Clive Dickinson

Jodrell Bank Centre for Astrophysics
University of Manchester

See BINGO concept paper (Battye et al.)
for more details (arXiv:1209.0343)

Mon. Not. R. Astron. Soc. **000**, ??–?? (0000) Printed 4 September 2012 (MN LaTeX style file v2.2)

HI intensity mapping : a single dish approach

R.A. Battye[1], I.W.A. Browne[1], C. Dickinson[1], G. Heron[1] , B. Maffei[1], A. Pourtsidou[1,2]
[1] *Jodrell Bank Centre for Astrophysics, School of Physics and Astronomy, University of Manchester, Oxford Road, Manchester M13 9PL, U.K.*
[2] *Dipartimento di Astronomia, Università di Bologna, via Ranzani 1, I-40127 Bologna, Italy*

4 September 2012

ABSTRACT
We discuss the detection of large scale HI intensity fluctuations using a single dish approach with the ultimate objective of measuring the Baryonic Acoustic Oscillations (BAO) and constraining the properties of dark energy. To characterise the signal we present 3D power spectra, 2D angular power spectra for individual redshift slices, and also individual line-of-sight spectra, computed using the S^3 simulated HI catalogue which is based on the Millennium Simulation. We consider optimal instrument design and survey strategies for a single dish observation at low and high redshift for a fixed sensitivity. For a survey corresponding to an instrument with $T_{sys} = 50\,K$, 50 feed horns and 1 year of observations, we find that at low redshift ($z \approx 0.3$), a resolution of ~ 40 arcmin and a survey of $\sim 5000\,deg^2$ is close to optimal, whereas at higher redshift ($z \approx 0.9$) a resolution of ~ 10 arcmin and $\sim 500\,deg^2$ would be necessary - something which would be difficult to achieve cheaply using a single dish. Continuum foreground emission from the Galaxy and extragalactic radio sources are potentially a problem. In particular, we suggest that it could be that the dominant extragalactic foreground comes from the clustering of very weak sources. We assess its amplitude and discuss ways by which it might be mitigated. We then introduce our concept for a dedicated single dish telescope designed to detect BAO at low redshifts. It involves an under-illuminated static ~ 40 m dish and a ~ 60 element receiver array held ~ 90 m above the under-illuminated dish. Correlation receivers will be used with each main science beam referenced against an antenna pointing at one of the Celestial Poles for stability and control of systematics. We make sensitivity estimates for our proposed system and projections for the uncertainties on the power spectrum after 1 year of observations. We find that it is possible to measure the acoustic scale at $z \approx 0.3$ with an accuracy $\sim 2.4\%$ and that w can be measured to an accuracy of 16%.

Key words: cosmology:observations – cosmology:theory

Intensity mapping workshop, Oxford, 23 November 2012

BINGO Players

- BAOs from Integrated Neutral Gas Observations

Manchester

- Richard Battye
- Michael Brown
- Ian Browne
- Richard Davis
- Peter Dewdney
- Clive Dickinson
- Keith Grainge (Jan 2013 onwards)
- Georgina Heron (ex-Manchester student)
- Bruno Maffei
- Shude Mao (NAOC)
- Alkistis Pourtsidou (-> Bologna)
- Peter Wilkinson

+KACST, Saudi Arabia (Yaser Hafez)

+UCL (Filipe Abdalla)

+Brazil/Uruguay (Raul Abrama, Jacques Lapine, Elcio Abdalla, Gonzalo Tancredi, Emilio Falco, Ana Mosquera…)

+other interested parties (we are looking for a site and/or partners)

Why single dish?

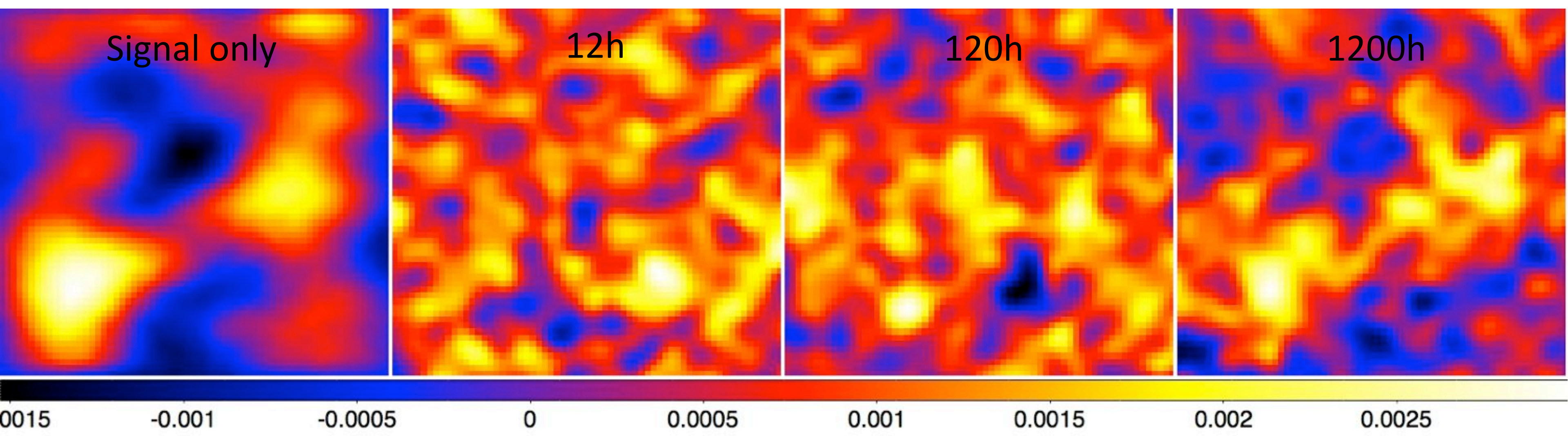
- Single dishes have their potential issues, BUT,
  - Simpler
  - Cheaper
  - "Optimum" surface brightness sensitivity (f~1)

- Interferometers have a number of advantages, BUT,
  - more complicated
  - more expensive
  - reduced surface brightness sensitivity

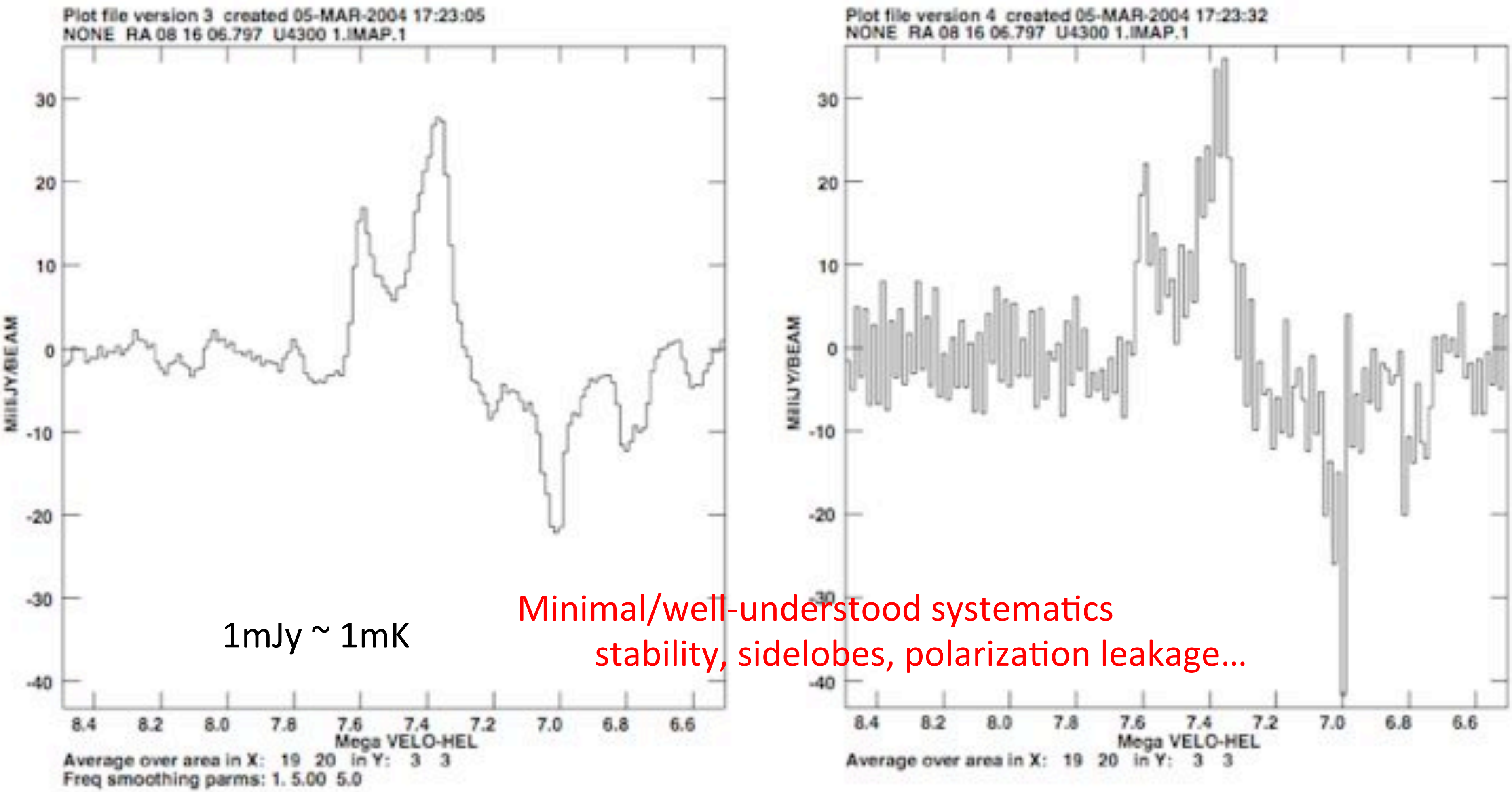
$$\Delta T \approx \frac{f \Delta S \lambda^2}{2k\Omega}$$

$$f = N(d/D)^2$$

MeerKAT simulation



Realising thermal noise is difficult!

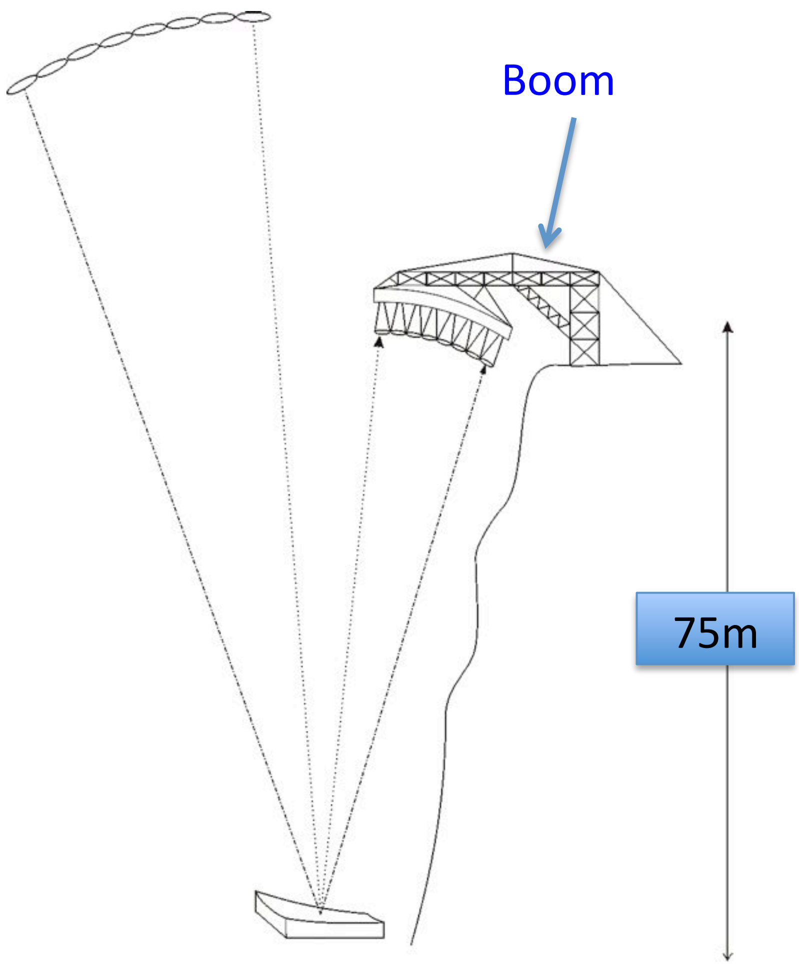


1mJy ~ 1mK

Minimal/well-understood systematics
stability, sidelobes, polarization leakage…

Test observations of UGC4300 with Lovell 76m MkI telescope (circa 2003)

Proposed BINGO Concept



Static 40m dish – offset parabola
(No moving parts)

Technical specifications

Dish diameter : 40m

Resolution : 2/3 deg

Frequency range : 960-1260MHz
(z= 0.12 - 0.48)

Focal ratio : F/D approx 3

Number of feeds : 50 (dual polarization)
- T_{sys} approx 50K

Survey Design

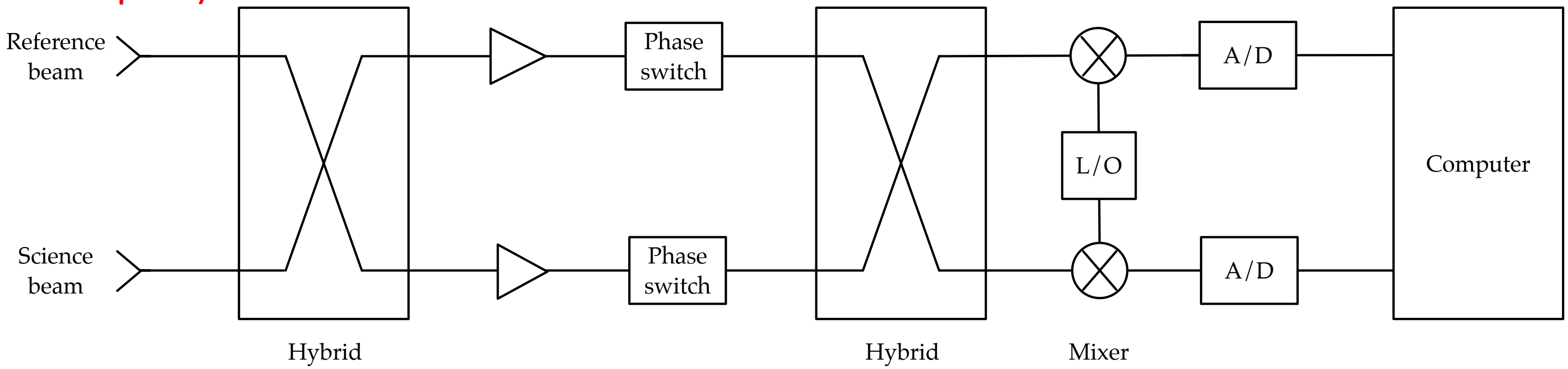
Observation time : 1 year on source

Area : 10 x 200 deg^2 – drift scan

Guiding principle : simplicity !

Correlation receiver

(Celestial pole)



- 1/f knee frequency of typical receivers is approx 1Hz

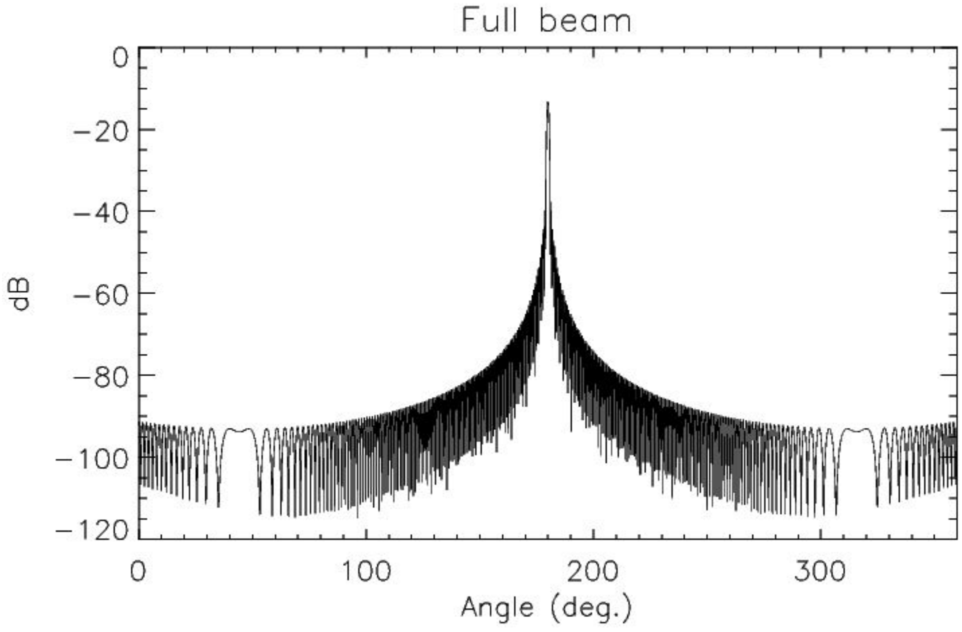
- Perfect pseudo correlation can remove the 1/f

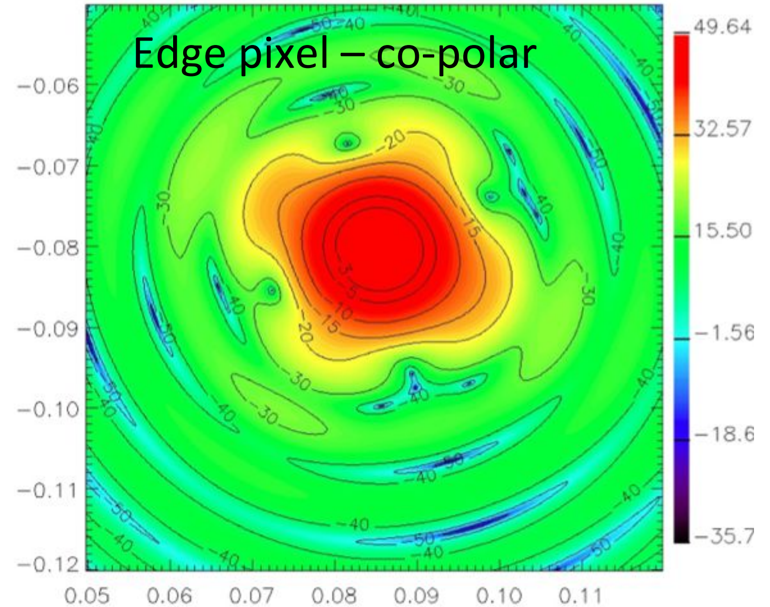
- To achieve approx 1mHz we need :

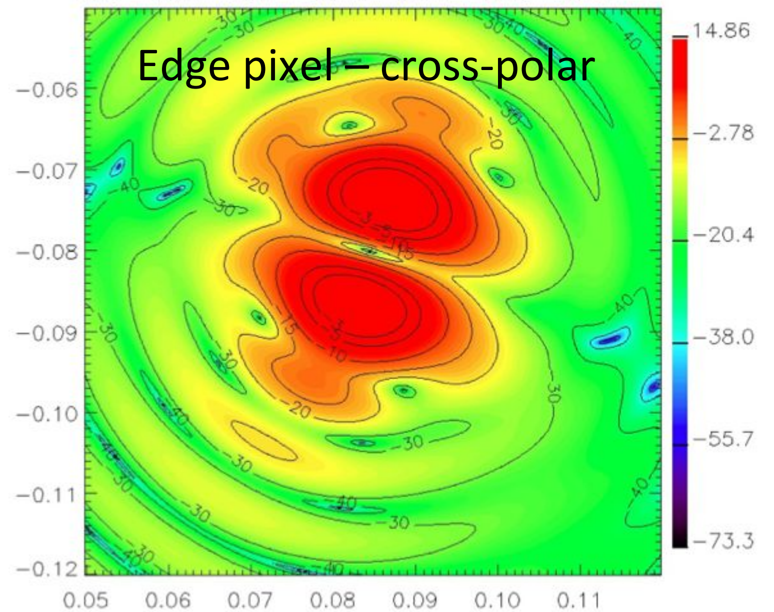
  - Input matching to < 3%
  - Hybrid accurate to < 1.5%

BINGO beams

Pixel Position	Forward Gain	Ellipticity	Peak X-Pol	FWHM
	dB		dB	arcmin
Centre	49.8	10^{-3}	-40	38
Edge	49.6	0.07	-35	39

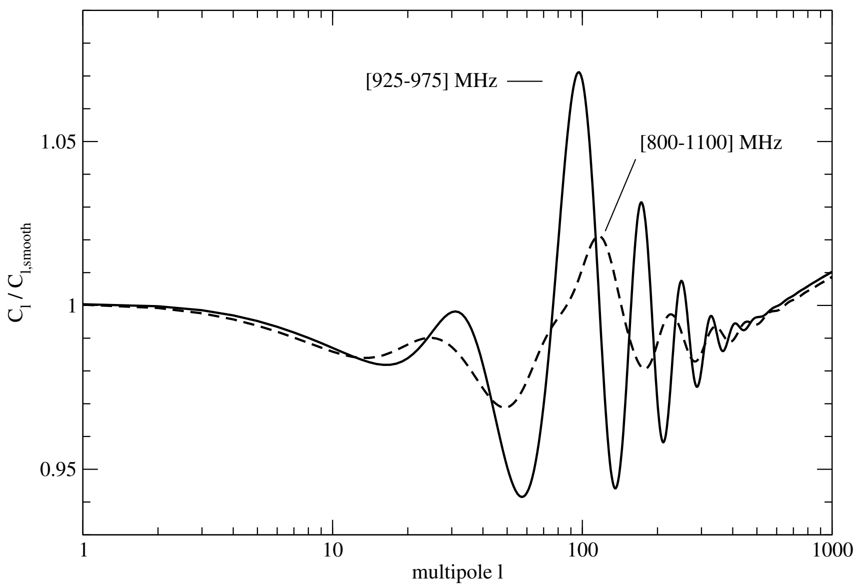




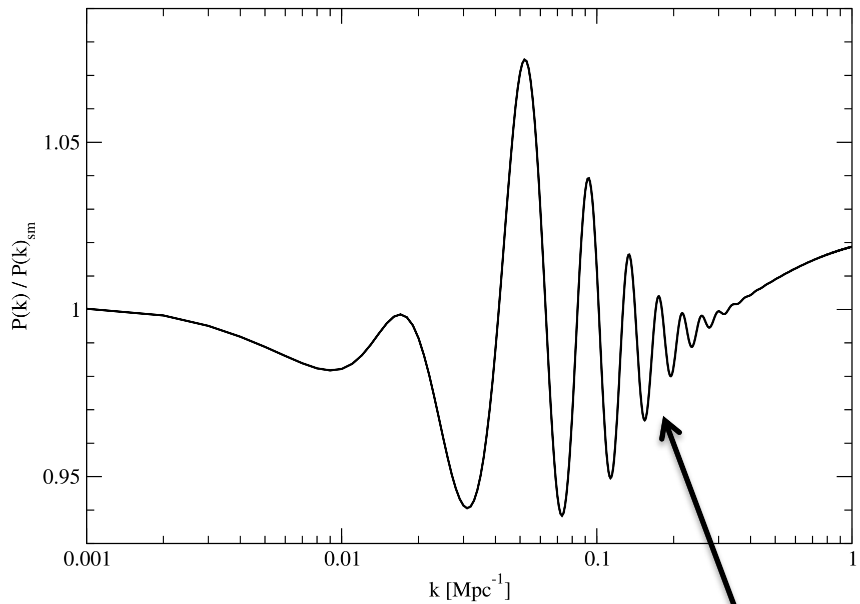


BAOs in 2D v 3D spectra

2D angular power spectra



3D power spectra

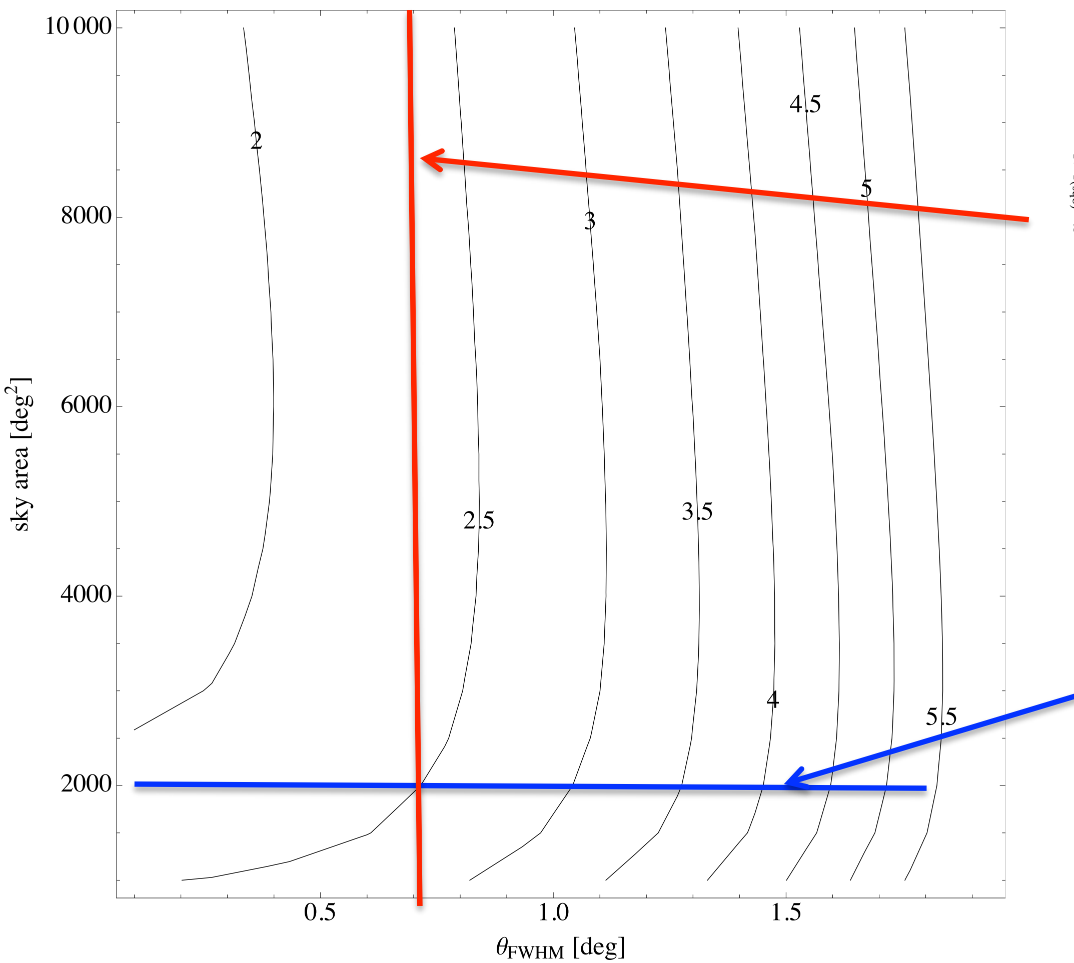


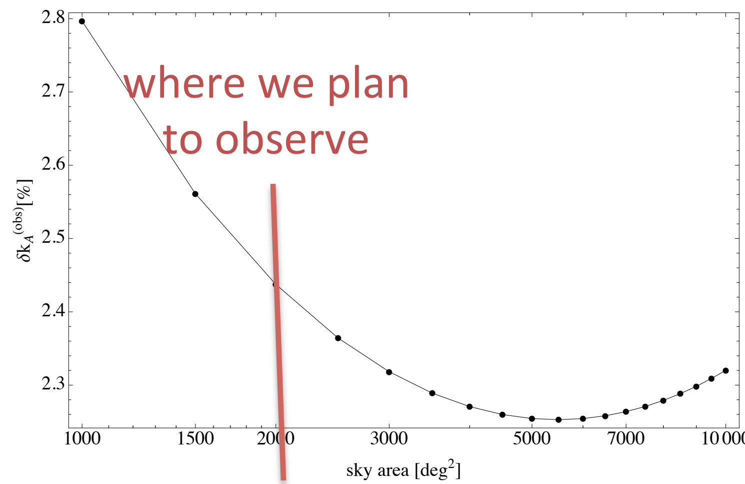
50 MHz (equivalent to Δz=0.05) is optimal

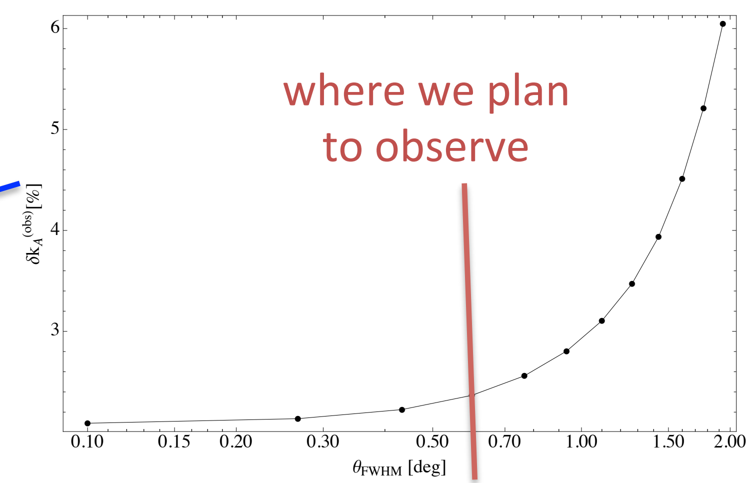
Not much signal beyond k = 0.2 $hMpc^{-1}$

Optimization Survey Design (Case A)

f = 960 – 1260 MHz (z = 0.13-0.48)





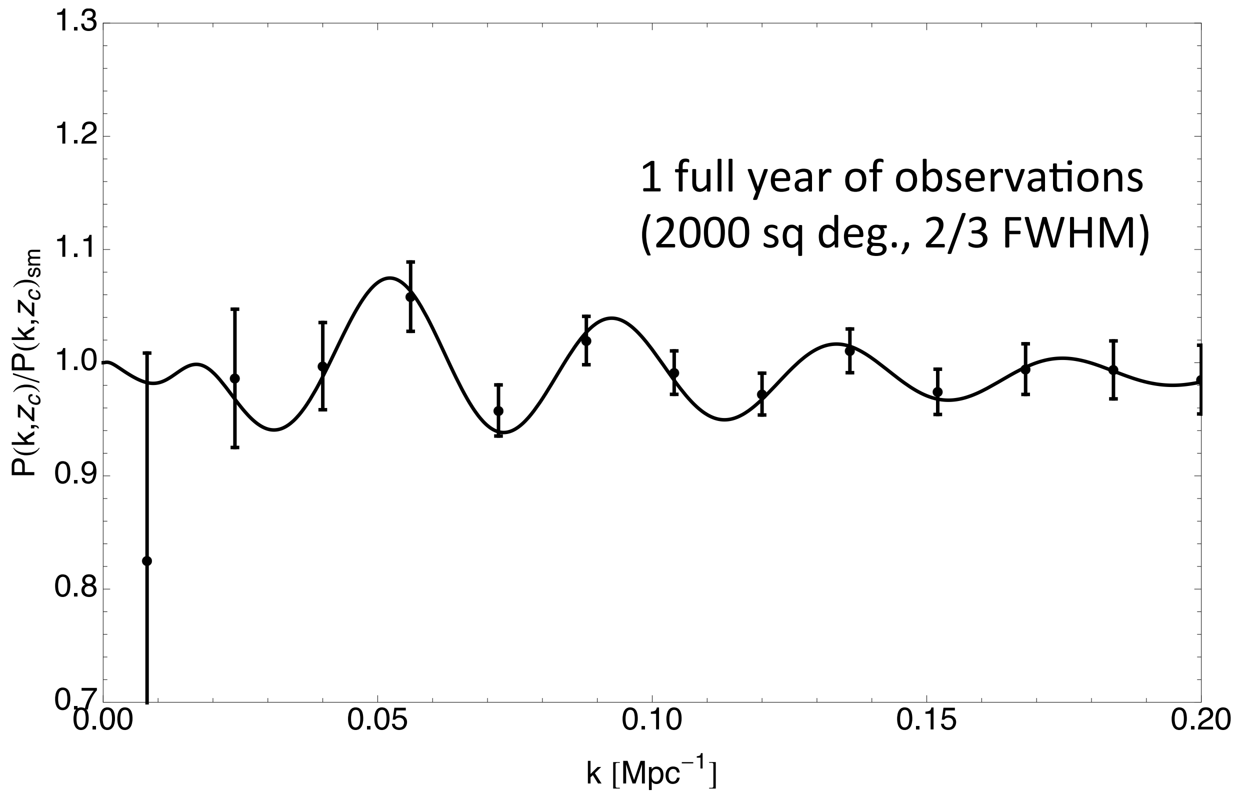


T_{sys} = 50K, N_{feed} = 50, t = 1 year

-> optimize resolution and sky area

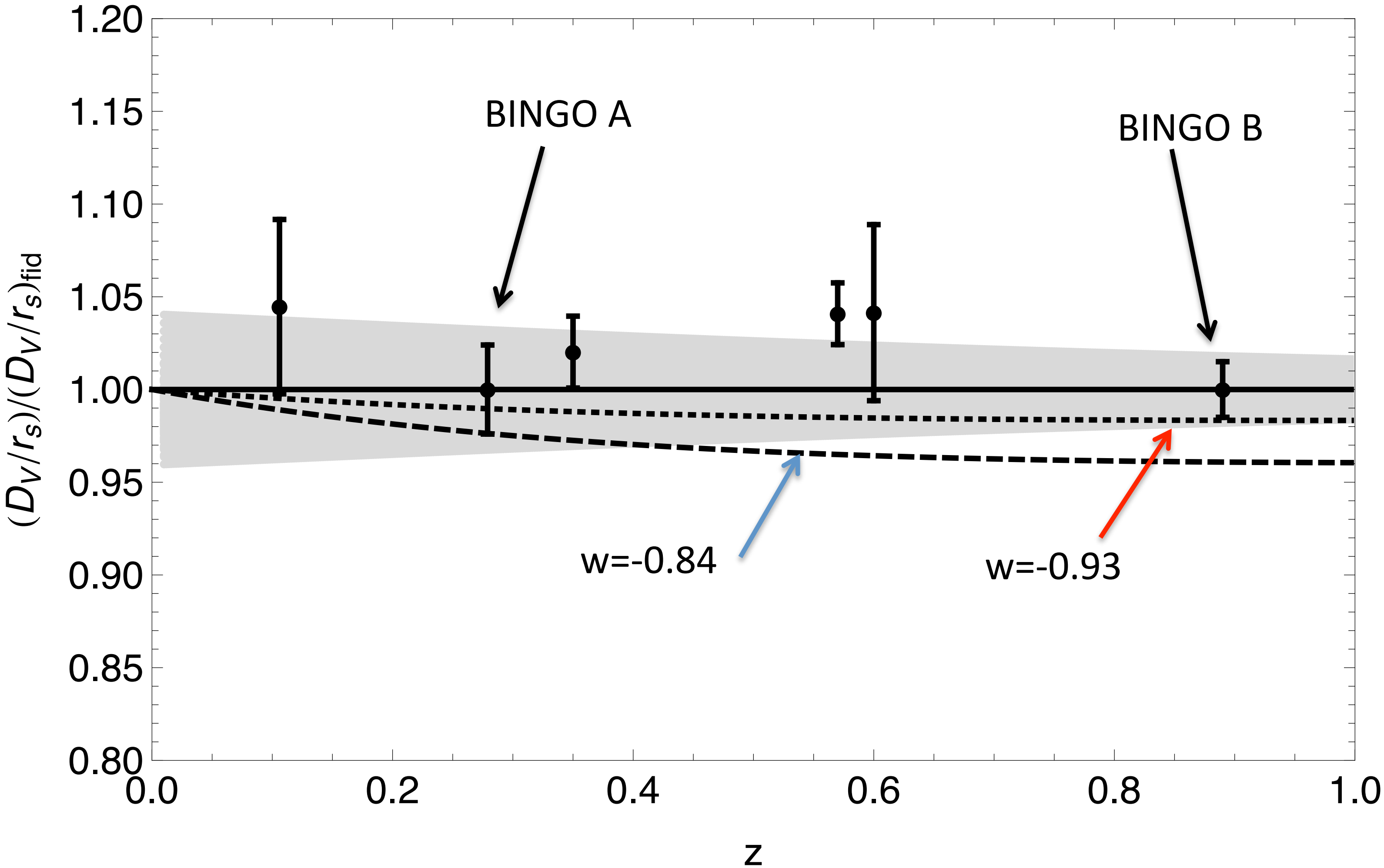
Survey design : conclusion

Case (A) : Law of diminishing returns from $\theta_{FWHM} \approx 2/3$ deg
Sky Area ≈ 5000 deg^2 but very shallow between 1000-10000 deg^2



- Measurement of acoustic scale to $\delta k_A/k_A \approx 0.024$
- Projected constraint on dark energy $\delta w/w \approx 0.16$

Residuals in BAO Hubble diagram



Contamination

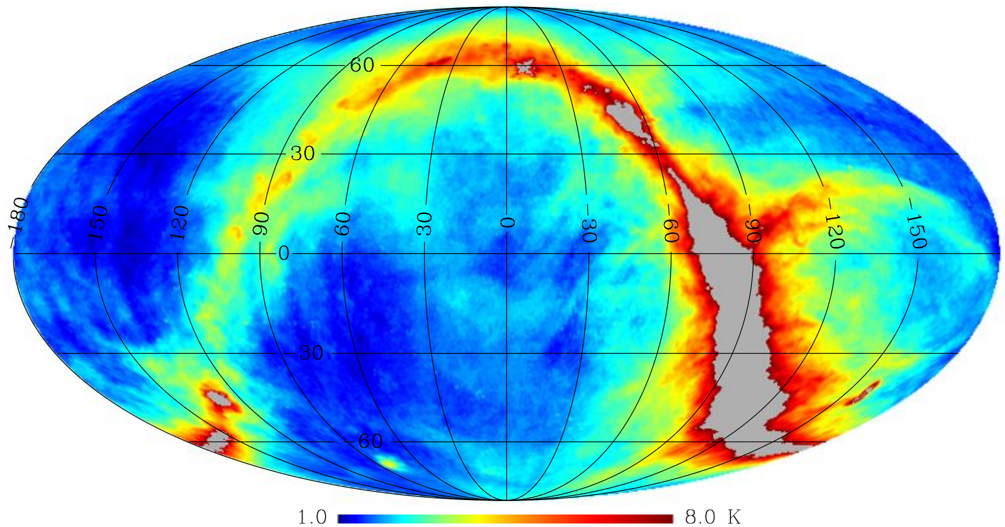
Typically continuum – with a smooth spectrum (should allow it to be extracted!)

Smooth

approx 5K @ 1GHz – mainly CMB and Synchrotron

RMS fluctuations on degree scales @ 1GHz

- Galactic synchrotron ≈ 70mK
- Extragalactic sources ≈ 50mK
- N.B. HI signal is ~0.1mK!



Extragalactic point sources

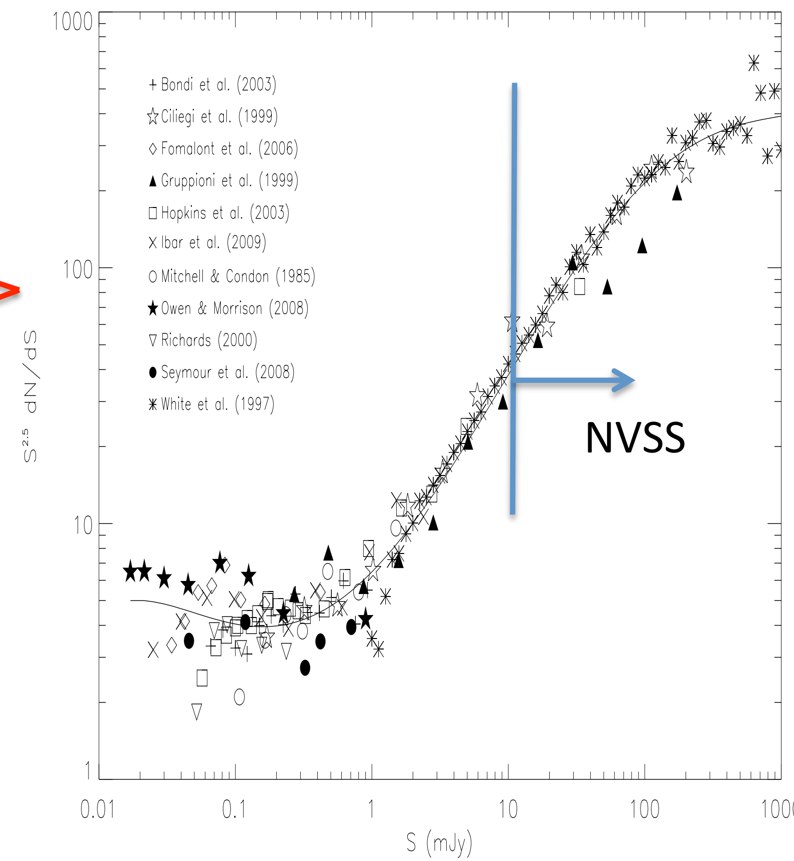
$$C_\ell^{\text{Poisson}} = \left(\frac{dB}{dT}\right)^{-2} \int_0^{S_{\text{cut}}} S^2 \frac{dN}{dS} dS$$

→ T ≈ 6 mK

$$C_\ell^{\text{clustered}} = w_\ell \left(\frac{dB}{dT}\right)^{-2} \left(\int_0^{S_{\text{cut}}} S \frac{dN}{dS} dS\right)^2$$

NVSS : $w_l \approx 4.8 \times 10^{-3}\, l^{-1.2}$

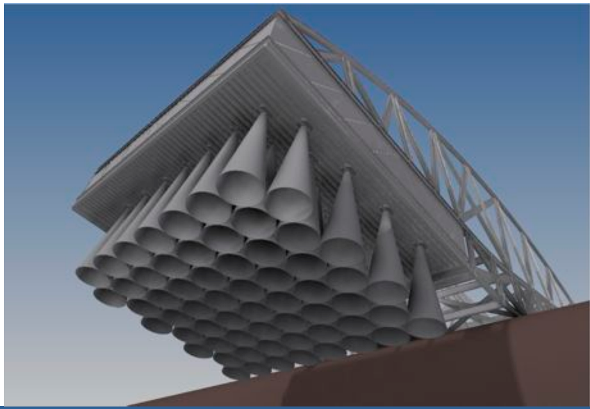
→ T ≈ 48 mK

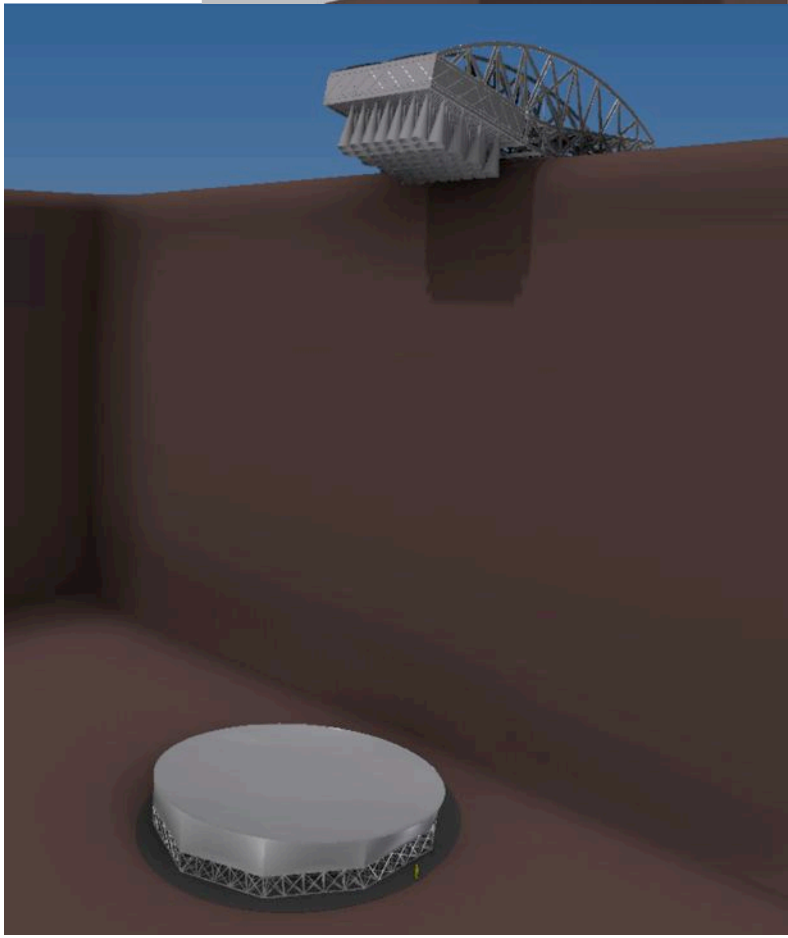


Possibility that the source contribution is dominated by the clustered component of very faint radio sources

Project status

- Paper (Battye et al.) to be published soon
  - arXiv:1209.0343
- Funding for receiver prototype (few 10K GBP)
  - already in the testing phase, not expecting any showstoppers!
- Basic mechanical design ready
- Estimated total cost : ≈1.5M GBP
  - Need a site : considering inside a quarry
  - Some funding from KACST (Saudi Arabia)
  - Exploring various overseas options and STFC
  - Proposal to Mercosur (Brazil/Uruguay)
- 2 PDRAs to begin early 2013 to work on foregrounds/HI data analysis/BINGO
  - Application deadline 4th January 2013
  - Email Clive.Dickinson@manchester.ac.uk





Courtesy Adrian Galtress