THE DARK ENERGY SURVEY

H0 Tension from the viewpoint of the Dark Energy Survey

Dillon Brout

2019 Einstein Fellow

Univ. of Pennsylvania

KITP Tensions between the Early and the Late Universe

July 17th 2019

Penn

University of Pennsylvania

NASA

Fermilab

THE DARK ENERGY SURVEY

DECam 570 Megapixels

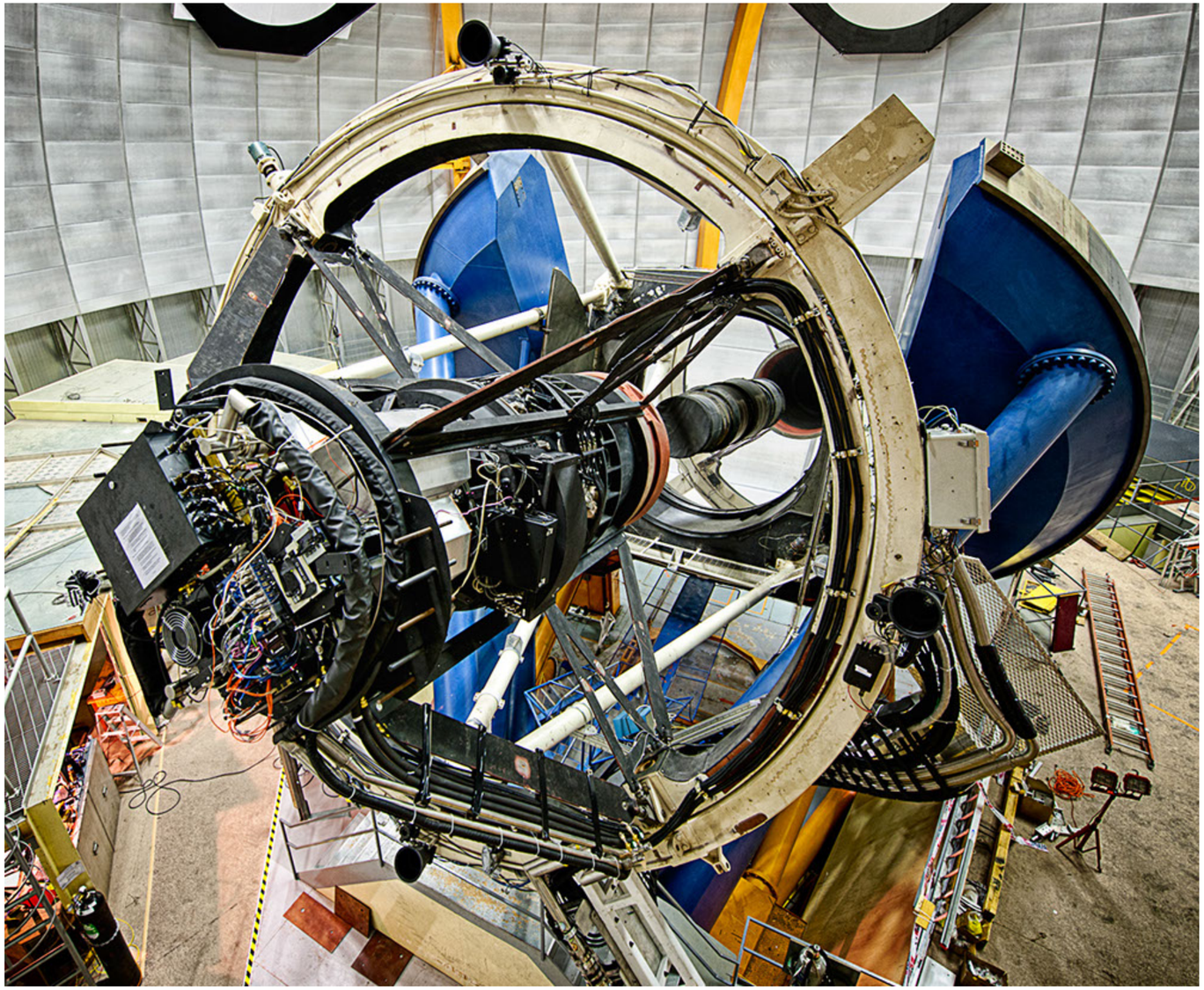
5000 Sq Degree Wide Survey

30 Sq Degree Transient Survey

DES 2013-2019 (758 nights)

>25,000 Transients

DR1: 300M galaxies, 39k exposures



www.darkenergysurvey.org

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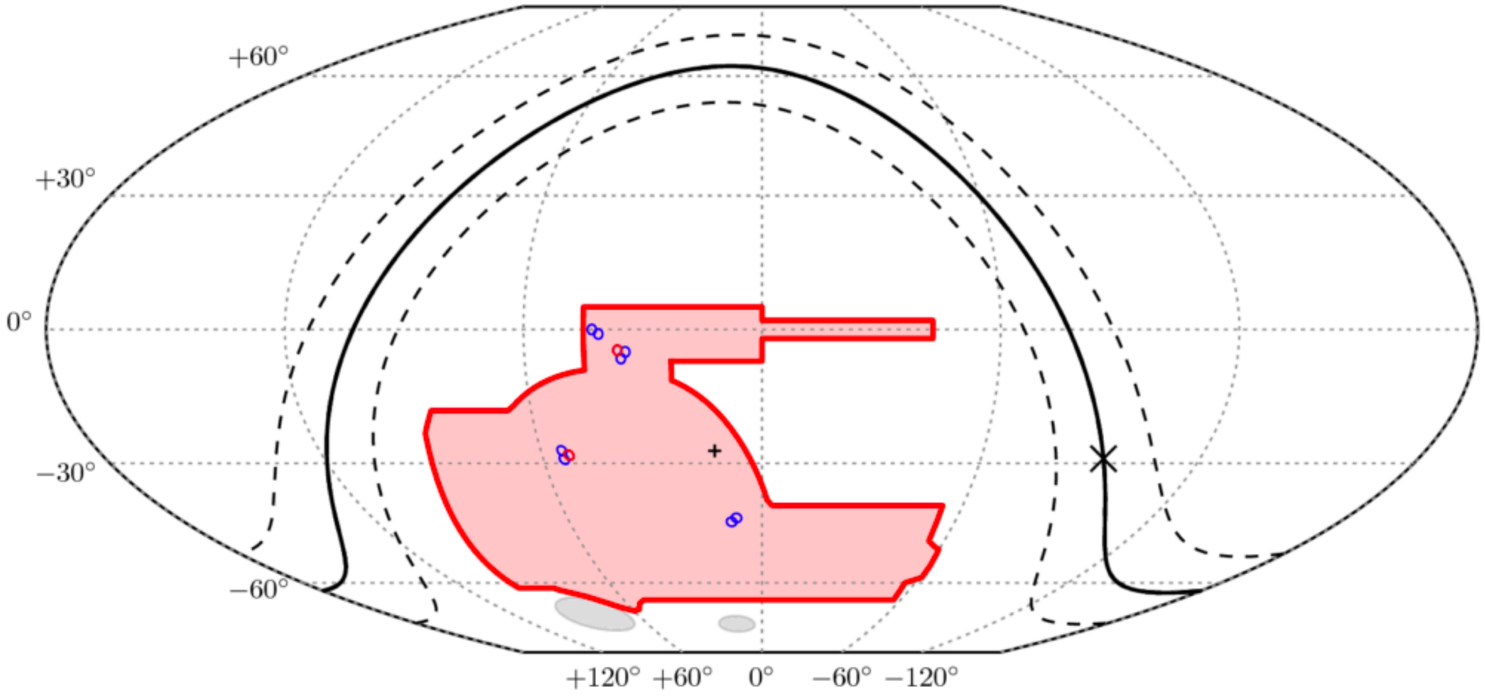

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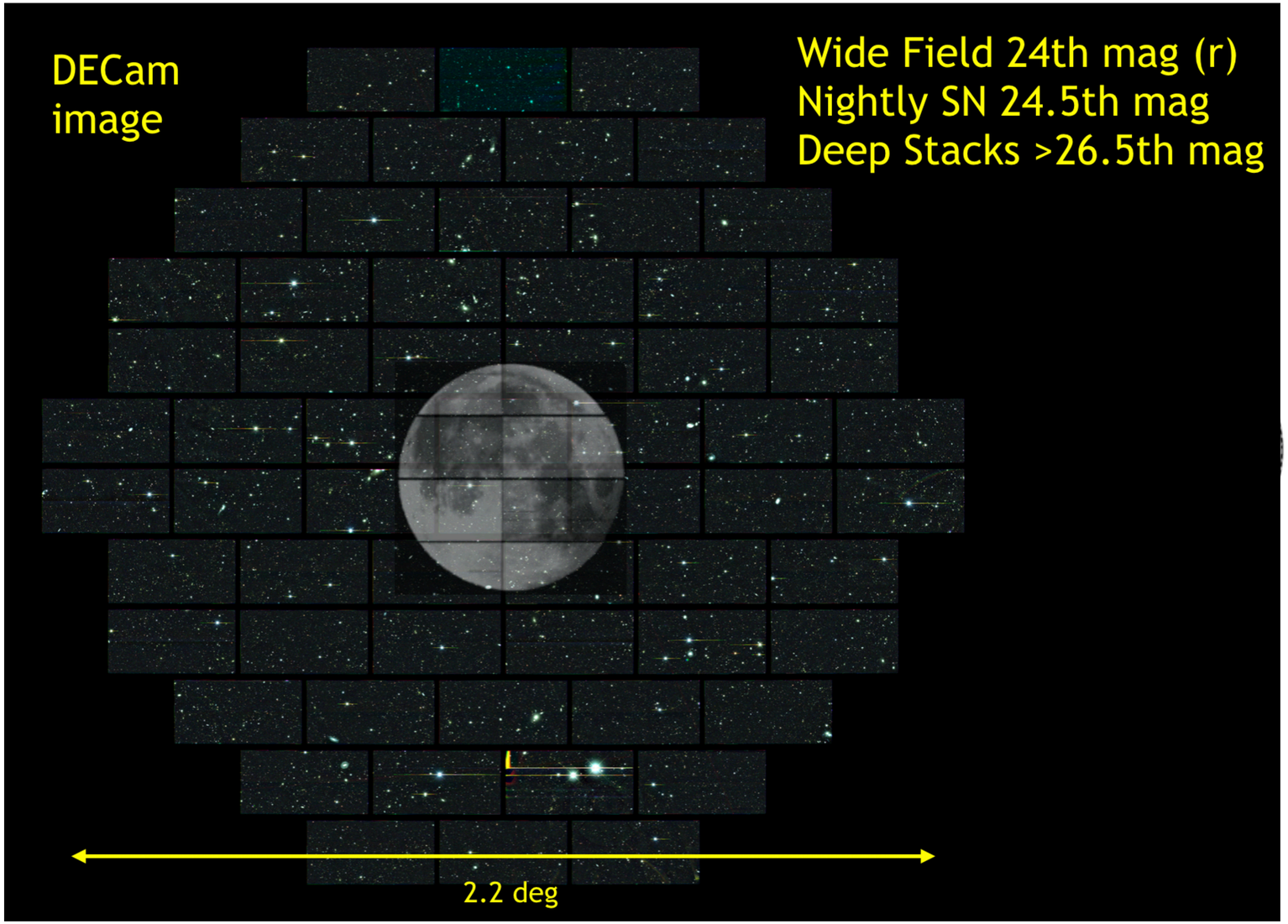

Pieces of the Discussion

DES Probes

Have contributed to the discussion in <u>many</u> ways.

Supernovae Ia

Weak Lensing

BAO

Strong Lensing

GW Followup

Pieces of the Discussion

Distance Ladder
- SN Host Environments
- Selection Effects

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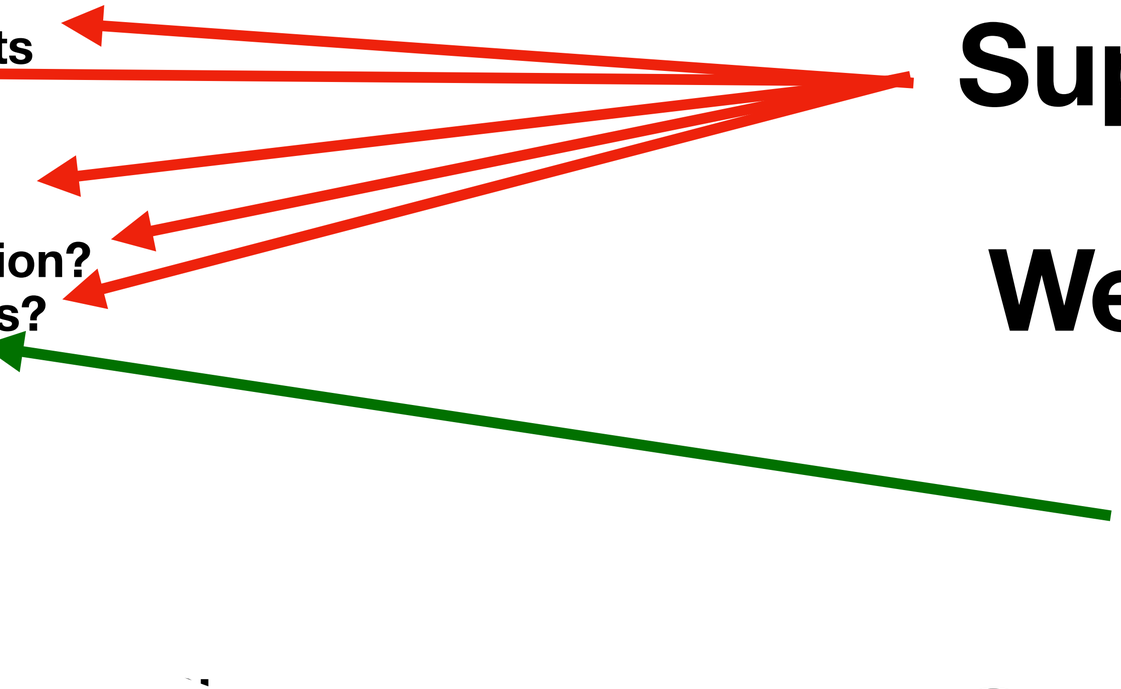

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- Physics at z>~1000
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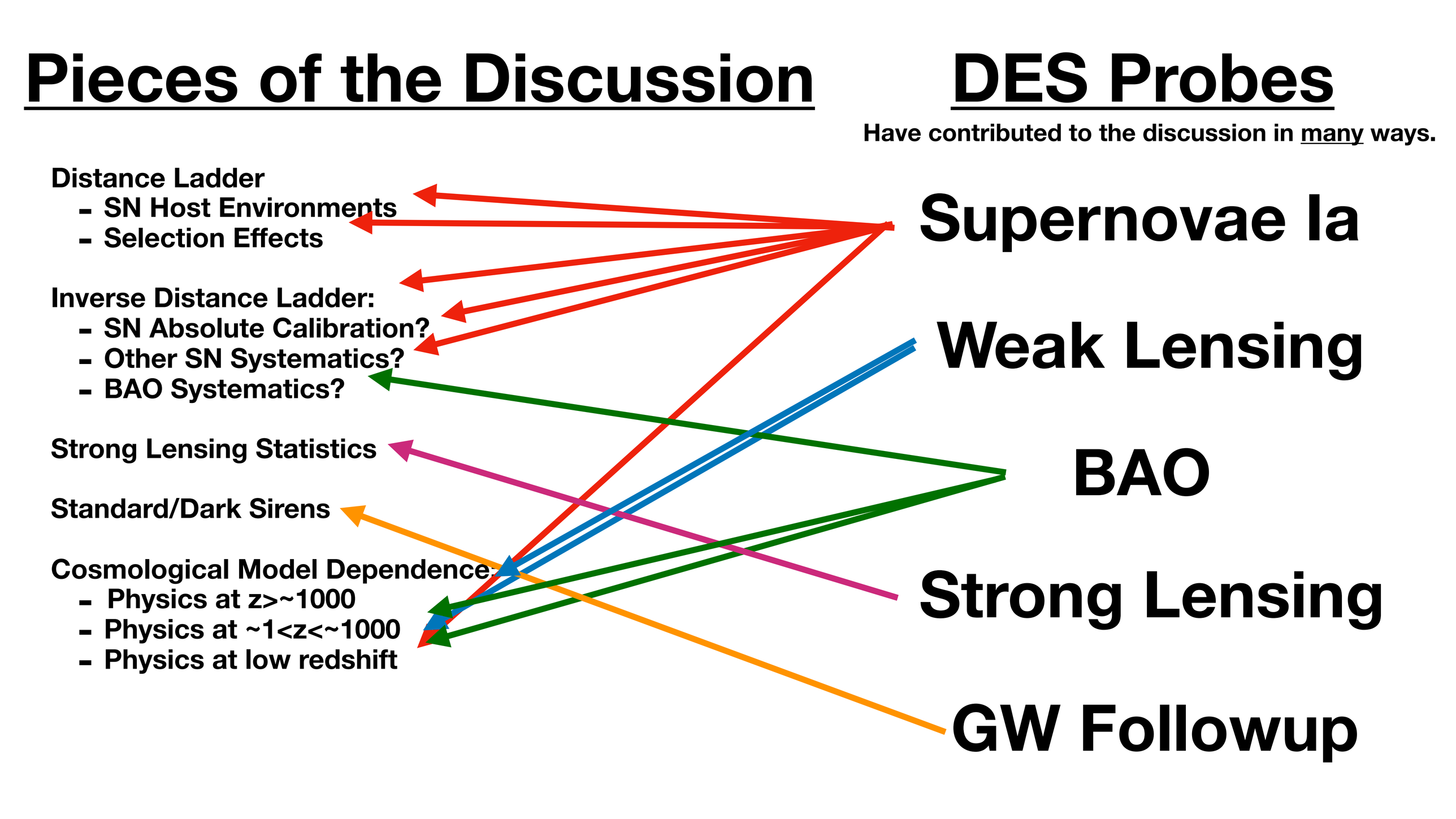

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- S8
- Sound Horizon

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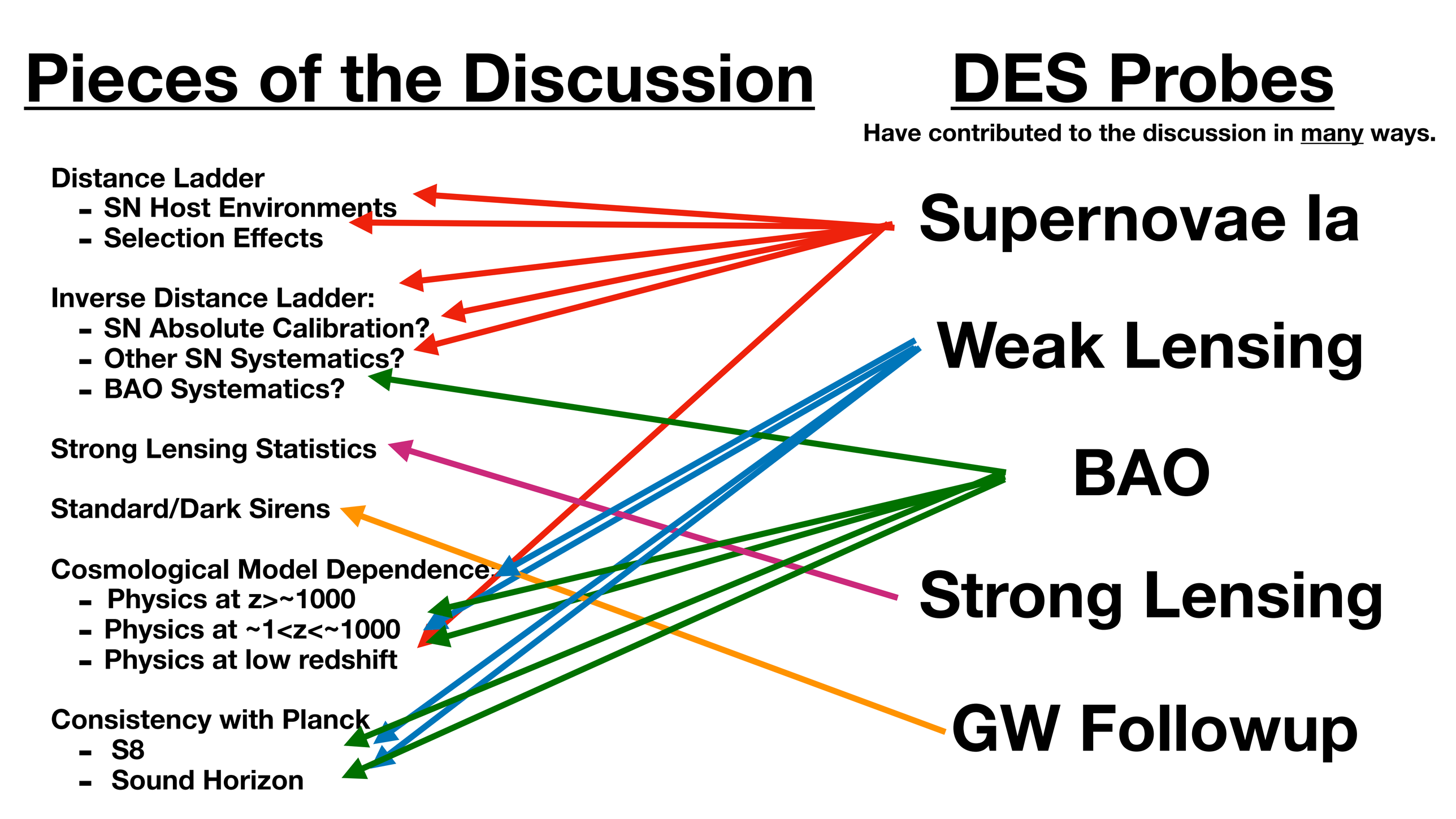

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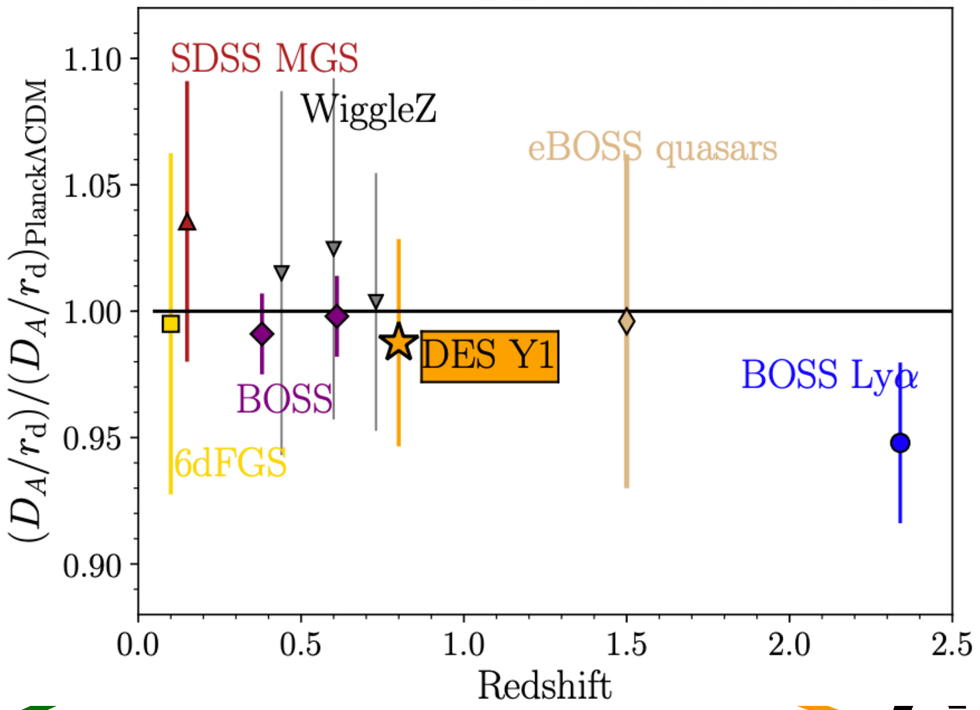
GW Followup

DES Collaboration 2018



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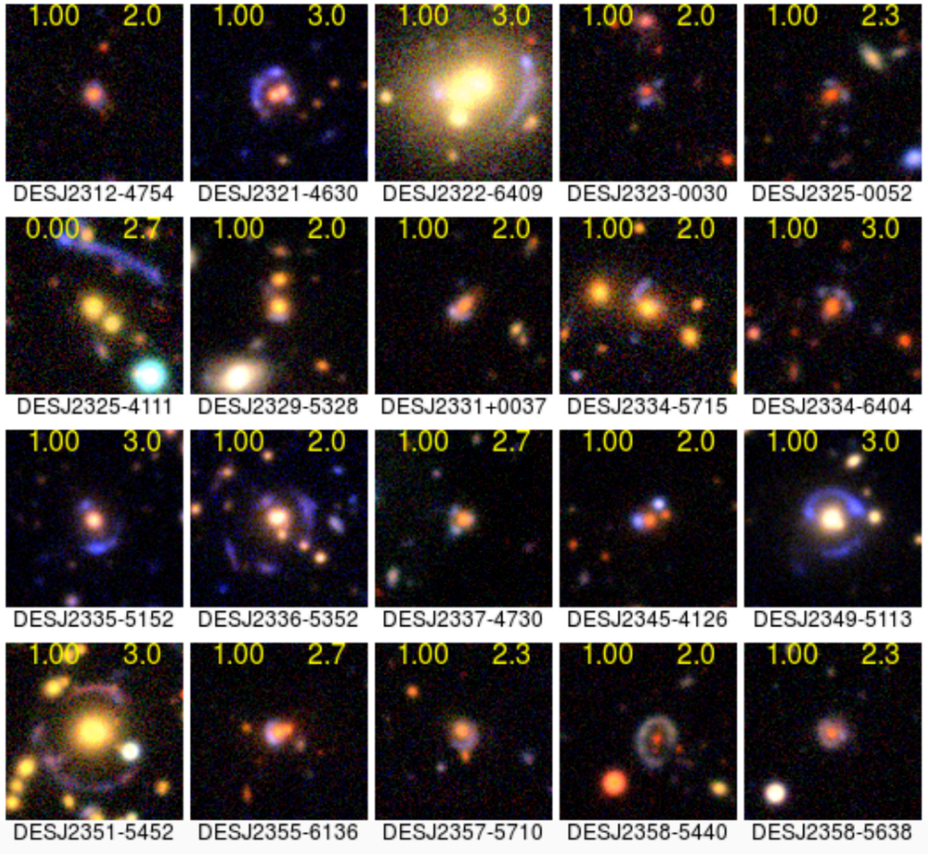
Jacobs et al 2019



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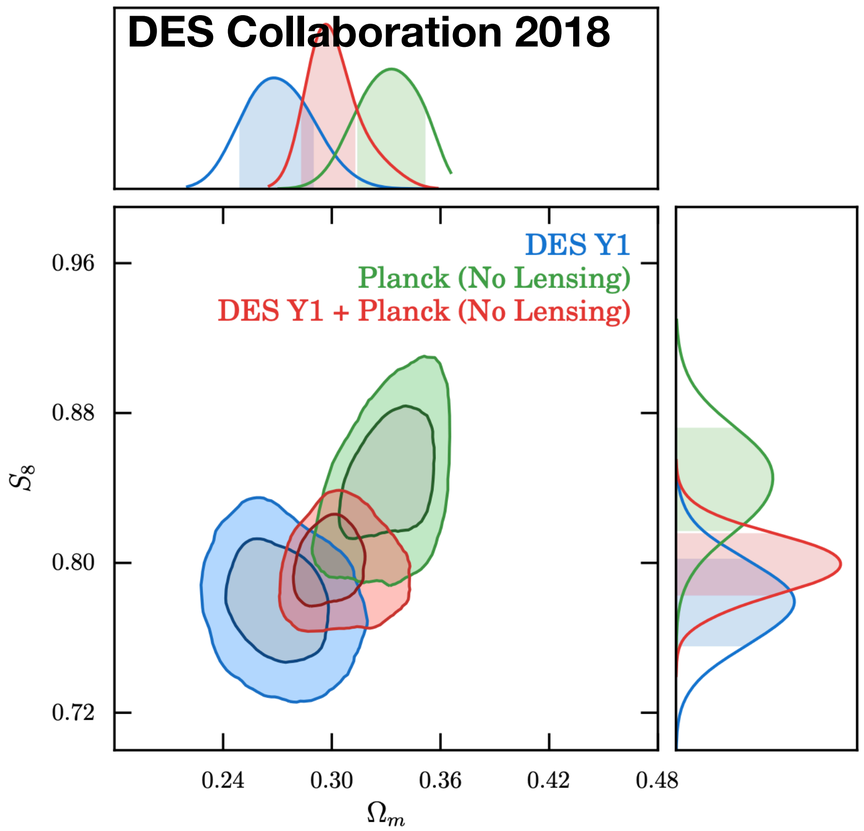

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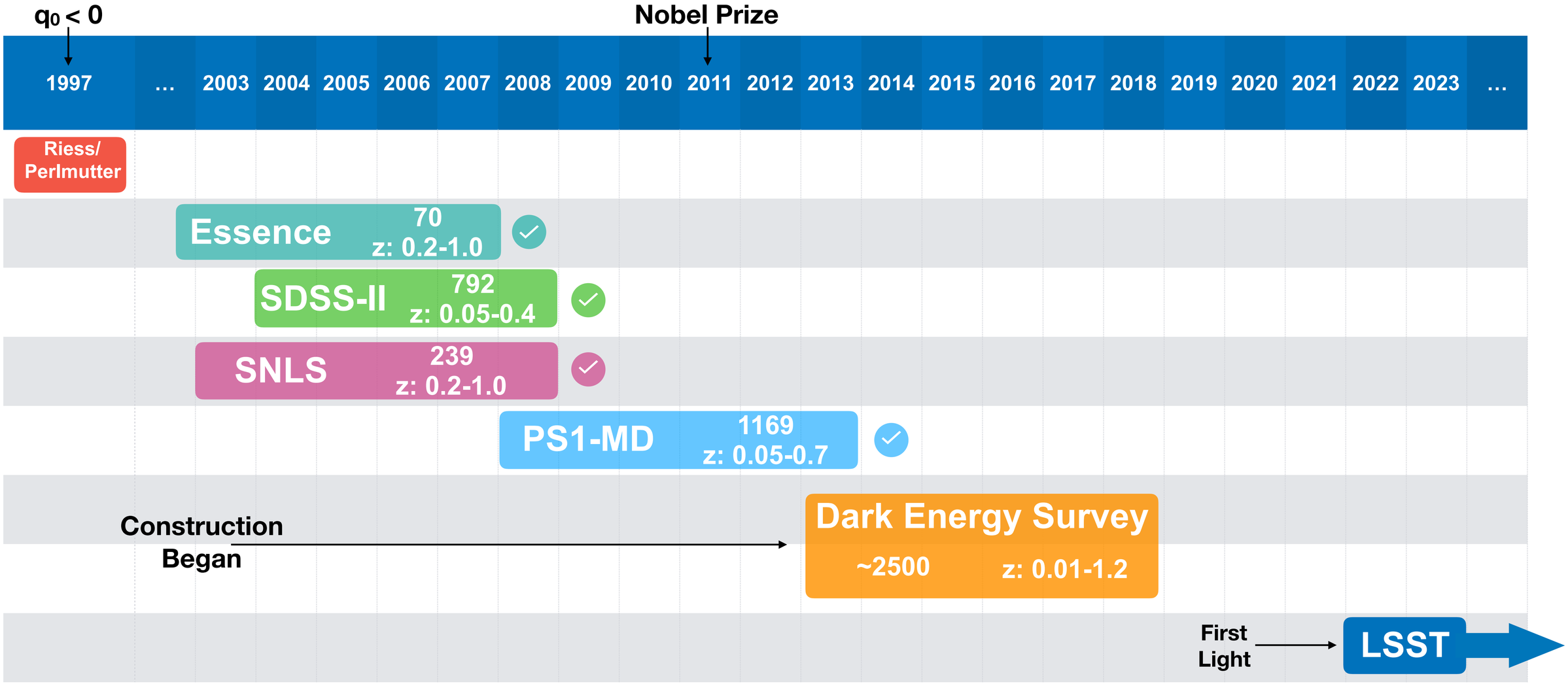
H0 from the Co-Discovery of GW170817

Landscape of High Redshift Rolling SN Surveys



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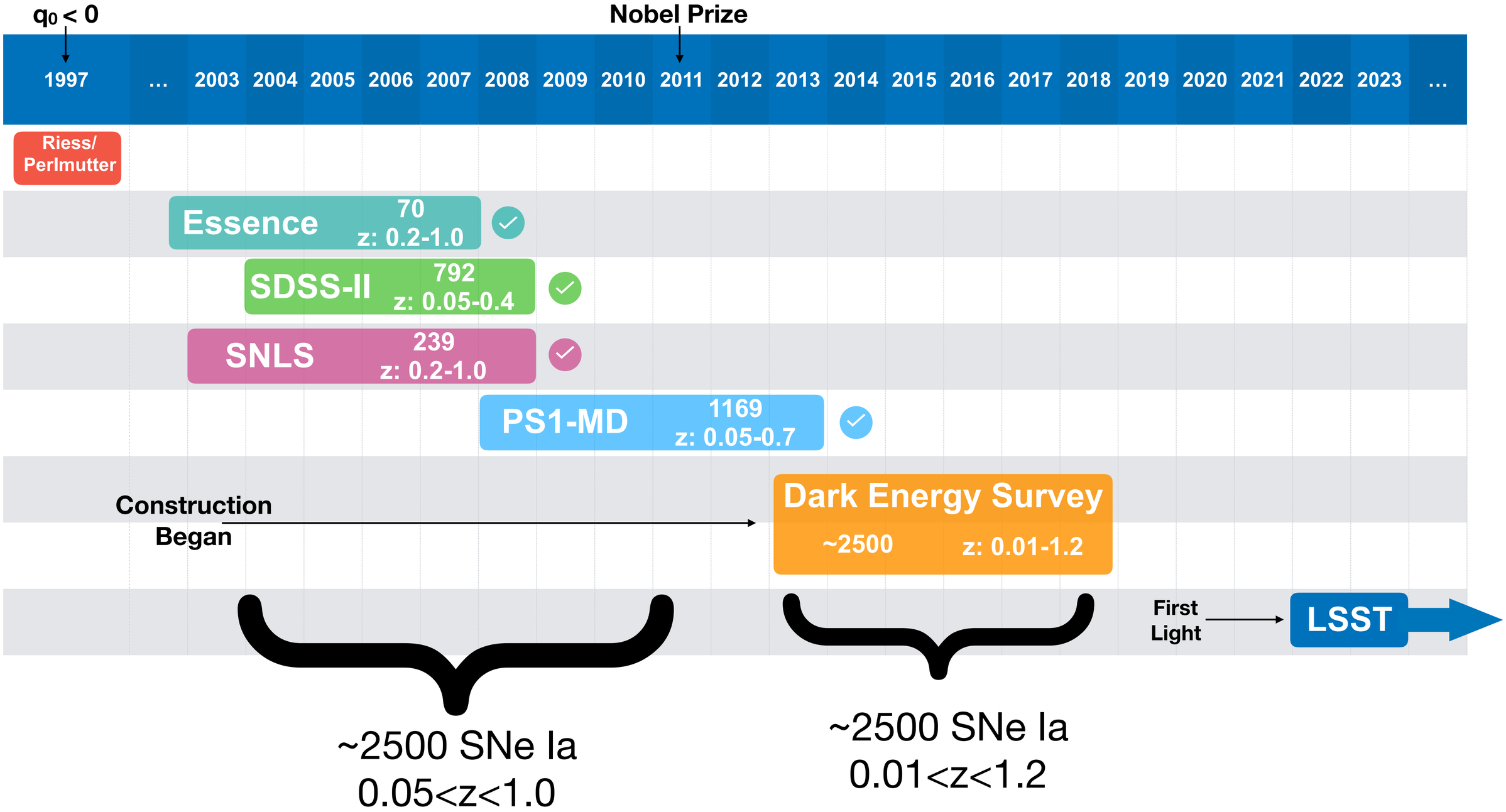
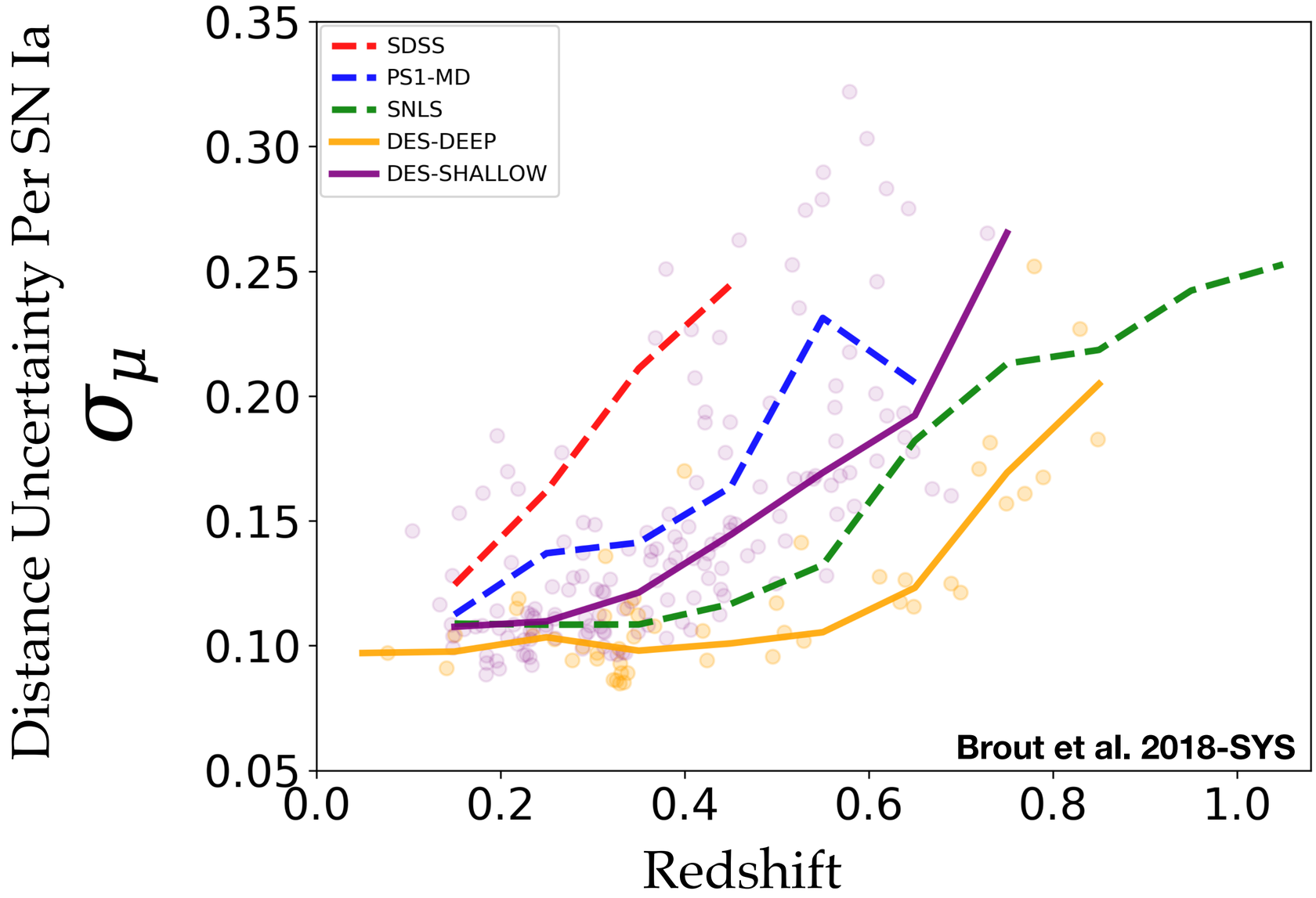


How Do DES SNe Stack Up?



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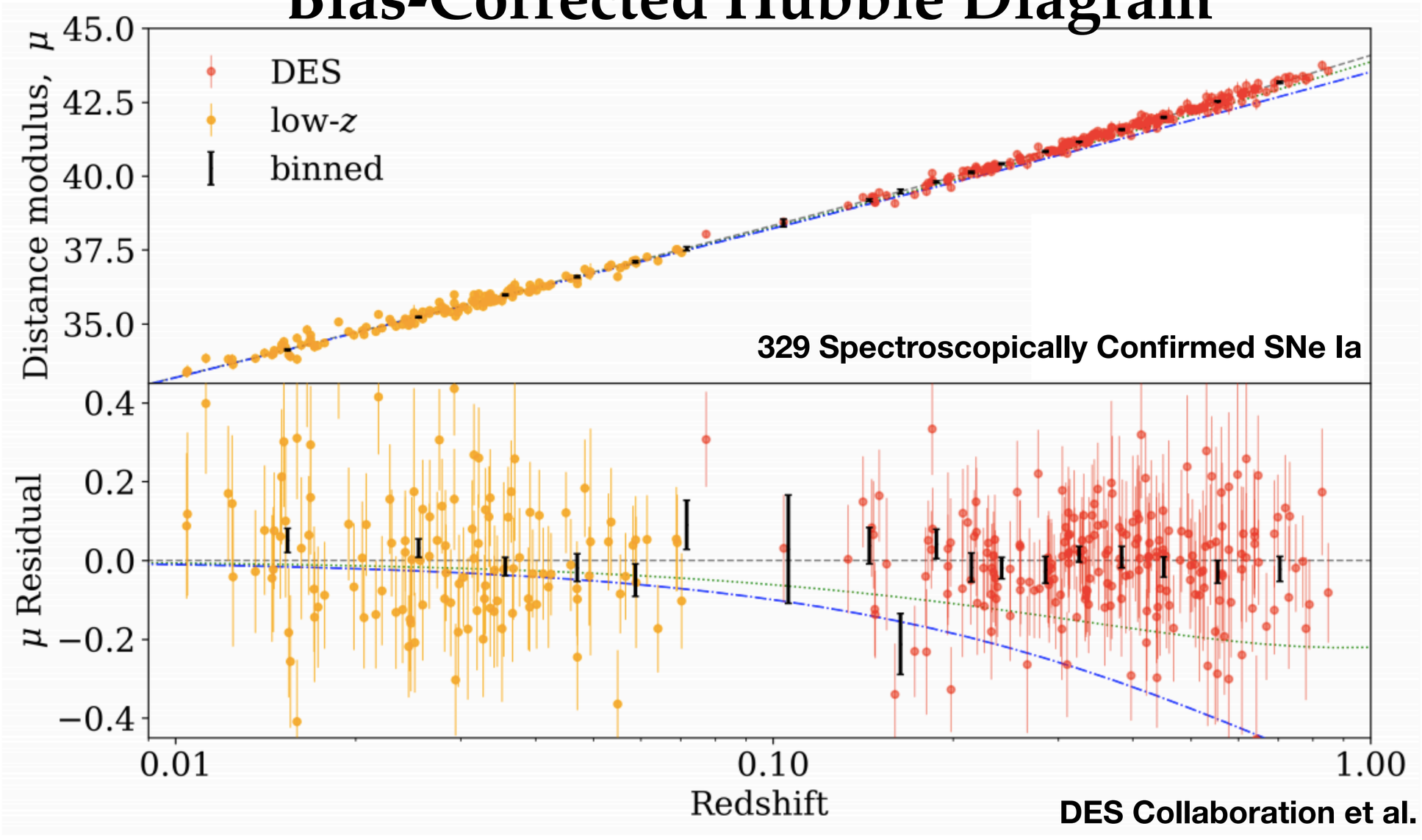
Bias-Corrected Hubble Diagram



DES Collaboration et al. 2019

DES-SN3YR Results!

Flat wCDM

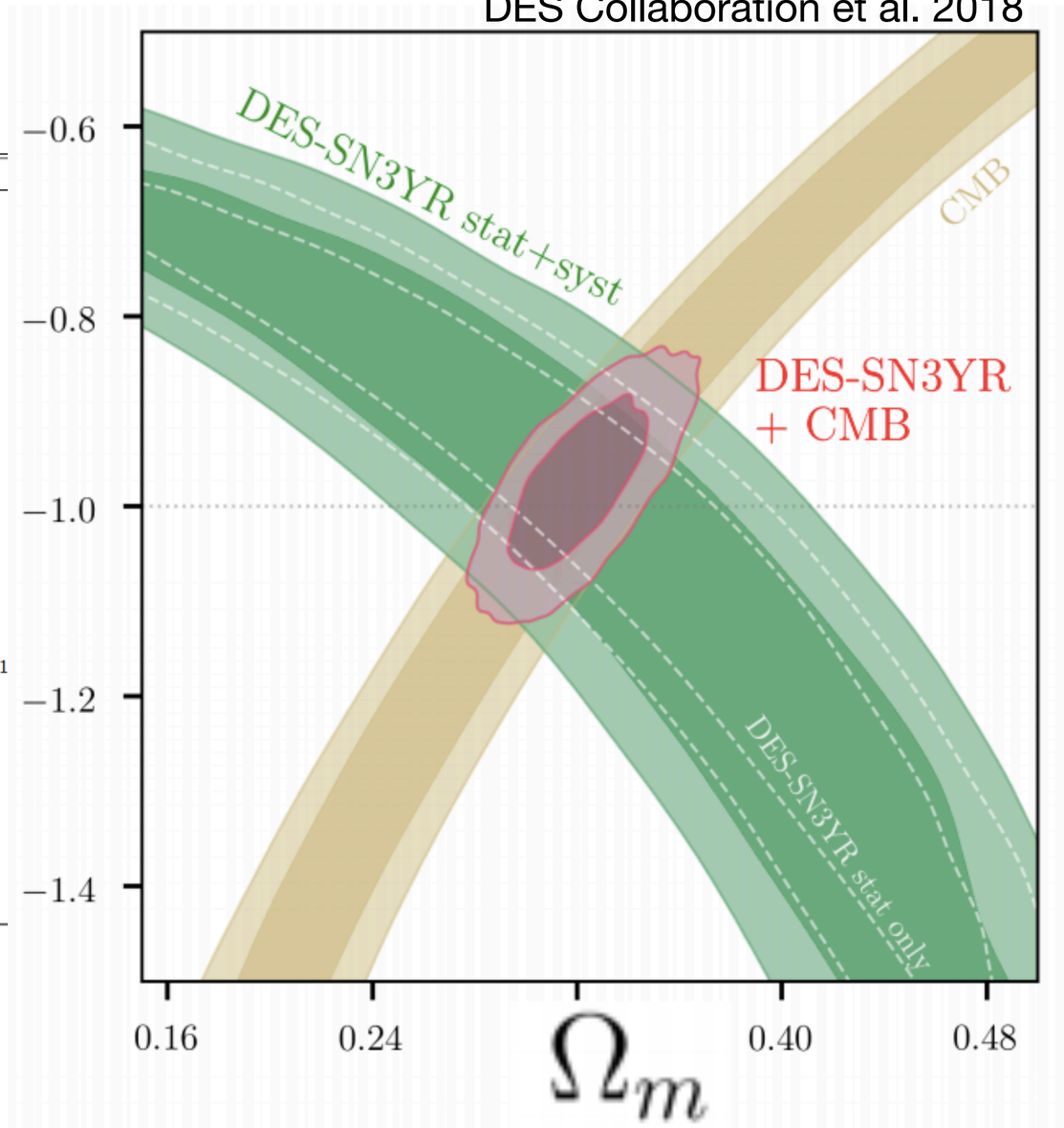
DES Collaboration et al. 2018

TABLE 4
SOURCES OF UNCERTAINTY

Size[a]	Description	Reference
	SN Photometry	
	From astrometry	
1 mmag		Bernstein et al. (2017)
1 mmag	Non-linearity of the CCD.	Bernstein et al. (2017)
1-2 mmag	Photometric zero pointing.	B18-SMP
3 mmag	Photometric bias determined by fakes.	B18-SMP
	Calibration	
$6/\sqrt{3}$ mmag	DECam $\sigma_{\rm uniformity}$	Burke et al. (2018)
0.6 nm	DECam filter curves uncertainty.	Abbott et al. (2018)
$[-2,-2,-1,5]$ mmag	Modeling of C26202 implemented as coherent shift $[g,r,i,z]$	Figure 4
5mmag/700 nm	HST Calspec spectrum modeling uncertainty	Bohlin et al. (2014)
1/3 No SuperCal	SuperCal process	S18, Scolnic et al. (2015)
Following S18	Low-z samples photometric calibration.	S18, Cf/
Following S18	Low-z samples filter curve measurement.	S18, Cf/
Following B14	SALT2 light curve model calibration.	B14
	Bias Corrections (Astrophysical)	
Table 3	c, x_1 Parent populations resulting in $\Delta\chi^2 = 2.3$	§ 4.3
1/2 (G10 − C11)	Model of intrinsic scatter variations	§ 4.2
Two $\sigma_{\rm int}$	Separate fit $\sigma_{\rm int}$ for each subset	§ 4.2
0.05 in w	†Cosmology in which the bias correction sample is simulated.	§ 4.5
4% Scaling	MW Extinction maps	§ 4.9, Schlafly & Finkbeiner (201
	Bias Corrections (Survey)	
$3.5\sigma \rightarrow 3\sigma$ outlier cut	†Low-z Hubble diagram outlier cut.	§ 4.7
$1\sigma_{\rm stat}$ Fluctuation	Spectroscopic selection function statistical fluctuations.	§ 4.4, Figure 8
Low-z Selection	Low-z subset magnitude → volume limited survey.	§ 4.3
5% $\sigma_{\rm phot}$ Underestimation	†Incorrect SN photometric uncertainties.	§ 4.8
	Redshifts	
4×10^{-5} in z	†Coherent z-shift.	§ 4.6, Calcino & Davis (2017)
$0.9 \times \beta_{\rm bias}$	Peculiar velocity modeling	§ 4.6, Zhang et al. (2017)

[a] Size adopted for each source of systematic uncertainty.
† Sources of systematic uncertainty that have not been included in previous analyses.

w



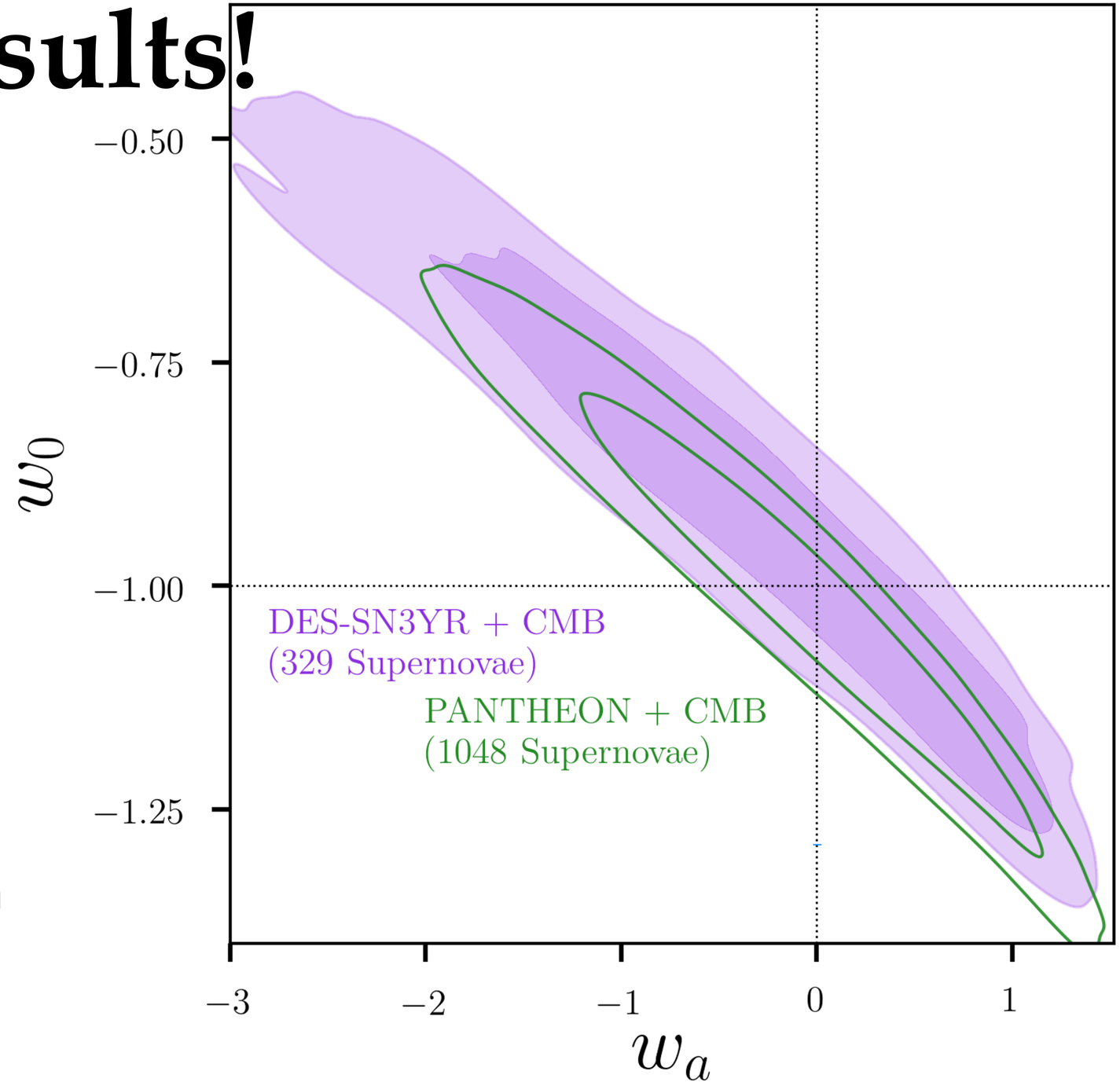
DES-SN3YR Results!

Flat w_0w_aCDM

$$w = w_0 + w_a(1 - a)$$

$$w_a = -0.387 \pm 0.430$$

The most powerful constraint on dark energy per SN to date



DES Only Results From Combined Probes

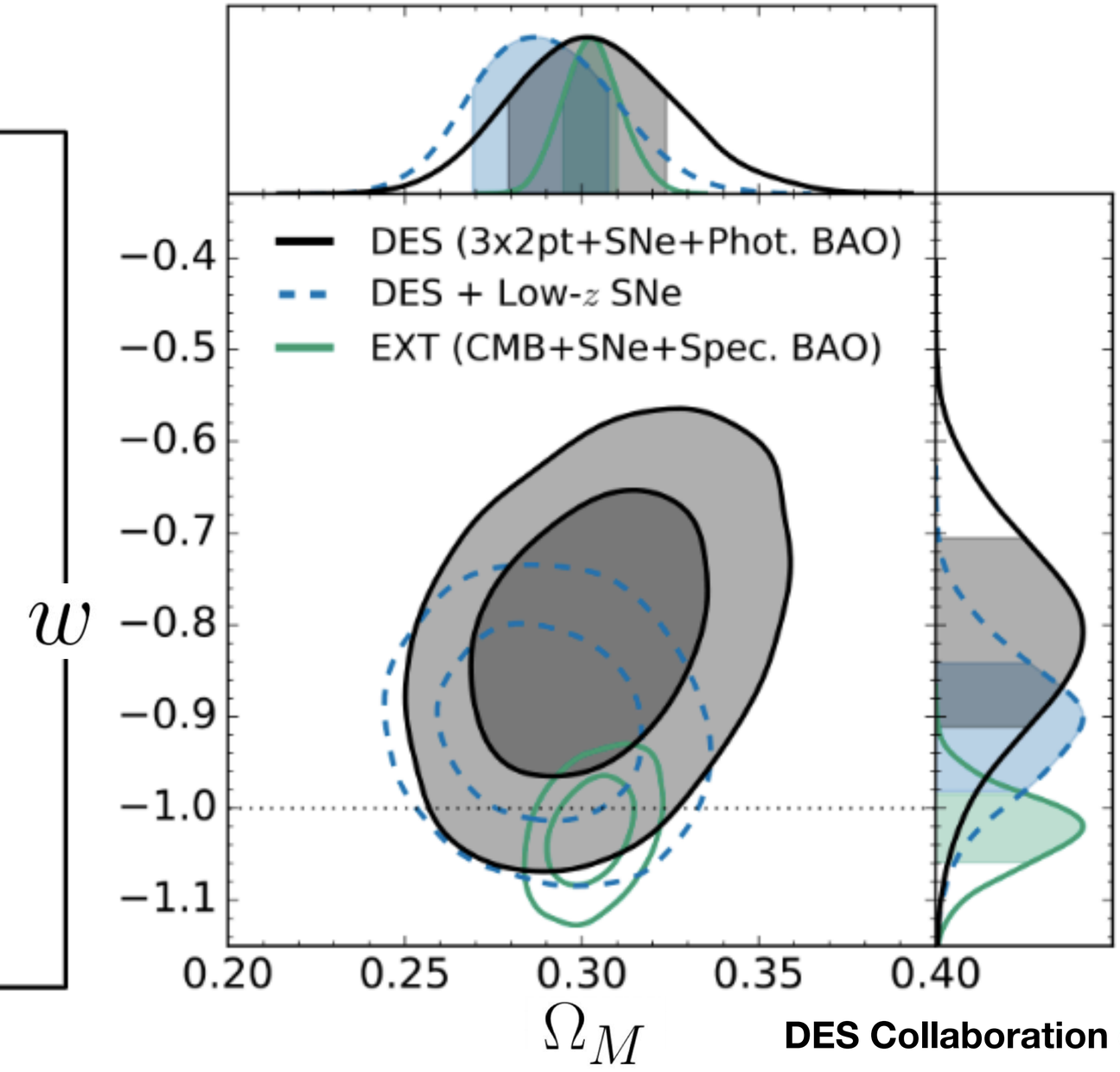
First single photometric probe to independently rule out a no dark energy universe.

DES: SN + 3x2pt + Phot. BAO

$$w = -0.80^{+0.09}_{-0.11}$$

DES-SN + Planck16

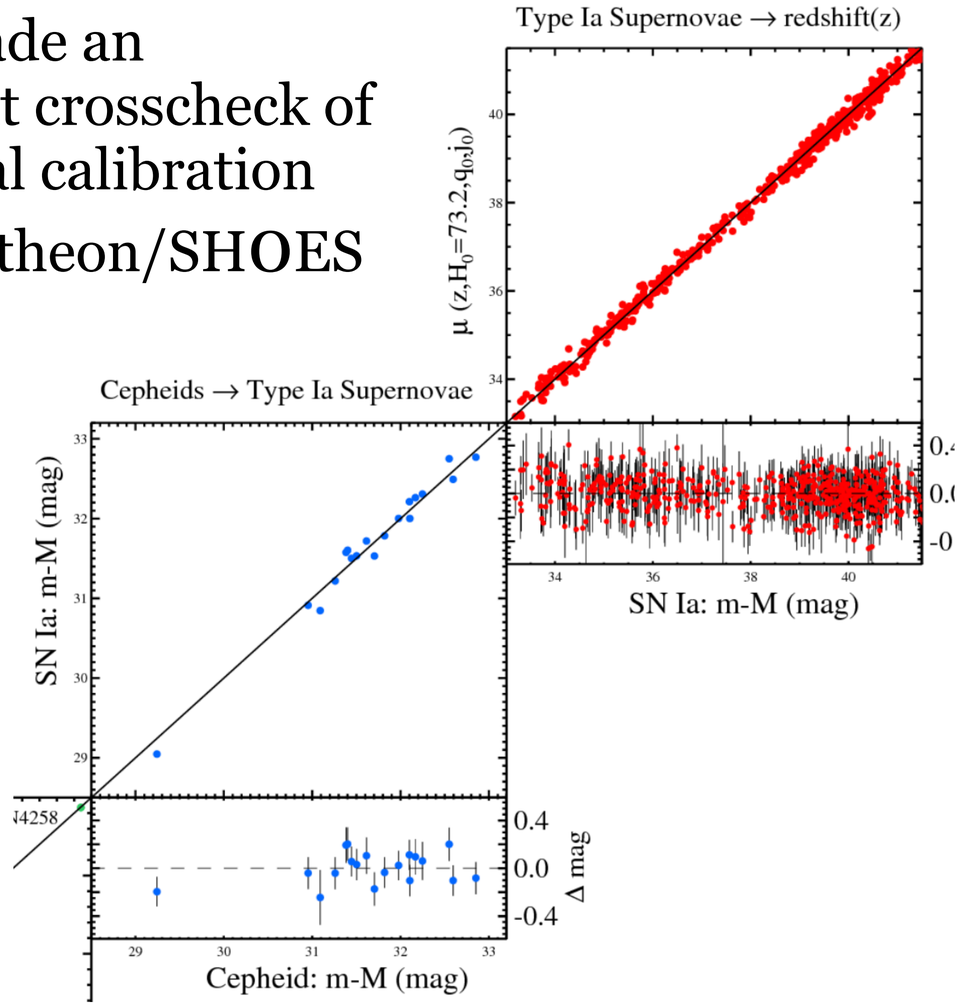
$$w = -0.911 \pm 0.087$$



DES Collaboration et al. 2018

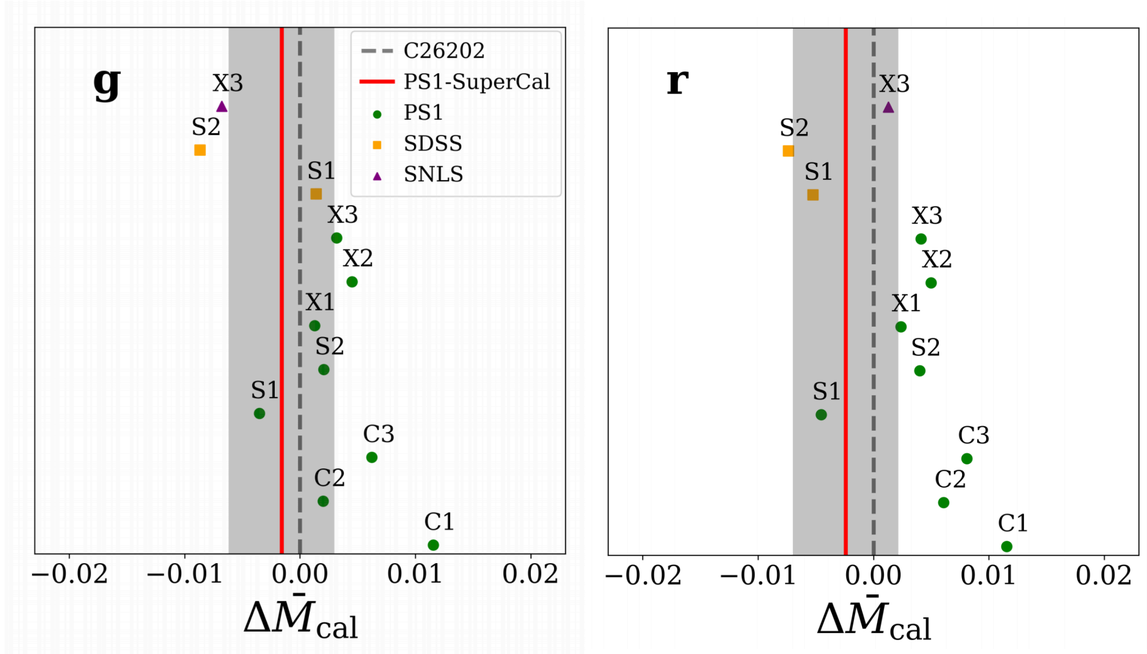
Calibration of SN Surveys

DES has made an independent crosscheck of the SuperCal calibration used in Pantheon/SHOES



Riess et al

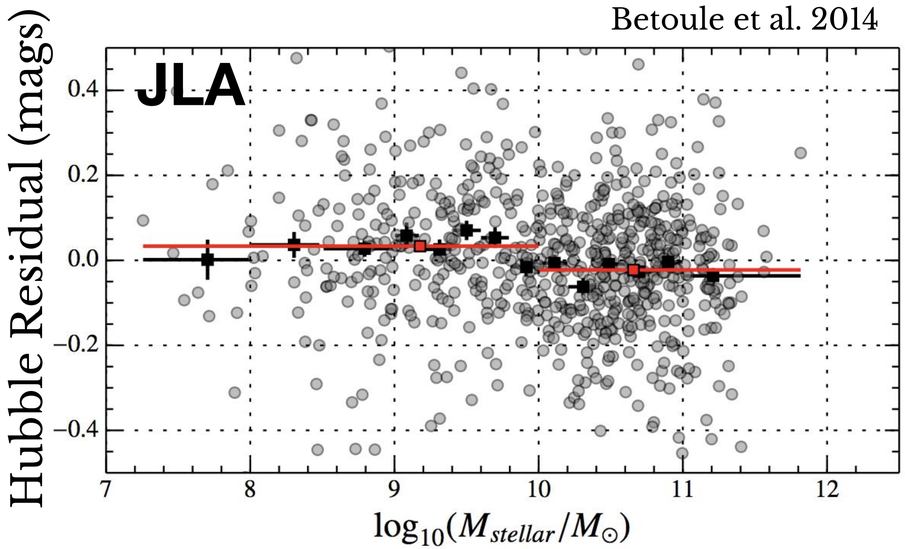
Brout et al. 2019



Here PS1 also = Foundation

The Host Mass Step is not seen in DES

Betoule et al. 2014



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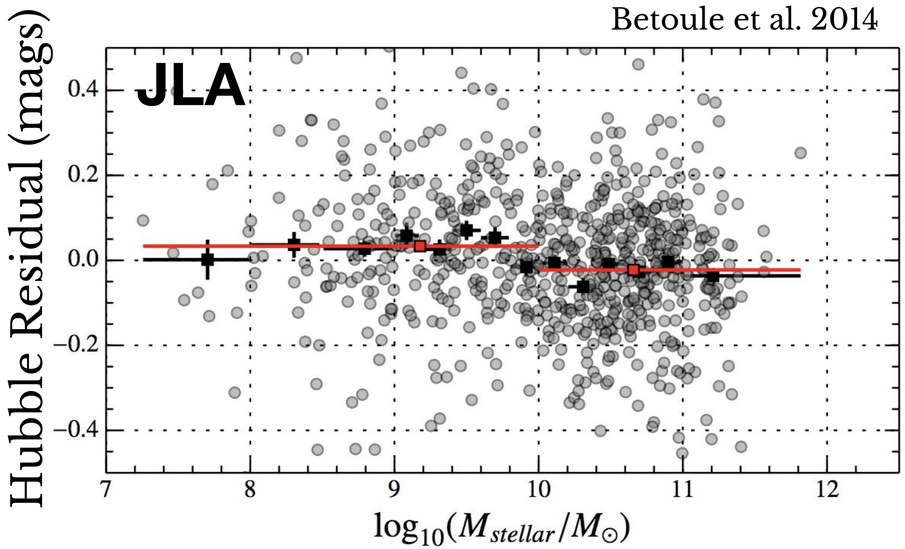

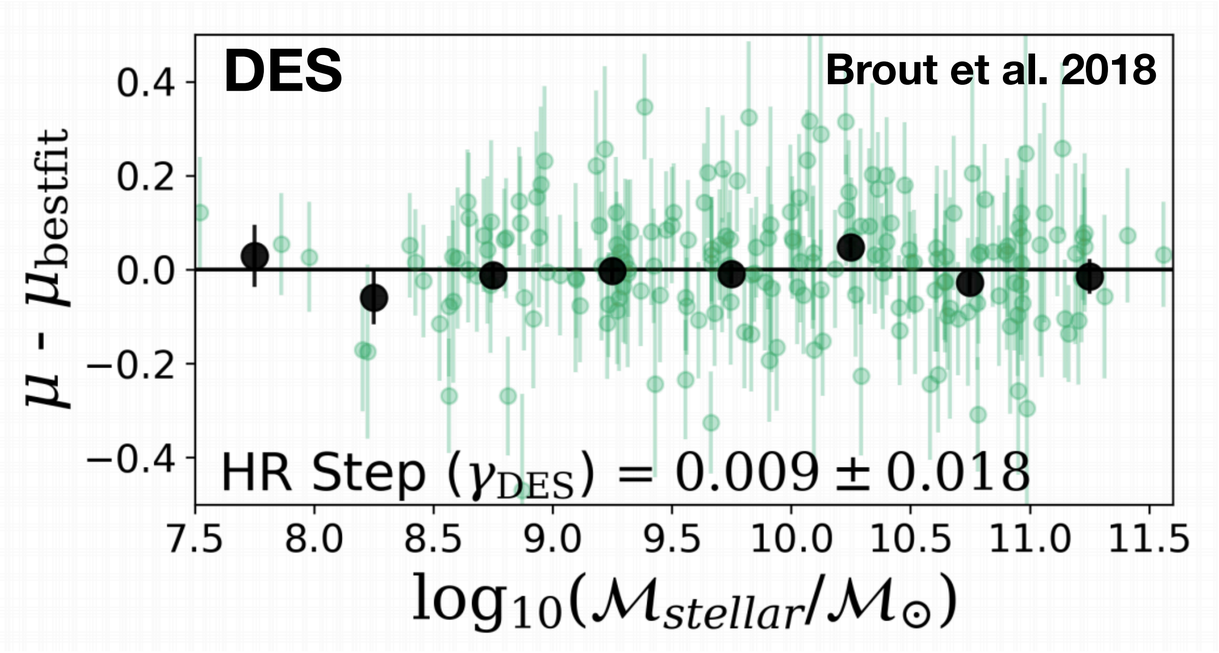

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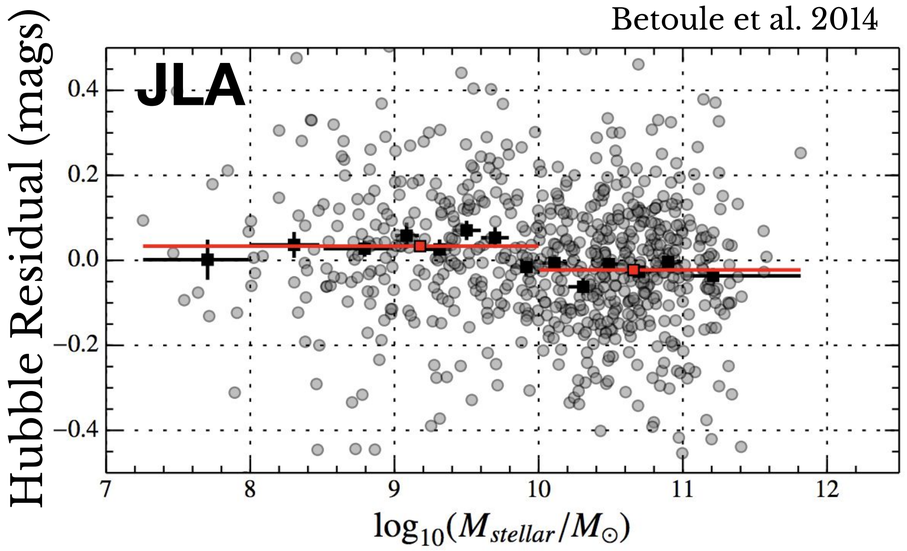
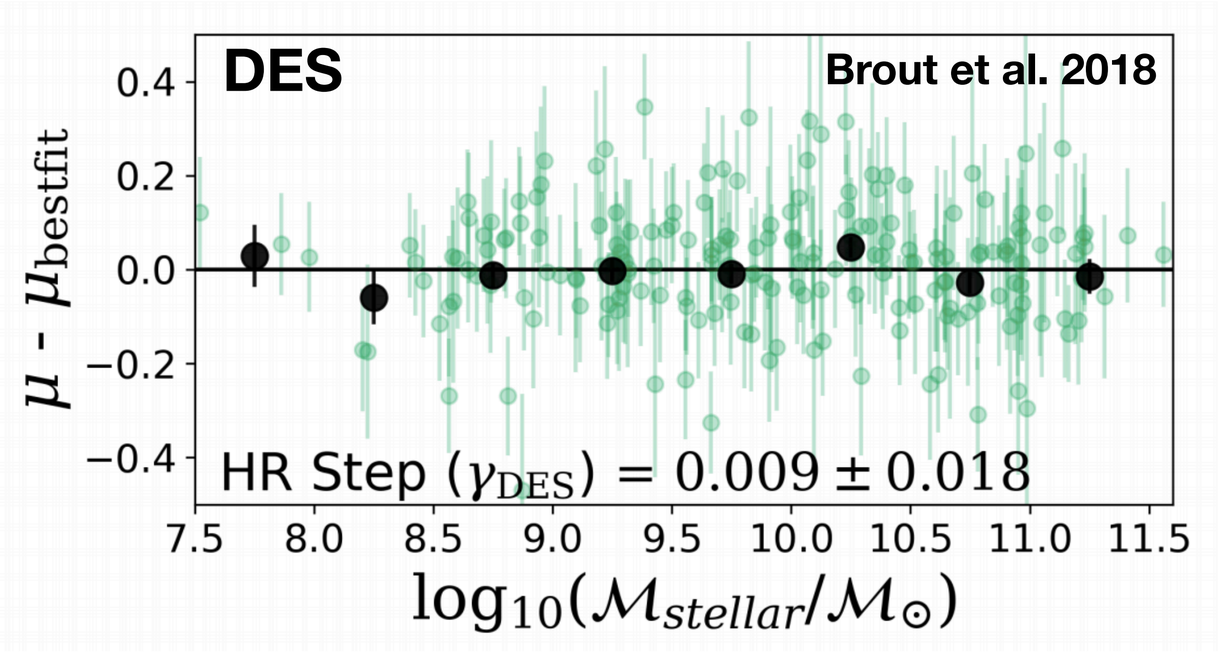
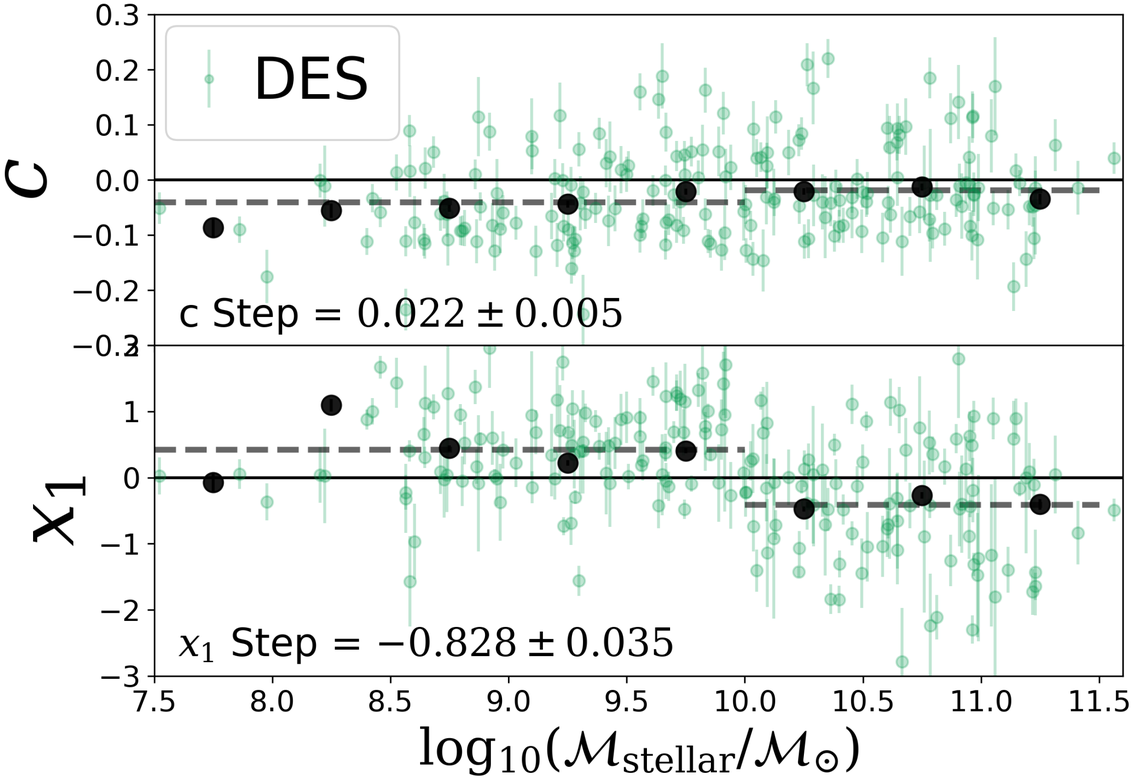




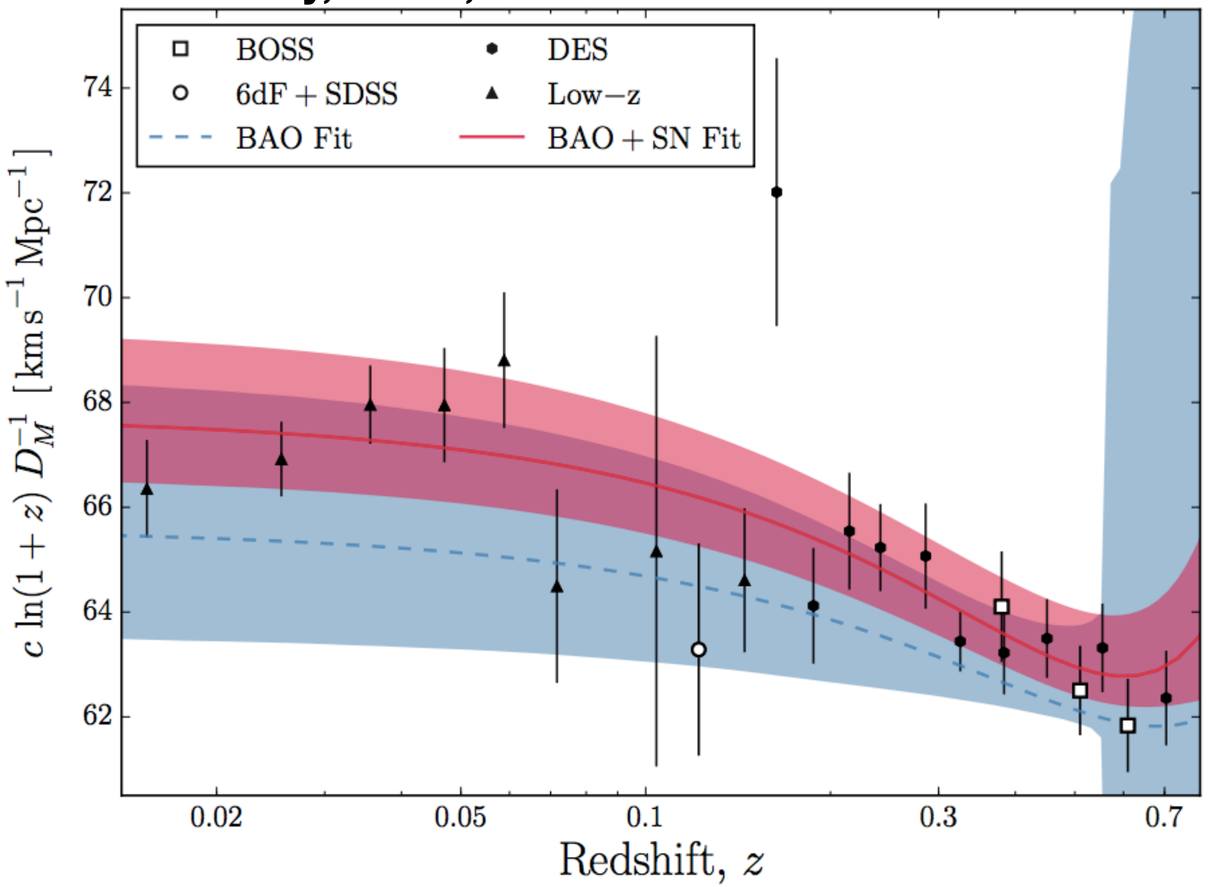
We do see correlations with c, x_1



Removing/reducing the correction made in SH0ES would raise H0

DES Supernova Inverse Distance Ladder H0 Technique

Macaulay, Smith, Brout et al.



Breaks degeneracy with peak intrinsic and H_0

Minimal assumptions about the underlying cosmological model.

Polynomial cosmographic model.

Gaussian prior on r_s = 147 +- 1

H0 = 67.77+- 1.30 km/s/Mpc

First done by Aubourg et al. 2015
with Pantheon: Feeney et al. 2018

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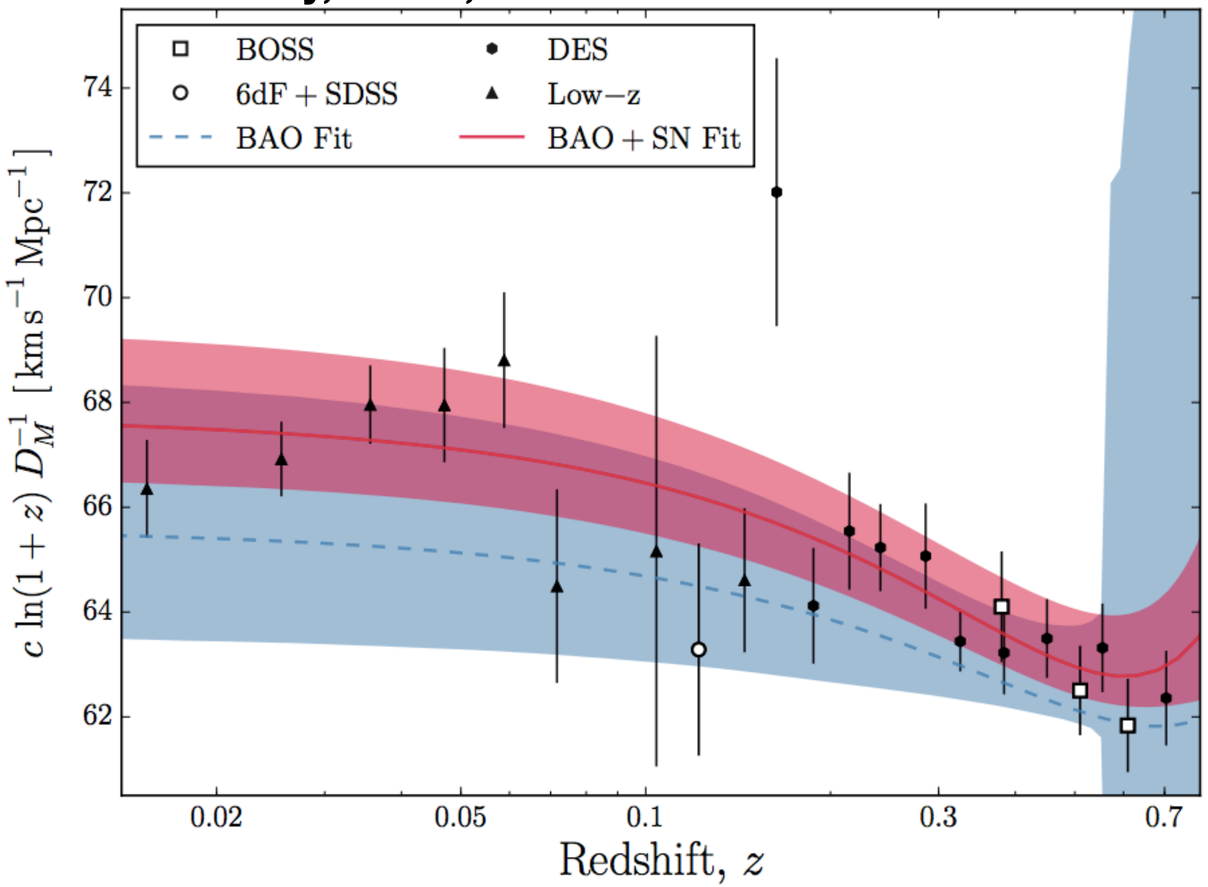

Description	H_0 shift	$\sigma_{\rm syst}$	$\sigma_{\rm syst}$ / $\sigma_{\rm stat}$
Total Stat.	0.000	1.048	1.00
Total Sys.	0.162	0.760	0.72
ALL Calibration	-0.078	0.375	0.36
DES Cal.	-0.016	0.276	0.26
Low-z Cal	-0.026	0.254	0.24
SALT	0.053	0.217	0.21
ALL Other	0.004	0.661	0.63
Intrinsic Scatter	0.129	0.330	0.31
$z + 0.00004$	0.036	0.083	0.08
c, x_1 Parent Pop.	-0.031	0.249	0.24
Low-z Vol. Lim.	-0.081	0.124	0.12
Flux Err.	-0.004	0.179	0.17
Spec. Eff	-0.091	0.125	0.12
Ref. Cosmo.	-0.065	0.134	0.13
Low-z 3σ Cut	0.498	0.193	0.18
Sys. Parent	0.370	0.222	0.21
PS1 Coherent Shift	0.064	0.246	0.23
$2\ \sigma_{\rm int}$	-0.068	0.231	0.22

First done by Aubourg et al. 2015
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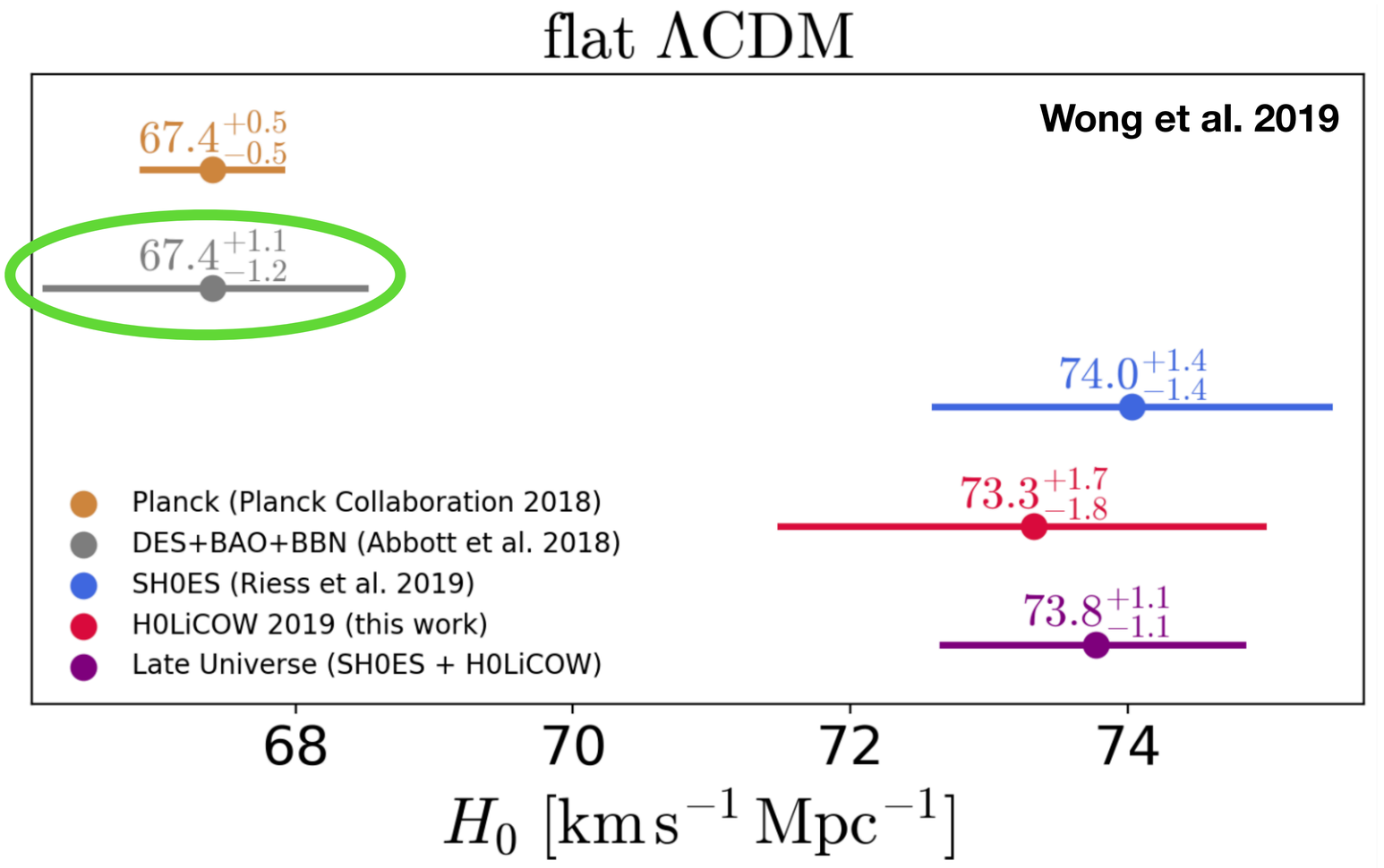
Supernovae

Weak Lensing & Clustering + BAO + BBN

H0 from the Co-Discovery of GW170817


flat ΛCDM
Wong et al. 2019
$67.4^{+0.5}_{-0.5}$
$67.4^{+1.1}_{-1.2}$
$74.0^{+1.4}_{-1.4}$
$73.3^{+1.7}_{-1.8}$
$73.8^{+1.1}_{-1.1}$
Planck (Planck Collaboration 2018)
DES+BAO+BBN (Abbott et al. 2018)
SH0ES (Riess et al. 2019)
H0LiCOW 2019 (this work)
Late Universe (SH0ES + H0LiCOW)
68
70
72
74
H_0 [km s^{-1} Mpc^{-1}]

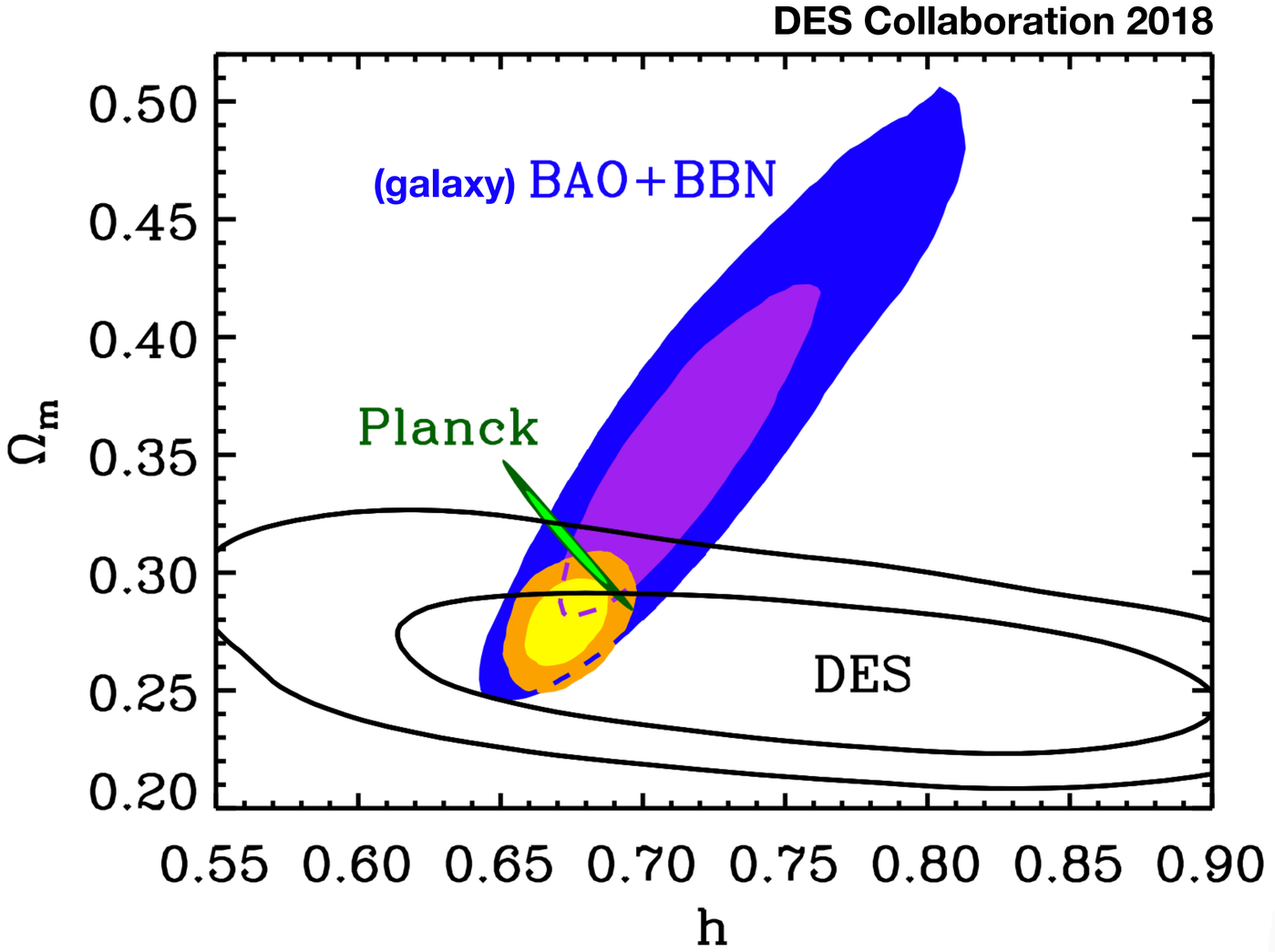
DES Weak Lensing & Clustering + BAO +BBN

BAO Observable

$$D_{\rm M}/r_{\rm s} \longleftarrow \Omega_{\rm m},\ \Omega_{\rm b}h^2,\ \text{and}\ h.$$

DES Weak Lensing Contribution to the H0 Discussion

DES Collaboration 2018



Low H0 independent of Planck!

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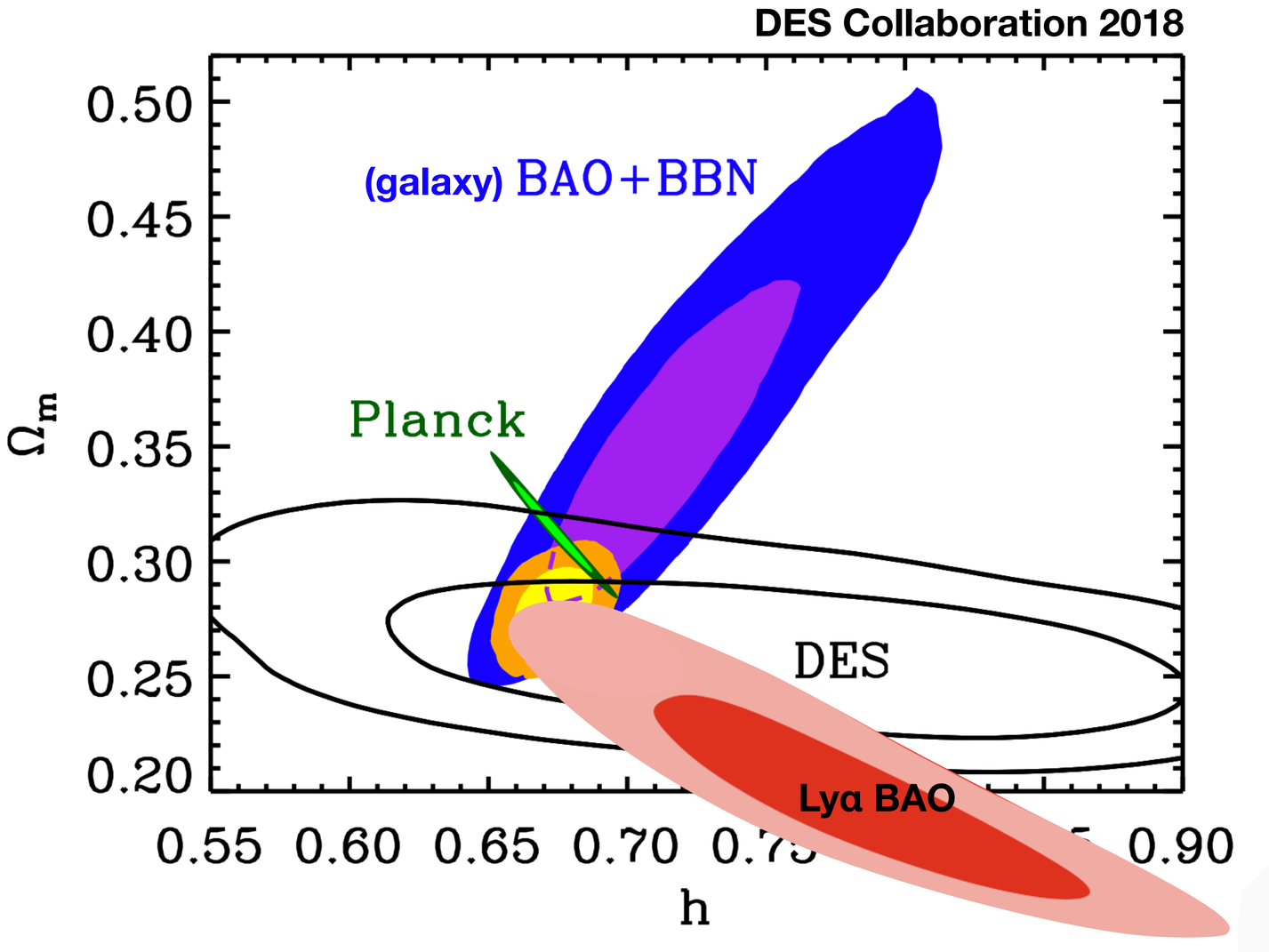

Low H0 independent of Planck!

Effective to swapping out Lyα BAO to break degeneracy with OM

Addison et al 2018

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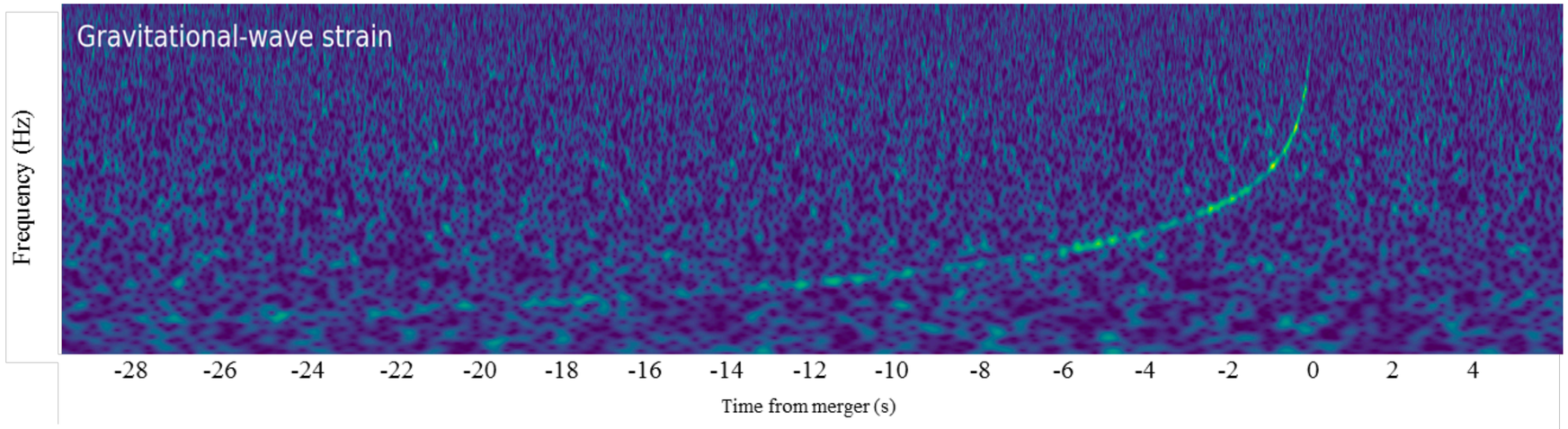
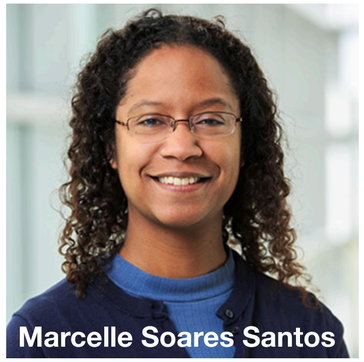
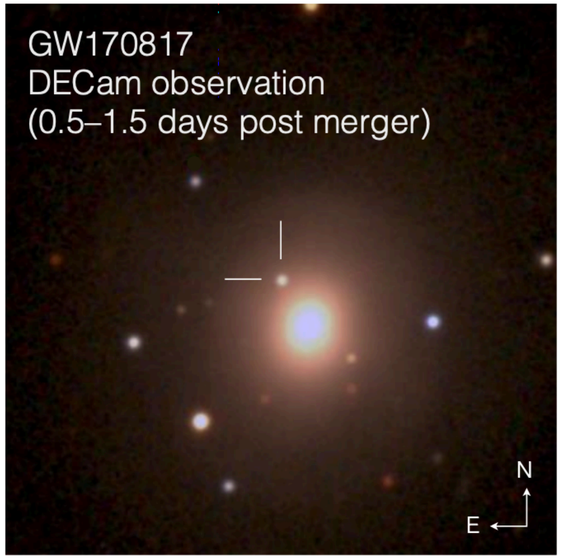
H0 from the Co-Discovery of GW170817

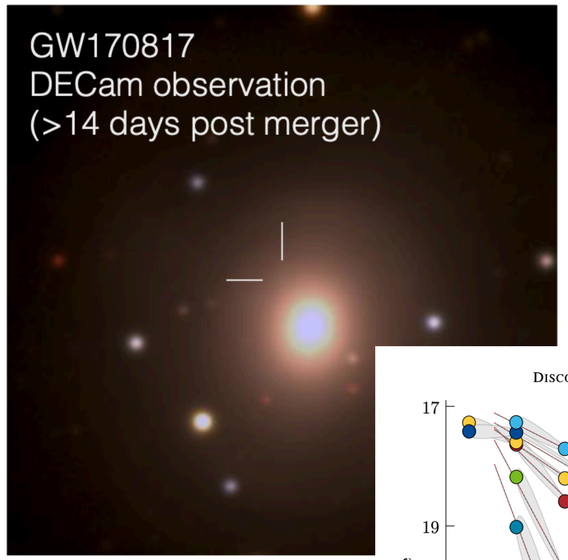
LIGO



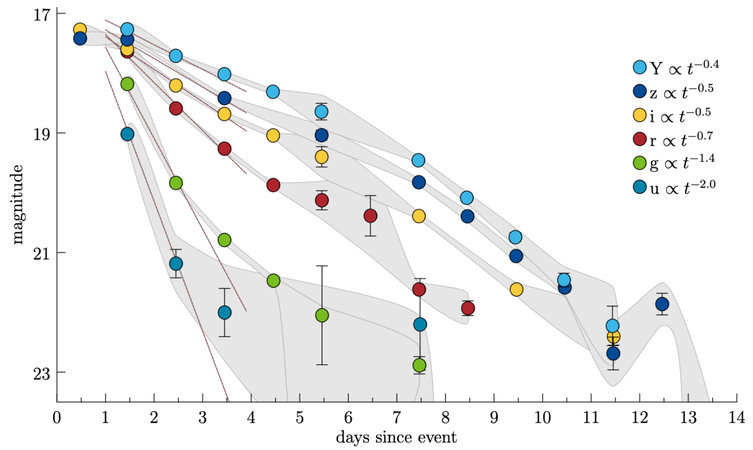
DES-GW







Soares-Santos et al 2017



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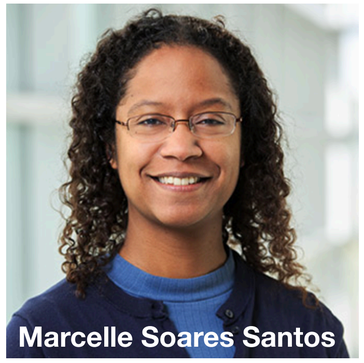


Re: All Eyes! G298048. Images will be downloadable

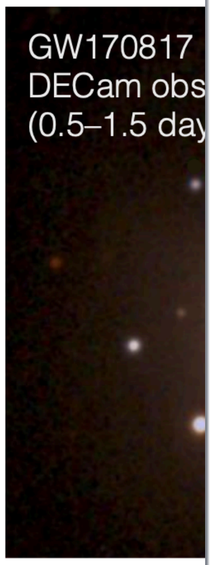
Ryan Chornock sent by owner-des-gw@listserv.fnal.gov

Sent: Thursday, August 17, 2017 at 7:42 PM

To: Sahar Allam; Berger, Edo; Douglas L Tucker

Cc: Philip S. Cowperthwaite; Dillon Brout; Marcelle Soares Santos; Dan Scolnic;

decam_38.jpg (139.6 KB); ps1-3pi.jpg (23.6 KB) Preview All



Soares-S

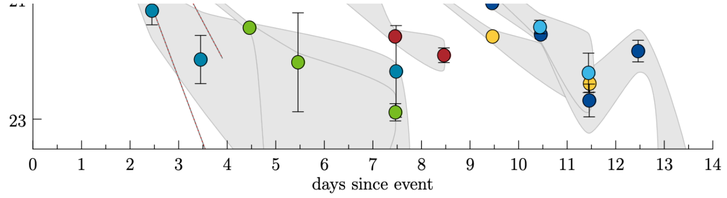
Holy ~~shit~~

Check out NGC 4993 in DECam_00668440.fits.fz[N5]

Attached is tonight's image + ps1-3pi.

Galaxy is at 40 Mpc.

-R



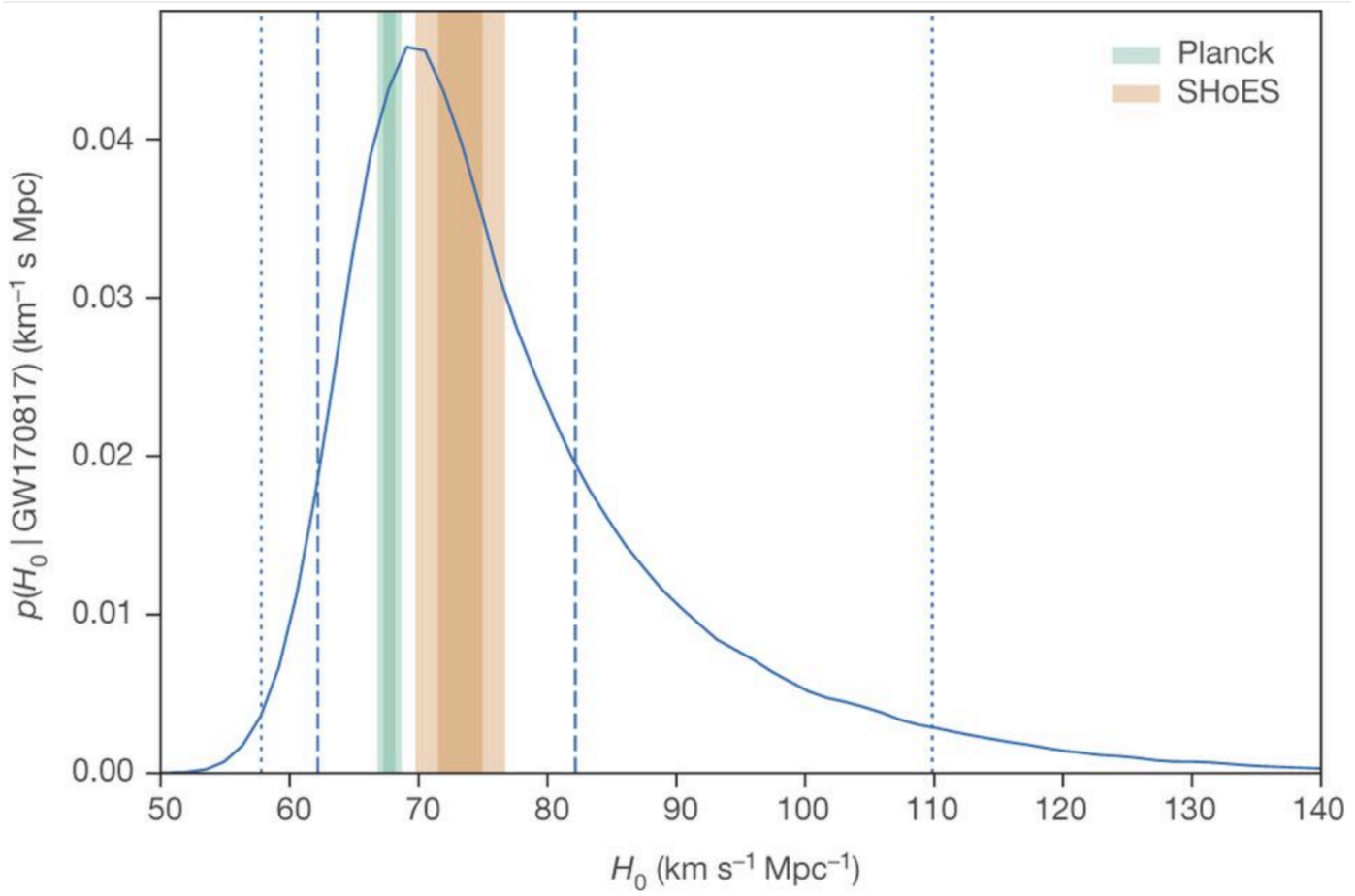
The First Standard Siren

A gravitational-wave standard siren measurement of the Hubble constant

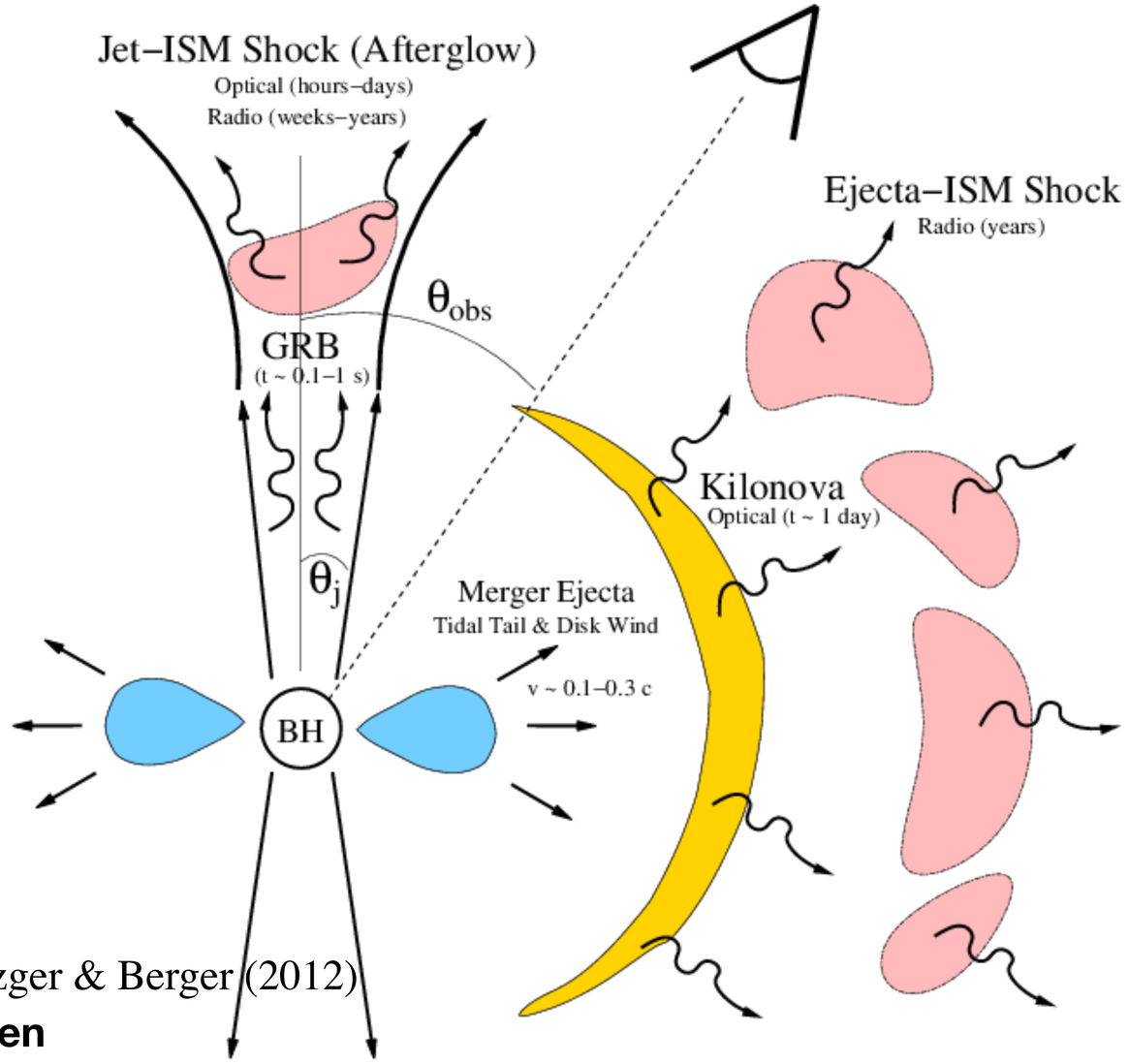
The LIGO Scientific Collaboration and The Virgo Collaboration, The 1M2H Collaboration, The Dark Energy Camera GW-EM Collaboration and the DES Collaboration, The DLT40 Collaboration, The Las Cumbres Observatory Collaboration, The VINROUGE Collaboration & The MASTER Collaboration

Nature **551**, 85–88 (02 November 2017) | doi:10.1038/nature24471

Precision of this LIGO distance estimate is limited by the peculiar velocity and by the degeneracy with inclination of the system.

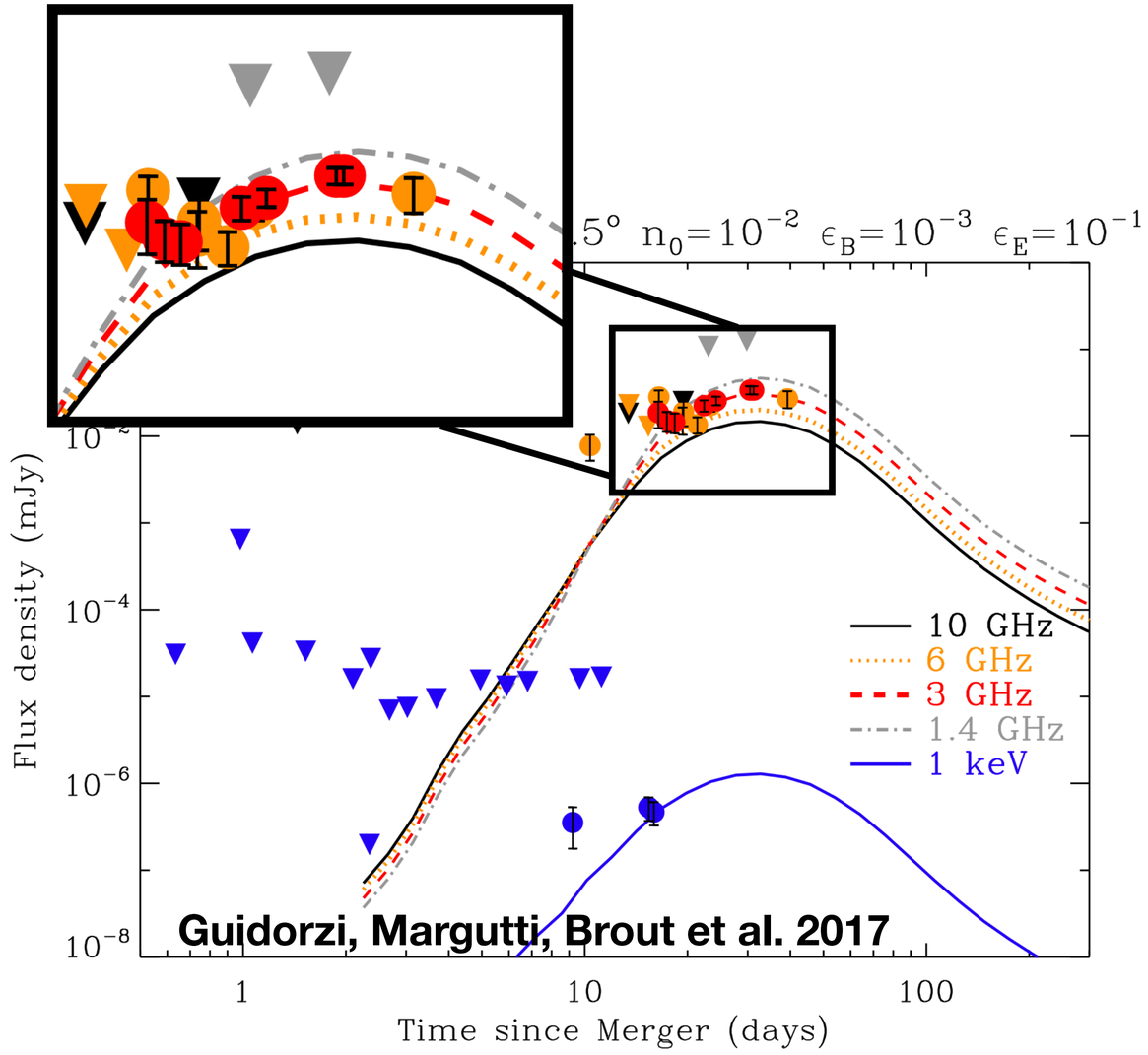


LIGO Distance Estimates Degeneracies Broken By Kilonova Modeling



Metzger & Berger (2012)

Kasen

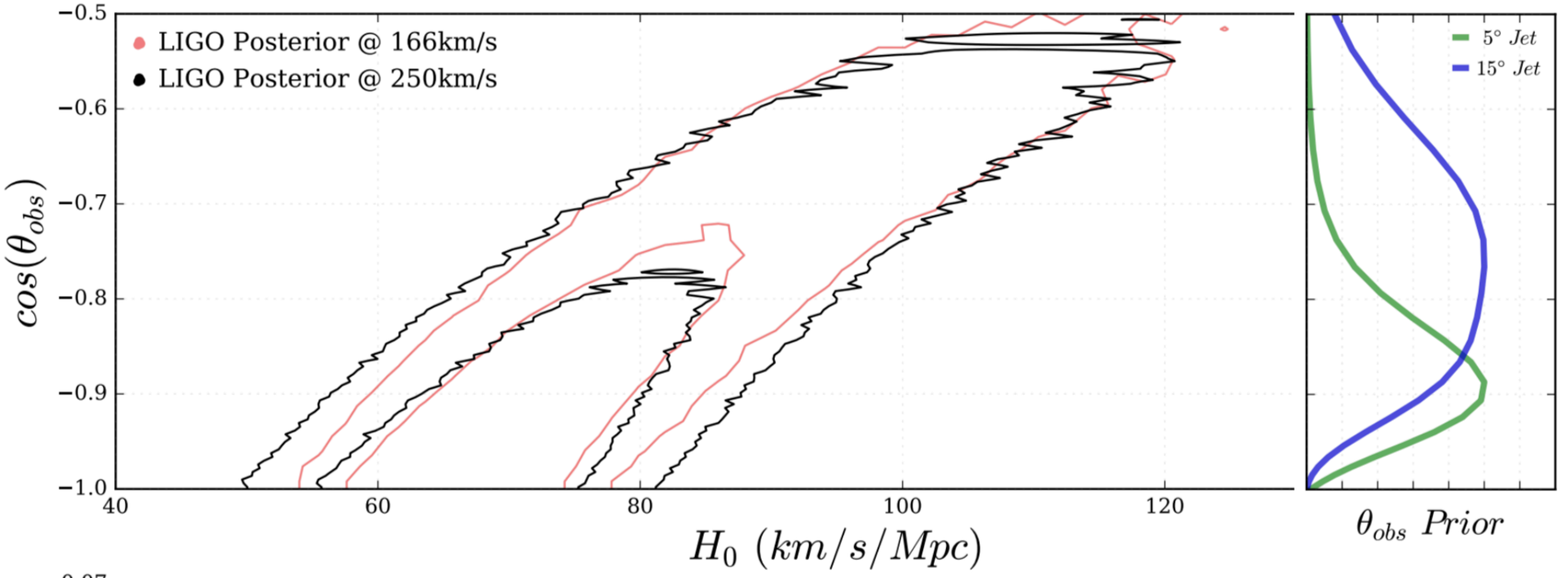


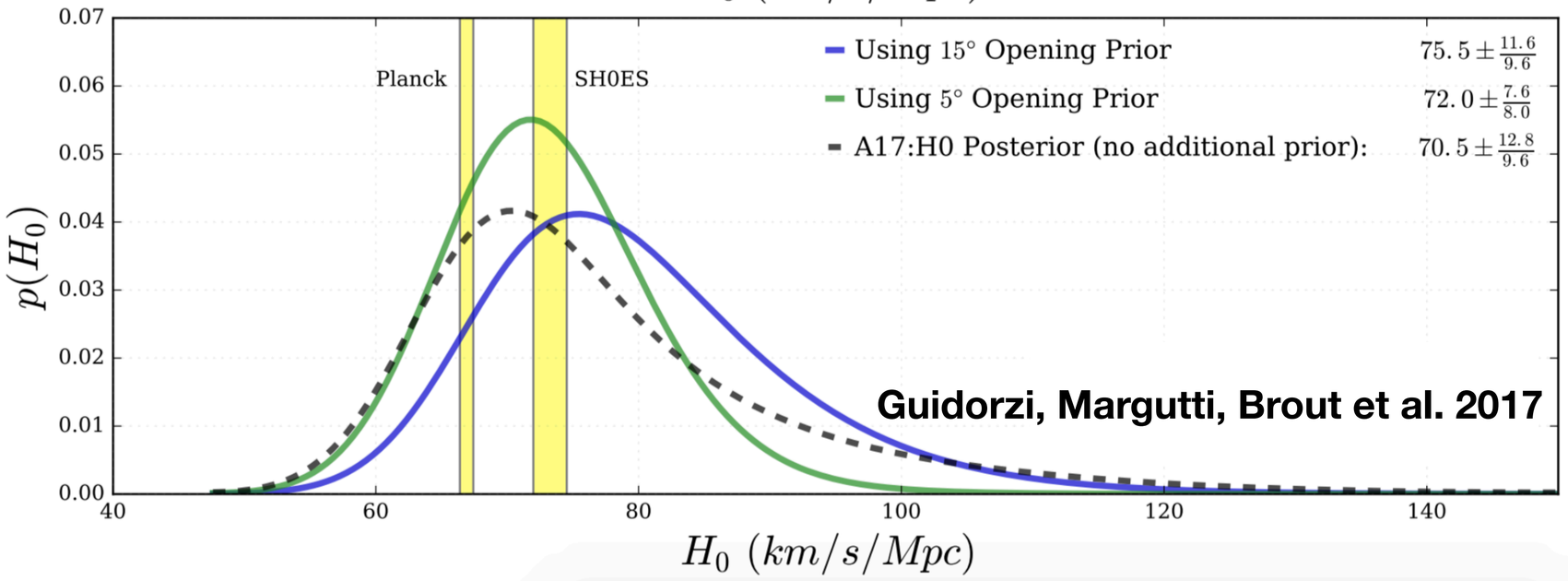
H0 From LIGO, DES, and KN Modeling

Show preference for 15deg opening (blue)

All modeling shows preference for off axis viewing

Off axis viewing leads to lower estimates of distance -> higher Ho





Summary: The future of DECam is exciting!

Kilonovae:

Last season's event was close and bright, the majority of future events will be further & fainter. DECam remains the most powerful Kilonova discovery tool in the southern hemisphere.

Potentially a few more this year with doubling of LIGO sensitivity.

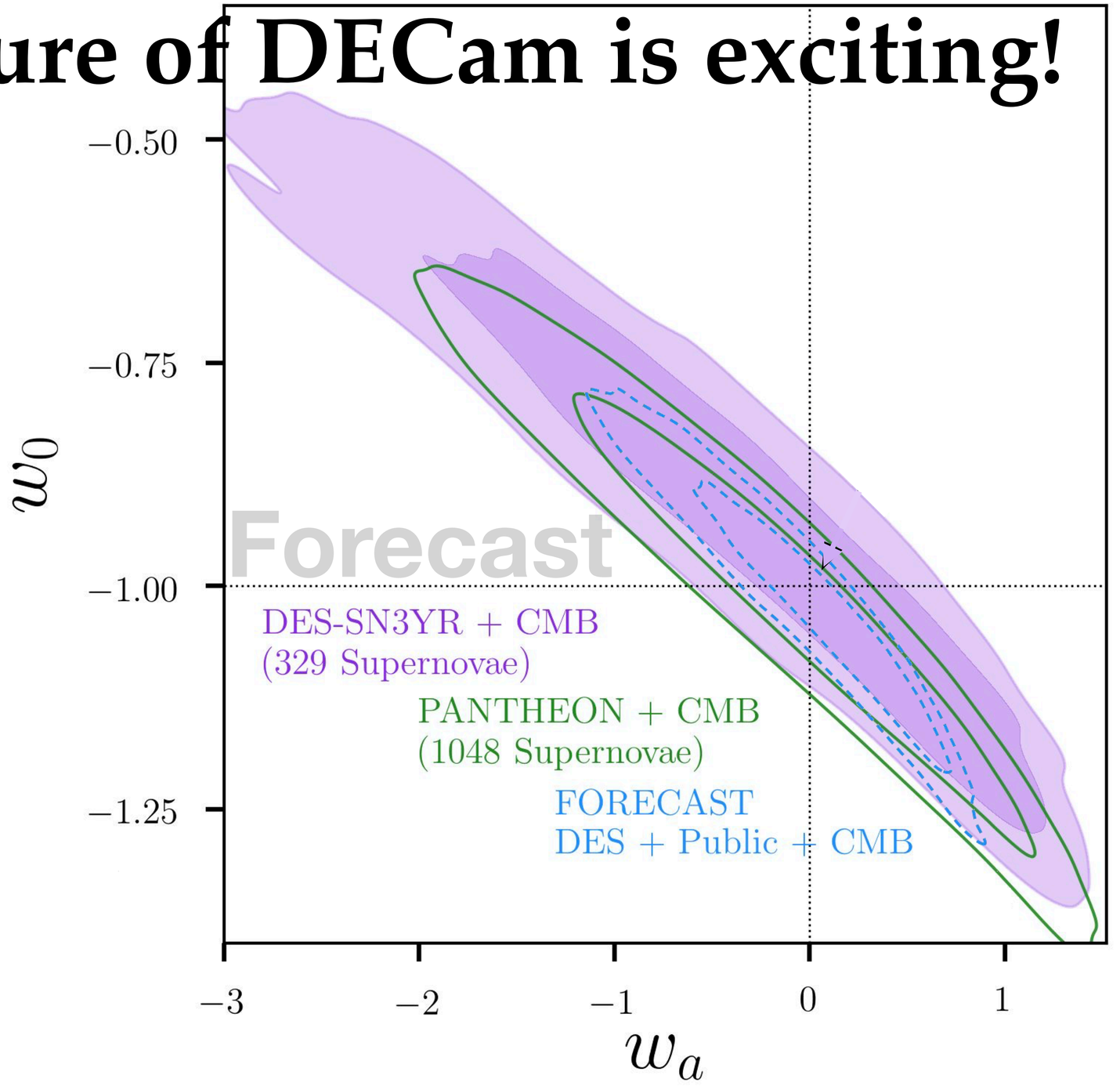
Supernovae:

DES 5 Year Dataset of ~2500 Type Ia SNe will double all currently available SN.

A strong tool to study SN environment dependencies and physics.

Other Probes:

DES 3YR WL, Clusters, BAO, coming "soon"



THE DARK ENERGY SURVEY

Thank You

Penn
University of Pennsylvania

NASA

Fermilab