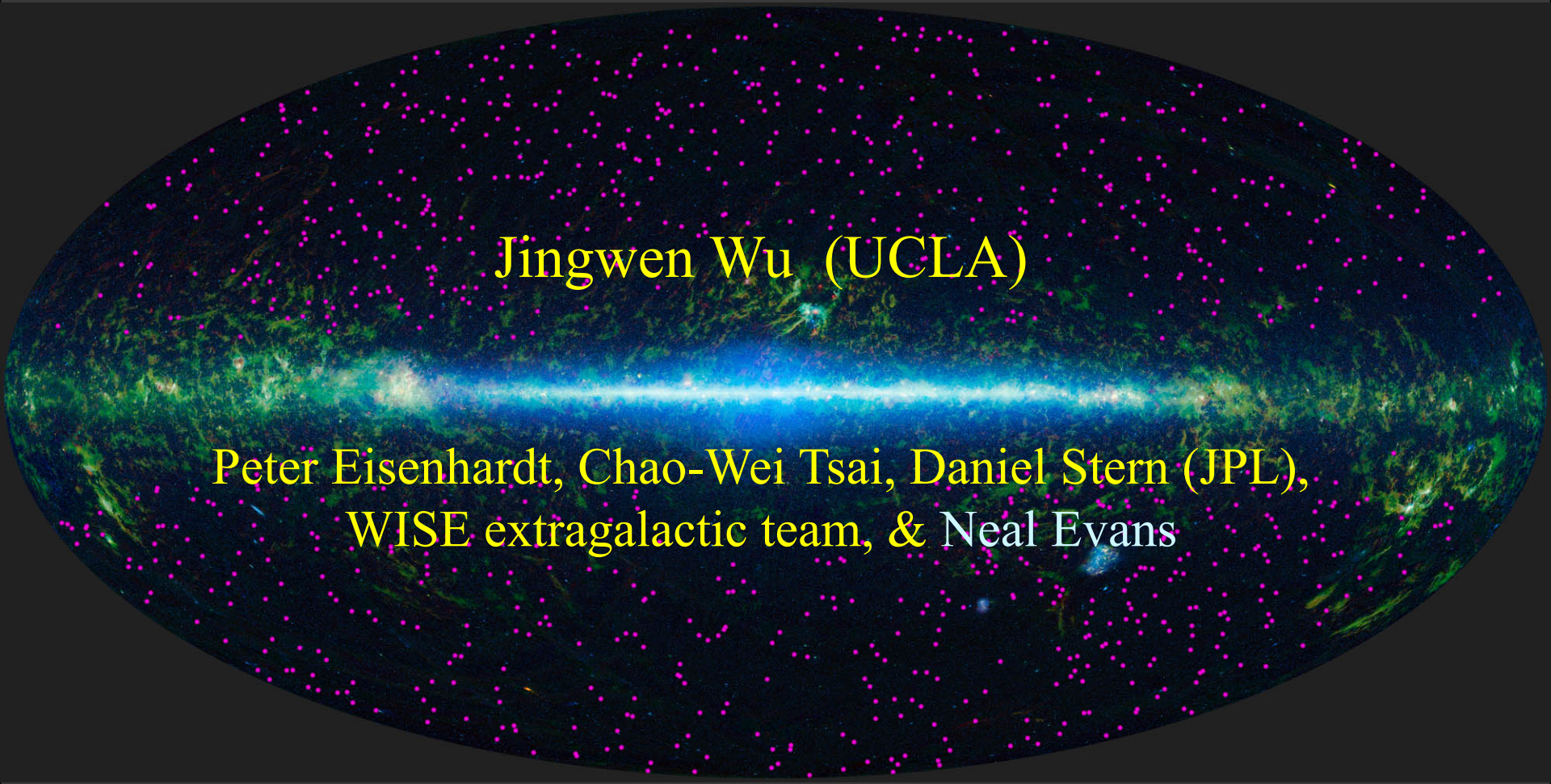
Hot DOGs: WISE Discovers the Most Luminous Galaxies in the Universe



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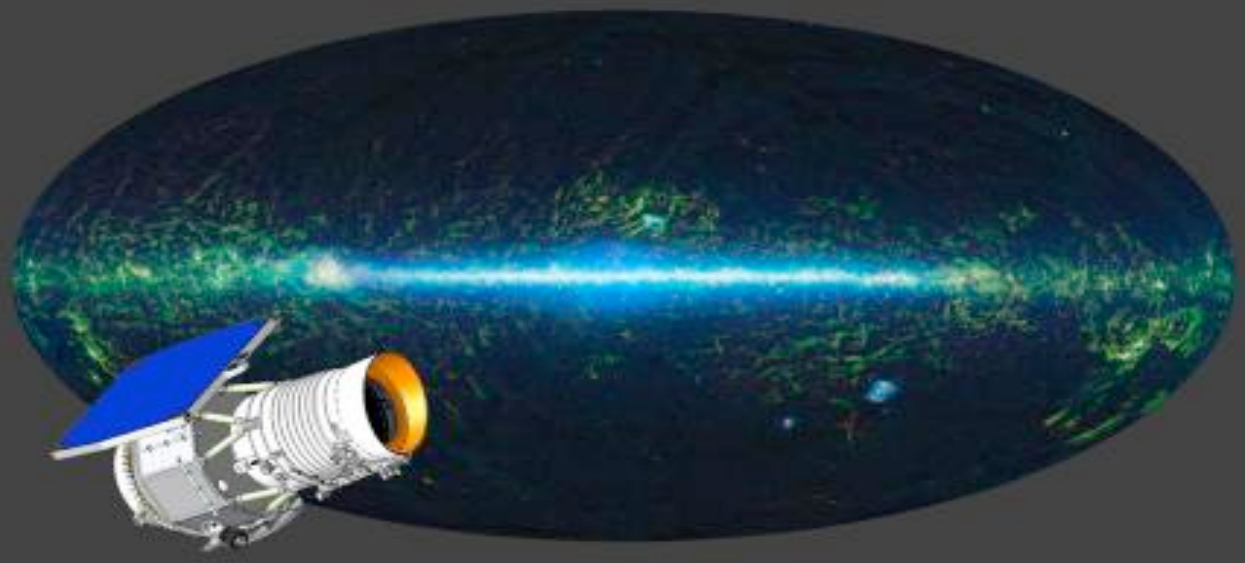
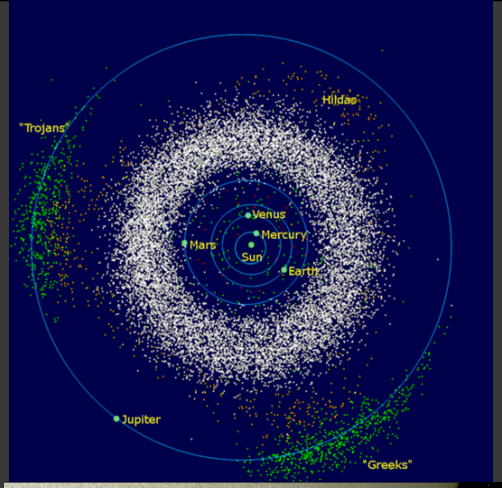
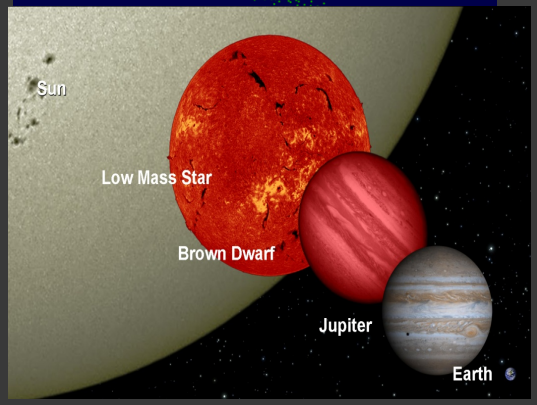
Peter Eisenhardt, Chao-Wei Tsai, Daniel Stern (JPL),
WISE extragalactic team, & Neal Evans

Neal Fest Apr 25-26 2013

NASA's Wide-field Infrared Survey Explorer (WISE) surveyed all-sky at 3.4, 4.6, 12, 22 um (W1-W4) in 2011. Data released on Mar 14, 2012





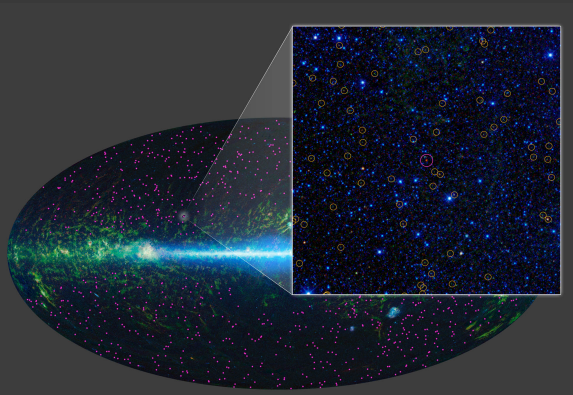


WISE primary science goals:

1) Observe asteroids in the solar system

2) To identify the coldest and nearest brown dwarfs:

3) Searching for the most luminous galaxies in the universe: Hot DOGs



Far-IR Surveys and New IR-Luminous Galaxy Populations

IRAS: LIRGs ($L_{IR} > 10^{11}\ L_\odot$) and ULIRGs ($L_{IR} > 10^{12}\ L_\odot$). [Sanders & Mirabel 1996]

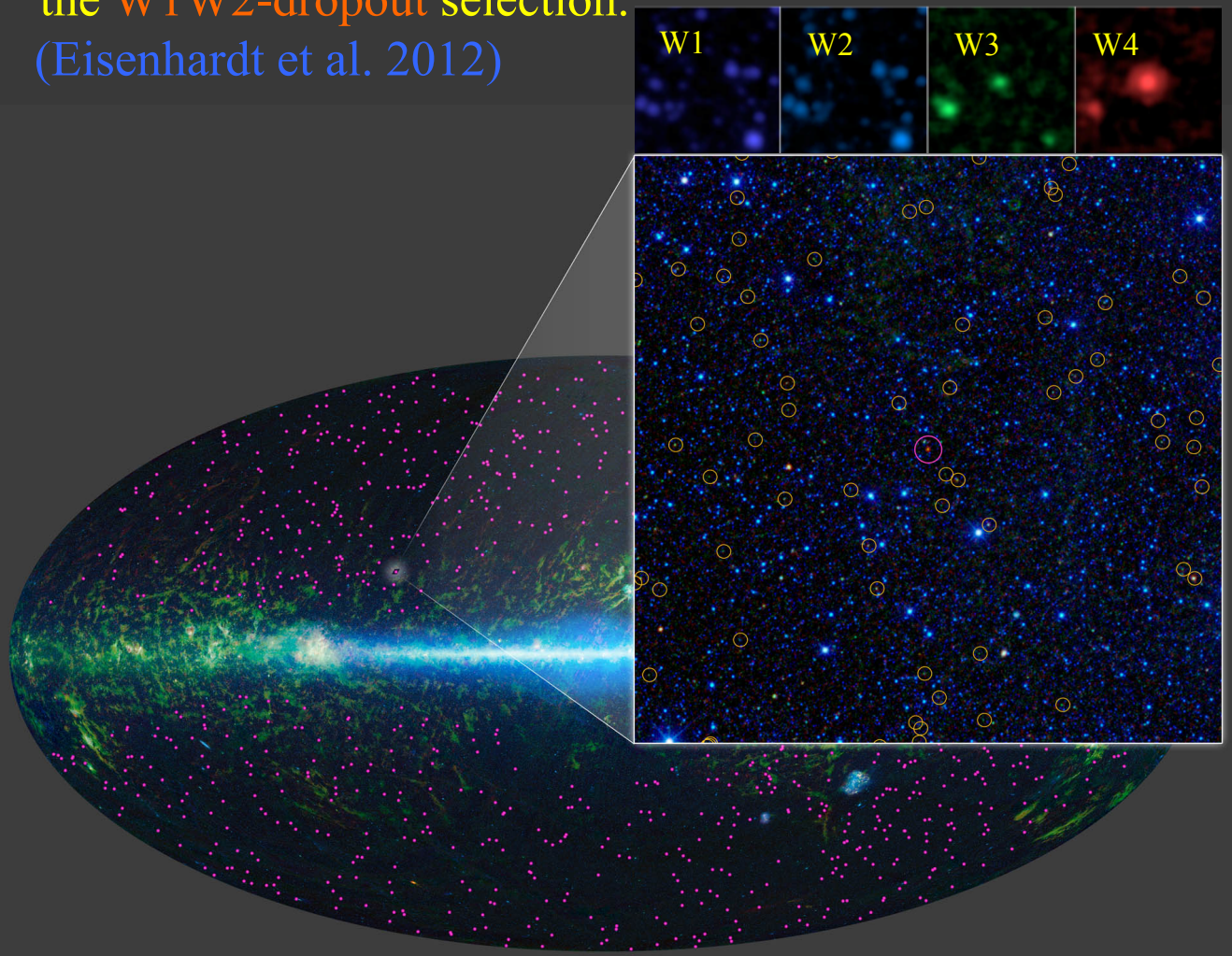
SCUBA+VLA: Submillimeter Galaxies (SMGs, $L_{IR} \sim 10^{12\text{-}13}\ L_\odot$).
Starburst powered, z~2-3 [Chapman et al. 2005]

Spitzer: Dust Obscured Galaxies (DOGs. $L_{IR} \sim 10^{12\text{-}13}\ L_\odot$).
AGN powered, z~2-3 [Dey et al. 2008]

WISE: Hot DOGs ($L_{IR} \sim 10^{13\text{-}14}\ L_\odot$, HyLIRGs). [Eisenhardt et al. 2012, Wu et al. 2012]

NASA's news release on Aug 29, 2012: http://www.nasa.gov/mission_pages/WISE/news/wise20120829.html

- WISE found Millions of hidden Black Holes, triple the numbers of Black Holes in the universe (e.g. Stern et al. 2012)
- Among those dust obscured galaxies, we selected a sample of the dustiest ones, whose W1,W2 are too faint to be detected, while W3, W4 are strongly detected: the W1W2-dropout selection. (Eisenhardt et al. 2012)

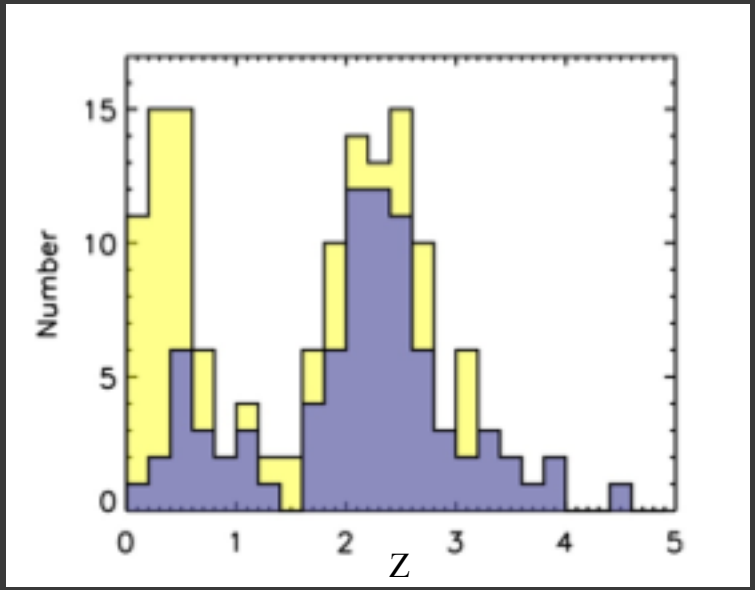


They are very rare: Only ~1000 over the sky

These selected galaxies are mostly at high-z

- Spectroscopy follow-up of more than 200 with Keck, GMOS, Palomar
- >65% are at 1.5<z<4.6, peak at z~2-3
- Most have obscured AGN spectra

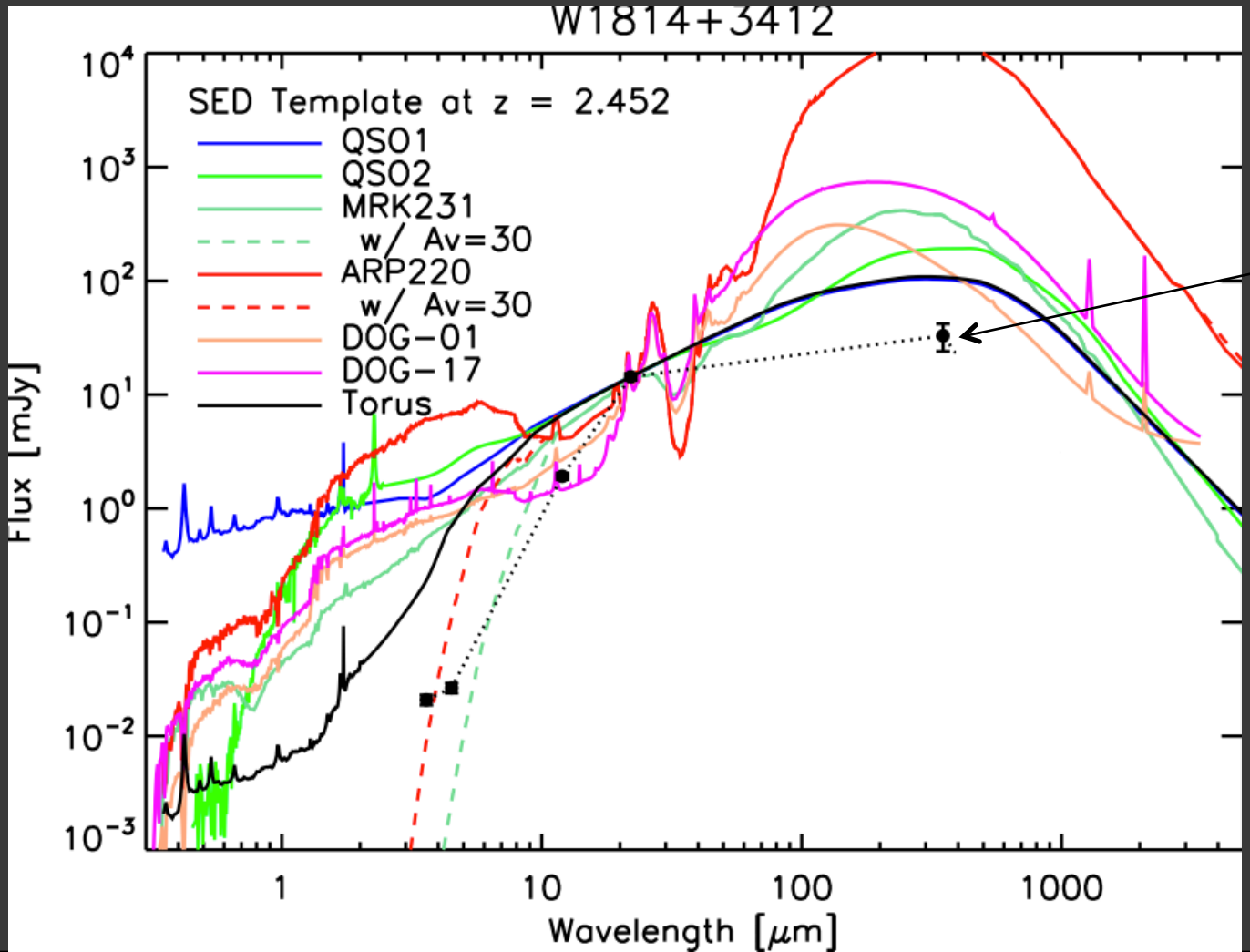
- Being strong at Mid-IR and locating at High-z, they are potentially hyper-luminous galaxies

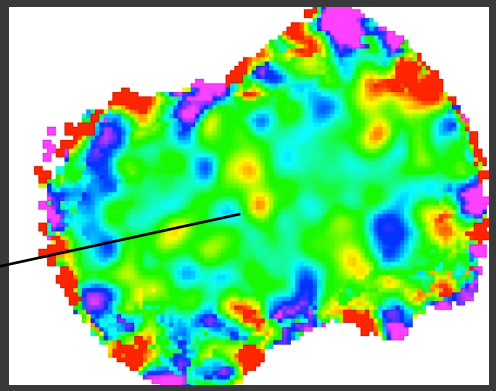


Need Far-IR and Submm follow-up to confirm

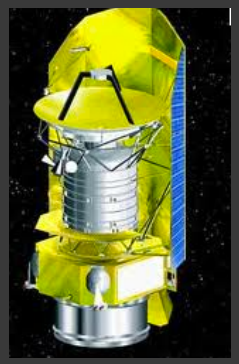
CSO SHARC2 (350um) follow-up

The first one was detected by Neal in July 2010 !



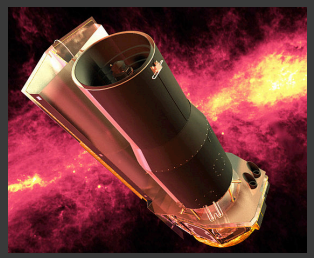


Since then, intensive follow-up campaign has been conducted

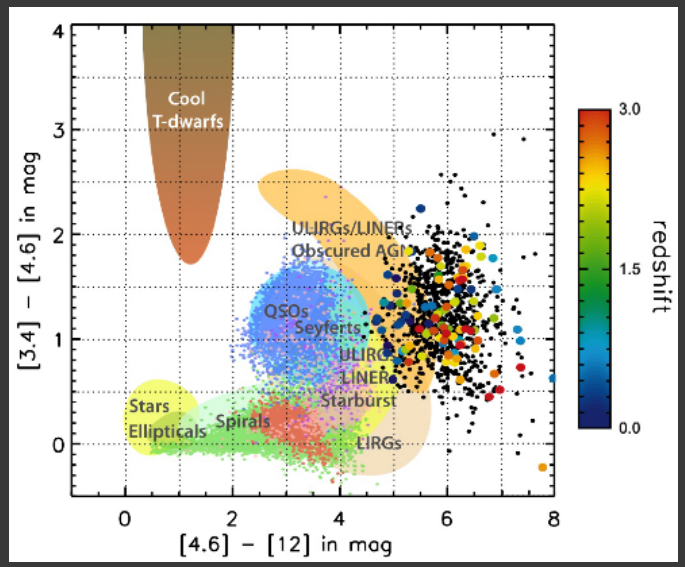


230 have been followed-up by Herschel with PACS+SPIRE

60+ by CSO with SHARC2 and Bolocam



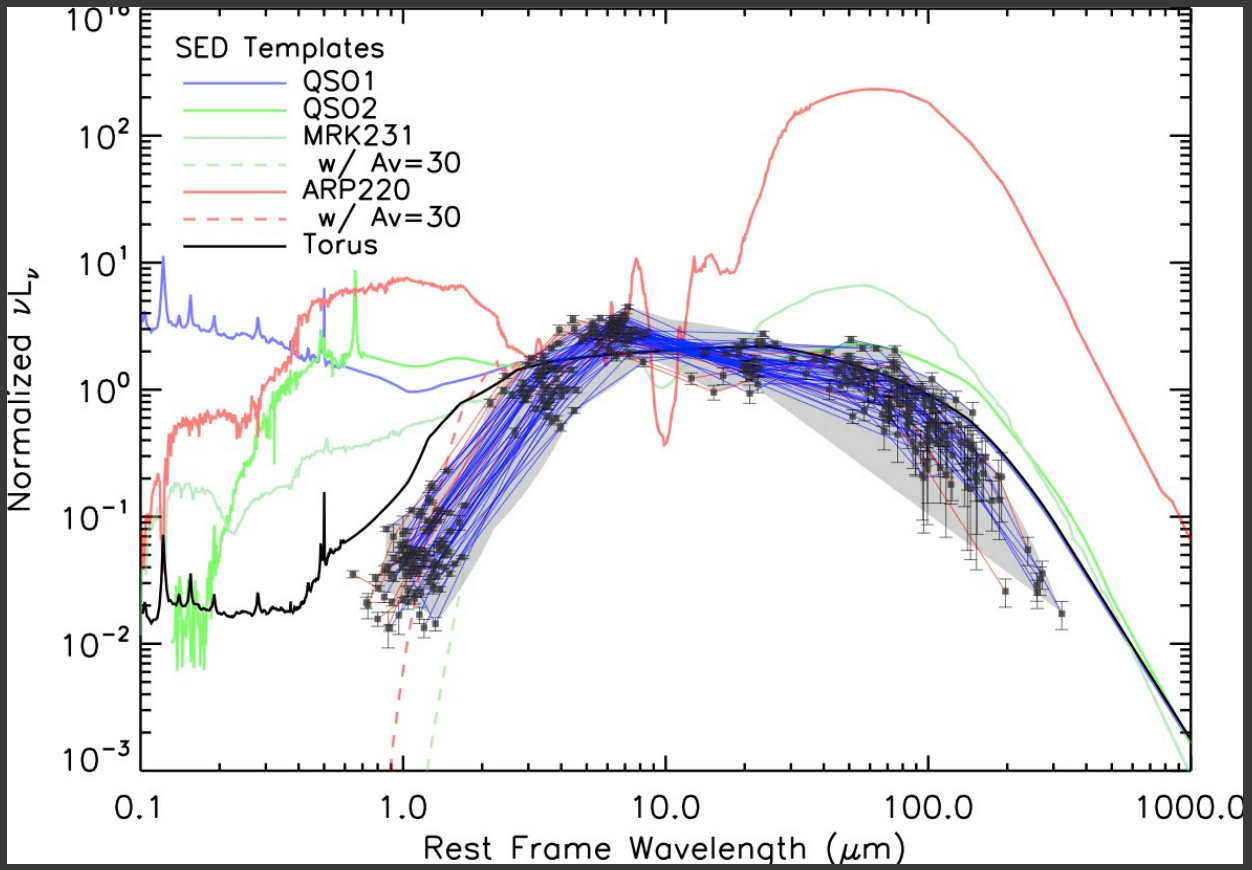
900+ with Warm Spitzer at 3.6, 4.5 um



Optical, NIR photometry of 200+ by NOAO facilities

Individual target with IRAM, CARMA, SMA.

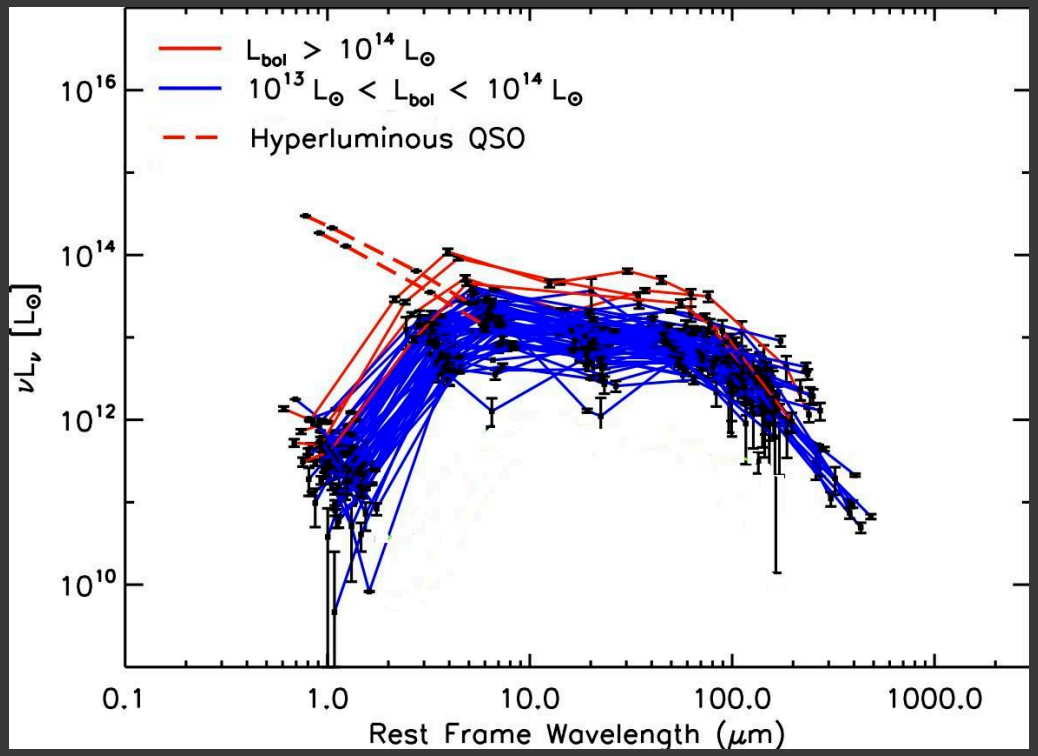
SED: Warm Spitzer+WISE+Herschel/CSO

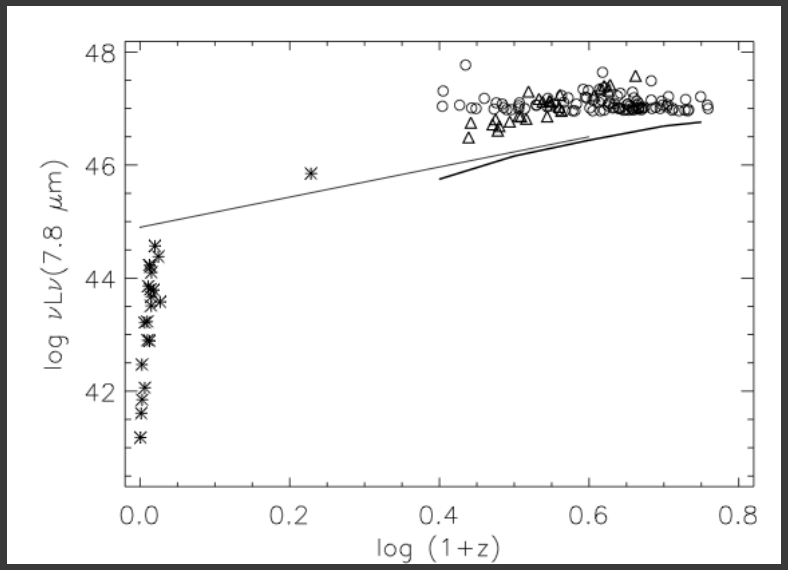


1) Uniform SED: power-law Mid-IR, flat mid-IR to submm, highly obscured.
2) Different from other existing populations : A new population?
3) Peaking at shorter wavelength, very-high mid-IR/submm ratio: dominated by hot dust emission.

If only use a single (characteristic) Temperature fitting: T=60-120K (~30-40K for SMGs & DOGs). But more likely to have >1 component

They are indeed Hyperluminous!





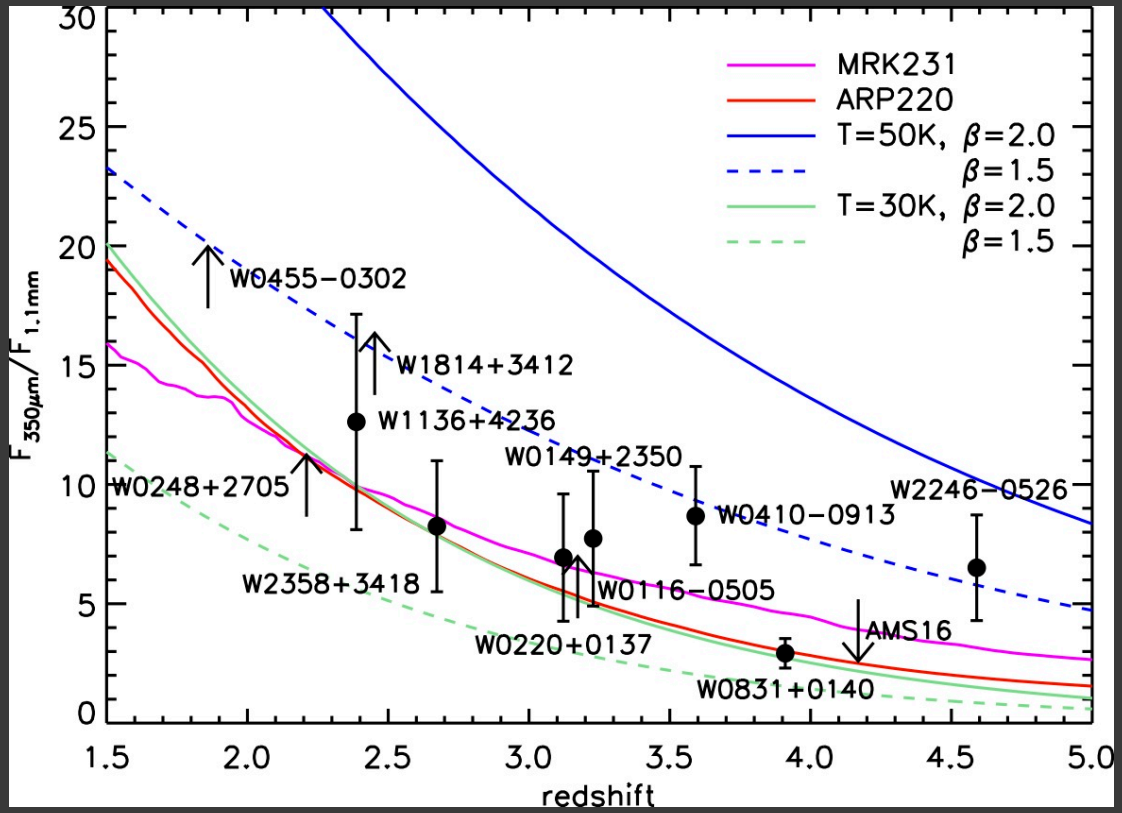
(Weedman et al. 2012)

- Most have L>10^13 Lsun, 10% exceed 10^14, comparable to the most luminous QSOs.
- AO & HST imaging show no obvious signs of lensing
- Intrinsically one of the most luminous galaxy population

What are they?

1) They have powerful AGNs

- Optical spectroscopy: most are obscured AGNs
- Mid-IR SED: power-law shape
- Very bright mid-IR emission
- Radio emission: 1/3 are NVSS sources

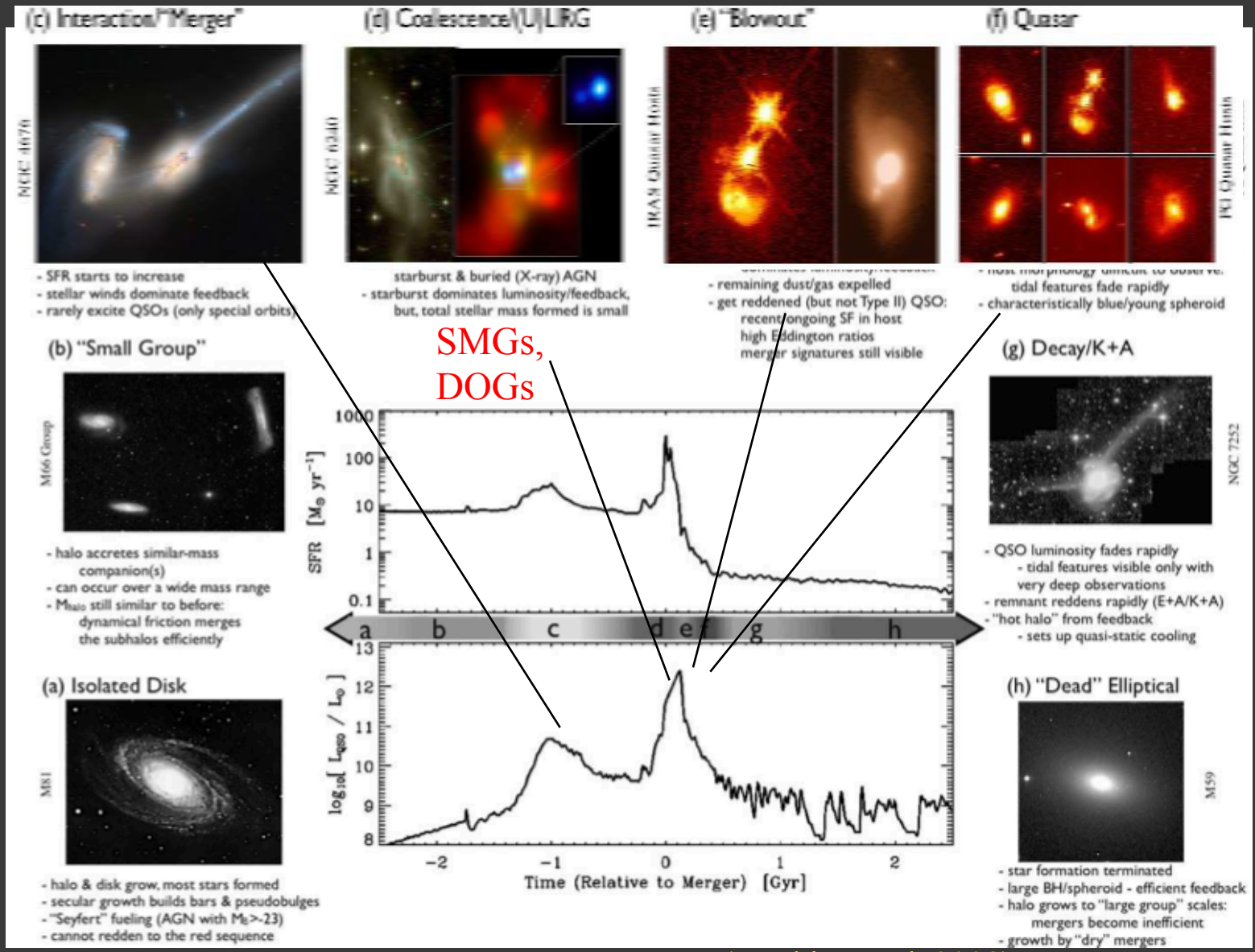


2) Starburst

They also have cold-dust component similar to those in starburst galaxies, in additional to the >100K hot component

Connecting to other AGN/starburst composite systems: SMGs, DOGs

A popular scenario of galaxy evolution through "merger"



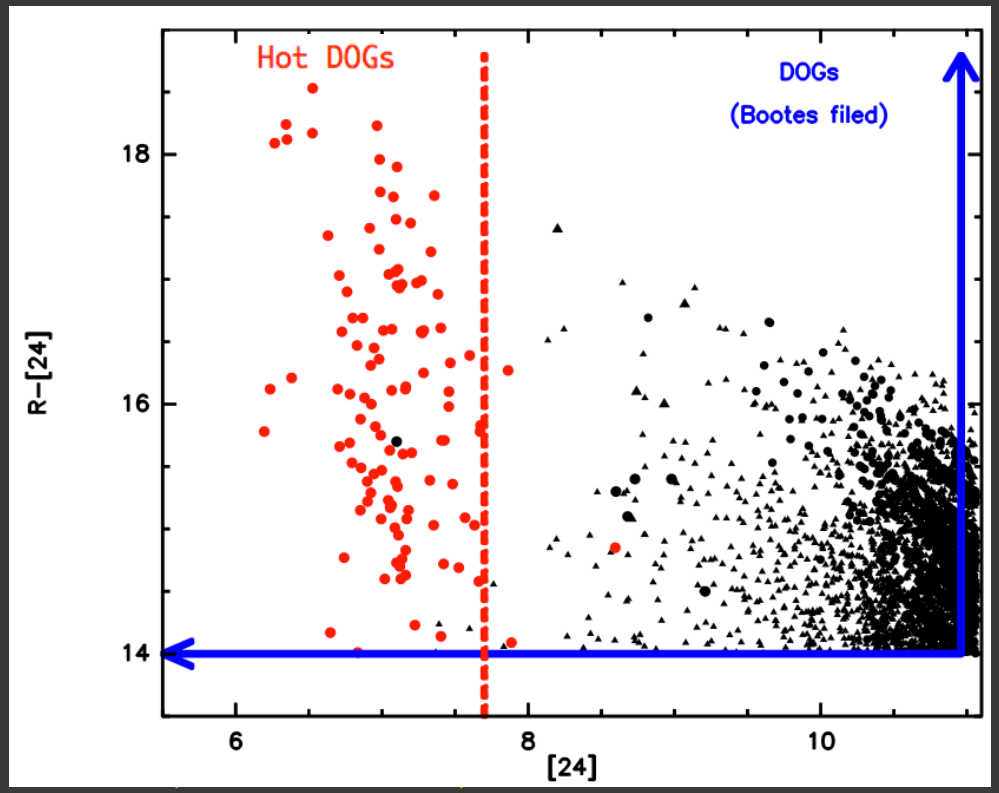
(Hopkins et al. 2008)

Dust Obscured Galaxies (DOGs):

Bump-DOGs :DOGS with stellar bump at mid-IR SED; starburst dominated, weaker 24um

Power-law DOGs: DOGs with a power-law mid-IR SED; AGN dominated, stronger 24um

W1W2drop-selected galaxies are super-power-law DOGs



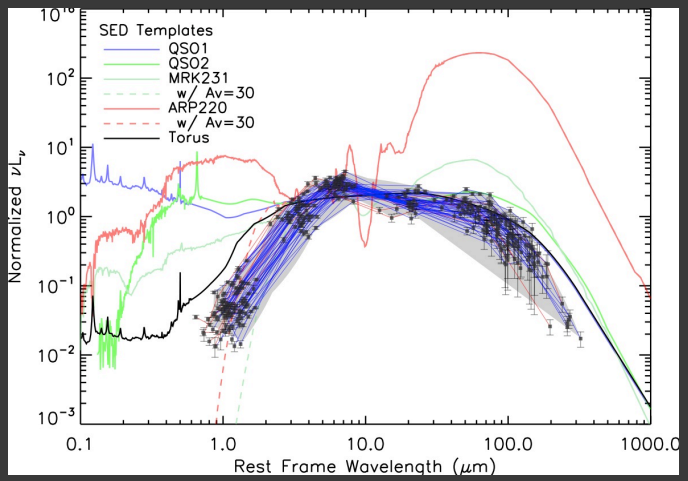
- Qualify DOG selection criterion ([24]>0.3mJy, R-[24]>14, Dey at al. 2008)
- > 2 times hotter
- 10 times more luminous
- 10,000 times rarer

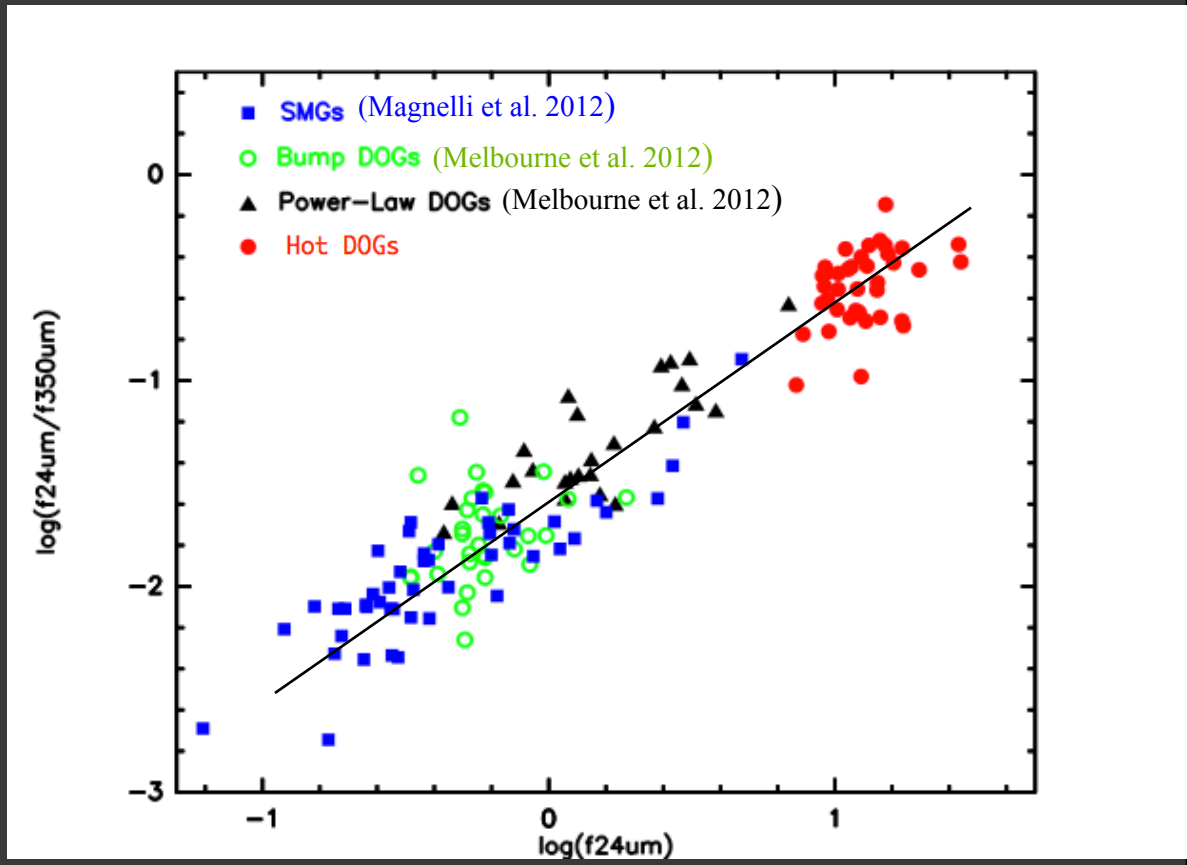
The W1W2-dropout selection are picking out the most luminous, hot DOGs from the entire sky

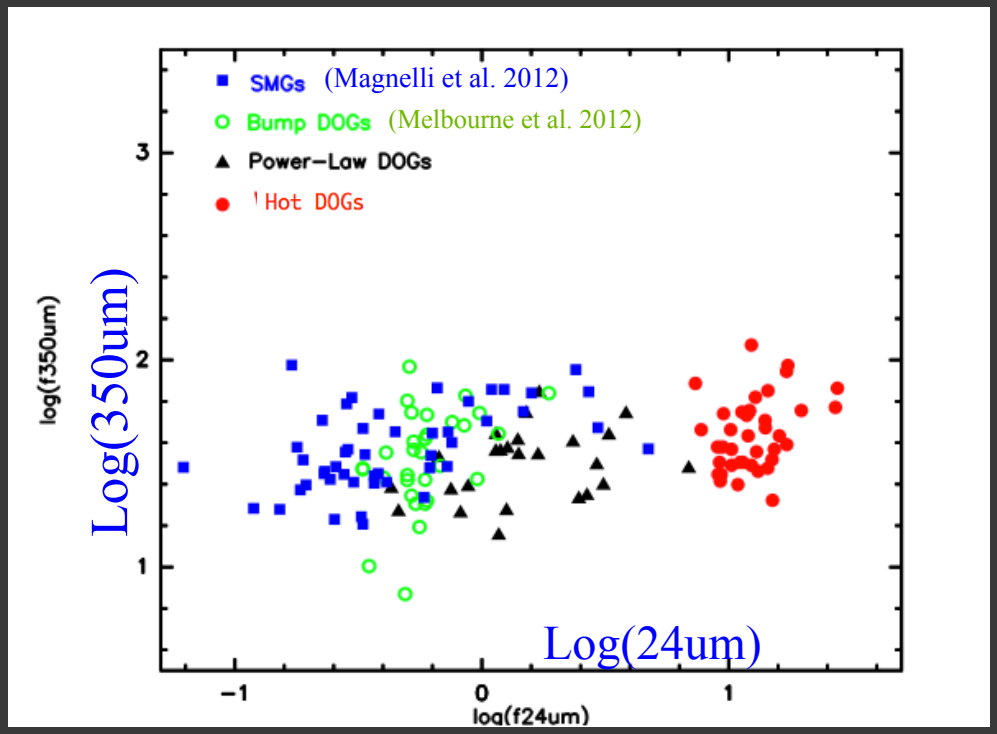
So they called Hot DOGs

It has been proposed (e.g. Narayanan 2010) that SMGs, bump DOGs, power-law DOGs may form an evolutionary sequence; but observational evidence is scant.

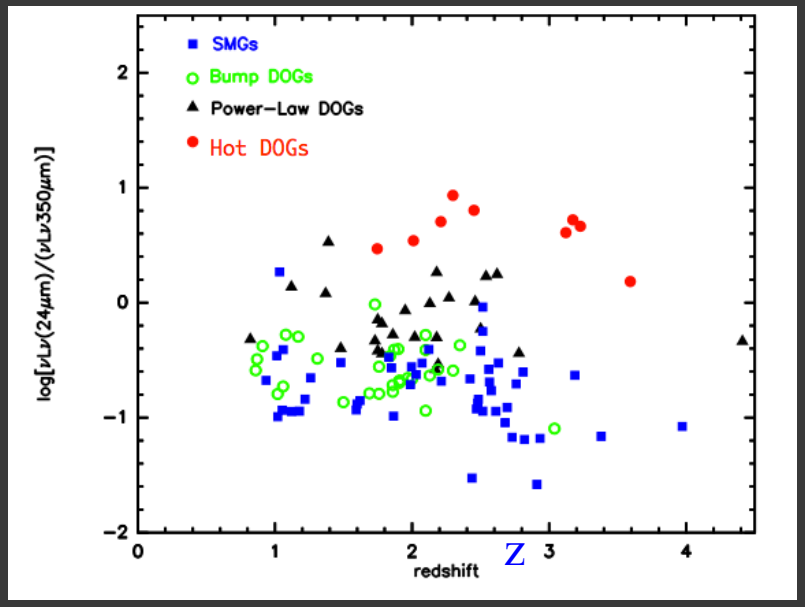
However, if consider there is an evolution of the shape of SED, we clearly see such a sequence at 24um/350um ratio vs. z plot, with Hot DOGs at an later stage:
SMGs → Bump DOGs → Power-law DOGs → Hot DOGs







Redshift distribution doesn't significantly affect 24/350 ratio

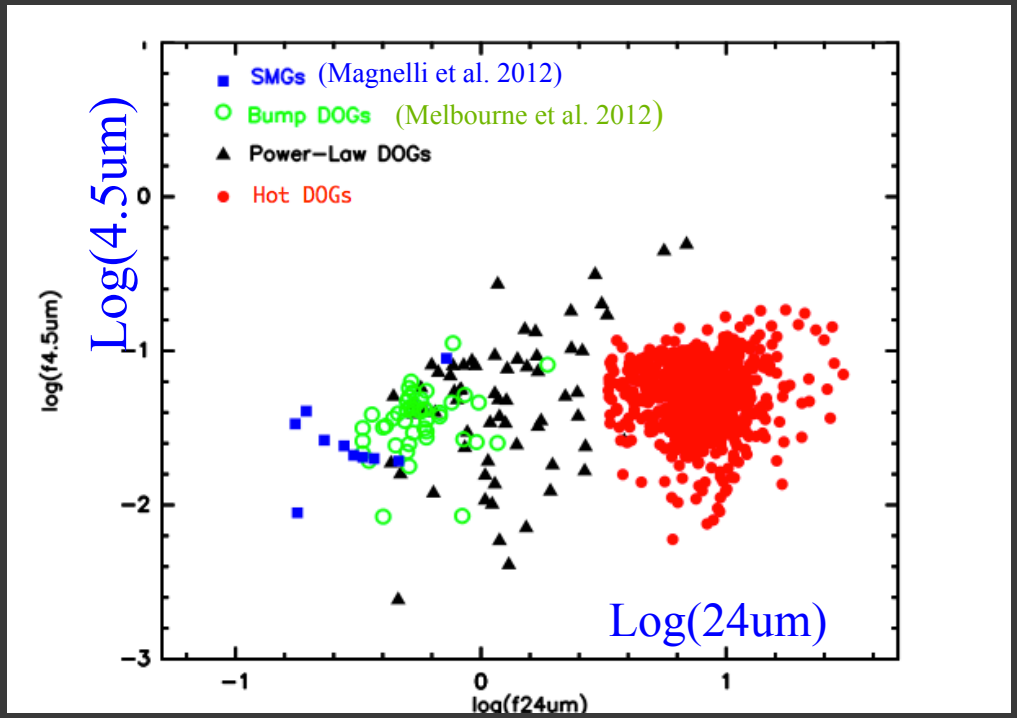


Almost constant 350um strength (starburst) while 24um (SMBH) increases >100 times

24um emission may trace the growth of the central SMBH

Question: Is star formation similar in all these merging systems?

Similar trend is seen between 4.5um (Stellar) and 24um (AGN)



* Hot DOGs may represent a late phase of the evolution, with more massive SMBHs but similar starburst components and stellar components to SMGs and DOGs.

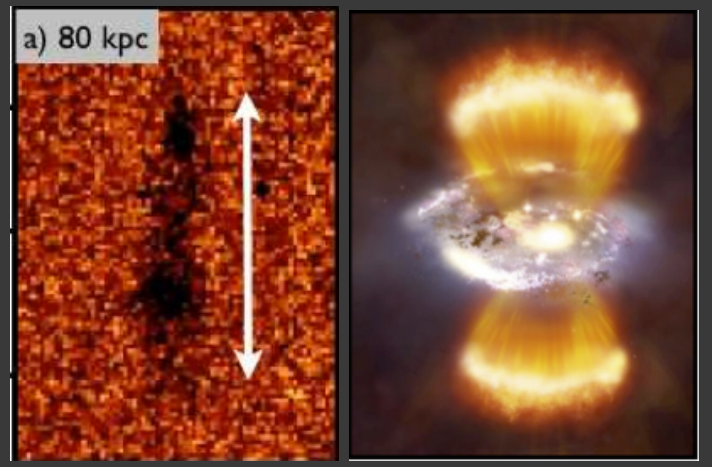
* Being the most luminous galaxies in the universe, they may hosting the most massive SMBH or experiencing most powerful AGN feedback over the sky.

A new phase in galaxy evolution?

1) Very hot dust

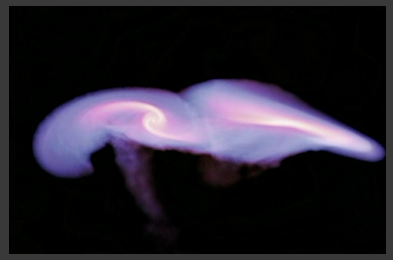
2) Growing SMBHs

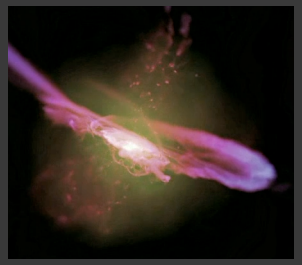
3) Unusually high ratio of
very extending HI halos (LyA blobs)

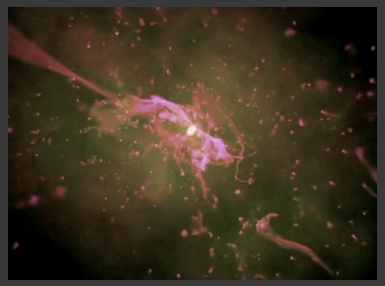


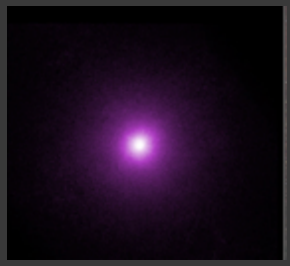
(Bridge et al. 2013)

We may be seeing a rare phase of galaxy evolution when gas and dust are being heated and ejected by its central SMBHs: a blowout phase









Summary

- Using pre-release WISE data, we have identified a rare, all-sky sample of Hyperluminous galaxies, the Hot DOGs. Rich follow-up data have been taken.

- They are very hot, and are among the most luminous galaxies in the universe. They may host the most massive SMBHs, or are experiencing most powerful AGN feedback activities in the sky.

- They may represent an short evolutionary stage after the SMGs and standard DOGs stages, but right before the emerging of optical QSOs.

And thanks to Neal!