eROSITAとKOOLS-IFUのタッグで実現した宇宙の正午に輝くSuper-Eddingtonクエーサーの発見

Discovery of a super-Eddington quasar at cosmic noon

achieved by the synergy between eROSITA ✖ KOOLS-IFU

Toba et al. 2024b, PASJ, in press.

国立天文台 NAOJ National Astronomical Observatory of Japan

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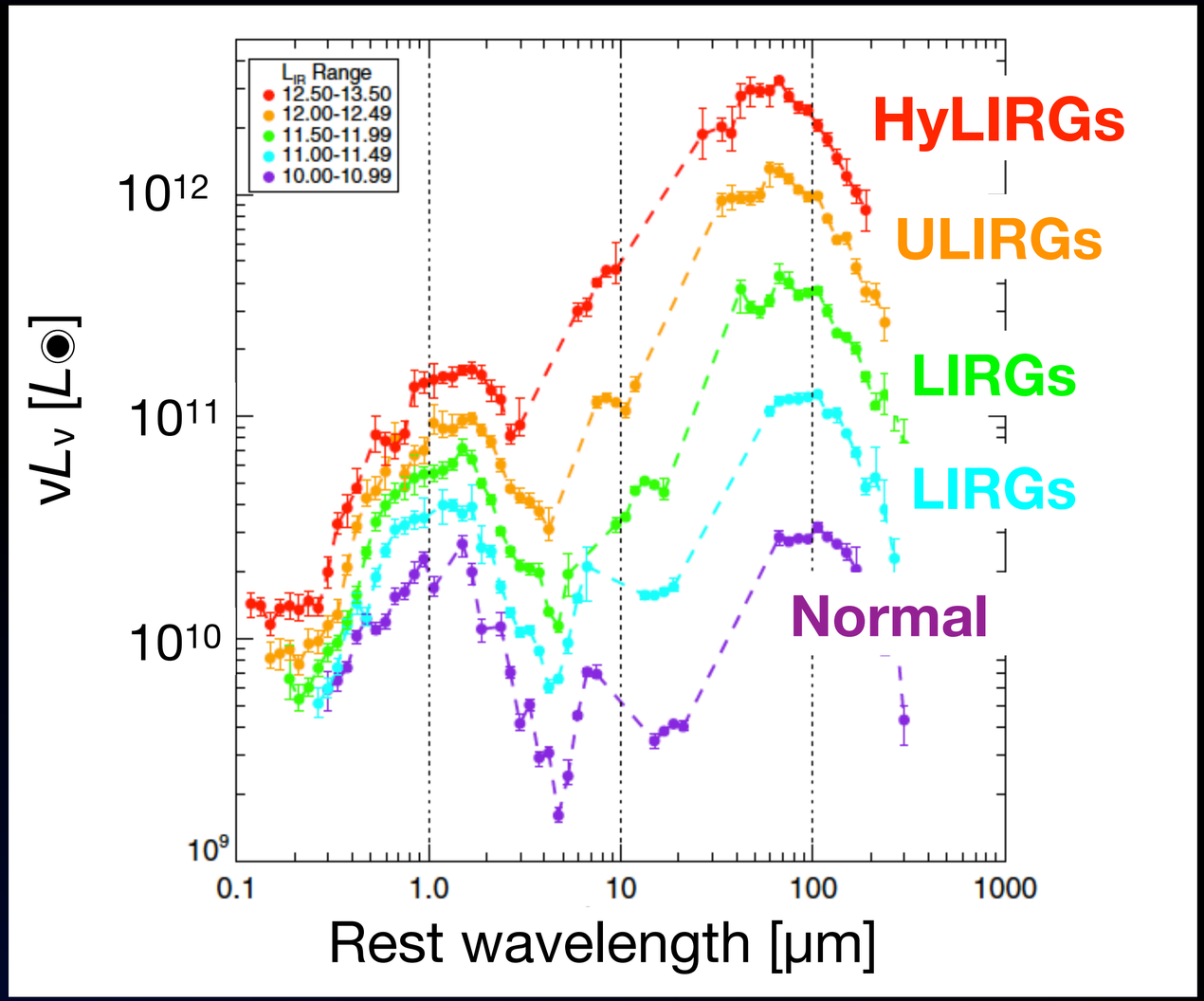
Introduction

- Galaxy classification based on IR luminosity
- Co-evolution of galaxies and SMBH
- Importence of HyLIRGs

Galaxy classification based on IR luminosity

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



Lee et al. (2013)

Ultra Luminous InfRared Galaxies (ULIRGs)

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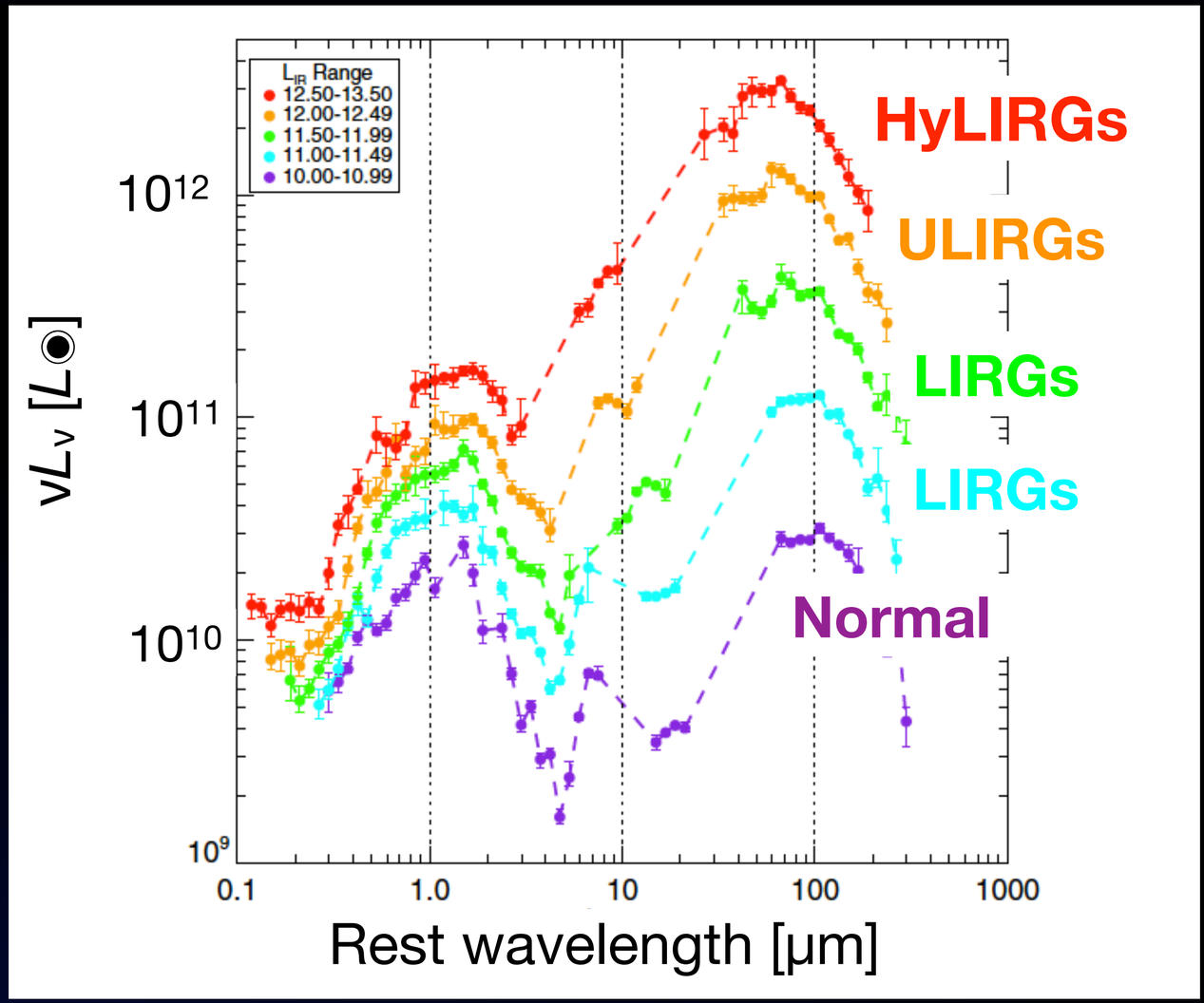

Lee et al. (2013)

Hyper Luminous InfRared Galaxies (HyLIRGs)

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LIRGs	11 - 12
ULIRGs	12 -13
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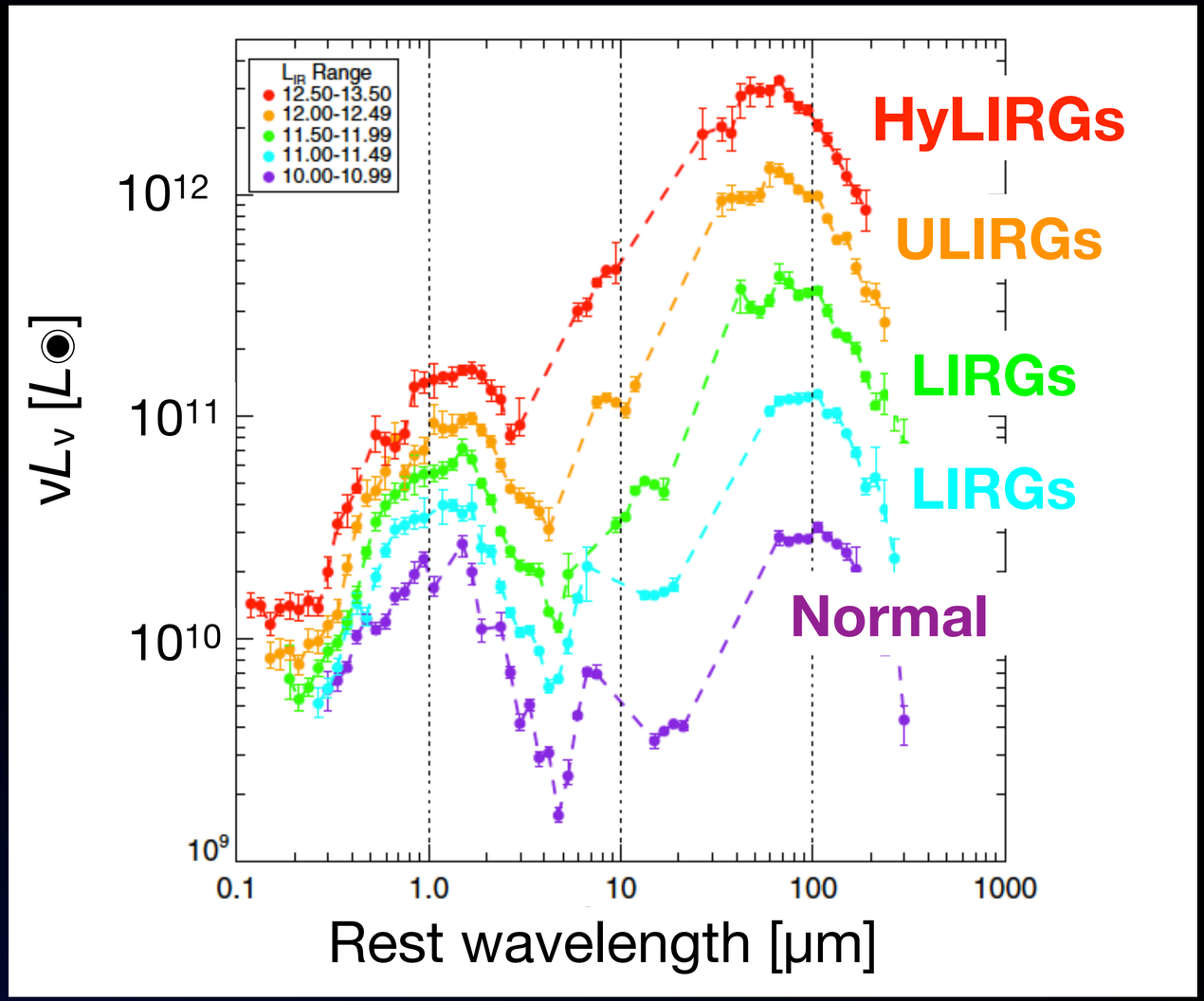

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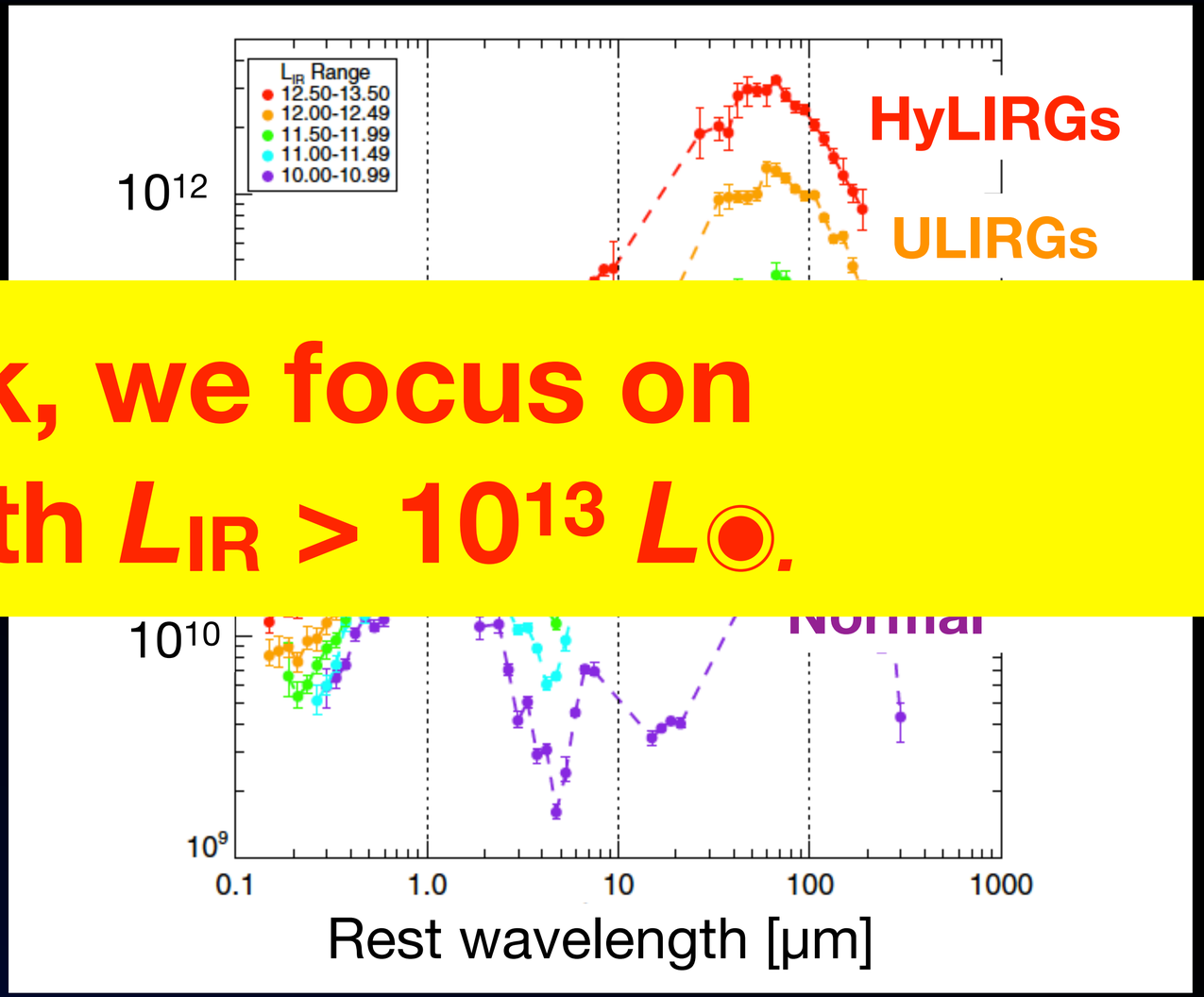


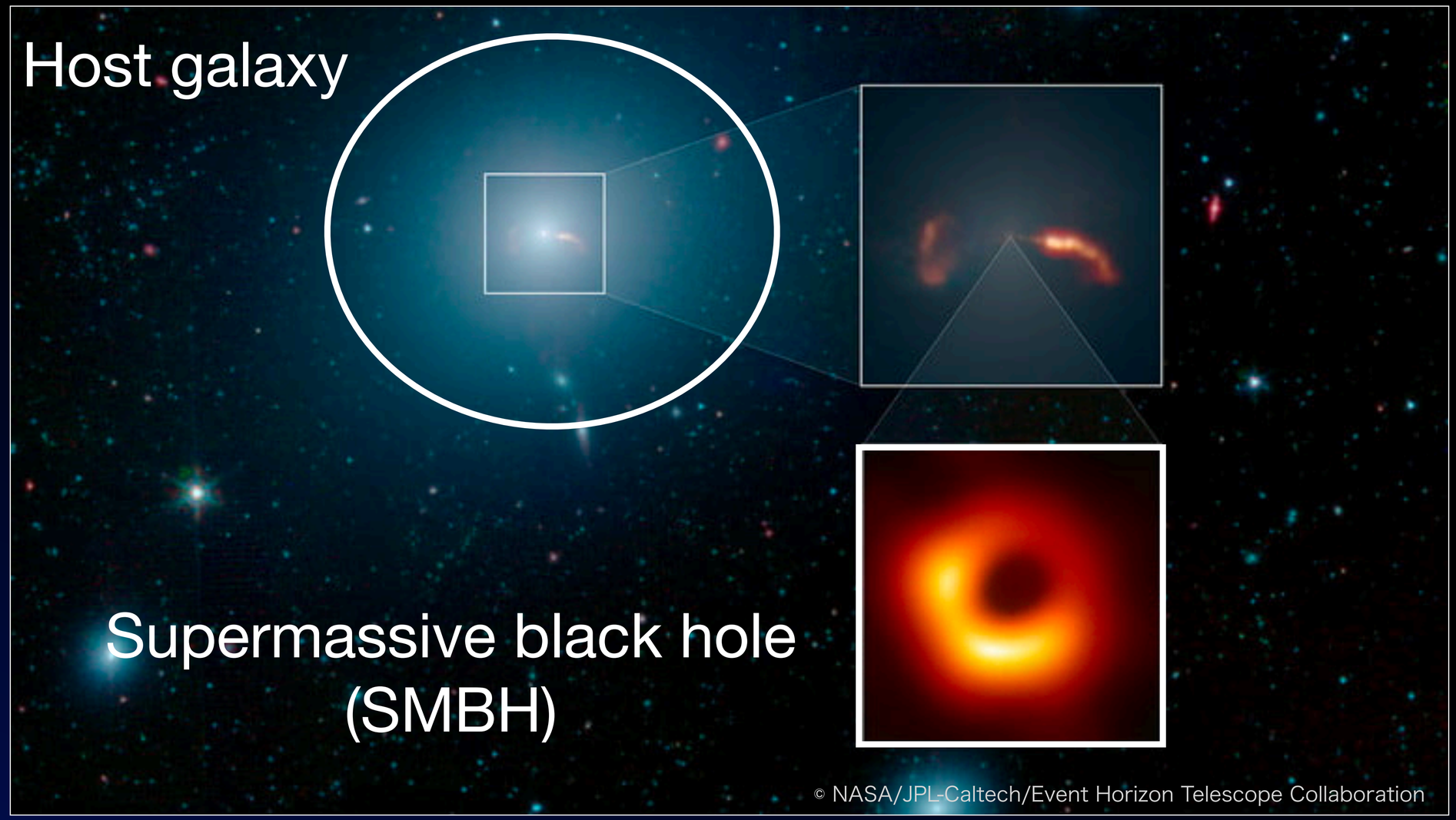
Lee et al. (2013)

In this work, we focus on HyLIRGs with $L_{IR} > 10^{13}\ L_\odot$.

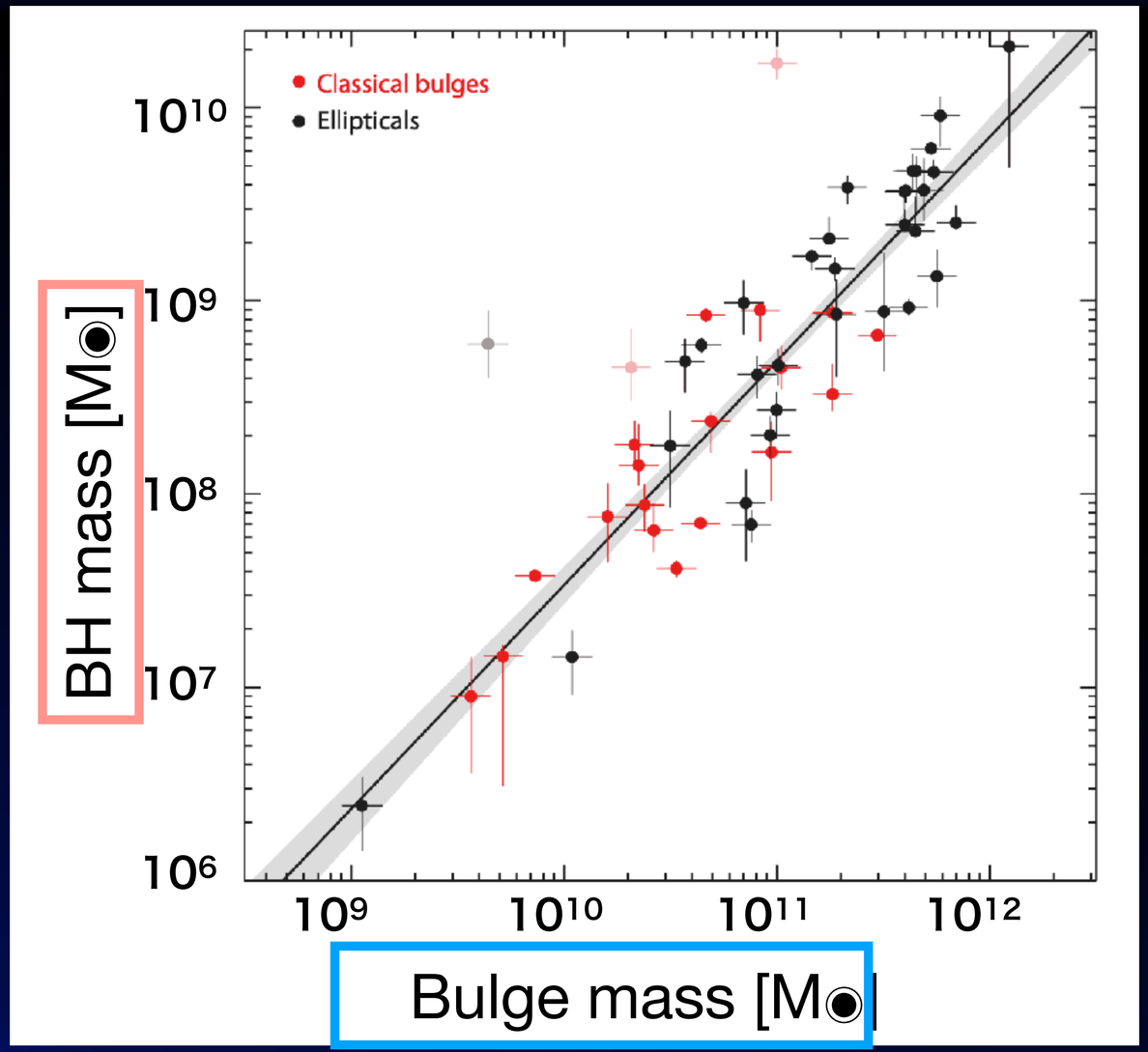
A mysterious relation between galaxies and SMBHs

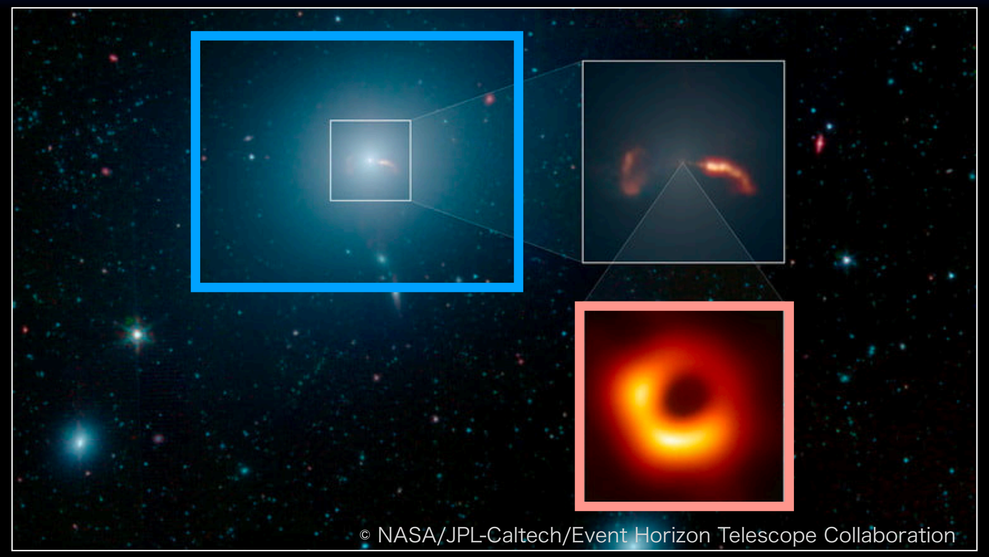
What is interesting about finding HyLIRGs?

A mysterious relation between galaxies and SMBHs



A mysterious relation between galaxies and SMBHs



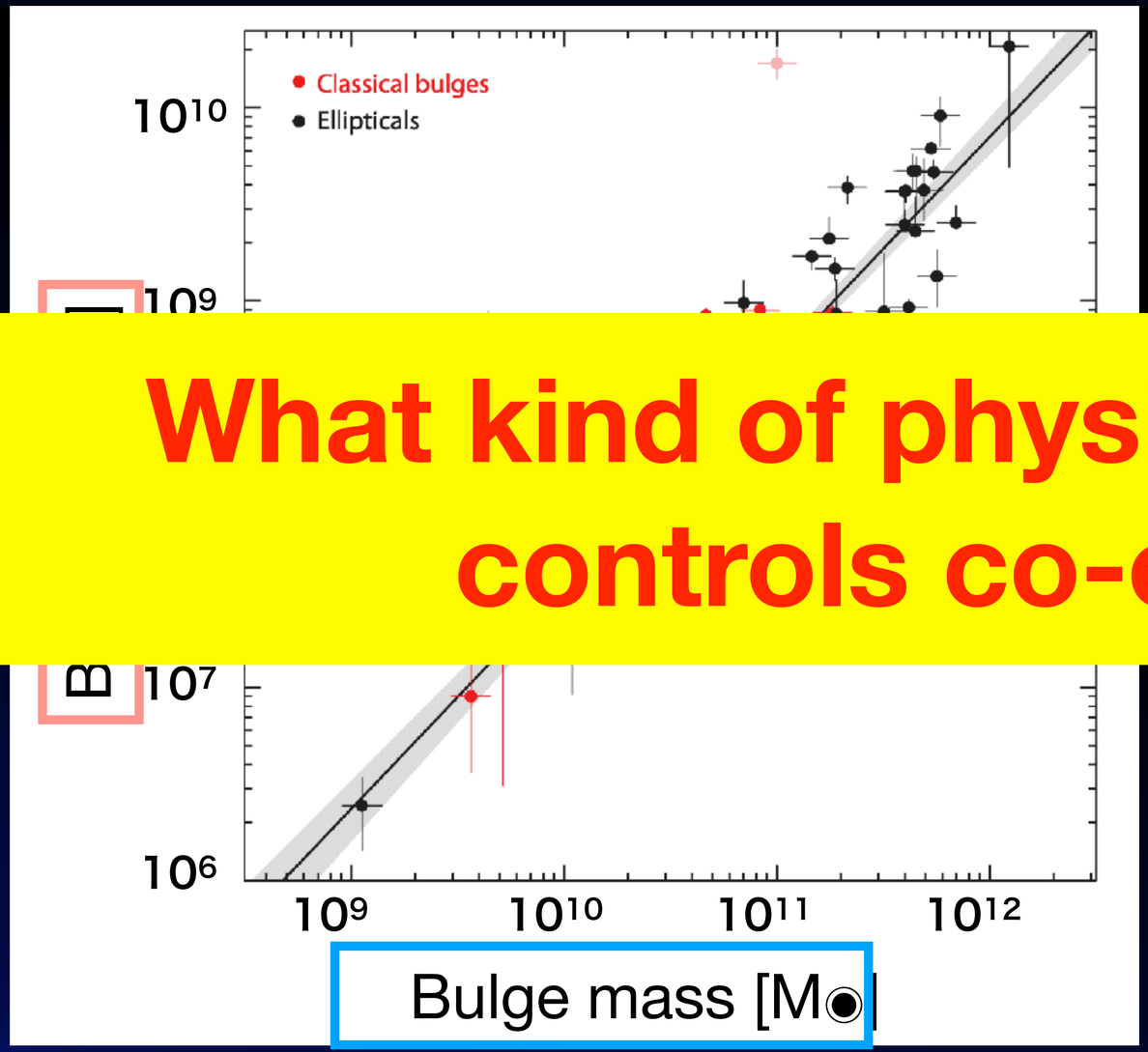


M_{SMBH} ~ 1/1000 M_{bulge}

※ The physical scale of the two is different by an order of 10!

Kormendy & Ho (2013)

A mysterious relation between galaxies and SMBHs



What kind of physical mechanism controls co-evolution?

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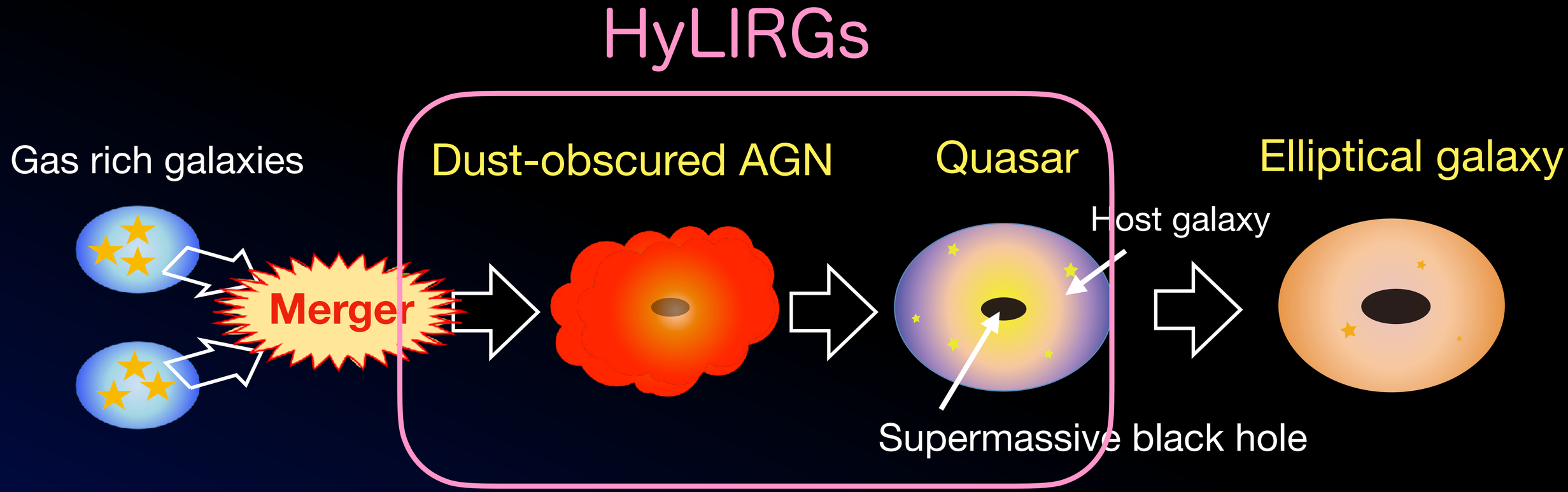
Kormendy & Ho (2013)

What is the importance of finding HyLIRGs?



See e.g., Hopkins et al. (2008), Dey et al. (20009).

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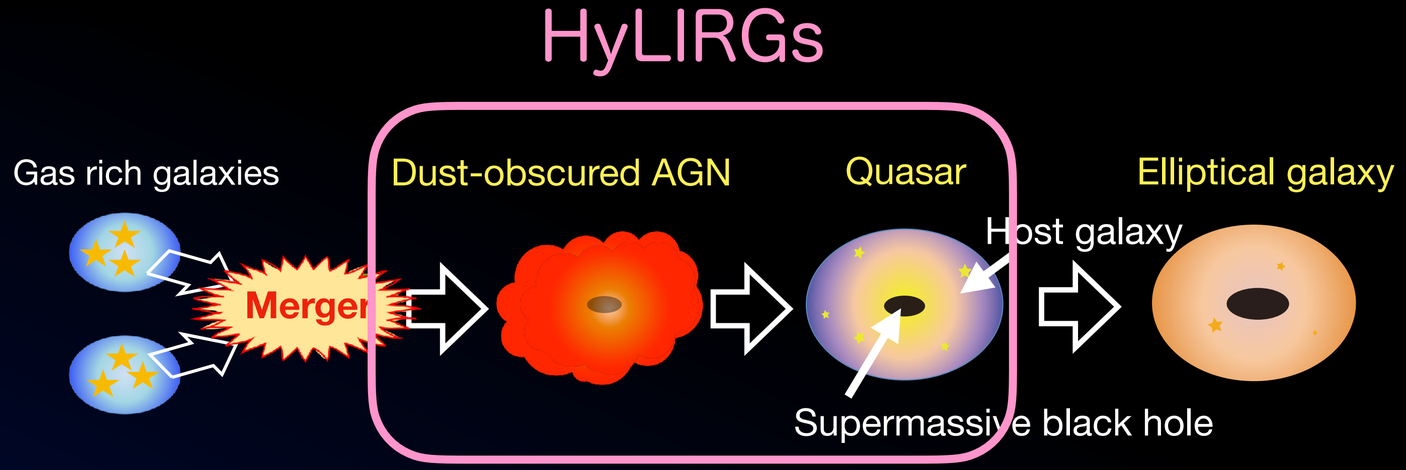
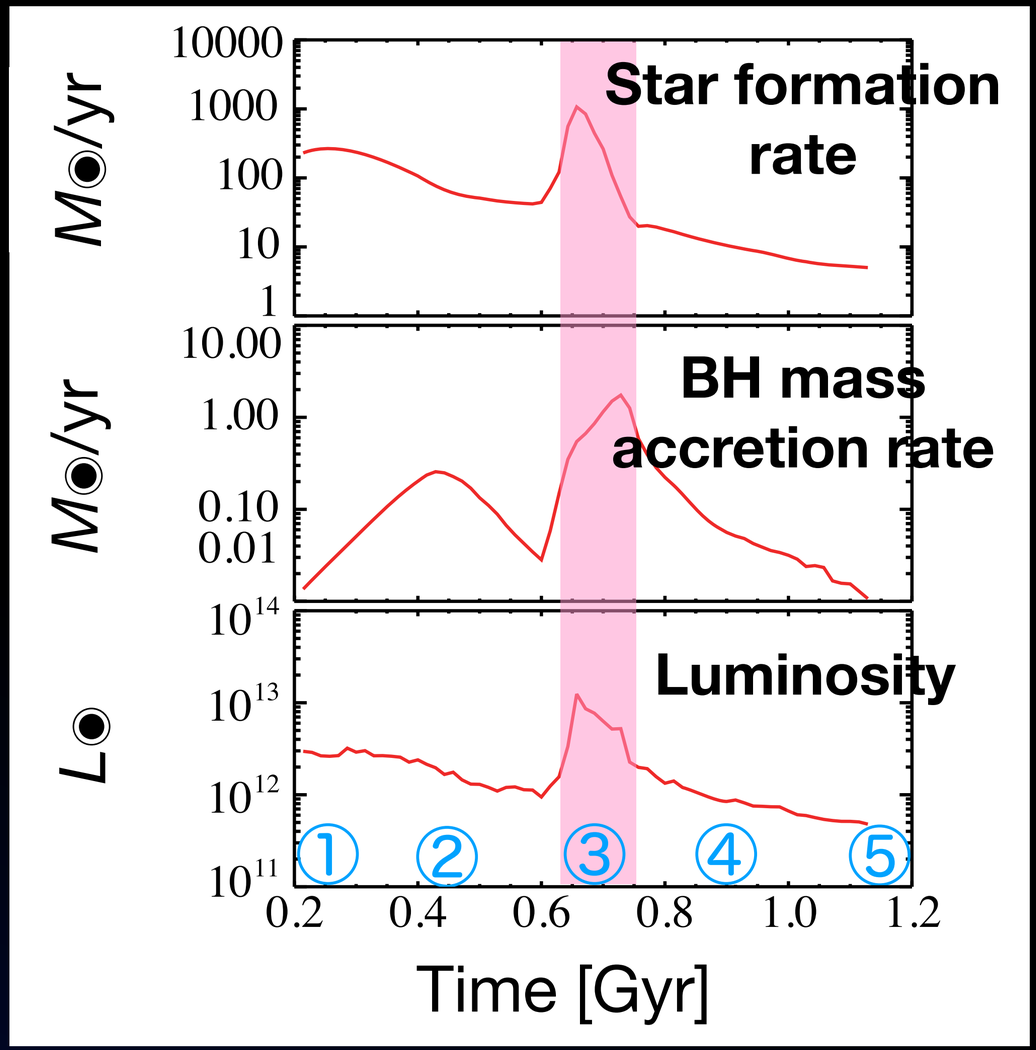


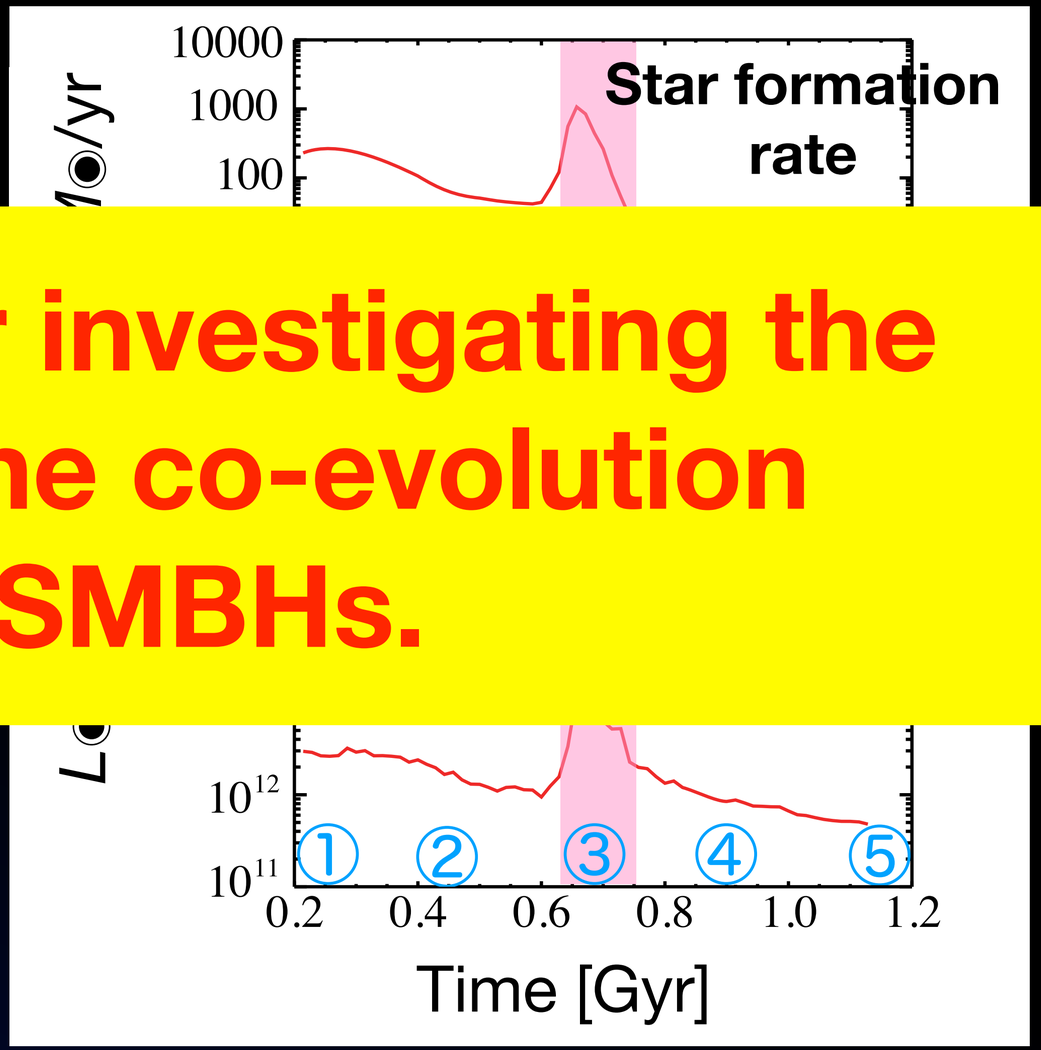
Narayanan et al. (2010) (see also e.g., Yutani, **Toba** et al. 2022).



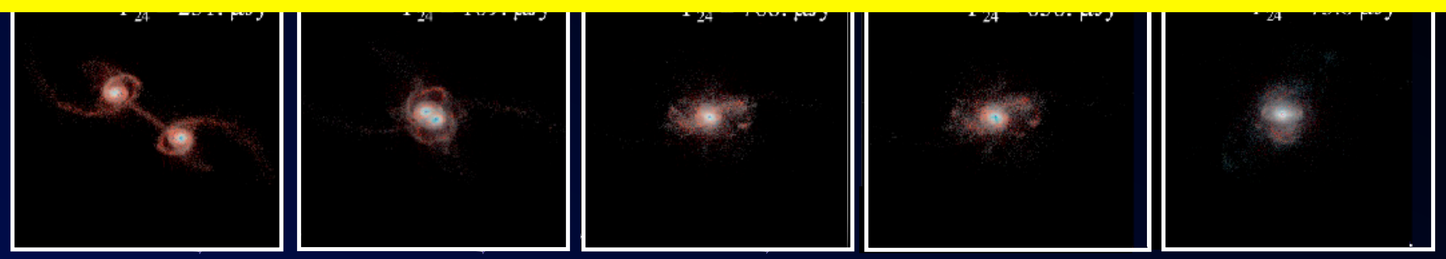
What is the importance of finding HyLIRGs?

HyLIRGs

Gas rich galaxies | Dust-obscured AGN | Quasar | Elliptical galaxy



HyLIRGs are essential for investigating the "maximum phase" of the co-evolution of galaxies and SMBHs.



Narayanan et al. (2010) (see also e.g., Yutani, **Toba** et al. 2022).

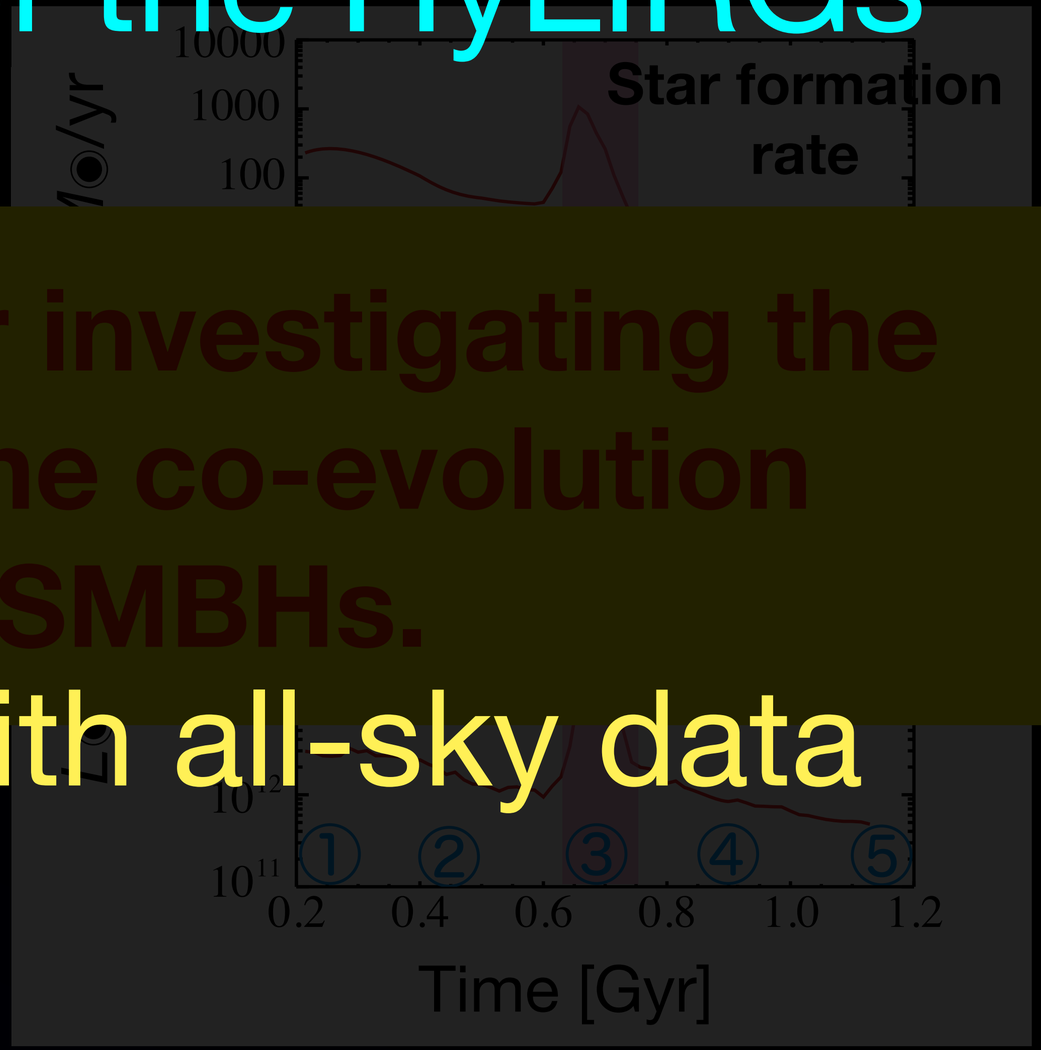
What is the importance of finding HyLIRGs?

The volume density of the HyLIRGs is extremely low..😢

HyLIRGs are essential for investigating the "maximum phase" of the co-evolution of galaxies and SMBHs.

A systematic search with all-sky data

Narayanan et al. (2010) (see also e.g., Yutani, **Toba** et al. 2022).

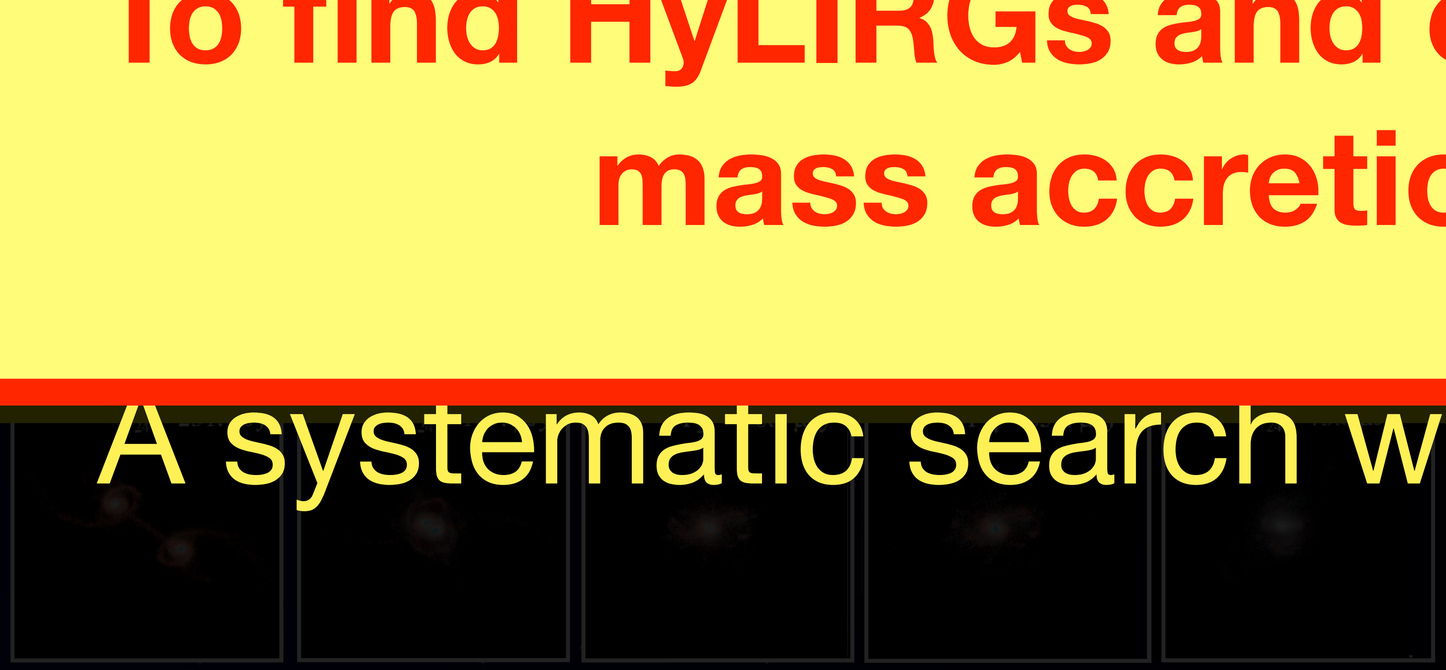


What is the importance of finding HyLIRGs?

The volume density of the HyLIRGs

To find HyLIRGs and confirm the BH mass accretion rate.

A systematic search with all-sky data



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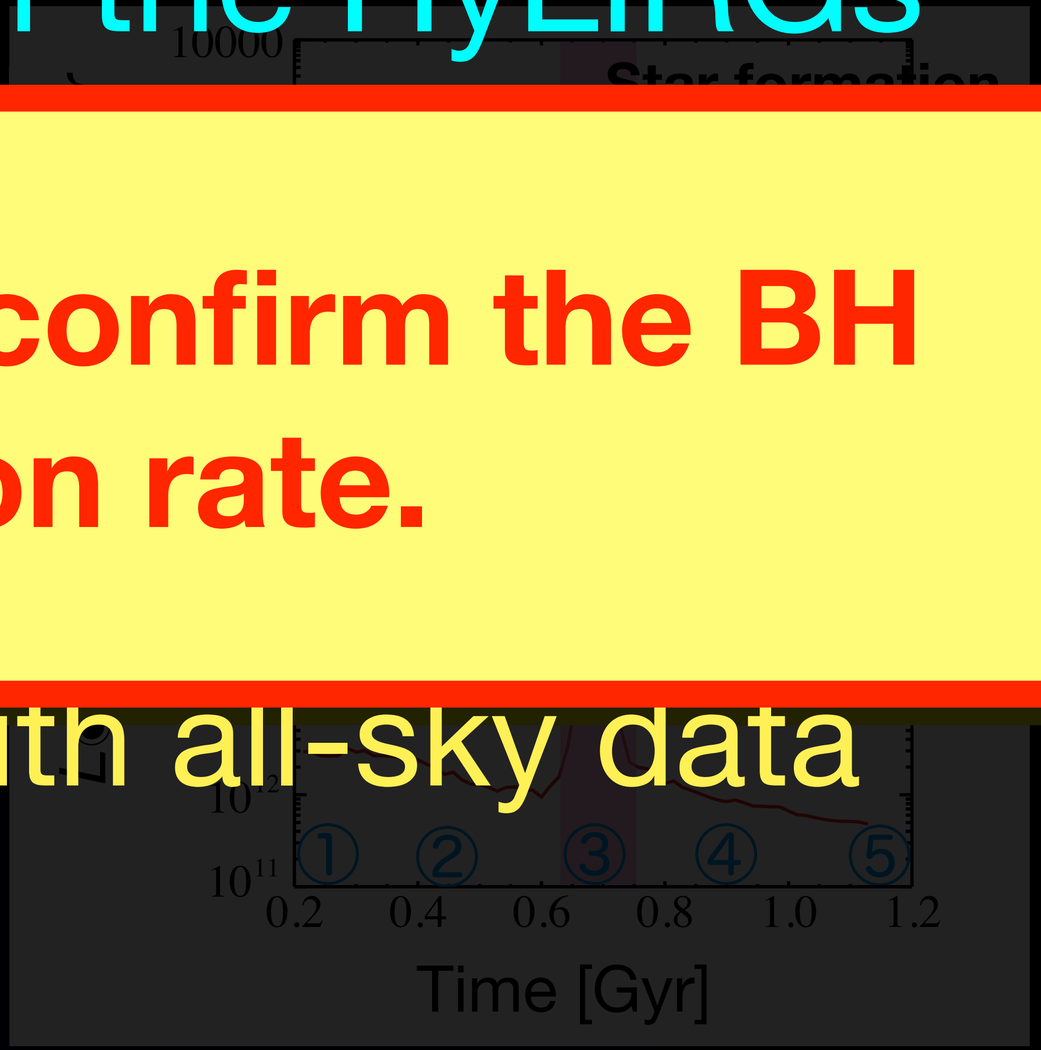
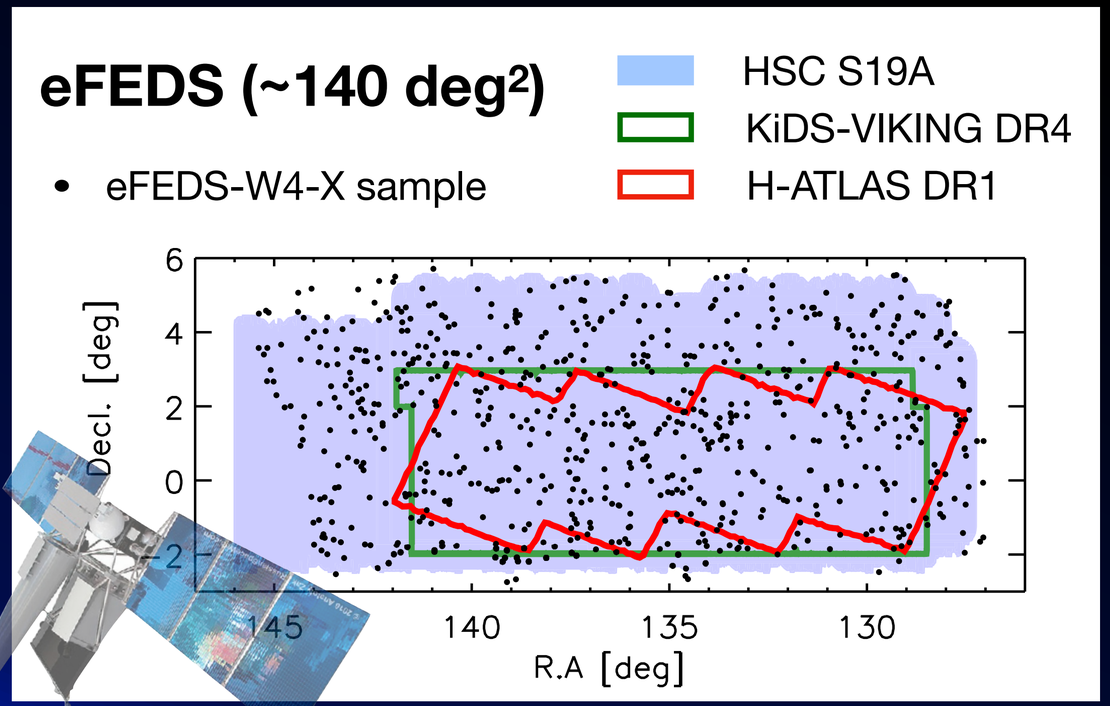


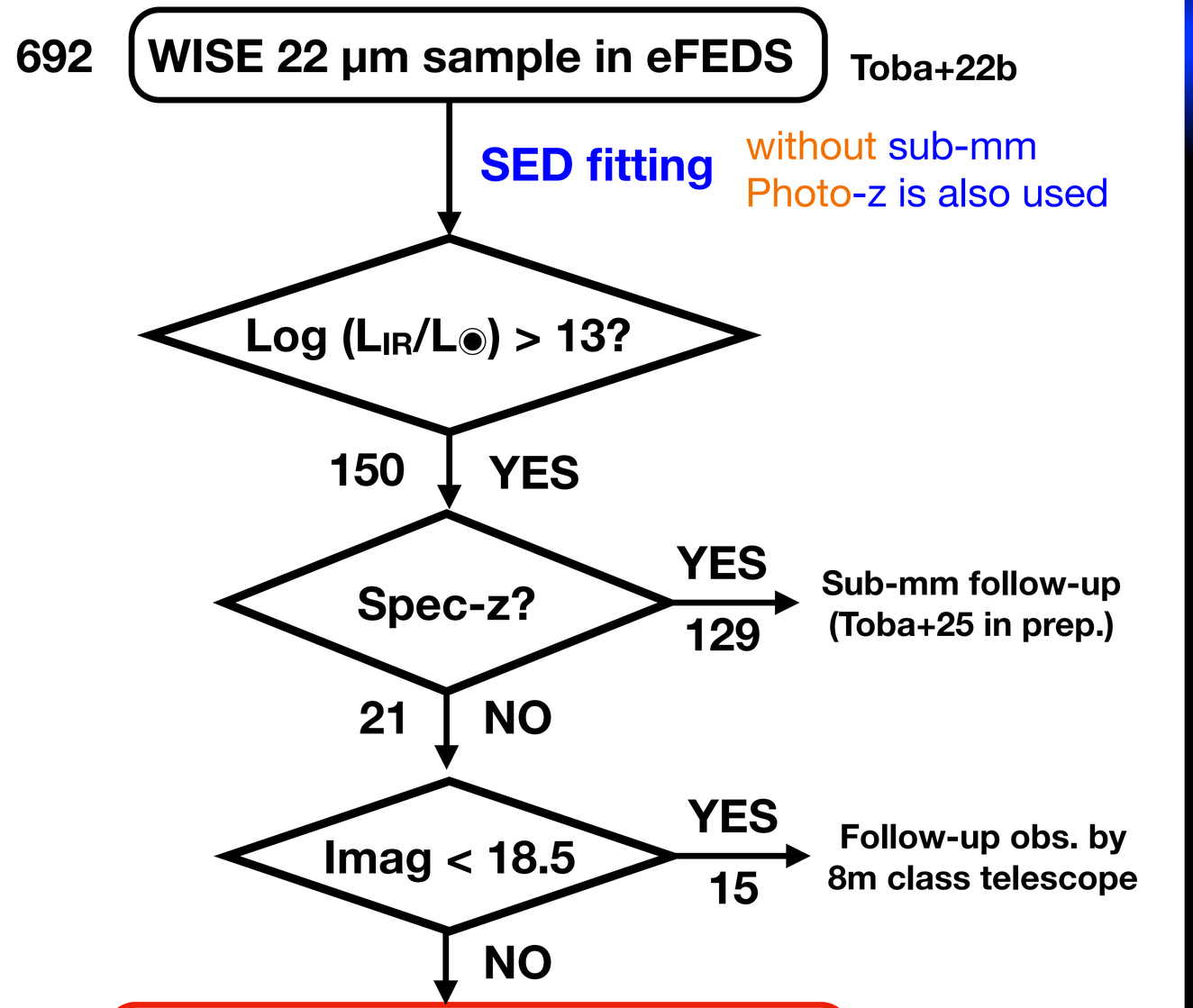
Data and analysis

- Sample selection
- Data set
- Spectral fitting method
- SED fitting method

Sample selection

- From 27,369 X-ray sources, 692 WISE 22 μm sources were studied in Toba+22.
- From Toba+22, 21 sources were selected as HyLIRGs candidates, and **6 objects were targeted for KOOLS-IFU observations.**





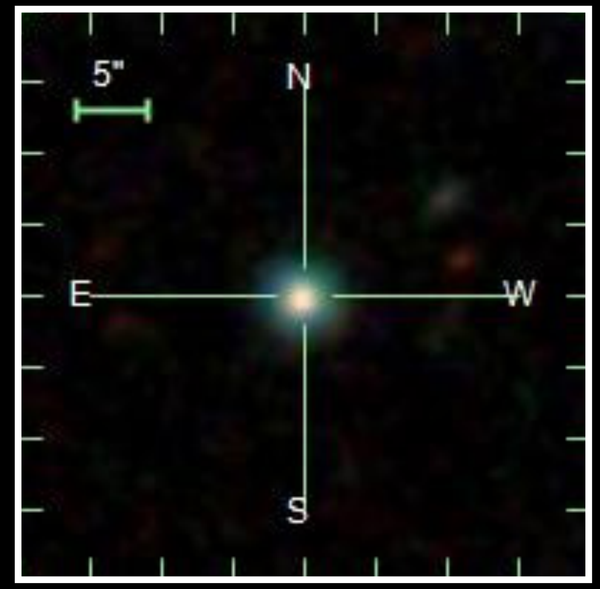
Observations and data reduction

Observations with KOOLS-IFU

Dates	Grism	Exp. Time [s]
Jan. 25, 2023	VPH-blue (4100-8900 Å) R ~ 500	7200
Jan. 27, 2023		3600
Feb. 13, 2024		600
Dec. 12, 2024		4200

~4.3 hours (in total)

SDSS image



Data reduction

- The data reduction tool (as of April 11, 2024) developed by Iwamuro-san is used to produce a 1D spectrum.

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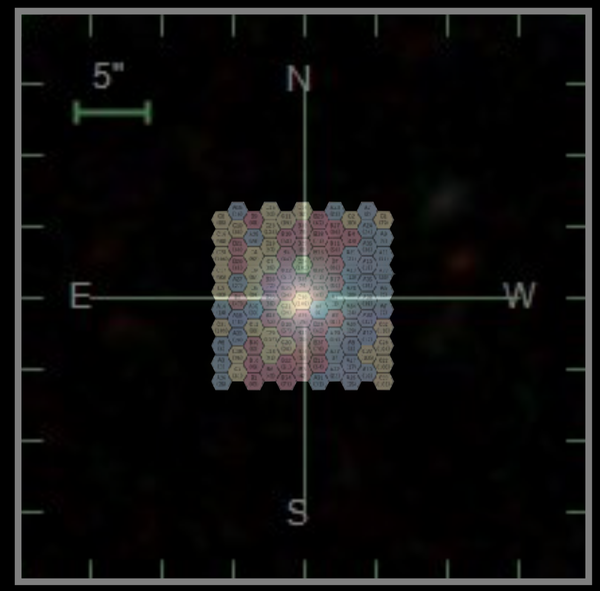

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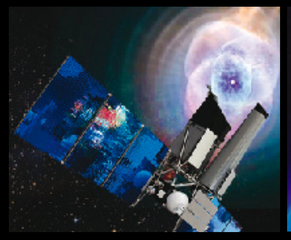
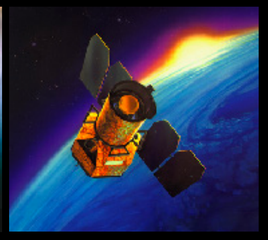
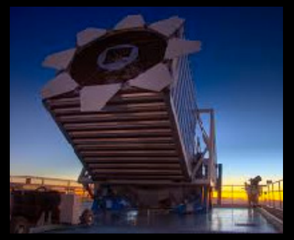
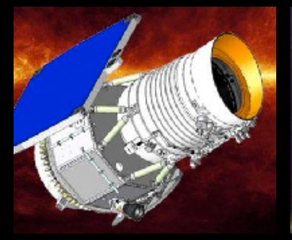
Multi-wavelength dataset

	X-ray	UV	optical	near-IR	mid-IR	far-IR / sub-mm	
Instrument	eROSITA	GALEX	SDSS	UKIDSS	WISE	AKARI	SCUBA-2
Band	2-10 keV	FUV NUV	u, g, r, i, z	Y, J, H, K	3.4, 4.6, 12, 22	90	450, 850
tracer	AGN		stellar population		hot dust	warm/cold dust	

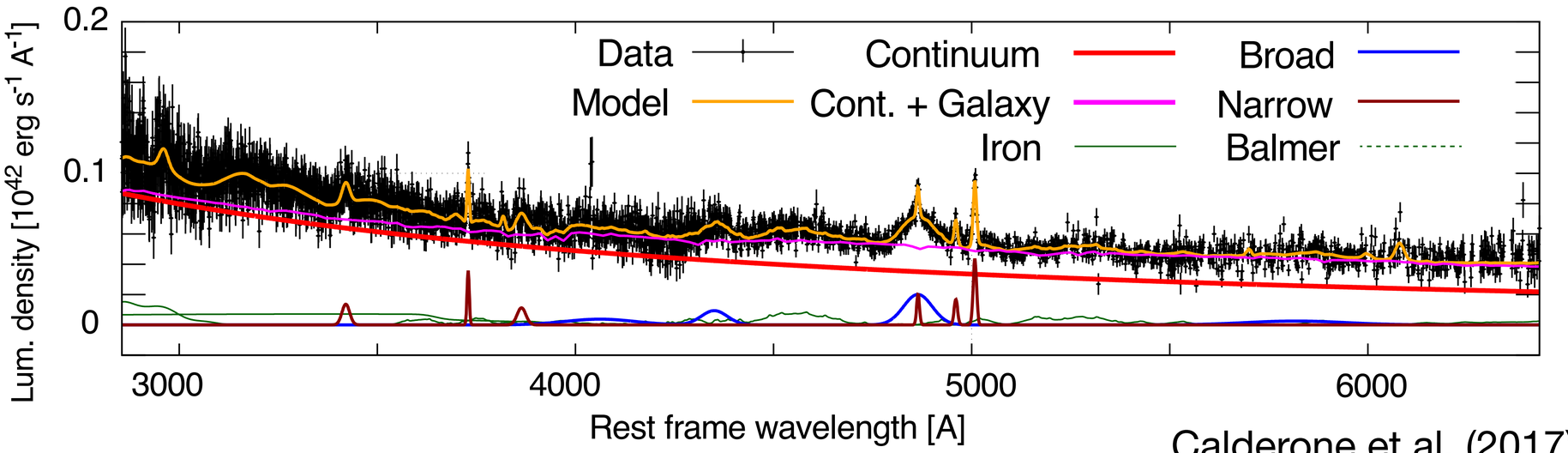






Spectral fitting

QSFit

$$\lambda_{Edd} = \frac{L_{bol}}{L_{Edd}} \propto \frac{L_{bol}}{M_{BH}}$$



Calderone et al. (2017)

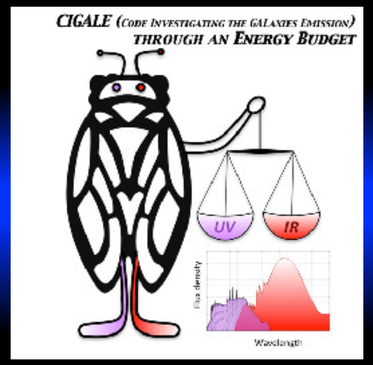
$$M_{\rm BH}\,[M_\odot] = 10^{6.86}\left[\frac{\rm FWHM\,(MgII)}{1000\,{\rm km\,s^{-1}}}\right]^2\left[\frac{\lambda L_\lambda\,(3000\,\text{Å})}{10^{44}\,{\rm erg\,s^{-1}}}\right]^{0.5}$$

Vestergaard & Osmer (2009)

$$L_{\rm bol}^{\rm AGN} = (5.2 \pm 0.2) \times \lambda L_\lambda\,(3000\,\text{Å})$$

Vestergaard & Osmer (2009)

SED fitting



Code Investigating GALaxy Emission

Boquien et al. (2019)

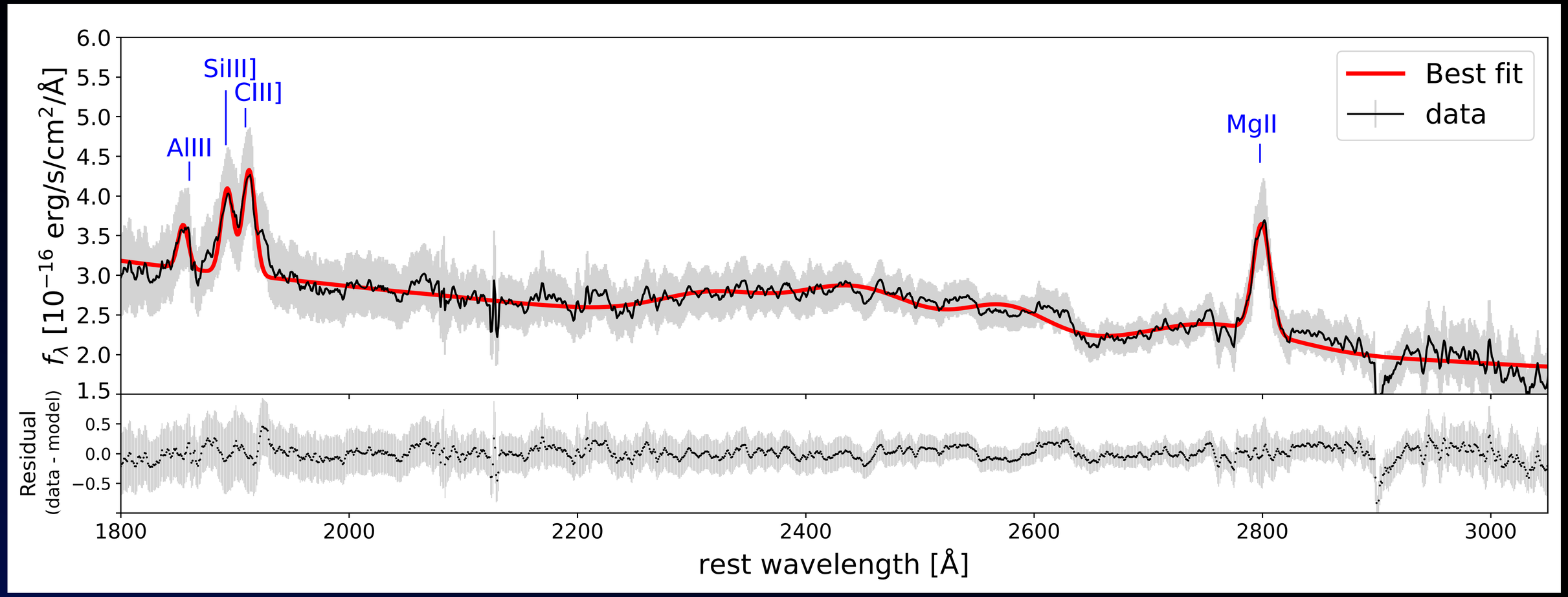
- CIGALE performs the SED fitting by considering the energy balance between UV/optical and IR.
- We need to assume, e.g., star-formation history, single stellar population, and AGN dust model.
- CIGALE tells us e.g., stellar mass, SFR, dust extinction of galaxies.

Parameter	Value
Delayed SFH with recent starburst (Ciesla et al. 2017)	
$\tau_{\rm main}$ [Gyr]	1.0, 4.0, 8.0, 12
age [Gyr]	0.5, 1.0, 1.5, 2.0
age of burst [Myr]	10, 50, 100
R_sfr	1, 5, 10
SSP (Bruzual & Charlot 2003)	
IMF	Chabrier 2003
Metallicity	0.02
Nebular emission (Inoue 2011)	
$\log U$	-3.0, -2.0, -1.0
Dust attenuation (Calzetti et al. 2000; Leitherer et al. 2002)	
$E(B-V)_{\rm lines}$	0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 1.0
AGN Emission (Stalevski et al. 2012; Stalevski et al. 2016)	
$\tau_{9.7}$	3, 7, 11
p	0.5, 1.5
q	0.5, 1.5
Δ [°]	40
$R_{\rm max}/R_{\rm min}$	30
θ [°]	0, 10, 20
$f_{\rm AGN}$	0.4, 0.5, 0.6, 0.7, 0.8, 0.9
Dust Emission (Draine et al. 2014)	
$q_{\rm PAH}$	2.50, 5.26, 6.63, 7.32
$U_{\rm min}$	10.0, 50.0
α	1.0, 1.5, 2.0
γ	0.01, 0.1, 1.0
X-ray Emission (Yang et al. 2022)	
AGN photon index (Γ)	2.0
$\alpha_{\rm OX}$	-2.0, -1.9, -1.8, -1.7
$\lvert\Delta\alpha_{\rm OX}\rvert_{\rm max}$	0.5

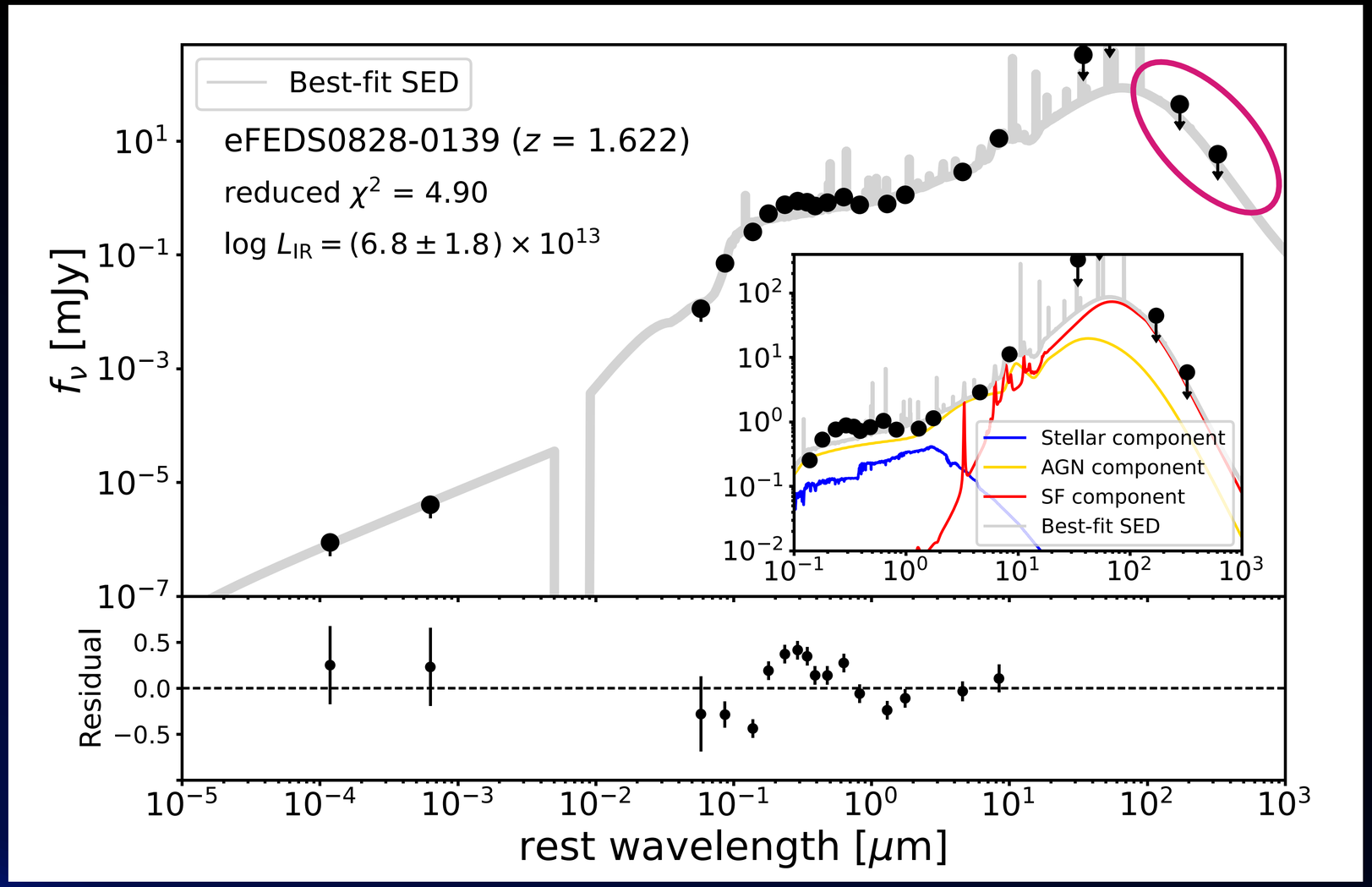
Results and discussion

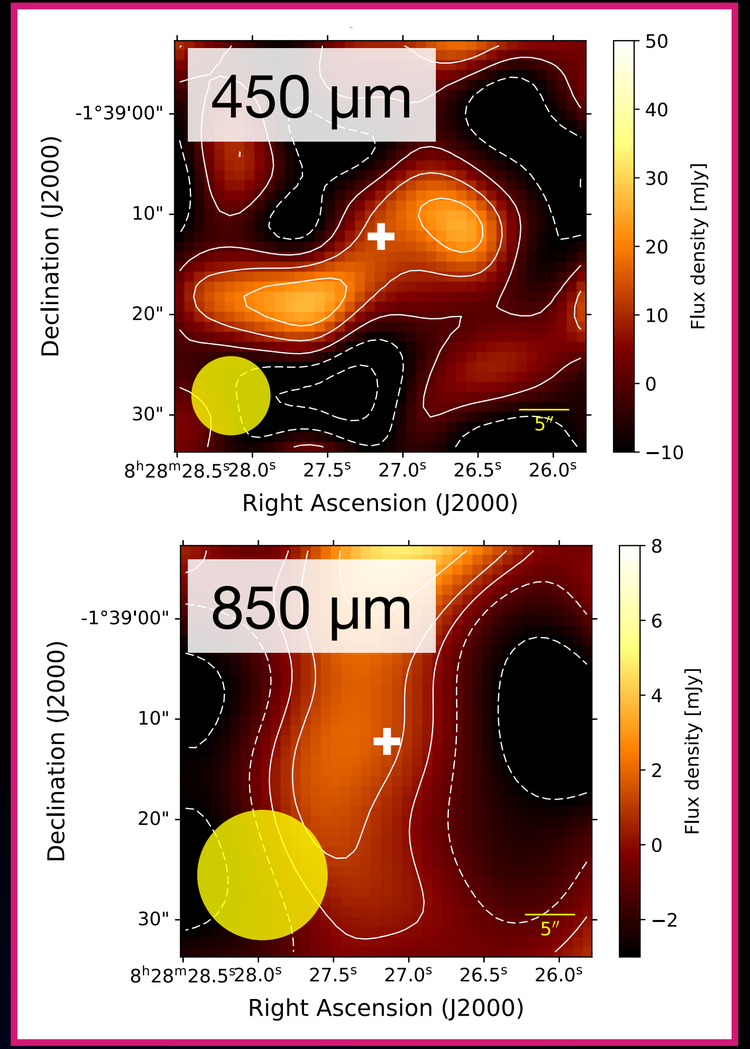
- Results of the spectral fitting
- Results of the SED fitting
- Discovery of supper-Eddington quasar

Result of the spectral fitting



Result of the SED fitting





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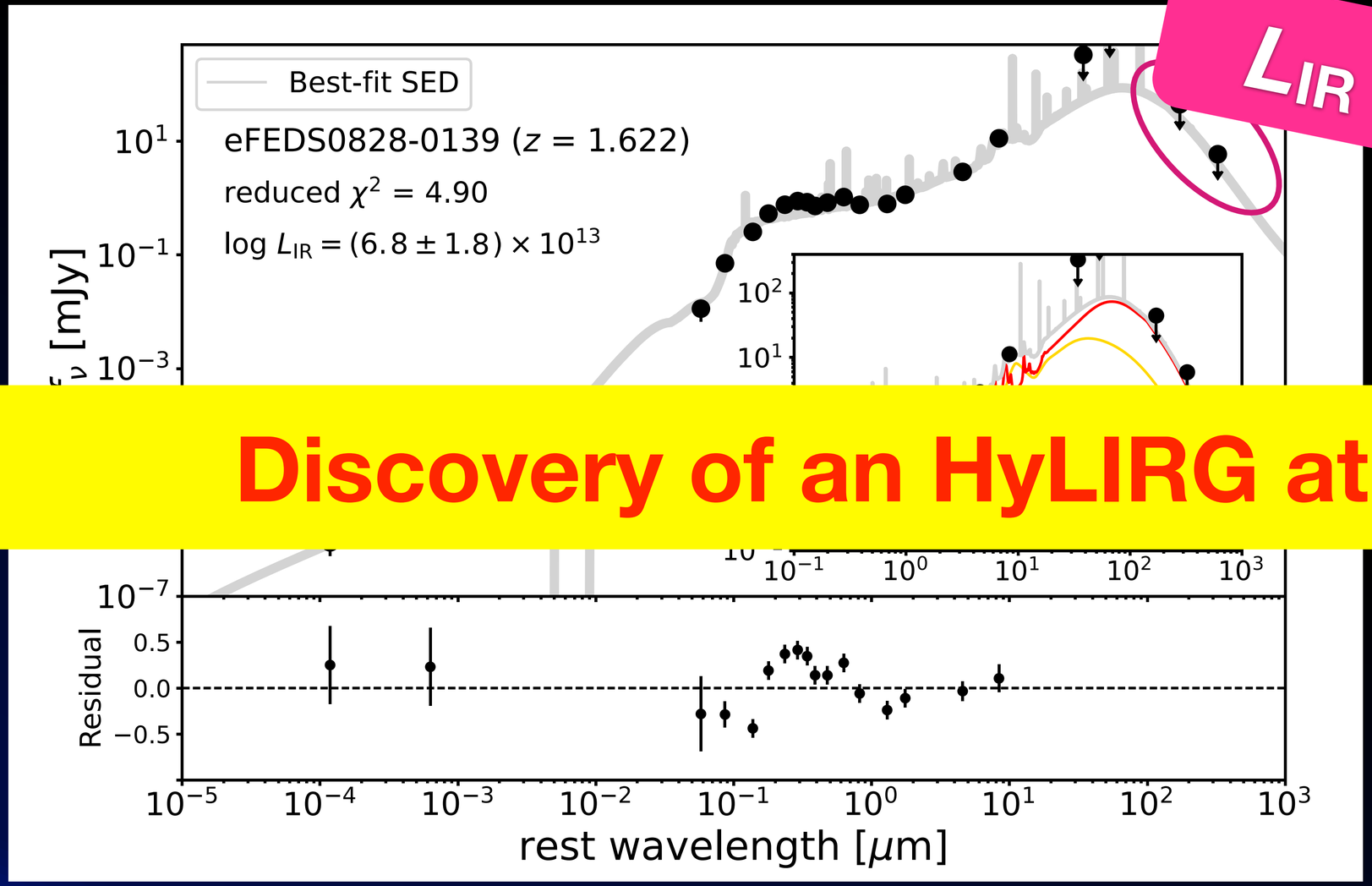
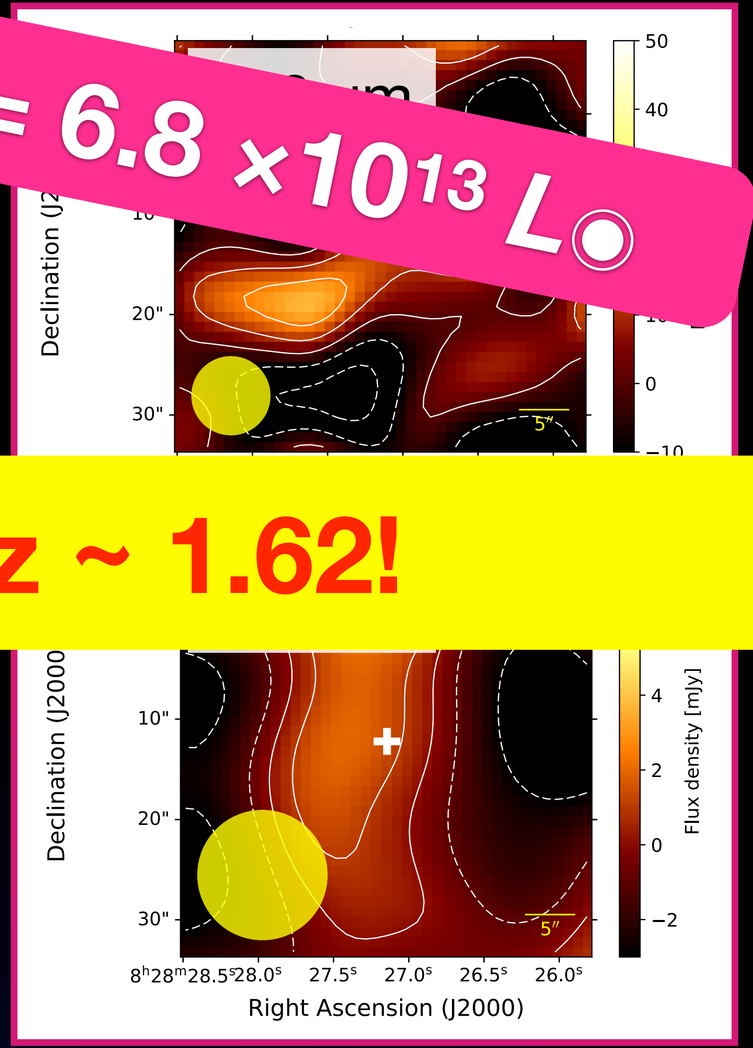
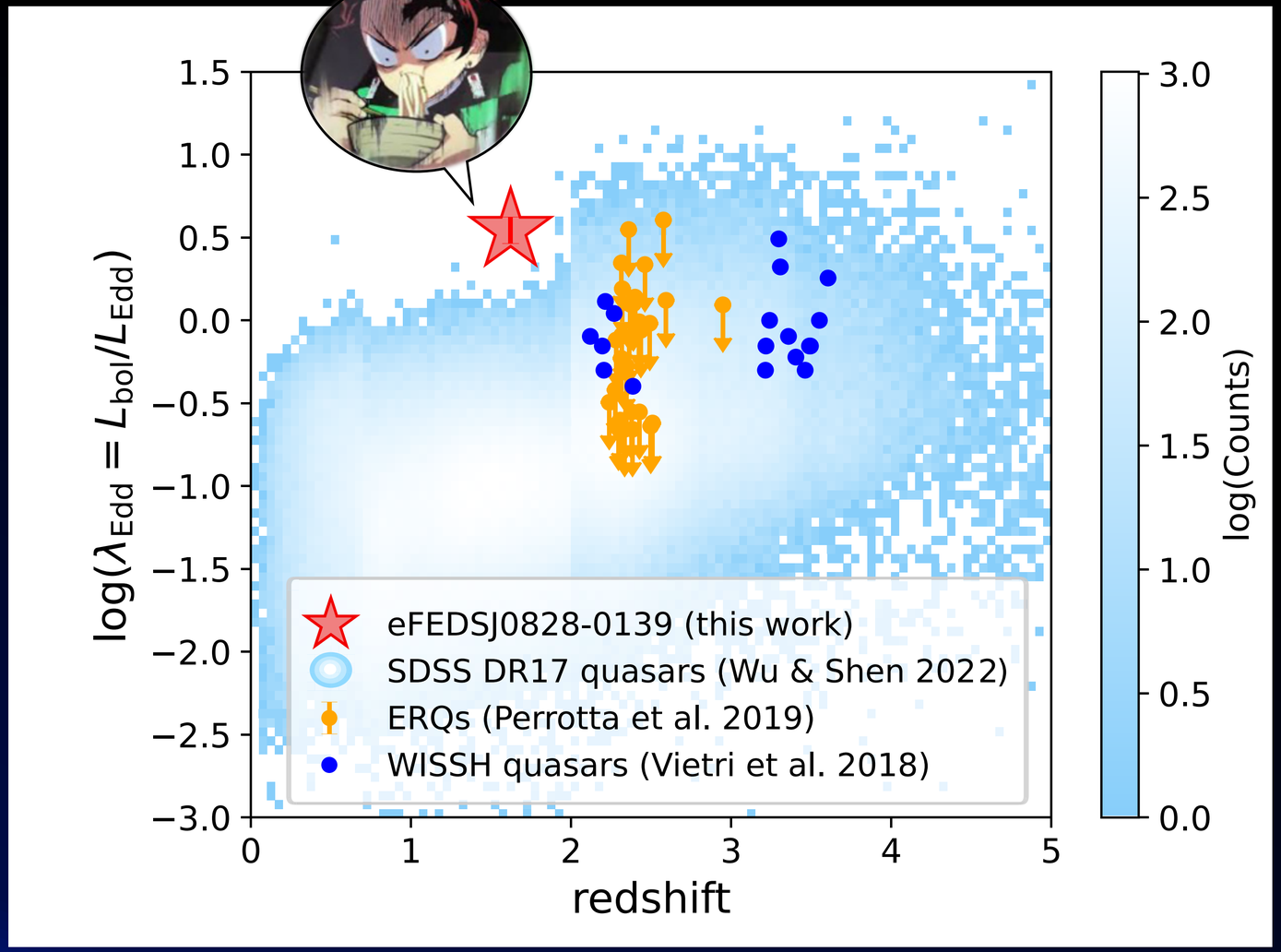


$L_{IR} = 6.8 \times 10^{13}\ L_\odot$



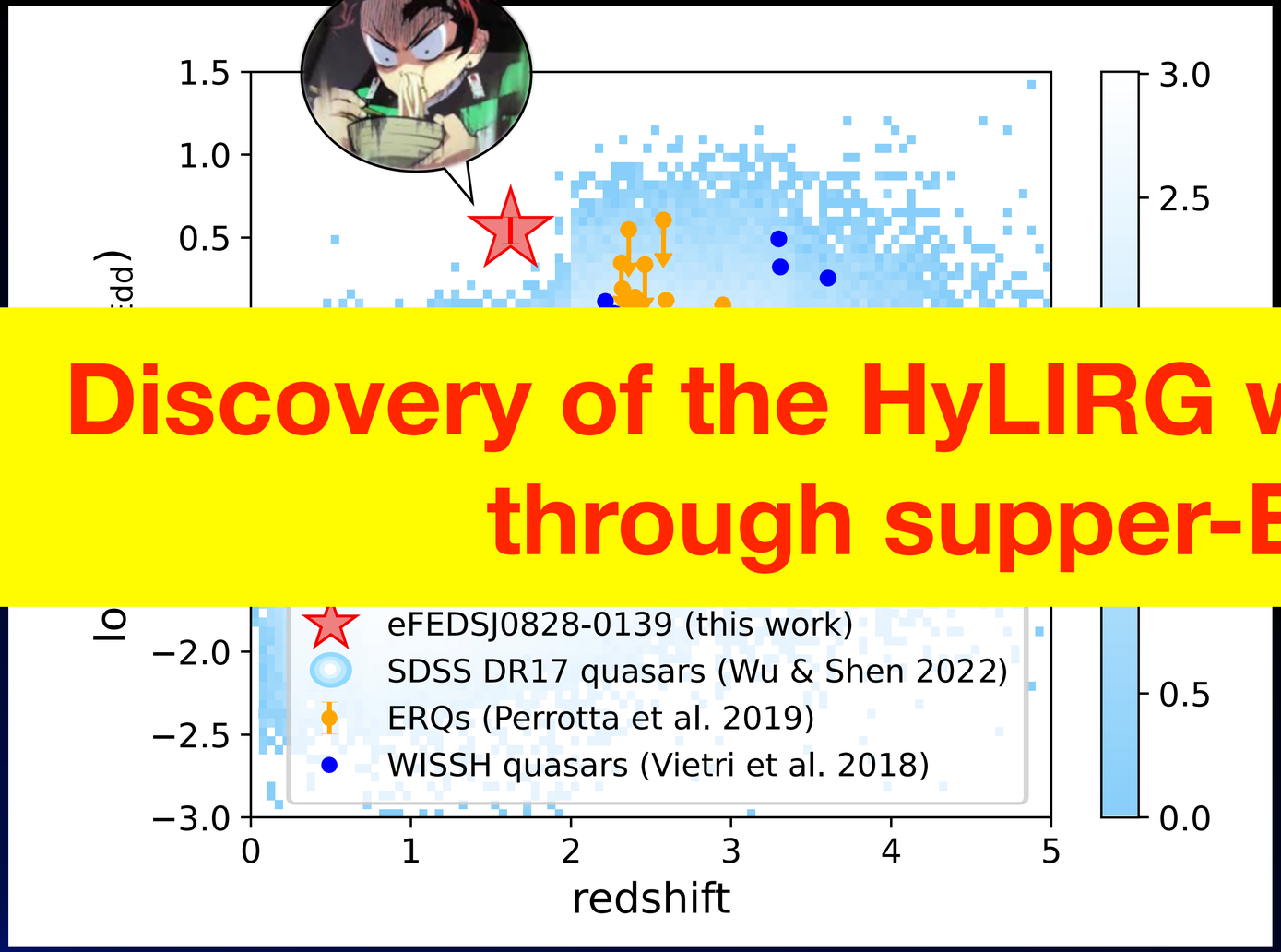
Discovery of an HyLIRG at z ~ 1.62!

Discovery of the hyperluminous quasar with supper Eddington ratio



Physical properties	Value
M^* [$M_\odot$]	$(3.9 \pm 2.0) \times 10^{11}$
SFR [$M_\odot$/yr]	$(1.3 \pm 0.5) \times 10^{3}$
L_{IR} [$L_\odot$]	$(6.8 \pm 1.8) \times 10^{13}$
L_{bol} [erg/s]	$(2.9 \pm 0.1) \times 10^{47}$
M_{BH}	$(6.2 \pm 1.2) \times 10^{8}$
λ_{Edd}	**3.6 ± 0.7**

Discovery of the hyperluminous quasar with supper Eddington ratio



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λ_{Edd}	**3.6 ± 0.7**

Discovery of the HyLIRG with SMBH growing through supper-Eddington!

Summary

Hyper-luminous infrared galaxies (HyLIRGs)

- HyLIRGs are a significant population in understanding the co-evolution of galaxies and SMBHs.
- KOOLS-IFU observed 4/21 HyLIRGs candidates.
- We discovered a super-luminous quasar with an Eddington ratio of ~ 3.6!☺️, which supports theoretical expectation.

END