

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

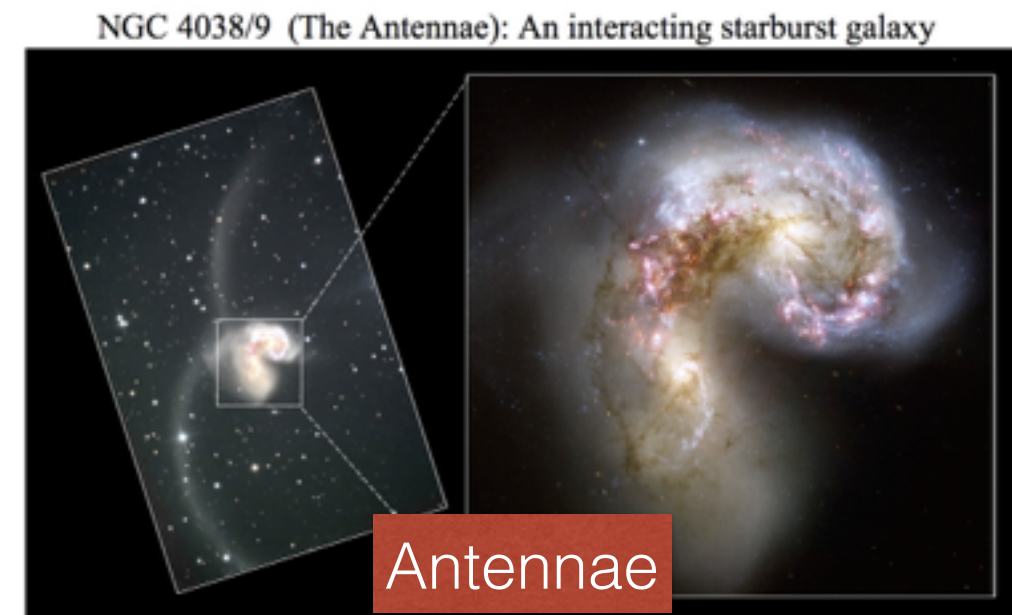
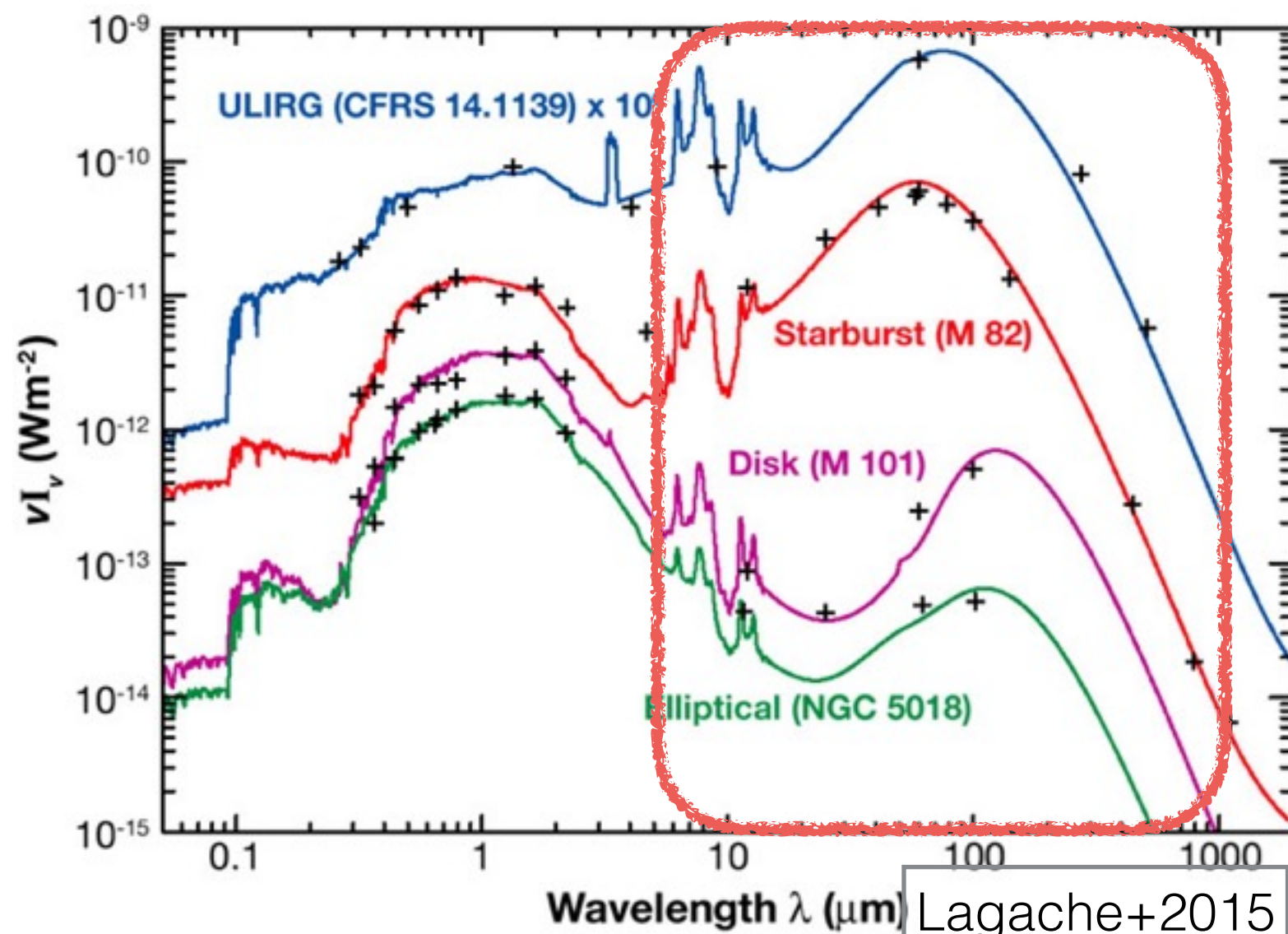
Def:

LIRG : $L_{8-1000\mu\text{m}} > 10^{11} L_{\odot}$

Ultra-LIRG : $L_{8-1000\mu\text{m}} > 10^{12} L_{\odot}$

Hyper-LIRG : $L_{8-1000\mu\text{m}} > 10^{13} L_{\odot}$

Extremely-LIRG : $L_{8-1000\mu\text{m}} > 10^{14} L_{\odot}$



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

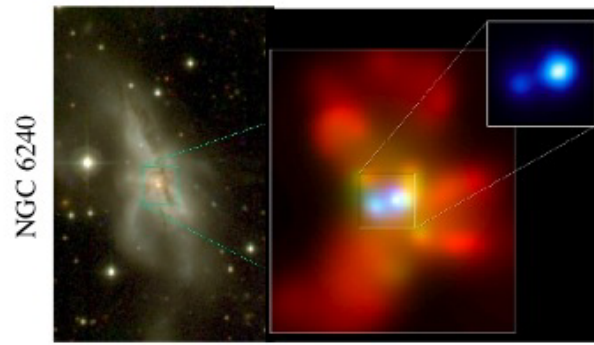
The co-evolution path of SMBHs and spheroids in massive galaxies

(c) Interaction/“Merger”



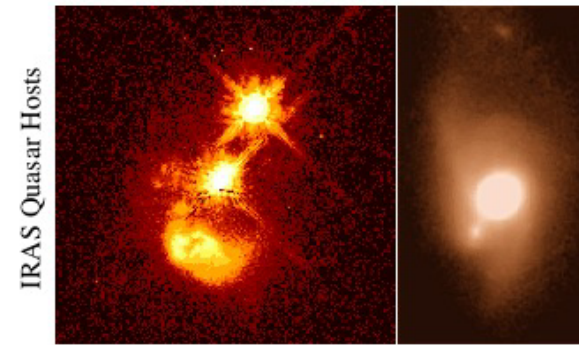
- now within one halo, galaxies interact & lose angular momentum
- SFR starts to increase
- stellar winds dominate feedback
- rarely excite QSOs (only special orbits)

(d) Coalescence/(U)LIRG



- galaxies coalesce: violent relaxation in core
- gas inflows to center: starburst & buried (X-ray) AGN
- starburst dominates luminosity/feedback, but, total stellar mass formed is small

(e) “Blowout”



- BH grows rapidly: briefly dominates luminosity/feedback
- remaining dust/gas expelled
- get reddened (but not Type II) QSO: recent/ongoing SF in host
- high Eddington ratios
- merger signatures still visible

(f) Quasar



- dust removed: now a “traditional” QSO
- host morphology difficult to observe: tidal features fade rapidly
- characteristically blue/young spheroid

(b) “Small Group”



- halo accretes similar-mass companion(s)
- can occur over a wide mass range
- M_{halo} still similar to before: dynamical friction merges the subhalos efficiently

(g) Decay/K+A



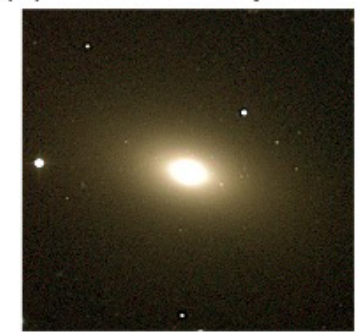
- QSO luminosity fades rapidly
- tidal features visible only with very deep observations
- remnant reddens rapidly (E+A/K+A)
- “hot halo” from feedback
- sets up quasi-static cooling

(a) Isolated Disk

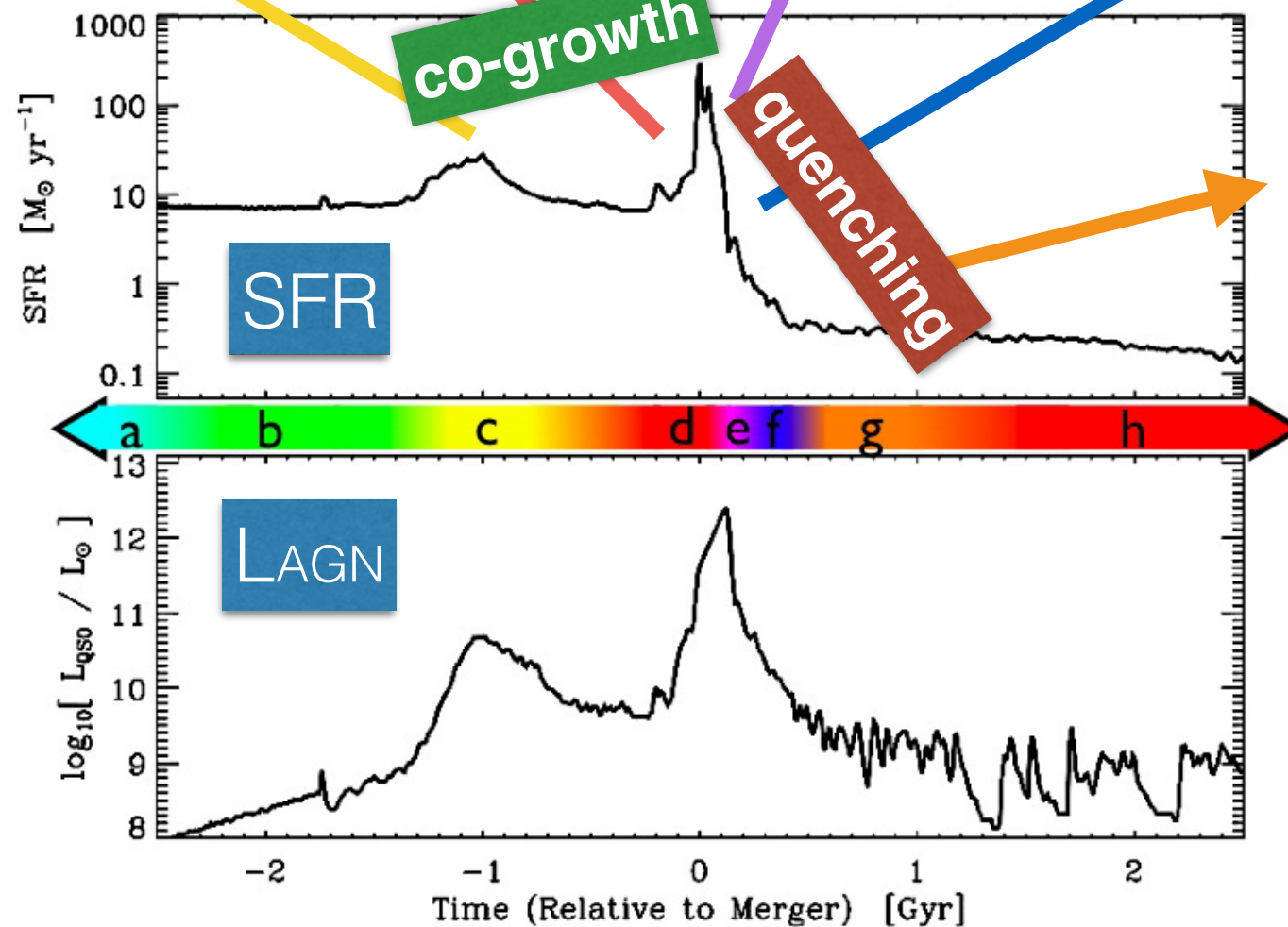


- halo & disk grow, most stars formed
- secular growth builds bars & pseudobulges
- “Seyfert” fueling (AGN with $M_B > -23$)
- cannot redden to the red sequence

(h) “Dead” Elliptical



- star formation terminated
- large BH/spheroid - efficient feedback
- halo grows to “large group” scales: mergers become inefficient
- growth by “dry” mergers



Hopkins+2008

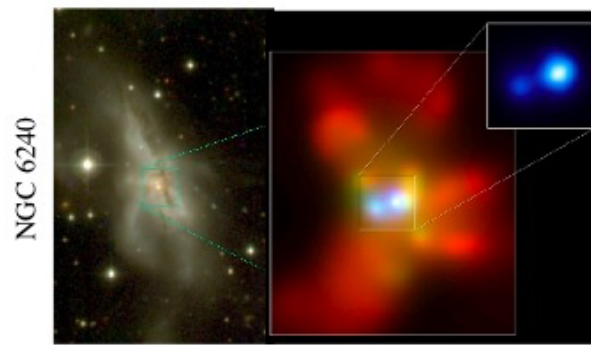
The co-evolution path of SMBHs and spheroids in massive galaxies

(c) Interaction/“Merger”

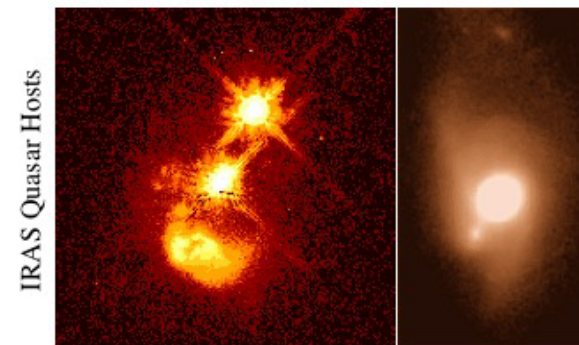


- now within one halo, galaxies interact & lose angular momentum
- SFR starts to increase
- stellar winds dominate feedback
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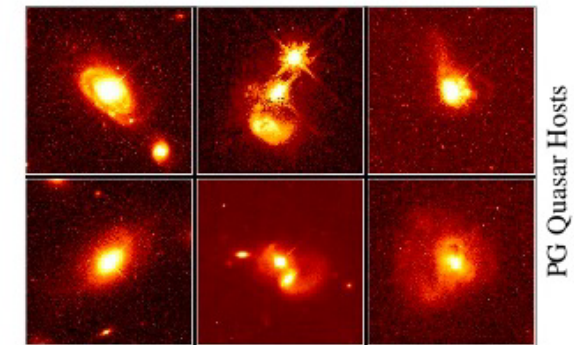
(d) Coalescence/(U)LIRG



(e) “Blowout”



(f) Quasar



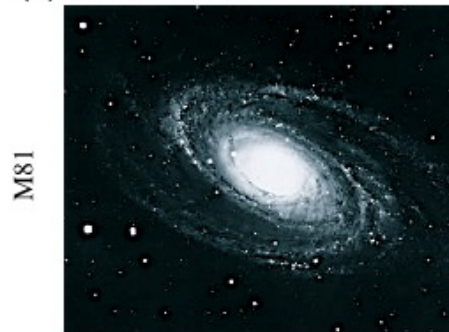
dust removed: now a “traditional” QSO host morphology difficult to observe: tidal features fade rapidly characteristically blue/young spheroid

(b) “Small Group”



- halo accretes similar-mass companion(s)
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(a) Isolated Disk



- halo & disk grow, most stars form
- secular growth builds bars & pseudobulges
- “Seyfert” fueling (AGN with $M_B > 10^7 M_\odot$)
- cannot redden to the red sequence

ULIRG is the important period in the co-evolution path.

(g) Decay/K+A

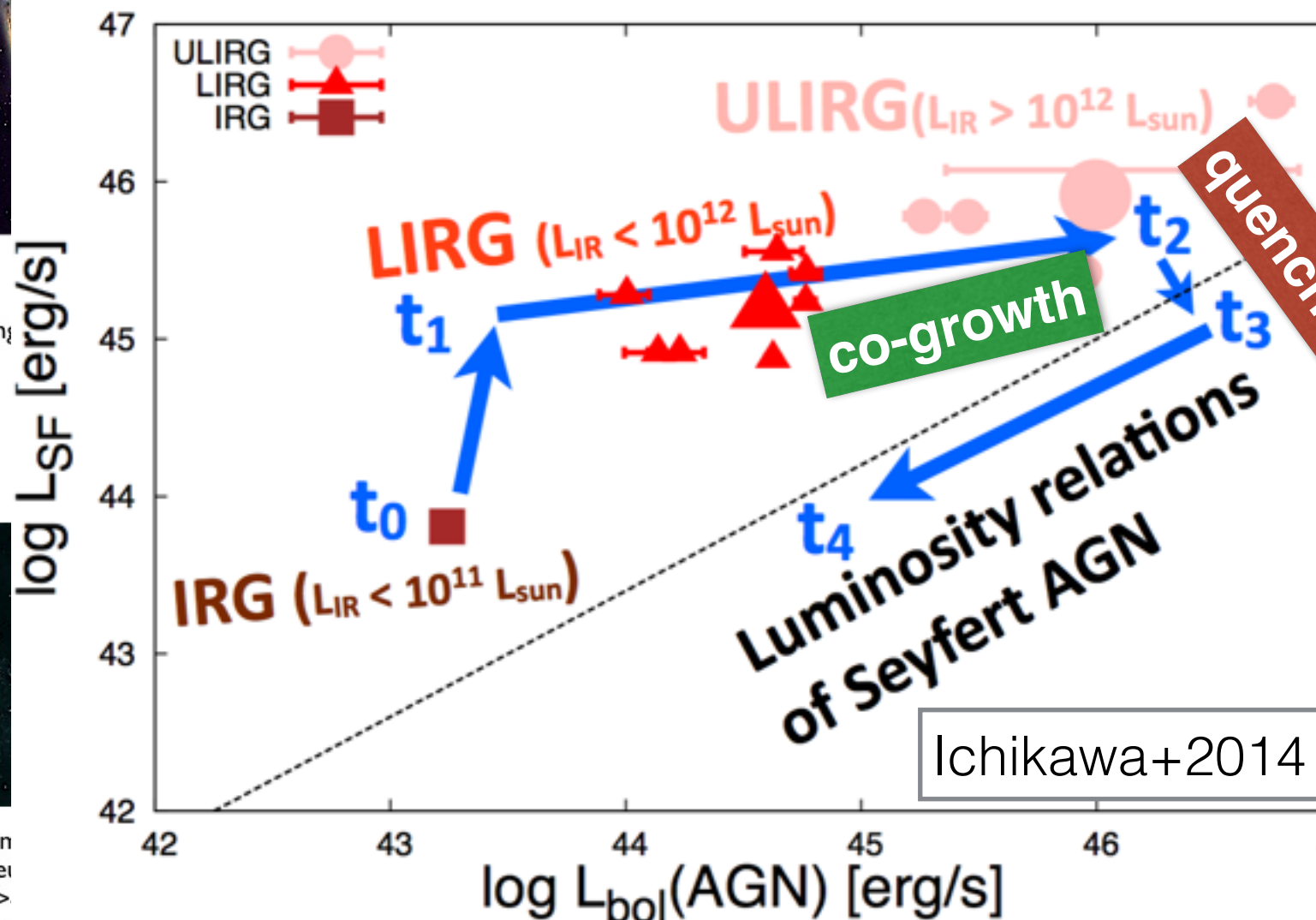


luminosity fades rapidly tidal features visible only with deep observations fades rapidly (E+A/K+A) from feedback sets up quasi-static cooling

“Dead” Elliptical

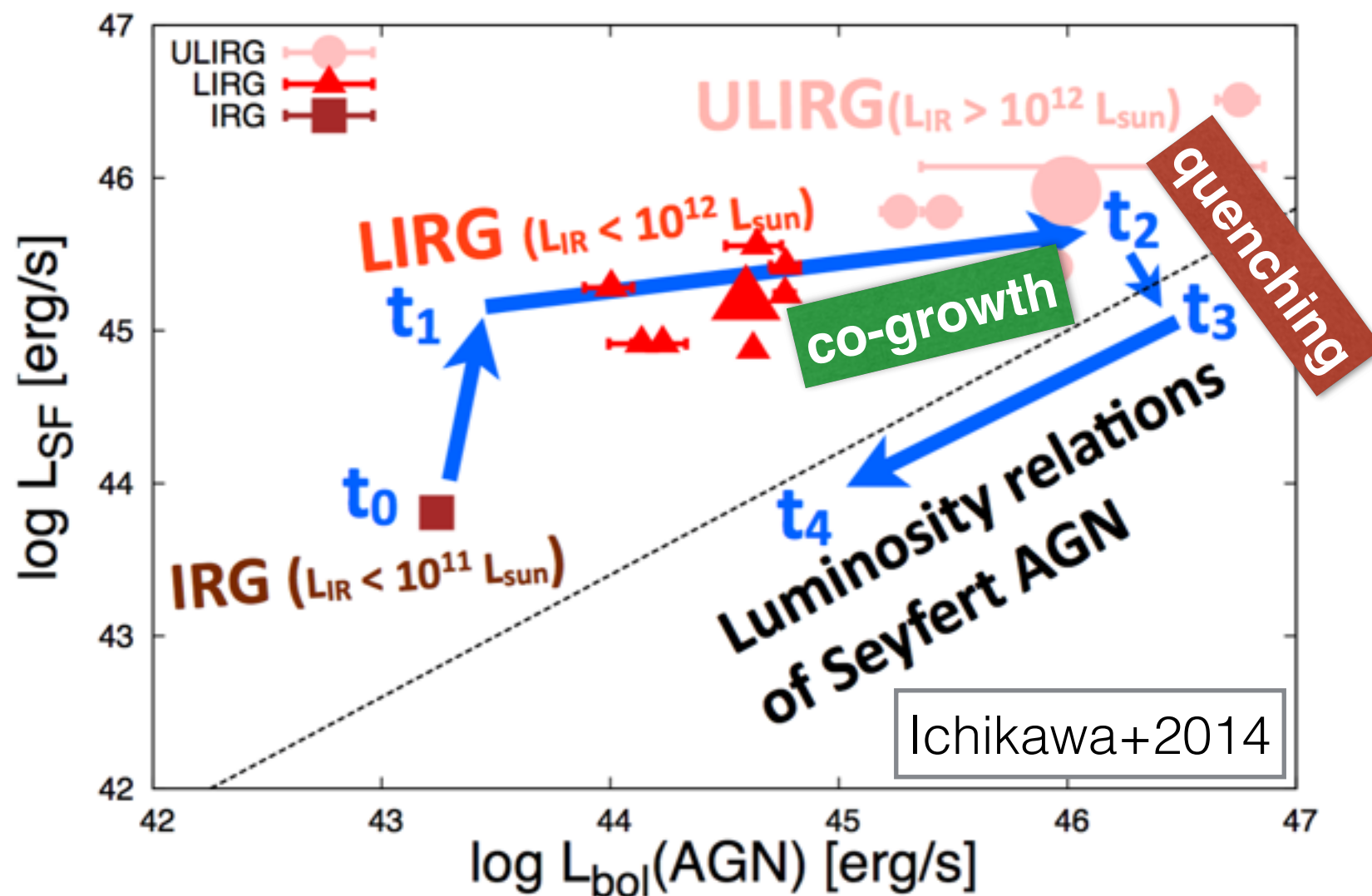


- formation terminated
- BH/spheroid - efficient feedback grows to “large group” scales: mergers become inefficient
- growth by “dry” mergers

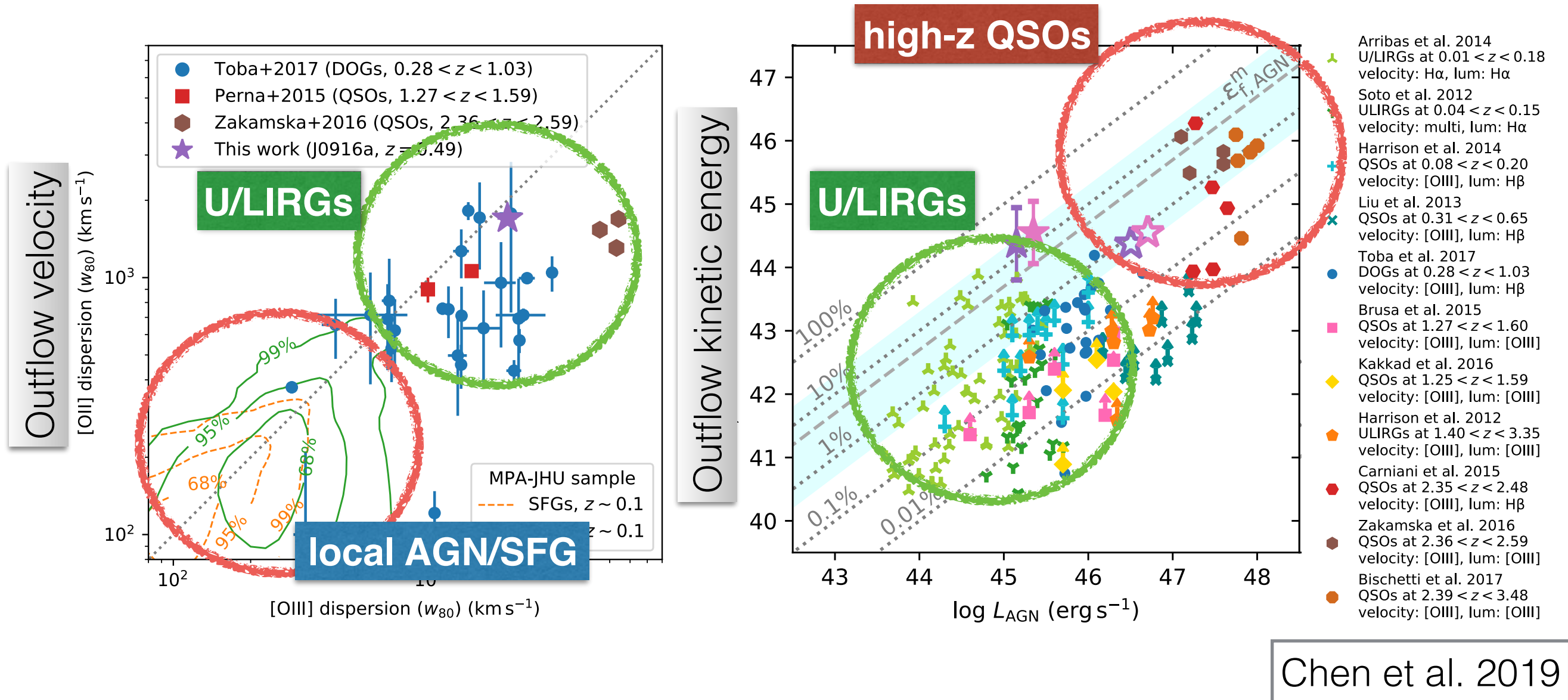


Two main topics

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



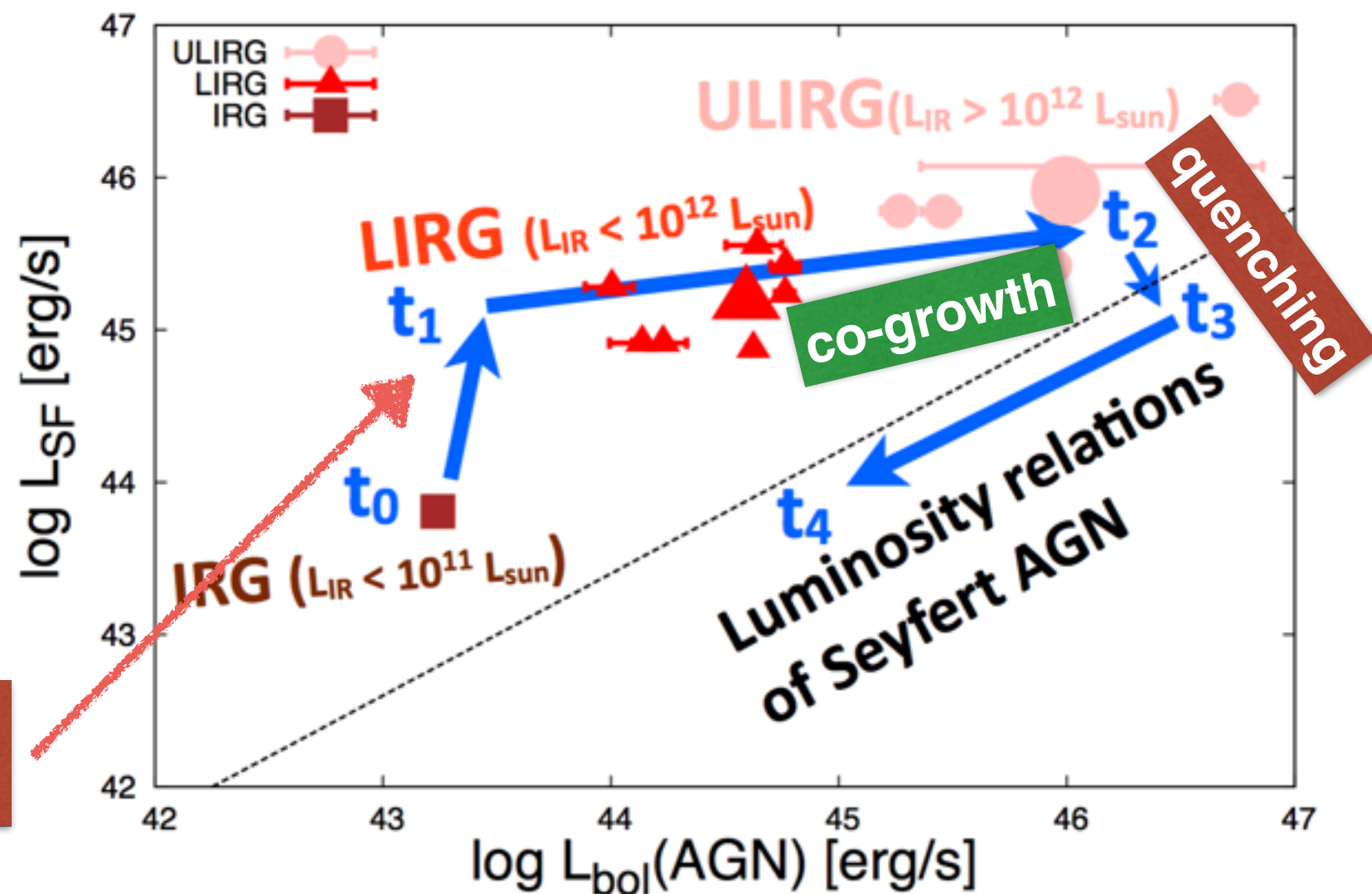
Outflow study in the literature



In the view of outflow, **U/LIRGs** 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.

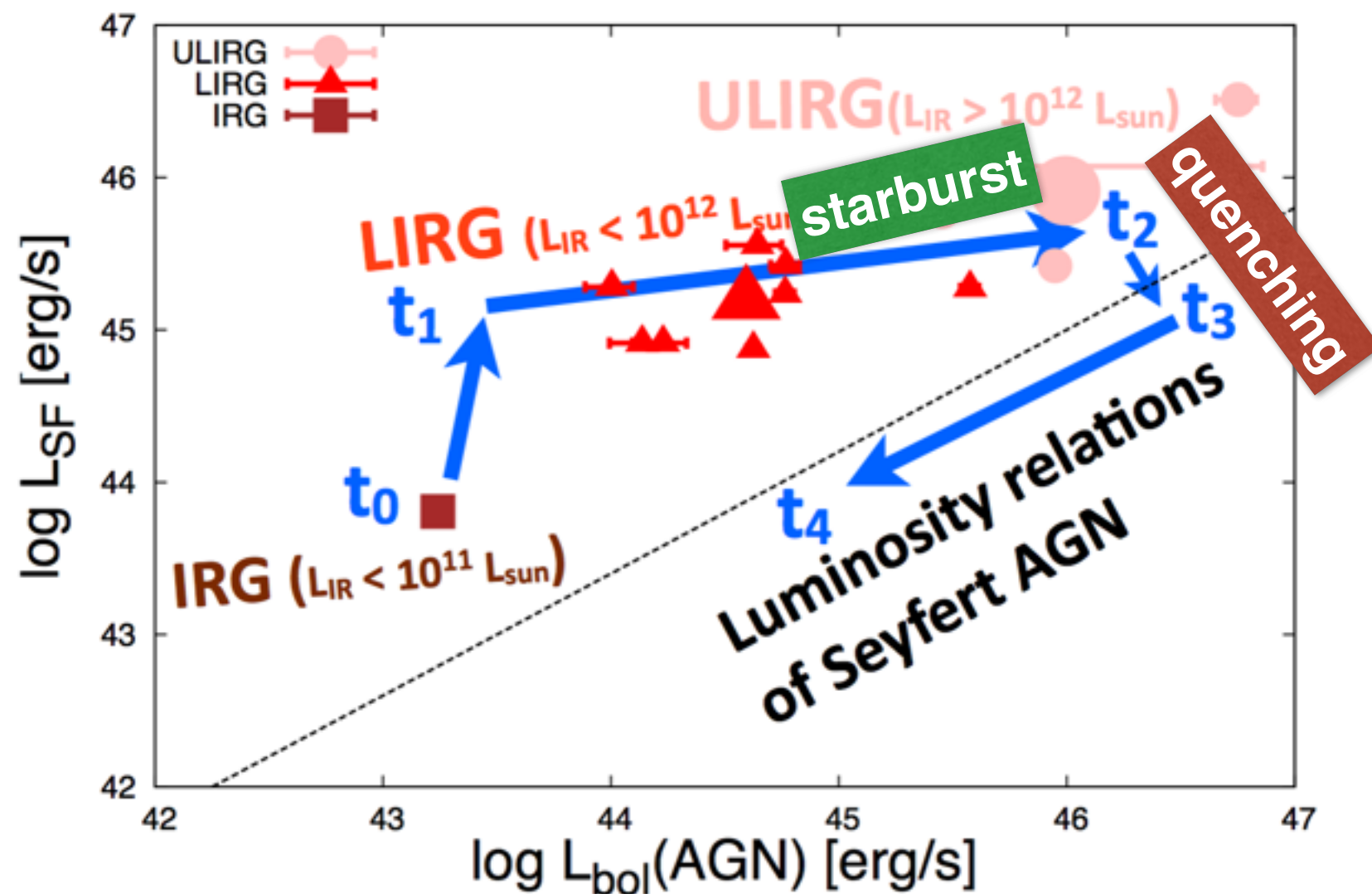


It is hard to get the time directly.

Quenched or Not quenched

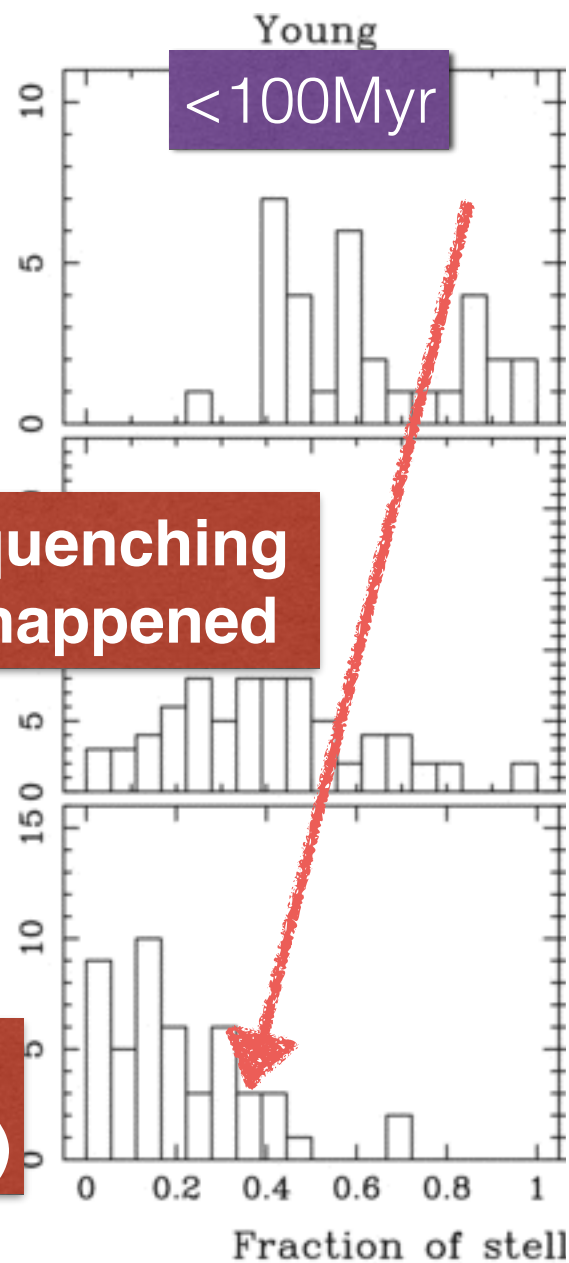
An alternative method is to evaluate the mass fraction of Young Stellar Population ($< \sim 100$ Myr) with a large sample.

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



Quenched or Not quenched

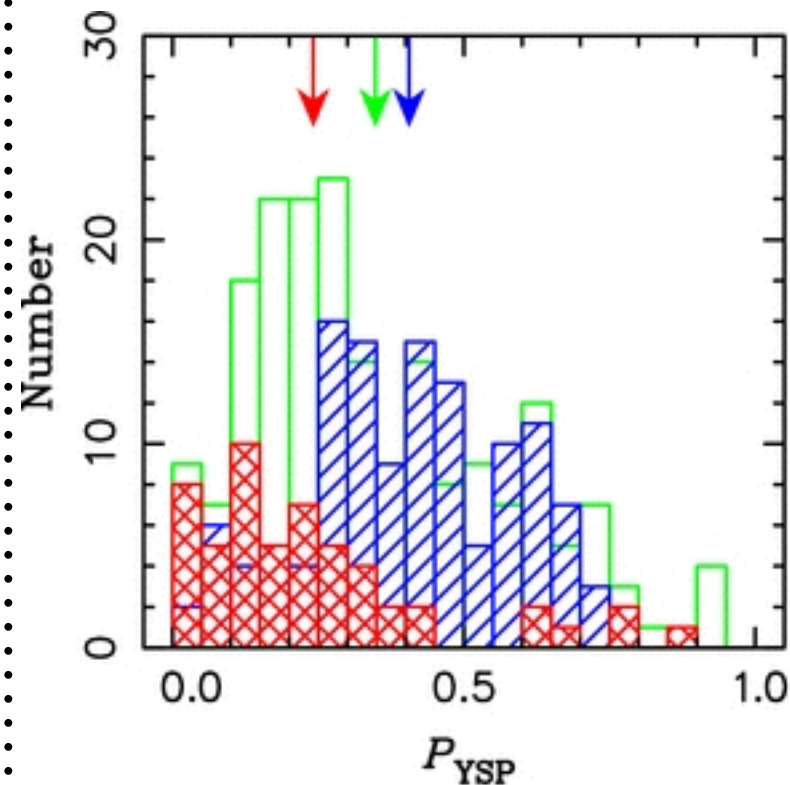
HII-like
(star-forming
dominated)



Seyfert 2
(AGN dominated)

Hou et al. 2011

160 ULIRGs from 1Jy IRAS catalog:



HII-like ULIRGs

Composite ULIRGs

Seyfert 2 ULIRGs

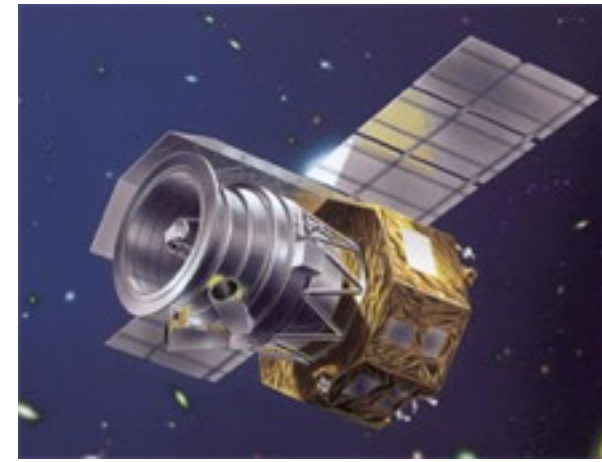
Su et al. 2013

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

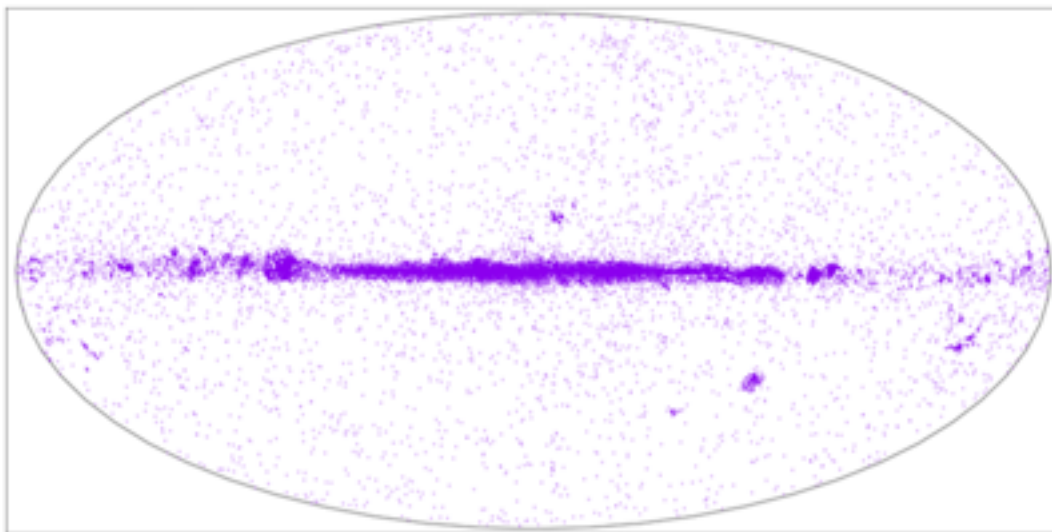
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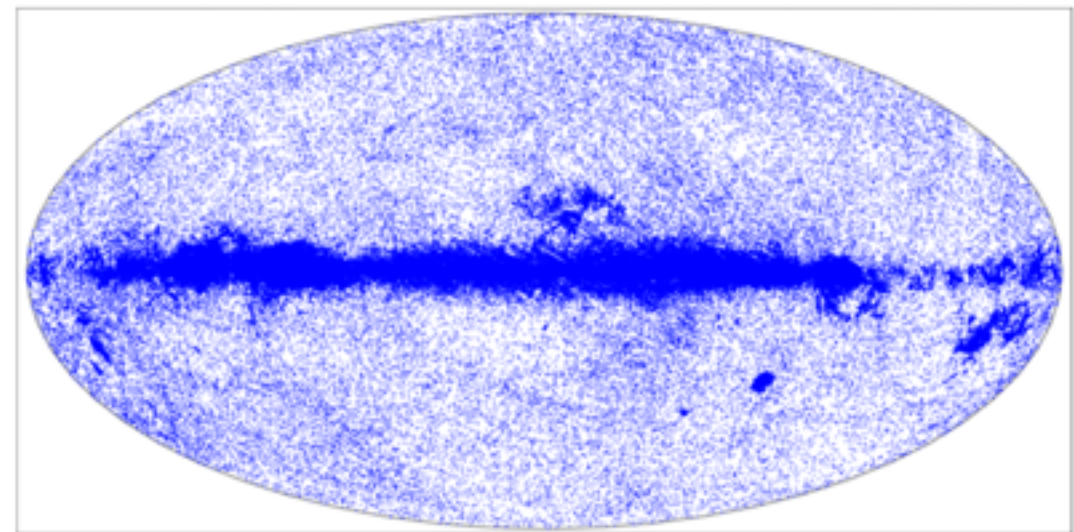
- Searching ULIRG in the **AKARI FIS Bright Source Catalog**



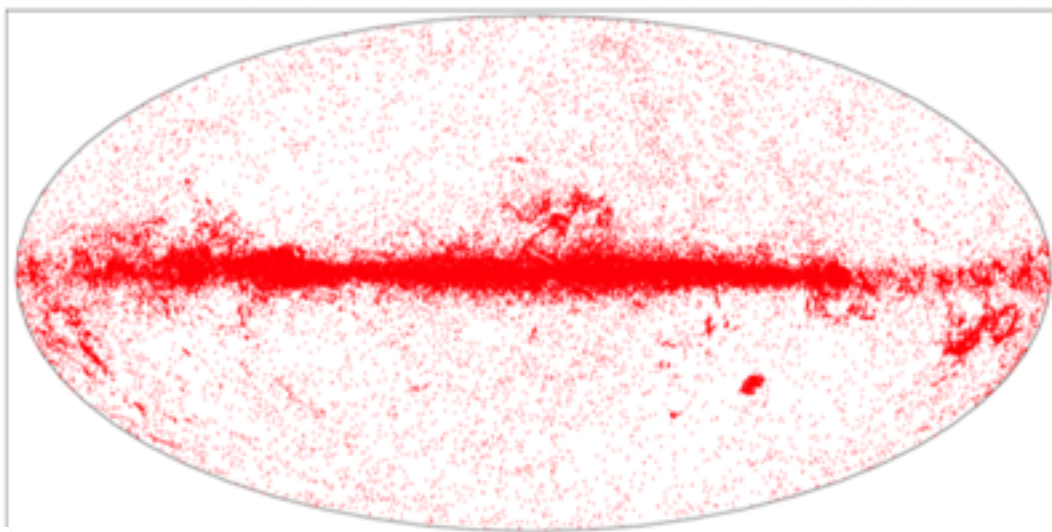
N60 (65 μm): 59,443 sources



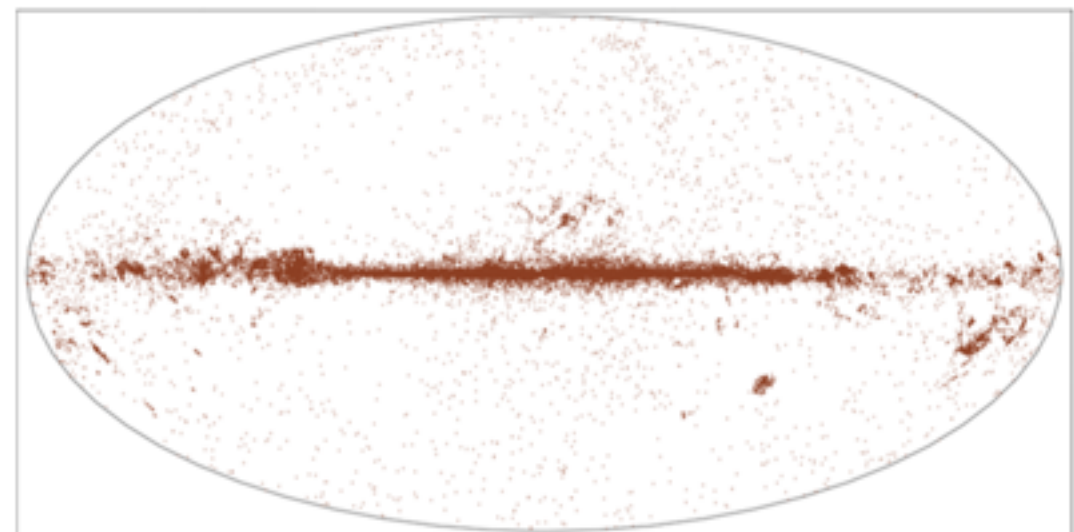
WIDE-S (90 μm): 461,842 sources



WIDE-L (140 μm): 203,594 sources



N160 (160 μm): 71,836 sources



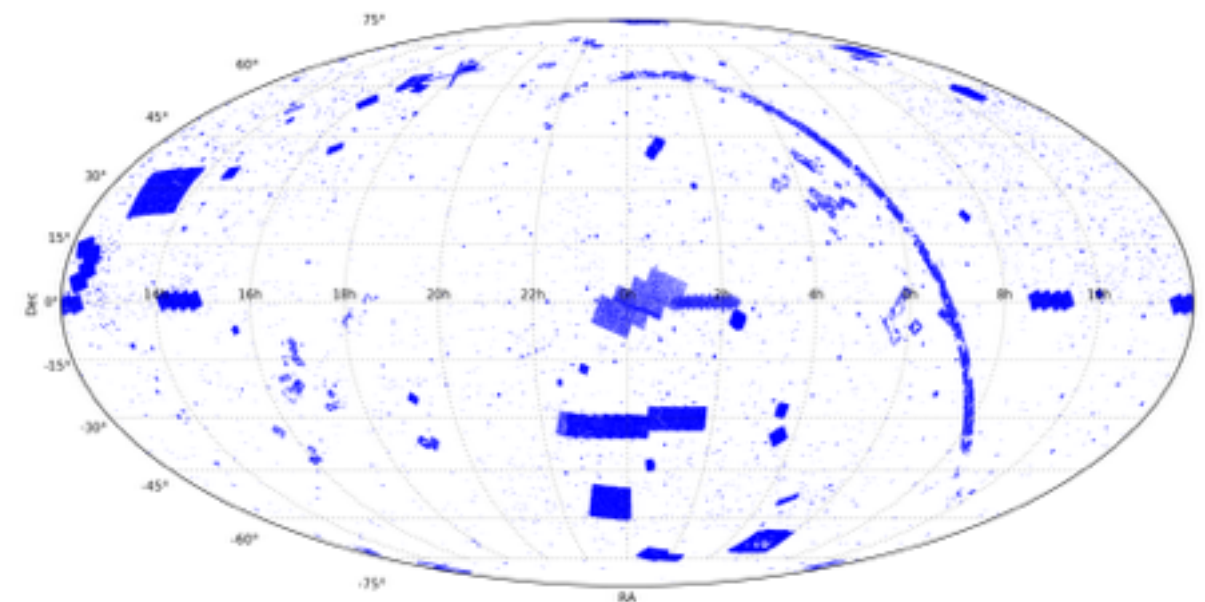
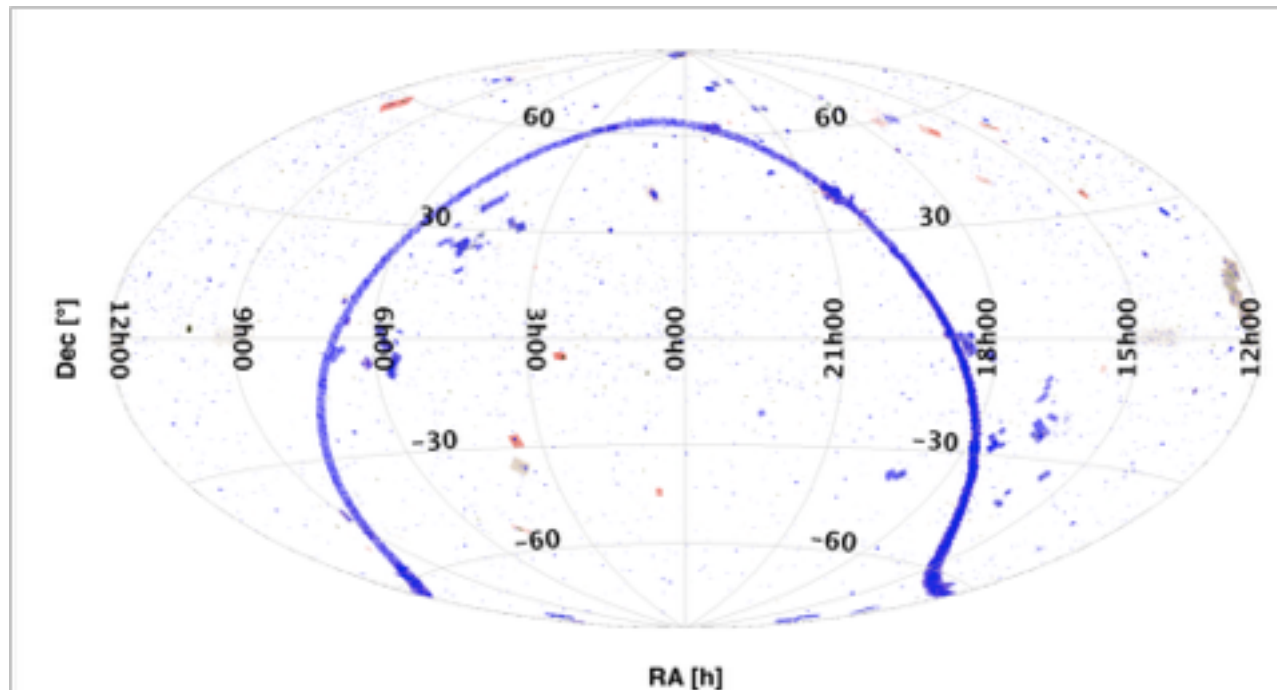
Yamamura et al.

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

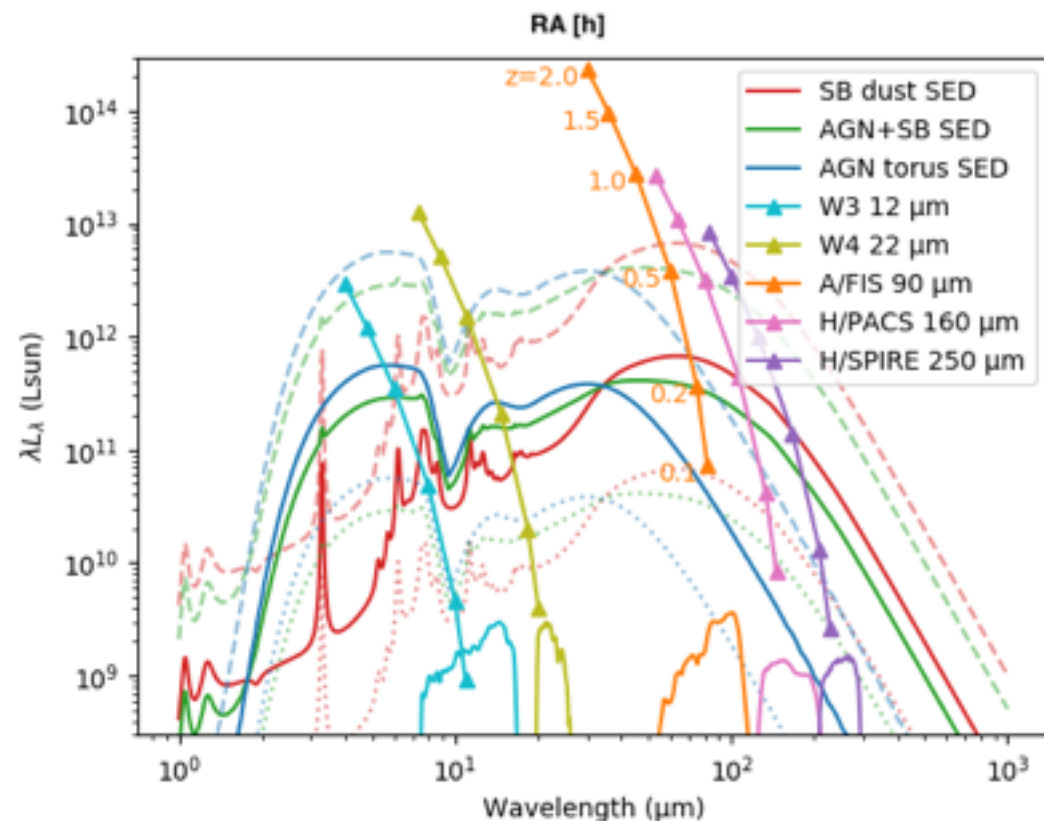
- Searching ULIRG in the **AKARI FIS Bright Source Catalog**,
- and the **Herschel PACS/SPIRE point source catalogs**.



PACS PSC
70/100/160 μ m



SPIRE PSC
250/350/500 μ m



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

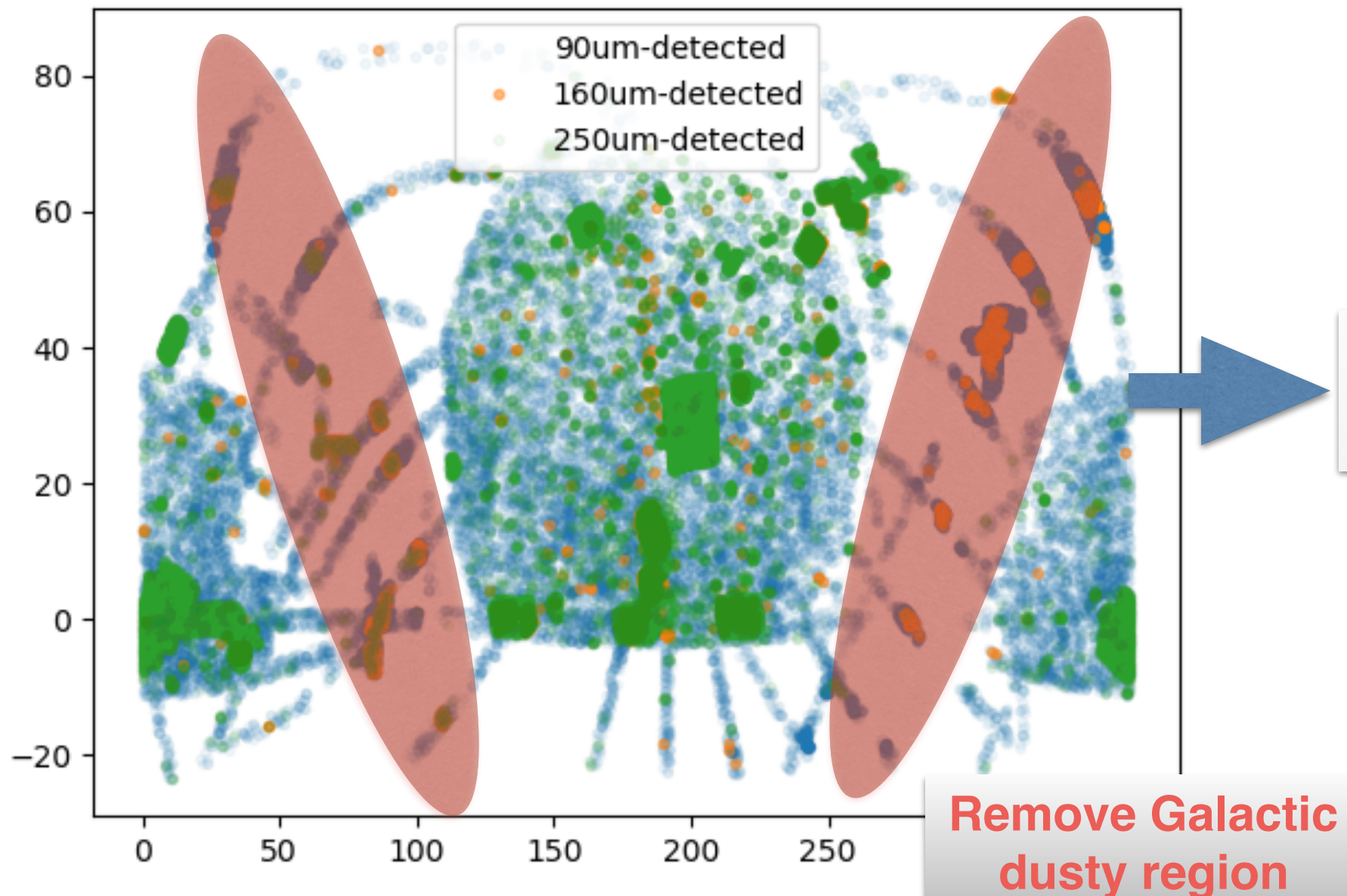
+

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

+

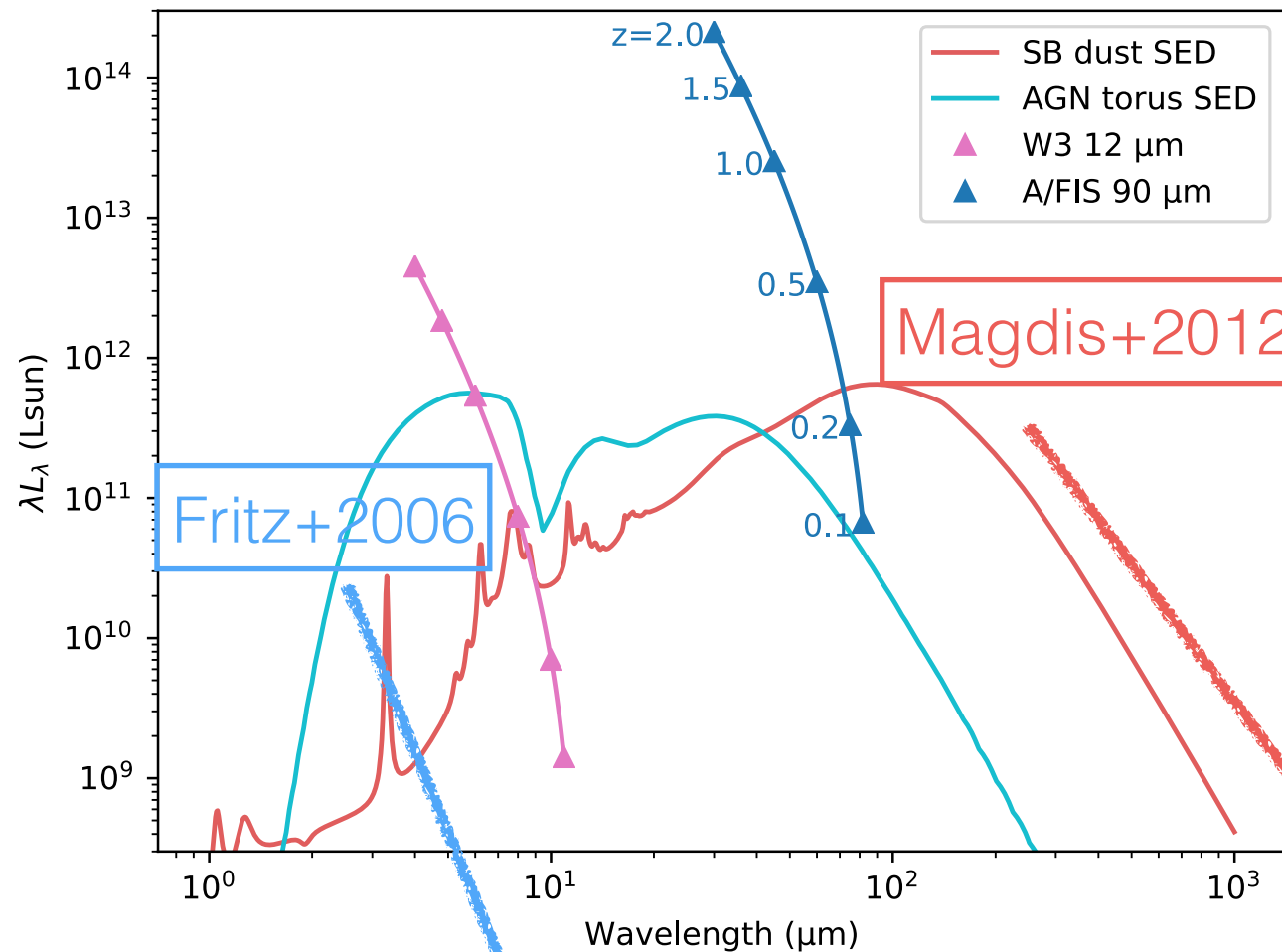
AKARI Catalog
(90 μm)

Herschel Catalog
(160/250 μm)



Total cross-matched:
146921

2-band SED estimation to select ULIRG



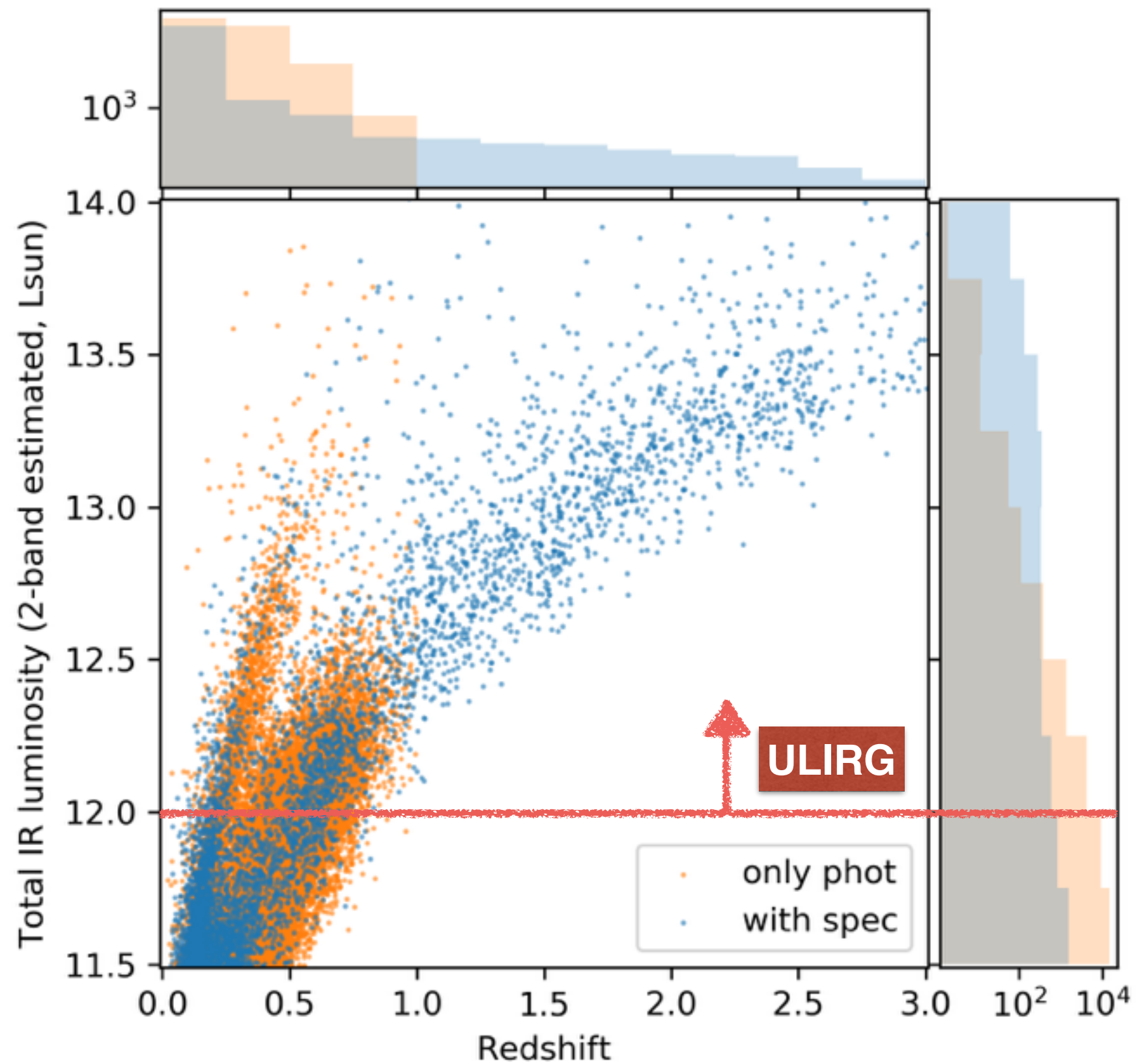
We can quickly estimate the IR AGN and starburst luminosity just with 2-band observation, when the SED are fixed to some typical choices.

$$L_{AGN} + L_{SB} \geq 1E12 L_{sun}$$

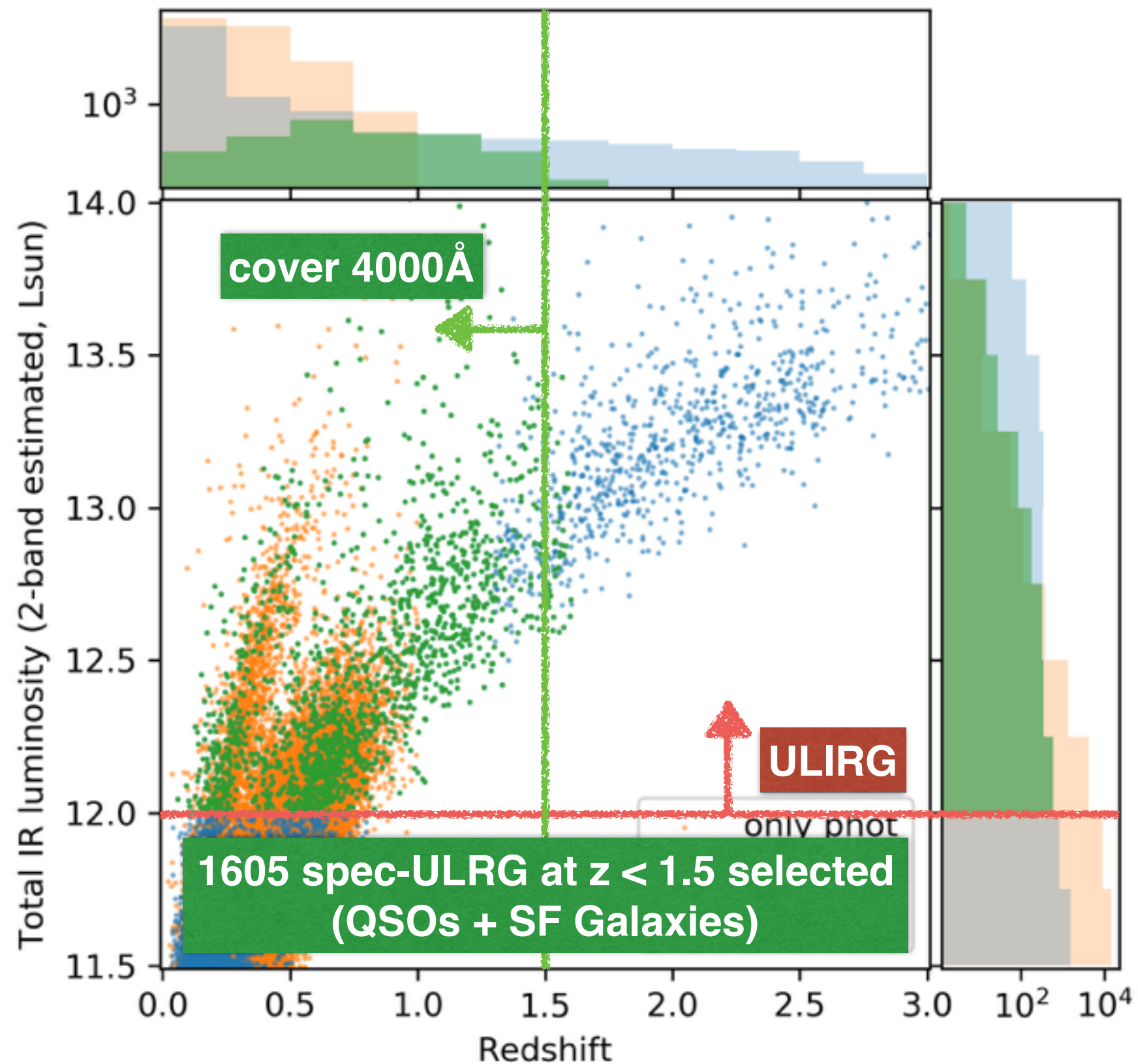
$$\begin{aligned} L_{AGN} * (SED_{torus} \otimes T_{12}) + L_{SB} * (SED_{SB} \otimes T_{12}) &= Flux_{12} \\ L_{AGN} * (SED_{torus} \otimes T_{90}) + L_{SB} * (SED_{SB} \otimes T_{90}) &= Flux_{90} \end{aligned}$$

band transmission

2-band SED estimation to select ULIRG

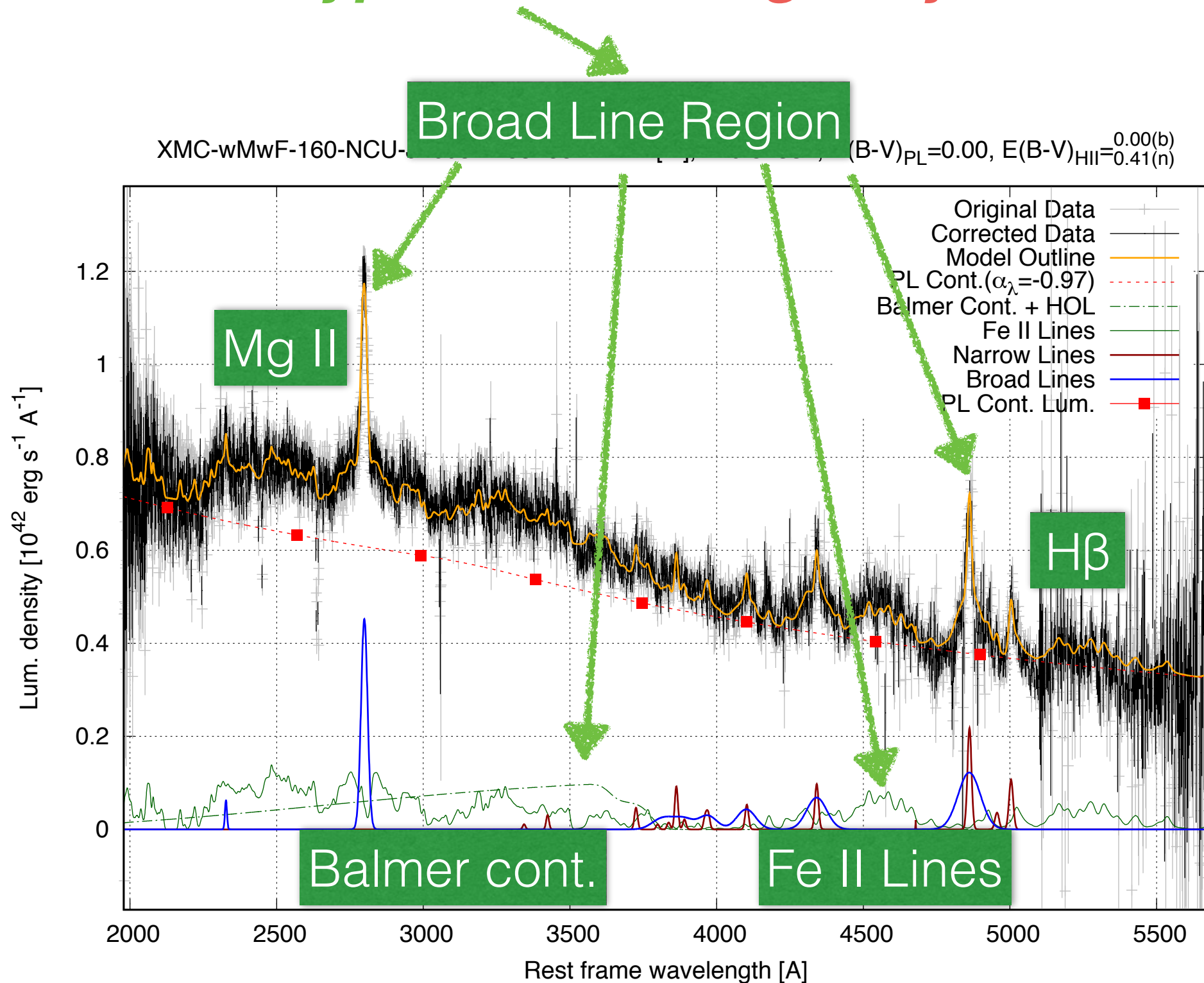


2-band SED estimation to select ULIRG



Spectral identification

type1 QSO? SF galaxy?



Spectral identification

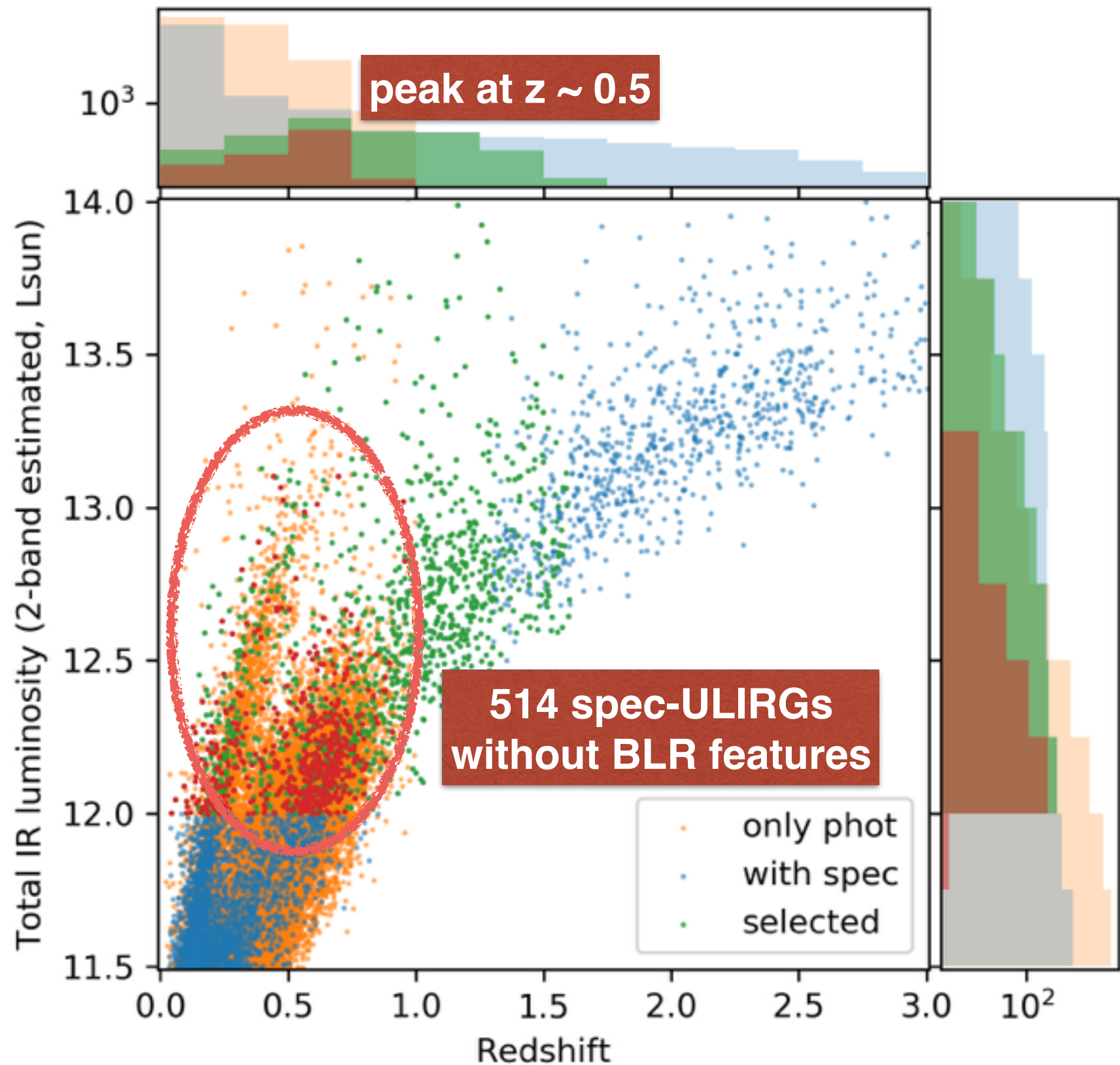
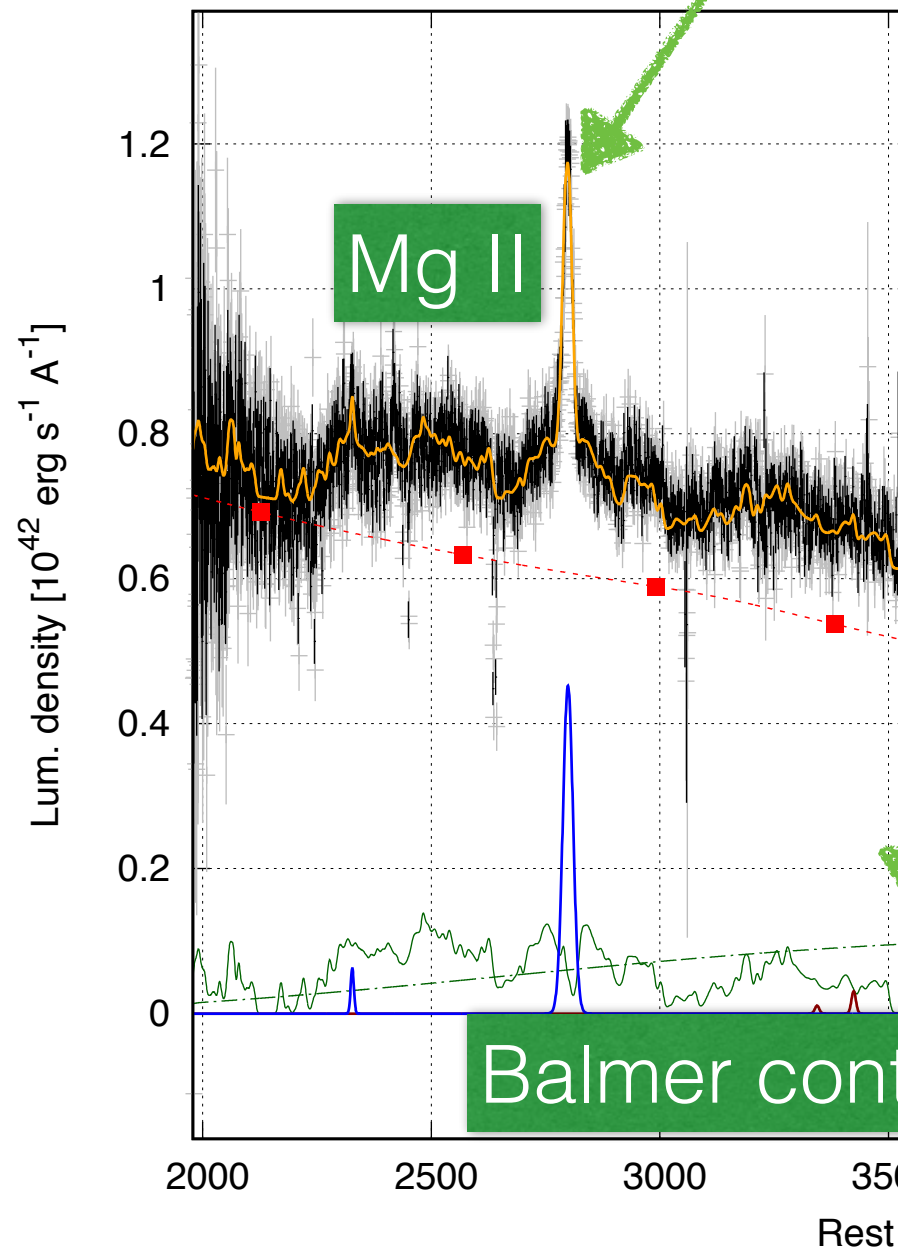
type1 QSO

XMC-wMwF-160-NCU-

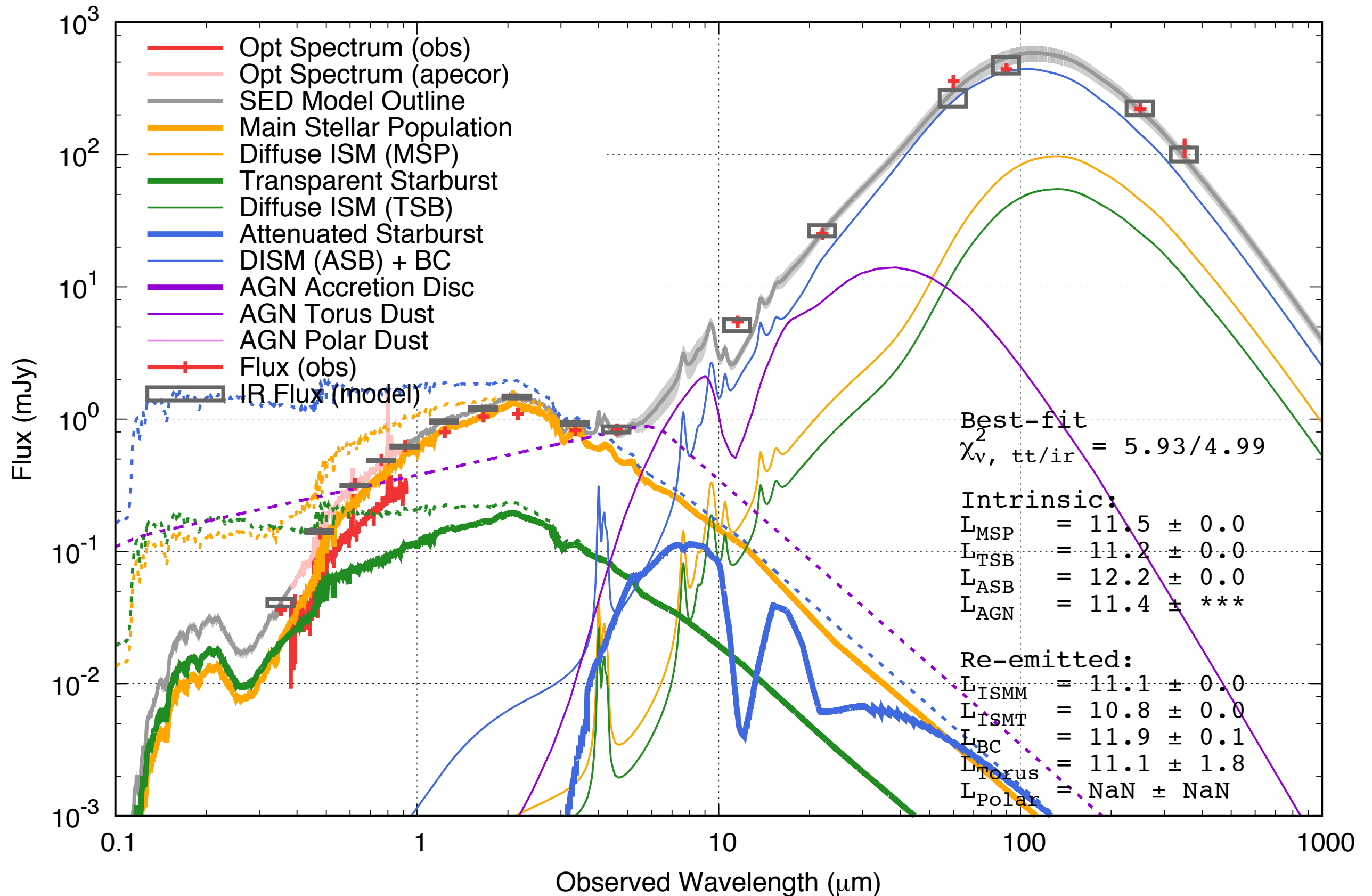
Broad

Mg II

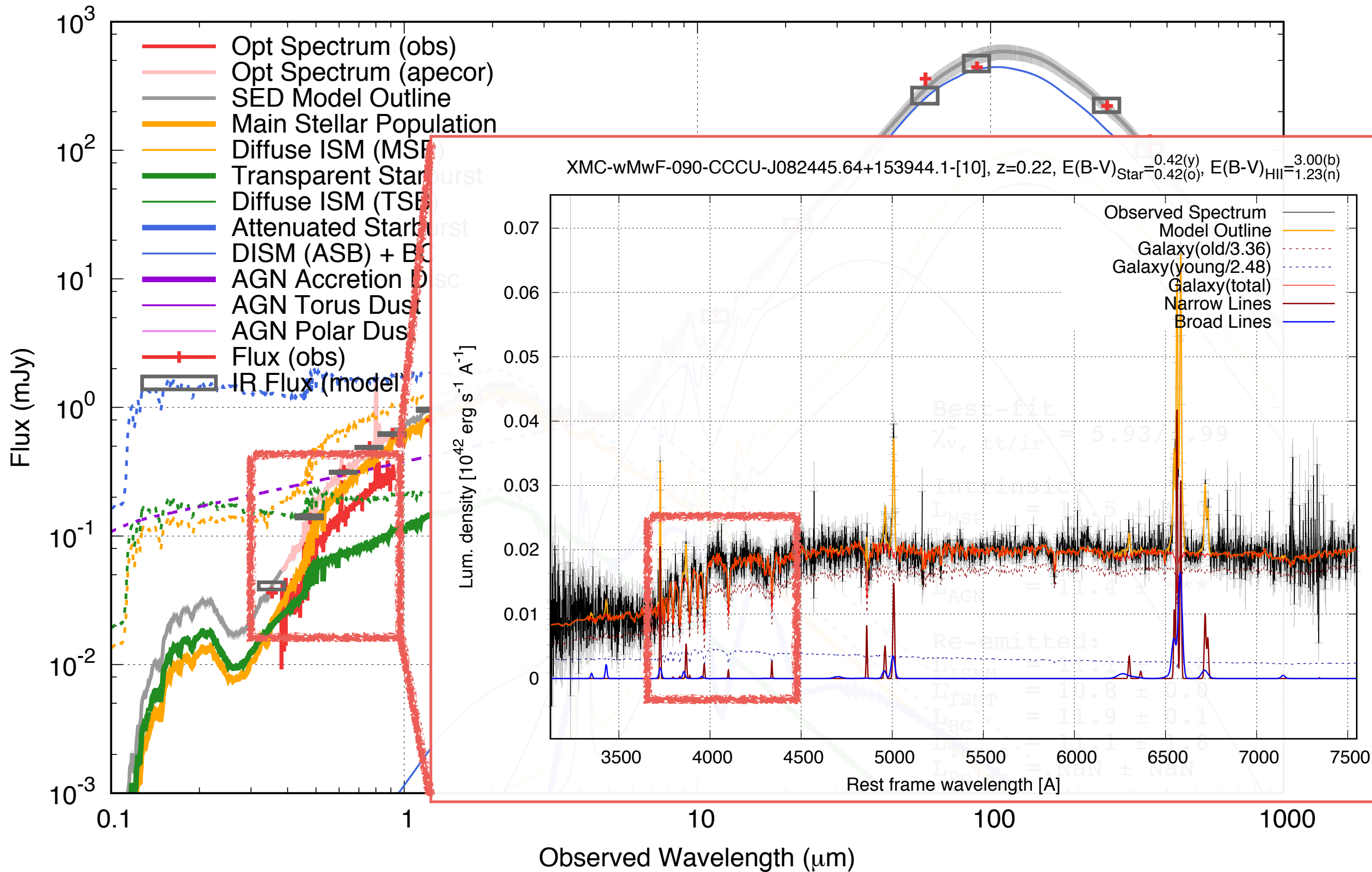
Balmer con



Joint Opt.Spec + SED fitting



Joint Opt.Spec + SED fitting



Ca K H



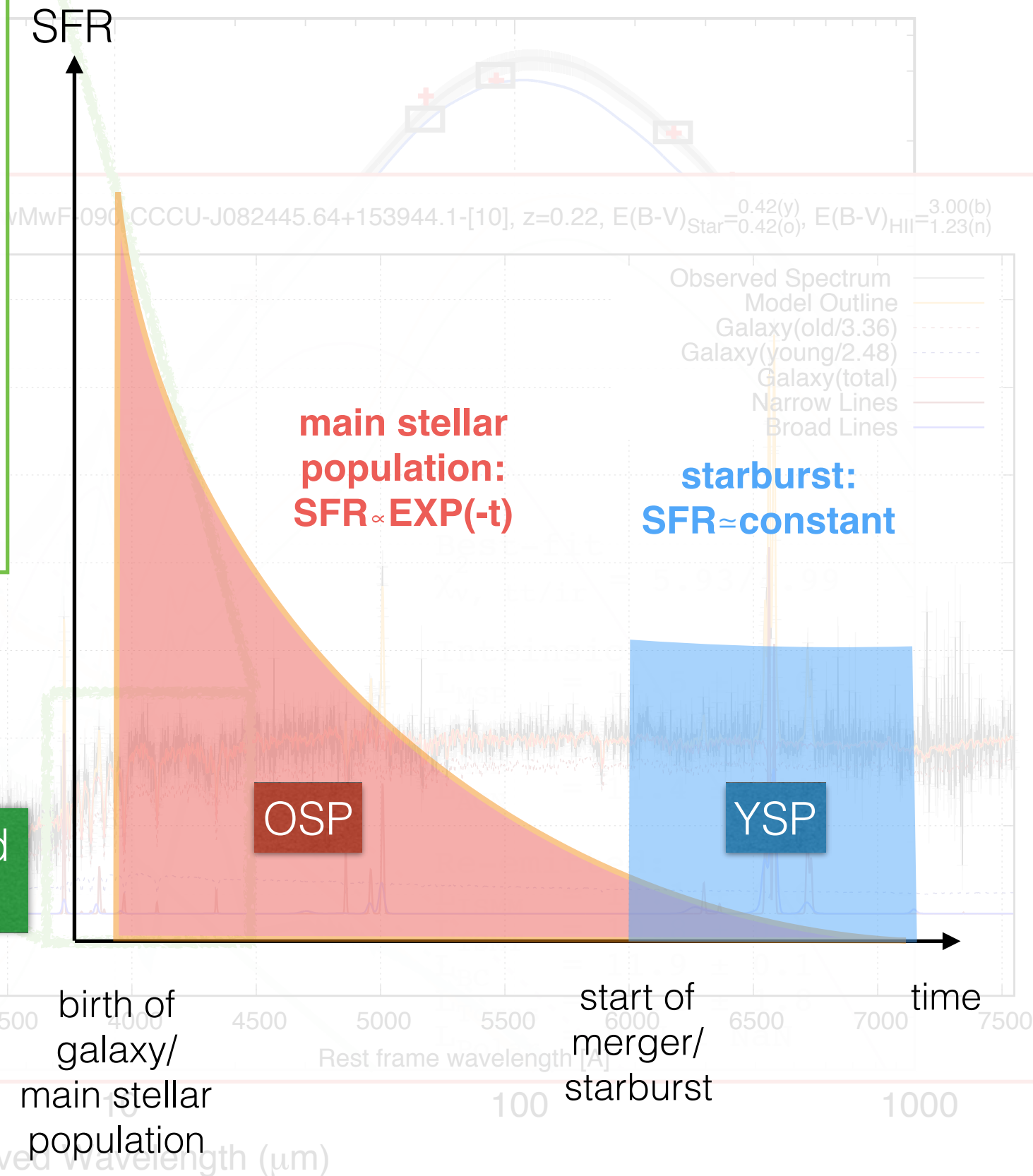
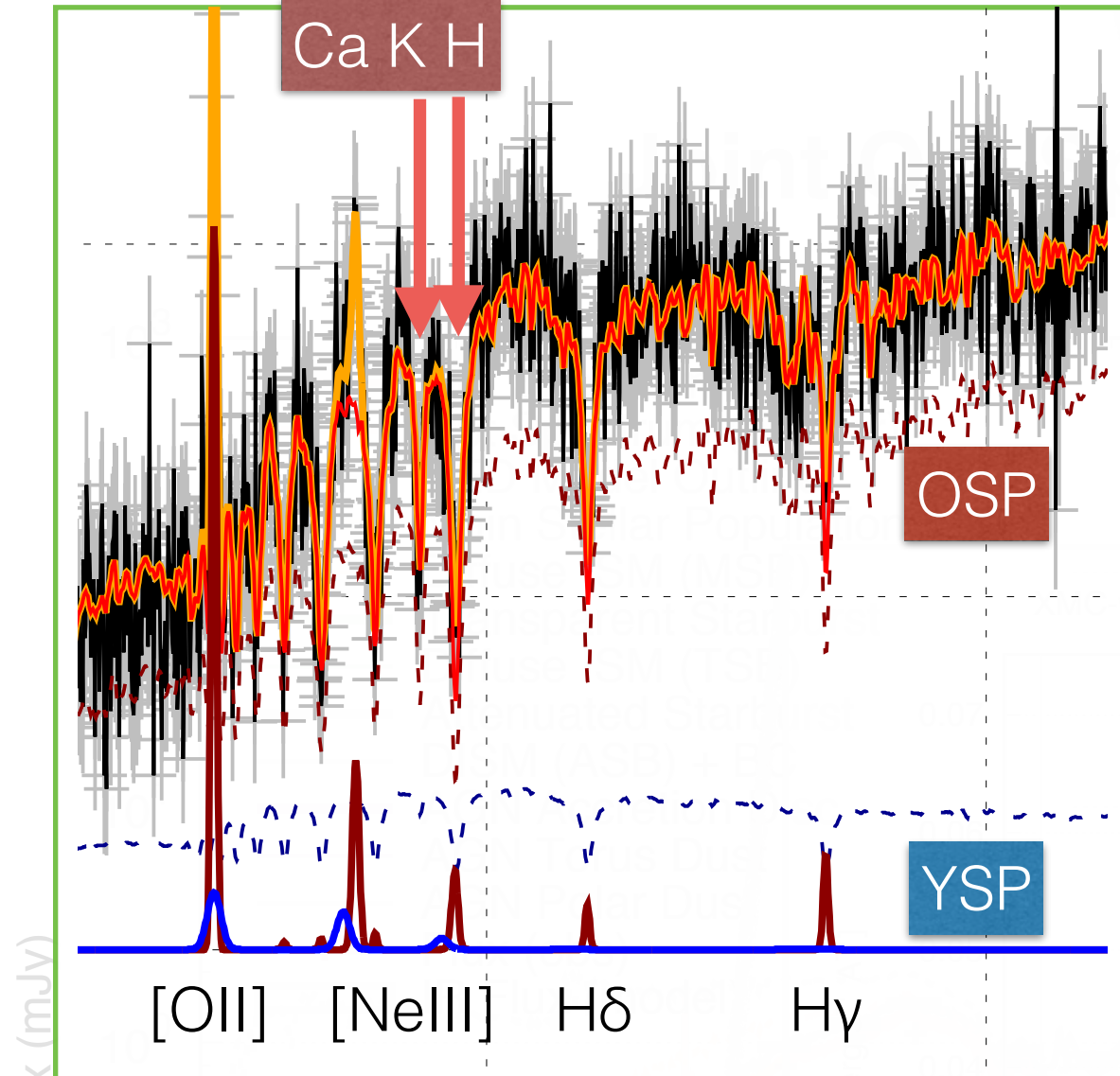
2017MwF-090 CCCU-J082445.64+153944.1-[10], $z=0.22$, $E(B-V)_{\text{Star}}=^{0.42(y)}_{0.42(o)}$, $E(B-V)_{\text{HII}}=^{3.00(b)}_{1.23(n)}$

YSP

Observed Spectrum ———
 Model Outline ———
 Galaxy(old/3.36) - - -
 Galaxy(young/2.48) - - -
 Galaxy(total) ———
 Narrow Lines ———
 Broad Lines ———

 $\text{um. density} [10^{42}]$

Spect + SED fitting



Spectral
Aperture
Correction

SSP: Bruzual and
Charlot, 2003

Ca K H

OSP

YSP

[OIII]

[NeIII]

H δ

H γ

From opt.spec:
1) galaxy population;
2) extinction;
3) outflow velocity.

main stellar
population:
 $SFR \propto \text{EXP}(-t)$

starburst:
 $SFR \approx \text{constant}$

OSP

YSP

Spectral
Aperture
Correction

SSP: Bruzual and
Charlot, 2003

birth of
galaxy/
main stellar
population

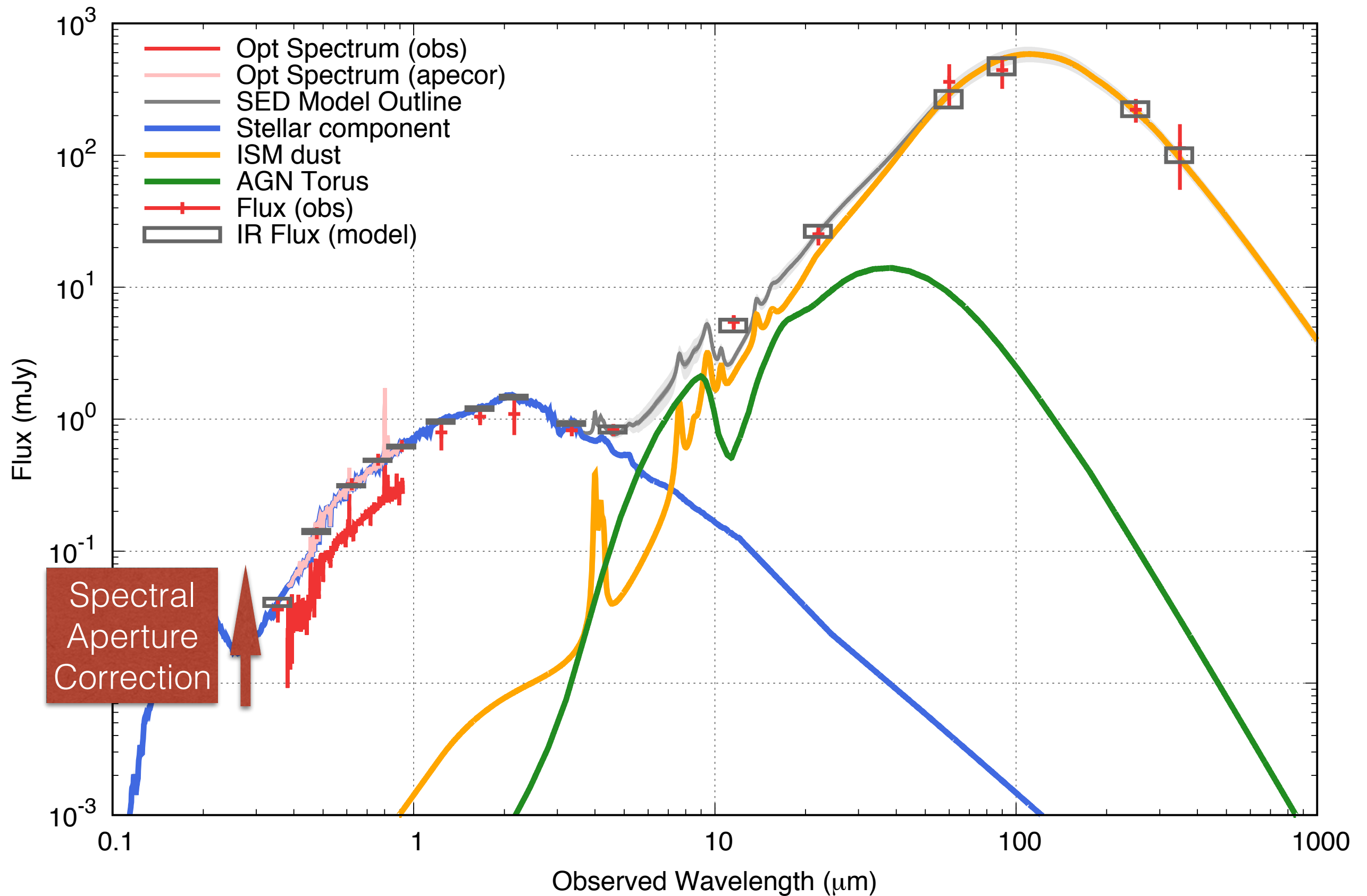
start of
merger/
starburst

time

Rest frame wavelength [Å]

Observed Wavelength (μm)

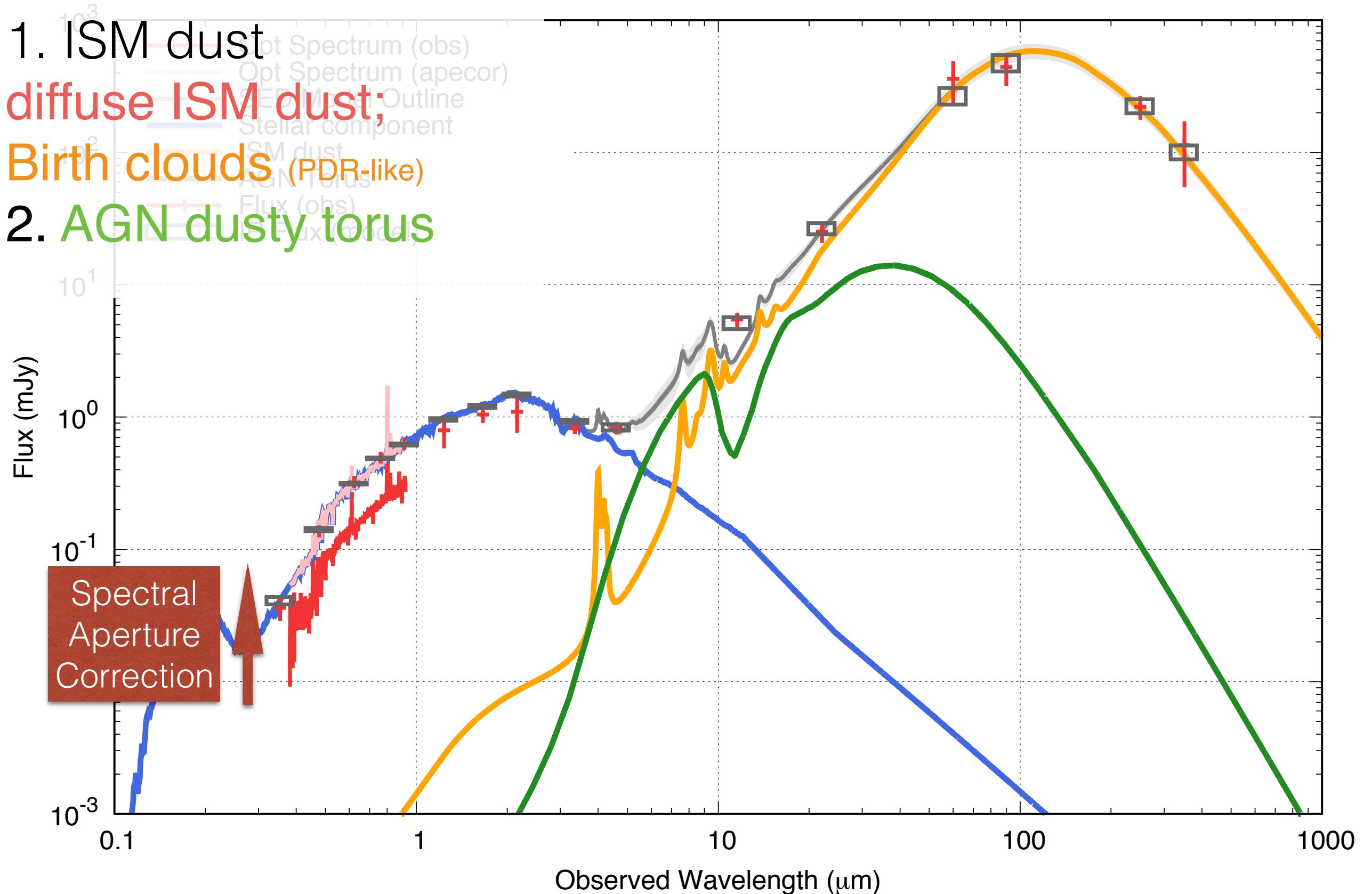
Joint Opt.Spec + SED fitting



Joint Opt.Spec + SED fitting

Two dust emitter:

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



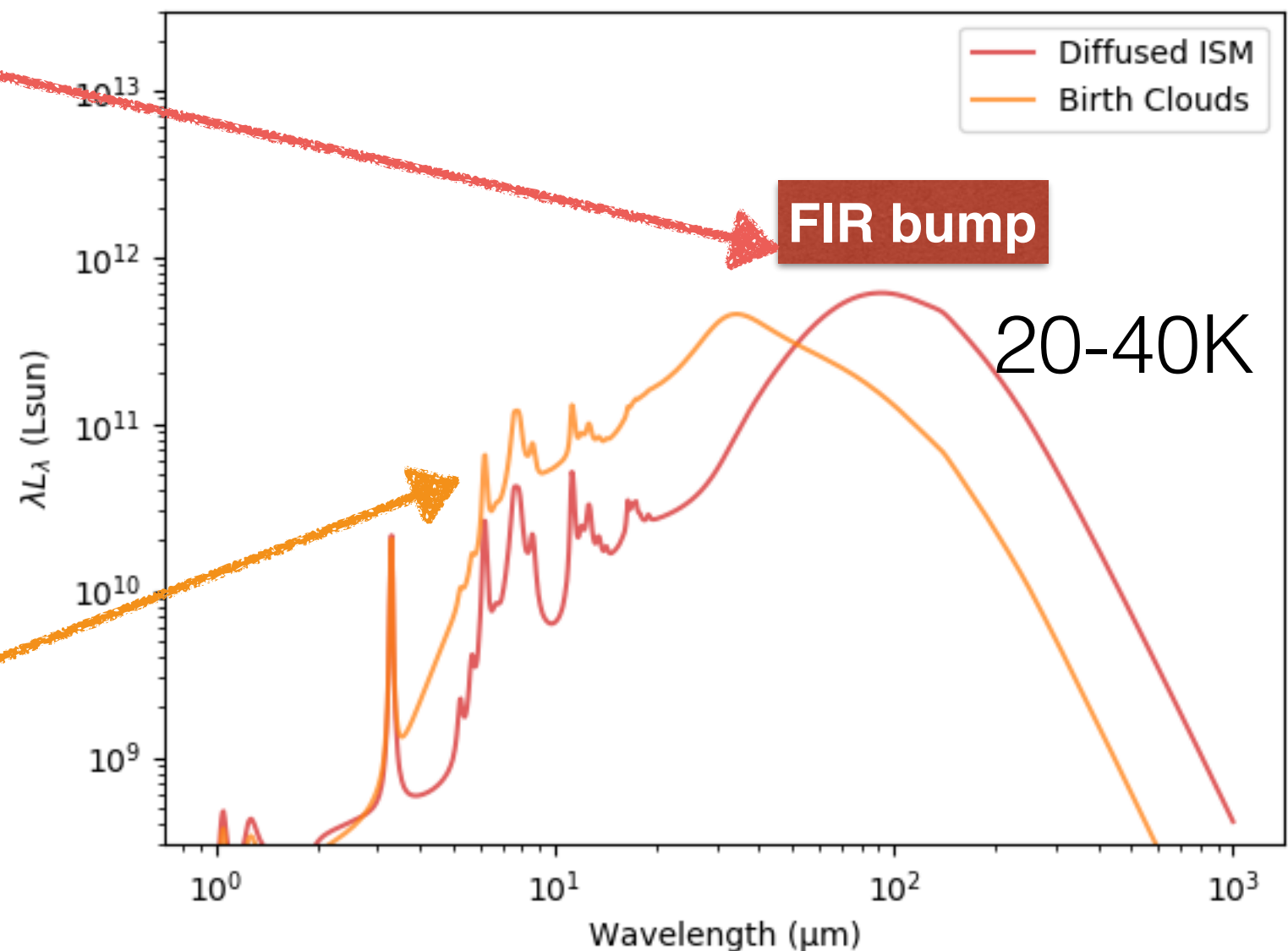
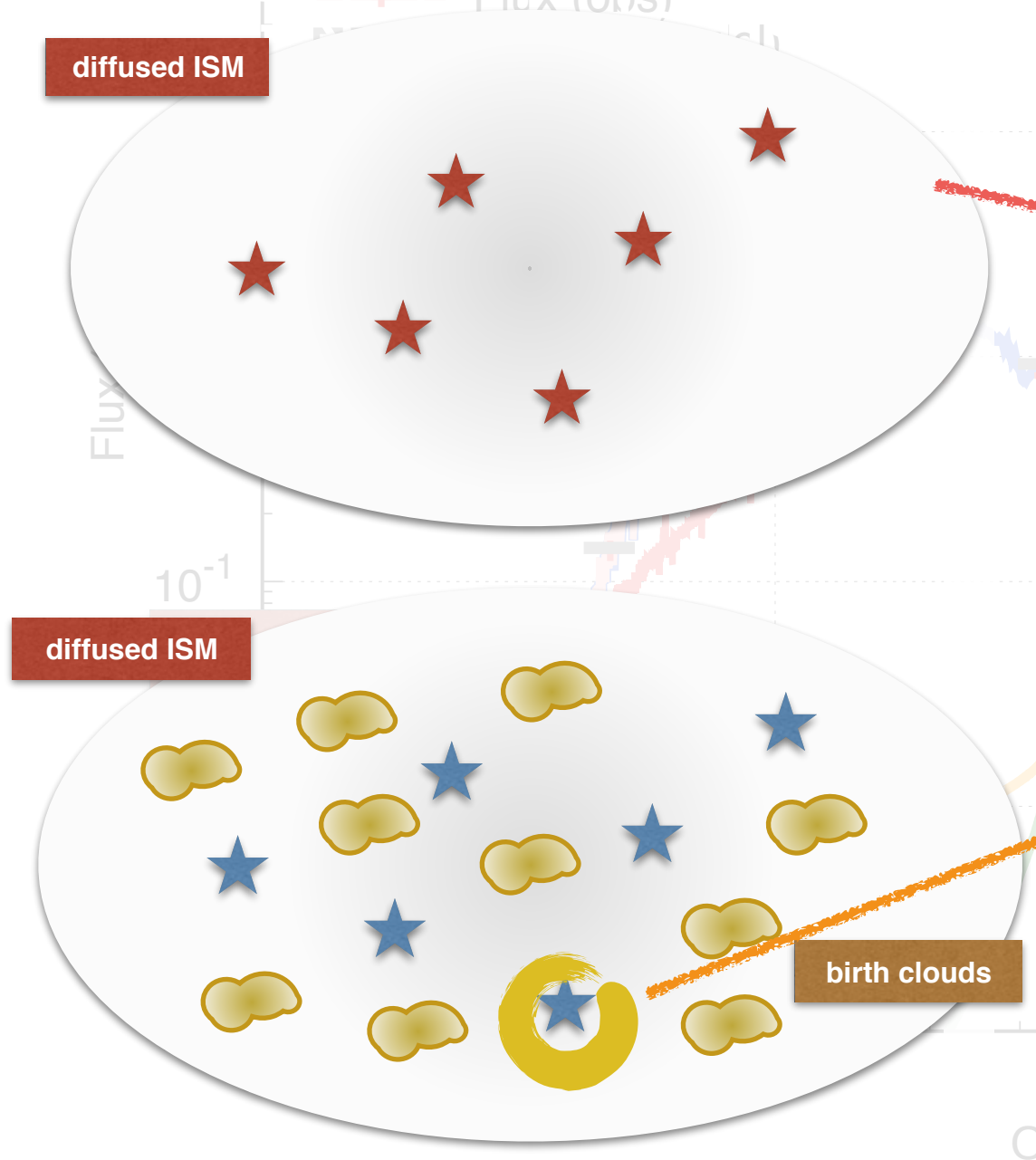
Joint Opt.Spec + SED fitting

Two dust emitter:

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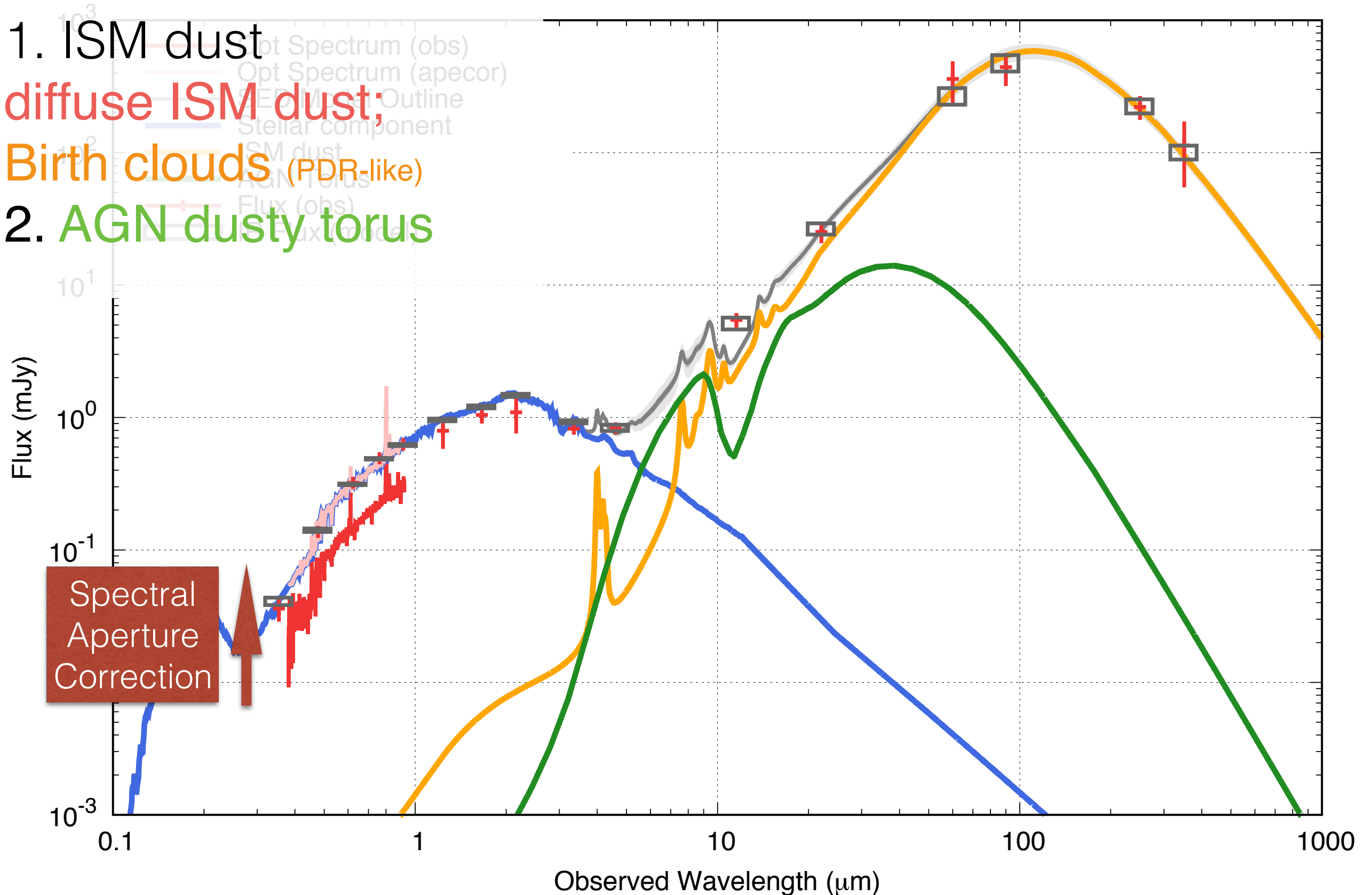
Calculated from THEMIS dust model



Joint Opt.Spec + SED fitting

Two dust emitter:

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Joint Opt.Spec + SED fitting

Two dust emitter:

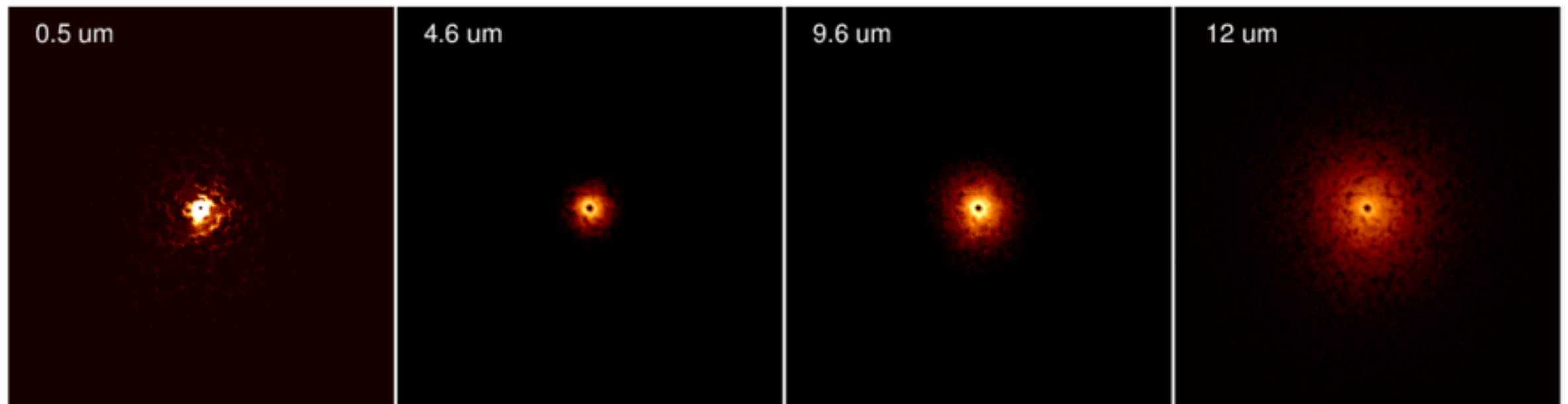
1. ISM dust
diffuse ISM dust;
Birth clouds (PDR-like)
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SKIRTOR 2.0

Stalevski et al. (2012,2016)

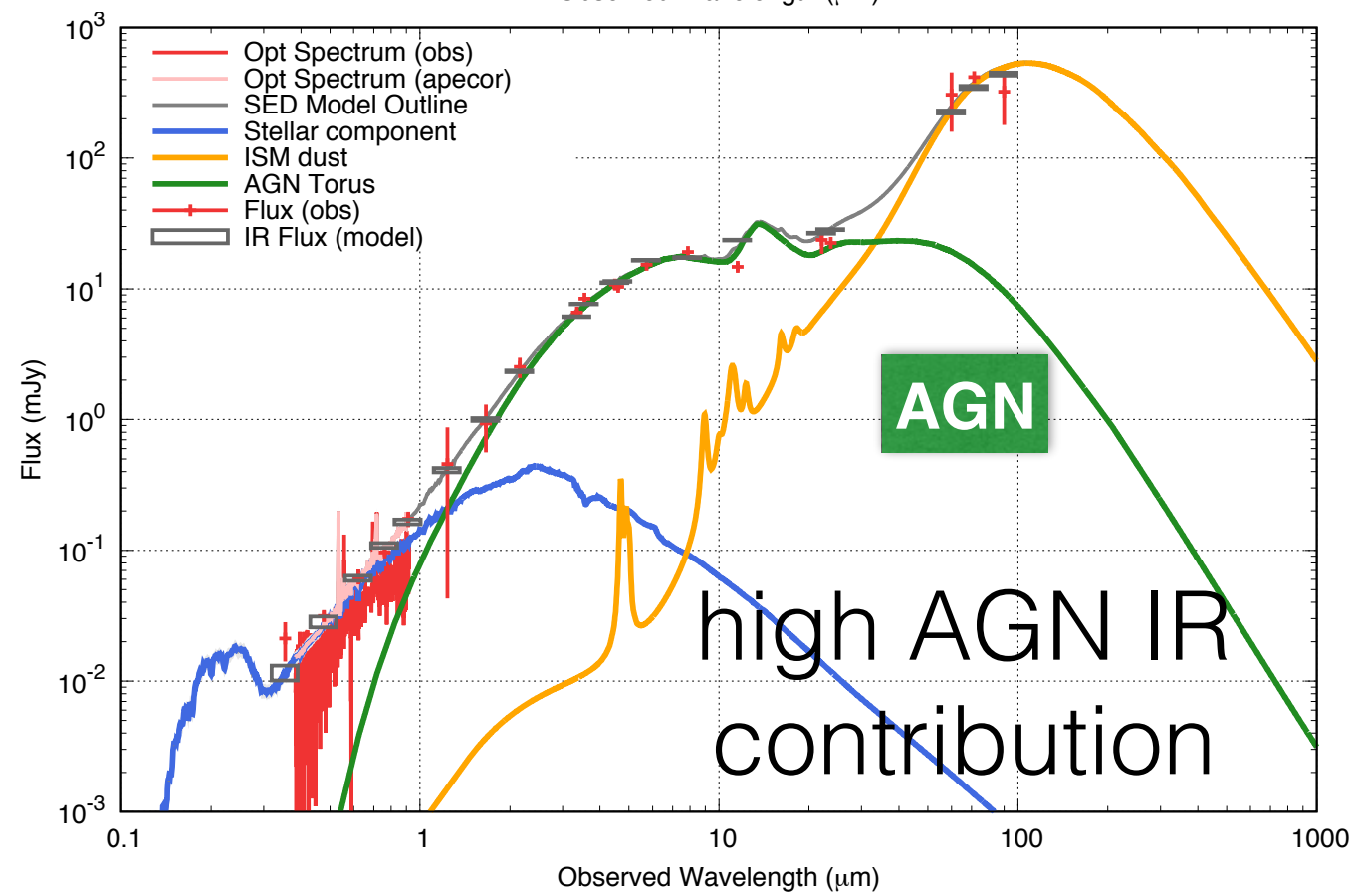
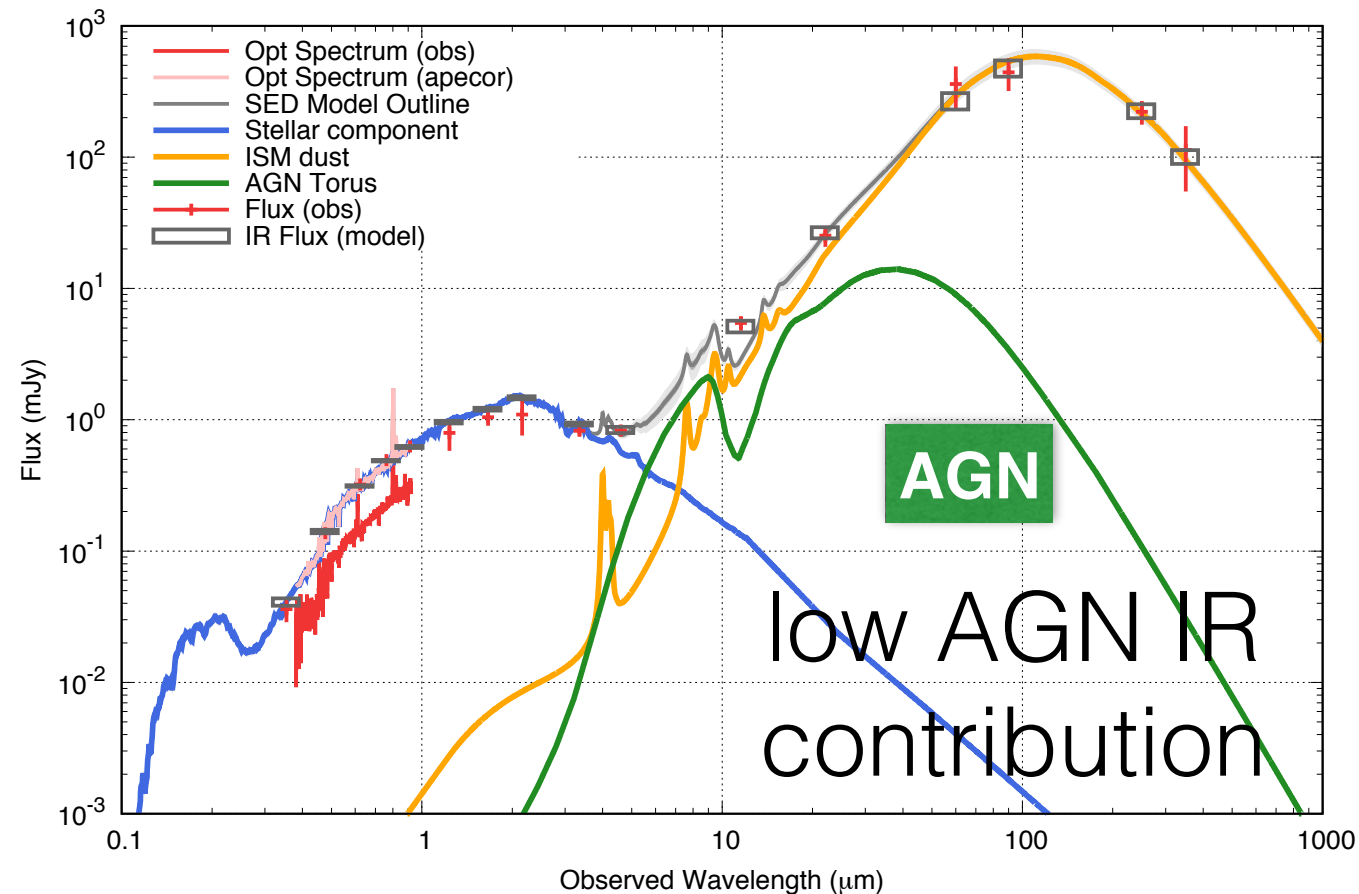
This website is home of SKIRTOR -- a library of emission models of the AGN dusty torus, calculated with [SKIRT](#), state-of-the-art radiative transfer code based on Monte Carlo technique.

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

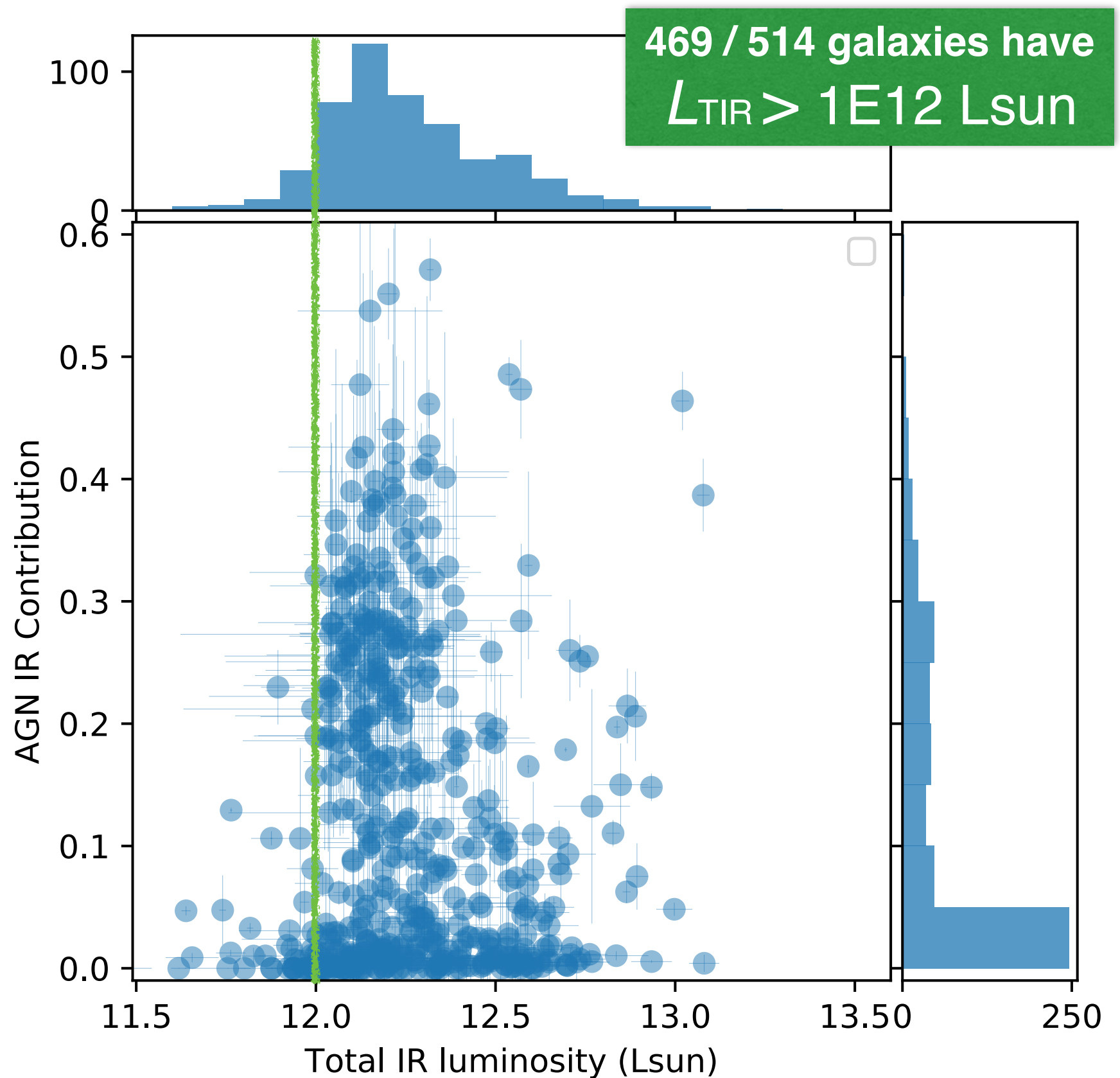
What about the results?

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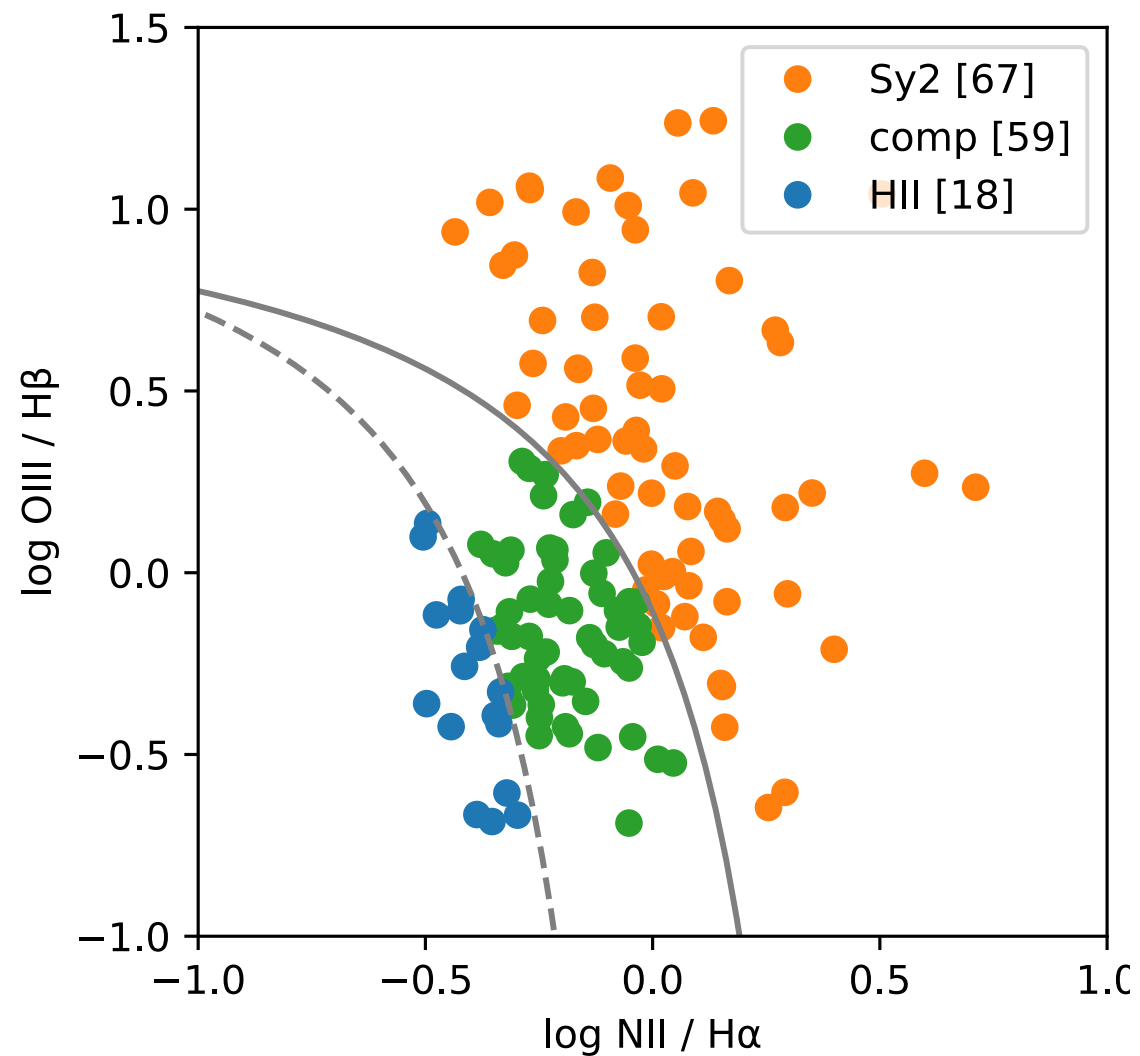
General properties of Spec+SED fitting

AGN contribution
 $= L_{\text{torus}} / L_{\text{TIR}}$

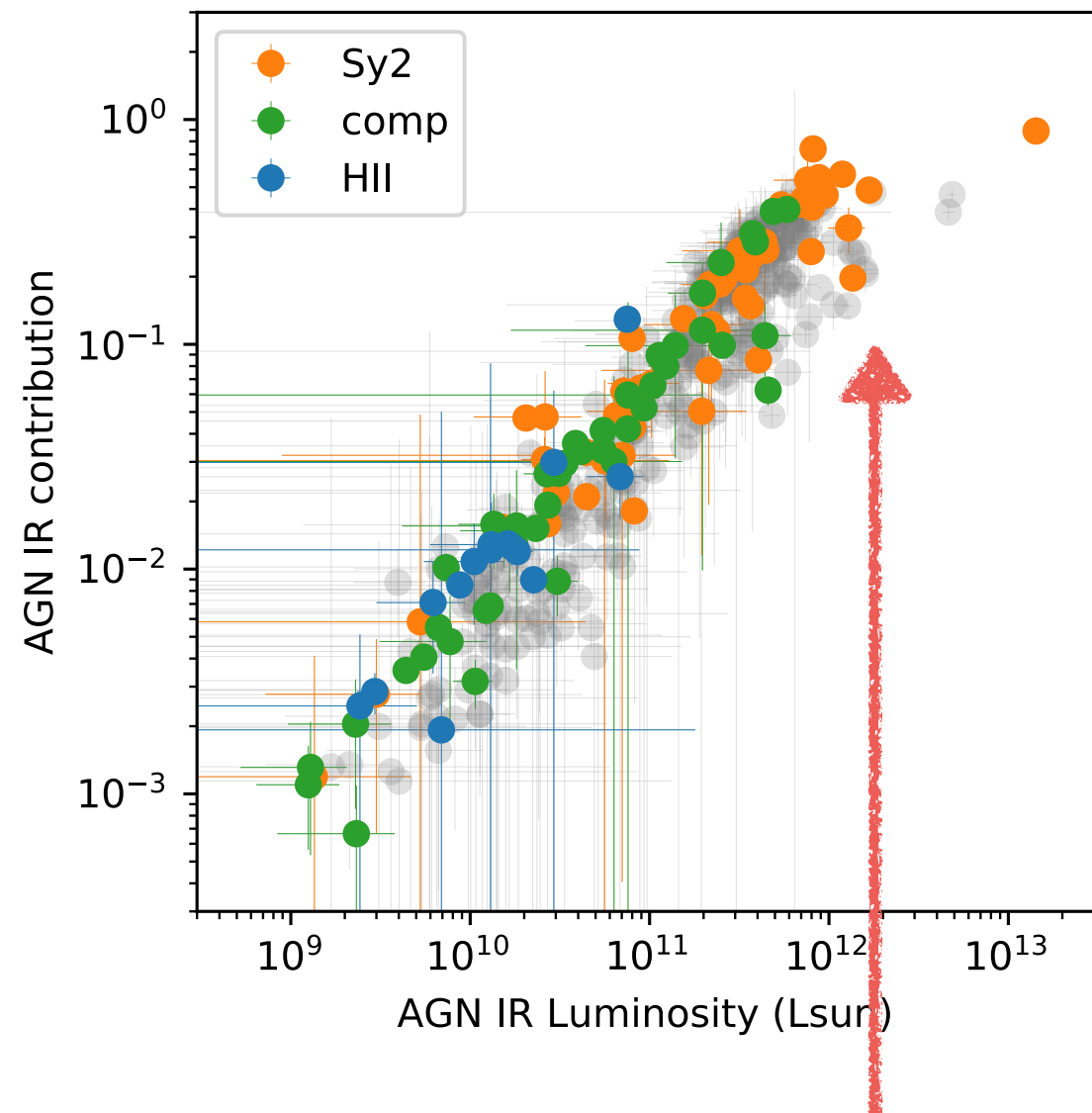


General properties of Spec+SED fitting

AGN contribution with BPT diagram check



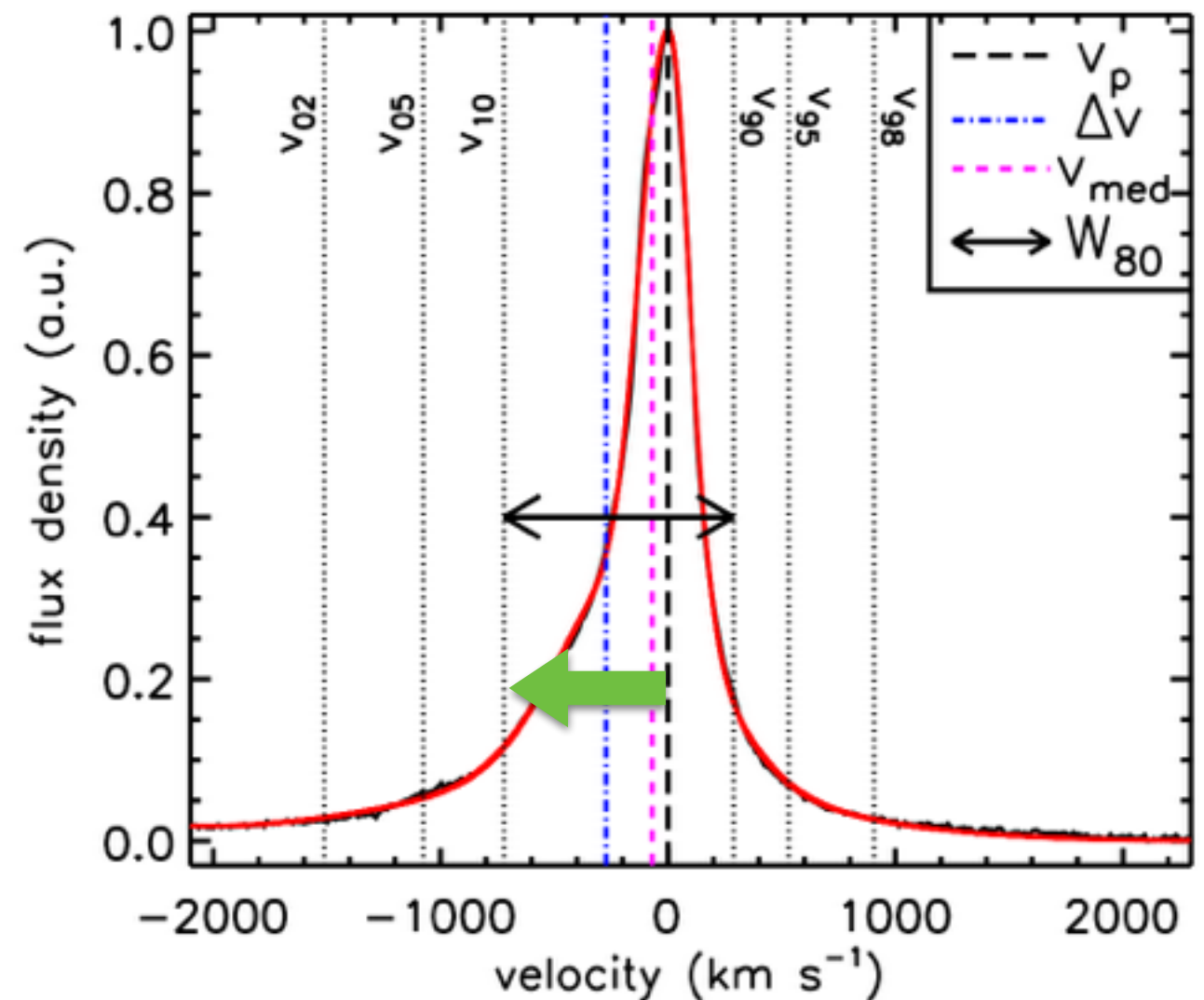
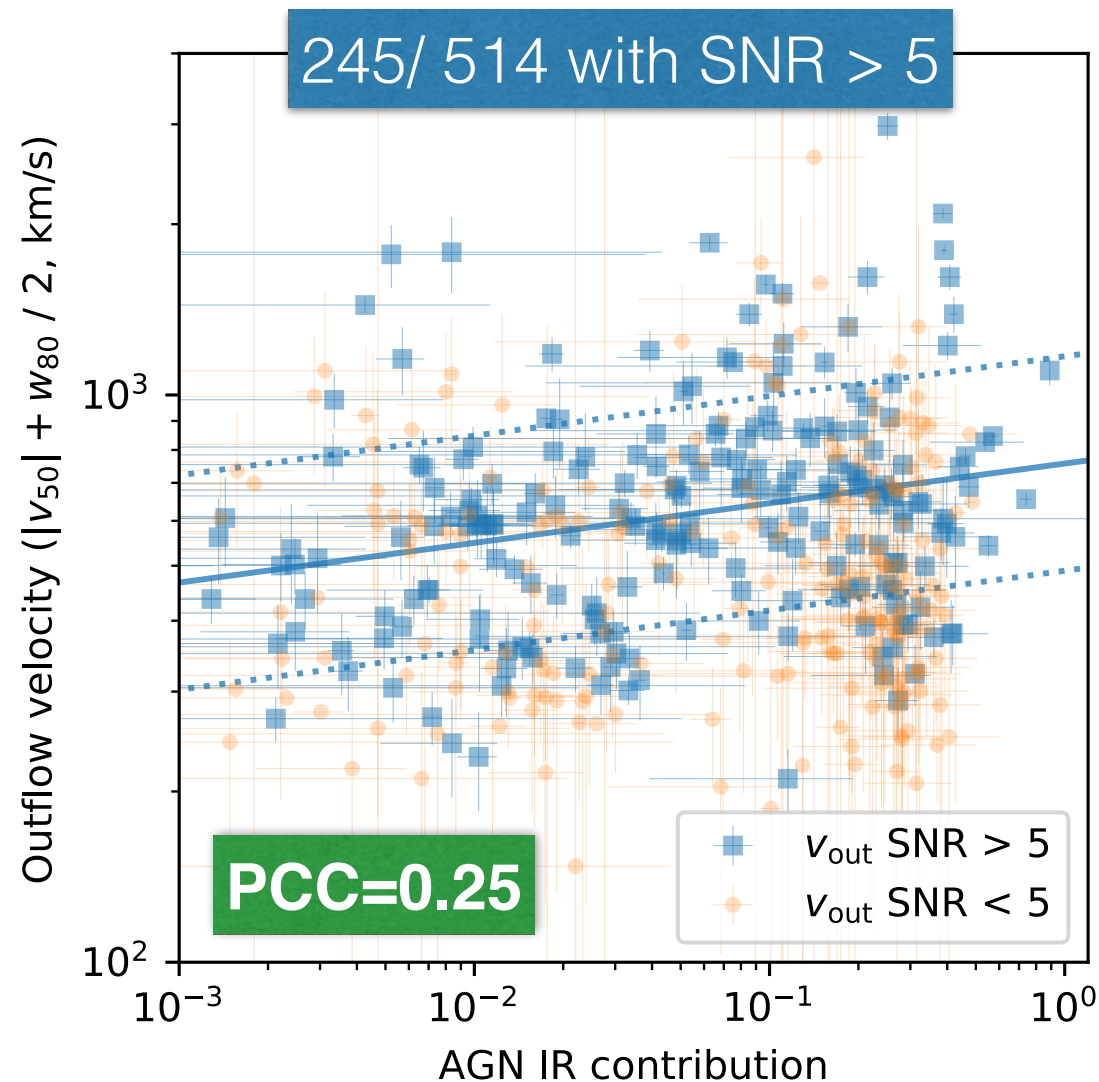
**144 / 514 galaxies have
[NII] flux SNR > 5**



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

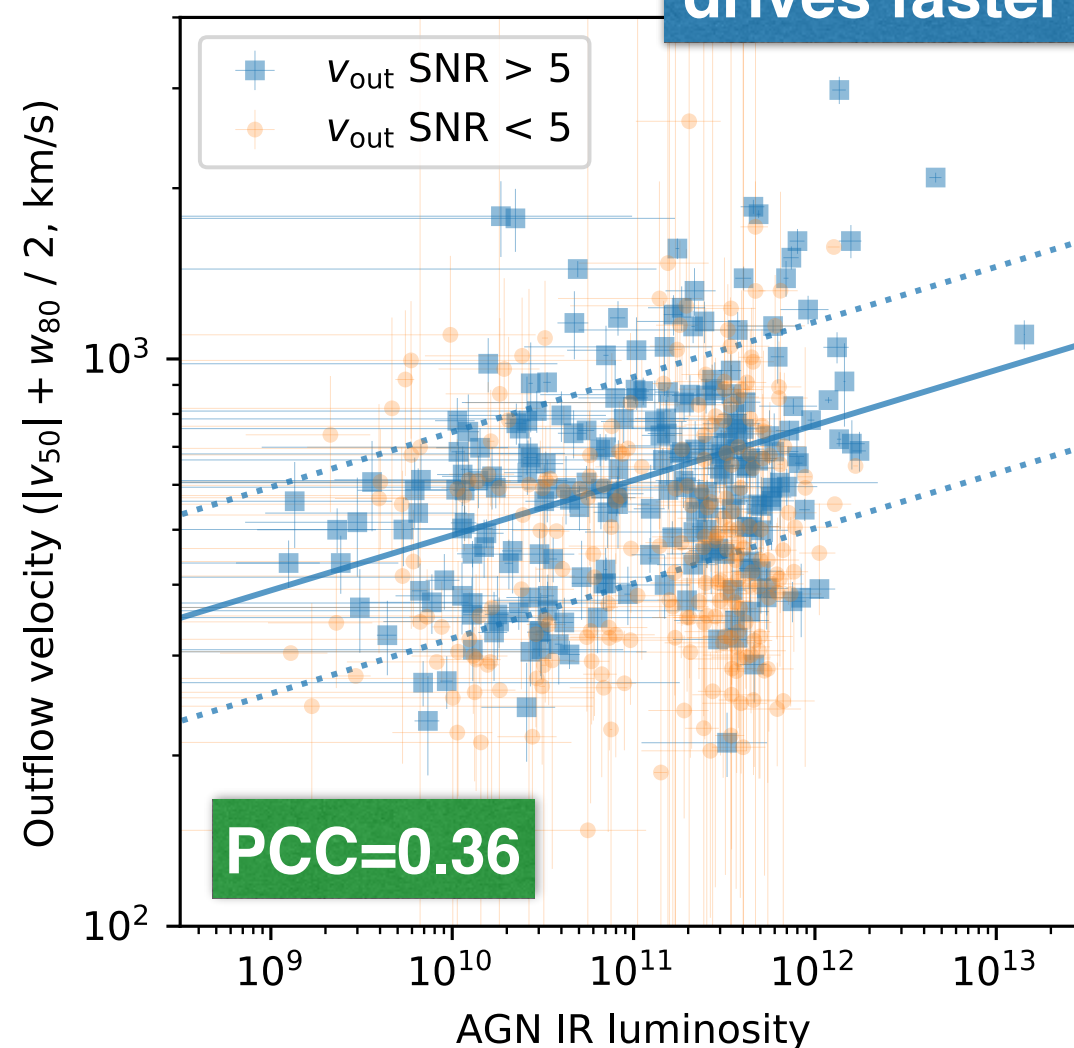
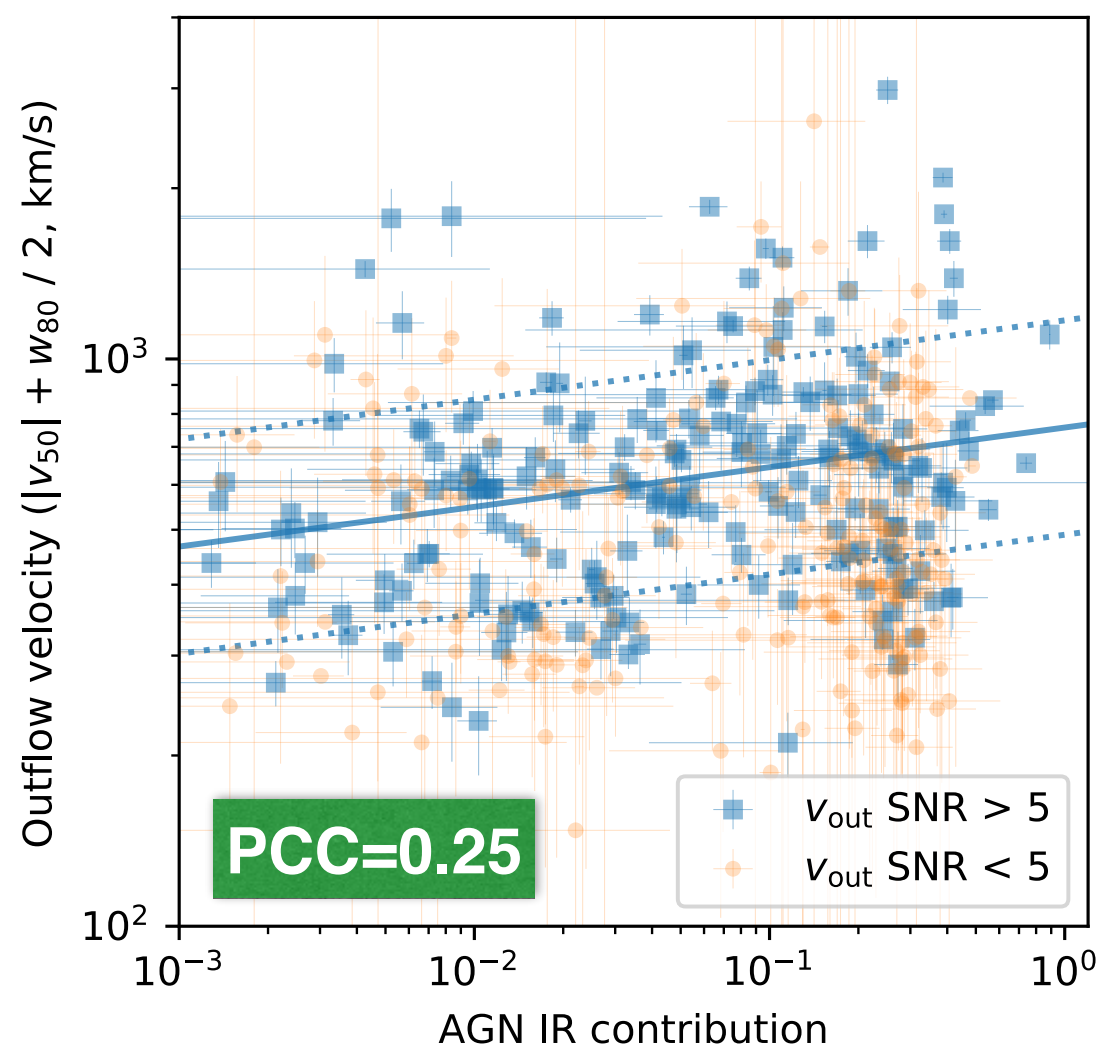
$$v_{\text{out}} = |v_{50}| + w_{80} / 2$$

Outflow velocity vs. AGN intensity

Outflow can be measured from the shift and width of emission lines.

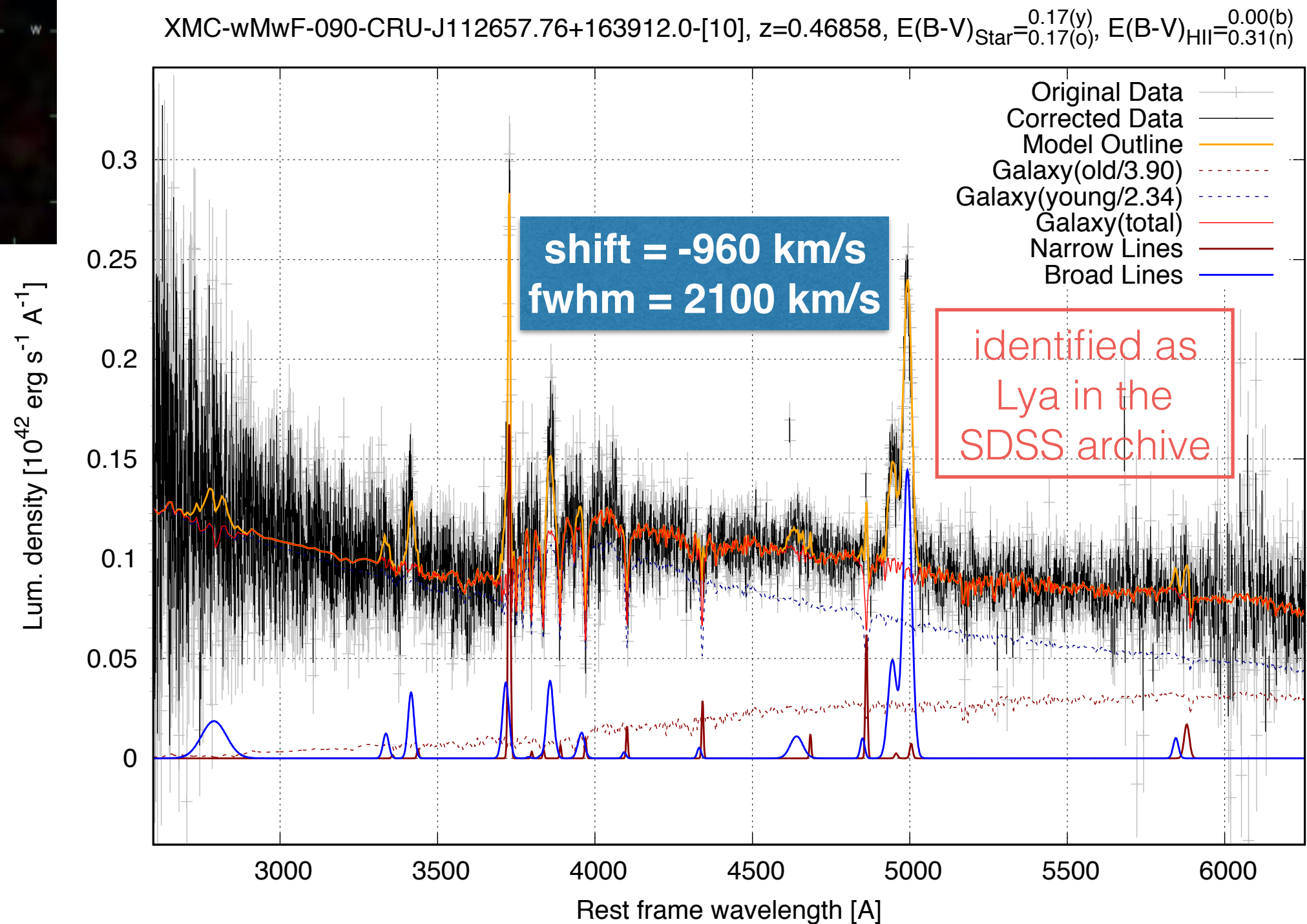
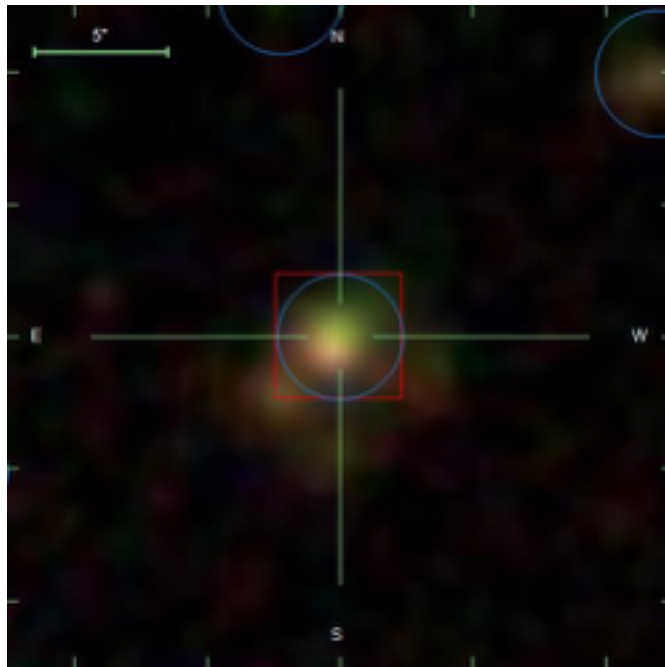
[OIII]5007 is one of the widely adopted indicators.

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

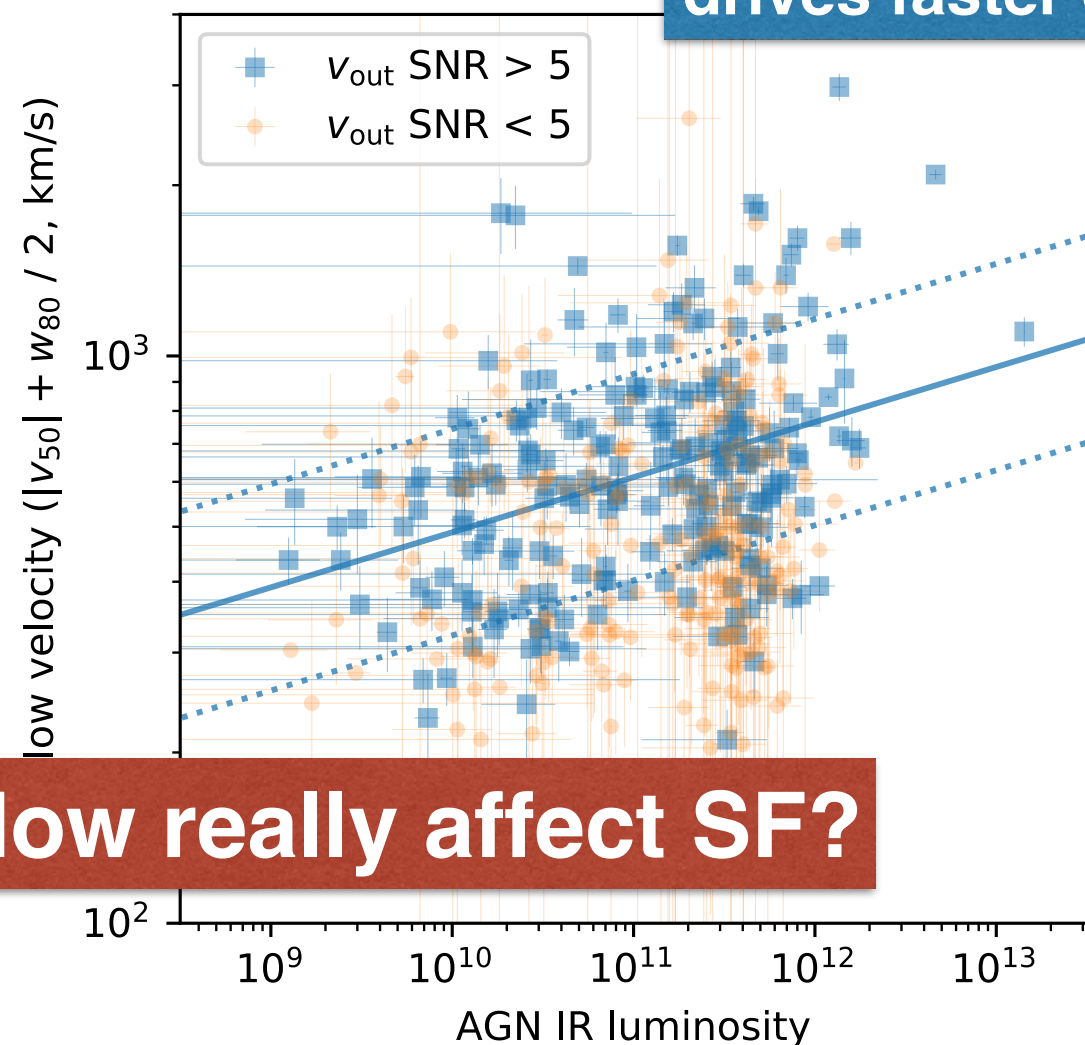
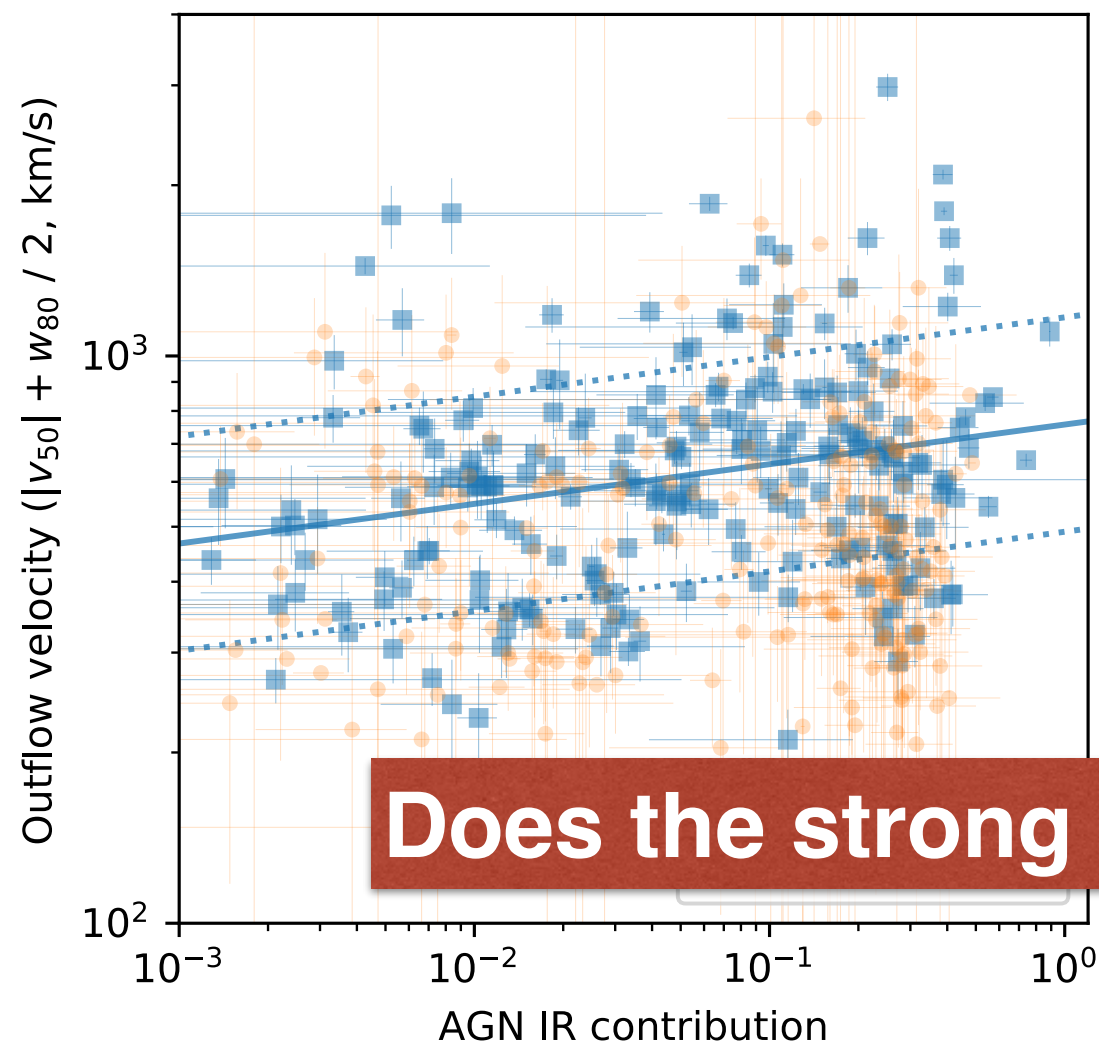


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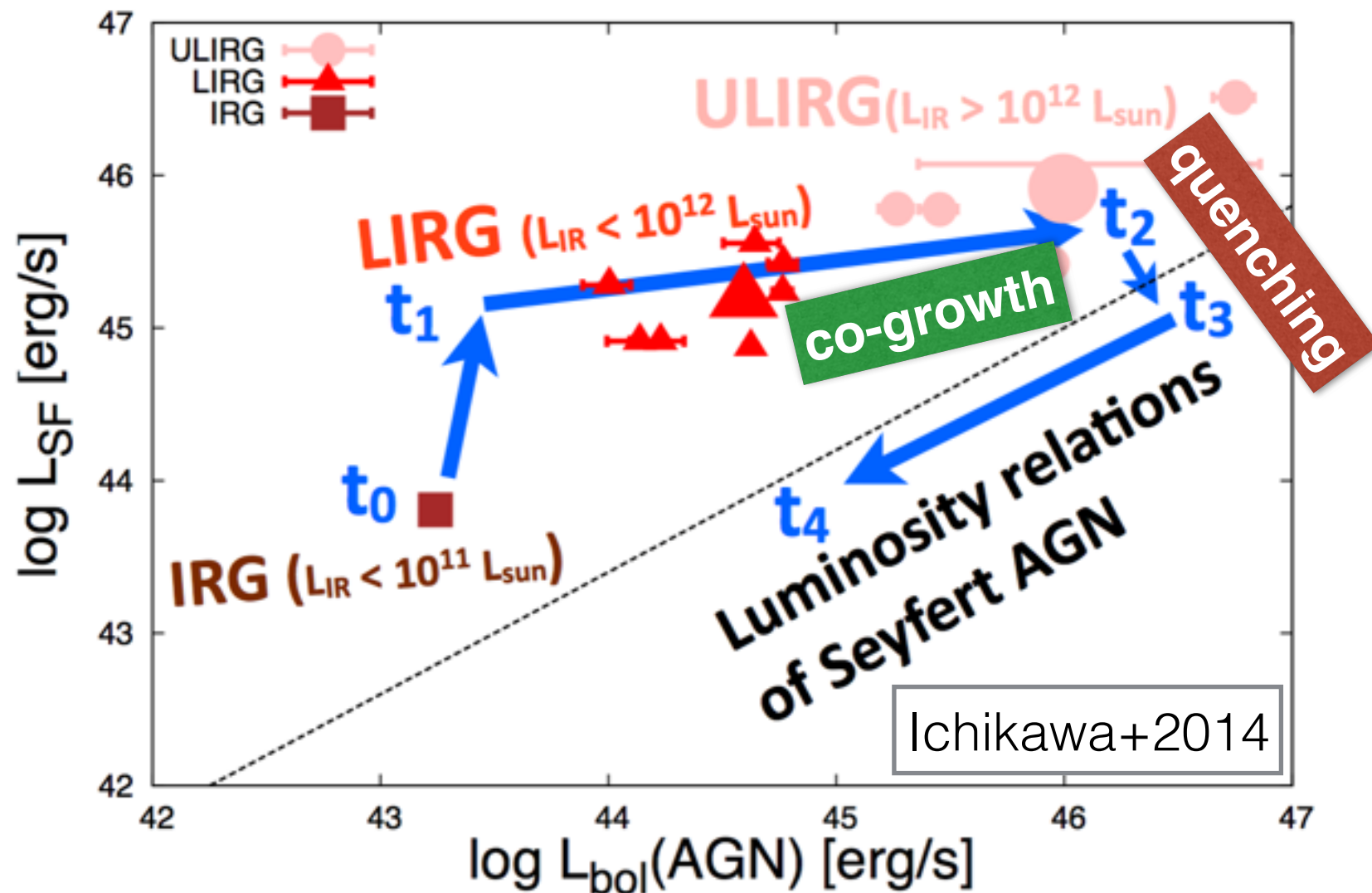
More powerful AGN drives faster outflow.



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

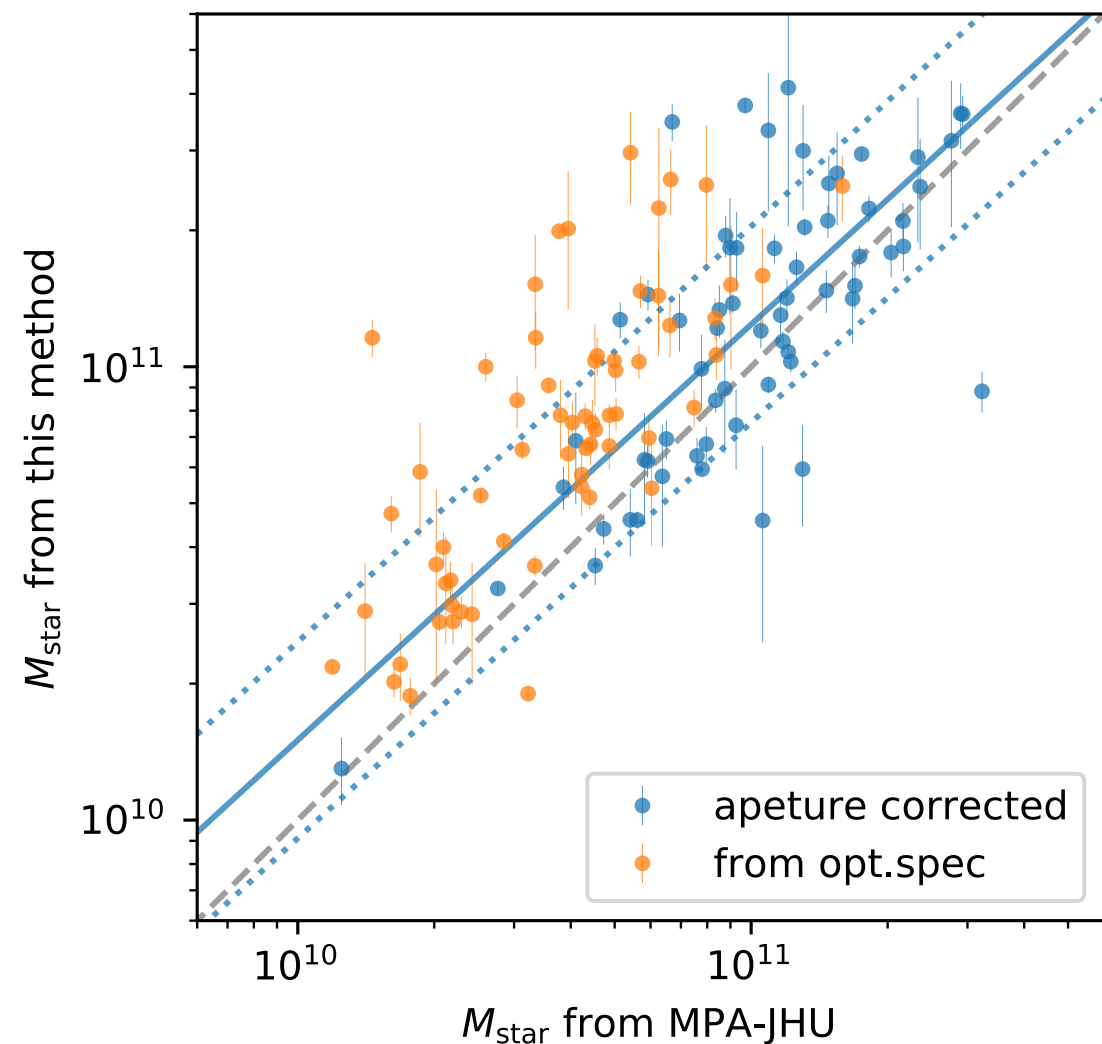
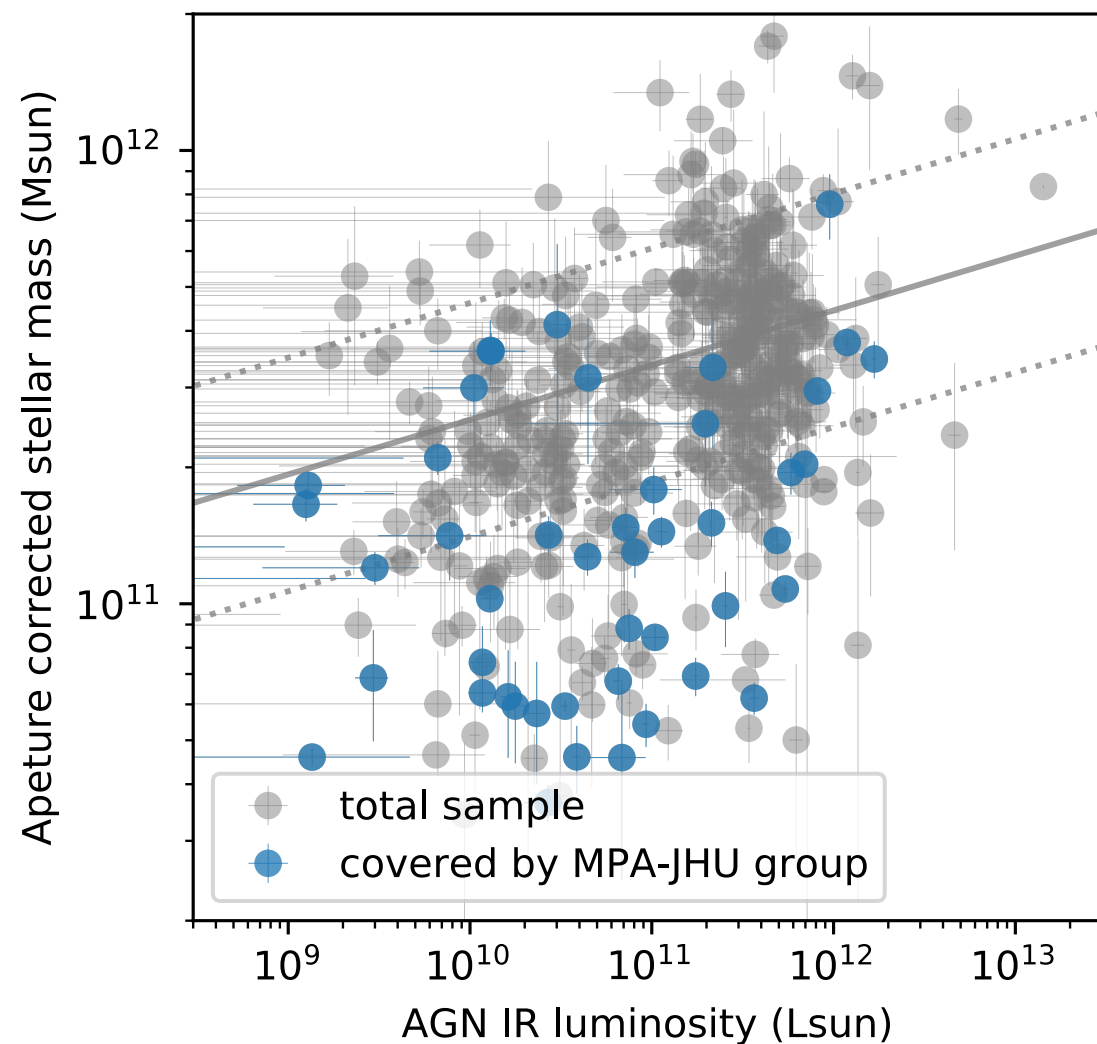


During ULIRG period,

Q1: Does the AGN(SMBH) co-grow with host galaxies?

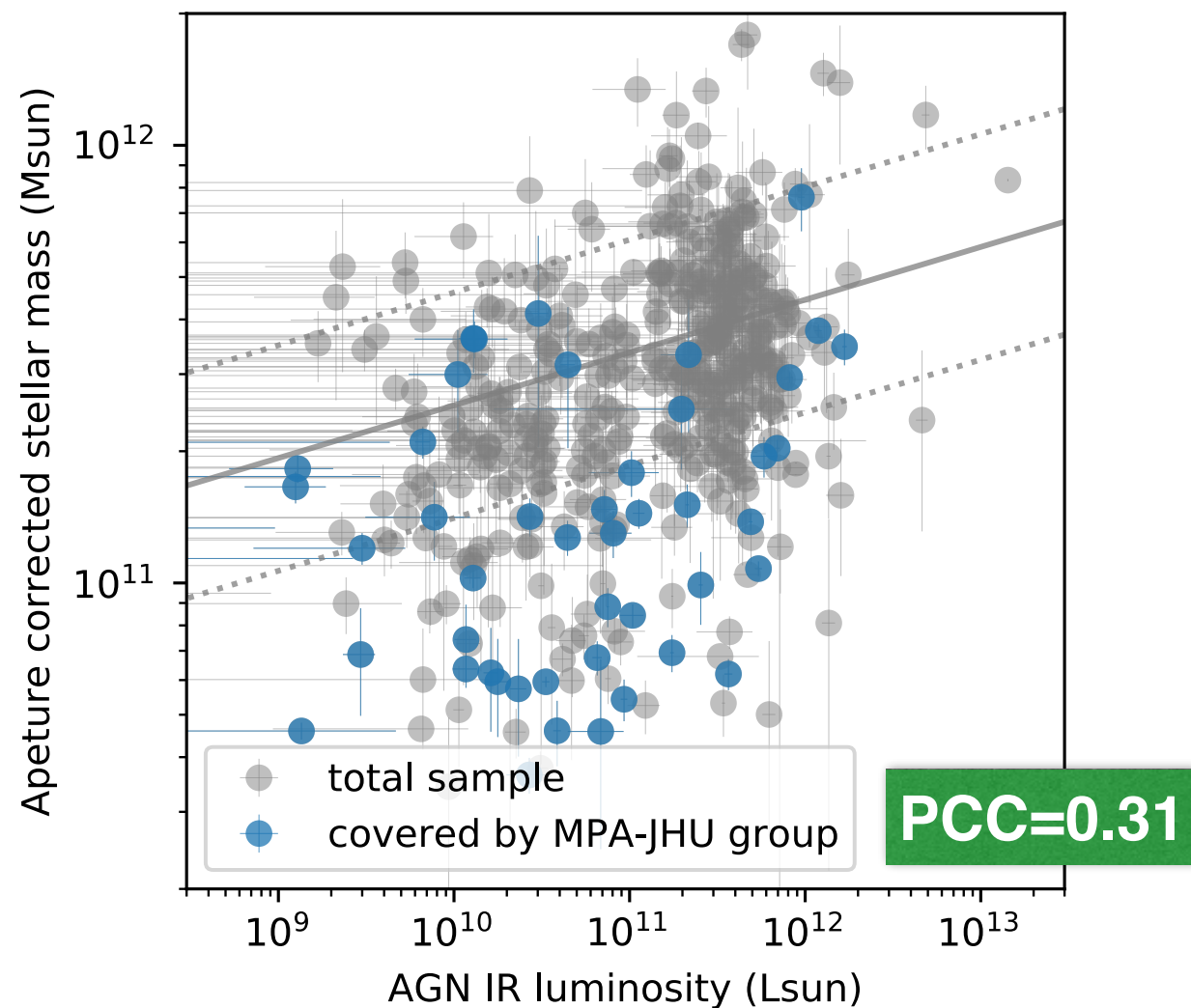
Q2: Does the feedback really take place?

Galaxy properties vs. AGN intensity

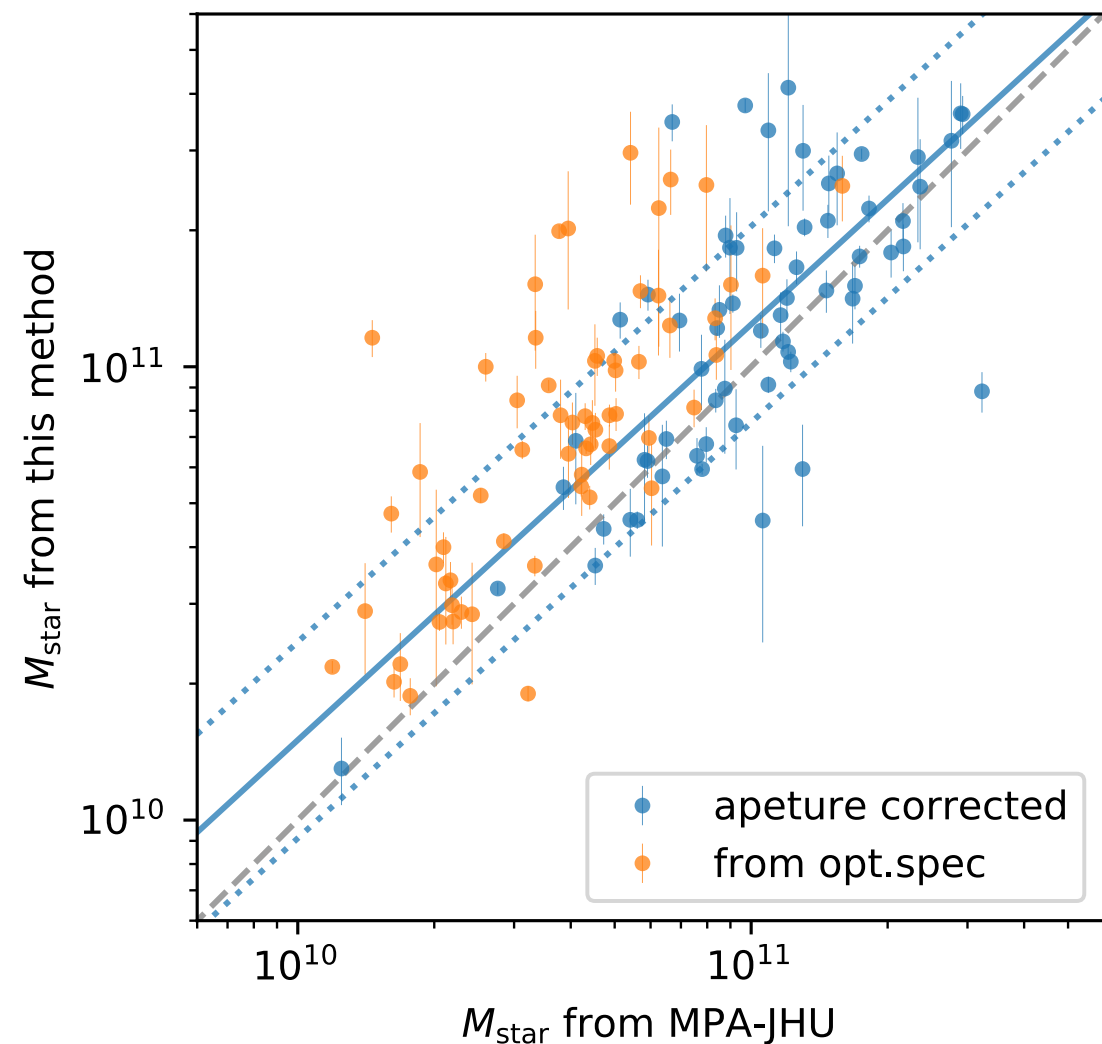


During ULIRG stage,
Q1: co-growth ?
Q2: feedback ?

Galaxy properties vs. AGN intensity

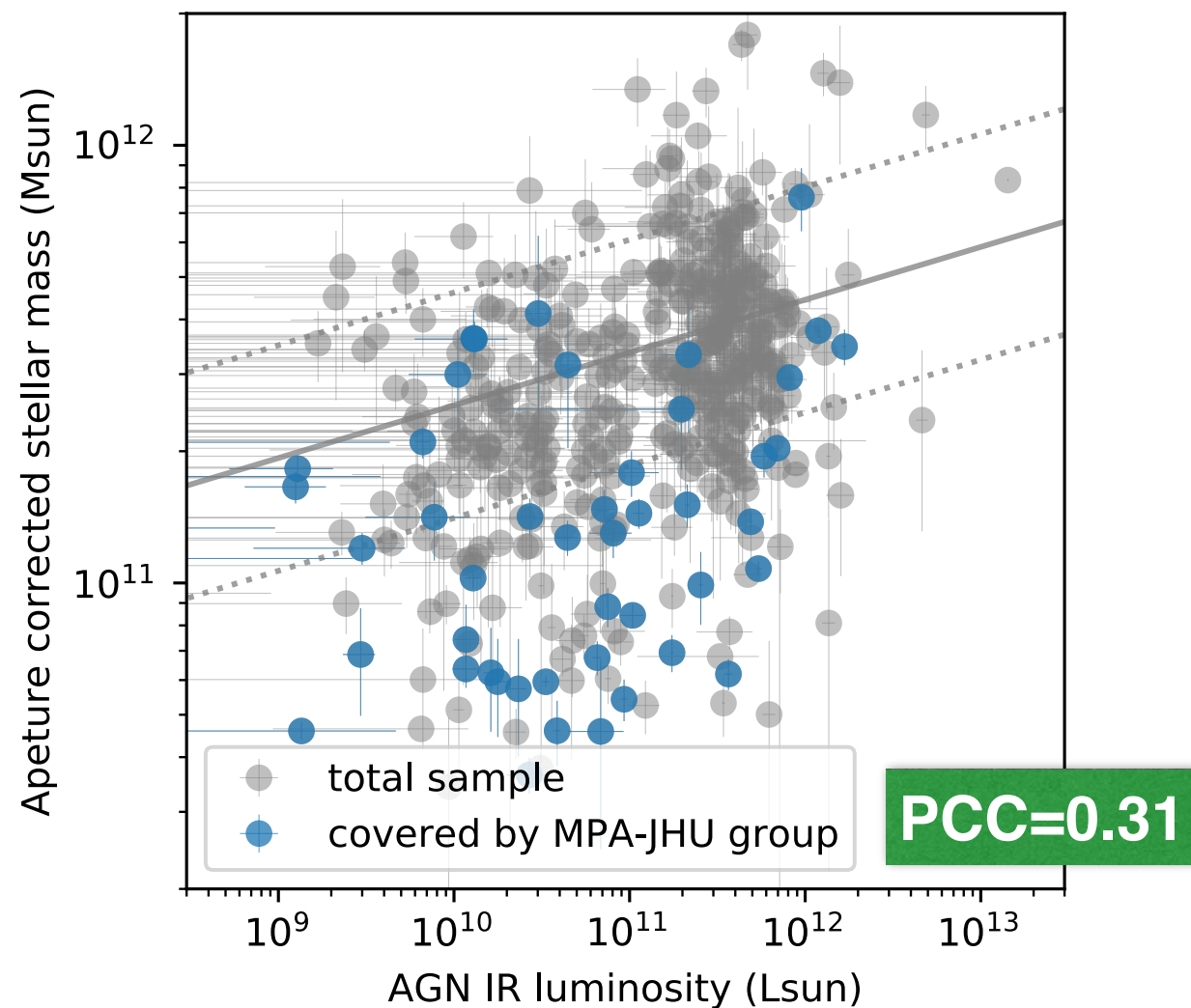


The most luminous AGN locates in the most massive galaxies.

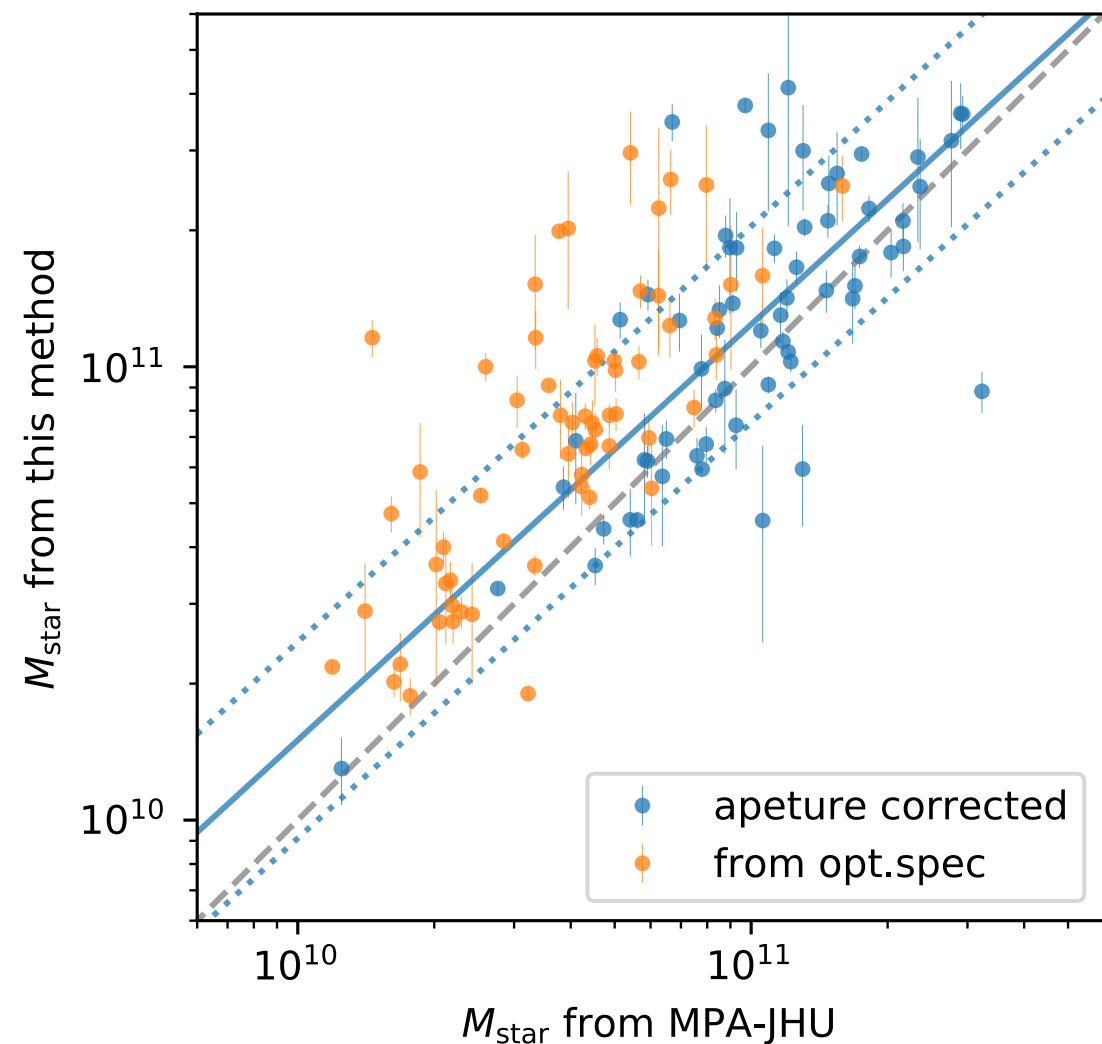


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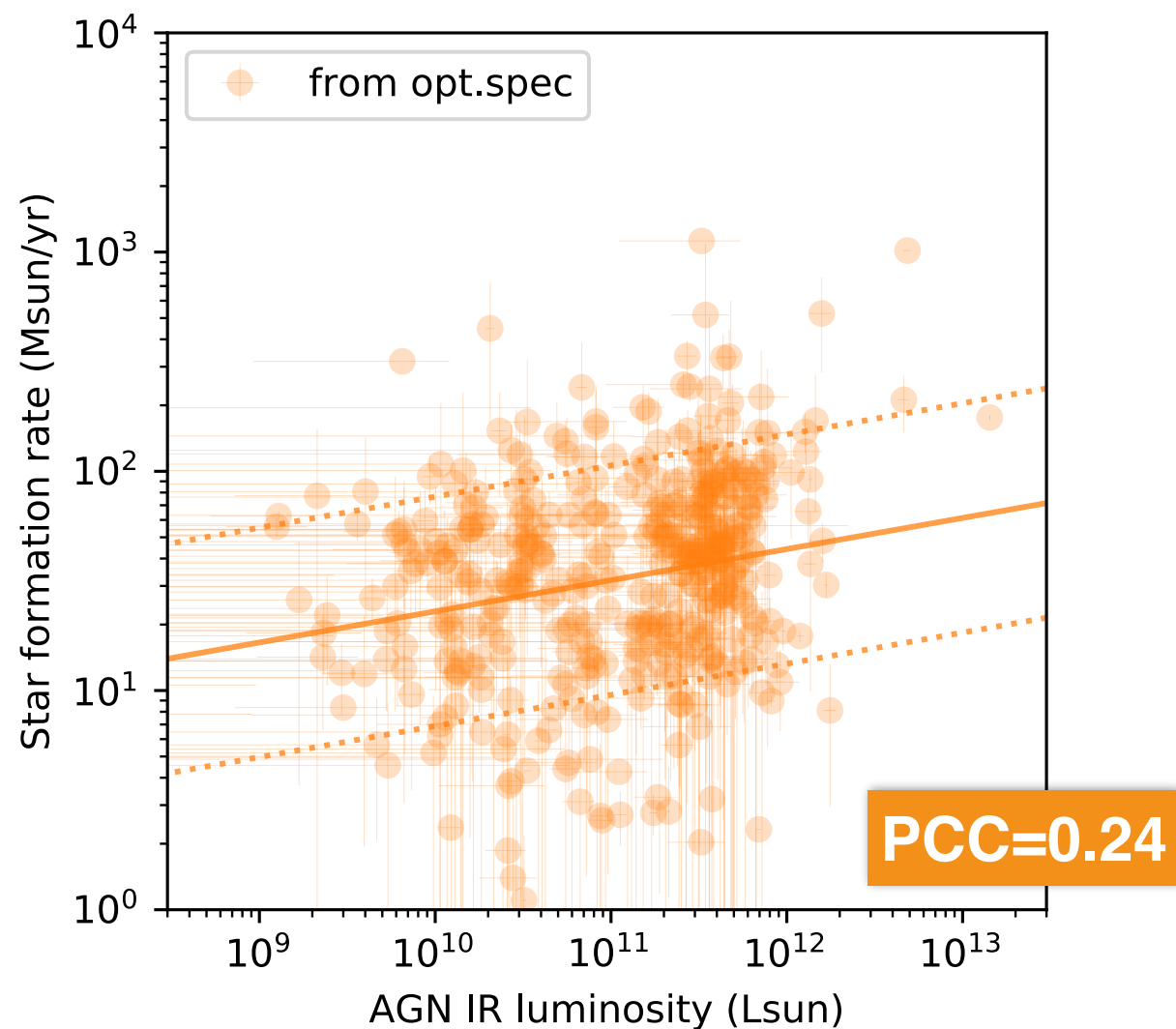


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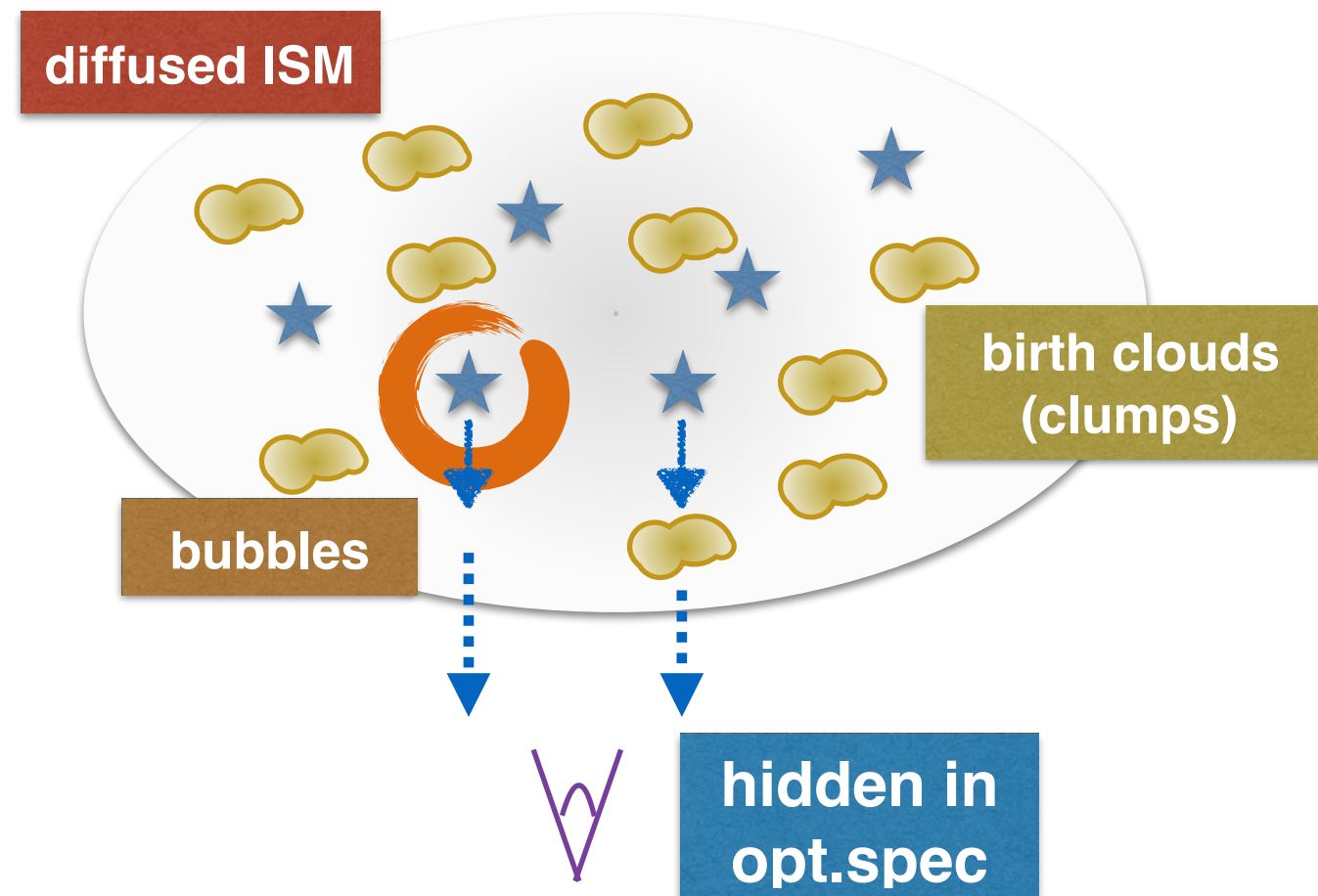
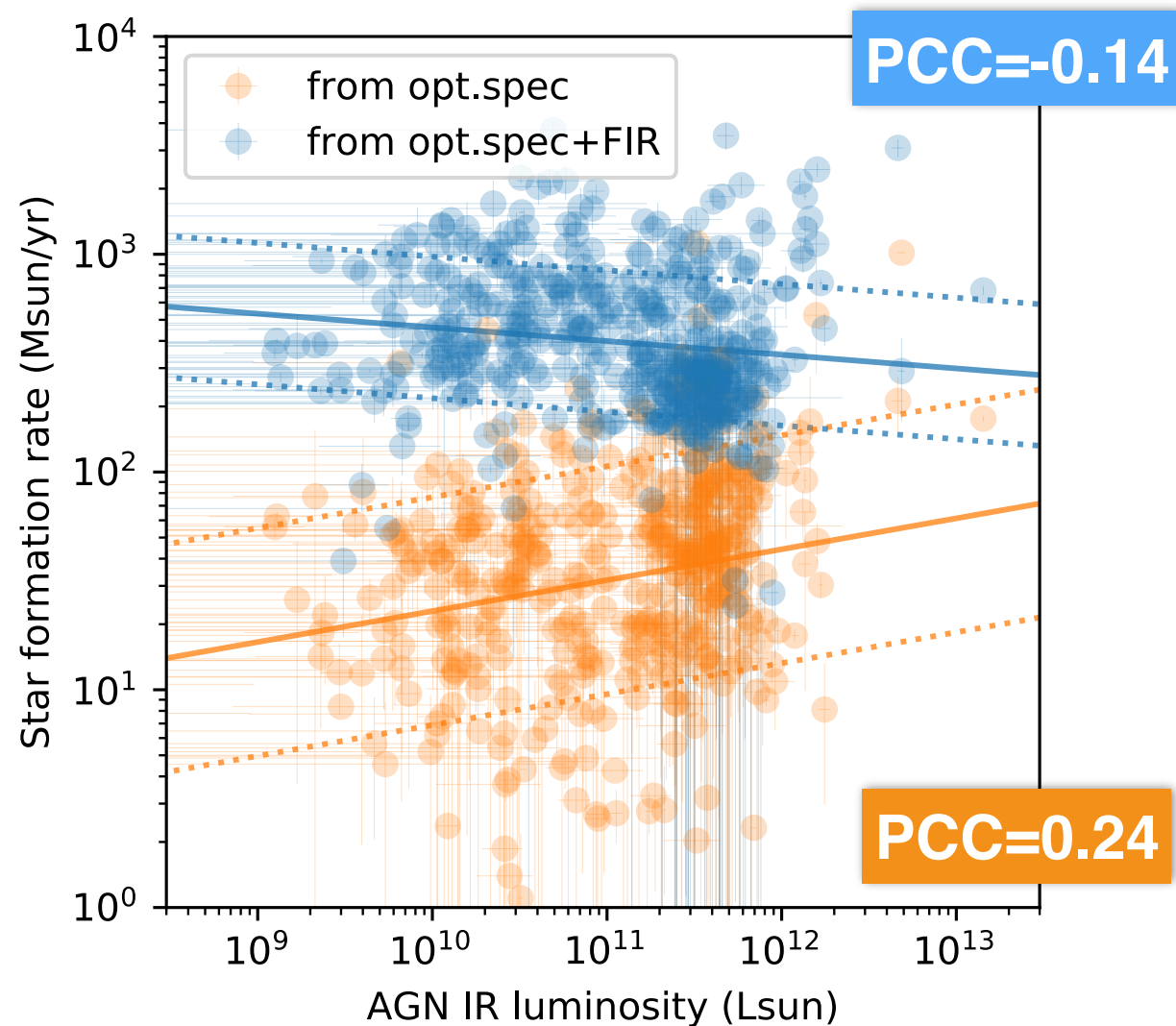
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Galaxy properties vs. AGN intensity



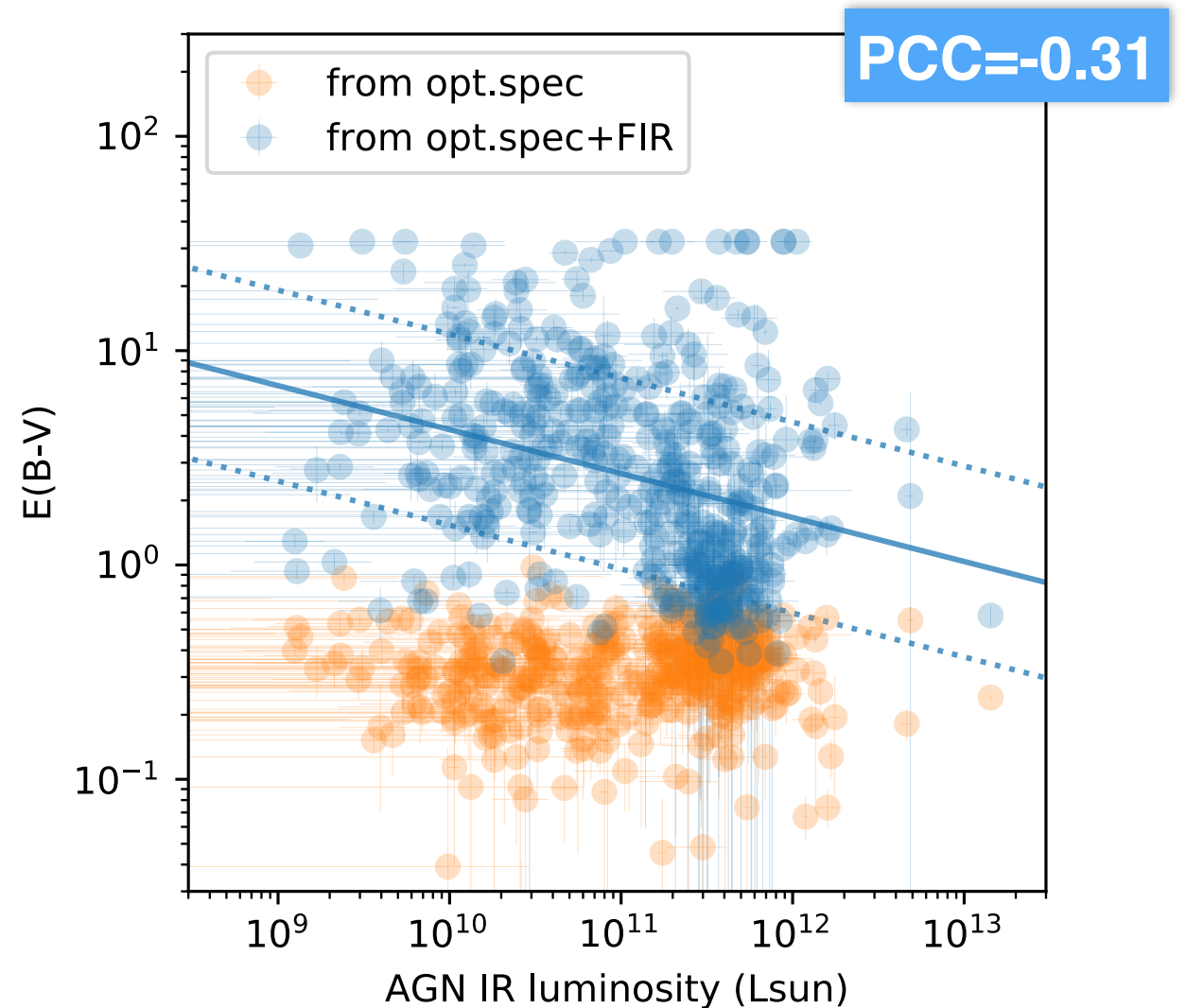
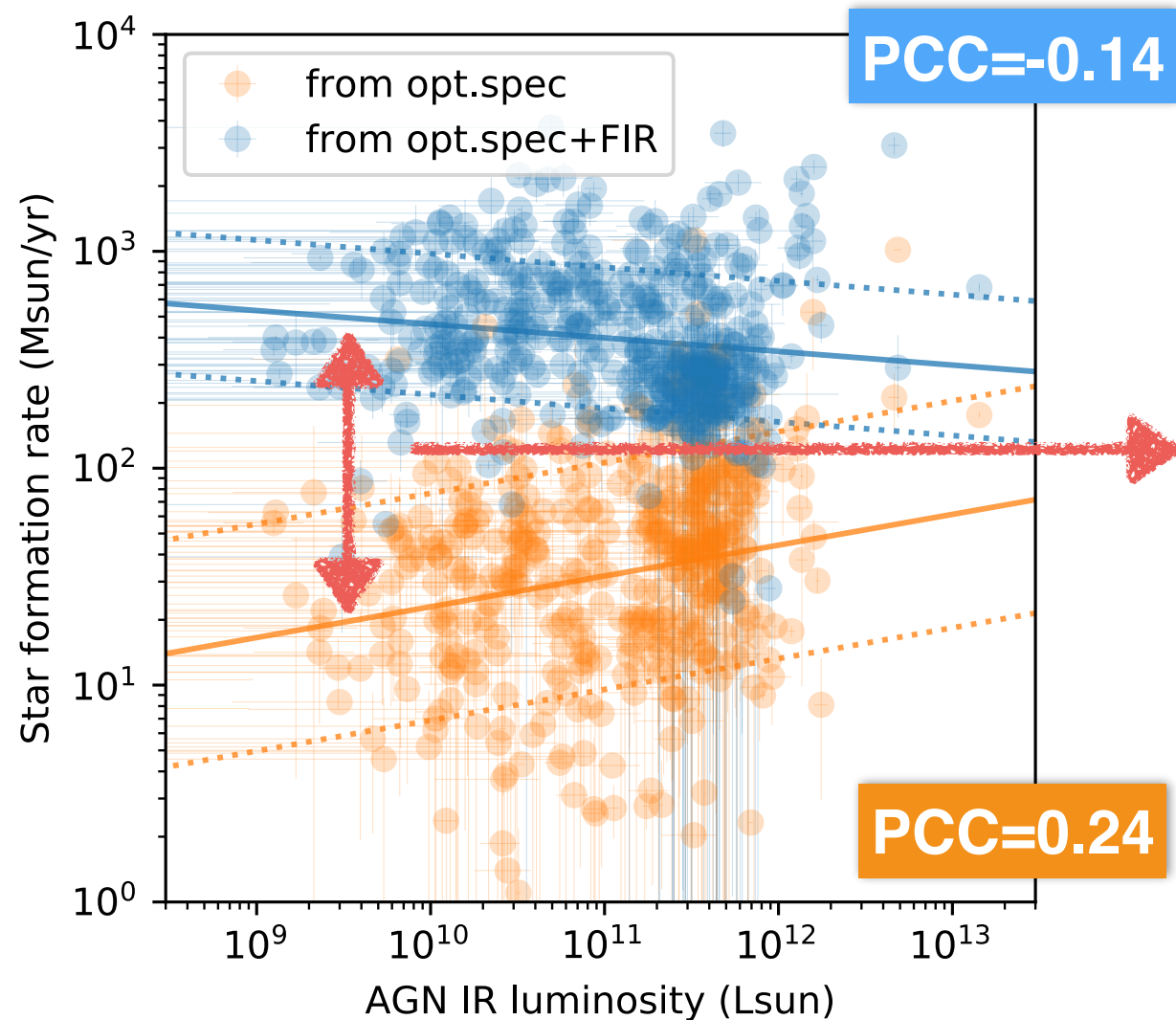
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Galaxy properties vs. AGN intensity



During ULIRG stage,
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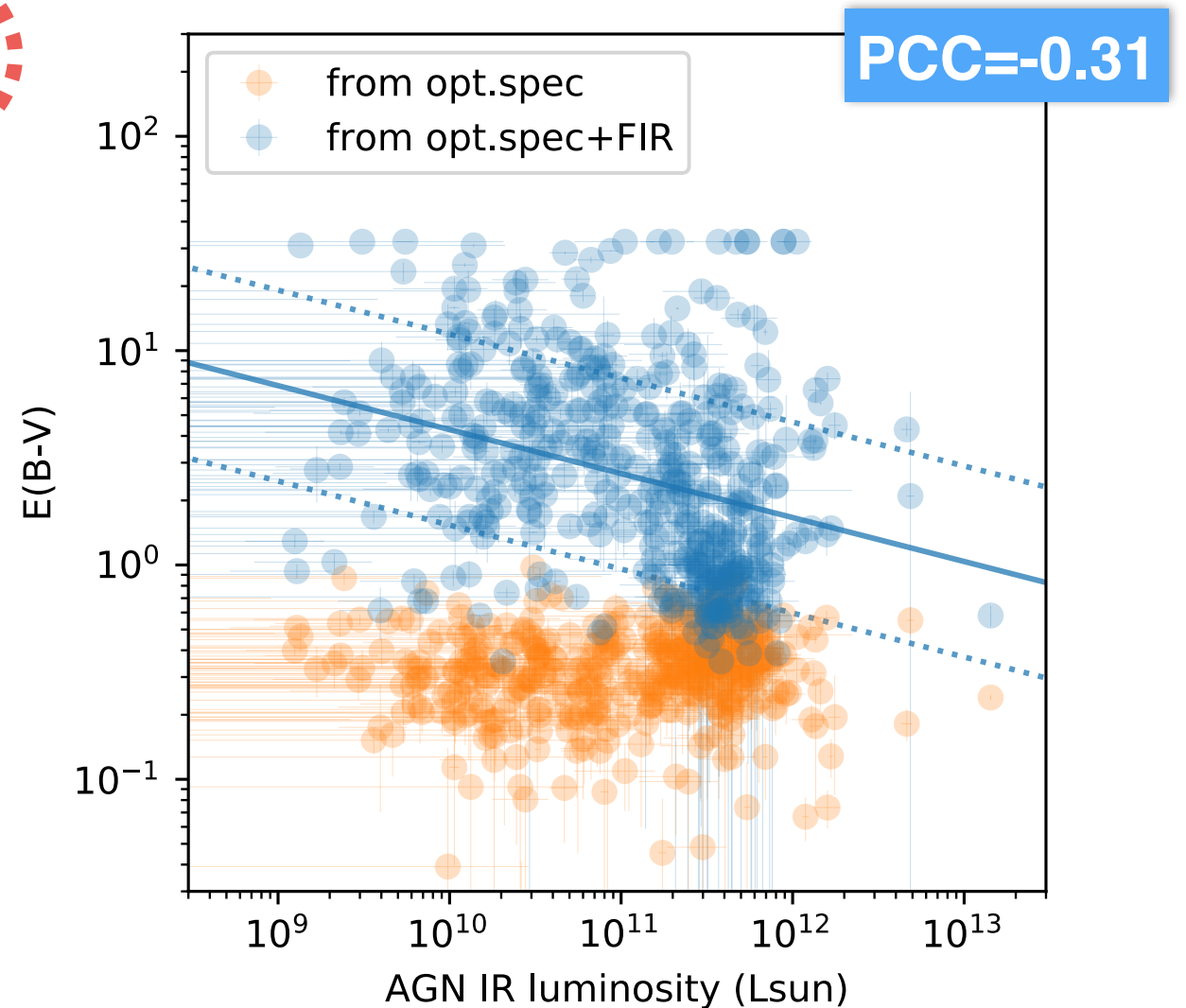
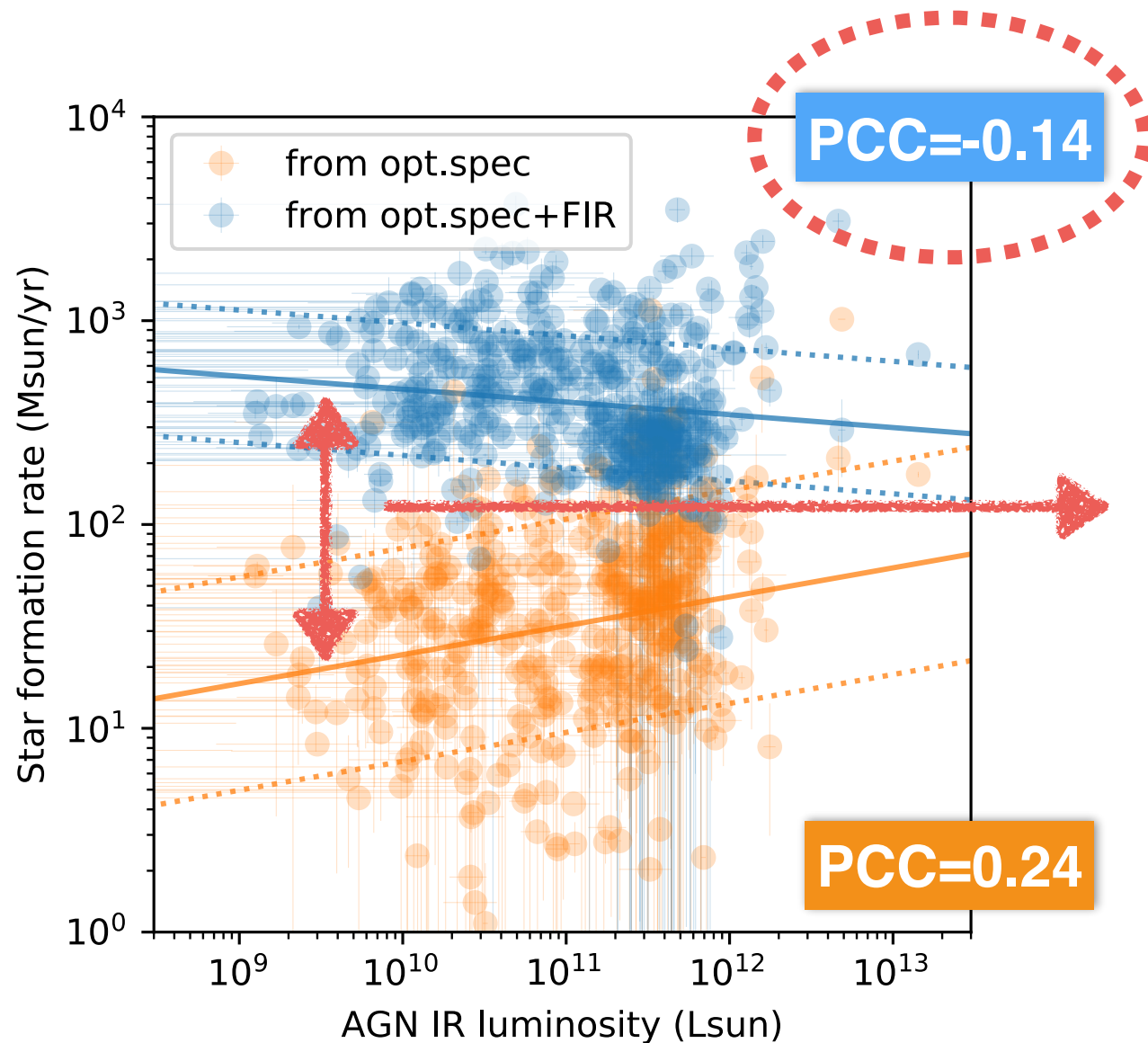
Galaxy properties vs. AGN intensity



The star-forming becomes transparent
as AGN becomes luminous.

During ULIRG stage,
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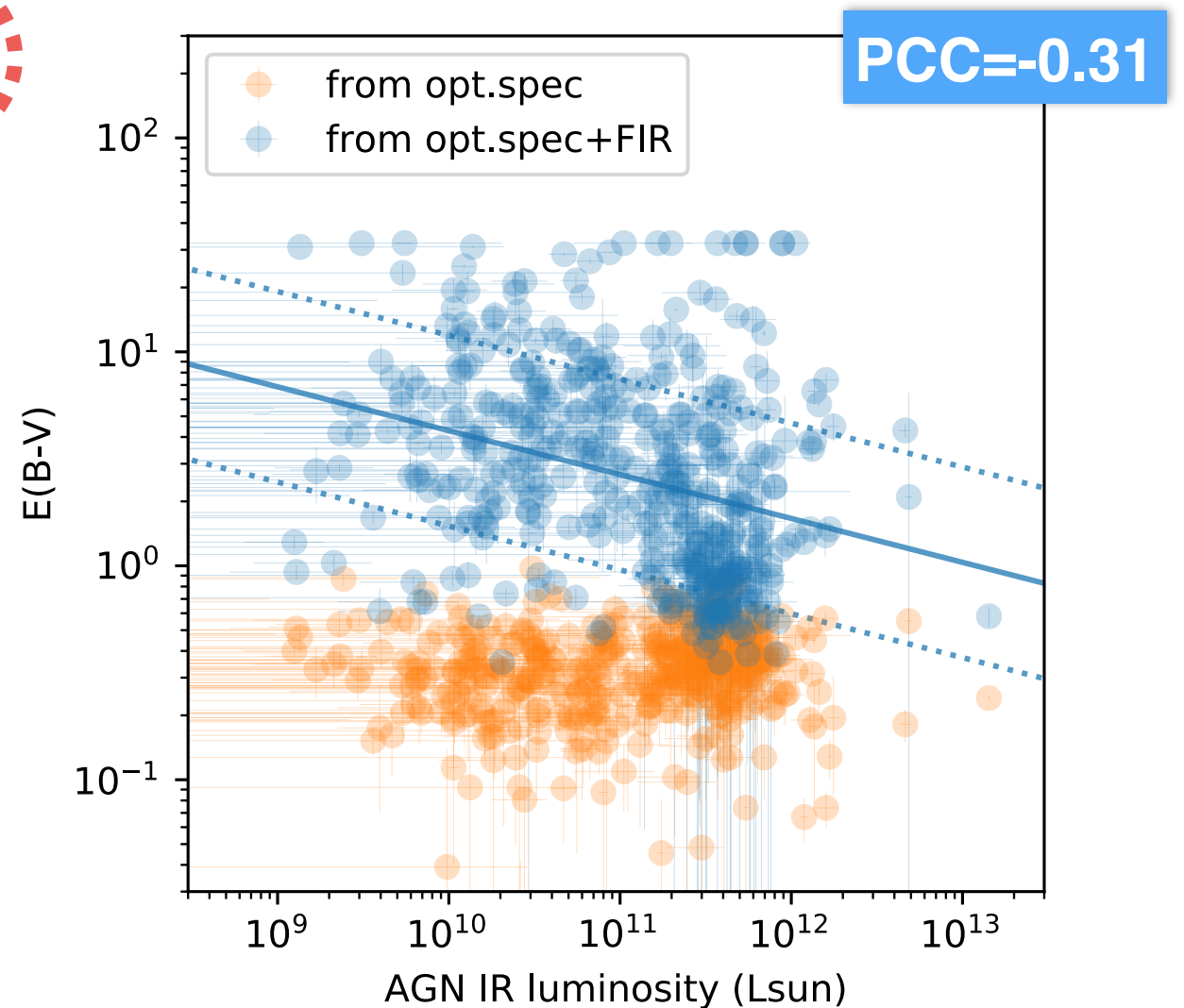
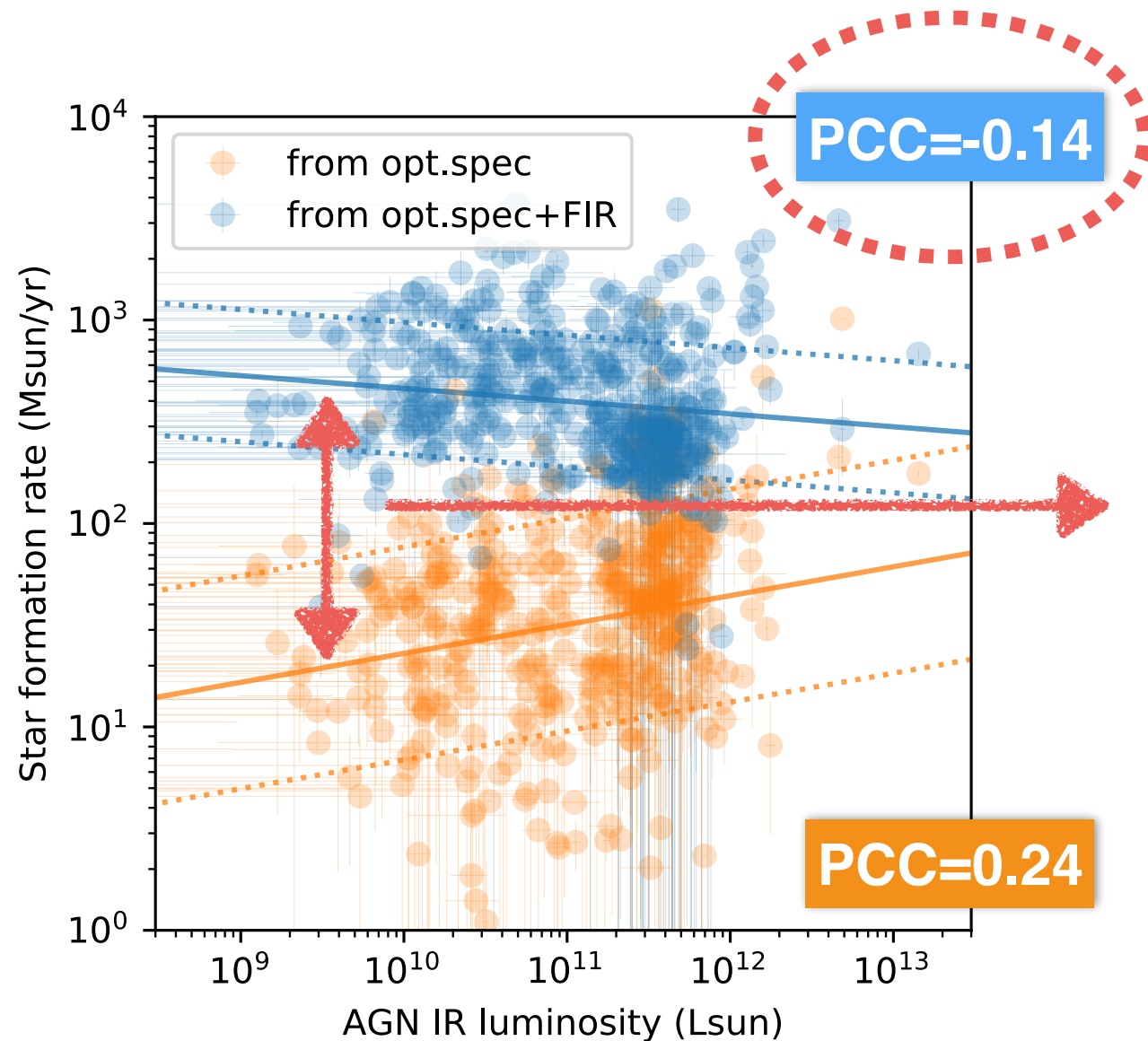
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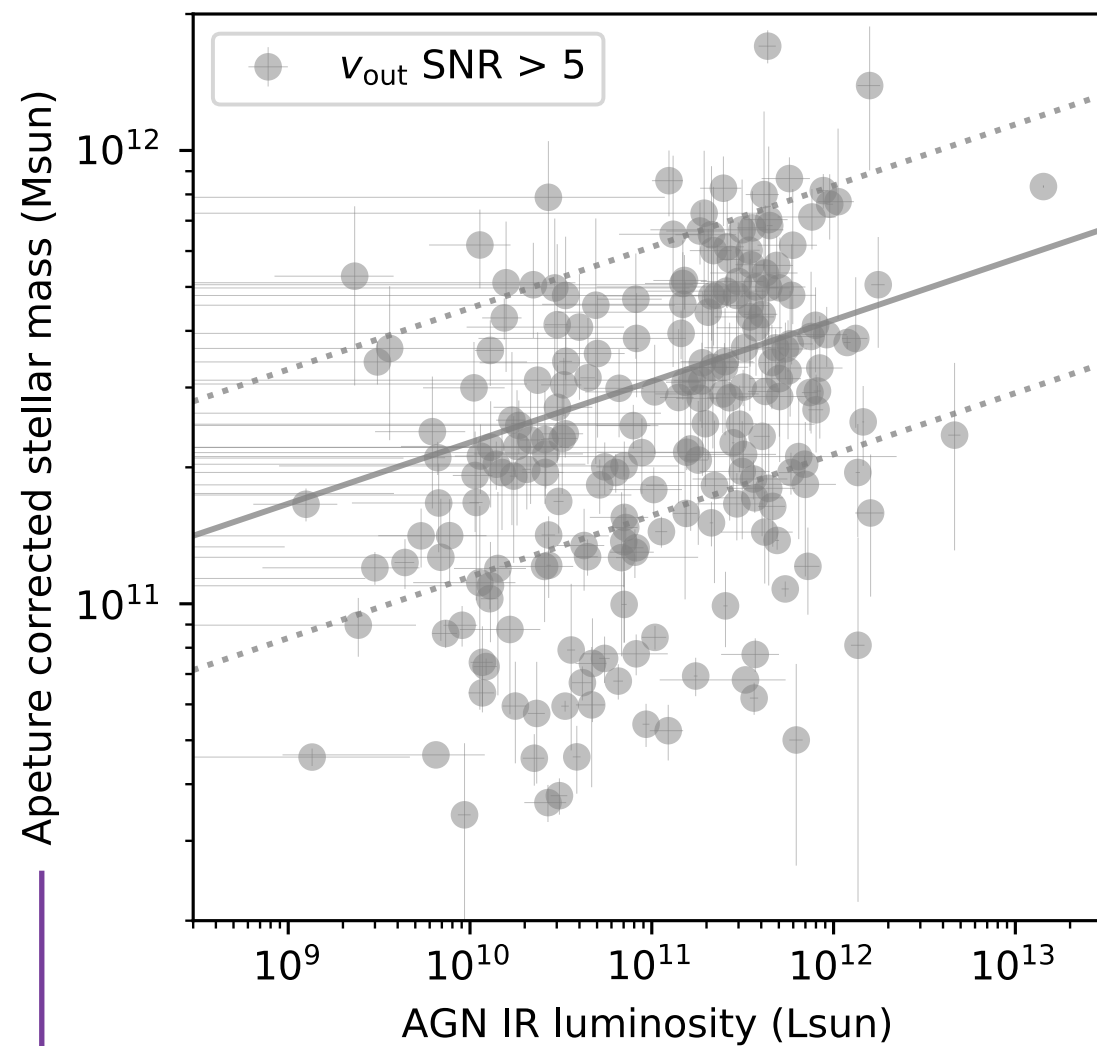
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Galaxy properties vs. AGN intensity

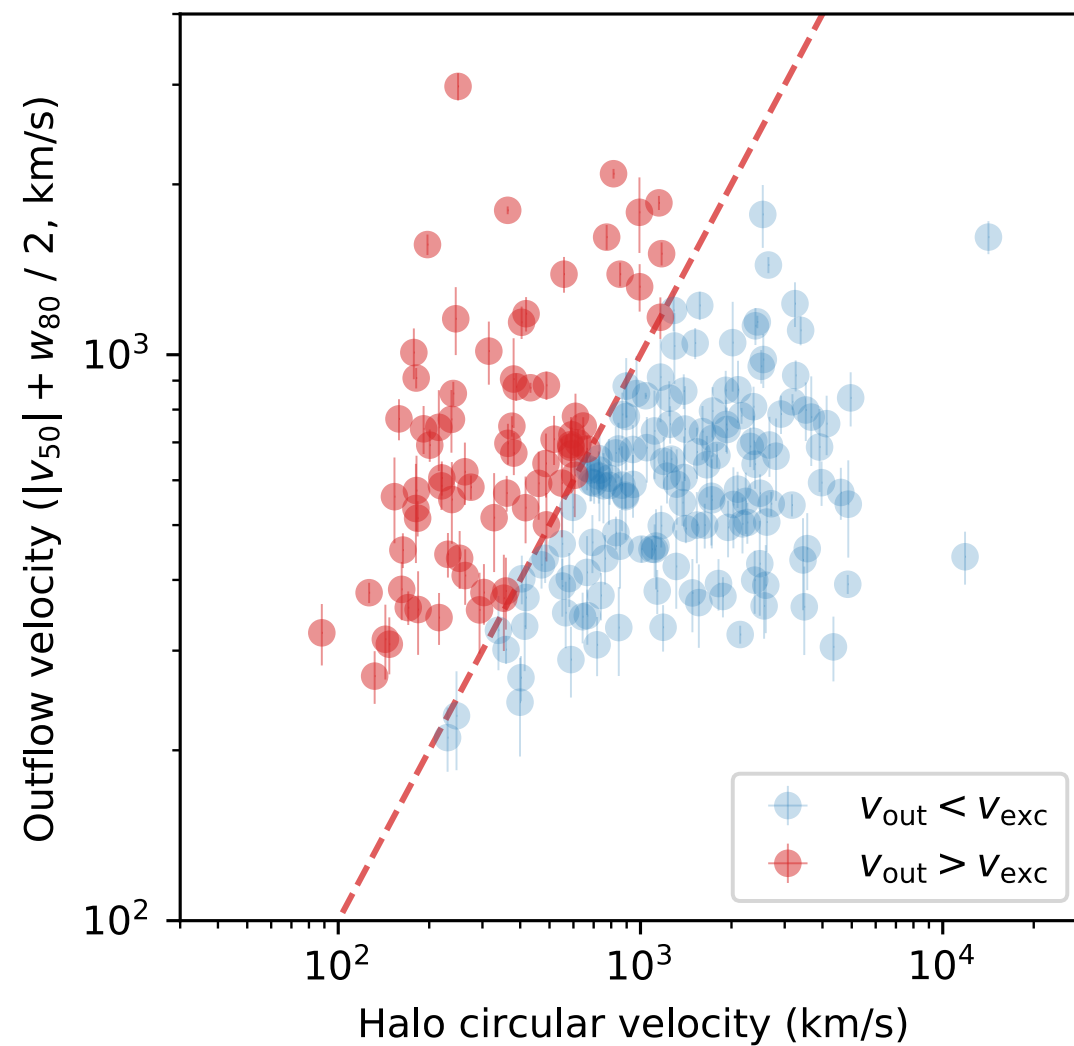
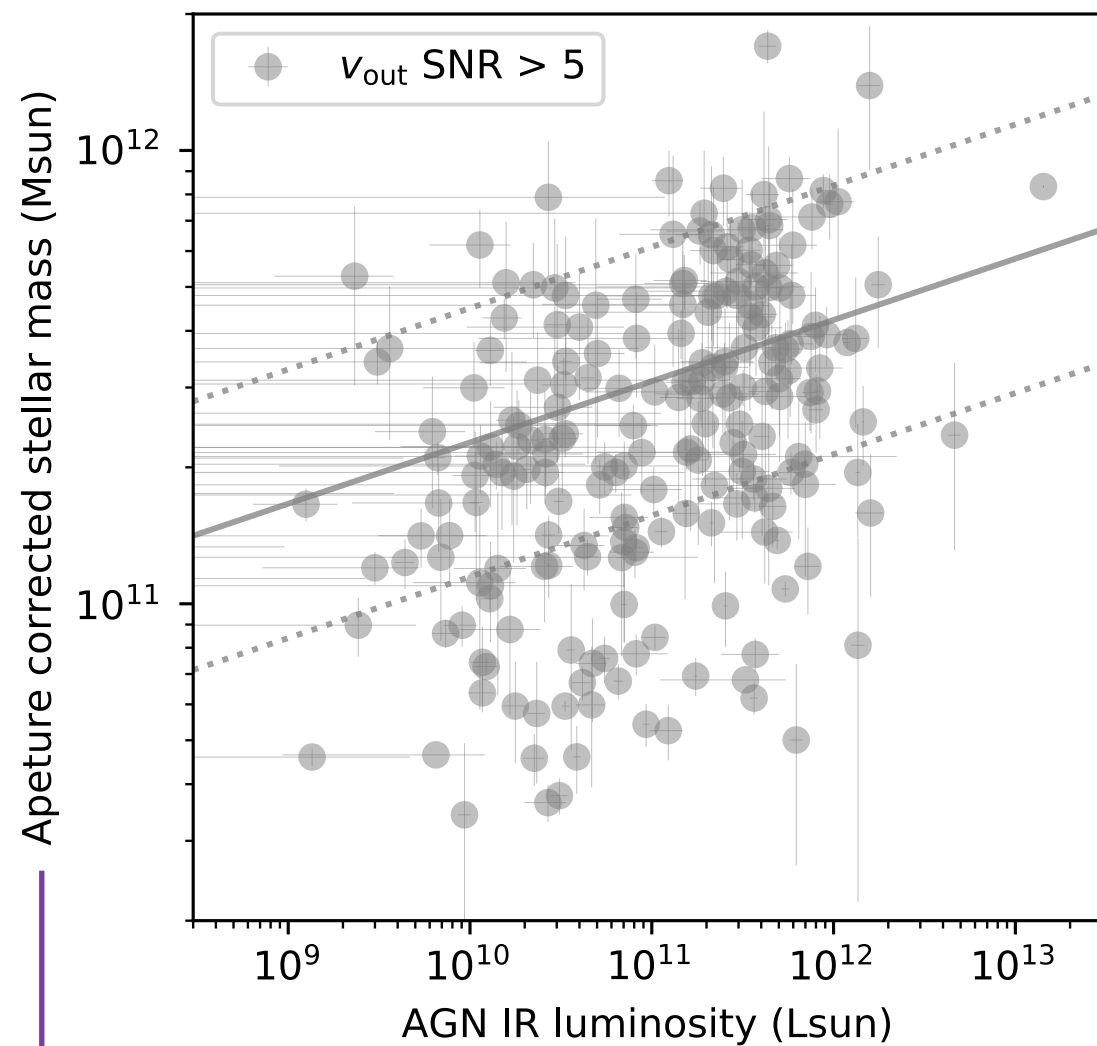


M_{star} $\longrightarrow$ M_{halo} $\longrightarrow$ $V_{\text{escaping}} \sim V_{\text{circular}}$

Moster et al. 2013

Mo & White et al. 2002

Galaxy properties vs. AGN intensity

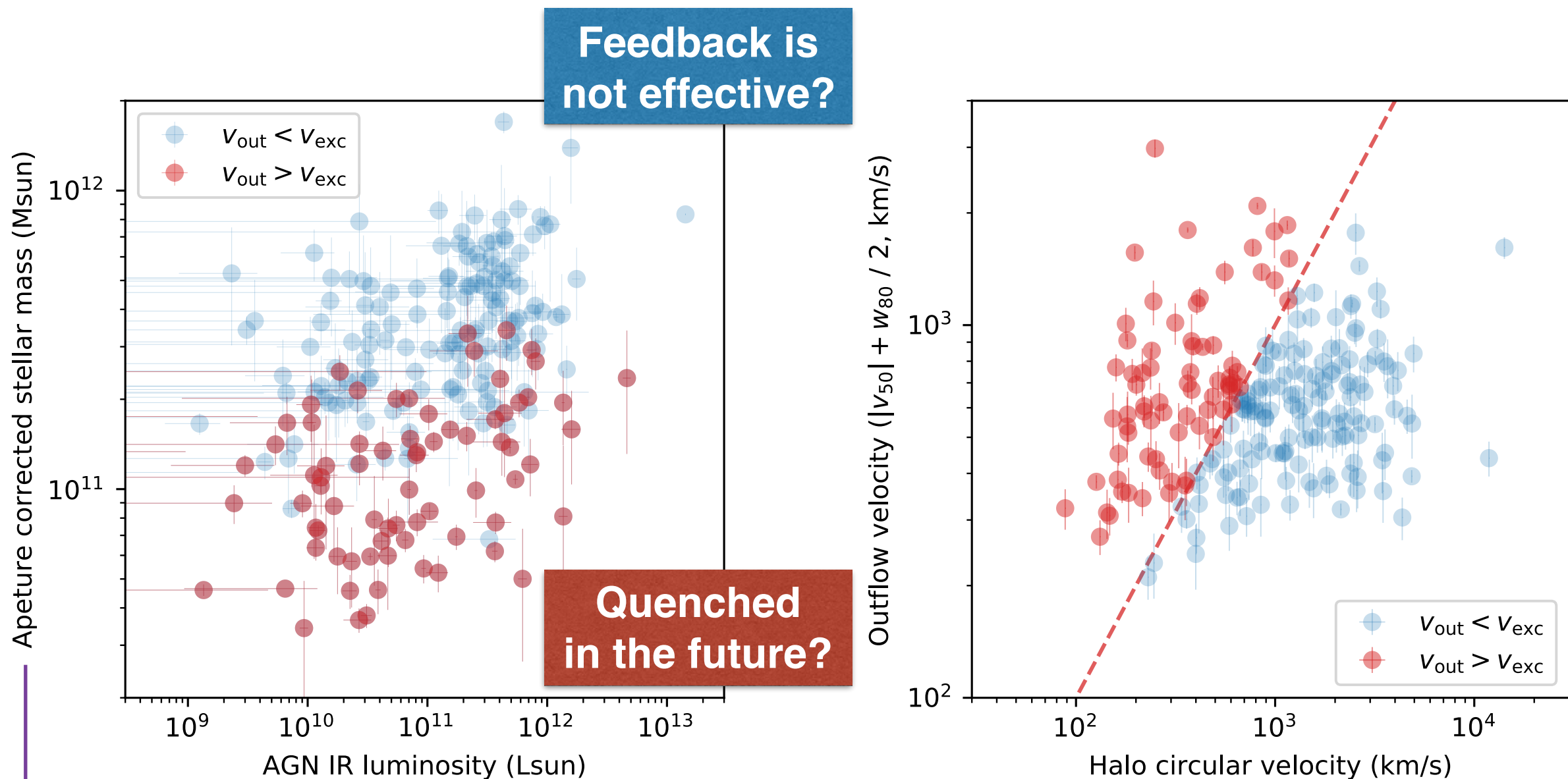


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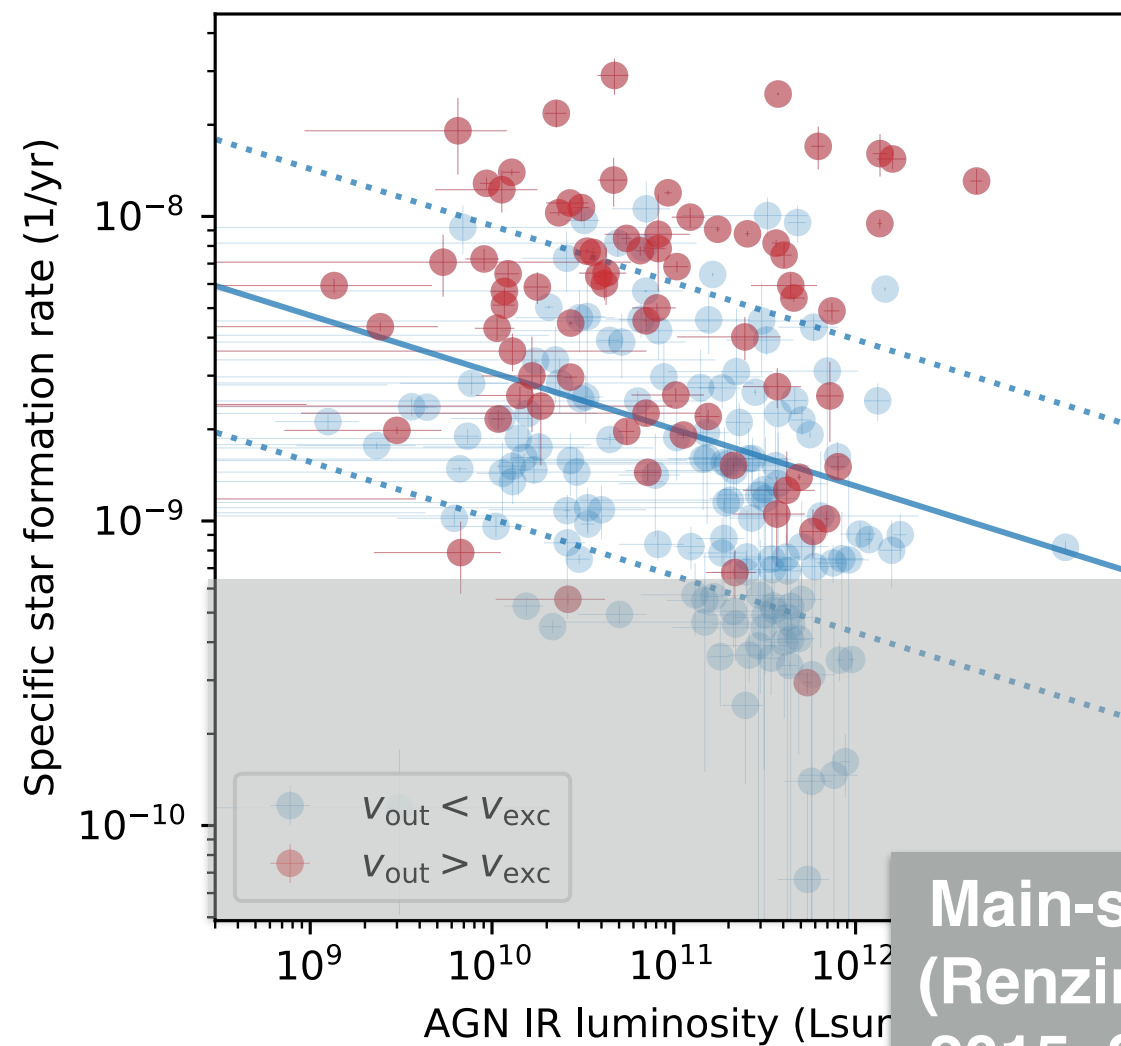


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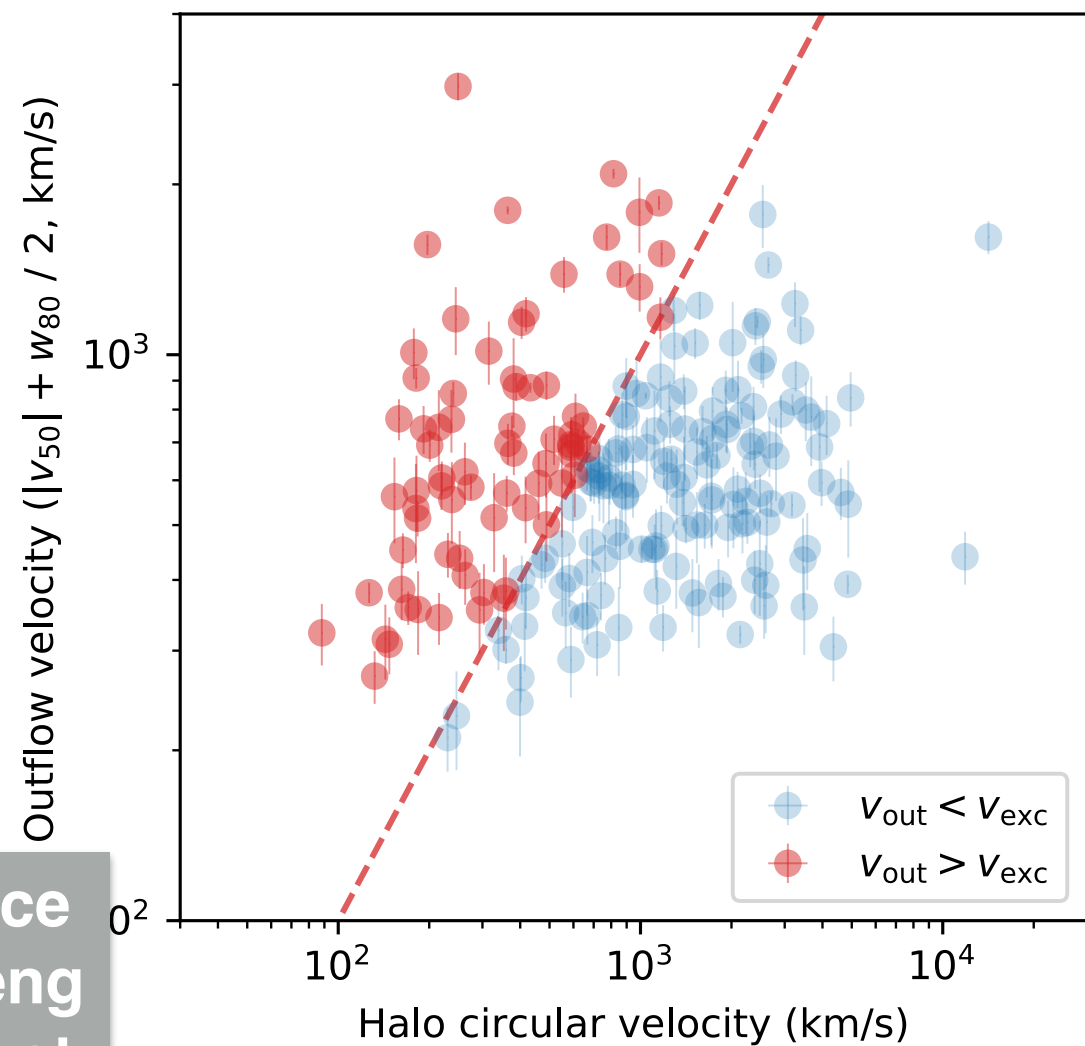
Moster et al. 2013

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 $\sim 300\text{-}1000\text{ Msun/yr}$;
- 4) *the ULIRG with $M_{\text{star}} \sim 1E11\text{ Msun}$* 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!