Cosmology with next generation surveys

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DARK ENERGY

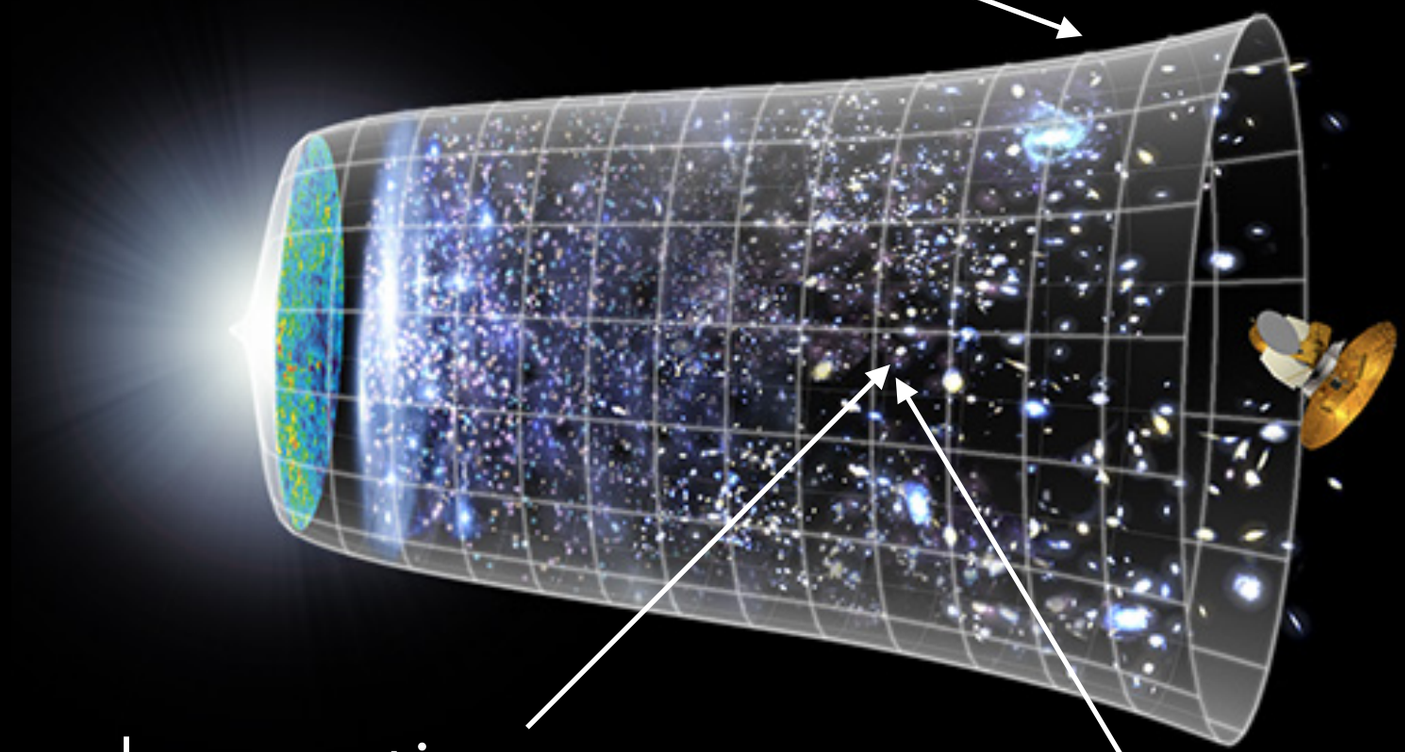
Observations of cosmological probes give evidence of:

- an expansion history, and
- a history of growth of structure

which are consistent with an accelerating expansion of the Universe.

COMBINED POWER OF PROBES

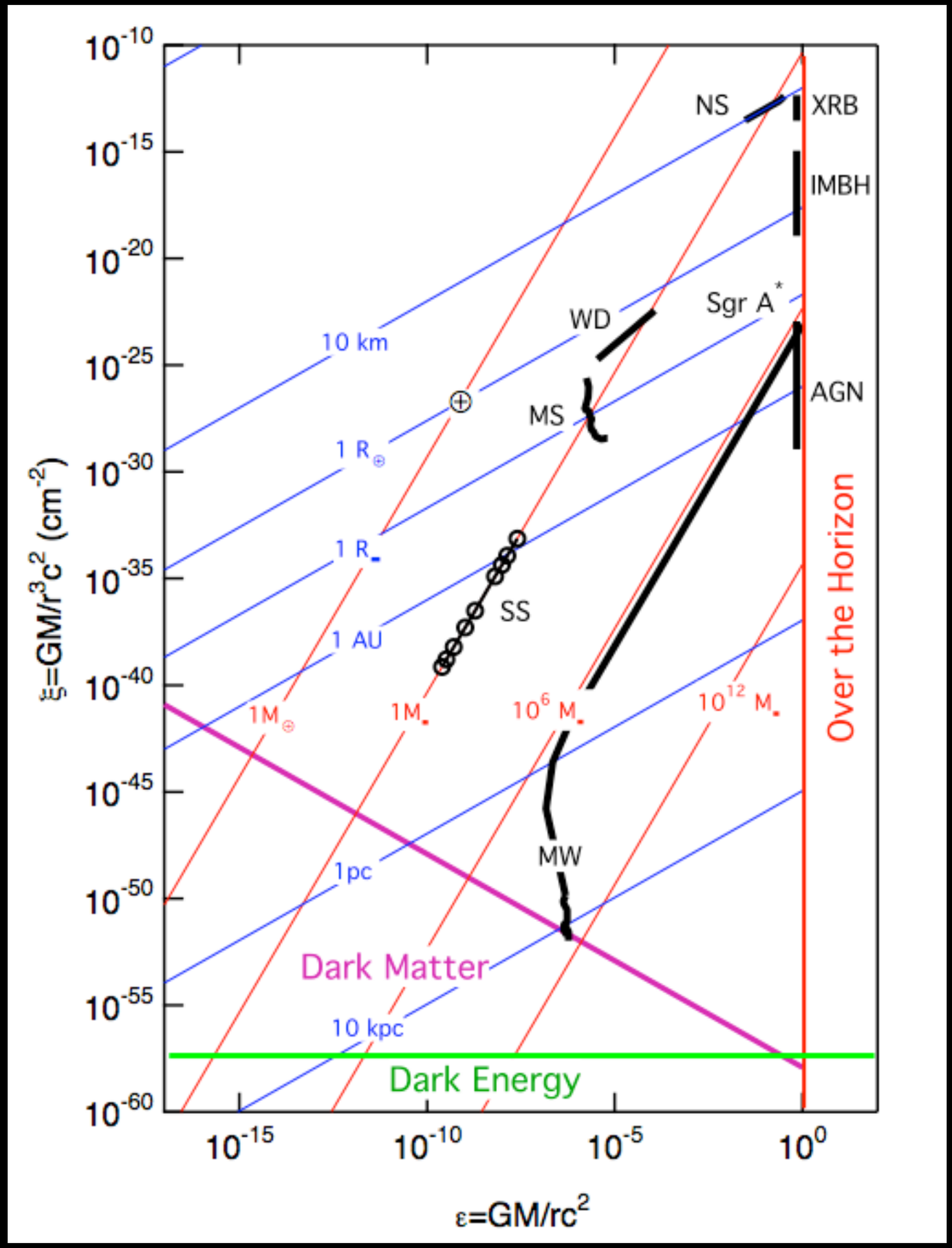
Some observations constrain expansion history



Some observations constrain growth history

Some care about time part, some +space part of metric

TESTS OF GRAVITY



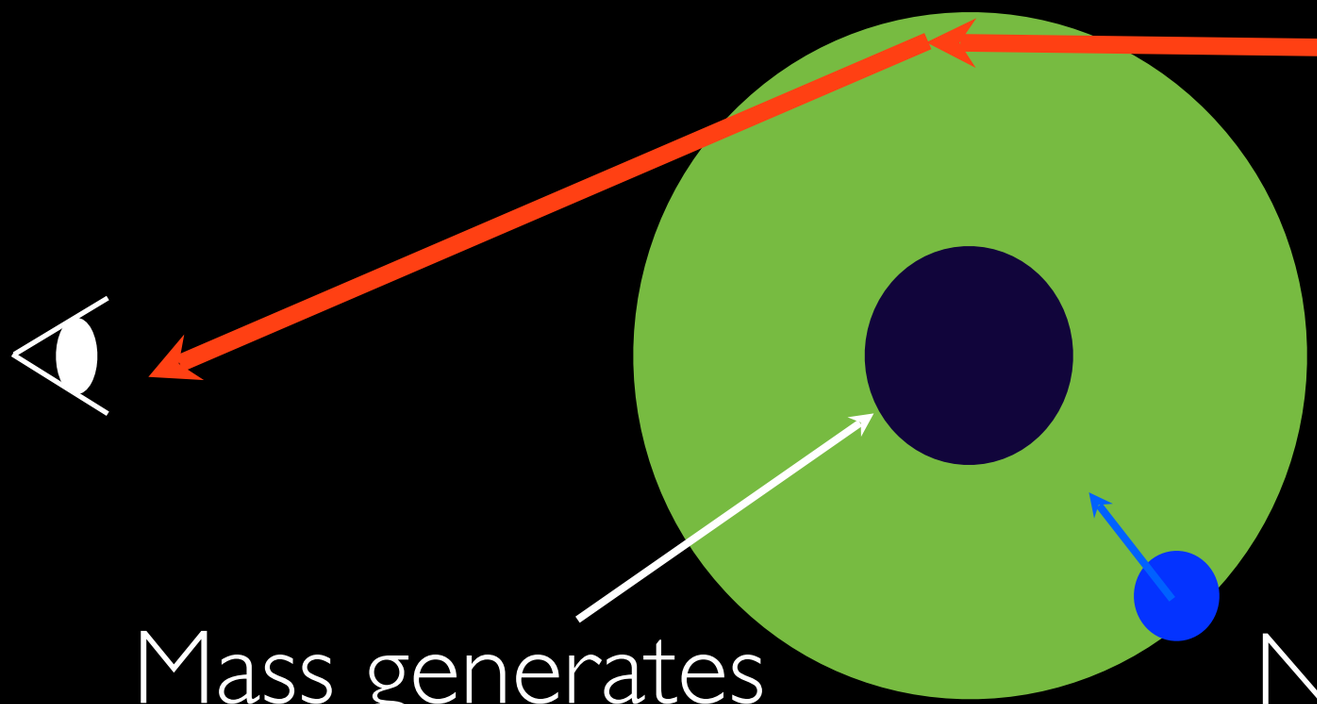
Psaltis 2008

GRAVITY TESTS

$$ds^2 = -(1+2\Psi)dt^2 + (1+2\Phi)a^2\delta_{ij}dx^i dx^j$$

Newtonian guage

Simpler approach:



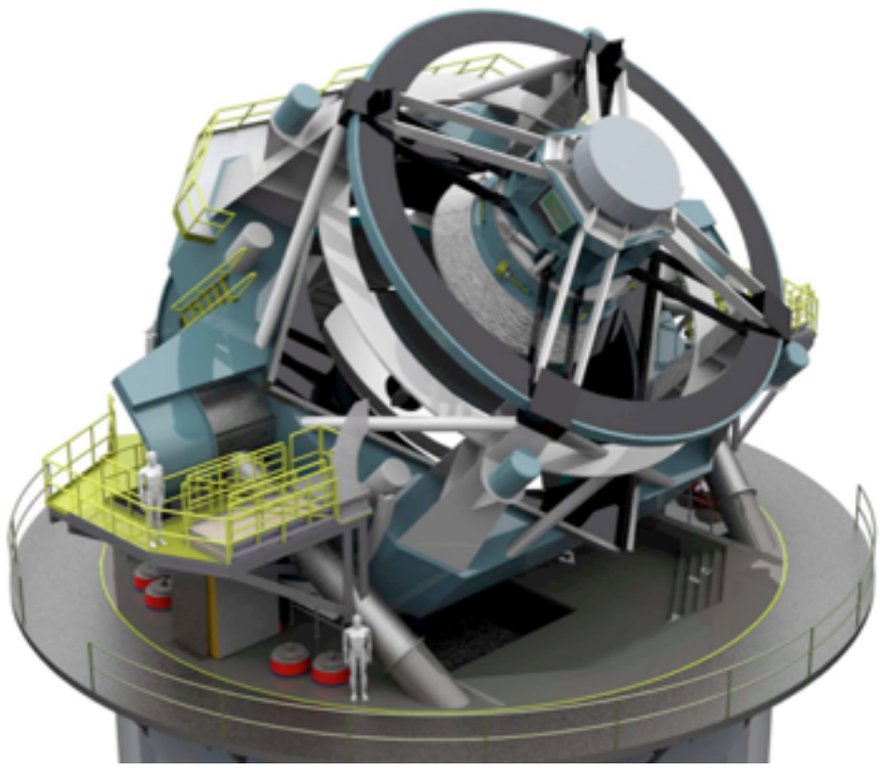
Lensing
feels $\Psi+\Phi$
Modification η

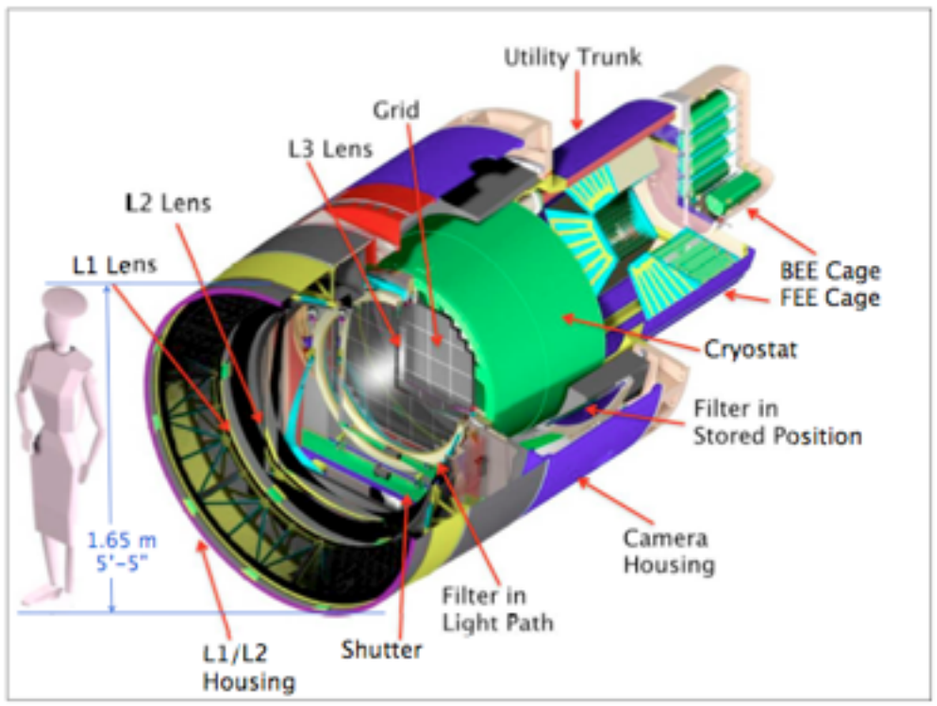
Mass generates
potential Ψ
(Poisson)
Modification μ

Non-relativistic
objects respond
to Ψ

Or: can find parameters for general action, e.g. Lagos et al 16

The Large Synoptic Survey Telescope





Taking an inventory of the Solar System
Mapping the Milky Way
Exploring the transient optical sky
Probing dark energy and dark matter

Cerro Pachón in northern Chile

First light around 2021
First public data releases around 2023

The LSST

Contiguous overlapping imaging of over half the sky

6 bands (ugrizy, 320–1050 nm)

50 PB imaging data

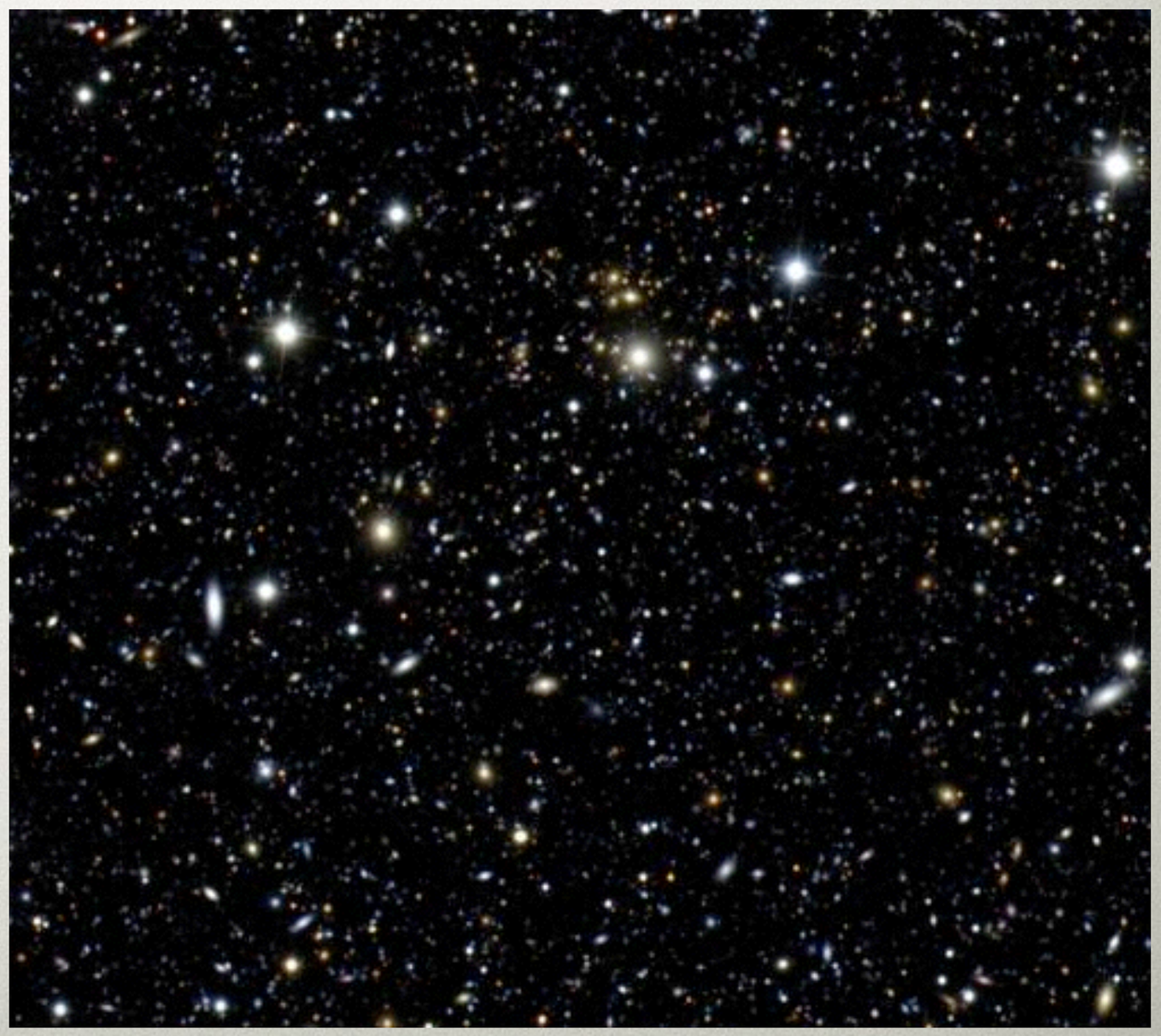
15 PB catalog database

~15 TB of raw imaging /nt

Effective diameter of 6.5m
3.2 Gigapixels

Large field of view (9.6 deg^2)

0.2×0.2 $arcsec^2$ pixels



Survey Specs

10,000 deg^2 of sky in 2 photometric bands every 3 nights
5σ depth for point sources of r ~ 24.5

30,000 deg^2 with $\delta < +34.5^\circ$
18,000 deg^2 visited over 800 times during 10 years.

Coadded data 5 mag deeper than SDSS (r ~ 27.5).
20 billion galaxies and a similar number of stars

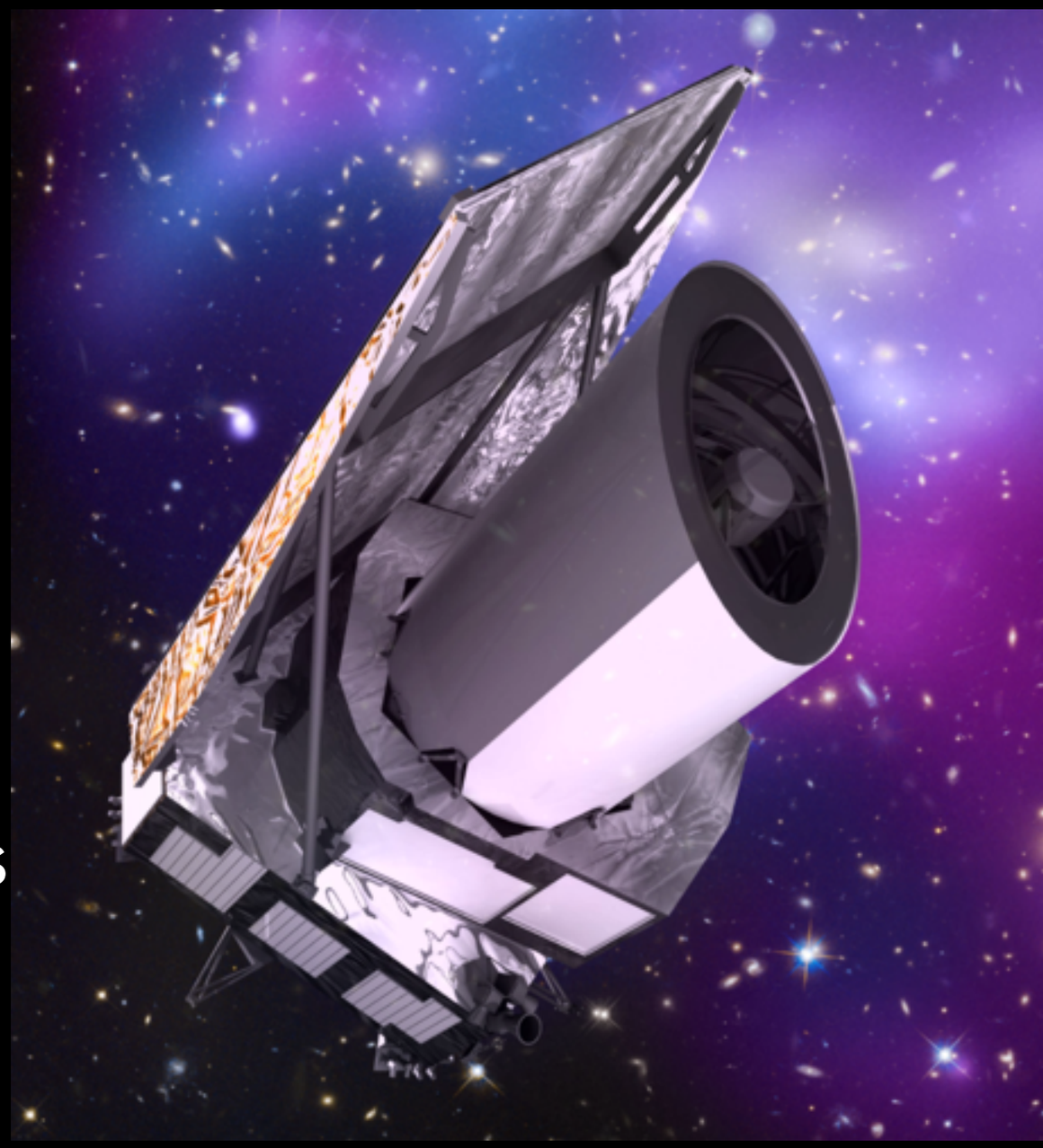
EUCLID

15000 sq deg wide survey
40 sq deg deep survey

1.2m mirror; FOV 0.53 sq deg

Visible (0.1”, R+I+Z)
1.6G galaxies (mag<24.5)
+NIR (Y,J,H) imaging
NIR spectroscopy - 45M galaxies

LSST provides time-resolved optical passbands, Euclid provides spatially-resolved optical and NIR data.



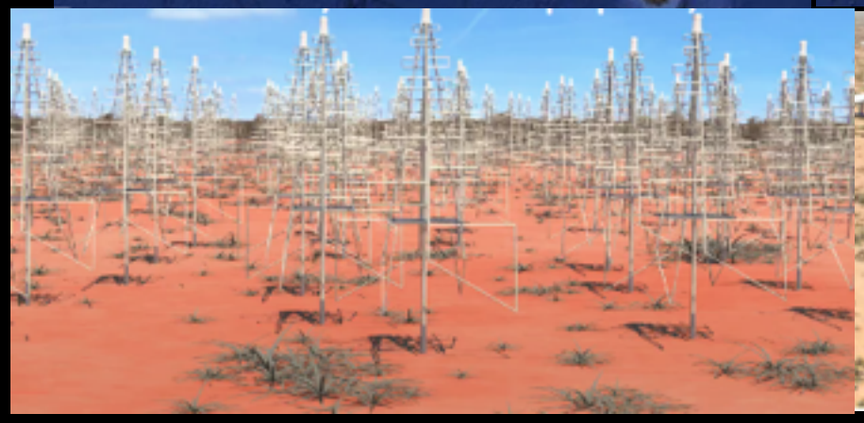
Launch 2020

SQUARE KILOMETRE ARRAY

SKA Phase 1 baseline design:
Frequency range: 50MHz -14GHz

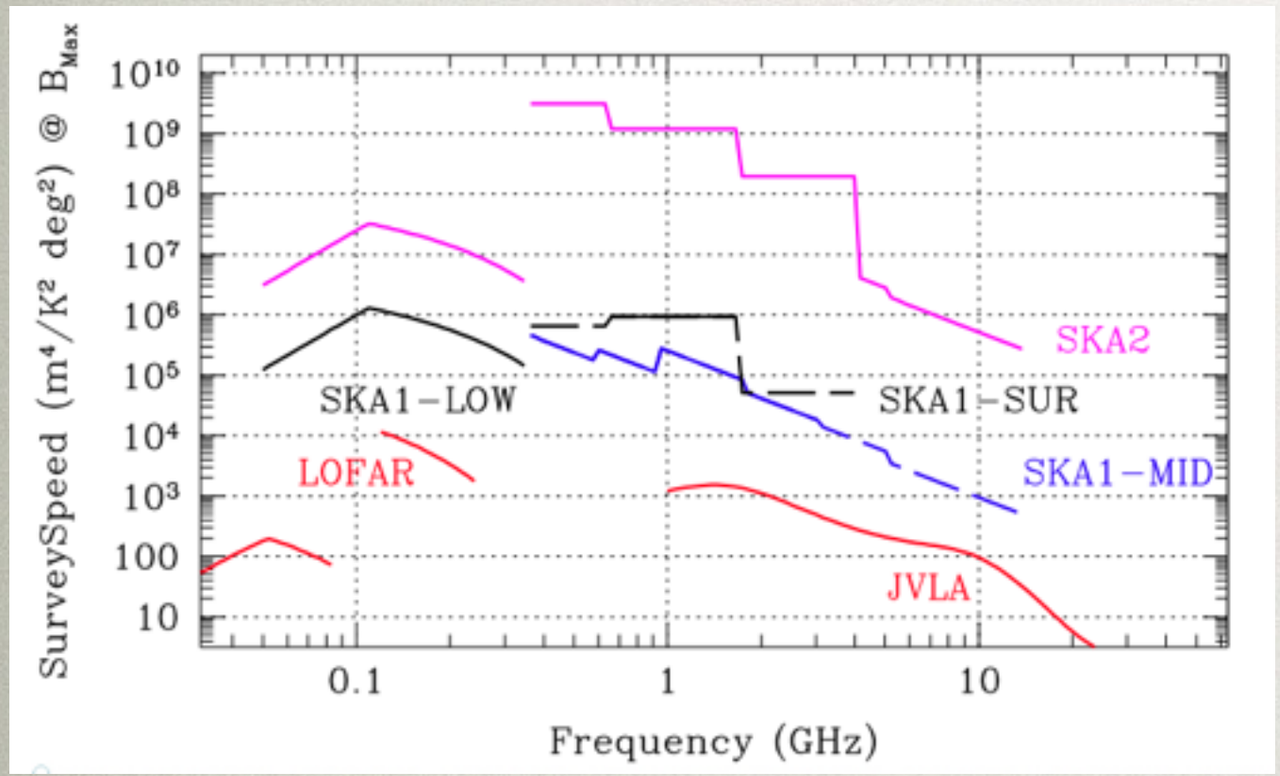
Construction 2019-23; commissioning & early science 21-23

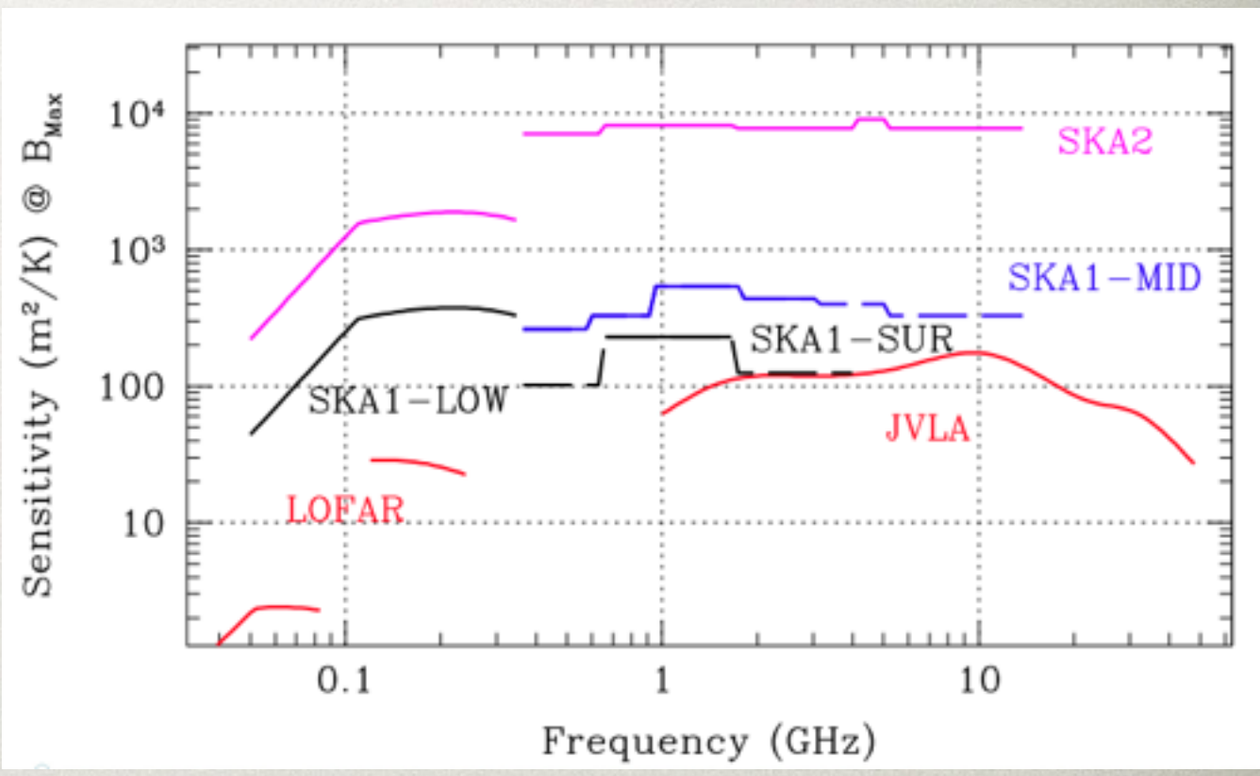
SKA-Low ~130,000 low frequency dipoles



SKA-Mid ~130 15m dishes + 64 MeerKAT

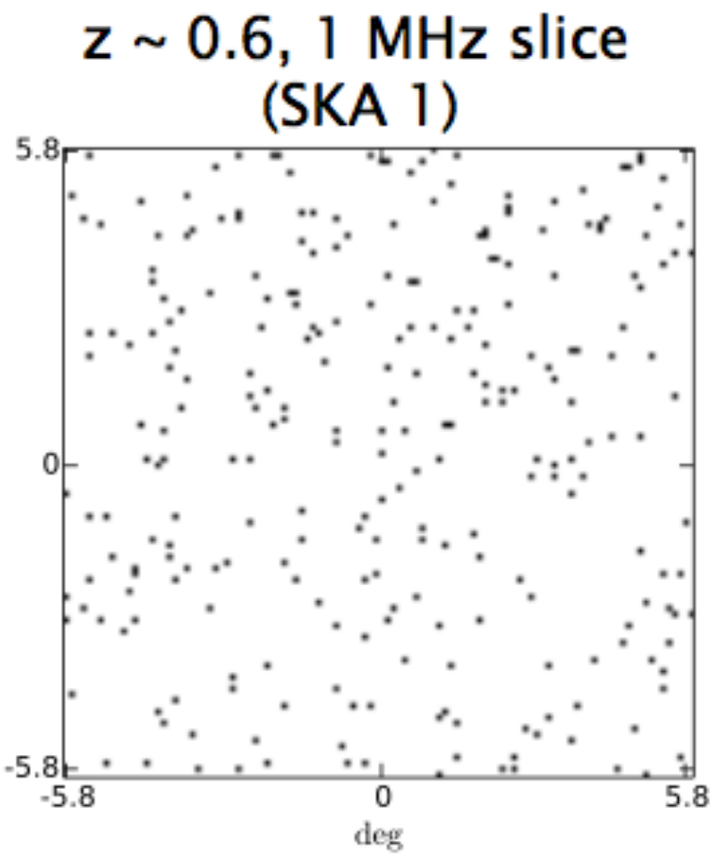
Huge increase in sensitivity



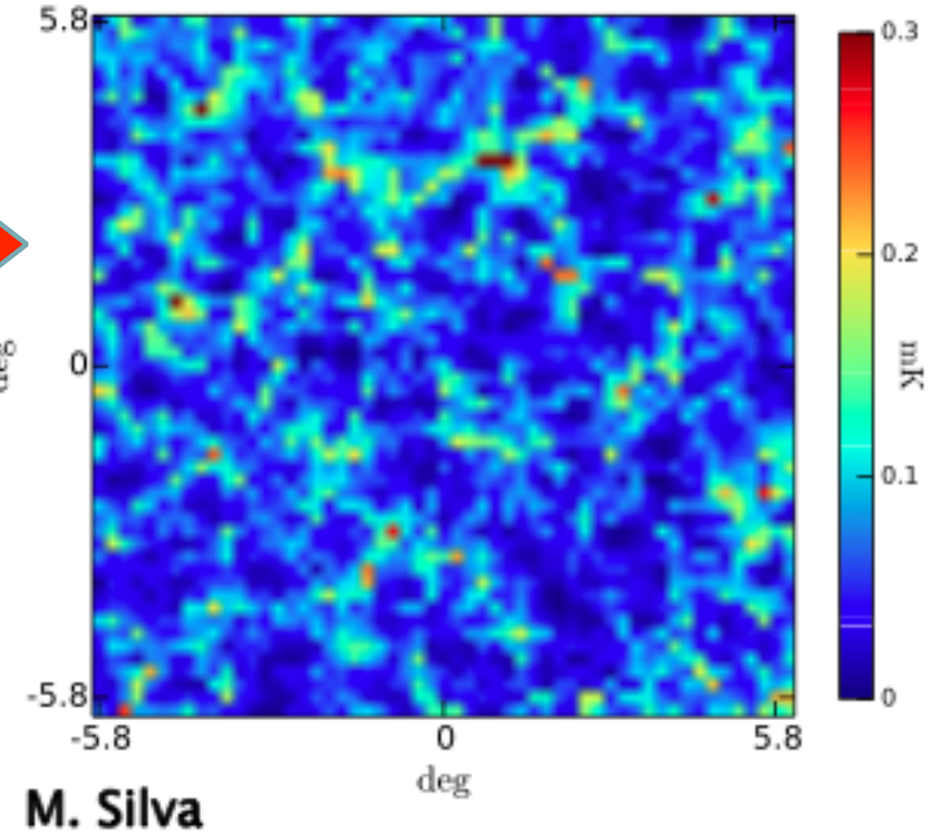


Intensity mapping

Galaxies



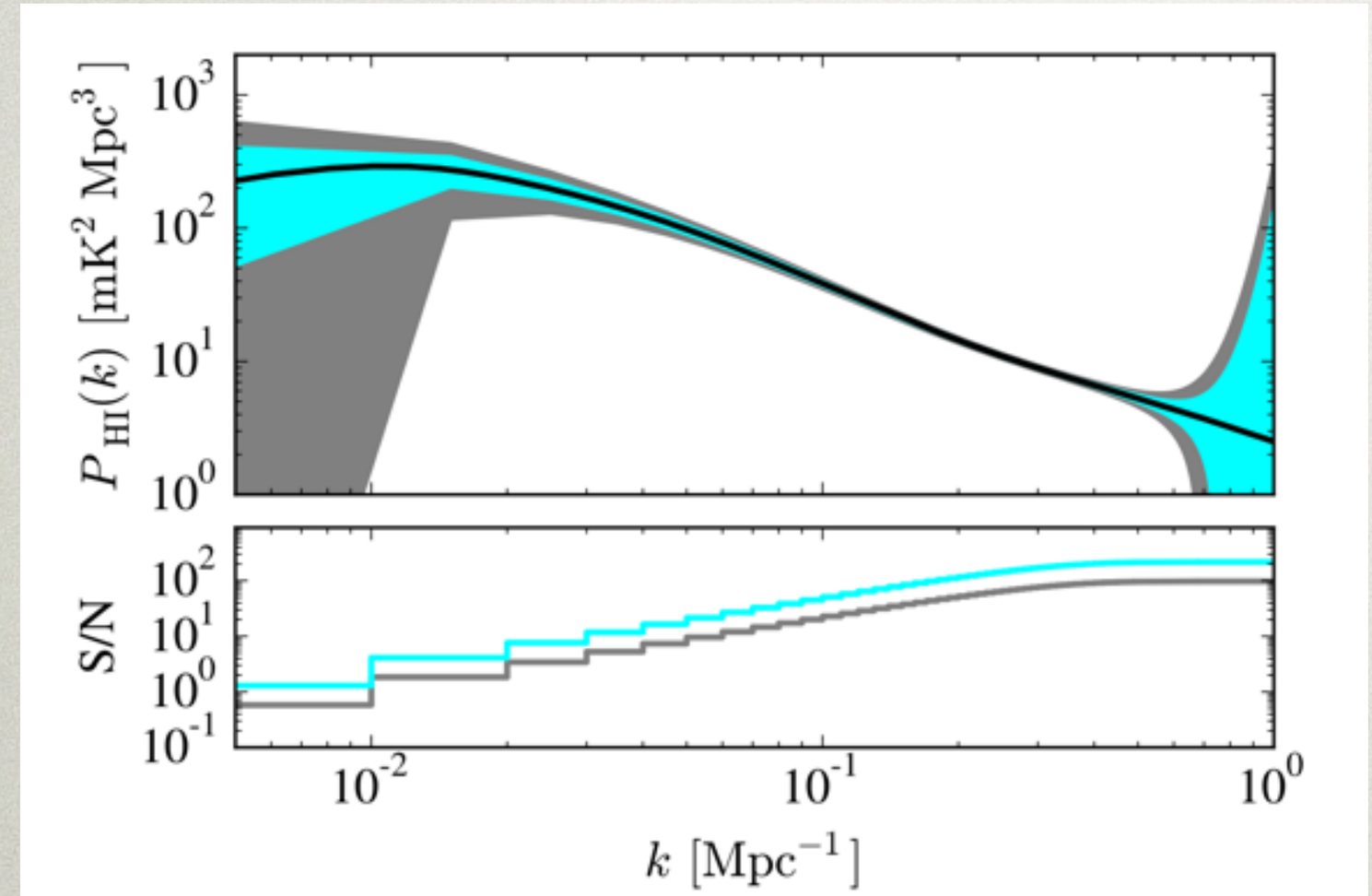
Maps of intensity



M. Silva

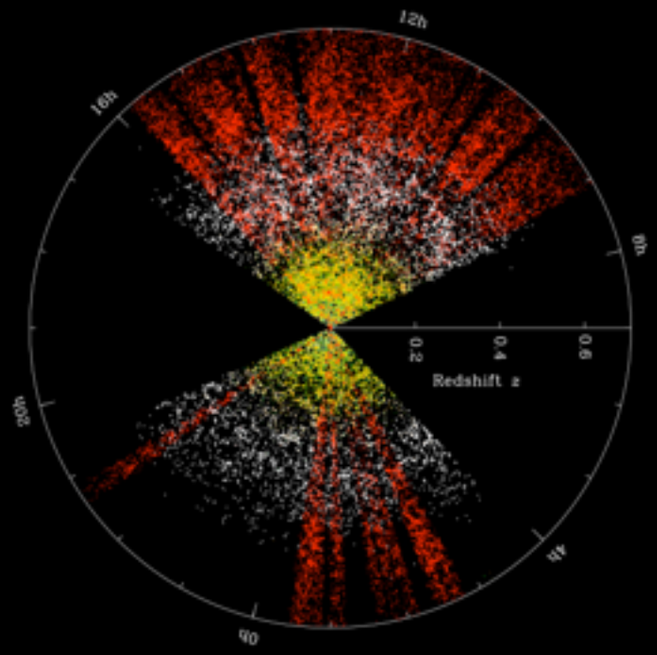
Intensity mapping

Pourtsidou, Bacon et al 15



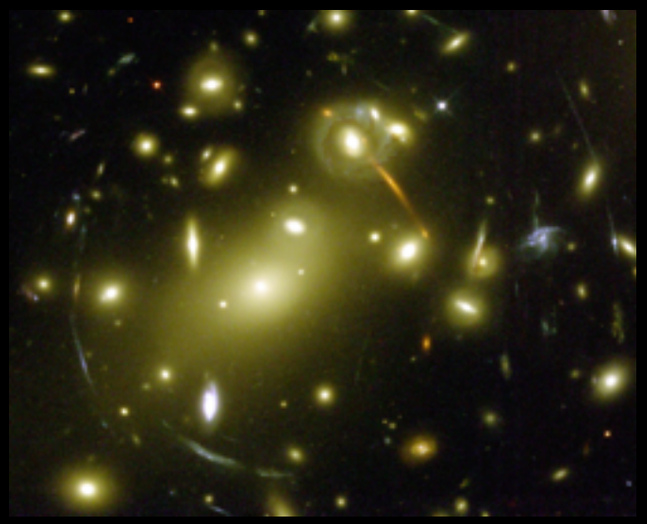
3 weeks or 15 weeks, MeerKAT-16

COSMOLOGICAL PROBES WITH THESE TELESCOPES



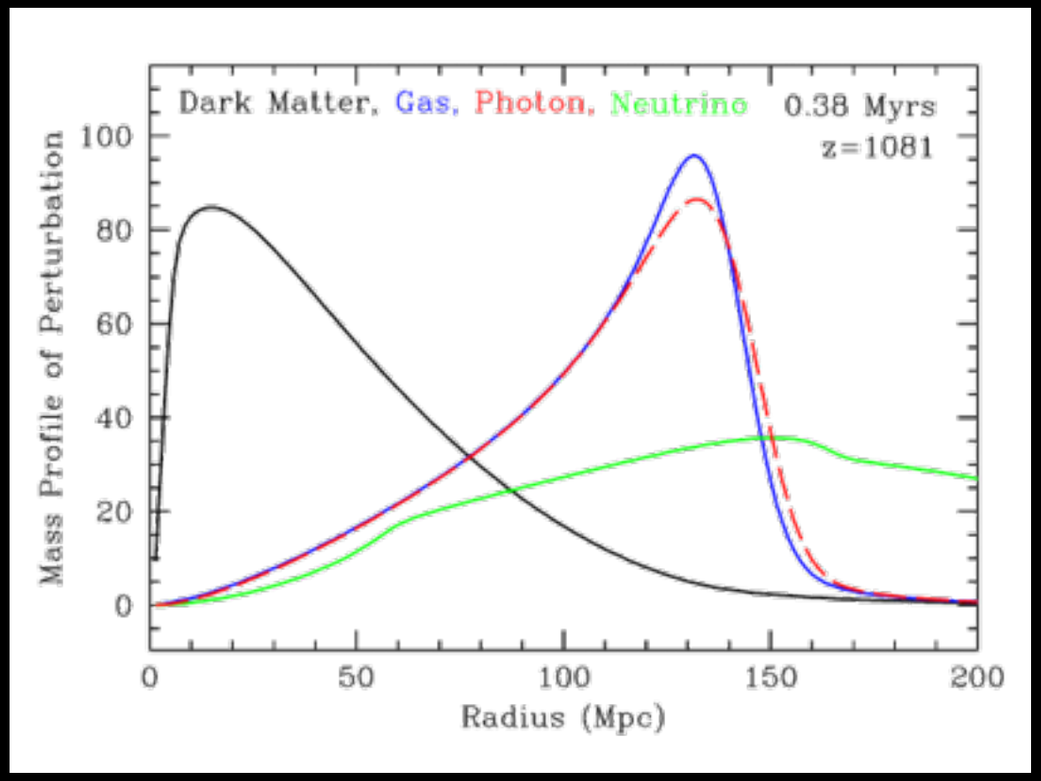
- e.g. Source clustering

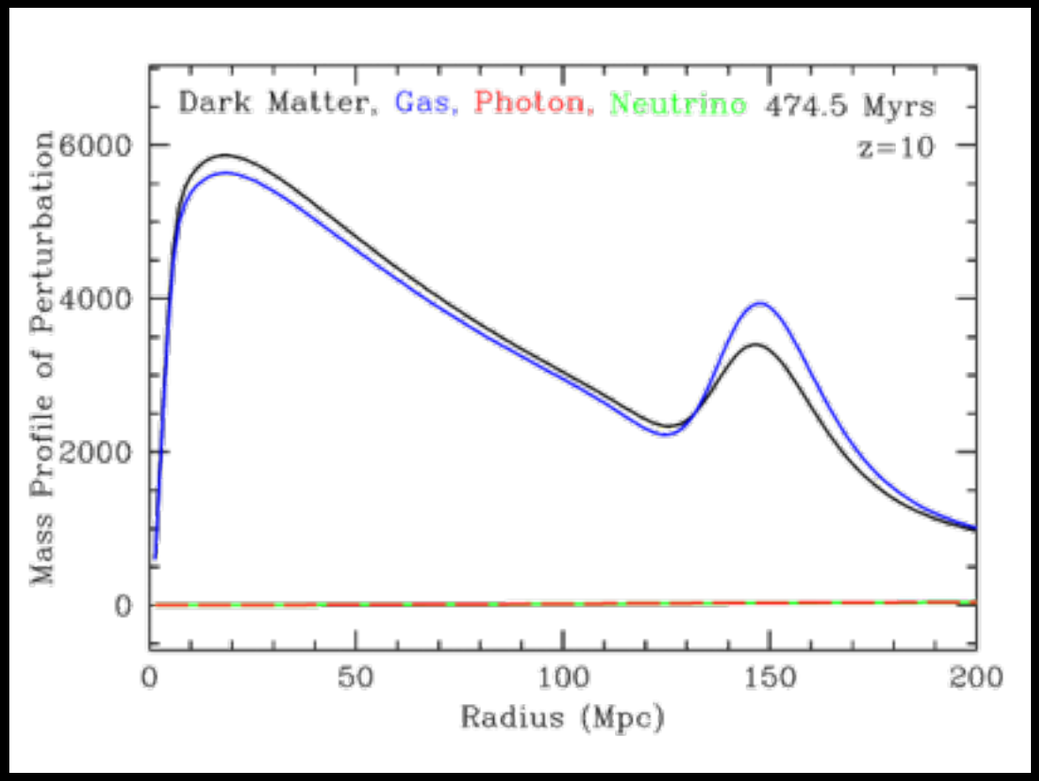
- including Baryon Acoustic Oscillations and Redshift Space Distortions (Euclid, SKA)

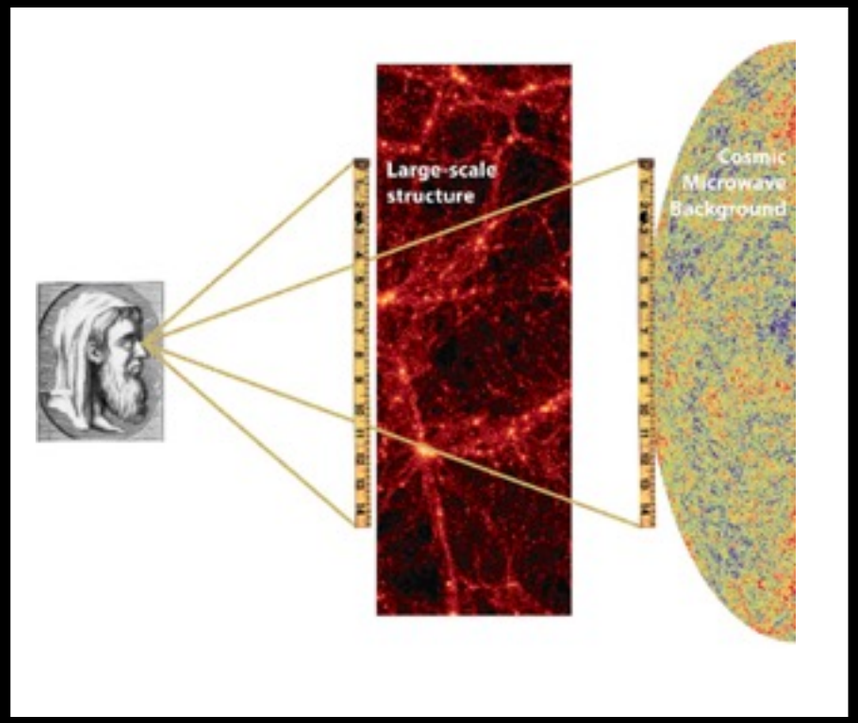


- Cosmic shear, shear-galaxy, strong lensing.

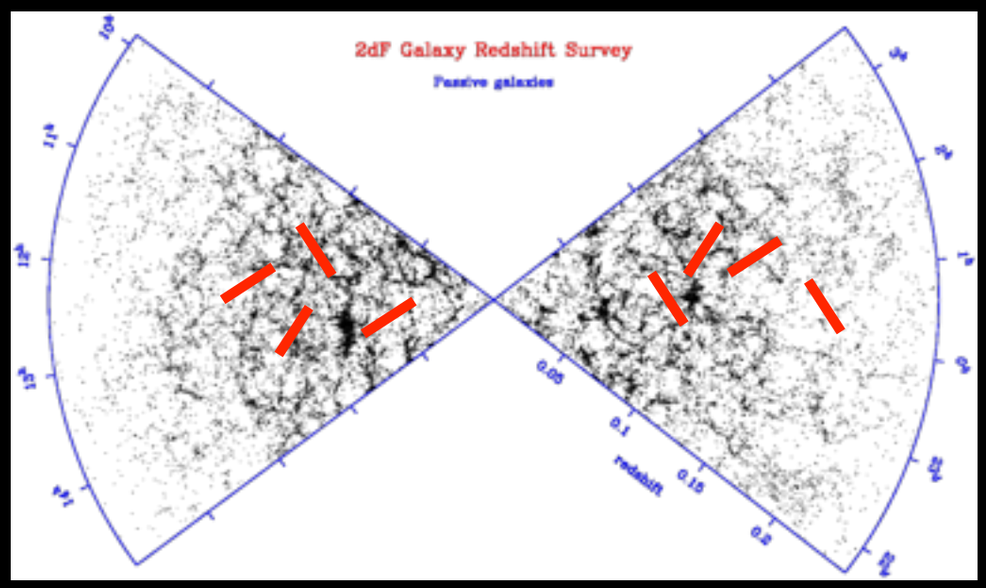
EXPANSION PROBE (RADIO + OPTICAL) - BARYON ACOUSTIC OSCILLATIONS



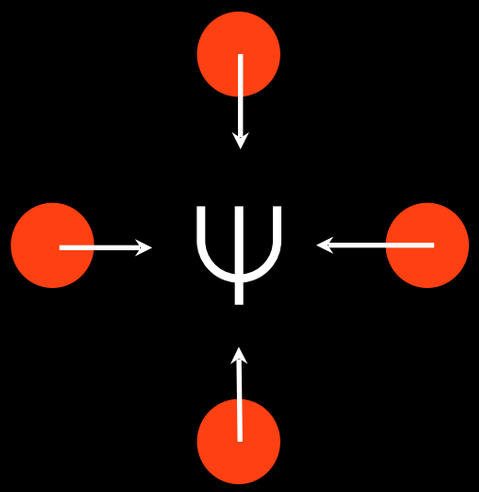




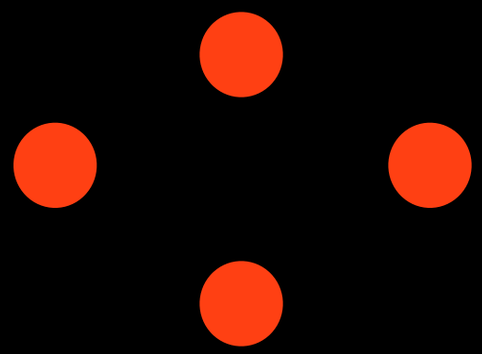
Eisenstein

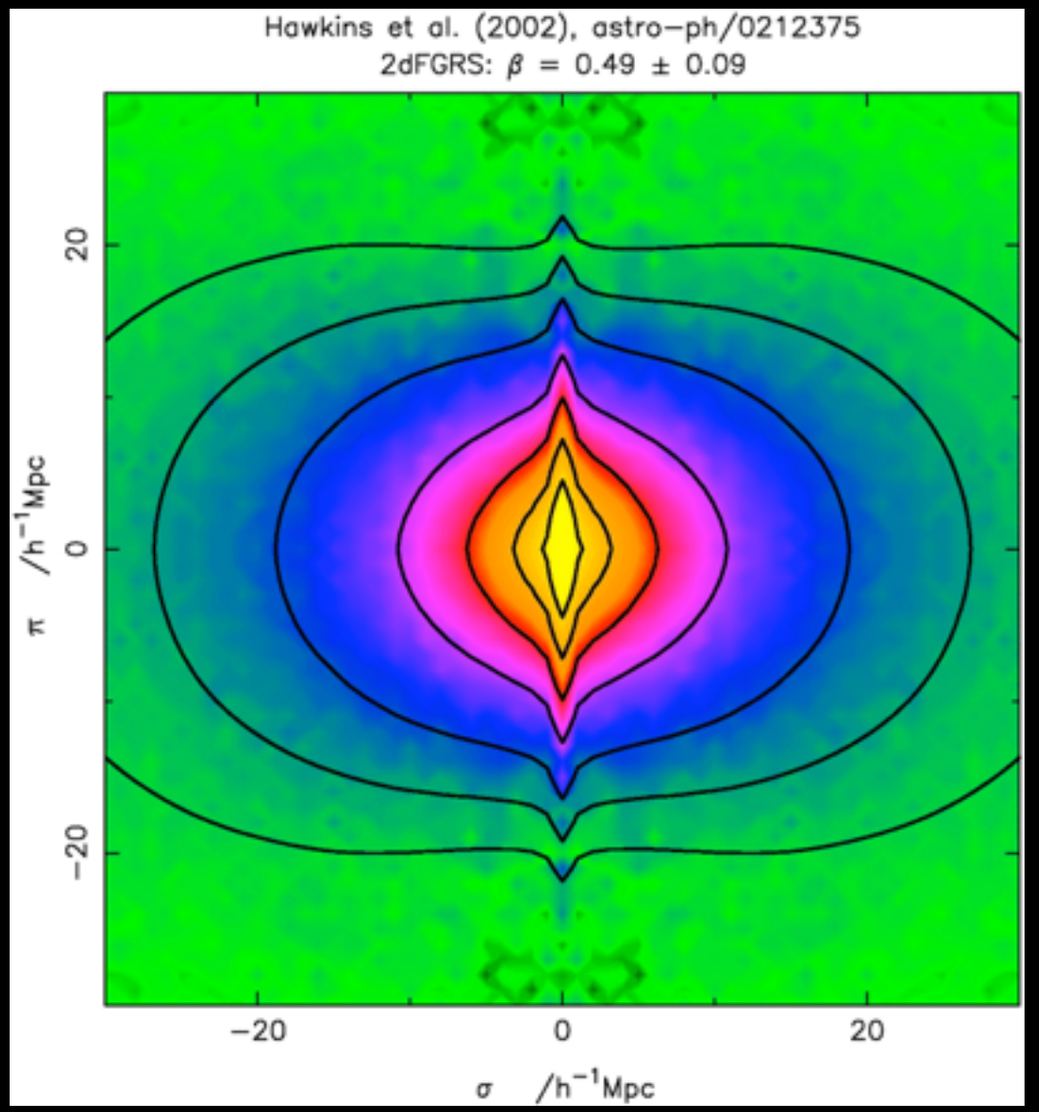


GROWTH PROBE (RADIO + OPTICAL) - REDSHIFT SPACE DISTORTIONS

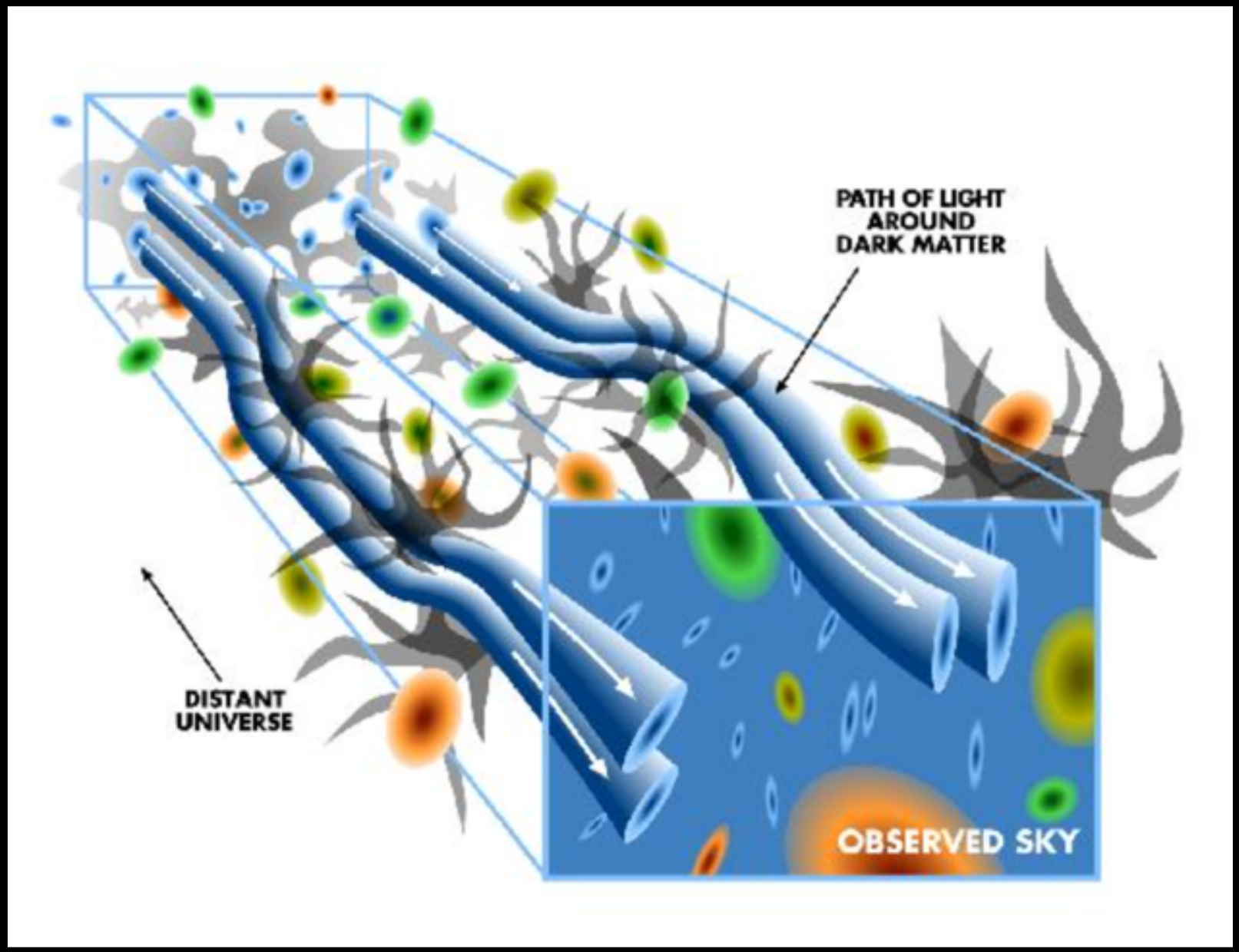


Observed





GROWTH/EXPANSION PROBE (RADIO+OPTICAL) - GRAVITATIONAL LENSING

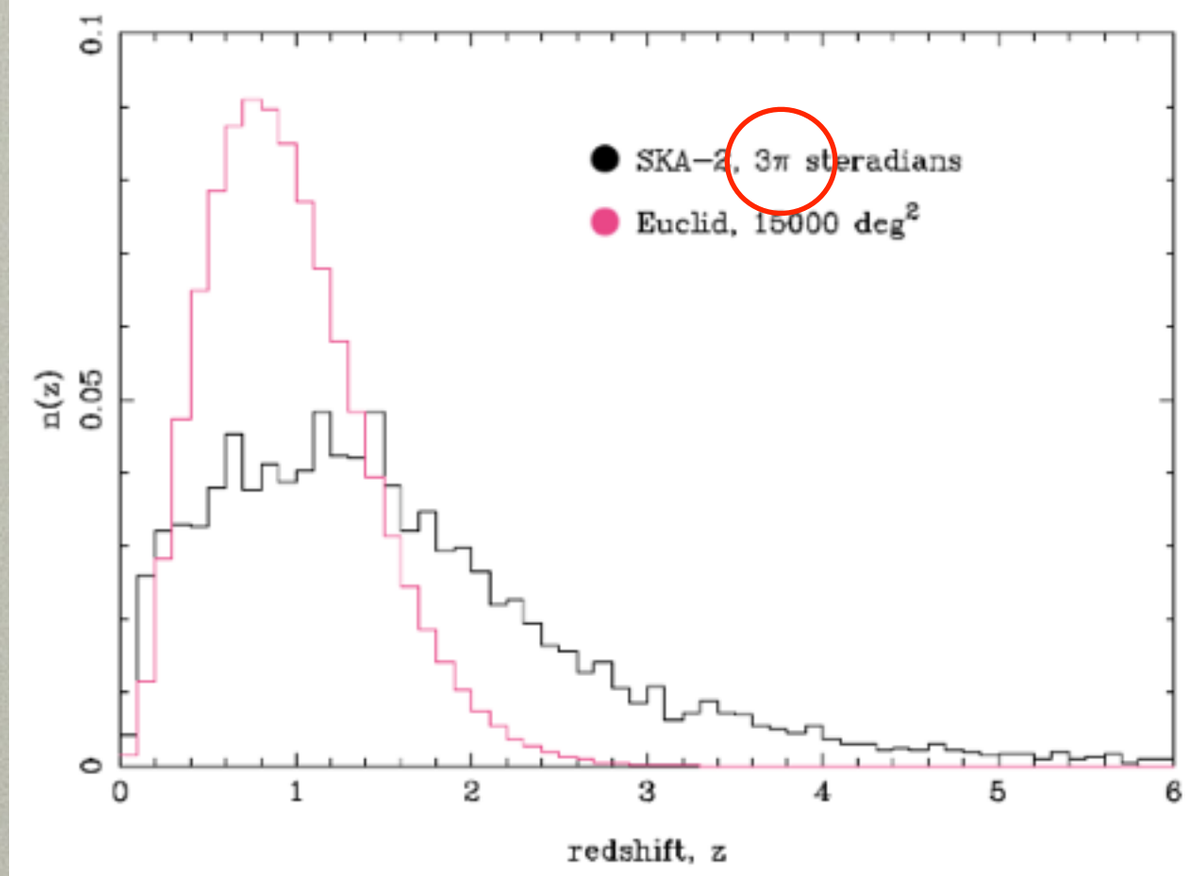


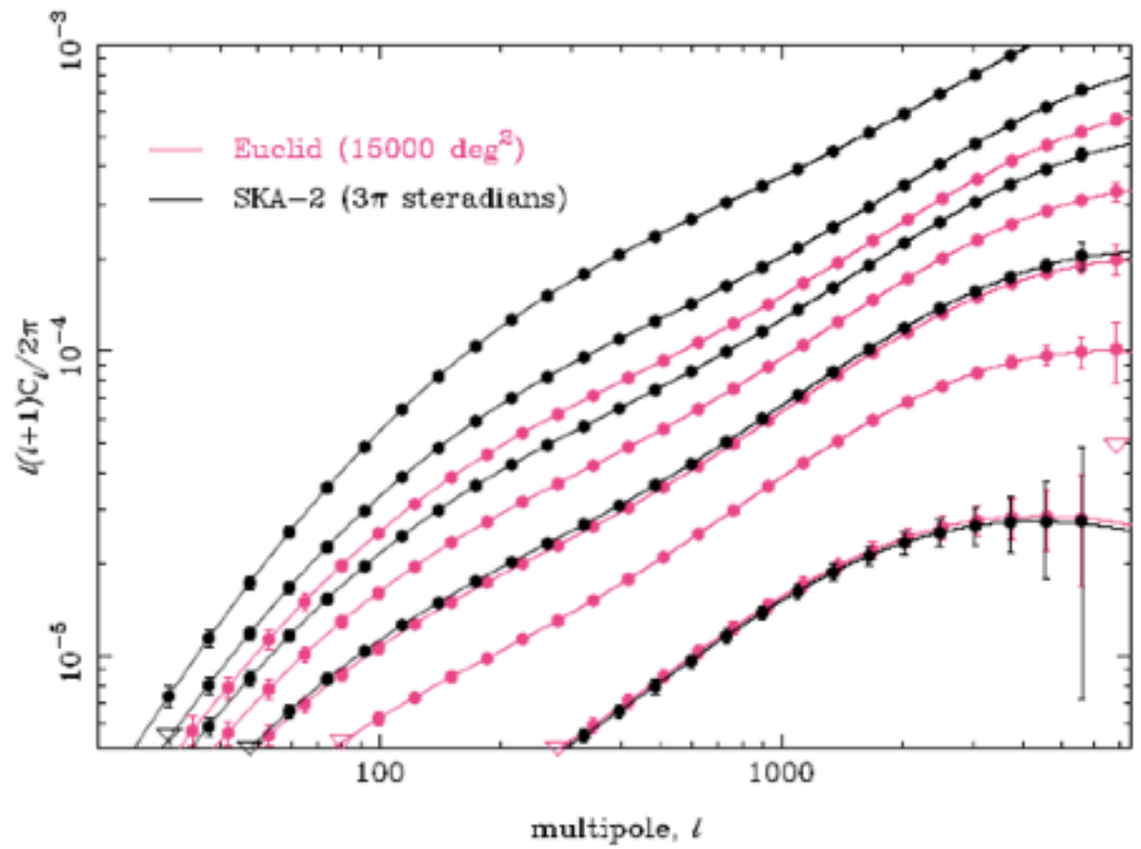
Wittman et al 00

Probing a combination of expansion, structure and gravity

Comparably powerful surveys

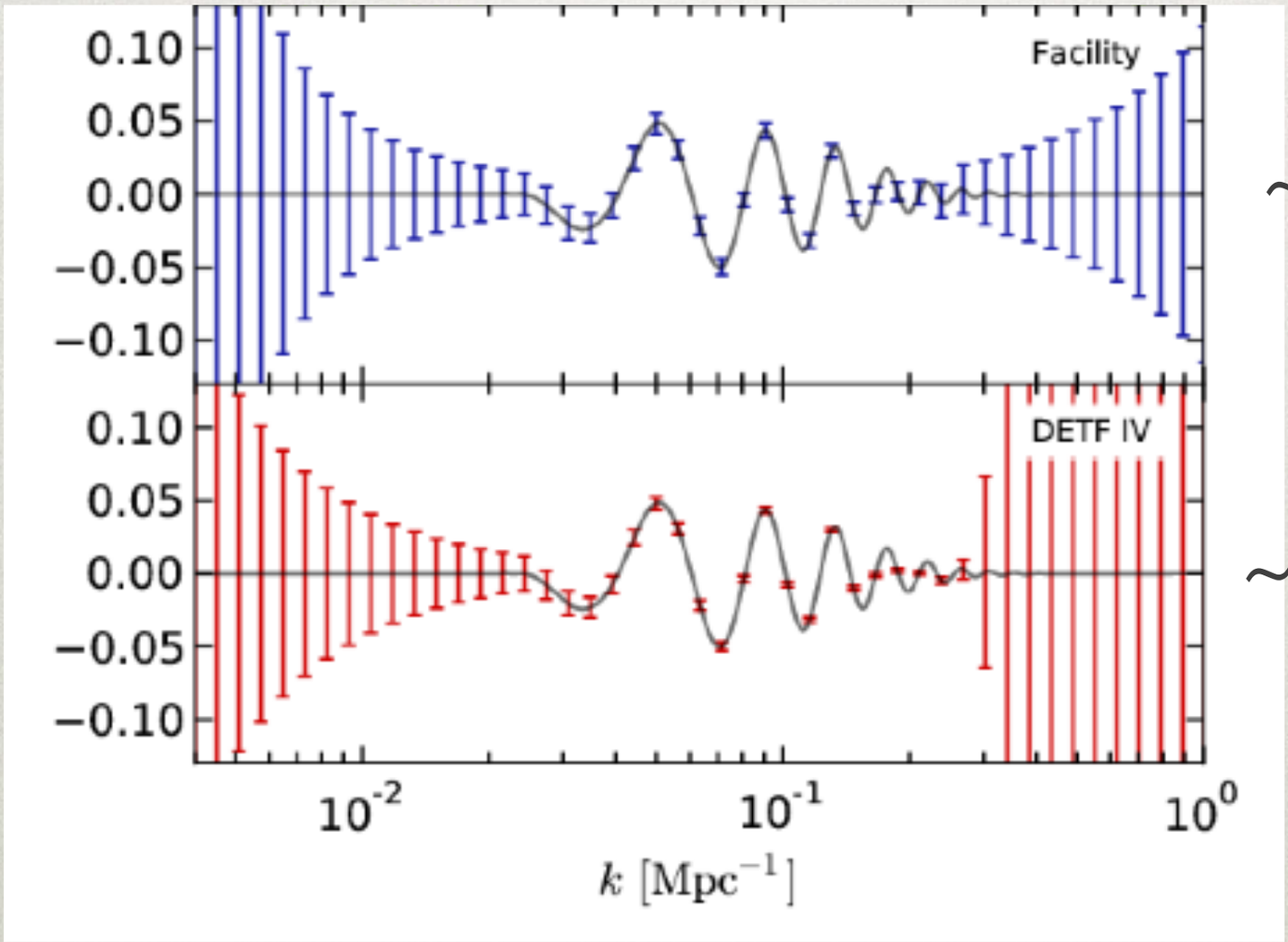
e.g. for lensing surveys:





Michael Brown

BAO predictions

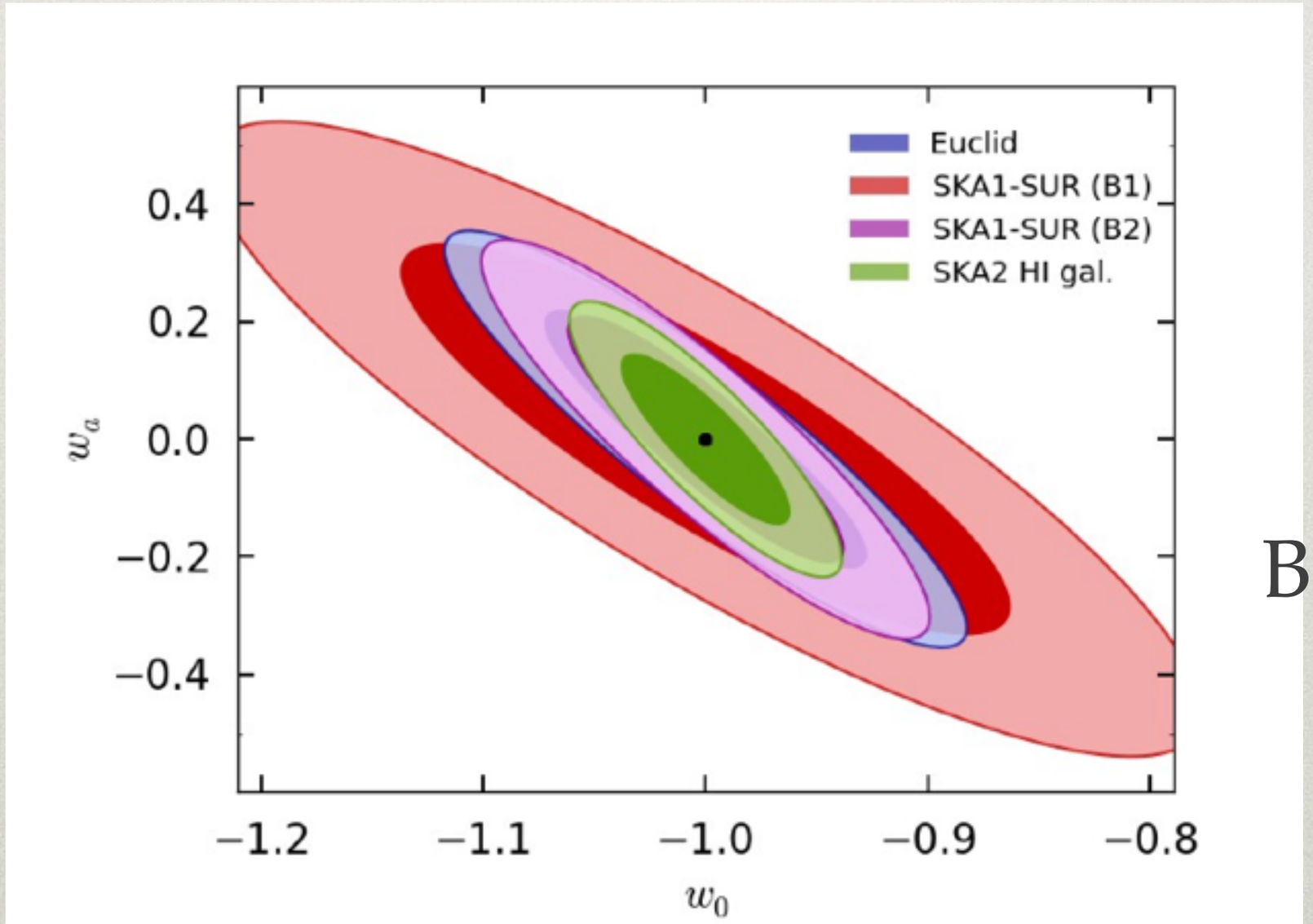


~SKA1 IM

~Euclid

Bull et al 2014

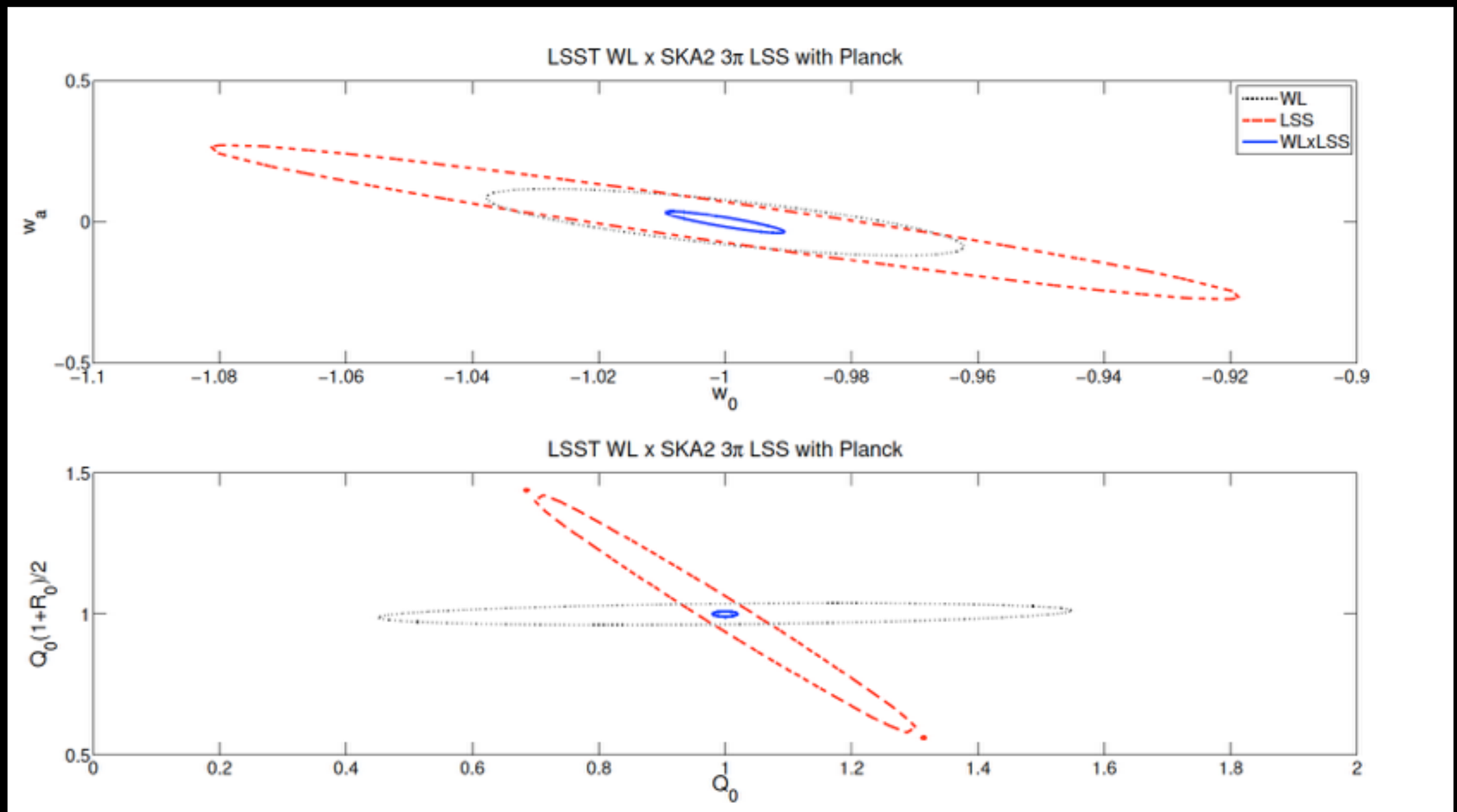
BAO predictions



Bull et al 2014

COMBINING SURVEYS - 1) AT THE END

e.g. Combining constraints from LSST lensing+SKA2 HI galaxy clustering (including RSD):



Bacon et al 15

THE SHAPE OF THINGS TO COME

What do we make of the tensions between current datasets?

Currently modest.

Perhaps these will become more pronounced in future datasets.

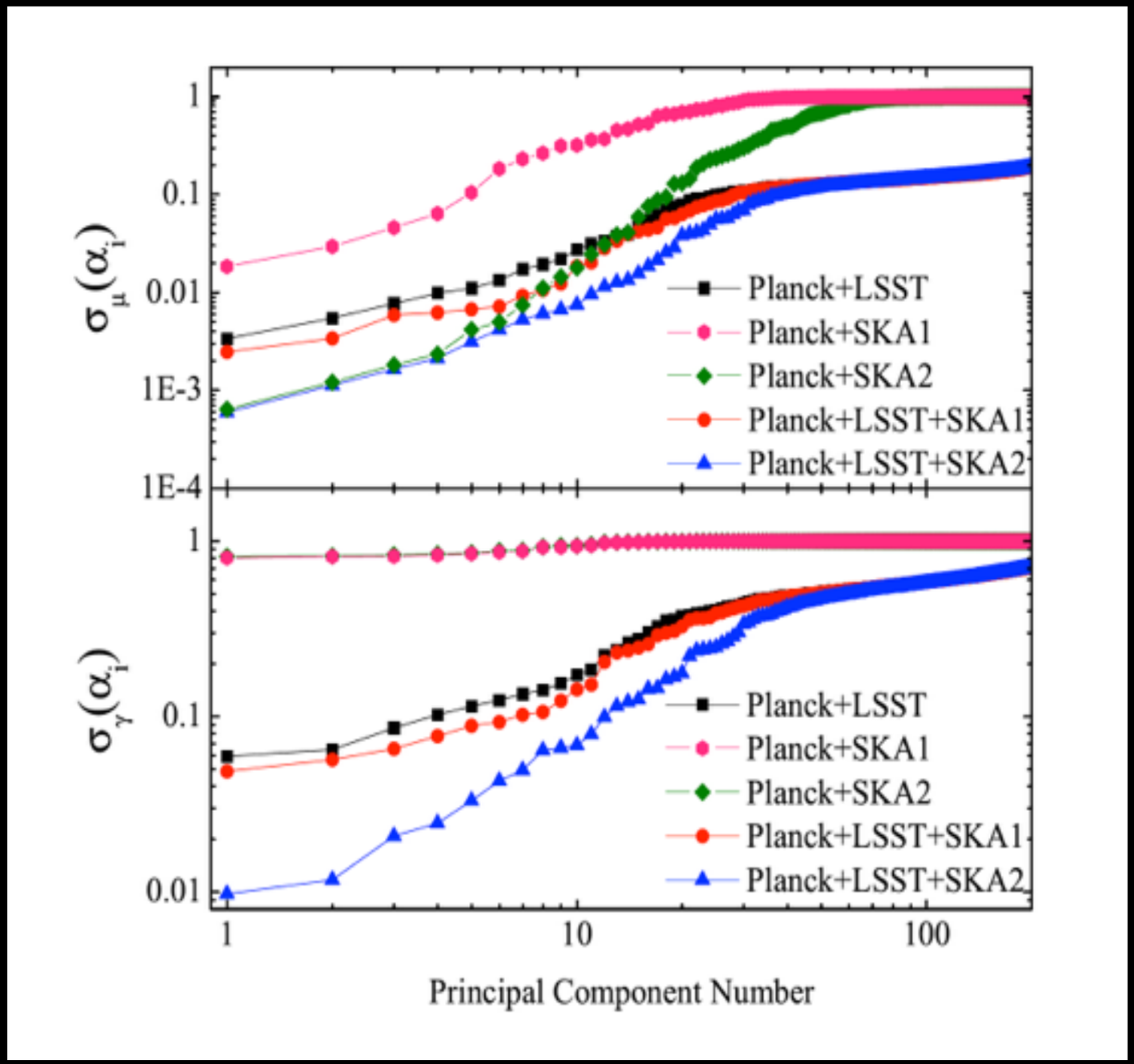
Some of the tension may herald exciting physics.

Some may indicate systematic effects.

Need careful calibration, modelling and cross-correlation.

COMBINING SURVEYS - 2) IN COMBINED STATISTICS

e.g. PCA approach: LSST lensing + SKA HI clustering

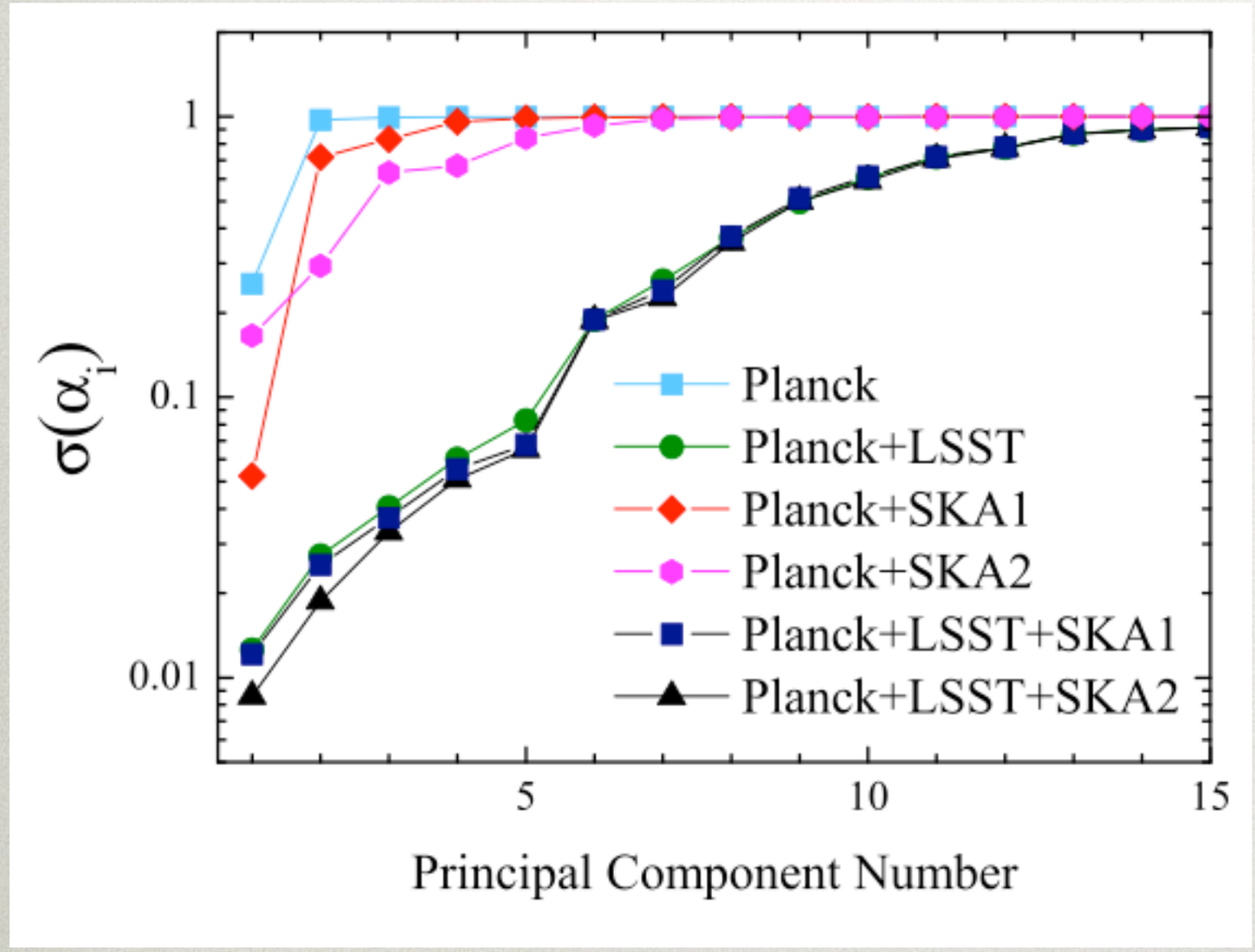


Allow gravity/DE parameters to be scale and z-dependent functions:

$$g(z)+1 = \sum \alpha_i \, e_i(z)$$

Bacon et al 15, Zhao et al 15

LSST+SKA dark energy



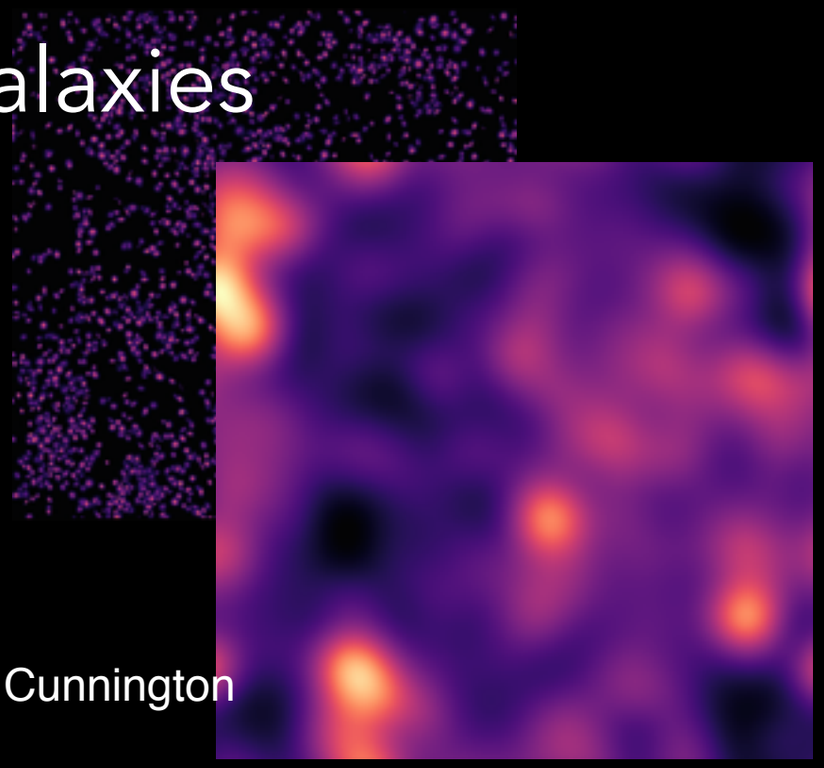
Dark energy equation of state

$$w(z)+1 = \sum_i \alpha_i \, e_i(z)$$

Bacon et al 15

INTENSITY MAPPING CROSS-CORRELATIONS

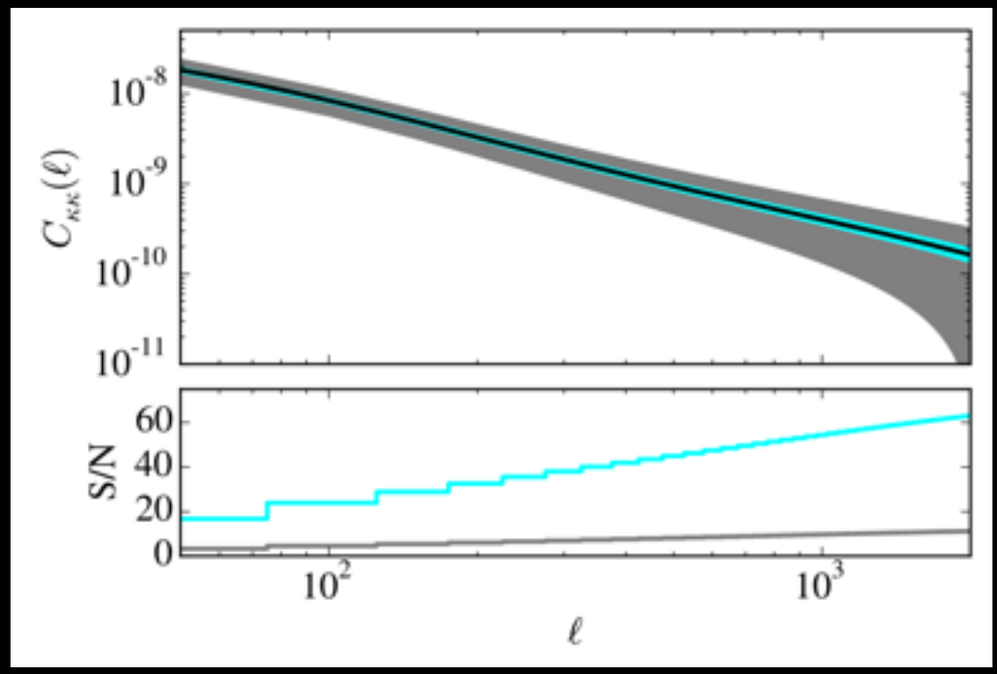
Galaxies



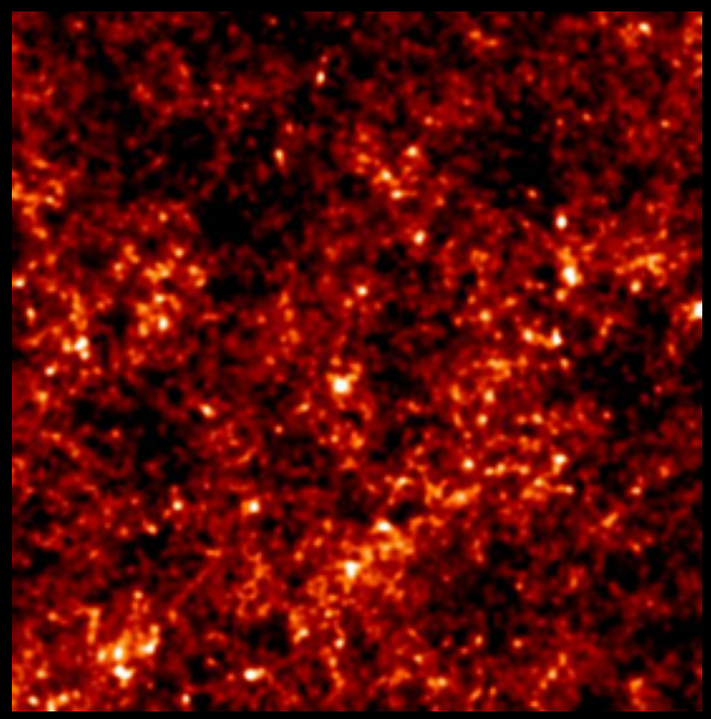
IM

Steve Cunnington

Pourtsidou et al 16



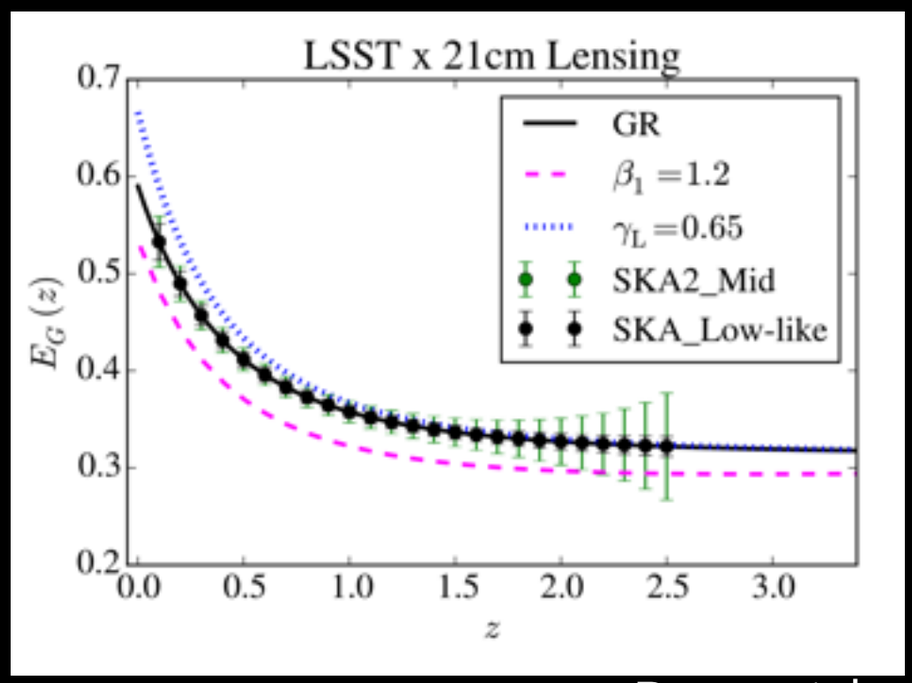
21 cm lensing at Epoch of Reionization:



20′

Hilbert et al 07

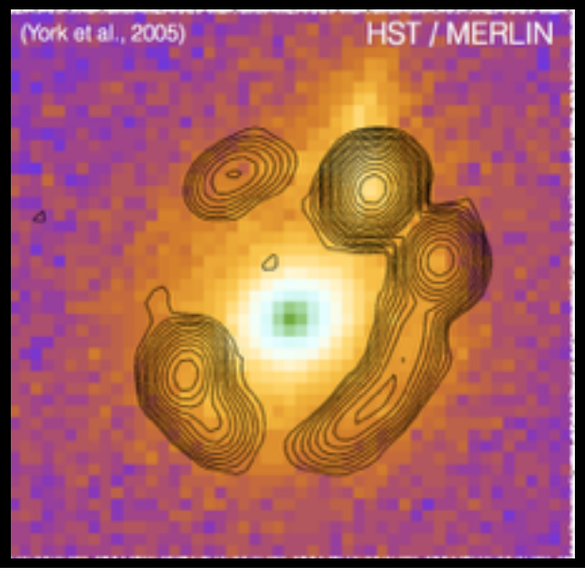
E_G parameter, sensitive to theory of gravity:



SNR =238

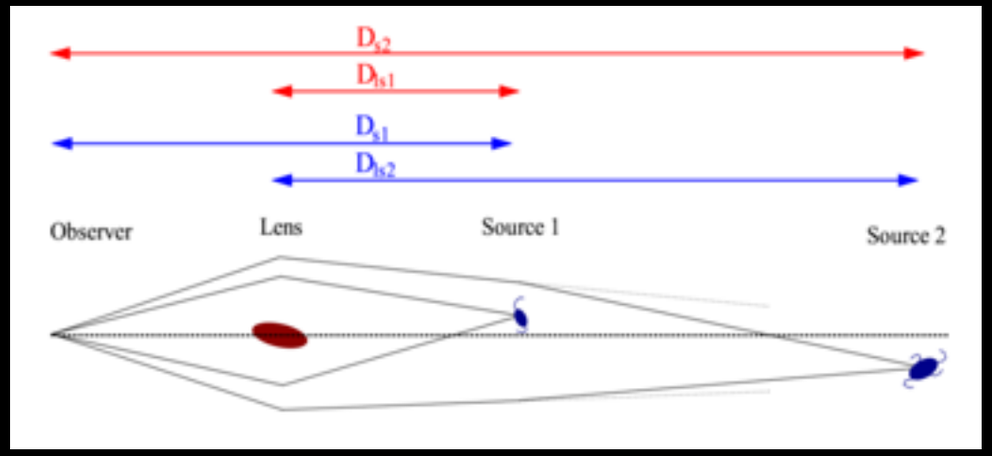
Pourtsidou 2016

RADIO + OPTICAL PRESENT DIFFERENT FEATURES

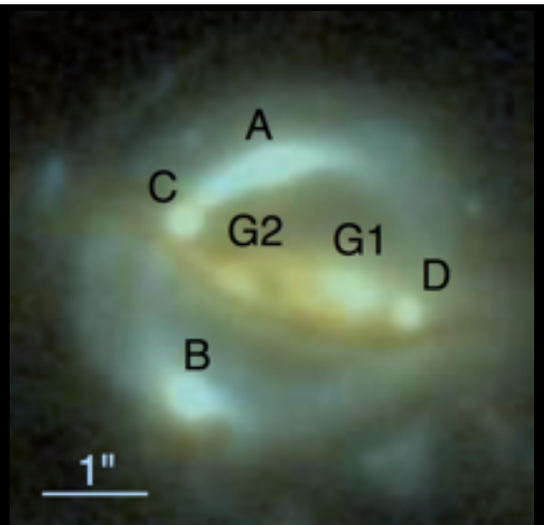


Joint selection of strong lensing systems (e.g. optical ellipticals + radio b/g sources)

10^4-10^5 lenses - examine sources at high magnification (McKean et al 15)



SL Cosmography (e.g. Collett & Auger 15, Collett & Bacon 16) - may find multiple arcs in optical + radio



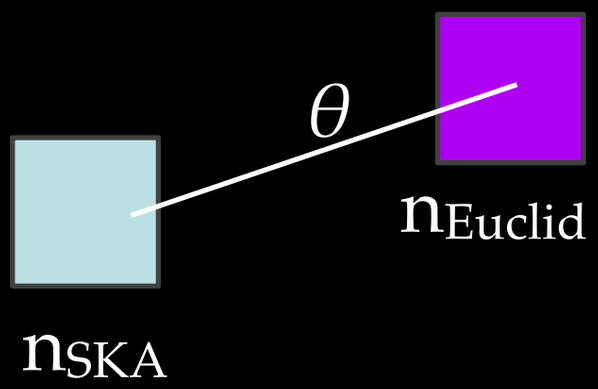
Time delays: radio quasars + optical extended arcs for mass model. (e.g. Suyu et al 2010)

Systematic Effects

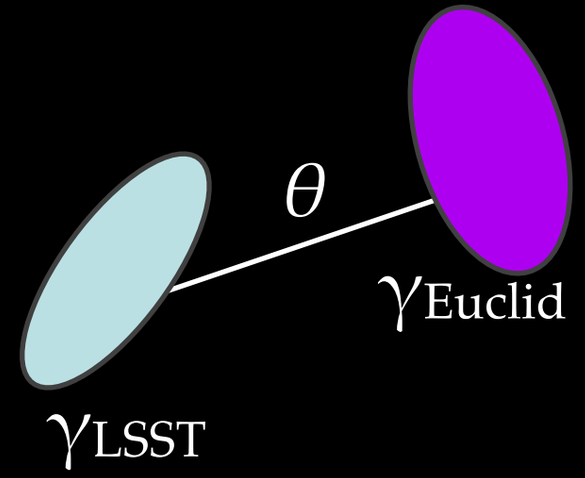
- With heroic efforts, future surveys will reduce statistical error bars on cosmological parameters.

- Even so, we are likely to enter a systematics dominated regime, for all probes.

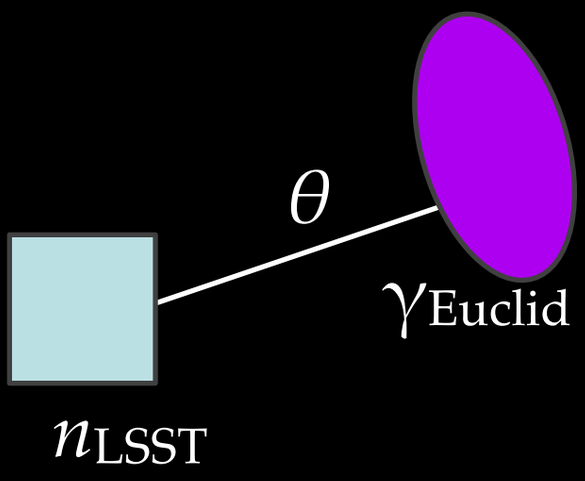
COMBINING SURVEYS - 3) OVERCOMING SYSTEMATIC ERRORS



Cross correlation of clustering picks out fluctuations which are not due to instrumental effects or e.g. stars.



Cross correlation of lensing shear picks out signal which is not due to telescope systematics.



Cross correlation of clustering and lensing picks out signal with different combination of systematics, and measures galaxy bias.

GALAXY EVOLUTION

SKA continuum will probe e.g. AGN and SF history over cosmic time and wide area

Redshifts and stellar masses from LSST+Euclid

Hi-res optical info from Euclid

Pathway from neutral (SKA HI) to molecular gas (ALMA) to star formation (SKA continuum, optical).

NB LSST deep drilling fields - will see high z objects (match with SKA)

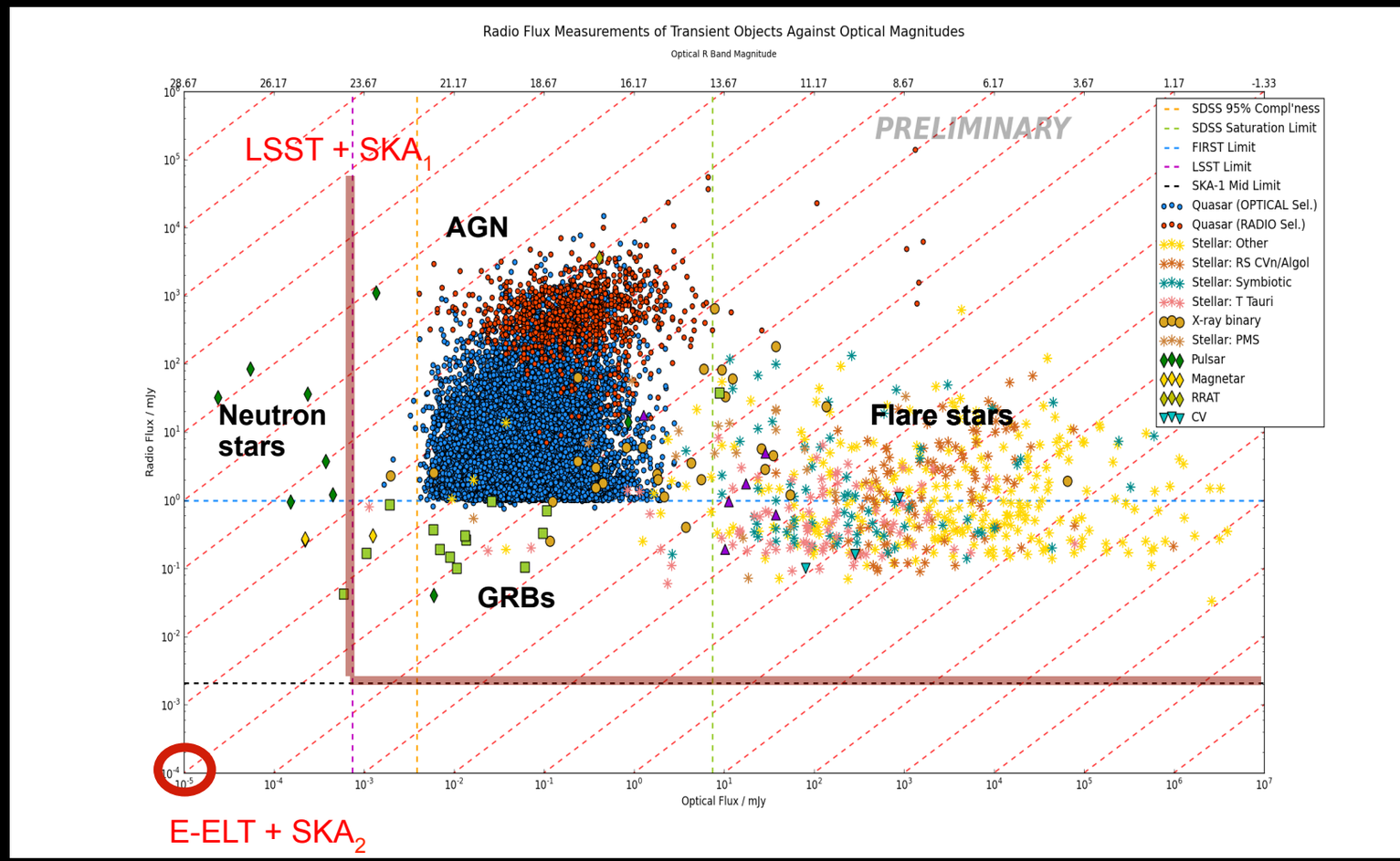
TIME DOMAIN

Stuart, Munoz-Darias & Fender

LSST transient events:
20 billion objects
routinely monitored;
10,000 events per night

If coordinated with SKA:

Euclid will provide well-resolved images of host galaxies.



What is the future of this field?

Everything depends on what is found. If we measure w=-1 to 1% or less, will large numbers of researchers continue in that problem? But if we *don't* find this, wow.

Regardless, detailed interactions of astrophysics and cosmology will become more important and popular - intrinsic alignments, scale-dep bias, baryon effects on dark matter.

What is the future of this field?

What happens in other fields will affect us too:

- Discovery of WIMP, or axion?
- Discovery of SUSY?
- Quantum computing?

SUMMARY

Using a combination of future surveys gives:

- Complementary physical constraints
- Removal of systematics
- Cross checks of results
- Mutual support (e.g. redshifts)
- A more complete picture (e.g. galaxy evolution)
- Exploitation of the time domain.