Commensal HI-continuum cosmology surveys

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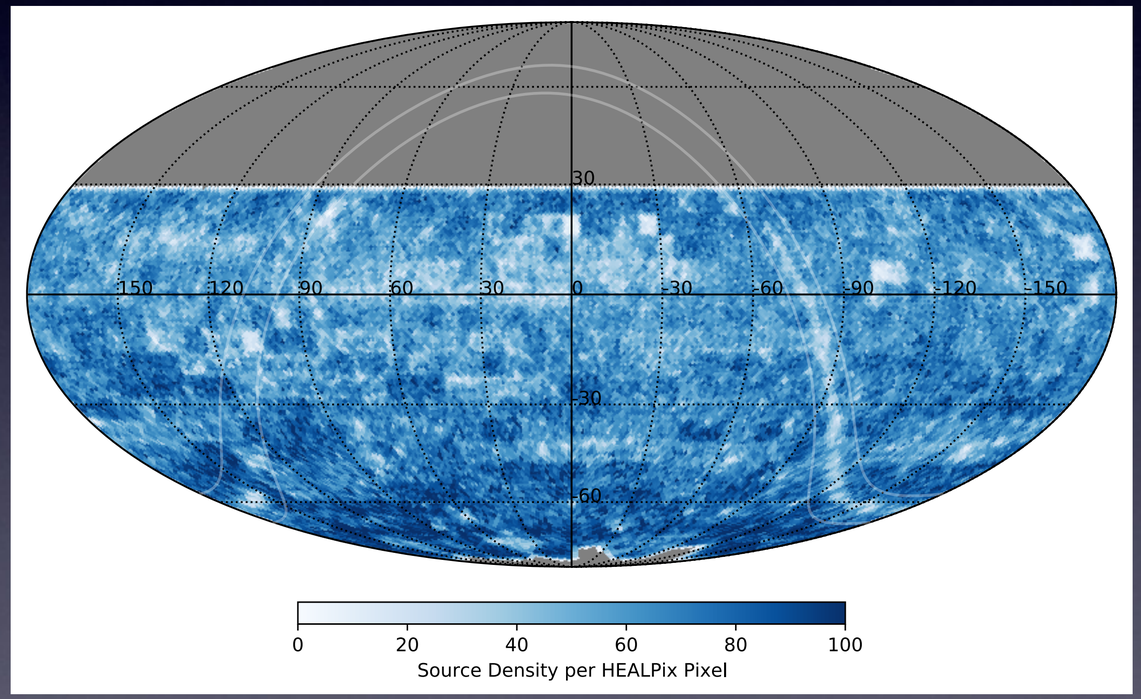
Outline

- Continuum Cosmology
- Red book forecasts - large area survey
- Importance of commesality

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
  - 2D rather than 3D map

Rapid ASKAP Continuum Survey - low



Bahr-Kalus et al (2022)

Cosmological Observables

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

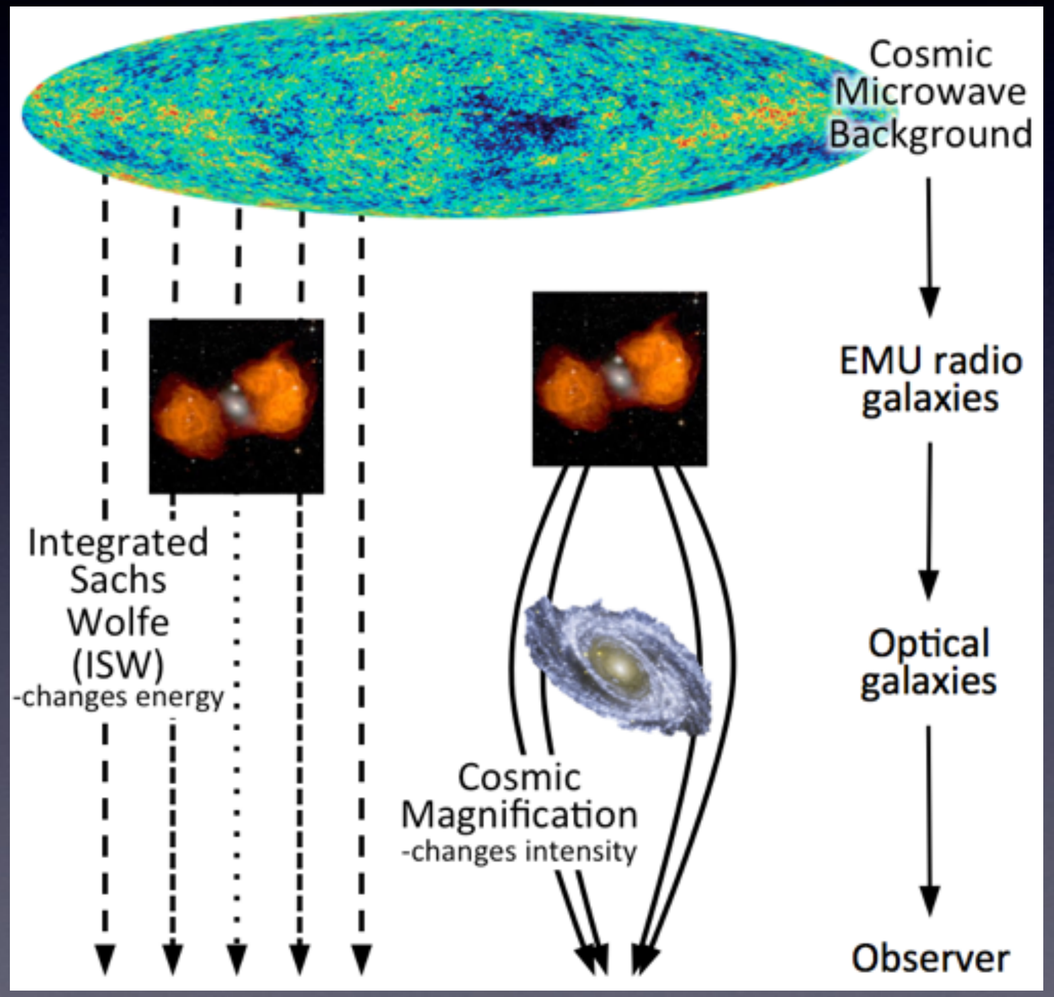


Image credit: Tamara Davis

Cosmic Magnification

- Measured density field has correction due to gravitational lensing magnification

$$\delta_n = \delta_g + \delta_\mu$$

- Effect takes the form of some ‘magnification bias’

$$\delta_\mu(\theta, z_0) = (5s(z_0) - 2)\times$$
$$\int_0^\infty dz \frac{c}{H(z)} g(z, z_0) \nabla_\perp^2 \phi(\chi(z)\theta, z_0)$$

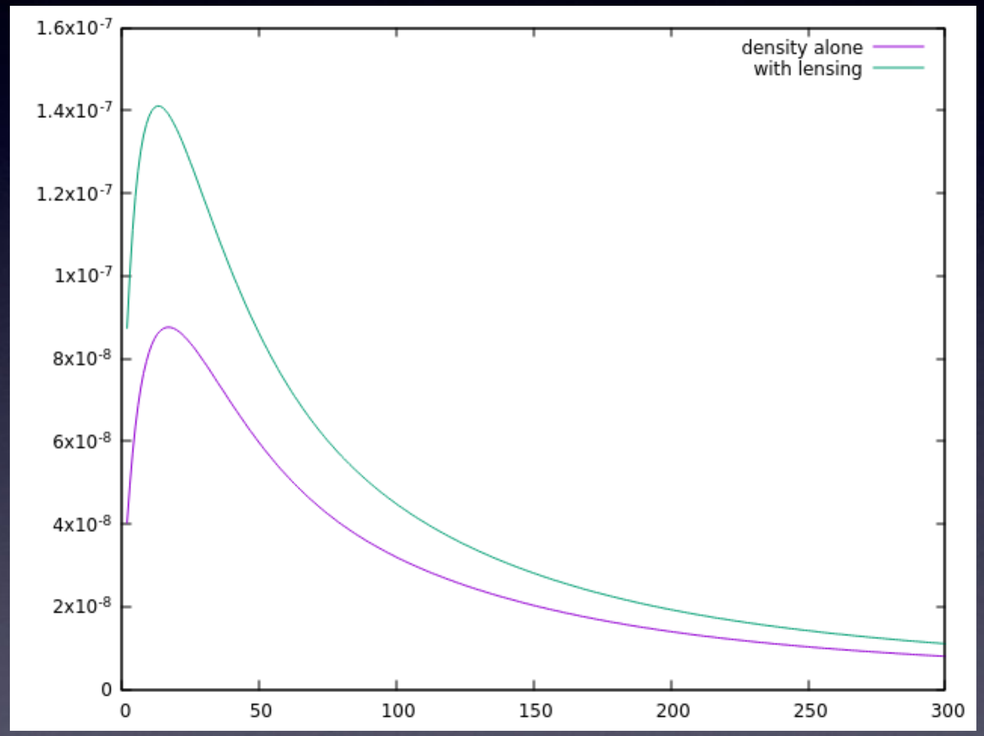
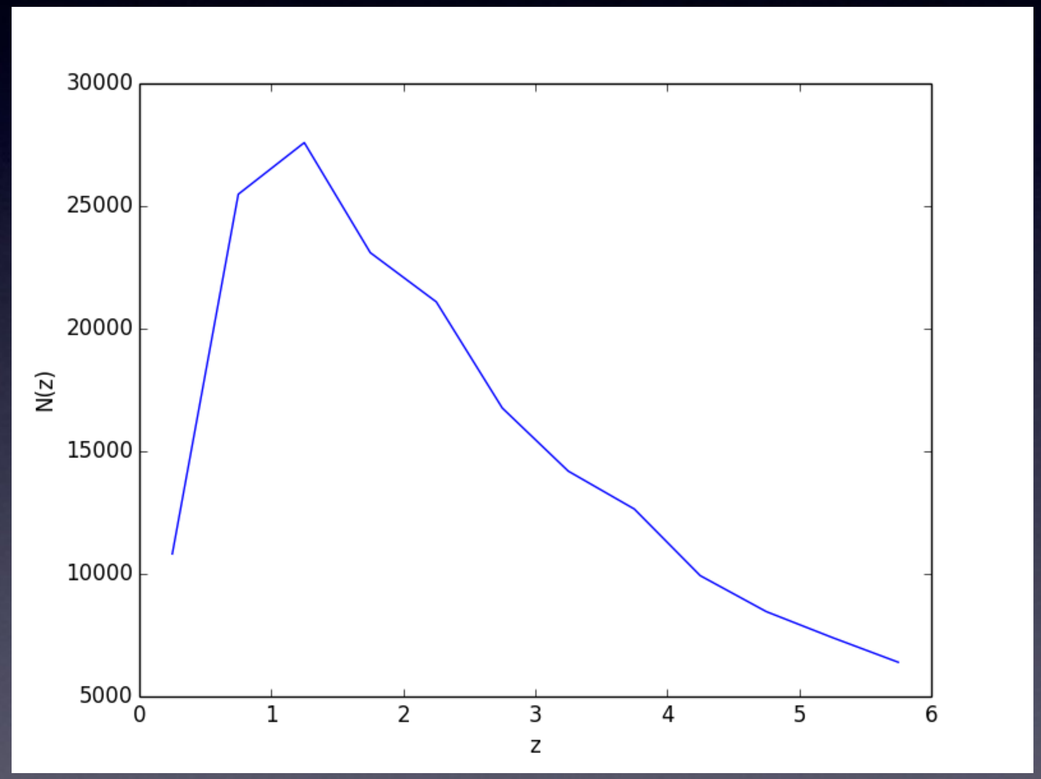


Image credit: Song Chen

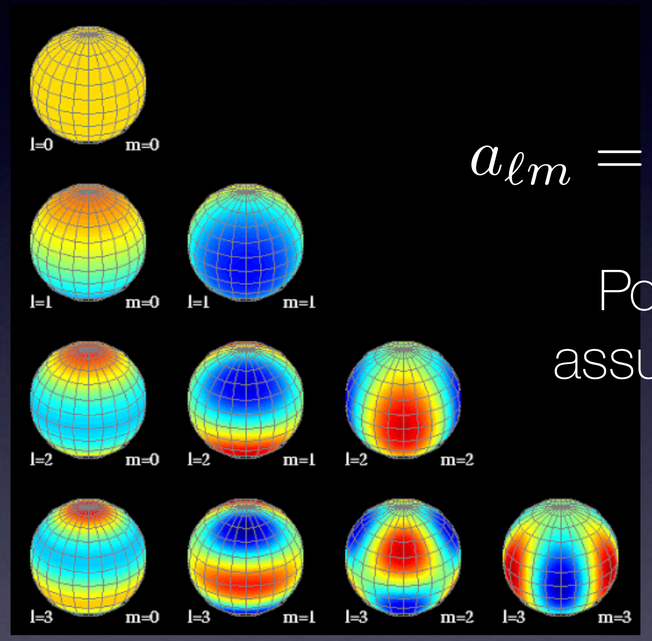
Long-tail bin

- Large-area and deep surveys give access to largest scales (modes larger than k_{eq}), both in radial and tangential directions
  - Early universe (non-Gaussianity)
  - Dark energy/modified gravity
  - large-scale features (dipole/ anisotropy)



Statistics and correlations

- An individual galaxy is not enough, need a measure of the distribution of galaxies
- For radio continuum, don't have accurate redshift information
  - Everything in 2D (angular)
- We describe distribution of galaxies through σ(θ) displacement field
  - Here θ is a particular direction
- σ(θ) decomposed into its multipole moment using spherical harmonics
- Compute either angular power spectrum (same as the CMB) or angular correlation function



$$a_{\ell m} = \int d\vec{\theta} Y^*_{\ell m} \sigma(\vec{\theta})$$

Power spectrum: assume isotropy and average

$$\langle a^*_{\ell m} a_{\ell' m'} \rangle = \delta_{\ell \ell'} \delta_{m m'} C_\ell$$

Connection to theory

- How can we connect measured correlations to cosmological parameters (e.g. density of matter, Hubble parameter today)?
- We infer the underlying matter power spectra P(k)

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

- But need to understand the window function Wℓ(k) of underlying populations

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

  - CMB Window function easy – localised at zrec.
  - Galaxy window function more difficult – signal can be confused with number or bias evolution

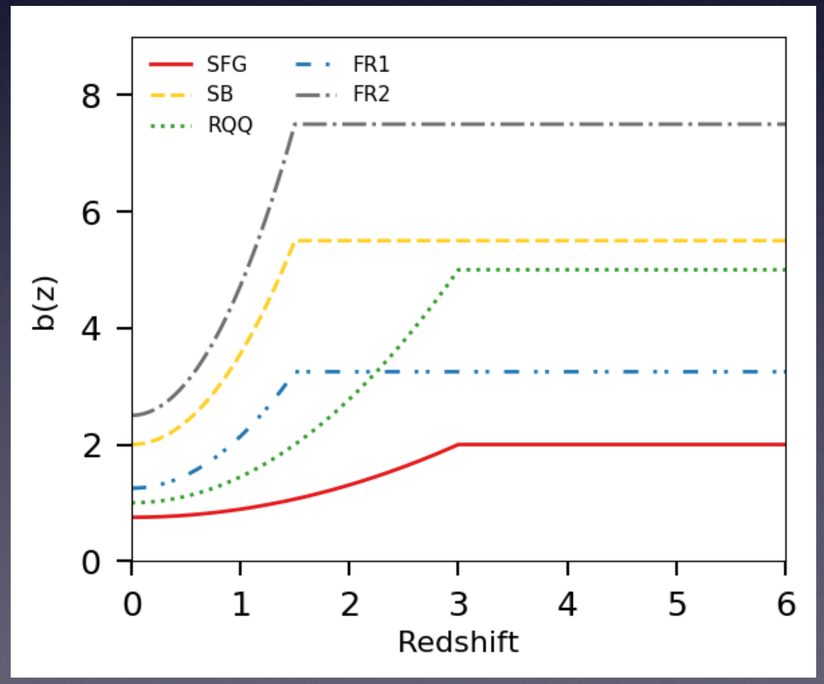
Shopping list

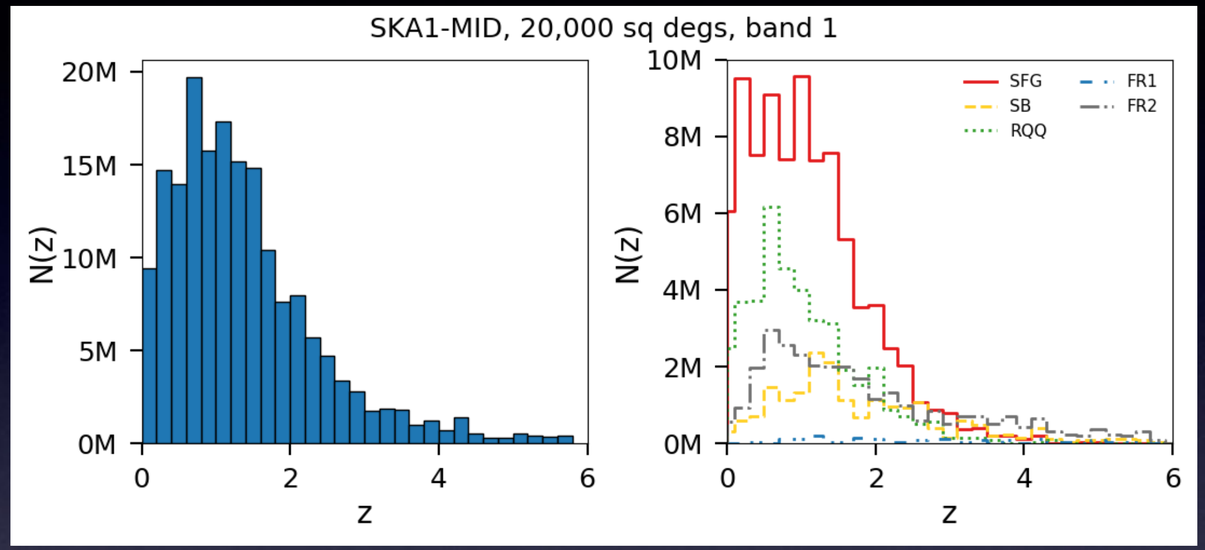
- (Observations)
  - a large sample (N) of galaxies
  - over a large area (A),
  - with few holes/gaps
  - that can be sub-divided by redshift into bins

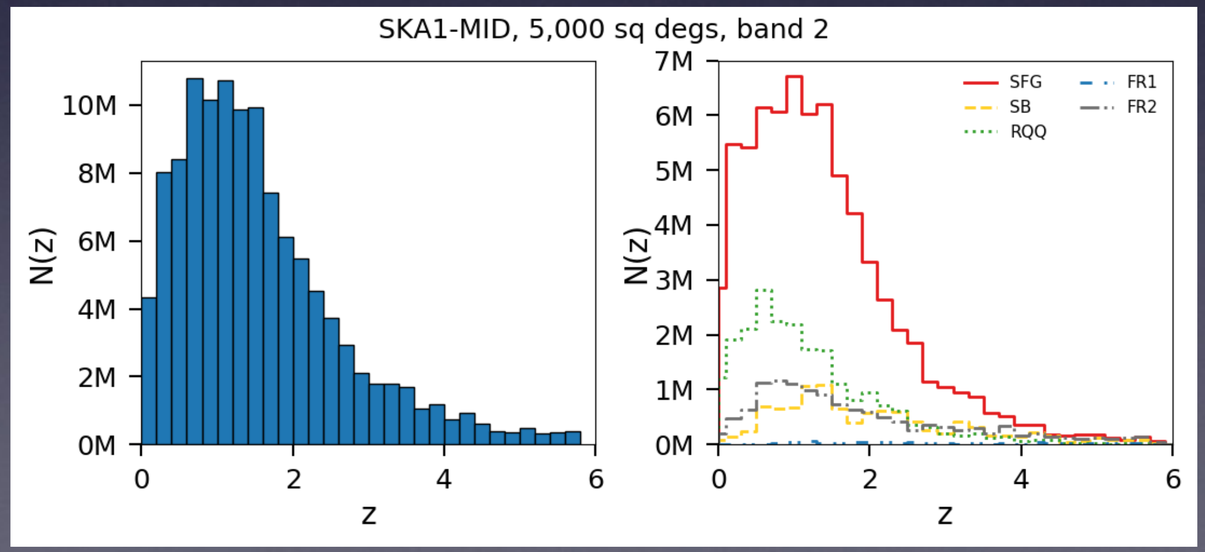
- (Theory understanding)
  - with known population number evolution n(z)
  - and known bias b(z)
  - and a known luminosity distribution L(z)
  - and a known evolutionary rate

Red Book Forecasts

- We forecasts the constraints for two continuum surveys on SKA1-MID:
  - Wide (20,000 sq degs, band 1)
  - Medium-Deep (5000 sq degs, band 2)

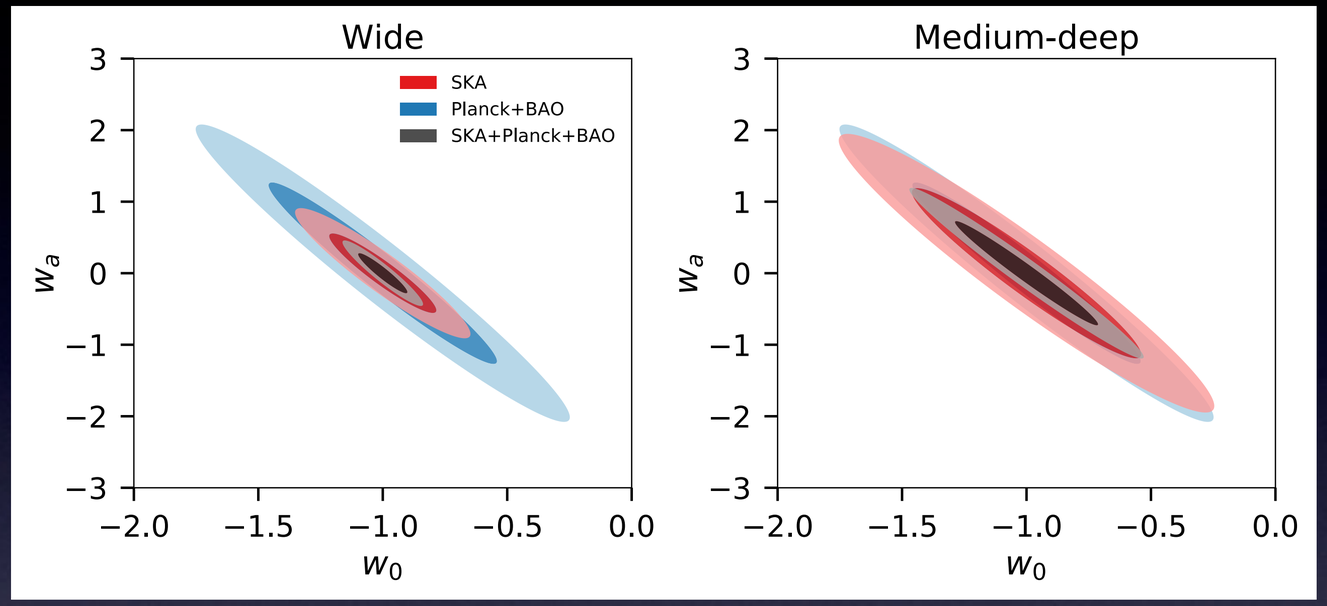


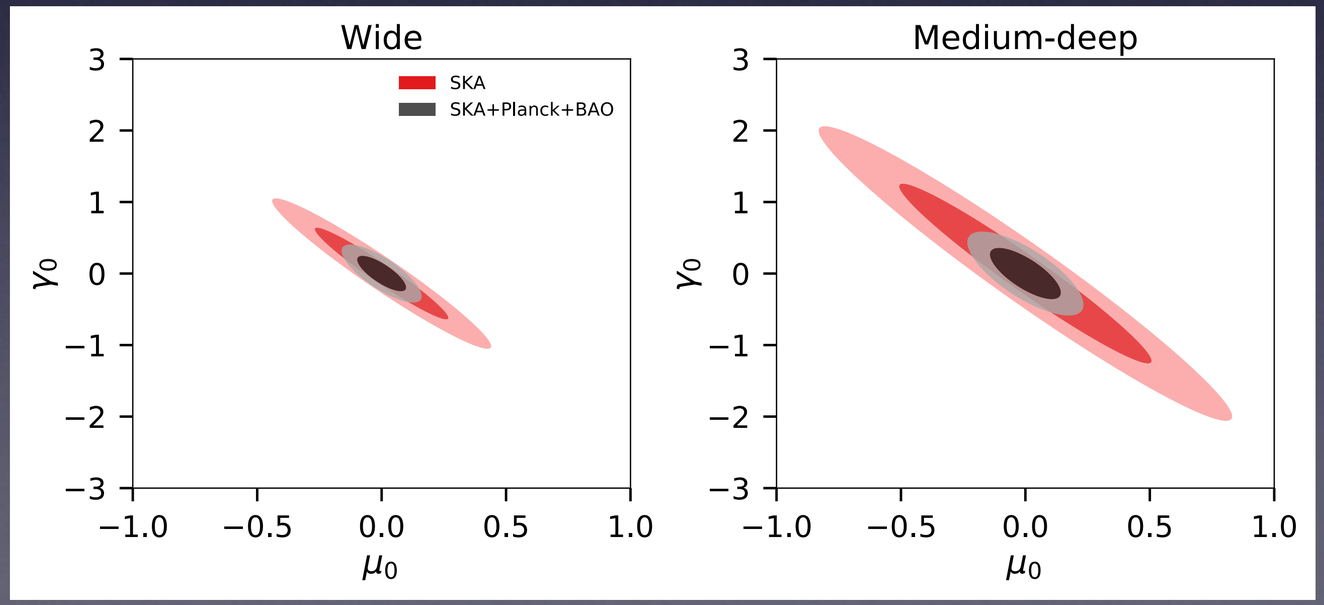




Red Book Forecasts

- Forecast includes all observables, including clustering, magnification, and ISW
- Medium-Deep survey is not competitive, and will not provide useful cosmological constraints
  - Though it will be useful for lensing shear measurements
- For a continuum survey to provide important cosmological constraints, it needs to be at least as big as the described Wide survey





Commensality

- To maximise sky area, continuum surveys must be commensal with other large-area surveys
- In our case, our best approach is combine with 21cm Intensity Mapping, which will survey using OTF (on-the-fly) mapping method
  - Short exposures being combined to make deeper images
- This technique is already being tested by MeerKLASS survey
- We do not know what the systematics will be, for such a survey strategy

Science with the continuum survey

Using the on-the-fly mapping method, MeerKLASS will also yield interferometric continuum images as well as spectral cubes (4k) over the UHF band, covering the same 10,000 deg^2 area. The most immediate data product will be 2-second images, which will provide an instant view of the sky over large areas, given the fast scanning strategy, and can be used to search for slow transients. These 2s samples can be combined to produce deeper images with a flux sensitivity of ~25 μJy and an angular resolution of ~13”. Uniquely, we will also be able to add the zero mode to these images from the single dish data, enhancing studies of diffuse emission for example. The continuum survey will detect about 15 million mostly star-forming galaxies, over a wide area, covering a unique frequency range down to 550 MHz. This can be used for several statistical analyses such as stacking and P(D), to study the galaxy

Discussion?

- A large-scale continuum clustering survey will provide important tests of the cosmological model on large-scales
  - Best possible continuum clustering survey has as wide an area as possible
- But, by themselves, they are not as competitive for dark energy w_0w_a as 21cm IM BAO, or as sensitive to modified gravity theories as weak lensing shear
- So, from a cosmological science perspective, the best approach would be for a commensal wide-area survey
  - This may not have the best outcome for other extragalactic continuum science, of course
- In fact, writing **any** chapter discussing continuum clustering, without first discussing survey strategy and commensality, might be pointless