Evidence for a UV bump of moderate amplitude in the attenuation curve of high redshift galaxies

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and
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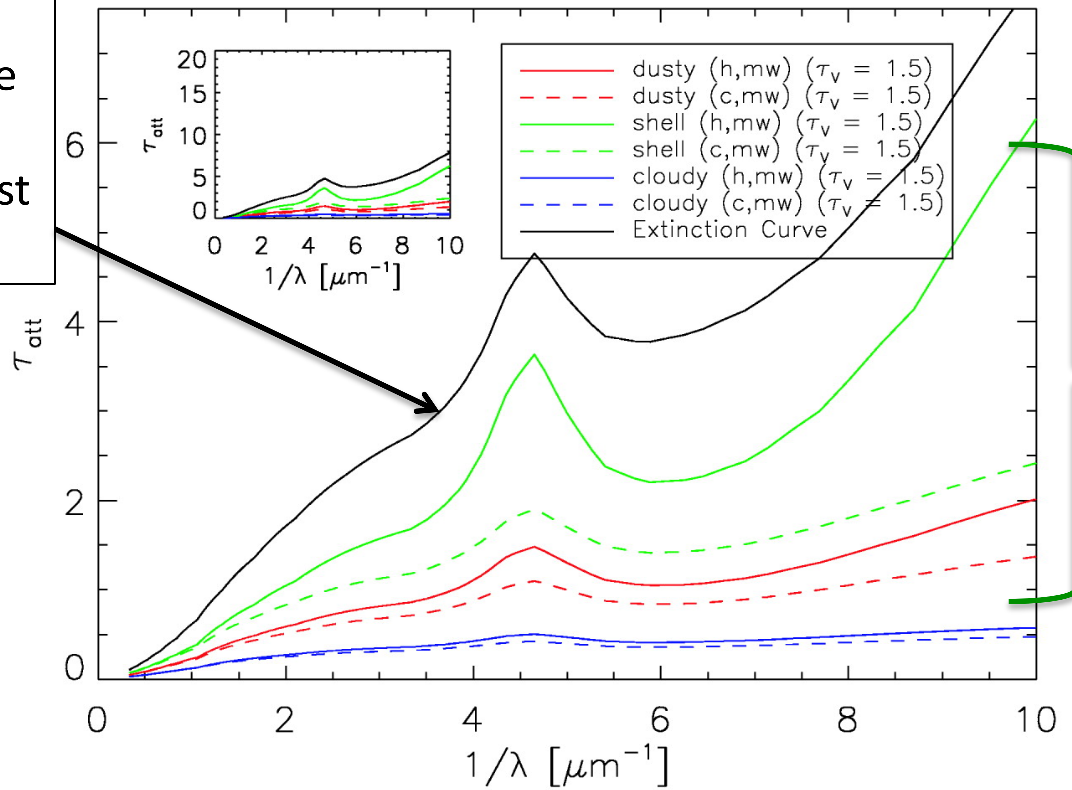
From dust to galaxies-IAP-27-01 june 2011

Attenuation & extinction laws in galaxies

They are different because of absorption & scattering of photons on dust particles

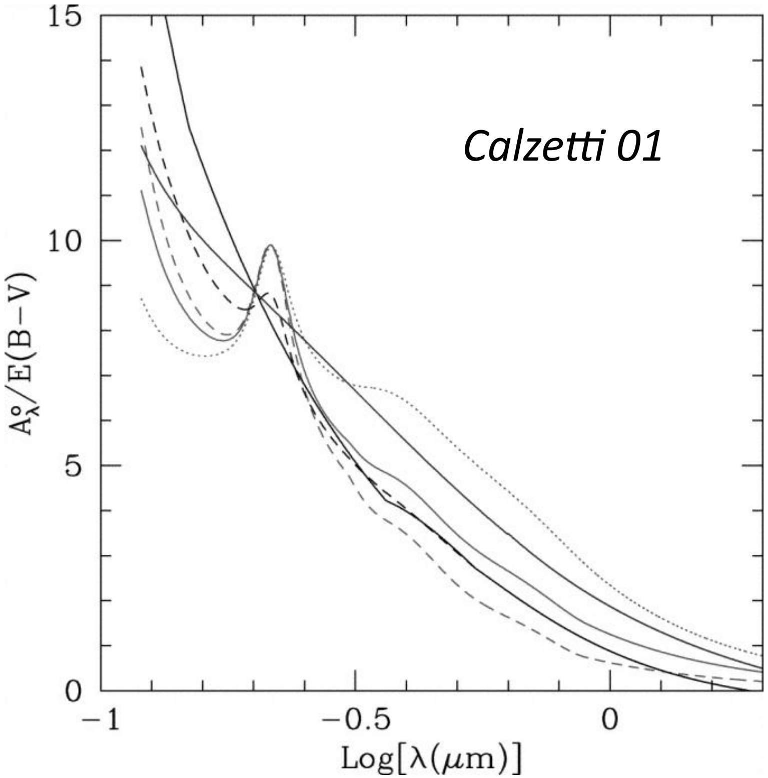
Witt & Gordon 2000

MW Extinction curve along one ligne of sight, depends on dust properties



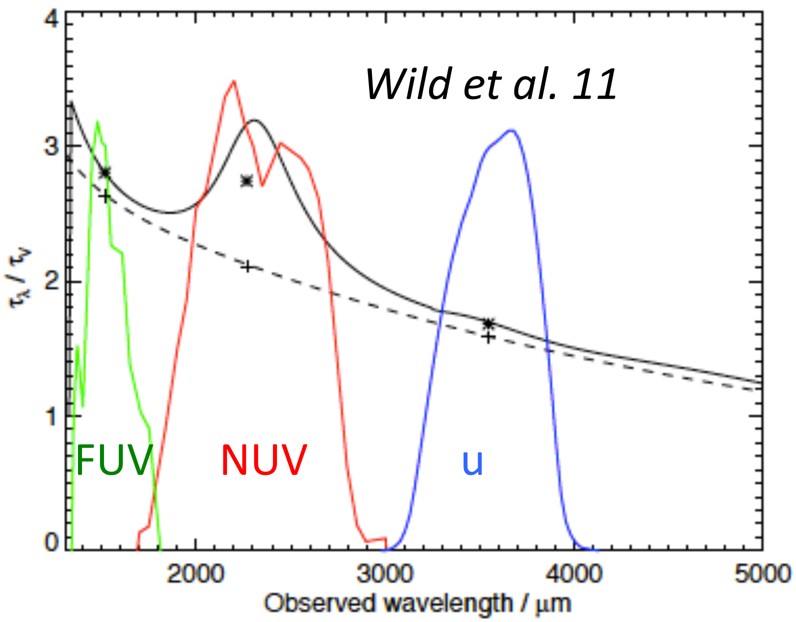
Attenuation law for extended objects depends on dust properties and dust-stars geometry

Attenuation curves of external galaxies: UV range
Is there any bump at 2175 A?



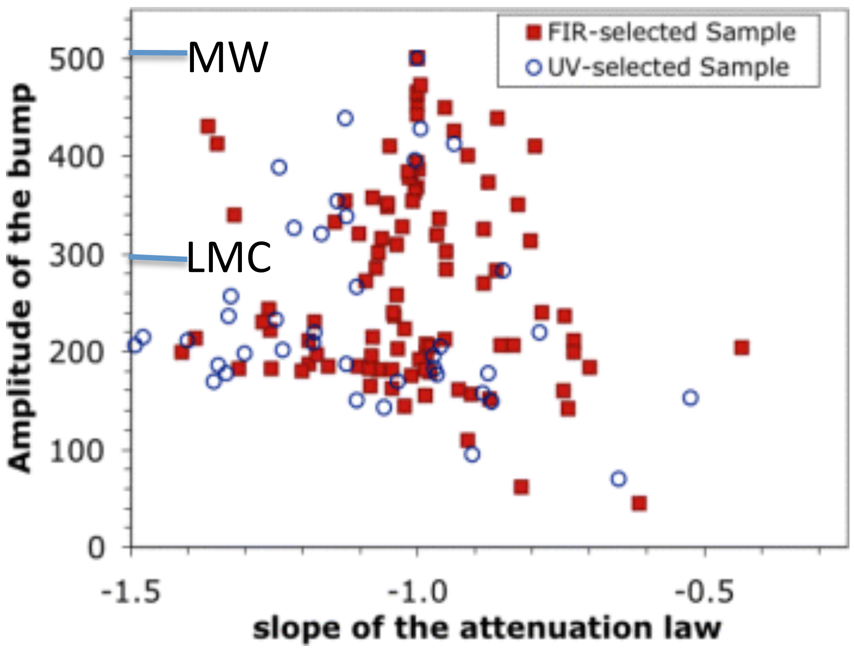
Calzetti et al. 94, 00: from spectroscopic data

no bump in local starburt galaxies, moderate rise in UV

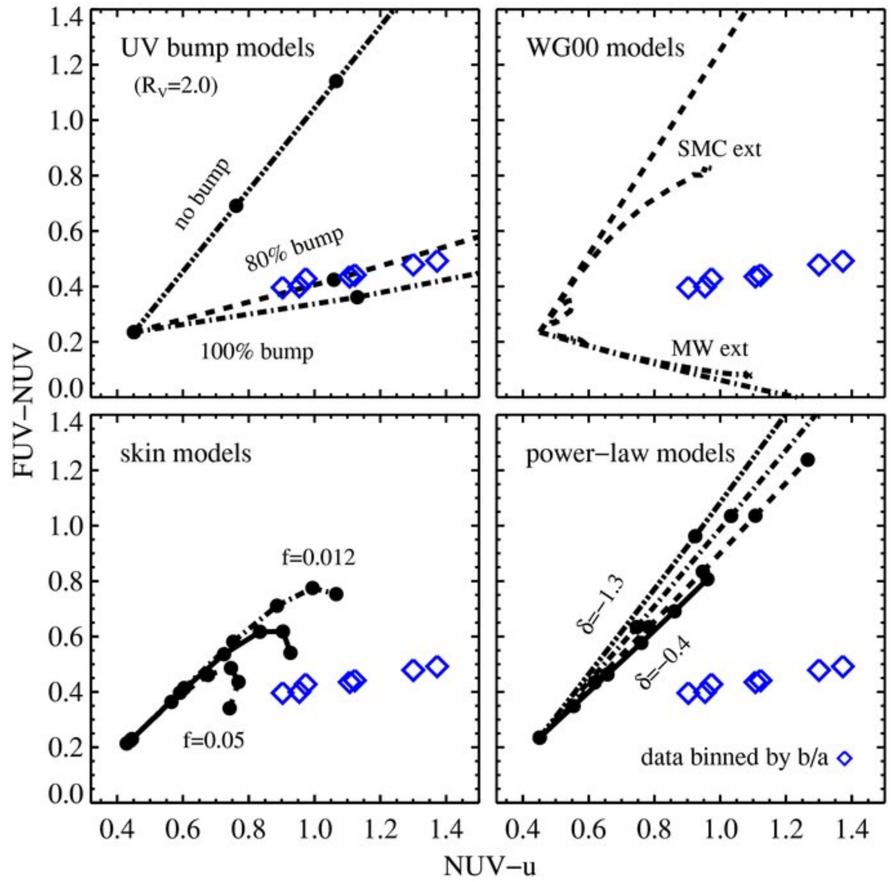


In local galaxies: GALEX UV bands and u(SDSS) well suited to test the presence of the bump

At low z: some evidence for a bump in local star forming galaxies from broad band analyses



Burgarella et al. 05- SED-fitting IRAS-GALEX data



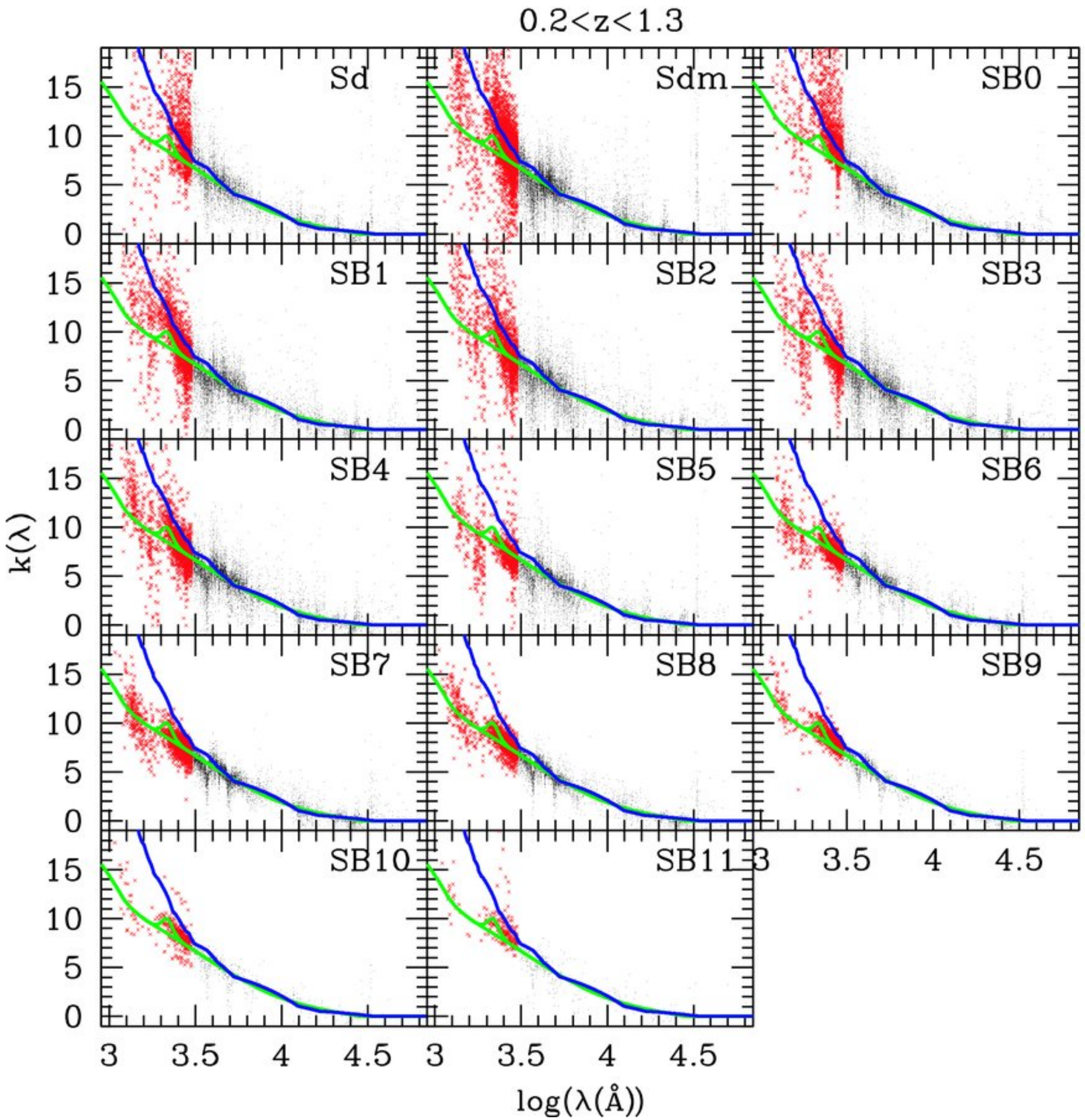
Conroy et al. 2010, broad band colours and model (SDSS)

Similar conclusion by Wild et al 11 but see also Wijesinghe et al. 2010, Johnson et al. 2007

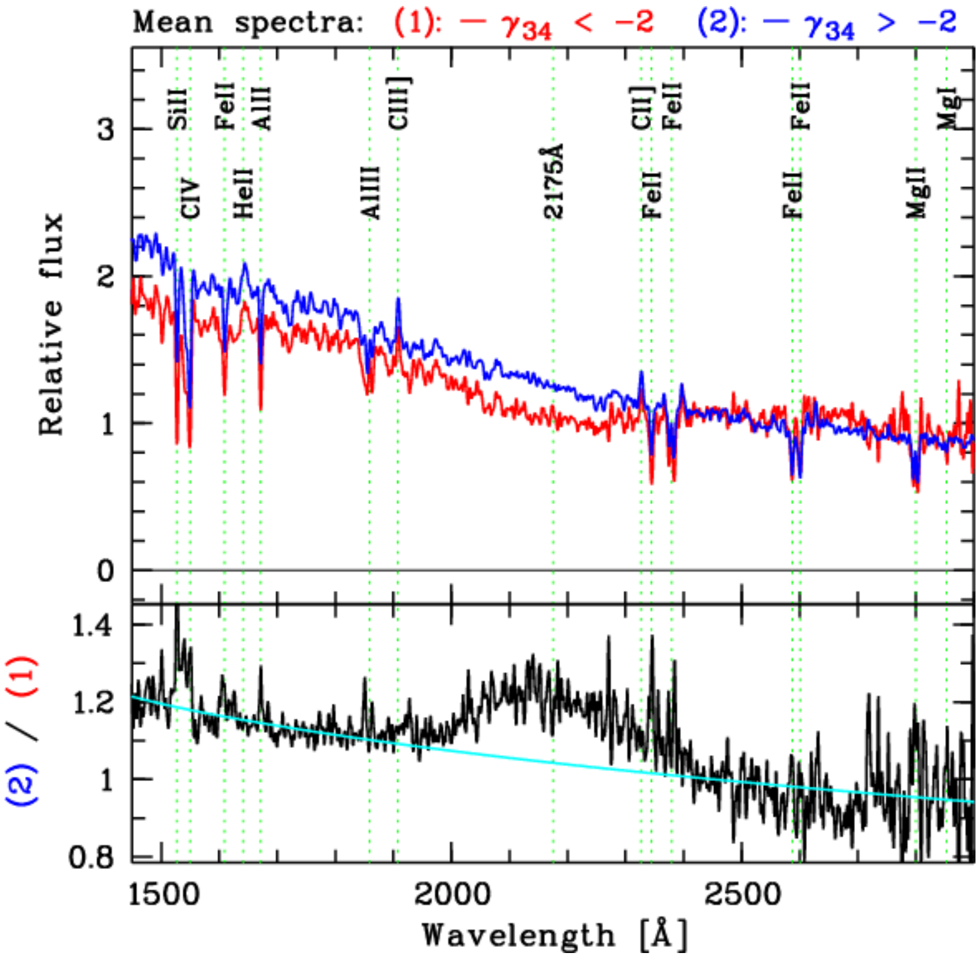
At high z:

Ilbert et al. 2009- Cosmos field-30 photometric bands from UV to NIR:

« A broad absorption excess at 2175 A seems necessary to explain the UV flux of some starburst galaxies »



Composite spectrum 1.5<z<2.5: evidence for a bump
Noll et al. 2009

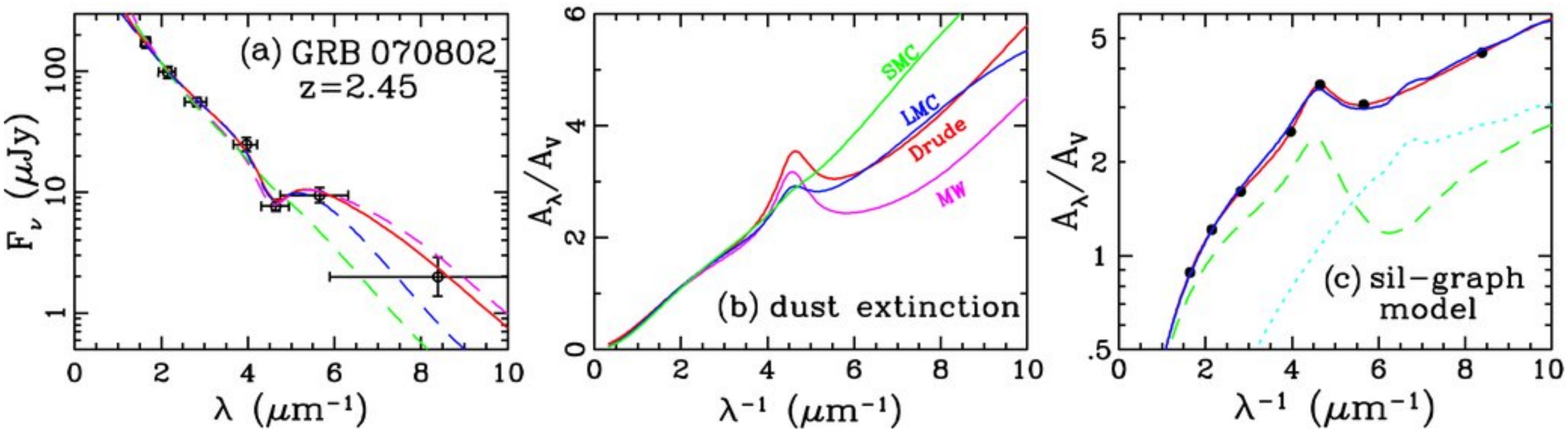


But no evidence for a bump in Lyman Break Galaxies at z≈2 (Vijh et al. 03, Reddy et al. 08)

Gamma-Ray burst afterglow to probe the extragalactic dust

Some evidence for UV bumps, wide diversity of extinction laws

Liang & Li, 2009, 2010



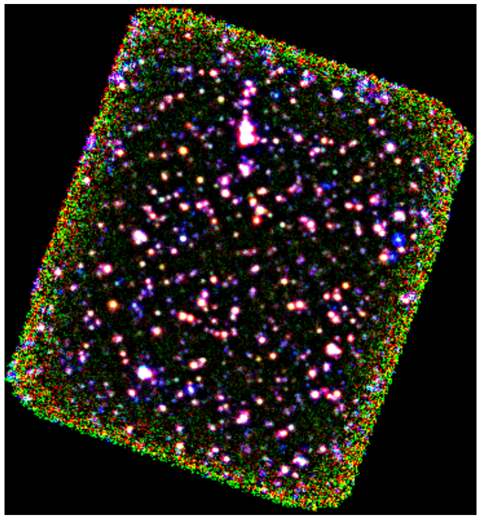
UV bumps also detected in dusty QSO intervening systems

→ Pasquier Noterdaeme's review

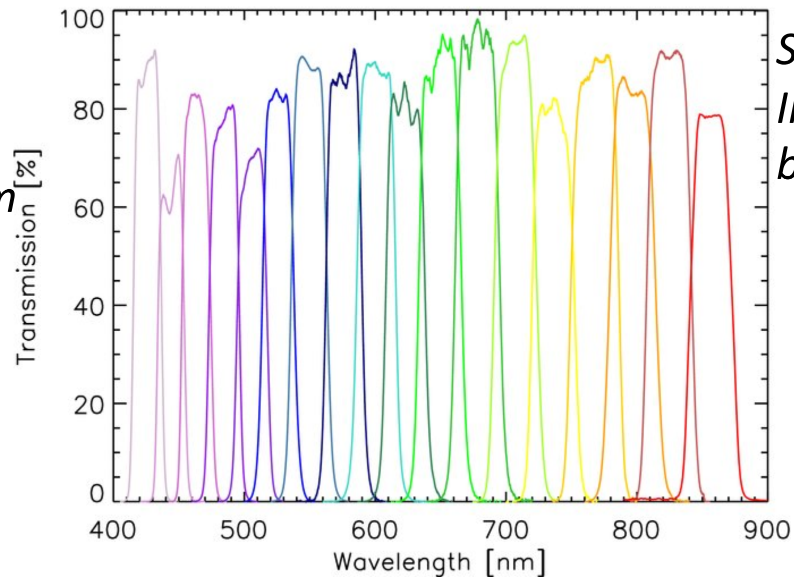
Our approach

- To work at high z to redshift the UV range in the visible
- To combine optical (UV rest-frame) and far-IR data: strong constraint on SFR and dust attenuation
- To use intermediate band filters in optical to tightly sample the UV rest frame

Working in the CDFS combining Herschel/PACS (GOODS-Herschel project) and Subaru/MUSYC broad and intermediate band filters (Cardamone et al. 2010) +IRAC & MIPS data (Dickinson et al. 2003)



GOODS-H-CDFS field at 24-100-160 μm



Subaru Intermediate band filters

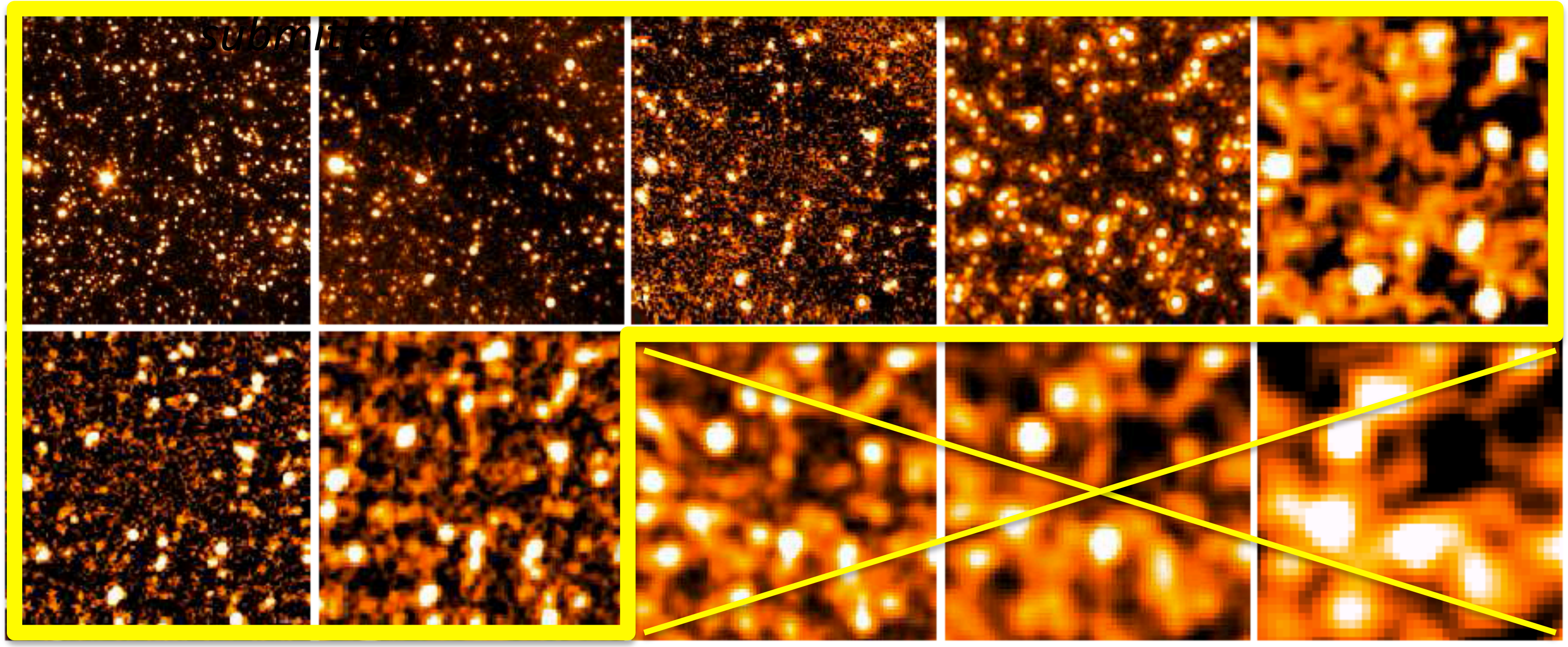
GOODS-*Herschel* project

P.I. D. Elbaz

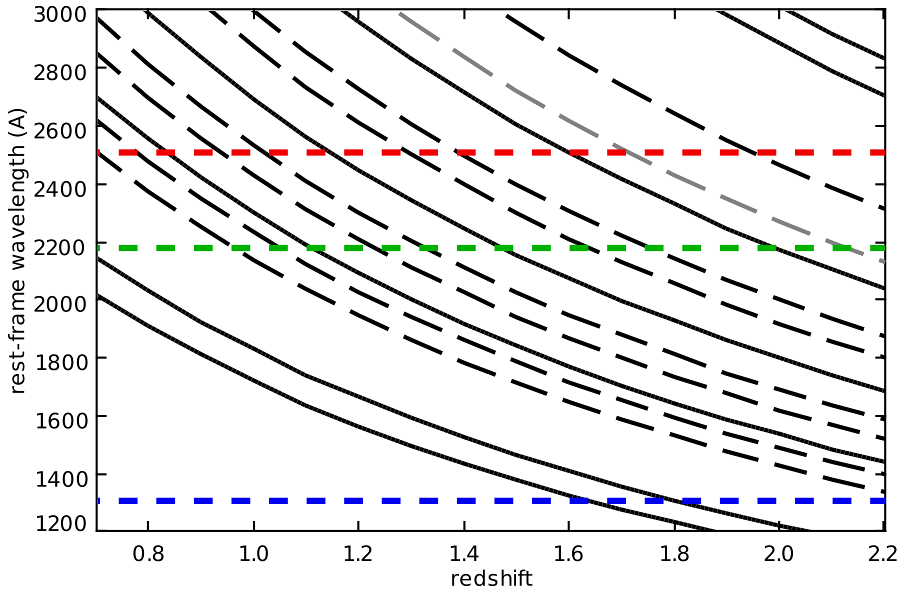
GOODS-N: 10’x15’ PACS+SPIRE, 100, 160, 250, 250, 500 µm 1 mJy @ 100 µm

GOODS-S: 10’x10’ PACS 100,160 µm down to the confusion limit at 100 µm ~0.7 mJy

***GOODS_N, Spitzer* IRAC & MIPS,** *Elbaz et al 2011 A&A submitted*



***Herschel*/PACS** ***Herschel*/SPIRE**



Selection of the sources with 1<z<2 to sample the region of the UV bump

Our sample:

30 sources (28 with spec-z) in the GOODS-S field with **1<z<2** and high SNR in all bands:
SNR > 5 in optical, NIR, mid-IR and at 100 µm, SNR > 3 at 160 µm:
30 photometric bands (12 intermediate band filters)

→SED fitting process applied to the whole SED (UV-to-farIR)
<A(FUV)> = 3.1 ± 1.1 mag <A(V)> = 0.9 ±0.4 mag

CIGALE : Code Investigating GALaxy Emission

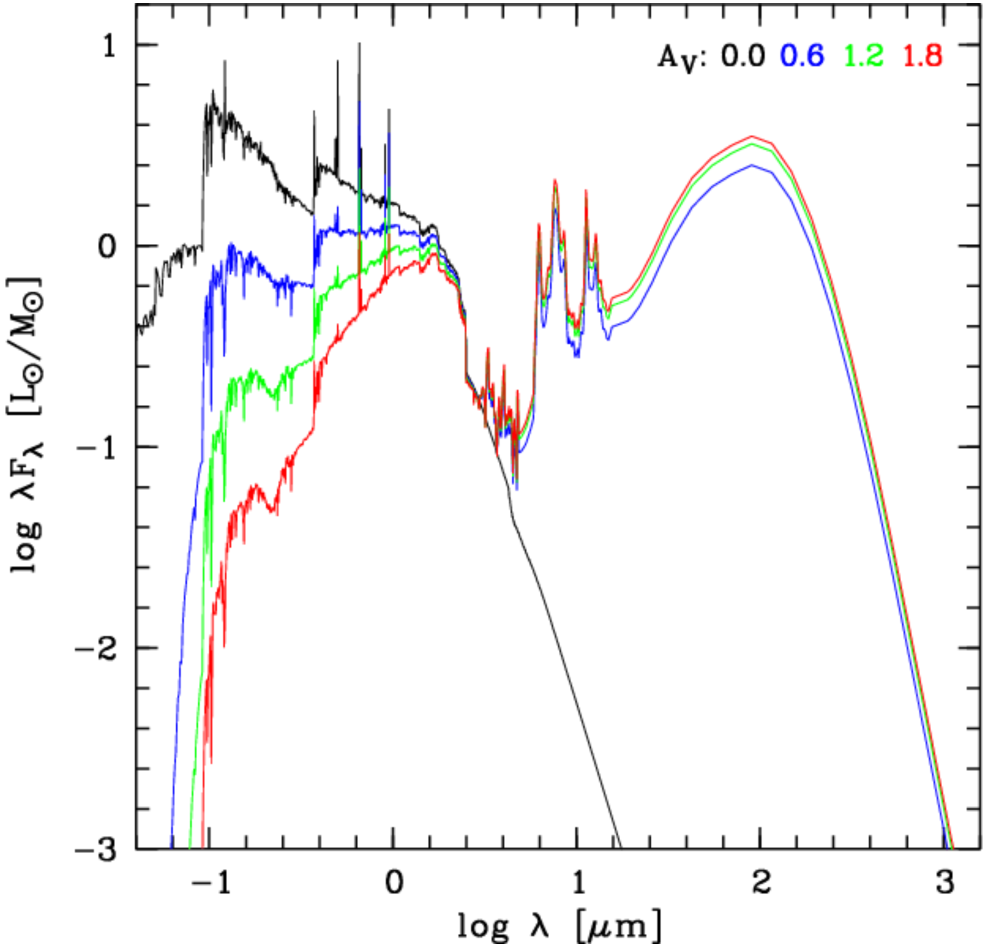
P.I. D. Burgarella (Noll et al. 2009) http://www.oamp.fr/cigale/

see also Elodie Giovannoli's poster

A physically-motivated code:

CIGALE combines a UV-optical SED & a dust IR emitting component:

Energetic balance fully conserved between stellar and dust emission.



INPUT PARAMETERS:

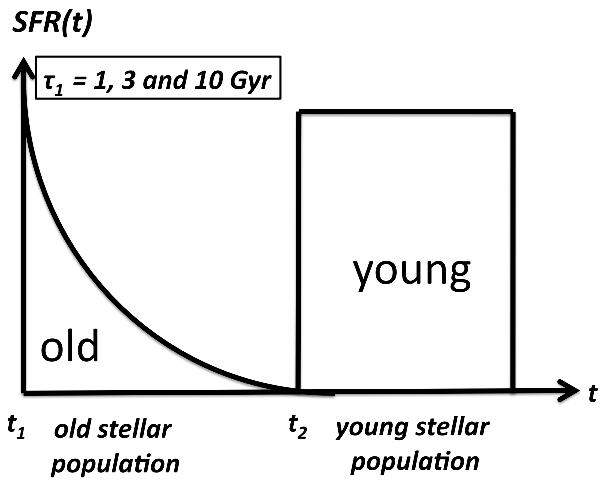
- Photometric data +errors
- Star Formation Histories
- Dust attenuation curves
- IR libraries

OUTPUT PARAMETERS :

All based on a Bayesian analysis

- input parameters
- Stellar Mass
- Dust luminosity
- Amount of obscuration
- D4000 break, slope of the UV continuum....

-STELLAR COMPONENT: two populations



Populations synthesis models of Maraston 2005

DUST ATTENUATION: different amount for the young and the old stellar population

[**Calzetti et al. (2000)** + **UV bump**] × **power law**

$$k(\lambda) = A(\lambda)/E(B-V)$$

$$\frac{E_{\rm bump}\,\lambda^2\gamma^2}{(\lambda^2-\lambda_0{}^2)^2+\lambda^2\gamma^2}$$

$$(\lambda/\lambda_V)^\delta$$

Central wavelength

Width

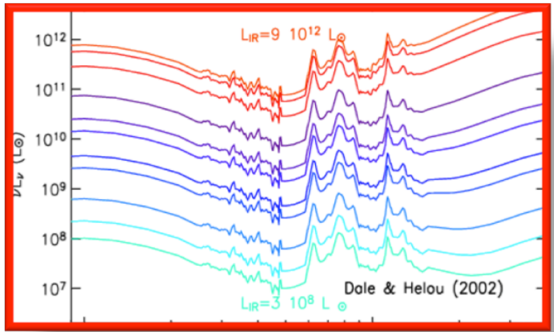
5500 Å

slope

Various mid and far-IR libraries

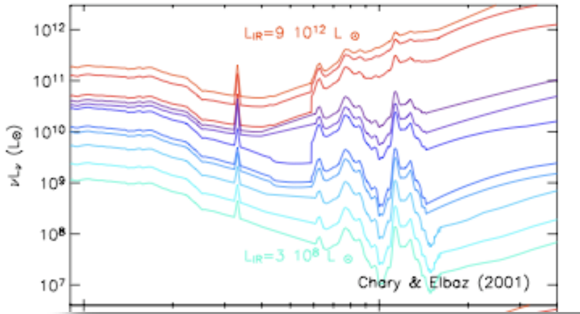
Dale & Helou (2002)

64 templates



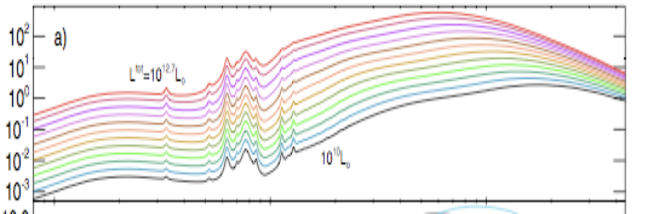
Chary & Elbaz (2001)

105 templates



Siebenmorgen & Krügel (2007)

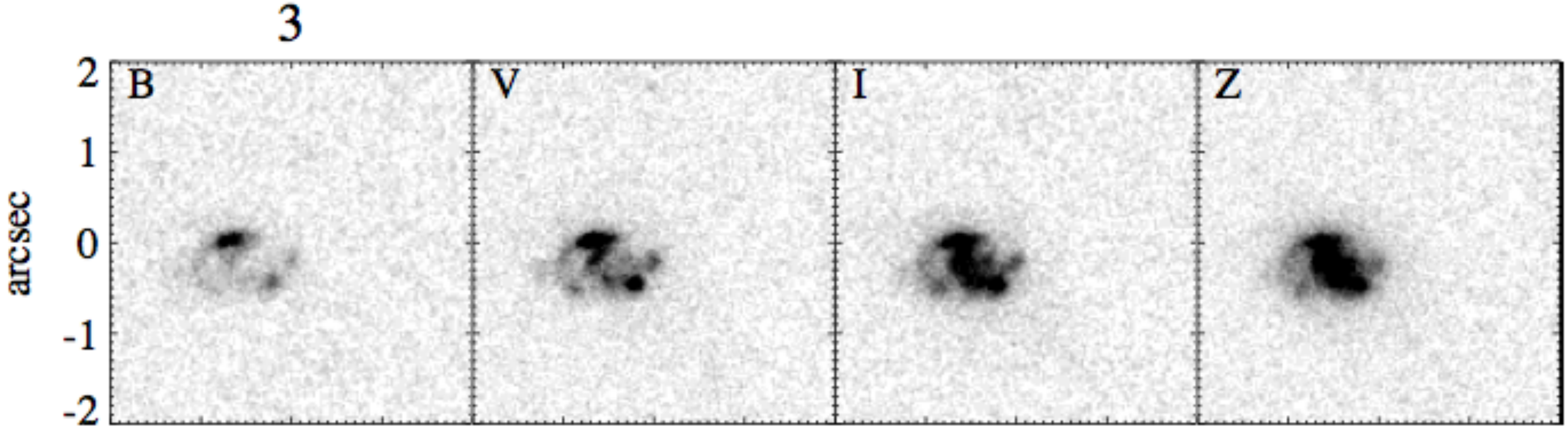
~7000 SEDs



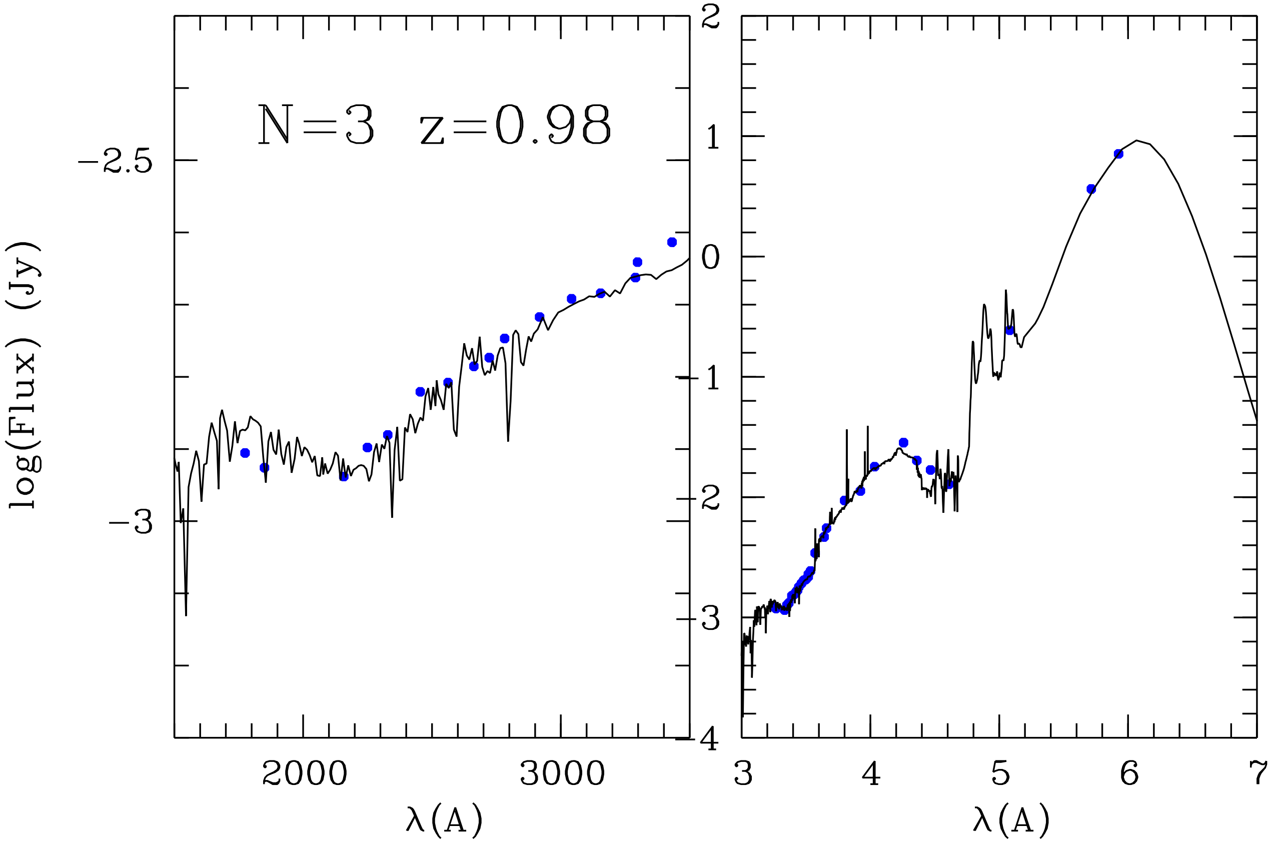
Library of modified Black bodies

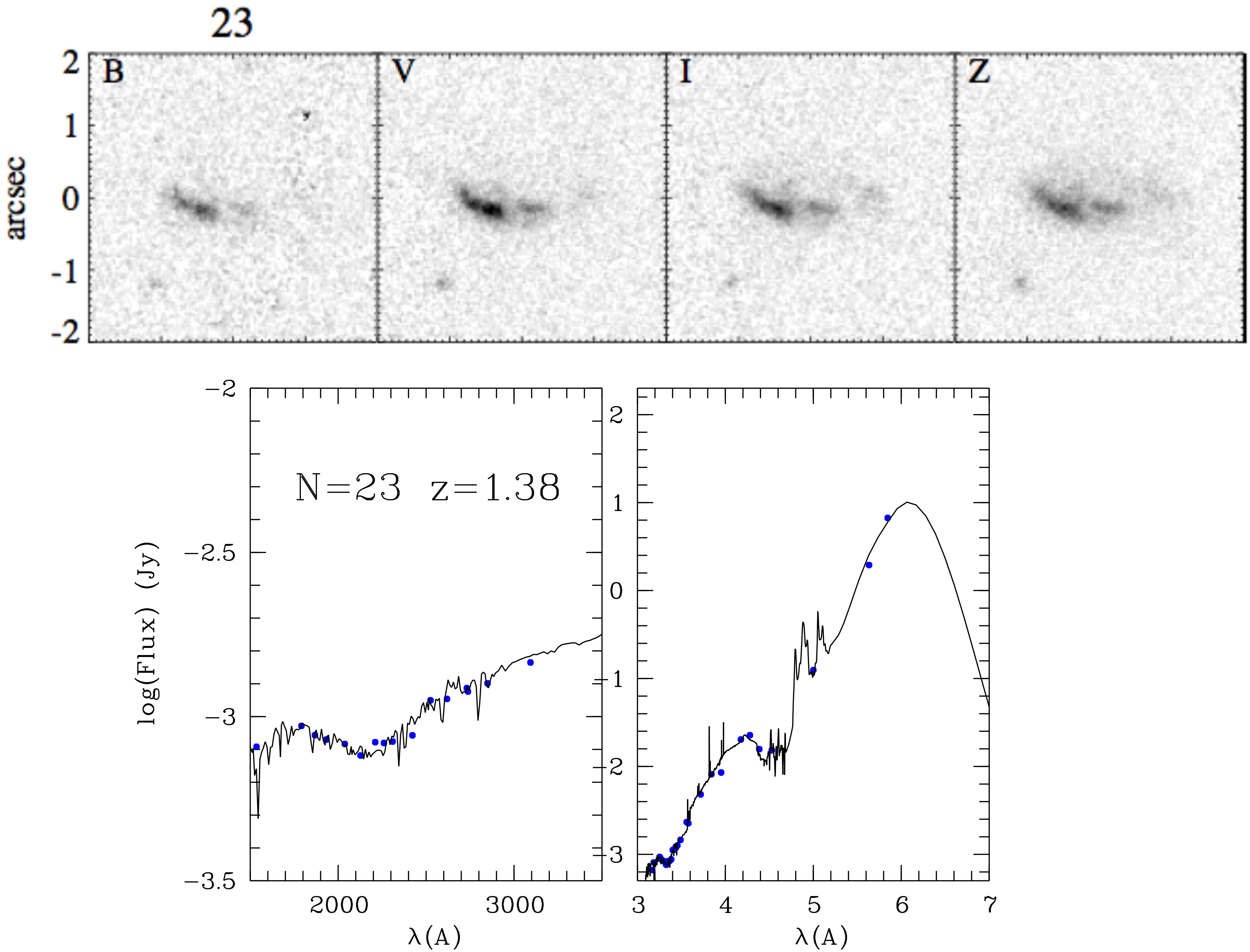
Now : β=1.5, Tdust varies

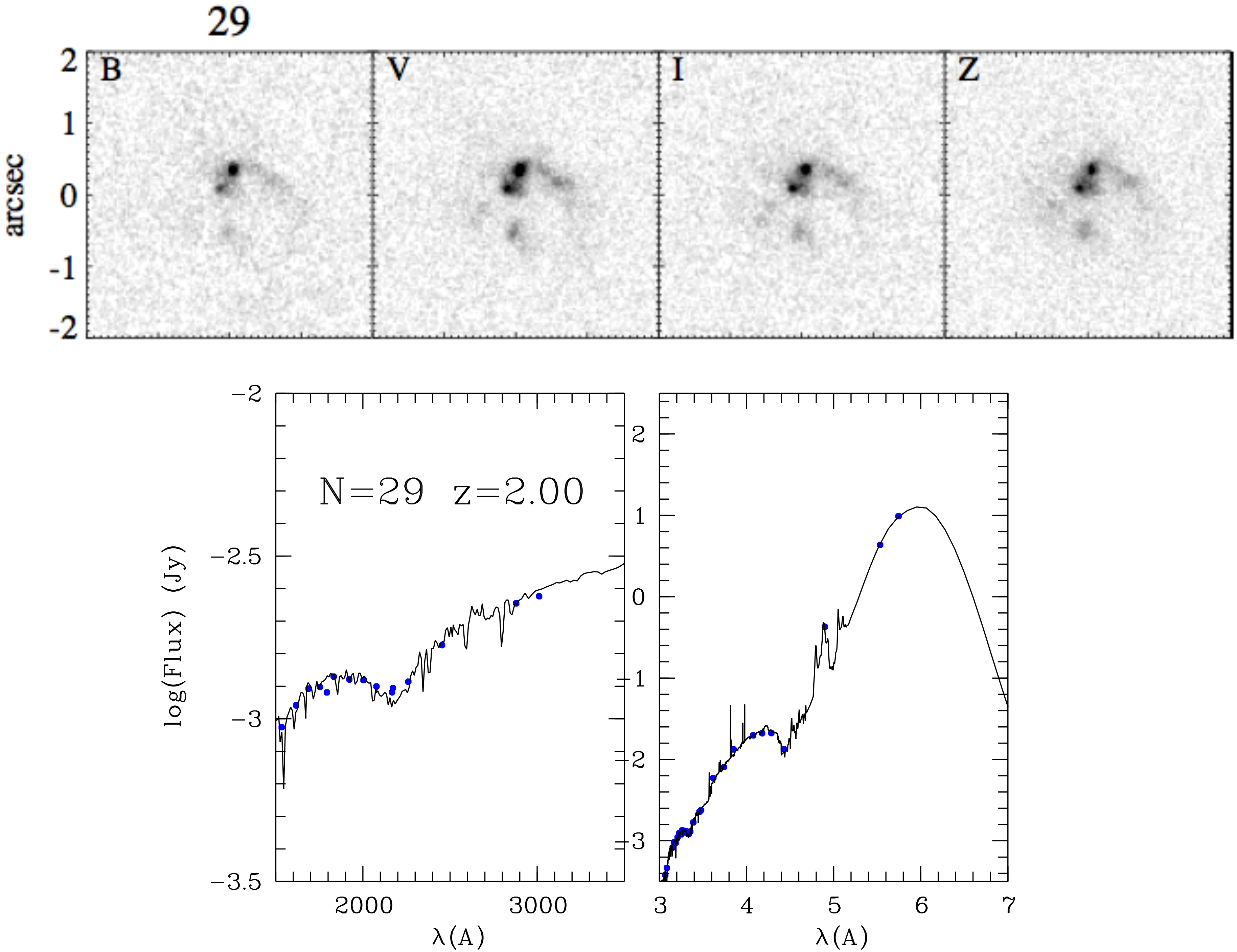
several β and Tdust: collaboration with the ***Herschel Reference Survey Team****, nearby universe*


3
B
V
I
Z
arcsec
2
1
0
-1
-2

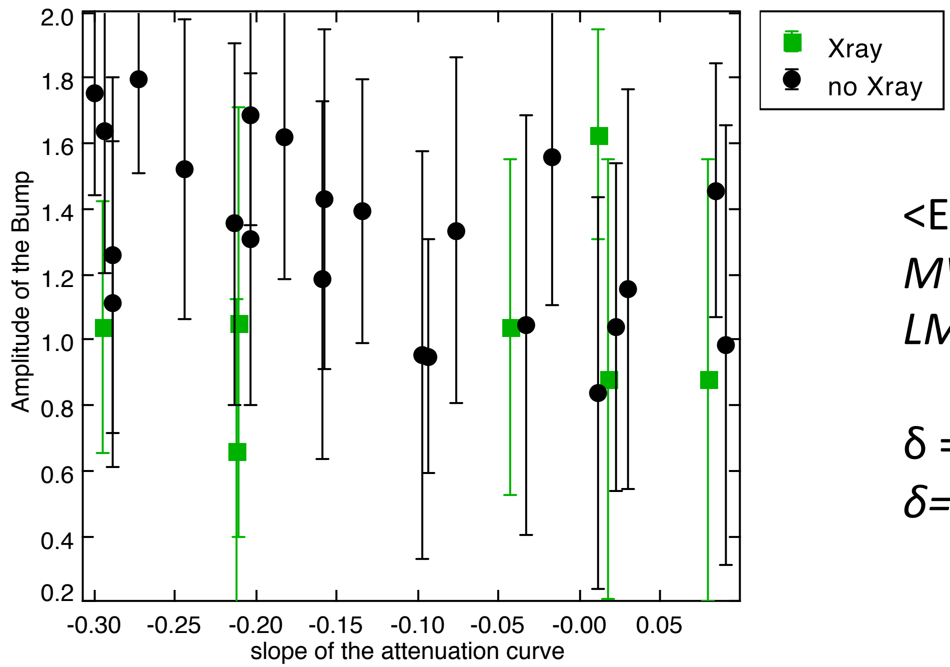
Best model


N=3 z=0.98
log(Flux) (Jy)
−2.5
−3
2000
3000
λ(A)
2
1
0
−1
−2
−3
−4
3
4
5
6
7
λ(A)


23
B
V
I
Z
arcsec
2
1
0
-1
-2
N=23 z=1.38
log(Flux) (Jy)
−2
−2.5
−3
−3.5
2000
3000
λ(A)
2
1
0
−1
−2
−3
3
4
5
6
7
λ(A)



29
B
V
I
Z
arcsec
2
1
0
-1
-2
N=29 z=2.00
log(Flux) (Jy)
−2
−2.5
−3
−3.5
2000
3000
λ(A)
2
1
0
−1
−2
−3
3
4
5
6
7
λ(A)



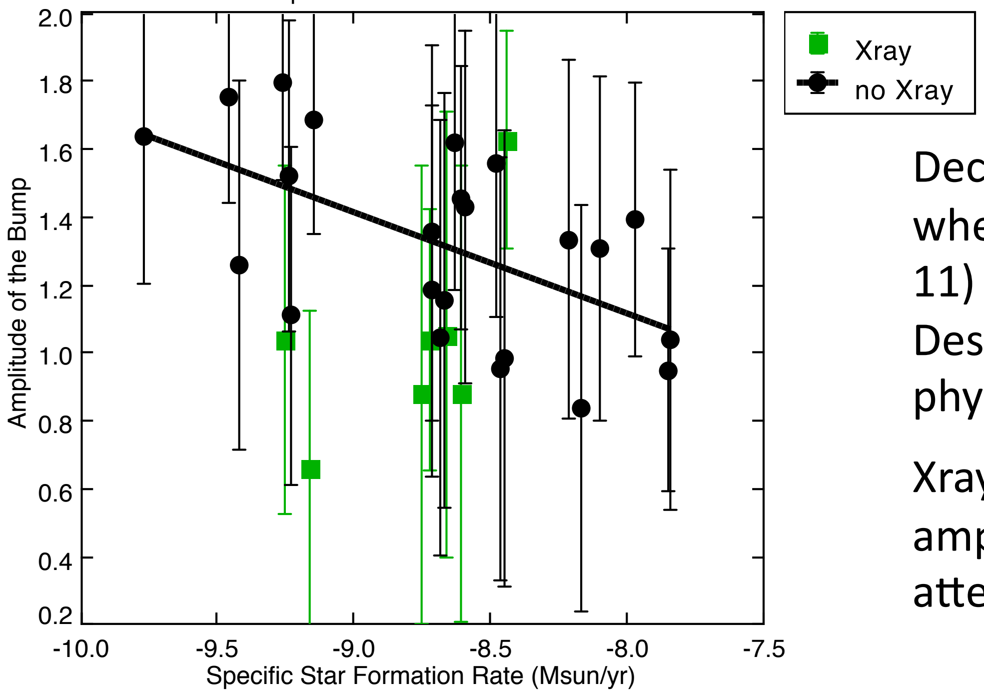
$\langle E_b \rangle = 1.26 \pm 0.30$

MW: $E_b^{MW} = 3.52 \rightarrow E_b \approx 0.35\ E_b^{MW}$

LMC2: $E_b^{LMC2} = 1.63 \rightarrow E_b \approx 0.76\ E_b^{LMC2}$

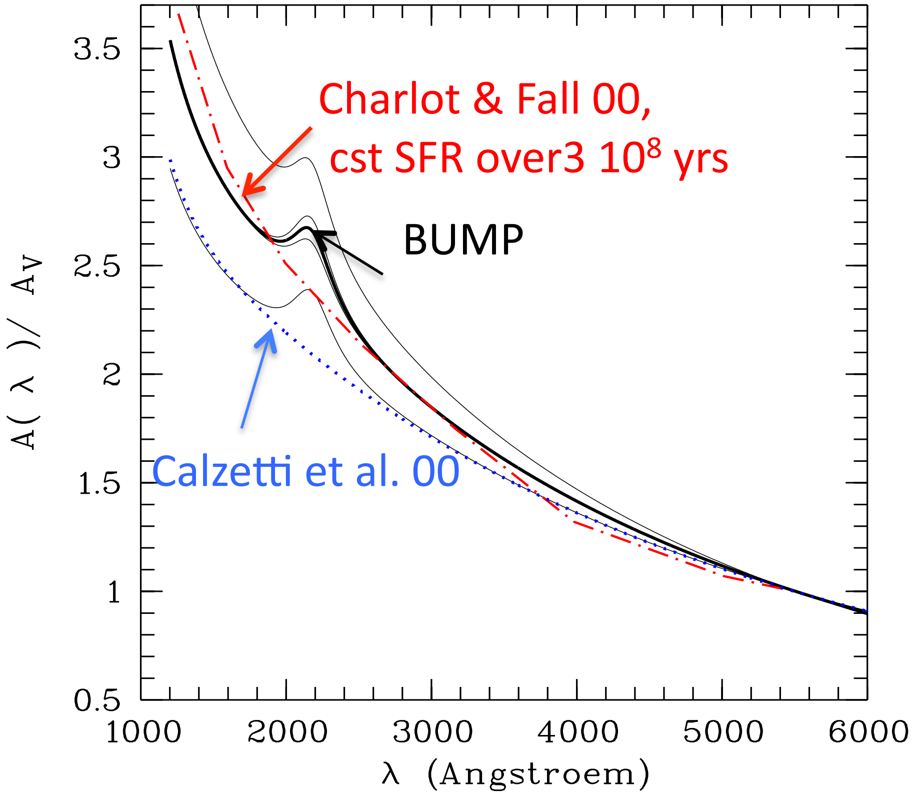
$\delta = -0.13 \pm 0.12$

$\delta = 0$ *, Calzetti et al. 00*



Decrease of the amplitude of the bump when SSFR increases (see also Wild et al. 11) →
Destruction of bump carriers in extreme physical environments?

Xray galaxies (7 sources): lower amplitude of the bump if any, steep attenuation curve



General shape of the average attenuation curve consistent with that of Charlot & Fall and (marginally) with that of Calzetti et al.

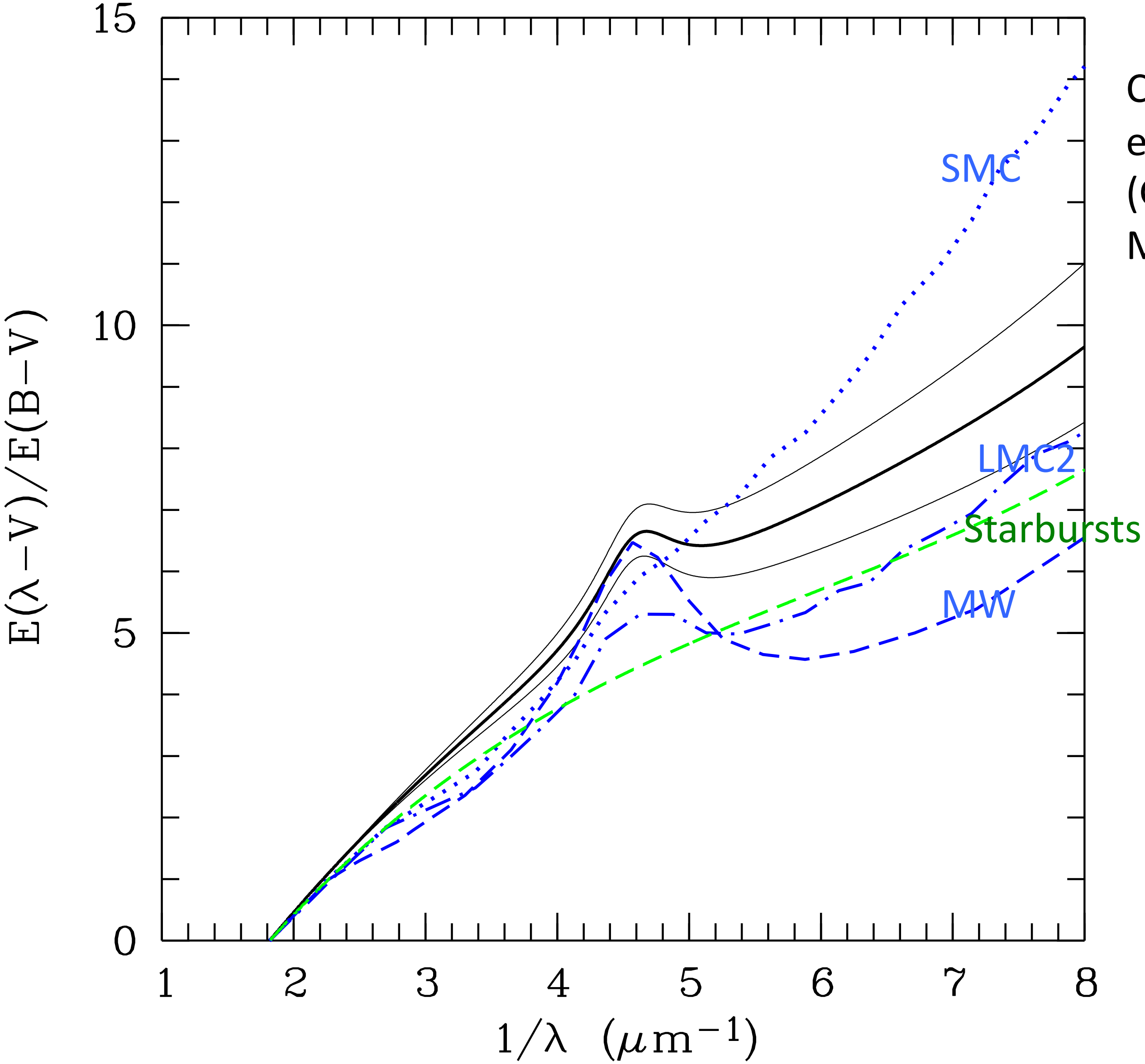
on top of which there is a bump at 2175 A whose amplitude is 35% (76%) that of the MW (LMC2) one .

Width of the feature: 356 Å (437 Å for the MW)

$$\frac{A(\lambda)}{A_V} = \frac{k'(\lambda) + D_{\lambda_0,\gamma,E_b}(\lambda)}{4.05}\left(\frac{\lambda}{\lambda_V}\right)^{-0.13} \quad (3)$$

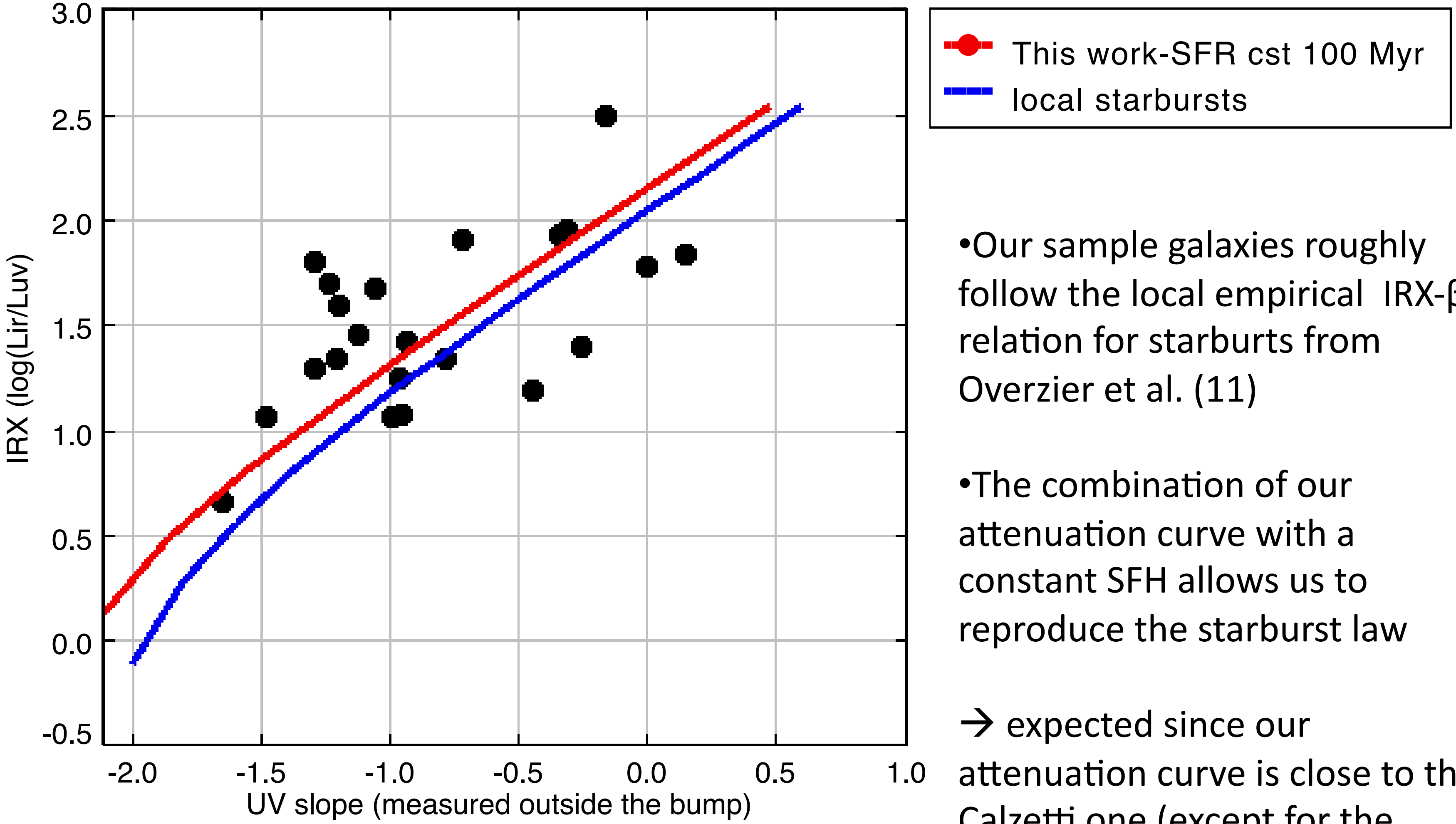
where $\lambda_V = 5500$ Å, $k'(\lambda)$ is given in Calzetti et al. (2000) (Eq.4) and

$$D_{\lambda_0,\gamma,E_b}(\lambda) = \frac{1.26 \times 356^2 \lambda^2}{(\lambda^2 - 2175^2)^2 + \lambda^2 \times 356^2} \quad (4)$$



Comparison with the extinction curves (Gordon et al. 03):SMC, MW and LMC2

IRX (L_{IR}/L_{UV})-β relation



$$f_\lambda \propto \lambda^\beta$$ 1200-2500 Å

- Our sample galaxies roughly follow the local empirical IRX-β relation for starburts from Overzier et al. (11)
- The combination of our attenuation curve with a constant SFH allows us to reproduce the starburst law

→ expected since our attenuation curve is close to the Calzetti one (except for the bump)

Influence of the bump on the determination of the so-called UV slope with broad band filters

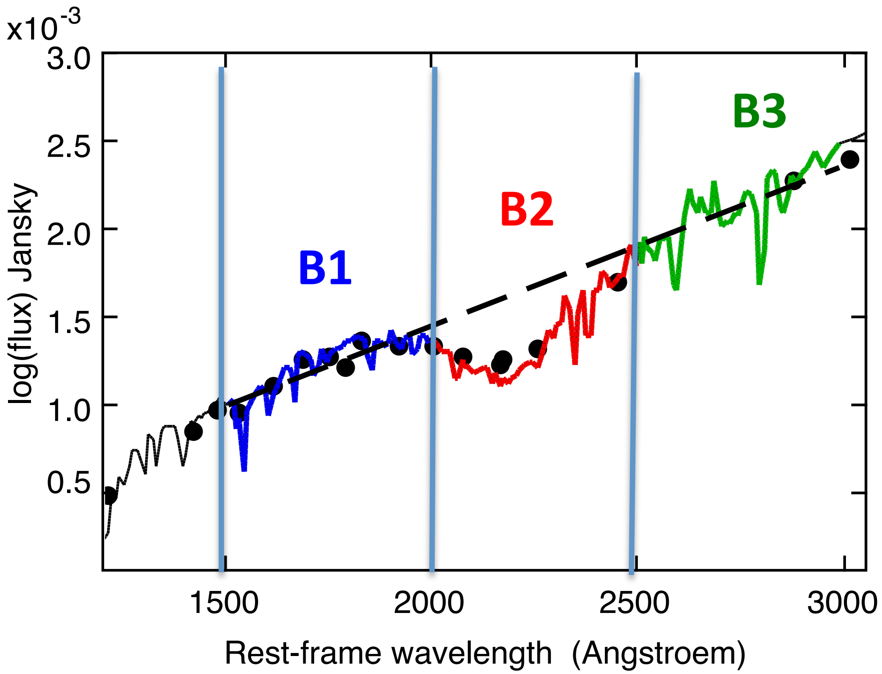
$$f_\nu \propto \lambda^{\alpha} \propto \lambda^{\beta+2}$$

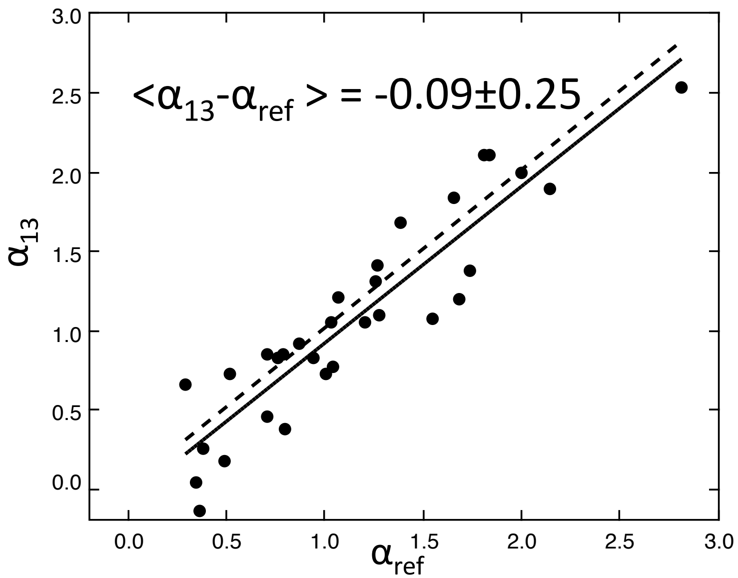
α_{ref} : UV slope (data points excluding 1975-2375 Å)

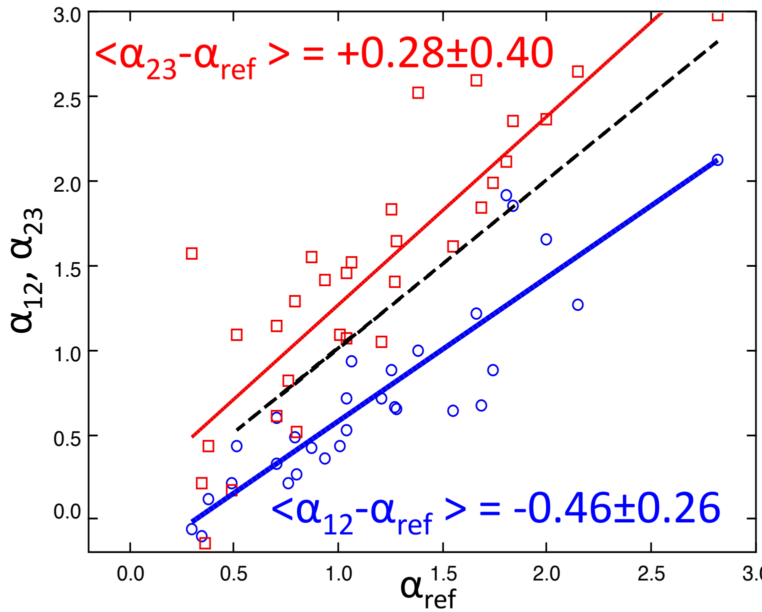
α_{13} with B1 and B3

α_{12} with B1 and B2

α_{23} with B2 and B3







Summary:
Main properties of the sample

- Sample of 30 galaxies with $\langle z \rangle = 1.3 \pm 0.3$, observed in 30 photometric bands from U38 to 160 μm
- SED fitting with CIGALE
- Mean dust attenuation of the sample:

  $\langle A(FUV) \rangle = 3.1 \pm 1.1$ mag $\langle A(V) \rangle$ 0.9 ± 0.4 mag

- **Evidence for a bump at 2175 A in the attenuation curve of these galaxies whose amplitude is 35% (76%) that of the MW (LMC2) extinction curve**

- UV rise slightly steeper than that of the Calzetti et al (2000) attenuation curve
- Our galaxy sample follows the IRX-ß relation found for local starbursts when the bump area is avoided to calculate ß.

BUT departures of 0.3-0.4 units (at most) can be found if ß is calculated from a broad band colour with one of the broad band filter bandpass covering the bump area.

Further analysis

•**Confronting our empirical attenuation curve to models:**
they must reproduce the (moderate) amplitude of bump and the (moderate)UV rise
→Either a destruction of bump carriers or dust-stars geometries to weaken the UV bump (starting with a MW-like dust) and to produce a rather gray UV attenuation curve
→Models of Pierini et al (2004), Panuzzo et al. (2006), Tuffs et al (2004) seem promising.

•**Exploring a larger sample of galaxies**
To study the variation of the attenuation curve as a function, for example, of the amount of attenuation (predicted by the models)