Active Galactic Nuclei in the infrared: identification, energetic and properties of the obscuring material

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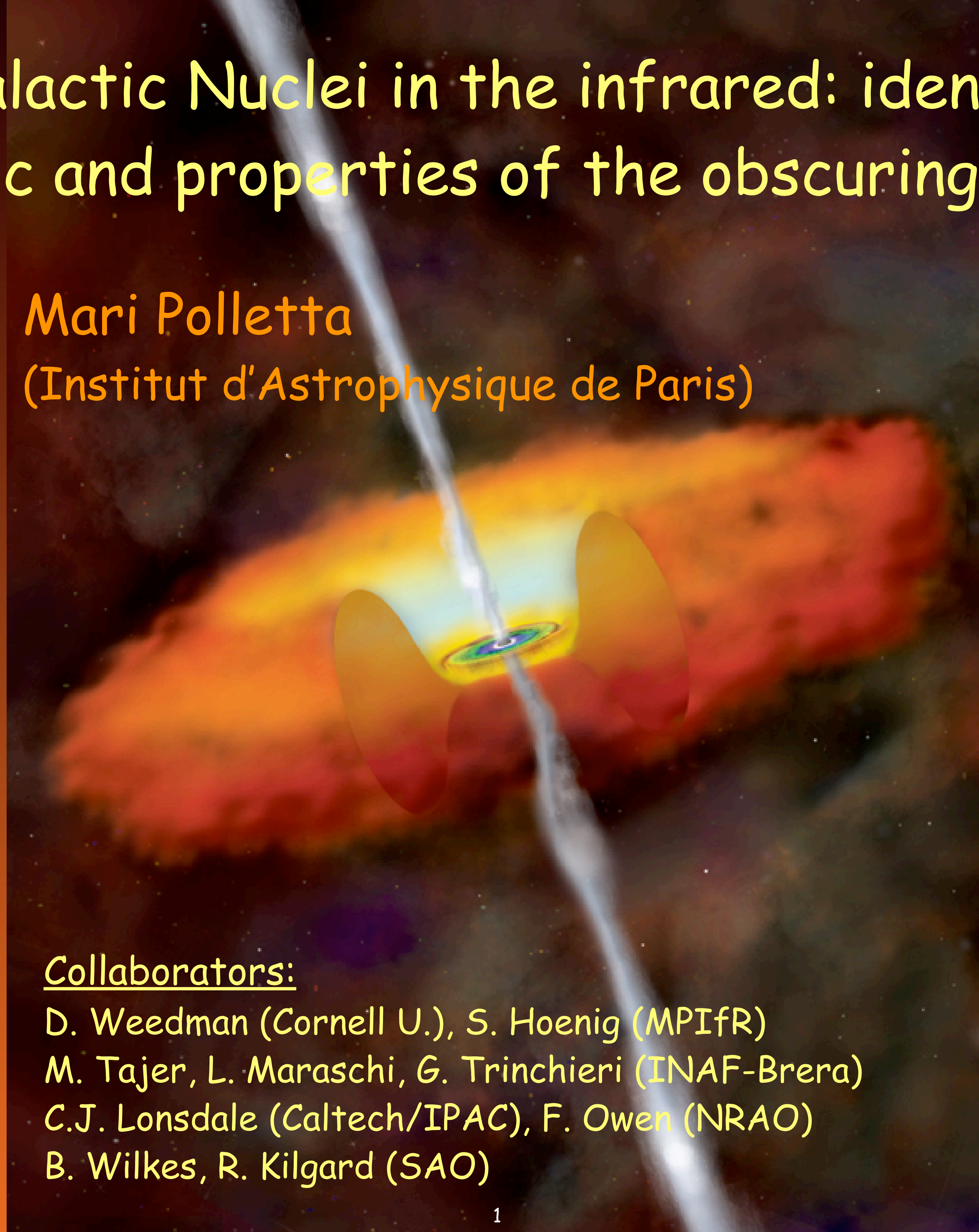

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Image by NASA/CXC/M. Weiss

Outline

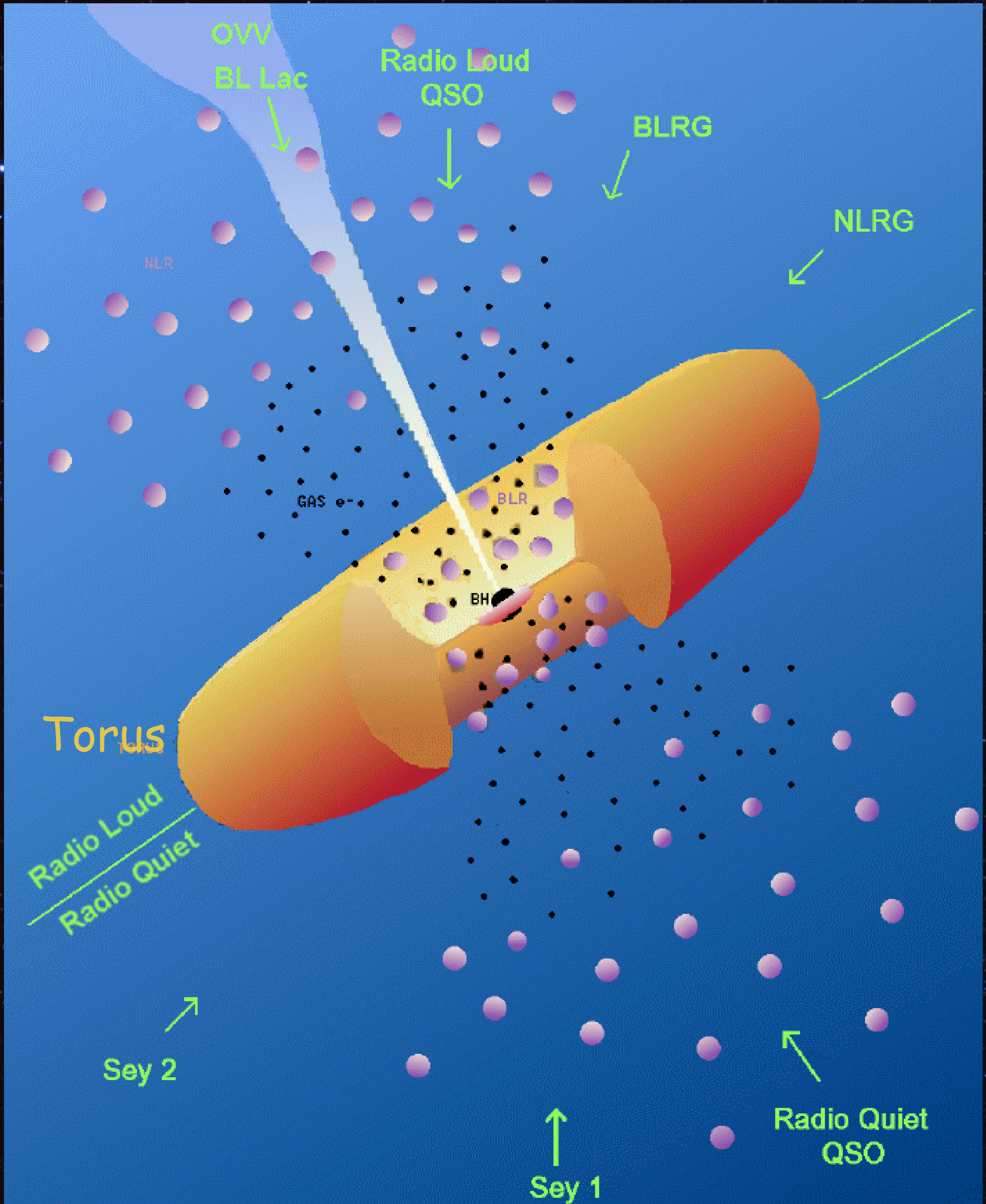
- A brief introduction on Active Galactic Nuclei (AGN)
- Properties of obscured AGN and their importance
- Identification of AGN and in particular of the rare obscured and extremely luminous AGN (QSOs)
- The obscuring matter in QSOs
- Implications on AGN (unified and evolutionary) models
- Herschel outlook on obscured QSOs

AGN Unification Model

AGN observed properties are orientation-dependent

λ	Type 1	Type 2
Optical spectrum	Broad lines	Narrow lines
Optical continuum	Blue	Red
X-ray	Soft/ unabsorbed	Hard/ absorbed
Silicates (10μm)	Emission	Absorption
Far-infrared	Warm	Warm

(Antonucci 1993)



(adapted from Urry & Padovani 1995)

AGN Unification Model

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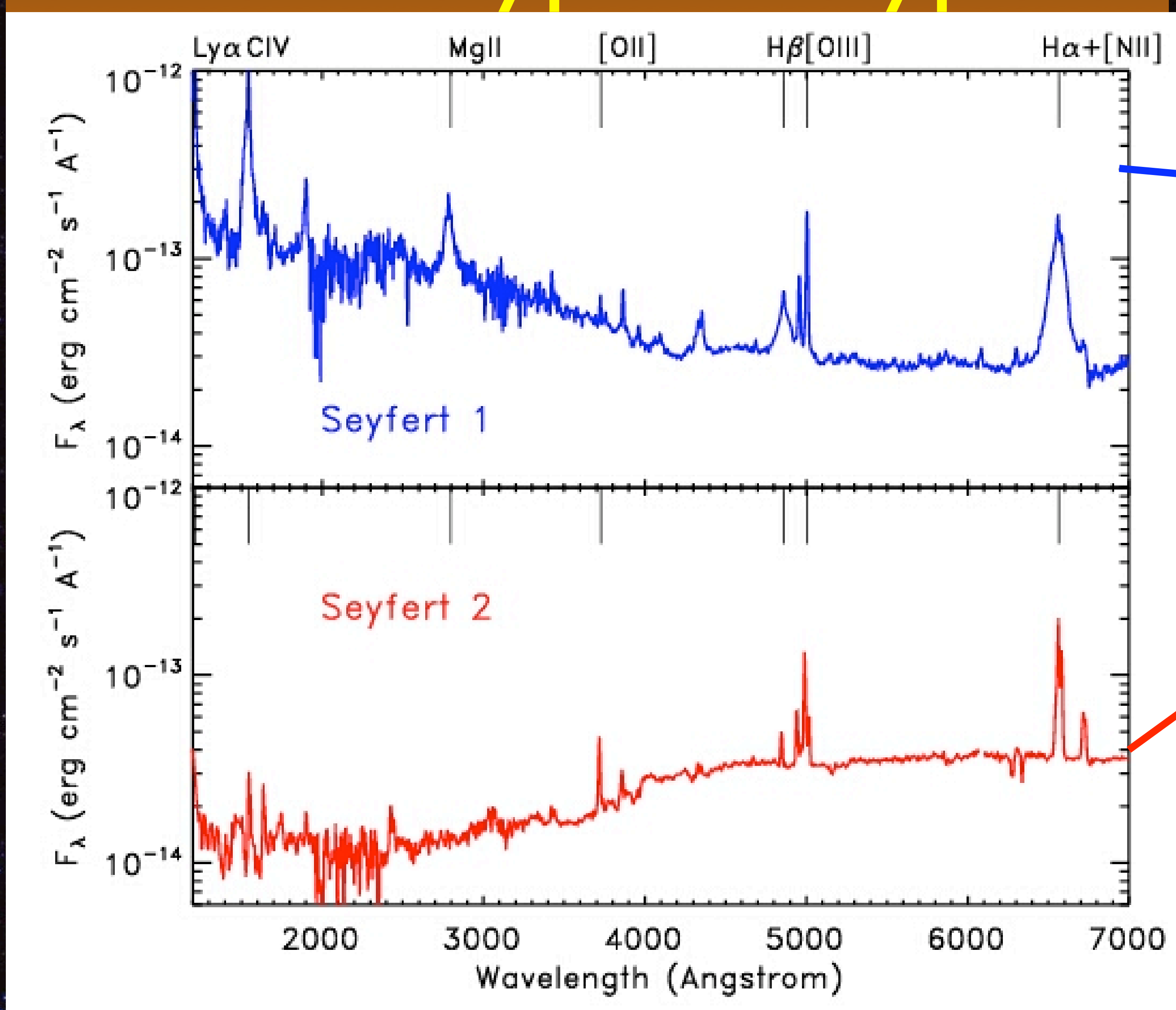
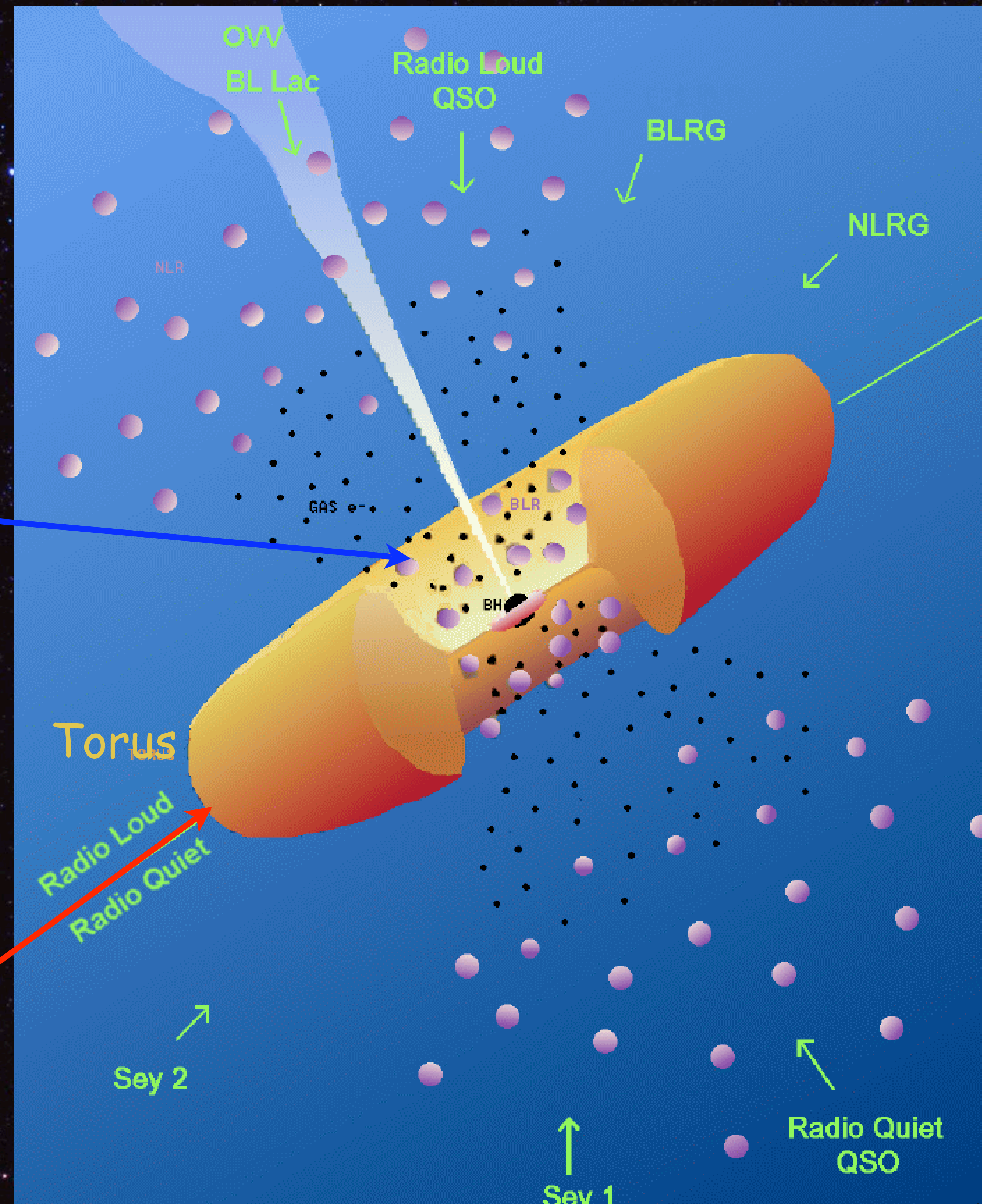
λ Type 1 Type 2



(Antonucci 1993)

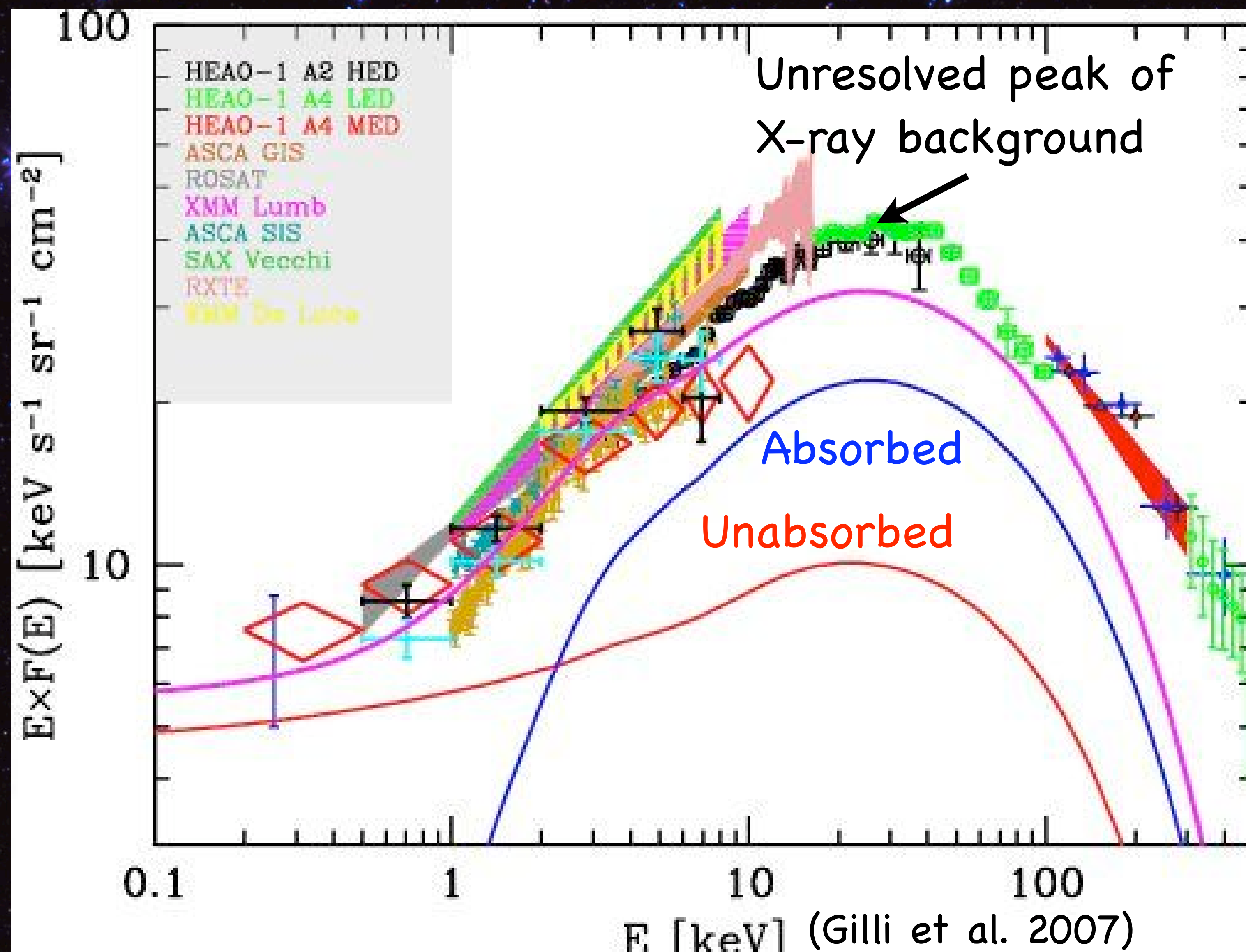


(adapted from Urry & Padovani 1995)

Indirect evidence of existence of heavily absorbed AGN

CXRB synthesis models require a population of heavily obscured AGN

➩ How and where can we find the missing AGN ?



(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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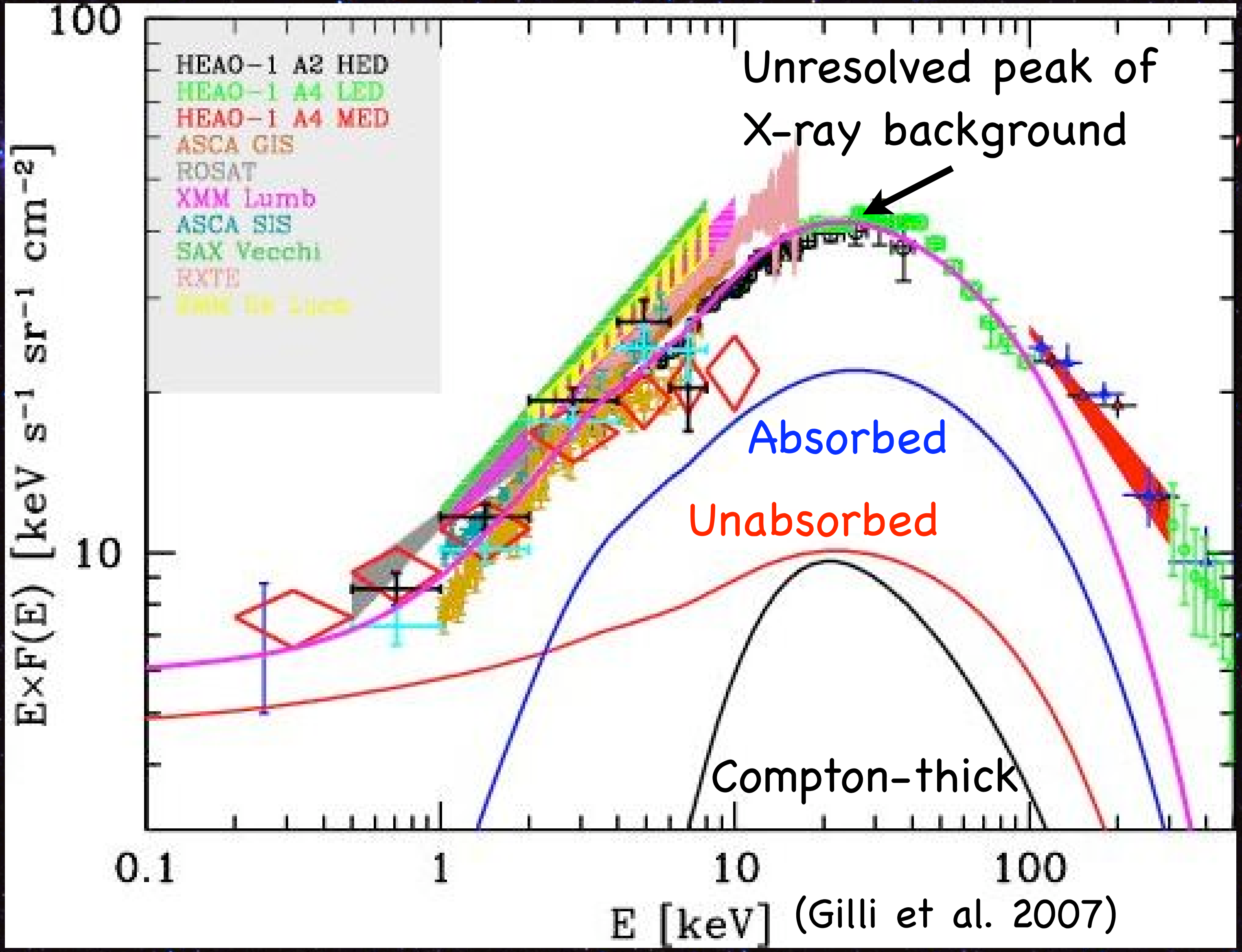
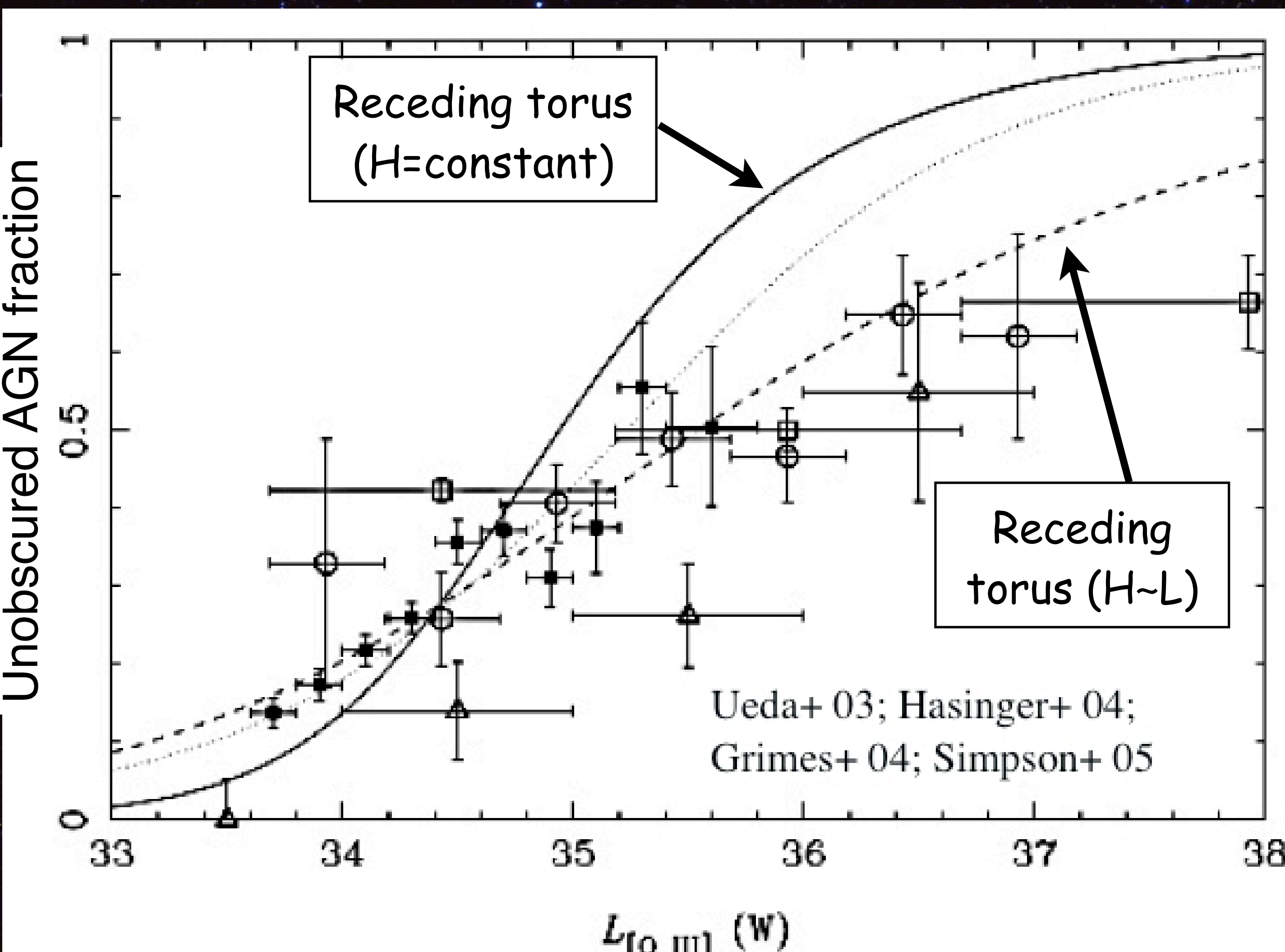
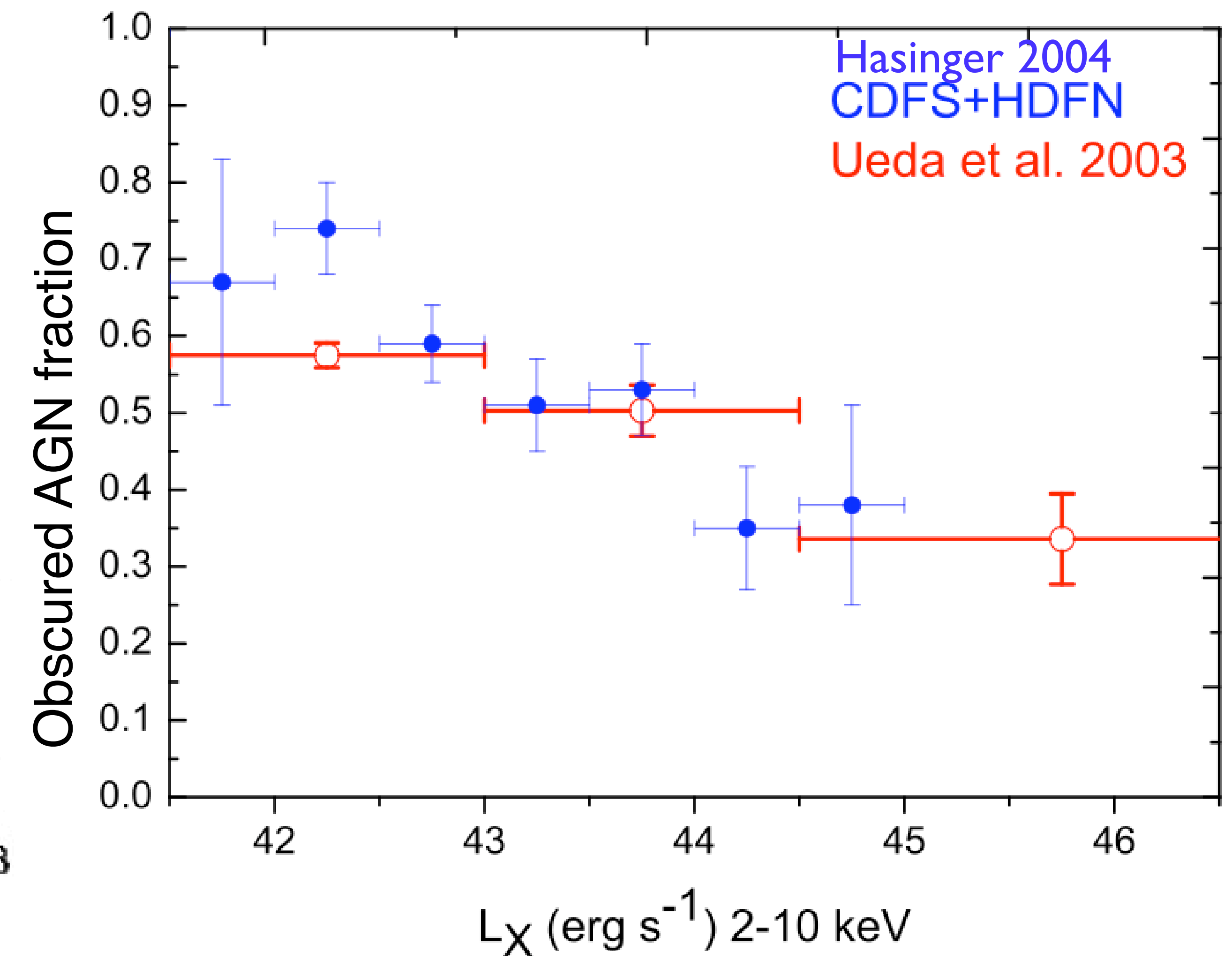


(Setti and Woltjer 1989, Comastri et al. 1995, Gilli et al. 2001, 2003, 2007; Worsley et al. 2004, 2005, Hopkins et al. 2005)

The fraction of obscured AGN decreases at larger luminosities

- Is the decrease of obscured AGN at high luminosity real or a selection effect ?
  - Is the obscuring matter (torus) affected by the AGN luminosity ?
  - Is the unification model valid at all redshifts and luminosities ?



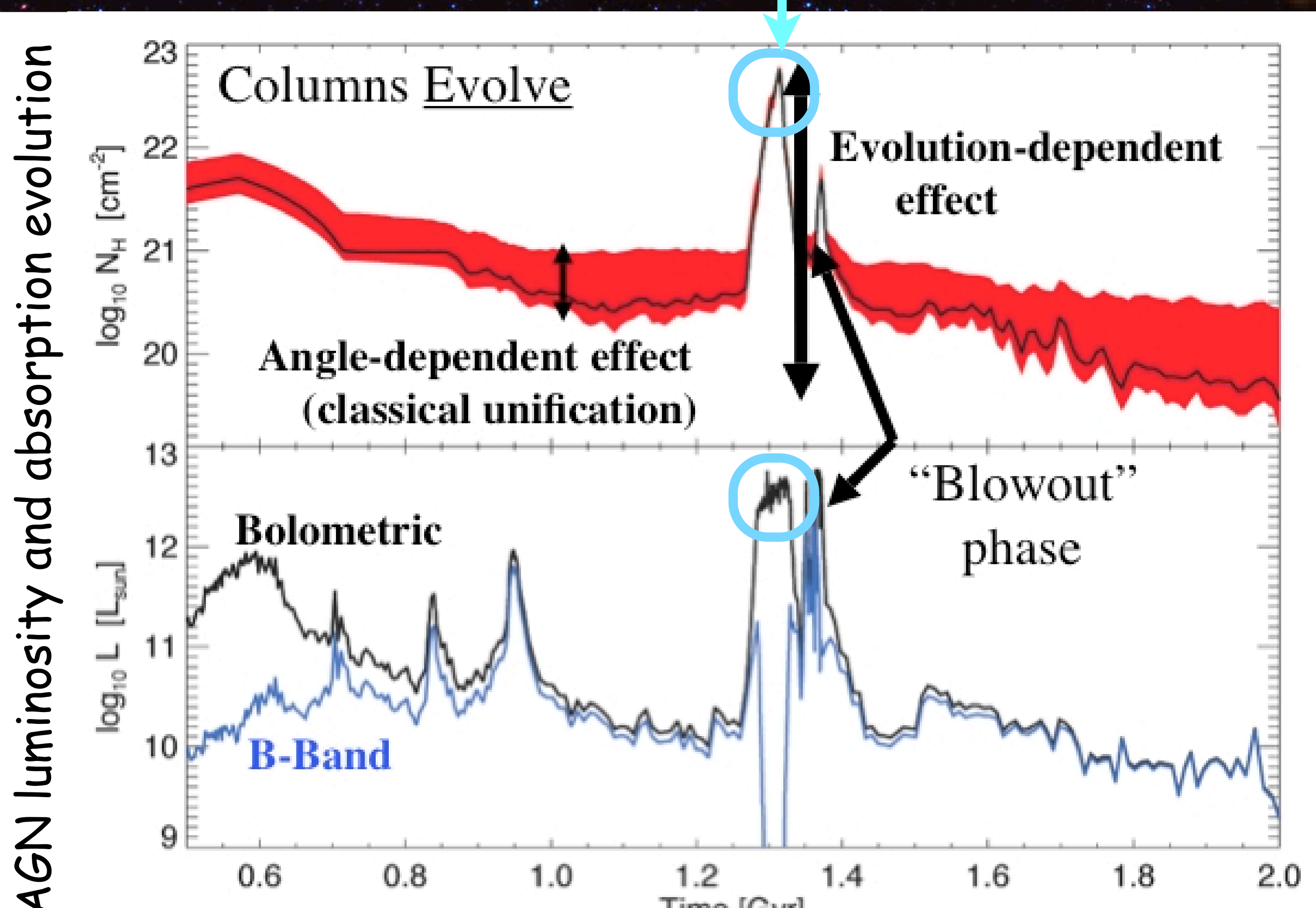


(Maiolino et al. 2007; Treister & Urry 2006; Akylas et al. 2006; Simpson 2005; La Franca et al. 2005; Hasinger 2004; see also Wang et al. 2007)

Obscured luminous AGNs represent a key evolutionary phase

➪ Is this evolutionary scenario correct ?

Obscured luminous phase



(Hopkins et al. 2005)

(Di Matteo et al. 2005)

(Silk & Rees 1998; Fabian et al. 1999; Granato et al. 2001; 2004; Springel et al. 2005; Di Matteo et al. 2005; Hopkins et al. 2005; Cattaneo et al. 2005; Kauffmann and Haehnel 2000)

In search of answers....
let's find the missing AGN

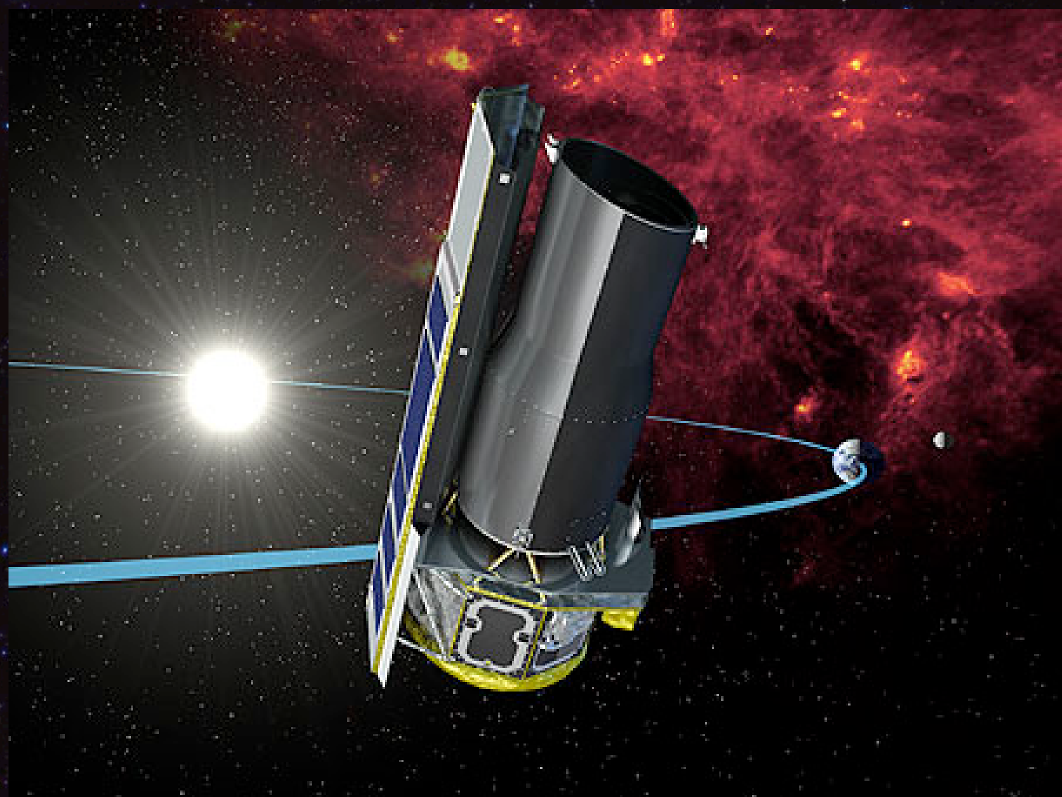
- ➪ How and where can we find the missing AGN ?
- ➪ Is the decrease of obscured AGN at high luminosity real or a selection effect ?
- ➪ Is there any evidence supporting the popular AGN evolutionary scenario ?

Need to find and study obscured AGNs !

Finding and understanding the obscured AGN population is also necessary to uderstand:

- ➡ the contribution from accretion activity (AGN) versus nucleosynthesis (star-formation) to the energy budget of the universe
- ➡ the origin of the X-ray background and of the IR background
- ➡ the evolution of AGN and star-forming galaxies
- ➡ the link between Black Hole (BH) growth, build-up ofstellar mass and AGN feedback

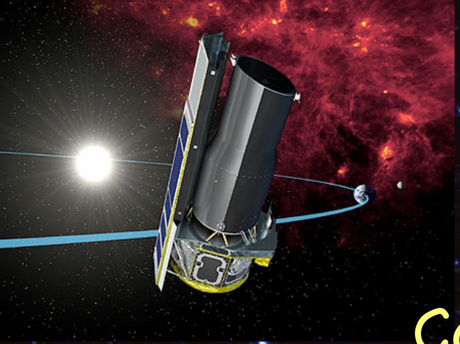
The Spitzer Wide Area Infrared Extragalactic Survey (SWIRE)



Spitzer Space Telescope
3.6, 4.5, 5.8, 8.0μm
24, 70, 160μm
+ multi-band optical data

➪ 2 Million Galaxies up to z=3 & hundreds of 100 Mpc scale cells

Lonsdale et al. 2003



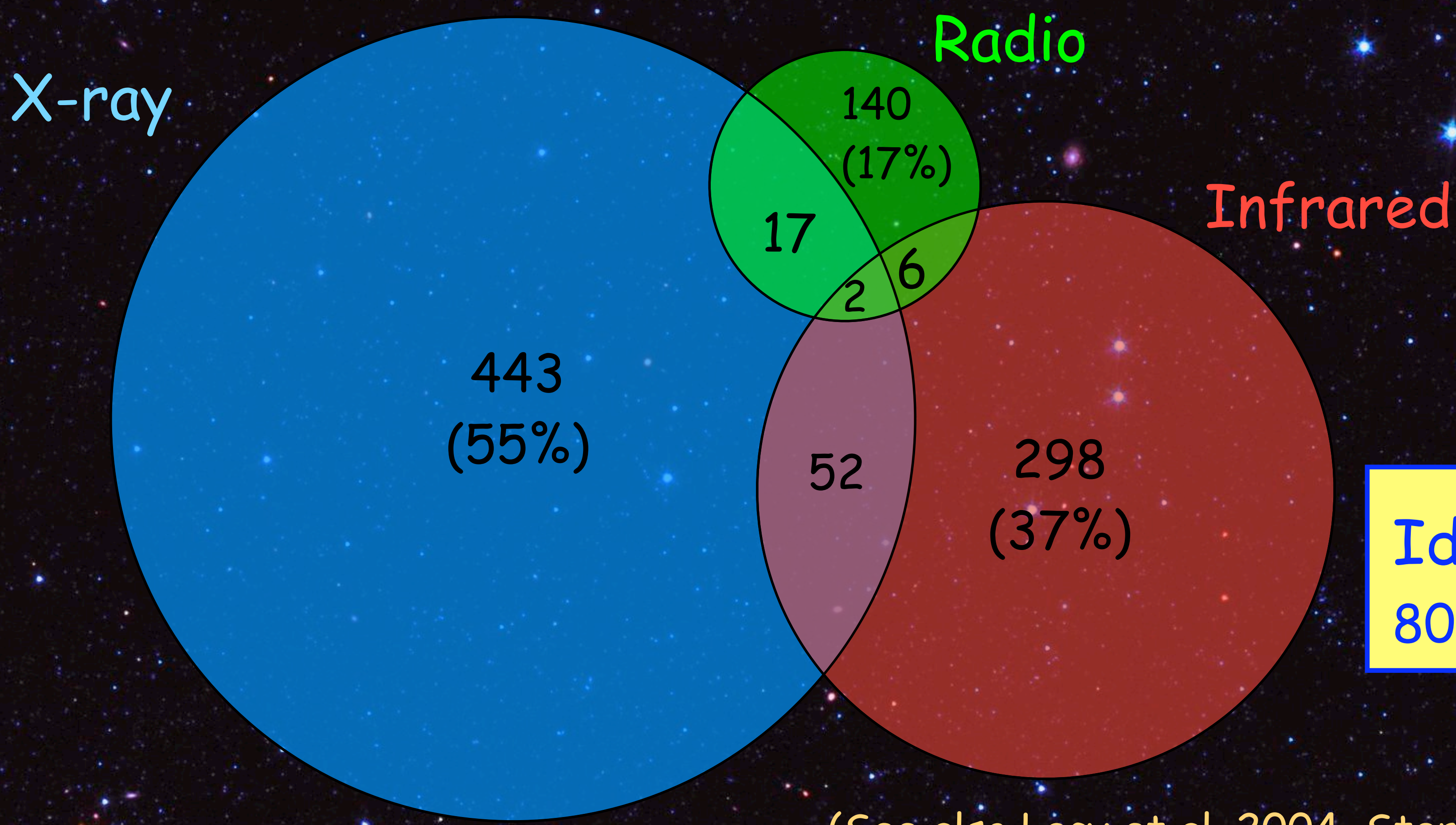
Can we identify all AGN ?

Combination of various selection methods to minimize selection biases

FIELD: Chandra/SWIRE survey: 0.35 deg^2 (Polletta et al. 2006):

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

Each selection is highly incomplete !!

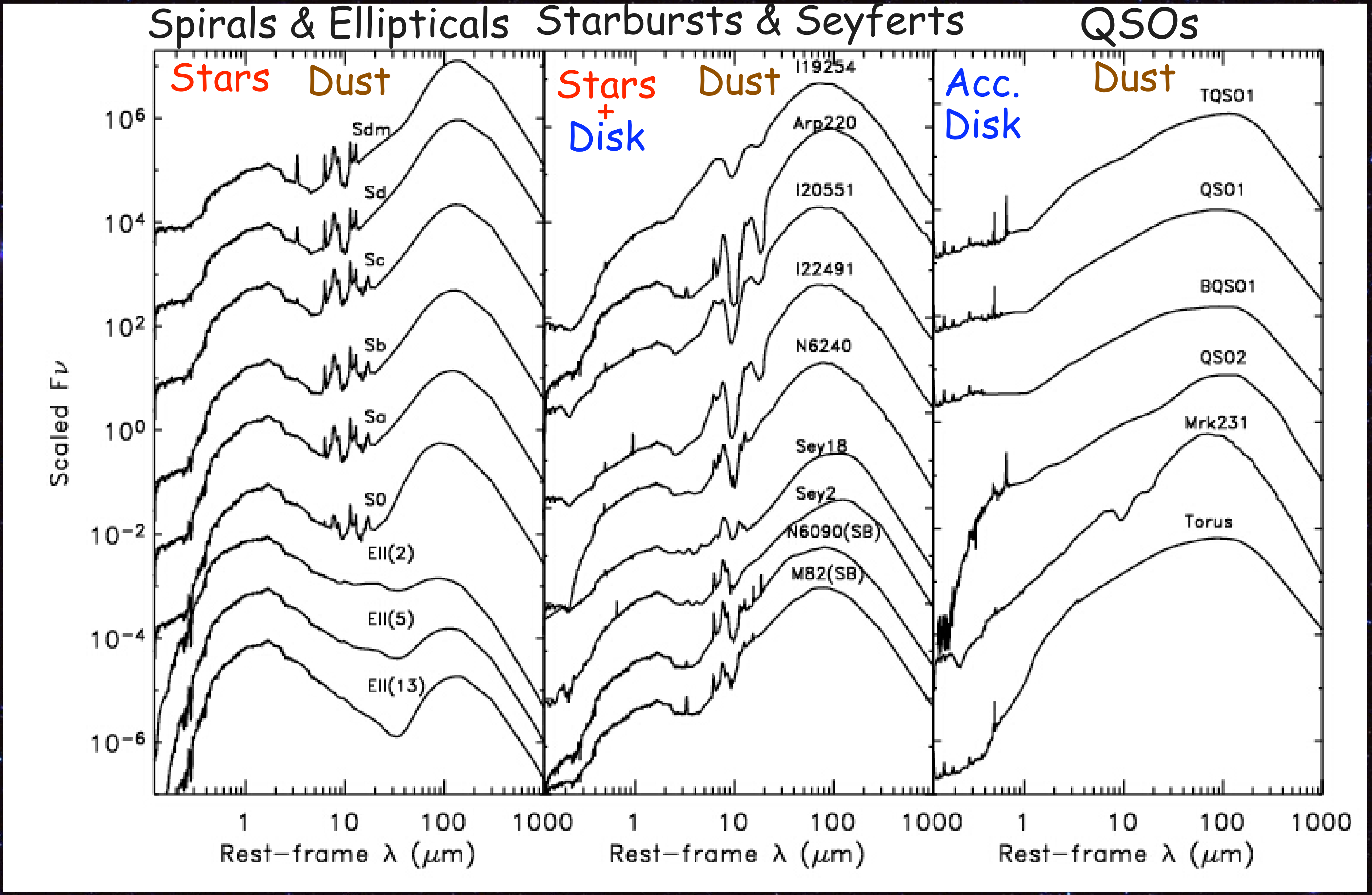


Identified AGNs:
808 (2315 deg^{-2})

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

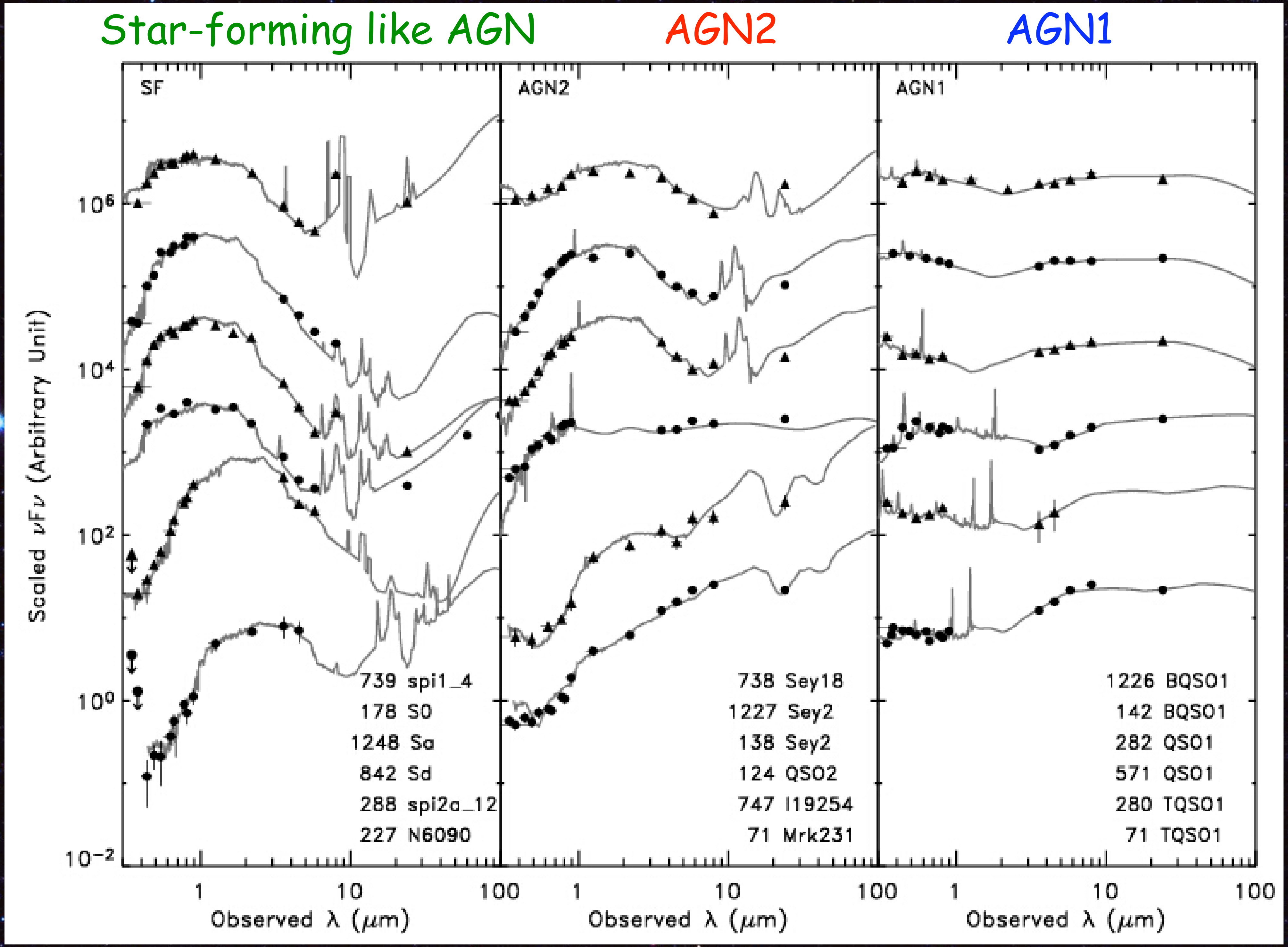
AGN characterization: Spectral Energy Distribution (SED) fits

Galaxy & AGN template Library



(Polletta et al. 2007; Silva et al. 1998; Berta et al. 2003; 2005; Hatziminaoglou et al. 2005)

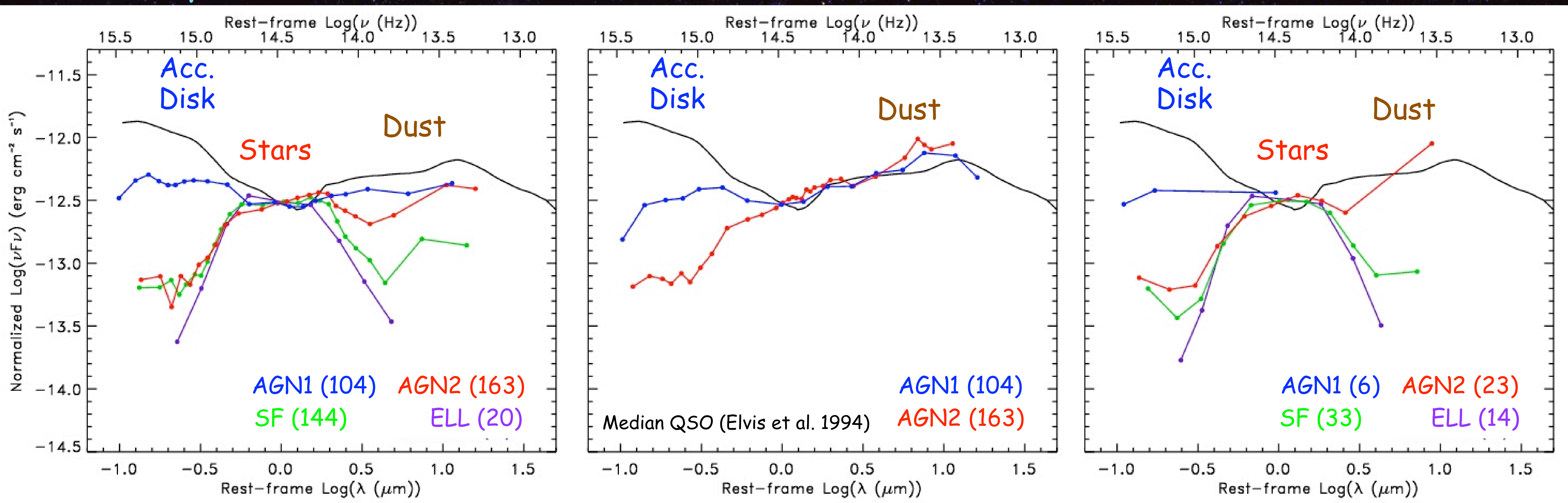
Spectral energy distribution classification

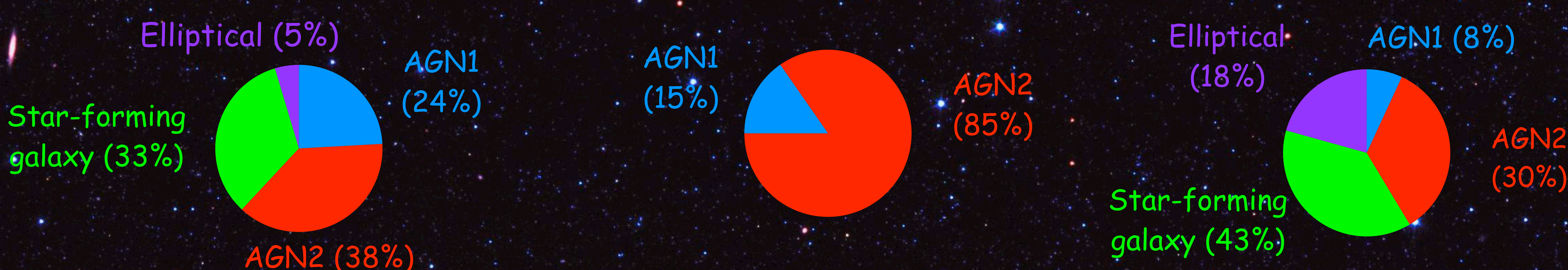


(Polletta et al. 2007)

Spectral energy distributions (SEDs) of all identified AGN

X-ray-selected AGN | Infrared-selected AGN | Radio-selected AGN

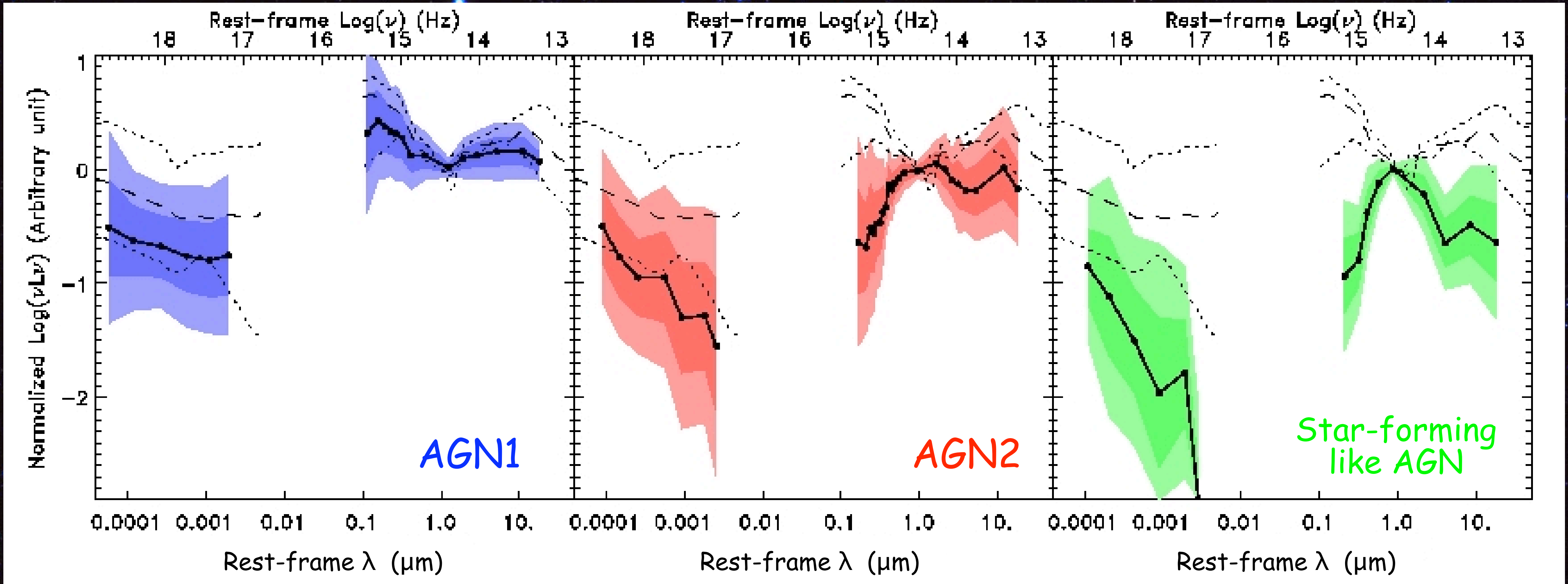




Total: Elliptical (4%) Star-forming galaxy (22%) AGN1 (19%) AGN2 (55%)

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

Based on the XMDS survey (Chiappetti et al. 2005)

(see also Eckart et al. 2006; Tozzi et al. 2006; Fiore et al. 2007; Daddi et al. 2007)

SEDs of X-ray detected Compton-thick AGN

Selection criteria:

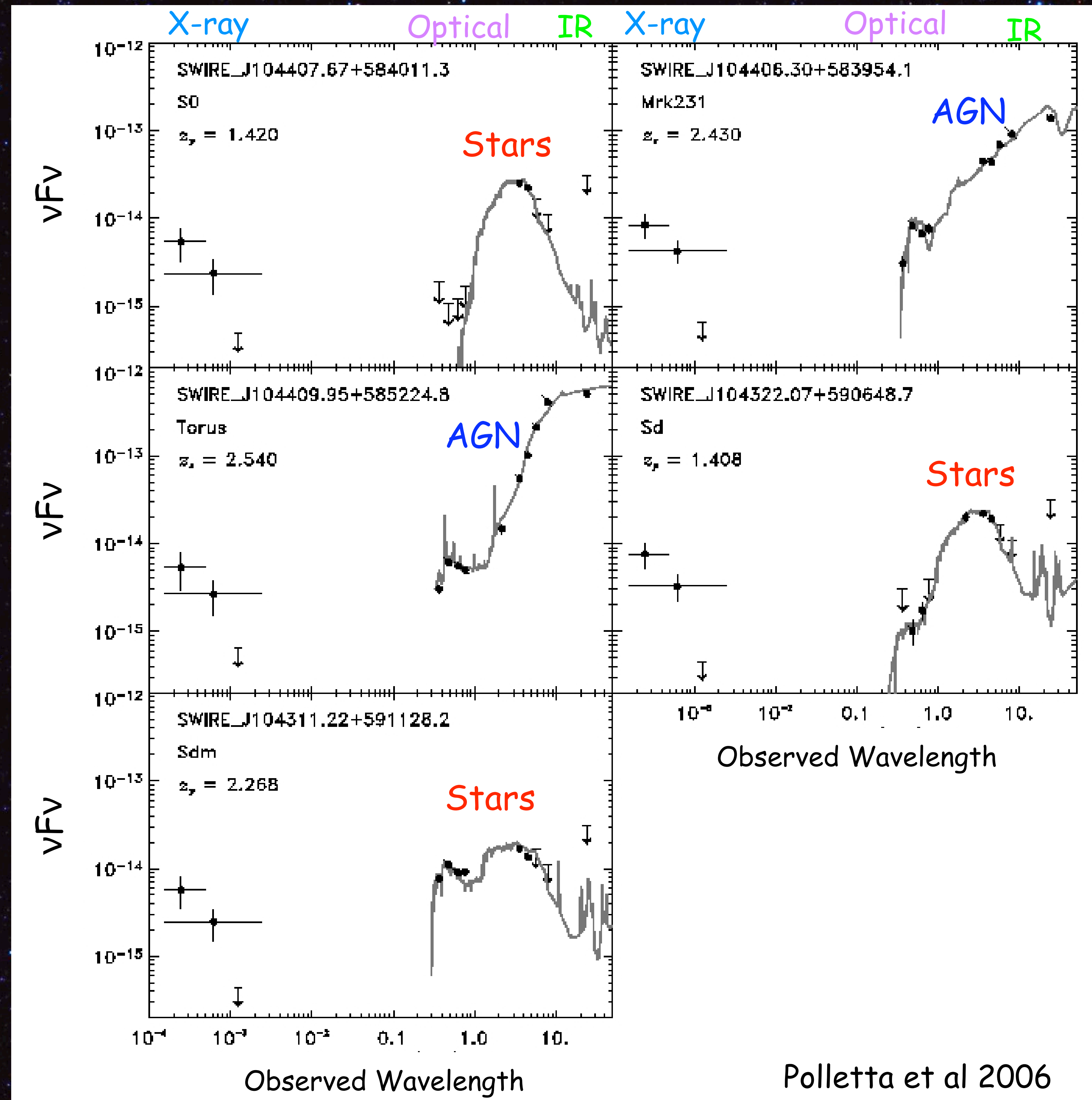
HR, z ⇒ $N_H \geq 10^{24}$ cm^{-2}

5 sources (z=1.4-2.5)

SEDs:

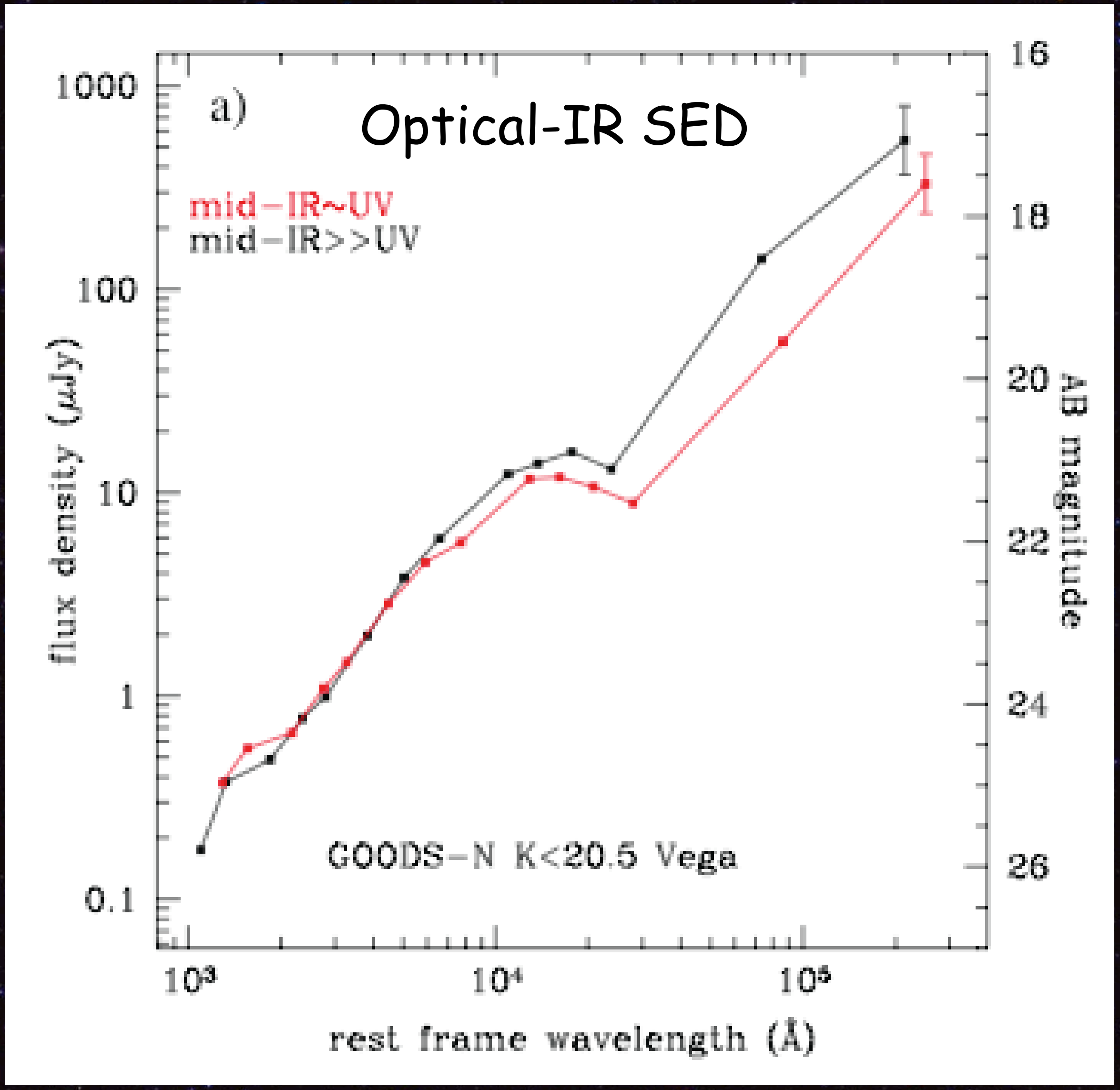
2 AGN2 SEDs (40%)

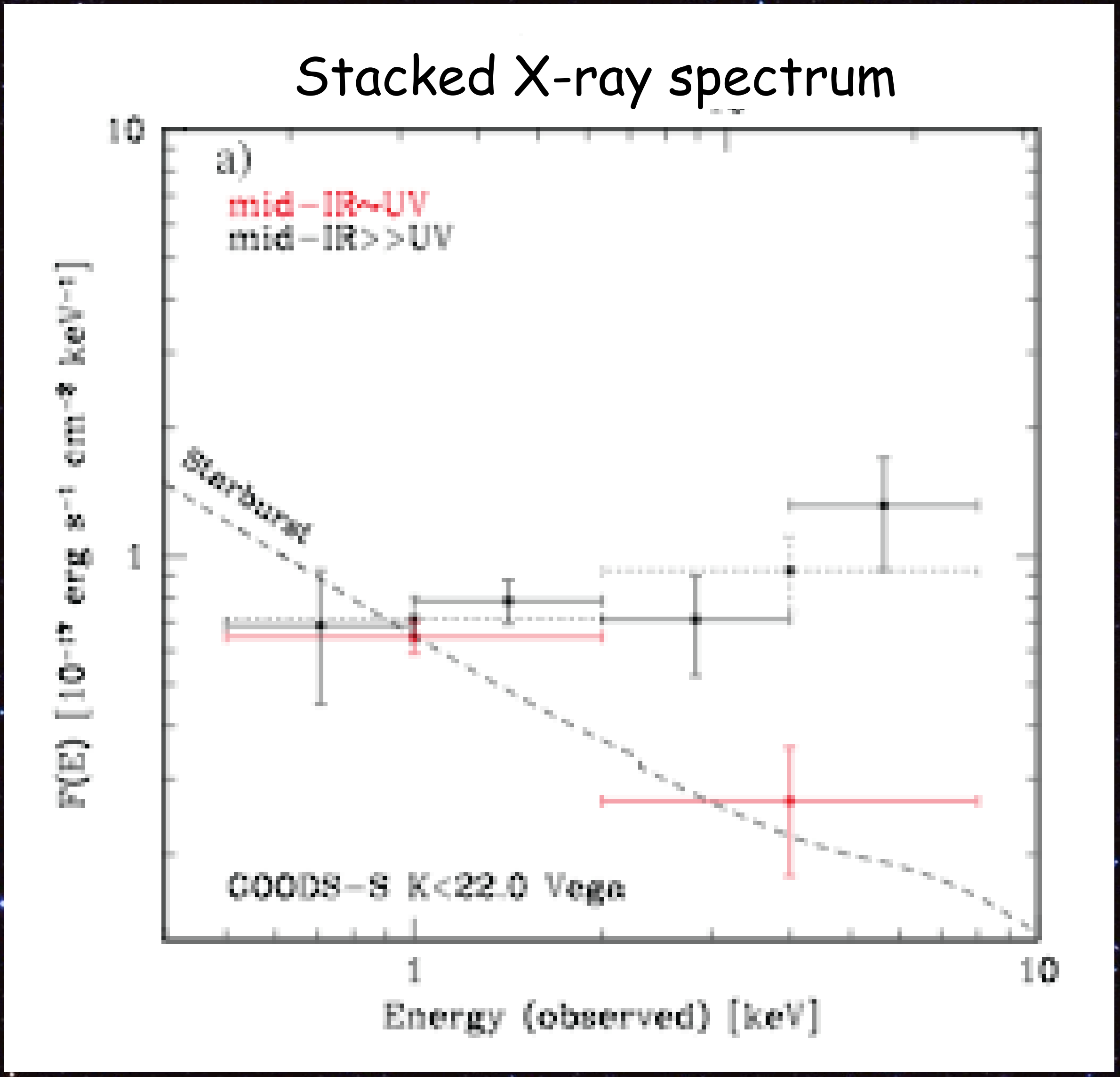
3 normal galaxy SEDs (60%)



The missing AGNs

"Star-forming galaxies" with mid-infrared excess
Hard X-ray emission detected by stacking Chandra images





Daddi et al. 2007

A sample of extremely luminous and obscured AGN

From the 3 Spitzer widest extragalactic surveys:

- optically faint & 24μm bright sources ($F_{24\mu m}/F_r > 500$ & $F_{24\mu m} > 1mJy$)
- AGN-dominated IR SEDs
- available IR spectra from Spitzer/IRS
- $L(6\mu m) > 10^{12} L_\odot$

Field	SWIRE (LH, N1, N2)	NDWFS	E-FLS	ALL
Area (deg^2)	24	9	3.7	36.7
N. sources★	11	5	5	21

★ 2: Houck et al. 2005, 5: Weedman, Polletta et al. 2006, 1: Desai et al. 2006, 5: Yan et al. 2007, 8: Polletta et al., 2008

Image by NASA/CXC/M. Weiss

Spectral Energy Distributions

F_ν (mJy) vs λ(μm)
Optical
IRAC
IRS spectrum
MIPS

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

$F_\nu \sim \nu^{-2}$ - - - -

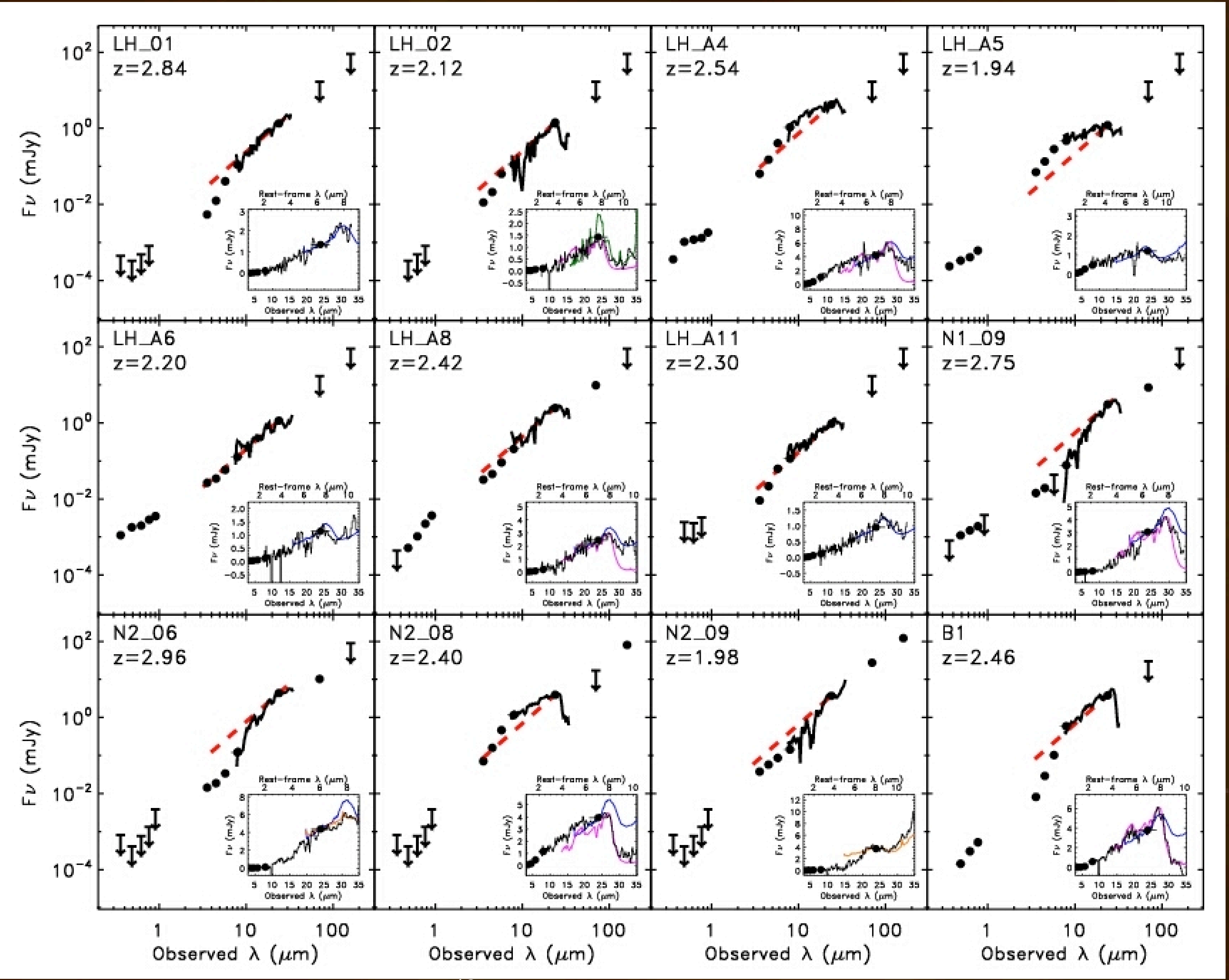


Image by NASA/CXC/M. Weiss

Infrared Spectra (IRS)

Silicate absorption feature at 9.7μm in 18/23 sources

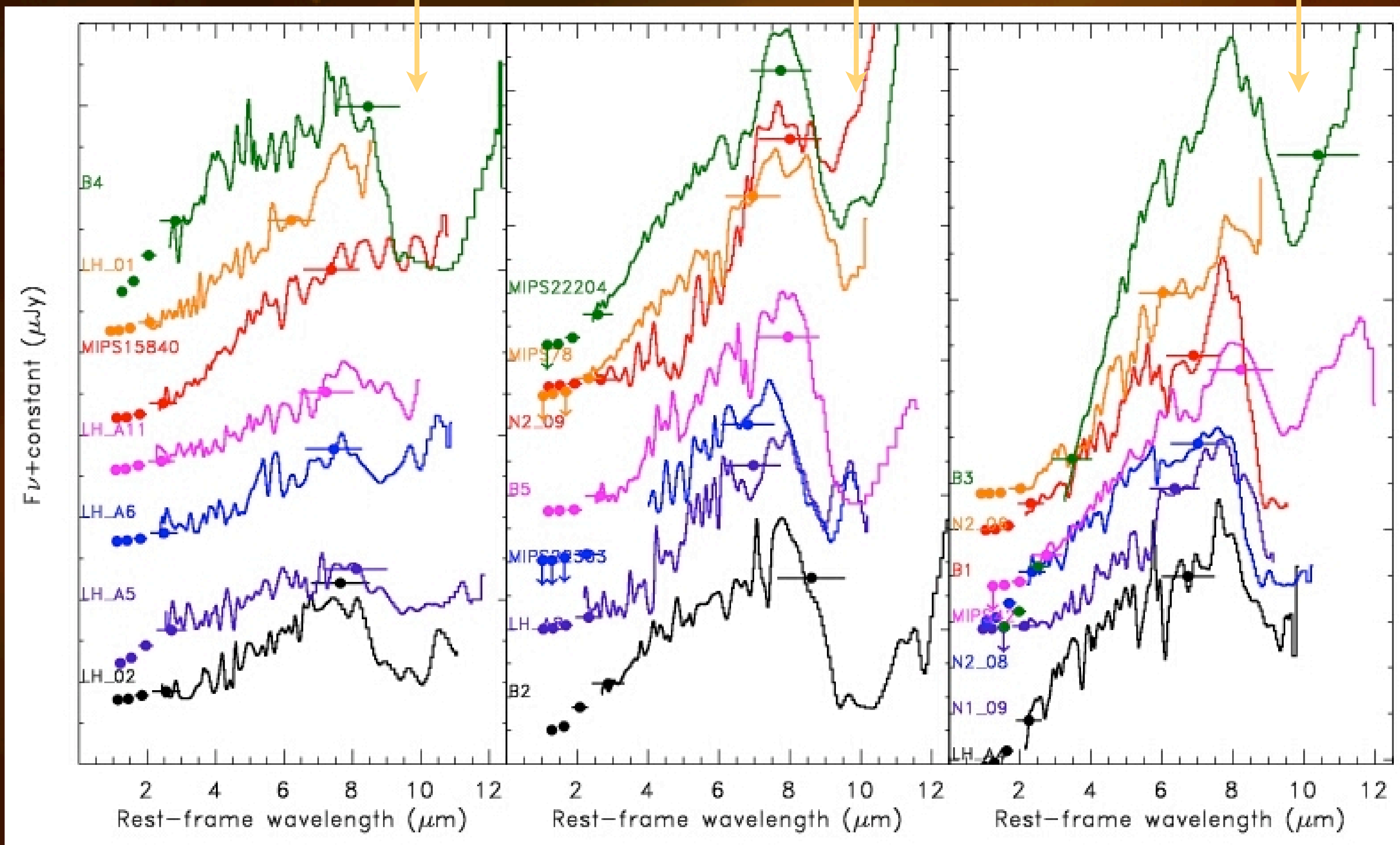
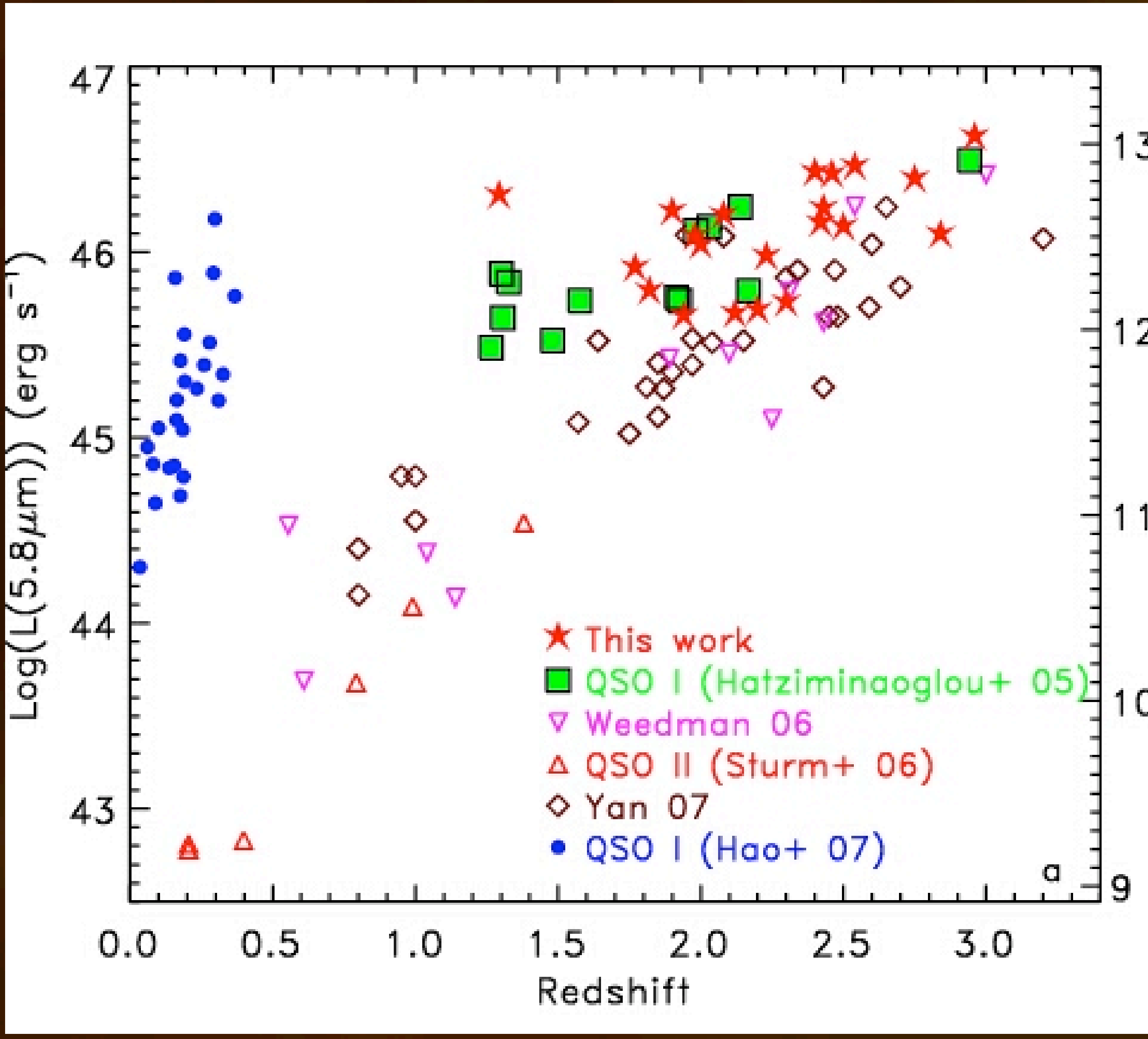
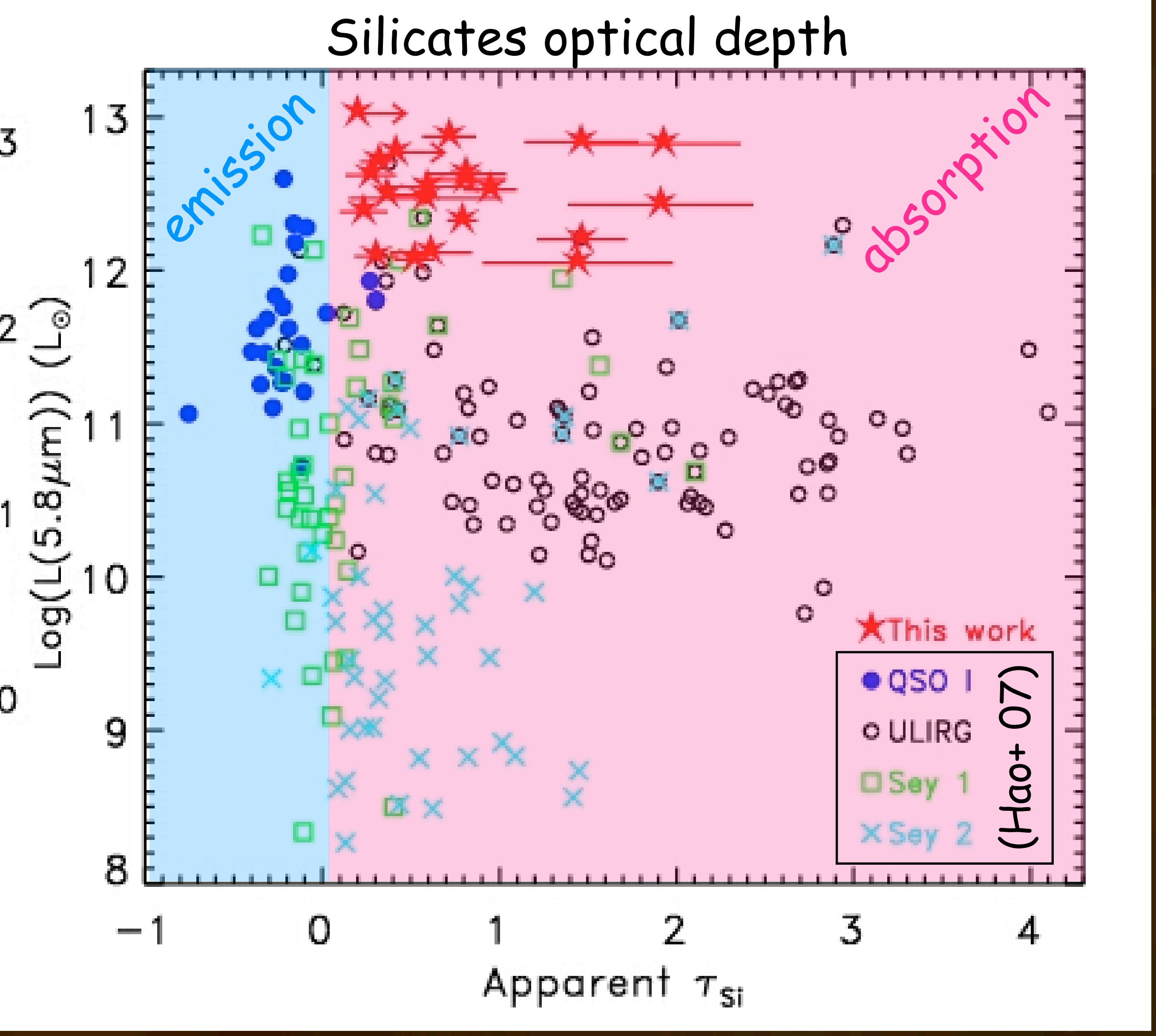


Image by NASA/CXC/M. Weiss

The selected sources include the most luminous & most obscured AGNs currently known





Silicates (9.7μm) optical depth:

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

Image by NASA/CXC/M. Weiss

SED Modeling: Clumpy torus

(Hönig et al. 2006)

Model parameters:

- cloud 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): = 0,15, 30,45,60,75,90 deg [7]
- random arrangements of clouds [5]

➪ 4 x 3 x 3 x 7 x 5 = 1260 models

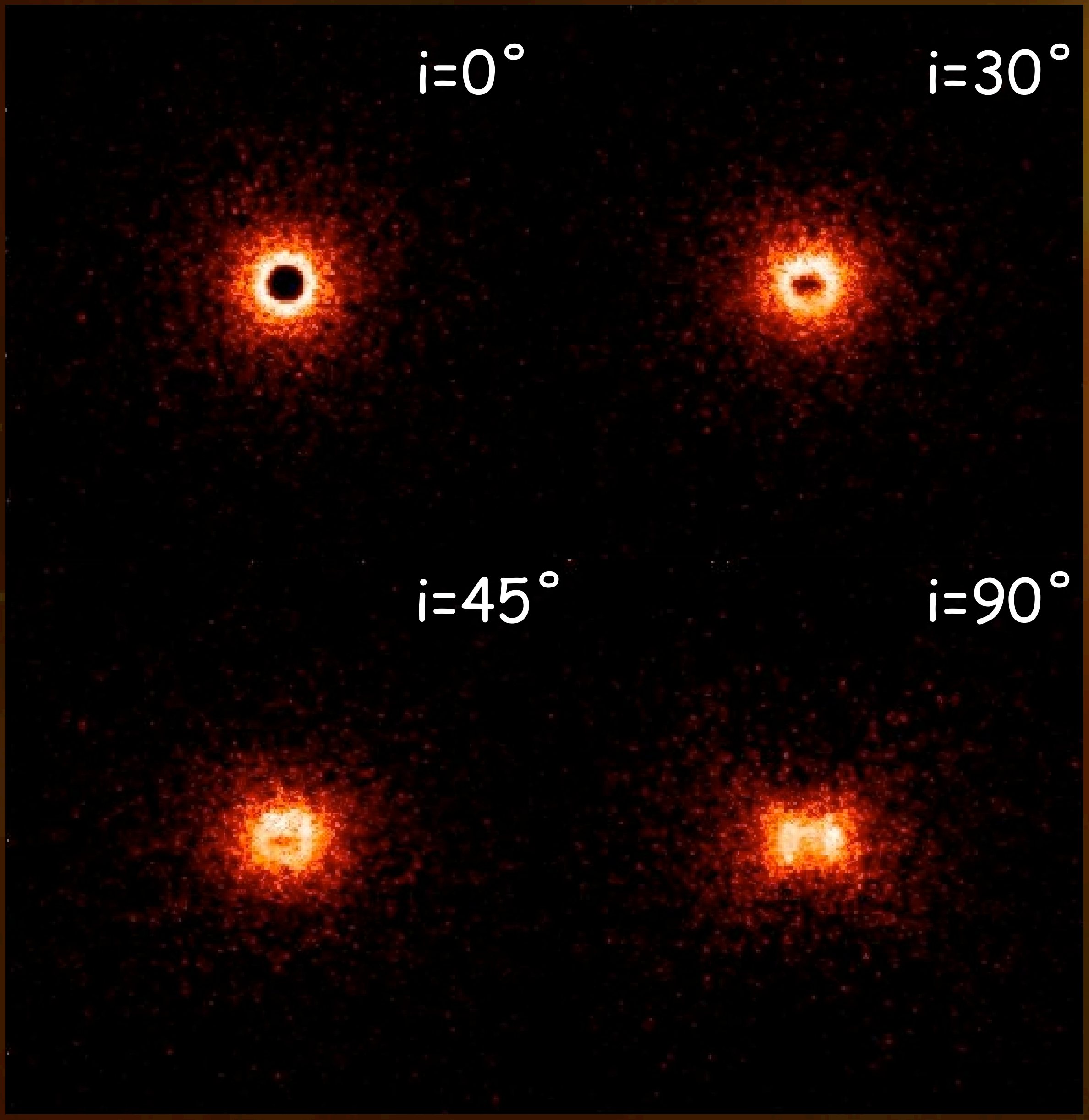
⇩

Fit 1-10μm rest-frame SED & spectrum

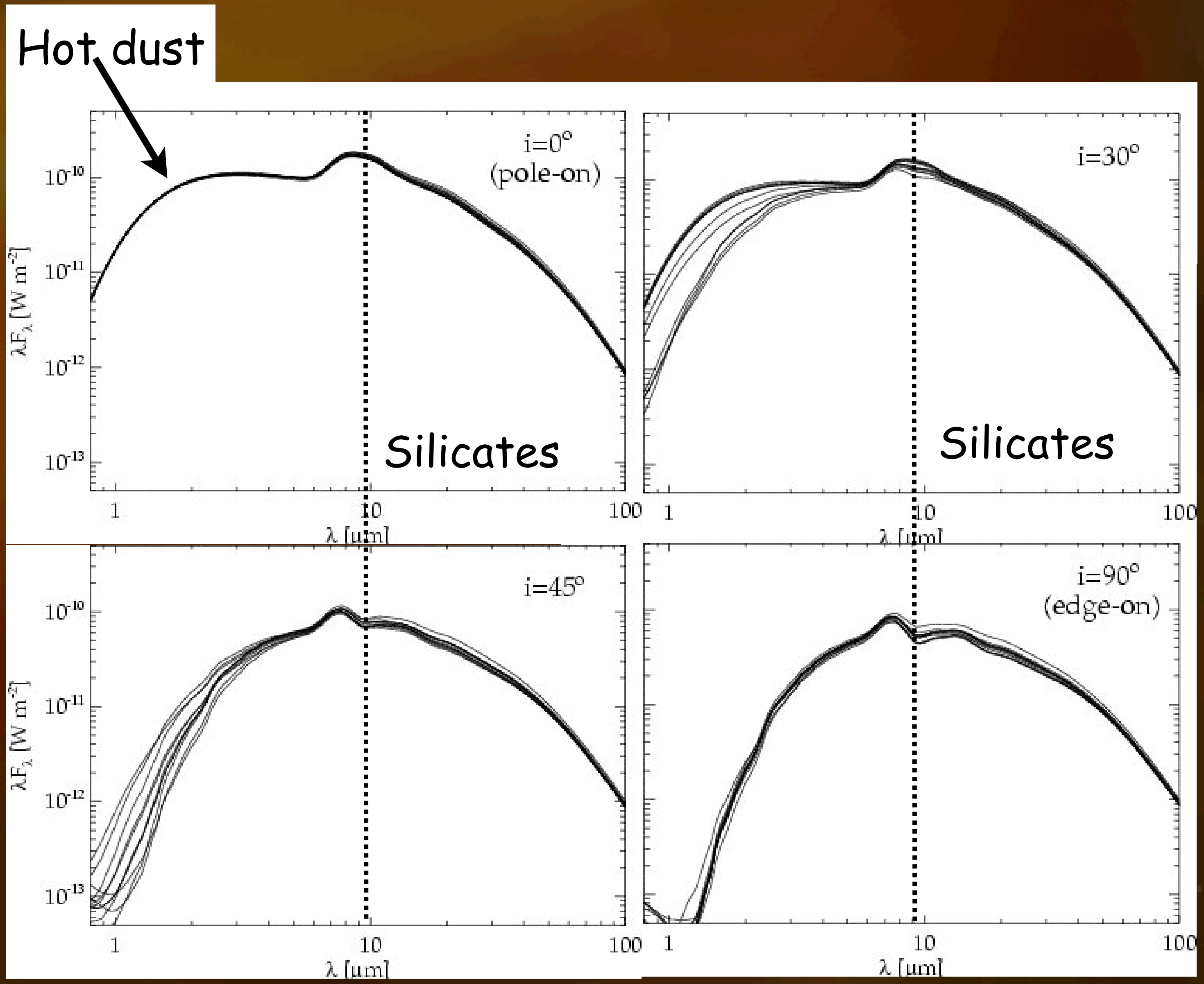
Image by NASA/CXC/M. Weiss

Effects of torus inclination on observed emission

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



Clumpy Torus Infrared SED



(Hönig et al. 2006)

Image credit: NASA/CXC/M. Weiss

SED fits with clumpy torus models + host

Clumpy Torus

Elliptical (host)

Total (host+torus)

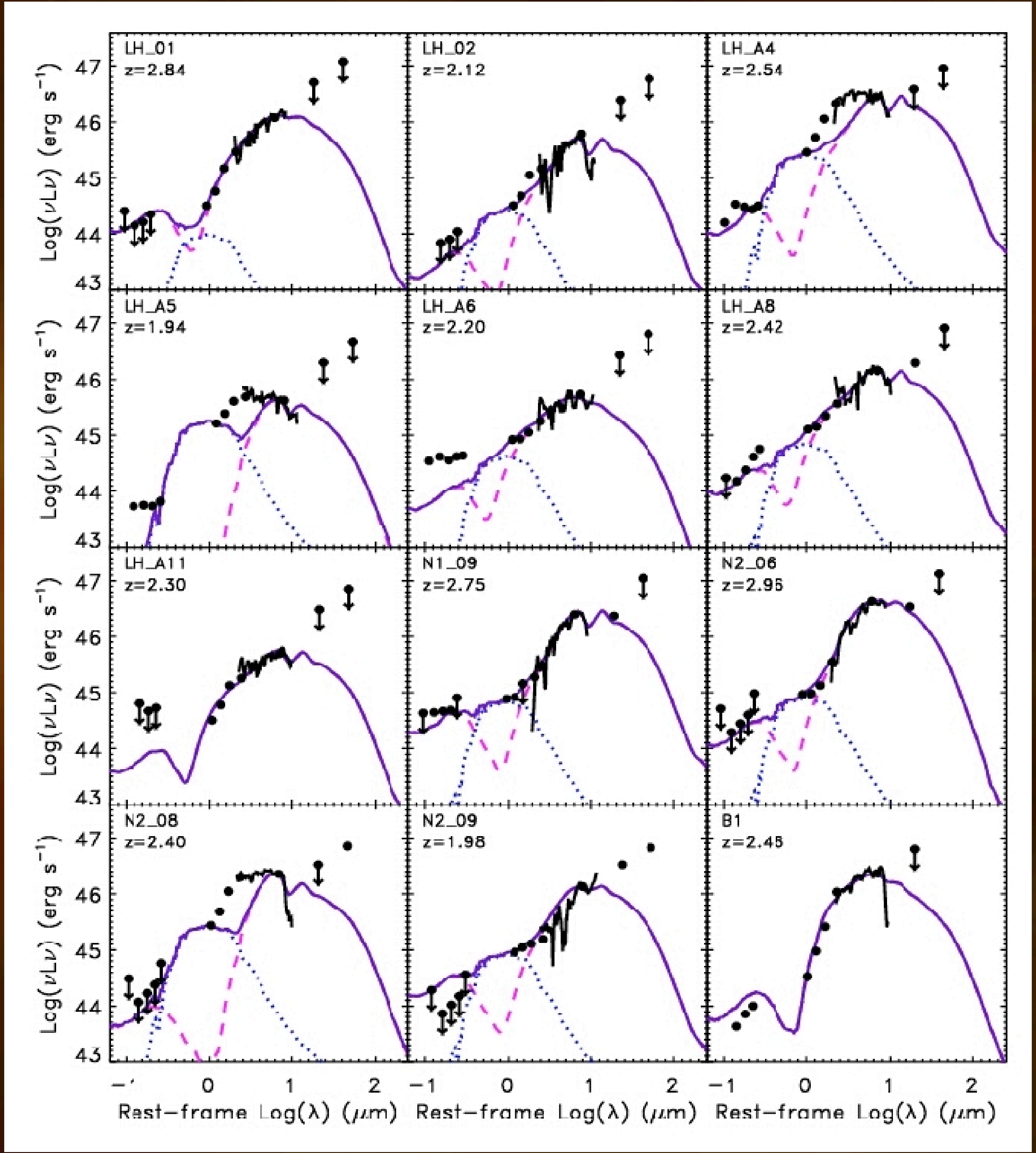


Image by NASA/CXC/M. Weiss

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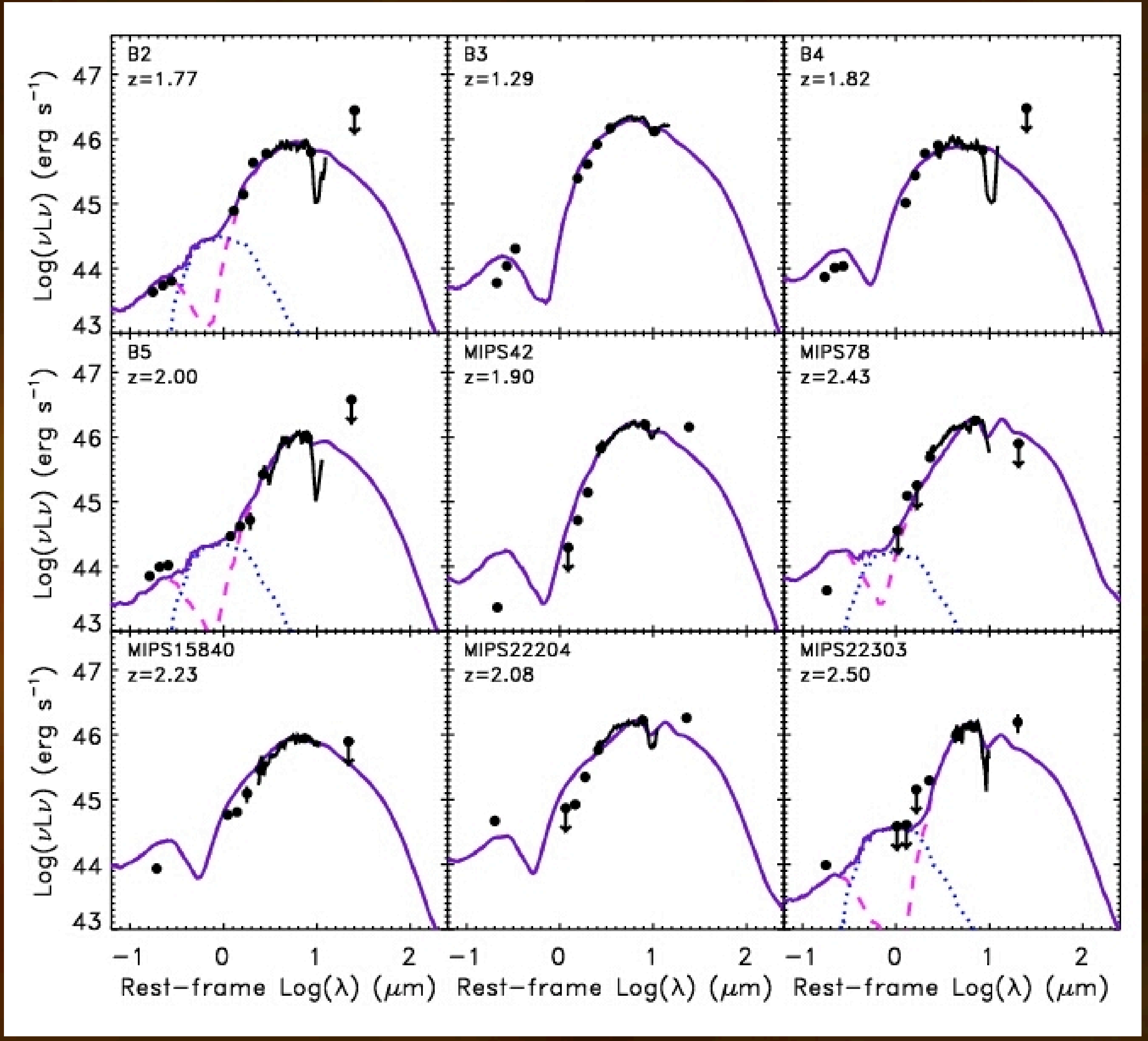


Image by NASA/CXC/M. Weiss

Evidence for external obscuration

Torus+Host
Torus
Host

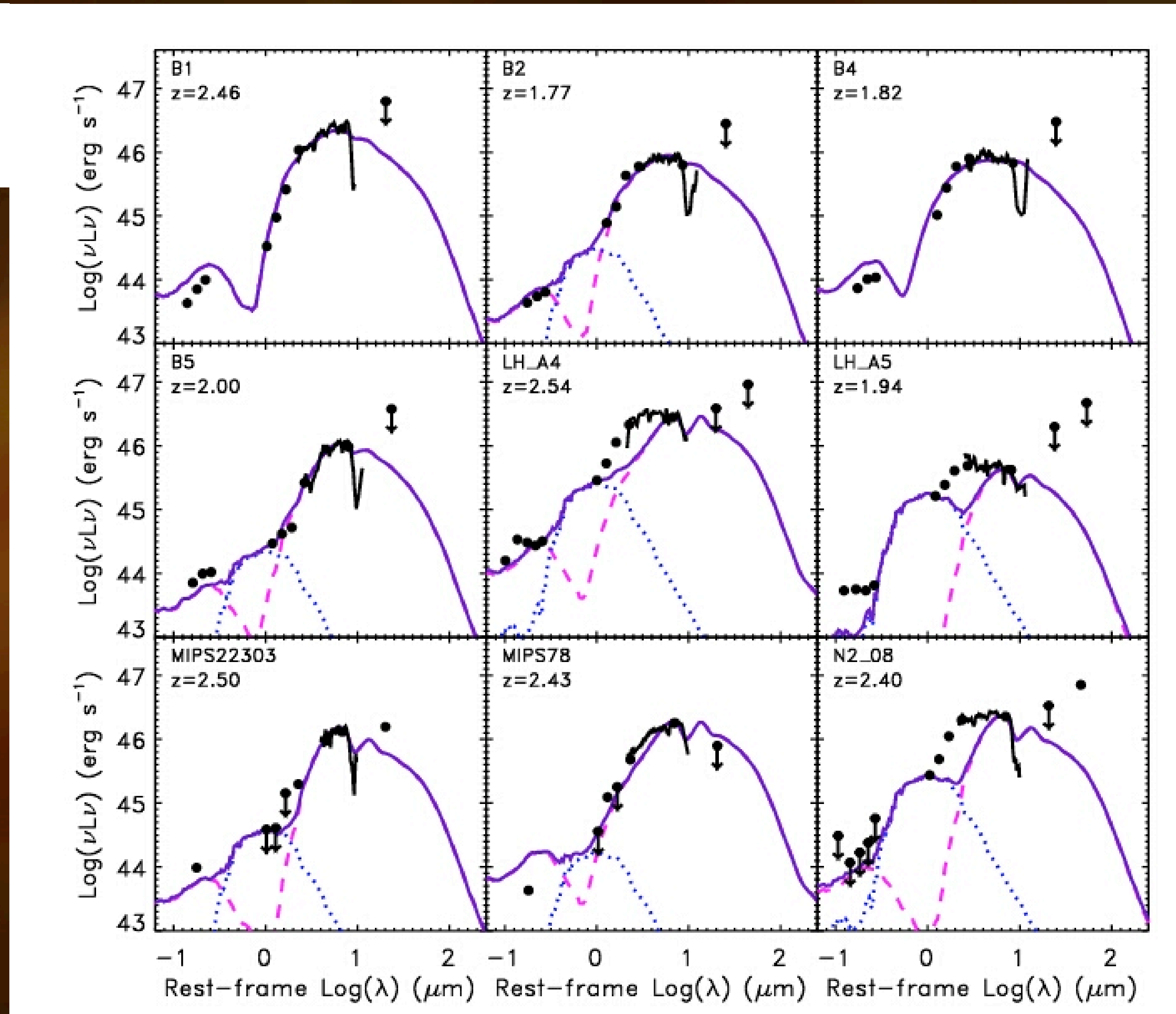
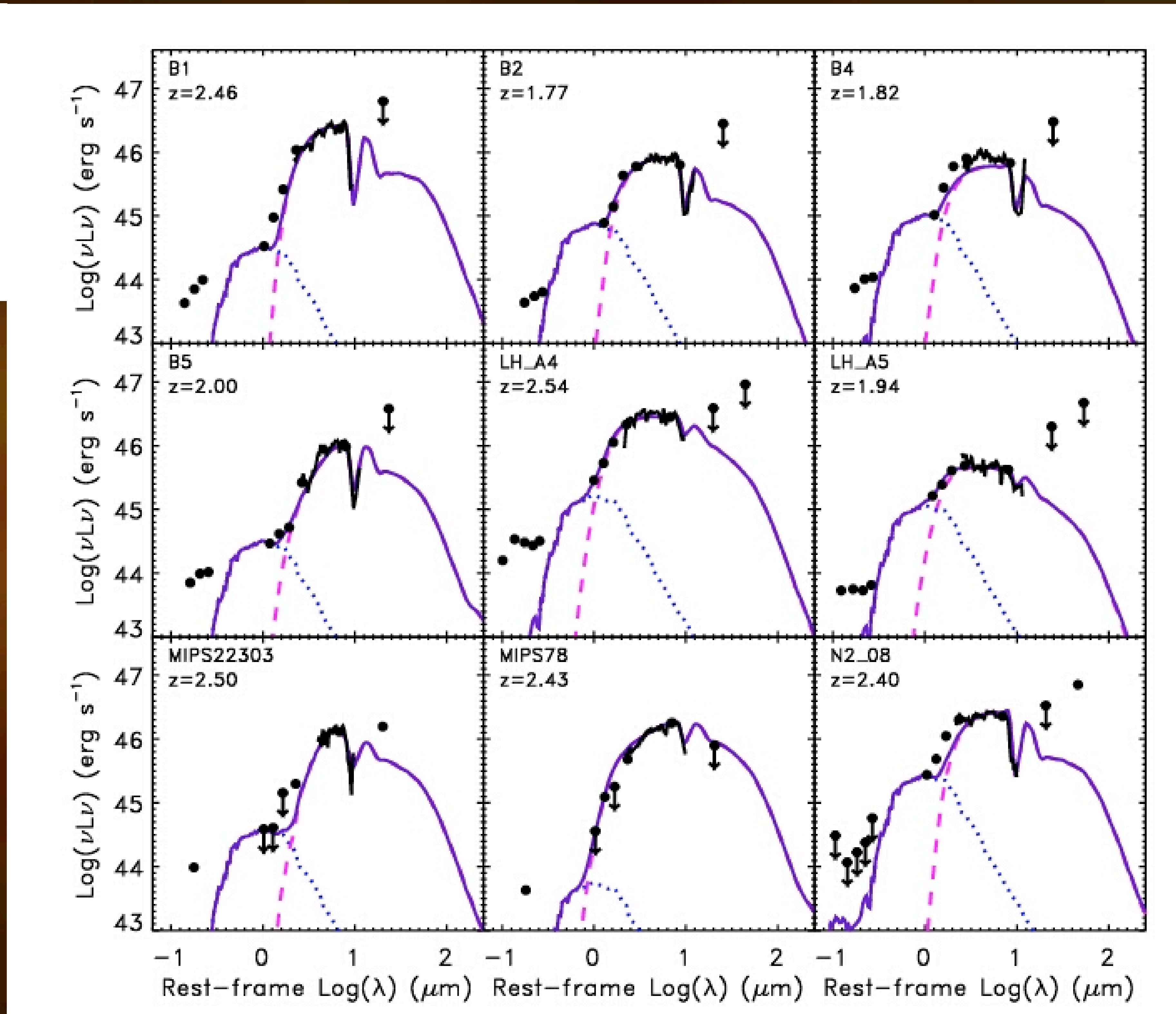


Image by NASA/CXC/M. Weiss

Evidence for external obscuration

Torus+Host+
COLD
ABSORBER
Torus
Host



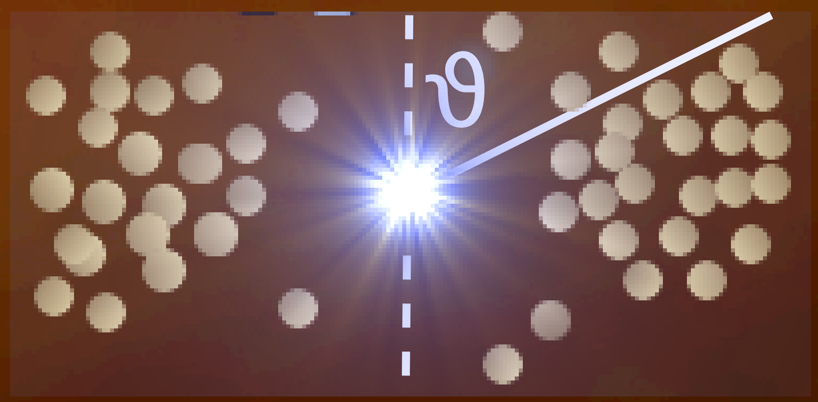
External obscuration already proposed by Keel 1980; Lawrence & Elvis 1982; see also Rigby et al. 2006; Brand et al. 2007, Urrutia et al. 2007; Sajina et al. 2007.

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

Image by NASA/CXC/M. Weiss

Torus inclination in mid-IR selected obscured QSOs

10/21 sources (8 modeled with torus + cold absorber, 2 with weak Silicates in absorption)



11/21 sources

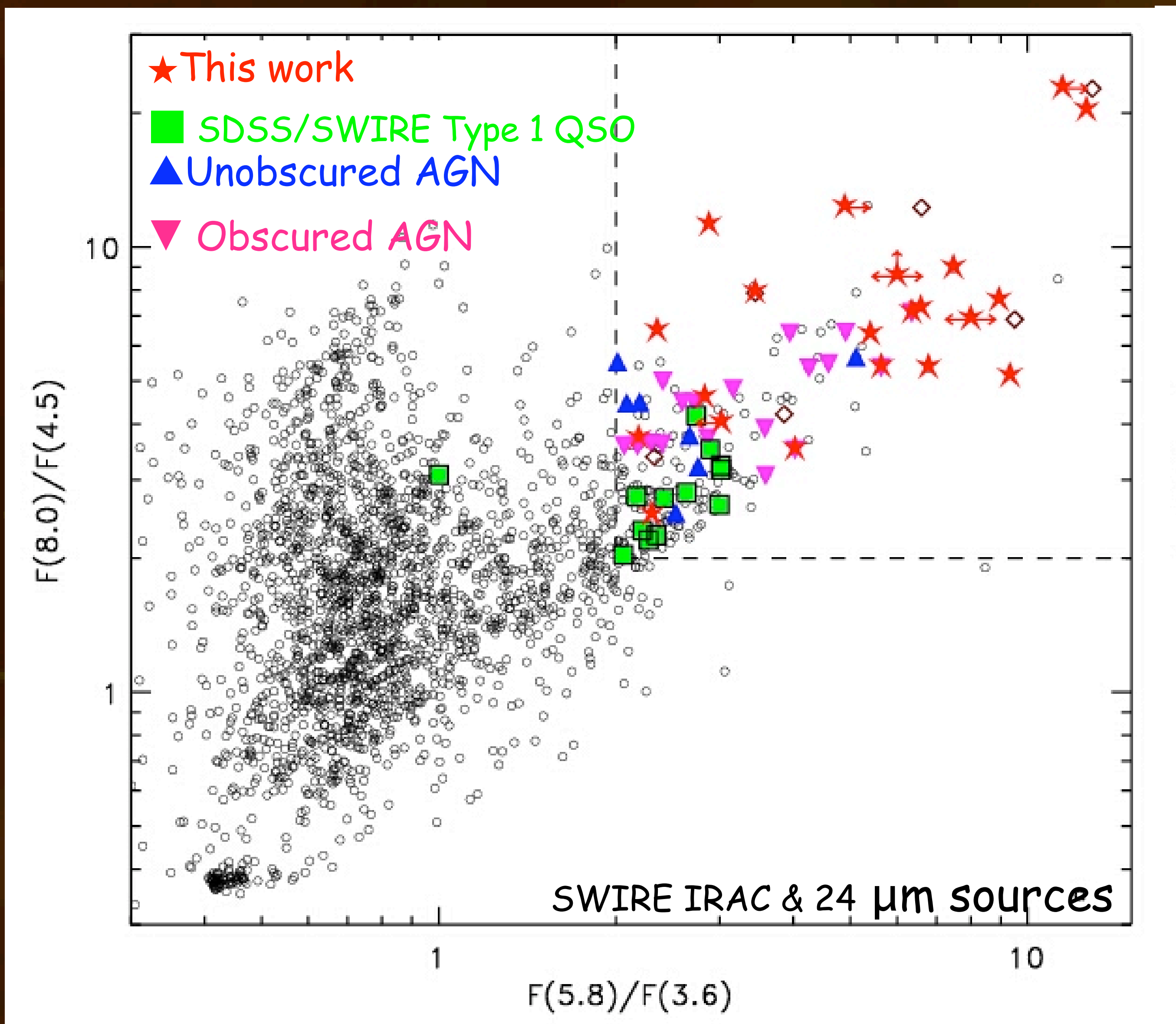
How common are these obscured QSOs ?
(What is the torus opening angle at these luminosities?)

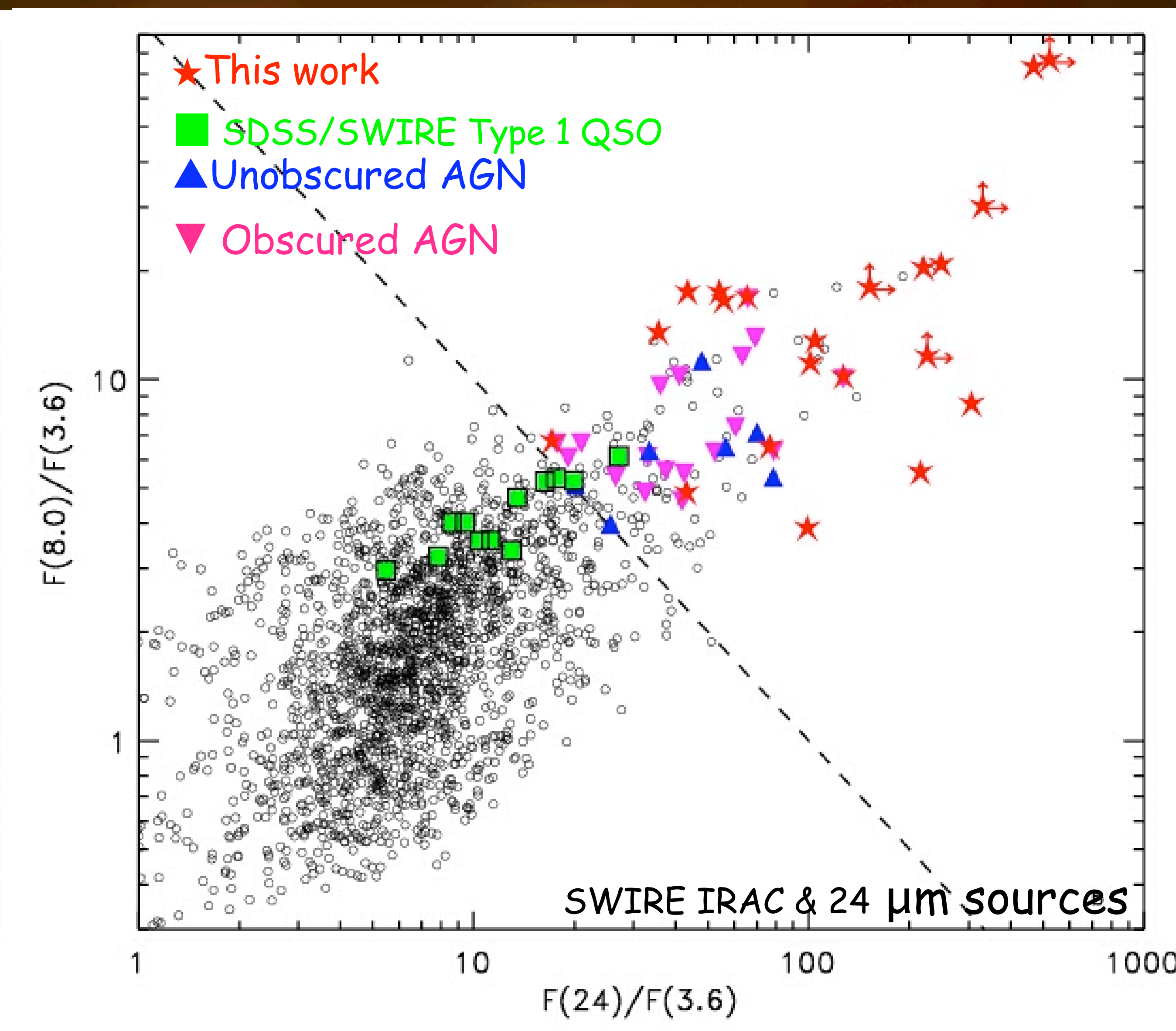
 Image by NASA/CXC/M. Weiss

Surface density of obscured and unobscured QSOs

OBSCURED: IRAC & 24 μm SWIRE sources: 1540 deg^{-2}

Extremely red IR colors & $F_{24\mu m}$ >1mJy : 22 deg^{-2} (5 ▲Unobscured AGN & 17 ▼ Obscured AGN)





UNOBSCURED: 11.7 deg^{-2} unobscured QSO (Brown et al. 2006)

⇨ OBSCURED:UNOBSCURED = 1.4-1.9:1

Image by NASA/CXC/M. Weiss

MIR obscured AGN fraction

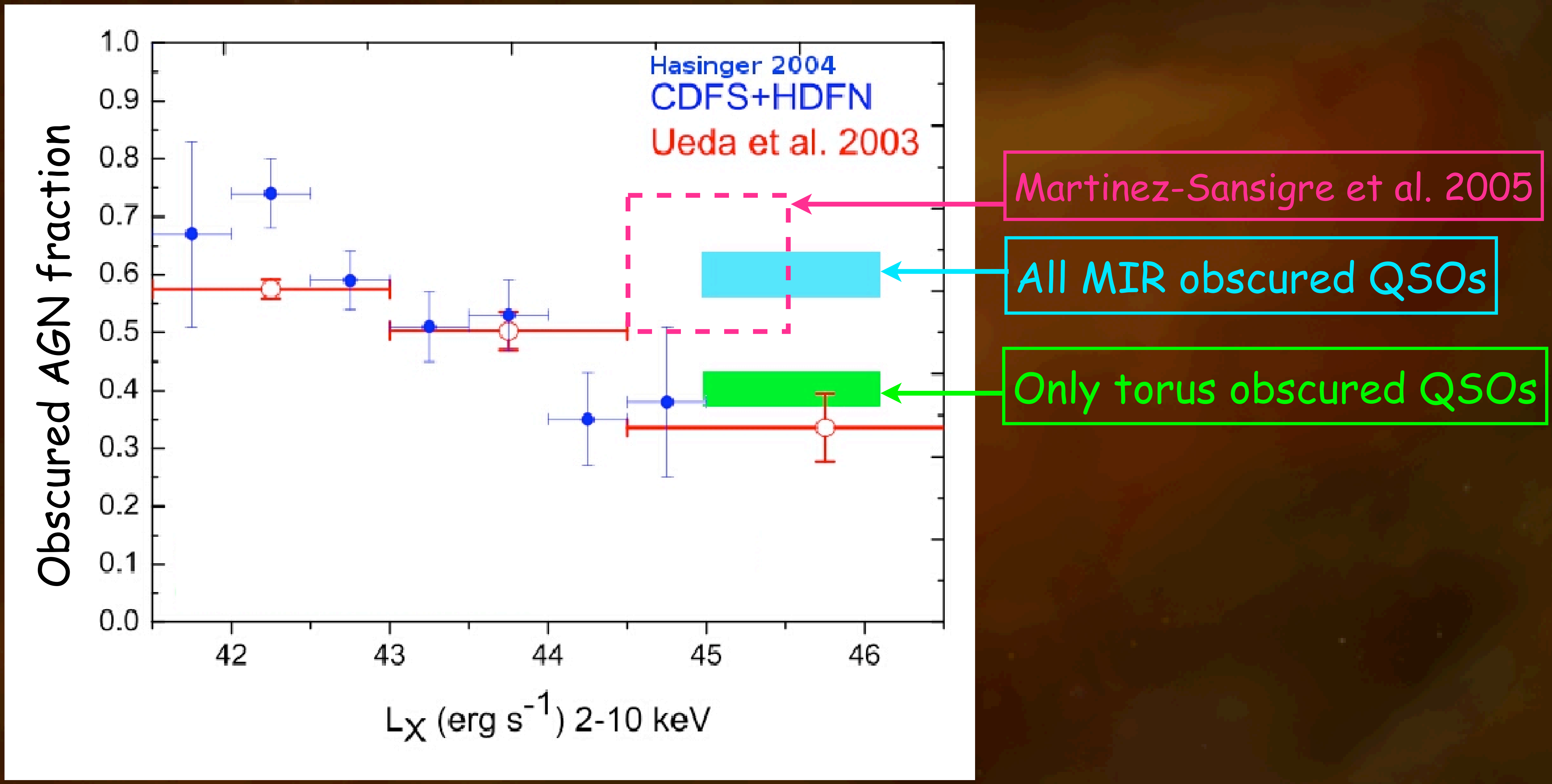


Image by NASA/CXC/M. Weiss

MIR obscured AGN fraction

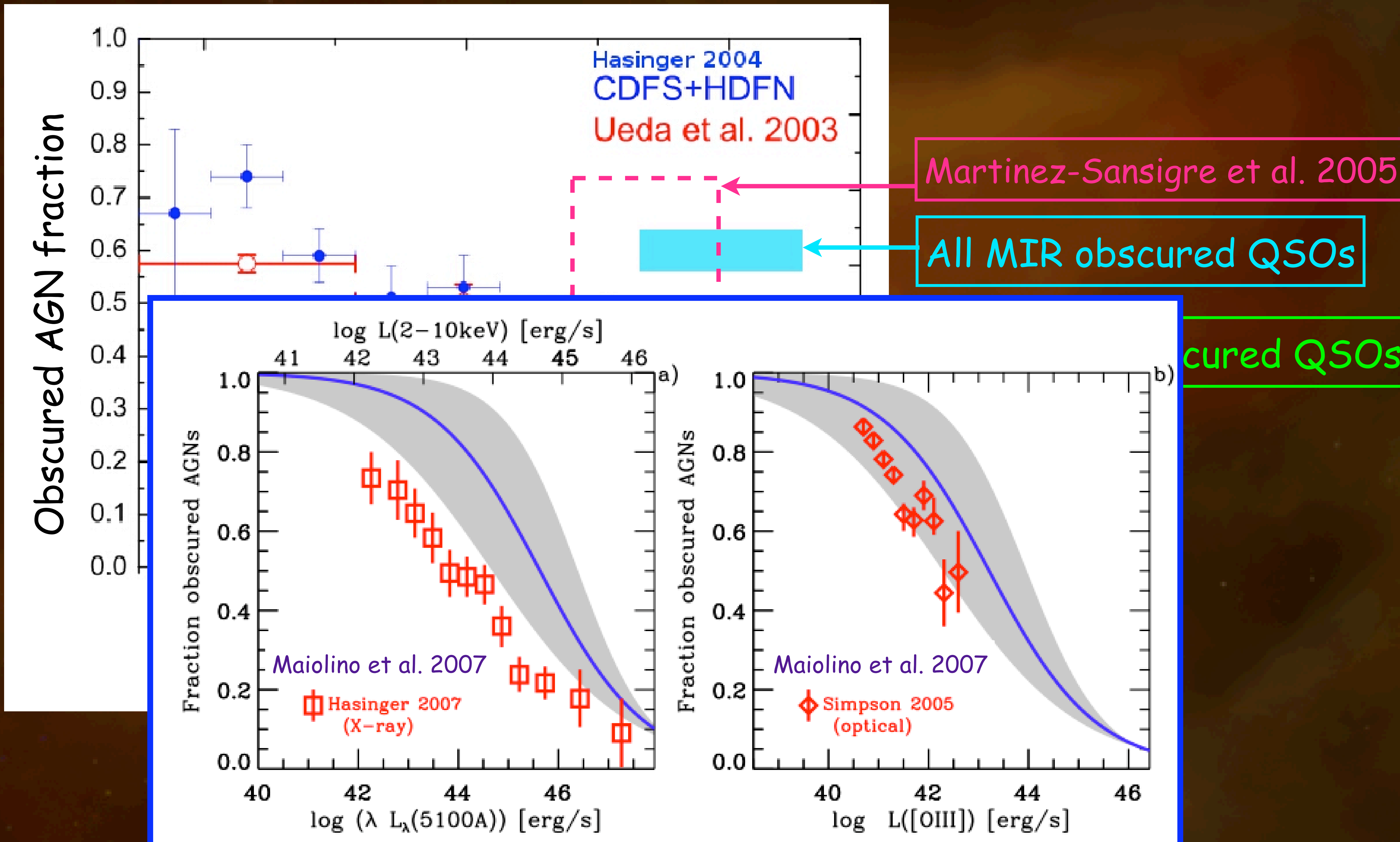
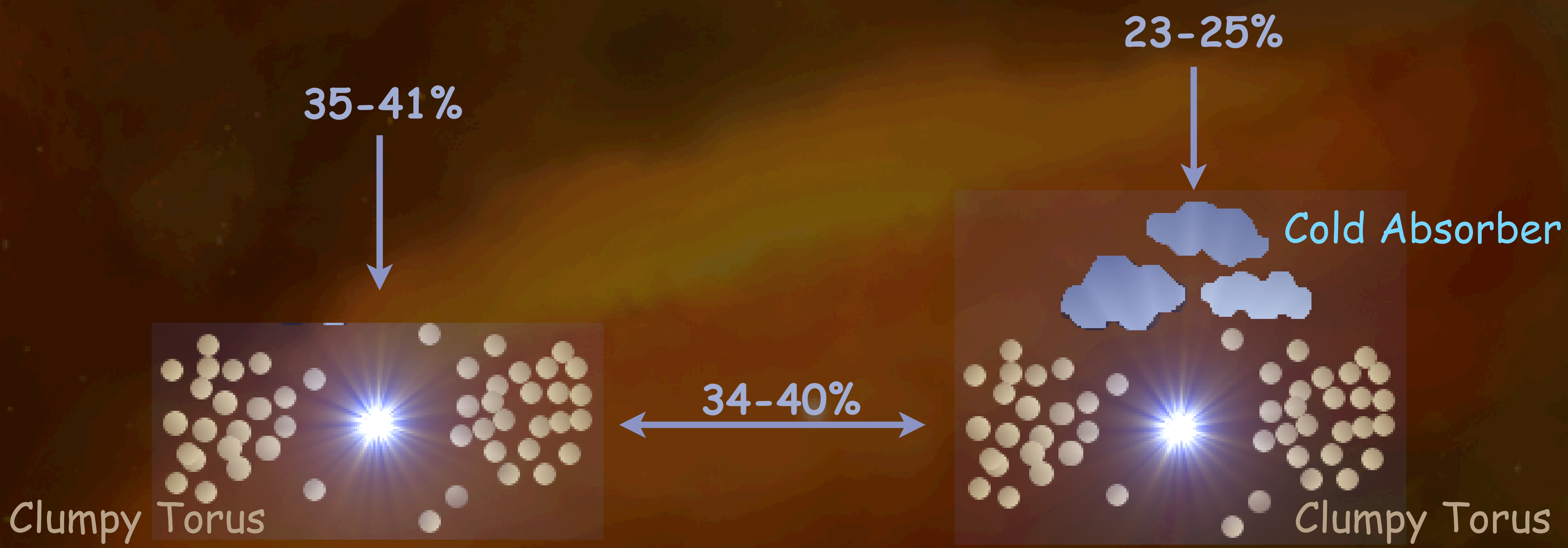


Image by NASA/CXC/M. Weiss

Possible obscuration scenario



➪ The torus covering fraction is ~34-40%

and

the torus half opening angle is ~ 67°

For local Seyfert galaxies: 46° (Schmitt et al. 2001)

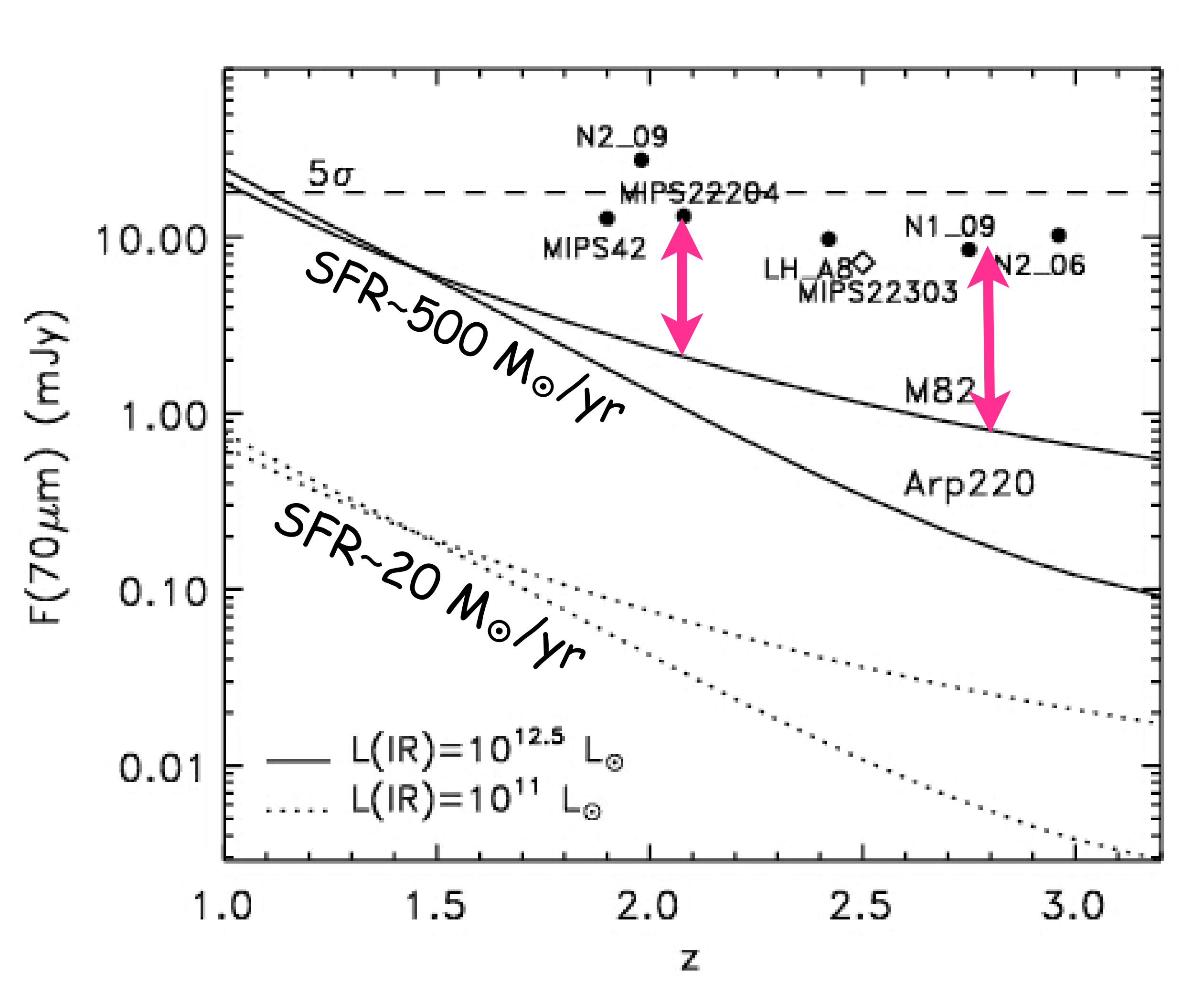
⇩

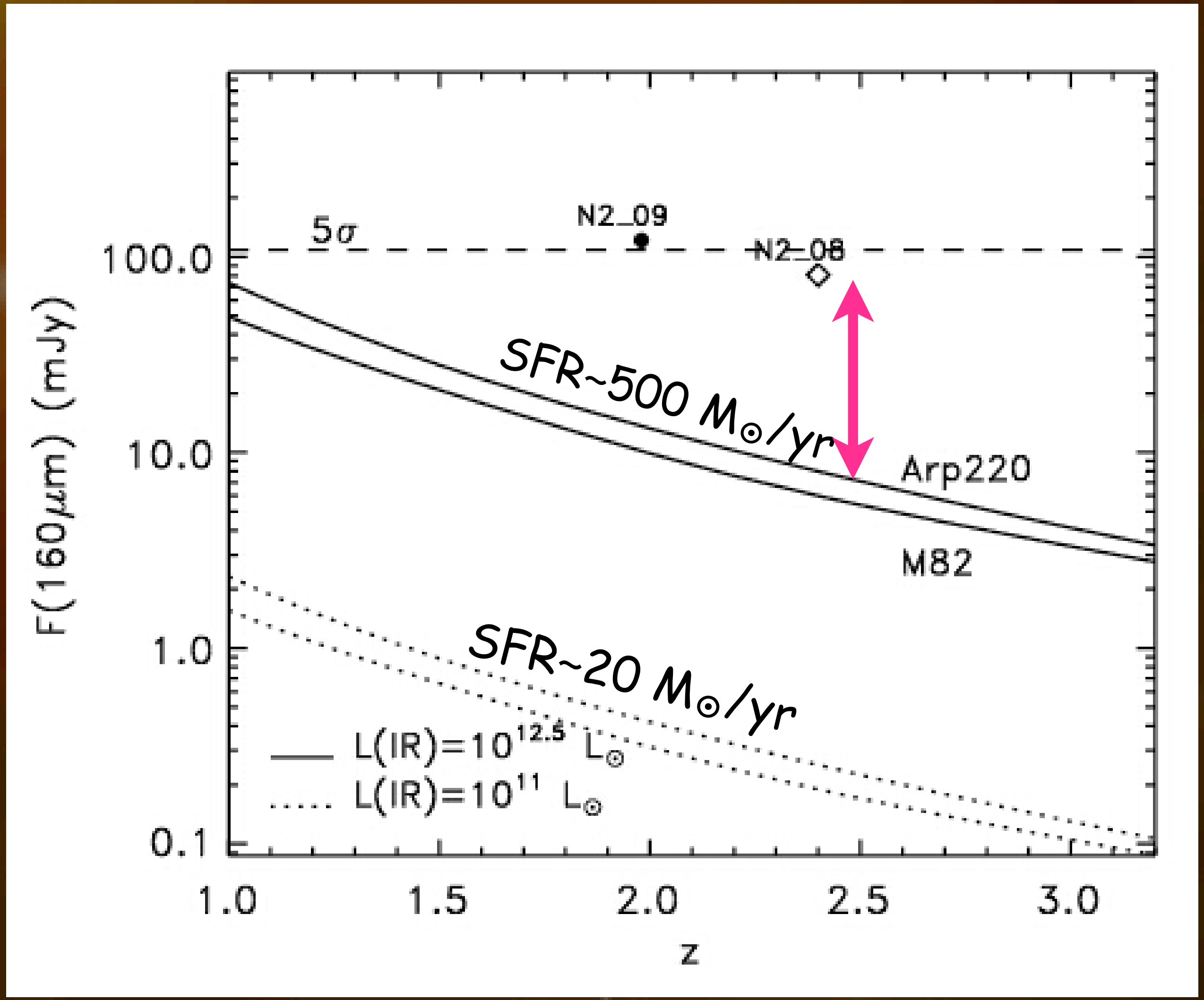
Evidence for receding torus

Is there evidence for 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

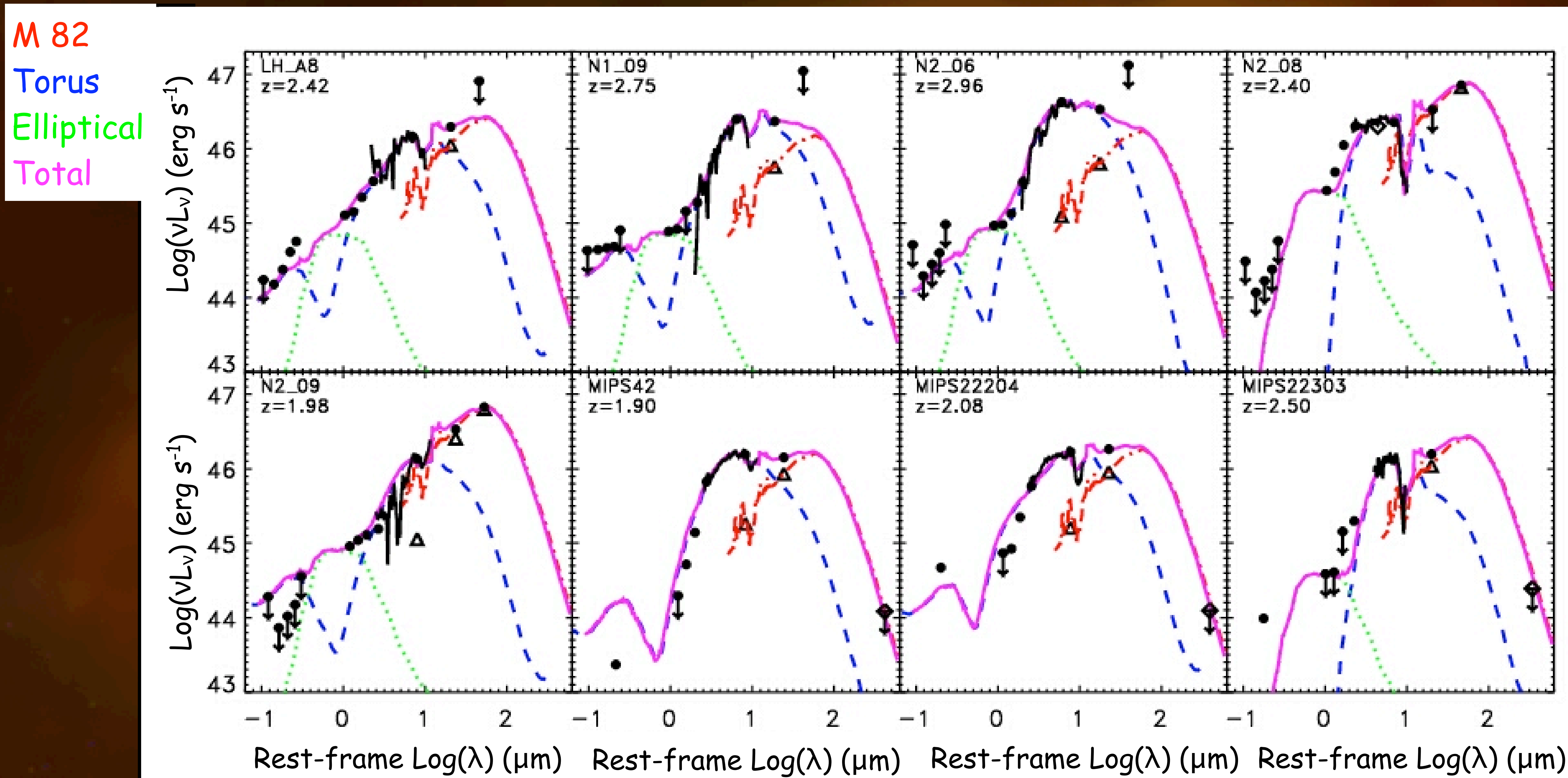




Origin of the far-infrared emission

8 sources detected in the far-IR:

2: far-IR ~ torus model & 6: far-IR > torus model



Starburst with L(FIR) ~ $10^{12.5-13.2}$ $L_\odot$ ⇨ SFR ~ 600-3000 $M_\odot$/yr ?

Image by NASA/CXC/M. Weiss

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} !

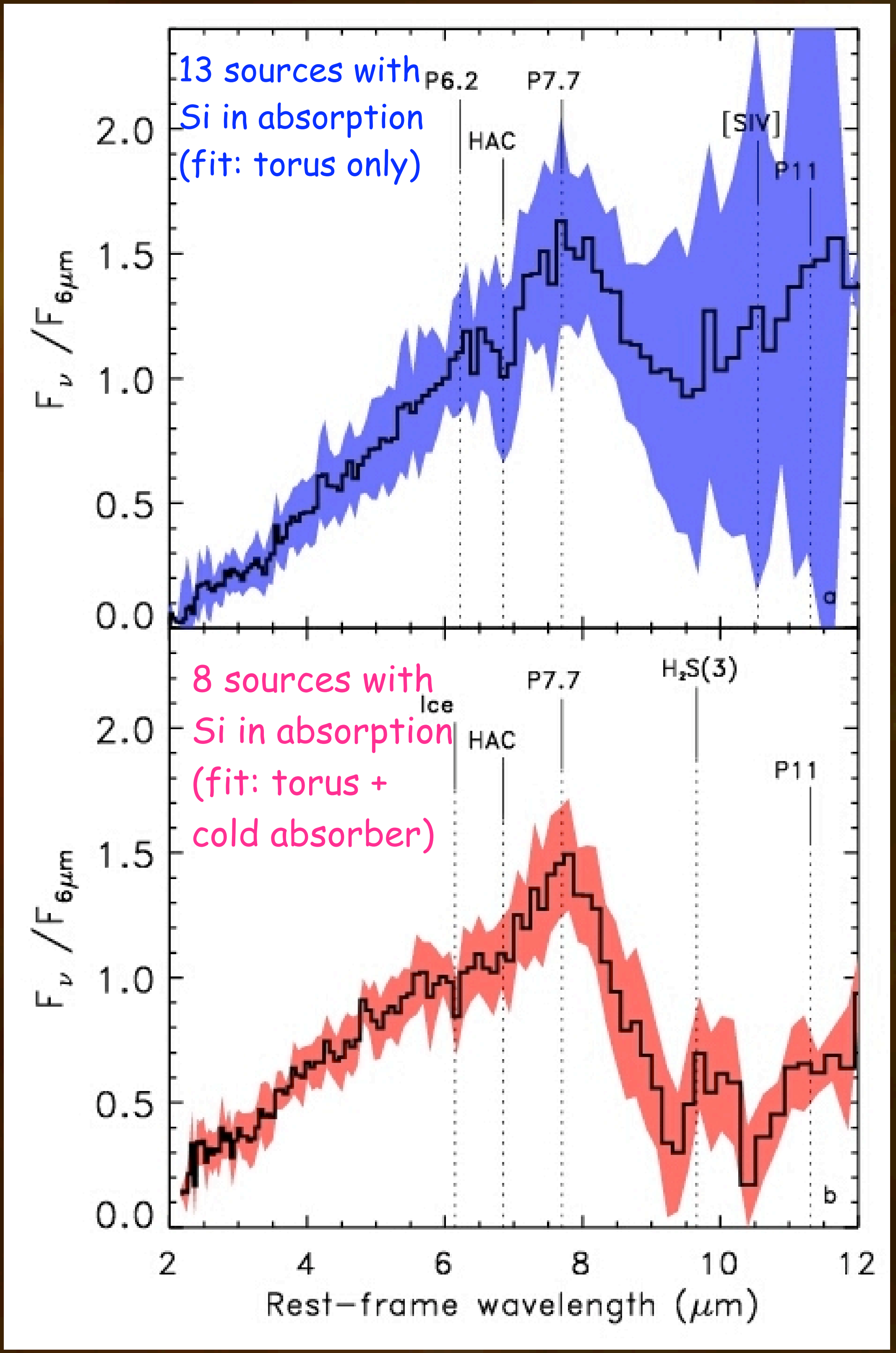


Image credit: NASA/CXC/M. Weiss

The Herschel perspective

- Characterize far-IR emission

  ➪ cold dust, star formation rate, bolometric luminosity, starburst contribution

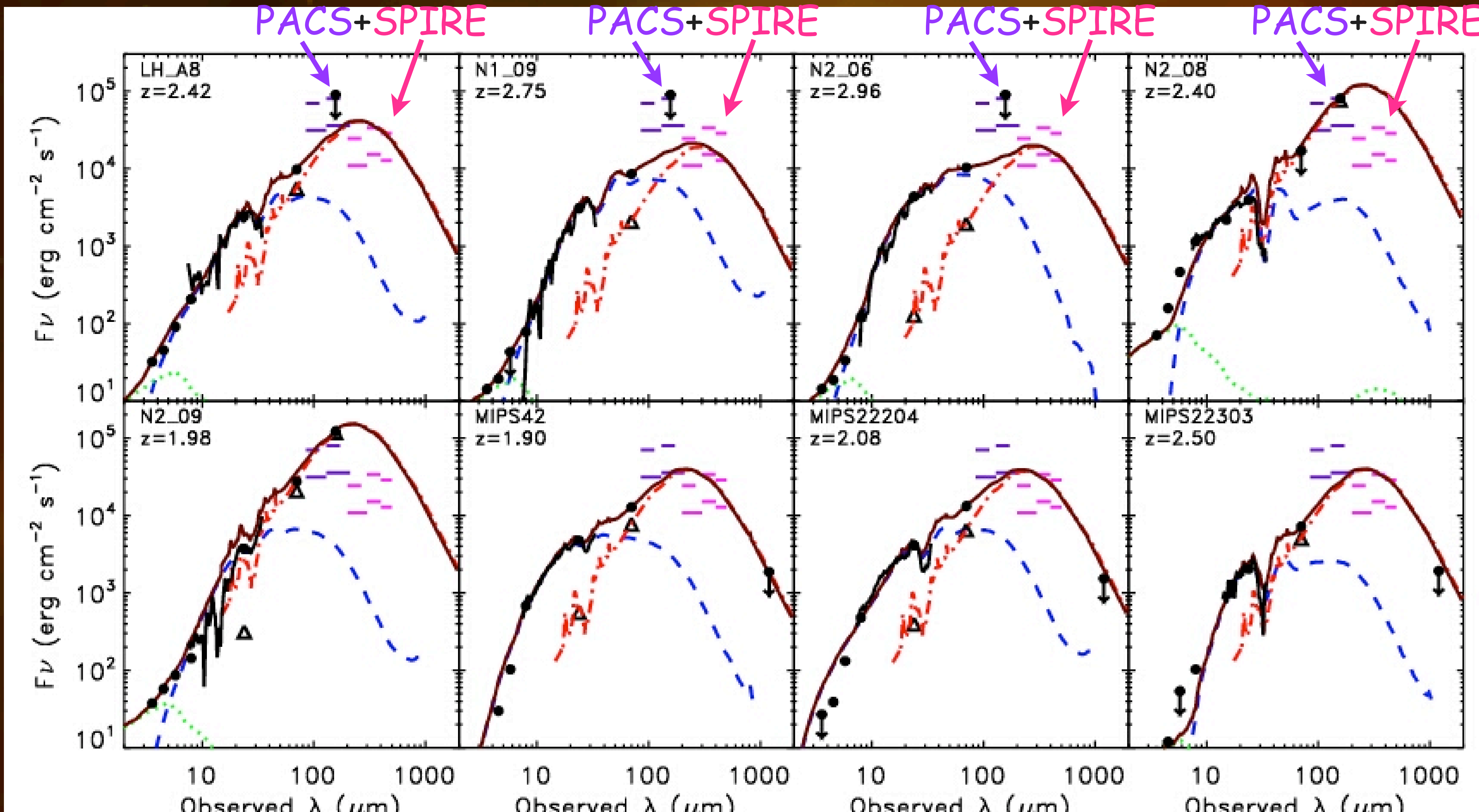
- FIR vs type, L, & obscuration to test unification model at high-z and L, and AGN evolutionary model

- Accretion contribution to the CIRB ?

	Instrument	PACS			SPIRE		
	λ (μm)	70 (Spitzer)	110	170	250	350	500
Level-6	SWIRE 5σ (mJy) (6 fields: 50 deg^2)	18	70	80	24	34	29
Level-5	SWIRE 5σ (mJy) (3 fields: 22 deg^2)	18	31	36	11	15	13

Herschel GT programs detection of high-z obscured QSOs

All will be detected by SPIRE in the Level 5 surveys
SPIRE [350μm] detection rate: 60% (L6), 100% (L5)



OATS-DAUT, 19 Dec 2007

Image credit: NASA/CXC/M. Weiss

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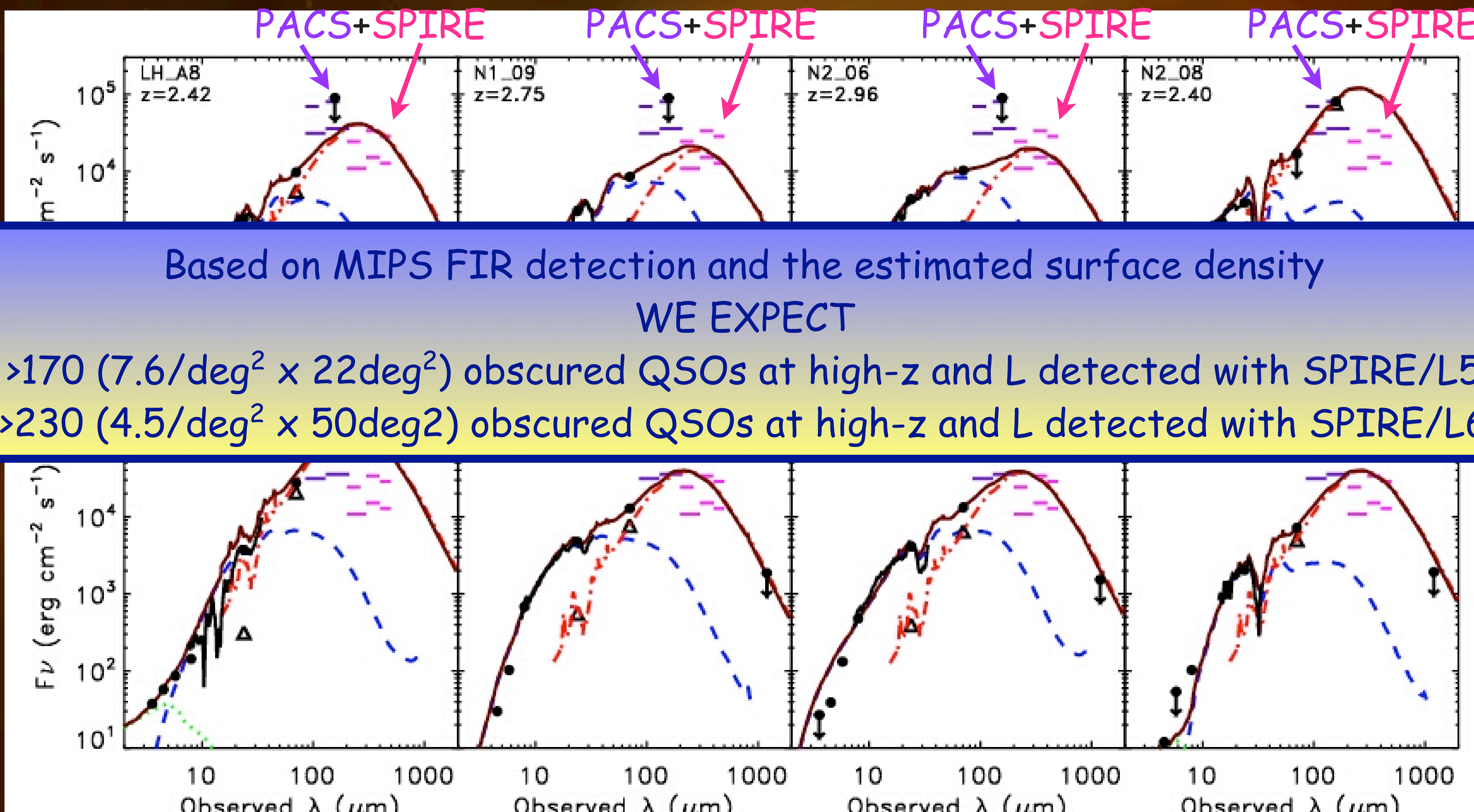

Based on MIPS FIR detection and the estimated surface density
WE EXPECT
>170 (7.6/deg^2 x 22deg^2) obscured QSOs at high-z and L detected with SPIRE/L5
>230 (4.5/deg^2 x 50deg2) obscured QSOs at high-z and L detected with SPIRE/L6

Summary

- AGN selection: A single band selection identifies only a small fraction of all AGNs, e.g. a radio, IR & X-ray selection yields 55% of all AGNs in the X-rays, 17% in the radio and 37% in the IR.
- AGN SEDs: The majority (~55%) of all identified AGN shows AGN2 SEDs, 19% AGN1 SEDs and 26% are characterized by normal galaxy SEDs (ellipticals, spirals or starbursts).
- Missing AGN: they look like AGN2 or star-forming galaxies with absorbed X-ray spectra
- Using mid-IR data we selected a sample of luminous & obscured QSOs
- Clumpy torus models well reproduce their observed IR SEDs and Silicates feature. Sources with NIR excess & deep Si absorption feature require a cold absorber.
- Obscured : unobscured QSOs = 1.4-1.9 :1, but half of the obscured QSOs are not obscured by the torus. ⇨ Evidence for larger torus opening angle at high luminosities and for receding torus.
- Some obscured QSOs show extreme FIR luminosity, consistent with Hyper-Luminous Starbursts (SFR~600-3000$M_\odot$/yr). On average a starburst with SFR~300$M_\odot$/yr could be present and contribute to <26% of the AGN bolometric luminosity.

Conclusions

⇨ How and where can we find the missing AGN ?

There is evidence for a large fraction of AGNs with star-forming galaxy SEDs, and extremely absorbed X-ray spectra.

⇨ Is the decrease of obscured AGN at high luminosity real or a selection effect ?

Although there are more obscured than unobscured QSOs, there is evidence for a decrease in the torus covering factor.

⇨ Is the AGN evolutionary scenario correct ?

Obscured QSOs hosted by powerful starbursts found by Spitzer might represent the rare phase where the blow-out phase is taking place. More work to be done...

Buone Feste