PhD Day

Studying the effect of the environment properties on the luminosity of the Type Ia Supernovae and its impact on cosmology

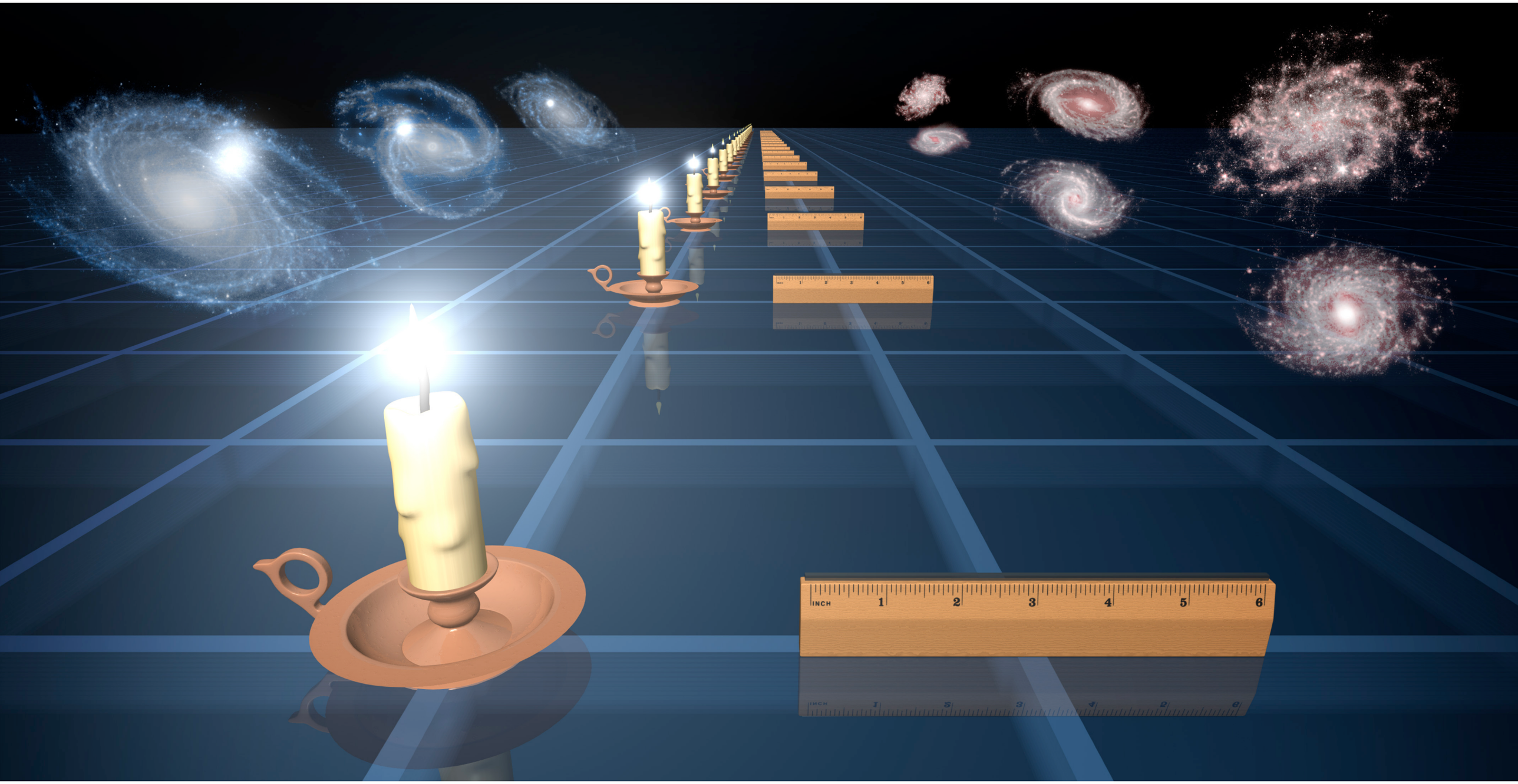
Martin BRIDAY - m.briday@ipnl.in2p3.fr

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement n°759194 - USNAC)


SN2011fe

Type Ia Supernovae

– standard candles –



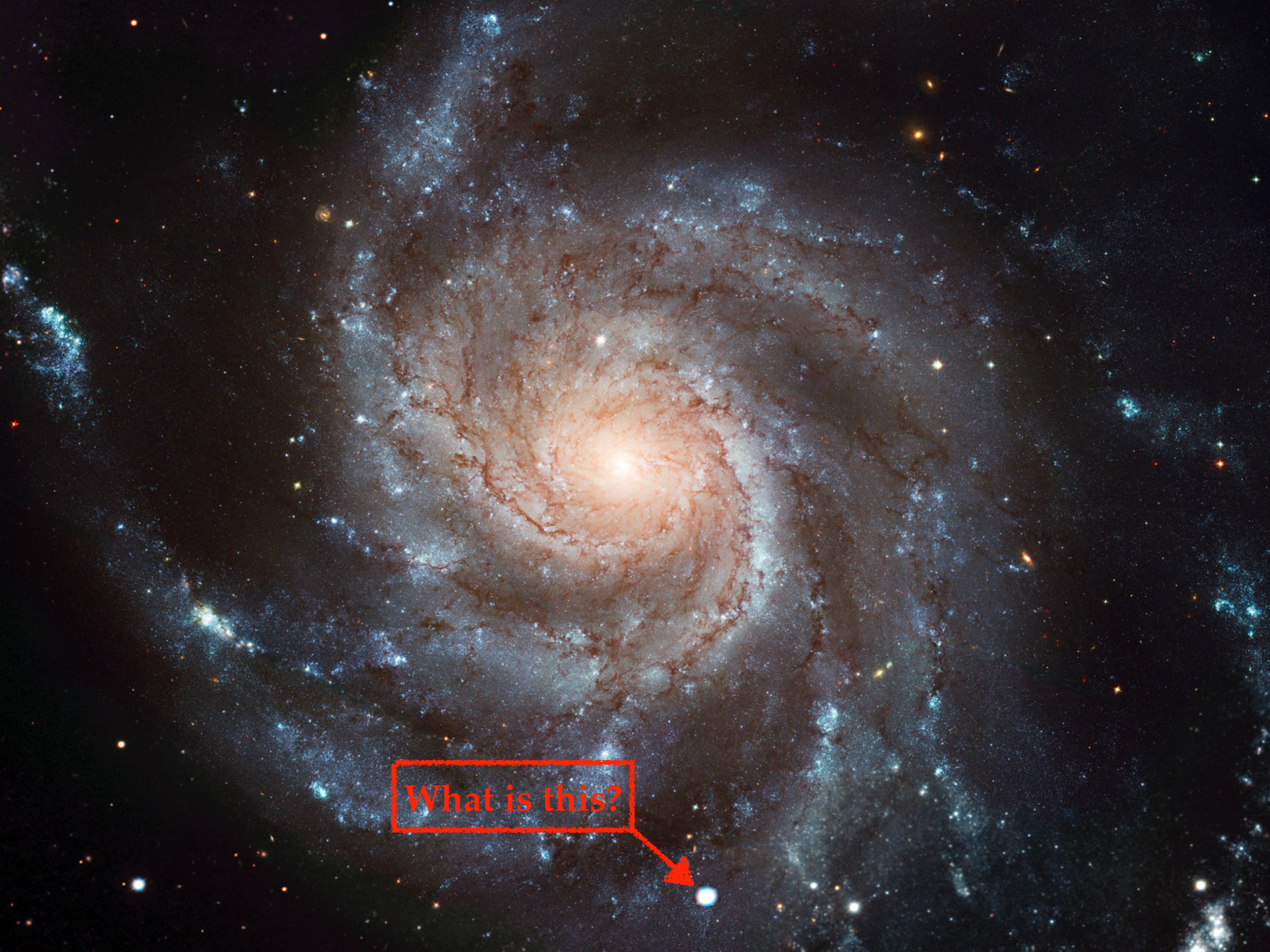
PhD Day, 27/01/21 - Martin BRIDAY - m.briday@ipnl.in2p3.fr

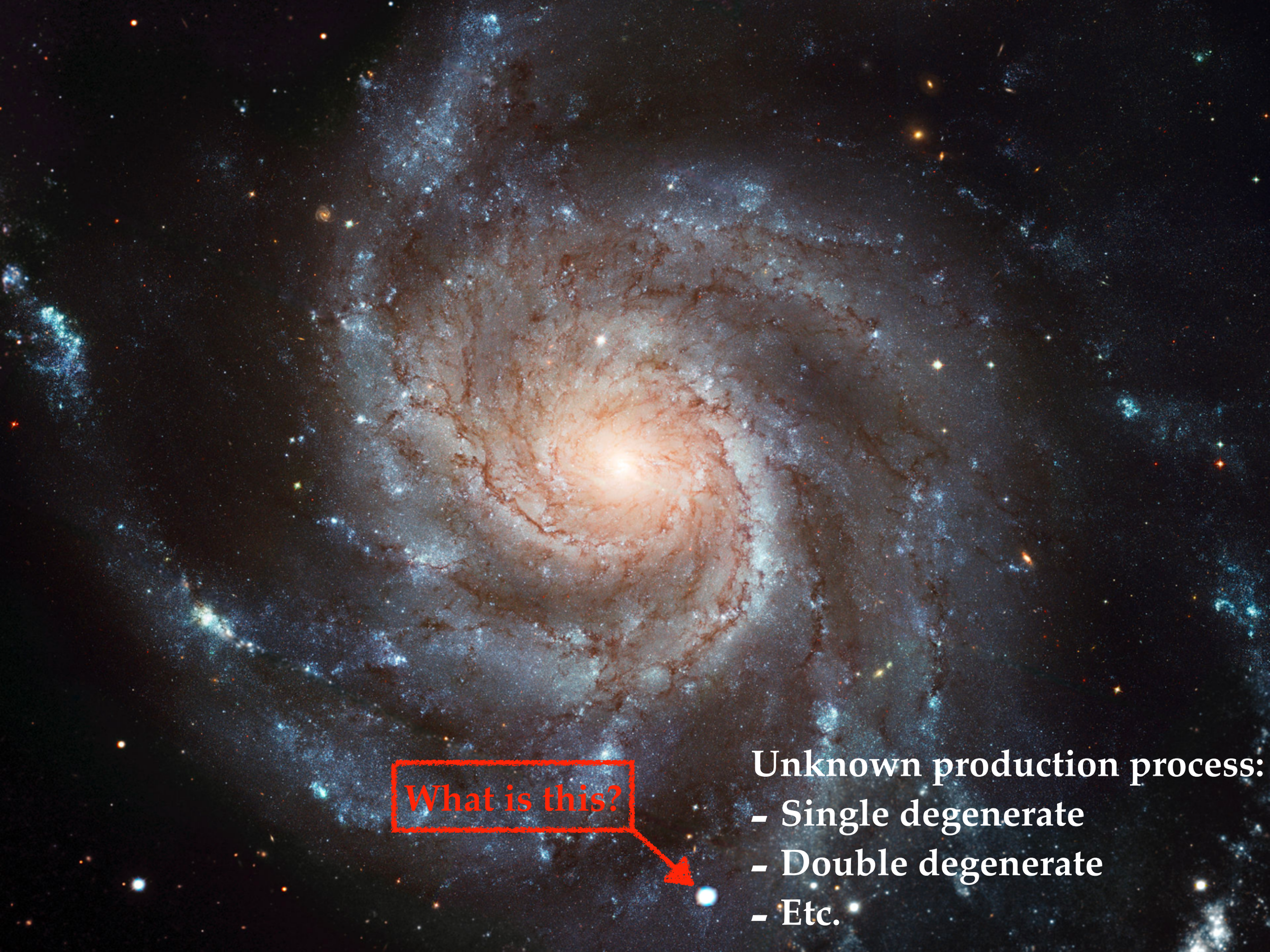
Type Ia Supernovae

– standard candles –

$$\mu = m - \boxed{M} = 5 \log_{10} \left(\frac{d}{10\,\mathrm{pc}} \right)$$

A priori known for a standard candle


What is this?


What is this?
Unknown production process:
- Single degenerate
- Double degenerate
- Etc.

Type Ia Supernovae

— standardizable candles —

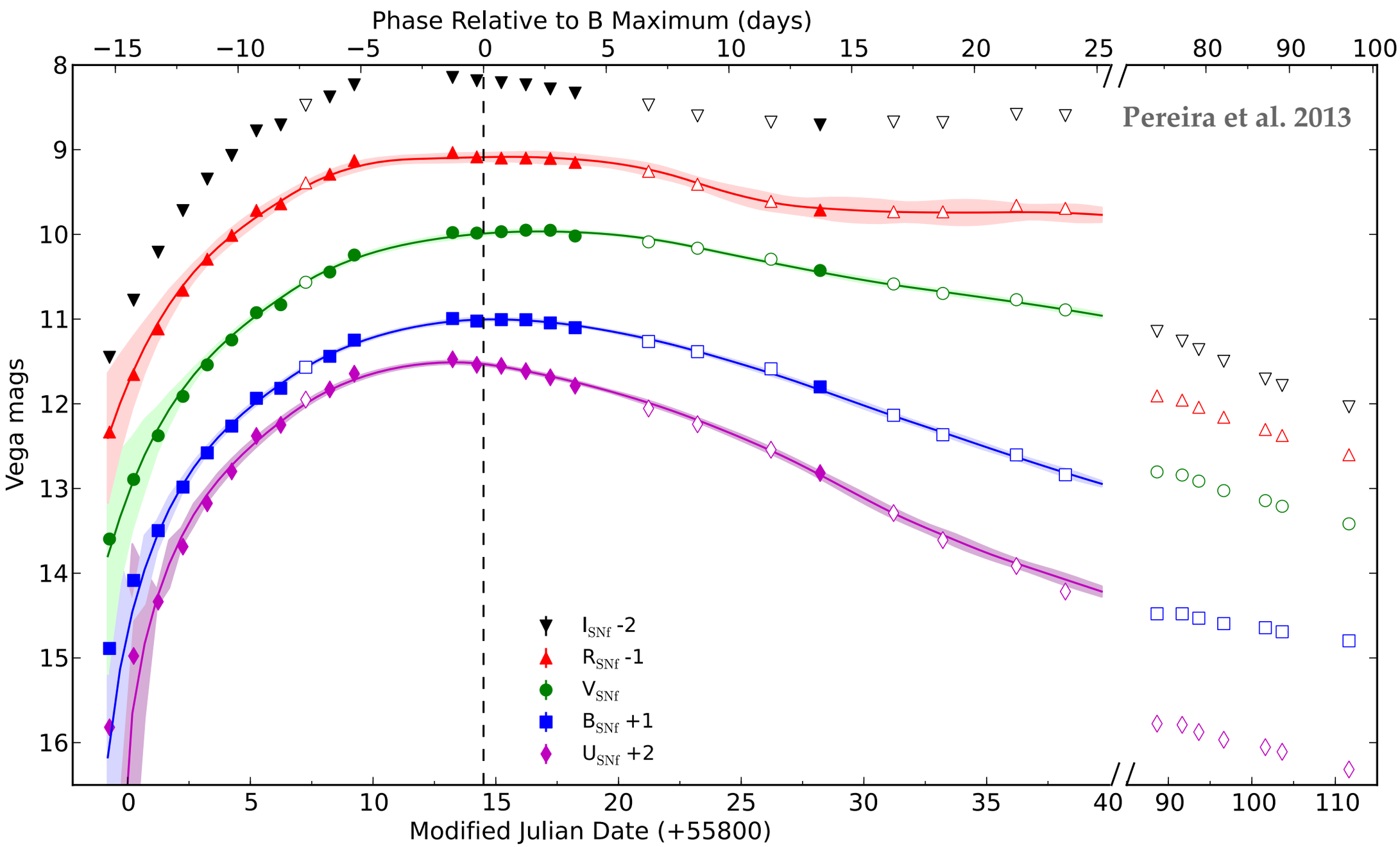
$$\mu = m - M = 5 \log_{10} \left(\frac{d}{10\,\mathrm{pc}} \right)$$

A priori known for
a standard candle

$$M = M_0 - \alpha x_1 + \beta c$$

Type Ia Supernovae

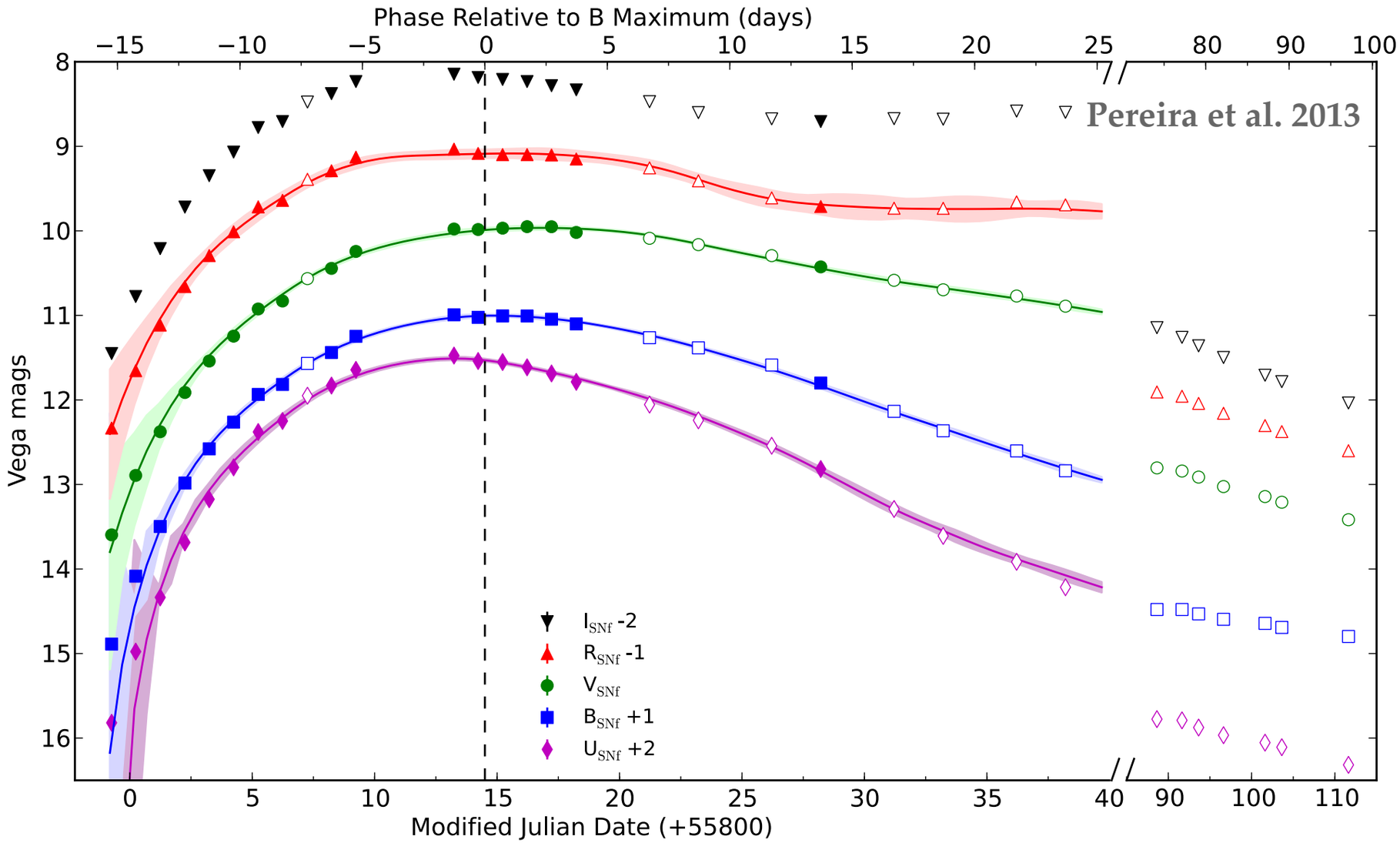
— light curves —



Type Ia Supernovae

– standardization –

$$\mu = m - M_0 + \alpha x_1 - \beta c$$



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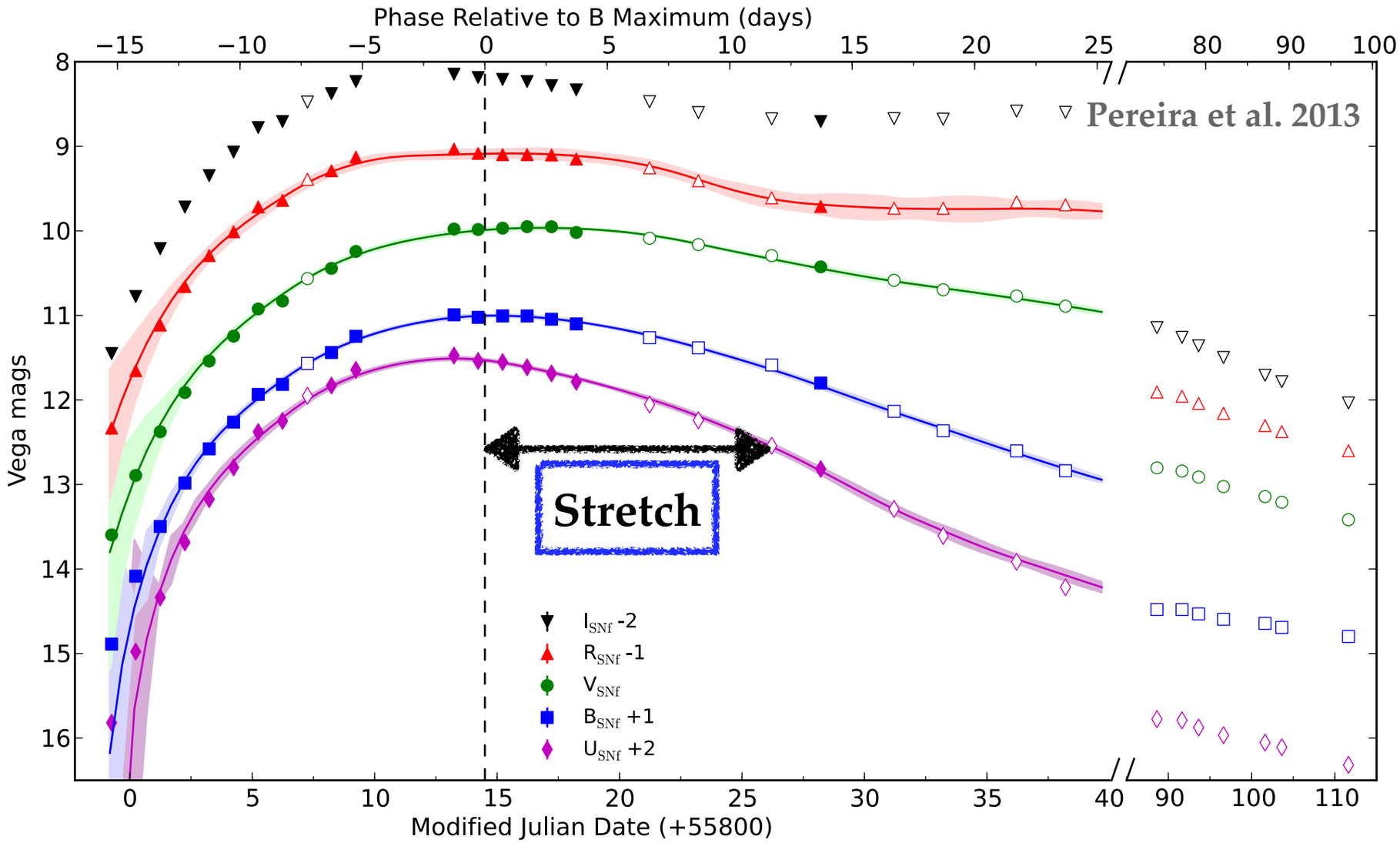

Type Ia Supernovae

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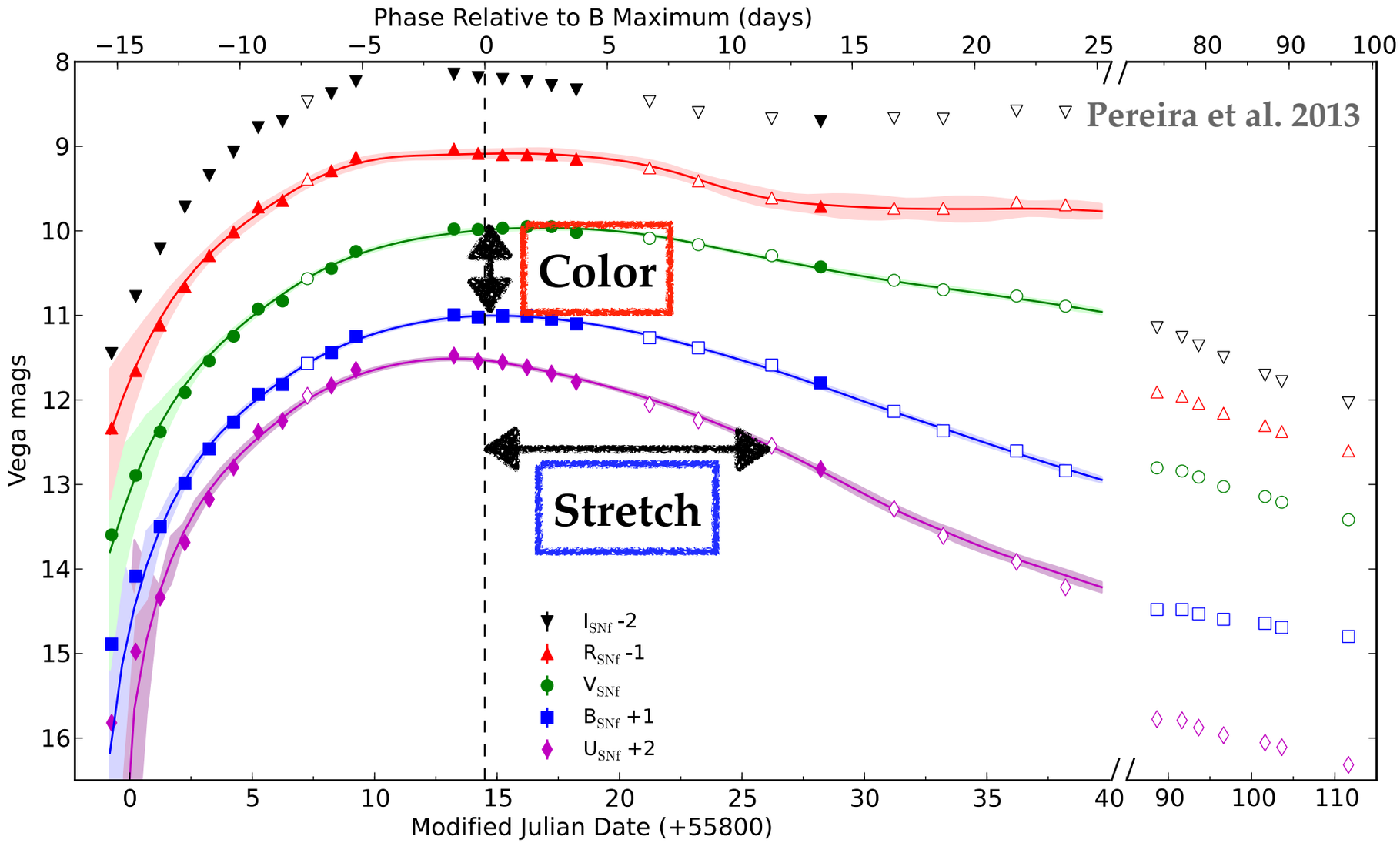
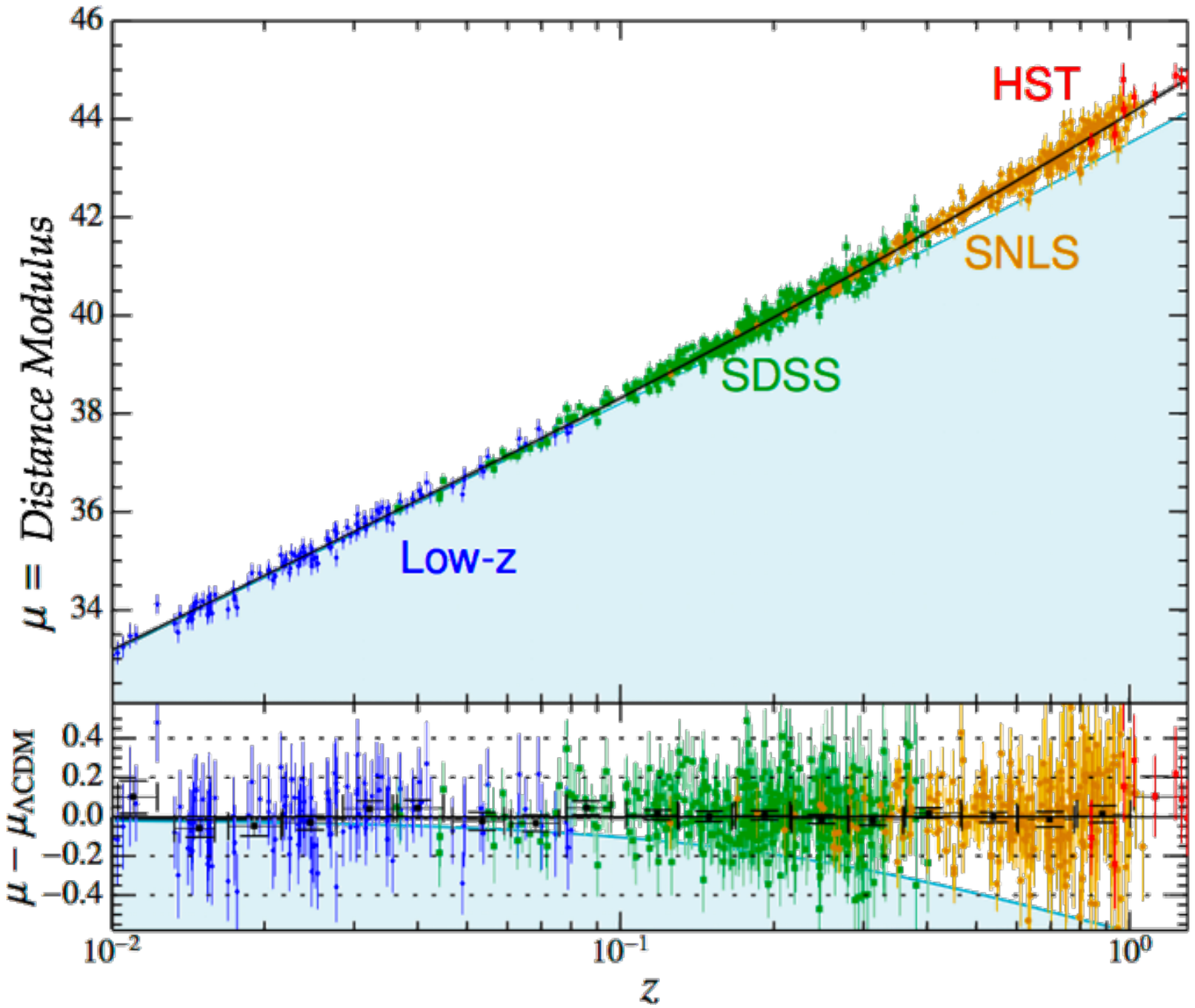


SNe Ia Cosmology

Betoule et al. 2014

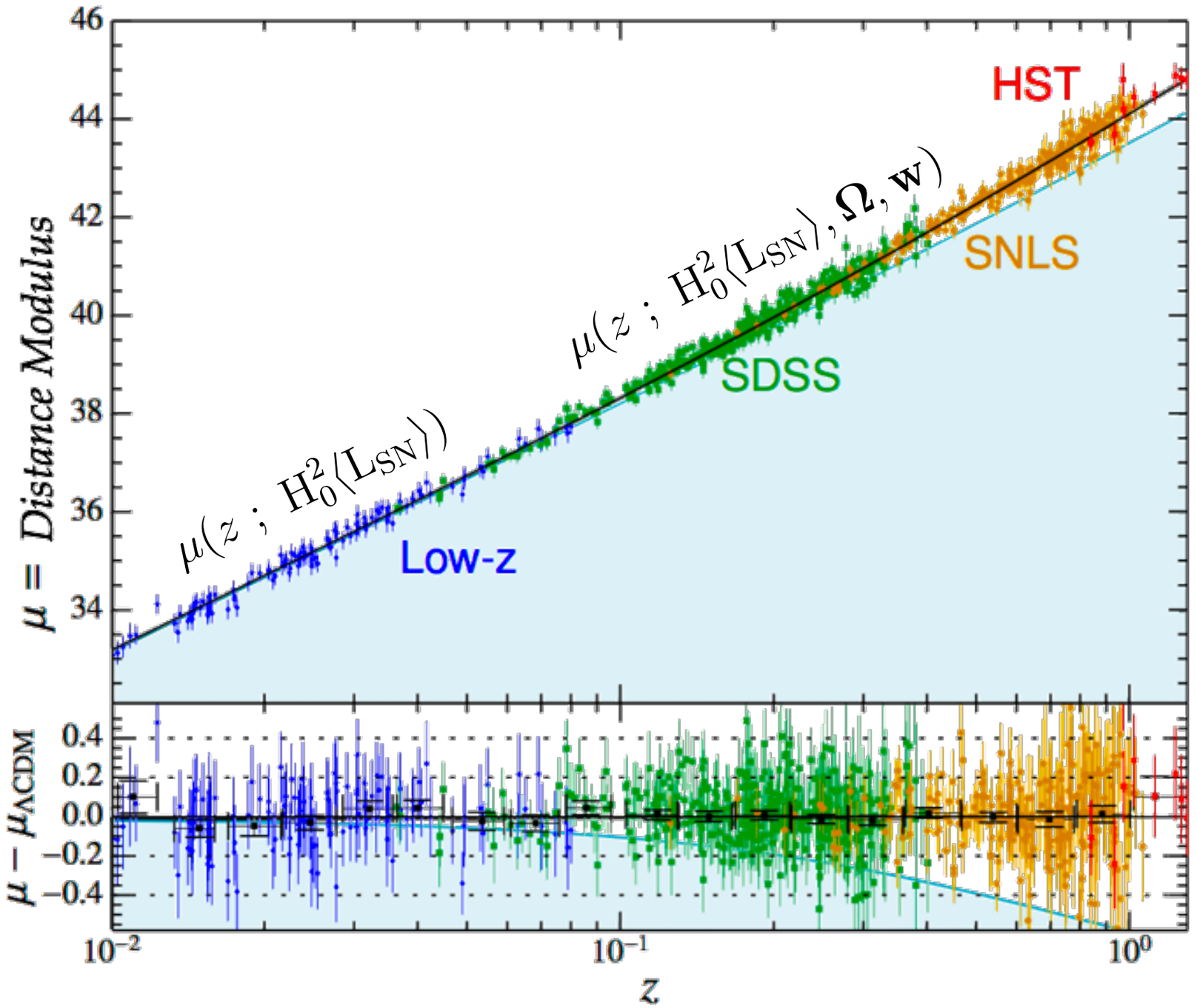


$\Omega_m = 0.295$
$\Omega_\Lambda = 0.705$

$\Omega_m = 1$
$\Omega_\Lambda = 0$

SNe Ia Cosmology

Betoule et al. 2014



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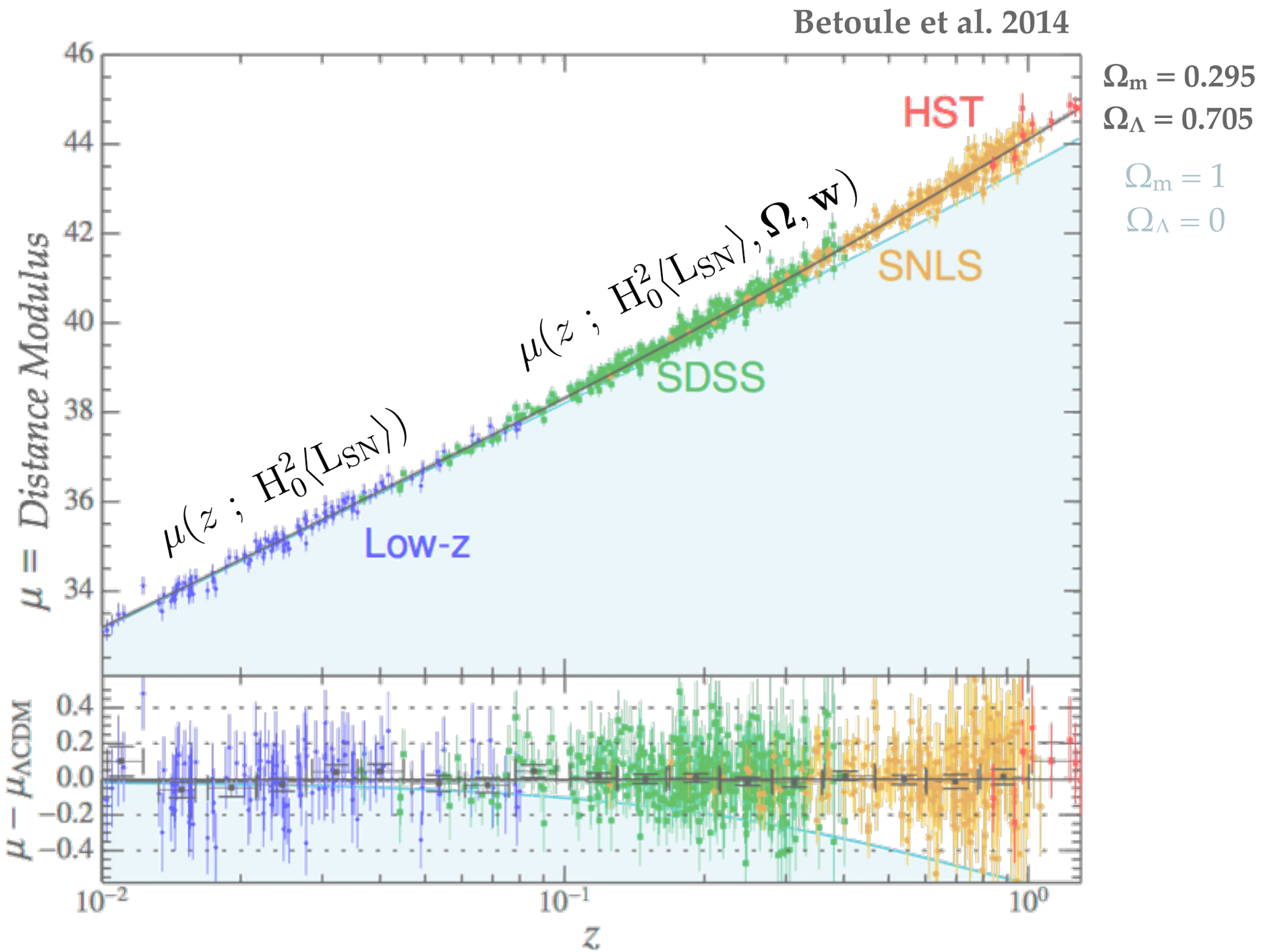
SNe Ia Cosmology | H_0



SNe Ia Cosmology | H_0

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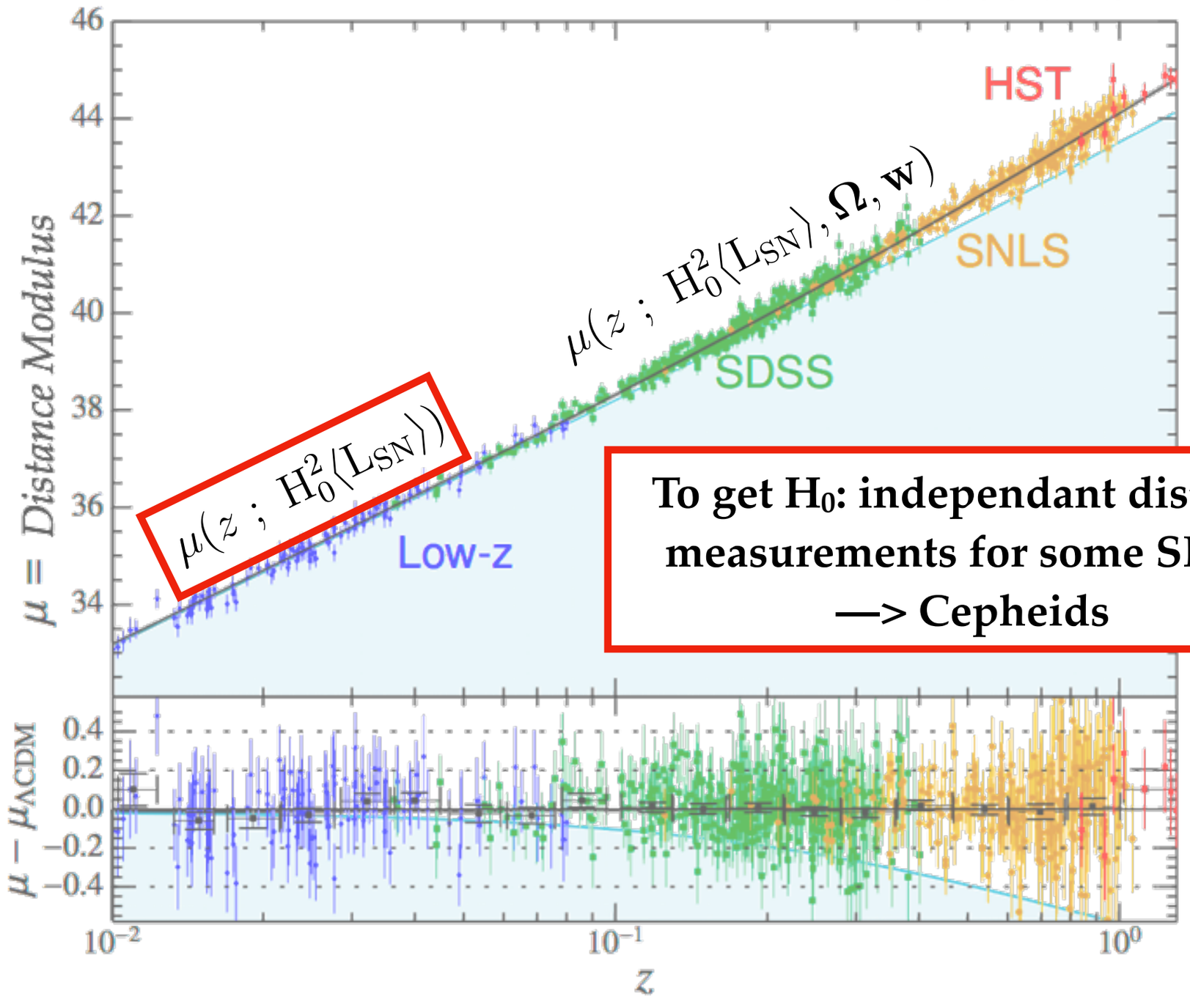

$\Omega_m = 0.295$
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$\Omega_m = 1$
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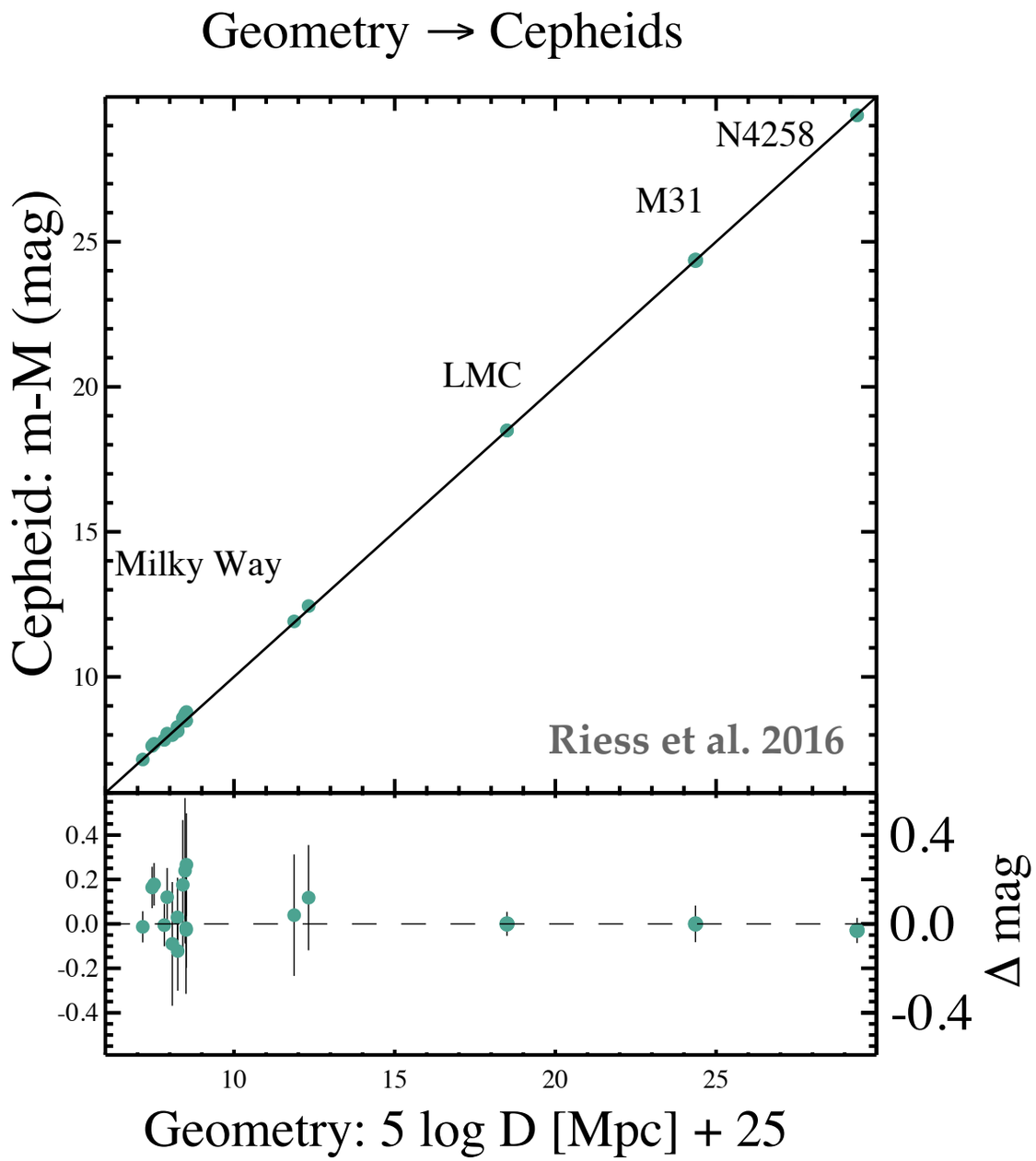
To get H_0: independant distance measurements for some SNeIa —> Cepheids

Type Ia Supernovae

— calibration —

Cepheids: bright young stars with a pulsation-luminosity relation



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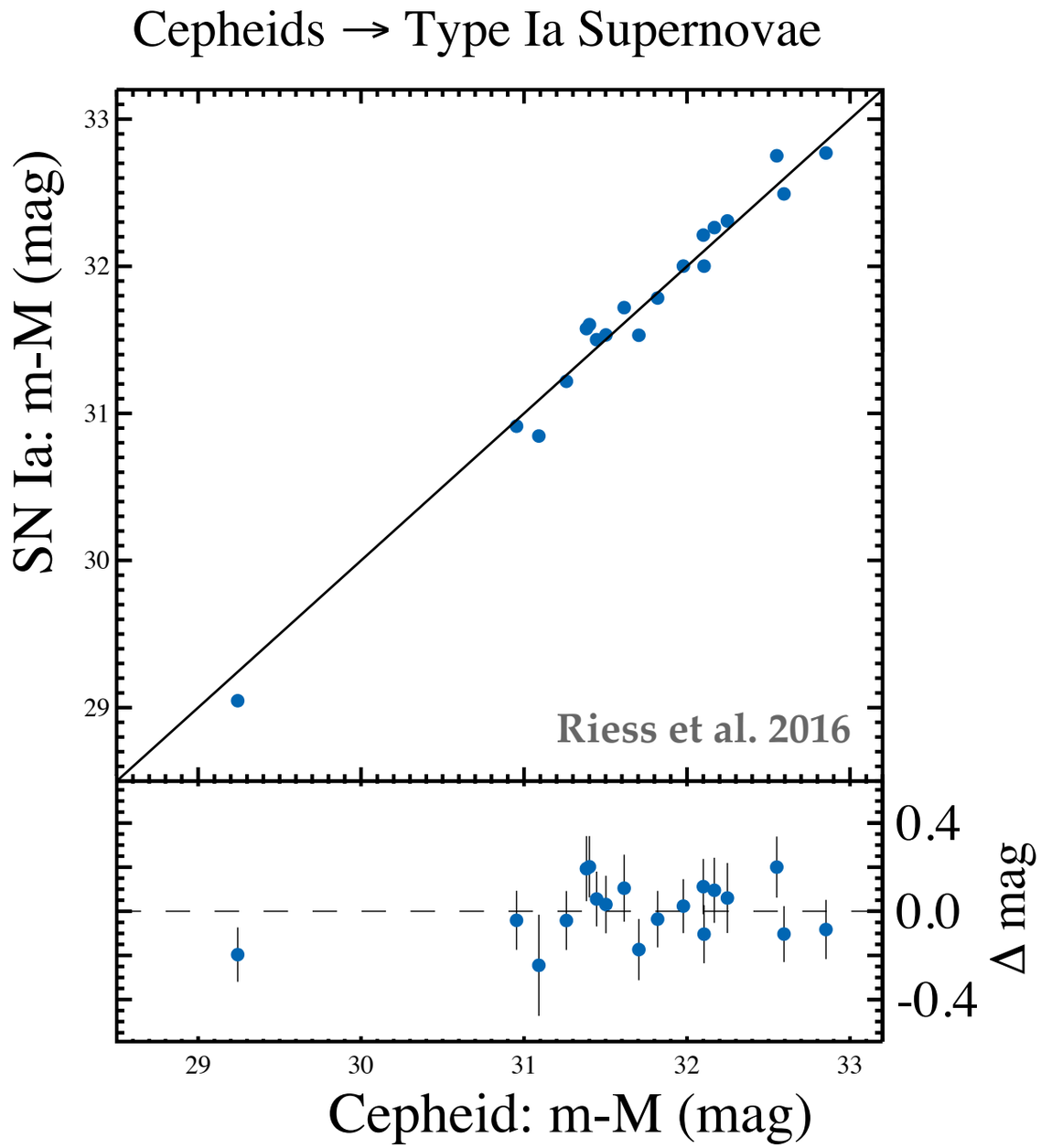
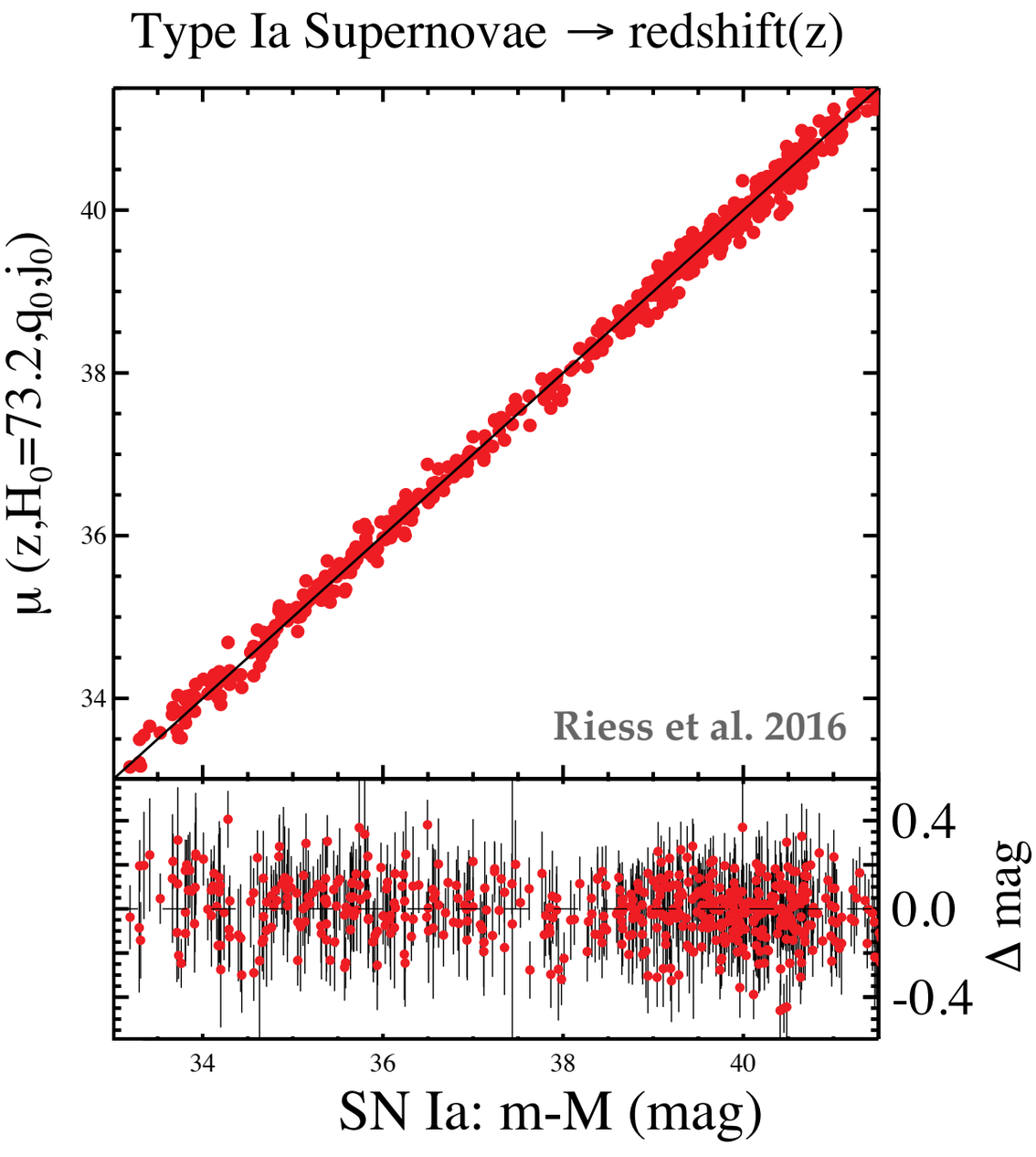


Type Ia Supernovae

— calibration —

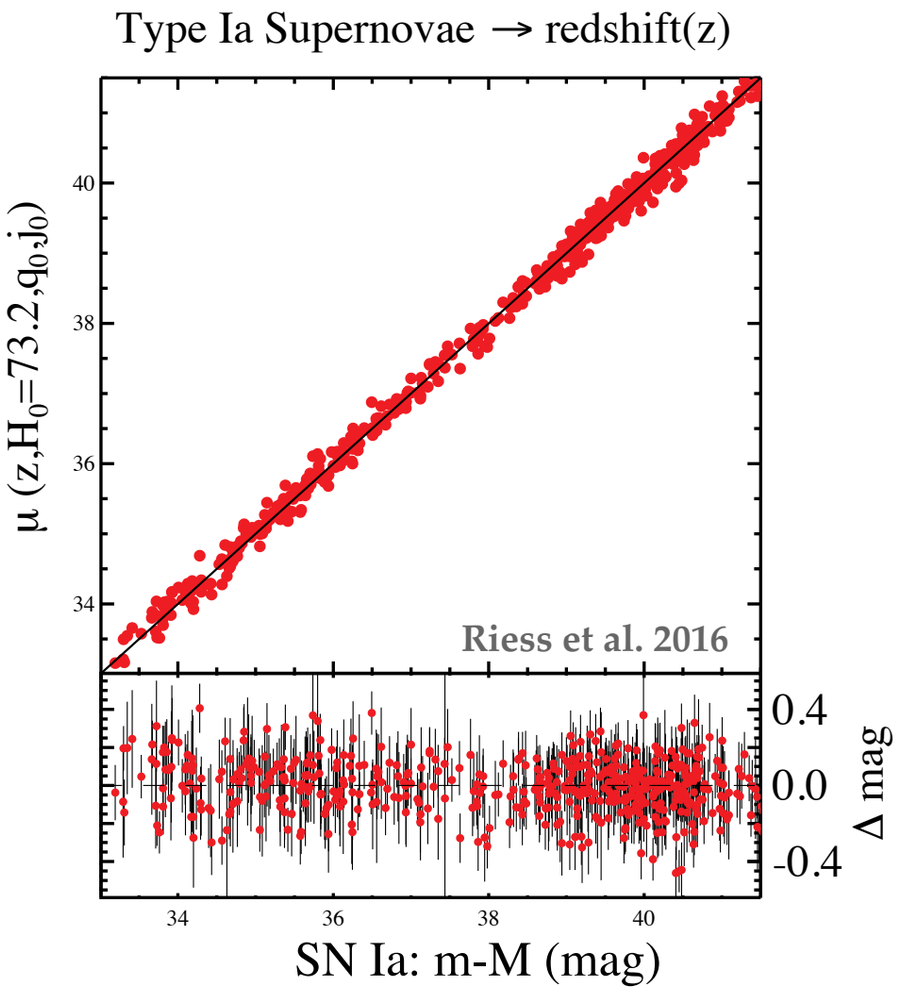
Cepheids: bright young stars with a pulsation-luminosity relation



Type Ia Supernovae

— direct measurement of H_0 —

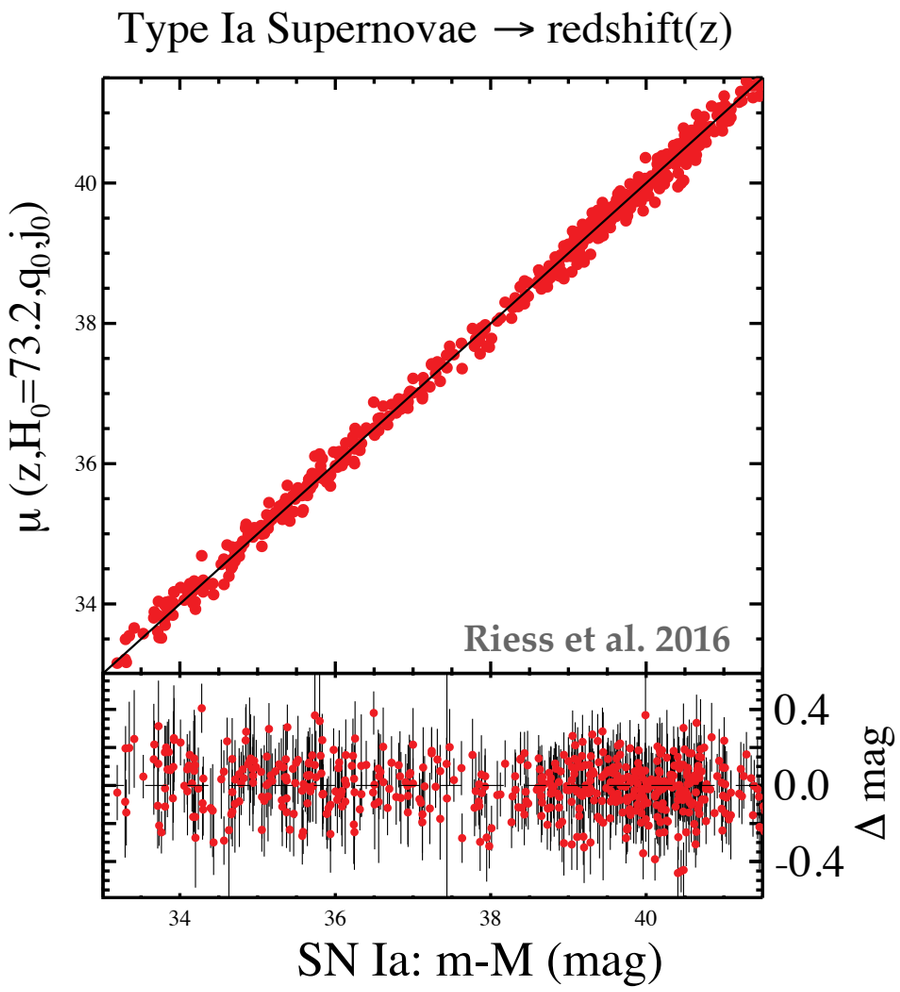
Cepheids: bright young stars with a pulsation-luminosity relation



Type Ia Supernovae

— direct measurement of H_0 —

Cepheids: bright young stars with a pulsation-luminosity relation

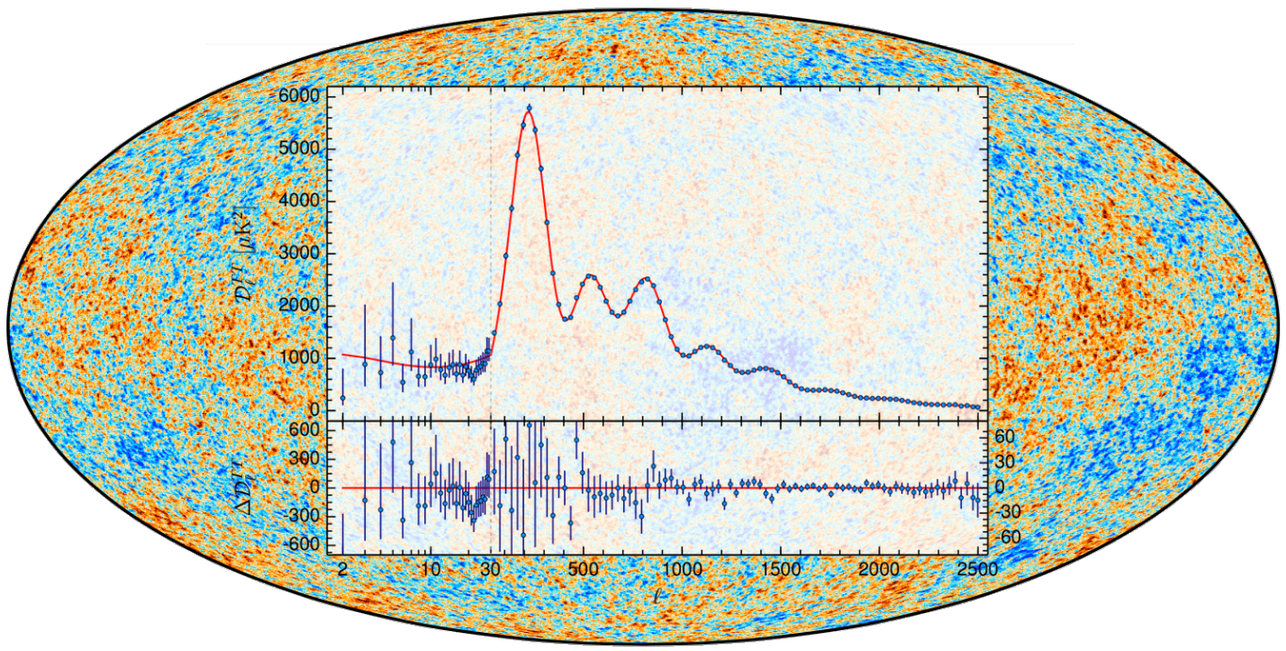


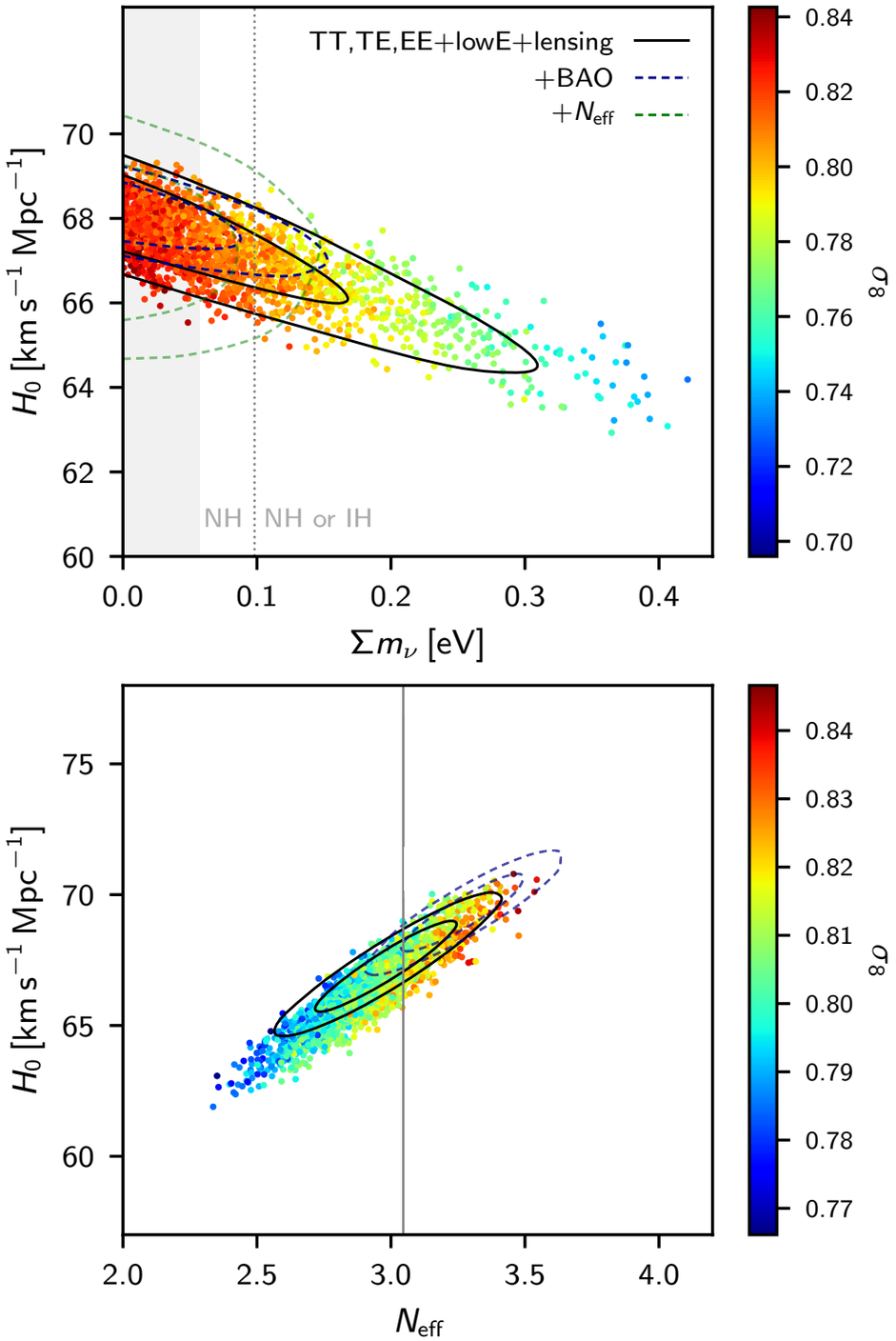
$$H_0 = 73.2 \pm 1.3\ km\ s^{-1}\ Mpc^{-1}$$

(1.8%; Riess et al. 2020)

H_0 prediction from ΛCDM | Planck

— indirect measurement of H_0 —





H_0 prediction from ΛCDM | Planck

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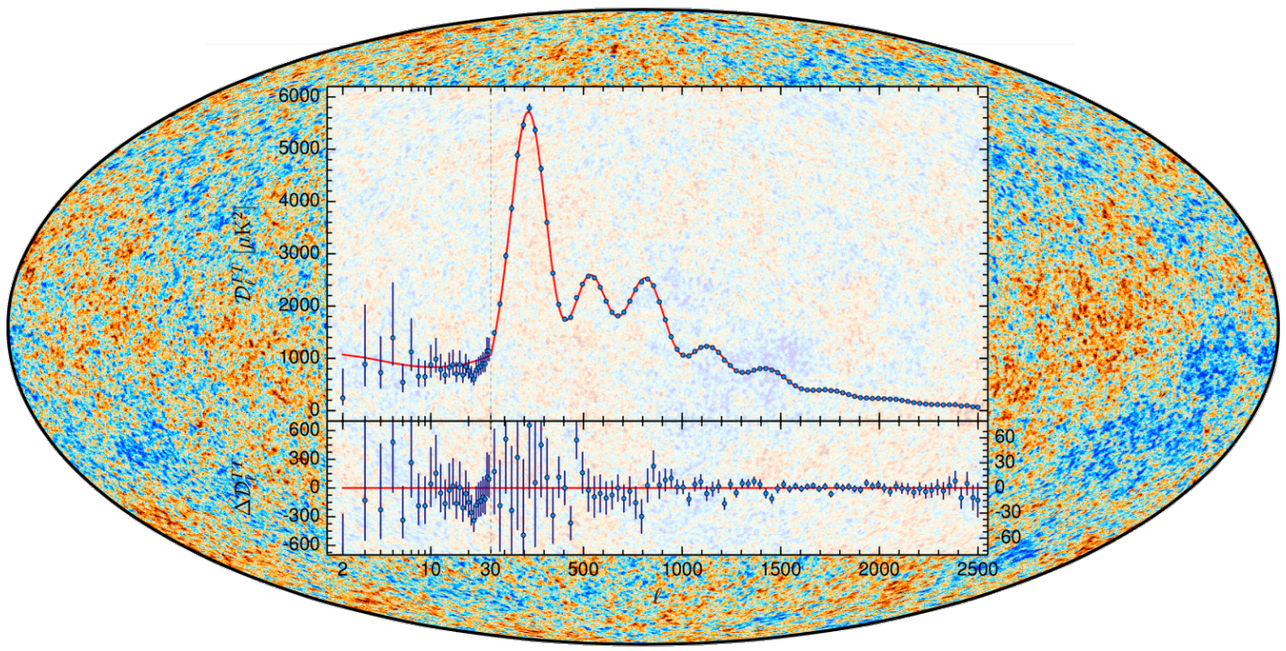
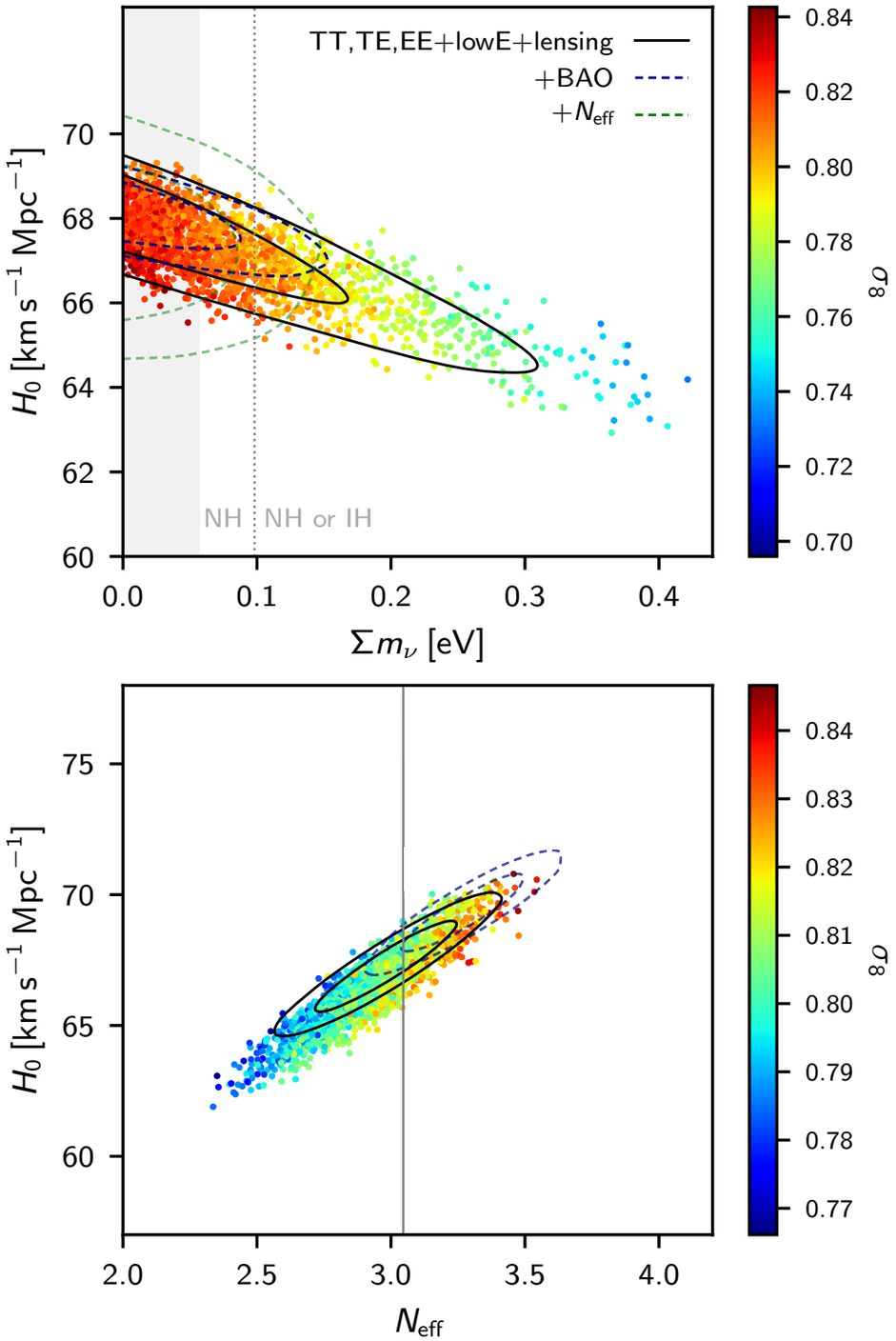
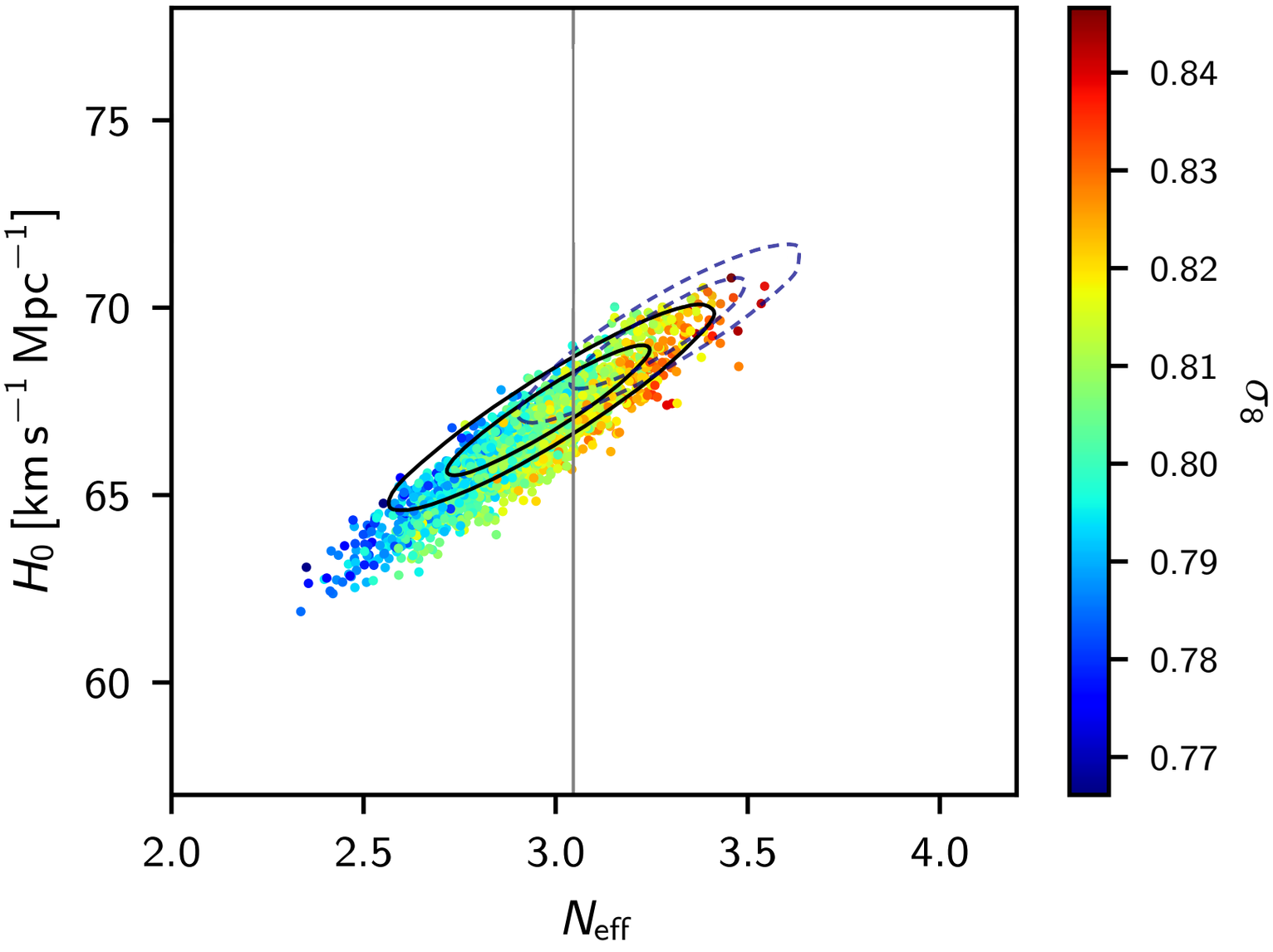


$$H_0 = 67.4 \pm 0.5\ km\ s^{-1}\ Mpc^{-1}$$

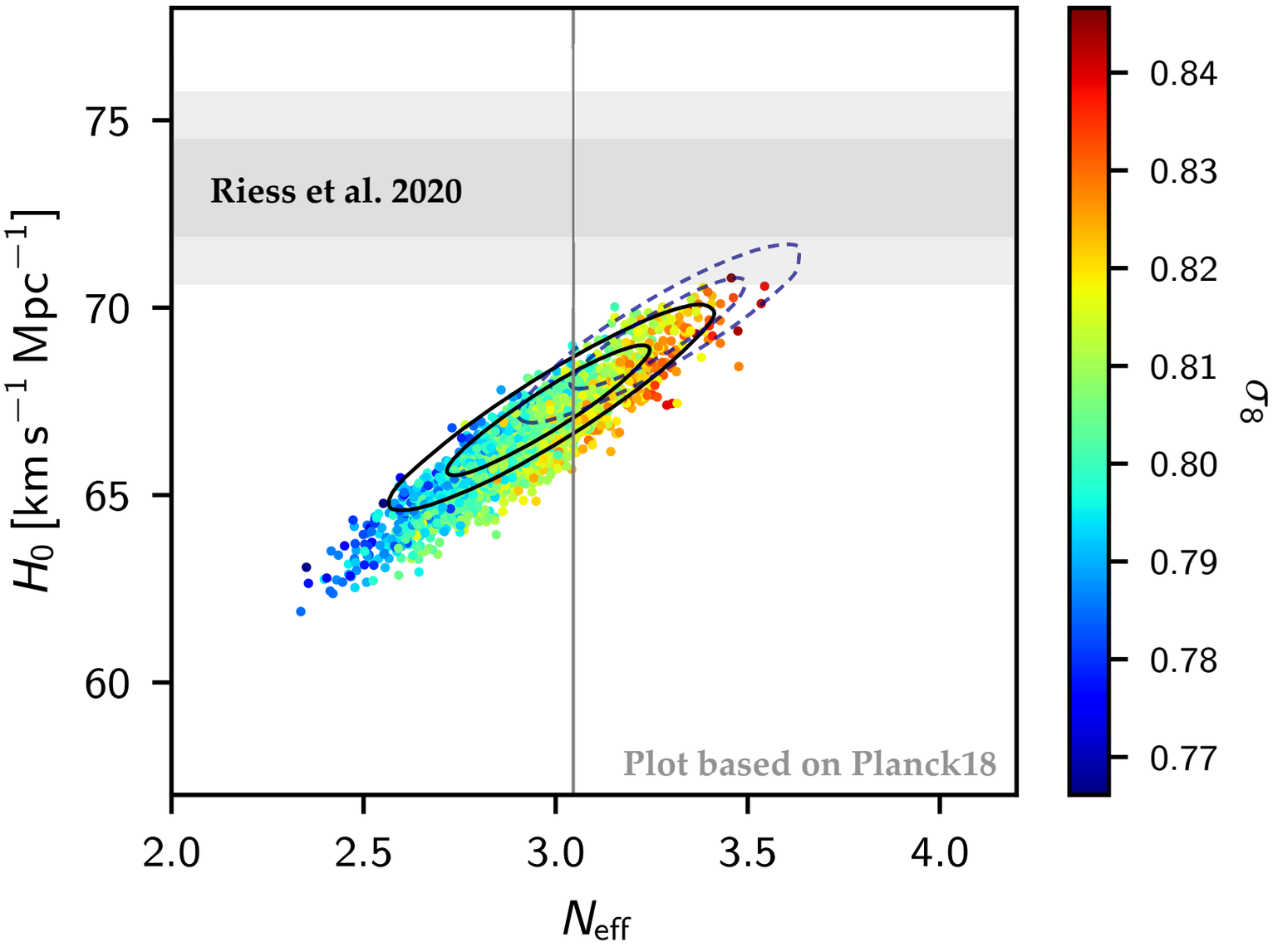
(0.7%; Planck et al. 2018)



H_0 tension ?


75
70
65
60
H_0 [km s^{-1} Mpc^{-1}]
2.0
2.5
3.0
3.5
4.0
$N_{\rm eff}$
0.84
0.83
0.82
0.81
0.80
0.79
0.78
0.77
σ_8

H_0 tension ?


Riess et al. 2020
Plot based on Planck18
H_0 [km s^{-1} Mpc^{-1}]
$N_{\rm eff}$
σ_8
75
70
65
60
2.0
2.5
3.0
3.5
4.0
0.84
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0.78
0.77

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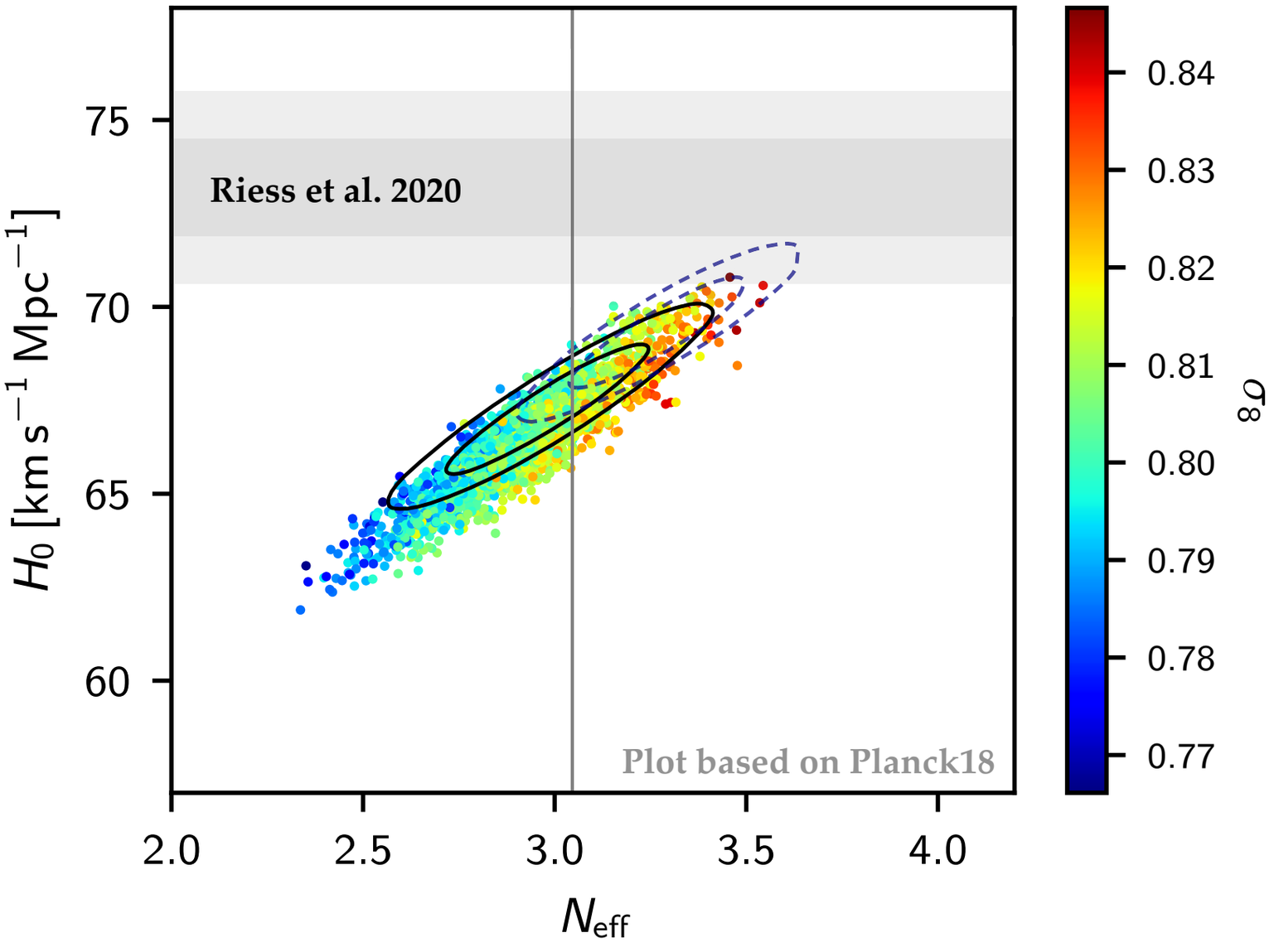
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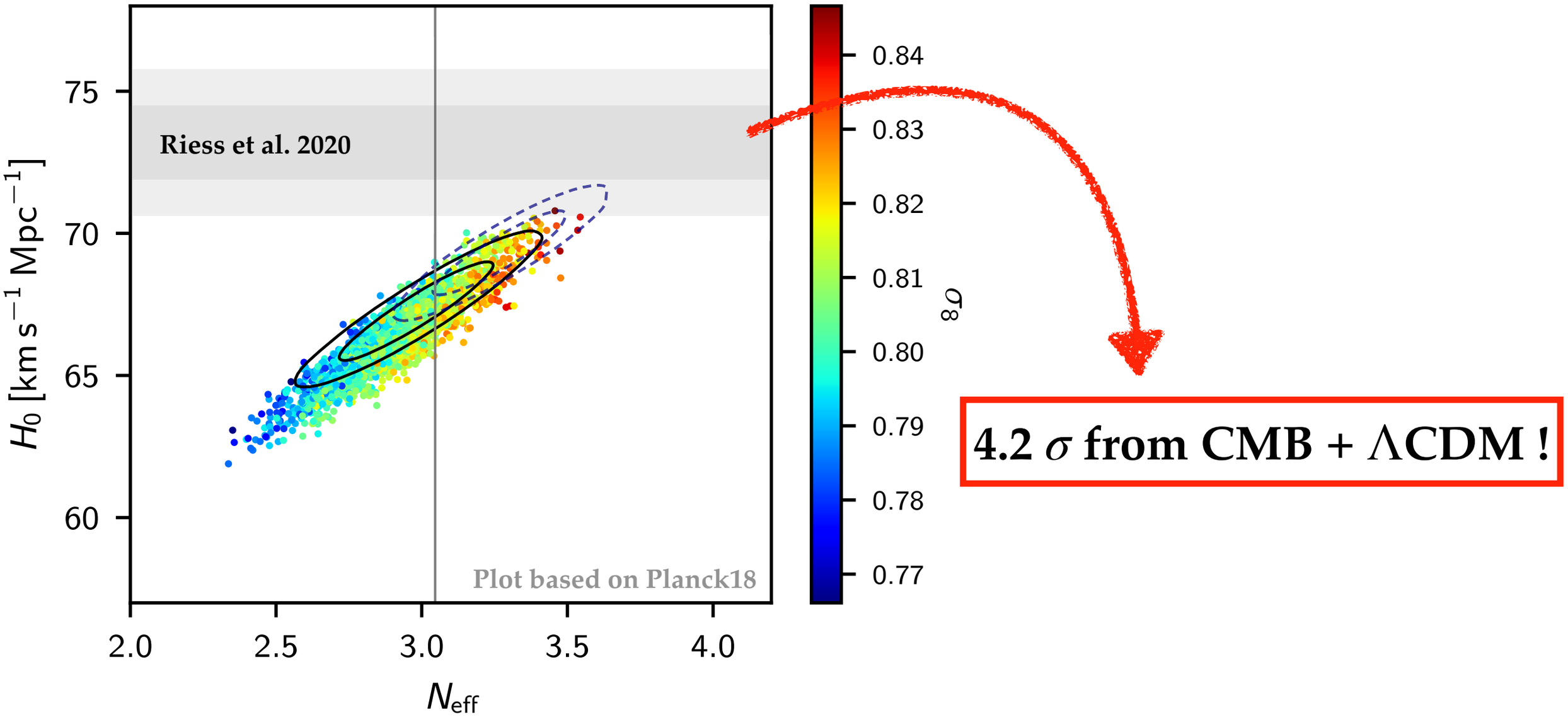
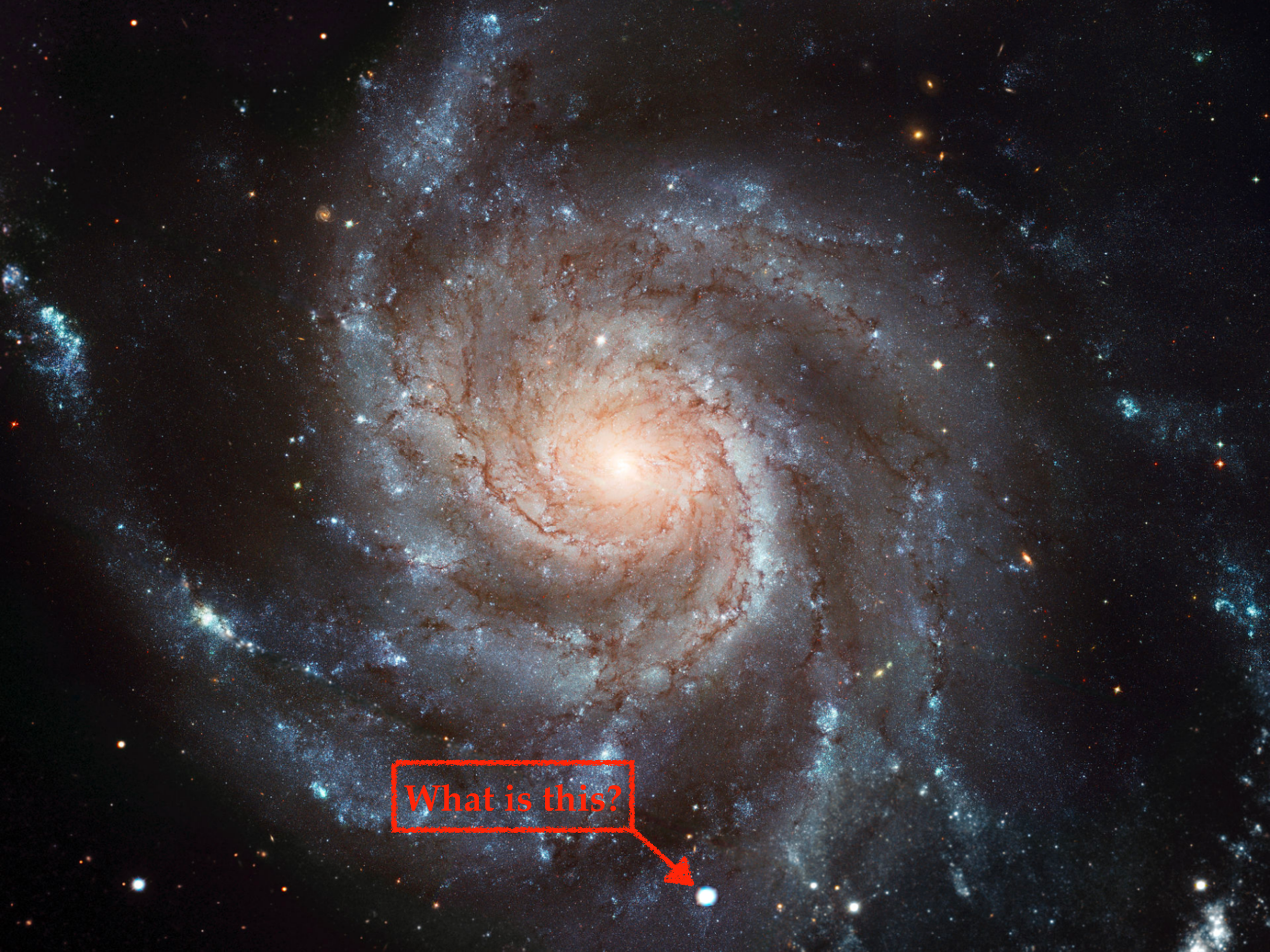
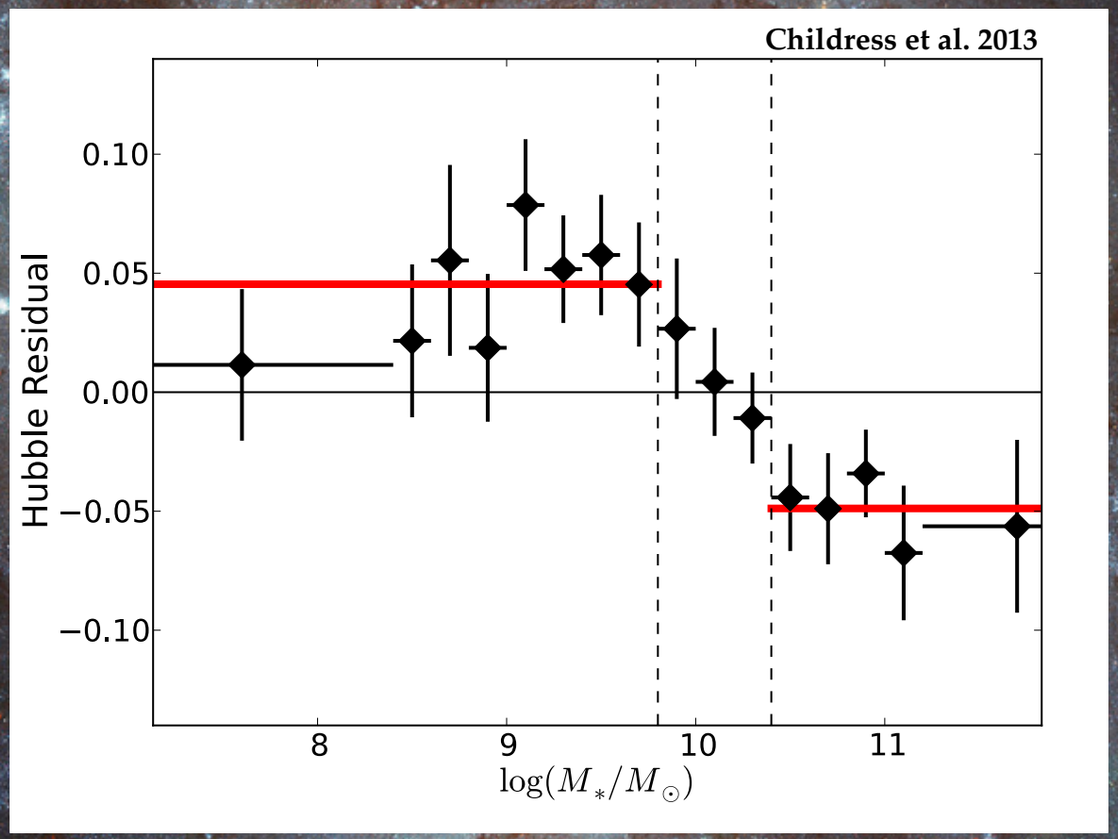
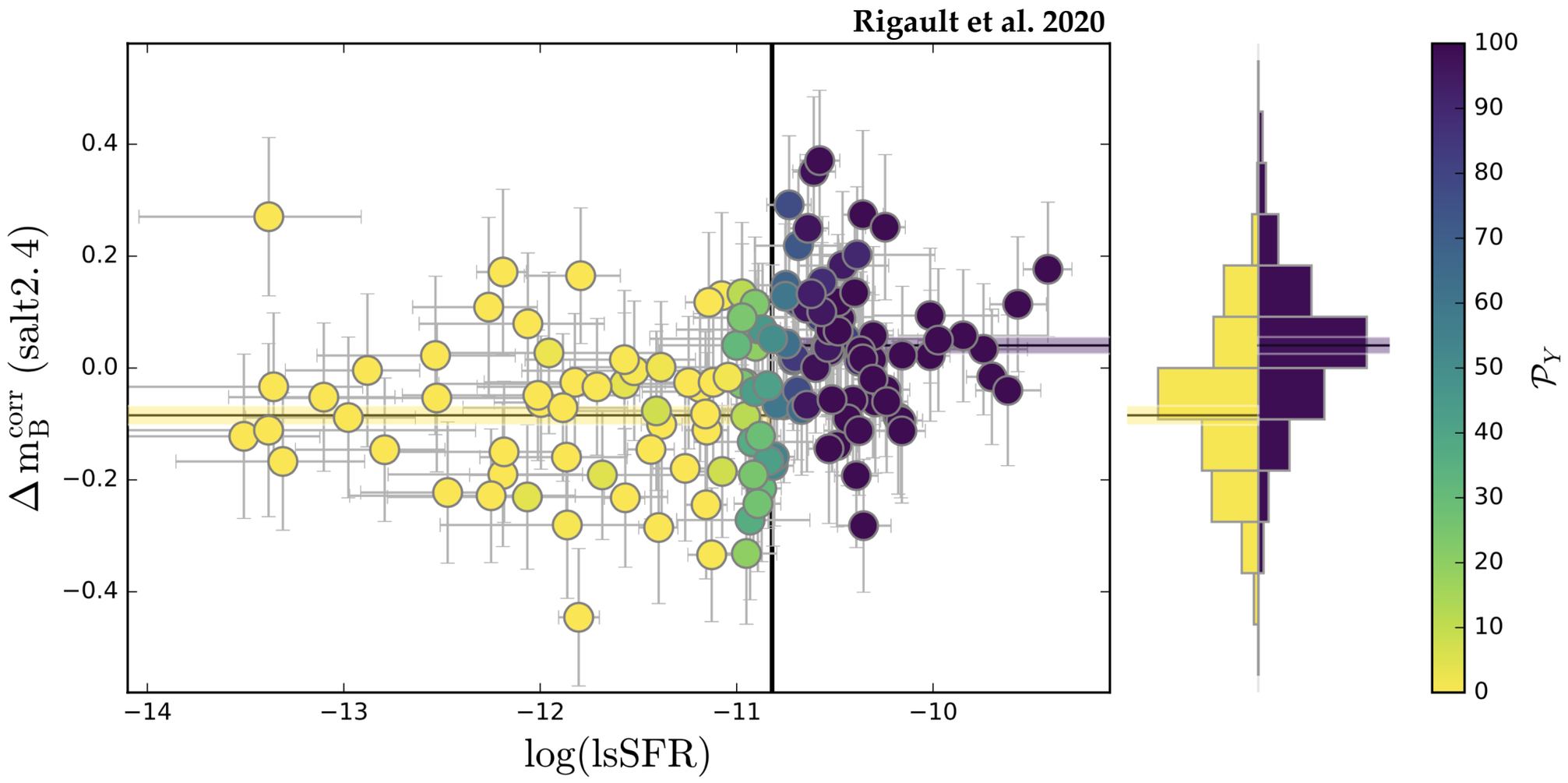

Riess et al. 2020
Plot based on Planck18
H_0 [km s^{-1} Mpc^{-1}]
$N_{\rm eff}$
σ_8
4.2 σ from CMB + ΛCDM !


What is this?

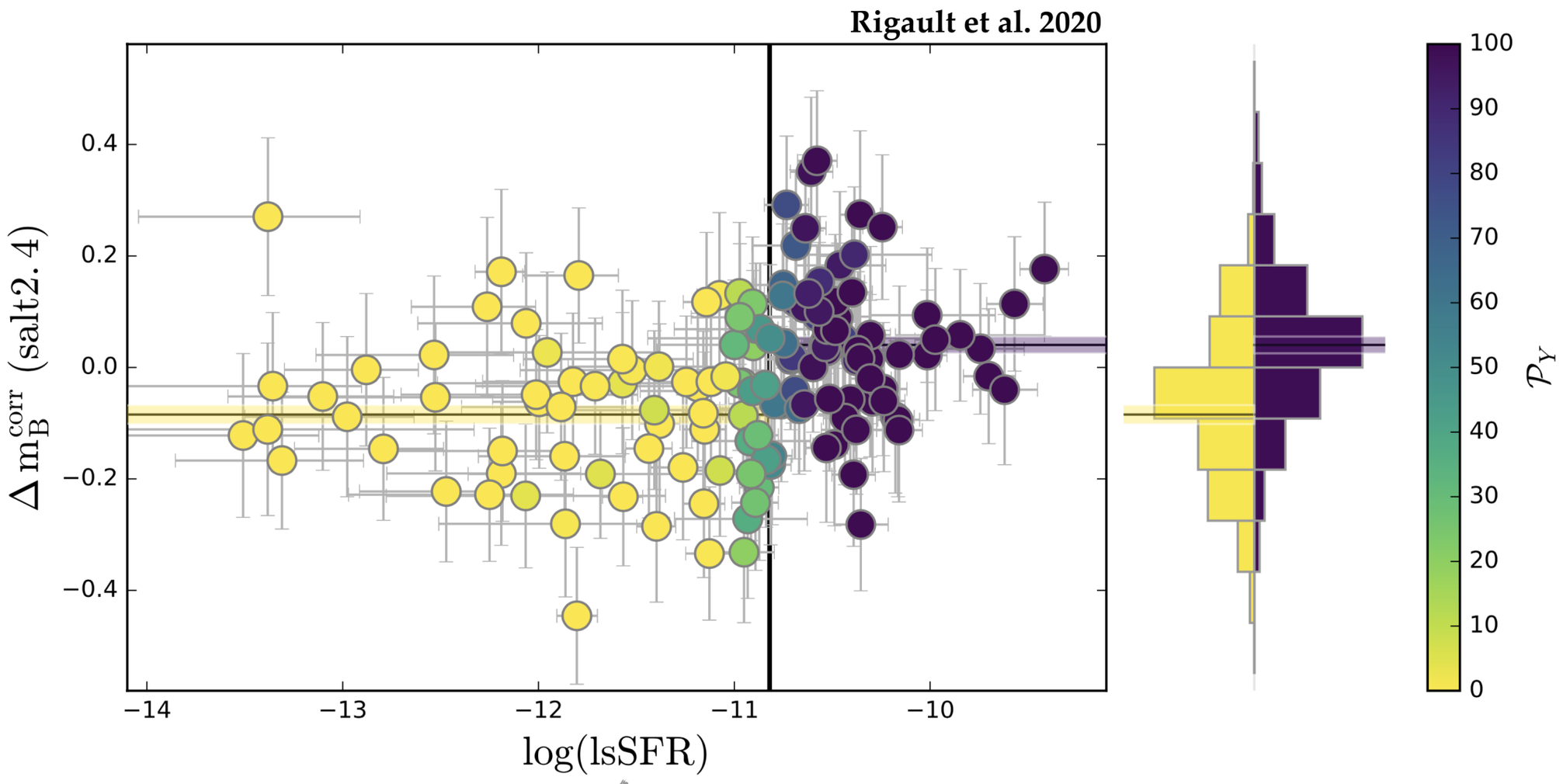

Childress et al. 2013
Hubble Residual
0.10
0.05
0.00
−0.05
−0.10
8
9
10
11
$\log(M_*/M_\odot)$

What is this?

SNe Ia & Astrophysical bias

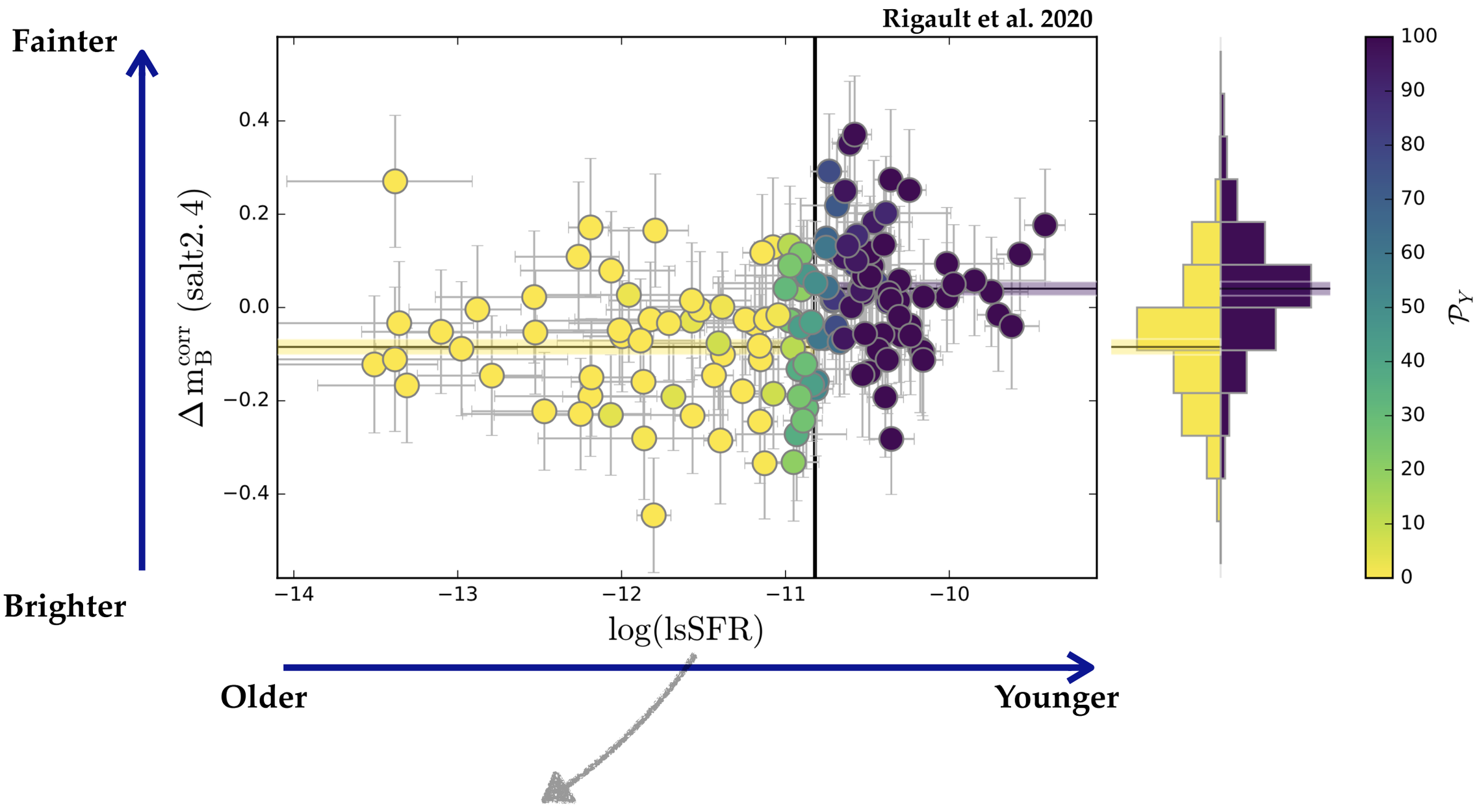


SNe Ia & Astrophysical bias



(lsSFR : local specific Star Formation Rate)
Accurate tracer for the age of a stellar environment

SNe Ia & Astrophysical bias



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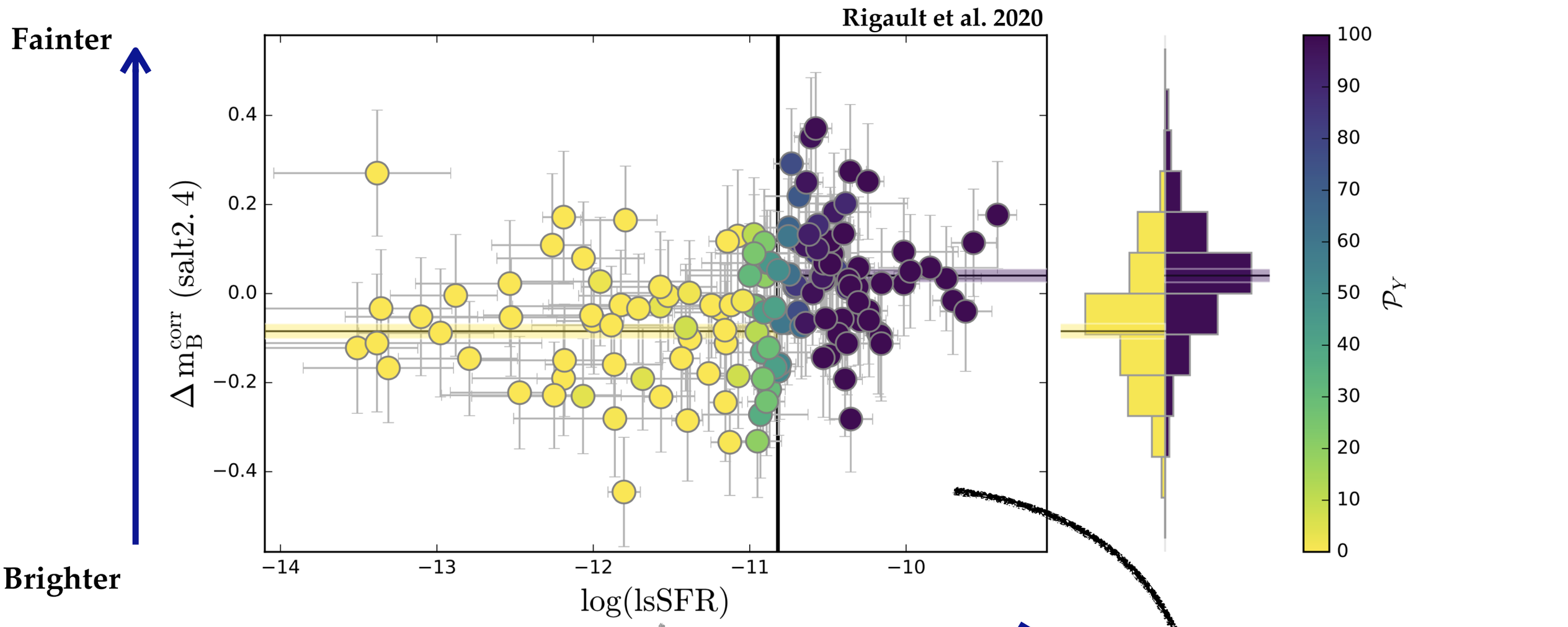
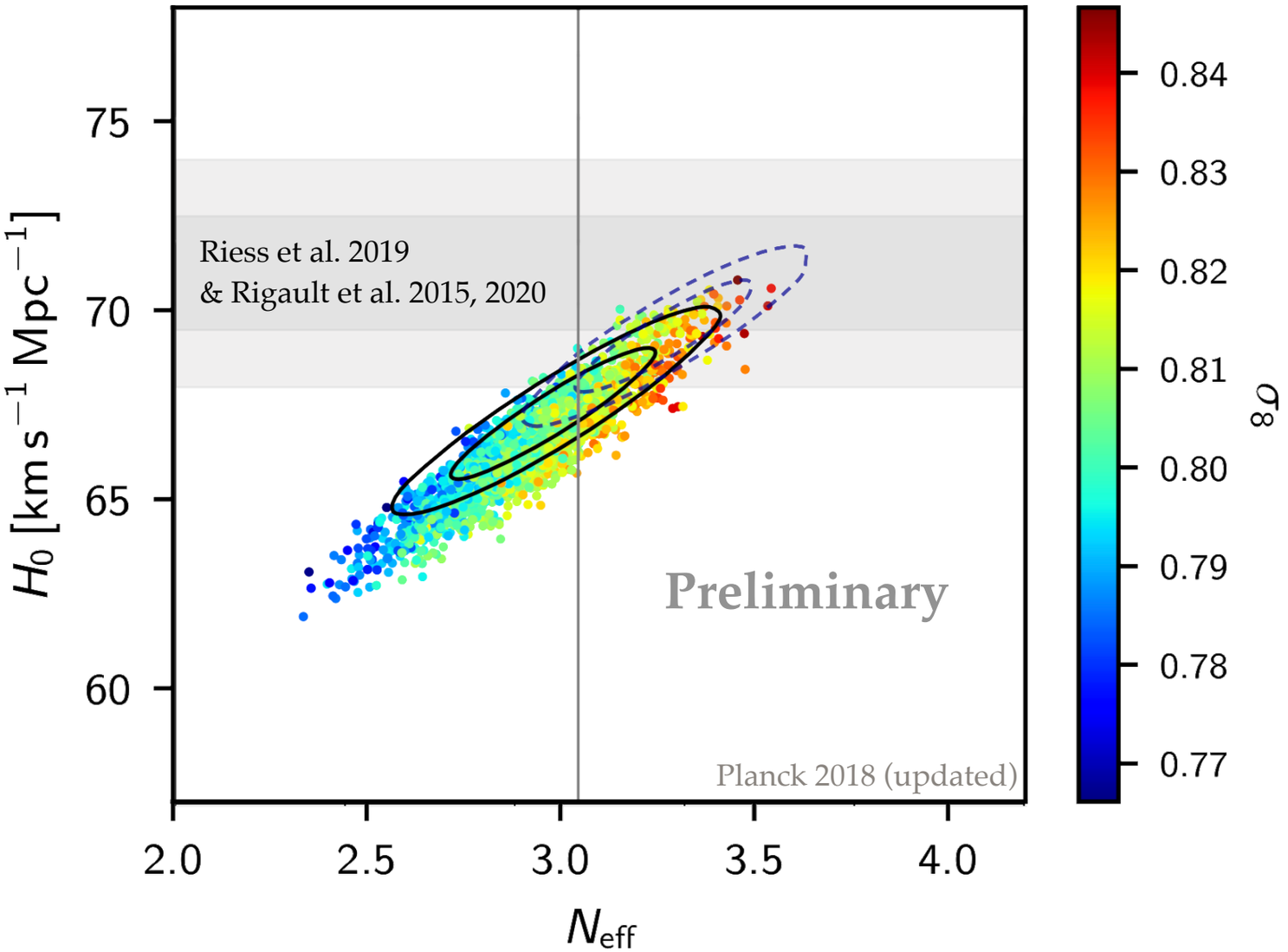


(lsSFR : local specific Star Formation Rate)
Accurate tracer for the age of a stellar environment

Two SNeIa populations
old / young local environment:
Δ HR = 0.163 ± 0.029 mag

Astrophysical bias & H_0



1. Different fraction of prompt

~95% in Cepheid-SN

vs. ~50% in Hubble flow-SN

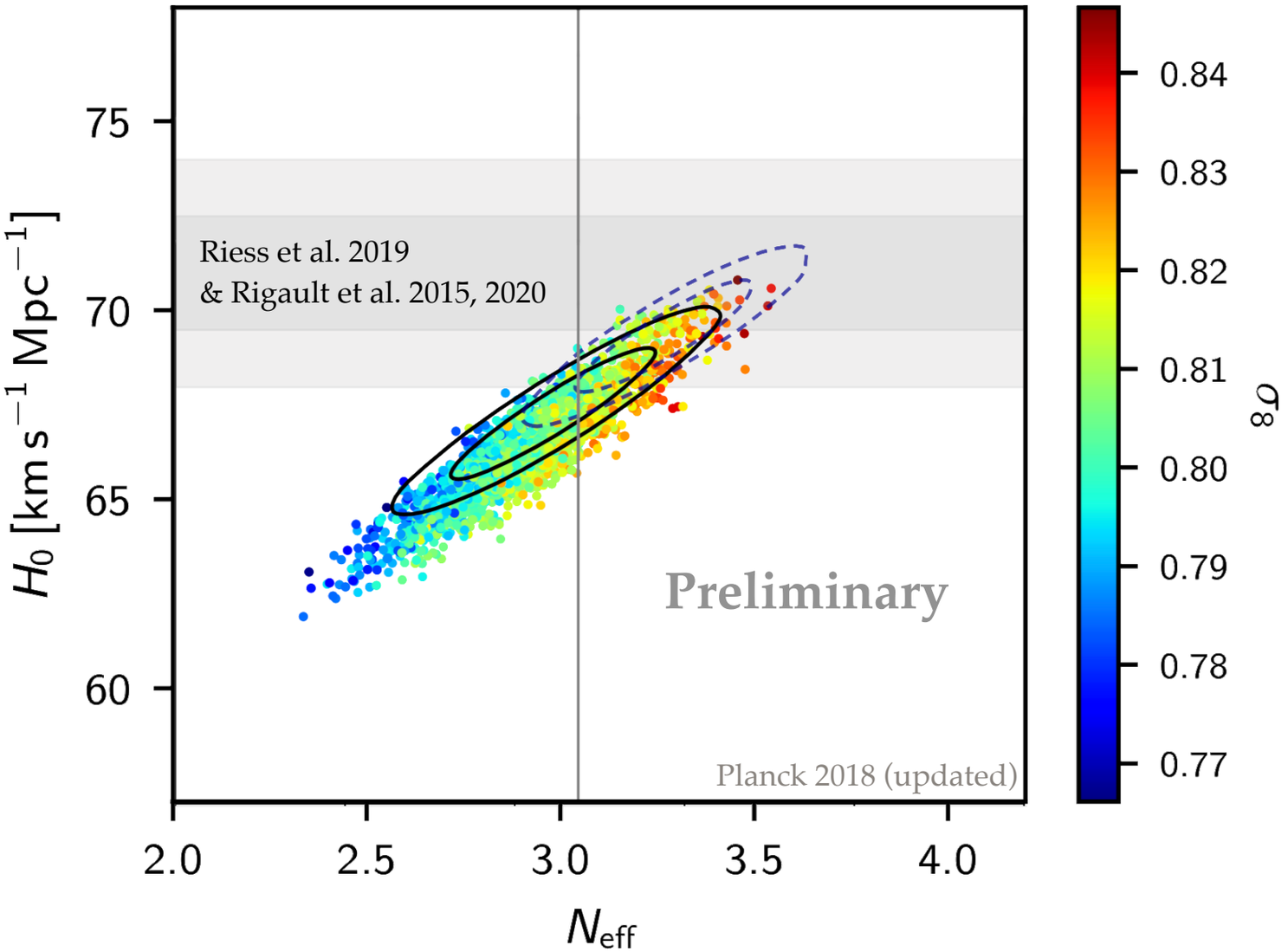
2. Magnitude difference between prompts and delayed SNeIa

age step ~0.15 mag

Rigault et al. 2015, 2020

Credits : Mickael Rigault

Astrophysical bias & H_0



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Astrophysical bias on H_0 **up to 3%**

Rigault et al. 2015, 2020

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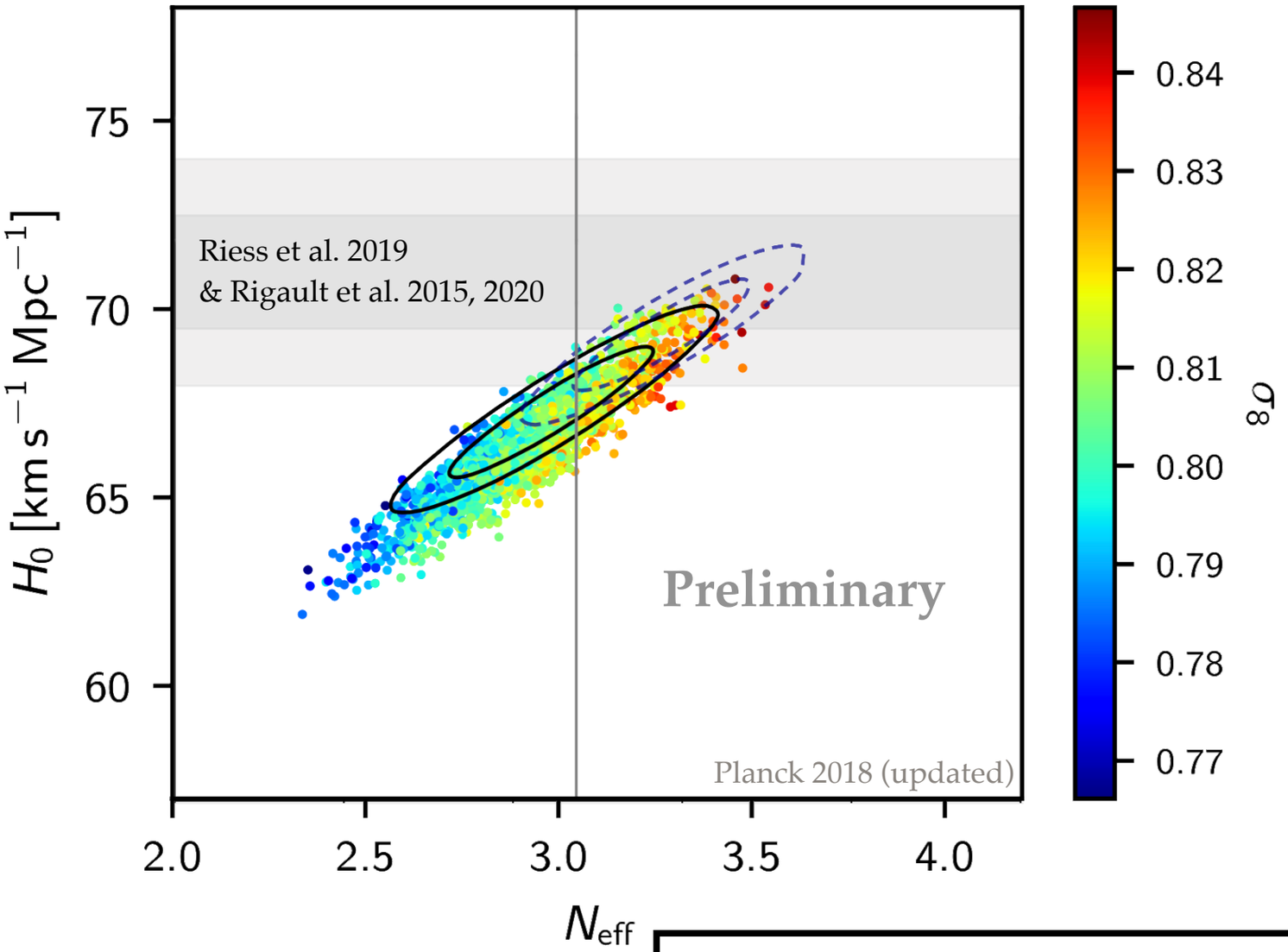
Astrophysical bias & H_0



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SHOES $H_0 = 73.5$ leads to

$$\boldsymbol{H_0 = 71.5^{*} \pm 1.6\ km\ s^{-1}\ Mpc^{-1}}$$

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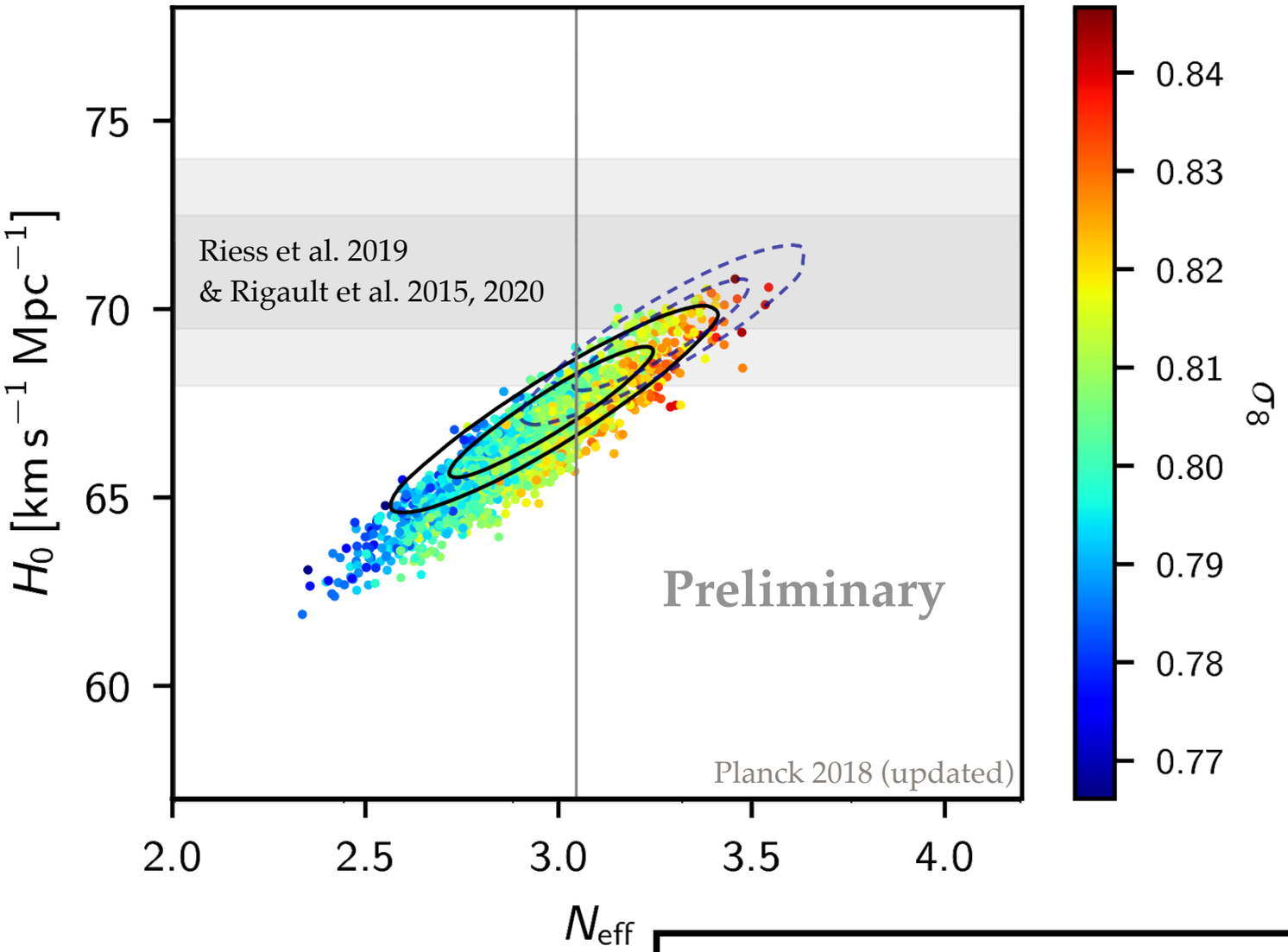
Astrophysical bias & H_0



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Rigault et al. 2015, 2020

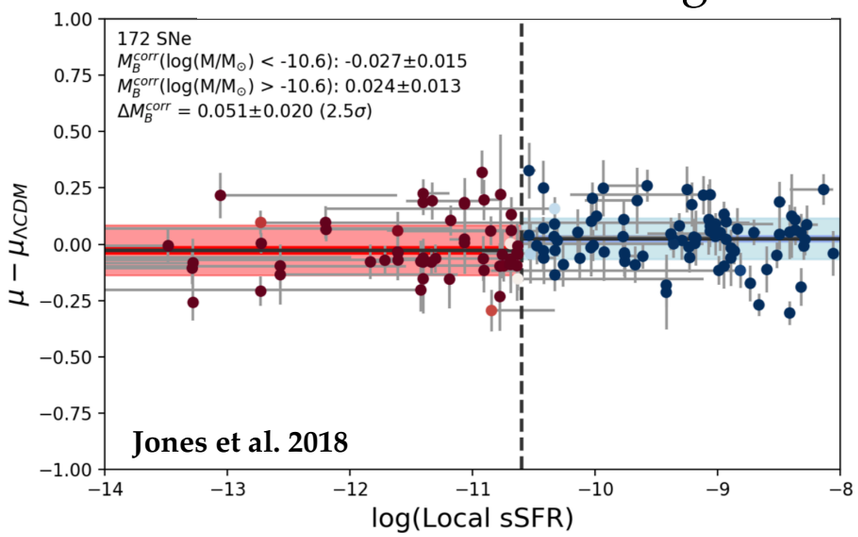
~ 2σ from CMB + ΛCDM

Credits : Mickael Rigault

Different environmental tracers…
Different results…

local photometric sSFR

0.051 ± 0.020 mag



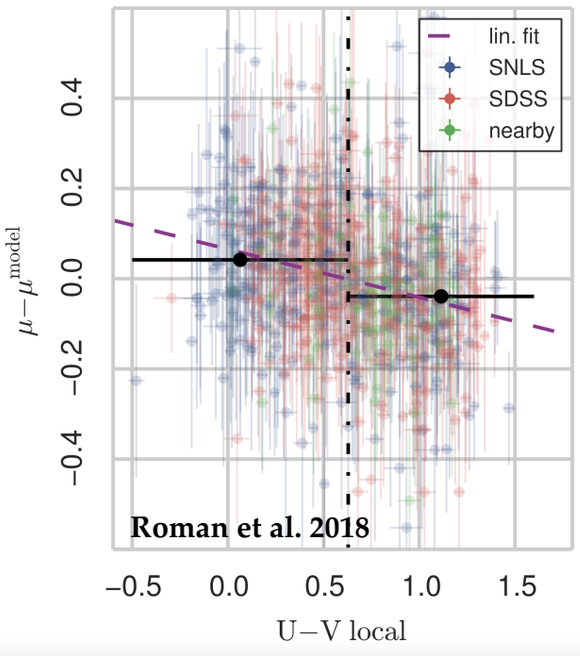
Various environmental tracers give different magnitude offset values!

So, is there an astrophysical bias, or not?

And if yes, what is the correct way to account for it?
As an additional standardization parameter?
And so, using a step? Or linear standardization? …

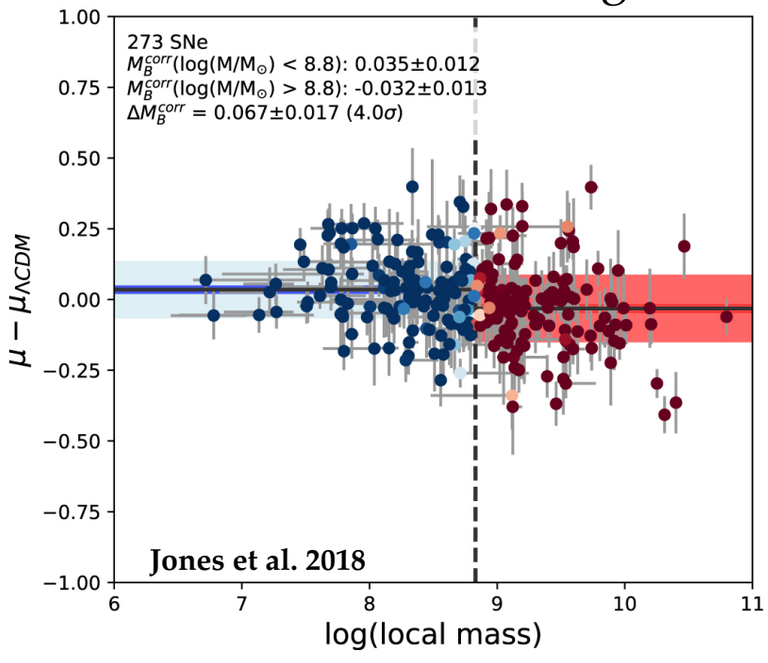
local U-V

0.091 ± 0.013 mag



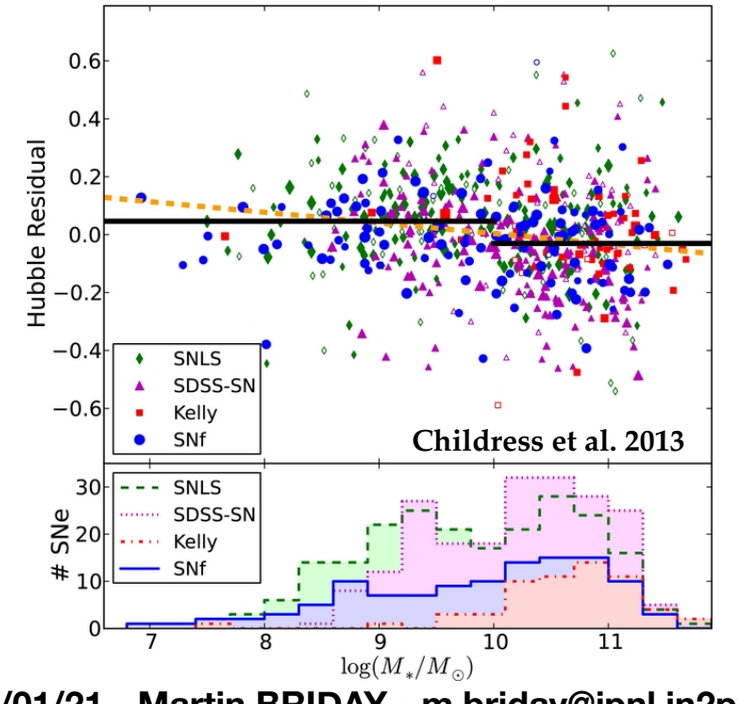
local mass

0.067 ± 0.017 mag



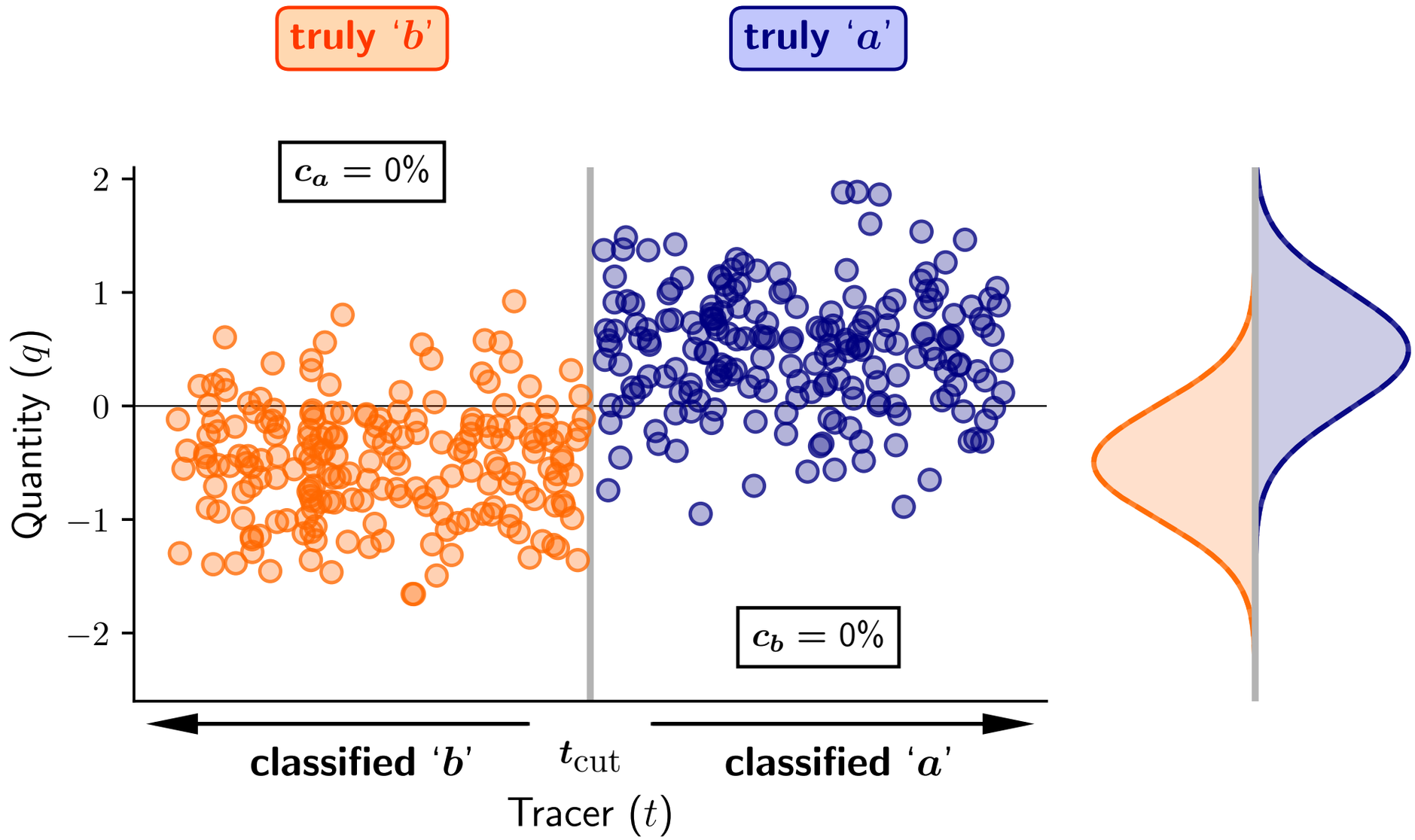
global mass

0.077 ± 0.014 mag



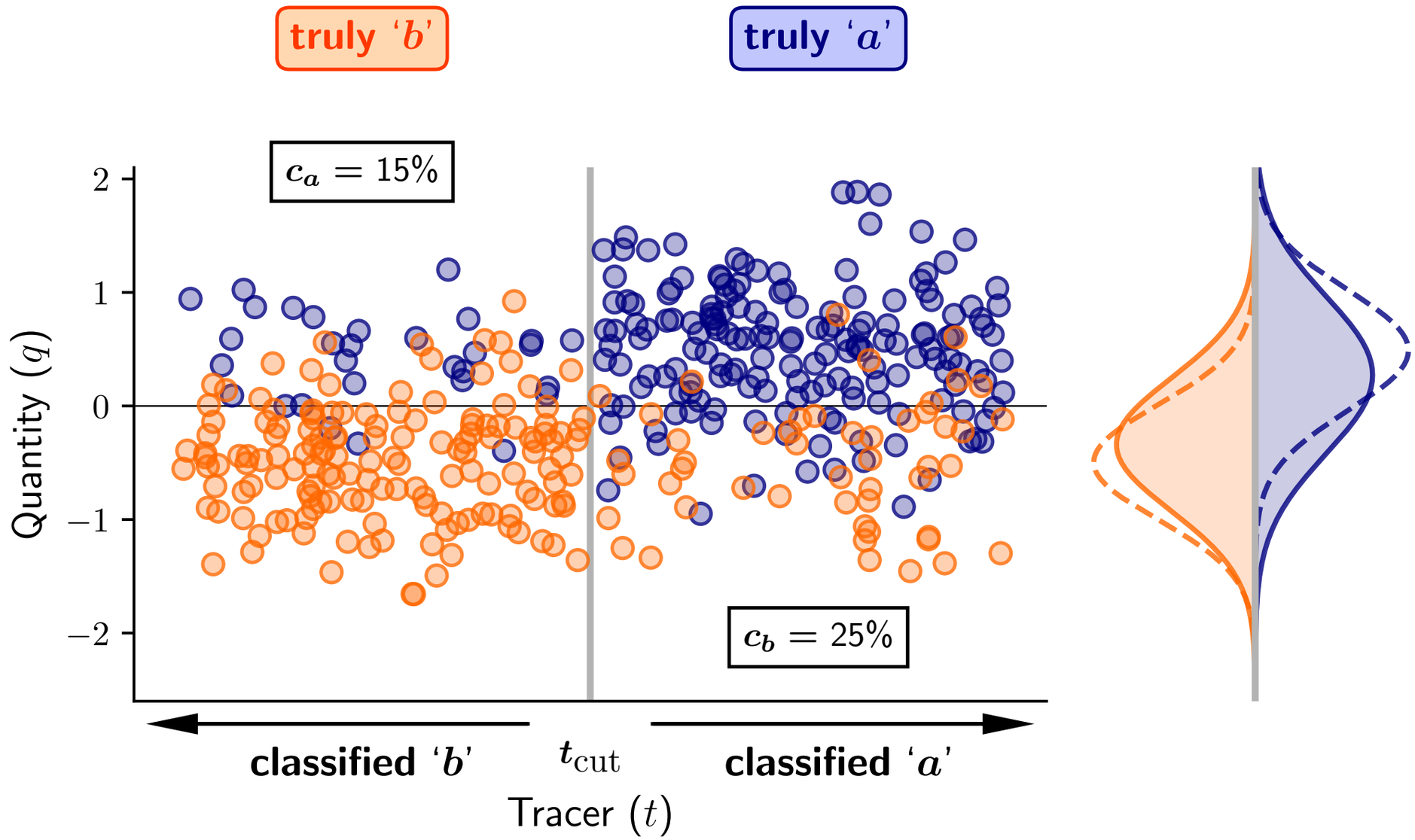
Mock data

— perfect tracer —



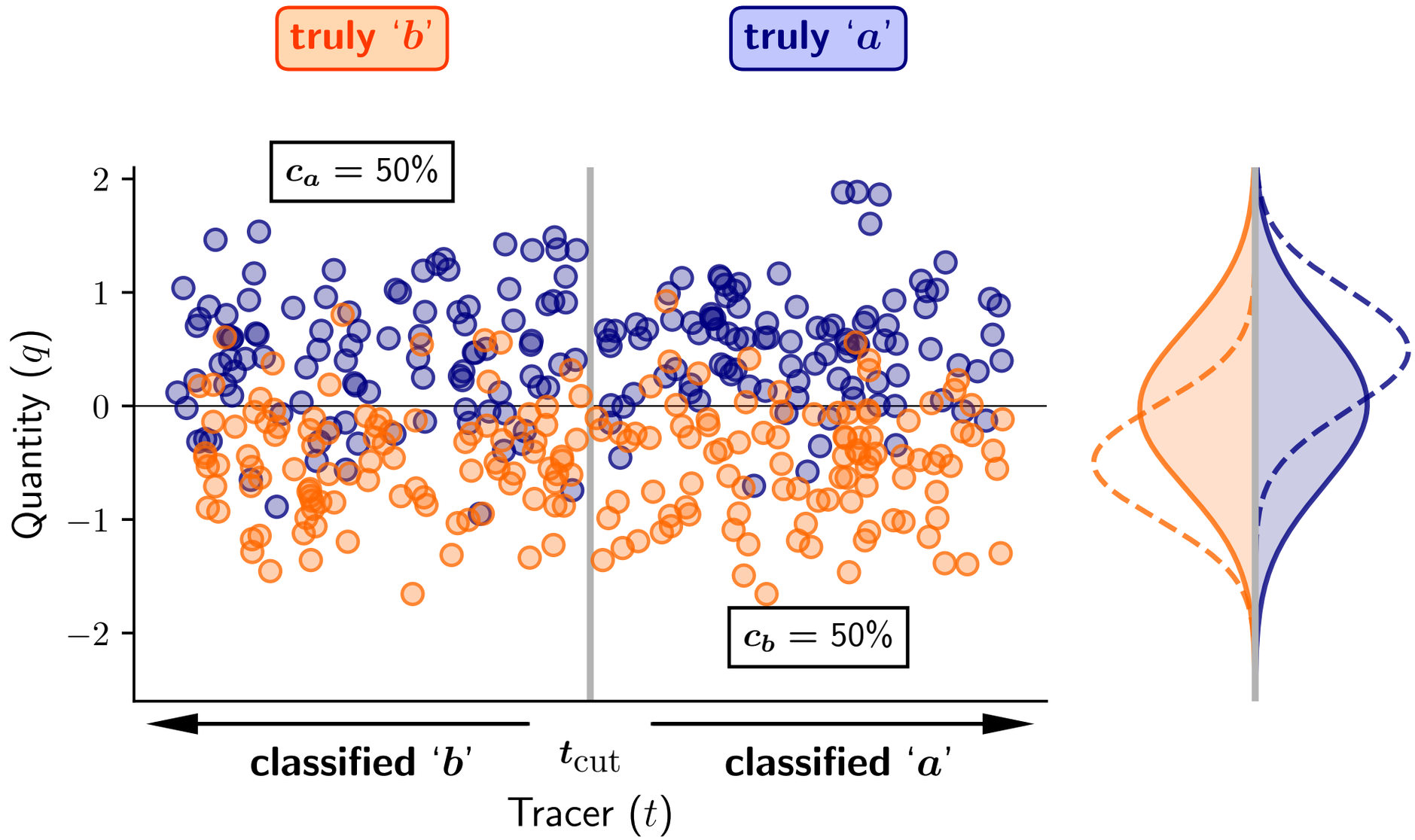
Mock data

— medium tracer —



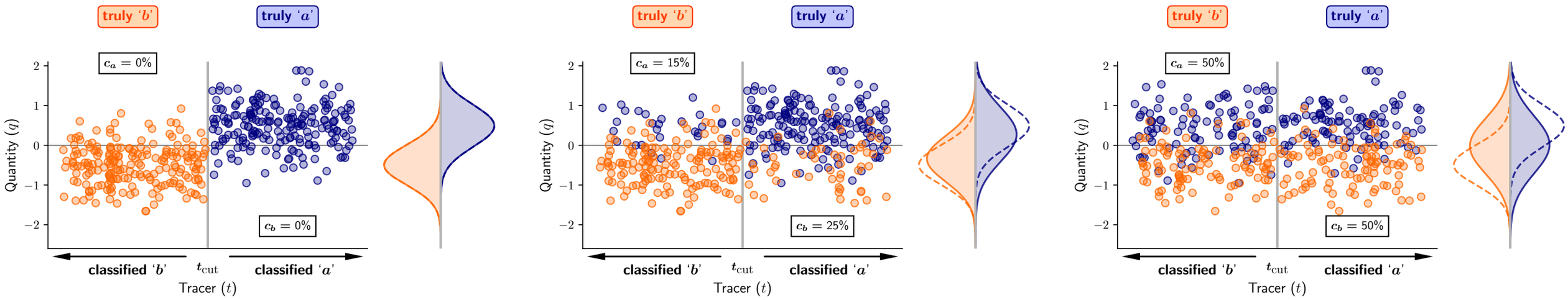
Mock data

— poor tracer —



Mock data

— step evolution —



Mock data

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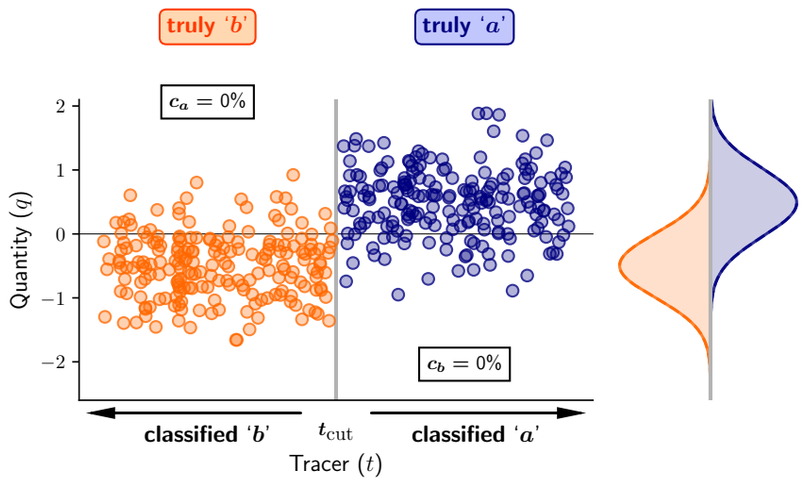
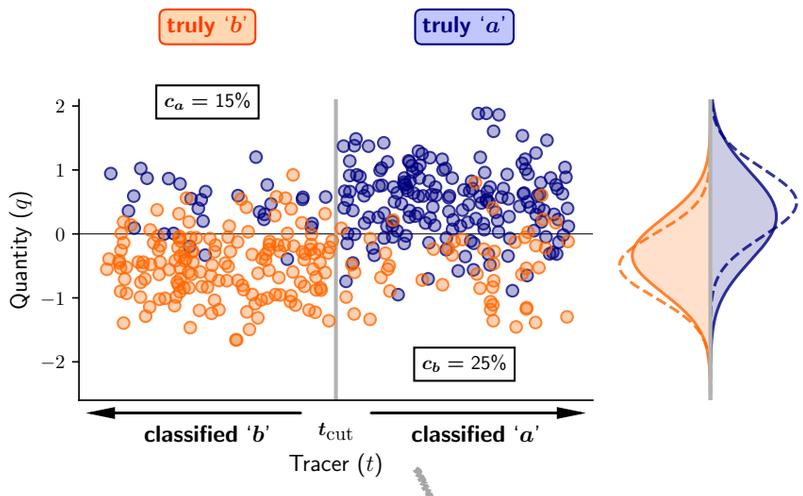
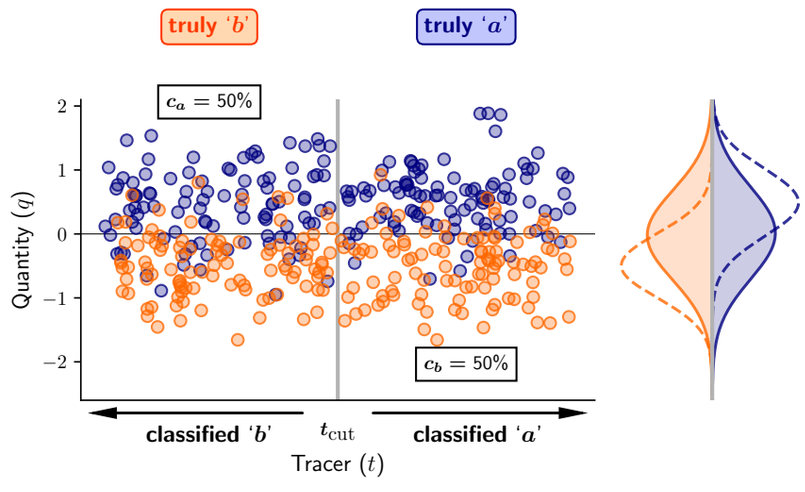
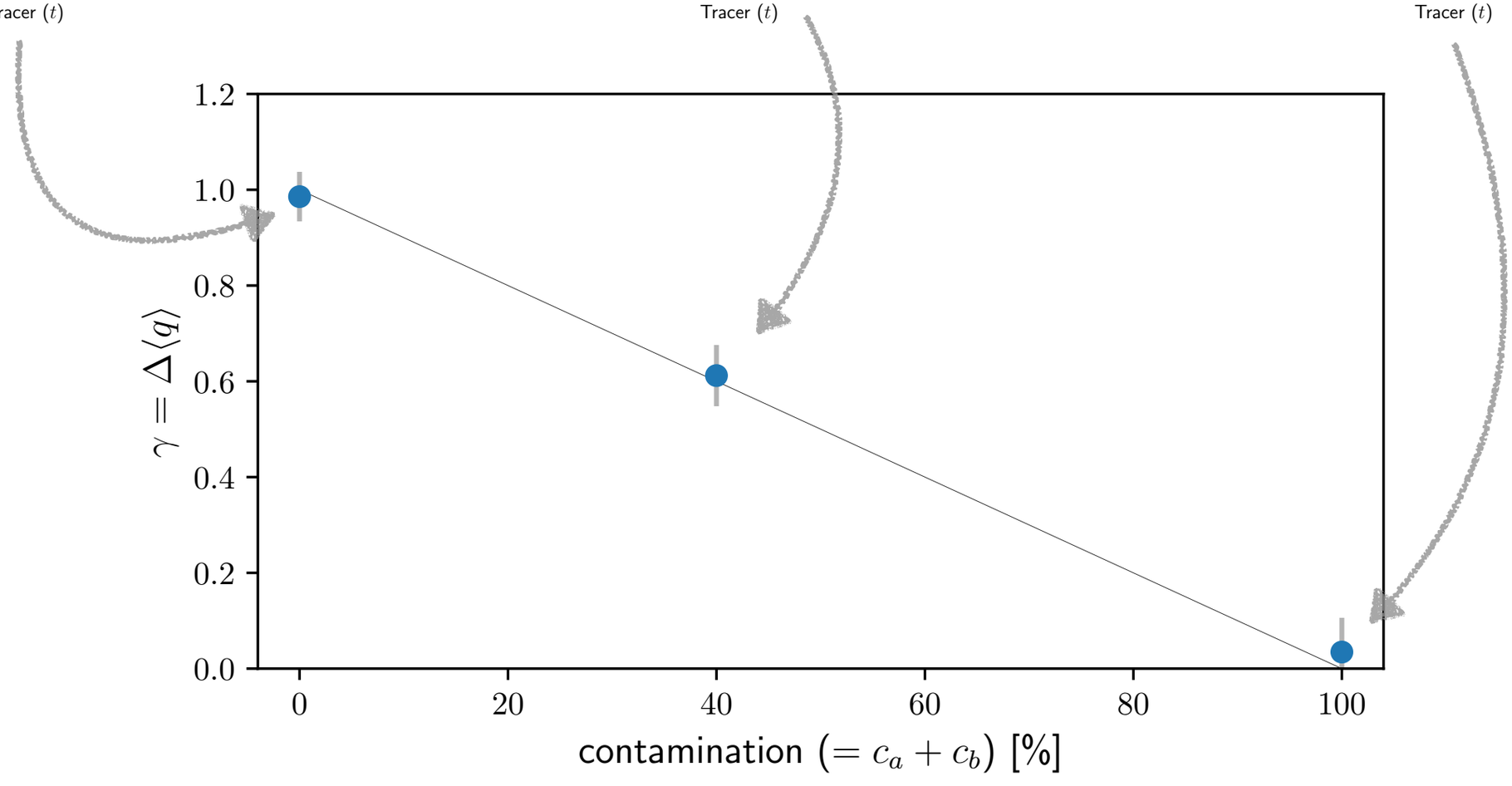
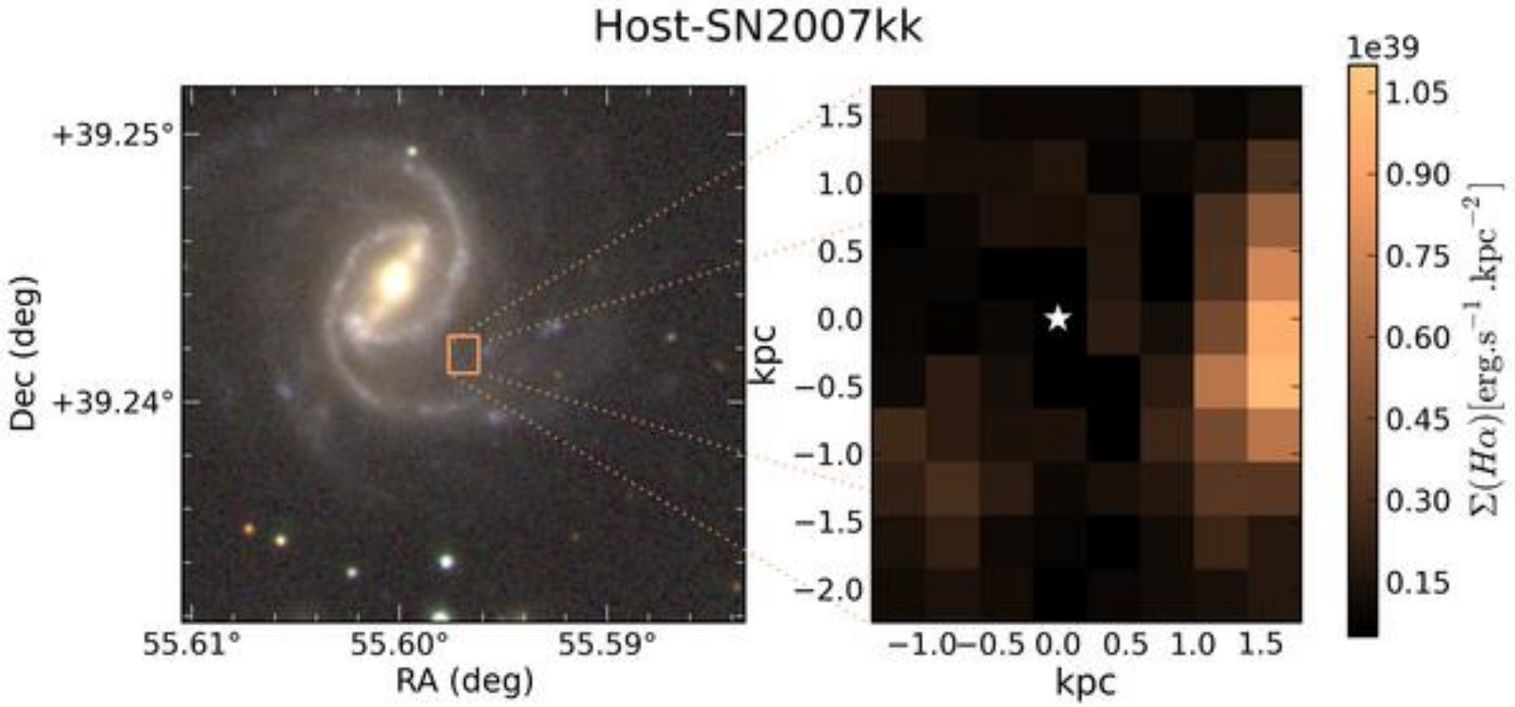








Concept of Contamination

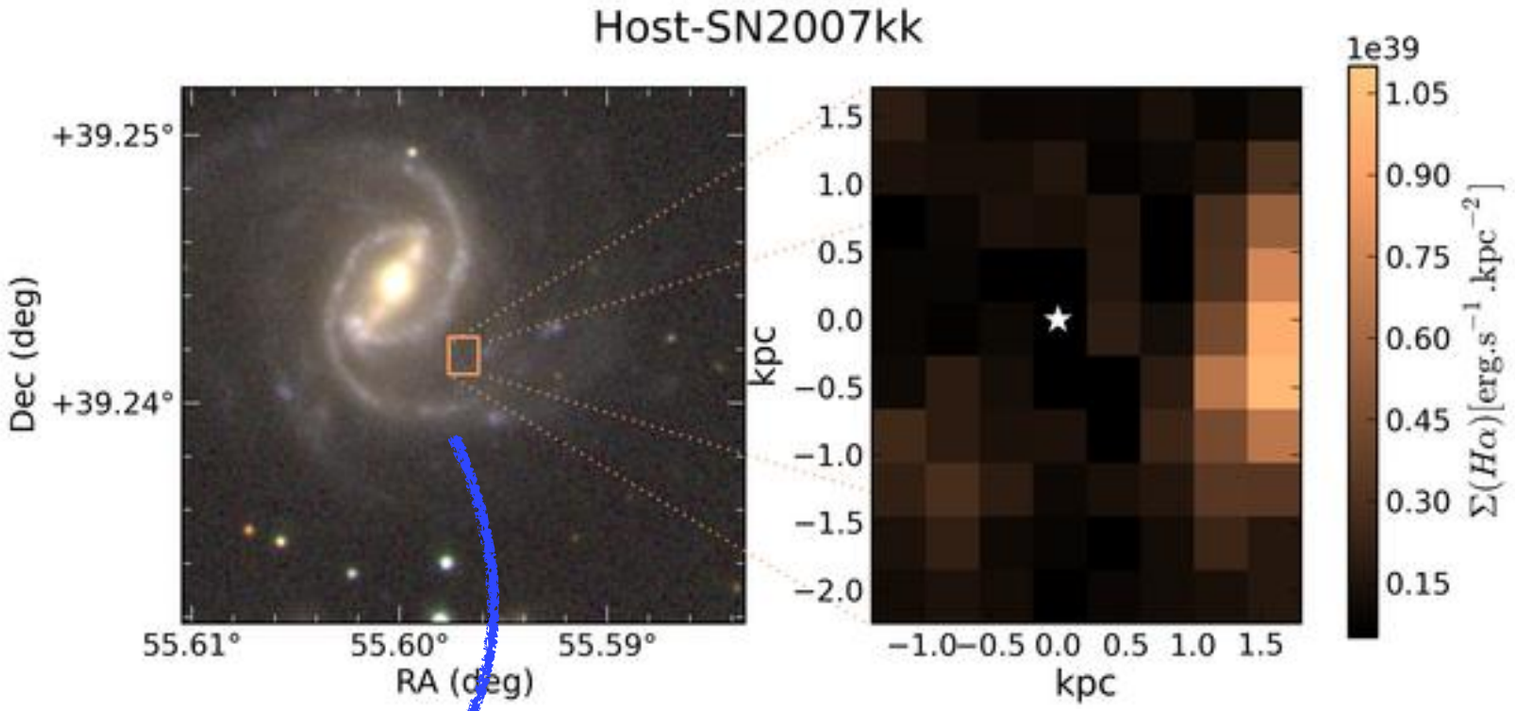


Misclassification = tracer inaccuracy

—> contamination

Credits : Mickael Rigault

Concept of Contamination



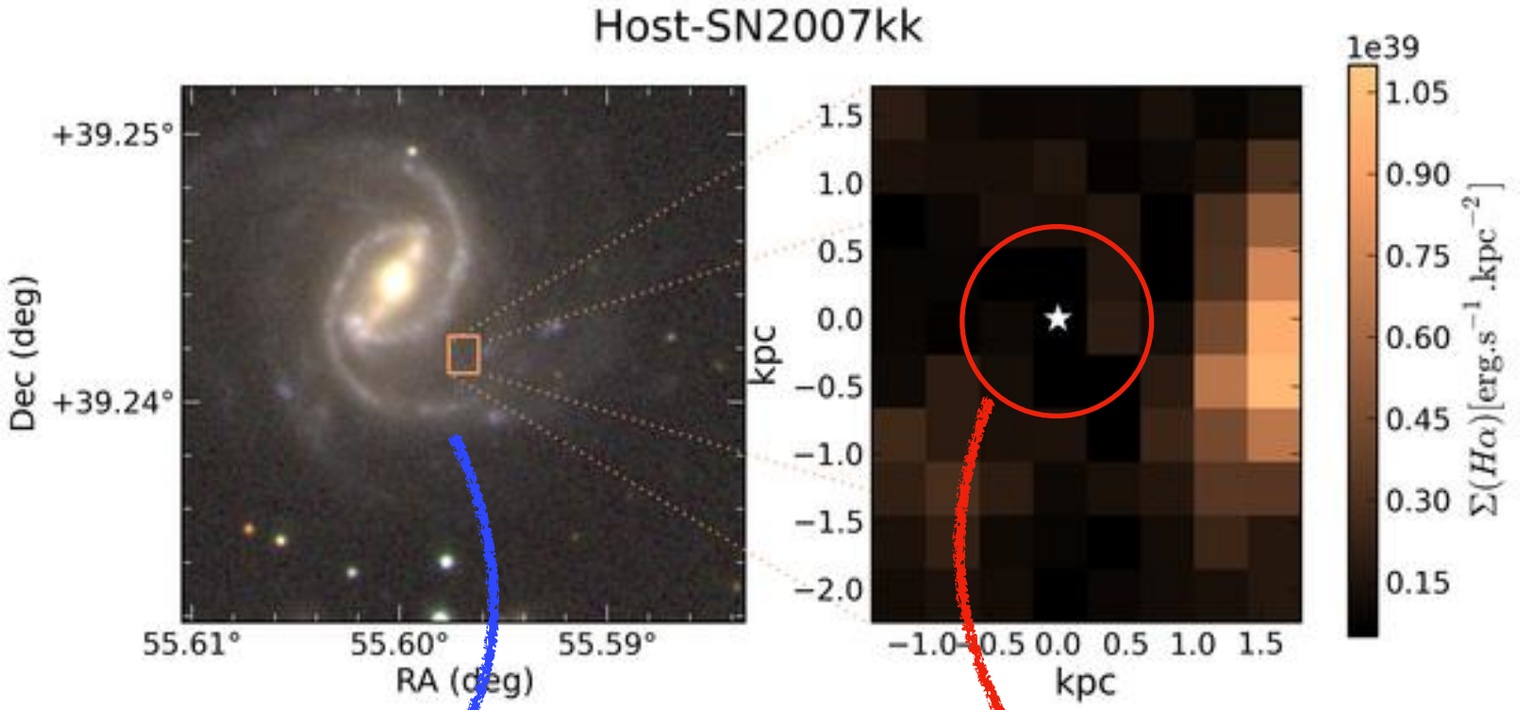
Spiral galaxy:
—> expected young stellar environment

Misclassification = tracer inaccuracy

—> contamination

Credits : Mickael Rigault

Concept of Contamination



Spiral galaxy:
—> expected young stellar environment

No star formation:
—> old environment in reality

Misclassification = tracer inaccuracy

—> contamination

Credits : Mickael Rigault

Environmental tracers

- Local specific Star Formation Rate (LsSFR)
- Stellar masses
- Colors
- Morphology
- Photometric LsSFR

} **Spectrometric:** SNIFS

} **Photometric:** SDSS + PanSTARRS

SNeIa sample : The Nearby Supernova factory (SNf)

Environmental tracers

—> reference choice

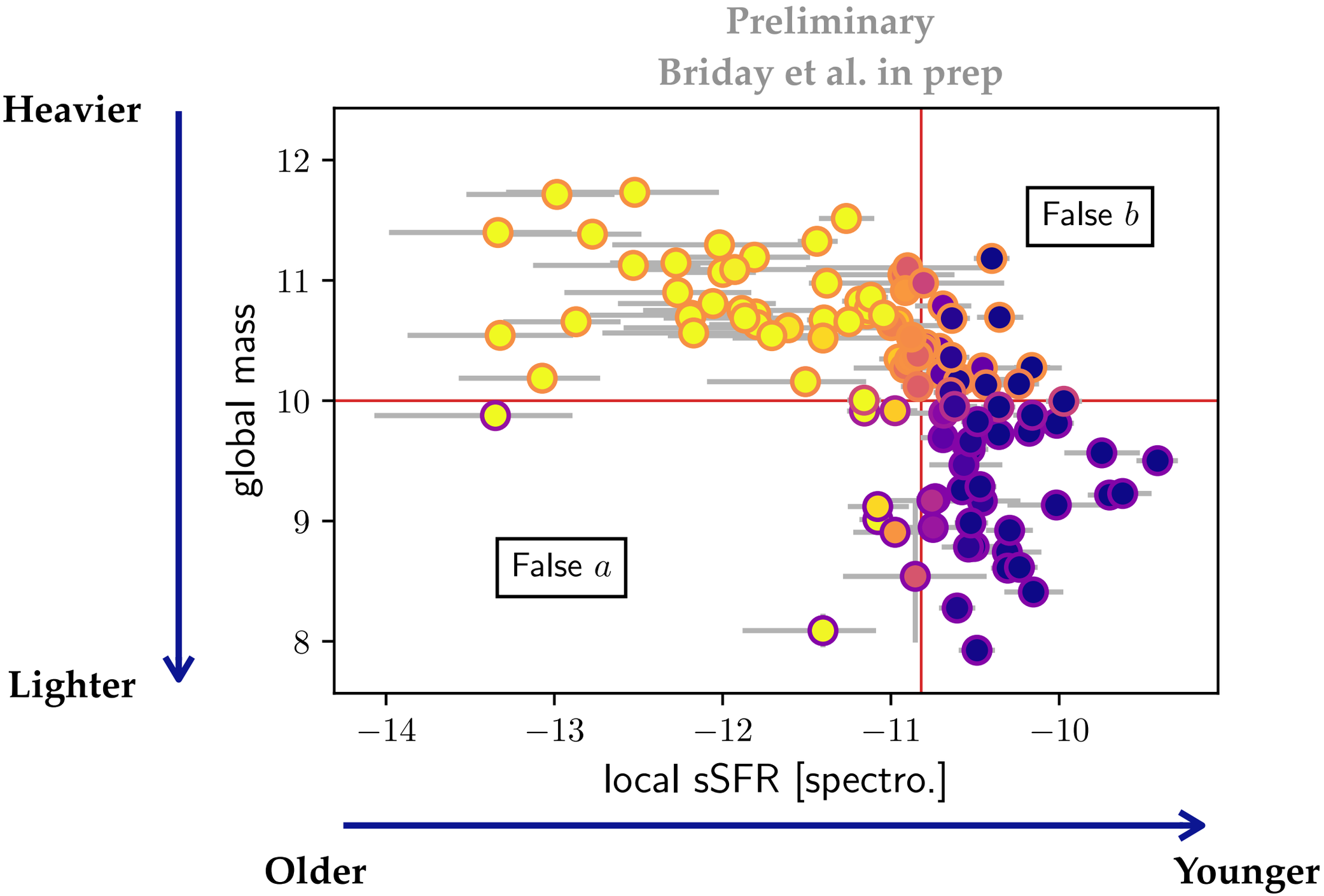
- Local specific Star Formation Rate (LsSFR) — **Reference** — **Spectrometric:** SNIFS
- Stellar masses
- Colors
- Morphology
- Photometric LsSFR

Photometric: SDSS + PanSTARRS

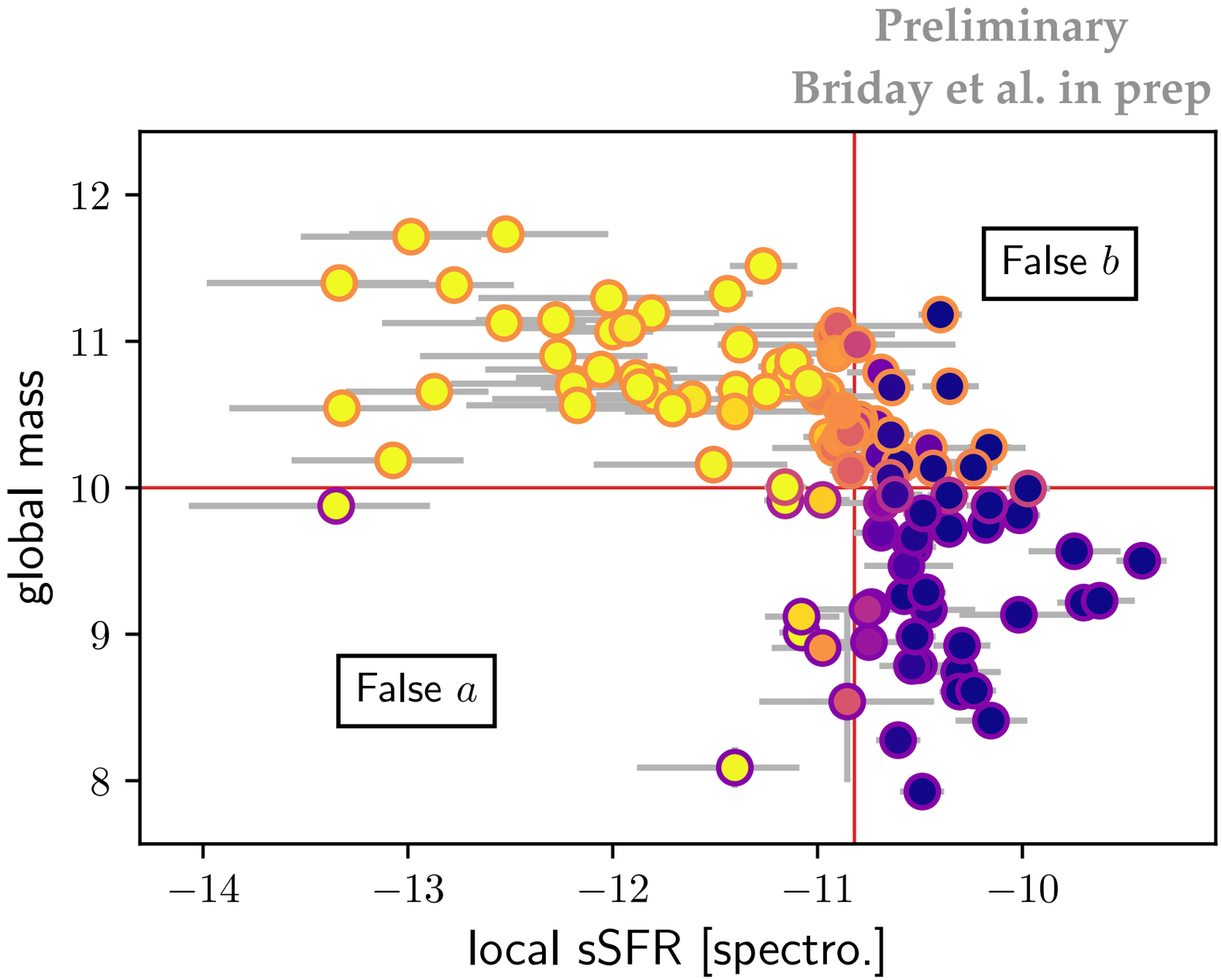
SNeIa sample : The Nearby Supernova factory (SNf)

Comparing the tracers

— Global mass vs. LsSFR —

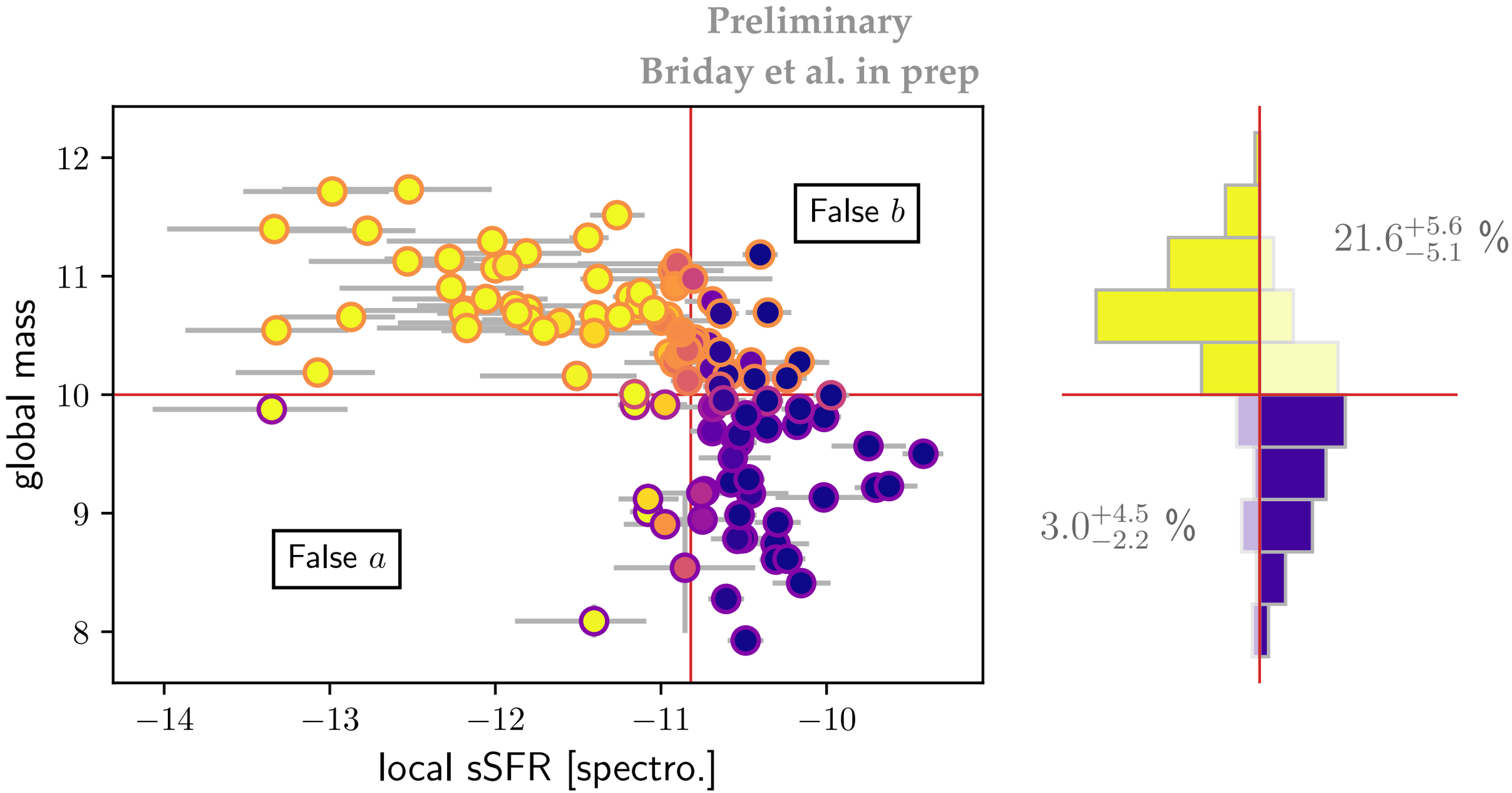


Comparing the tracers
— contamination process —



Comparing the tracers

— contamination process —



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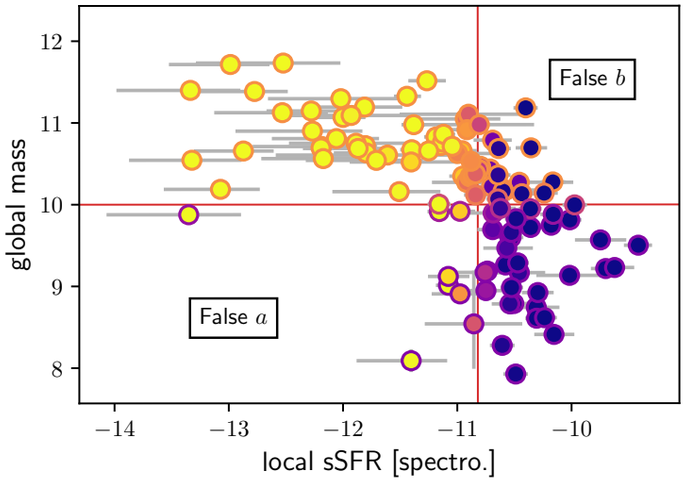
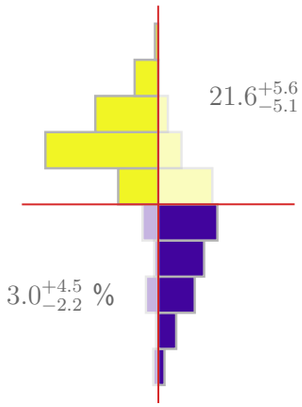
Are all tracers probing the same things ?

— every tracers vs. LsSFR —





Preliminary

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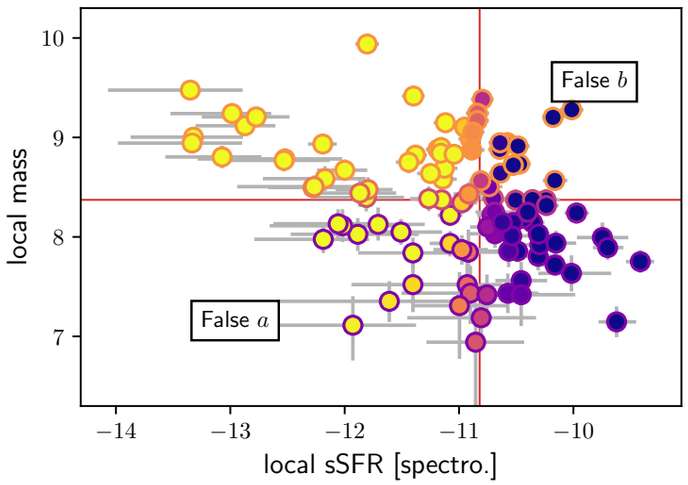
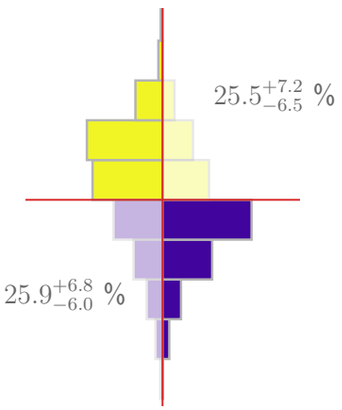
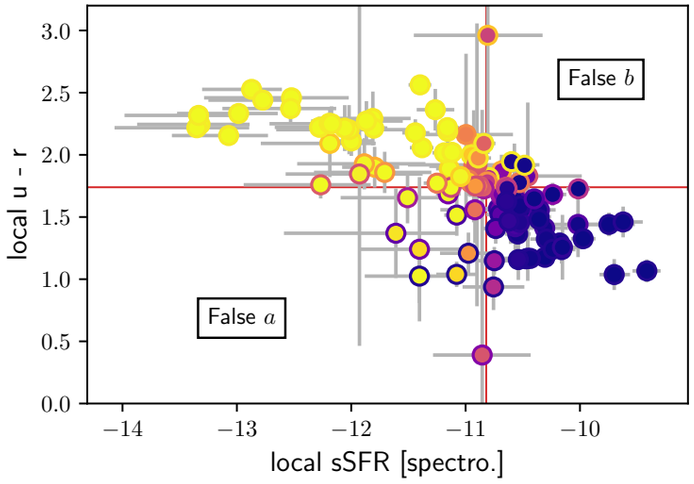
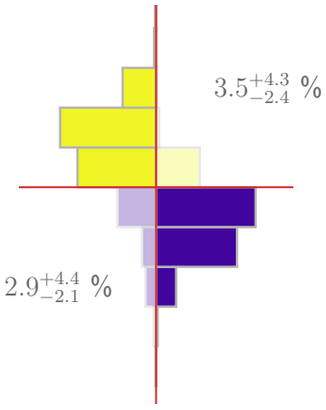
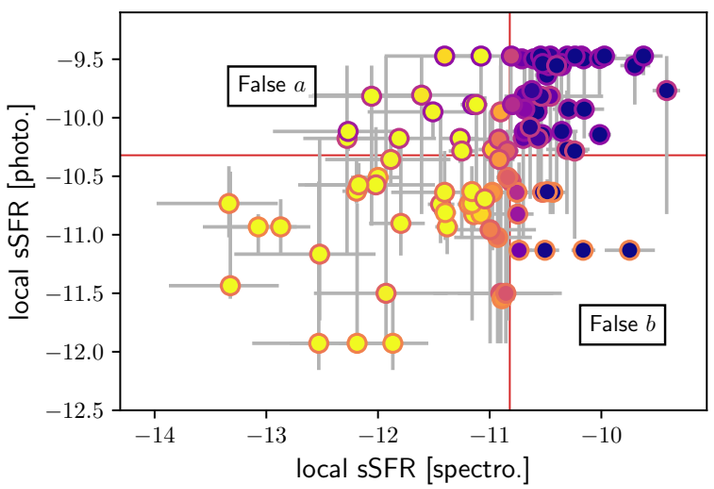
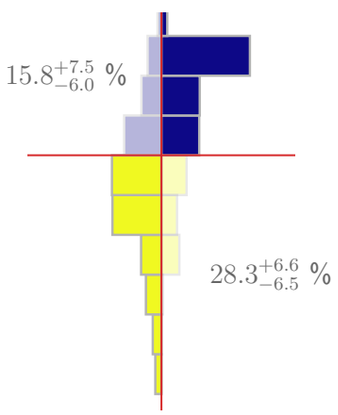


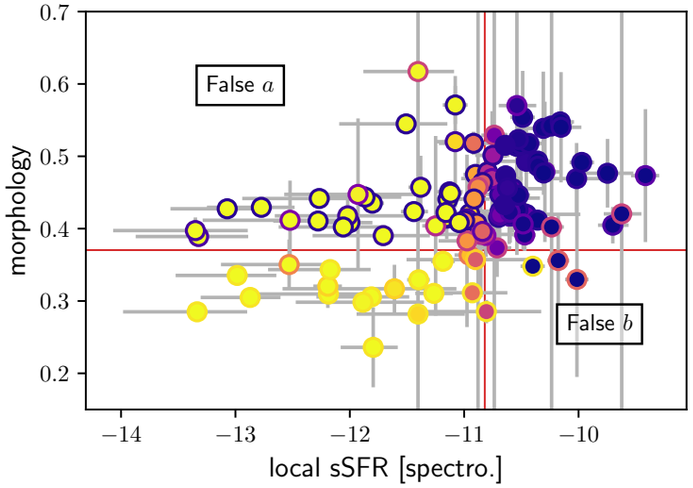


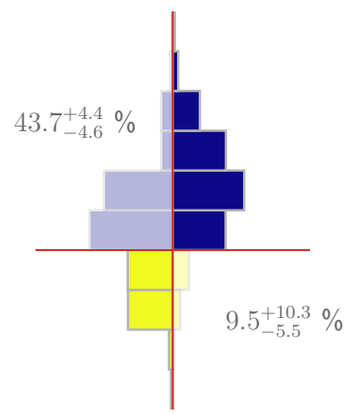




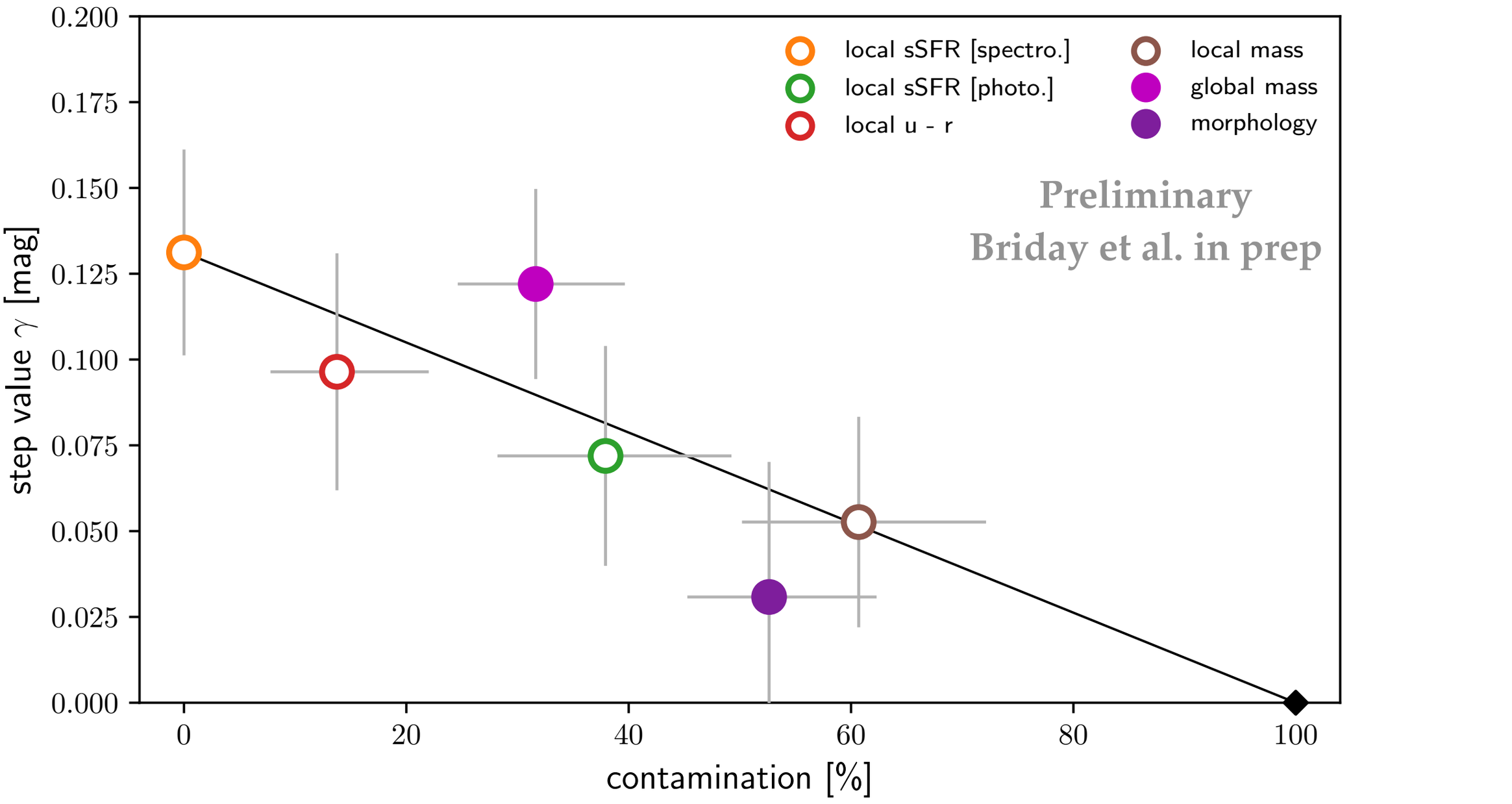




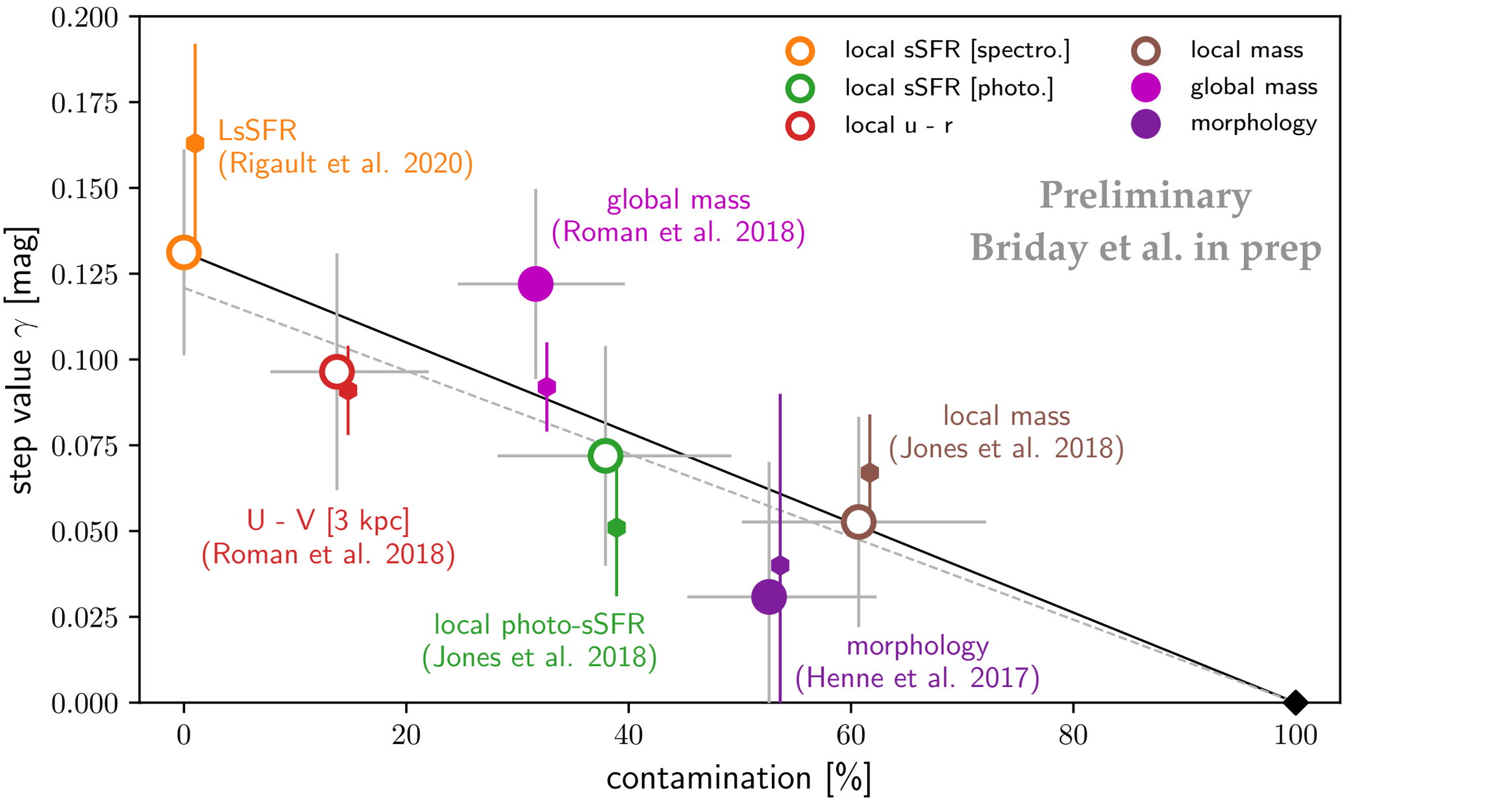




The contamination diagonal



The contamination diagonal



The contamination diagonal

— changing the reference tracer —

Preliminary

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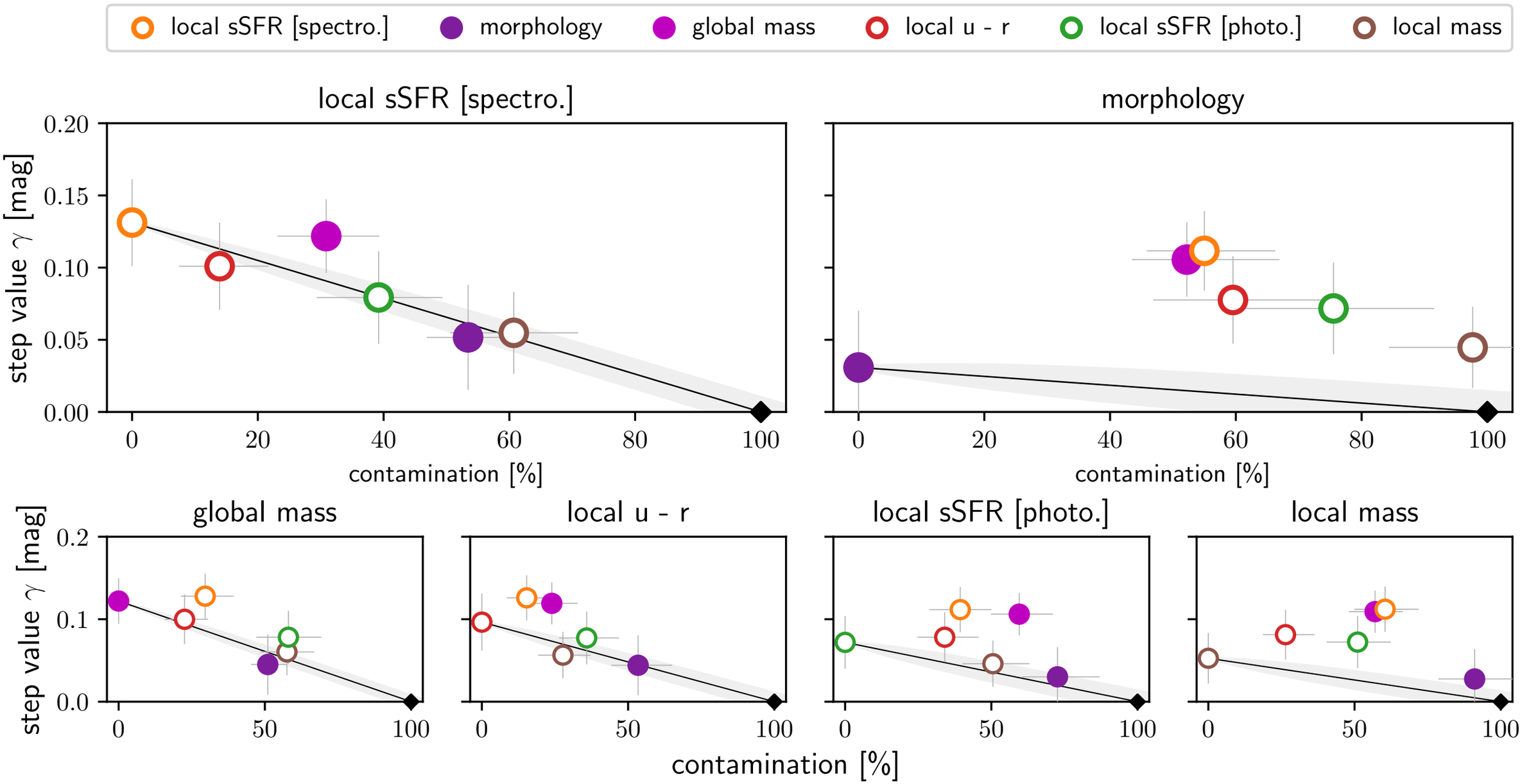
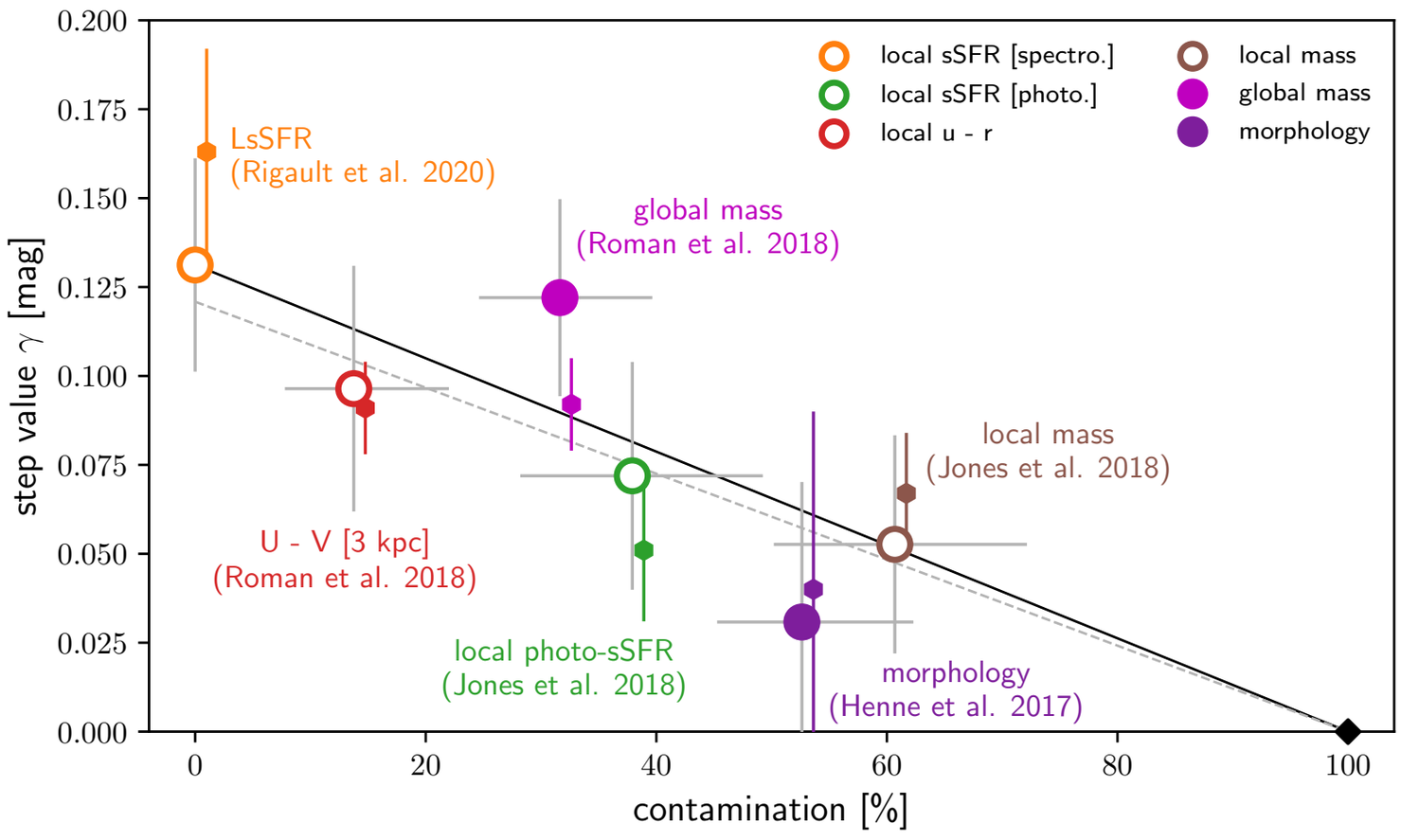


Conclusions

- **Our model of the two SN Ia populations is explaining well the observed variations of the magnitude offset;**

- **Among the available tracers, the spectroscopic local sSFR is the most able to explain all the observations;**



Conclusions

- Regarding the observations and this work, we confirm the existence of an astrophysical bias which has an impact on the luminosity of the Type Ia Supernovae;
- It tends to confirm that we can take into account a magnitude offset between two SN Ia populations about 0.15 mag that:
  - reduces the gap between the direct and indirect measurements of H_0;
  - impacts on every other cosmological parameters derived from the SNe Ia (such as the dark energy equation of state parameter w).

Thank you for your attention!