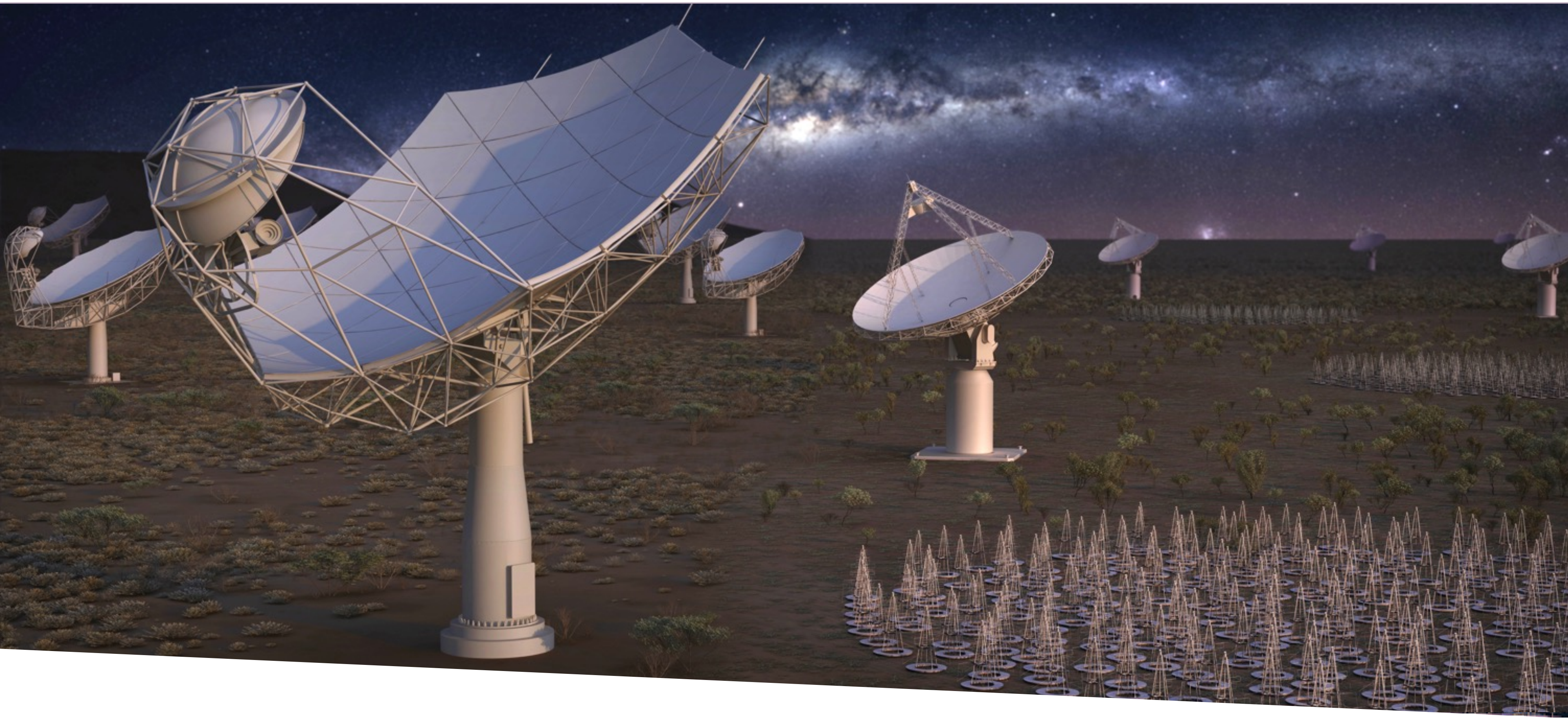
Dark Energy with SKA



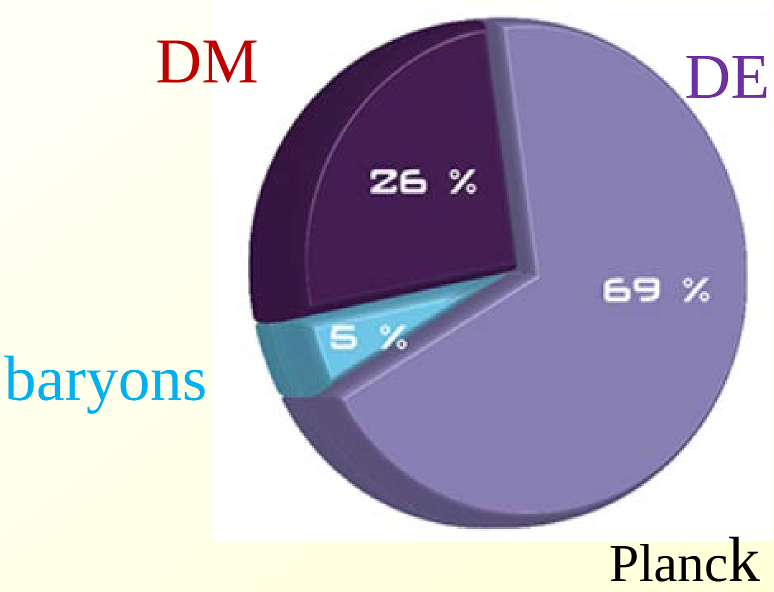
SQUARE KILOMETRE ARRAY

Exploring the Universe with the world's largest radio telescope

Françoise Combes
Observatoire de Paris

November 2019

SKA & cosmology: main questions



Dark energy:
Is it varying with time?

Matter in the Universe
Dark matter/visible matter vs z

How is the Universe re-ionized?
End of the dark age: cosmic dawn, EoR

How do baryons assemble into the large-scale structures?
Galaxy formation and evolution
Star formation history, quenching
Environment: groups and galaxy clusters

Strong-gravity with pulsars and black holes

Translation into Main Parameters

1-What is dark energy: w   P= w ρ

Equation of state and nature of DE, through expansion and growth rates, 5 tools: Weak Lensing, BAO, RSD, Clusters, ISW

2-Gravity beyond Einstein: γ

Testing modified gravity, by measuring growth rate exponent γ

3-The nature of dark matter, m_ν

Testing the CDM theory, and measuring neutrino mass

4- The seeds of cosmic structures

Improve   n= spectral index

σ_8=amplitude of power spectrum,

f_{NL}= non-gaussianities, inflation?

Rebaselining 2015

The SKA cost was **1 billion euros**

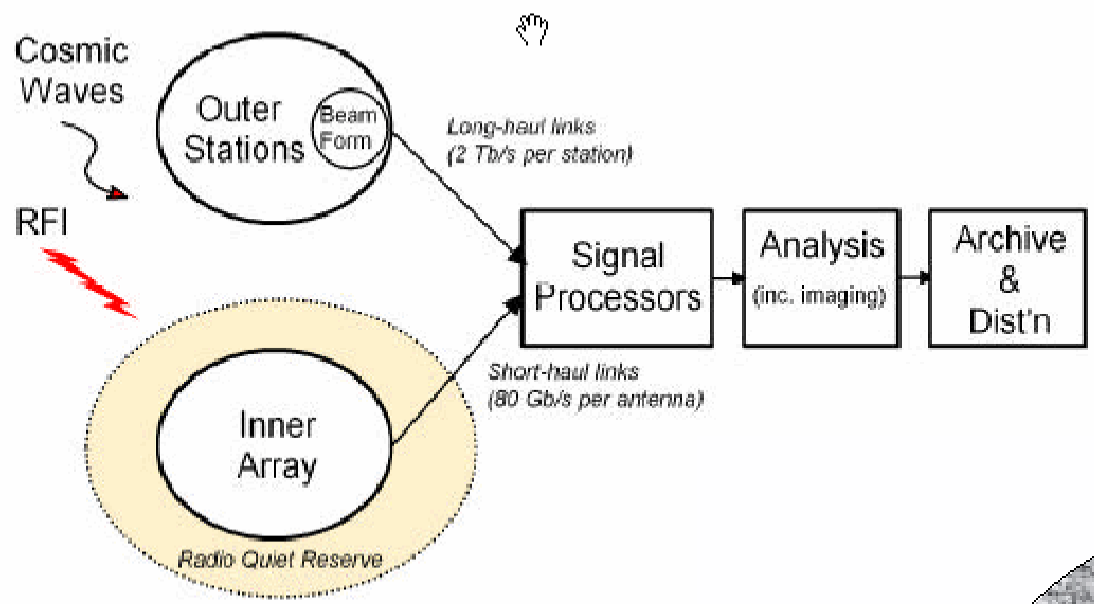
In 2014, SKA board capped at **650 Meuros**

➔Deferring the SKA1-survey
➔Reducing SKA1-mid to 70%
➔Reducing SKA1-low to 50%

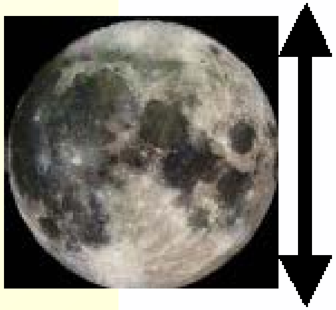
2017: Deployment baseline

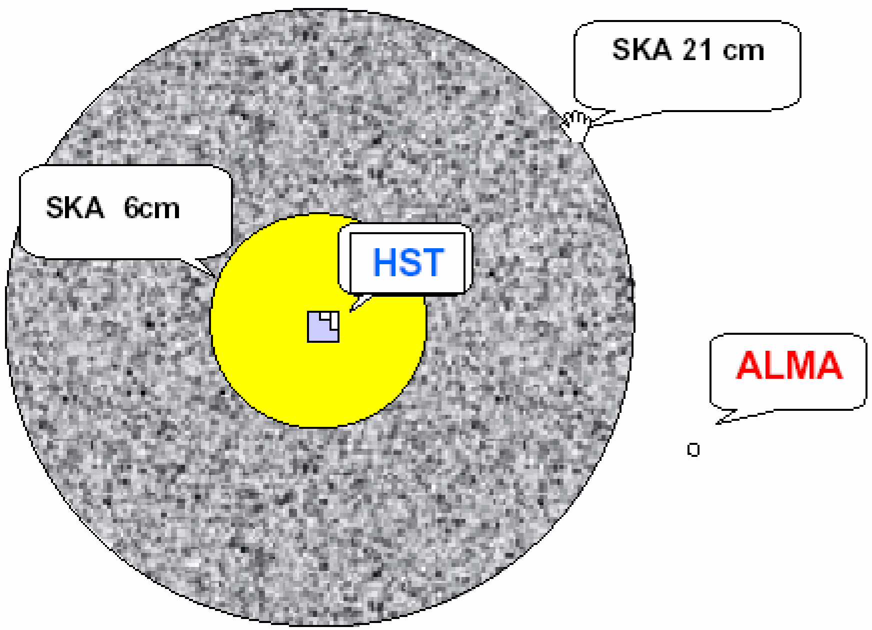
New science book: 2000 pages, 135 chapters, published in 2015
Organisations from 13 countries are currently members of the SKAO – Australia, Canada, China, France, Germany, India, Italy, New Zealand, South Africa, Spain, Sweden, the Netherlands, UK
40% of world population!

Field of View



At least 1 square degree
Goal 50-100 sq deg.





SKA1-Low

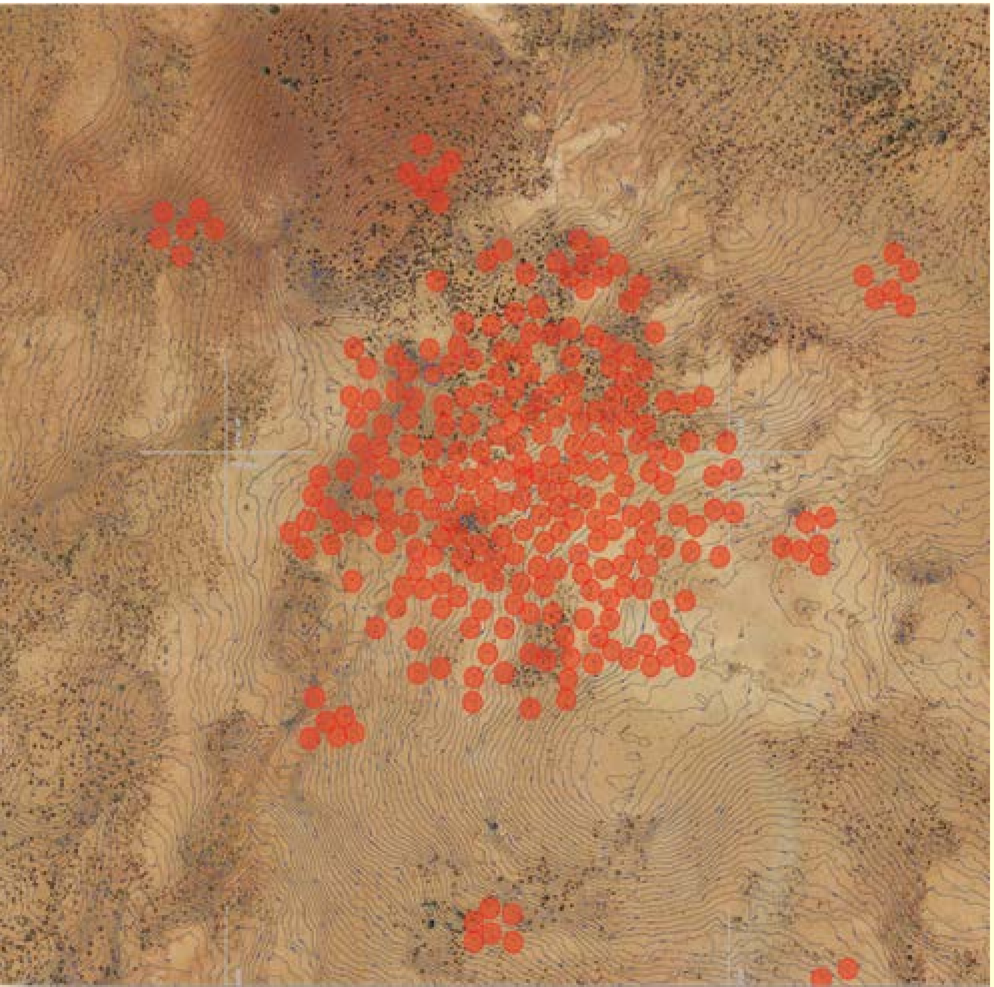
50-350 MHz   ($\Delta\nu$ = 300Mhz)

SKA1 Low: 130,000 dipoles, in 512 array stations of 256 in the Boolardy site in **Western Australia**

50% within 1 km core

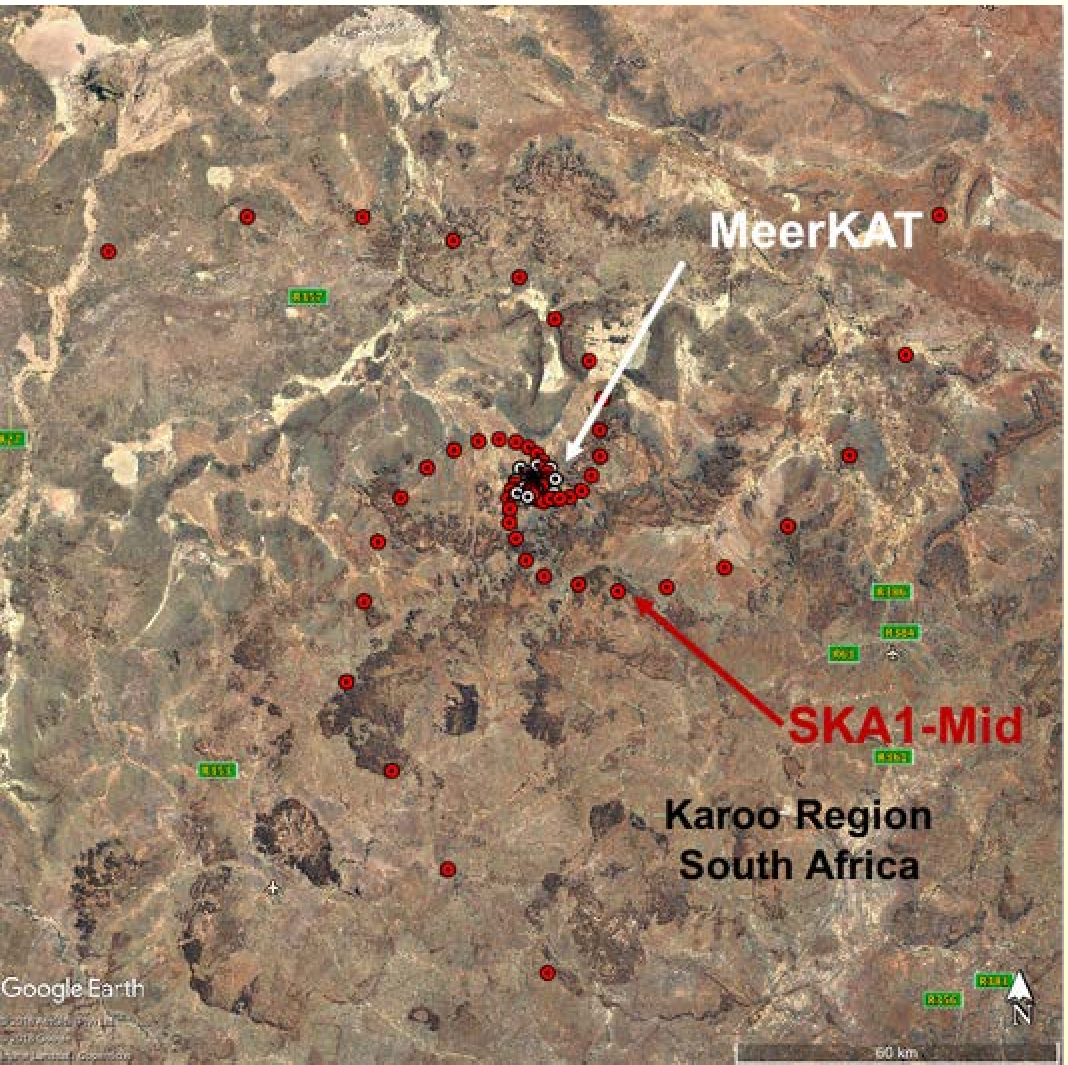
50% clusters of 6 stations on three modified spiral arms

maximum baseline = 65 km.



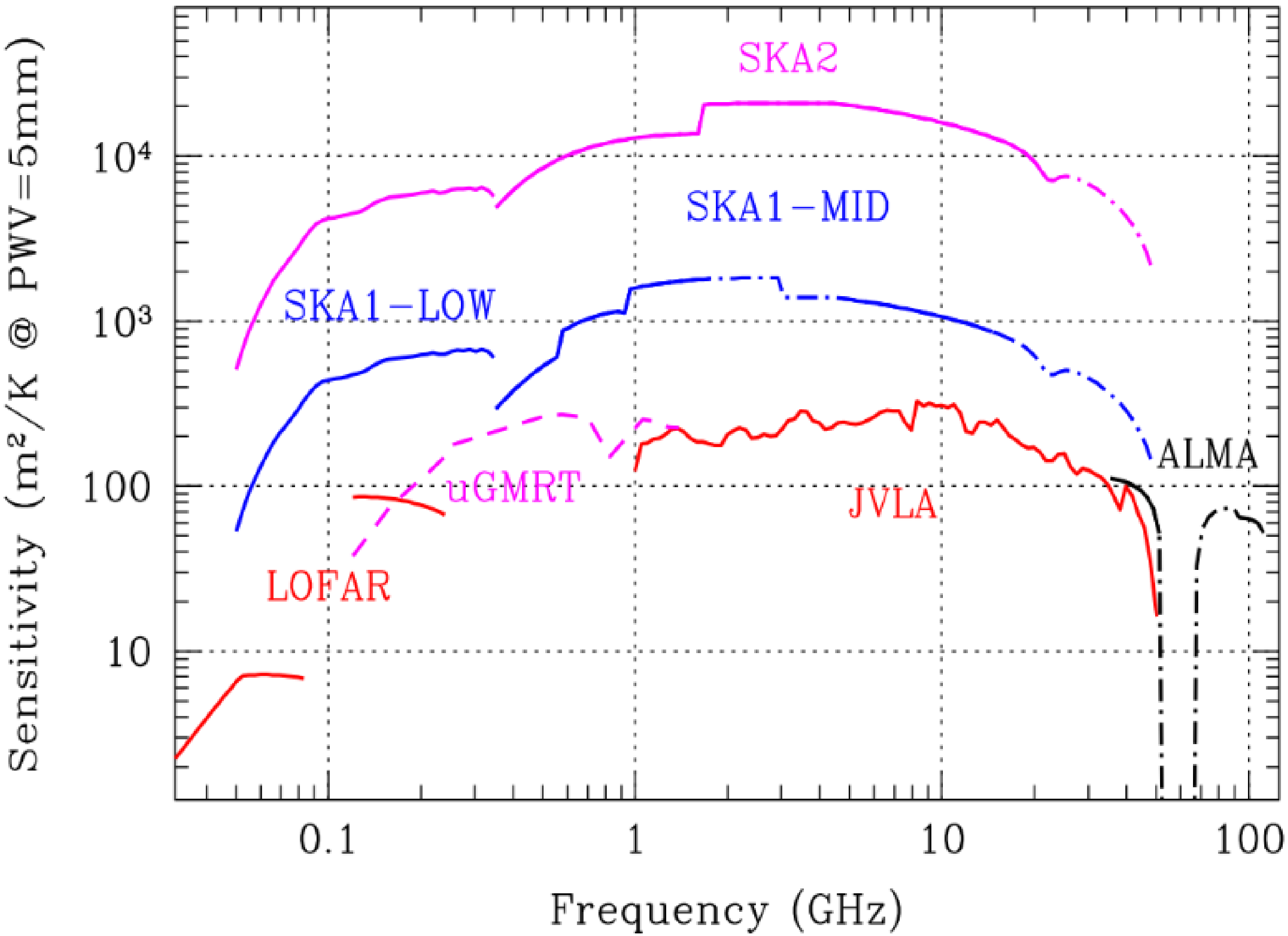
SKA1-Mid

0.35 – 24 GHz (15–24 GHz 2nd phase)

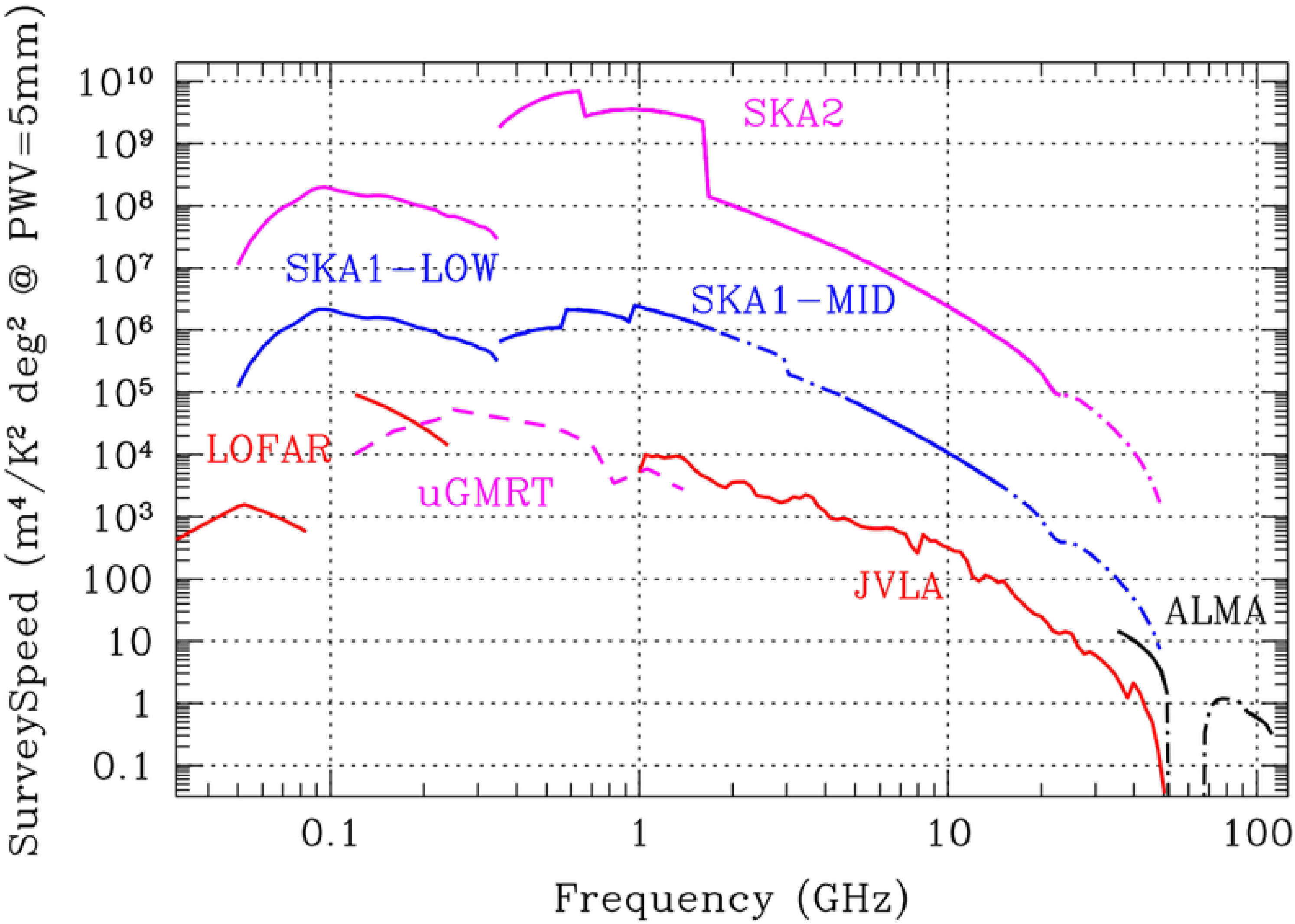


SKA1-Mid: 133 x15m dishes
+64 x13.5m Meerkat dishes
Karoo site **in South Africa**
50% in the core, randomly distributed within 2 km
3 logarithmic spiral arms
maximum baseline = 150 km

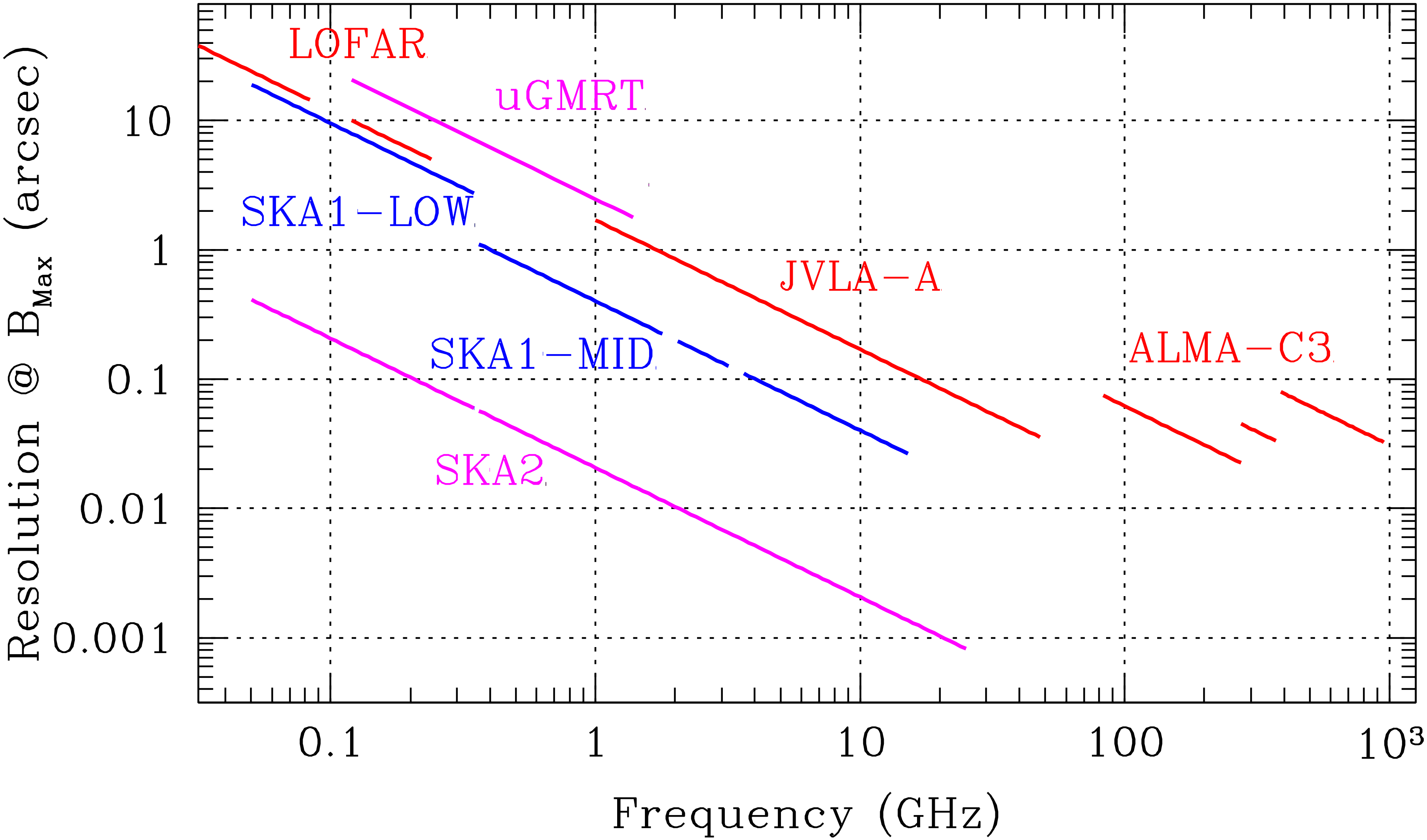
Sensitivity Comparison



Survey Speed Comparison



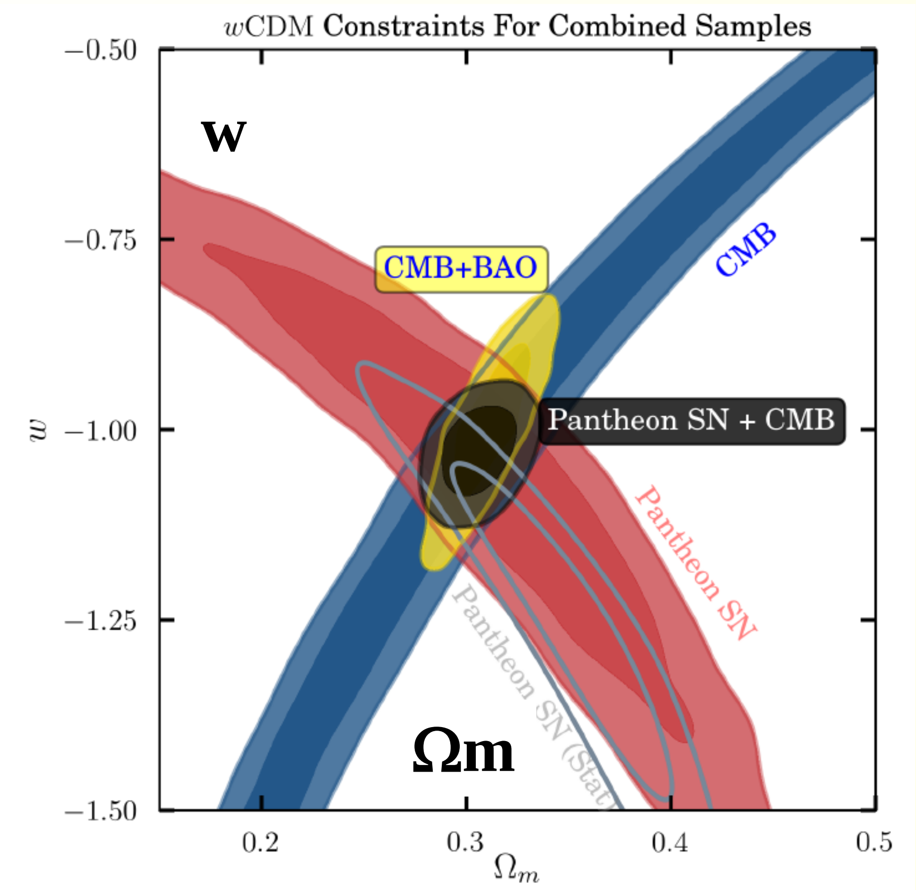
Resolution Comparison

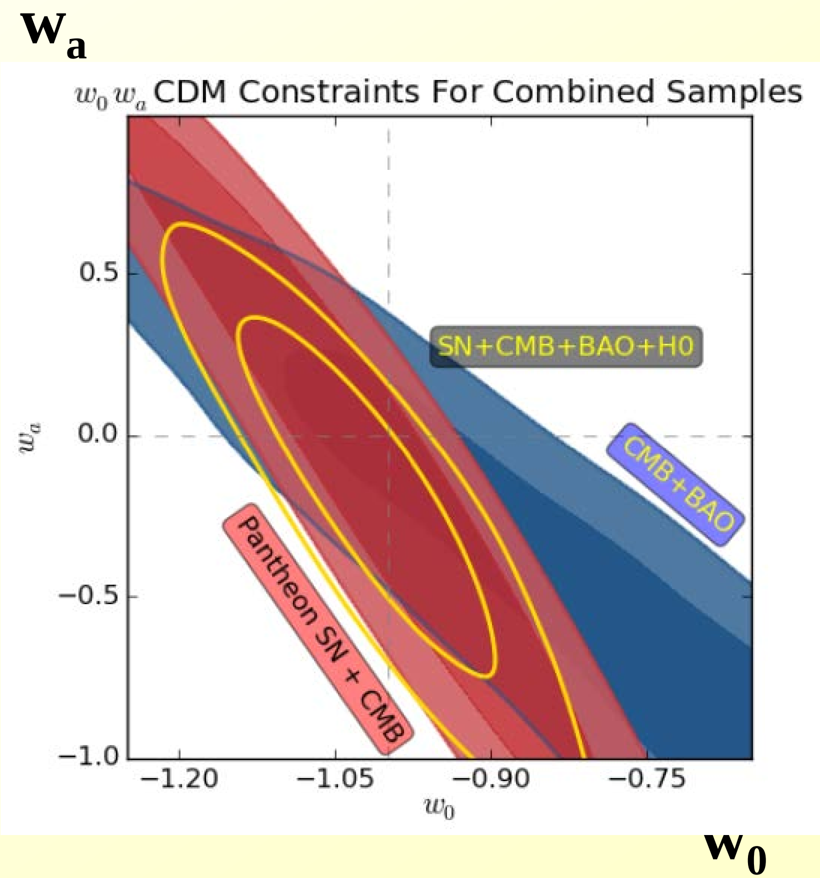


Accelerating universe from SNIa

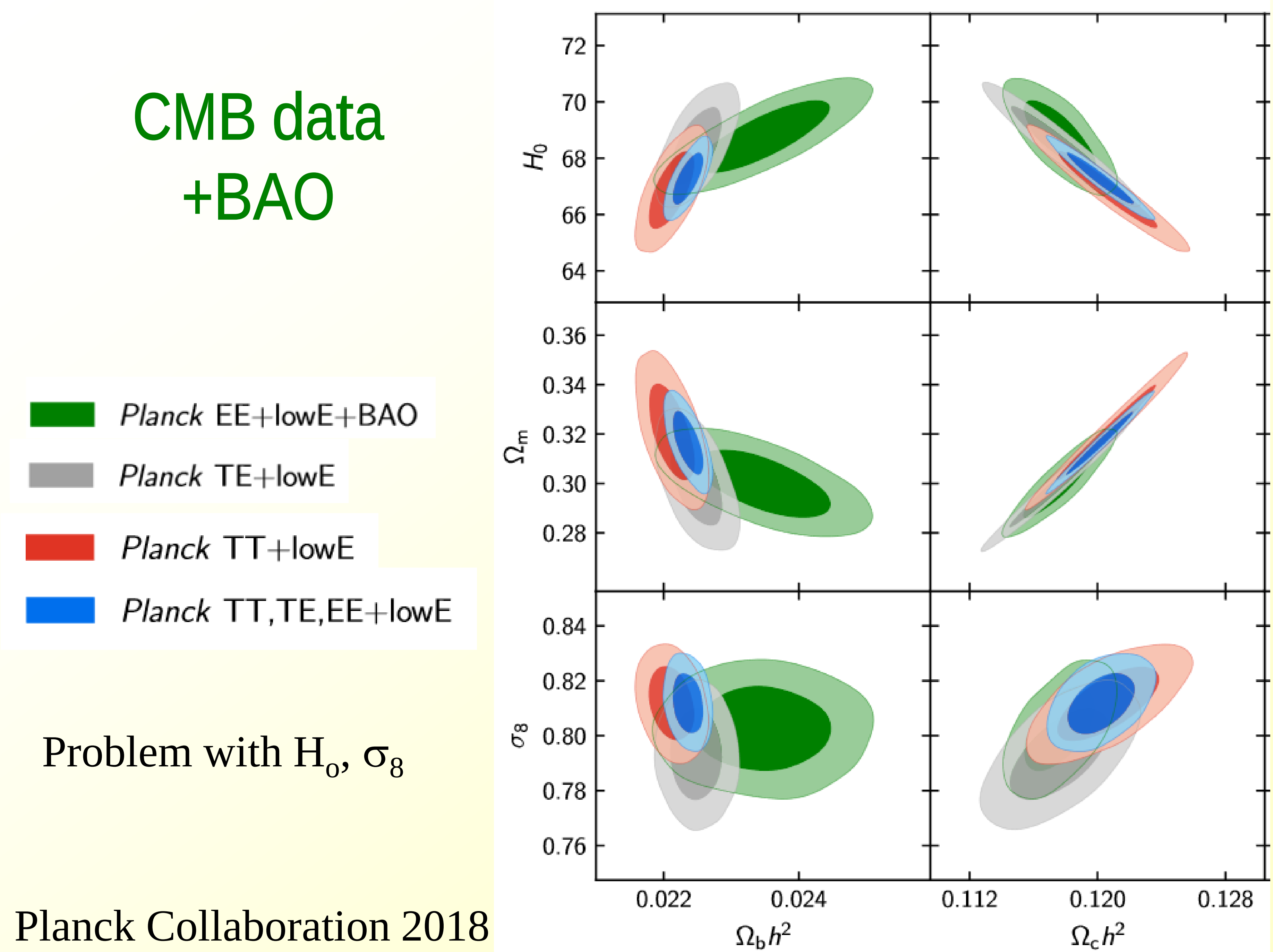
Scolnic et al 2018
Pantheon sample 1048 SN
$0.01 < z < 2.3$

$P = w\,\rho \qquad w(a) = w_0 + w_a\,(1-a)$
with $a = 1/(1+z)$





CMB data +BAO



Problem with H_o, σ_8

Planck Collaboration 2018

CMB and Dark energy

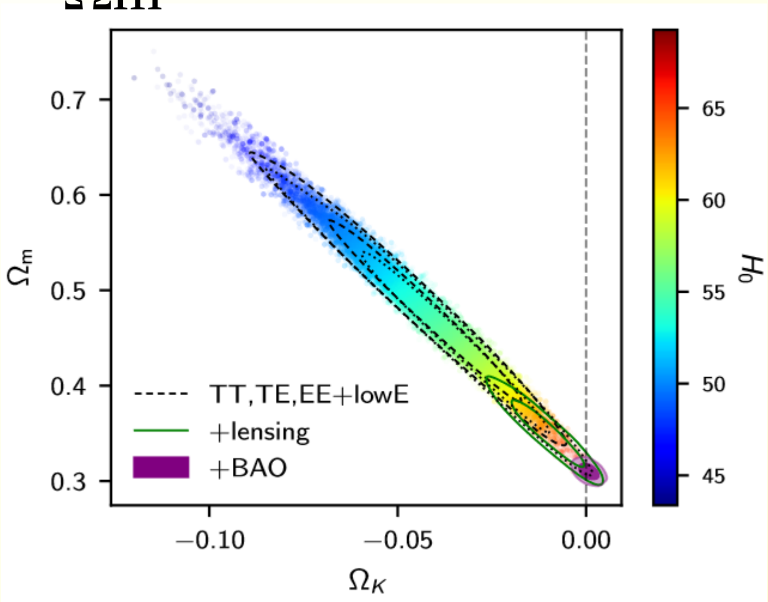
Concordance model, between CMB, Supernovae Ia, Large-scale structure (LSS) (weak lensing, BAO= Baryonic Oscillations)

Planck 2019

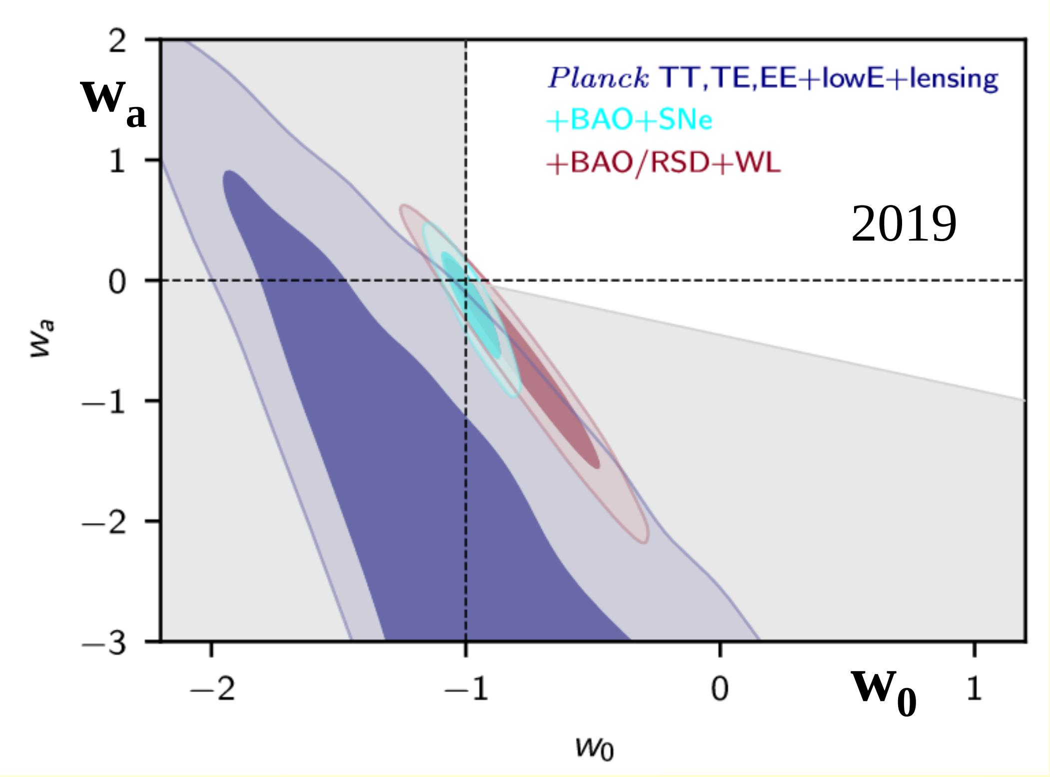
P = w ρ   w(a)= w0 +wa (1-a)

wo~-1
wa~0

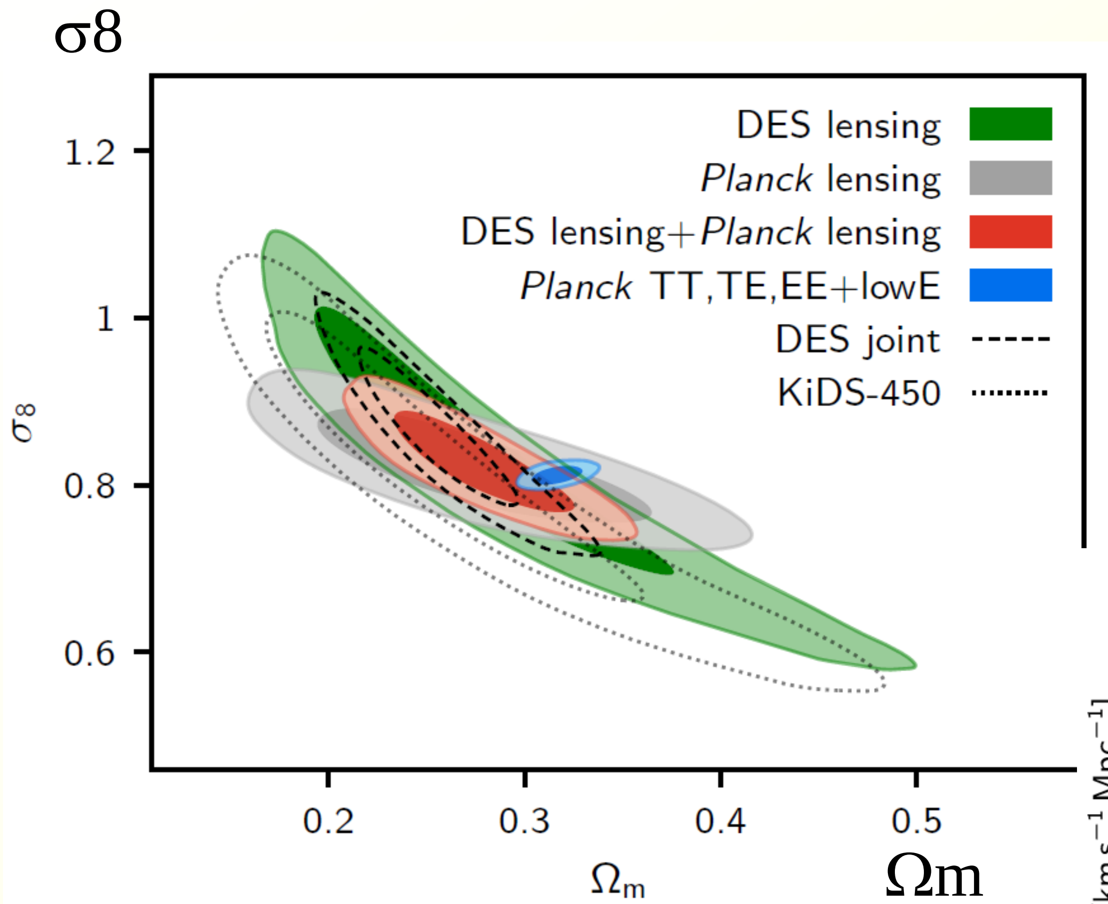
Ωm



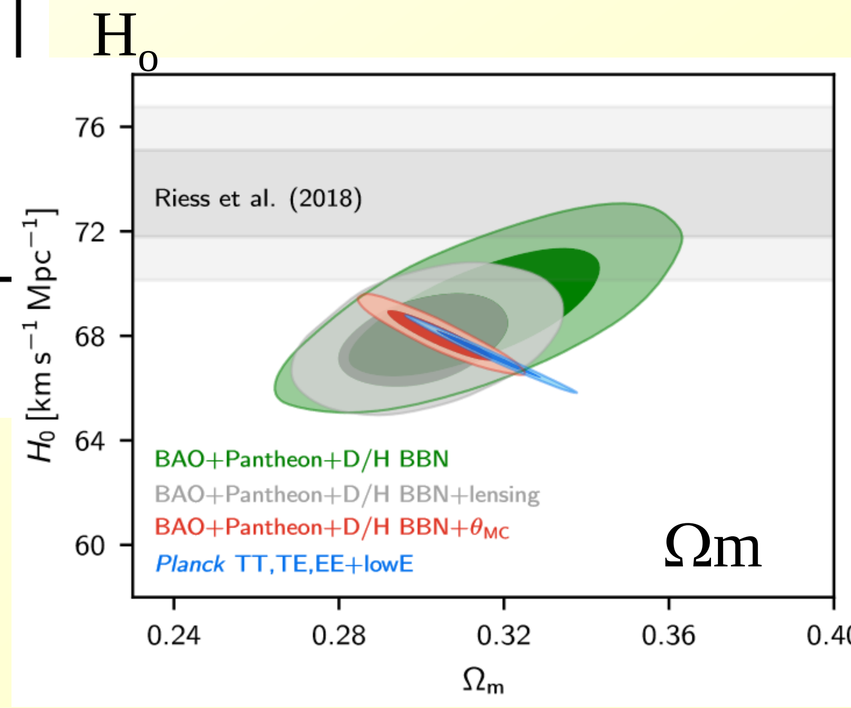
ΩK



Current constraints: Planck + others



BAO+SNIa
+DES, lensing
LSS

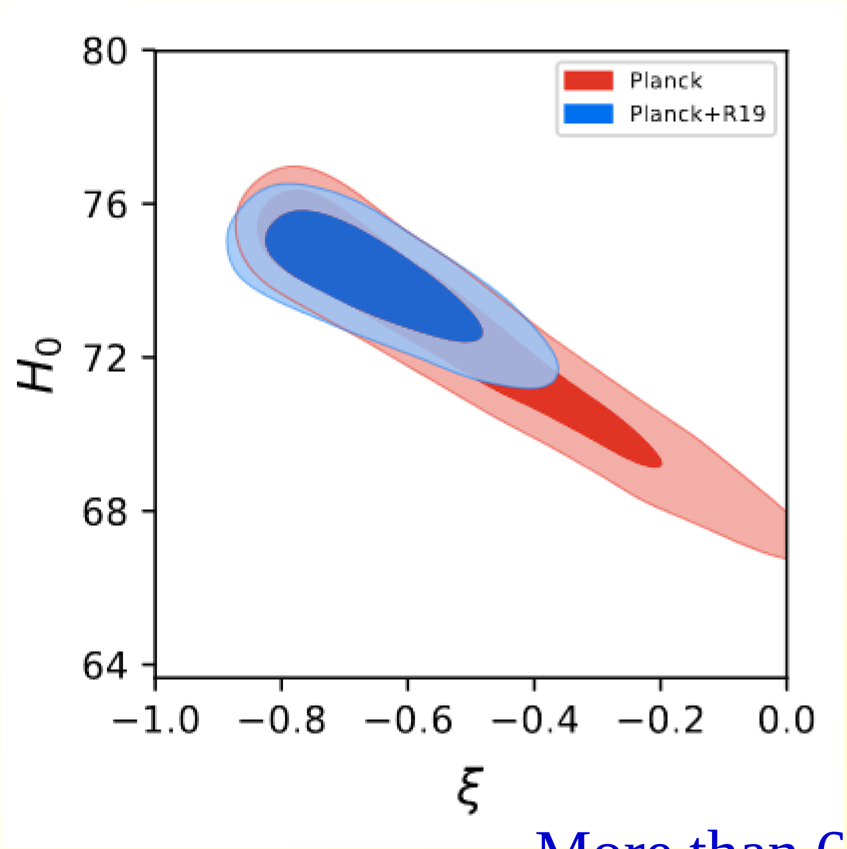


Planck 2019

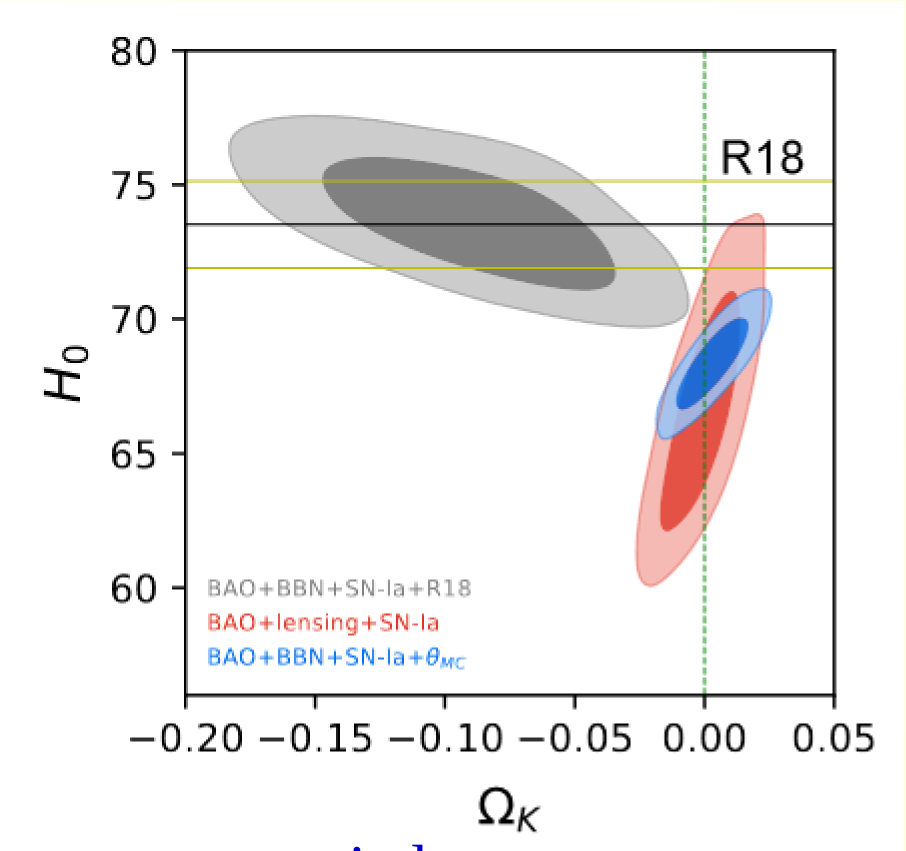
How to solve the H_0, σ_8 tension

R18
Riess et al
2018

Interacting DE?



A closed universe?

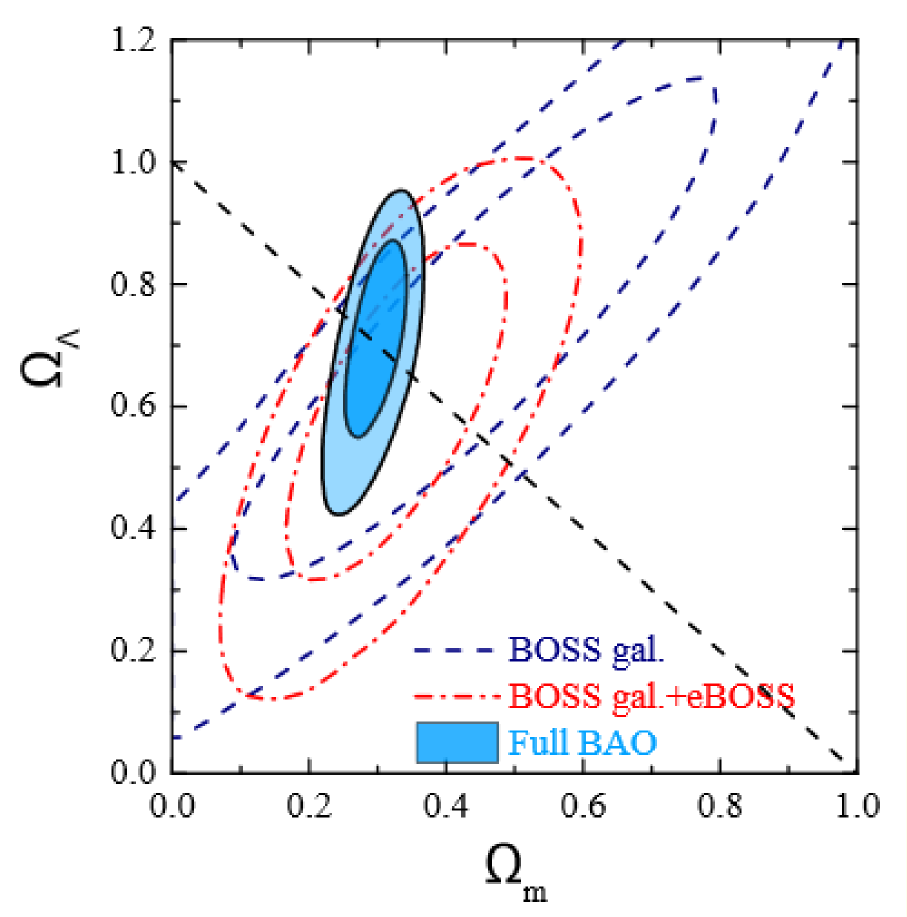


More than 6 parameters varied

Di Valentino et al 2018, 2019

BAO z=0.8-2.2 from quasars e-BOSS

(last release DR14 SDSS-IV)



147 000 quasars
over 2040 $°^2$

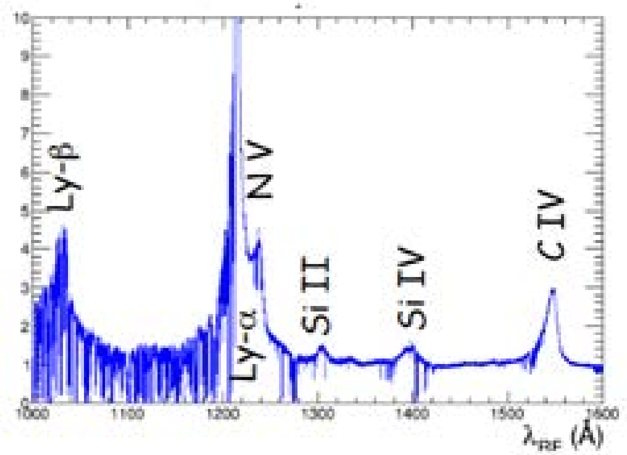
Compatible with ΛCDM
$\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$

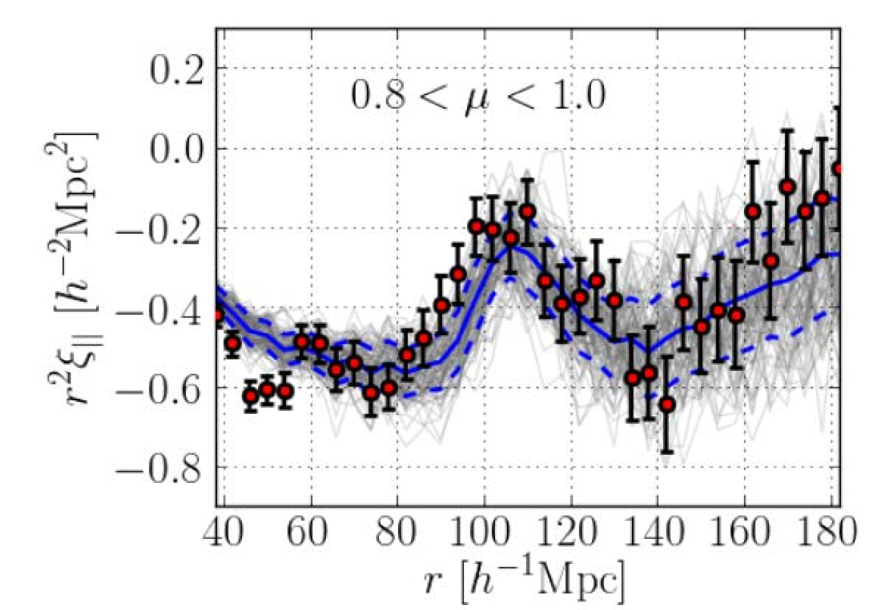
The QSO are very good tracers!

Ata et al 2018

Full BAO: including Lyα

Survey in Lyα absorption



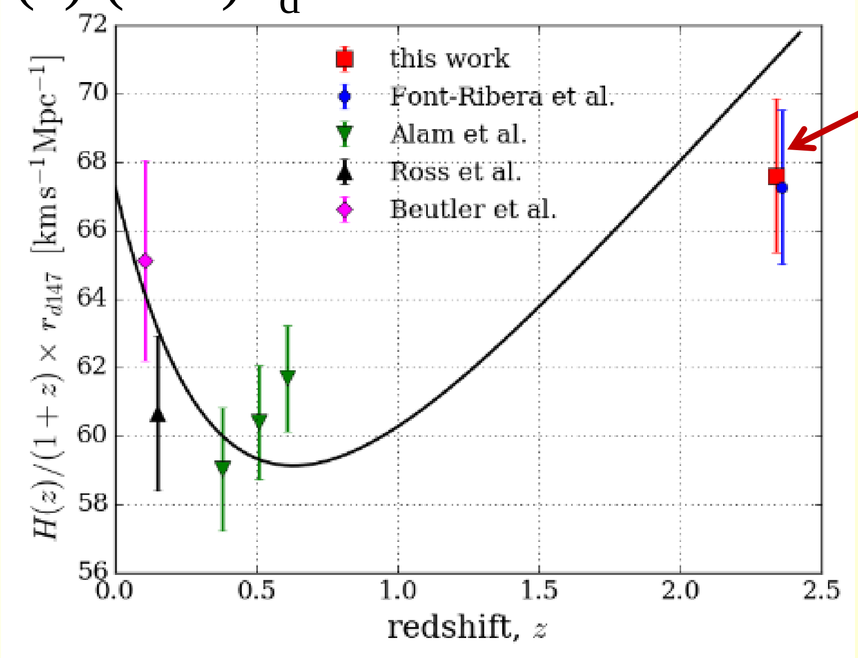


Absorption of Lyα line at z=2.3

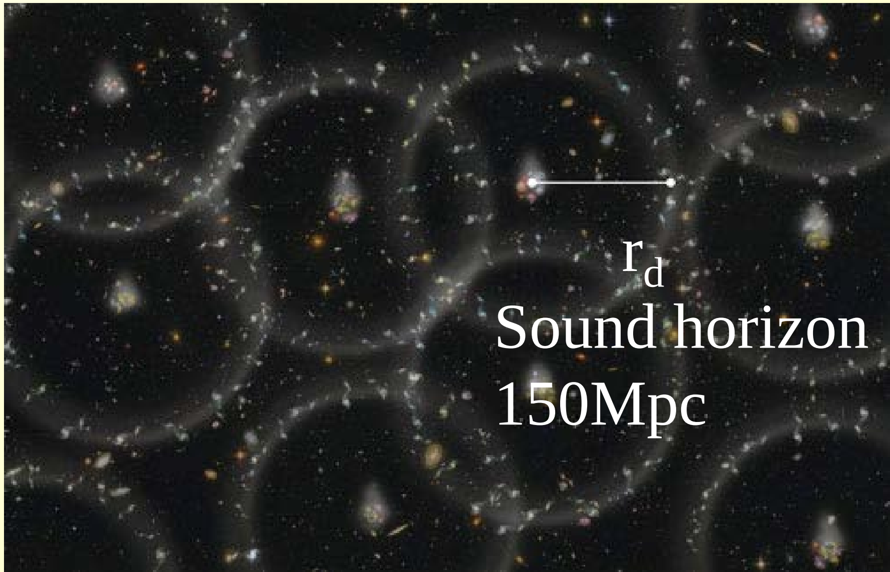
Delubac et al 2014

Red dots versus QSO simul (grey)

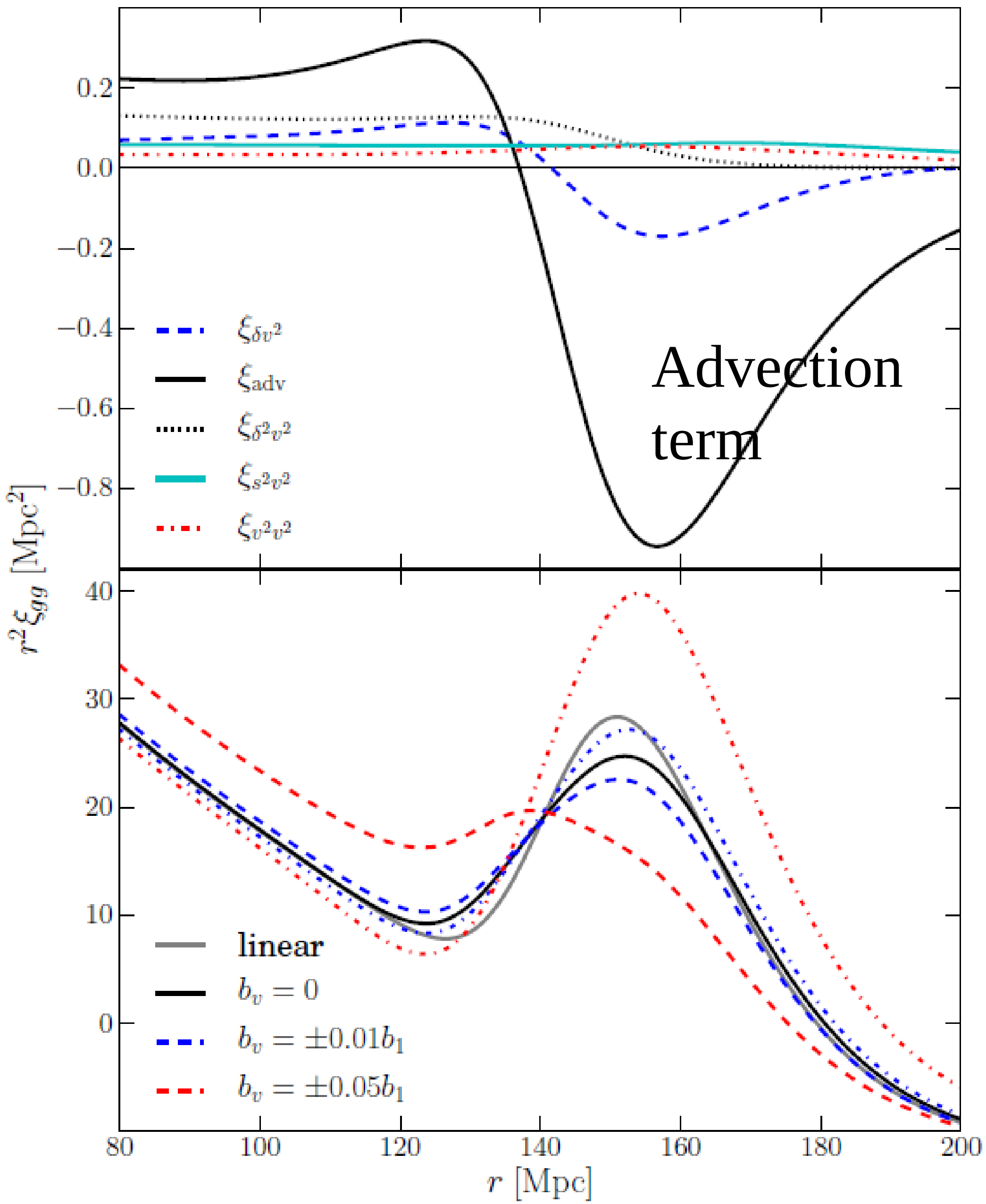
H(z)/(1+z) r_d



Bautista et al 2017



Peculiar velocity DM-baryons



It was realized in 2010 that V_b-V_{DM}= 33km/s at decoupling

The HI σv = 6km/s
➔Supersonic

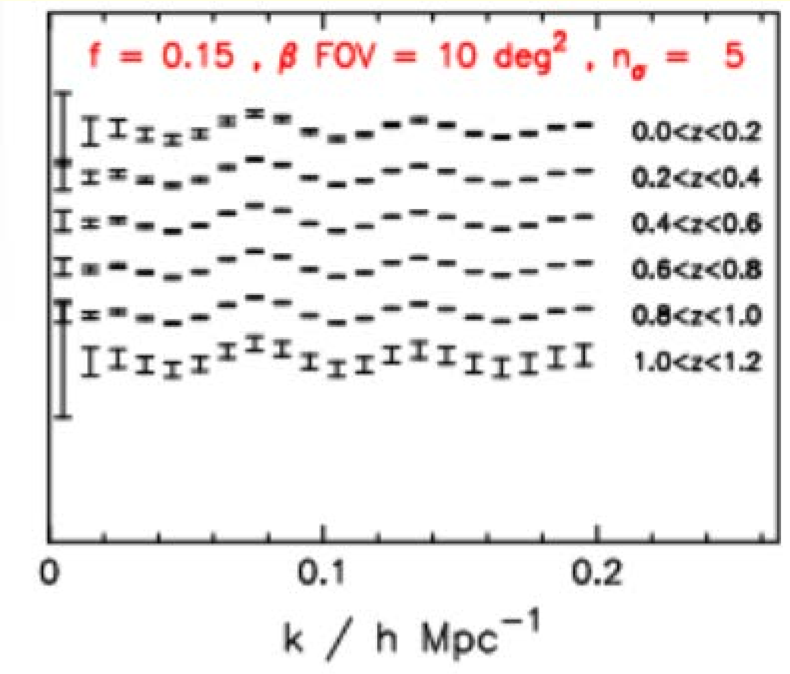
➔Could impact small mass structures
Modifies BAO

Blazek et al 2015

HI surveys for BAO with SKA-1

All sky survey: 4 10^6 gal z=0.2 3π sr
Wide-field survey 2 10^6 gal z=0.6 5000 deg^2
Deep-field survey 4 10^5 gal z=0.8 50 deg^2

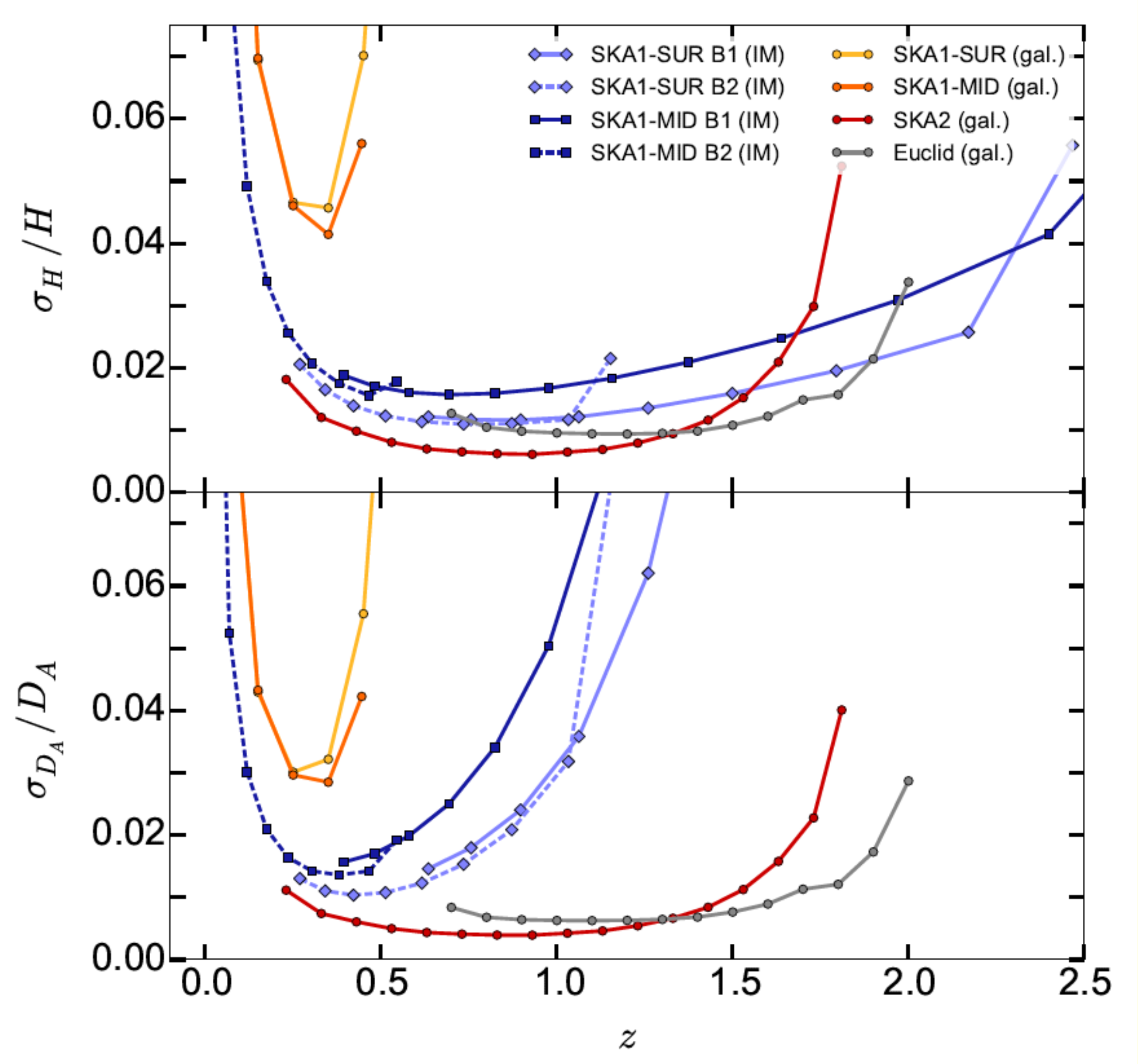
More competitive: HI intensity mapping 30 000 deg^2 up to z=3
Deep and wide, large volumes, ~Euclid



SKA2 will help to provide pure sample
1 billion HI galaxies in total

Weak shear
10 billions galaxies in continuum

Radial and transverse BAO

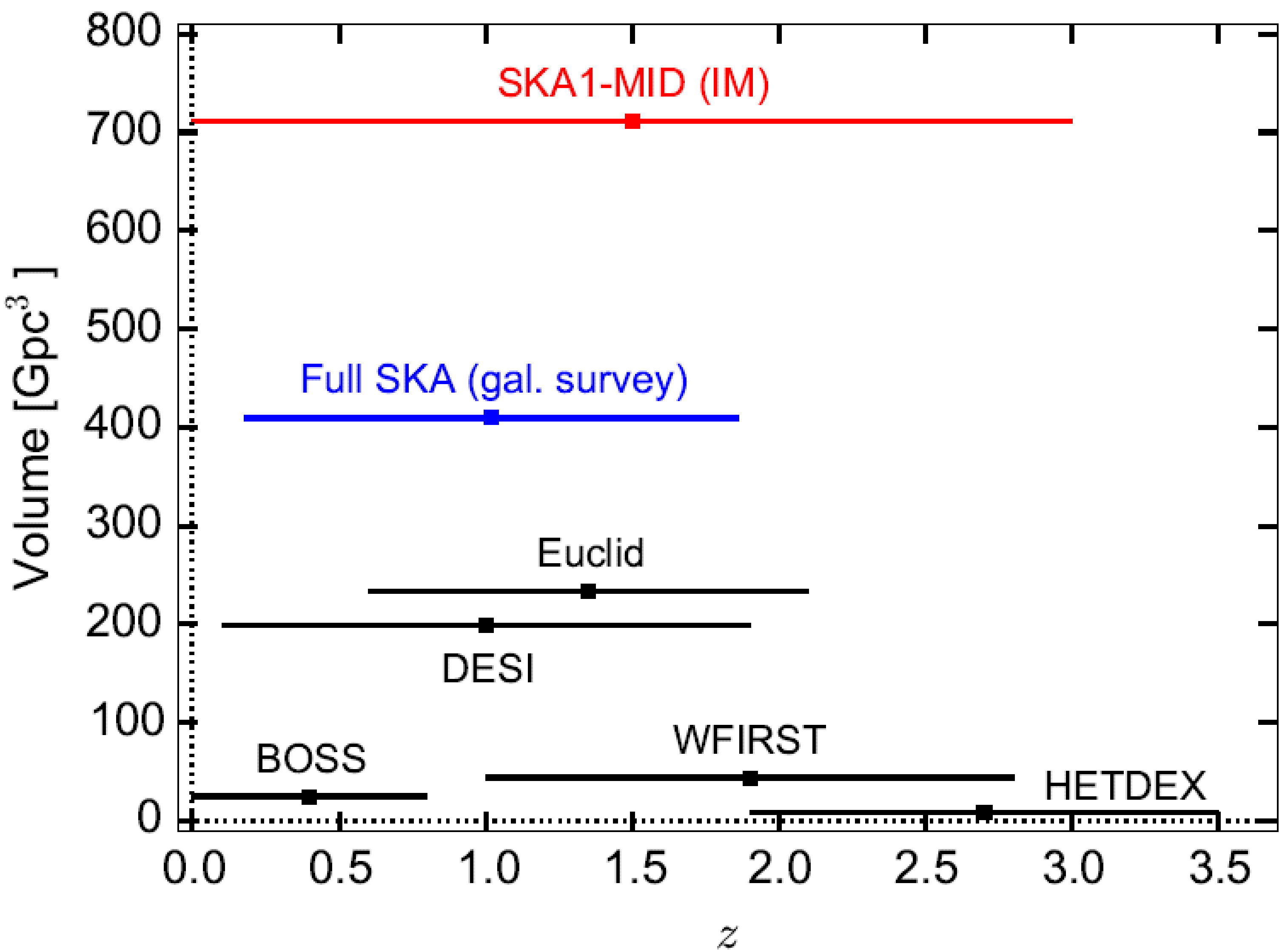


IM: HI Intensity mapping
Gal: HI galaxy surveys

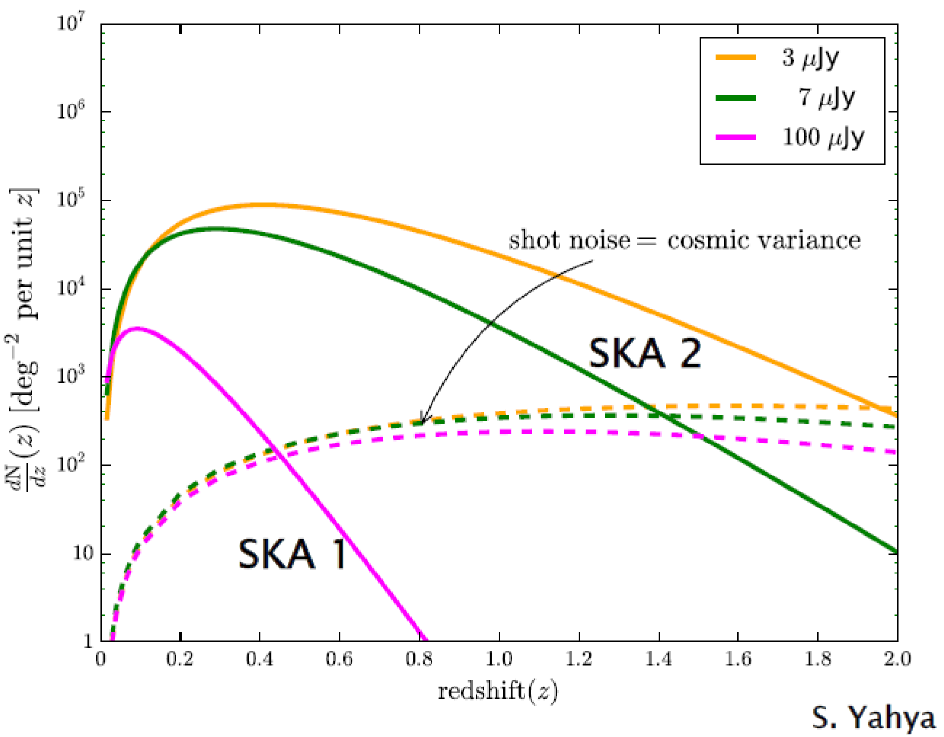
B1 low-frequency band
B2 high-frequency band

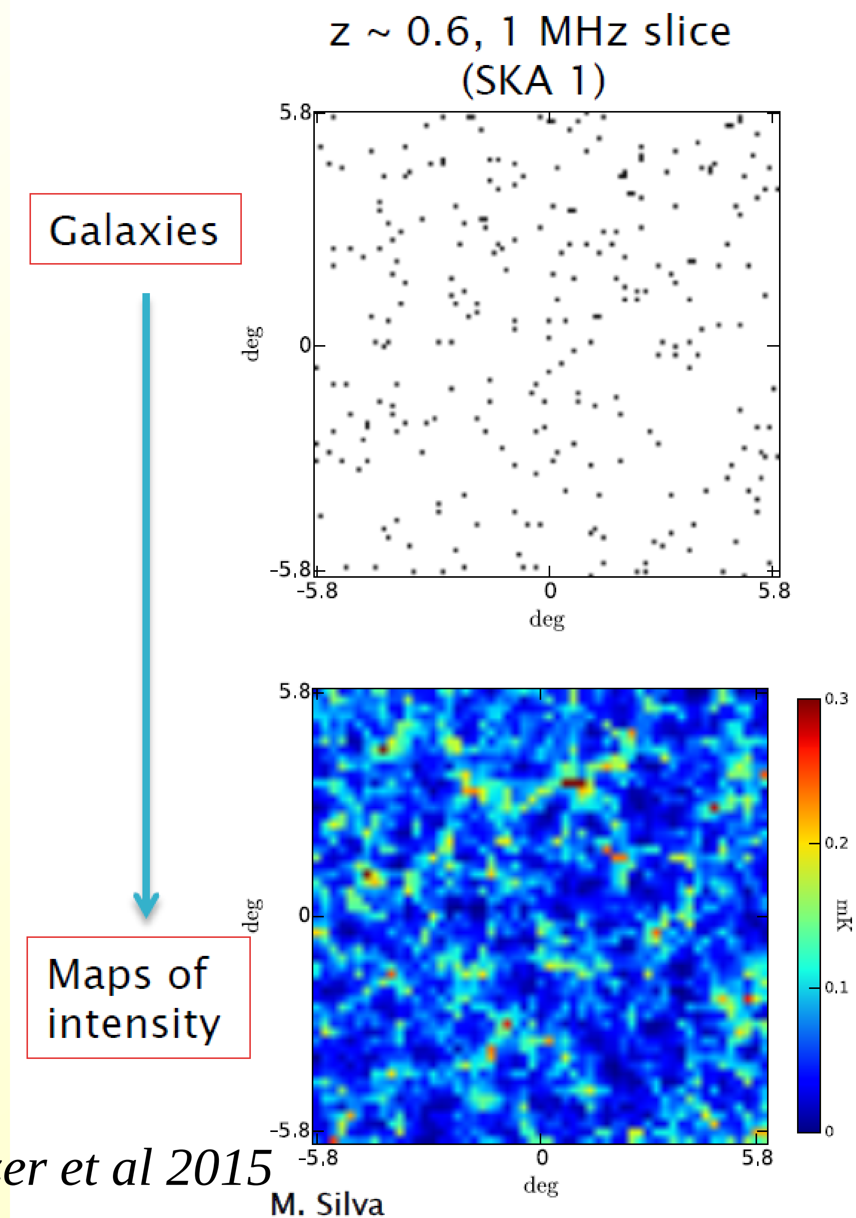
Maartens et al 2015

Comparison of Volume covered



HI gal survey vs intensity mapping





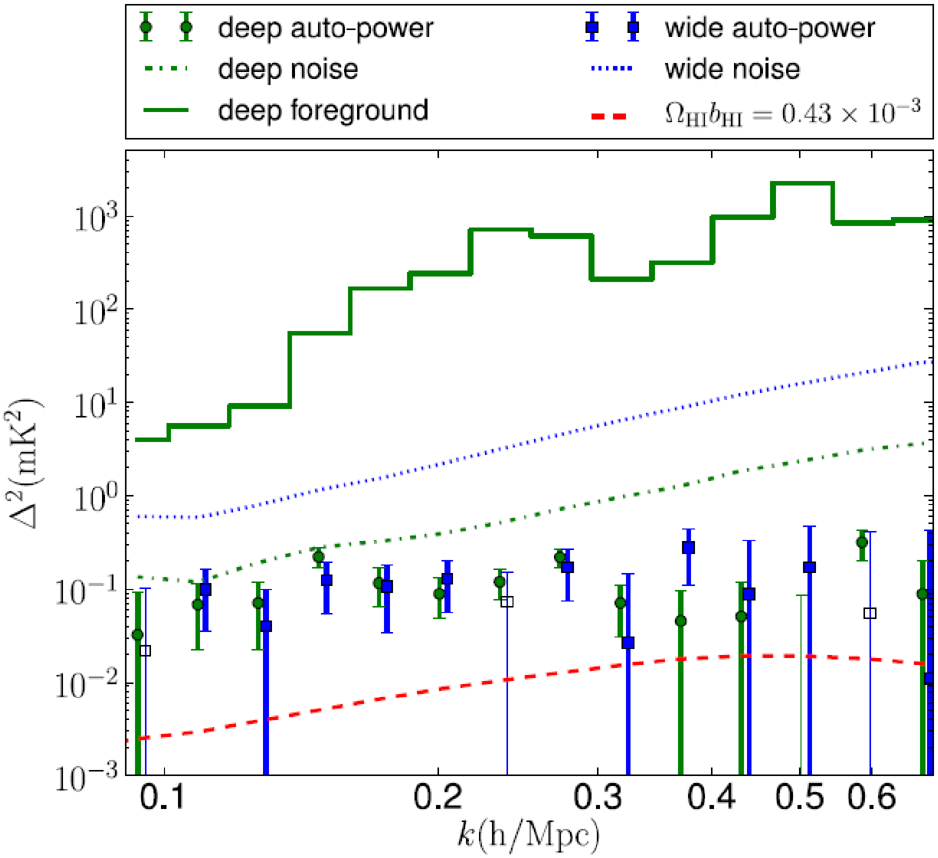
HI intensity mapping: main problem is the foreground, due to continuum

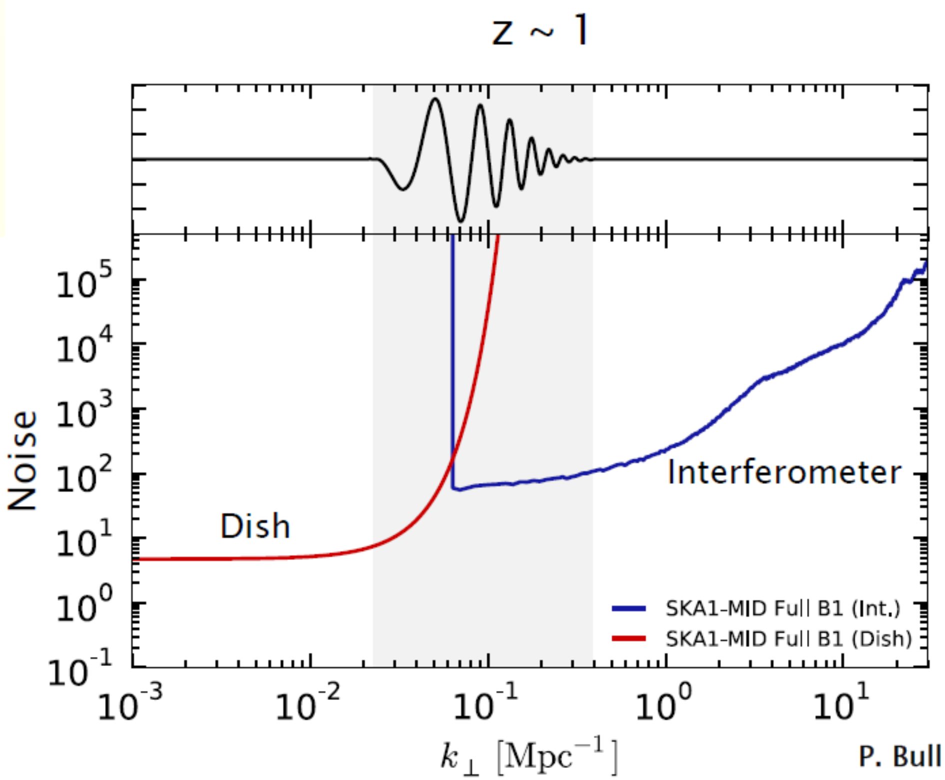
1000 x the expected signal

Not smoother in frequency, but fewer bright spectral degrees of freedom *Switzer et al 2015*

First results HI intensity mapping (GBT)

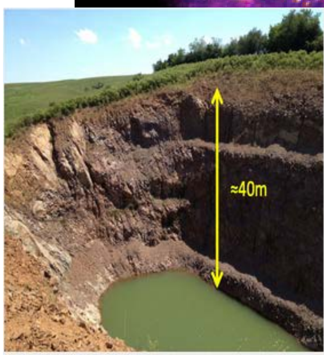
Not enough short baselines
(BAO require 20m)
➔use N single dishes
(auto-correlation)



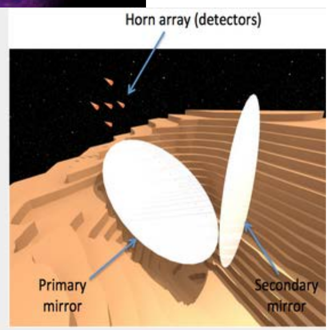


Switzer et al 2014

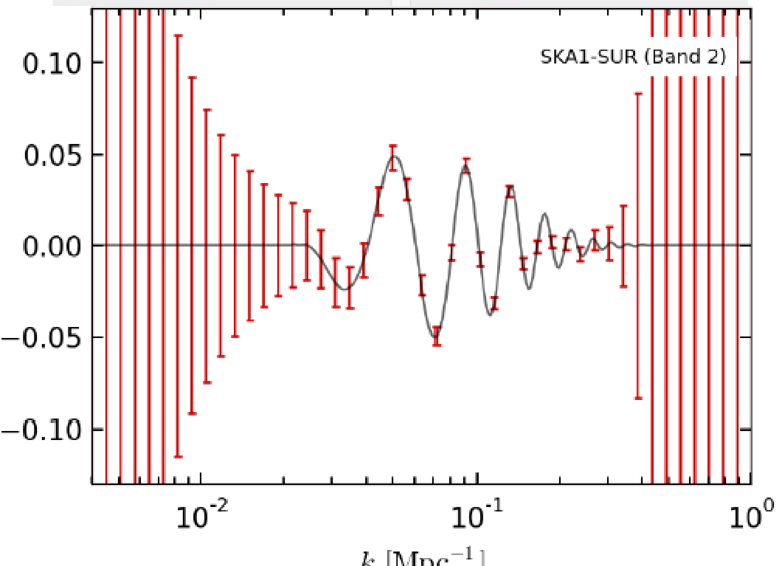
BAO with SKA1 Intensity mapping

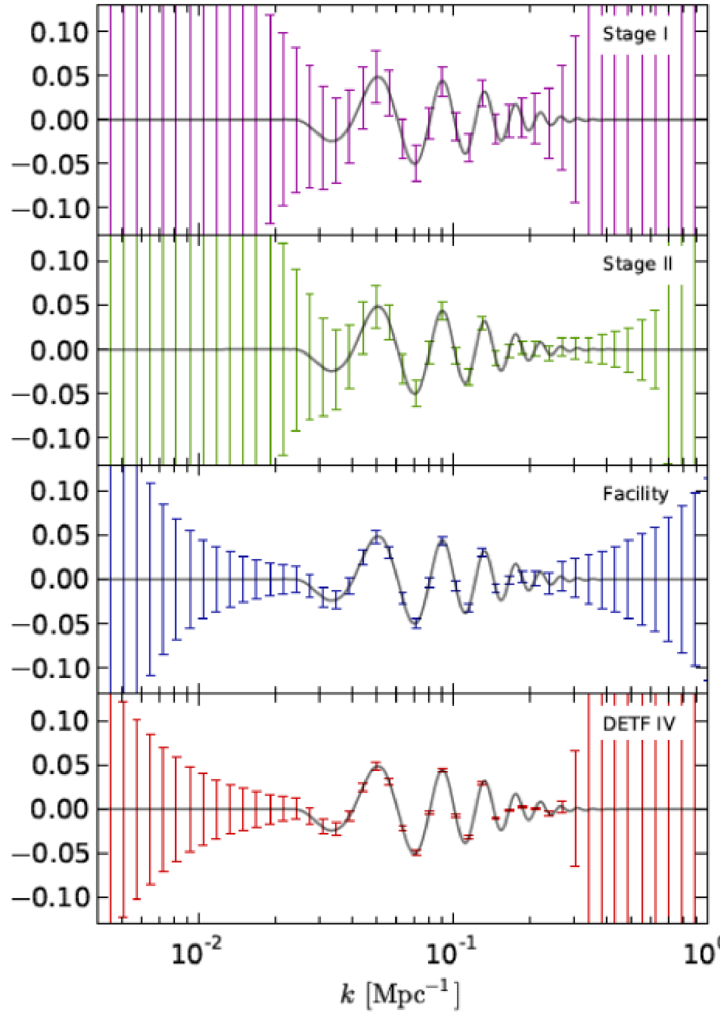


[Quarry Castrillon]



[A 3D view of the BINGO telescope]





40m

~ BINGO

z=0.13-0.48

~ MeerKAT

~ SKA1-Mid base (up to z ~ 2.0)

~ Euclid

RSD Redshift space distortions

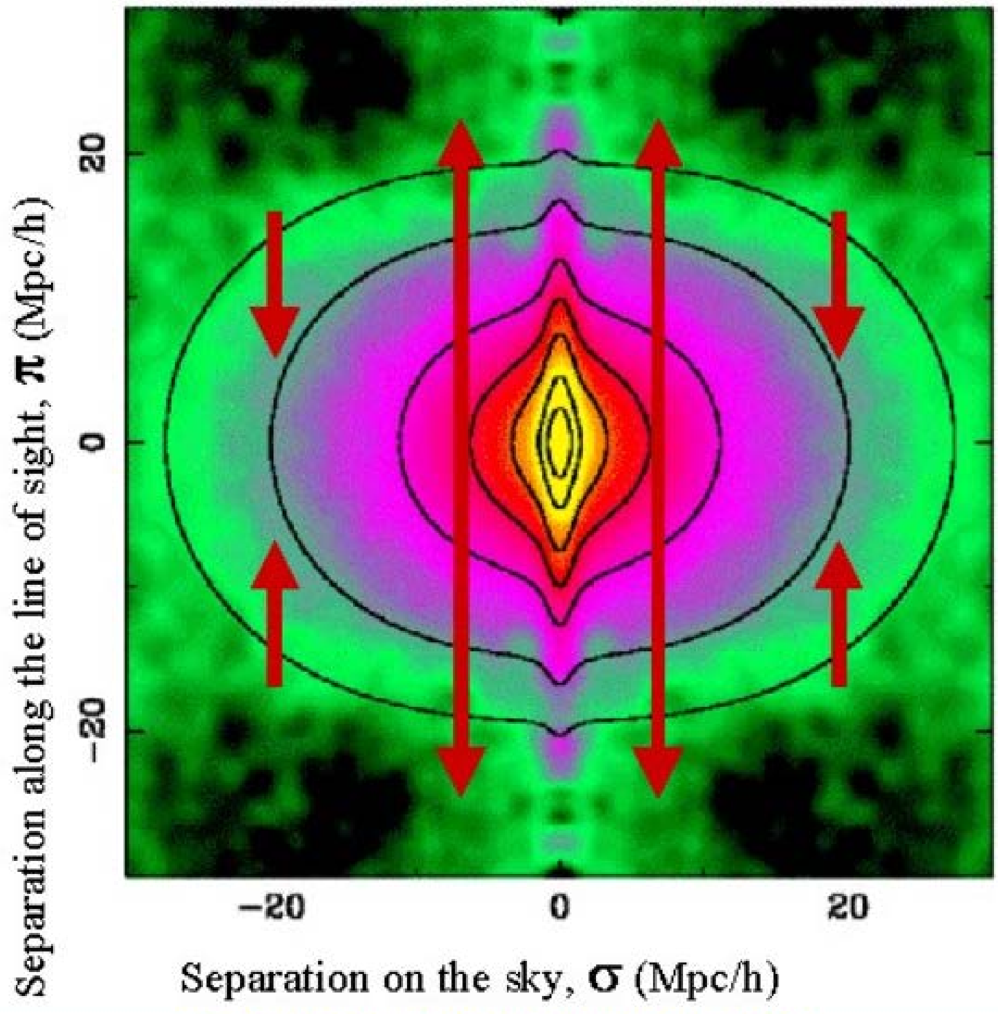
Distortions due to peculiar velocities on the line of sight (fingers of god!)

Kaiser effect in clusters
Systematic infall

More than random allows to determine

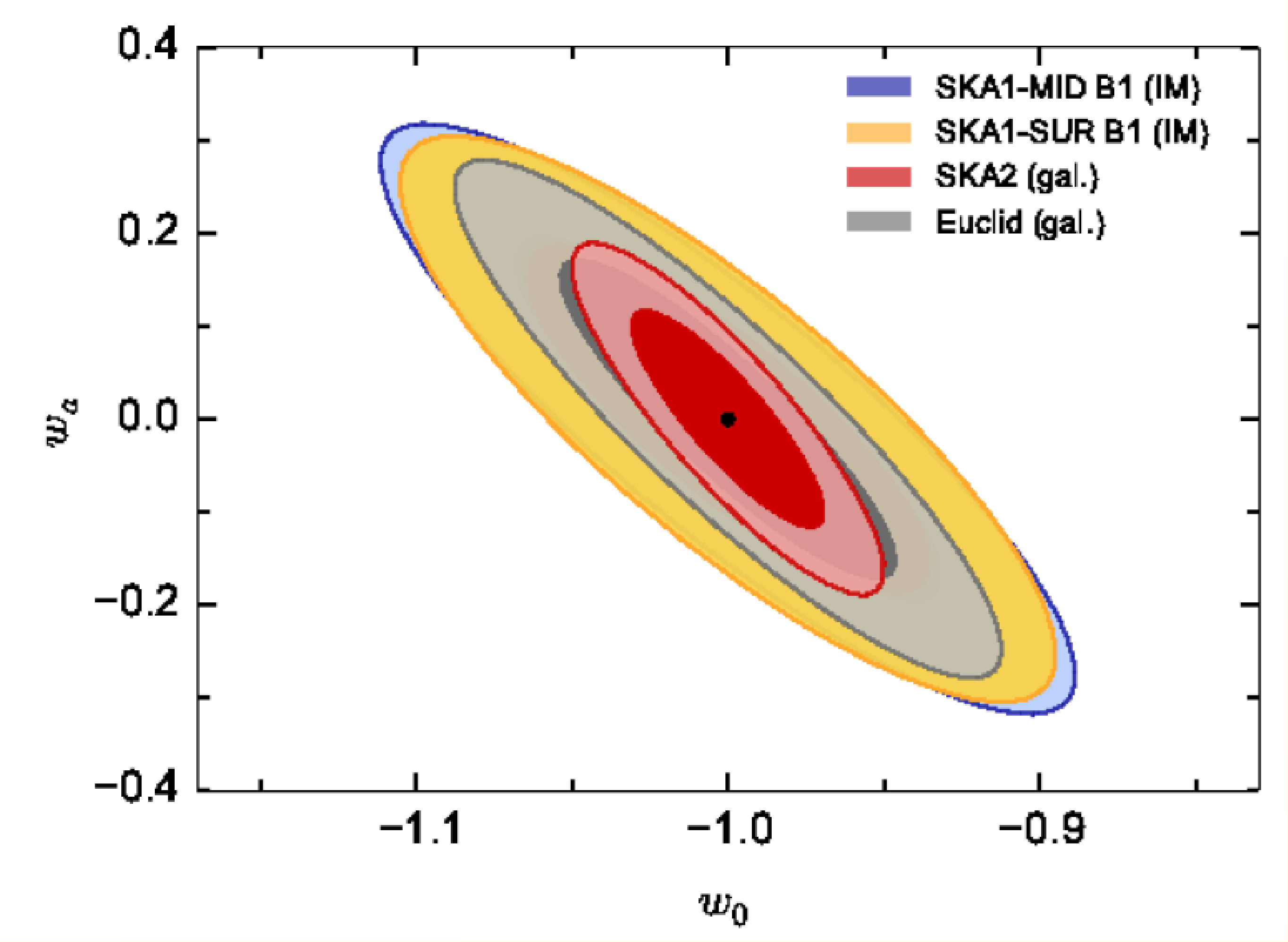
$\beta = \Omega_m^{0.6}/b$

bias $\delta_{galaxies} = b\ (\delta_{mass})$ and σ_{gal}



The 2dF Galaxy Redshift Survey Team (2001)

Constraints on DE with HI gal survey

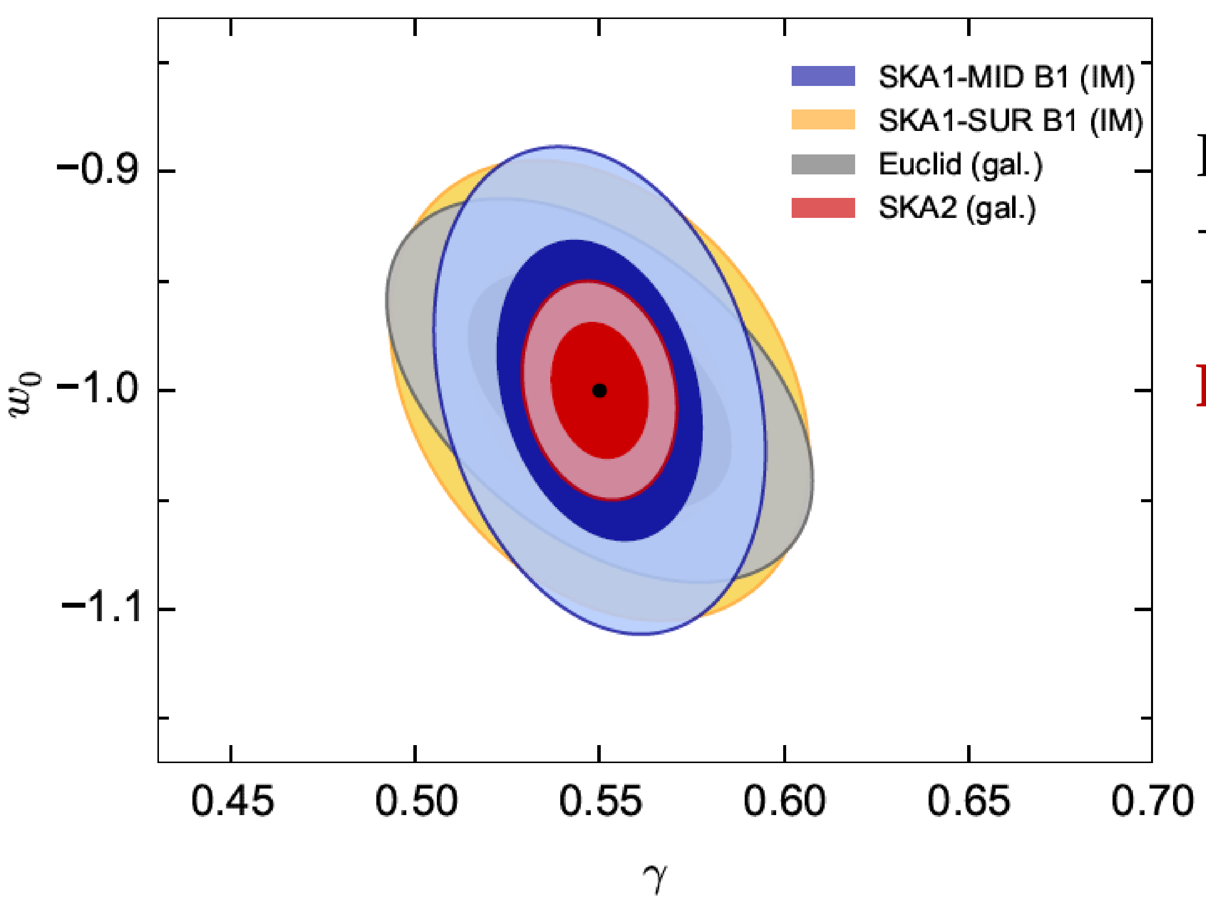


RSD

SQUARE KILOMETRE ARRAY

Raccanelli et al 2015

Dark energy and growth factor

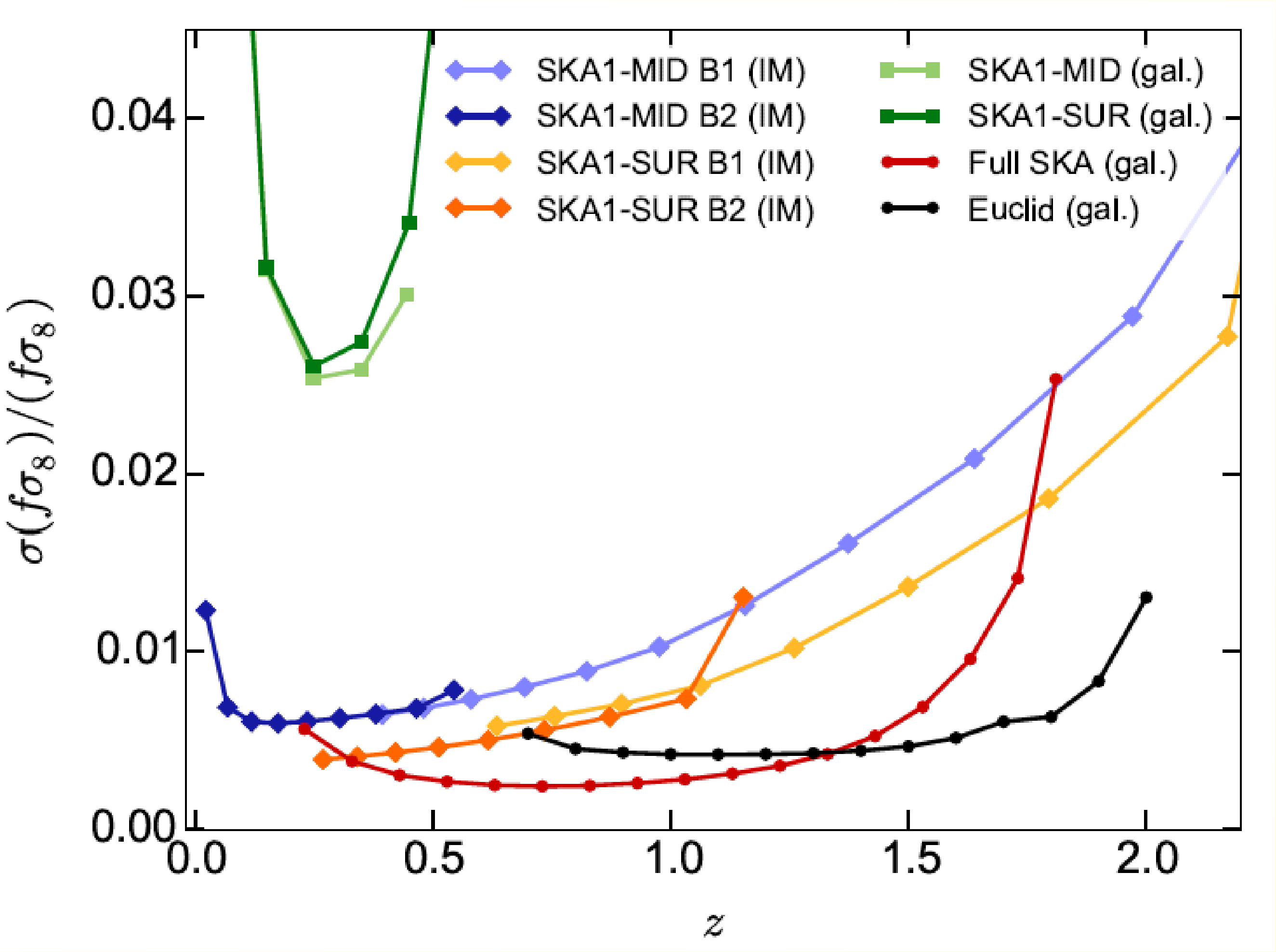


Including Planck + BOSS + priors

RSD

Raccanelli et al 2015

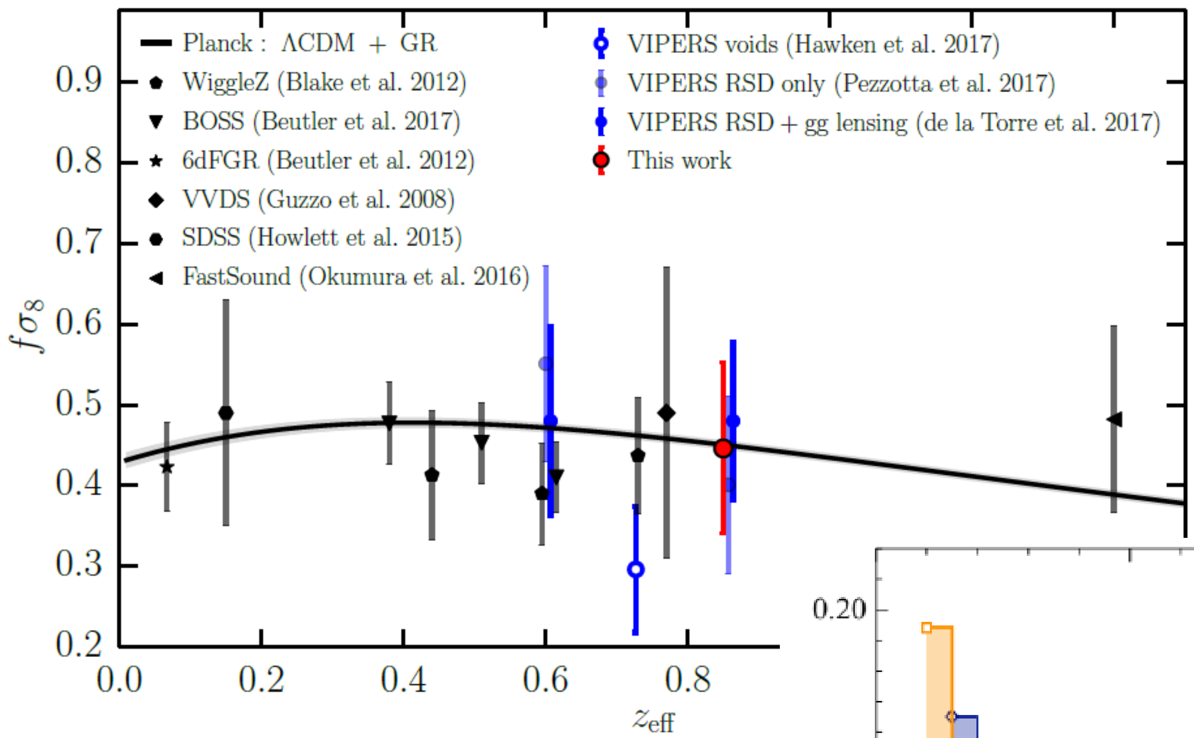
Constraints on $f\sigma_8$



SKA1-gal not Competitive, but IM yes, and SKA2 much improved

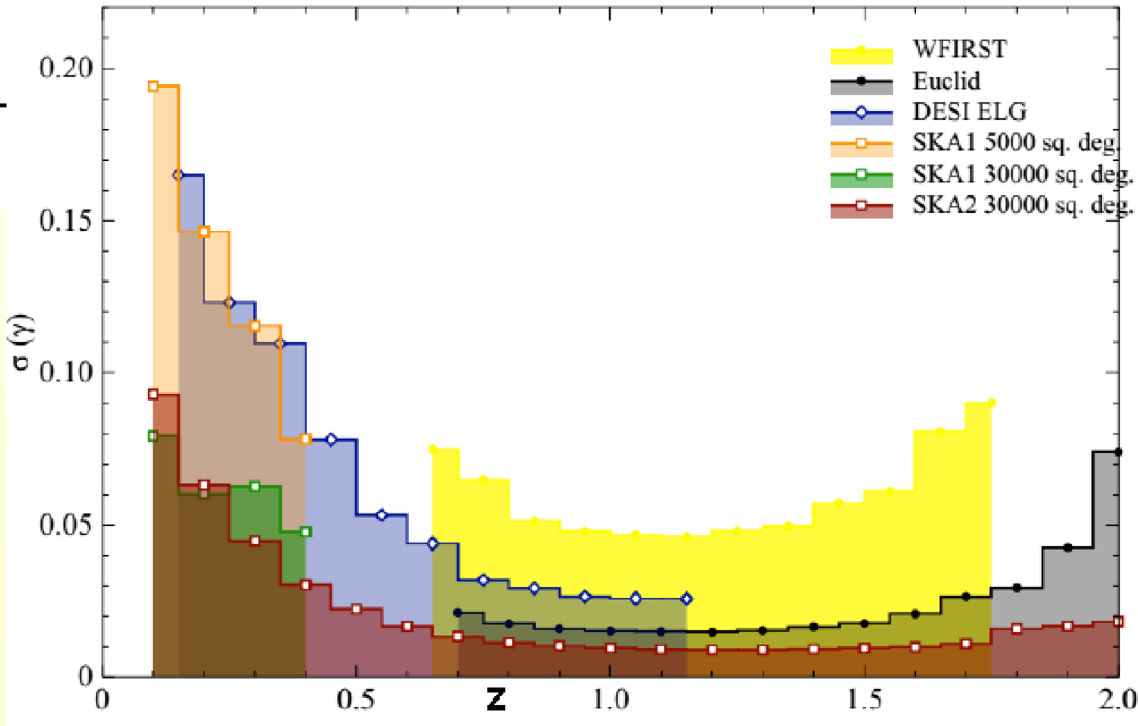
Raccanelli et al 2015

RSD: Redshift Space Distortions



Taux de croissance linéaire des structures f(z) x σ8

Tests de gravité modifiée



Various galaxy surveys
VIPERS,
Mohammad et al 2018

Mohammad et al 2018

VIPERS Blue galaxies

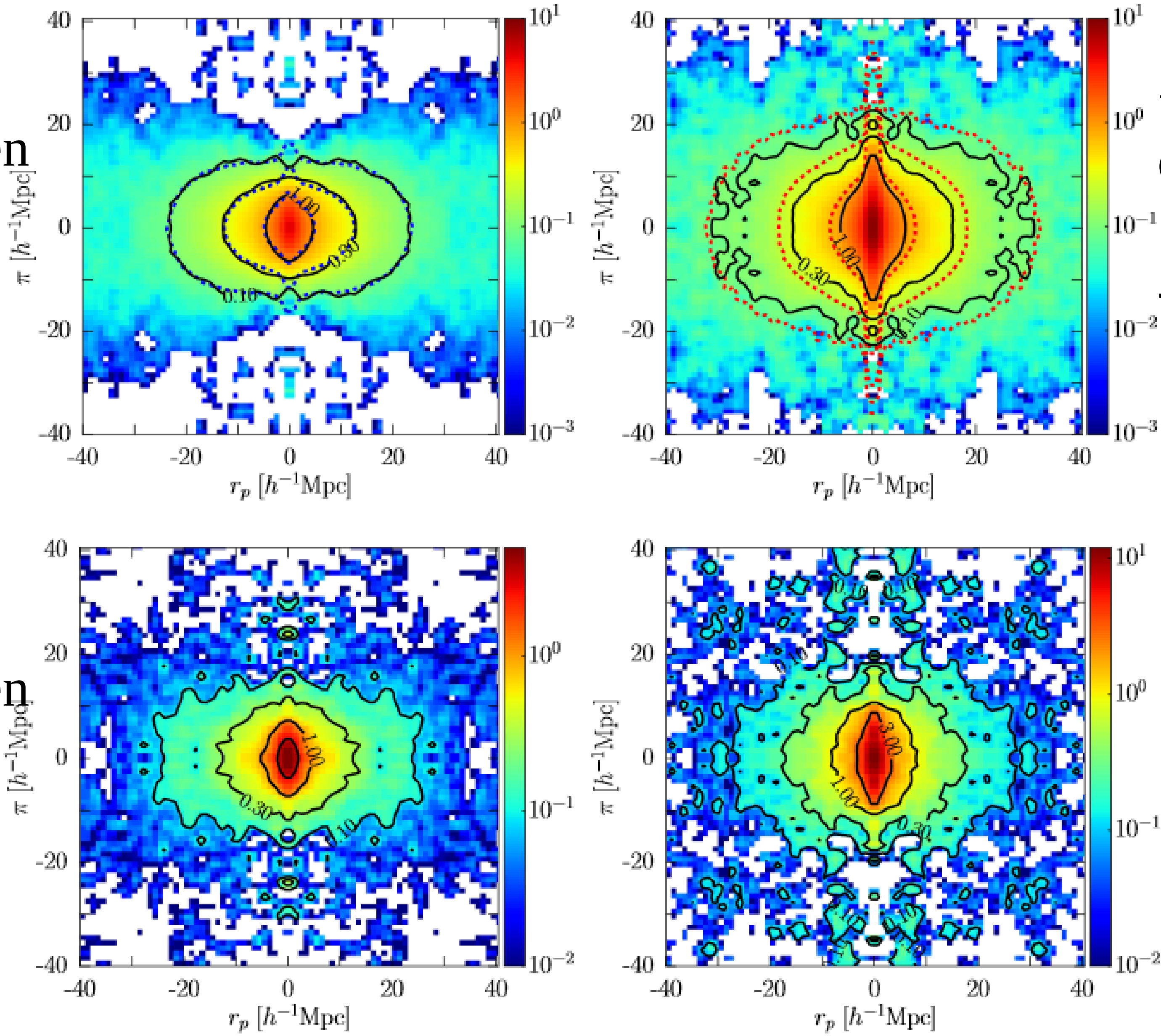
Red galaxies

Limité en flux

Limité en volume

+ allongé en rouge

--- simul



Continuum surveys with SKA1

In 2yrs achieve 2 μJy rms would provide ≈4 galaxies arcmin^2 (>10σ)

PSF is excellent quality circular Gaussian from about 0.6 – 100”
With almost uniform sky coverage of 3π sr

➔Total of **0.5 billion radio sources, for All sky survey**
for weak lensing and Integrated Sachs Wolfe (WL, ISW)

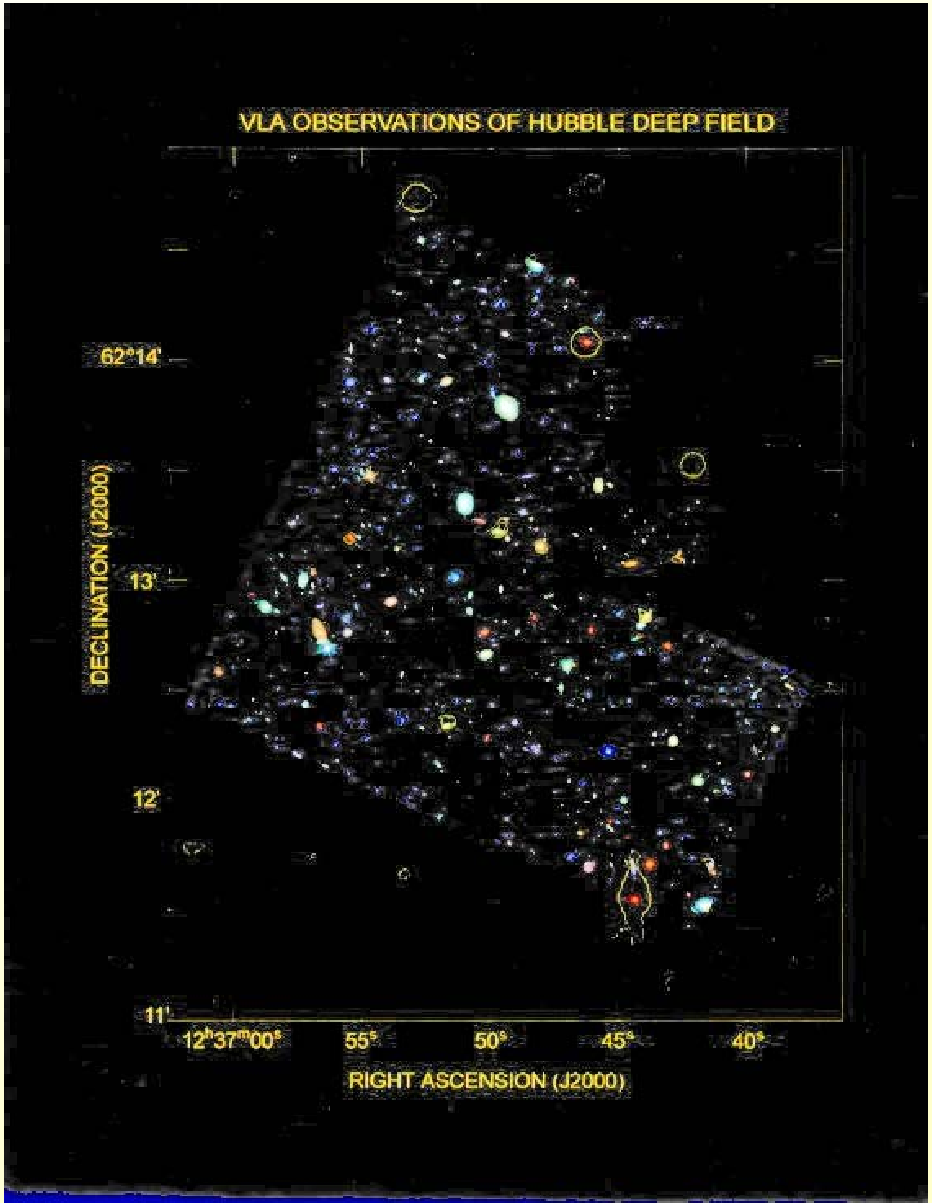
For wide-field (5000 deg2) **2 μJy rms** ≈6 galaxies arcmin^2 (>10σ)
For deep-field (50deg2) **0.1 μJy rms**, ≈20 galaxies arcmin^2 (>10σ)

Present status of radio surveys

HDF-N 5 x 5 arcmin area to I ~29th magnitude

Fomalont et al., ApJ 475, L5 (1997)

6 sources detected by VLA with $S_{8.4}$ > 12 μJy (50 hour observation)



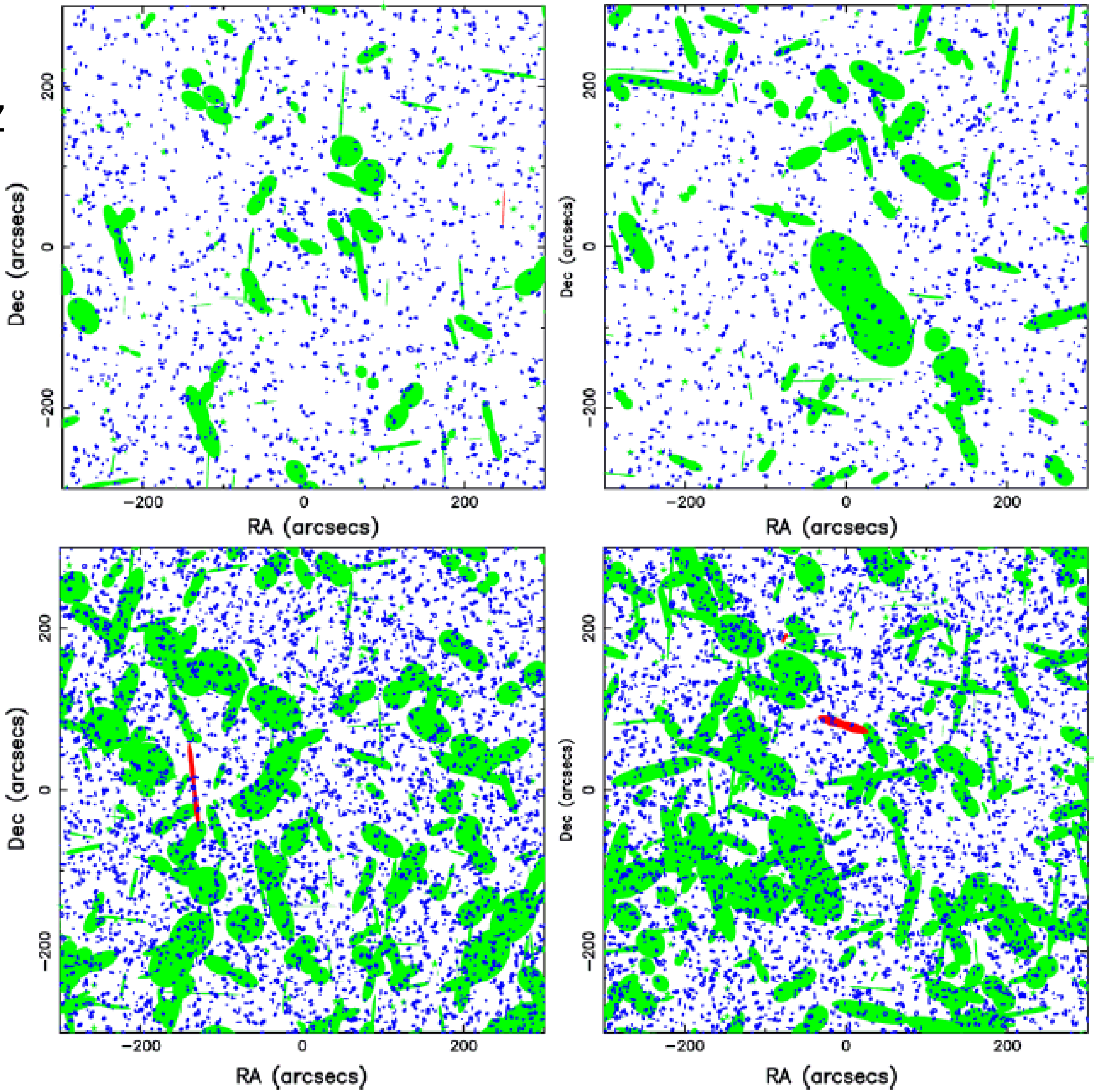
Deep radio sky
10’ size, @ 1.4GHz

1mJy top
100nJy bottom
Left and Right
Cosmic variance

FRI: green, double
FRII: red, double

Beamed FRI:
green dot
Beamed FRII:
red dot
Star-forming: disk

Jackson 2004

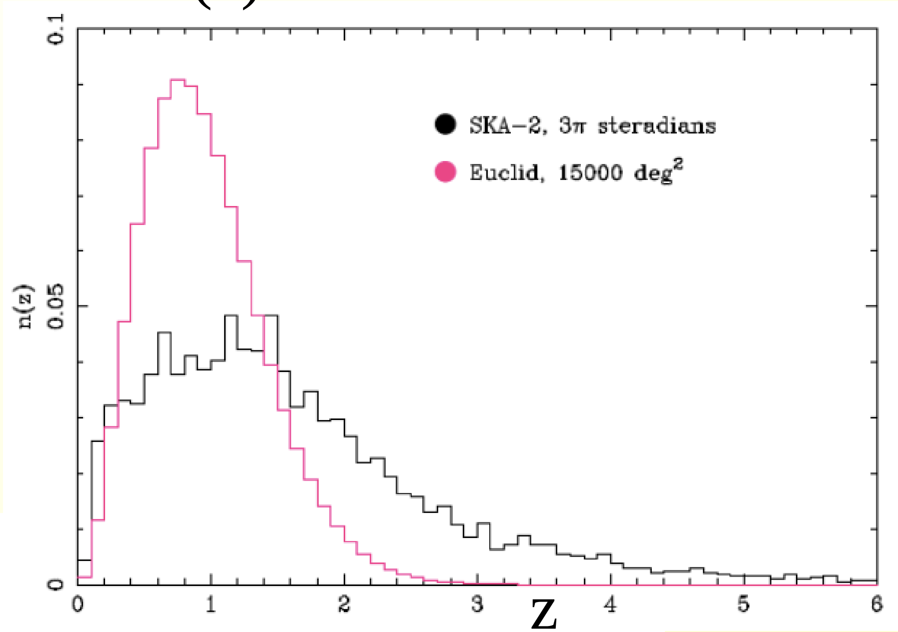


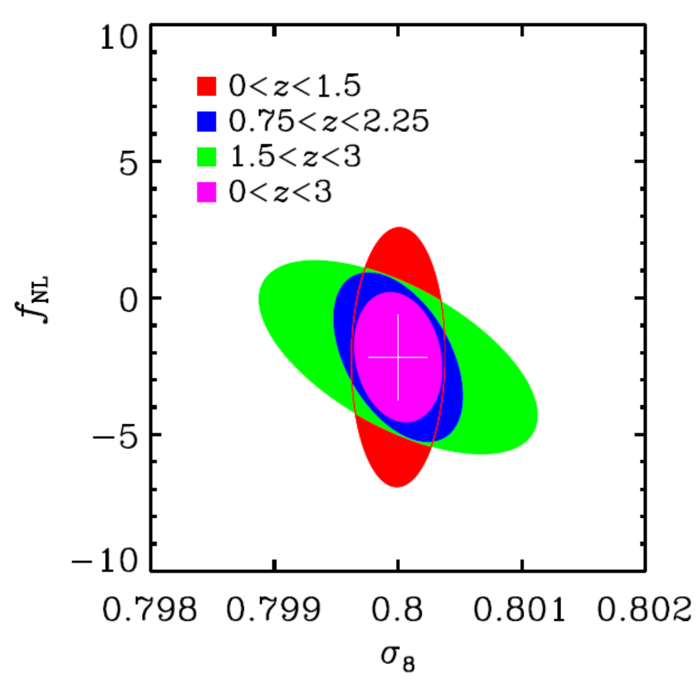
Weak Lensing & LSS in radio

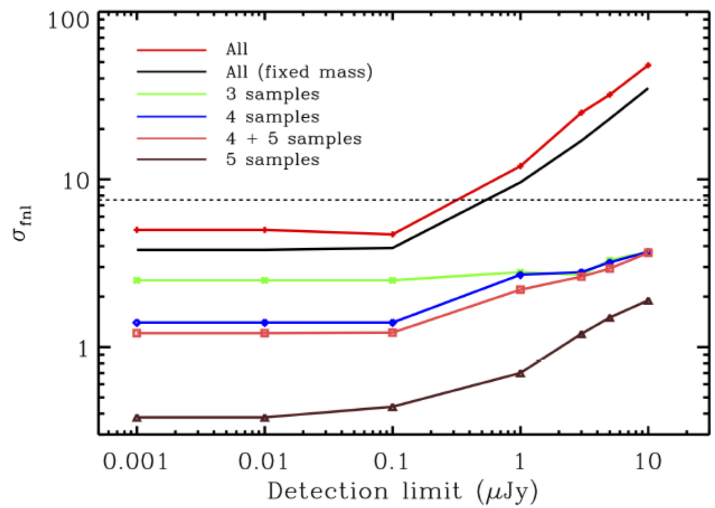
Number of objects
extends to higher z with SKA

The amplitude of non-gaussianity
f_{NL} = -2.2 in standard GR
$\sigma(f_{NL})$ = 7.5 (Planck)
= 2.3 (SKA1) & =1 (SKA2)

dN(z) dz

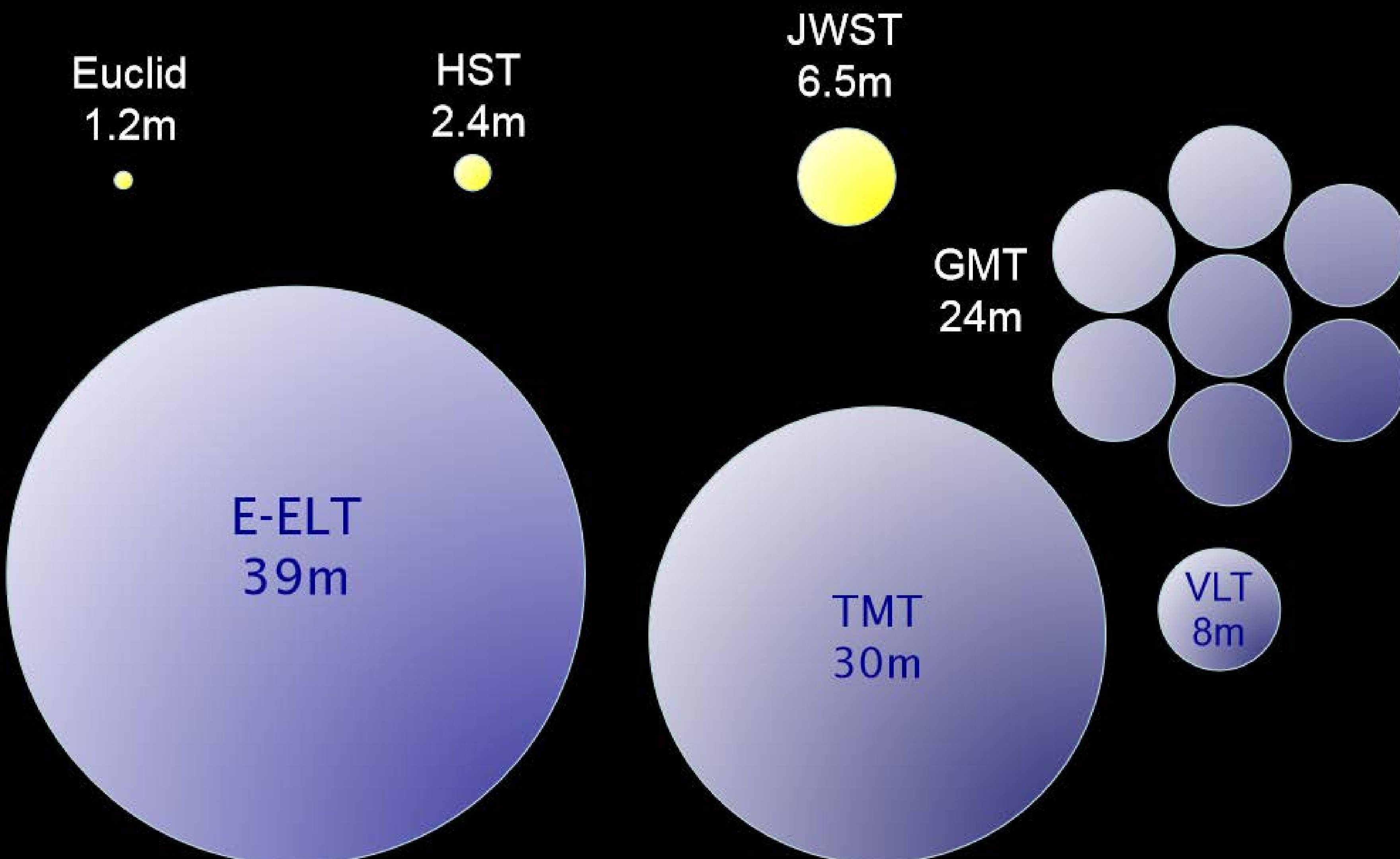






SKA1 &
SKA2
Radio
$\sigma(f_{NL})$

Telescope primary mirrors



Collecting area = sensitivity
Diameter = resolution
Field of view = mapping speed

SKA footprint to scale /100,000