# Galaxy studies at z<2 with HSC

1 – How do we 'understand' the galaxy evolution

2 – Low/Medium-z galaxy science case

3 – Photometric redshifts

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# *1 – Understanding the galaxy evolution*

# How do we 'understand' the galaxy evolution

Dark Energy : e.g., measure 'w' in the equation of state.

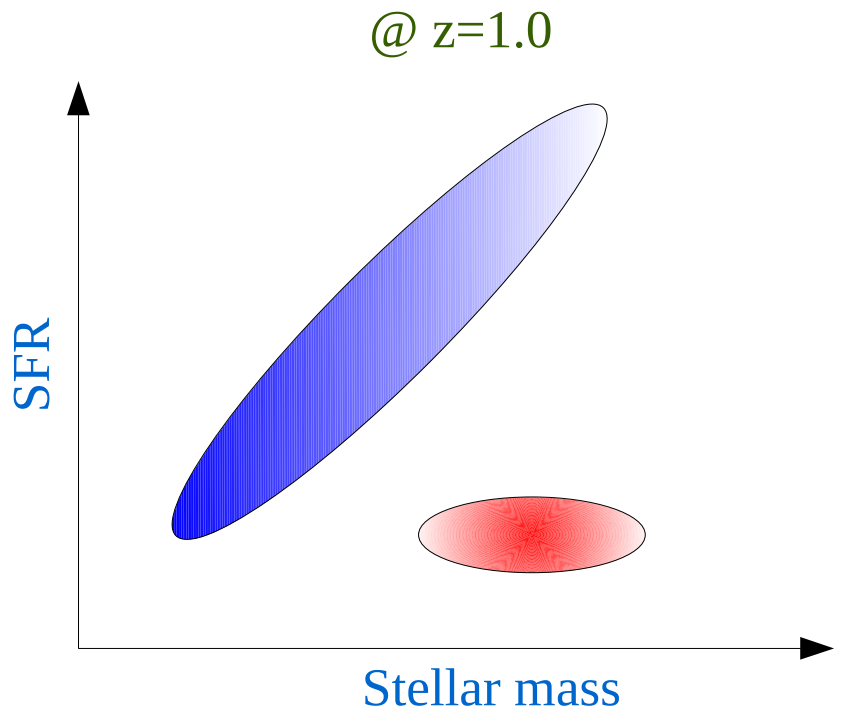
Reionization : measure the ionized fraction.

Galaxy evolution : what should we measure?
Luminosity/Stellar mass function, SFR, morphology, size, AGN fraction as functions of environment and time? We can measure those, but at what point can we say “yes, we now understand the galaxy evolution.”?

This 'understanding' comes in two phases :
1 – we just empirically know how galaxies evolve. ← HSC+PFS
2 – we know what physics is driving the evolution. ← PFS+external data

# Galaxies in multivariate space

Imagine a multivariate space $\phi(M^*, SFR, z)$. This is a volume density of galaxies as functions of M*, SFR, and redshift.



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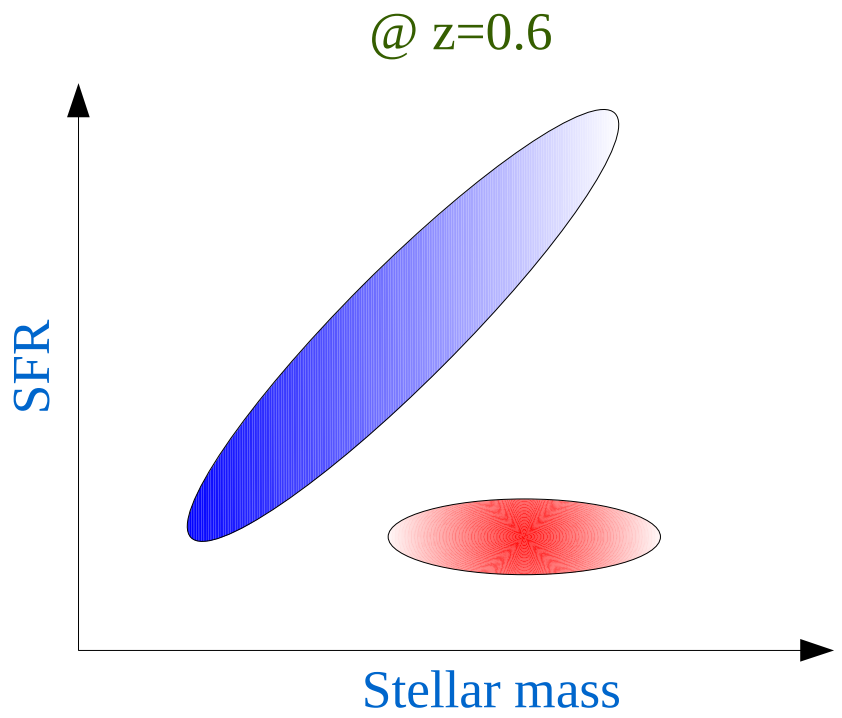

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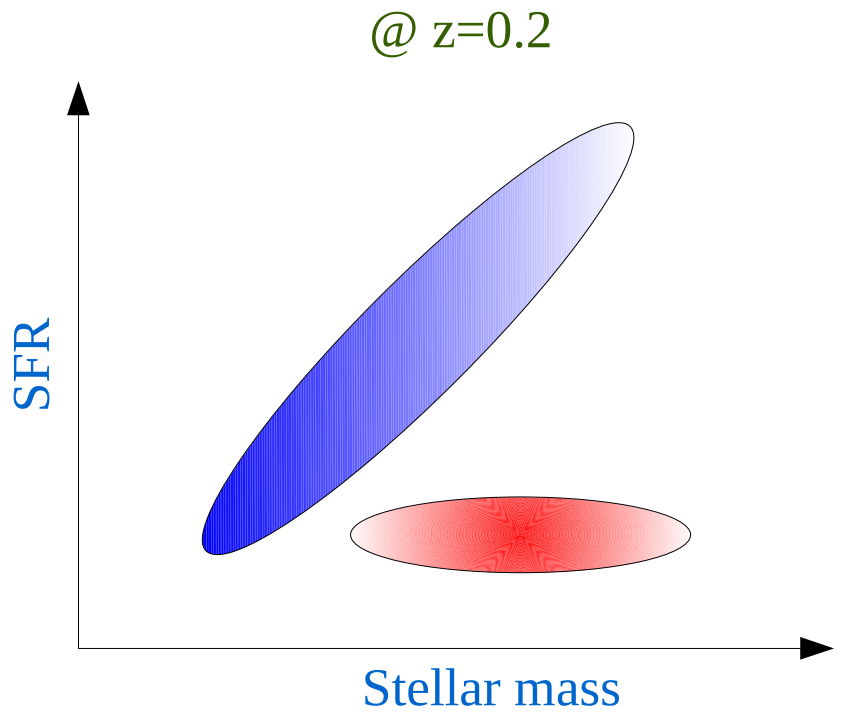
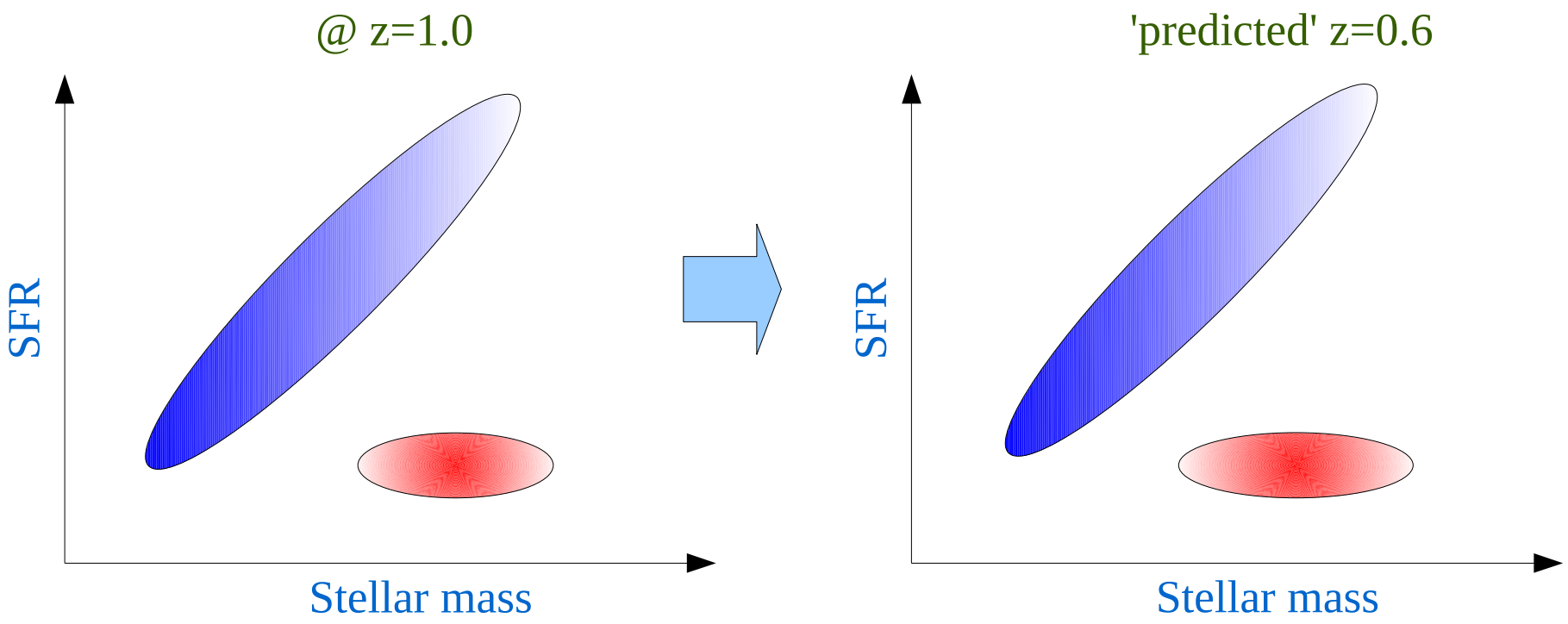


# Continuity equation

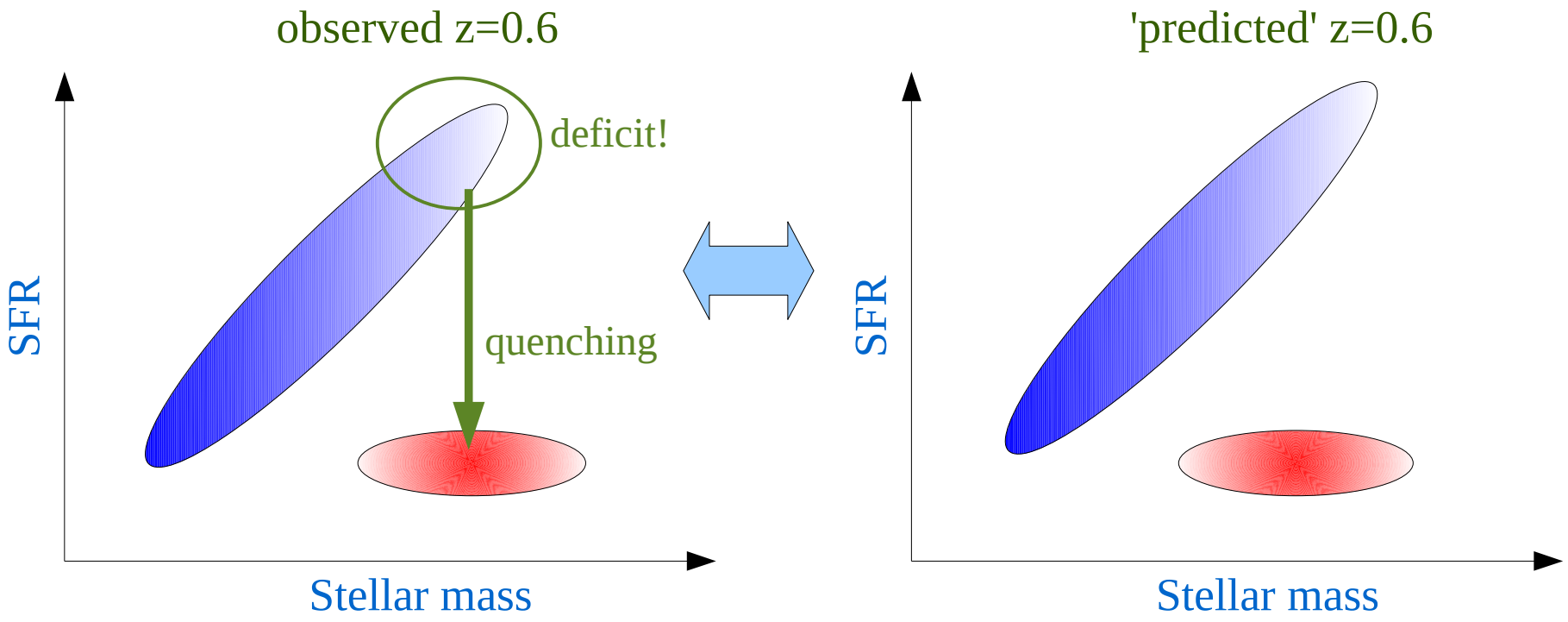
Now evolve the z=1.0 relation down to z=0.6 using the continuity equation.




$$\frac{d}{dz}M^*(z) = SFR(M^*, z) - M^*_{loss}(M^*, z) + M^*_{merger}(M^*, z)$$

# Time derivative of the multivariate space

Then compare the 'predicted' and the observed relations.
Can we describe the observed change with the continuity equation?



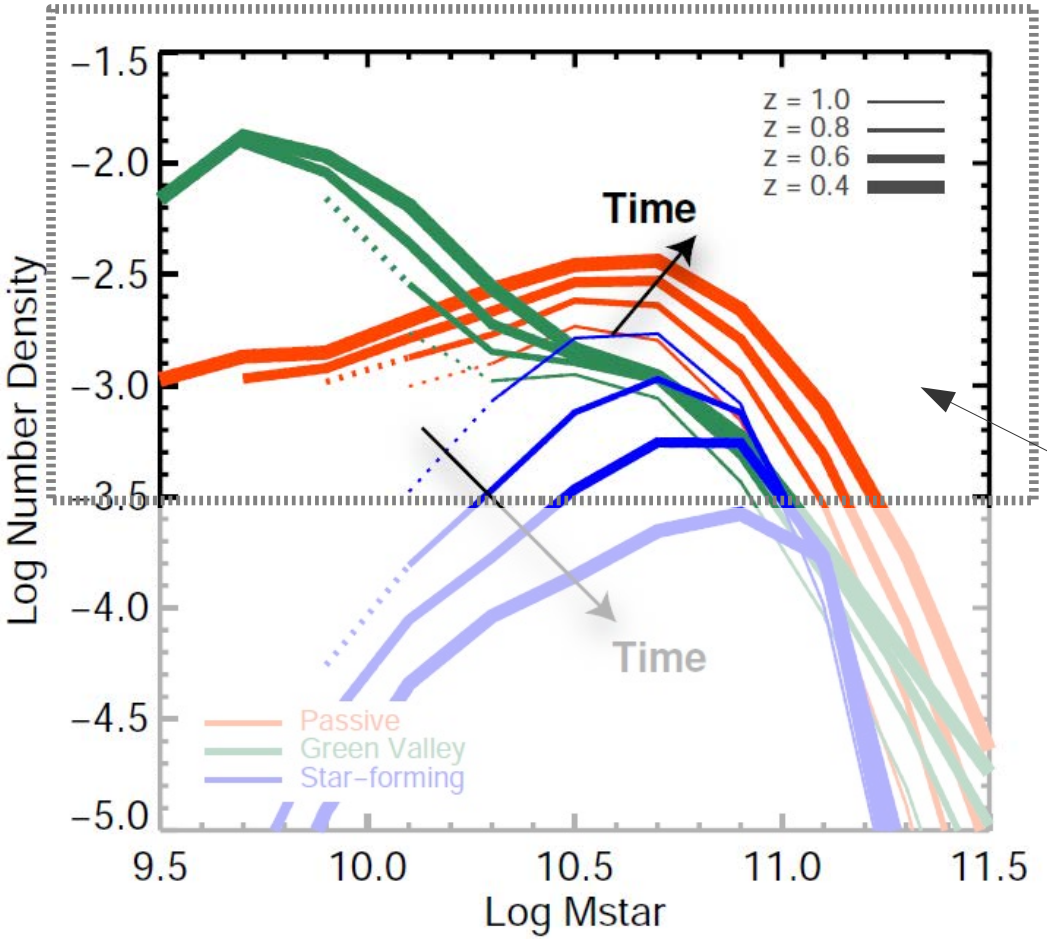

$$\frac{d}{dz}M^*(z) = Q(M^*,z)\cdot SFR(M^*,z) - M^*_{loss}(M^*,z) + M^*_{merger}(M^*,z)$$

# Galaxy studies with HSC

- My personal view is that the goal is to describe the observed $\phi(M^*, SFR, z)$ with a set of (partially empirically motivated) simple continuity equations.

# *2 – Low/Medium-z science case*

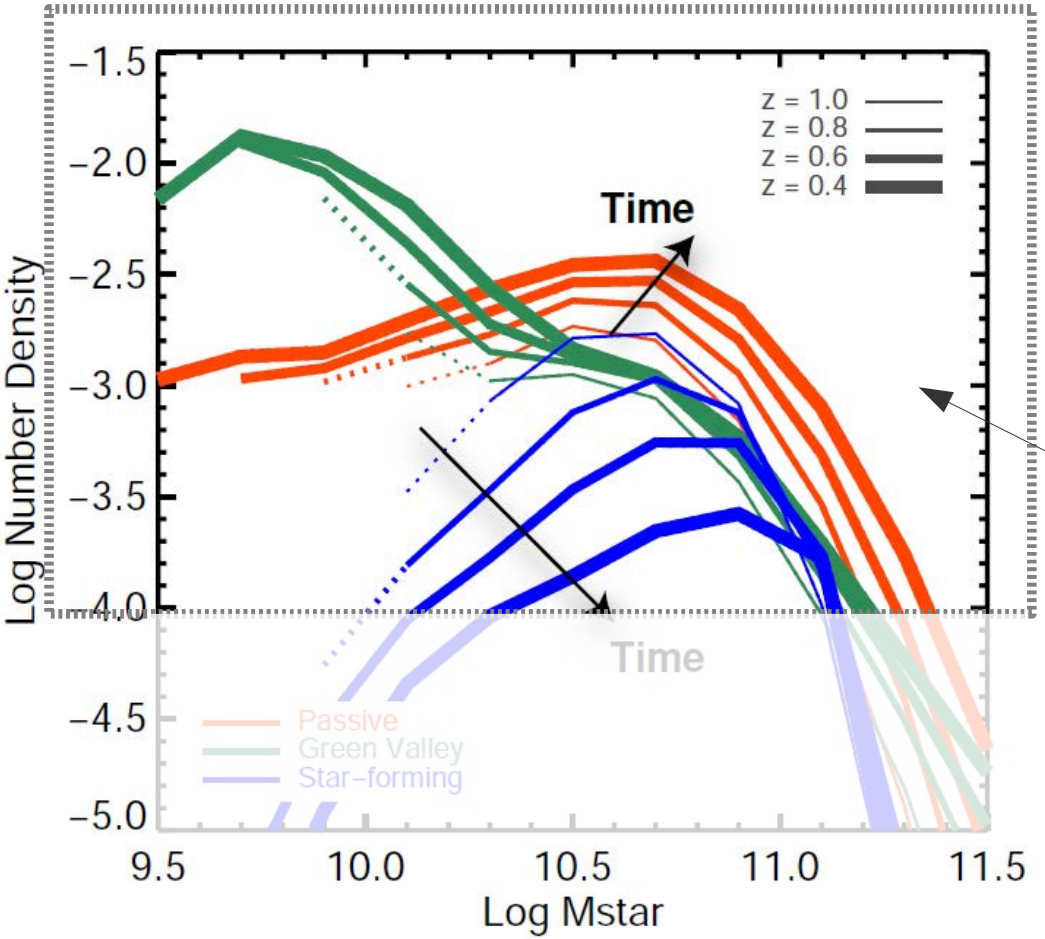
# Science case 1a : stellar mass function




HSC-Wide

*From the galaxy evolution section of the SSP proposal*

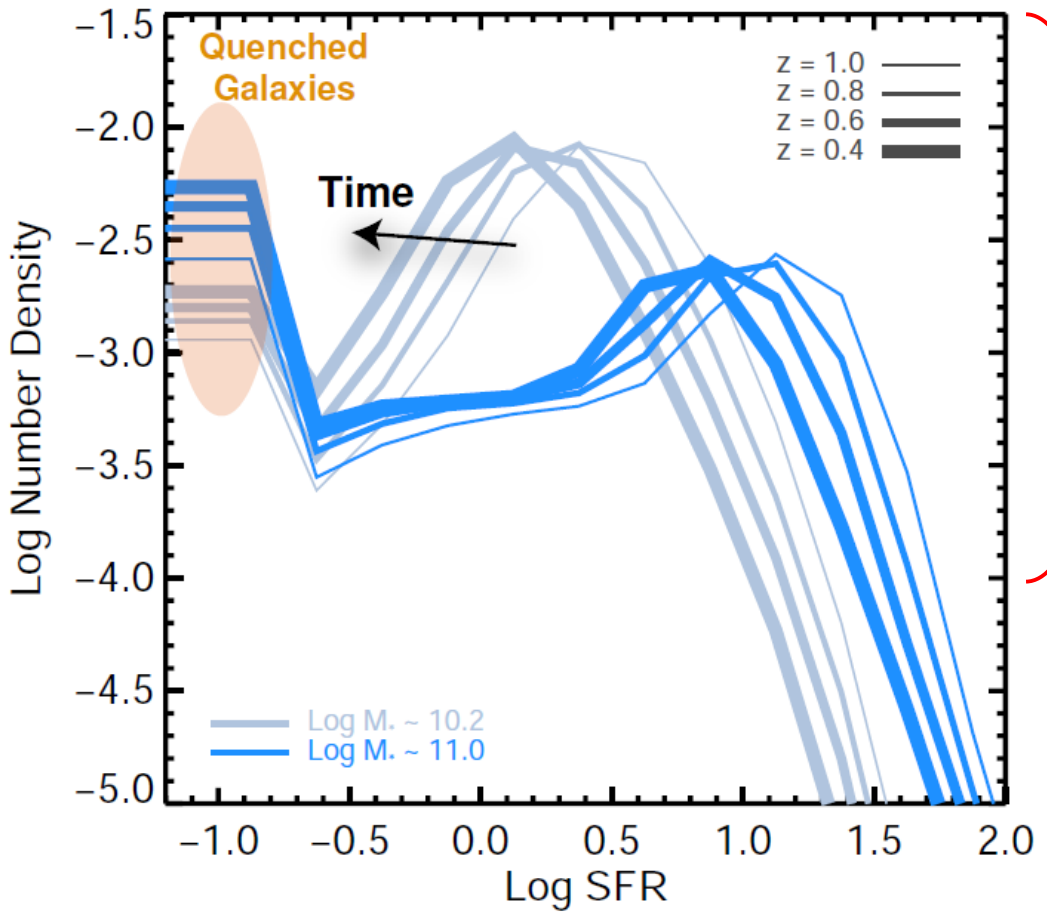
# Science case 1a : stellar mass function




HSC-Deep
up to z~2

*From the galaxy evolution section of the SSP proposal*

# Science case 1b : SFR function




HSC-Wide

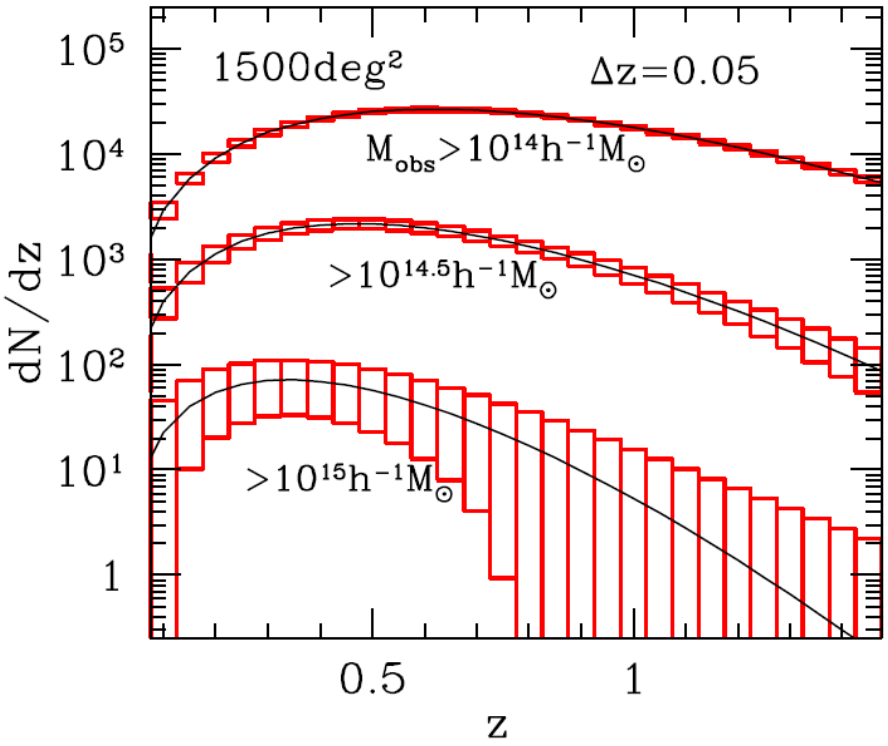
HSC-Deep up to z~2

We could include size and morphology parameter in the multivariate space.

*From the galaxy evolution section of the SSP proposal*

# Science case 2 : cluster science

Oguri & Takada 2011




Lots of groups and clusters for statistical studies! We would be able to get redshifts for a good fraction of z<0.8 clusters from the BOSS survey. A short list of science ideas include:

– include environment parameter in the continuity equation.

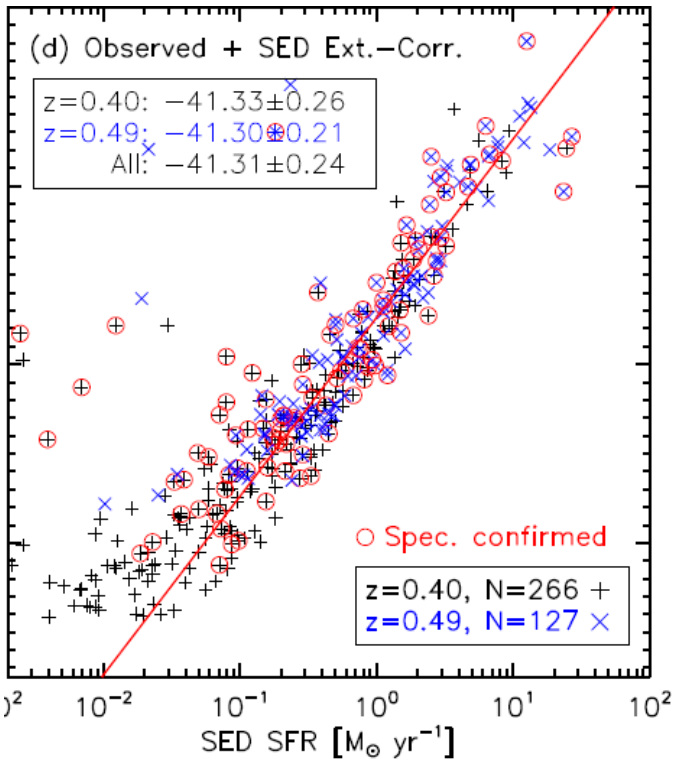
– study BCG evolution as functions of redshift and cluster mass.

– look for lensed (high-z) objects.

– do (stacked) weak-lensing anlaysis.

– study intra-cluster light (via stacking)???

# Science case 3 : emission line galaxies




Ly et al. arXiv 1202:0278

NB387 : [OII] emitters at z=0.04

NB527 : [OII] emitters at z=0.41

NB718 : Ha emitters at z=0.09, [OII] emitters at z=0.93

NB816 : Ha emitters at z=0.24, [OII] emitters at z=1.19

NB921 : Ha emitters at z=0.40, [OII] emitters at z=1.47

NB101 : Ha emitters at z=0.54, [OII] emitters at z=1.70

NB objects are useful to

1 – quatify SFR function

2 – calibrate SFRs from SED fits

3 – identify AGNs???

# Science case 4 : misc.

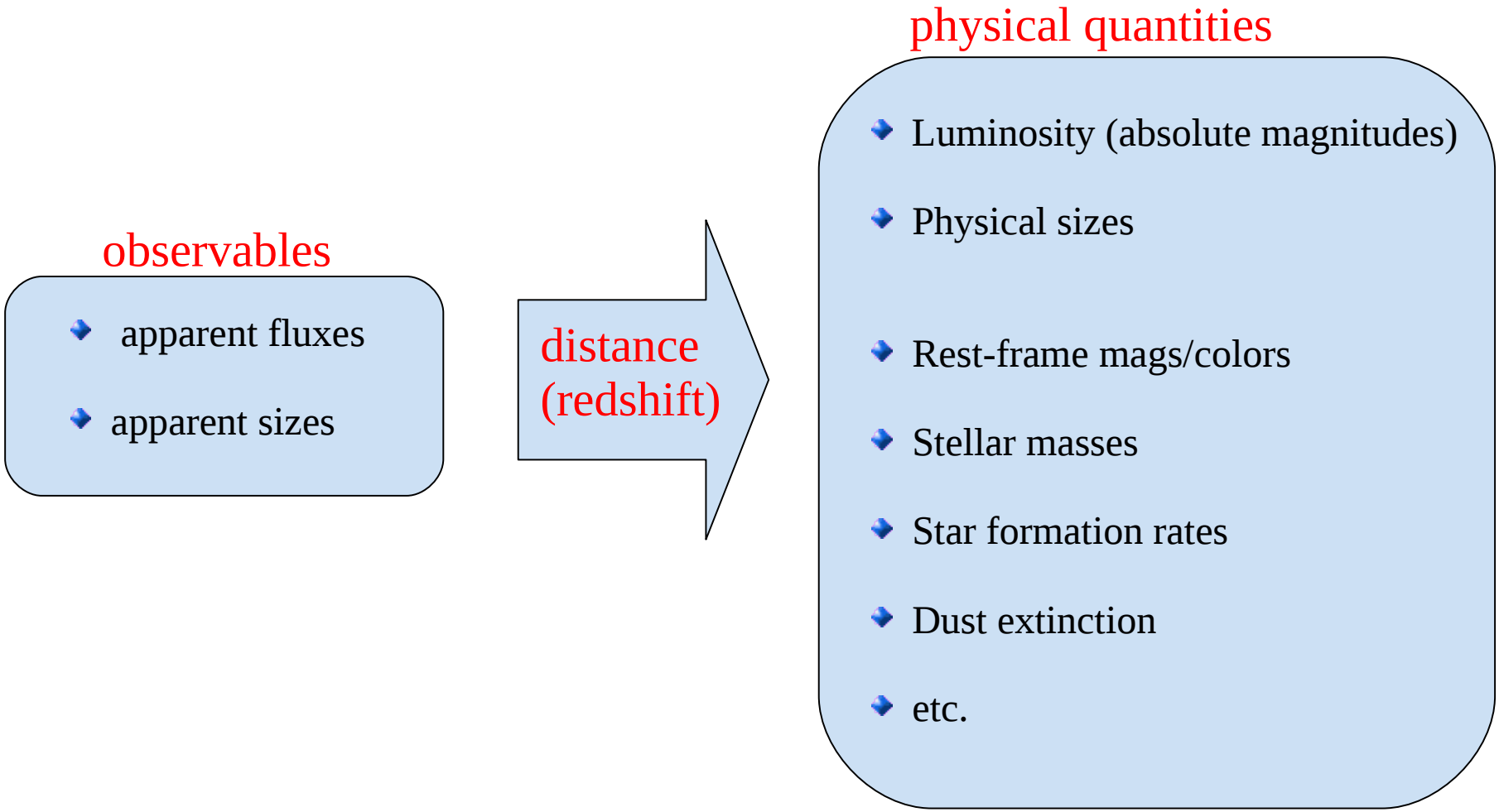
A lot more can be done with HSC + PFS!

How well can we do the science suggested here?

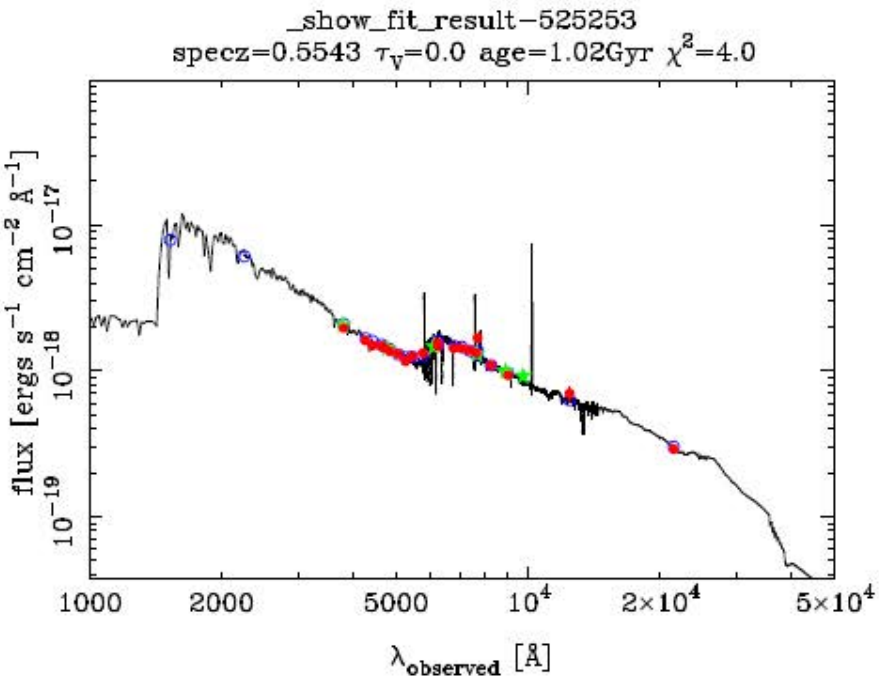
Note photo-z is not part of the photometric pipeline.
Apologies for the mess in the email list...

## *3 – Photometric Redshifts*

# Why do we need (photometric) redshifts?



# HSC photo-z simulation




- Observed photometry
- Model photometry
- HSC photometry

1 – collect public medium/broad- band photometry in COSMOS

2 – collect public/private spec-z's

3 – supplement the spec-z's with 30-band photo-z's

4 – fit SEDs of objects with i<25

5 – convolve the best-fit SED with the HSC filters to derive synthetic mags

6 – perturb the photometry and assign mag_err to each object according to the mag limits.

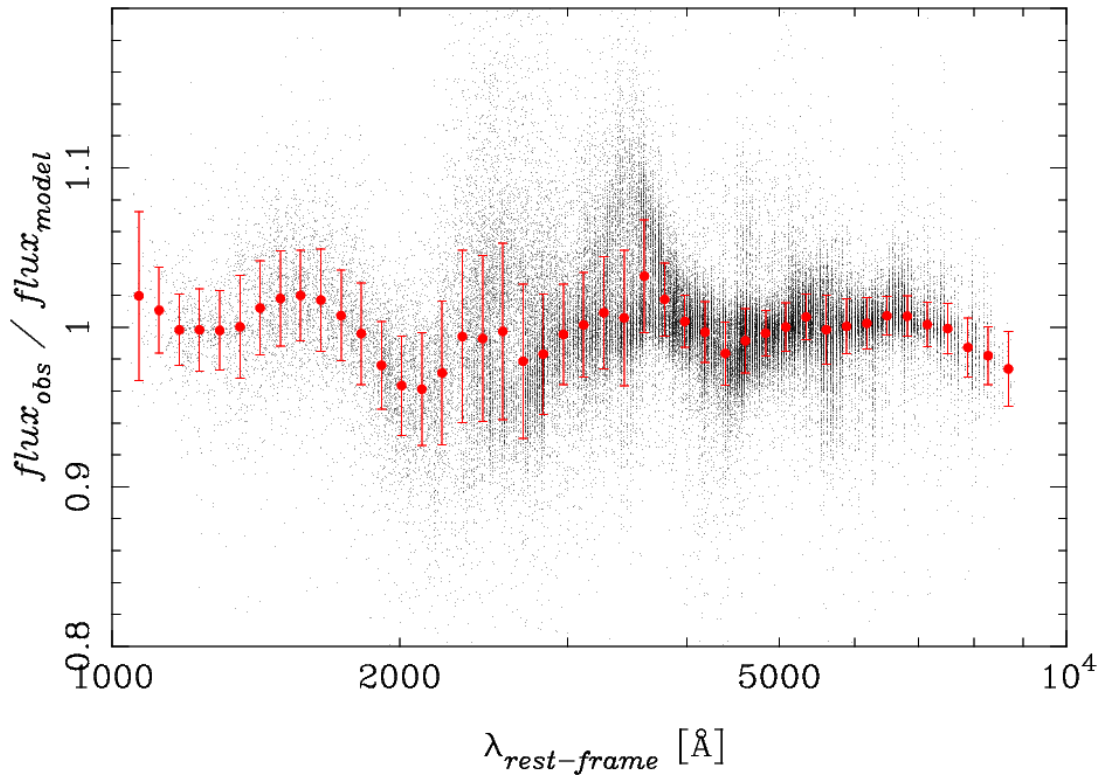
# Private photo-z code by Tanaka

- **Based on Charlot & Bruzual 2007 population synthesis models.**
  - Solar metallicity models only
  - Calzetti attenuation law
  - Chabrier IMF
  - Emission lines included (Inoue et al. 2011)
  - *Thermal emission from dust is not included yet*
  - Assumed exponentially decaying SFRs (tau=0 to infinity)
  - Attenuation due to neutral H (Madau+ '96)
  - Template error function included

- **Baysian priors on physical properties**
  - N(z) prior
  - Extinction vs SFR prior
  - SFR vs stellar mass prior
  - *Size prior is yet to be included*
  - *Morphology prior is yet to be included*

This is for HSC-Wide. Some of the physical priors will be disabled for HSC-Deep.

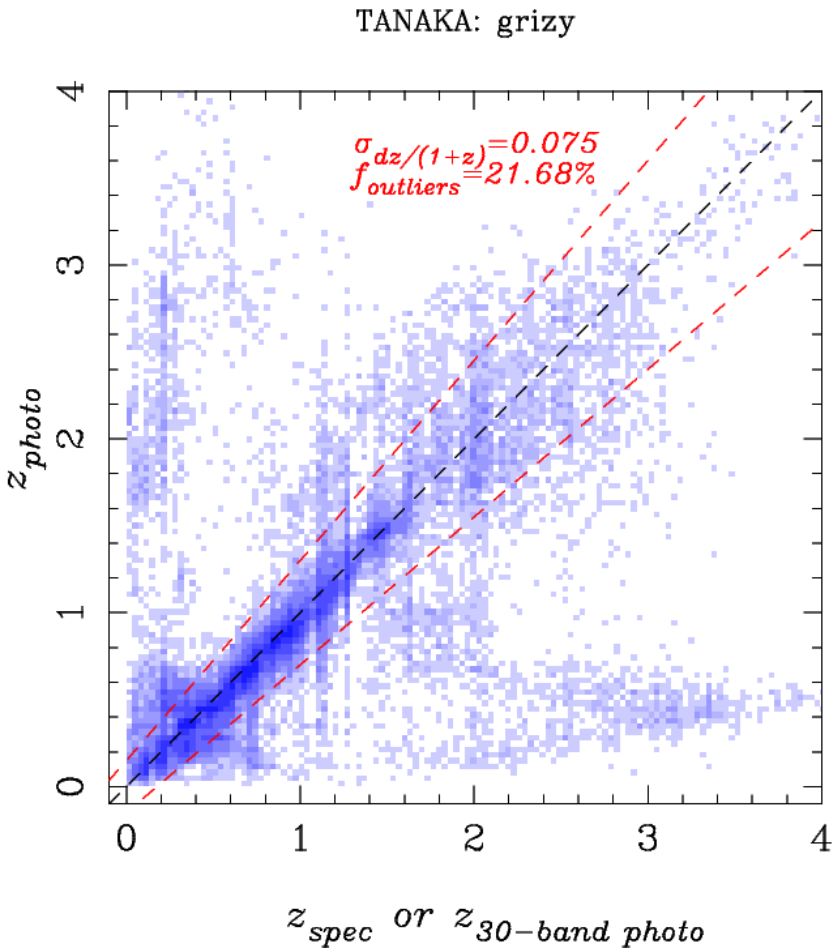
# Template error function

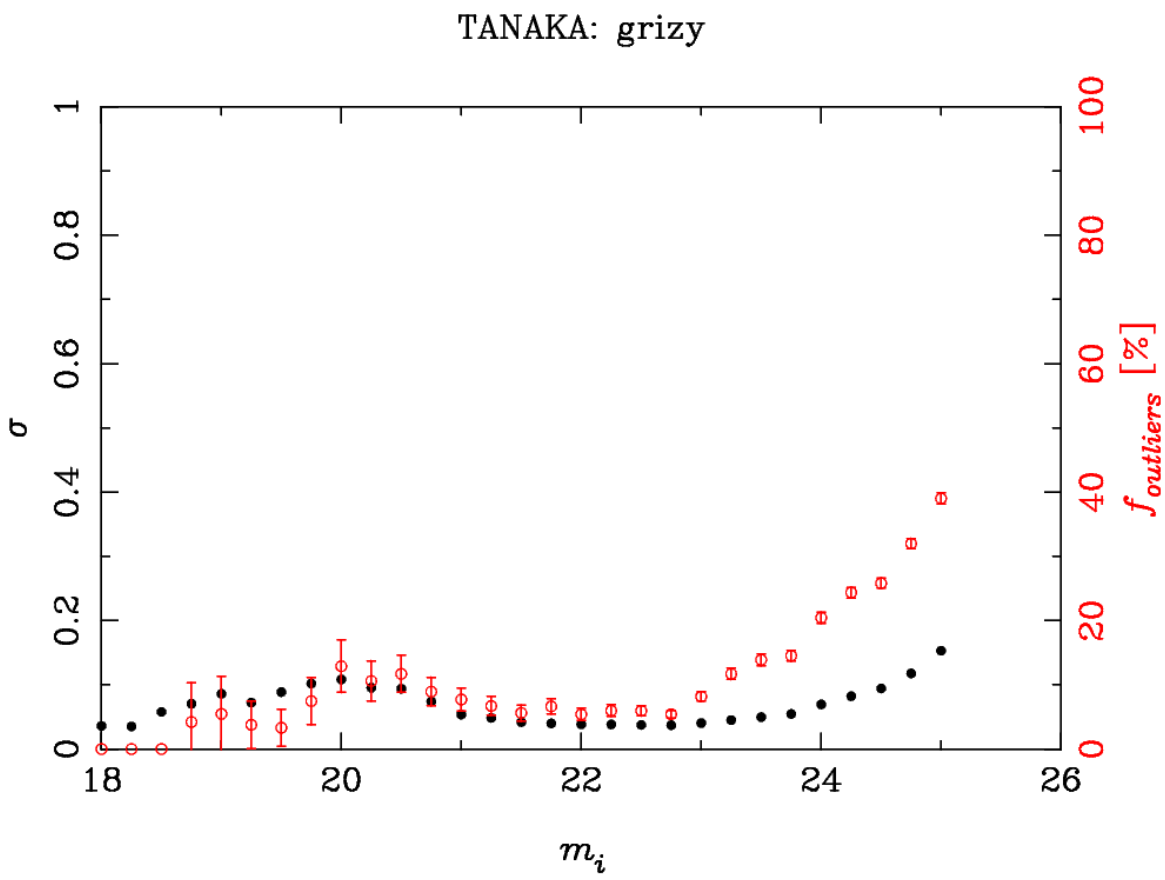



Model templates are never perfect and there is always a mismatch between templates and observed SEDs. A 'master' template error function reduces such a mismatch and properly weights each photometric data point.

This is just a snapshot of the 'expected' HSC photo-z's.

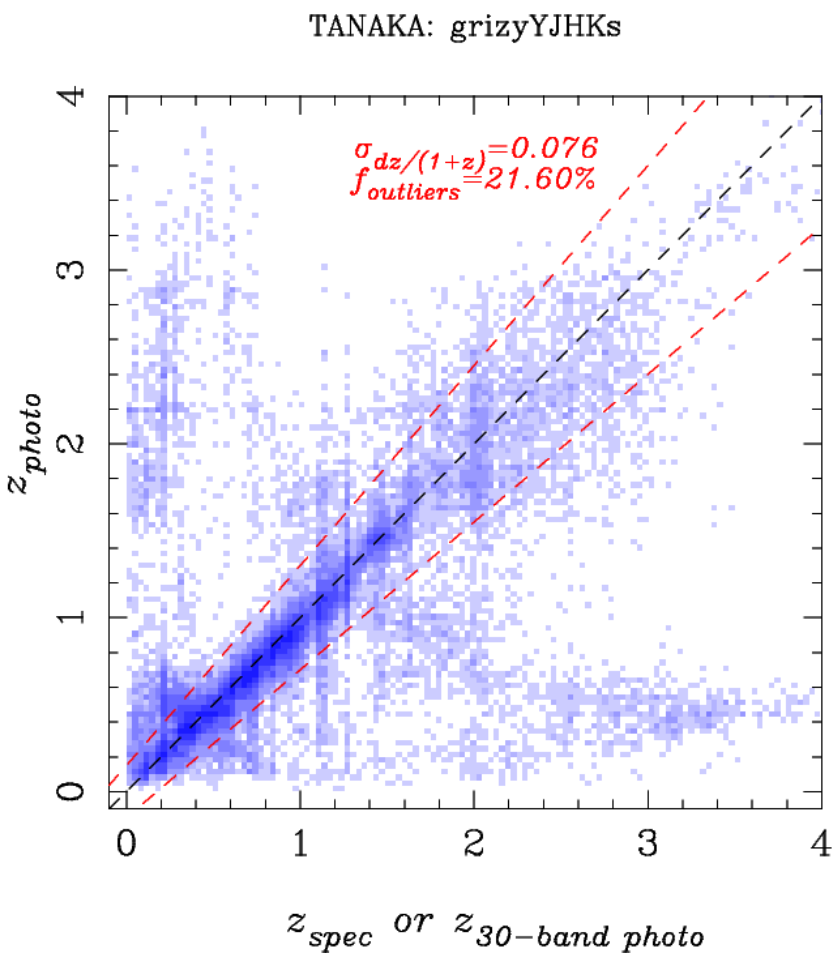
# HSC-Wide only

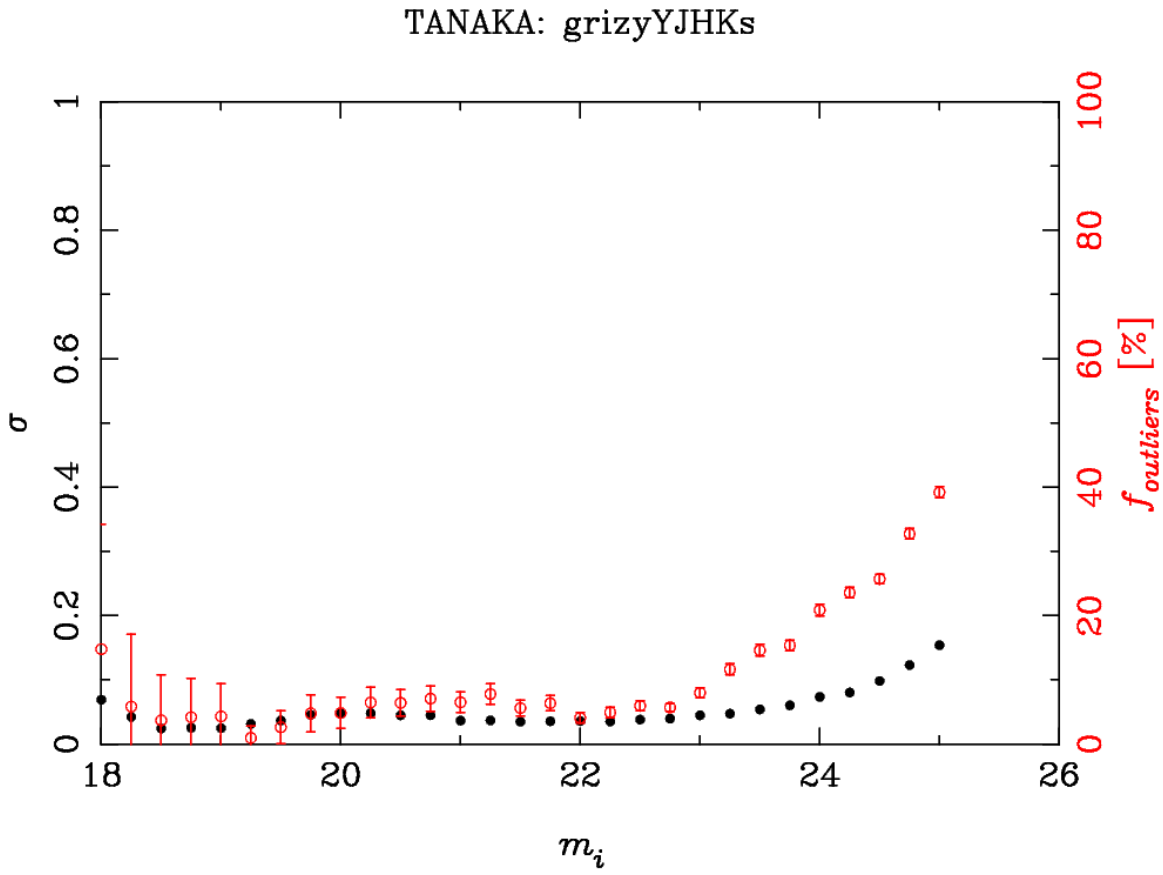



| Wide | Band | $g$ | $r$ | $i$ | $z$ | $y$ |
|---|---|---|---|---|---|---|
| | Depth | 26.7 | 26.2 | 26.0 | *25.2* | *24.4* |

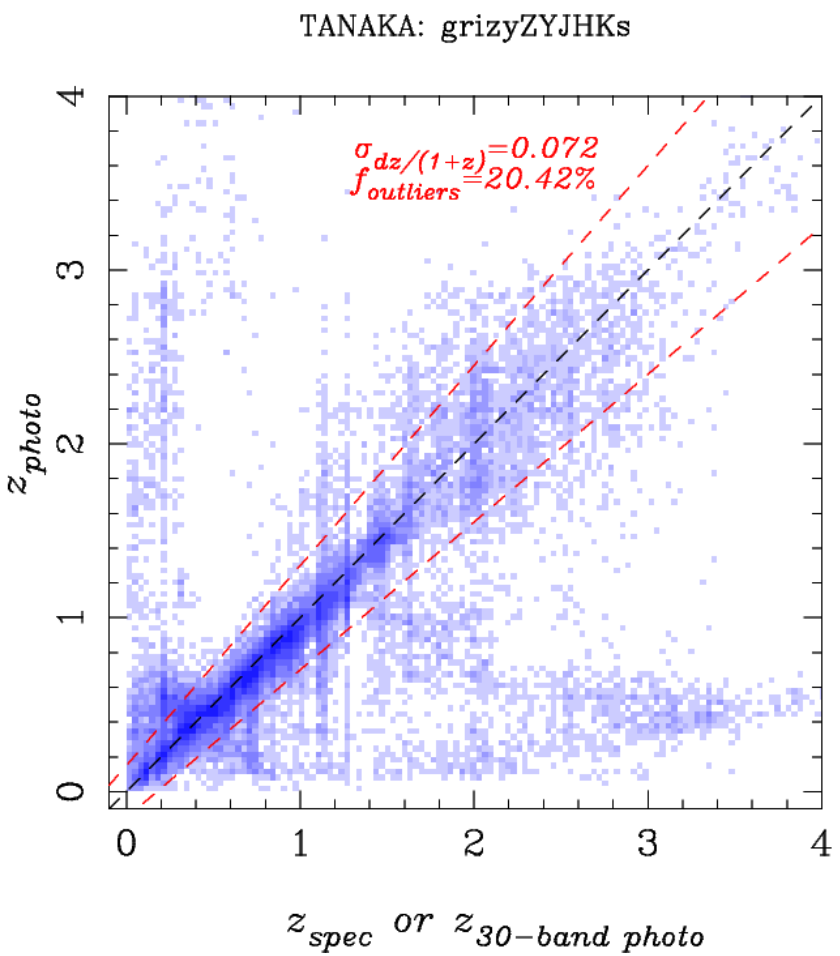
# HSC-Wide + UKIDSS-LAS

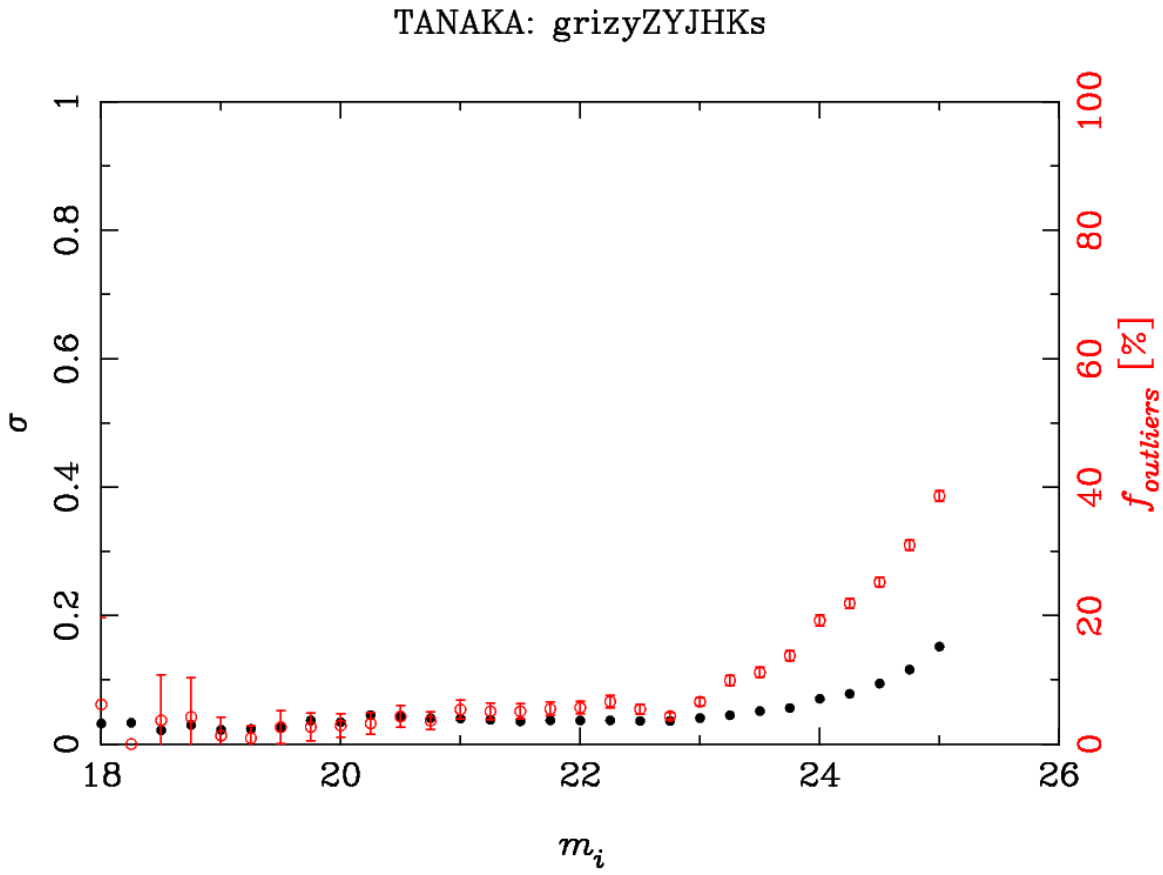



| Wide + LAS | Band | $g$ | $r$ | $i$ | $z$ | $y$ | $Y$ | $J$ | $H$ | $K_s$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | Depth | 26.7 | 26.2 | 26.0 | *25.2* | *24.4* | *20.8* | 20.5 | *20.2* | 20.1 |

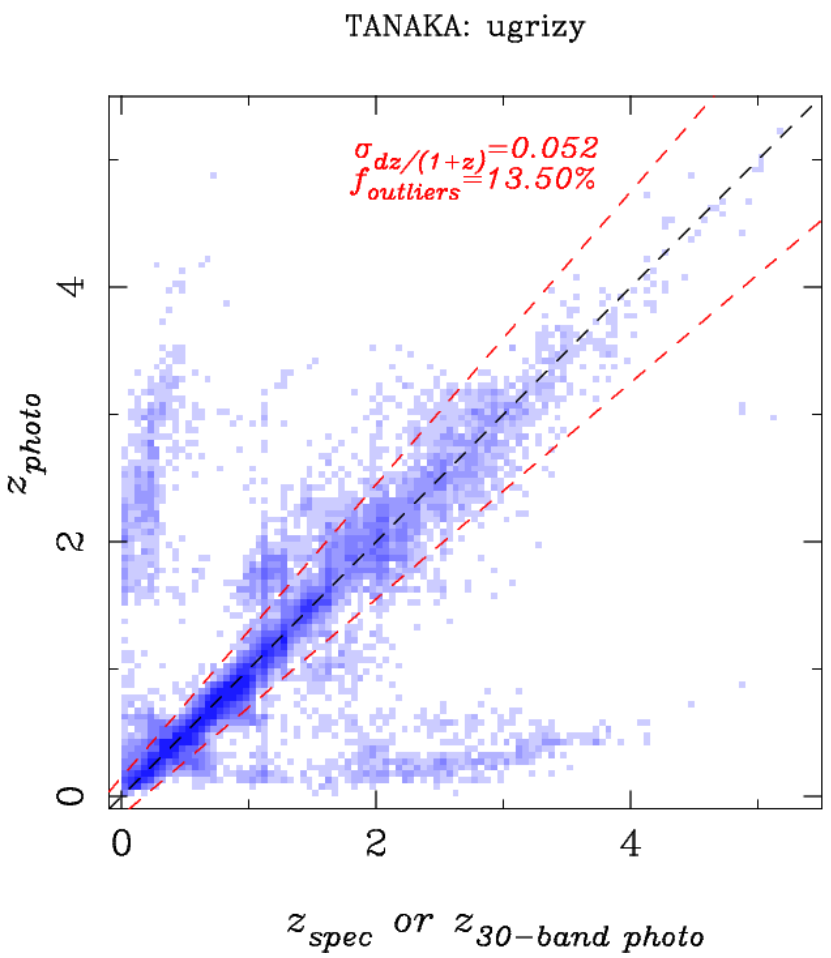
# HSC-Wide + VISTA-VIKING

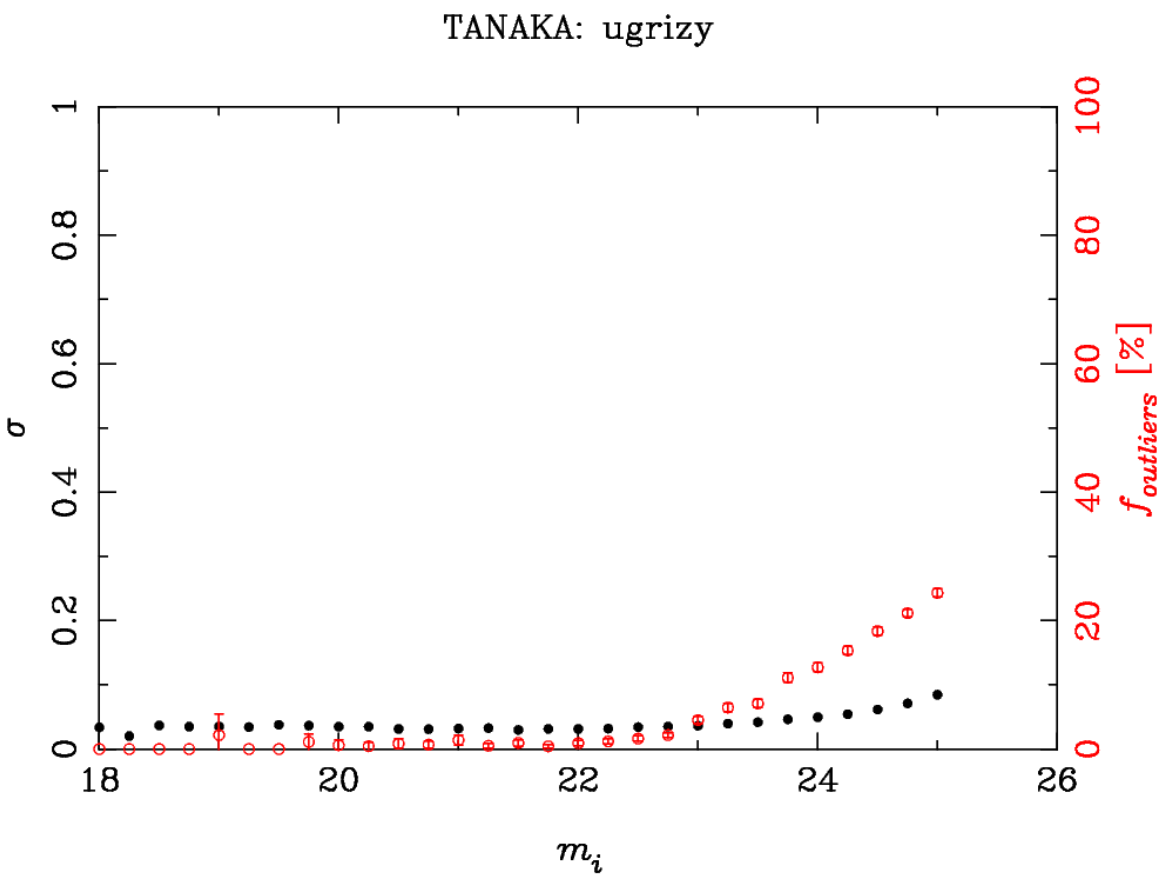



| Wide + VIKING | Band | $g$ | $r$ | $i$ | $z$ | $y$ | $Z$ | $Y$ | $J$ | $H$ | $K_s$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Depth | 26.7 | 26.2 | 26.0 | *25.2* | *24.4* | *23.1* | *22.3* | 22.1 | *21.5* | 21.2 |

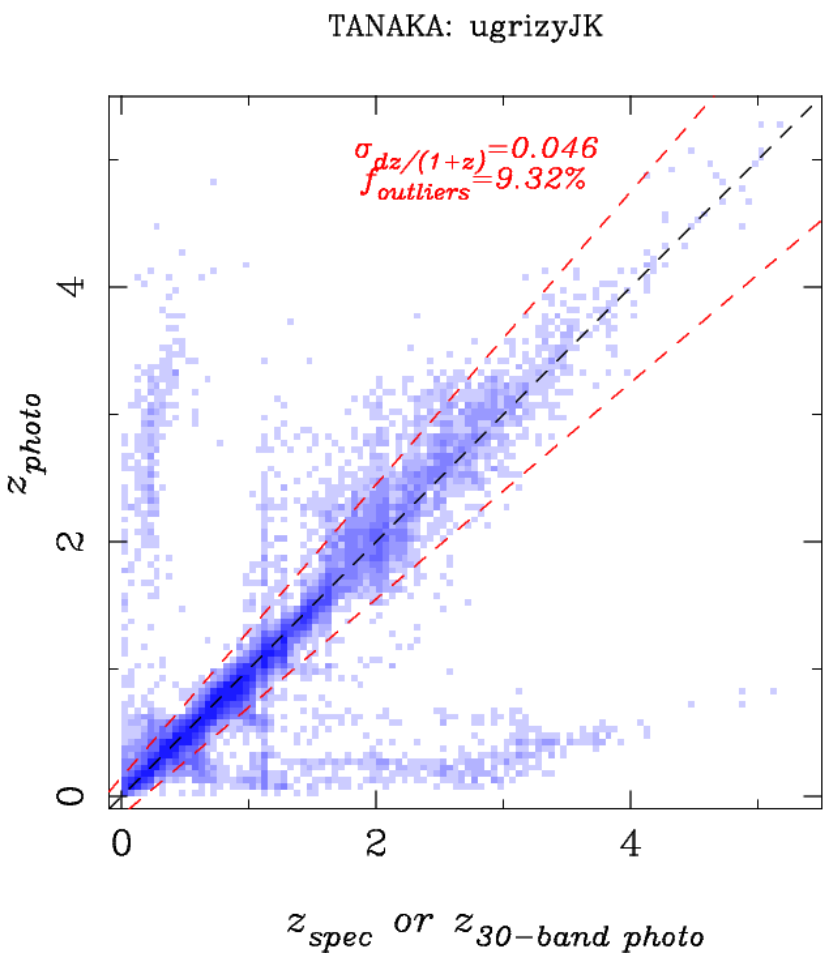
# HSC-Deep : COSMOS and DEEP2-F3

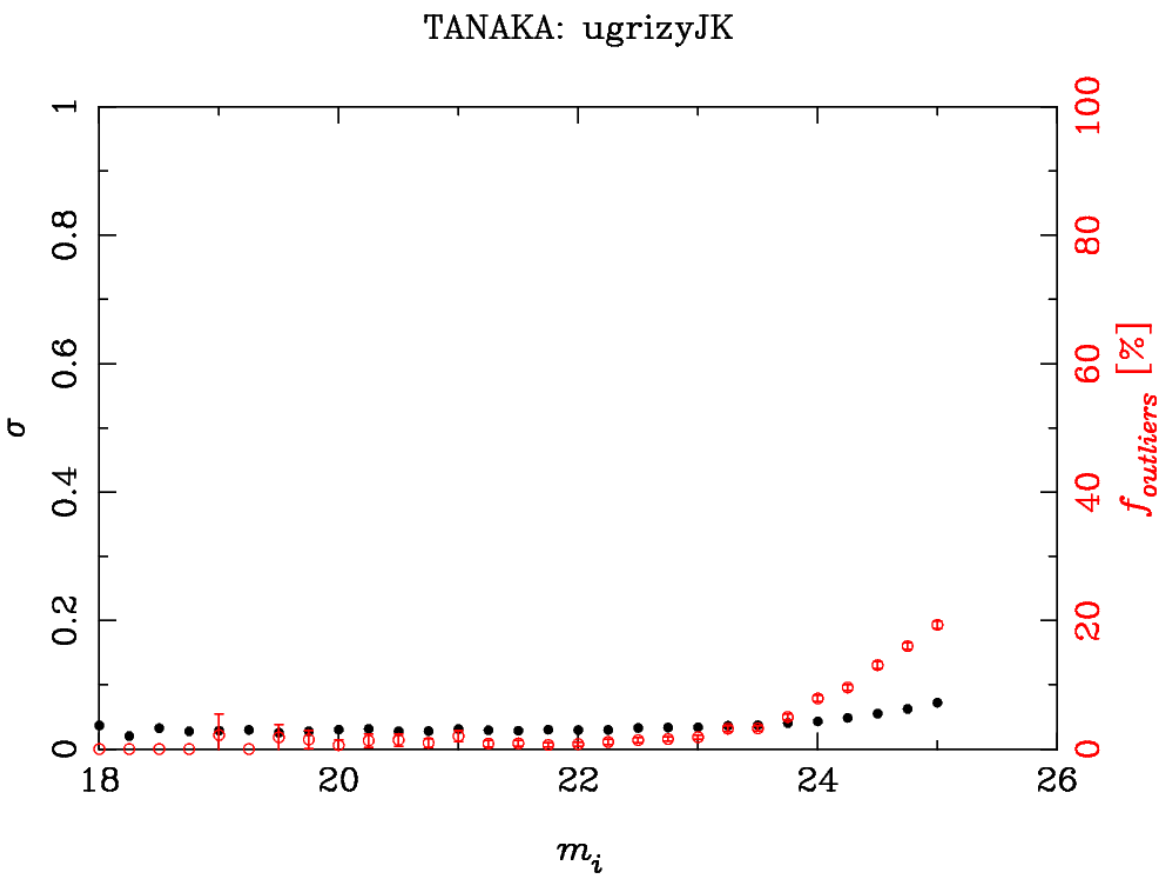



| DEEP2-F3 | Band | $u$ | $g$ | $r$ | $i$ | $z$ | $y$ |
|---|---|---|---|---|---|---|---|
| | Depth | 25.5 | 27.5 | 27.2 | 27.0 | 25.9 | 24.7 |

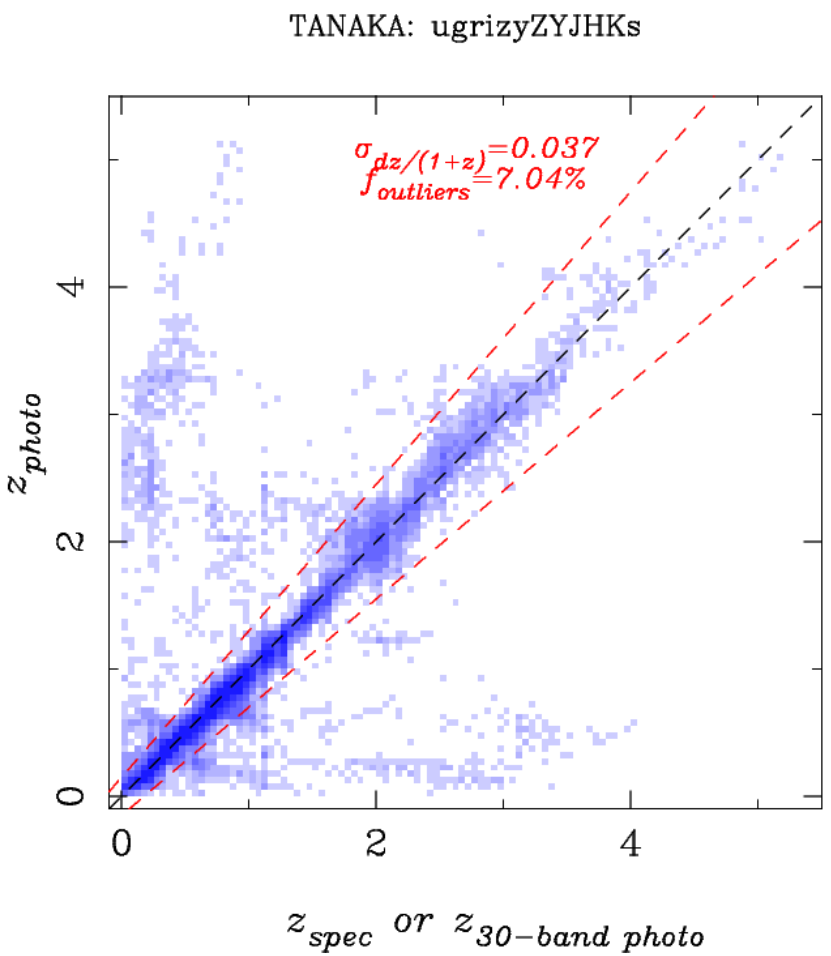
# HSC-Deep : ELAIS-N1

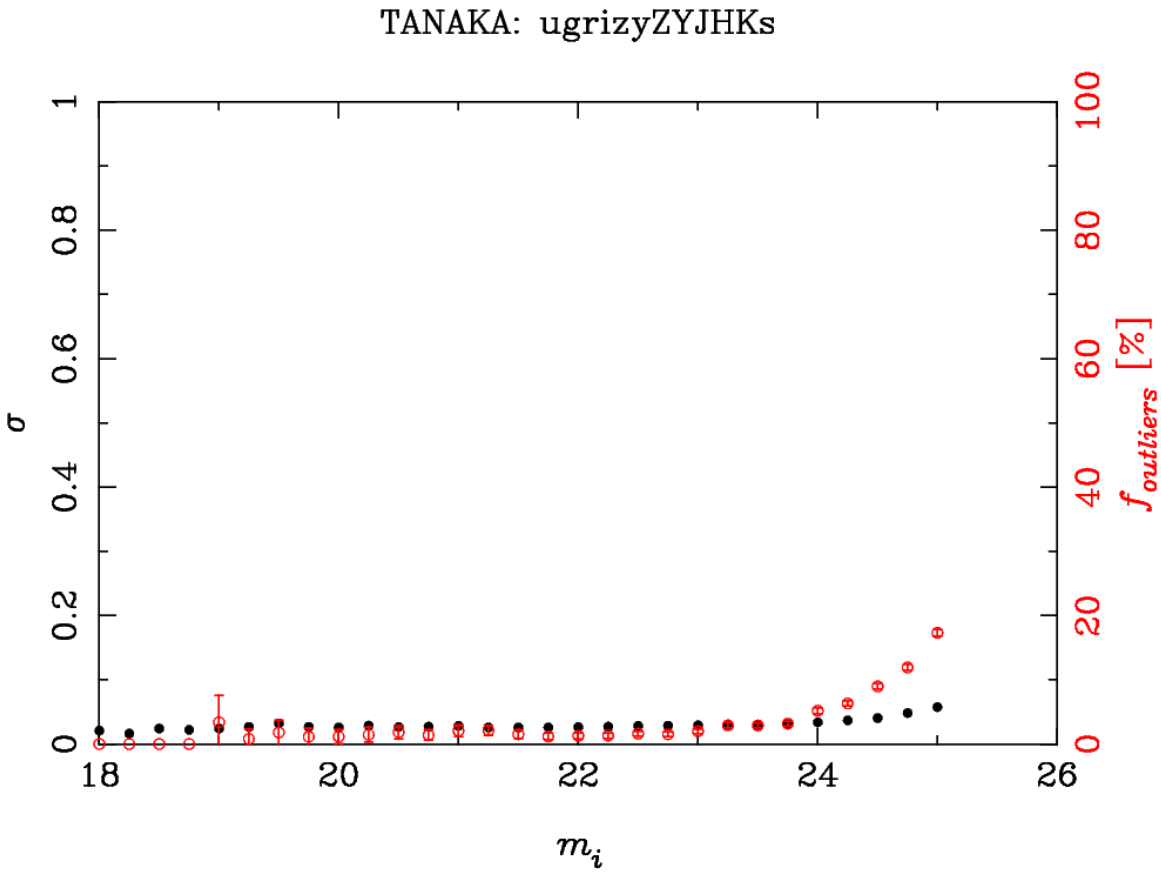



| ELIAS-N1 | Band | $u$ | $g$ | $r$ | $i$ | $z$ | $y$ | $J$ | $K$ |
|---|---|---|---|---|---|---|---|---|---|
| | Depth | 25.5 | 27.5 | 27.2 | 27.0 | 25.9 | 24.7 | 23.3 | 23.0 |

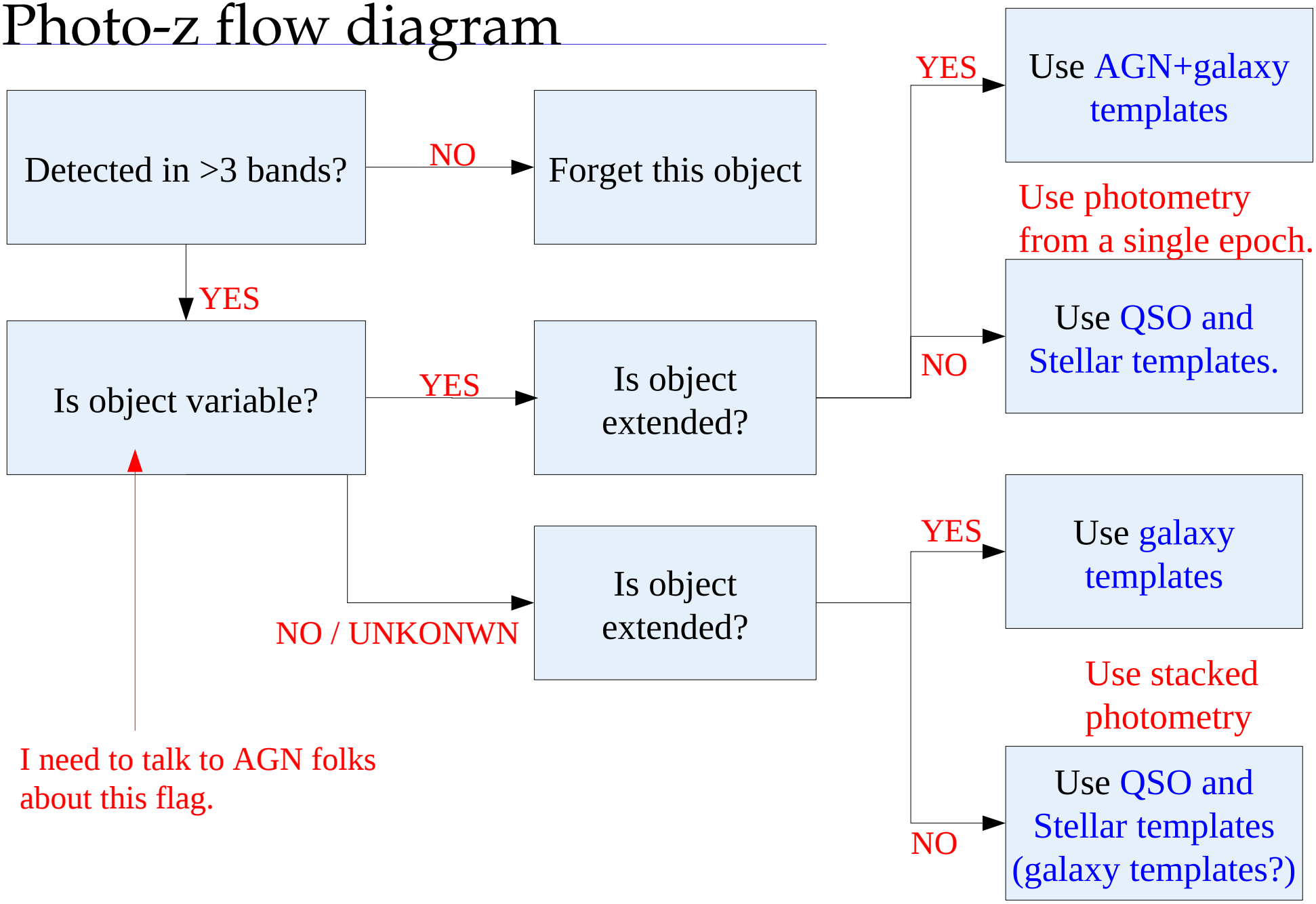
# HSC-Deep : SXDF




| SXDS | Band | $u$ | $g$ | $r$ | $i$ | $z$ | $y$ | $Z$ | $Y$ | $J$ | $H$ | $K_s$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Depth | 25.5 | 27.5 | 27.2 | 27.0 | 25.9 | 24.7 | 25.7 | 24.6 | 24.5 | 24.0 | 23.0 |

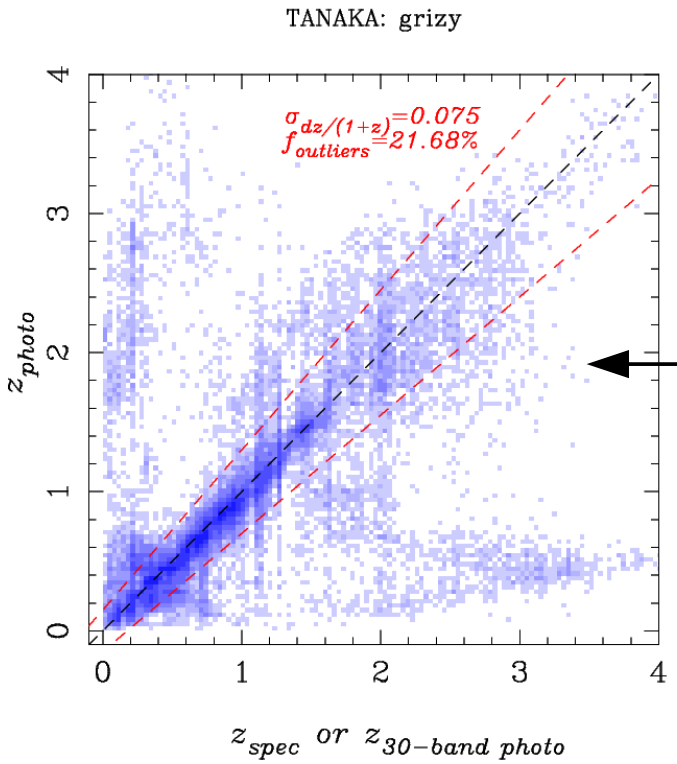
# Photo-z flow diagram



# Weak-lensing: photo-z clipping

For weak-lensing anlaysis, we do not care about galaxy populations, but we do care about photo-z outliers. So, we throw away *'bad'* photo-z's. So far, I use the redshift variance defined by Nishizawa et al (2010):

$$variance = \int_0^\infty dz \frac{(z - z_{phot})^2}{1 + z_{phot}} P(z),$$




- $variance < 0.06$
- $|z_{upper,95\%} - z_{lower,95\%}| < 0.3$
- $\chi^2_\nu < 2$
- $SFR < 500 \mathrm{M}_\odot\ \mathrm{yr}^{-1}$
- $M_{stellar} < 5 \times 10^{11}\ \mathrm{M}_\odot$

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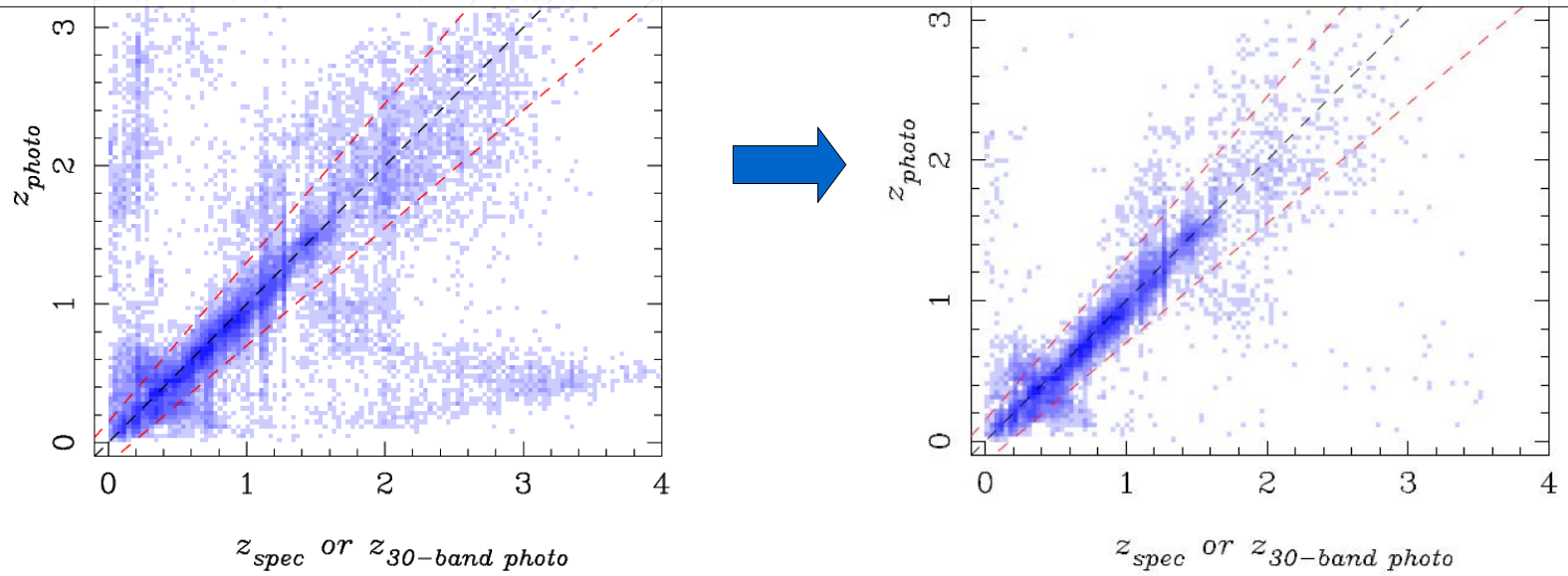
$$variance = \int_0^\infty dz \frac{(z - z_{phot})^2}{1 + z_{phot}} P(z),$$

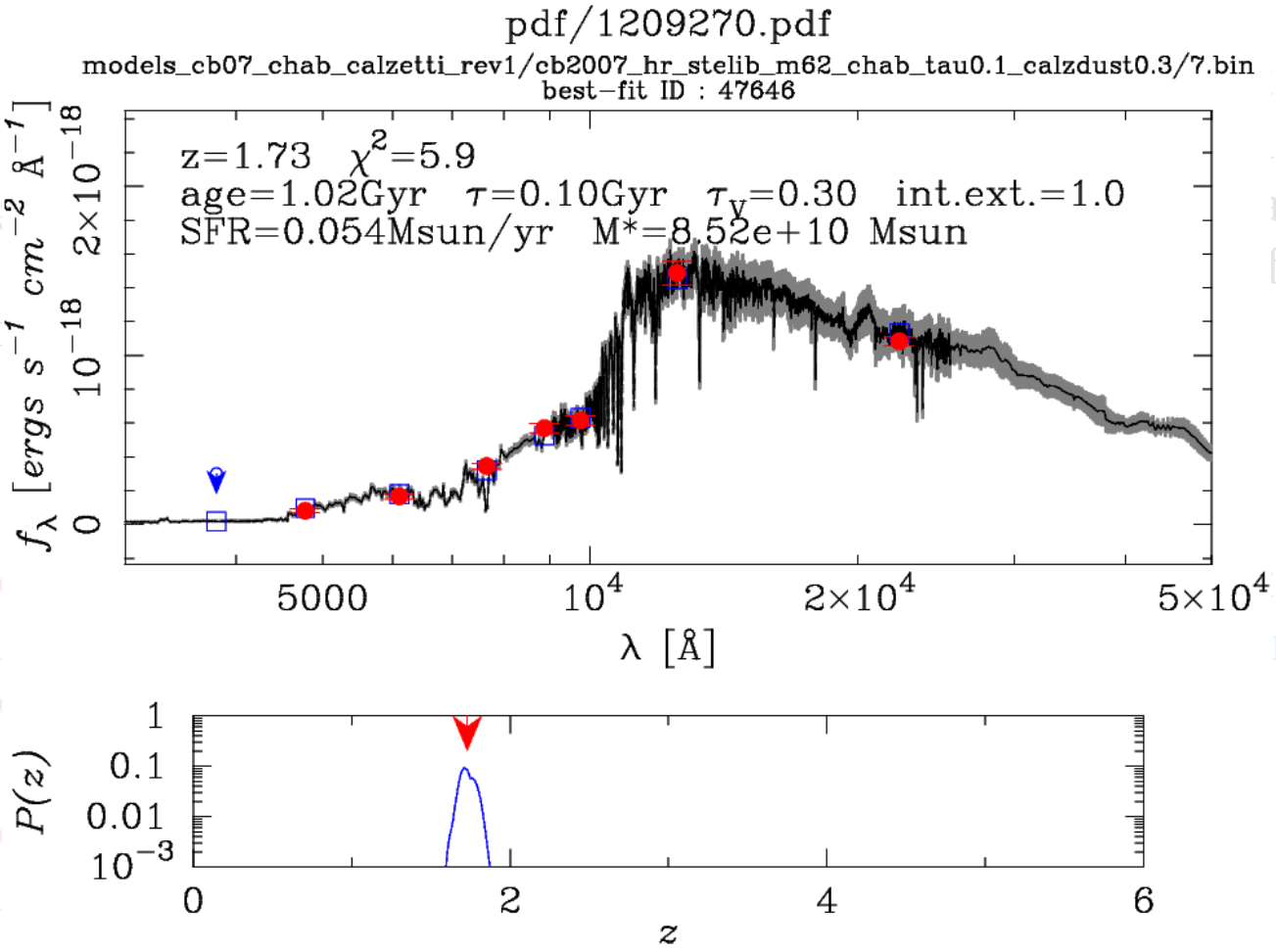
1 – Any ideas to reduce outliers are welcome!

2 – Is 7% outlier rate high? What accuracy would you need?



# Galaxy evolution: physical properties of galaxies

Would it be useful to have SED plots for your objects?



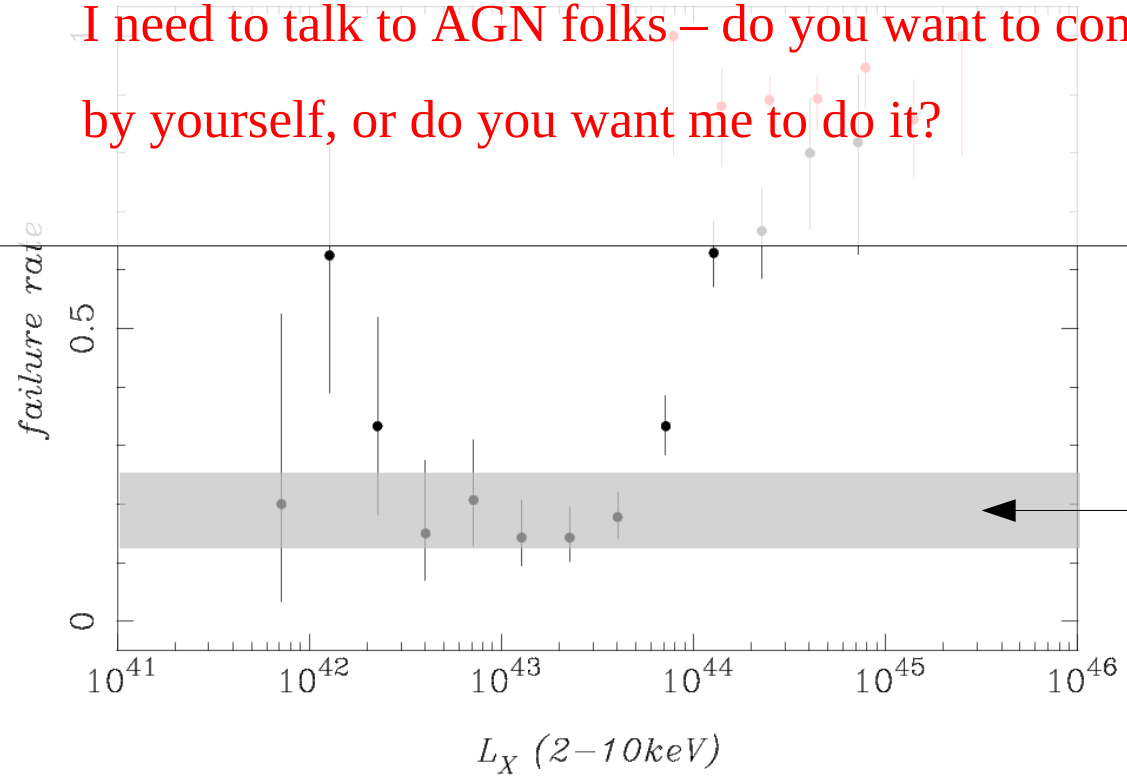
# AGNs: need your inputs

As shown in the flow diagram, AGN templates are *NOT* used for most objects. This is bacause AGN templates degrade photo-z's for normal galaxies and AGNs are minor population (~1%).

As a result, we miss AGNs with *Lx* > several * 10^43 erg/s.

I need to talk to AGN folks – do you want to compute AGN photo-z's by yourself, or do you want me to do it?

Assumed:
*grizy* at HSC-Wide depth




z<1.5

z>1.5

Typical accuracy for normal galaxies

# *4 – Summary*

# Summary

- In order to understand the galaxy evolution,
  - 1 – we try to describe the galaxy distributions in the multivariate space with simple continuity equations.
  - 2 – We then try to understand the physics.
- HSC is only the first step towards phase-1. PFS and multi-wavelength data would be needed for phase-2.

- I hope I gave you an idea of HSC photo-z's in the Wide and Deep layers.
- It is hard to summarize the photo-z results with words, so please look at PDF of this slide, which I guess will be posted to the web.

- Any thoughts/comments/whatever on photo-z would be appreciated.