THE DARK ENERGY SURVEY

DES-SN

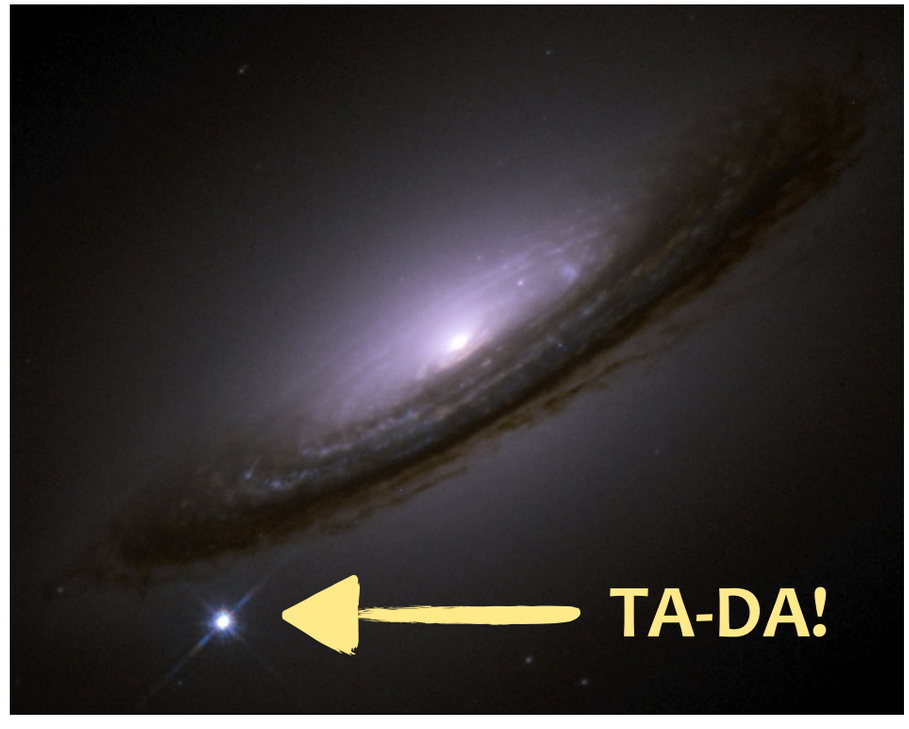
Supernova systematics in the era of LSST*

MATHEW SMITH

THE DARK ENERGY SURVEY

**astrophysical (I can't cover them all!)*

Supernova cosmology: the basics



Brief Takeaway:

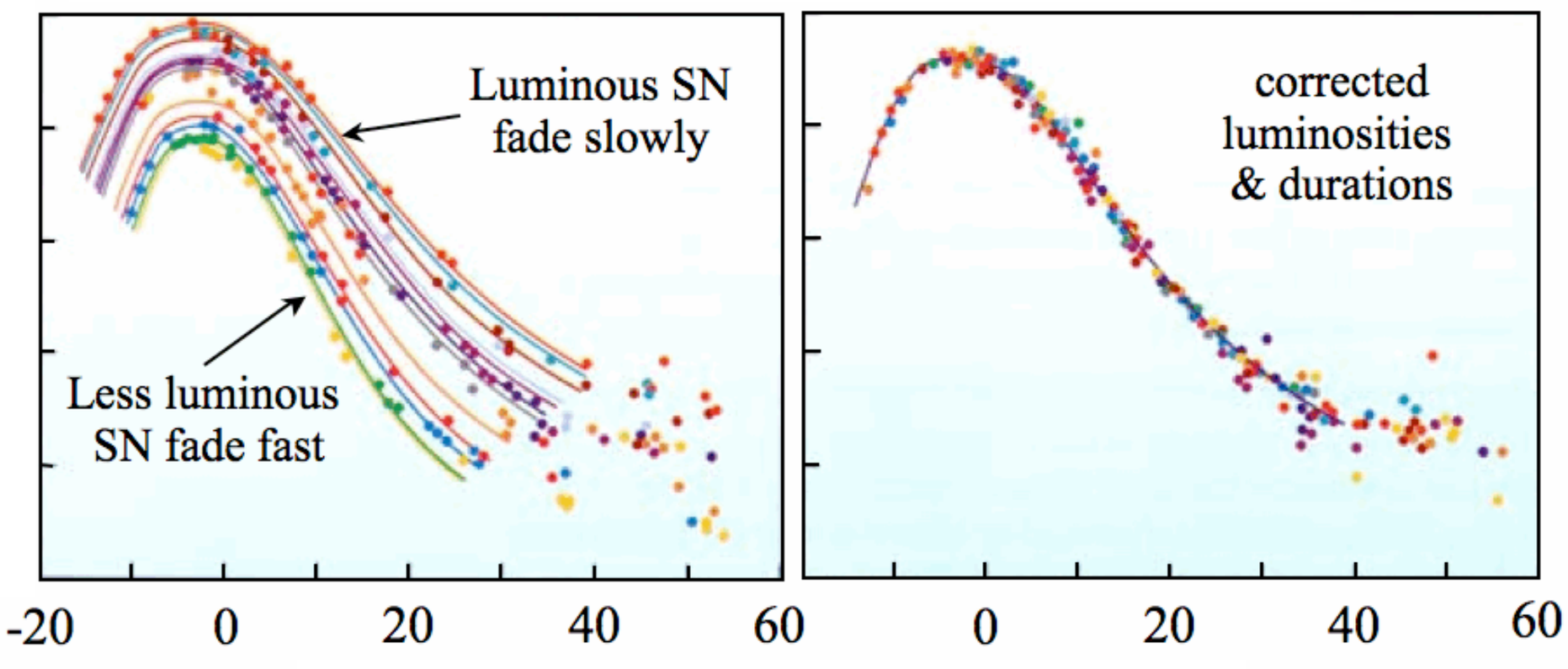
*Supernova => SNe Ia**

Bright + 'standardly bright'

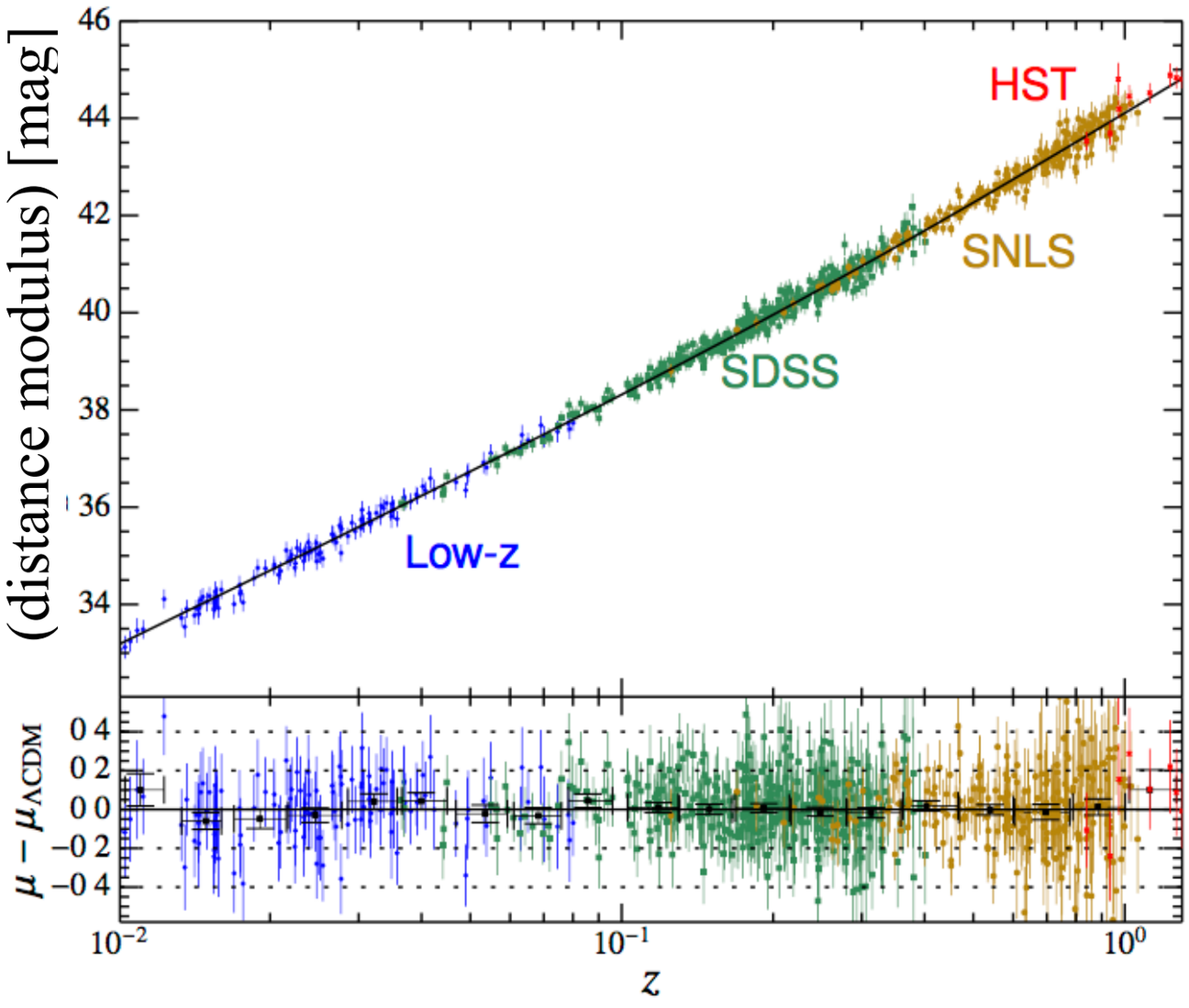
We don't know what they are

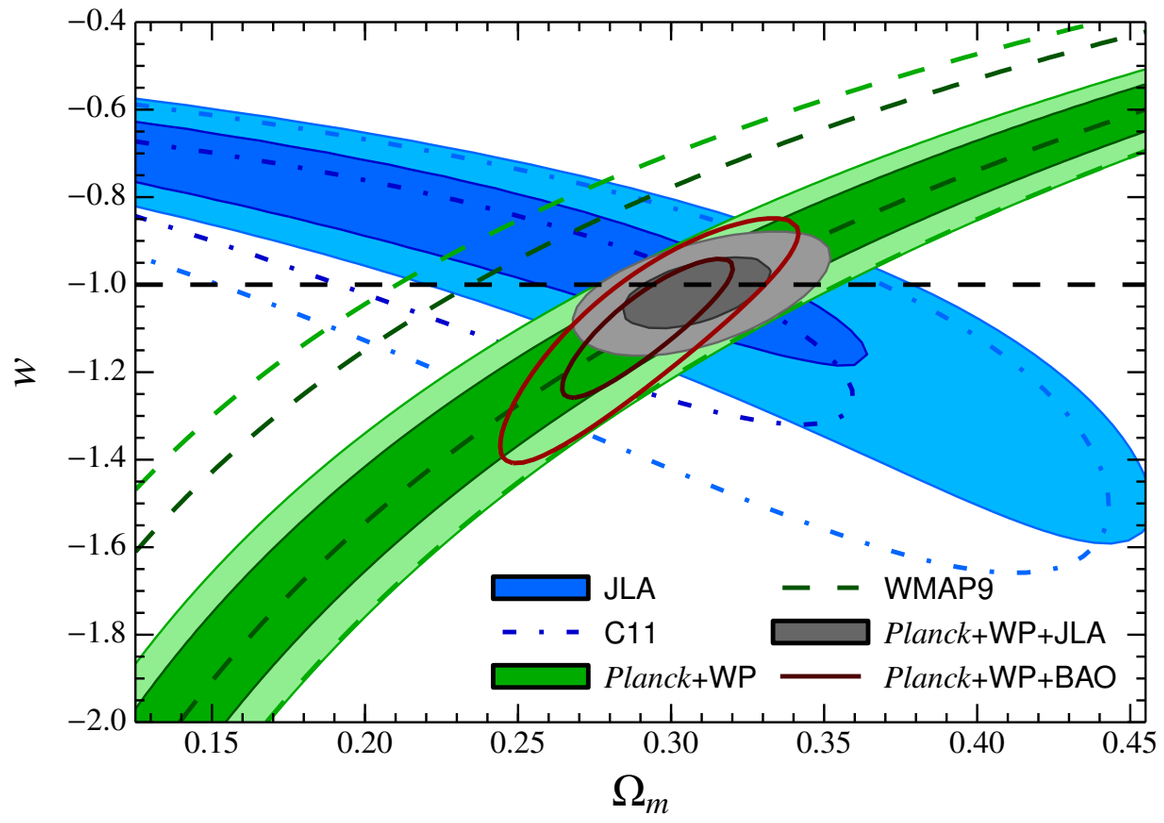
- it kind of doesn't matter

(as long as they are the same today as the past)



Supernova cosmology: 'today'





750 - 1000 SNIa to z>1

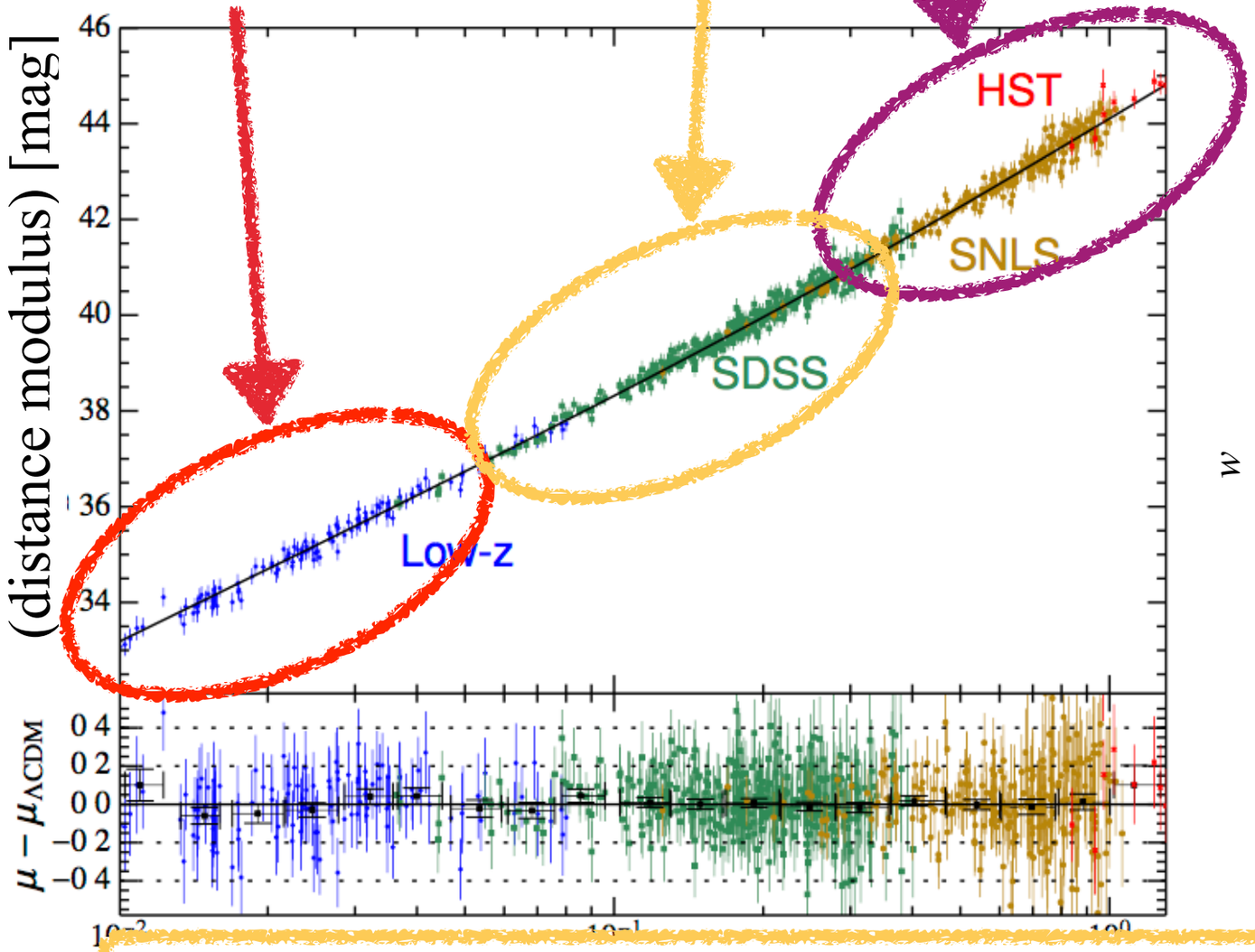
w to ~5%

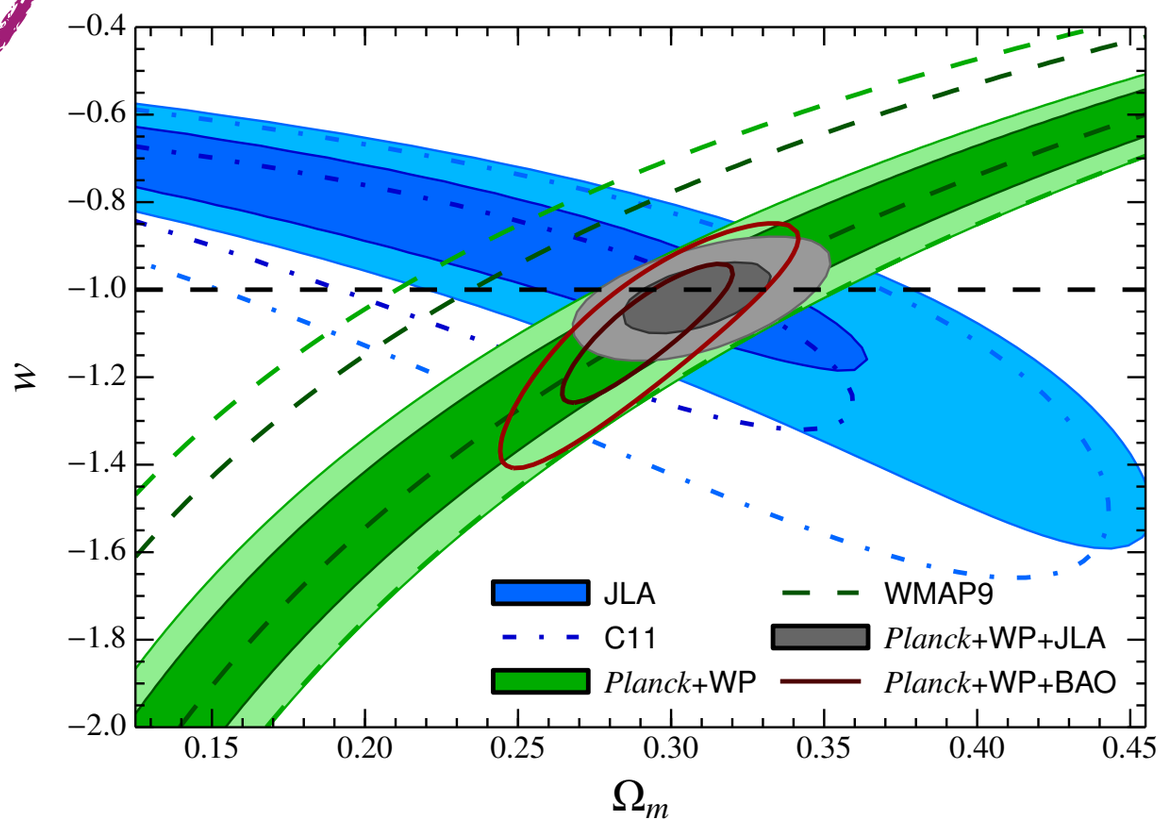
Supernova cosmology: 'today'

'all sky' + targeted

'hybrid'

'pencil beam' + space





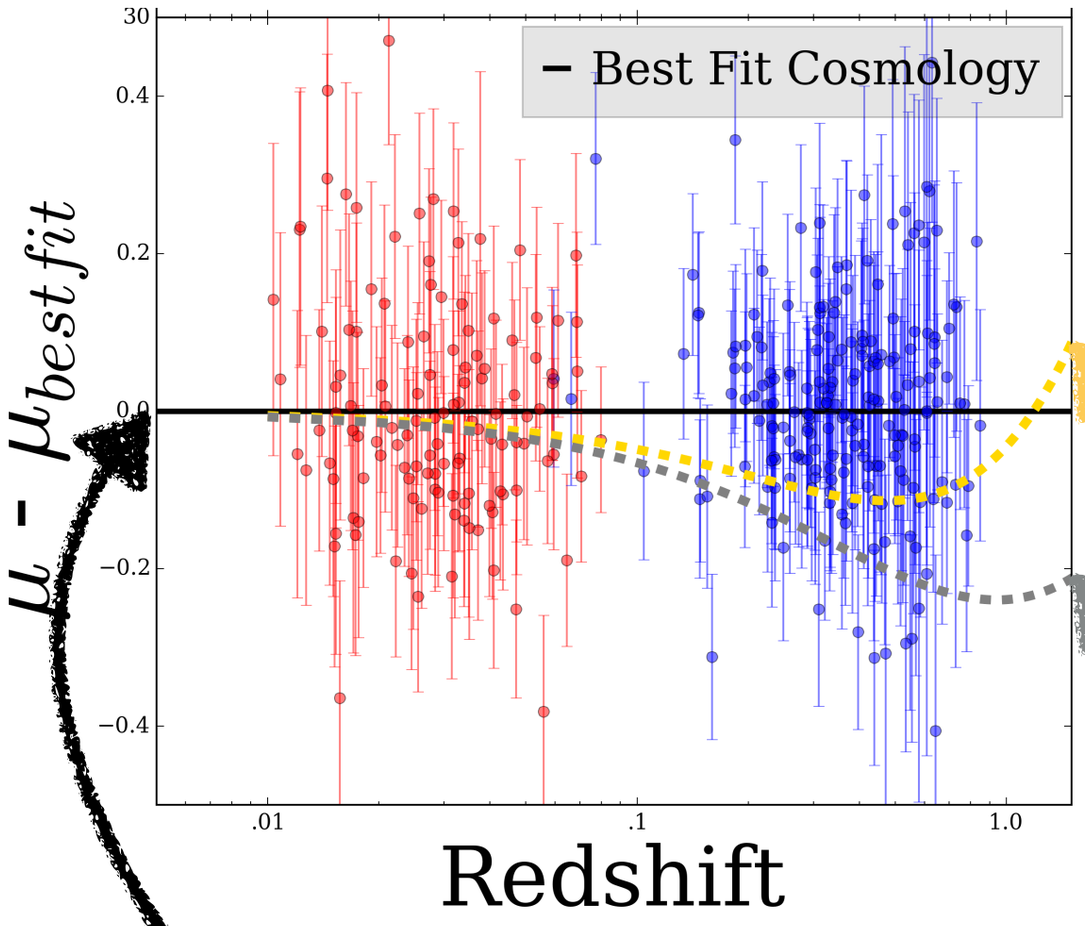
Different strategies;

filters; instruments; cadence; selection…

Supernova cosmology: the challenge

Precision cosmology

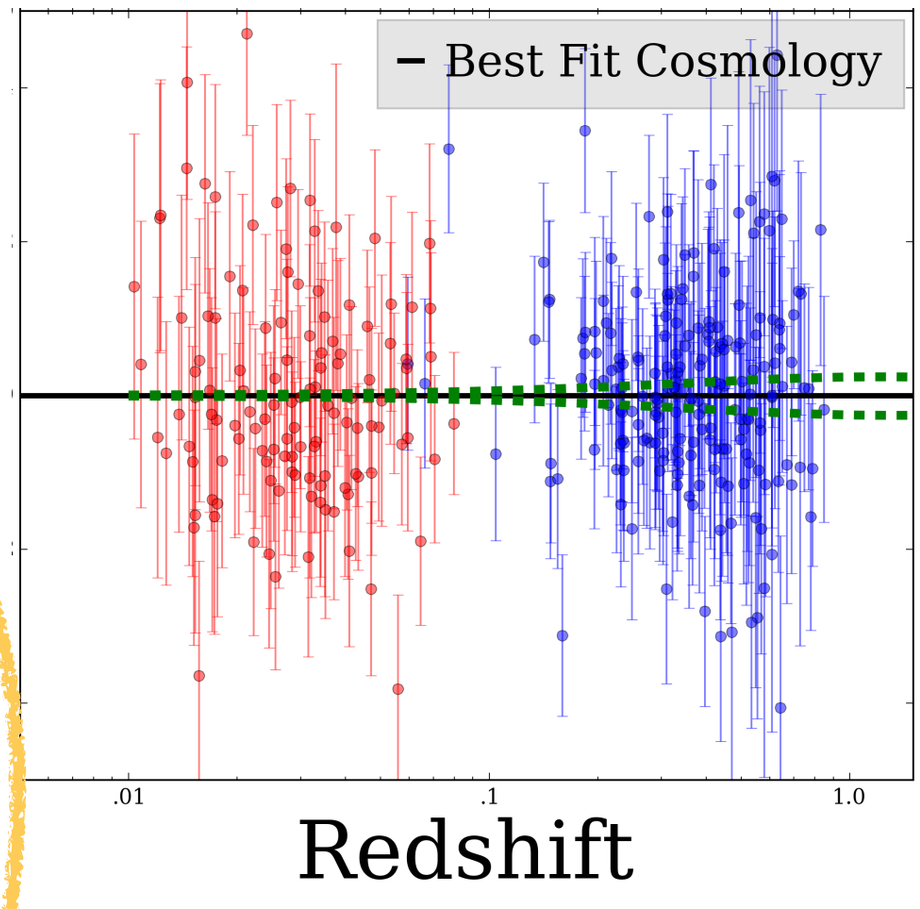
today: LCDM v CDM



Acceleration

No Dark Energy

2025: LSST: wCDM?

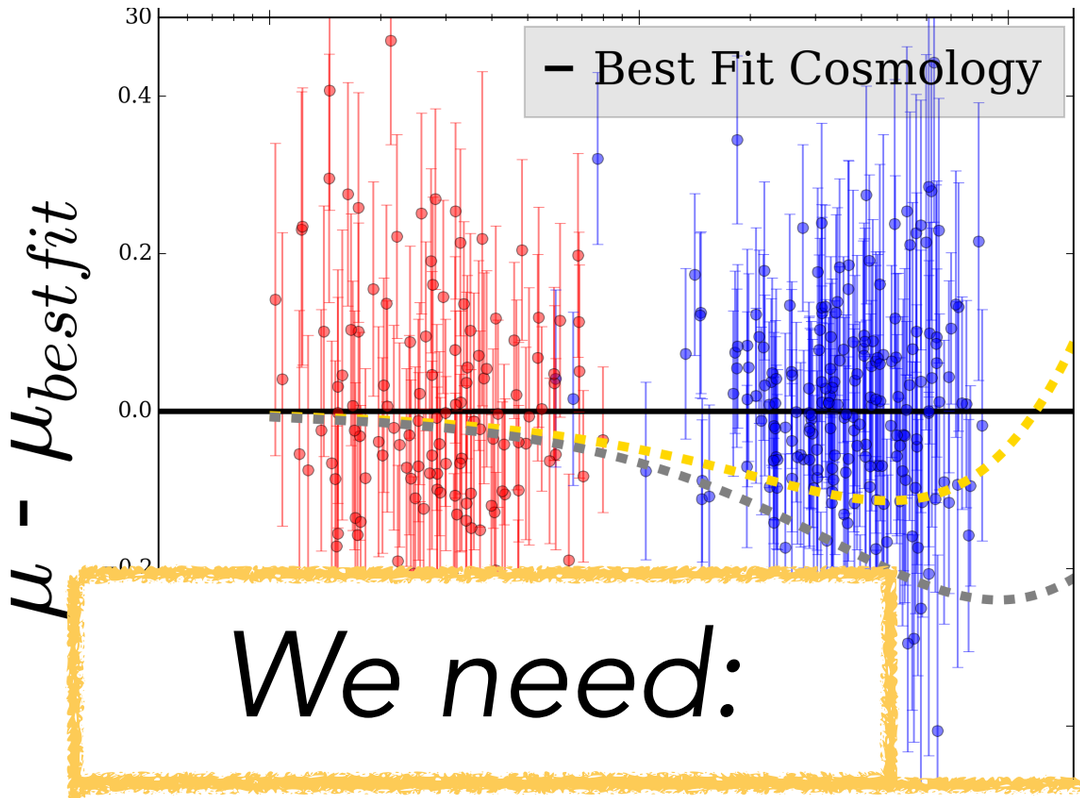


w != -1

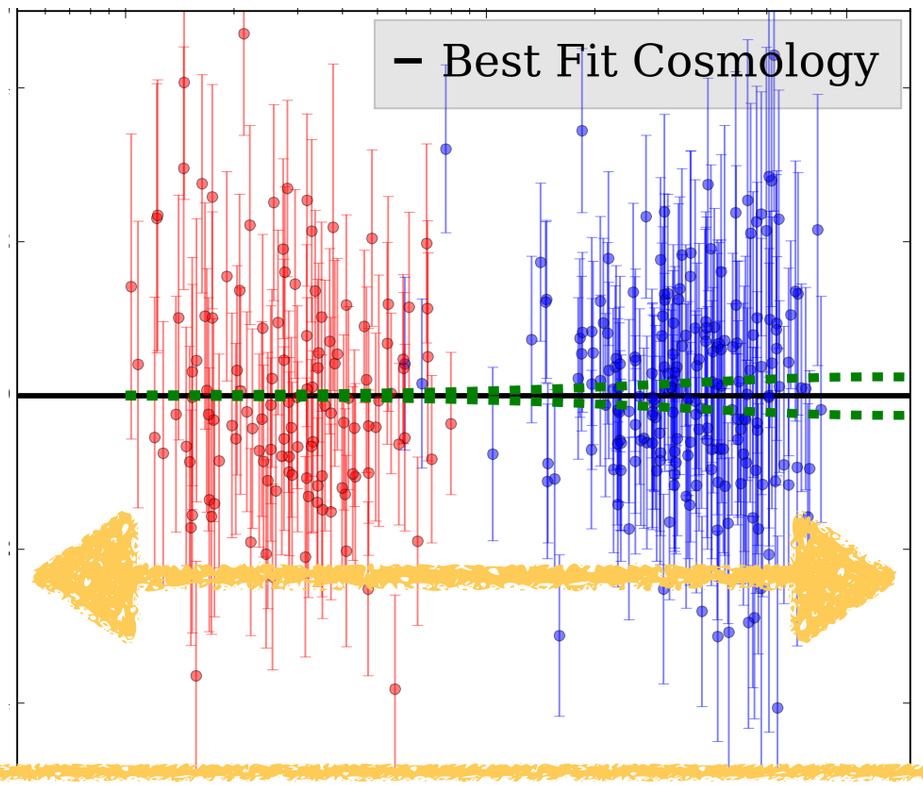
Supernova cosmology: the challenge

Precision cosmology

today: LCDM v CDM



2025: LSST: wCDM?



We need:

One survey; one strategy

LSST ***(or, first-up,*** **DES***...)*

Ac

1

THE DARK ENERGY SURVEY: IN ONE SLIDE

One survey, comprised of multiple probes, to determine the nature of cosmic acceleration

"EVERYTHING WITH ONE SURVEY"

"LSST-light"

DES-Wide

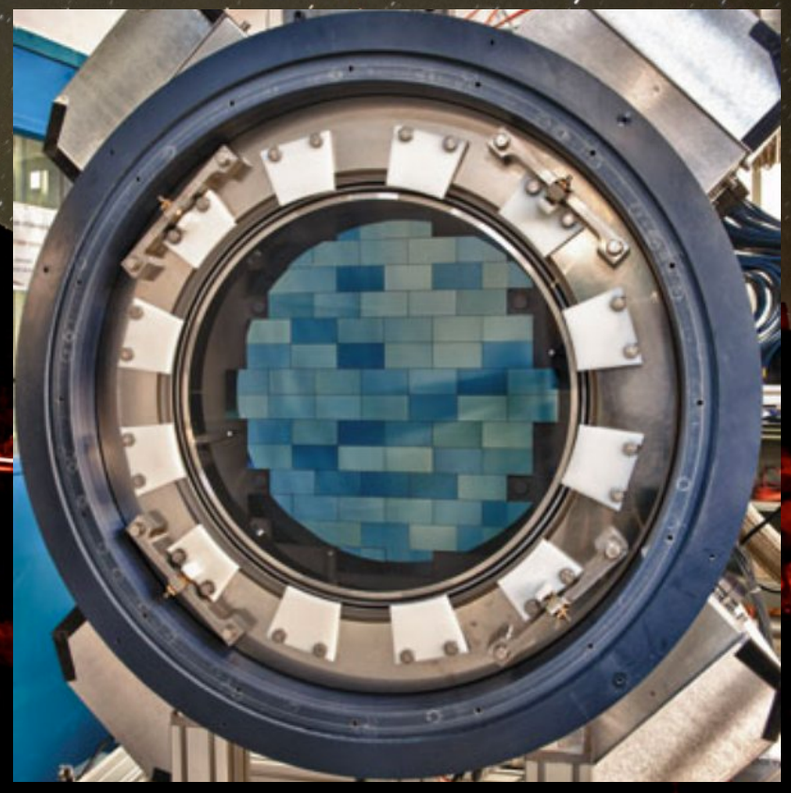
- 5000 deg^2 in *grizY*: r_{AB} ~ 24.3, i_{AB} ~23.5 (10σ)
- Large Scale Structure, Weak Lensing & Galaxy Clustering

DES-SN

- ~ 6-day cadenced *griz survey* over 27 deg^2
- Type Ia supernovae & other transients

Overall

- Probes of both Distance v Redshift & Growth of Structure
- Multiple probes to break degeneracies & minimise systematics
- Lots of ancillary science (understatement alert)



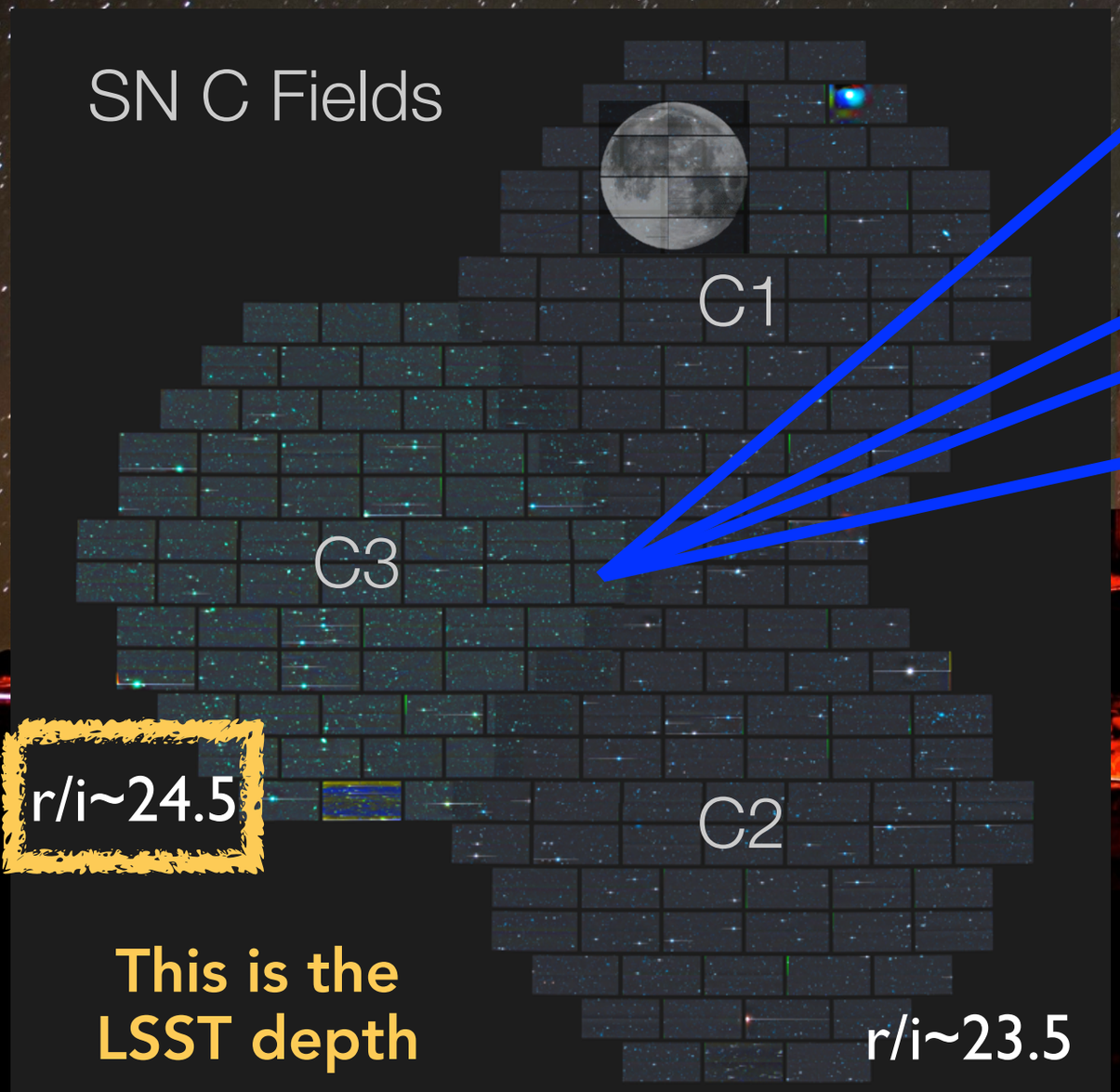
- ***First WF cosmology results recently released …***
- ***Most distant SN discovered …***
- ***Multiple MW satellites discovered …***
- ***New population of fast transients discovered …***
  - ***and so much more …***

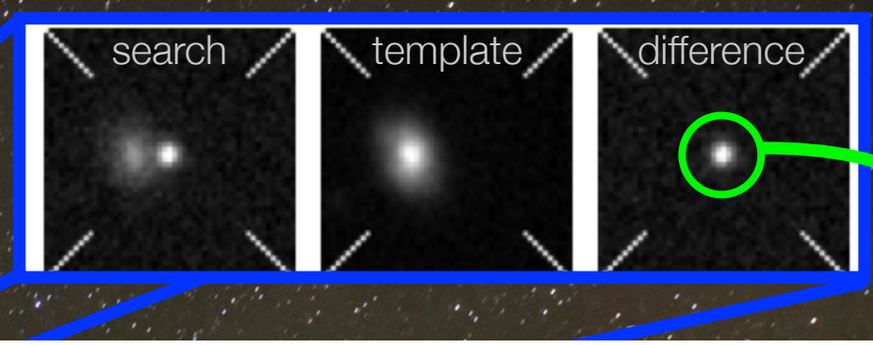
THE DARK ENERGY SURVEY: SUPERNOVA PROGRAM

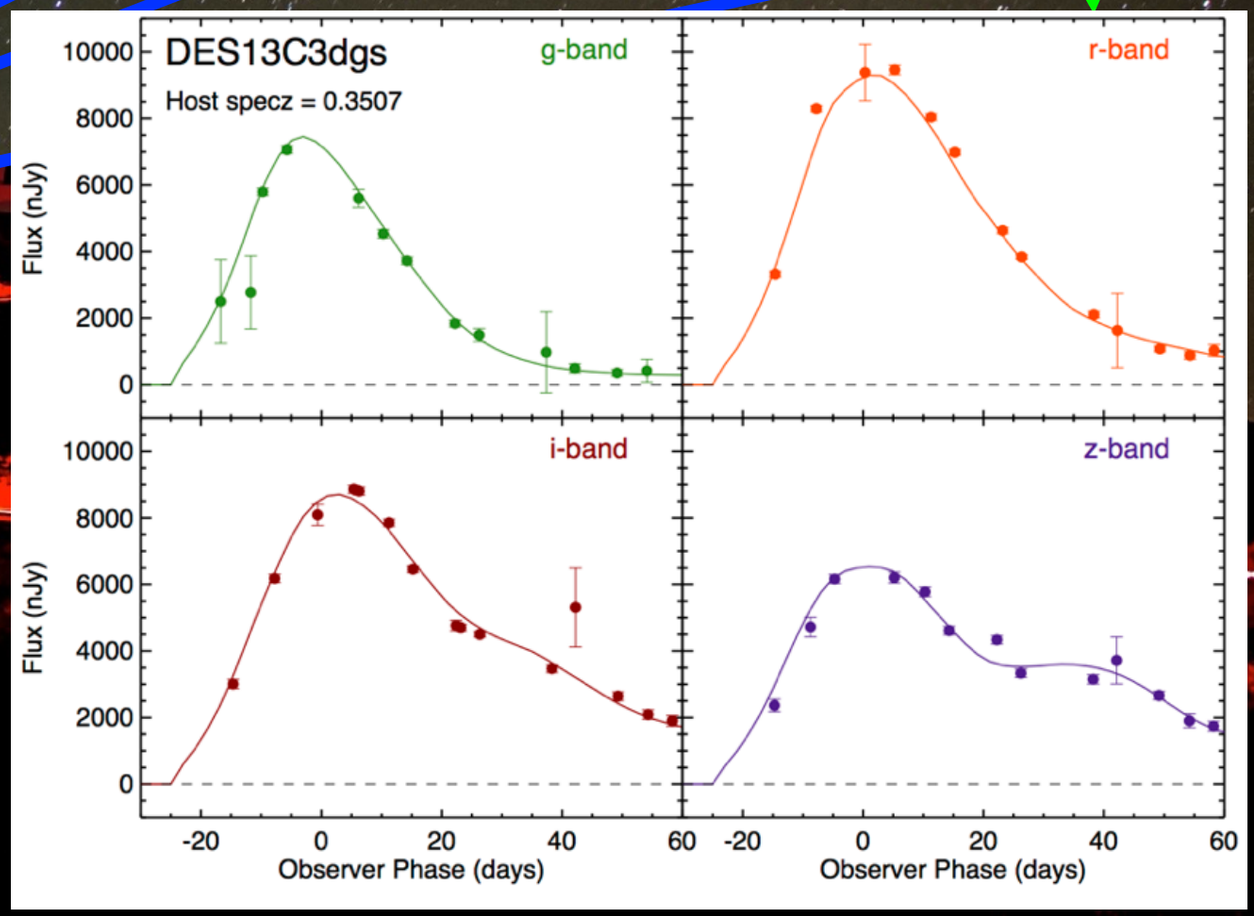
- 10 fields (8 shallow, 2 deep) in 4 filters (griz)
- Every 7 nights, for 5+ months for 5 years

} ~3500 SNIA

Basically: LSST DDF / 10







THE DARK ENERGY SURVEY: SUPERNOVA PROGRAM

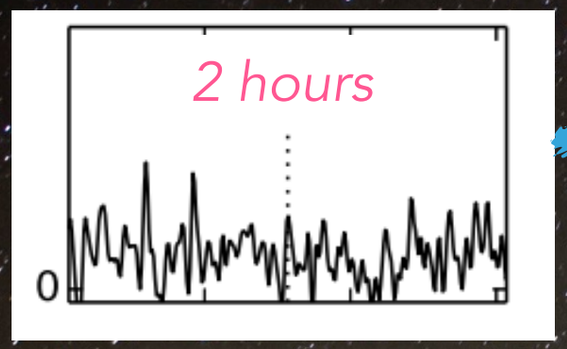
TO FIND, CHARACTERISE & FOLLOW 3000+ SN TO Z>1

- 10 fields (8 shallow, 2 deep) in 4 filters (griz)
- Every 7 nights, for 5+ months for 5 years

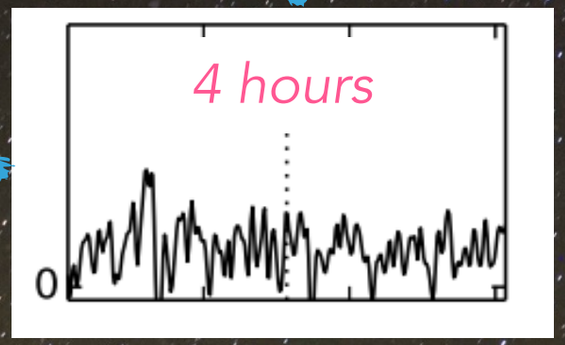
} ~3500 SNIA

DES SPECTROSCOPY: Targeted followup + host spec_z

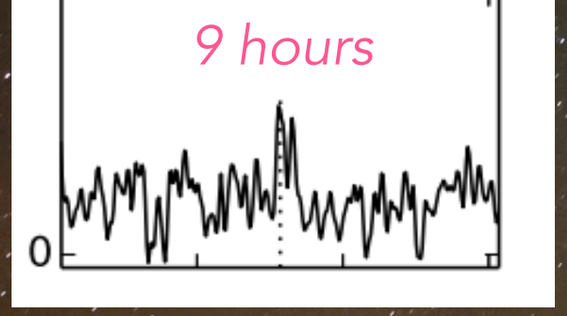
OzDES: Targeting the hosts of all live transients to measure redshifts



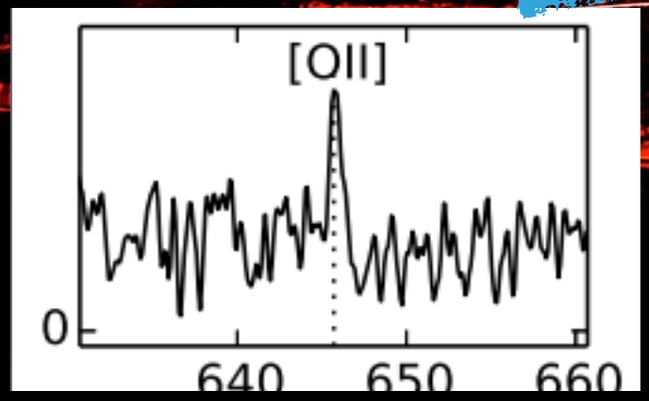
+ 2 hours



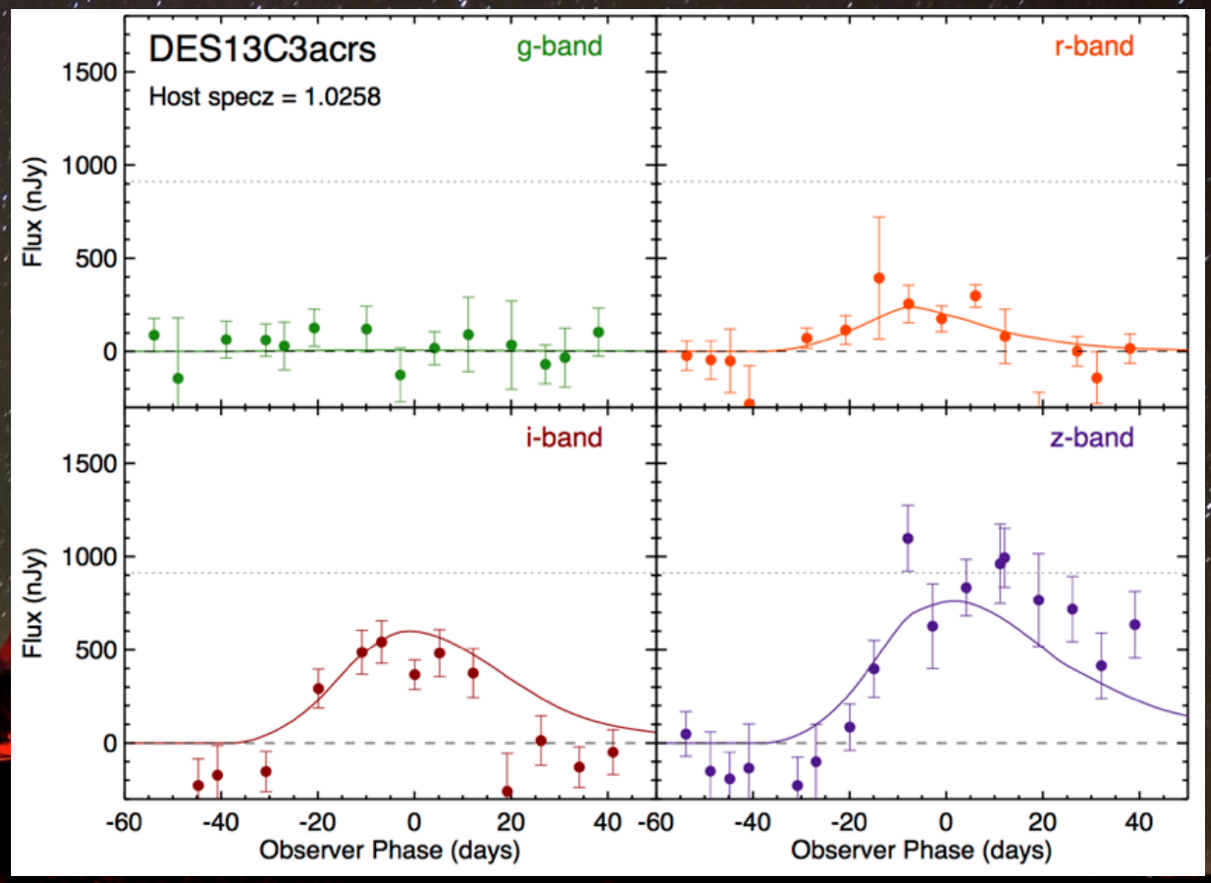
+ 5 hours



+ 6 hours



15 hours on source: z=1.03

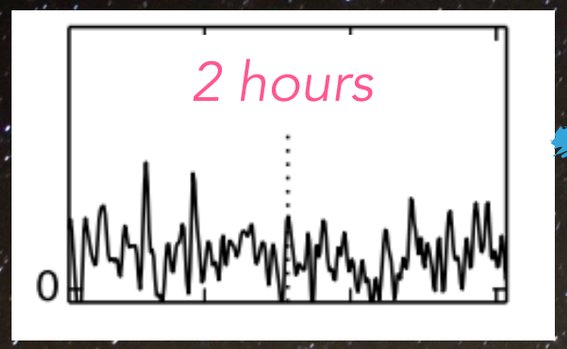


SN exploded in 2013; redshift obtained in 2016

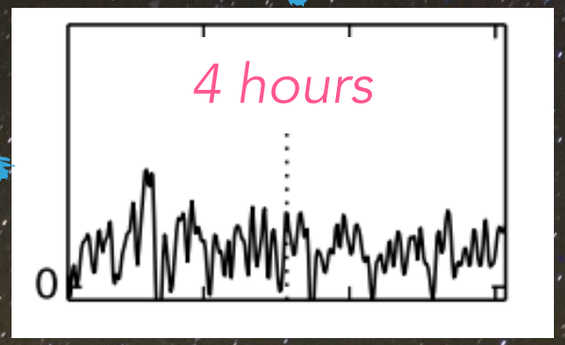
Most SNe not confirmed

DES SPECTROSCOPY: Targeted followup + host spec_z

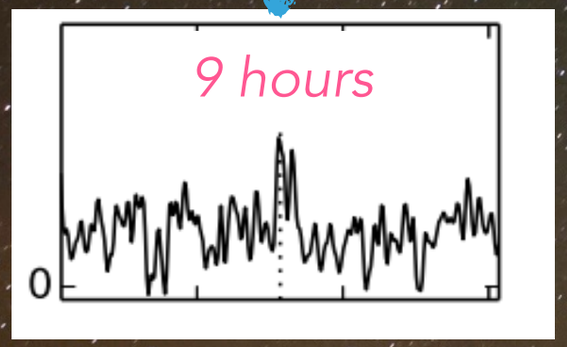
OzDES: Targeting the hosts of all live transients to measure redshifts



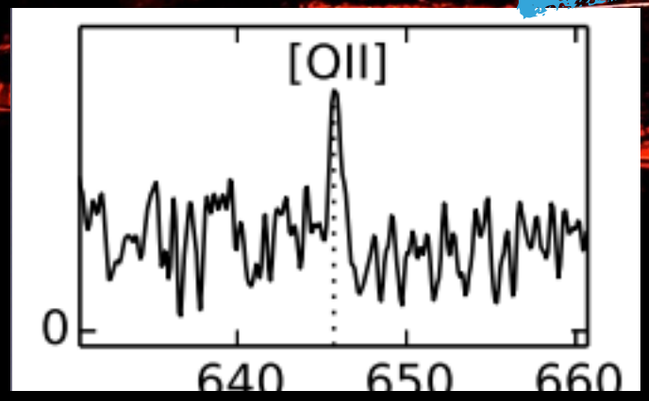
+ 2 hours



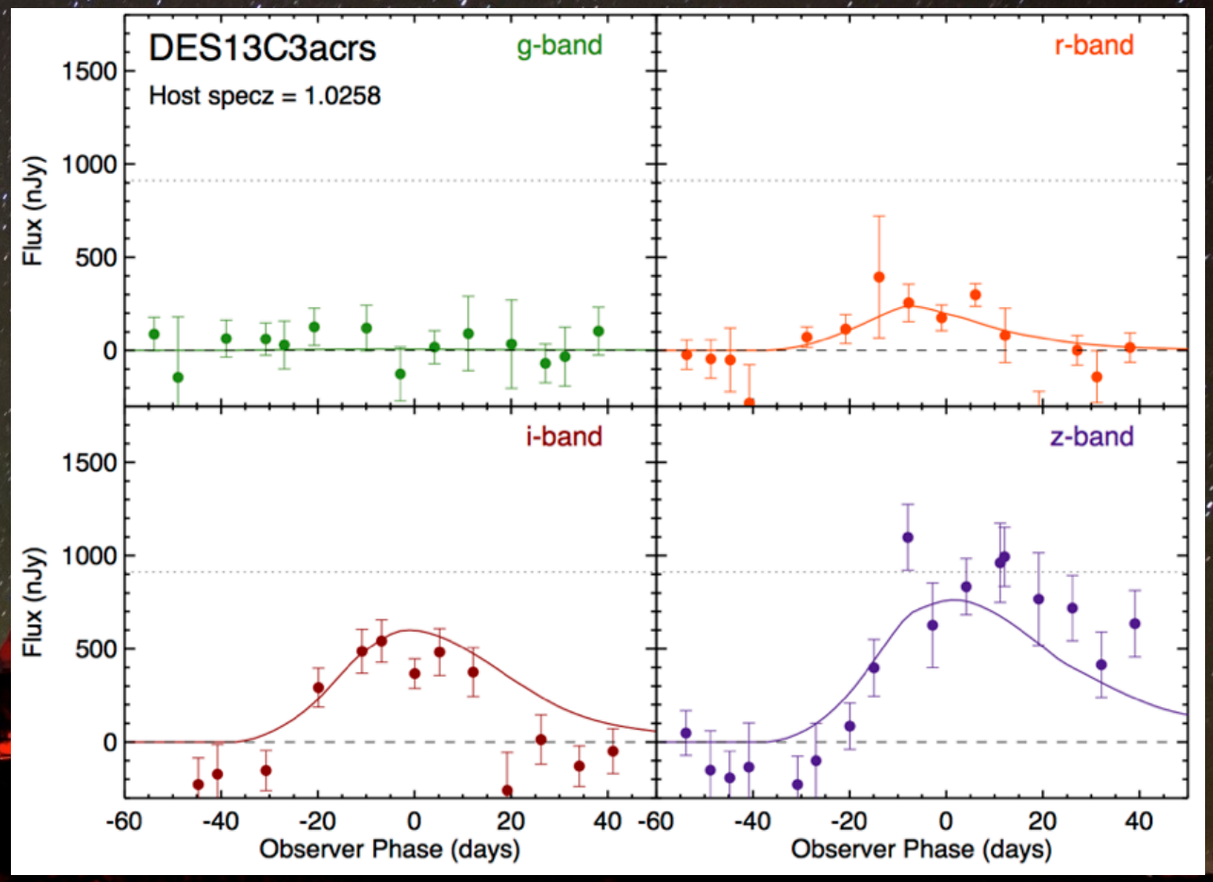
+ 5 hours



+ 6 hours



15 hours on source: z=1.03



LSST 1-0-1 ***ed in 2013;***
ained in 2016

Most SNe not confirmed

DES-SN: where we are:

SURVEY	N_SNIa	wErr (stat + sys)
JLA (2014)	740	0.054
Pantheon (2018)	1049	0.04

Consistent calibration but
fewer systematics considered

"the same"

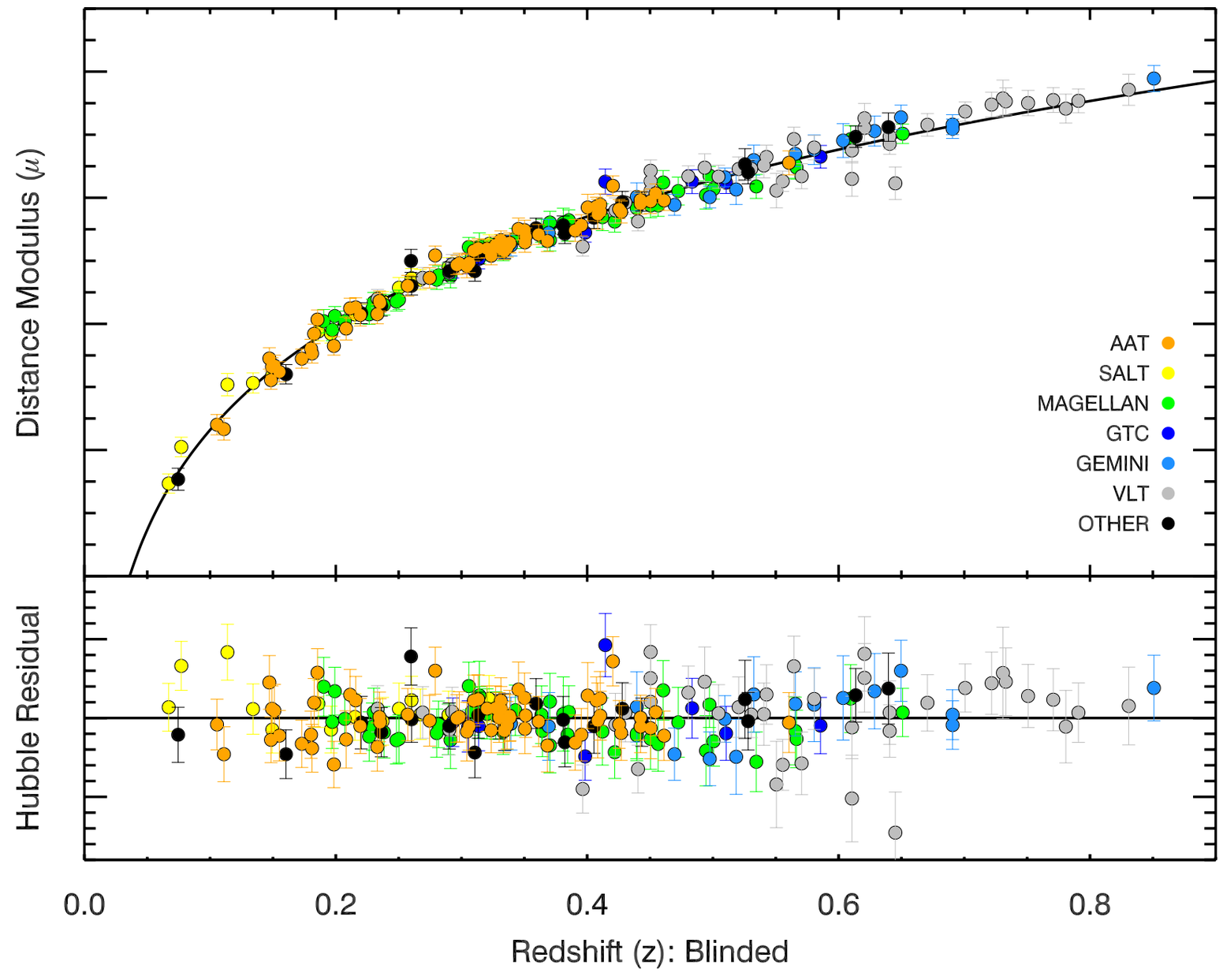
DES-SN: where we are:

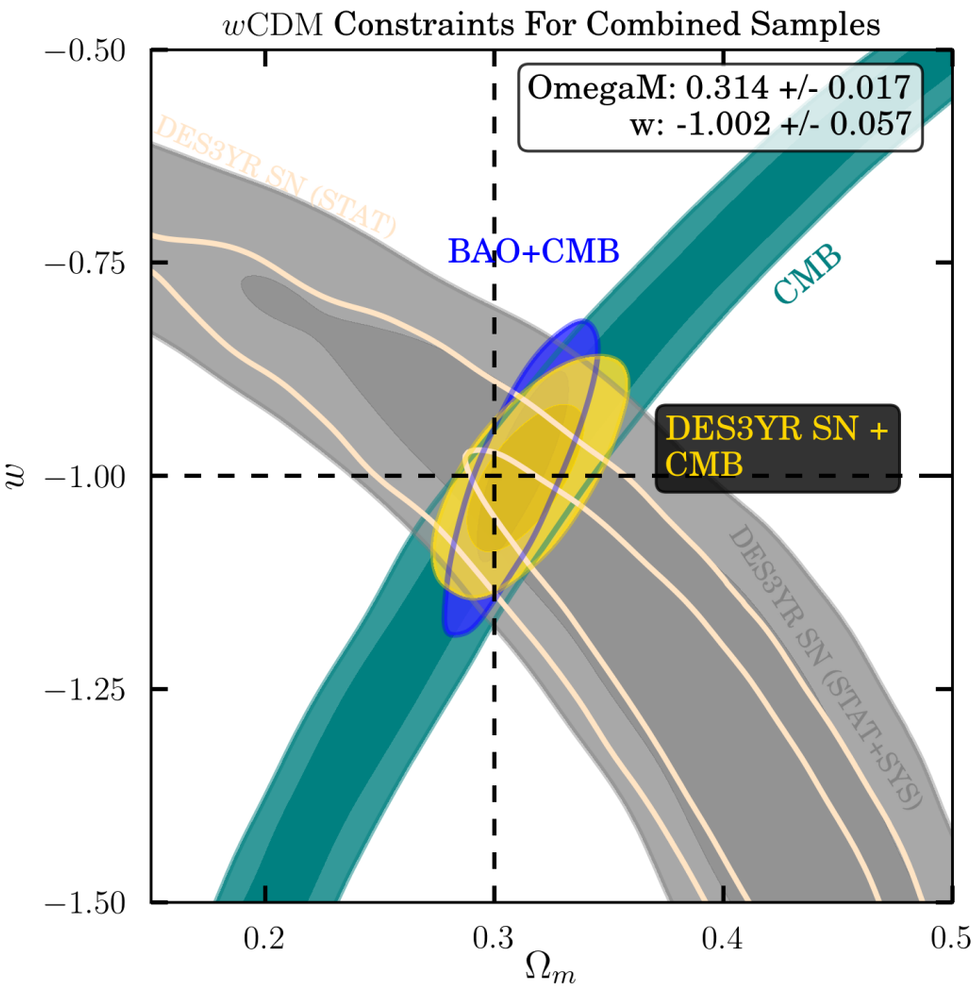
SURVEY	N_SNIa	wErr (stat + sys)
JLA (2014)	740	0.054
Pantheon (2018)	1049	0.04
DES 3YR (2018)	334 *(206 DES)*	0.057
DES 5YR (2021)	~1800	??

DES-3YR: Cosmology

Hubble Diagram:

spec-conf only





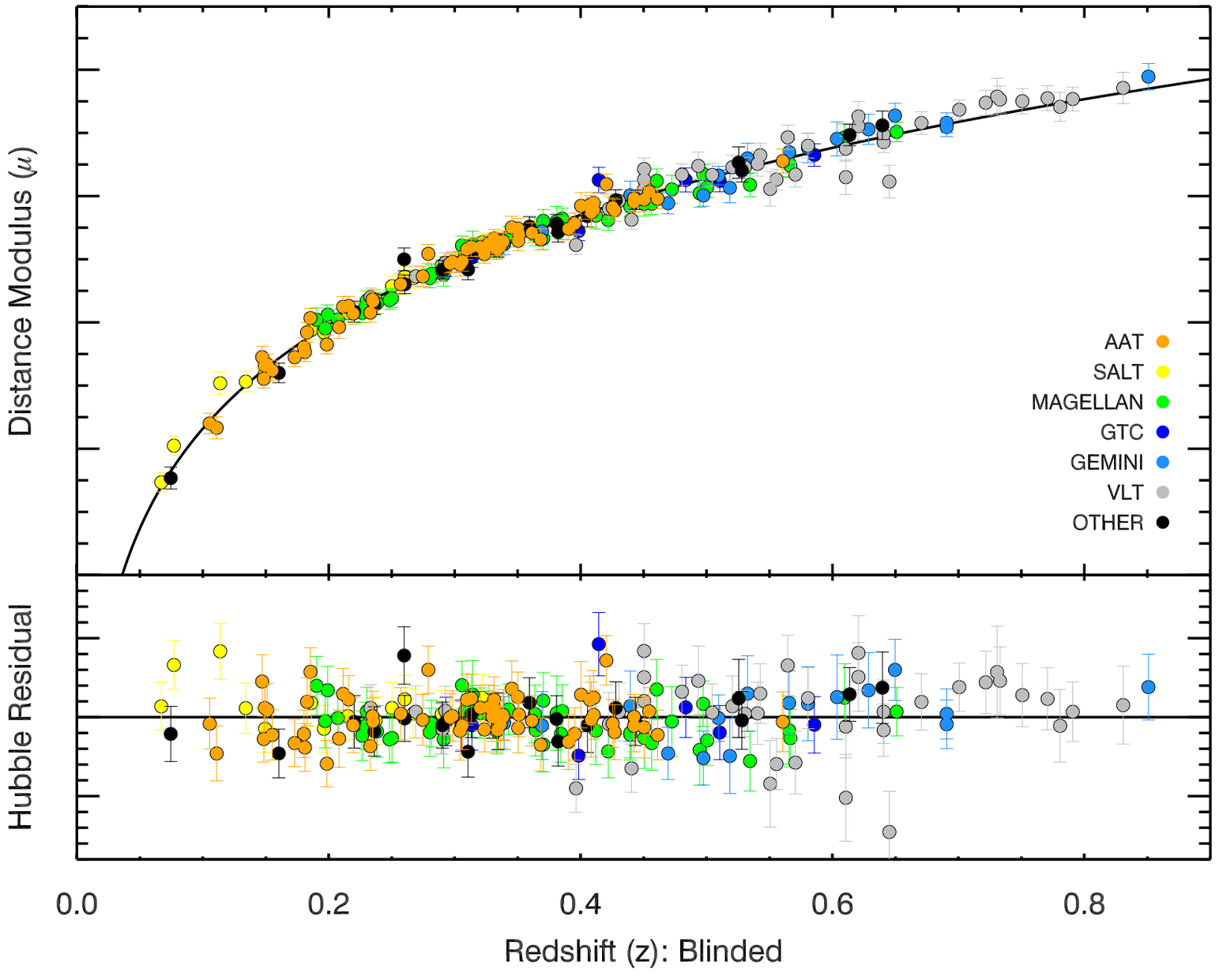
$$w = -1.002 \pm 0.057$$

the power of calibration:

200 SN == 750 SN

'best constraints today'

DES-SN: What's coming



200 SN

DES-SN: What's coming

Cosmology coming in 2021

1800 SN

DES-3YR: Systematics

Description[b]	σ'_w	$\sigma'_w/\sigma_w^{\rm stat}$	w shift
Total Stat ($\sigma_w^{\rm stat}$)	0.042	1.00	0.000
Total Syst[c] ($\sigma_w^{\rm total\ syst}$)	0.042	1.00	−0.006
[Photometry and Calibration]	**[0.021]**	**[0.50]**	**[−0.005]**
Low-z	0.014	0.33	−0.003
DES	0.010	0.33	0.001
SALT2 model	0.009	0.21	−0.003
HST Calspec	0.007	0.17	0.001
1/3 No SuperCal	0.005	0.12	−0.001
SuperCal Coherent Shift[d]	0.005	0.12	−0.001
[μ-Bias Corrections: Survey]	**[0.023]**	**[0.55]**	**[−0.001]**
[e]Low-z 3σ Cut	0.016	0.38	0.005
Low-z Volume Limited	0.010	0.24	0.009
Spectroscopic Efficiency	0.007	0.17	0.001
[e]Flux Err Modeling	0.001	0.02	−0.001
[μ-Bias Corrections: Astrophysical]	**[0.026]**	**[0.62]**	**[−0.003]**
Intrinsic Scatter Model	0.014	0.33	−0.001
c, x_1 Parent Population	0.014	0.33	0.000
[e]Two $\sigma_{\rm int}$	0.014	0.33	−0.005
MW Extinction	0.005	0.12	−0.001
[e]w, Ω_M for bias corr	0.006	0.14	0.001
[Redshift]	**[0.012]**	**[0.29]**	**[0.003]**
[e]$z + 0.00004$	0.006	0.14	−0.001
Peculiar Velocity	0.007	0.17	0.004

DES-SN+ 2019

DES-5YR: Systematics

What do we have to solve?

Description[b]	σ'	$\sigma'_w/\sigma_w^{\rm stat}$	w shift
Total Stat ($\sigma_w^{\rm stat}$)	0.042	1.00	0.000
Total Syst[c] ($\sigma_w^{\rm total\ syst}$)	0.042	1.00	−0.006
[Photometry and Calibration]	**[0.021]**	**[0.50]**	**[−0.005]**
Low-z	0.014	0.33	−0.003
DES	0.010	0.33	0.001
SALT2 model	0.009	0.21	−0.003
HST Calspec	0.007	0.17	0.001
1/3 No SuperCal	0.005		
SuperCal Coherent Shift[d]			
[μ-Bias Corrections		[0.55]	[−0.001]
[e]Low-z 3σ Cut	0.016	0.38	0.005
Low-z Volume Limited	0.010	0.24	0.009
Spectroscopic Efficiency	0.007	0.17	0.001
[e]Flux Err Modeling	0.001	0.02	−0.001
[μ-Bias Corrections: Astrophysical]	**[0.026]**	**[0.62]**	**[−0.003]**
Intrinsic Scatter Model	0.014	0.33	−0.001
c, x_1 Parent Population	0.014	0.33	0.000

+ photometric classification

Systematics dominate today!

DES is systematics limited

LSST == DES+++

DES-5YR: Systematics

What do we have to solve?

Description[b]	σ'_w	$\sigma'_w/\sigma_w^{\rm stat}$	w shift
Total Stat ($\sigma_w^{\rm stat}$)	0.042	1.00	0.000
Total Syst[c] ($\sigma_w^{\rm total\ syst}$)	0.042	1.00	−0.006
[Photometry and Calibration]	**[0.021]**	**[0.50]**	**[−0.005]**
Low-z	0.014	0.33	−0.003
DES	0.010	0.33	0.001
SALT2 model	0.009	0.21	−0.003
HST Calspec	0.007	0.17	0.001
1/3 No SuperCal	0.005	0.12	−0.001
SuperCal Coherent Shift[d]	0.005	0.12	−0.001
[μ-Bias Corrections: Survey]	**[0.023]**	**[0.55]**	**[−0.001]**
[e]Low-z 3σ Cut	0.016	0.38	0.005
Low-z Volume Limited	0.010	0.24	0.009
Spectroscopic Efficiency	0.007	0.17	0.001
[e]Flux Err Modeling	0.001	0.02	−0.001
[μ-Bias Corrections: Astrophysical]	**[0.026]**	**[0.62]**	**[−0.003]**
Intrinsic Scatter Model	0.014	0.33	−0.001
c, x_1 Parent Population	0.014	0.33	0.000
[e]Two $\sigma_{\rm int}$	0.014	0.33	−0.005
MW Extinction	0.005	0.12	−0.001
[e]w, Ω_M for bias corr	0.006	0.14	0.001
[Redshift]	**[0.012]**	**[0.29]**	**[0.003]**
[e]z + 0.00004	0.006	0.14	−0.001
Peculiar Velocity	0.007	0.17	0.004

Astrophysical uncertainties dominant…

limiting systematic

DES-SN+ 2019

Host galaxy studies

correlations between SN and host:

improve standardisation
insights into astrophysical scatter

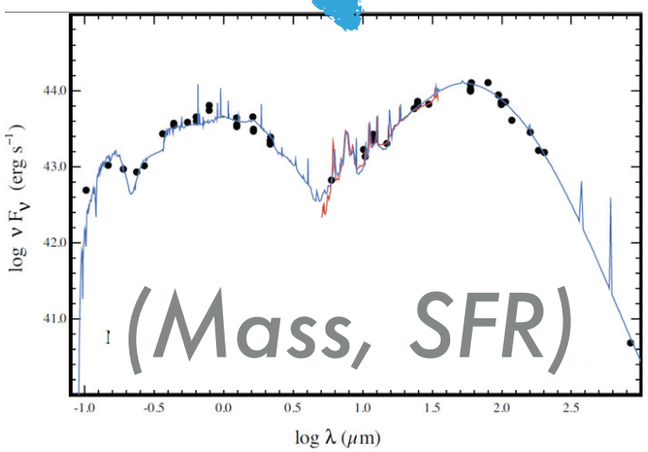
DES-SN: Astrophysical systematics

'what is a SNIa?'

Host galaxy studies:

206 SNe → *very deep stacks* → 202 Hosts

SEDfit → (Mass, SFR)

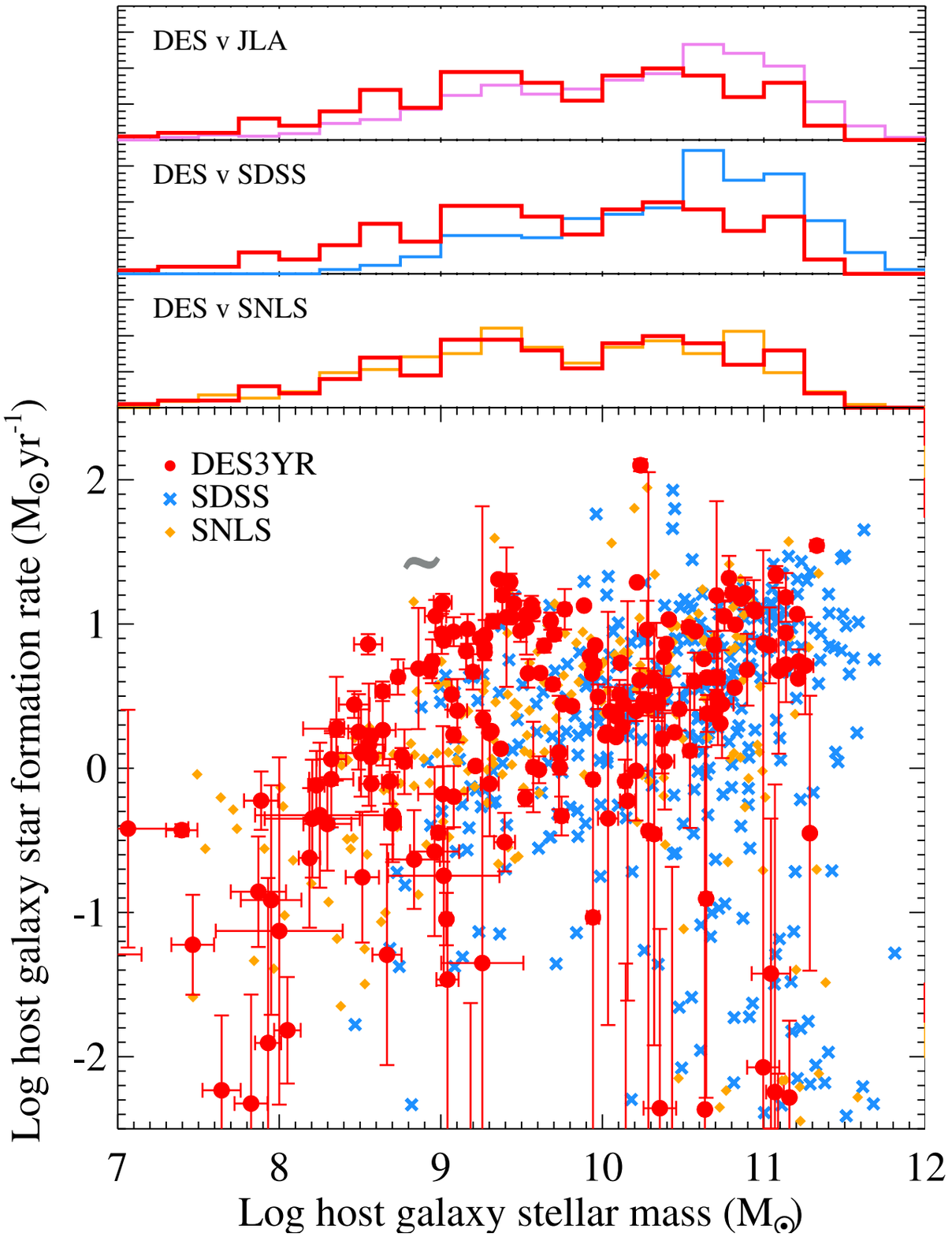


SNe Ia found in:

70%: low mass + SF'ing

30%: high mass + passive

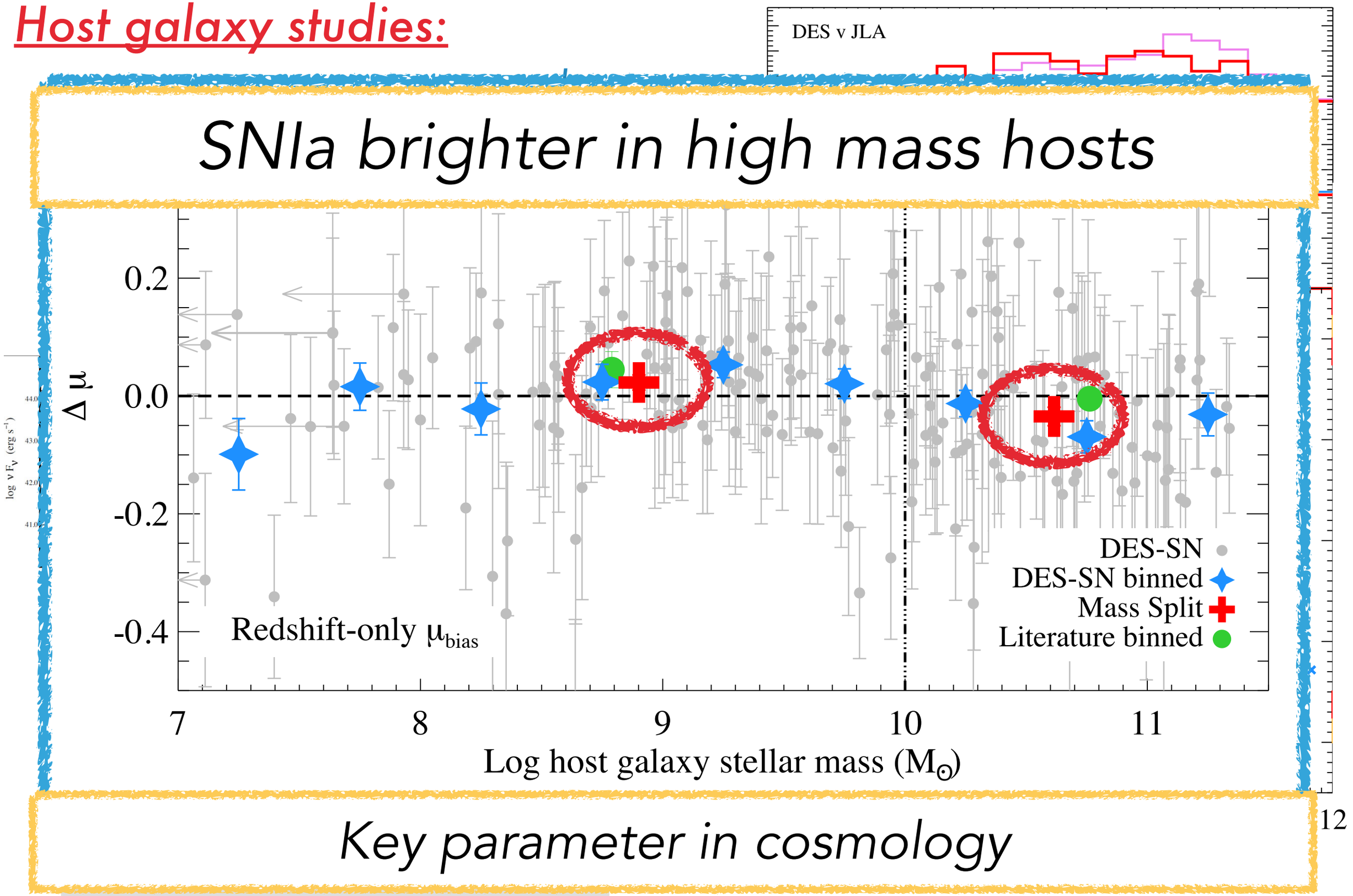
Key: mass estimates are stable



Host galaxy studies:

DES v JLA

SNIa brighter in high mass hosts



Key parameter in cosmology

SN cosmology in 2020:

SN observable

Mass term

step function split at: $M_* = 10$

distance

$$\mu = m_B - M + \alpha \times x_1 - \beta \times c + \gamma + \mu_{\rm bias}$$

nuisance parameter

Selection term:

Previously: $\mu_{\rm bias} = f(z)$ '1D'

For DES3YR: $\mu_{\rm bias} = f(z, x_1, c)$ '5D'

$+ \alpha, \beta$

effectively:

$$\mu = (m_B - \Delta m_B) - M + \alpha \times (x_1 - \Delta x_1) - \beta \times (c - \Delta c) + \gamma$$

selection terms: the "BBC" formalism

Results:

Mass term

step function split at: $M_* = 10$

$$\mu = m_B - M + \alpha \times x_1 - \beta \times c + \gamma + \mu_{\rm bias}$$

Sample	Biascor	Best-fit γ
DES-SN	5D	0.040 ± 0.019
DES3YR	5D	0.043 ± 0.018
Pantheon	5D	0.053 ± 0.009
PS1	5D	0.039 ± 0.016
DES-SN	1D	0.066 ± 0.020
DES3YR	1D	0.064 ± 0.019
SNLS5YR	1D	0.070 ± 0.013
JLA	1D	0.070 ± 0.023
Pantheon	1D	0.072 ± 0.010
PS1	1D	0.064 ± 0.018

'2020':

'2015':

$\gamma \sim 0.045$

???

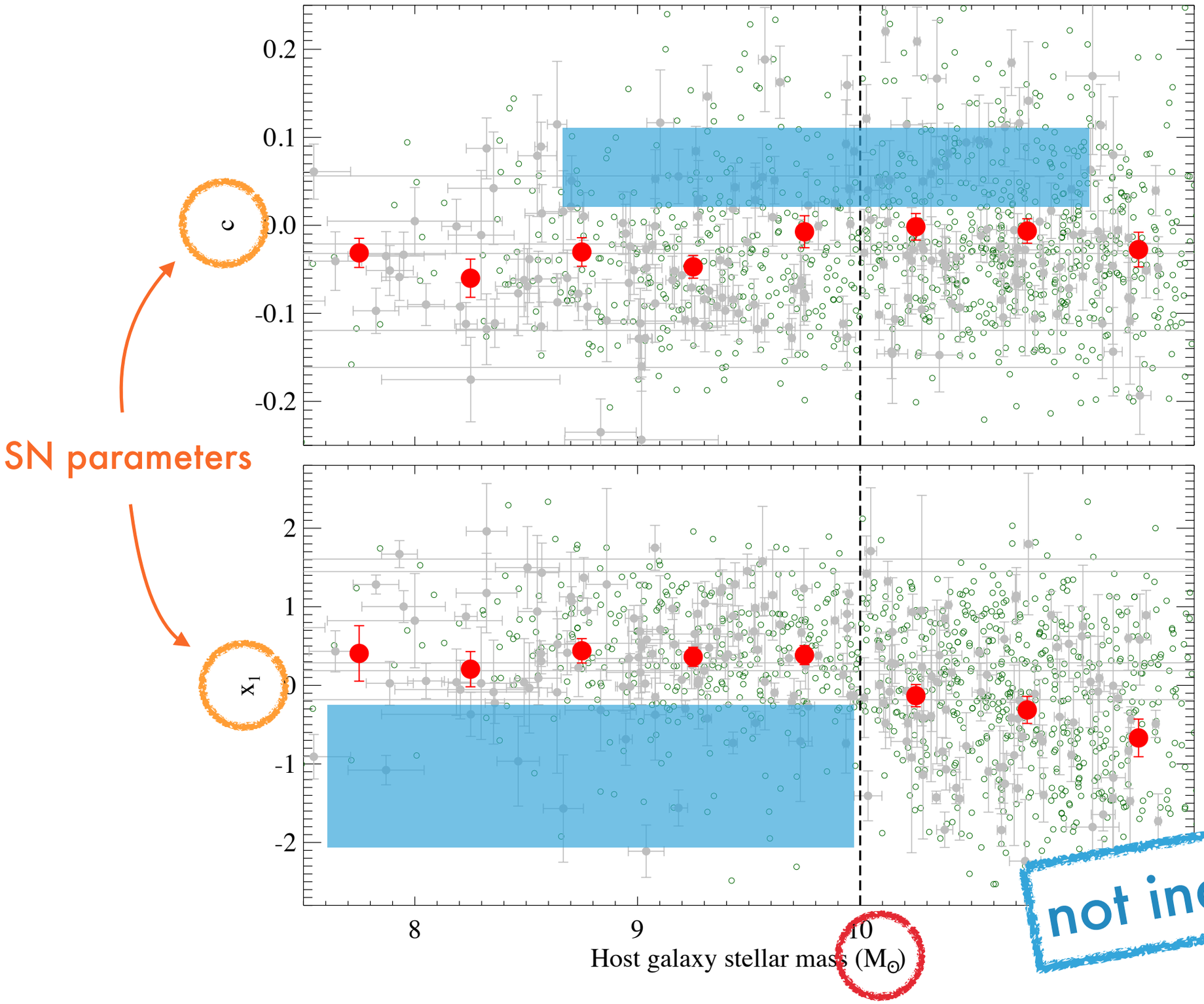
$\gamma \sim 0.065$

what happened?
what's right?

SN assumed independent of host:

$$\mu_{\rm bias} = f(z, x_1, c)$$

$$\mu = m_B - M + \alpha \times x_1 - \beta \times c + \gamma + \mu_{\rm bias}$$



SN parameters

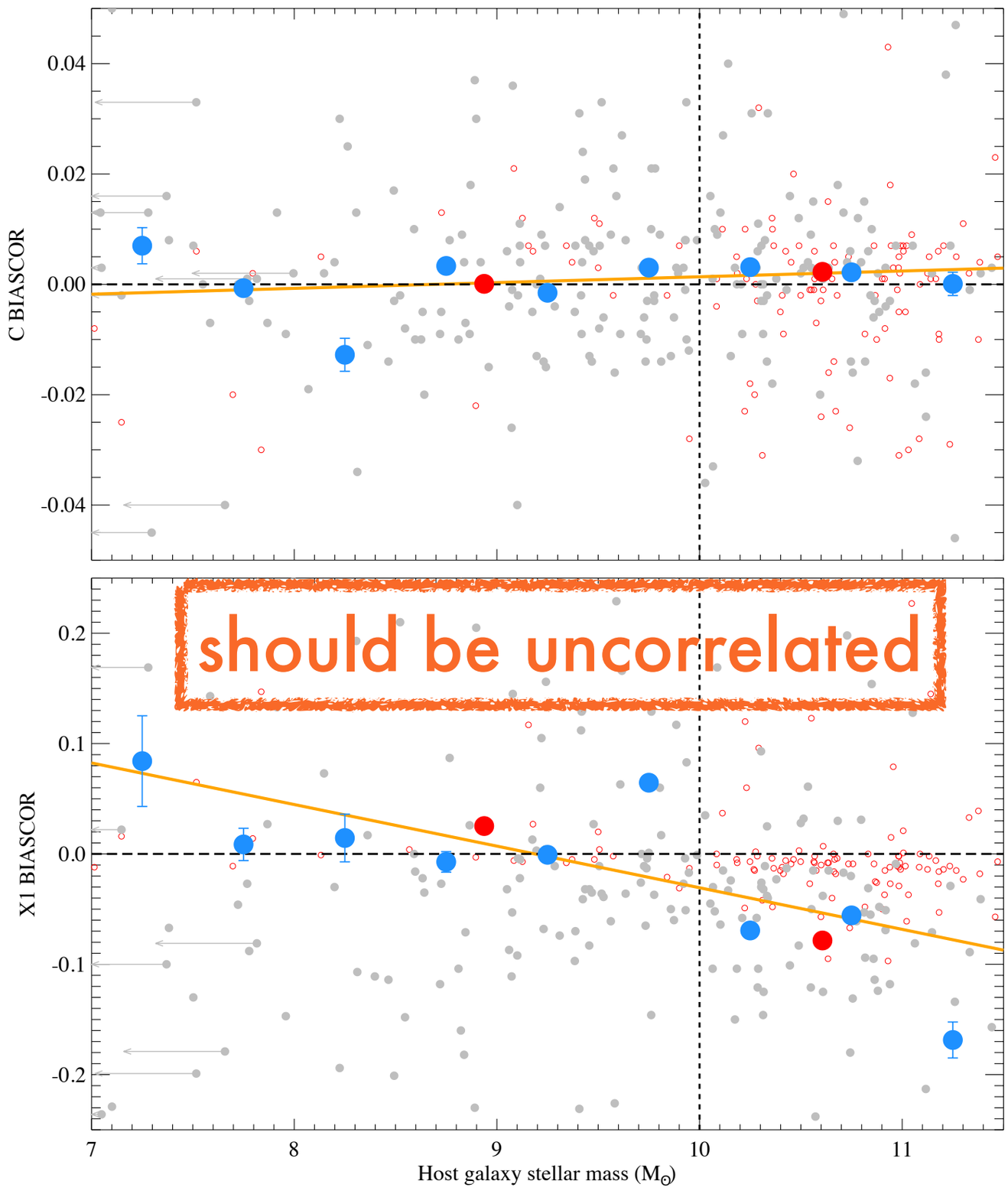
but

not independent:

so

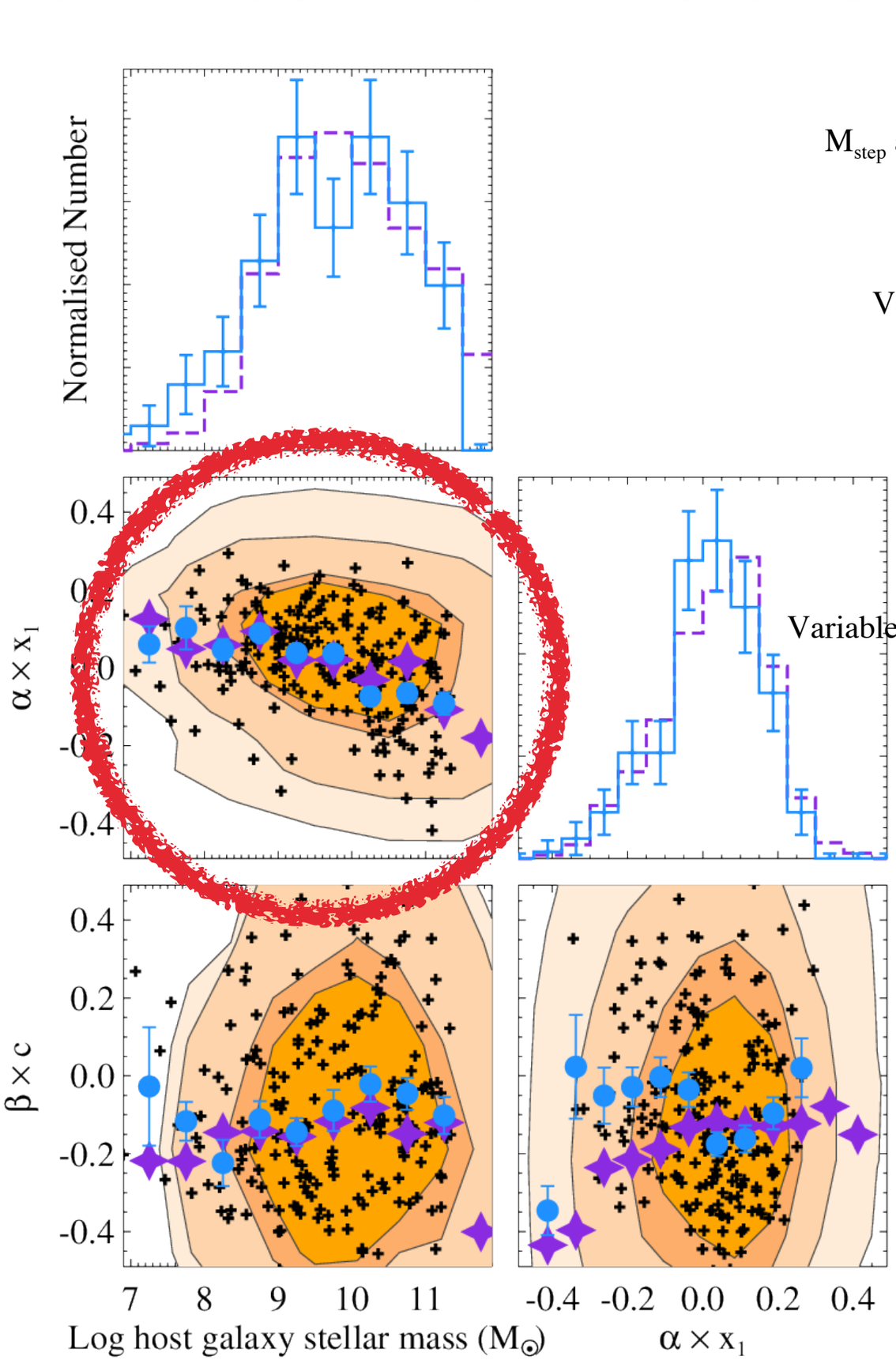
$$\mu = m_B - M + \alpha \times x_1 - \beta \times c + \gamma + \mu_{\rm bias}$$

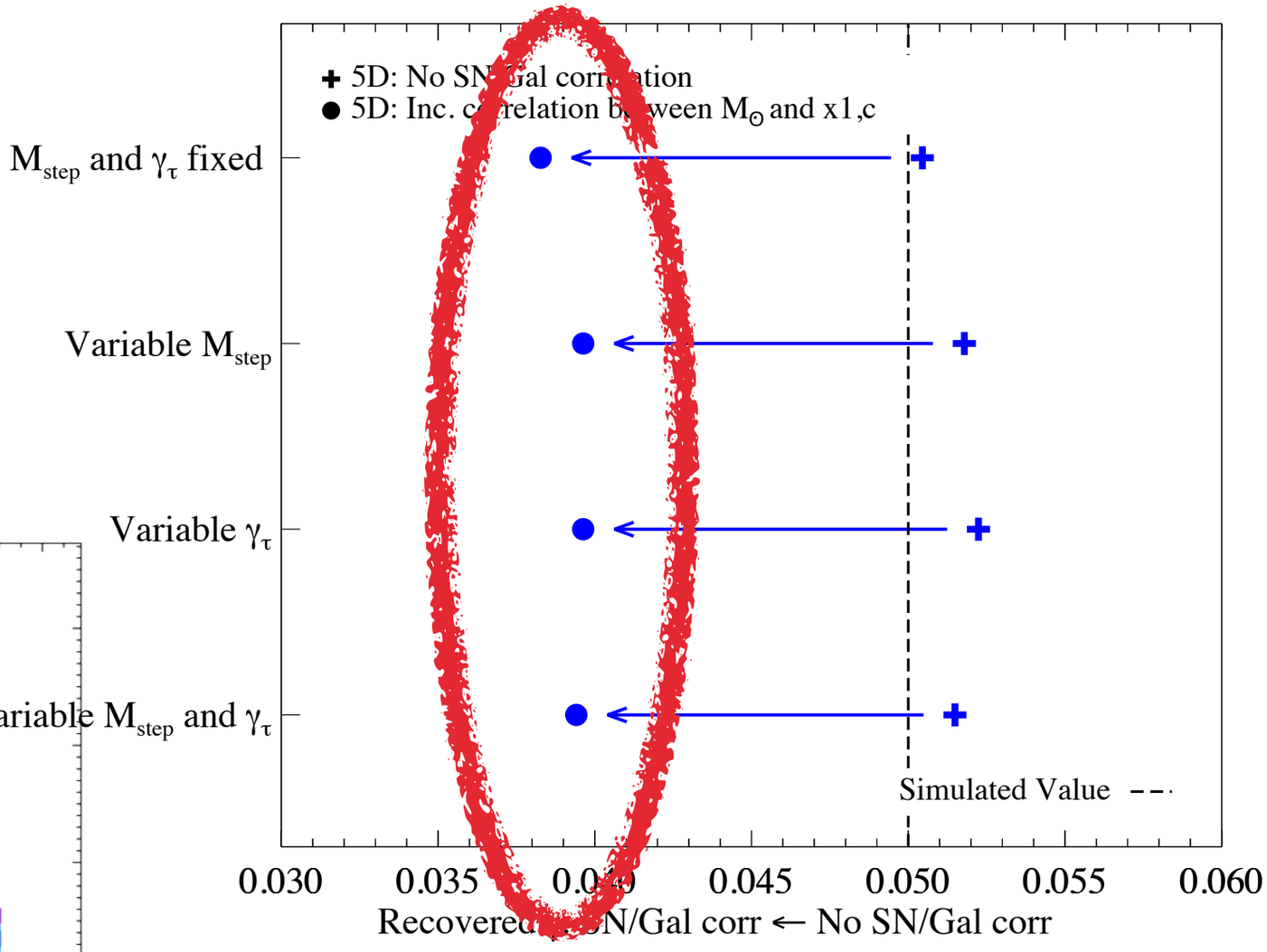
$$\mu_{\rm bias} = f(z, x_1, c)$$



bias??

from 'realistic' simulations:

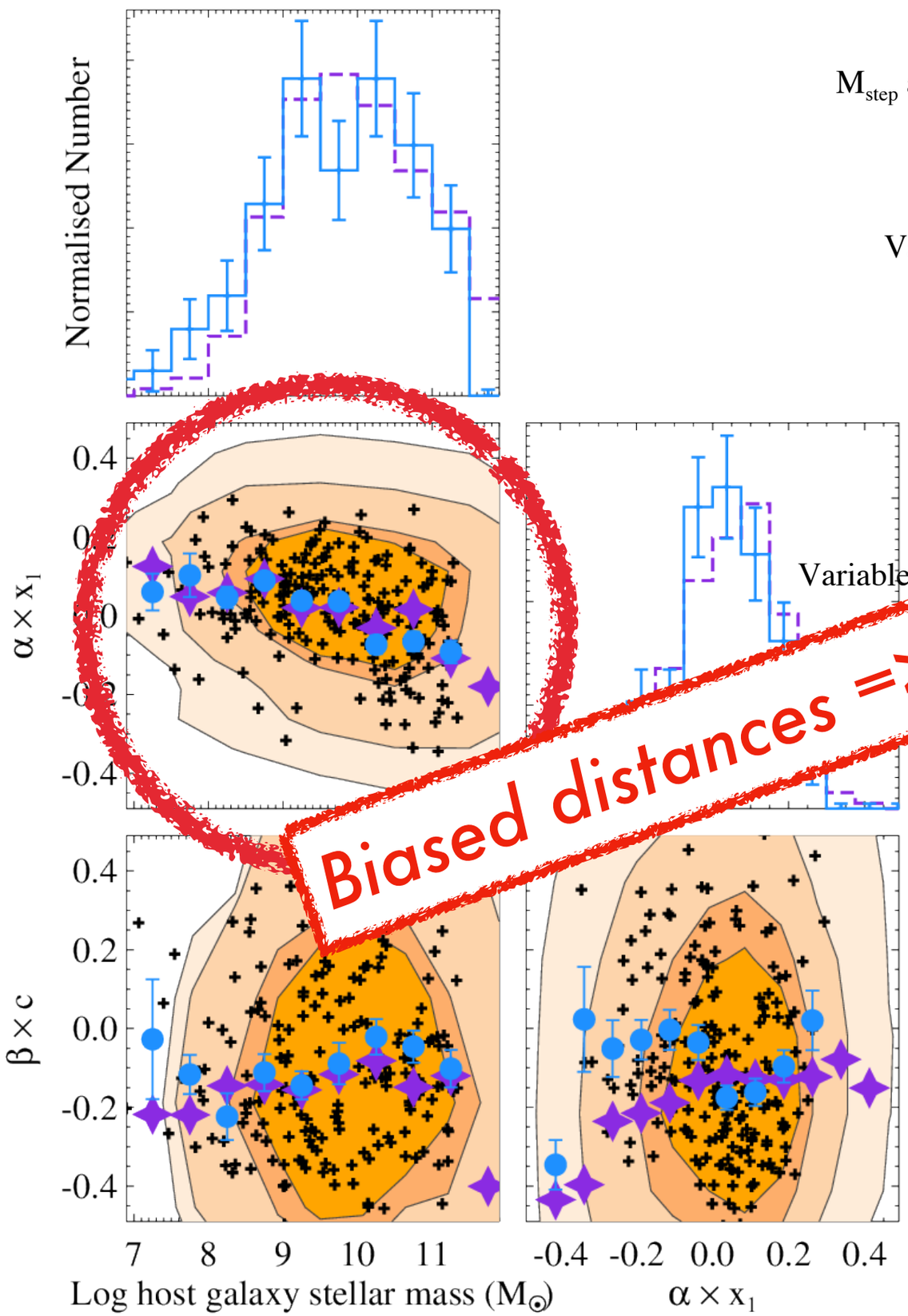


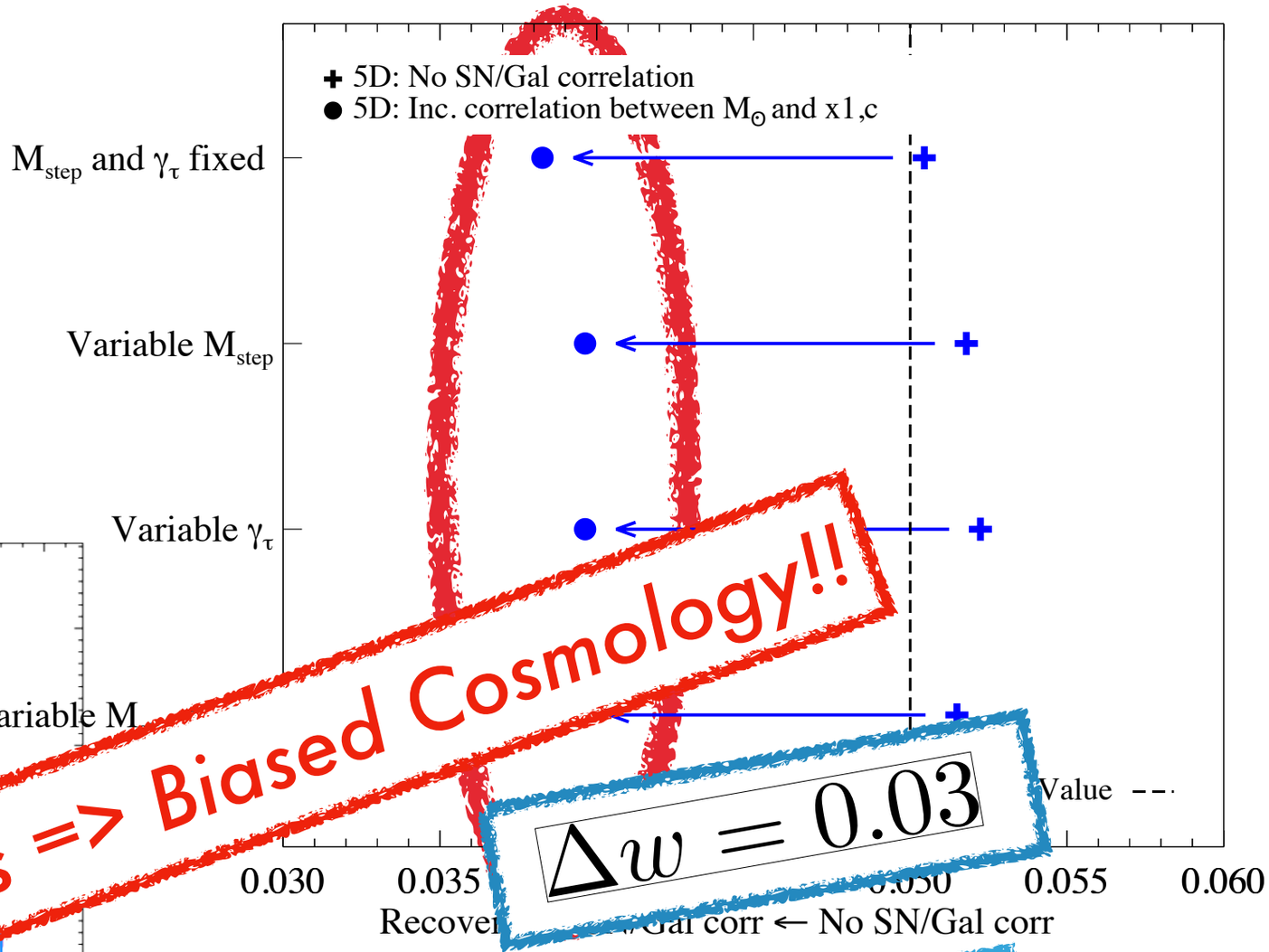


$\Delta\gamma_{5D} \sim 0.012$

consistently wrong

from 'realistic' simulations:





Biased distances => Biased Cosmology!!

$\Delta w = 0.03$

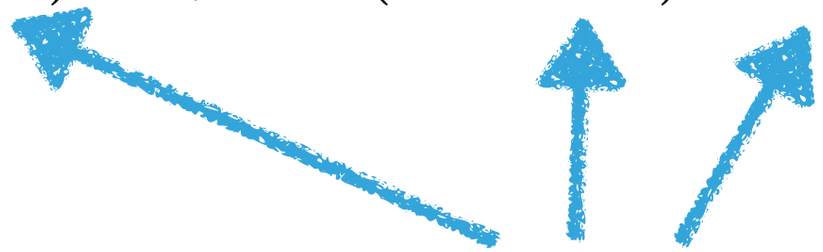
"hmmm" 0.012

consistently wrong

"The solution":

7D correction

$$\mu = (m_B - \Delta m_B) - M + \alpha \times (x_1 - \Delta x_1) - \beta \times (c - \Delta c) + \gamma$$



now allow for correlations

but

Also M isn't the truth, and it's degenerate with SFR, dust, sSFR, Z, local, ...*

in all cases still need to get SN/host correlation right

...

also:

$$\mu = (m_B - \Delta m_B) - M + \alpha \times (x_1 - \Delta x_1) - \beta \times (c - \Delta c) + \gamma$$

is mass the right parameter?

'local colour' is better?

...

Kelsey+ 2020

DES-SN: Astrophysical systematics

DES-5YR is ideal for this

need to understand SELECTION, CONTAMINATION and UNDERLYING CORRELATIONS
==> lots of SIMULATIONS
(ongoing)

intriguing early results: ask me in a couple of months ;)

That's it for now.

DES-SN is great

2000 SNIa with 0.1 < z < 1.2; all with hosts

precursor to LSST deep

200 SN == state-of-the-art

highlights the power of 'one survey' approach

Not modelling SN v host correctly can lead to biased γ

must know how: SN $\propto$ galaxy

DES5YR (in 2020) will trace γ v z to probe fundamental cause and optimal standardisation

Ideal test-bed for LSST

That's it for now.

DES-SN is great

2000 SNIa with 0.1 < z < 1.2; all with hosts

precursor to LSST deep

200 SN == state-of-the-art

highlights the power of 'one survey' approach

Not modelling SN v host correctly can lead to biased γ

must know how: SN $\propto$ galaxy

DES5YR (in 2020) will trace γ v z to probe fundamental cause and optimal standardisation

Ideal test-bed for LSST

Thank you!