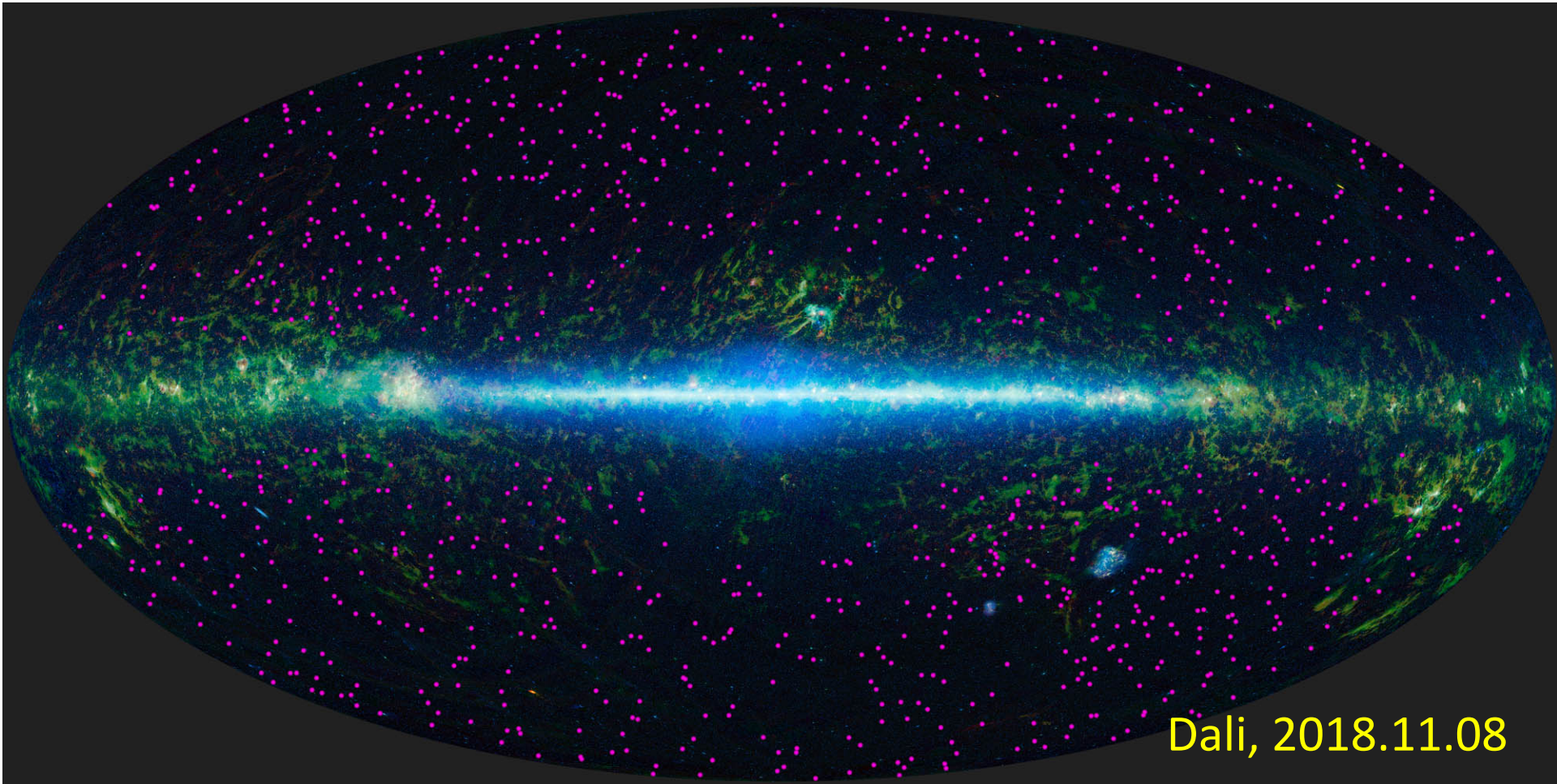
WISE Hot DOGs and AGN

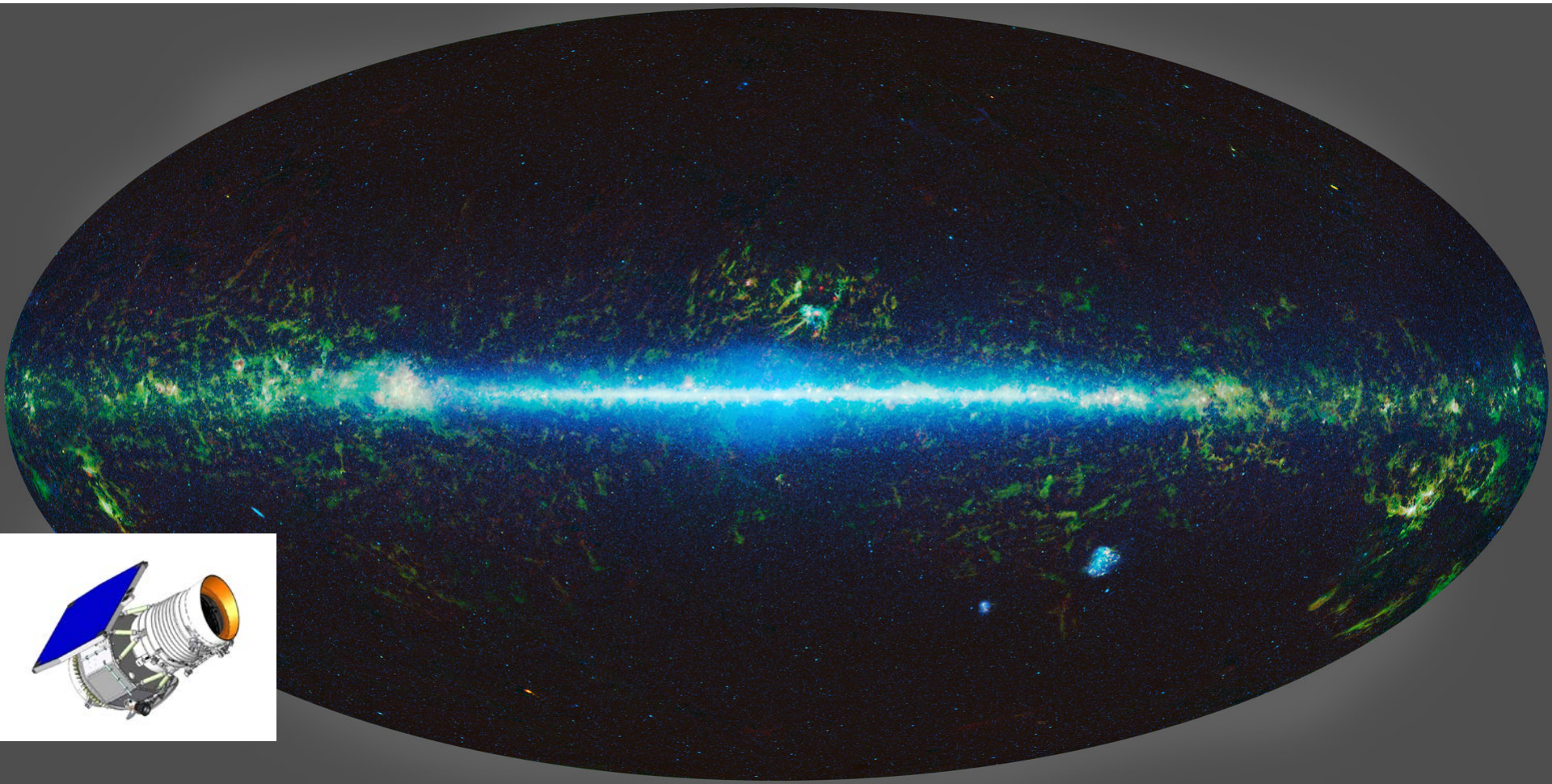
Jingwen Wu
(National Astronomical Observatories, CAS)

Collaborators: Petrer Eisenhardt(JPL), C.W.Tsai (NAOC), Andrew Blain (U. Leicester)
R. Assef, T. Diaz-Santos (U. Diego Portales), D. Stern (JPL), H. Jun (JPL), Ned Wright (UCLA)



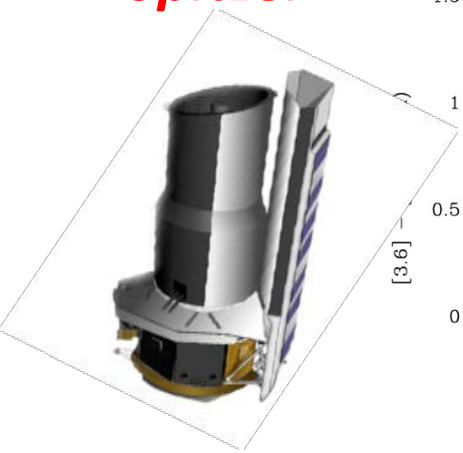
NASA's WISE mission (3.4, 4.6, 12, 22 um all-sky survey) have made major contribution to the AGN study

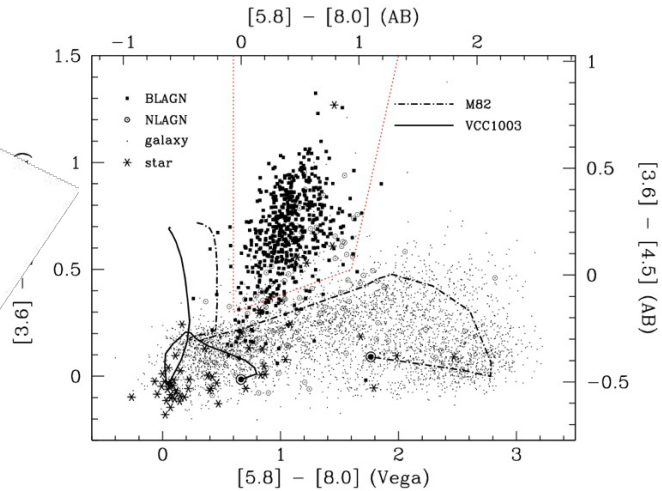
- Reveal a huge amount of hidden (obscured) AGNs
- Locating the most luminous obscured AGNs

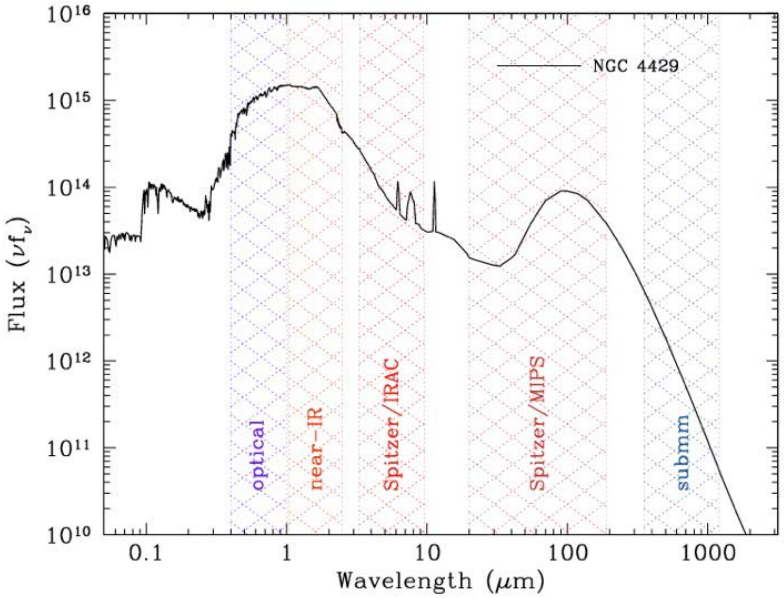


Spitzer/WISE can efficiently select AGNs:

Spitzer

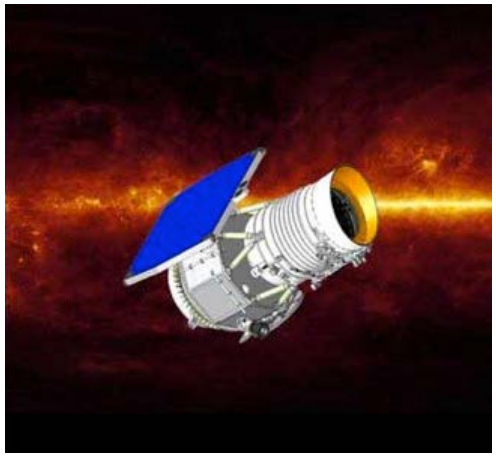


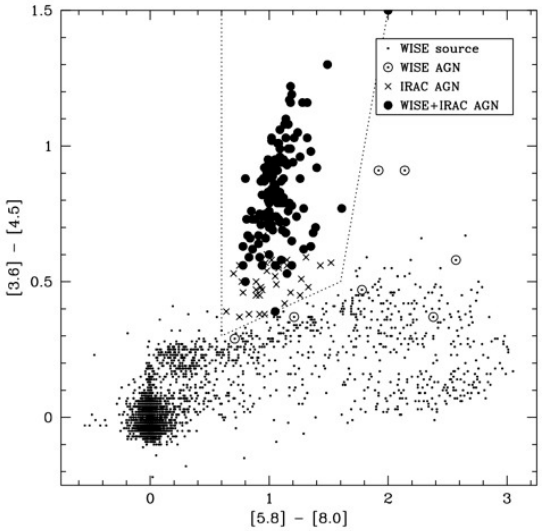




Stern et al. 2005

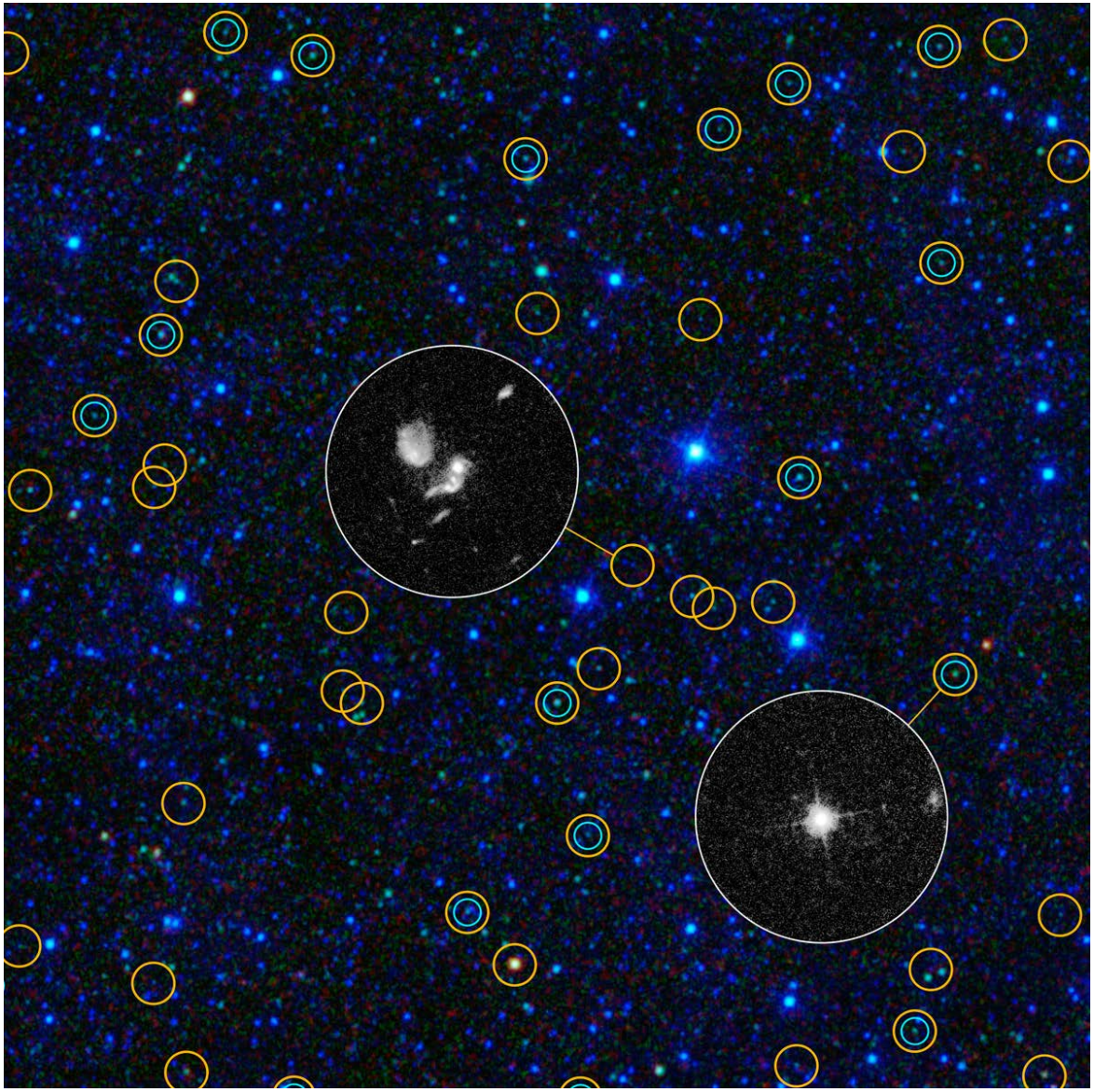
WISE





Stern et al. 2012
Assef et al. 2013

WISE reveals a hidden AGN world:
There are more obscured than unobscured AGNs



Green circle: SDSS AGNs
Yellow circle: WISE AGNs

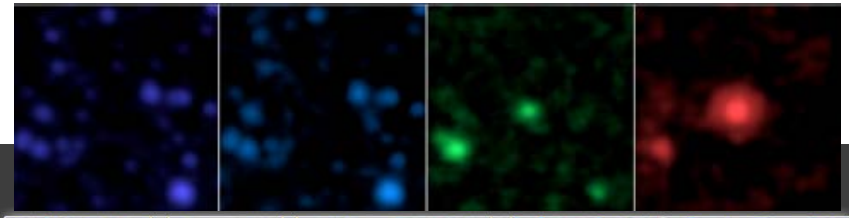
Obscured: Un-obscured

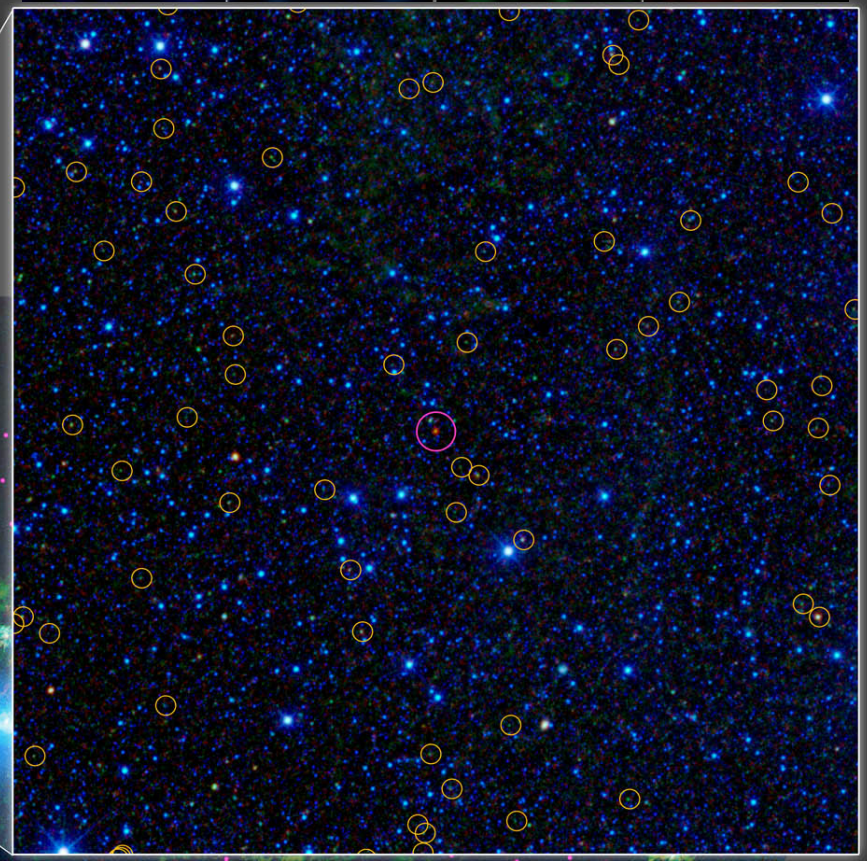
COSMOS: 3:1

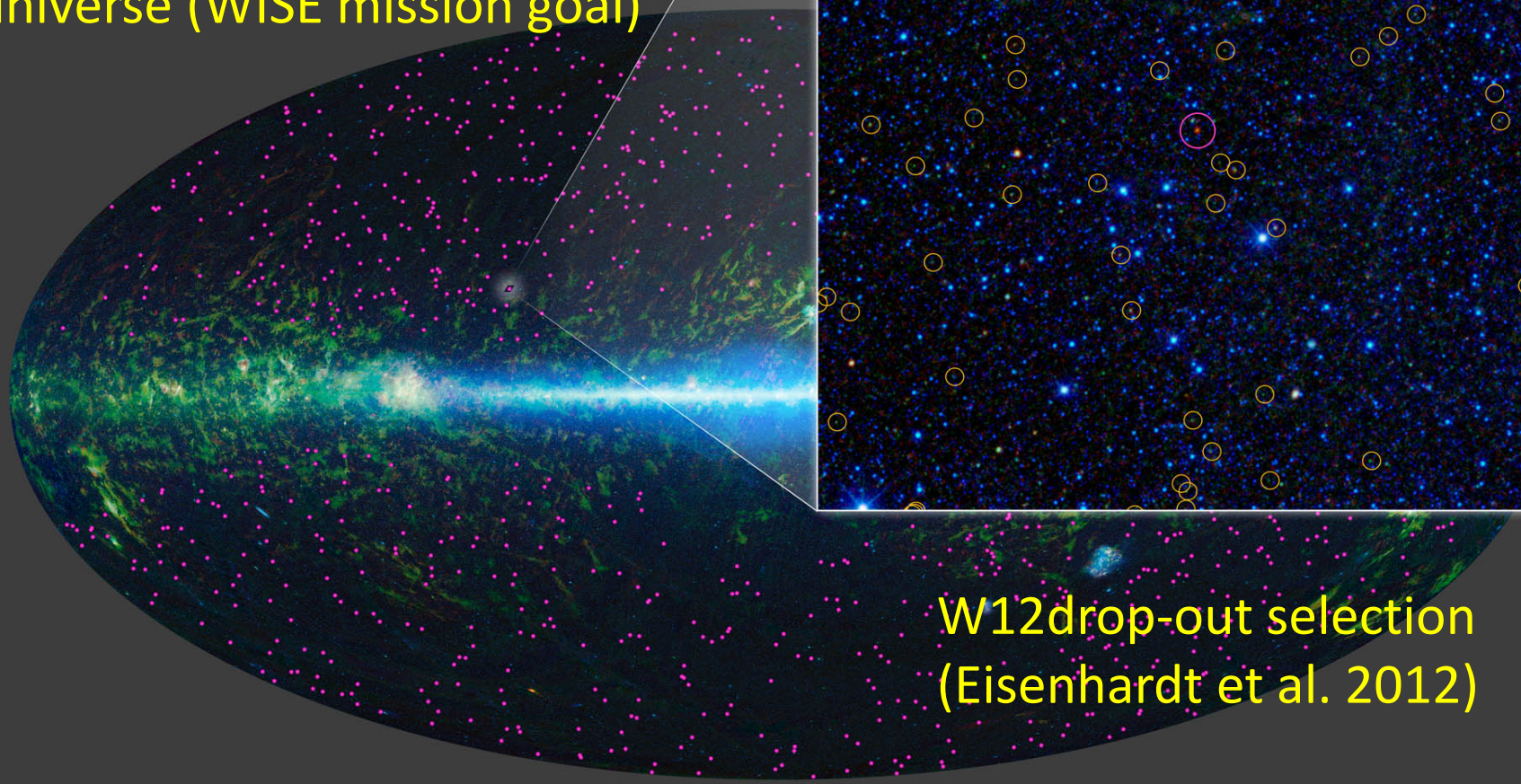
Bootes: 6:1

(Stern et al. 2012)
(Assef et al. 2013)

We discovered Hot DOGs, the reddest, dustiest WISE galaxies; The most luminous obscured galaxies in the universe (WISE mission goal)







W12drop-out selection (Eisenhardt et al. 2012)

Plot Credit: C.W.Tsai

intensive follow-up campaigns

- > 200 Spectra & redshifts from Keck/GMOS-S/Palomar
- > 900 *Spitzer* IRAC1+IRAC2
- > 200 *Herschel* PACS+SPIRE
- > 200 Opt/IR photometry with NOAO facilities
- > 40 CSO SHARCII+Bolocam
- > 10 JCMT SCUBA2
- > 30 with EVLA
- > 25 with *HST*
- >25 *Chandra, XMM, NuSTAR*
- > 10 ALMA follow-ups

Publications of Hot DOGs by our group:

Eisenhardt et al. 2012; Wu et al. 2012, 2014, 2018,
Griffith et al. 2012; Bridge et al. 2013; Jones et al. 2014;
Stern et al. 2014; Assef et al. 2015; 2016, Tsai et al. 2015; 2018,
Ricci et al. 2016, Díaz-Santos et al. 2016, 2018

Hot DOGs Highlight

- High redshift:

  1<z<4.6, mostly at z~2-3

- Hyper-luminous:

  Lbol ~10^{13} $L_\odot$ -10^{14} $L_\odot$,

  ~10% > $10^{14}L_\odot$(ELIRGs)

  No sign of lensed

- Hot

  Tdust ~ 60-100K

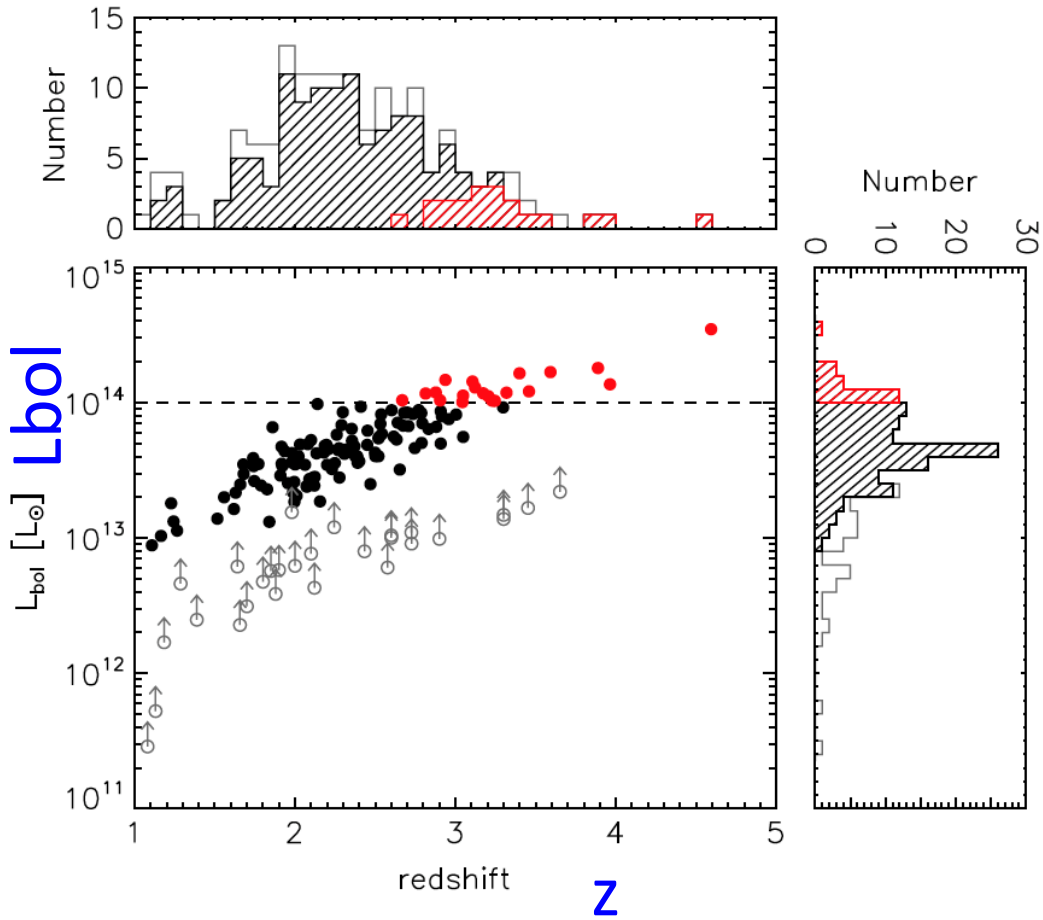
- Rare

  1 per 30 dg^2

- Highly Obscured, AGN

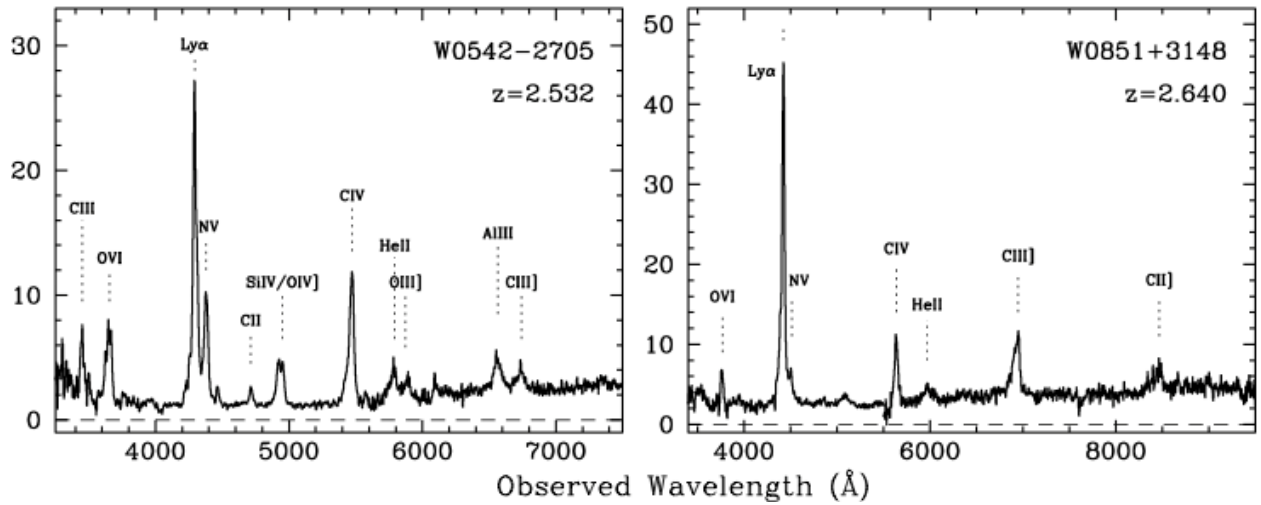
  Av ~ 20-60;

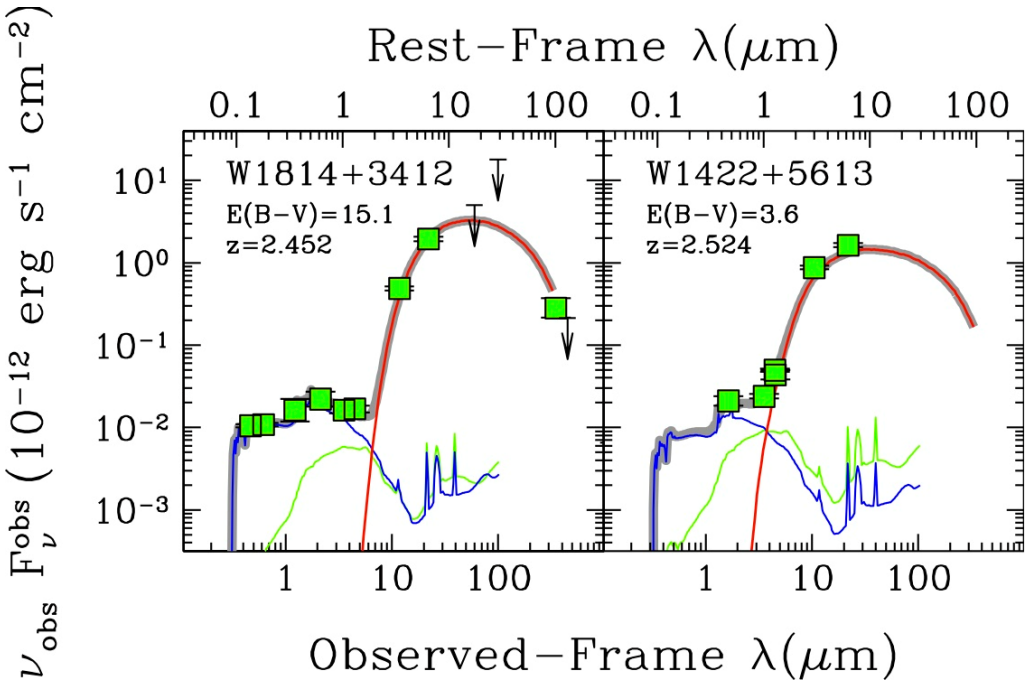
  $\log N_{H2}$~24, Compton thick.



(Tsai et al. 2015)

Characteristic AGN emission lines, most are type II (Obscured).



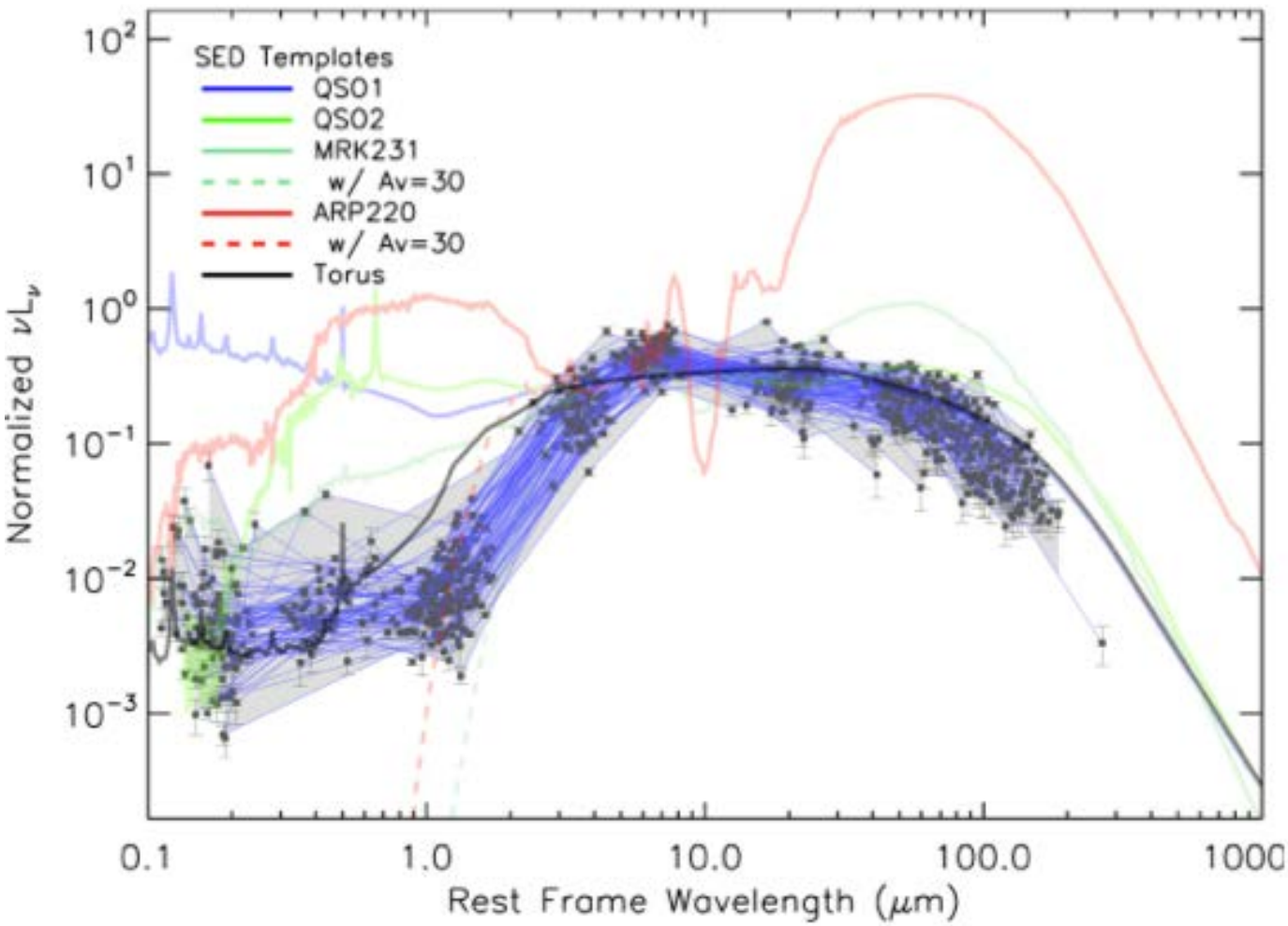


AGN dominates luminosity

Blue: Starburst
Green: Sbc spiral
Red: Type 1 AGN with Av extinction

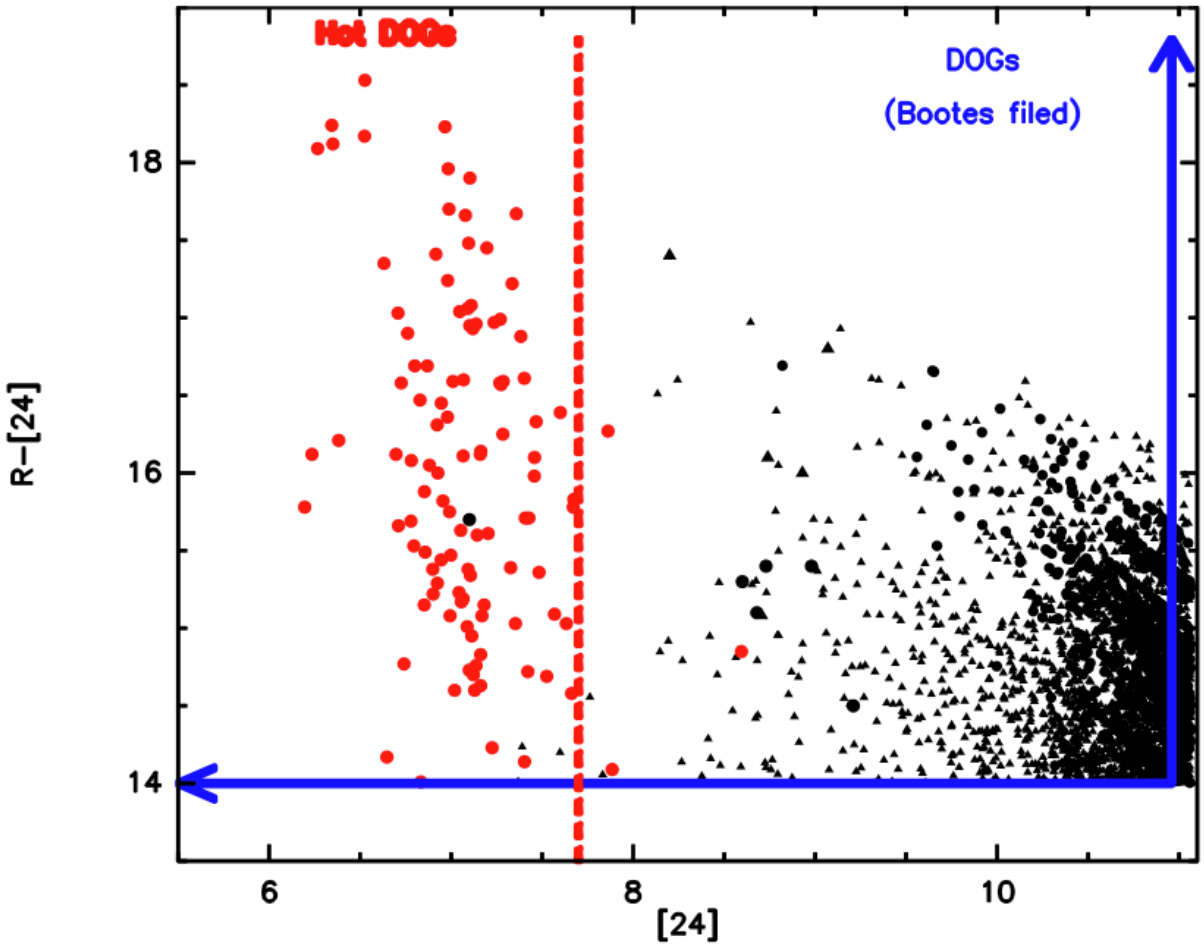
Hot DOG SEDs:

SED: Optical+Spitzer+WISE+Herschel+CSO



- Consistent SED shapes, but quite different from known galaxy templates
- Unusually high mid-IR to submm ratios, dominated by hot dust emission.

Plot Credit: Chao-Wei Tsai



- They qualify DOG selection criterion ([24]>0.3mJy, R-[24]>14, Dey at al. 2008)

- They are much hotter
- 10 times more luminous
- 10,000 times rarer

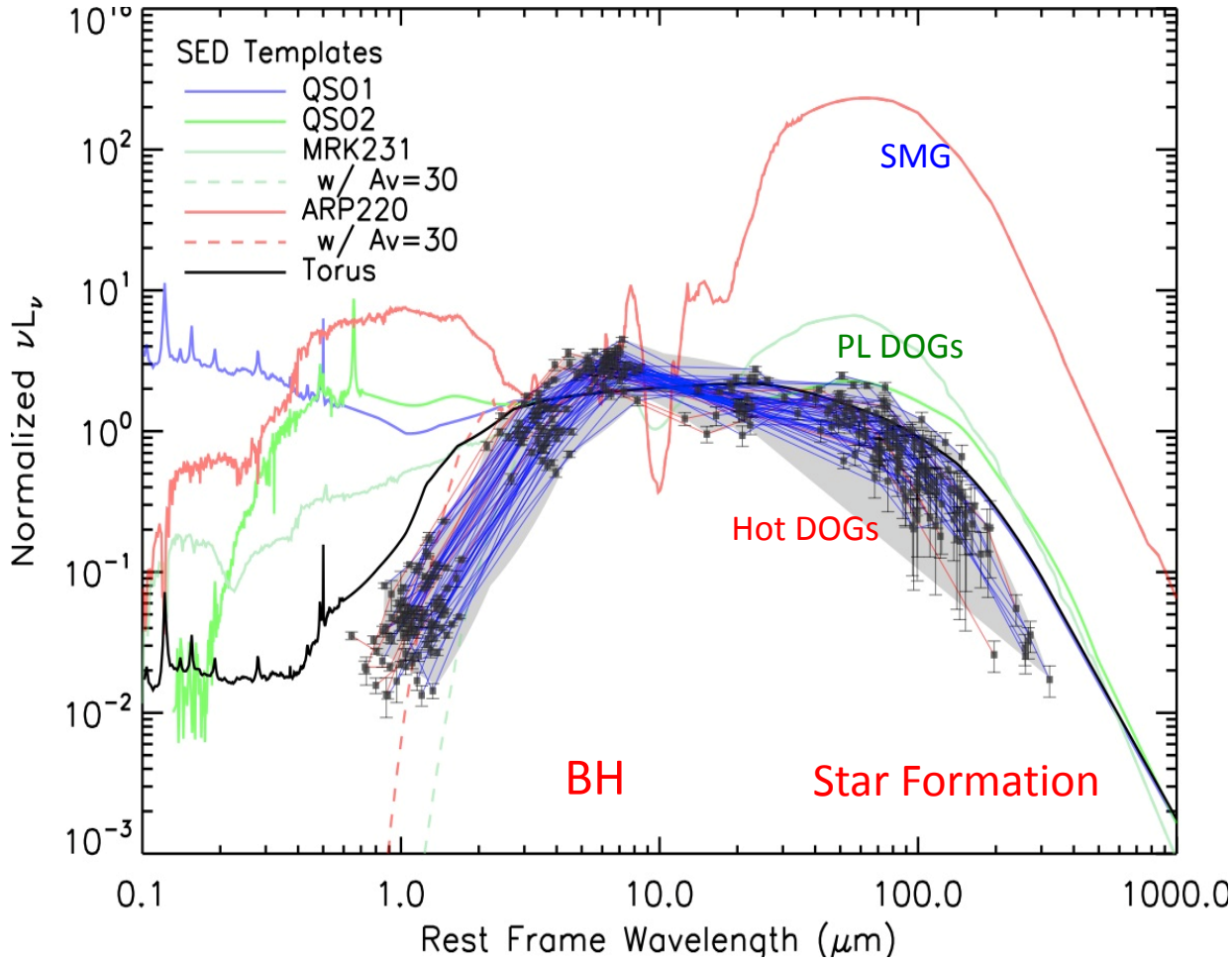
So we call them

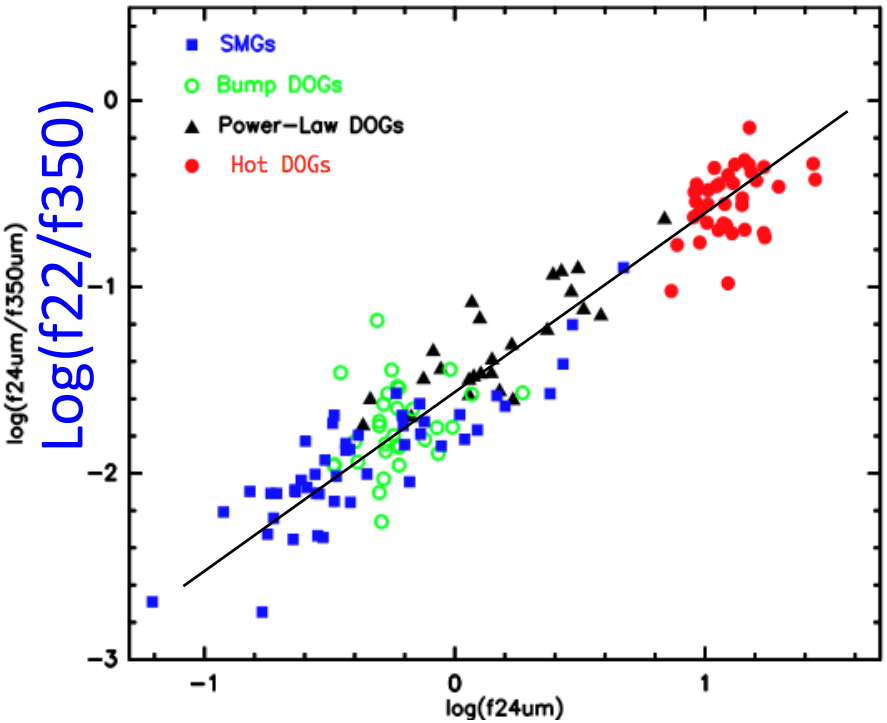
Hot DOGs

(Wu et al. 2012)

Given the similar z distribution with SMGs and DOGs; all are AGN+starburst systems

An evolutionary connection to SMGs and DOGs ?



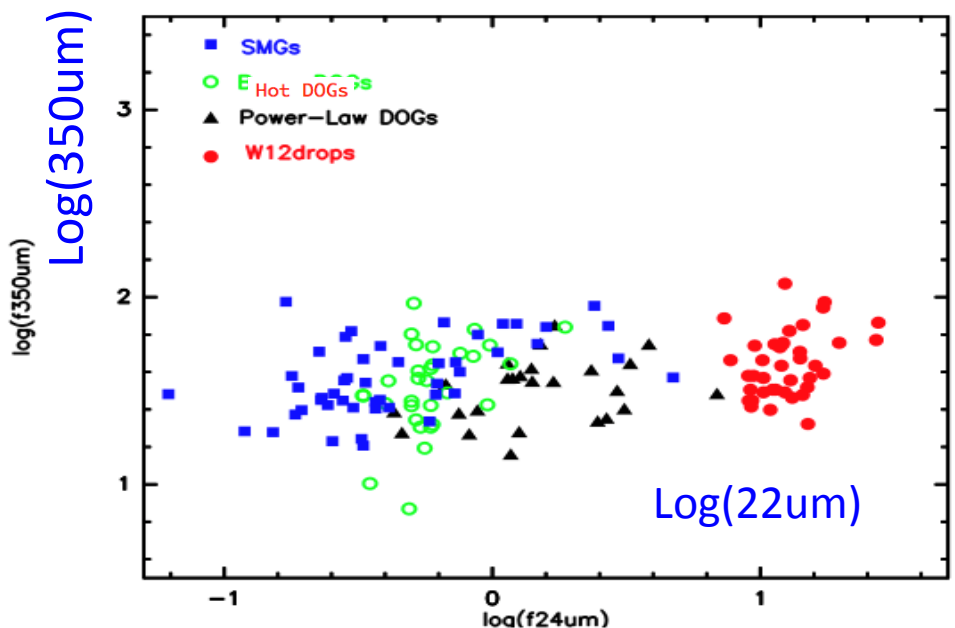


SMGs

Bump (starburst) DOGs

Power-law DOGs

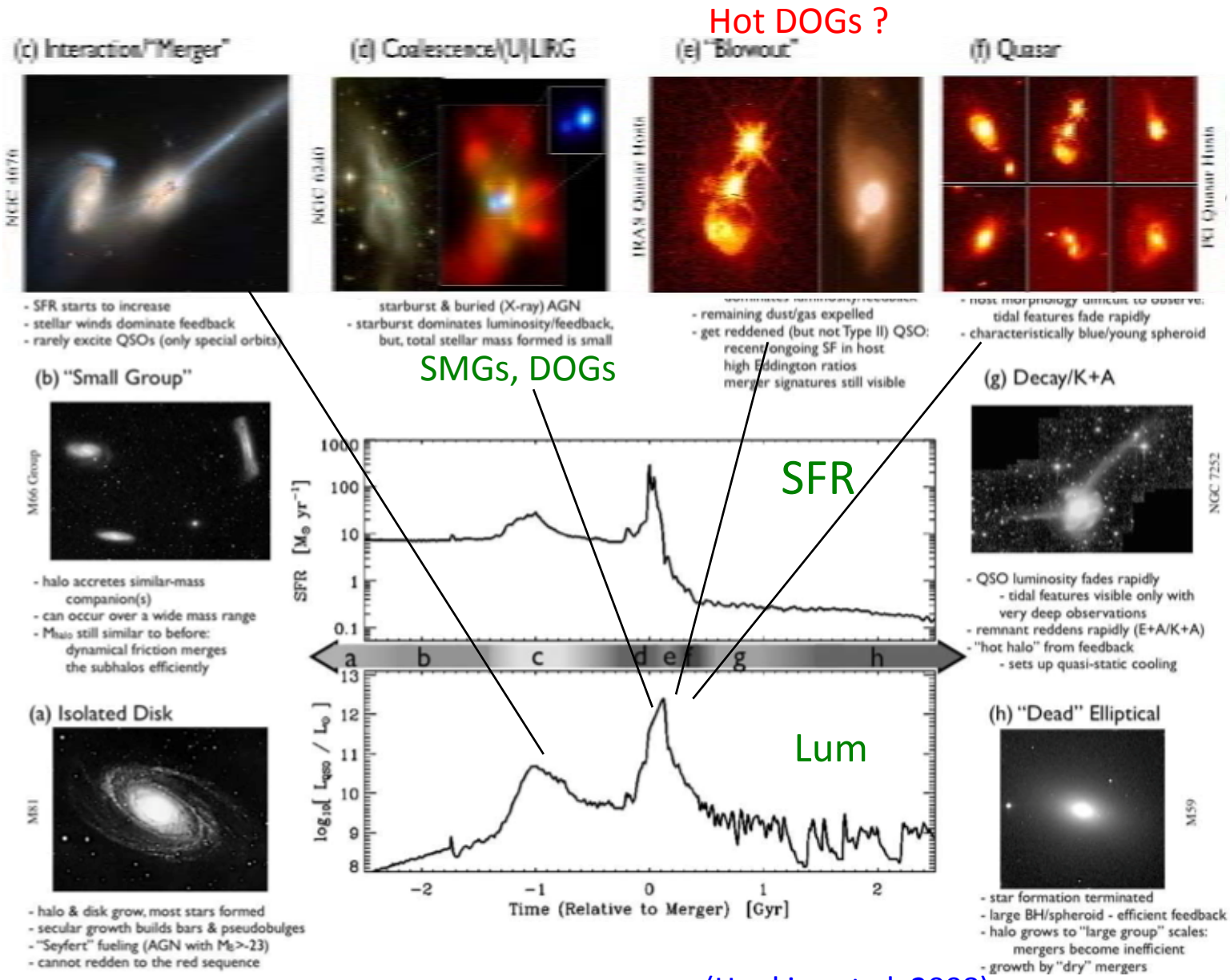
Hot DOGs



An evolution driven by the growth of the central SMBHs ?

(Wu et al. 2012)

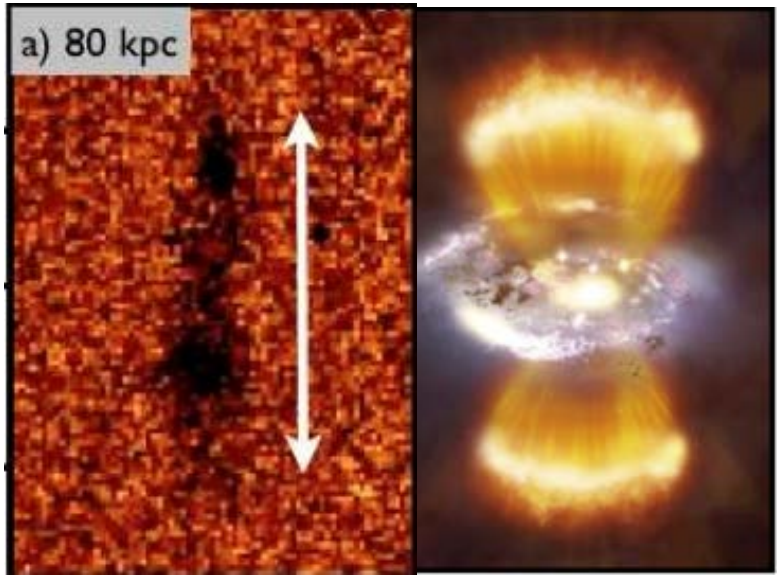
A popular model of galaxy evolution via merging



(Hopkins et al. 2008)

Is Hot DOG the “blow-out” phase？

Other Evidence:
A large fraction show
Lyman A Blobs > 20 kpc

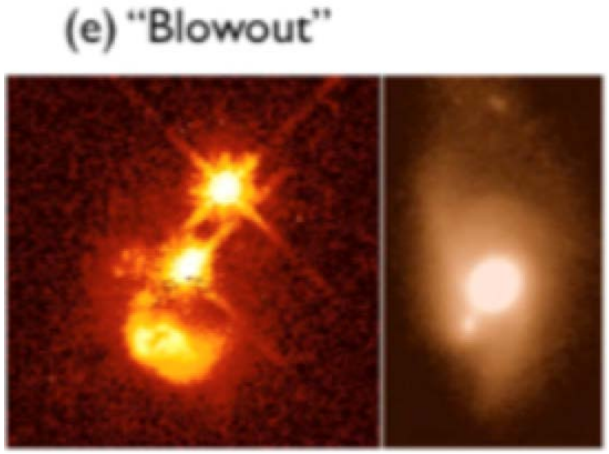


(Hot DOG LABs, Bridge et al. 2013)

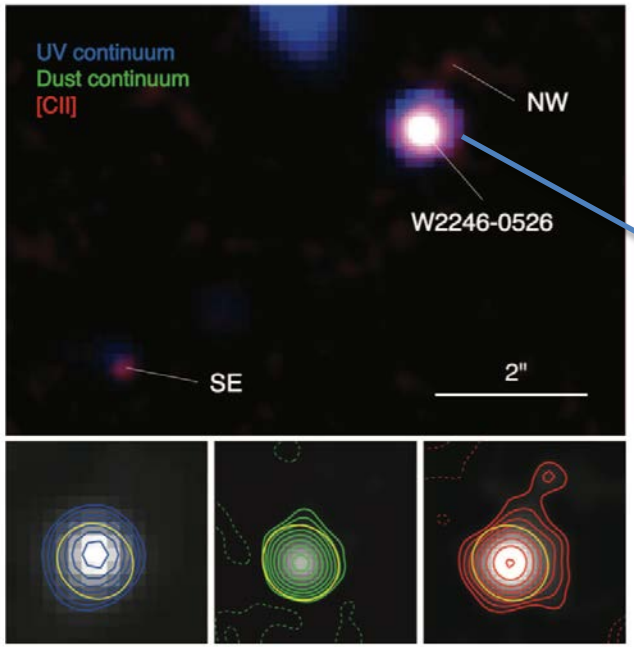
The high luminosity and hot dust

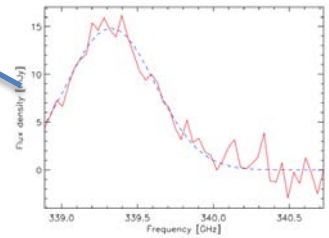
An evolutionary sequence?

SMG -> DOGs -> Hot DOGs -> QSOs

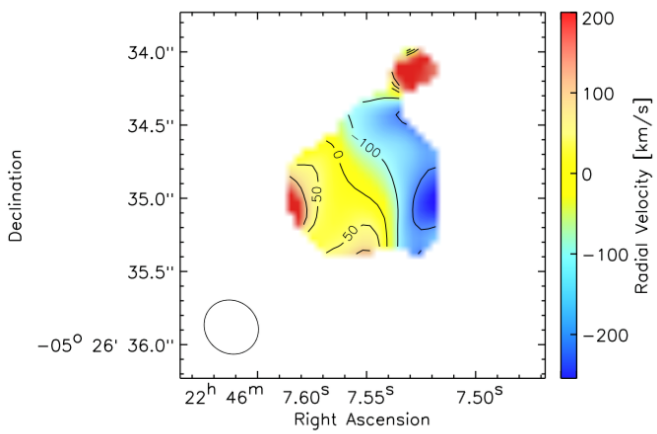


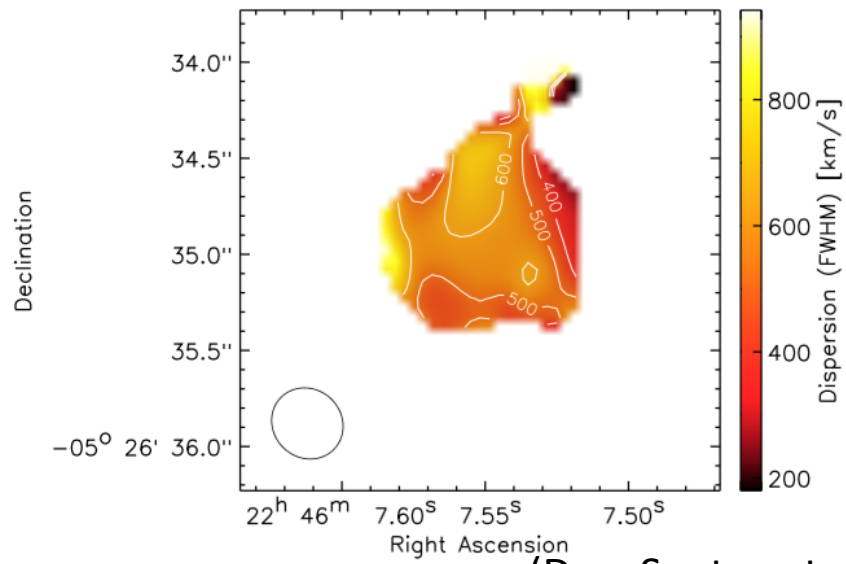
Evidence: CII lines in the most luminous obscured galaxy: Hot DOG W2246-05 (z=4.6)





Isotropic outflow or Explosive event



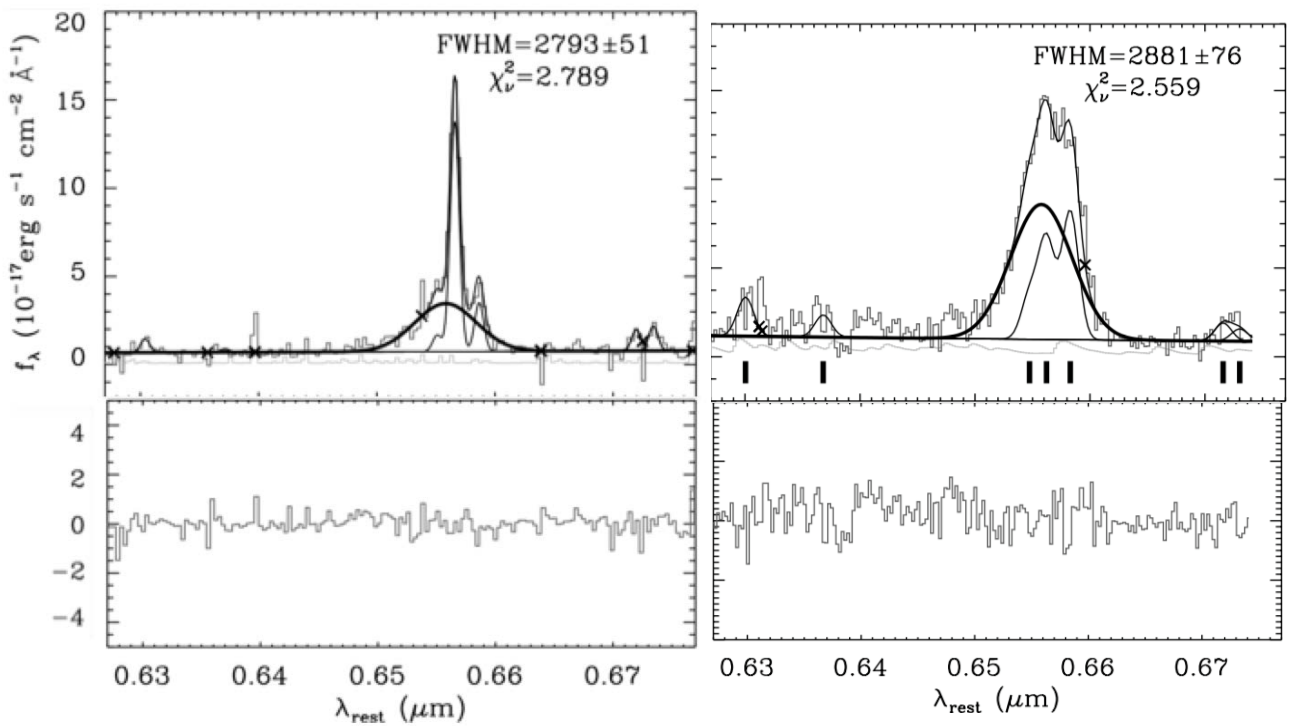


(Diaz-Santos et al. 2016)

An ALMA CII observation reveals a surprisingly large (>2.5 kpc), uniform, extended turbulence (FWHM~600 km/s) albeit much smaller velocity gradient (~100km/s).

The unusually high-luminosity of Hot DOGs can either come from a very massive SMBH well above BH-host relation, or from a normal SMBH with very high accretion rate, even super Eddington accretion.

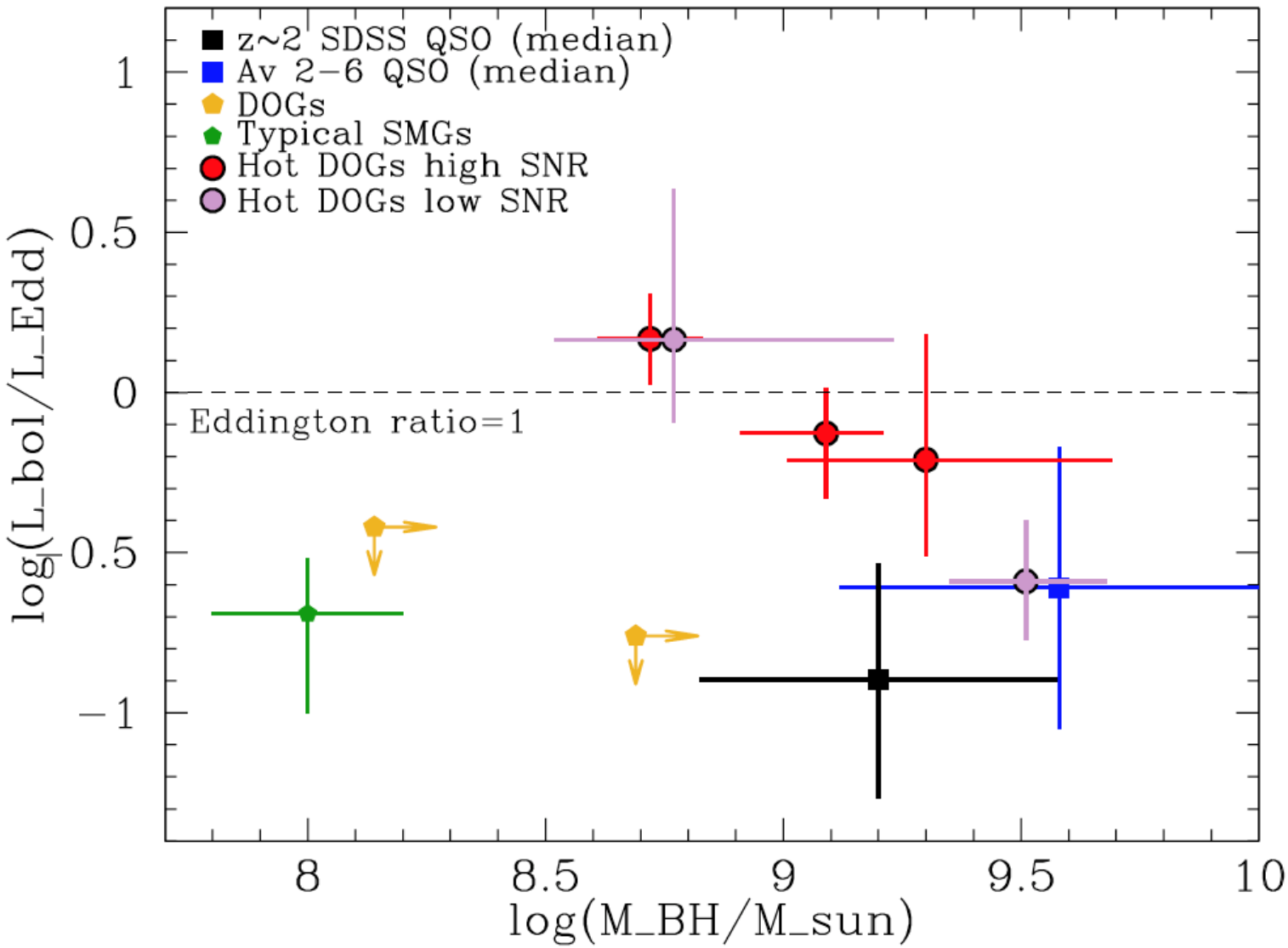
Directly measure their BH masses.



BH masses of 5 z~2 Hot DOGs from Keck/Gemini

(Wu et al. 2018)

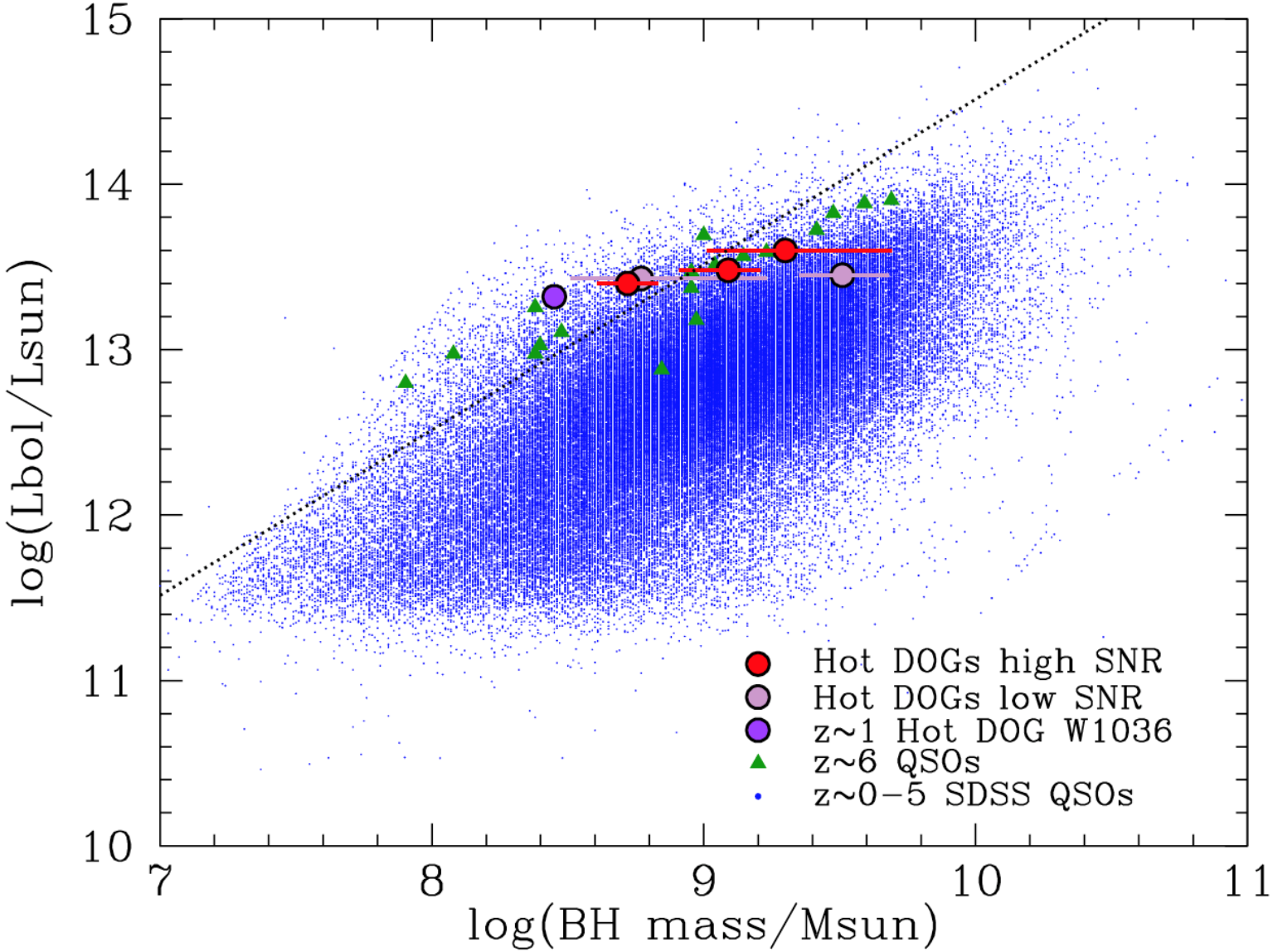
z~2 Hot DOGs have BH masses greater than SMGs and DOGs， comparable to QSOs， but with a much higher accretion rates that are close to Eddington limit.



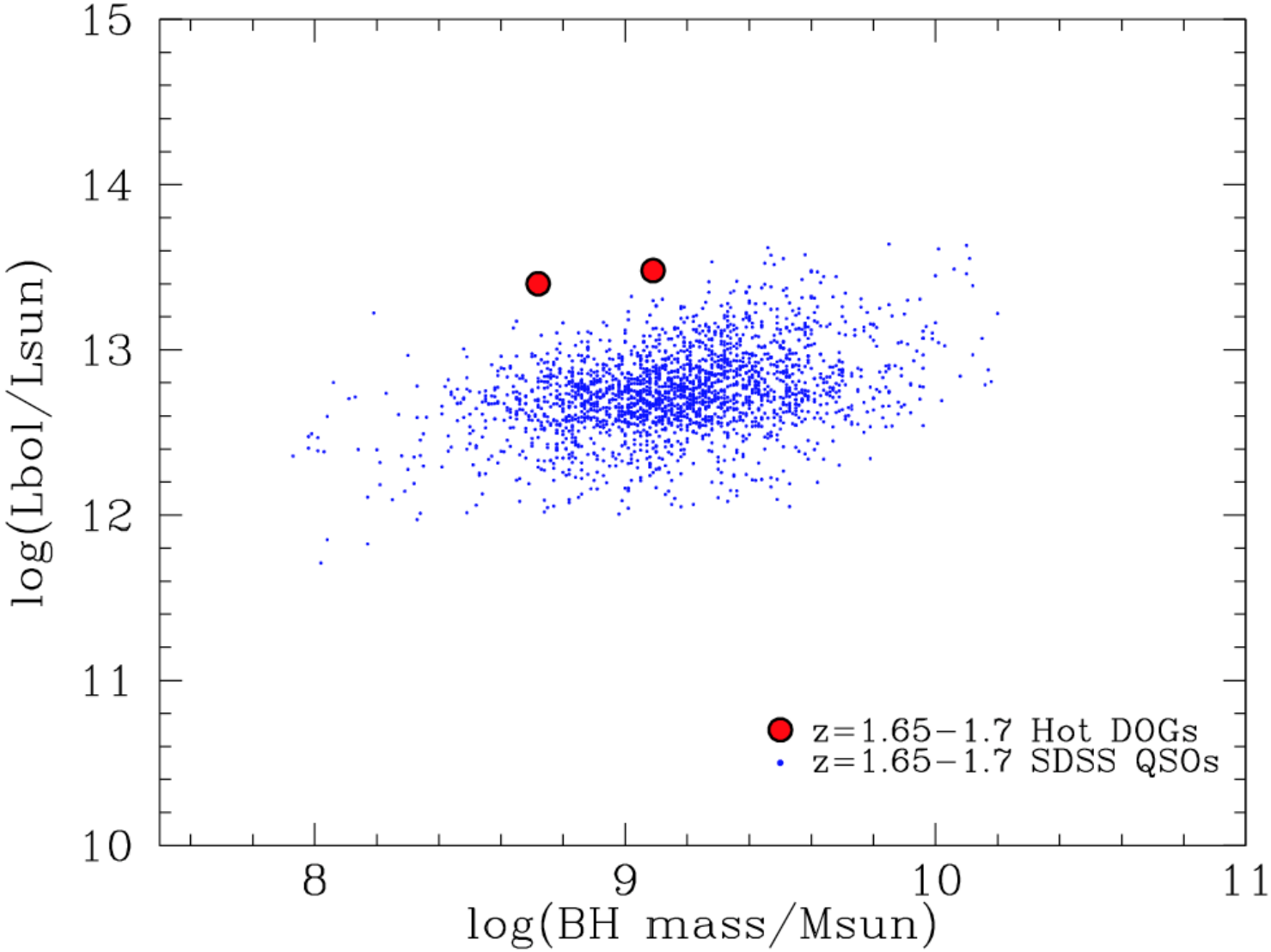
Wu et al. 2018

Compare Hot DOGs to all SDSS QSOs:

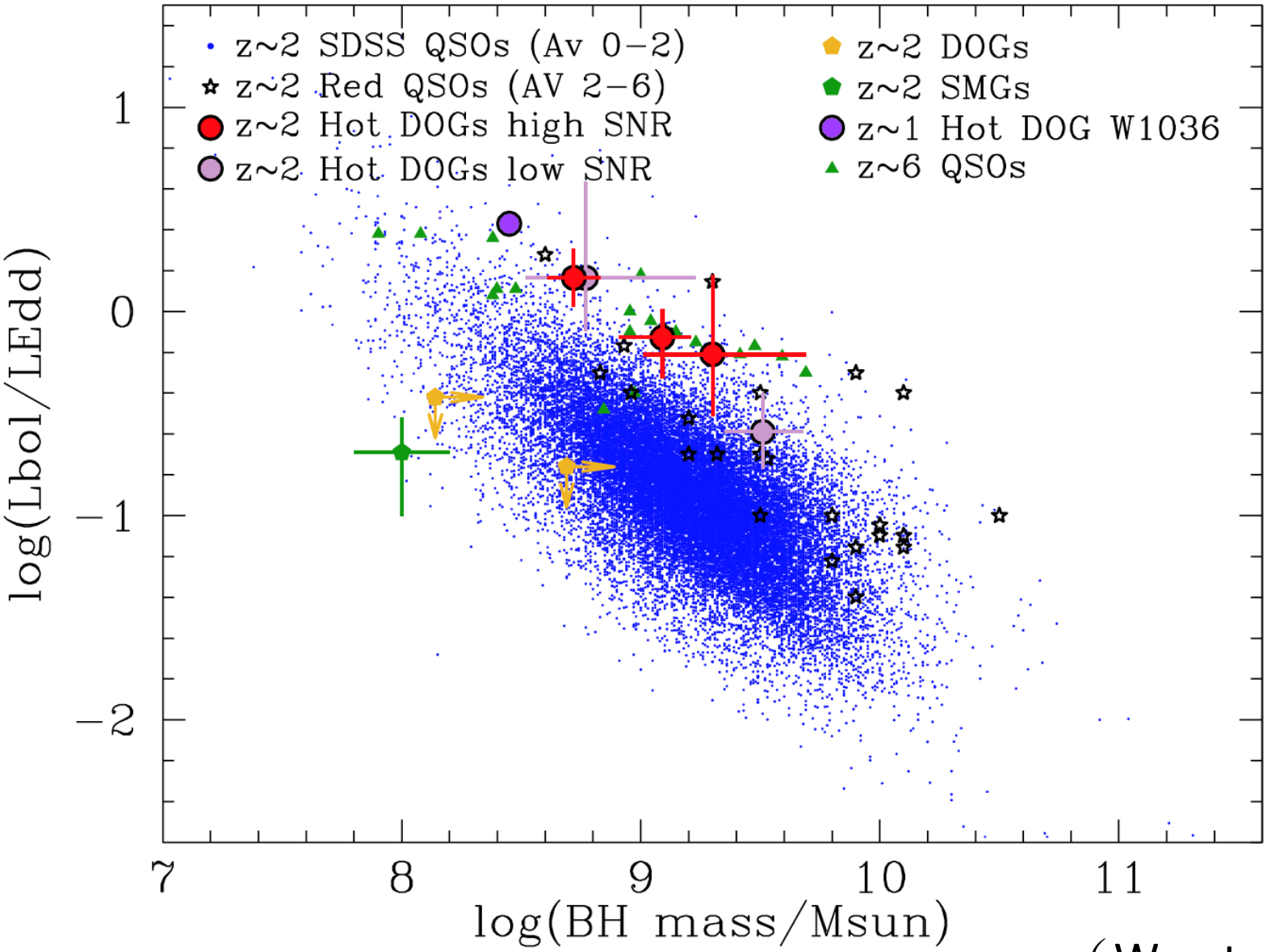
Maximum level luminosity for given BH masses



Hot DOGs and SDSS QSOs at similar redshifts

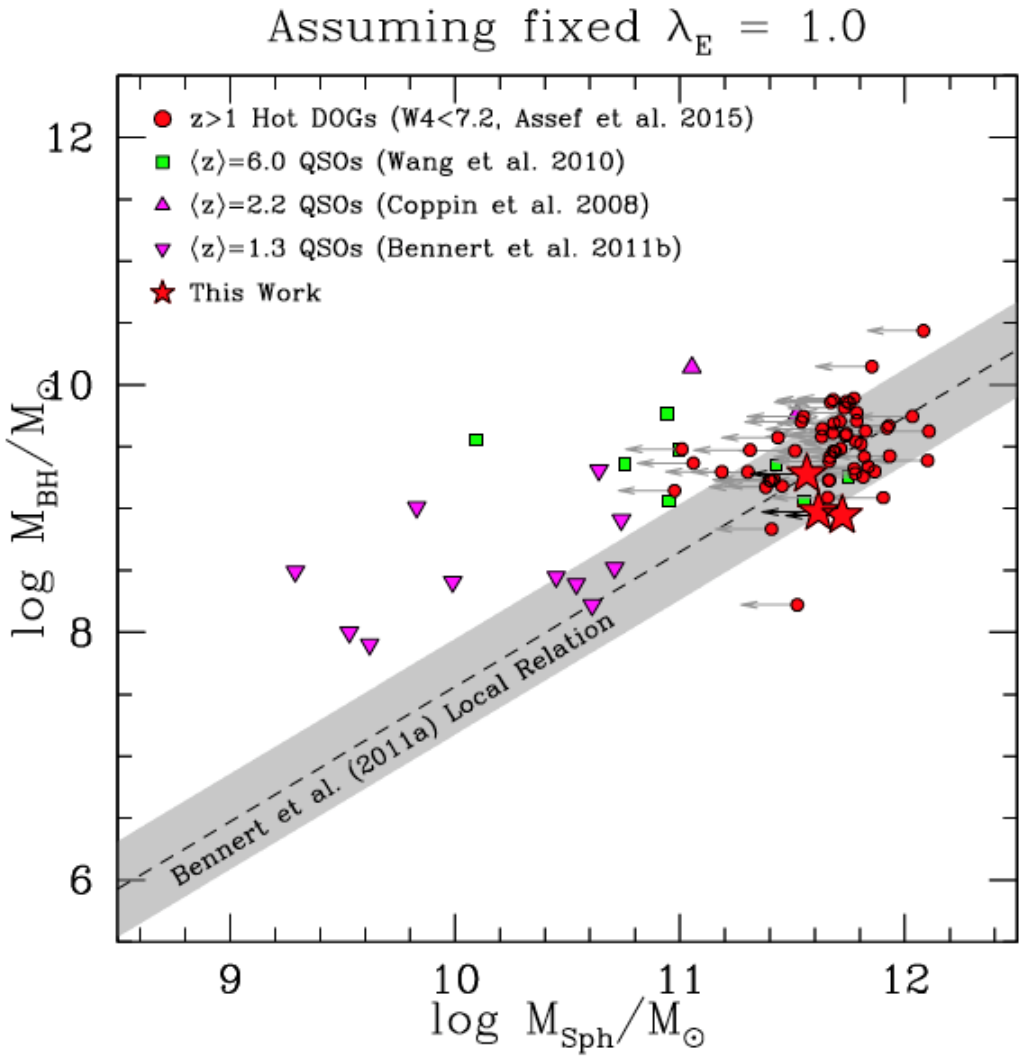


An evolutionary trace of quasars at z~2



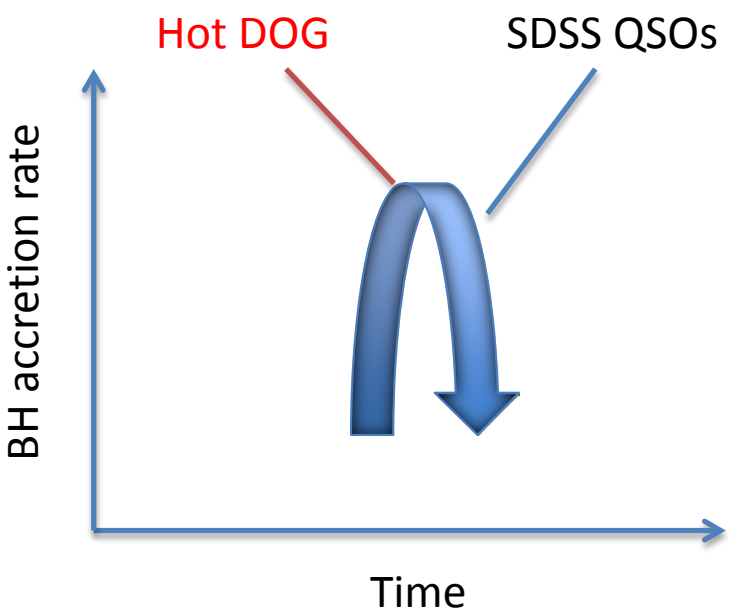
（Wu et al. 2018)

z~2 Hot DOGs & z~6 quasars



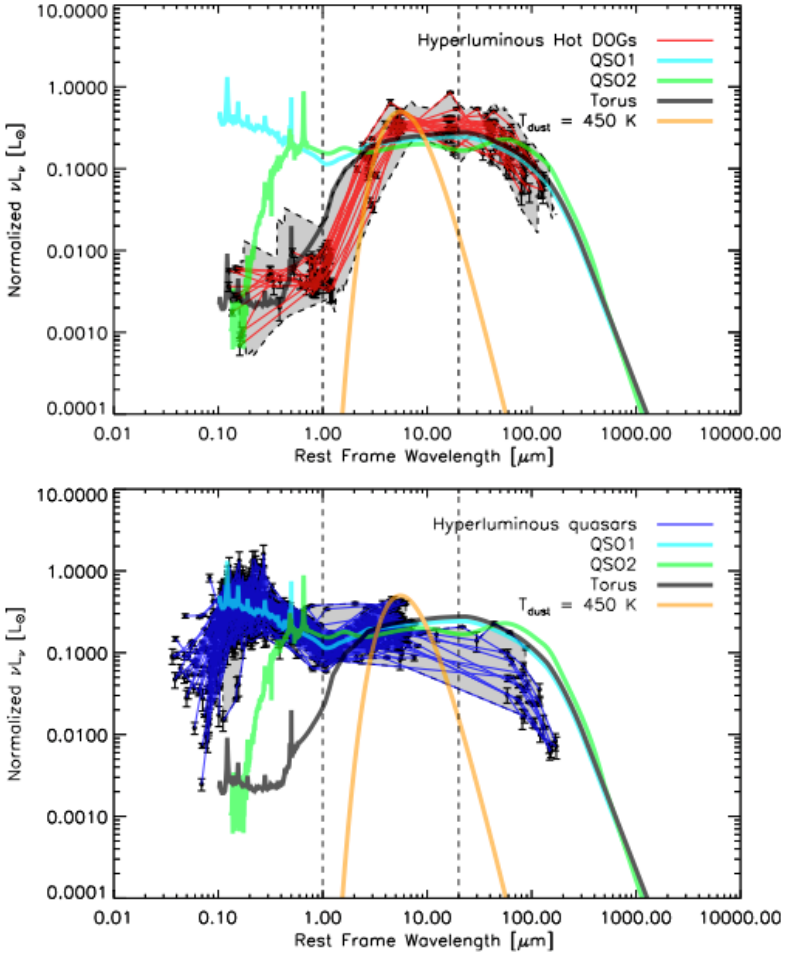
They may overlap in M_BH – M_host relation plot

Z=2-3 galaxies accretion history



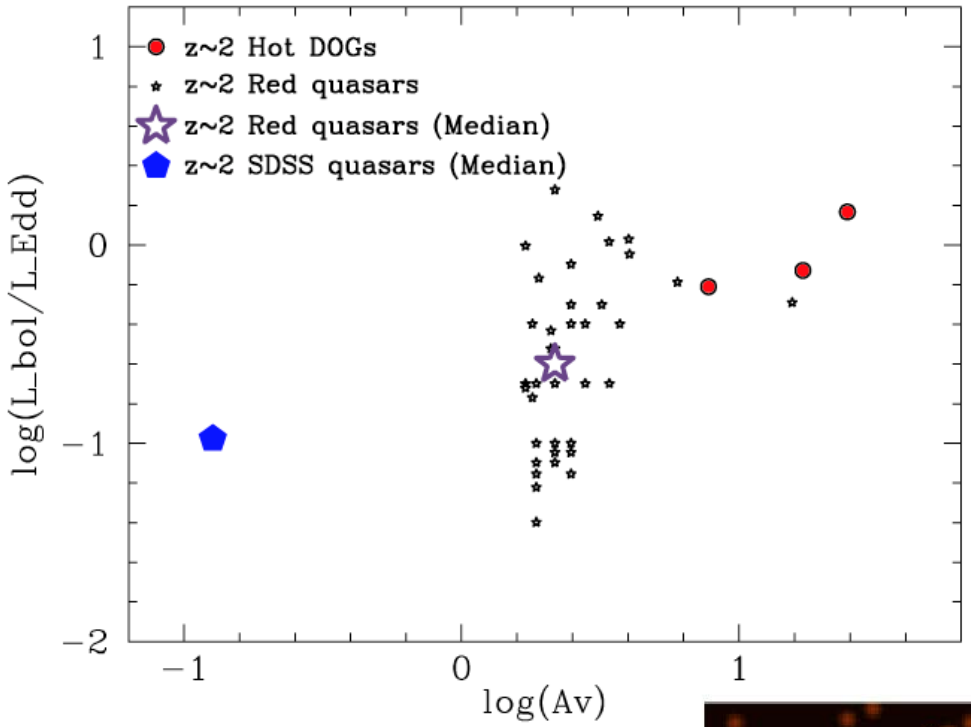
From Hot DOGs to the most luminous SDSS QSOs: ELIRGs

Staying at high luminosity, when BH accretion rates reach and cross a peak.

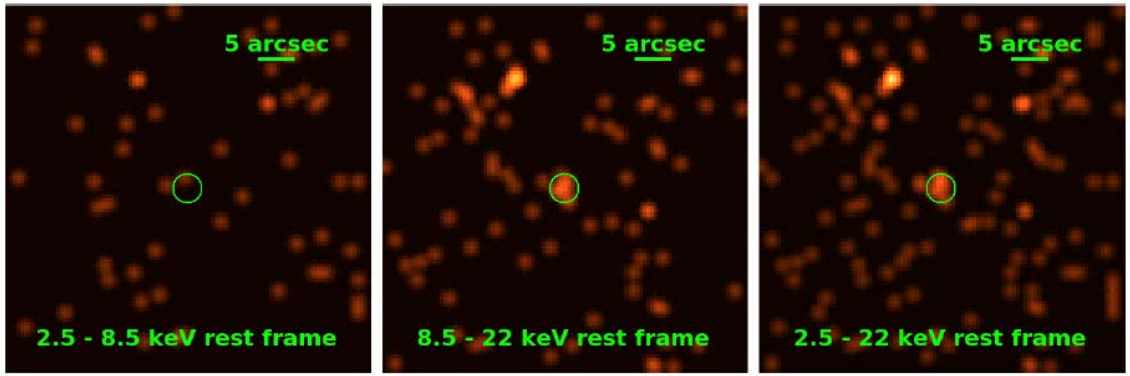


(Tsai et al. 2015)

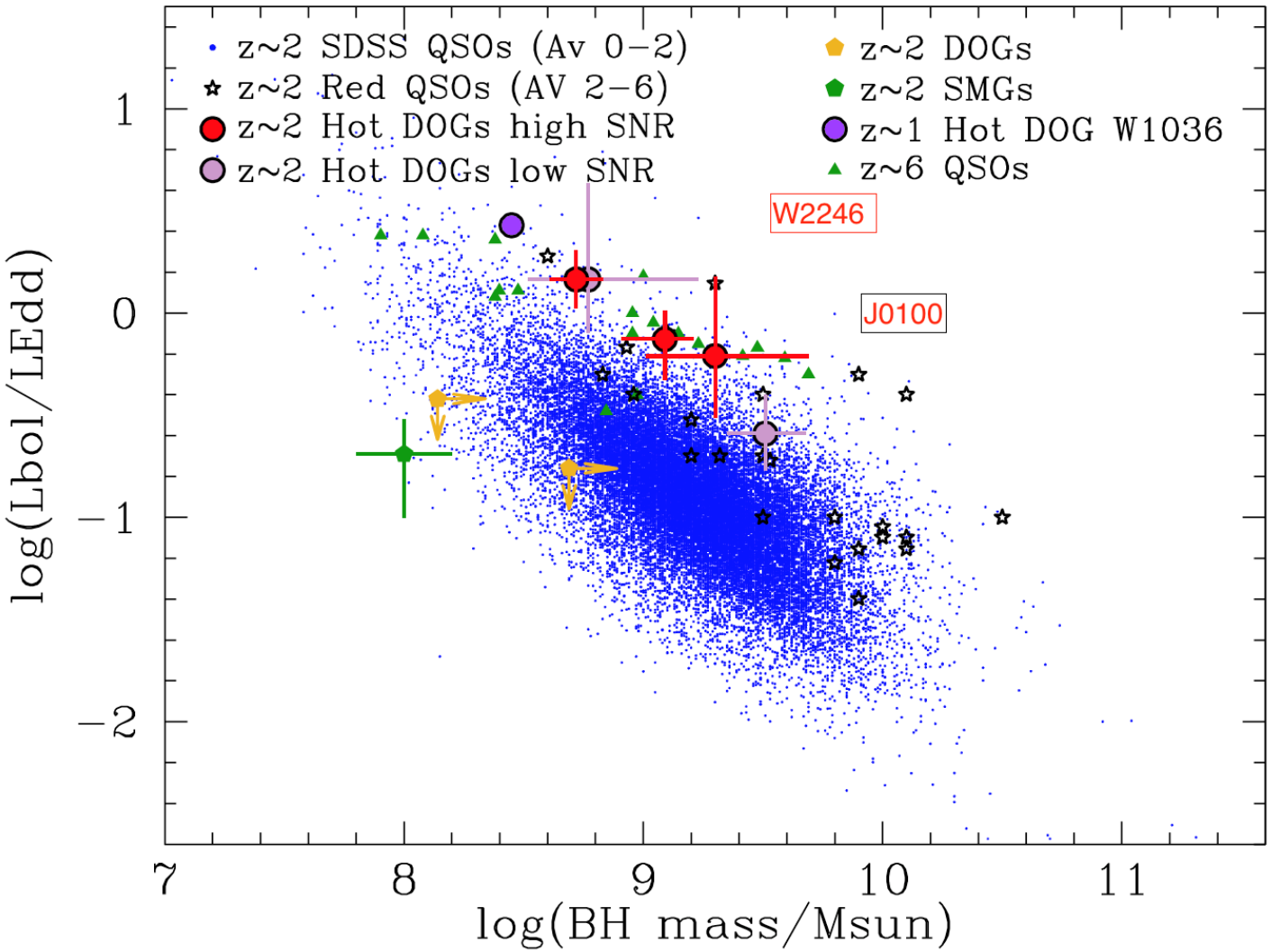
Hot DOGs may not only the peak phase of accretion, but also the heaviest obscuration phase.



X-ray observations towards 20 top luminouse Hot DOGs
⇒ They are compton thick
Vito et al. (2018.)

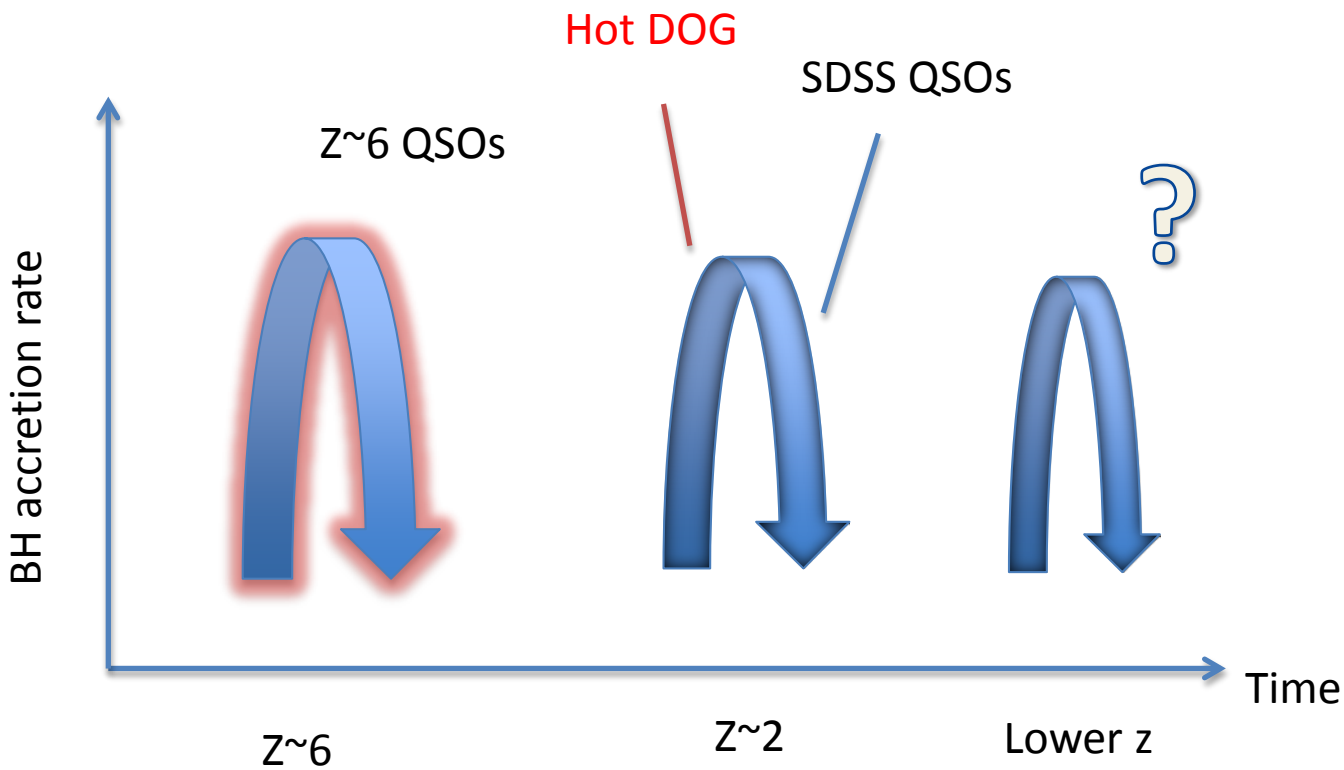


An evolutionary trace + accretion history, extends to other redshifts



SMG/DOG – Hot DOGs – Red quasars – SDSS quasars

Such a phase during galaxy evolution should be seen in other redshifts

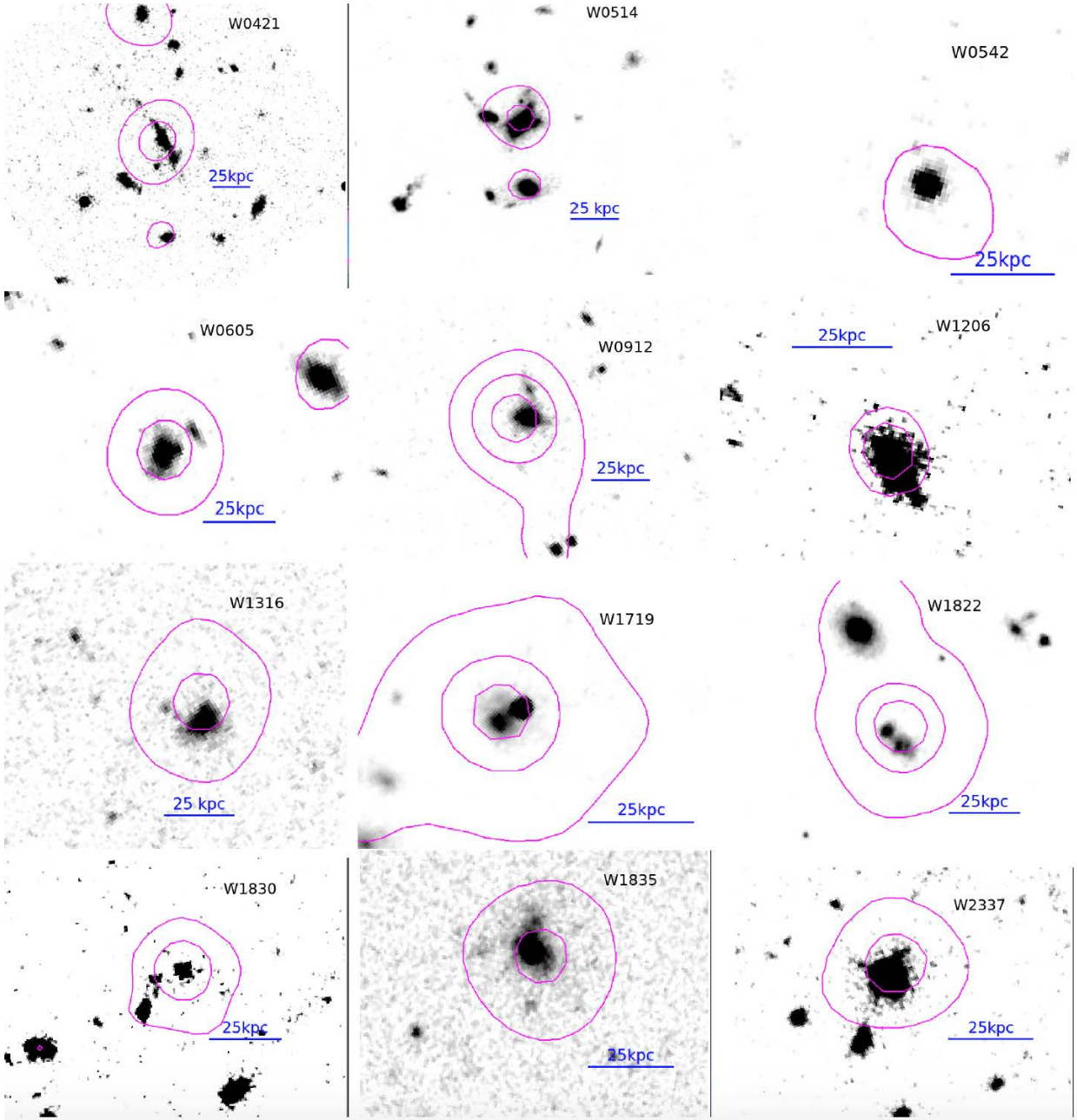


Catching the high-accreting phase of SMBHs throughout cosmic time

Earliest generation
Gas-rich environment
Duty cycle~1

Peak generation
Feedback terminate accretion & starburst

Recent generation



HST/WFC3 images for 12 z~2 Hot DOGs (Farrah et al. 2017)

Summary

- Hot DOGs are a linking population to connect obscured and un-obscured quasars.

- Hot DOGs may accrete at the highest possible rates for their BHs. This is also true to known z~6 quasars, which make them the most luminous objects in their own epoch.

- Suggested evolutionary sequence: SMG--DOG—Hot DOG—red QSO— SDSS QSO. Hot DOGs may be the peak phase of both the accretion and the obscuration.

- Hot DOGs may exist in different cosmic epochs.