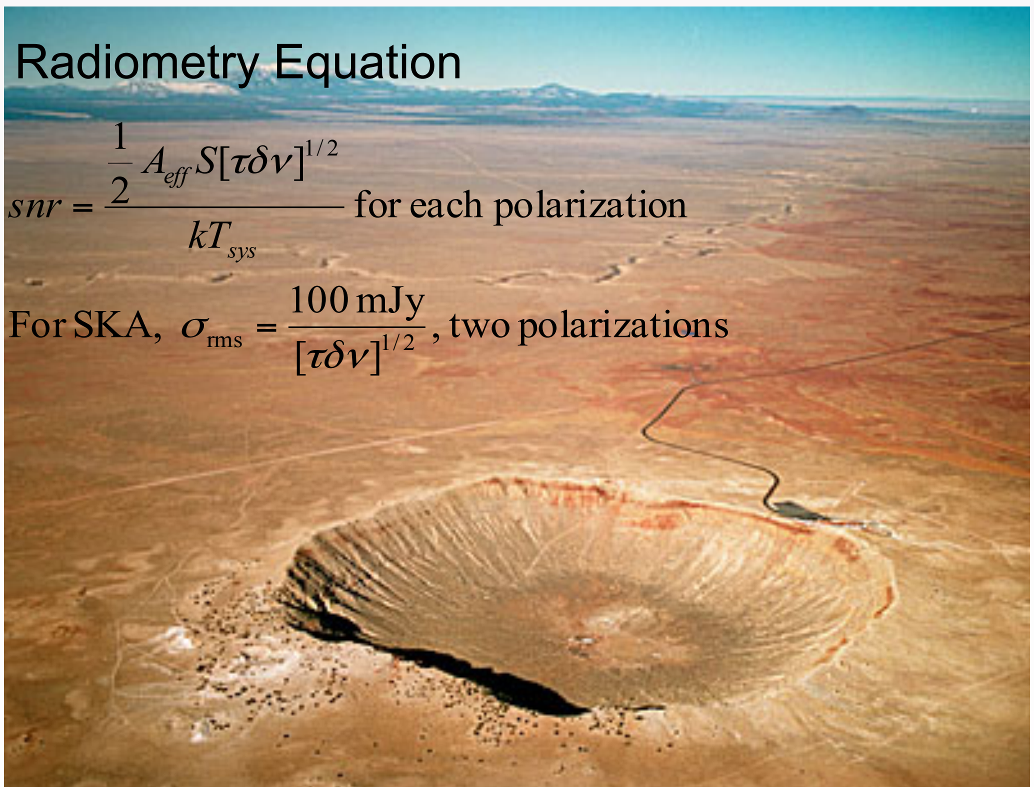
UCL

HI Cosmology with the Square Kilometer Array



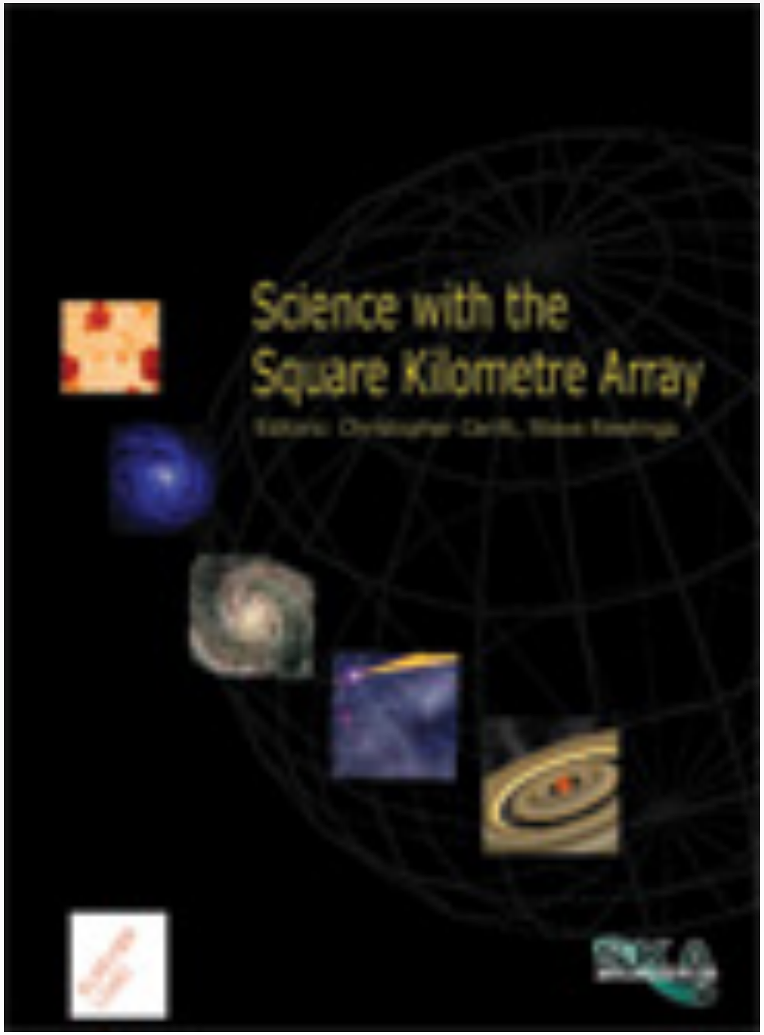
Filipe B. Abdalla

THE ROYAL SOCIETY
CELEBRATING 350 YEARS

The Cosmology science case back in 2004

- Galaxy surveys for BAO
- Weak Lensing surveys
  - BAO & WL for dark energy
- H0 with Masers

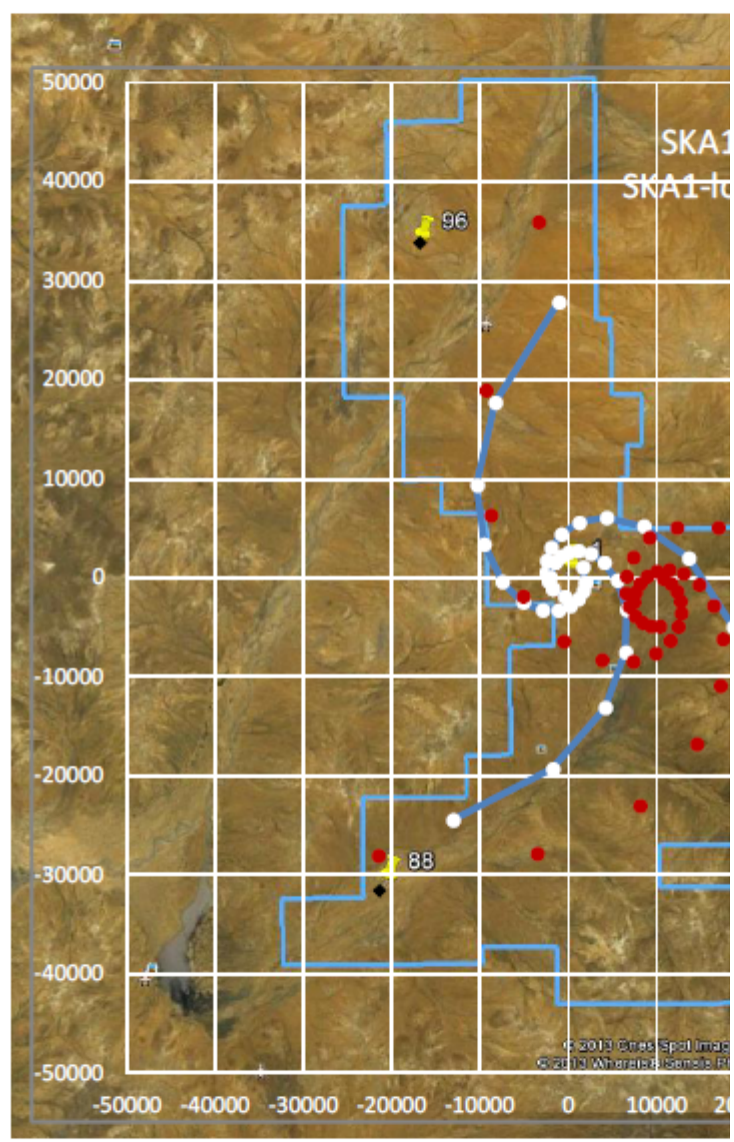
- Much has been done in the above three areas and many others since...

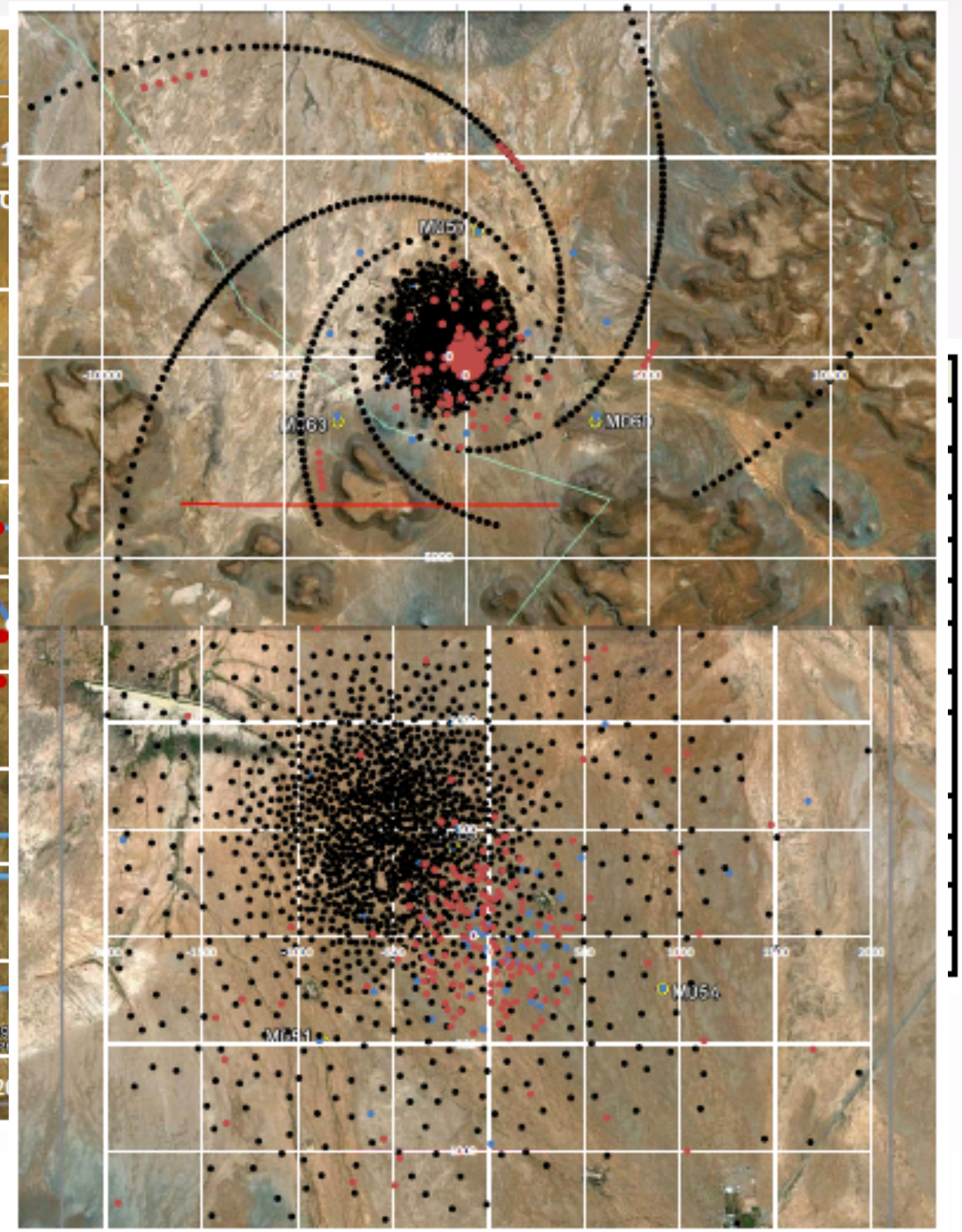


Carilli and Rawlings 2004

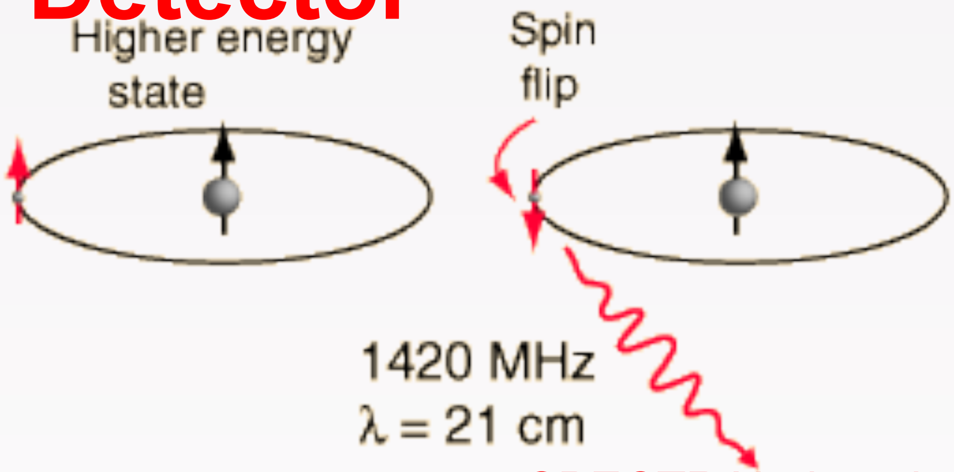
W

- Thr
  Low
  all c
  cos
  spe
- This
  very
  pro
  opt
  the
  ove
- SKA
  to t
  capabilities of the SKA

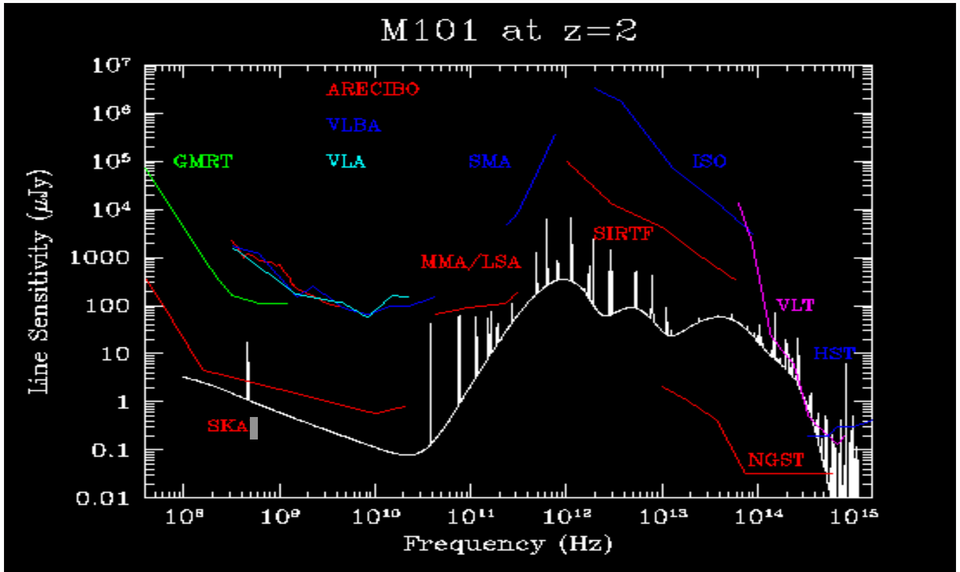




21cm: a Hydrogen Detector



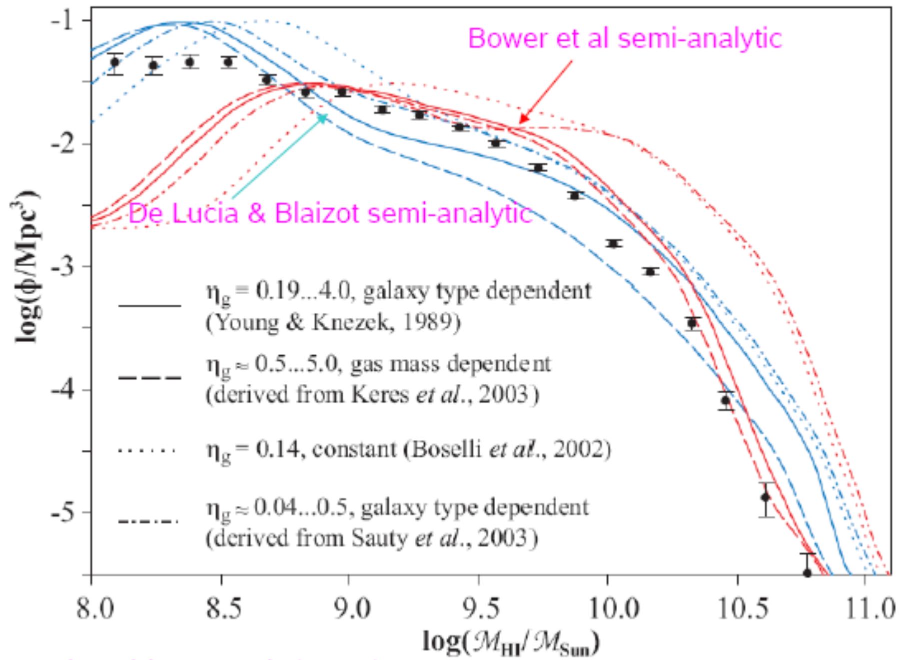
SPECTRAL domain
0.5 to 1.4 GHz



- Detection of the HI disk, a bit larger than the continuum disk!
- HI only on a line, continuum over all band!
- SKA1 will quickly pinpoint ~10^{7-8} galaxies in 3D (cf ~10^6 galaxies in Sloan, Euclid ~ $6*10^7$) SKA2 will whickly pinpoint ~10^9 galaxies in 3D (cf ~10^6 galaxies in Sloan)
- Continuum ~10^{10} galaxies in 2D

modelling SKADS sims

Constant η_g inadequate



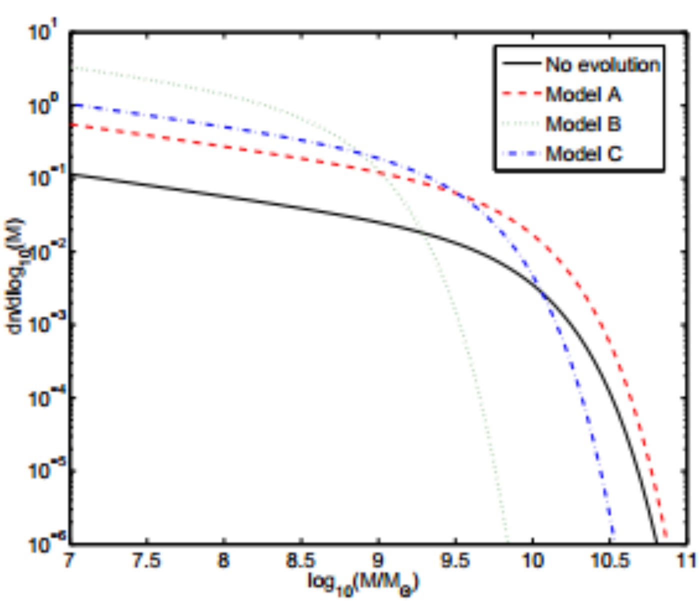
Obreshkow et al. (2008)

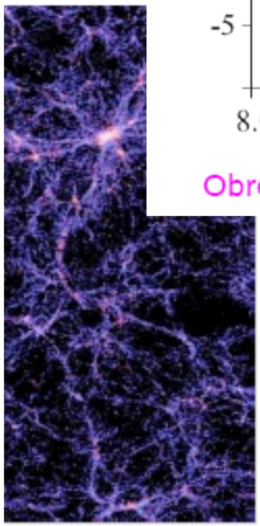
Millennium Simulation (Springel et al. 05)

Dark matter

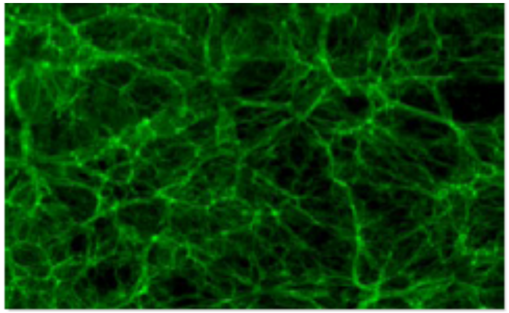
Semi-analytics (De Lucia et al. 06/07

Visible matter



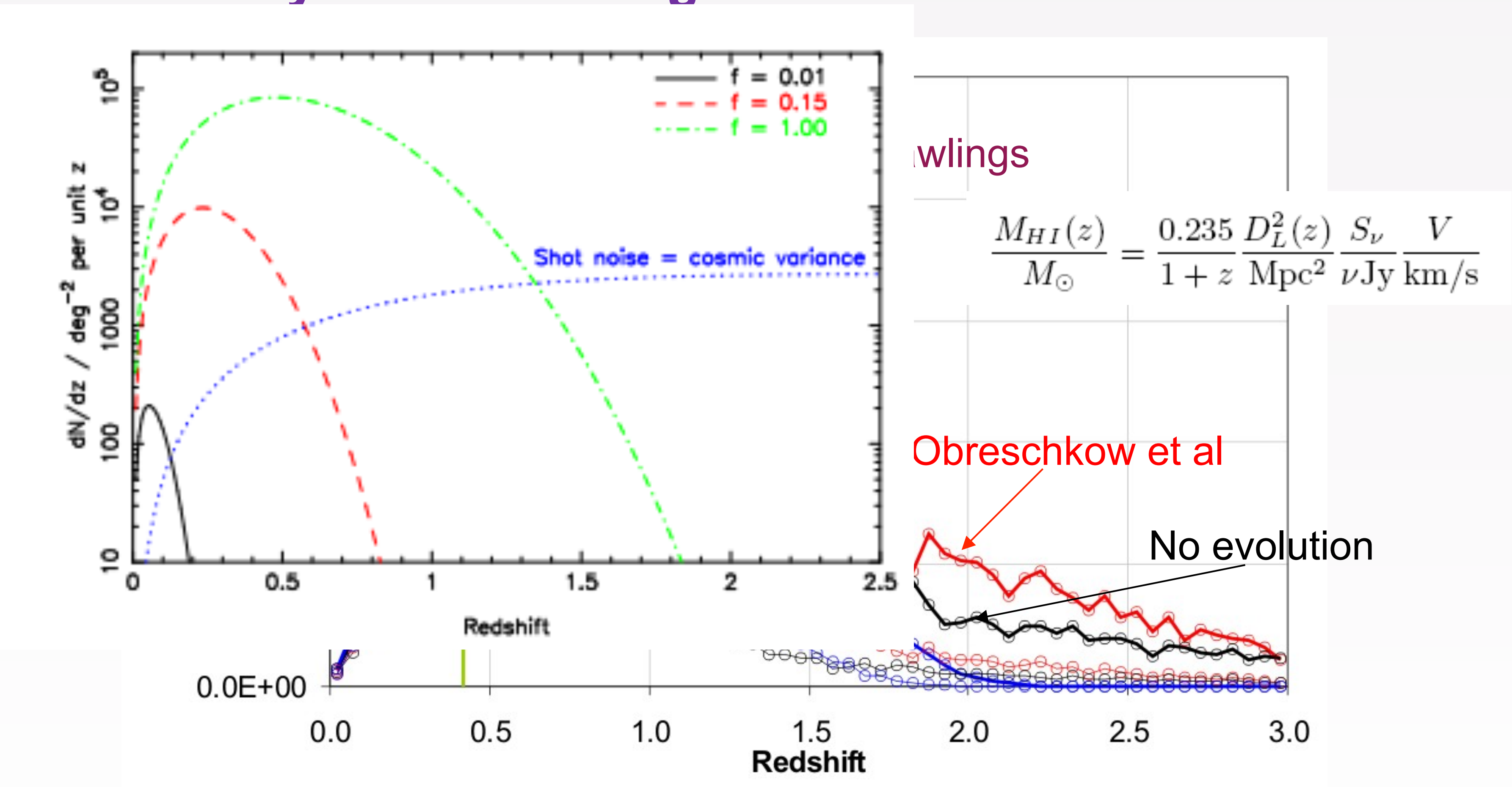


s mass



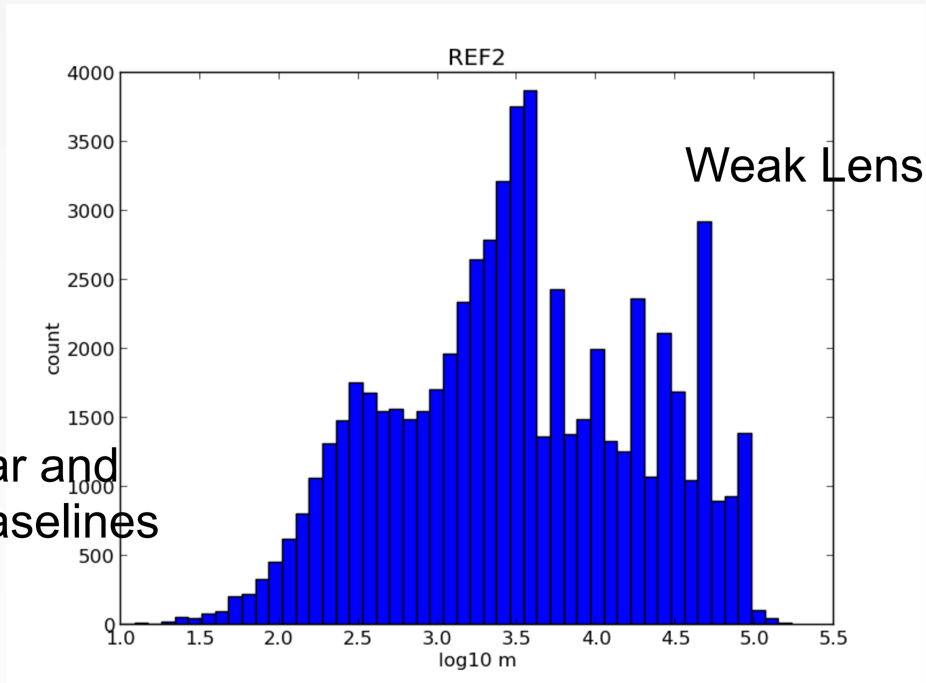
HI from cold gas mass

Full SKA Predictions
Have to rely on educated guesses



- SKA1 deliver >$10^{7\text{-}8}$ galaxies over ~20,000 deg^2 to z~0.6, SKA2 deliver >10^9 galaxies over ~20,000 deg^2 to z~2

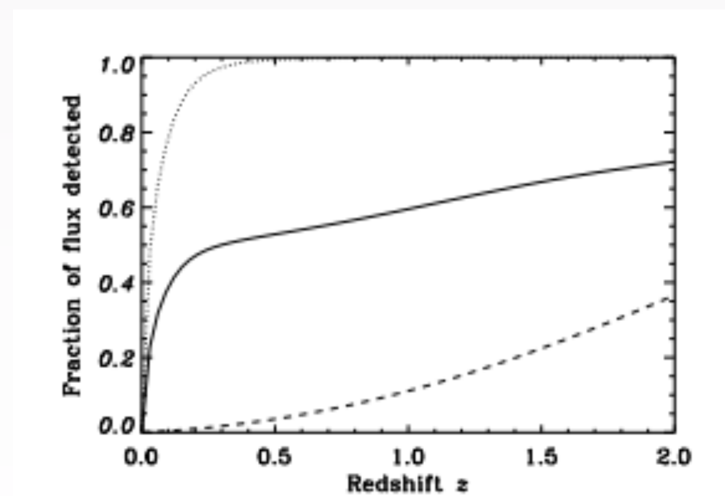
Importance of the baseline distribution here:



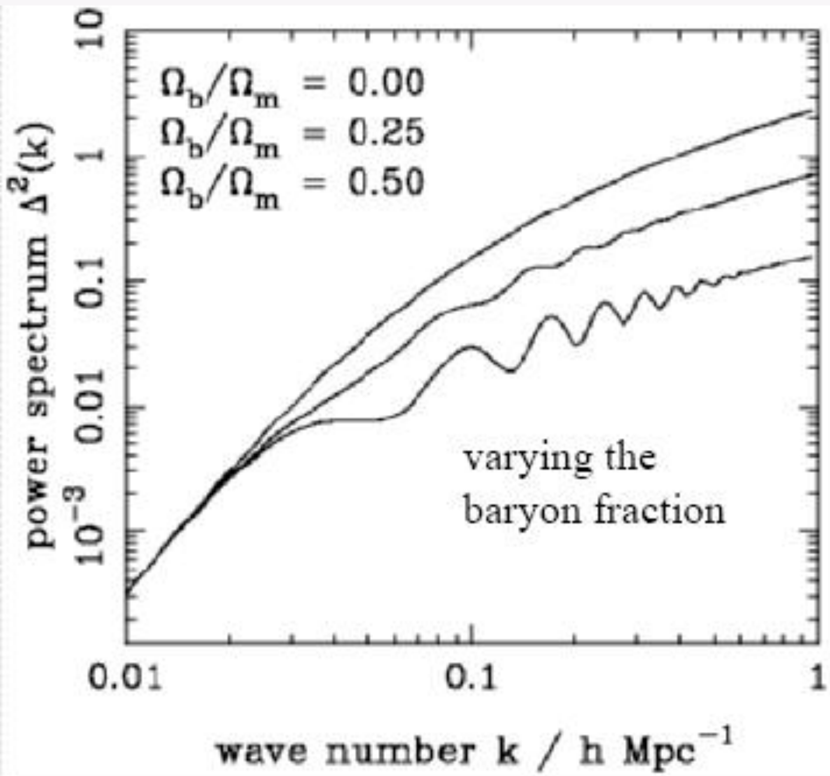
Weak Lensing baselines!

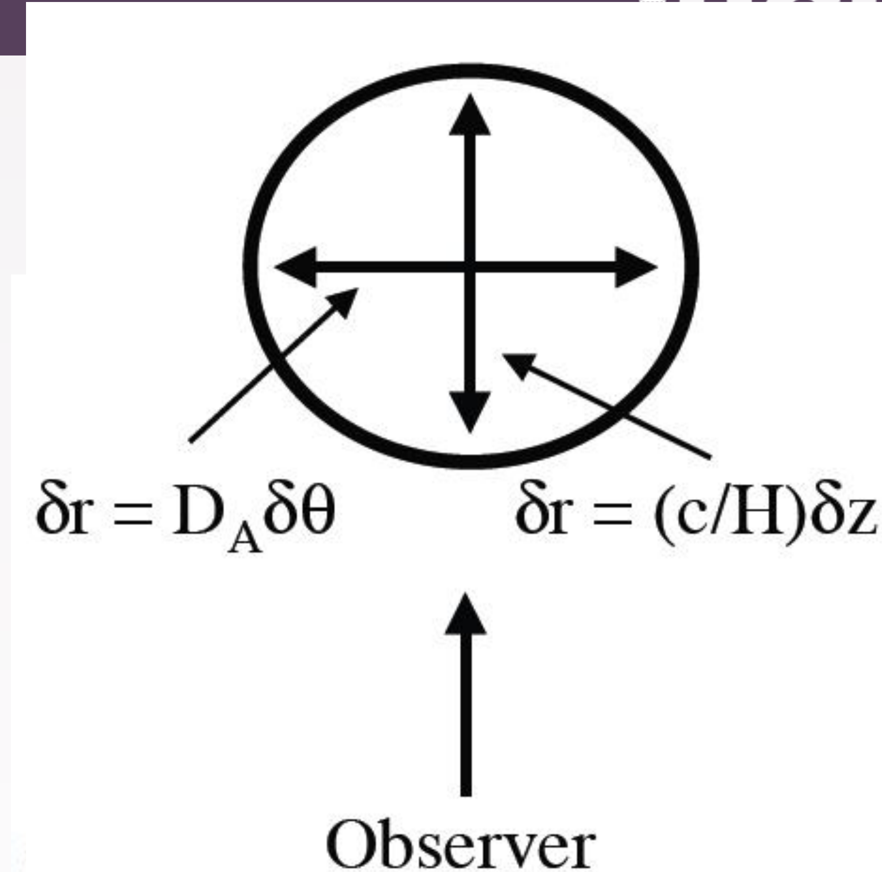
Pulsar and
IM baselines

HI baselines



BAO in LSS





$$H(z) = h\sqrt{\Omega_m(1+z)^3 + \Omega_X \exp\left[3\int_0^z \frac{1+w(z)}{1+z}dz\right]}$$

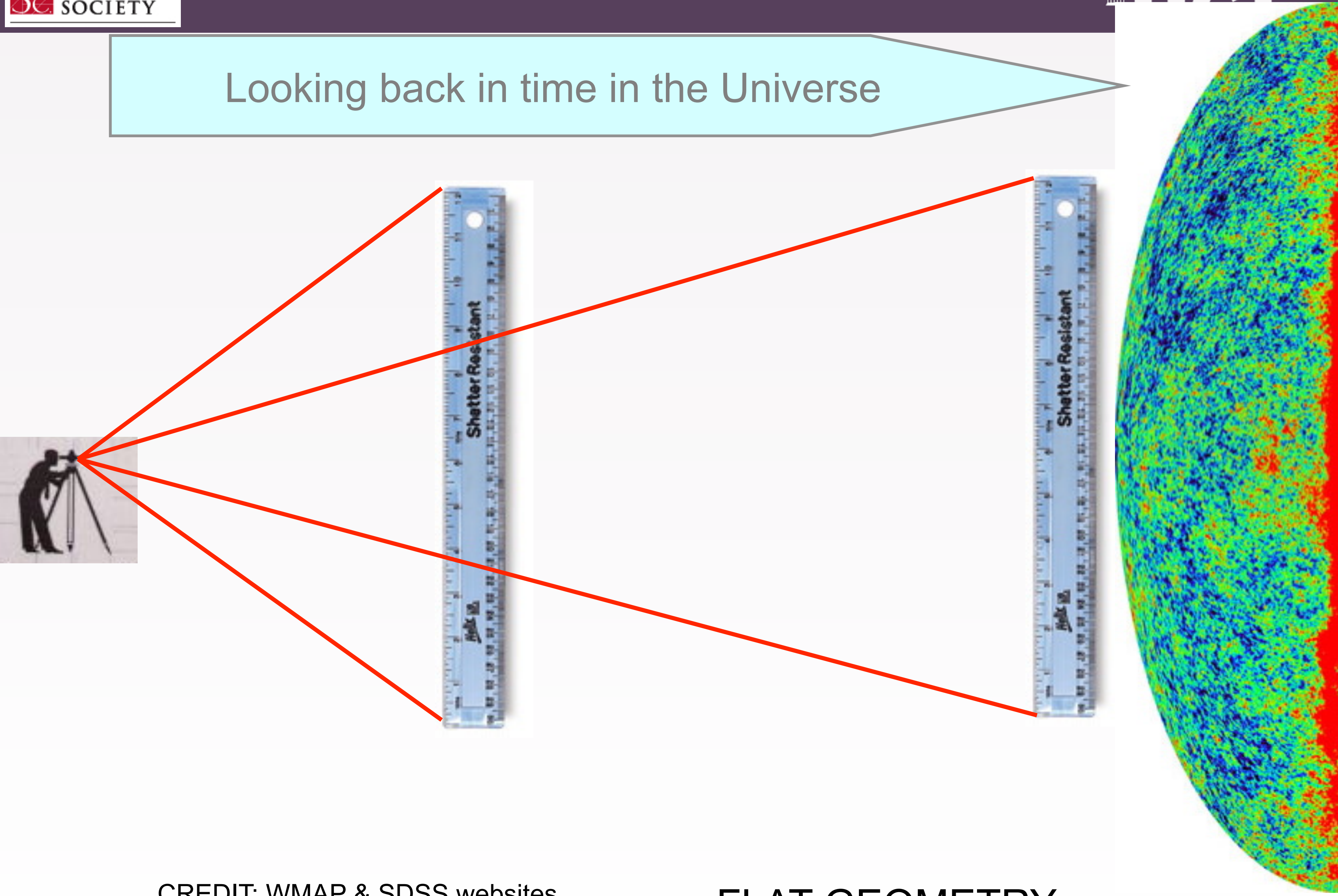
$$D_A(z) = \frac{c}{1+z}\int_0^z \frac{dz}{H(z)}$$

$$r_\parallel = \frac{c\Delta z}{H(z)}$$

$$r_\perp = (1+z)D_A(z)\Delta\theta$$

$$P_{\rm obs}(k_{{\rm ref}\perp}, k_{{\rm ref}\parallel}) = \frac{D_A(z)^2_{\rm ref} \times H(z)}{D_A(z)^2 \times H(z)_{\rm ref}} P_{\rm true}(k_\perp, k_\parallel)$$

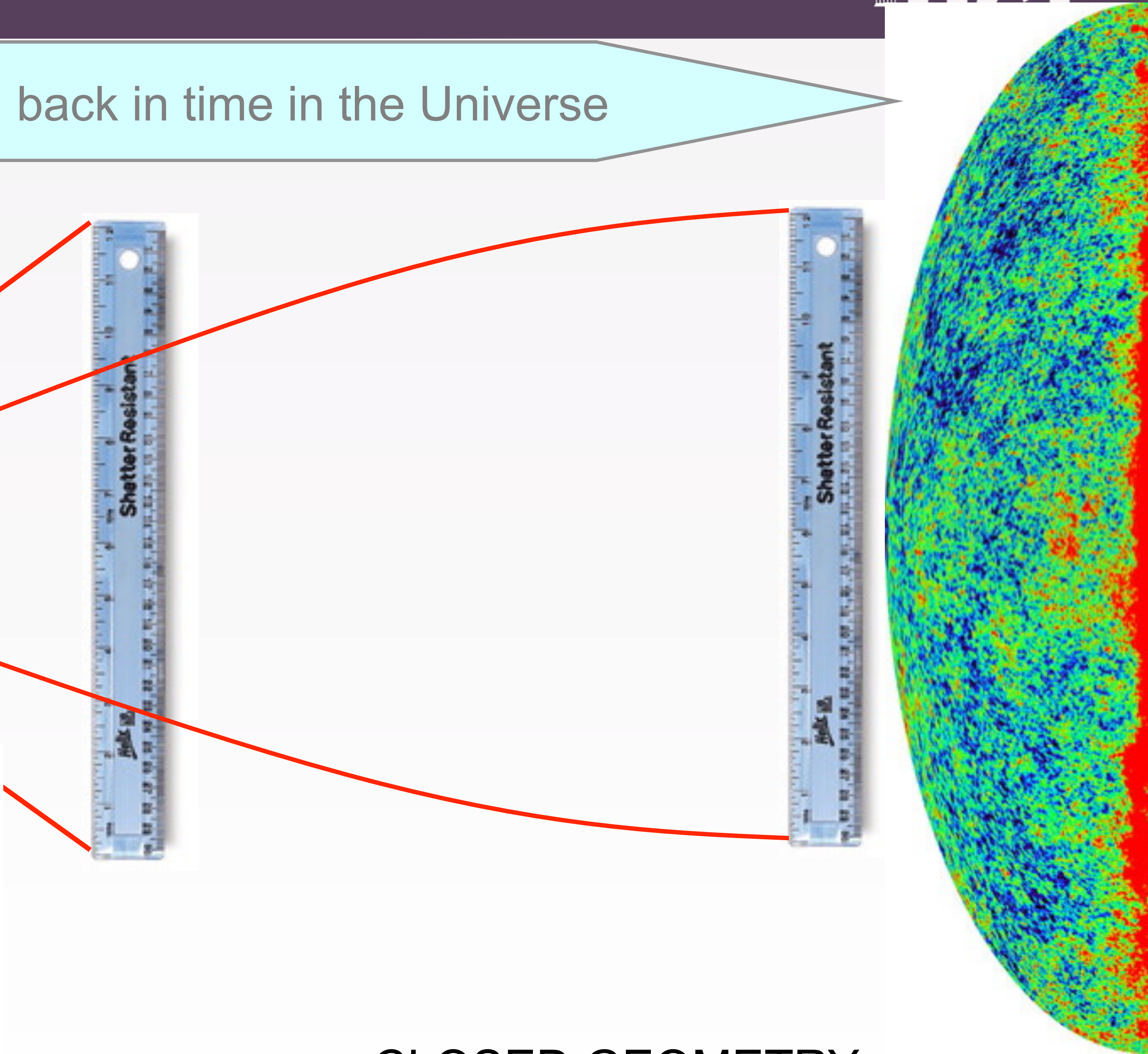
Looking back in time in the Universe

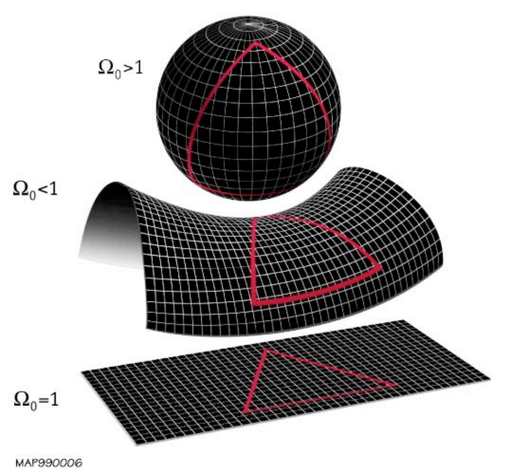


CREDIT: WMAP & SDSS websites

FLAT GEOMETRY

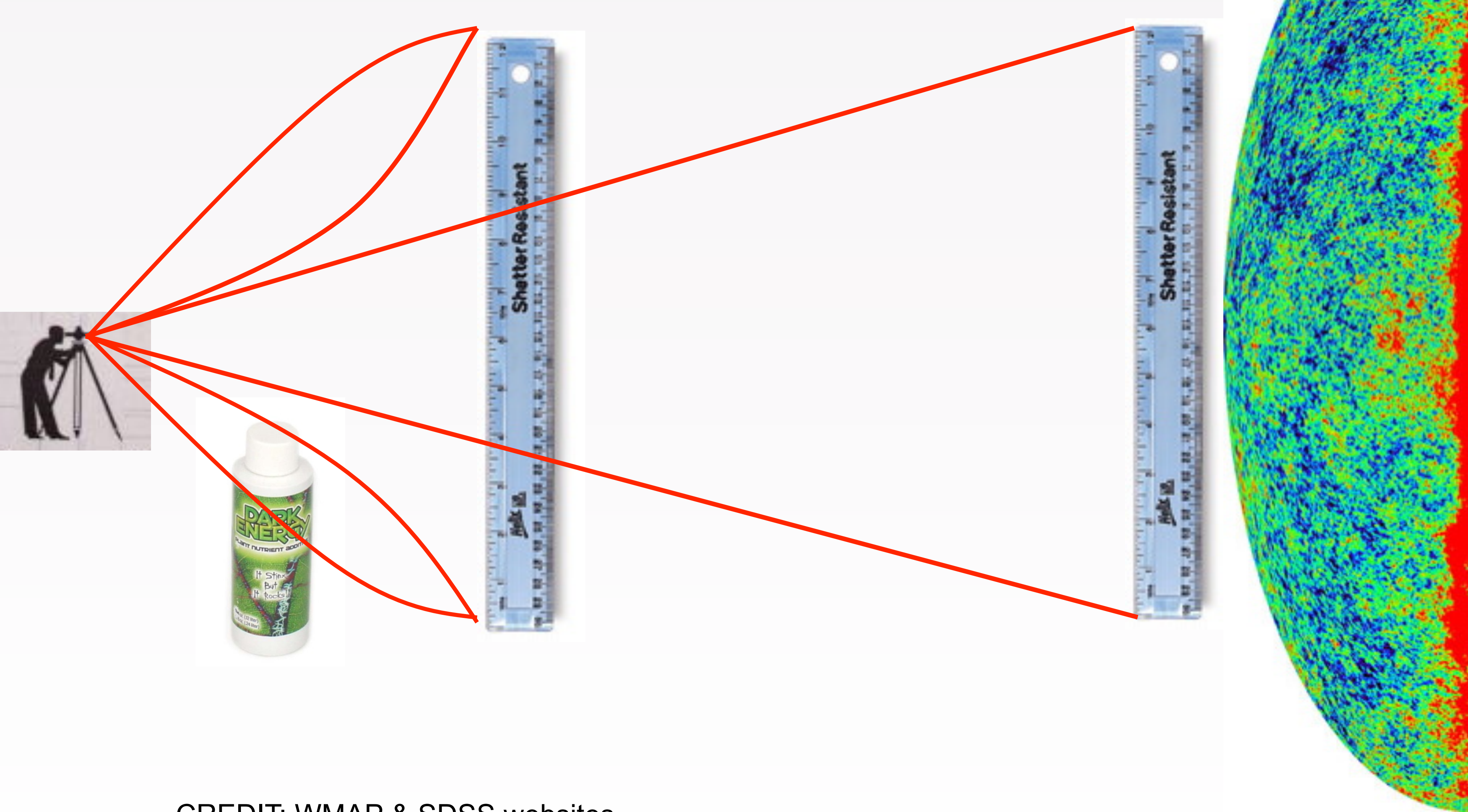
Looking back in time in the Universe





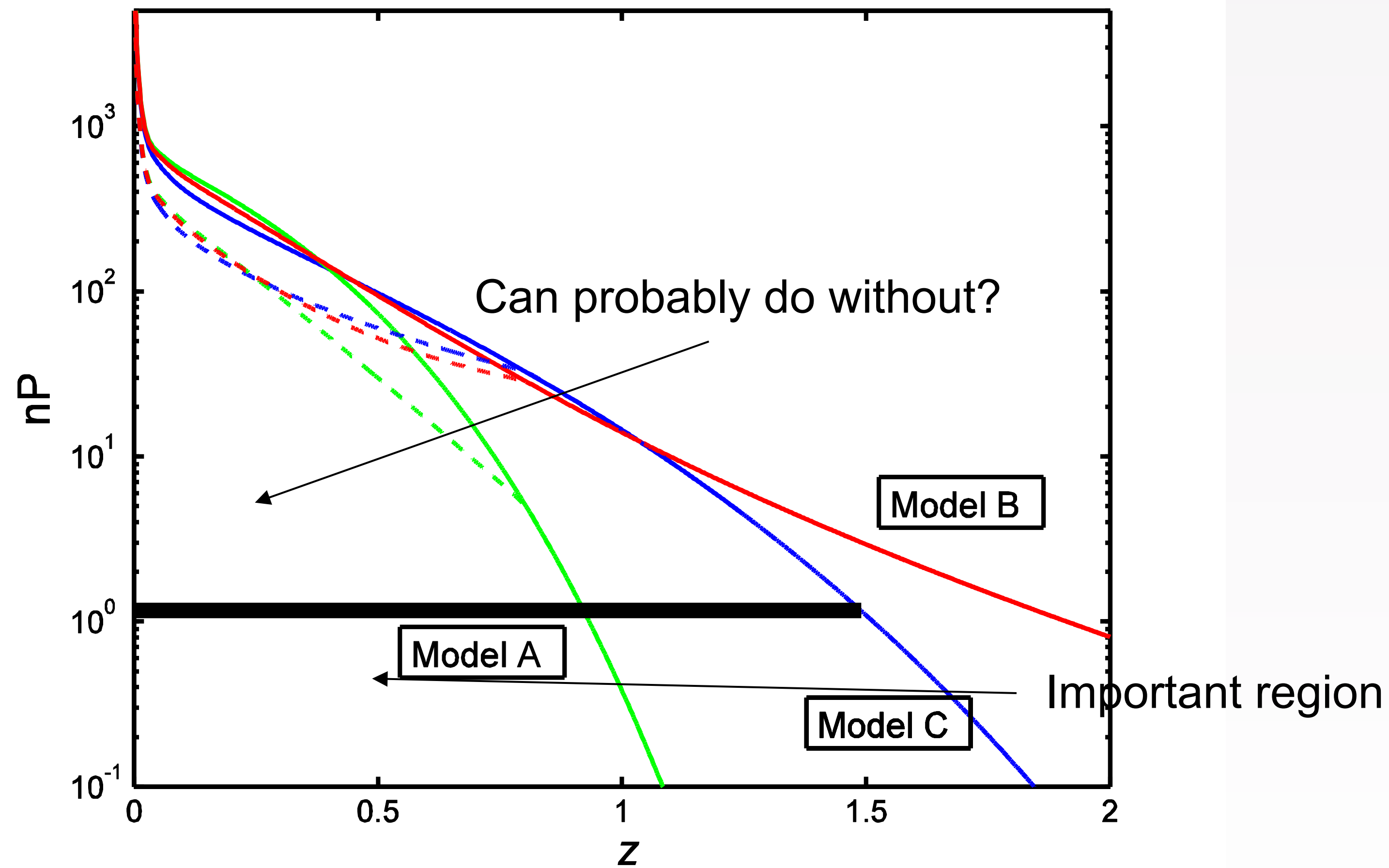
CLOSED GEOMETRY

Looking back in time in the Universe



CREDIT: WMAP & SDSS websites

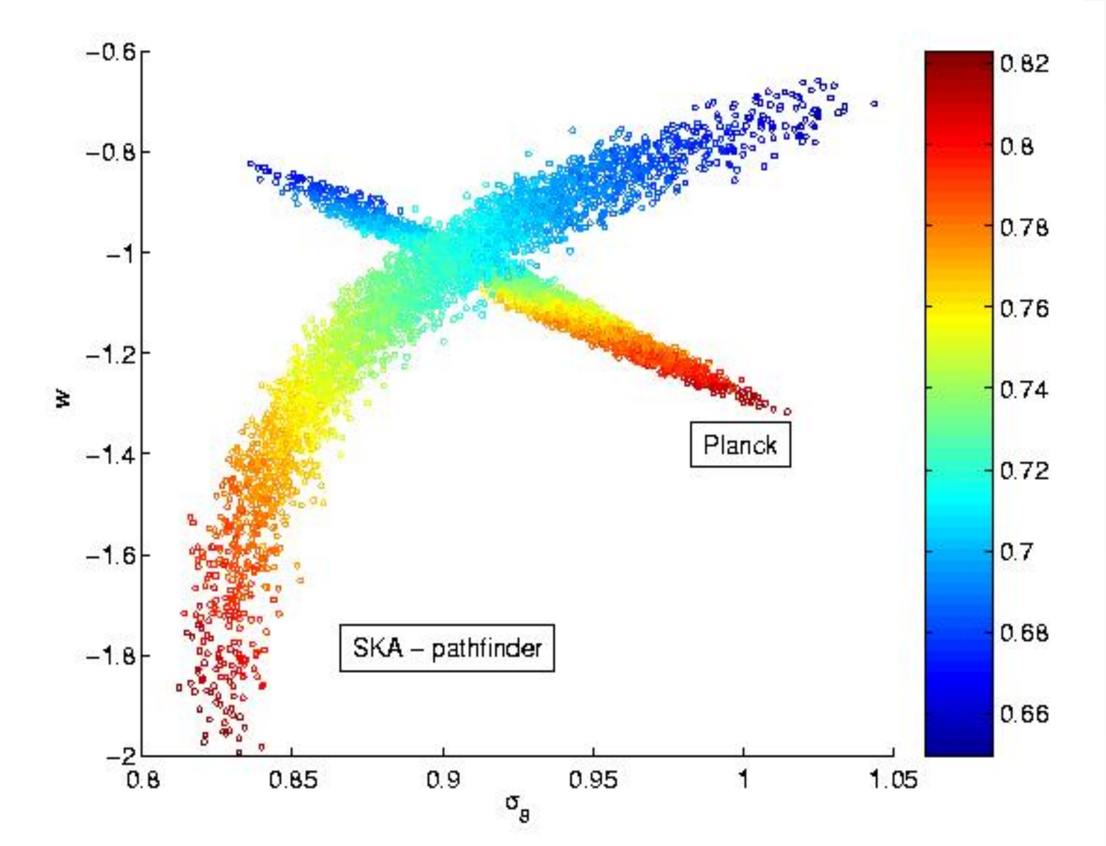
SKA number density



SKA1 deliver >10^8 galaxies over ~20,000 deg^2 to z~0.6,

SKA2 deliver >10^9 galaxies over ~20,000 deg^2 to z~2

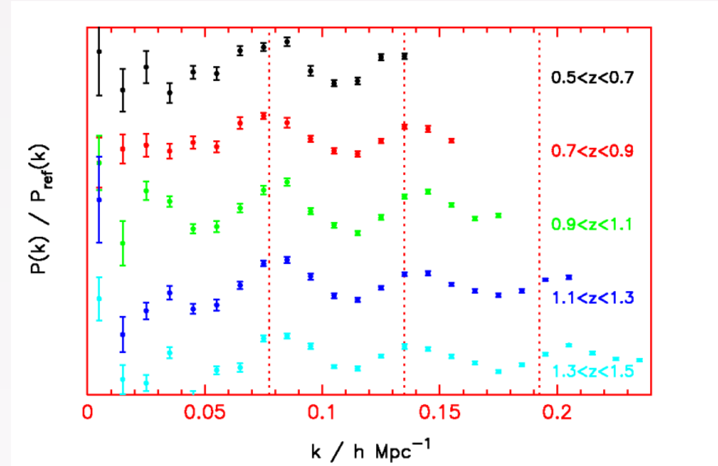
SKA results on w:

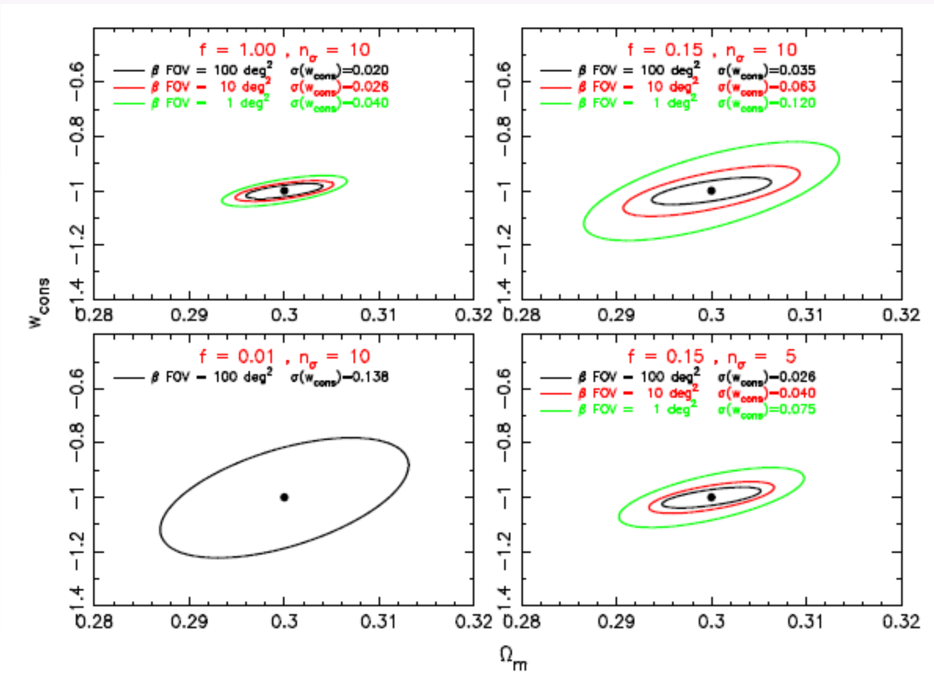


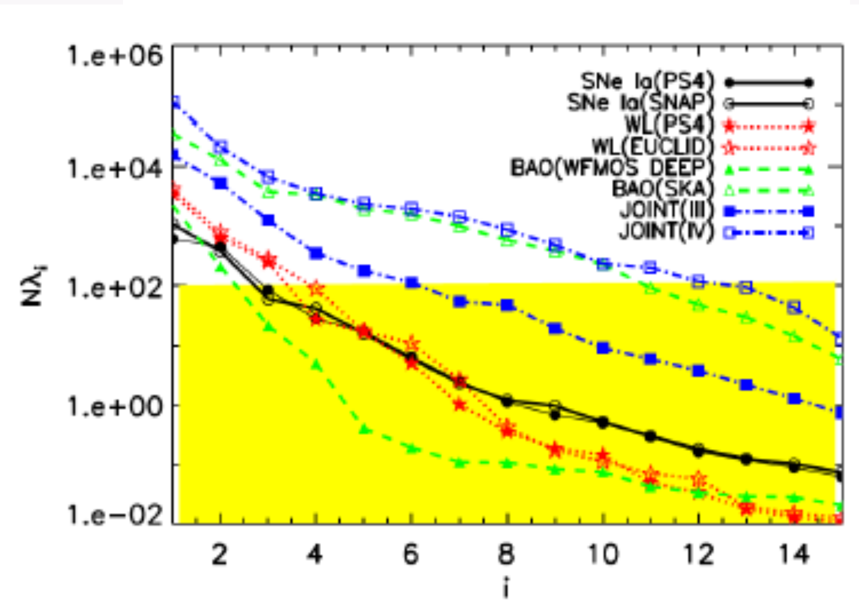
- Pathfinder equivalent to WFMOS ~ below 5%
- Need ~15% SKA or a ~10% compact SKA for this to be cosmologically interesting.
- Full SKA gets error to ~.7% with wiggles +CMB
- Number of galaxies probed: $\sim 10^9$ from z=0 to z=2 (Abdalla & Rawlings 05)
- Probe which is independent of Planck priors.

Abdalla, Blake & Rawlings 09

What can the SKA do in terms of cosmology?



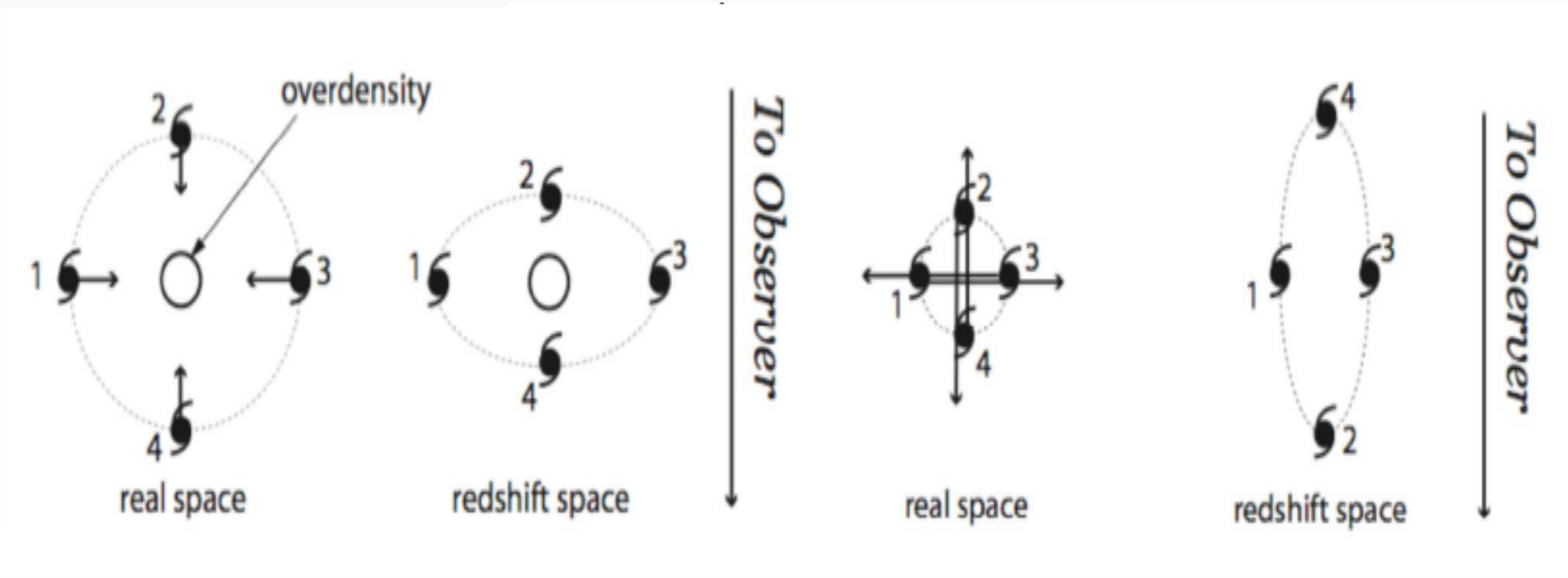




- The DETF advocated using an FOM w0-wa, then advocated using a binning PCA approach. (Abdalla, Blake & Rawlings 09; Tang, Abdalla & Weller 10)

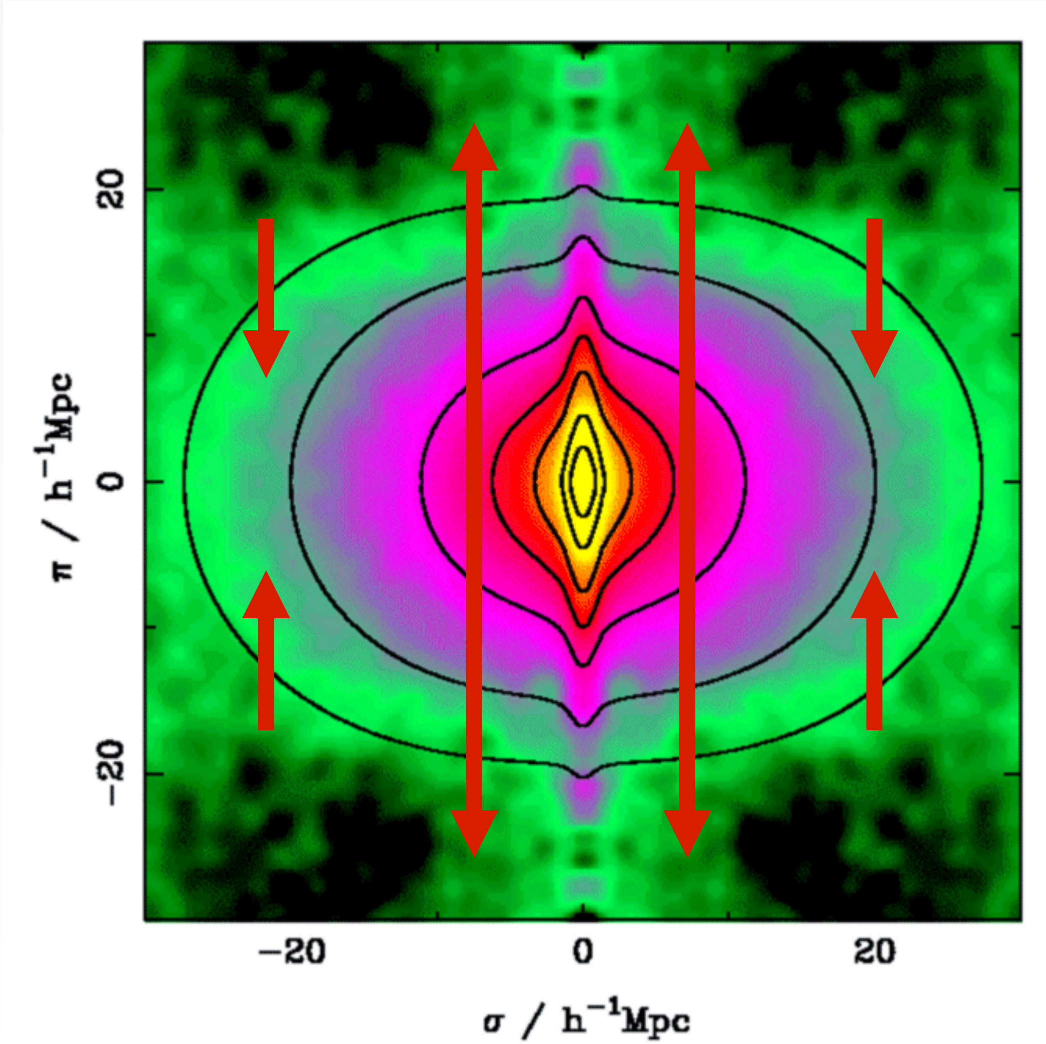
Redsfhit space distortions…

- On large scales velocities towards overdensities relate to derivative of the growth $\delta + 2H\,\delta = 4\pi G\rho m\,\delta$ with respect to time
- On small scales they relate to the circular velocity of collapsed objects.

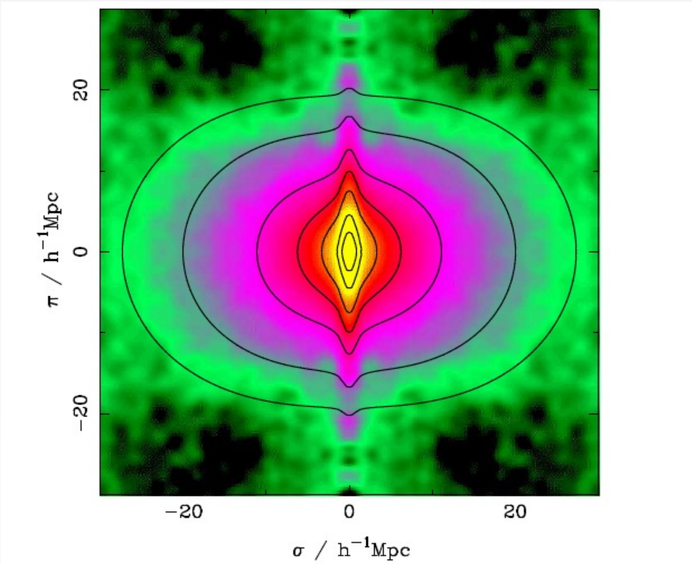


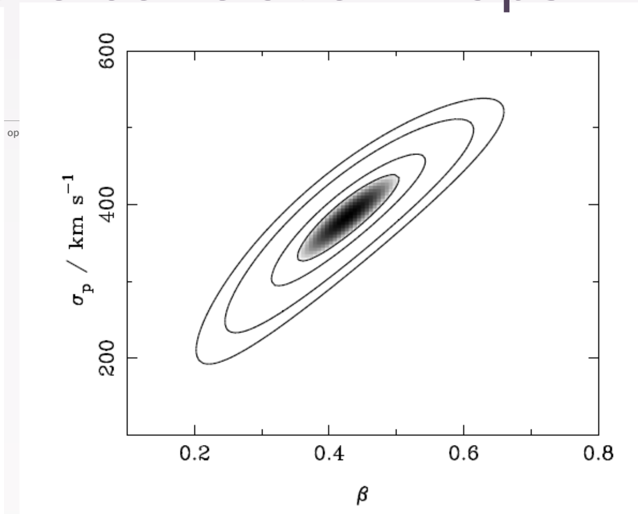
Redshift-space clustering

- z-space distortions due to peculiar velocities are quantified by correlation fn ξ(σ,π).
- Two effects visible:
  - Small separations on sky: ‘Finger-of-God’;
  - Large separations on sky: flattening along line of sight



Redshift distortions in the correlation maps : Results

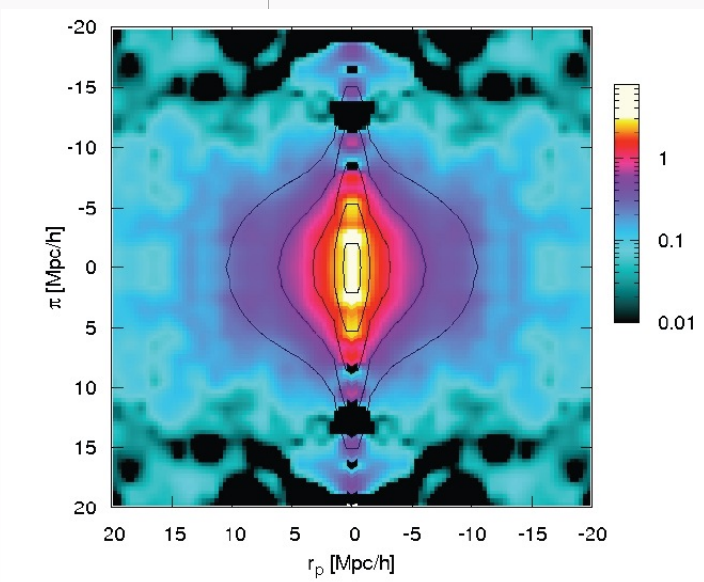


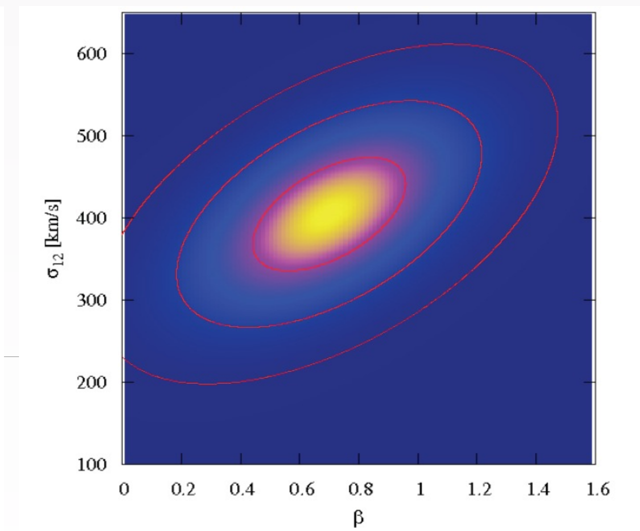


(Peacock et al. 2001, Nature)

2dFGRS
(Colless et al. 00)

<Z>=0.1
250,000 galaxies
f=0.5±0.1
σ=390±50 km/s





VVDS
LeFevre et al. 05

<Z>=0.75
10,000 galaxies
f=0.9±0.4
σ=400±50 km/s

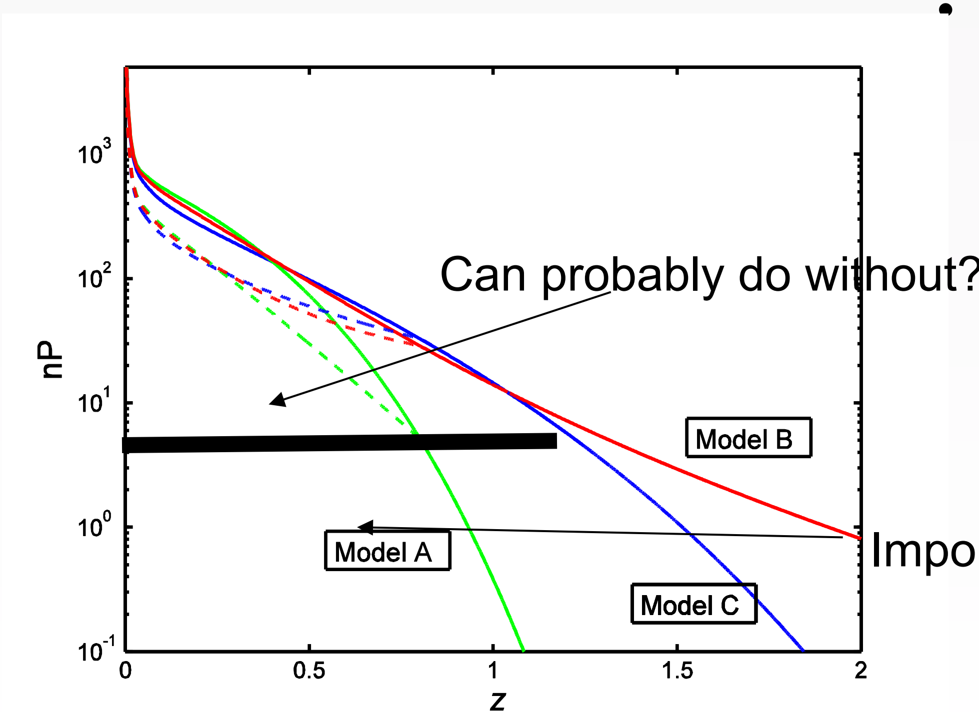
(Guzzo et al. 2007)

McDonald & Seljak: more galaxies beat cosmic variance:

$$\delta_{gi} = \left(b_i + f\mu^2\right)\delta + \epsilon_i$$

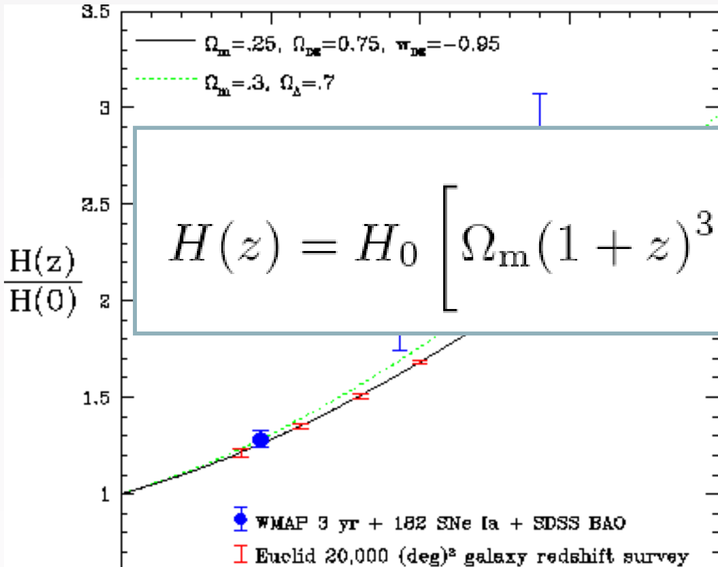
$$\delta_{g1} = f\left(\beta^{-1} + \mu^2\right)\delta + \epsilon_1 \ ,$$
$$\delta_{g2} = f\left(\alpha\beta^{-1} + \mu^2\right)\delta + \epsilon_2 \ .$$

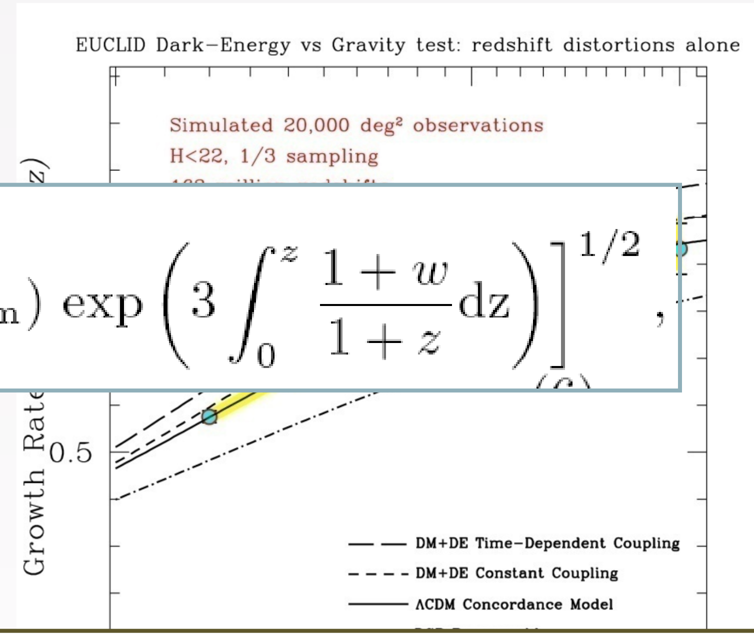
$$\frac{\delta_{g2}}{\delta_{g1}} = \frac{\alpha\beta^{-1} + \mu^2}{\beta^{-1} + \mu^2} .$$



- If we take the ratio of the deltas for different galaxy types, the delta from the underlying density drops out. Hence it is not dependent on the previous error bar.

Predictions for the expansion history and growth rate





$$H(z) = H_0 \left[\Omega_{\rm m}(1+z)^3 + (1-\Omega_{\rm m}) \exp\left(3 \int_0^z \frac{1+w}{1+z} {\rm d}z \right) \right]^{1/2},$$

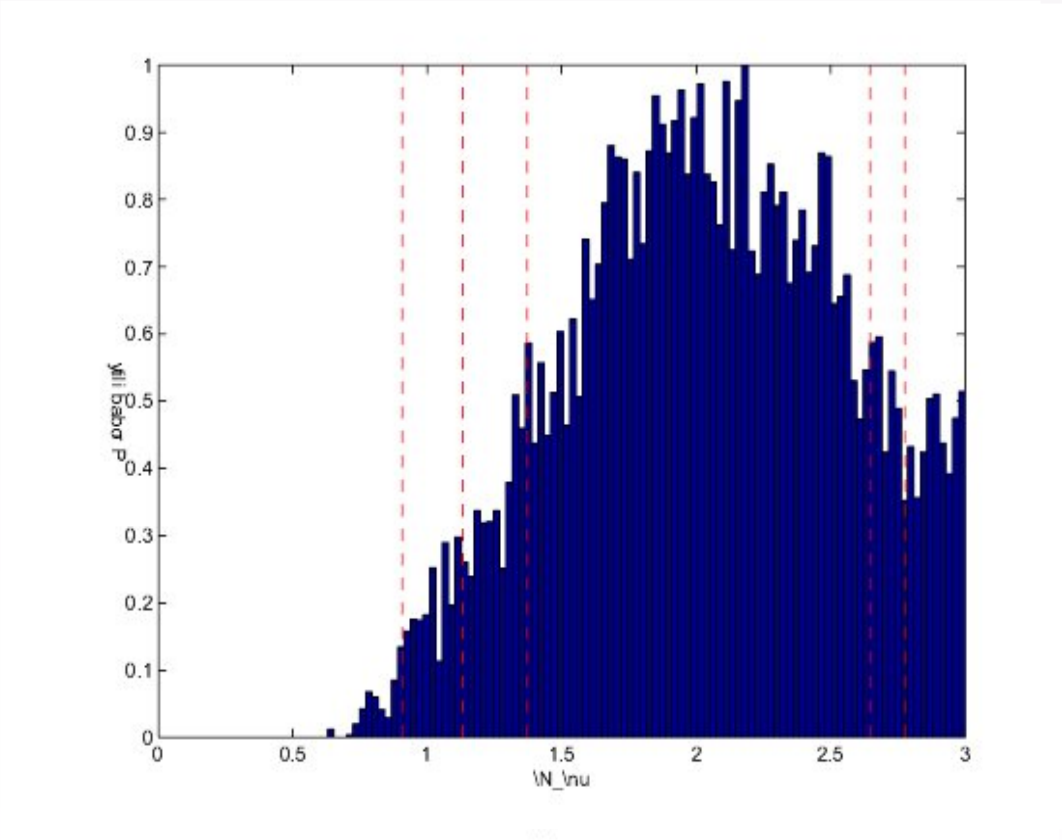
$$\delta_m'' + \frac{3}{2} a^{-1} \left[1 - w(a)\left(1 - \Omega_{\rm m}(a)\right) \right] \delta_m' - \frac{3}{2} a^{-2} \Omega_{\rm m}(a) \delta_m = 0\,,$$

forecast for Euclid measurement of H(z) is obtained using a fisher matrix code (from Y. Wang)

distortions on two-point correlation function (from L. Guzzo).

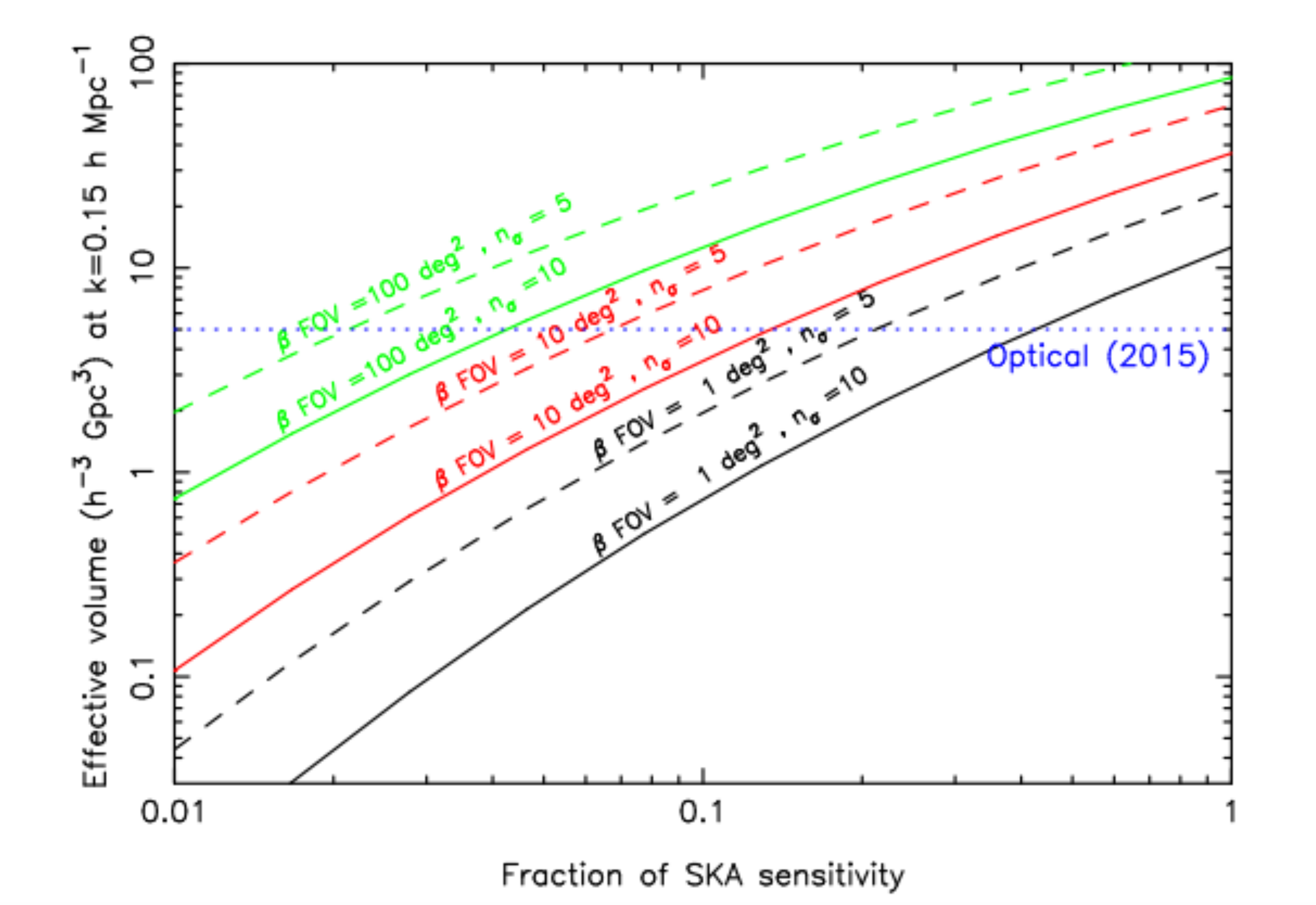
Can constrain Modified gravity as Einstein's Eqns have a one to one relation of geometry and growth

Lowest neutrino mass allowed: ~0.05eV and potentially the hierarchy



- LSS cannot measure a mass of 0.05 eV
- However LSS + CMB experiments can
- For such small masses N_nu is unconstraint
- However is the mass is so small we have detected a normal hierarchy
- A combination of both can constrain N_nu to a certain extent.

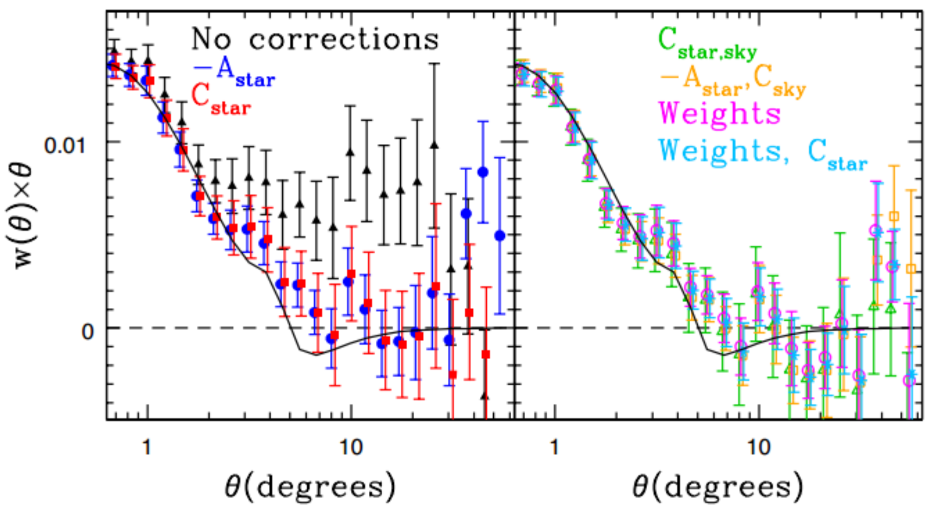
Scaling as a function of SKA size:

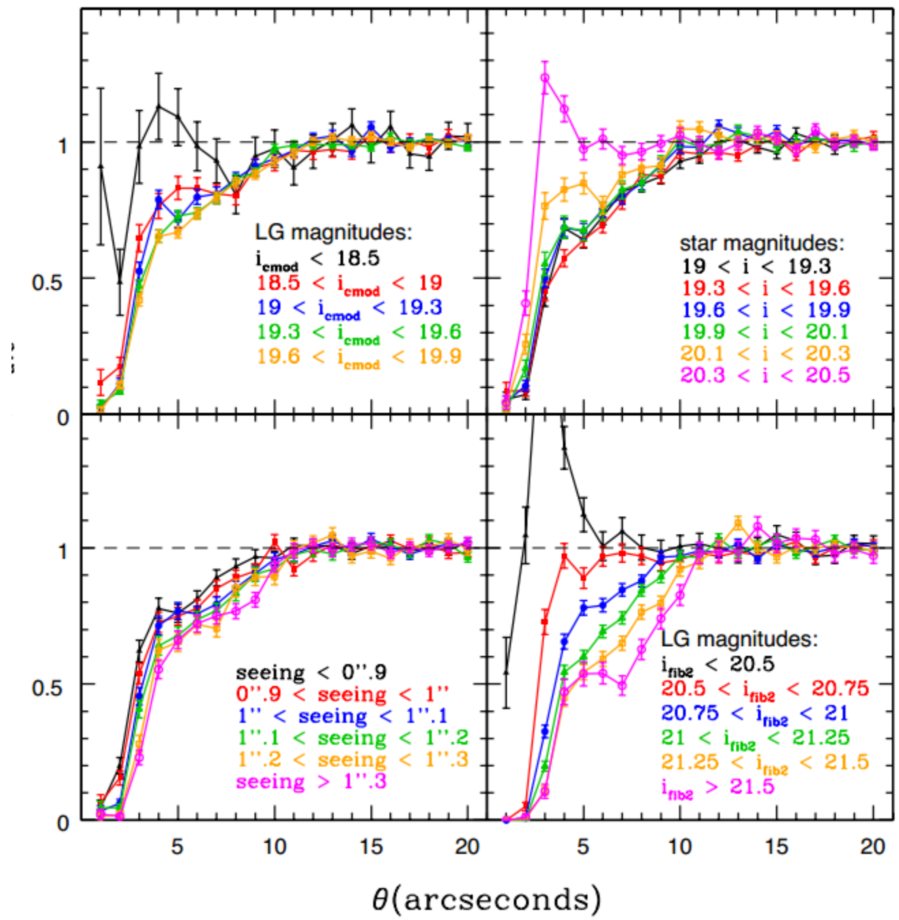


Caveats:

- For BAO only SKA1 will match more or less current state of the art. Will not be much better than for HI galaxies (not true for intensity mapping). In terms of volume...
- Matching with IM systematics... See Mario's talk.
- Calculations not done but number density of galaxies will be much greater than for other surveys such as Euclid... Possible improvement on techniques like Hirata and Seljak test on cosmic variance.
- Systematic effects such as redenning/selection/star contamination/ obscuration

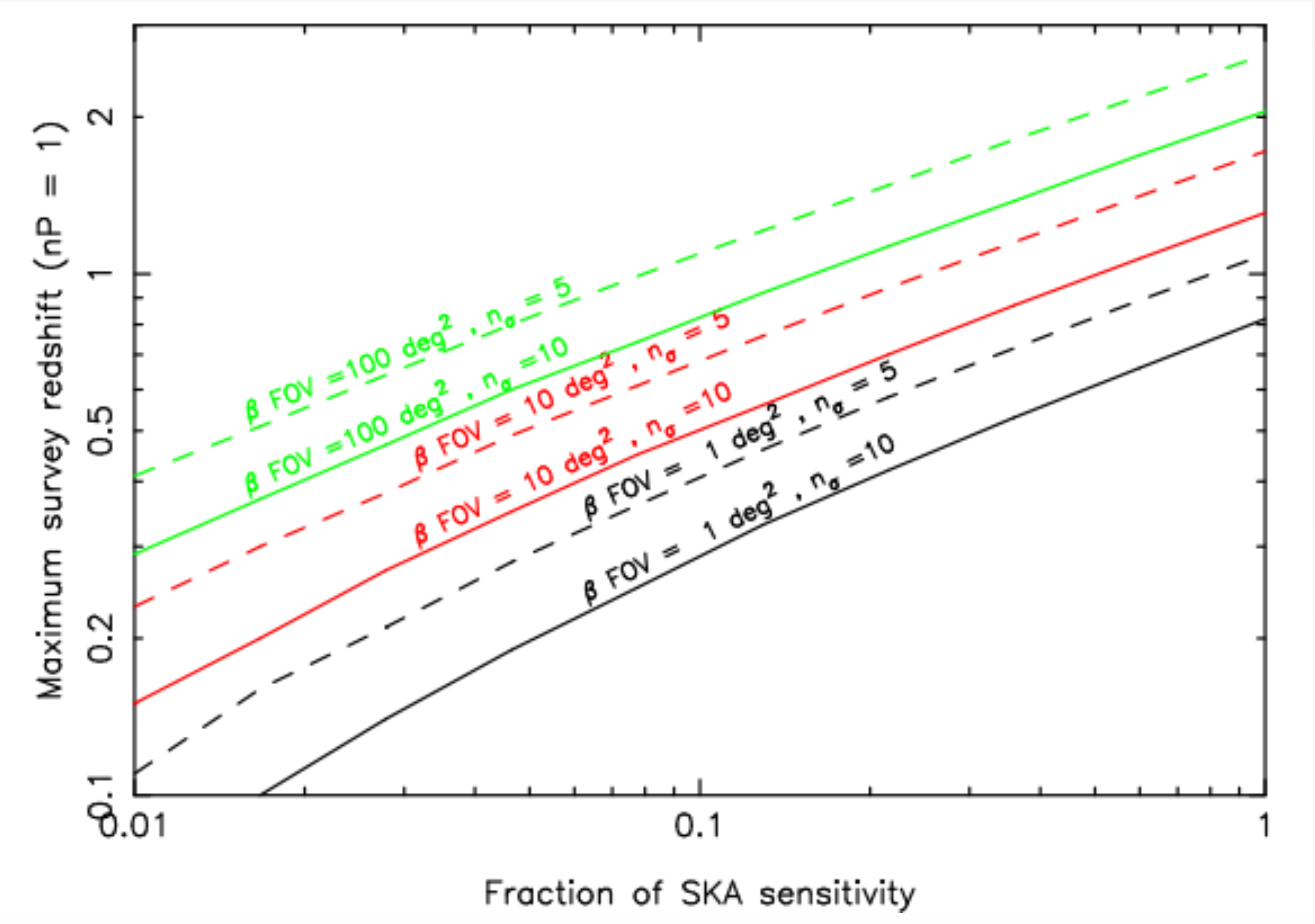
Stellar obscuration!
An issue for the optical!



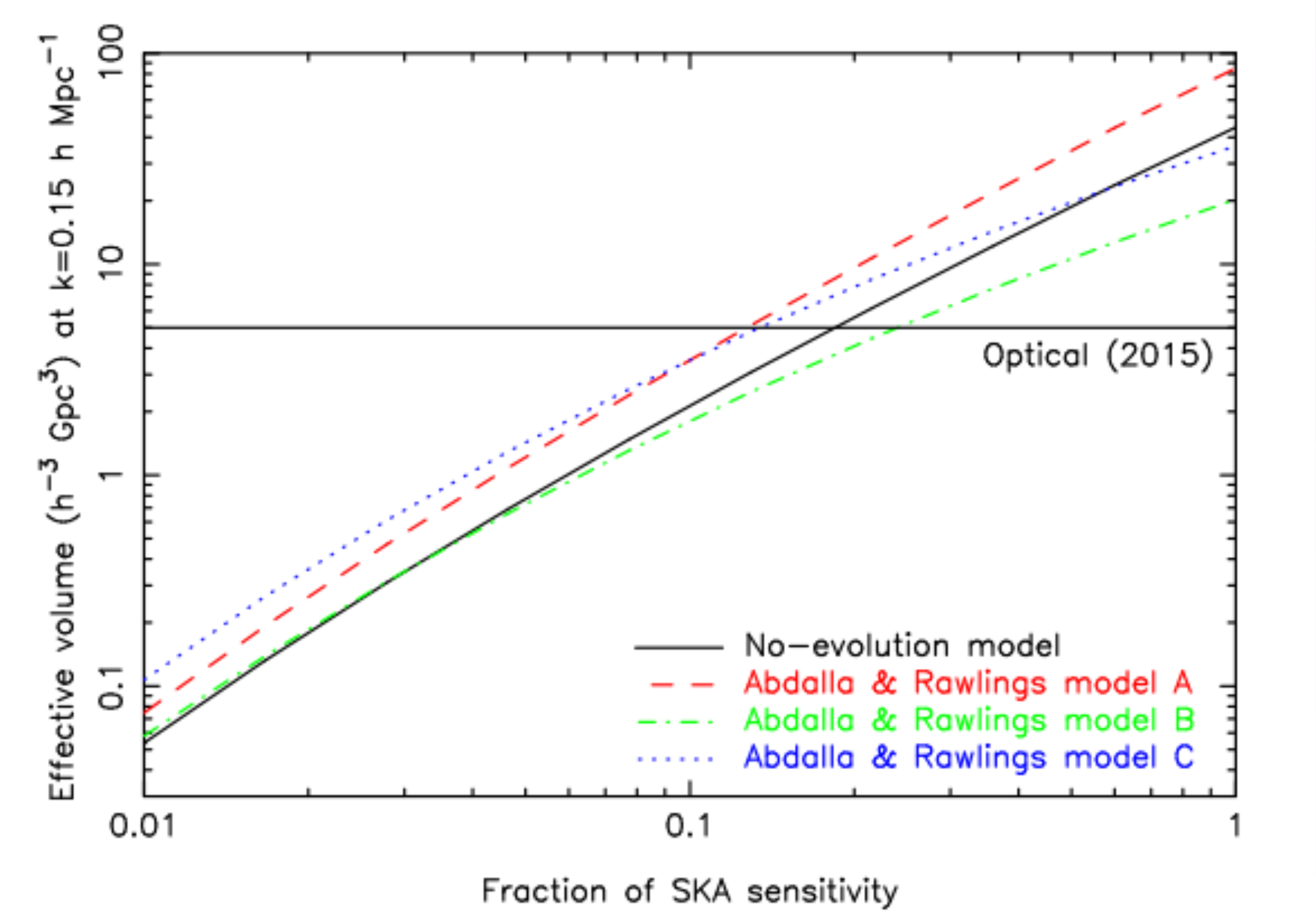


- Ross et al. 12

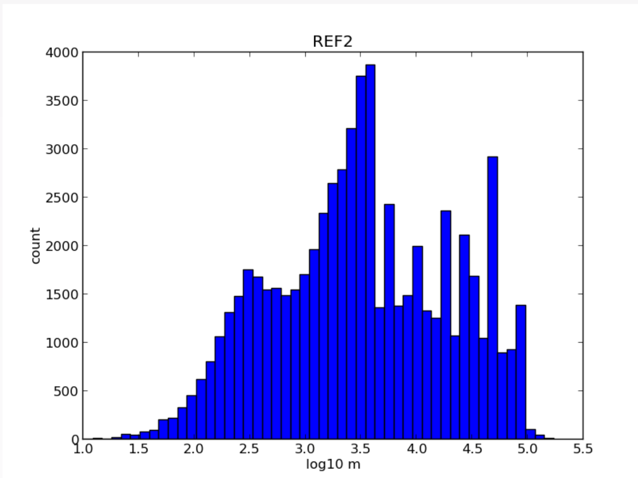
Scaling as a function of SKA size:

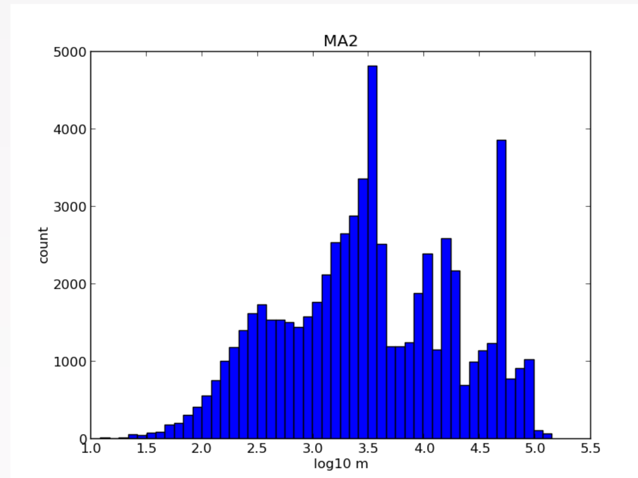


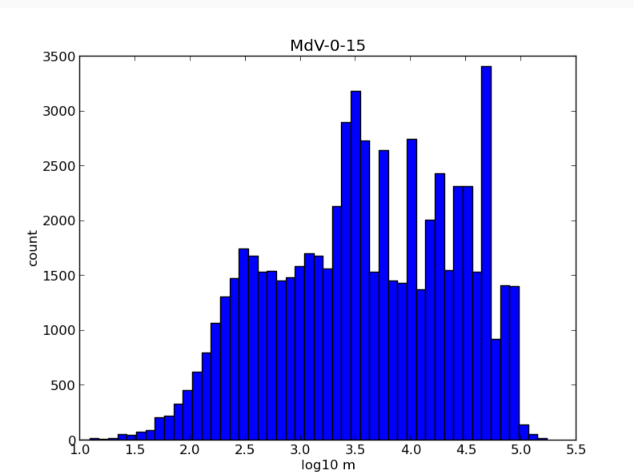
Scaling as a function of SKA size:

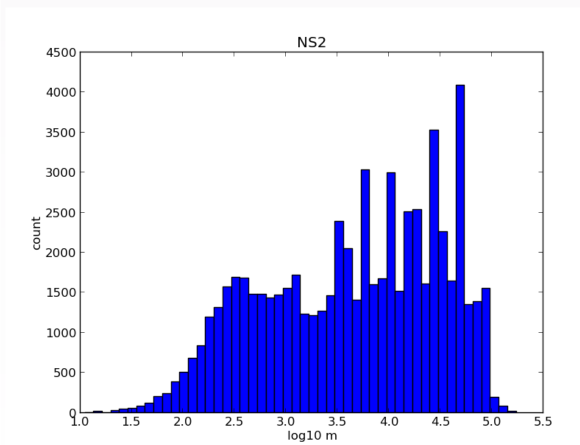


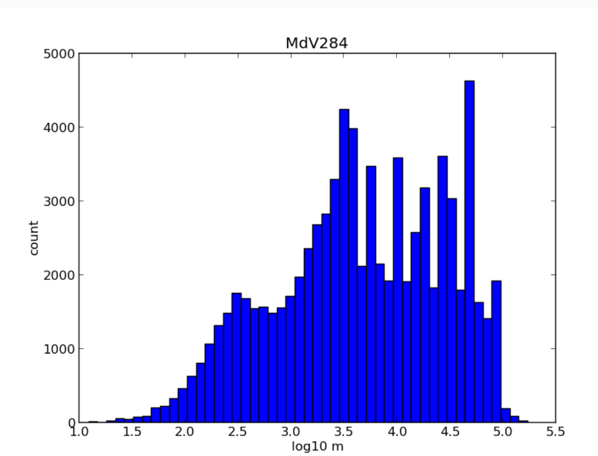
Importance of the baseline distribution here:



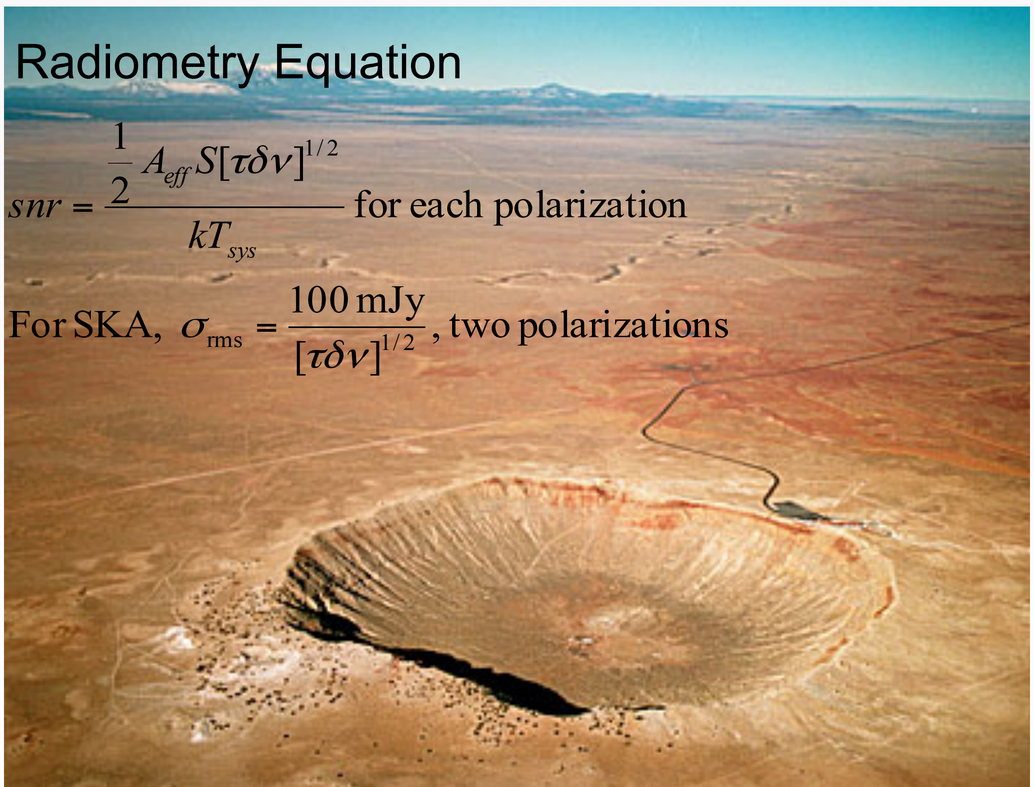








Foreground issues for Cosmology with the Square Kilometer Array



Radiometry Equation

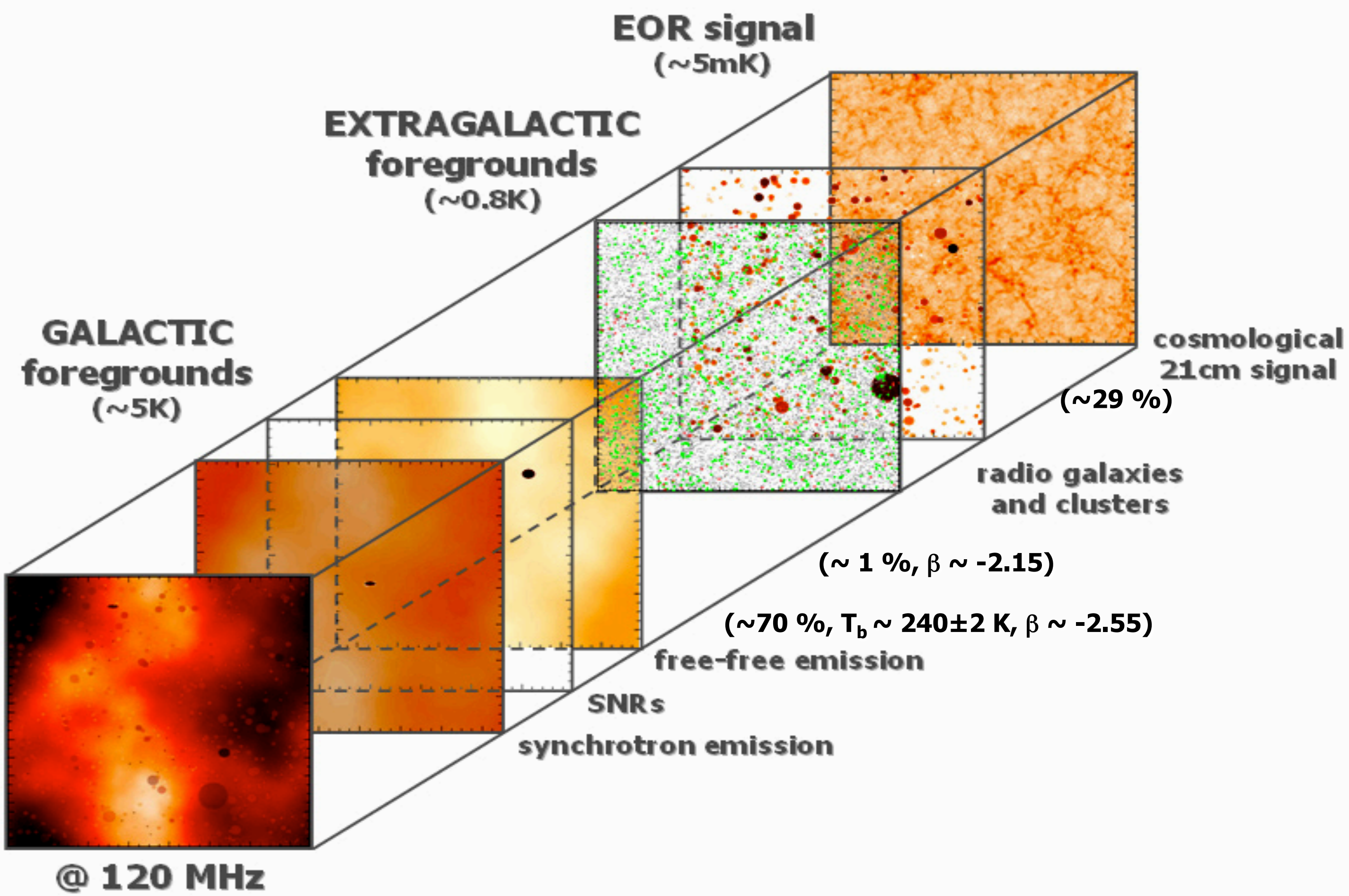
$$snr = \frac{\frac{1}{2} A_{eff} S[\tau\delta\nu]^{1/2}}{kT_{sys}} \text{ for each polarization}$$

$$\text{For SKA, } \sigma_{\text{rms}} = \frac{100\text{ mJy}}{[\tau\delta\nu]^{1/2}}\text{, two polarizations}$$

Filipe B. Abdalla

THE ROYAL SOCIETY
CELEBRATING 350 YEARS

FG simulations

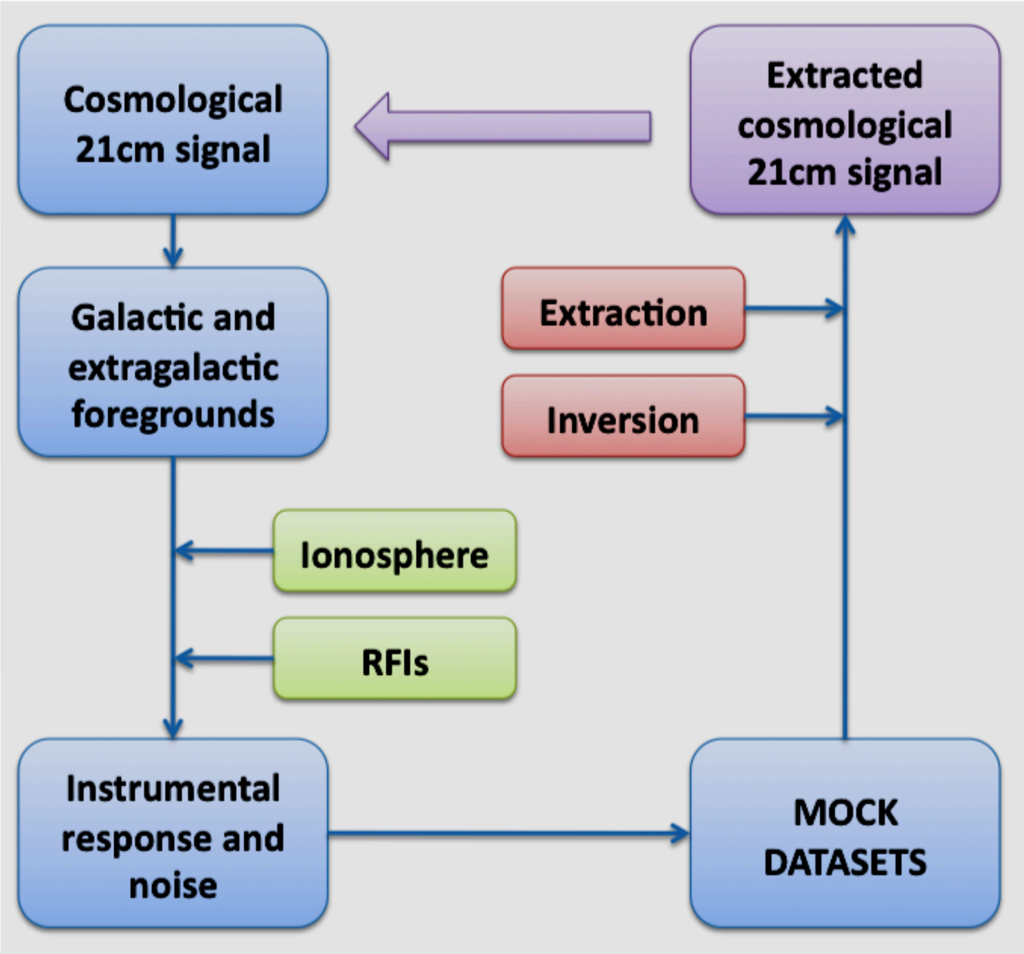


- featureless power law
- variation in spectral index with position on the sky and with frequency

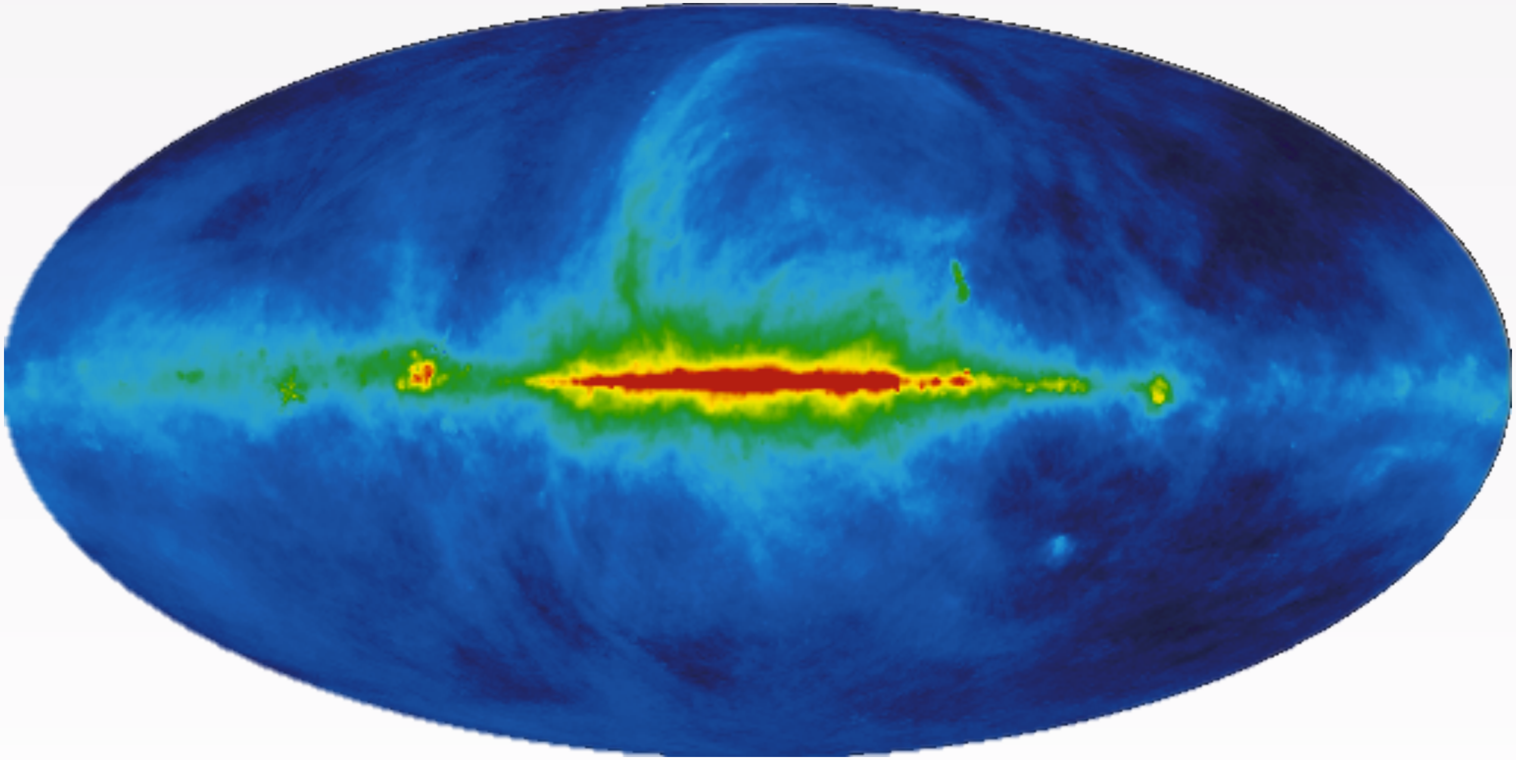
SIMULATIONS: 5º x 5º filed of view, ~ 0.6 arcmin resolution and freq. range: 115-180 MHz LOFAR 50-370 SKA-low

Jelic et al., 2008, MNRAS

The problem outline:



Galactic foreground emission

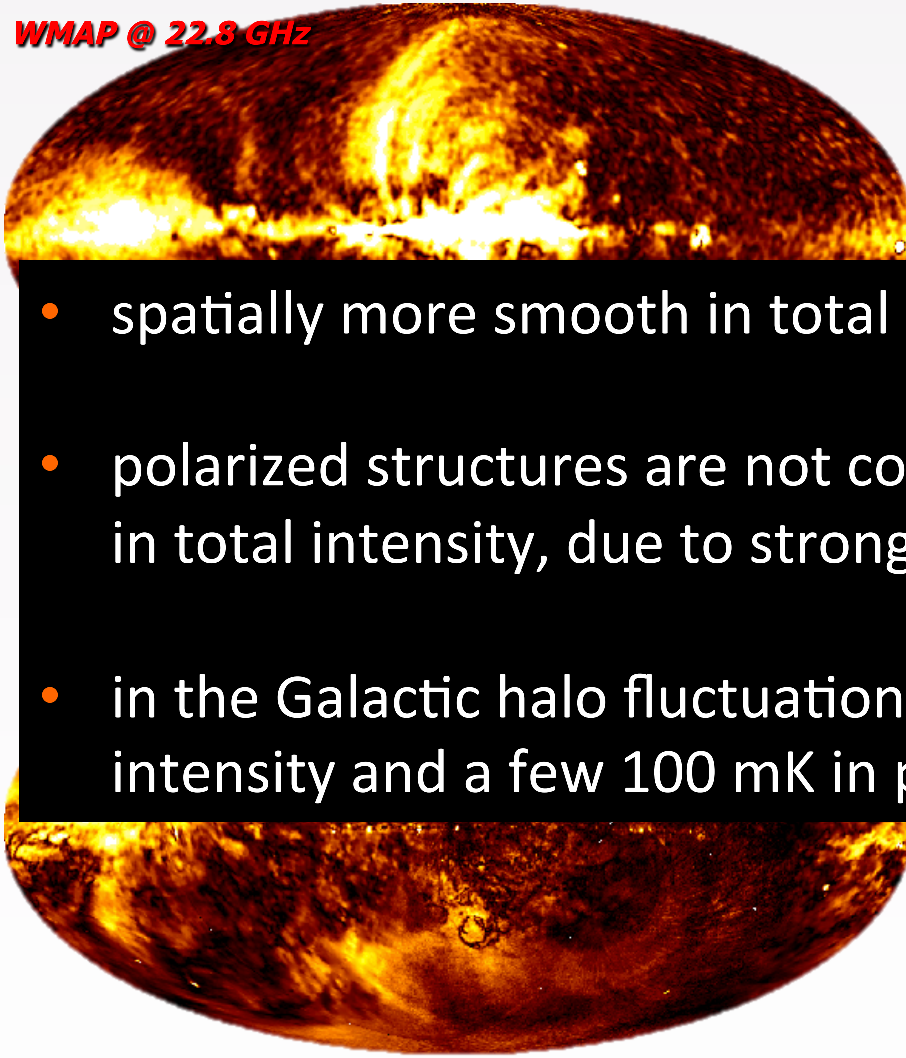


0.85^{0} resolution
Galactic map @ 408 MHz
Haslam et al. 1982

5^{0} resolution
Galactic map @ 150 MHz
Landecker & Wielebinski et al. 1982

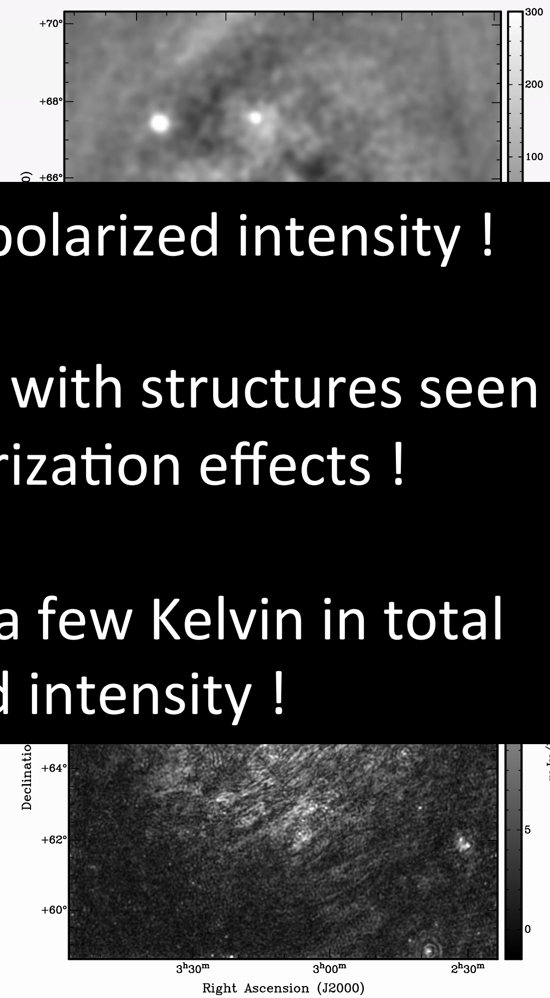
Polarized Galactic foreground emission

WMAP @ 22.8 GHz



Sun et al. 2008

Fan region in total intensity @ 150 MHz

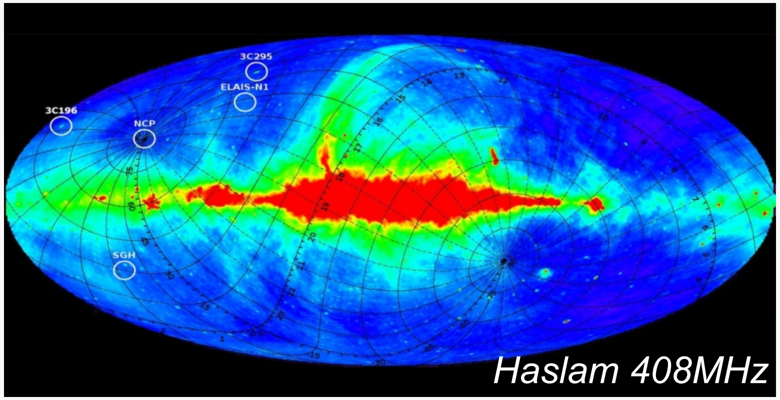


Bernardi et al. 2009

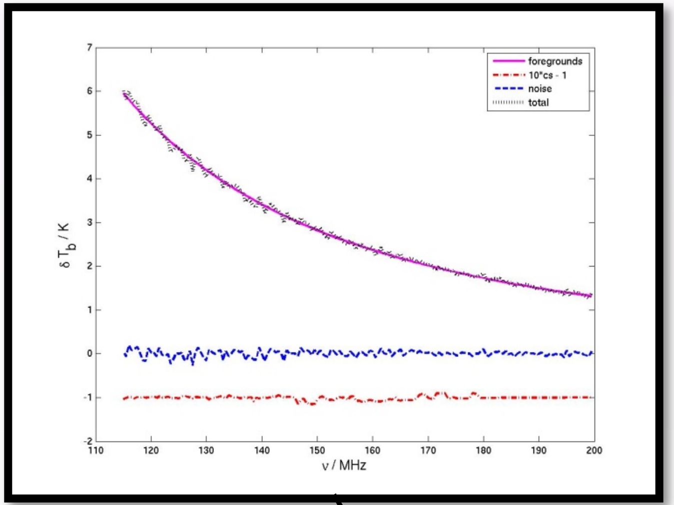
- spatially more smooth in total than in polarized intensity !
- polarized structures are not correlated with structures seen in total intensity, due to strong depolarization effects !
- in the Galactic halo fluctuations are of a few Kelvin in total intensity and a few 100 mK in polarized intensity !

Extraction of the signal!

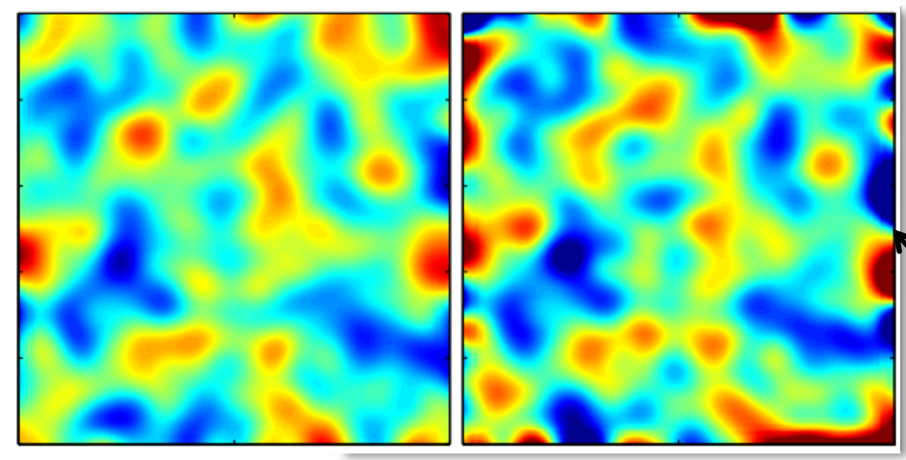
LOFAR EoR windows.



The Galaxy is 10000 times brighter than the signal sought



Chapman, FBA et al 2012a
Chapman, FBA et al 2012b

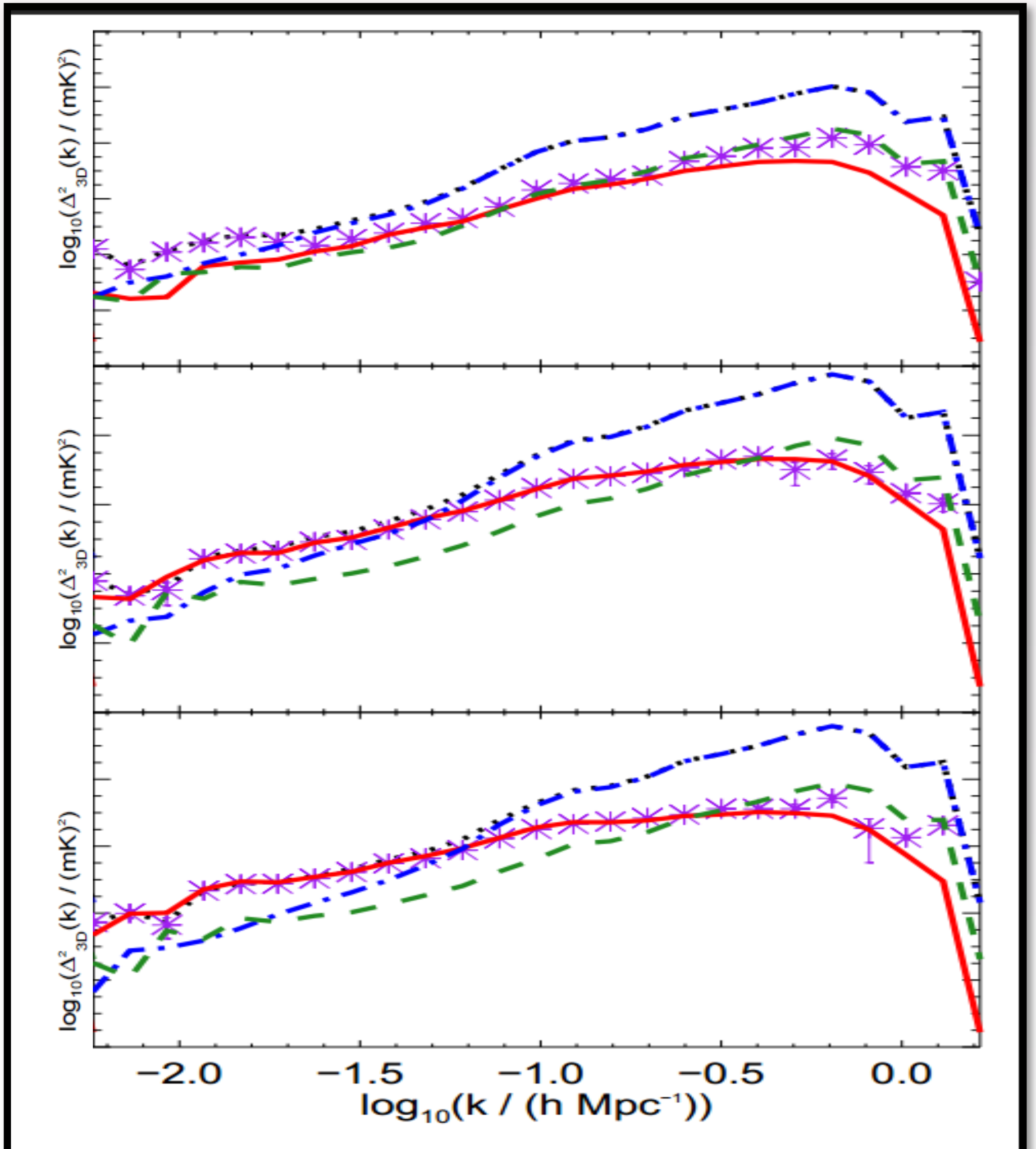


Real signal Reconstruction

Use methods, e.g. the cocktail party problem solution, and wavelet decomposition in order to separate the galaxy from the signal
Our pipeline is on the LOFAR cluster ready to be used on the data.

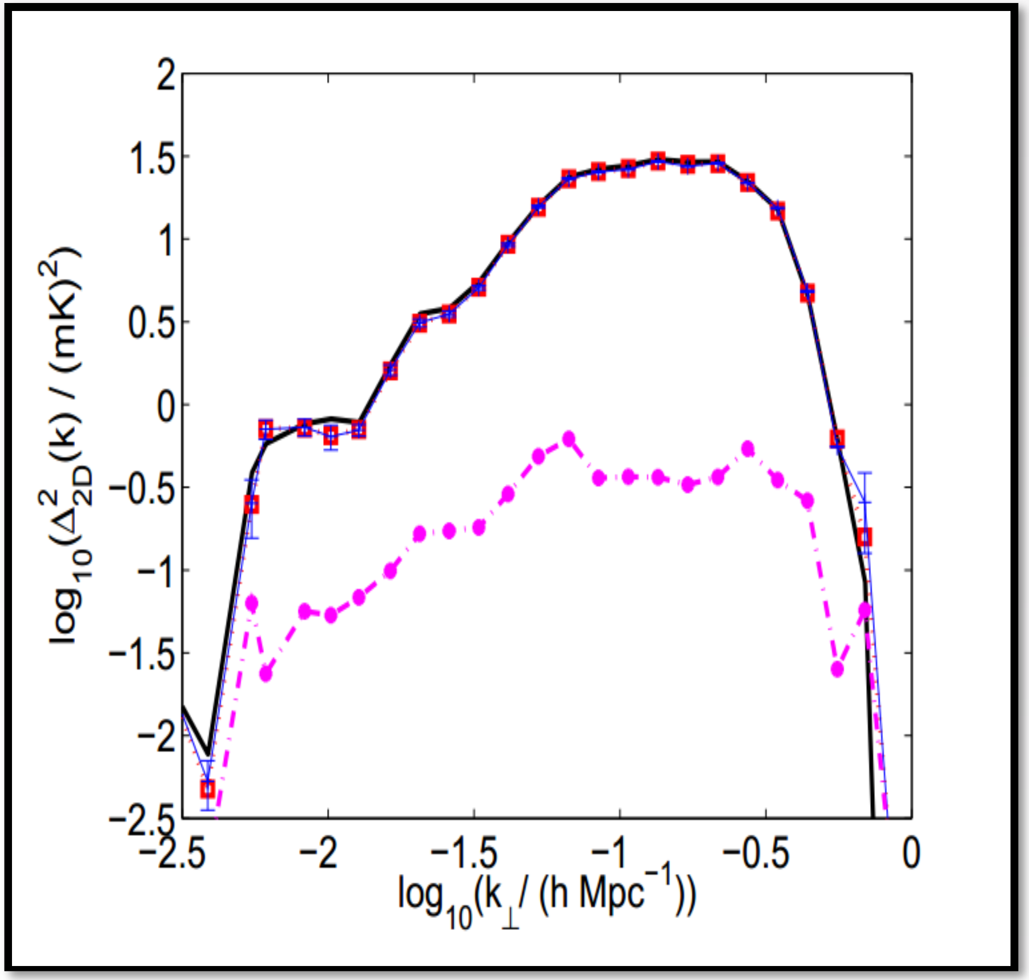
THE ROYAL SOCIETY

UCL



Results GMCA: 3D Power Spectrum – 131 MHz, 151 MHz and 171MHz

Area covered in the sky: Residual Projection



fg: blue,dash

reconstructed fg: red, solid

simulated noise + cs: yellow,solid

C_{nocs}: green,dashdotdotdot

simulated cs: red,dashdot

reconstructed no+cs: black,dotted

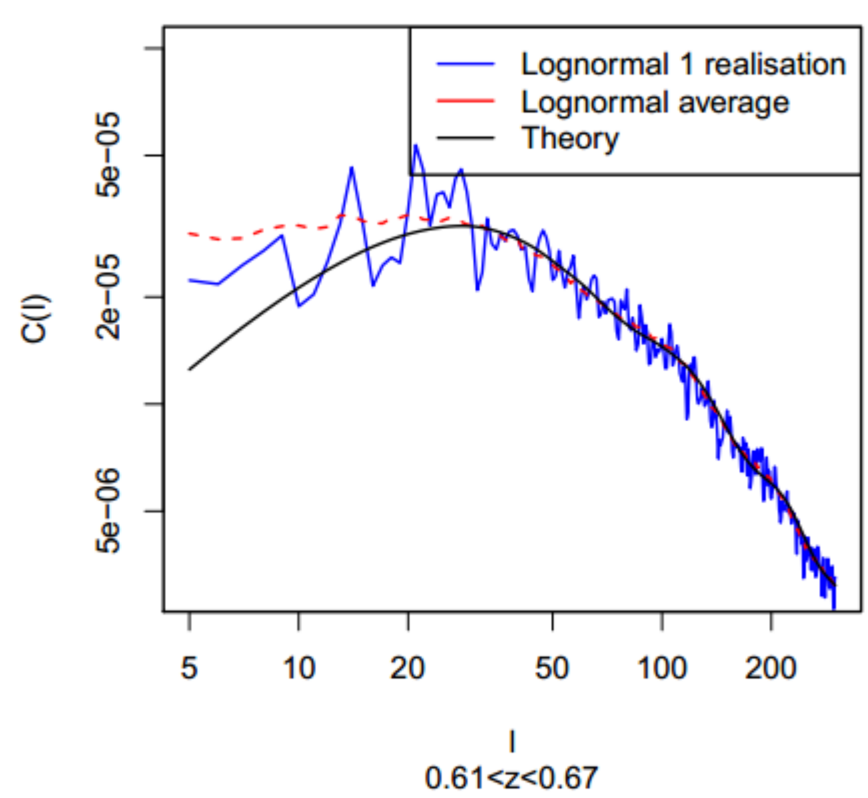
R_{fg}: purple,dotted

Last plot: different wavelets

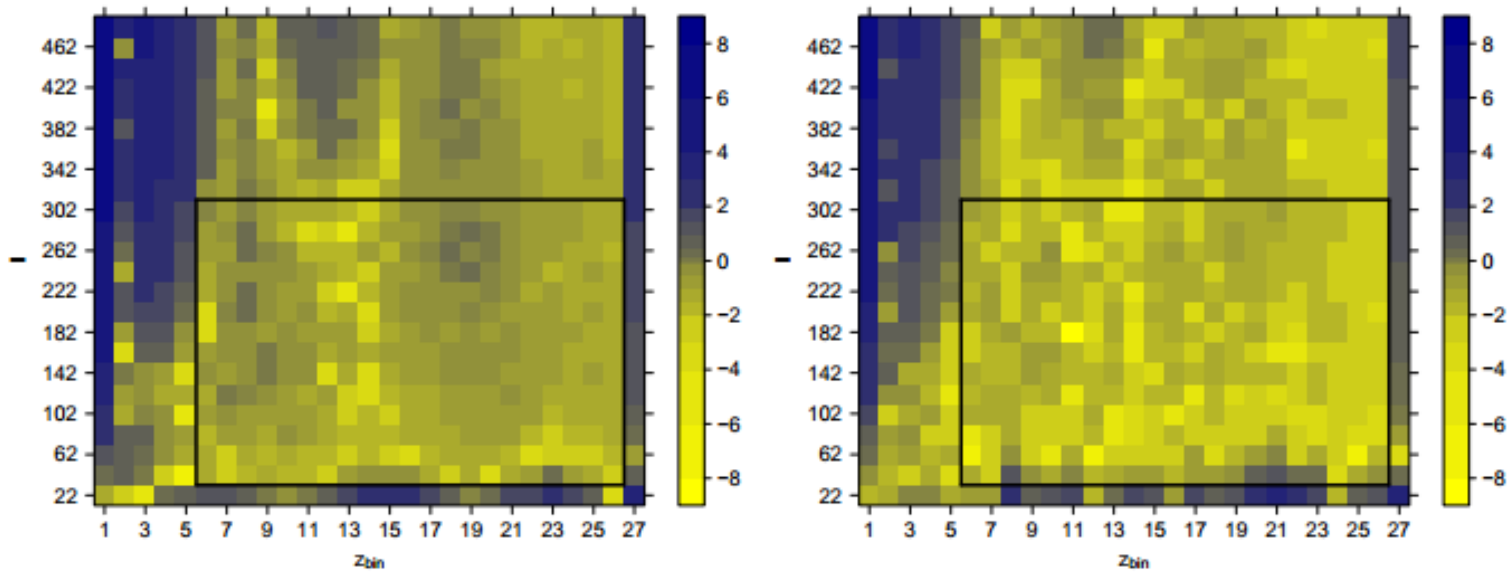
Intensity mapping: If we degrade the resolution to the binning we will do anyway:

$$\bar{T} = 44\,\mu\mathrm{K} \left(\frac{\Omega_{\mathrm{HI}}(z)h}{2.45\times 10^{-4}}\right)\frac{(1+z)^2}{E(z)}$$

- Collect signal from all HI in that bin, obtain a spectrum.
- Mean signal will be from the mean HI content of that shell
- Fluctuations will be related to the large scale structure.
- Wolz et al. To be submitted

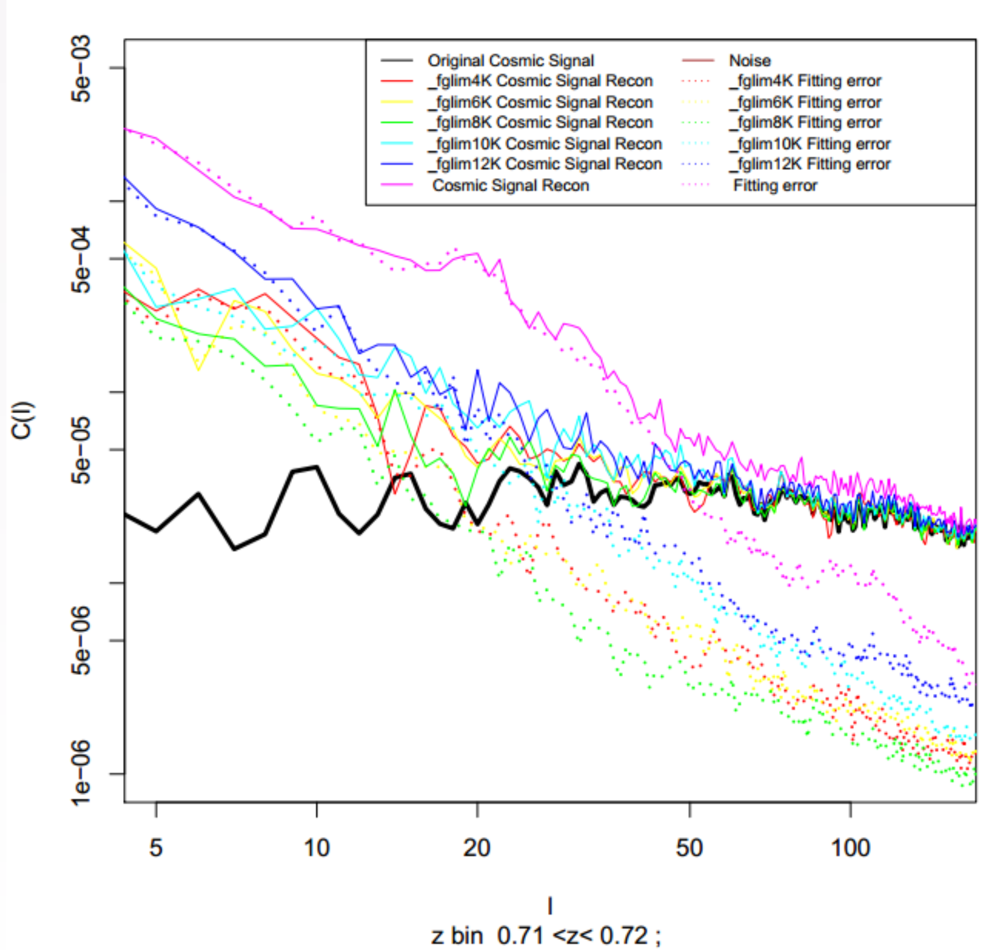


Systematic effects from foreground subtraction!



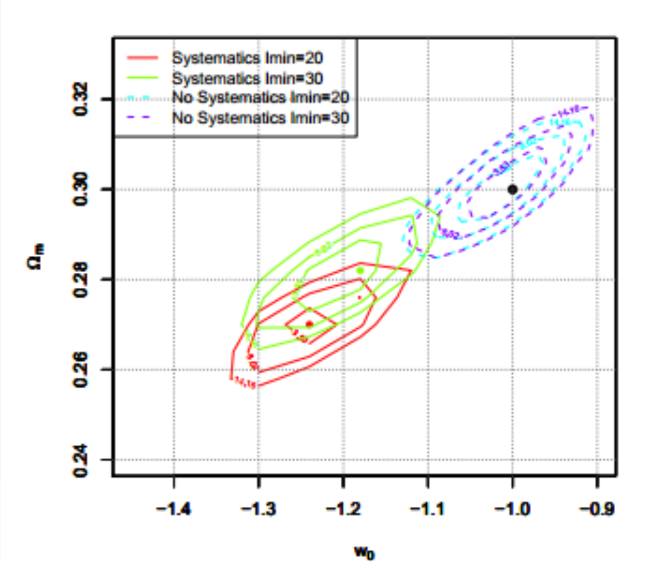
Area coverage in the sky: station size and beams.

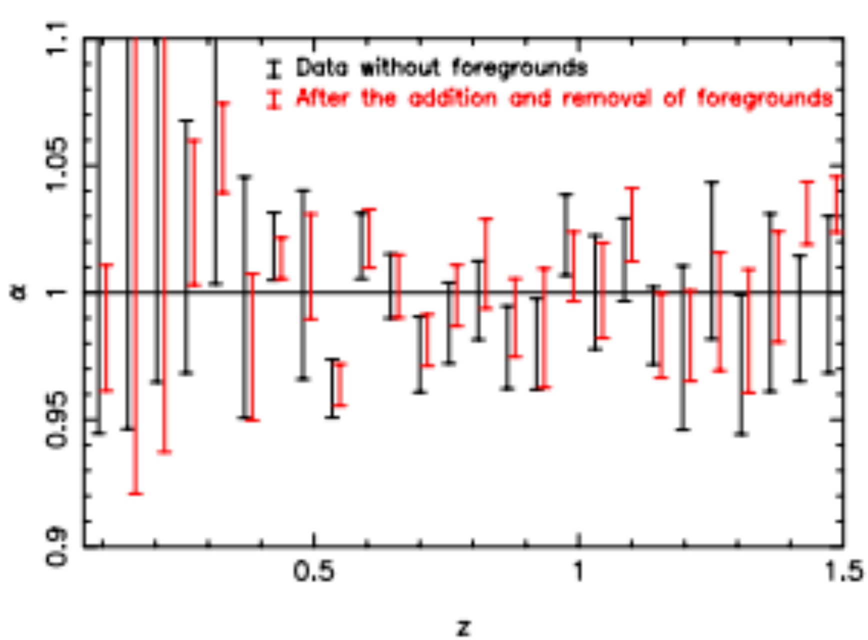
- Foreground subtraction if all sky were available!
- Residuals are of the order of 0.1mK even in the center.
- This is a strong function of the area covered as the previous results for the LOFAR-EoR show bias at large scales.
- If all sky available sims, with proper masks, show biases at scales of l~20, which means ~ 10 degs scales. -> implications on science



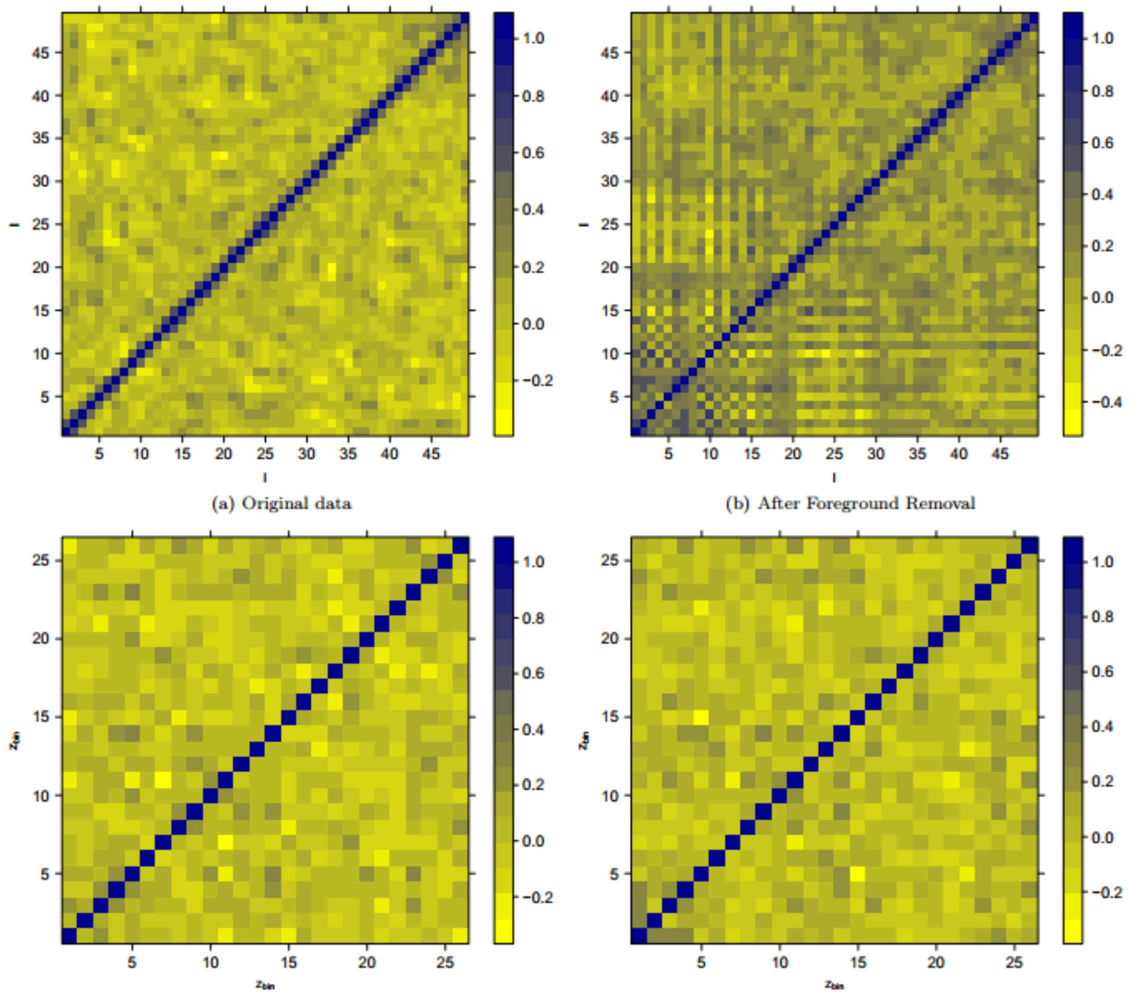
Intensity mapping

- Theoretical Model of the power spectrum Cl
- Statistically speaking SKA w intensity mapping can measure fnl/ Modified gravity to a gret accuracy see M. Santos/others talks.
- Depends on cosmological parameters like (Omegam;w0; b; fnl)
- Contours are biased towards a different best fit when systematics are included
- BAO fit is not biased. (Wolz et al.)





Intensity mapping correlations



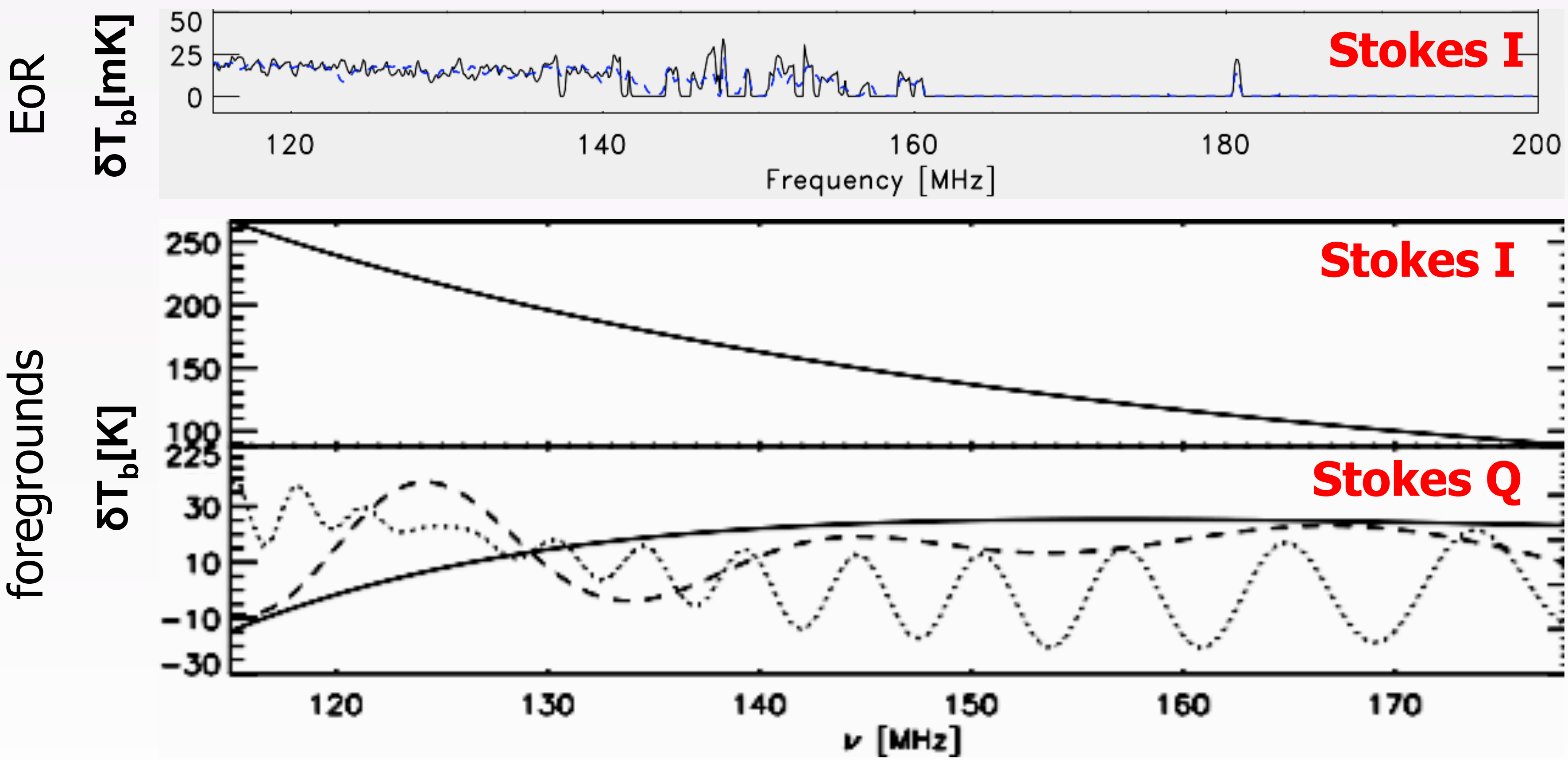
(a) Original data

(b) After Foreground Removal

(a) Original data

(b) After Foreground Removal

Problem of the polarized foregrounds



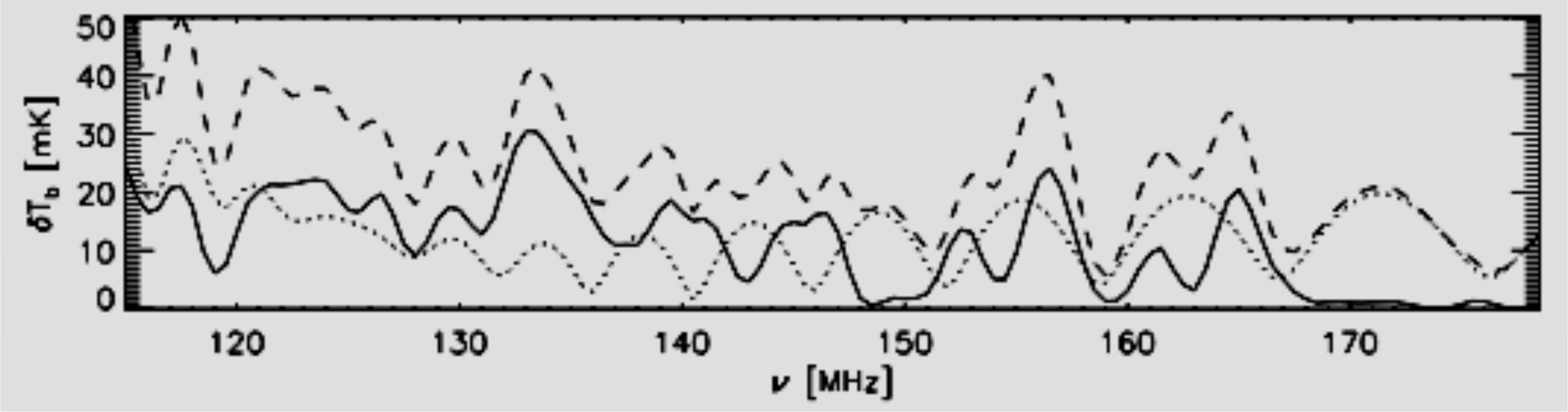
➢ the leaked polarized emission can mimic the cosmological signal: extraction much more difficult

➢Leakage has to be controlled on a calibration level! Currently no FG separation method which deals with polarisation leakage. Leakage calibratable.

Problem of the polarized foregrounds

EoR ~ 25 mK

FG ~ 2 K
residual leakage ~ 1.5 % (30mK)



Jelic et al. 2010
Geil et al. 2011

Frequency coverage!

- Generic feature that we need a few MHz aside the central frequencies in order to obtain best foreground subtraction -> If band pass stops at 50Mhz, likely to not be able to remove foregrounds down to 60MHz...
- Frequency: EoR absorbtion signal & EoR heating period & 21cm Intensity mapping at high redshift < EoR?