First Results from the SRG/eROSITA All-Sky Survey: From Stars to Cosmology

Hyper-luminous AGN candidates in eFEDS viewed with SCUBA-2 on JCMT and KOOLS-IFU on Seimei Telescope





Yoshiki Toba (NAOJ)

Keito Masu, Naomi Ota, Anri Yanagawa, Neiro Kurokawa, Sayaka Takeuchi, Sorami Soga, Yukana Tsujita (Nara Women's U.), Zhen-Kai Gao, Wei-Hao Wang (ASIAA), Masatoshi Imanishi, Masayuki Tanaka (NAOJ), Satoshi Yamada (RIKEN), Itsuki Dosaka, Seira Kobayashi, Kohei Shibata, Tohru Nagao (Ehime U.), Takumi Kakimoto (SOKENDAI), Aika Oki (U.Tokyo), Yoshihiro Ueda (Kyoto U.)

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Toba et al., 2024c, ApJ, in prep.



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Co-evolution of galaxies and SMBH Importence of HyLIRGs

Galaxy classification based on IR luminosity





Galaxy classification based on IR luminosity

name	log (L _{IR} /L)
Normal	
LIRGS	11 - 12
ULIRGS	12 -13
HyLIRGs	>13

Introduction







Ultra Luminous InfRared Galaxies (ULIRGs)

name	log (L _{IR} /L)
Normal	
LIRGS	11 - 12
ULIRGS	12 -13
HyLIRGs	>13

Introduction







Hyper Luminous InfRared Galaxies (HyLIRGs)

name	log (L _{IR} /L)
Normal	
LIRGS	11 - 12
ULIRGS	12 -13
HyLIRGs	>13

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Introduction











Galaxy classification based on IR luminosity

name	log (Lir/Lo)

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

ULIRGS	12 -13
HyLIRGs	>13

Introduction











A mysterious relation between galaxies and SMBHs

What is interesting about finding HyLIRGs?

Introduction

NASA/JPL-Caltech/Event Horizon Telescope Collaboration

Host galaxy

A mysterious relation between galaxies and SMBHs

Supermassive black hole (SMBH)

Introduction







A mysterious relation between galaxies and SMBHs



Introduction





<u> Msmвн ~ 1/1000 Mbulge</u>

* The physical scale of the two is different by an order of 8-9!

Kormendy & Ho (2013)





A mysterious relation between galaxies and SMBHs



What kind of physical mechanism controls co-evolution?



Introduction



* The physical scale of the two is different by an order of 8-9!

Kormendy & Ho (2013)





What is the importance of finding HyLIRGs?



Introduction

See, e.g., Hopkins et al. (2008), Blecha et al. (2018).





What is the importance of finding HyLIRGs?



Introduction

Quasar

What is the importance of finding HyLIRGs?

HyLIRGs

Gas rich galaxies

Dust-obscured AGN

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

Introduction

The volume density of the HyLIRGs is extremely low. 100 "maximum phase of the co-evolution of clalaxies and SMBHs.

A systematic search with eROSITA! 10^{11}

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

Time [Gyr]

0.4

0.2

0.6 0.8 1.0

1.2

The volume density of the Hyl IRGs

To find HyLIRGs and investigate their physical properties.

A systematic search with eROSITA! 10^{11} 0.4 0.6 0.8 1.0 1.2 0.2 Time [Gyr]

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

Data and analysis

 Candidates 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.
- One object with zphot was targeted for lacksquareKOOLS-IFU, while four objects with z_{spec} were targeted for SCUBA-2 obs.

KOOLS-IFU on Seimei Telescope

Kyoto Okayama Optical Low-dispersion Spectrograph with optical-fiber Integral Field Unit

Number of fibers	117 (= 110 for objects and 7 for s
FoV of a fiber	regular hexagon of 0.42 arcsec in
Fiber pitch	0.84 ± 0.07 arcsec
Total FoV	8.4 x 8.0 arcsec for object and 2.5 FoV for aladin (vot file). Please see
Fiber core filling factor	~100%

Examples of the KOOL-IFU observations for nearby U/LIRGs (Toba et al. 2020)

Data and analysis

Target list for KOOLS-IFU and SCUBA-2

Object name	Spec-z	AGN tyoe	KOOLS- IFU obs?	SCU ob
eFEDSJ0828				
eFEDSJ0841	1.839	quasar		
eFEDSJ0856	1.515	quasar		
eFEDSJ0908	1.266	quasar		
eFEDSJ0926	1.429	quasar		

Data and analysis

Multi-wavelength dataset

	X-ray	UV	optical	near-IR	mid-IR	far-IR / s	ub-mm
Instrument	eROSITA	GALEX	SDSS	UKIDSS	WISE	AKARI	SCUBA
Band	2-10 keV	FUV NUV	u, g, r, i, z	Y, J, H, K	3.4, 4.6, 12, 22	90	450, 85
tracer	AG	Ν	stellar po	opulation	hot dust	warm/c	old dust

Data and analysis

$$M_{\rm BH}[M_{\odot}] = 10^{6.86} \left[\frac{\rm FWHM \, (MgII)}{1000 \, \rm km \, s^{-1}} \right]$$

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

Data and analysis

Vestergaard & Osmer (2009)

Hyper-luminous AGNs in eFEDS

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 0 history, single stellar population, and AGN dust model.
- CIGALE tells us e.g., stellar mass, SFR, dust extinction of galaxies.

Delayed SFH with recent starburst (Ciesla et al. 2017 τ_{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 Metallicity 0.02 Nebular emission (Inoue 2011) log U log U -3.0, -2.0, -1.0 Dust attenuation (Calzetti et al. 2000; Leitherer et al. 20 $E(B - V)_{\text{lines}}$ 0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 1. AGN Emission (Stalevski et al. 2012; Stalevski et al. 200 $\tau_{9.7}$ 3, 7, 11 p 0.5, 1.5 q 0.5, 1.5 q 0.5, 1.5 q 0.5, 1.5 Δ [°] 40 R_{max}/R_{min} 30 θ [°] 0, 10, 20 f_{AGN} 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 Dust Emission (Draine et al. 2014) q q 0.1, 5, 2.0 γ 0.01, 0.1, 1.0 χ -ray Emission (Yang et al. 2022) AGN photon index (Γ) 2.0	Parameter	Value
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$\begin{array}{c c} \Delta \left[^{\circ} \right] & 40 \\ R_{\max}/R_{\min} & 30 \\ \hline \\ \theta \left[^{\circ} \right] & 0, 10, 20 \\ \hline \\ f_{AGN} & 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 \\ \hline \\ \hline \\ Dust Emission (Draine et al. 2014) \\ \hline \\ q_{PAH} & 2.50, 5.26, 6.63, 7.32 \\ \hline \\ U_{\min} & 10.0, 50.0 \\ \hline \\ \alpha & 1.0, 1.5, 2.0 \\ \hline \\ \gamma & 0.01, 0.1, 1.0 \\ \hline \\ \hline \\ \gamma & 0.01, 0.1, 1.0 \\ \hline \\ X-ray Emission (Yang et al. 2022) \\ \hline \\ AGN photon index (\Gamma) & 2.0 \\ \hline \\ \alpha_{OX} & -2.0, -1.9, -1.8, -1.7 \\ \hline \\ \Delta \alpha_{OX} _{\max} & 0.5 \\ \hline \end{array}$	q	0.5, 1.5
$\begin{array}{c c} R_{\rm max}/R_{\rm min} & 30 \\ \theta [^{\rm o}] & 0, 10, 20 \\ \hline f_{\rm AGN} & 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 \\ \hline \\ & {\rm Dust \ Emission \ (Draine \ et \ al. \ 2014)} \\ \hline \\ q_{\rm PAH} & 2.50, 5.26, 6.63, 7.32 \\ U_{\rm min} & 10.0, 50.0 \\ \alpha & 1.0, 1.5, 2.0 \\ \gamma & 0.01, 0.1, 1.0 \\ \hline \\ & {\rm X-ray \ Emission \ (Yang \ et \ al. \ 2022)} \\ \hline \\ AGN \ photon \ index \ (\Gamma) & 2.0 \\ \hline \\ & \alpha_{\rm OX} & -2.0, -1.9, -1.8, -1.7 \\ \hline \\ & \Delta \alpha_{\rm OX} _{\rm max} & 0.5 \\ \hline \end{array}$	Δ [°]	40
$ \begin{aligned} \theta [^{\circ}] & 0, 10, 20 \\ \hline f_{AGN} & 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 \\ \hline \text{Dust Emission (Draine et al. 2014)} \\ \hline q_{PAH} & 2.50, 5.26, 6.63, 7.32 \\ \hline U_{min} & 10.0, 50.0 \\ \hline \alpha & 1.0, 1.5, 2.0 \\ \hline \gamma & 0.01, 0.1, 1.0 \\ \hline X\text{-ray Emission (Yang et al. 2022)} \\ \hline AGN \text{ photon index (Γ)} & 2.0 \\ \hline \alpha_{OX} & -2.0, -1.9, -1.8, -1.7 \\ \hline \Delta \alpha_{OX} _{max} & 0.5 \\ \end{aligned} $	$R_{\rm max}/R_{\rm min}$	30
$\begin{array}{c c} f_{\rm AGN} & 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 \\ \hline & {\rm Dust \ Emission \ (Draine \ et \ al. \ 2014)} \\ \hline q_{\rm PAH} & 2.50, 5.26, 6.63, 7.32 \\ U_{\rm min} & 10.0, 50.0 \\ \alpha & 1.0, 1.5, 2.0 \\ \gamma & 0.01, 0.1, 1.0 \\ \hline & {\rm X-ray \ Emission \ (Yang \ et \ al. \ 2022)} \\ \hline {\rm AGN \ photon \ index \ (\Gamma)} & 2.0 \\ \hline & \alpha_{\rm OX} & -2.0, -1.9, -1.8, -1.7 \\ \hline & \Delta \alpha_{\rm OX} _{\rm max} & 0.5 \\ \hline \end{array}$	θ [°]	0, 10, 20
$\begin{array}{c c} & \text{Dust Emission (Draine et al. 2014)} \\ \hline q_{\text{PAH}} & 2.50, 5.26, 6.63, 7.32 \\ U_{\text{min}} & 10.0, 50.0 \\ \alpha & 1.0, 1.5, 2.0 \\ \gamma & 0.01, 0.1, 1.0 \\ \hline \chi - ray Emission (Yang et al. 2022) \\ \hline \text{AGN photon index (}\Gamma) & 2.0 \\ \alpha_{\text{OX}} & -2.0, -1.9, -1.8, -1.7 \\ \hline \Delta \alpha_{\text{OX}} _{\text{max}} & 0.5 \\ \end{array}$	$f_{ m AGN}$	0.4, 0.5, 0.6, 0.7, 0.8, 0.9
$\begin{array}{cccc} q_{\rm PAH} & 2.50, 5.26, 6.63, 7.32 \\ U_{\rm min} & 10.0, 50.0 \\ \alpha & 1.0, 1.5, 2.0 \\ \gamma & 0.01, 0.1, 1.0 \\ \hline & {\rm X-ray\ Emission\ (Yang\ et\ al.\ 2022)} \\ \hline & {\rm AGN\ photon\ index\ (\Gamma)} & 2.0 \\ \alpha_{\rm OX} & -2.0, -1.9, -1.8, -1.7 \\ \hline & \Delta \alpha_{\rm OX} _{\rm max} & 0.5 \\ \hline \end{array}$	Dust Emissio	on (Draine et al. 2014)
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X-ray Emission (Yang et al. 2022)AGN photon index (Γ)2.0 α_{OX} $-2.0, -1.9, -1.8, -1.7$ $ \Delta \alpha_{OX} _{max}$ 0.5	γ	0.01, 0.1, 1.0
AGN photon index (Γ) 2.0 α_{OX} -2.0, -1.9, -1.8, -1.7 $ \Delta \alpha_{OX} _{max}$ 0.5	X-ray Emissi	ion (Yang et al. 2022)
$\alpha_{OX} = -2.0, -1.9, -1.8, -1.7$ $ \Delta \alpha_{OX} _{max} = 0.5$	AGN photon index (Γ)	2.0
$ \Delta \alpha_{\rm OX} _{\rm max}$ 0.5	αοχ	-2.0, -1.9, -1.8, -1.7
	$ \Delta \alpha_{\rm OX} _{\rm max}$	0.5

Results and discussion

 Results of the spectral fitting Results of the SED fitting Discovery of new HyLIRGs

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Discovery of the hyperluminous quasar with supper Eddington ratio

Physical properties	Value
L _{bol} [erg/s]	(2.9 ± 0.1) ×
Mвн	(6.2 ± 1.2) >
λ _{Edd}	$3.6 \pm 0.$

On-going works

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

Result of the SED fitting

Results and discussion

Result of the SED fitting

Discovery of an HyLIRG at z ~ 1.62!

Results and discussion

eFEDSJ0908+0339

On-going works

Zhen-Kai (ASIAA)

Toba, Gao, Wang et al. In prep.

few more HyLIRGs!

Objects	Redshift	Log LIR	
eFEDS0841	1.84	14.2	
eFEDS0858	1.52	1-4.0	
eFEDS0908	1.27	14.2	
eFFDS0926	143	137	

All the HyLIRGs candidate are indeed HyLIRGs!

On-going works

few more HyLIRGs!

Zhen-Kai (ASIAA) Wei-Hao (ASIAA)

Toba, Gao, Wang et al. In prep.

First Results from the SRG/eROSITA All-Sky Survey: From Stars to Cosmology

Hyper-luminous infrared galaxies (HyLIRGs)

the co-evolution of galaxies and SMBHs.

candidates, respectively.

ratio of ~ 3.6.

16 September, 2024

Summary

- HyLIRGs are a significant population in understanding
- **KOOLS-IFU and SCUBA-2 observed 1 and 5 HyLIRG**
- We confirmed all the candidates are HyLIRGs ; and particularly one HyLIRG has an Eddington

