SKA1-low design impact on EoR & Cosmic Dawn science

http://*homepage.sns.it/*
mesinger/EOS.html

Andrei Mesinger
& Brad Greig
for the EoR/CD SWG

AiDA

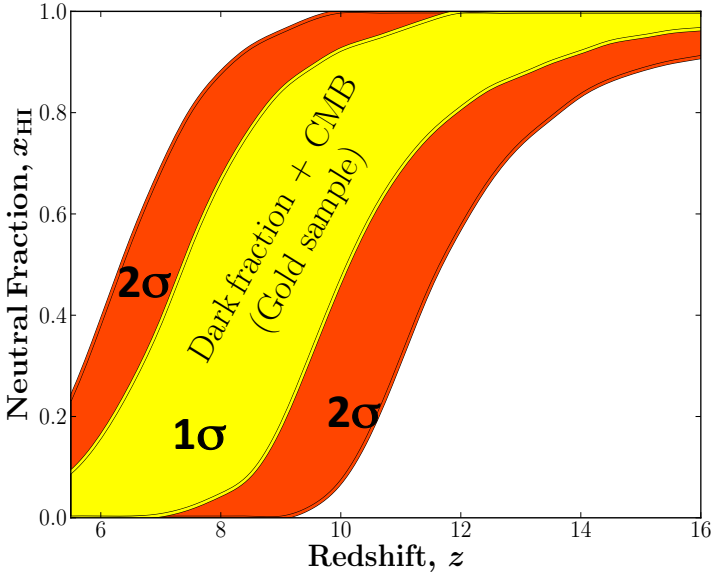
SCUOLA NORMALE SUPERIORE

European Research Council

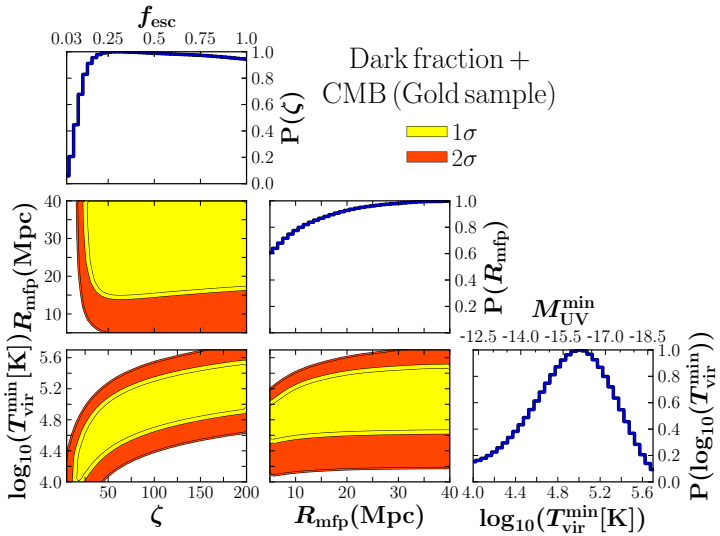
THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION
HORIZON 2020

What to expect for the Cosmic Signal?

- We know almost nothing: expect the unexpected…



Reionization history is *weakly constrained*



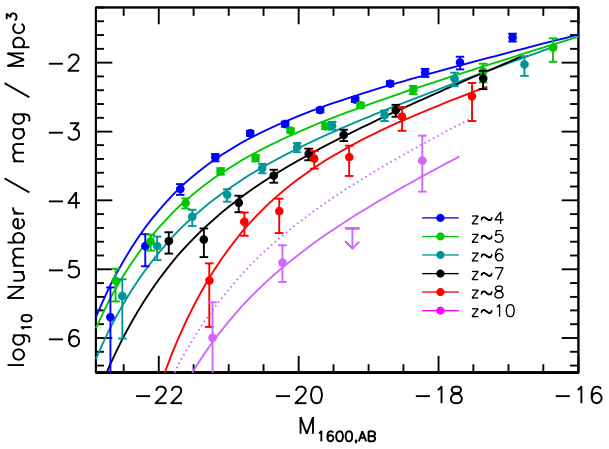
Reionization astrophysics is *completely unconstrained*

Greig & Mesinger, in prep
see also Mitra+ 2015

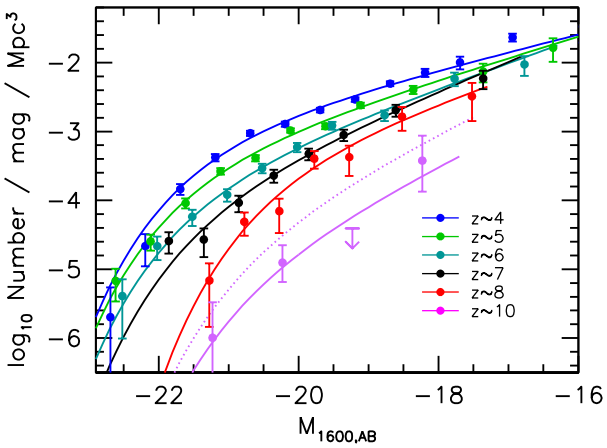
We want to find the missing population of first galaxies

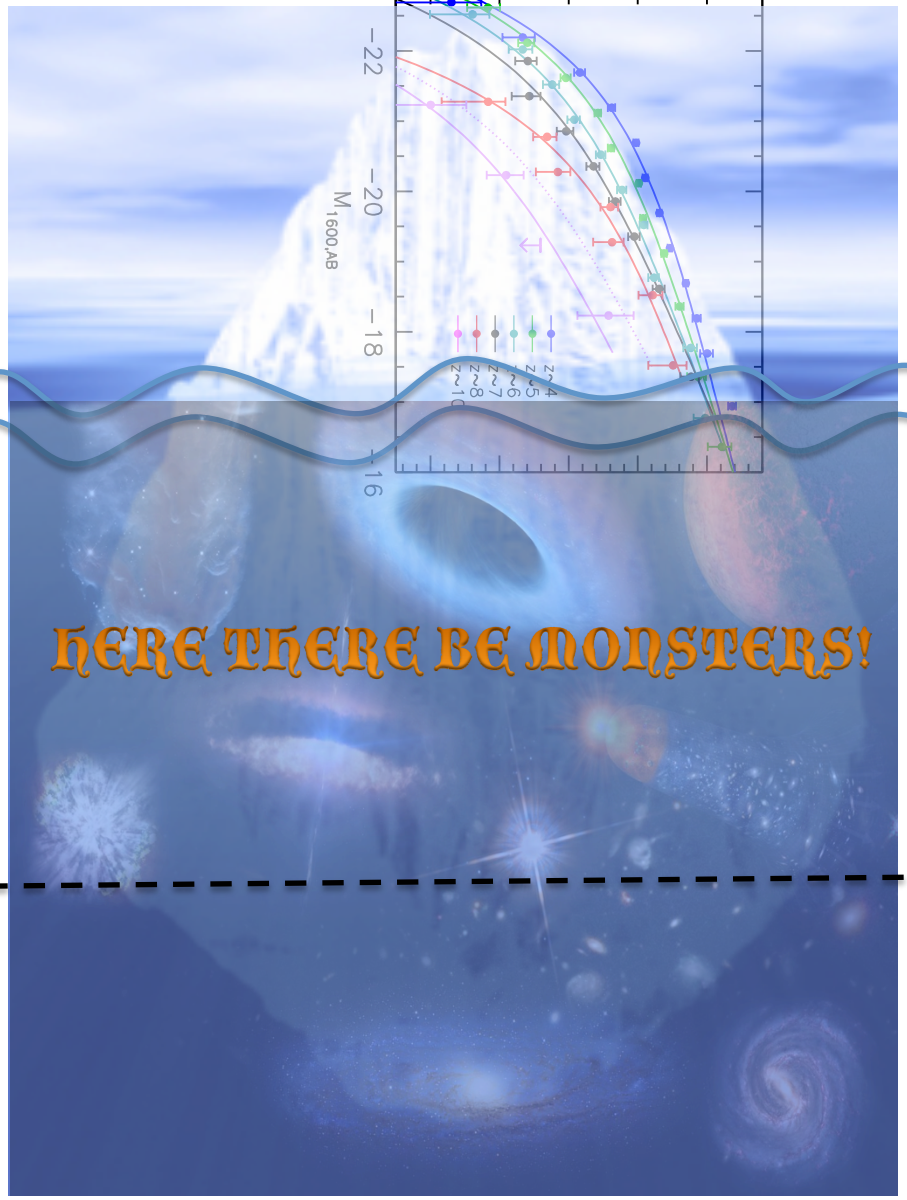
- Galaxy candidates have been found out to z~10. Are these the sources of reionization?? Estimates suggest they are too few…

Bouwens+(2014)



Tip of the iceberg





Hubble limit

JWST limit

H-cooling threshold

H_2 cooling

M_{AB}= -22

M_{AB}= -18

M_{AB}= -14

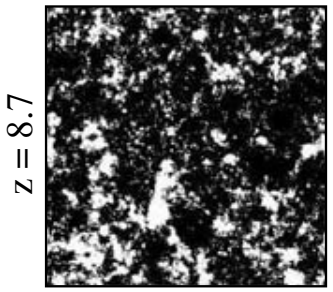
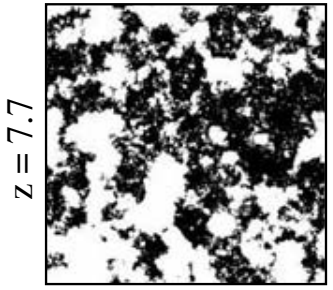
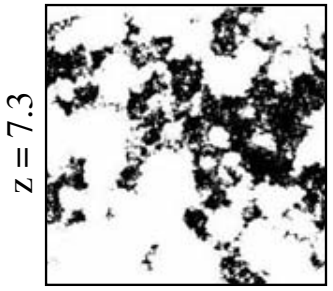
M_{AB}= -10

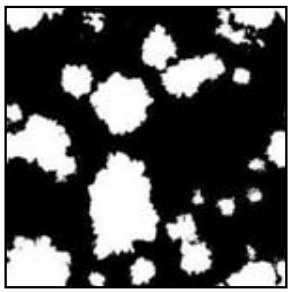
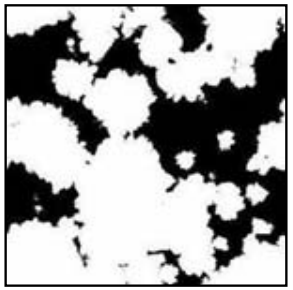
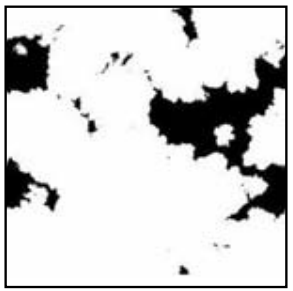
M_{AB}= - 6

hidden population of abundant ,faint galaxies??

How do we detect the first galaxies?

- Galaxy clustering + stellar properties → *evolution of large-scale EoR/CD structures*

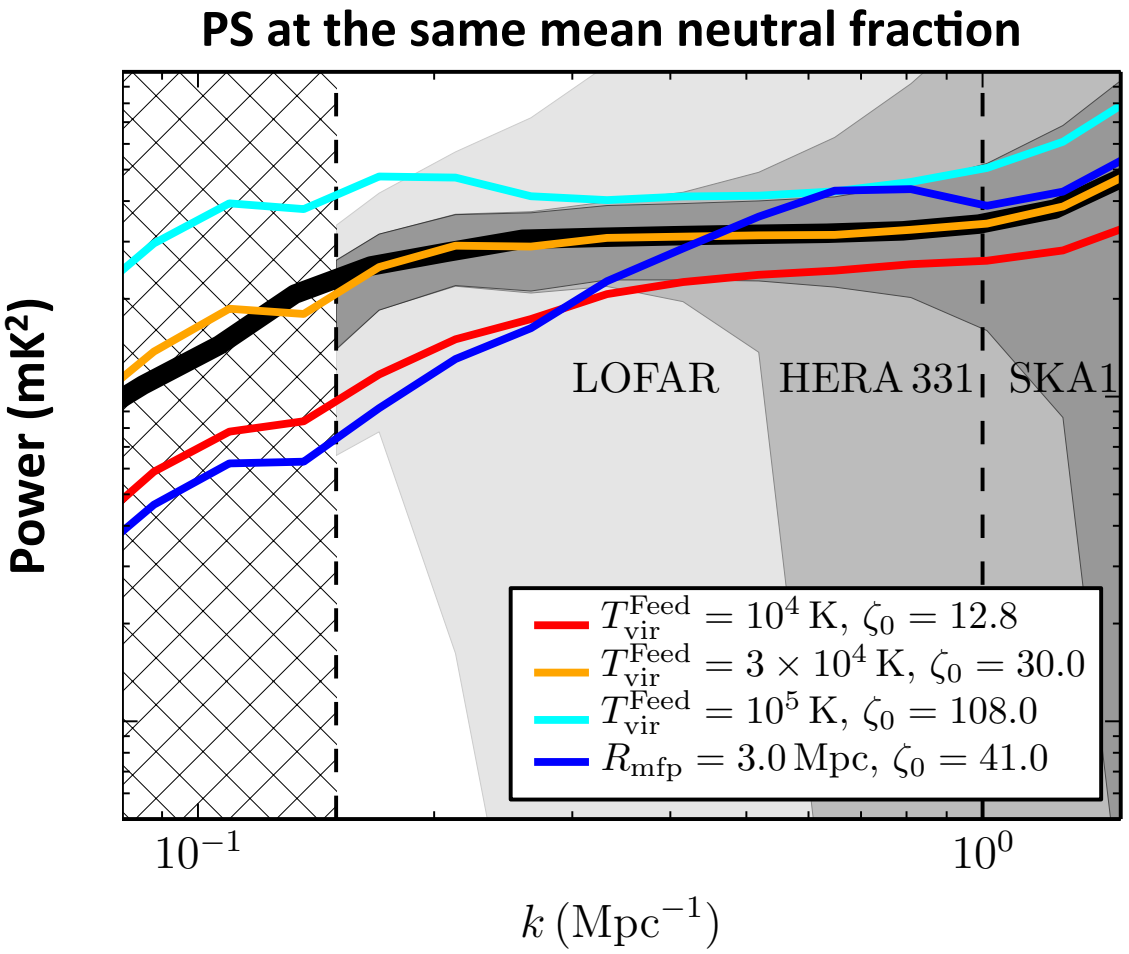
94 Mpc ~
30 arcmin

McQuinn+ 2007

Abundant, faint galaxies vs **Rare, bright galaxies**

Pictures are nice, but we need numbers

- Common/simple statistic: power spectrum during EoR



Greig & Mesinger (2015)

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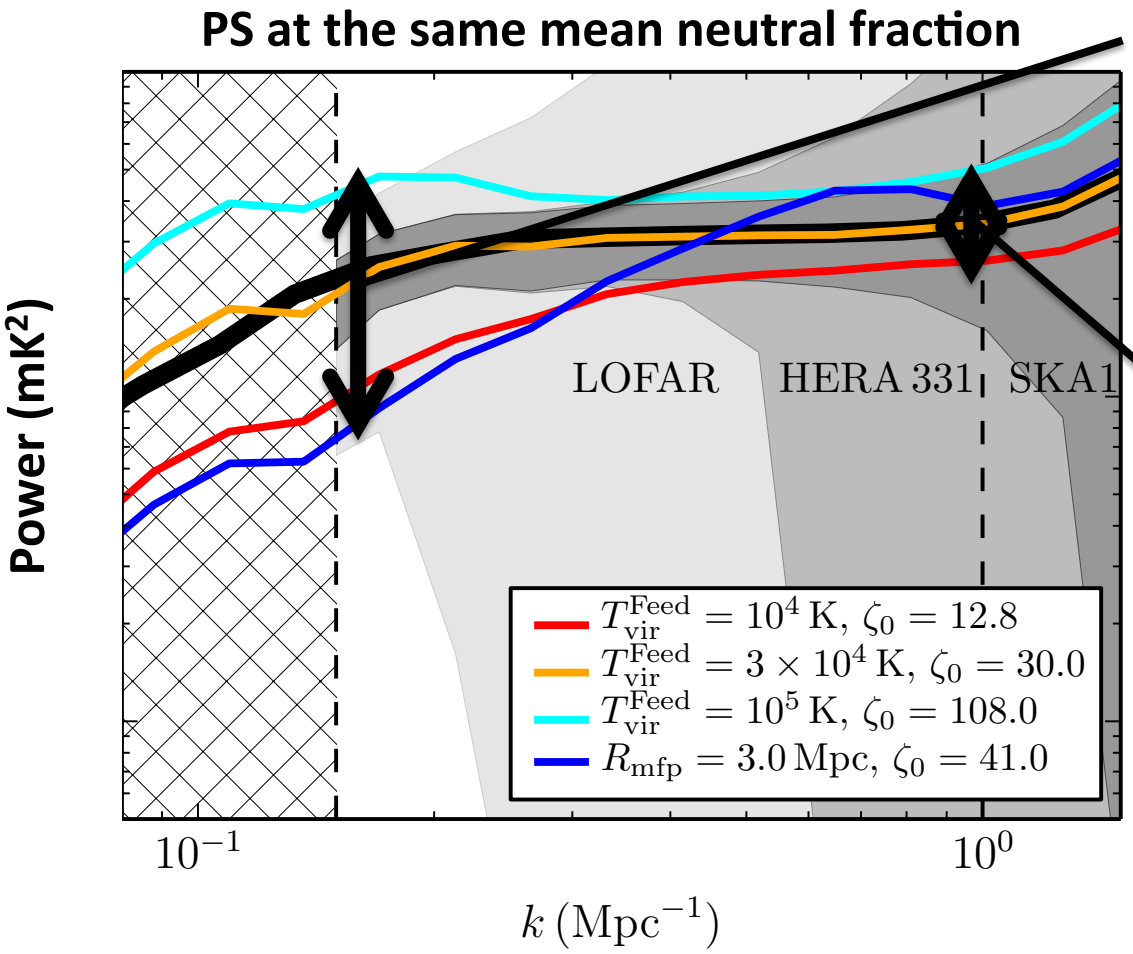


Factor of ~10 variation on large scales between astrophysical models, at a fixed EoR epoch.

Factor of ~2 variation on small scales between astrophysical models, at a fixed EoR epoch.

hint: large-scale power is a better discriminant of EoR astrophysics

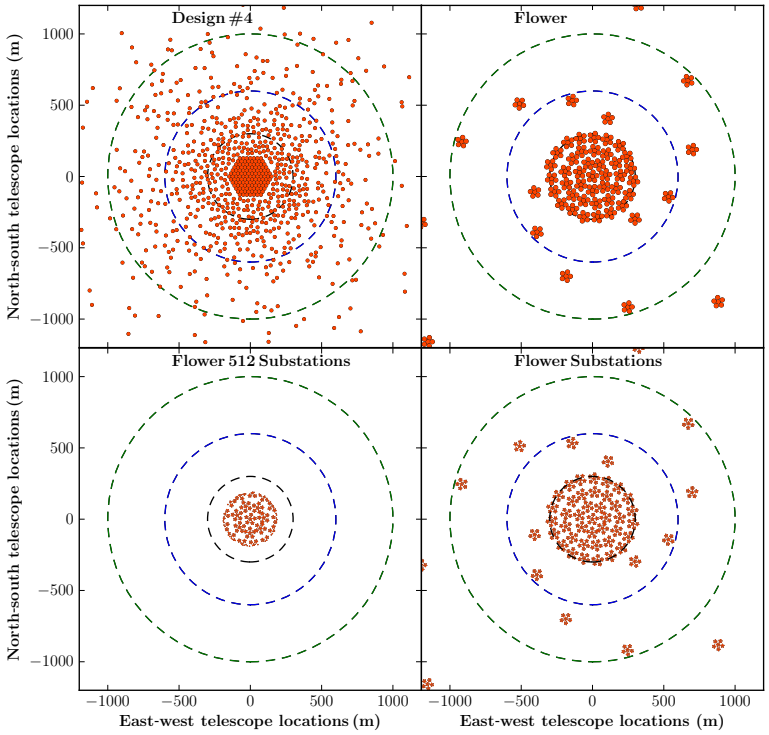
Greig & Mesinger (2015)

Can we detect this?

- Compare four SKA1-Low designs, for a 1000 h observation

Design #4 from Greig+2015**:** 2014 Baseline Design + packed core, ½ number of antennas per station, 866 x 25m stations in R~1km core

Flower design (V4D):
564 x 30m stations, no substations, All stations correlated.

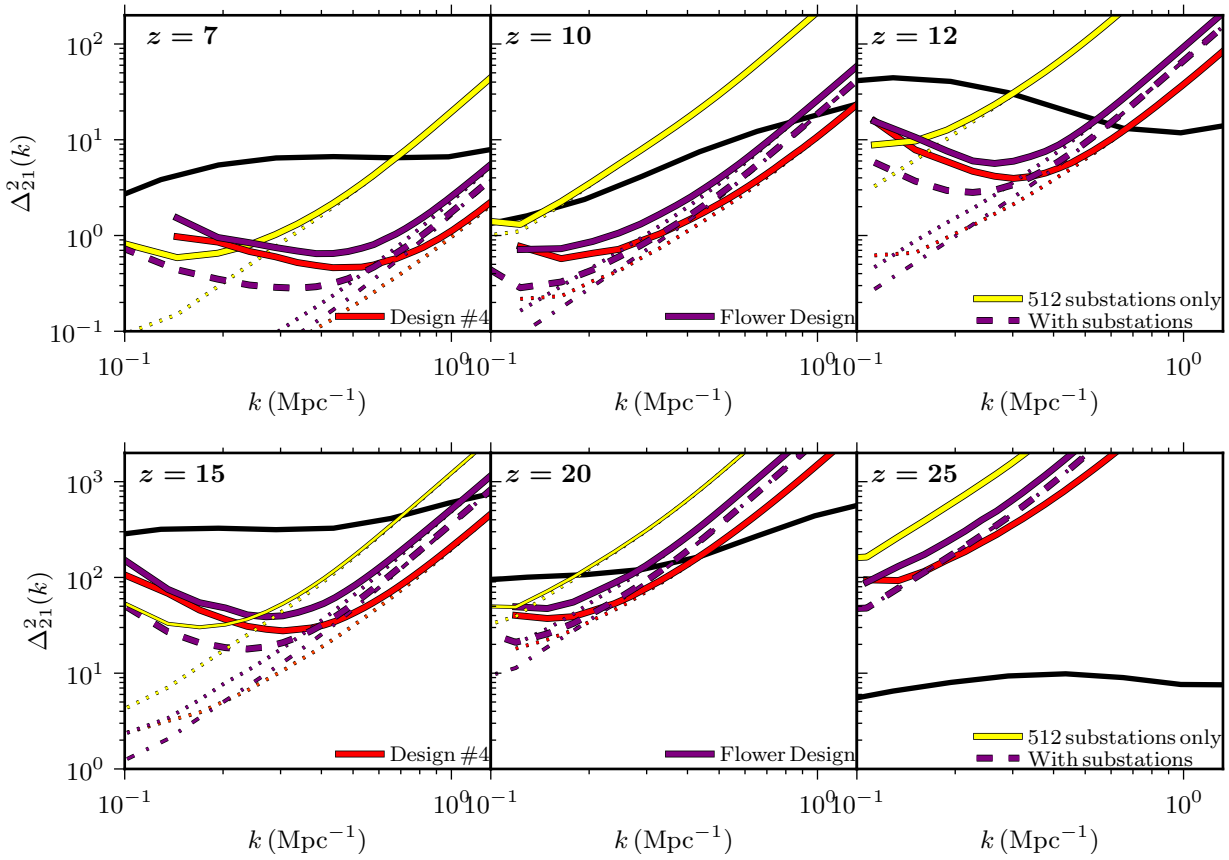


Flower design w. 512 substations (V4A_512):
3384 x 10m substations (1440 in core), N=512 correlations of core substations.

Flower design w. substations (V4A):
3384 x 10m substations (1440 in core), All substations correlated.

Can we detect this?

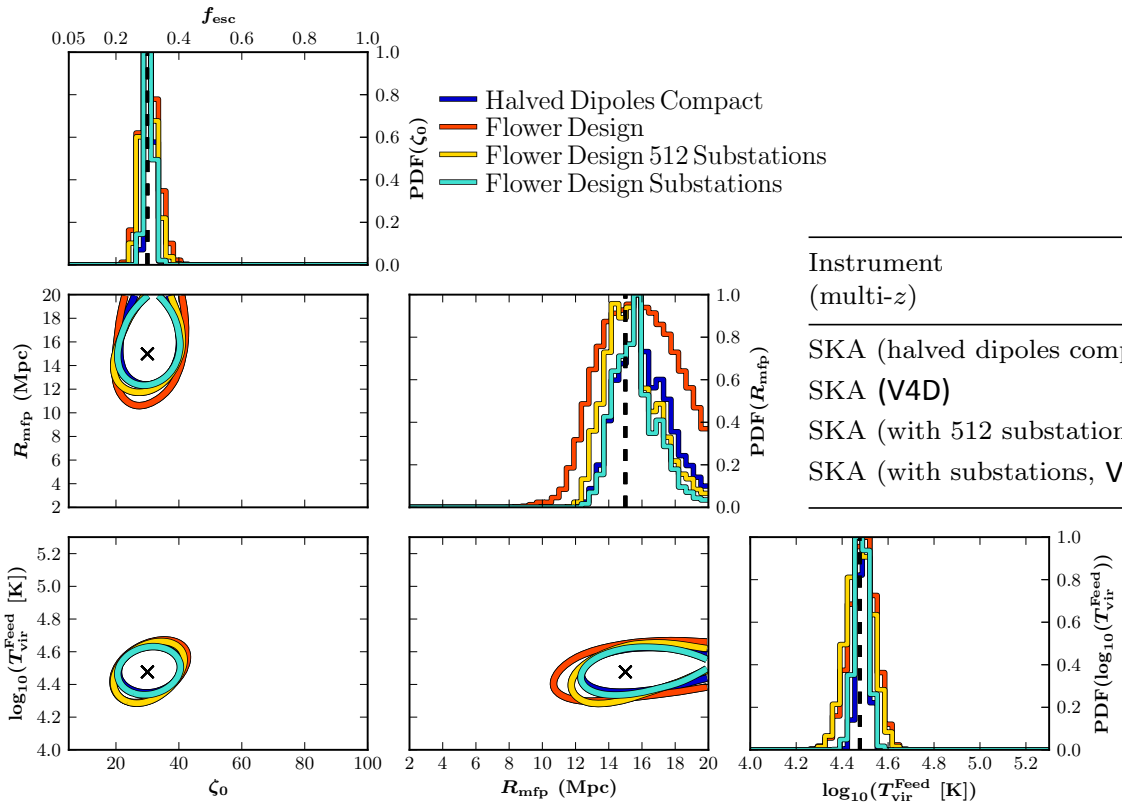
- PS sensitivity, foreground avoidance (e.g. Pober+2014)



- **Design #4** from Greig+2015 is best at reducing thermal noise.
- **V4A with full** (**N=1400** in core) substation correlation is best at reducing cosmic variance.
- **V4A with only N=512** correlations is generally the worst in terms of total S/N, though not so bad at EoR parameter recovery…

Bayesian EoR parameter recovery

- Use 21CMMC (Greig & Mesinger 2015) to recover astrophysical constraints → better "figure of merit" than S/N



21CMMC (Greig & Mesinger 2015)
https://github.com/BradGreig/21CMMC

Instrument (multi-z)	Parameter % uncertainty ζ	$R_{\rm mfp}$(Mpc)	$\log_{10}(T_{\rm vir}^{\rm min})$
SKA (halved dipoles compact)	7.60%	19.05%	1.04%
SKA (V4D)	18.72%	27.27%	2.54%
SKA (with 512 substations V4A)	15.89%	20.13%	2.50%
SKA (with substations, V4A)	8.51%	16.98%	1.28%

2σ constraints

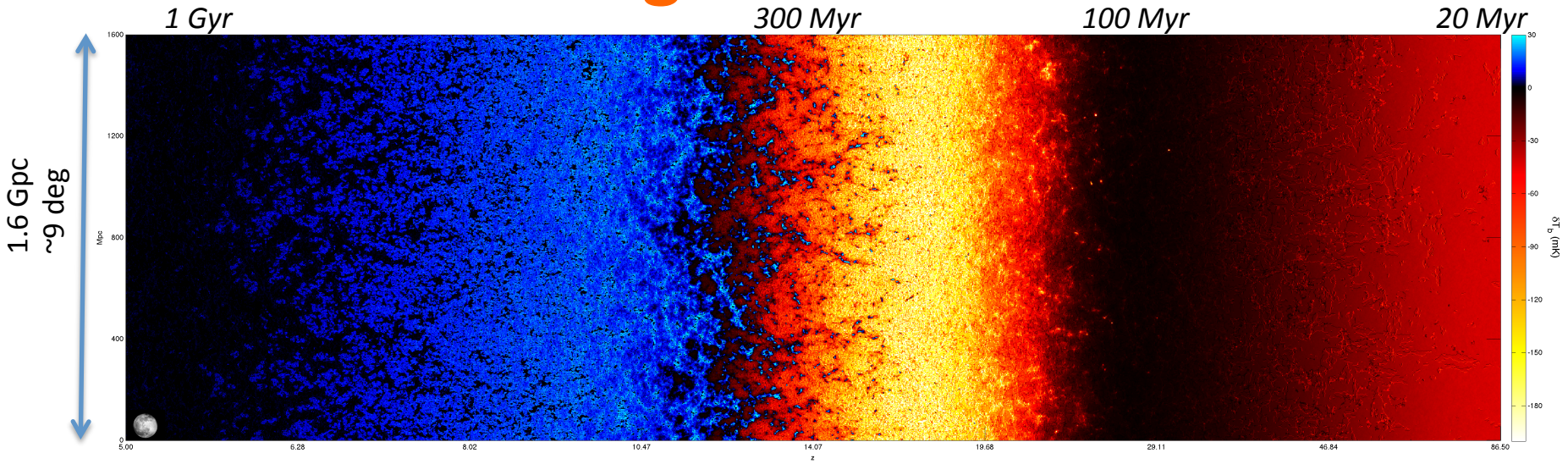
As seen earlier, EoR parameters are more sensitive to evolution of large-scale power→ favors minimizing cosmic variance.

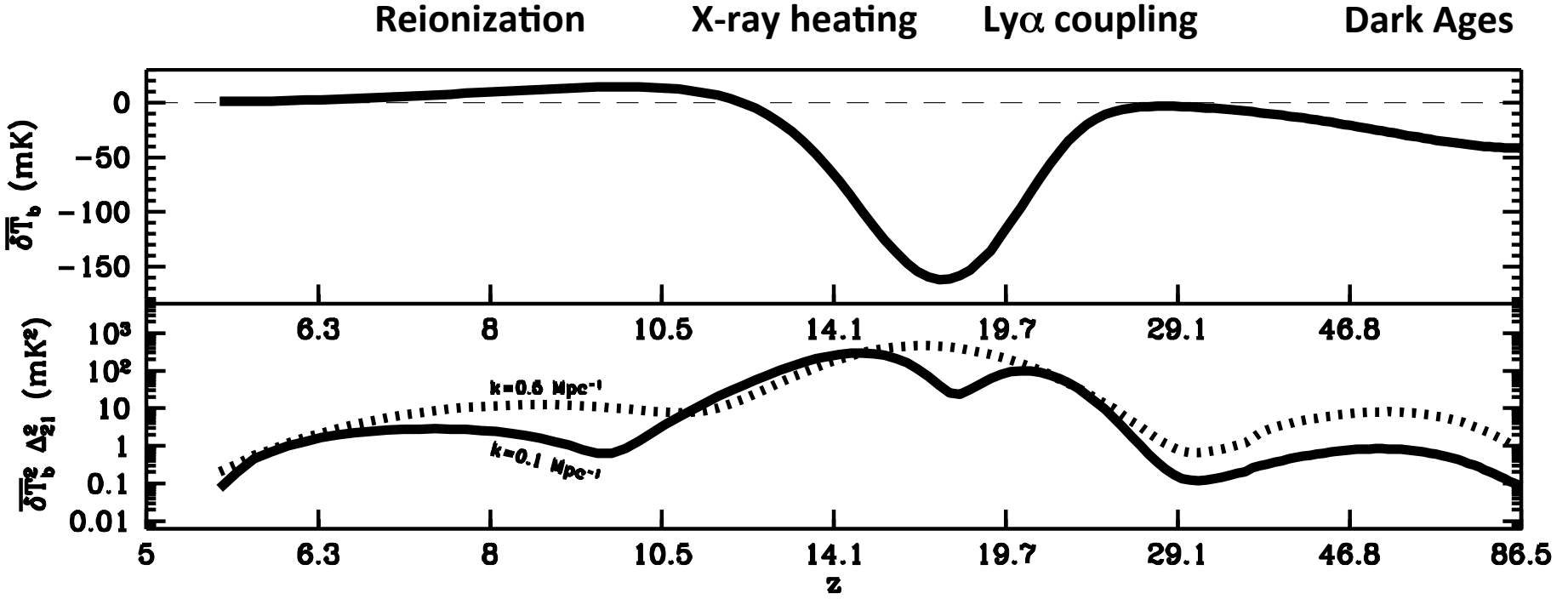
EoR winners: Design#4 and V4A with full correlations

But there is so much more…

In addition to statistical characterization of EoR, the transformational SKA1-Low science will be (i) EoR tomography (see Cath's talk) and (ii) Cosmic Dawn

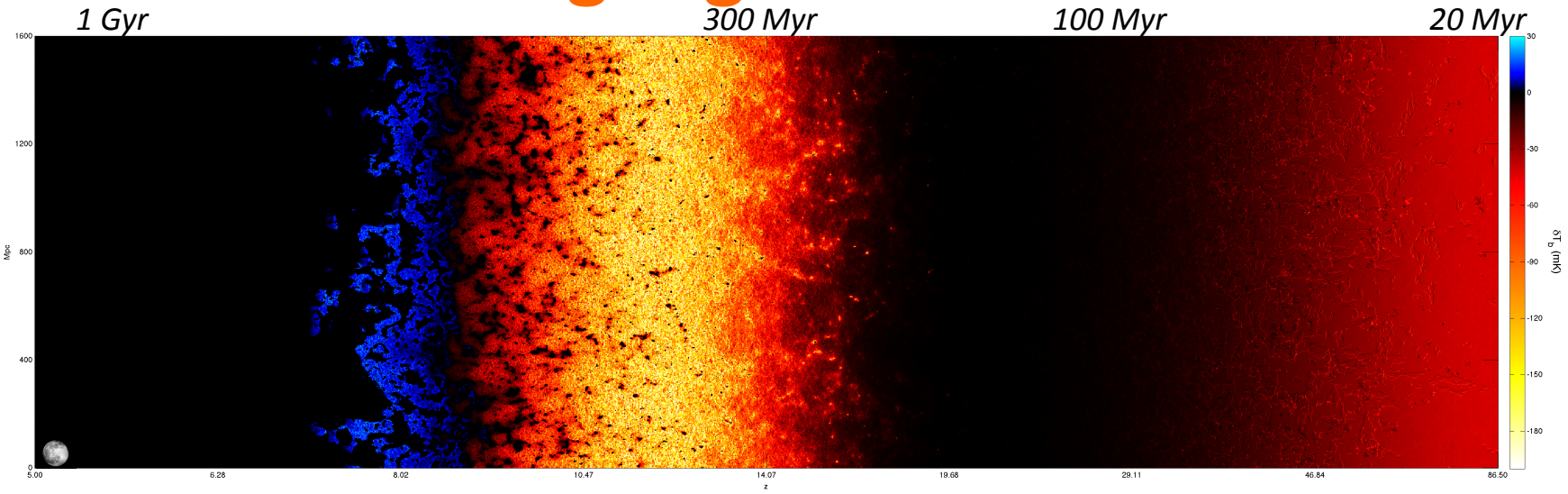
Faint galaxies model



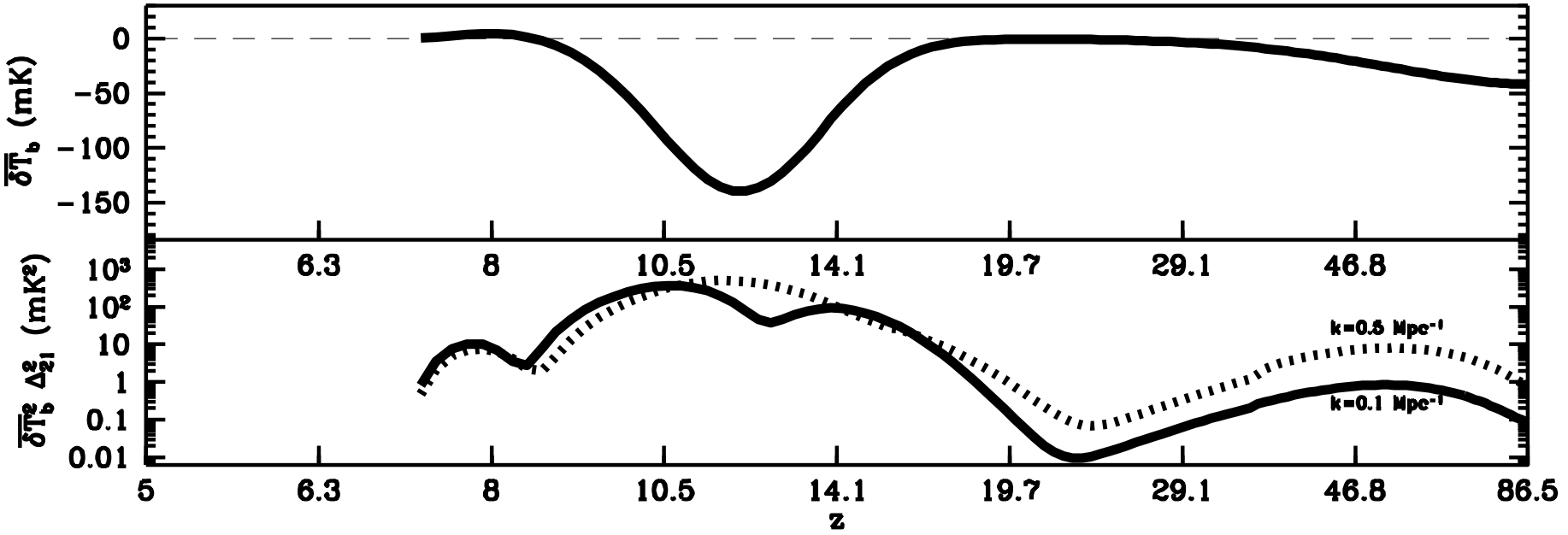


Evolution of 21cm Structure (EOS) 2016 data release. Mesinger+ (2016)

or…. Bright galaxies model

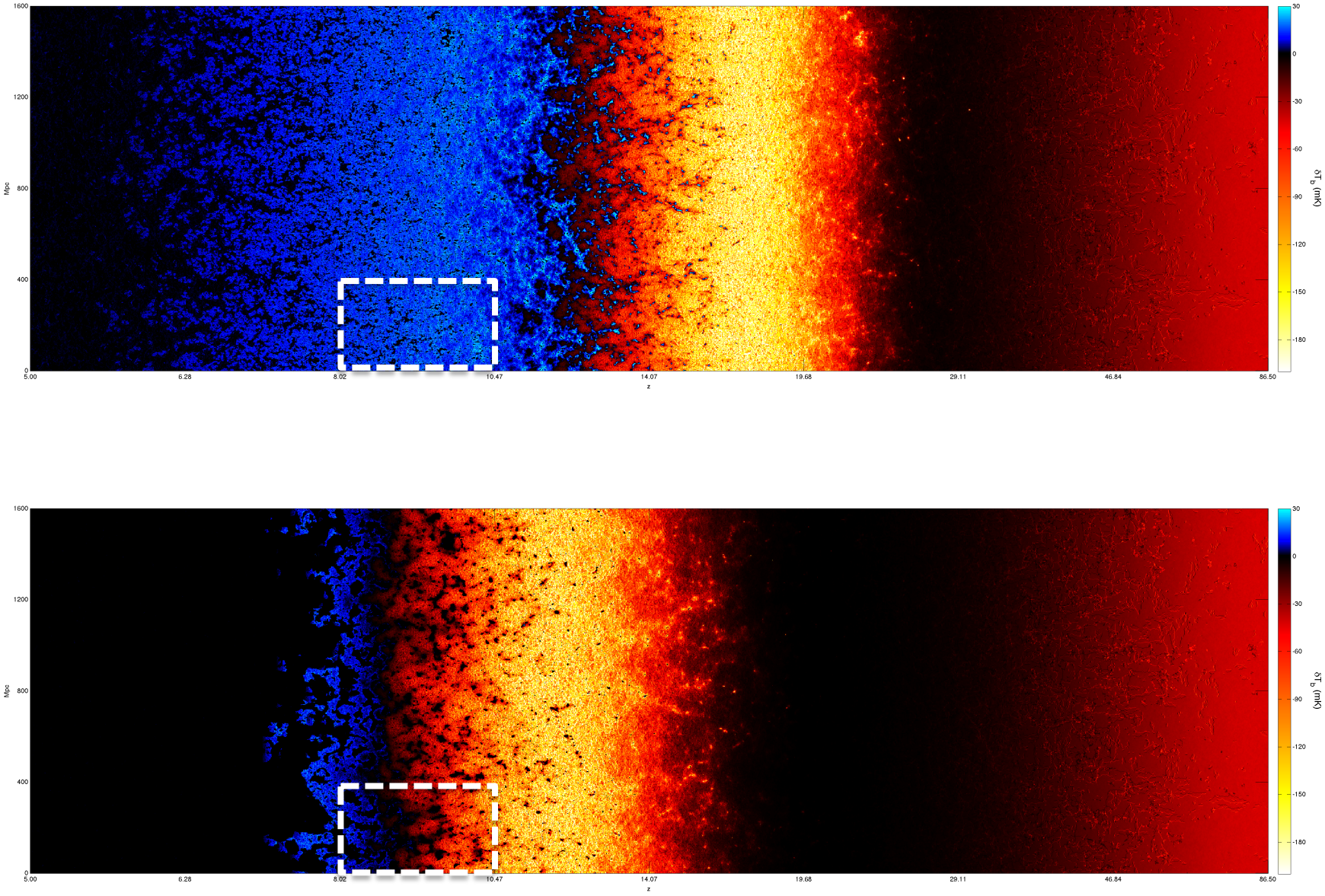


Reionization **X-ray heating** **Lyα coupling** **Dark Ages**

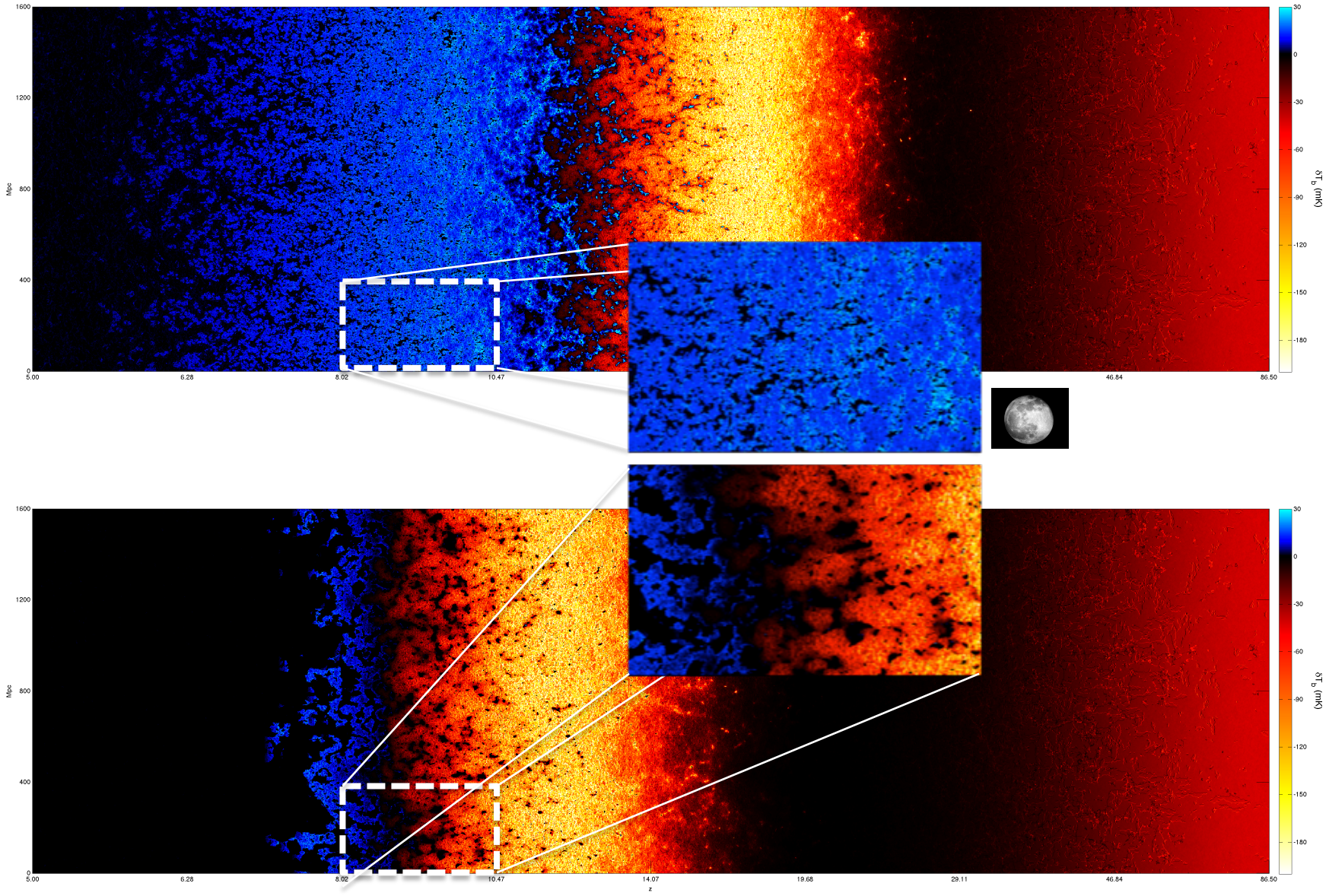


Evolution of 21cm Structure (EOS) 2016 data release. Mesinger+ (2016)

21cm structures tell the story of unseen galaxies

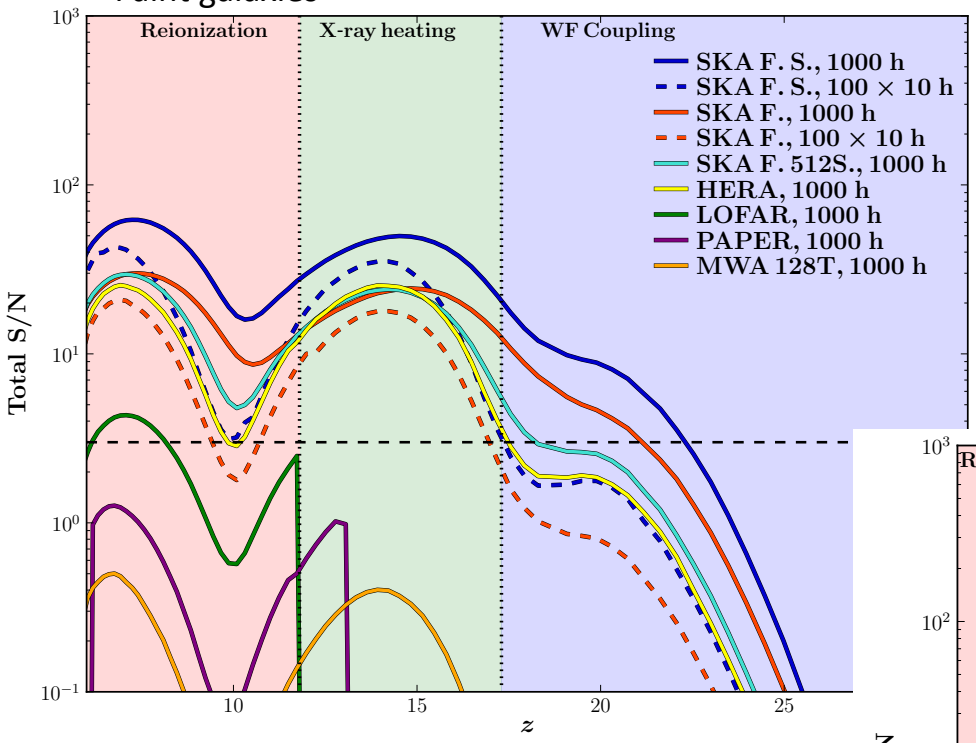


21cm structures tell the story of unseen galaxies



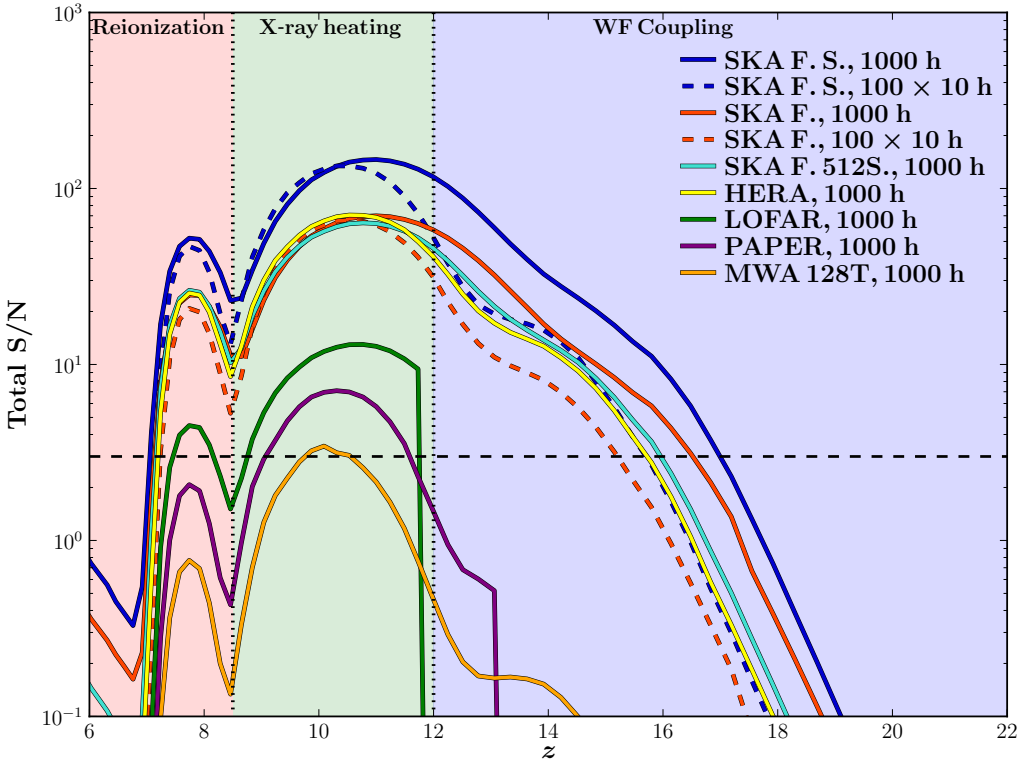
Total S/N evolution

Faint galaxies



- ***Overall S/N winner is: V4A with full substation correlation.***
- ***We need to correlate the inner N~1000 substations for V4A to be better than V4D during Cosmic Dawn.***
- ***V4A_512 would be a comparable instrument to HERA.***

Bright galaxies



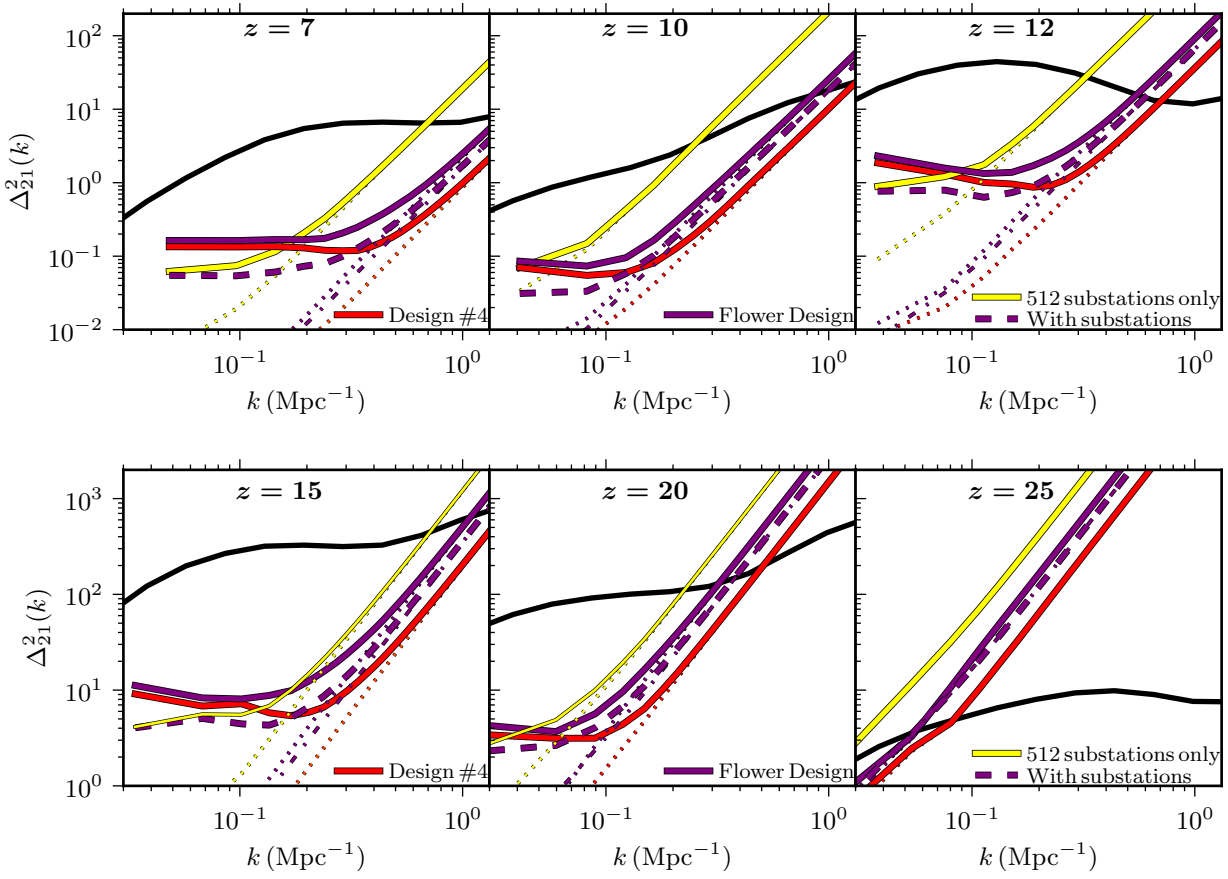
High S/N during EoR and X-ray heating should allow imaging!

Mesinger, Greig, Sobacchi (2016)

Conclusions

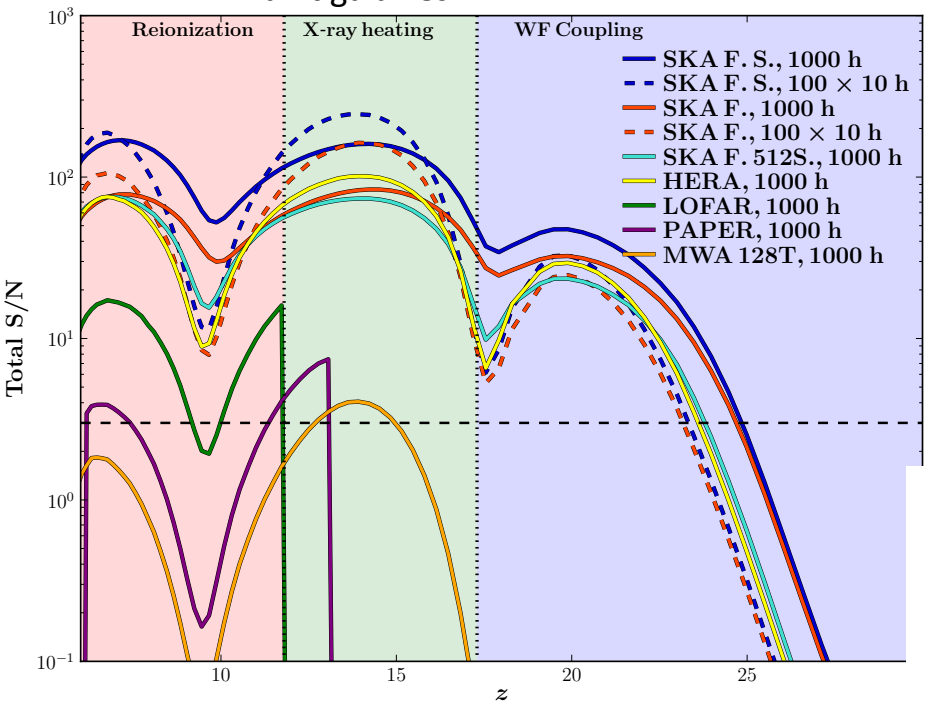
- We don't know what is out there so we need to be flexible.
- EoR parameter constraints prefer packed cores and wide beams minimizing cosmic variance (large modes, k~0.1/Mpc, best descriminate EoR models).
  - Substations (V4A) can improve EoR parameter constraints over V4D by up to a factor of 2.
  - Improvements scale with number of correlations (up to N~1400 in the core). *Note correlator prices decrease with time!*
- EoR tomography and calibration → *see Cath's talk*
- Cosmic Dawn detections are more sensitive to thermal noise than the EoR at higher frequencies. Winners are:
  - V4A with complete substation correlation;
  - V4D (factor of ~2 lower S/N than V4A with complete correlation)
- ***Suggestions:***
  - ***Be flexible by building V4A with a packed core, waiting until stations are on the ground to buy the best possible correlator, N~1000.***
  - ***Be flexible by having antennaes with a flat frequency response over a wide range (the low frequency range of SKA1-Low will be transformational science).***

Sensitivity, foreground subtraction



S/N evolution, foreground subtraction

Faint galaxies



Bright galaxies