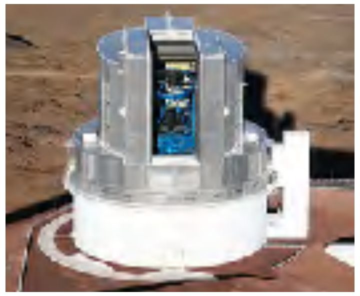
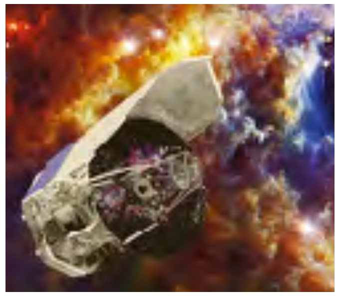
SMBHs: Environment and Evolution @ CORFU 19th June, 2019

Physical properties of luminous radio galaxies at 0 < z < 1.7 selected with Subaru Hyper Suprime-Cam and VLA FIRST survey

Toba et al. (2019b), ApJS, 243, 15

Yoshiki Toba (Kyoto U.)

Takuji Yamashita (Ehime U.), Tohru Nagao (Ehime U.),
Wei-Hao Wang (ASIAA), Yoshihiro Ueda (Kyoto U.),
Kohei Ichikawa (Tohoku U.), and WERGS team

Introduction

- Importance of radio galaxies (RGs)
- Our project (a search for optically-faint RGs)
- Purpose of this work

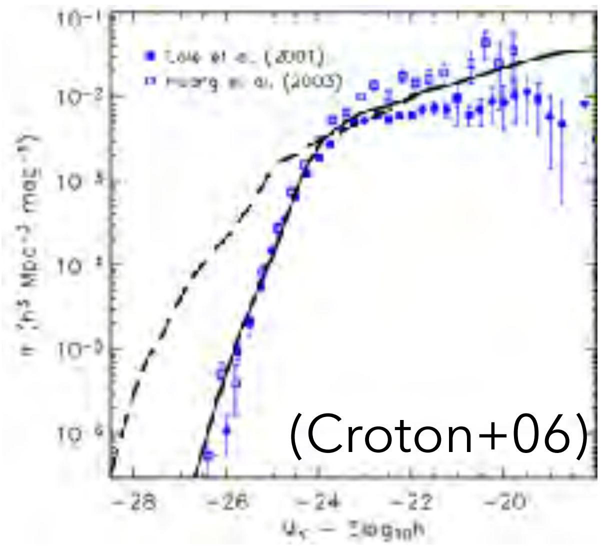
Importance of Radio Galaxies (RGs)

Cosmic evolution

- Local RGs are passive and massive host galaxies, and their SMBHs show low accretion rates, while high-z RGs show an active SF.

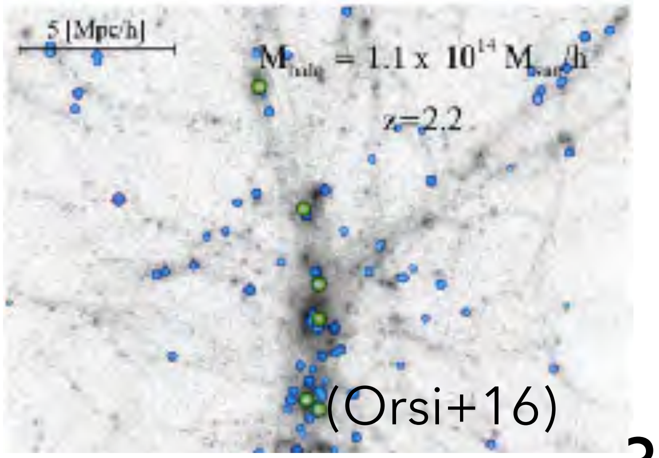
AGN feedback

- Powerful radio jets can regulate SF in host galaxies and surrounding galaxies (radio-mode AGN feedback).

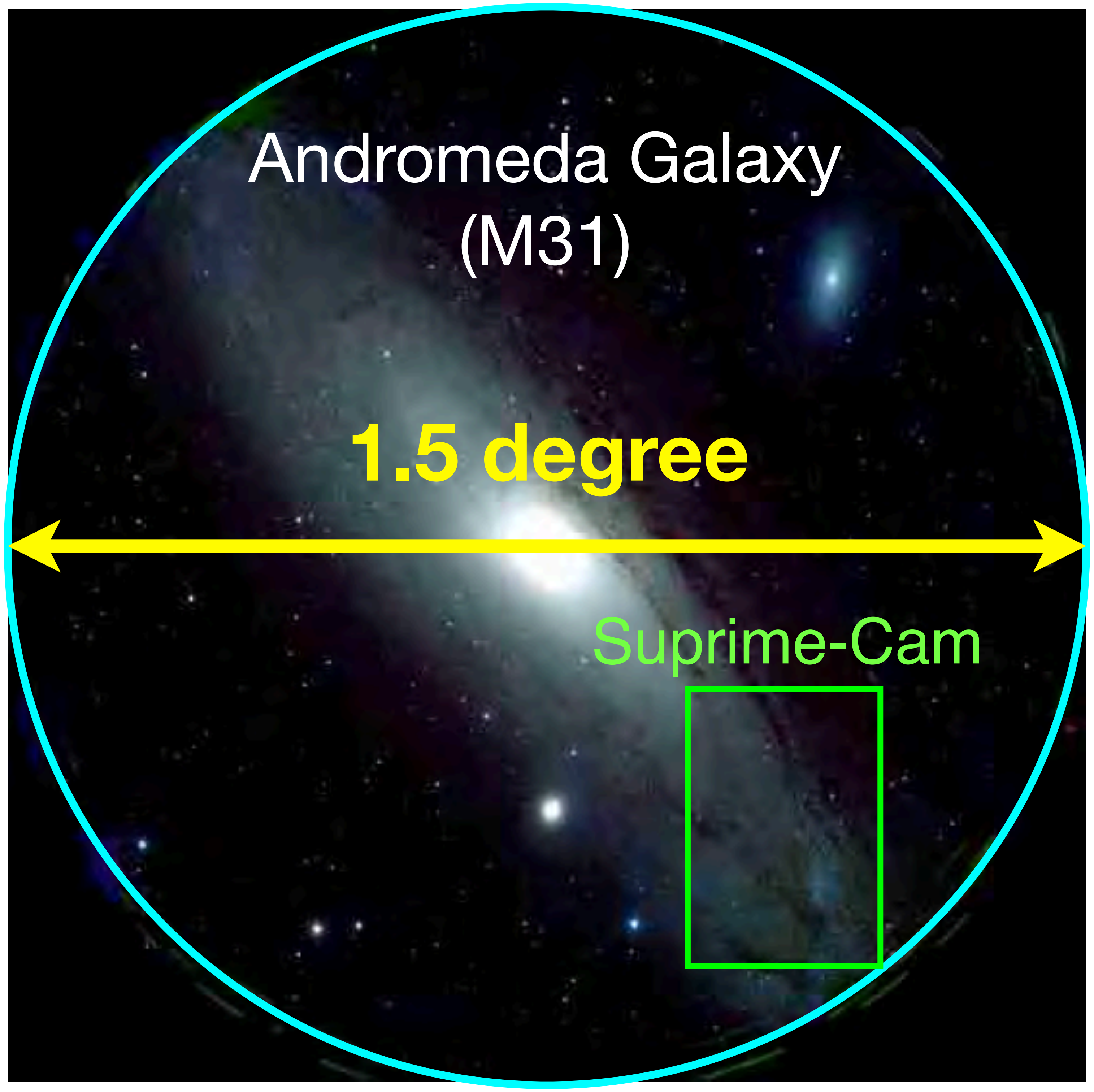


Protocluster

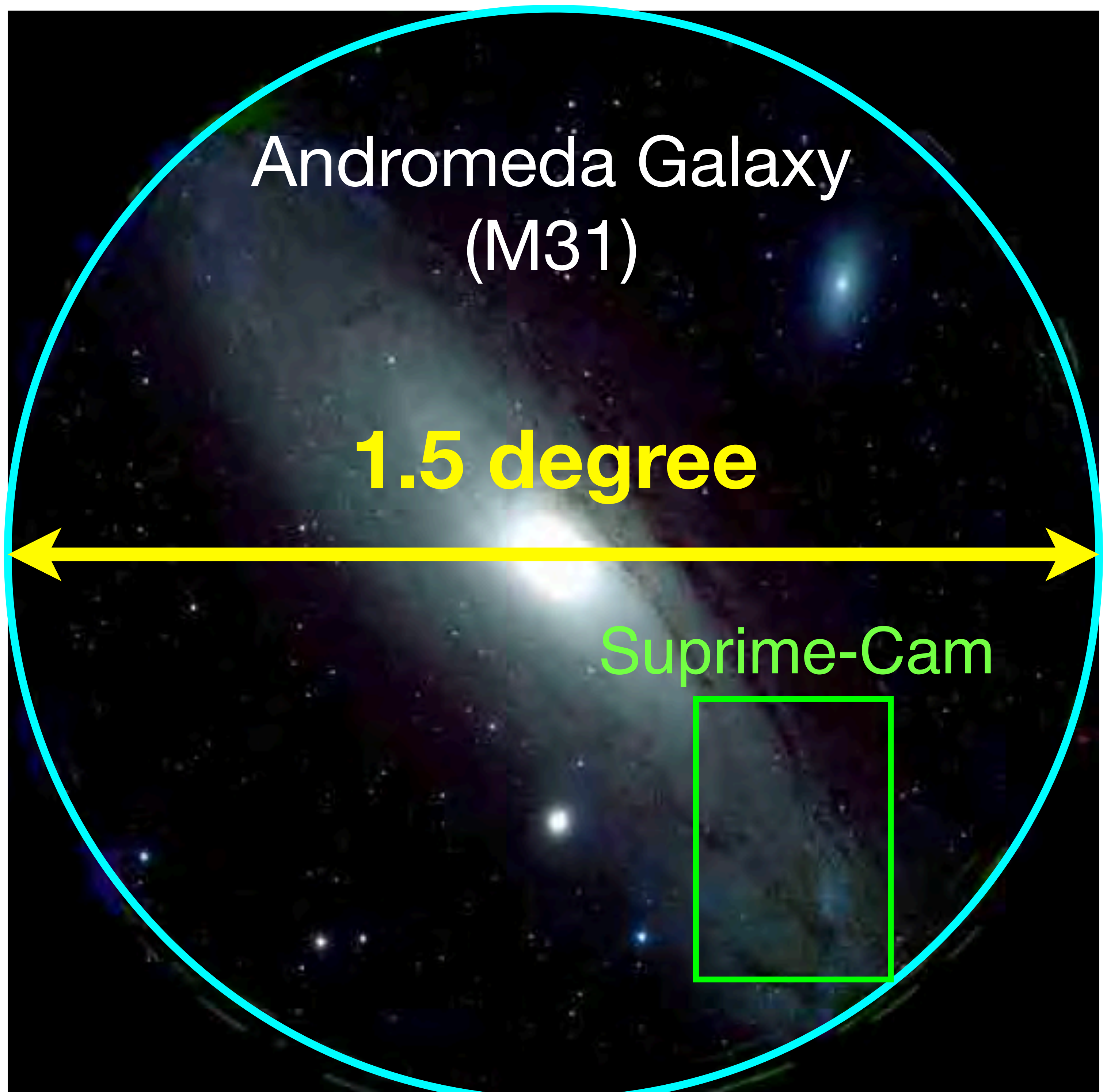
- RGs are often found in over-dense regions, suggesting that RGs may be a good tracer of protocluster.

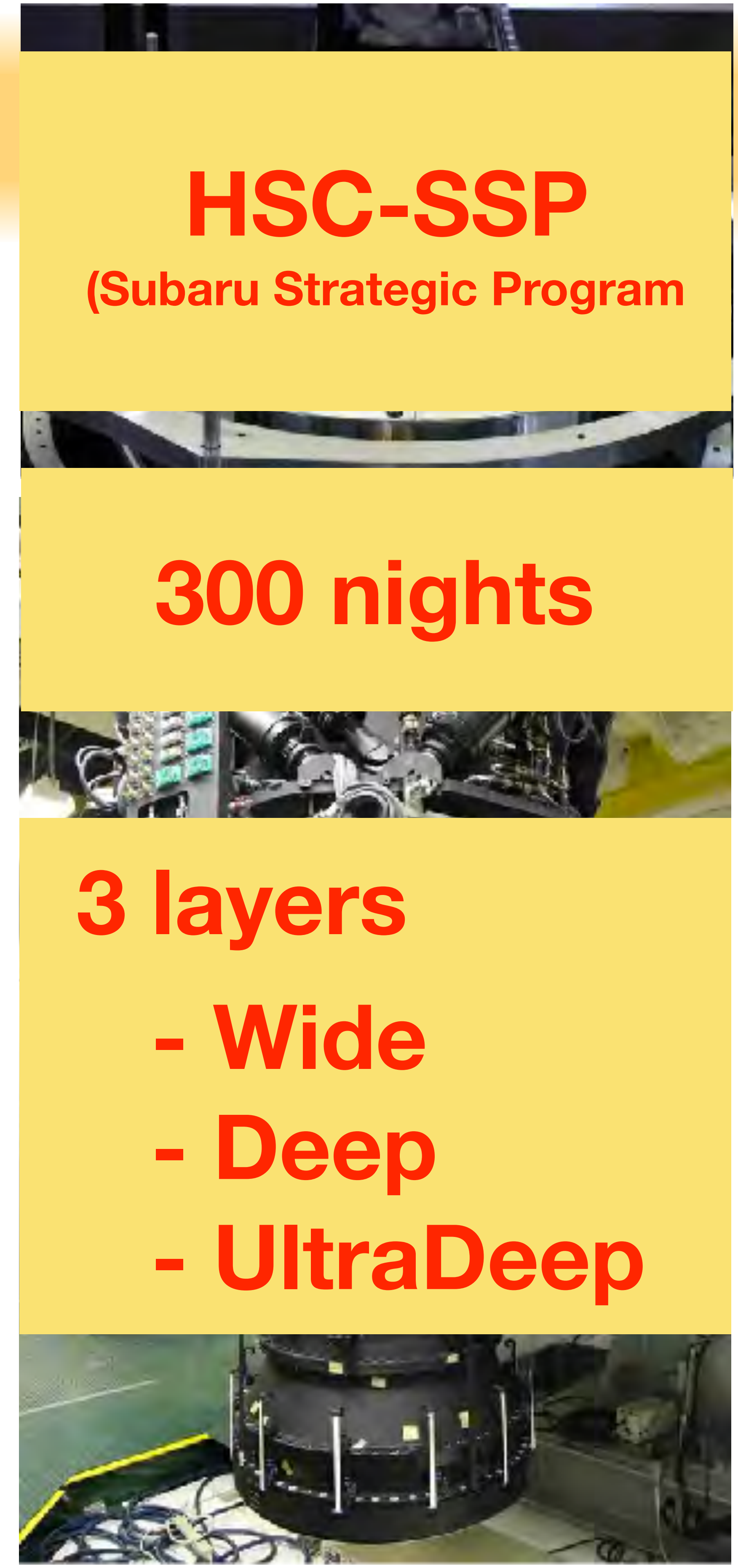


Subaru Hyper Suprime-Cam



Subaru Hyper Suprime-Cam



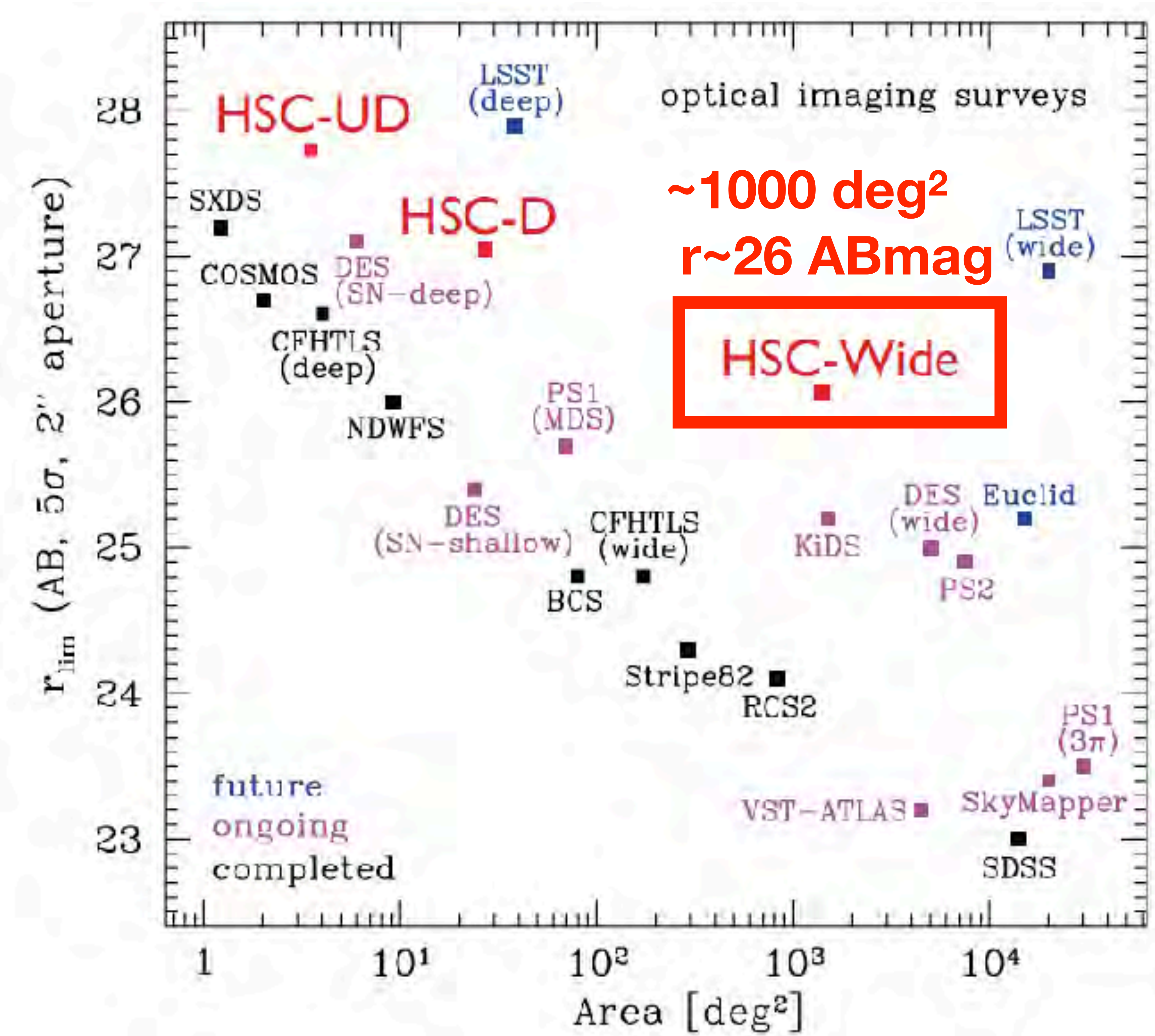


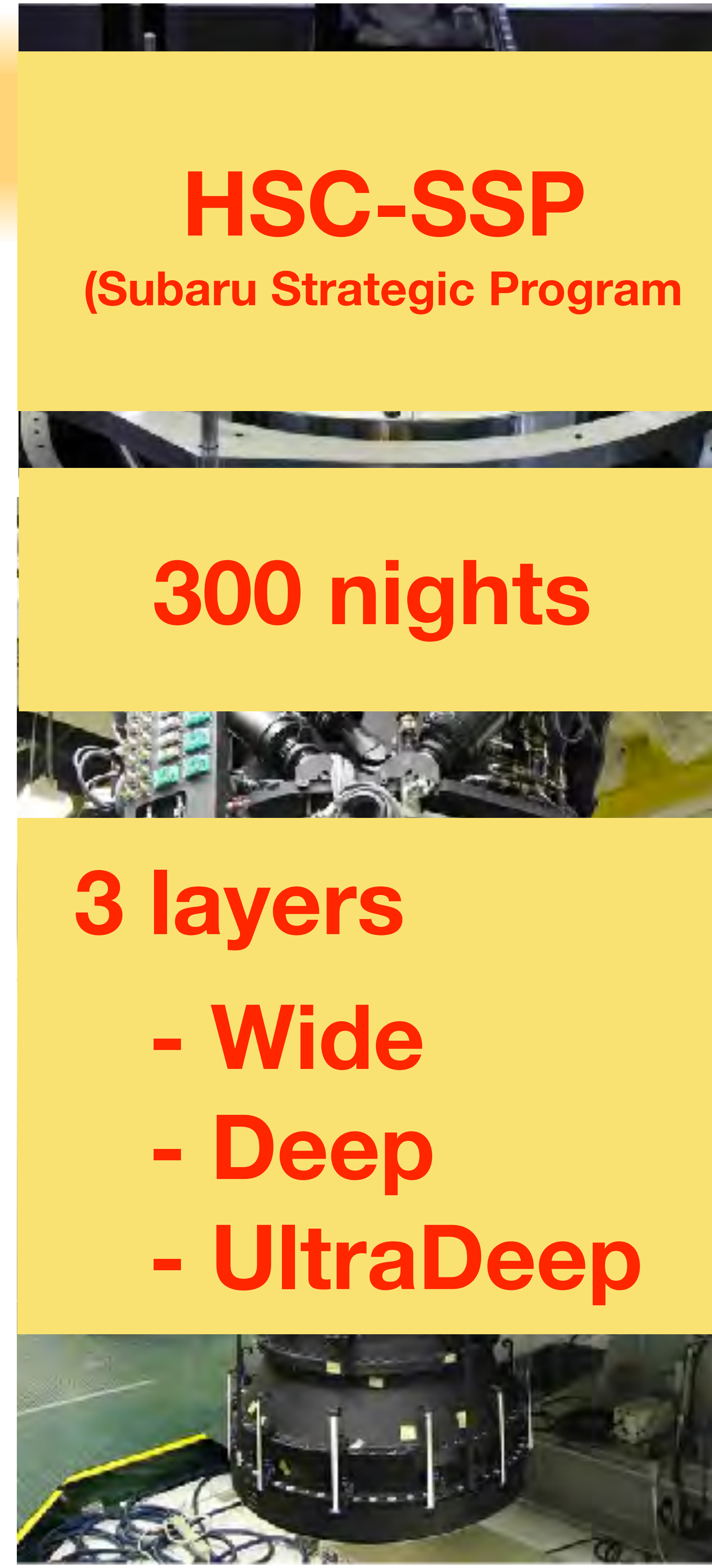
HSC-SSP
(Subaru Strategic Program

300 nights

3 layers
- **Wide**
- **Deep**
- **UltraDeep**

Subaru Hyper Suprime-Cam





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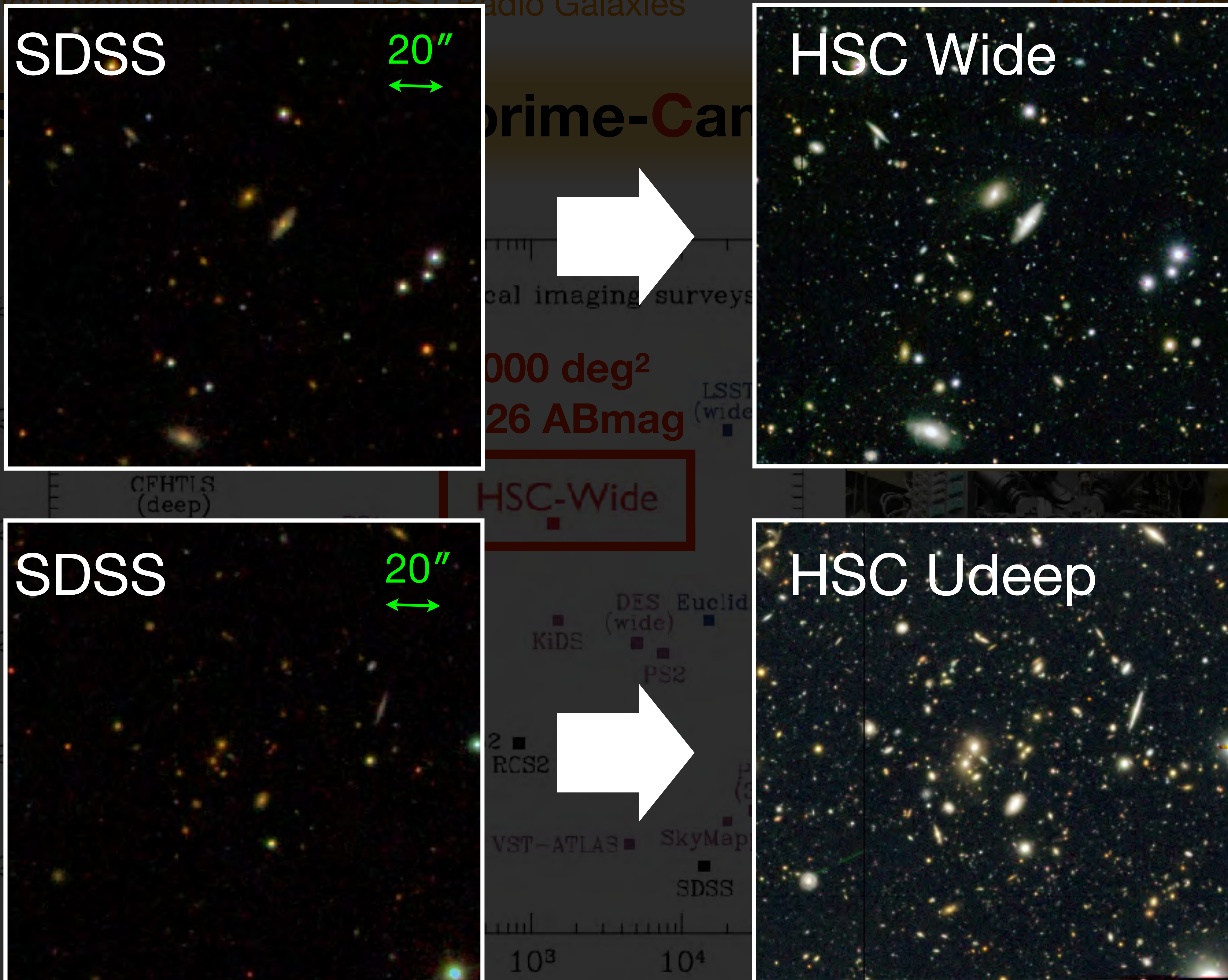
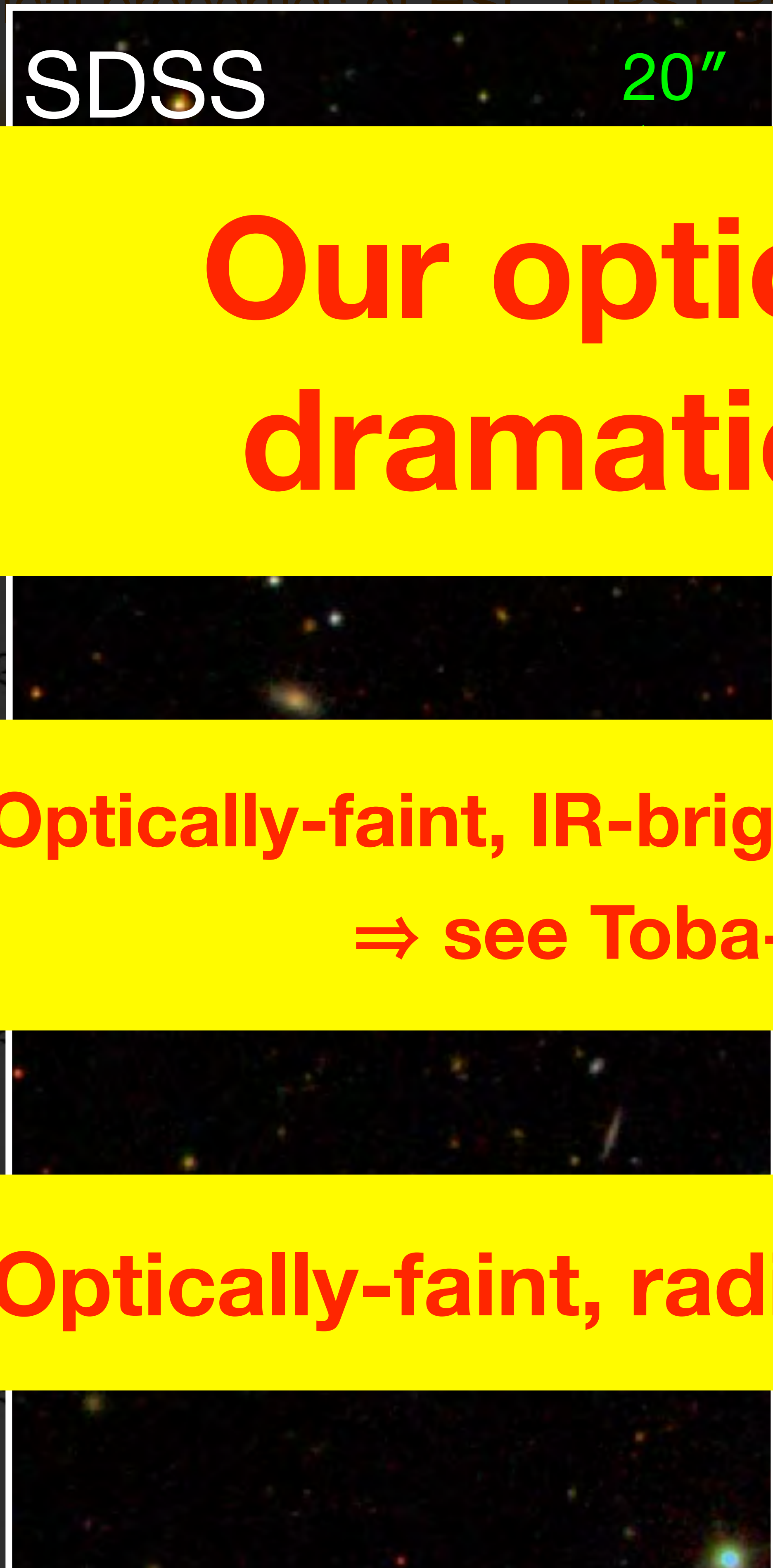

SDSS
20″
HSC Wide
SDSS
20″
HSC Udeep



Our optical view is now dramatically changed!

Optically-faint, IR-bright dust-obscured galaxies (DOGs)
⇒ see Toba+15, 16, 17(a)(b)(c)(d), 18

Optically-faint, radio bright galaxies (This work)

The WERGS project

T.Yamashita
NAOJ (Japan)

- **WERGS: Wide and Deep Exploration of Radio Galaxies with Subaru HSC**
  - Exploration of high-z or optically faint radio galaxies with Subaru HSC in order to tackle the issues on the galaxy/AGN evolution.

HSC-SSP

- Wide & Ultra-Deep COSMOS layers
- S/N (r,i,z) > 5

	Wide	Ultra-Deep
Limiting mag i [mag]	26.4	27.0
Area [deg^2]	154	2

X

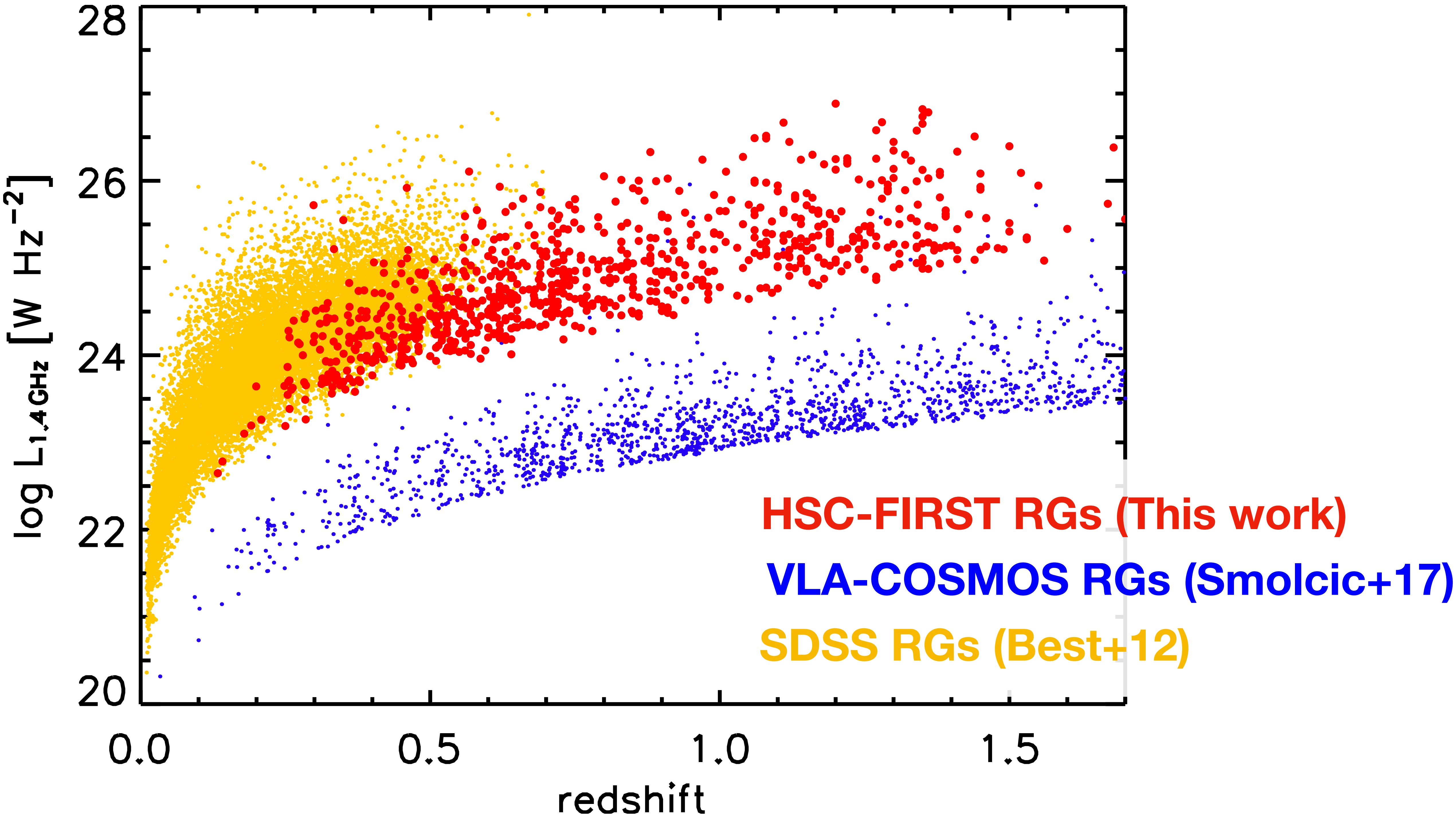
VLA FIRST 1.4GHz survey

- 1.4 GHz (20 cm) imaging
- Area = 10,575 deg^2; ~ SDSS
- Detection limit = 1 mJy (at z>0.5, SF galaxies are not detected.)
- Resolution = 5″ , Accuracy < 0.5″

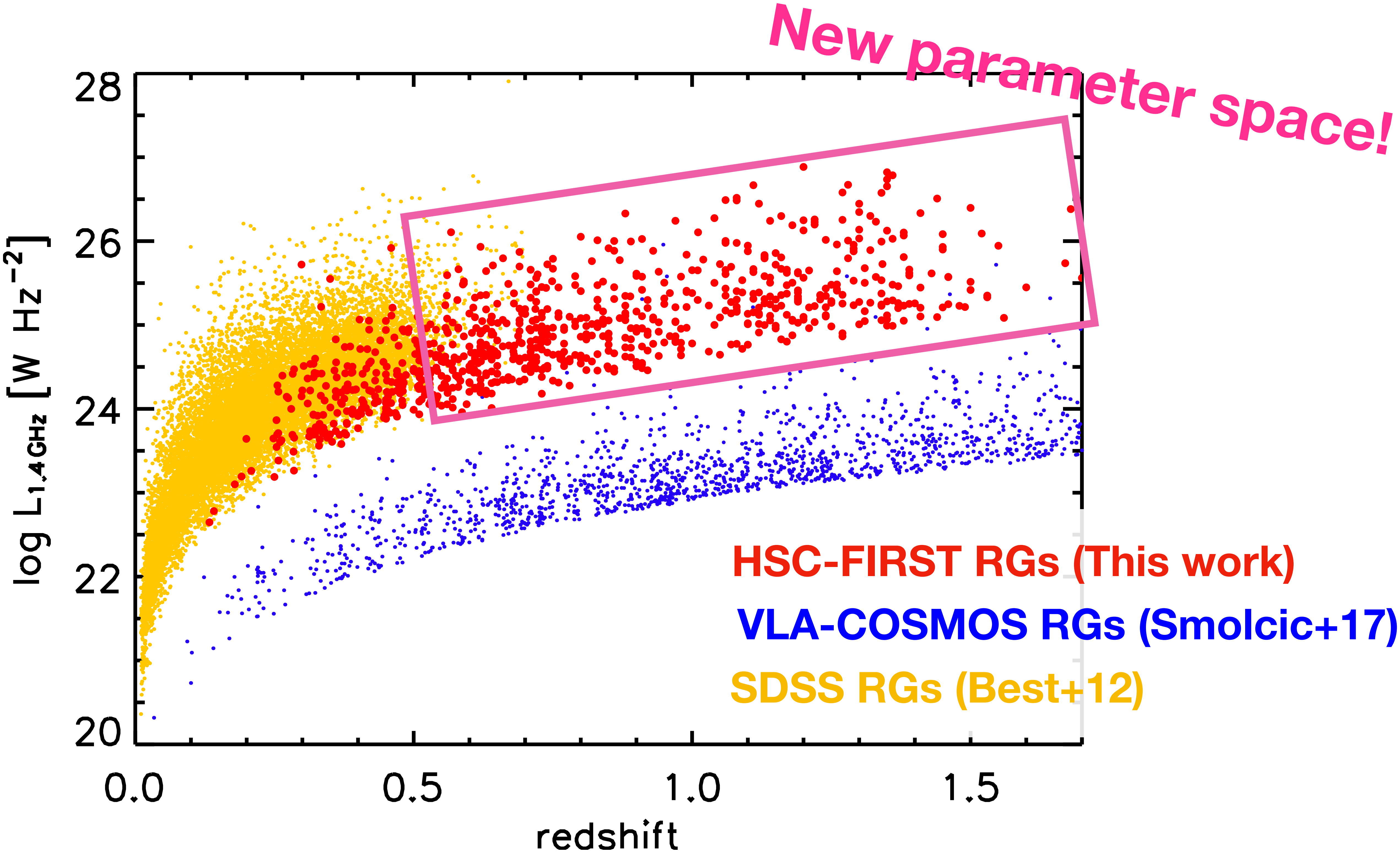
Photo-z Sample (Yamashita et al. 2018)

	Matches	Area
Wide	3,579	154 deg^2
UD-COSMOS	63	1.8 deg^2

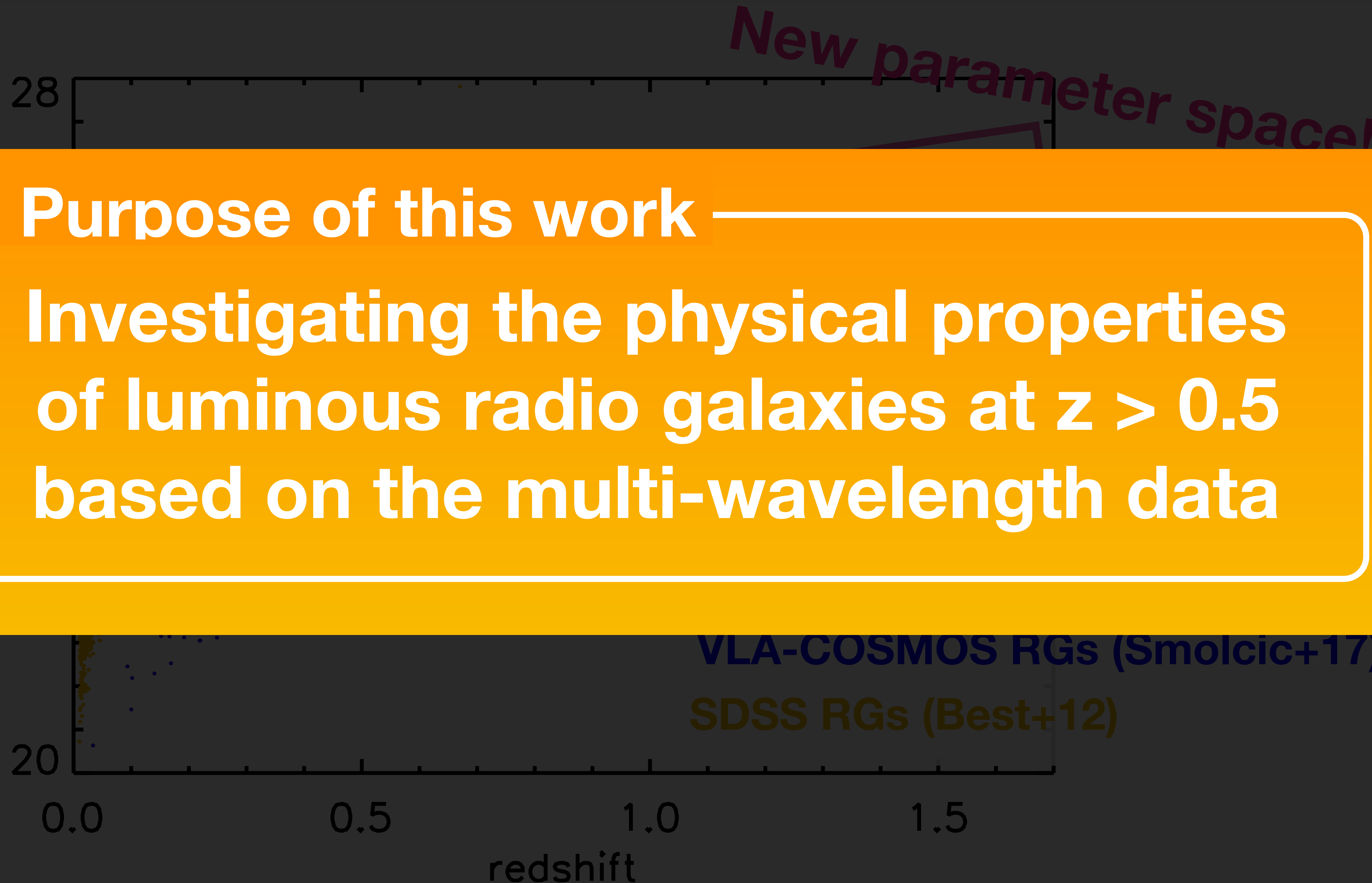
Parameter space of our RGs



Parameter space of our RGs



Parameter space of our RGs



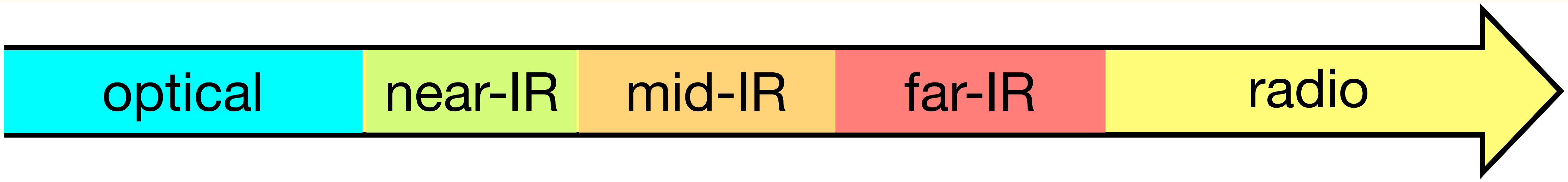
Purpose of this work

Investigating the physical properties of luminous radio galaxies at z > 0.5 based on the multi-wavelength data

Data and Analysis

- Dataset
- Sample selection for the SED fitting
- SED fitting with CIGALE

Multi-wavelength dataset



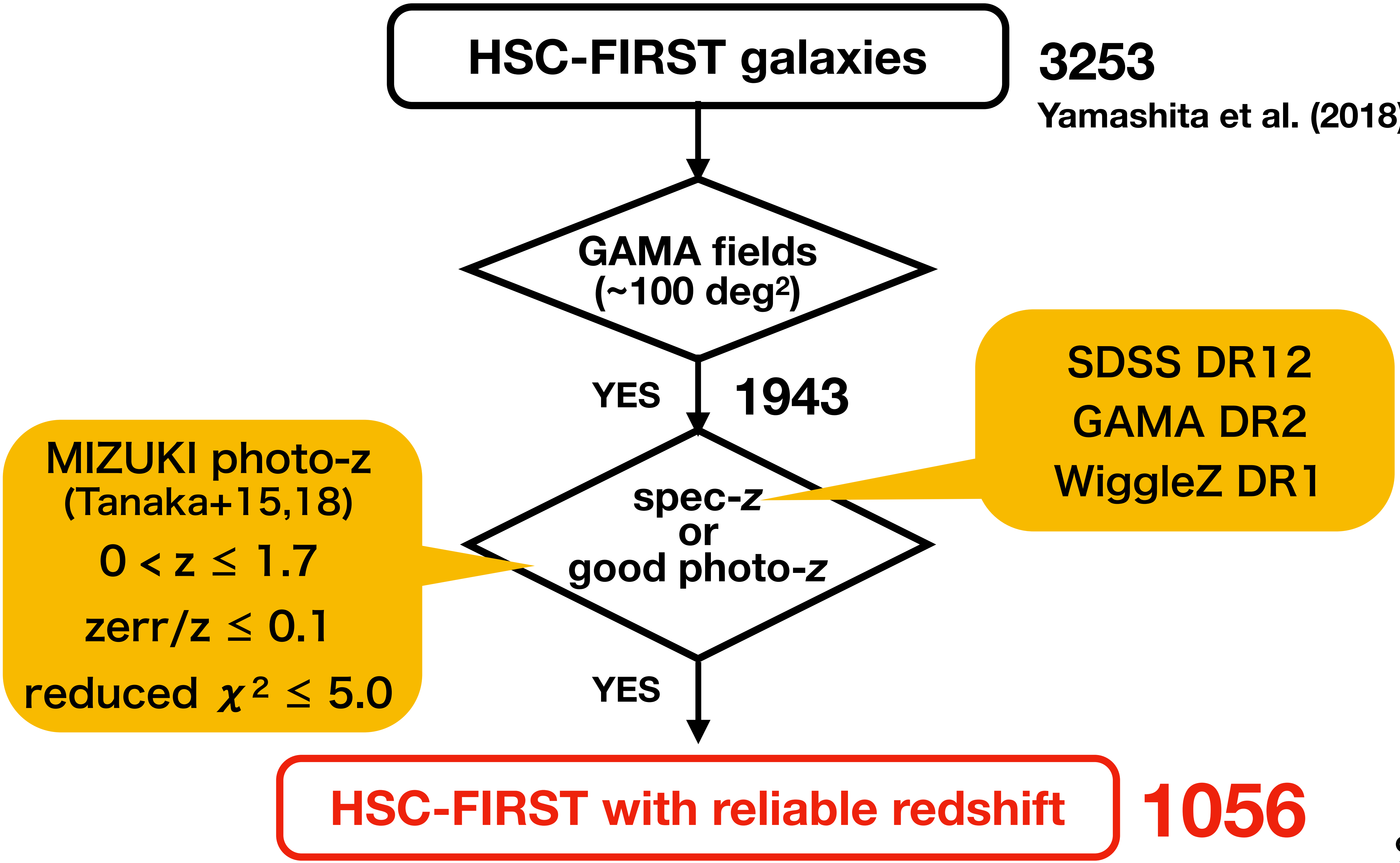
Survey	KiDS	HSC	VIKING	WISE	H-ATLAS	FIRST	TGSS
band	u	g,r,i,z,y	J,H,Ks	3.4, 4.6, 12, 22	100, 160, 250, 350, 500	20 cm (1.4 GHz)	2 m (150 MHz)
DR	DR3	S16A	DR3	ALLWISE	DR1	final	ADR1
sensitivity	u~24.3 AB mag	i ~26 AB mag	Ks ~ 20.4 AB mag	f_{22} ~ 6 mJy	f_{250} ~22 mJy	~ 0.2 mJy/beam	~5 mJy/beam



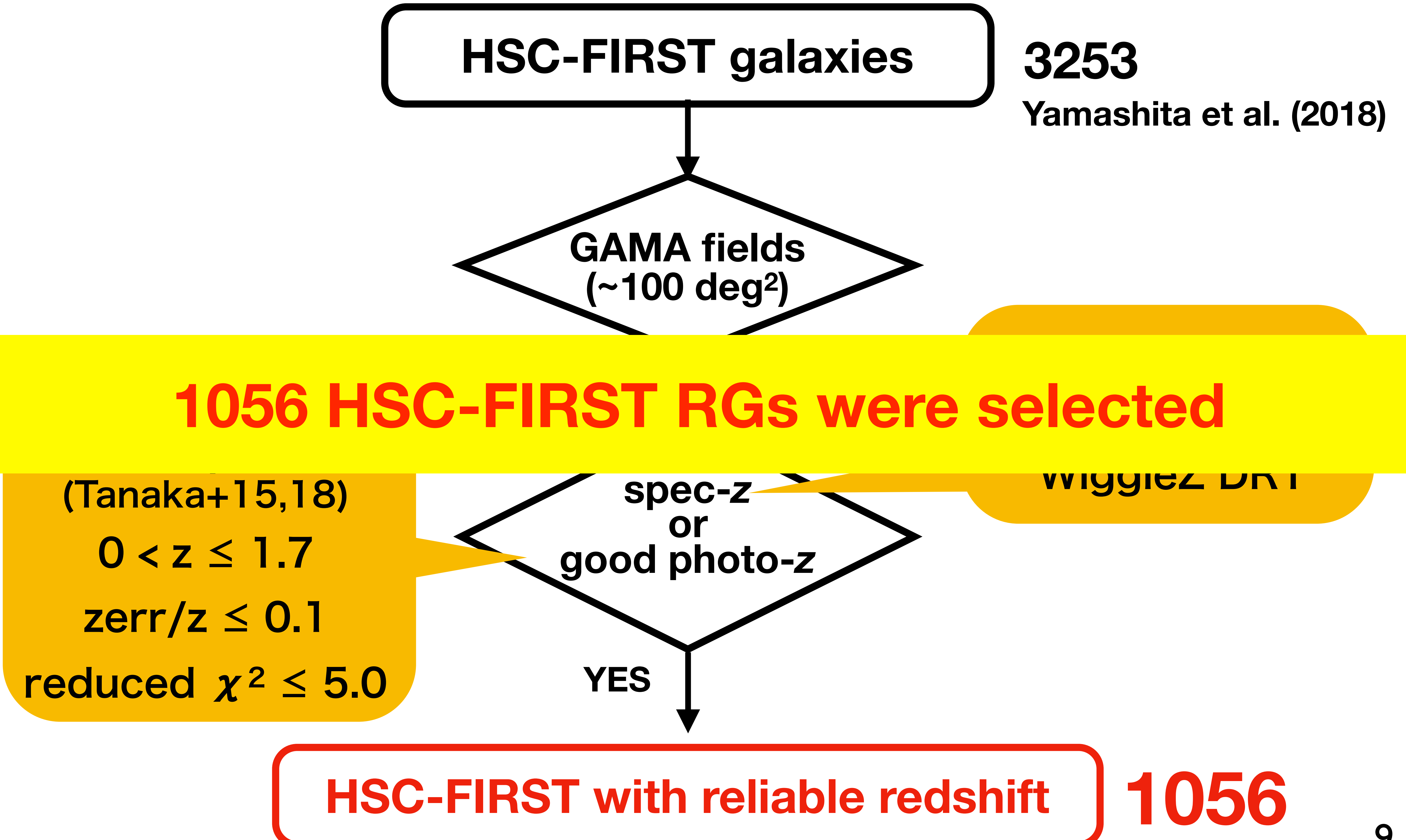




Sample Selection



Sample Selection

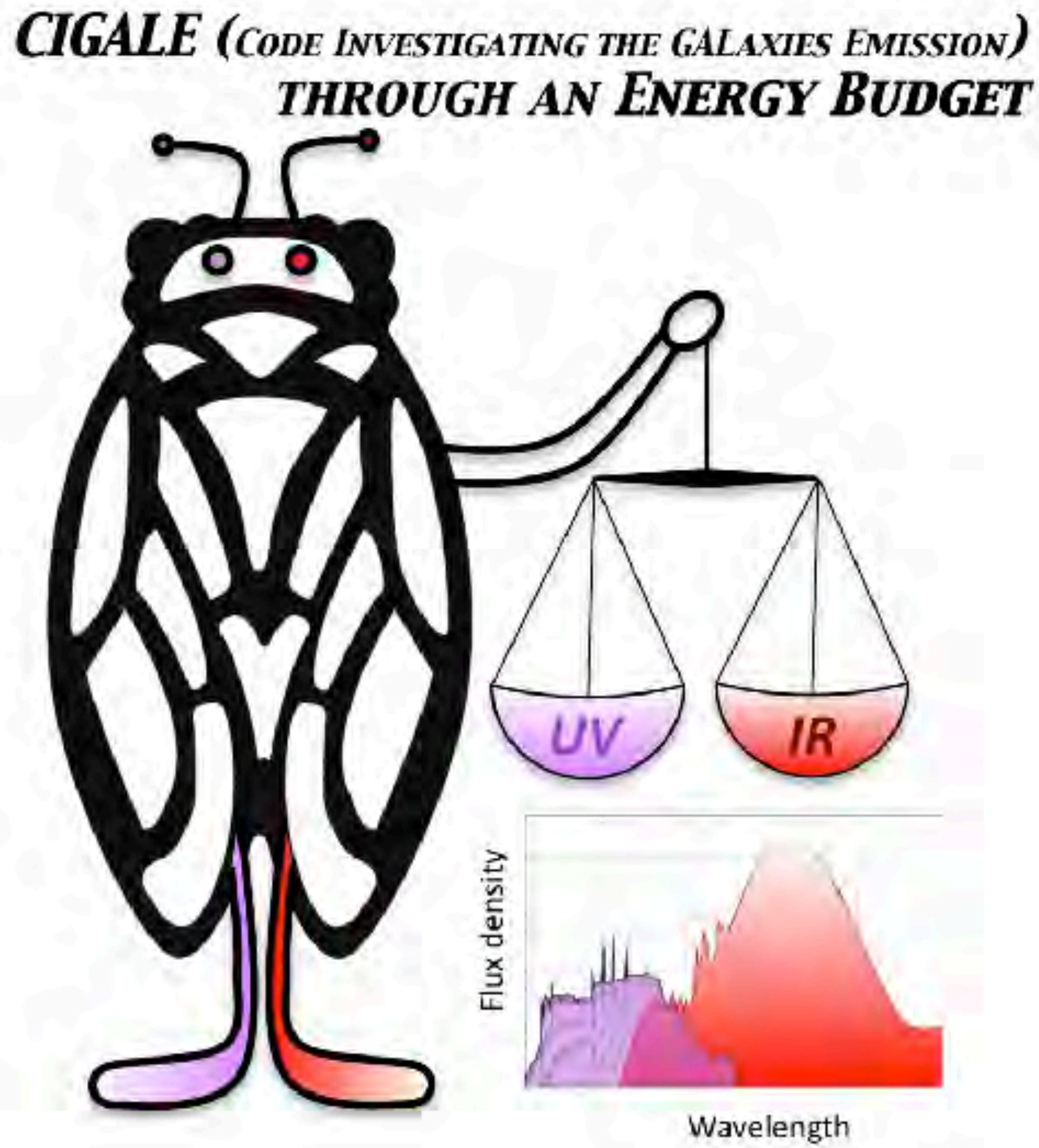


1056 HSC-FIRST RGs were selected

Code Investigating GALaxy Emission

Prof. Denis Burgarella

- A SED fitting code provided by Denis et al.
- Python 3.
- It is updated almost every year.
- Considering the energy balance between UV/optical and IR.
- CIGALE tells us e.g., stellar mass, SFR, dust extinction of galaxies.



Code Investigating G

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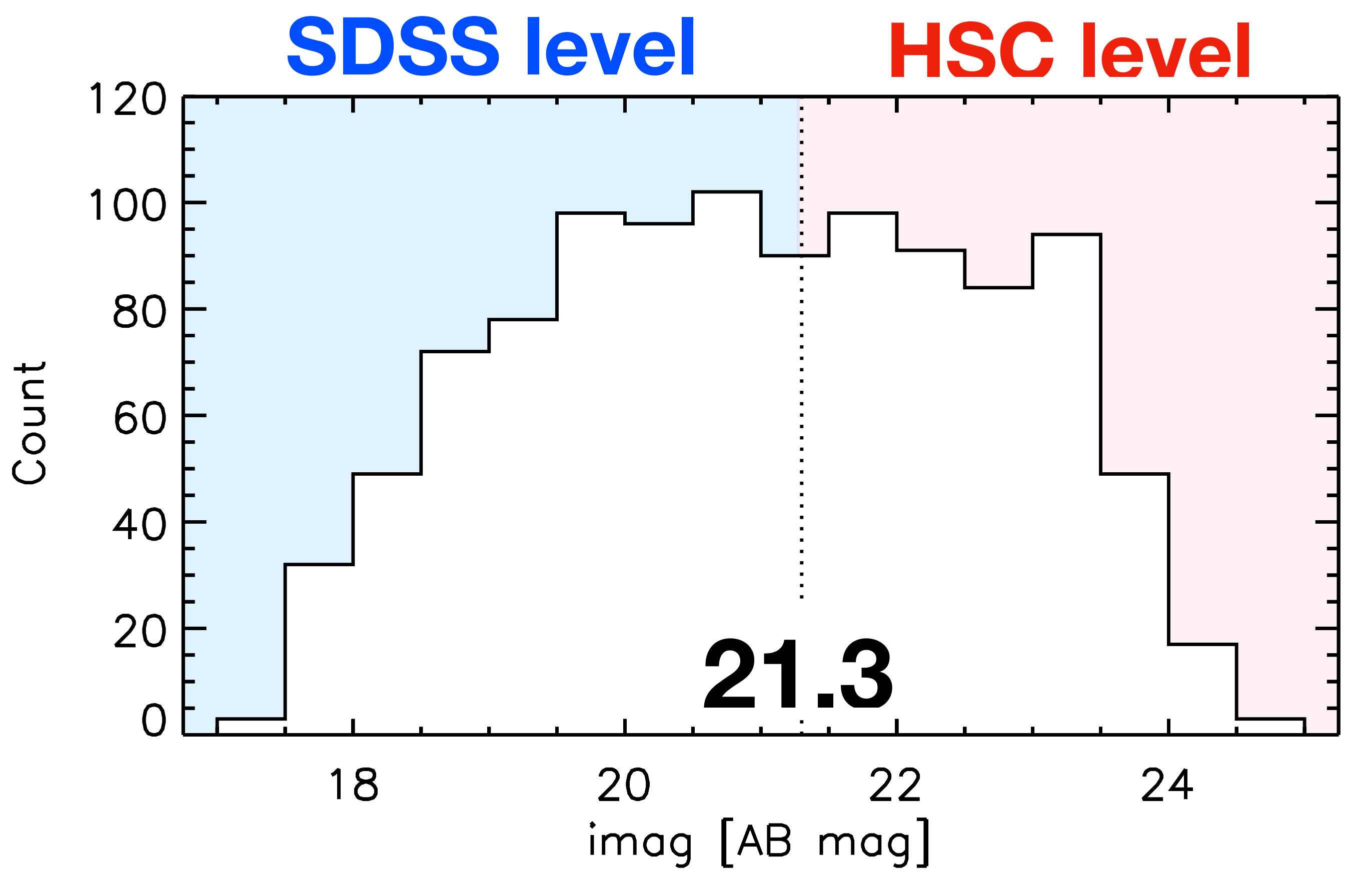
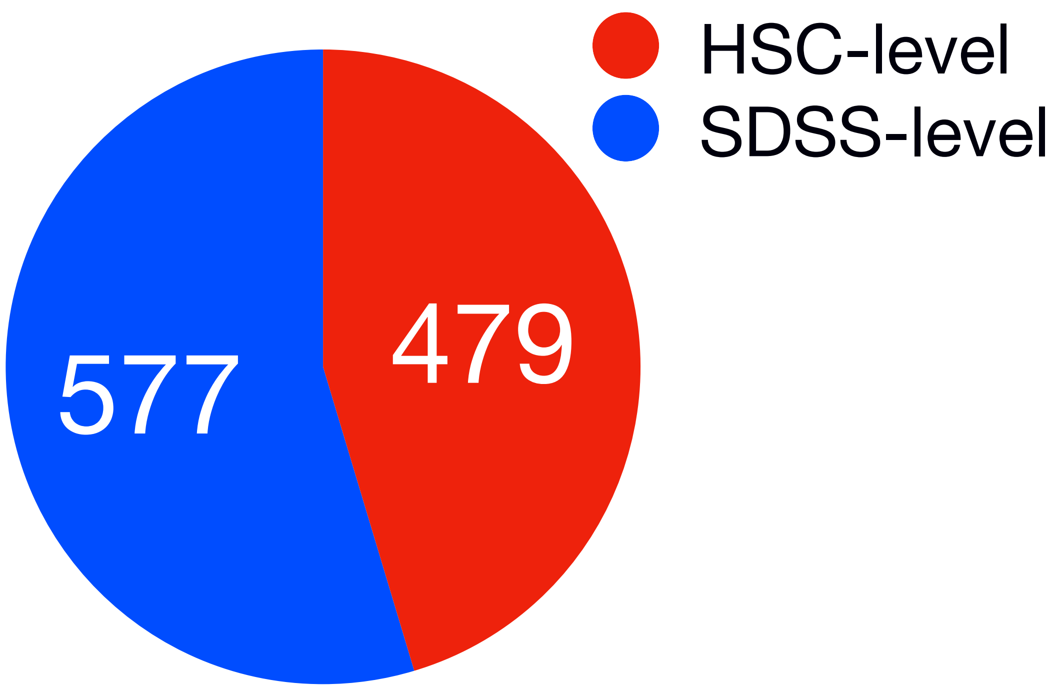
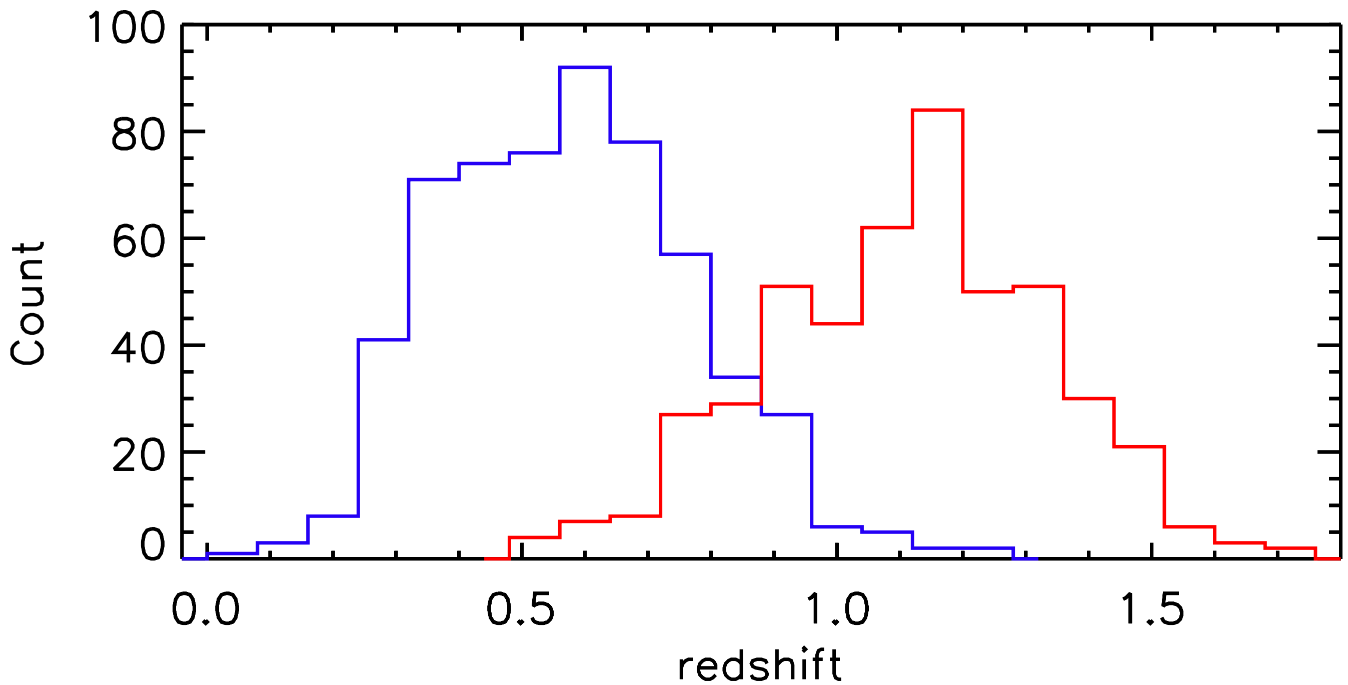
Paramerer	Value
Double exp. SFH	
$\tau_{\rm main}$ [Myr]	1000, 3000, 4000, 6000
$\tau_{\rm burst}$ [Myr]	3, 5, 8, 15, 80
$f_{\rm burst}$	0.001, 0.1, 0.3
age [Myr]	1000, 4000, 6000, 8000, 10000
SSP (Bruzual & Charlot 2003)	
IMF	Chabrier (2003)
Metallicity	0.02
Dust attenuation (Calzetti et al. 2000)	
$E(B-V)_*$	0.01, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5, 0.55, 0.6, 0.8, 1.0
AGN emission (Fritz et al. 2006)	
$R_{\rm max}/R_{\rm min}$	60
$\tau_{9.7}$	6.0
β	-0.50
γ	0.0
θ	100.0
ψ	0.001, 60.100, 89.990
$f_{\rm AGN}$	0.1, 0.5, 0.9
Dust emission (Dale et al. 2014)	
IR power-law slope ($\alpha_{\rm dust}$)	0.0625, 0.2500, 1.0000, 2.0000
Radio emission	
$L_{\rm FIR}/L_{\rm radio}$ coefficient ($q_{\rm IR}$)	00.01, 0.1, 0.3, 0.5, 1.0, 2.5
spectral index ($\alpha_{\rm radio}$)	0.5, 0.7, 0.9 1.1, 1.3

SDSS- and HSC-level RGs







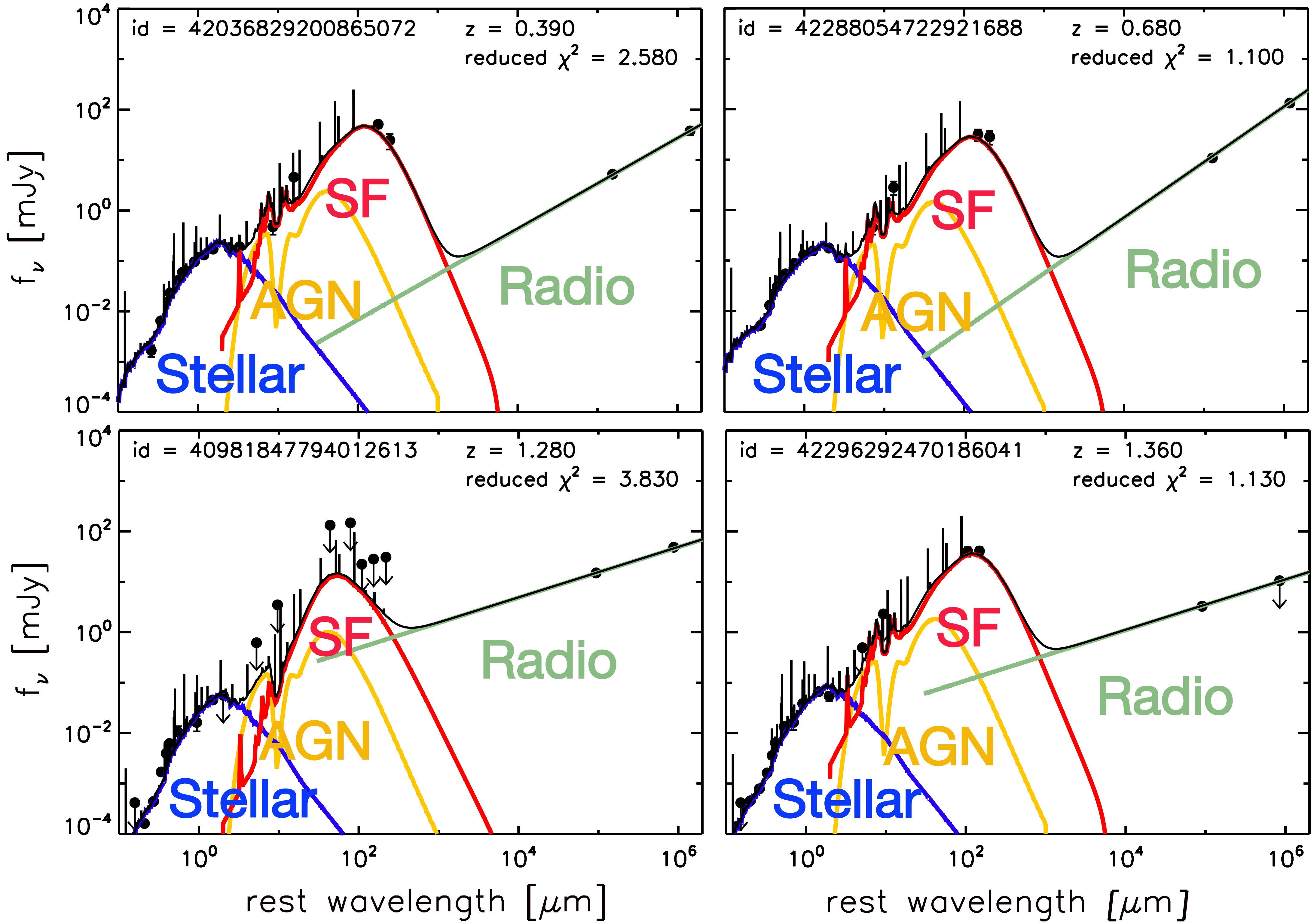
z (SDSS) = 0.57 ± 0.20

z (HSC) = 1.10 ± 0.20

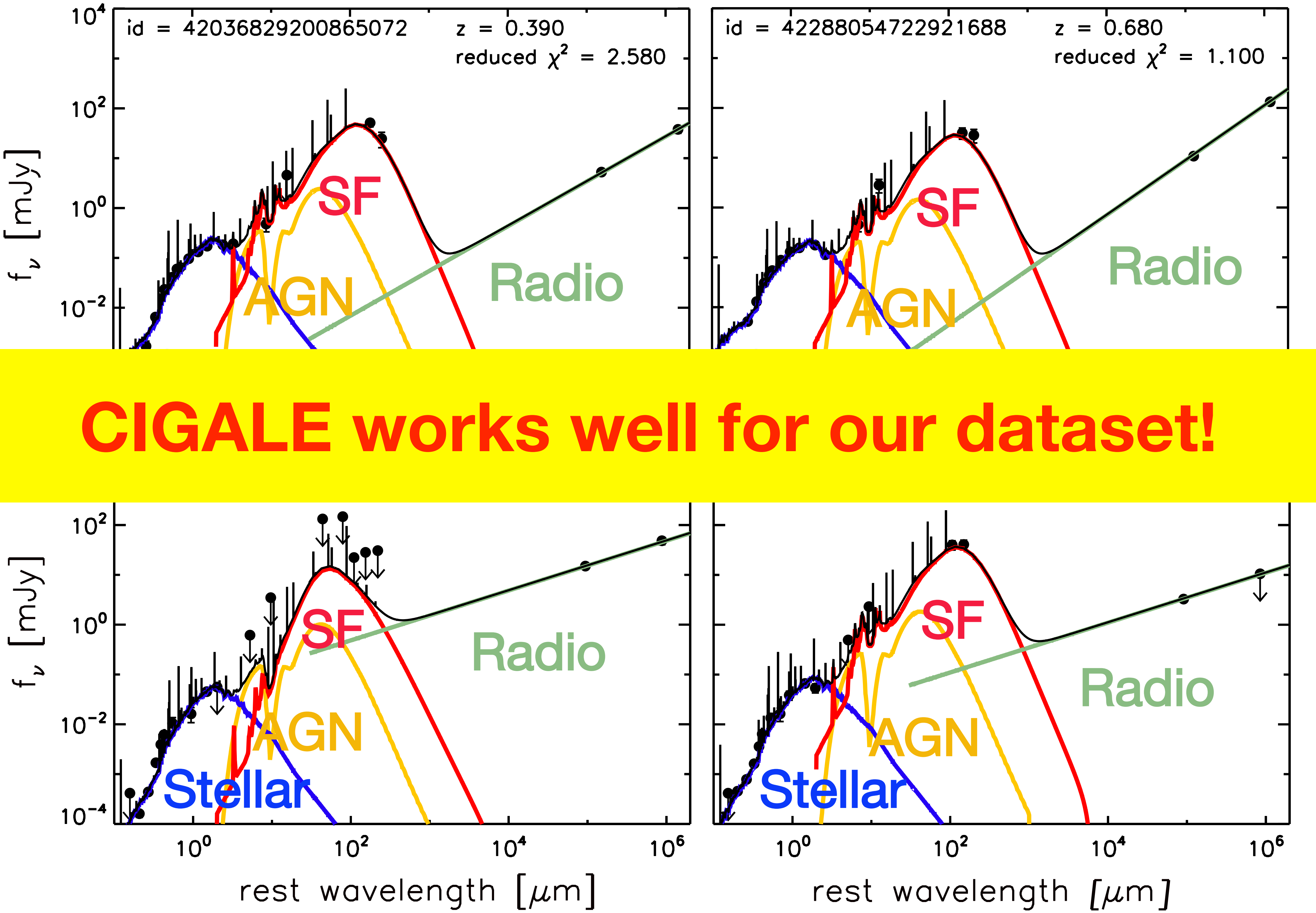
Results and Discussions

- Examples of SED fitting
- Physical properties of SDSS- and HSC-level RGs

Examples of SED



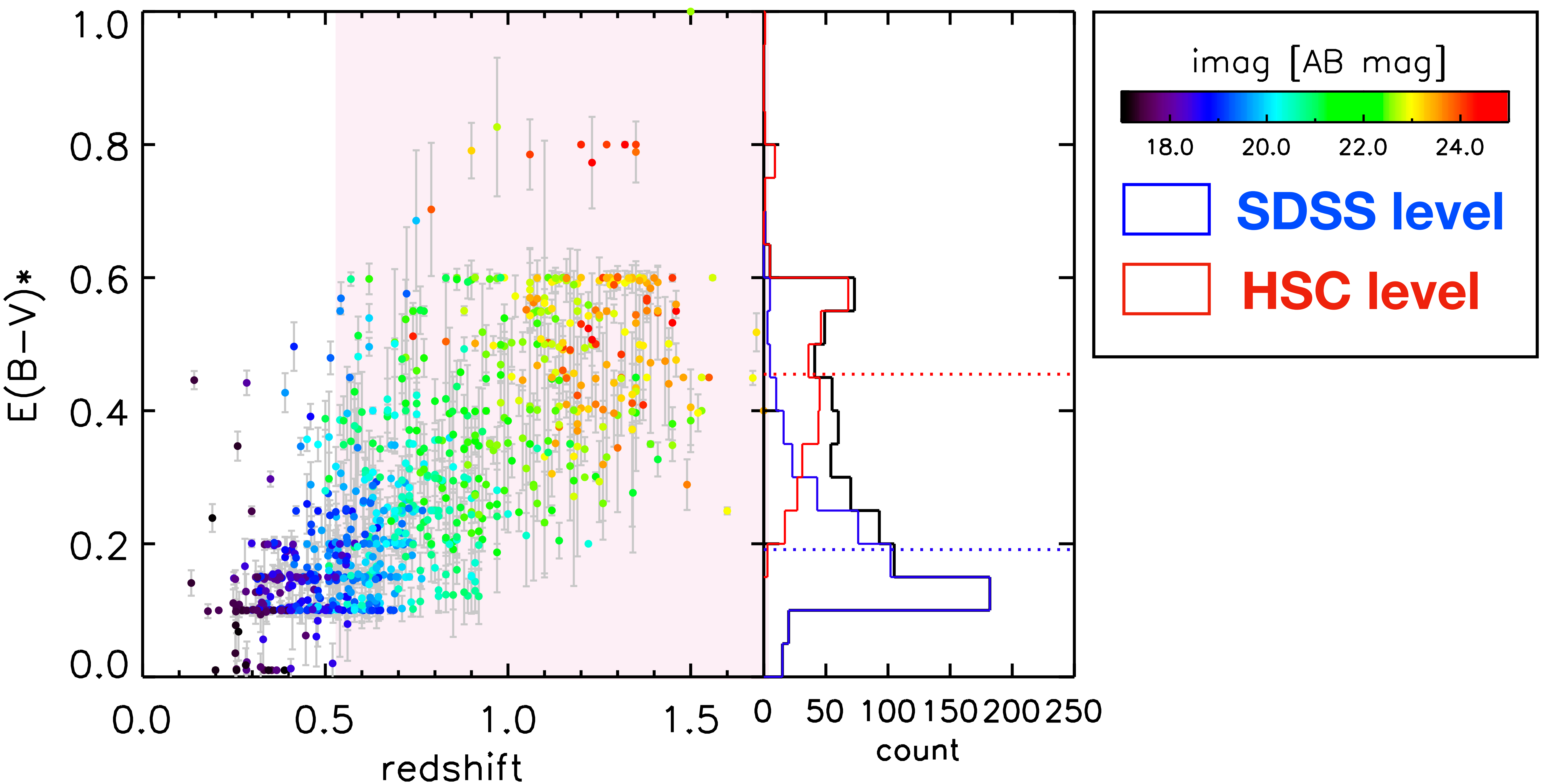
Examples of SED



CIGALE works well for our dataset!

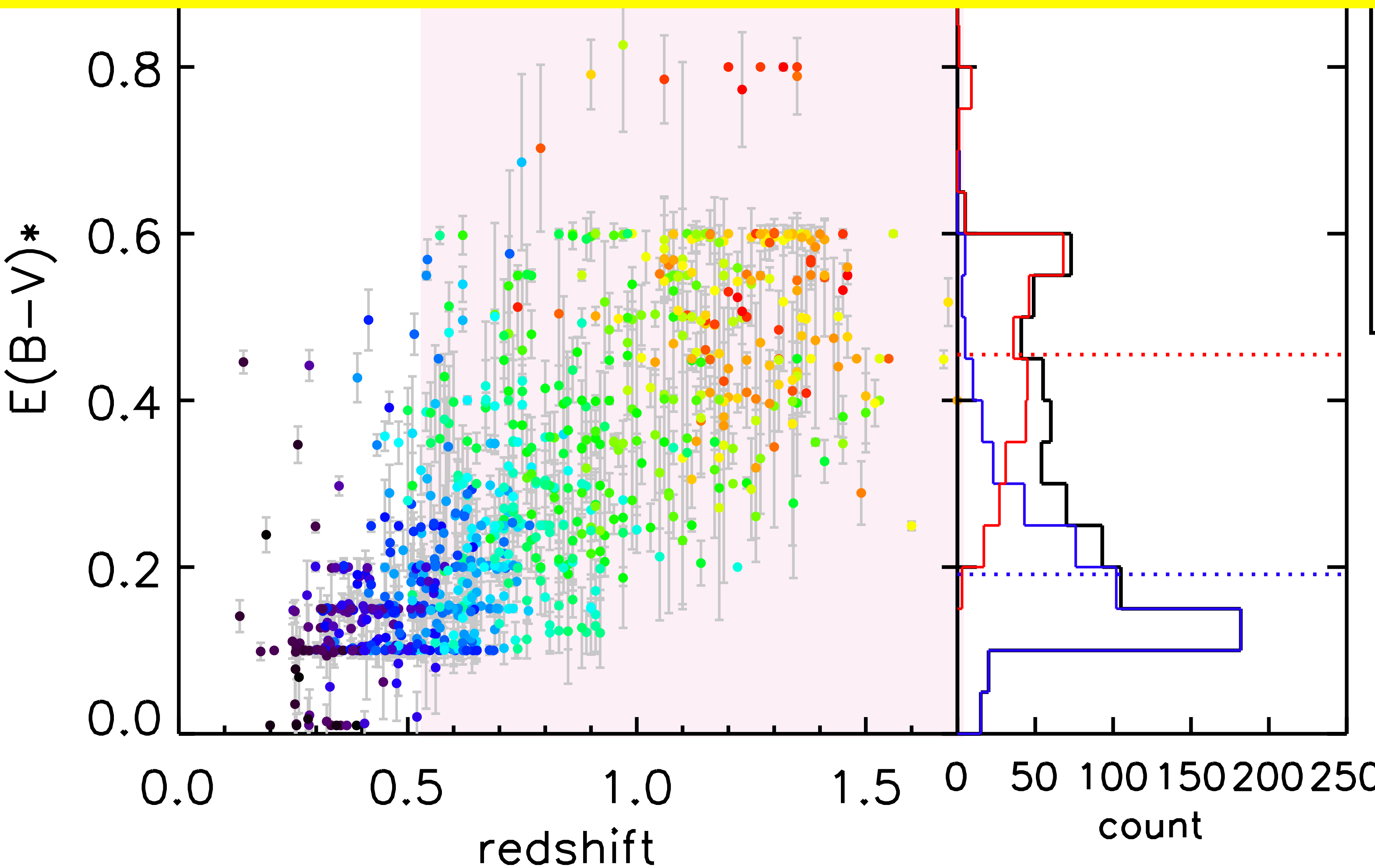
z vs. *E* (*B*-*V*)*


Optical
NIR
MIR
FIR
Radio


E(B−V)*
redshift
count
imag [AB mag]
18.0
20.0
22.0
24.0
SDSS level
HSC level

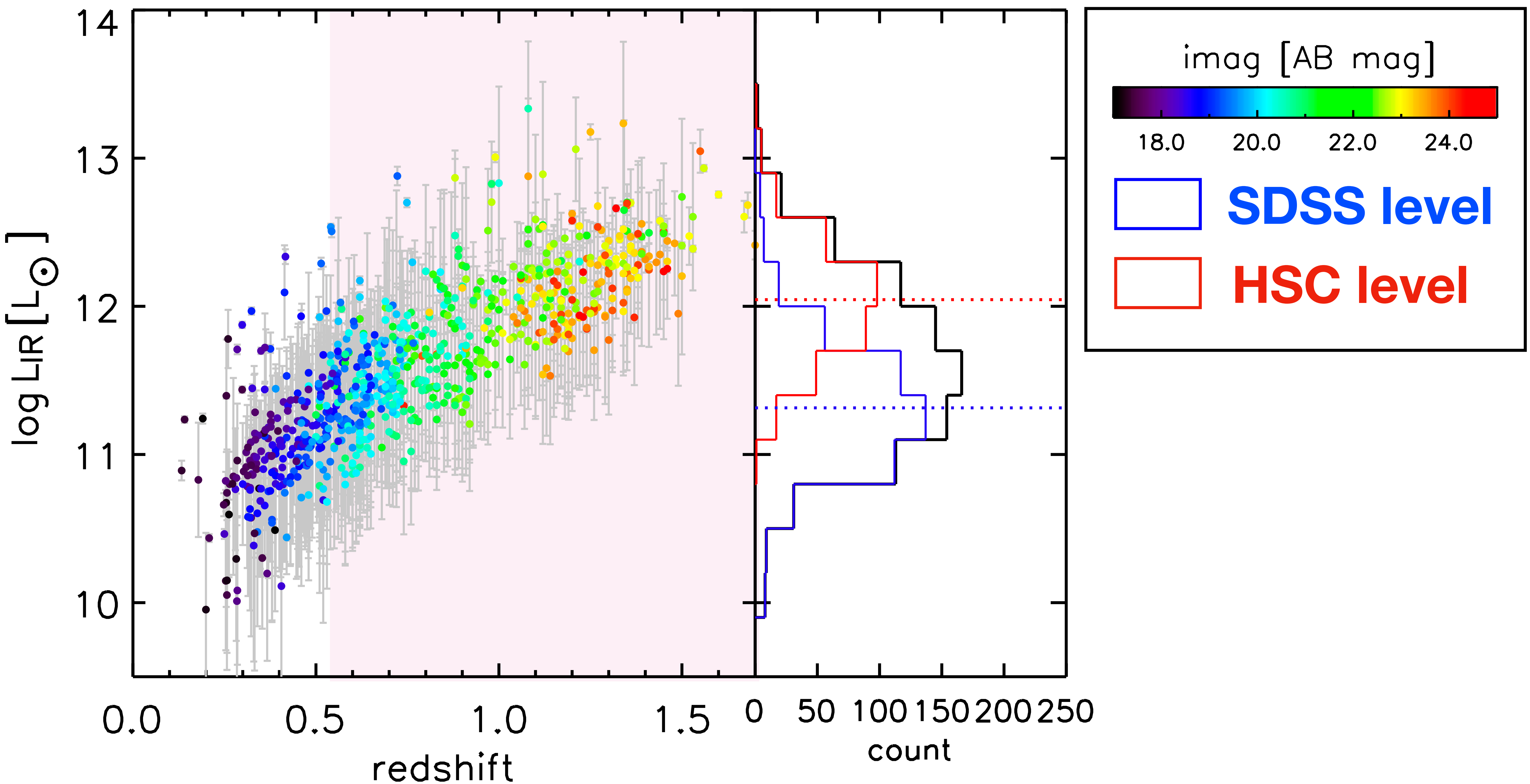
z vs. *E* (*B*-*V*)*

HSC-level RGs have large *E*(*B*-*V*)*

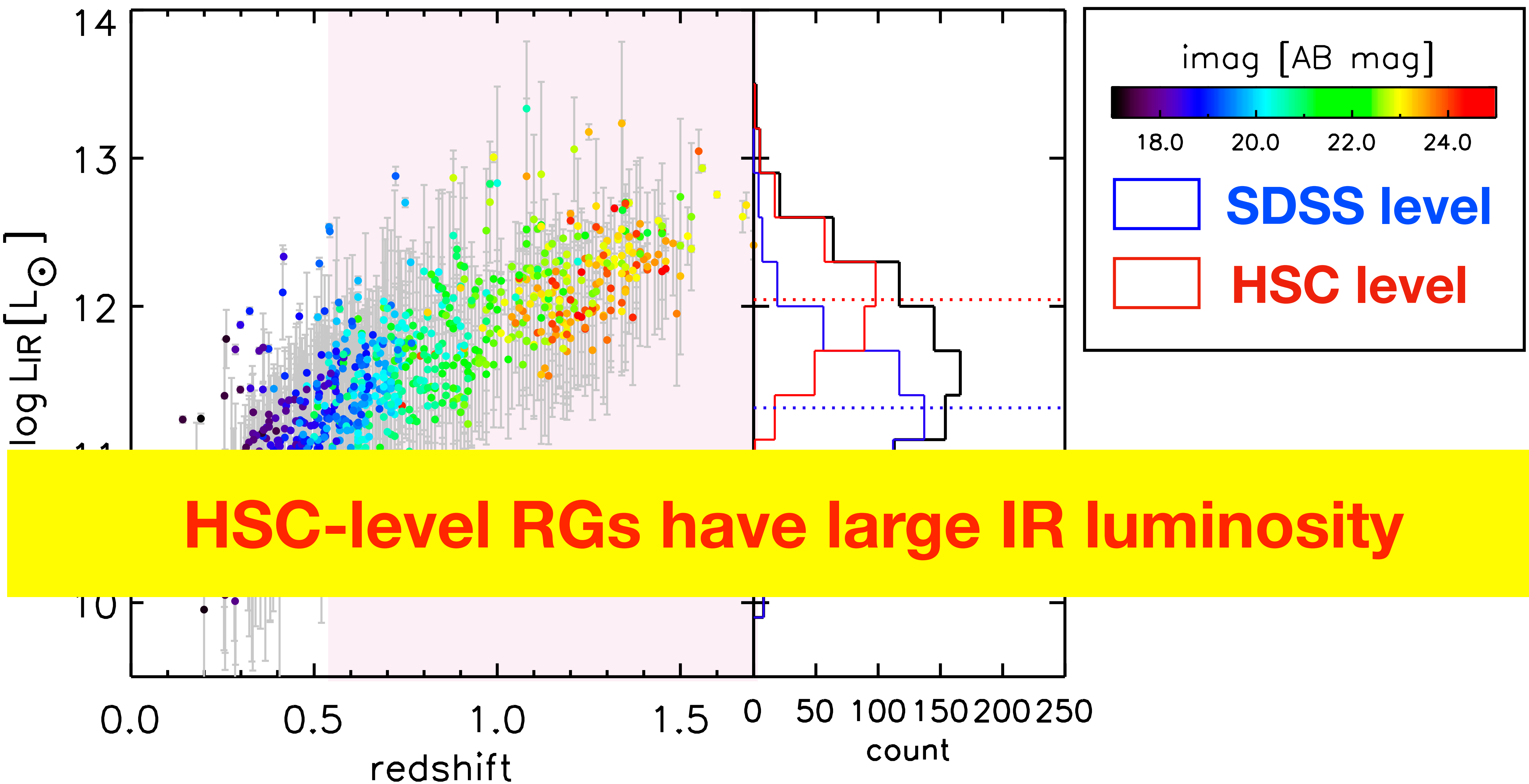


z vs. L_{IR}


Optical
NIR
MIR
FIR
Radio

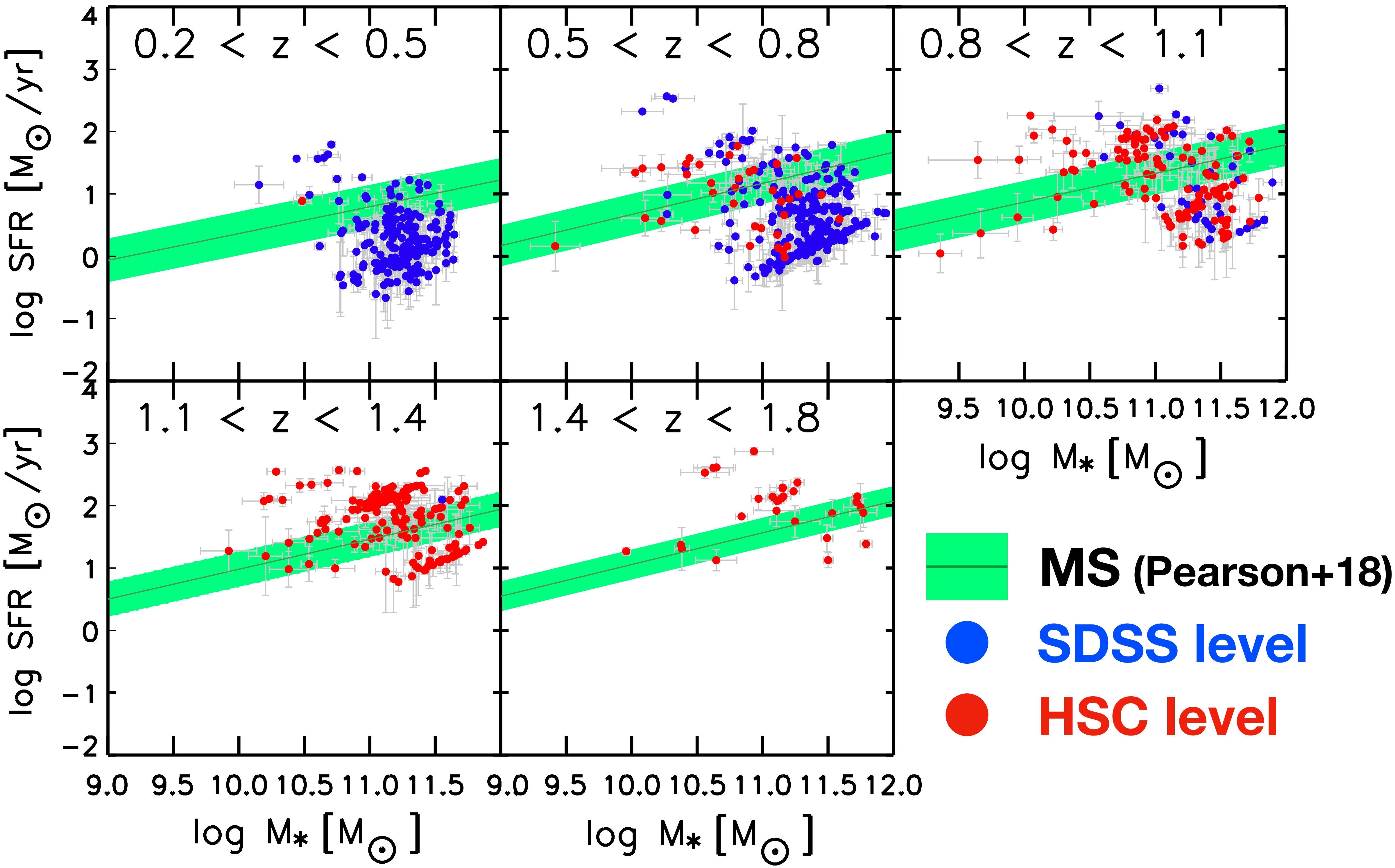

imag [AB mag]
18.0
20.0
22.0
24.0
SDSS level
HSC level
log LIR [L⊙]
14
13
12
11
10
0.0
0.5
1.0
1.5
redshift
0
50
100
150
200
250
count

z vs. L_{IR}

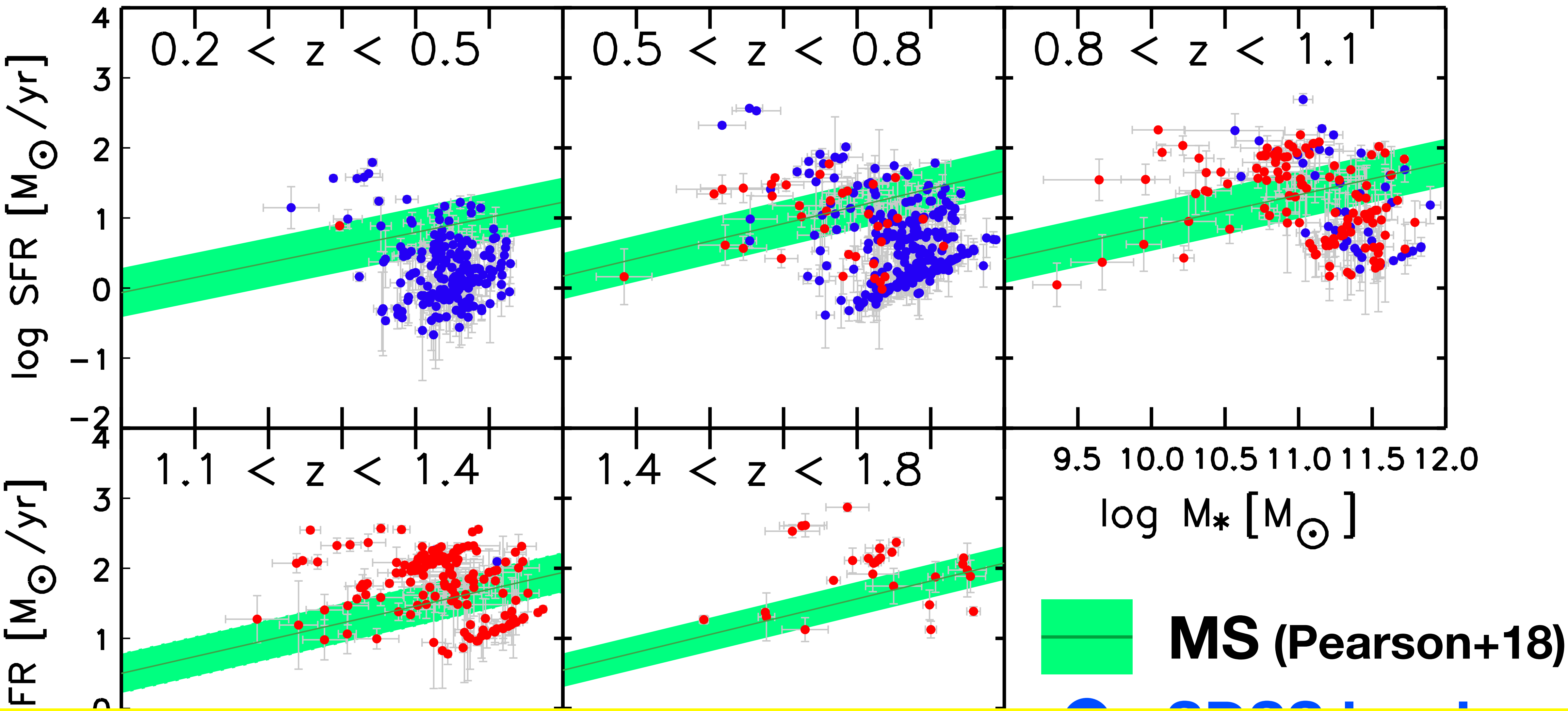


HSC-level RGs have large IR luminosity

$M_{stellar}$ vs. SFR as a function of redshift



$M_{stellar}$ vs. SFR as a function of redshift

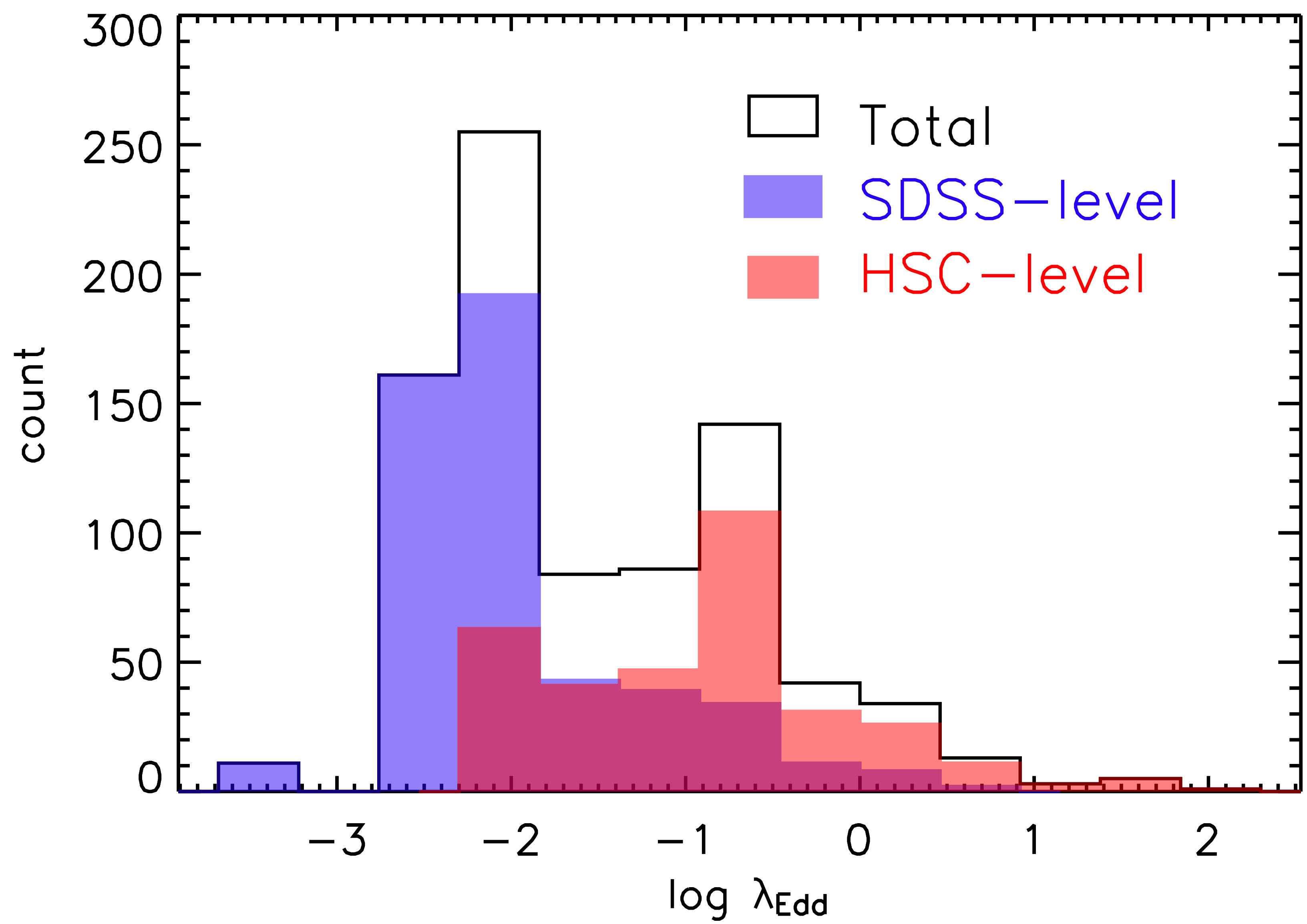


Our RG sample contains classical passive, MS, and starburst galaxies

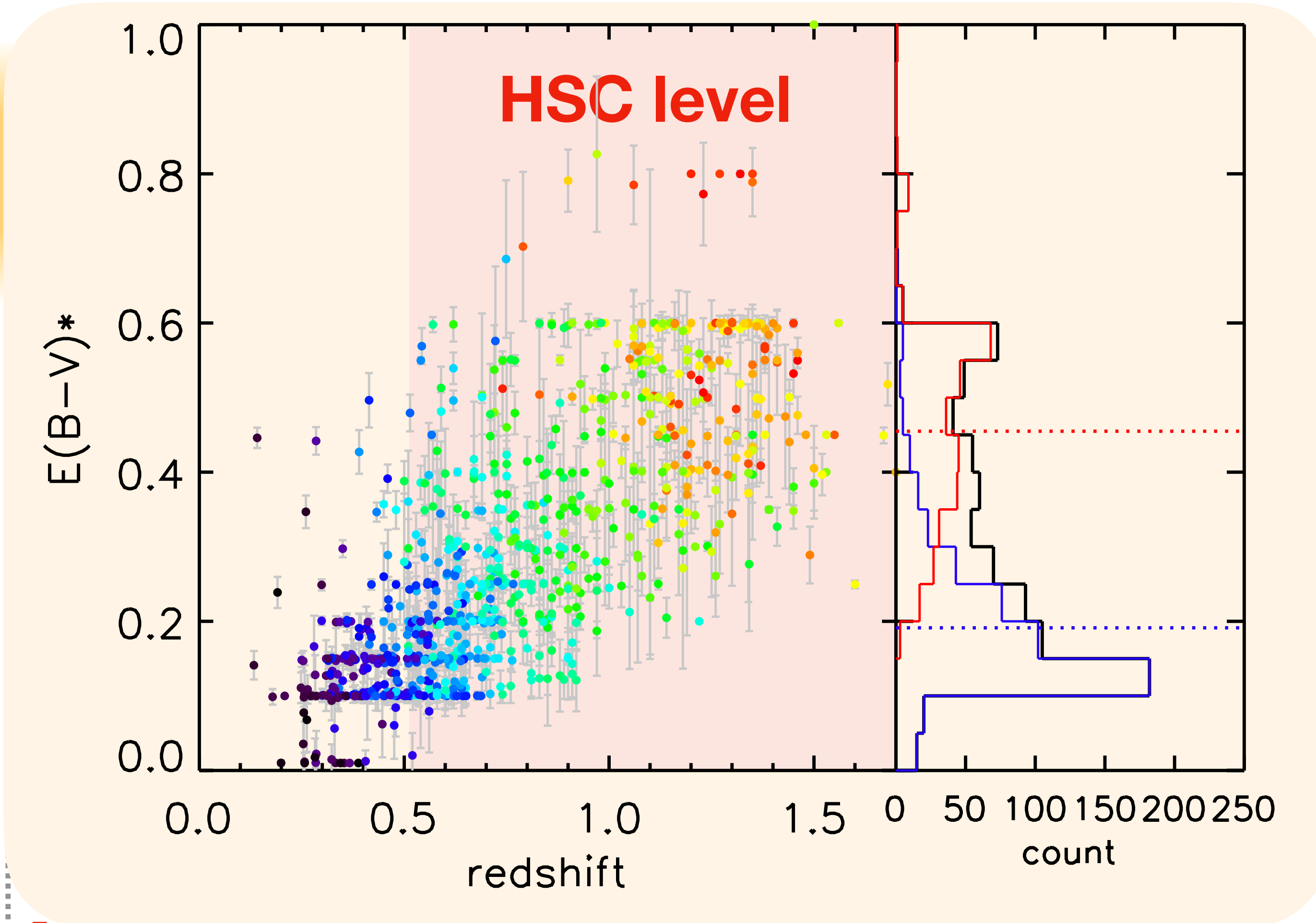
Eddington ratio ($\lambda_{Edd} = L_{bol}/L_{Edd}$)

Stellar mass
↓ (Reines & Volonter+15)
BH mass
↓
L_{Edd}

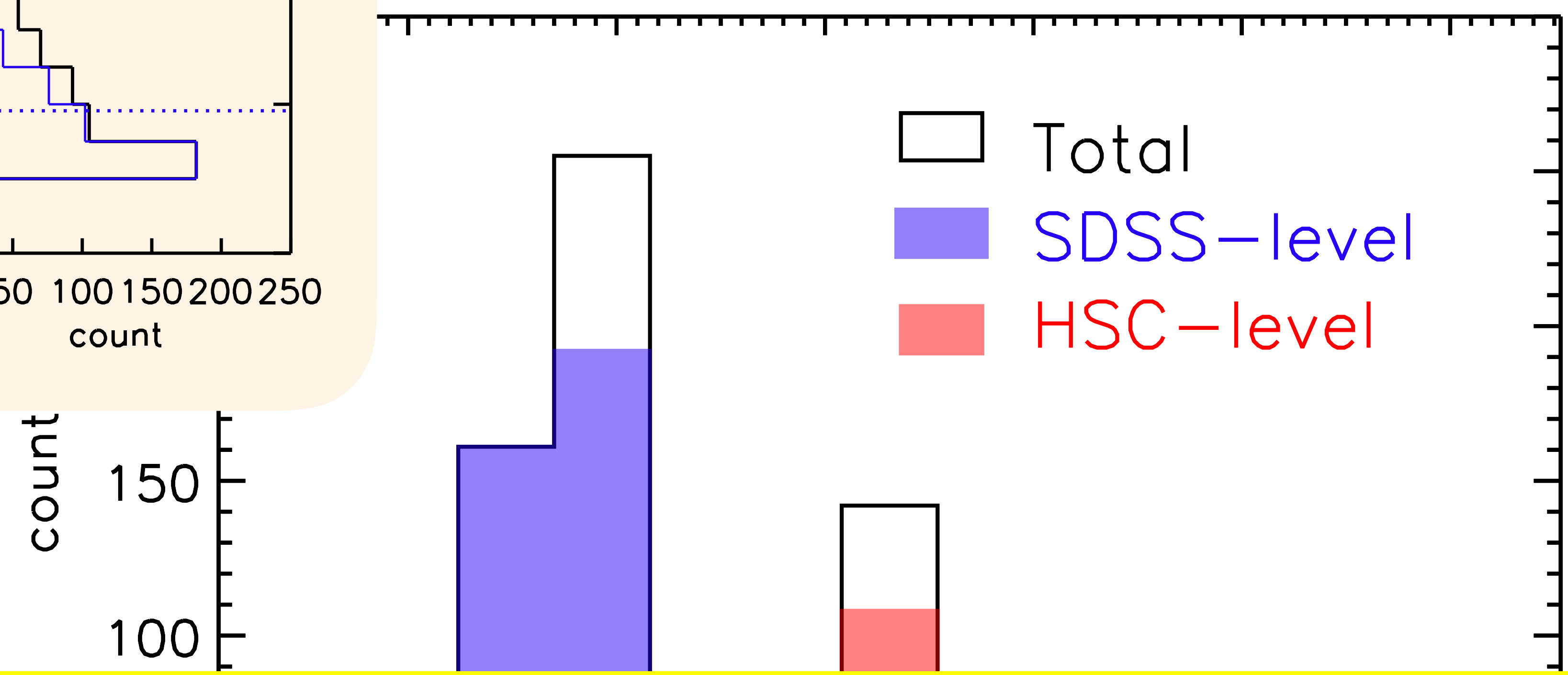
Integration of AGN SED
↓
L_{bol}



($\lambda_{Edd} = L_{bol}/L_{Edd}$)



L_{Edd}



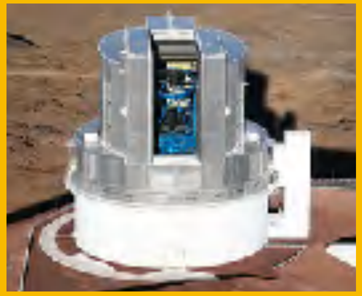
Some HSC–level RGs would harbor actively growing black holes behind a large amount of dust

Summary

Optically-faint radio galaxies discovered by the HSC and FIRST are

- **Dusty**
- **Less massive**
- **High SFR**
- **High λEdd**

	SDSS level ($i_{AB} < 21.3$)	HSC level ($i_{AB} \geq 21.3$)
$E(B-V)_*$	0.2	0.5
$\log M_*$	11.3	11.1
log SFR	0.6	1.5
log LIR	11.3	12.1
λEdd	-2.0	-0.9




Radio galaxy catalog (R.A, Decl., multi-band photometry, M*, SFR, LIR etc.)

Best-fit SED template for each RG

↓

Publicly available now!
Catalog is [here]
Best-fit SEDs are [here]