Demystifying the Diverse IR SEDs of Type-1 AGNs from z~0 to z~6

J. Lyu & G. H. Rieke 2018, ApJ, 866, 92
(arXiv: 1809.03080)

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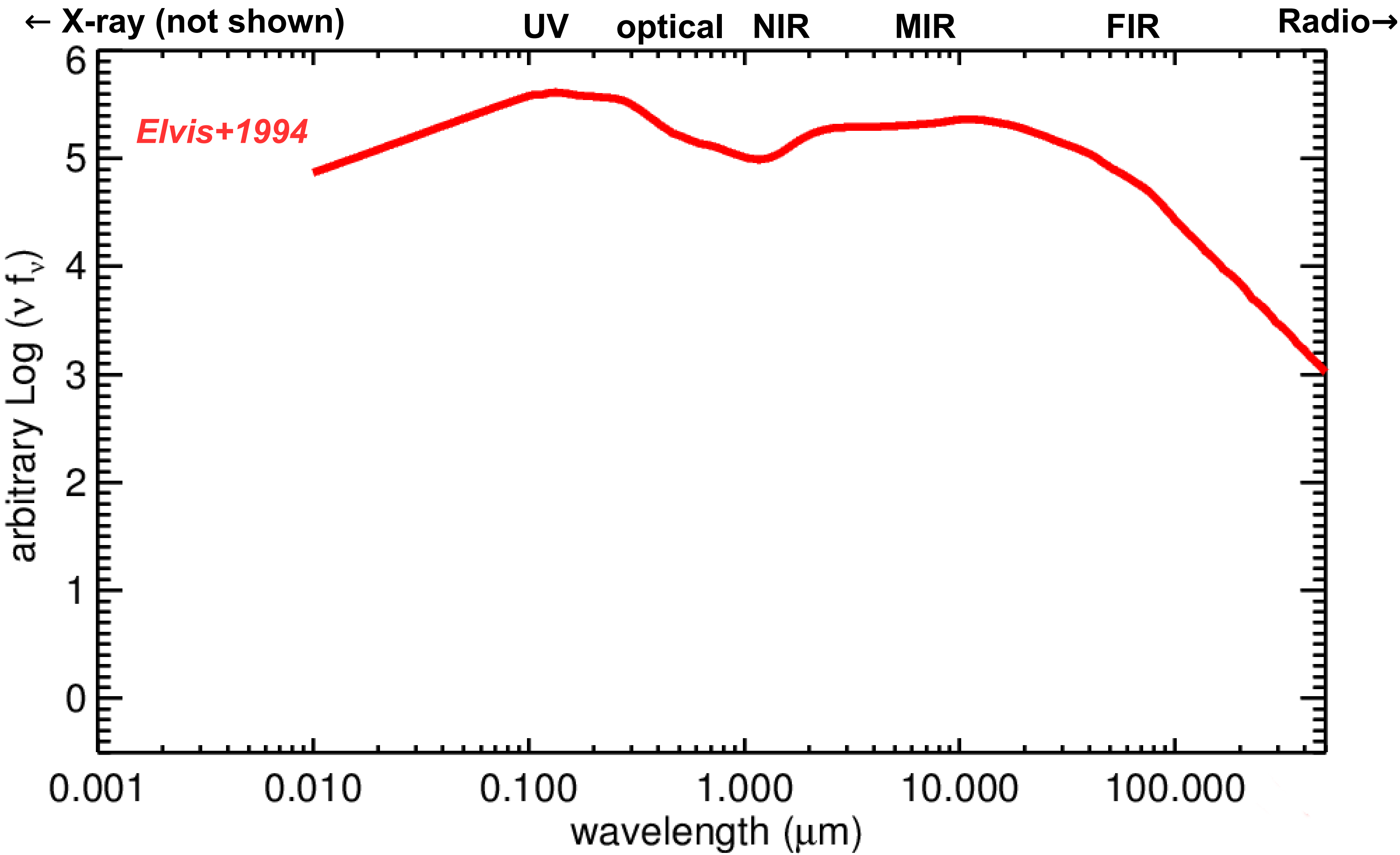
AGN Spectral Energy Distribution (SED)



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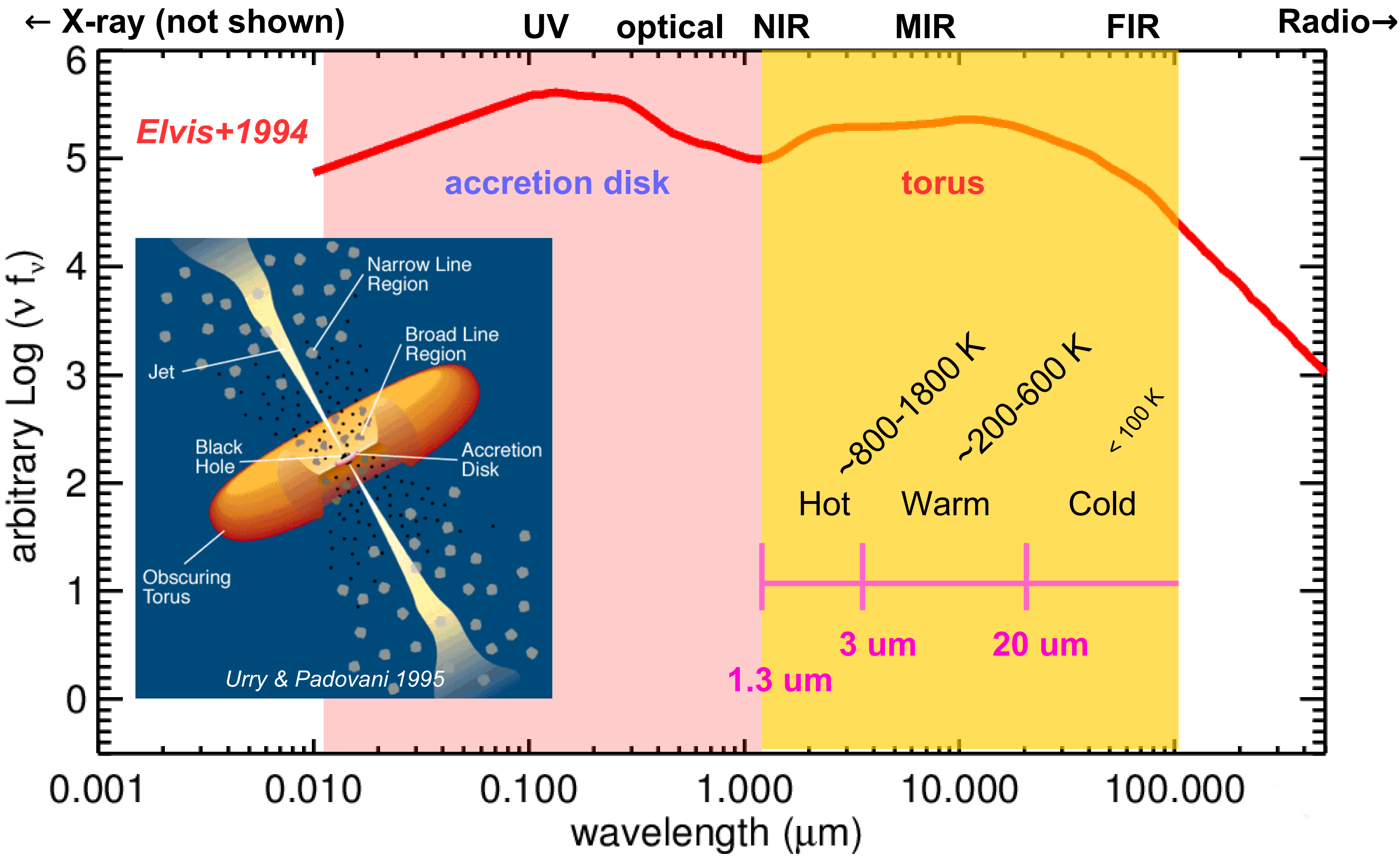
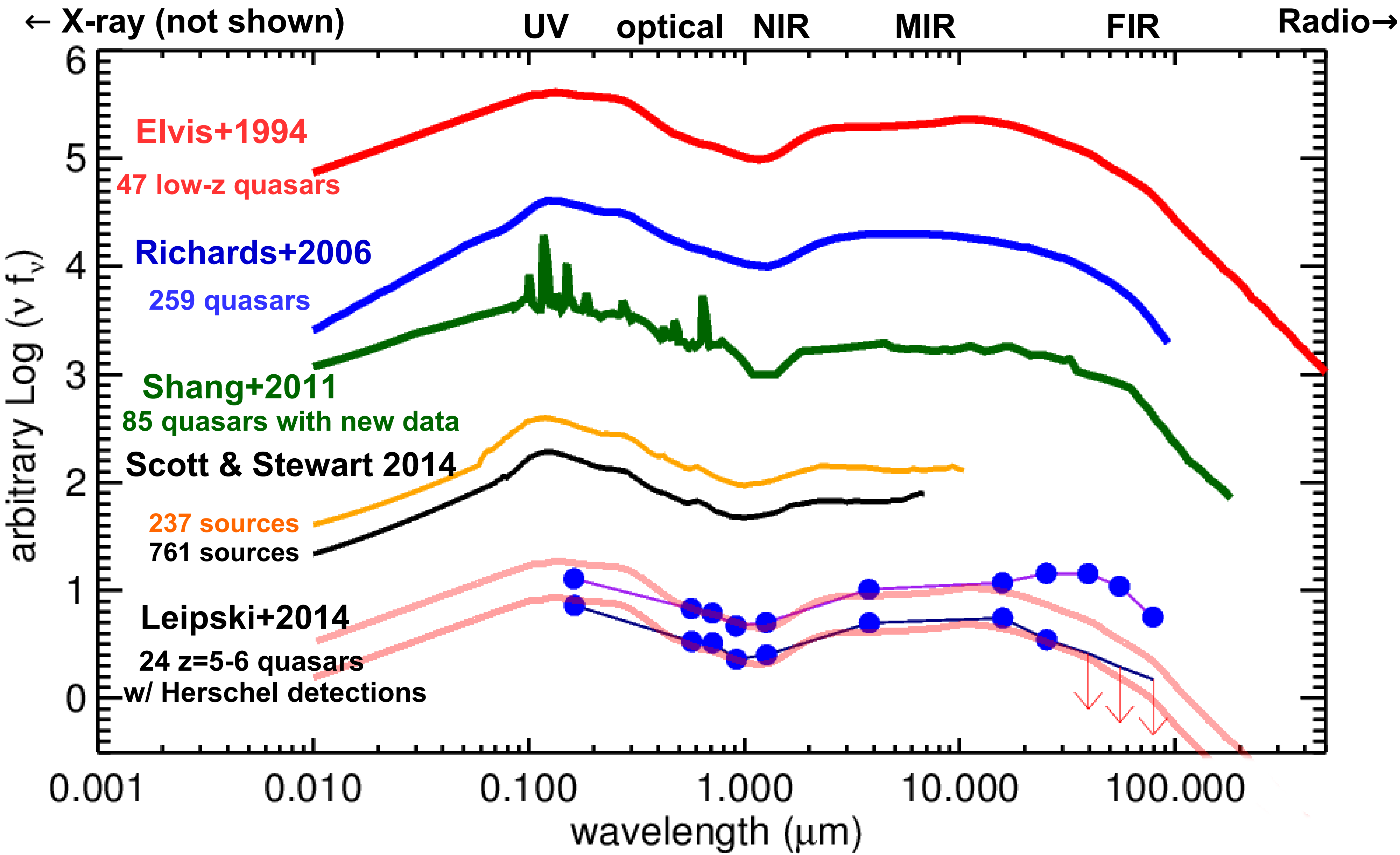
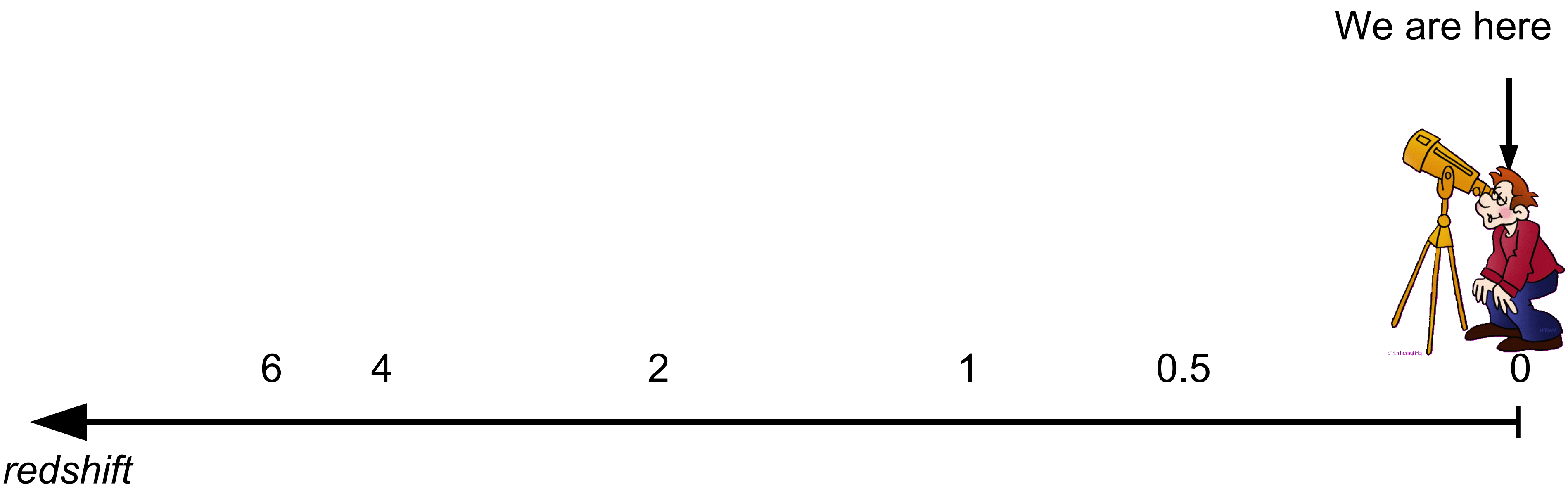
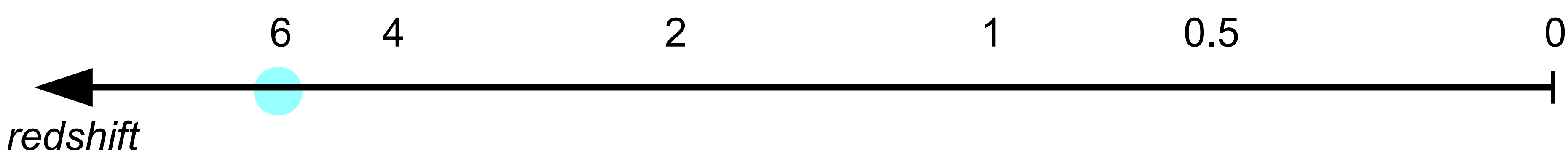


The quasar SED seems universal...



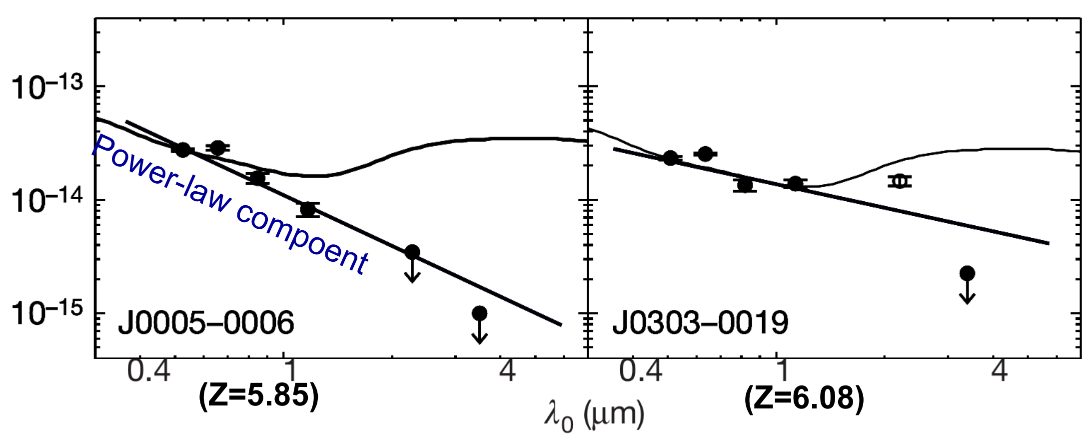


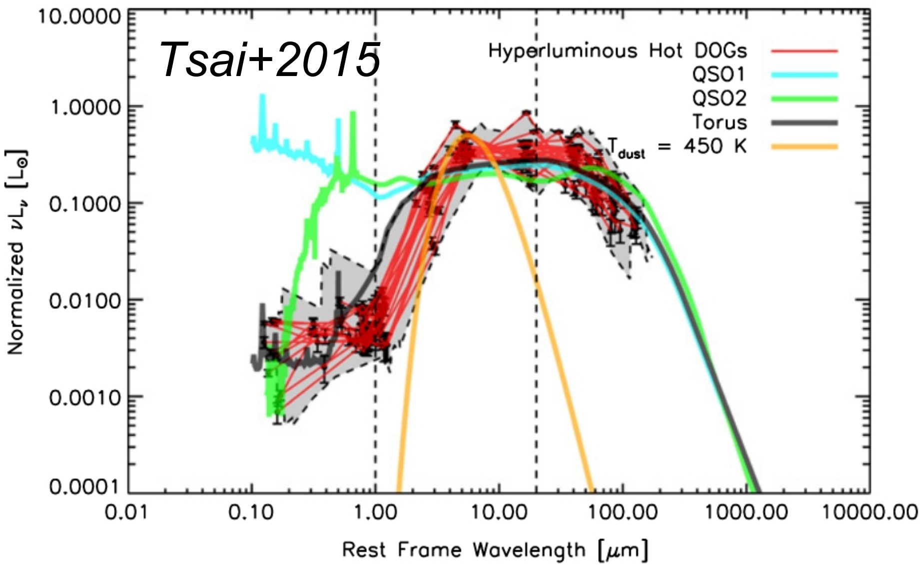
We are here
6
4
2
1
0.5
0
redshift



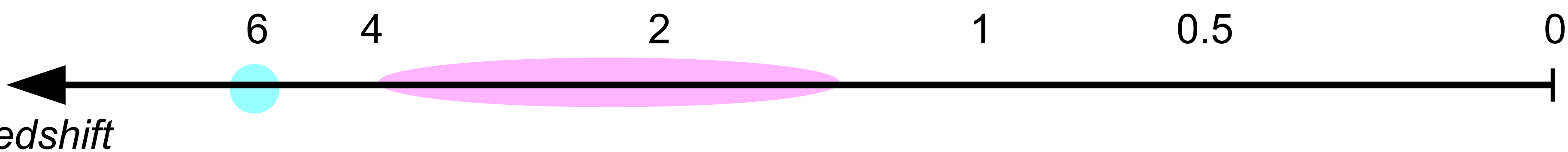
(hot-)dust-free quasars

Jiang+2010





hot-dust-obscured galaxies



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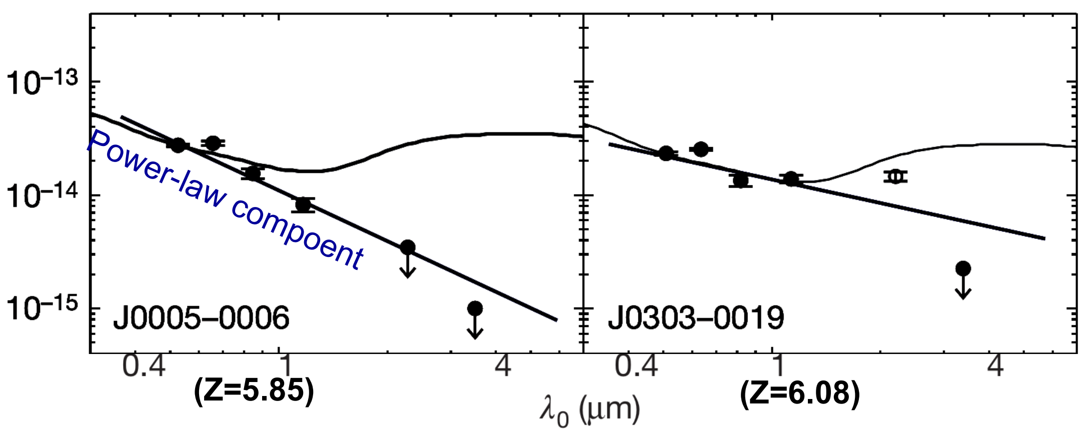

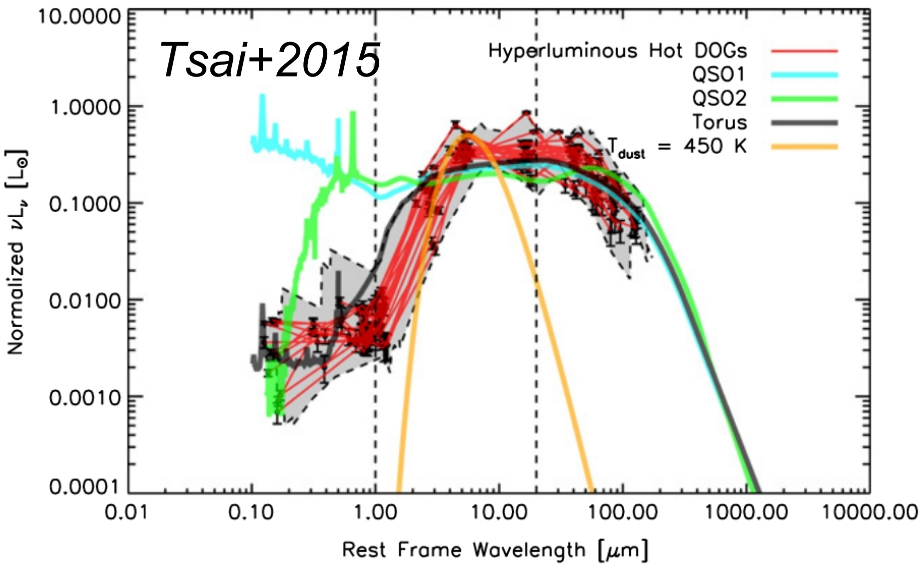

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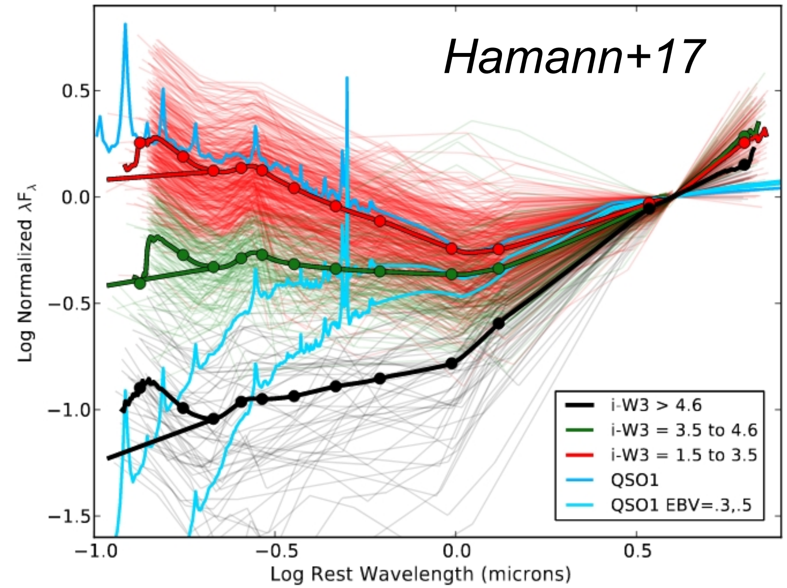
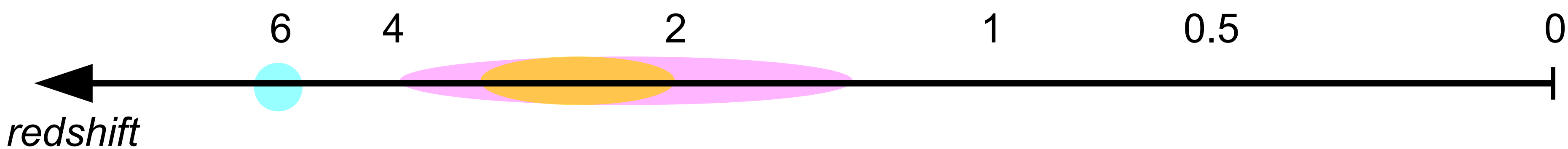


extremely red quasars



(hot-)dust-free quasars

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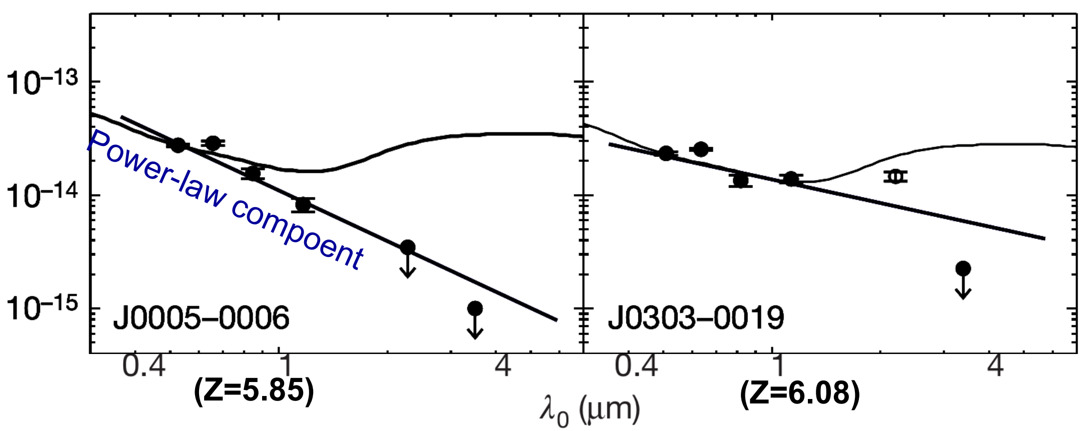
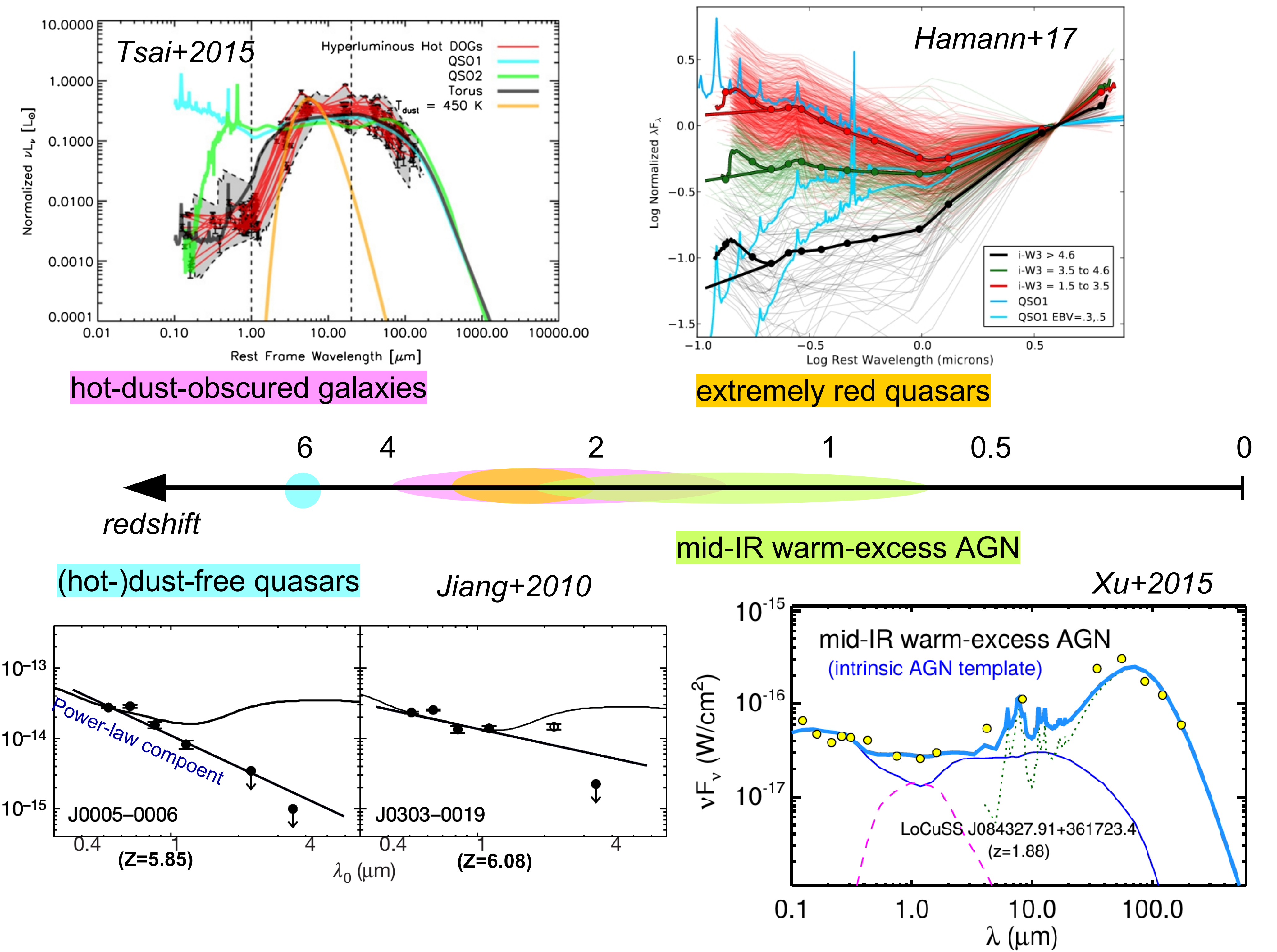
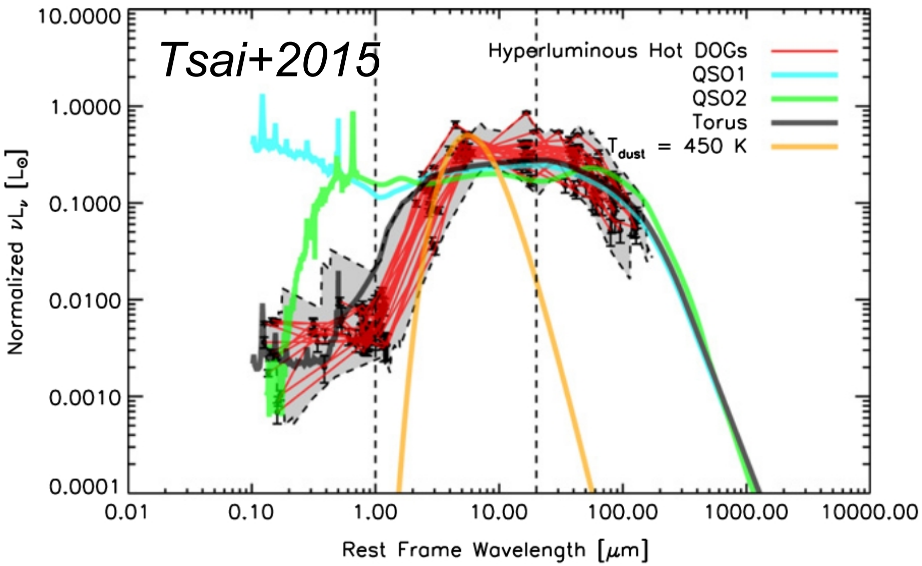
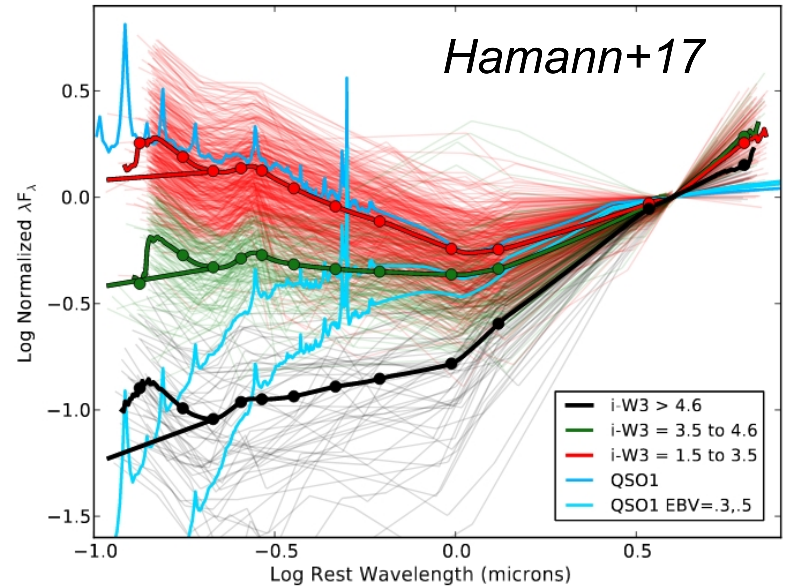



Tsai+2015
Hyperluminous Hot DOGs
QSO1
QSO2
Torus
T_dust = 450 K
Normalized νL_ν [L_⊙]
Rest Frame Wavelength [μm]
hot-dust-obscured galaxies
Hamann+17
Log Normalized λF_λ
Log Rest Wavelength (microns)
i-W3 > 4.6
i-W3 = 3.5 to 4.6
i-W3 = 1.5 to 3.5
QSO1
QSO1 EBV=.3,.5
extremely red quasars
6
4
2
1
0.5
0
redshift
mid-IR warm-excess AGN
(hot-)dust-free quasars
Jiang+2010
Power-law compoent
J0005–0006
(Z=5.85)
J0303–0019
(Z=6.08)
λ_0 (μm)
Xu+2015
mid-IR warm-excess AGN
(intrinsic AGN template)
νF_ν (W/cm^2)
LoCuSS J084327.91+361723.4
(z=1.88)
λ (μm)



hot-dust-obscured galaxies



extremely red quasars

mid-IR warm-excess AGN

(hot-)dust-free quasars

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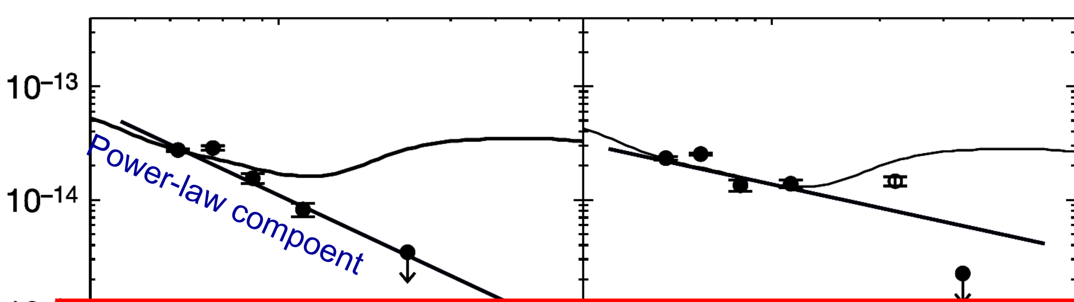
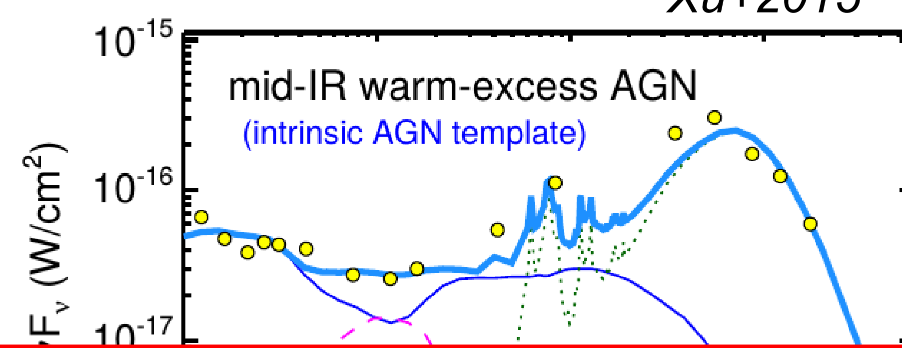


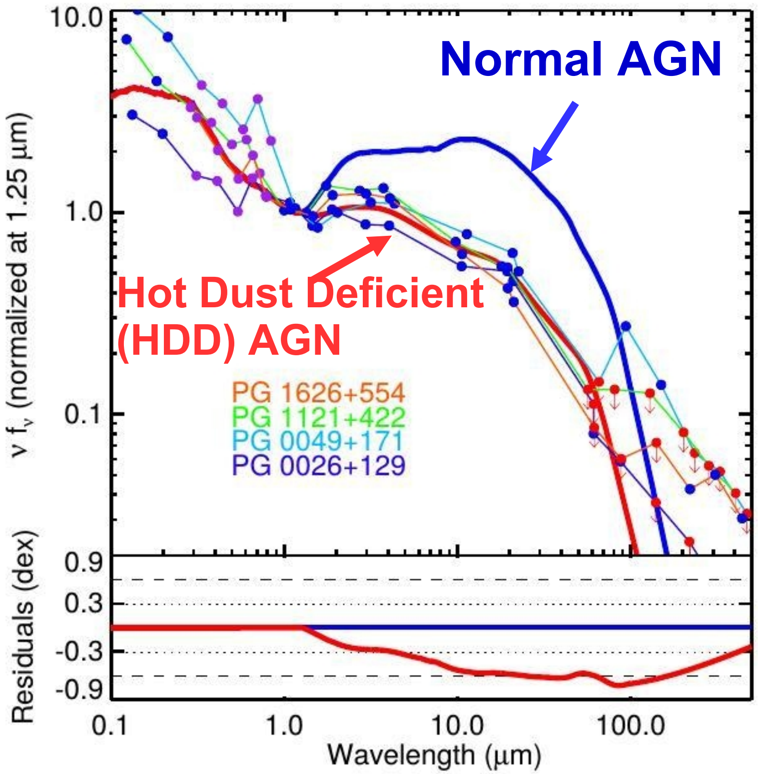
Xu+2015

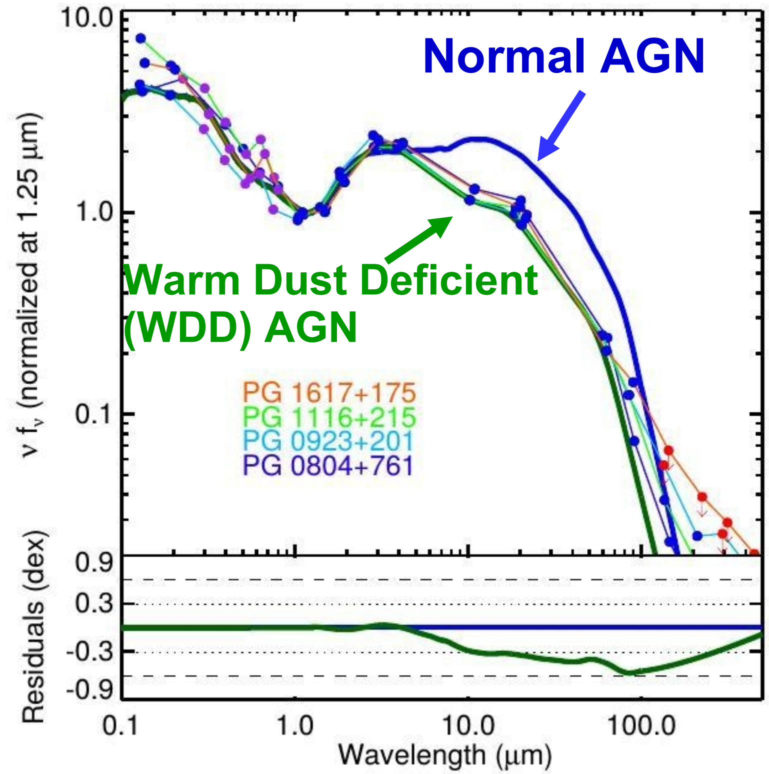


What causes these SED variations?
Peculiar AGNs only at high-z?
Can be reconciled with low-z objects?

What are the ranges of AGN intrinsic IR SED variations?

Two kinds of dust-deficient quasars





	Hot-dust-deficient quasars (lower f_Edd)	Warm-dust-deficient quasars (higher L_AGN)
Z<0.5 PG sample	**~17-22 %**	**~14-17%**
Z~0.5-2.5 LoCuSS sample	**~4%**	**~2%**
Z~5-6.5 Leipski sample	**~16%**	**>14%~50%**

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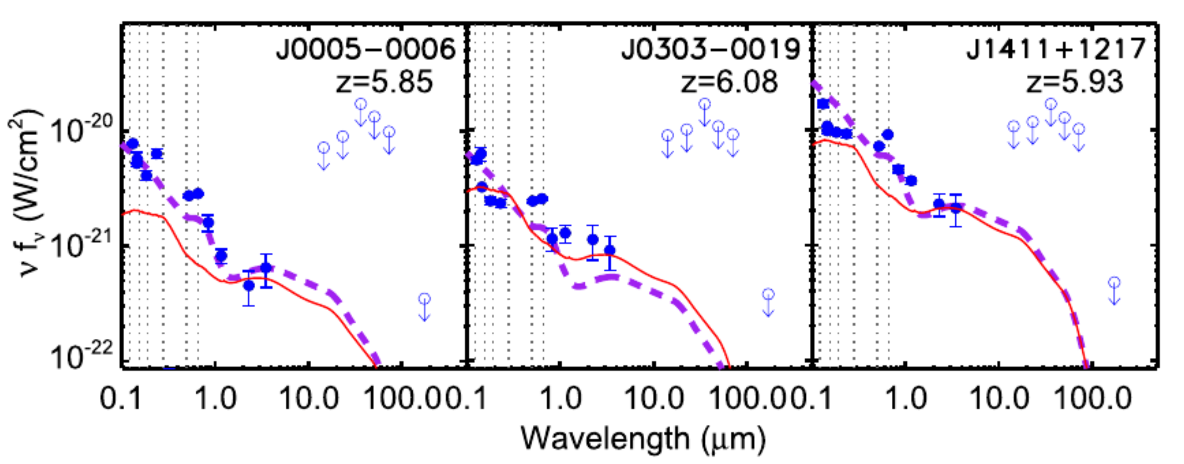
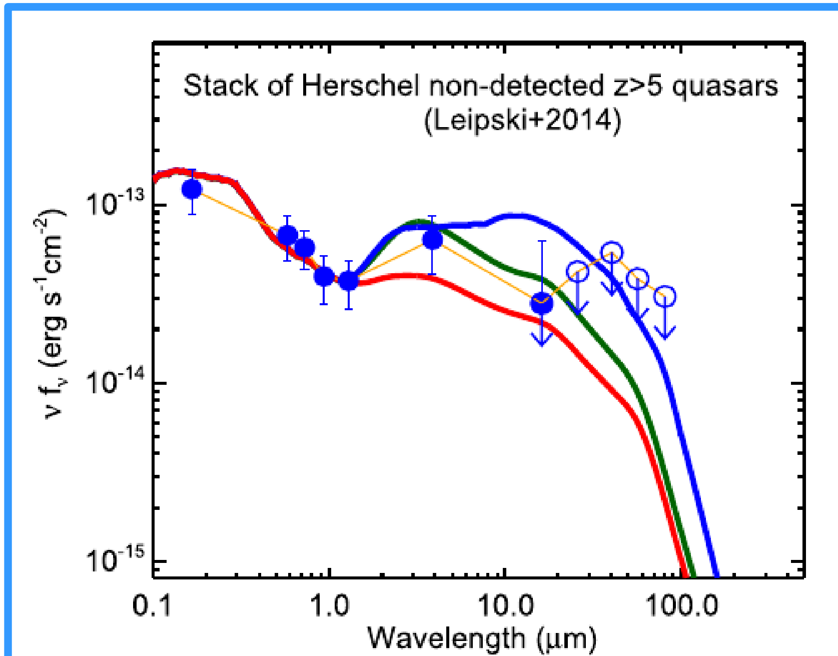
Dust-deficient quasars at z>5



HDD template
PG 0049+171
(the most HDD case in the PG sample)

SEDs of the so-called "dust-free" quasars

Stacked SED of
Herschel non-detected quasars



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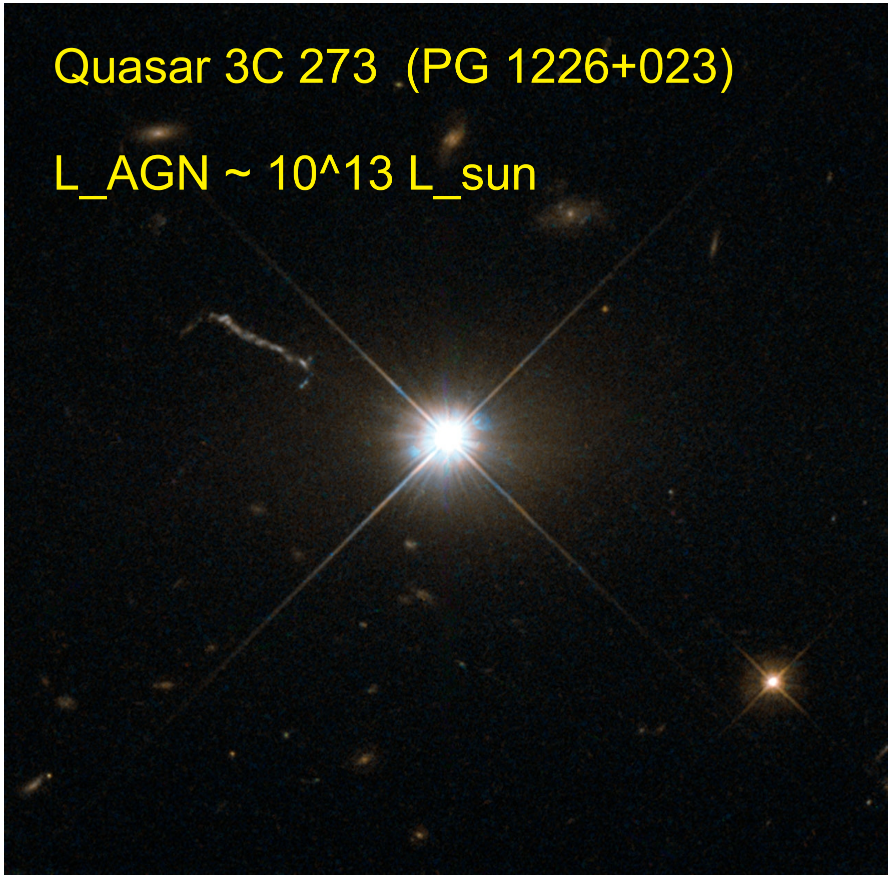
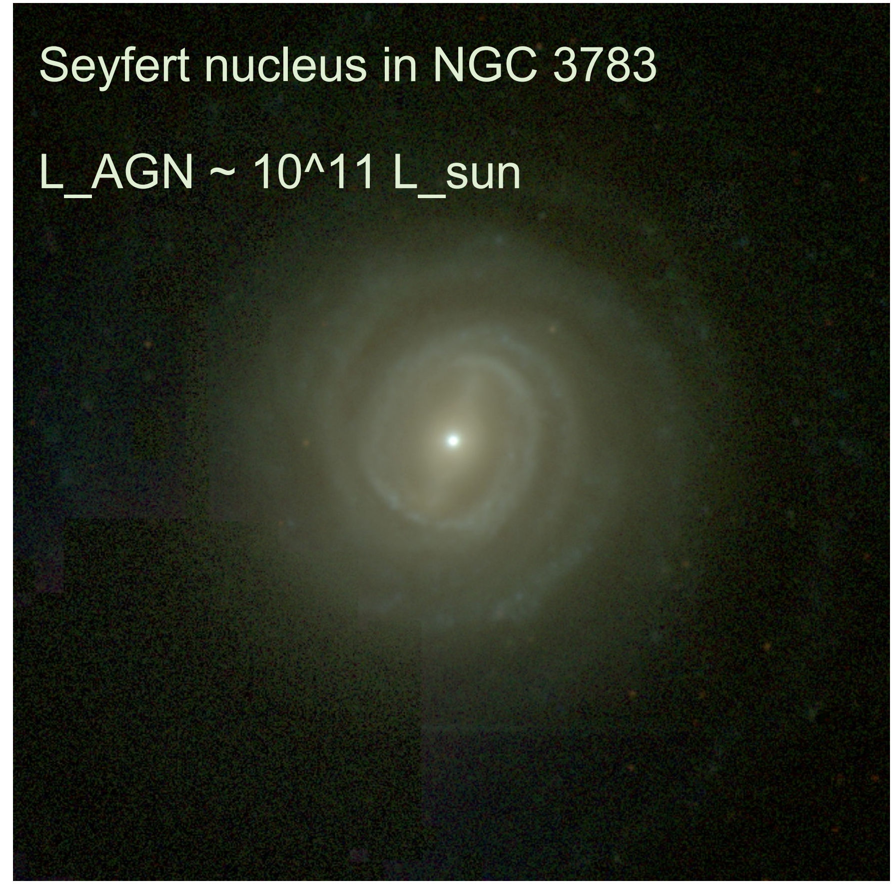


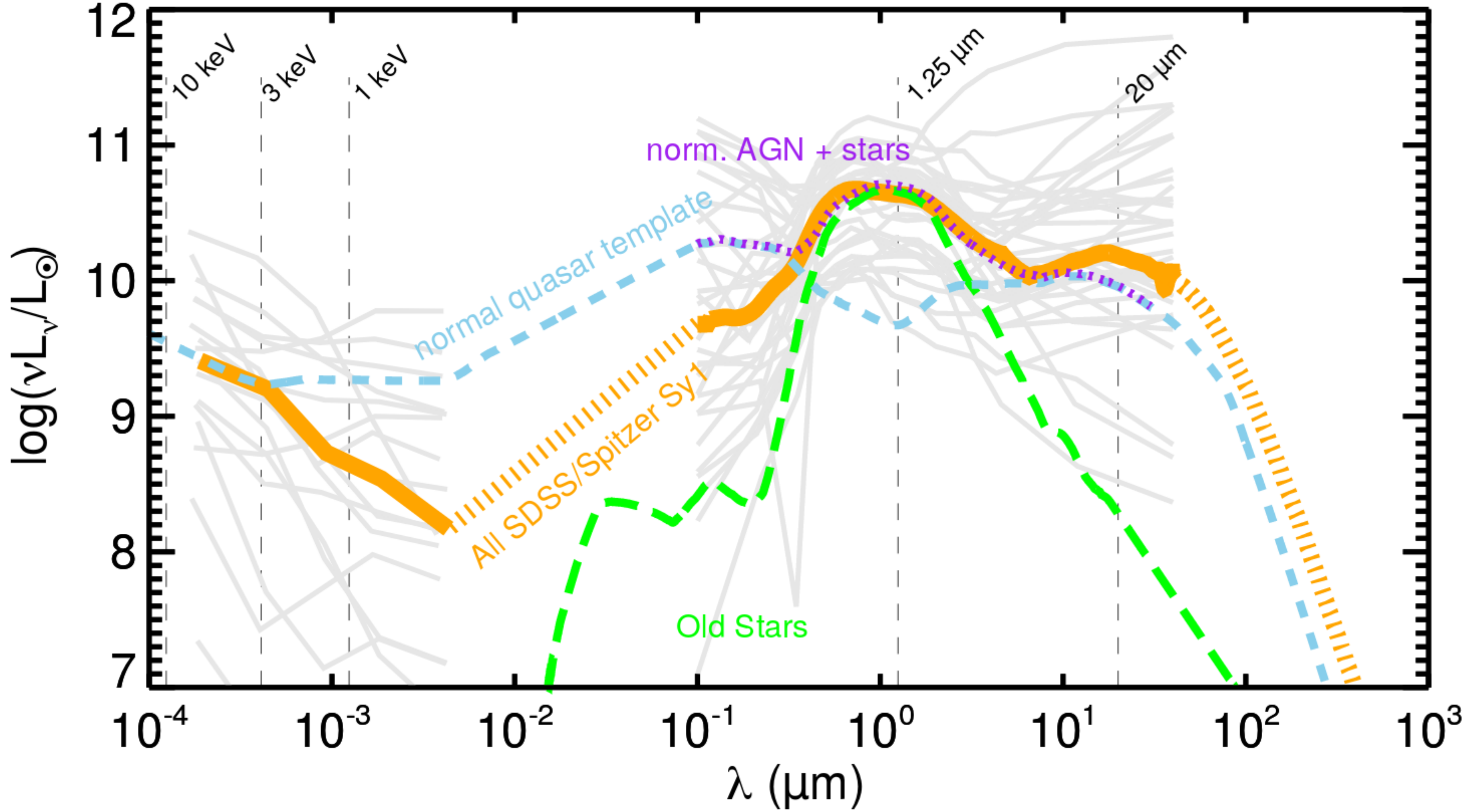


What about Seyfert nuclei?

aka, relatively low-luminosity AGNs with L_AGN ~ 10^8 – 10^11 L_sun

(for quasars, L_AGN ~ 10^11 – 10^14 L_sun)

Composite SED of Seyfert-1 nuclei



~30 low-z Seyfert-1 nuclei observed by SDSS and Spitzer/IRS without evidence of star-formation in the mid-IR.
Photometry data are compiled from XMM-newton/Chandra, GALEX, SDSS, 2MASS, WISE, Spitzer/IRS

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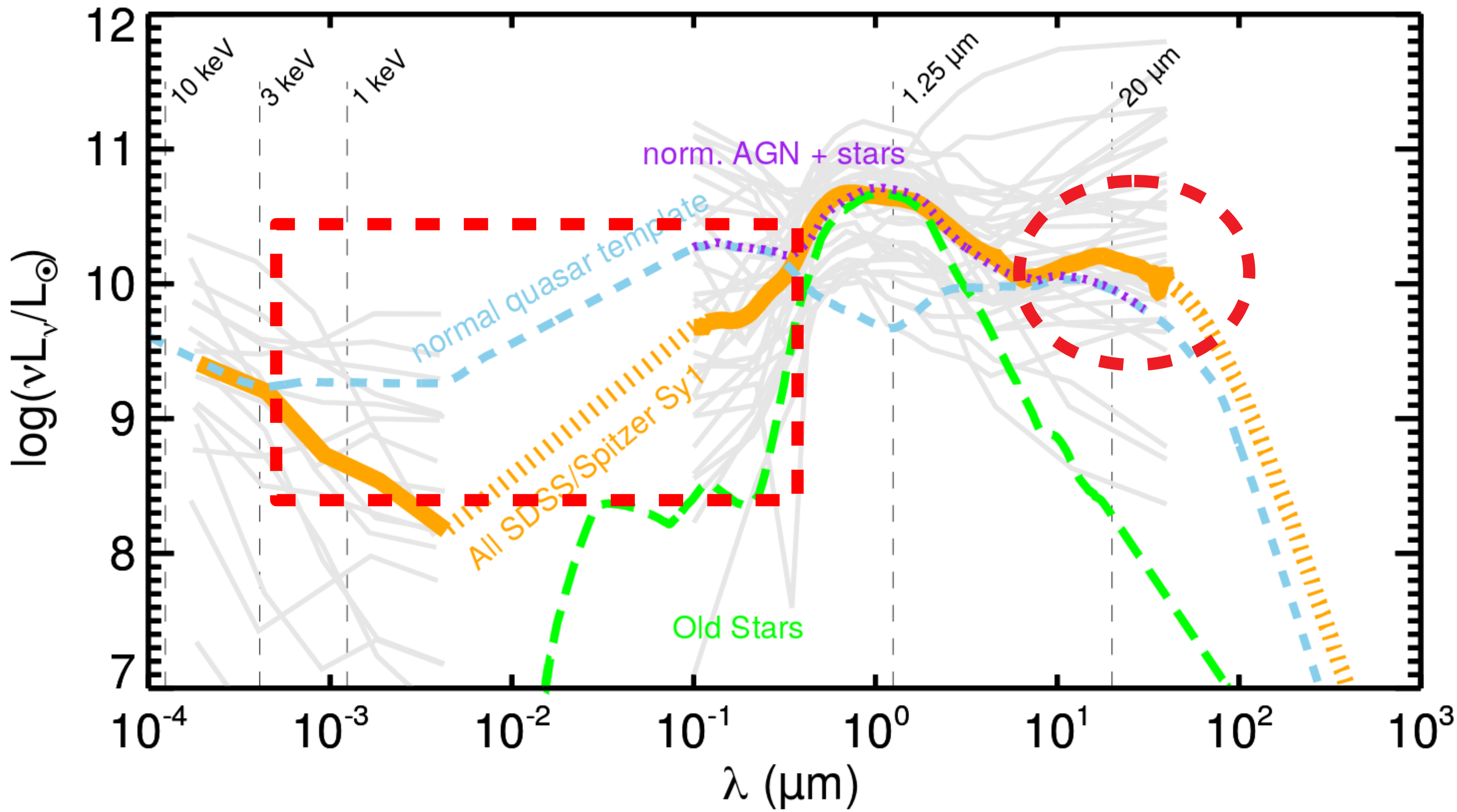

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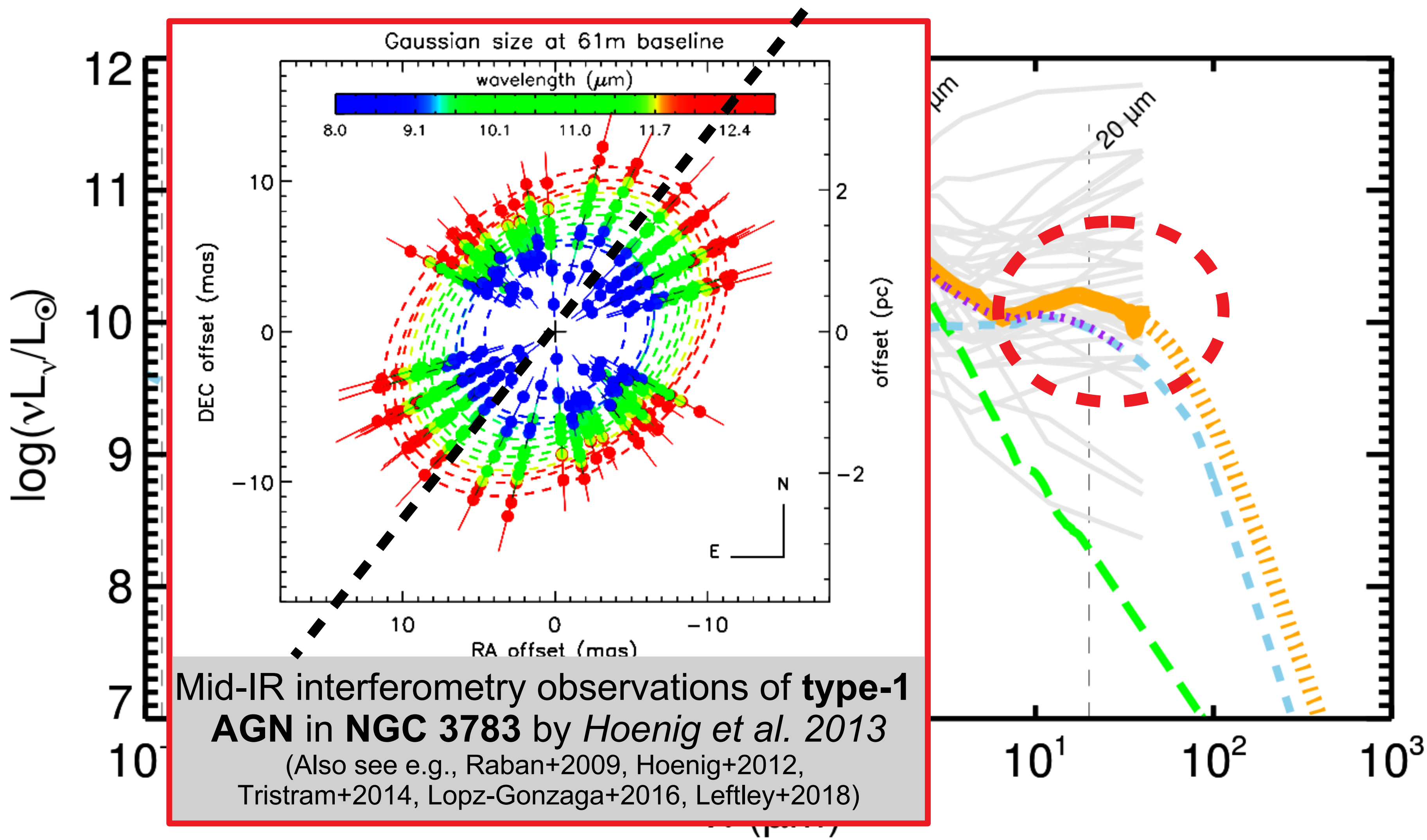

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Let's build an reddened type-1 AGN model...

- Accretion disk + torus (a face-on viewpoint)
  - described by intrinsic AGN templates:

    Normal, WDD, HDD from Lyu et al. 2017a, b
- **Possible obscuration by an extended dust component**
  - Radial density profile $\rho(r) \propto r^{-\alpha}, \quad r_{\rm in} < r < r_{\rm out}$
  - Classical silicate:graphite mixture with grain size distribution dn/da ~ a^(-3.5) but allowing a_max and a_min to be changed
- **1-D radiation transfer calculations** with the DUSTY (Ivezic et al. 2017) code

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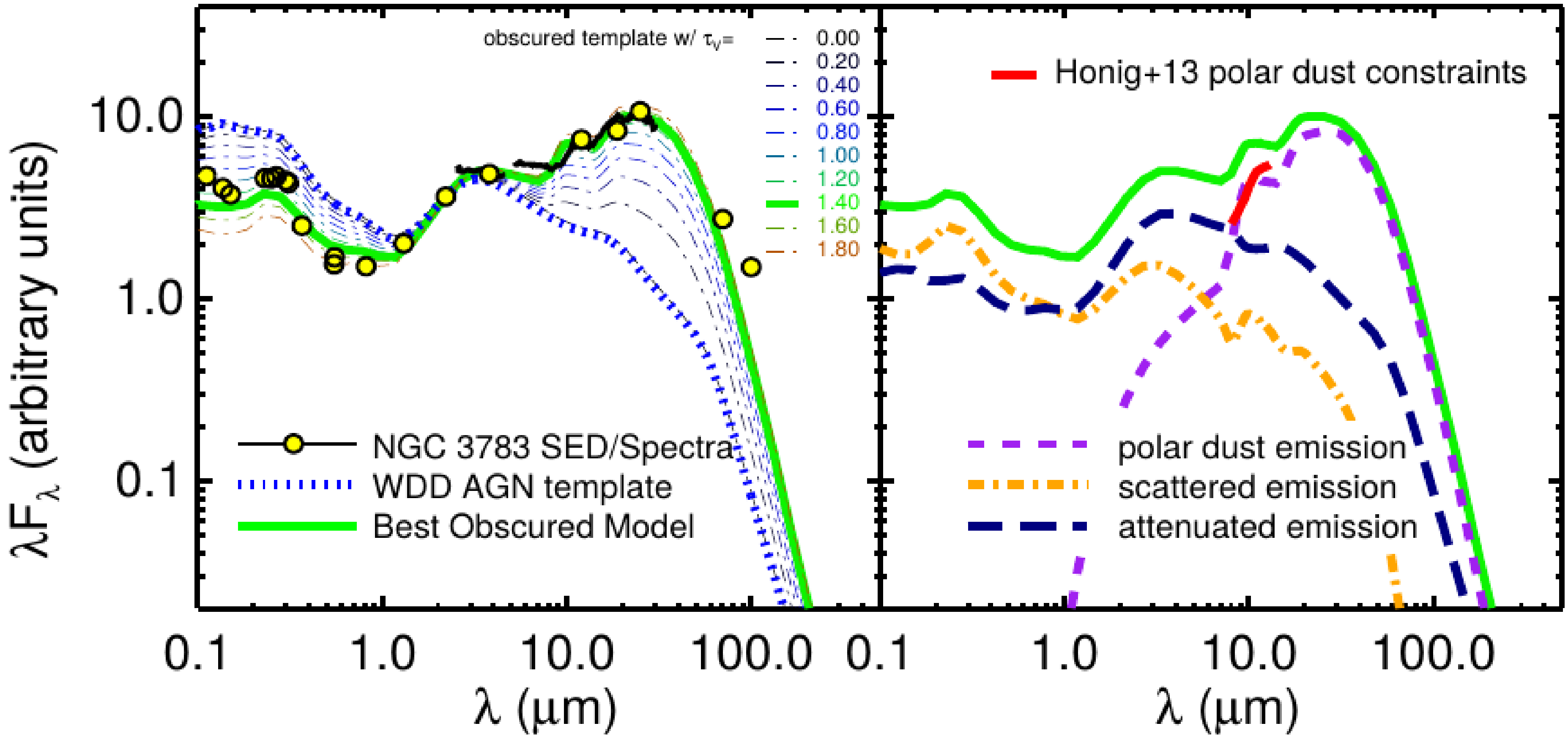
Reproducing the observations of NGC 3783

(the first type-1 AGN with robust polar dust emission constraints)



High-spatial-resolution data adopted from Prieto+2010, Garcia-Gonzalez+2016

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Geometry

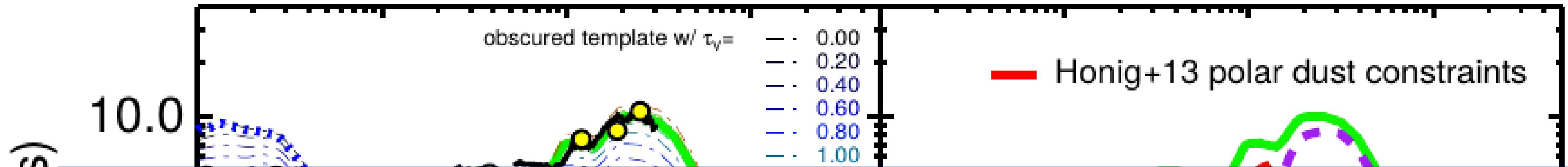
- Density profile: ρ(r) ~ r^{-0.5}
- Outer-to-inner radius r_out/r_in = 500
- Inner Boundary T_in = 1500 K

Grain properties

- Standard ISM mixture (sil:gra=0.53:0.47)
- Standard grain size distribution p=3.5
- Larger size cutoffs a_min = 0.04 um, a_max = 10 um

Reproducing the observations of NGC 3783

(the only type-1 AGN with robust polar dust emission constraints)



Three known type-1 AGNs with the detections of Mid-IR polar dust emission

Name	F(polar)/F(total) at lambda ~ 10 microns	
	from Mid-IR interferometry	from our SED analysis
NGC 3783	~60-80% (Hoenig et al. 2013)	~75%
NGC 4507	~75% (Lopez-Gonzaga et al. 2016)	~78%
ESO 323-77	~35% (Leftley et al. 2018)	~30%

Geo

D

C

Inner Boundary T_in = 1500 K

)

Larger size cutoffs a_min = 0.04 um, a_max = 10 um

The Low-z Seyfert-1 Nuclei

Nearby type-1 AGNs with high-spatial-resolution observations

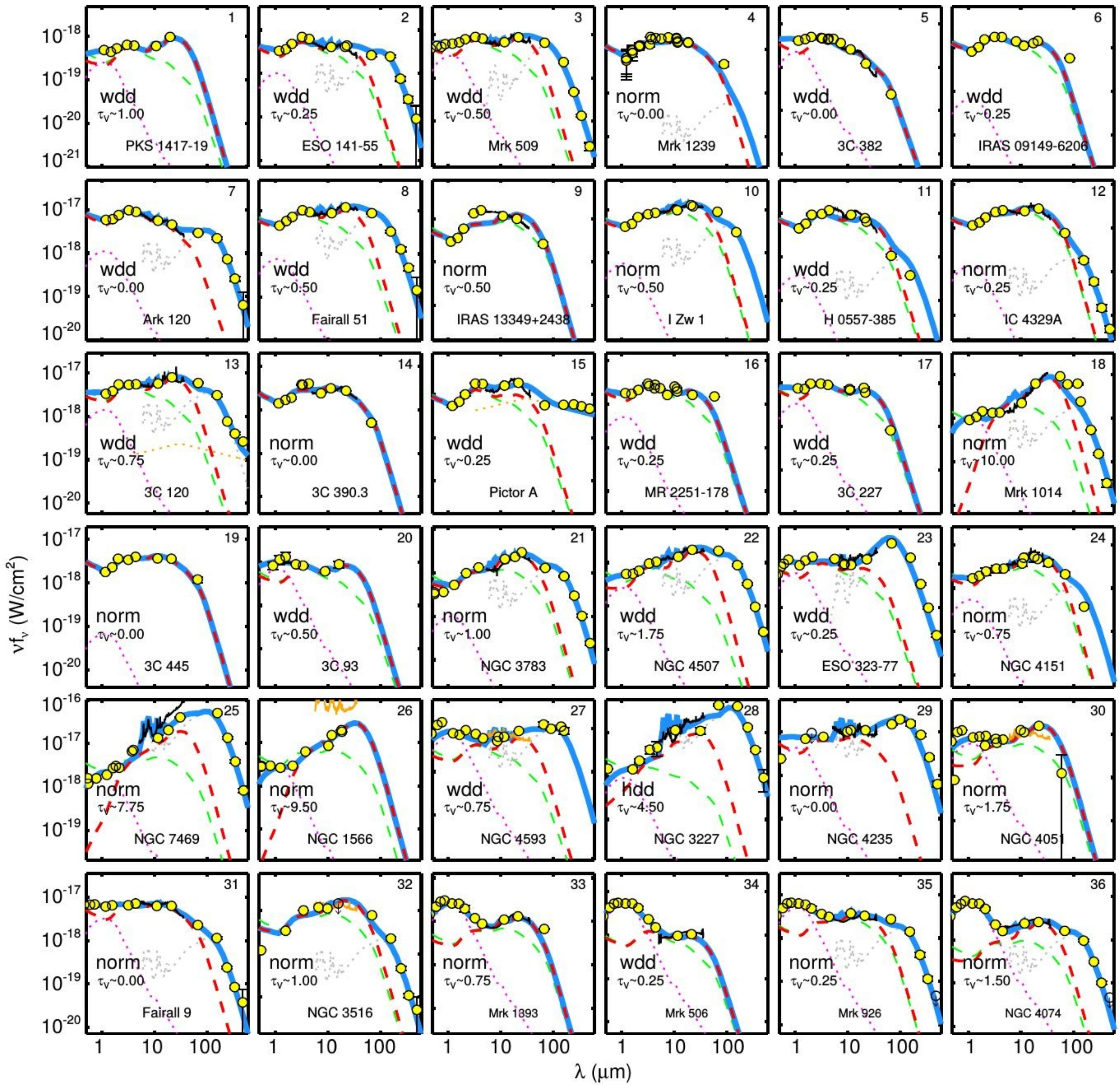
- A subset of the Asmus et al. (2014) sample with Sy 1-1.5
- No extended mid-IR emission by comparing the ground-based subarsec10-12 micron photometry and the *WISE* W4 (~12 arcsec FWHM) flux

Broad-line AGNs that observed by SDSS and *Spitzer*/IRS

- FWHM(Hα) > 1200 km/s from optical spectral decomposition
- 11.3 PAH EW < 0.1 micron & SF continuum contribution at 5-15 micron < 5%

In total, 65 type-1 nuclei with weak evidence of mid-IR SF at z=0.002-0.2

Reproducing the IR SEDs of individual Seyfert-1 nuclei



Photometry data from 2MASS, WISE, Spitzer, AKARI, Herschel, etc.

3-component SED model: AGN + stars (+ SF_dust)

Two parameters for the SED shape of the AGN Component:

1) intrinsic type

2) optical depth, tau_V

(**everything else follows NGC 3783**)

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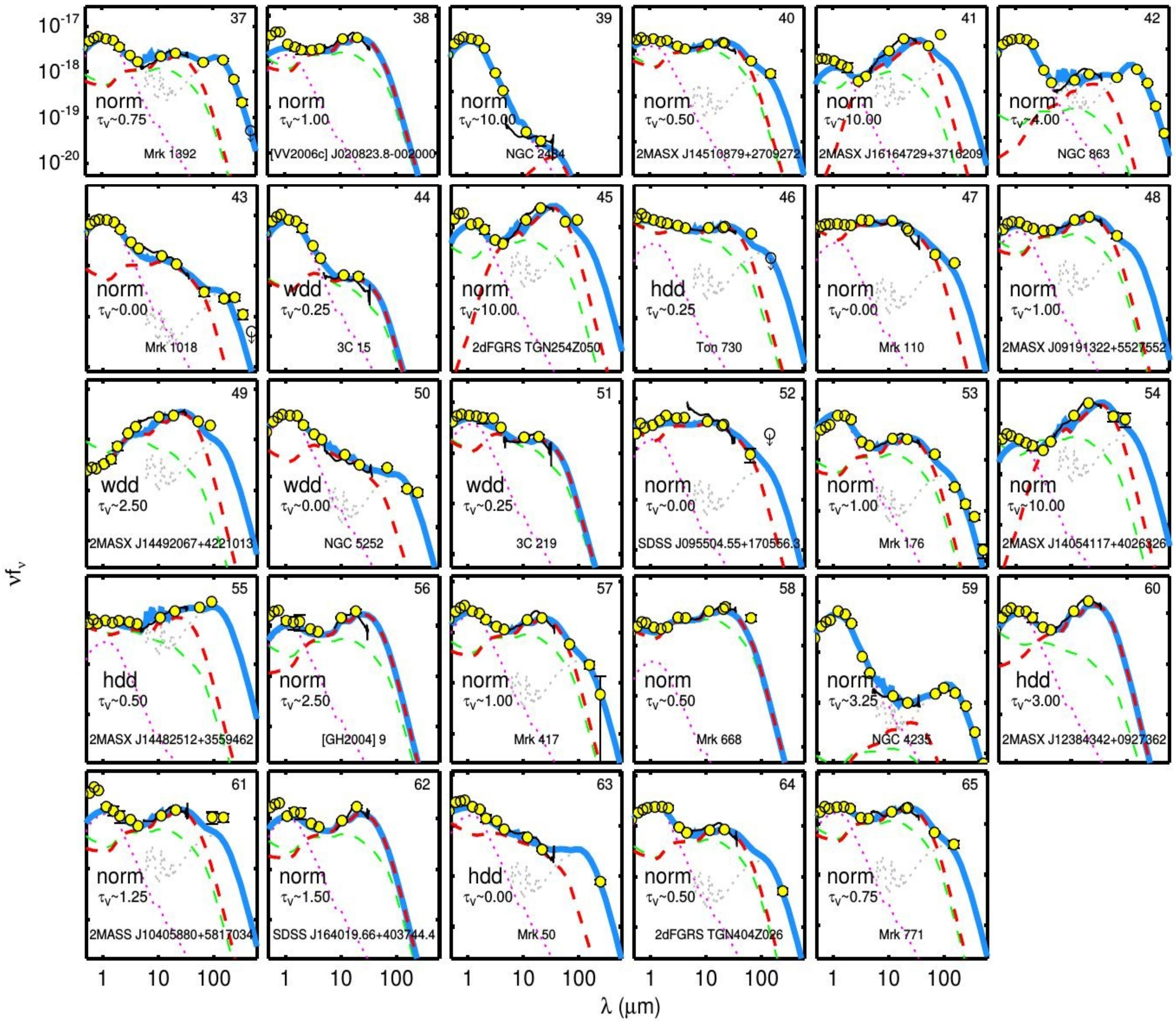
Reproducing the IR SEDs of individual Seyfert-1 nuclei



The vast majority have very good fittings

~80% of the sample have tau_V <~ 2

~30% of the sample are directly matched by the intrinsic templates

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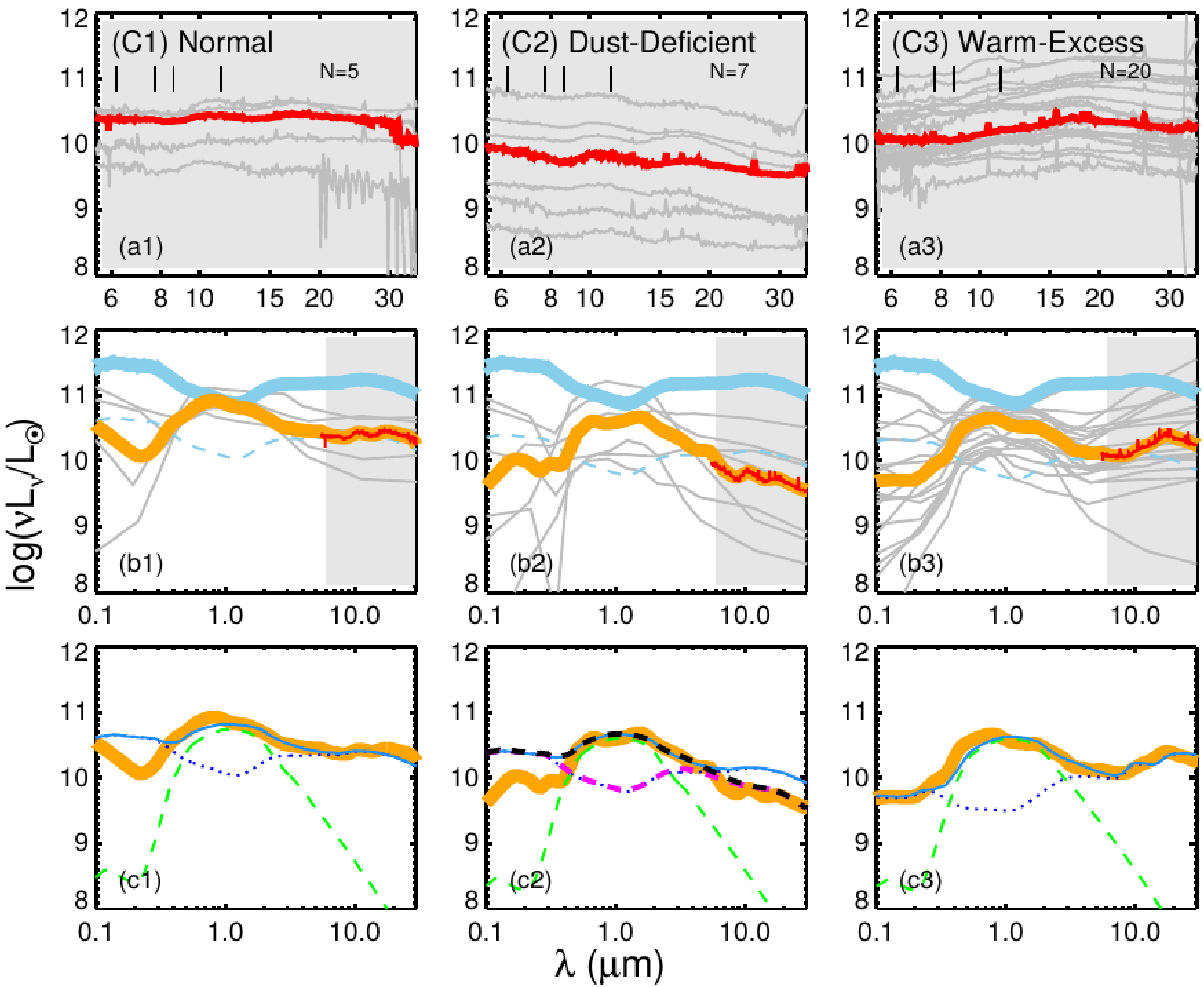
UV-to-MIR composite SEDs of Seyfert-1 nuclei

mid-IR spectra

Broad-band SEDs

Model fittings



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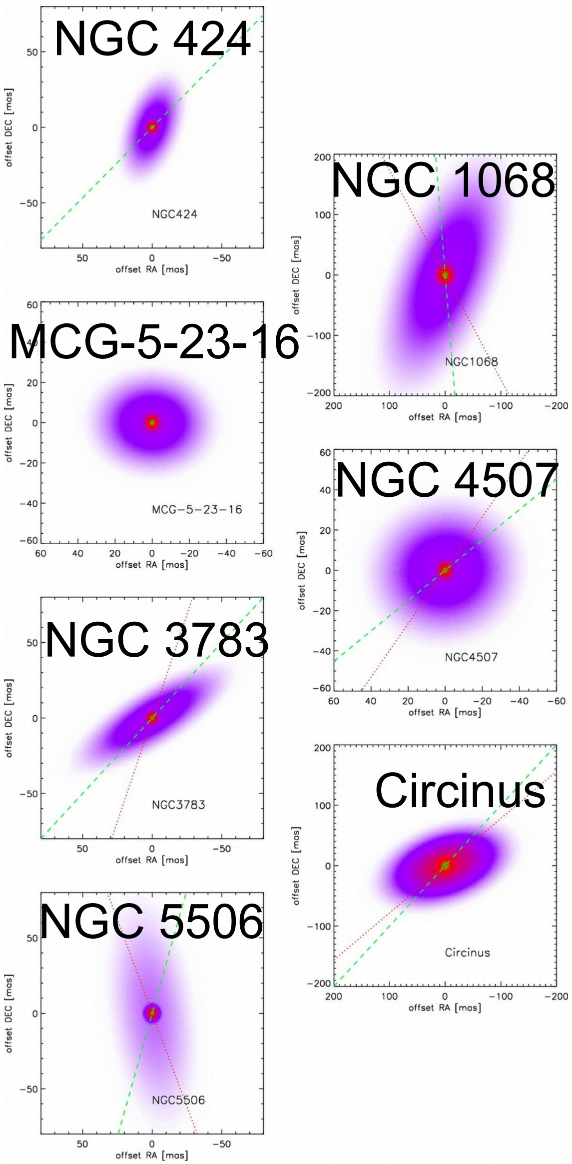
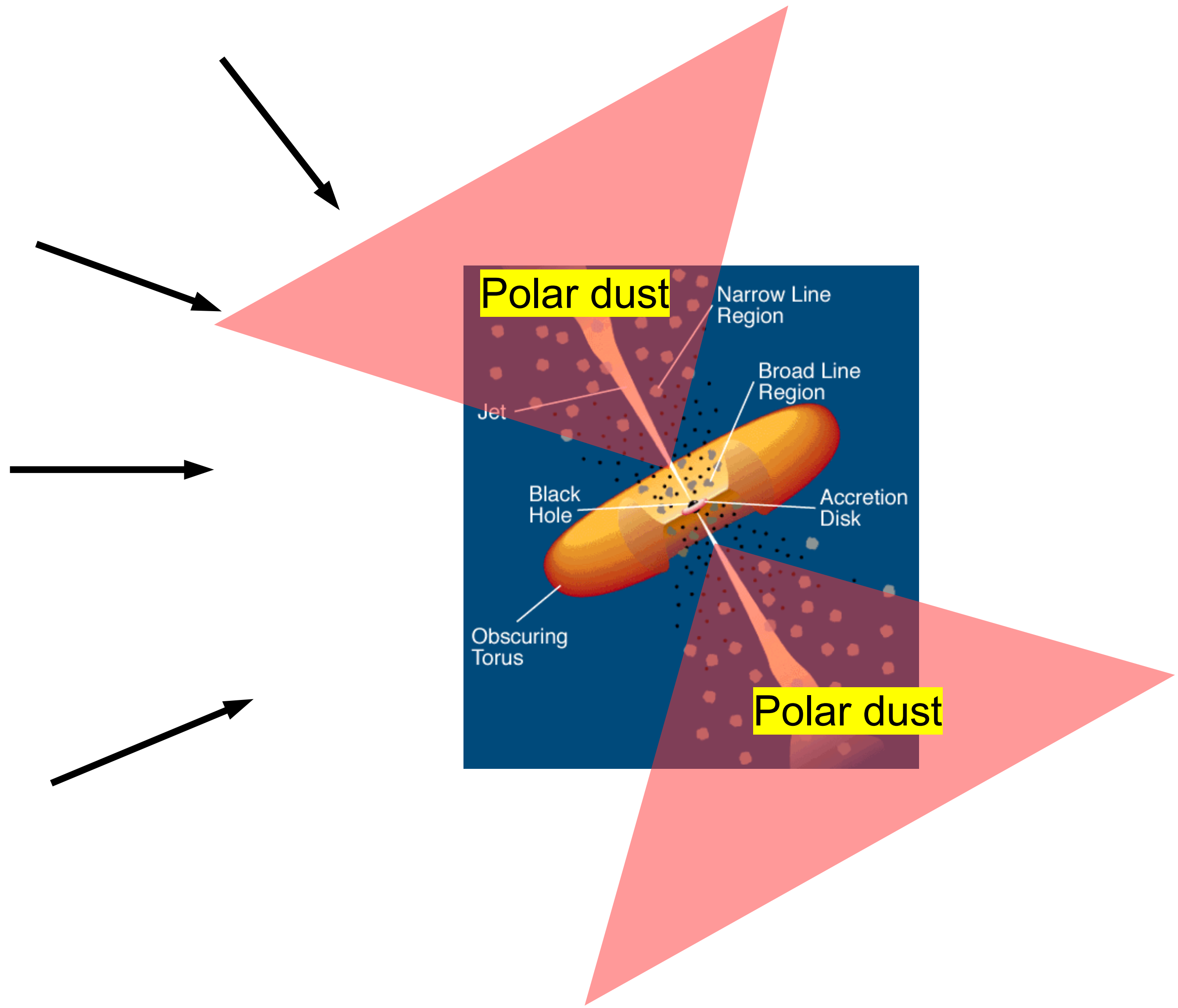
Why could this simple model work?!



López-Gonzaga, N. et al. 2016



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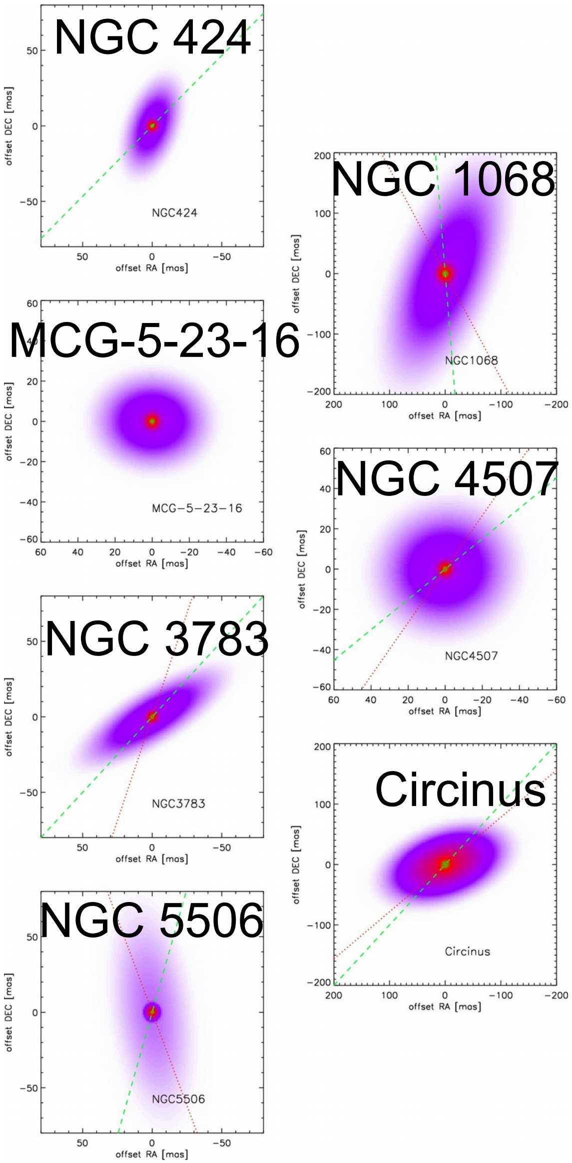

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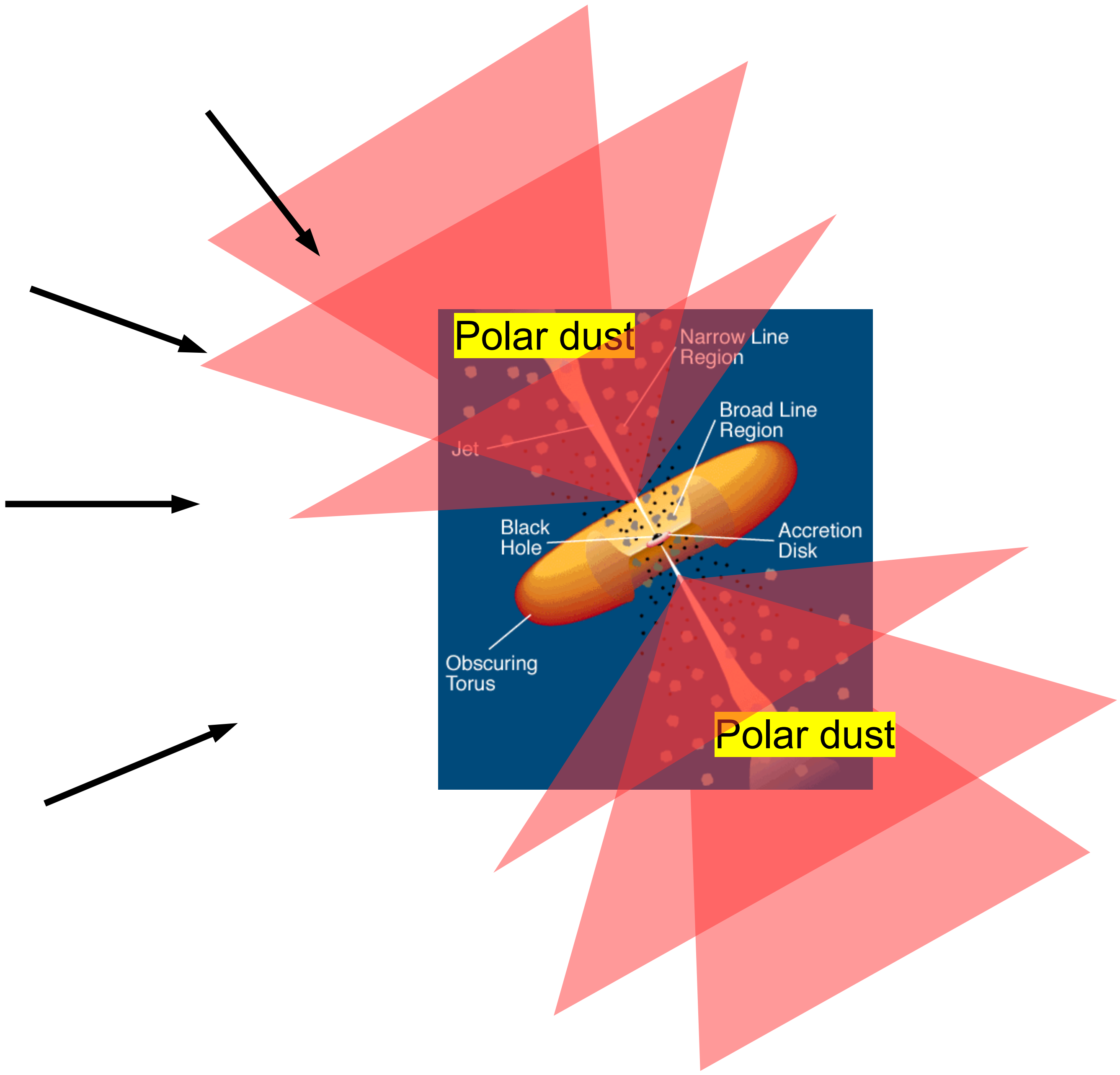

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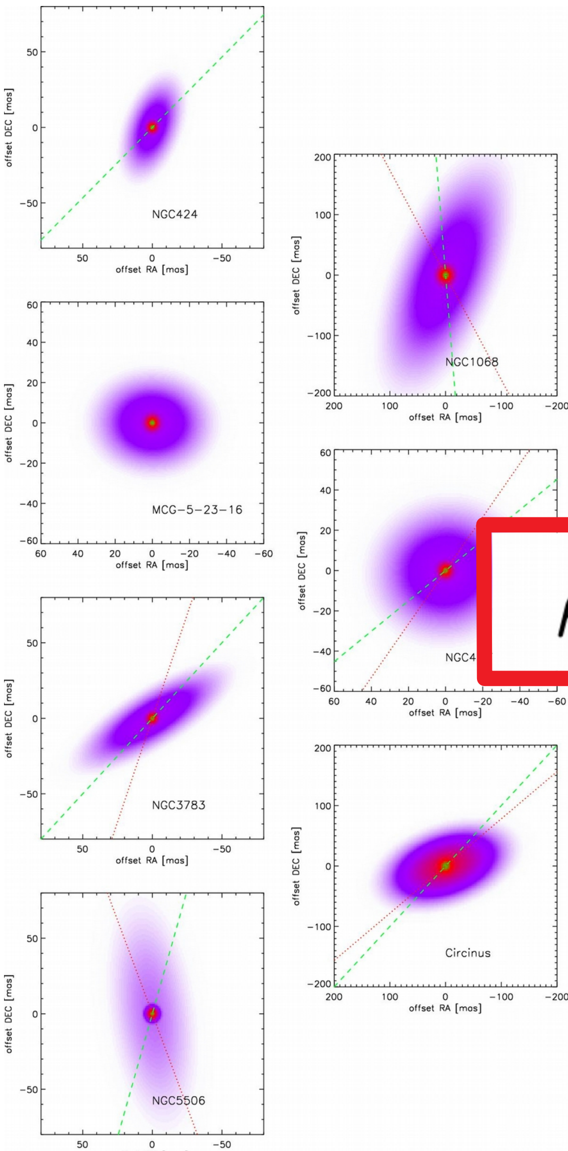
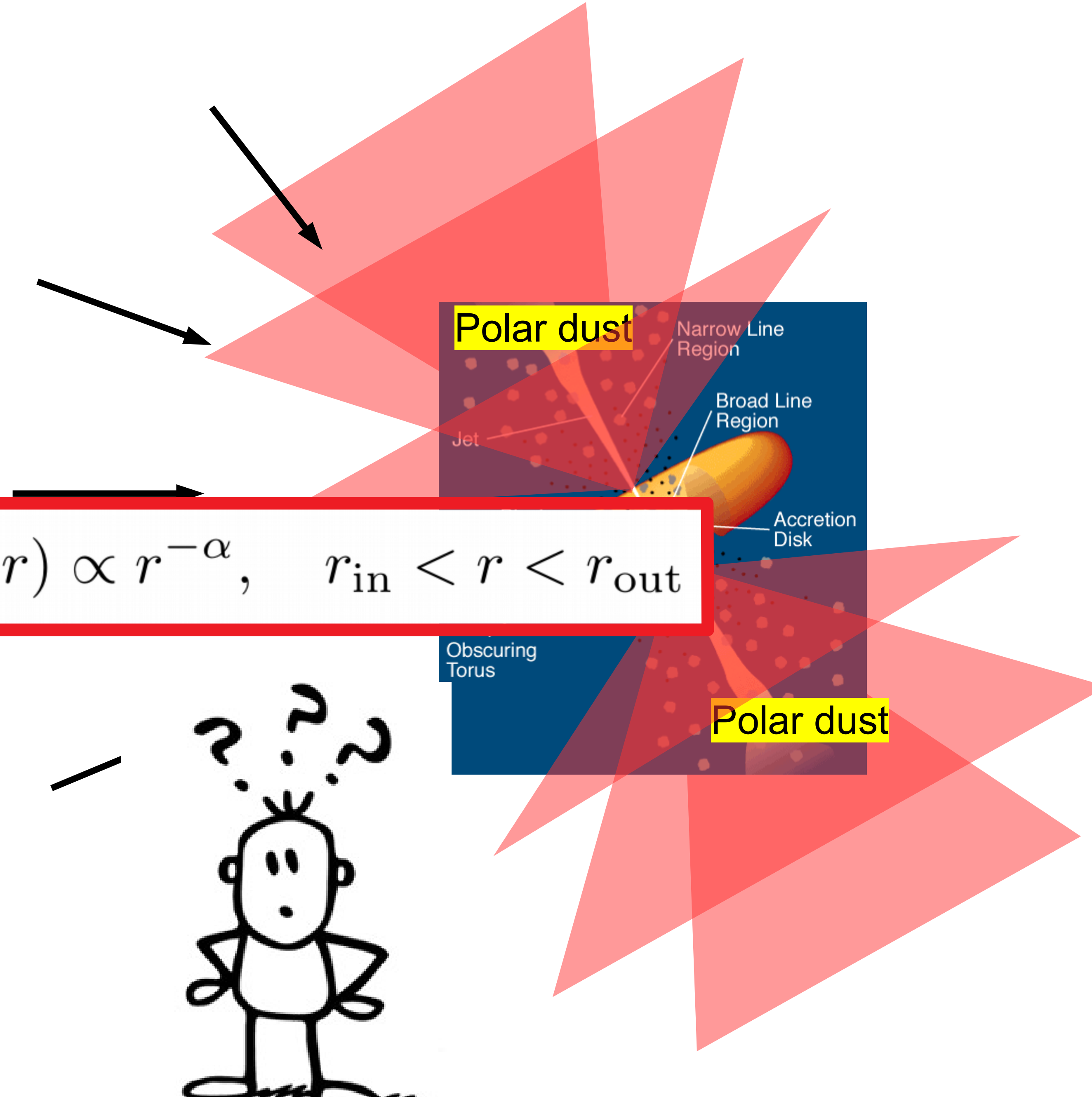


López-Gonzaga, N. et al. 2016

$$\rho(r) \propto r^{-\alpha}, \quad r_{\rm in} < r < r_{\rm out}$$



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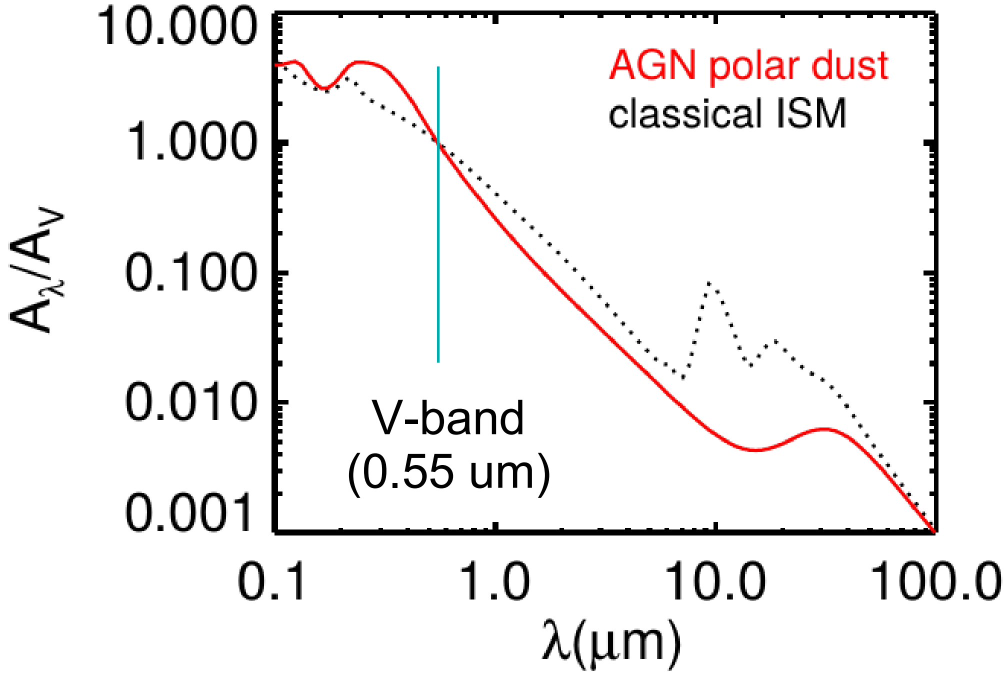

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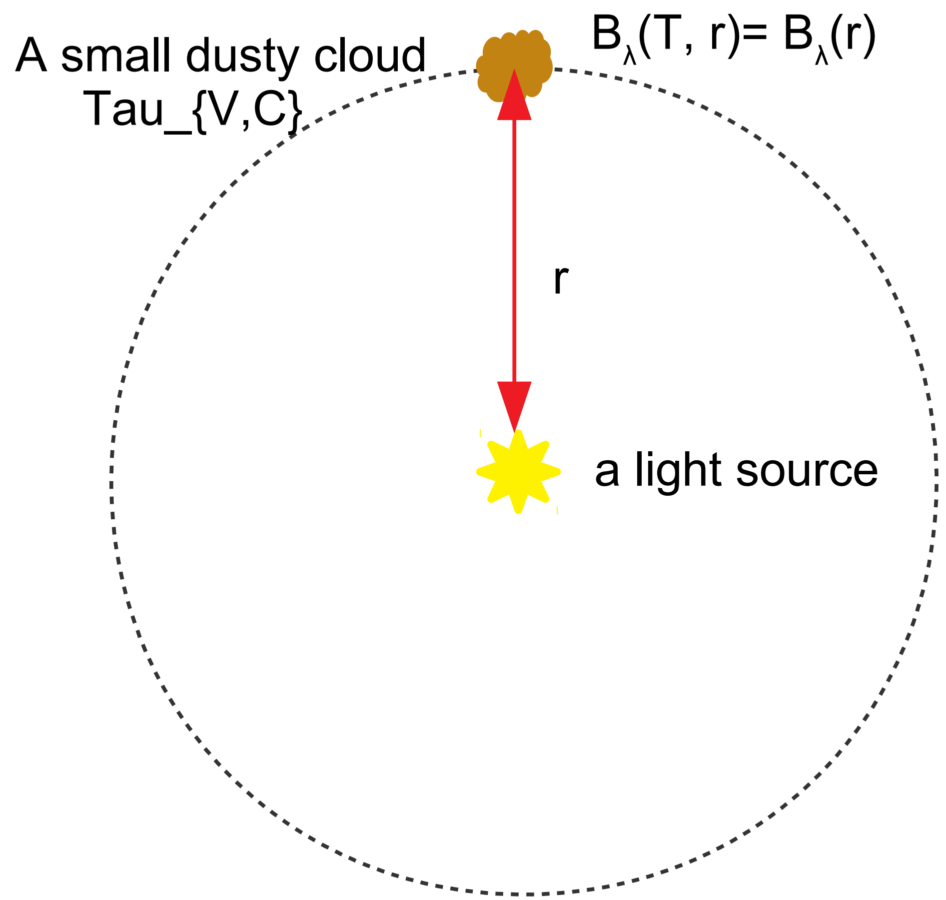

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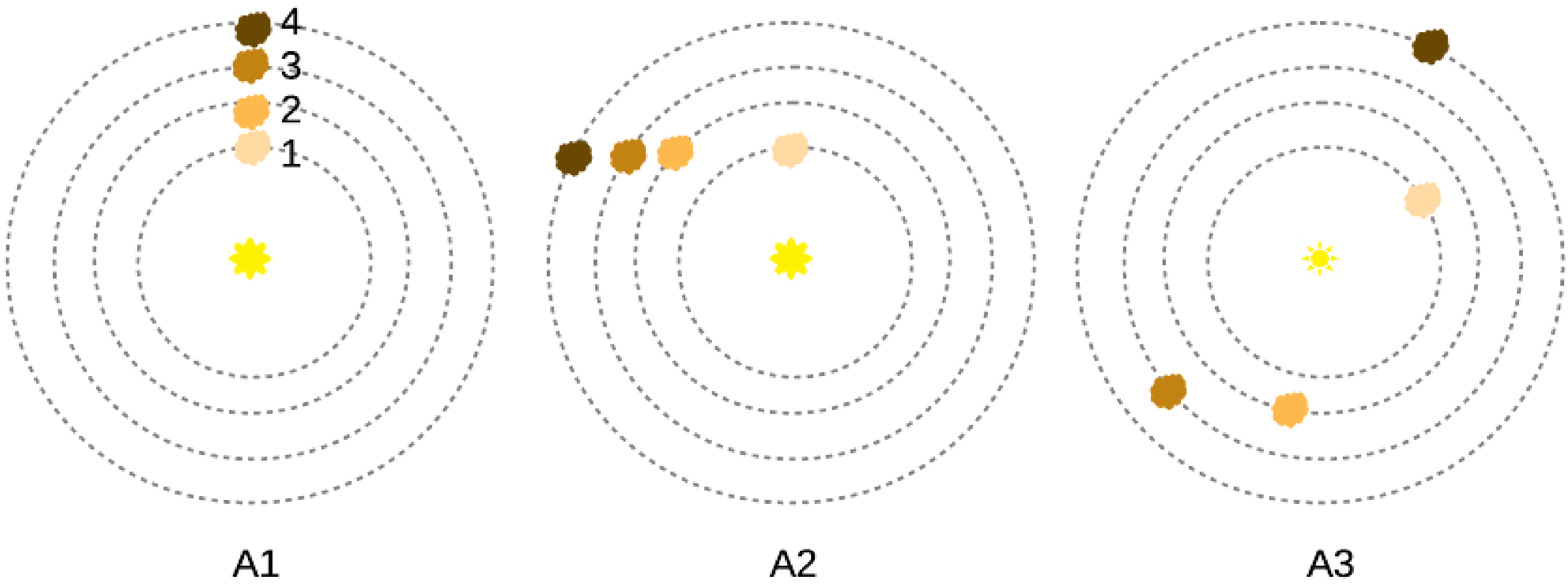
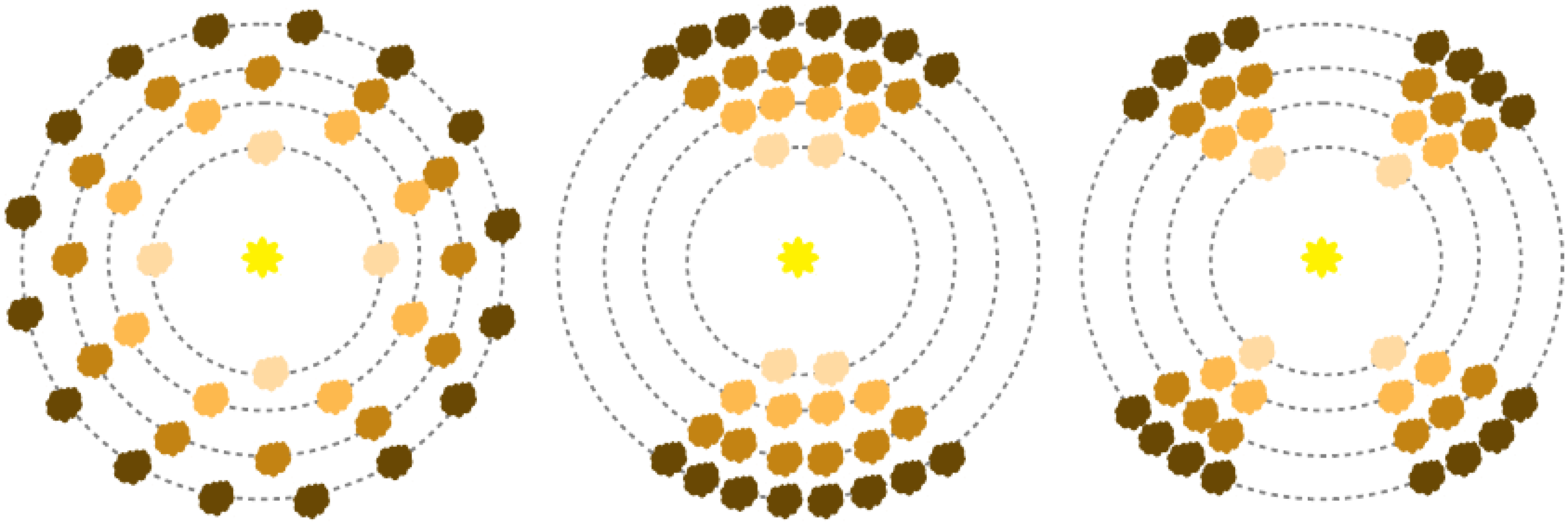


$$F_{\mathrm{tot,A}} = F_1 + F_2 + F_3 + F_4$$

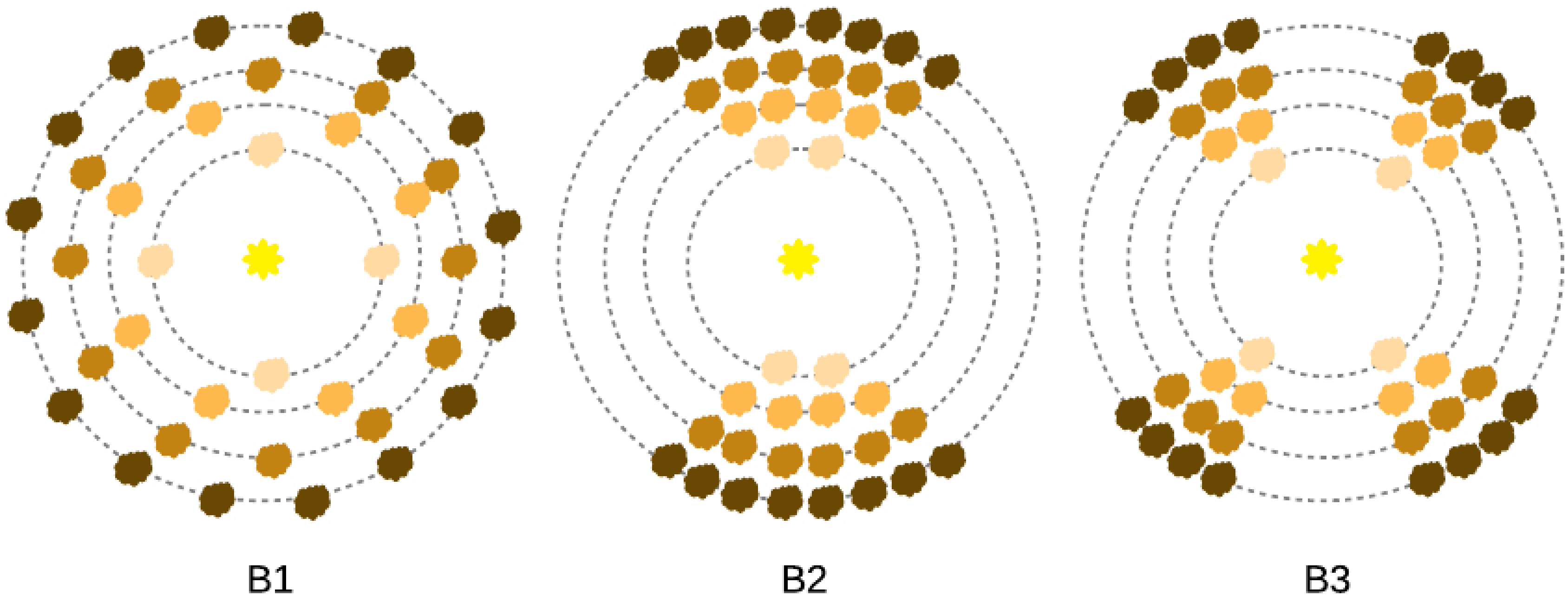
Why could this simple model work?!



B1 B2 B3

$$\bar{F}_{\mathrm{tot,B}} = N_1F_1 + N_2F_2 + N_3F_3 + N_4F_4 = 2F_1 + 4F_2 + 6F_3 + 8F_4$$

Why could this simple model work?!



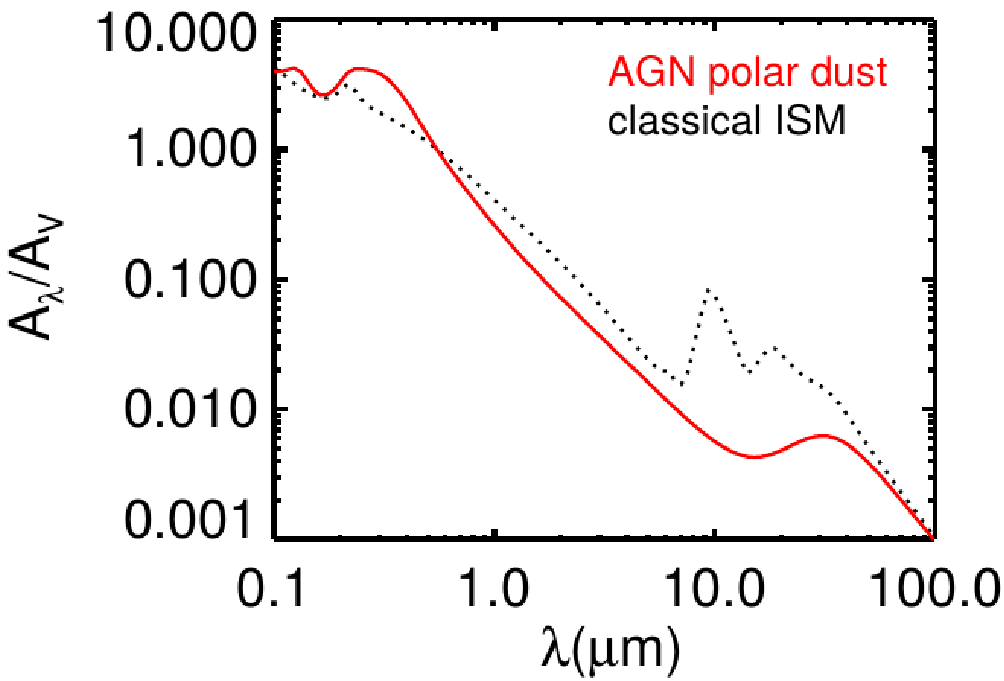
$$\bar{F}_{\mathrm{tot,B}} = N_1F_1 + N_2F_2 + N_3F_3 + N_4F_4 = 2F_1 + 4F_2 + 6F_3 + 8F_4$$

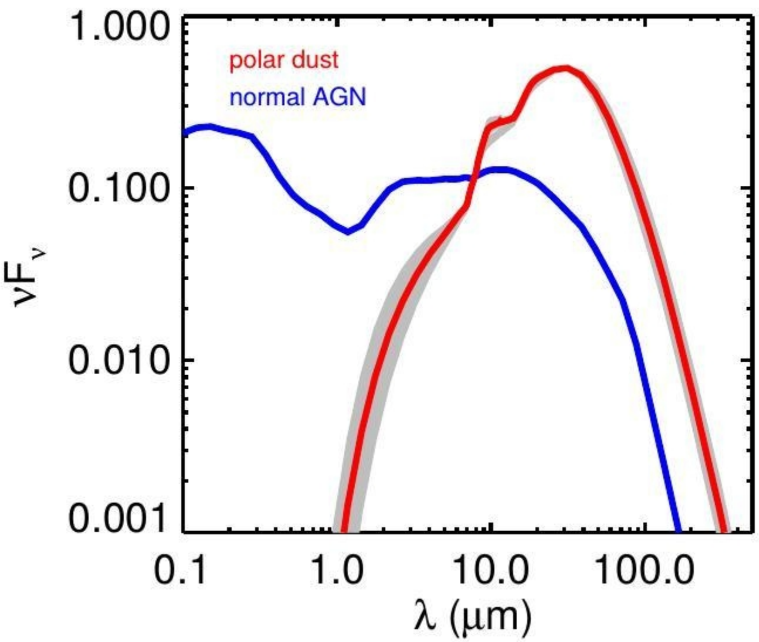
total SED: $$F_\lambda \simeq \int_{r_{\mathrm{in}}}^{r_{\mathrm{out}}} \rho(r) B_\lambda(r) dr \ .$$

total optical depth: $$\tau_{\mathrm{V}} = \int_{r_{\mathrm{in}}}^{r_{\mathrm{out}}} \rho(r) C_{\mathrm{ext,V}} dr = C_{\mathrm{ext,V}} \int_{r_{\mathrm{in}}}^{r_{\mathrm{out}}} \rho(r) dr$$

$$\rho(r) \propto r^{-\alpha}, \quad r_{\mathrm{in}} < r < r_{\mathrm{out}}$$

Why could this simple model work?!





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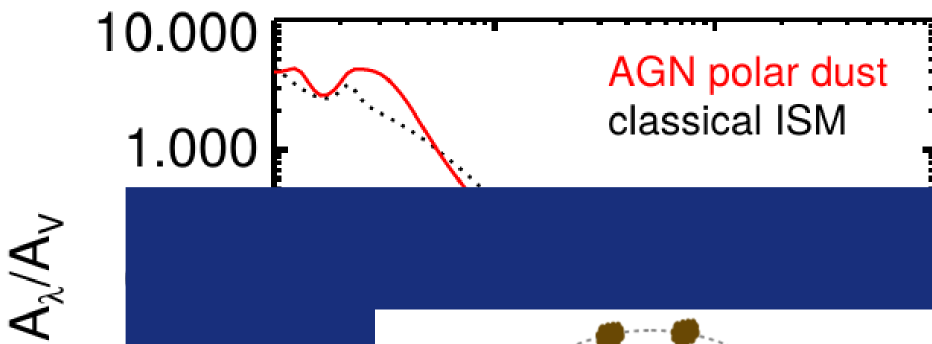
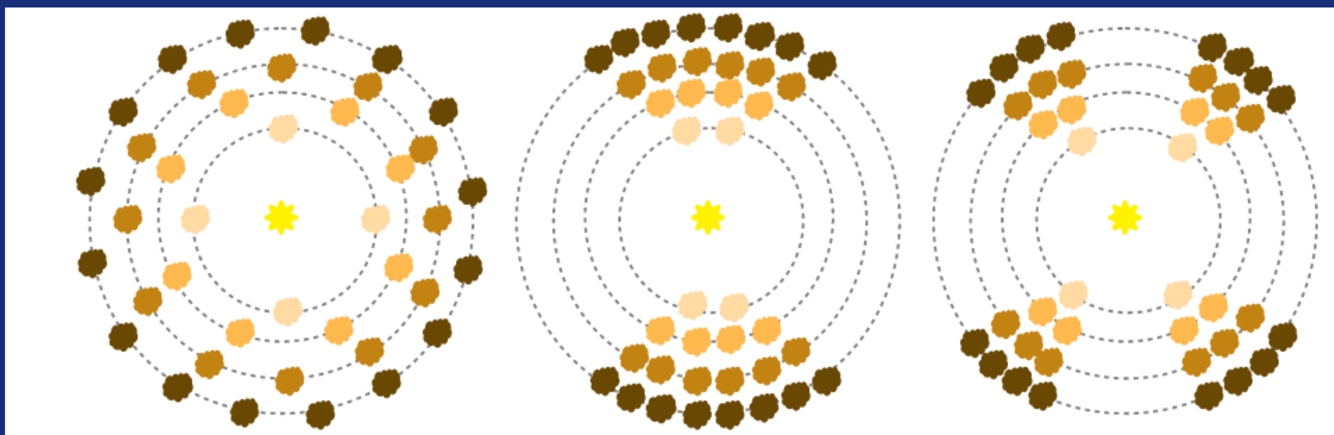
Up to tau_v = 5, the IR SEDs of the polar dust component are quite identical

The SED of polar dust emission does not care much about the geometry (along ө and φ directions), neither the observing angle!

Why could this simple model work?!

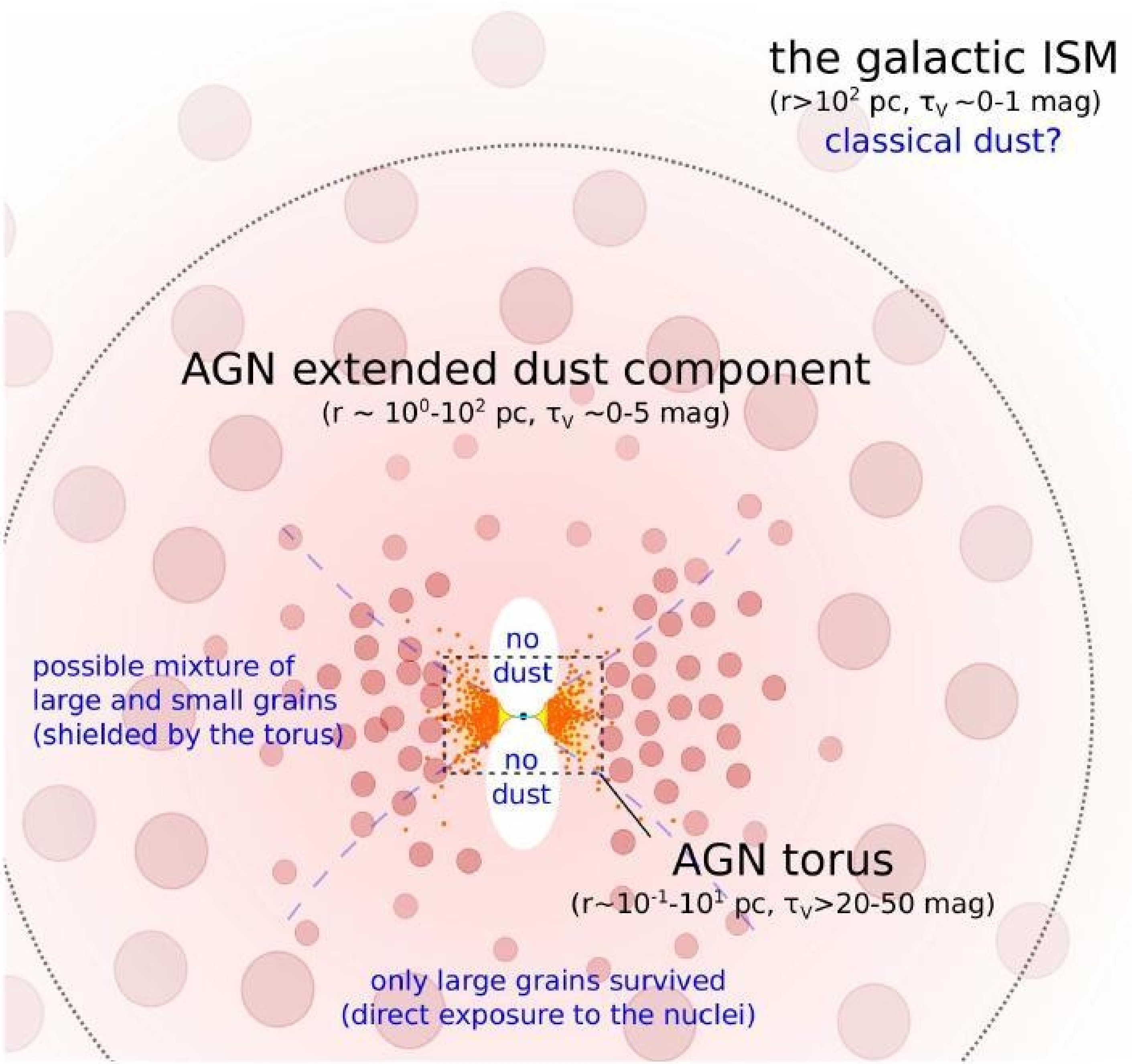




Q1: Can we constrain the AGN dust-covering factors from the SEDs?
Q2: How robust is it to use L_{MIR} to estimate L_{AGN, bol}?
Q3: How should we test any torus models?

The SED of polar dust emission does not care much about the geometry (along ɵ and φ directions), neither the observing angle!

The dust environment of a typical Seyfert nucleus



Density profile:
ρ(r) ~ r^{-0.5}
Outer-to-inner radius
r_out/r_in = 500
Inner Boundary
T_in = 1500 K

Large dust grains
a_min = 0.04 um
a_max = 10 um

Integrated optical depth
tau_V ~ 0 – 5

With L_AGN=10^11 L_sun, the extended polar dust that can be heated by the central engine can extended to a few*10^2 pc

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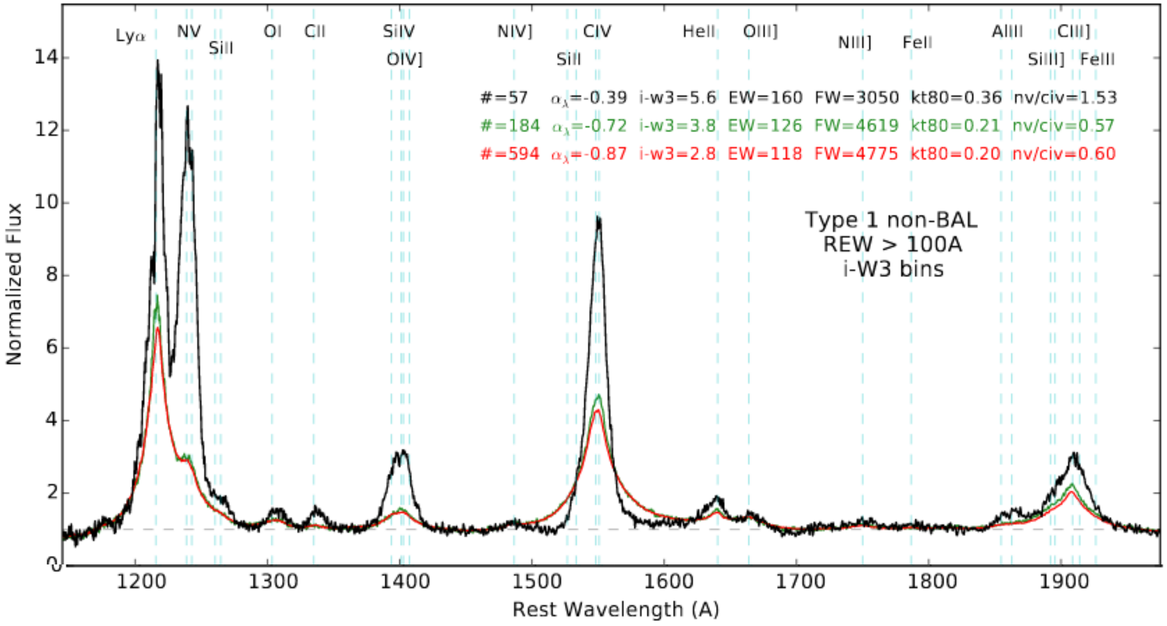
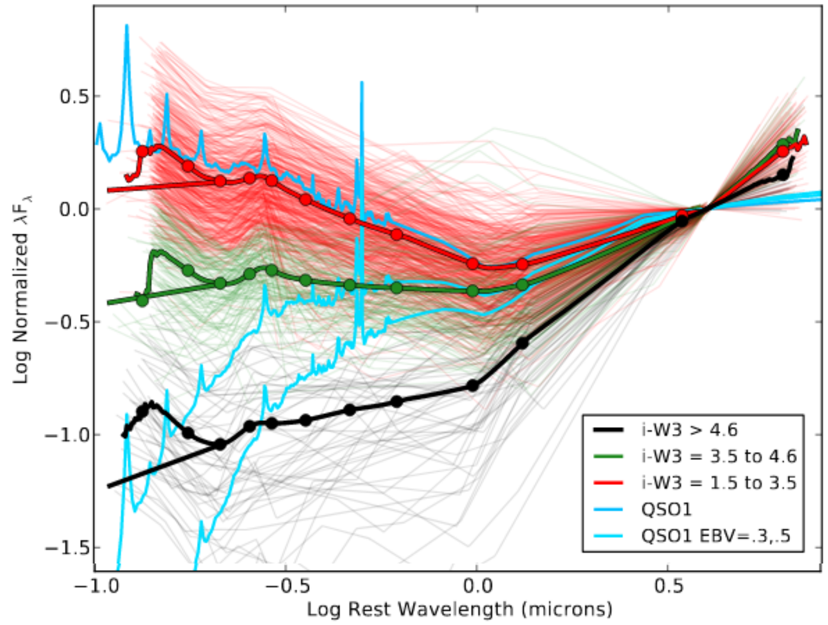
Do the SEDs of high-z type-1 AGNs behave similarly?

Extremely red quasars at z~2-3.4

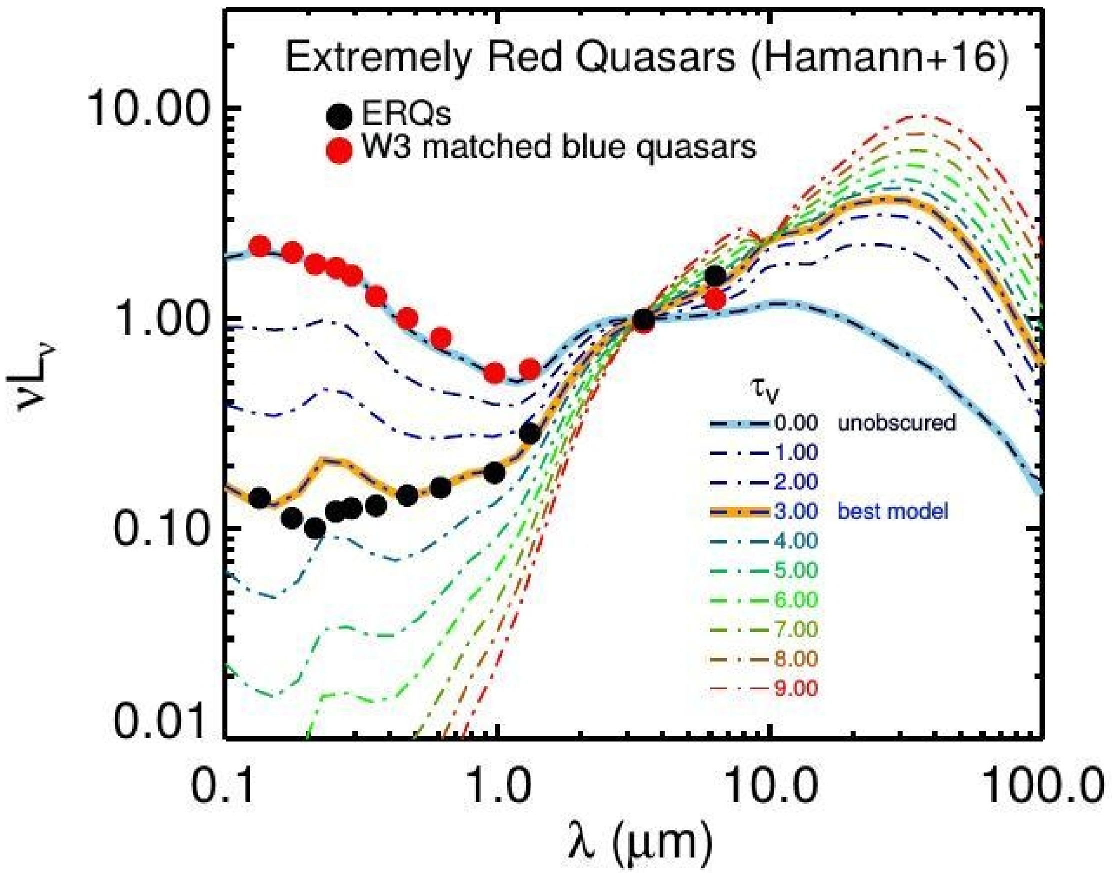




(Hamann+17)

L_{AGN,bol} > 10^13 L_sun,
Strong outflow features

Extremely red quasars at z~2-3.4



Two parameters for the SED shape of the AGN Component:
1) intrinsic type
2) optical depth, tau_V
(**everything else follows NGC 3783**)

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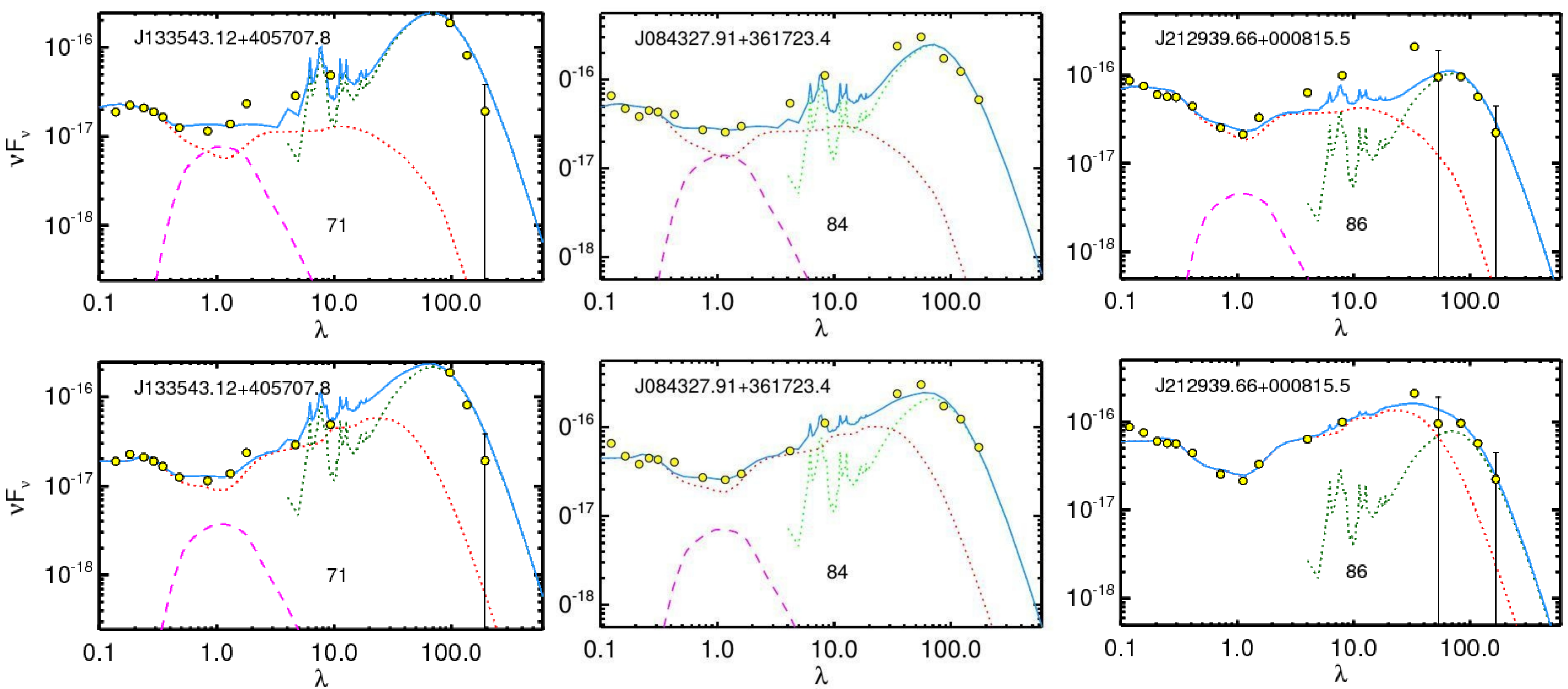
AGNs with mid-IR warm-excess emission at z=0.7-2.3

(Xu+2015)



Two parameters for the SED shape of the AGN Component:
1) intrinsic type
2) optical depth, tau_V
(**everything else follows NGC 3783**)

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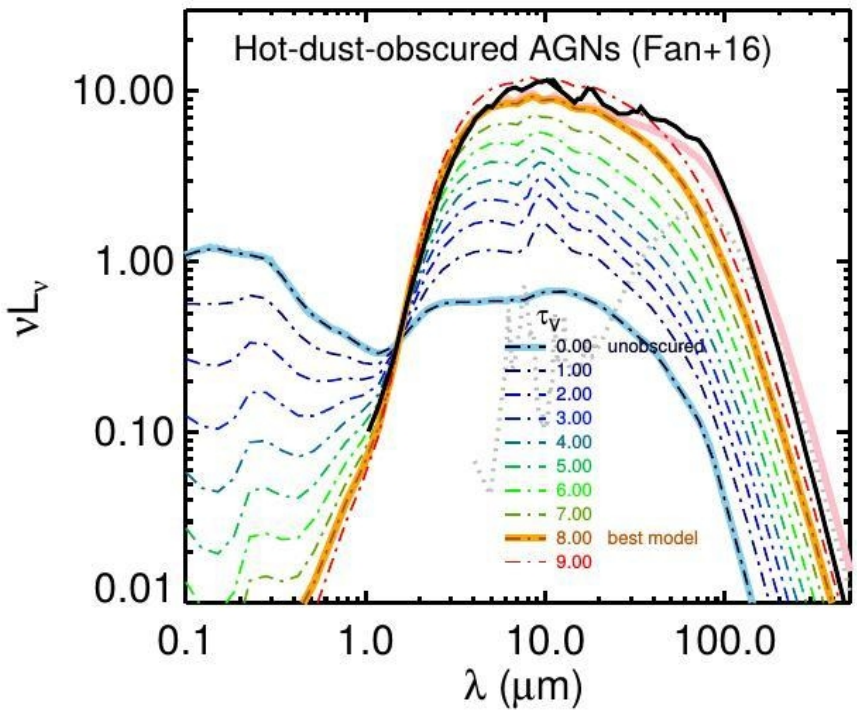
Hot dust-obscured galaxies at z~2-4



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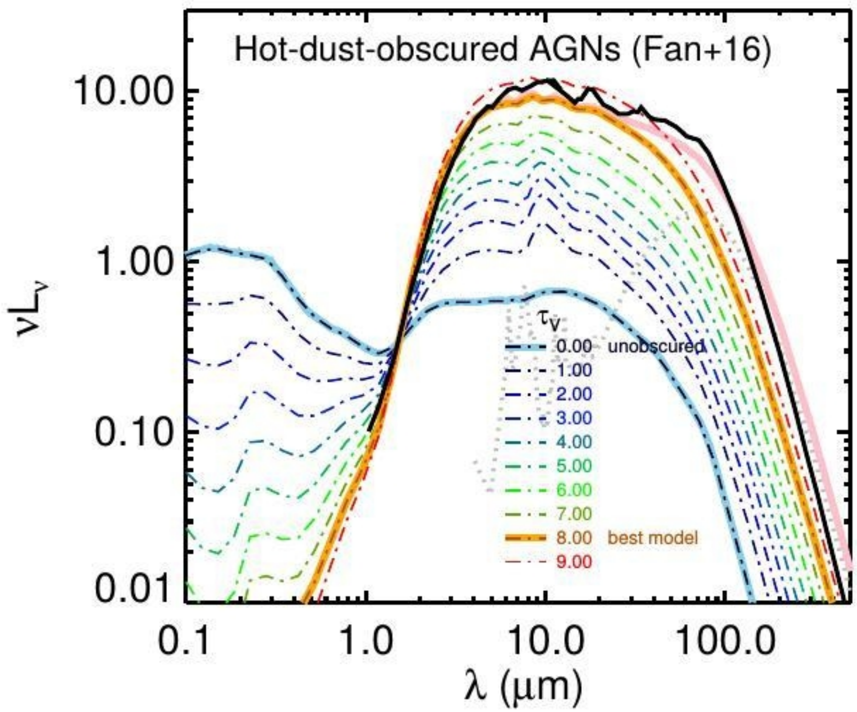
Density profile $r^{-0.5} \rightarrow r^{-1.5}$
Outer-to-inner radius $r_{out}/r_{in} = 500 \rightarrow 5000$
(dust grains properties and T_{in} follow NGC 3783)

Hot dust-obscured galaxies at z~2-4



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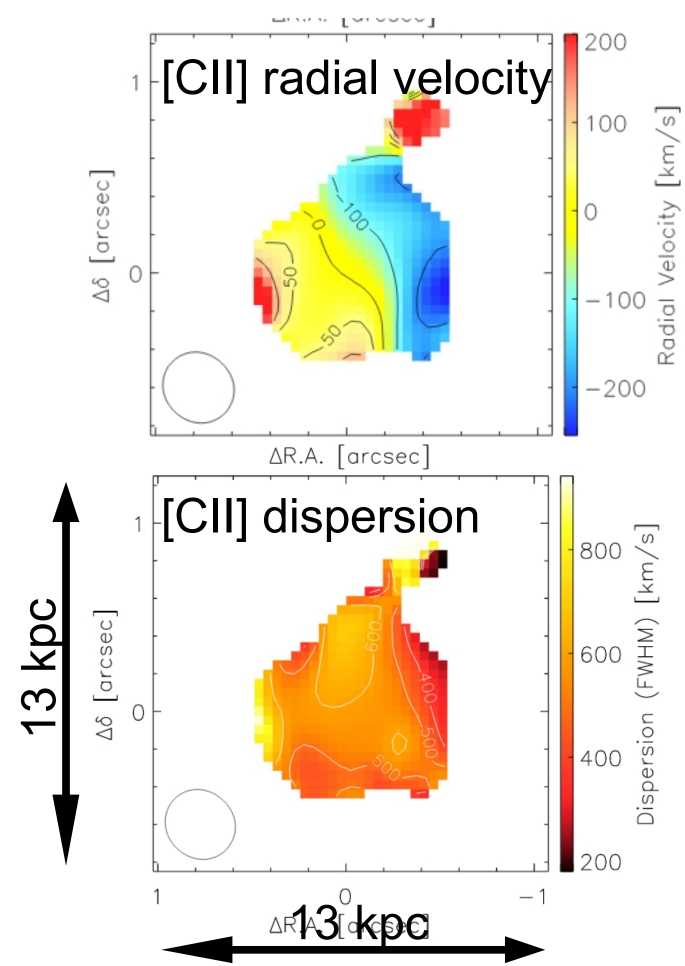
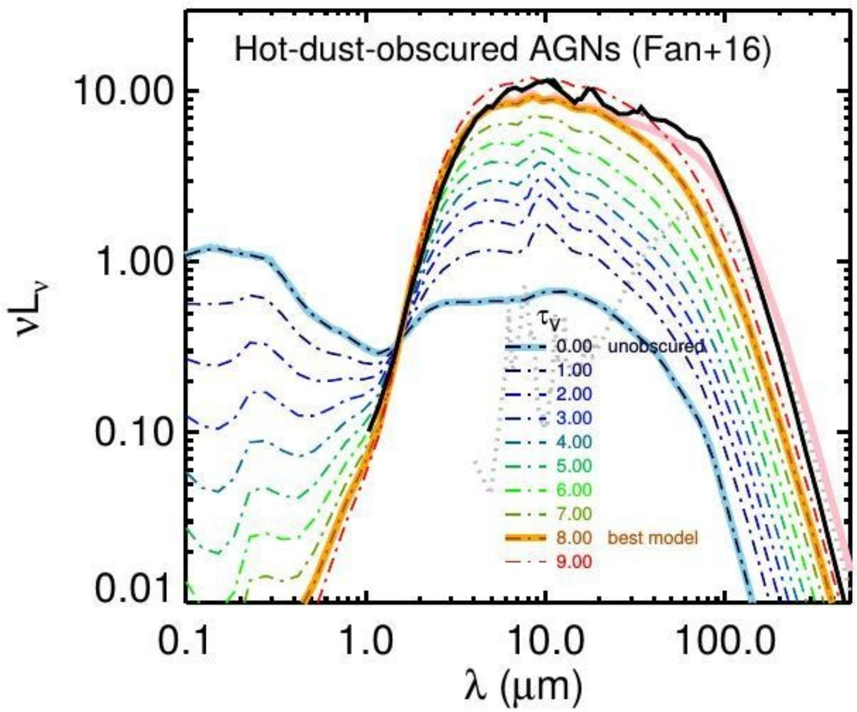


Diaz-Santos et al. 2016

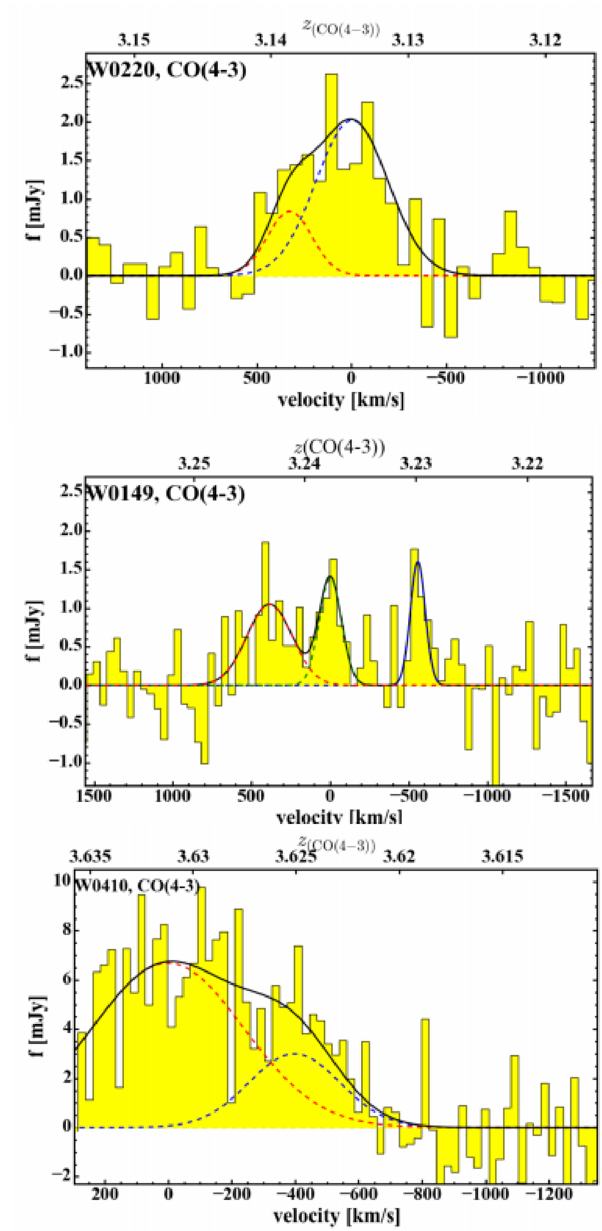
Density profile $r^{-0.5} \rightarrow r^{-1.5}$
Outer-to-inner radius $r_{out}/r_{in} = 500 \rightarrow 5000$
(dust grains properties and T_{in} follow NGC 3783)

ALMA observations of W2246-0526 shows the strikingly uniform, highly turbulent ISM over the entire galaxy

Hot dust-obscured galaxies at z~2-4



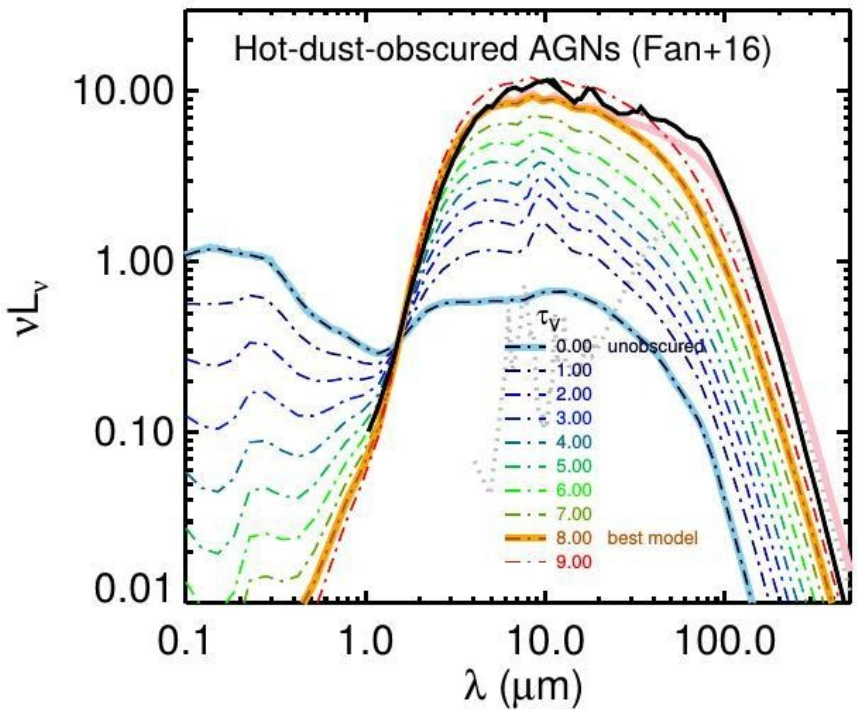
J. Lyu & G. Rieke 2018

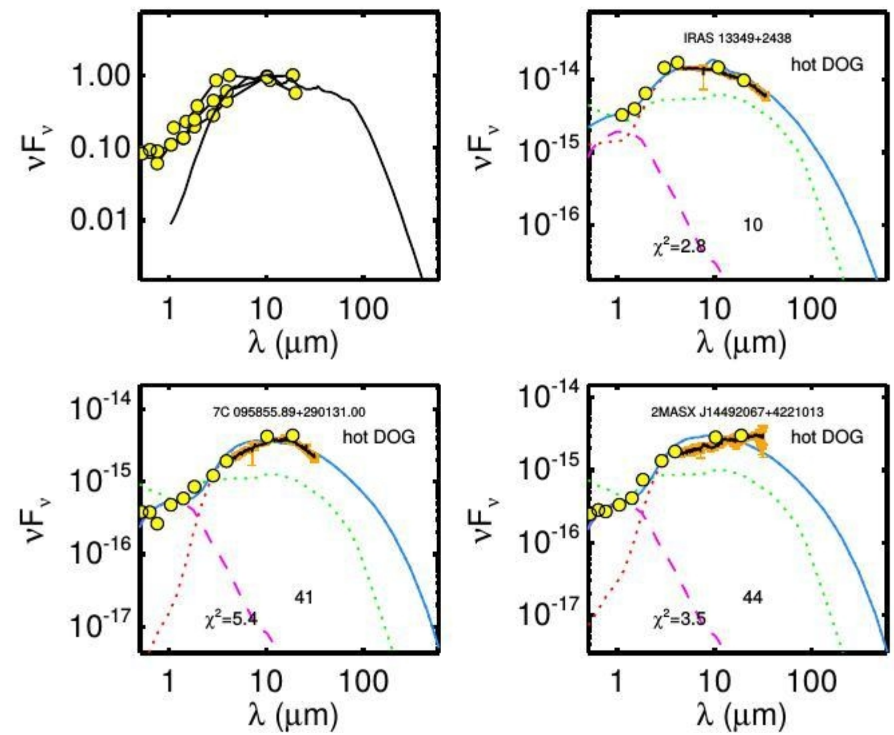


Density profile r^{-0.5} → r^{-1.5}
Outer-to-inner radius r_out/r_in = 500 → 5000
(dust grains properties and T_in follow NGC 3783)

Fan et al. 2018

Hot dust-obscured galaxies at z<0.5



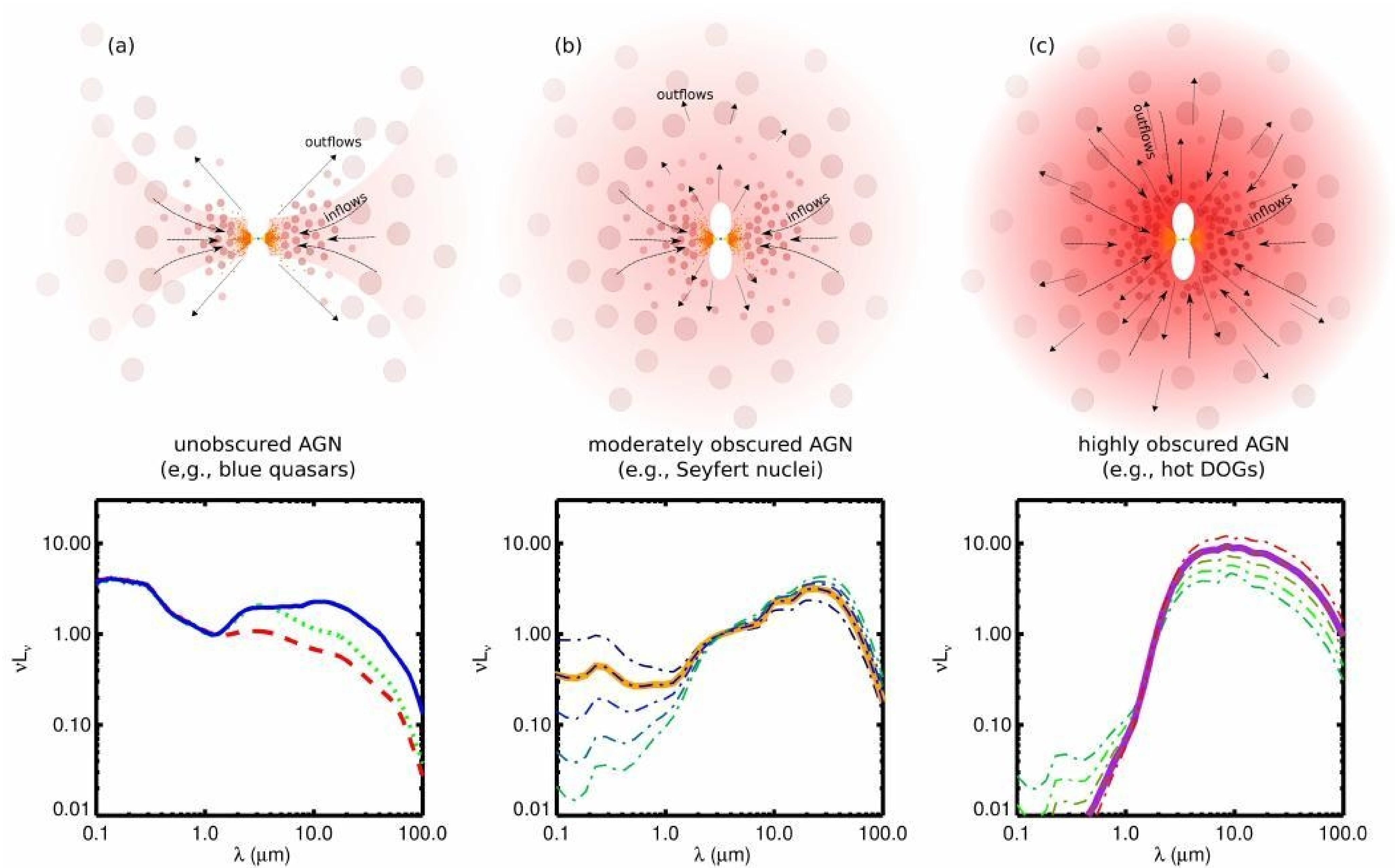


J. Lyu & G. Rieke 2018

J. Lyu & G. Rieke 2018

Density profile r^{-0.5} → r^{-1.5}
Outer-to-inner radius r_out/r_in = 500 → 5000
(dust grains properties and T_in follow NGC 3783)

Similar model explains the low-z AGNs with hot-dust-excess emission



J. Lyu & G. Rieke 2018

Take-home messages

1. AGN intrinsic IR variations: normal, WDD and HDD;

(see more in Lyu, Rieke & Shi 2017; Lyu & Rieke 2017)

2. Regardless of luminosity and redshift, a two-free parameter model is good enough to reconcile the IR SEDs of most type-1 AGNs

intrinsic AGN types,   tau_V of the polar dust component

3. In the first order, the AGN dust environment has two components:

    the torus (~1-10 pc) – determined by the BH accretion processes;

    the extended polar dust component (~0.1- 1 kpc) – controlled by feedback from AGN and/or host galaxy

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(*see the real poster on Friday*)