Identification of obscured QSOs and properties of their obscuring matter

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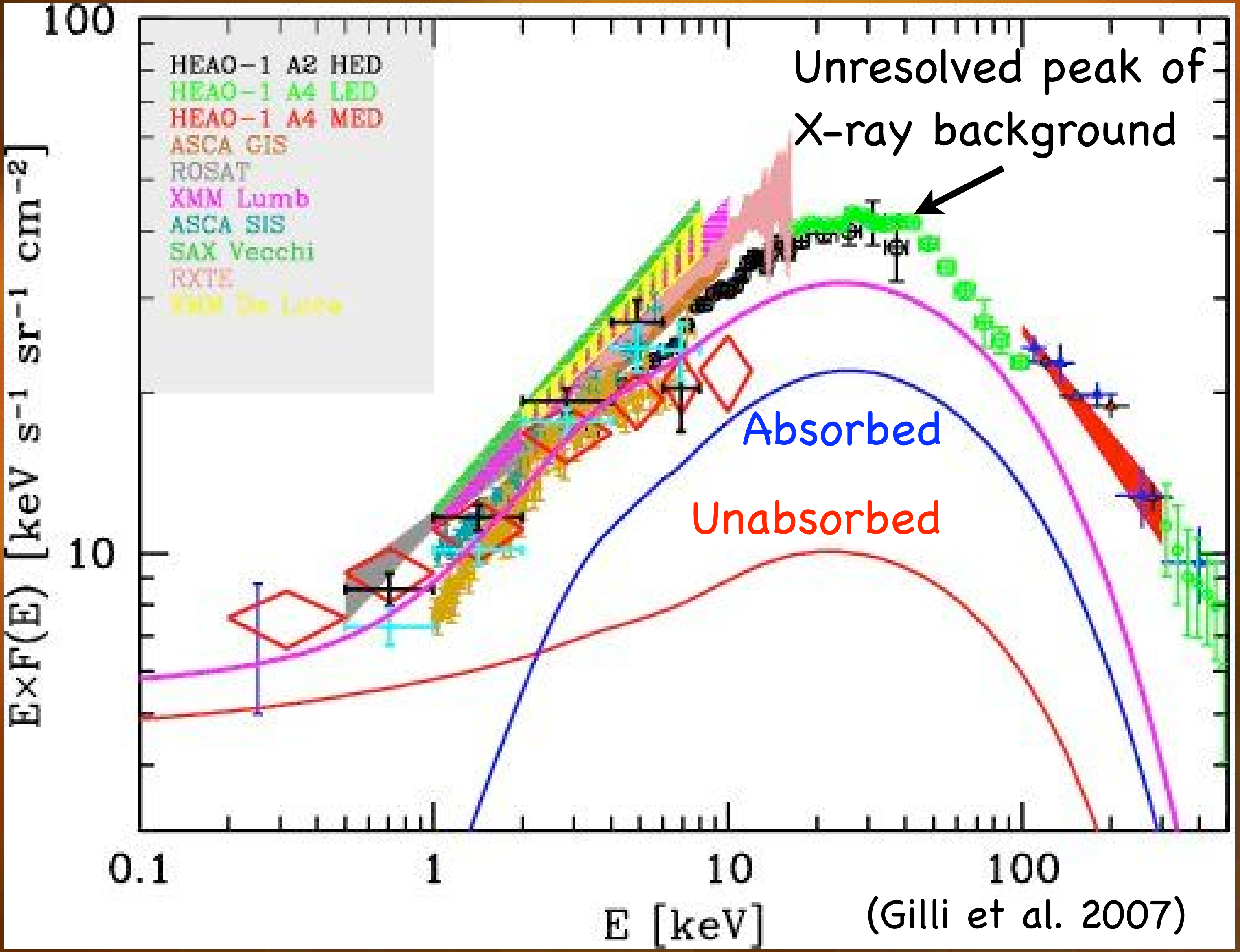
Facts & Questions

- There is a missing AGN population, likely obscured AGN at moderate redshift and luminosities (e.g. Worsley et al. 2006; Gilli et al. 2007)

  ➪ How and where can we find the missing AGN ?

Indirect evidence of existence of heavily absorbed AGN

CXRB synthesis models require a population of heavily obscured AGN, but consistent with decreasing obscured fraction with luminosity



(Setti and Woltjer 1989, Comastri et al. 1995, Gilli et al. 2001, 2003, 2007; Worsley et al. 2004, 2005, Hopkins et al. 2005)

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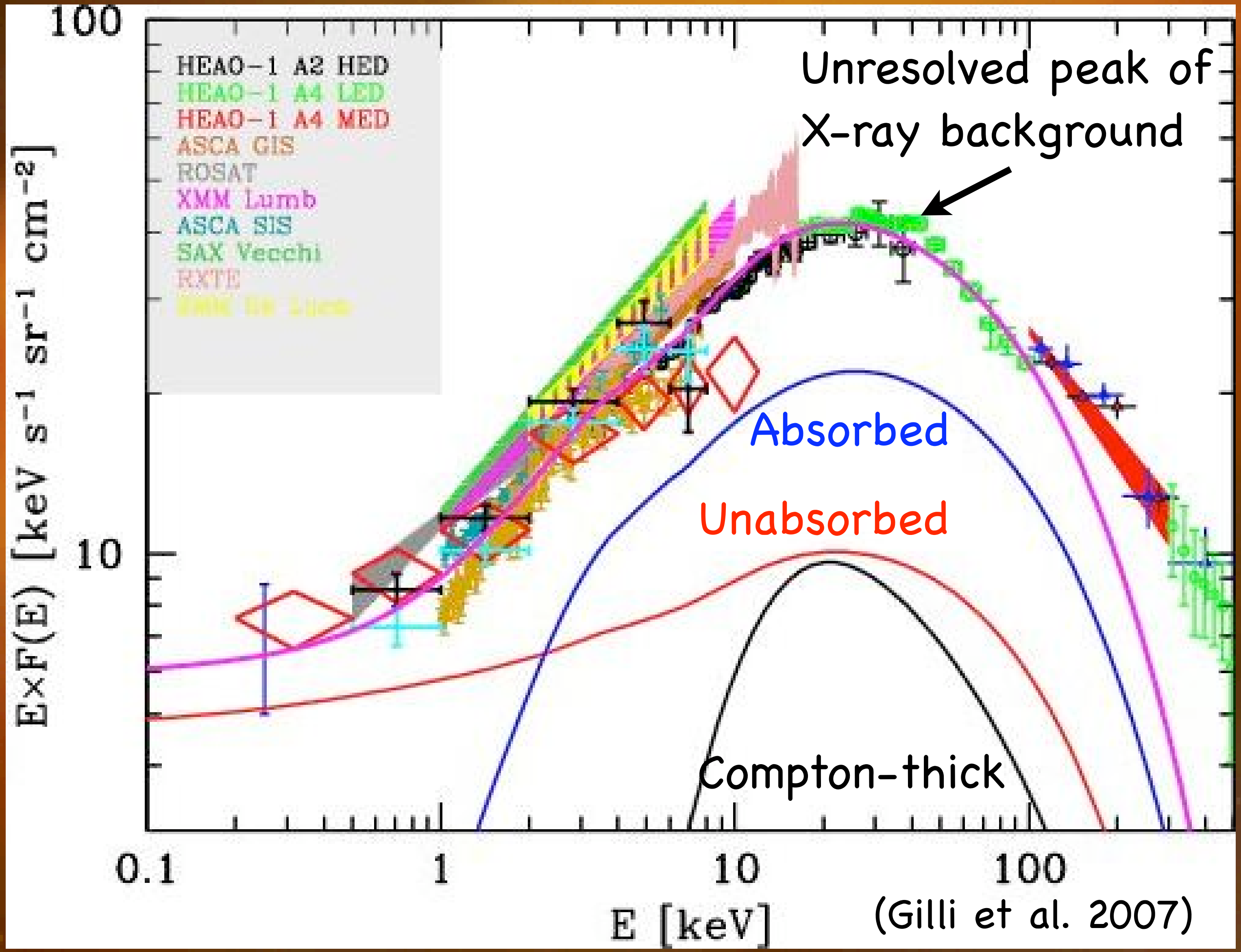

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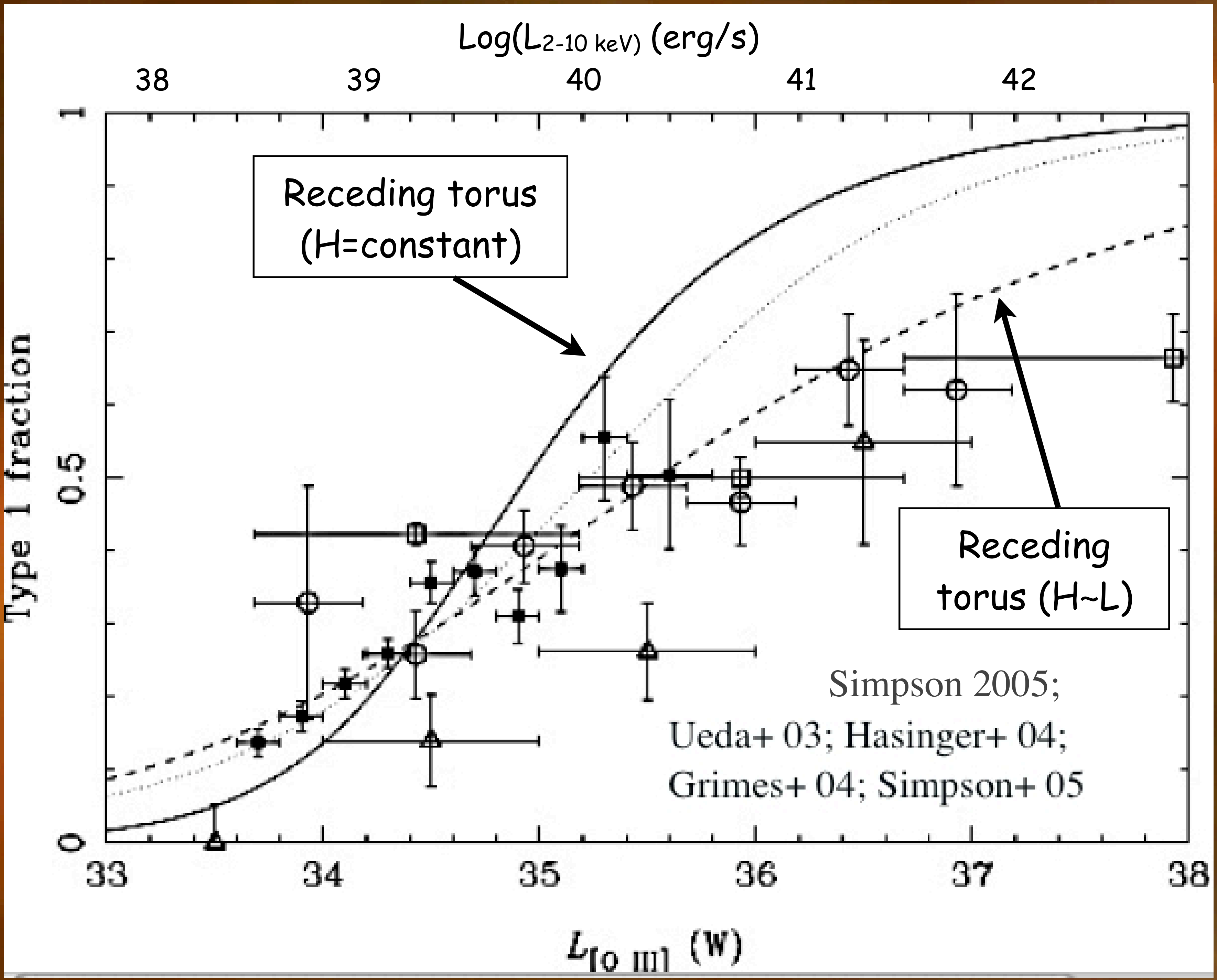
- Fewer obscured AGN are found at high luminosities (e.g. Simpson 2005; La Franca et al. 2005)

  ➪ Is the paucity of obscured AGN at high luminosity real or a selection effect ? Is the obscuring matter (torus) affected by the AGN luminosity ?

The fraction of obscured AGN decreases at larger luminosities



(Simpson 2005; La Franca et al. 2005)

Image credit: NASA/CXC/M. Weiss

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- The multi-wavelength obscuration properties in 20-30% of AGN are not consistent with the standard unification model (e.g. Perola et al. 2004; Tozzi et al. 2006; Tajer et al. 2007; Sturm et al. 2006; Brand et al. 2007).

➪ What are the properties of the obscuring matter in AGN ?

Image credit: NASA/CXC/M. Weiss

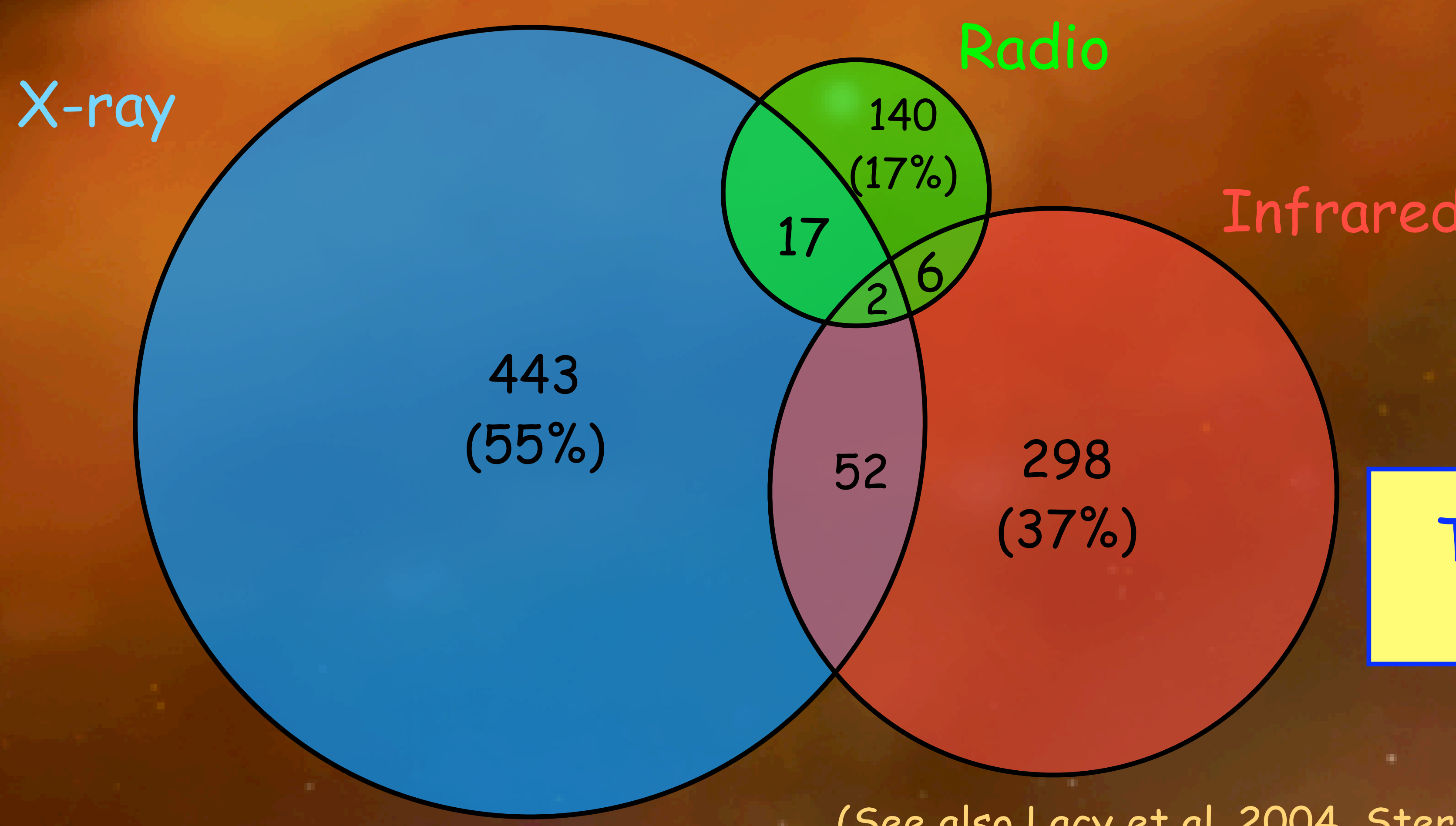
Can we identify all AGN ?

Combine various selection method to minimize selection biases

In Chandra/SWIRE survey: 0.6 deg^2 (Polletta et al. 2006):

- X-ray: $L_X > 10^{42}$ erg s^{-1}
- Infrared: red power-law ($\nu F_\nu \propto \lambda^2$)
- Radio-loud: $\log(F_{20cm}/F_{2500Å}) > 2.5$ or $F_{24\mu m}/F_{20cm} < 1$

Each selection is highly incomplete !!



Total AGNs: 808
(2315 deg^{-2})

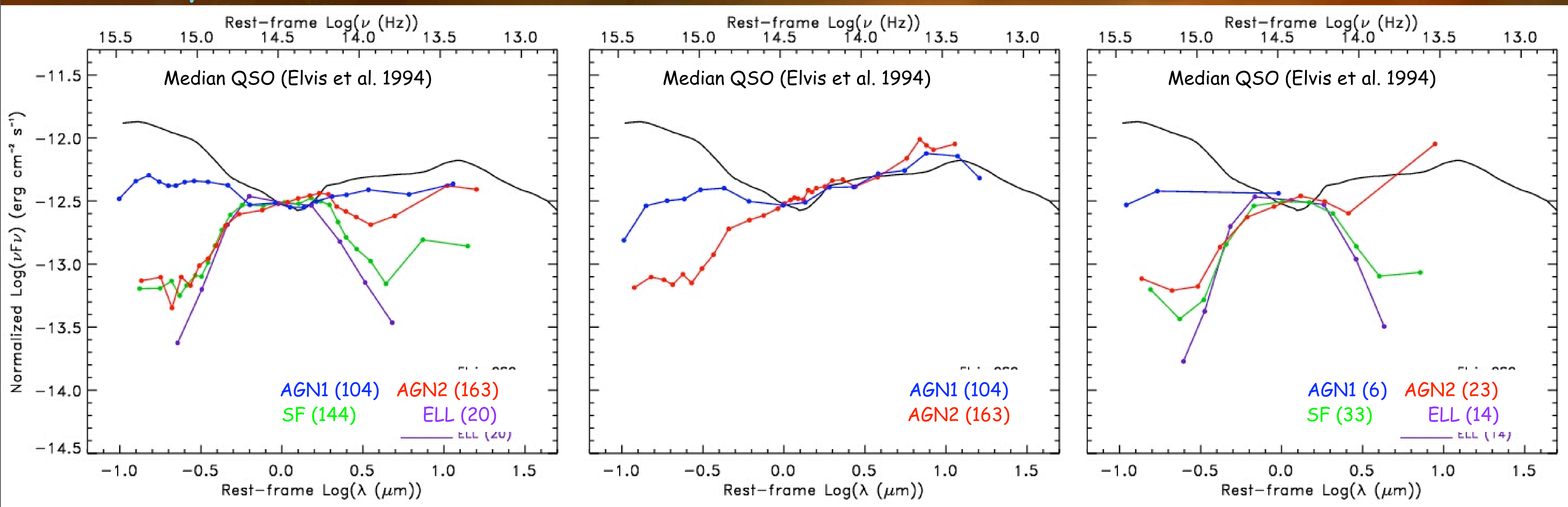
(See also Lacy et al. 2004, Stern et al. 2005; Donley et al. 2006, Alonso-Herrero et al. 2006)

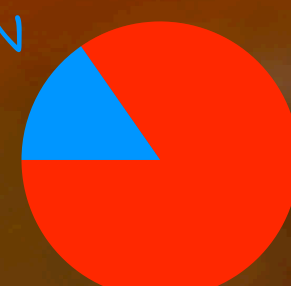
Spectral energy distributions (SEDs) of all identified AGN

X-ray-selected AGN

Infrared-selected AGN

Radio-selected AGN

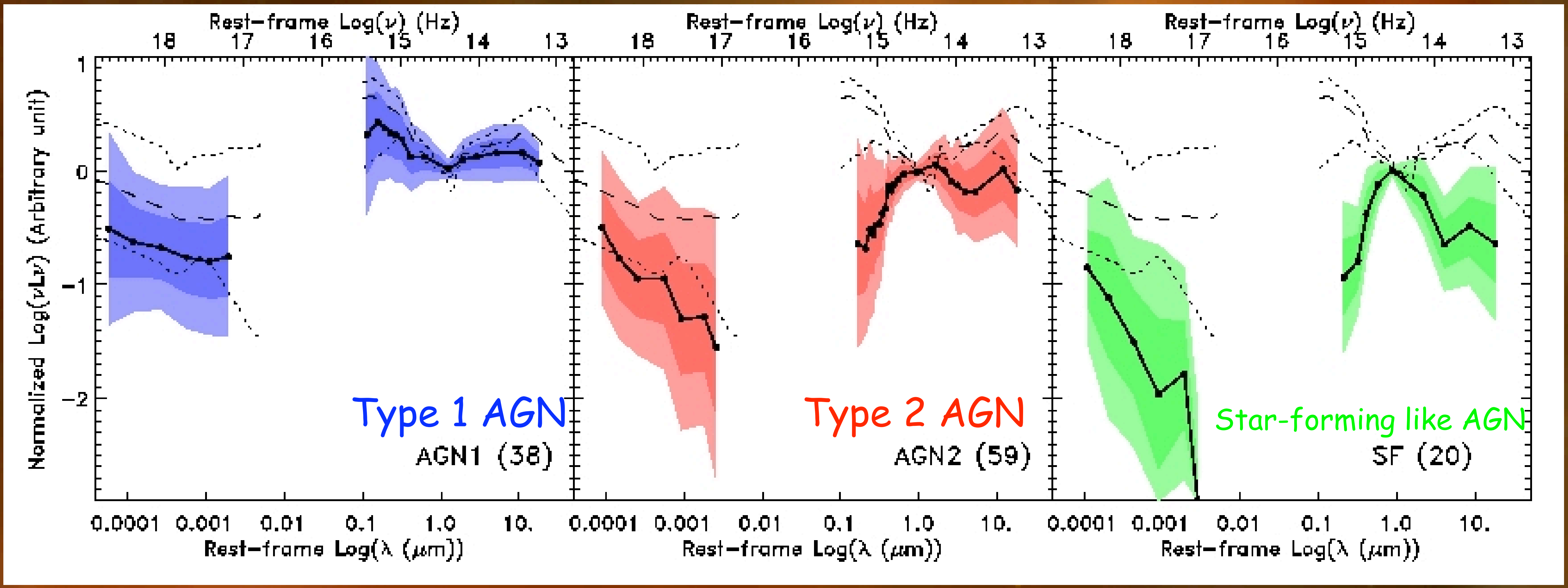




Total: Elliptical (4%) Star-forming galaxy (22%) Blue AGN (19%) Red AGN (55%)

X-ray properties vs optical-IR SEDs

Average SEDs of X-ray selected AGNs (Polletta et al. 2007)



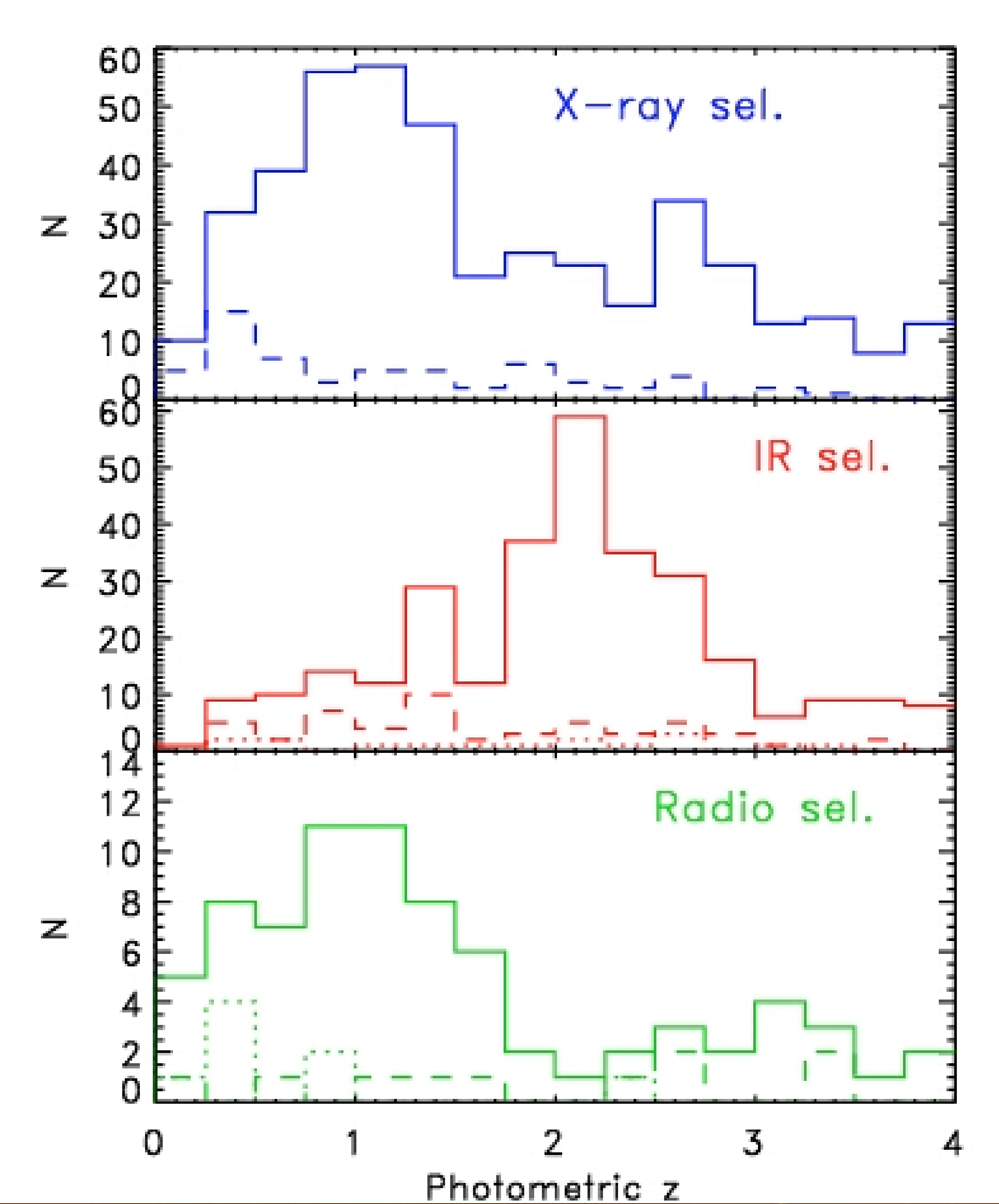
Dominant energy source vs λ

Class	Optical	Infrared	X-ray
AGN1	AGN	AGN	Unabsorbed
AGN2	Host galaxy	AGN	Absorbed
SF	Host galaxy	Host galaxy	Very absorbed

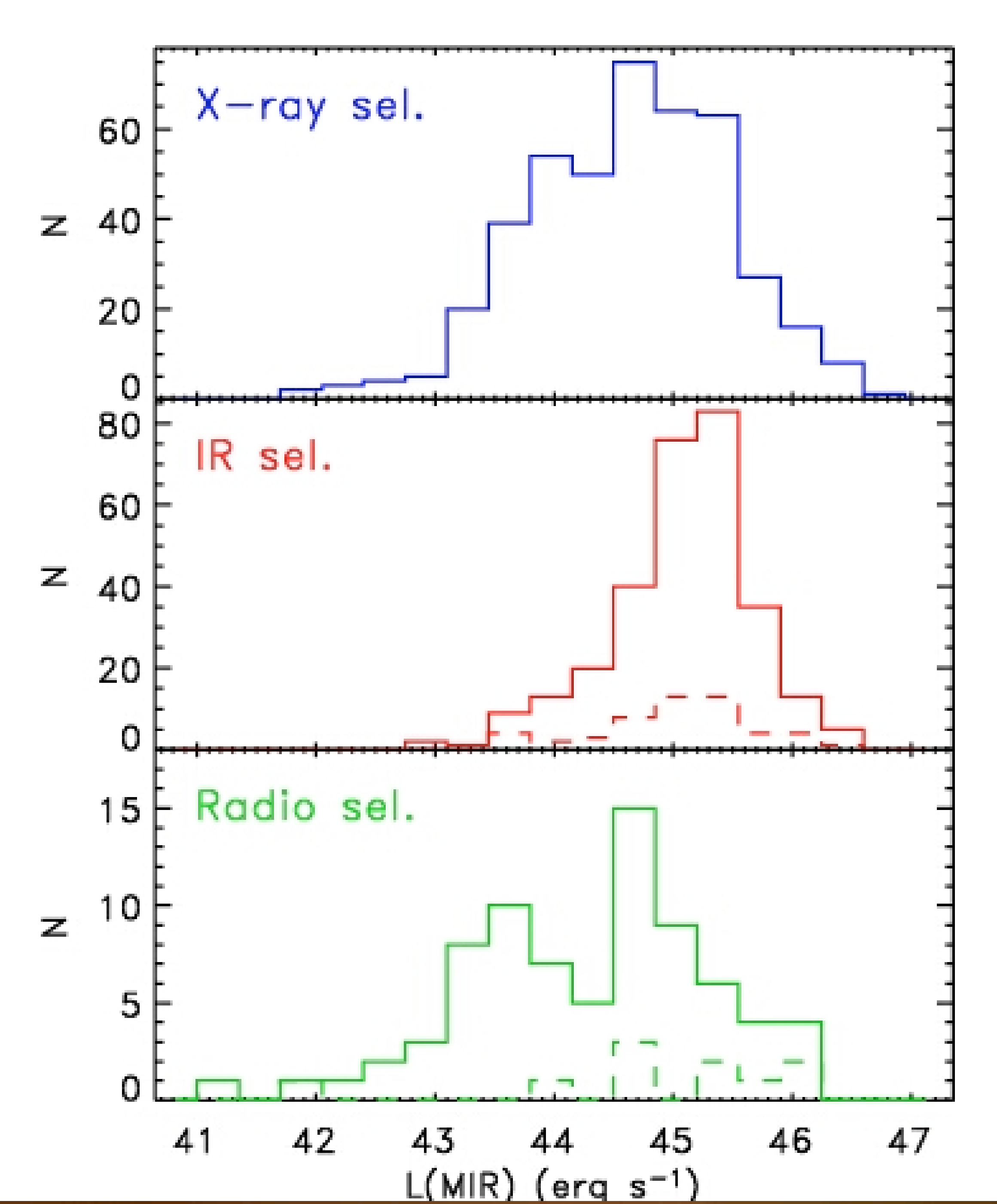
Image credit: NASA/CXC/M. Weiss

Redshift & L_{MIR} distribution vs selection

z distributions



$L_{3\text{-}20\mu m}$ distributions



The MIR-selection favors luminous AGN at z~2

A sample of extremely luminous and obscured AGN

From the 3 Spitzer widest extragalactic surveys:

- optically faint & 24μm bright sources ($F_{24\mu m}/F_r > 500$)
- AGN-dominated SEDs
- available IR spectra from Spitzer/IRS
- L(6μm) > 10^{12} $L_\odot$

Field	SWIRE (LH, N1, N2)	NDWFS	E-FLS	ALL
Area (deg^2)	24	9	3.7	36.7
N. sources★	13	5	5	23

★ 2: Houck et al. 2005, 6: Weedman, Polletta et al. 2006, 1: Desai et al. 2006, 5: Yan et al. 2007, 3: Smith et al., in prep., 6: Polletta et al., ApJ submitted

Spectral Energy Distributions

F_ν (mJy) vs λ(μm)

1-5 Optical

4 IRAC

IRS spectrum

3 MIPS

$F_\nu \sim \nu^{-\alpha}$ with $\alpha \geq 2$

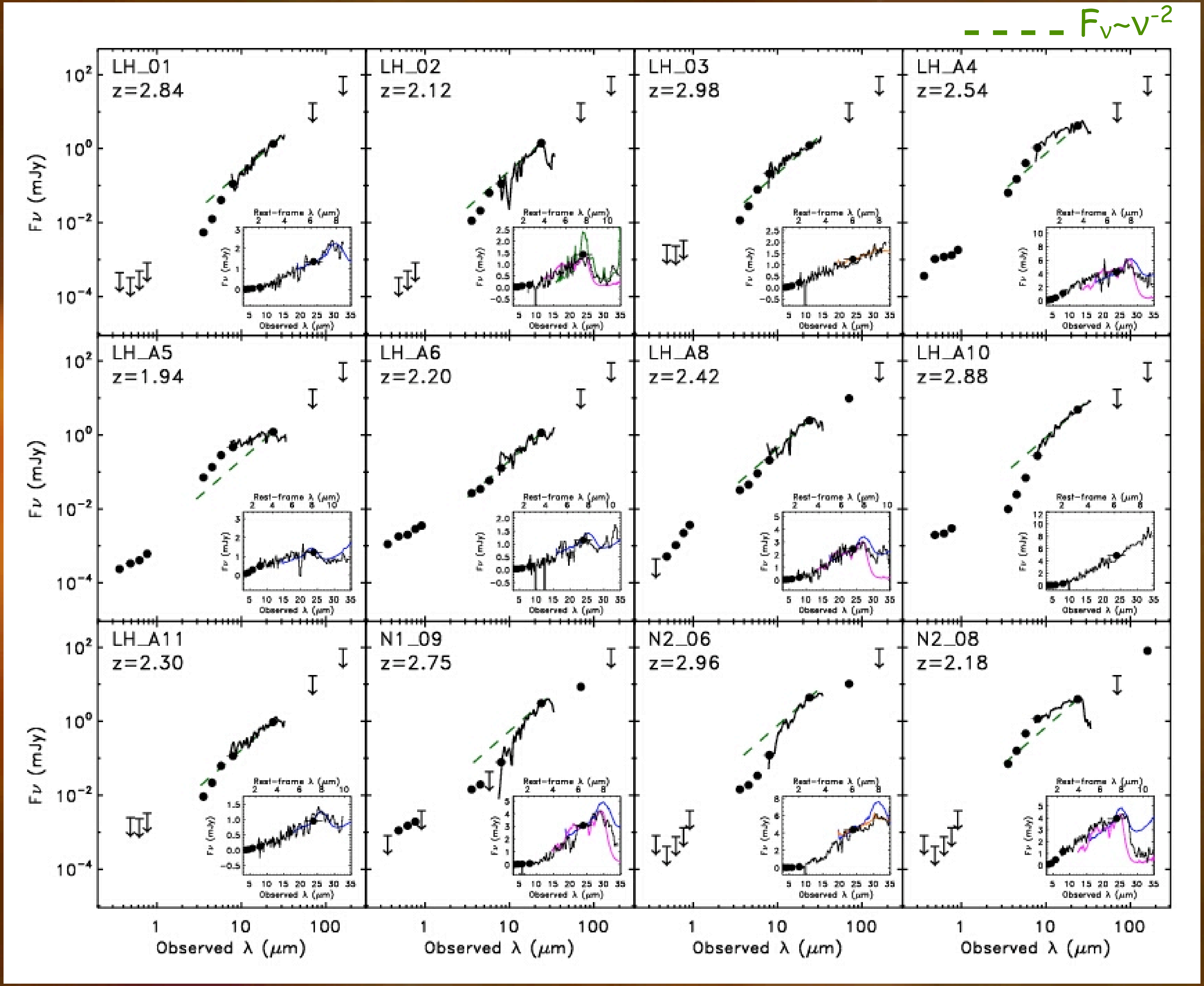
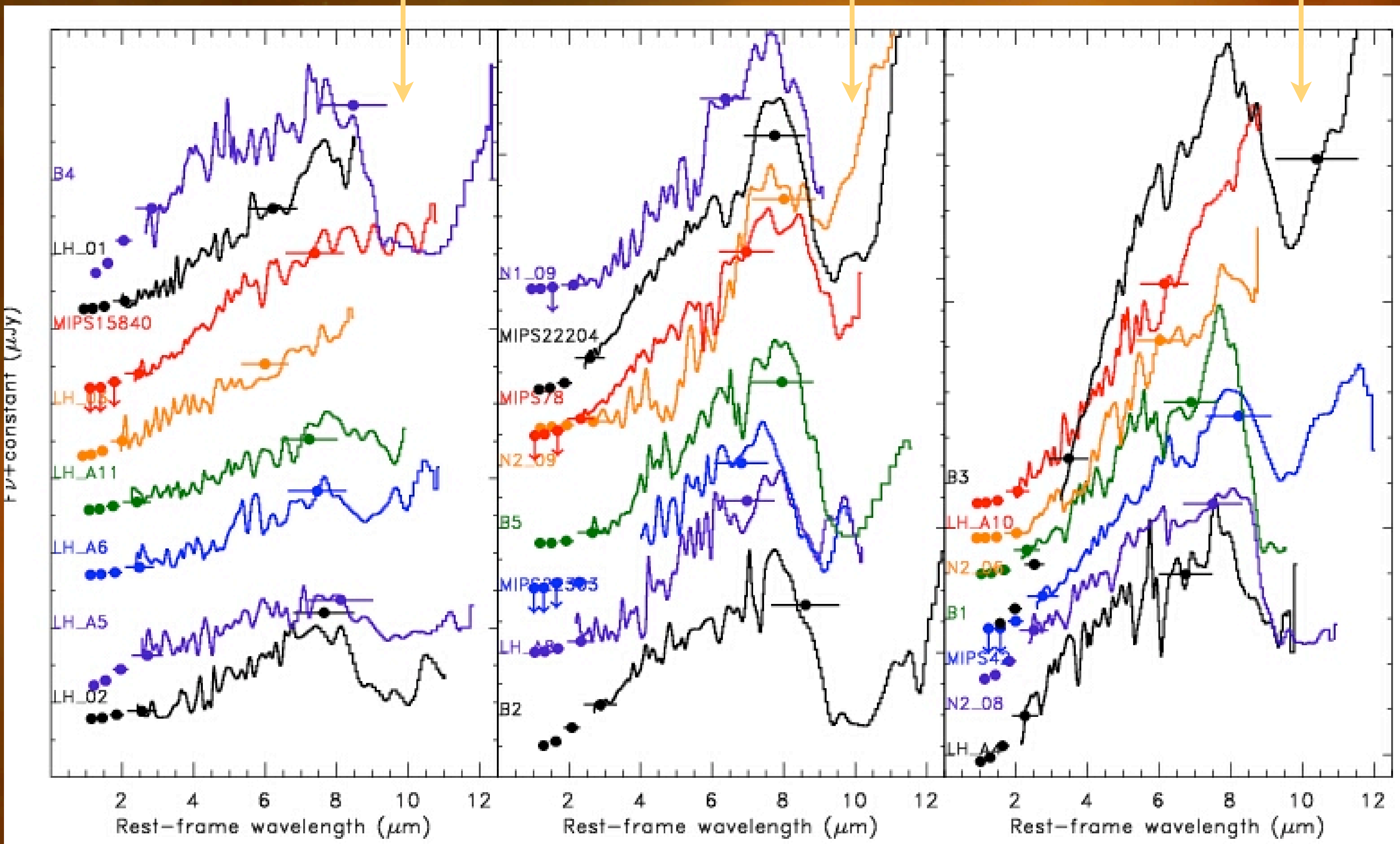


Image credit: NASA/CXC/M. Weiss

Infrared Spectra (IRS)

Silicate absorption feature at 9.7μm in 18/23 sources



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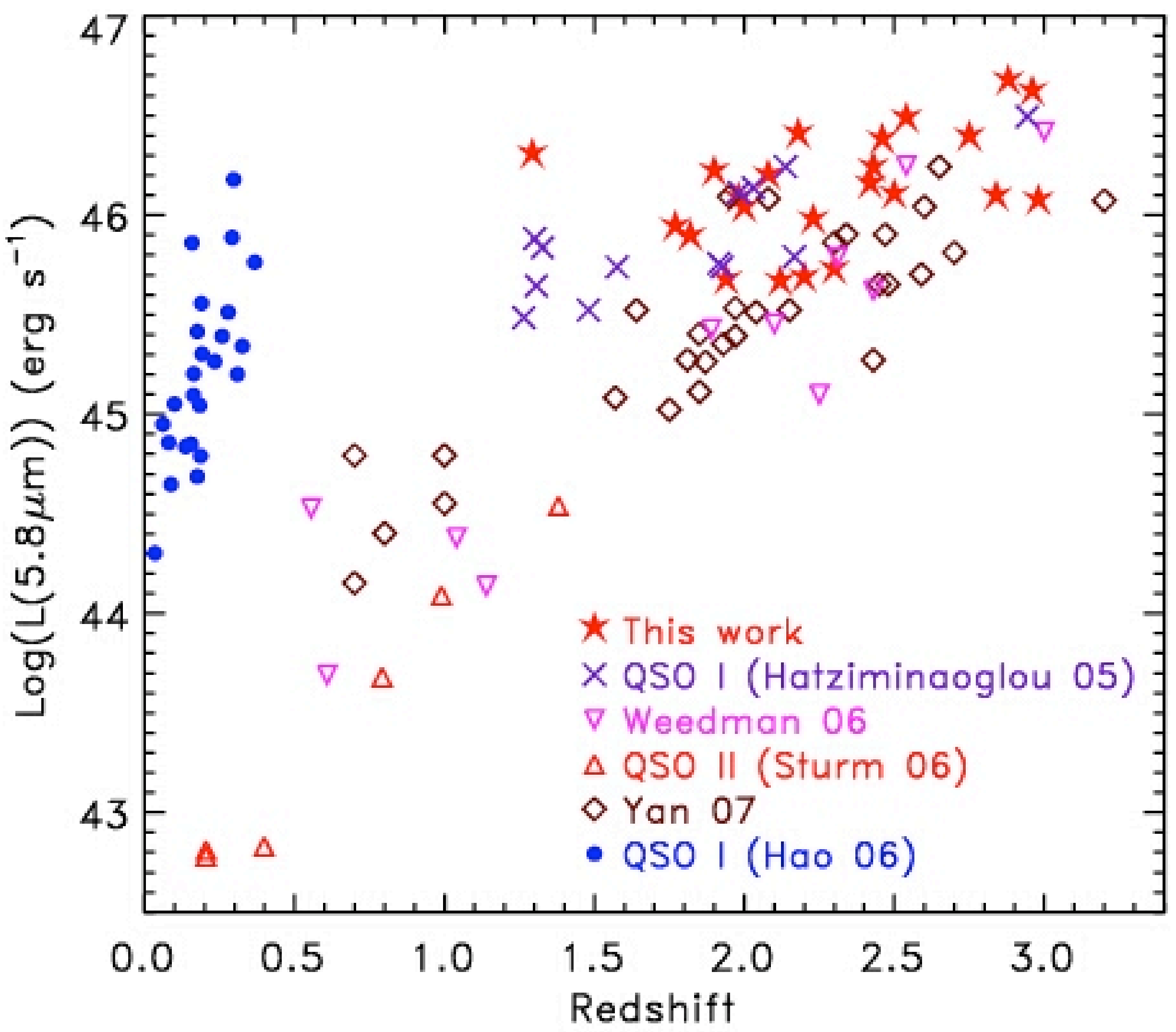
The selected sources include the most luminous AGN currently known



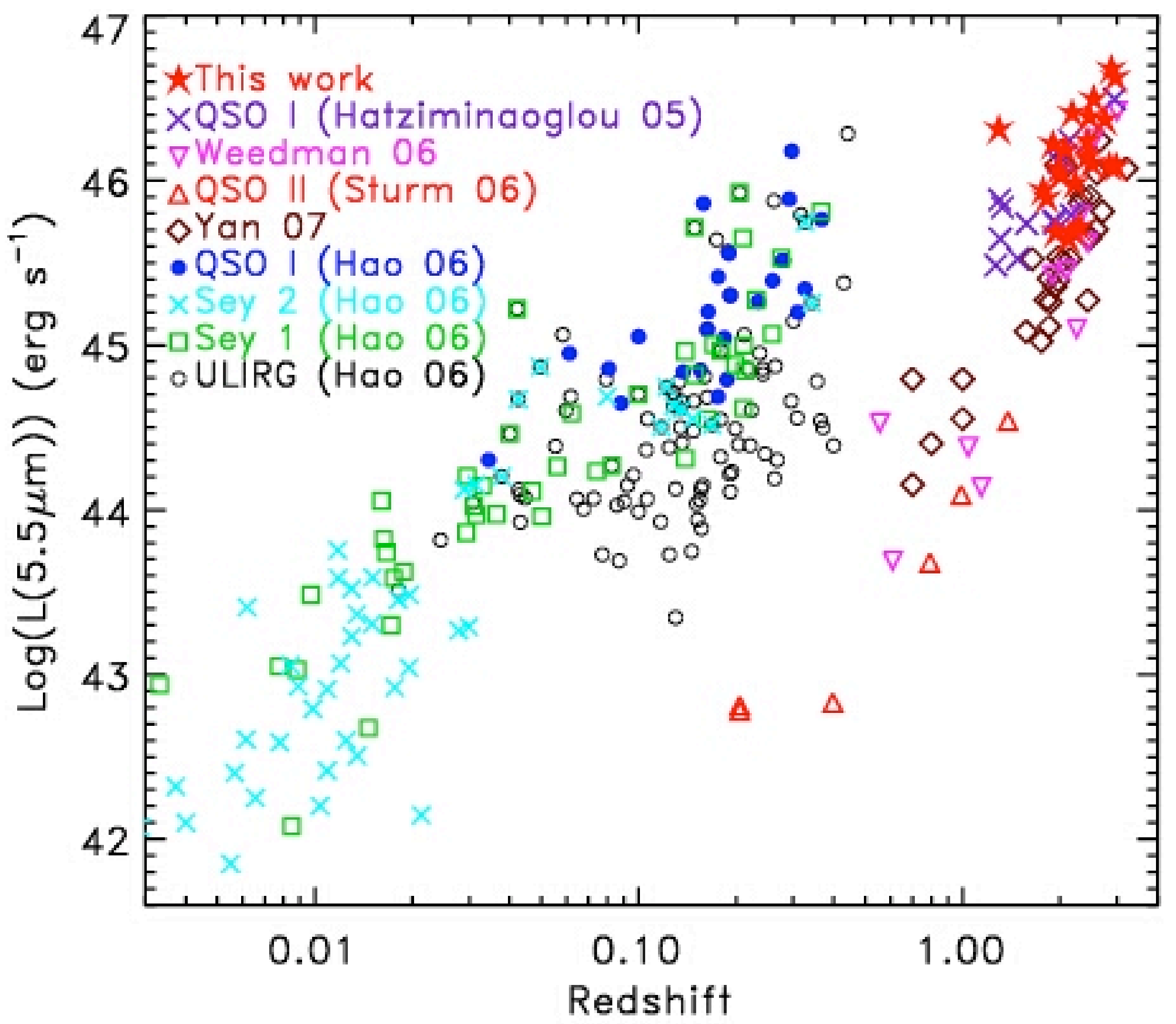


Image credit: NASA/CXC/M. Weiss

... and cover a new parameter space in mid-infrared luminosity and absorption

Silicates (9.7µm) optical depth:

$\tau_{Si} = \ln(F_{9.7}^{cont}/F_{Si}^{obs})$

F_{Si}^{obs} from spectrum

$F_{9.7}^{cont}$ from:

1. 4-8µm power-law extrapolation
2. type 1 QSO fit

QSO 1, ULIRG, Sey 1, Sey 2 (Hao et al. 2006)

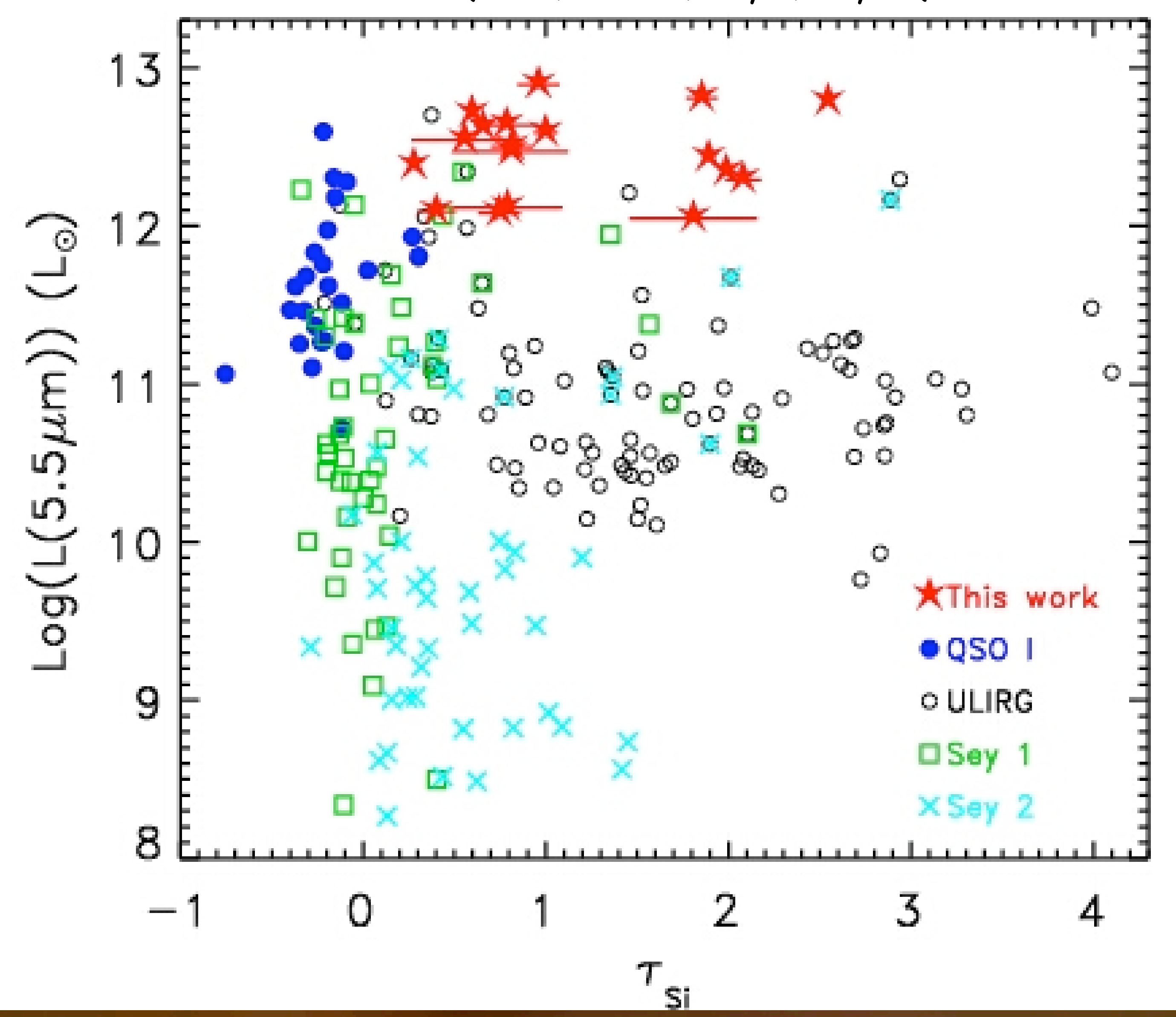


Image credit: NASA/CXC/M. Weiss

SED Modeling: Clumpy torus

(Hönig et al. 2006)

<u>Model parameters:</u>

- clouds density distribution vs radius: $n(r) \sim r^{-1,-1.5,-2,-3}$ [4]
- total number of clouds N_{cl} in the torus: 10,000; 15,000; 20,000 [3]
- vertical distribution: $H(r) \sim r^{1,1.2,1.5}$ (no, moderate, strong flaring) [3]
- torus inclination (ϑ): = 0,30,45,60,75,90 deg [6]
- random arrangements of clouds [5]

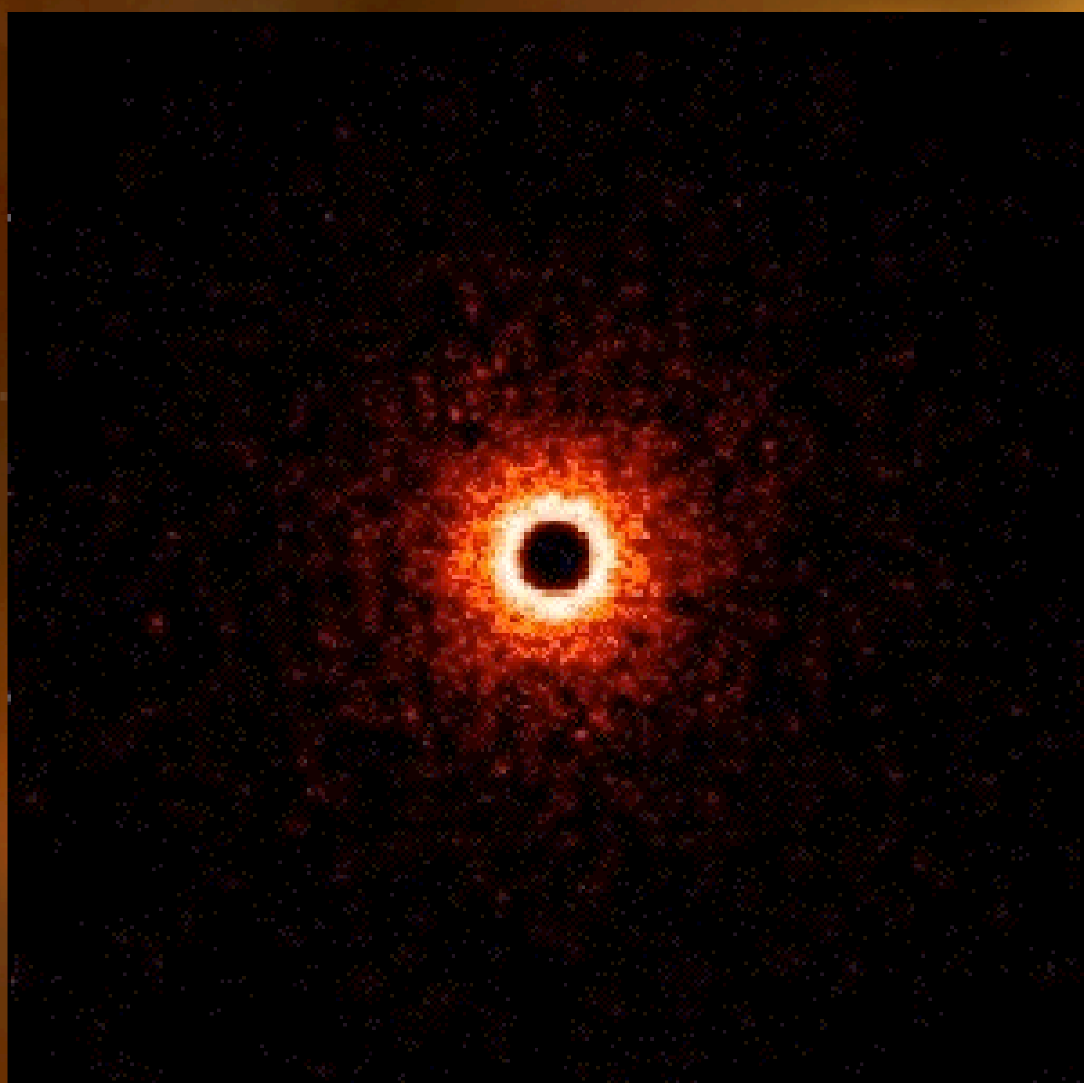
⇨ 4 x 3 x 3 x 6 x 5 = 1080 models

⇩

Fit 1-10µm rest-frame SED & spectrum

Effects of torus inclination on observed emission

Clumpy torus (from face-on to edge-on)



Clumpy Torus Infrared SED

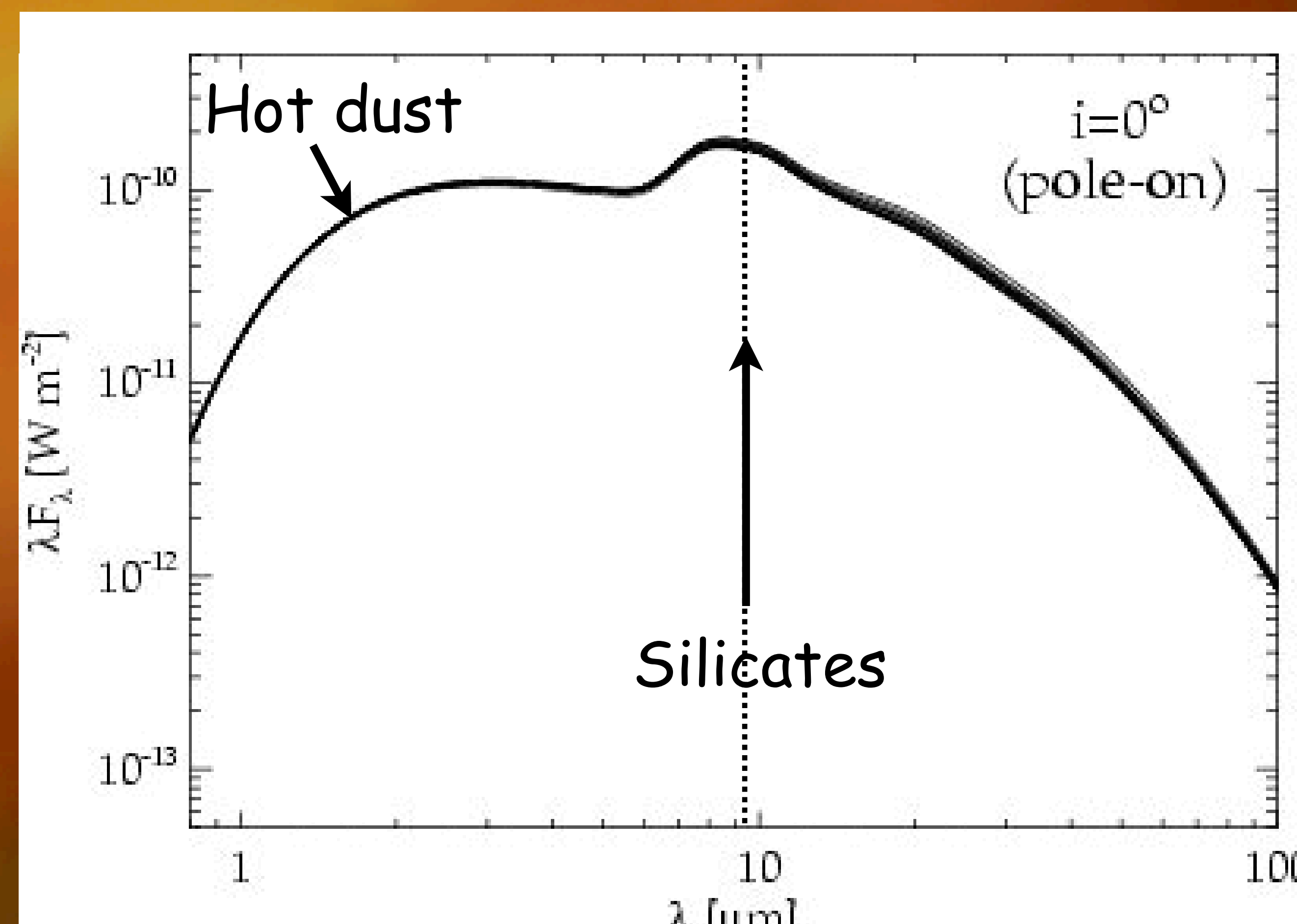


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Image credit: NASA/CXC/M. Weiss

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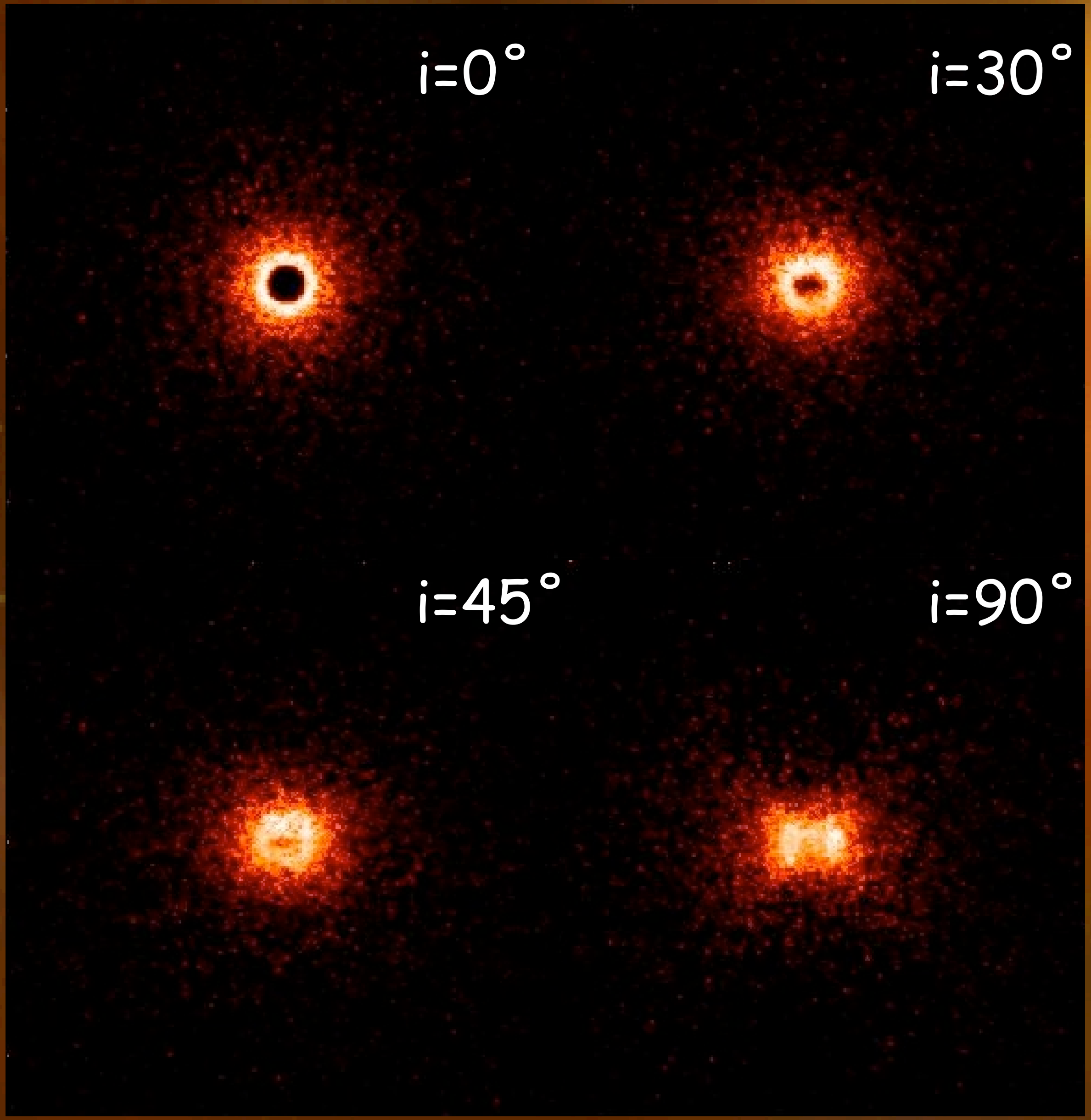

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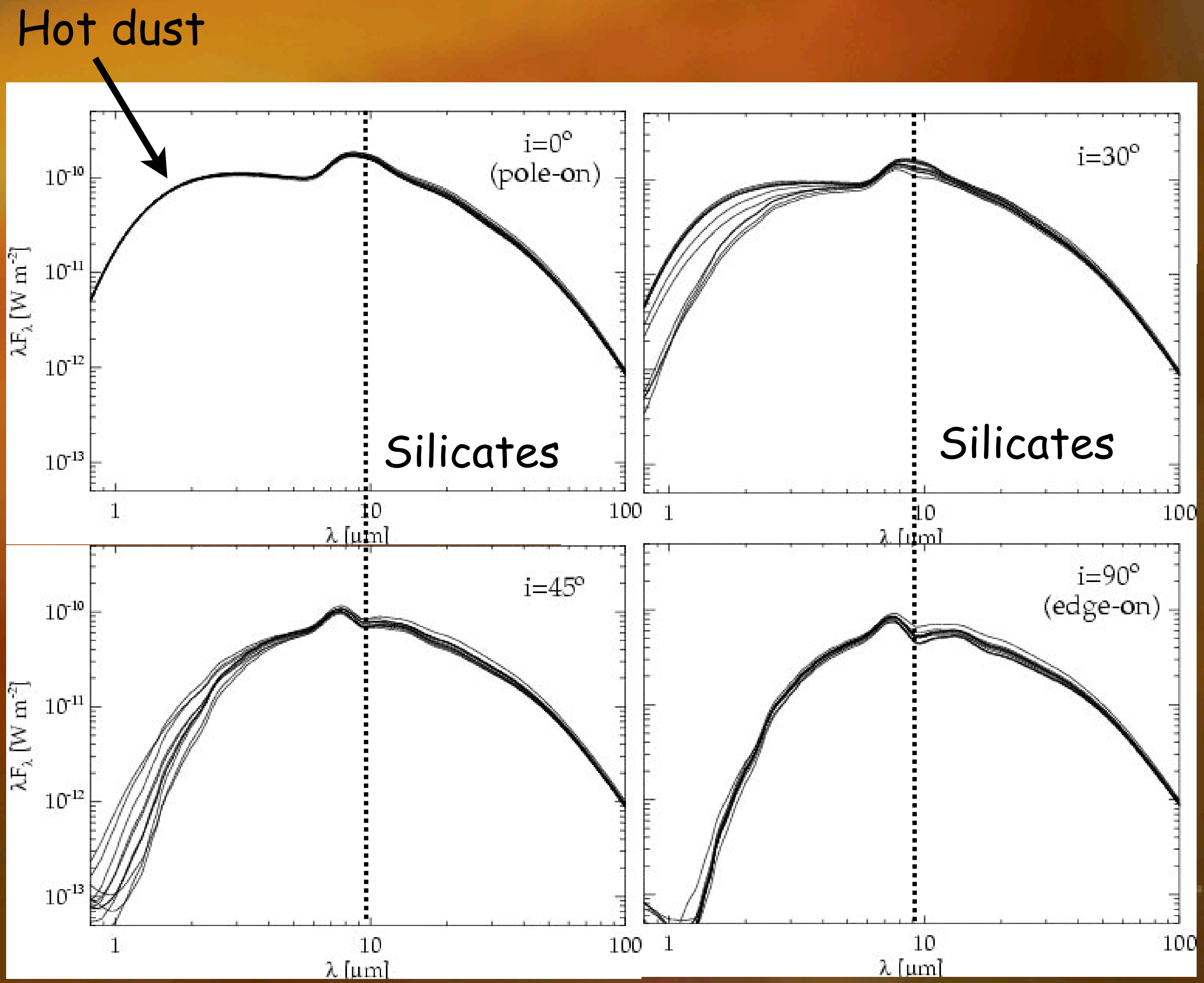


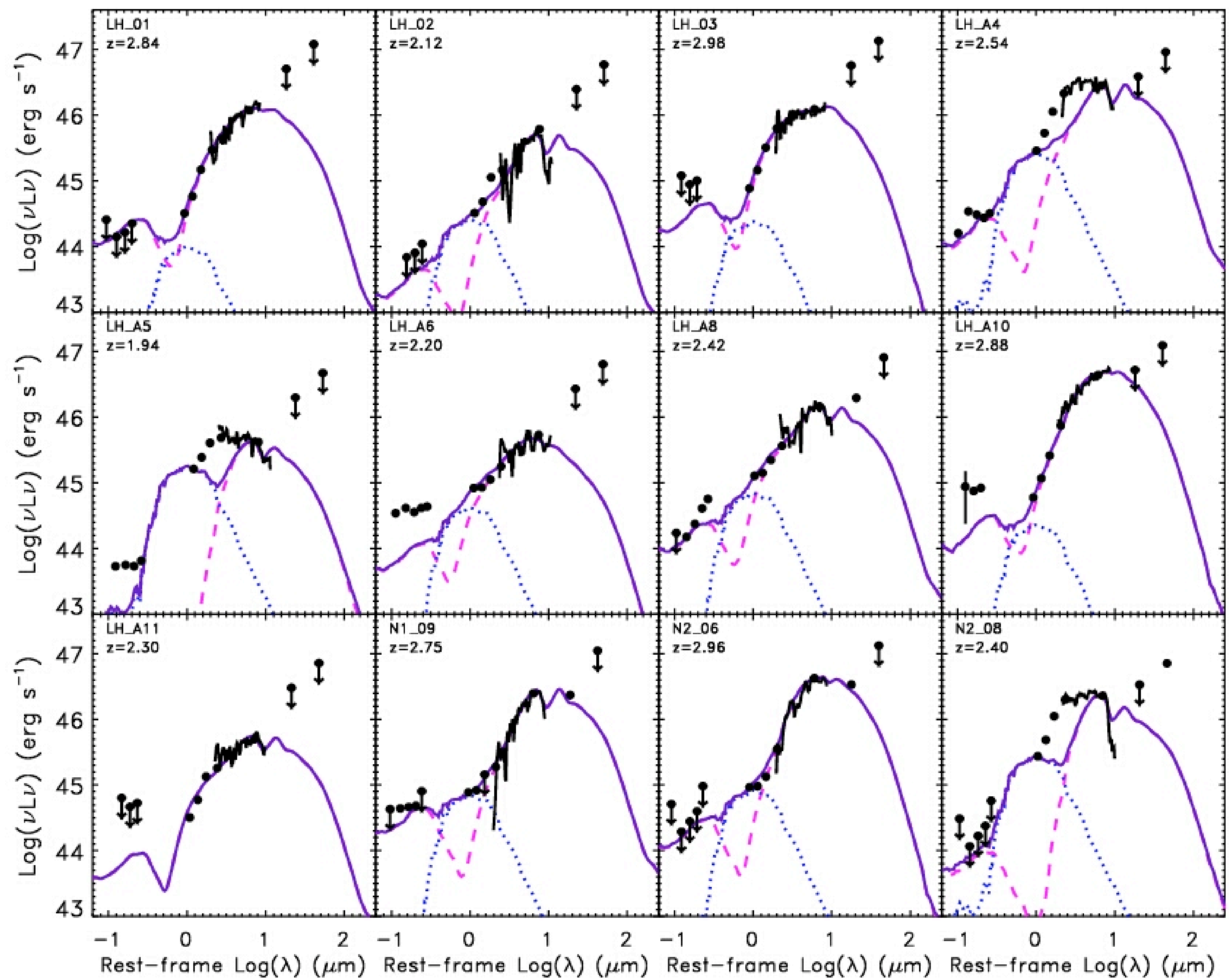
Image credit: NASA/CXC/M. Weiss

SED fits with clumpy torus models + host

Clumpy Torus

Elliptical (host)

Total (host+torus)



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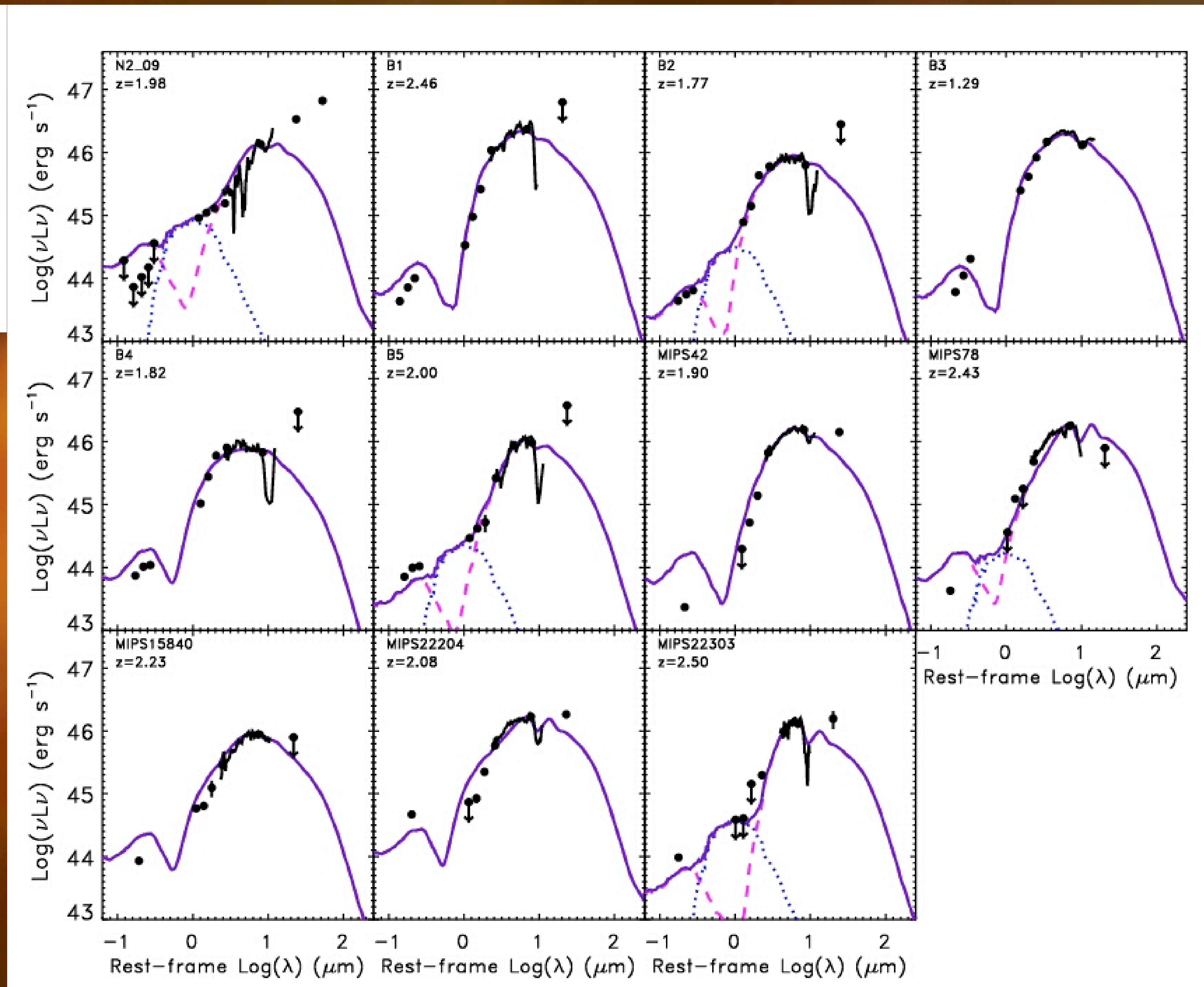

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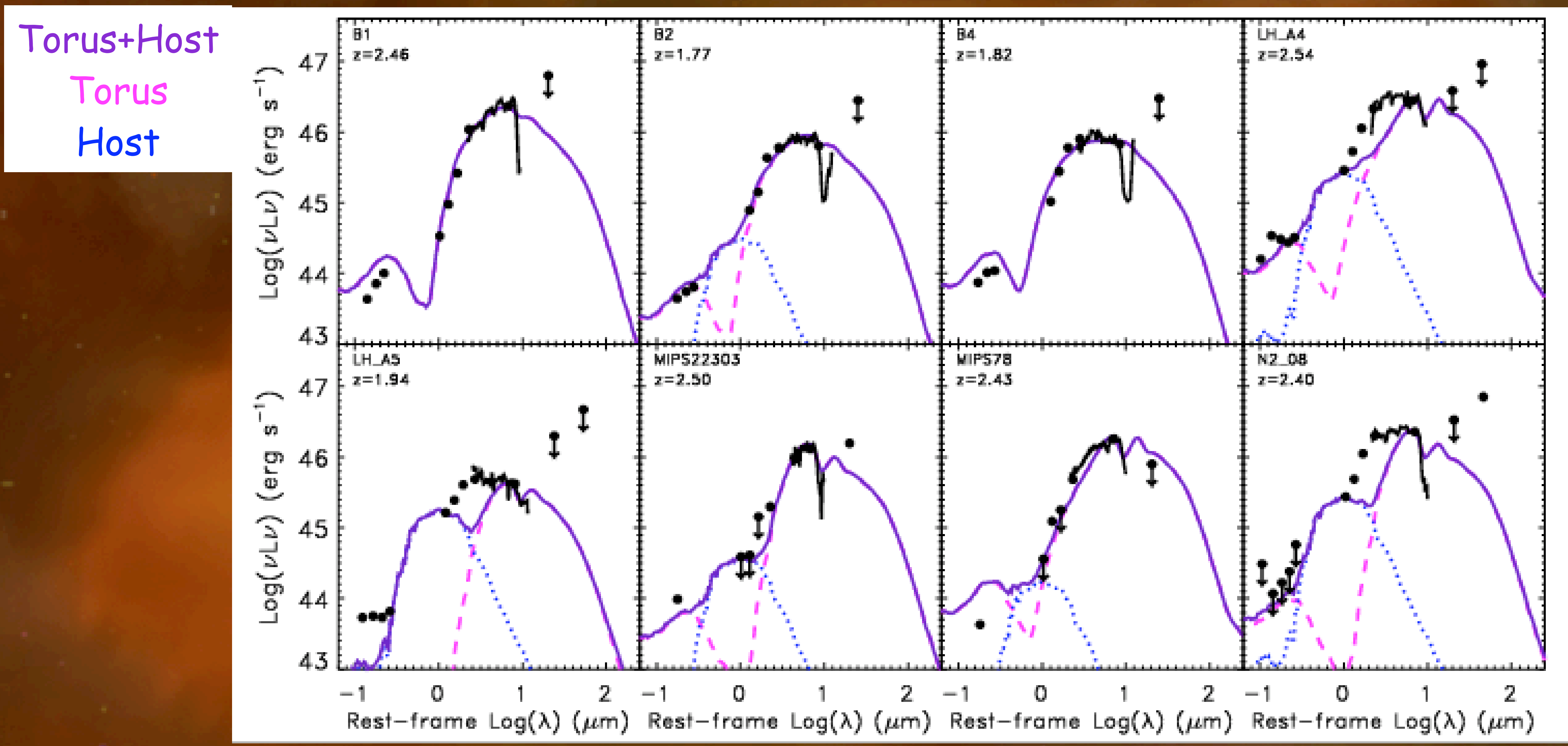
SED fits with clumpy torus models + host +cold absorber

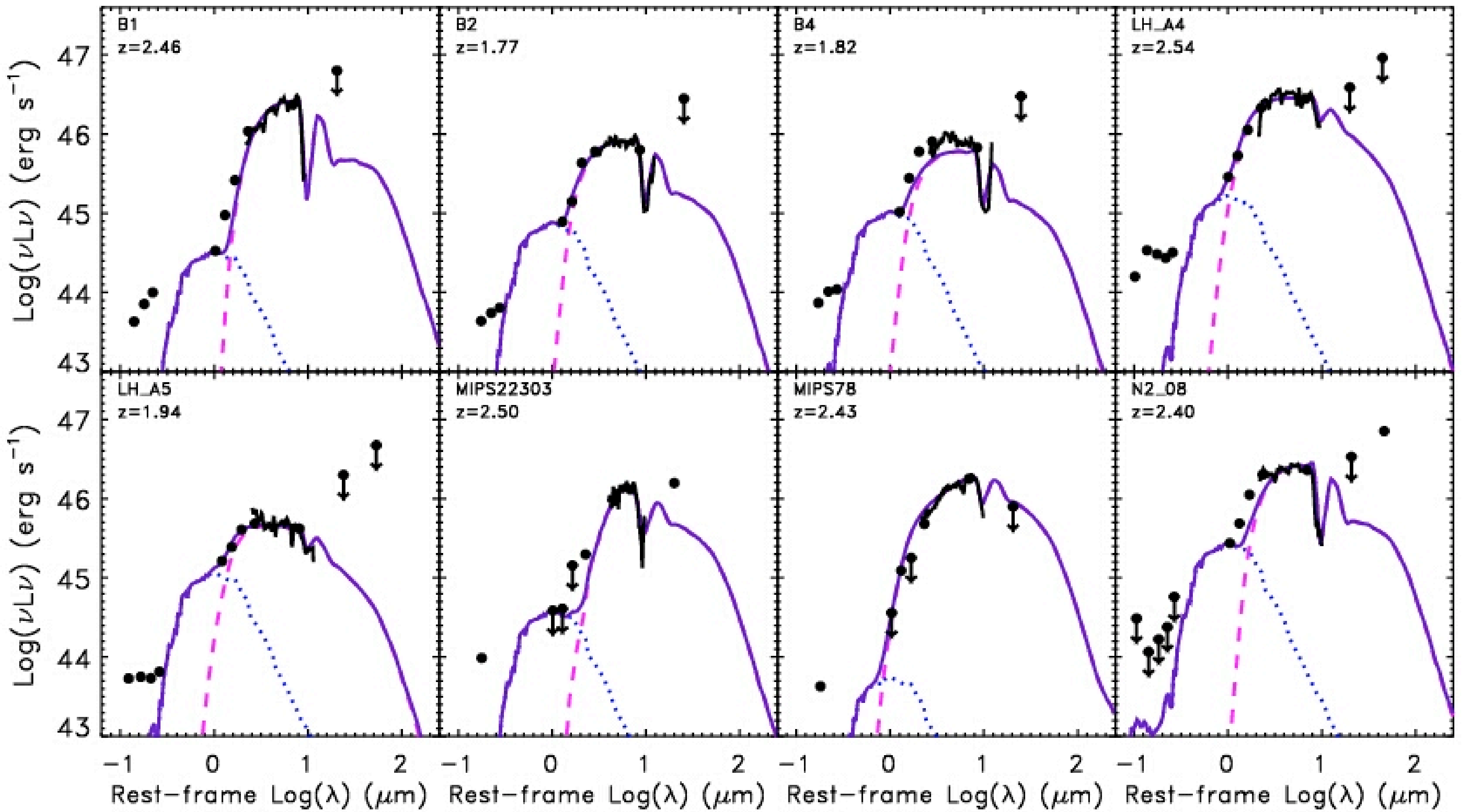


External obscuration already proposed by Keep 1980; Lawrence & Elvis 1982; see also Rigby et al. 2006; Brand et al. 2007.

Cold Absorber: Galactic center extinction curve (Chiar & Tielens 2006)

SED fits with clumpy torus models + host +cold absorber

Torus+Host
+
COLD
ABSORBER
Torus
Host



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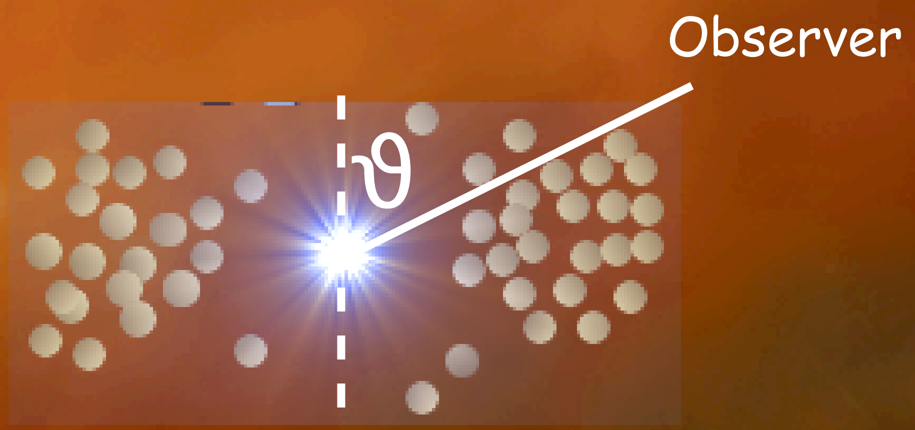
Cold Absorber: Galactic center extinction curve (Chiar & Tielens 2006)

Model parameters

Preferred parameters:

- compact torus: radial distribution $n(r) \sim r^{-3}$
- non-flaring torus $H(r) \sim r$
- range of inclinations:



ϑ>45° in 12 sources modeled with torus model and with Silicates in absorption;

ϑ<30° in 11 sources modeled with torus + cold absorber or without Silicates in absorption;

How common are these obscured QSOs ?

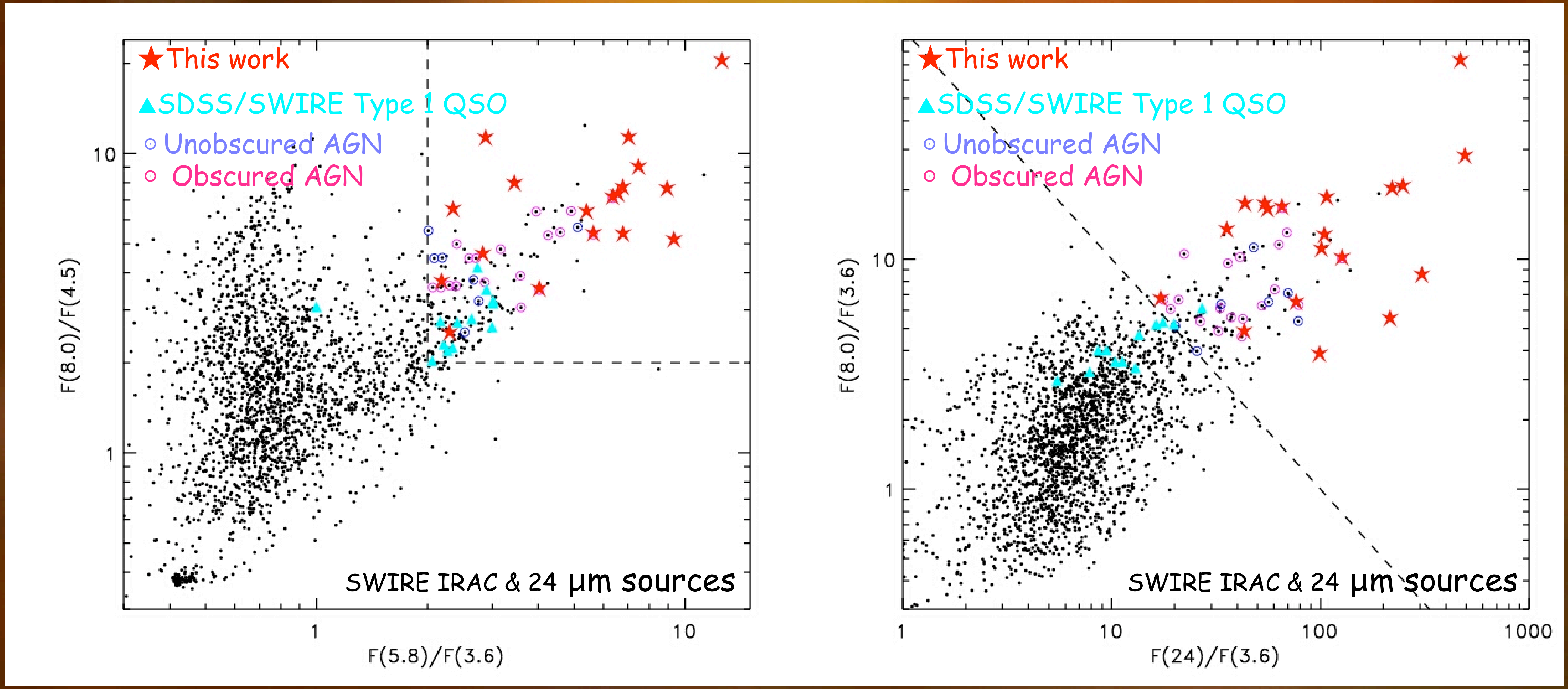
Surface density:

IRAC & 24 μm SWIRE sources: 1439 deg^{-2}

Extremely red IR colors & $F_{24\mu m}$ >1mJy : 25 deg^{-2}

7 consistent with unobscured AGN & 18 show red optical-IR colors (⇨ obscured AGN)

⇨ obscured:unobscured = 3:1



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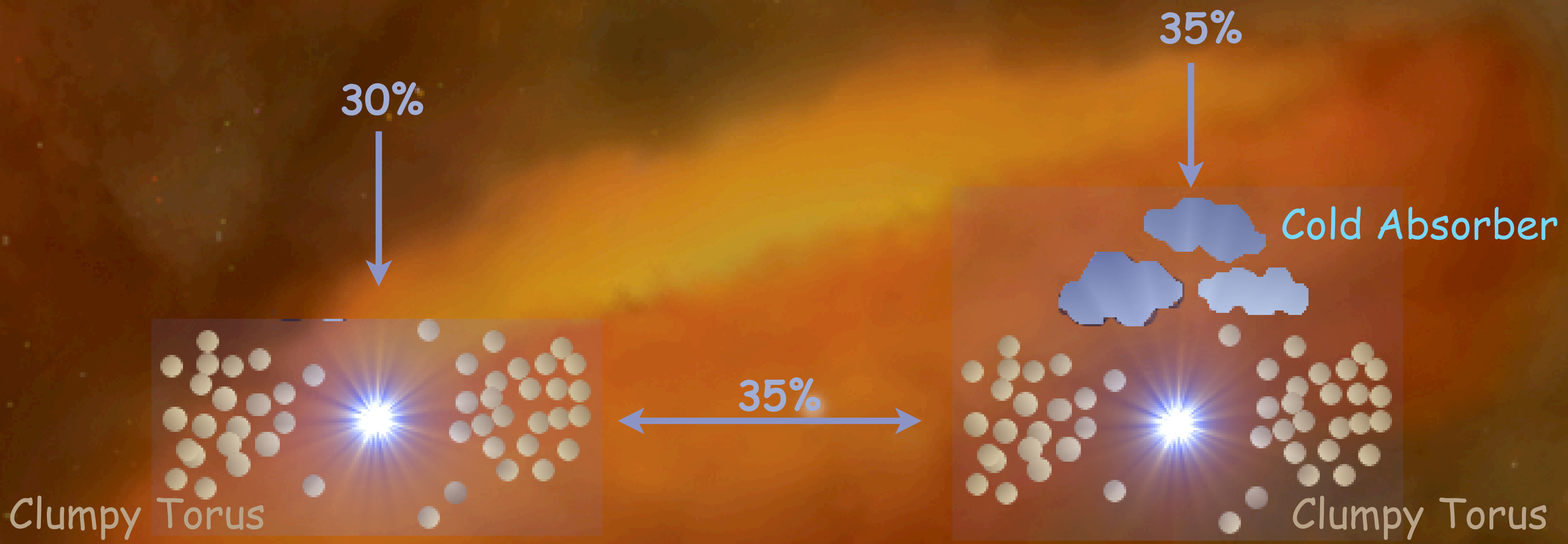
Possible obscuration scenario



➪ The torus covering fraction is ~35%

and

the opening angle is ~ 80°

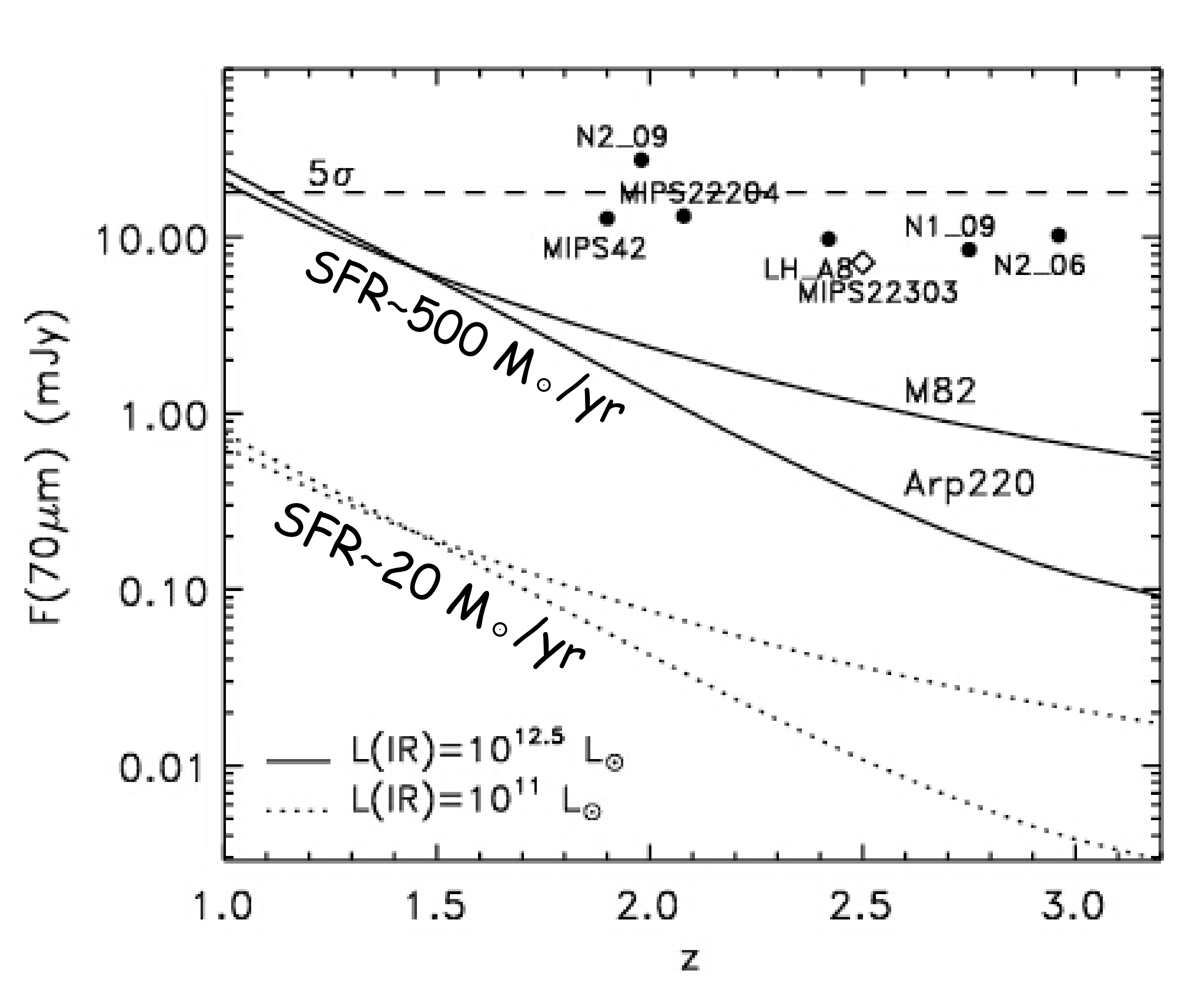
For local Seyfert galaxies: 45° (Schmitt et al. 2001) and 70° (Hao et al. 2005)

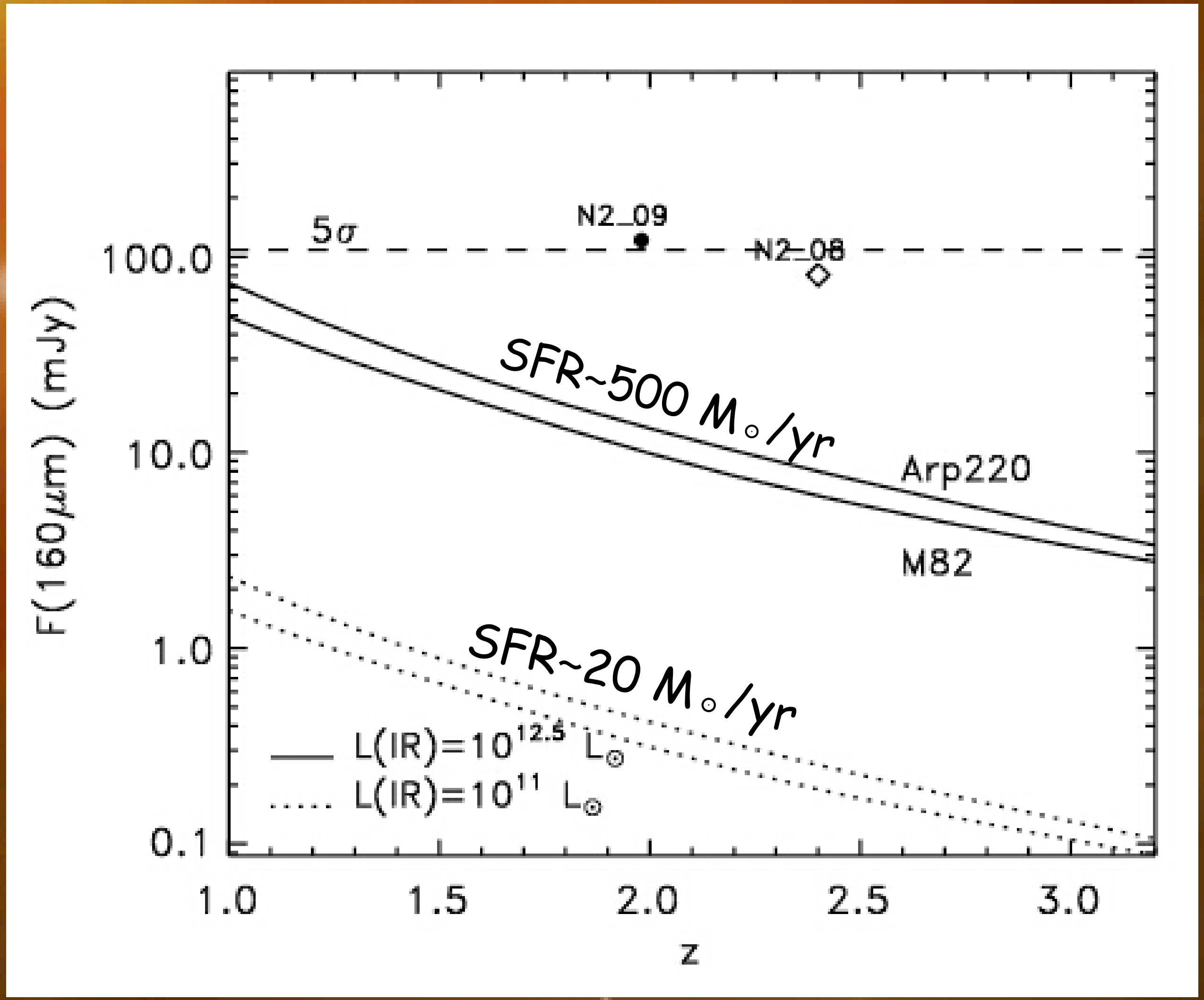
Image credit: NASA/CXC/M. Weiss

Is the cold absorber associated with a starburst component ?

- Signatures of a starburst component can be found in the mid-infrared (PAH features) or in the far-infrared (cool dust)

8 (out of 18 SWIRE & E-FLS) sources are detected in the far-IR





Starburst signatures in the composite IR spectra

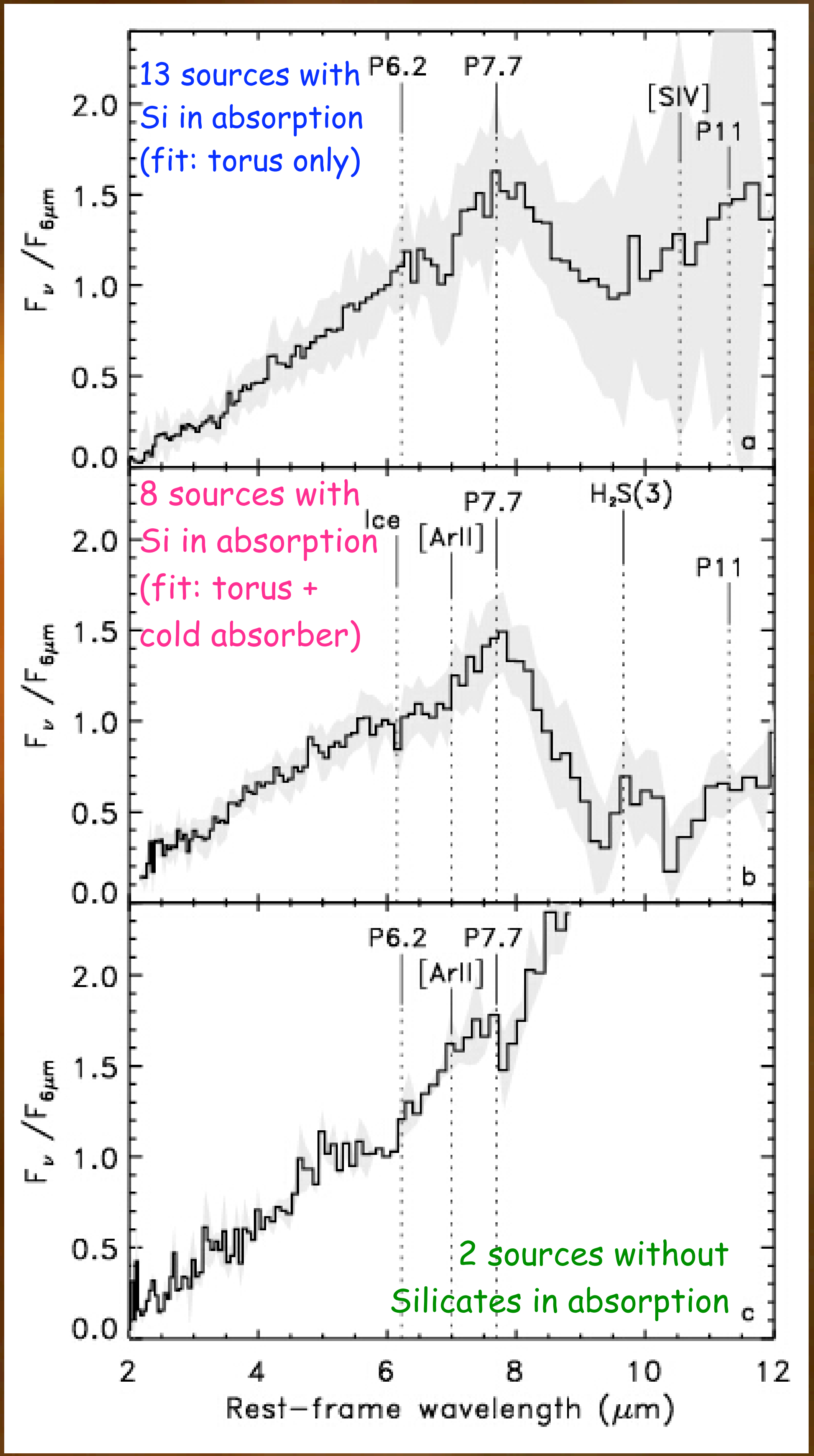
Higher S/N to look for PAH fetures (6.2, 7.7μm)
Observed $F_{7.7\mu m} \leq$ 10% of the continuum at 7.7μm
$L^{SB}_{bol} \sim L_{PAH(7.7\mu m)}$

(Houck et al. 2007; Brandl et al. 2006)

Average Starburst luminosity
$L^{SB}_{bol} \sim 2\times10^{12}\ L_\odot$

➪ SFR~350 $M_\odot$/yr (Kennicutt 1998)

Only 26% of L^{AGN}_{bol} !



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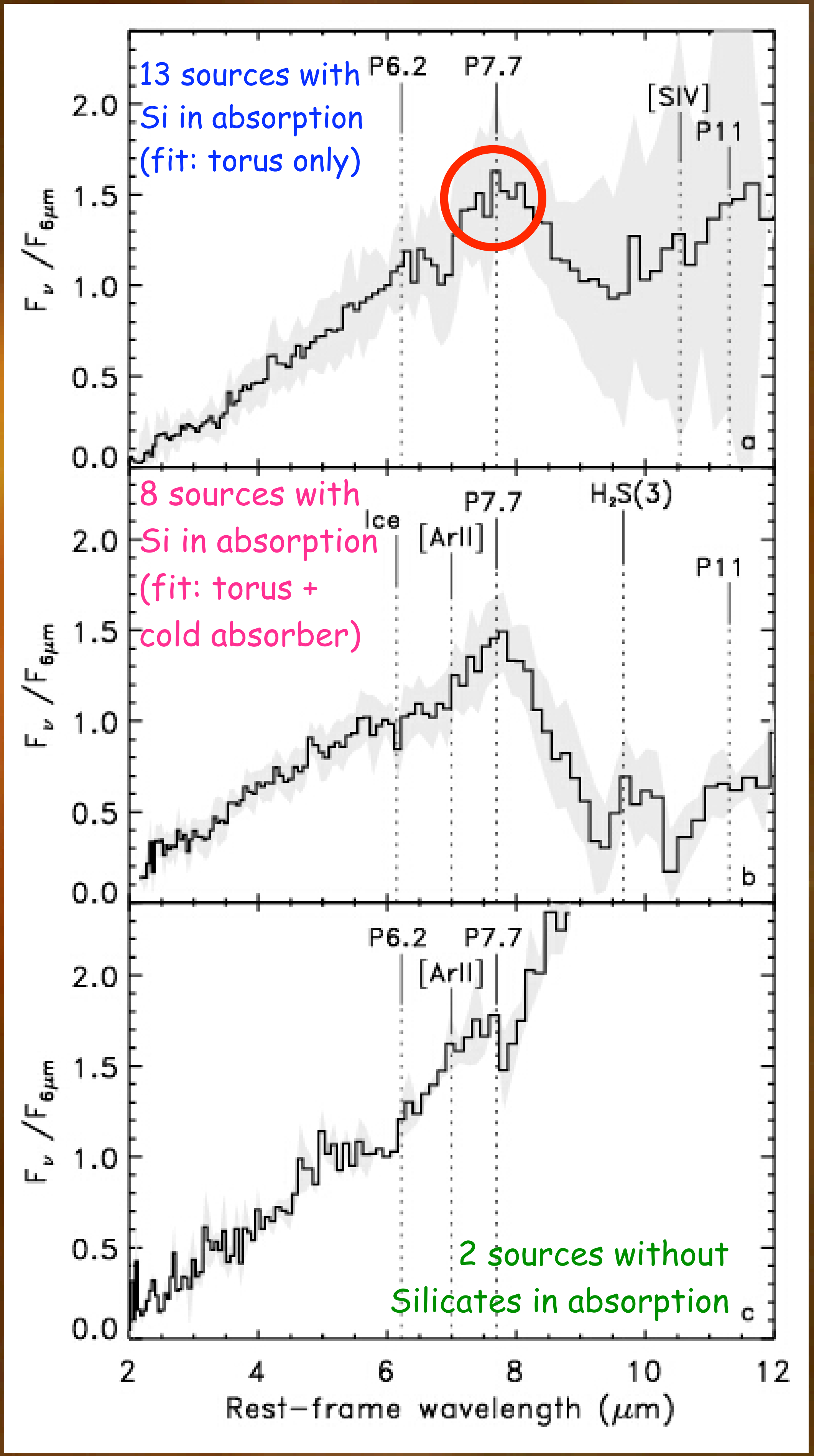


Image credit: NASA/CXC/M. Weiss

Conclusions

➩ How and where can we find the missing AGN ?

- Their optical-infrared SEDs resemble those of normal galaxies. We can statistically constrain their surface density, but not identify them.

➩ Is the paucity of obscured luminous AGN real or a selection effect ? Is the obscuring matter (torus) affected by the AGN luminosity ?

- Obscured AGN are 3 times more common than unobscured AGN at high luminosities, but half of them are not obscured by the torus.

➩ What are the properties of the obscuring matter in AGN ?

- Obscuration at X-ray, optical and infrared wavelengths is due to patchy absorbing gas or dust located along the line of sight clouds at various distances from the center (see Elitzur et al. 2006 and talks by Risaliti and Brand).

Origin of the far-infrared emission: starburst or AGN?

Out of 8 sources detected in the far-IR:
in 2 the far-infrared data are consistent with the torus model;
in 6 the far-infrared data are in excess compared to the model predictions.

1. AGN heats dust at large distances
2. starburst with SFR≥3000 $M_\odot$/yr

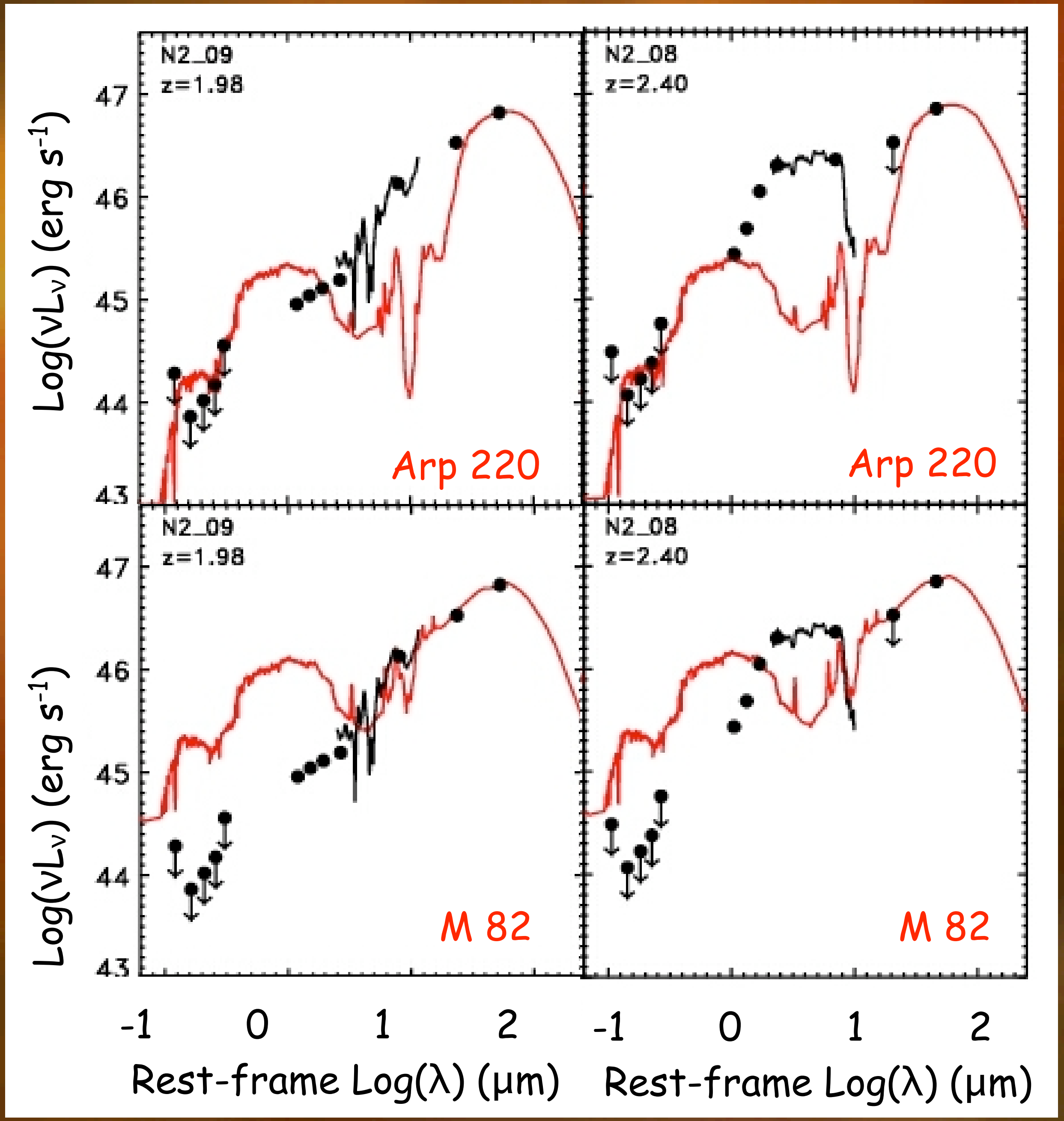
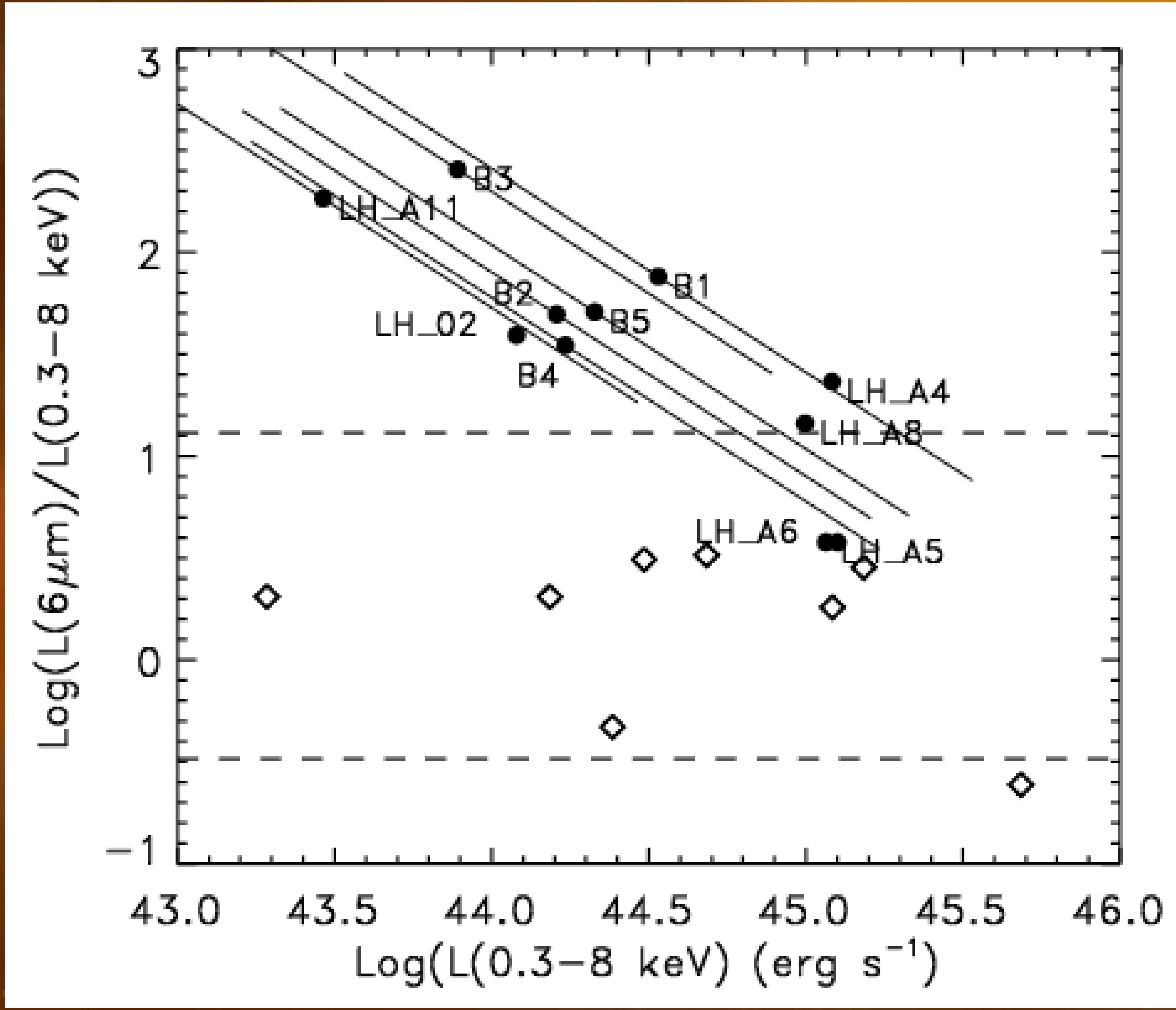


Image credit: NASA/CXC/M. Weiss

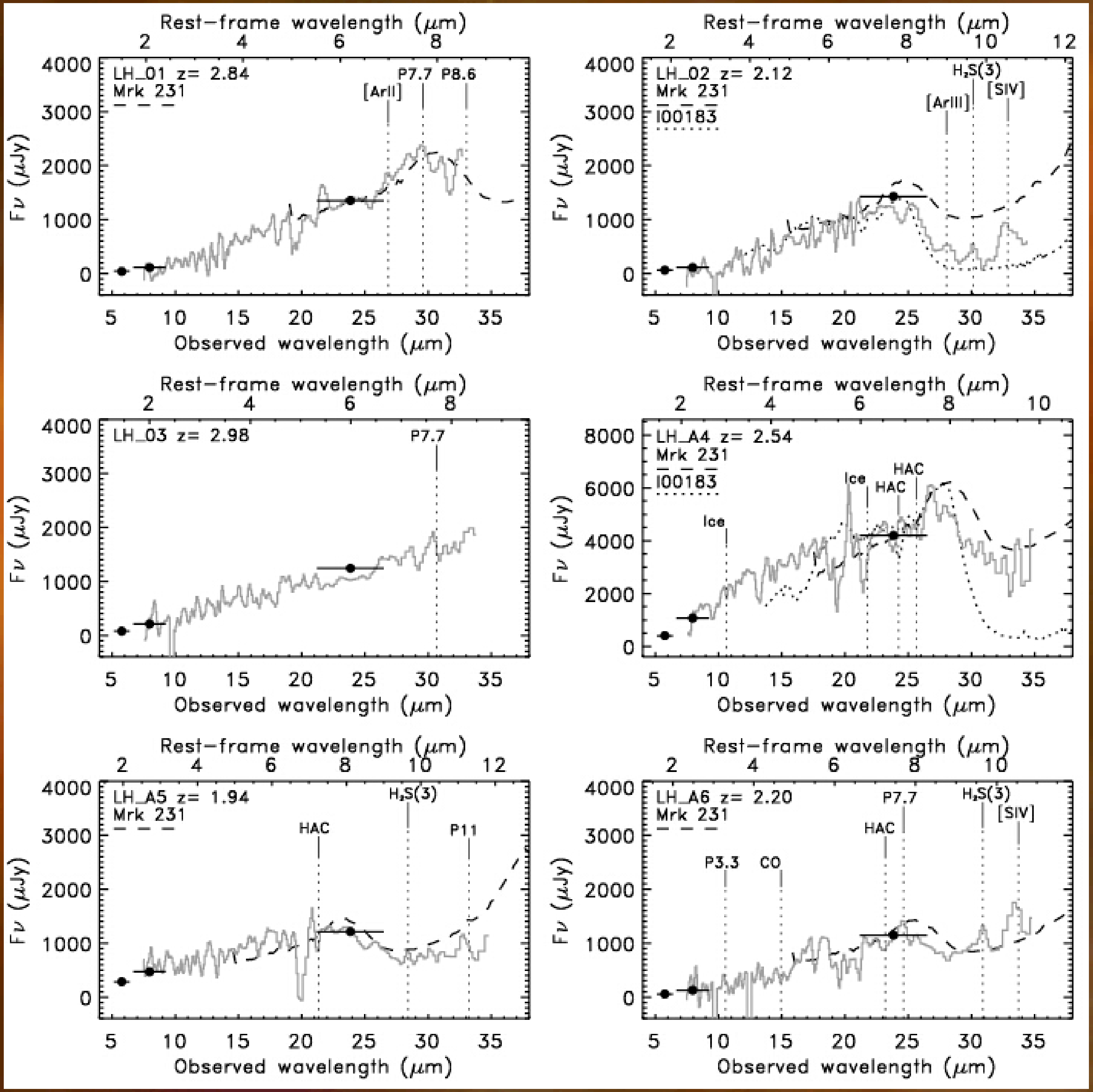
Dust covering fraction

Larger L_{MIR}/L_X than in the majority of AGN
➪ larger dust covering factor ?



• Mid-infrared selected luminous QSOs (Polletta et al. 2007b)
◇X-ray selected absorbed type 2 QSOs (Sturm et al. 2006)

IRS Spectra



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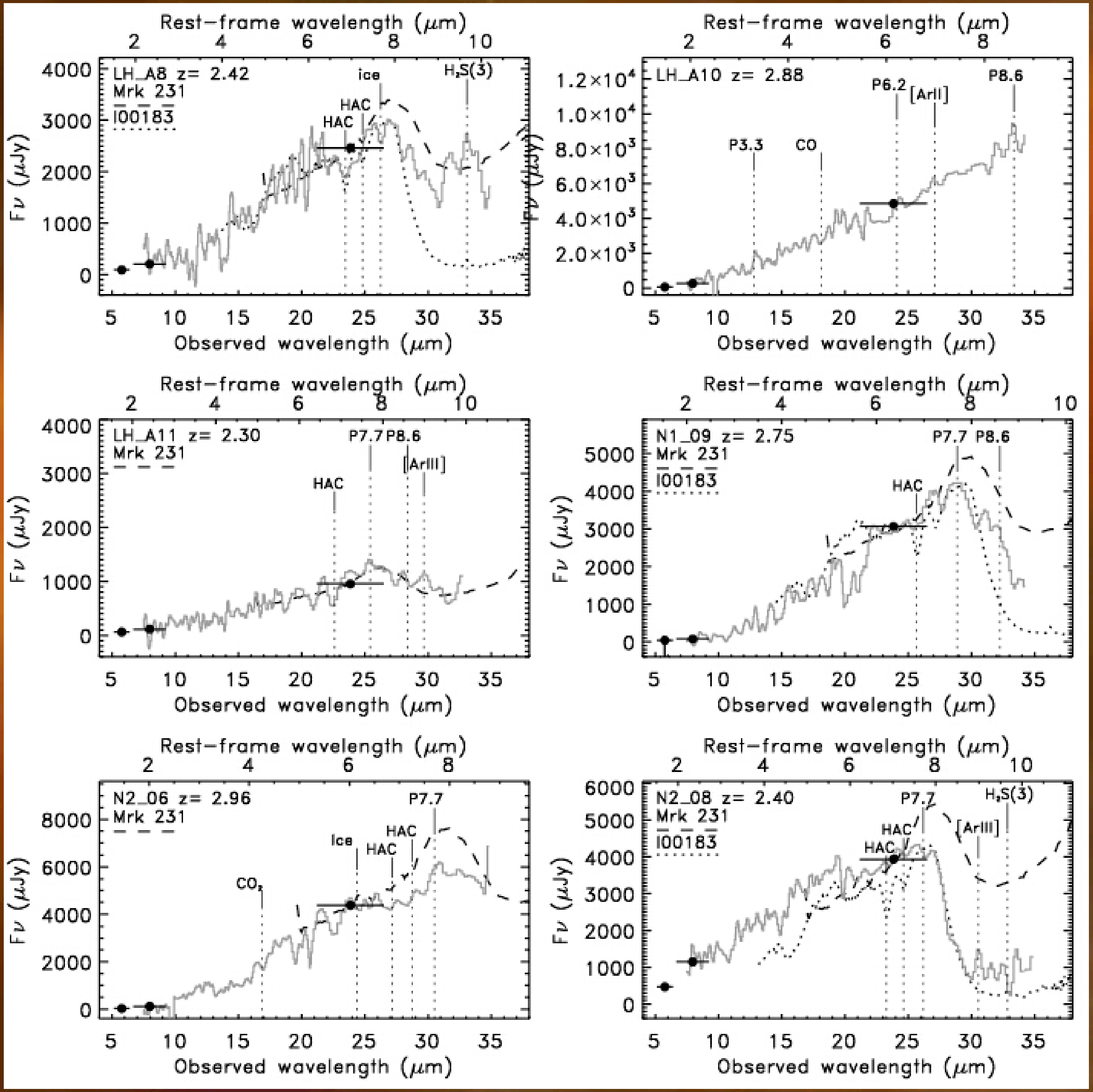

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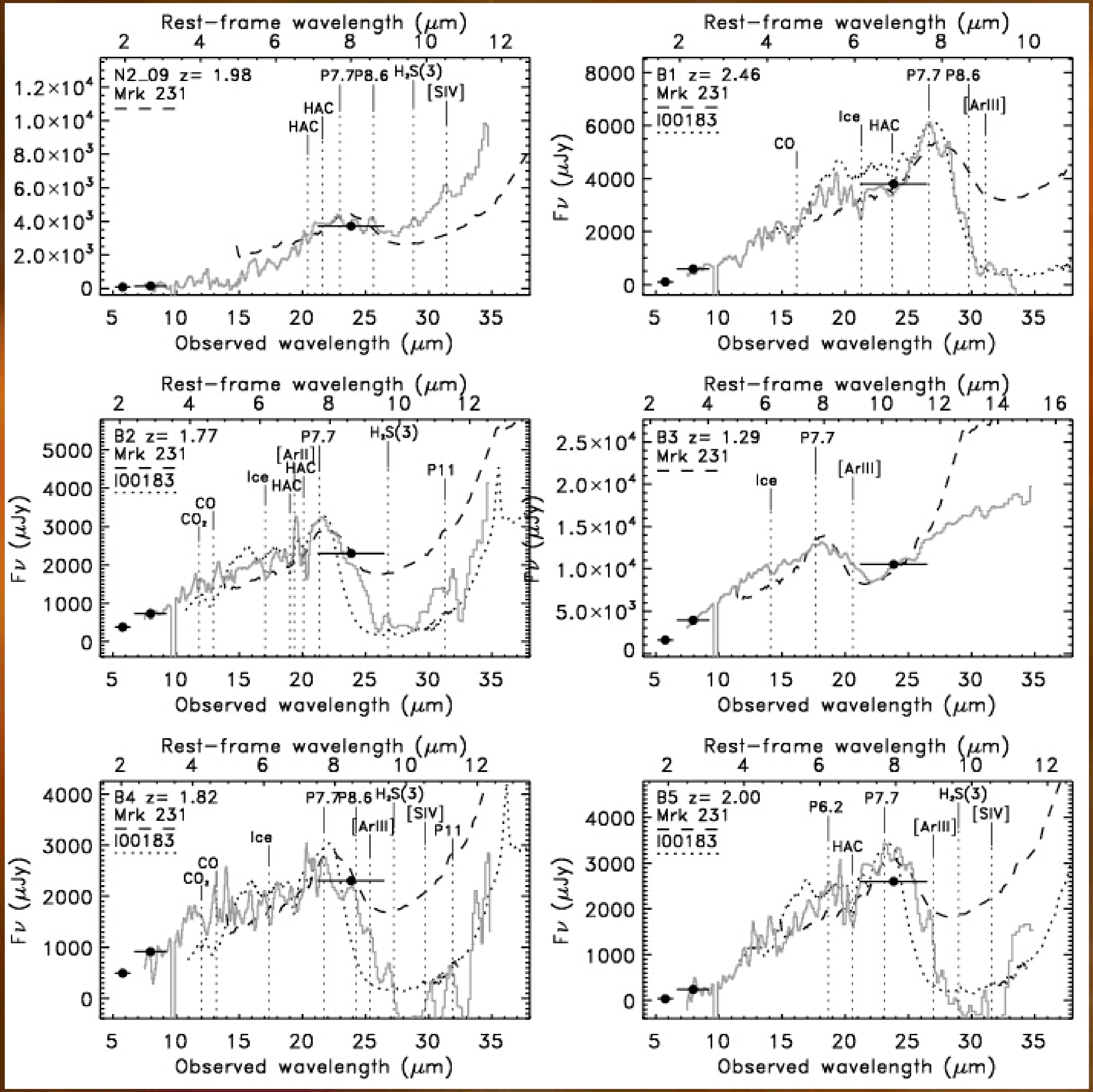

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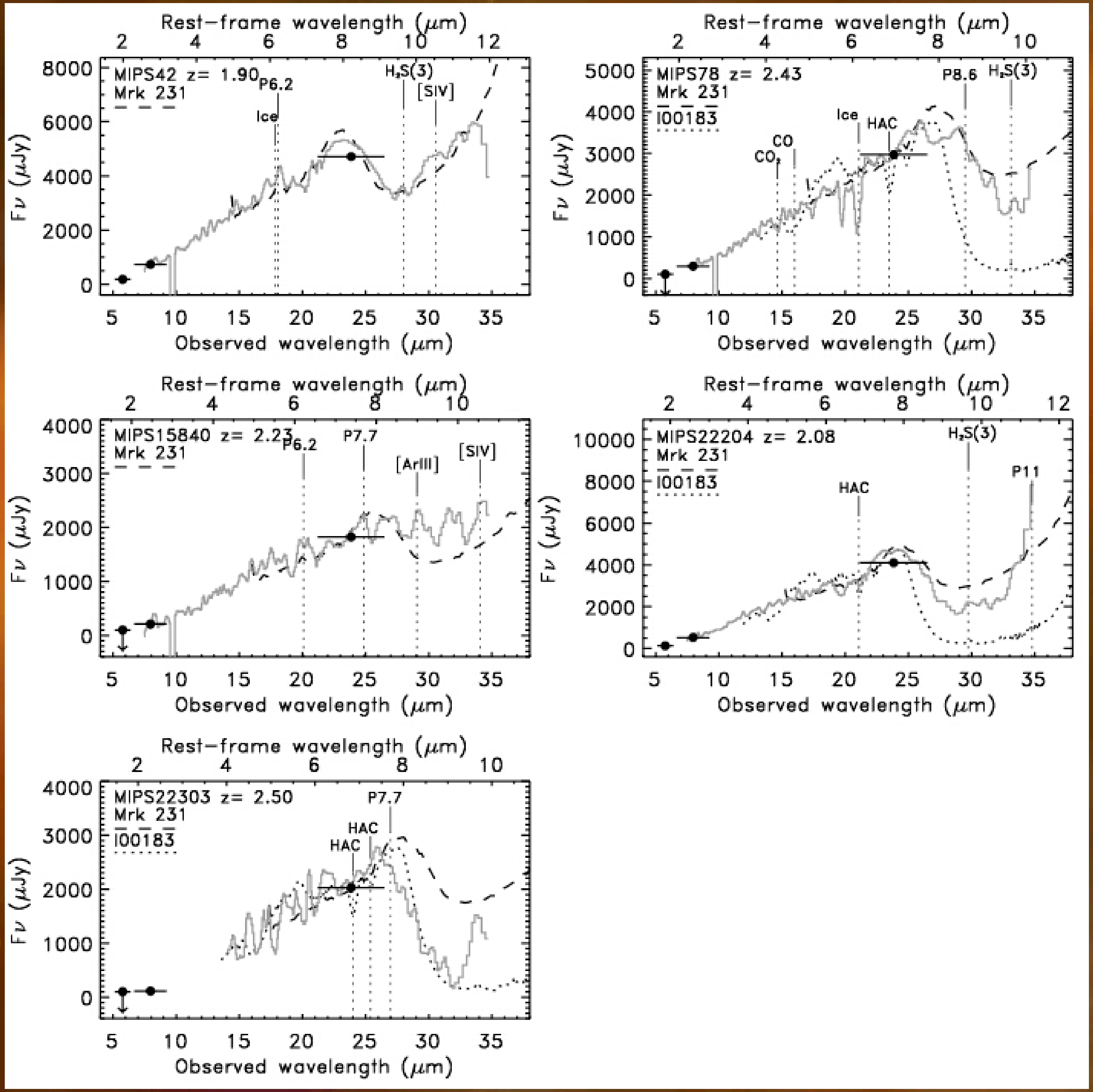

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Dust obscuration (τ_{Si}) vs gas absorption (N_H)

X-ray absorption is higher than expected from the IR and weakly correlated (Polletta et al. ApJ, submitted, Shi et al. 2006)

Image credit: NASA/CXC/M. Weiss

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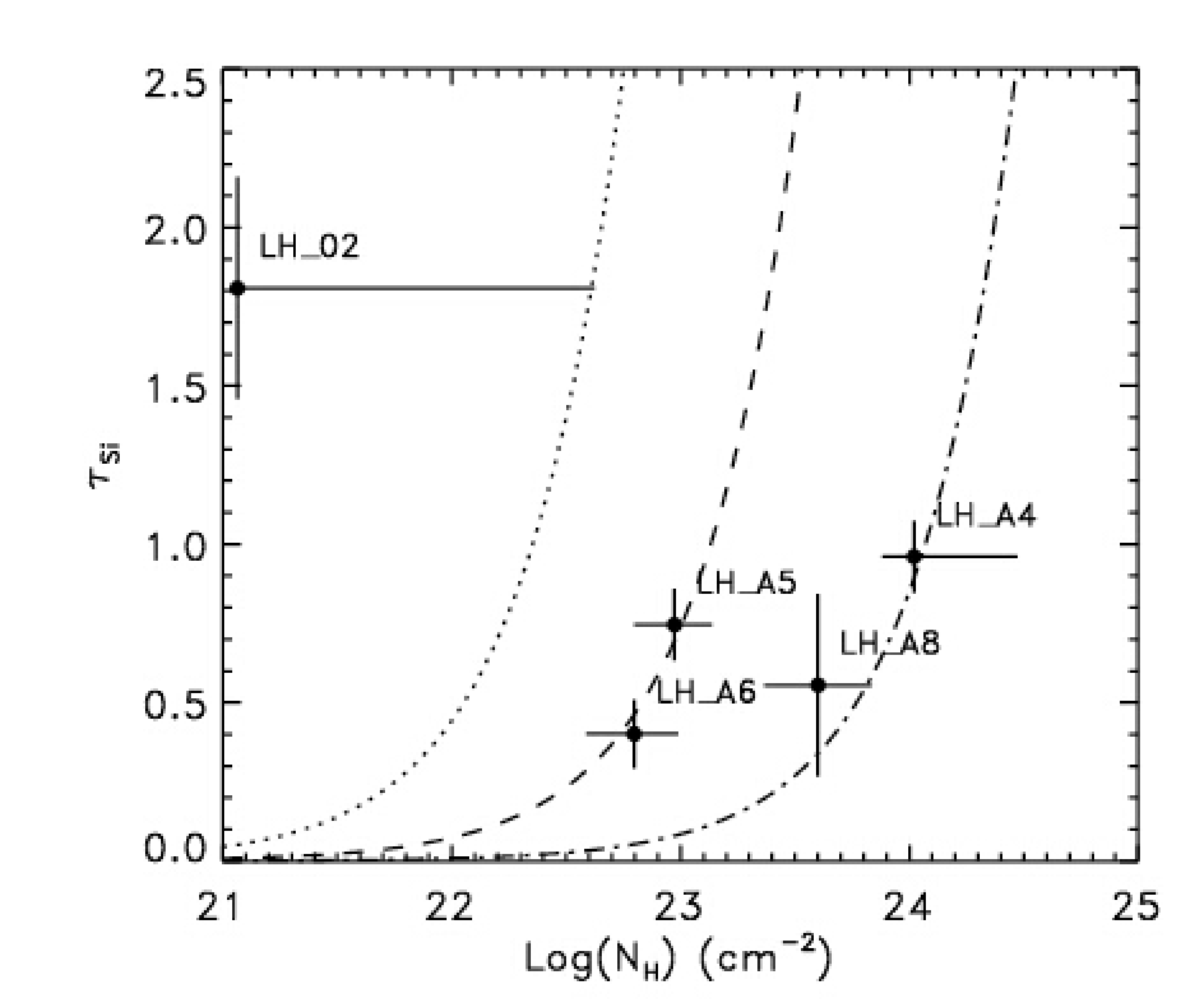


Image credit: NASA/CXC/M. Weiss

Dust optical depth

τ_V

type 1 QSO + absorption to fit 1-10μm SED (Galactic ext. curve)

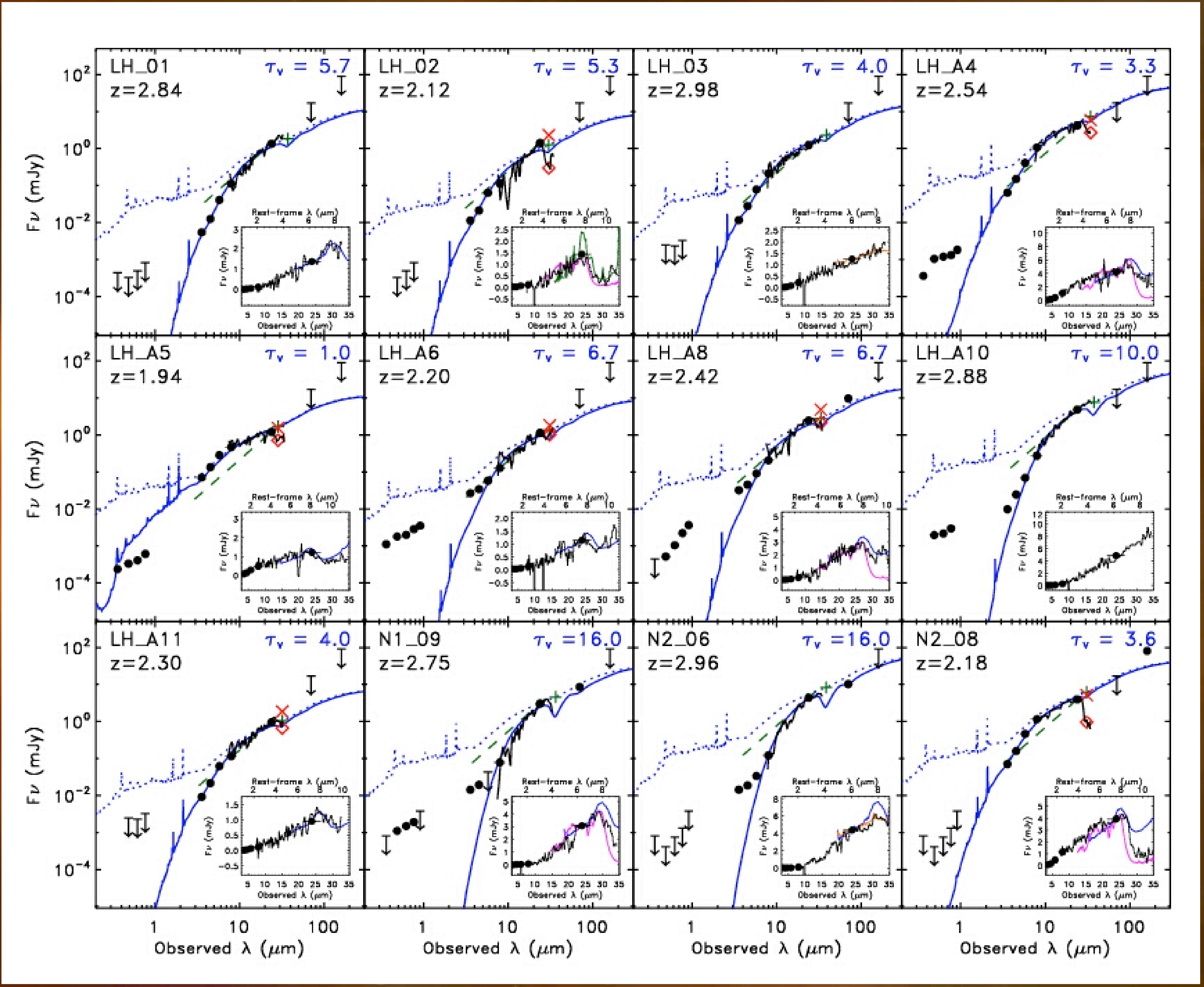
τ_{Si} (if z<2.7)

$\tau_{Si} = \ln(F_{Si}^{unabs}/F_{Si}^{obs})$

F_{Si}^{obs} from spectrum

F_{Si}^{unabs} from:

1. 4-8μm power-law extrapolation
2. type 1 QSO fit



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