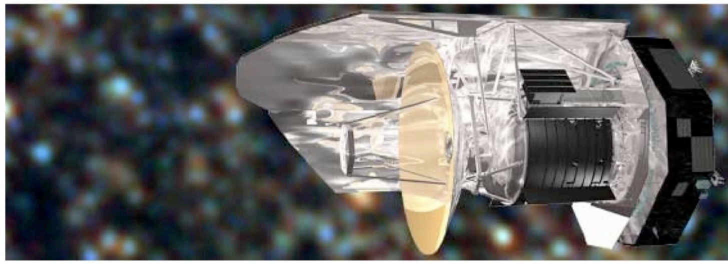
Herschel PEP/HerMES: On the Redshift Evolution ($0 \le z \le 4$) of Dust Attenuation and of the Total (UV+IR) Star Formation Rate Density

D. Burgarella, V. Buat, C. Gruppioni, O. Cucciati, S. Heinis,
& the PEP/HerMES Team (2013, A&A 554, 70)

HERMES

Herschel PEP / HerMES Collaboration



PACS EVOLUTIONARY PROBE
HERSCHEL MULTI-TIERED EXTRAGALACTIC SURVEY

HerMES mapped ~400deg^2 and has uncovered several 10^5 distant star-forming galaxies

The Herschel Multi-Tiered Extragalactic Survey: HerMES

HERMES

Seb Oliver[1], Jamie Bock[2], Charlotte Clarke[1], Lingyu Wang[3], Marco Viero[2] and the HerMES Consortium
[1]University of Sussex, [2]Caltech/JPL, [3]University of Durham

HerMES Data releases:

2013 October — **Second data release (DR2)**
SPIRE maps and catalogues from all fields from levels 1-6

2012 April 3rd, — **First data release (DR1) of HerMES data.**
The maps cover ~74 deg^2 of the sky, i.e. a volume of 6.6e8 (Mpc)^3 for z<1.5 (and many of the galaxies that we see are expected to be at z>1.5) q.v. the SDSS which maps a volume of 3.5e8 (Mpc)^3 for z<0.17.
The catalogues extracted from these maps include over 50, 000 catalogue entries, representing over 17,000 galaxies.

2011 Sept.19th, — **Second *Early Data Release* of HerMES data.**

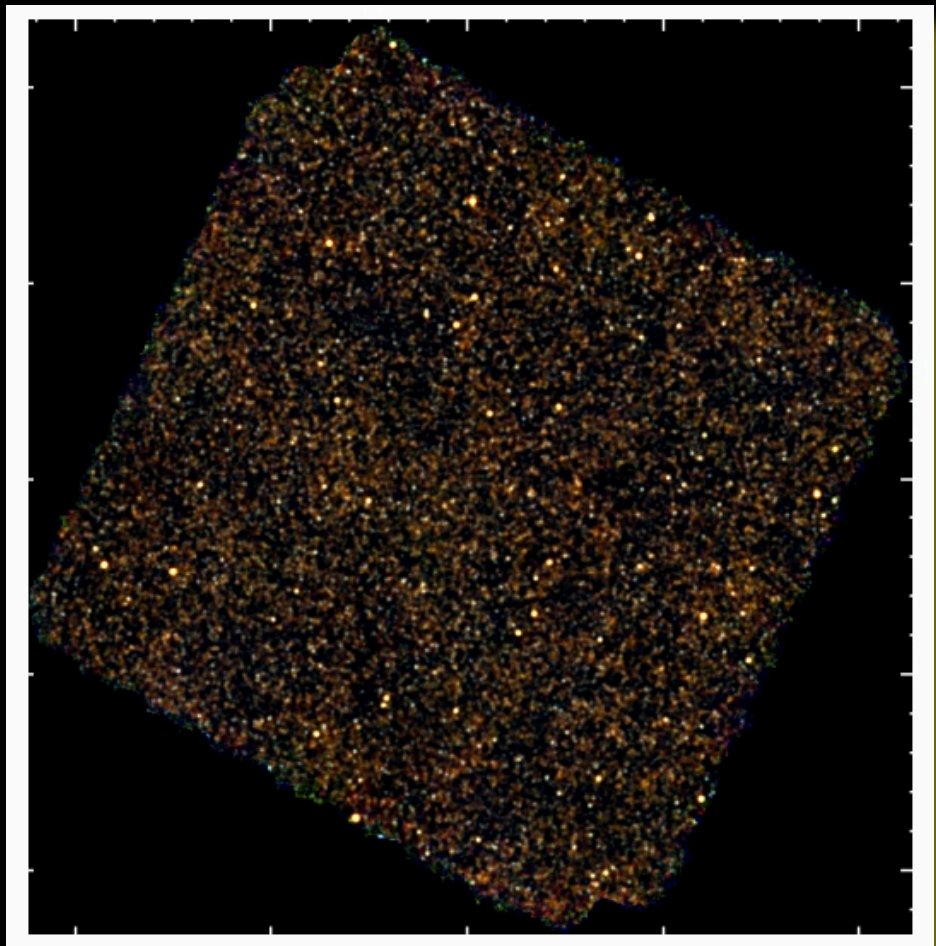
2010, July 1st, — **First release of data.**

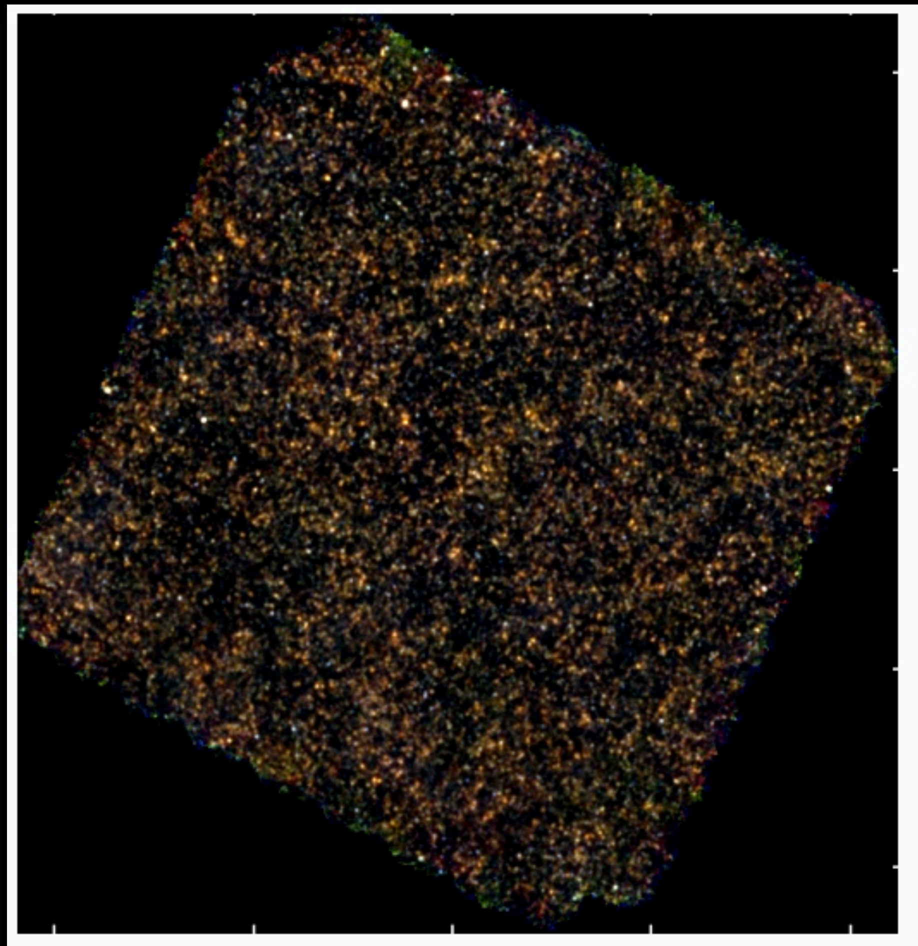
hedam.lam.fr/HerMES/

These images are RBG versions of SPIRE 250, 350 and 500µm maps of the HerMES COSMOS fields.

- ONE IS THE REAL IMAGE
- ONE IS A SIMULATION based on an extended halo model of galaxies including their luminosities and clustering which fits the SPIRE P(D) and cross Power Spectra (see S. Oliver's poster)

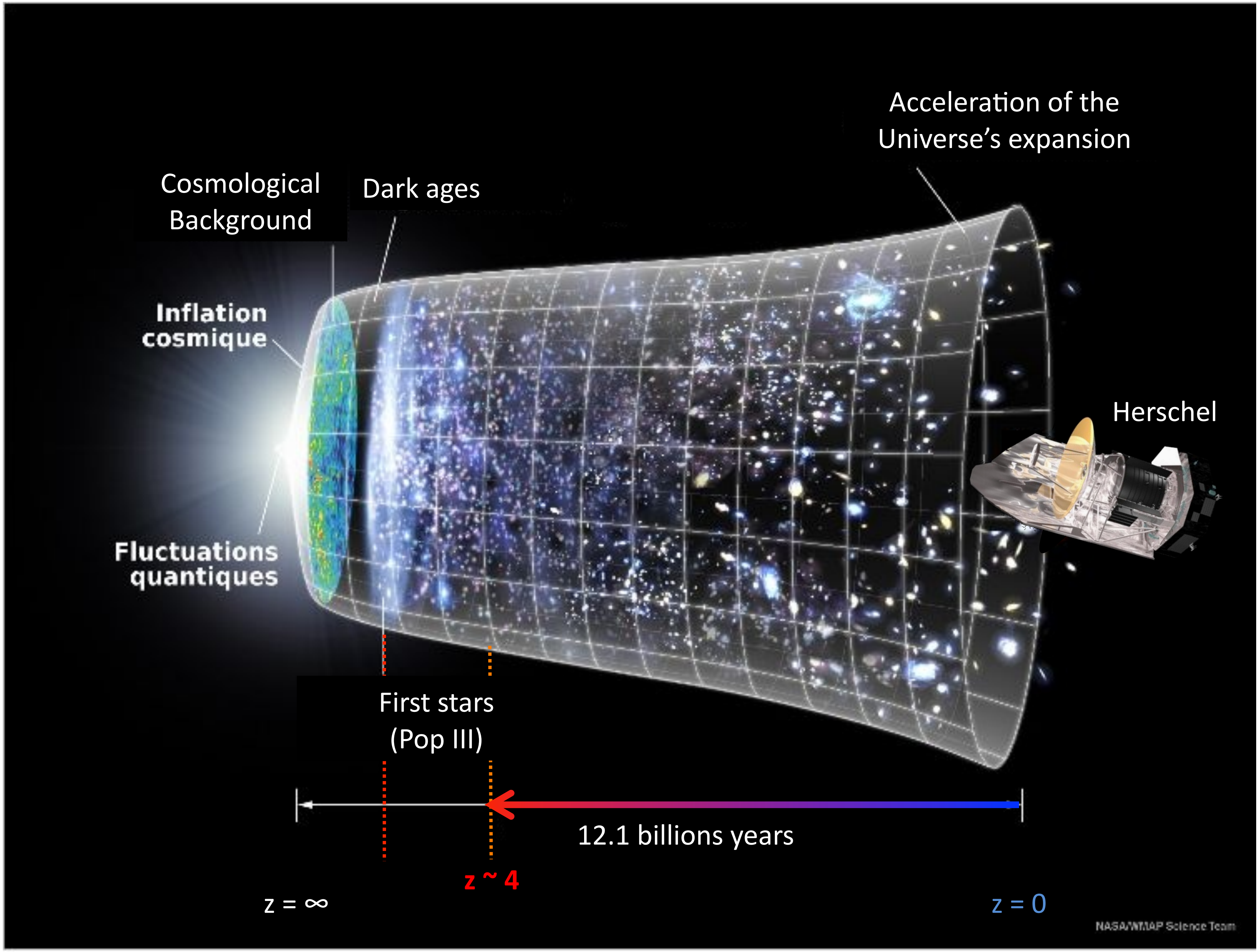
Which is the real image and which is the simulation? -------->Vote now: http:/bit.ly/GNPCGd





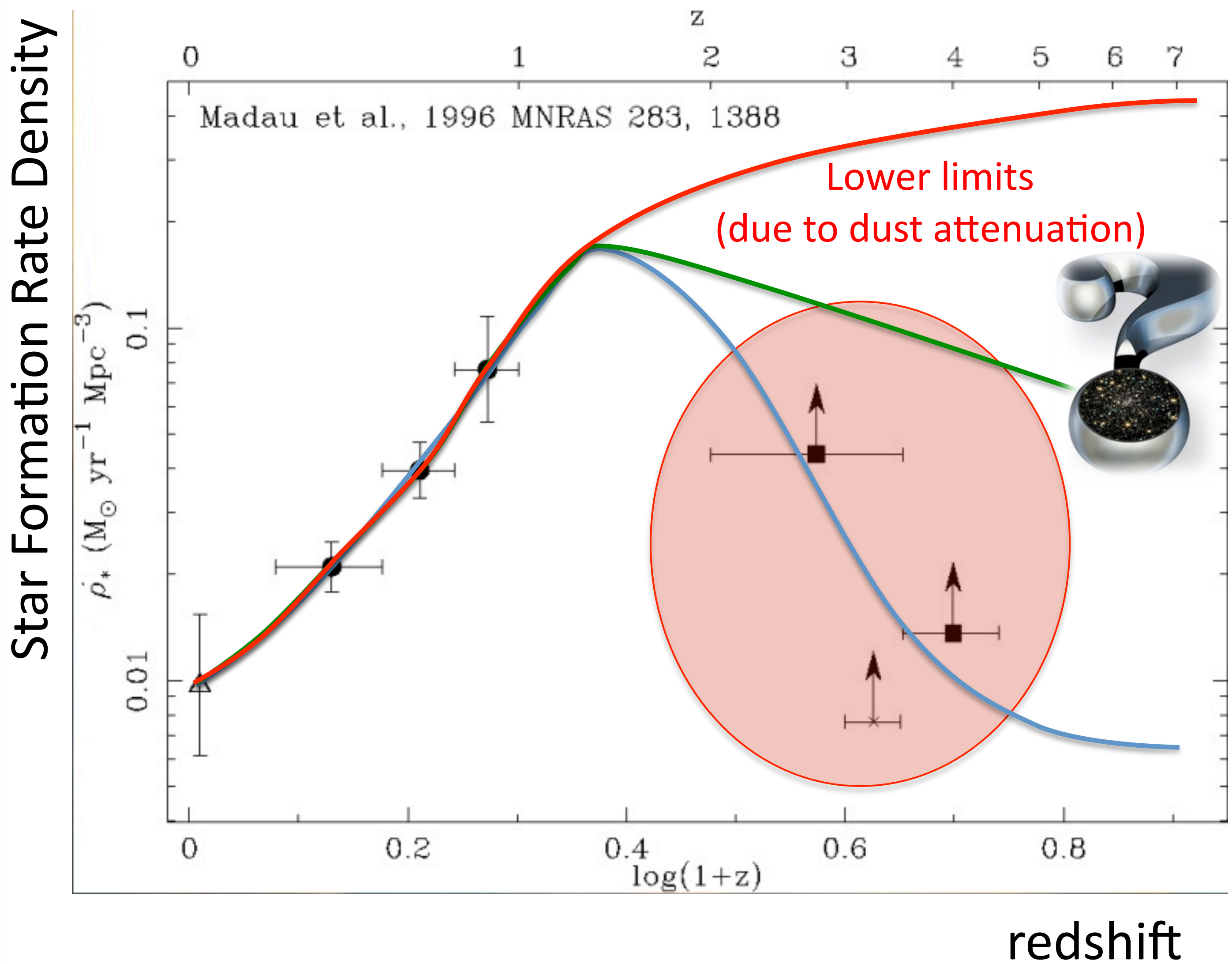
Questions:

- What is the redshift evolution of the total SFRD?
- What is the redshift evolution of the Cosmic Dustiness?
- How could we better understand the results and move to higher redshifts?

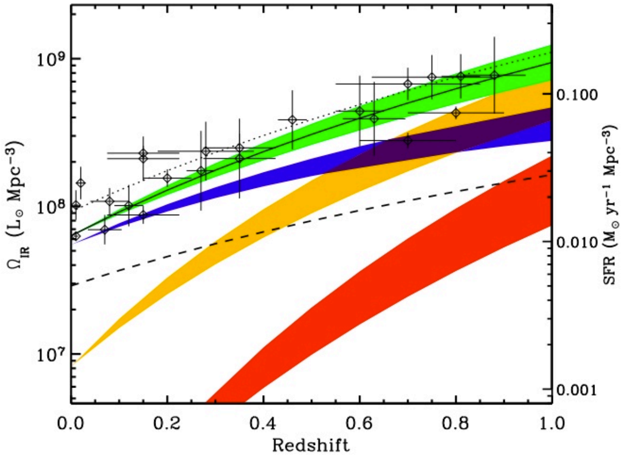


Acceleration of the
Universe's expansion
Cosmological
Background
Dark ages
Inflation
cosmique
Fluctuations
quantiques
Herschel
First stars
(Pop III)
12.1 billions years
z ~ 4
z = ∞
z = 0
NASA/WMAP Science Team

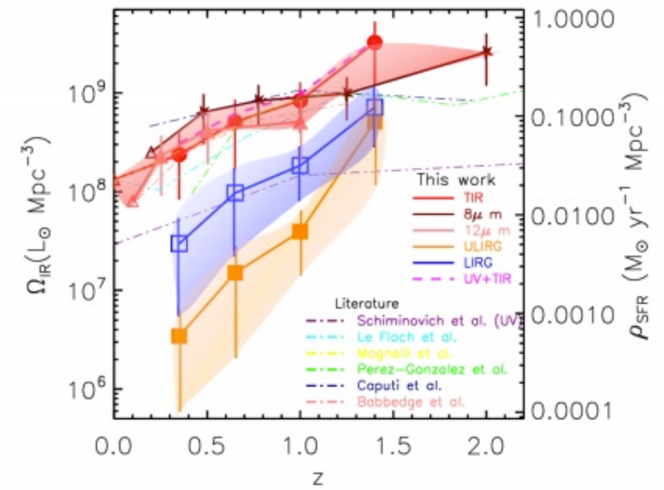
Madau Plot (1996)



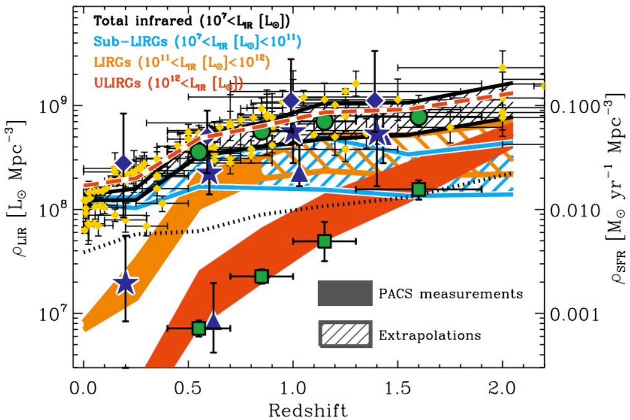
Previous status (selection of papers)



Le Floc'h et al. (2005) from Spitzer to z ~ 1



Goto et al. (2010) from Akari to z ~ 1.5

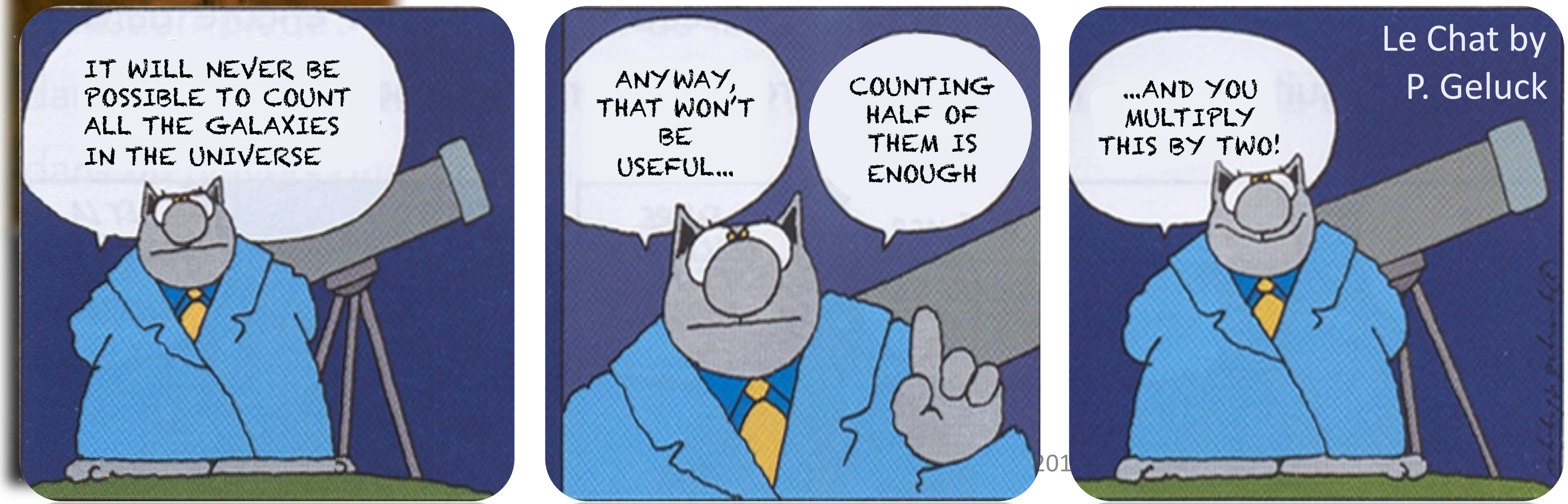


Magnelli et al. (2012) from Herschel/PACS to z ~2

The Far-IR sources of data

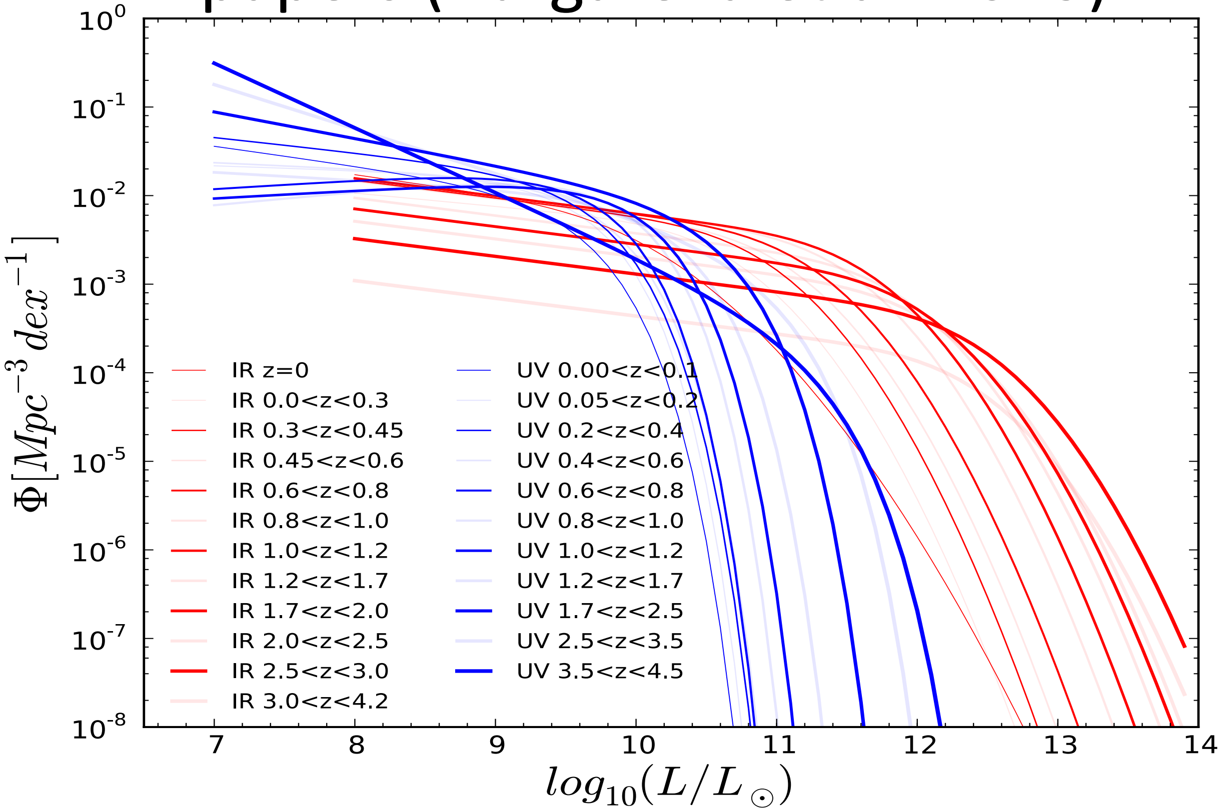
See poster by C. Gruppioni et al.
(Poster #19)

Of course...



Le Chat by P. Geluck

Far-UV + Far-IR LFs from the two previous papers (Burgarella et al. 2013)



Redshift evolution of the FIR (red, Gruppioni et al. 2013) and FUV (blue, Cucciati et al. 2012) LFs. Note that the FUV LFs are uncorrected for dust attenuation. The LFs at every other redshift are plotted boldly. The others are fainter to lighten the figure. The LFs are plotted within the limits of integration.

What is the redshift evolution of the Cosmic Dustiness?

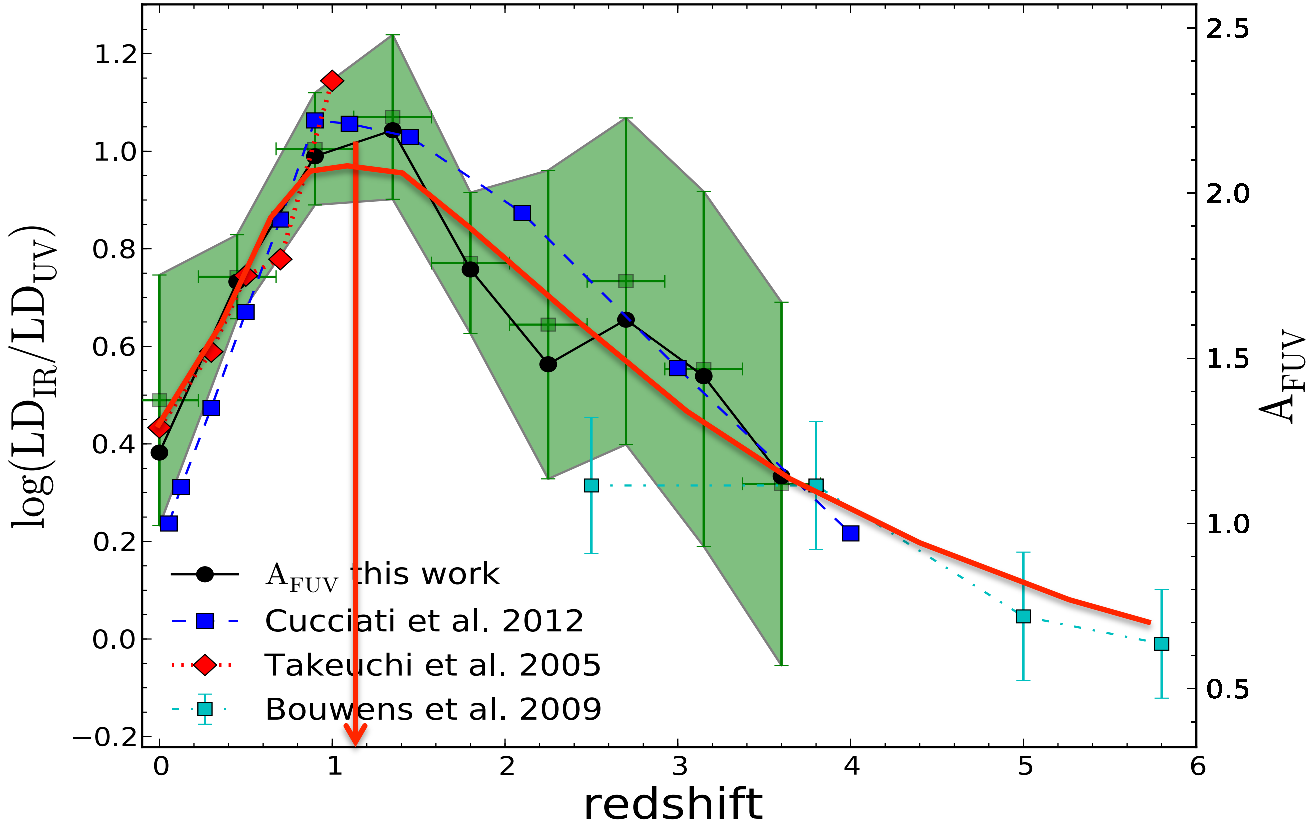
L_{IR} / L_{UV}

Cosmic Dustiness: A_{FUV} (z)

The best fit is given by:

$A_{FUV}(z) = (a+bz) / [1+(z/c)^d]$

with a = 1.20, b = 1.50, c = 1.77, and d = 2.19



Takeuchi et al. (2005) (red diamonds) used an approach identical to ours while a SED analysis (no FIR data) is performed in Cucciati et al. (2012) (blue boxes). Bouwens et al. (2009) are estimates based on the UV slope β.

A_{FUV} (z)

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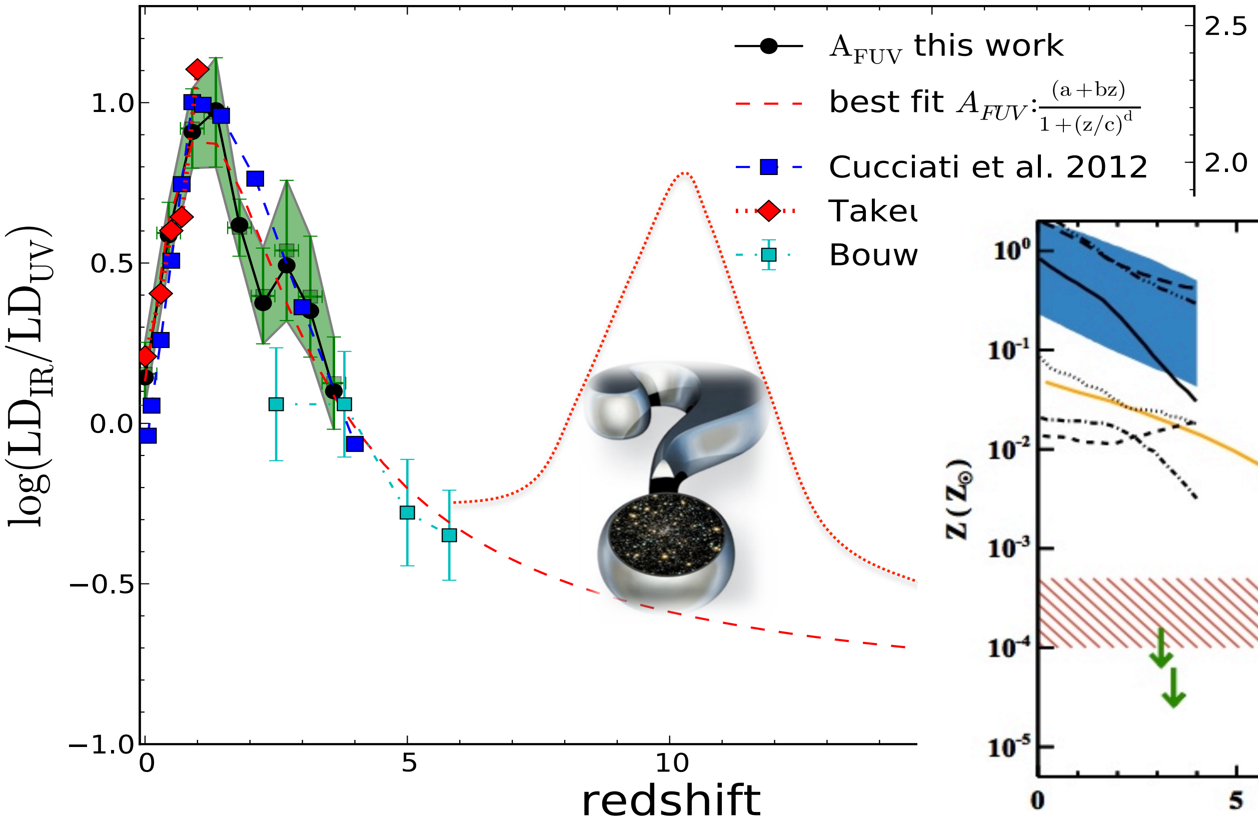
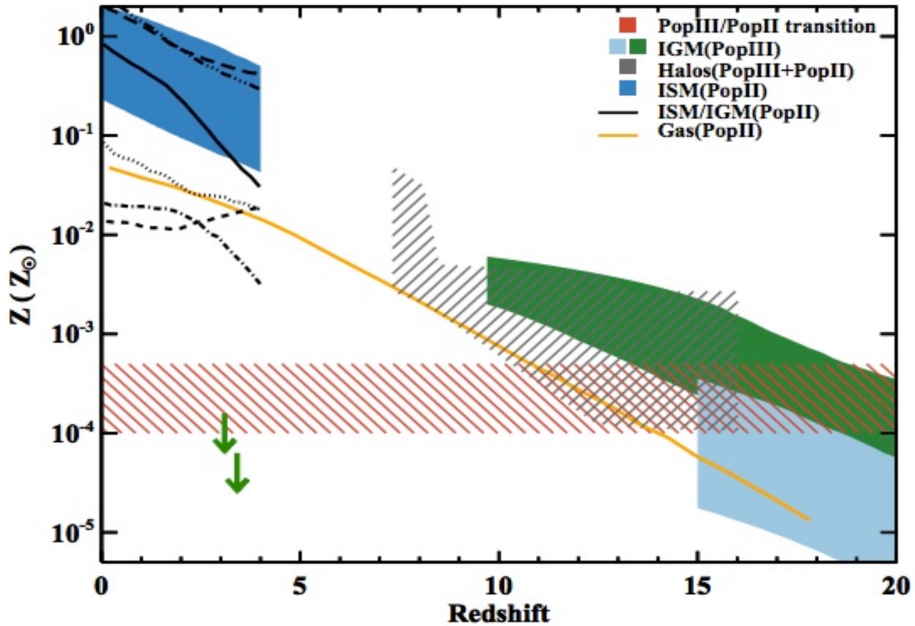




At z = 3.6, A_{FUV} reaches about the same value as at z = 0. What about the very high redshift range? We very likely expect a monotoneous decrease that still needs to be confirmed.

What is the redshift evolution of the total SFRD?

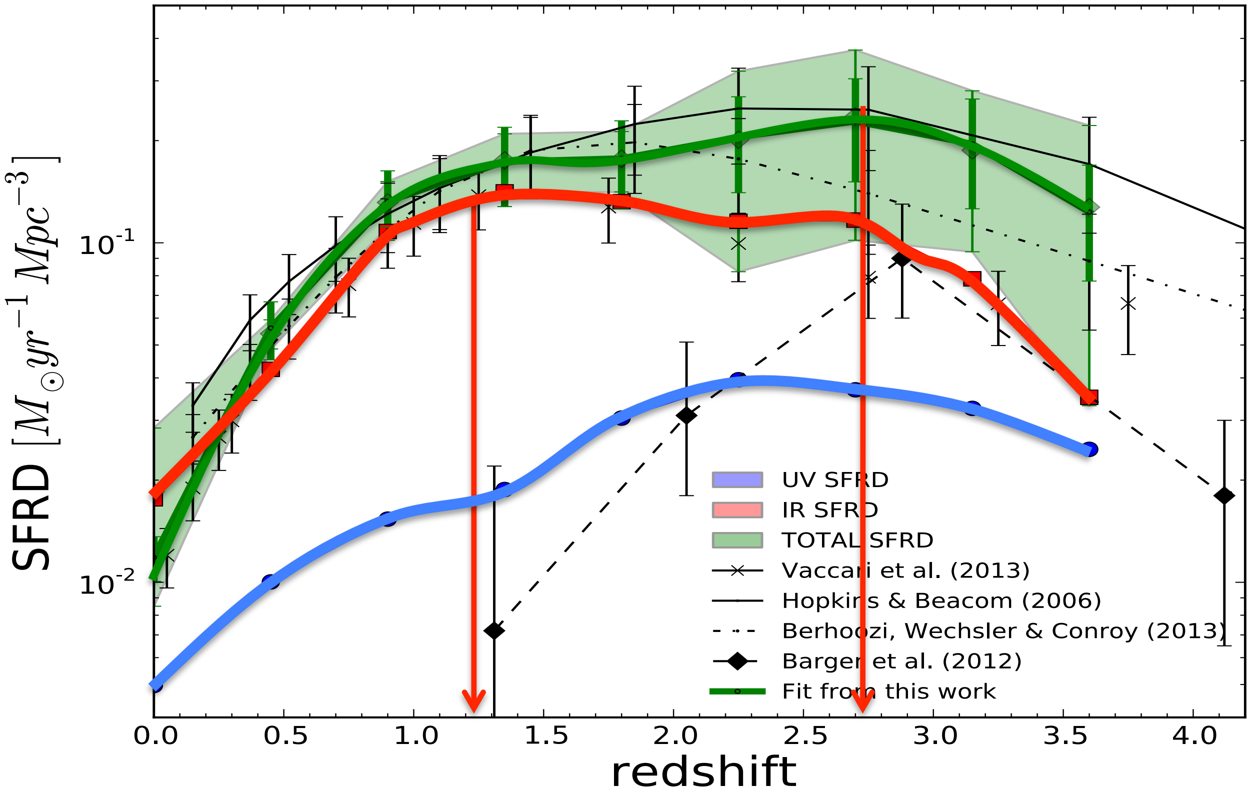
Two gaussians needed to fit the SFRD from $z = 0$ to $z \approx 4$

At $z \le 3.6: a_1 e^{-\frac{(z-z_1)^2}{2\sigma_1^2}} + a_2 e^{-\frac{(z-z_2)^2}{2\sigma_2^2}}$

with $\begin{cases} a_1 = 0.13 \pm 0.02;\ z_1 = 1.14 \pm 0.10;\ \sigma_1 = 0.51 \pm 0.07 \\ a_2 = 0.23 \pm 0.02;\ z_2 = 2.72 \pm 0.08;\ \sigma_2 = 0.82 \pm 0.10 \end{cases}$

L_{IR} + L_{UV}

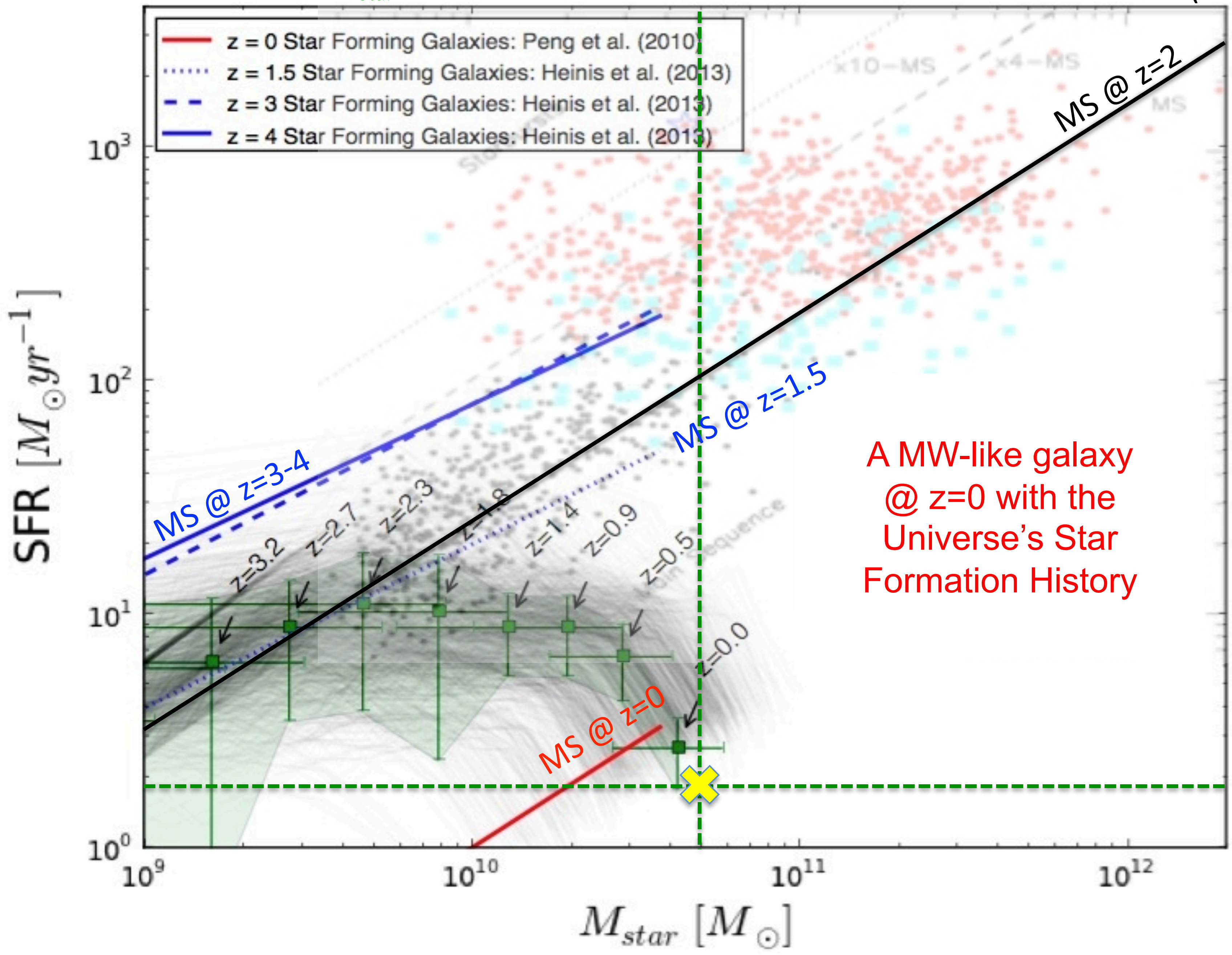
1st $SFRD_{TOT}$ to z ~4



Lines are mean values. Filled colors show uncertainties from 2000 realizations. Globally, over $0 < z \le 3.6$, the total SFRD is slightly below Hopkins & Beacom (2006); above Behroozi et al. (2013 at $z < 2$). SCUBA-2 (Barger et al. 2012) and preliminary SPIRE results (Vaccari et al. 2013) are also shown.

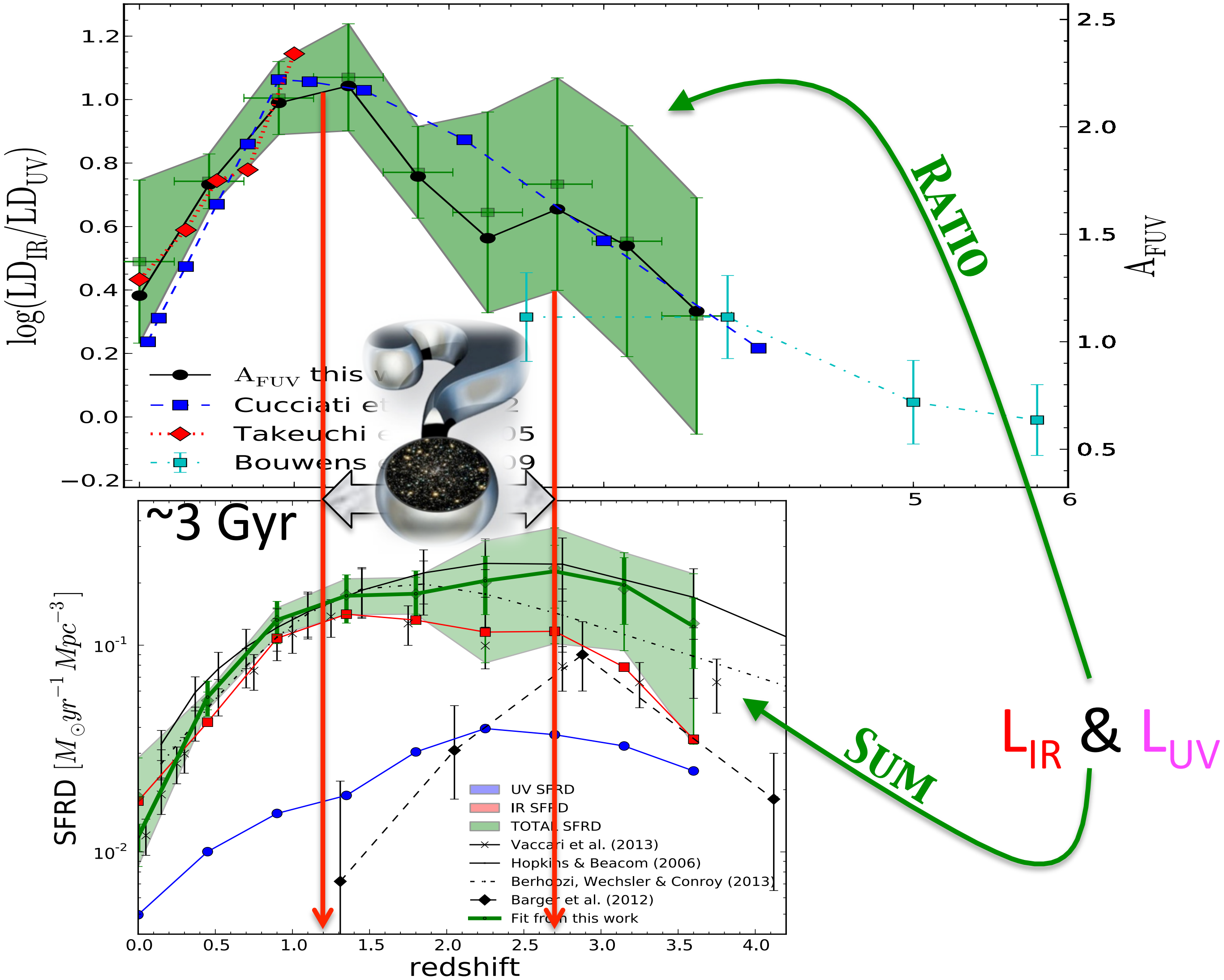
Chomiuk & Povich (2011) -> SFR_MW = 1.9 ± 0.4 M☉ yr−1.
Hammer et al. (2007) -> M_{star}_MW = 5e10 Msun

Rodighiero et al. (2011)
Heinis et al. (2013)



VLT/VVDS + Herschel/PEP+HerMES

(Burgarella et al. 2013)



How could we better understand the results and move to higher redshifts?

• To understand what is going on, we need to carry out spectroscopic surveys of galaxies at $1 < z < 4$.

• This will allow to disentangle the effects of the evolution of the LFs, the role of in/out-flows, the timescales for building and destructing dust grains.

➢ SPICA

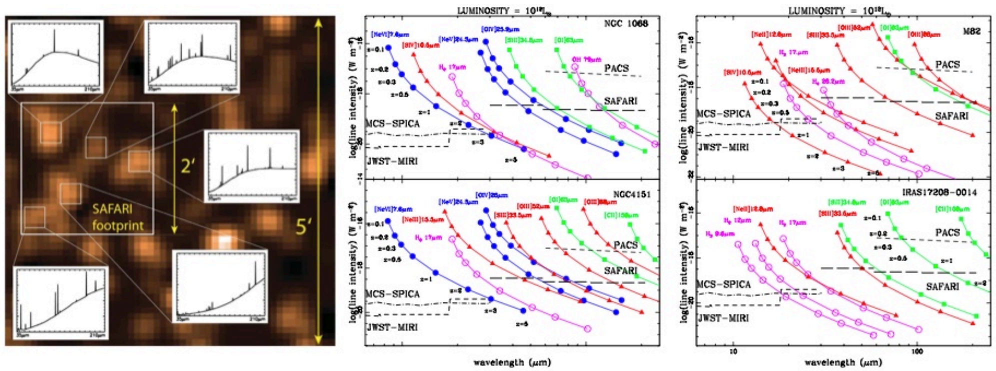
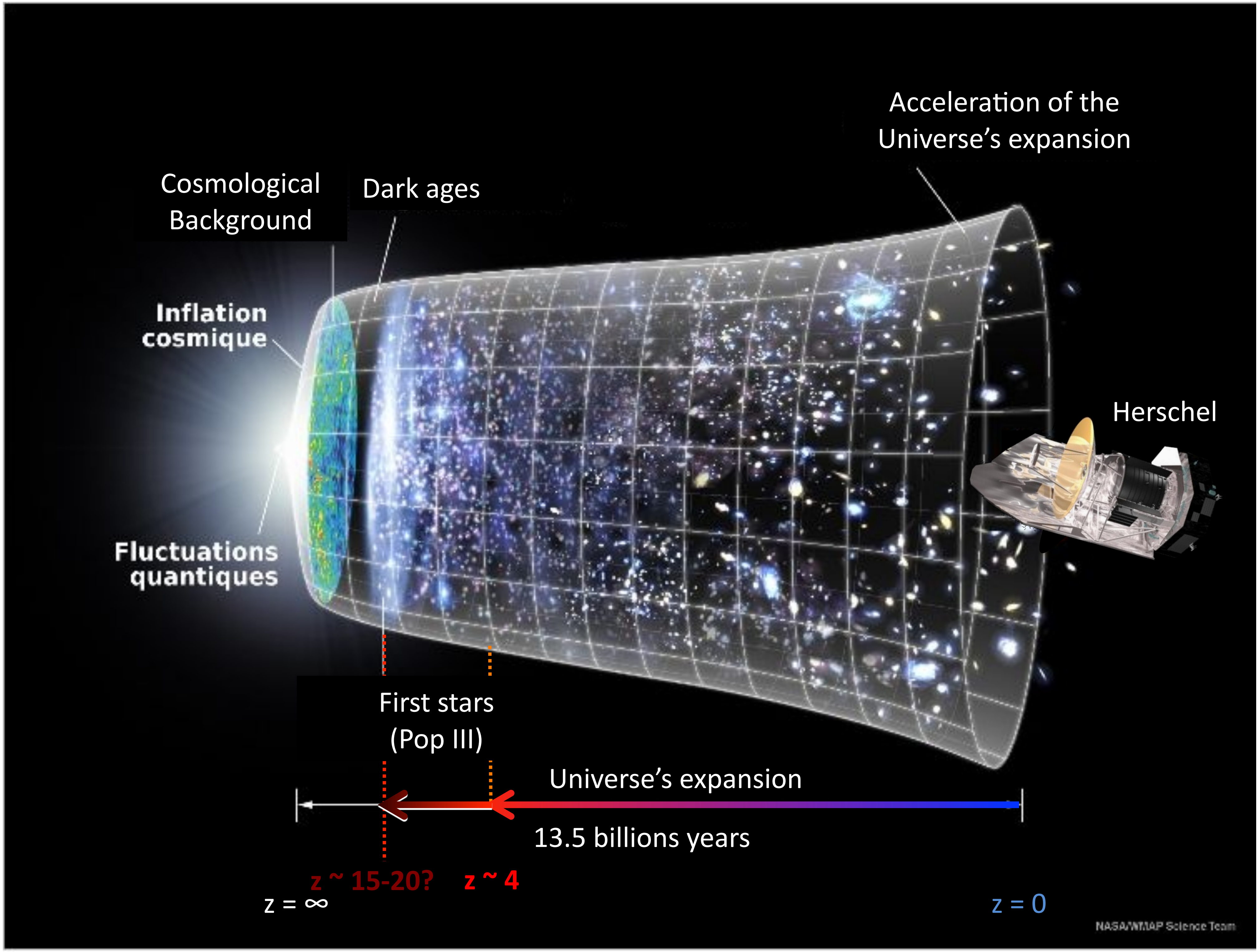


Figure 1.17: ***(a) Left panel:*** *A 5′ × 5′ region taken from a 250 μm Herschel SPIRE image, with the 2′ × 2′ FOV of SAFARI outlined. With its spectral imaging capability, SAFARI will be able to obtain spectral information covering the full 34 – 210 μm range, in multiple sources, simultaneously.* ***(b,c) Central and right panels:*** *Line predictions (Spinoglio et al. 2012) and their observability with SPICA. A few selected diagnostic lines are shown as a function of redshift (from top to bottom at z=0.1, 0.2, 0.3, 0.5, 1, 2, 3, 5) for the four template objects NGC1068, NGC4151, M82 and IRAS17208-0014 scaled at a luminosity of $L=10^{12}L_{\odot}$. Blue solid circles represent AGN lines, red triangles: HII region lines, green squares: PDR lines and magenta open circles: molecular lines. Line intensities are given in $W\,m^{-2}$. The long dashed lines give the 5σ, 1 hour sensitivities of SPICA-SAFARI. For comparison, the sensitivity of Herschel PACS and those expected for the SPICA-MCS and MIRI spectrometers are also indicated.*



Acceleration of the Universe's expansion
Cosmological Background
Dark ages
Inflation cosmique
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First stars (Pop III)
Universe's expansion
13.5 billions years
z ~ 15-20?
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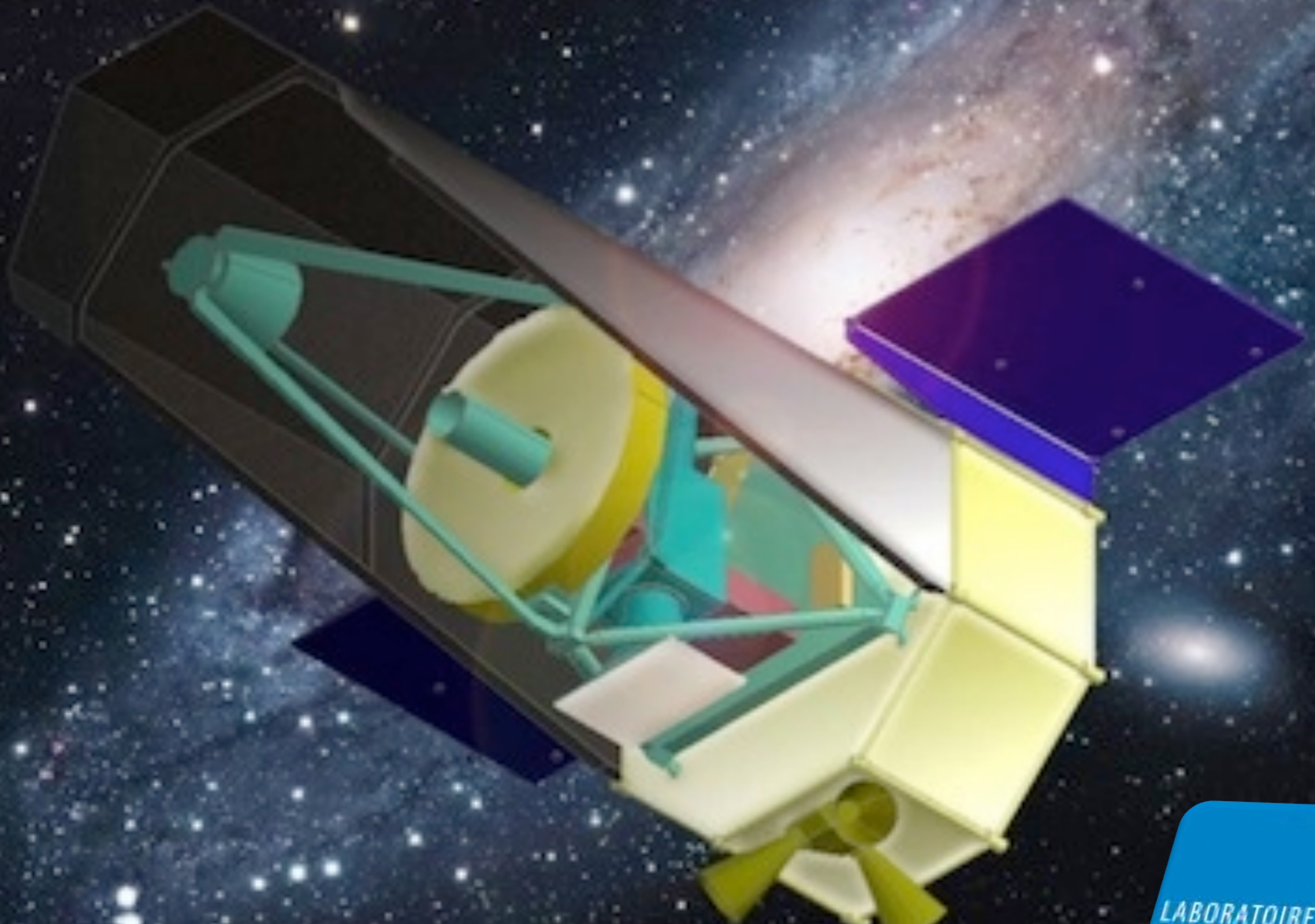
NASA/WMAP Science Team

Wide-field Imaging Surveyor for High-redshift

WISH space telescope project



LAM
LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

Wide-field Imaging Surveyor for High-redshift (WISH)

- The very high redshift universe might experience a low dust attenuation.
- Statistically*, this might imply that the very high-redshift universe ($z > 5$) might be better studied in the rest-frame Far-UV.
- We need large and deep photometric surveys to detect faint high-z galaxies.
- However important the photometric surveys are we need a spectroscopic mode for WISH.
- WISH is complementary to JWST, SPICA, Euclid and the 30 – 40m ELTs

* with all the warnings related to the estimated uncertainties …

What is WISH?

Launch	~ 2020
Lifetime	5 years
Optics	• M1: ⃠1.5m @ L2 • Cooled to 100K • Diffract. limited (0.2''@ 1µm)
λ range	1 – 5 µm
Imaging	900 arcmin², 0.155''/pixel
Spectro	Two options: Priority 1: IFU, ⃠ 1'(TBC), R~1000, parallel obs. Priority 2: Slitless, 900arcmin², R~100

Photometry (900 arcmin²)

- UDS: m_{AB} = 28 over 100deg²
- UWS: m_{AB} = 24-25 over 1000deg²
- ES: m_{AB} = 29-30 over 0.25deg²

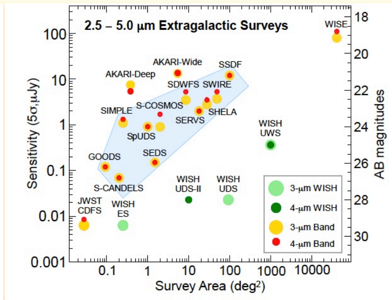
Spectroscopy (1' x 1' IFU):

- UDSS: 8x10^{-17} erg cm^{-2} s^{-1} over ~ 1deg²
- UWSS: 8x10^{-16} erg cm^{-2} s^{-1} over ~10deg²

Table D2. Prime WISH Surveys

	Depth (5σ) (AB Mag.)	Area (deg²)	Center Wavelengths (µm)	Survey Time[a] (years)	Proposal Section
Ultra-Deep Survey (UDS)	28	100	1.0, 1.4, 1.8, 2.3, 3.0	3.48	D2.1
Ultra-Deep Survey, 4µm (UDS-II)	28	10[b]	UDS + 4.0	0.24	D2.2
Ultra-Wide Survey (UWS)	25	1,000	1.0, 1.4, 1.8, 2.3, 3.0, 4.0	0.24	D2.3
Extreme Survey (ES)	29.5	0.24	1.0, 1.4, 1.8, 2.3, 3.0	0.13	D2.4

[a] Assumes 85% observing efficiency toward the ecliptic pole, a QE of 70%, a dark current of 0.05 e^-/s, a read noise of 15 e^- (for N=1, CDS), a throughput of 74%, and Fowler 4 sampling (see Section E1.3); [b] Within the UDS field.



Imaging

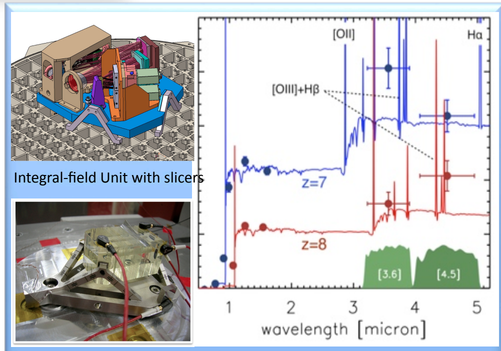
1) Over 100 deg²
WISH will detect photometrically:

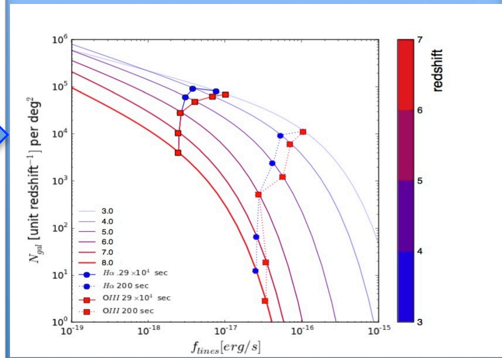
~10² galaxies at z=14-17
~10^{3-4} galaxies at z=11-12
~10^{4-5} galaxies at z=8-9

Spectroscopy

2) Over 1 deg²
WISH will detect spectroscopically:

~10^{4-5} galaxies at z=3-9





http://people.lam.fr/burgarella.denis/denis/WISH.html

What is WISH?

- *WISH is an M Japan-led project* (*PI: T. Yamada*).
- WISH-Spec A spectrograph (IFU, D. Burgarella et al.)
- SAO (G. Fazio et aL.) & Canada (M. Sawicki et al.) involved
- Main science objective: first galaxies in the Universe… but not only (Solar system, ISM, galaxies, ...)

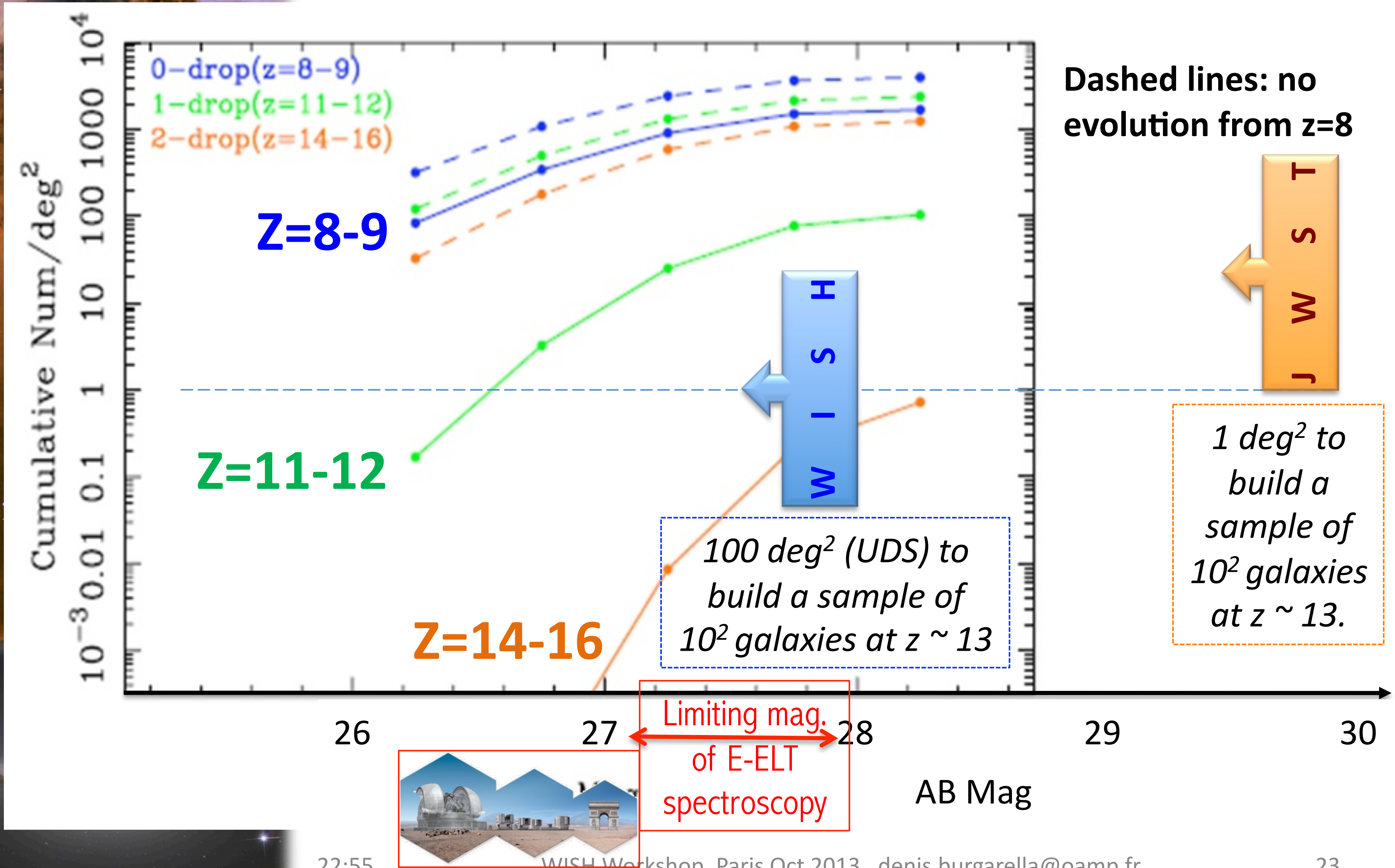
The Wide-field Infrared Surveyor for High-redshift (WISH)

Burgarella D., Pello R., Combes F., Schaerer D., Adami C., Amram P., Bacon R., Boissier S., Boquien M., Boselli A., Braine J., Buat V., Charlot S., Contini T., Cuby J.G., E. Daddi, Delsanti A., Dole H., Epinat B., Ferrari C., Flores H., Groussin O., Hammer F., Heinis S., Ilbert O., Lagache G., Lançon A., Leborgne J.F., Marcelin M., Maurogordato S., Perret V., Pointecouteau E., Prieto E., Puech M., Puy D., Reylé C., Slezak E., Surace C., Vernazza P., Wozniak H., etc.

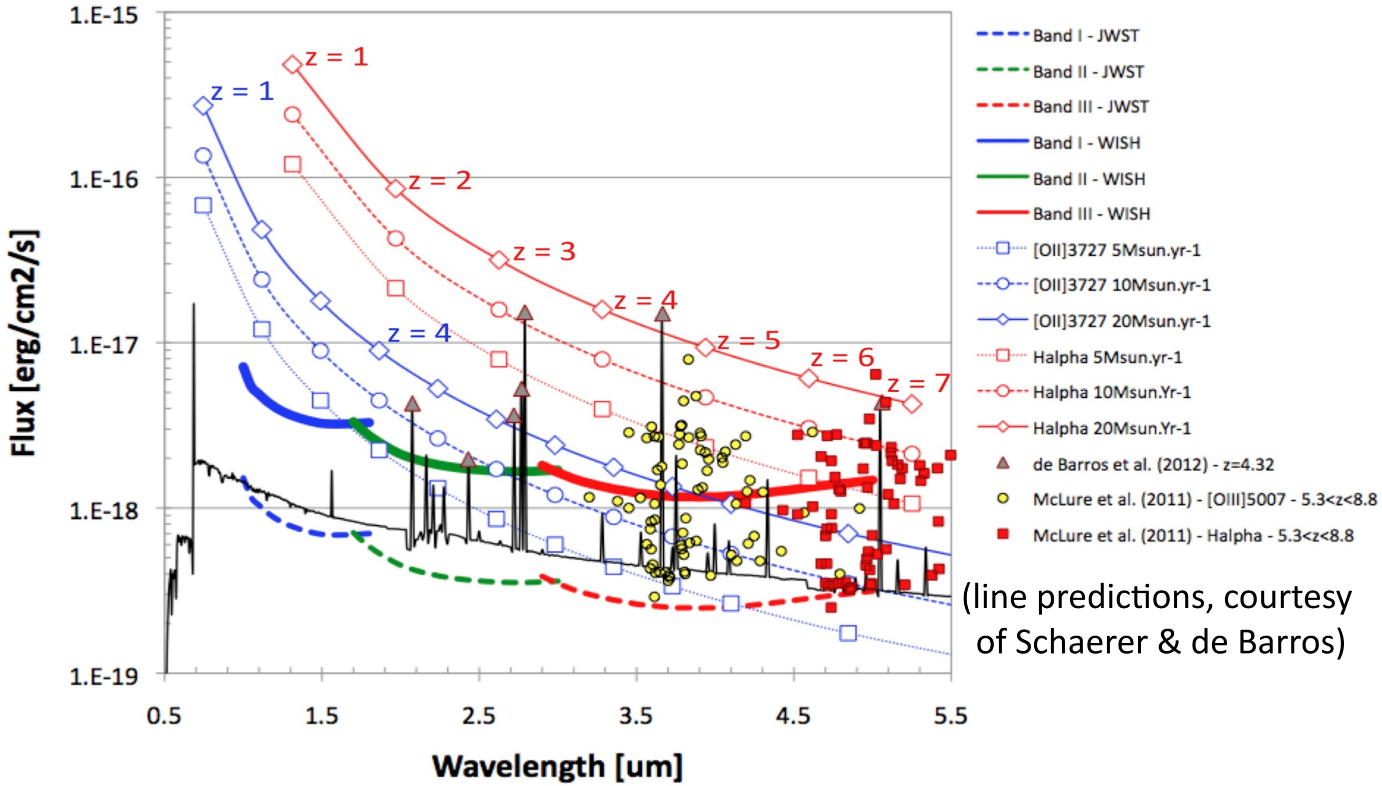
(French team only).

Expected Number of Galaxies in 1 deg^2

Extrapolation of z=6-8 UV LF by Semianalytic Model by Kobayashi et al. (of course this is strongly model-dependent)



A spectroscopic mode for WISH for $10^4 – 10^5$ galaxies at $3 < z < 8$



(line predictions, courtesy of Schaerer & de Barros)

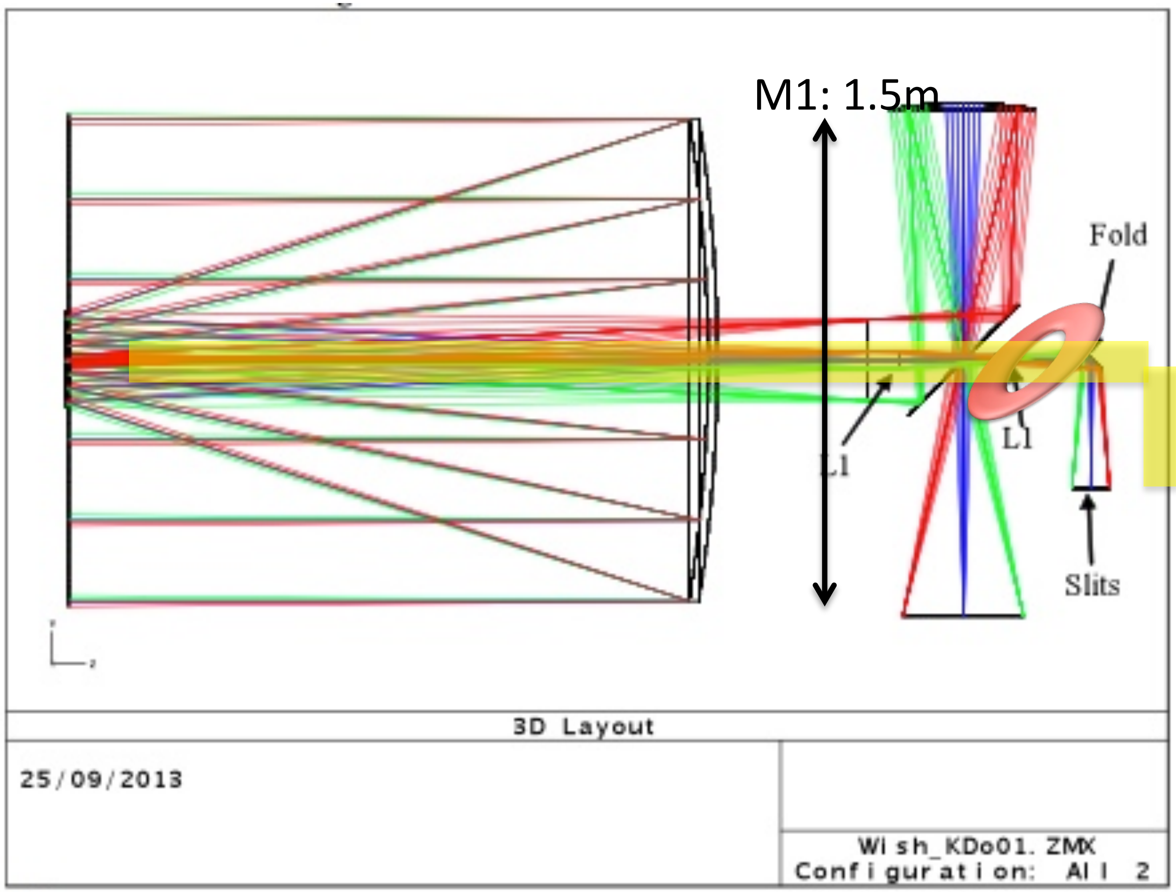
Expected lines fluxes and sensitivity of WISH and JWST. We overplot a spectrum of a sub-L LBG (M_{UV} = -20.) at z = 4.32 from de Barros et al. (2012, black). The **main lines in the rest-frame optical range can be detected at S/N=10**. Yellow dots and red boxes correspond to [OIII]5007 and Hα lines from McLure et al. (2011) at 5.3 < z < 8.8. Almost half of them can be detected showing that we are able to confirm the redshift of these objects and to measure in detail the strength of these lines. Thin blue lines (continuous, dashed, dotted for 20 M_{Sun}/yr, 10 M_{Sun}/yr & 5 M_{Sun}/yr) correspond to [OII]3727 from z = 1 to z = 11 while the thin red lines (same as blue but from z = 1 to z = 7) correspond to Hα. Both are computed assuming Kennicutt (1998).*

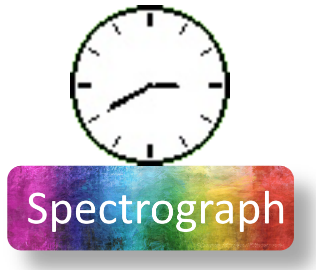
Conclusions

- The variation of the cosmic dust attenuation with redshift as estimated from the IR-to-FUV luminosity ratio suggests the **presence of a peak in the dust attenuation at z ~ 1.2 followed by a decline up to at least z = 3.6**.
- The **total (FUV+FIR) SFRD starts declines at z > 3–4** and reaches the same level at z ~ 5 – 6 as is measured locally.
- We observe a **3-Gyr delay between max A_{FUV} & $SFRD_{TOT}$** that we do not understand, yet. **But, with SPICA we will !**
- **By integrating the observed cosmic SFRD**, we are **able to recover the SMD** evaluated from galaxy surveys over most of the Hubble time.
- Our results suggest that the **universe's dusty era** (meaning dust attenuation larger than in the local universe) **started at z = 3 – 4**.
- **WISH is the next step forward to study large sample of galaxies at 3 < z < 15-20 and follow them up with E-ELT, JWST + provide crucial data to interpret EUCLID data.**

Merci

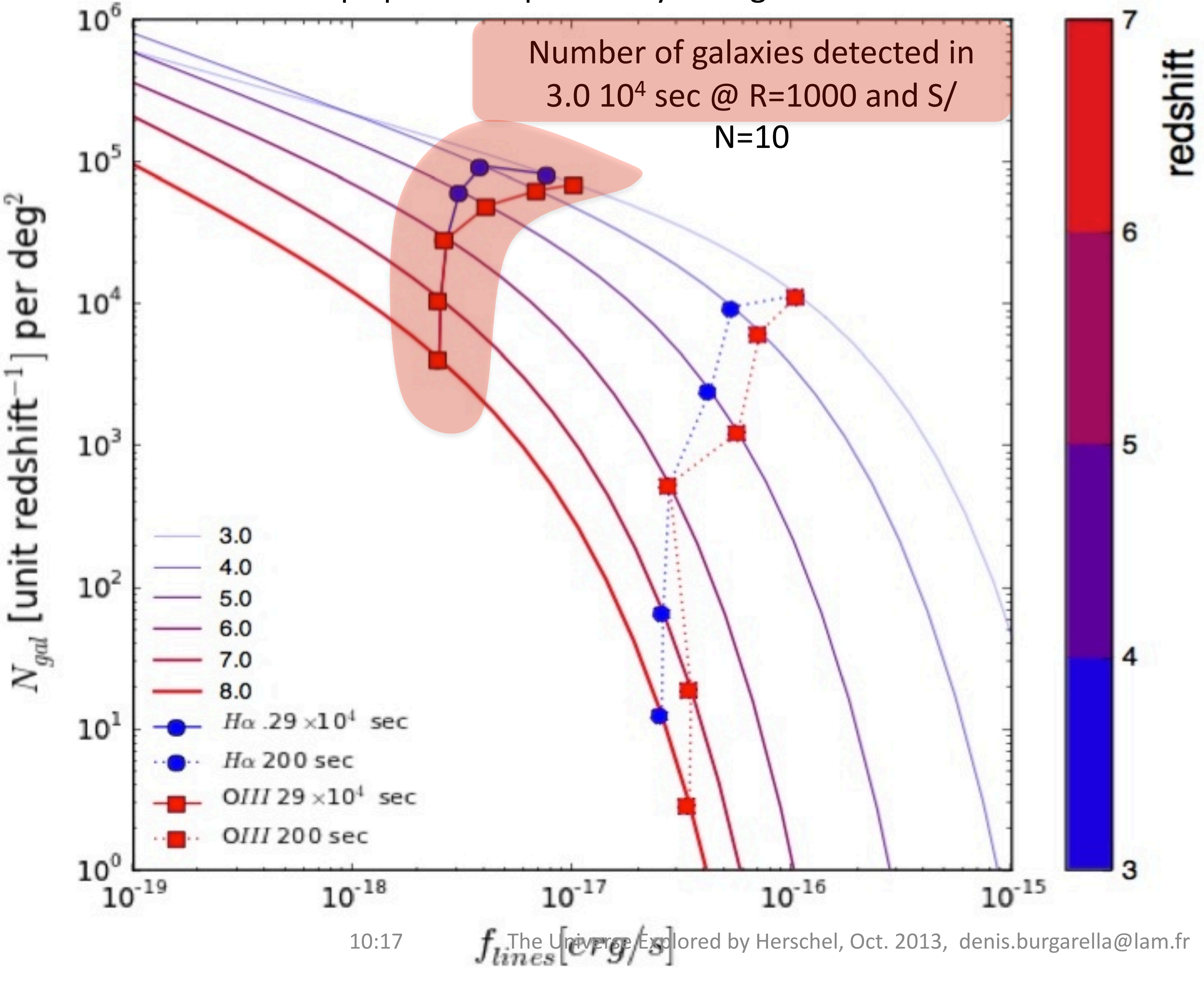
WISHSpec





- If we assume an IFU spectrograph, it will observe in a parallel mode.
- Translated into exposures times, it means as many hours of spectroscopic observation as we observe a single photometric field, but of course, only for the central part.

Deep Spectroscopic Survey: 1 deg^2



Wide Spectroscopic Survey: 10 deg^2