Cosmology at the largest scales
Opportunities with SKA and its pathfinders

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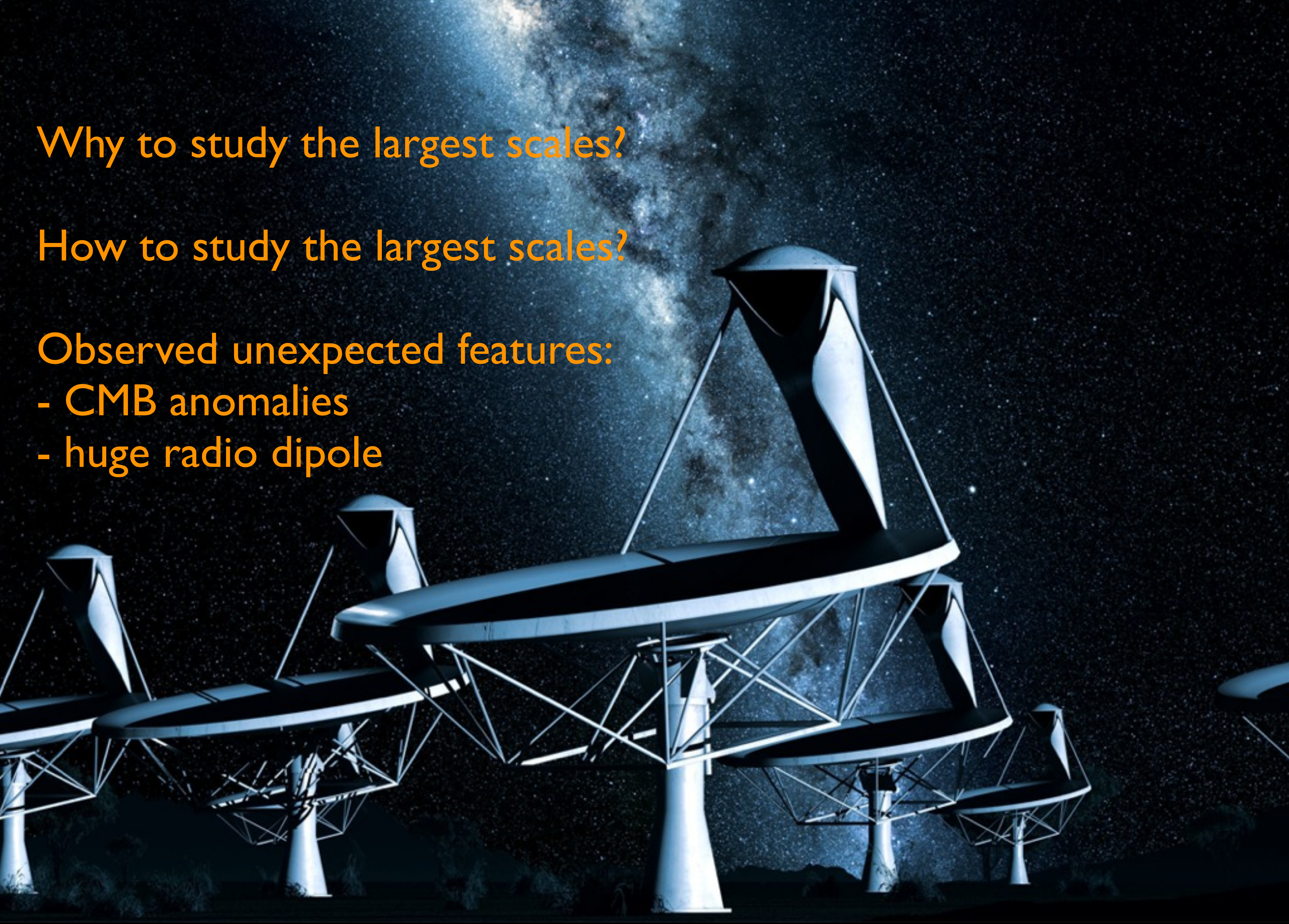
DESY Theory Workshop, September 2014

Why to study the largest scales?

How to study the largest scales?

Observed unexpected features:
- CMB anomalies
- huge radio dipole



The larges observable scales

initial conditions:

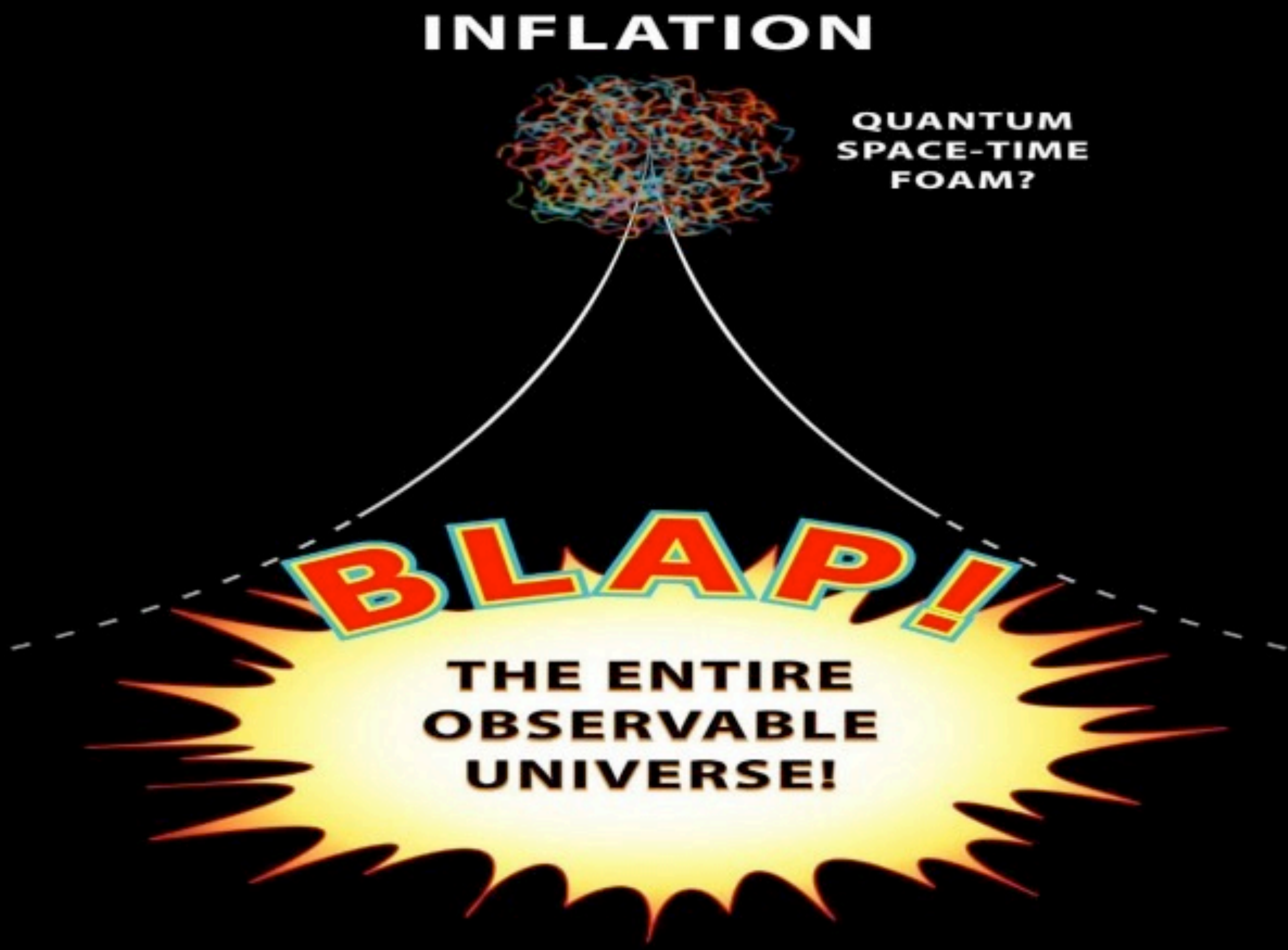
- isotropy and homogeneity
- curvature
- scale invariance
- gaussianity

cosmic reference frame:

- kinetic vs. structure dipole

large scale structure:

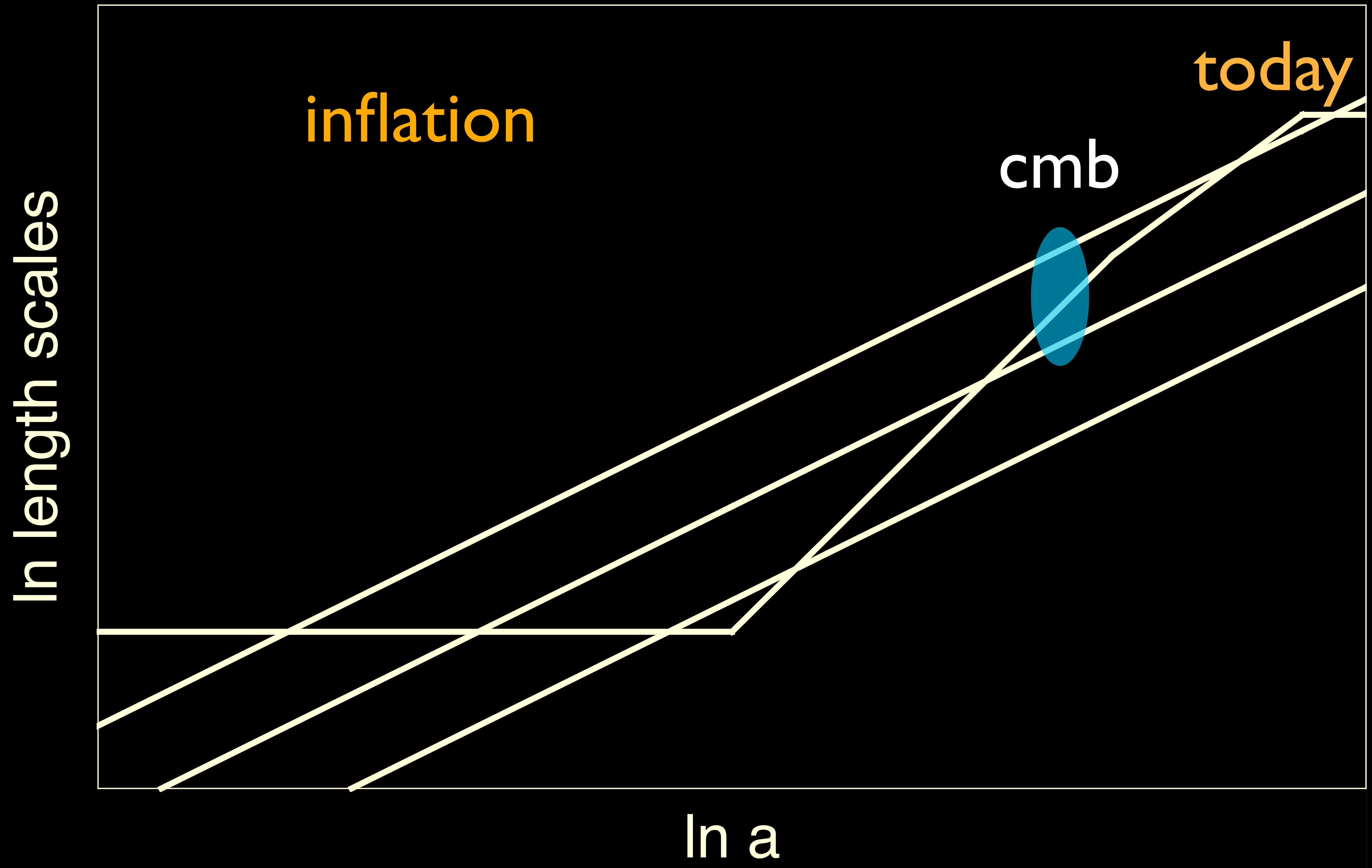
- linear regime
- relativistic effects
- bias and cosmic variance


INFLATION
QUANTUM SPACE-TIME FOAM?
BLAP!
THE ENTIRE OBSERVABLE UNIVERSE!

Cosmological Inflation

d Hubble distance

Cosmological Inflation



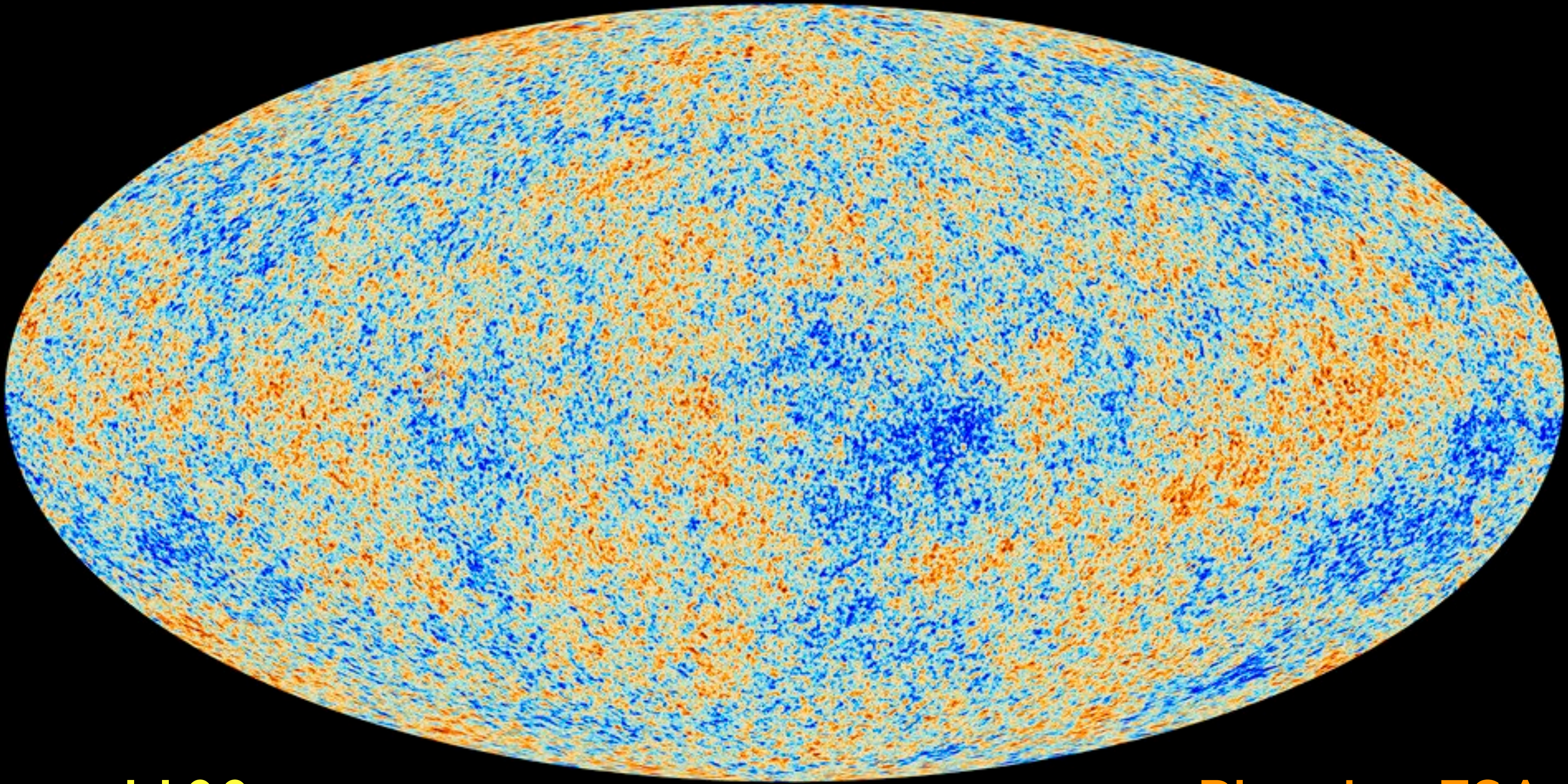
Initial Conditions

- cosmic initial conditions are replaced by principles
- copernican principle: we are not special
- cosmological principle:
  isotropic and homogeneous Universe
- statistical cosmological principle
  consequence of cosmological inflation?

Isotropy

- Observed in radio, CMB, IR, ..., γ, ...
  at per cent accuracy; CMB: $T_0 = 2.7$ K
- CMB dipole $T_1 = 3$ mK;
  cosmic reference frame (CMB frame)
  e.g. relevant for H_0
- higher CMB multipoles $\Delta T \sim 10\ \mu$K

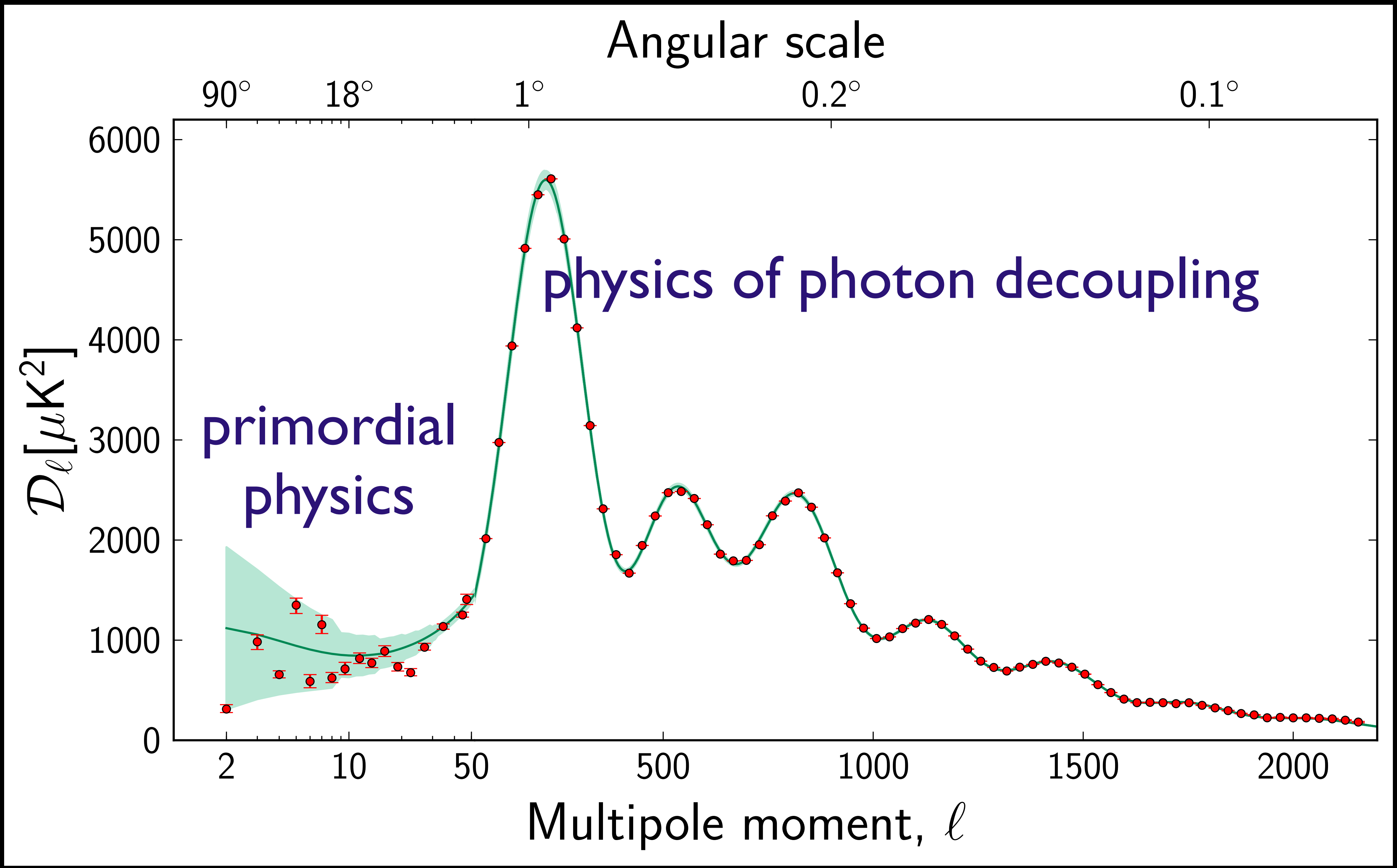
Cosmic microwave sky



z ~ 1100

Planck - ESA

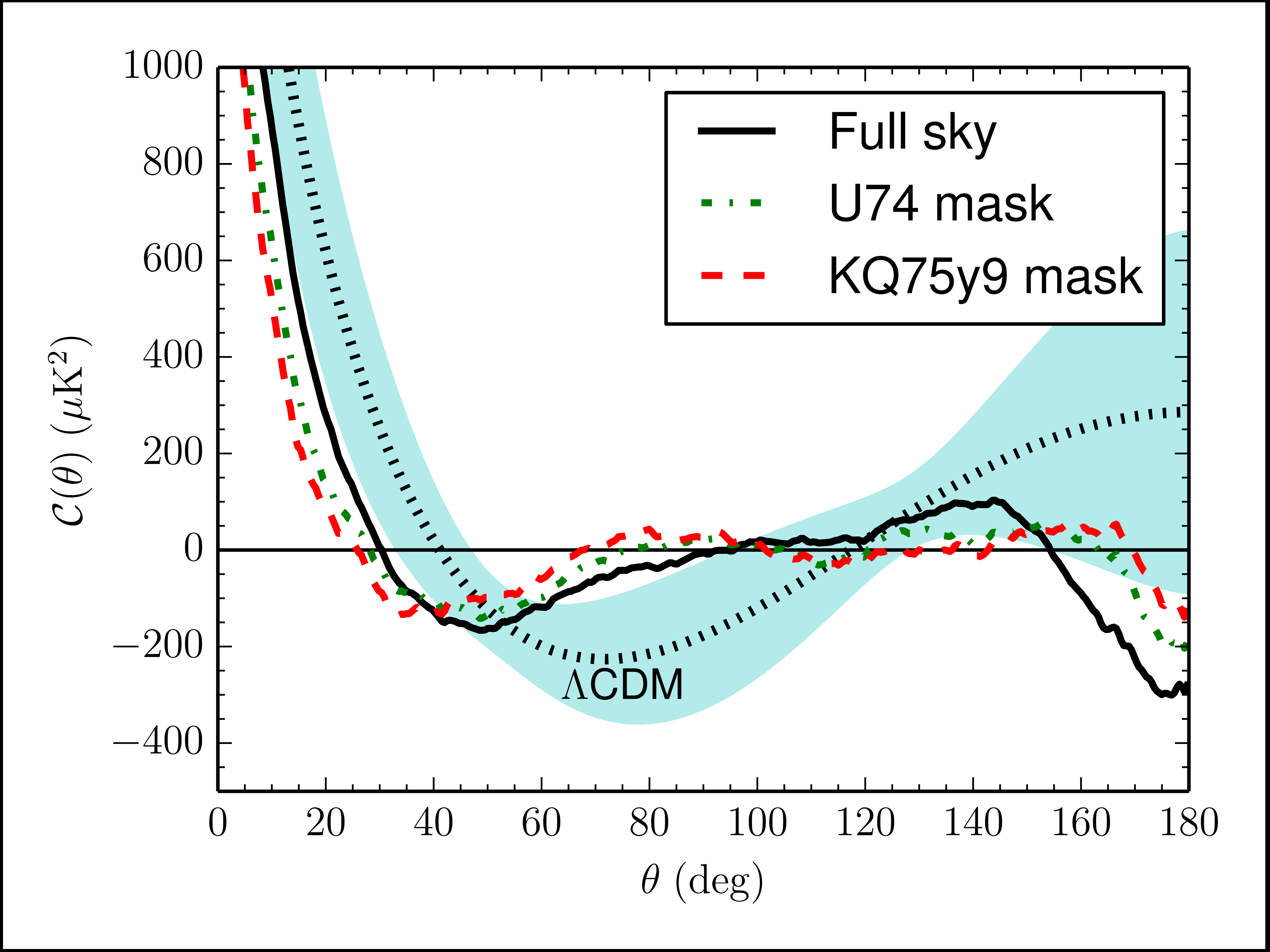
Angular Power Spectrum



Planck - ESA

CMB anomalies (WMAP & Planck)

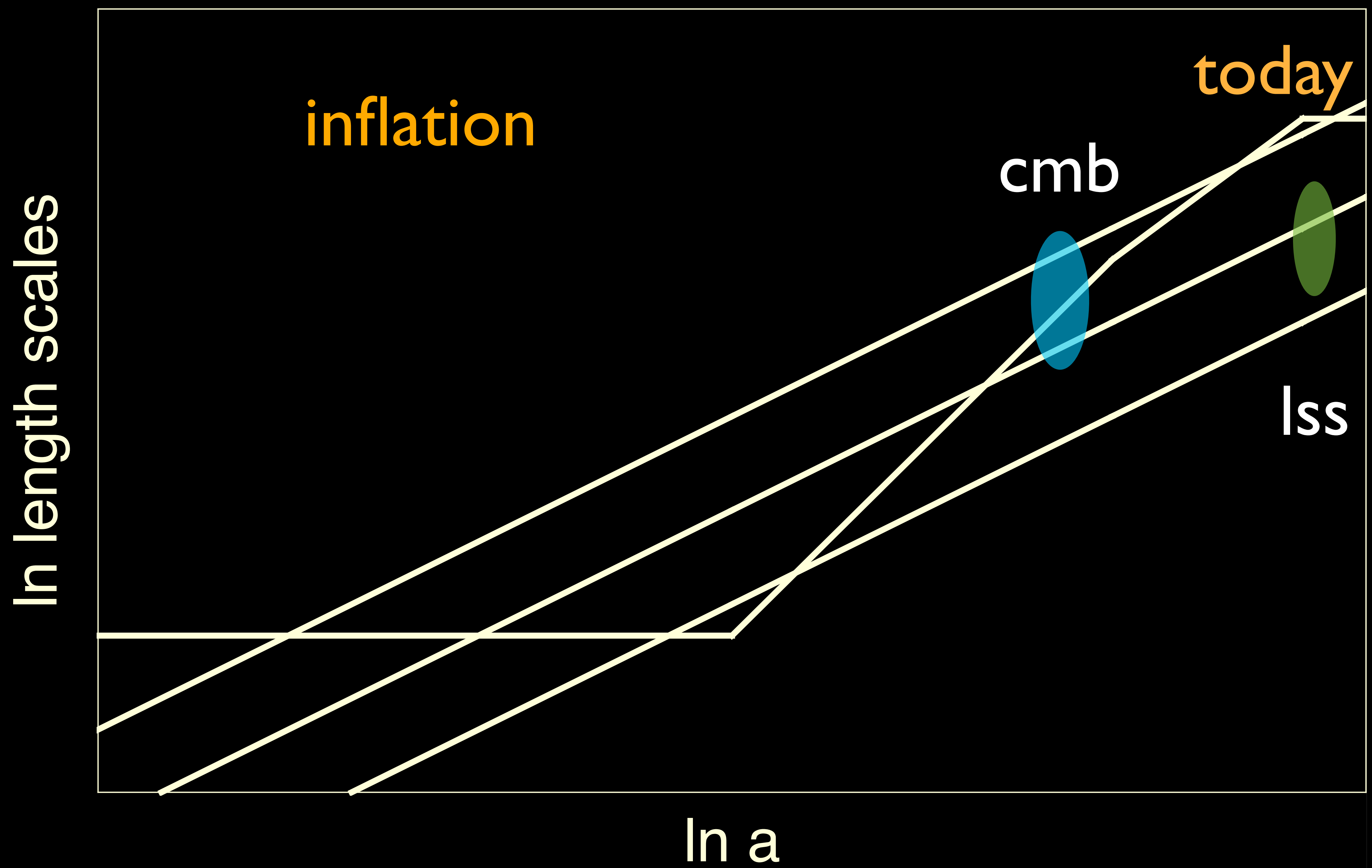
lack of angular correlation at > 60 degrees



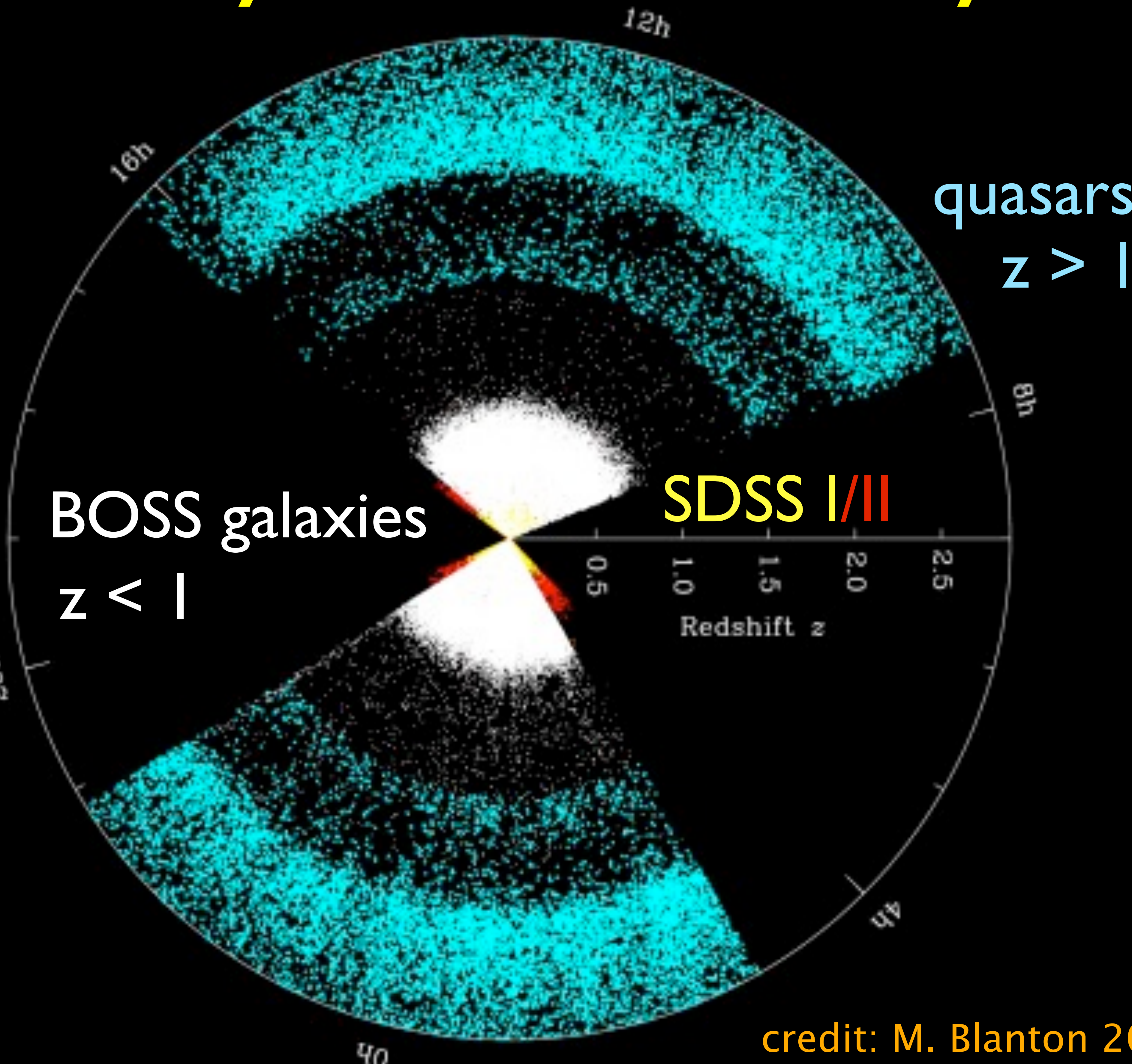
violation of scale invariance or isotropy, or foreground issue or fluke?

Copi et al. 2013

Cosmological Inflation



Galaxy redshift surveys



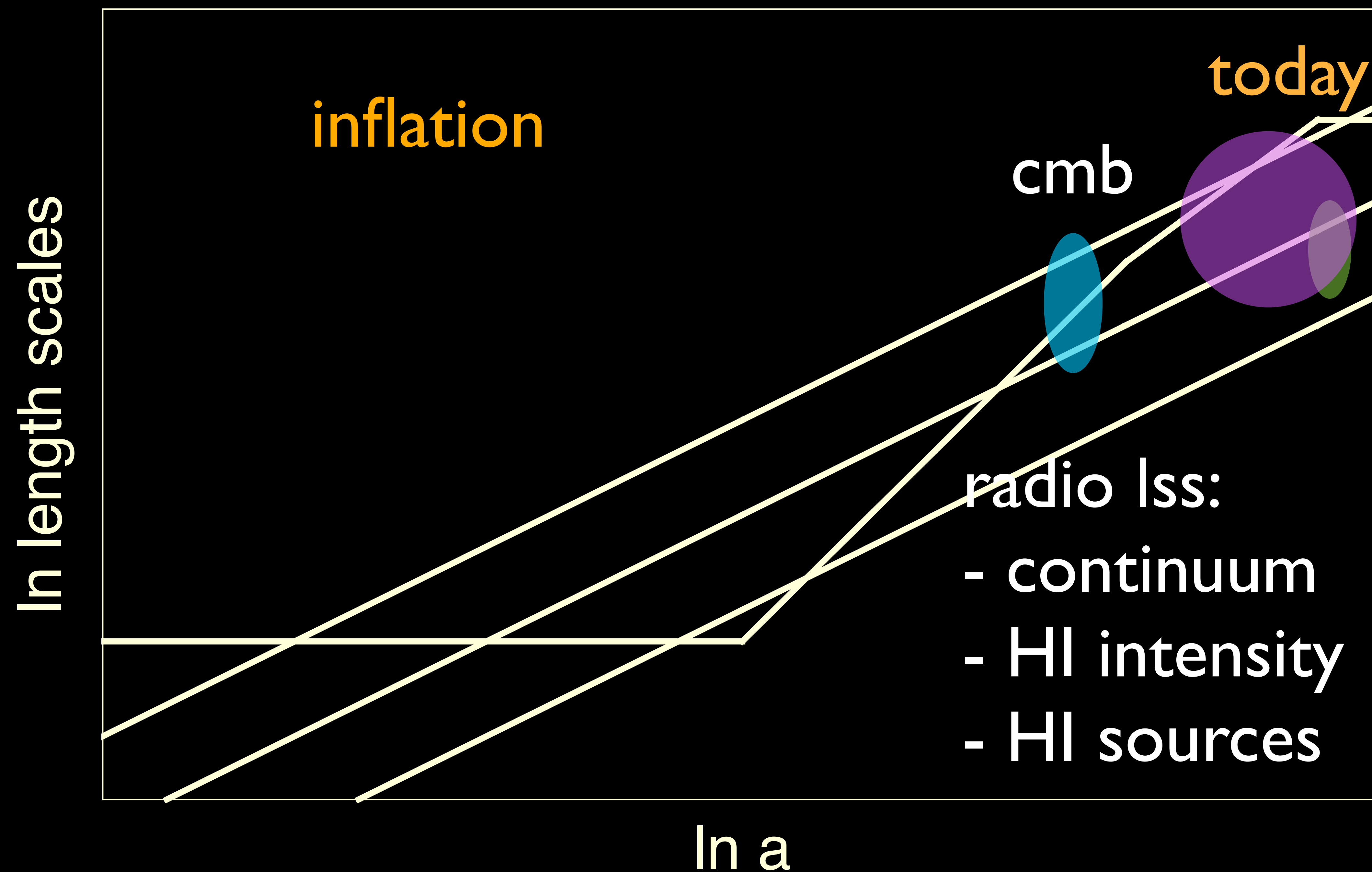
credit: M. Blanton 2011

Homogeneity

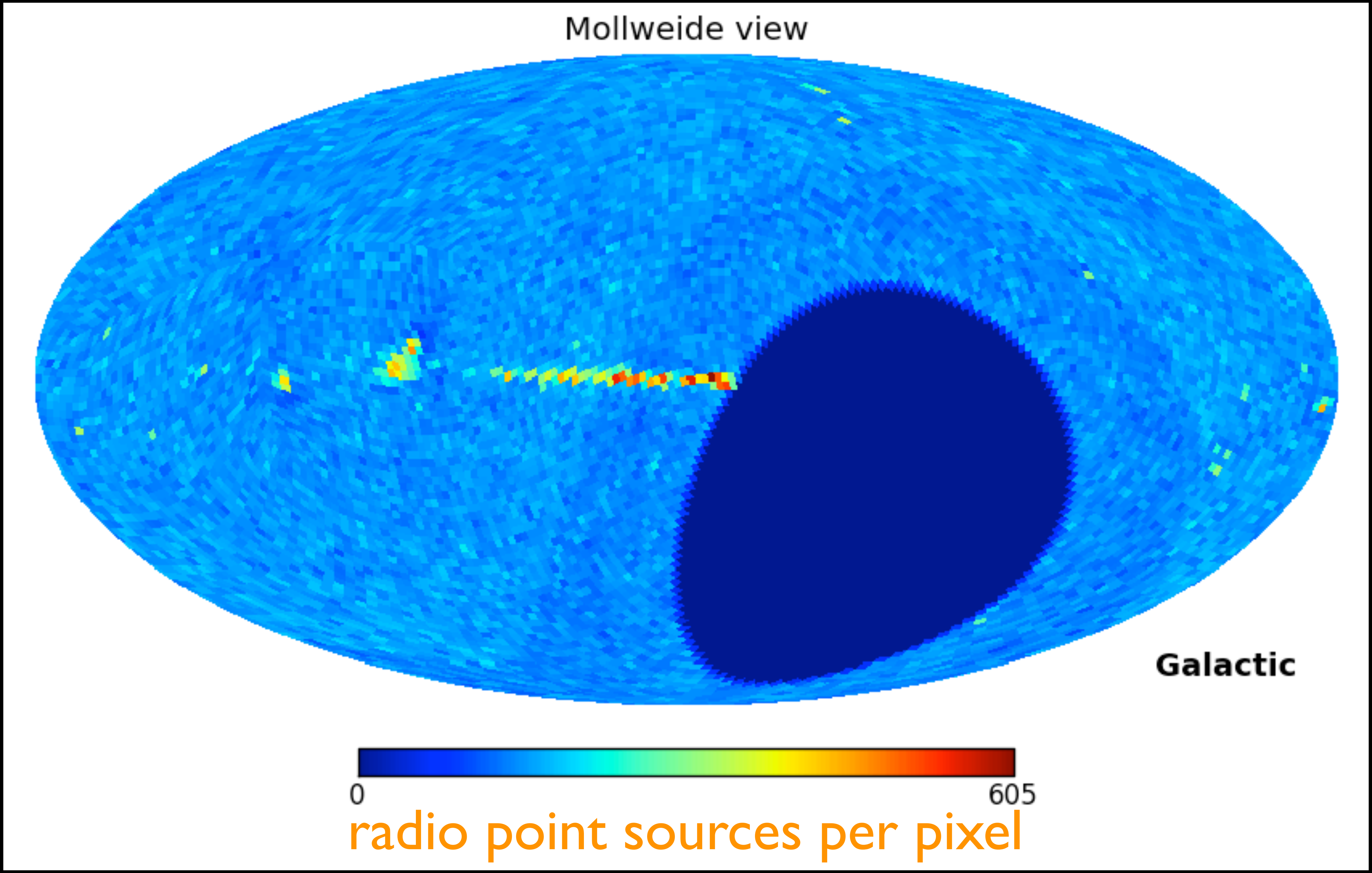
- observed isotropy and copernican principle leads to homogeneity
- cosmic time/age of Universe, H_0
- thermal history of Universe, $T(z) = (1+z)T_0$
- inhomogeneous models provide alternative to cosmic acceleration (dark energy)
- homogeneity scale ~ 100 Mpc

study consistency relations based on BAOs

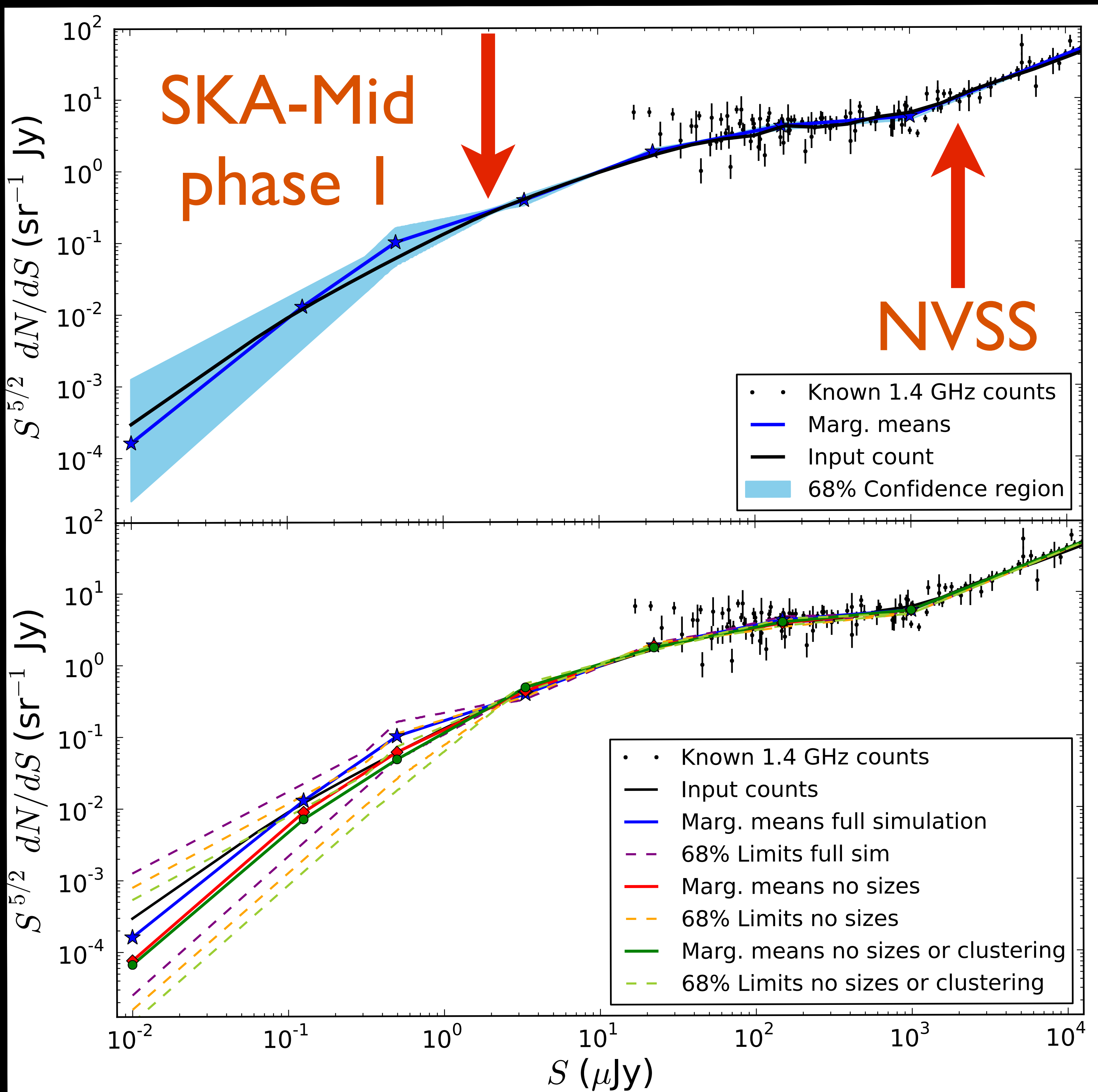
Cosmological Inflation



Radio continuum survey
(NVSS, 1.4 GHz, 2 mJy)



Radio source counts



JVLA, Vernstrom et al. 2013

two populations:

* AGNs (FRI-II, RQQ)

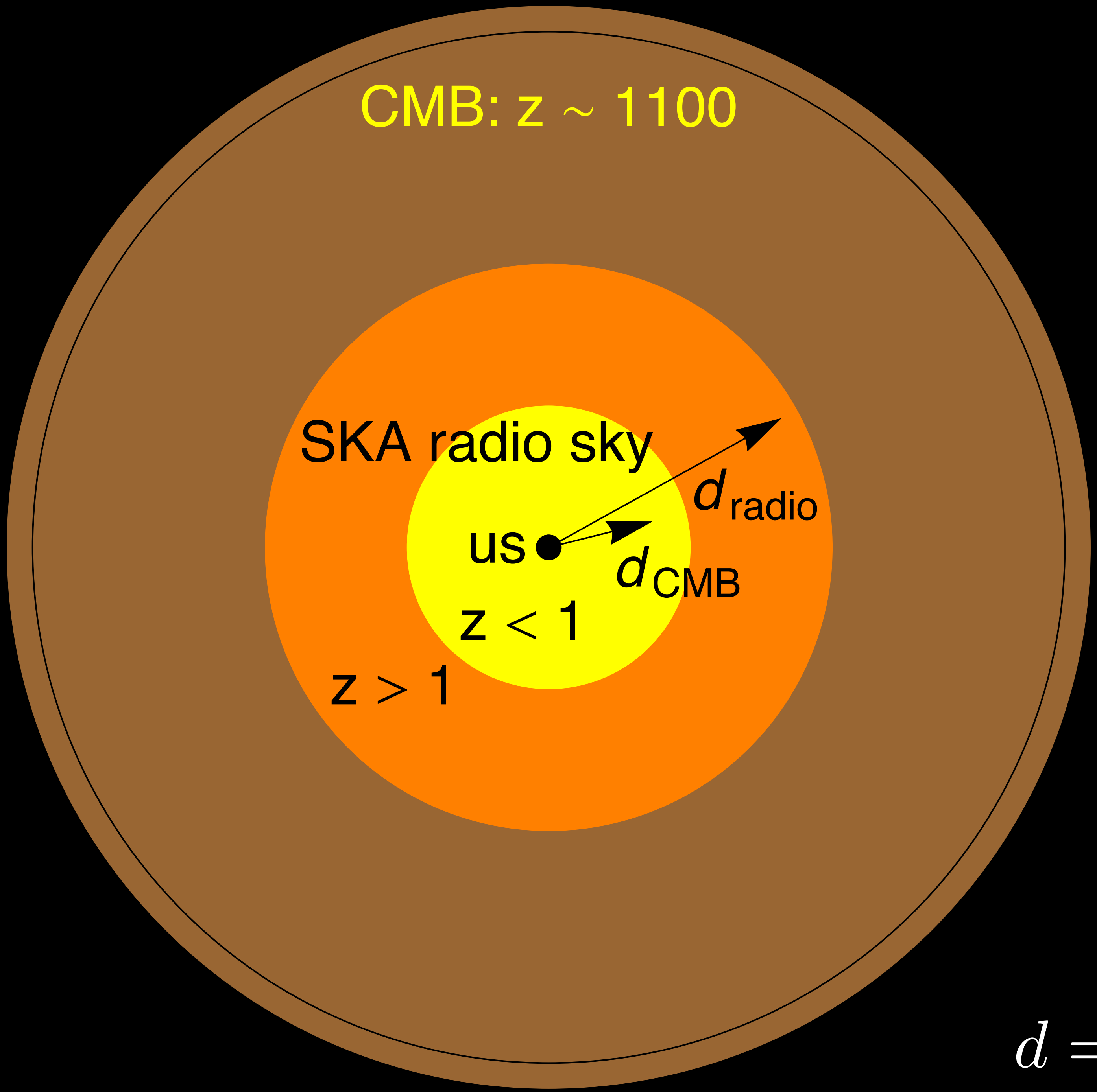
* galaxies (SFG, SBG)

AGNs dominate at large fluxes

star forming galaxies dominate below ~ 1 mJy

identification of morphology for angular resolution 0.5”

Cosmic radio dipole



$d_{cmb} = d_{radio}$?

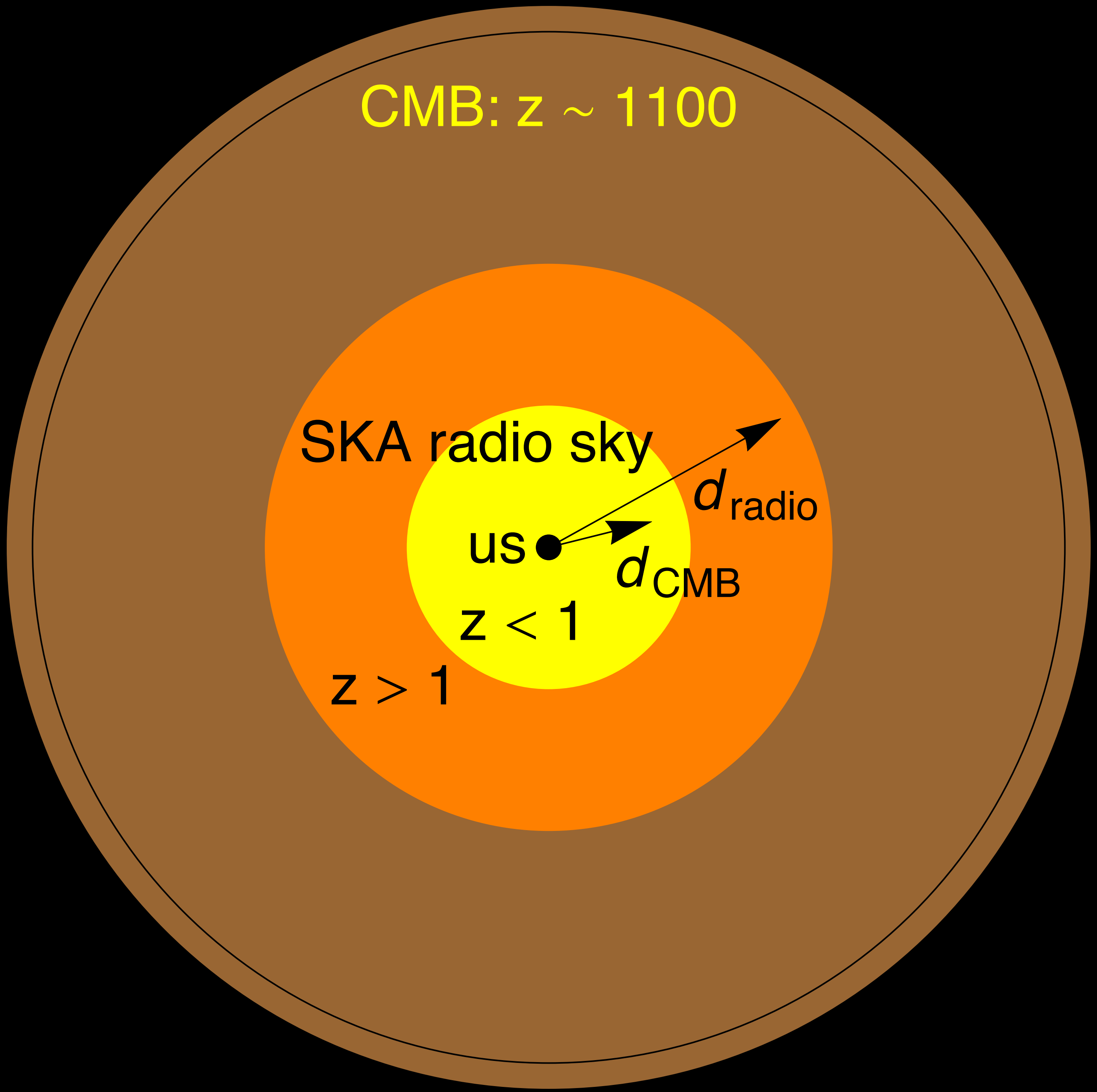
kinetic dipole

Ellis & Baldwin 1984

$$\frac{\mathrm{d}N}{\mathrm{d}\Omega}(>S) = aS^{-x}[1 + d\cos\theta + ...]$$

$$d = [2 + x(\alpha+1)]\frac{v}{c}, \quad S \propto \nu^{-\alpha}$$

Cosmic radio dipole



$d_{cmb} = d_{radio}$?

NVSS (1.4 GHz)
& WENSS (345 MHz):
directions are consistent, amplitude by factor 2 - 4 too large

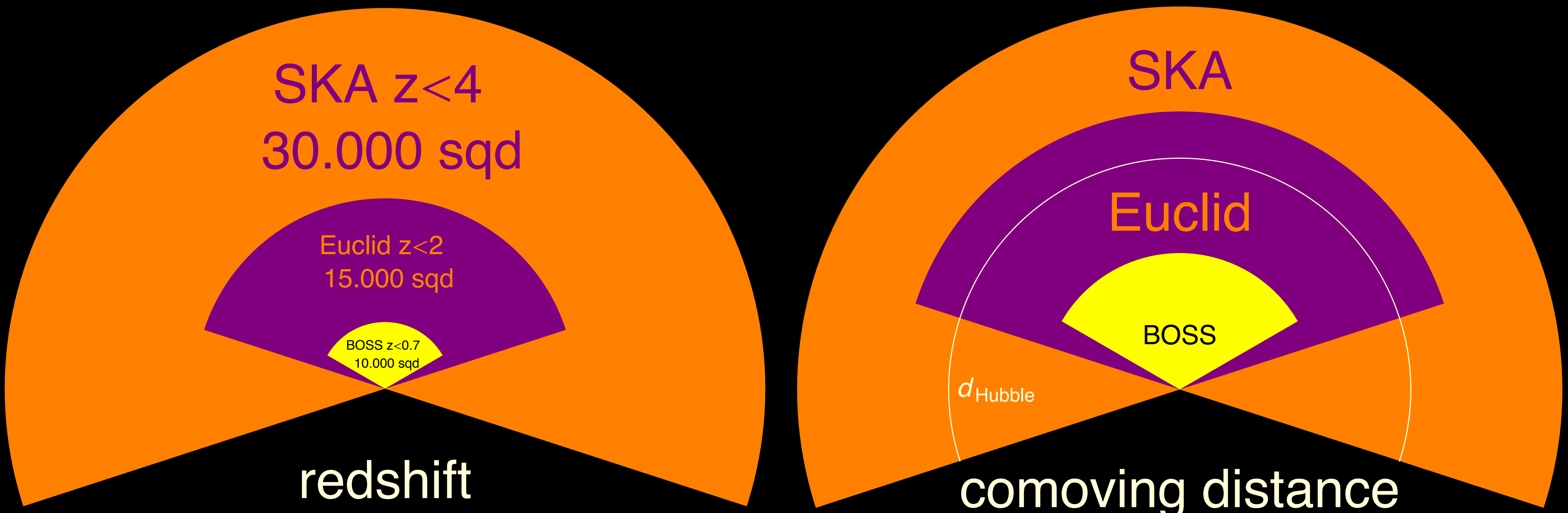
Blake & Wall 2002
Rubart & Schwarz 2013

bulk flows?

local structure dipole?

Rubart, Bacon & Schwarz 2014

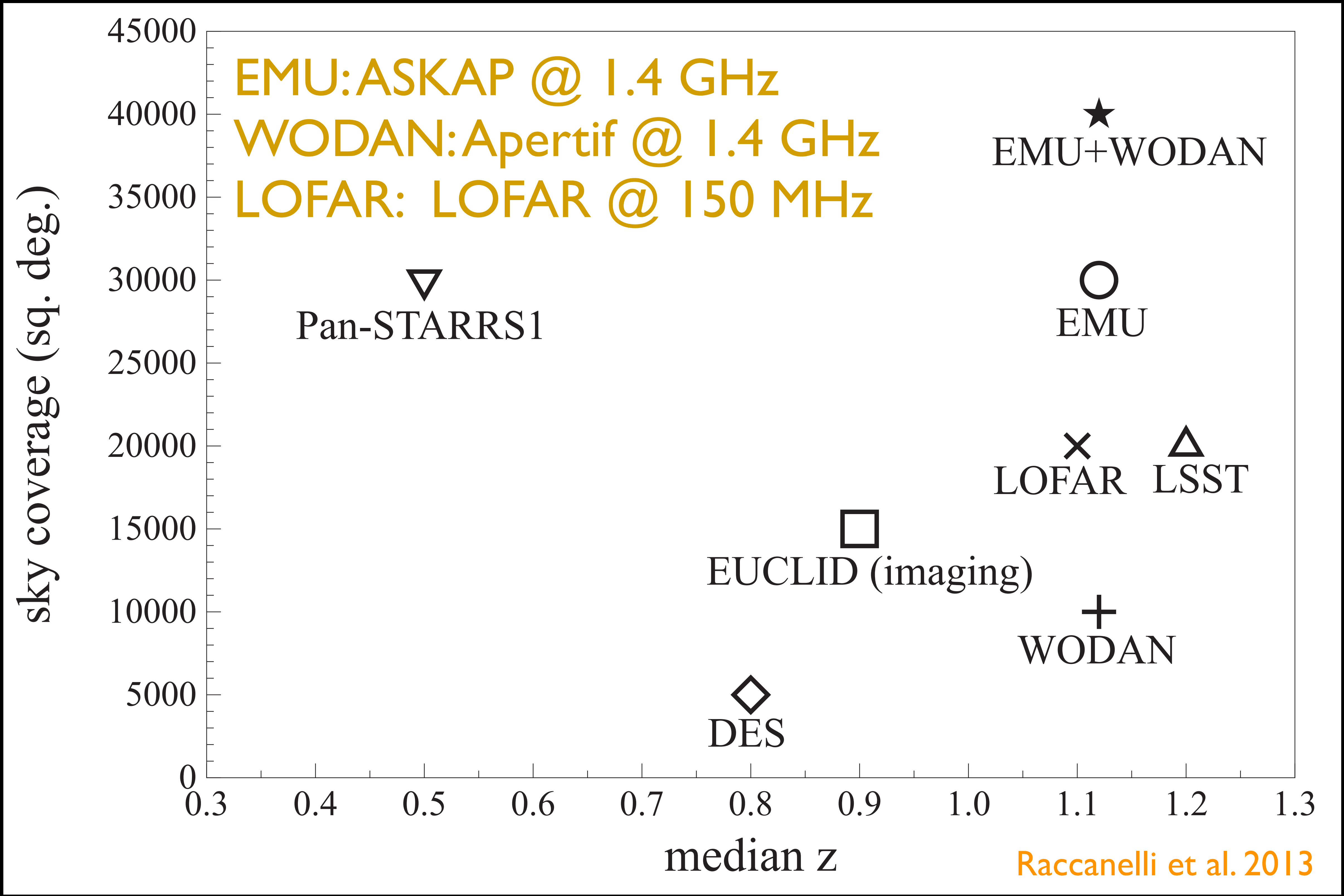
Cosmic volumes probed



Key advantages of radio continuum and HI surveys:

* more independent modes that optical/ir/cmb
* different systematics from optical/ir

Radio continuum surveys



LOFAR

Low Frequency ARray in operation since 2013

todays world biggest telescope

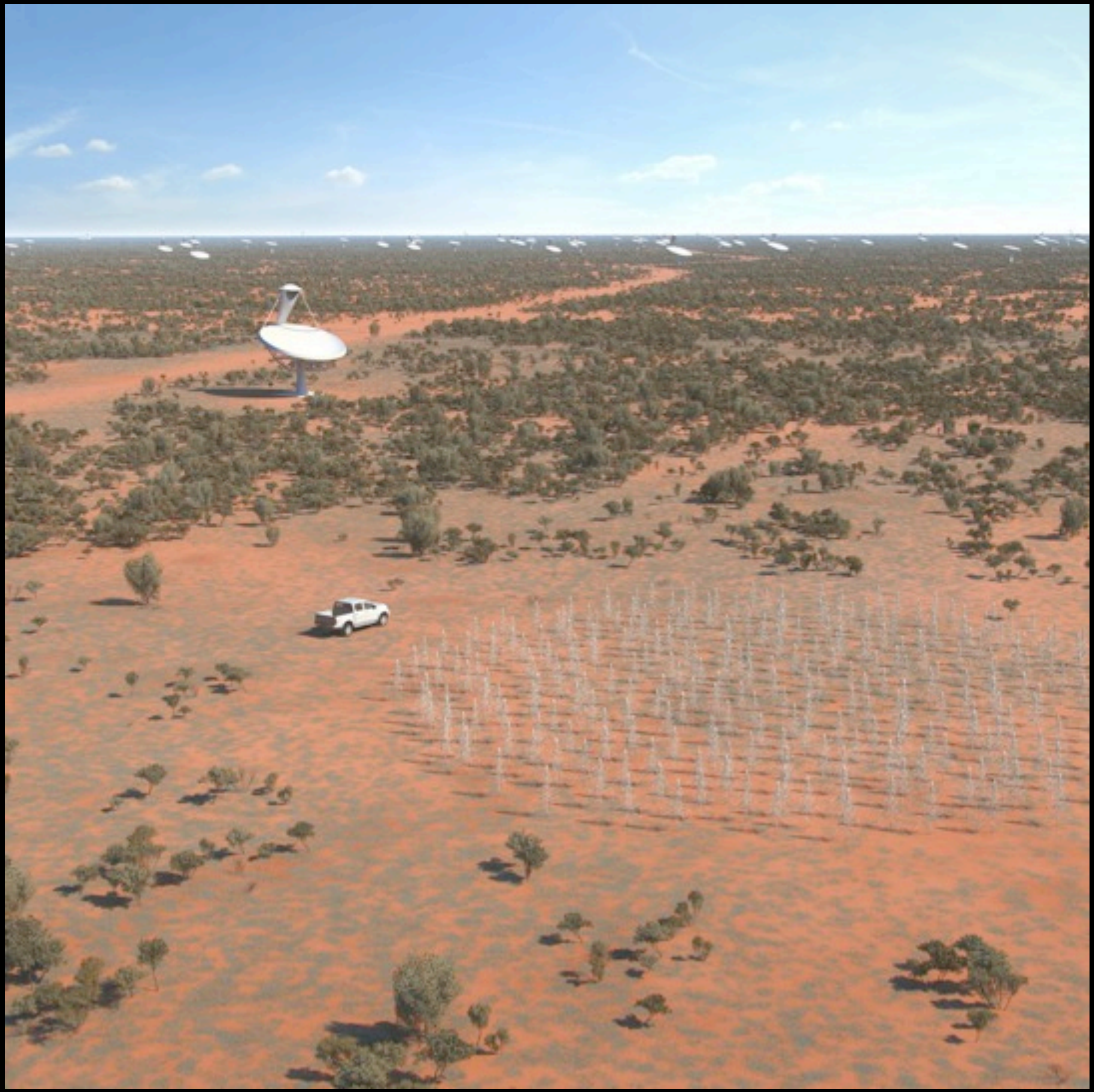
Key Science:
- Epoch of Reionisation
- Surveys
- Transients
- Cosmic Magnetism
- Cosmic Rays
- Solar Physics

30 - 250 MHz; 40 NL, 5+1 D, 1 F, 1 UK, 1 S, + 3 PL

SKA

Square Kilometre Array, Early Science in 2020

will be biggest telescope for decades



Science Goals:

- Cosmic Dawn & EoR
- Gravitational Waves & Gravity
- Cosmology
- Cosmic Magnetism
- Craddle of Life

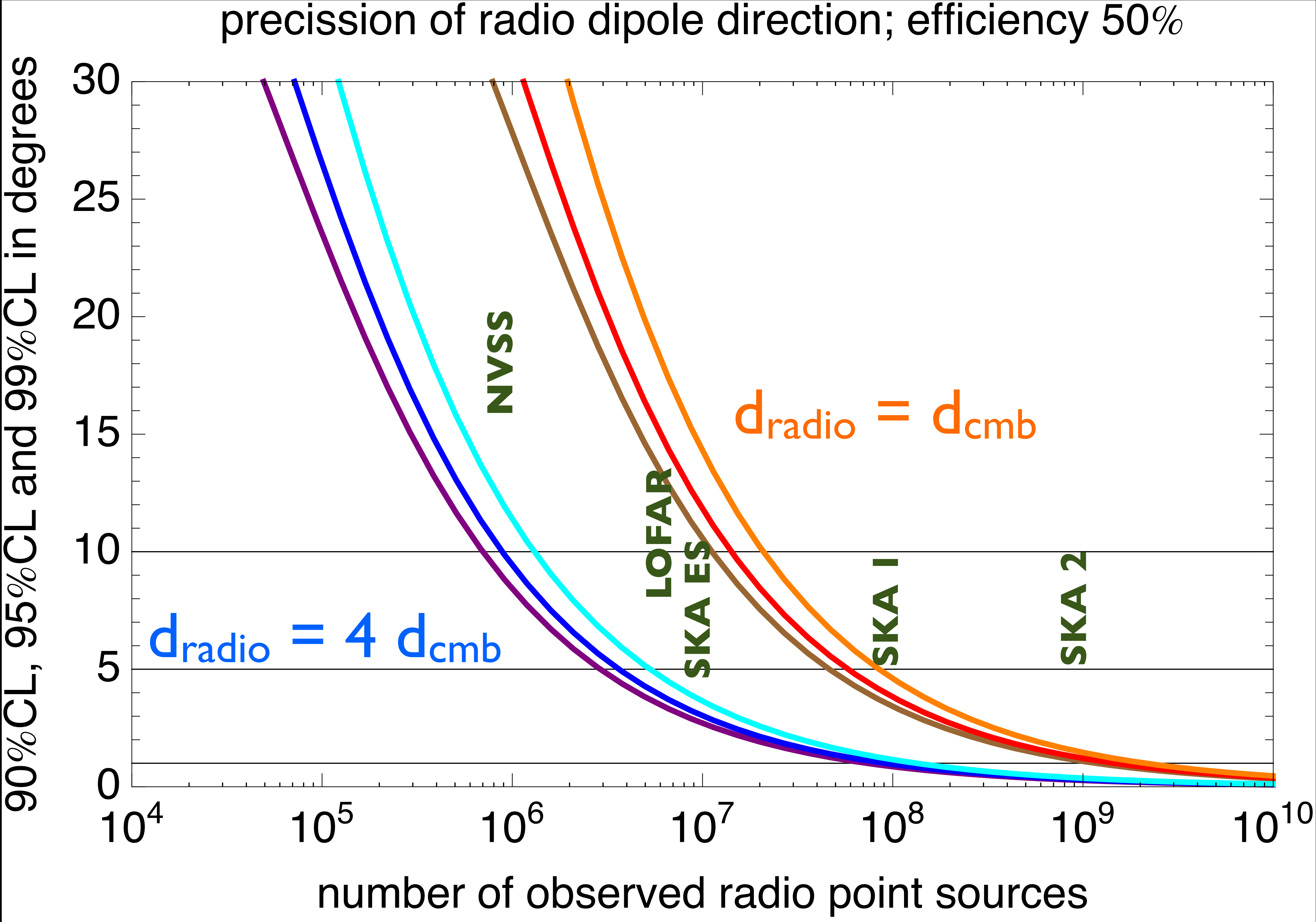
cover 3 decades in frequency
at high resolution and
high sensitivity; REDSHIFTs !

Africa & Australia; 2 Phases; 11 (?) states

SKA cosmology probes

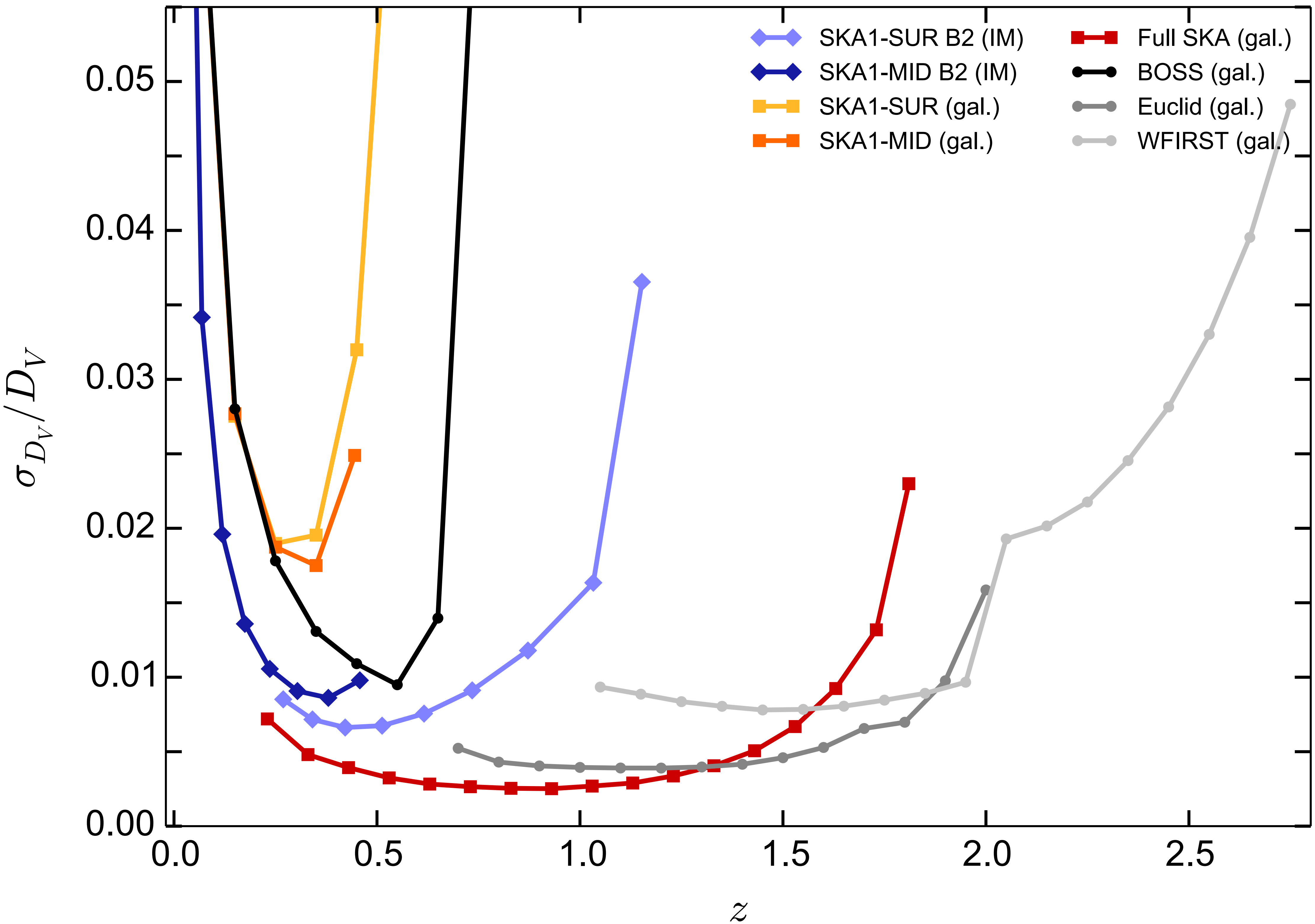
- continuum survey (0.5", morphology resolved, all sky): dipole, autocorrelation, integrated Sachs-Wolfe, cosmic magnification
- HI galaxy survey (0.2 < z < 4, all sky): P(k), bao, f(z), weak lensing, ...
- HI intensity mapping (interferometer and/or dish survey): bao most powerfull

Cosmic radio dipole



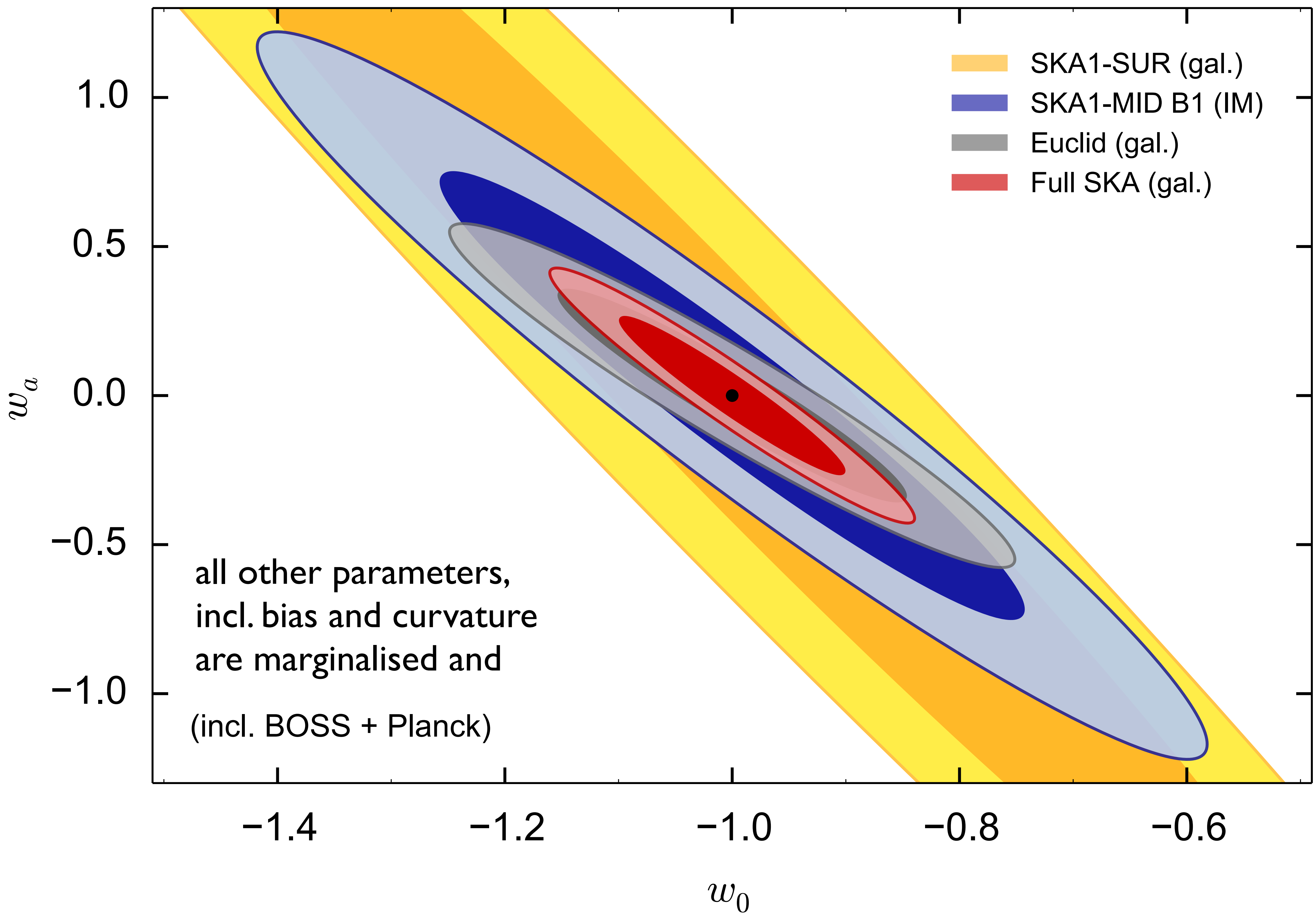
Schwarz et al., submitted to SKA Science Book

Baryon Acoustic Oscillations with SKA



Bull et al., submitted to SKA Science Book

Baryon Acoustic Oscillations with SKA



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Summary

largest scales test fundamental assuptions of modern cosmology:
- initial conditions and symmetries
- relativistic effects
- evolution

radio surveys will probe largest volumes
- in solid angle
- in redshift
- frequency range
- complementary systematics to optical/ir

JVLA, LOFAR, ASKAP, MeerKAT, and SKA