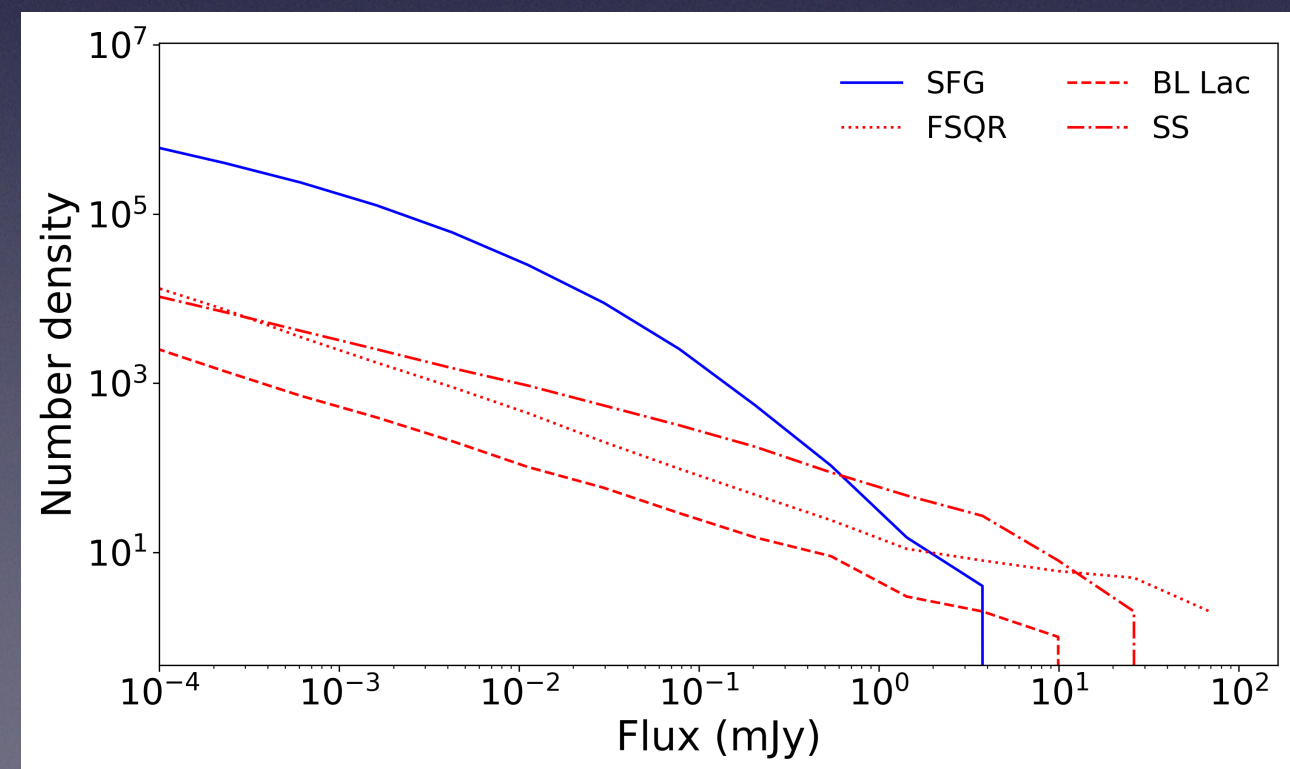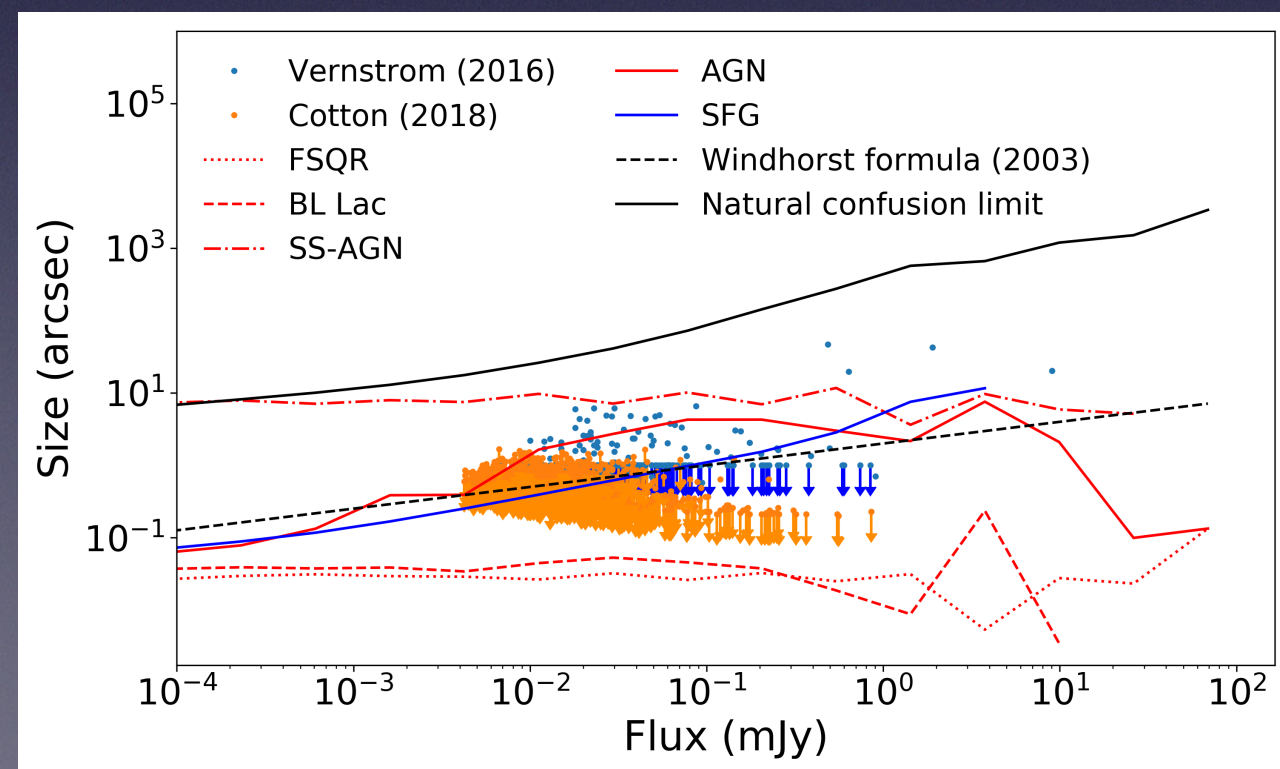
Natural confusion limit

- At some moment, sources may have a natural confusion limit when they already overlap due to the inherent size of the sources.

  Natural confusion noise limit:

  $$\beta_{\mathrm{n.c.}} = [N(> S_0)\Omega_{\mathrm{source}}]^{-1}.$$

- If T-RECS monster AGNs are real, we will not be able to reach depths beyond 100 nJy because they will overlap in the sky.

Masking bright sources

- Another natural limit is that for a given dynamical range (DR) between the faint limit and the bright limit of the survey, the cleaning of bright sources will produce artefacts in the faint end. Therefore, this bright sources need to be masked, removing the area that can be used for clustering analysis.
- For a 100 nJy survey to keep the total fraction of sky, we need a DR of 70 db.

Dinamical range:

$$DR = 10 \log_{10} \left(\frac{S_{max}}{S_{min}} \right),$$
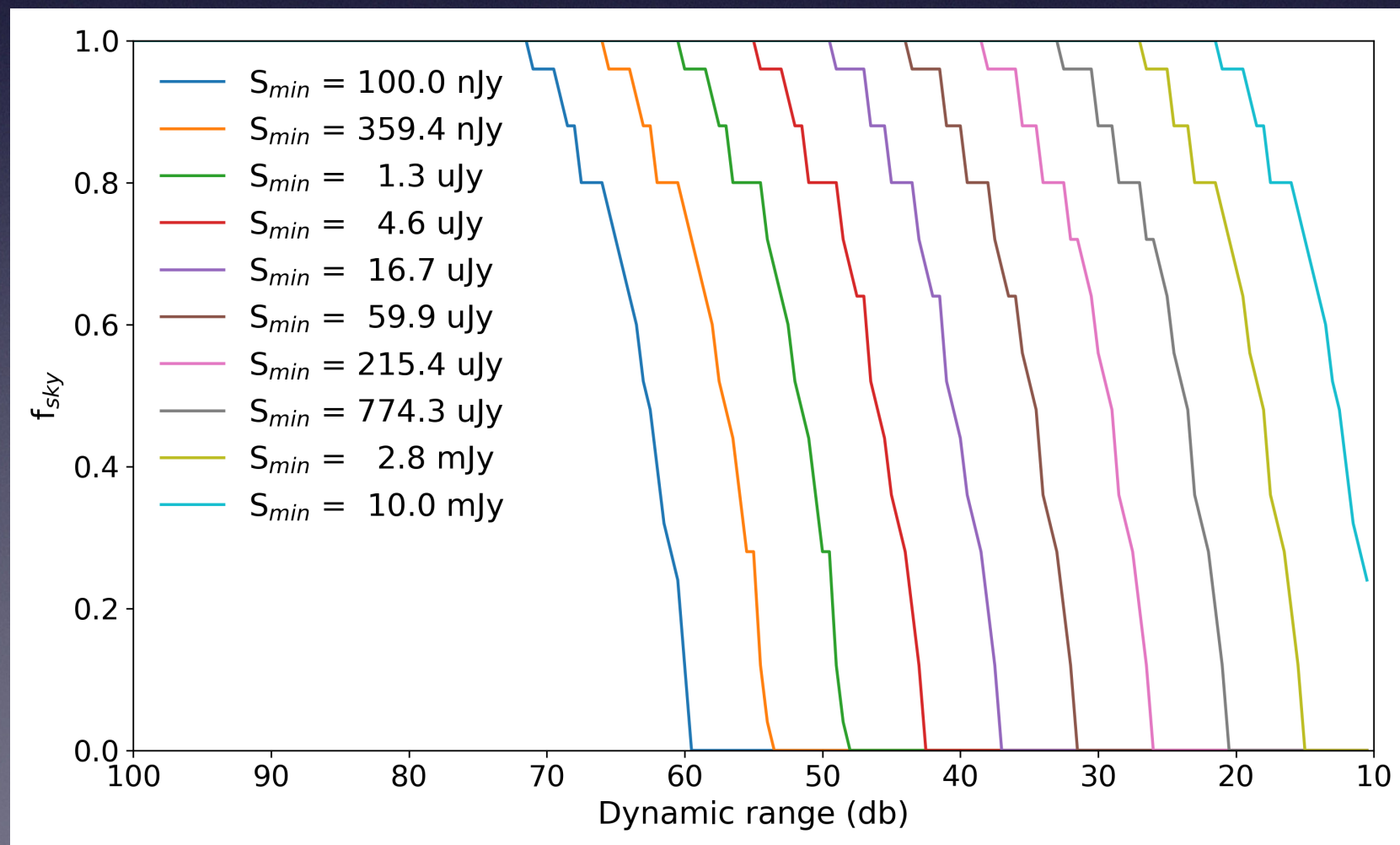
Summary

- Radio continuum cosmology surveys will allow us to explore the "redshift desert" and allow us to shade light in the open questions of Cosmology. We study the limits of these type of surveys.

- For continuum surveys such as EMU & MeerKAT with a 100 µJy limit, we would only be able to use one redshift bin. In order to **subdivide** our galaxy sample, we need to reach a **50 nJy rms** level.

- The small AGN population is the limiting factor for multi-tracer analysis.

- Foreground contamination may not be the limiting factor for continuum surveys but the object sizes. If there is a population of monster AGN, as predicted by the T-RECS simulation, we may not be able to reach deeper fluxes than **100 nJy** due to the natural confusion limit.

- To reach a sub µJy flux limit, we need to reach a dynamic range of **70 db.**

Survey	Observatory	Frequency (MHz)	Flux limit	f_{sky}	Optimal n_{bins}
NVSS	VLA	1350-1450	2.5mJy	0.65	–
LoTSS	LoFAR	120-168	500 µJy	0.65	–
EMU	ASKAP	800-1400	50 µJy	0.65	1
MeerKLASS	MeerKAT	900-1670	25 µJy	0.1	1
SKA-Mid medium cosmology	SKA-MID B2	950-1750	8 µJy	0.12	2
SKA all-sky cosmology	SKA Survey	800-1400	1 µJy	0.65	4

¡Thank you!