Galaxy Evolution Studies with the AKARI North Ecliptic Pole Survey

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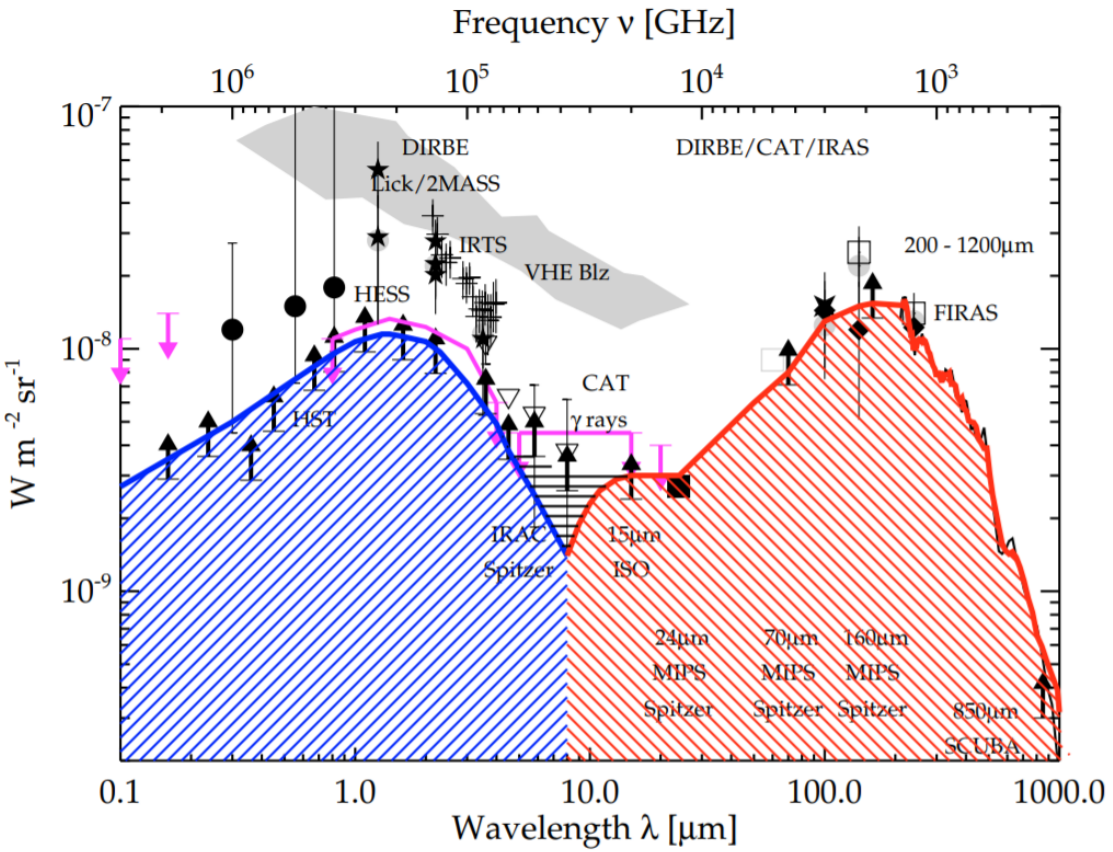
Infrared Universe

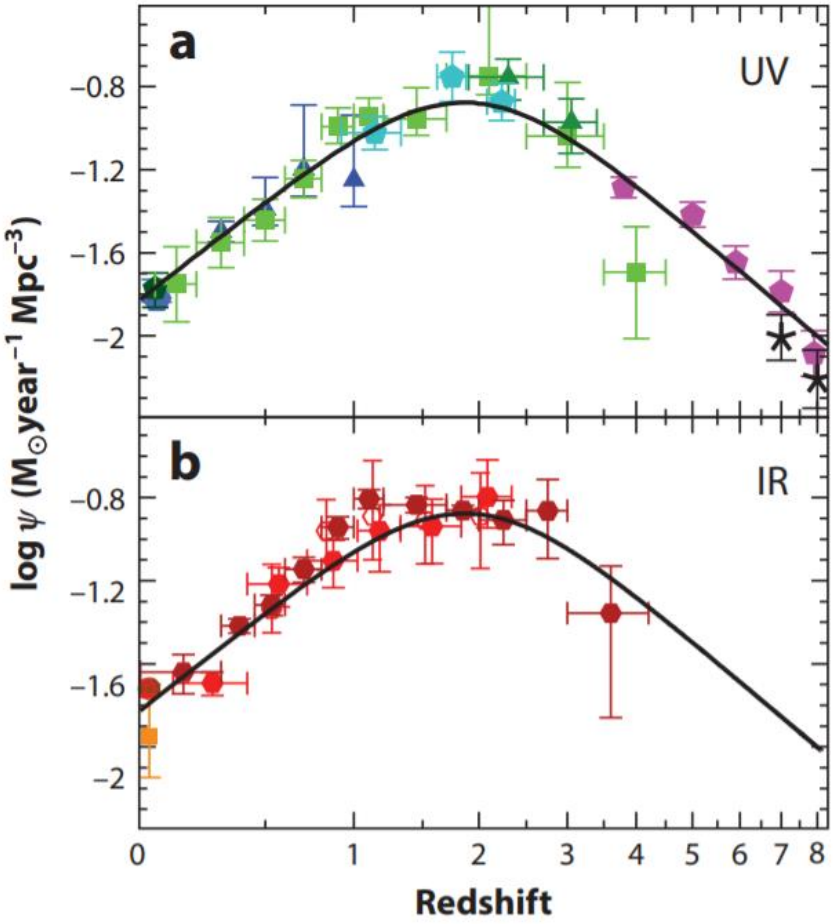


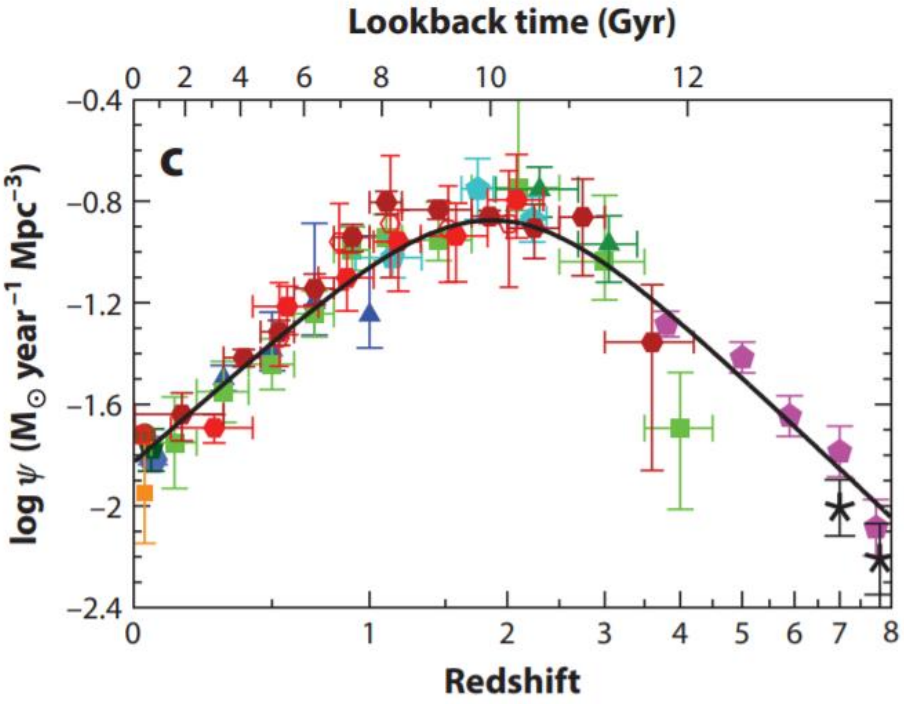
Optical **Infrared**

Cosmic extragalactic background light – models and observations, Dole et al. (2006)

EBL (model) is governed by processes related to galaxy formation (How much radiation comes out from what process – SF? Accretion? How is the structure formed? How does it evolve?). And we see "infrared" is as important as optical.

Cosmic star formation

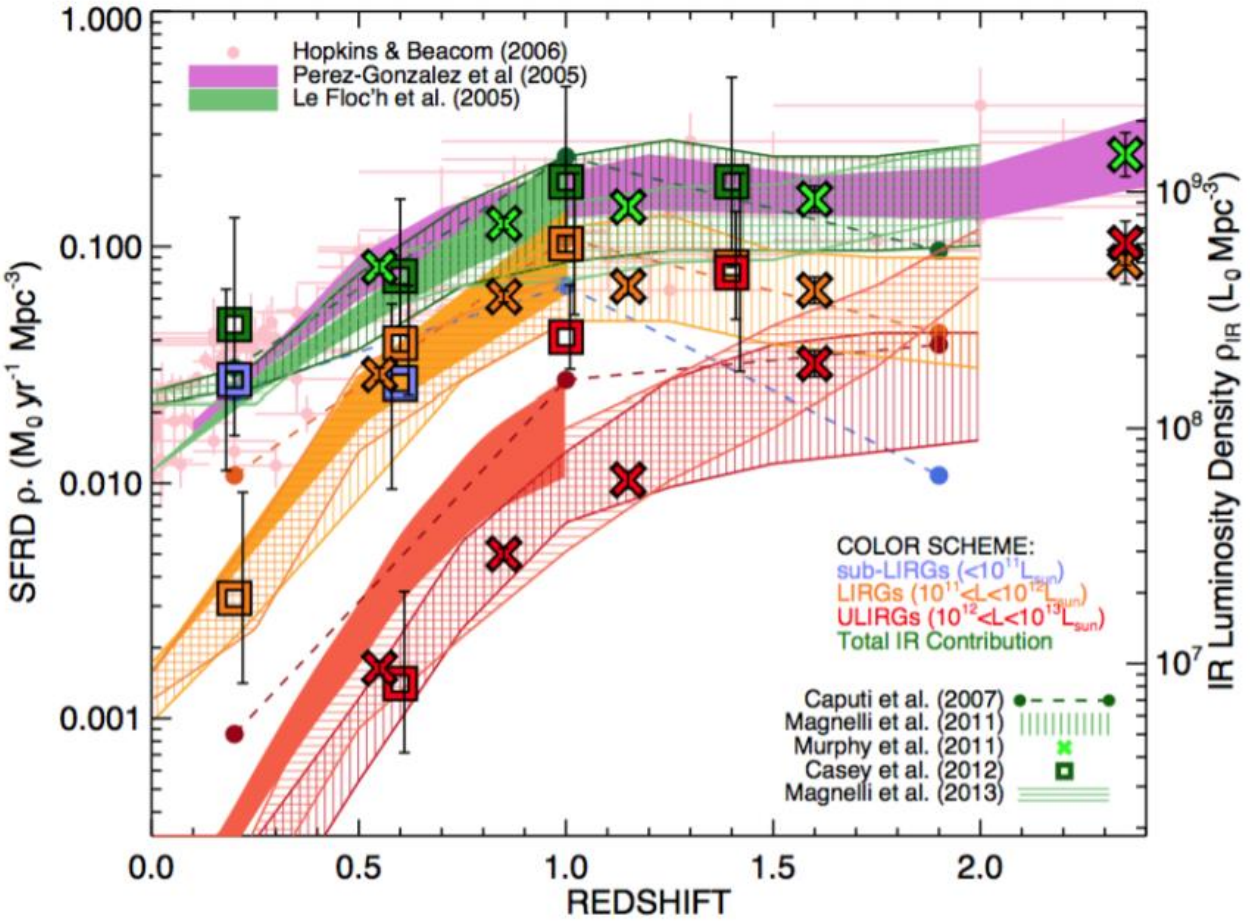




Madau & Dickinson (2014)

Different star formation rate indicators (UV, IR, …) seems to agree that the cosmic star formation rate density peaked at z~2. AGN must have played a role in this …

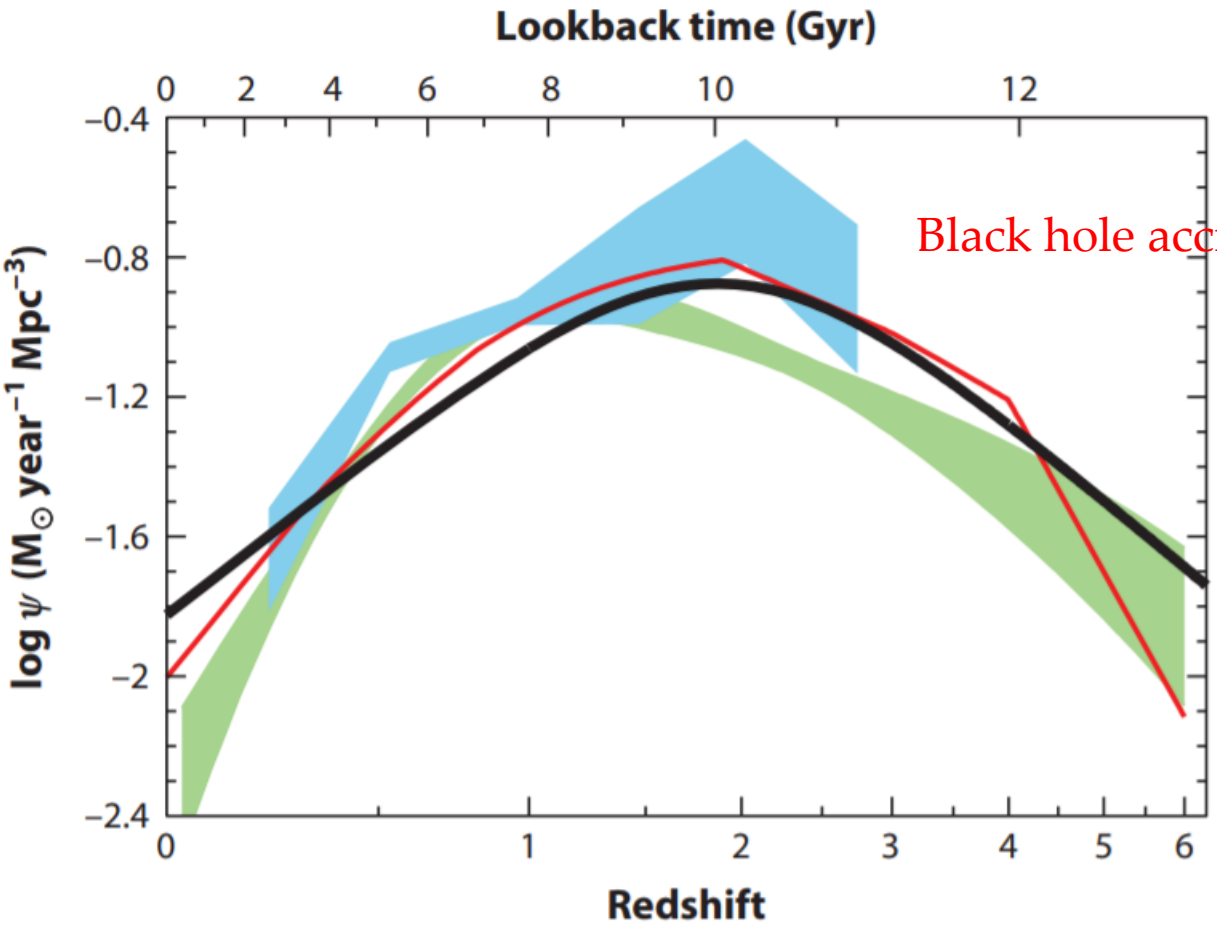
Cosmic star formation



Casey et al. (2014)

Contribution of the "infrared-luminous" galaxies to the total cosmic star formation rate density increases at high redshift. Understanding these populations (why are they so luminous? Purely do to the SF or due to the AGN?) would be important to make a complete picture for galaxy formation and evolution.

Cosmic star formation

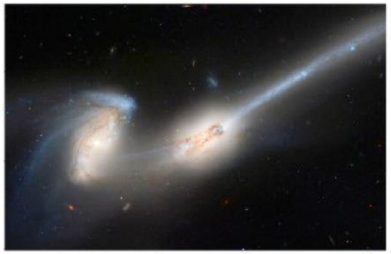


Black hole accretion history (Xray Infrared)

Madau & Dickinson (2014)

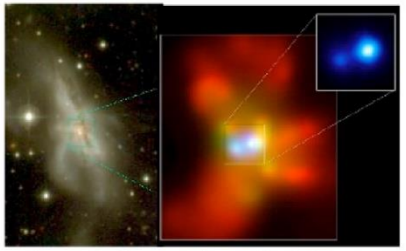
Different star formation rate indicators (UV, IR, …) seems to agree that the cosmic star formation rate density peaked at z~2. AGN must have played a role in this …

(c) Interaction/"Merger"



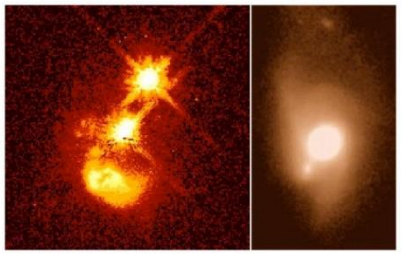
- now within one halo, galaxies interact & lose angular momentum
- SFR starts to increase
- stellar winds dominate feedback
- rarely excite QSOs (only special orbits)

(d) Coalescence/(U)LIRG



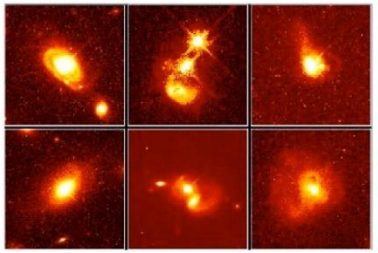
- galaxies coalesce: violent relaxation in core
- gas inflows to center: starburst & buried (X-ray) AGN
- starburst dominates luminosity/feedback, but, total stellar mass formed is small

(e) "Blowout"



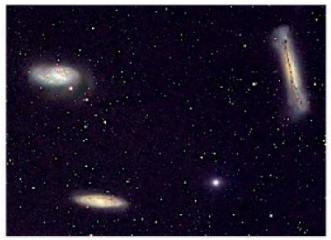
- BH grows rapidly: briefly dominates luminosity/feedback
- remaining dust/gas expelled
- get reddened (but not Type II) QSO: recent/ongoing SF in host high Eddington ratios merger signatures still visible

(f) Quasar

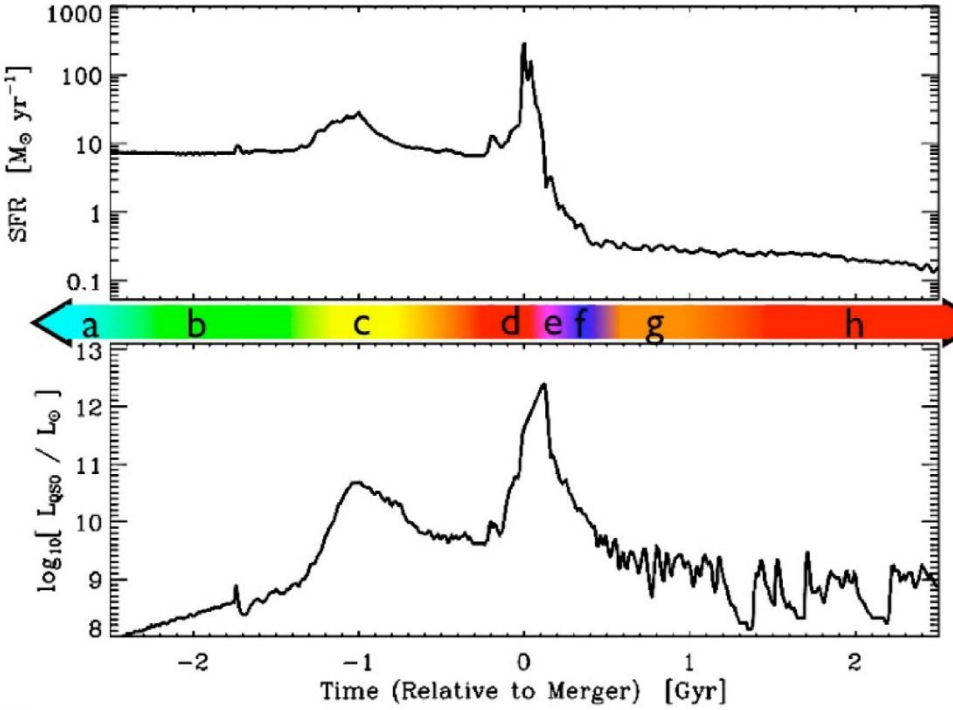


- dust removed: now a "traditional" QSO
- host morphology difficult to observe: tidal features fade rapidly
- characteristically blue/young spheroid

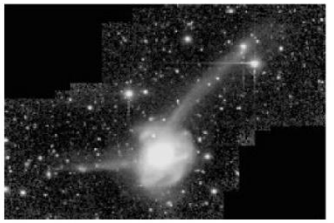
(b) "Small Group"



- 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 et al. (2008)

Motivations of the exgal "survey"

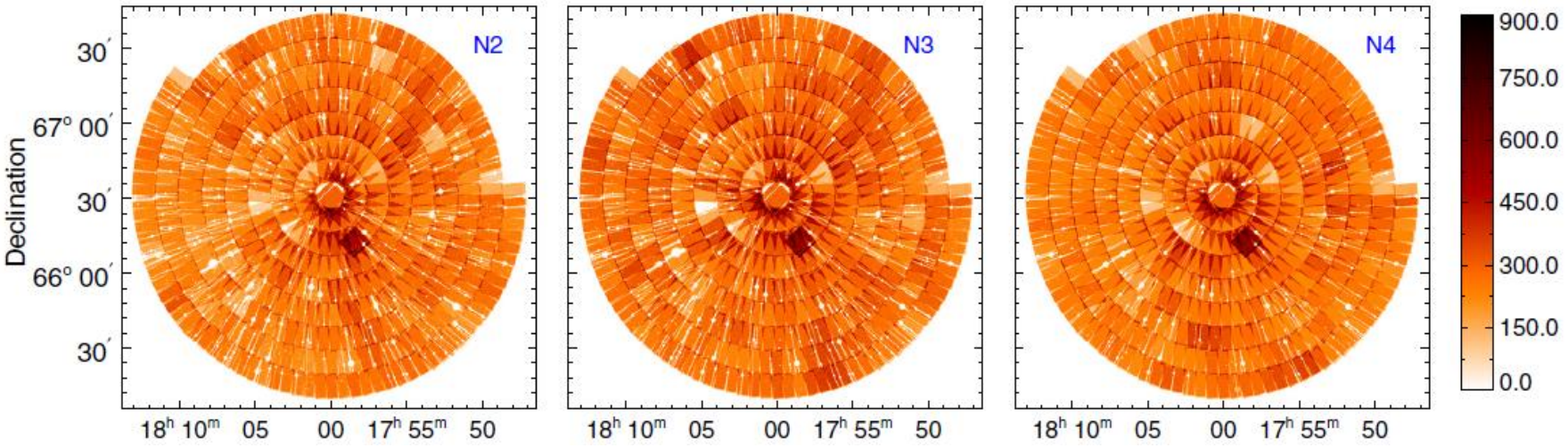
- Resolving the Extragalactic Background Light
  - The intensive coincident near-infrared data useful for detecting cosmic near-infrared background atvarious angular scales
  - the wealth of multi-wavelength data that enables good characterization of the foreground populations

- Dust Enrichment and Obscured Star Formation in Low- and High-redshift Galaxies
  - Red objects
  - Star formation and dust processing

- Co-evolution of SMBH and their Host Galaxies
  - Identification of galaxies that harbour an actively accreting SMBH and reliably decomposing its emission from that of its host galaxy.

NEP overview

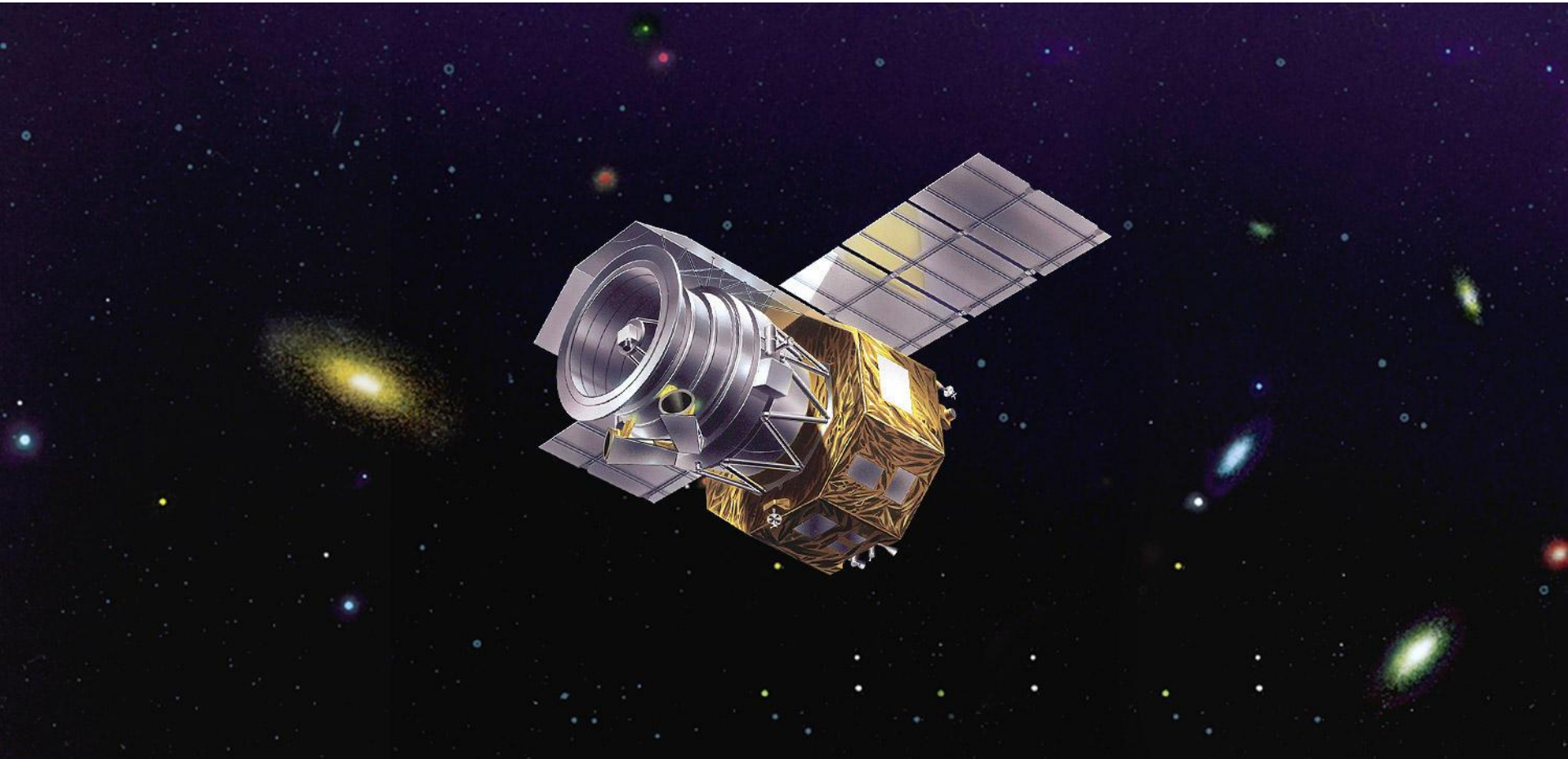
- **N**orth **E**cliptic **P**ole ($18^h\ 00^m\ 00^s$, $66^d\ 30^m\ 00^s$)
- A region with exceptionally high visibility for space missions with specific orbit (e.g., AKARI IR telescope)



Kim et al. (2012)

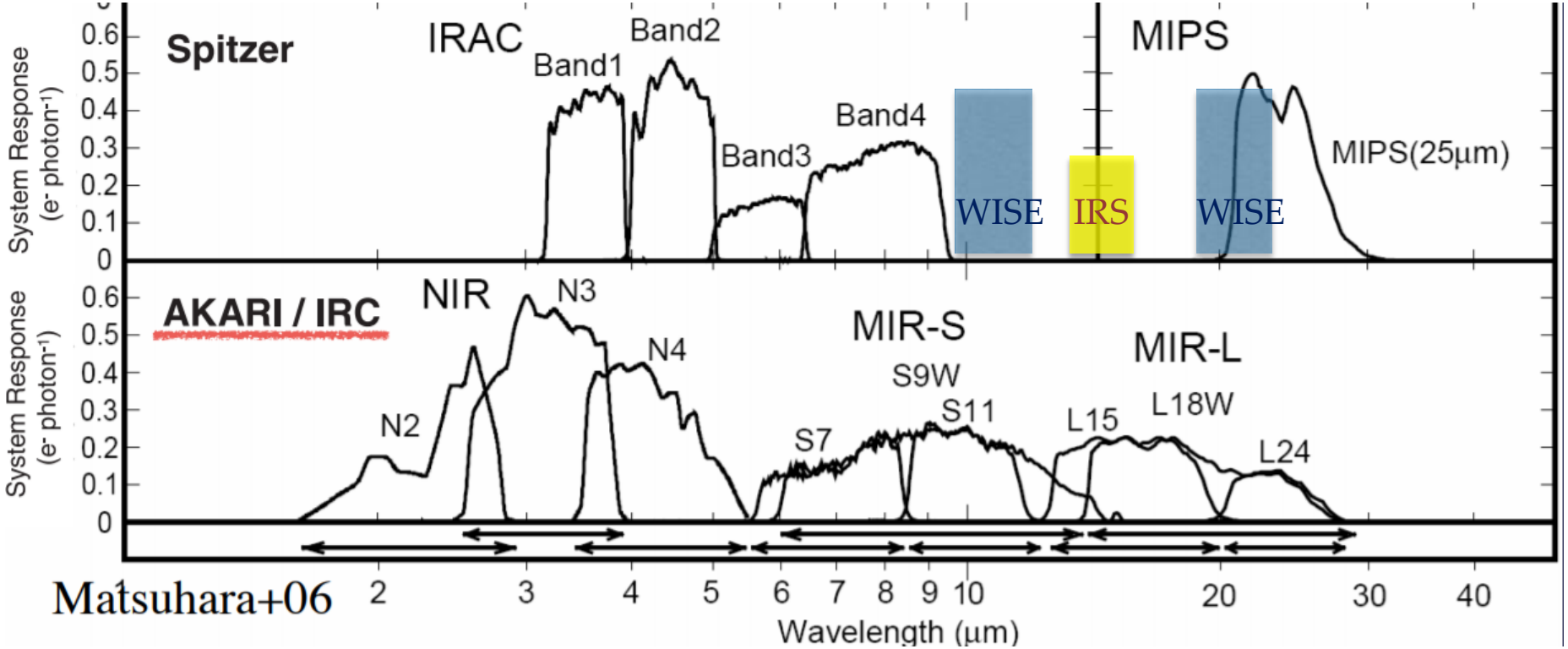
AKARI space infrared telescope

Operated during 2006-2011, MIR-FIR instruments (imaging and prism spectroscopy), mainly by Japan (JAXA), with great cooperation with Korea, UK/Europe (and other regions). ... Earlier times of EAO?



NEP overview

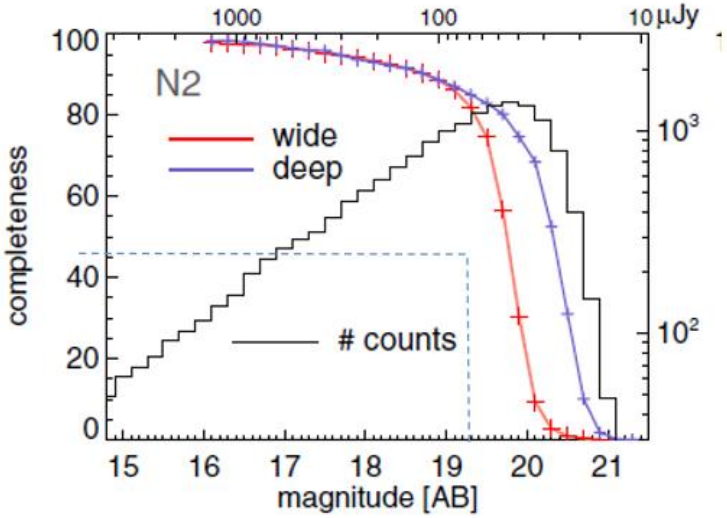
- AKARI mapped ~5.4 deg^2 around NEP with 9 **MIR** bands, completely covering **2-24μm** wavelength range.

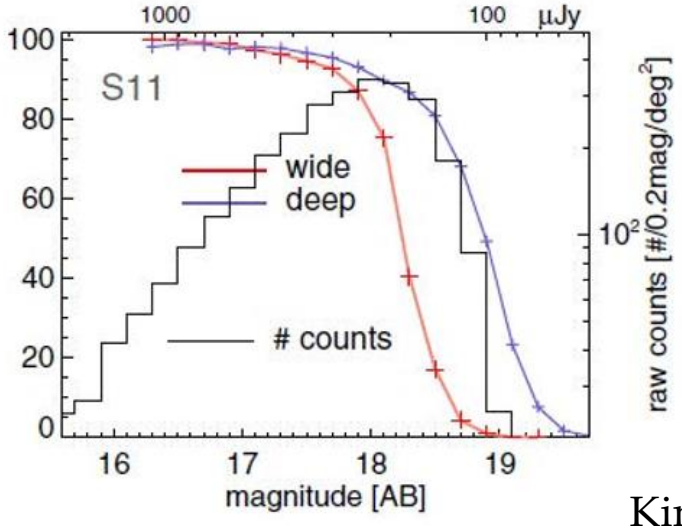


NEP overview

Basically, NEP survey is kind of two-tiered survey: NEP-Deep (inner ~0.6 deg^2), and NEP-Wide (~5.4deg^2). The existing NEP collaboration is a team with loose, open relationship – leaders (were) Japan (Deep) and Korea (Wide).

	N2	N3	N4	S7	S9W	S11	L15	L18W	L24
Number of detected sources	87,858	104,170	96,159	15,390	18,772	15,680	13,148	15,154	4,019
Detection limit in AB	20.93	21.09	21.07	19.48	19.33	18.97	18.59	18.70	17.98
(in μJy)	(15.42)	(13.30)	(13.55)	(58.61)	(67.30)	(93.76)	(133.1)	(120.2)	(233.3)
50% completeness in AB	19.75	19.81	19.87	18.7	18.6	18.2	17.9	18.0	16.8
(in μJy)	(45.71)	(43.39)	(41.02)	(120.2)	(131.8)	(190.5)	(251.2)	(229.1)	(691.8)





Kim et al. (2012)

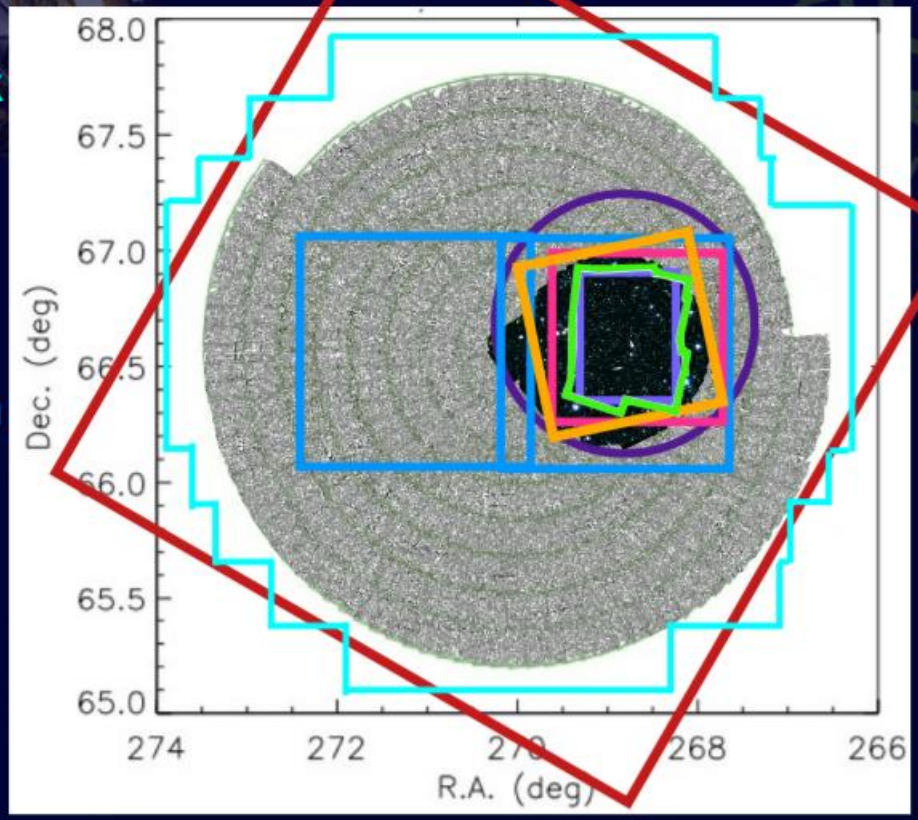
multi-band follow-up

This is what we had done by AKARI 3rd conference in Oxford

Maidanak

MegaCam
g,r,i,z

SPIRE



Chandra

GALEX

S-Cam

MegaCam

WIRCam

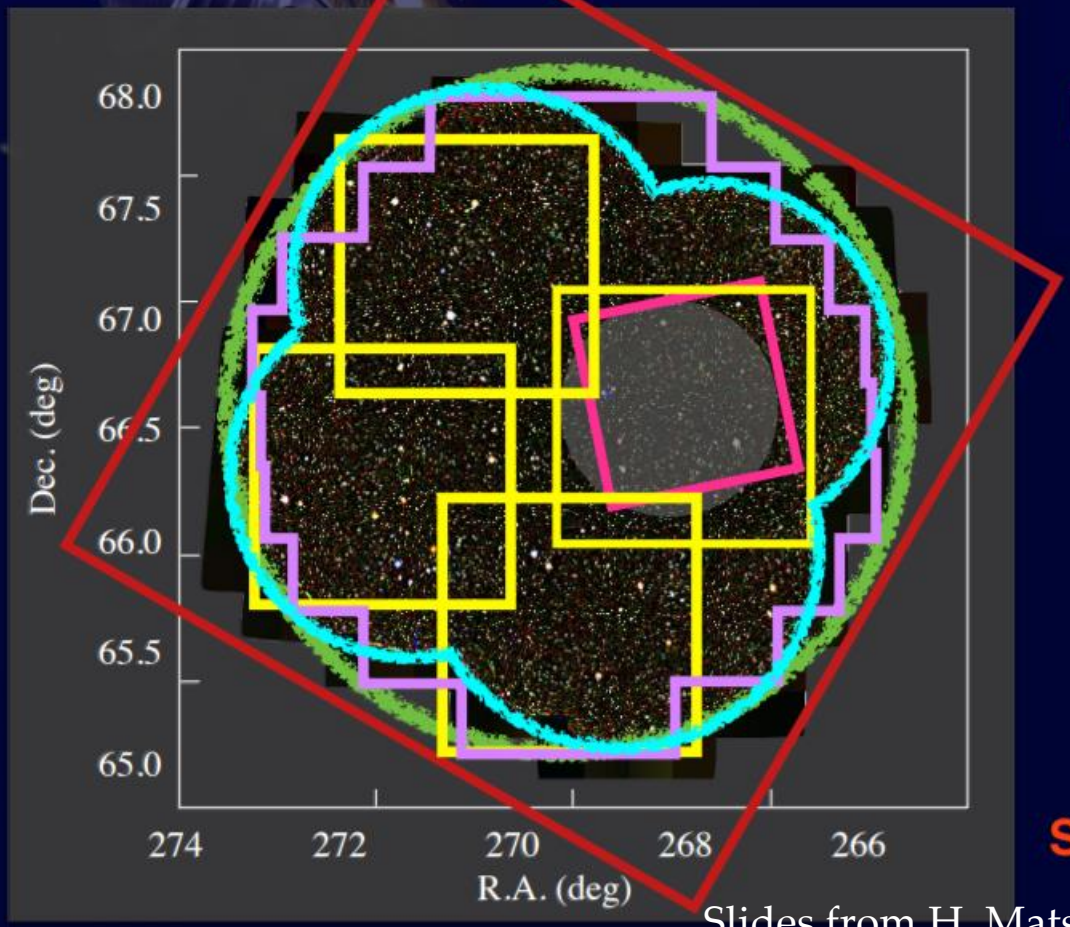
PACS

Most of the follow up observations were carried out over NEPD.
Only shallow(r~23mag) optical (*BRI*) data cover NEPW.

Slides from H. Matsuhara, N. Oi (Nov 2017)

multi-band follow-up

This is what we got after the AKARI 3rd conference upto today



NEPW(~5.4deg²)

MegaCam/u

HSC/g,r,i,z,y

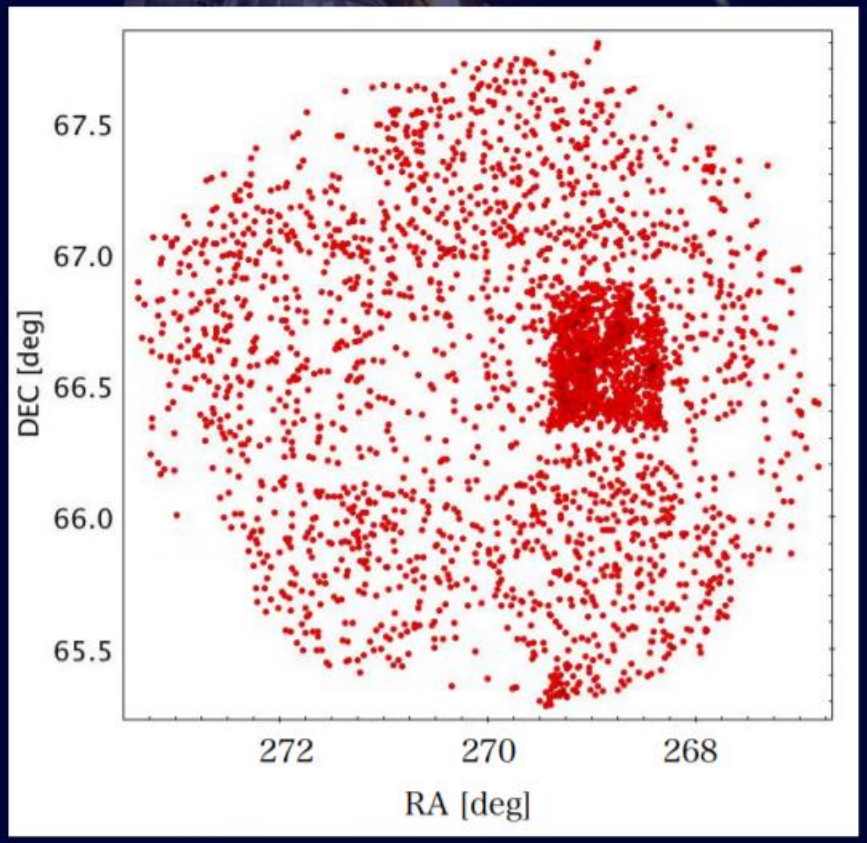
FLAMINGOS/J,H

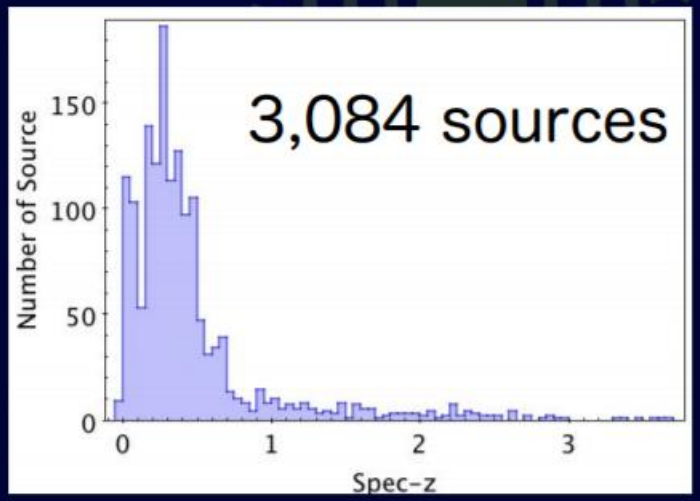
PACS/100,160μm

SPIRE/250,350,500μm

Slides from H. Matsuhara, N. Oi (Nov 2017)

Spectroscopic data



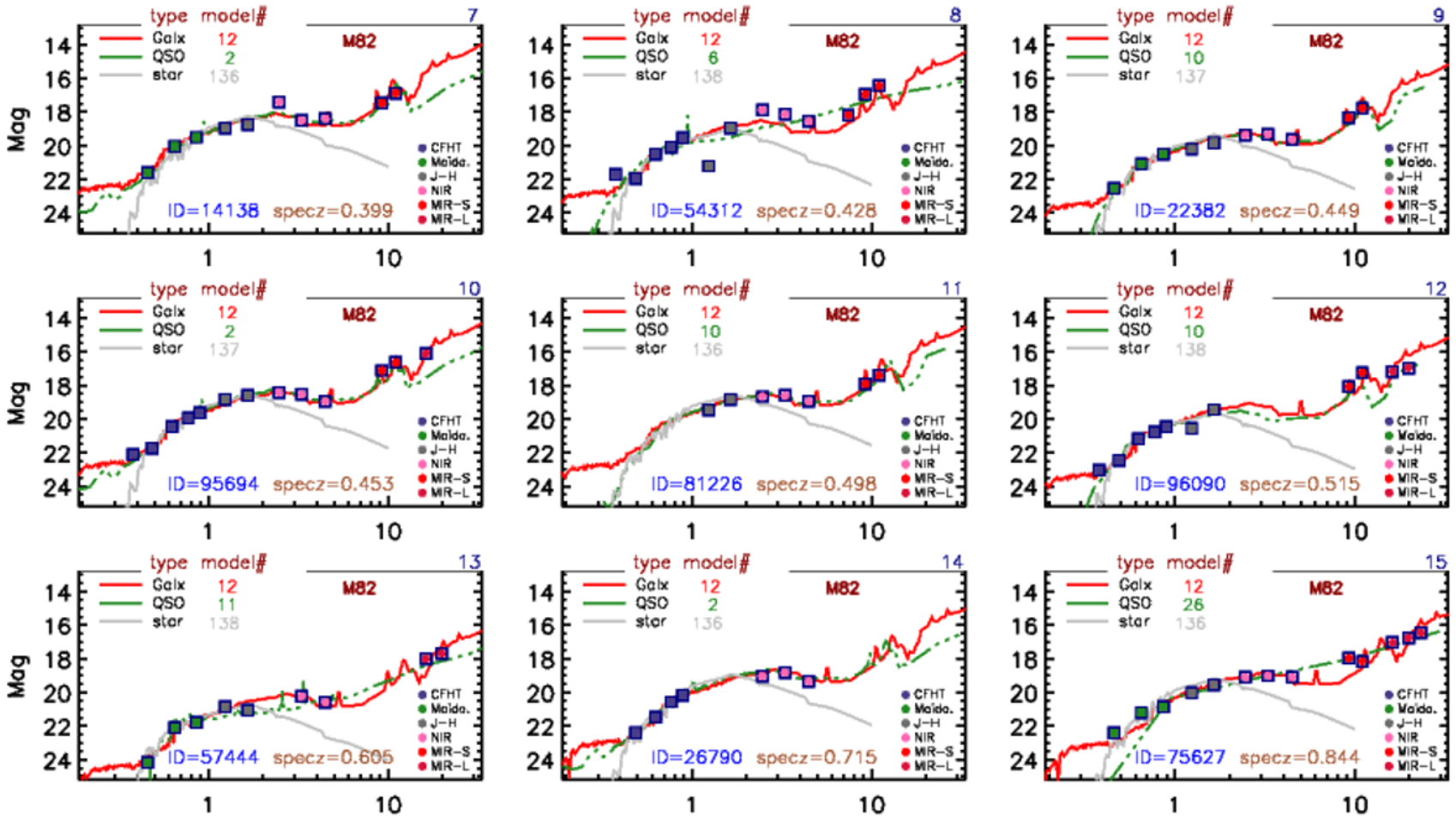


Shim et al 2013,
Oi et al. 2017,
Takagi + in prep
Miyaji + in prep
Kim, Malkan + in prep
Shogaki + in prep

Slides from H. Matsuhara, N. Oi (Nov 2017)

AGN/SF classification

Thanks to the continuous MIR coverage, AGN/SF classification is clear through the SED fitting analysis.



Kim et al. (2015)

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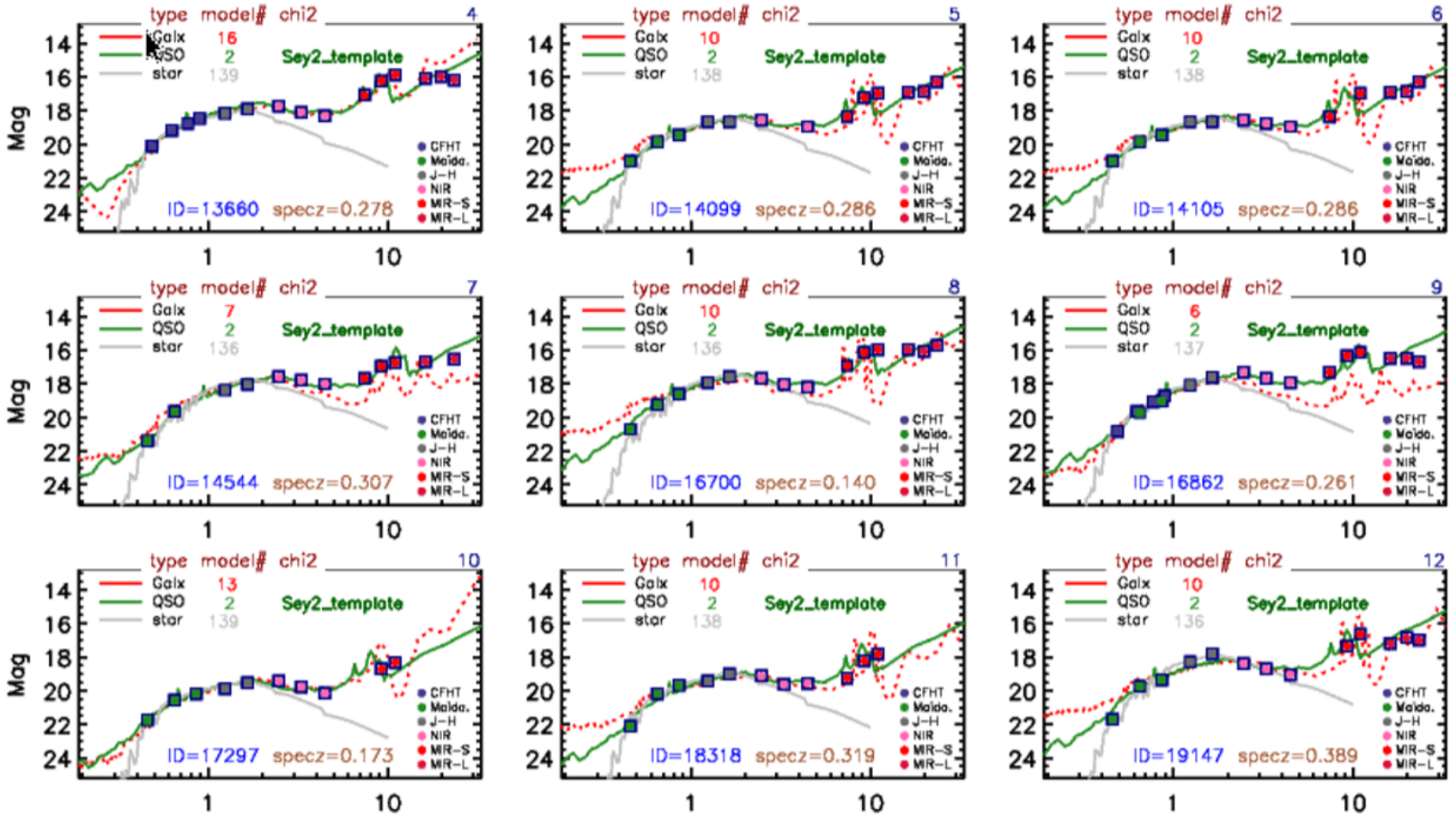


Kim et al. (2015)

with JCMT large program

- Inner 1 deg^2 was covered by JCMT SCUBA-2 Cosmological Large Survey (S2CLS, Geach et al. 2016)
- Our survey aims to observe <u>remaining ~4 deg^2</u>
  - PONG1800 observations

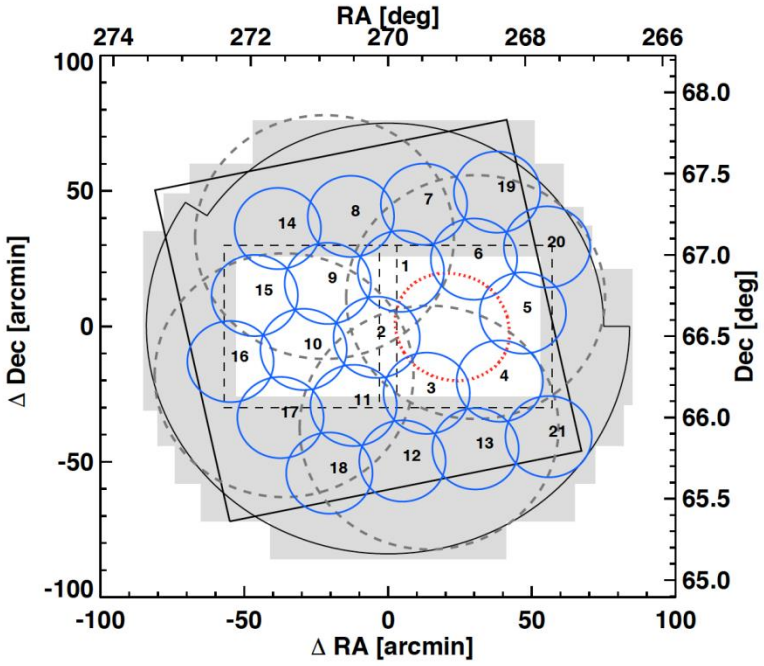
    : 1-σ semsitivity of 1.83 mJy
  - Expected Observing time

    : 400 hours

    : 21 fields × 28scans × 40min

    : ranked as B

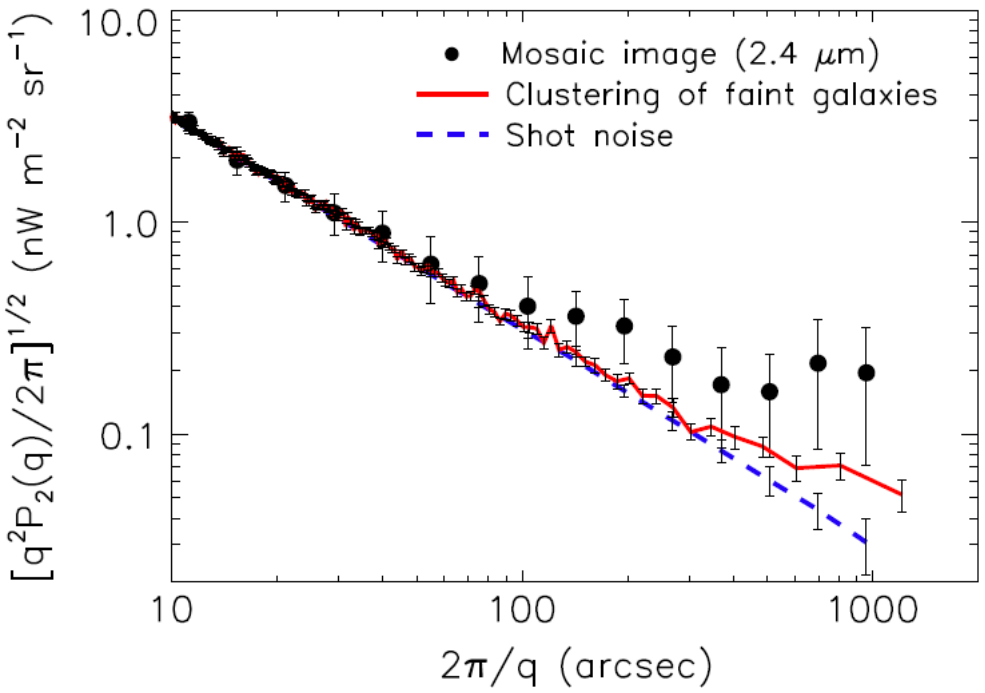
  – but the progress seems pretty good.



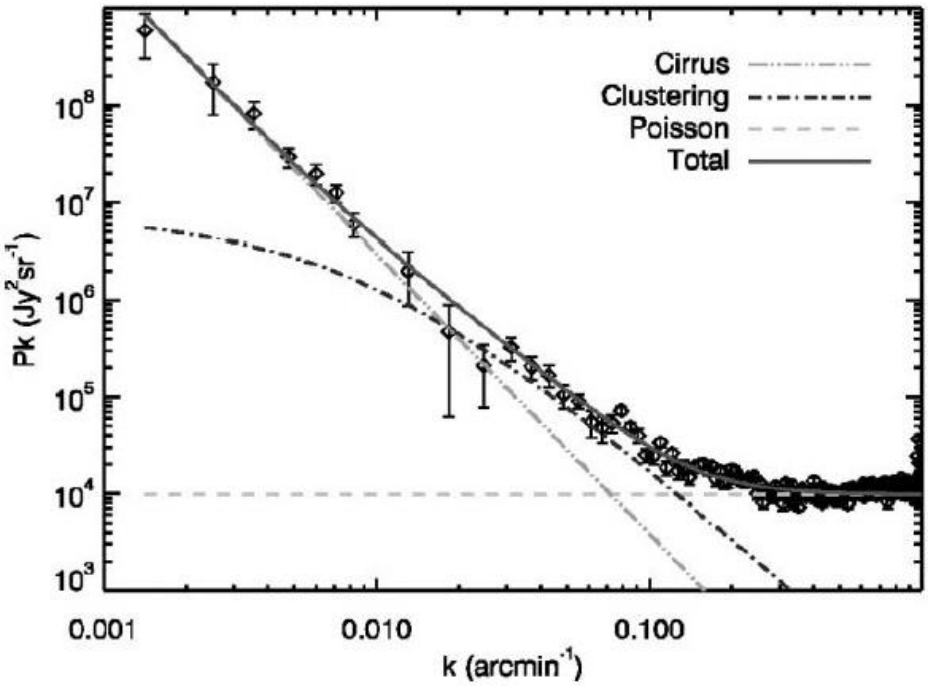
Resolving Cosmic IR background

- Cross-correlation between NIR and FIR CIB fluctuation signal is a test marker that can constrain the cause of CIB fluctuation.

- Near-IR (Seo+ 15, 2.4μm)

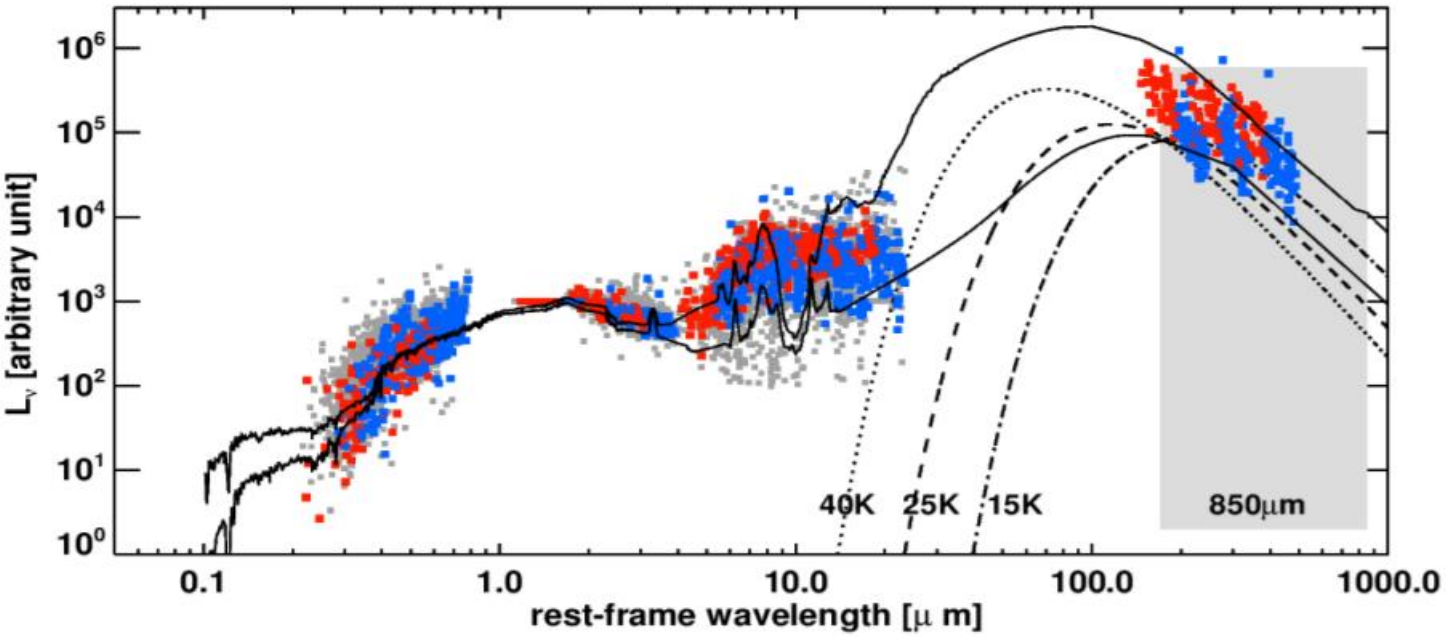


- Far-IR (Lagache+ 07, 160μm)



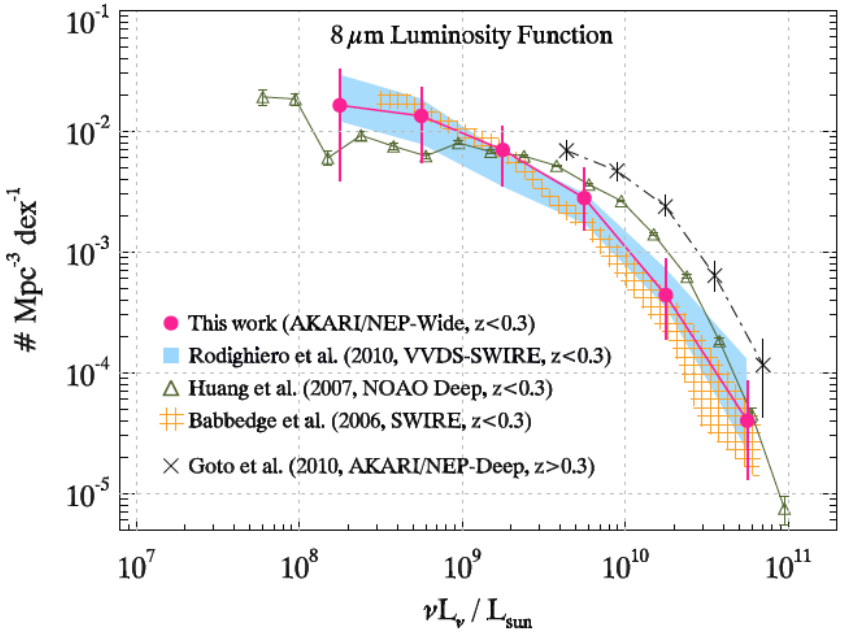
Dust in local and high-z galaxies

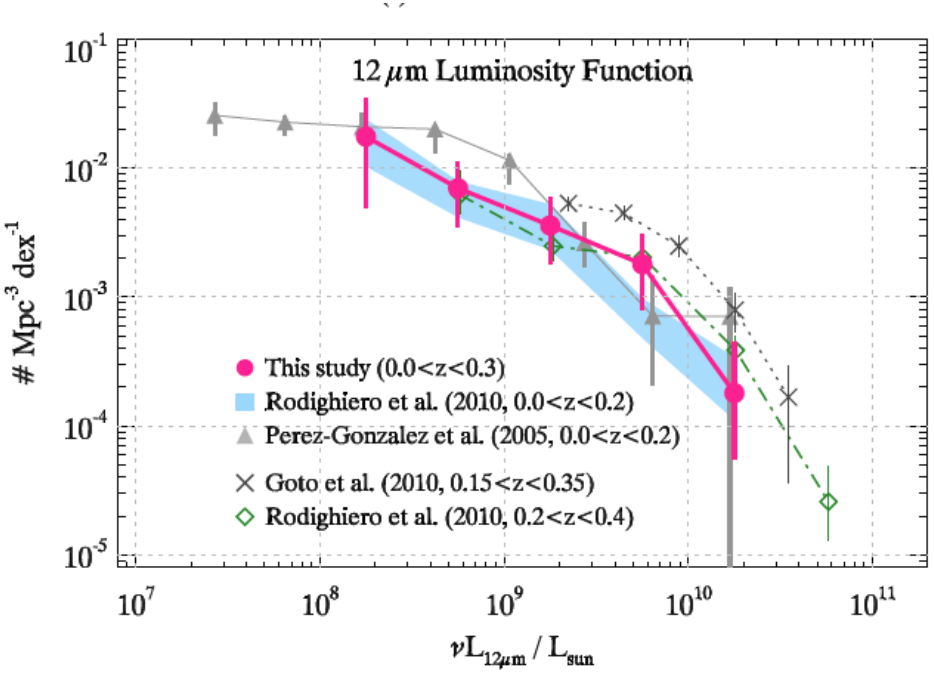
- Uncertainties in the FIR SED fitting are mainly due to the dust temperatures and dust composition, which would greatly be reduced with the addition of 850μm.



Dust in local and high-z galaxies

- The correlation between the MIR (8μm) luminosity function and the total IR luminosity function would provide the z-evolution of dust properties.

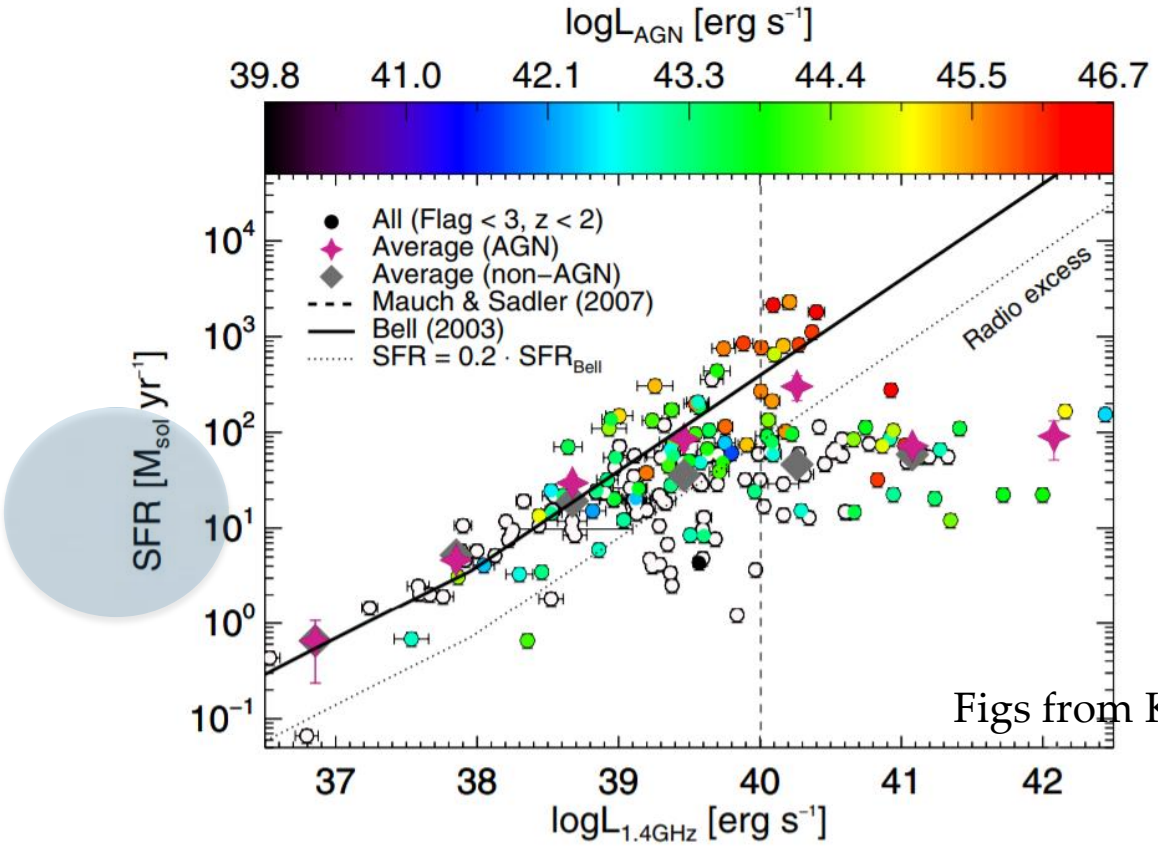




Figs from Kim et al. (2015)

Evolution of SMBH

- The (possible) suppression of the star formation by radio-loud AGNs should be investigated further with the 850μm.



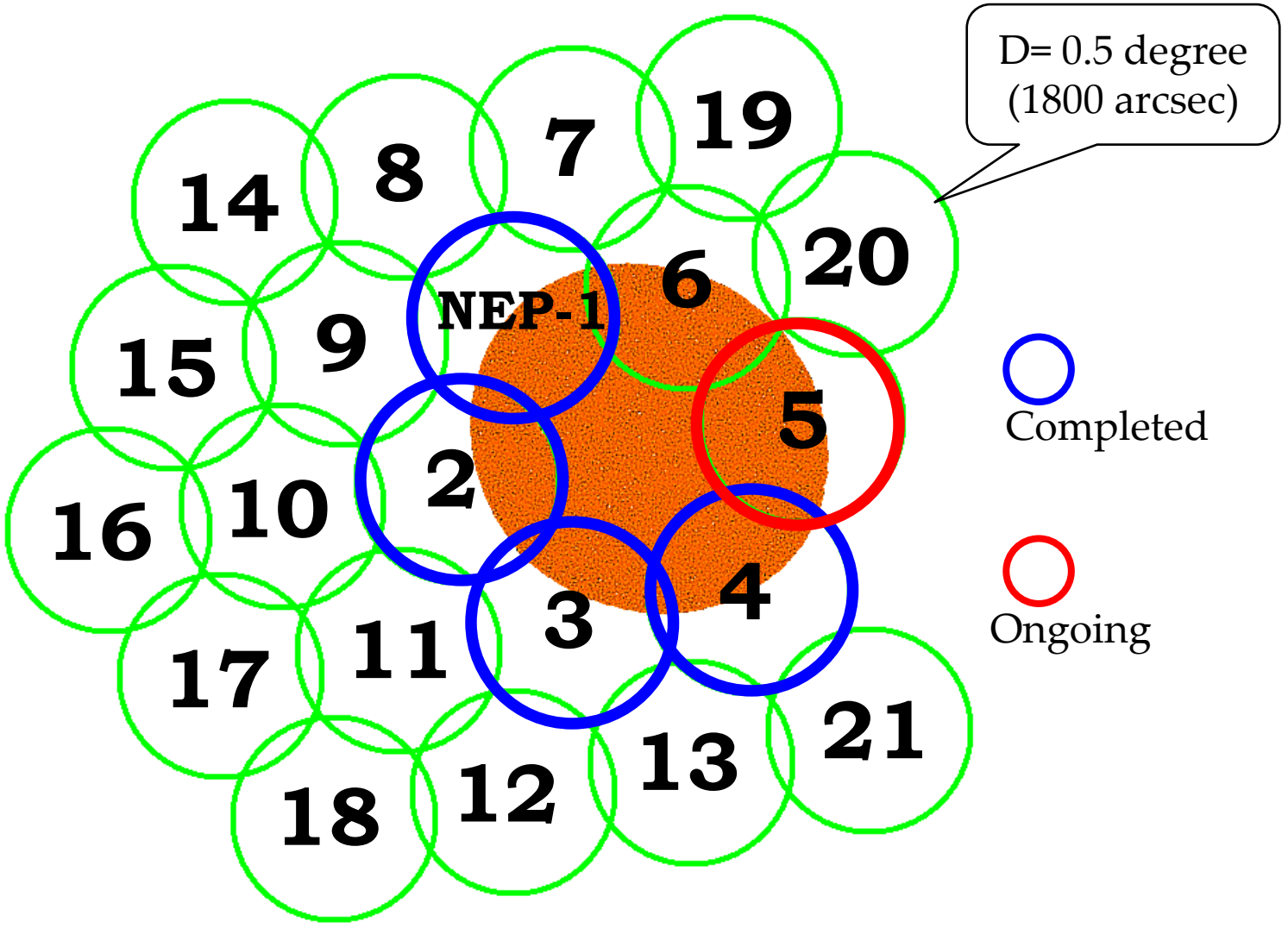
Figs from Karouzos et al. (2014)

Evolution of SMBH

- Samples of differently selected AGNs over the wide NEP region would enable study of the contribution to cosmic star formation by AGN host galaxies as a function of redshift.

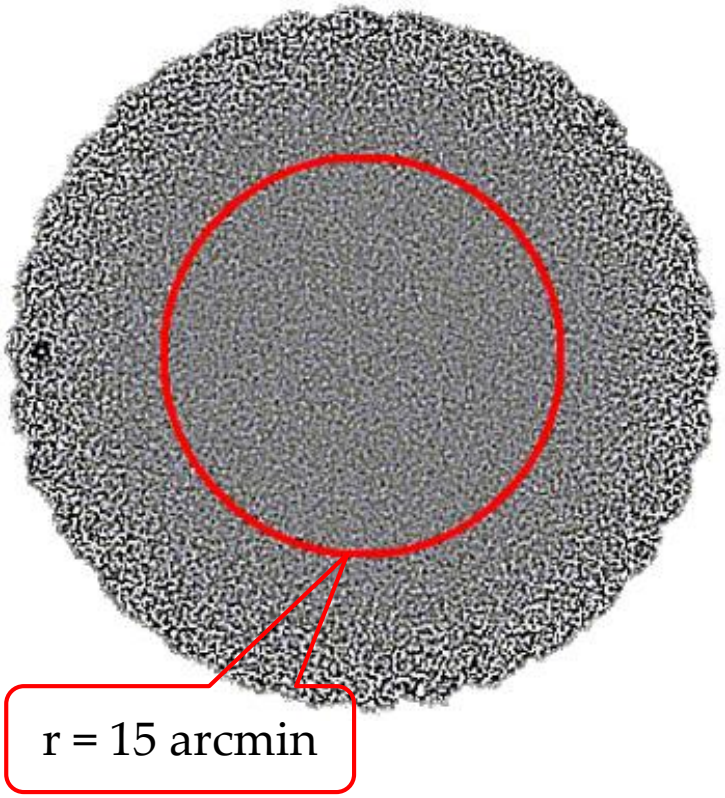
- Radio selected AGNs
- X-ray selected (Compton-thick) AGNs
- Optically selected (spectroscopically confirmed) AGNs
- MIR selected AGNs (based on the MIR PAH features)
- SED selected AGNs (benefited by the multi-λ data)

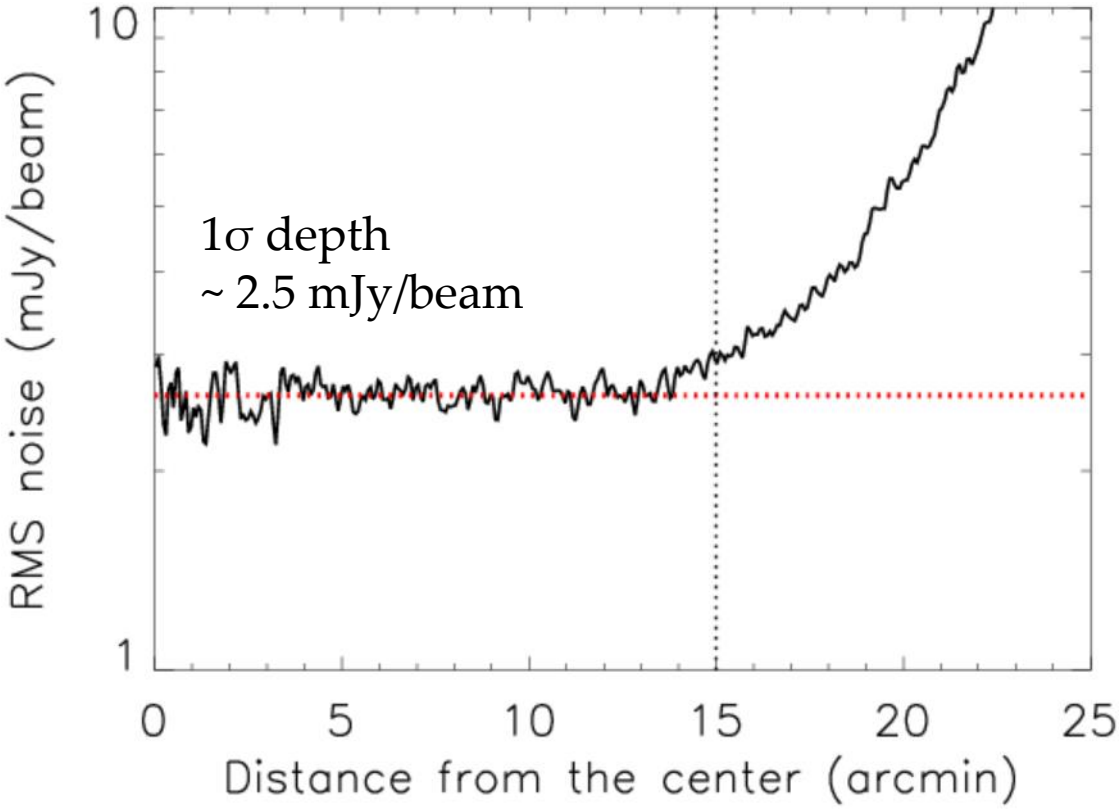
Current Status (as of 2019/03)



Survey Depth Estimation

- Central ~15 arcmin has uniform depth of 2.5mJy/beam

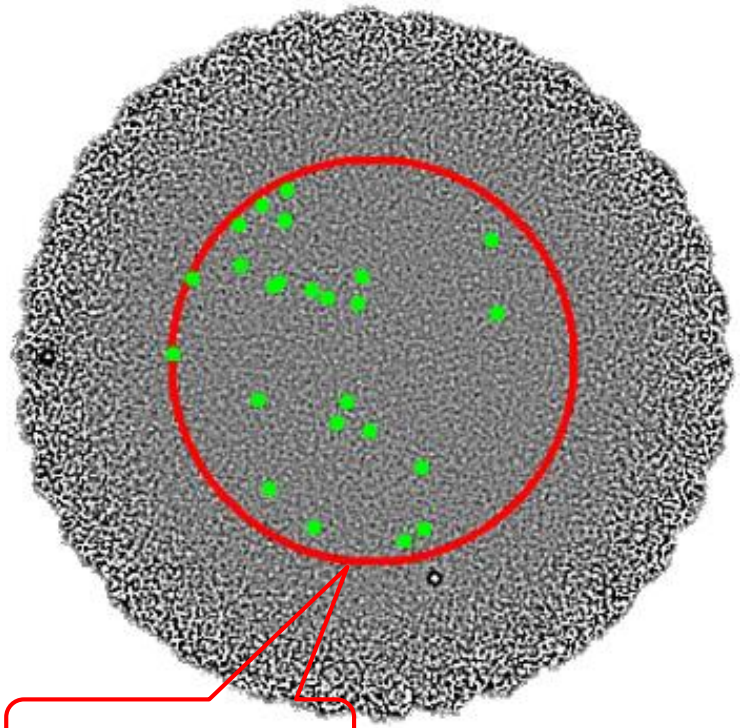




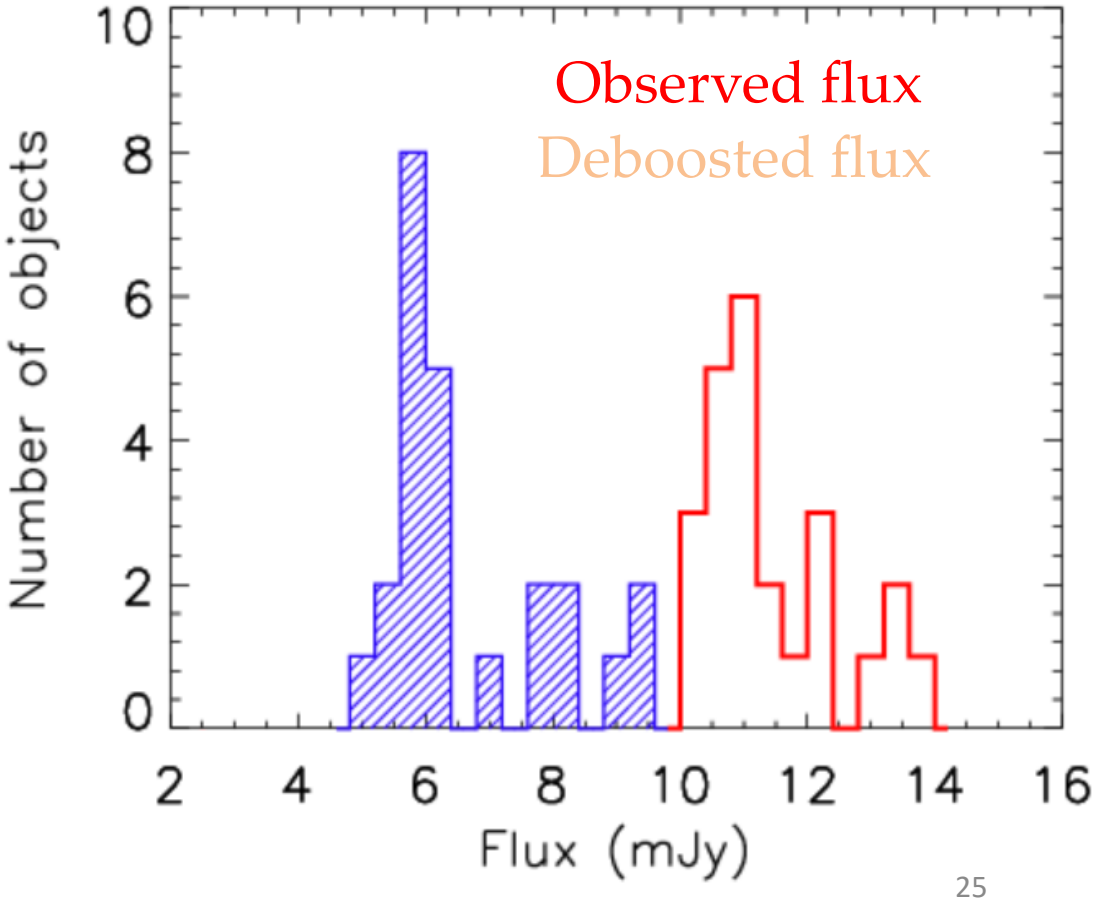
Figs from H. Seo (Jan 2018) for NEP-1 pointing, similar noise in other regions

Source Extraction

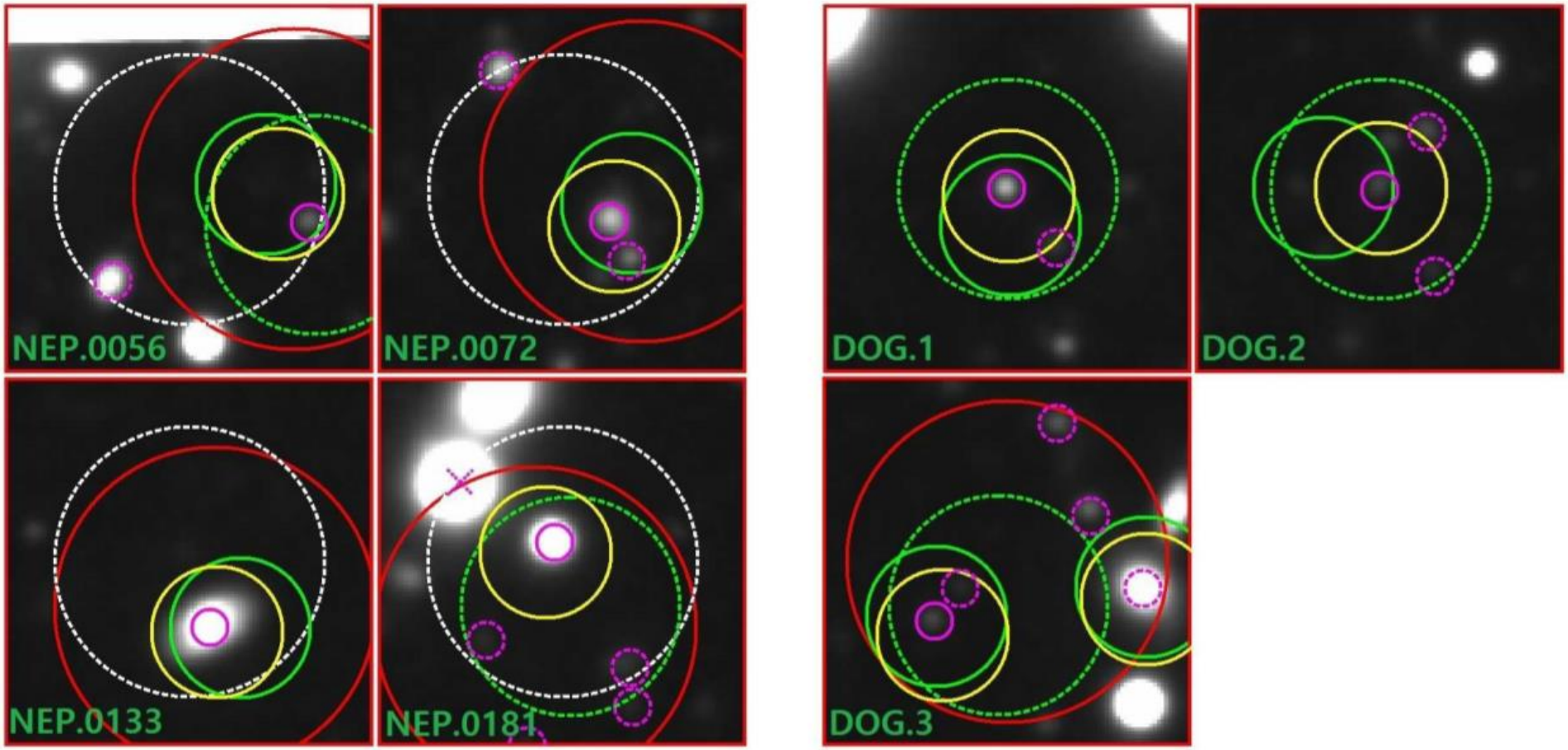
- 24 sources are detected at > 4σ
- The number will be ~500 once the survey is completed



Figs from H. Seo (Jan 2018)

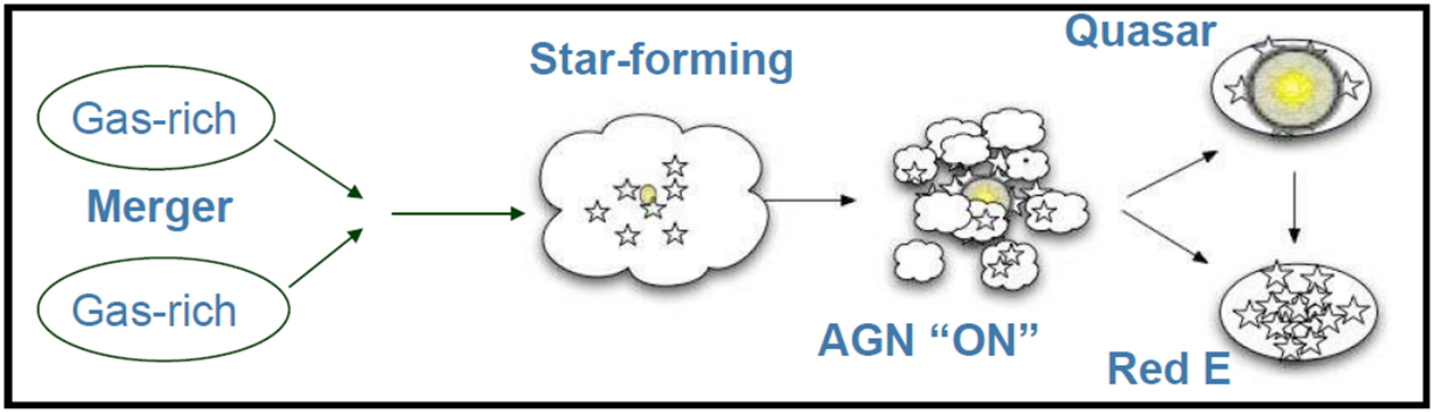


Prelimary work w/ S2CLS



850micron-detected sources (SMGs) and DOGs in the NEP-Deep region (Seo et al. 2018)

Evolution of submm galaxies?



Dey+ (2009) **SMG** ⟶ **DOG**

- Earlier-stage of merger
- SF dominated phase

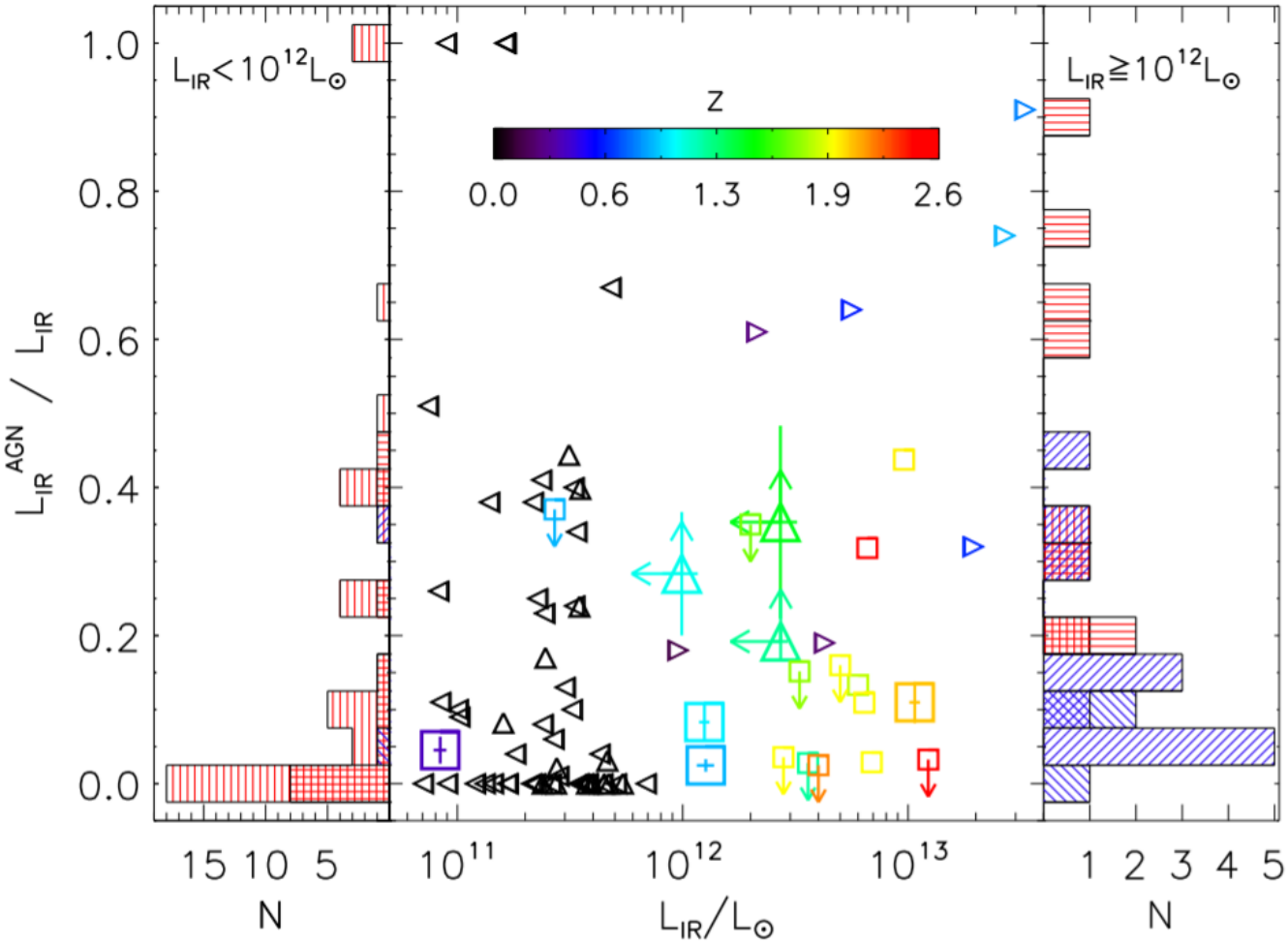
- Late-stage of merger
- AGN dominated phase

Contribution of AGN in SMG < **Contribution of AGN in DOG**

SED fitting, AGN contribution

SMGs
(squares)

DOGs
(triangles)



AGN contribution is smaller in SMGs than DOGs.

Summary-

• NEP survey – started from the MIR Deep/Wide imaging, now there are many ancillary datasets to be used in the galaxy formation and evolution studies.(Next generation missions such as EUCLID will visit NEP again)

• With JCMT/SCUBA-2 observations, we would be able to reduce uncertainties in the derived L(IR), and the SED fitting analysis of dusty galaxies in NEP region.