第５回 銀河進化研究会

2018.06.07

Discovery of an Extremely Luminous Dust-obscured Galaxy Observed with SDSS, WISE, JCMT, and SMA

Toba et al. 2018, ApJ, 857, 31

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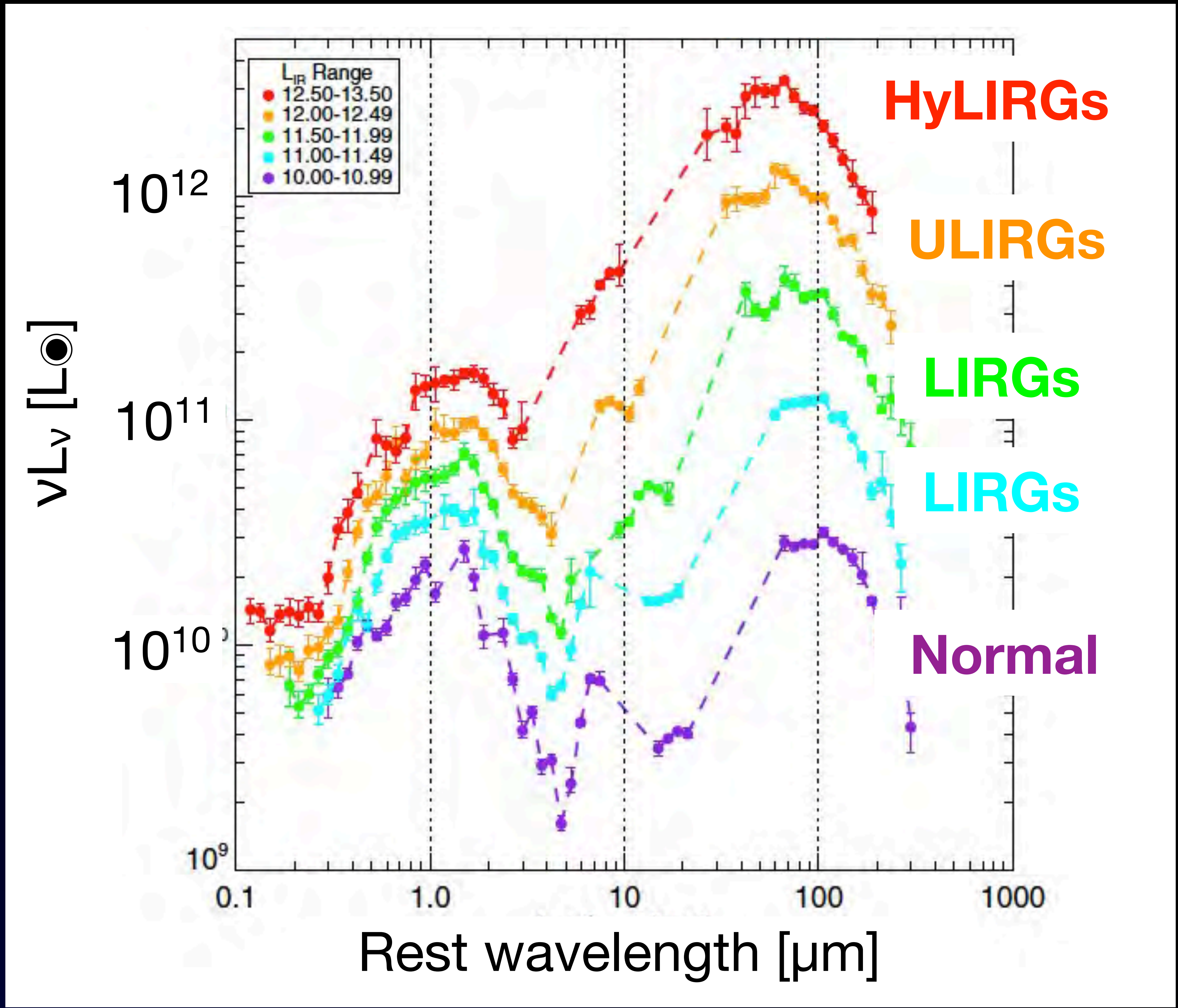
Introduction

- IR luminous galaxies
- Importance of this work
- Dust-Obscured Galaxies

Classification of galaxies based on L_{IR}

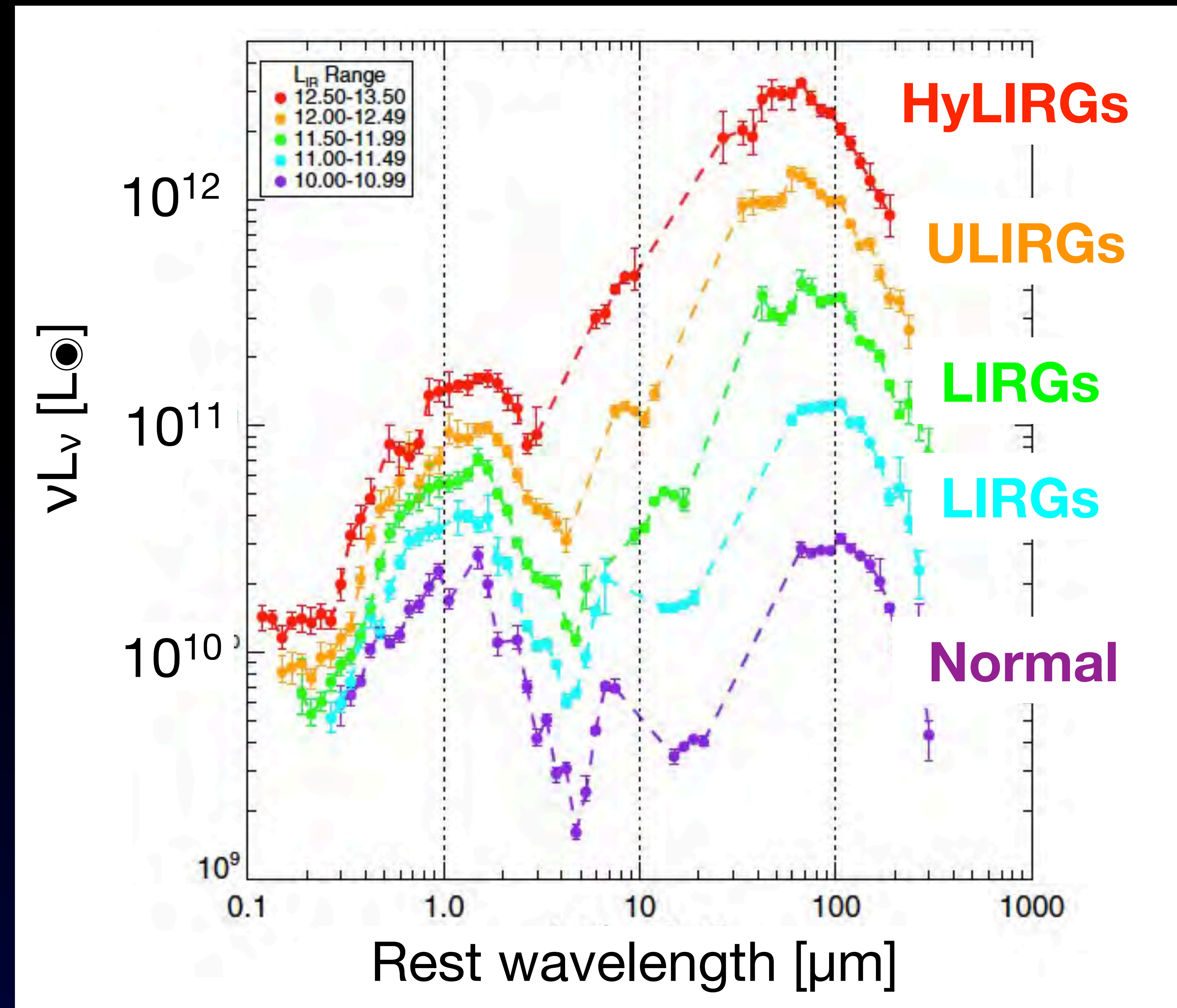
name	log ($L_{IR}/L_\odot$)
Normal	< 11
LIRGs	11 - 12
ULIRGs	12 -13
HyLIRGs	13 -14
ELIRGs	> 14



Lee+13

Ultra Luminous InfRared Galaxies

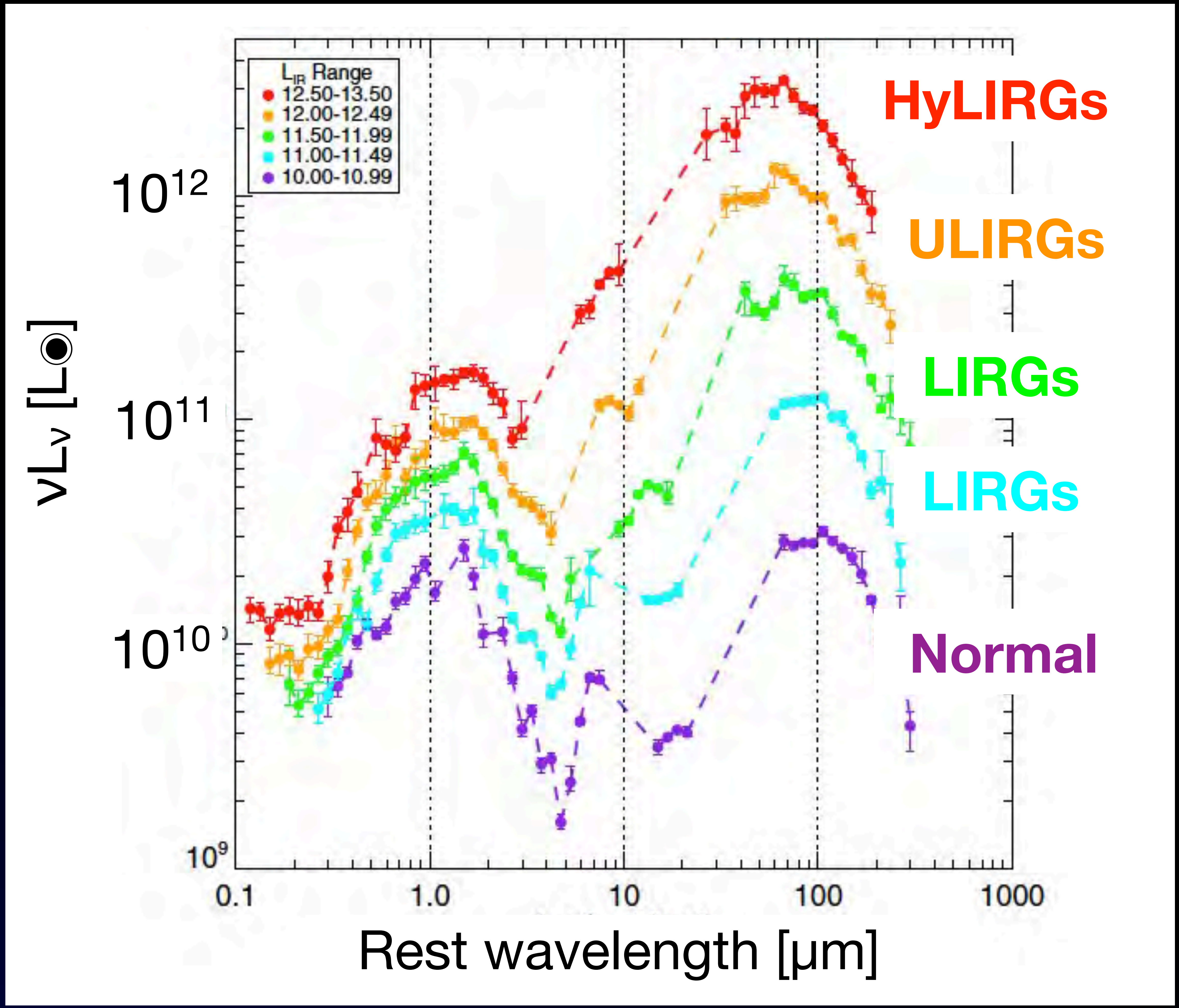
name	log ($L_{IR}/L_{\odot}$)
Normal	< 11
LIRGs	11 - 12
ULIRGs	12 -13
HyLIRGs	13 -14
ELIRGs	> 14



Lee+13

Hyper Luminous InfRared Galaxies

name	log ($L_{IR}/L_{\odot}$)
Normal	< 11
LIRGs	11 - 12
ULIRGs	12 -13
HyLIRGs	13 -14
ELIRGs	> 14



Lee+13

Extremely Luminous InfRared Galaxies

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Normal	< 11
ULIRGs	12 - 13
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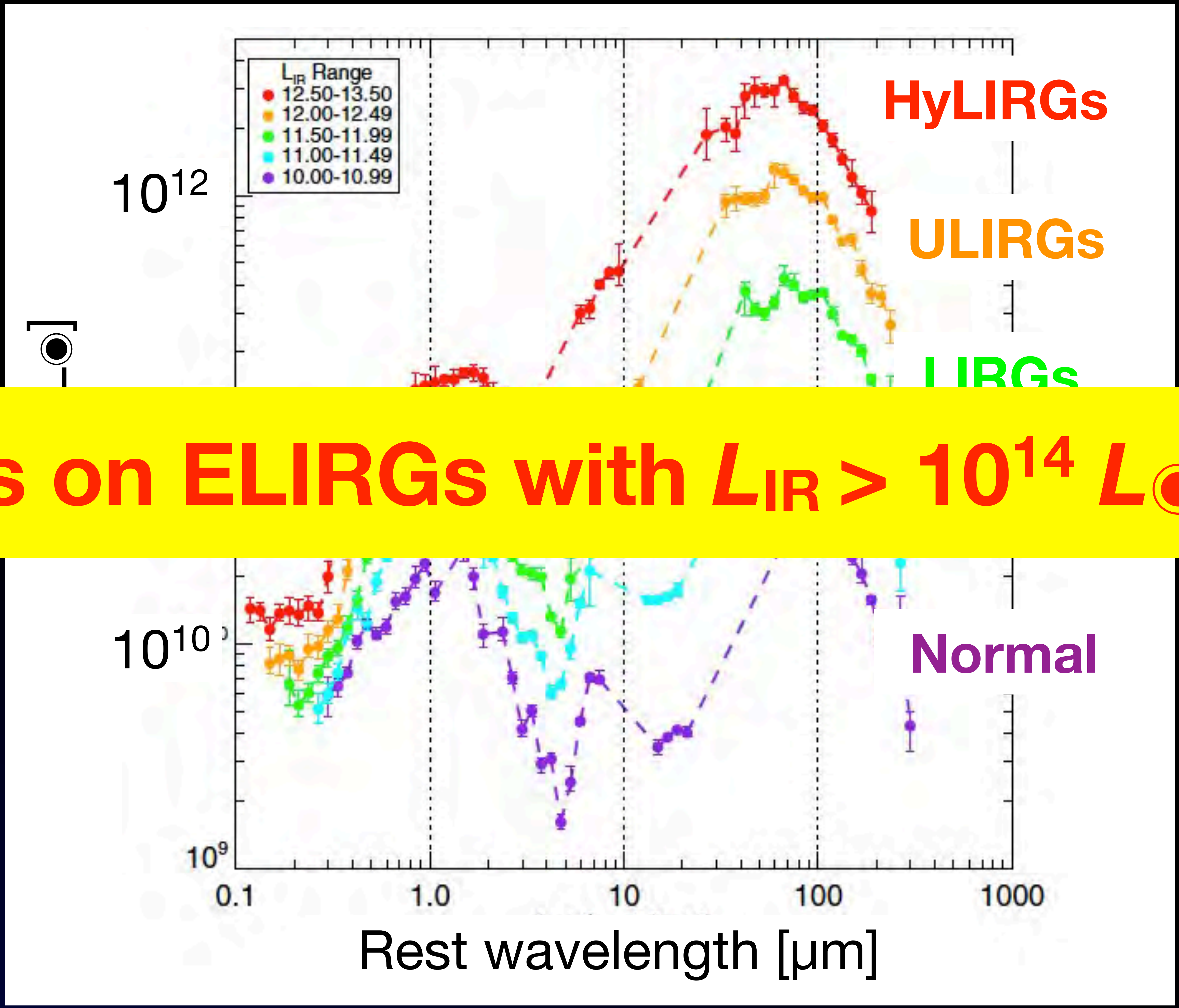
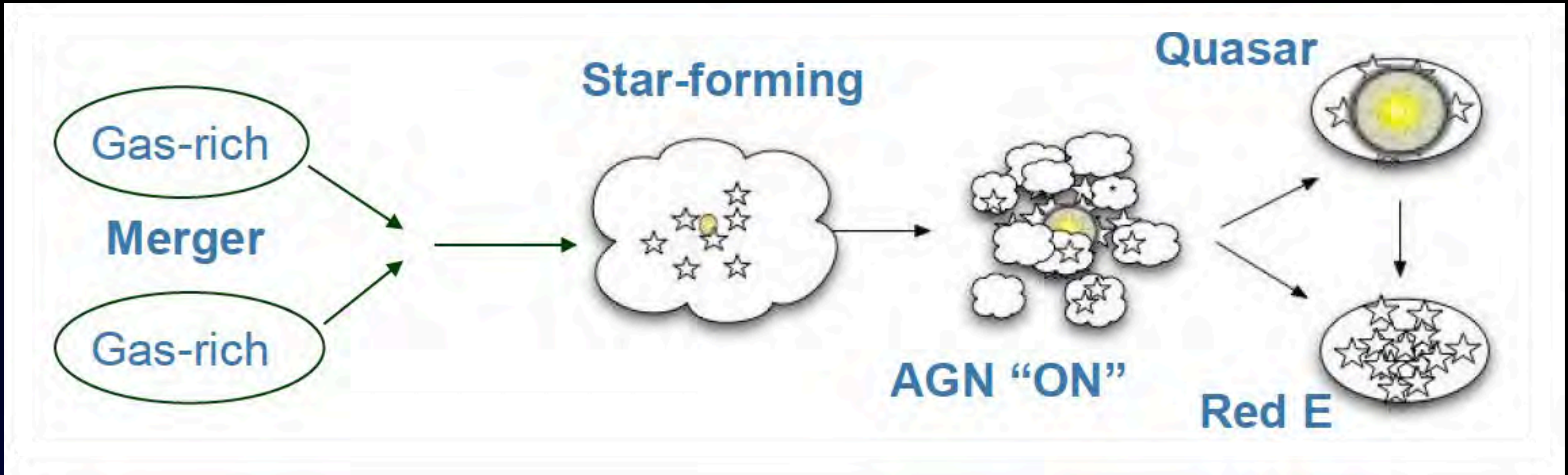


In this work, we focus on ELIRGs with $L_{IR} > 10^{14}\ L_{\odot}$

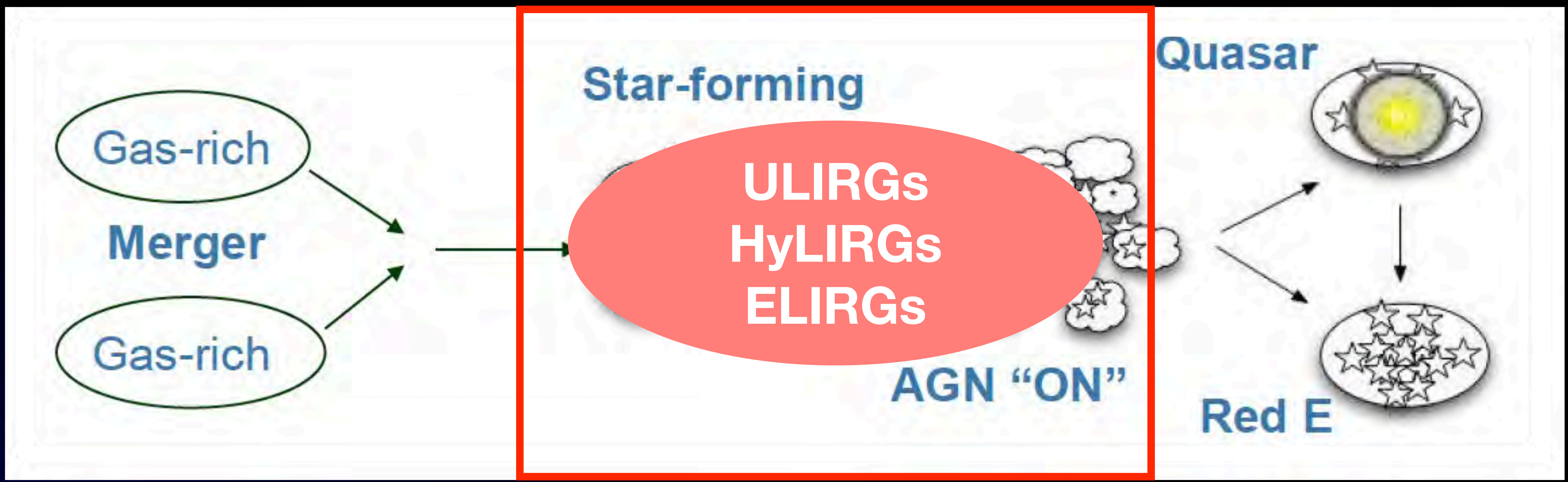
Lee+13

Why are ELIRGs important?



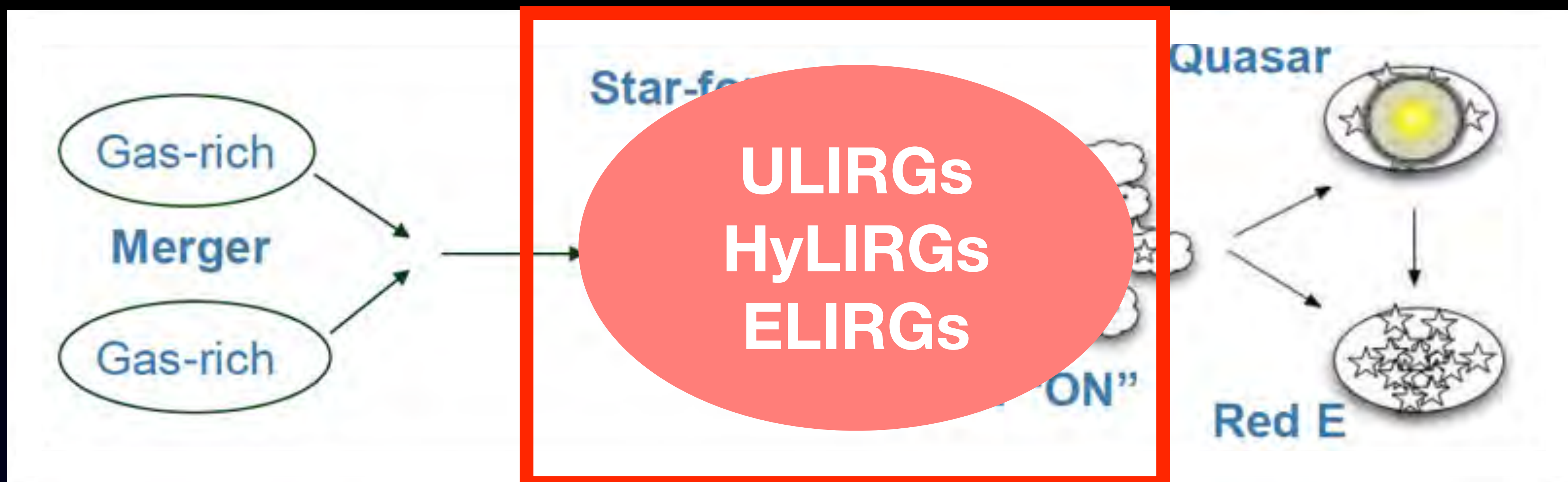
Dey+08

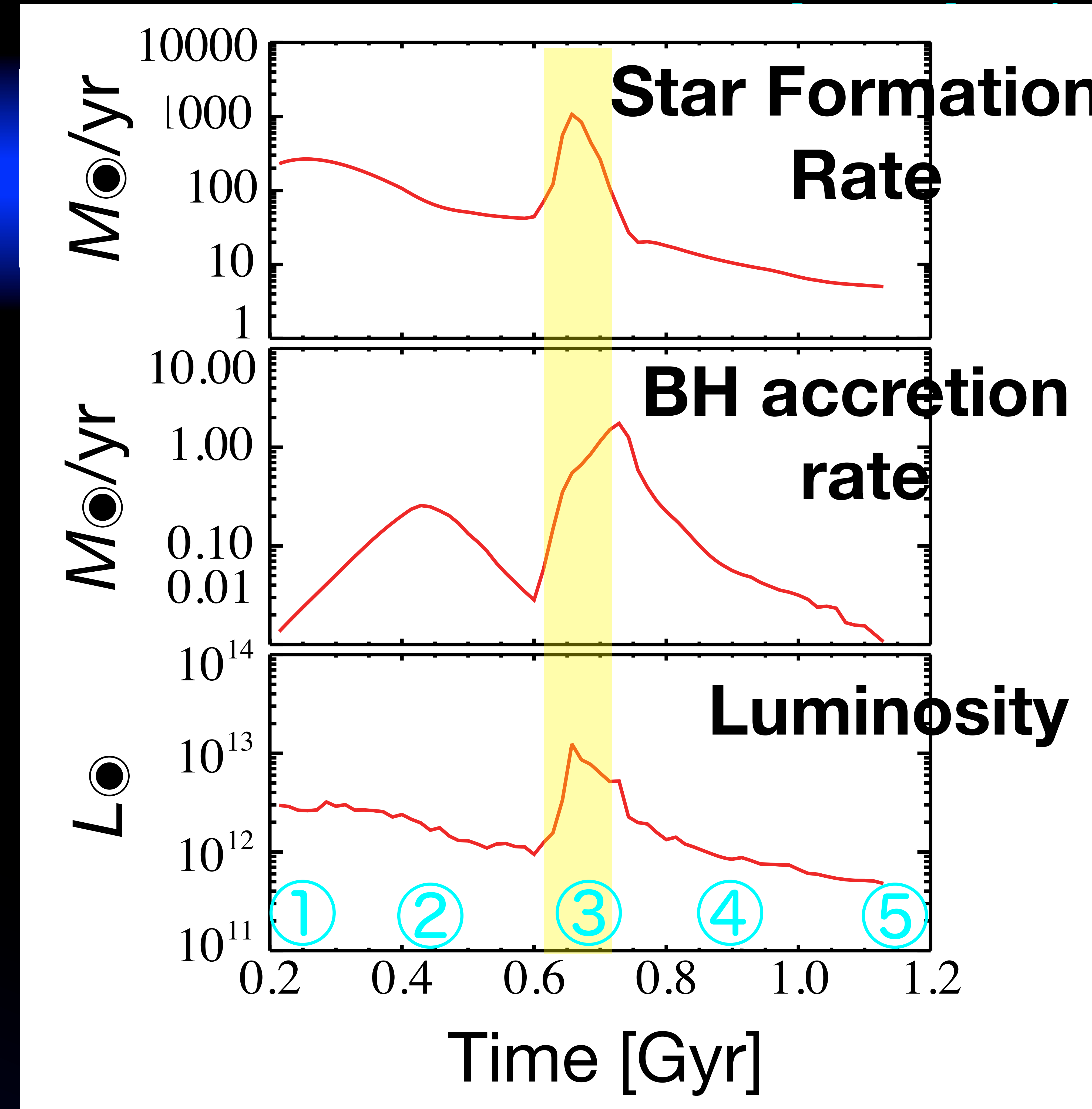
Why are ELIRGs important?

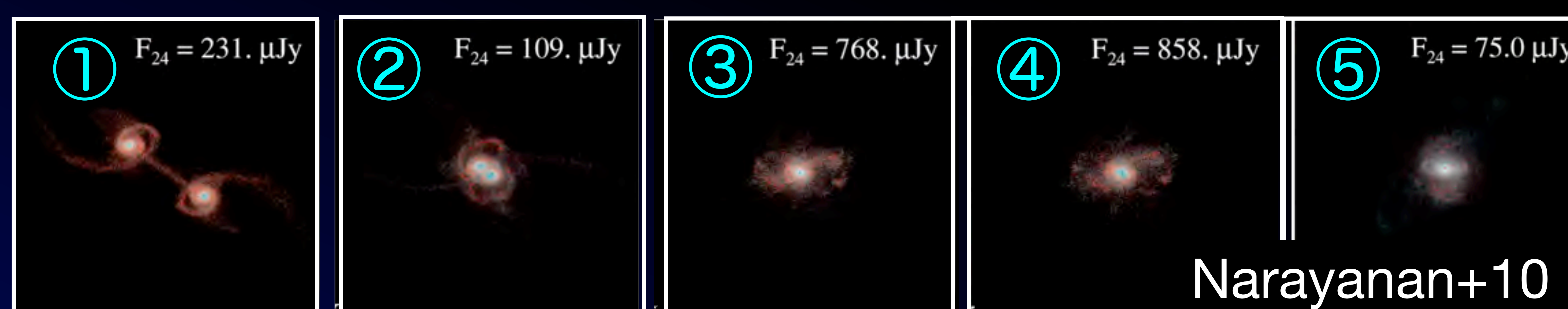


Dey+08

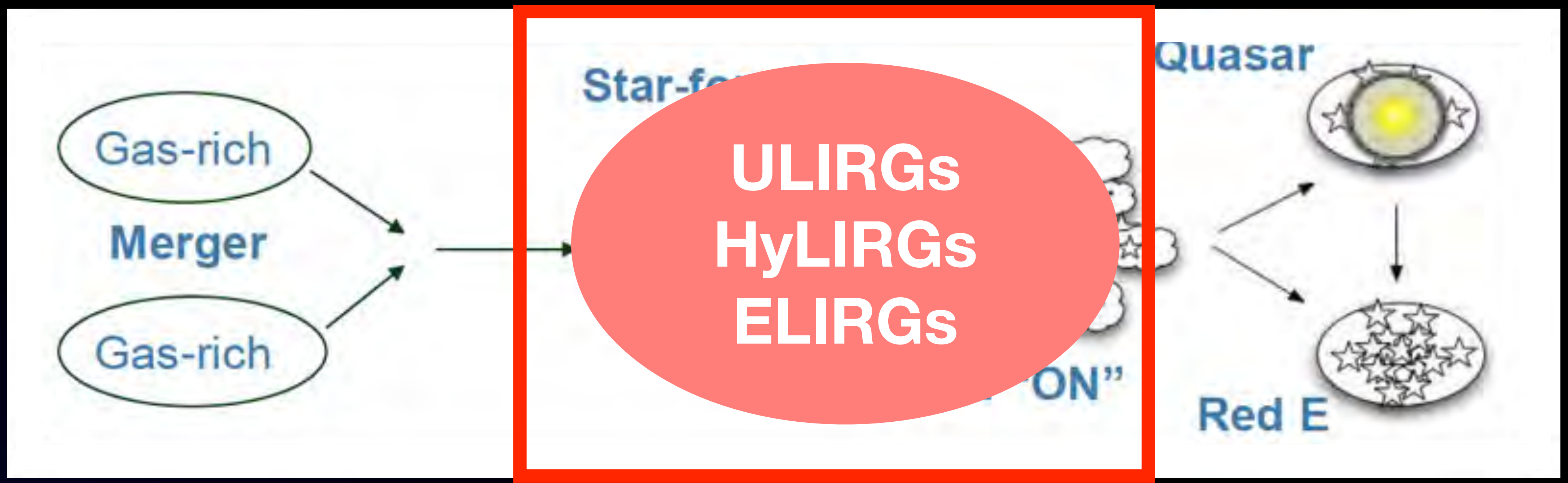
Importance of ELIRGs

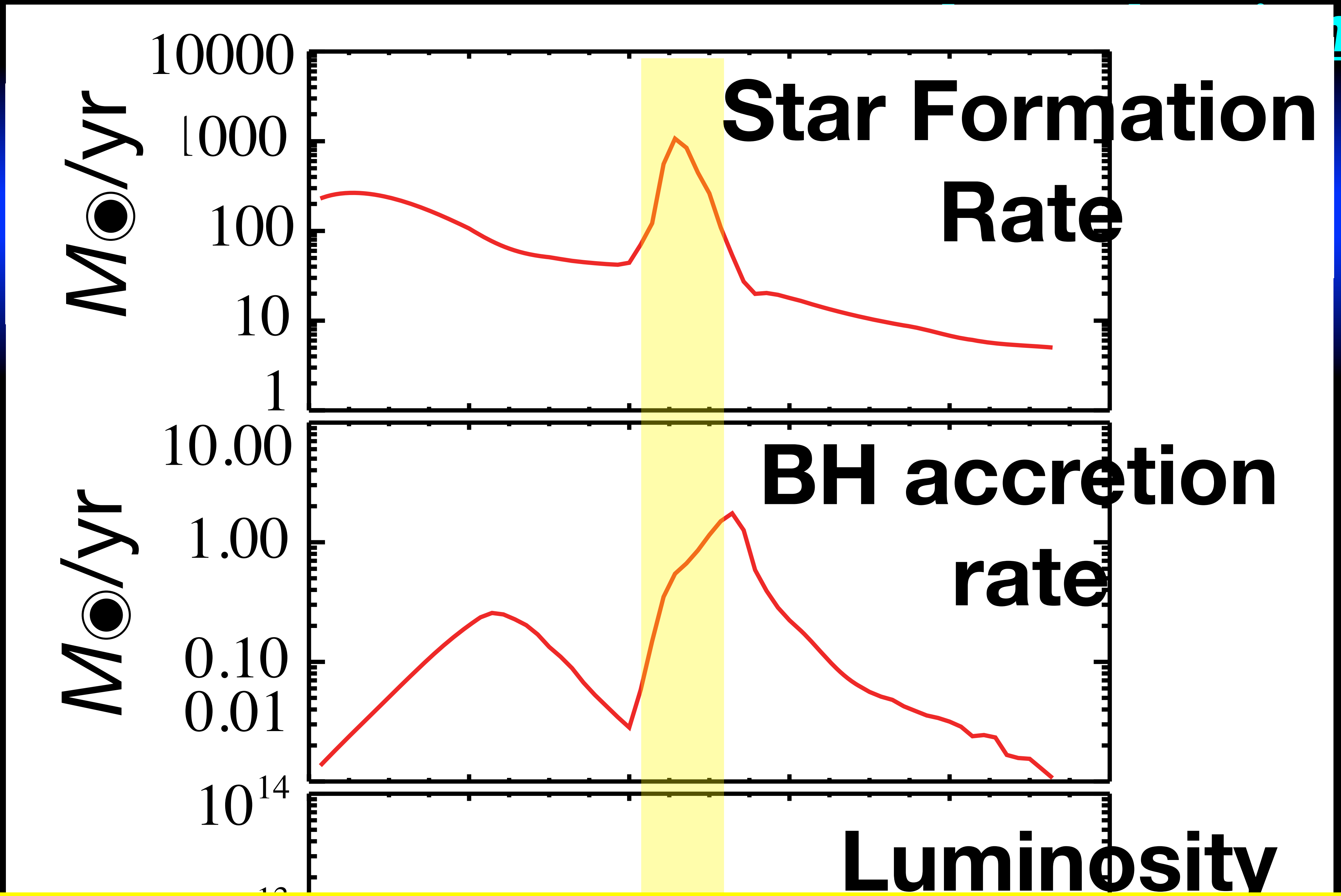




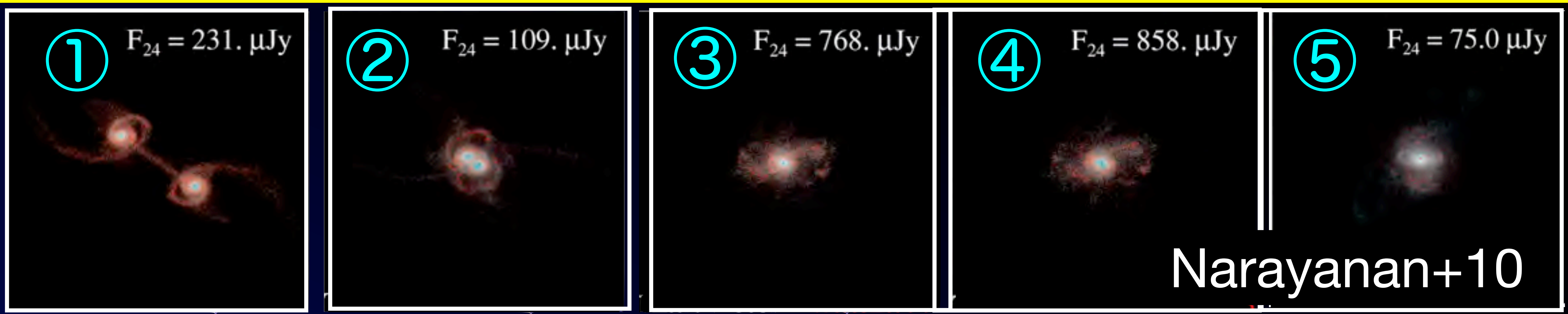


Importance of ELIRGs

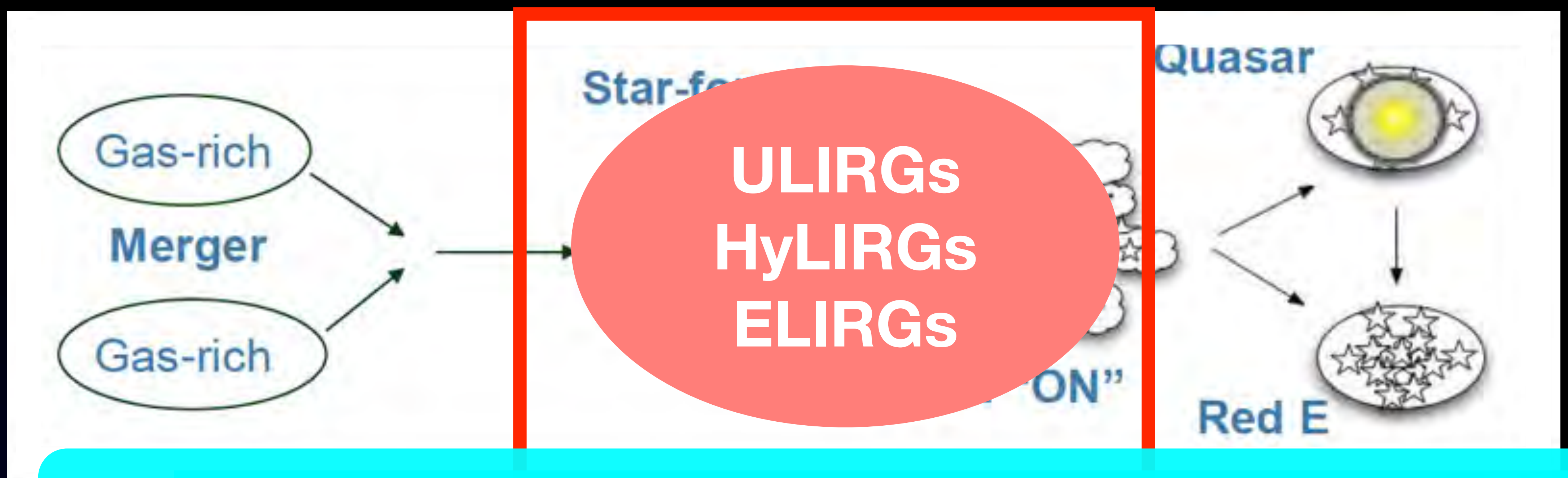


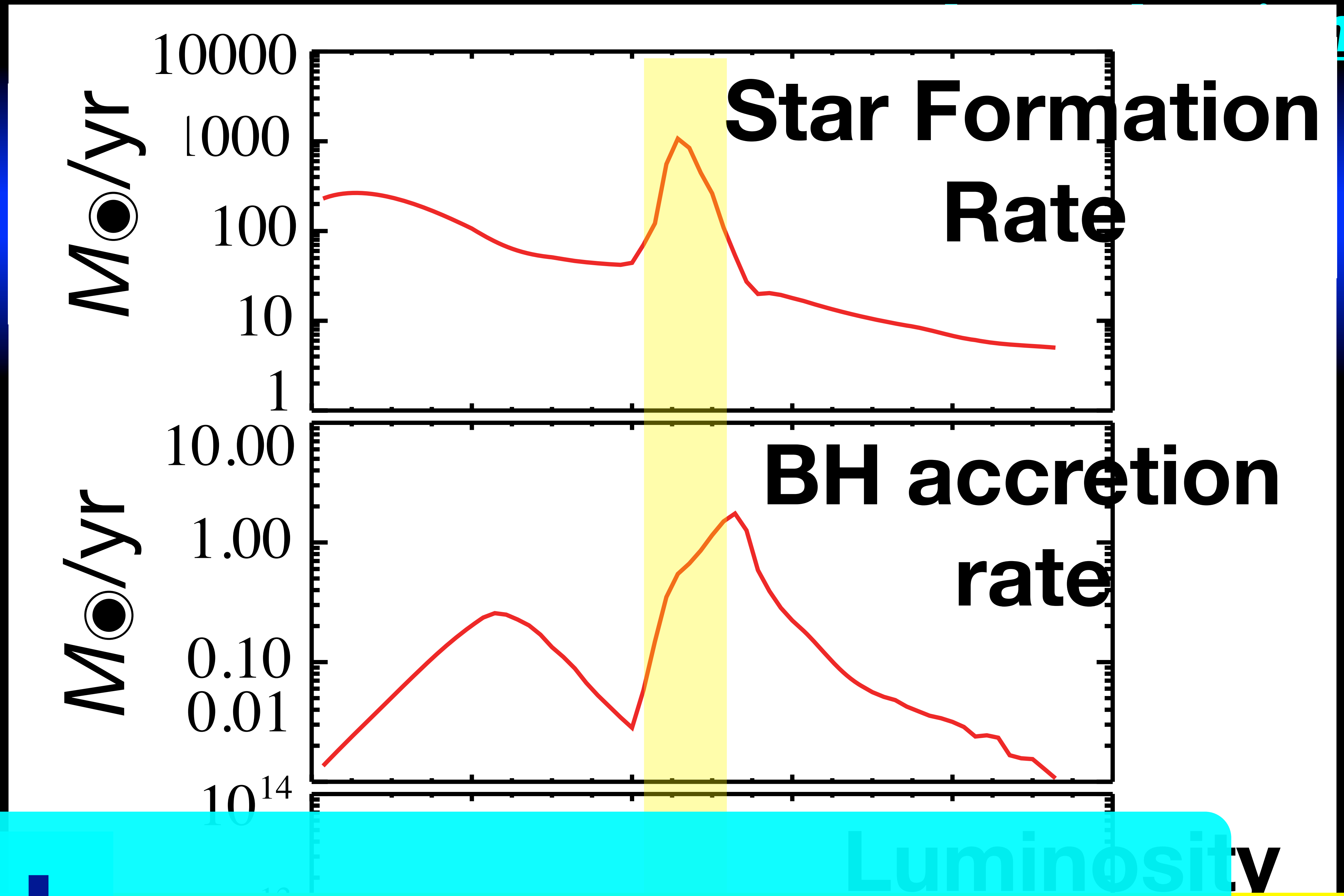


ELIRGs could constitute a key population for understanding the co-evolution of galaxies and SMBHs



Importance of ELIRGs



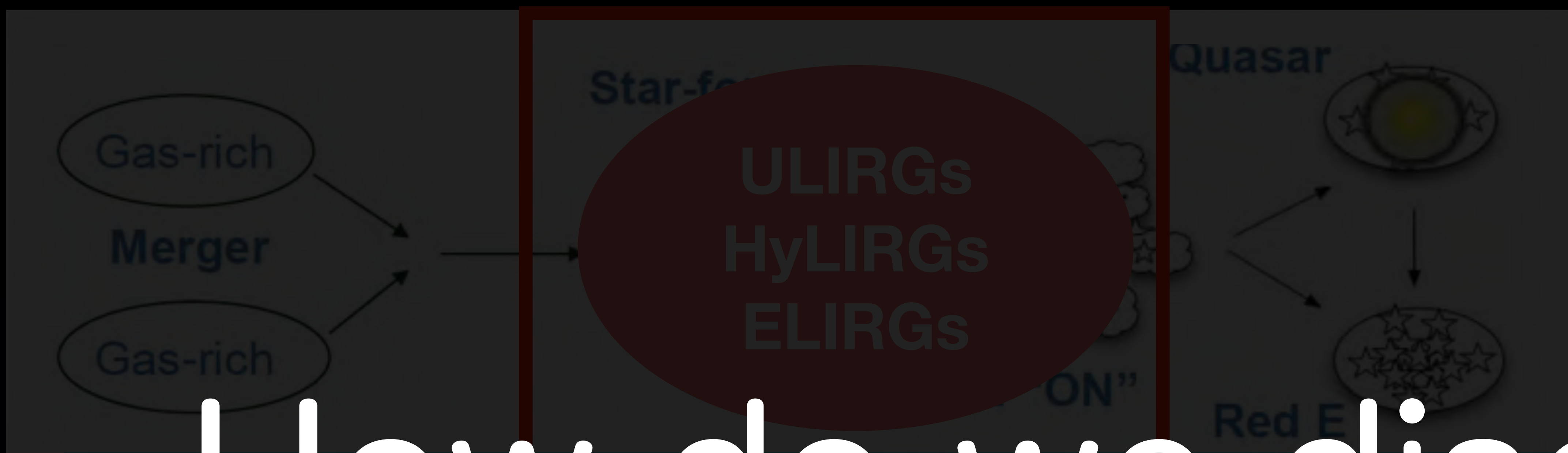


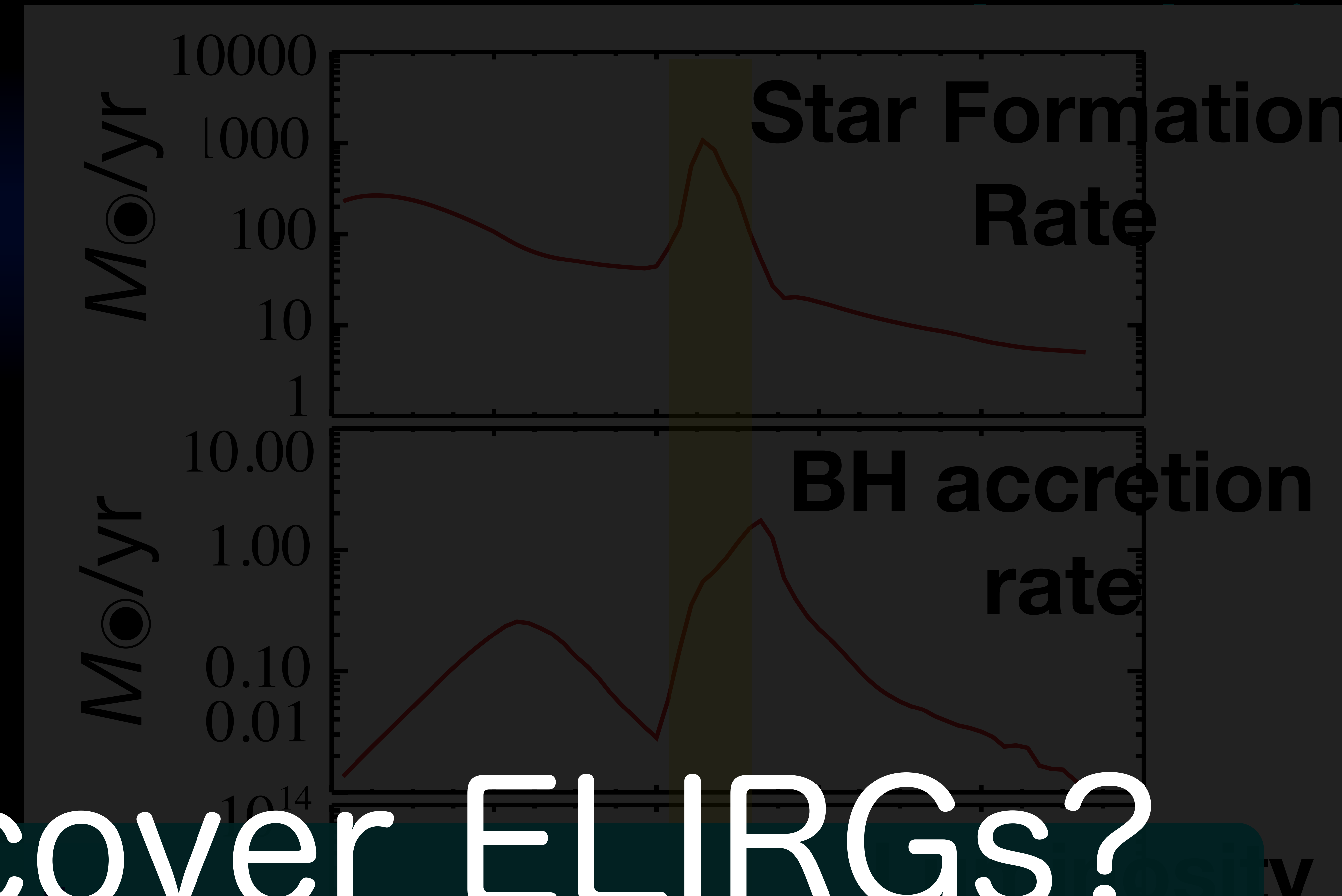
Purpose of this work

Search for extremely-luminous infrared galaxies (ELIRGs) based on wide area surveys

Narayanan+10

Importance of ELIRGs





How do we discover ELIRGs?

Purpose of this work

ELIRGs could constitute a key population

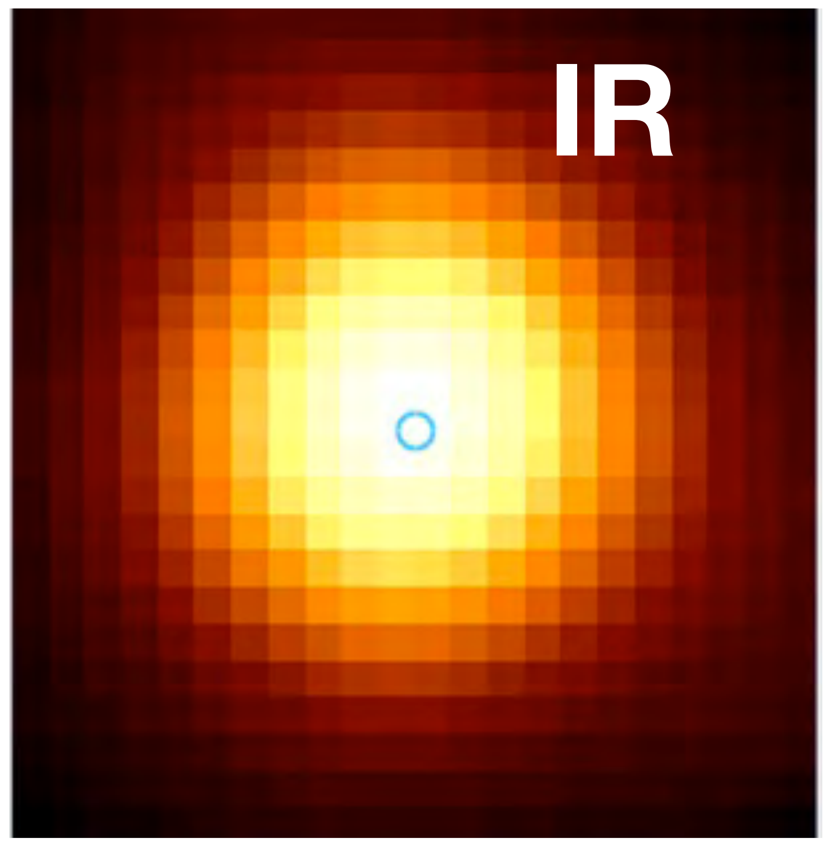
Search for extremely-luminous infrared galaxies (ELIRGs) based on wide area surveys

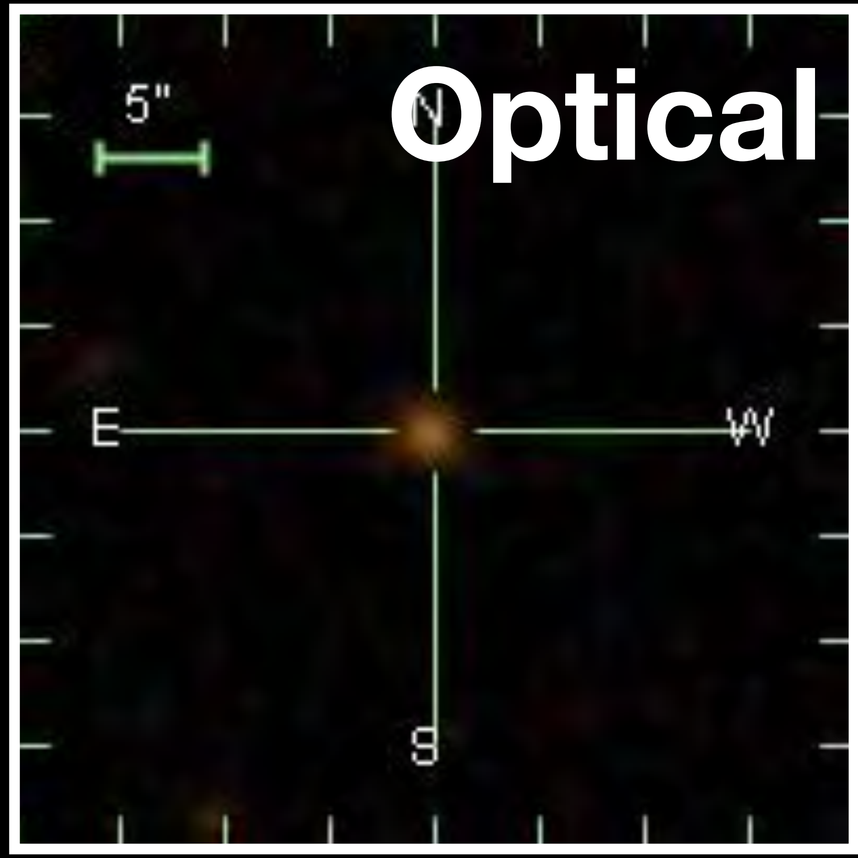
Dust-Obscured Galaxies

Dust-Obscured Galaxies

R - [24] ≥ 7.5 (AB mag)

- An optically faint but IR bright objects.

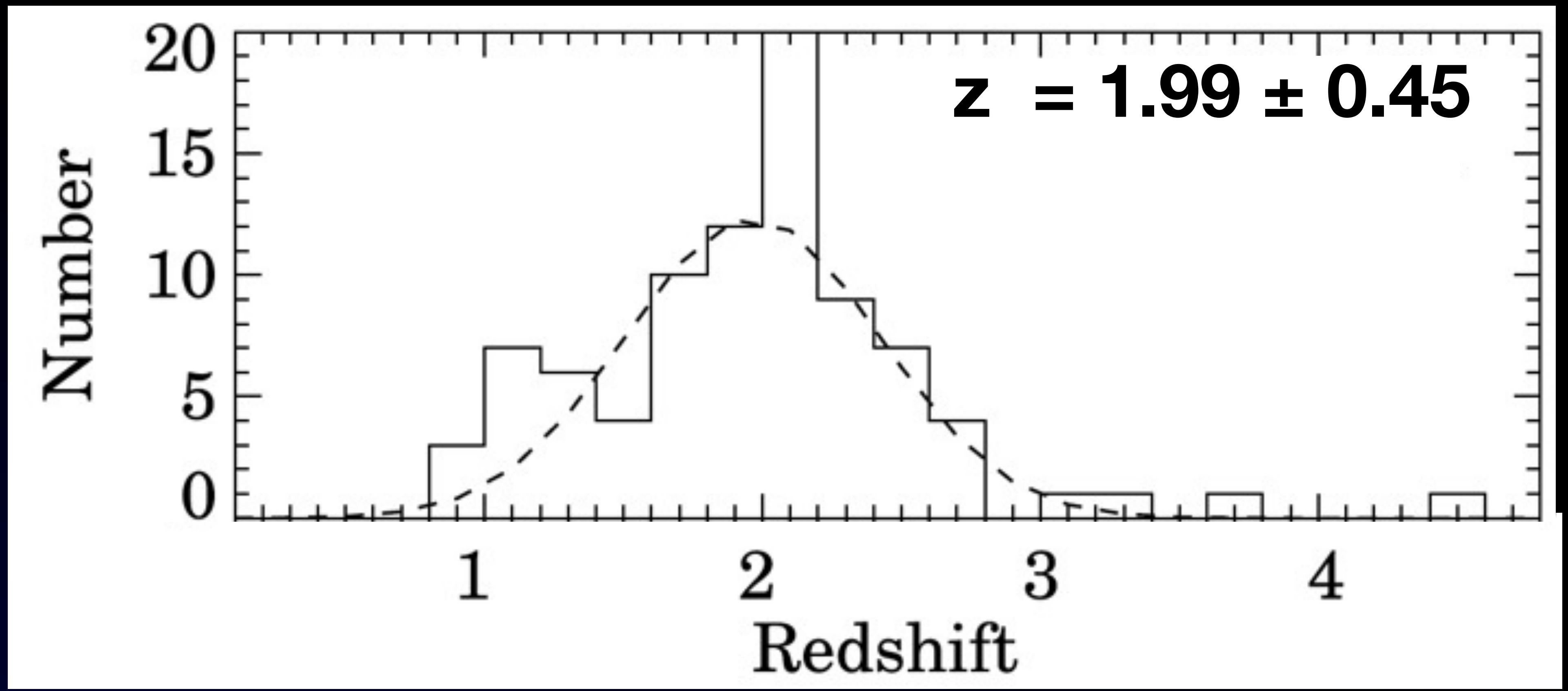




F(IR) > **1000** × F(optical)

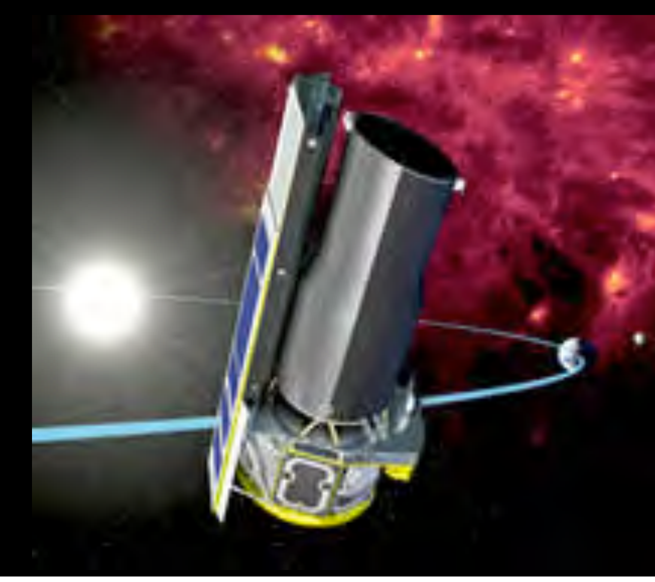
~ ULIRGs/HyLIRGs at z ~2

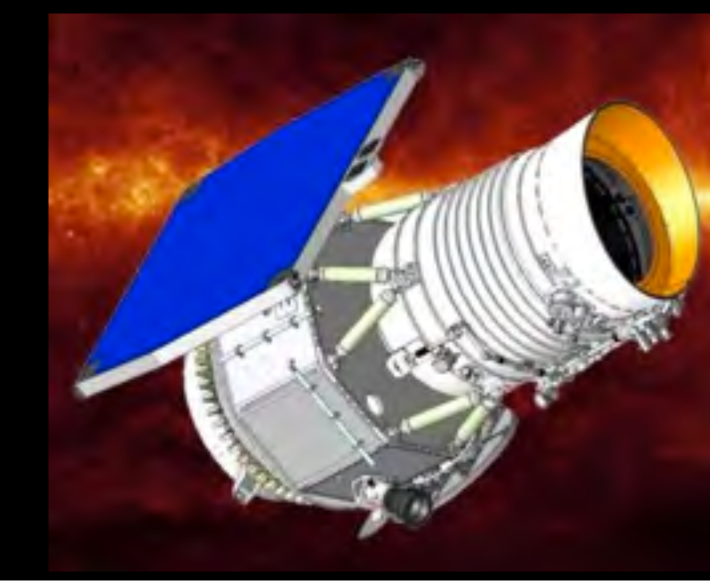
- Most DOGs are ultra-luminous IR galaxies (ULIRGs: $L_{IR} \geq 10^{12}$ L_{sun}).
- A few DOGs are even hyper-luminous IR galaxies (HyLIRGs: $L_{IR} \geq 10^{13}$ L_{sun}).



Dey+08

Basic idea of ELIRGs survey using DOGs





DOGs survey	Spitzer		WISE
Survey region	10-100 deg^2		All-Sky
MIR flux	~0.3 mJy	×10	~3 mJy
L_{IR}	$> 10^{12\text{-}13}$ L	×10	$> 10^{13\text{-}14}\ L_\odot$
Population	ULIRGs/HyLIRGs		HyLIRGs/ELIRGs

Basic idea of ELIRGs survey using DOGs

DOGs selection with WISE would be useful to search for ELIRGs

DOGs survey	Spitzer		WISE
Survey region	10-100 deg^2		All-Sky
MIR flux	~0.3 mJy	×10	~3 mJy
L_{IR}	$> 10^{12-13}$ L	×10	$> 10^{13-14}$ $L_\odot$
Population	ULIRGs/HyLIRGs		HyLIRGs/ELIRGs

Data and Analysis

- Survey strategy (3 steps!)
- Data set
- SED fitting method
- Selection of candidates

Survey Strategy

Step 1

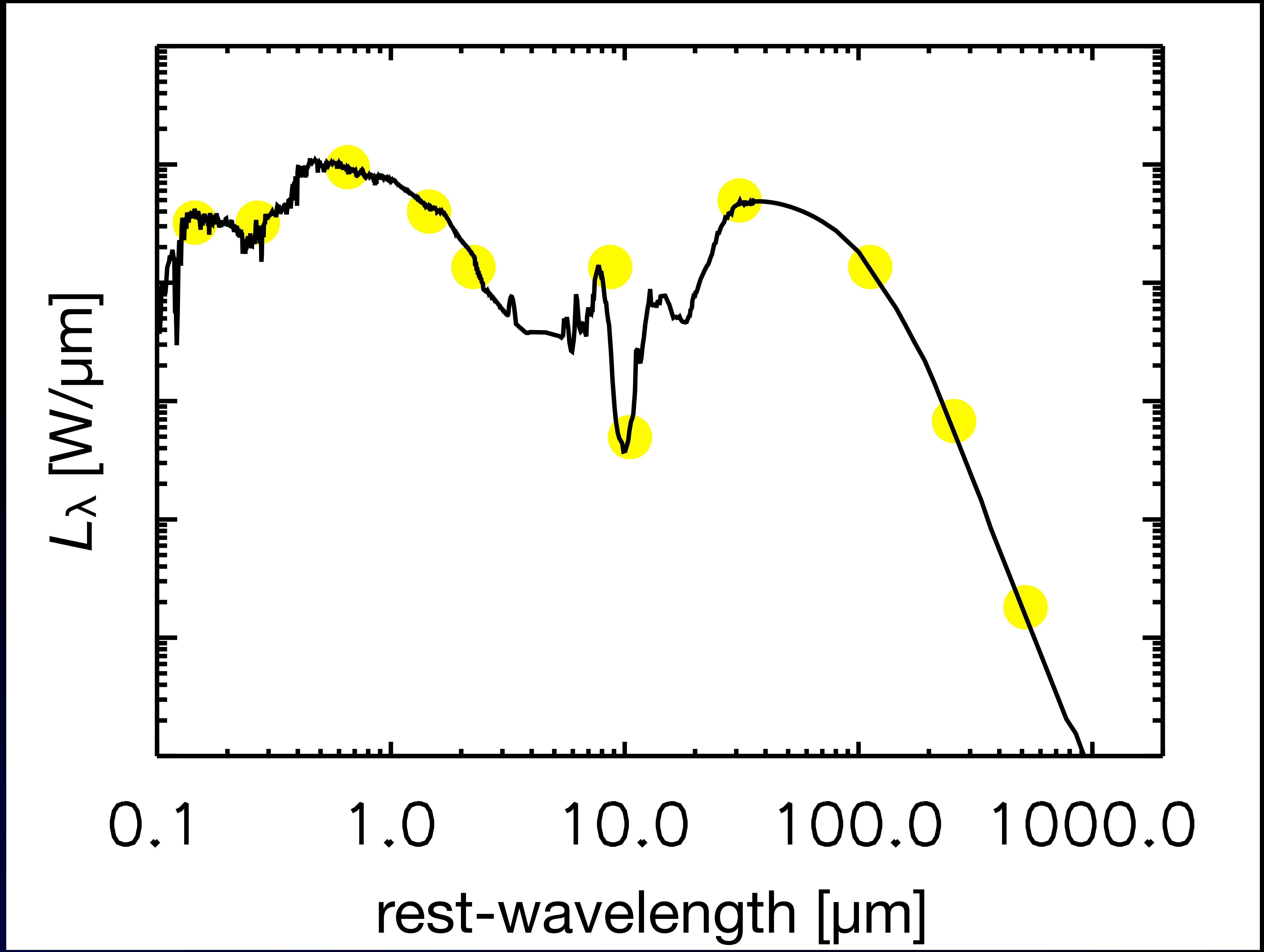
Selection of candidate

Step 2

Collect multi-wavelength data set.

Step 3

SED fitting and estimate IR luminosity (L_{IR})



Survey Strategy

$$L_{\rm IR}\ (8-1000\ \mu{\rm m}) = \int_{8}^{1000} L_\lambda {\rm d}\lambda$$

Step 1

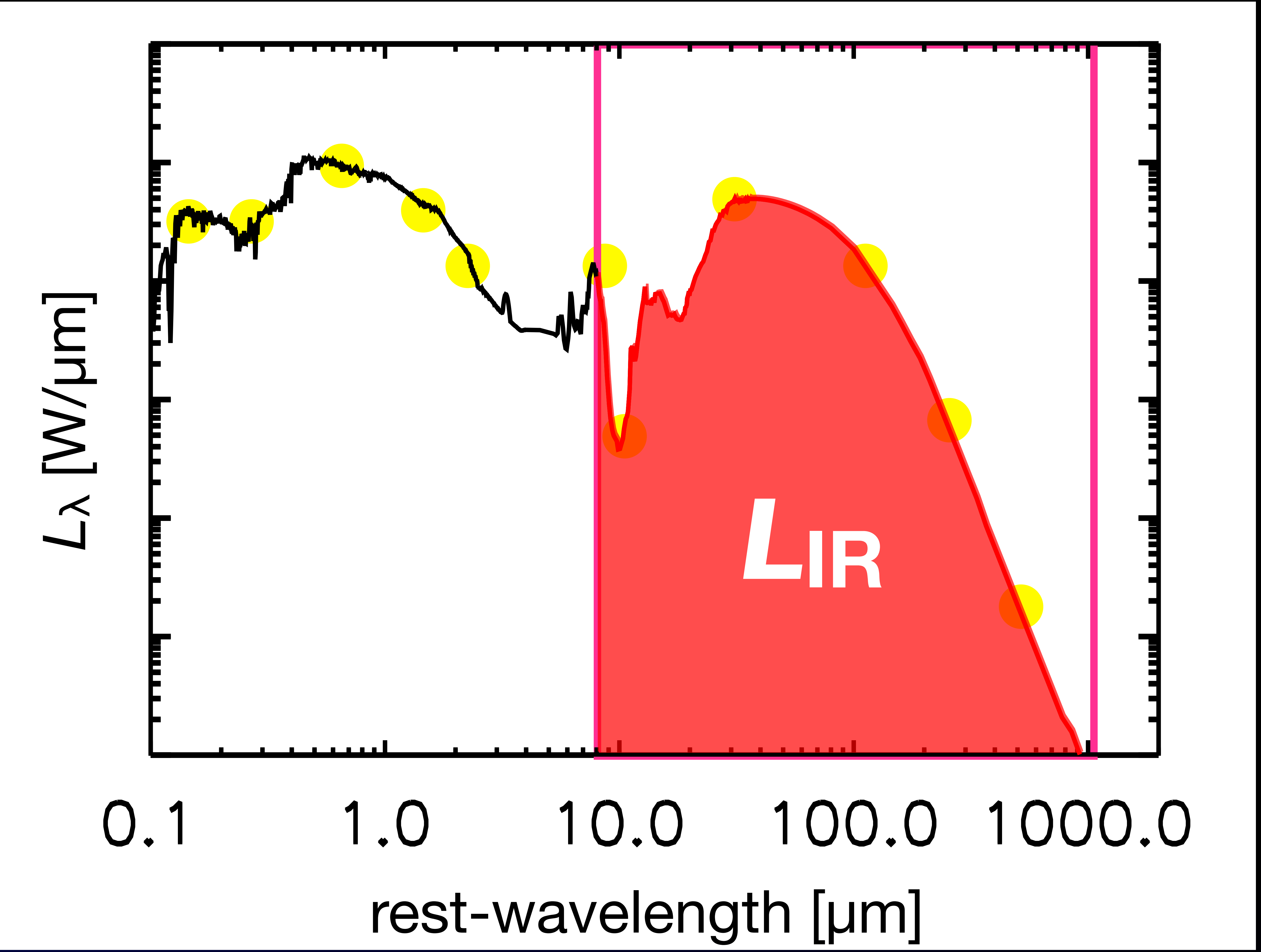
Selection of candidate

Step 2

Collect multi-wavelength data set.

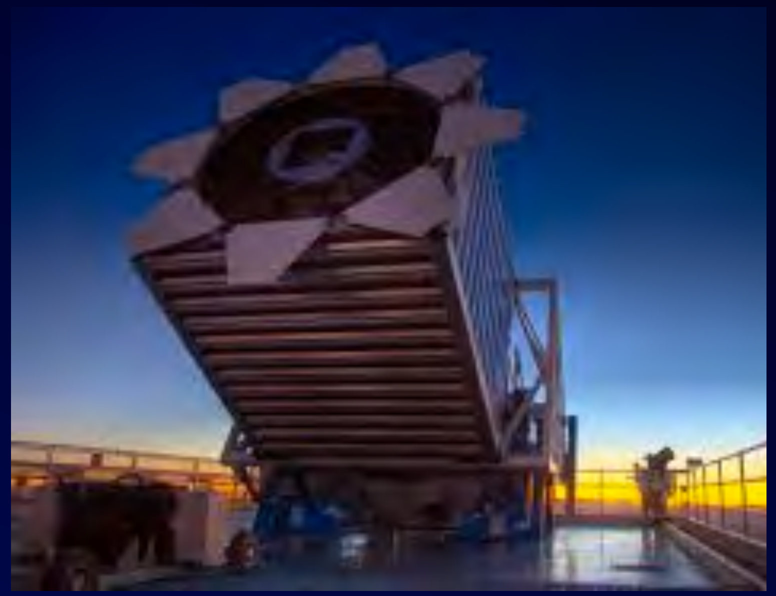
Step 3

SED fitting and estimate IR luminosity ($L_{\rm IR}$)



Data set

	optical	mid-IR	submm	mm
Instrument	SDSS	WISE	SCUBA-2	SMA
Wavelength [μm]	u, g, r, i, z (0.3 - 0.9)	3.4, 4.6, 12, 22	450, 850	870, 1300
tracer	star	hot dust	cold dust	

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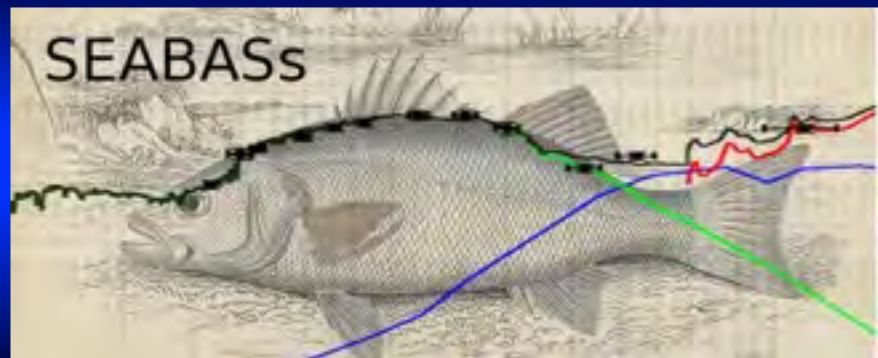
Selection of candidates

Follow-up observations



SED fitting code

SED Analysis using Bayesian Statistics

Rovilos et al. 2014

AGN component

SF component

Users can choose the SED templates flexibility [e.g., SWIRE (Polletta +07), Silva+04), Mullaney+11]

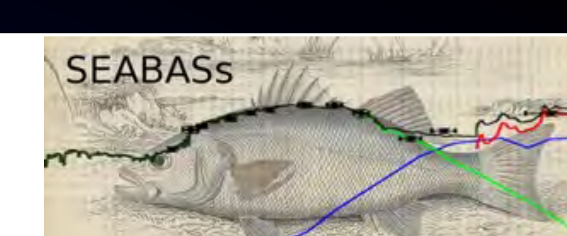
Stellar component

Bruzual & Charlot+03 with Calzetti+00 dust extinction law = 1500 templates

Best fit SED

$M_{stellar}$, SFR, L_{IR} etc.

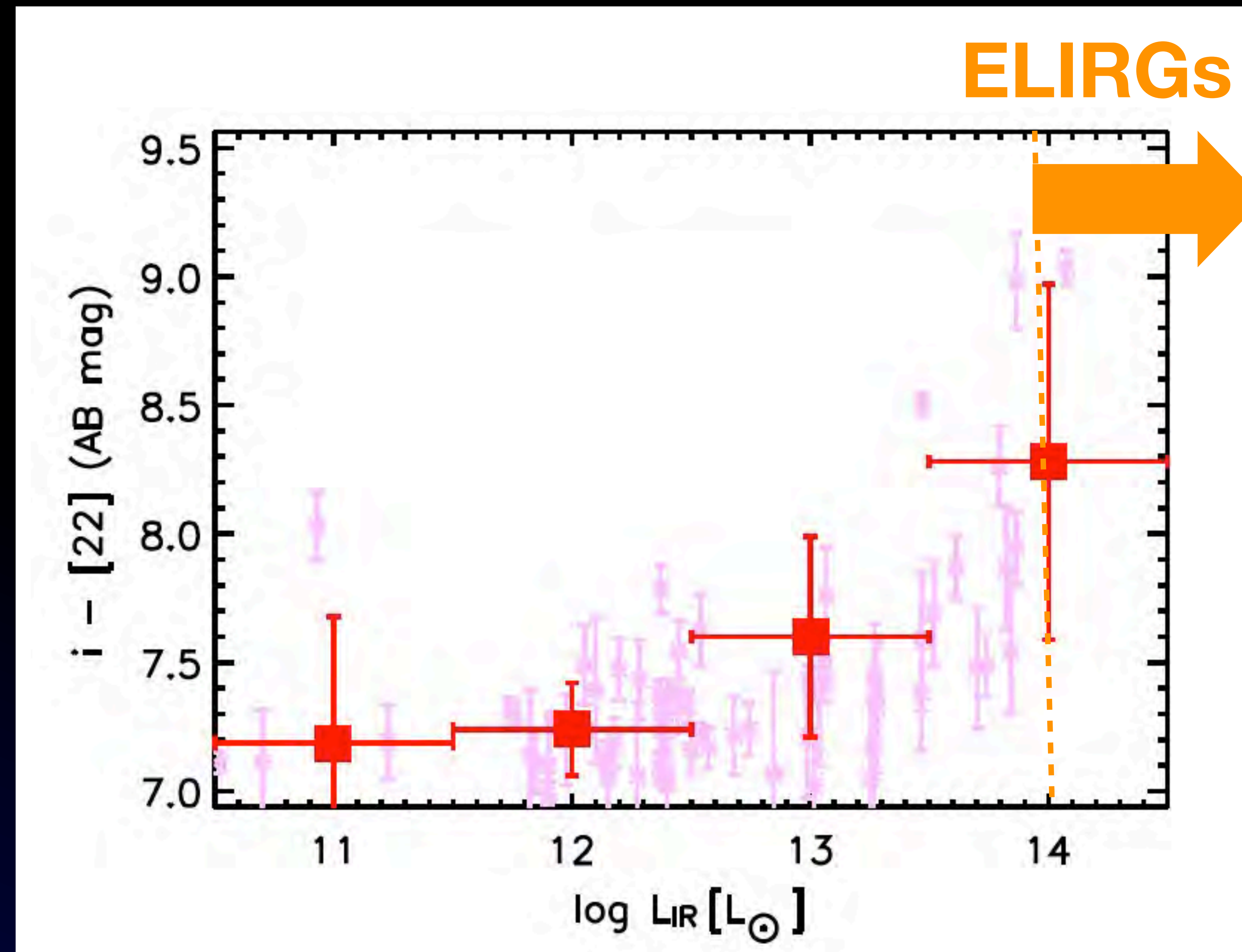
input



output

Step 1 Selection of candidates

- *i* - [22] > 8.0 (AB mag)
- SED fitting with SDSS and WISE data



SDSS	WISE
i-band (0.7μm)	22 μm

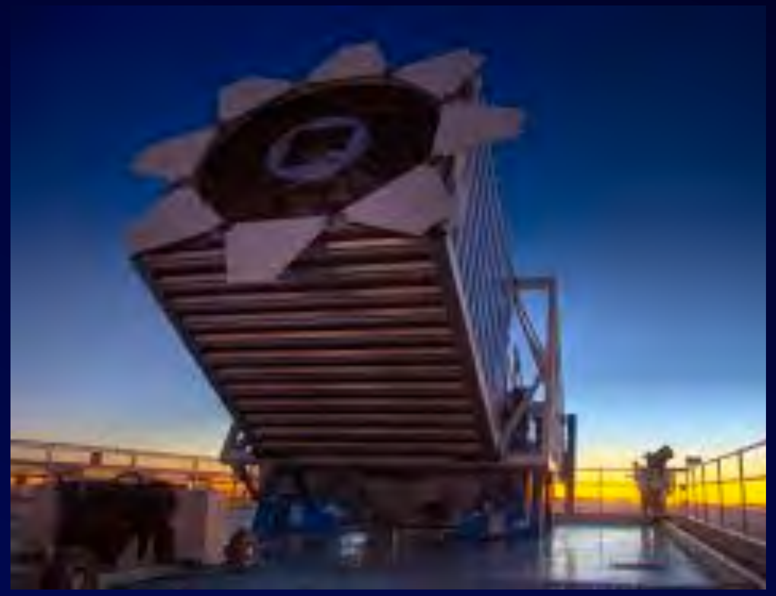
Toba & Nagao (2016)

Step 1 Selection of candidates

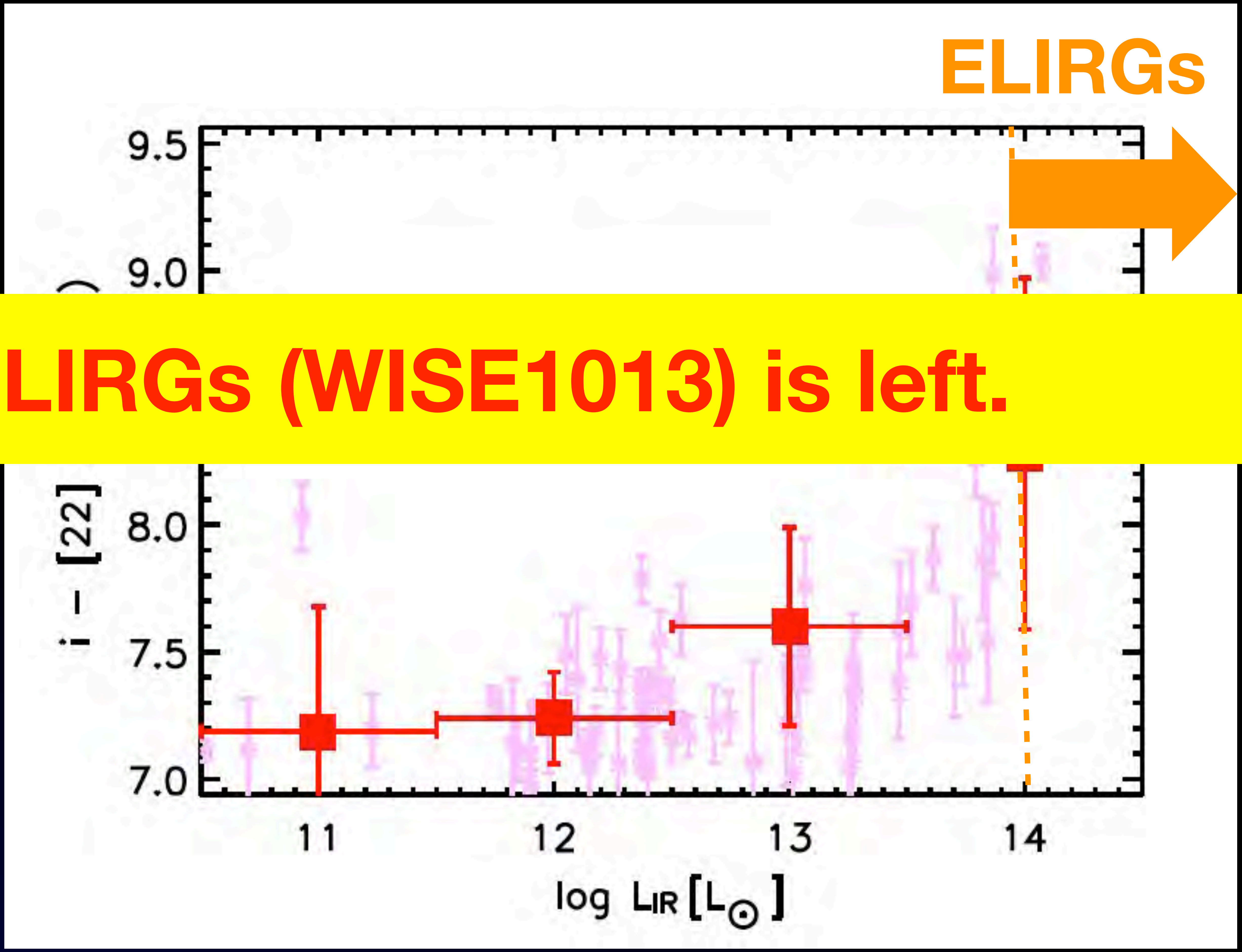
- *i* - [22] > 8.0 (AB mag)
- SED fitting with SDSS and WISE data

A candidate of ELIRGs (WISE1013) is left.

SDSS
i-band (0.7μm)



WISE
22 μm



Toba & Nagao (2016)

Step 1 Selection of candidates

WISE1013

$z = 3.70$

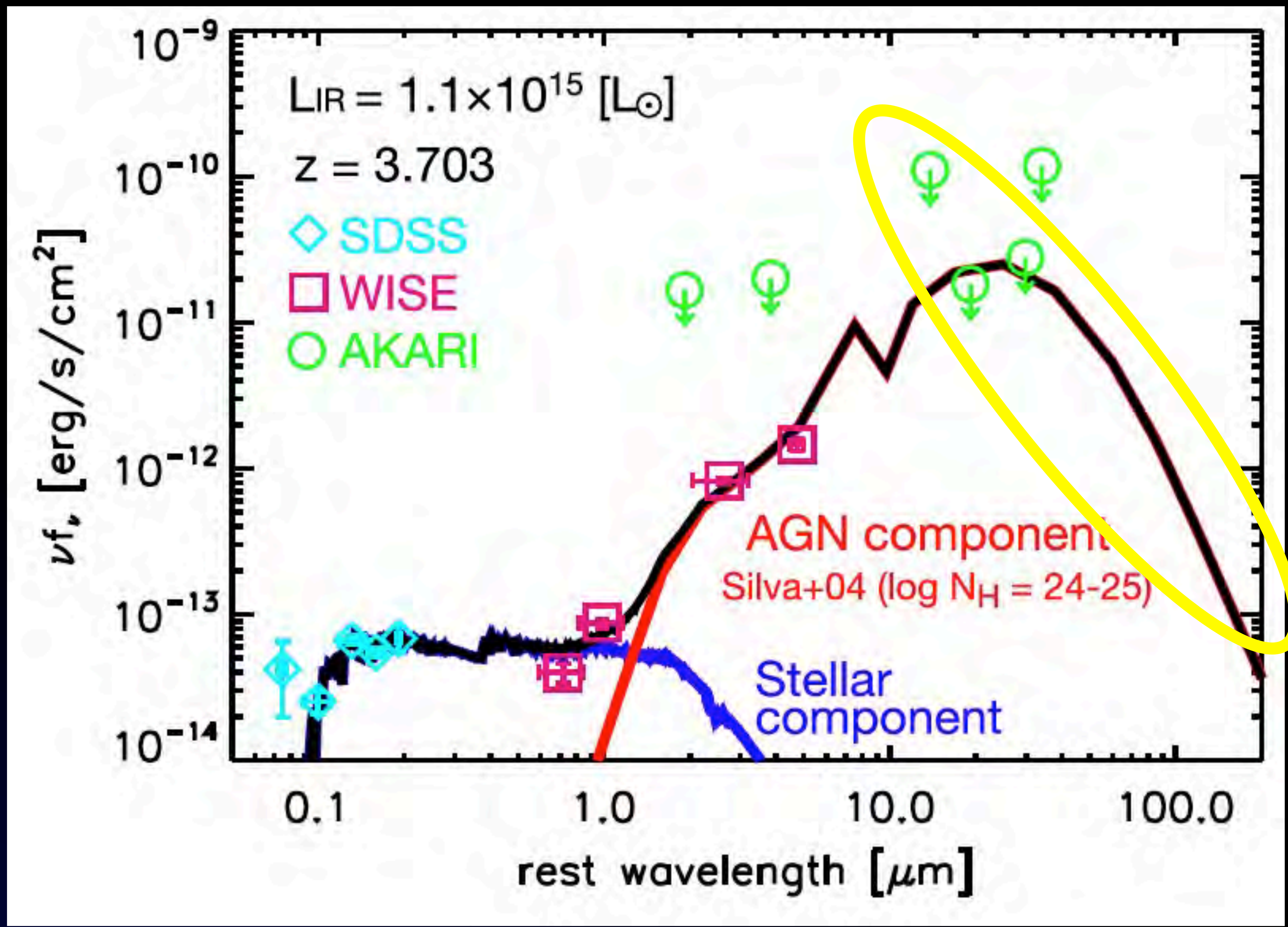
$L_{\mathrm{IR}} = 1.1\times10^{15}\ L_{\odot}$

c.f.

most luminous galaxy:

$z = 4.69$

$L_{\mathrm{IR}} = 3.7\times10^{14}\ L_{\odot}$



Toba & Nagao (2016)

Step 1 Selection of candidates

WISE1013
$z = 3.70$
$L_{IR} = 1.1\times10^{15} L_\odot$

We need rest-frame FIR data!

c.f.
most luminous galaxy:
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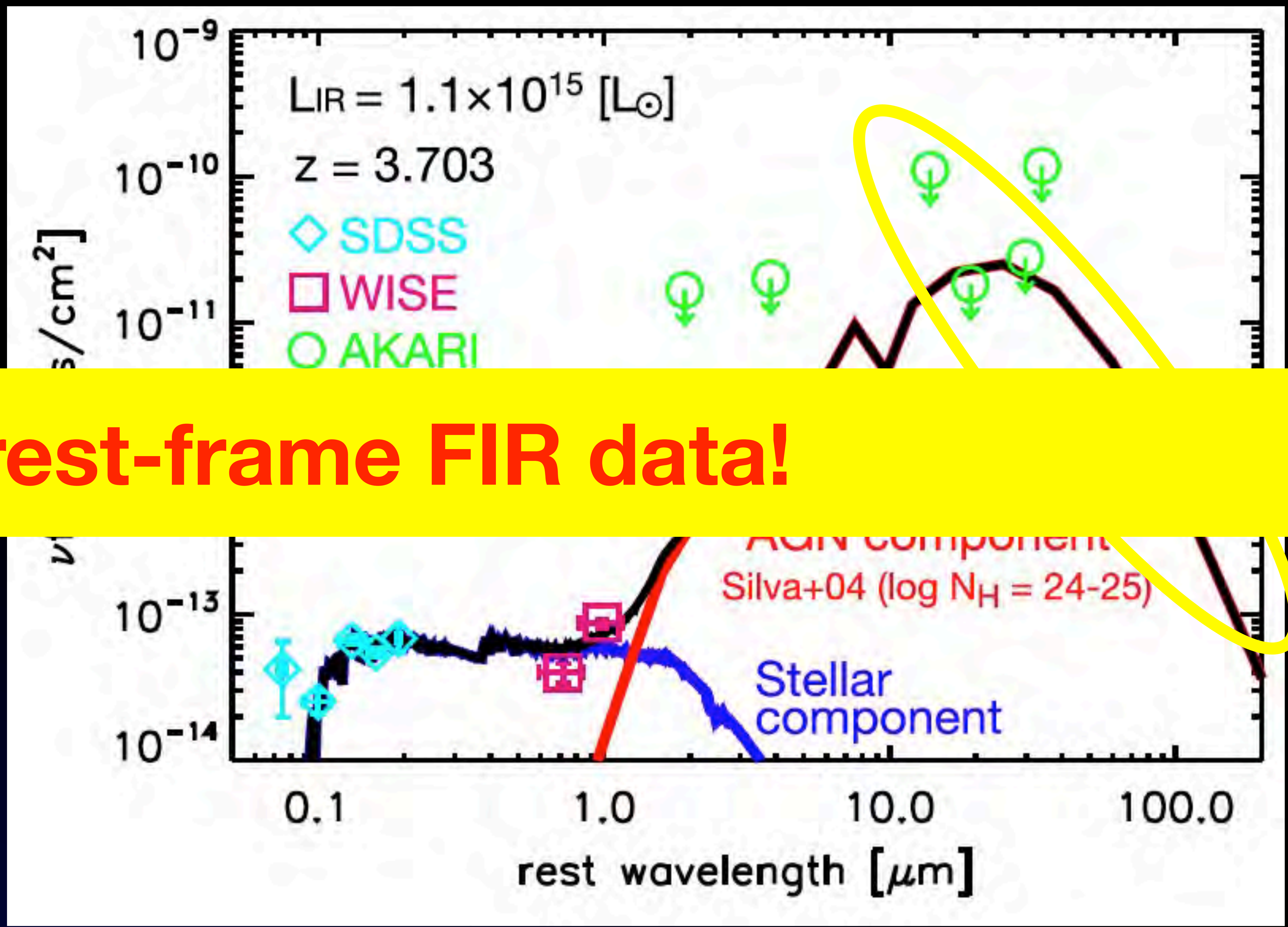
$L_{IR} = 3.7\times10^{14} L_\odot$



Toba & Nagao (2016)

Step 2 Follow-up observations of WISE1013

Submillimetre **C**ommon-**U**ser **B**olometer **A**rray **2**
The **S**ub**M**illimeter **A**rray

PI: Y. Toba

Instrument	SCUBA-2/JCMT	SMA
	450, 850 μm	870 μm, 1.3 mm
Observing date	May 8, 18 (2017)	December 28 (2016)
Integration time	2 hours	2 hours

Step 2 Follow-up observations of WISE1013

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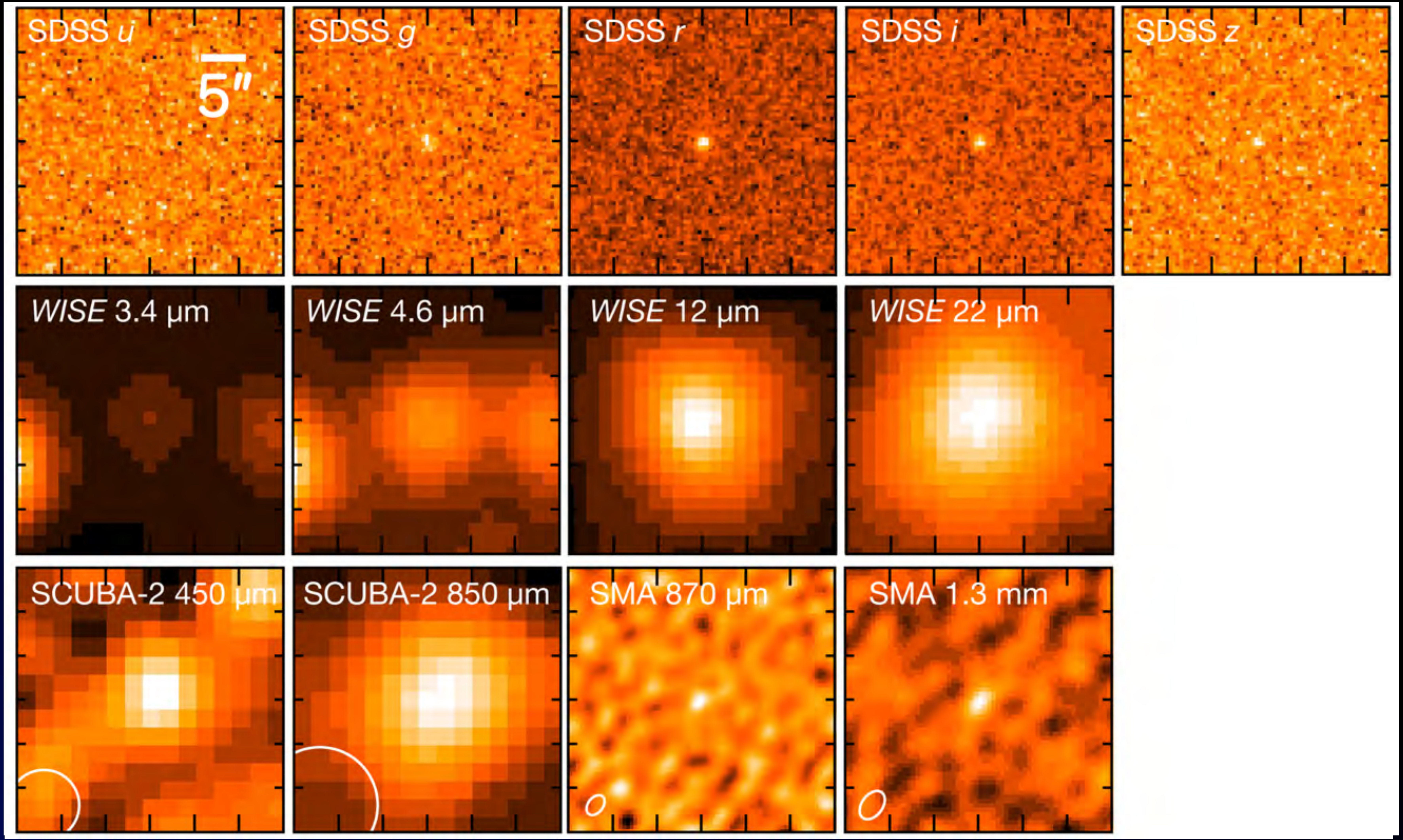
Chen-Fatt Lim (NTU/ASIAA)

Junko Ueda (NAOJ)

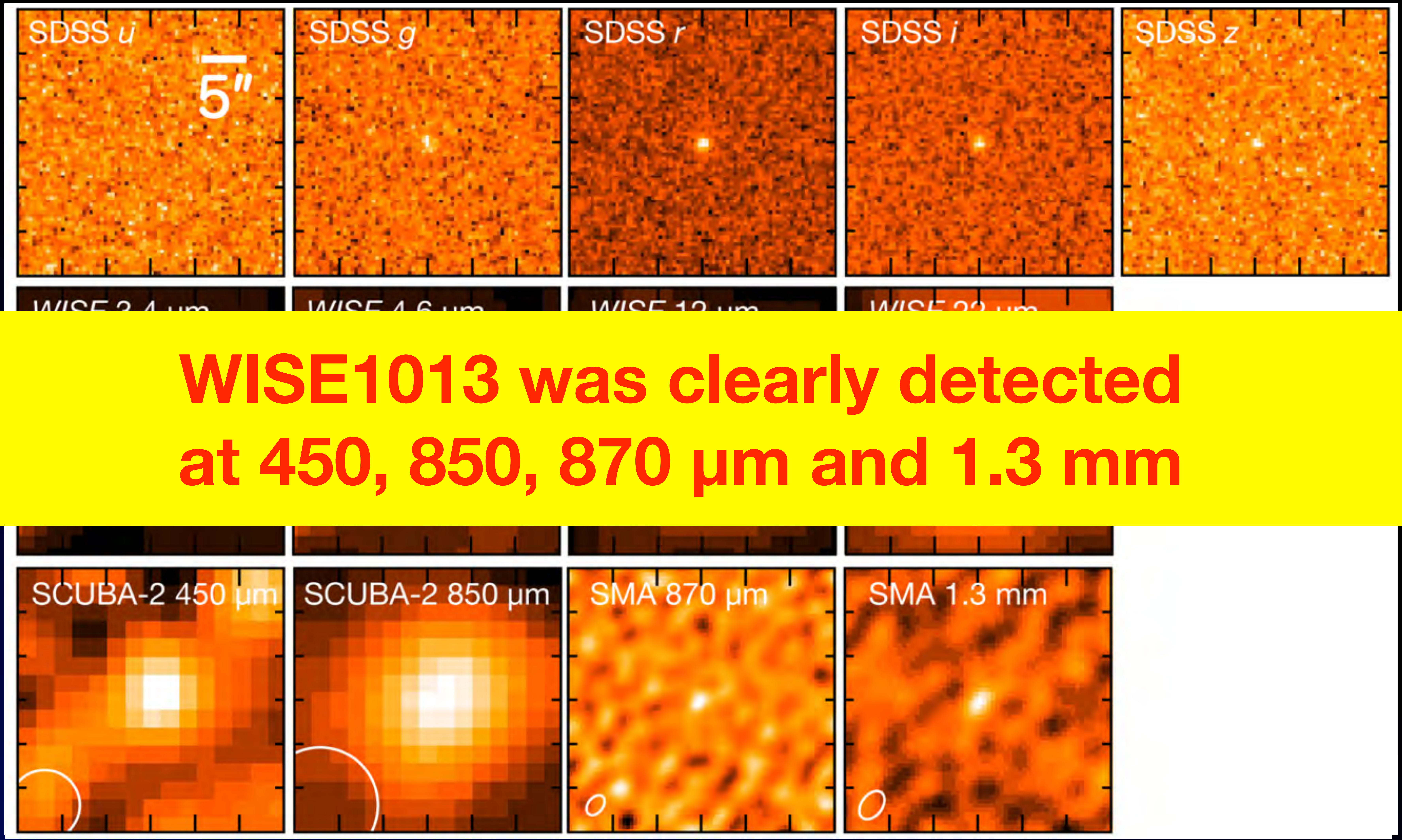
Results and Discussions

- Multi-wavelength images
- Result of the SED fitting
- Hot dust vs. cold dust
- Stellar mass and SFR relation

Multi-wavelength images of WISE1013

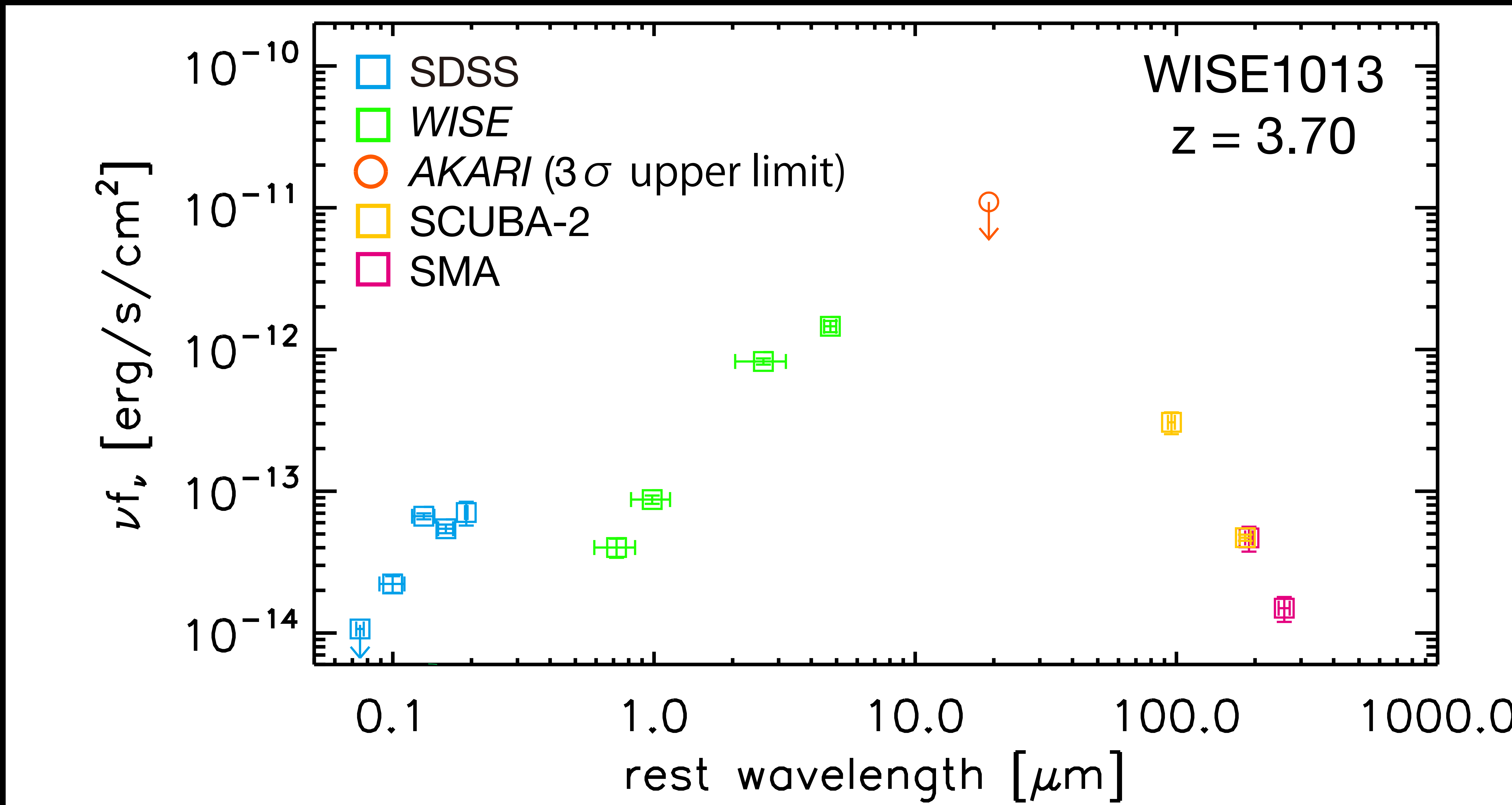


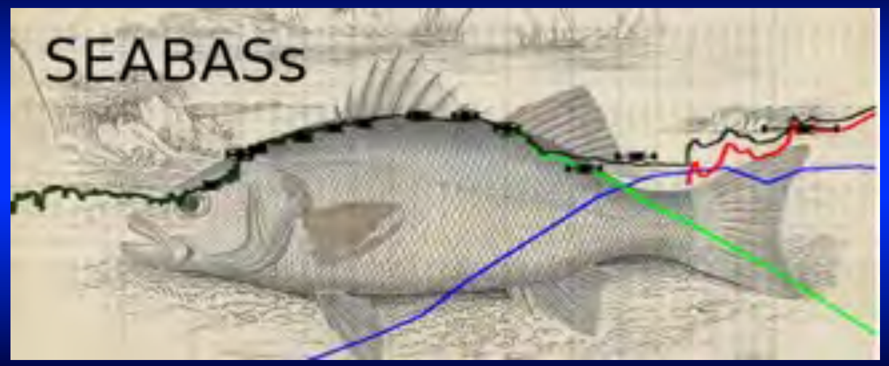
Multi-wavelength images of WISE1013



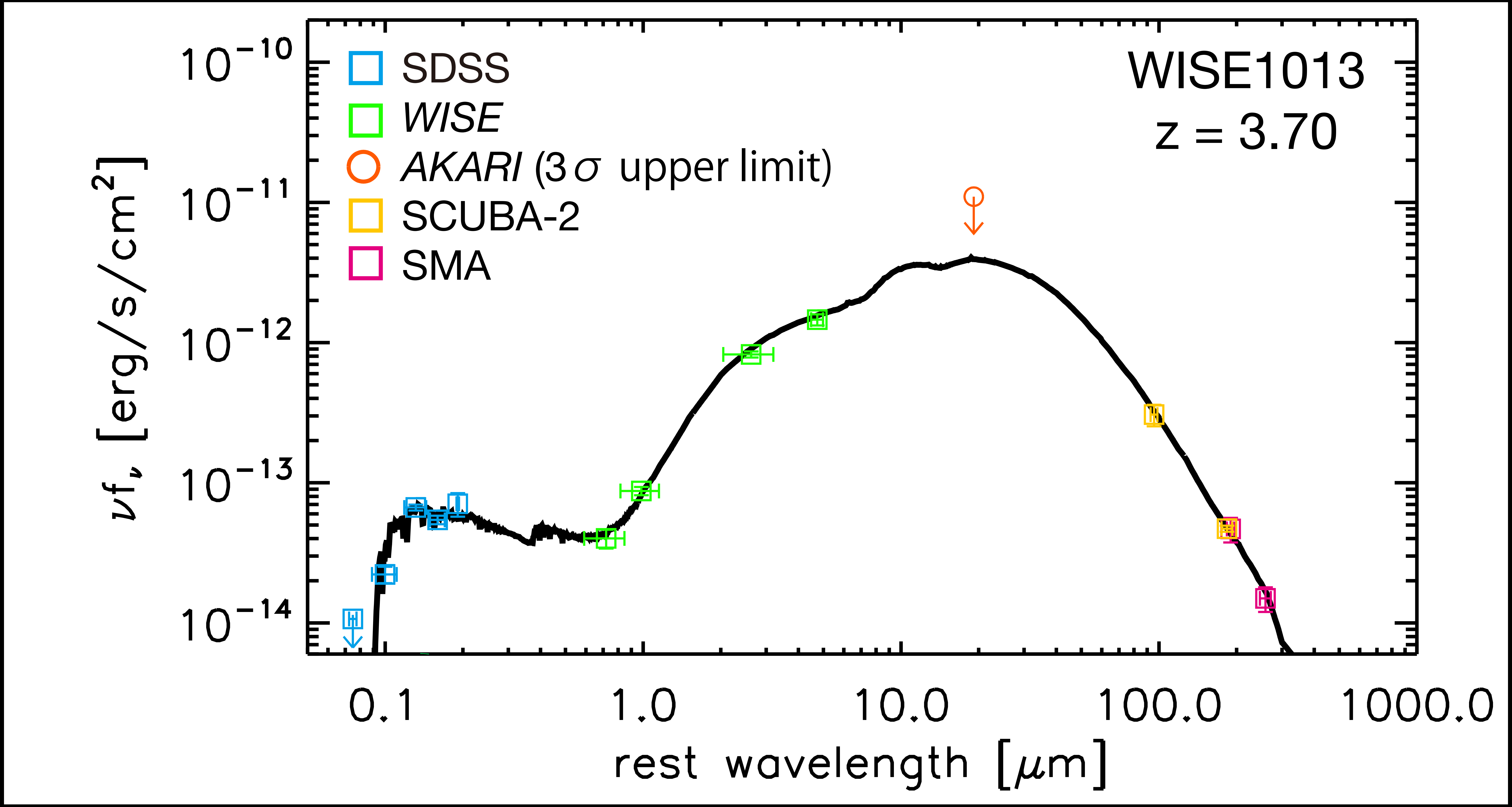
WISE1013 was clearly detected at 450, 850, 870 μm and 1.3 mm

SED fitting


SDSS
WISE
AKARI (3σ upper limit)
SCUBA-2
SMA
WISE1013
z = 3.70
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
νf_ν [erg/s/cm^2]
0.1
1.0
10.0
100.0
1000.0
rest wavelength [μm]


SEABASs

SED fitting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1.0
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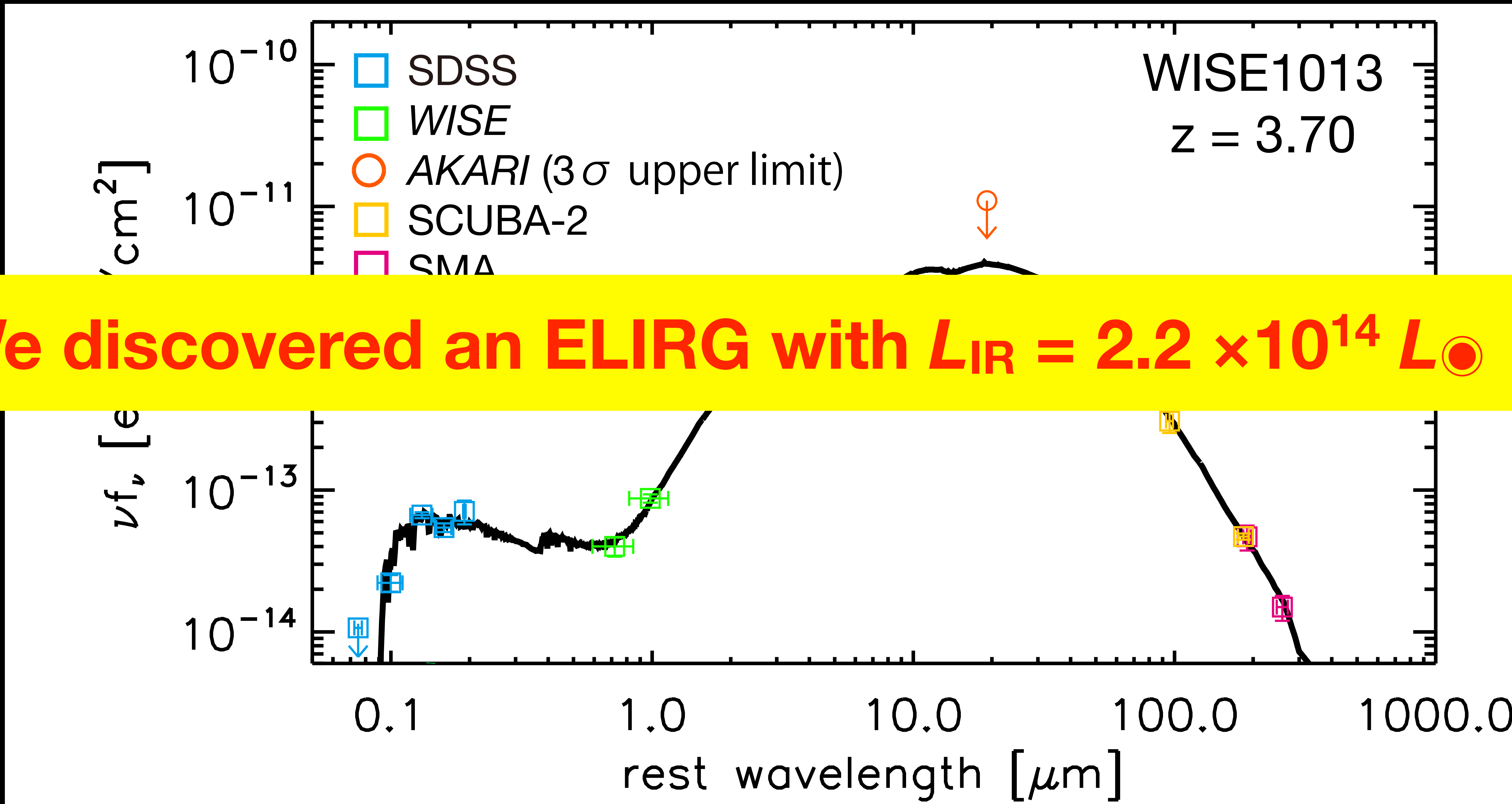
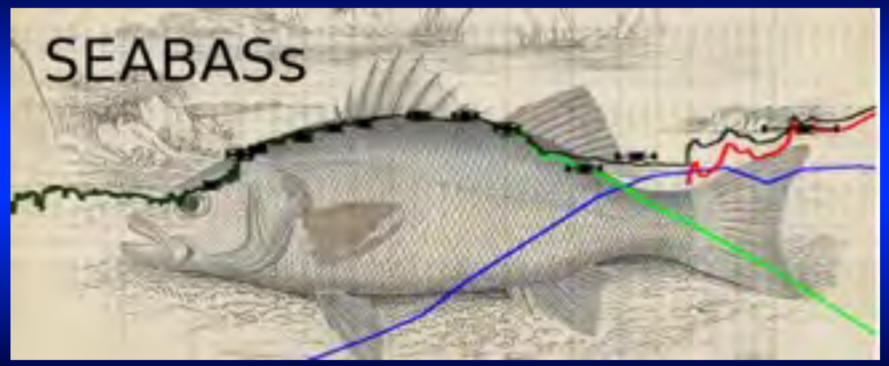
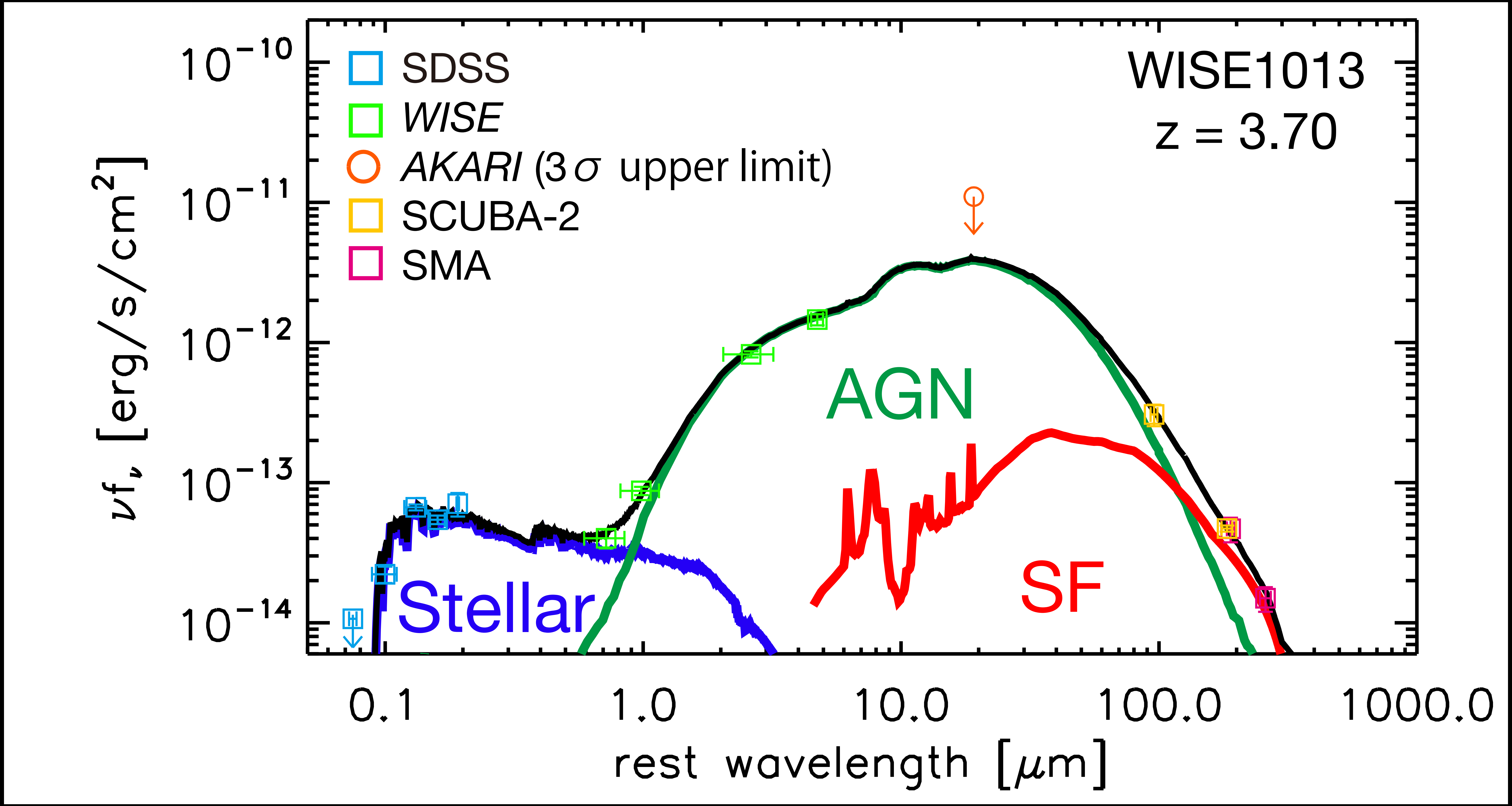
SED fitting



We discovered an ELIRG with L_{IR} = 2.2 ×10^{14} $L_\odot$


SEABASs

SED fitting


SDSS
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AKARI (3σ upper limit)
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WISE1013
z = 3.70
AGN
SF
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10^{-11}
10^{-12}
10^{-13}
10^{-14}
νf_ν [erg/s/cm^2]
0.1
1.0
10.0
100.0
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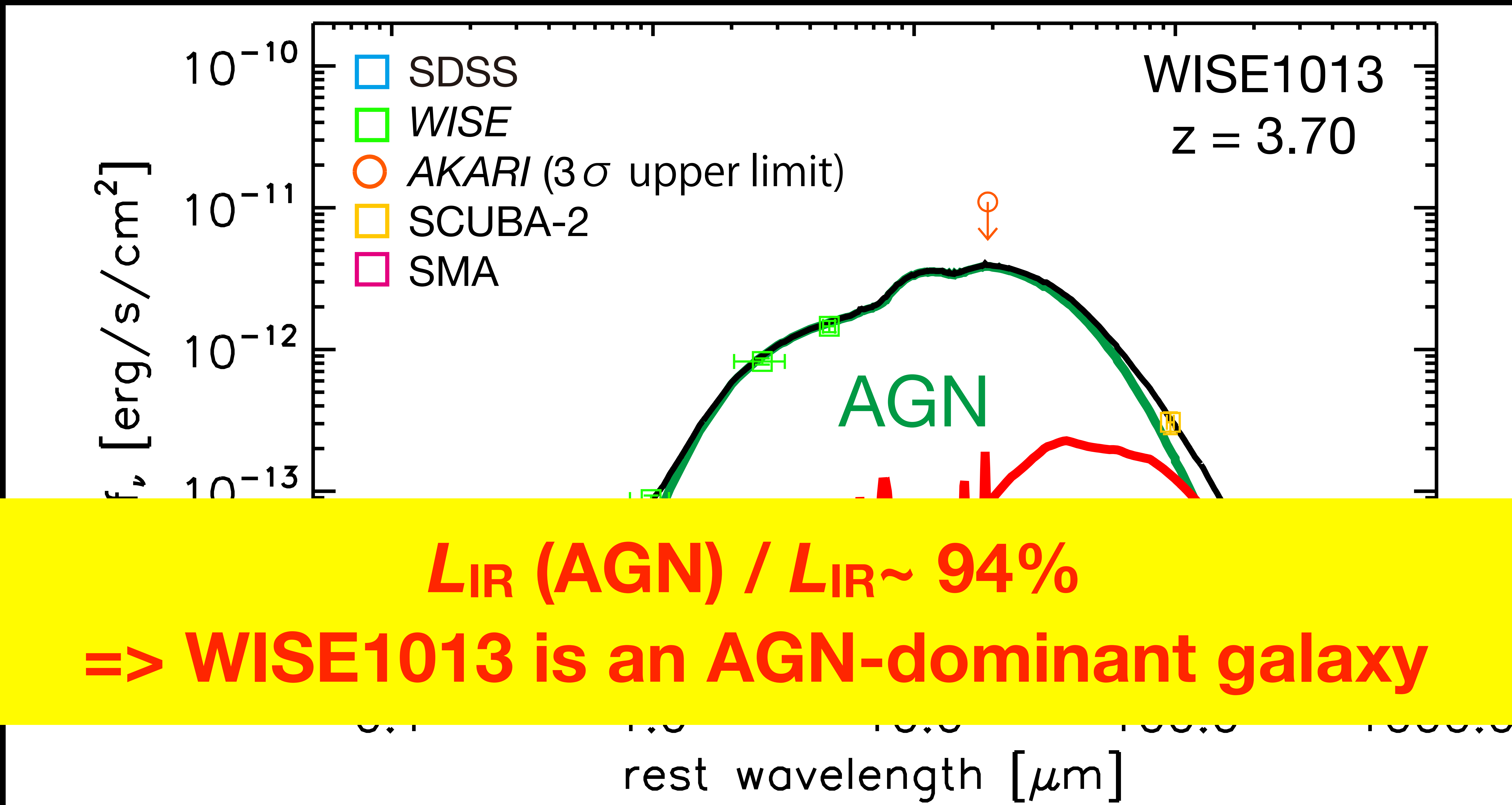
rest wavelength [μm]

SED fitting

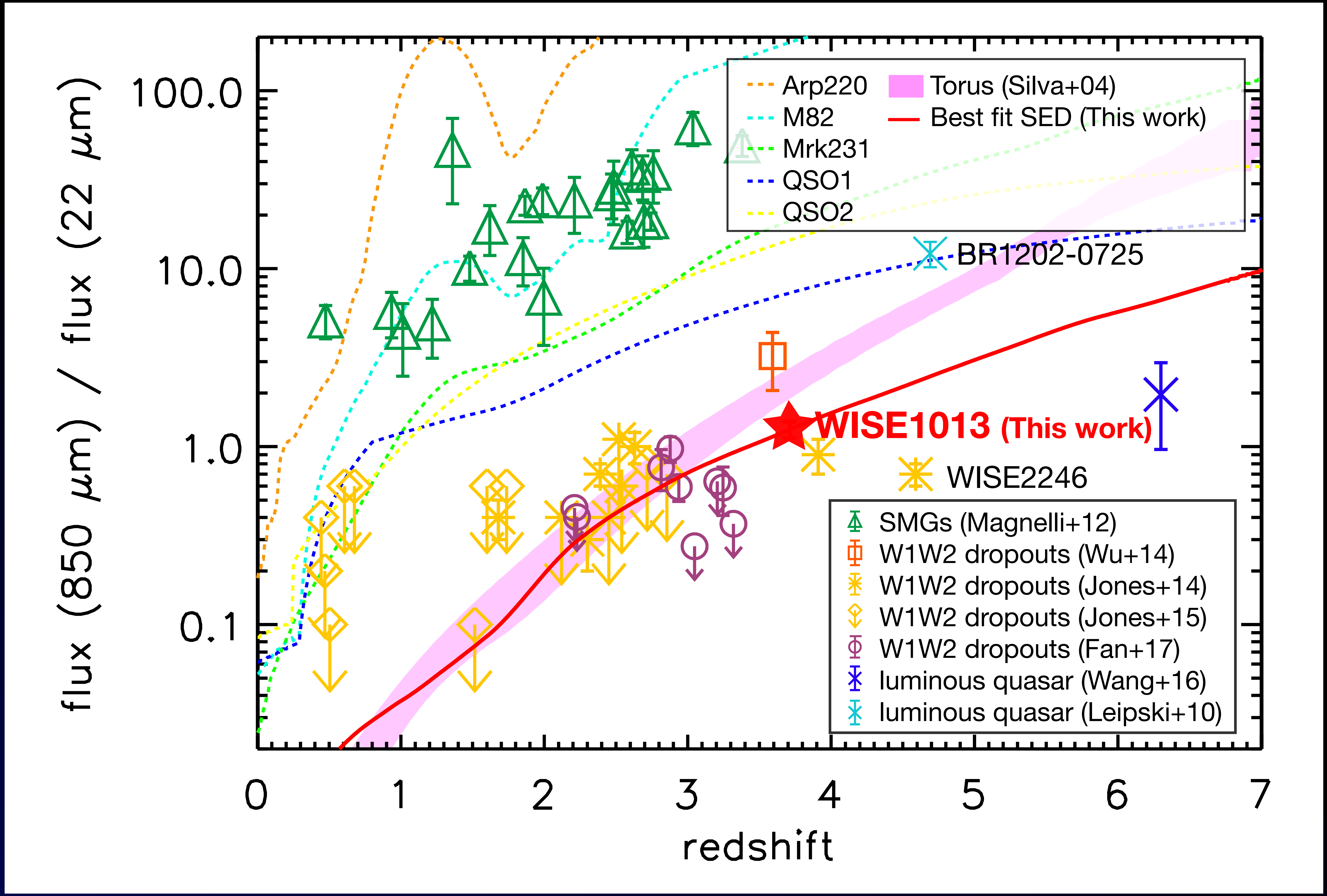


L_{IR} (AGN) / L_{IR} ~ 94%
=> WISE1013 is an AGN-dominant galaxy

flux ratio of 850 μm and 22 μm

Colder dust

Hotter dust



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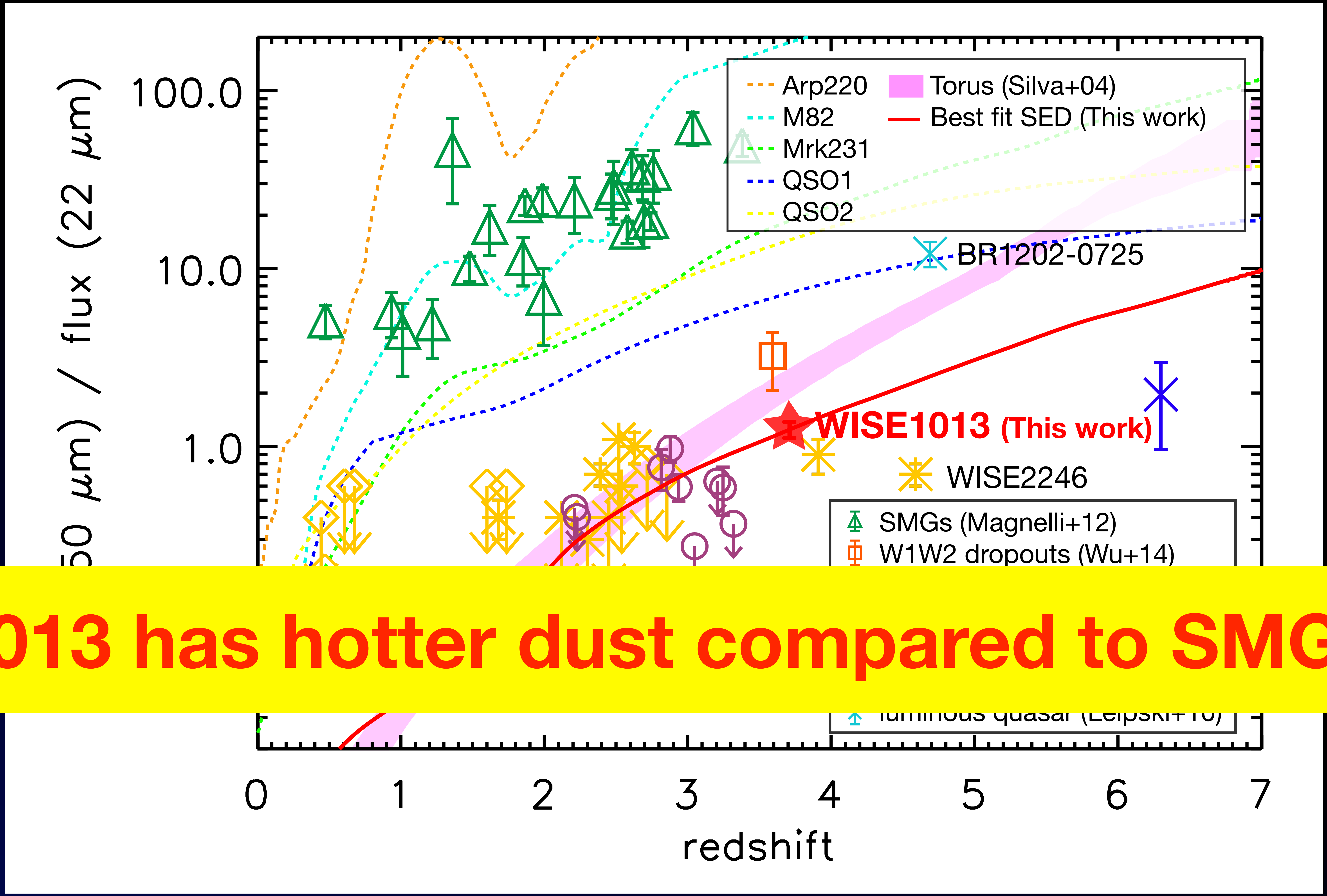
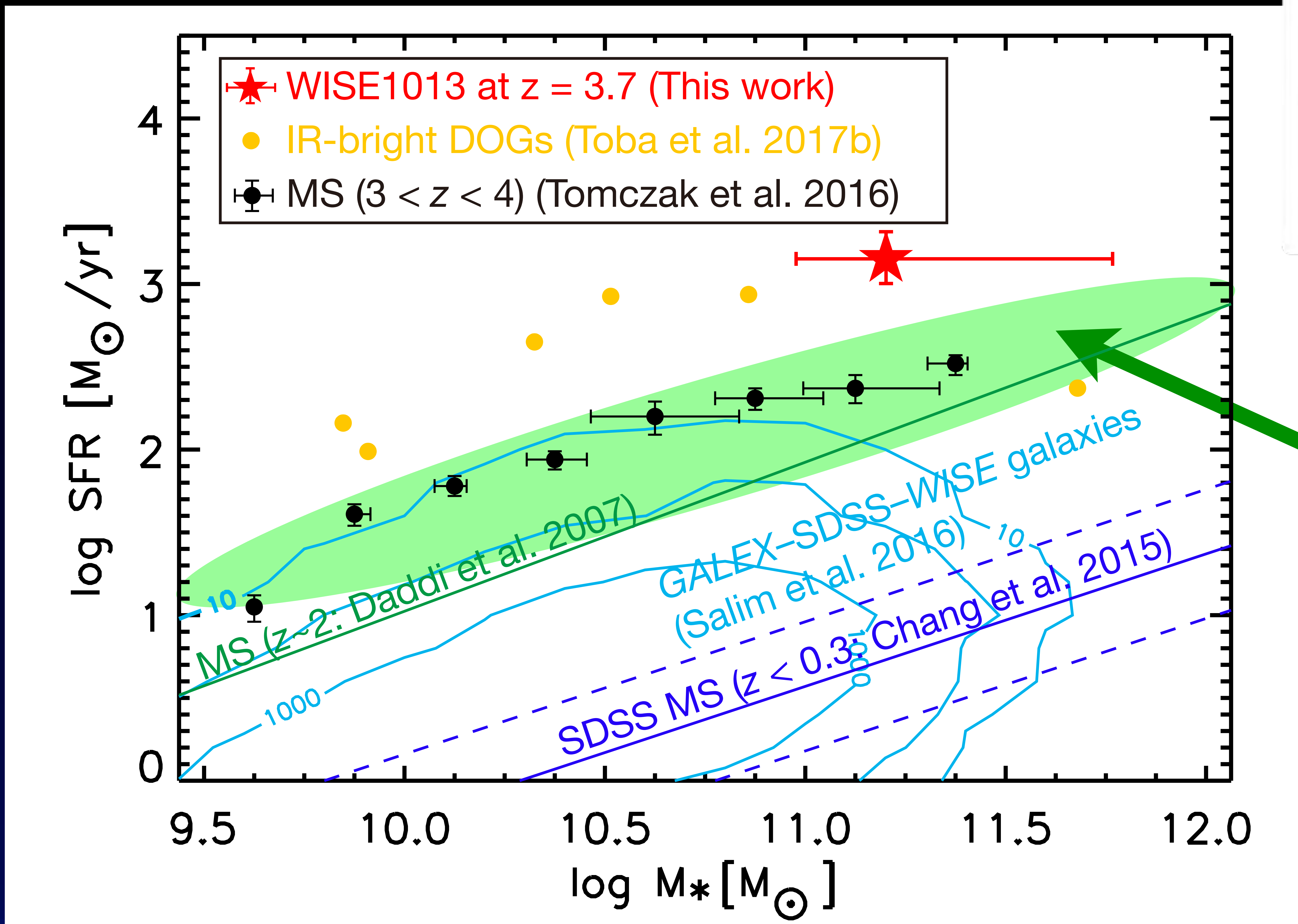
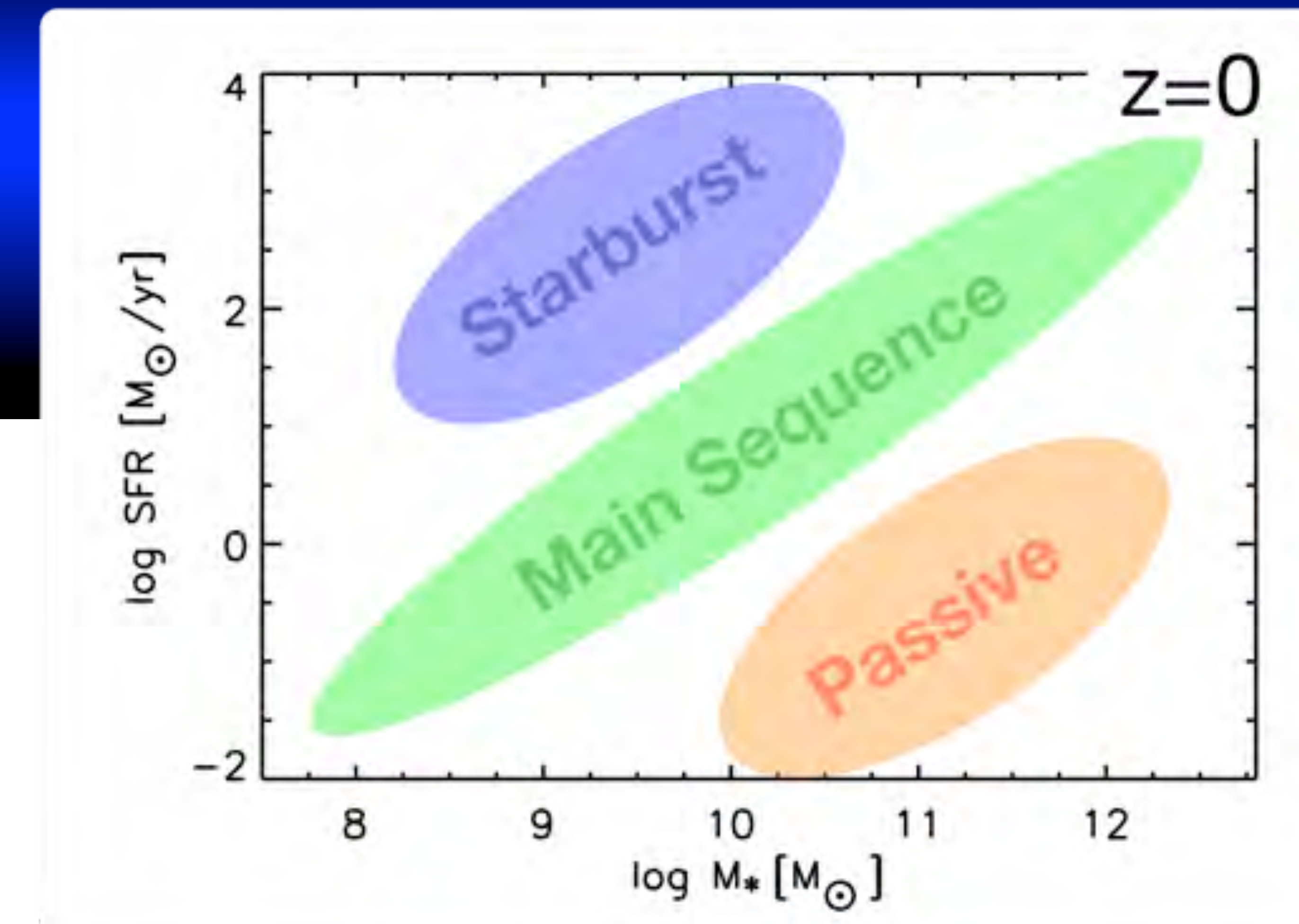


WISE1013 has hotter dust compared to SMGs

Hotter dust

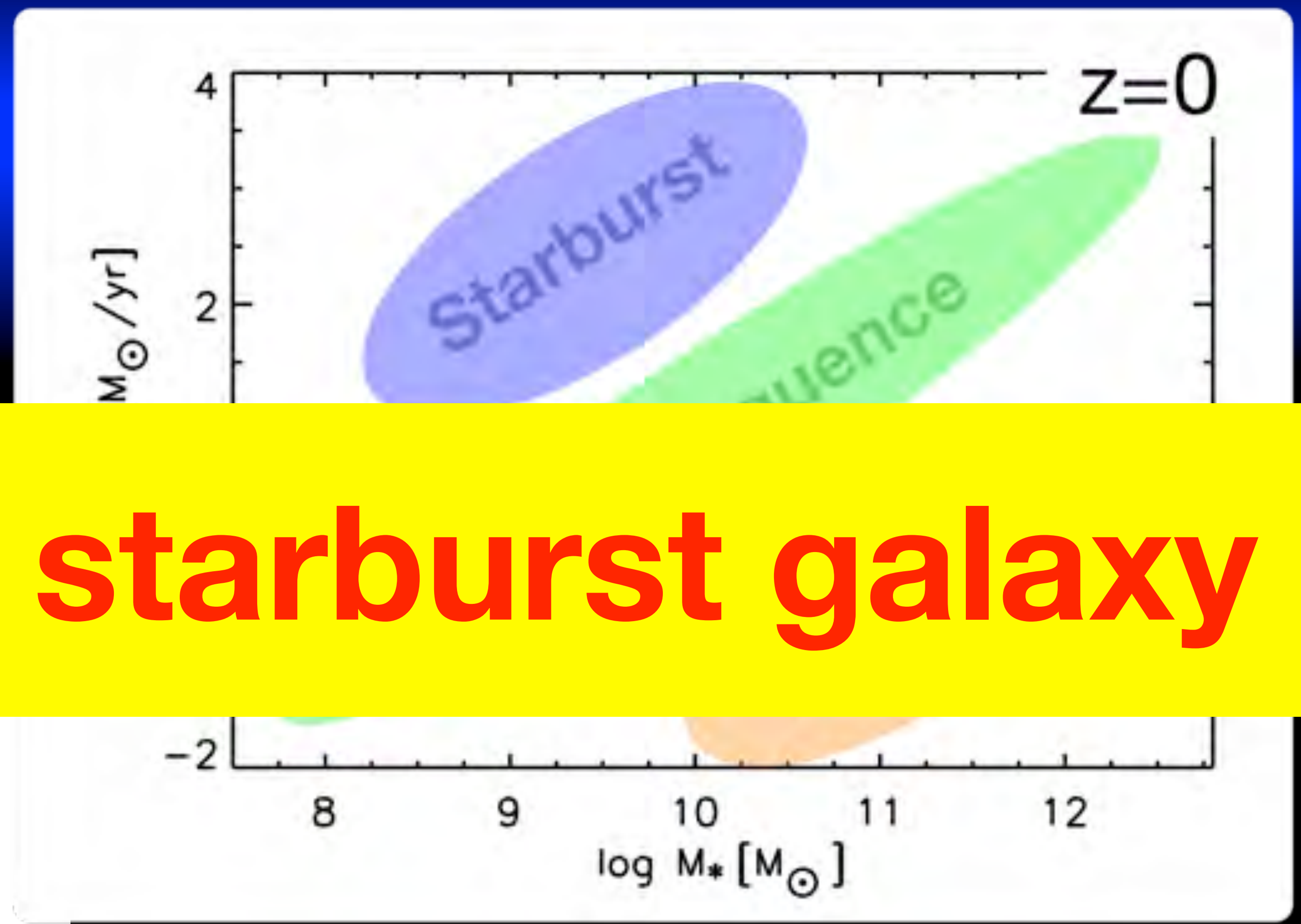
Stellar mass vs. SFR



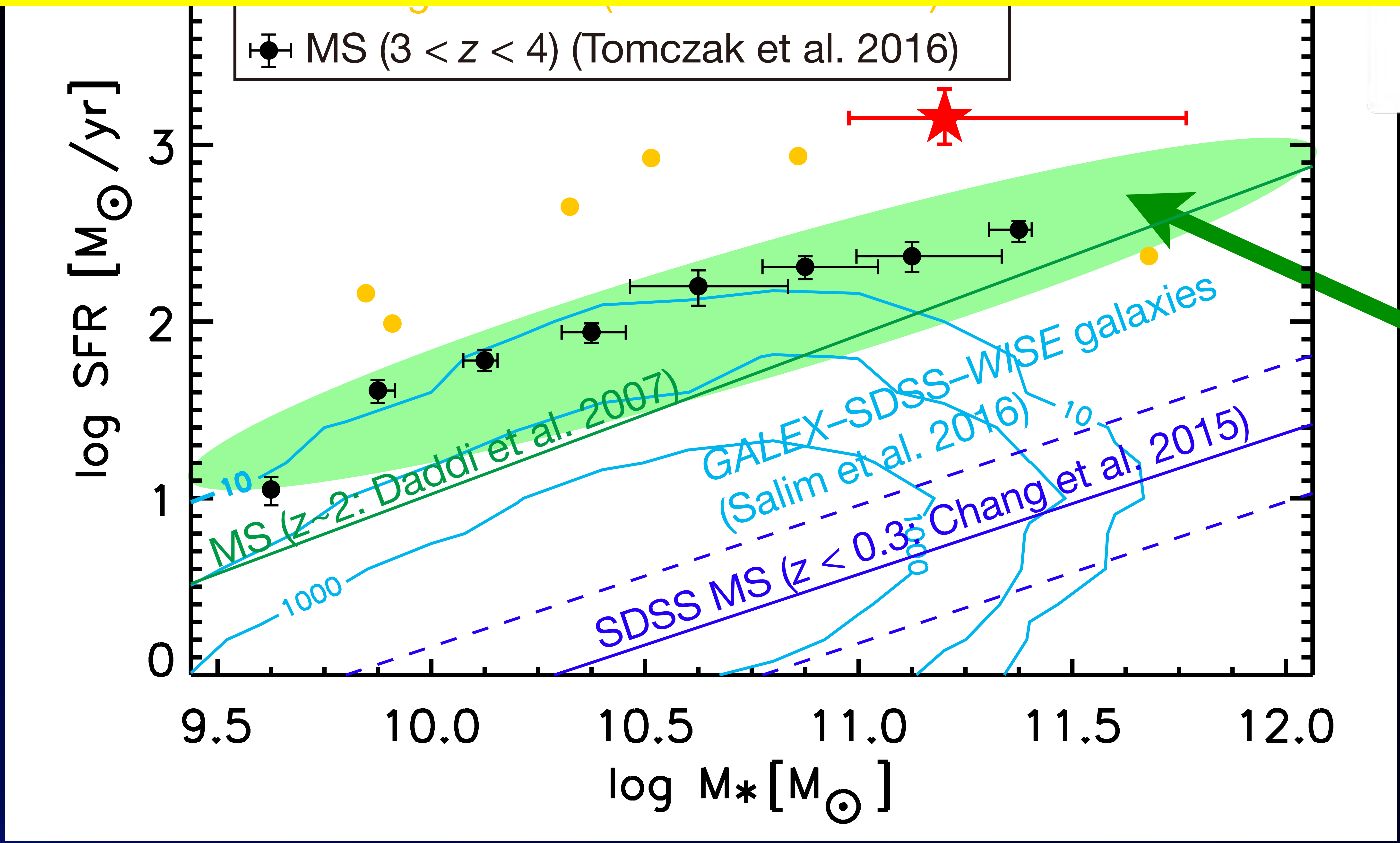


Main Sequence @ z ~4

Stellar mass vs. SFR

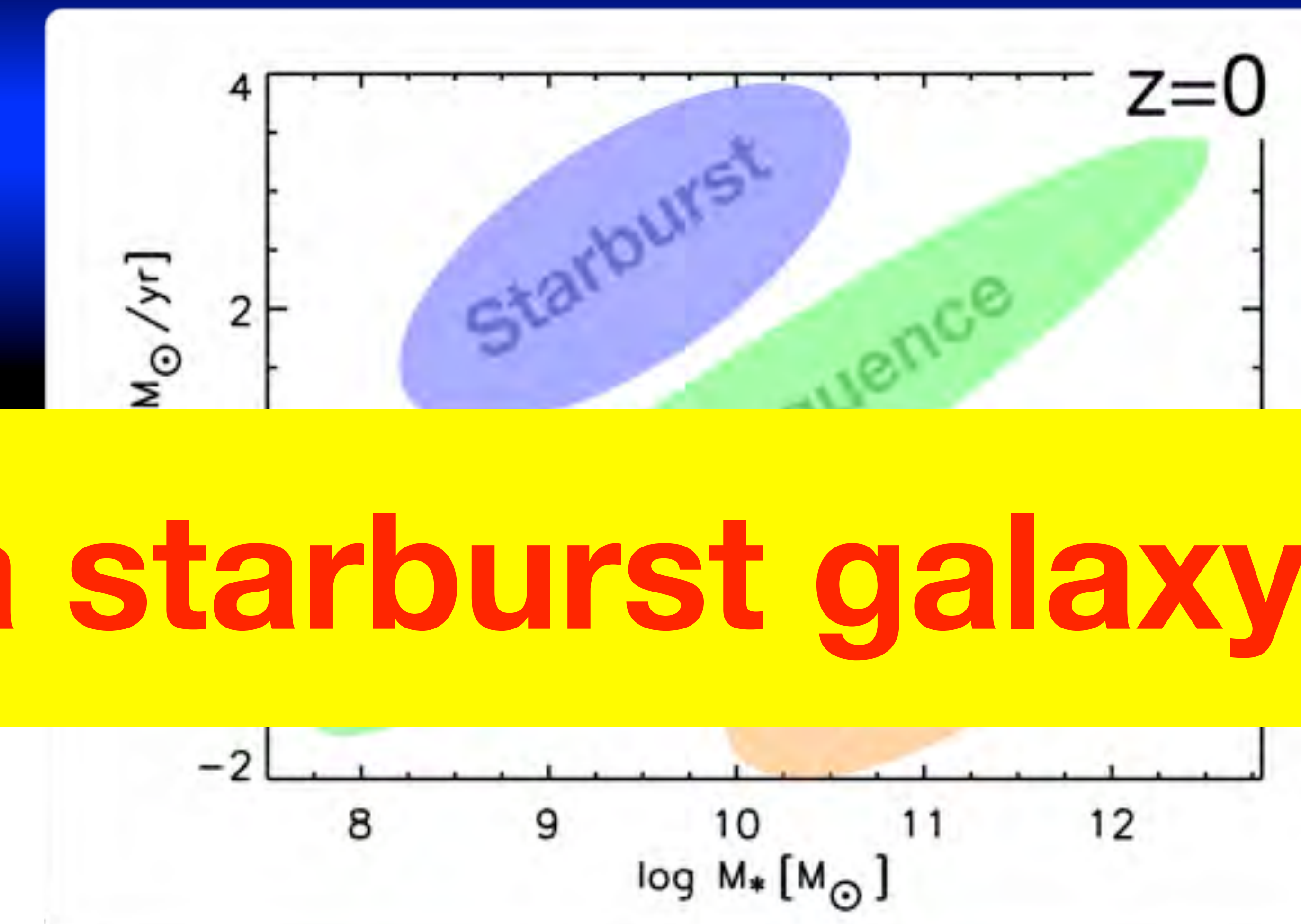


WISE1013 can be considered as a starburst galaxy



Main Sequence
@ z ~4

Stellar mass vs. SFR



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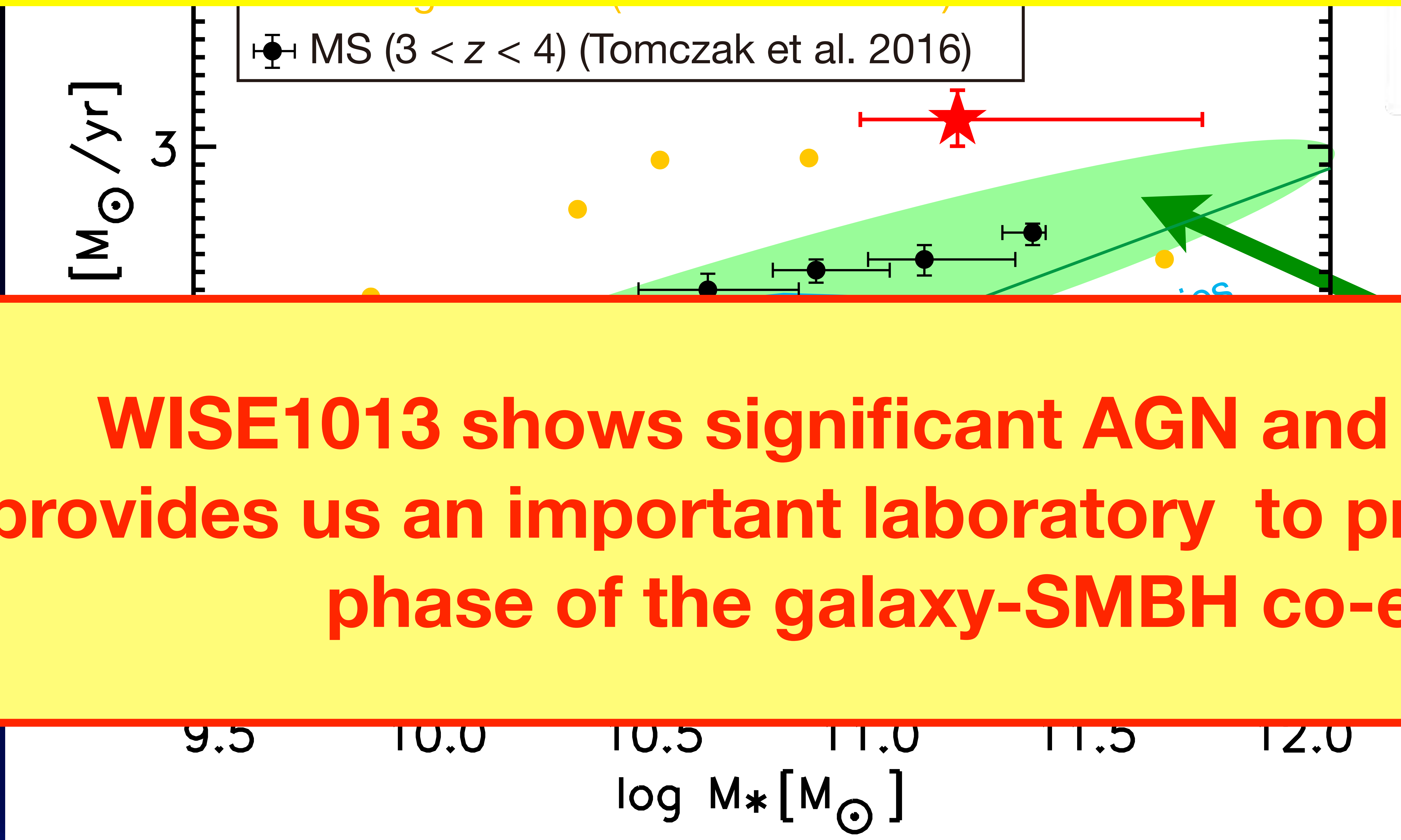

WISE1013 shows significant AGN and SF activity that provides us an important laboratory to probe the maximum phase of the galaxy-SMBH co-evolution

Summary

- ELIRGs are important population to understand co-evolution of galaxies and SMBHs

- Step: 1 Selection of candidates (DOGs selection)
  Step 2: Follow-up observations
  Step 3: Estimate L_{IR} based on the SED fitting

- **An ELIRG with L_{IR} = 2.2 ×10^{14} $L_{\odot}$ (z=3.7) is discovered!**


I ♥ DOGs