Galaxy Evolution Workshop 2019

Tracing the co-evolution path of SMBHs and spheroids with ULIRGs selected from AKARI/Herschel catalogs

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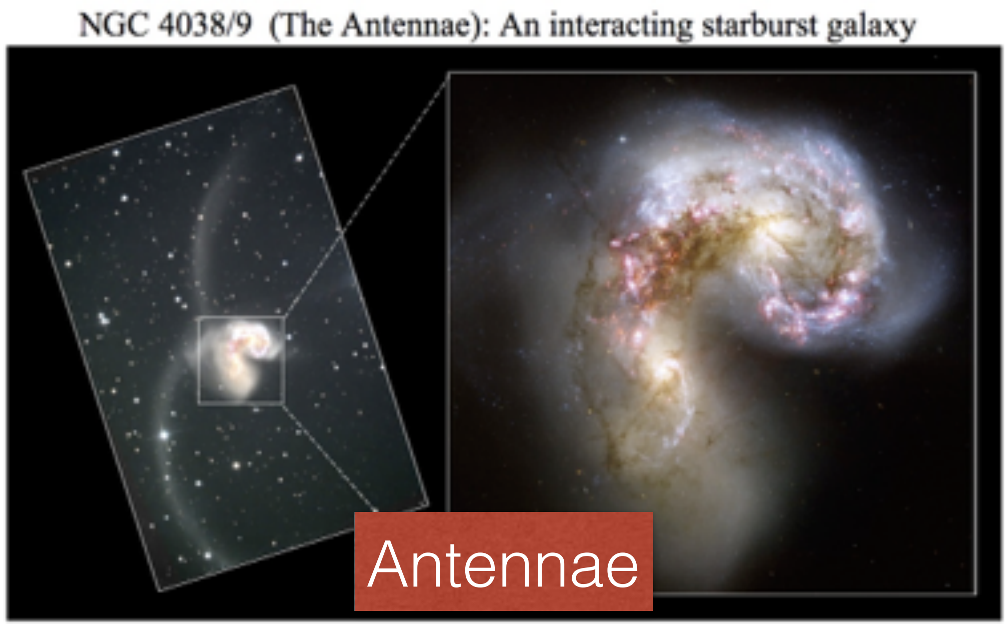
Outline

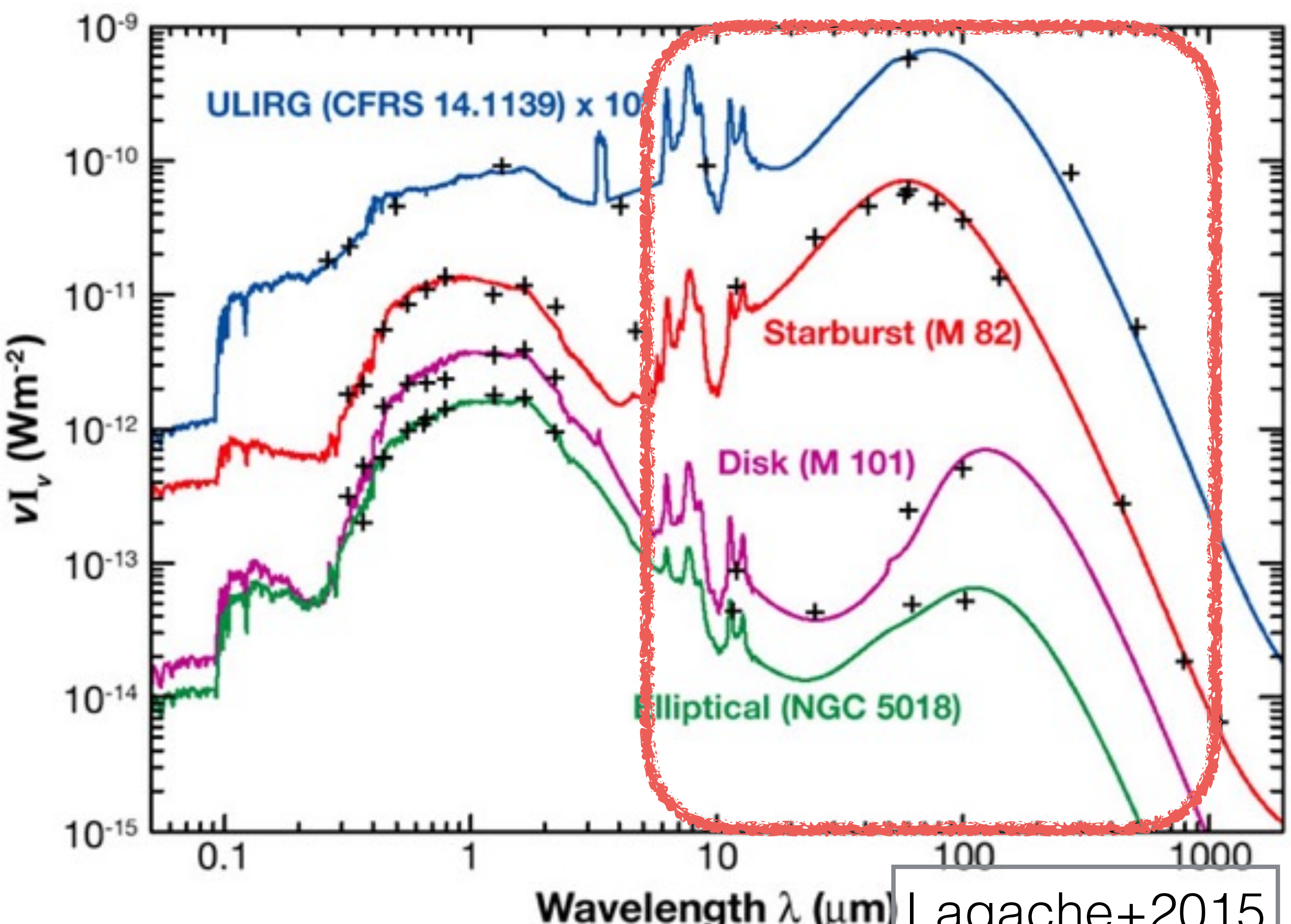
- **1. Background**
- 2. Sample and Method
- 3. Results and Discussion
- 4. Summary

Ultra-Luminous InfraRed Galaxies

Def:

LIRG : $L_{8\text{-}1000\mu m} > 10E{+}11\ L_\odot$
Ultra-LIRG : $L_{8\text{-}1000\mu m} > 10E{+}12\ L_\odot$
Hyper-LIRG : $L_{8\text{-}1000\mu m} > 10E{+}13\ L_\odot$
Extremely-LIRG : $L_{8\text{-}1000\mu m} > 10E{+}14\ L_\odot$

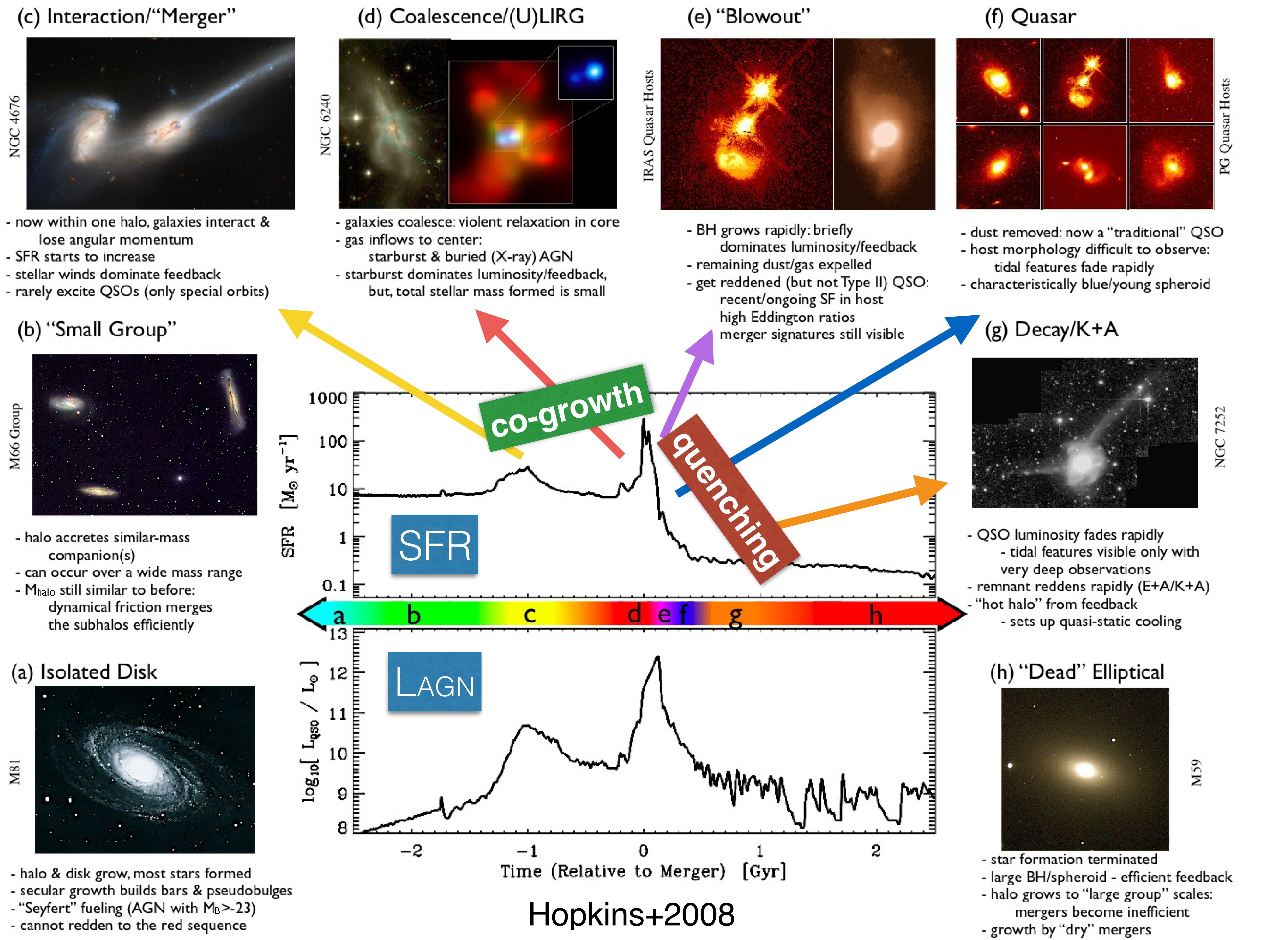




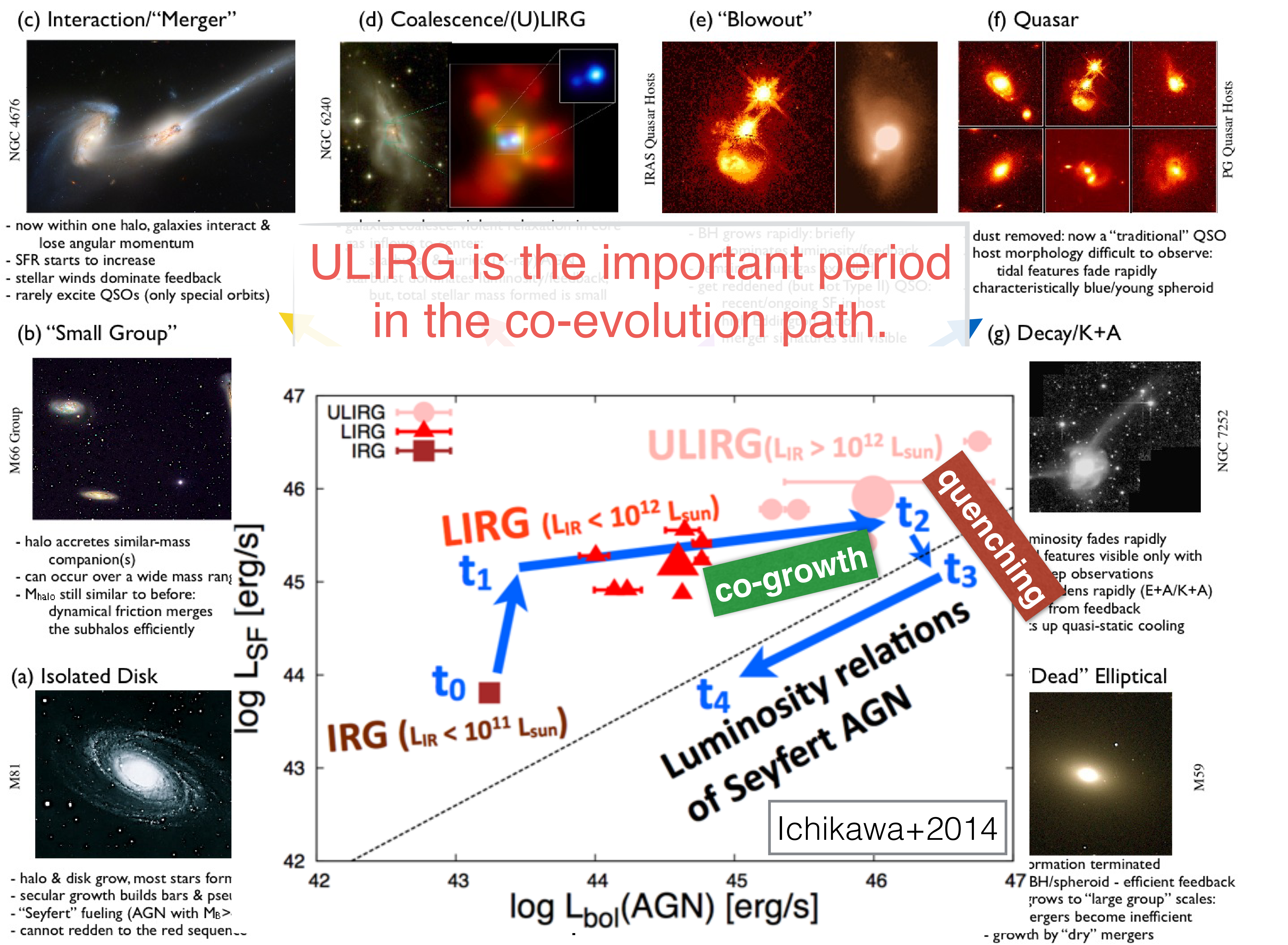
Lagache+2015

~90% radiation **emitted in infrared band by dust** heated by starburst (O/B stars) and/or AGN.

The co-evolution path of SMBHs and spheroids in massive galaxies

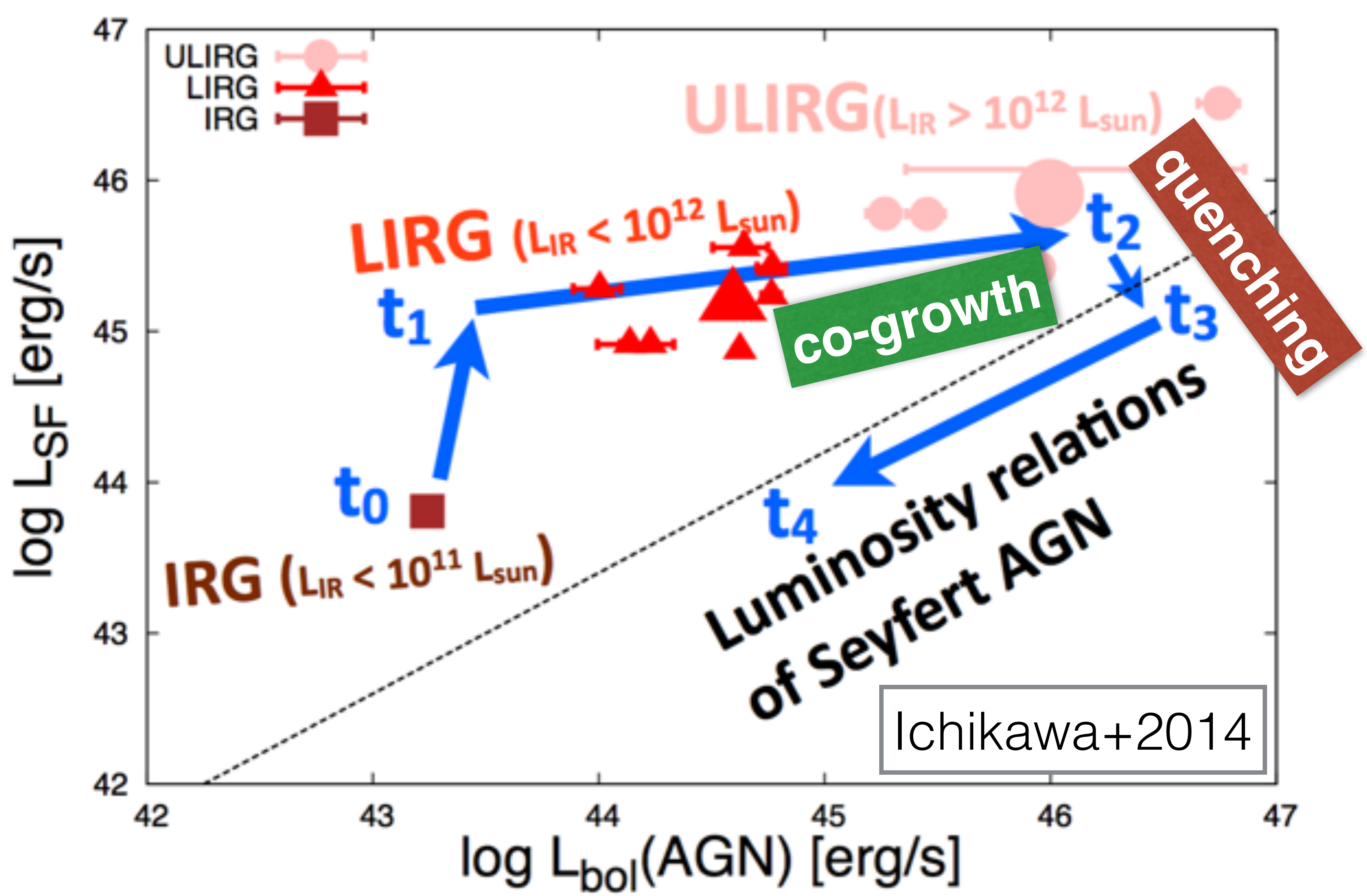


The co-evolution path of SMBHs and spheroids in massive galaxies

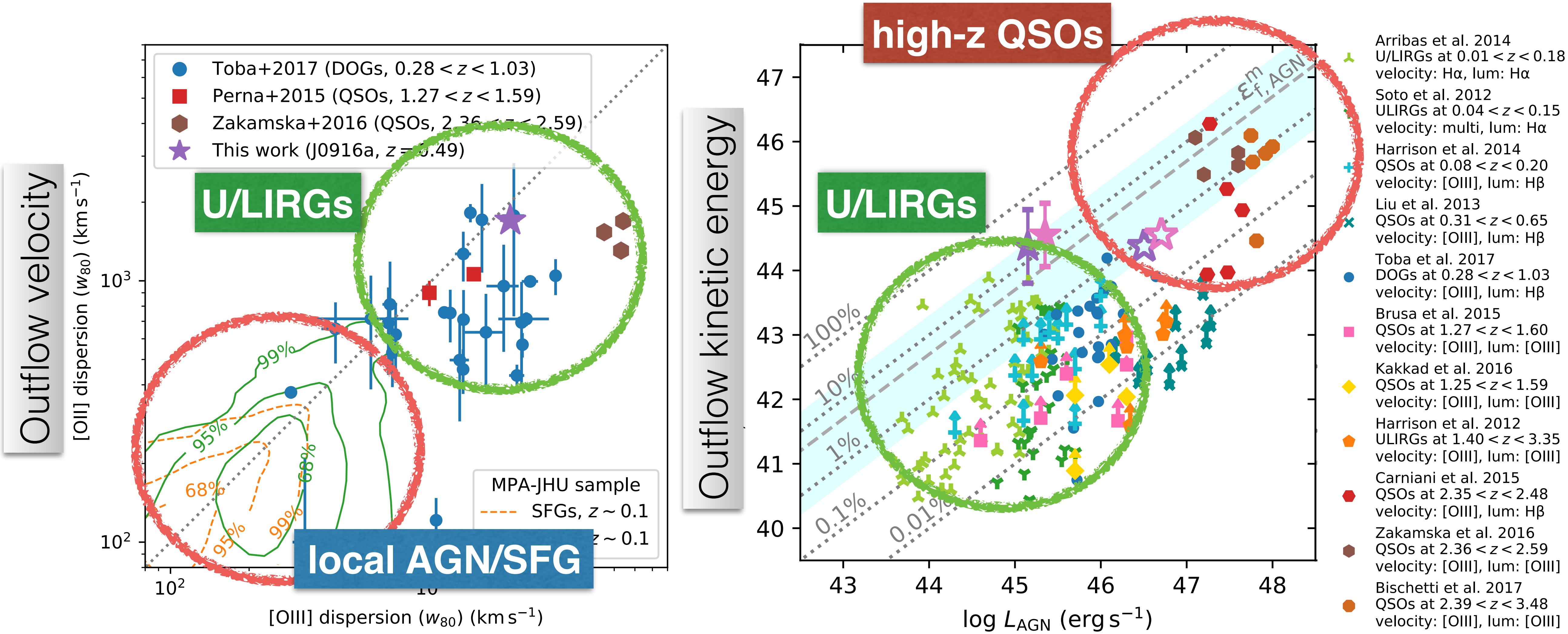


Two main topics

1) the process to push the evolution: **outflow;**
2) the result of the evolution: **luminous AGN** and **quenched star formation.**



Outflow study in the literature

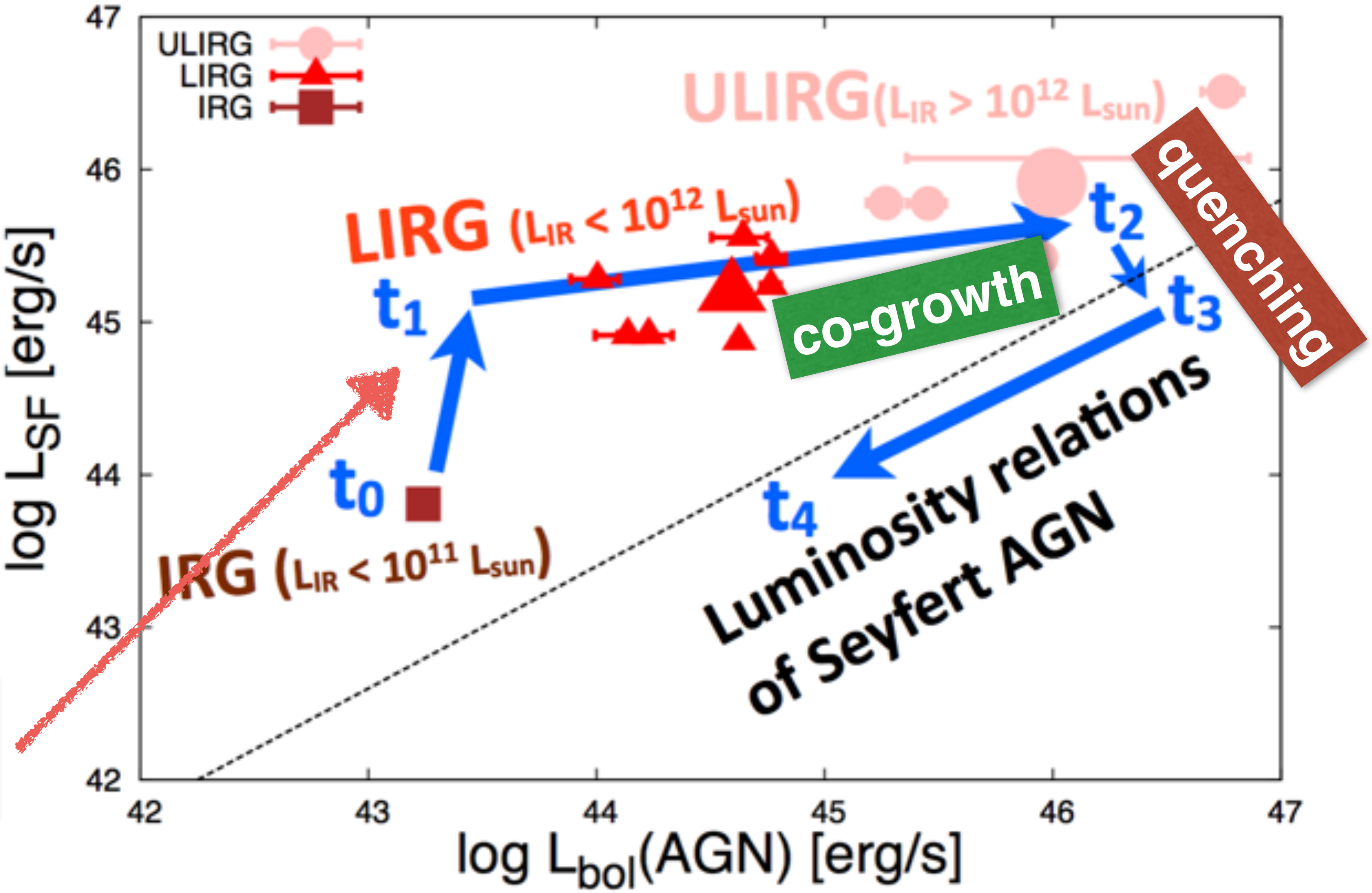


Chen et al. 2019

In the view of outflow, ULIRGs locate at the *transition position* between local AGN / star-forming galaxies, and the very luminous high-z QSOs.

Quenched or Not quenched

Although the merger scenario provide a history of the phase transition of ULIRGs, the detailed measurement of evolution time is challenging.

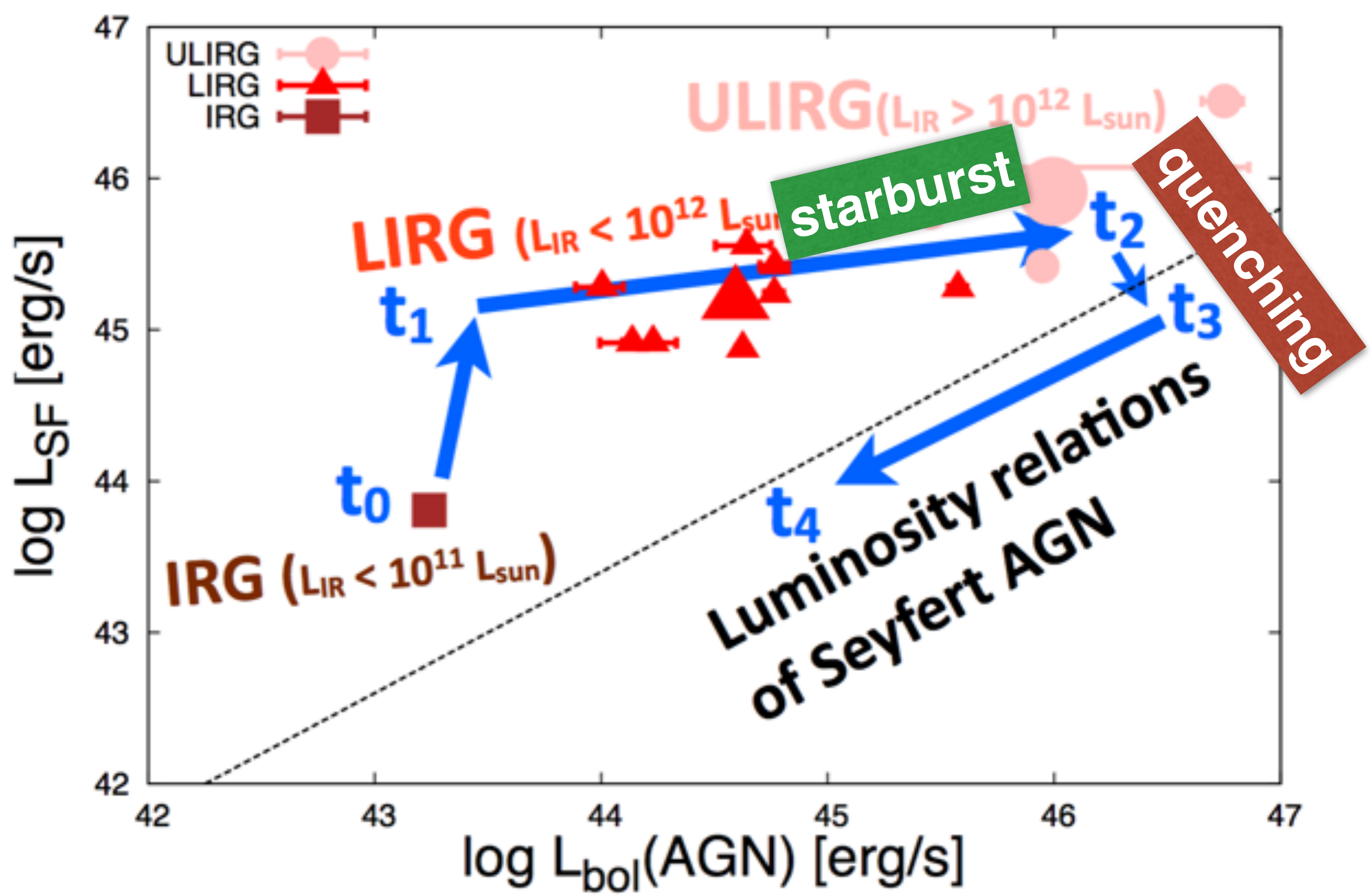


It is hard to get the time directly.

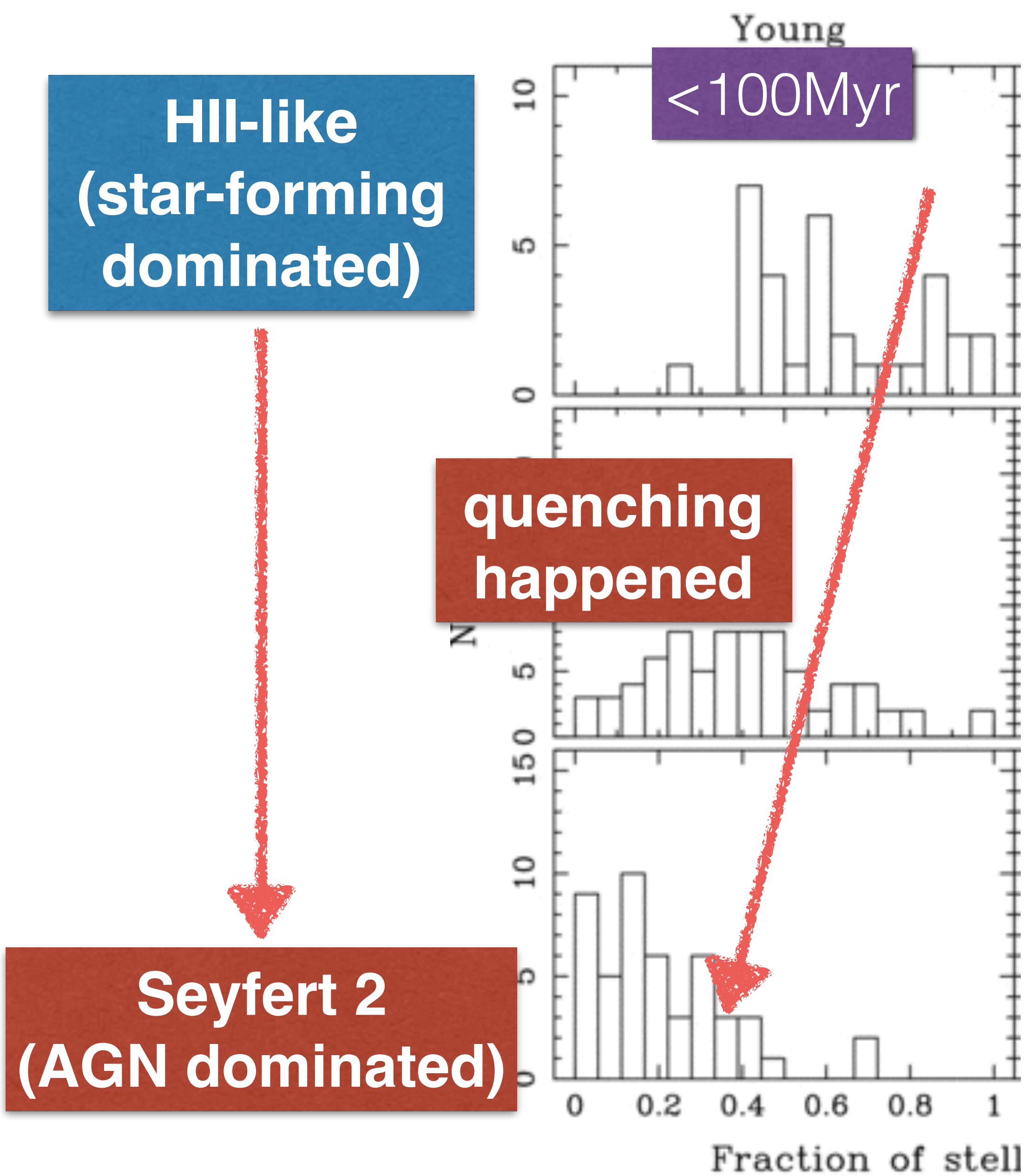
Quenched or Not quenched

An alternative method is to evaluate the mass fraction of Young Stellar Population (< ~ 100 Myr) with a large sample.

Since the ULIRG evolution starts from a starburst, if the quenching process really occurs, the young fraction should decreases significantly when compared to its early stage.

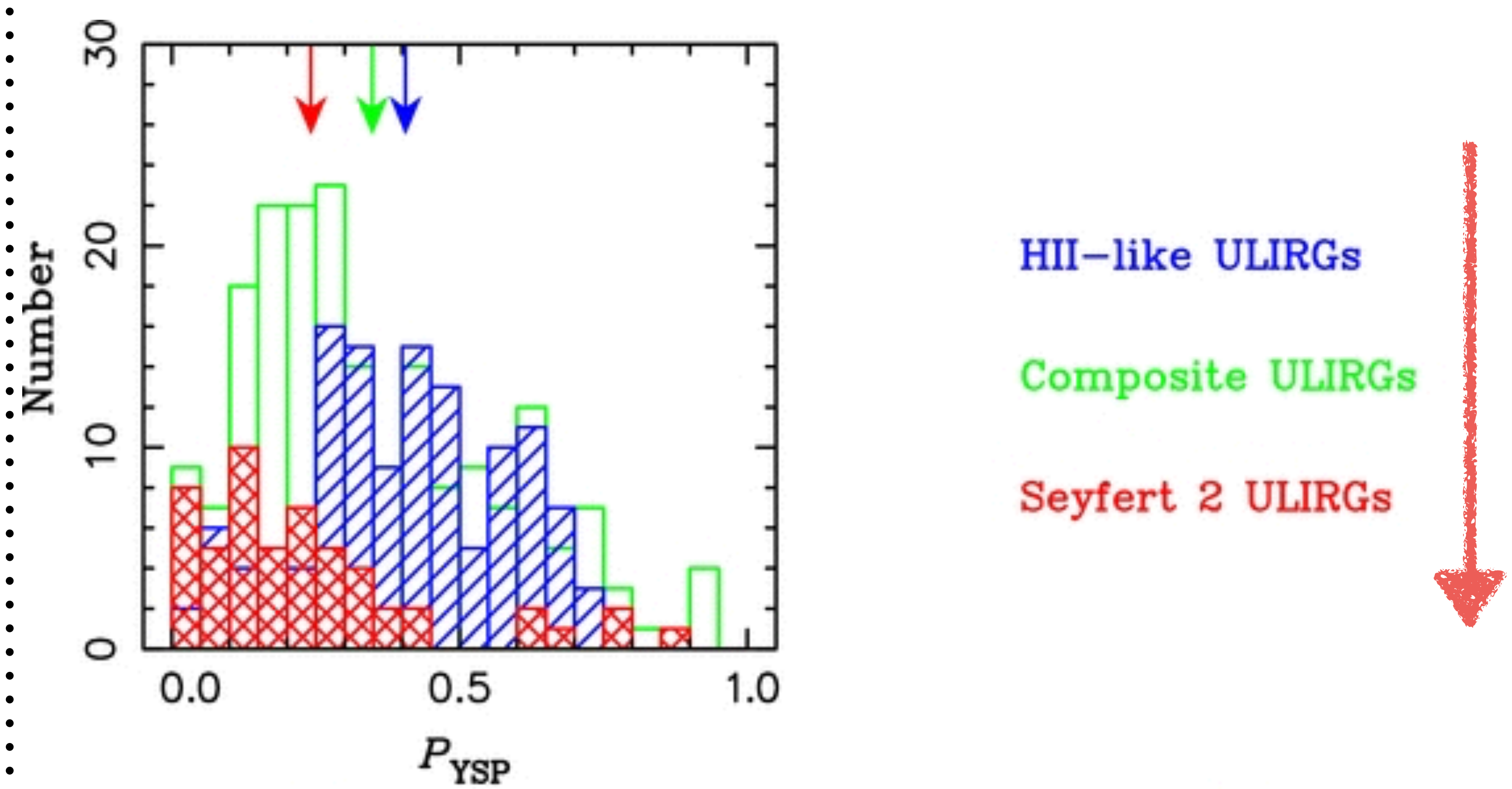


Quenched or Not quenched



Hou et al. 2011

160 ULIRGs from 1Jy IRAS catalog



Su et al. 2013

419 ULIRGs from *WISE catalog*,
no FIR confirmed. biased?

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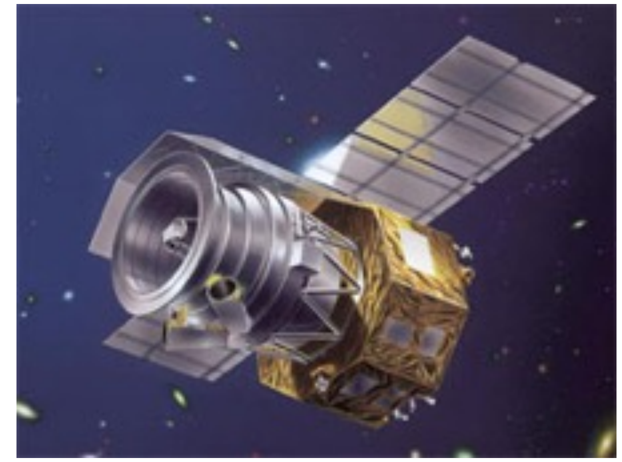
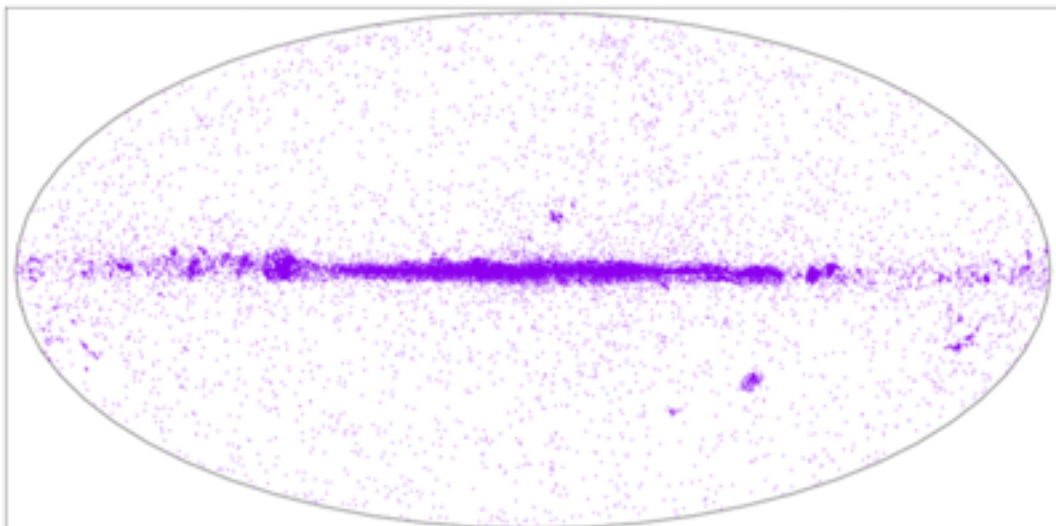
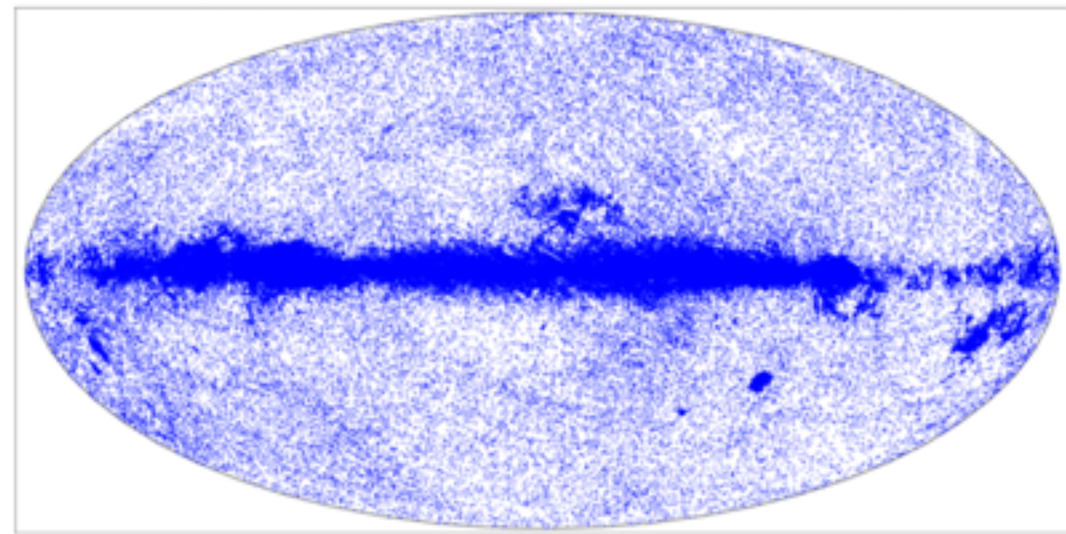
- Searching ULIRG in the **AKARI FIS Bright Source Catalog**



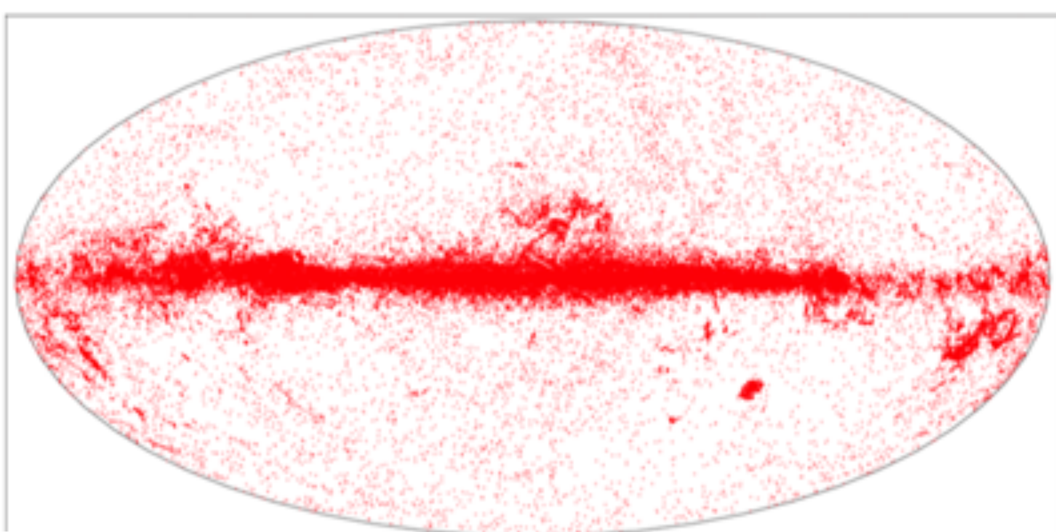
N60 (65 μm): 59,443 sources



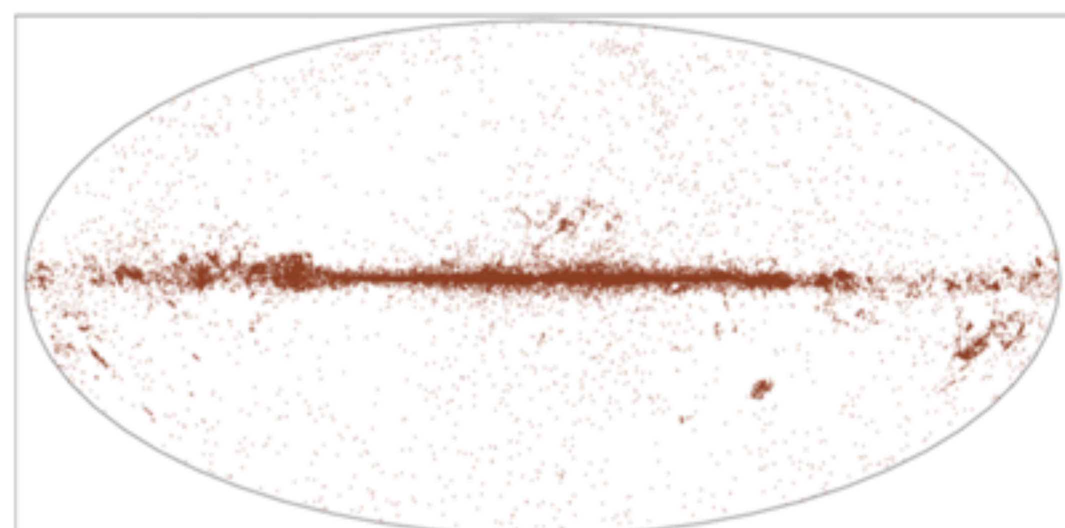
WIDE-S (90 μm): 461,842 sources



WIDE-L (140 μm): 203,594 sources



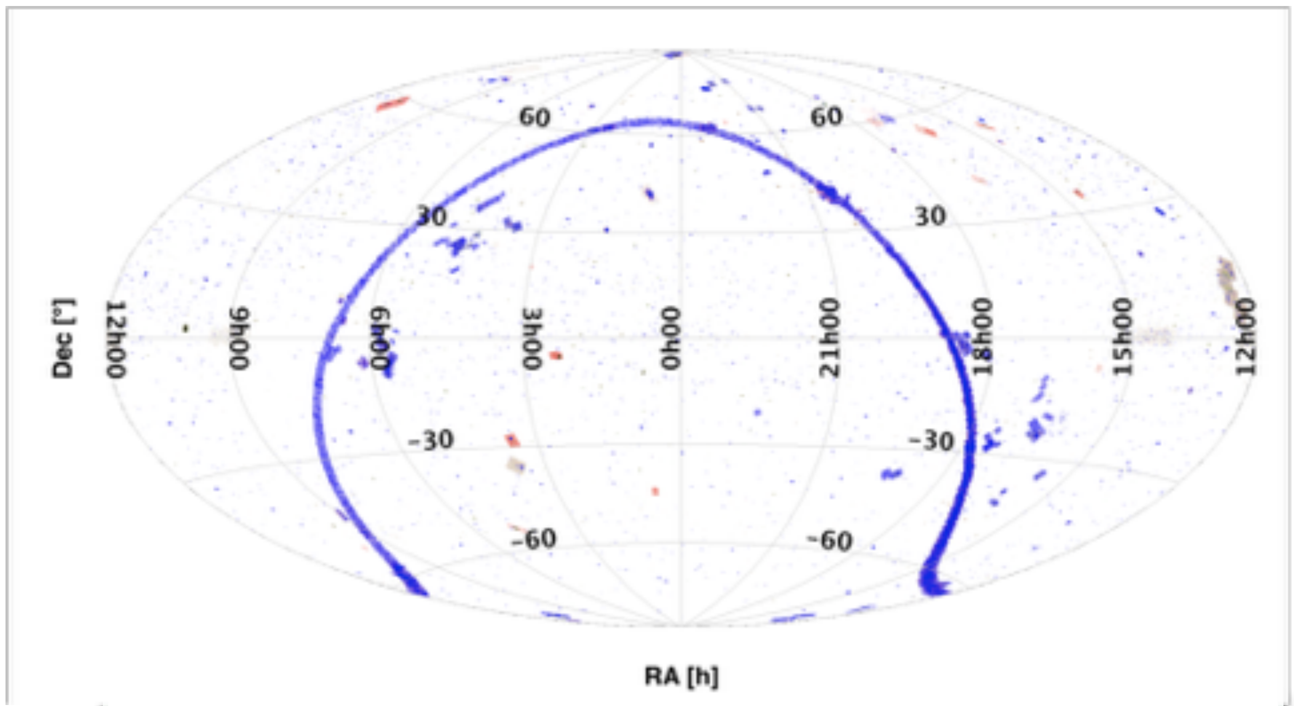
N160 (160 μm): 71,836 sources

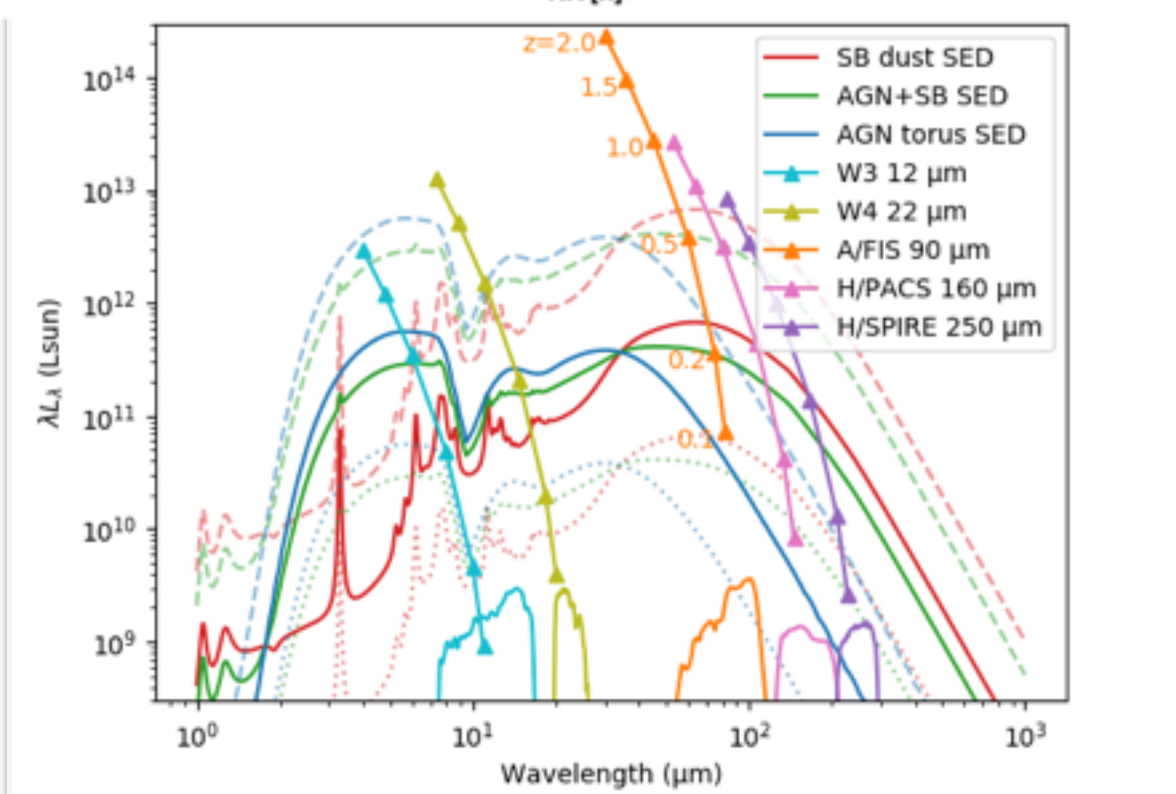


Yamamura et al.

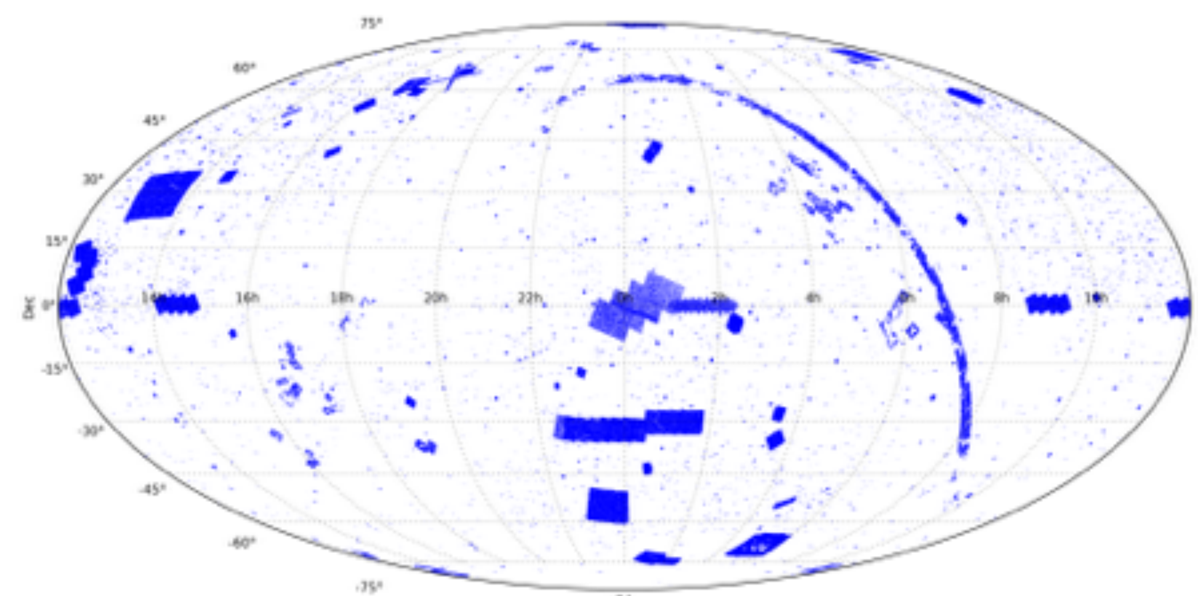
AKARI-FIS Bright Source Catalogue Ver.2 Release Note (preliminary version 1.1; 2016/04/26)

- Searching ULIRG in the **AKARI FIS Bright Source Catalog**,
- and the **Herschel PACS/SPIRE point source catalogs**.





PACS PSC
70/100/160um



SPIRE PSC
250/350/500um

SDSS DR15 PhotoObj Catalog (u, g, r, i, z)

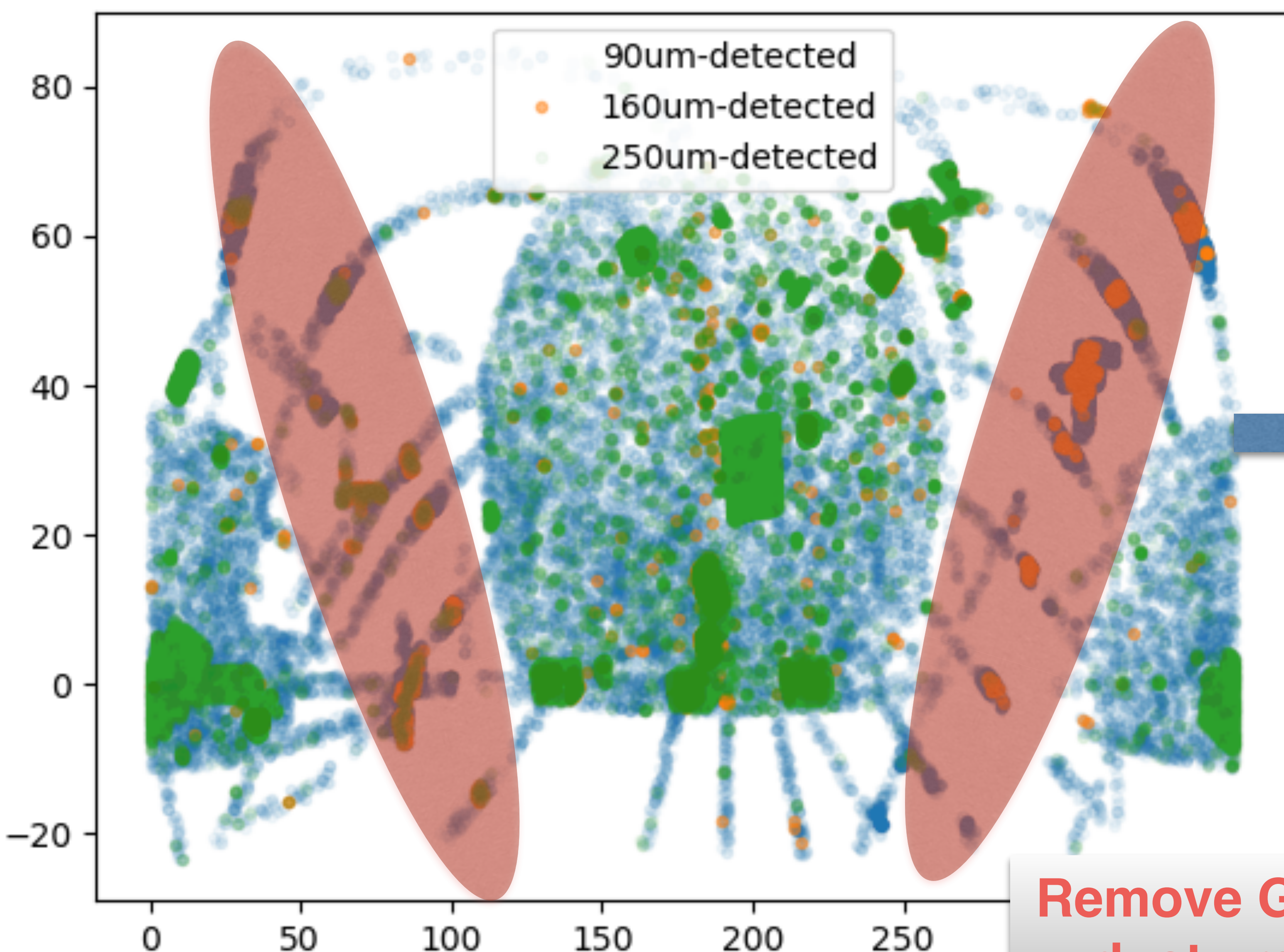
+

WISE AllWISE Catalog (3, 4, 12, 22 um)

+

AKARI Catalog (90um)

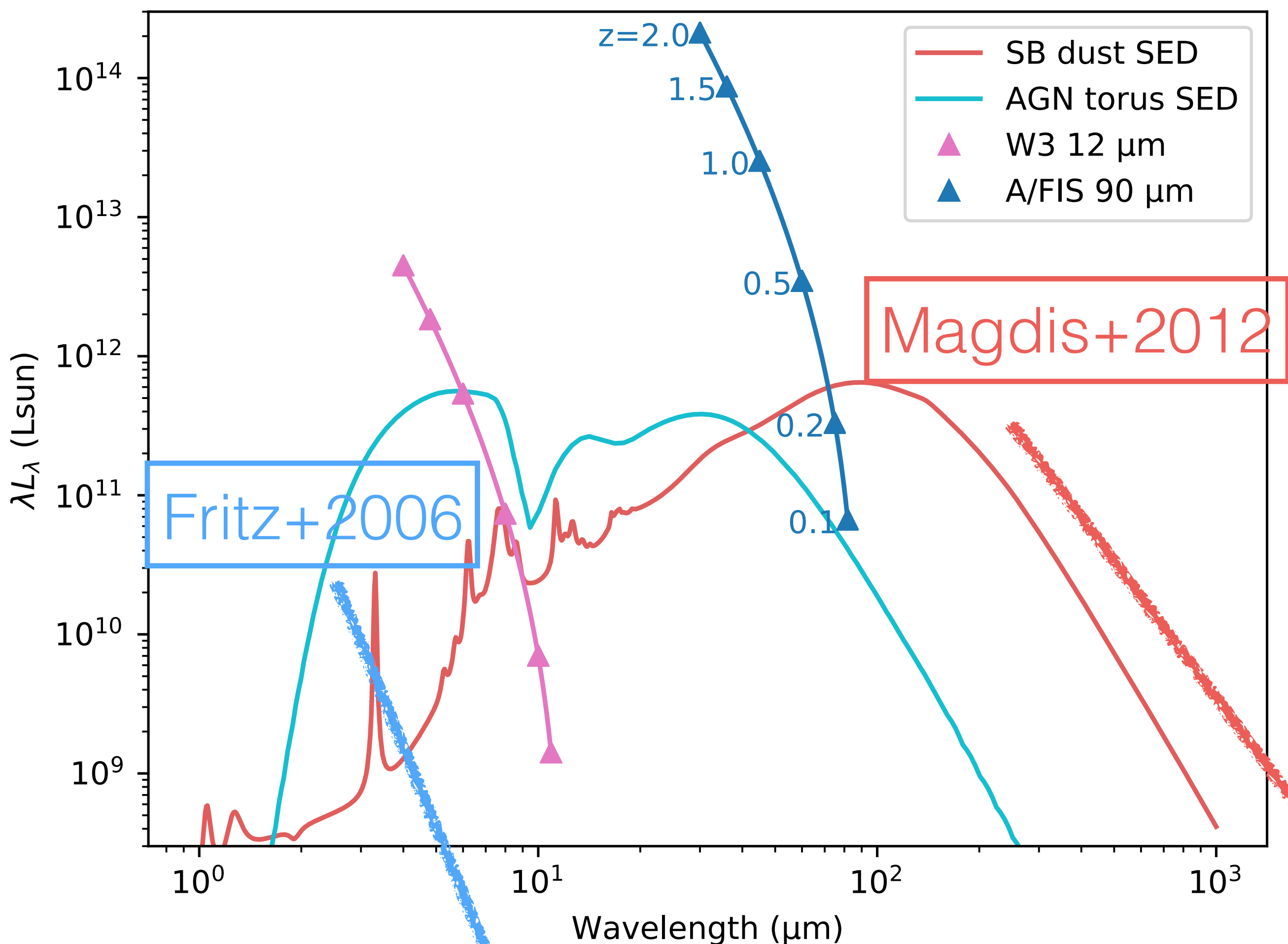
Herschel Catalog (160/250um)



Remove Galactic dusty region

Total cross-matched: 146921

2-band SED estimation to select ULIRG



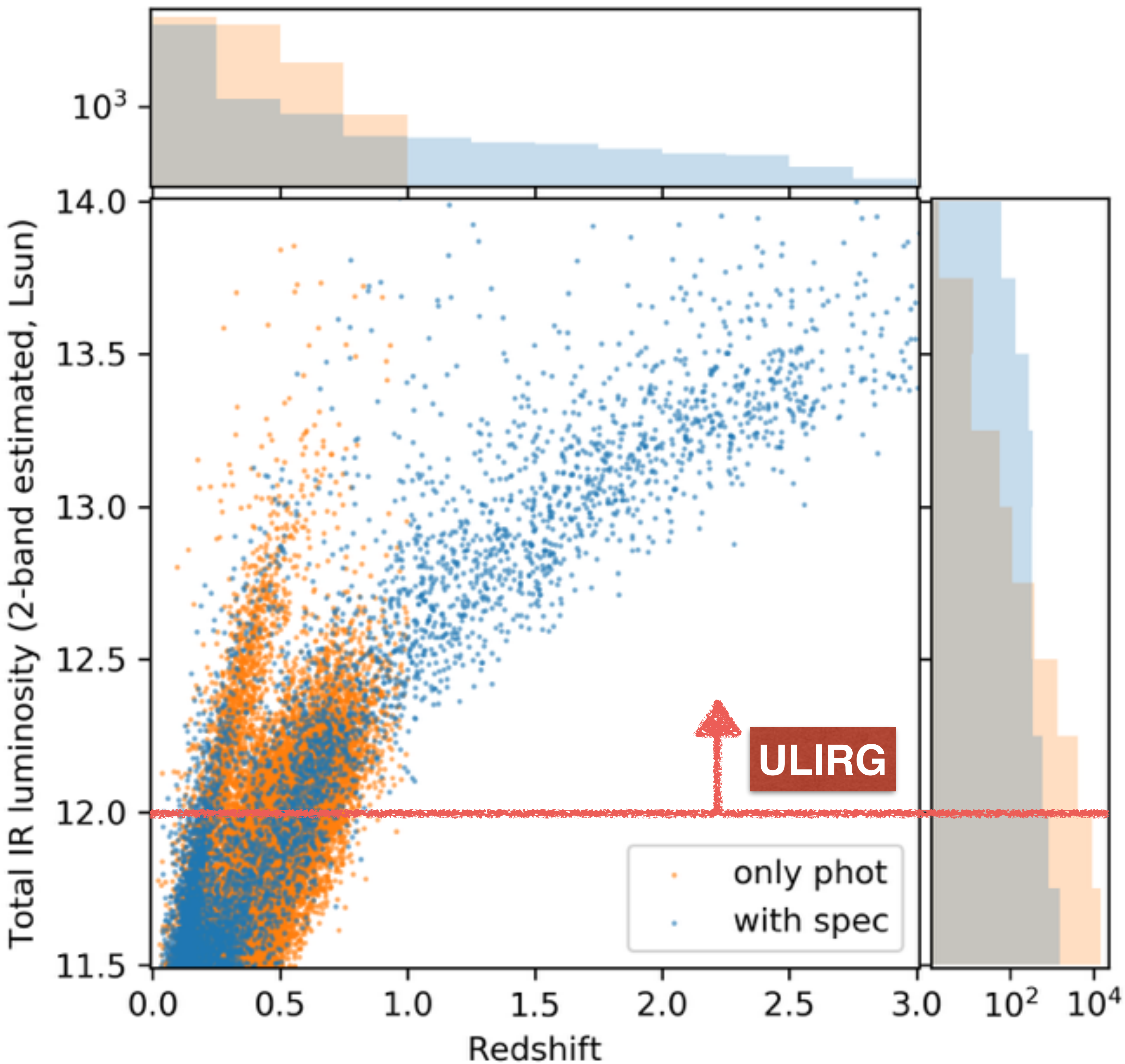
We can quickly estimate the IR AGN and starburst luminosity just with 2-band observation, when the SED are fixed to some typical choices.

$L_{AGN} + L_{SB} >= 1E12\ L_{sun}$

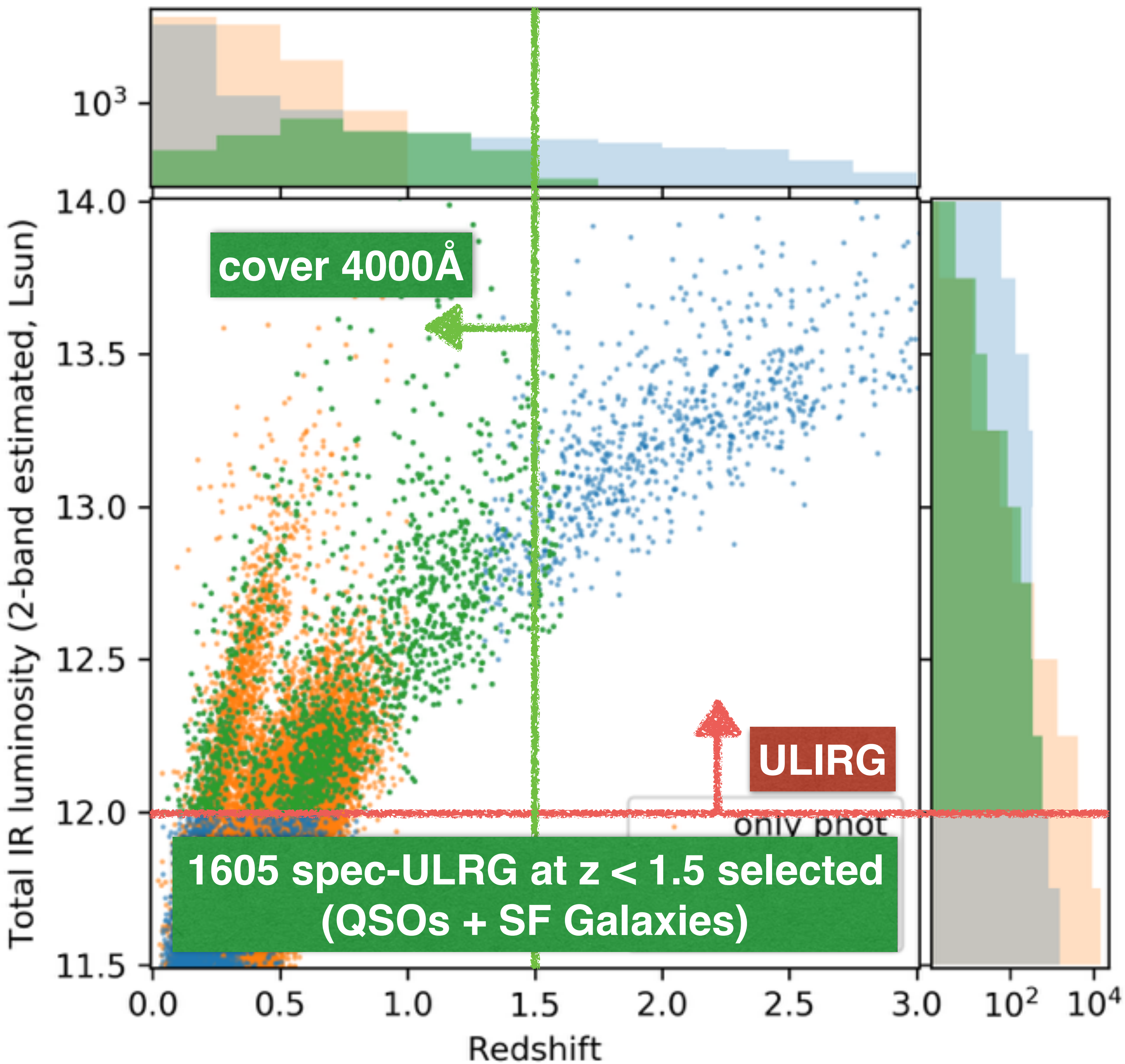
$$L_{AGN} * (SED_{torus} \otimes T_{12}) + L_{SB} * (SED_{SB} \otimes T_{12}) = Flux_{12}$$
$$L_{AGN} * (SED_{torus} \otimes T_{90}) + L_{SB} * (SED_{SB} \otimes T_{90}) = Flux_{90}$$

band transmission

2-band SED estimation to select ULIRG

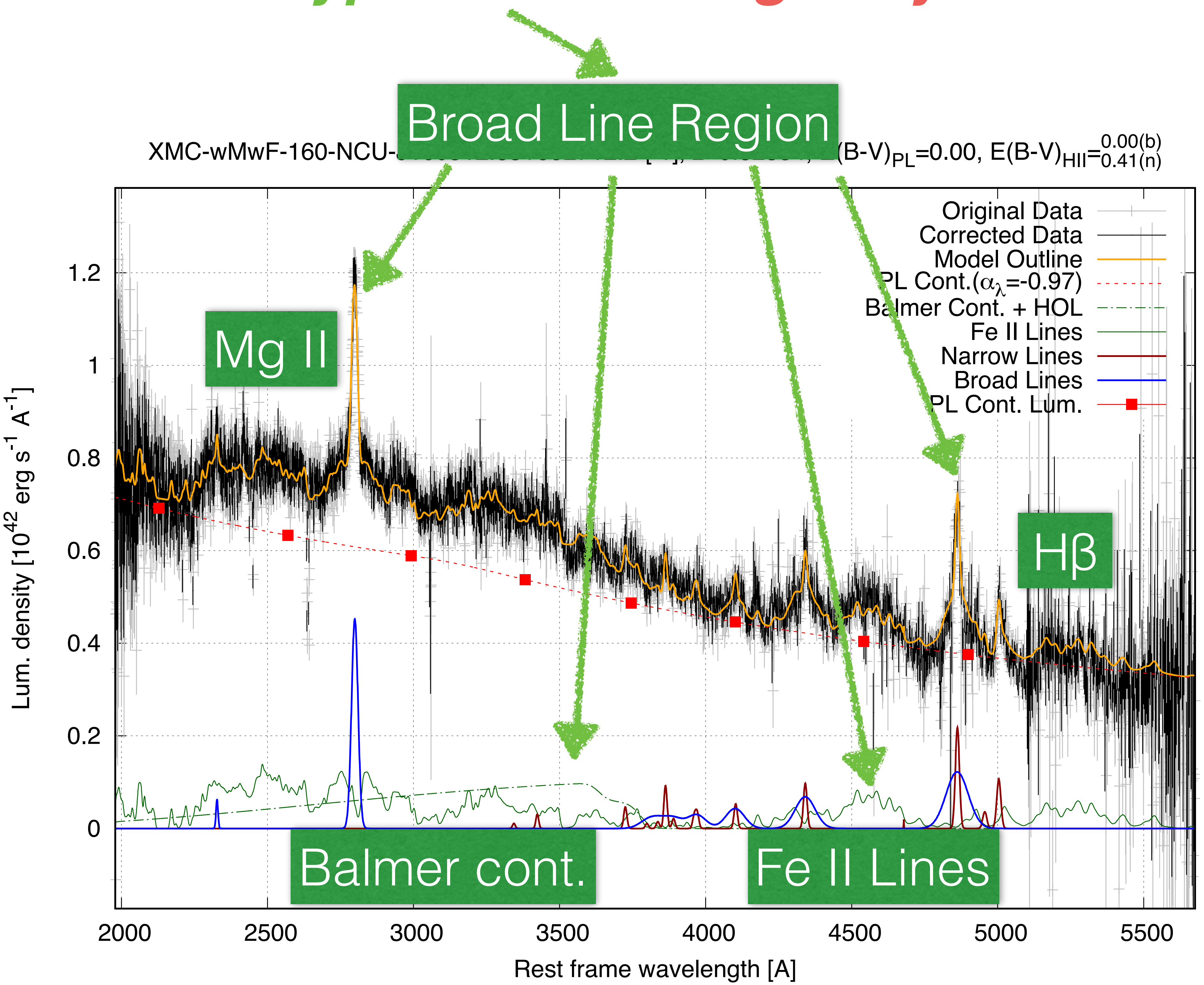


2-band SED estimation to select ULIRG

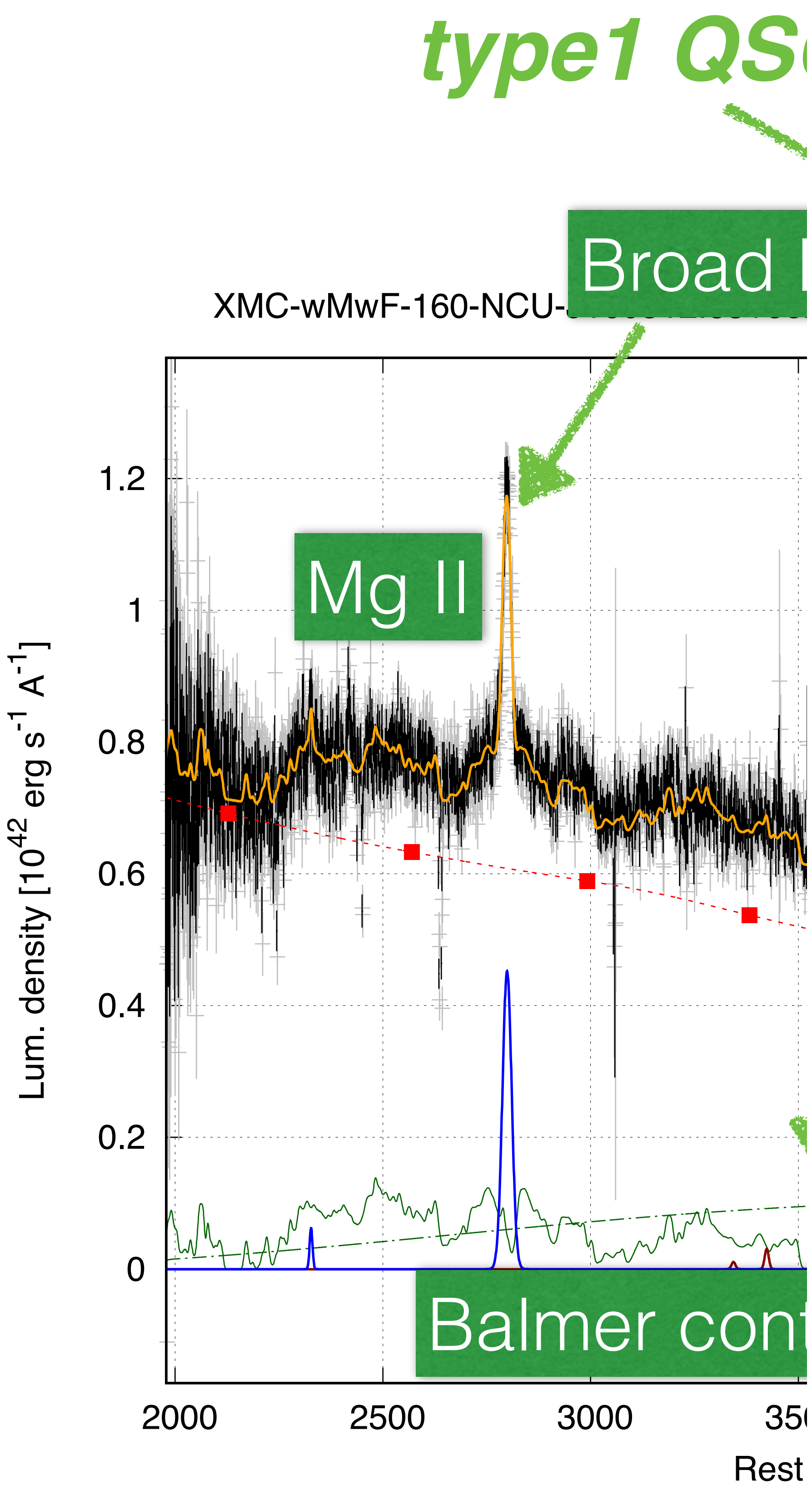


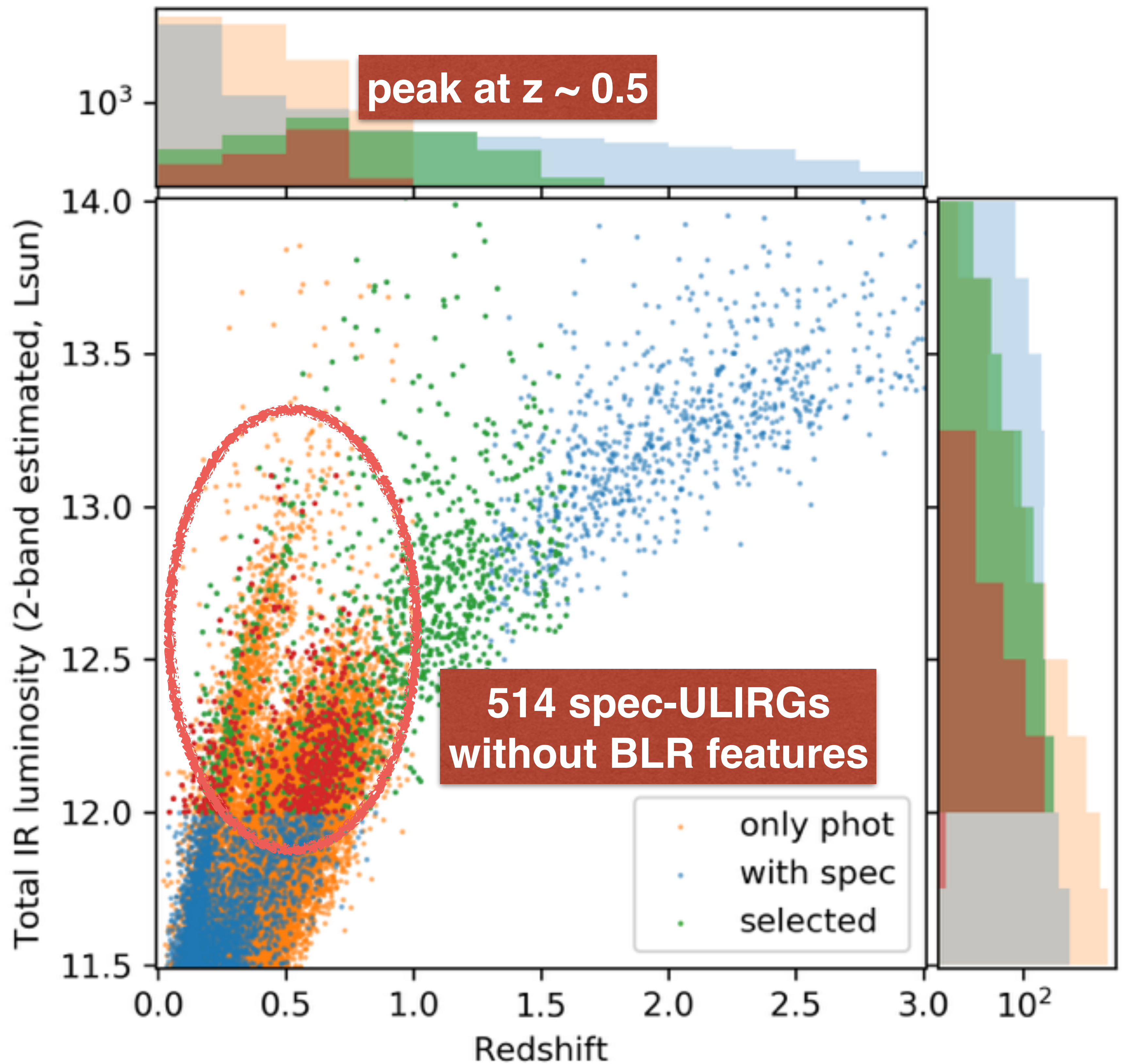
Spectral identification

type1 QSO? SF galaxy?

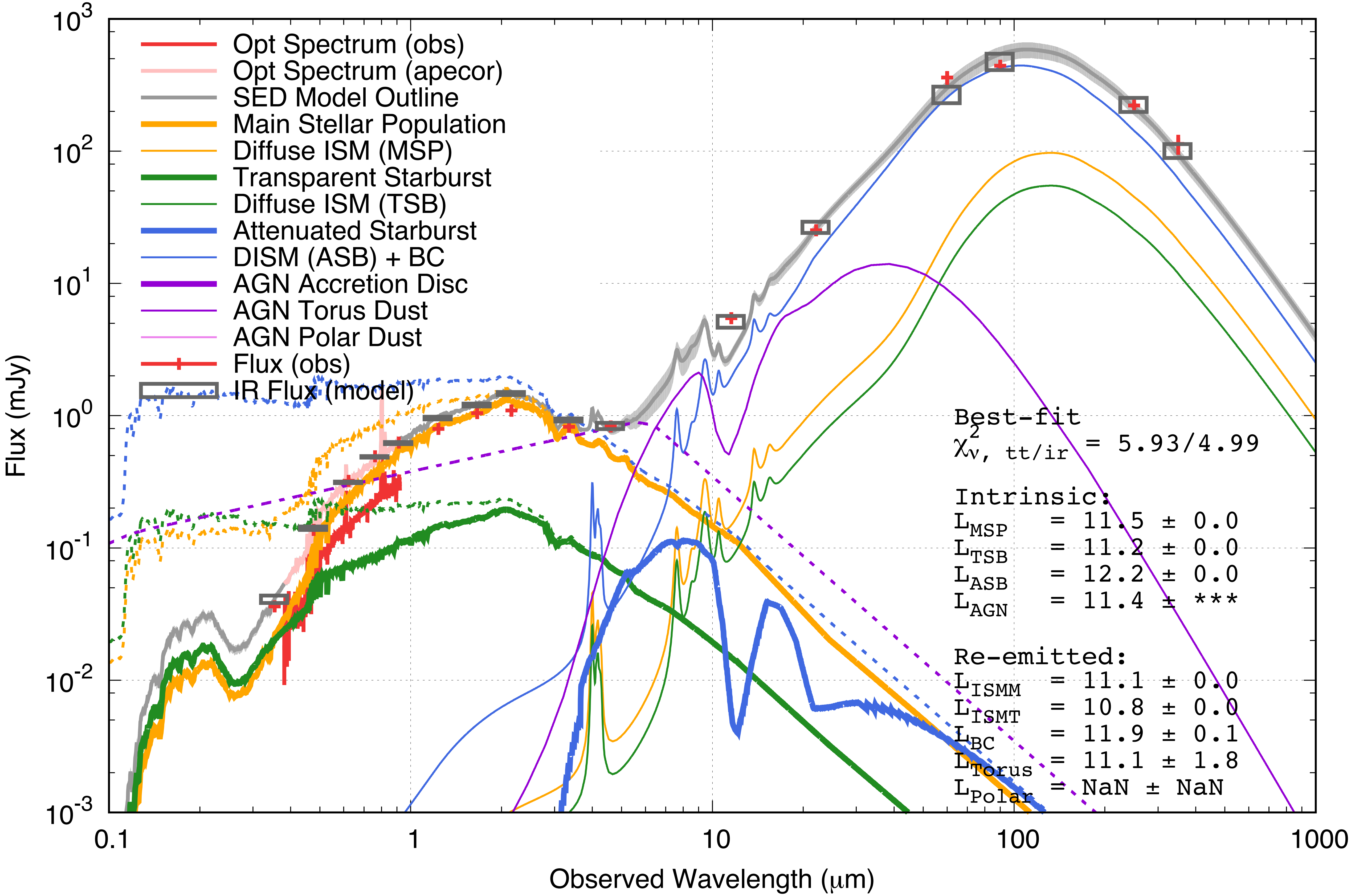


Spectral identification

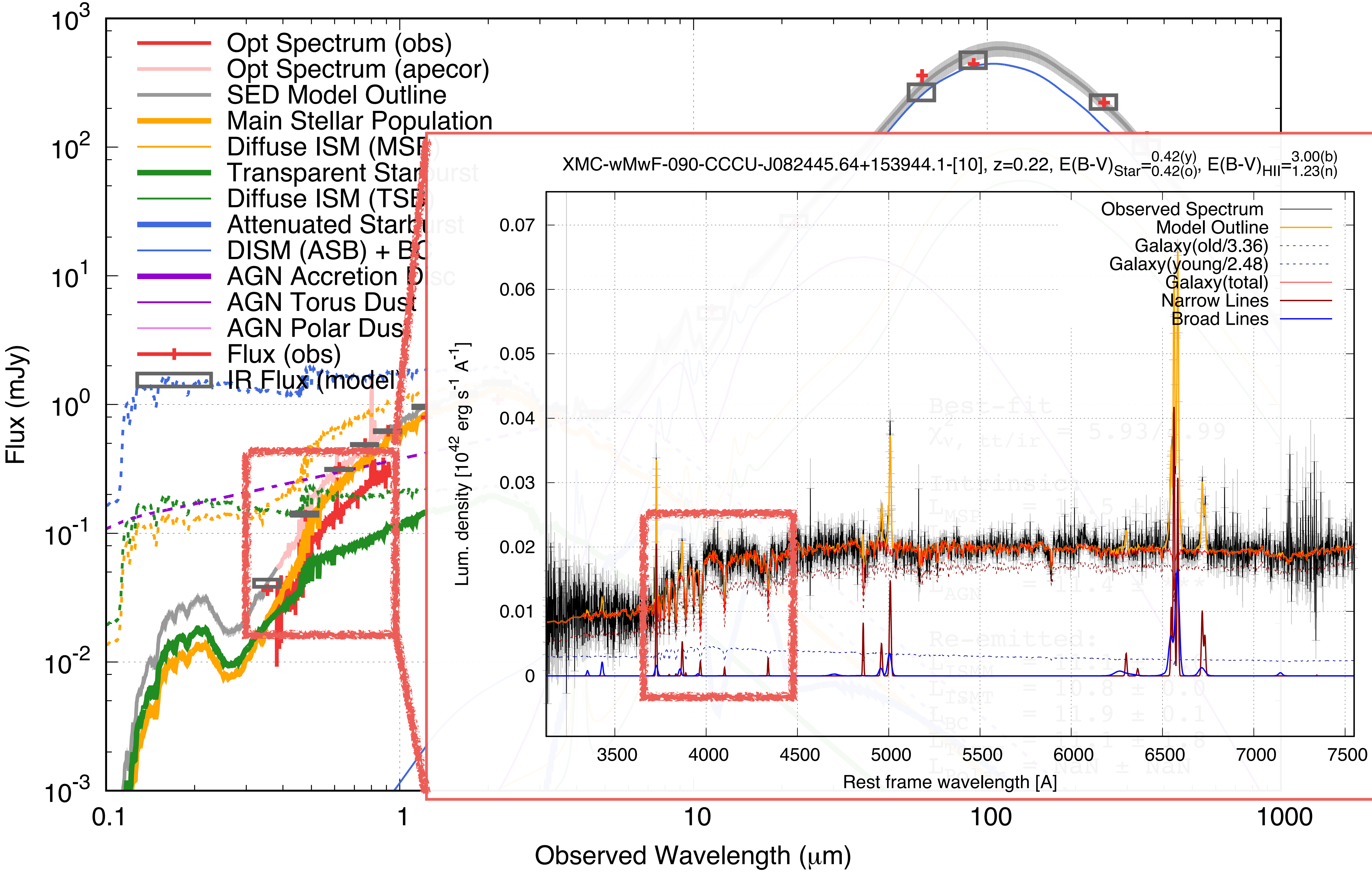


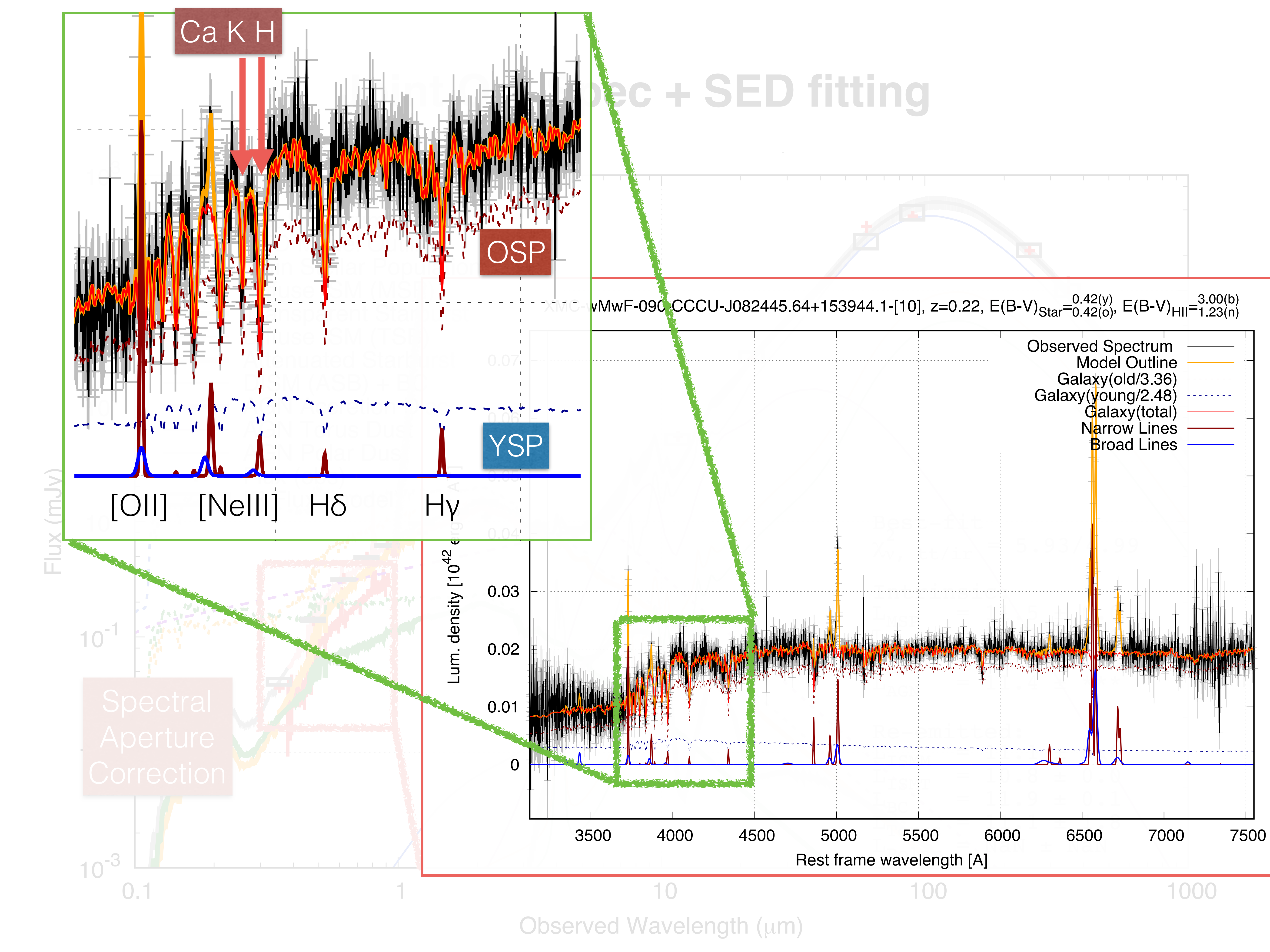


Joint Opt.Spec + SED fitting

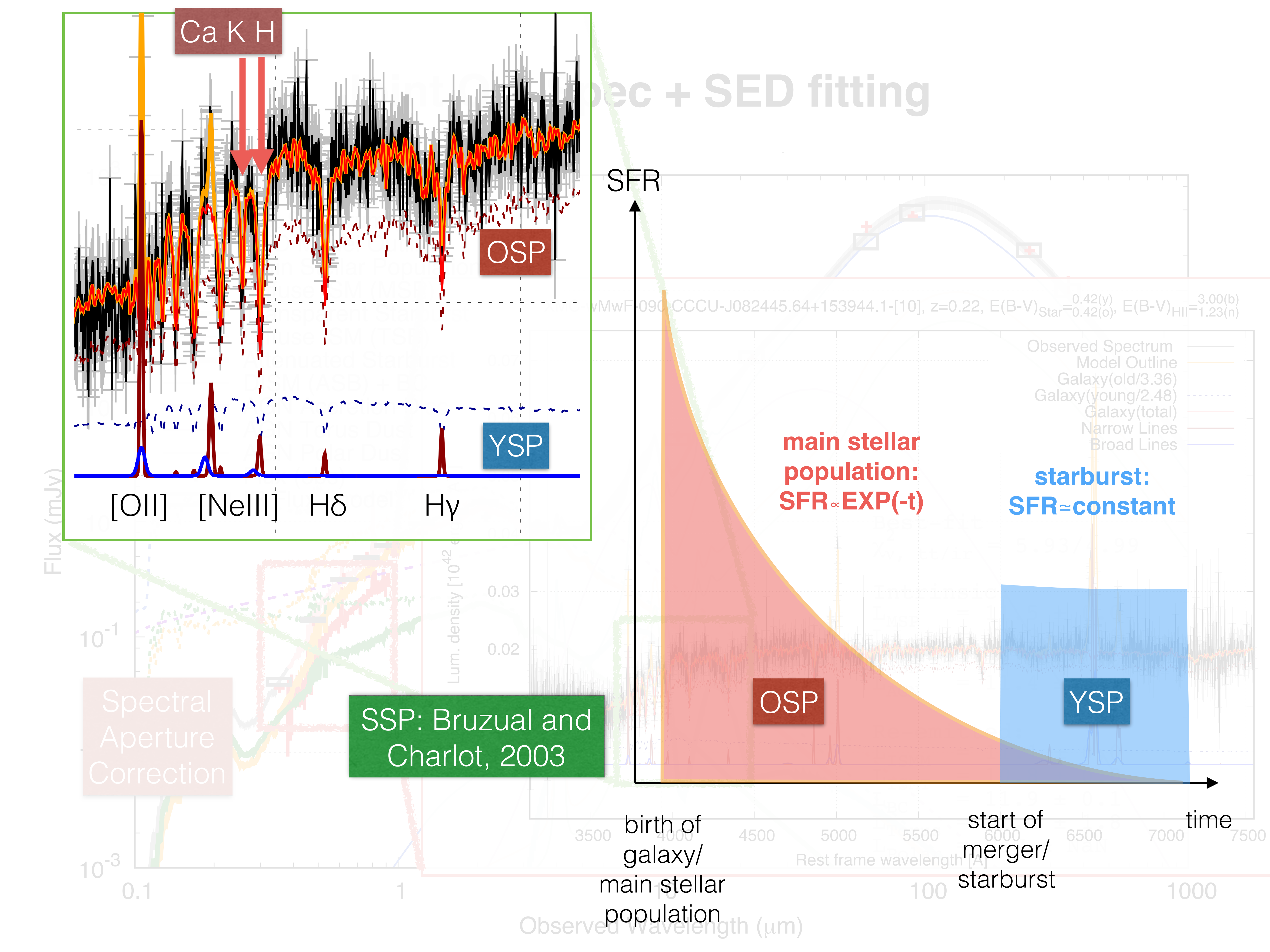


Joint Opt.Spec + SED fitting

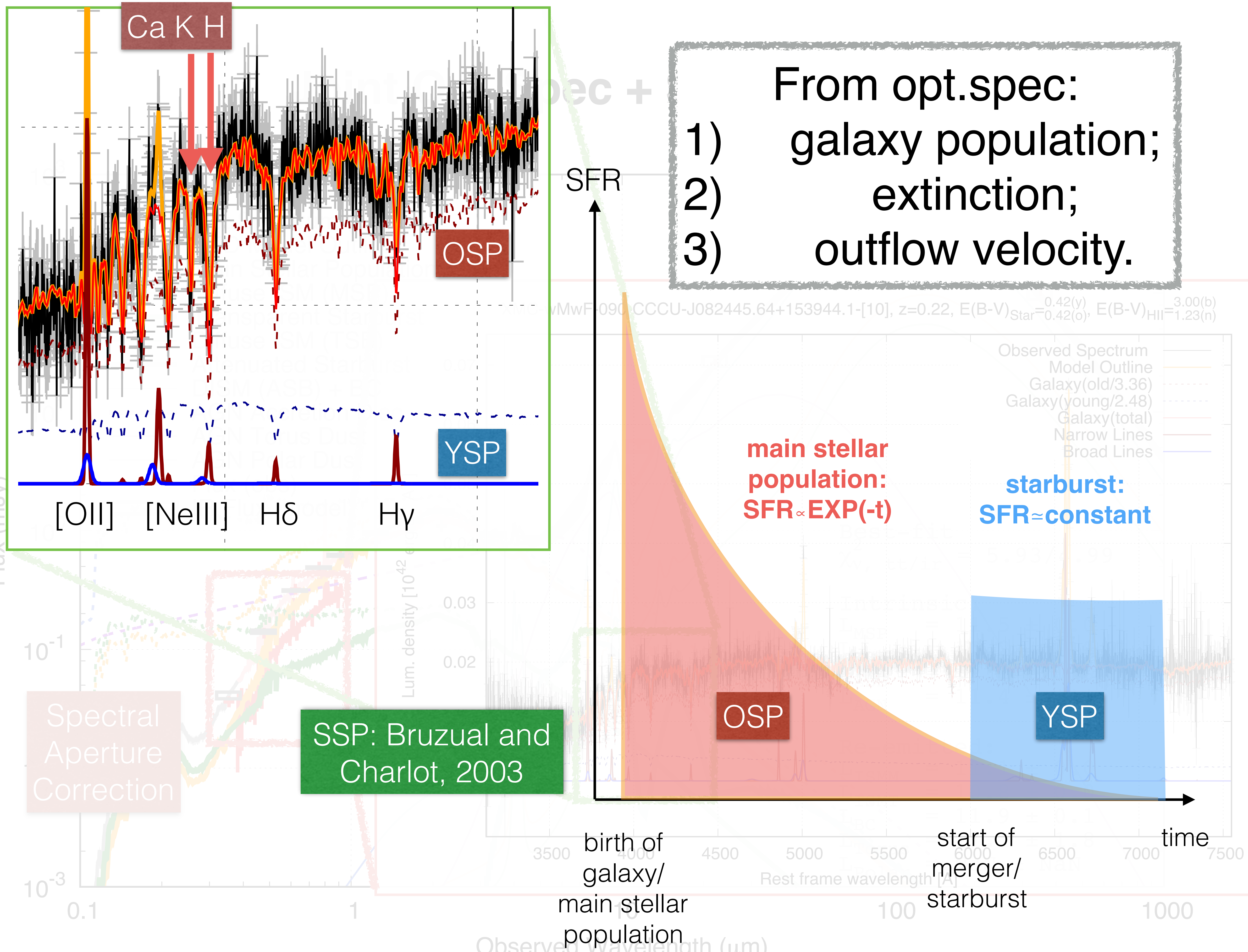




Ca K H
OSP
YSP
[OII]
[NeIII]
Hδ
Hγ
z=0.22
Observed Spectrum
Model Outline
Galaxy(old/3.36)
Galaxy(young/2.48)
Galaxy(total)
Narrow Lines
Broad Lines
Lum. density [10^42
0.03
0.02
0.01
0
3500
4000
4500
5000
5500
6000
6500
7000
7500
Rest frame wavelength [A]
Spectral Aperture Correction
Flux (mJy)
10^-1
10^-3
0.1
1
10
100
1000
Observed Wavelength (μm)
SED fitting

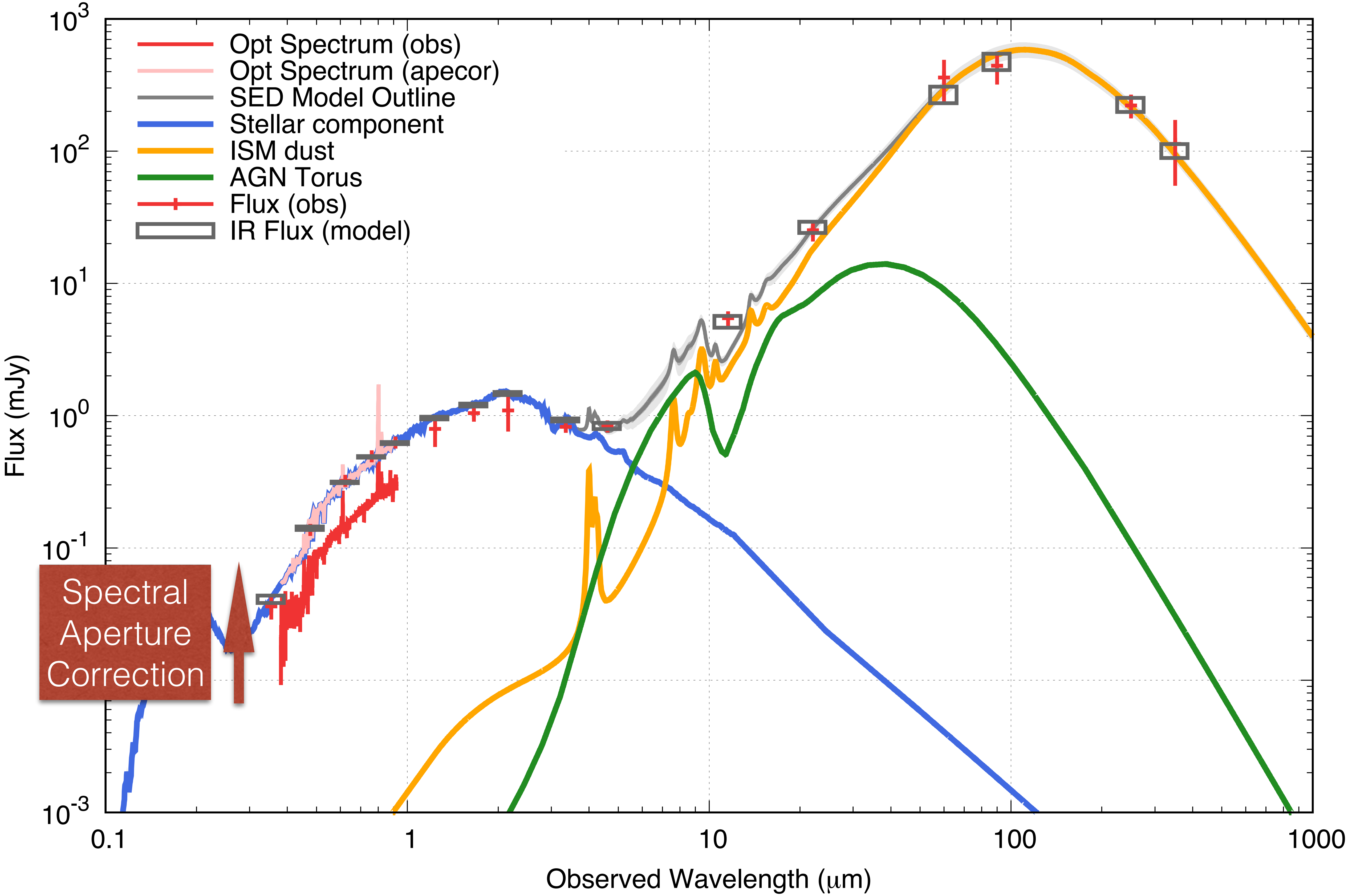


Ca K H
OSP
YSP
[OII]
[NeIII]
Hδ
Hγ
SFR
main stellar population: SFR∝EXP(-t)
starburst: SFR≃constant
OSP
YSP
SSP: Bruzual and Charlot, 2003
birth of galaxy/ main stellar population
start of merger/ starburst
time



From opt.spec:
1) galaxy population;
2) extinction;
3) outflow velocity.
Ca K H
OSP
YSP
[OII]
[NeIII]
Hδ
Hγ
SSP: Bruzual and Charlot, 2003
SFR
main stellar population: SFR∝EXP(-t)
starburst: SFR≃constant
OSP
YSP
birth of galaxy/ main stellar population
start of merger/ starburst
time

Joint Opt.Spec + SED fitting



Joint Opt.Spec + SED fitting

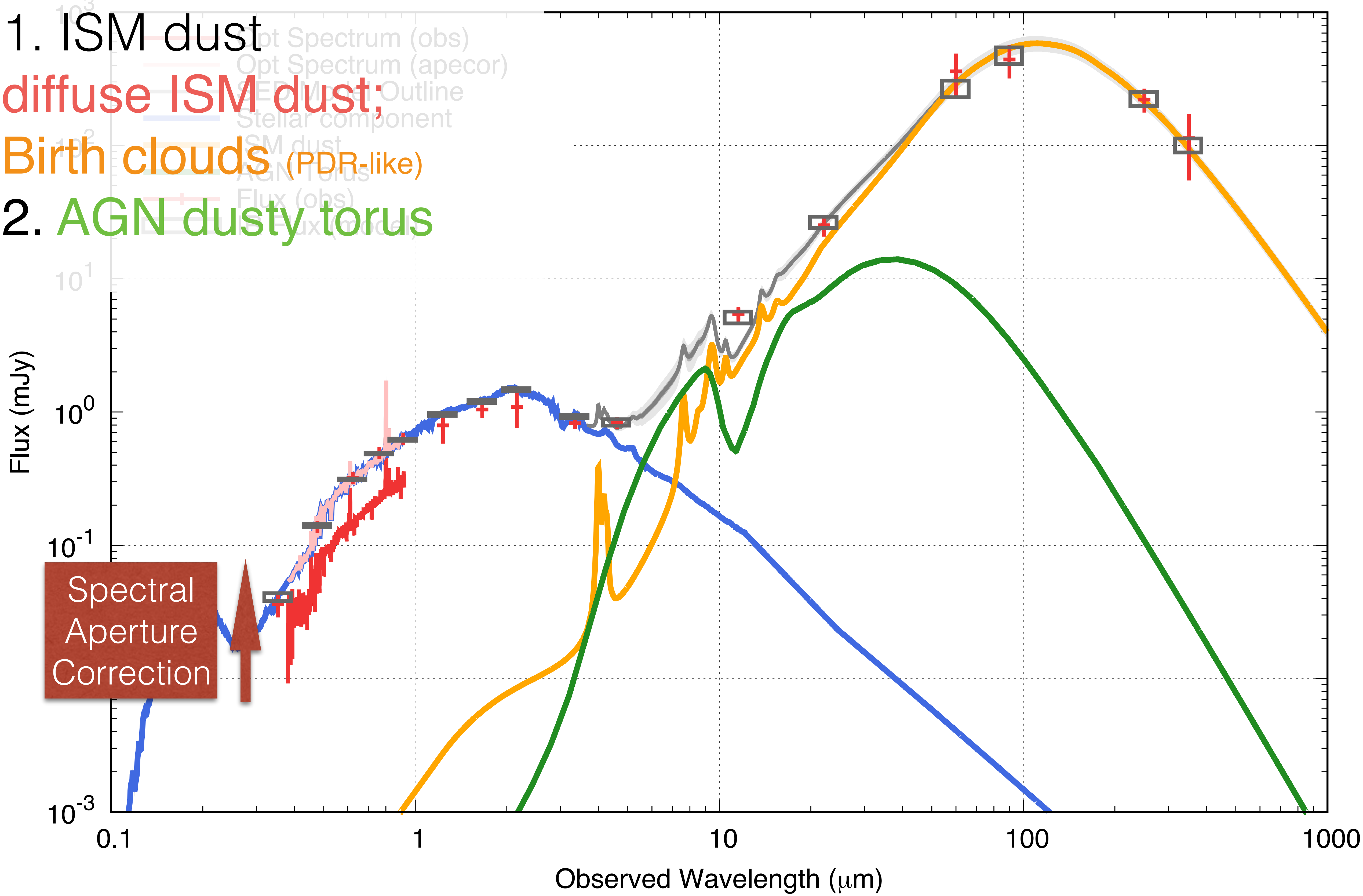
Two dust emitter:

1. ISM dust

diffuse ISM dust;

Birth clouds (PDR-like)

2. AGN dusty torus



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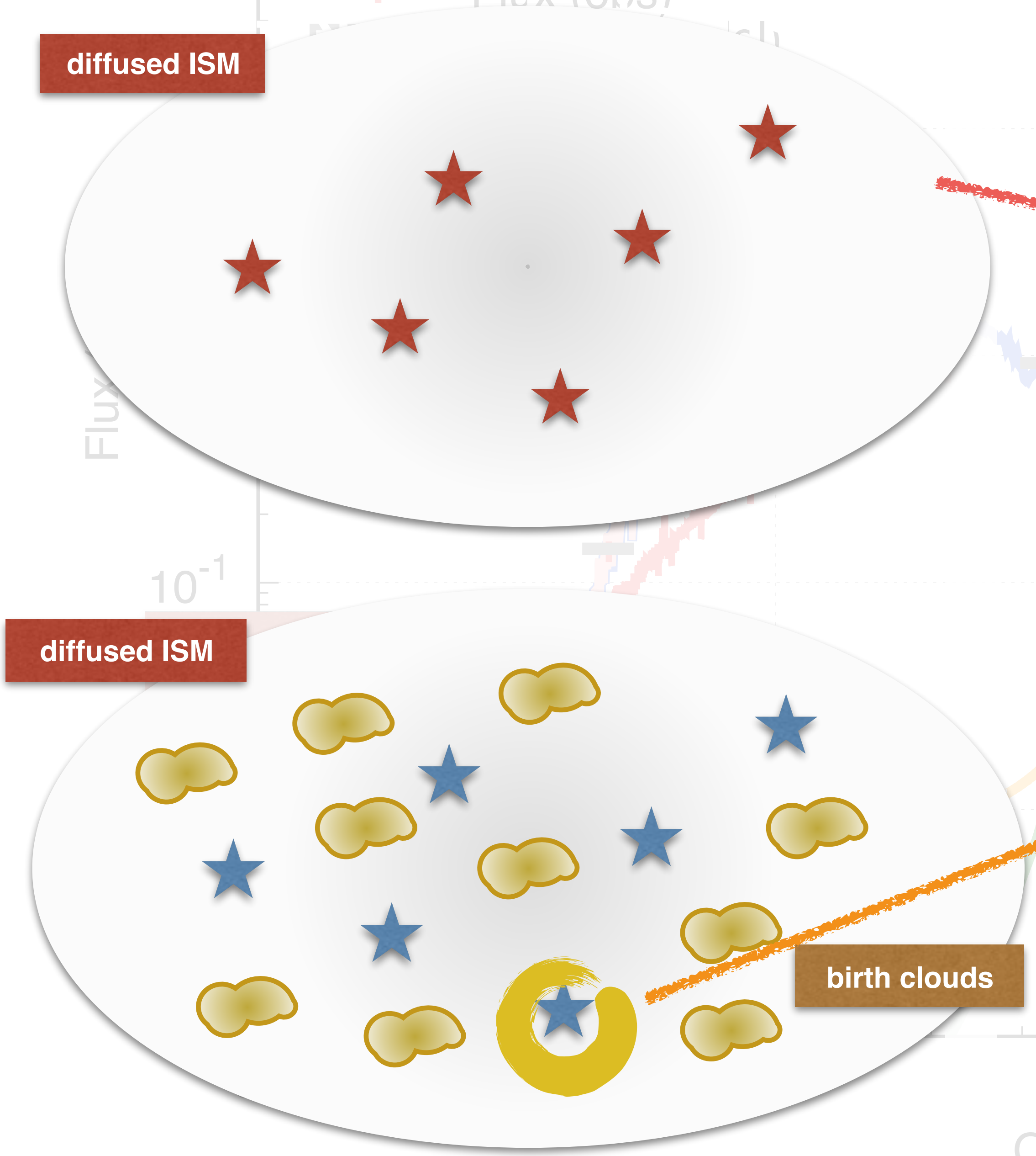
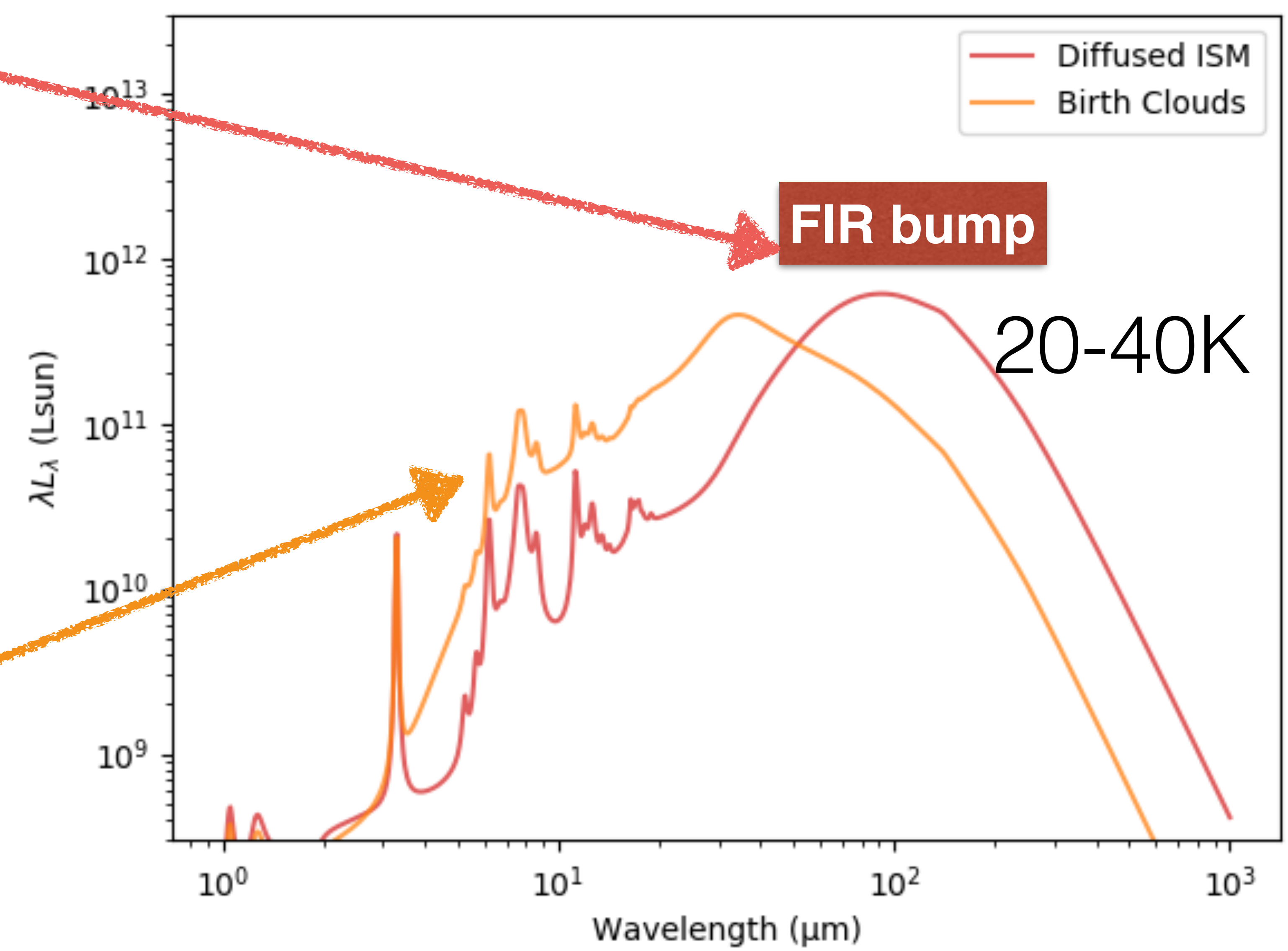


Calculated from THEMIS dust model



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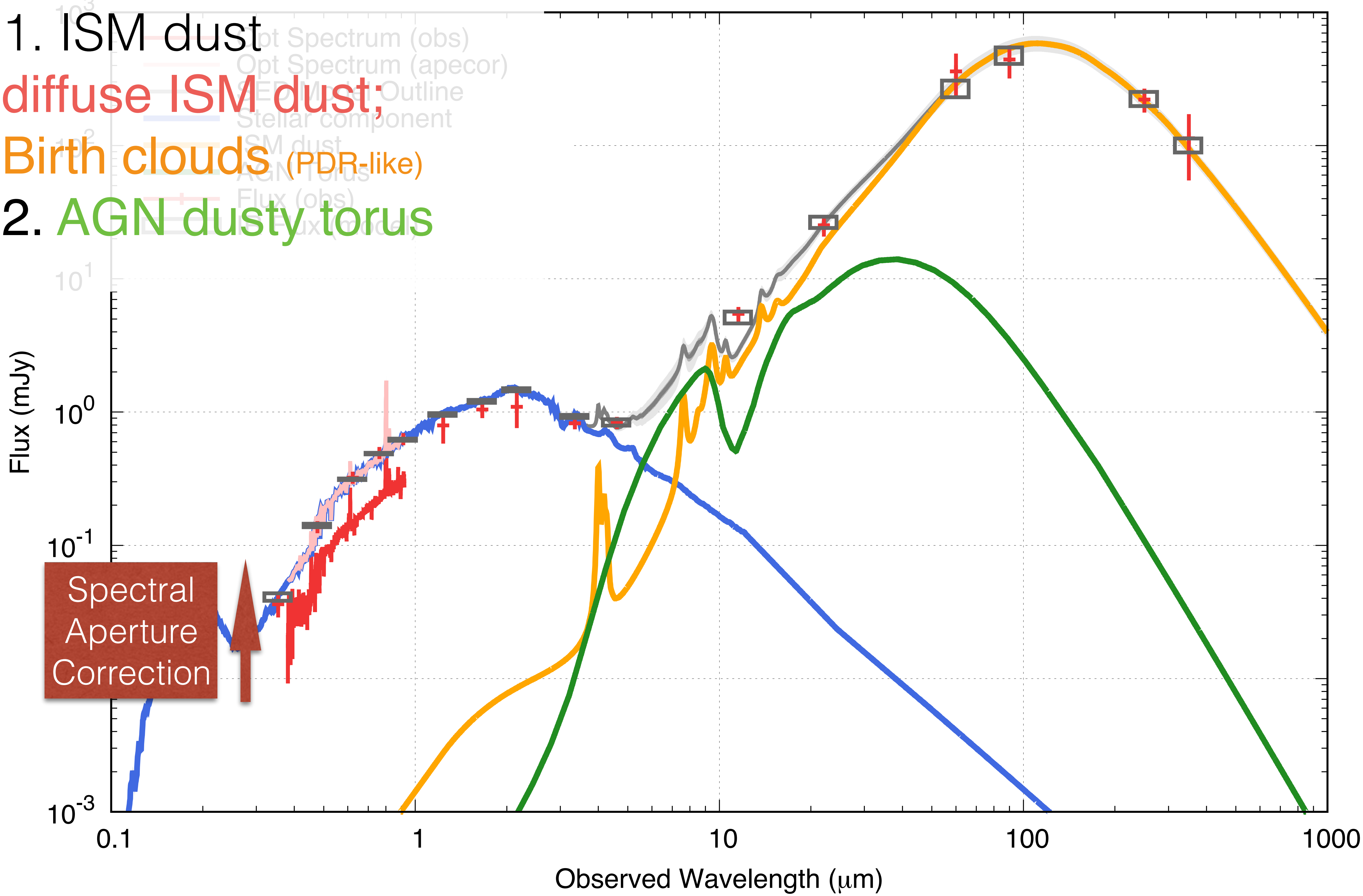

Joint Opt.Spec + SED fitting

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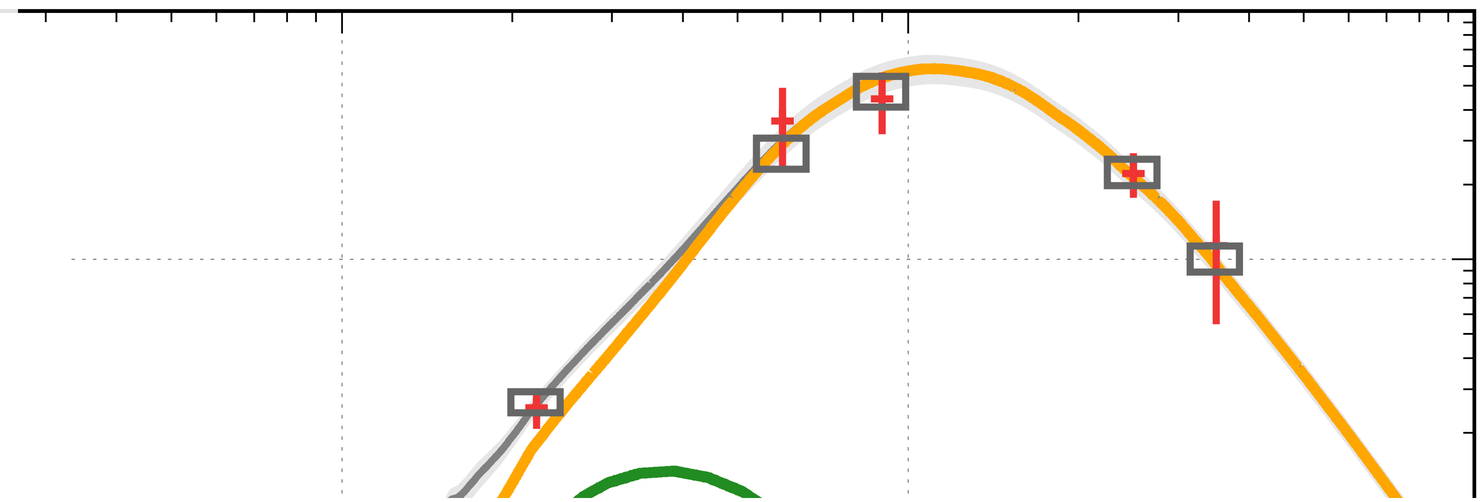
diffuse ISM dust;
Birth clouds (PDR-like)
2. AGN dusty torus

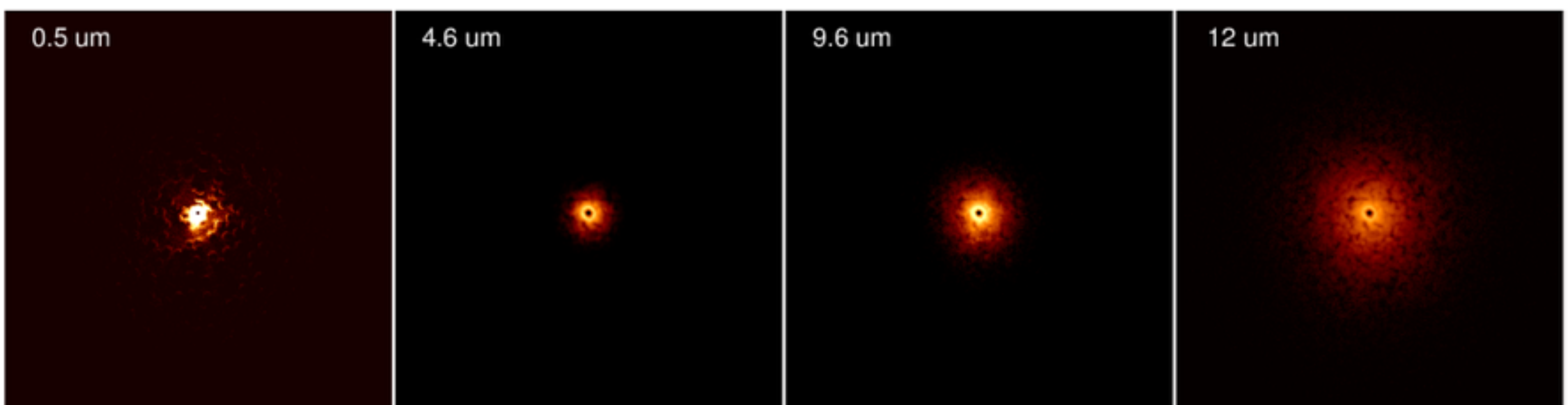


SKIRTOR 2.0

Stalevski et al. (2012,2016)

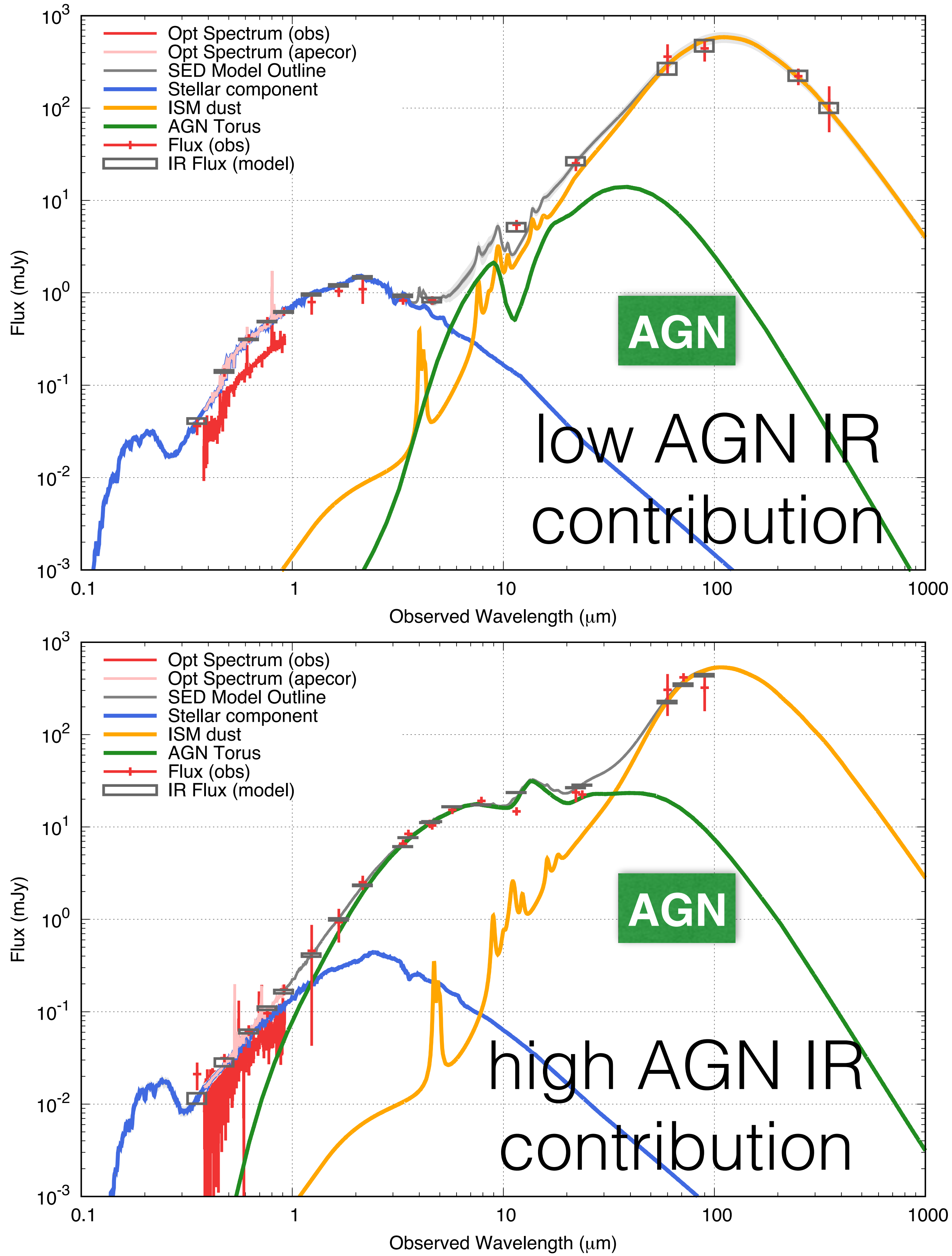
This website is home of SKIRTOR -- a library of emission models of the AGN dusty torus, calculated with SKIRT, state-of-the-art radiative transfer code based on Monte Carlo technique.

Emission models are originally presented in Stalevski et al. (2012a), with an update in Stalevski et al. (2016).



Torus model images at different wavelengths.

Joint Opt.Spec + SED fitting



From opt.spec:

1) galaxy population;
2) extinction;
3) outflow velocity.

From SED decomp.:

1) AGN luminosity;
2) Starburst lum., SFR

What about the results?

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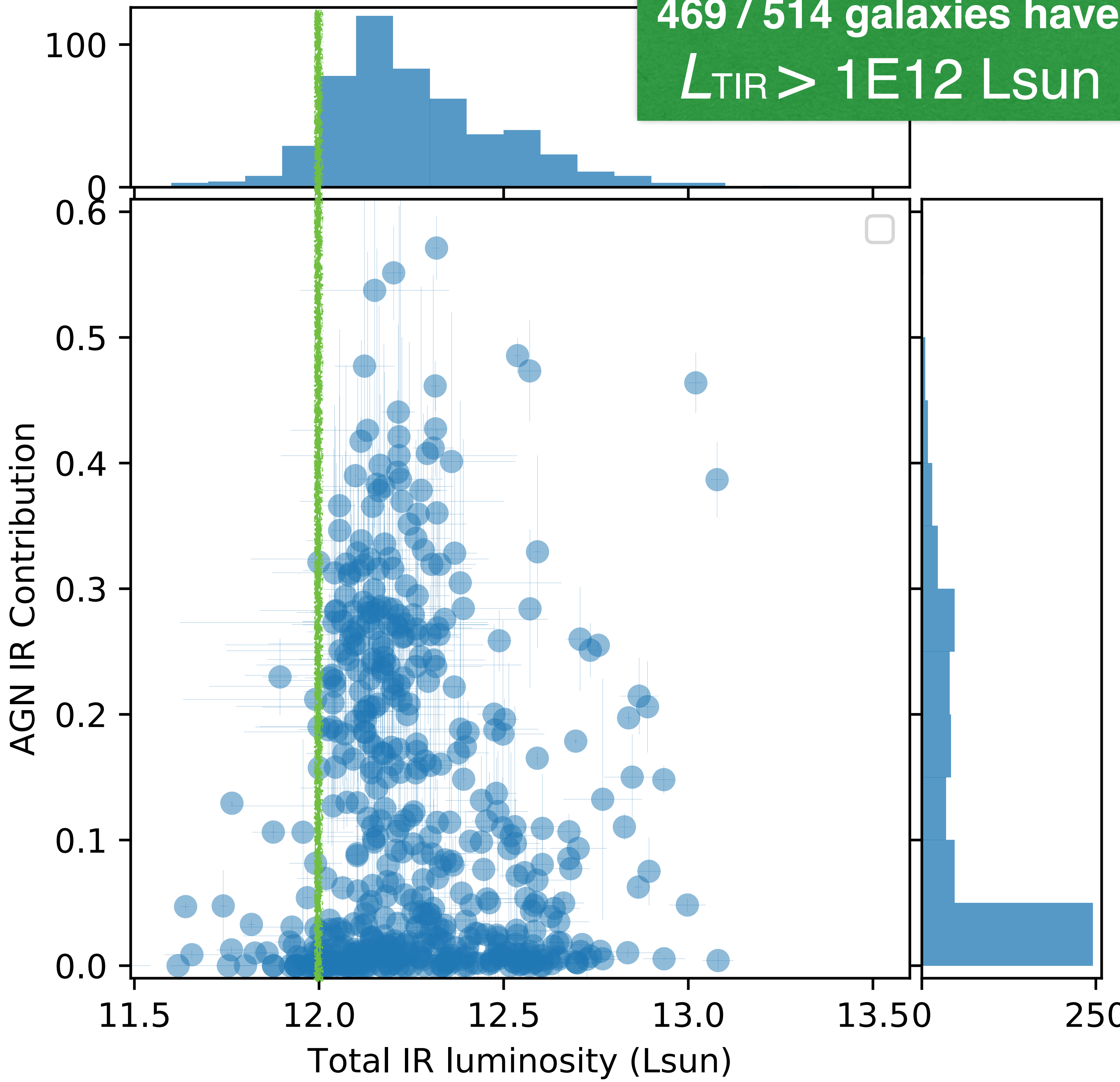
General properties of Spec+SED fitting

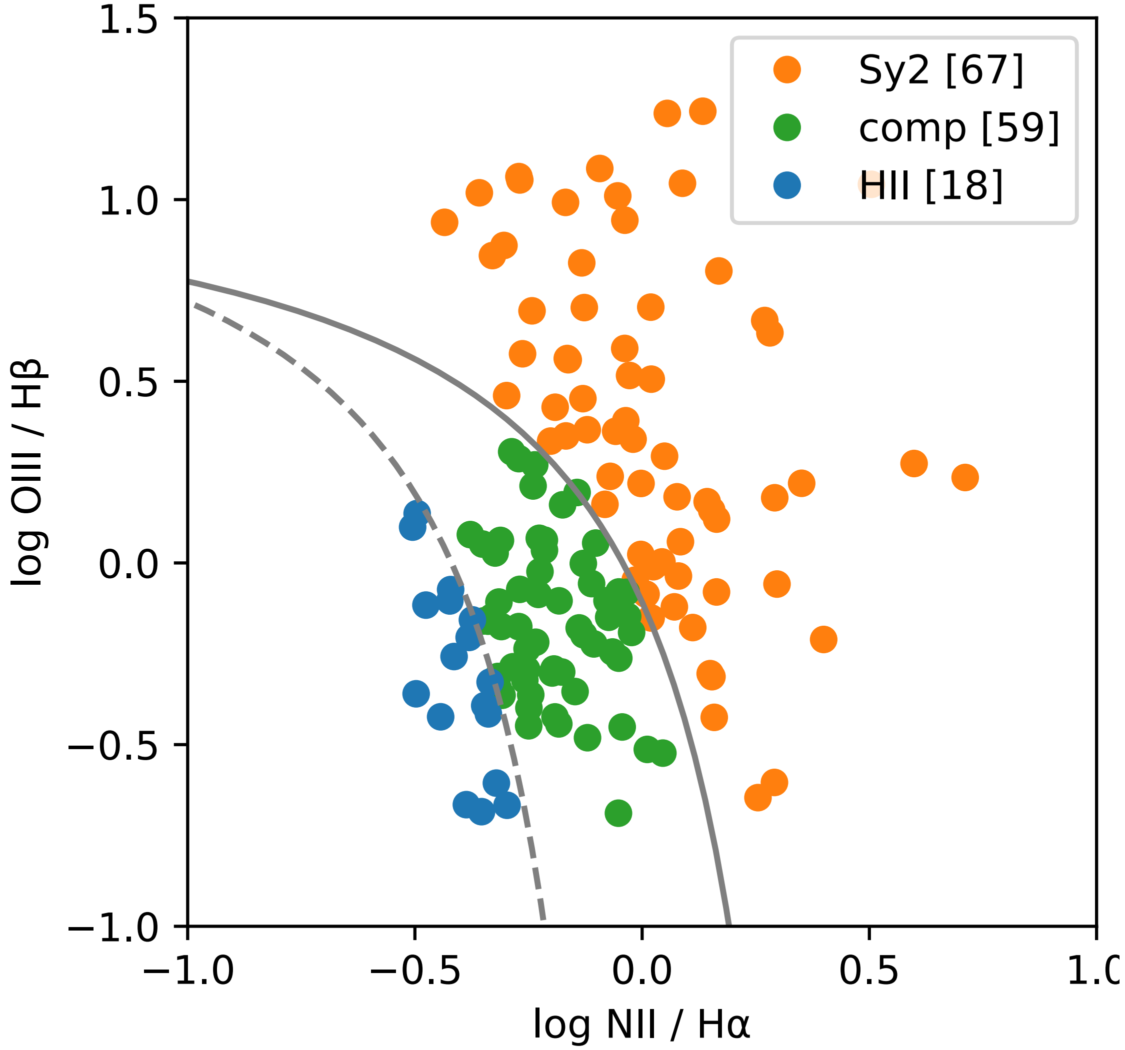


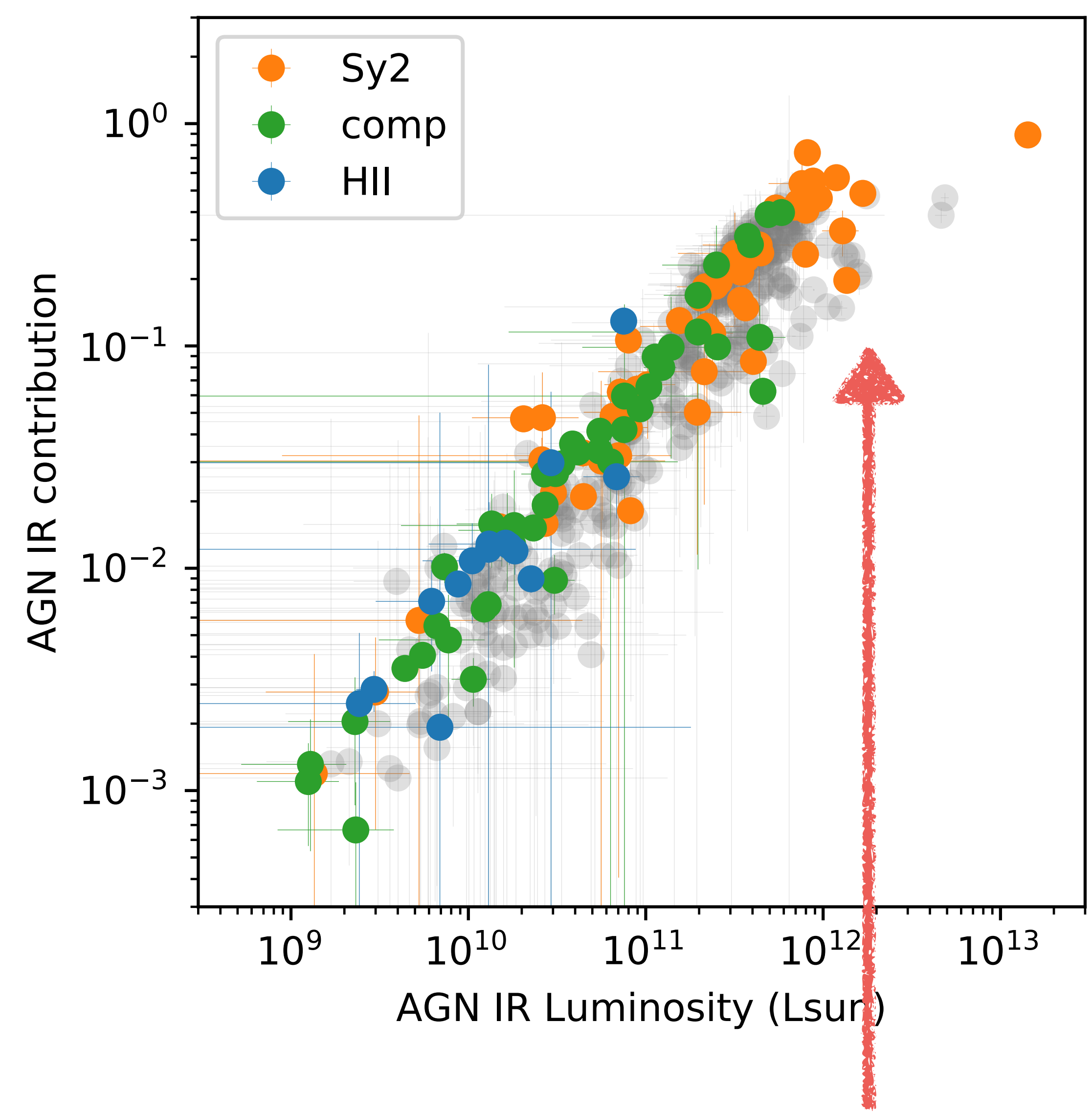
469 / 514 galaxies have
L_{TIR} > 1E12 Lsun

AGN contribution
= L_{torus} / L_{TIR}

General properties of Spec+SED fitting

AGN contribution with BPT diagram check



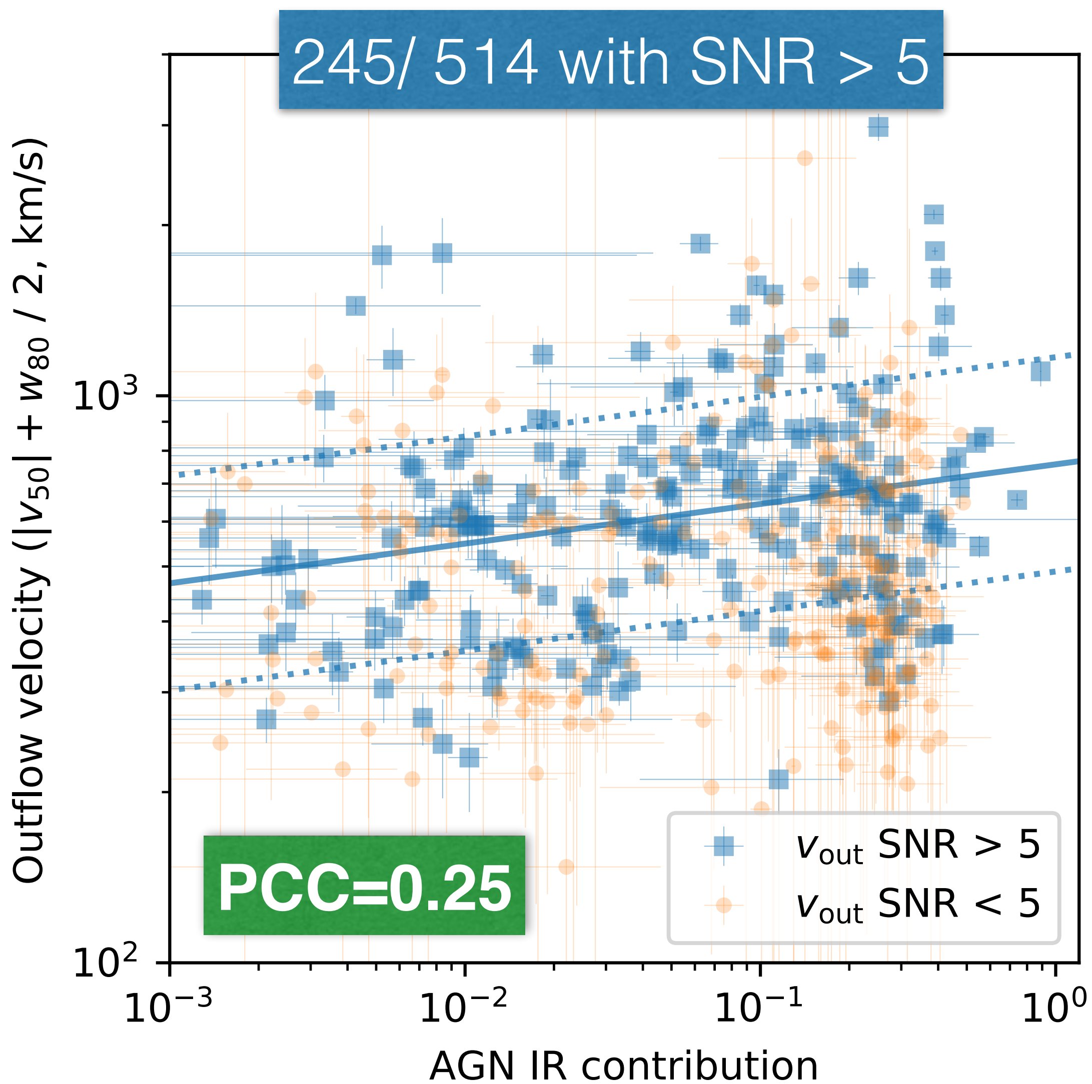


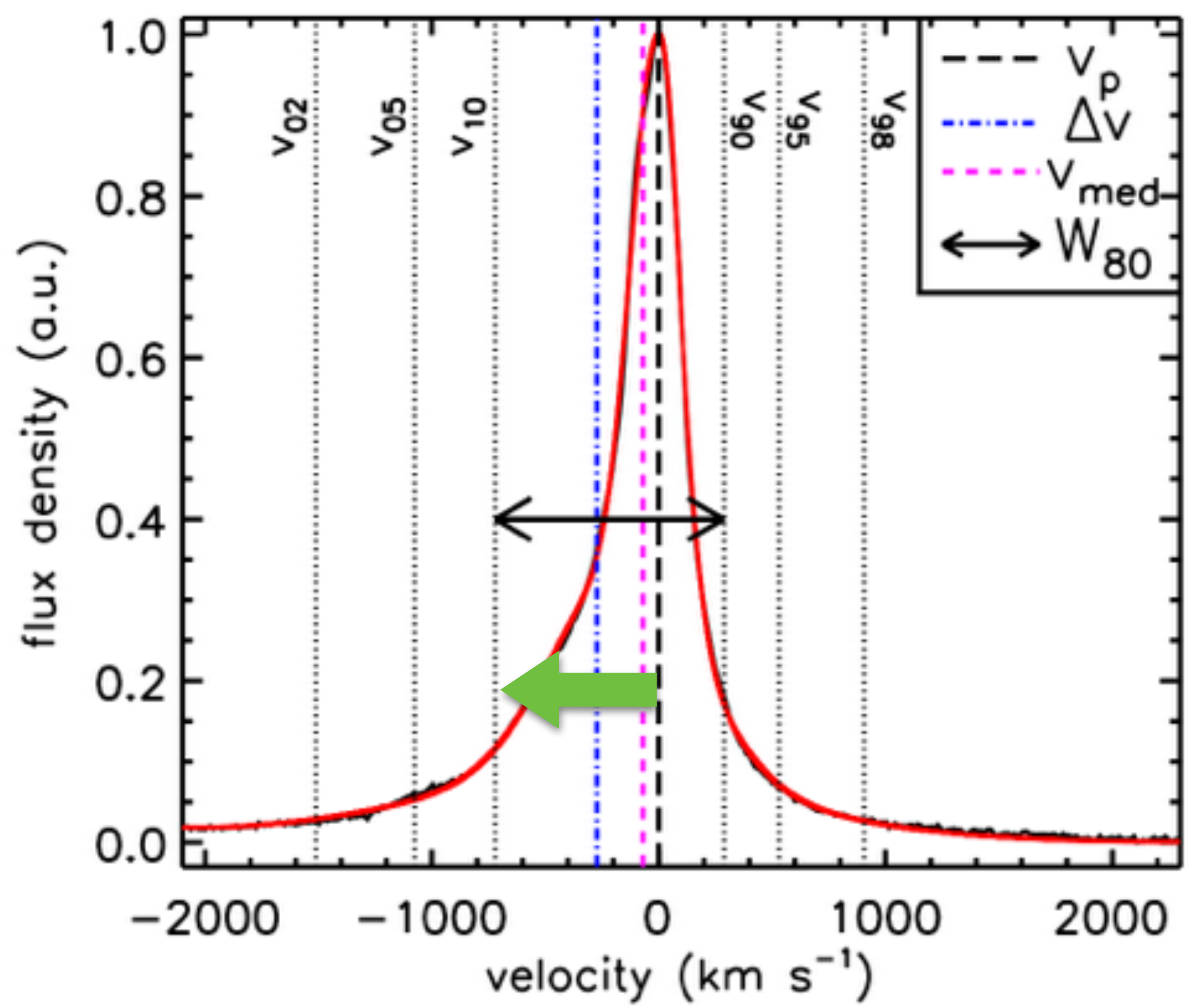
144 / 514 galaxies have
[NII] flux SNR > 5

AGN dominates the ionization as it becomes luminous.

Outflow velocity vs. AGN intensity

Outflow can be measured from the shift and width of emission lines. [OIII]5007 is one of the widely adopted indicators.





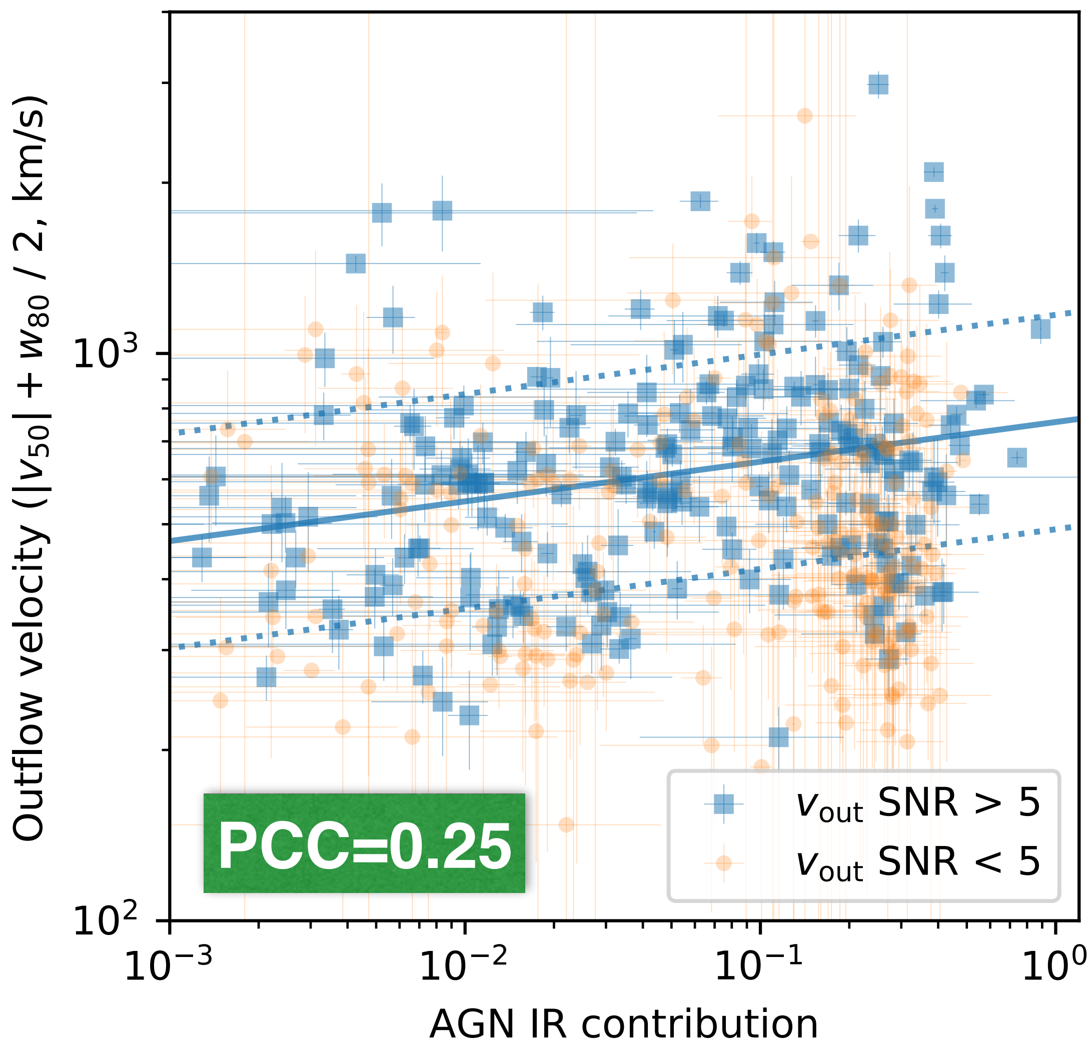
PCC = Pearson correlation coefficient

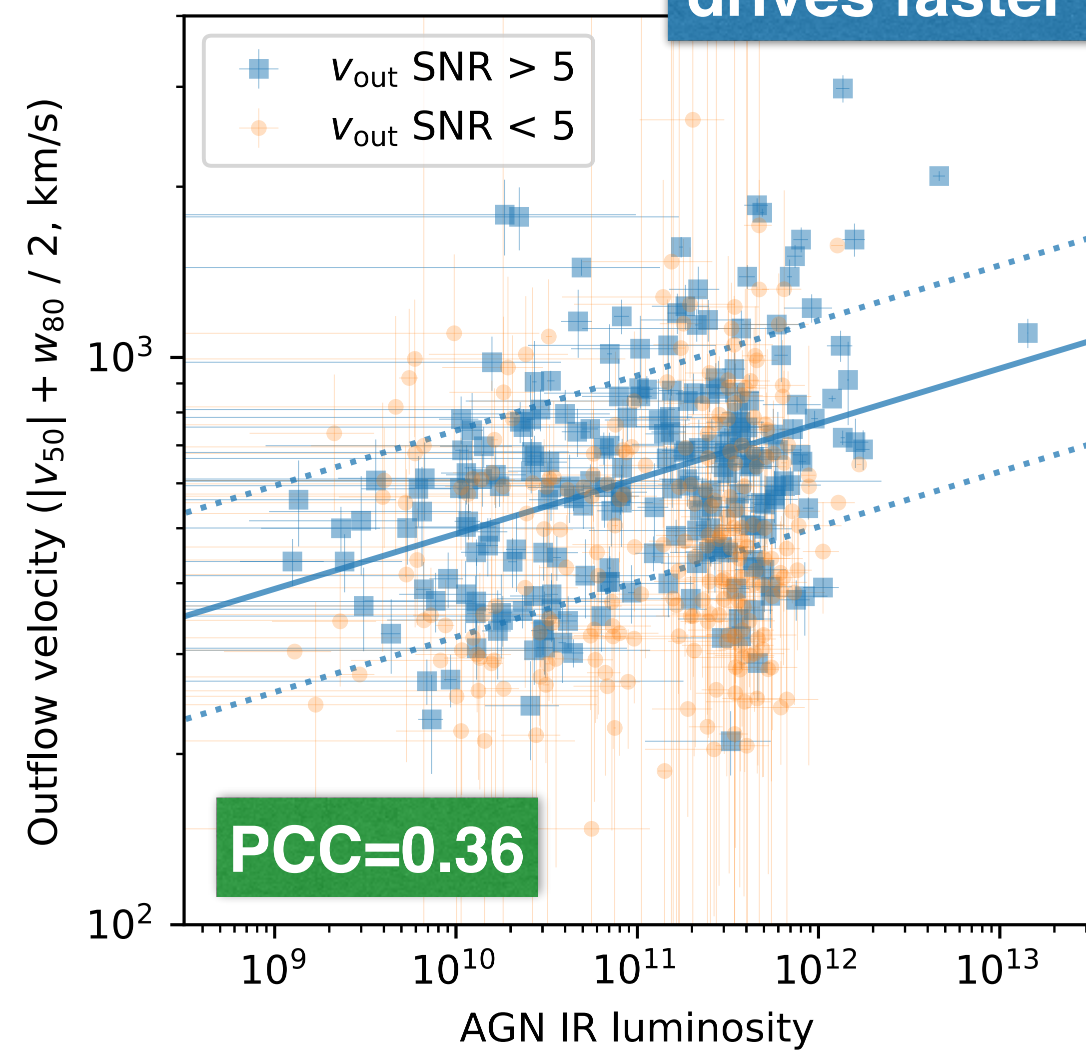
$V_{out} = |V_{50}| + W_{80} / 2$

Outflow velocity vs. AGN intensity

Outflow can be measured from the shift and width of emission lines.
[OIII]5007 is one of the widely adopted indic

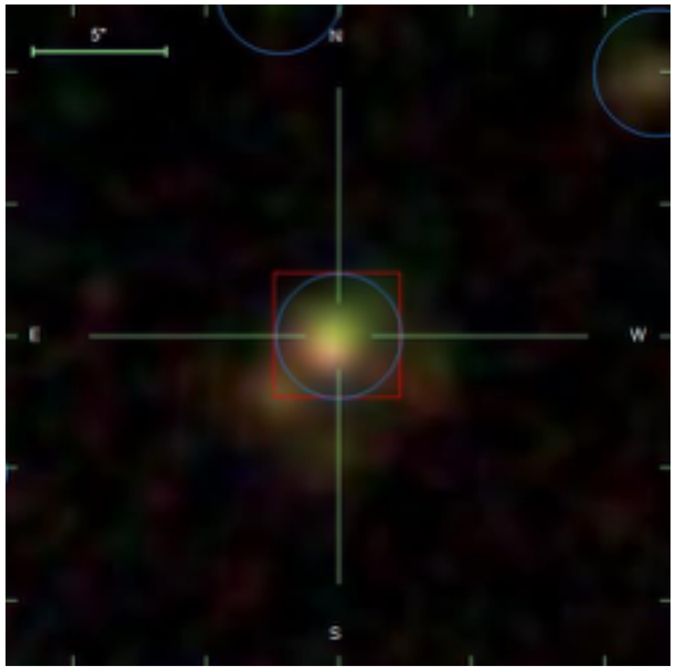
More powerful AGN drives faster outflow.

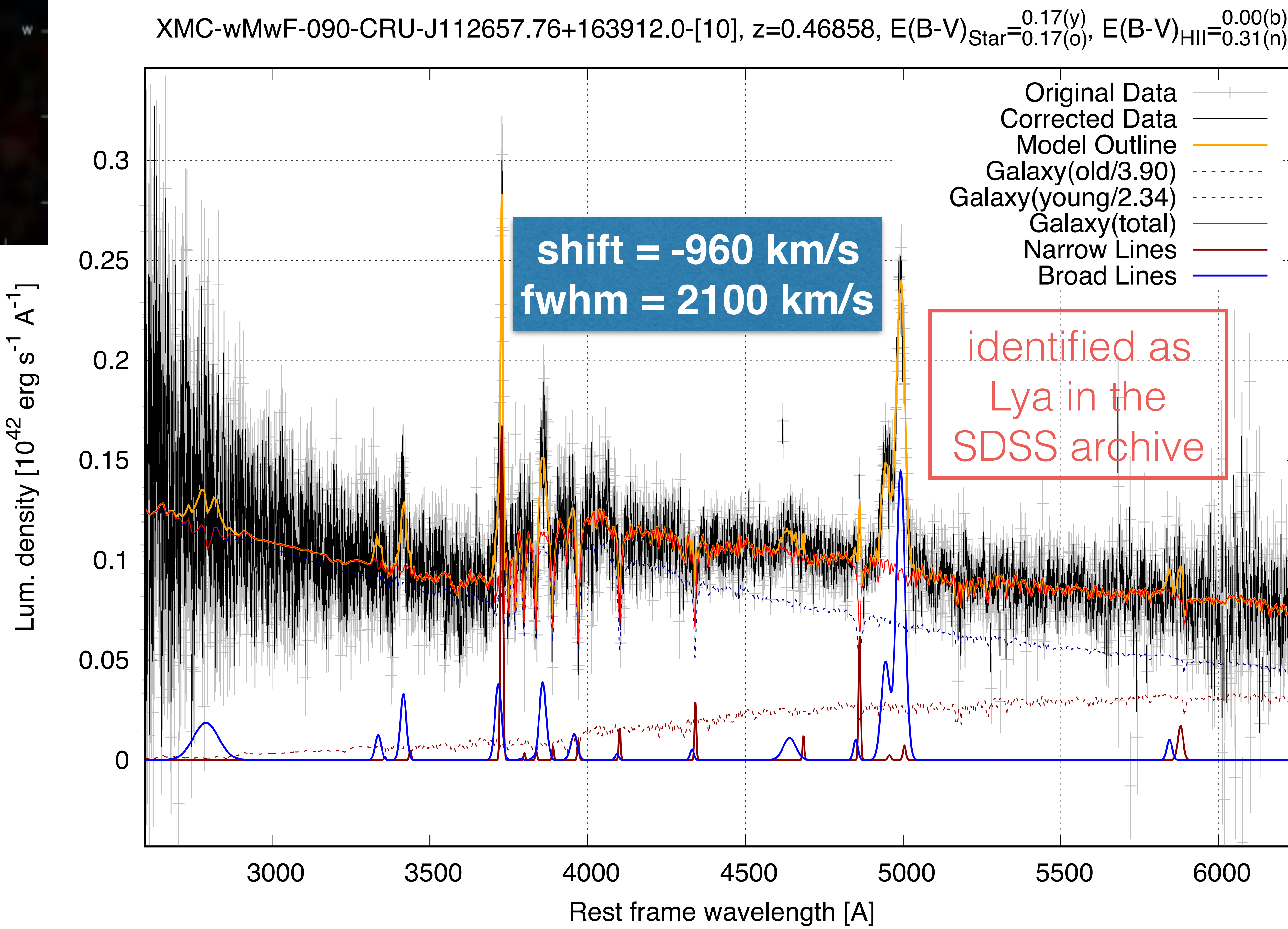




Outflow velocity is more tightly related with absolute AGN intensity (LAGN),
and less tightly related with relative intensity (fAGN).

Outflow velocity vs. AGN intensity





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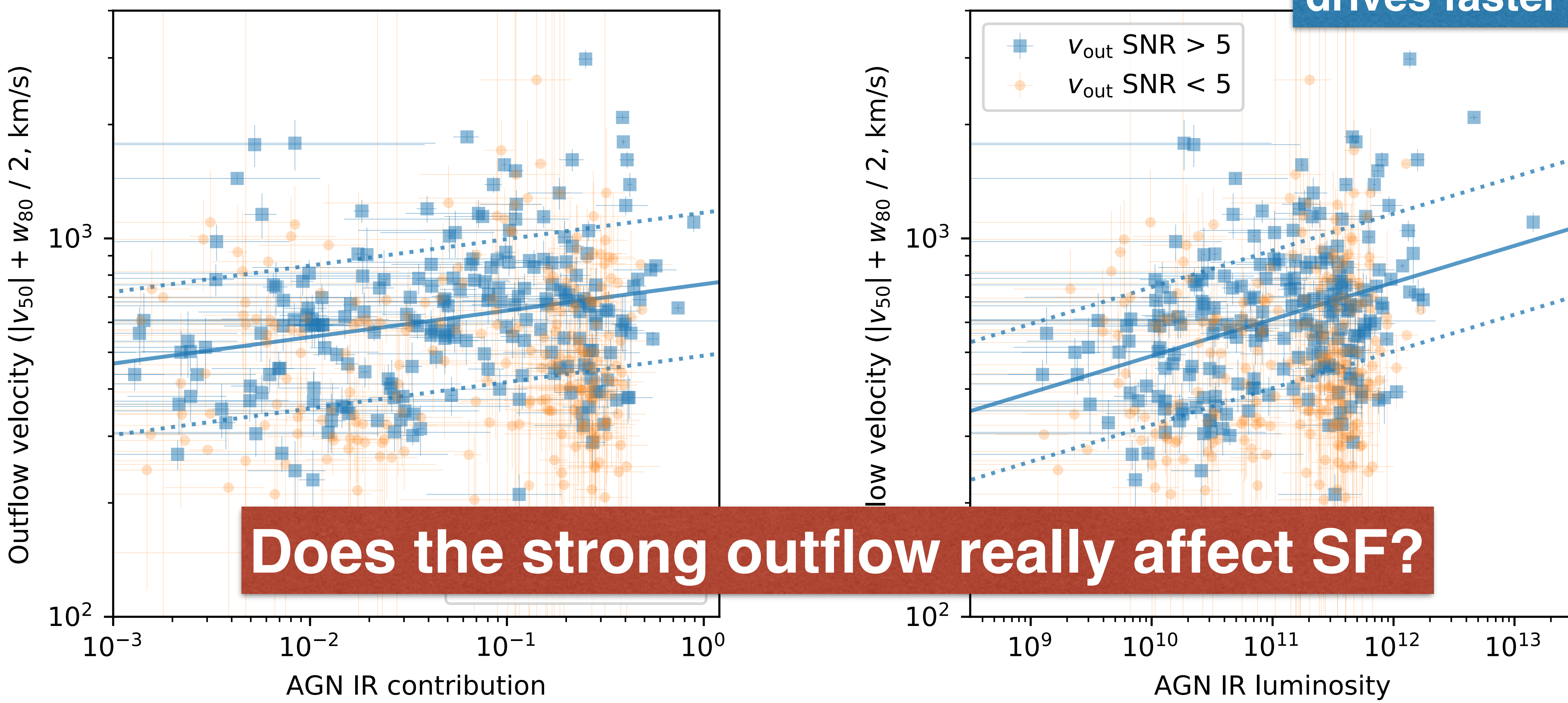
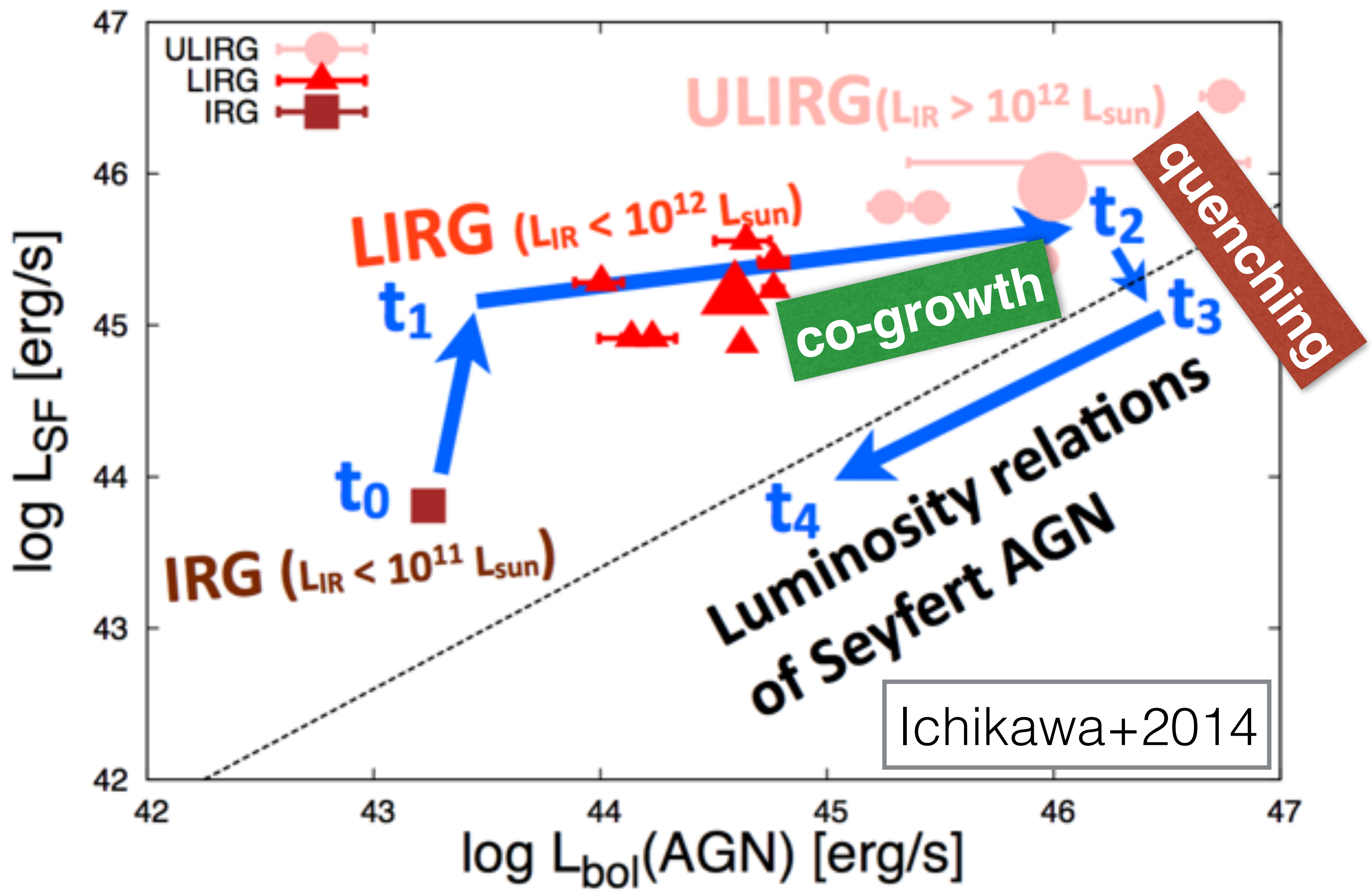


Does the strong outflow really affect SF?

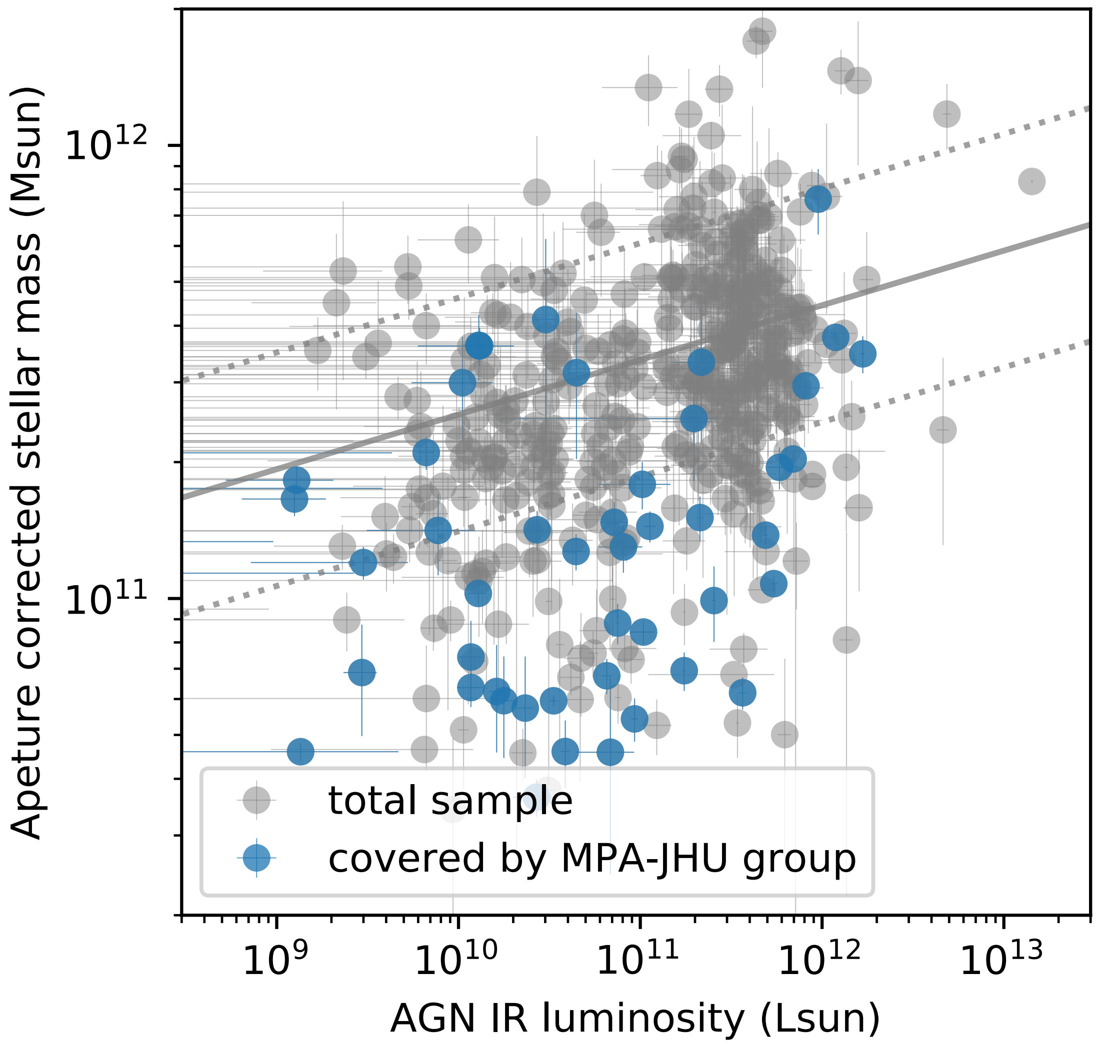
Outflow velocity is more tightly related with absolute AGN intensity (LAGN),
and less tightly related with relative intensity (fAGN).

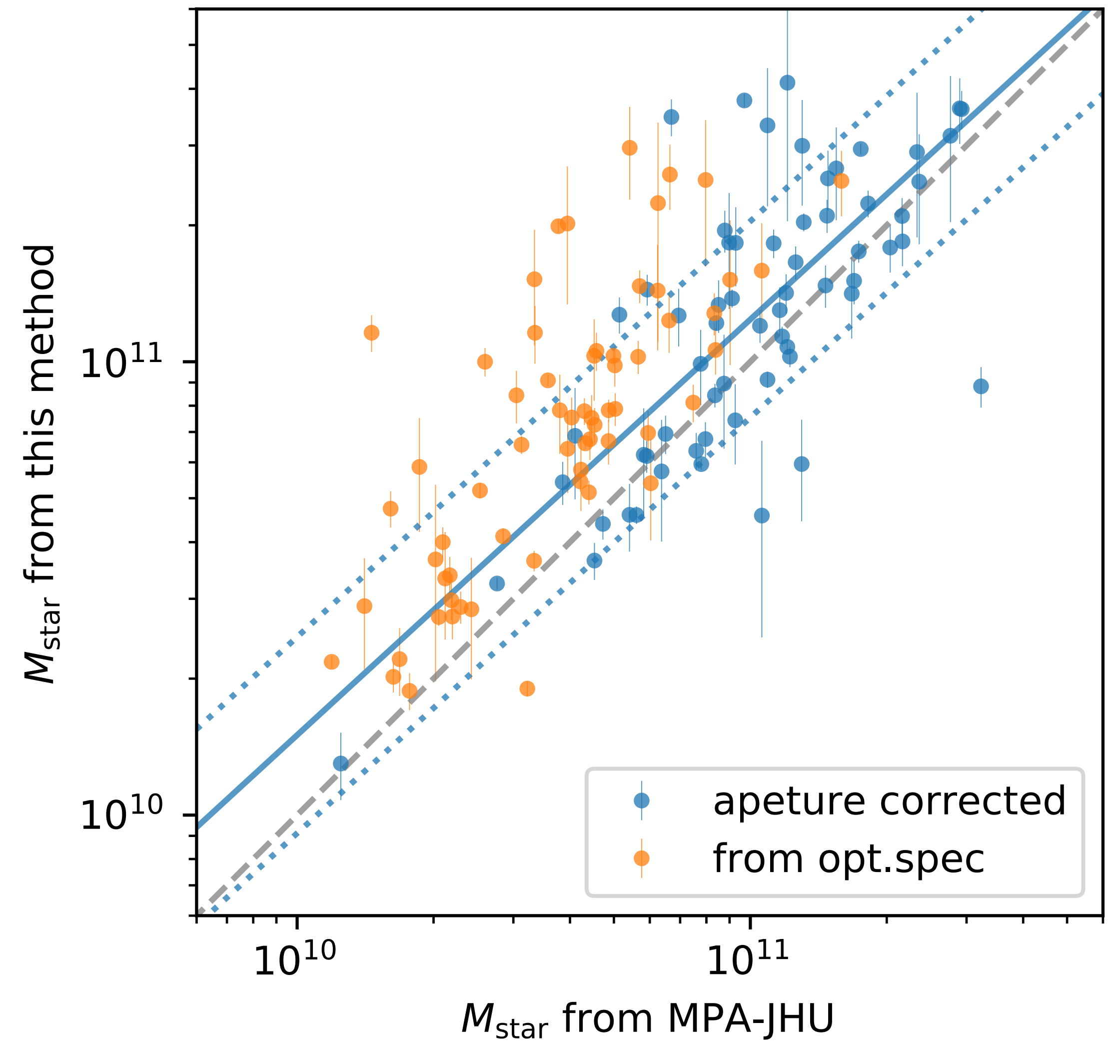
Galaxy properties vs. AGN intensity



During ULIRG period,
Q1: Does the AGN(SMBH) co-grow with host galaxies?
Q2: Does the feedback really take place?

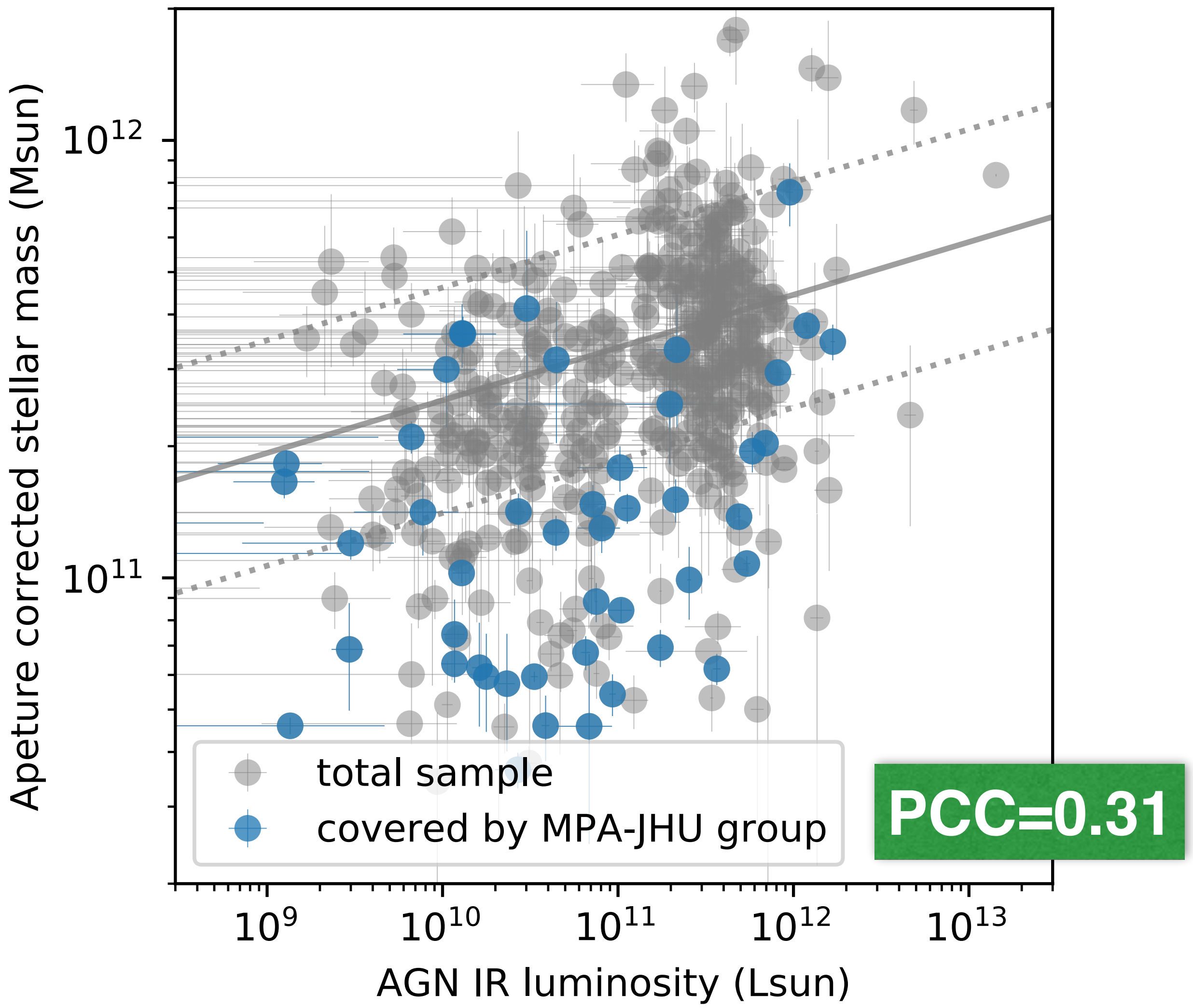
Galaxy properties vs. AGN intensity

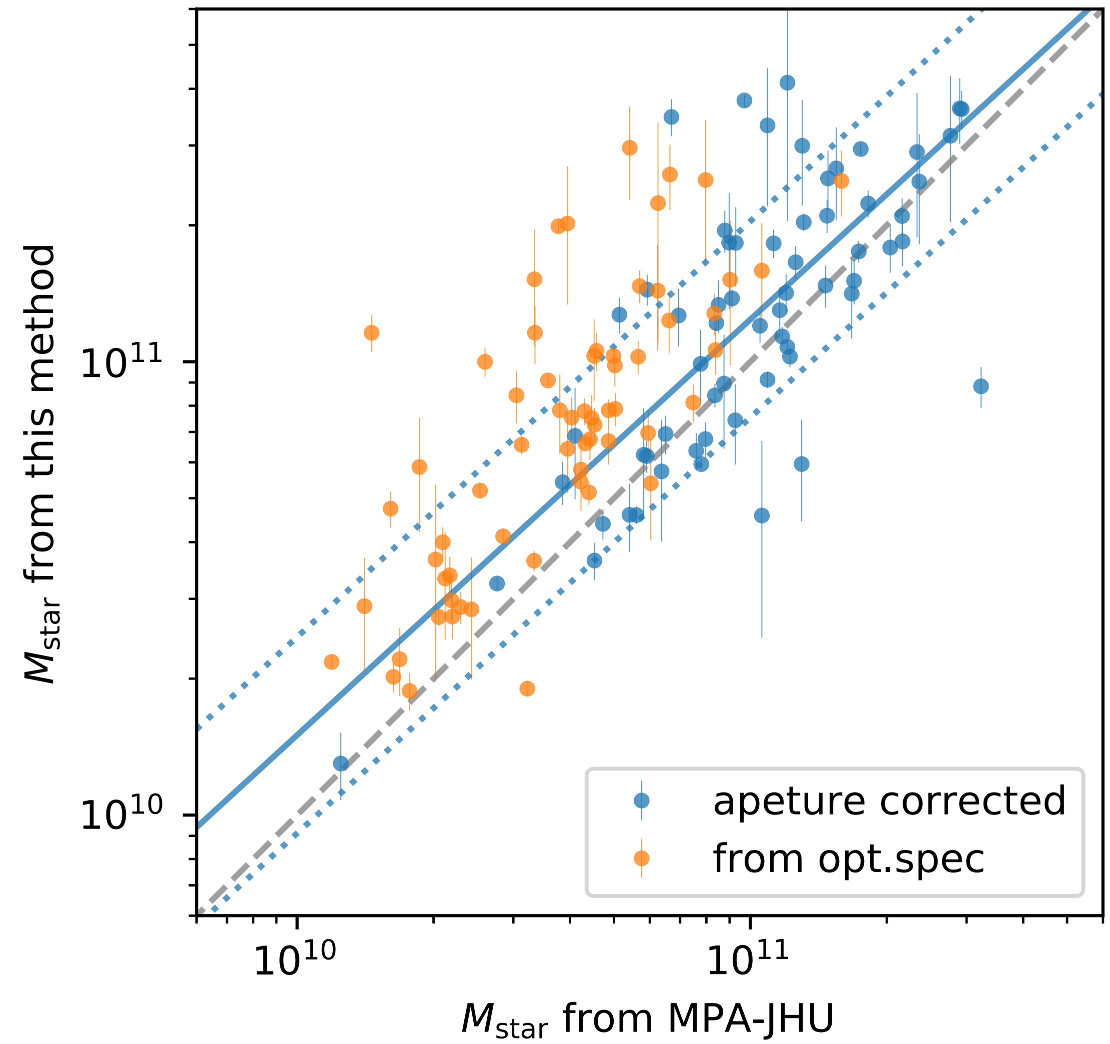




During ULIRG stage,
Q1: co-growth ?
Q2: feedback ?

Galaxy properties vs. AGN intensity

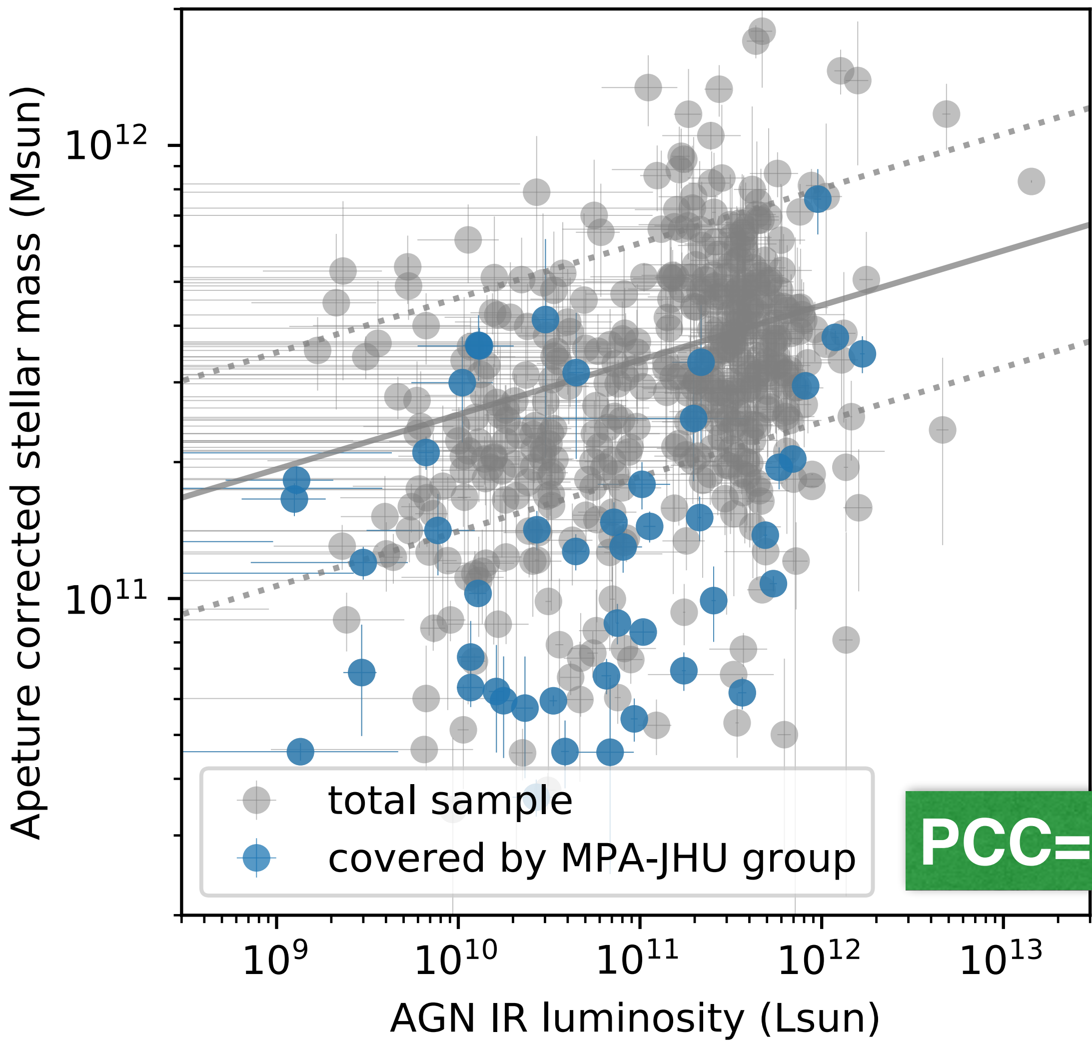




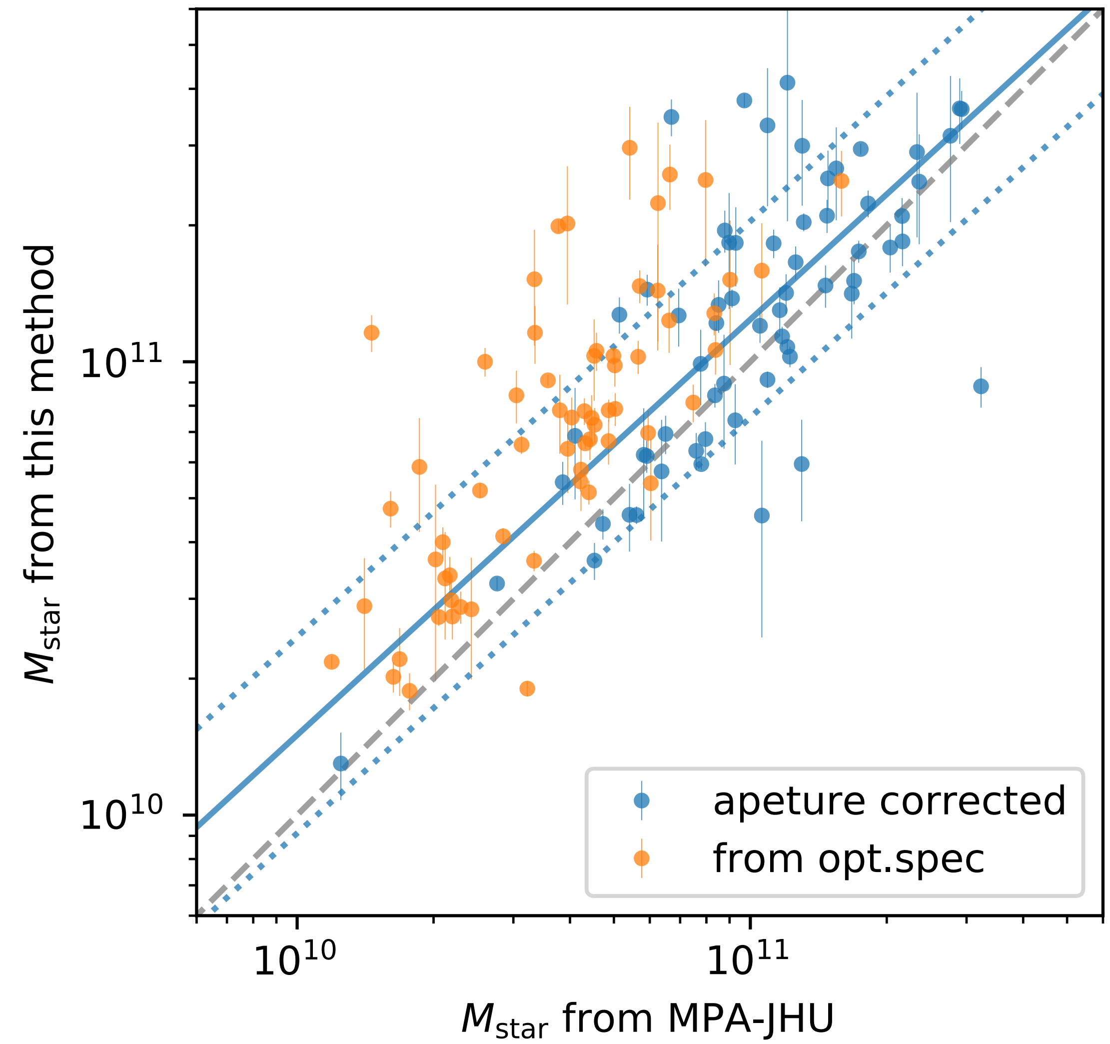
The most luminous AGN locates in the most massive galaxies.

During ULIRG stage,
Q1: co-growth ?
Q2: feedback ?

Galaxy properties vs. AGN intensity



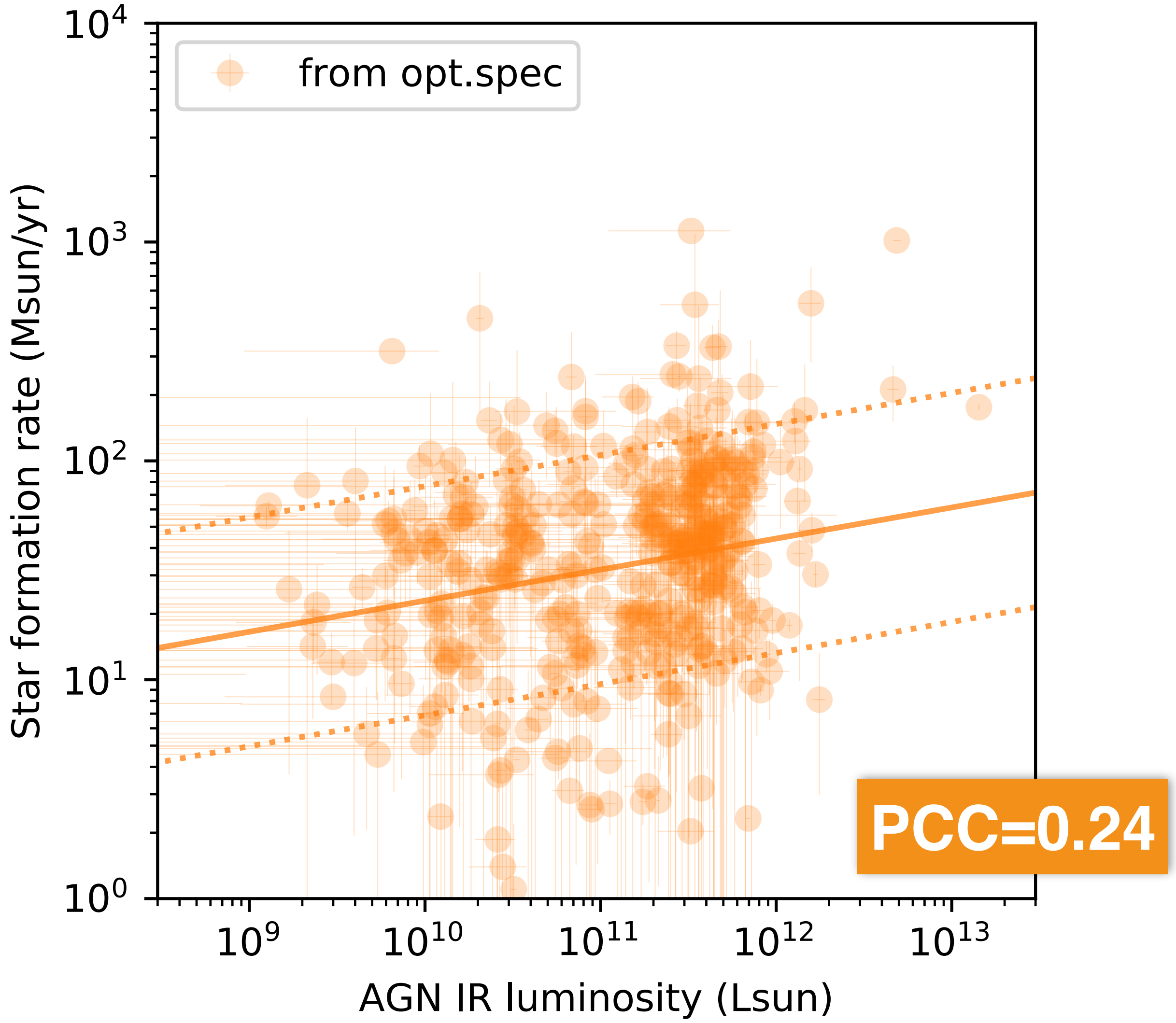
PCC=0.31



The most luminous AGN locates in the most massive galaxies.

During ULIRG stage,
Q1: co-growth ? **Yes**
Q2: feedback ?

Galaxy properties vs. AGN intensity



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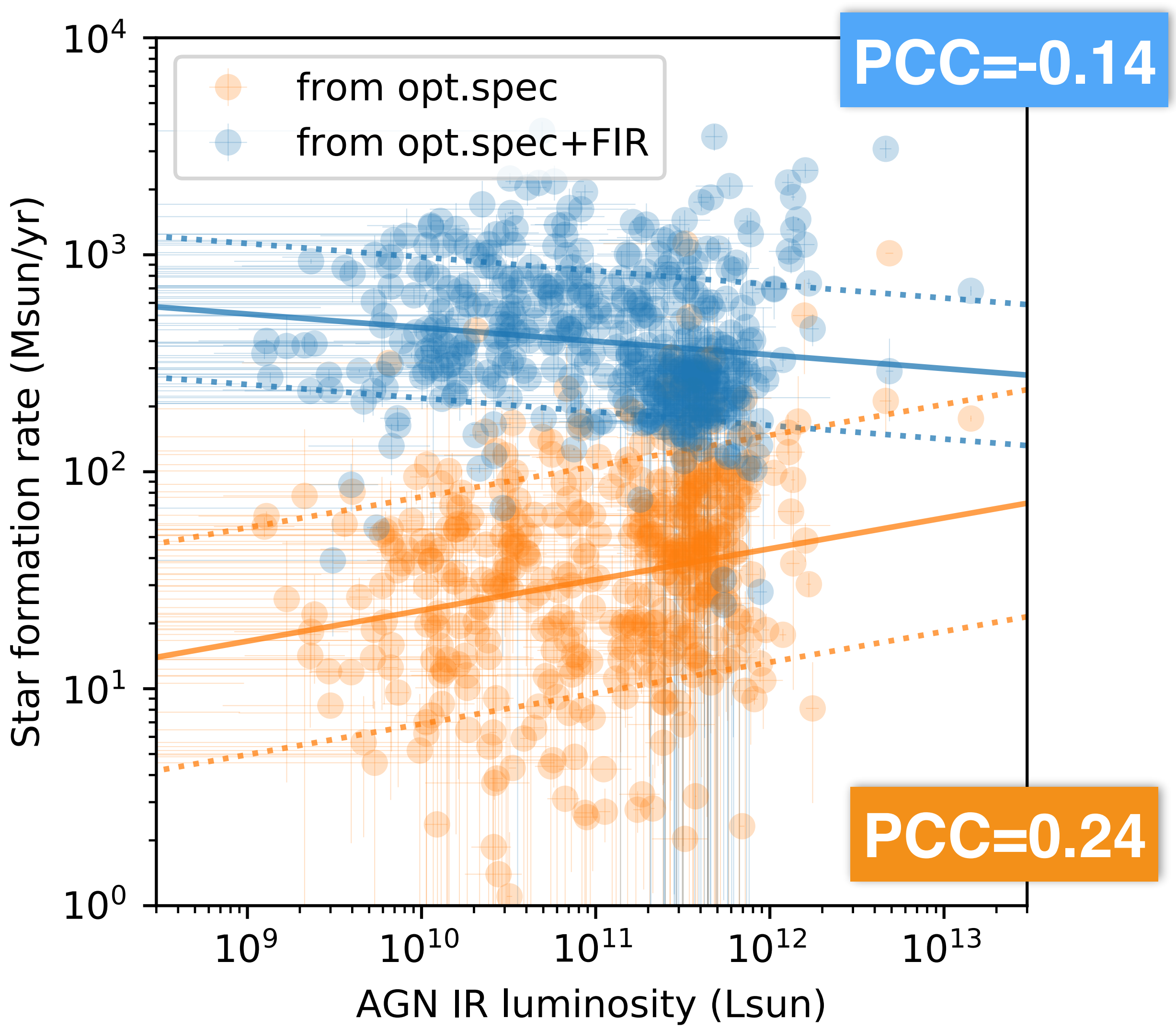

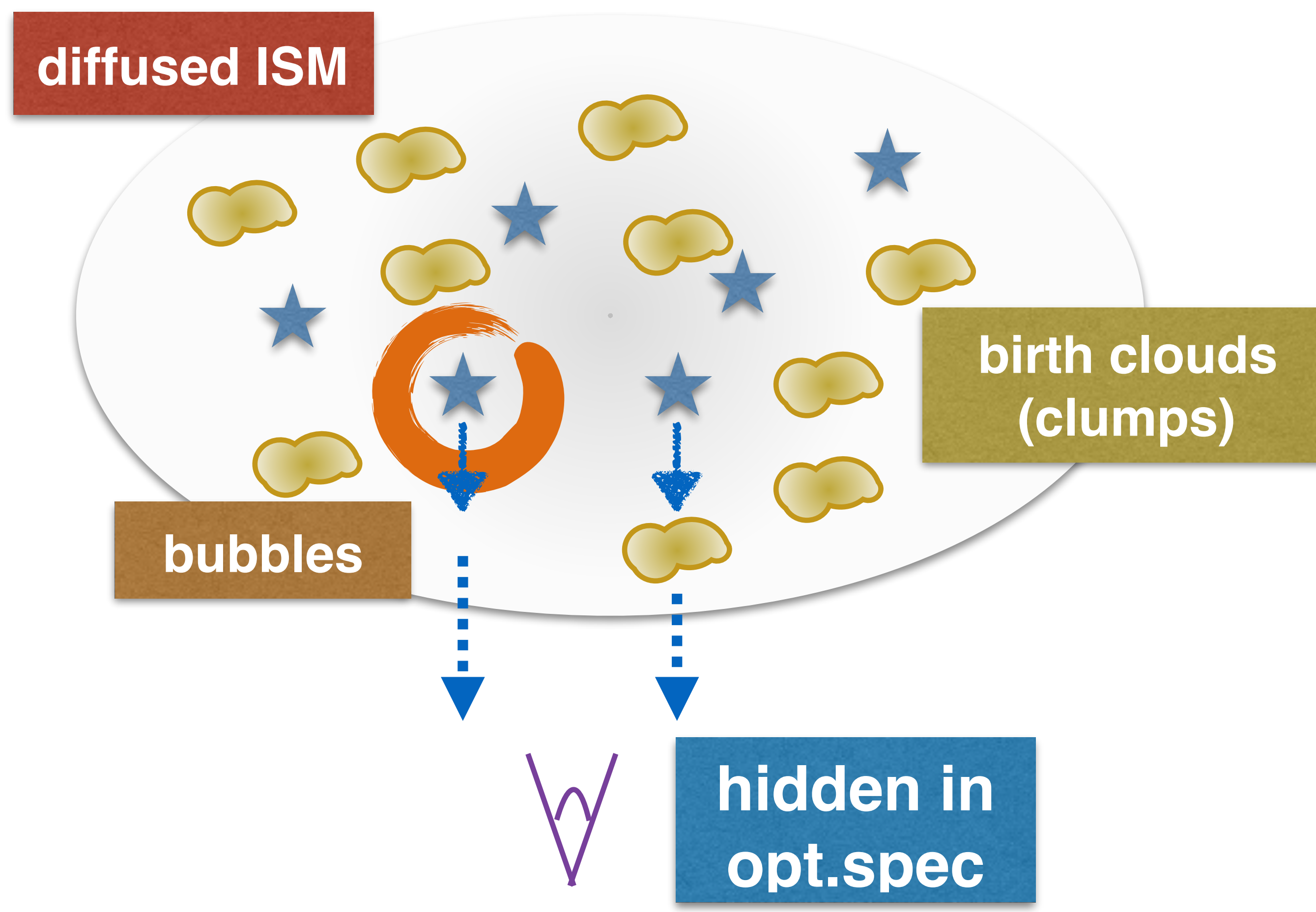

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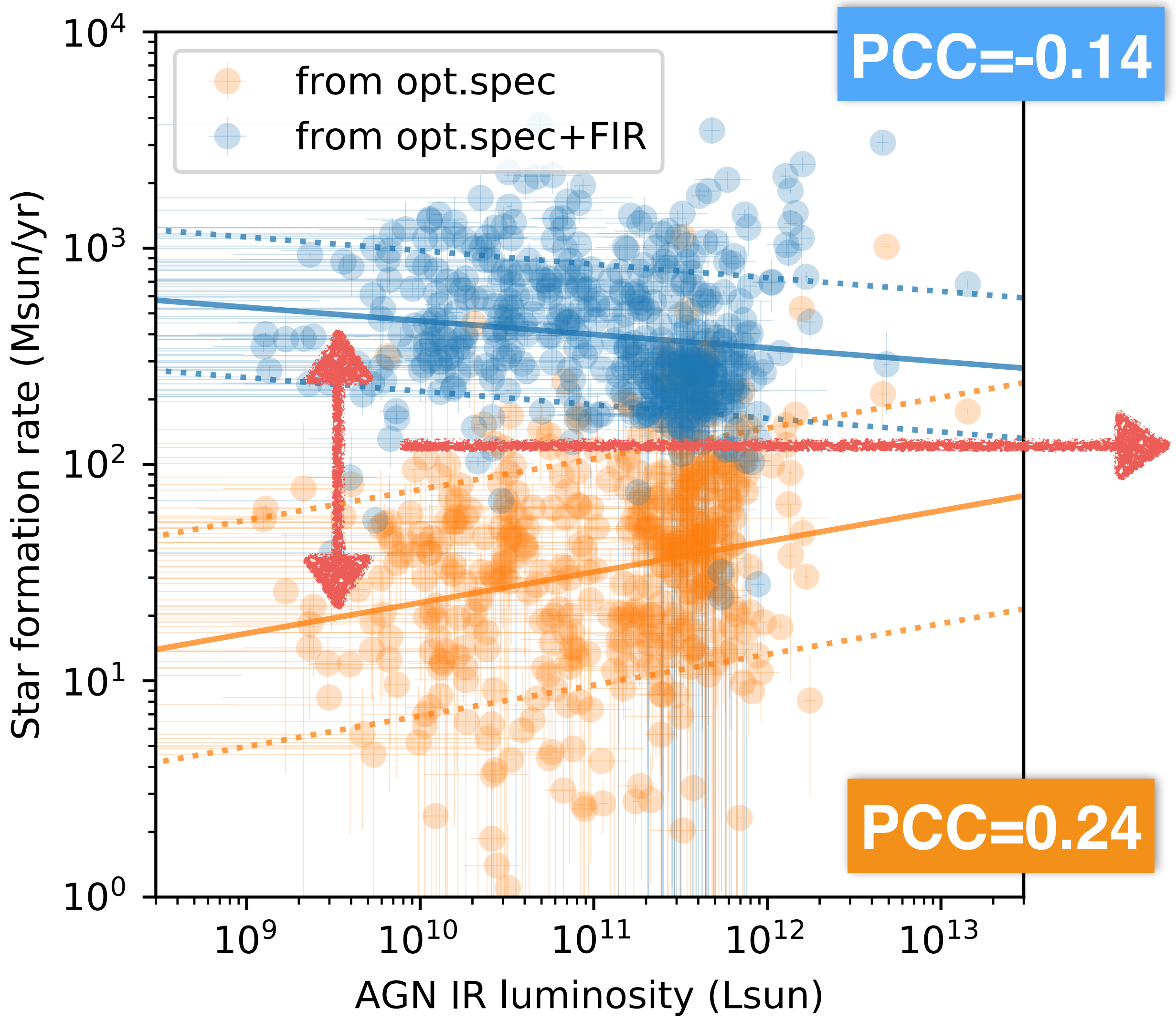
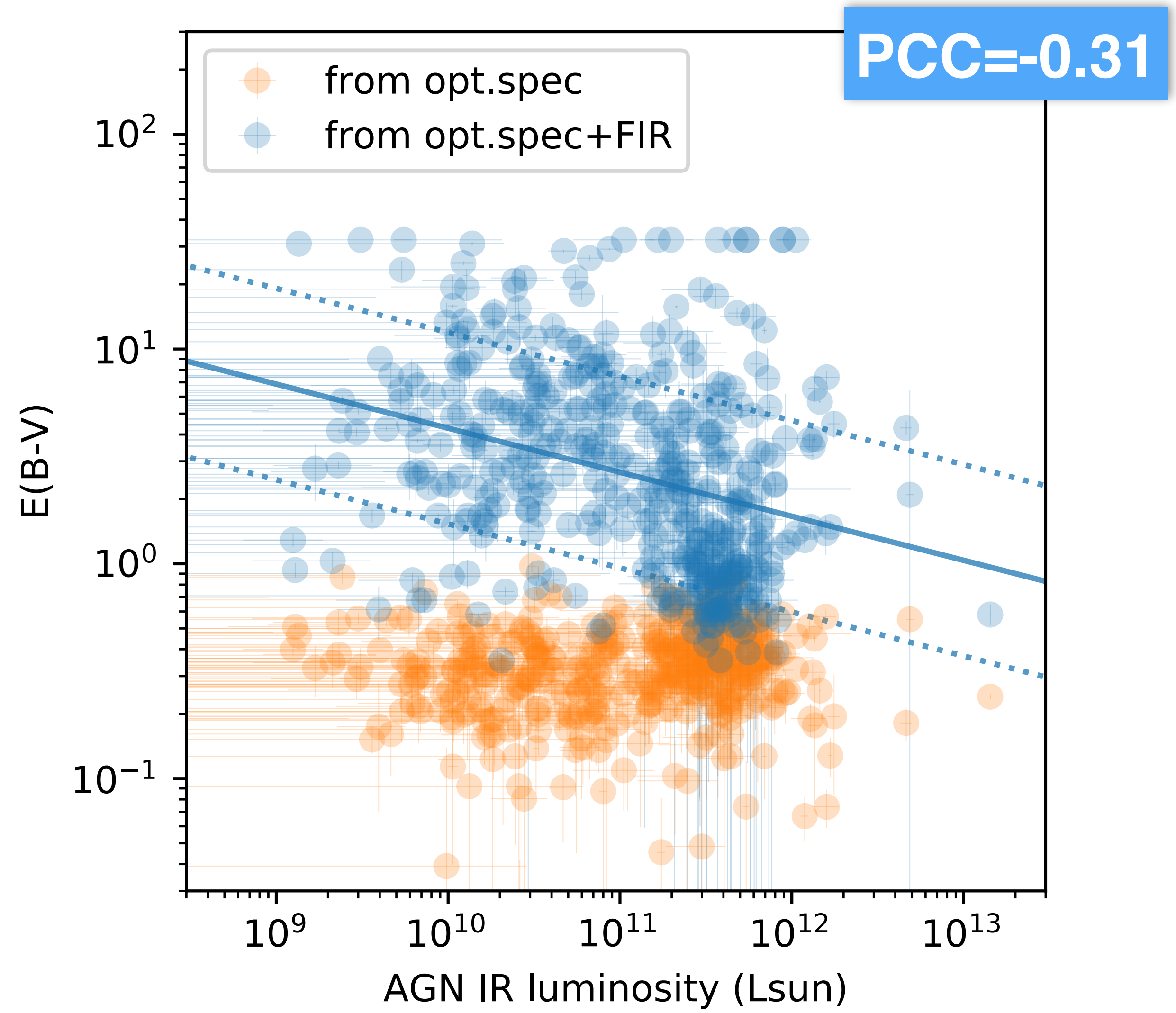
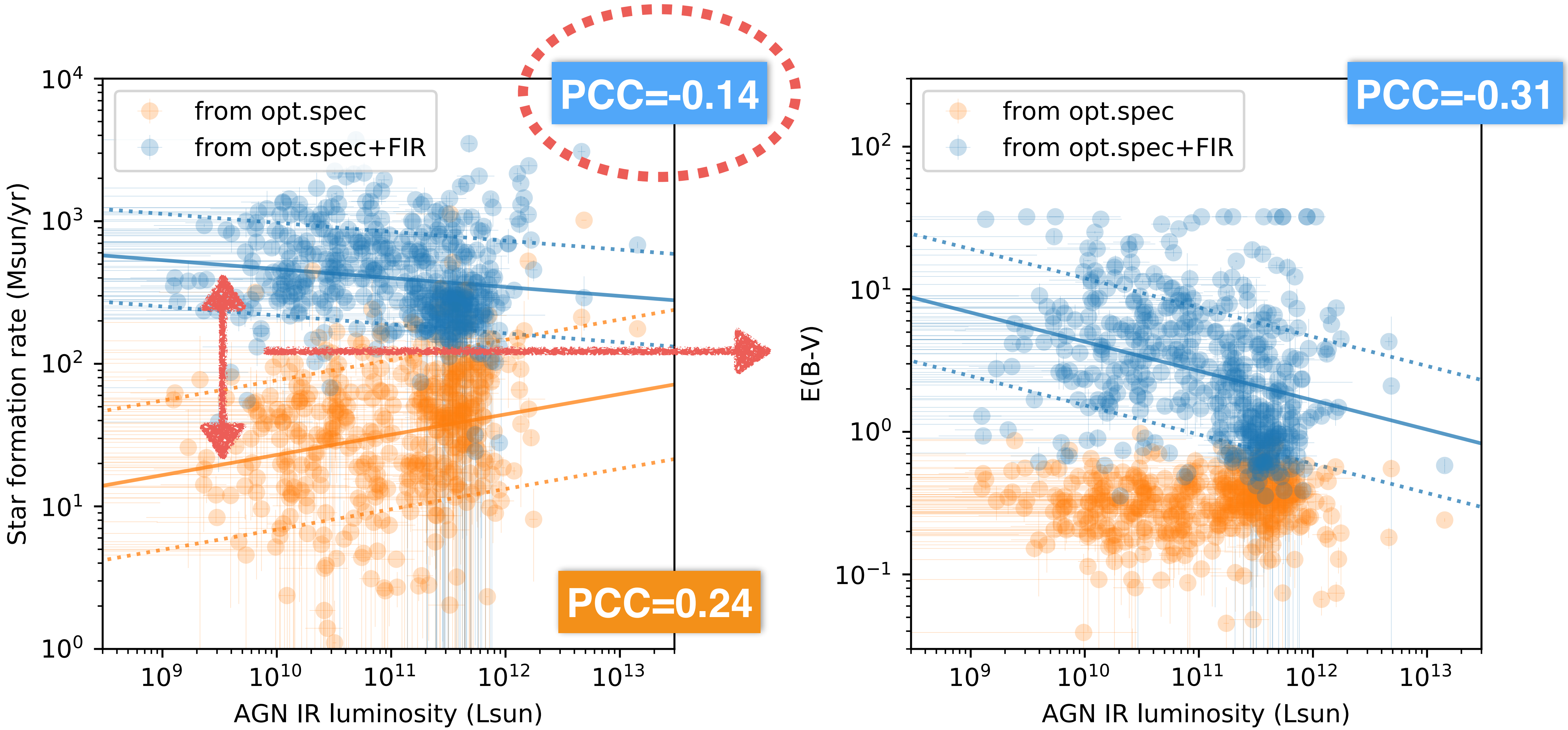




The star-forming becomes transparent as AGN becomes luminous.

During ULIRG stage,
Q1: co-growth ? **Yes**
Q2: feedback ?

Galaxy properties vs. AGN intensity



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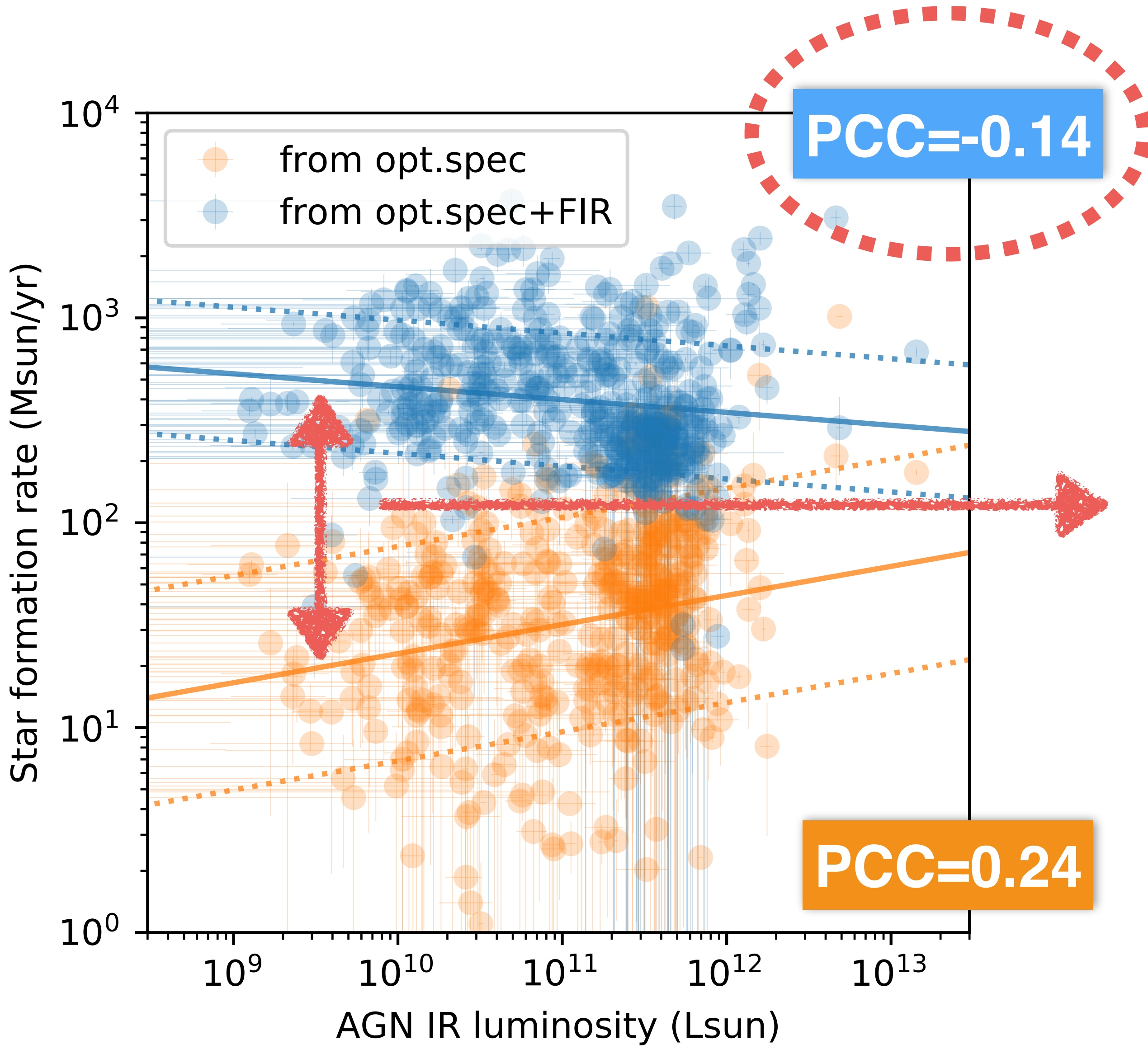
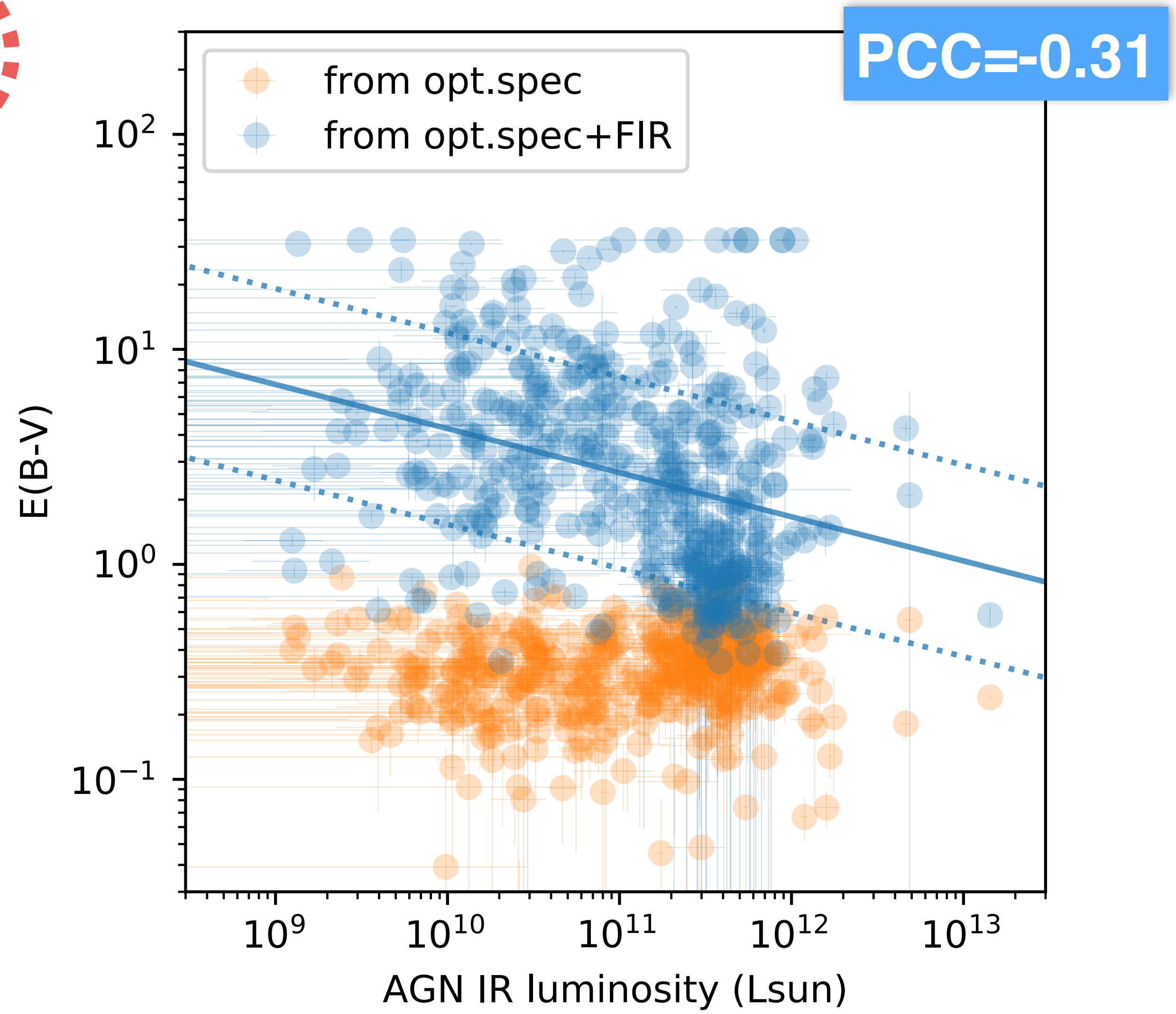
Galaxy properties vs. AGN intensity





The star-forming becomes transparent as AGN becomes luminous.

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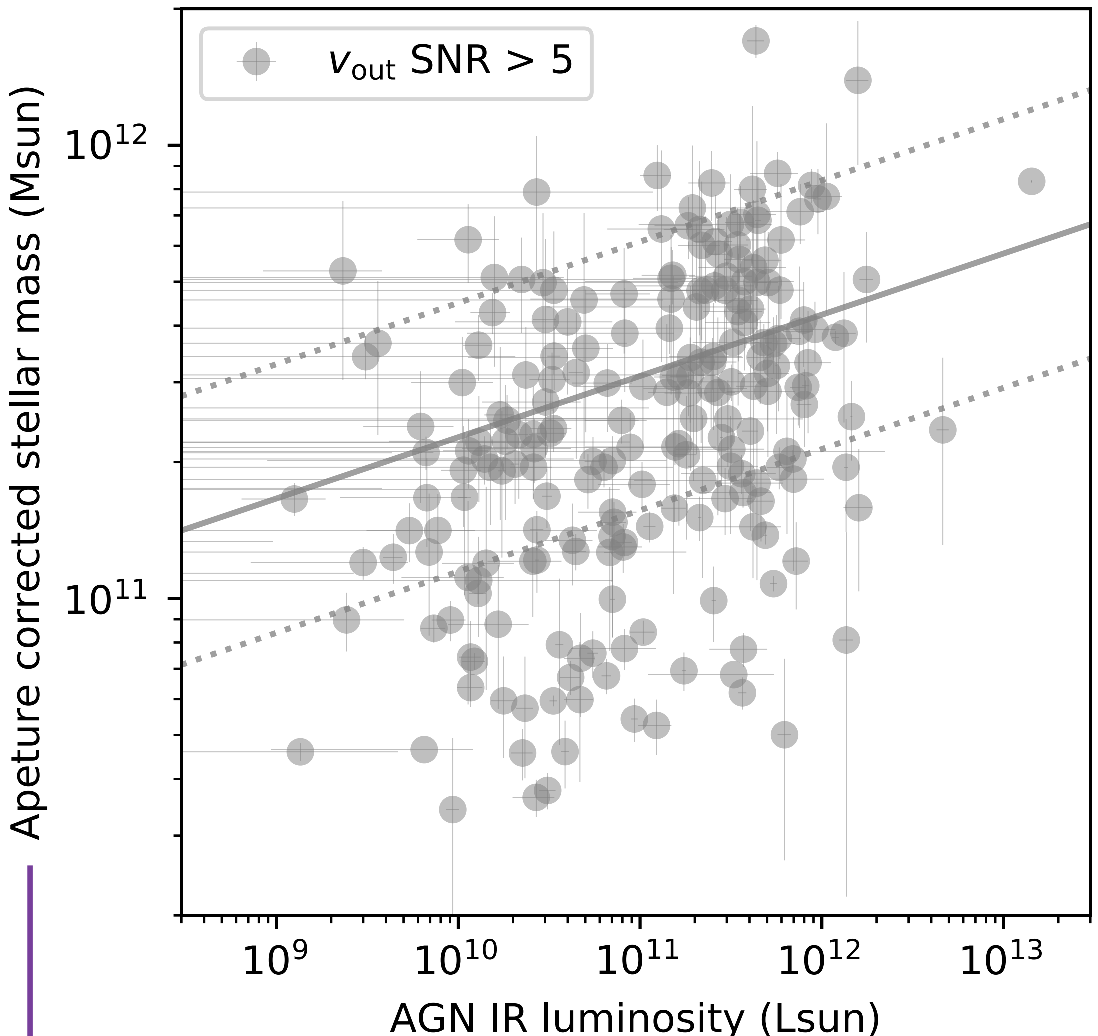
Q2: feedback ? **Yes?**

Galaxy properties vs. AGN intensity

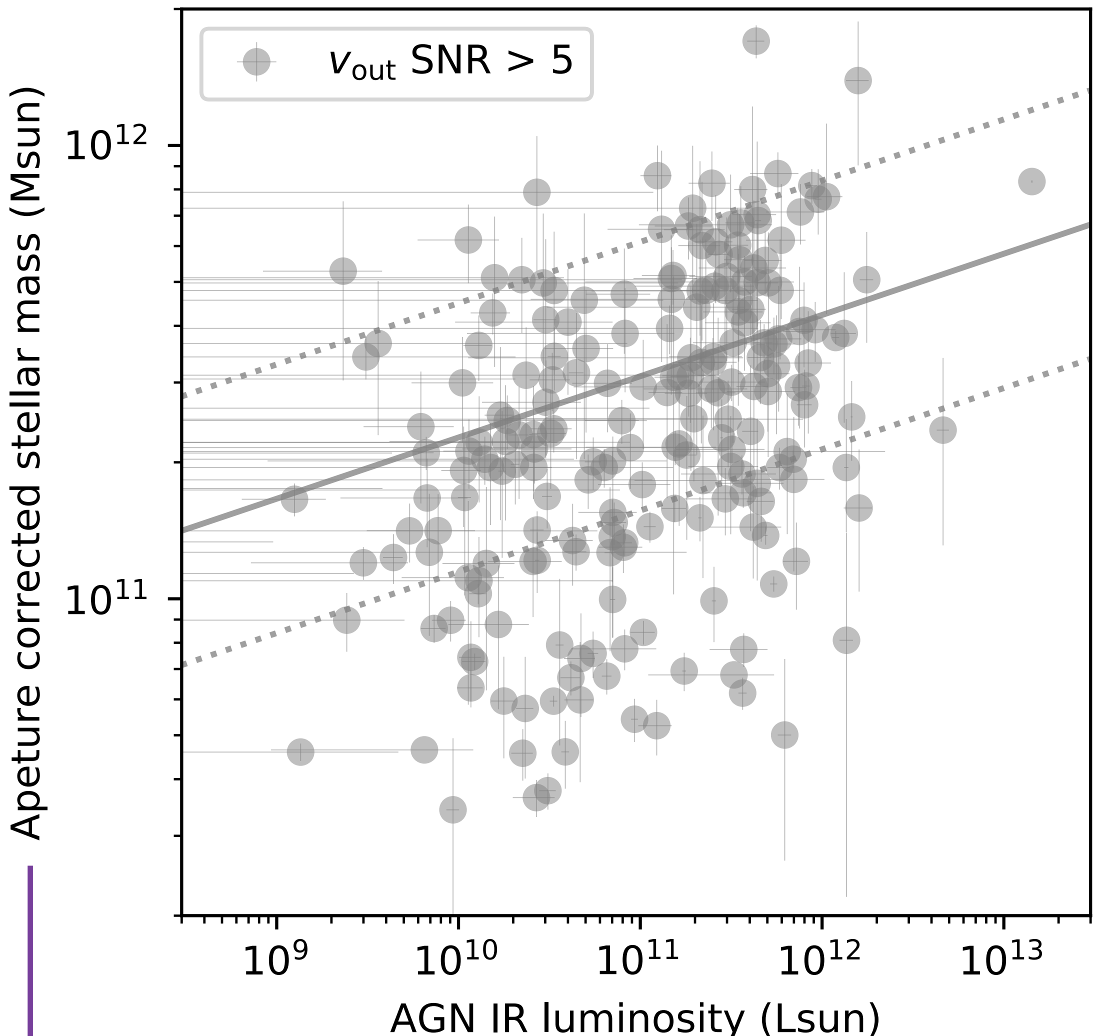


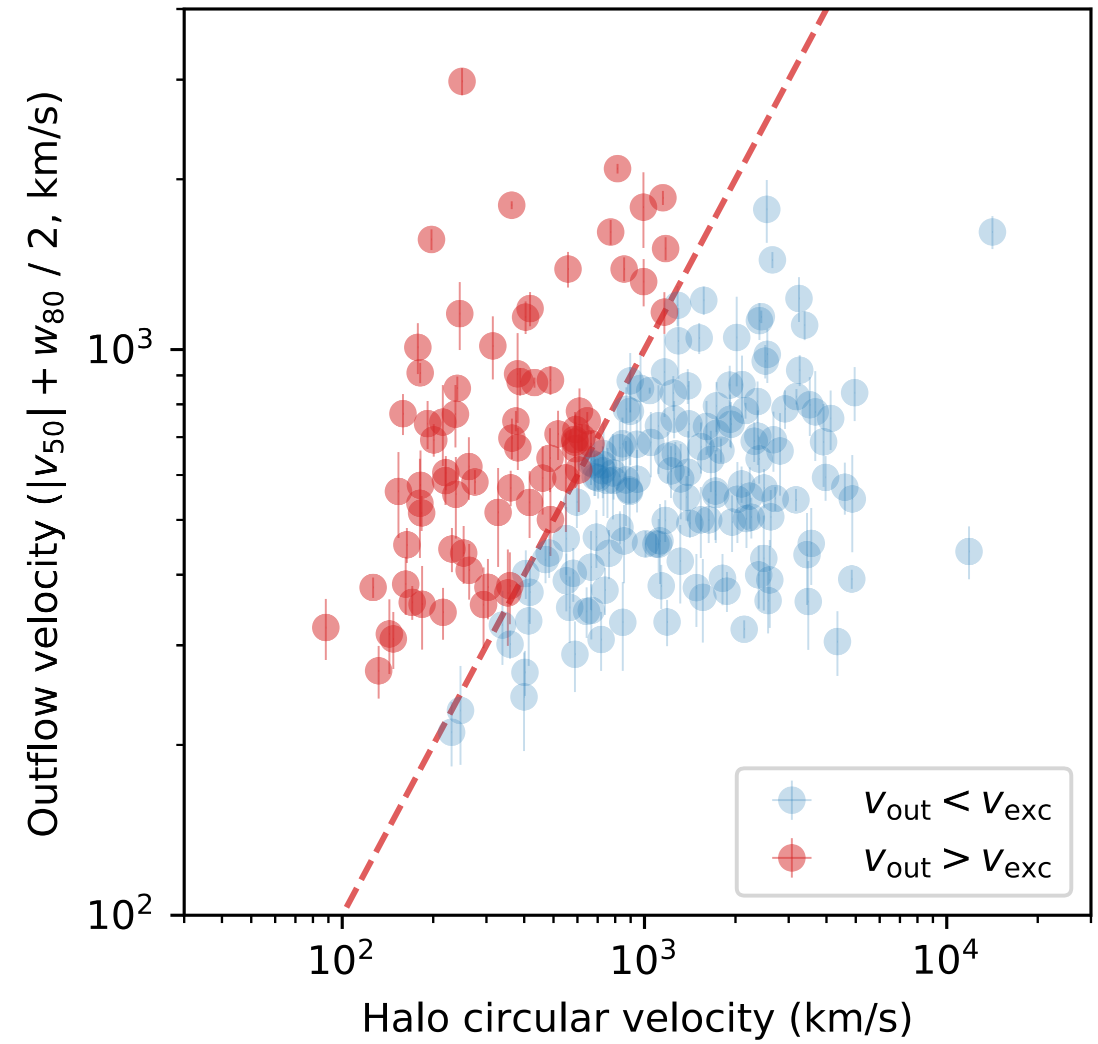
M_{star} → M_{halo} → $V_{escaping} \sim V_{circular}$

Moster et al. 2013

Mo & White et al. 2002

Galaxy properties vs. AGN intensity





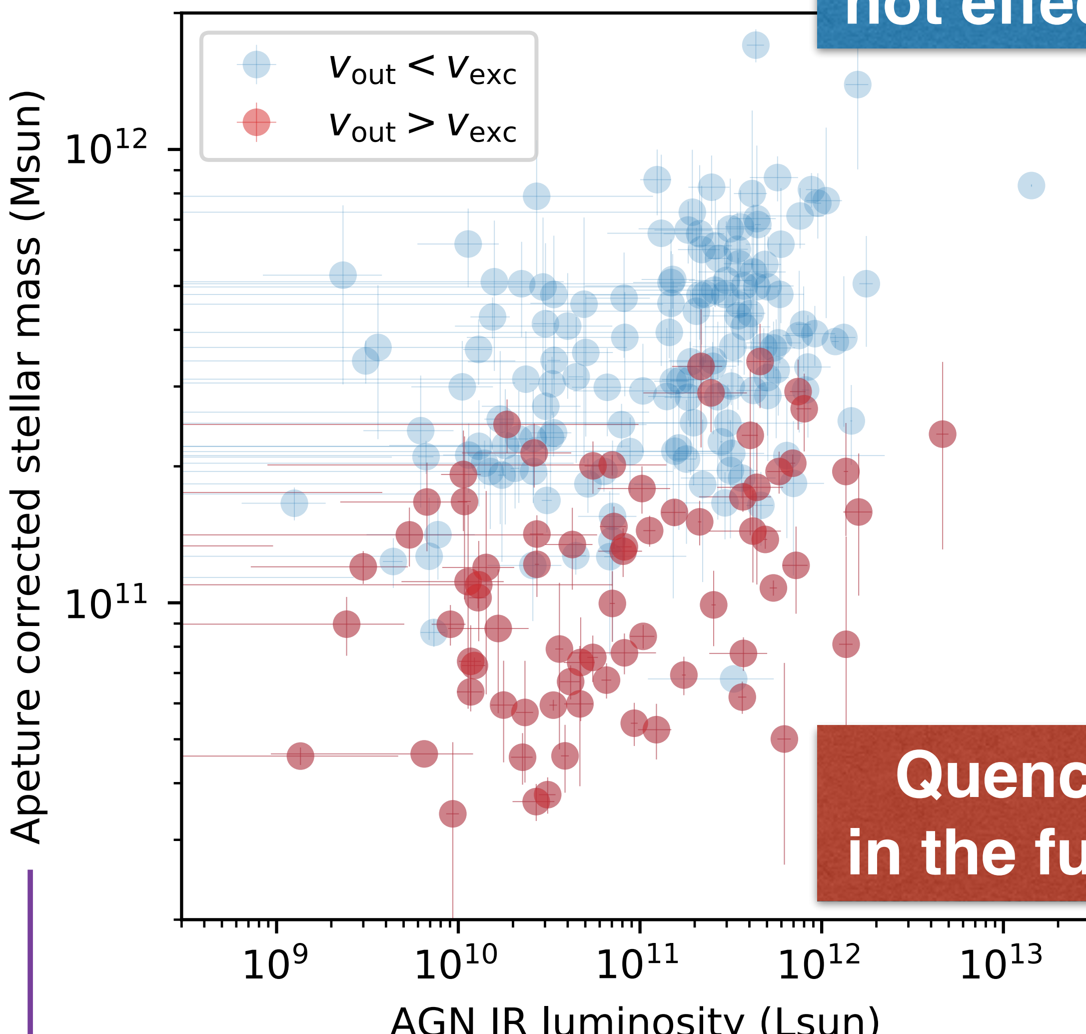
M_{star} M_{halo} $V_{\text{escaping}} \sim V_{\text{circular}}$

Moster et al. 2013

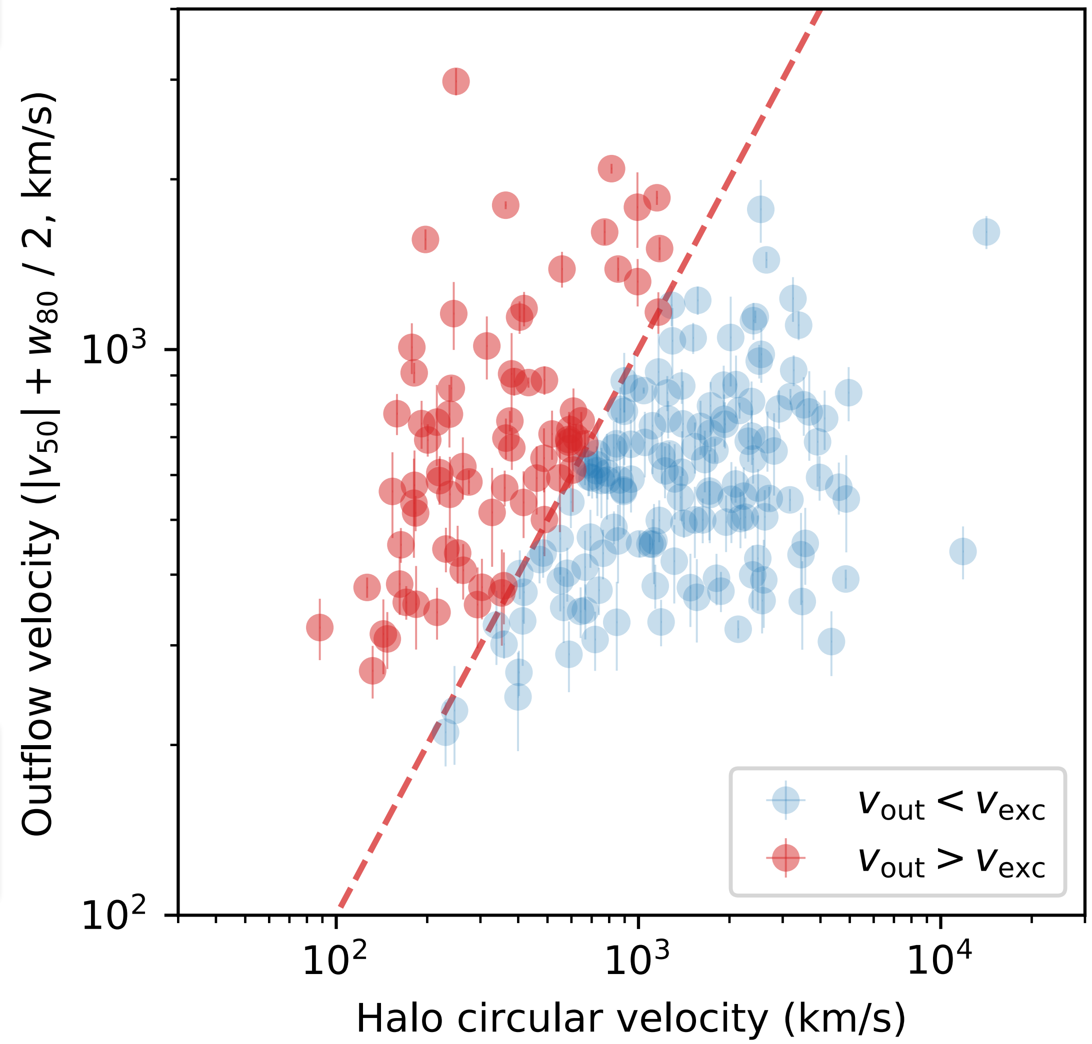
Mo & White et al. 2002

Galaxy properties vs. AGN intensity

Feedback is not effective?



Quenched in the future?

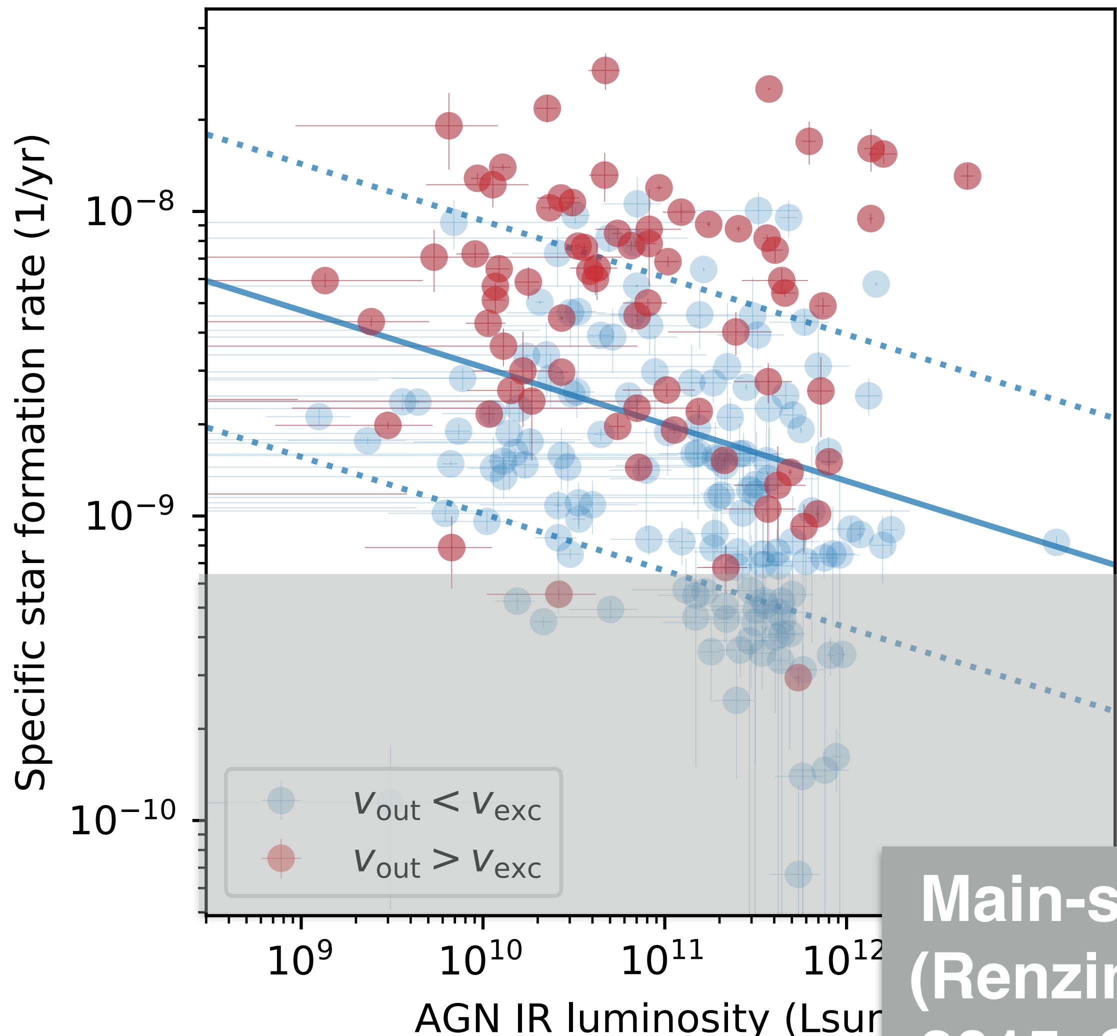


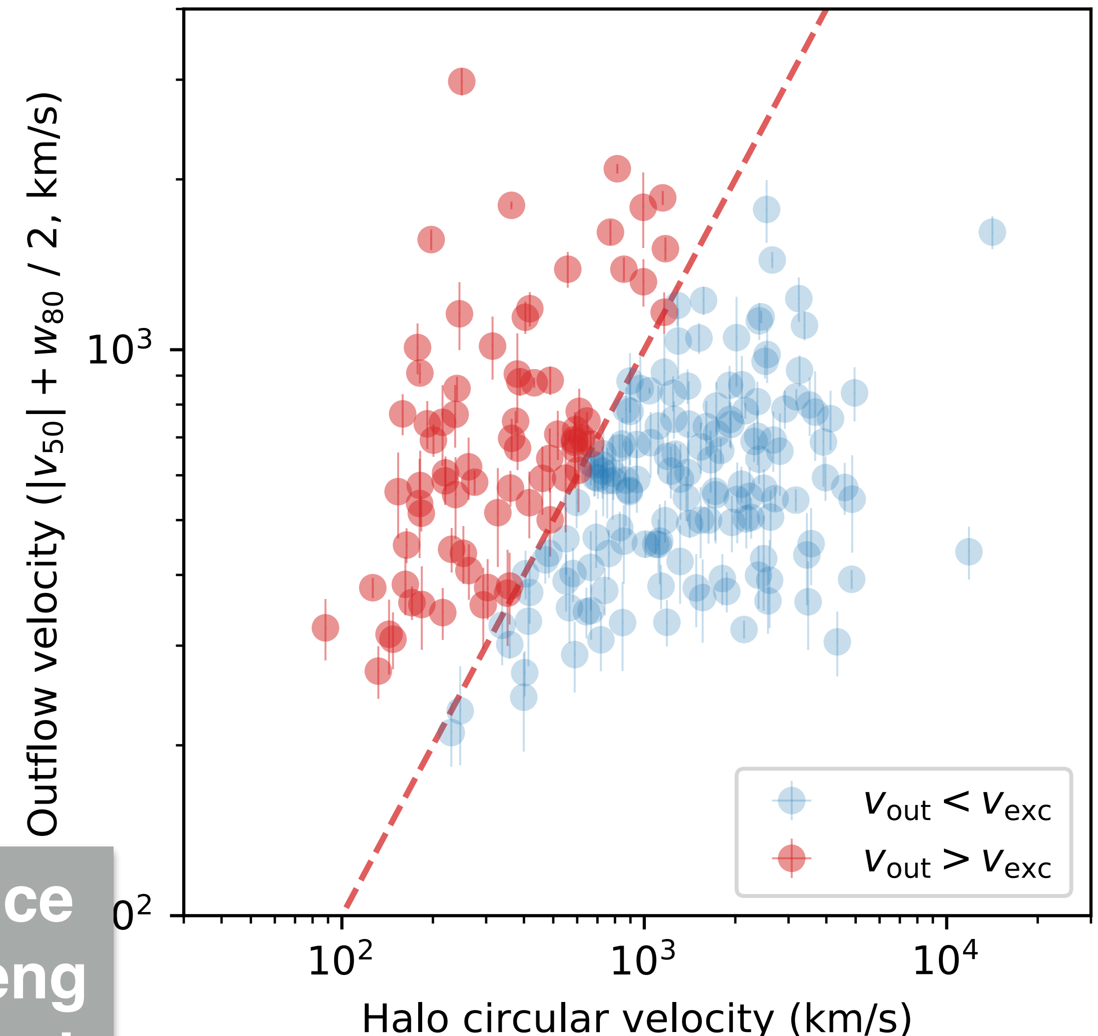
$M_{\mathrm{star}} \rightarrow M_{\mathrm{halo}} \rightarrow V_{\mathrm{escaping}} \sim V_{\mathrm{circular}}$

Moster et al. 2013

Mo & White et al. 2002

Galaxy properties vs. AGN intensity





Main-sequence (Renzini & Peng 2015, Spilker et al. 2018)

Outline

- 1. Background
- 2. Sample and Method
- 3. Results and Discussion
- **4. Summary**

Summary

In order to statistically study the co-evolution of SMBHs and stellar components in ULIRGs, we performed **a new method combining optical spectral fitting and IR SED fitting**, to ~ **500 ULIRGs selected with AKARI and Herschel FIR catalog**, we found:

1) the ***outflow velocity shows a clear dependence on AGN luminosity***;
2) as ***AGN becomes luminous***, the ***star-forming regions*** in the host galaxy become from ***dusty to transparent***;

1)+2):

a powerful AGN is capable to blow out the gas and dust out of the host galaxies;

3) ***currently the star formation*** in this ULIRG sample ***is not quenched***, with SFR ~ 300-1000 Msun/yr;
4) ***the ULIRG with Mstar ~ 1E11 Msun*** shows outflow ***exceeding the escaping velocity*** of the halo, those galaxies ***might be quenched in the future.***

Future step:
1) Hard X-ray follow-up observation to confirm the reliability of the AGN luminosity from IR SED decomposition;
2) ALMA follow-up to determine the distribution of cold gas reservoirs, and check whether the cold gas is affected by the ionized outflow or not.

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Thanks for your attention!