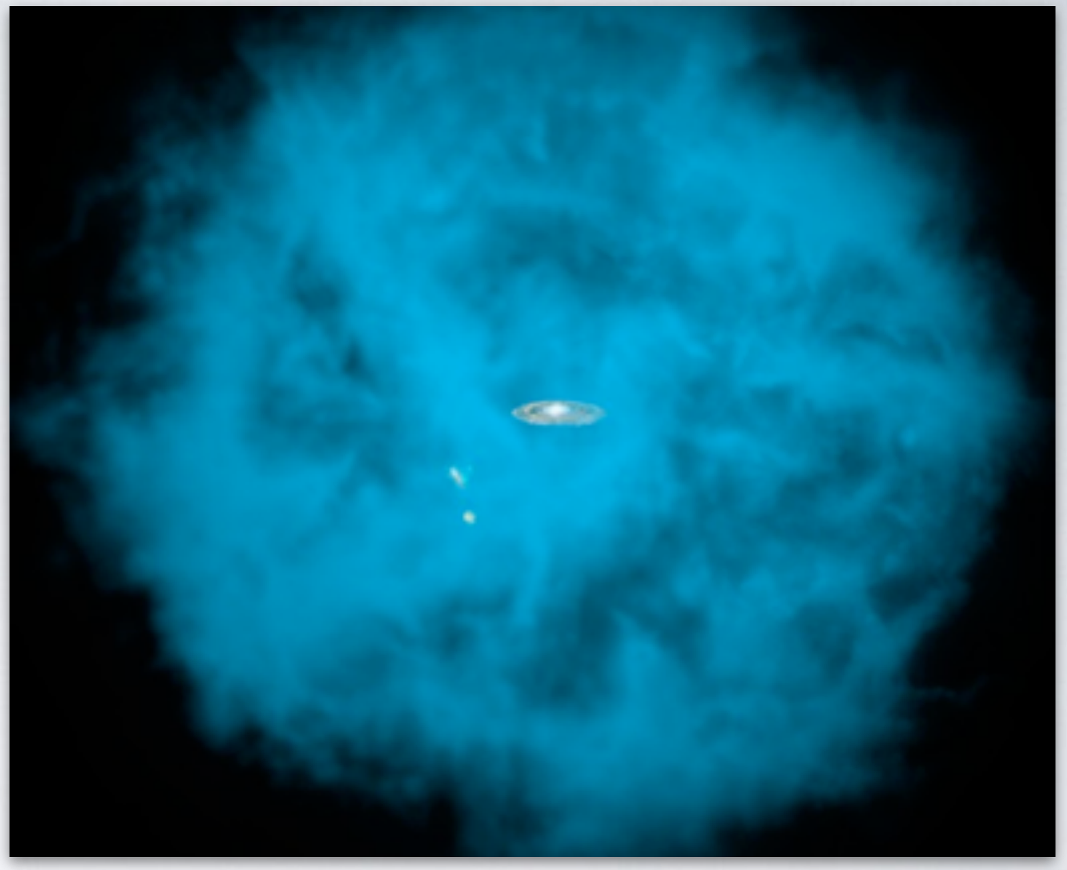

Can we detect the circumgalactic medium with Apertif?

SUMMARY

- Probably not

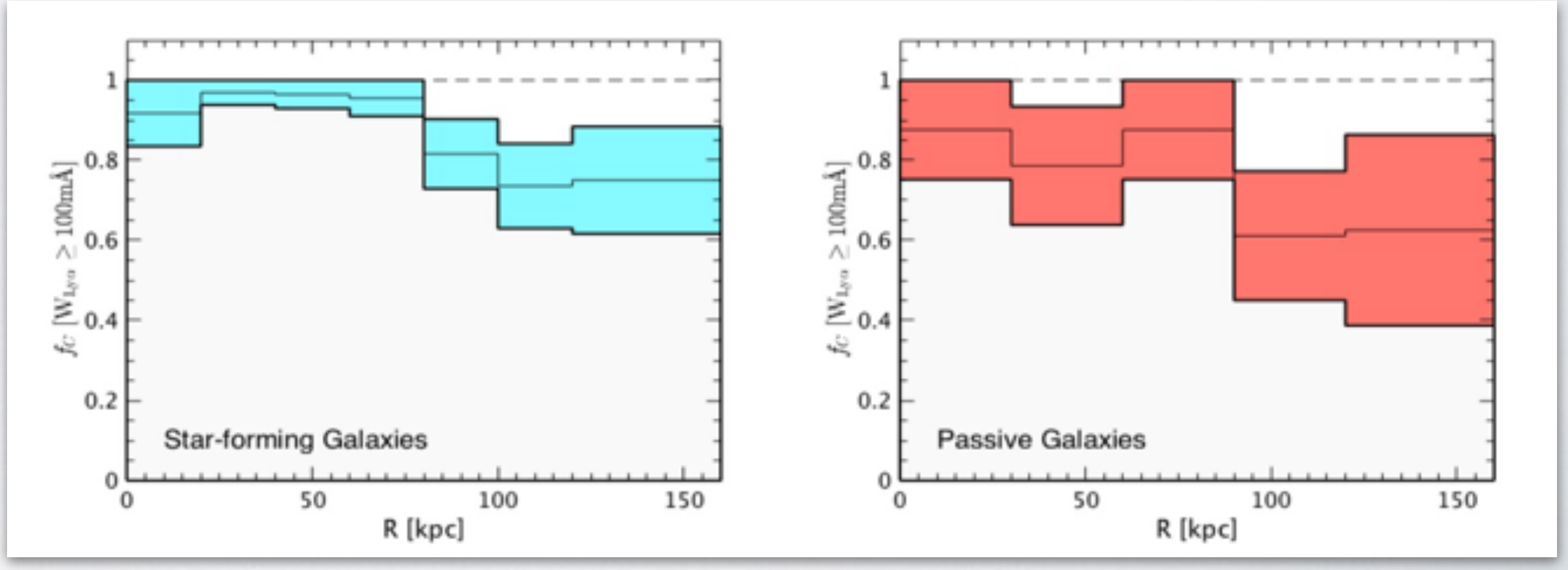
CAN WE DETECT THE CGM?



- The ‘cold’ gas reservoir of galaxies consists of two major zones:
  - high column density disk ($>10^{19}$ cm^{-2})
    - 10-50 kpc in size
    - large fraction is atomic
  - low column density CGM ($<10^{19}$ cm^{-2})
    - extends to >~200 kpc
    - almost fully ionised, but contains a trace of HI

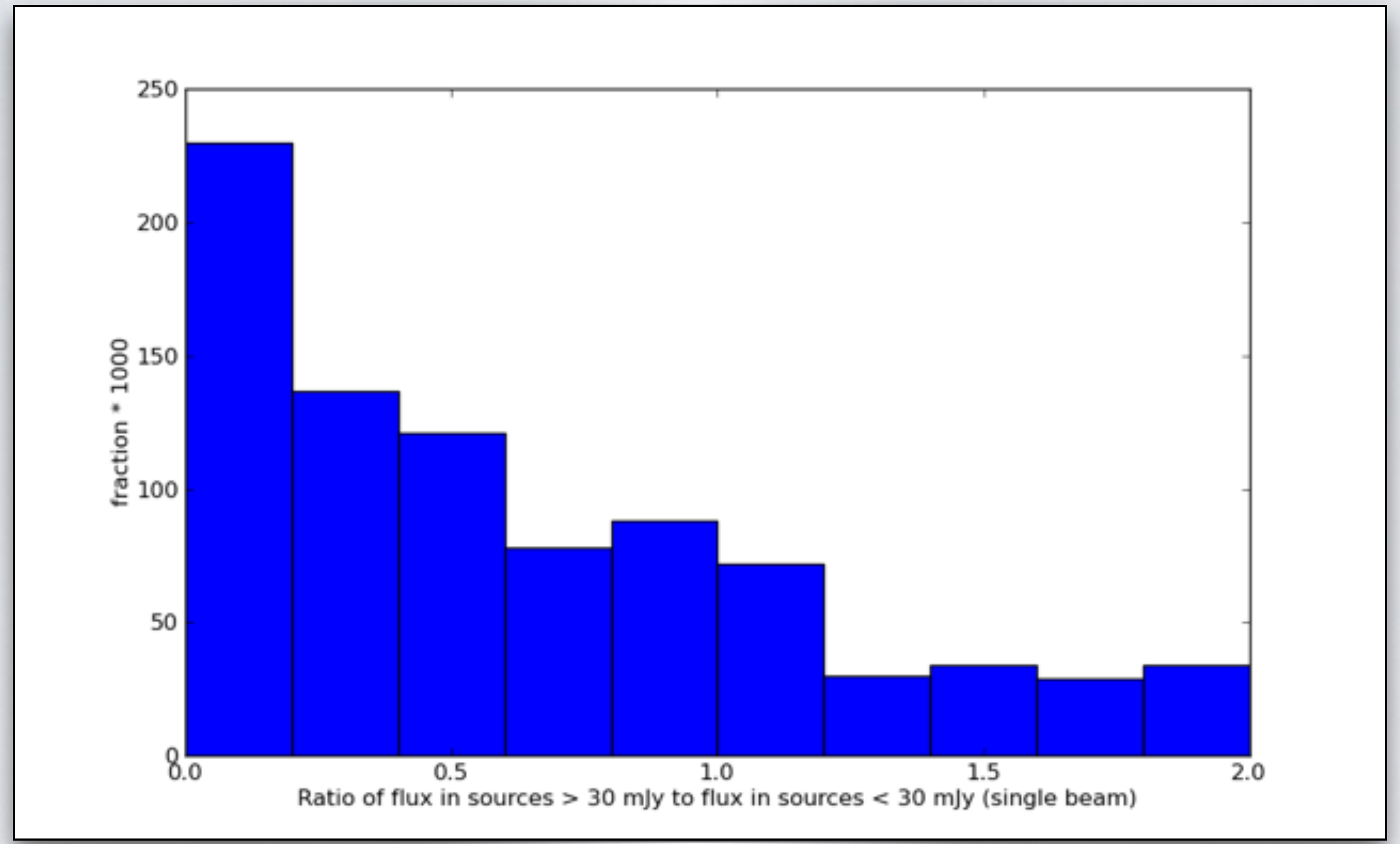
Covering fraction of Lyα absorption around nearby galaxies is large!!

Even around early-type galaxies!!!



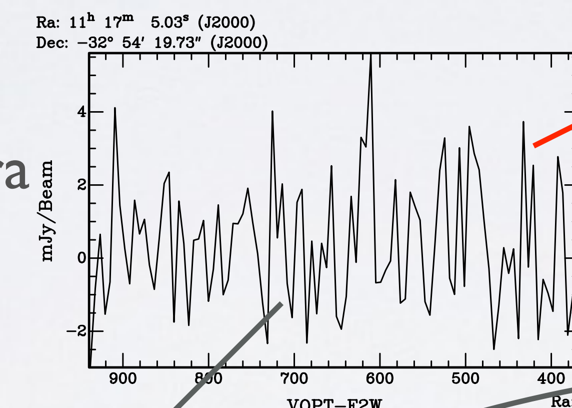
Bordoloi+ 2017

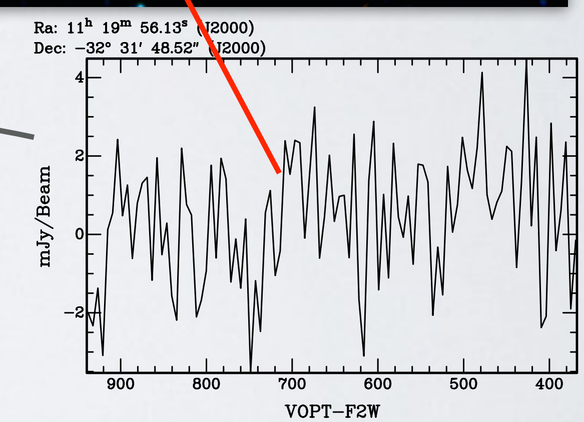
For a typical Apertif beam, most of the flux is in faint sources.
Can they serve as background sources to look for H I absorption?

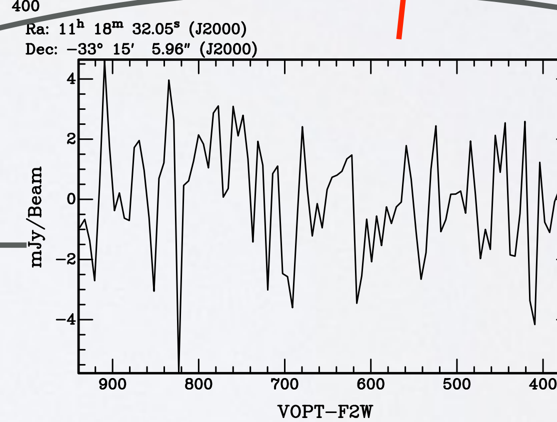


- In most Apertif beams there is more flux in faint sources than there is in strong sources
- For every foreground galaxy, we take the spectra against all background continuum sources outside the HI disk, but within 200 kpc, de-redshifted to the redshift of the foreground galaxy

- We stack all these de-redshifted spectra
- No detection in individual spectra
- Detection in stack?







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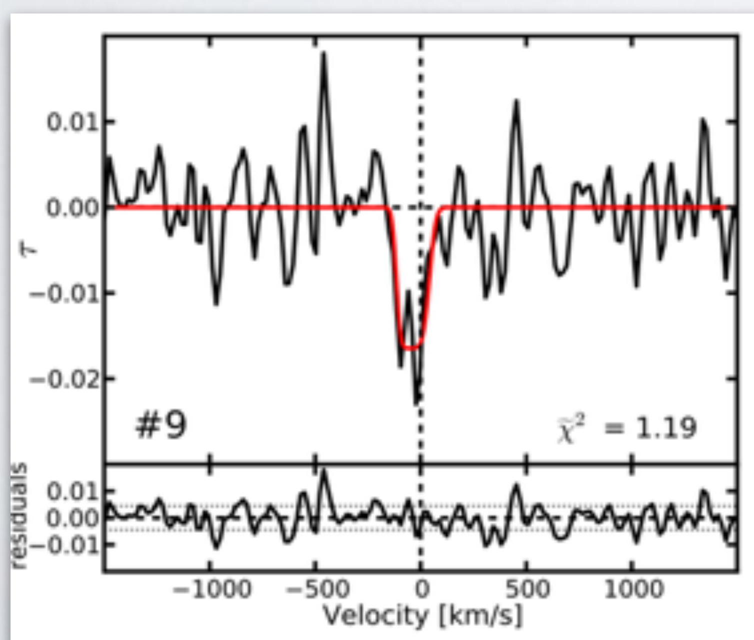


- There are many foreground galaxies and even more background sources which we can use several times

NOISE BUDGET

(ignoring many possible complications….)

optical depth $\tau = \frac{s(\nu)}{s_\mathrm{c}}$ with noise $\sigma_\tau = \frac{\sigma_\circ}{s_\mathrm{c}}$

σ_τ scales as $s_{\mathrm{c},i}^{-1}$

so optimum estimator of optical depth is $\langle\tau\rangle = \frac{\sum \tau_i\, s_{\mathrm{c},i}^2}{\sum s_{\mathrm{c},i}^2}$

with error $\sigma_\tau^2 = \frac{\sigma_\circ^2}{\sum s_{\mathrm{c},i}^2}$

So stacking a large number of spectra has the same error as a single spectrum

of a continuum source with $s_\mathrm{eff} = \sqrt{\sum s_{\mathrm{c},i}^2}$

Note that s_eff increases as $N^{1/2}$

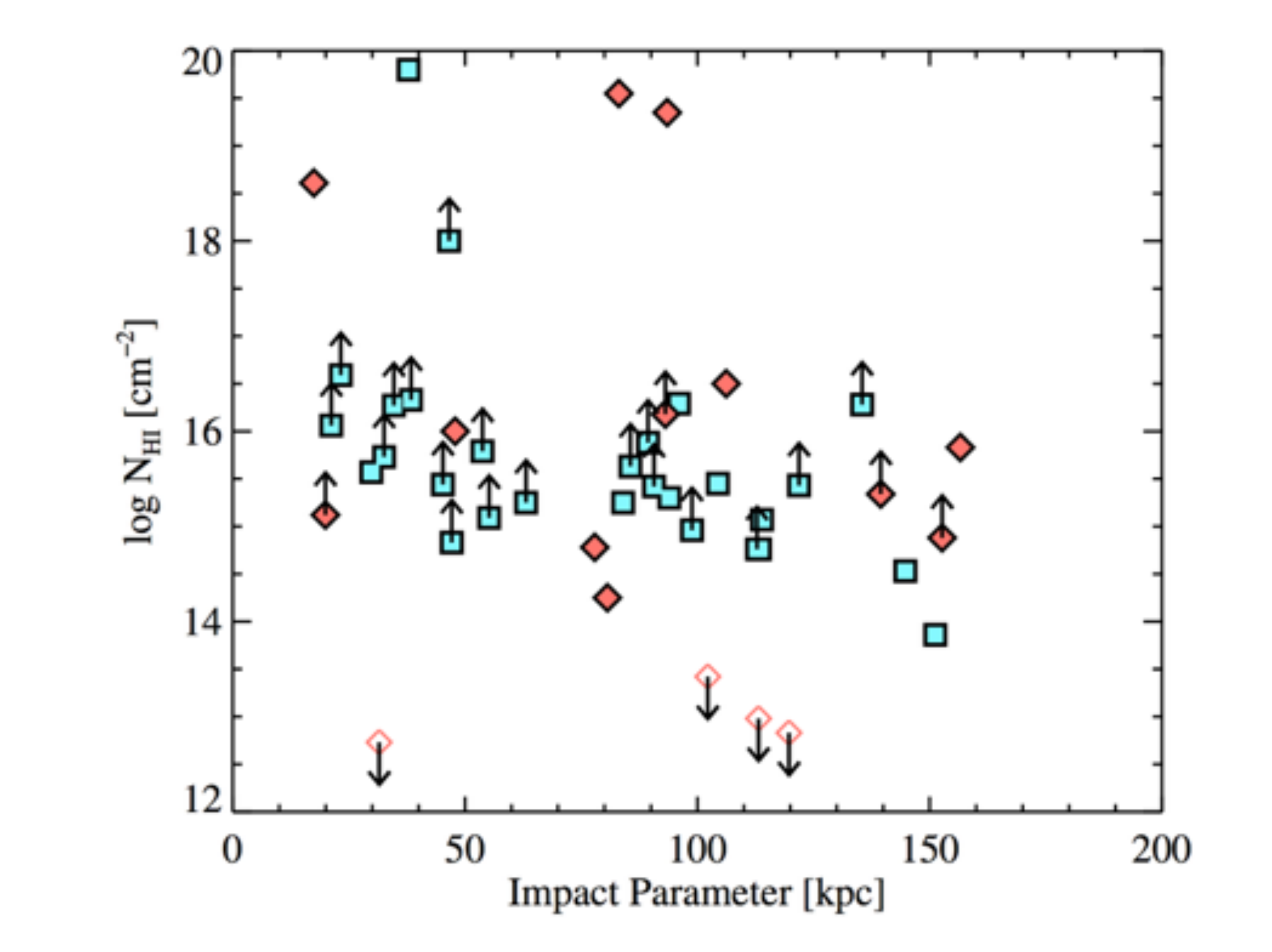
s_eff is determined by the strong sources. E.g.: $s_1 = 10$, $s_2 = 1$: $s_\mathrm{eff} = 10.005$

WHAT IS REQUIRED?

- Expected column densities are (>) 10^{16} cm^{-2}
- Velocity offset ~ 100 km/s

- Noise in column density for absorption from a single spectrum from shallow survey against a 1 Jy source is ~ 10^{20} cm^{-2} (T_{spin} = 1000 K, 100 km/s)
- in Medium Deep Survey ~ factor 3 better

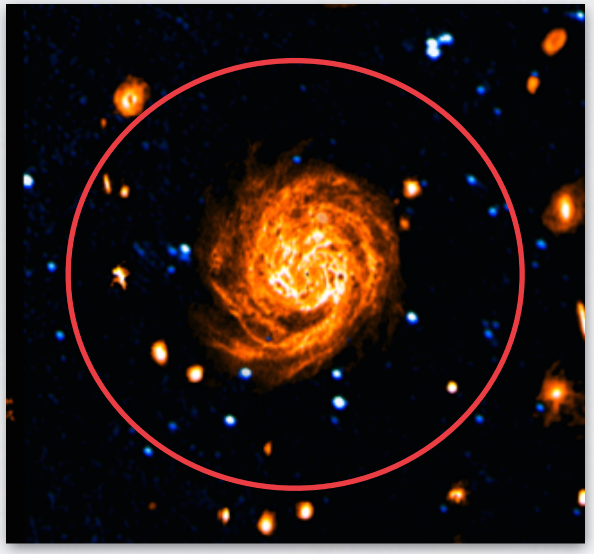
- So s_{eff} has to be > 1000 Jy

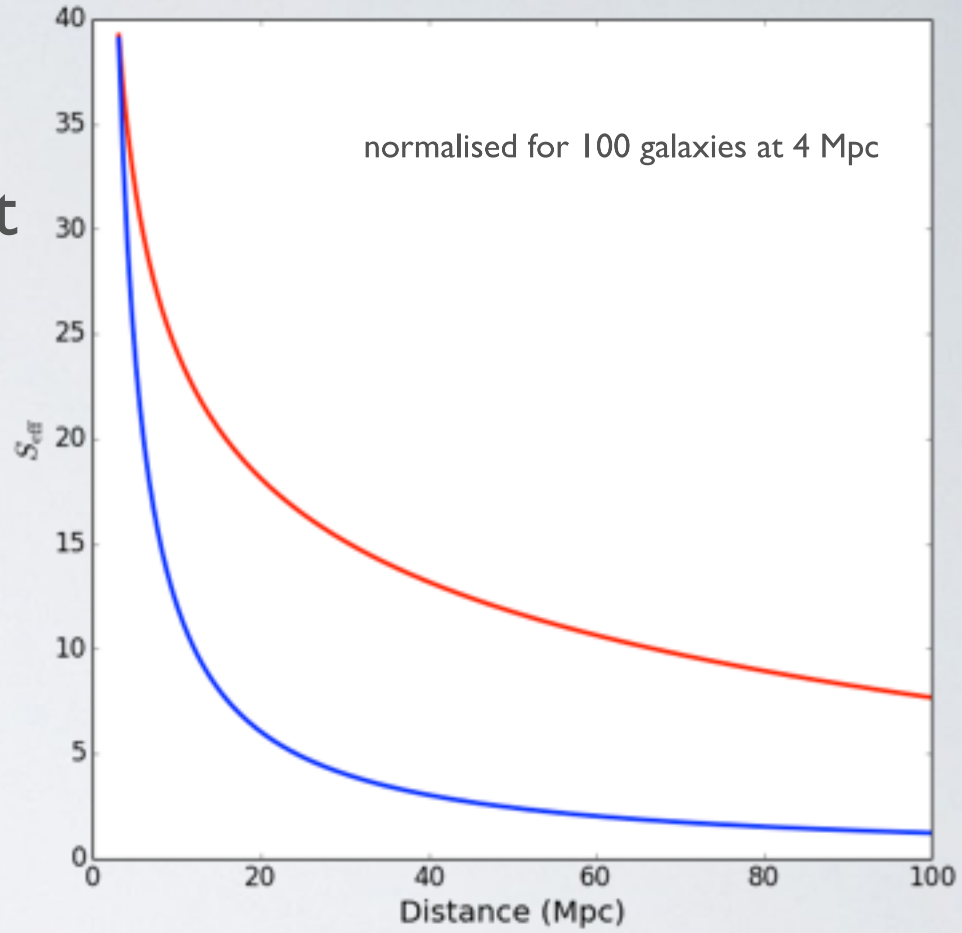


Tumlinson+ 2013

HOW LARGE IS S_{EFF} ?

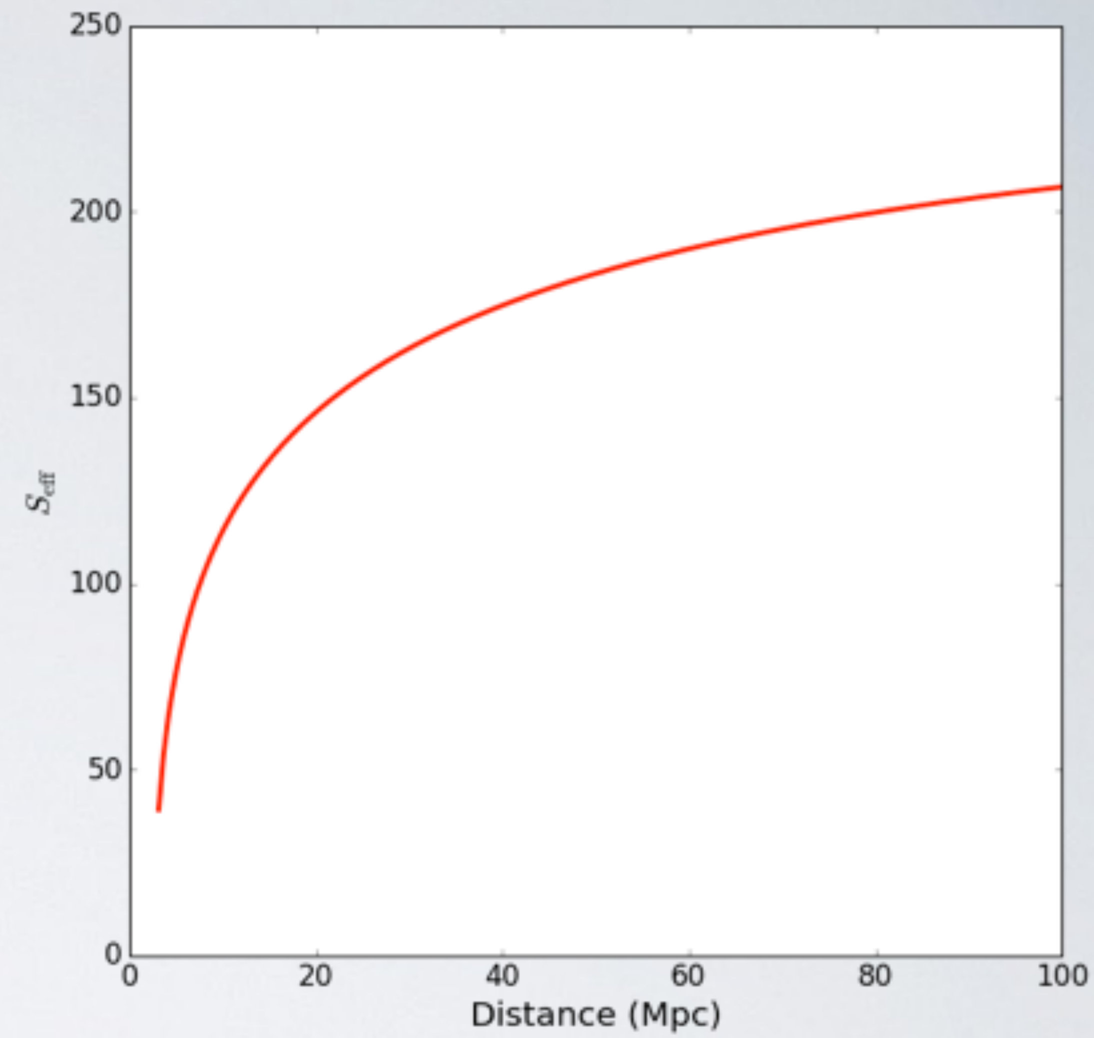
- Simulation using NVSS
- pick *N* random foreground positions at a given redshift
- compute s_{eff} using all sources within 200 kpc





- s_{eff} for *N* fixed to 100 (blue) decreases fast (D^{-1}) with redshift (obvious) (100 is about the number of galaxies at $D \sim 4$ Mpc in survey area)
- But there are more foreground galaxies at larger distance (up to some redshift) so *N* increases with *D*. s_{eff} decreases slower (red)
- s_{eff} well below 1000 Jy…

ADD EVERYTHING



Stacking all foreground galaxies over all redshifts

i.e. cumulative s_{eff}

all normalised to 100 foreground objects at
D = 4 Mpc

We need s_{eff} > 1000 Jy

Getting closer, but

SUMMARY

- Stacking all spectra against background continuum source for all foreground galaxies will most likely not detect the CGM (we are short by at least a factor 10 in noise)
  - even if you ignore complications (data quality, confusion with emission, T_{spin}….)
- Perhaps by choosing the survey area in a clever way, one can gain a bit, but a similar analysis of stacking the environment of the Local Group gives a similar result.

  Perseus-Pisces cluster?

- But:
  - MeerKat is ~10 times more sensitive than Apertif
  - SKA1 another factor 3 or so

  - so perhaps there is some hope in the future….