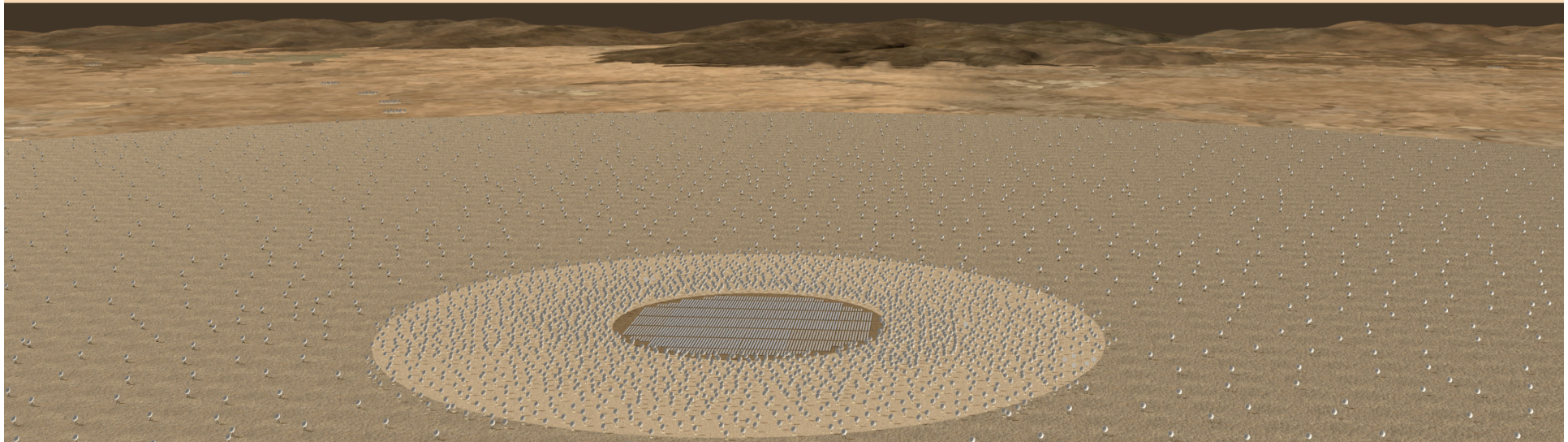
Synergies Between SKA and ALMA/ELT



1500 dishes in the central 5 km; 3000 total (0.5-10 GHz) +

10^6 m^2 of aperture arrays (0.05-1 GHz)

Western Australia or Southern Africa (phased roll-out begun)

- Precursors (ASKAP, MeerKAT) 2010, then site decision
- Phase-1 2015
- Phase-2 2020

Steve Rawlings, Oxford

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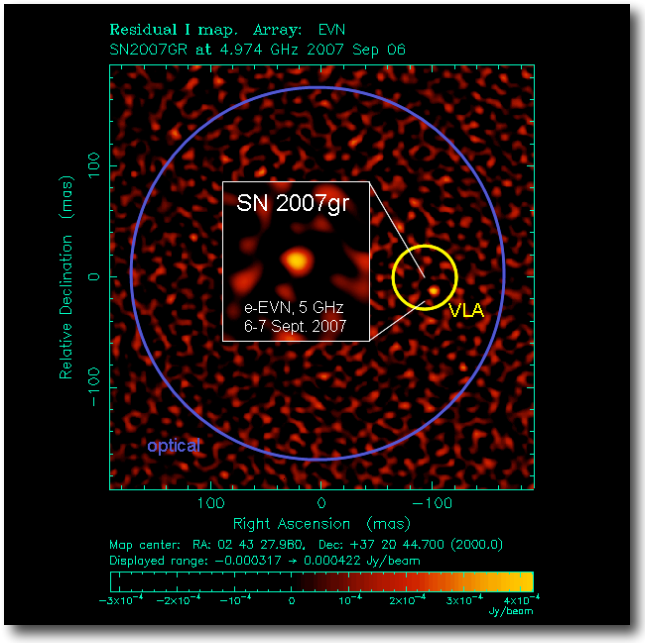
Globally co-ordinated technology programme

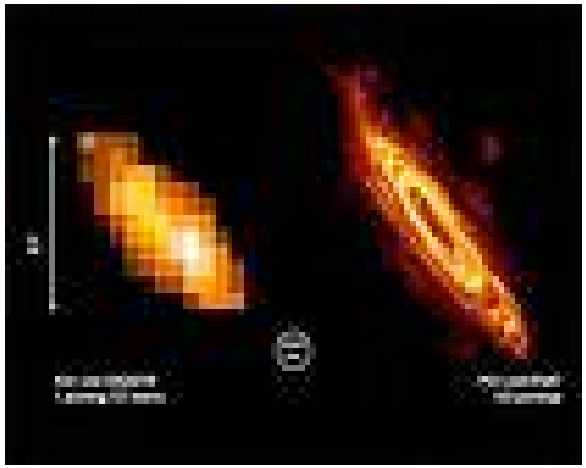
ZA: 15 m fibreglass+foam dish (<2mm r.m.s.)

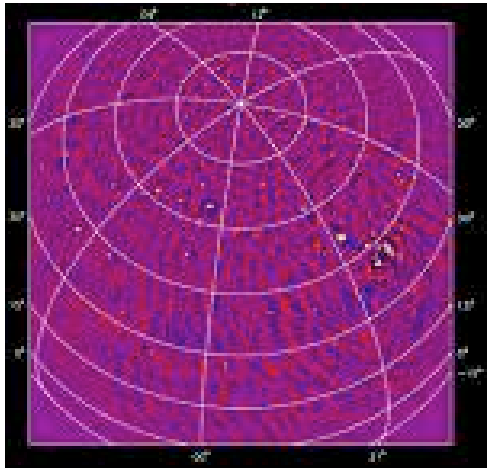
USA: 0.5-11 GHz feed for the ATA



eEVN: data transferred by optical fibres for real-time correlation

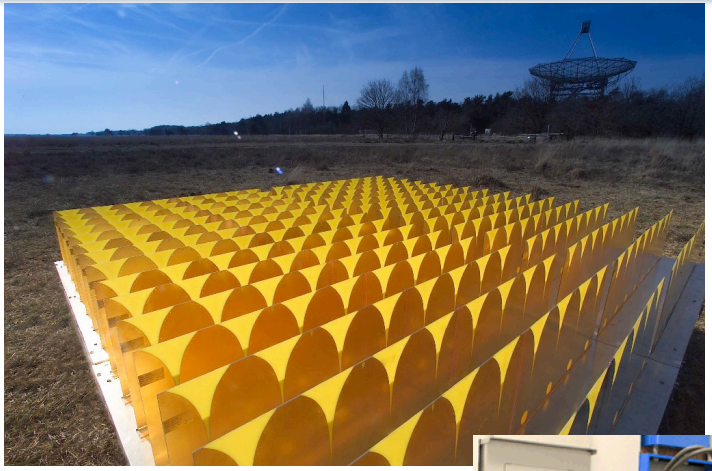
The Netherlands: APERTIF (DIGESTIF) - first images with a Focal Plane Array

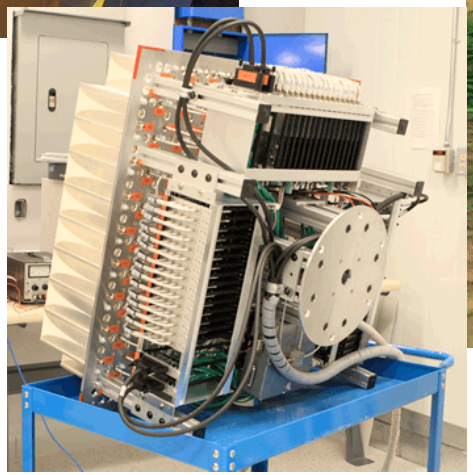


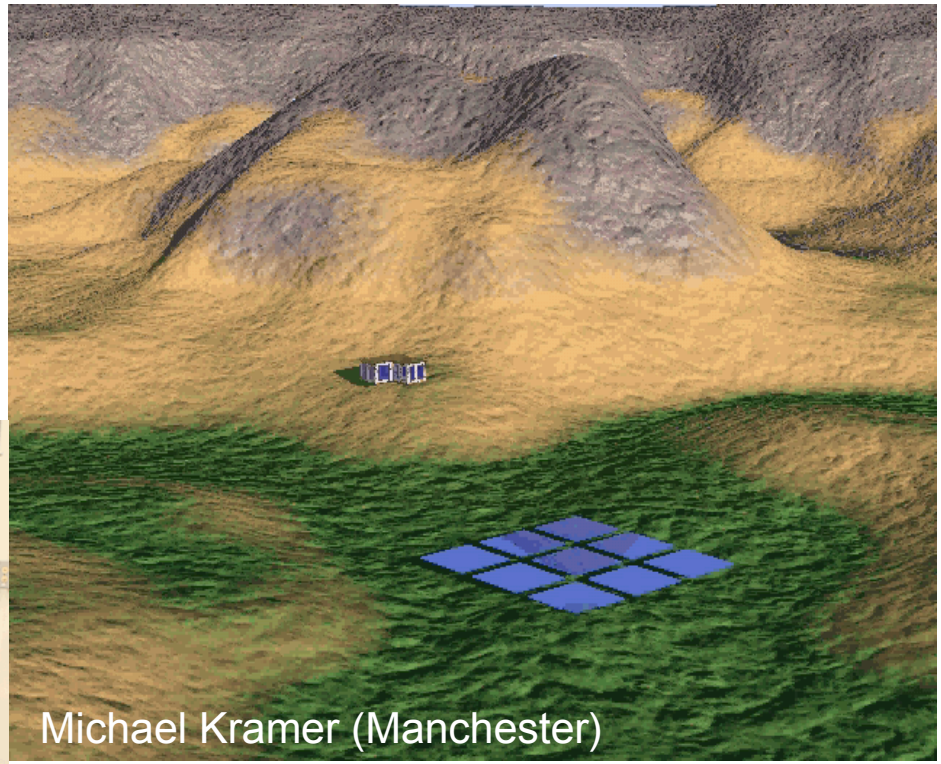


The Netherlands: LOFAR - first images with an Aperture Array

Phased arrays transform mapping speed





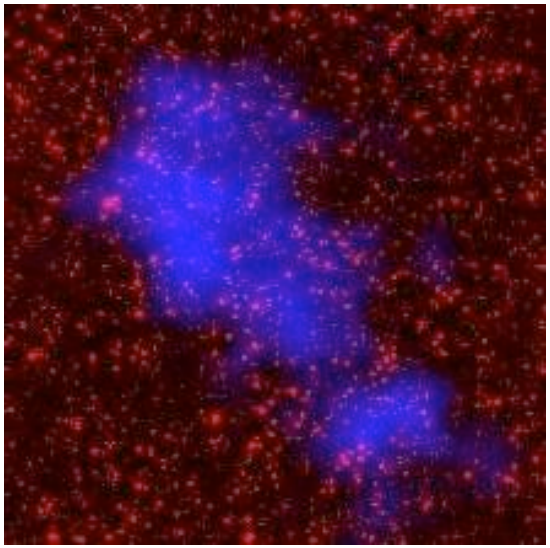


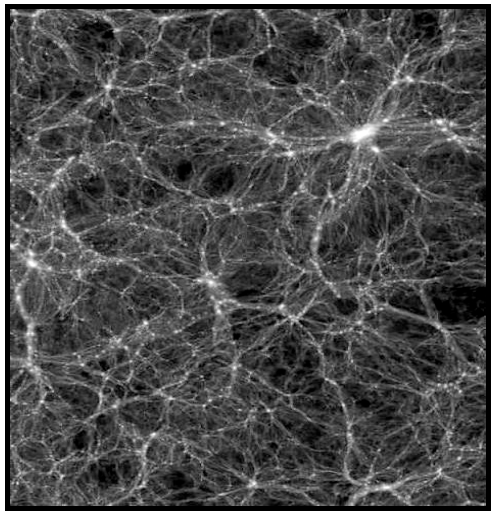
- ~10^8 `omni-directional' elements, separated by $\lambda/2$ to fully sample the wavefront
- design "All digital" to follow 'Moores Law': 250 distributed (out to ~200 km) `stations' gives <<1 arcsec resolution over 250 deg^2 in one shot; time buffering possible
- `Mapping speed' = FoV x $(A / T_{sys})^2$ improves on VLA by $10^2 \times 10^2 \times [10^2 \times 10] \sim 10^7$

Precursors Phase-1 [Phase-2]

SKA/ALMA/ELT Synergy Example I: Galaxy Evolution

HI → **H2** → **Stars**

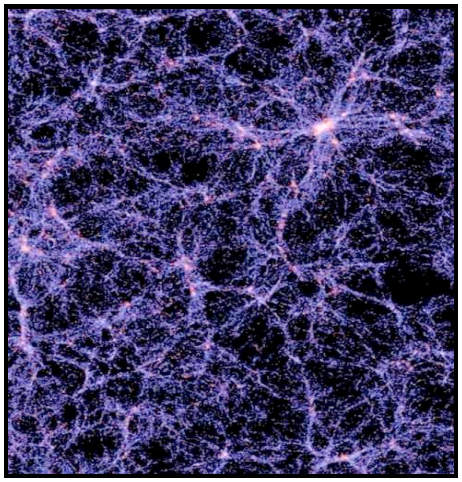




SKADS Simulated Skies

http://s-cubed.physics.ox.ac.uk

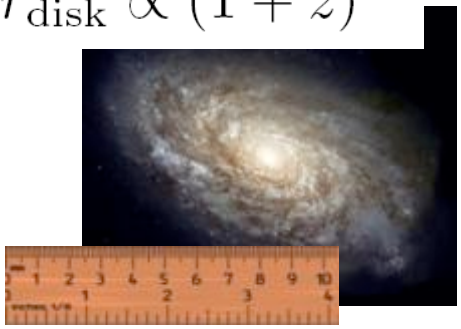
Now useable for ALMA too

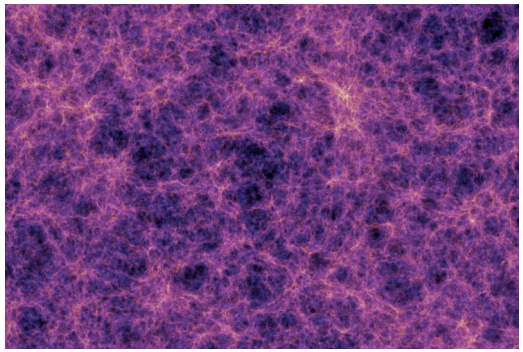


Dark Matter → **Gas** → **Stars**

HI and H_2 in Galaxies

$$r_{\rm disk} \propto (1+z)^{-1}$$



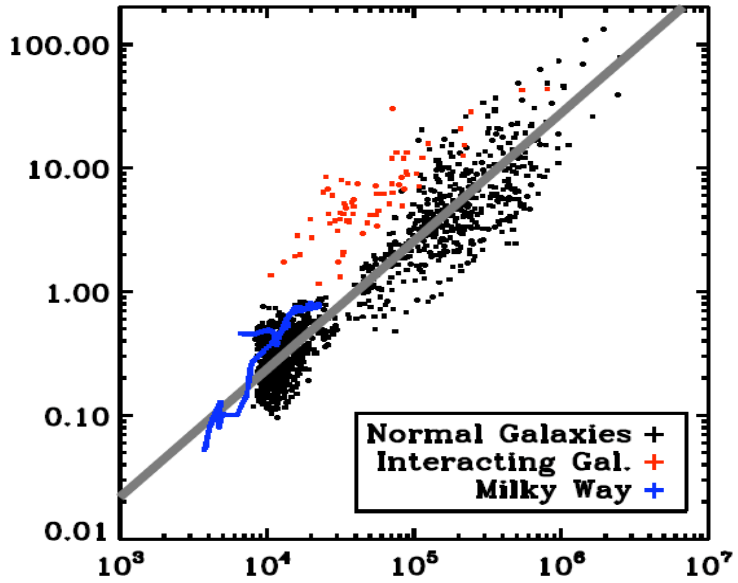


Parameters from Millenium Simulation plus semi-analytics

Our Model

No tunable parameters!

Properties of HI and H2



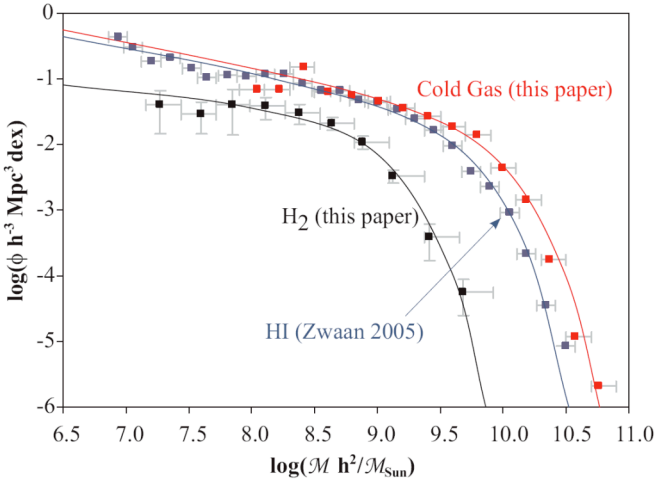
Molecular fraction from Pressure

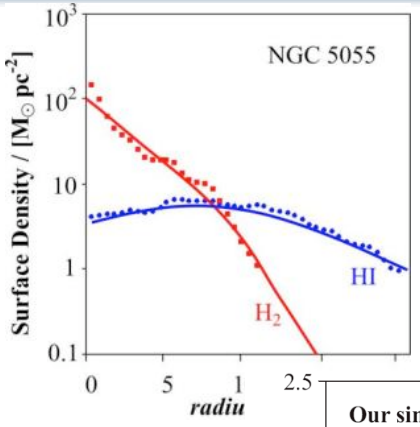
Obreschkow et al., 2009, ApJ, in press

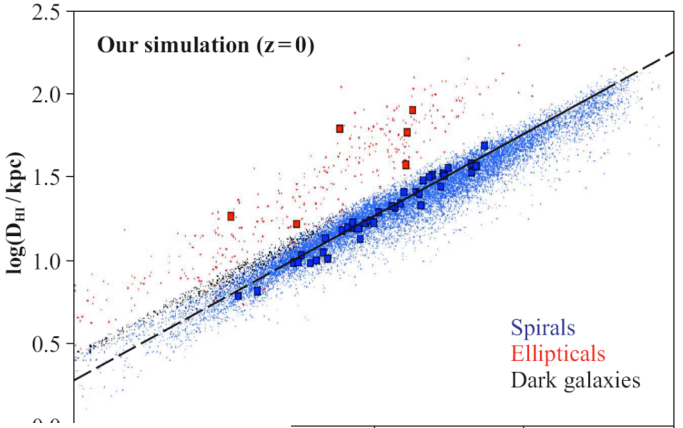
Verification against local observations

⇨Radial Profiles

⇨Mass Functions of HI and H2

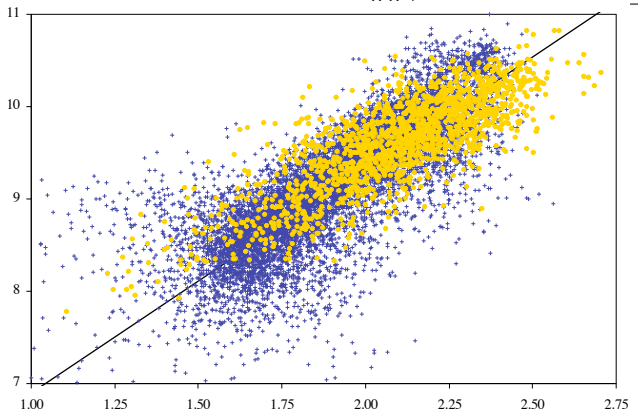






⇨ Mass-Diameter relations

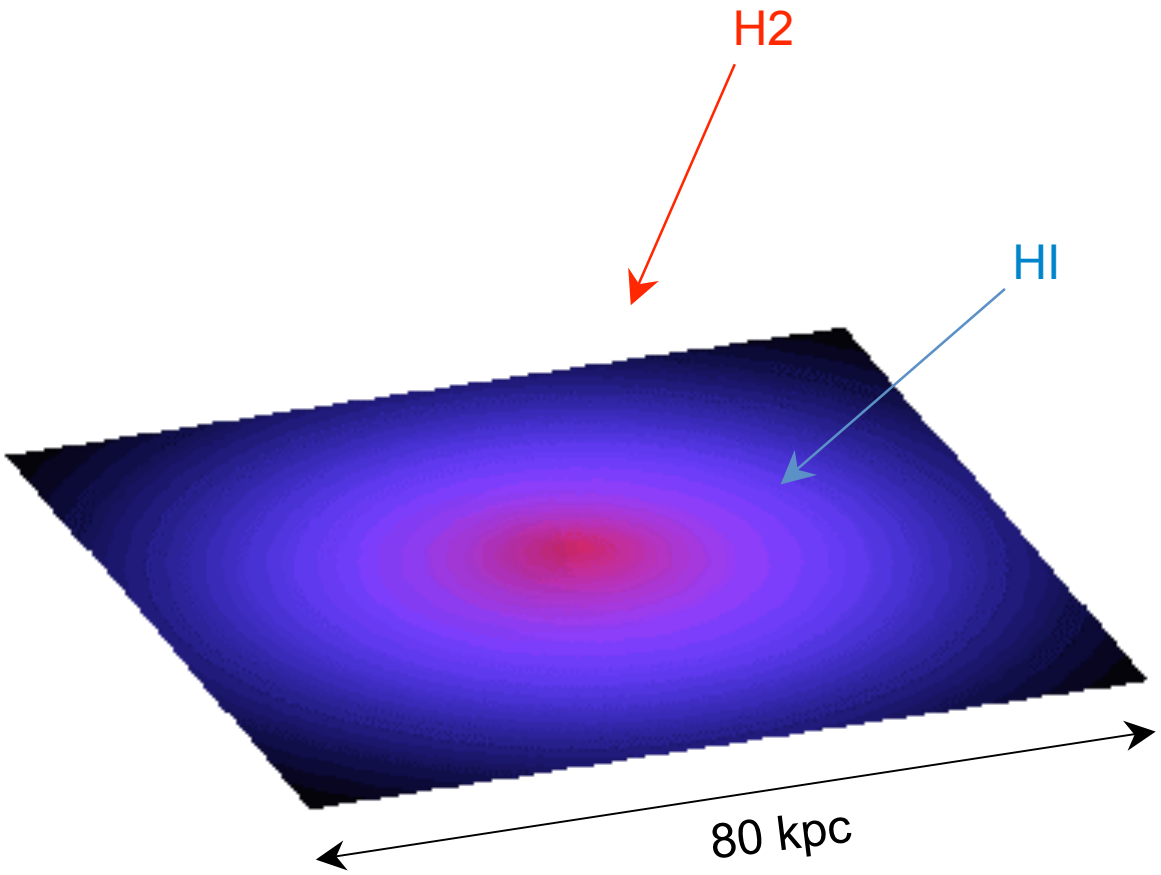
⇨ Mass-Velocity relations



Obreshkow & Rawlings 2009; Obreschkow et al., 2009, ApJ, in press

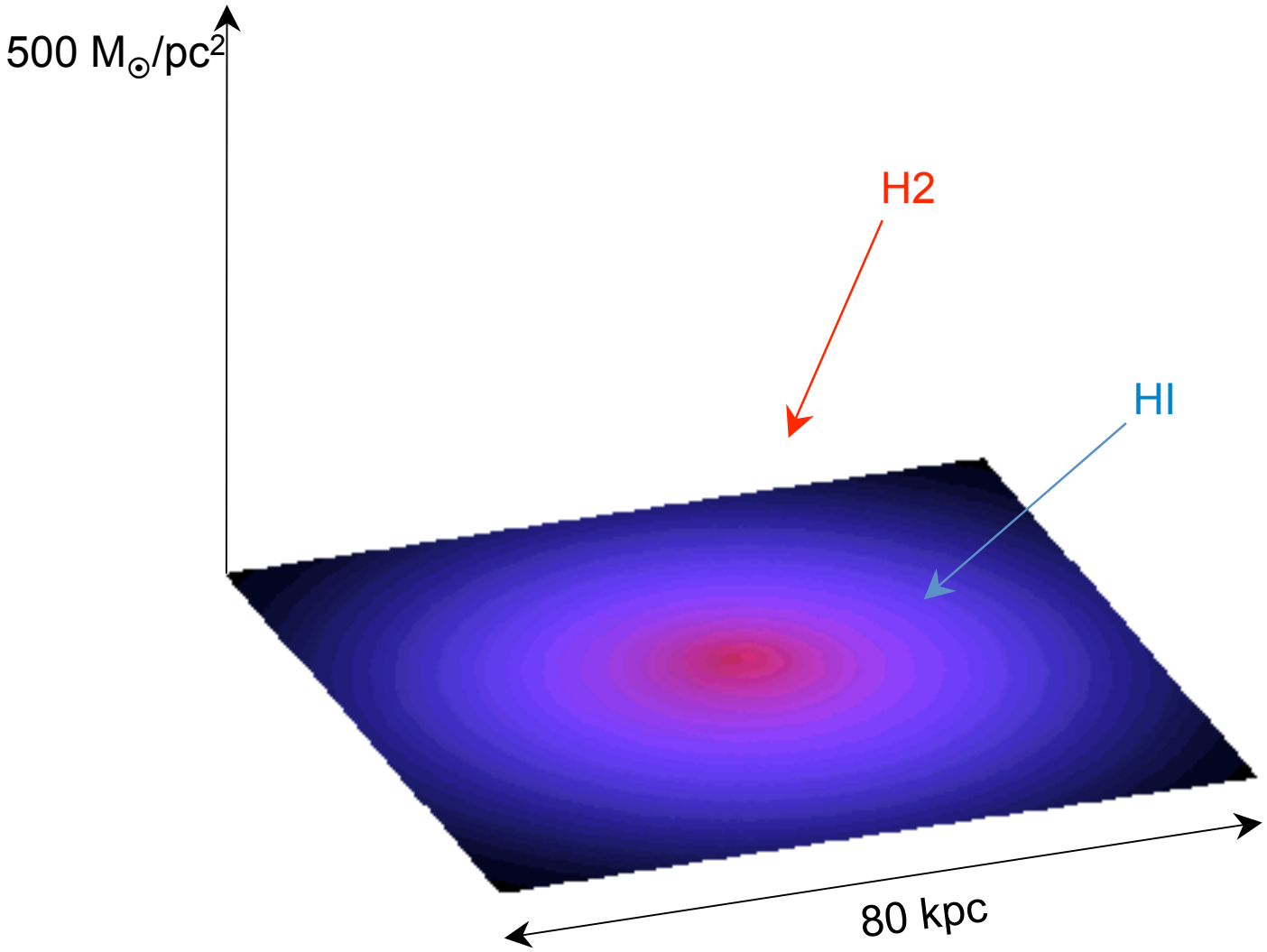
Milky Way

Redshift z = 0.00

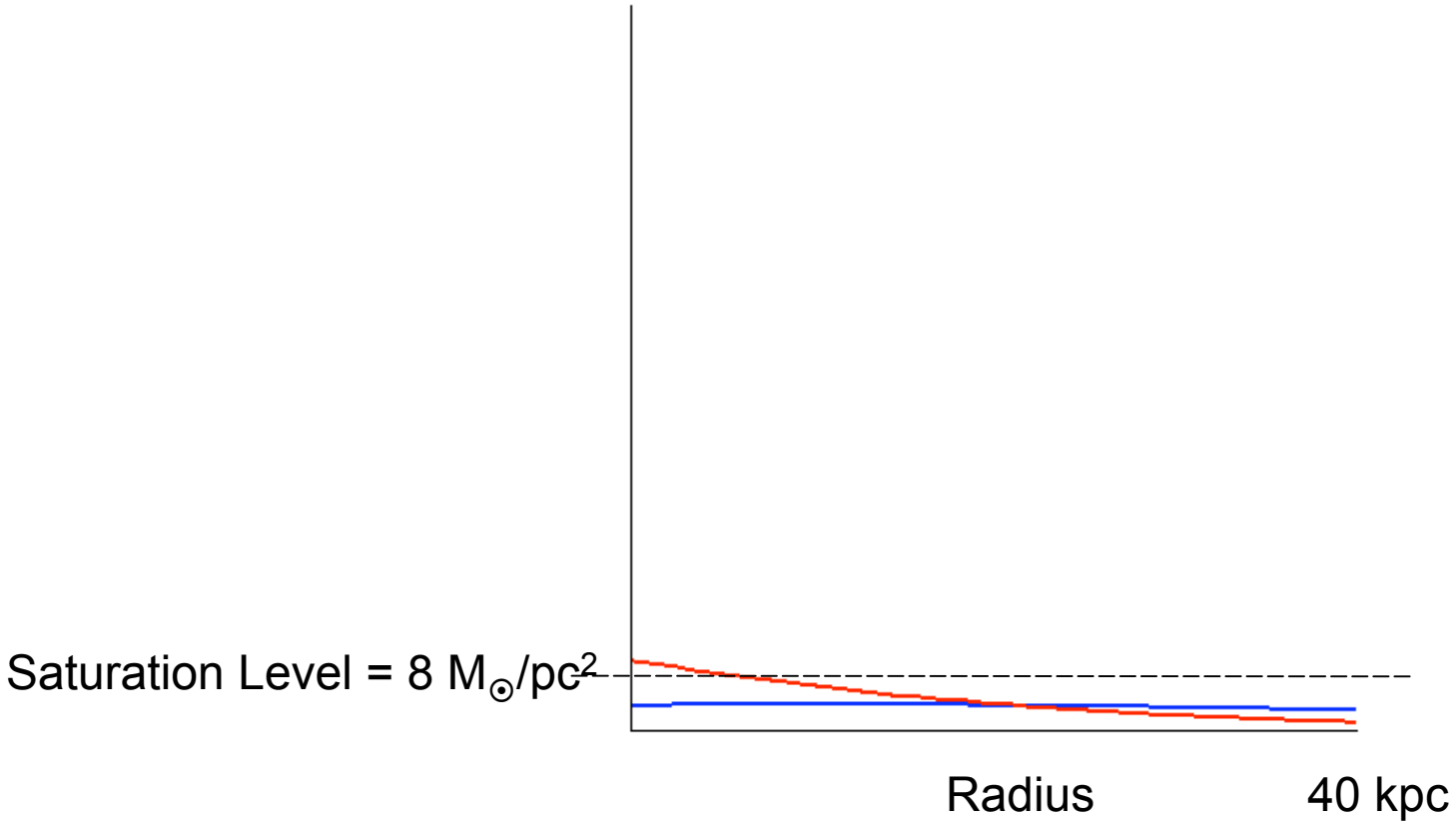


Credit: Obreschkow

Evolution of Milky Way Type Galaxy with Redshift

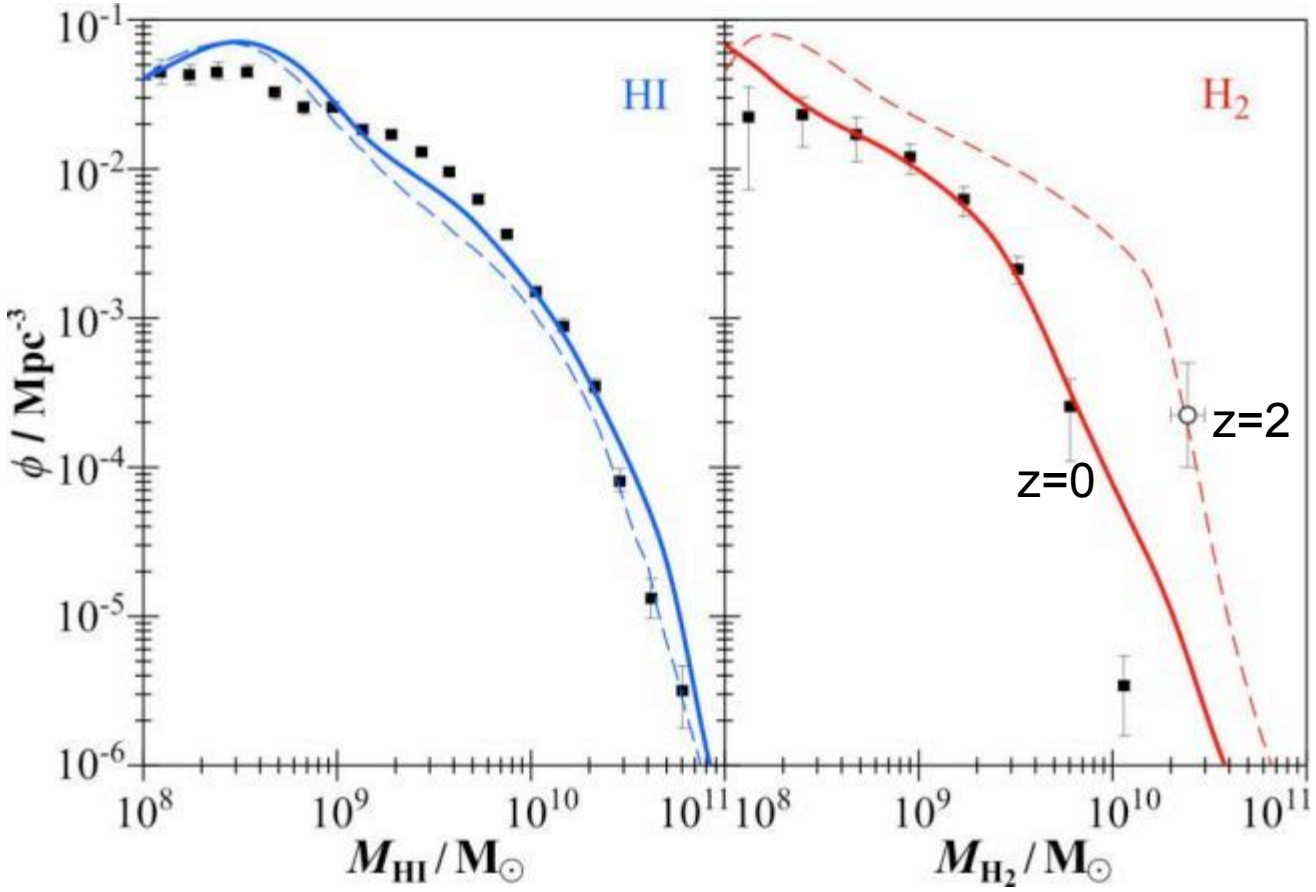


HI saturates



Credit: Obreschkow

Cosmic Evolution of the Mass Functions

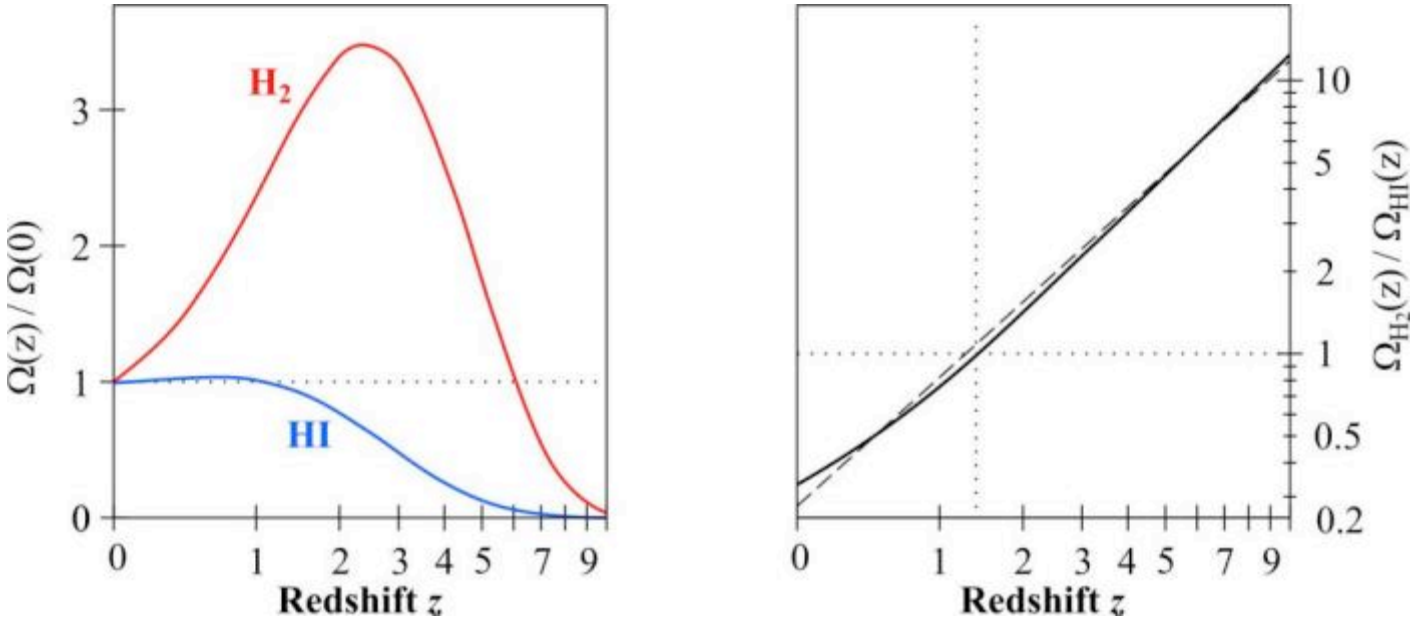


Dark matter theory ⇨ Cold gas disks were smaller at high redshift .

Pressure ⇨ H2/HI-ratio in galaxies increases strongly with redshift.

Obreschkow & Rawlings, 2009, ApJL, in press

Cosmic Evolution of Space Densities



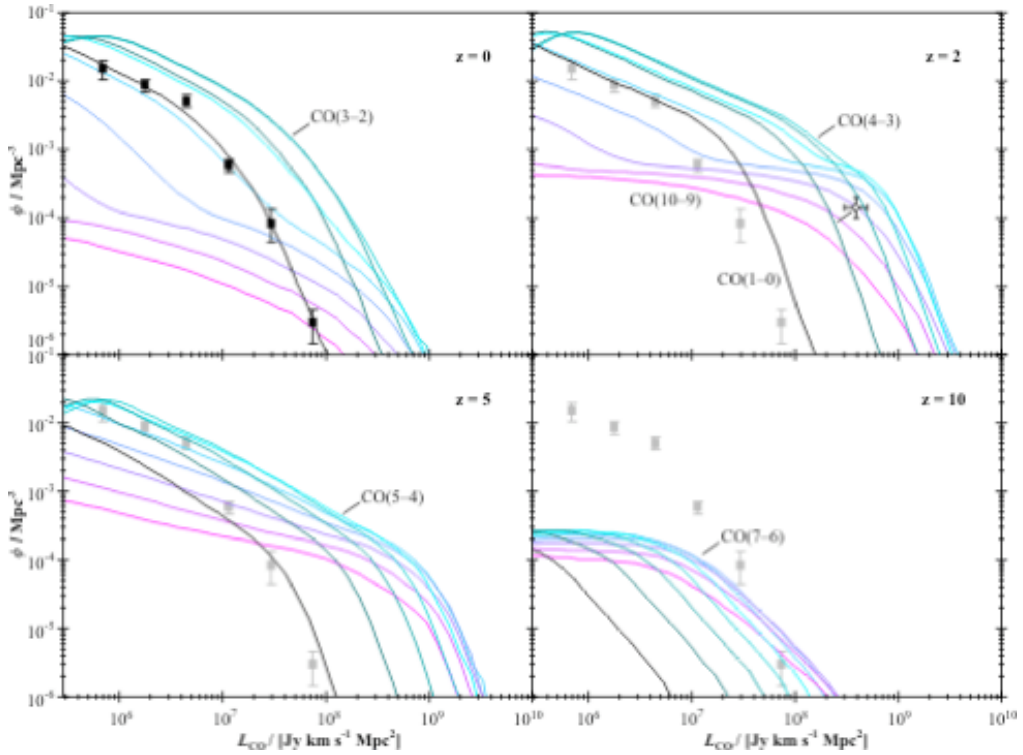
$$\Omega_{H_2}/\Omega_{HI} \propto (1+z)^{1.6}$$

Of course we need both ALMA and SKA working to actually MEASURE this!

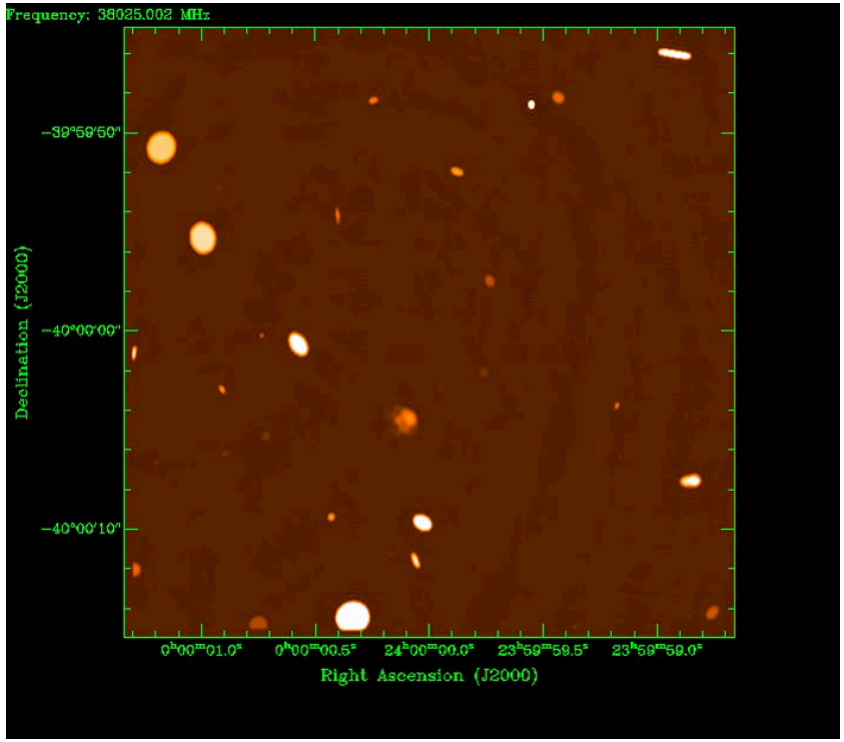
Deep Fields with Phase-1 SKA will study individual galaxies to *z* ~ 2-4 in HI emission

Obreschkow & Rawlings, 2009, ApJL submitted

ALMA/SKA end-to-end simulation tools



MeqTrees-based simulator publically available soon.



http://s-cubed.physics.ox.ac.uk

Will soon contain simulated CO and [CII] fluxes as well as HI for ~20 deg^2 of sky

z~2 CO galaxy shifted into ALMA Band 1

Obreschkow et al, in prep; Heywood et al, in prep

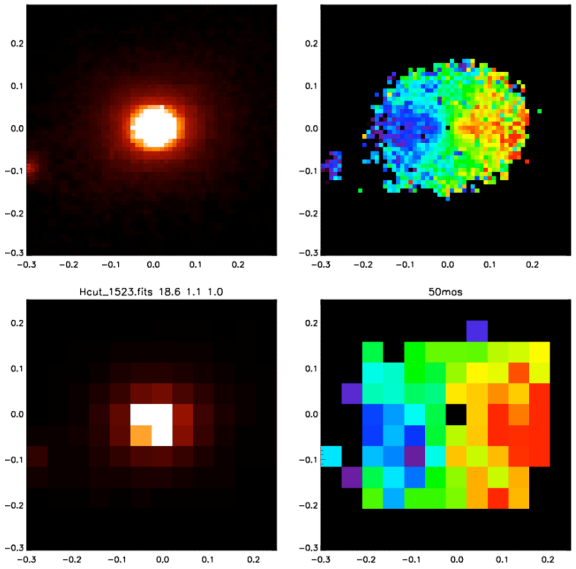
An E-ELT view of high-*z* galaxies

e.g HARMONI

- 4, 10, 20 and 40 mas spaxel scales
- ~128 x 256 spaxels (~32000 simultaneous spectra)
- Instantaneous Field of View: 5” × 10”, 2.5” × 5”, 1.25” × 2.5” and 0.5” × 1.0”
- Wavelength range 0.5 to 2.45 microns (split into 2 channels, visible and NIR)
- Spectral resolution: 4000 (all λ), 20000,10000 – restricted λ ranges
- 8 NIR spectrograph channels, 2 visible spectrograph channels
- 35% average throughput
- Works with no-AO, GLAO(4 laser stars) and LTAO (6 laser stars)

for galaxies at *z*=2-5

- Size & luminosity distribution of HII regions
- HII regions as tracers of SFH, mass & mergers
- Measure abundances for individual SF regions



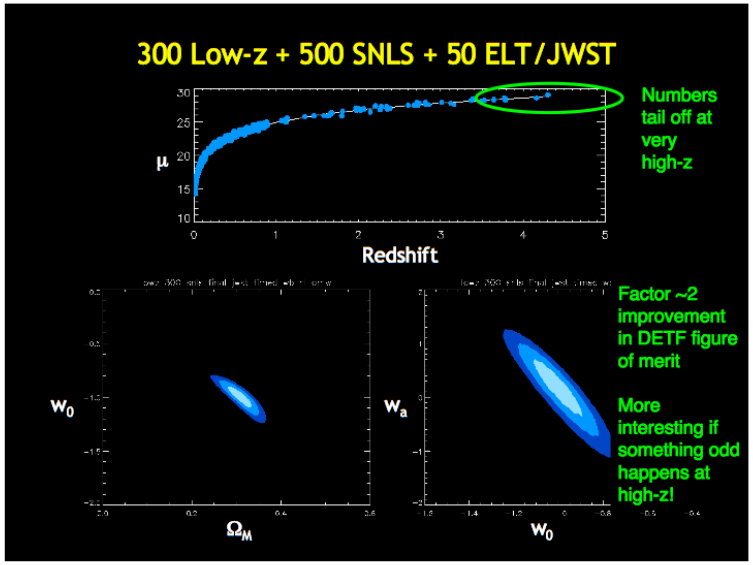
Slide amended from Thatte - HARMONI PI

SKA/ALMA/ELT Synergy Example 2: Cosmology

E-ELT Science Case strongly features

- Supernovae as probes of dark energy
- Variations of Fundamental Constants

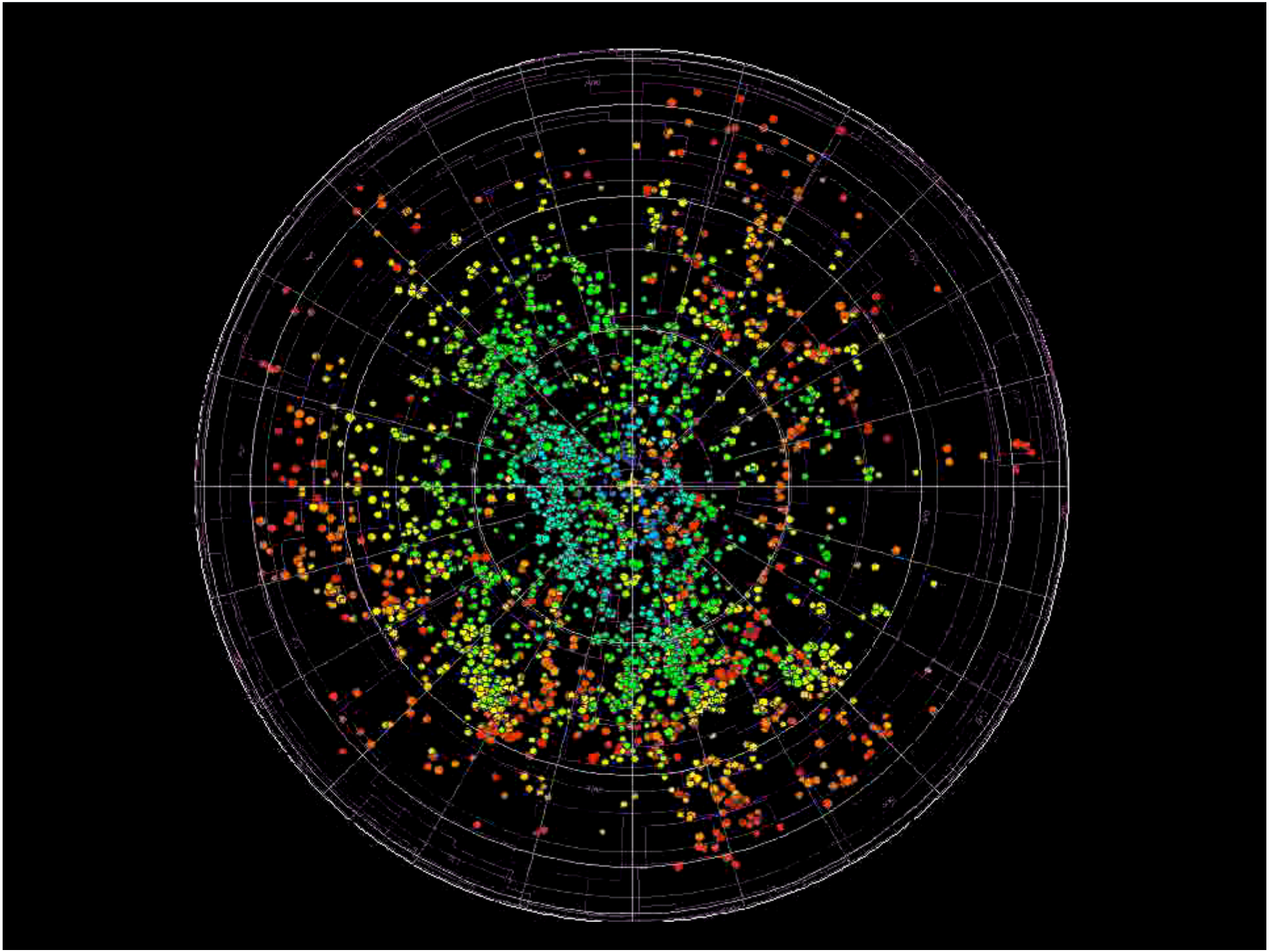
  (and direct expansion)
- EoR probes

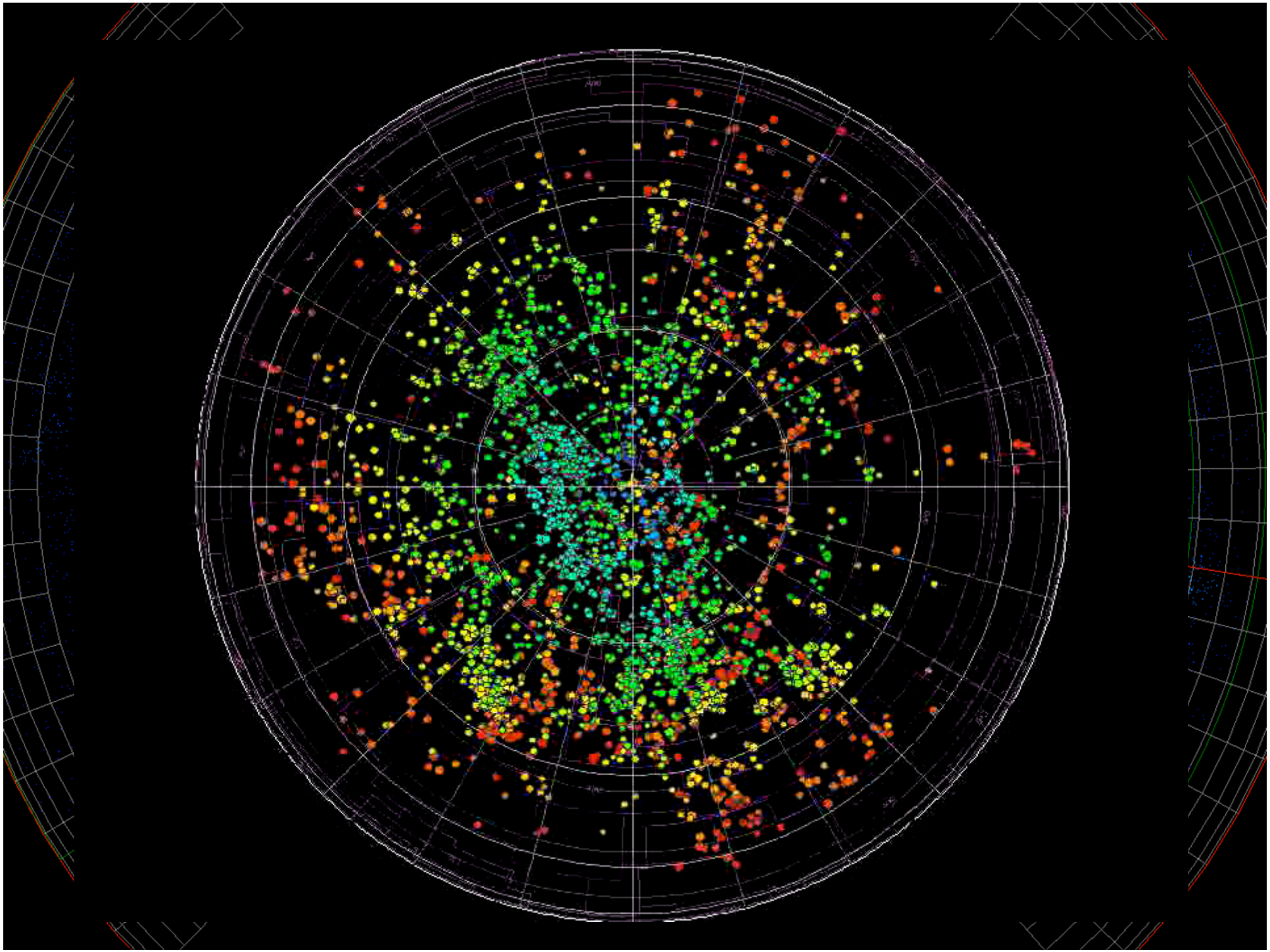


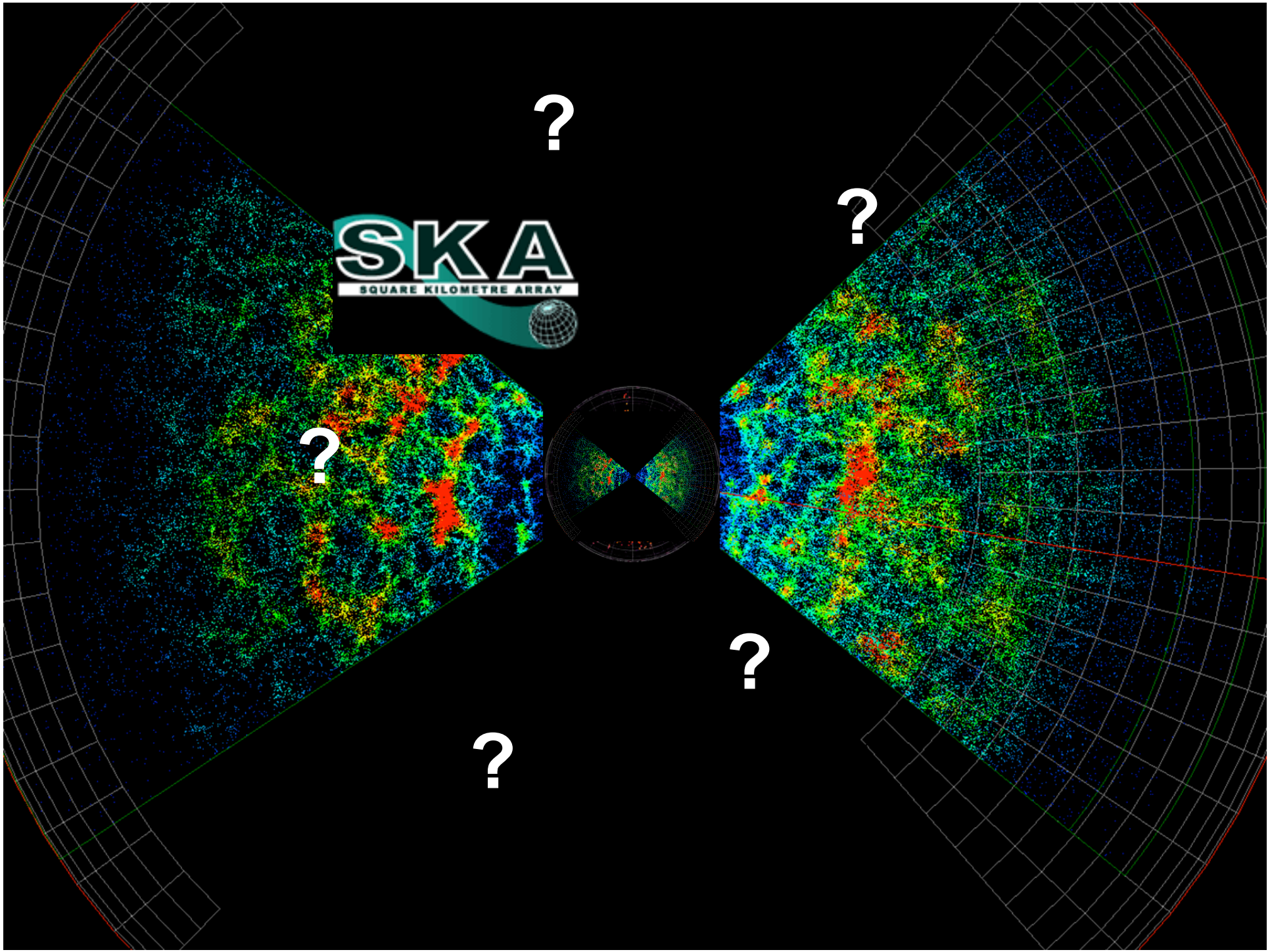
But NOT BAOs because of the survey speed issue

This makes their cosmology science cases **remarkably complementary**

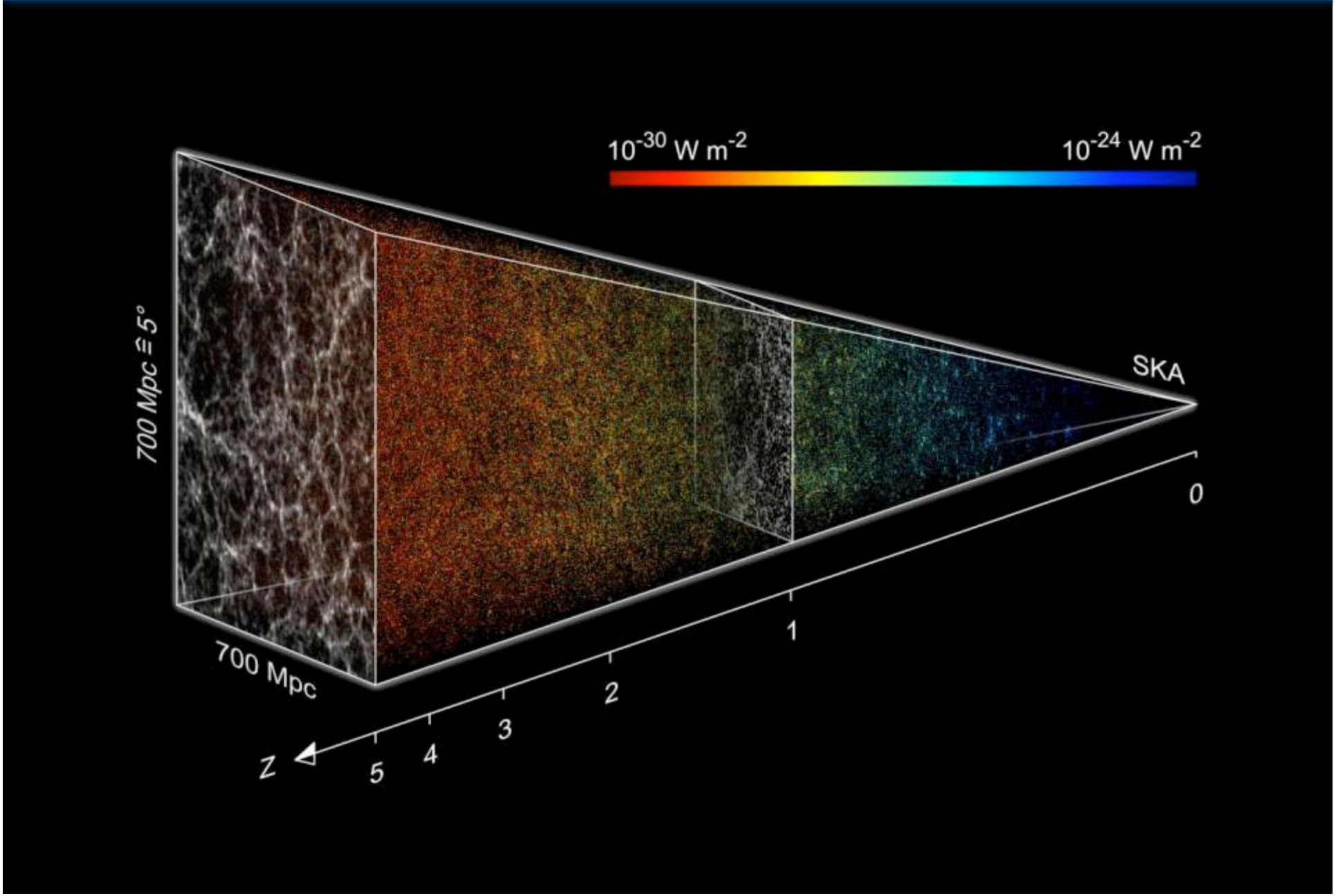
Transformational survey speed of SKA Phase-2 will allow a definitive redshift survey of ~$10^{9\text{-}10}$ galaxies to z~2-4



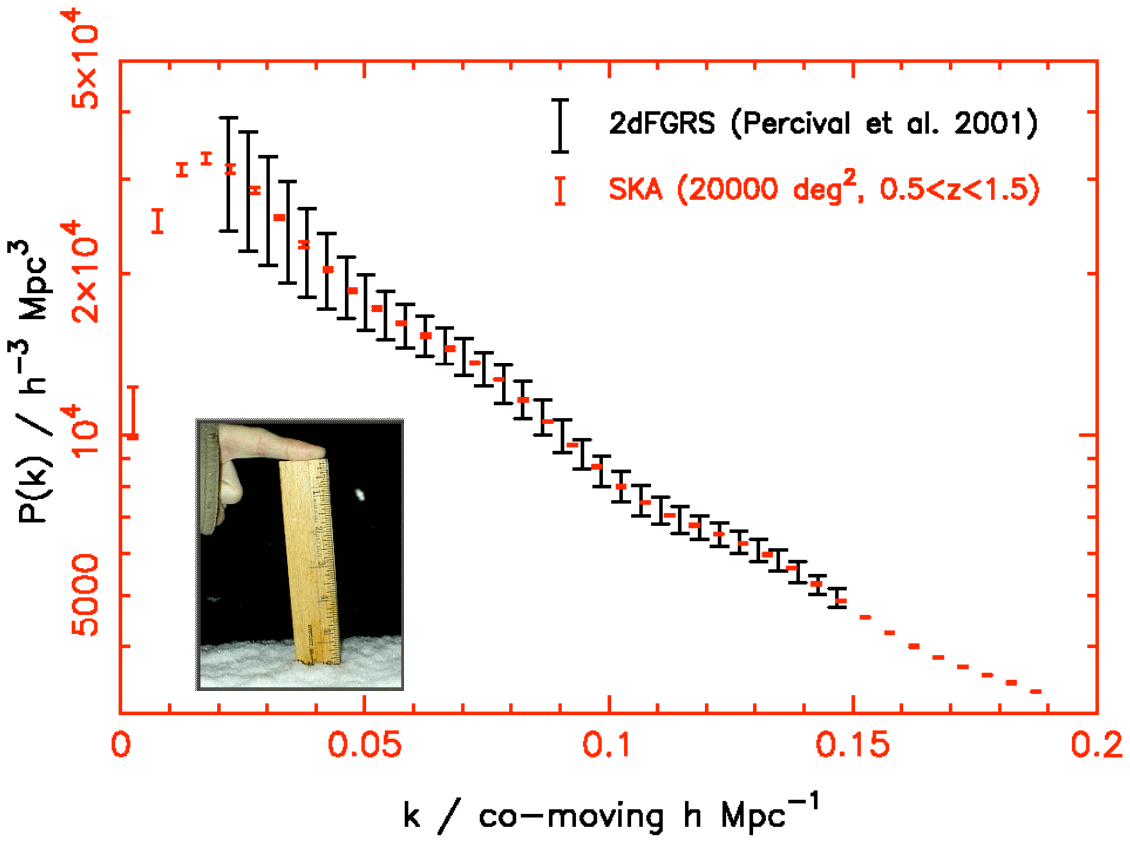



?
?
SKA
SQUARE KILOMETRE ARRAY
?
?
?

SKADS : “Mock Cone”



High Precision *P(k)*



Galaxy redshifts over ~1000-times volume ***V***

Measure 3D power spectrum of galaxies

Errors (due to cosmic variance) scale as $\sqrt{V}$

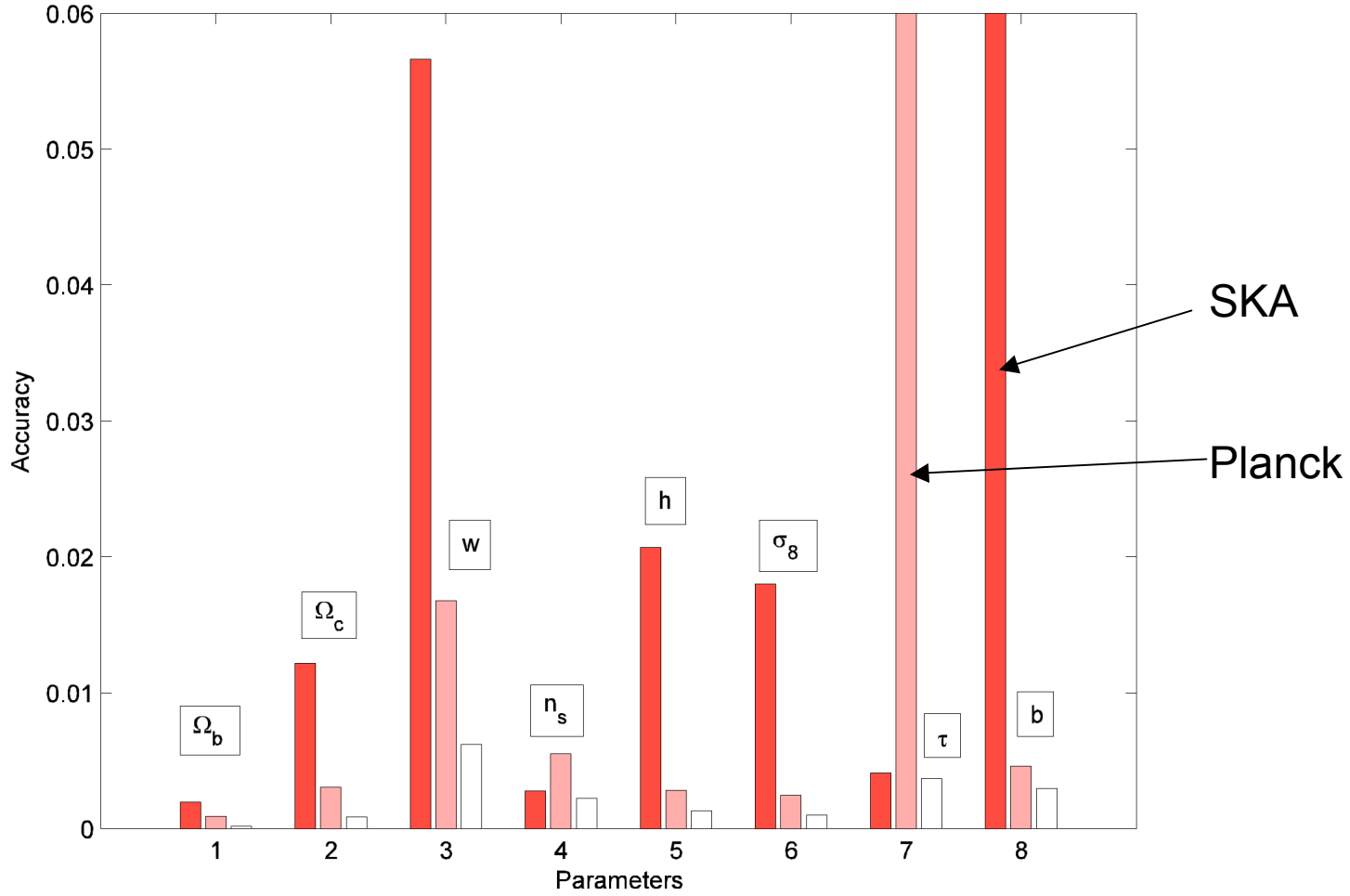
And errors much less correlated

But 'bias' is likely to be stochastic, scale-dependent, non-local & non-linear, CARE!

Emphasises importance of redshift surveys with $nP>>1$

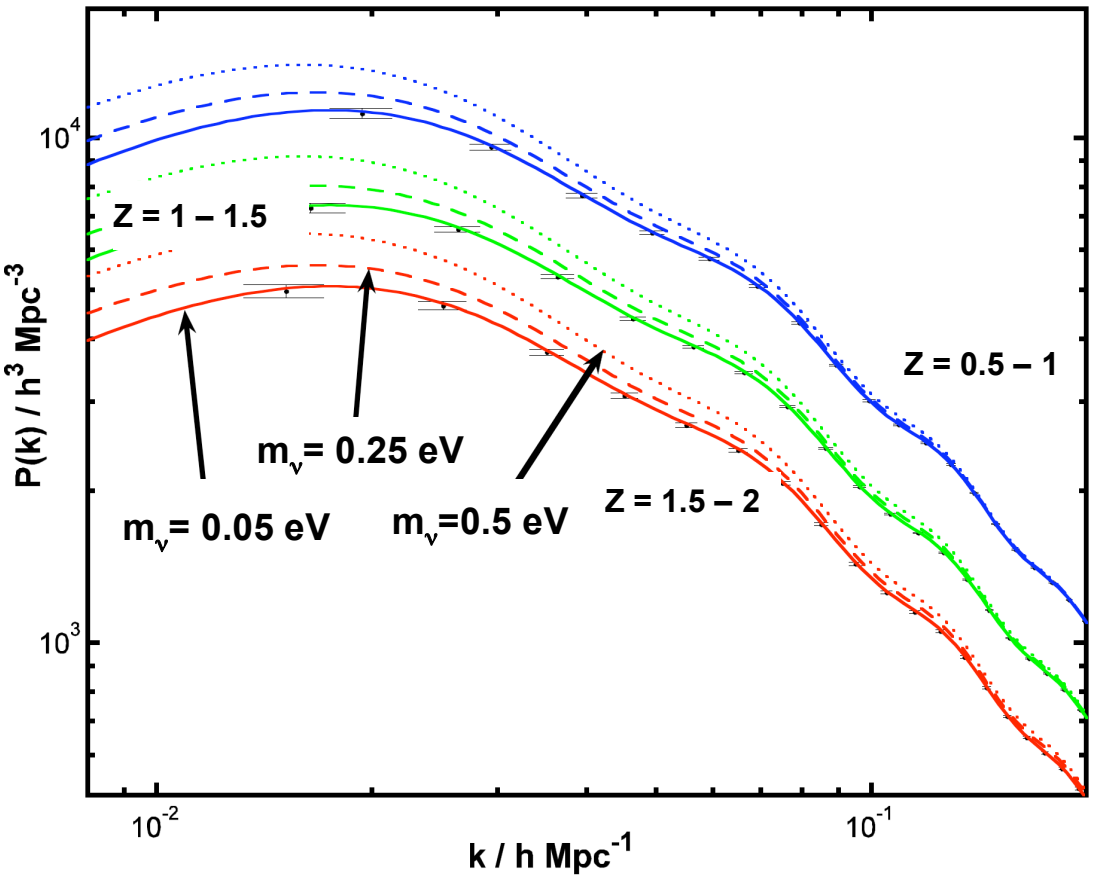
Abdalla, Blake & Rawlings (2009), MNRAS, in press

SKA versus Planck



Credit: Abdalla

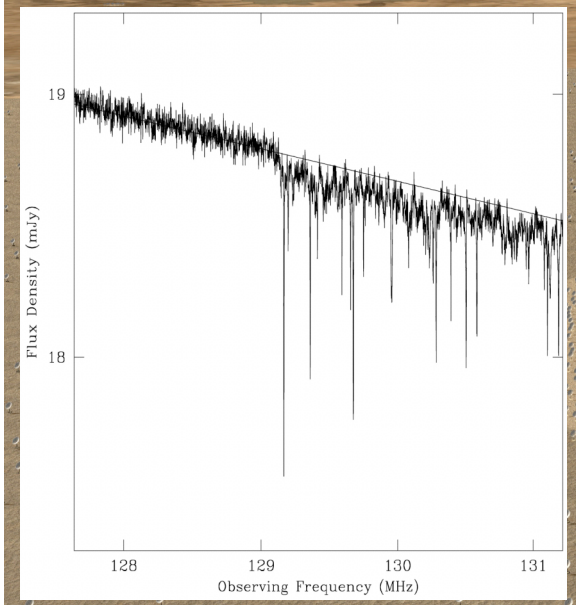
Neutrino absolute mass scale



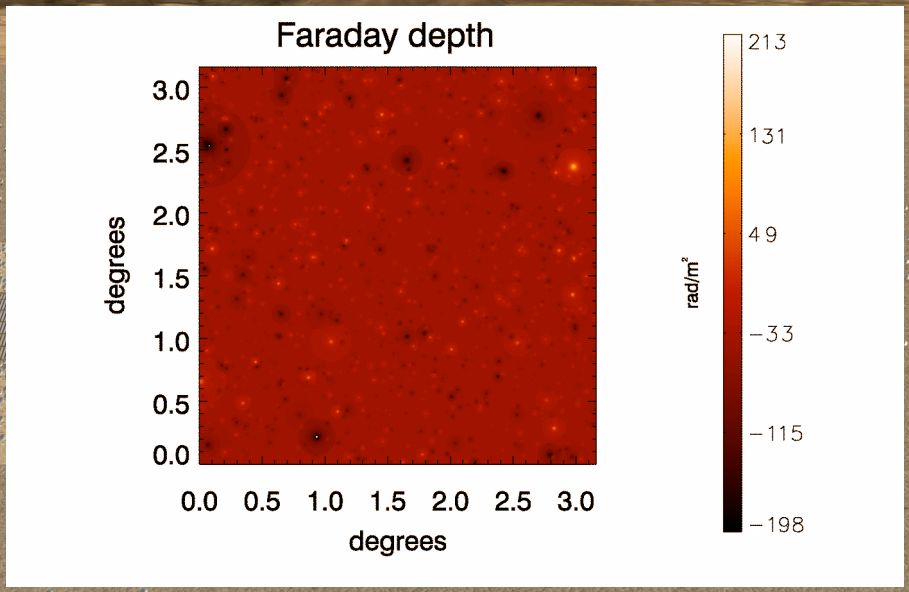
- particle physicists tell us should be in the range
  0.05 – 2 eV
- SKA sensitivity sufficient and necessary to push down to ~0.05 eV and be ‘guaranteed’ to ‘measure’ this mass scale
- *z*-bins probe model dependencies
- Fantastic synergy with experimental neutrino research: combination could prove sterile neutrinos or neutrino masses varying with time

Abdalla & Rawlings (2007)

Science Vision I



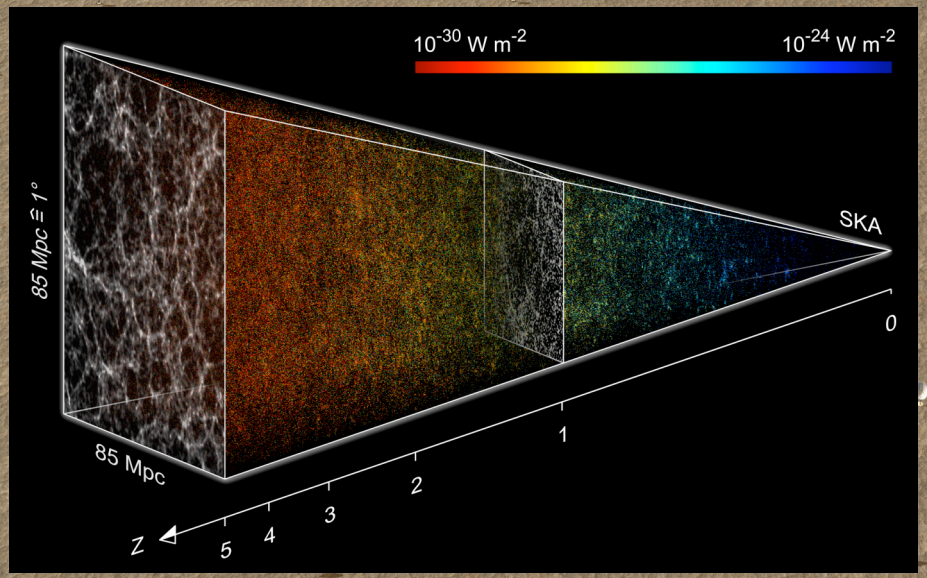
Magnetism: magnetic fields in clusters, galaxies and the IGM. Breakthrough science in Phase-1

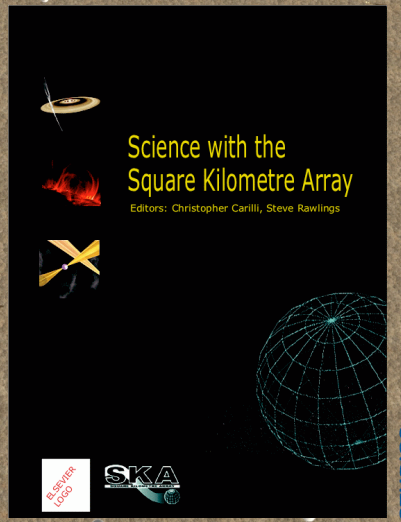


EoR: neutral HI towards a z=10 radiogalaxy: first detections possible with Pathfinders

Cosmology: ~10^7 galaxies to z~0.8 in Phase-1, ~10^9 galaxies to z~2 in Phase-2.

Hence dark energy w and neutrino mass.





Carilli & Rawlings (2004)

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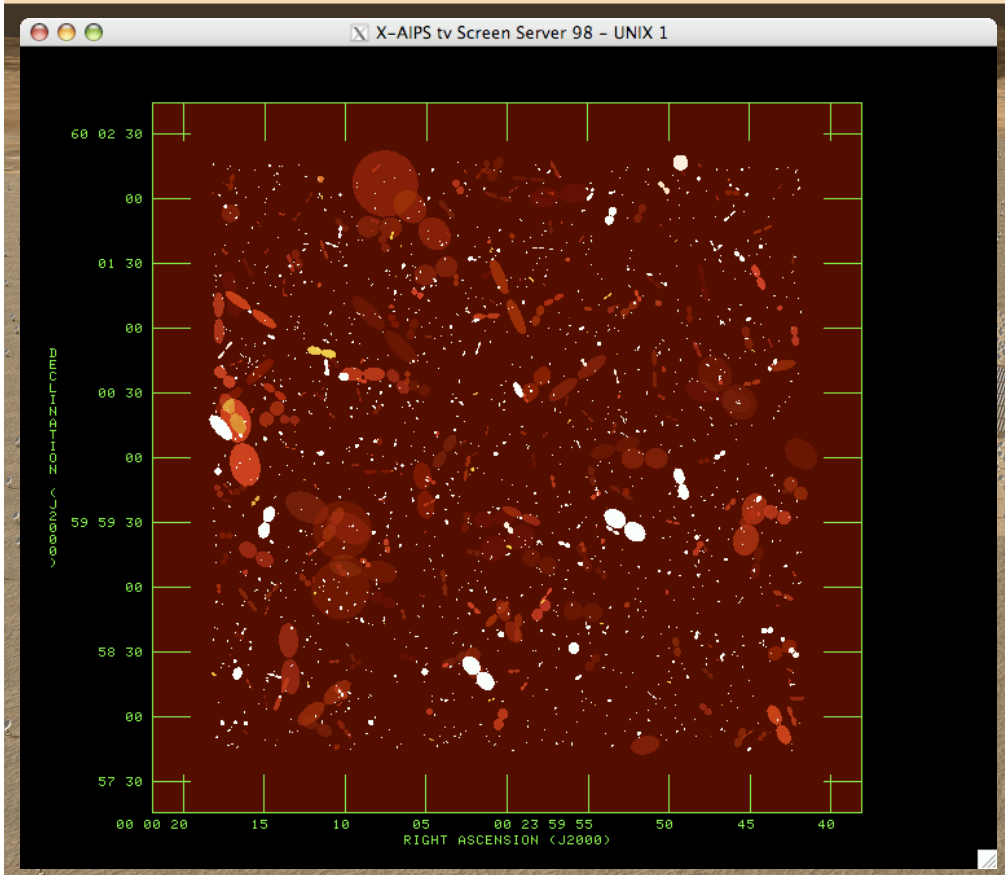
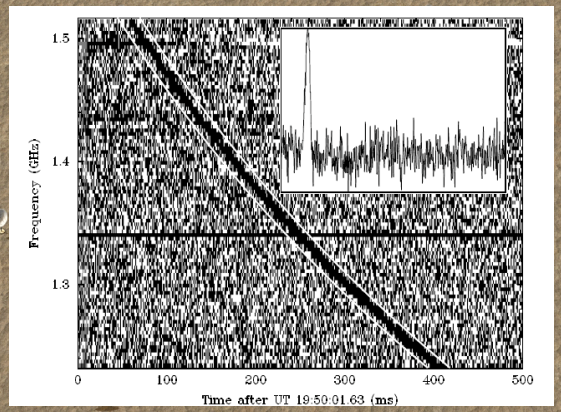
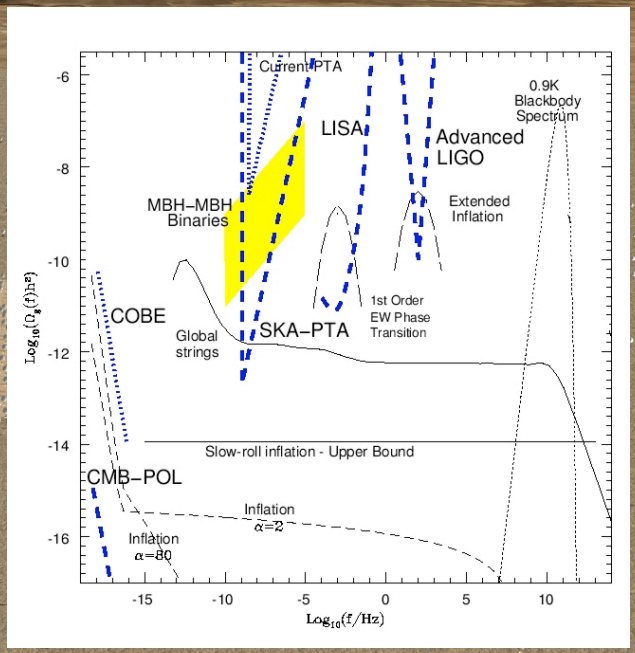
Science Vision II



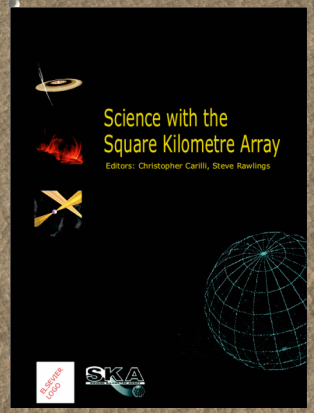
Deep Continuum surveys and gravitational lensing

Transients: new classes of objects and new ways of studying known objects, e.g. exoplanets





Gravity via Pulsars: detection of gravitational waves via Pulsar Time Array, possibly in Phase 1



Very broad science case

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Closer scientific synergies will benefit us all .....

A new era is dawning in Astronomy with the advent of extremely sensitive new facilities to probe the universe across the electromagnetic spectrum. We plan to bring together the radio and optical communities for a workshop in **Crete in the late spring of 2010**. The workshop will be aimed at developing linked science cases for the giant, next generation telescopes including the E-ELT and SKA and other key ground- and space-based facilities.