Cosmic Shear Tomography from the Deep Lens Survey

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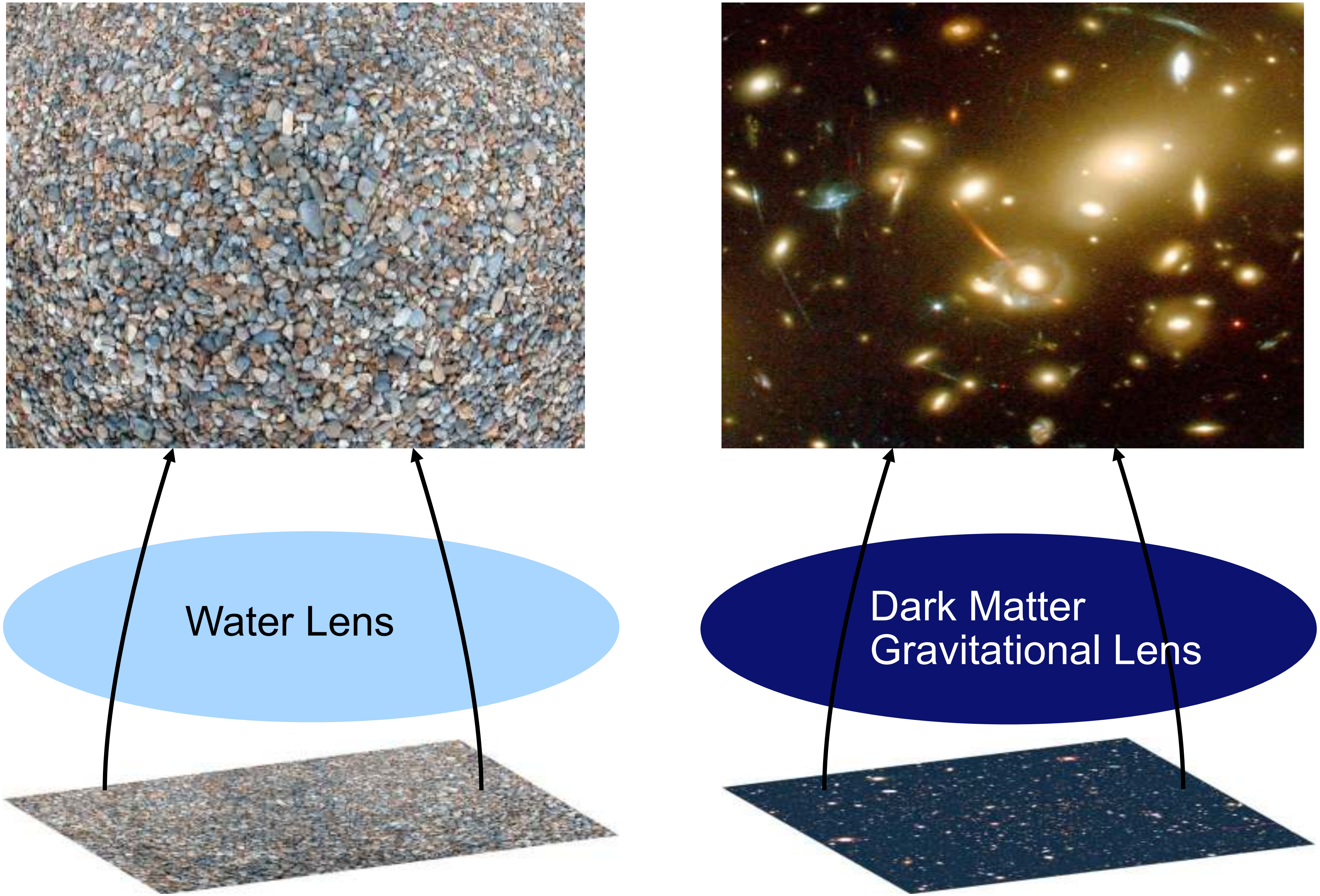
Talk is based on ***Jee et al. 2013, ApJ, 765, 74*** *&* ***Jee et al. 2016, ApJ, 824, 77***

The 7th KIAS Workshop on

Cosmology and Structure Formation

IN THE SKY ...

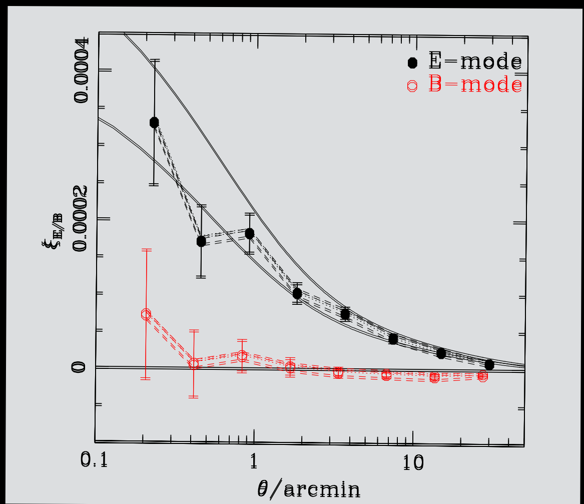


Cosmic Shear Made Easy

Observation

Galaxies Distorted

Big Bang

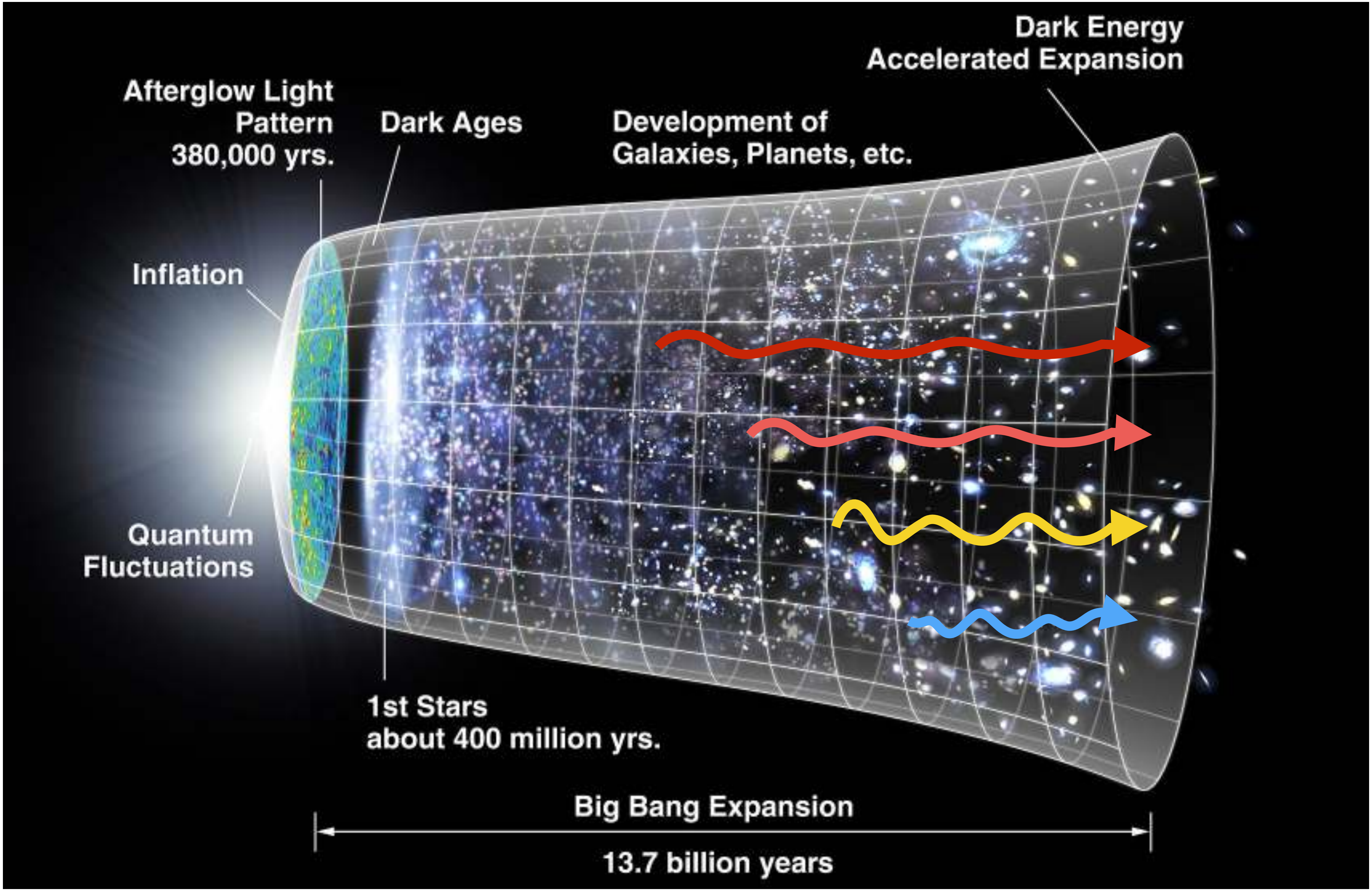


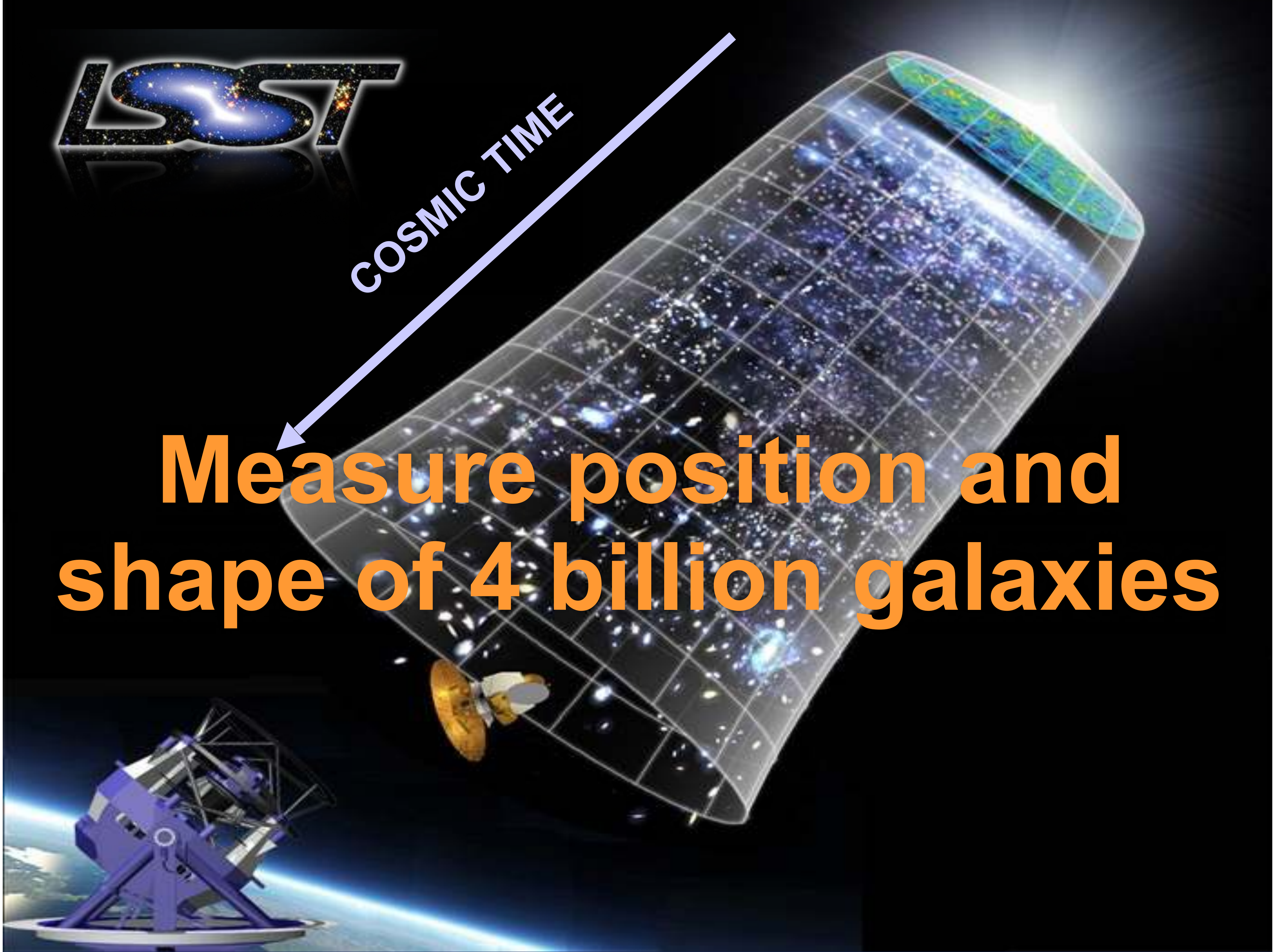
Analysis

You Estimate:

- Velocity of the Stone
- Mass of the Stone
- Size of the Stone
- Time since the Impact
- Height of the Girl

Cosmology


Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
380,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years

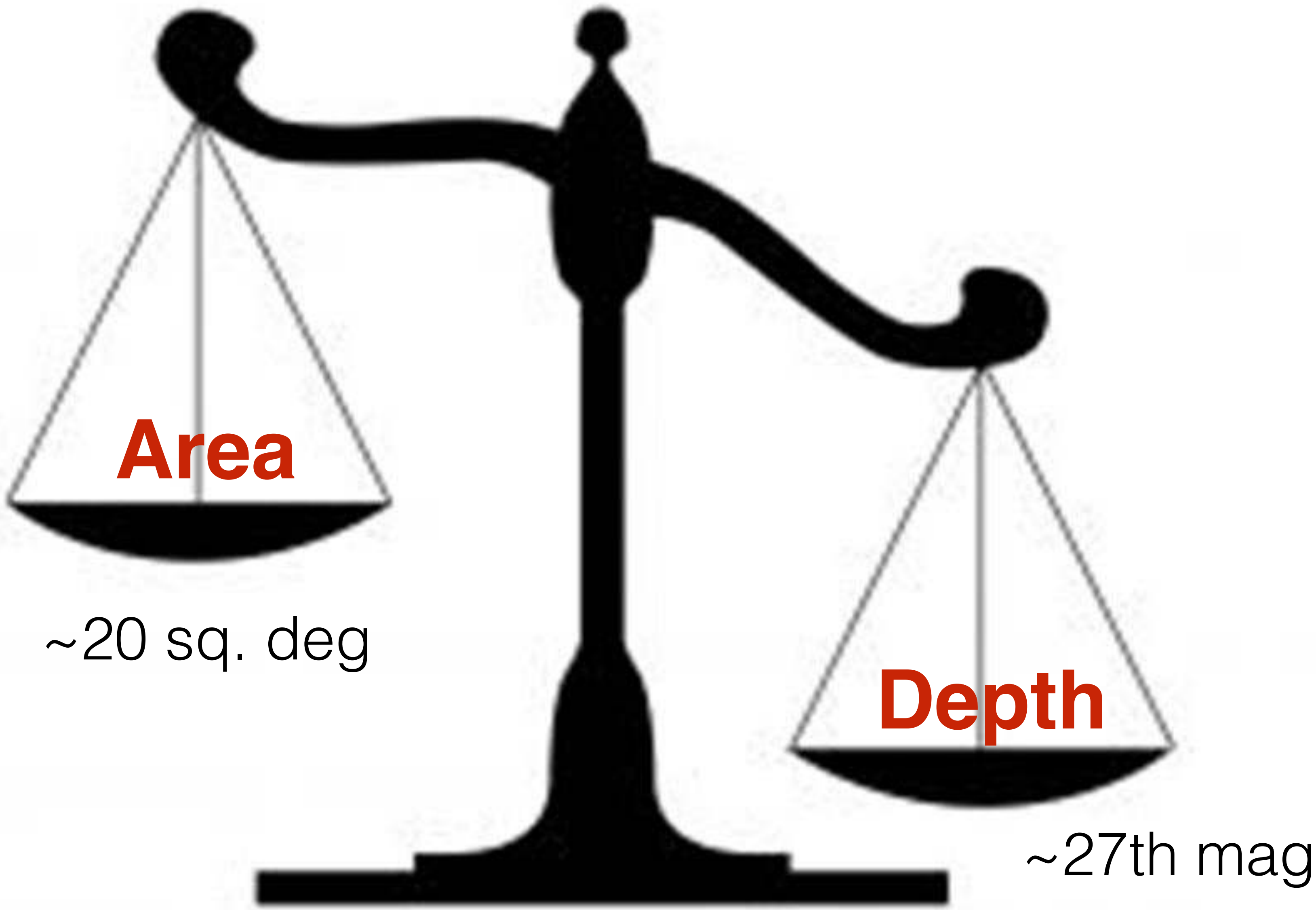

LSST
COSMIC TIME
Measure position and shape of 4 billion galaxies

Deep Lens Survey (DLS)

Mayall at Kitt Peak

Blanco at CTIO

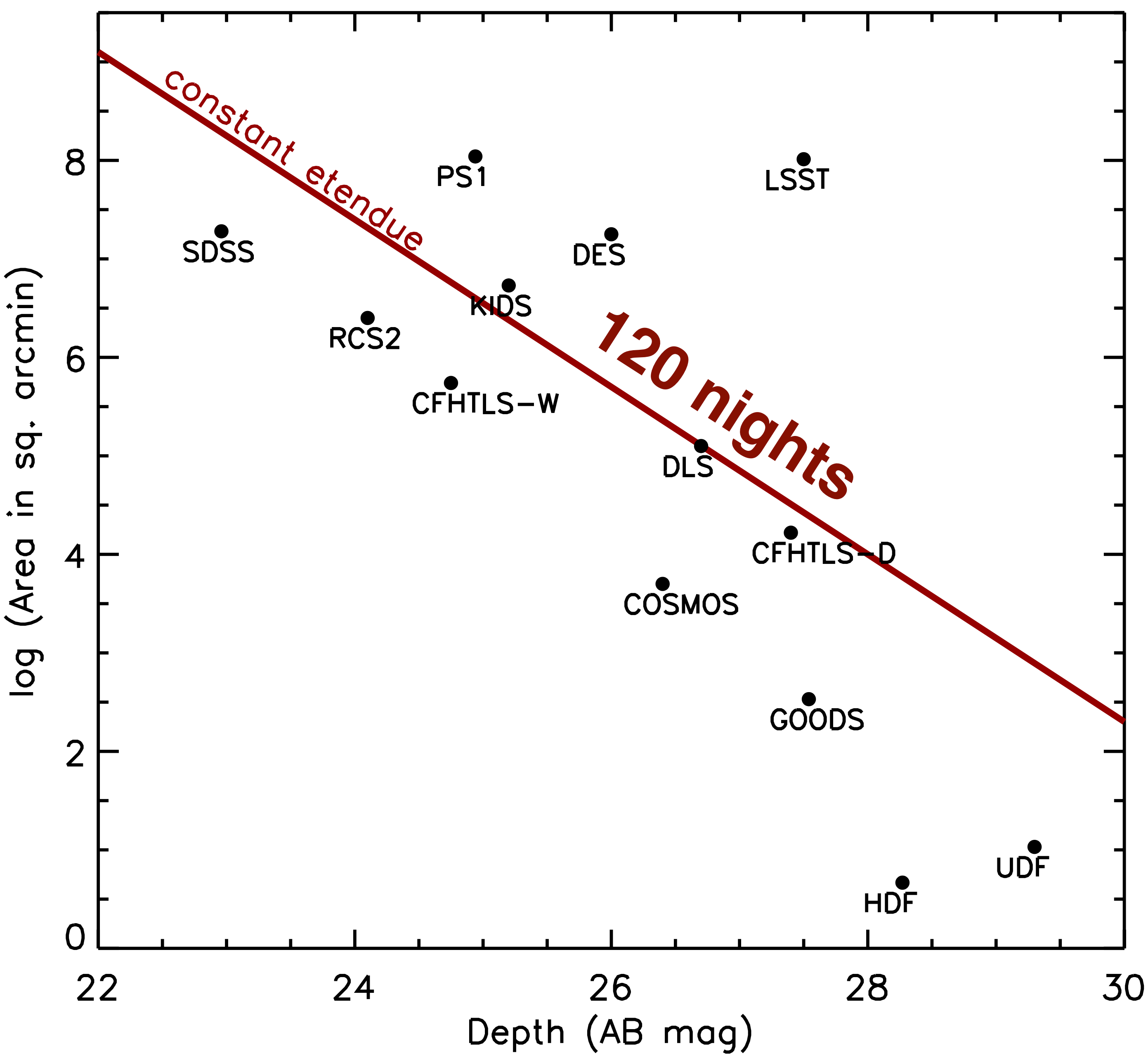
- Weak-lensing survey with two NOAO telescopes
- Precursor to LSST
- 120 nights in 2001!


Area
~20 sq. deg
Depth
~27th mag

Sloan Digital Sky Survey

Deep Lens Survey

Area vs. Depth



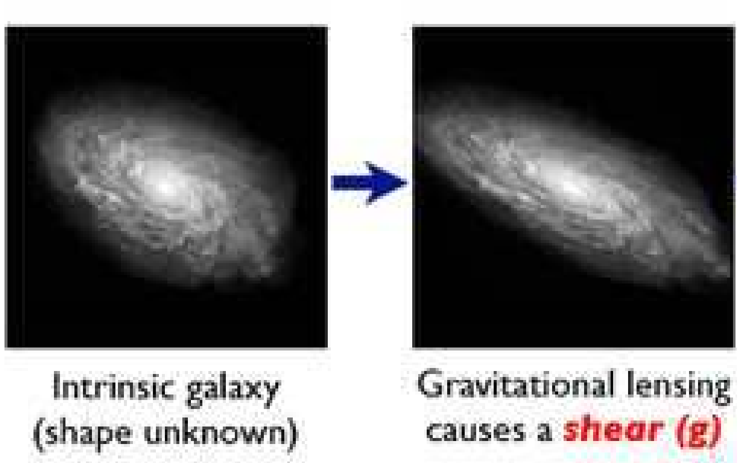
Why Depth?

- Longer redshift baseline
- Volume gain along the light-of-sight direction
- Higher lensing signals due to geometric effect
- Reduced shot noise
- Mitigation of intrinsic alignment

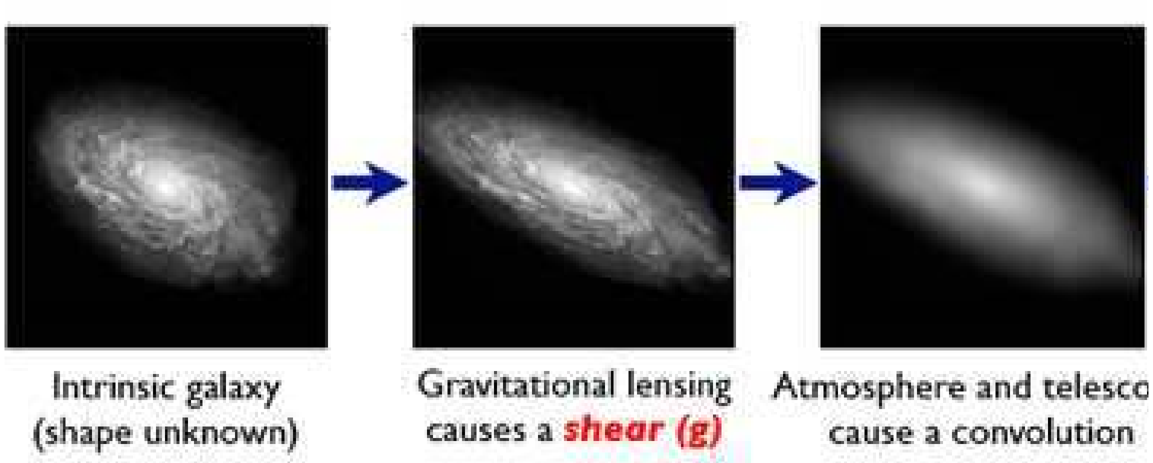
HOWEVER, LENSING IS HARD!

Intrinsic galaxy
(shape unknown)

HOWEVER, LENSING IS HARD!



HOWEVER, LENSING IS HARD!



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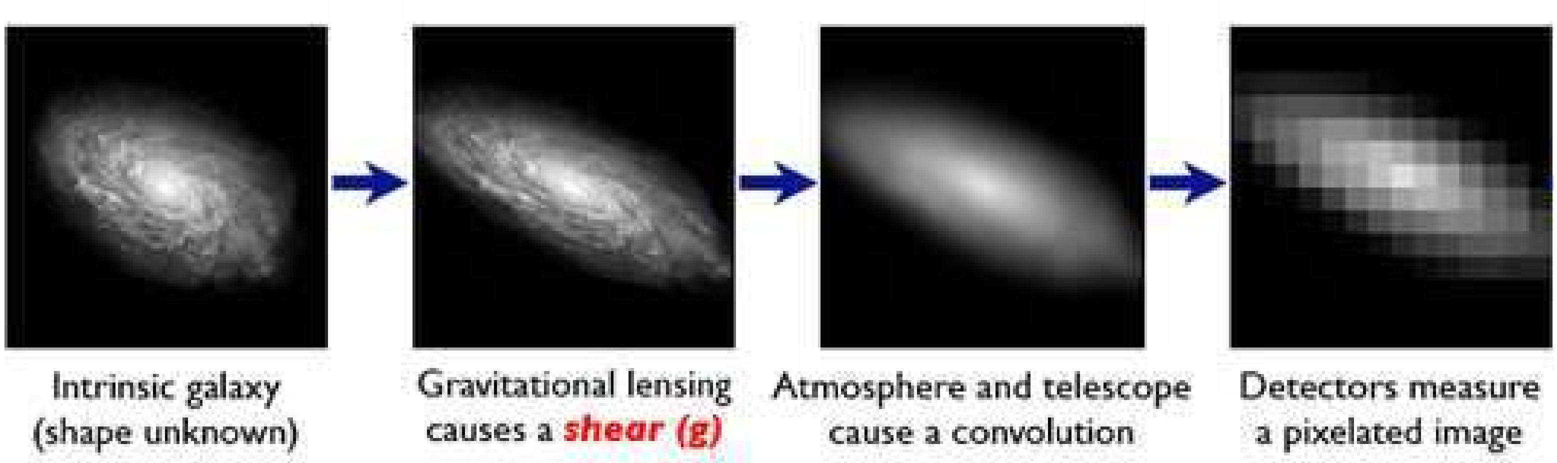
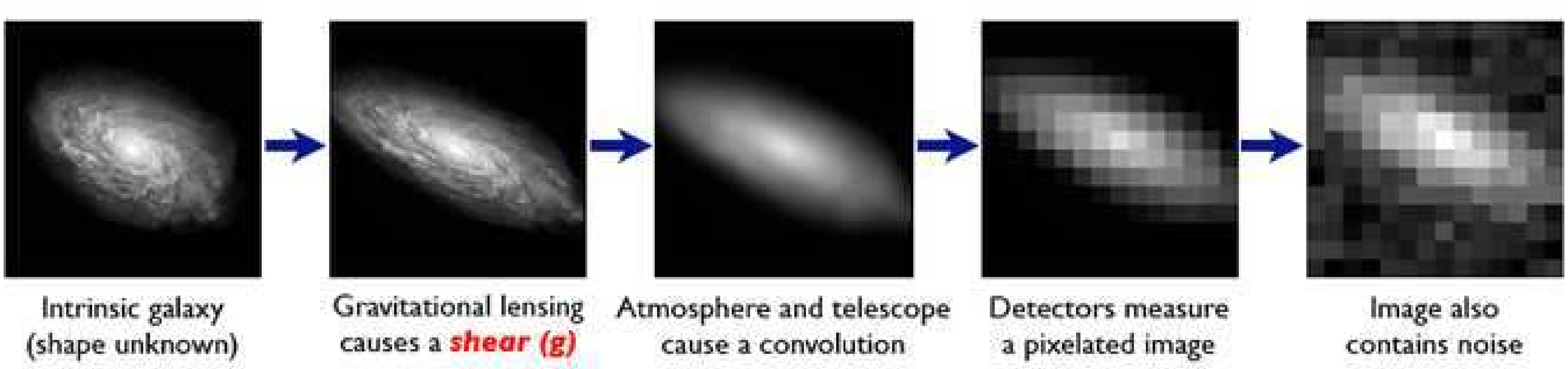


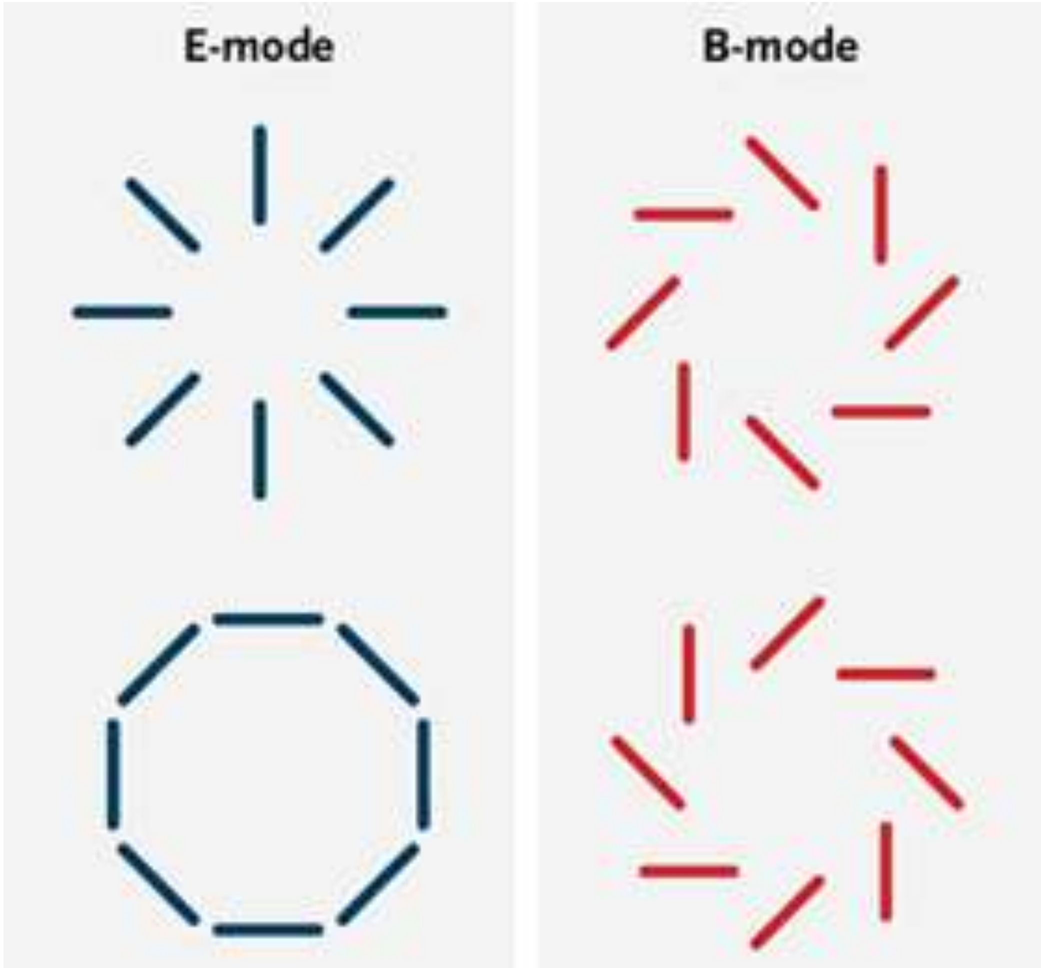
HOWEVER, LENSING IS HARD!



Cosmic shear must pass various systematics tests.

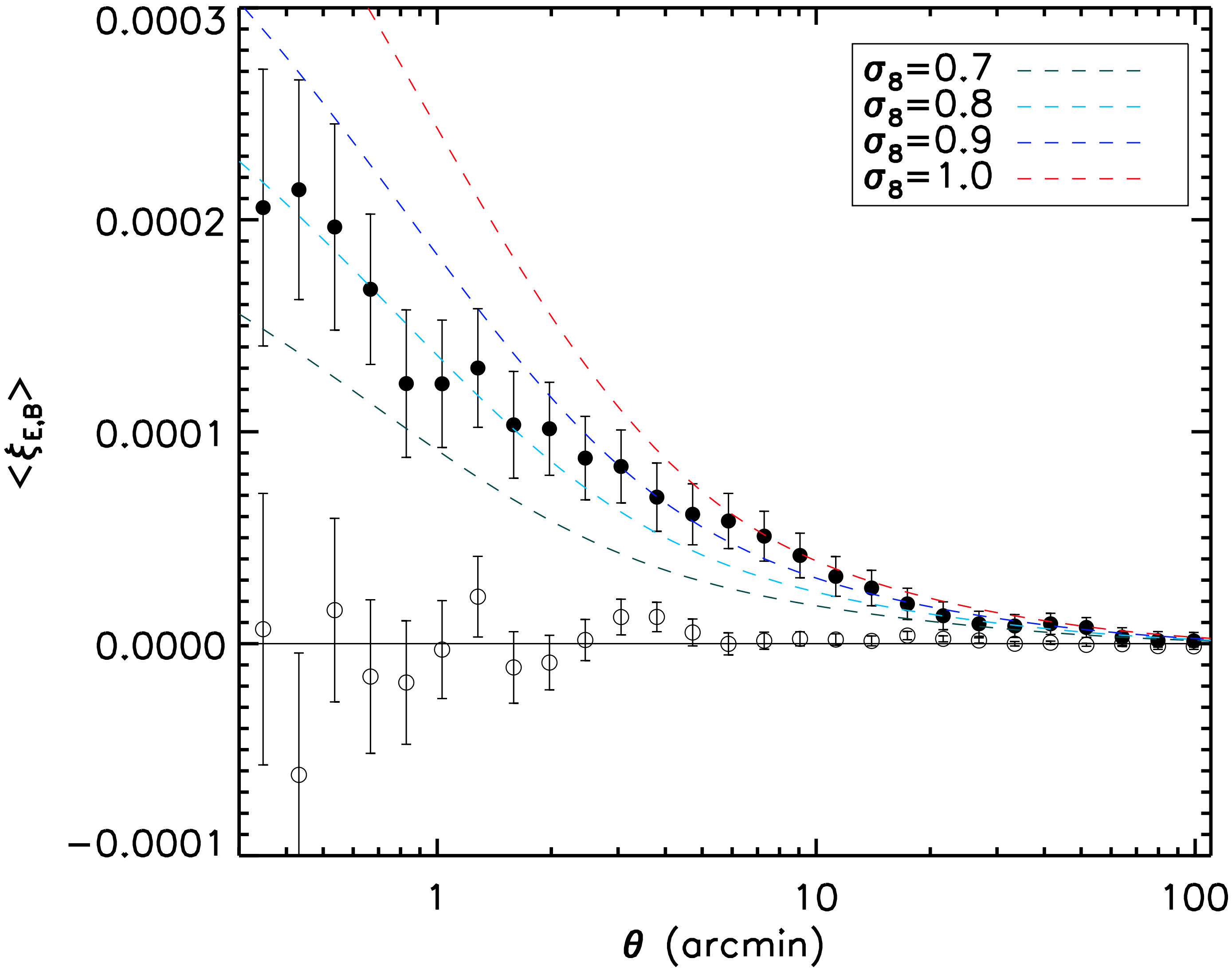
We have passed all important tests.

E/B-mode Test



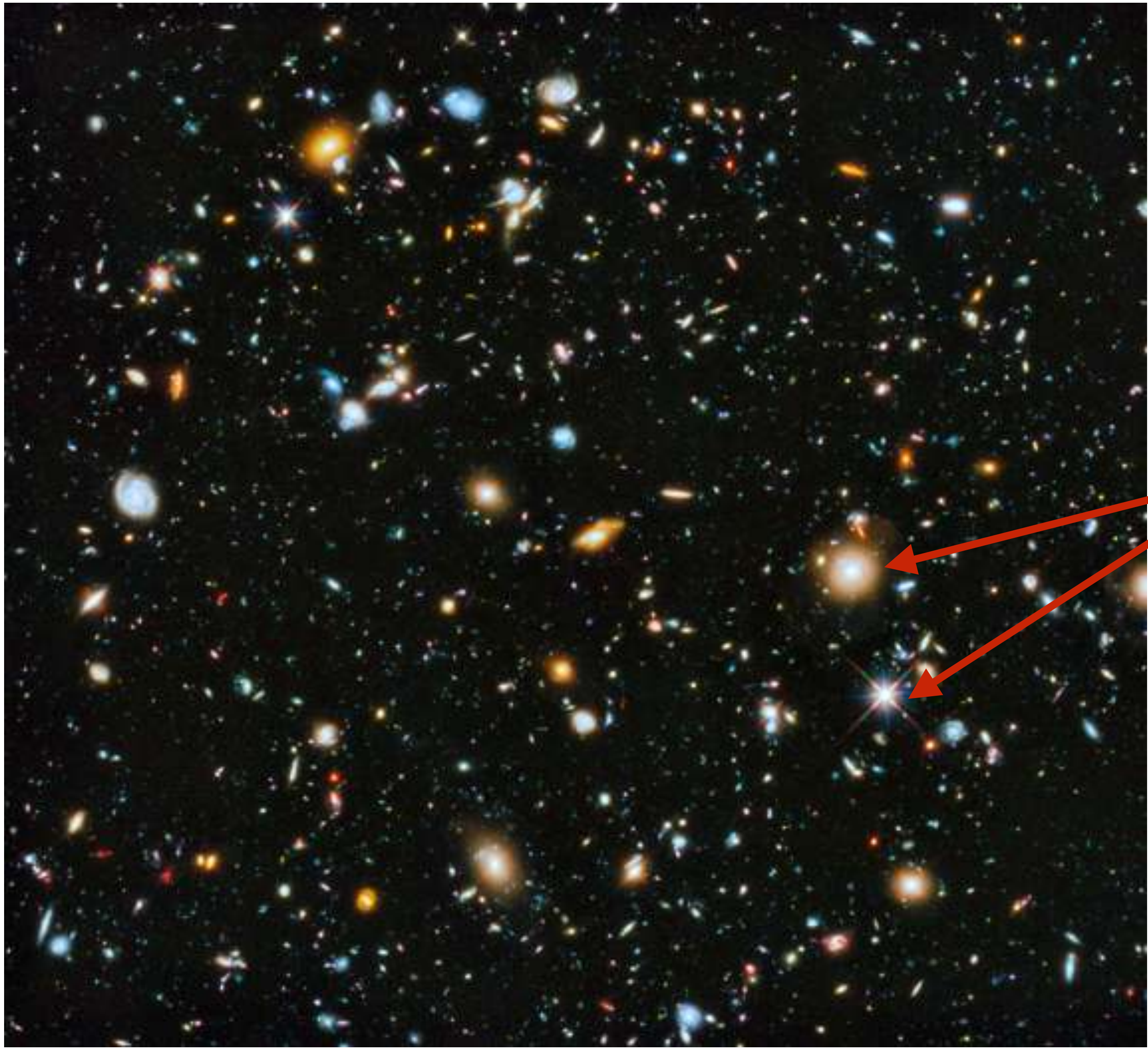
Lensing Systematics

E/B-mode Test



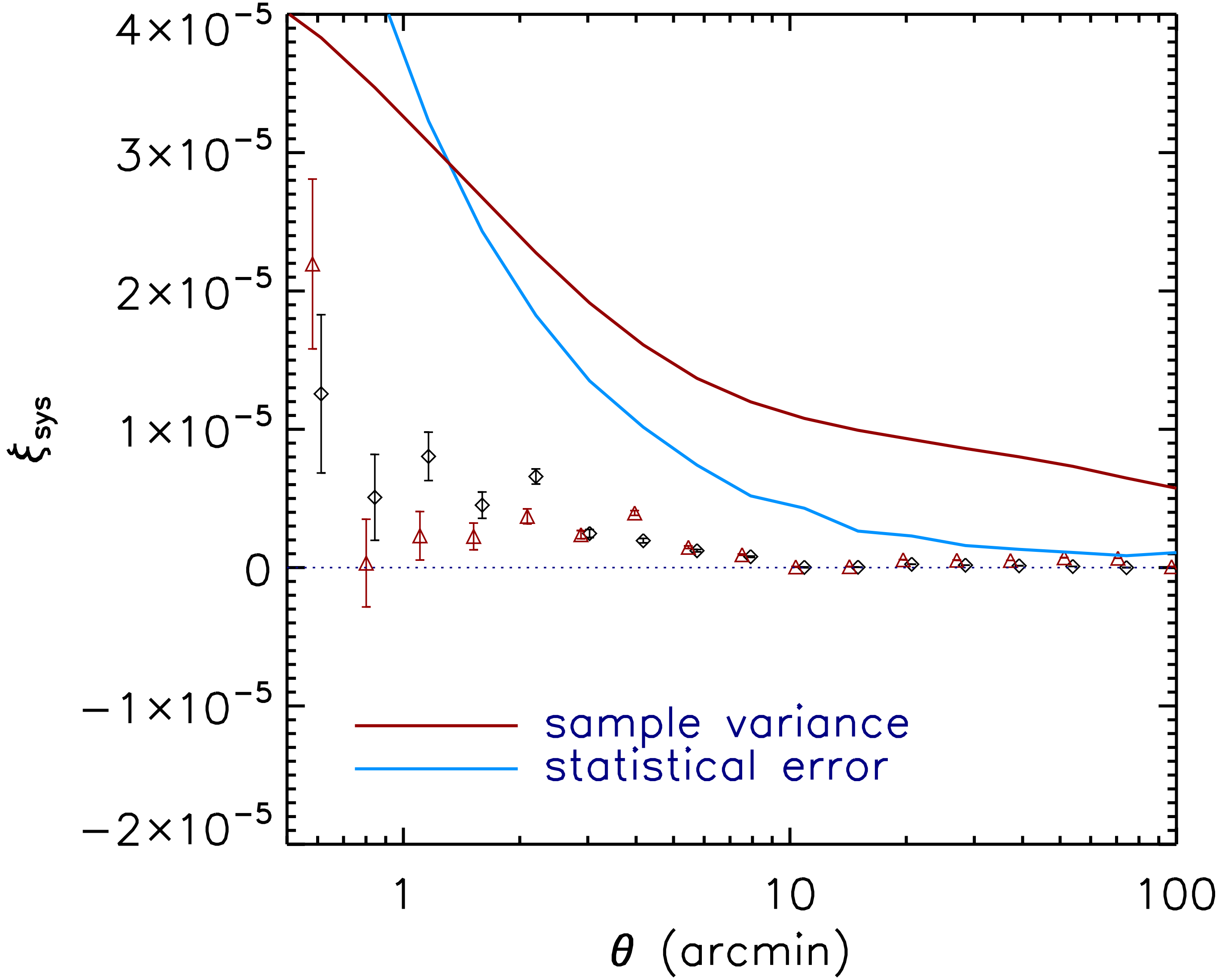
0.0003
0.0002
0.0001
0.0000
−0.0001
1
10
100
θ (arcmin)
<ξE,B>
σ8=0.7
σ8=0.8
σ8=0.9
σ8=1.0

Star-Galaxy Correlation Test



They should not be correlated.

Star-Galaxy Correlation Test



DLS Algorithm Won GREAT3

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **450,** 2963–3007 (2015) doi:10.1093/mnras/stv781

GREAT3 results – I. Systematic errors in shear estimation and the impact of real galaxy morphology

Rachel Mandelbaum,[1★] Barnaby Rowe,[2★] Robert Armstrong,[3] Deborah Bard,[4,5] Emmanuel Bertin,[6] James Bosch,[3] Dominique Boutigny,[5,7] Frederic Courbin,[8] William A. Dawson,[9] Annamaria Donnarumma,[6] Ian Fenech Conti,[10] Raphaël Gavazzi,[6] Marc Gentile,[8] Mandeep S. S. Gill,[4,5] David W. Hogg,[11] Eric M. Huff,[12] M. James Jee,[13] Tomasz Kacprzak,[2,14] Martin Kilbinger,[15] Thibault Kuntzer,[8] Dustin Lang,[1] Wentao Luo,[16] Marisa C. March,[17] Philip J. Marshall,[4] Joshua E. Meyers,[4] Lance Miller,[18] Hironao Miyatake,[3,19] Reiko Nakajima,[20] Fred Maurice Ngolé Mboula,[15] Guldariya Nurbaeva,[8] Yuki Okura,[21] Stéphane Paulin-Henriksson,[15] Jason Rhodes,[22,23] Michael D. Schneider,[9] Huanyuan Shan,[8] Erin S. Sheldon,[24] Melanie Simet,[1] Jean-Luc Starck,[15] Florent Sureau,[15] Malte Tewes,[20] Kristian Zarb Adami,[10,18] Jun Zhang[25] and Joe Zuntz[26]

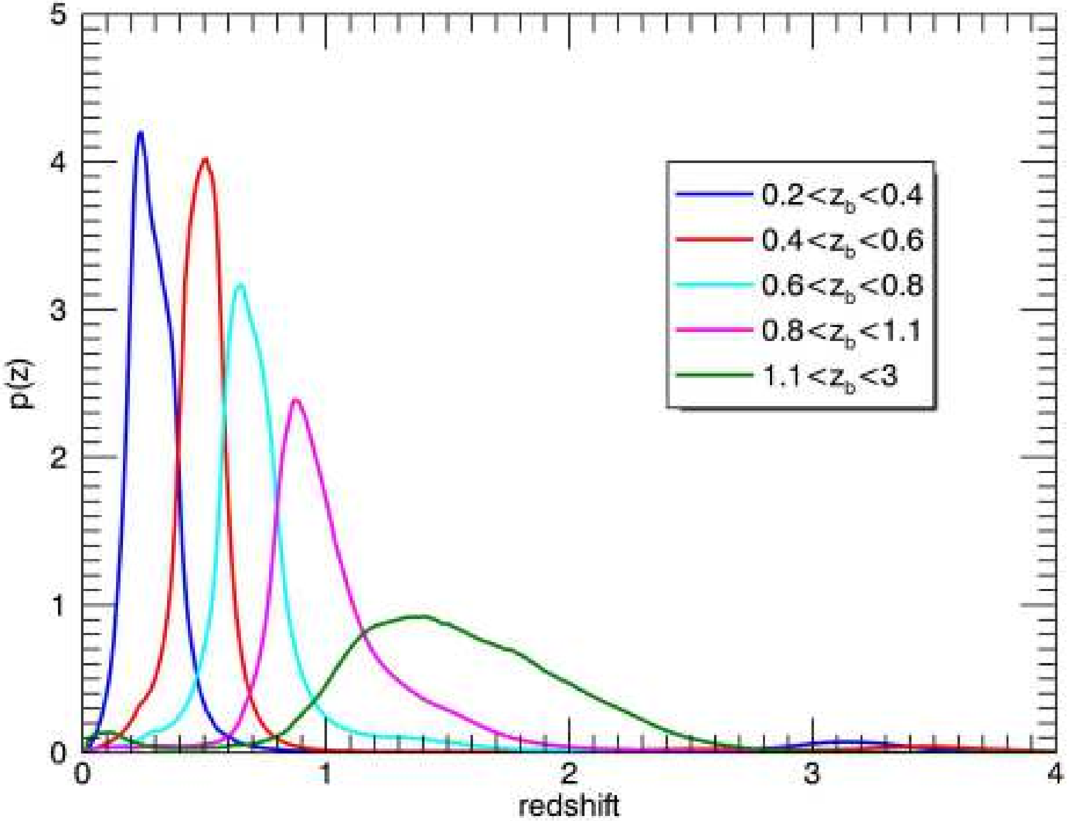
Affiliations are listed at the end of the paper

Team	Class	Weighting	Calibration philosophy	Limitations	N_{branch}	Rank	Exact PSF?	New software	Time per galaxy
			Ellipticity penalty	None	16	2	Yes	Some	0.1–1 s
			$p(\varepsilon)$ from deep data	Variable shear	2	-	Yes	Yes	<1 s
		+	None	None	8	6	Yes	Yes	1–3 s
			None	None	20	3	Yes	Yes	1–3 s
			None	None	8	-	Yes	No	0.03 s
			External simulations	Variable shear	2	N/A	Yes	Some	0.03 s
			External simulations	None	12	N/A	Yes	Yes	1 s
		+	External simulations	None	12	8	Yes	No	1–3 s
			None	None	7	-	Yes	Yes	2–3 s
			None	None	4	-	Yes	No	0.001–0.002 s
			None	None	5	-	Yes	Yes	2–3 s
	moments	variance	External simulations	None	12	N/A	Yes	Some	∼1 s
Fourier_Quad	Fourier moments	Various	None	None	6	5	Yes	No	0.001–0.002 s
HSC/LSST-HSM	Moments	Inverse variance	External simulations	None	4	N/A	Yes	Some	0.05 s
MBI	Bayesian hierarchical	Implicit	Inferred $p(\varepsilon)$	Variable shear, PSF	4	9	No	Some	10 s
MaltaOx (LensFit)	Partially Bayesian	Inverse variance	Self-calibration	None	3	7	Yes	Some	0.05 s
MegaLUT	Supervised	Constant +	External	None	16	4	Yes	Some	0.02 s
	model-fitting		deep data	shear					
sFIT	Maximum likelihood	Inverse variance	External simulations	None	20	1	Yes	Yes	0.8 s

sFIT	Maximum likelihood	Inverse variance	External simulations (iterative)	None	20	1	Yes	Yes	0.8 s

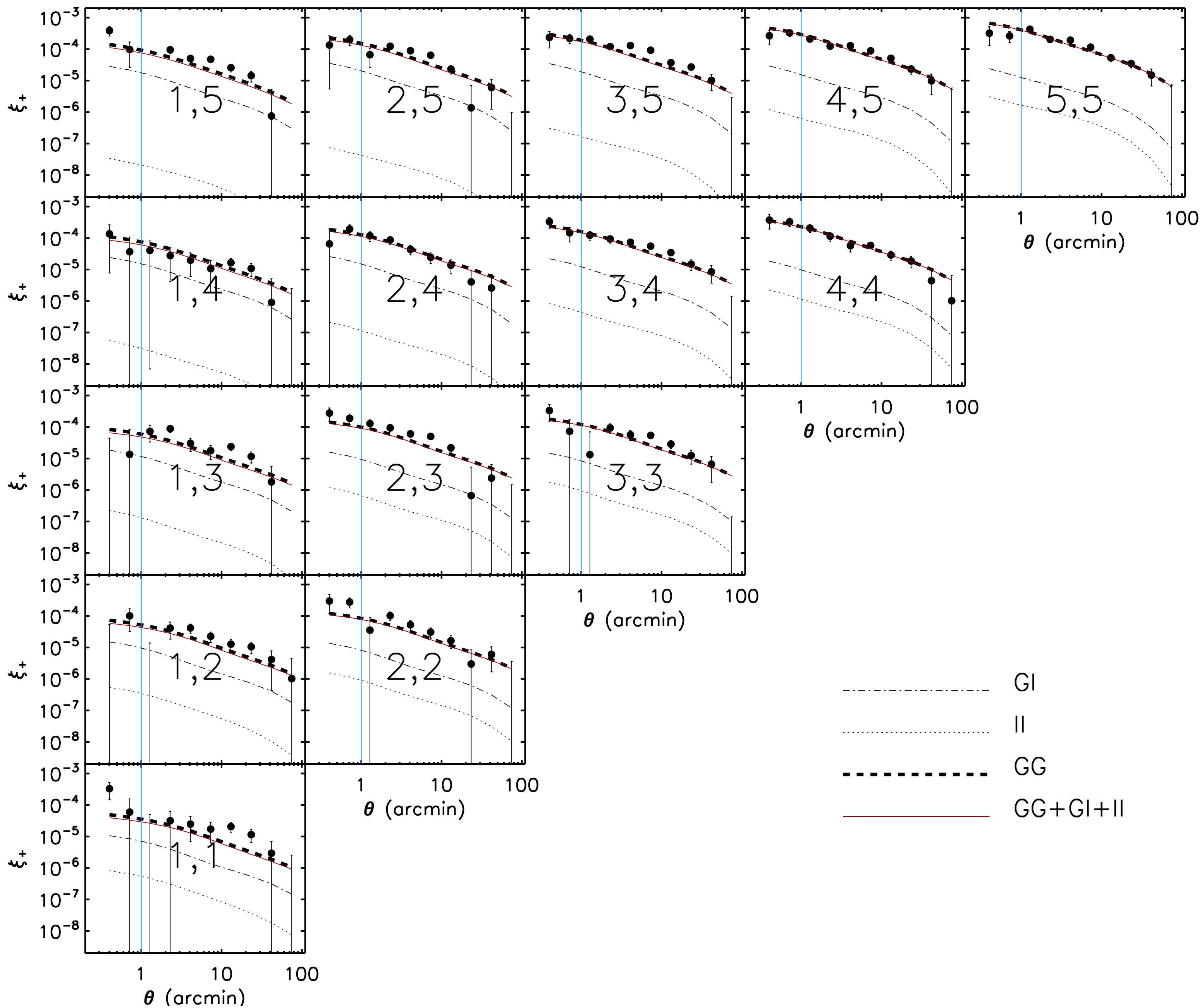
Cosmological Parameters from DLS

DLS Tomographic Bins

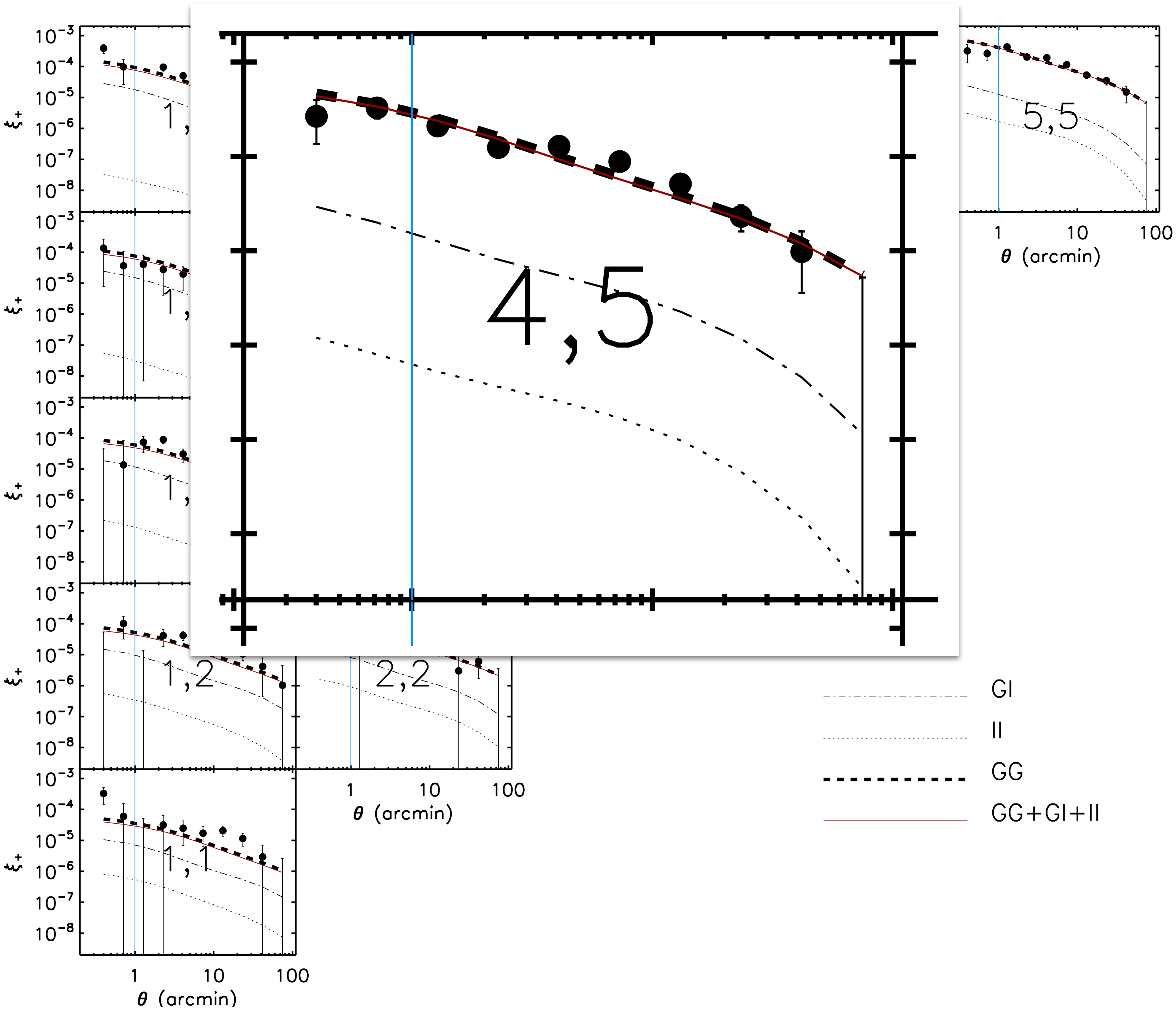


Bin	Range in z_b	$\langle z_b \rangle$
1	0.2–0.4	0.29
2	0.4–0.6	0.48
3	0.6–0.8	0.68
4	0.8–1.1	0.93
5	1.1–3.0	1.50

Auto- and Cross-correlations of Shear



Auto- and Cross-correlations of Shear

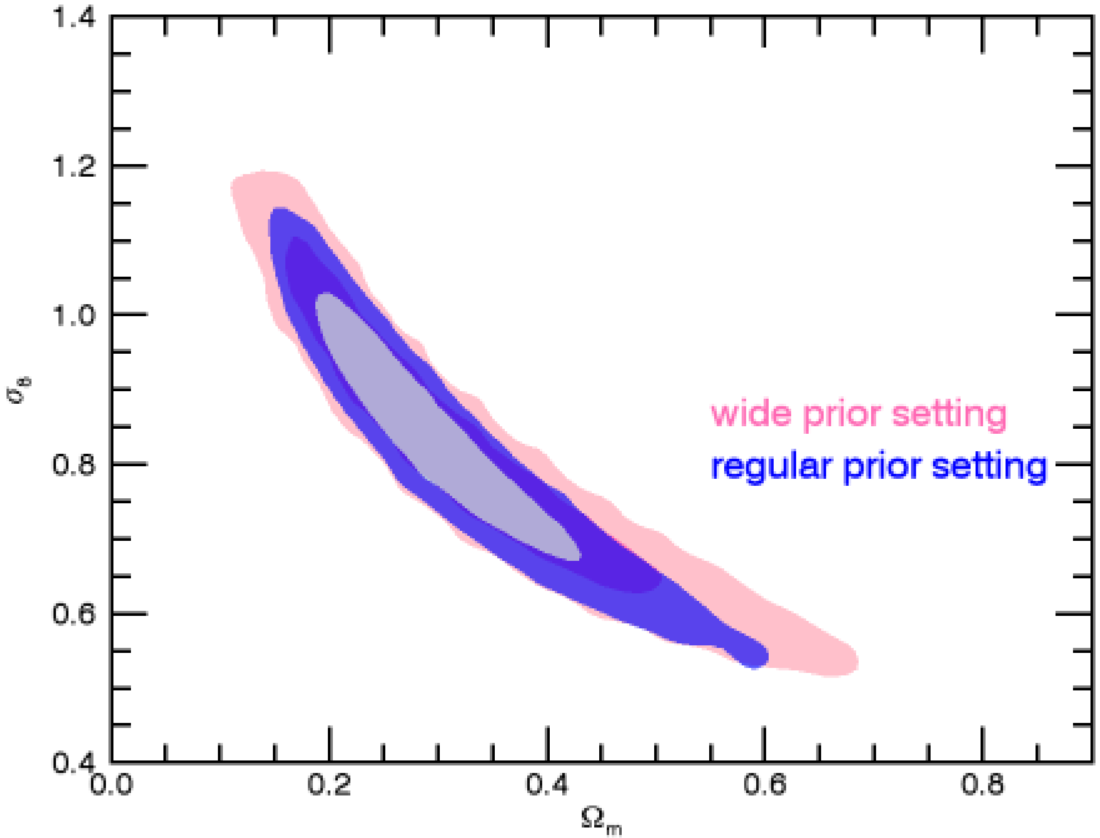


Cosmological Parameters from DLS

Summary of cosmological parameter constraints from joint probes.

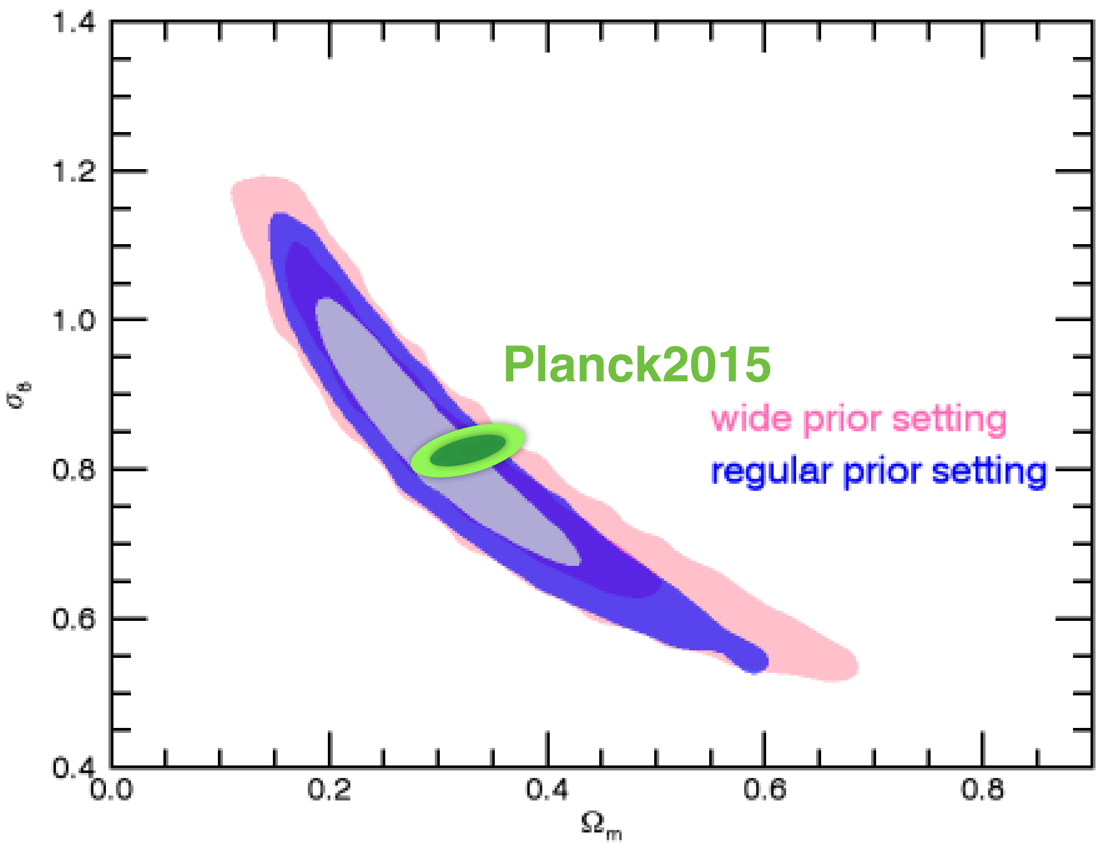
Parameter	Joint probe	ΛCDM ($\Omega_k \equiv 0$)	ΛCDM ($\Omega_k \neq 0$)	wCDM ($\Omega_k \equiv 0$)	wCDM ($\Omega_k \neq 0$)
Ω_m	DLS+BAO	$0.291^{+0.039}_{-0.035}$	$0.291^{+0.039}_{-0.033}$	$0.286^{+0.043}_{-0.037}$	$0.259^{+0.052}_{-0.047}$
	DLS+WMAP9	$0.293^{+0.012}_{-0.014}$	$0.315^{+0.038}_{-0.024}$	$0.191^{+0.085}_{-0.051}$	-
	DLS+BAO+WMAP9	$0.297^{+0.010}_{-0.012}$	$0.297^{+0.011}_{-0.012}$	$0.290^{+0.020}_{-0.017}$	$0.269^{+0.029}_{-0.024}$
	DLS+BAO+WMAP9+SN	$0.283^{+0.007}_{-0.005}$	$0.286^{+0.009}_{-0.011}$	$0.286^{+0.008}_{-0.011}$	$0.279^{+0.012}_{-0.009}$
σ_8	DLS+BAO	$0.827^{+0.064}_{-0.058}$	$0.827^{+0.059}_{-0.068}$	$0.831^{+0.060}_{-0.061}$	$0.908^{+0.092}_{-0.108}$
	DLS+WMAP9	$0.833^{+0.011}_{-0.018}$	$0.805^{+0.025}_{-0.025}$	$0.922^{+0.129}_{-0.091}$	-
	DLS+BAO+WMAP9	$0.833^{+0.011}_{-0.018}$	$0.837^{+0.022}_{-0.013}$	$0.845^{+0.025}_{-0.039}$	$0.853^{+0.051}_{-0.033}$
	DLS+BAO+WMAP9+SN	$0.837^{+0.013}_{-0.015}$	$0.841^{+0.010}_{-0.016}$	$0.841^{+0.022}_{-0.011}$	$0.849^{+0.026}_{-0.017}$
n_s	DLS+WMAP9	$0.966^{+0.010}_{-0.013}$	$0.968^{+0.012}_{-0.013}$	$0.962^{+0.014}_{-0.011}$	$0.968^{+0.012}_{-0.013}$
	DLS+BAO+WMAP9	$0.965^{+0.008}_{-0.012}$	$0.967^{+0.014}_{-0.010}$	$0.961^{+0.012}_{-0.012}$	$0.967^{+0.015}_{-0.011}$
	DLS+BAO+WMAP9+SN	$0.978^{+0.006}_{-0.010}$	$0.974^{+0.011}_{-0.016}$	$0.961^{+0.013}_{-0.009}$	$0.962^{+0.018}_{-0.009}$
Ω_b	DLS+WMAP9	$0.0475^{+0.0013}_{-0.0012}$	$0.0518^{+0.0049}_{-0.0044}$	$0.0330^{+0.0138}_{-0.0030}$	$0.0366^{+0.0086}_{-0.0063}$
	DLS+BAO+WMAP9	$0.0478^{+0.0009}_{-0.0010}$	$0.0487^{+0.0018}_{-0.0016}$	$0.0469^{+0.0036}_{-0.0033}$	$0.0437^{+0.0056}_{-0.0026}$
	DLS+BAO+WMAP9+SN	$0.0469^{+0.0008}_{-0.0007}$	$0.0467^{+0.0011}_{-0.0012}$	$0.0455^{+0.0014}_{-0.0012}$	$0.0461^{+0.0015}_{-0.0017}$
h	DLS+WMAP9	$0.686^{+0.014}_{-0.012}$	$0.680^{+0.040}_{-0.052}$	-	-
	DLS+BAO+WMAP9	$0.685^{+0.006}_{-0.011}$	$0.683^{+0.006}_{-0.014}$	$0.678^{+0.033}_{-0.009}$	$0.701^{+0.041}_{-0.023}$
	DLS+BAO+WMAP9+SN	$0.697^{+0.003}_{-0.004}$	$0.697^{+0.004}_{-0.004}$	$0.701^{+0.006}_{-0.006}$	$0.697^{+0.009}_{-0.004}$
Ω_k	DLS+WMAP9	0	$-0.010^{+0.013}_{-0.015}$	0	-
	DLS+BAO+WMAP9	0	$-0.004^{+0.005}_{-0.006}$	0	$-0.006^{+0.011}_{-0.011}$
	DLS+BAO+WMAP9+SN	0	$-0.001^{+0.006}_{-0.005}$	0	$-0.001^{+0.009}_{-0.009}$
w	DLS+BAO	-1	-1	$-1.06^{+0.17}_{-0.15}$	-
	DLS+WMAP9	-1	-1	$-1.54^{+0.55}_{-0.18}$	-
	DLS+BAO+WMAP9	-1	-1	$-1.02^{+0.10}_{-0.09}$	$-1.13^{+0.13}_{-0.21}$
	DLS+BAO+WMAP9+SN	-1	-1	$-1.03^{+0.03}_{-0.03}$	$-1.09^{+0.09}_{-0.07}$

Matter-density vs. Normalization



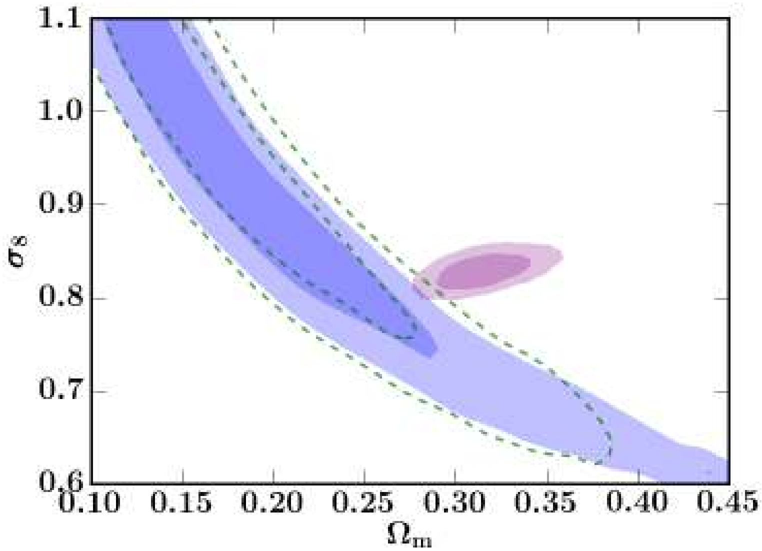
The tightest ever constraints from the existing cosmic shear studies.

Matter-density vs. Normalization



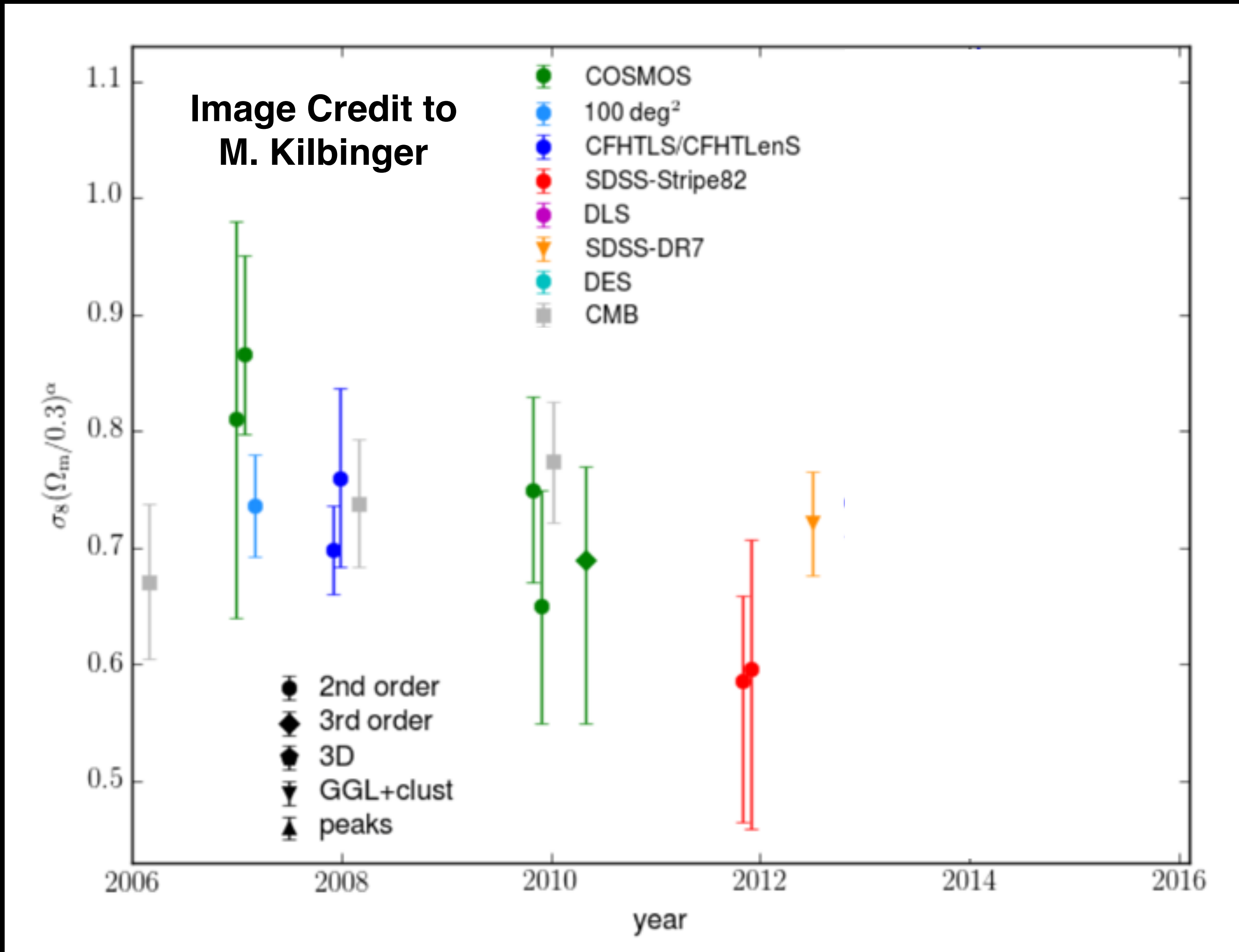
Consistent with the Planck 2015 result.

Matter-density vs. Normalization



MacCrann et al. (2015)

Constraints in Existing Cosmic Shear Surveys



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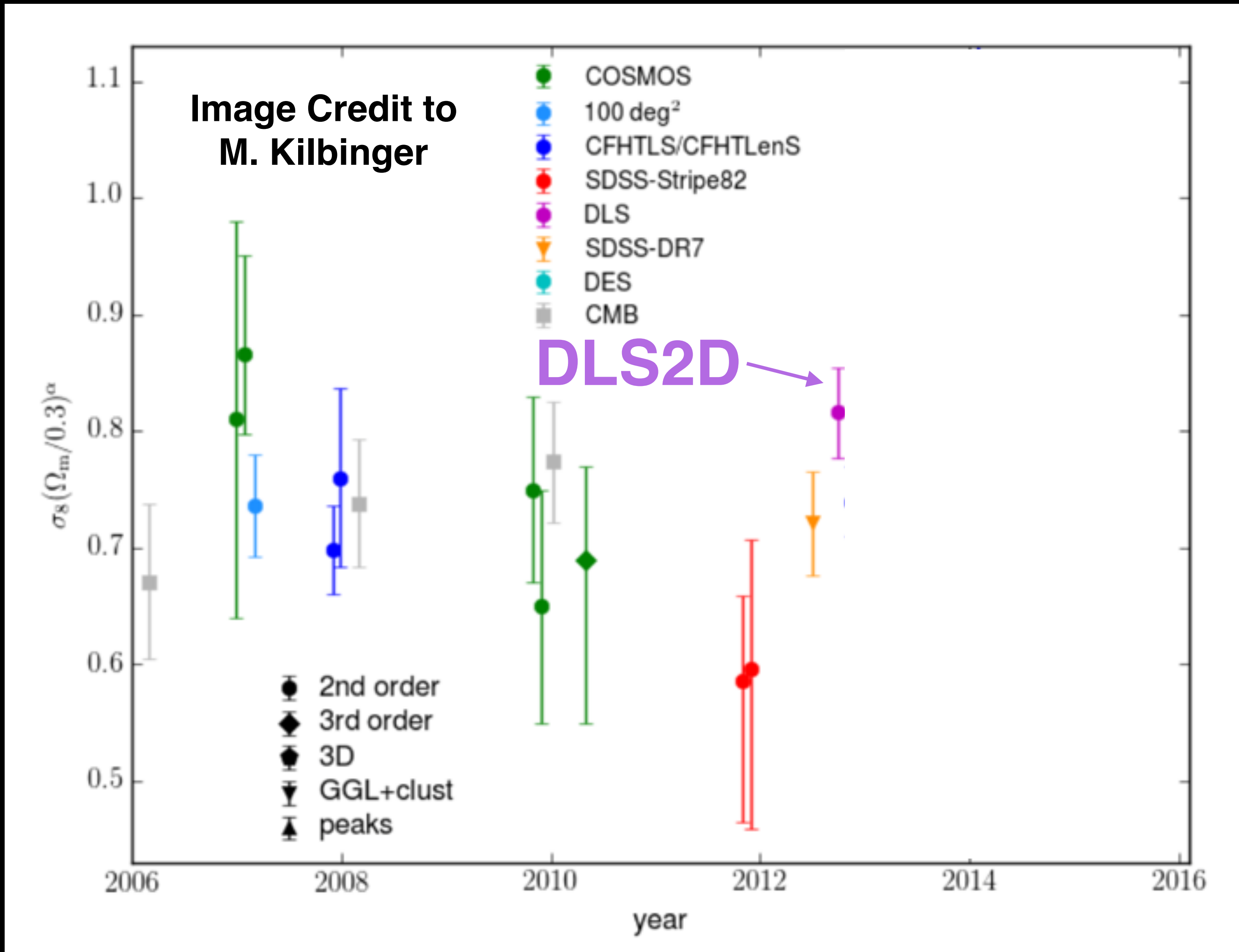
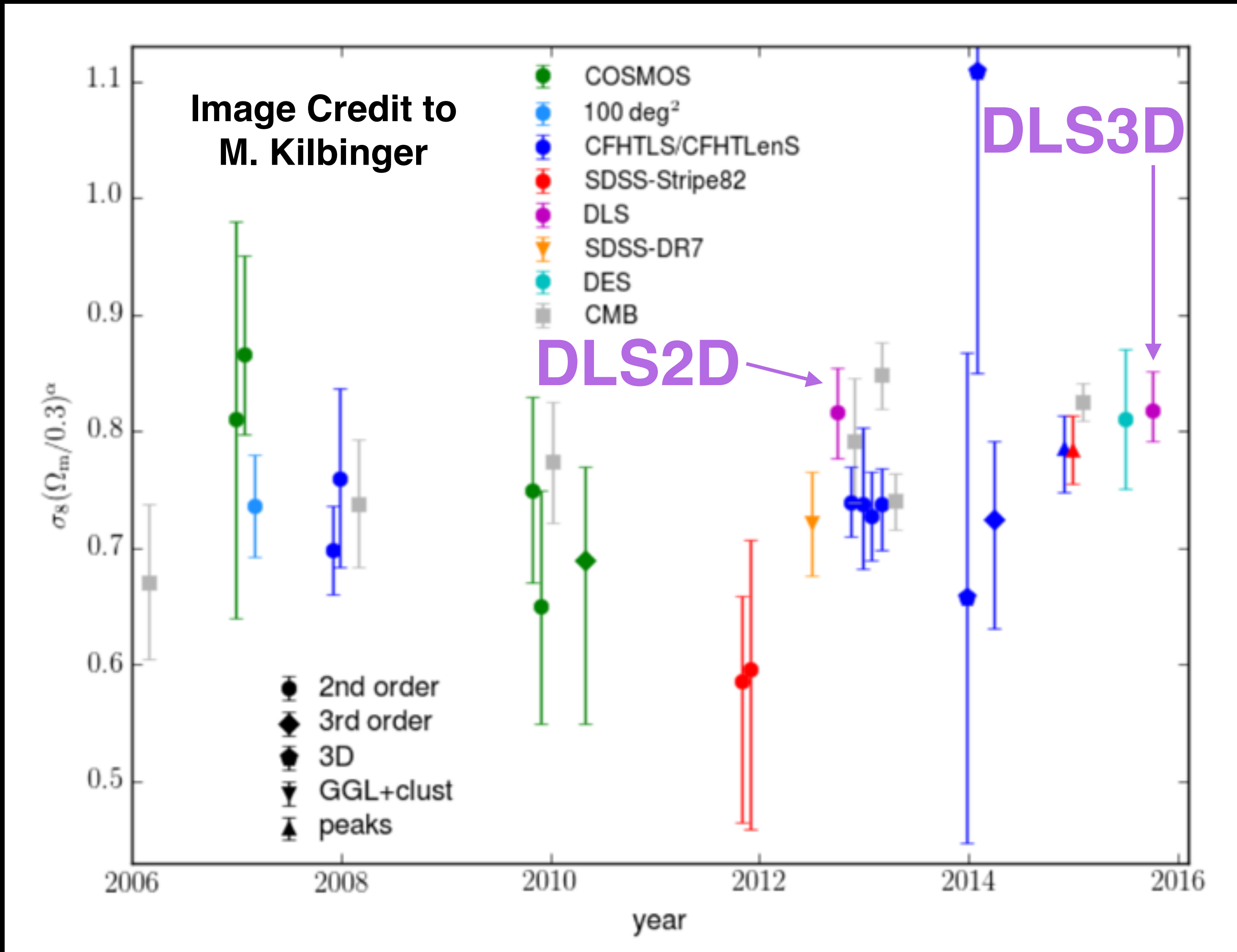
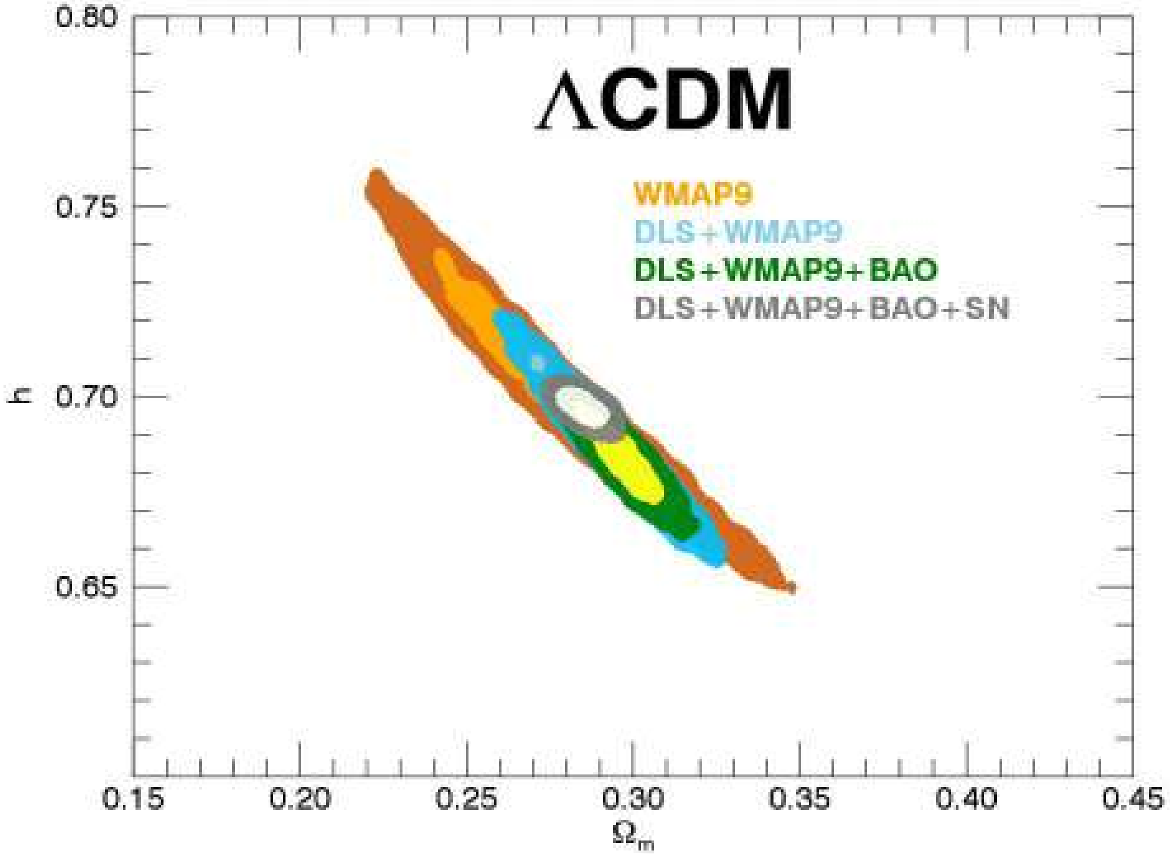


Constraints in Existing Cosmic Shear Surveys

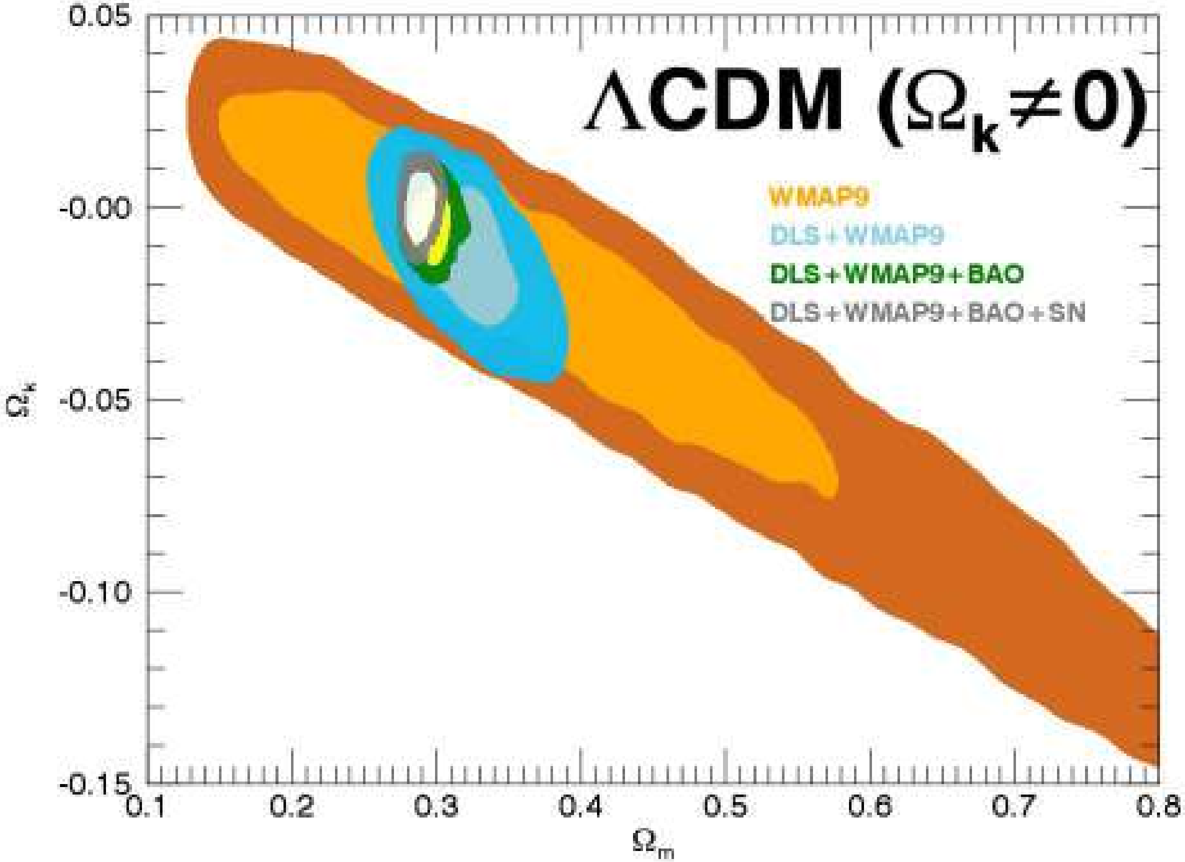


Hubble Constant



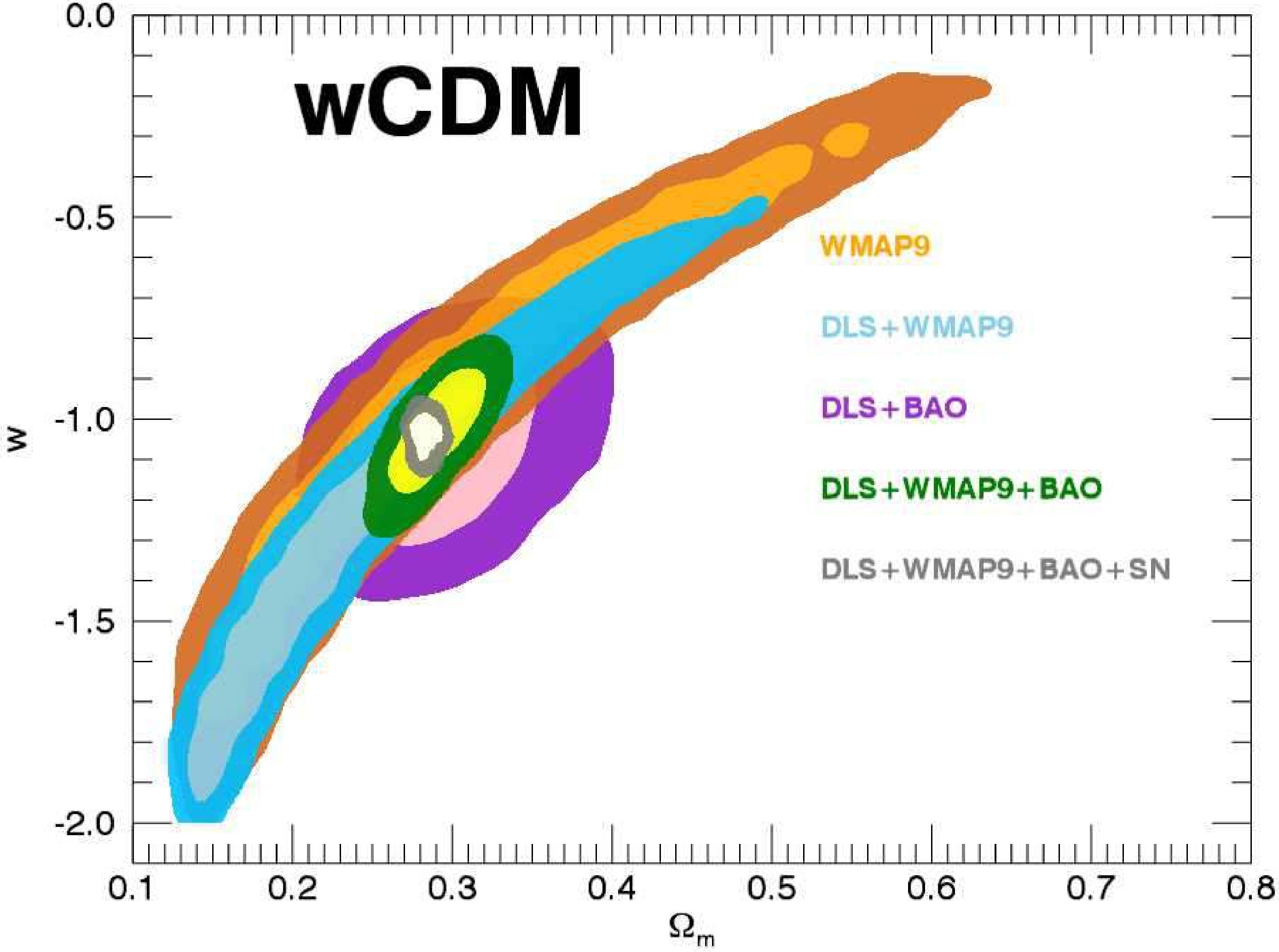
We obtained h=0.686±0.013 from DLS+WMAP9.
The value is consistent with the Planck 2015 result h=0.678±0.009 (TT+lowP+lensing).

Curvature



The WMAP9 curvature uncertainty is reduced by more than a factor of two when DLS is added.

w Equation of State



DLS+BAO can constrain the w parameter strongly.

Summarize

- DLS is a precursor to LSST with an emphasis on depth.

- Our choice of depth over area resulted in the tightest constraints on matter density and normalization.

- The DLS results are consistent with the Planck2015 results.

- Future weak-lensing studies will not be limited by statistical errors, but by systematics.