21-cm roadmap summary

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on behalf of the 21 cm roadmap WG

An existential crisis (started at last CVDE meeting)

What science am I going to do 15 years from now ?

Is there any room to improve over DESI/CMB-S4/Euclid/WFIRST/LSST ?

But improve what ?

And how to quantify ? Frustration with FOM and Fisher. Small scales probes are hard to forecast.
Very likely improvement will come outside P(k) at linear and mildly non linear scales.

Incremental improvement is not enough !
Precision cosmology means benchmarks to be achieved.

Examples are neutrino masses, inflationary parameters, N_eff, curvature.

Dark energy is the elephant in the room in this discussion.

No modes left behind

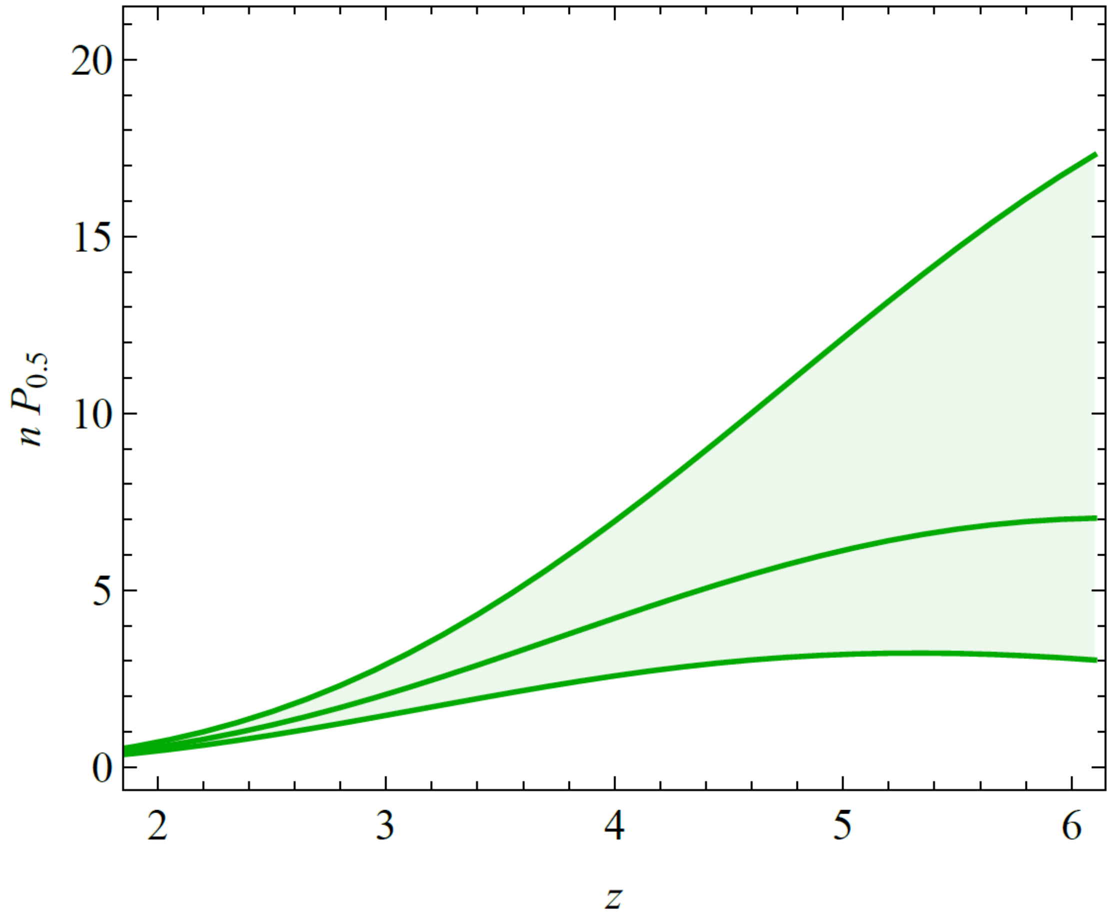
Neutral hydrogen is the field with the largest cosmological signal

nP(k)<<1 : shot-noise limited

nP>>1 : Cosmic Variance limited.

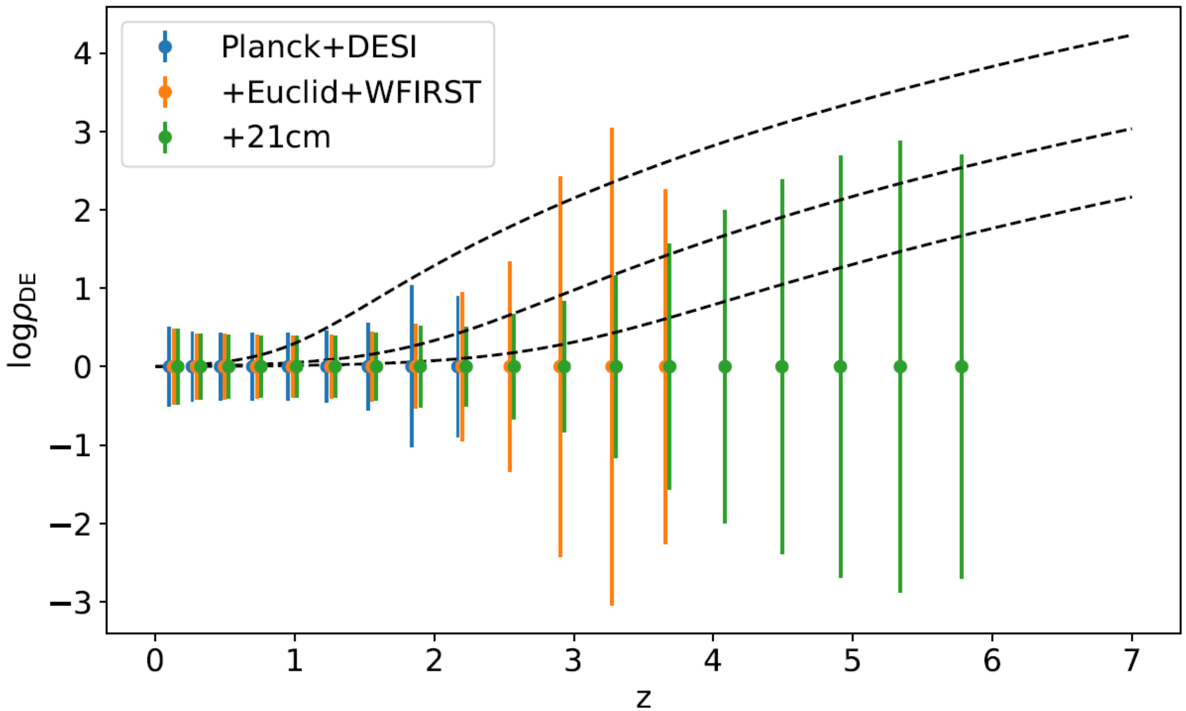
<u>HI offers the possibility of CV limited measurements down to very small scales.</u>
Existing and planned spectro-z surveys have nP~1 @ k=0.2 h/Mpc

Foregrounds and calibration error reduce S/N, but this should motivate us to work harder to solve these issues



Always keep in mind that P(k) Fisher forecast might not be the right way to quantify the information content of such a field.
21 cm lensing @ S. Foreman and new ideas about x-corr with CMB @ Kavi Moodley

The case for DE at high z



The absence of a theory target for DE forces us to check that at high z that the Universe behaves as expected.

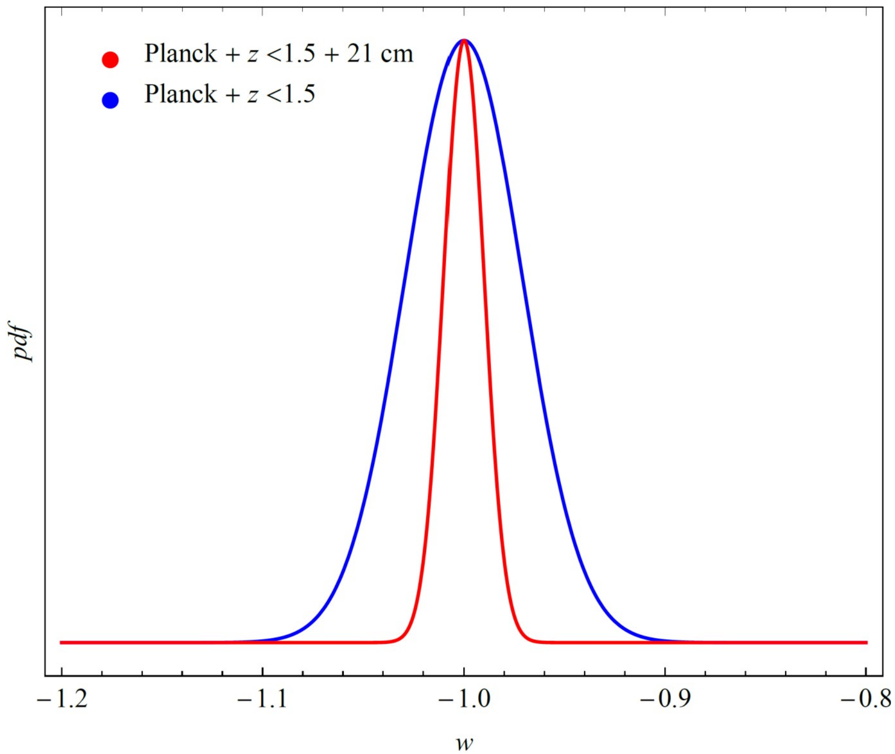
21 cm offers a unique possibility to constraint DE deep in the matter-dominated era.

21 cm helps breaking the degeneracy between DE and neutrinos.

3 % error on EOS w/o 21 cm

1 % with 21 cm

<u>These numbers include basic foregrounds, wedge and instrumental noise.</u>



Relativistic number of DOF

Another reason to go to high z with a CVL experiment

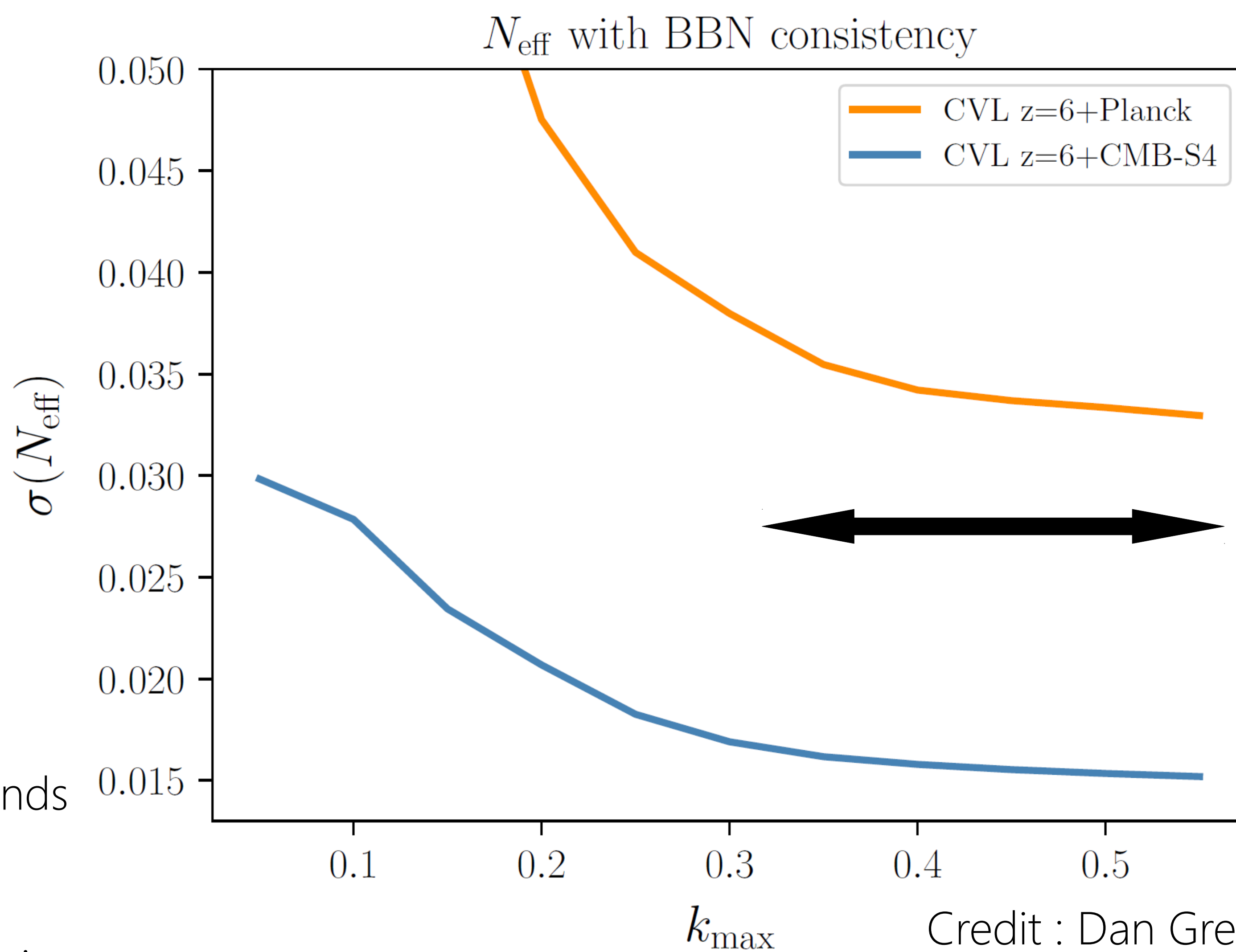
Information on Neff
is mostly in the broadbad.

A CVL experiment improve
substantially over CMB-S4

In our forecasts

$$\sigma_{N_{\rm eff}} \simeq 0.02$$

Including noise and foregrounds



Credit : Dan Green

A similar results hold for neutrino masses

$$\sigma_{m_\nu} \simeq 0.02 \text{ eV}$$

OK… but what about the foregrounds?

The numbers I have shown could improve and reach the CVL with lower system noise.
Three roads:

- Observe for more time (cheap)

- Cryogenic cooling (expensive)

- Bigger arrays (doable)

However the way we deal in the foregrounds in the Fisher might not be enough.

Jeff Peterson: ''**If we had asked a CMB person 25 years ago about measuring polarization at low ell they would have told us it is impossible**.''

Need to come up with requirements on instrumental uncertainties, e.g. beams, similar to LSST ones on photo-z. If beam is solved foregrounds are less of a problem.

Shaw+14 present numbers for CHIME, ~.1% to successfully remove the wedge

BAO science is anyway very robust.

The burden

21 cm IM is a very young field, first detection Chang+08

GBT has shown it works in cross correlation, and it is working on auto and RSD.

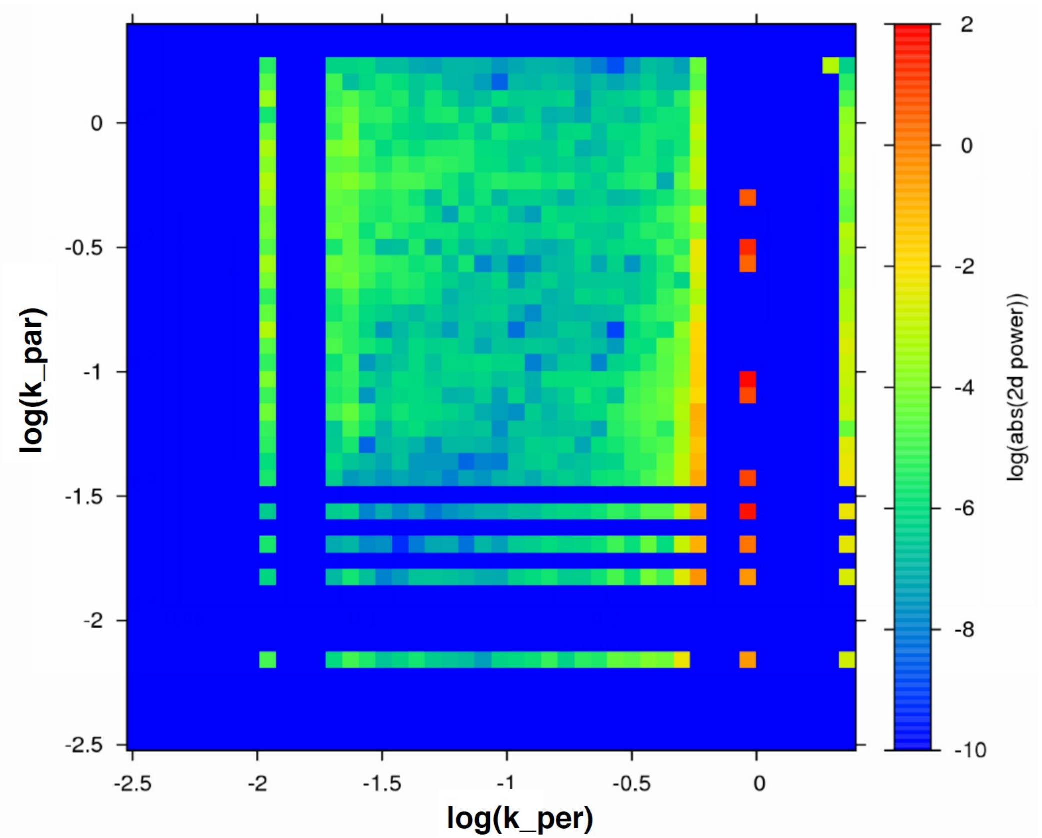
In single dish progress with
beam, polarization leakage, no wedge.

Interferometers:

HIRAX: prototype built, very clean site,
128 array already funded.

CHIME: pathfinder analysis ongoing,
Commissioning the full instrument.

Tianlai: small array built, flexible configuration
to optimize S/N



@ Tzu-Ching Chang

21 cm roadmap

	White Paper Expt	Post LSST/DESI	Dark Ages	Context
2018-2020	Path finder experiment design & construction			CHIME first resuts
2020-2025	data taking / analysis			HIRAX first results, SKA online
2025-2030	data analysis	Collaboration forming and CD0/1		SKA results coming
2030-2035		Construction, start of data taking	feasibility study, preliminary design	?
2035 - 2040		data taking & analysis	Construction	?
2040 -			Data taking	?

21 cm roadmap: 1st step

16x16 array is large enough to do interesting science and be a fair representation of the big array. Small enough to serve as a technology testbed.

In the redshift range 1<z<3, is a test of large bandwidth experiments.

Overlap with DESI QSOs and Lyman-alpha forest.

BAO in 3 auto-correlations and cross-correlations.
Useful to robustly measure auto P(k) in 21 cm.

Continue DOE leadership in BAO science across redshifts.

Unique method to test fundamental physics up to z~6,
and possibly dark ages.

It turns out we would build something like HIRAX !

Very clean RFI site, take advantage of
existing infrastructure in a cost effective way.
128 array already funded by South Africa.

Conclusions

21 cm provides a unique way to test the fundamental physics.

The ultimate cosmological probes are dark ages.

- The 1st step is a stepping stone experiment to demonstrate the promise.
  At the same time BAO science can be improved at $1<z<3$

  Join HIRAX with a 16x16 array, and contribute to feed and electronic design, data analysis and project managment.

- The 2nd step would be a really aggressive experiment in late 20's.
  Dark energy science, inflationary physics and neutrino physics.