Star Formation Rate Densities & Dust Attenuation Through Cosmic Times

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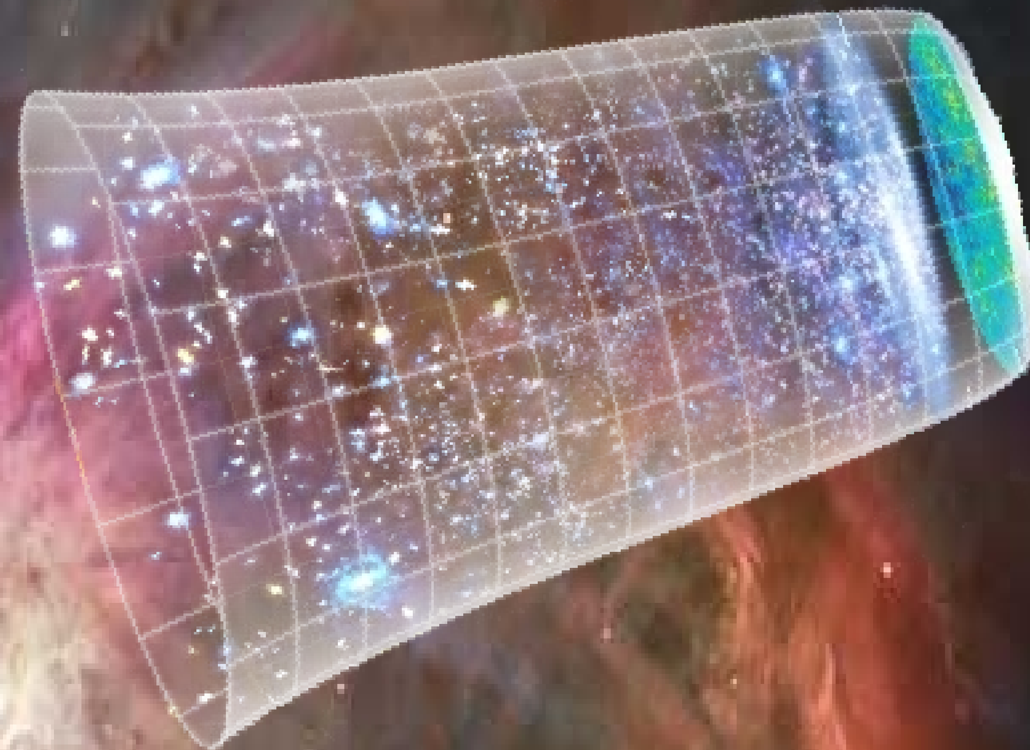
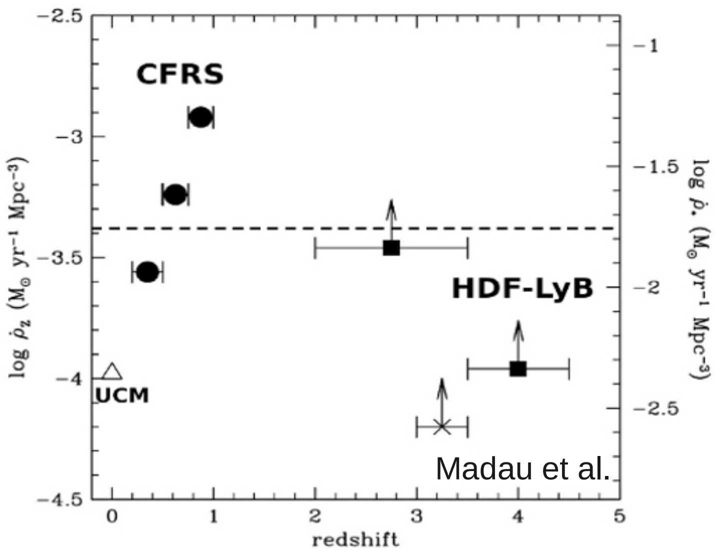


Workshop "Numerical Simulations of Galaxy Formation in the Era of Large Scale Surveys"
Lyon, 17–19 October 2011

The Cosmic Star Formation Rate Densities

A strong constrain for galaxy formation and evolution scenario.
Outlined thanks to deep redshift surveys.
Surveys yield the global SFRD without being perturbed by individual stochastic evolution.

Compilation in 1996 CDM
No dust correction

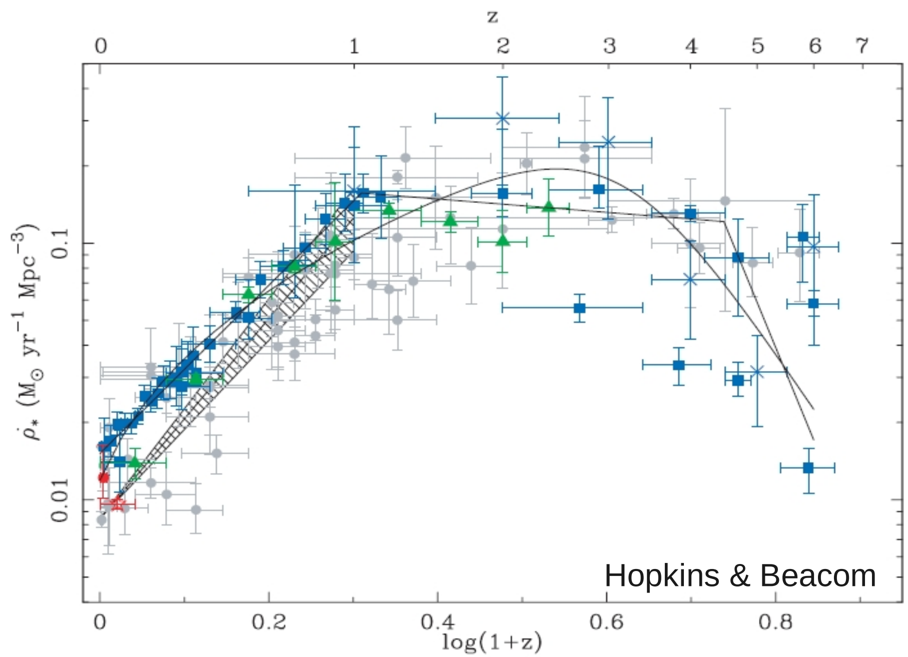


Three different **redshift** surveys
Hα/I-band/LBG selections

10 yrs later...

a fully filled dust-corrected CSFRD

Compilation in 2006 ΛCDM
Dust accounted for



Many surveys or single points
Many assumptions on dust
Many underestimated errors
....blurring the picture

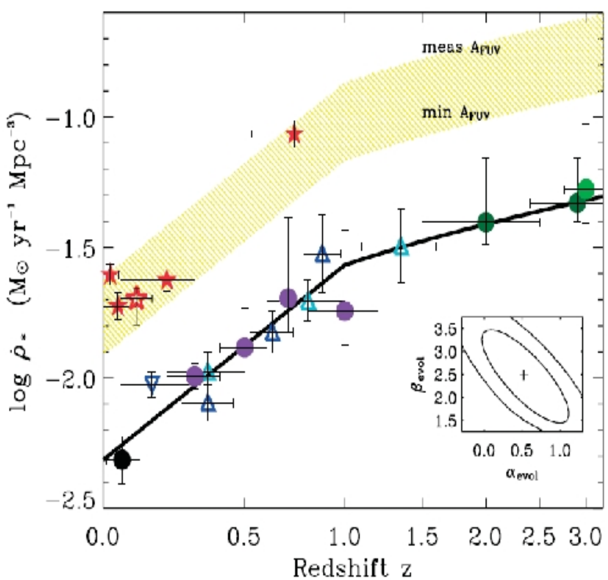
Yet, the drop at z < 1 & the rise at z < 5 are persistent

The VIMOS VLT Deep Survey (VVDS)

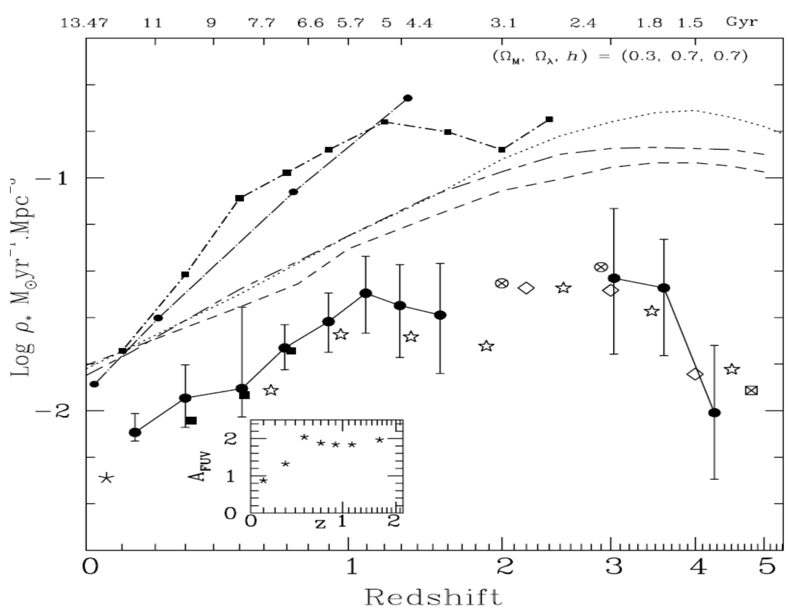
Previous Works with VVDS-Deep datasets on the CSFRD

Selection	I_{AB} = [17.5 – 24.0] **VVDS-Deep**
Spectra	TSR ~24% [10 000 over 0.5 deg^2 in 02h + 1600 over 0.1 deg^2 in 03h]
Redshift baseline	z = [0 – 2] & [2.7 – 5] (red grism: 5500 < λ < 9500 Å)

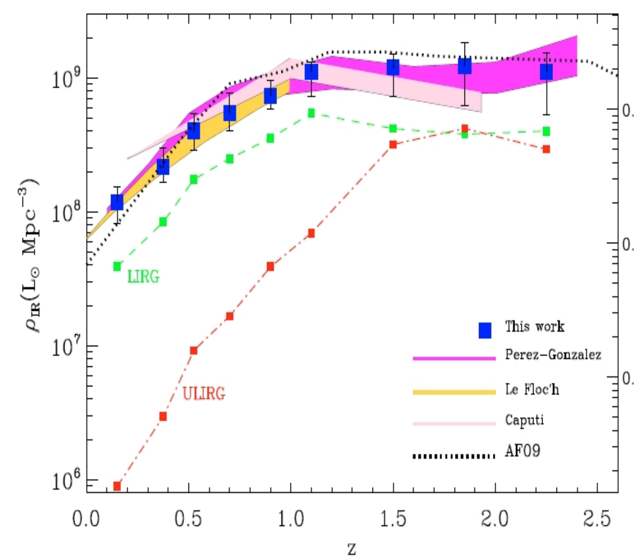
GALEX-VVDS (z<1.2)
+ HDF (z>1.75)
NUV-selection
Attenuation not set
1<A_{FUV}<1.7 mag, and constant
Schiminovich et al. 2005



VVDS U,12K-BVRI
I-selection
Redshift desert not covered
FUV LF slope set to α=-1.6
Evolution of the attenuation
Downsizing in FUV
Tresse et al. 2007



Spitzer-VVDS (S_{24}>400 μJy)
+Spitzer-GOODS (S_{24}>80 μJy)
24 μm-selection
TIR LF slope set to α=-1.2
Plateau at 1<z<2
Downsizing in IR
Rodighiero et al. 2010



The VIMOS VLT Deep Survey (VVDS) cont'd

Work with combined VVDS Deep & Ultra-Deep datasets on the CSFRD

Selection	I_{AB} = [17.50 – 24.00] **VVDS Deep**
	I_{AB} = [23.00 – 24.75] z > 1.4 **VVDS Ultra-Deep**
Spectra	TSR ~24% [12608 spectra over 0.6 sq. deg in 02h]
	TSR ~4% [1200 spectra over 0.2 sq. deg in 02h]
Redshift baseline	z = [0 – 5]
Re-observations	blue+red grisms: 3700 < λ < 9500 Å
	excellent control of the redshift success rate

Deep photometric samples: CFHT-12K BVI, CFHTLS-Megacam ugriz , CFHT-Wircam JHK (Wirds)

- excellent constraint for SED fitting
- zphot to I_{AB} = 26

- tests of the stability of our results based on an I-band selection

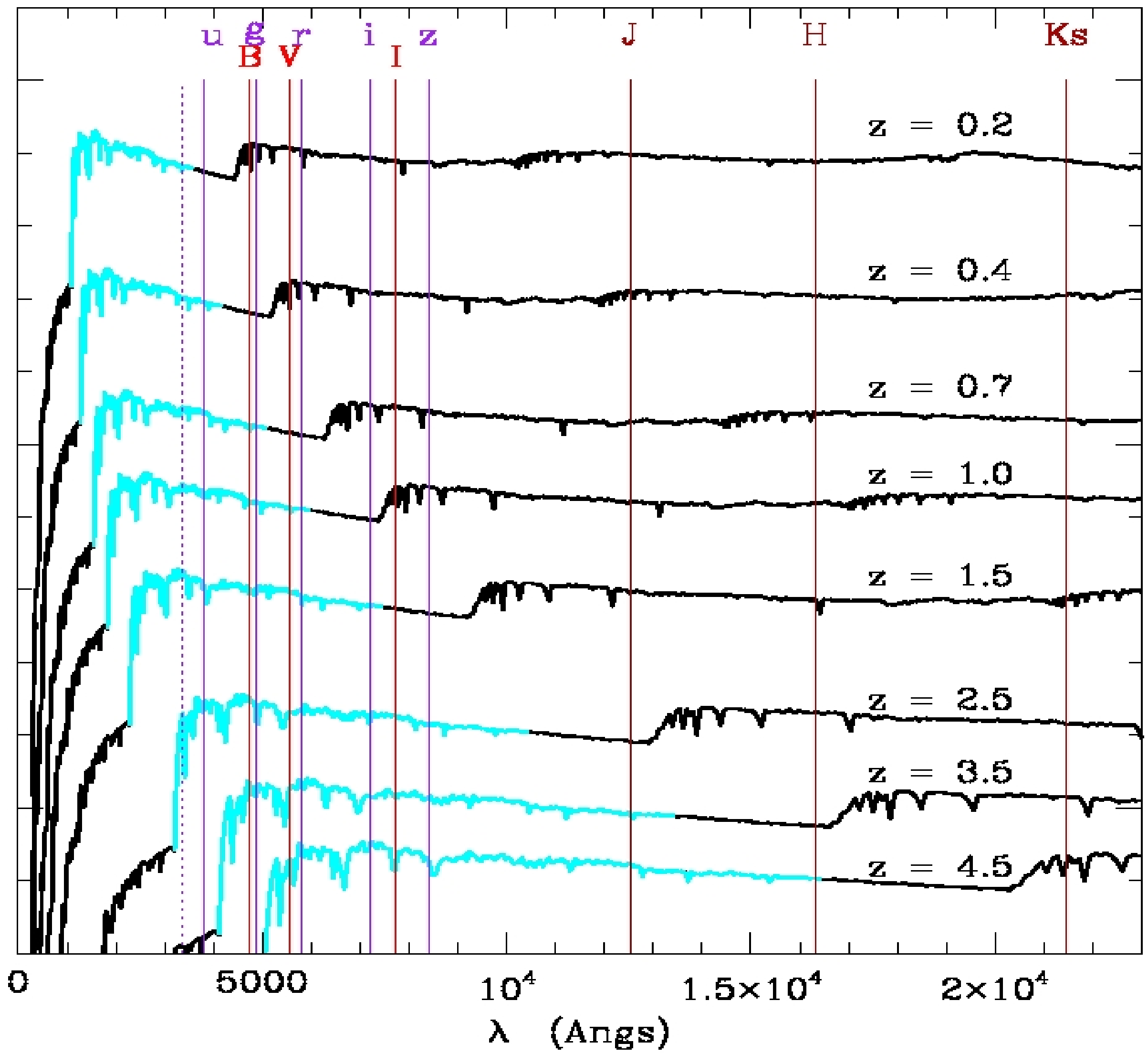
The SFRD requires a control of observable volumes
a well-defined source selection function
a knowledge of the distribution of the galaxies (LF)

We can trace the FUV-derived dust-corrected CSFRD over 12 Gyrs using a single methodology

Study presented in Cucciati et al. (2011)

The Observed Rest-Frame UV Window

The UV continuum (912-3000) is directly spanned from z > 0.1
i.e. NUV-2500 at z > 0.2   FUV-1500 at z > 0.9
Deep u* = 26 mag

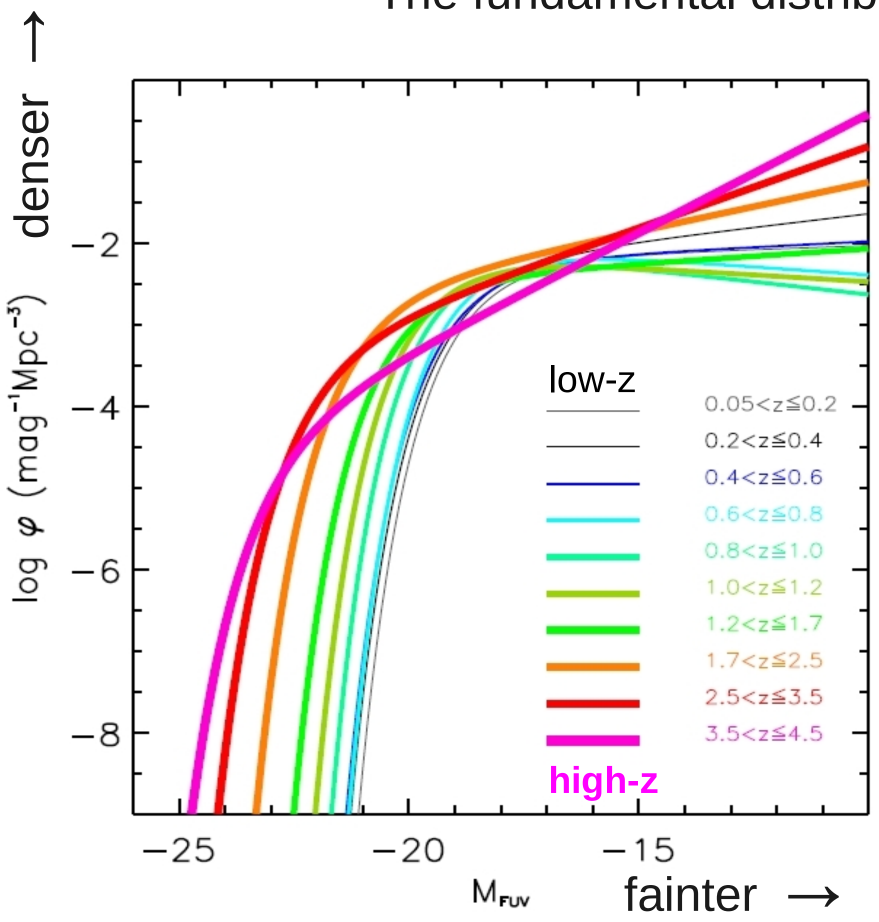


Can be traced at every cosmic epochs

Multi-wavelength, very deep, optical+NIR photometry enable to detect very faint, normal, dusty galaxies.
The aim is to account for all main contributors to the SFRD.

Evolution of the Observed Rest-Frame FUV Luminosity Function

The fundamental distribution of SFR of the galaxy population



Continuous decrease of M* of ~4 dex since z~4

Fast	~1.8 dex	2 < z < 4.5	(2.0 Gyrs)
	~1.7 dex	1 < z < 2	(2.6 Gyrs)
Slower	~0.6 dex	0 < z < 1	(8.0 Gyrs)

Persistent constant flat faint-end slope since z~2

Φ* increases down to z~0.8 (x90)
x30 down to z~2, then x3 down to z~0.8
decreases down to z~0 (/1.4)

At z > 2, the LF knee is unlocked

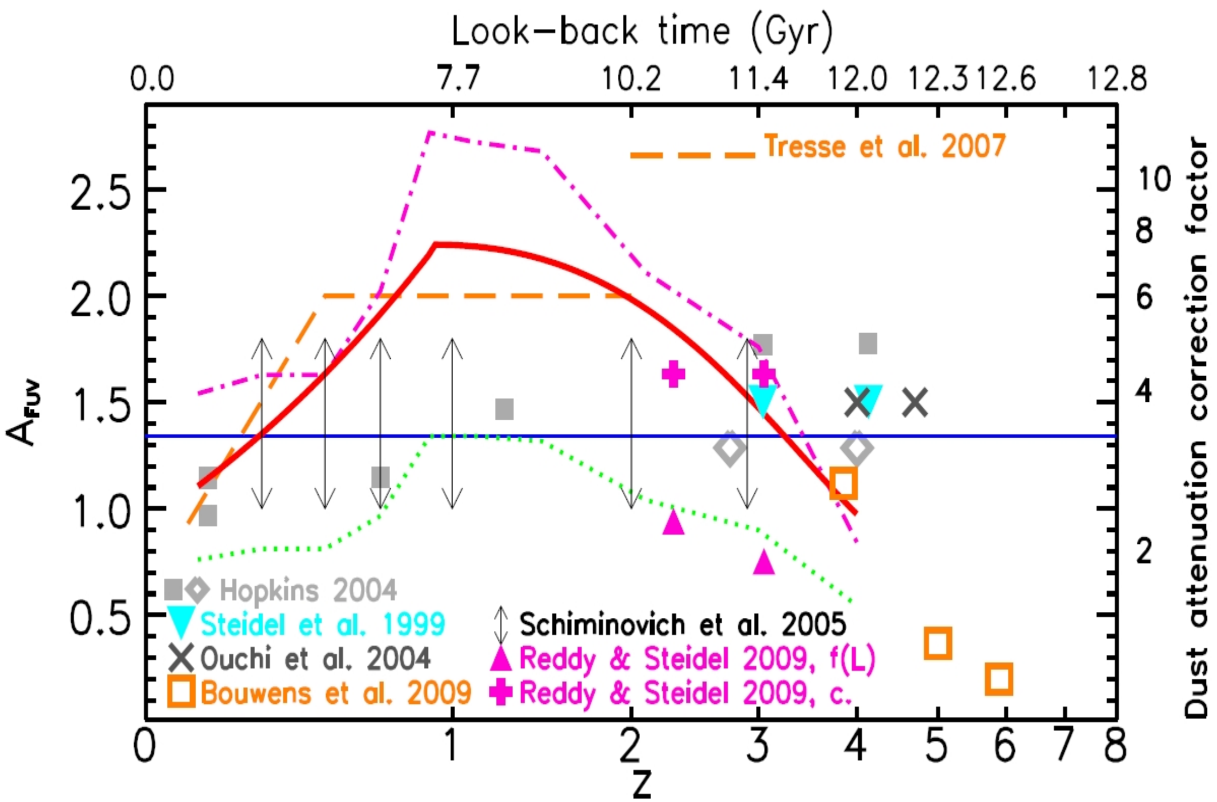
- the non-linear processes (dust/feedbacks,...) start to inefficiently act and unlock the LF knee
- the population is loosing its SF dichotomy between the bright and faint SF galaxies

It does not mean
an homogeneous evolving high-z gas-rich population
but likely,
long time scale (t >3 Gyrs) processes have not yet raised and dominated the galaxies' SFR

Evolution of the Average Cosmic Dust Attenuation

Average attenuation

ie. dominated by the typical state of visible galaxies at a given epoch



Calzetti (2000) law

IRX-β relation Meurer (1999)

but β depends strongly on the galaxy type, cf. Treyer 2007, Wijesinghe 2011

β slope Kong et al. (2004)

β slope Cortese et al. (2006)

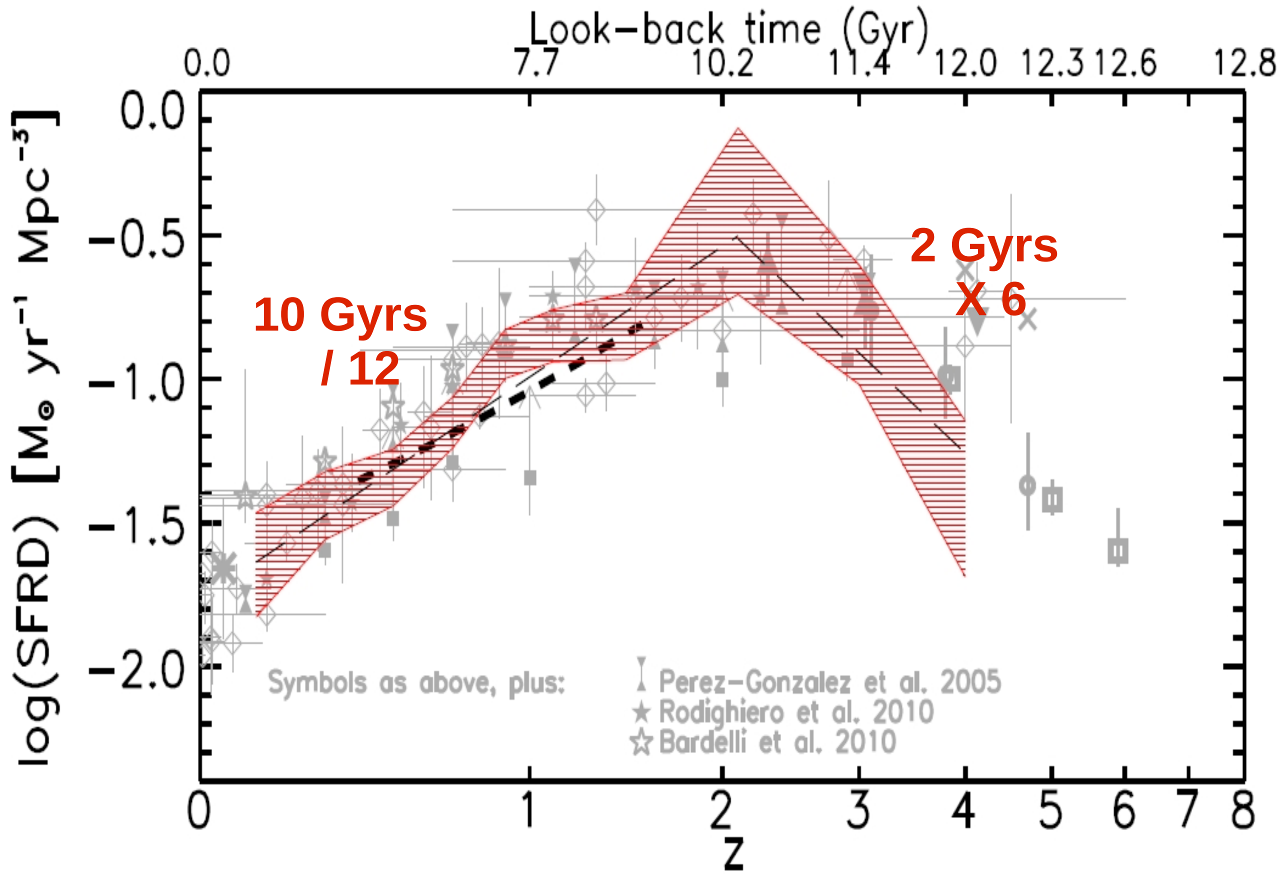
The FUV emissivity is the most absorbed at 0.8 < z < 2

Whatever the method to derive the dust attenuation,

the amount of dust in the universe increases from the earliest epochs to reach a plateau at z~1-1.5

Evolution of the SFRD over 12 Gyrs

SFRD FUV-derived and dust corrected
$SFRD(z) = 1.4\ 10^{-28} \times LD_{FUV}(z) \times 10^{0.4\ A_{FUV}(z)}$

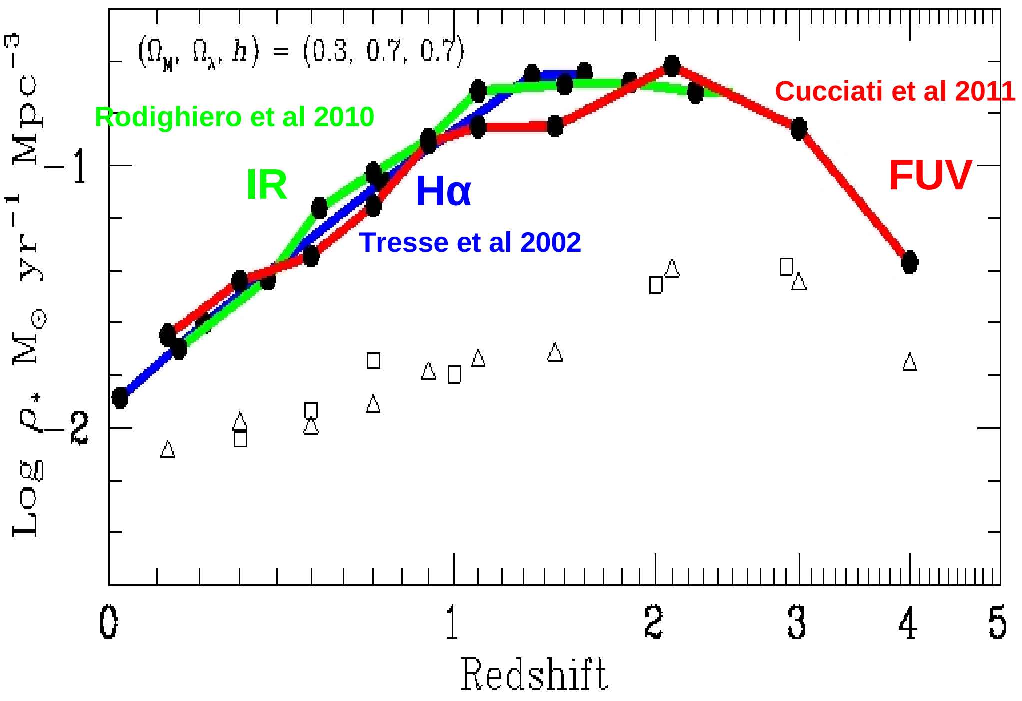


Full account of errors
(LF param., weights, Poisson, CV)
...often underestimated in the literature

SFRD evolves as $(1+z)^a$
z > 2 a = -3.6 ± 1.9
z < 2 a = 2.6 ± 0.4

Using a single sample and a coherent method over 12 Gyrs
we can set a definitive clear SFRD maximum at z~2

Zoom on the 1 < z < 2 SFRD Critical Era



at z < 1

consensus between FUV, Hα, IR estimates

consensus with the SM assembly

⟶ we do not miss any major SFRD contributors

at 1 < z < 2

data exhibit some discrepancies ~0.2dex

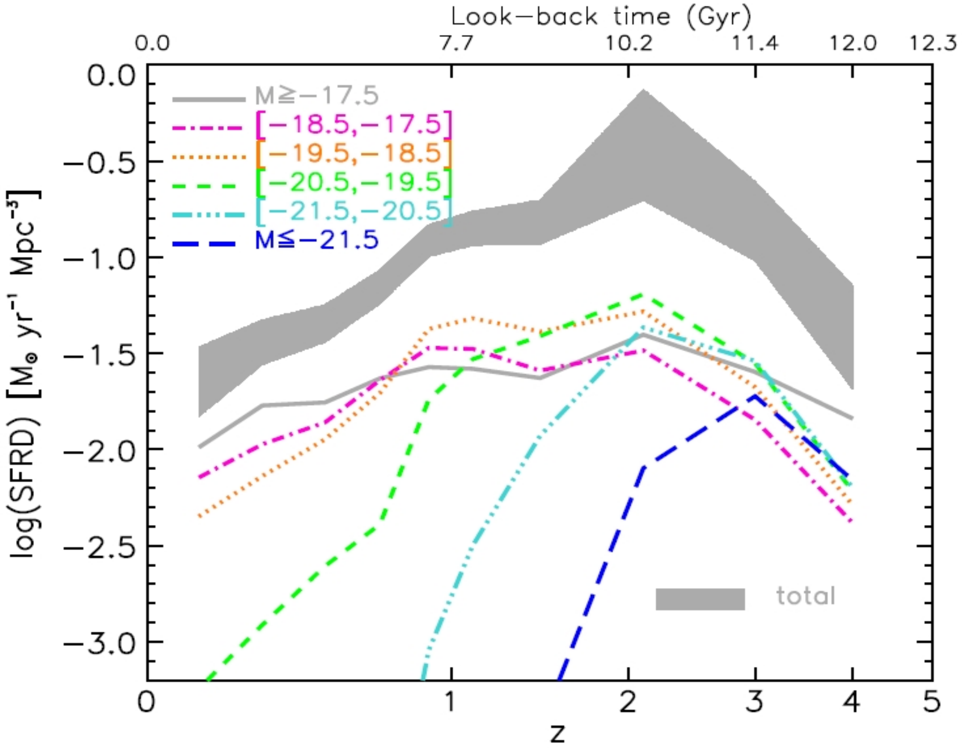
At 1 < z < 2

M_{FUV} < -20 SFRDs drop

M_{FUV} > -20 SFRDs are flat, drop occurs at z < 1

Transition both in UV and IR:

- the dominance of ULIRG at z>1.5
- the dominance of bright UV galaxies at z>1.5

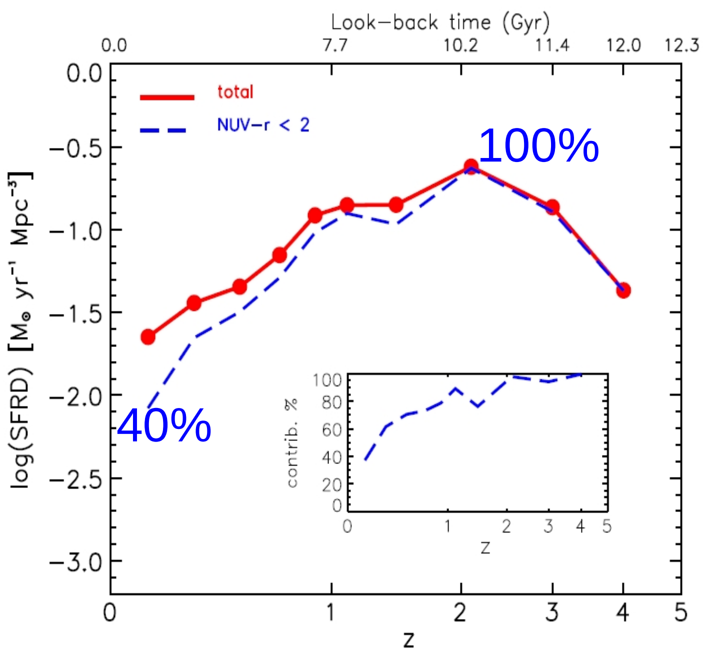


Discrepancies are likely due to different selection criteria in a period where occurs:

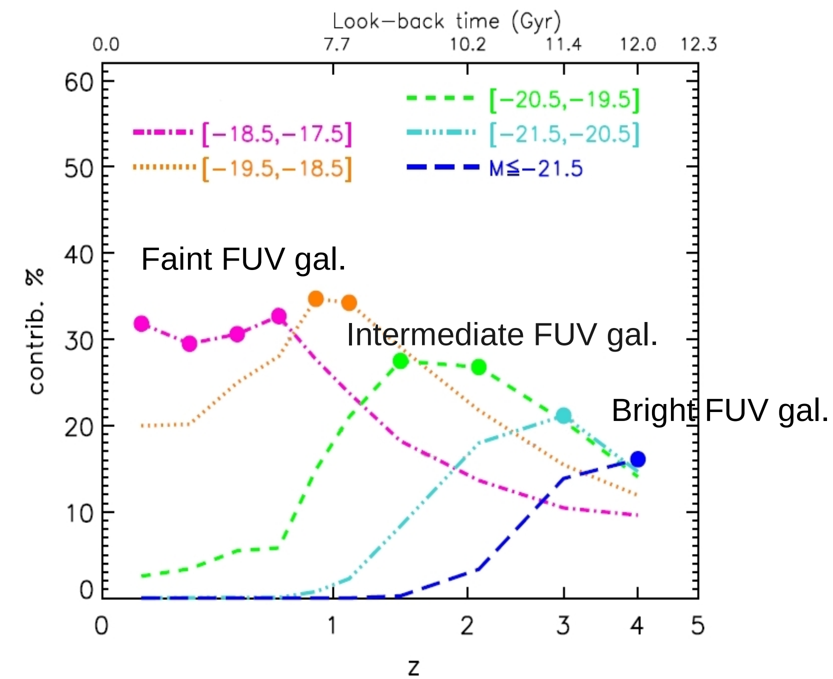
- the maximum plateau of dust
- the redshift desert (use of zphots)
- the transitional shape of the FUV LF

The Downsizing Patterns

The highest **sSFR** population contributes to 100% at z>2 downwards to 40% at z~0, cf. the sSFR plateau at z>2



The fainter SF populations undergo their highest activity as time goes

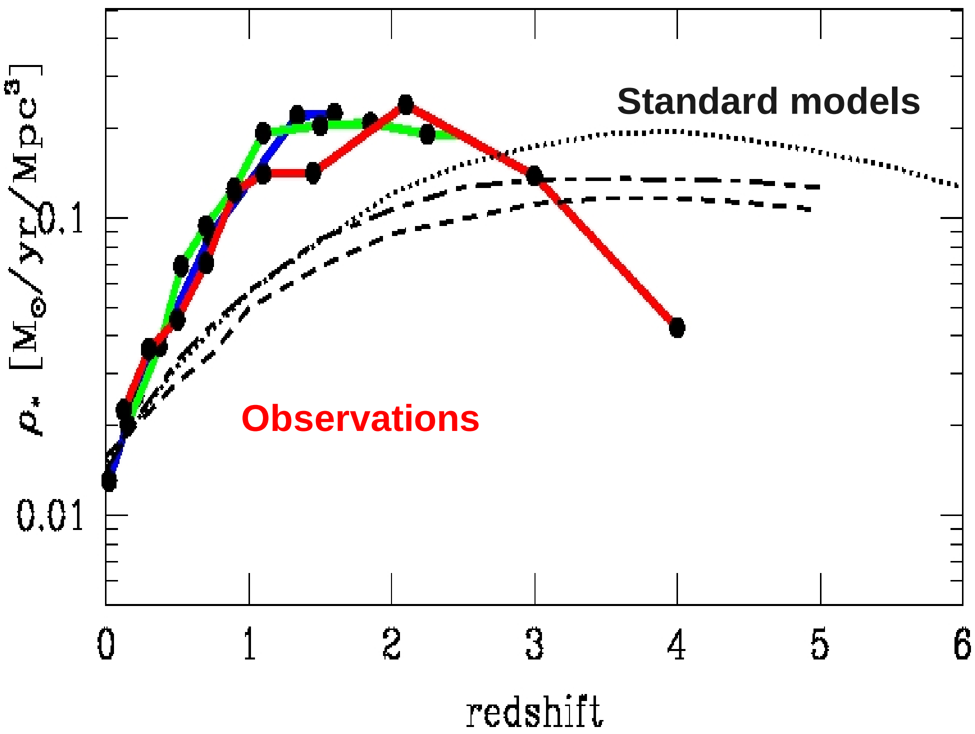


Redshift ~2 is a transitional phase in the universe

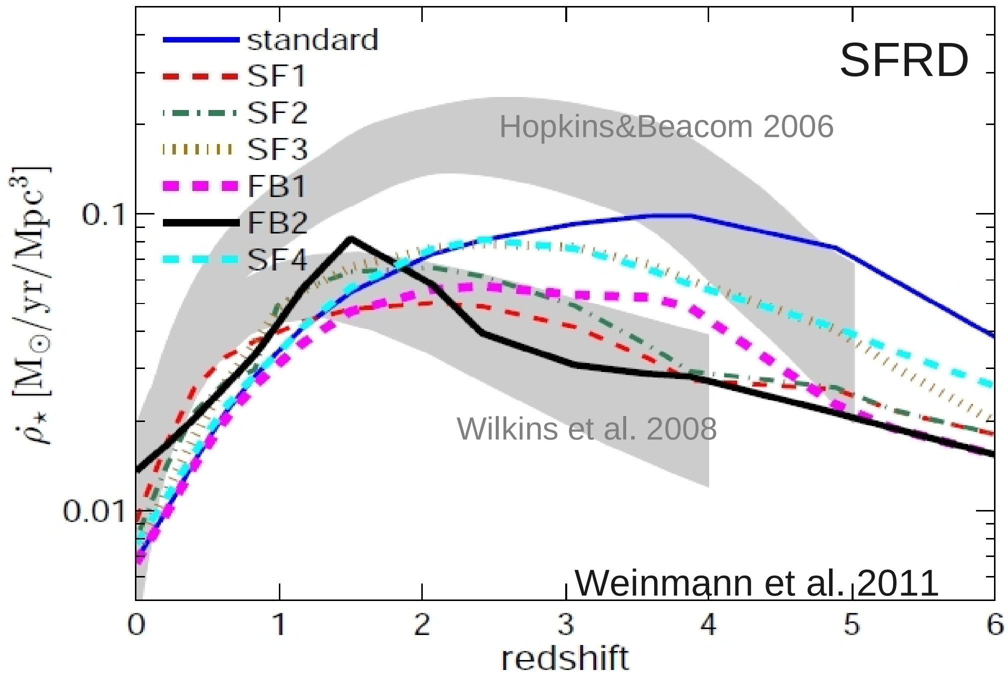
The very intense SF population ($M_{FUV,uncorr}$ > -20) ceases to dominate the FUV emissivity

The SFRD Observational Constraints and Models

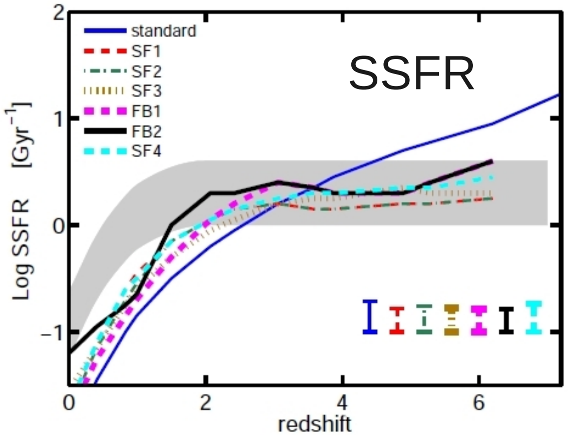
Observations: snapshots of subsets of the galaxy population at selected epochs.
To make sense of data, we need to link them to theory of galaxy formation and evolution



Simple ad-hoc modifications to the standard physical recipes



The closest shapes (FB2) imply strong early feedback & reincorporation of ejective/non-ejective FB phase back to the cold gas phase



The Survival of Dust on Long Time Scales

How to conciliate the epochs of maximum SFRD and maximum dust?

Our Observations

The SFRD peaks at z~2 and the dust peaks at z~1, **i.e. ~2.5 Gyrs later on** with a sort of plateau from z~1.5 to z~1, i.e. from ~1 Gyr after the SFRD peak

Literature on Stars and Dust

SFRD = based on observed emissivity of short-lived, massive stars
Stars > 8 $M_\odot$ explode as SN (SN typeII-P are those producing dust...)
Dwek (1998): the peak of dust production happens
- < 1 Gyr later for SNII events
- ~3-4 Gyrs later for intermediate-mass (1-8 $M_\odot$), long-lived stars

Review of Gall et al. (2011): AGB stars (0.85-8 $M_\odot$)
- release dust through intense mass-loss
- most efficiently at the very end stages of evolution

For z_{form}=10, the lowest mass star potentially source of dust at z=6 is 3 $M_\odot$

The delayed dust attenuation peak at z~1 is likely due to intermediate-mass long-lived stars

It would explain
- the low level of dust at z > 2 mainly produced by SNe
- the delayed rise up to z~0.9-1 produced by the numerous intermediate-age stars
- the delayed fast drop of dust at z < 1 linked to the cease of new stars from z~2.

Conclusions

First time, that the SFRD and Dust Attenuation have been measured from a single survey with the same methodology rather than a compilation of various datasets at different redshifts

z = 2 (10 Gyrs) is the maximal SF activity in the Universe
- the SF activity is shifting downwards the numerous faint SF galaxies as time goes
- large fraction of cold gas must be available in systems at z < 2

The 1 < z < 2 period is strongly affected by long-time scale dust production processes
- explain the growing bend of the observed FUV LF
- critical era: need to be further constrain with FUV/IR studies

The maximal dust attenuation is delayed wrt the maximal SFR activity
- likely due to intermediate-mass star dust production
- dust must grow fast in the early universe within SN ejecta and remnant