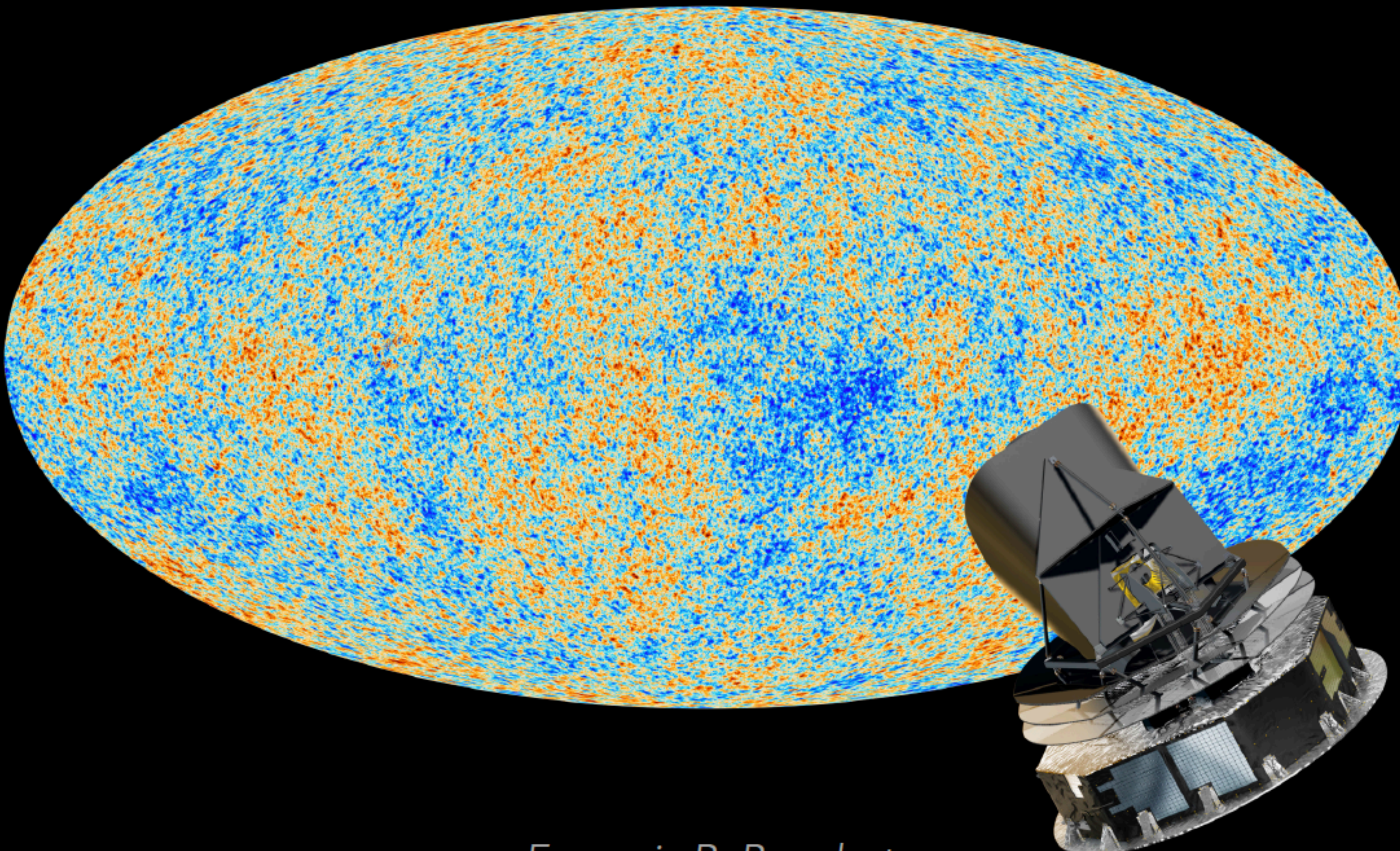
Dark Energy Summary

Tim Eifler
(JPL/Caltech, University of Arizona)

Disclaimer:

- Not a complete overview
- Somewhat biased as a function from which talks I could easily copy slides…
- Apologies to those who feel underrepresented…

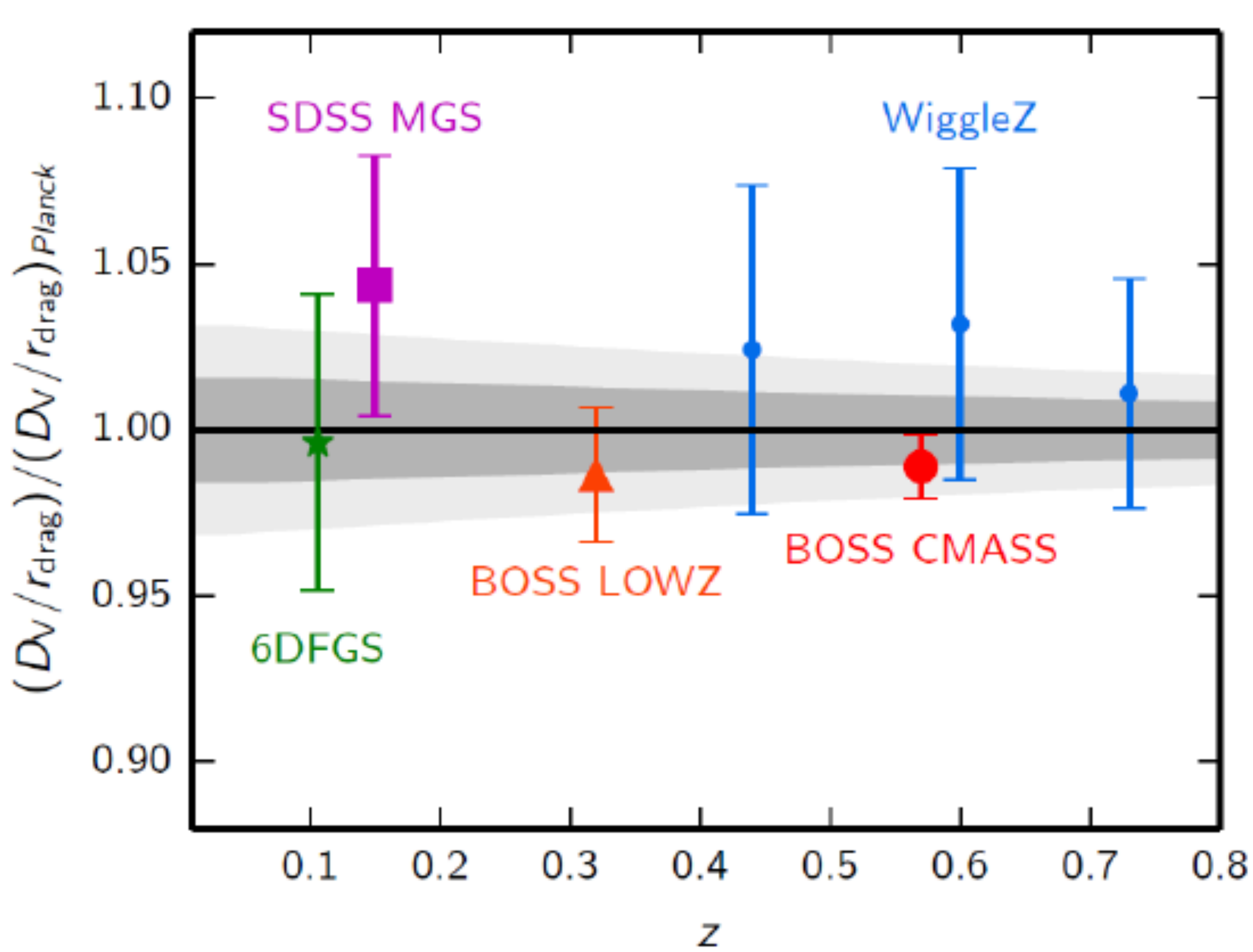
CMB: The Planck experiment status and prospects

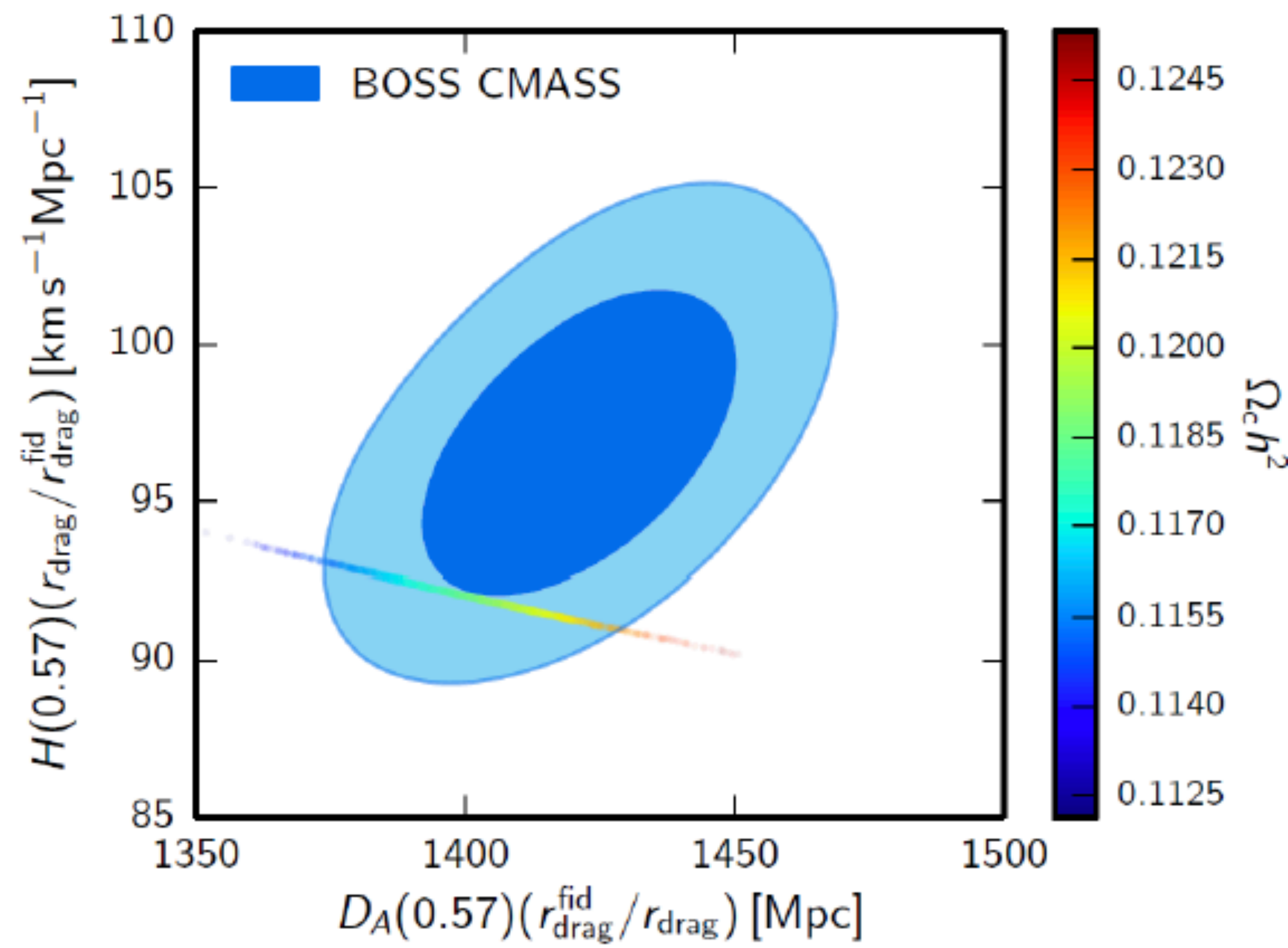


François R. Bouchet

Baryonic Acoustic Oscillations / Planck

The spherical sound wave from an initial overpressure stalls after decoupling at a distance estimated by Planck of 147.5 ± 0.6 Mpc (within LCDM)

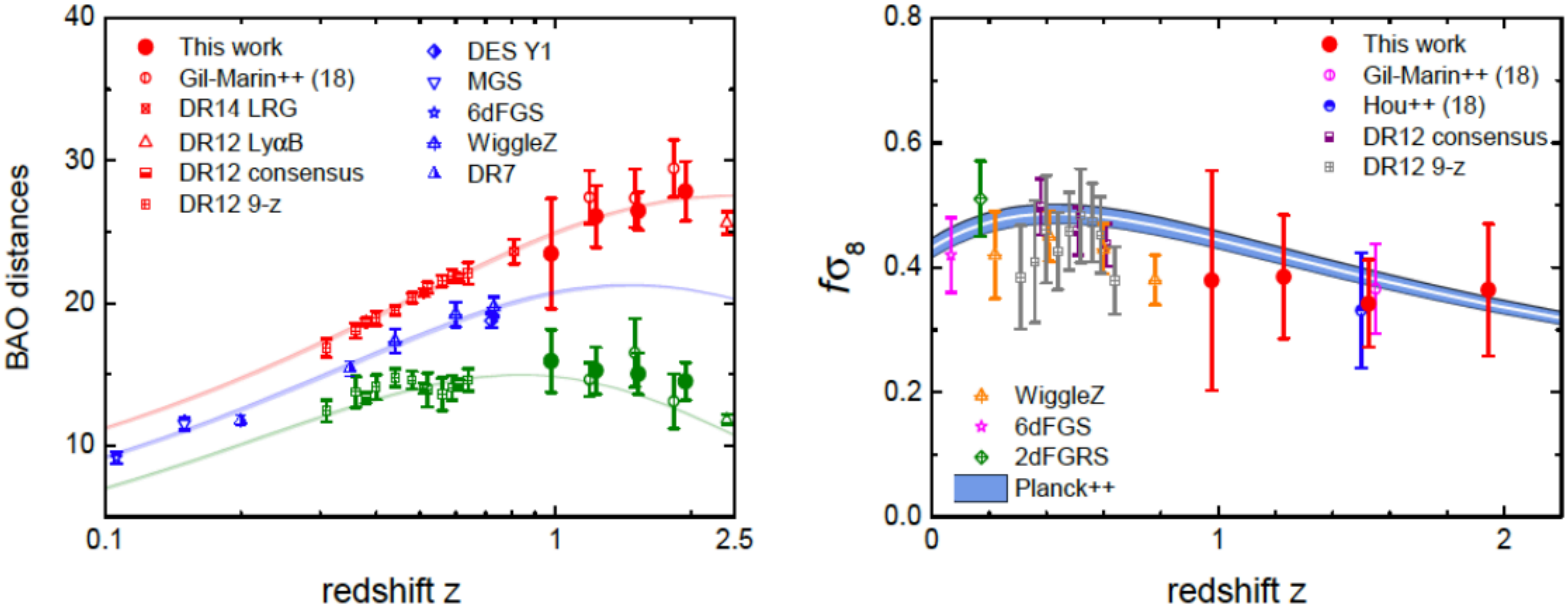




Grey band is Planck TT+LowP 1(2) sigma range [P15 Parameters]

Acoustic-scale distance ratio, $D_V(z)/r_s$, divided by the distance ratio of the Planck TT base model.

Recent BAO data



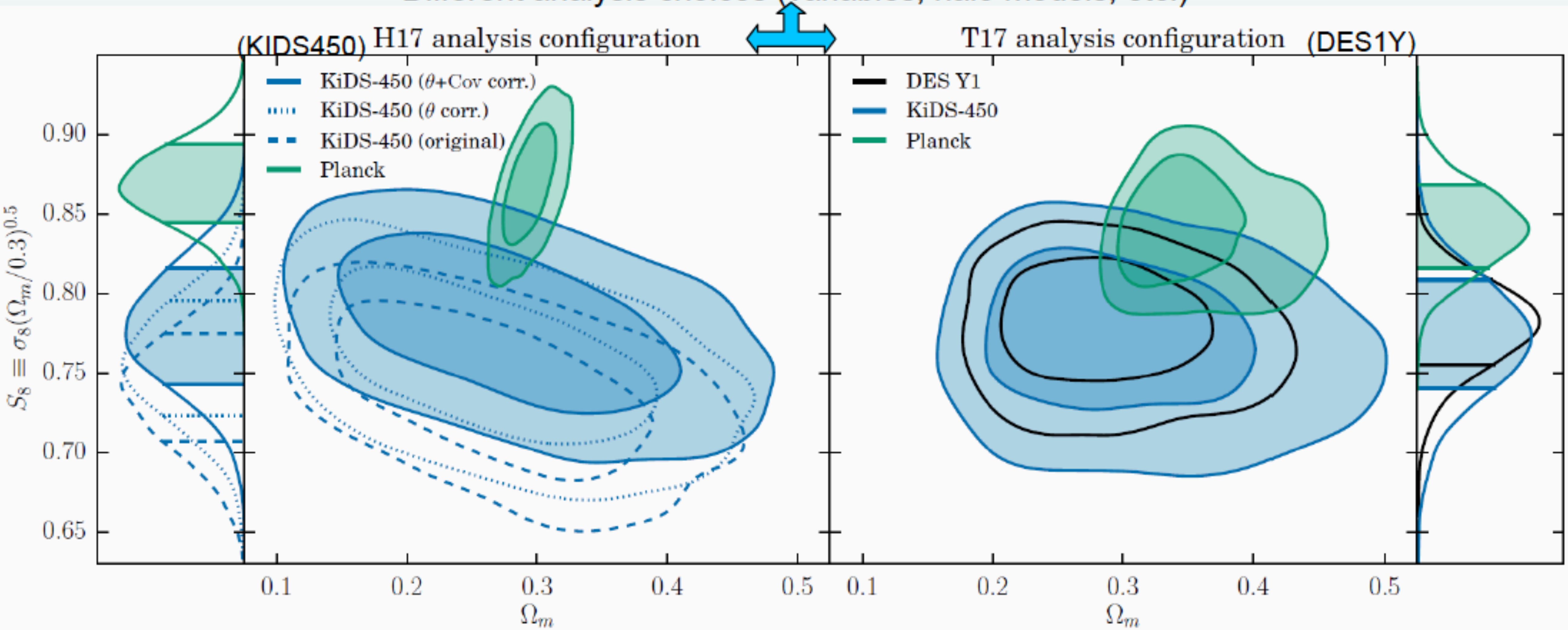
… still agree very well with Planck data prediction within LCDM

Zhao+ arXiv:1801.03043

(See also Zarrouk+ arXiv:1801.03062)

KIDS450-DES1Y: Impact of survey geometry

Different analysis choices (variables, halo models, etc.)



Troxel+ arXiv:1804.10663

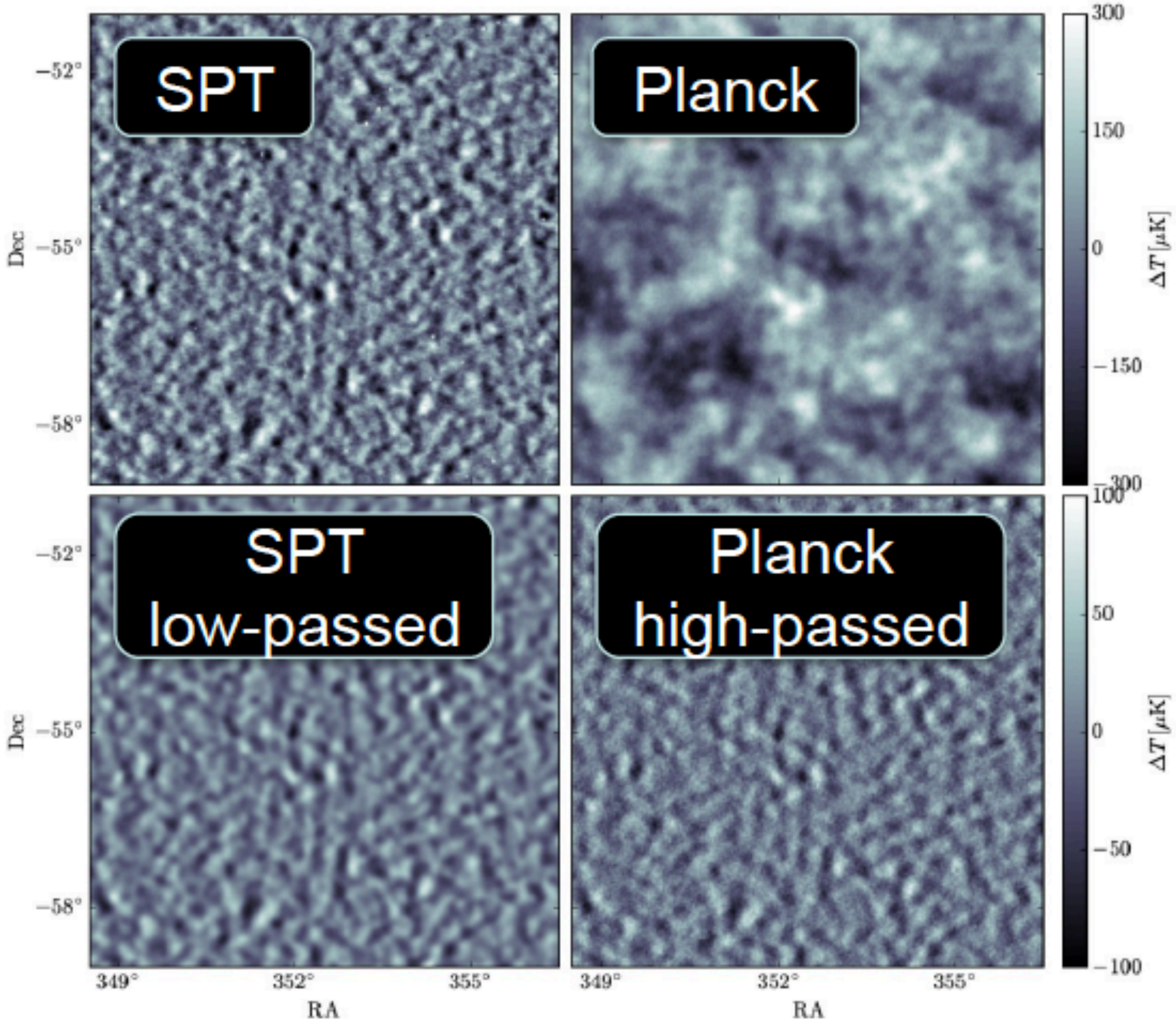
After correction (weighting the pair separation, Cov. mat improvement), the relatively strong tension of KIDS-450 with Planck essentially evaporates!

Both analyses (with these corrections) agree very well between themselves, and with Planck

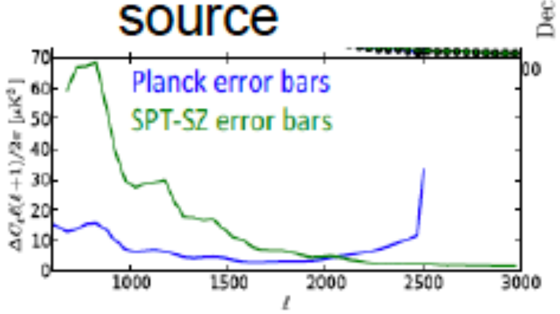
- These correction may also help with the lack of internal consistency pointed out by Lemos & Efstathiou 2018.
- These relatively new analyses are maturing: it may be that other effects currently neglected may re-increase the tensions in the future and lots of new data soon will permit more stringent tests!.

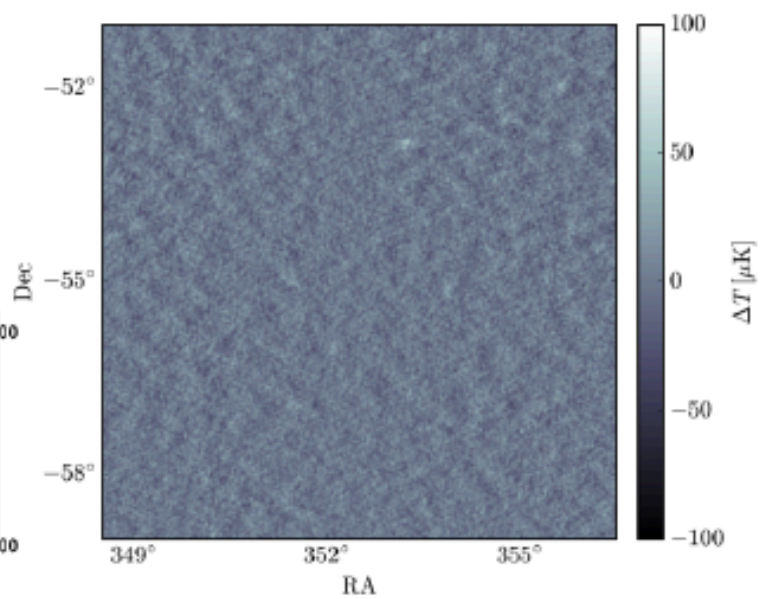
SPT@150GHz vs Planck@143GHz

Hou+ arXiv:1704.00884v1



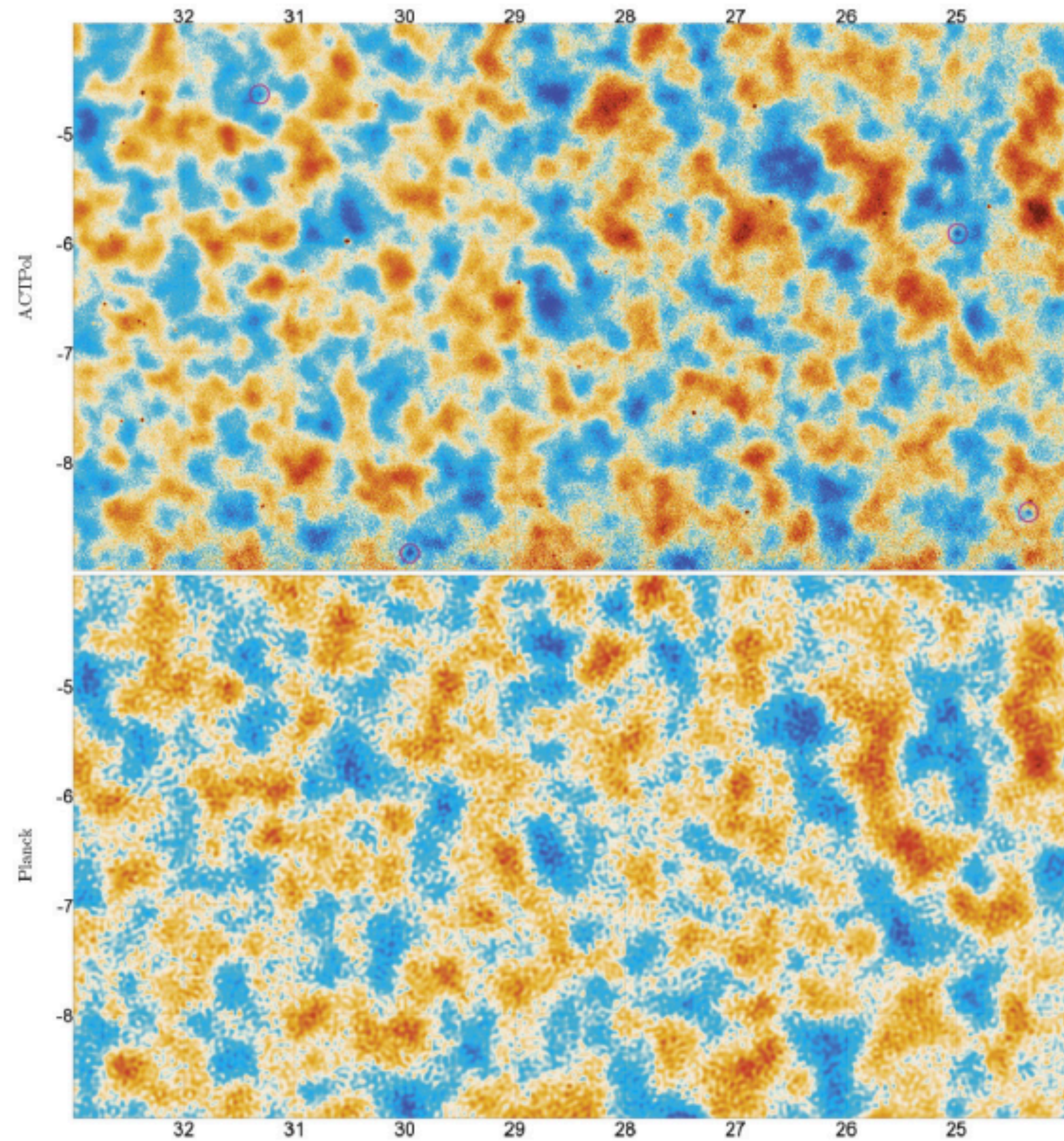
Little residual in SPT-low minus Planck-high, but a variable source





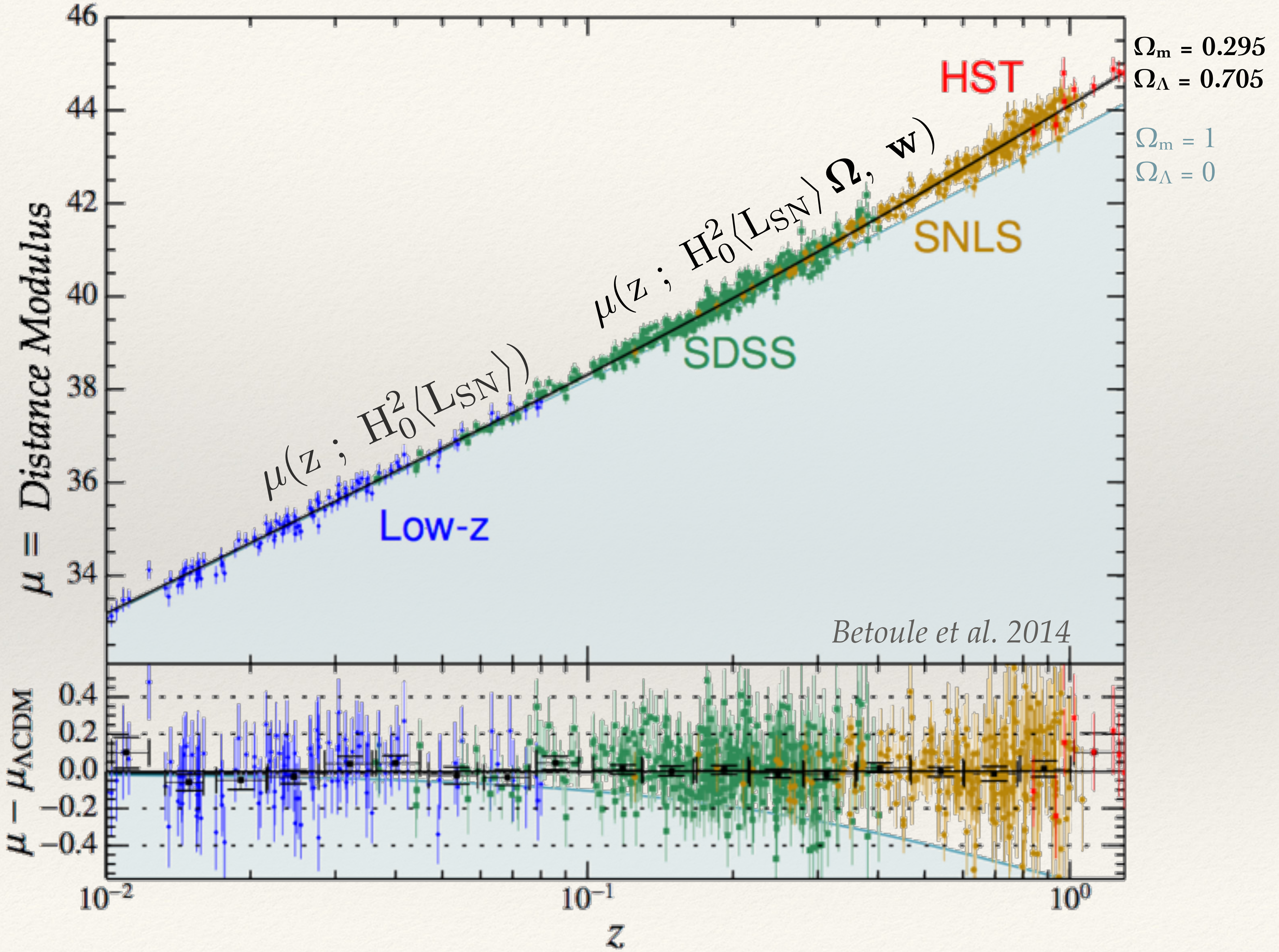
ACT@150GHz vs Planck@143GHz

Louis+ arXiv:1610.02360v1



➔ Excellent consistency at map level around 150GHz for Planck vs SPT & ACT

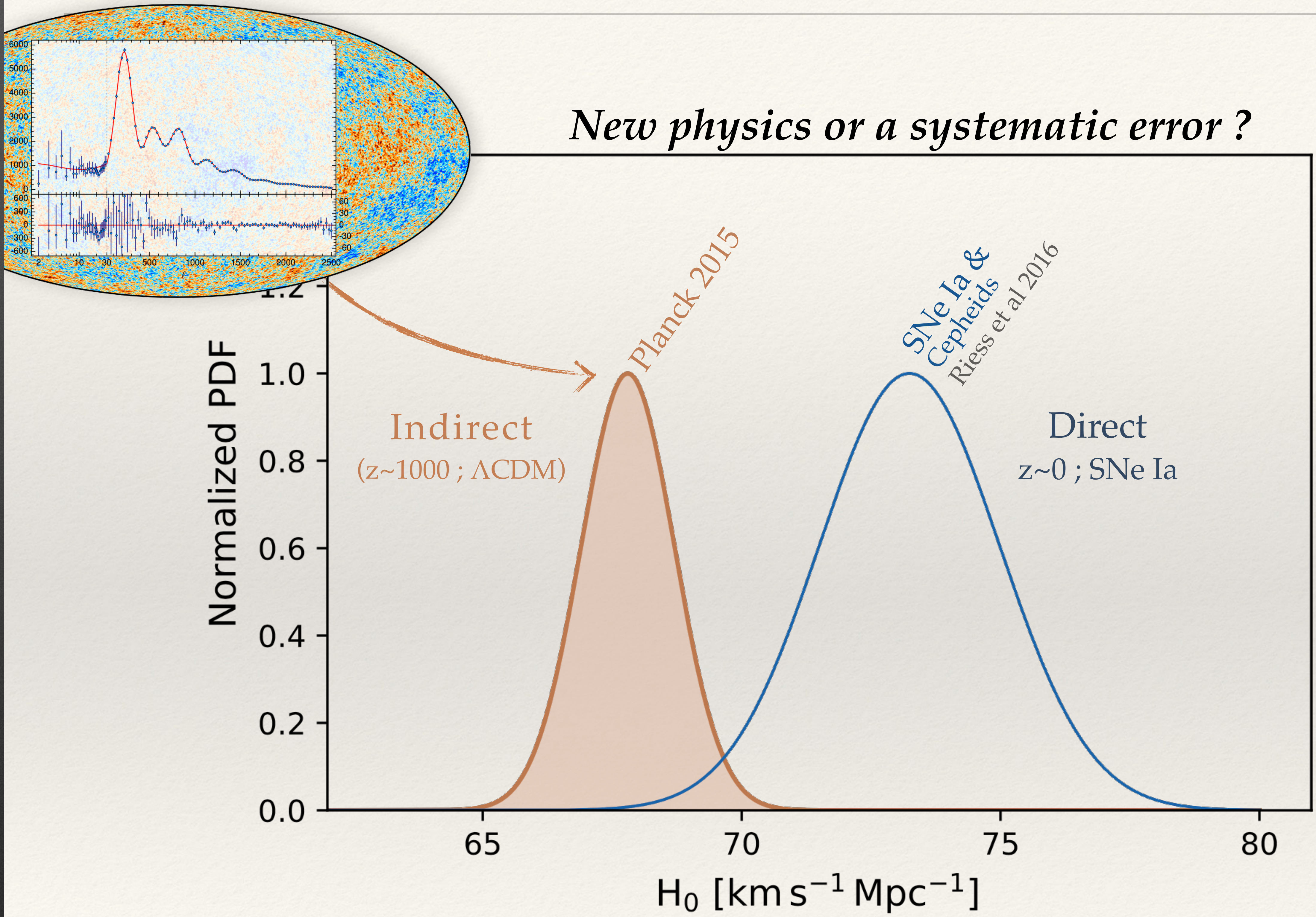
Type Ia Supernova Cosmology



Tension in the concordance model?

~4σ

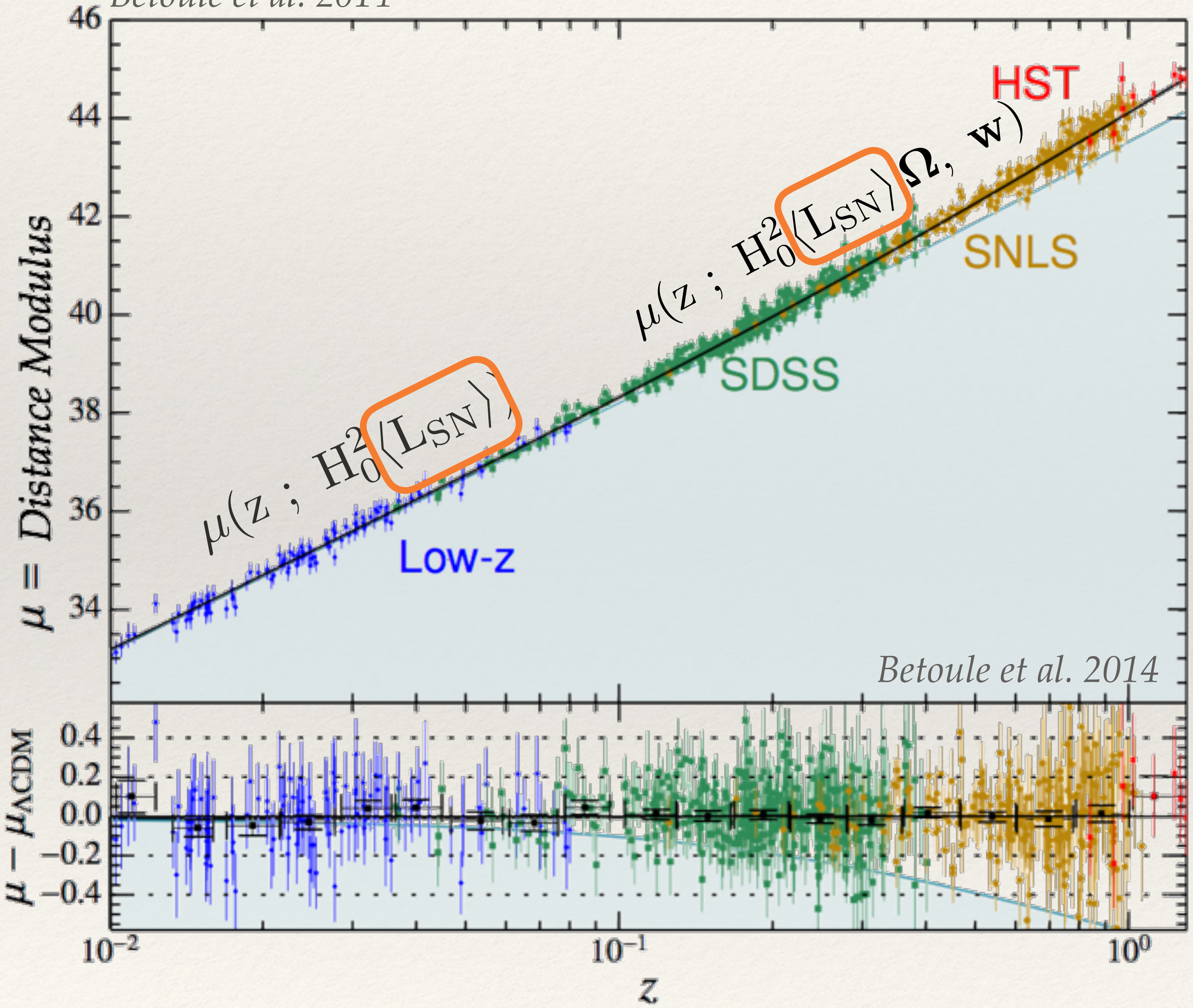
New physics or a systematic error ?



Supernova Challenges

We need to make sure SN standardised magnitudes are predictable at any redshift *(at a constant if not H_0)*

Betoule et al. 2014



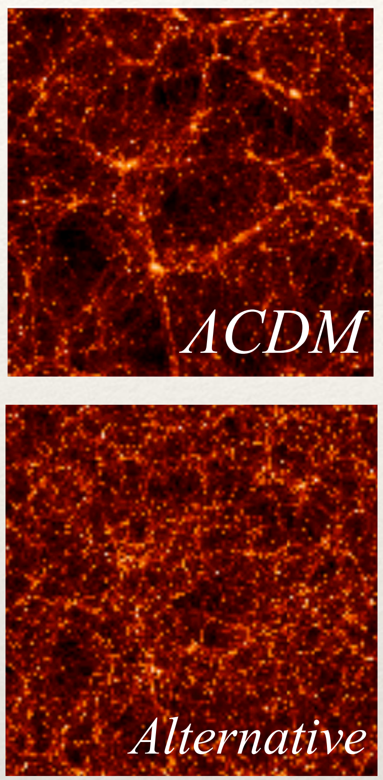
Calibration

Follow Up

Astrophysics

New SNeIa Cosmology area | *growth of Structure*

z~0



Dark Matter

Dark Energy

General Relativity

$f\sigma_8$

clumpiness

Weak Lensing ***Tough***

Redshift Space Distortion ***Biased***

Peculiar Velocities

Type Ia supernovae

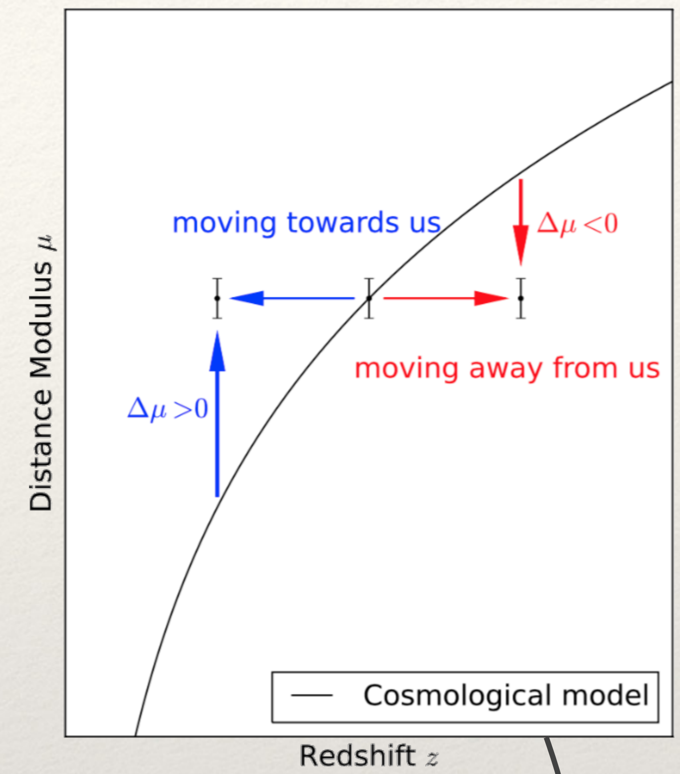
5%

- 1 SN = 25 Galaxies
- Well controlled systematics

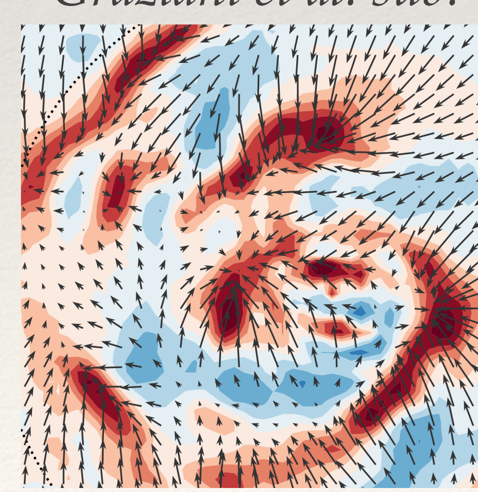
ZTF → 4000 SNeIa → ~10% precision

Galaxy Distances 25%

Finite sample

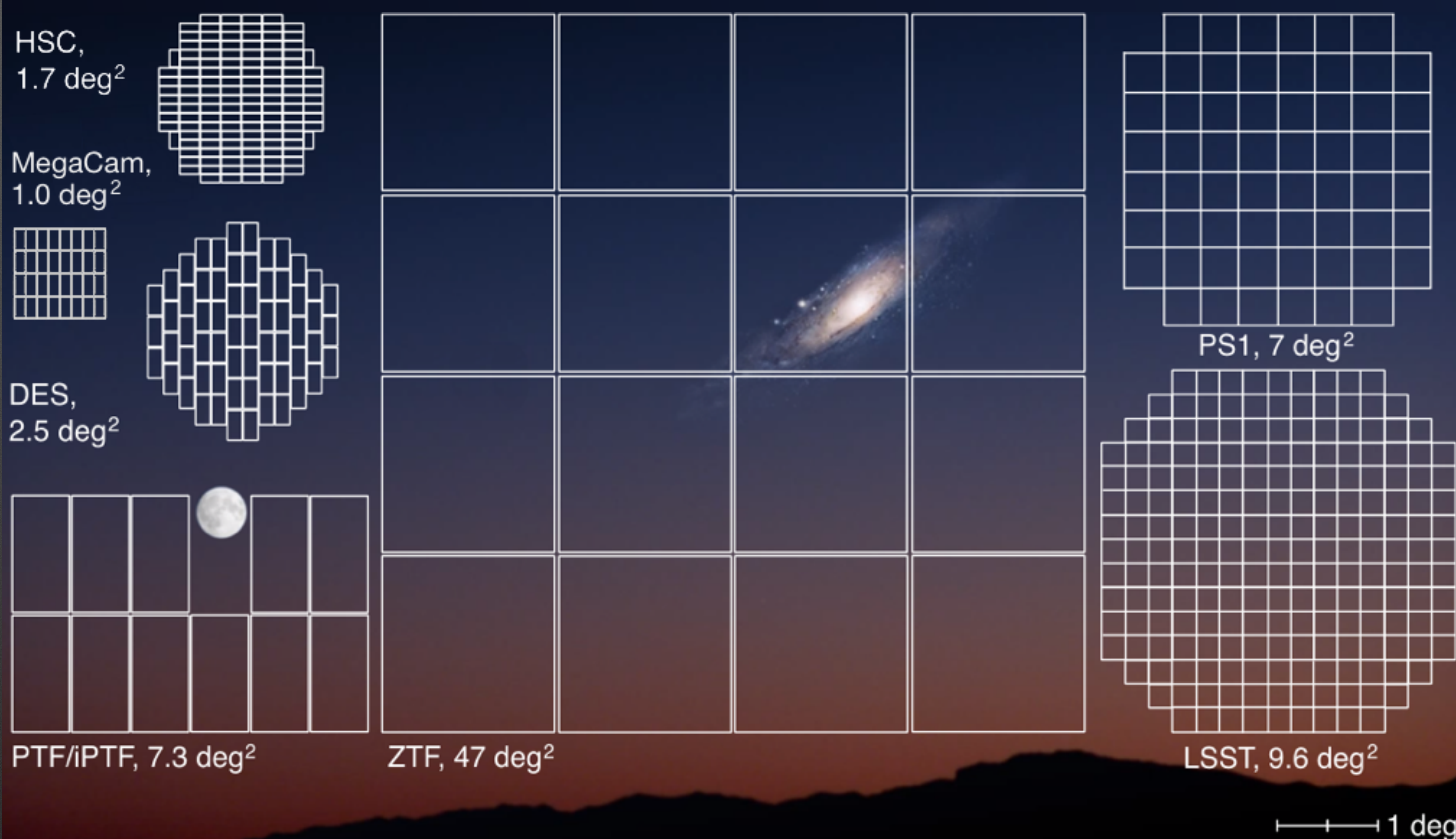


Graziani et al. sub.



Extract density maps from Hubble residual

New Generation of SN Surveys



ZTF | 2018-2021+ | ~3000 SNeIa z<0.1 — LSST | 2022-2032 | 200 000 SNeIa<0.3

+WFIRST (space telescope 2030+ ~1000 SNeIa z>1)

Galaxy clustering and Baryon Acoustic Oscillations: status and prospects

B. Hoeneisen

Universidad San Francisco de Quito
25 June 2018

	This BAO analysis	PDG 2018
Ω_Λ	0.719 ± 0.003	0.692 ± 0.012
Ω_k	0.002 ± 0.007	$-0.005^{+0.008}_{-0.009}$
d'_{BAO}	$(150.3 \pm 0.9) \times \frac{0.678}{h}$ Mpc	144.9 ± 0.4 Mpc
N_{eff} $(m_\nu = 0)$	2.64 ± 0.20 $(h = 0.678)$	3.13 ± 0.32
	4.2 ± 0.9 $(h = 0.720)$	
$\sum m_\nu$	$0.711 - 0.335 \cdot \delta h$	< 0.68 eV, 95% conf.
	$+ 0.050 \cdot \delta b \pm 0.063$ eV	

Comparison of this BAO analysis with PDG 2018 (mostly CMB, Planck collab. (2015)). 68% confidence. $\delta h \equiv (h - 0.678)/0.009$. $\delta b \equiv (\Omega_b h^2 - 0.02226)/0.00023$. (See references for details.)

Major ongoing lensing surveys

Dark Energy Survey (DES)

Image: fnal.gov (Reidar Hahn)

Hyper-Suprime Cam (HSC)

Image: phys.org

Kilo-Degree Survey (KiDS)

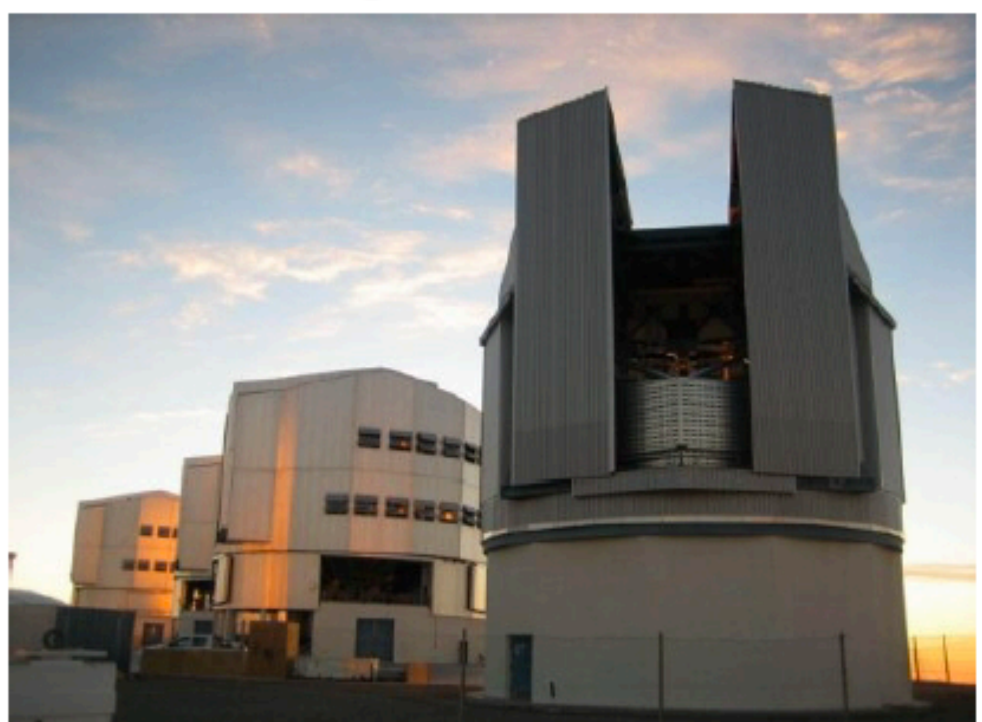


Image: kids.strw.leidenuniv.nl

Image: lsst.org

Danielle Leonard
Carnegie Mellon University
for LSST DESC
June 25, 2018

Dark Energy Survey (DES)

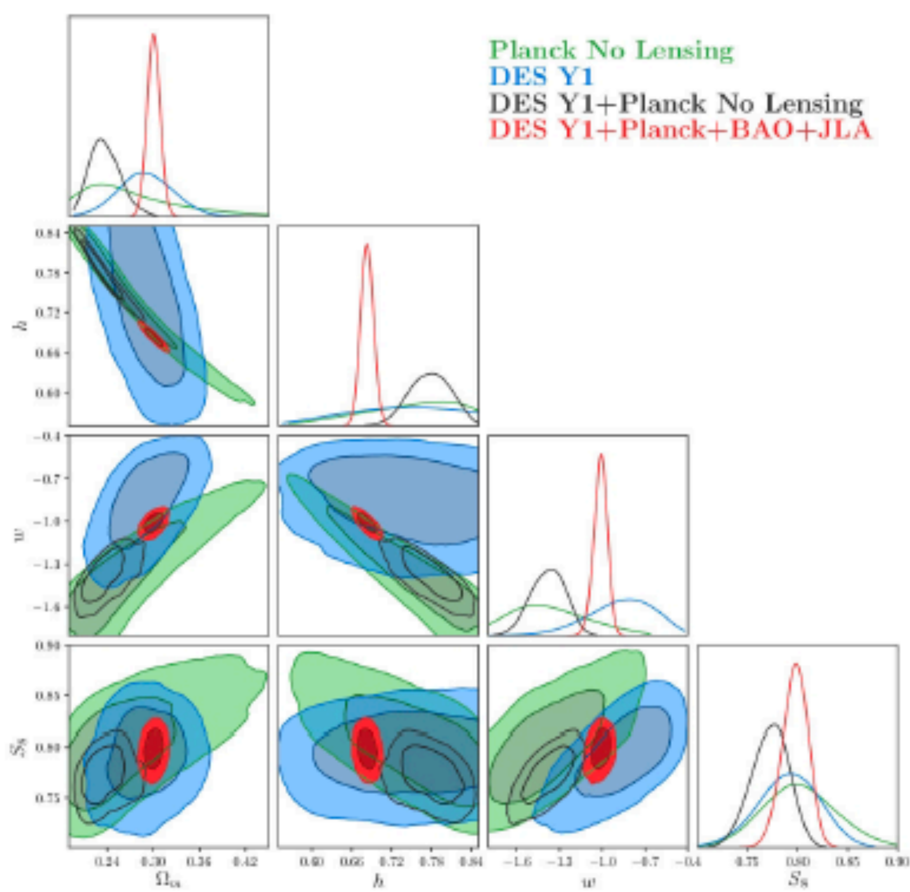
Image: fnal.gov (Reidar Hahn)

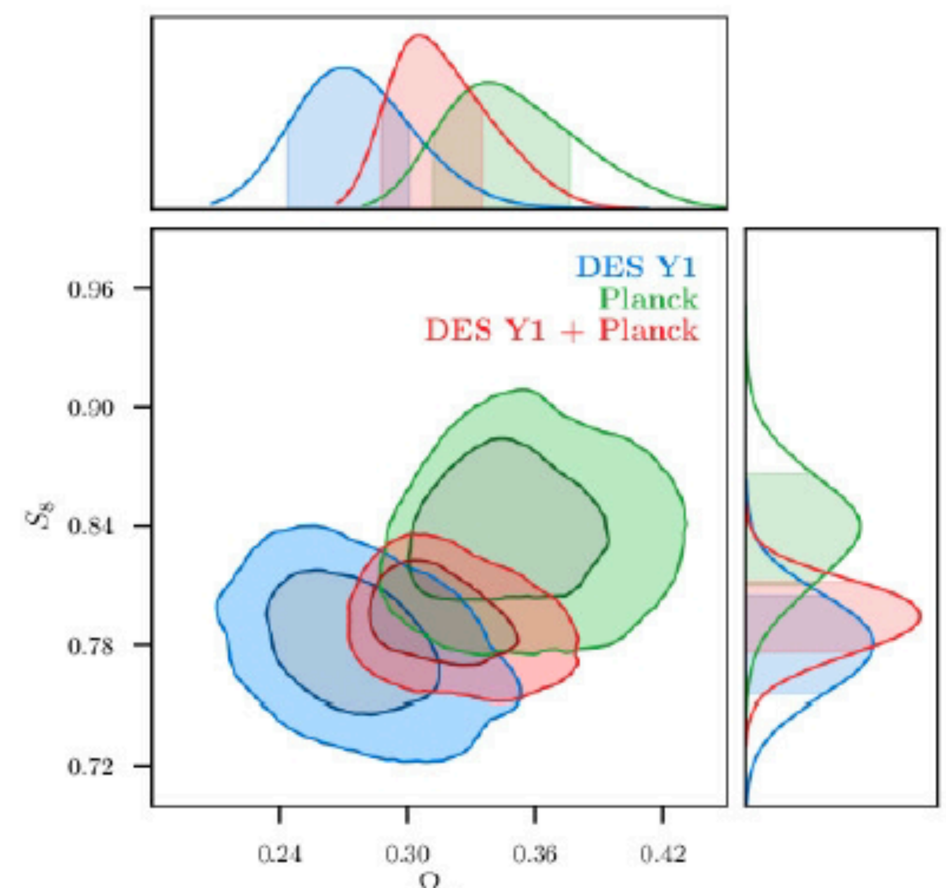
Final anticipated area: 5000 deg^2

Depth: ~ 24 (r-band)

Data collection: 2013 – 2018

Year 1 data key analysis released (~1300 square degrees). Some image-level data released, Y1 data vectors soon to follow.





Figures: DES Collaboration et al. 2017

Kilo-Degree Survey (KiDS)

Final anticipated area: 1500 deg^2

Depth: ~ 24 – 25

Data collection: 2011 - ongoing

First 450 square degrees of data public
Corresponding cosmology analysis released

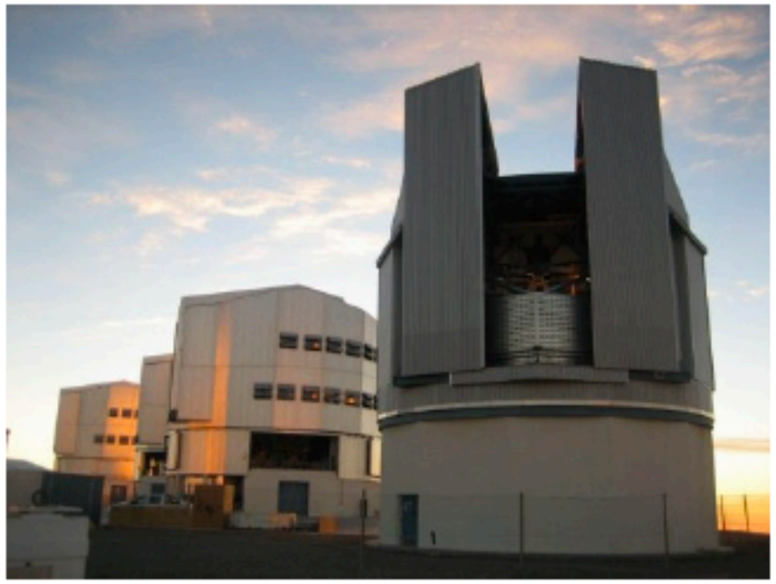
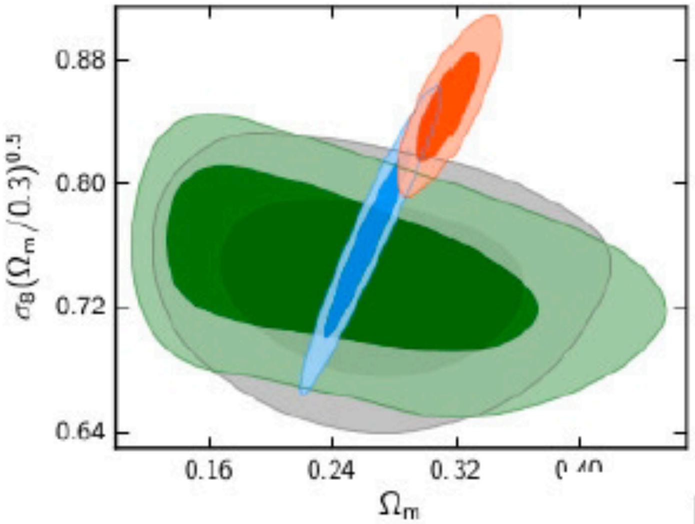
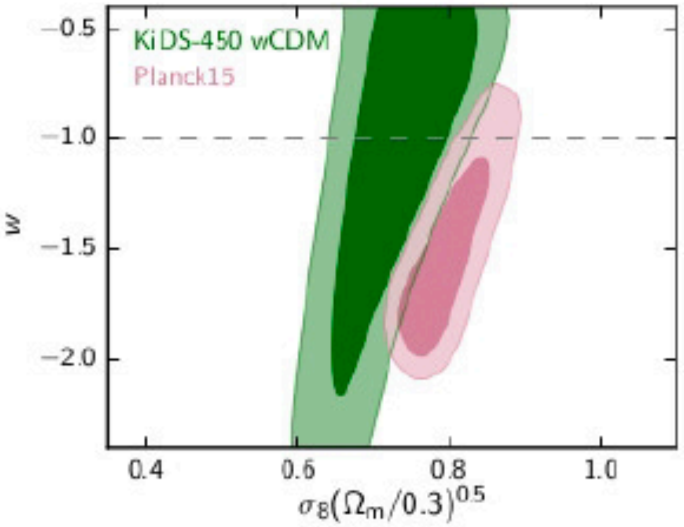
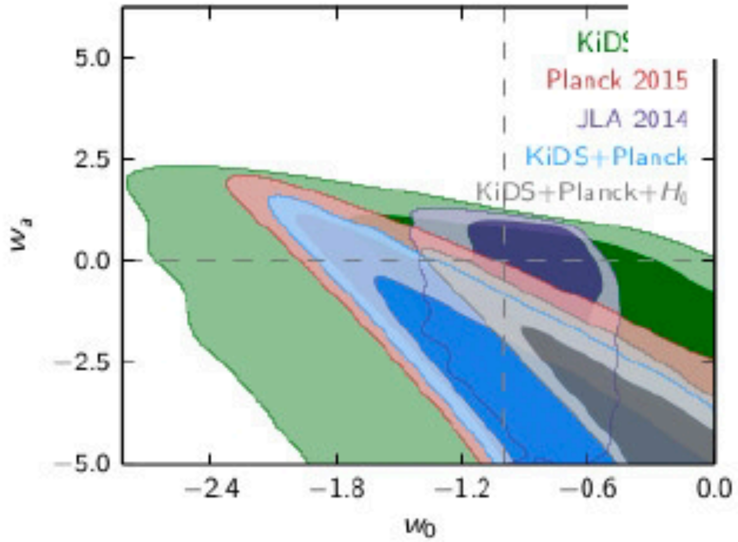
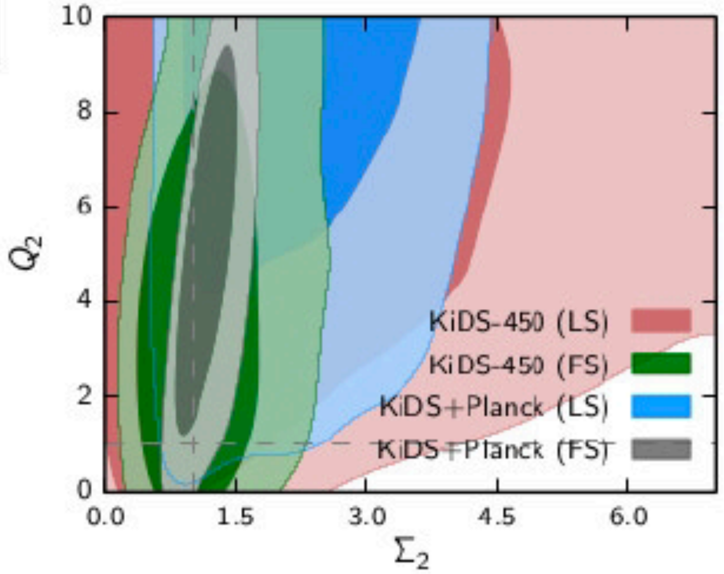


Image: kids.strw.leidenuniv.nl









Figures: Hildebrandt et al. 2017, Joudaki et al. 2017

Major upcoming lensing surveys

The Large Synoptic Survey Telescope (LSST)

Image: lsst.org

Euclid

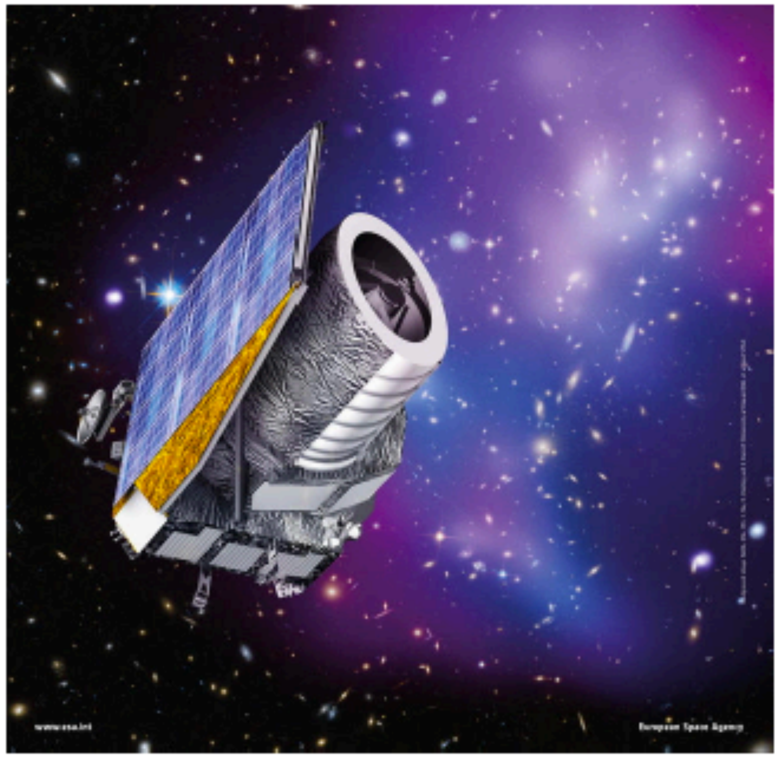


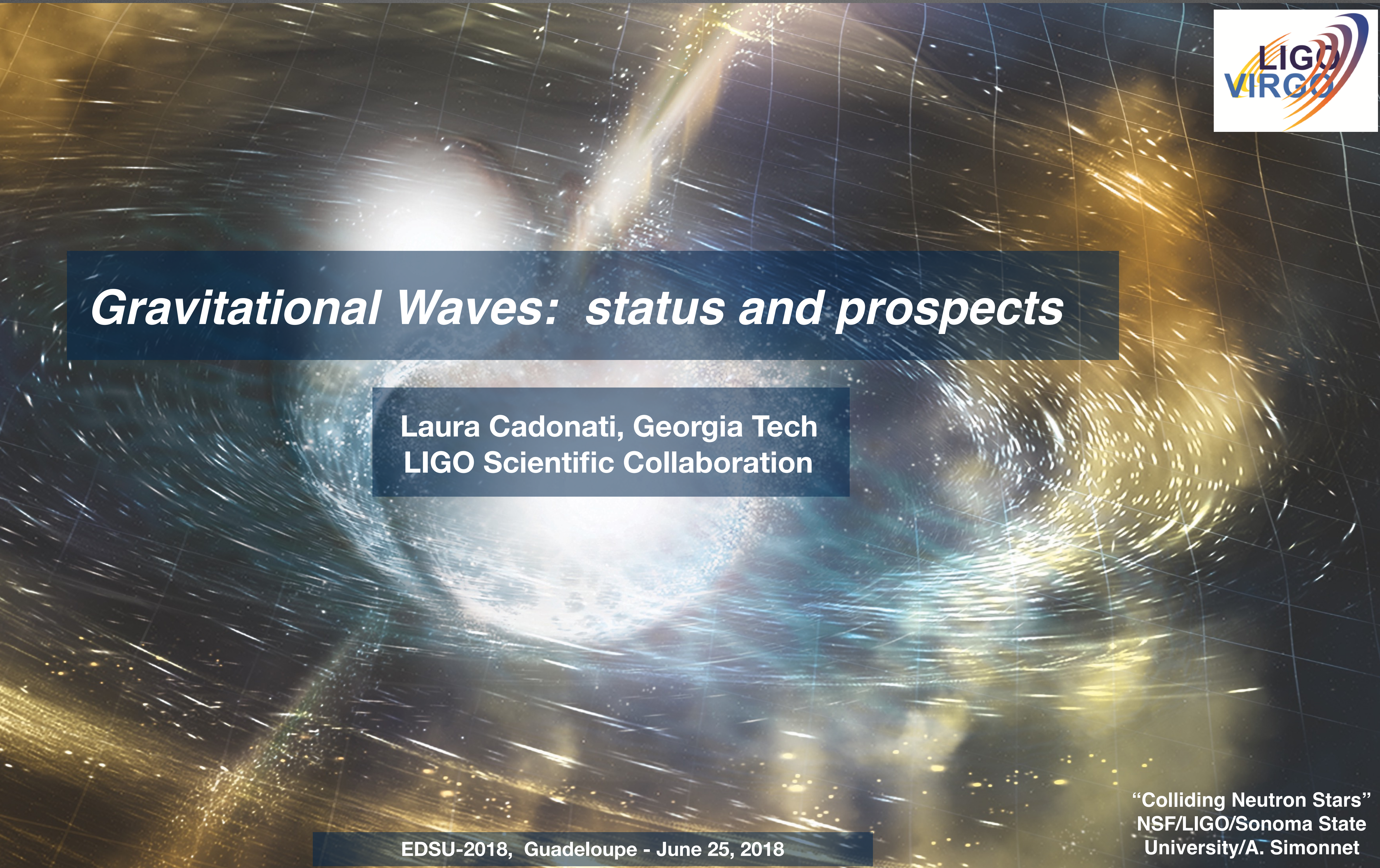
Image: ESA

The Wide Field Infrared Survey Telescope (WFIRST)

Image: Harris Corporation / TJT Photography

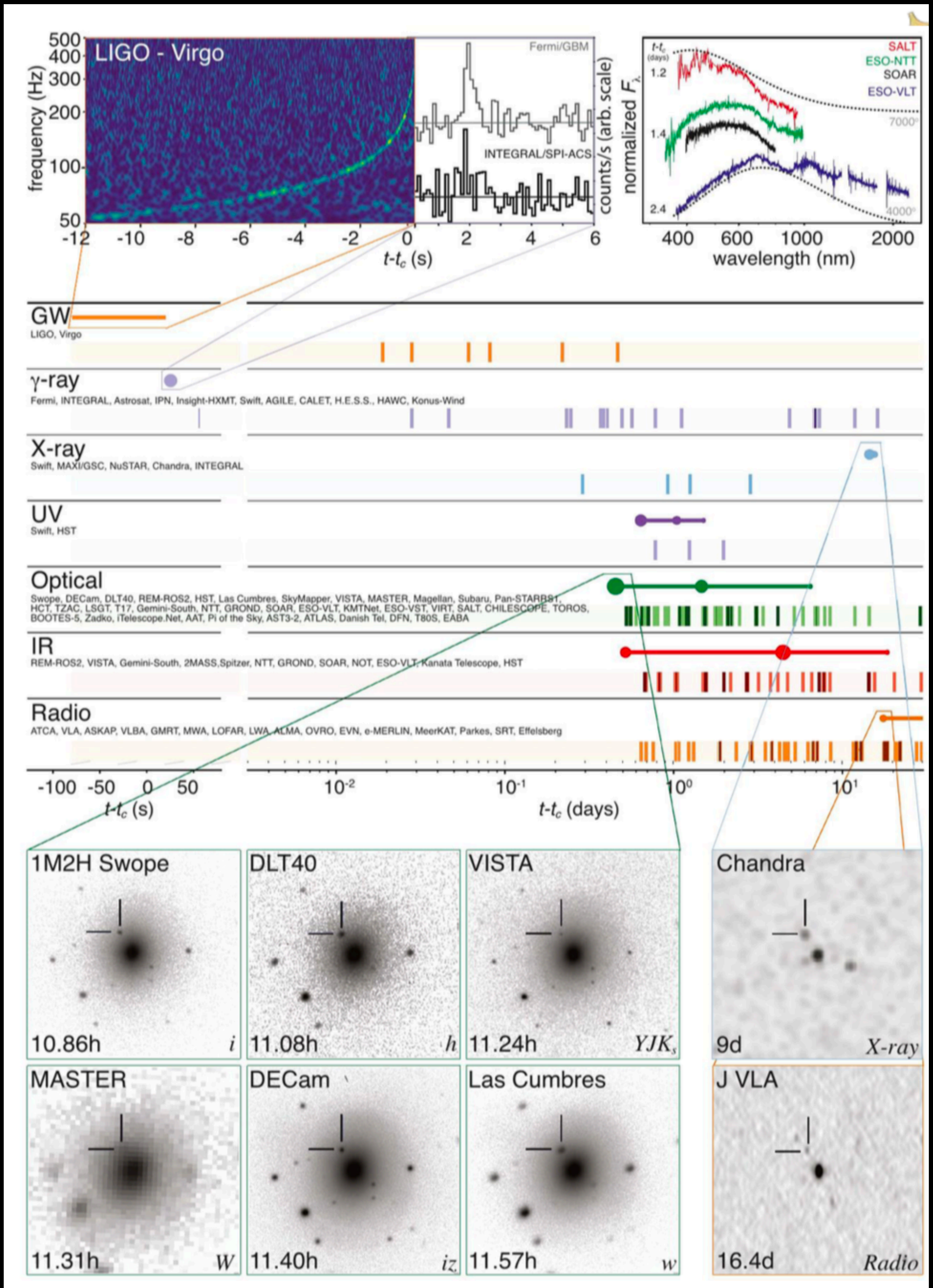
Gravitational Waves: status and prospects

Laura Cadonati, Georgia Tech
LIGO Scientific Collaboration



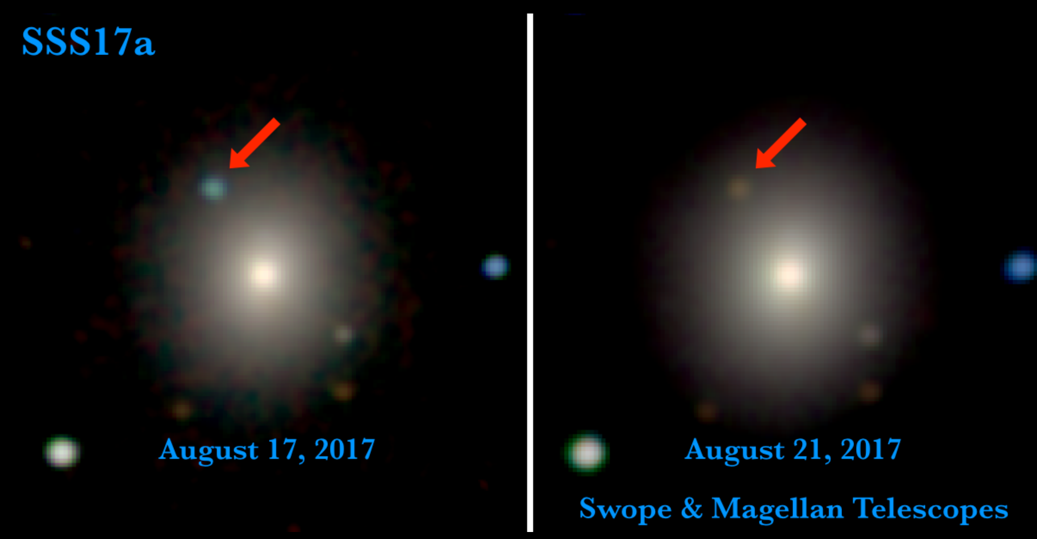
"Colliding Neutron Stars"
NSF/LIGO/Sonoma State University/A. Simonnet

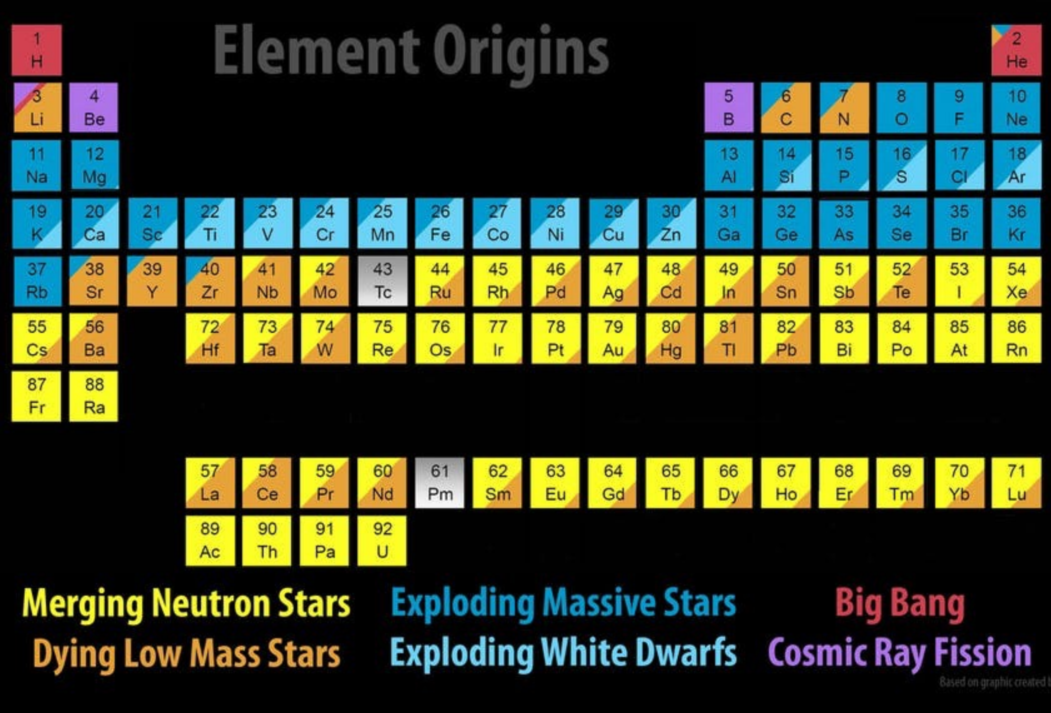
EDSU-2018, Guadeloupe - June 25, 2018



Multi-messenger Observations of a Binary Neutron Star Merger
The Astrophysical Journal Letters, 848:L12, 2017

EM Followup Campaign and discovery of a Kilonova





Theory Space: Breaking GR

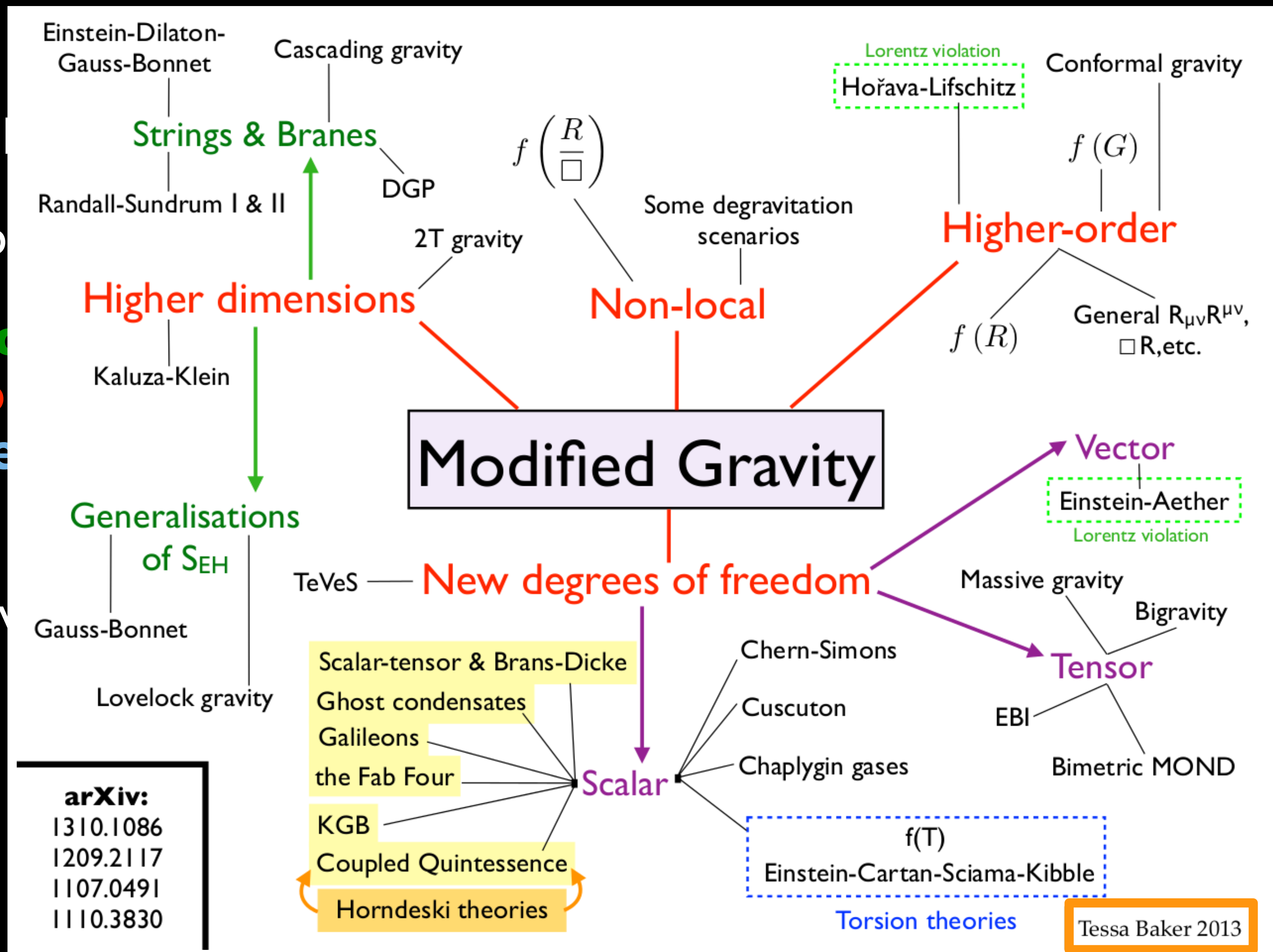
Many new l

Most can b

The only lo be derived from a fo from the metric te

theorem (1969)

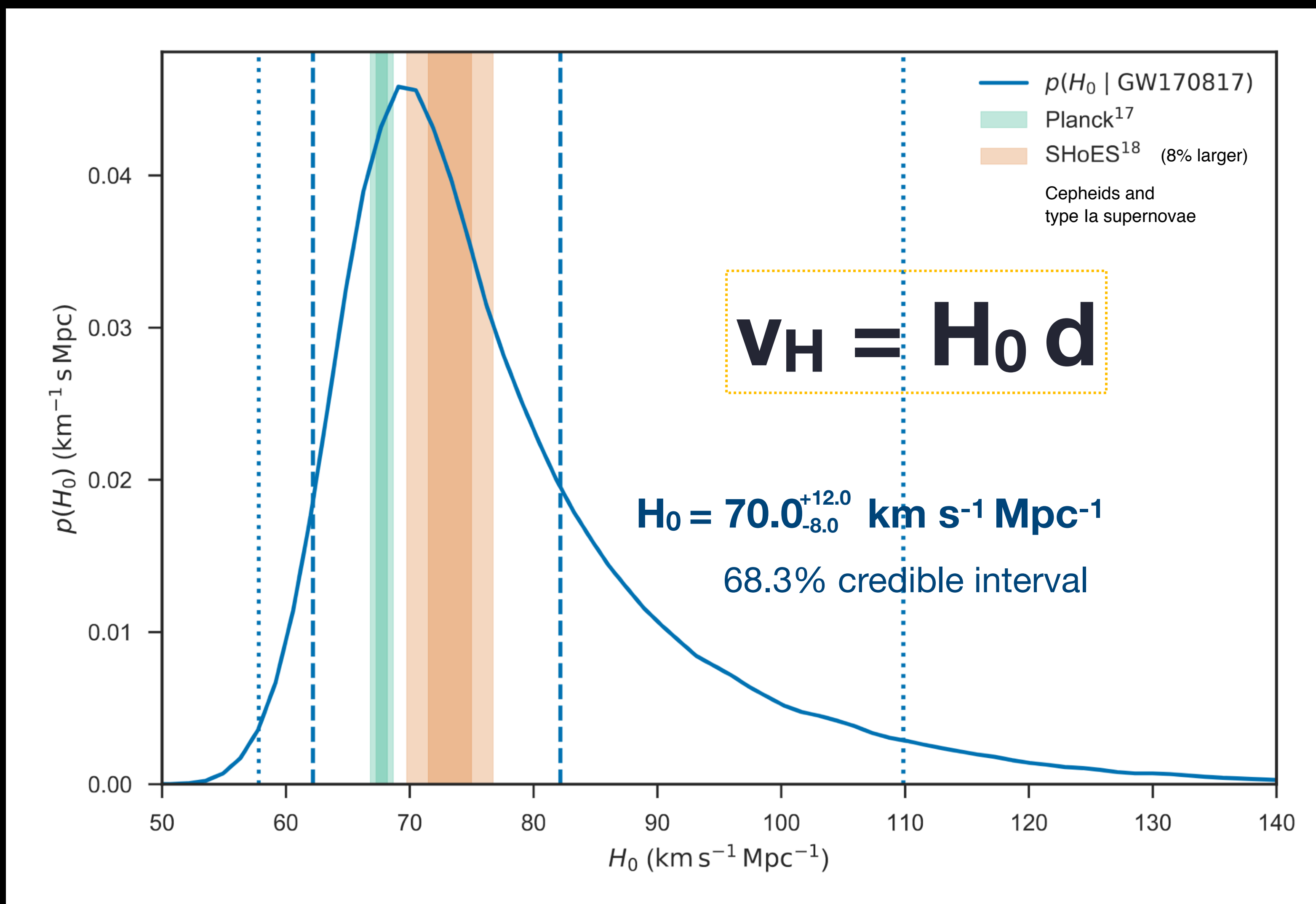
subject to v



No favored alternative theory, theory space hard to summarize succinctly

Need unifying frameworks + phenomenology to compare to data

BNS as Standard Sirens



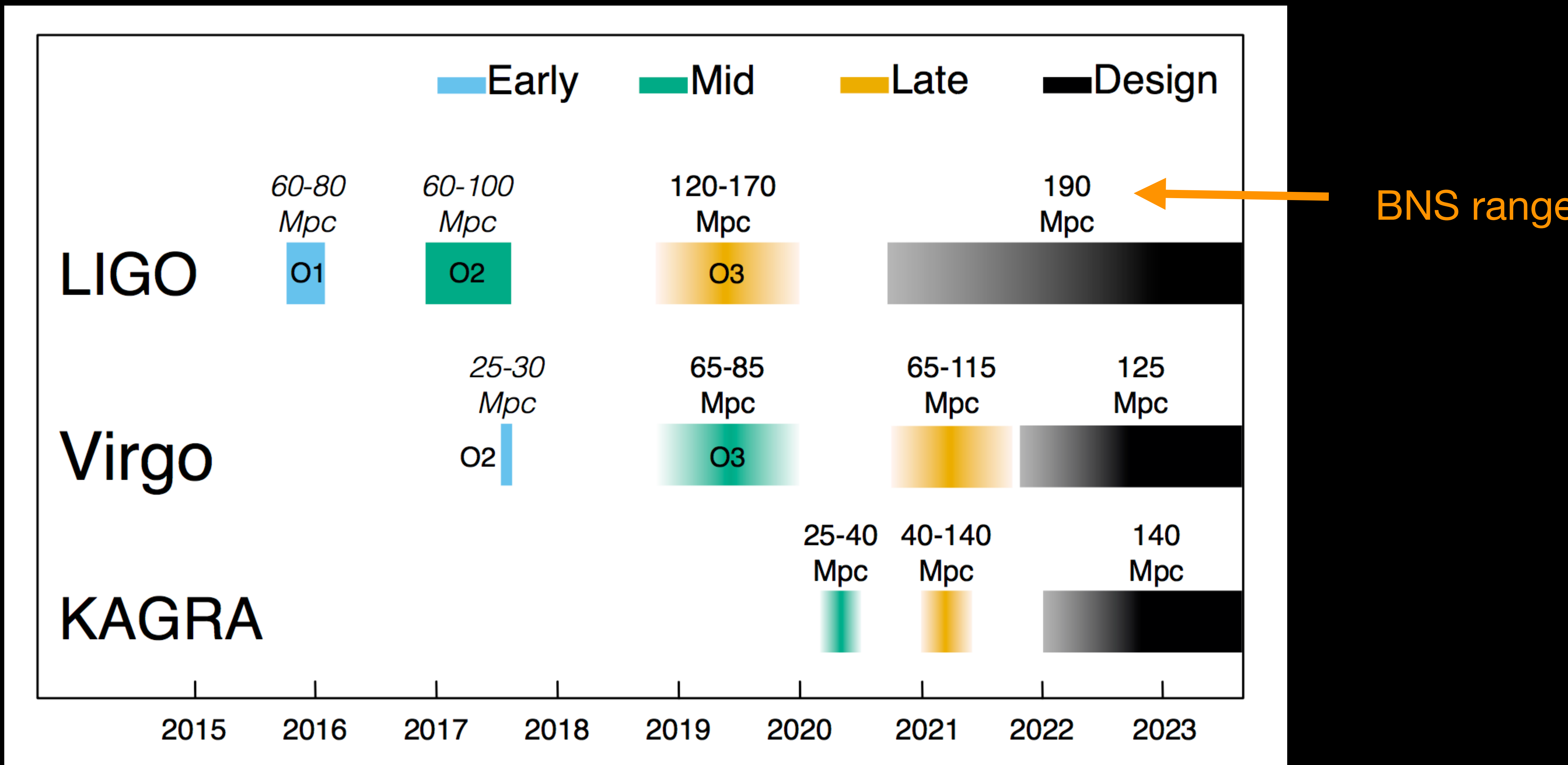
A gravitational-wave standard siren measurement of the Hubble constant
Nature, 551:85, 2017

Gravitational wave cosmology:
BNS as standard sirens to measure the rate of expansion of the Universe

v_H - local "Hubble flow" velocity of the source - Use optical identification of the host galaxy NGC 4993

d - distance to the source - Use the GW distance estimate

Observing Scenarios



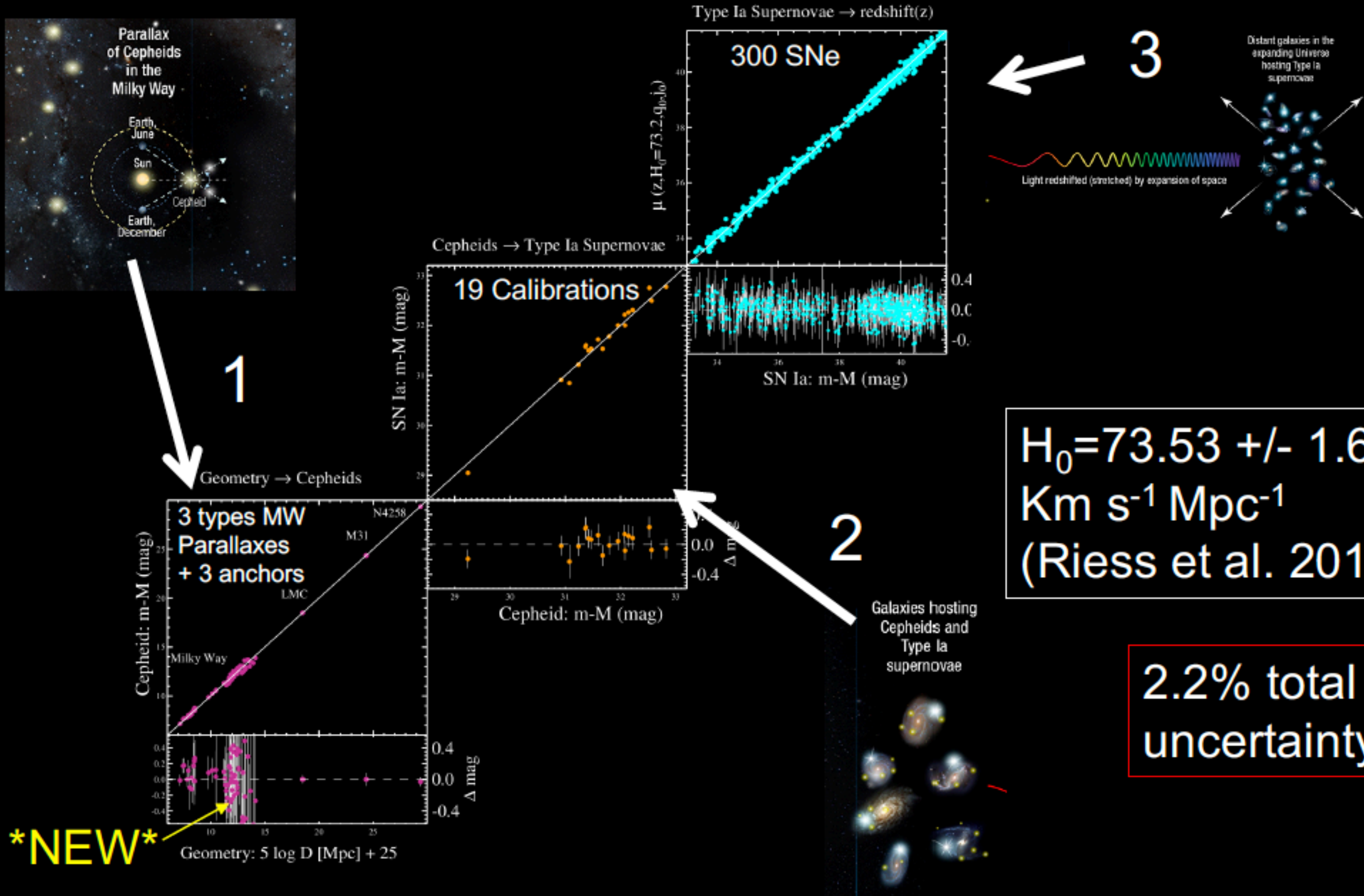
Prospects for Observing and Localizing Gravitational-Wave Transients with Advanced LIGO and Advanced Virgo and KAGRA — https://dcc.ligo.org/LIGO-P1200087/public

Johns Hopkins University
Space Telescope Science Institute

A New Measurement of the Expansion Rate of the Universe, Hints of New Physics?

SH_0ES Team

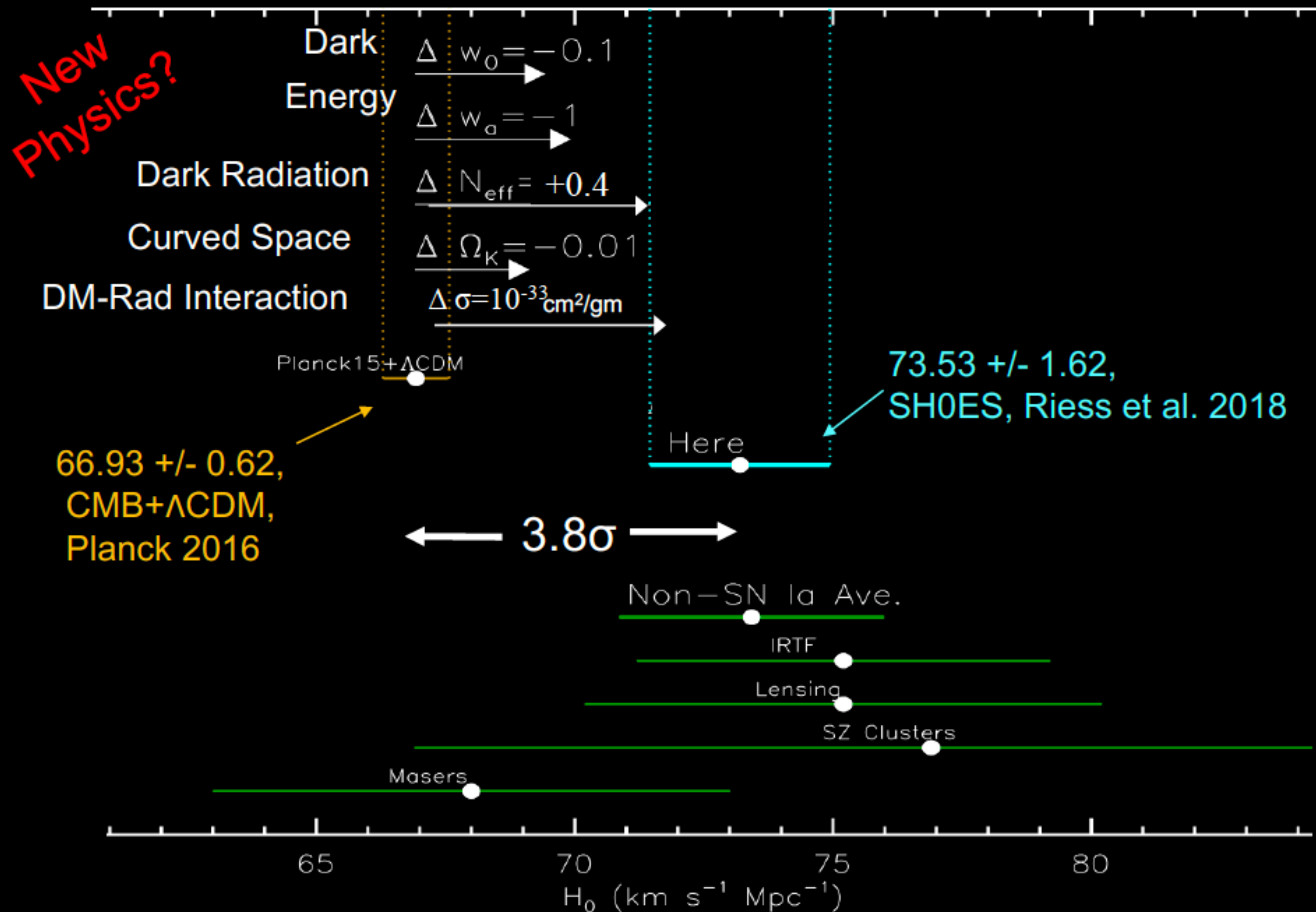
The Hubble Constant in 3 Steps: Present Data



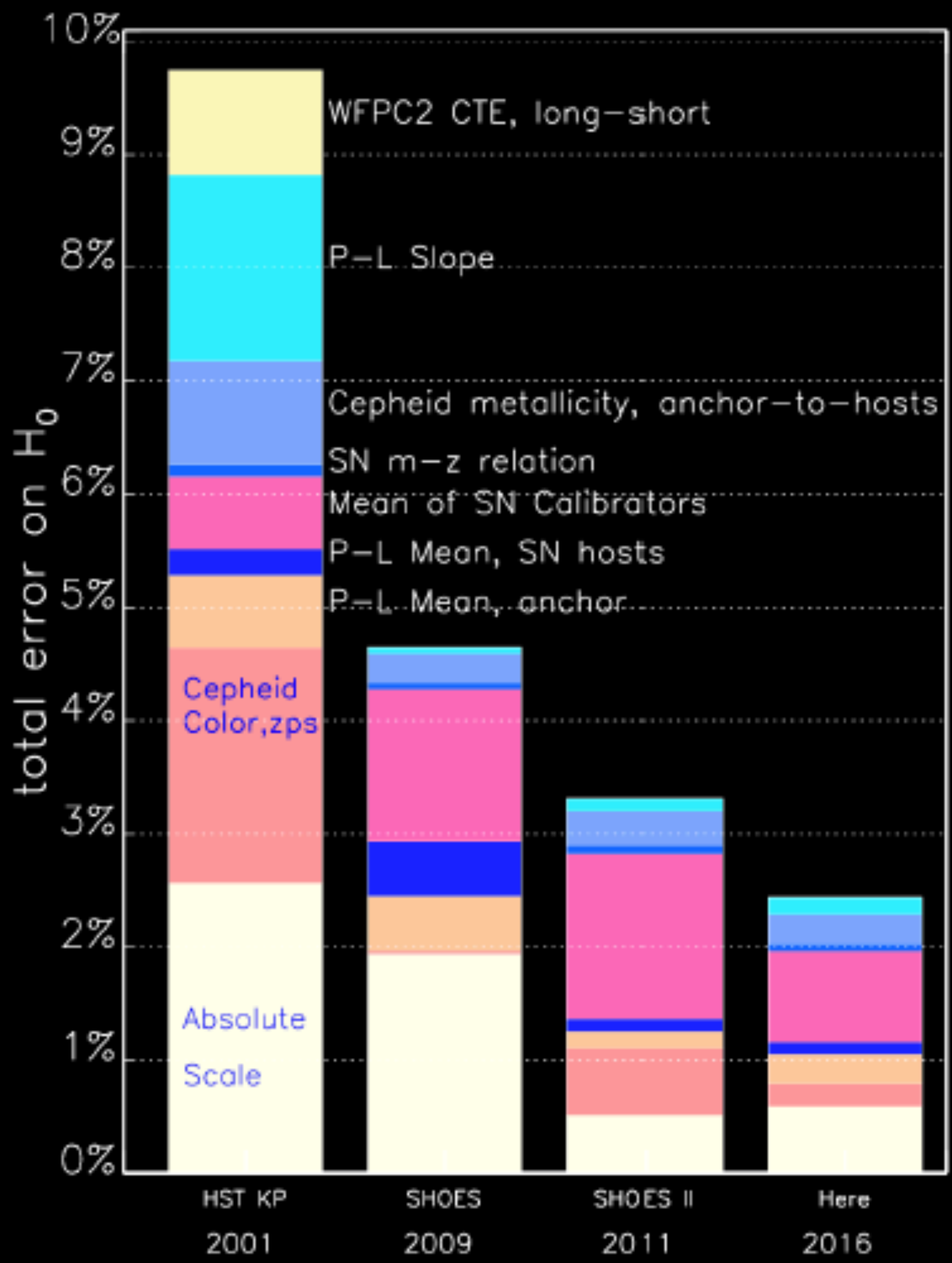
H_0=73.53 +/- 1.62, Km s^{-1} Mpc^{-1} (Riess et al. 2018)

2.2% total uncertainty

H_0, Measured vs. Predicted from Initial Conditions (CMB)



Error Budget for H_0 from 2016; 2.4% uncertainty, 2018: 2.2%



2.4% Total Uncertainty

Term		KP LMC %	R09 4258 %	R11 ALL %	R16 ALL %
Anchor distance		5.0	3.0	1.3	1.3
Cepheid reddening, zeropoints (anchor-to-hosts)		4.5	0.3	1.4	0.3
P-L slope, d log P (anchor-to-hosts)		4.0	0.5	0.6	0.5
Cepheid metallicity dependence (anchor-to-hosts)		3.0	1.1	1.0	0.5
WFPC2 CTE, long-vs-short zeropoints		3.0	–	–	–
Mean of SN Ia calibrators		2.5	2.5	1.9	1.2
Mean of P-L in anchor		2.5	1.5	0.8	0.7
Mean of P-L in SN hosts		1.5	1.5	0.6	0.4
SN Ia m-z relation		1.0	0.5	0.5	0.4
Analysis Systematics (based on 23 variants)		NA	1.3	1.1	1.0
Total, % error H_0		10	4.8	3.3	2.4

SH_0ES, Riess et al 2005: 73.0 2009: 74.2 2011: 73.8 2016: 73.2 2018: 73.5

How does this compare to the CMB measurements?

Takeaways

- Universe now appears to be expanding ~9% (+/- 2.2%) faster -than-expected based ΛCDM+Planck CMB

- There are independent checks on each measurement so, either a *conspiracy* of errors or a new feature of LCDM

- We anticipate significant improvements in these measurements in just the next few years which may reveal the cause.

- With additional measurements HST and Gaia can enable a 1% measurement of H_0, a benchmark for constraining the cosmological model.

Ask me about Gaia DR2 results.

Is Dark Energy simulated by structure formation in the Universe ?

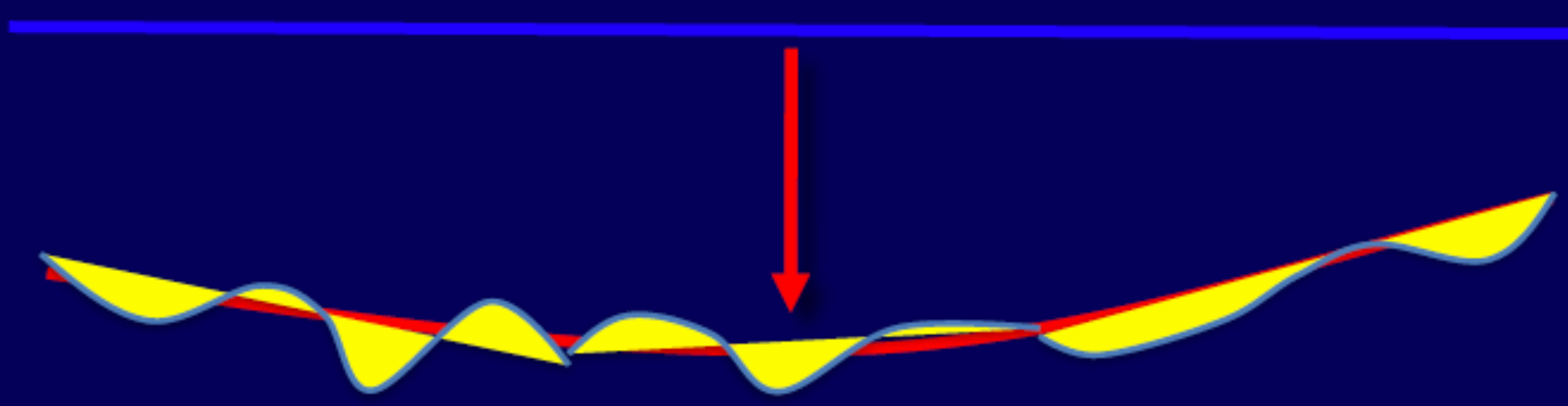
THOMAS BUCHERT

CRAL

European Research Council
Established by the European Commission

Fixed global background model

Average model may be non-perturbatively away



Background-free approach

Average model as (scale-dependent) background

Take home summary I

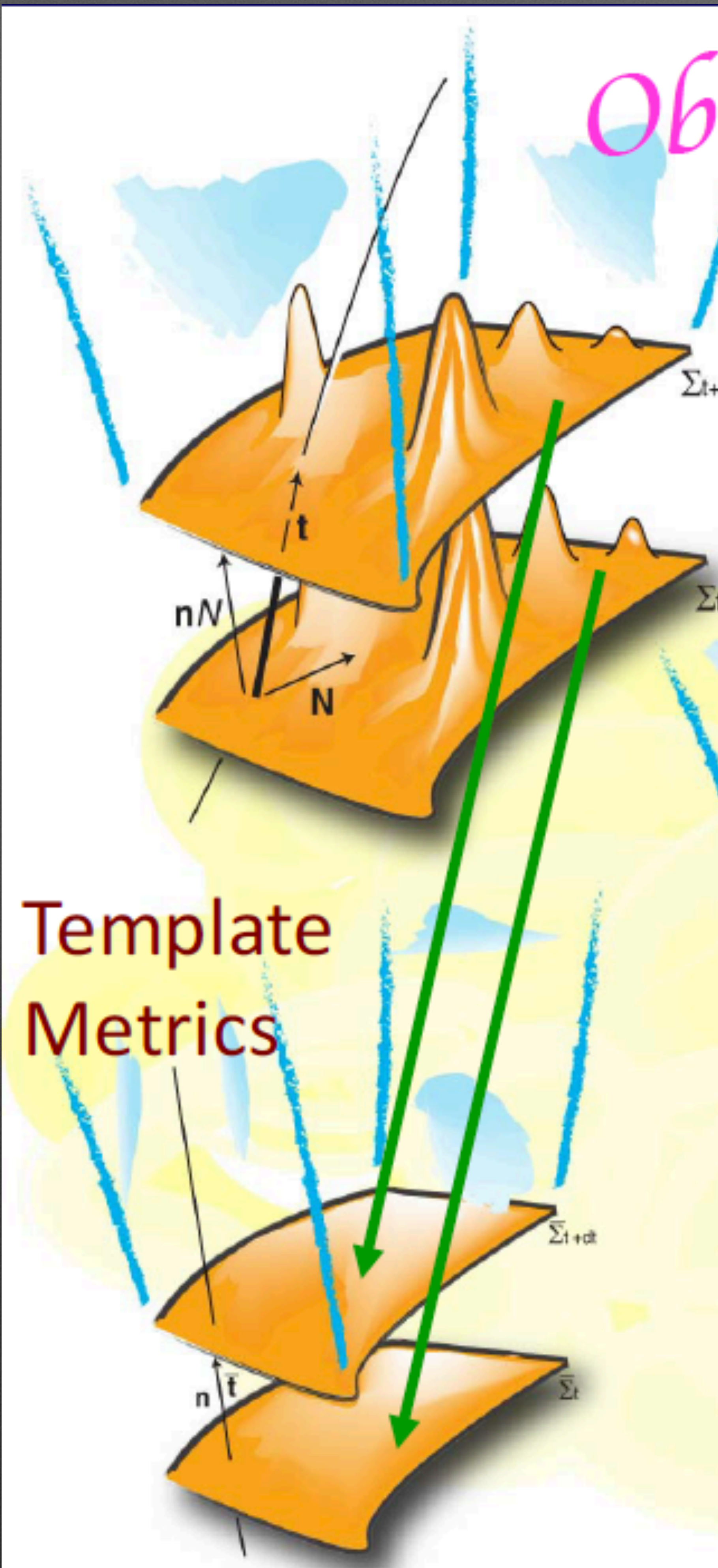
Backreaction describes the deviations of the average from an assumed homogeneous-isotropic FLRW solution

Backreaction arises when the fluctuations are allowed to determine the dynamics of the average model
Structures ‘talk‘ to the ‘background‘

Backreaction arises from inhomogeneities in geometry

Backreaction can be described as an effective scalar field

Observational Strategies

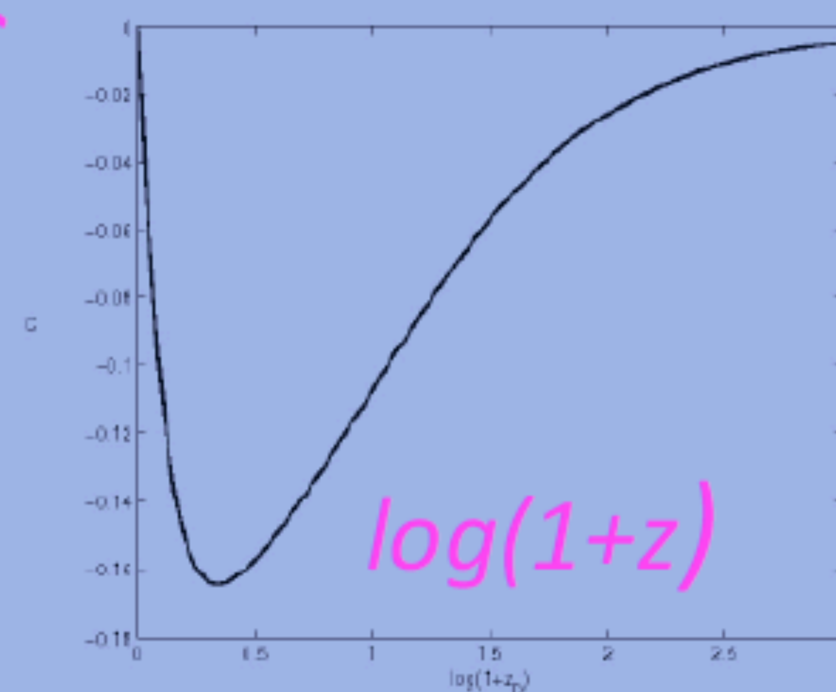


Template Metrics

- $C(z) = 1 + H^2(DD'' - D'^2) + HH'DD'$ with $D \equiv (1+z)d_A$ is identically zero for FRW, different from 0 otherwise [C. Clarkson & al, arXiv:0712.3457]
- In our models:

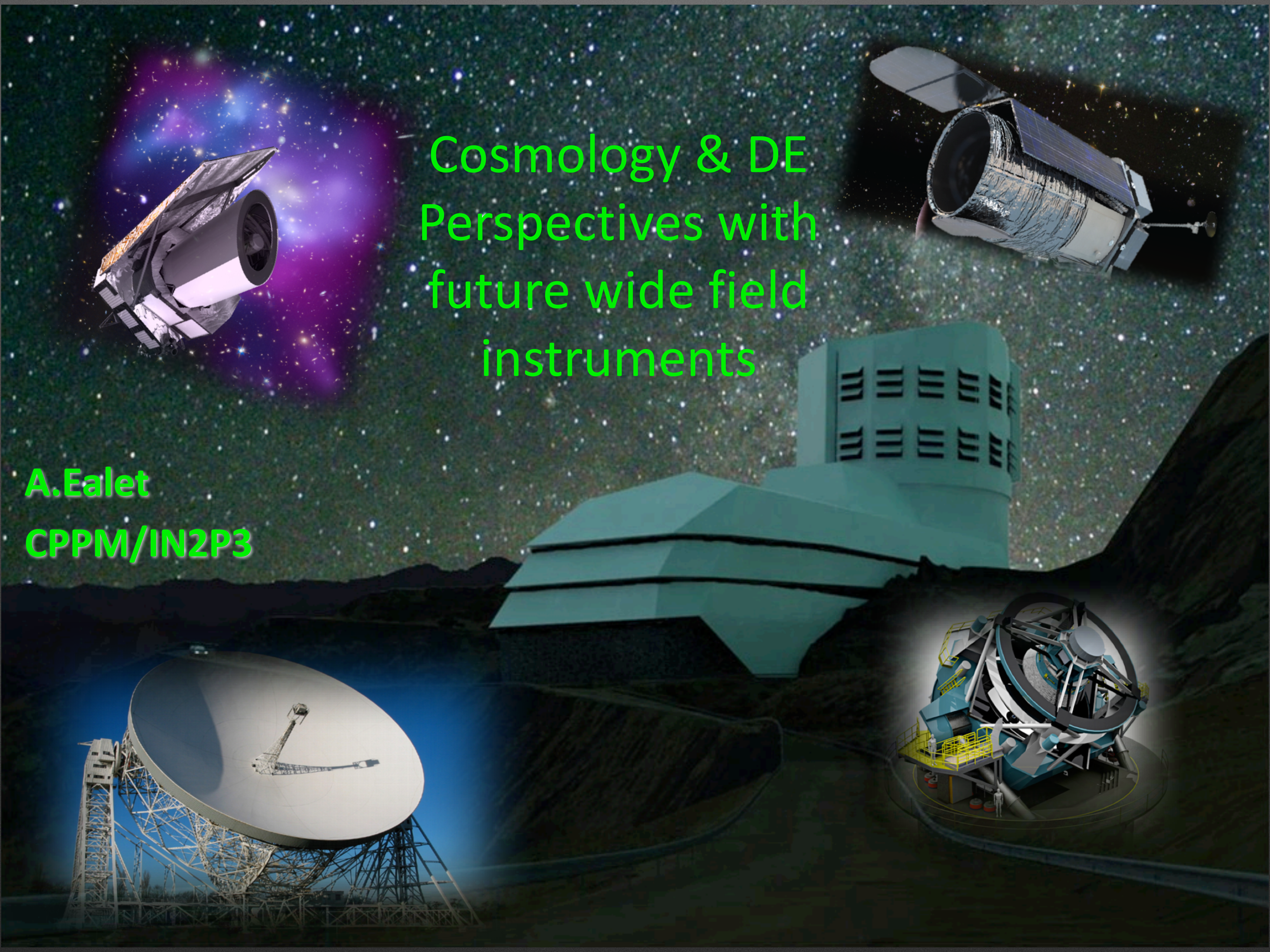
$$C(z_{\mathcal{D}}) = -\frac{H_{\mathcal{D}}(z_{\mathcal{D}})r(z_{\mathcal{D}})\kappa'_{\mathcal{D}}(z_{\mathcal{D}})}{2H_{\mathcal{D}_0}\sqrt{1-\kappa_{\mathcal{D}}(z_{\mathcal{D}})r^2(z_{\mathcal{D}})}} .$$

- Testable prediction of the model.
- Can allow to make the difference with a quintessence field with the same n.

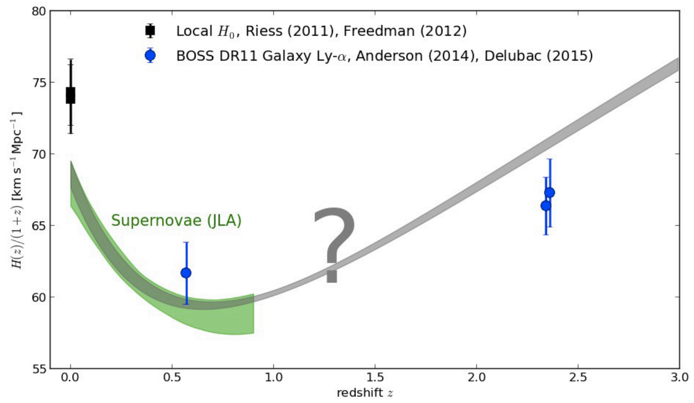


Larena, Alimi, Buchert, Kunz, Corasaniti arXiv: 0808.1161

Euclid


Cosmology & DE Perspectives with future wide field instruments
A.Ealet
CPPM/IN2P3

The goal : COMBINING ….



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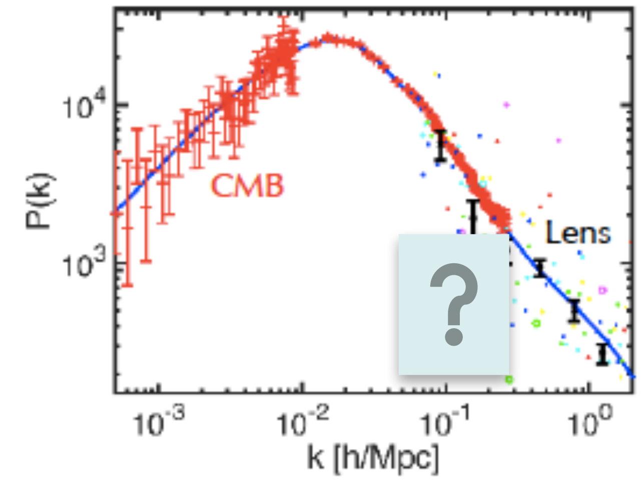
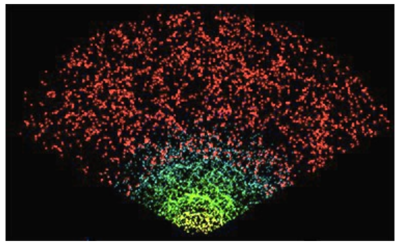


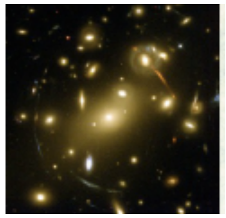
Supernovae : distance.

Photometry
Multi bands



Clustering /Large scale structure (LSS) (BA0, RSD…)
distance + ordinary matter power spectrum
+ growth of structures

Spectroscopy
Redshift survey



Weak gravitational shear.
distance + dark matter power spectrum,
growth of structure

Imaging
Photometry

Galaxy cluster / Voids
count, power spectrum

Photometry+
spectroscopy

DE strategy for > 2020 multi probes and multi projects

Goal → -reduce by **1 order of magnitude the errors on DE equation of state.**

-distinguish from modified gravity

Method → **Large sky Surveys & deep (24-27 mag)**

Key issue → **Systematic Errors**

→ **Combining probes**

Observables →

- **Galaxy Clustering : BAO,RSD,growth**
- **Weak Lensing : growth of structure**
- **Supernovae : standard candle**
- **Cluster counts /voids .....**

- **H1 survey mapping**

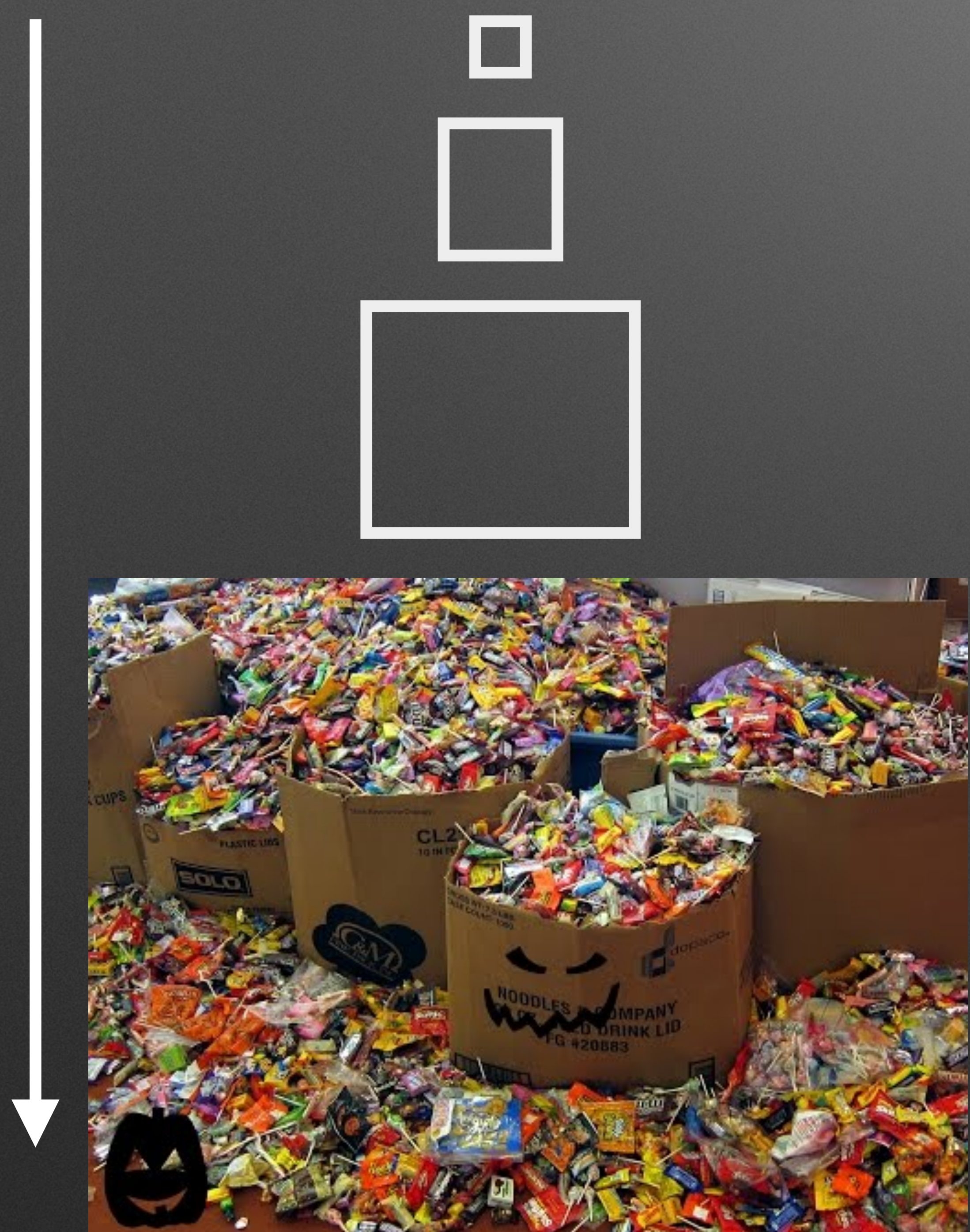
Large US ground Project
DESI

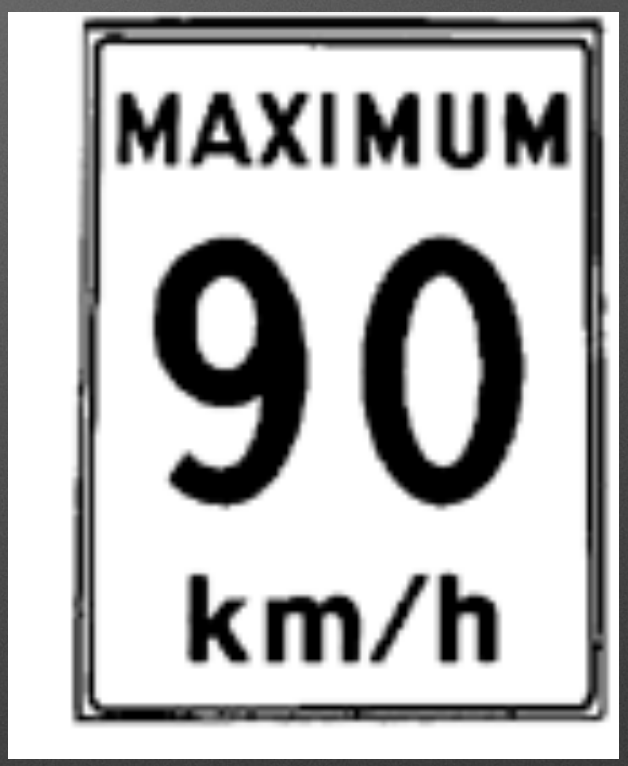
A large europeen
space Project selected:
EUCLID.

Large US ground Project
LSST (photo)

A large europeen network of
radio antenna
SKA

We also learned that Andrei Linde is an incredible powerful person who can



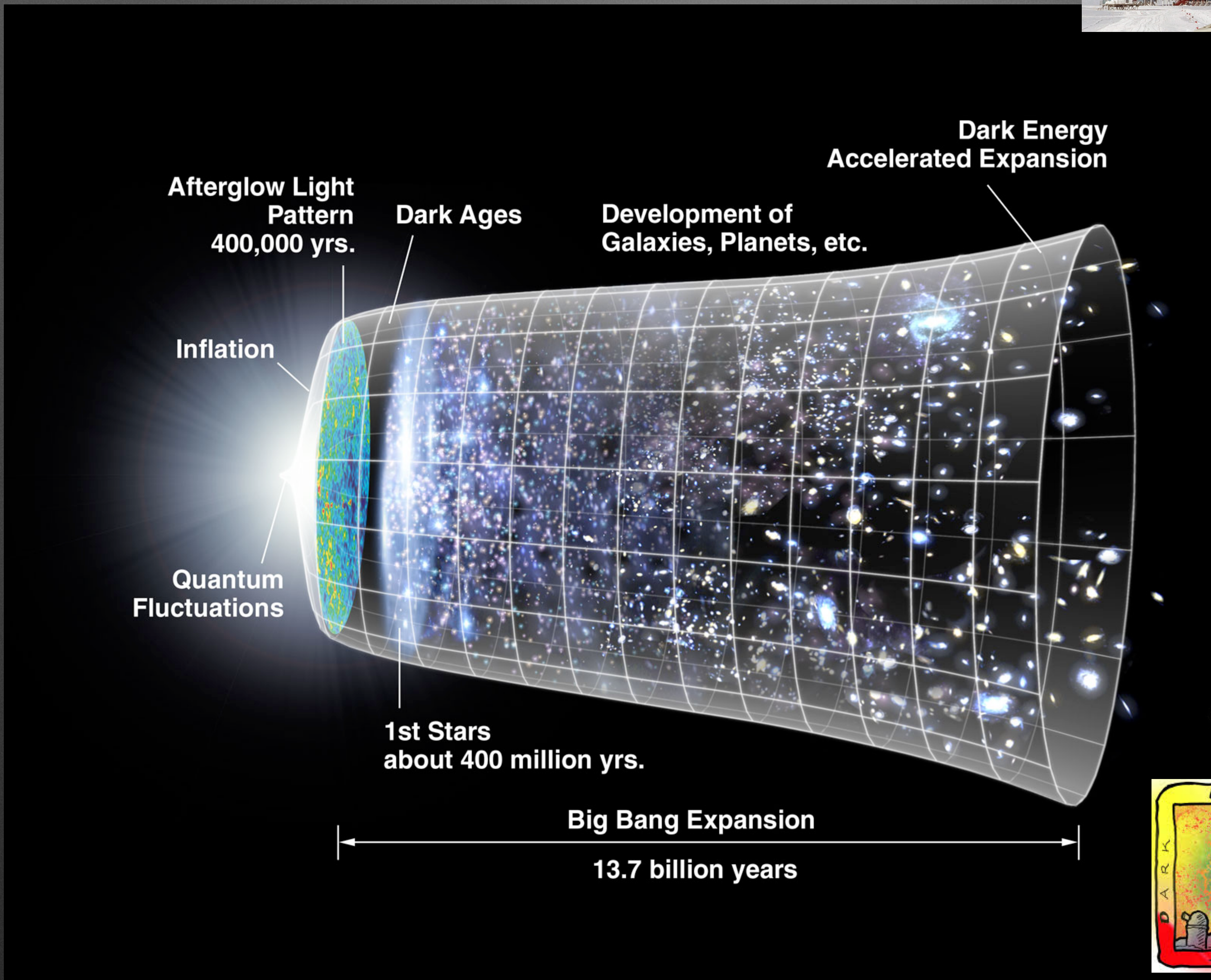


Big Bang universe at the Planck time and density

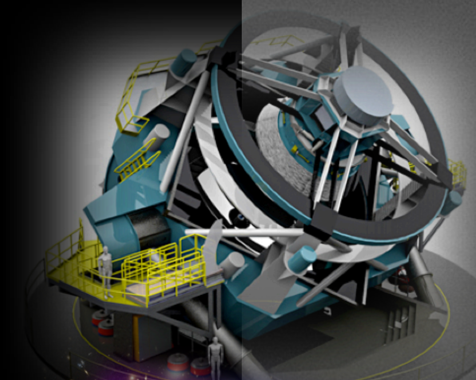
In quantum gravity it is very convenient to use system of units where

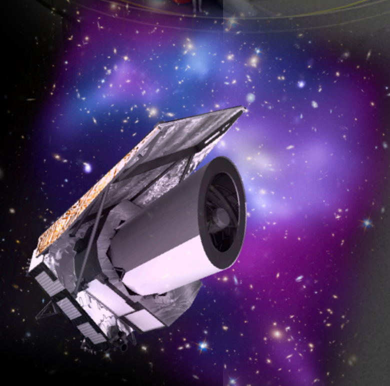
$$c = \hbar = G = 1$$

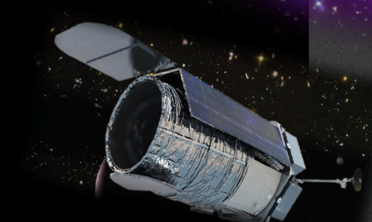
The Future


Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Dark Energy
Accelerated Expansion
Inflation
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years


CMB-S4
Next Generation CMB Experiment



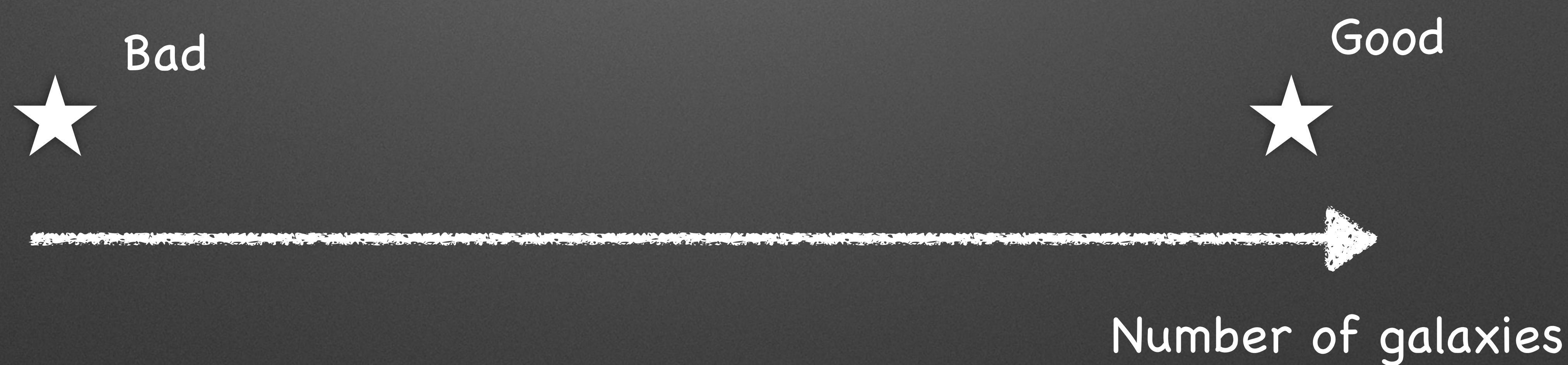




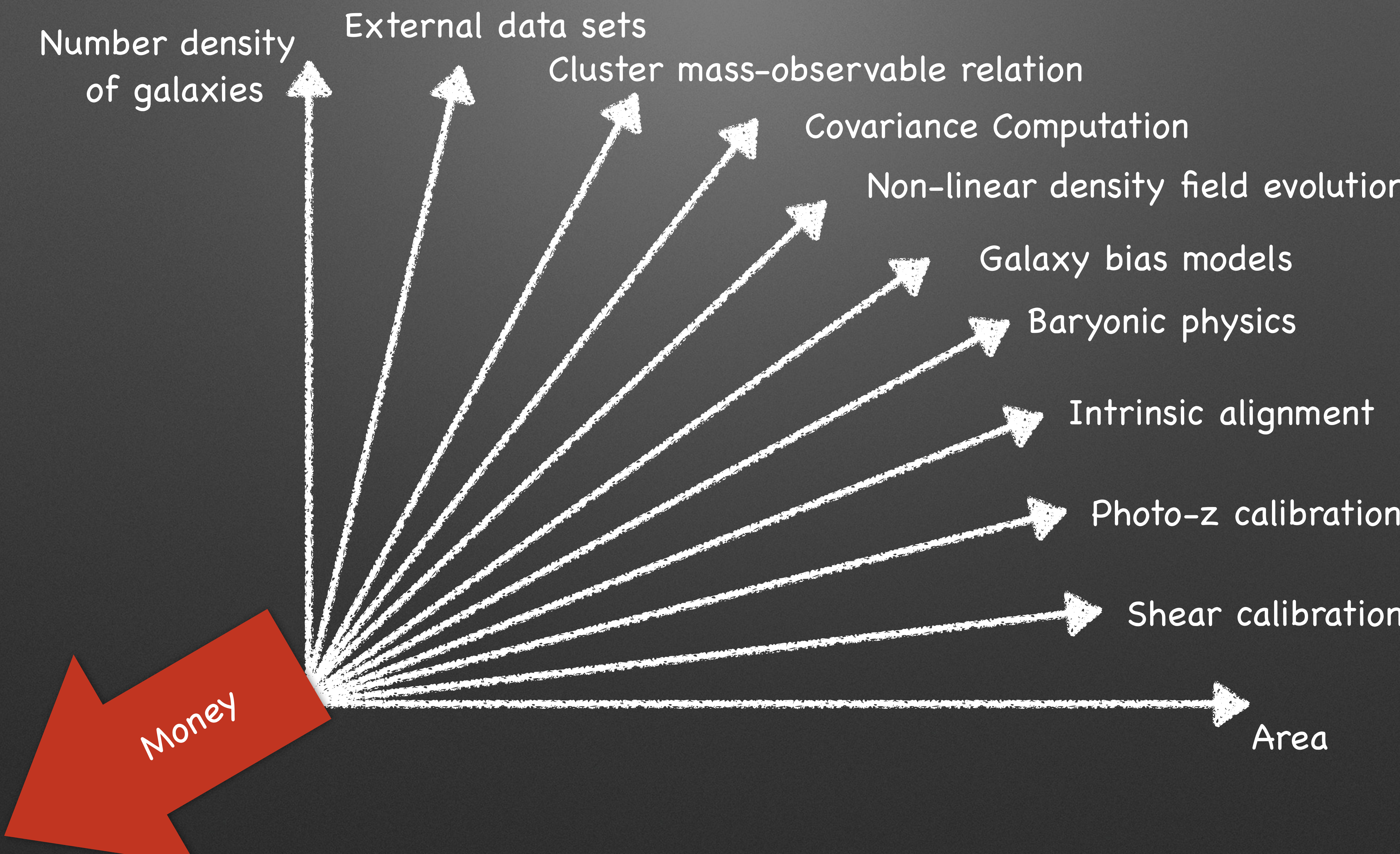

DARK
ENERGY
SPECTROSCOPIC
INSTRUMENT

Past Survey Optimization

(Galaxy surveys)

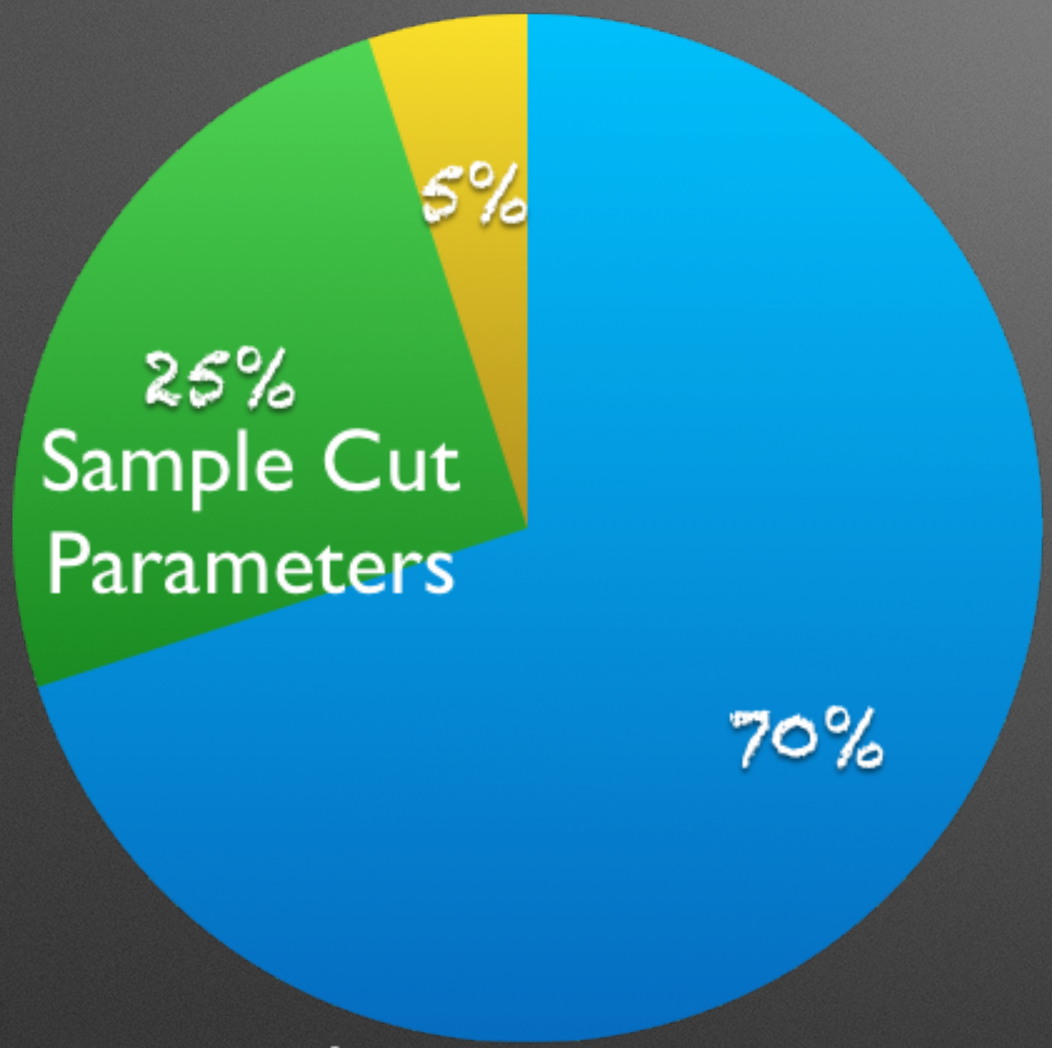


Today's Survey Optimization
(Galaxy surveys)



Work Effort Pie Chart

Cosmology Parameters



"Systematics Parameters"

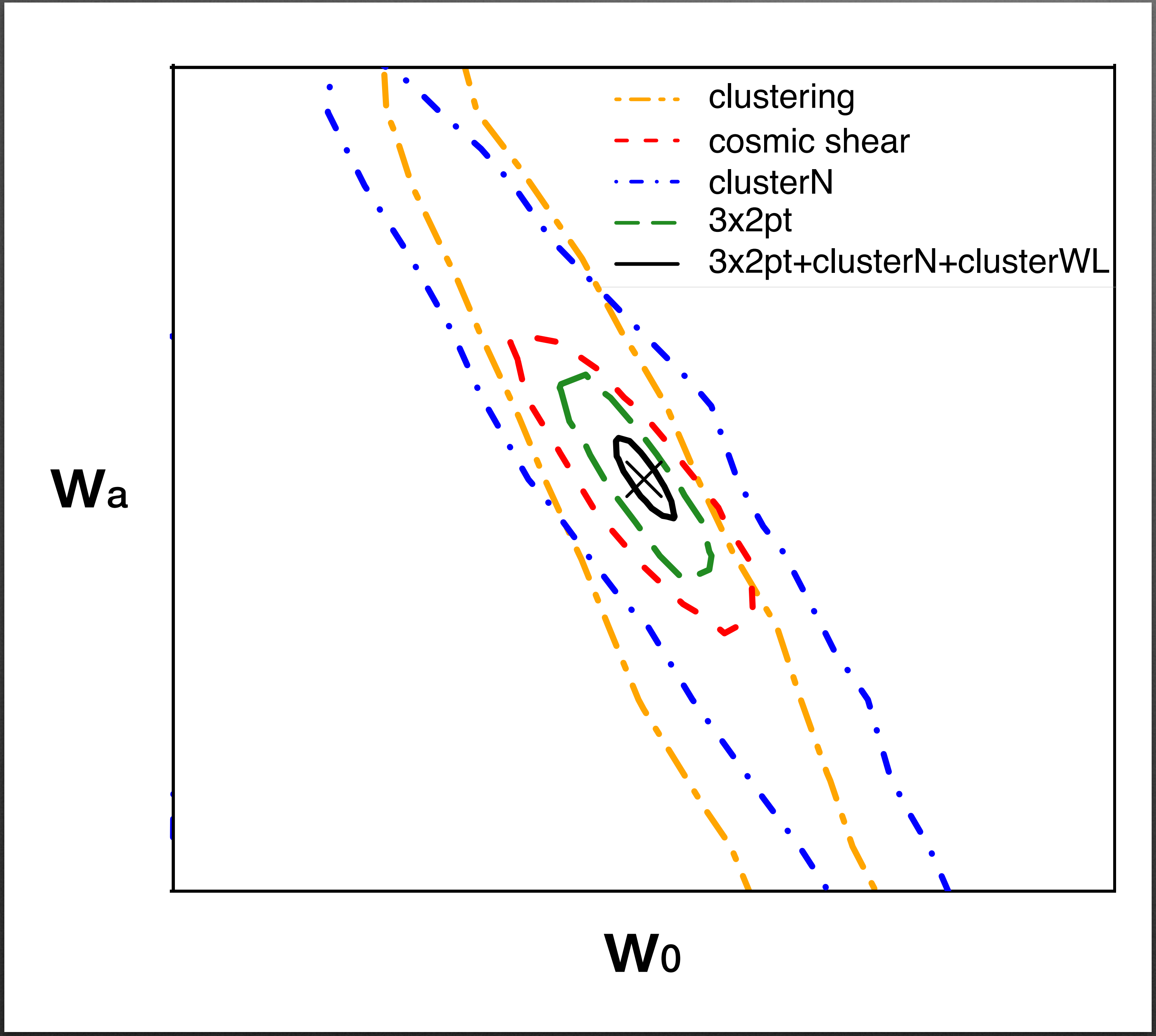
- observational systematics
  - survey specific
- astrophysical systematics
  - observable + survey specific

sample cuts + systematics highly interconnected
95% systematics…

-> multi-probe cosmology + external data is the way to go

Why are we still optimistic about future dark energy endeavors?

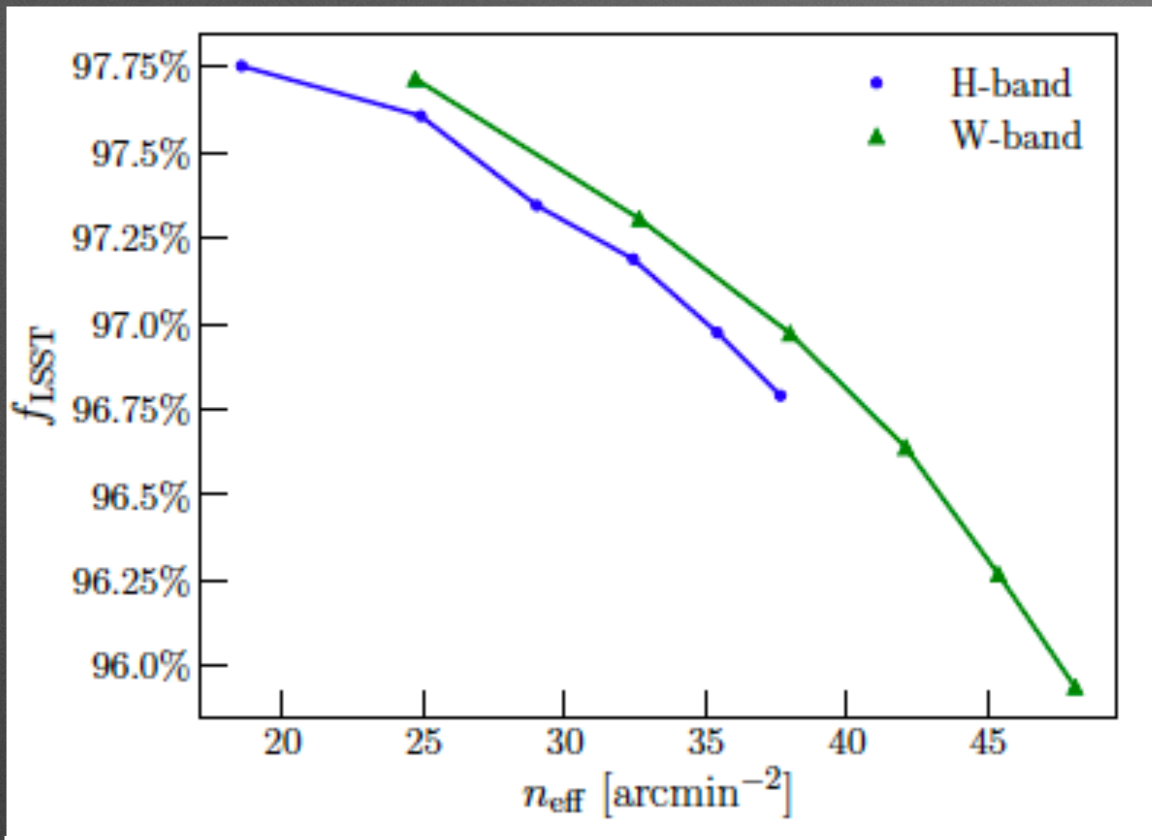
Optimism 1: Multiple Probes

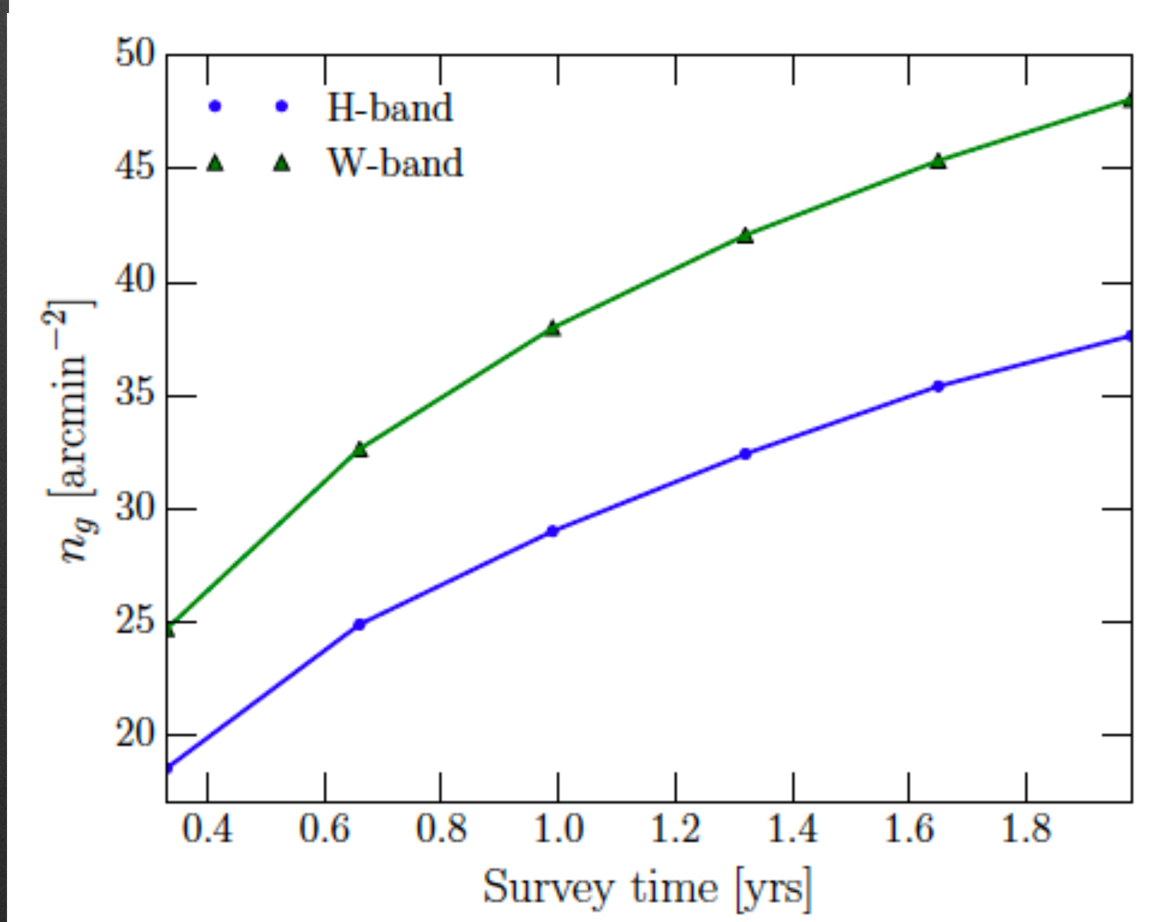


Realistic LSST likelihood analysis

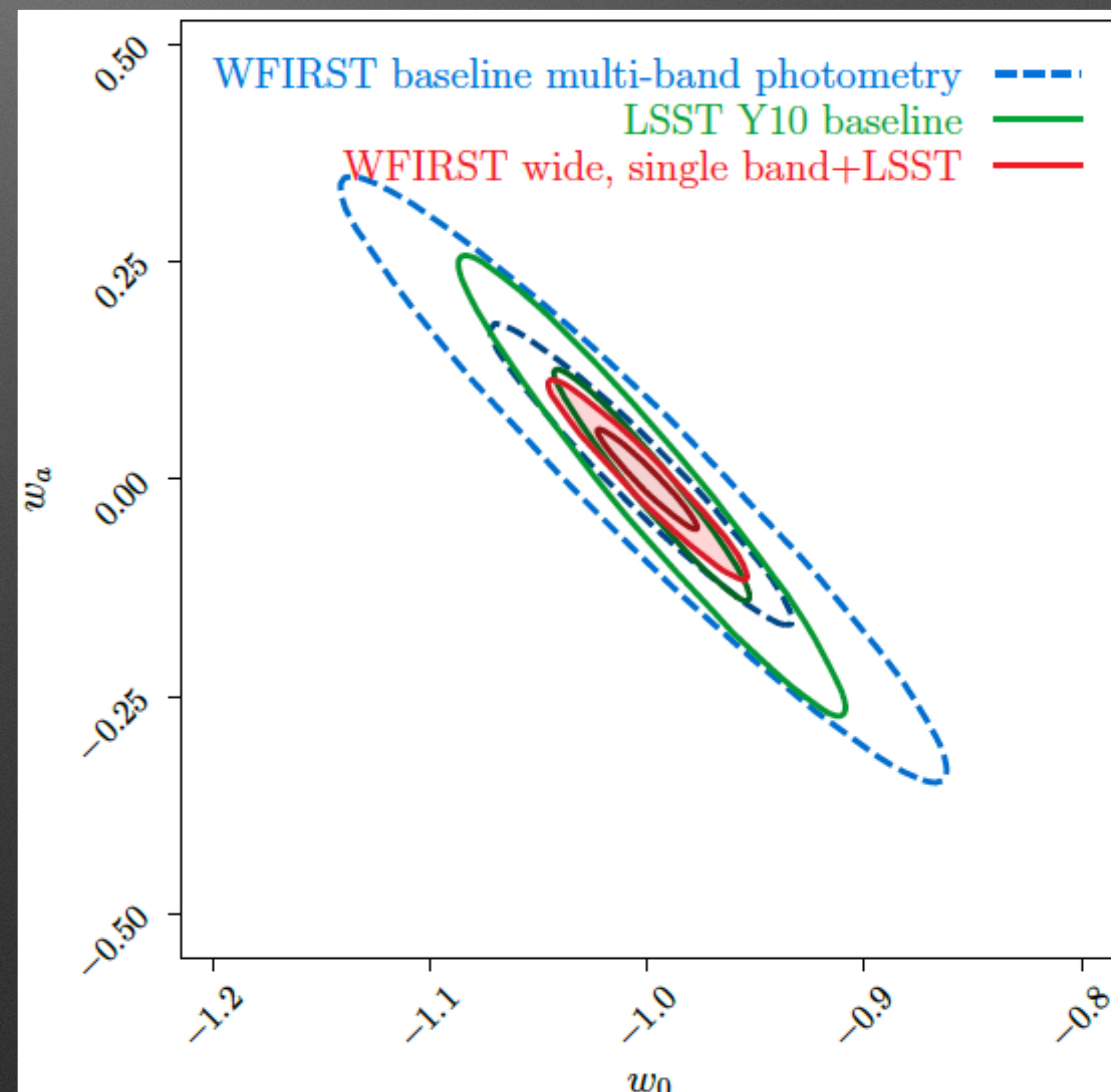
7 cosmological parameters
49 nuisance parameters

Optimism 2: Multi-Survey





Possible WFIRST extension of 1.6 years overlapping with LSST



Is there a failure mode where we find the equivalent to the Higgs and nothing else?

Not really,

- We improve existing constraints on LCDM by an order of magnitude
- We map the Universe at unprecedented depth, image quality, and speed (transients)
- Strong synergies with gravitational wave detection, CMB experiments
- Exciting results for galaxy formation and astrophysics,
- It’s not about “w”… it’s about understanding the universe as a whole


Thank you!