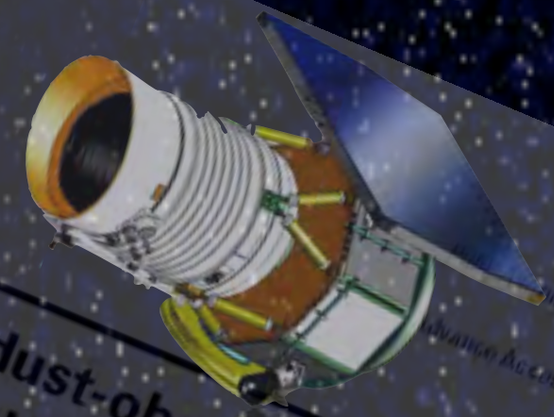
RCSCE EHIME U.
RESEARCH CENTER FOR SPACE AND COSMIC EVOLUTION

愛媛大学



Statistical Properties of Dust Obscured Galaxies discovered by HSC, VIKING, and WISE

Toba, Nagao et al. 2015, PASJ, 67, 86

Yoshiki TOBA
(Ehime University => ASIAA)

Tohru Nagao, Michael A. Strauss, Kentaro Aoki,
Tomotsugu Goto, Masatoshi Imanishi, Toshihiro Kawaguchi,
Yuichi Terashima, Yoshihiro Ueda, and the HSC-DOGs team

Statistical Properties of Dust Obscured Galaxies discovered by HSC, VIKING, and WISE

RESEARCH CENTER FOR SPACE AND COSMIC EVOLUTION

IR Luminosity Function

IR Luminosity Density

Toba+15

Yoshiki TOBA

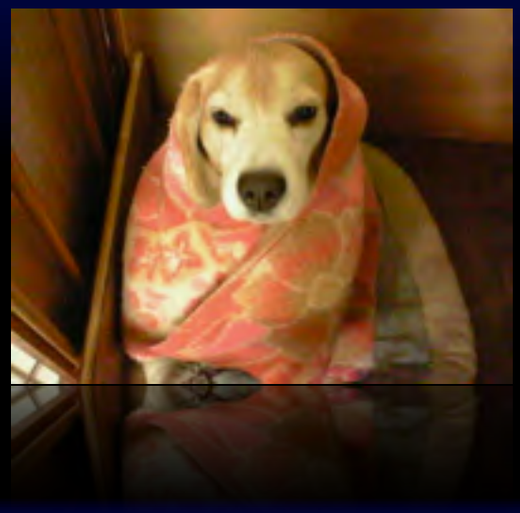
Auto Correlation Function

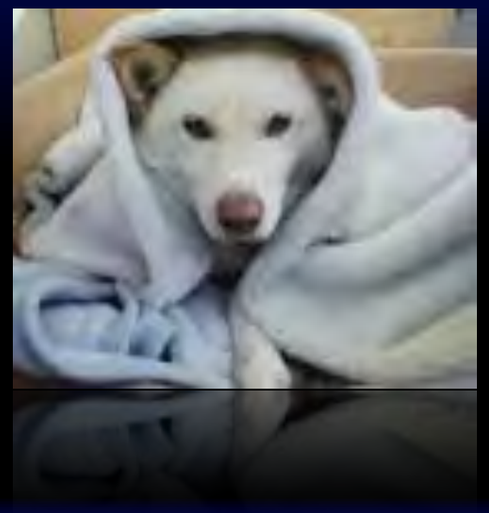
Toba+16 in prep.

Tohru Nagao, Michael A. Strauss, Kentaro Aoki,
Tomotsugu Goto, Masatoshi Imanishi, Toshihiro Kawaguchi,
Yuichi Terashima, Yoshihiro Ueda, and the HSC-DOGs team

狗 σκυλί dog hond

Dogs are obscured by blanket..





Introduction

perro

What are Dust Obscured Galaxies (DOGs)?

cane hund chien cão 犬 собака

Dust Obscured Galaxies

R - [24] ≥ 7.5 (AB mag)

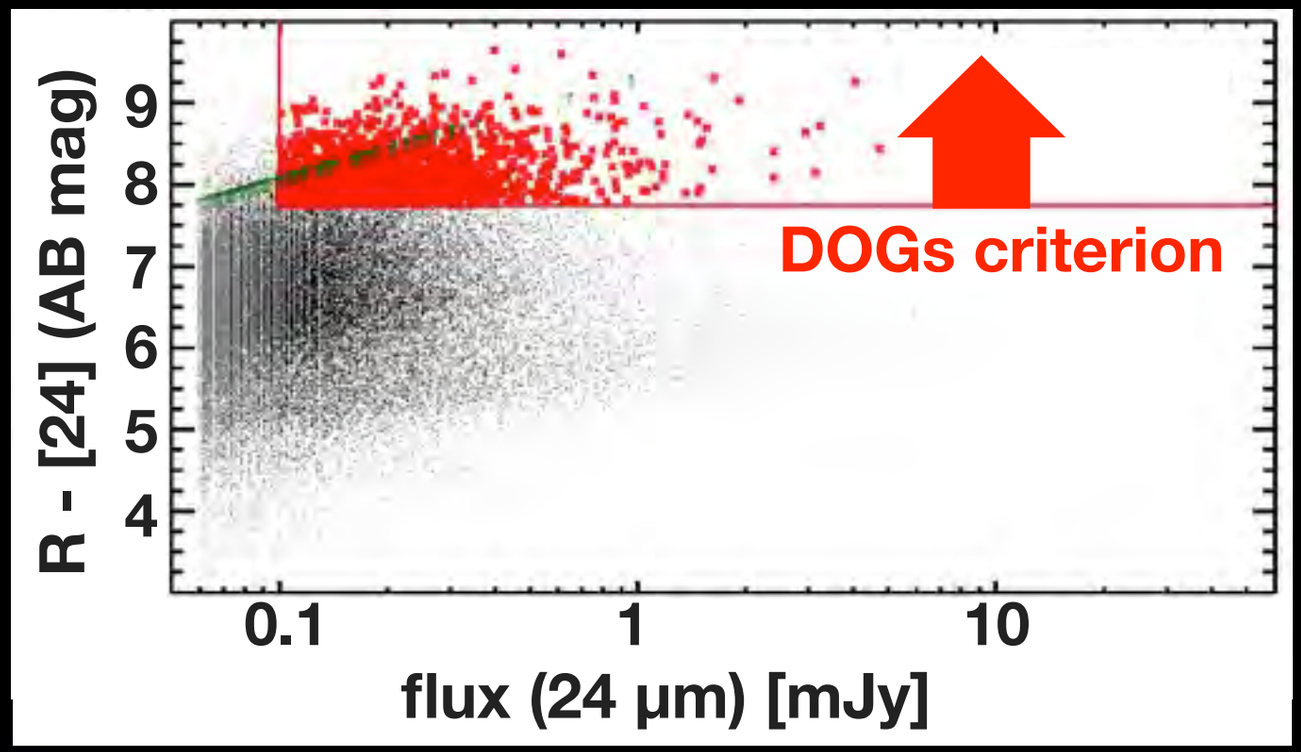
- An optically faint but IR bright objects.

~ ULIRGs

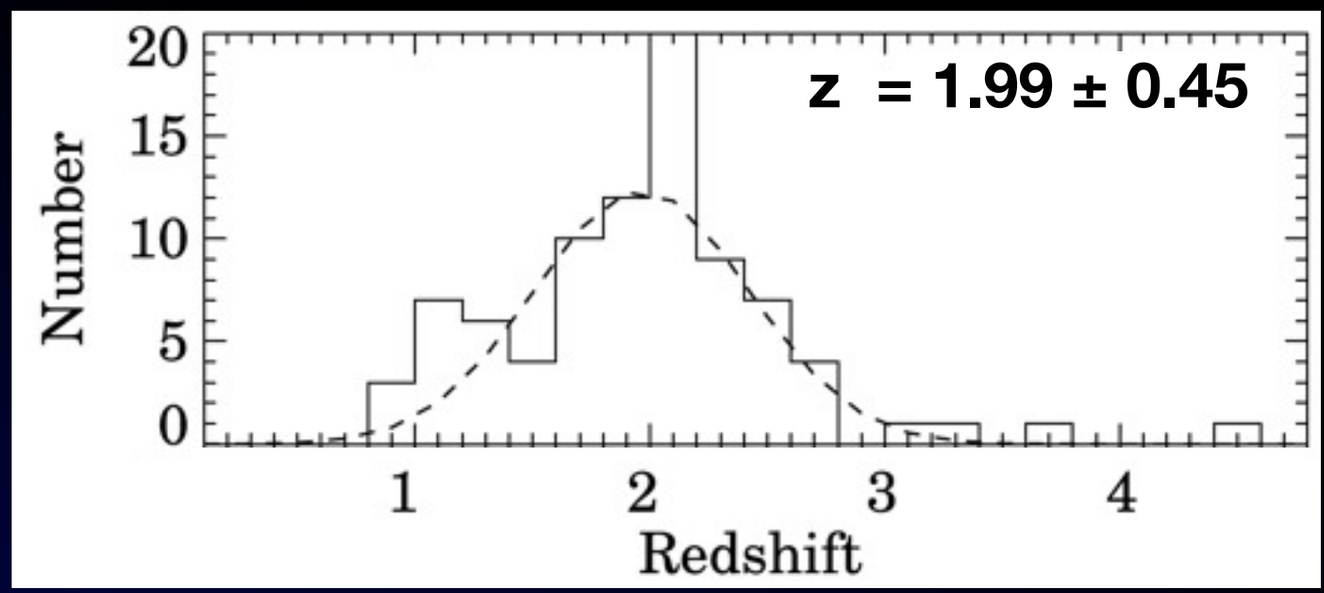
- Most DOGs are ultra-luminous infrared galaxies (ULIRGs: $L_{IR} \geq 10^{12}\ L_{sun}$).

z ~ 2

- Confirmed from follow-up observations (NIR and MIR spectroscopy).



Calanog+13



Dey+08

Two types of DOGs

Power-Law (PL) DOGs

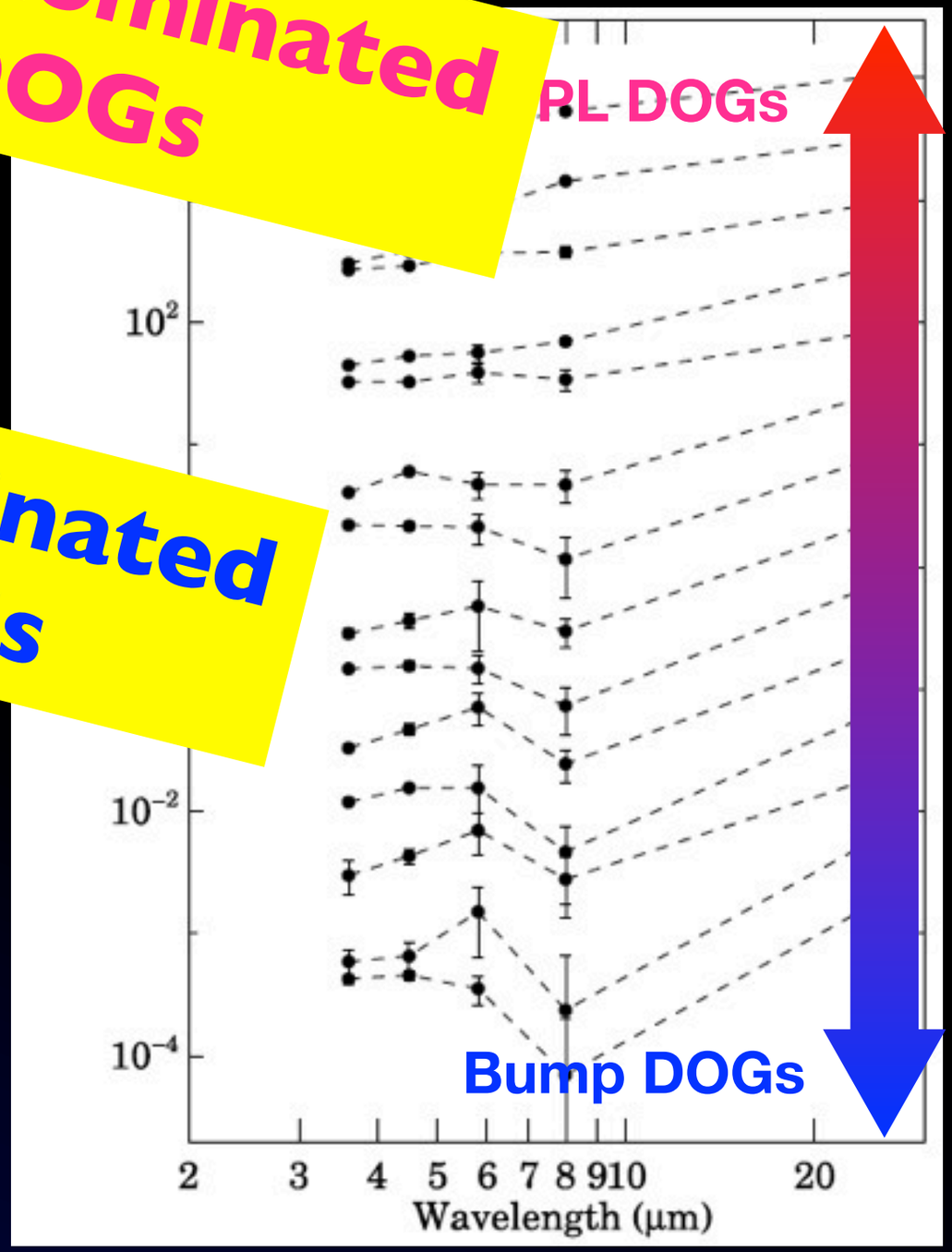
- They show a rising power-law SED, which indicates an AGN activity.

Bump DOGs

- They show a rest-frame 1.6 μm “bump” in their SEDs.
- They also show strong PAH emission.,which indicates a SF activity.

AGN-dominated DOGs

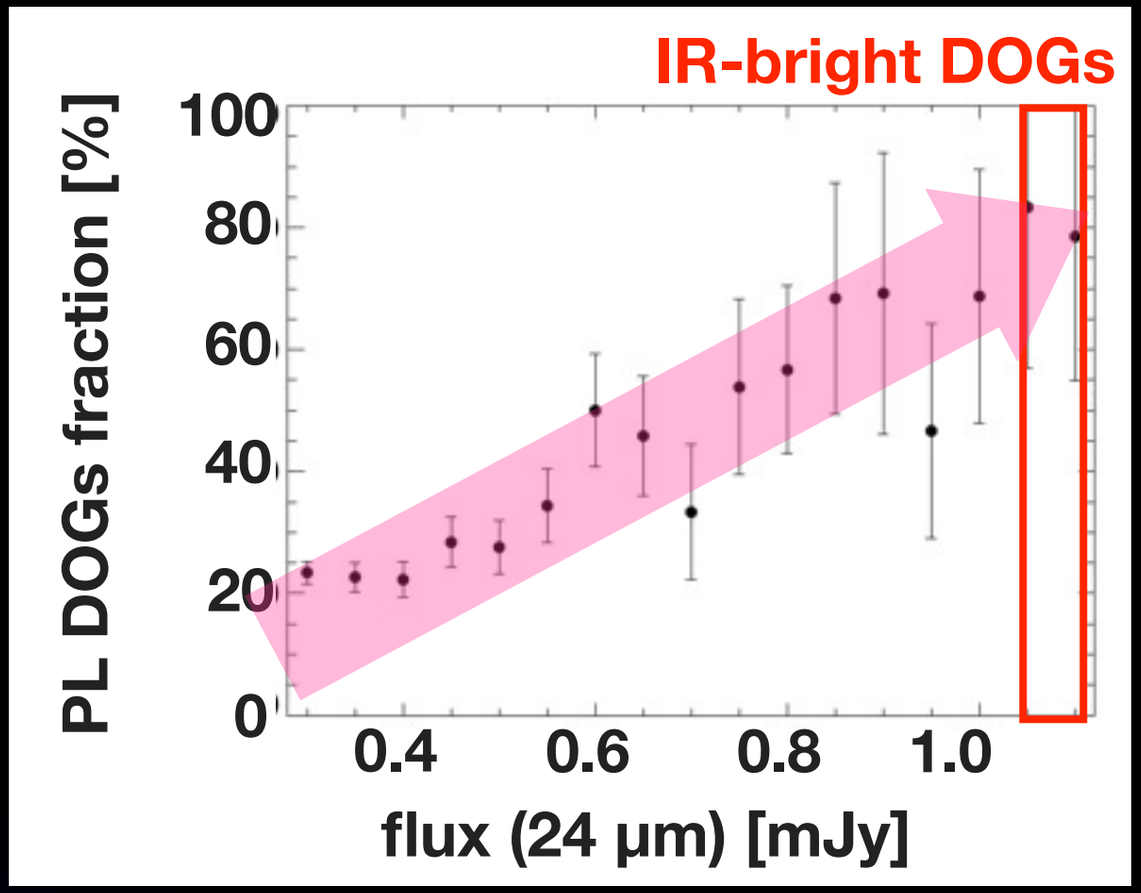
SF-dominated DOGs

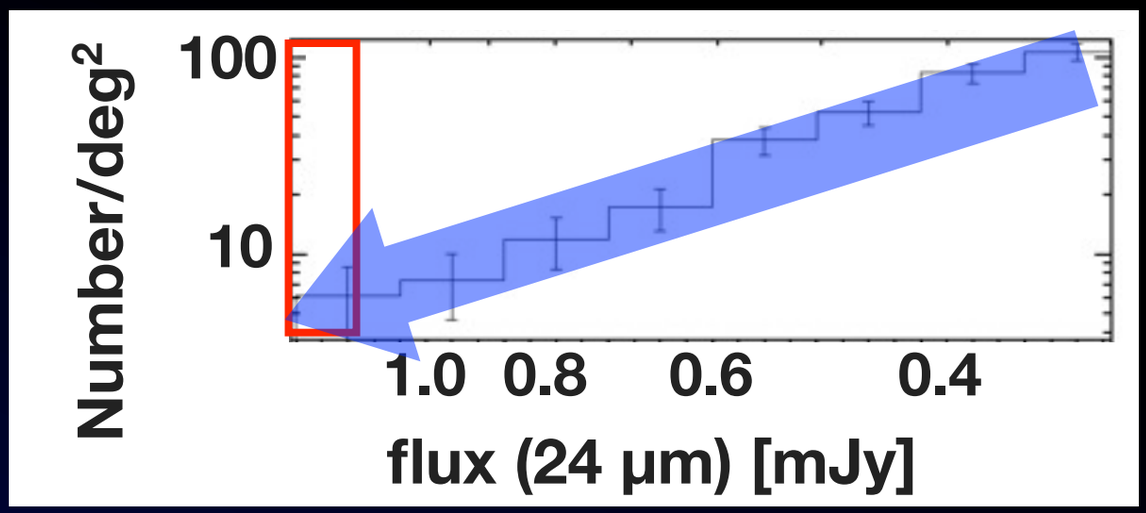


Dey+08

IR bright DOGs ≃ PL DOGs

- The fraction of PL DOGs (i.e., AGN-dominated DOGs) increases with increasing MIR flux.
- IR-bright DOGs are expected to be AGN dominated DOGs.
- The number densities of DOGs decreases with increasing MIR flux., which means IR-bright DOGs are very low.
- It requires a large area survey.





Dey+08

What are the DOGs?

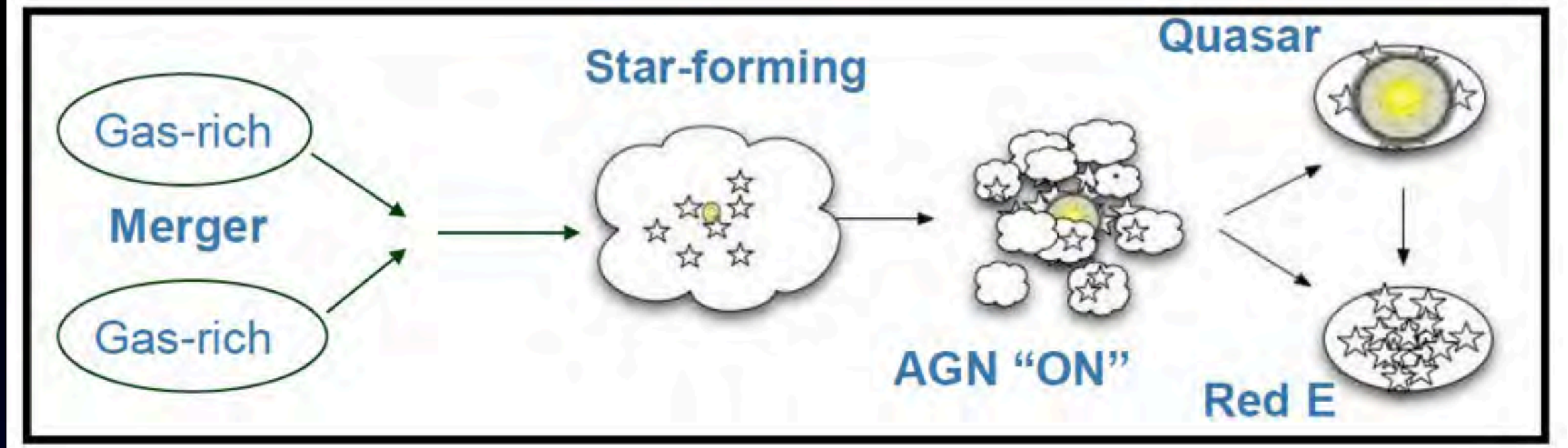
optically faint ULIRGs at z~2

Bump DOGs・ PL DOGs

IR bright DOGs ≃ PL DOGs

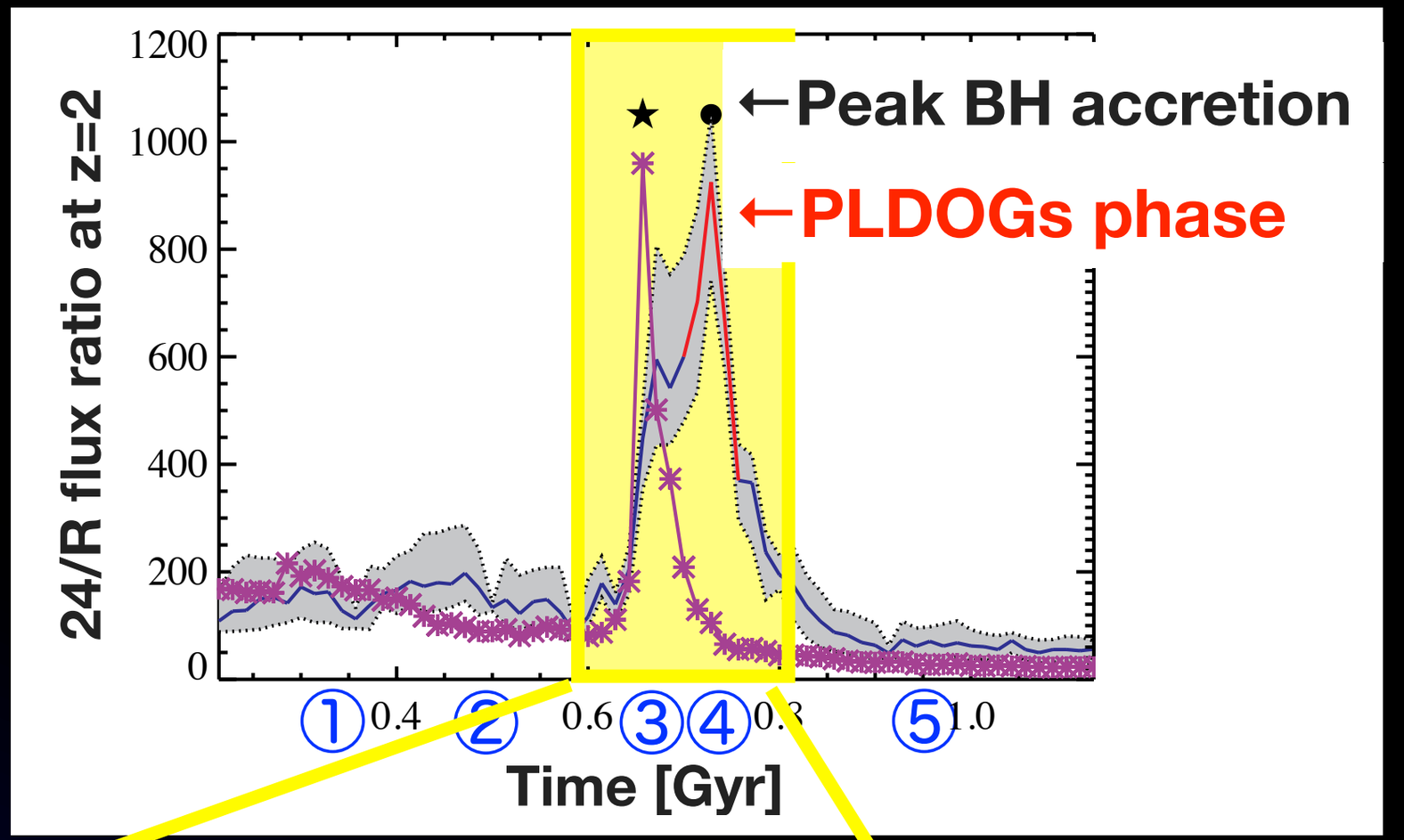
≃ AGN-dominated DOGs

Importance of DOGs



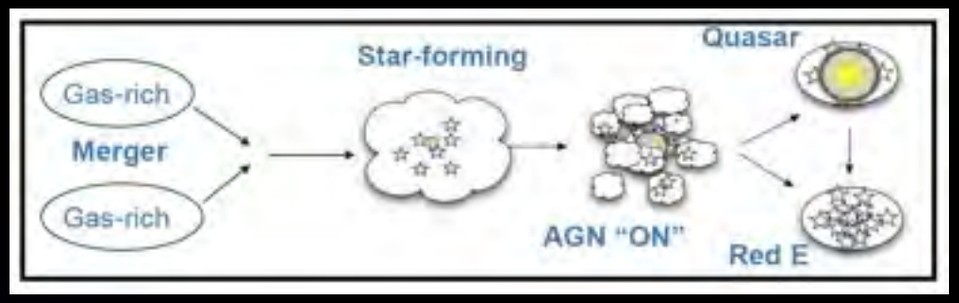
Importance of DOGs

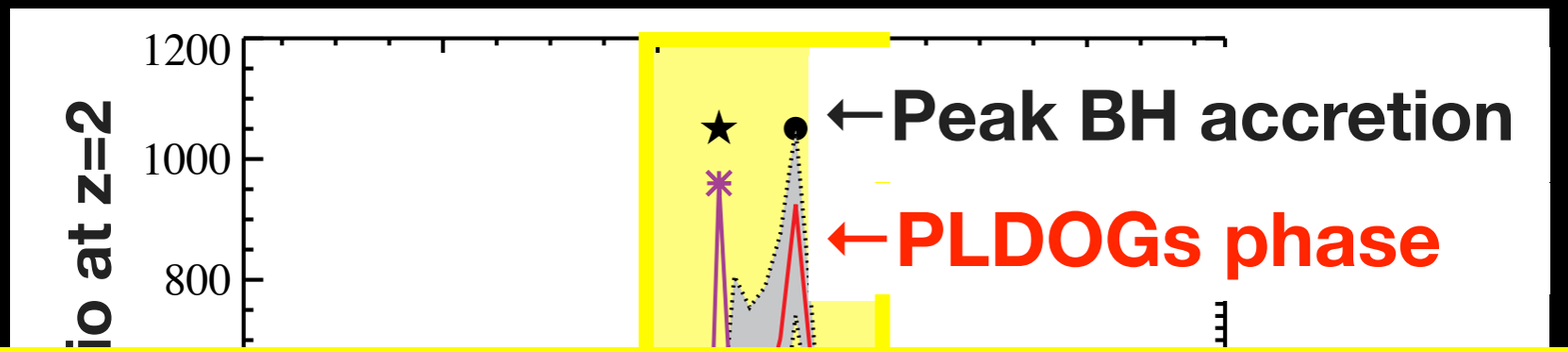
Importance of DOGs



Narayanan+10

Importance of DOGs





IR-bright DOGs could constitute a key population for understanding the co-evolution of galaxies and SMBHs.

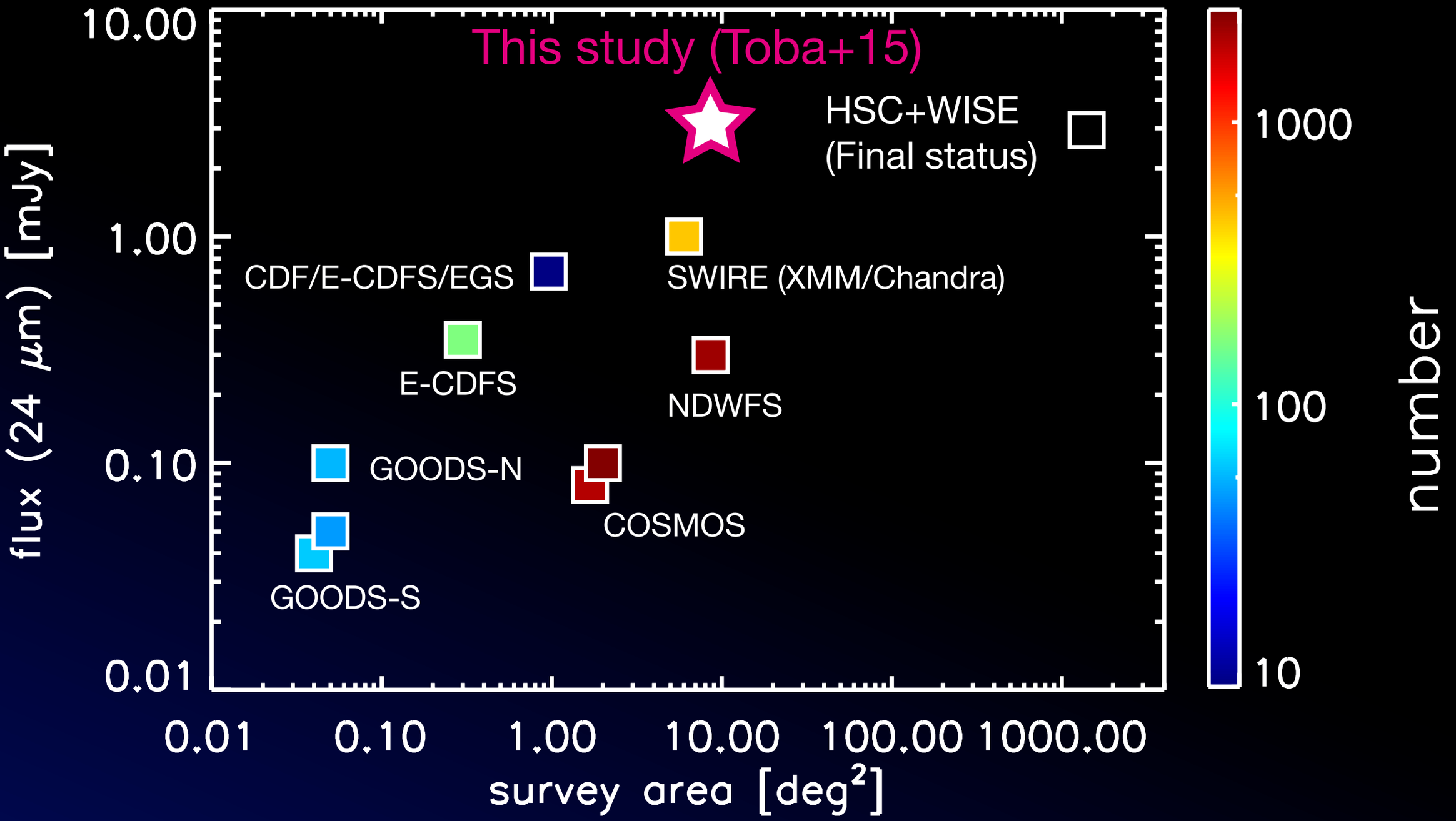
Narayanan+10

Purpose of this study

(1) Search for IR-bright DOGs based on the HSC with VIKING and WISE

(2) Investigating their photometric and statistical properties

Purpose of this study



Data and Analysis

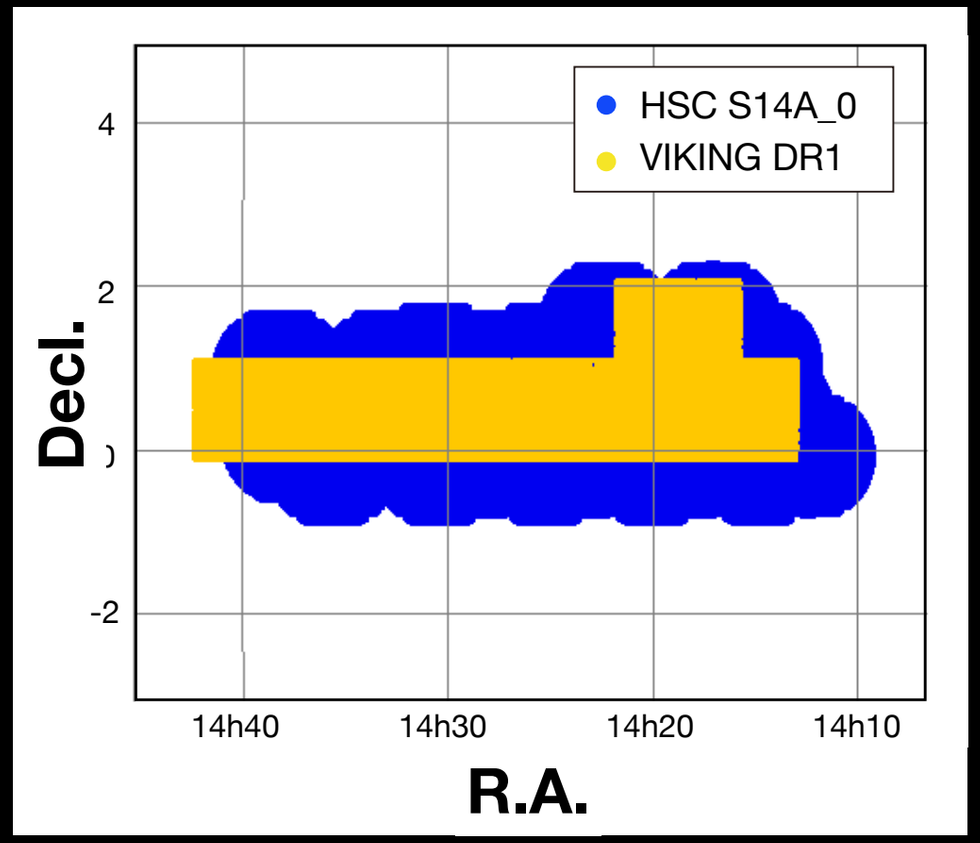
How do we discover IR bright DOGs?

HSC, VIKING, and WISE

	band	limiting mag (5σ、2″)	Total number of objects
HSC S14A_0	i	~26	16,392,815
	y	~24	
VIKING DR1	Z	23.1	14,773,385
	Y	22.3	
	J	22.1	
	H	21.5	
	Ks	21.2	
ALLWISE	3.4	19.6	747,634,026
	4.6	19.3	
	12	16.4	
	22	14.5	

※ AB mag

GAMA 14hr field (~10 deg^2)



We used those bands to search for IR-bright DOGs

Sample Selection

16,392,815 mosaic_sourcelist__deepcoadd

filter01 = 'HSC-I'
deblend_nchild = 0 AND
flag_detect_is_tract_inner is True
flag_detect_is_patch_inner is True
AND
flag_flags_pixel_edge is False
flag_flags_pixel_saturated_center is False
flag_flags_pixel_cr_center is False
flag_flags_pixel_bad is False
flag_cmodel_flux_flags is False
flag_centroid_sdss_flags is False

YES

6,024,570 HSC sample

In the overlap region with VIKING?

3,414,154 YES

14,773,385 VIKING DR 1

In the GAMA 14 region ?

672,843 YES

priOrSec = 0
OR
priOrSec= FrameSetID
AND
ksppErrBits = 0
SN (Ks mag) ≥ 5

YES

234,286 VIKING sample

747,634,026 ALLWISE

w4_sat= 0
w4_cc_map= 0
ext_flg = 0
SN (22 μm) ≥ 3

YES

9,439,990 WISE sample

In the overlap region with VIKING?

1,339 YES

Sample Selection

16,392,815 mosaic_sourcelist__deepcoadd

14,773,385 VIKING DR 1

747,634,026 ALLWISE

① Create the clean subsample

AND
flag_flags_pixel_edge is False
flag_flags_pixel_saturated_center is False
flag_flags_pixel_cr_center is False

672,843 YES

Clean HSC i-selected catalog

Clean VIKING Ks-selected catalog

Clean WISE 22 μm-selected catalog

6,024,570 HSC sample

234,286 VIKING sample

9,439,990 WISE sample

In the overlap region with VIKING?

3,414,154 YES

In the overlap region with VIKING?

1,339 YES

Clean HSC i-selected catalog

Clean VIKING Ks-selected catalog

Clean WISE 22 μm-selected catalog

3,414,154 YES

1,339 YES

Cross-match with VIKING
search radius ≤ 1 ″

②

178,062 YES

i mag - ks mag ≥ 1.2

③

YES

83,910 HSC-VIKING sample

Cross-match with WISE
search radius ≤ 3 ″

207 YES

3,414,154 YES

Cross-match with VIKING
search radius ≤ 1 ″

②

178,062 YES

i mag - ks mag ≥ 1.2

③

YES

83,910 HSC-VIKING sample

1,339 YES

Clean WISE 22 μm-selected catalog

Cross-match with WISE
search radius ≤ 3 ″

④

207 YES

i mag - [22] ≥ 7.0

⑤

YES

48 HSC-WISE DOGs

3,414,154 YES

Cross-match with VIKING
search radius ≤ 1 ″

②

178,062 YES

i mag - ks mag ≥ 1.2

③

YES

1,339 YES

Clean WISE
22 μm-selected
catalog

48 IR-bright DOGs were selected

Cross-match with WISE
search radius ≤ 3 ″

④

207 YES

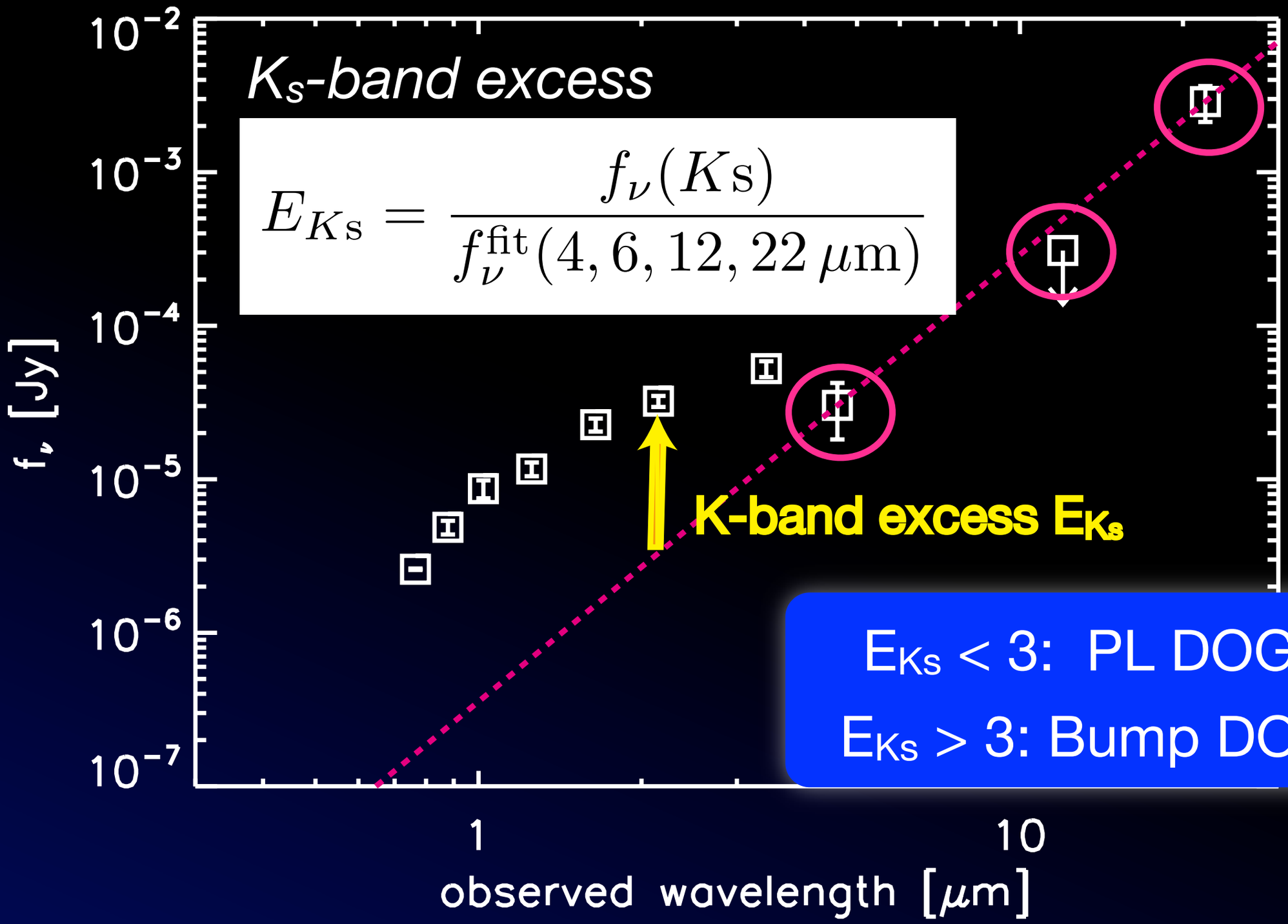
i mag - [22] ≥ 7.0

⑤

YES

48 HSC-WISE DOGs

Type Classification (PL /Bump)

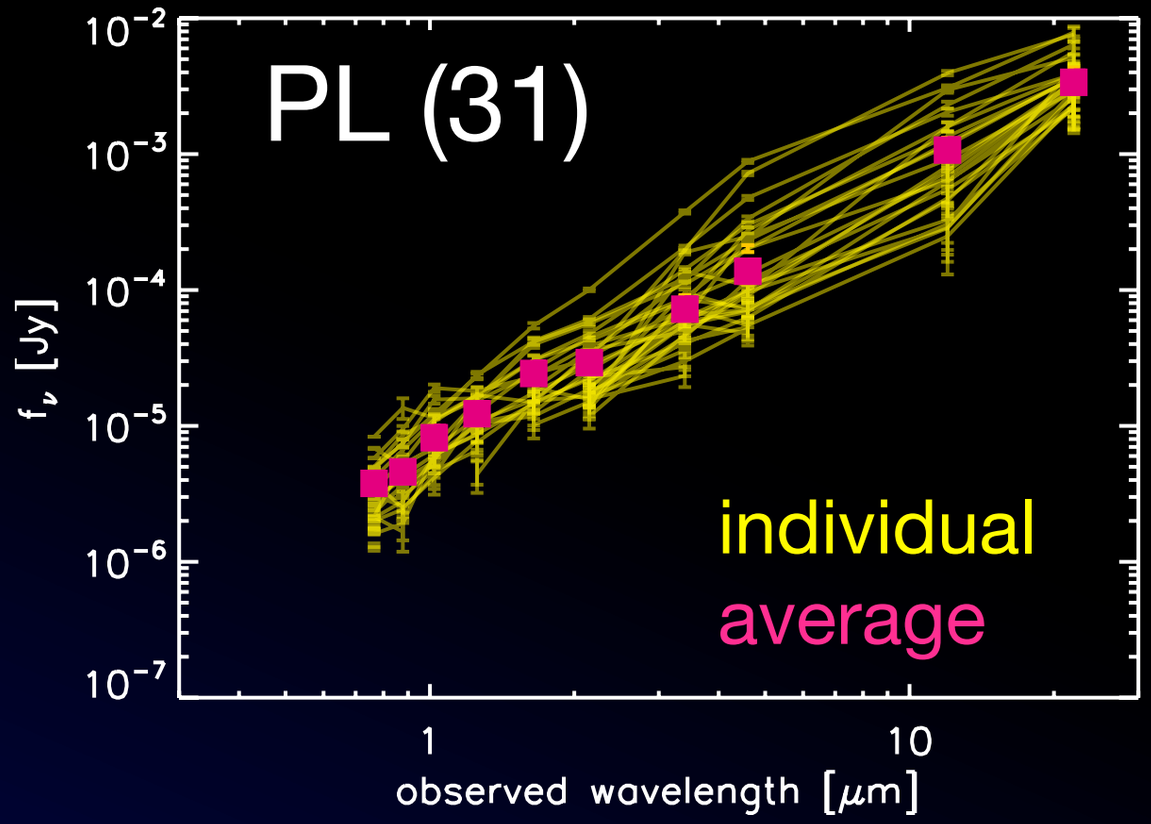


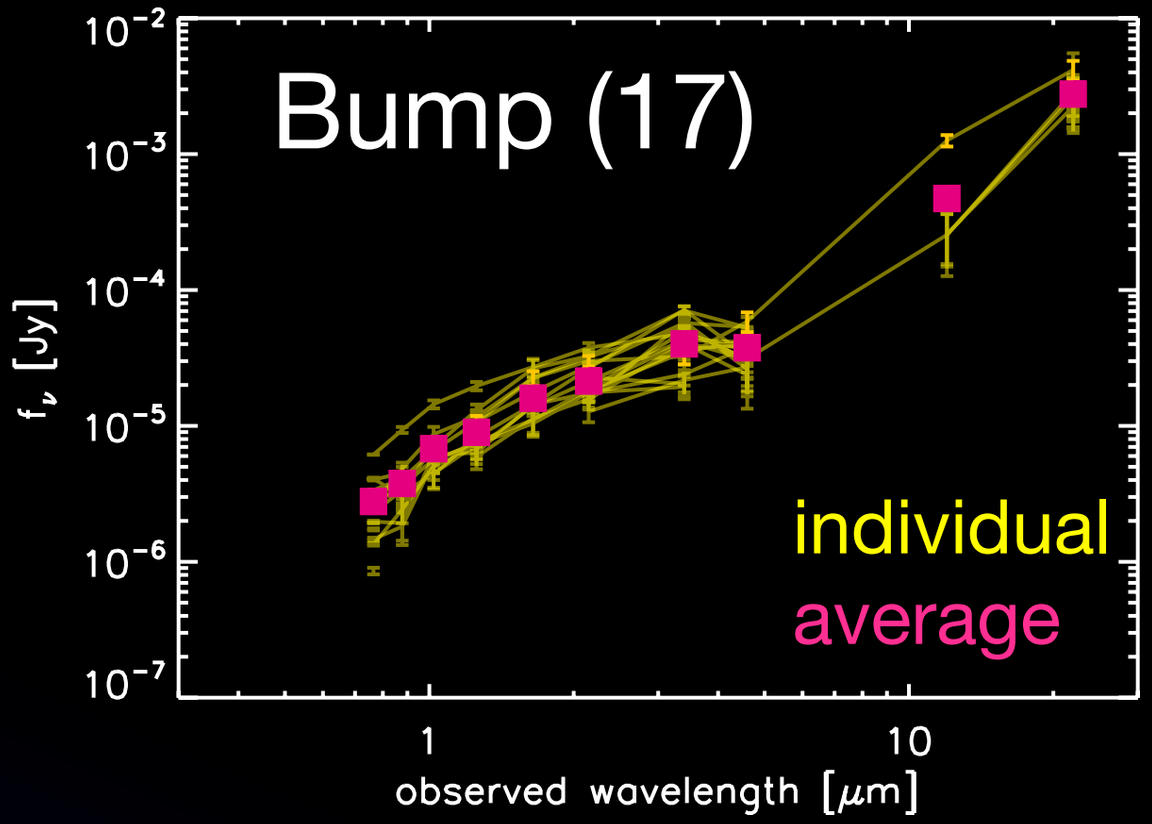
Results and Discussions

Photometric and Statistical properties of IR-bright DOGs

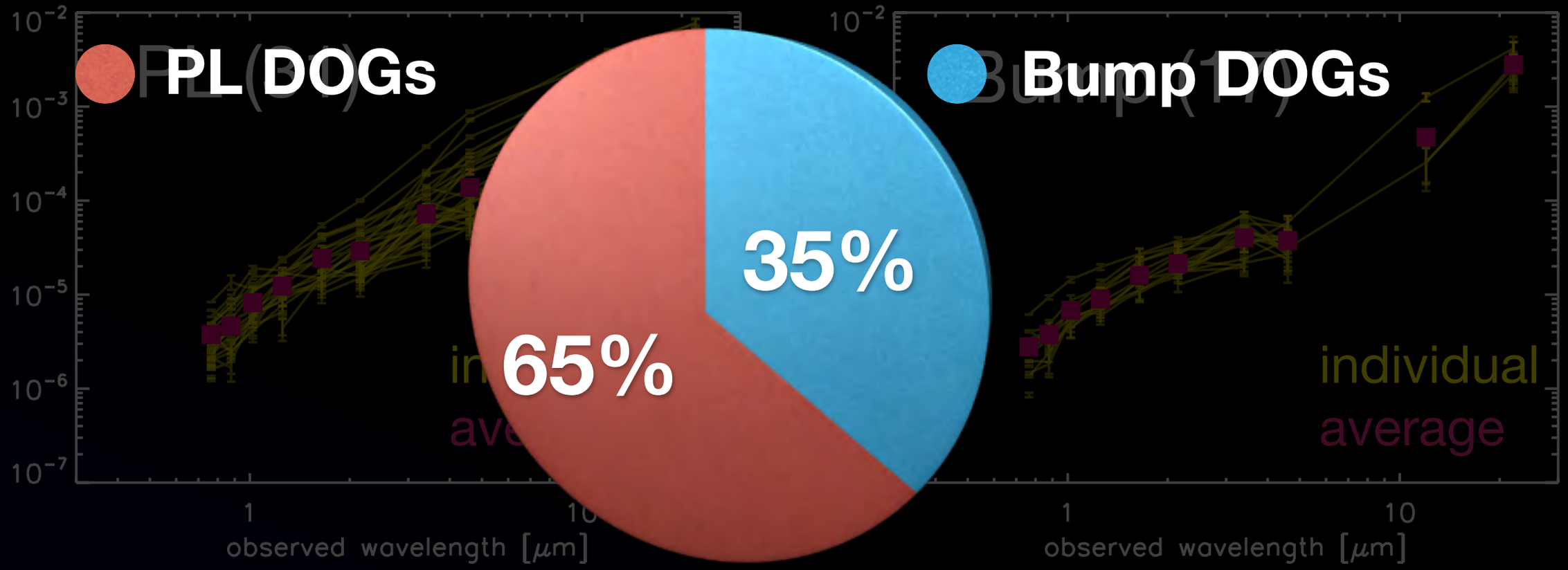
- Spectral Energy Distributions
- WISE colors
- Luminosity Function
- Luminosity Density

SEDs for PL and Bump DOGs



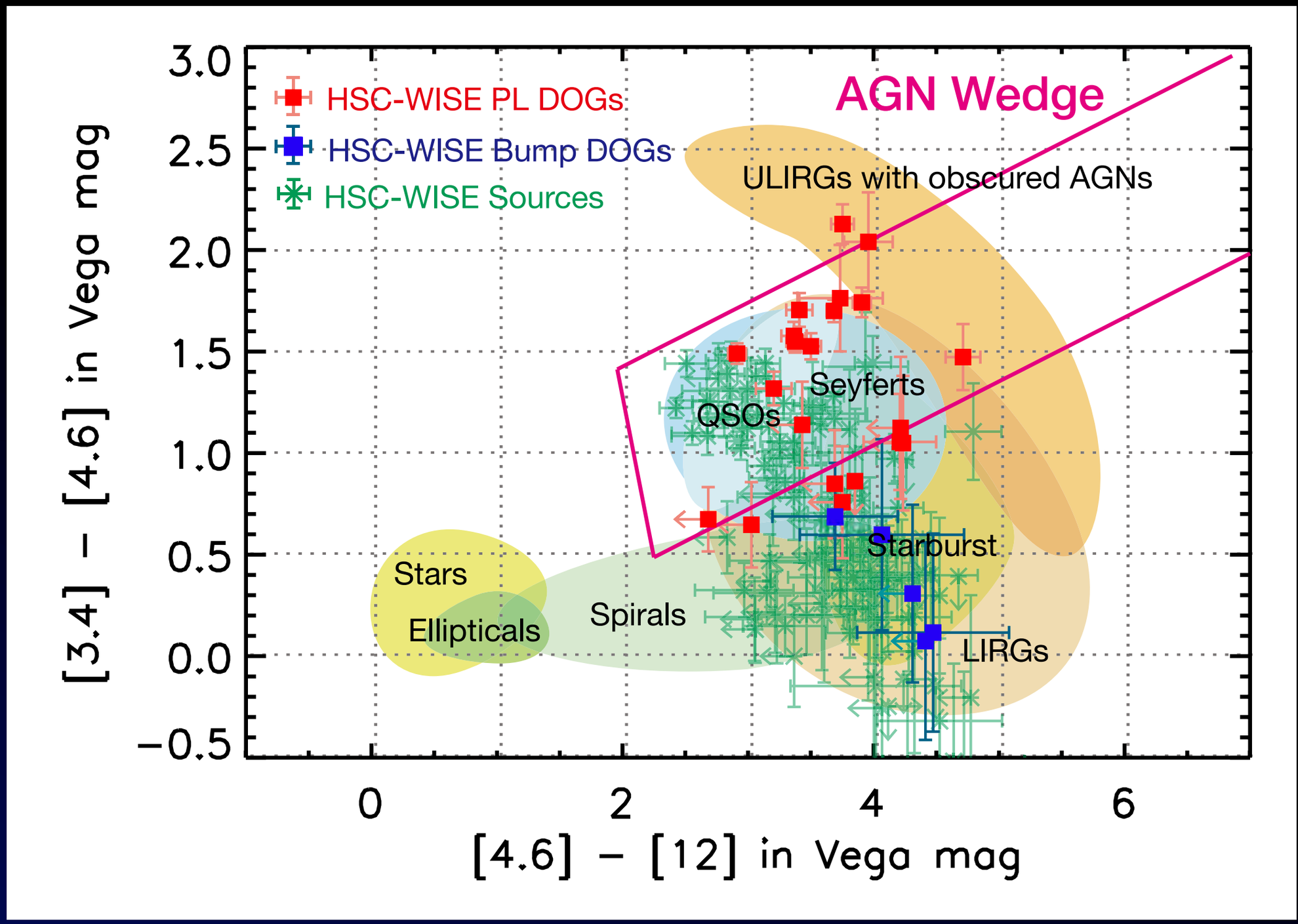


SEDs for PL and Bump DOGs

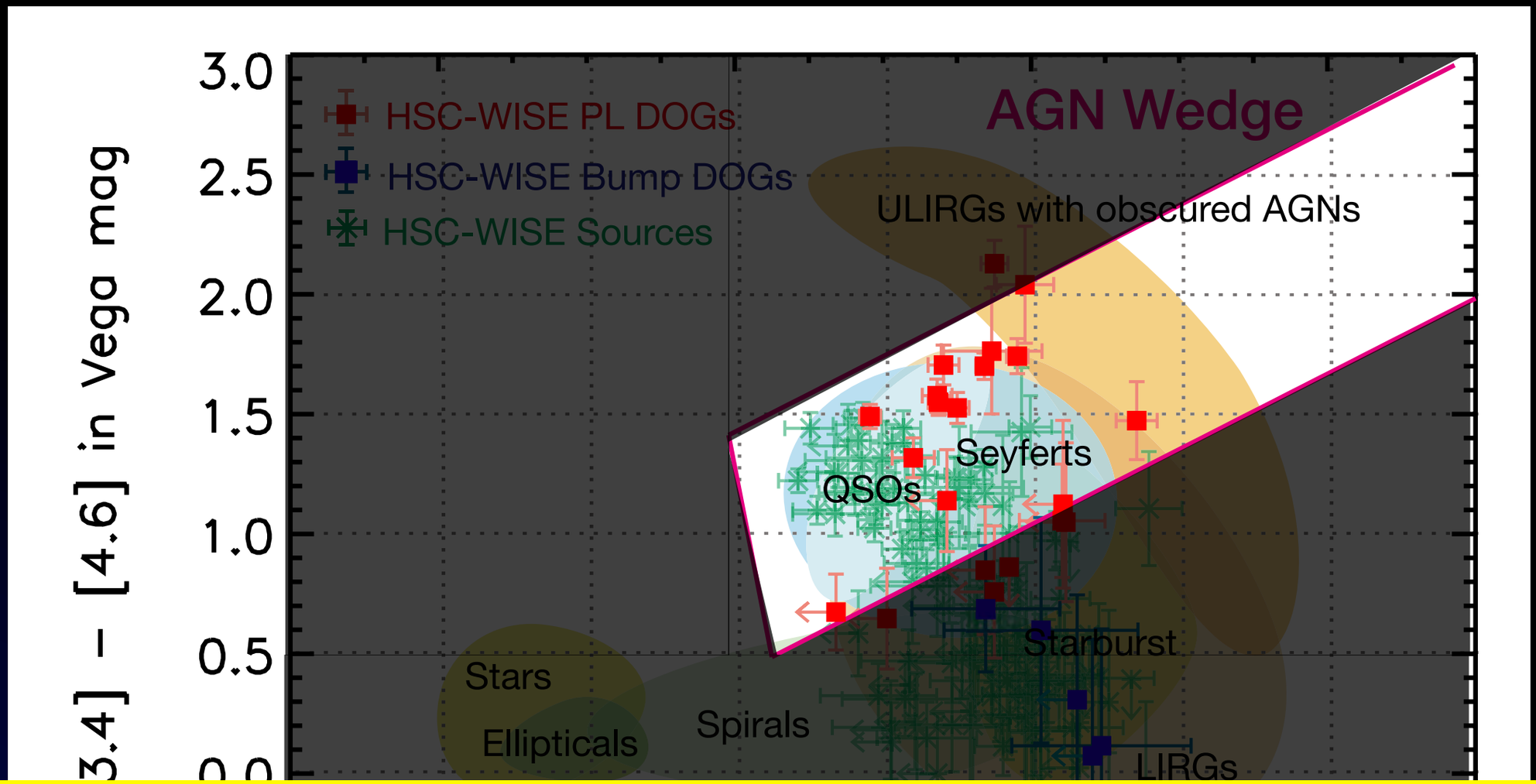


About 65% of our DOGs sample were classified as PL DOGs

WISE colors


HSC-WISE PL DOGs
HSC-WISE Bump DOGs
HSC-WISE Sources
AGN Wedge
ULIRGs with obscured AGNs
Seyferts
QSOs
Starburst
LIRGs
Stars
Ellipticals
Spirals
[3.4] − [4.6] in Vega mag
[4.6] − [12] in Vega mag
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
0
2
4
6

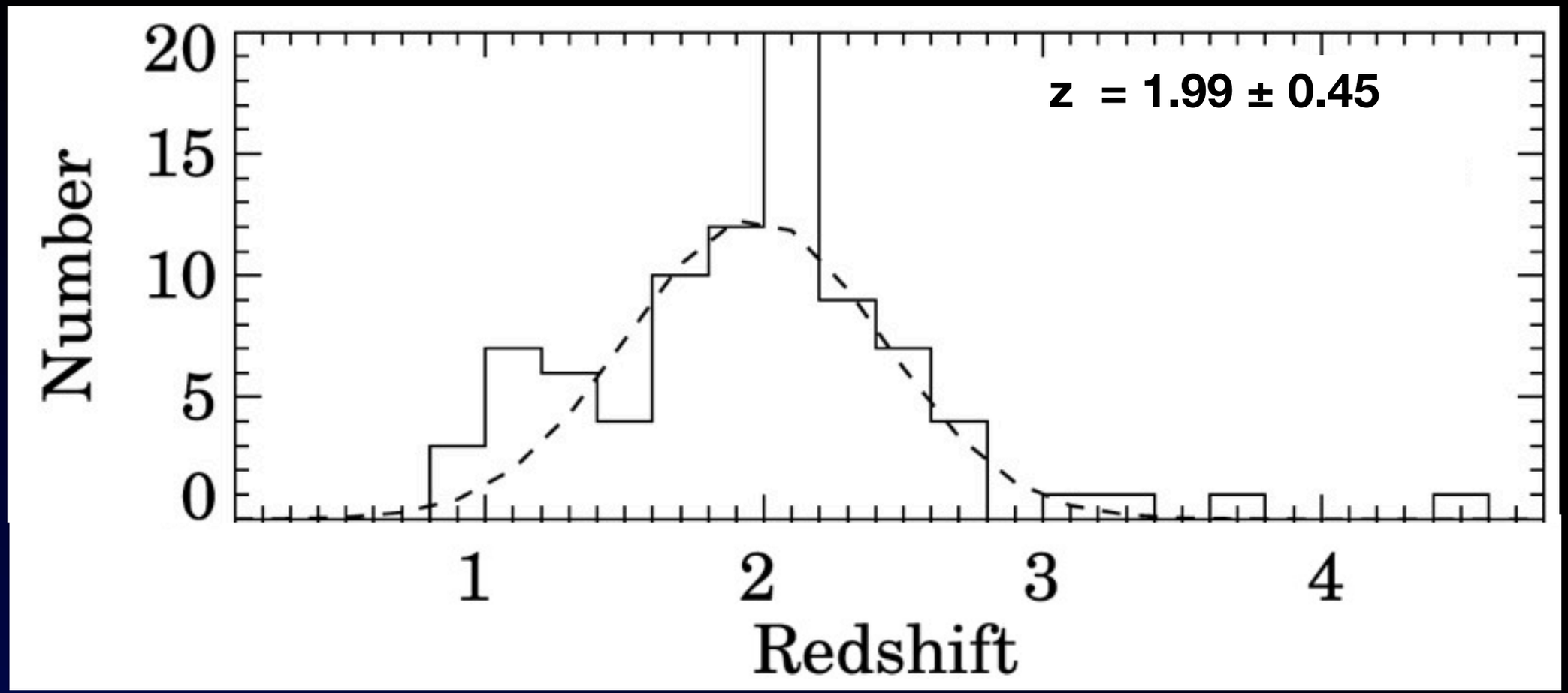
WISE colors



The WISE colors are roughly consistent with those of Mateos et al. (2012, 2013).

Total IR luminosity function

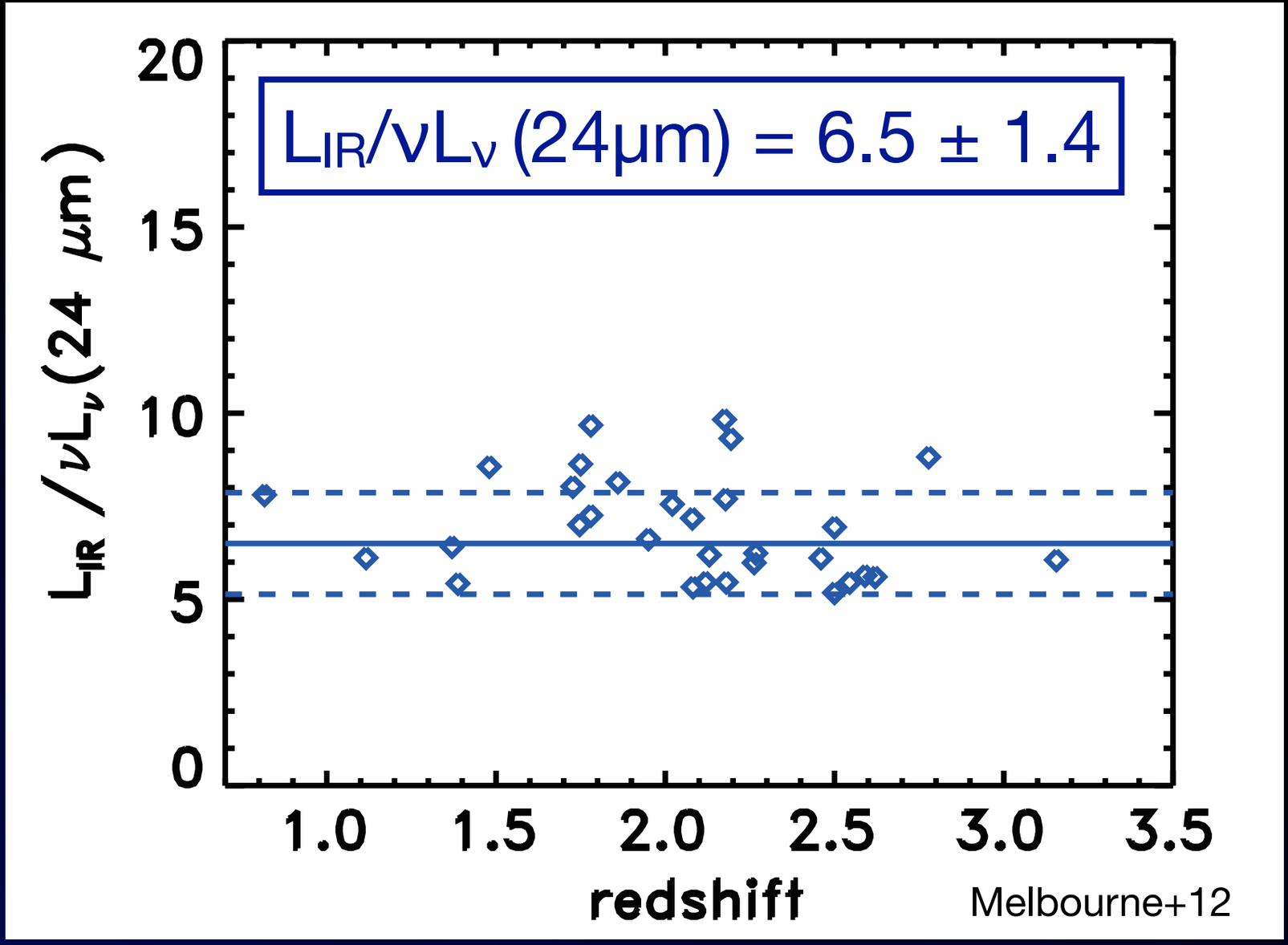
Assuming that the redshift distribution for our DOG sample is Gaussian (z= 1.99 ± 0.45; Dey et al. 2008)



Dey+08

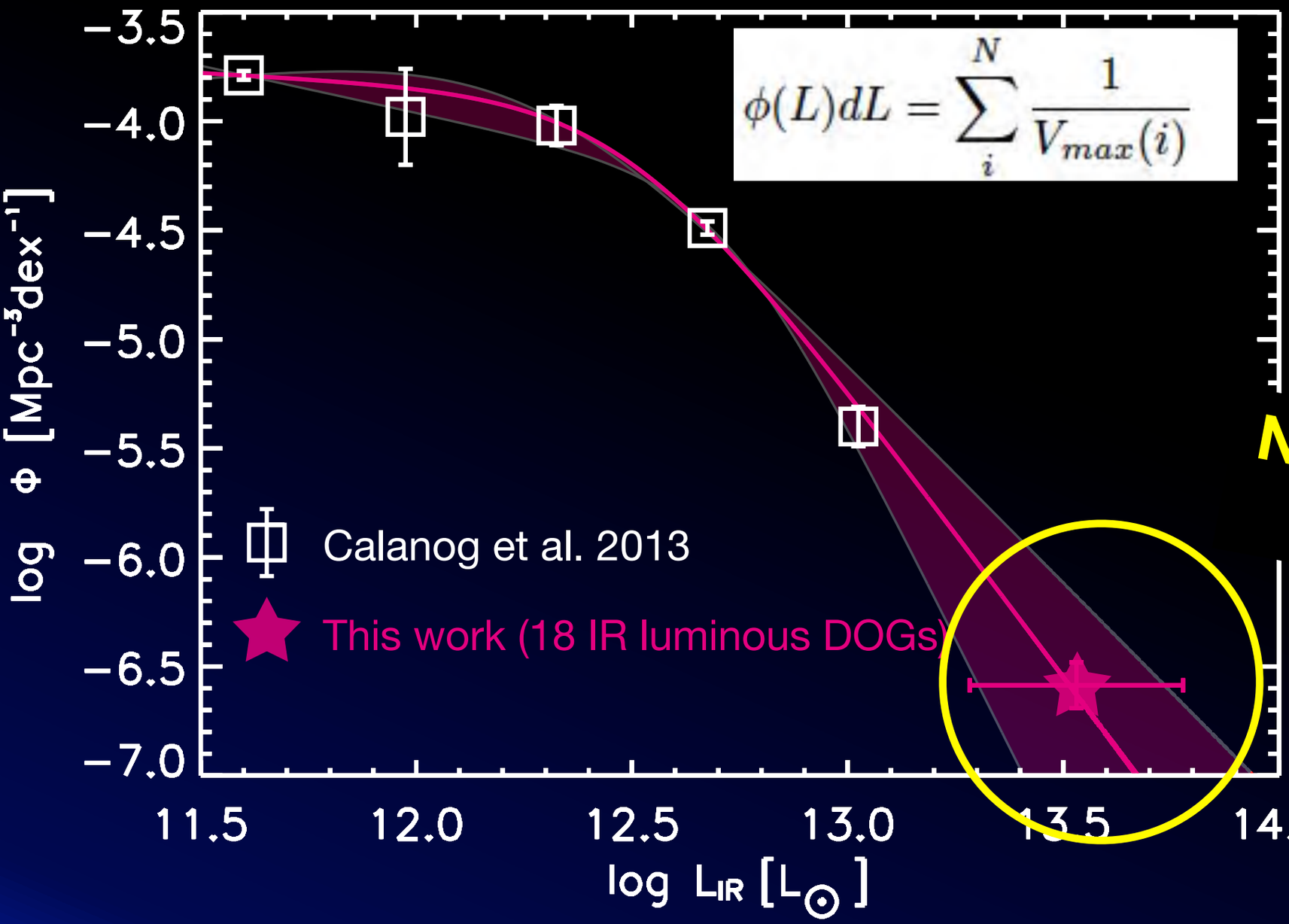
Total IR luminosity function

Assuming that the redshift distribution for our DOG sample is Gaussian (z= 1.99 ± 0.45; Dey et al. 2008)



Total IR luminosity function

Assuming that the redshift distribution for our DOG sample is Gaussian (z= 1.99 ± 0.45; Dey et al. 2008)

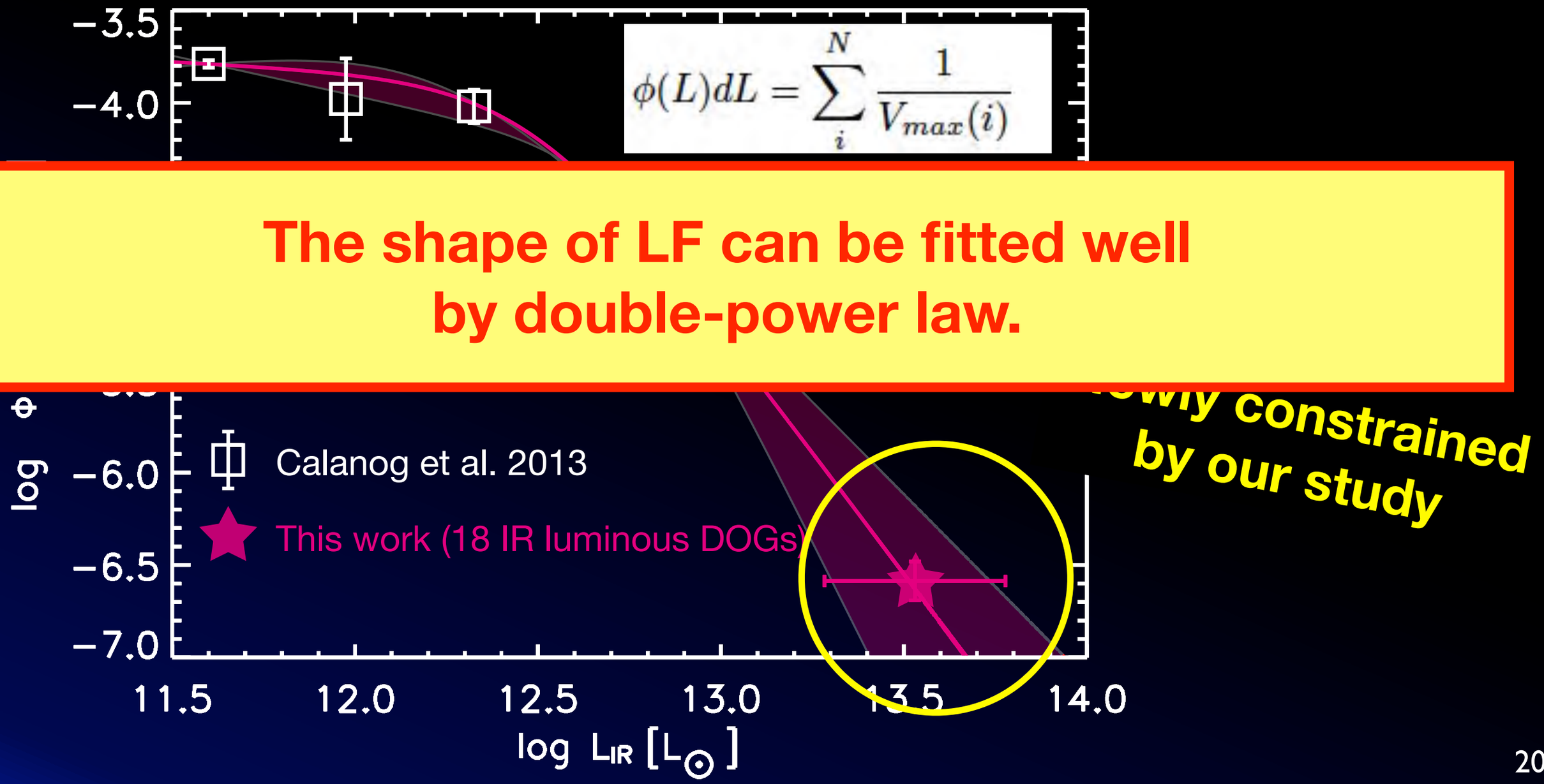


Total IR luminosity function

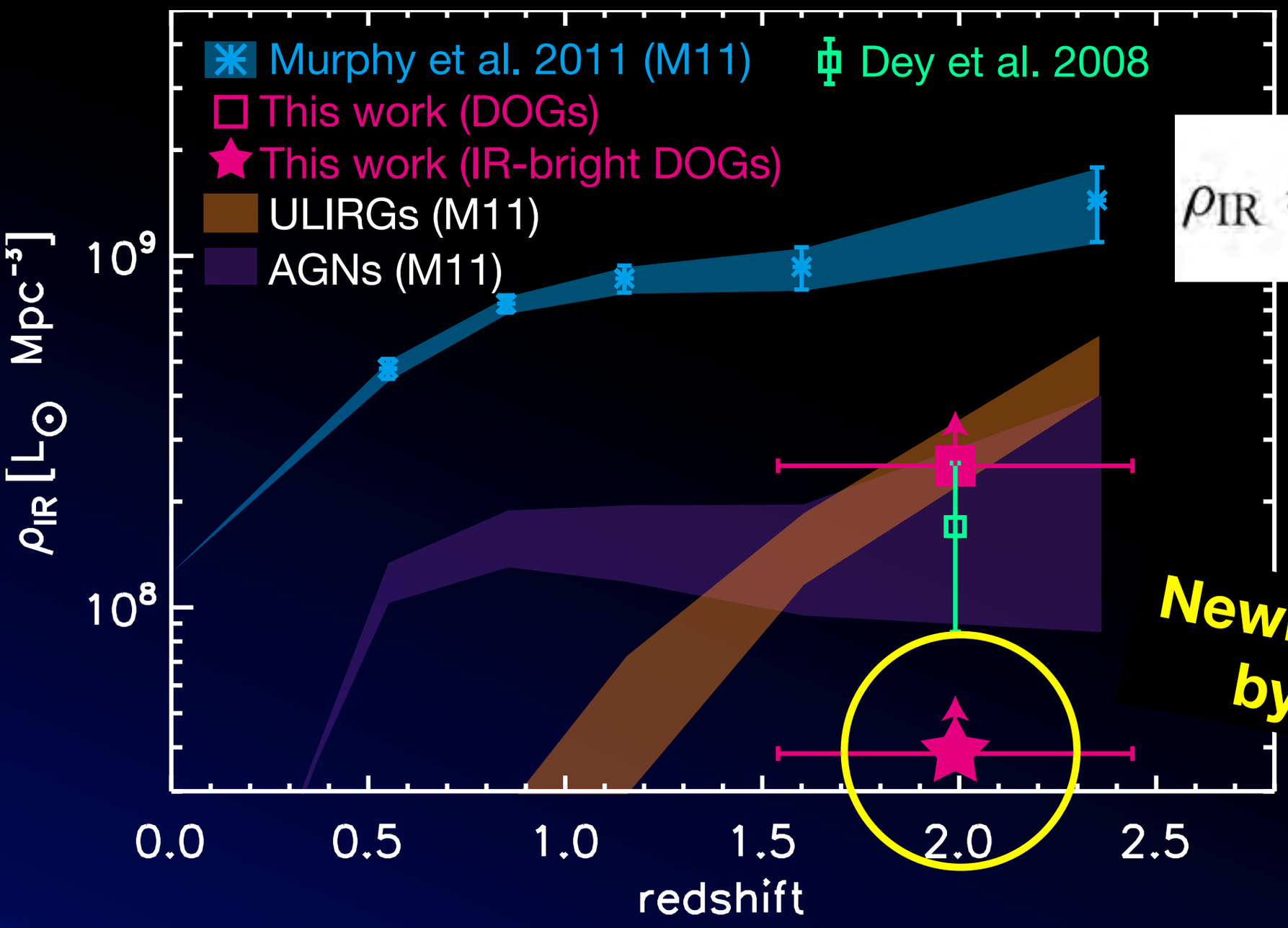
Assuming that the redshift distribution for our DOG sample is Gaussian (z= 1.99 ± 0.45; Dey et al. 2008)

$$\phi(L)dL = \sum_{i}^{N} \frac{1}{V_{max}(i)}$$

The shape of LF can be fitted well by double-power law.



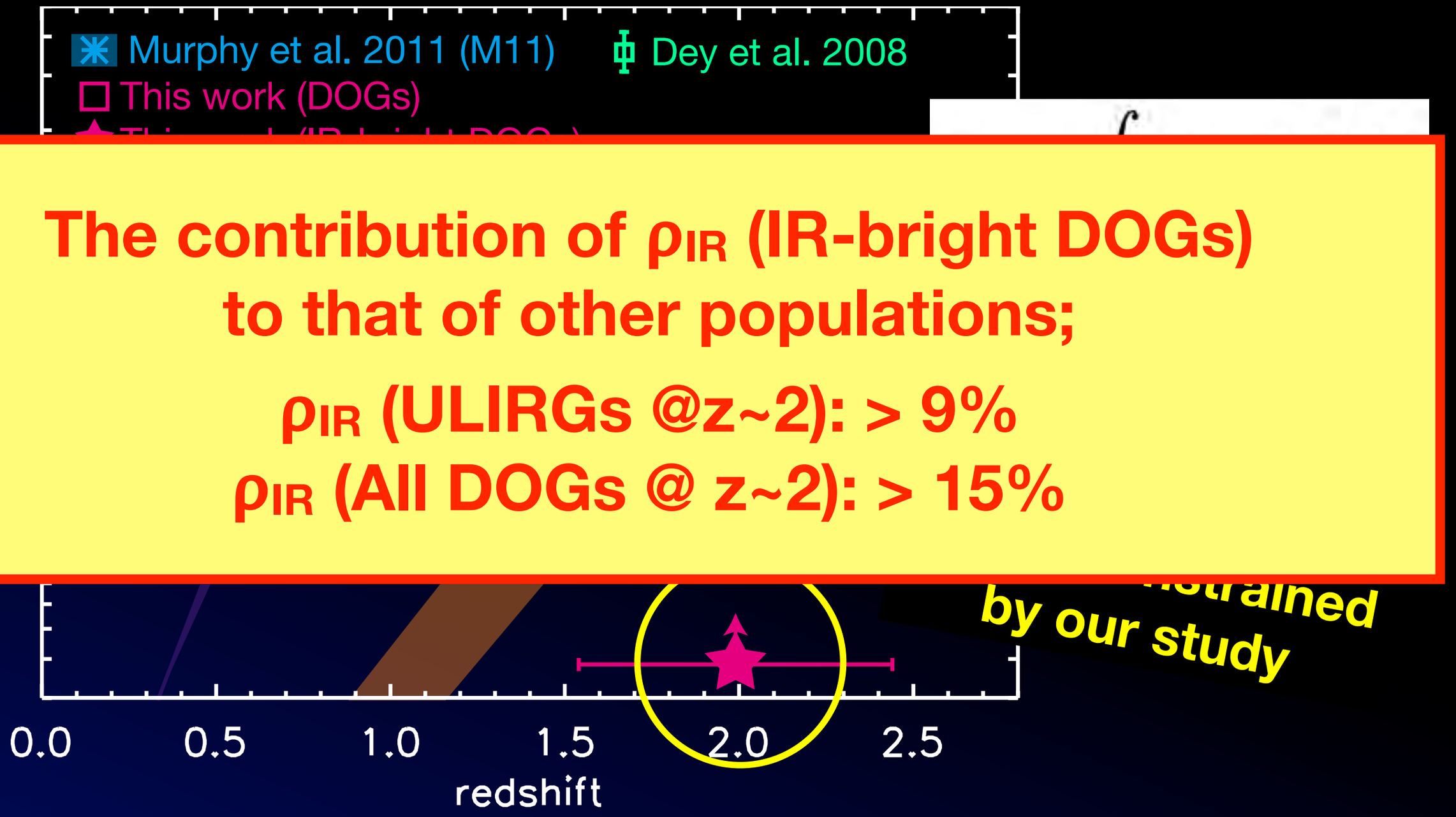
Total IR luminosity density ρ_{IR}



$$\rho_{IR} = \int L_{IR}\phi(L)\mathrm{d}L$$

Newly constrained by our study

Total IR luminosity density ρ_{IR}



The contribution of ρ_{IR} (IR-bright DOGs) to that of other populations;

ρ_{IR} (ULIRGs @z~2): > 9%

ρ_{IR} (All DOGs @ z~2): > 15%

Preliminary

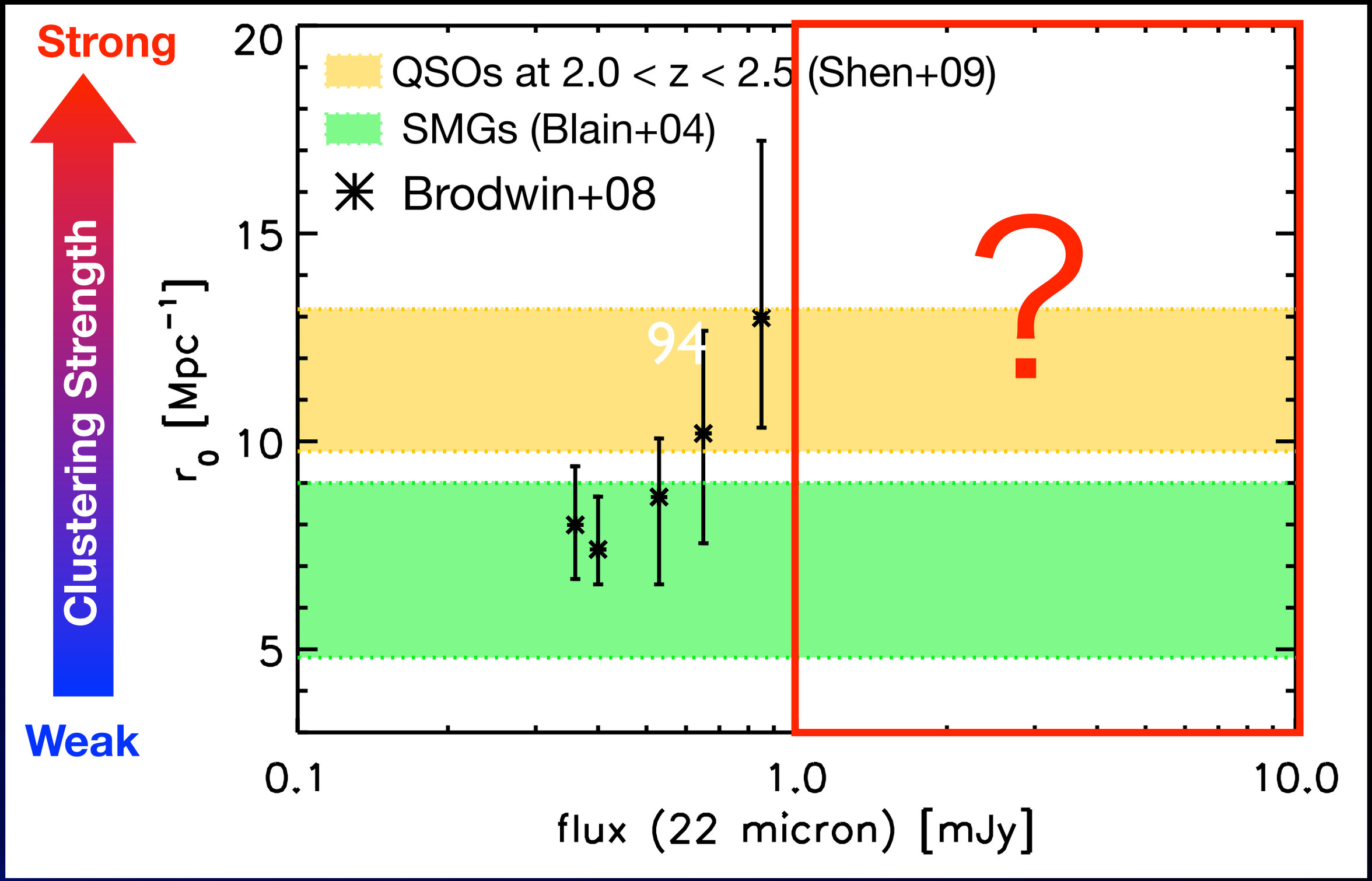
Current Status of DOGs search

Search for IR-bright DOGs based on latest dataset

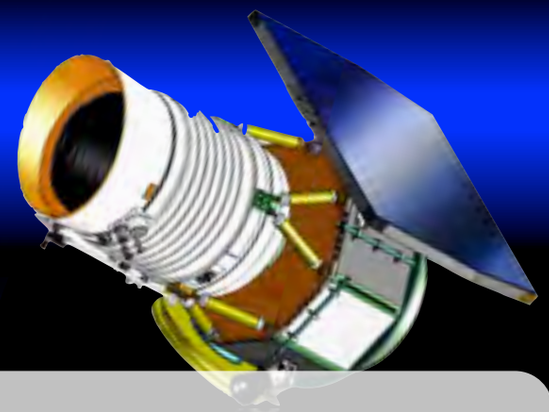
Clustering properties of IR-bright DOGs discovered by HSC S15A, VIKING DR2, ALLWISE

Toba, Nagao, Kajisawa et al. in prep.

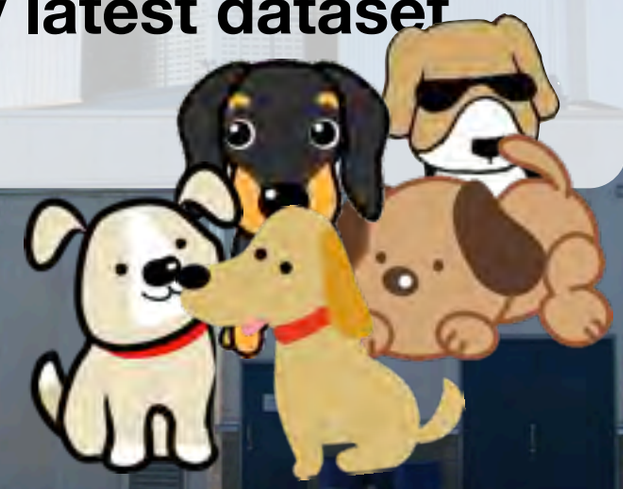
Spatial Distribution of DOGs



Summary



- We **newly discovered 48 DOGs based on the HSC, VIKING, and WISE data.**
- **Assuming that the redshift distribution for our DOGs sample (z = 1.99 ± 0.45), we derived the space density of them. The IR LF including data obtained from the literature is fitted well by a double-power law.**
- **We also derived lower limit of IR LD for our sample, and its contributions to the ρ_{IR} (ULURGs) and ρ_{IR} (All DOGs) are >9%, and >15%, respectively**
- **The clustering analysis of 526 DOGs discovered by latest dataset could indicates that they are strongly clustered.**



I ♥ DOGs