

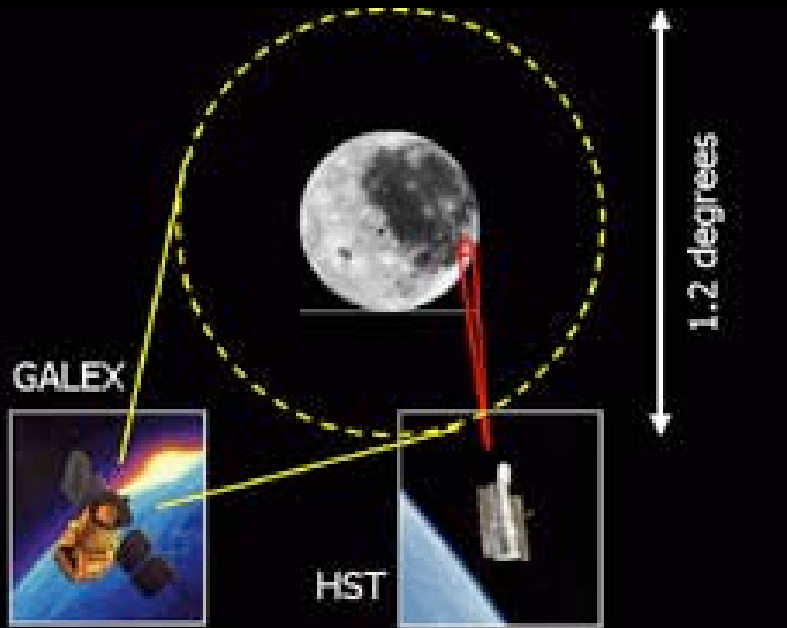


**GALEX**  
**Galaxy Evolution**  
**Explorer**

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# Qu'est-ce que GALEX ?



- ❖ P.I. : C. Martin (CALTECH) + JHU + Korea + OAMP/LAM (CNES)
- ❖ 50-cm Ritchey-Chretien
- ❖ Field of View :  $\varnothing$  1.24-deg
- ❖ 2 bands : FUV about 150nm & NUV about 250nm
- ❖ Spatial Resolution: 3-5 arcsecs FWHM (like UIT)
- ❖ Imaging
- ❖ Slitless Spectroscopy :  $R = 100 - 200$
- ❖ Launch : April 03 and 1st light May 03

# La Mission de GALEX

GALEX a été sélectionné par la NASA pour conduire plusieurs 'surveys' :

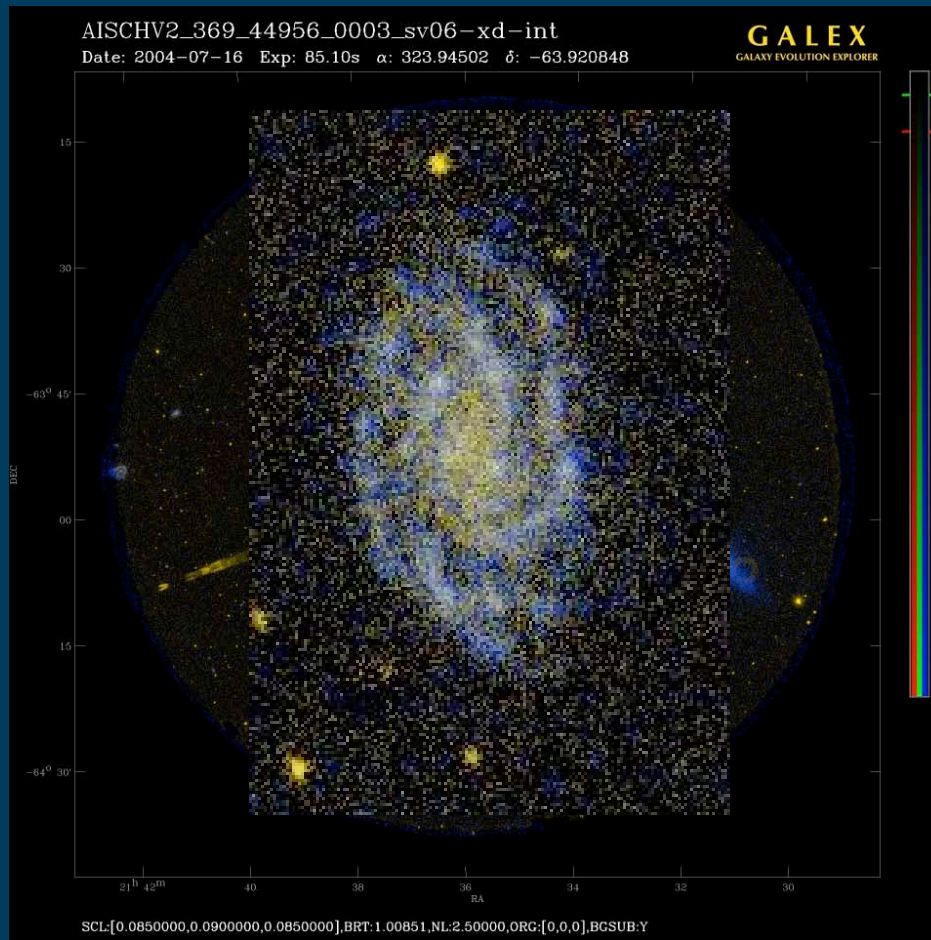
SURVEY	Area [deg]	Length [Month]	Expos [ksec]	m lim	log #Gals	Volume	$\langle z \rangle$	Comments
All-sky (AIS)	>35,000	4	0.1	20.5	7	1.5	0.2	Galactic caps first
Medium Imaging (MIS)	1000	2	1.5	23	6.5	~1	0.6	SDSS, 2dF overlap
Deep Imaging (DIS)	80	4	30	25	7	~1	0.85	<a href="#">Fields</a>
Ultra-Deep Image (UDIS)	4	1	200	26	5.5	0.05	0.9	<a href="#">Fields</a>
Nearby Galaxy (NGS)	200	0.5	1.5	27.5 m	2.5	---	0.001	Galaxy List
Wide Spectroscopic (WSS)	80	4	30	20	4.5	0.03	0.15	Same area as DIS
Medium Spectroscopic (MSS)	8	2	300	21-23	4.5	0.03	0.5	Centers of WSS
Deep Spectroscopic (DSS)	2	4	1500	22.5-24	4.5	0.04	0.9	<a href="#">Fields</a>

# All-sky Imaging Survey (AIS)

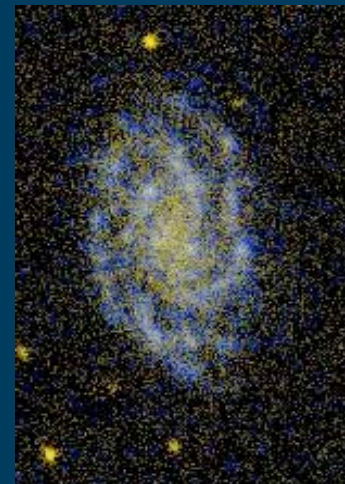
- Temps de pose de l'ordre de 100 sec  
□ magnitude (AB) limite 21
- Disque de la Voie Lactée peu observé (risques pour le détecteur)
- A ce jour : 7183 champs sur 6850 degrés carrés et tps pose total de 900000 sec ou 10 jours
- Mise à disposition de 3500 degrés carrés lors du GR1

# All-sky Imaging Survey (AIS)

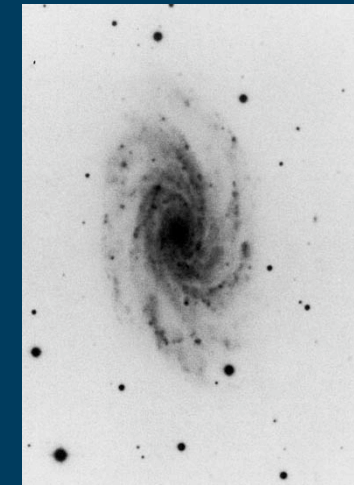
## Image AIS (85 sec) du champ NGC 7083



UV



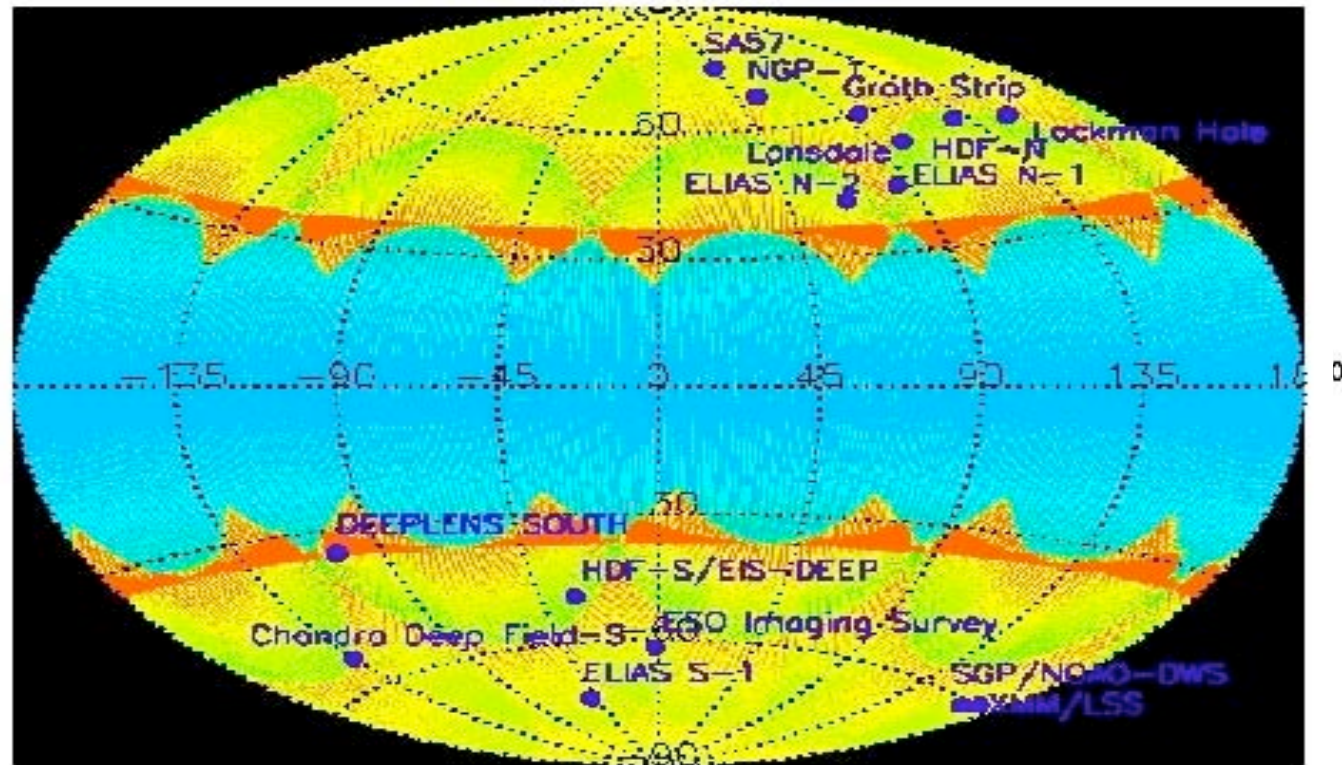
B



# All-sky Imaging Survey (AIS)

GALEX Mission Status as of 041117T14.3602Z  
Coverage depth (seconds)

- Out of range
- > 4
- > 16
- > 64
- > 2.6e+02
- > 1e+03
- > 4.1e+03
- > 1.6e+04
- > 6.6e+04
- > 2.6e+05
- > 1e+06



Coverage depth (seconds)

amorin 17-Nov-2004 08:01

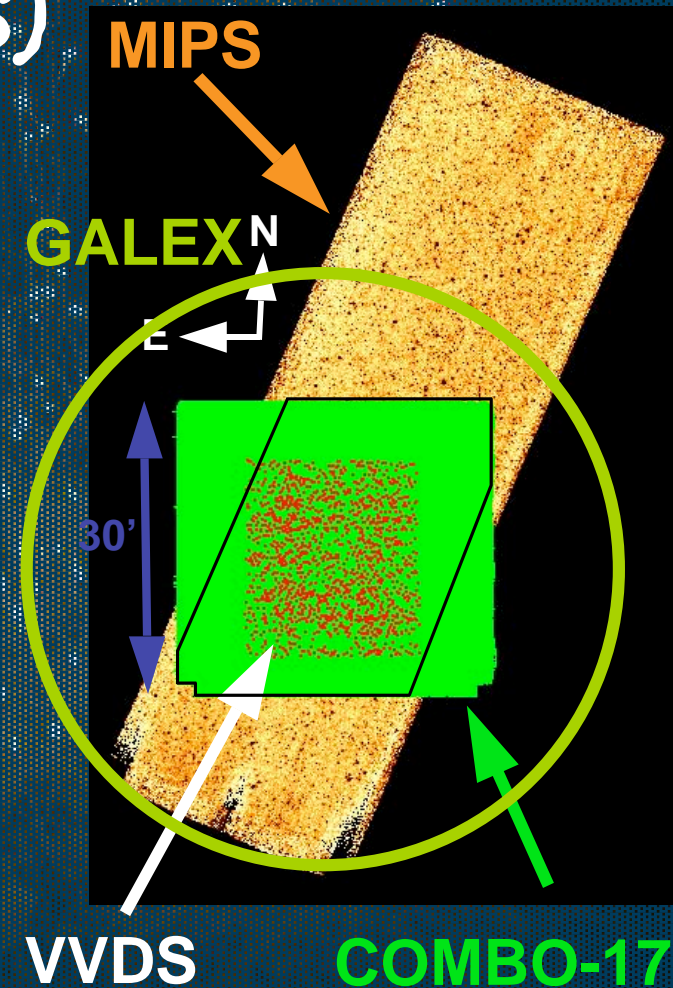
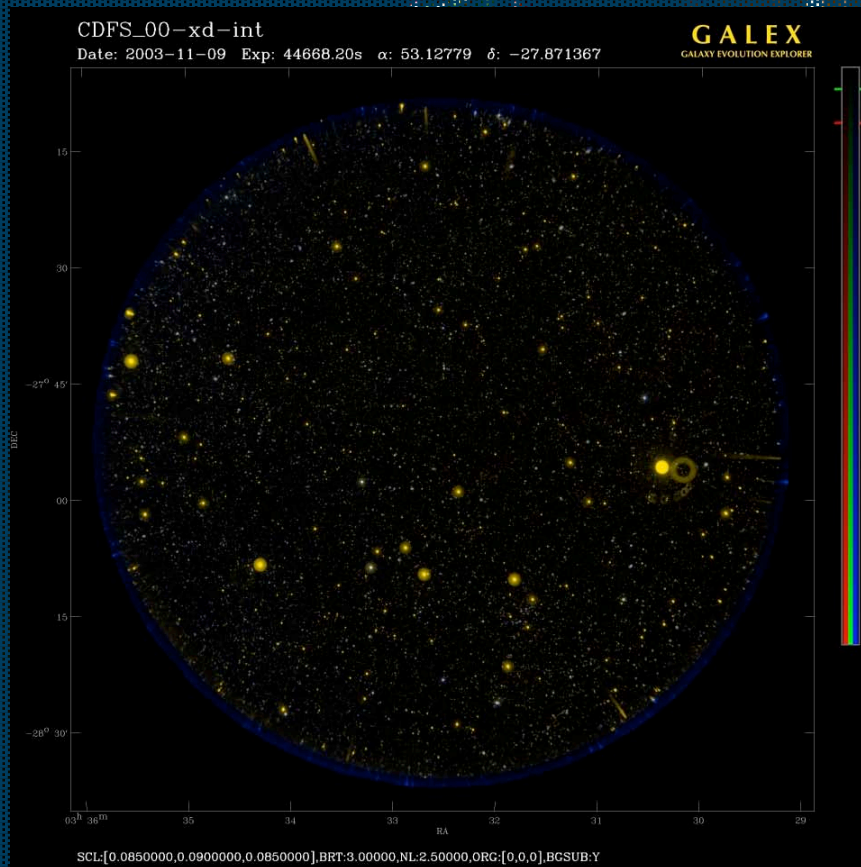
# Deep Imaging Survey (DIS)

- Exposition de l'ordre de  $4.5 \times 10^4$  sec par bande  $\square$  mag (AB) limite 25
- 80 deg<sup>2</sup> (pose moyenne :  $2 \times 10^4$  sec)
- Données multi- $\square$  disponibles ou en acquisition
- Champ Ultra-DIS ( $2 \times 10^5$  sec et MAB (lim = 26) : non déterminé

Region	RA	DEC	#FIELDS [deg <sup>2</sup> ]	GALEX				COROLLARY					
				DIS	WSS	UIS	MSS	DSS	20 cm	FIR	NIR	Opt	X-ray
Deep Regions													
Chandra Deep Field-S	53.128	-27.871	7	X	X	X		X		SWIRE, GOODS	ESO	VIMOS	C
COSMOS	150.12	2.2058	4	X	X	X	X						HST
DEEPLENS	79.440	-48.99	6	X	X								DEEP Lensing
ELAIS S-1	9.539	-43.990	15	X	X					SWIRE			
ELAIS N-1	243.404	54.984	10	X	X					SWIRE			
ELAIS N-2	249.212	41.039	5	X	X					SWIRE			
GALEX Low background	TBD	TBD	~3	X	X	X							
Groth Strip	214.992	52.782	5	X	X	X	X			SIRTF			DEEP
Lockman Hole	162.683	58.729	15	X	X					SWIRE			
NOAO Deep Wide Survey	219.156	35.171	12	X	X	X		X		SIRTF			DWS
SIRTF 1st Look	259.124	59.909	6	X	X		X			SIRTF			R-band
XMM/LSS	36.661	-4.48	10	X	X	X	X			SWIRE			WDS, VIMOS X

# Deep Imaging Survey (DIS)

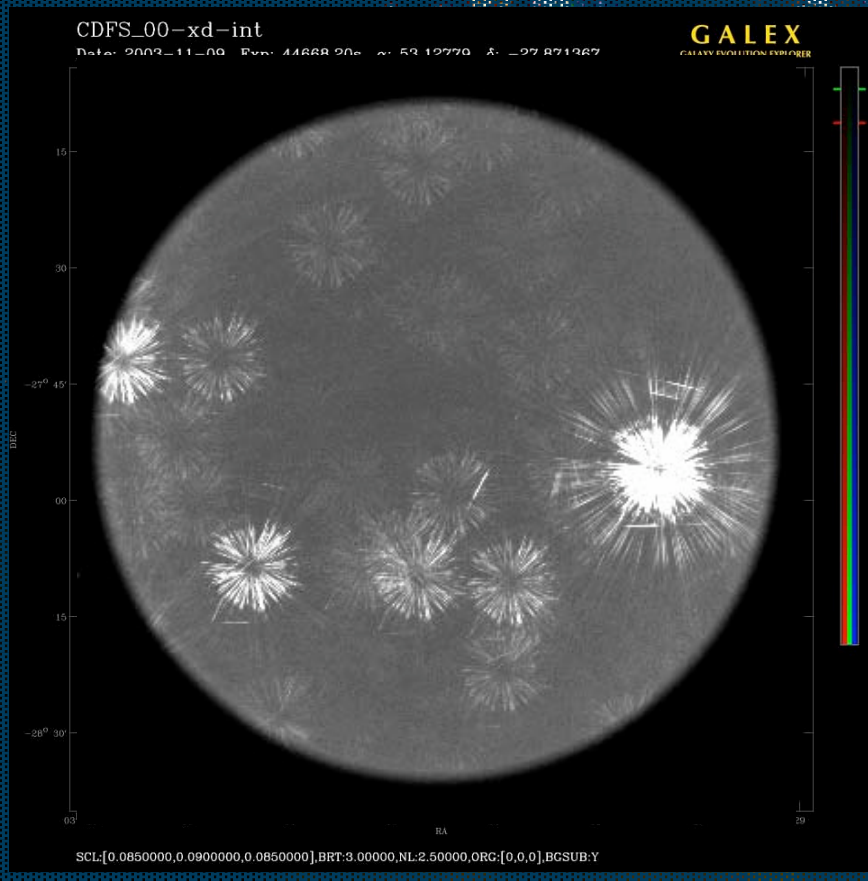
- Le champ DIS centré sur le Chandra Deep Field South (CDFS)





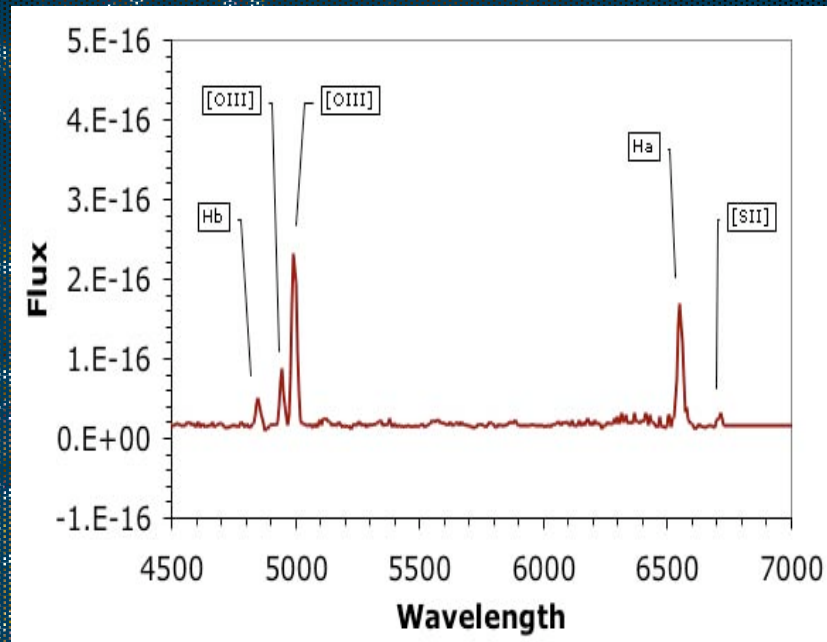
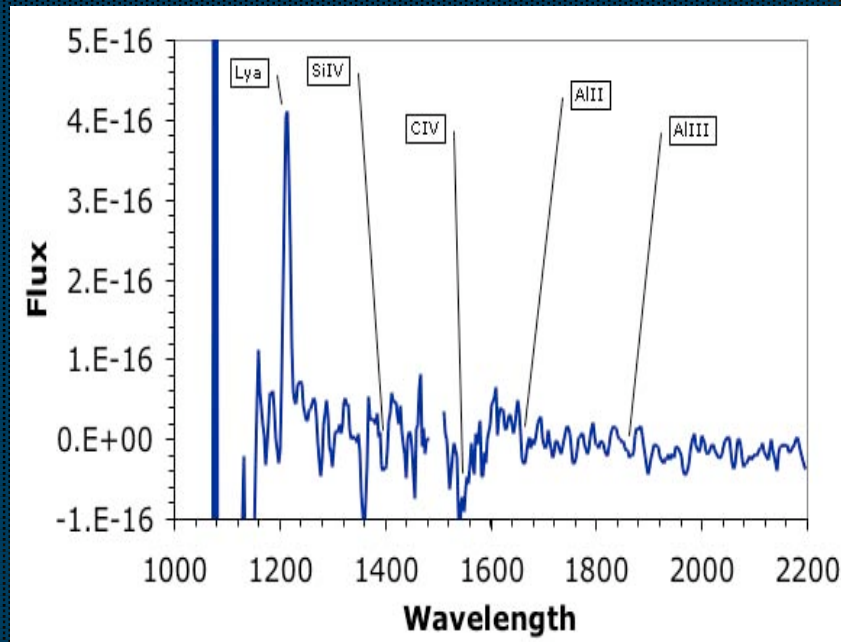
# Deep Spectroscopic Survey (DSS)

- Exposition de l'ordre de  $2 \times 10^5$  sec ( $\approx 3 \times 10^5$ ) mag (AB) limite 23-24



Region	RA	DEC	#FIELDS [deg <sup>2</sup> ]	GALEX					COROLLARY				
				DIS	WSS	UIS	MSS	DSS	20 cm	FIR	NIR	Opt	X-ray
Deep Regions													
Chandra Deep Field-S	53.128	-27.871	7	X	X	X		X		SWIRE, GOODS	ESO	VIMOS	C
COSMOS	150.12	2.2058	4	X	X	X	X					HST	
DEEPLENS	79.440	-48.99	6	X	X							DEEP Lensing	
ELAIS S-1	9.539	-43.990	15	X	X					SWIRE			
ELAIS N-1	243.404	54.984	10	X	X					SWIRE			
ELAIS N-2	249.212	41.039	5	X	X					SWIRE			
GALEX Low background	TBD	TBD	~3	X	X	X							
Groth Strip	214.992	52.782	5	X	X	X	X			SIRTF		DEEP	
Lockman Hole	162.683	58.729	15	X	X					SWIRE			
NOAO Deep Wide Survey	219.156	35.171	12	X	X	X		X		SIRTF		DWS	
SIRTF 1st Look	259.124	59.909	6	X	X		X			SIRTF		R-band	
XMM/LSS	36.661	-4.48	10	X	X	X	X			SWIRE		WDS, VIMOS	X

# Exemple de GALEX + VIMOS



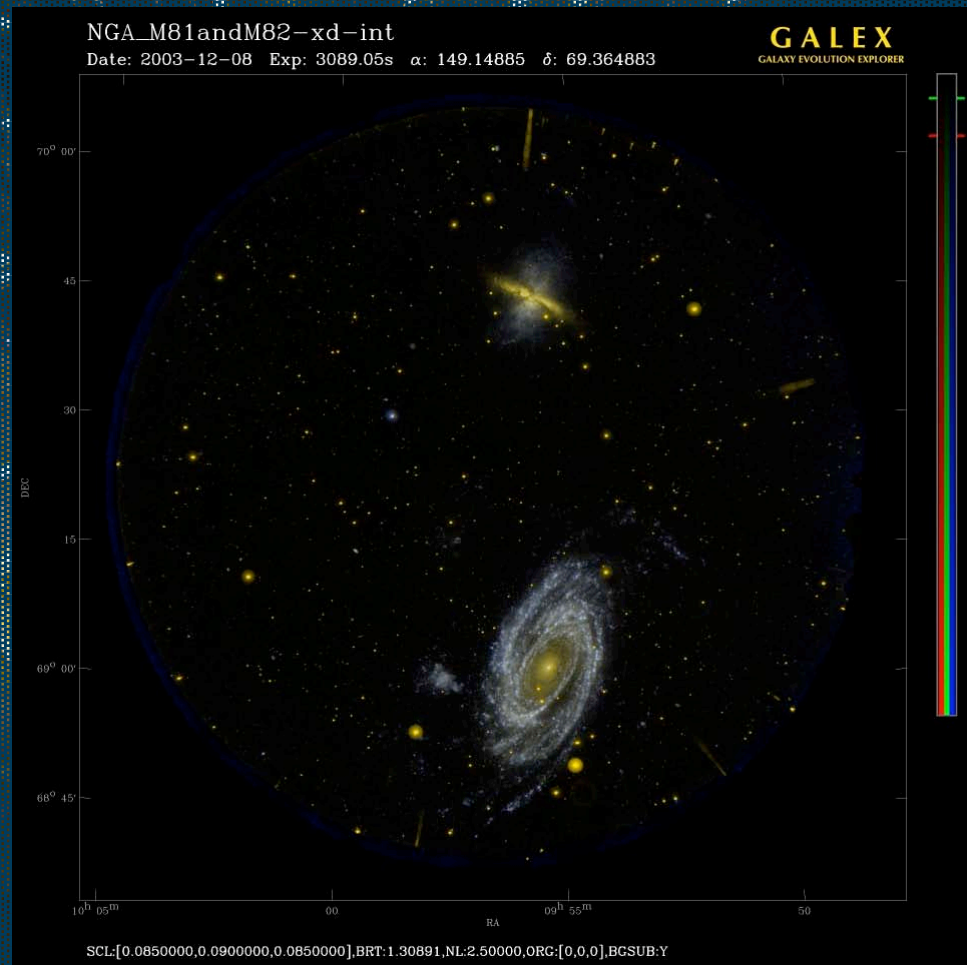
**STARBURST IN THE CHANDRA DEEP FIELD SOUTH OBSERVED BY GALEX IN ULTRAVIOLET AND BY VIMOS**

**([HTTP://CENCOSW.OAMP.FR/](http://cencosw.oamp.fr/))**

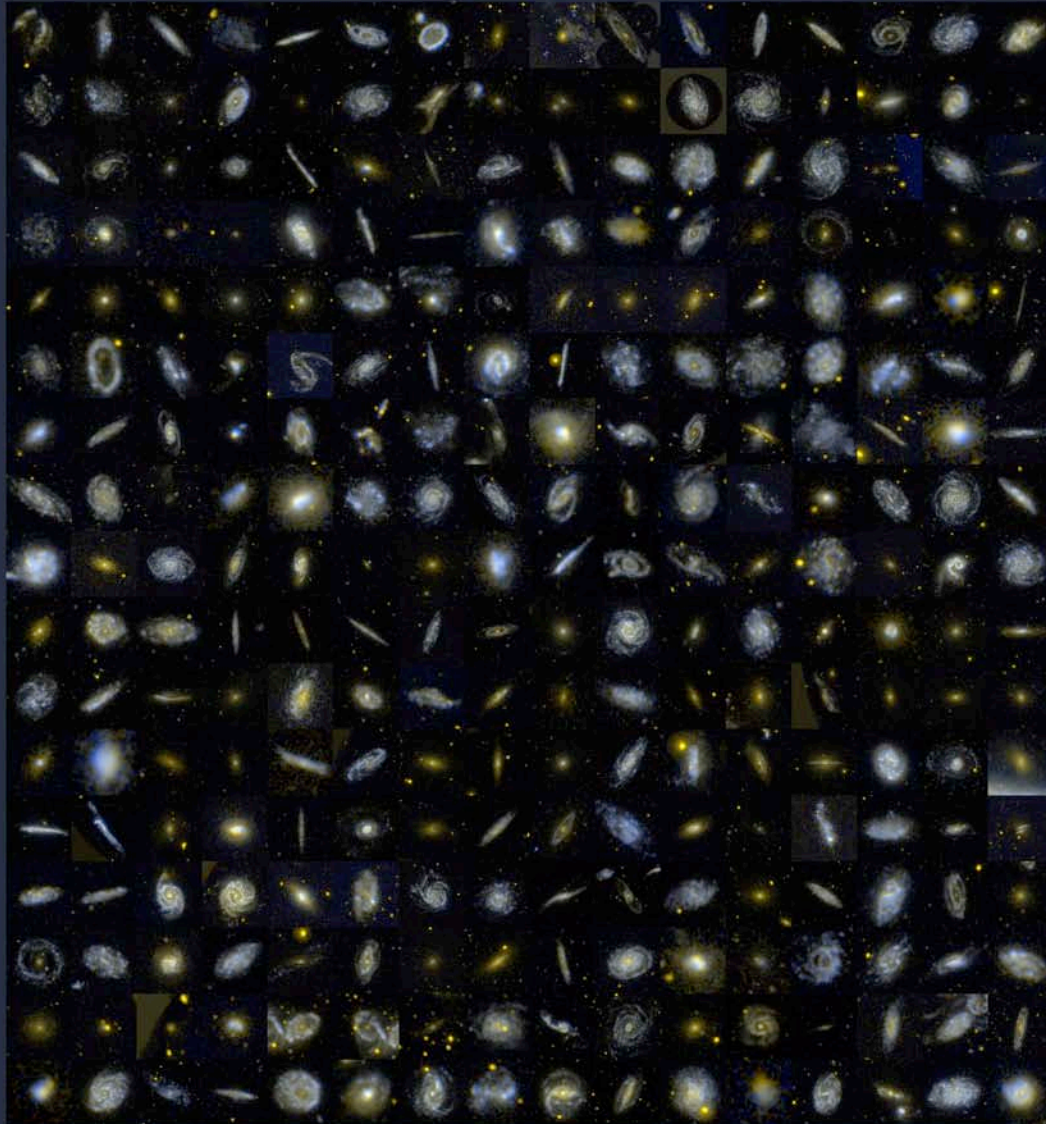
**A CLEAR LYMAN  $\alpha$  EMISSION IS DETECTED IN THE SPECTRUM OF THIS GALAXY AT A REDSHIFT  $z = 0.2258$ .**

# Nearby Galaxy Survey (NGS)

- Champ M82+ M82 : 3100 sec / filtre
- M31, M33, M101 et environ 40 autres galaxies
- 300 galaxies dans le NGS à terme avec 1000 - 3000 sec de pose / filtre



# The GALEX Atlas of Nearby Galaxies



AAS Poster

272  
galaxies  
observées  
par GALEX  
(Gil de Paz  
et al.  
2005)

# Temps Ouvert GALEX

- Guest Investigator #1 :
  - 117 propositions acceptées
  - 3 programmes «français»\* (Buat et al., Boissier et al., Iglesias-Paramo et al.)
- Guest Investigator #2 :
  - Notice Of Intent date March 2005
  - Proposal due date April 2005

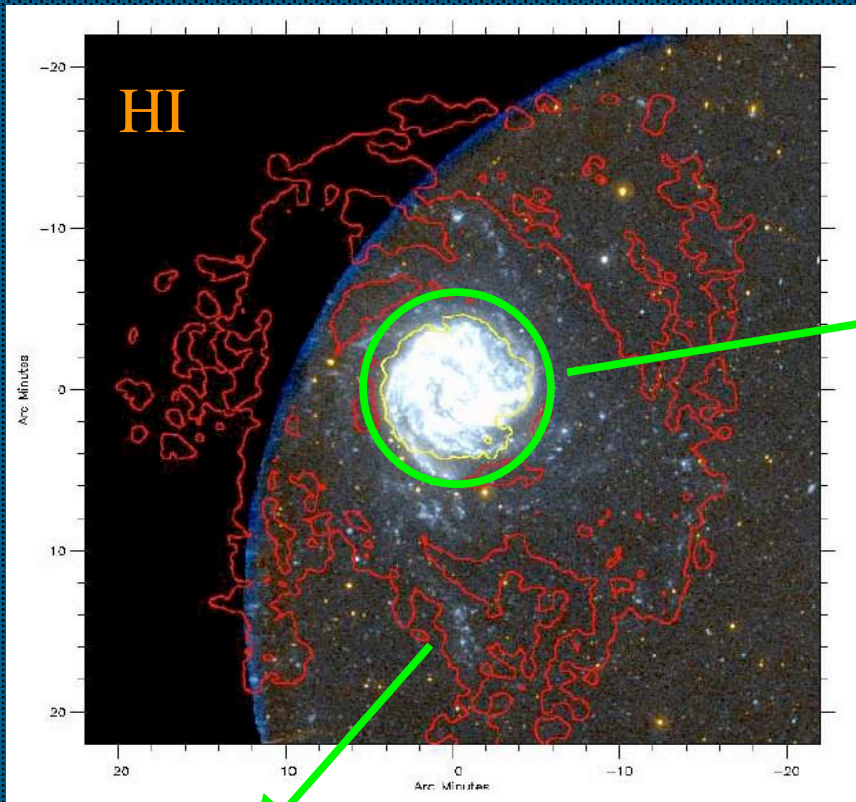
\* PI français ou dans labo en France

# Numéro ApJL spécial GALEX

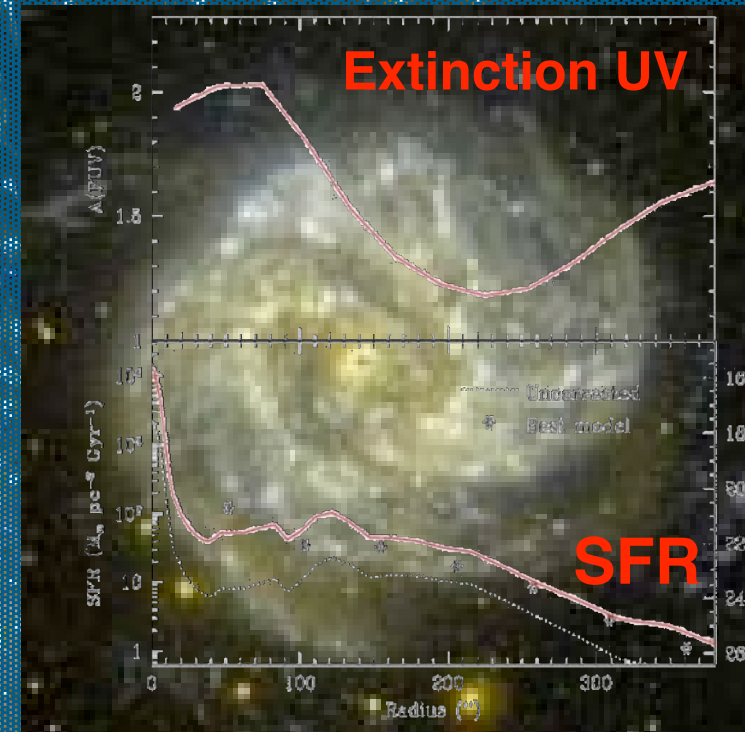
## • Publication (29 articles) fin janvier 2005

- Arnouts<sup>\*</sup> et al.
- Boissier<sup>\*</sup> et al.
- Burgarella<sup>\*</sup> et al.
- Gil de Paz et al.
- Hoopes et al.
- Martin et al. (x2)
- Neff et al.
- Rey et al.
- Salim et al.
- Schiminovich et al.
- Treyer<sup>\*</sup> et al.
- Xu et al. (x2)
- Bianchi et al. (x2)
- Budavari et al.
- Buat<sup>\*</sup> et al.
- Heckman et al.
- Lee et al.
- Morrissey et al.
- Popescu et al.
- Rich et al.
- Seibert et al. (x2)
- Thilker et al. (x2)
- Wyder et al.
- Yi et al.

# M83 vue par GALEX



Formation stellaire dans les parties externes de la galaxie  
*Thilker et al. (GALEX ApJL)*



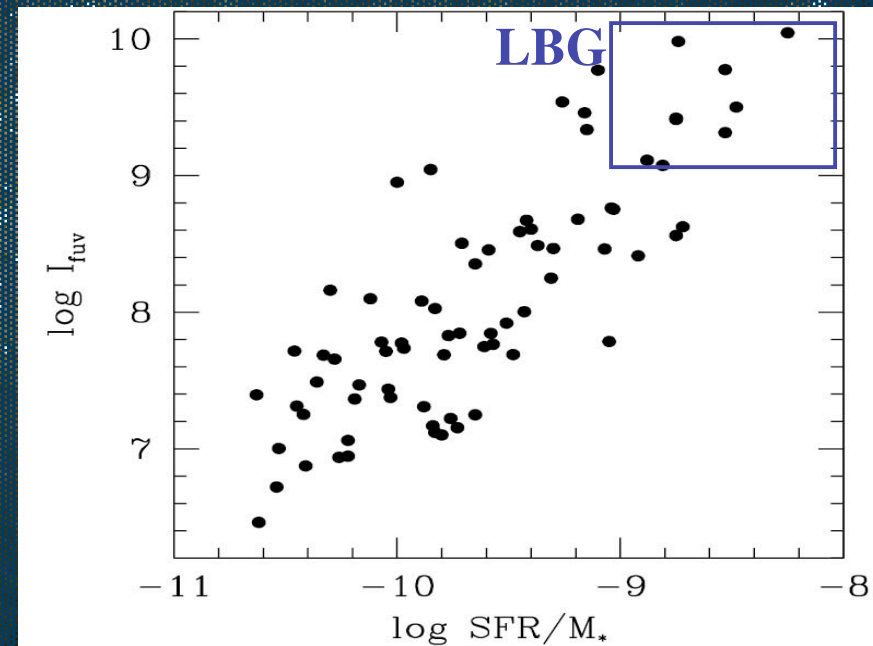
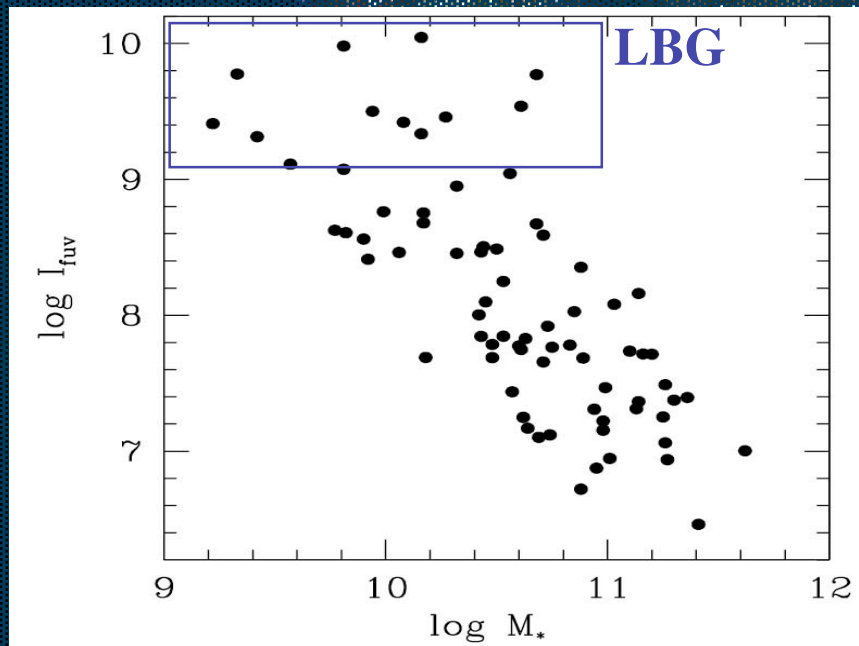
Extinction et SFR : profils radiaux à l'intérieur du disque optique  
*Boissier et al. (GALEX apJL)*

$10^{-5} \text{ Mpc}^{-3}$

# UltraViolet Luminous Galaxies (UVLG)

	Large UVLGs	Compact UVLGs	LBGs
$\text{Log } L_{\text{FUV}} (L_{\odot})$	10.3 - 10.5	10.35 - 10.65	10.3 - 11.3
$\text{Log } I_{\text{FUV}} (L_{\odot})$	6.9 - 7.8	8.2 - 9.8	9 - 10
$\text{Log } M_{\star} (M_{\odot})$	10.5 - 11.3	9.5 - 10.7	9.5 - 11.0
$A_{\text{FUV}} (\text{mag})$	0.3 - 2.0	0.6 - 2.1	1 - 3
$12 + \text{Log } (O/H)$	8.55 - 8.75	8.2 - 8.7	7.7 - 8.8

- 74 galaxies @  $z < 0.3$
- $L_{\text{UVLG}} = L_{\text{LBG}}$
- $3 < \text{SFR} (M_{\odot}/\text{yr}) < 30$
- Large UVLGs not starbursts
- Compact UVLGs starbursts





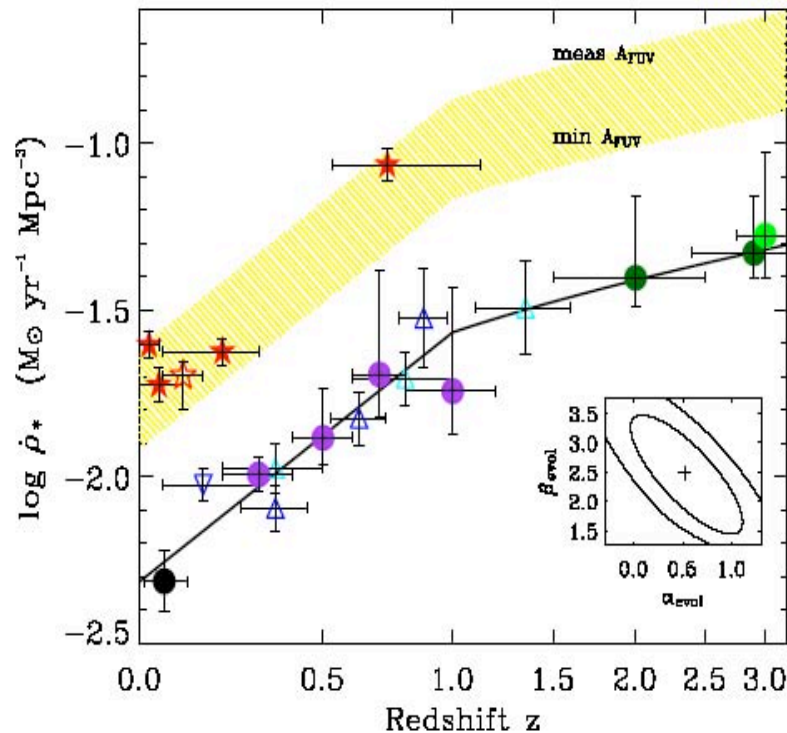


FIG. 5.— Star formation rate density vs.  $z$ . Filled circles from measurements at  $1500\text{\AA}$  (uncorrected for dust) same as in Figure 1. Blue comparison points are rest-frame UV measurement uncorrected for dust attenuation. Inverted blue triangle from Sullivan et al. 2000. Dark blue triangles from Lilly (1996). Light blue triangles from Wilson et al. (2002) for  $\alpha = -1.5$ . Solid line rises as  $(1+z)^{2.5}$  for  $z < 1$  and then  $(1+z)^{0.5}$  for  $z > 1$  based on chi squared fit to our sample (see inset;  $1\sigma$  and  $2\sigma$  confidence contour shown). Shaded region shows range corresponding to max/min dust-attenuation. Filled red stars from dust-corrected  $H\alpha$  measurements (with increasing redshift) from Pérez-González et al. (2003), Gronwall (1999), Tresse & Maddox (1998), Tresse et al. (2002). Open red star from SDSS ( $H\alpha$ /emission line) Brinchmann et al. 2004.

## FUV Luminosity Density & Cosmic SFR

Schiminovich et al. (05)

- LF from Arnouts et al. (05) @  $150\text{nm}$  avec  $10^3$  galaxies
- Evolution en  $(1+z)^{2.5 \pm 0.7}$  □  $z=1$
- Evolution en  $(1+z)^{0.5 \pm 0.4}$  pour  $z > 1$
- UVLG responsable de  $> 25\%$  de la densité de lum. FUV à  $z=1$
- Densité de lum. des UVLG avec  $L > 0.2 L_*$  x30 entre  $0 < z < 1$

# Bivariate UV - FIR Luminosity Function

Martin et al. (GALEX ApJL)

- $L_{FIR}$  correle avec  $L_{FUV}$  pour  $L_{tot} < 10^{10} L_{\odot}$
- $L_{FUV}$  sature à  $10^{10} L_{\odot}$
- $L_{tot} = L_{FIR}$  pour fortes luminosités

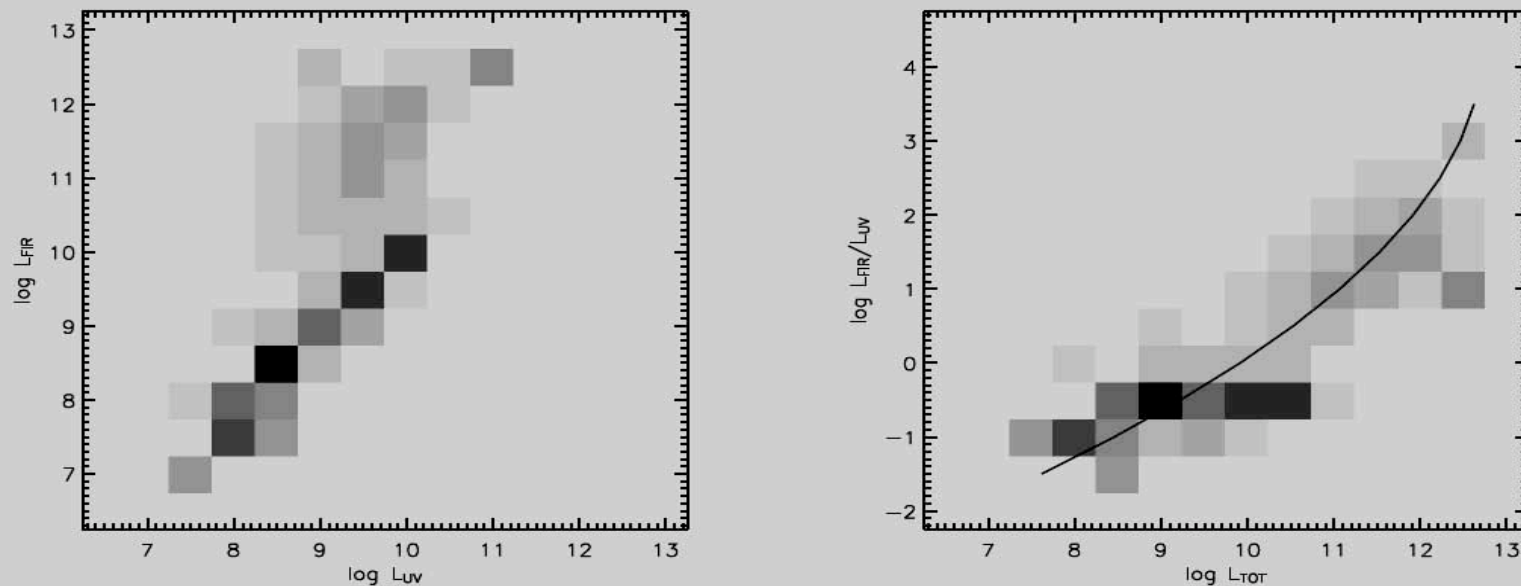


FIG. 2.— LEFT: a) The bivariate luminosity function  $\phi(L_{FUV}, L_{FIR})$ , normalized by  $\phi(L_{TOT})$  to compress the dynamic range. RIGHT: b) The BVLf rebinned as  $\phi'(L_{TOT}, L_{FIR}/L_{FUV})$ , again normalized by  $\phi(L_{TOT})$ . The line shows a quadratic fit discussed in the text. In both cases the grayscale density scales linearly with the normalized distribution.

# Pente UV : $f(\lambda)$



- Kinney et al. (1996) : influence de l'atténuation sur la pente UV

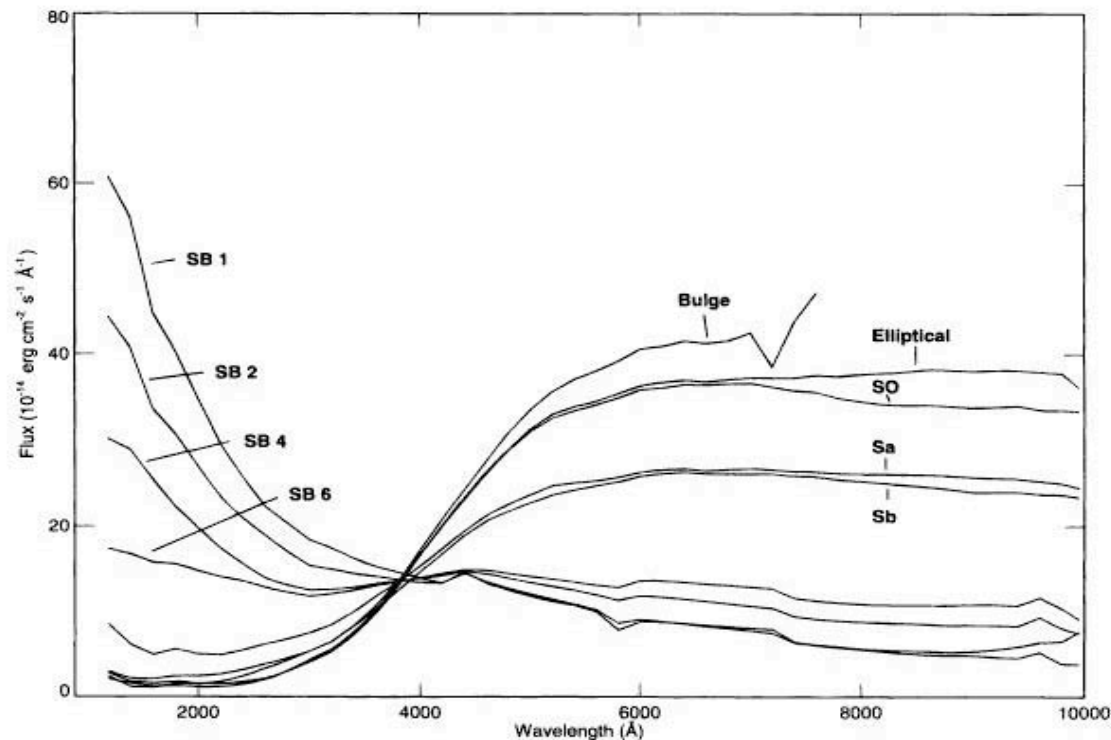
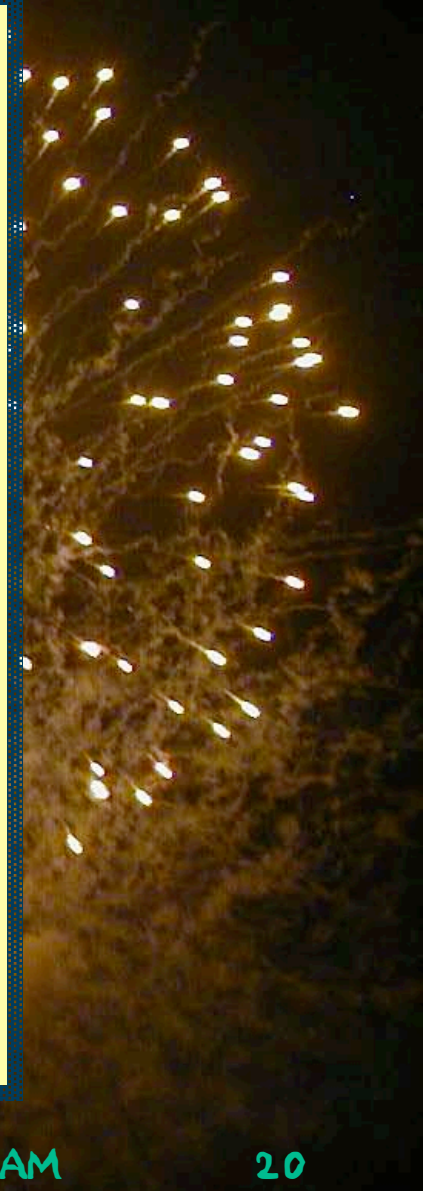
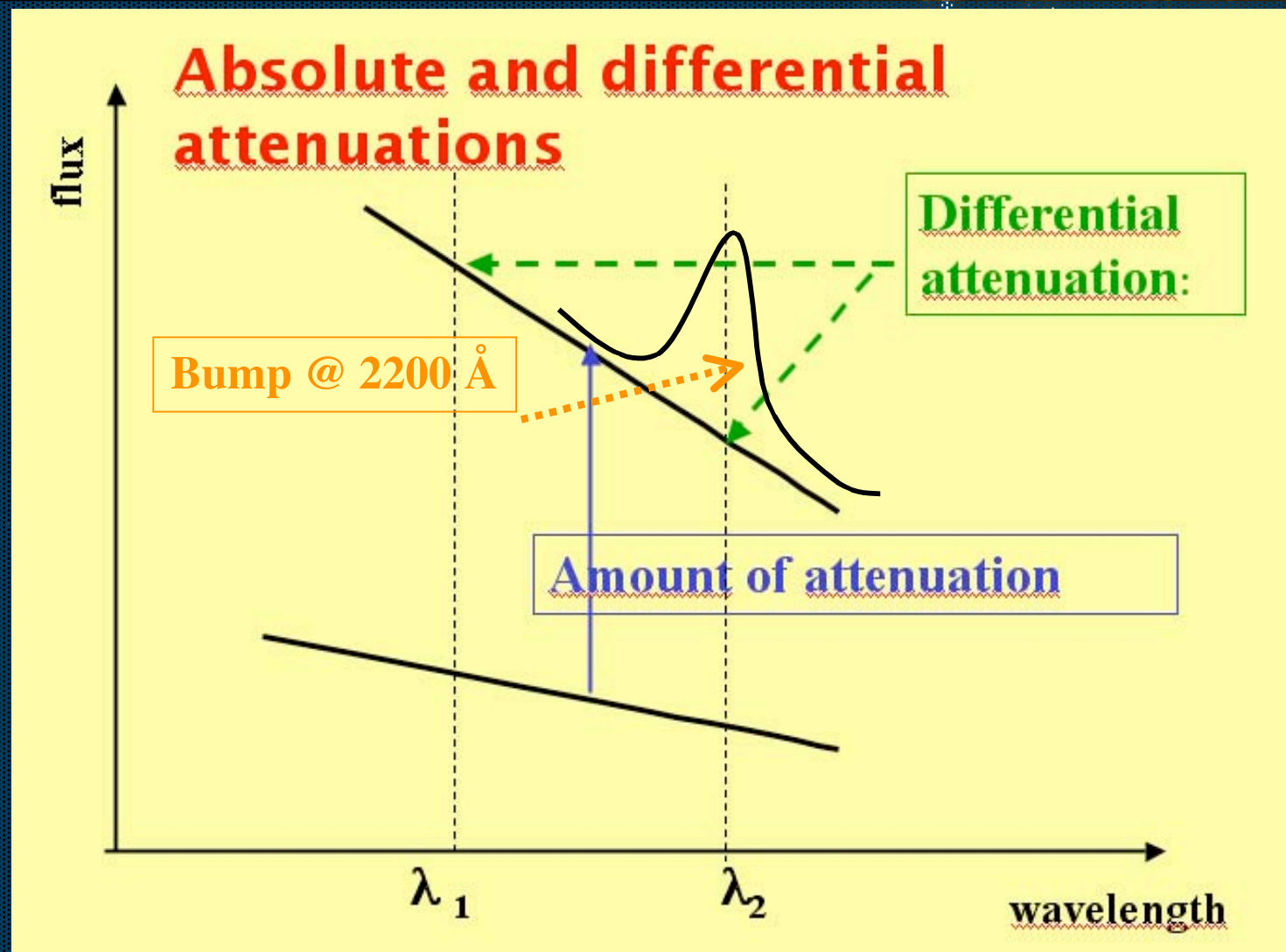


FIG. 1.—The spectra binned in 200 Å bins are shown between 1200 and 10,000 Å, normalized at 4000 Å for the bulge, elliptical, S0, Sa, Sb, and starburst galaxies with varying dust content. The starburst galaxy templates are grouped according to the mean color excess value  $E(B-V)$  and are labeled as SB1 for  $E(B-V) < 0.10$ ; SB2 for  $0.11 \leq E(B-V) \leq 0.21$ ; SB4 for  $0.39 \leq E(B-V) \leq 0.50$ ; and SB6 for  $0.61 \leq E(B-V) \leq 0.70$ .

# Paramètres influant l'atténuation par les poussières



## Deux méthodes de correction

From the studies at low  $z$  there are two major ways to correct the UV fluxes for the dust extinction:

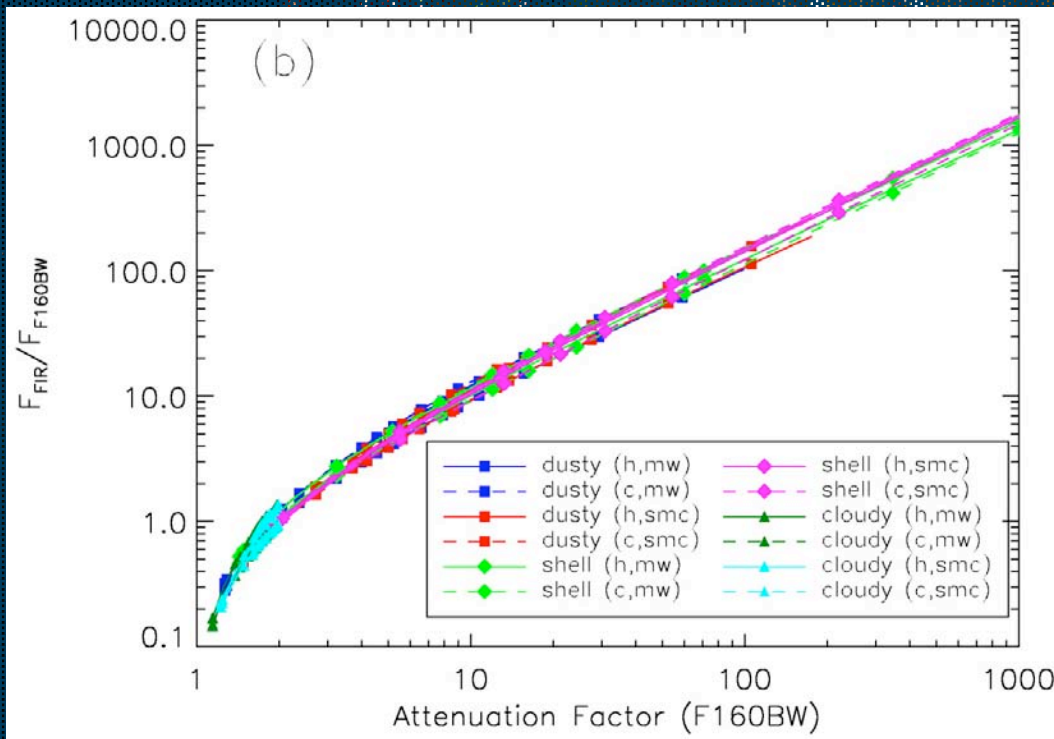
- Using the  $F_{\text{dust}} / F_{\text{UV}}$  ratio to perform an energetic budget (Buat & Xu 96, Meurer et al, 99)

→ absolute amount of dust attenuation

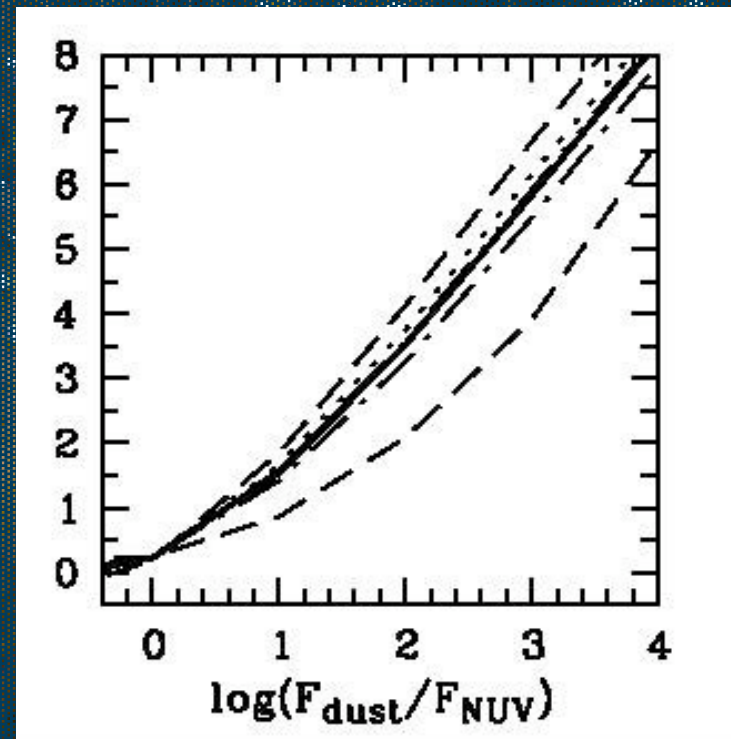
- Using the slope of the UV continuum (1200-2500 Å) (Calzetti et al. 94):  $f(\lambda) \propto \lambda^{\beta}$   
→ dust attenuation (differential)

# Rapport FIR/UV stable

Various geometries &  
dust properties  
Gordon et al. 2000

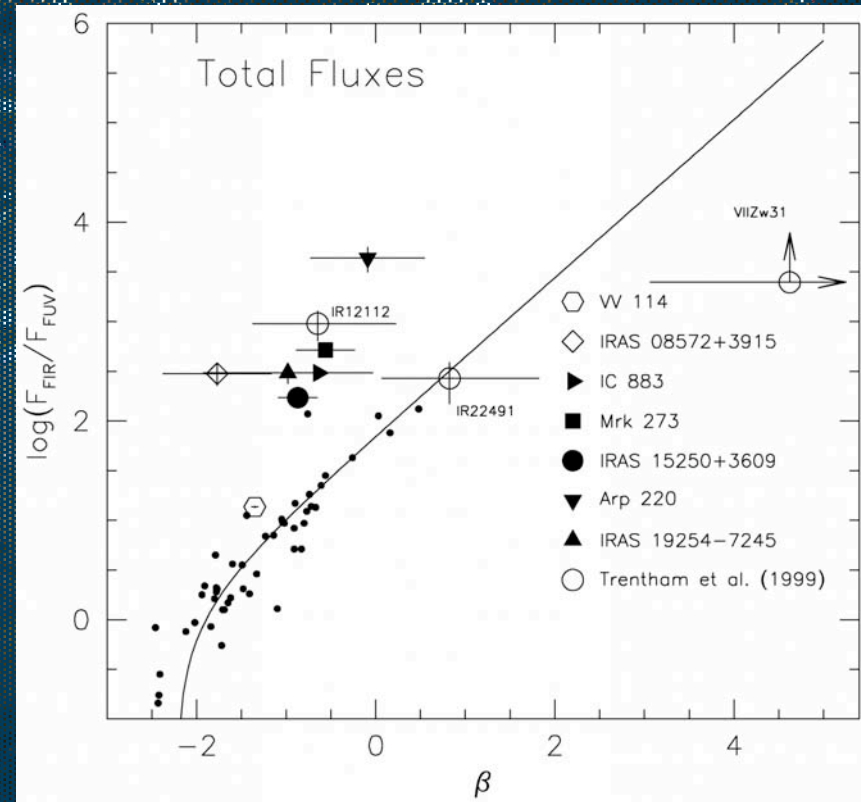
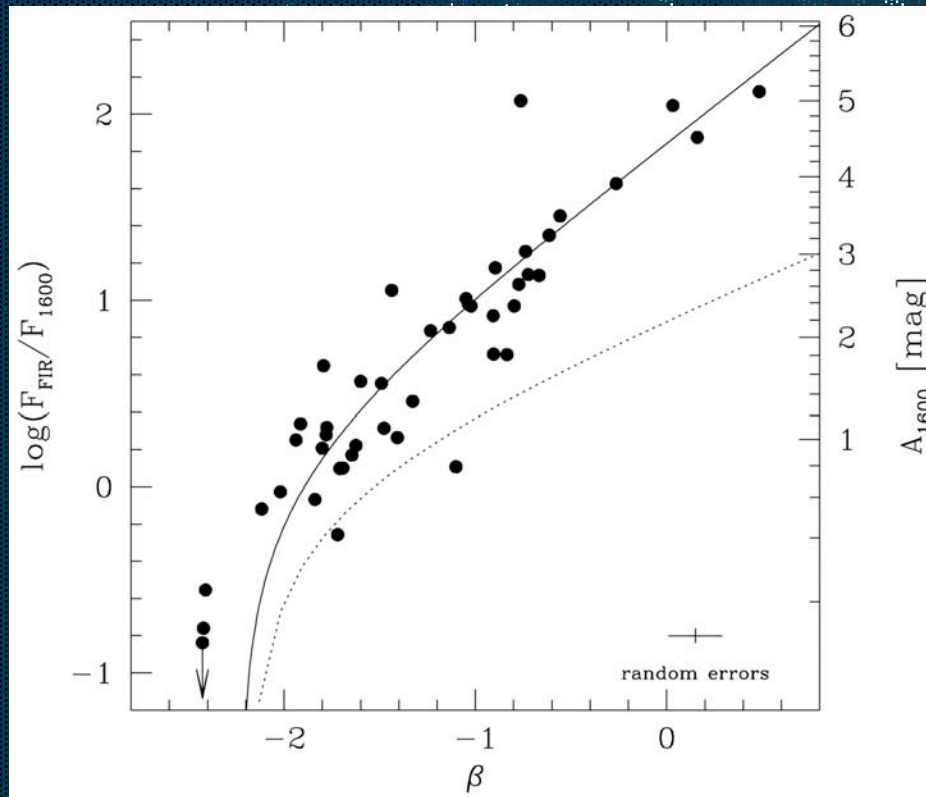


Various star  
formation histories  
Buat et al 05 ApJL  
special issue (GALEX)

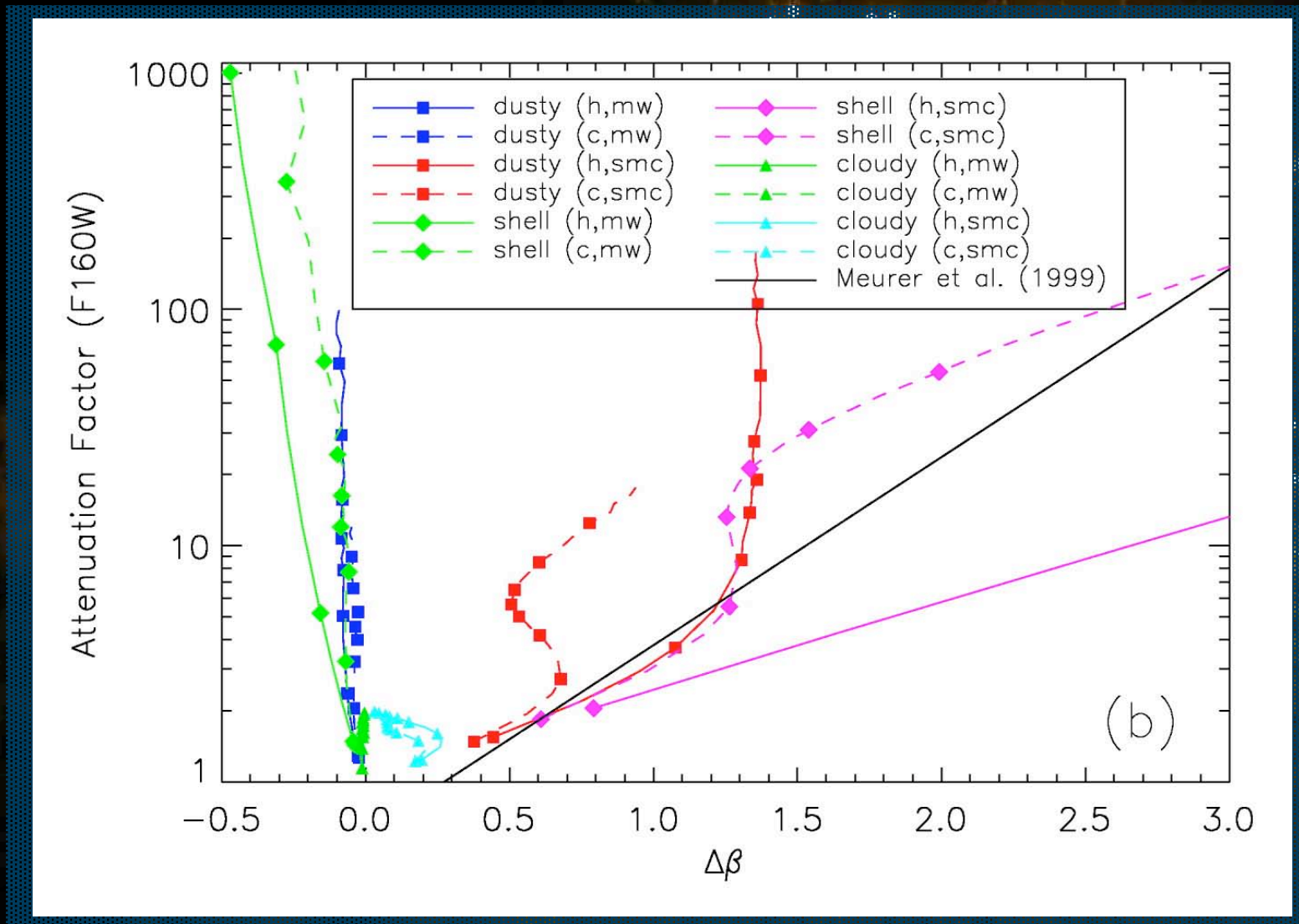


# La pente UV est-elle un bon estimateur (à tout z) ?

- Galaxies à starburst (Meurer et al. 99) □ OK
- ULIRGs (Goldader et al. 02) et galaxies normales (Bell 02) □ problème ?



# Modèles très dispersés (Witt & Gordon 2000)





# Apport de GALEX (Buat et al. 05)

About 600 sq deg. analysed

FUV band : 1530Å

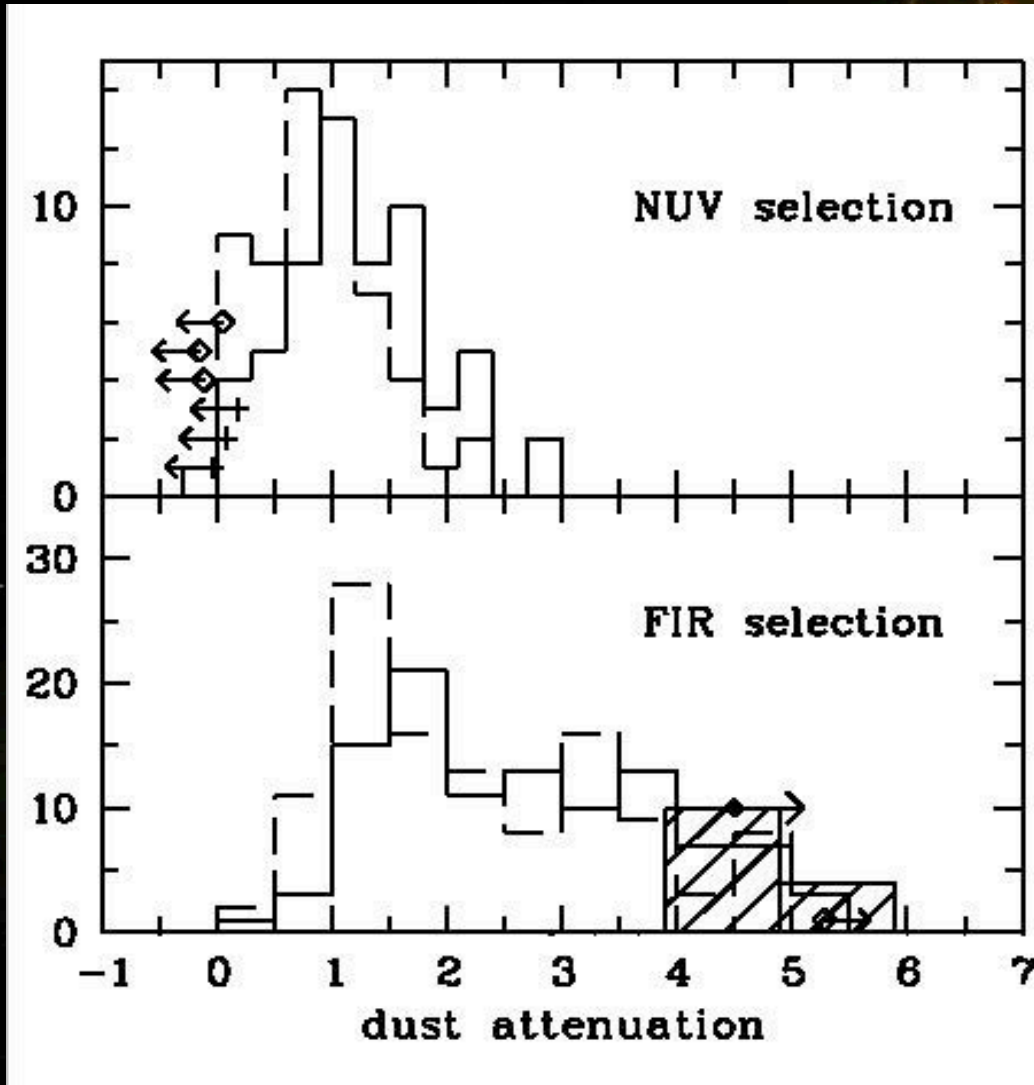
NUV band : 2310Å

FIR fluxes : 60µm (100µm)

- A pure NUV selected sample: down to  $m(\text{NUV})=16$ , 88 galaxies, all but 3 are detected by IRAS
- A pure FIR selected sample drawn from the PSCz ( $f(60) > 0.6$  microns), 118 galaxies all but 1 is detected by GALEX

# Attenuation moyenne pour les deux échantillons purs

Buat et al (ApJL)

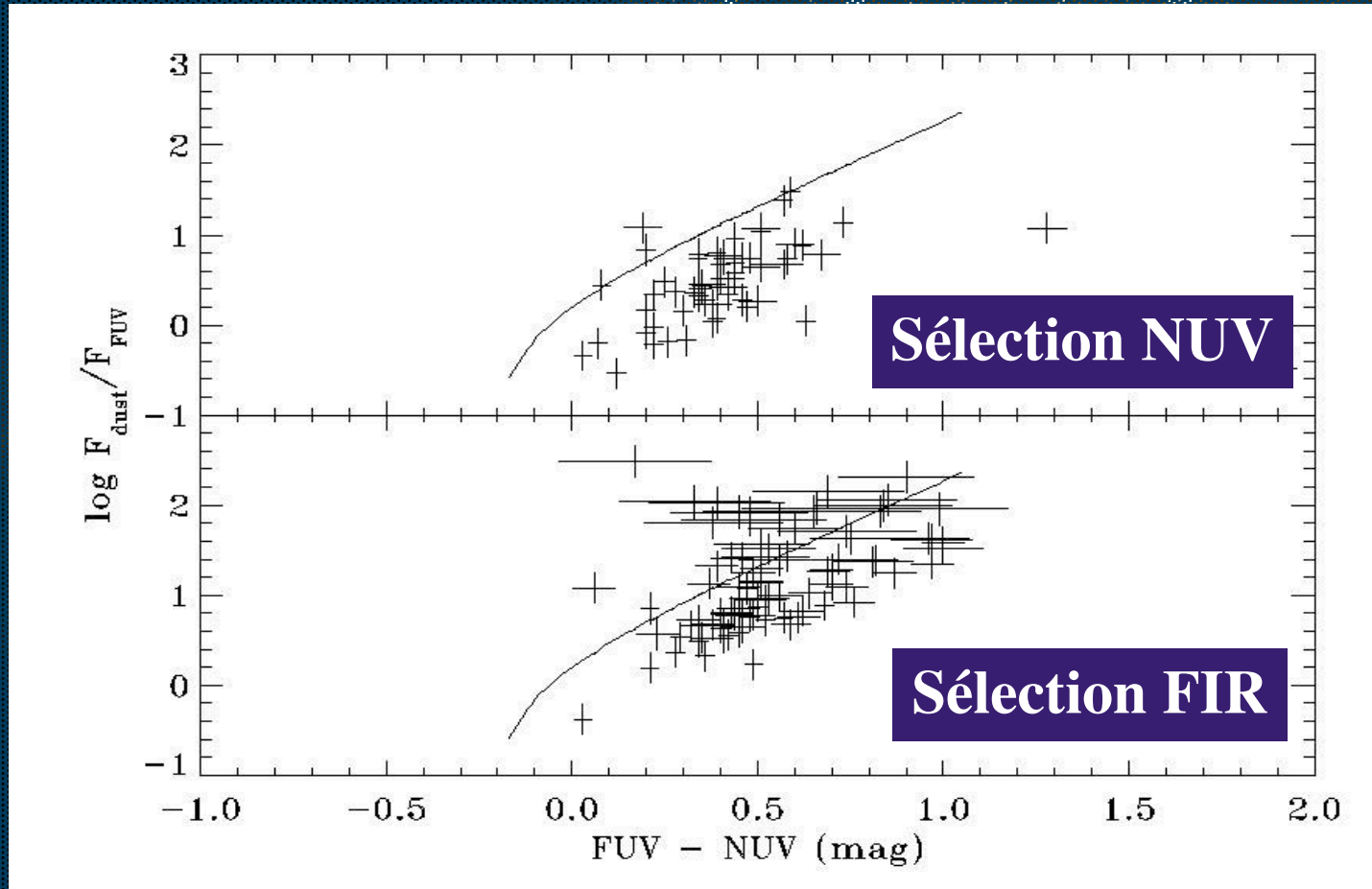


- NUV-sel sample :
  - $\langle A(\text{NUV}) \rangle = 0.8 \pm 0.3$
  - $\langle A(\text{FUV}) \rangle = 1.1 \pm 0.3$
- FIR-sel sample :
  - $\langle A(\text{NUV}) \rangle = 2.1 \pm 1.0$
  - $\langle A(\text{FUV}) \rangle = 2.9 \pm 1.0$

# Deux échantillons Deux régions

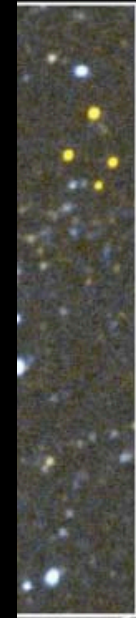
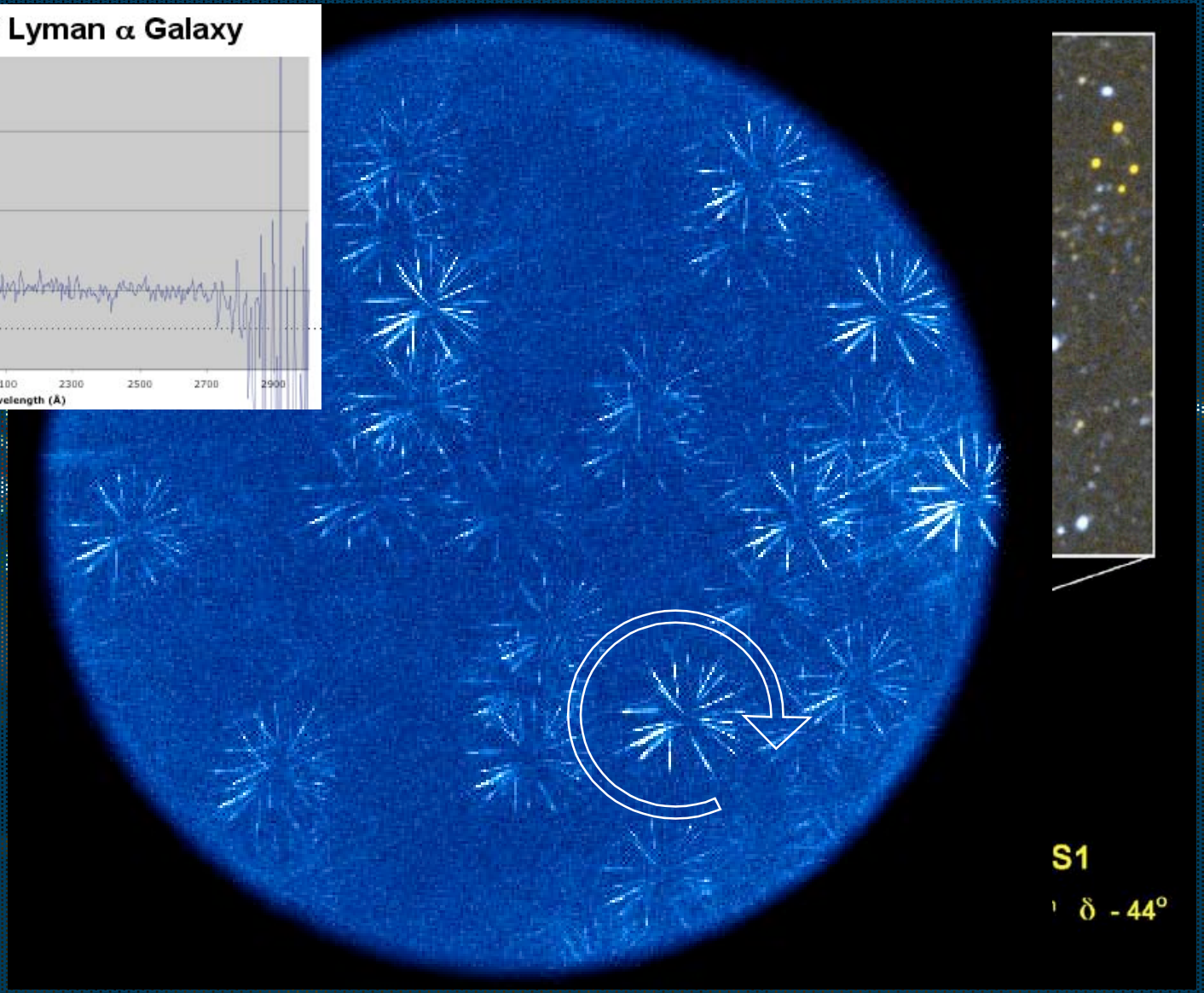
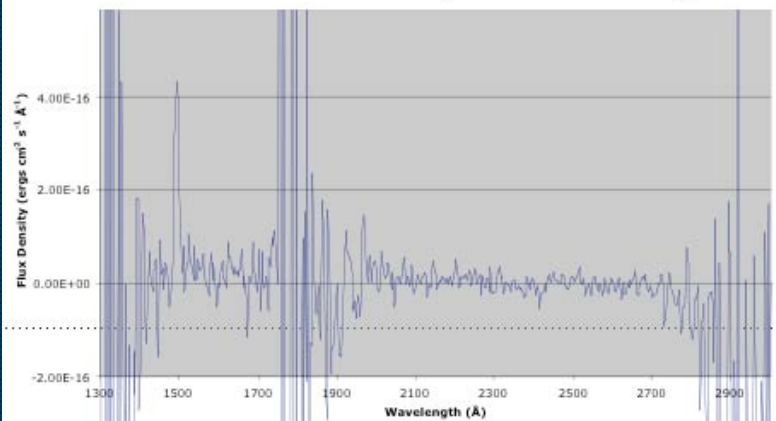
Buat et al. (GALEX ApJL)

Les galaxies ne suivent pas la relation des starbursts (ligne continue : Meurer et al. 99)



# Spectroscopie UV

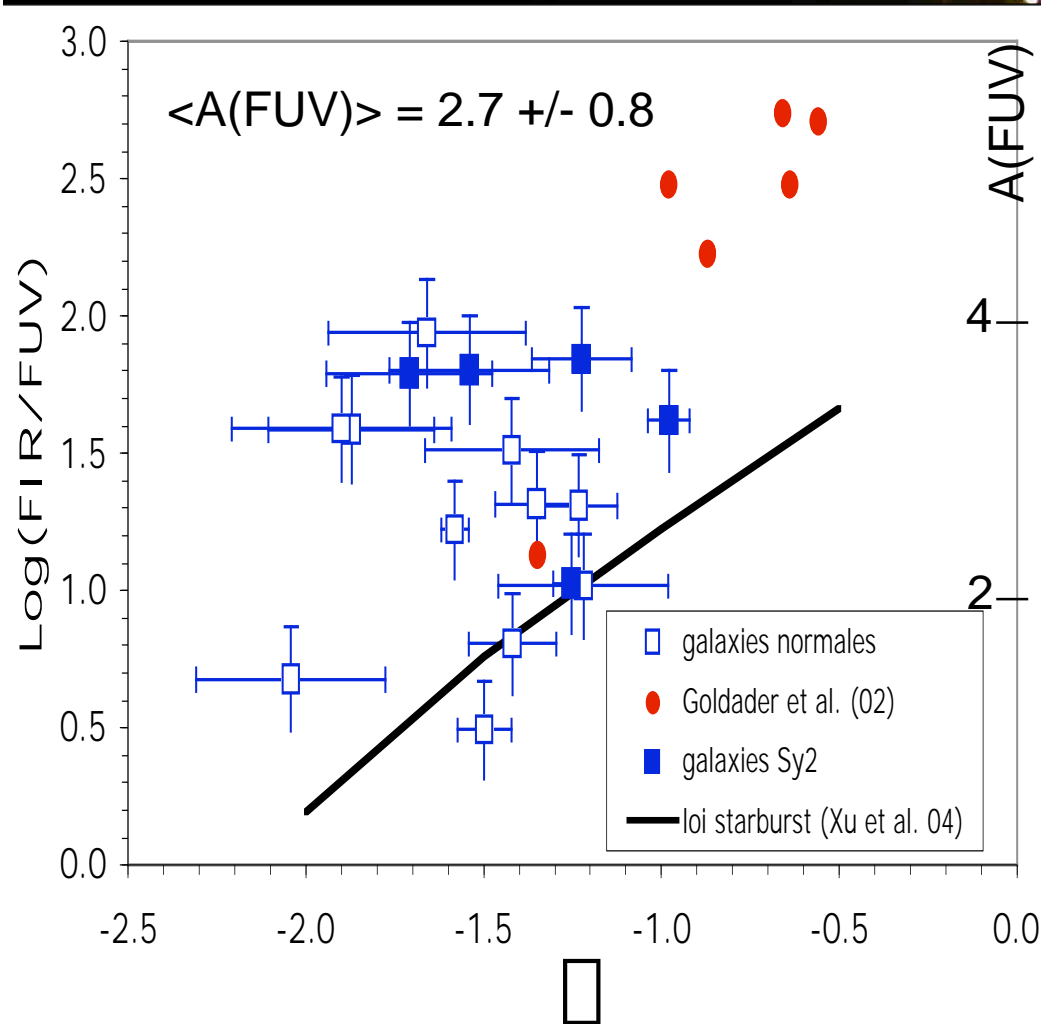
Z=0.23 FUV=21.6 Lyman  $\alpha$  Galaxy



# Pentes $\square$

Burgarella et al. (GALEX ApJL)

spectroscopiques



- $A_{FUV}$  estimé à partir de  $L_{IR}/L_{UV}$
- Galaxies normales  $\square$  (U)LIRGs
- Pas de corrélation ( $A_{FUV}$  vs.  $\square$ )
- $A_{FUV} = 2.7 \pm 0.8$  des LIRGs similaires aux FIR-selected de Buat et al.

# Bump ou pas Bump

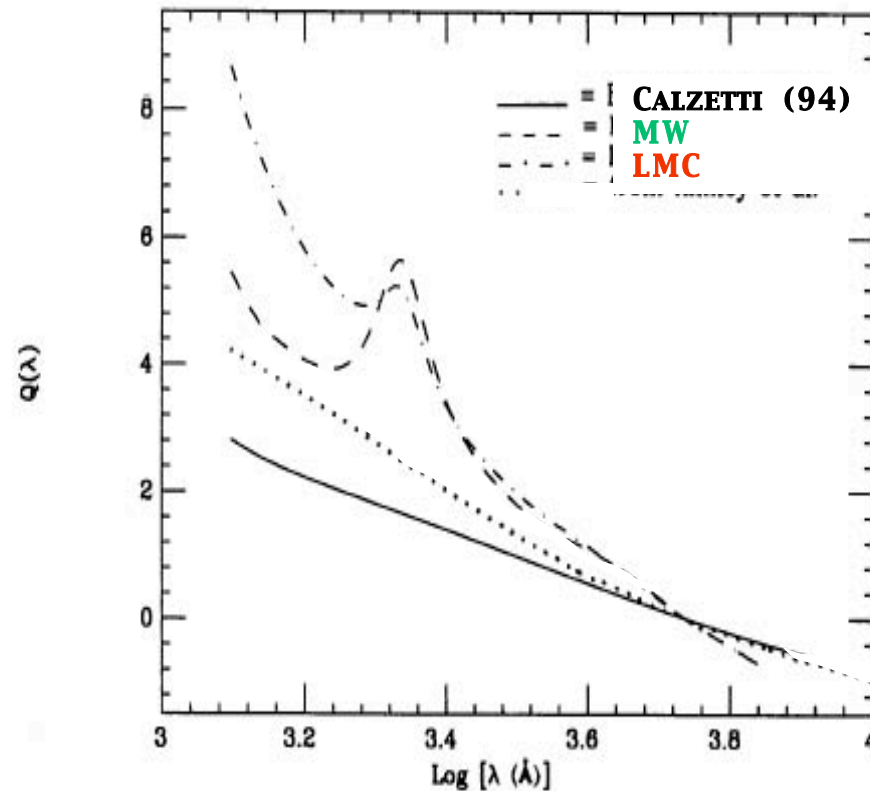


FIG. 21.—The extinction law derived in this work (eq. [25], *continuous line*) is compared with the Milky Way (*dashed line*) and the LMC (*dot-dashed line*) extinction laws. The extinction law derived by Kinney et al. (1994b) is also shown (*dotted line*). The zero point of the four curves is arbitrary and has been chosen to be the value  $Q(5500) = 0.0$ .

- Quel type de loi d'atténuation ?
- Quelle influence sur la structure du diagramme  $\text{Log} (\text{FIR/UV})$  vs.  $\square$  ?

# Présence d'un 'bump' dans la loi d'atténuation UV des LIRGS

Voir aussi Motta et al.  
À  $z=0.83$  et Gordon et al.  
dans M33

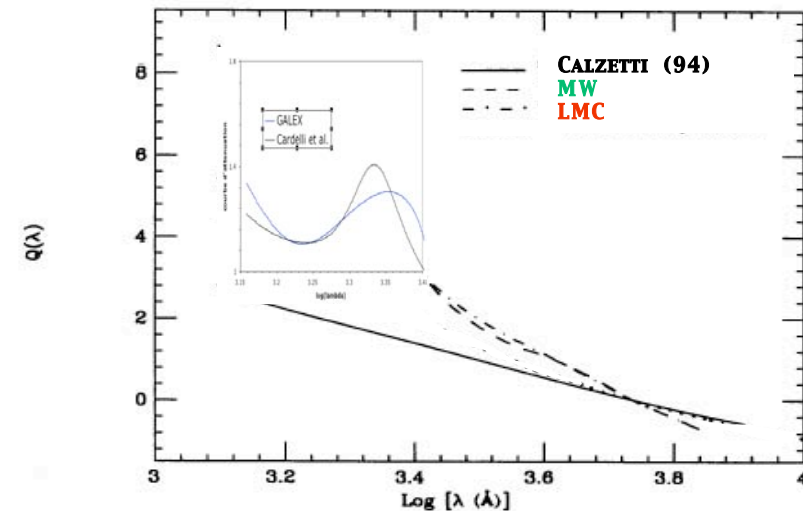
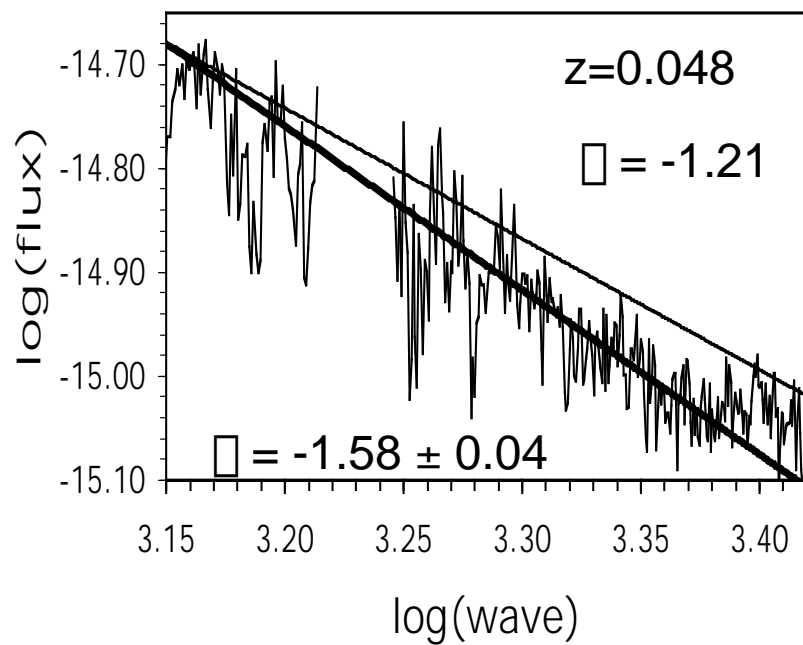
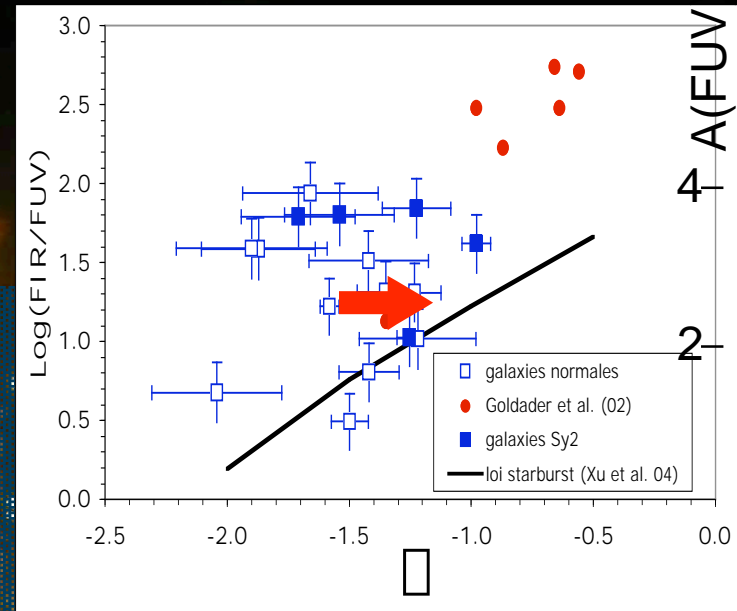


FIG. 21.—The extinction law derived in this work (eq. [25], *continuous line*) is compared with the Milky Way (*dashed line*) and the LMC (*dot-dashed line*) extinction laws. The extinction law derived by Kinney et al. (1994b) is also shown (*dotted line*). The zero point of the four curves is arbitrary and has been chosen to be the value  $Q(5500) = 0.0$ .

# Atténuation moyenne dans l'univers local

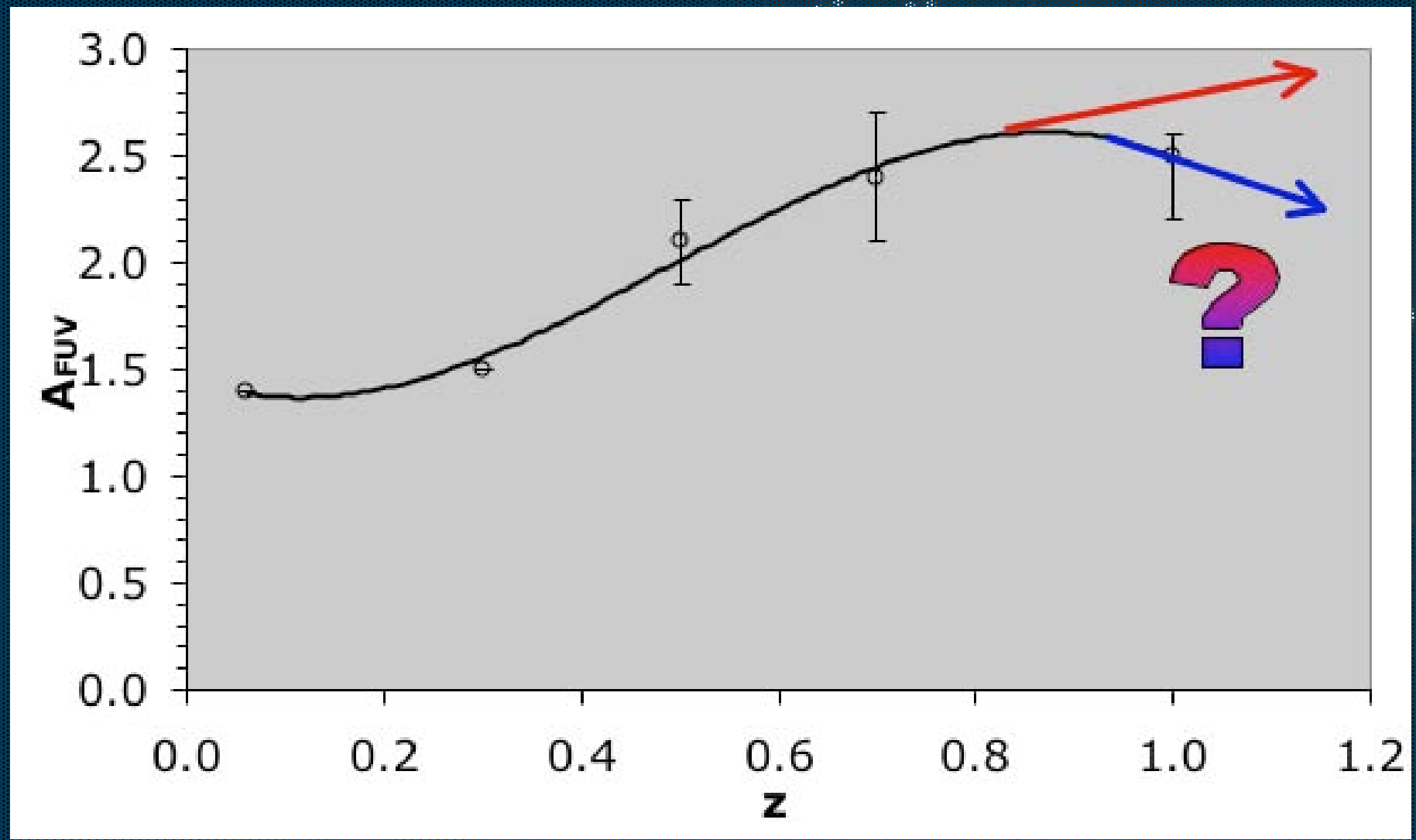
- $\rho(\text{FIR}) = 3.9 \cdot 10^7 L(\text{sun})/\text{Mpc}^3$   
(Saunders et al. 1990)
  - $\rho(\text{NUV}) = 1.8 \cdot 10^7 L(\text{sun})/\text{Mpc}^3$  &  
 $\rho(\text{FUV}) = 1.9 \cdot 10^7 L(\text{sun})/\text{Mpc}^3$   
(Wyder et al. 2004)
- $\langle A(\text{NUV}) \rangle = 1.1 \text{ mag}$  &  
 $\langle A(\text{FUV}) \rangle = 1.6 \text{ mag}$

L'atténuation moyenne dans  
l'univers local est faible



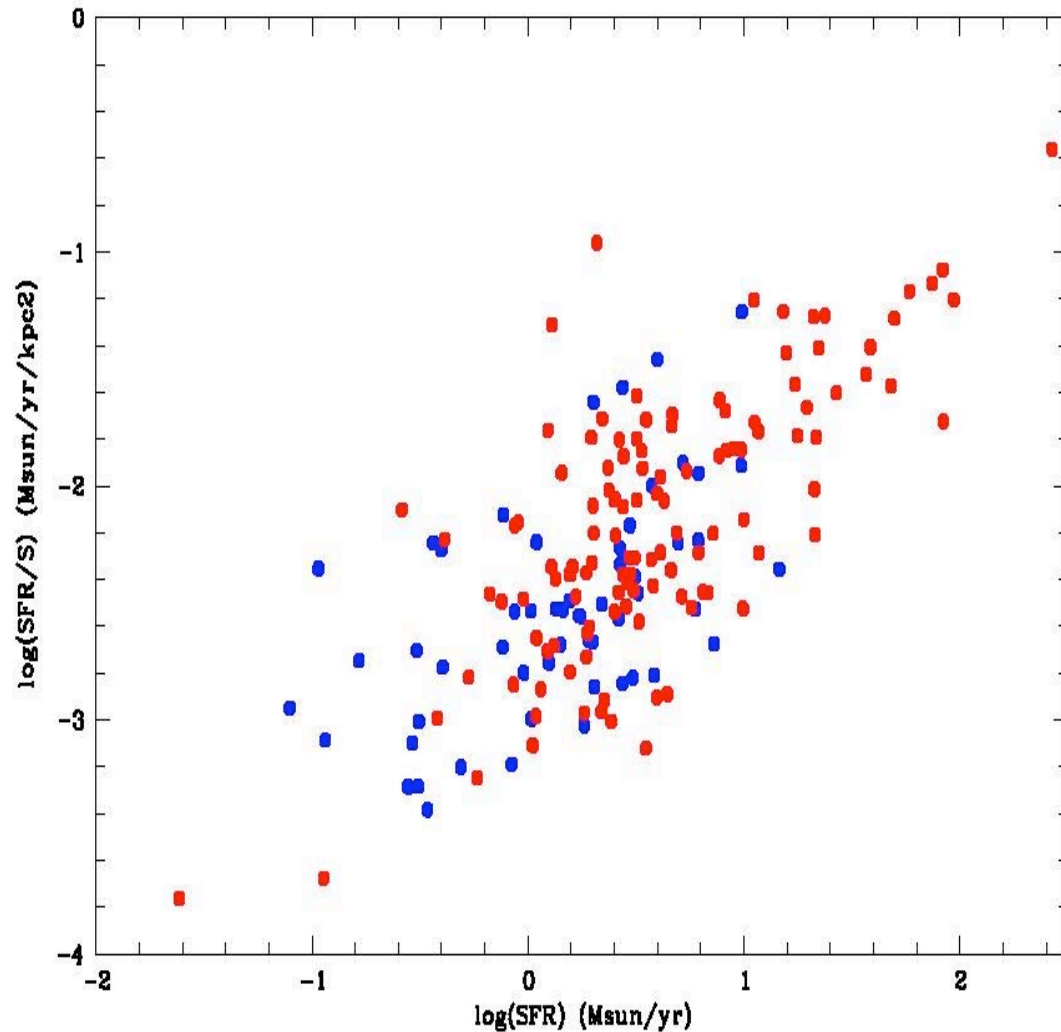
# Evolution de l'atténuation moyenne en FUV

Buat et al. (en prep.)



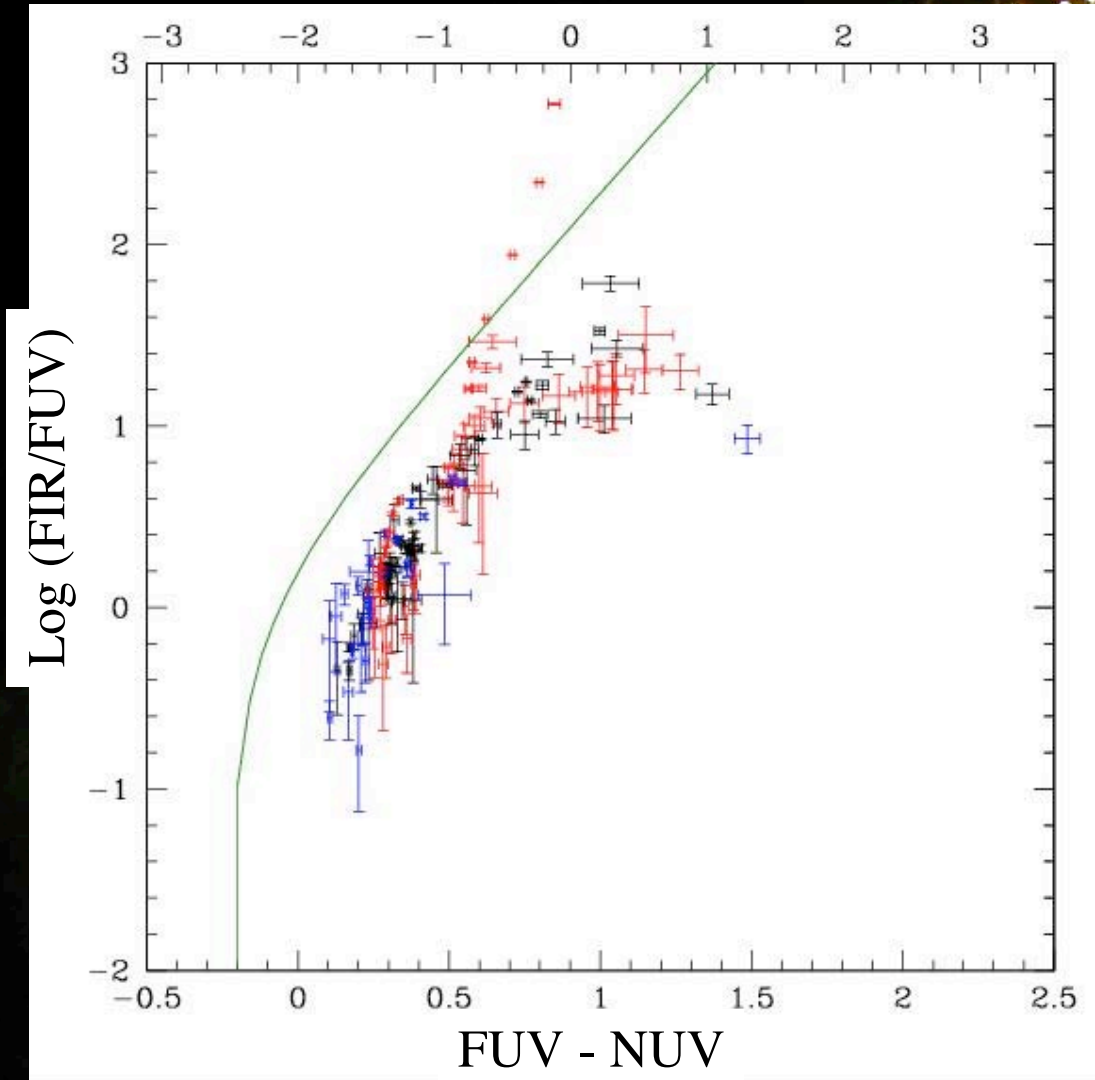
# 'Star Formation Activity'

Buat et al. (en prep.)



- FIR selected galaxies appear more active in star formation than NUV selected ones
- No strong starbursts selected

# Galaxies résolues



Boissier et al.  
(en prep.)

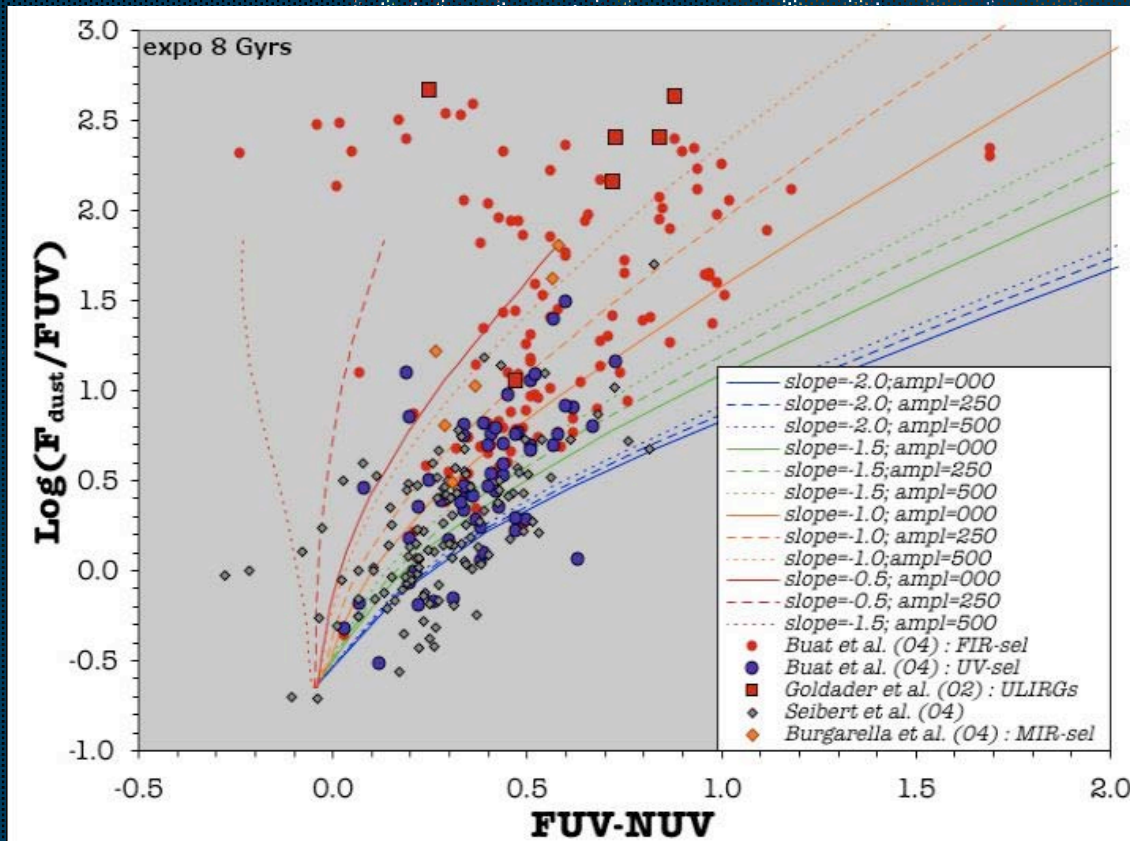
39 spirales avec  
profils  
IRAS + GALEX

-> Extinction UV

# Propriétés physiques des galaxies

Burgarella et al. (en prep)

- PEGASE 2
- $\sigma^{-n} + A / (2\sigma\sigma_0)^{1/2} \exp(-(\sigma - \sigma_m)/(2\sigma_0^2))$
- $\sigma_m = 2175 \text{ \AA}$  &  $\sigma_0 = 200 \text{ \AA}$  fixed



Méthode  
Bayésienne sur  
données  
GALEX + IRAS

- Kauffmann et al. sur données SDSS
- Salim et al. sur données SDSS + GALEX

# 'SED Fitting'

Méthode utilisée pour la détermination des paramètres physiques des galaxies à bas et haut redshift, e.g.:

2004 A SUBSTANTIAL POPULATION OF RED GALAXIES AT  $Z > 2$ :  
MODELING OF THE SPECTRAL ENERGY DISTRIBUTIONS OF AN EXTENDED SAMPLE <sup>1</sup>

N. M. FÖRSTER SCHREIBER<sup>2,3</sup>, P. G. VAN DOKKUM<sup>4</sup>, M. FRANX<sup>2</sup>, I. LABBÉ<sup>2</sup>, G. RUDNICK<sup>5</sup>, E. DADDI<sup>6</sup>, G. D. ILLINGWORTH<sup>7</sup>, M. KRIEK<sup>2</sup>, A. F. M. MOORWOOD<sup>6</sup>, H.-W. RIX<sup>8</sup>, H. RÖTTGERING<sup>2</sup>, I. TRUJILLO<sup>8</sup>, P. VAN DER WERF<sup>2</sup>, L. VAN STARKENBURG<sup>2</sup>, S. WUYTS<sup>2</sup>

Deep mid-infrared observations of Lyman-break galaxies  
2004

P. Barmby<sup>1</sup>, J.-S. Huang<sup>1</sup>, G.G. Fazio<sup>1</sup>, J.A. Surace<sup>2</sup>, R.G. Arendt<sup>3</sup>, J.L. Hora<sup>1</sup>, M.A. Pahre<sup>1</sup>, K.L. Adelberger<sup>4</sup>, P. Eisenhardt<sup>5</sup>, D.K. Erb<sup>6</sup>, M. Pettini<sup>7</sup>, W.T. Reach<sup>2</sup>, N.A. Reddy<sup>6</sup>, A.E. Shapley<sup>8</sup>, C.C. Steidel<sup>6</sup>, D. Stern<sup>5</sup>, Z. Wang<sup>1</sup>, S.P. Willner<sup>1</sup>

THE REST-FRAME OPTICAL PROPERTIES OF  $z \approx 3$  GALAXIES<sup>1</sup>

ALICE E. SHAPLEY AND CHARLES C. STEIDEL<sup>2</sup>

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2001 Institute of Astronomy, Madingley Road, Cambridge CB3 0HA, UK

Received 2001 March 23; accepted 2001 July 20

# Two Parts

- Inputs :
- SFH (t)
  - Metallicity =  $Z_{\odot}$
  - Extinction = 0.

PEGASE 2

Outputs :  
Dust-free  
Spectra

- Inputs :
- E(B-V)
  - Attenuation laws

GALUVE  
(GALEX UV  
Extinction)

- Outputs :
- 23760 attenuated models
  - $\text{Log}(F_{\text{dust}}/\text{UV})$
  - $b_0, b_7, b_8$
  - Colors

For every galaxy

For every model

- Minimize  $\chi^2$
- Likelihood that models matches galaxy fluxes ( $F_{\text{UV}} \square F_{\text{IR}}$ )  $e^{(-\chi^2/2)}$

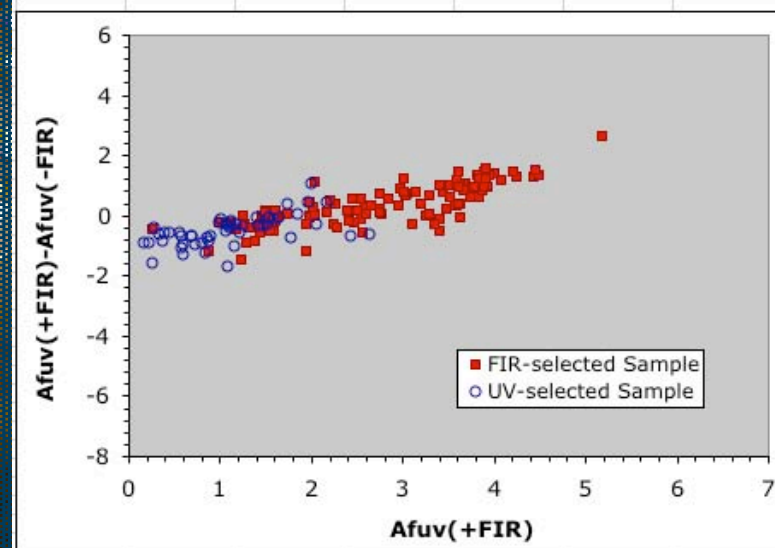
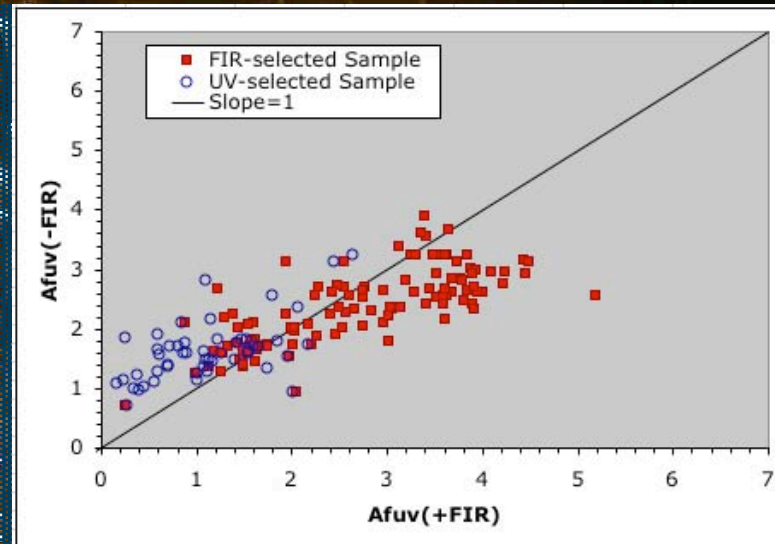
Build the Probability Distribution Function for each parameter and for galaxy (Bayesian approach)

Estimate expectation values, variances and standard deviations for each parameter

Dust attenuation, age of burst, shape of attenuation law, ...

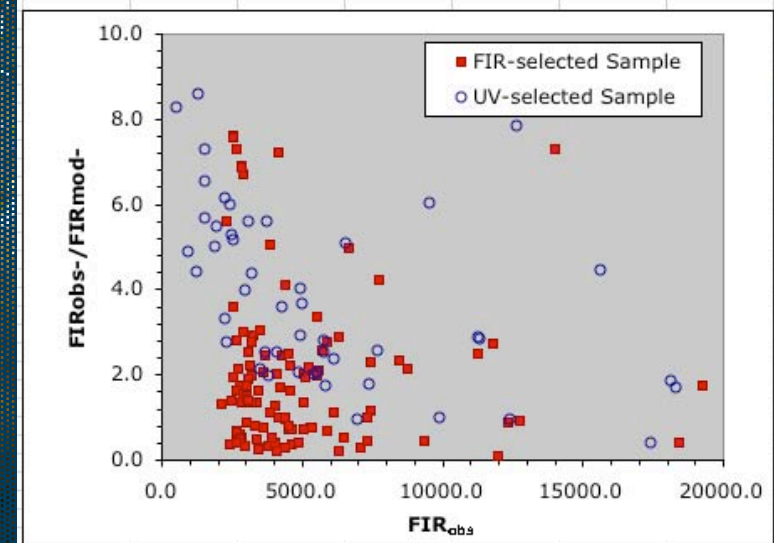
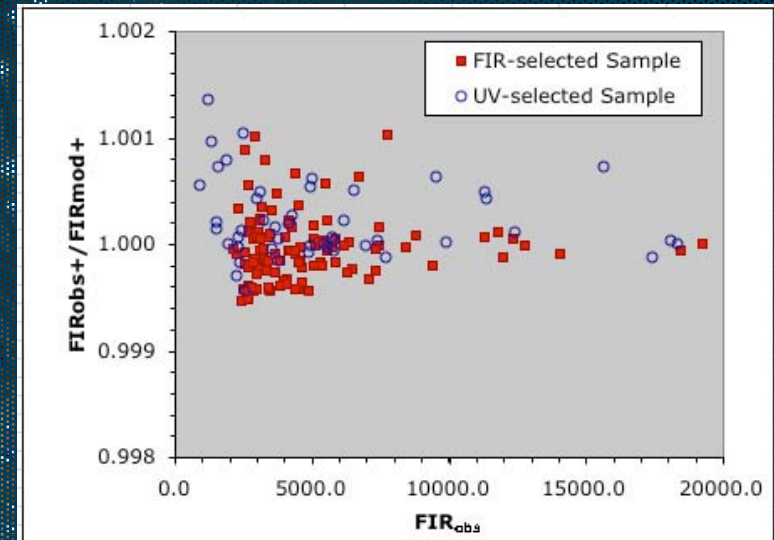
# Détermination de l'atténuation UV avec et sans le FIR

- Mauvaise détermination de l'atténuation en FUV si le FIR n'est pas pris en compte (1 à 2 Mag.)
- $A_{FUV}$  sur-estimé pour galaxies sélect. en UV
- $A_{FUV}$  sous-estimé pour galaxies sélect. en FIR



# Origine du problème

- Le flux FIR est bien estimé s'il est contraint (0.1 %)
- Le flux FIR est mal estimé s'il n'est pas contraint (1000 %)
- Pour les galaxies sélectionnées UV et FIR

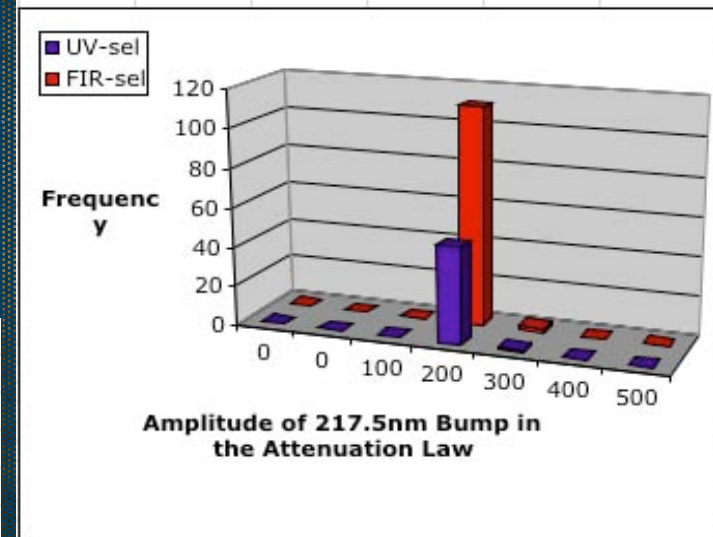
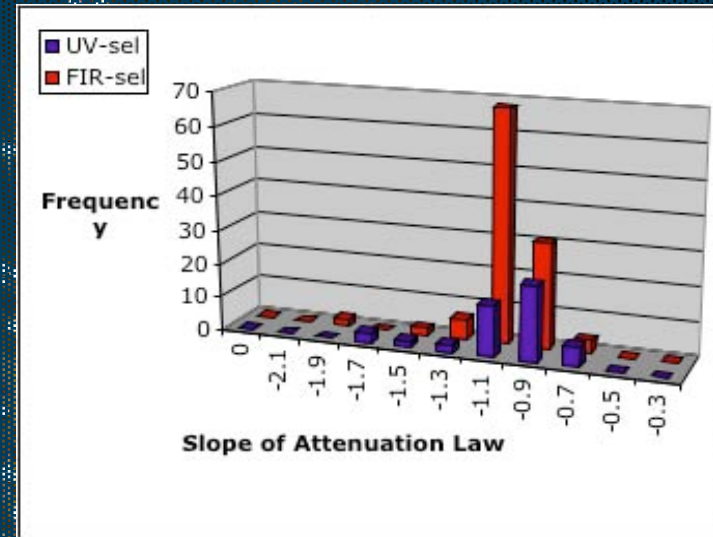




# Loi d'atténuation

- Pente de la loi d'atténuation :  $\lambda^{-n}$  avec  $n \approx -0.7$  (consistant avec Charlot & Fall 2000)
- Présence d'un bump (intermédiaire entre LMC et MW)

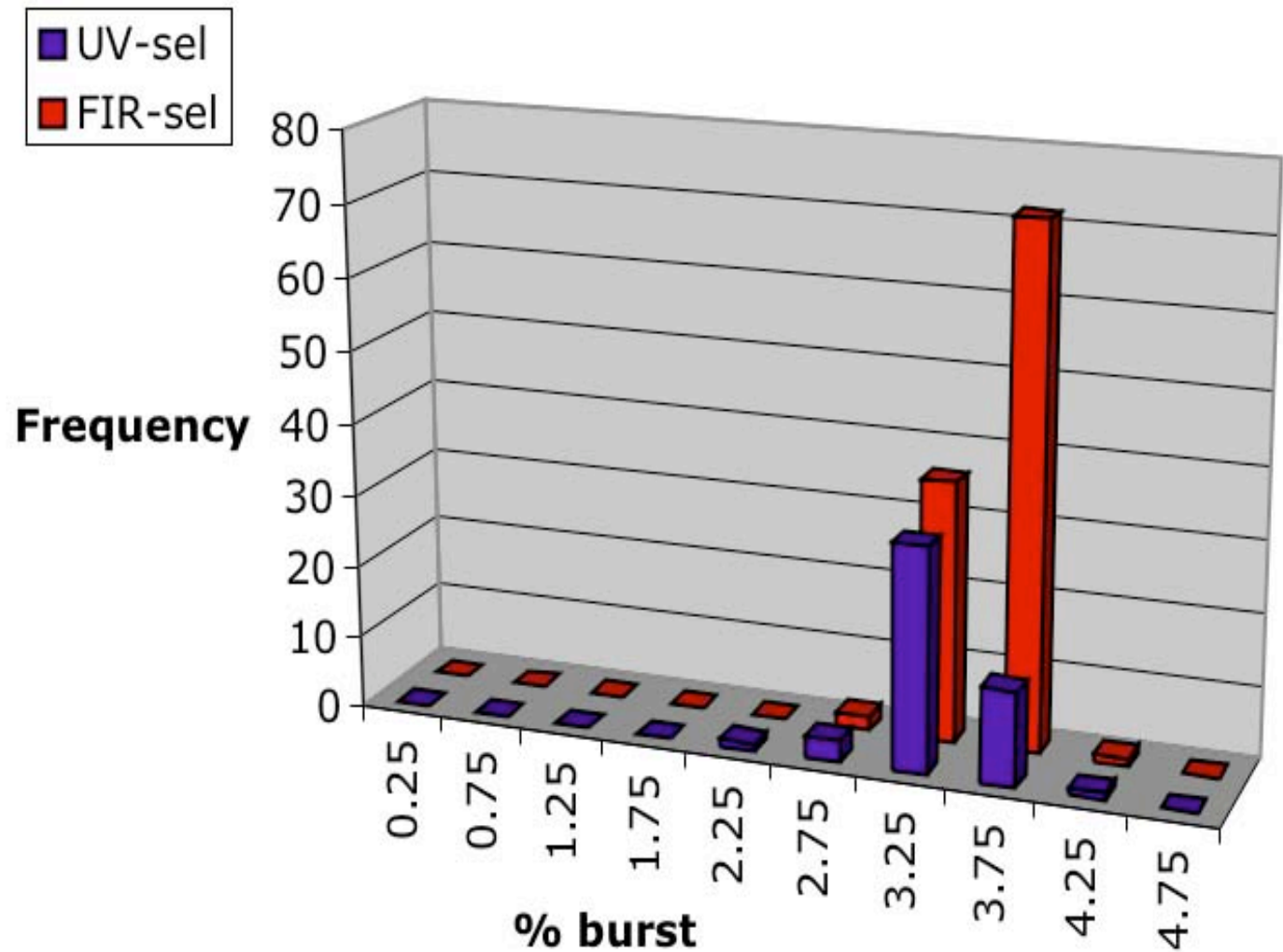
type	alpha	A	mean	sigma
MW	-0.85	400	2175	200
LMC	-1.00	150	2175	200
SMC	-1.30	0	2175	200
Calzetti et al. (1994)	-0.95	0	0	0
Charlot & Fall (2000)	-0.70	0	0	0



# 'Star Formation History' des galaxies GALEX

## SFH

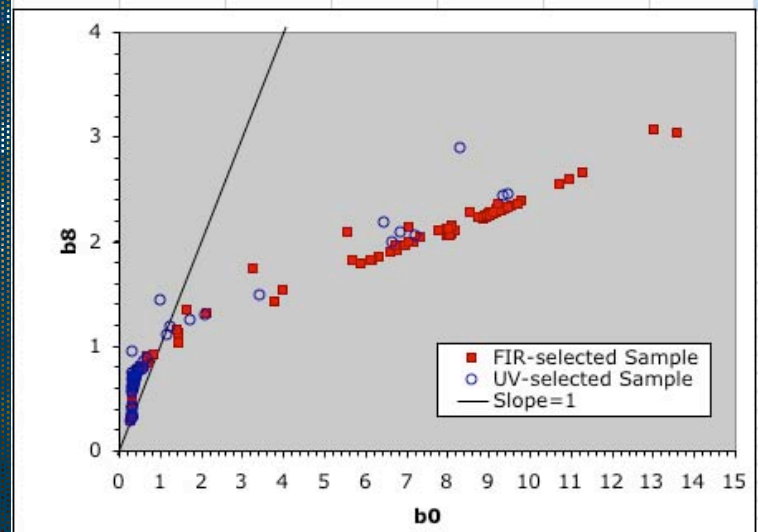
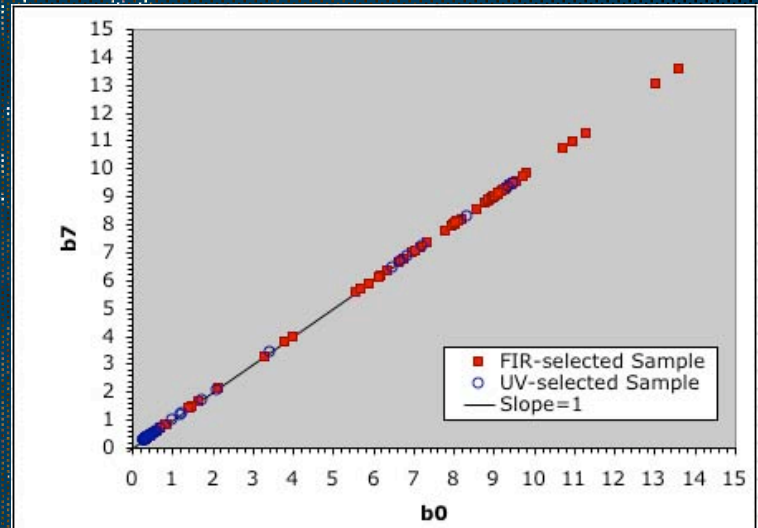
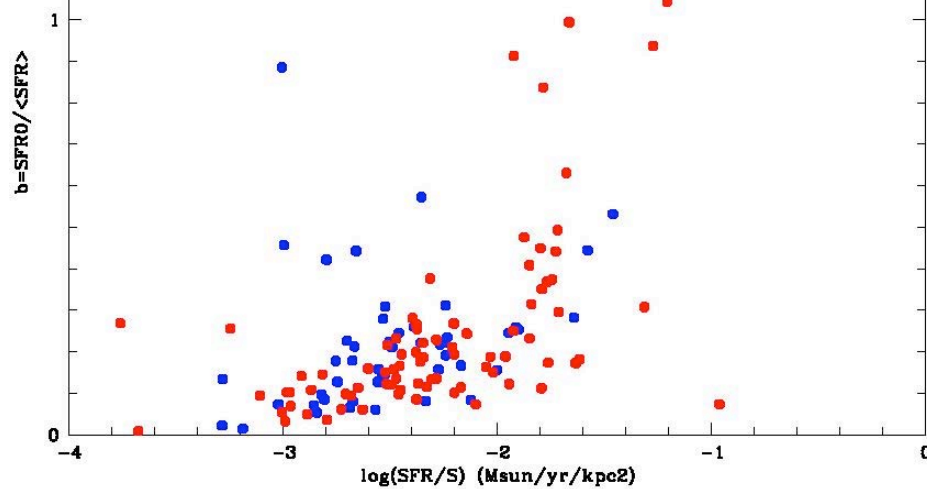
- Expo décroissant
- = 5 Gyrs + burst
- Age du dernier burst 1-2 Gyrs
- Environ 3-4 % de la masse totale dans le burst



# Present-to-Past SFR : paramètre b

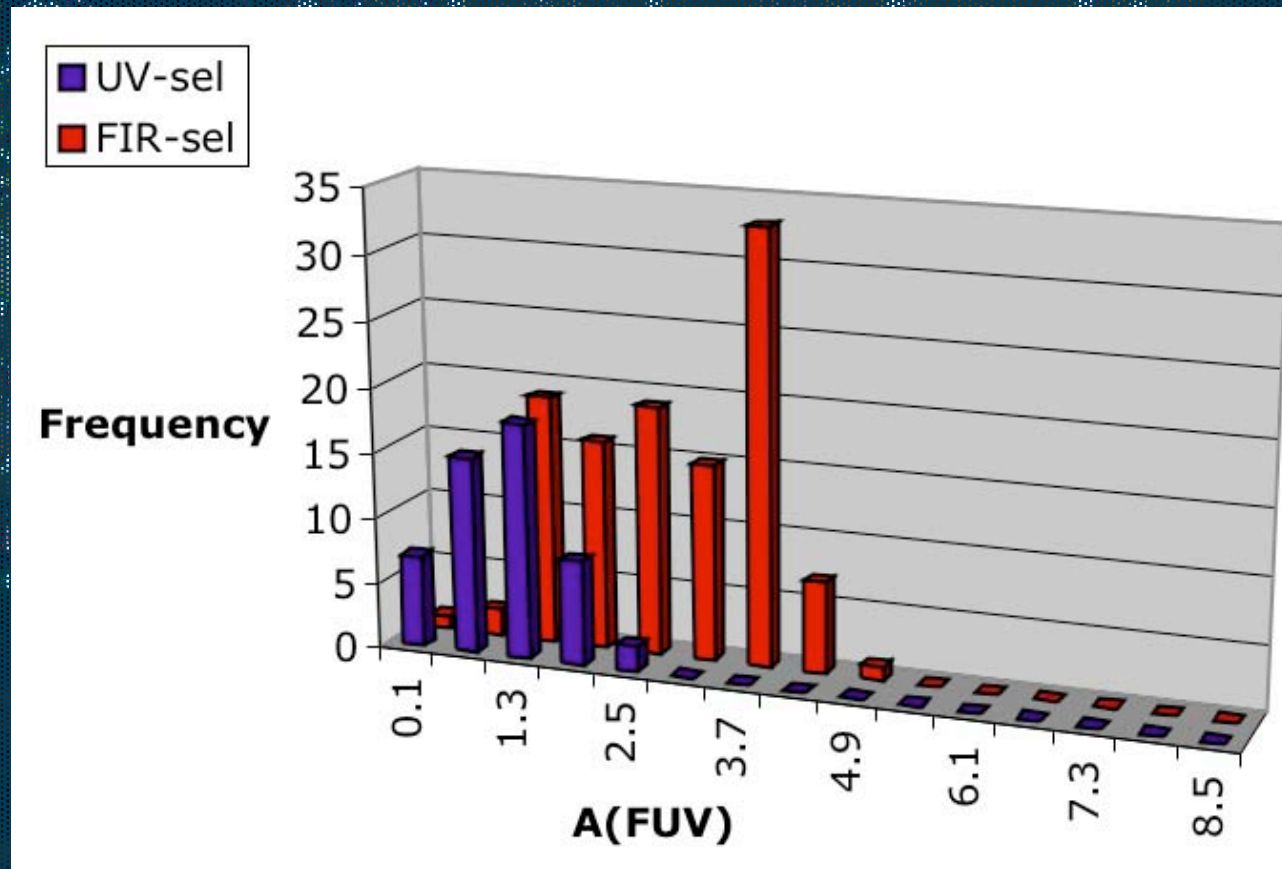
- Valeur  $b_8$  (intégrée sur 100 Myrs) mieux que  $b_0$  (inst.)
- UV  starbursts
- FIR  starbursts

Buat et al. (en prep.)  
b mesuré à partir de H/FUV



# Atténuation en FUV

- Les résultats confirment les analyses directes réalisées par Buat et al. (GALEX ApJL)



# Conclusion

- Numéro spécial de GALEX
- Propositions de temps GALEX cycle 2
- GALEX permet une analyse statistique qui n'était pas réalisable jusqu'à présent
- Nécessité d'une approche multi- $\lambda$  pour appréhender complètement la nature des galaxies :
  - ❖ Buat et al. champs ELAIS (SWIRE + GALEX)
  - ❖ Burgarella et al. CDFS (MIPS + GALEX)
  - ❖ Boissier et al. (galaxies résolues (Spitzer + GALEX))