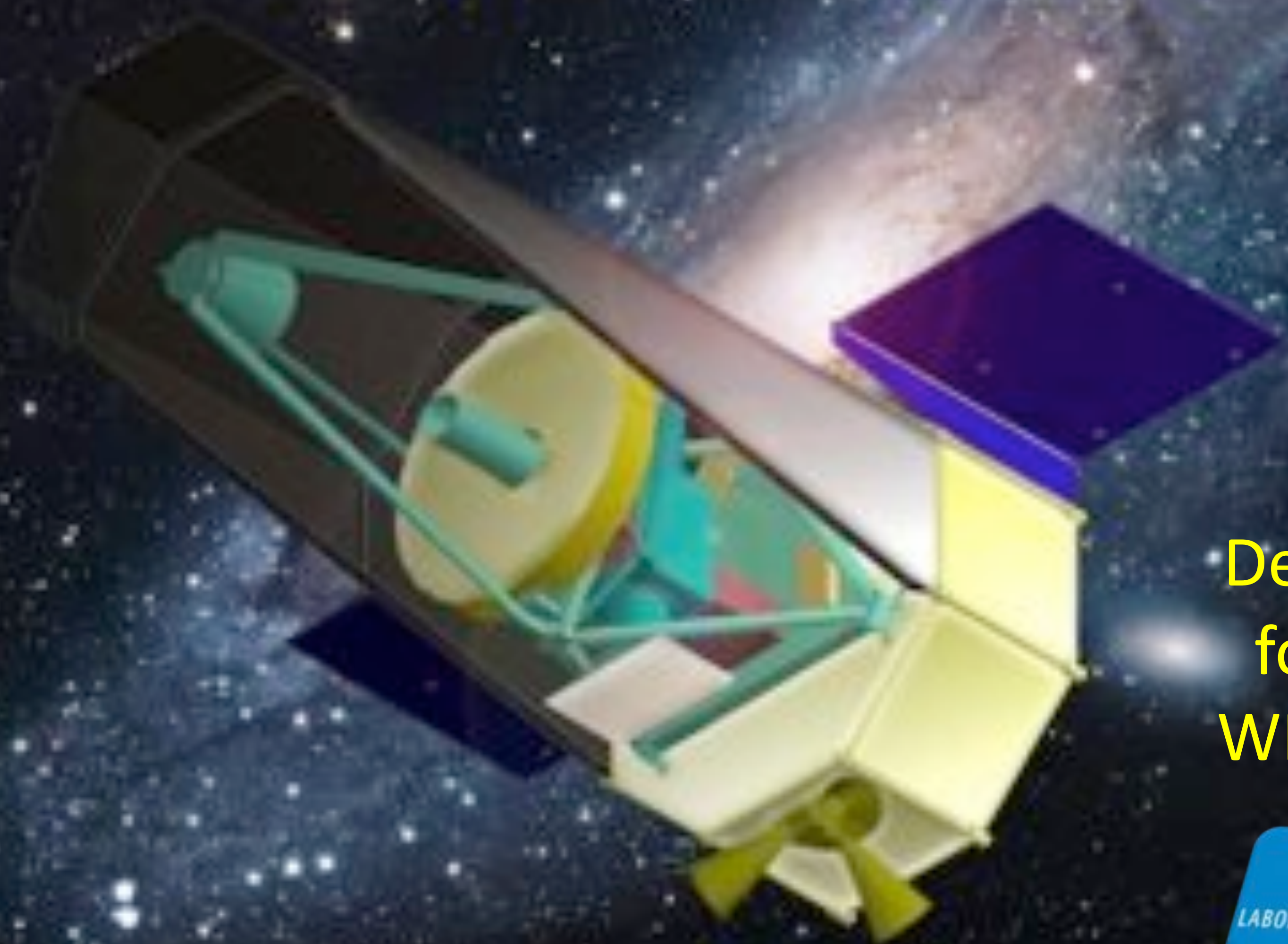
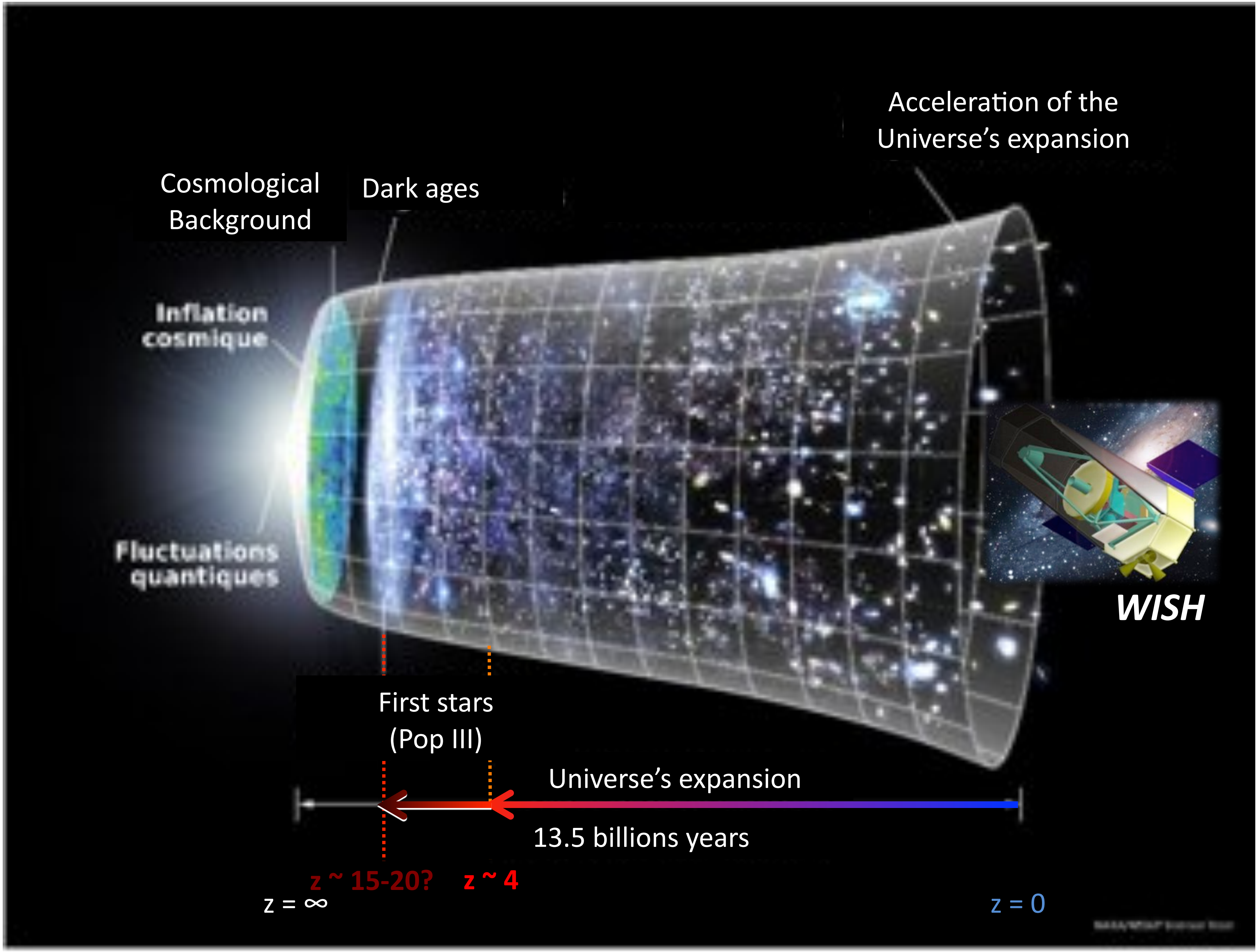
Integral Field Spectroscopy onboard the WISH wide-field, 1-5µm, Space Telescope



Denis Burgarella
for the French
WISH-Spec team

LAM
LABORATOIRE D'ASTROPHYSIQUE
DE MARSEILLE



Acceleration of the Universe's expansion
Cosmological Background
Dark ages
Inflation cosmique
Fluctuations quantiques
WISH
First stars (Pop III)
Universe's expansion
13.5 billions years
z ~ 15-20?
z ~ 4
z = ∞
z = 0

What is WISH?

Launch	~ 2020
Lifetime	5 years
Optics	• M1: ⃠1.5m @ L2 • Passively 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 observ. 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

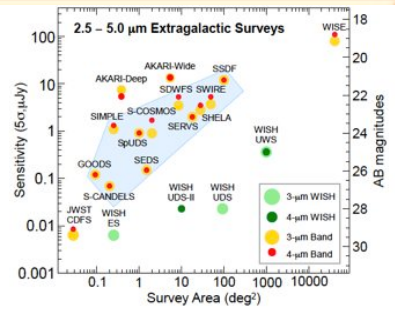
Spectroscopy (1' x 1' IFU):

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

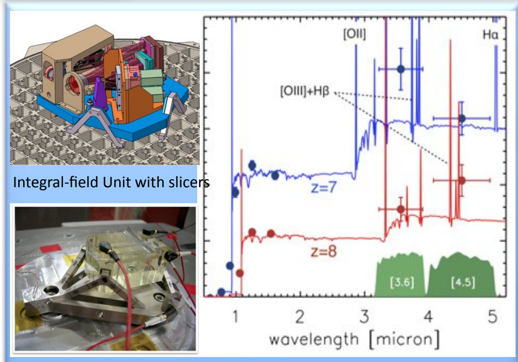
~10² galaxies at z=14-17
~10³⁻⁴ galaxies at z=11-12
~10⁴⁻⁵ galaxies at z=8-9

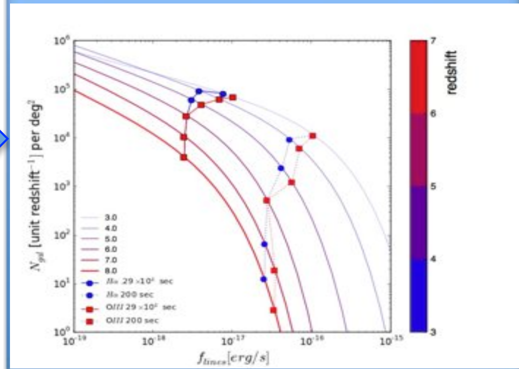
Spectroscopy

2) Over 1 deg²
WISH will detect spectroscopically:

~10⁴⁻⁵ 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 also (Solar system, ISM, galaxies, ...)

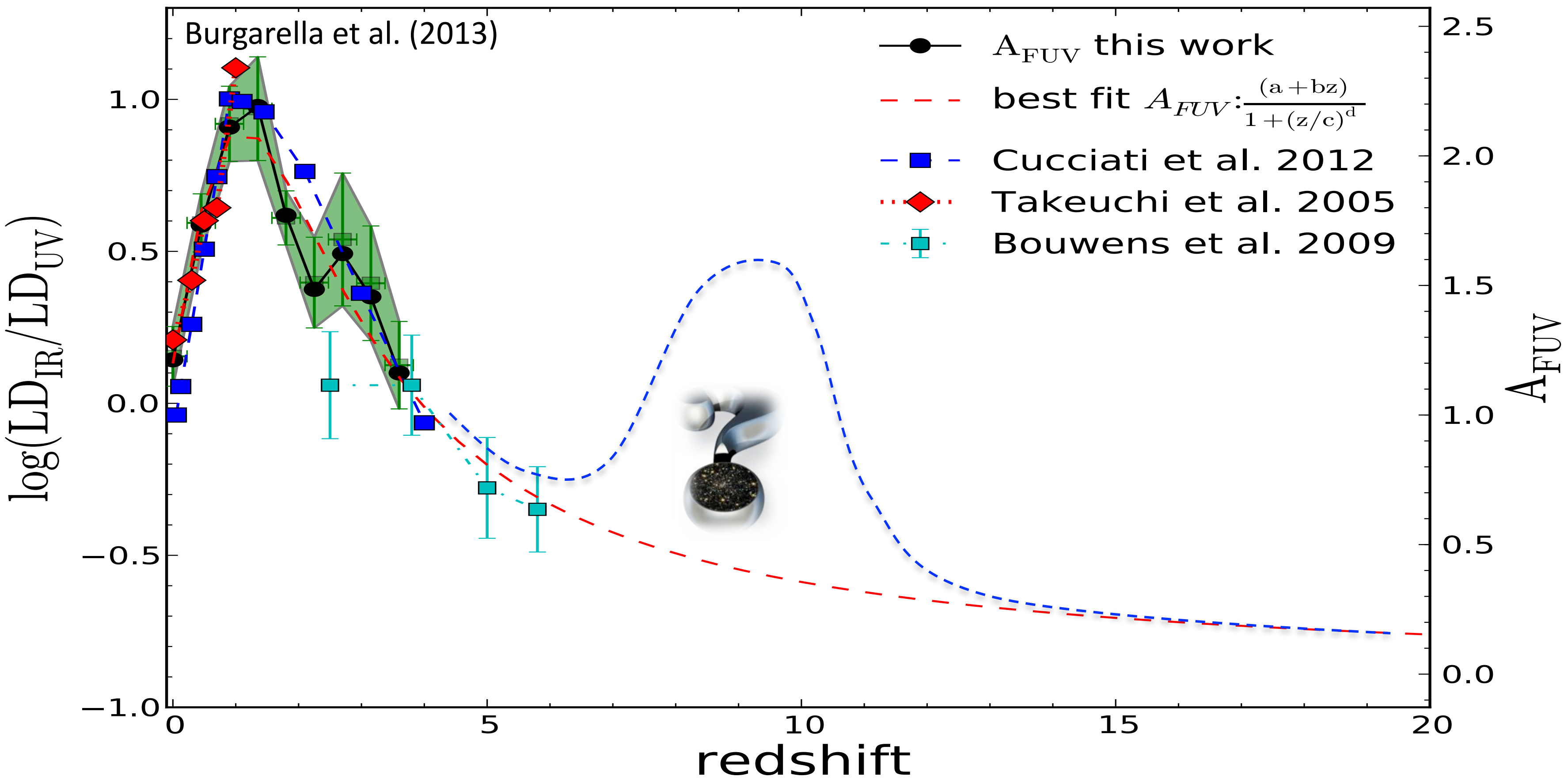
The Wide-field Infrared Surveyor for High-redshift (WISH)

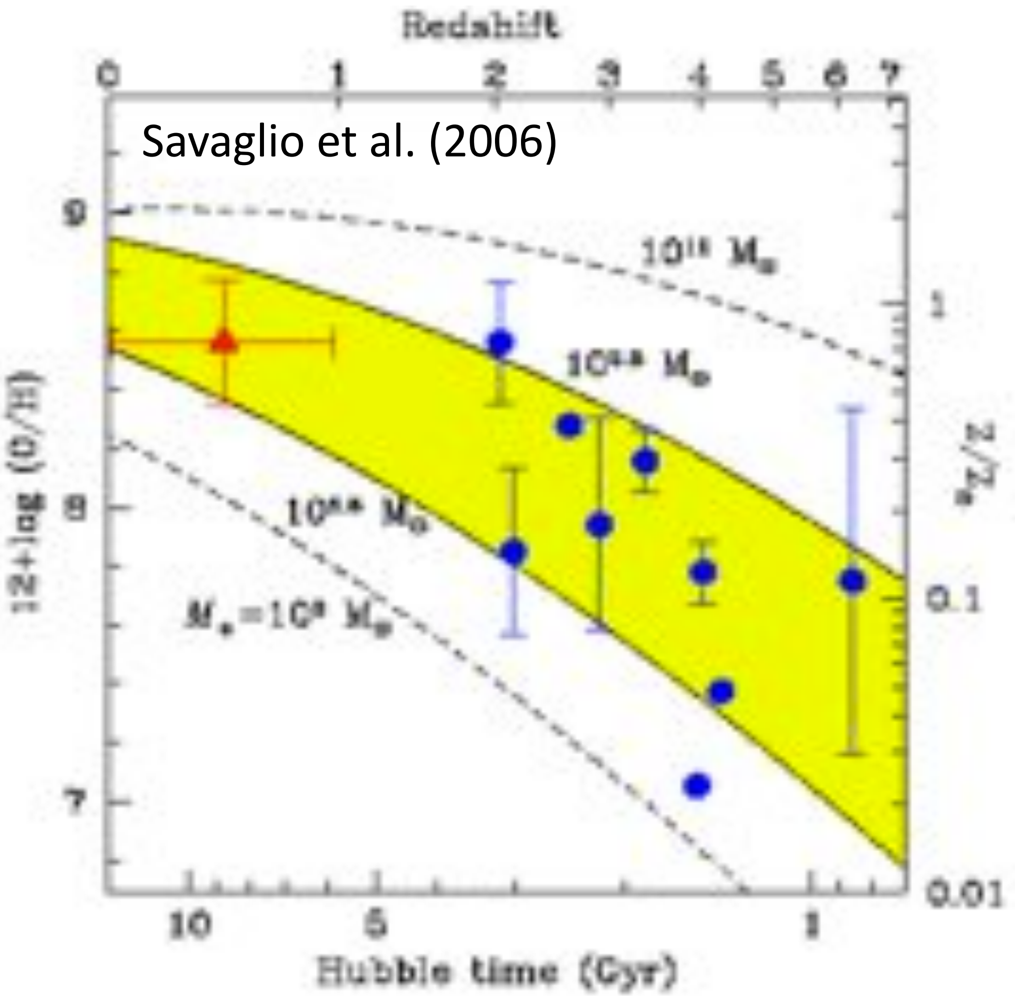
Burgarella D., Pello R., Combes F., Schaerer D., Adami C., Amram P., Bacon R., Boissier S., Boquien M., Boselli A., Braine J., Buat V., Charlot S., Contini T., Cuby J.G., E. Daddi, Delsanti A., Dole H., Epinat B., Ferrari C., Flores H., Groussin O., Hammer F., Heinis S., Ilbert O., Lagache G., Lançon 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).

Where (what wavelength range) should we look for the very high redshift and the primordial galaxies?

The dust attenuation of the Universe reached a maximum at z ~ 1.2





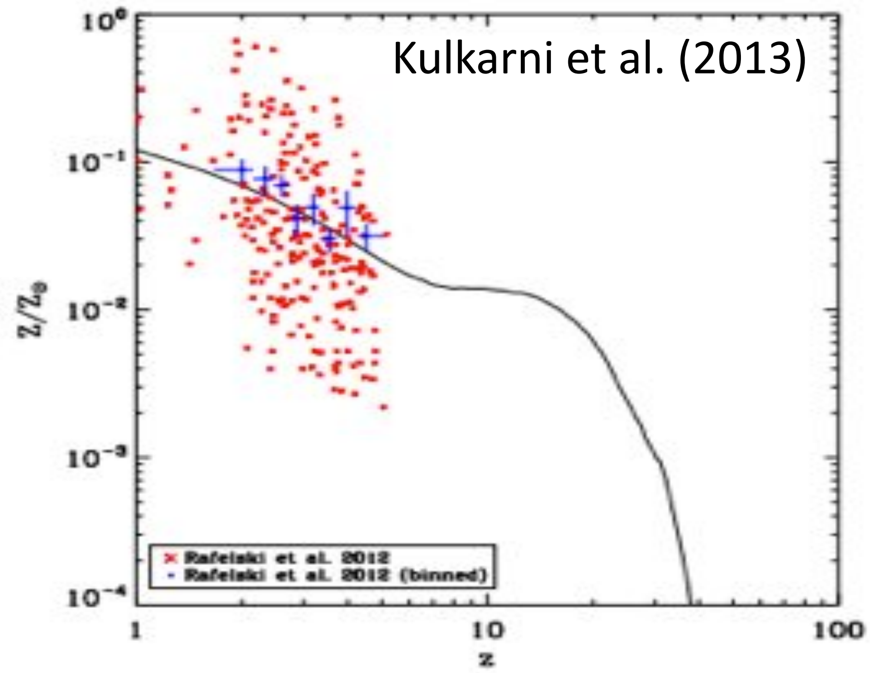


Figure 9. The "age-metallicity" relation in our model, which is given by an absorption cross section weighted average of gas phase metallicity of all mass bins. Red crosses are measurements of a sample of 241 DLAs by Rafelski et al. (2012). The blue points are mean values in different redshift bins, as presented by Rafelski et al. (2012). Vertical error bars on the blue points represent 1σ error bars.

Figure 7. Metallicity as a function of Hubble time (lower x-axis) or redshift (upper x-axis) derived for GRB-DLAs (—as in figure 5), and the mean value derived for a sample of $z < 1$ GRB hosts (▲, vertical and horizontal bars are the 1σ dispersion and the redshift interval of the sample, respectively). The curves are predictions from the empirical model of [19], for different total stellar masses. The shaded area indicates the range of stellar masses more favourable for the observed metallicities.

The very high redshift universe very likely experience a low dust attenuation (lower than the local one).

Statistically, this means that the very high-redshift universe (z > 5) would be better studied in the rest-frame Far-UV.

Context

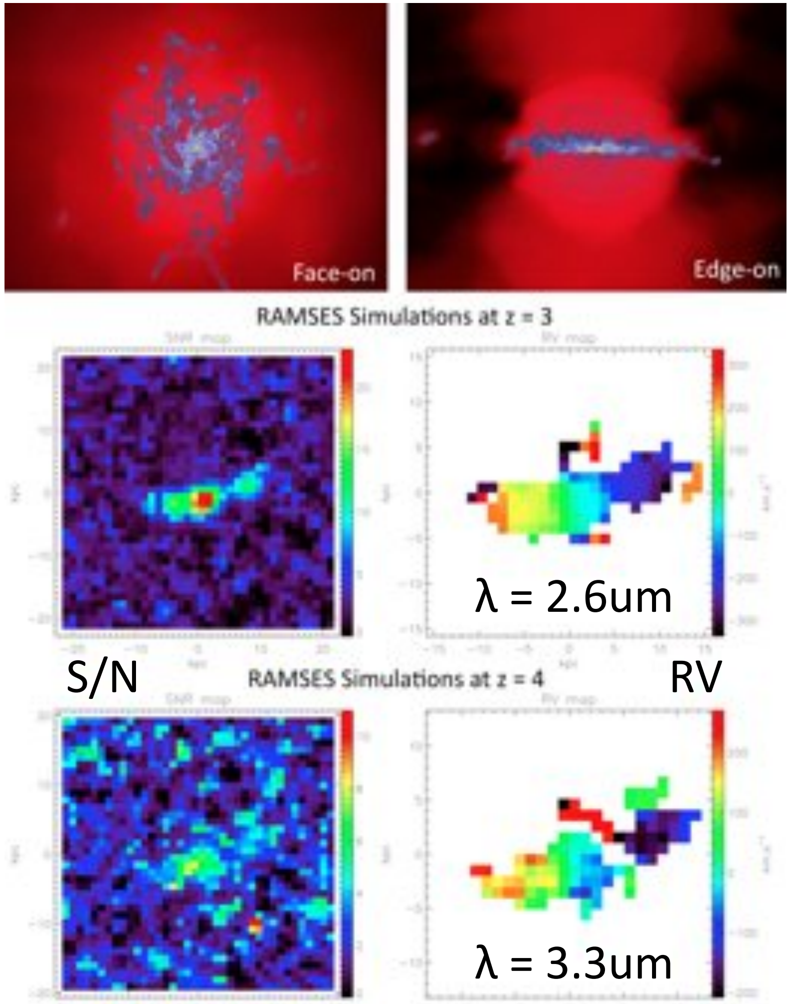
- The Wide-field Imaging Surveyor for High-redshift (WISH) is a proposed mission concept now being developed by the WISH Working Group in Japan under the Science Committee of Institute of Space and Astronautical Science (ISAS) and the Japan Aerospace Exploration Agency (JAXA).

- We propose to contribute (*mission of opportunity frame*) to this project both scientifically and instrumentally under the coordination of the Laboratoire d'Astrophysique de Marseille in cooperation with French institutes (IRAP, Paris Obs. identified so far).

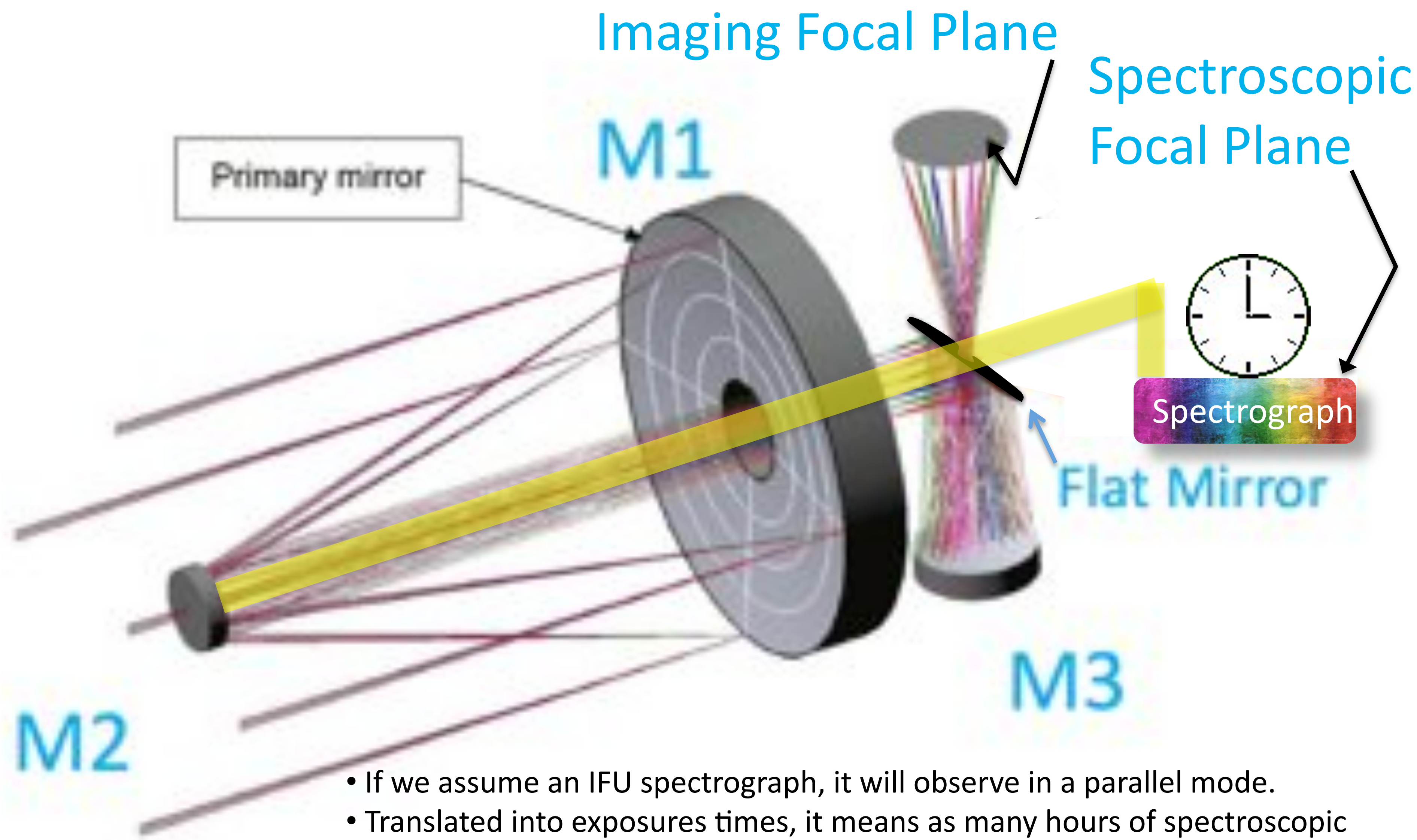
I'LL COME BACK TO THIS POINT LATER ON

The need for WISH-Spec

- A spectrograph onboard WISH will help estimating redshifts for galaxies up to and beyond the re-ionization.
- With a spectrograph onboard WISH, we will be able to detect emission lines, especially [OIII] and Hα for about half of the high-redshift galaxies (say $5 < z < 8$) samples. Spectral resolutions $500 < R < 1000$ => metallicities.
- Moreover, if an IFU option is selected, we will be able to:
  - detect serendipitously galaxies in the deep spectroscopic observations.
  - study the kinematics of distant galaxies.

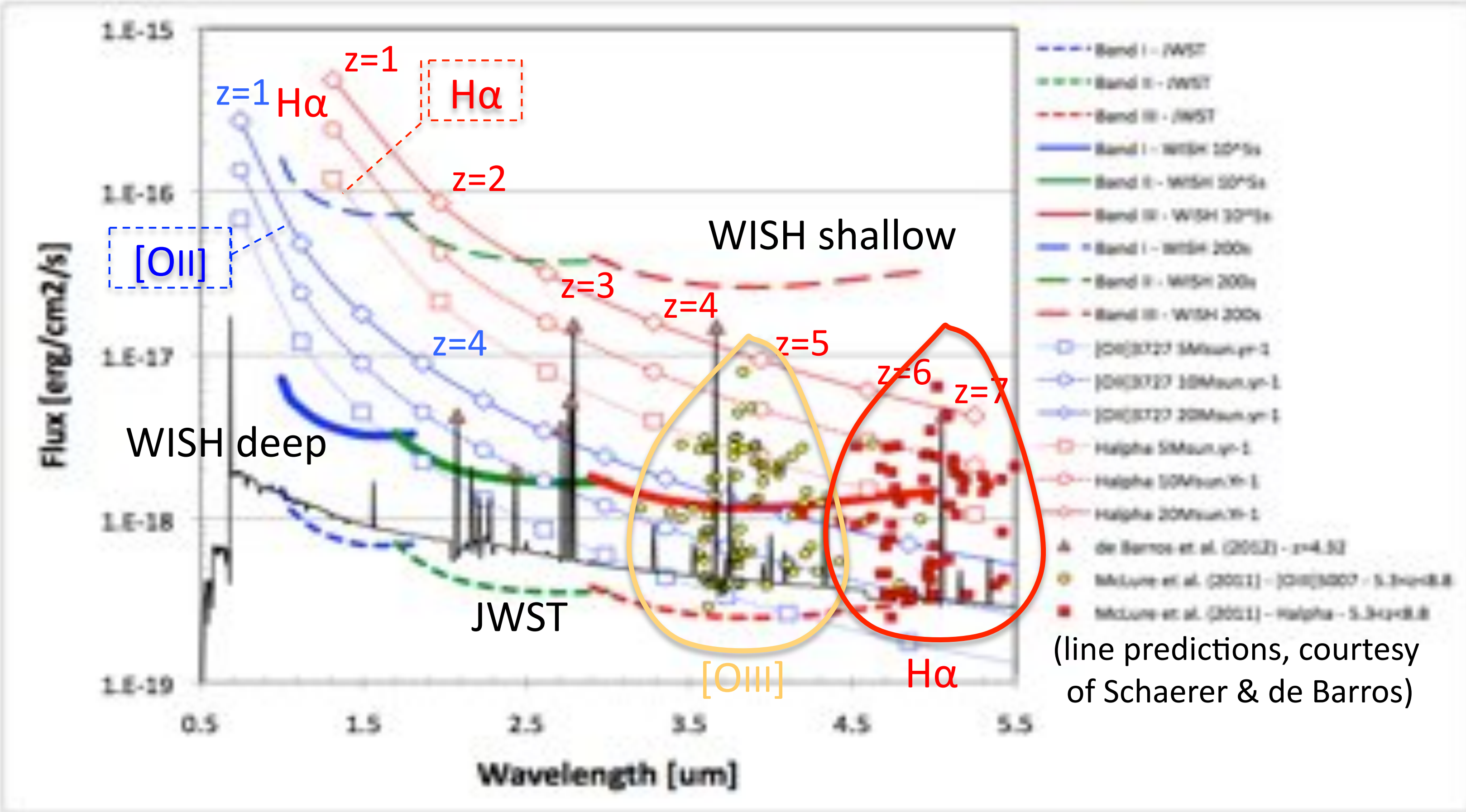


Two simulations by V. Perret of the same modelled galaxy corresponding to an isolated disk.



- 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 over 5 years, but of course, only for the central part of the field.
- Very deep observations (exposure time) without confusion (IFU).

A spectroscopic mode for WISH



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).*

- Comparison of several (spectroscopic) facilities to perform galaxy physics (**at least 5 lines in the optical range:** *[OII]λ3727, [OIII]λ4959, 5007, Hβ*, *[NII]λ6584* and *Hα* ratio) and to measure redshifts (at least 2 lines) as a function of the redshift. Note that we do not take UV lines and NIR lines and PAH into account.

• As expected from the usable wavelength ranges of each of the telescopes, WISHSpec and JWST/NIRSpec are much more adapted to the very high redshift (i.e. z > 3).

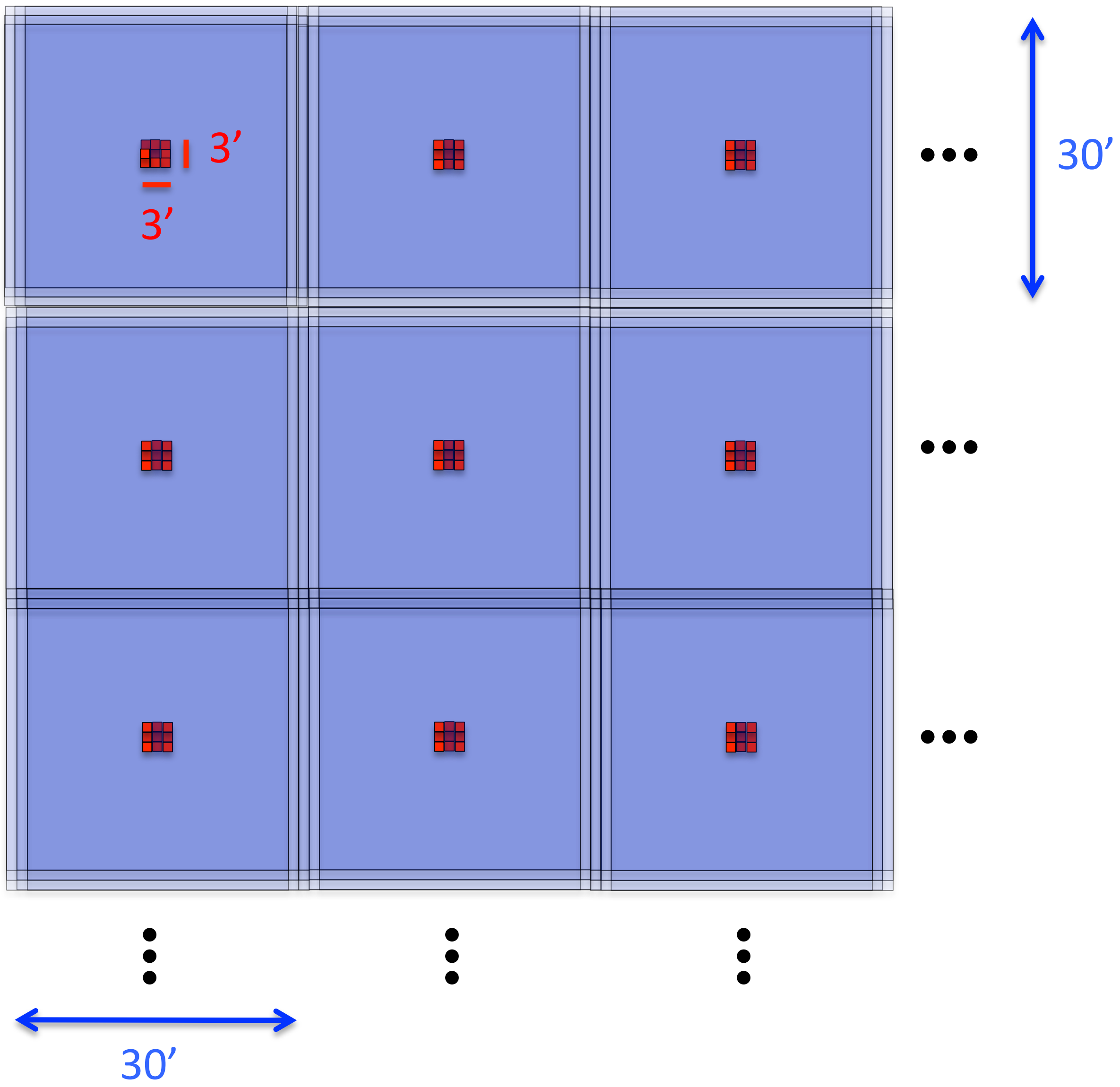
• On the spectroscopic side, assuming ~ 1 x 1 arcmin^2 field of view, WISHSpec **should observe more spectra than NIRSpec**. JWST would collect 10^5 galaxies down to AB=25 (R=100) to calibrate the photometric redshifts. NIRSpec would collect 10^4 galaxies (Franx 2011) over JWST lifetime (100 simultaneously, at all redshifts and part (how many?) at low R.

REDSHIFT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
WISH/SPEC	4	7	7	7	7	7	5	5	4	2	2	2	1	1	1
JWST/NIRSPEC	4	7	7	7	7	7	5	5	4	2	2	2	1	1	1
EUCLID/NISP	6	7	3	1	0	0	1	1	1	1	1	1	1	1	0
HST/WFC3IR	6	4	1	0	0	0	1	1	1	1	1	1	0	0	0
WFIRST	6	7	3	1	0	0	0	0	0	0	0	0	0	0	0
SPICA/MCS	0	0	0	0	0	0	3	3	4	6	6	6	7	7	7
JWST/MIRI	0	0	0	0	0	0	3	3	4	6	6	6	7	7	7

Physics OK | Redshift OK | BAD

Table valid for the optical lines ***[OII]λ3727, [OIII]λ4959, 5007, Hβ***, ***[NII]λ6584*** and ***Hα***

How many galaxies for WISH-Spec surveys?

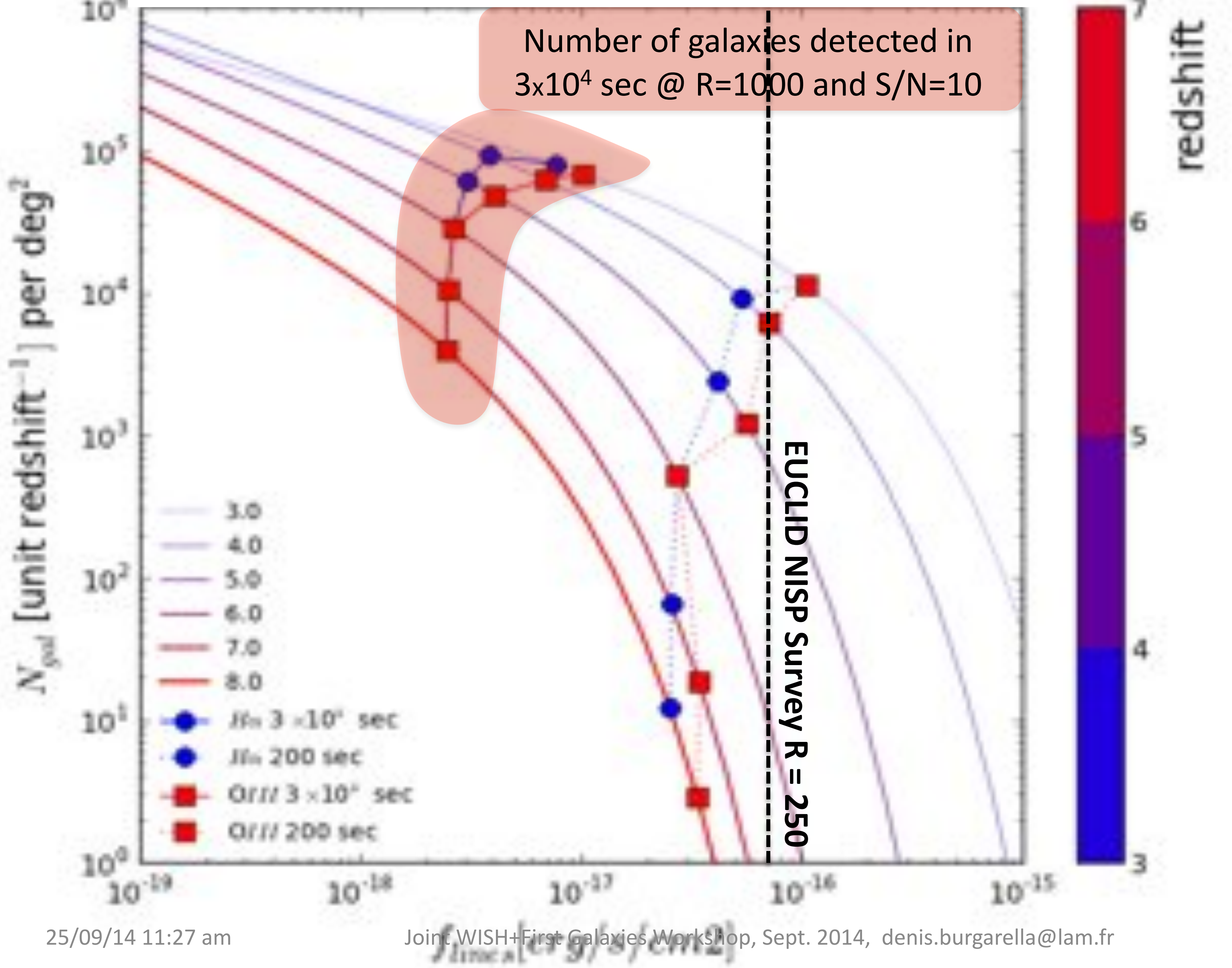


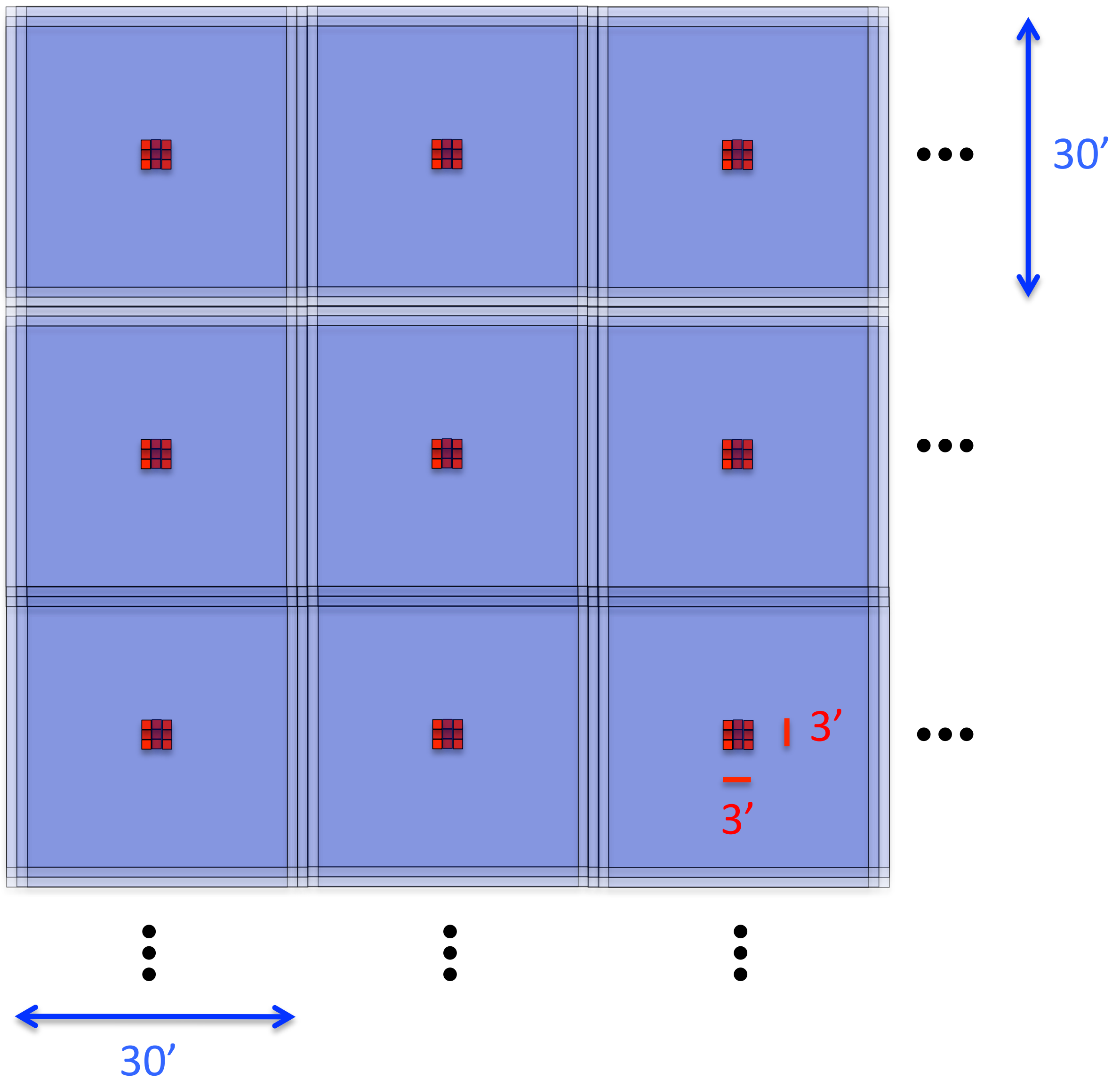
Ultra Deep Spectroscopic Survey

- For each 3.0×10^4 sec on a 30'x30' sub-field of the UDSPhot, we dither the field of view by ± 1'
  => the UDSSpec FOV amounts to 9*(1'x1') per each UDSPhot FoV
- That means that $9'^2/900'^2$ = 1/100 of the UDSPhot area will be covered by the UDSSpec
- The UDSSpec is observed in parallel to the UDSPhot
  => no additional time required.
- The exposure time for each UDSSpec FOV is 3.0×10^4 sec
- The exposure time per 1'x1' field for the UDSPhot/Spec is 3.0×10^4 sec * 9 * 400 = 1.1×10^8 sec
- The total area covered by the UDSPhot is ~100deg^2
- **=> the total area covered by the UDSSpec is ~1deg^2**
- **For UWS, the total area covered by the WDSSpec is ~10deg^2**

Spectroscopic instantanenous FOV = 1'x1'
UDS = Ultra Deep Survey
UDSS = Ultra Deep Spectroscopic Survey

Spectroscopic Survey – Option 1 over 1 deg²



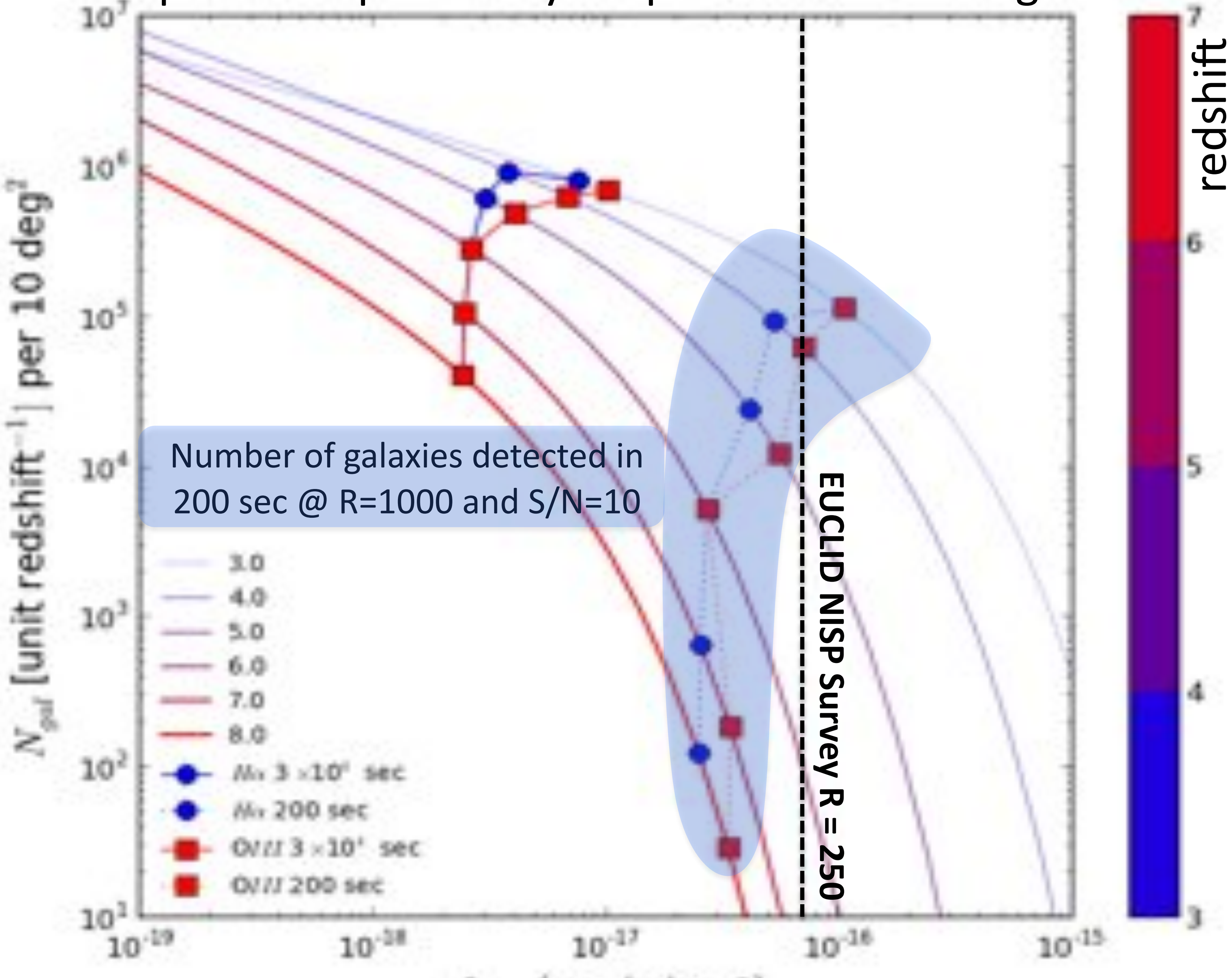


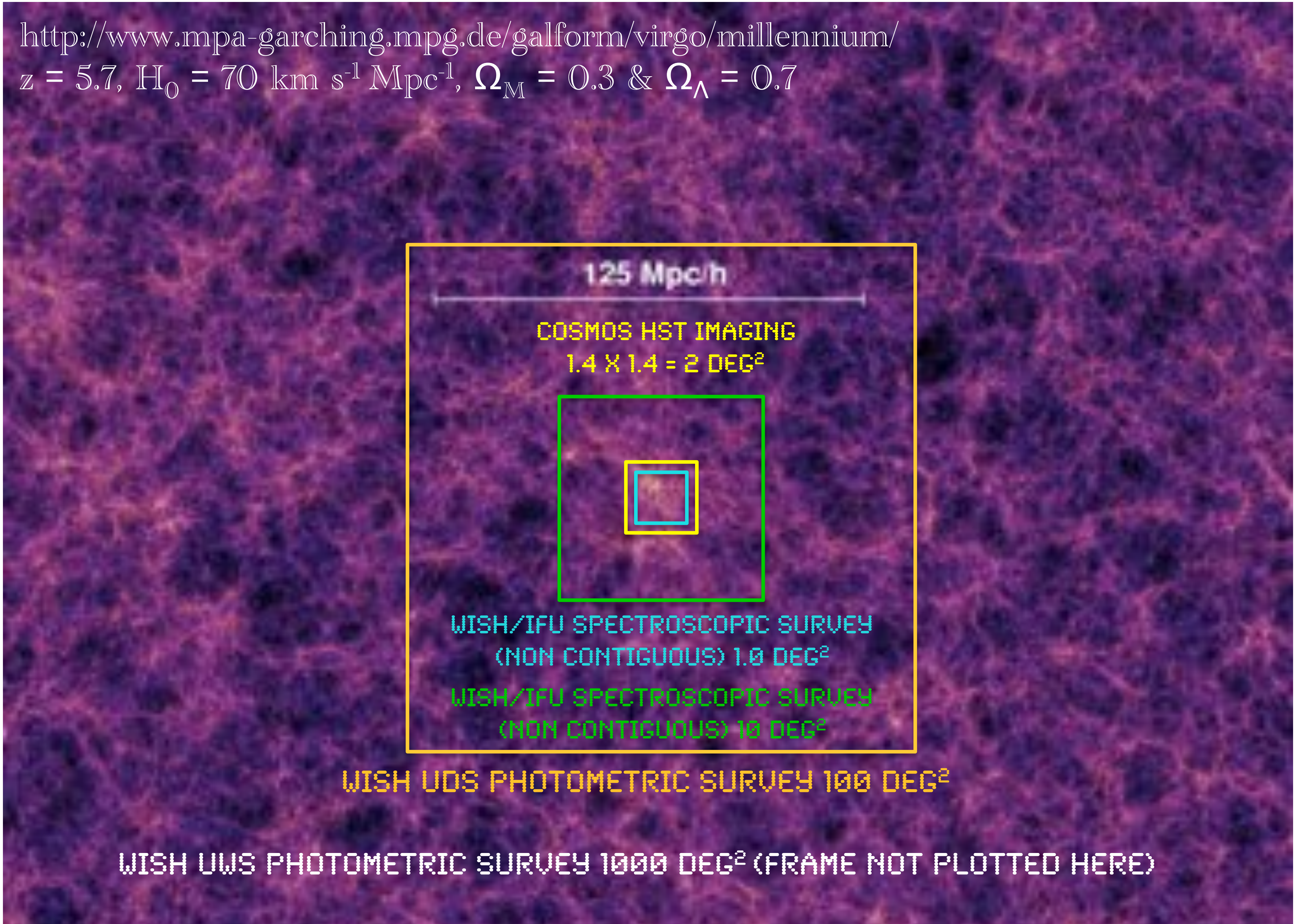
- For each 200 sec on a 30'x30' sub-field of the WDSPhot, we dither the field of view by ± 1'
  => the WDSpec FOV amounts to 9*(1'x1') per each WDSPhot FoV
- That means that $9'^2/900'^2$ = 1/100 of the WDSPhot area will be covered by the WDSSpec
- The WDSSpec is observed in parallel to the WDSPhot
  => no additional time required.
- The exposure time for each WDSSpec FOV is 200 sec
- The total exposure time for the WDSPhot/Spec is 200 sec * 9 * 4000 = 7.6×10^6 sec
- The total area covered by the photometric WDS is ~1000deg^2
- => the total area covered by the WDSS is ~10deg^2

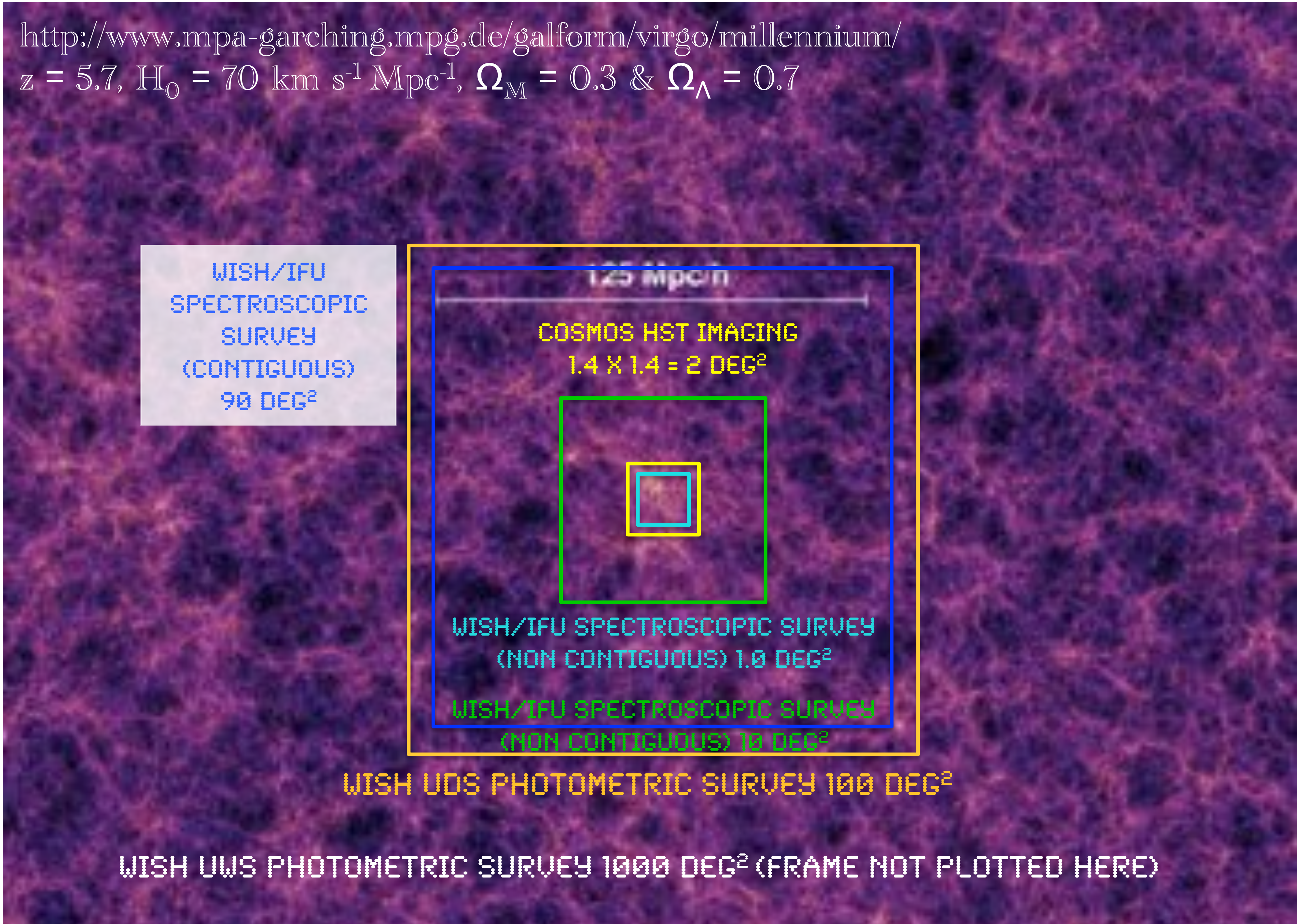
Ultra Wide Spectroscopic Survey

Spectroscopic instantanenous FOV = 1'x1'
WDS = Ultra Wide Survey
WDSS = Ultra Wide Spectroscopic Survey

Spectroscopic Survey – Option 1 over 10 deg²

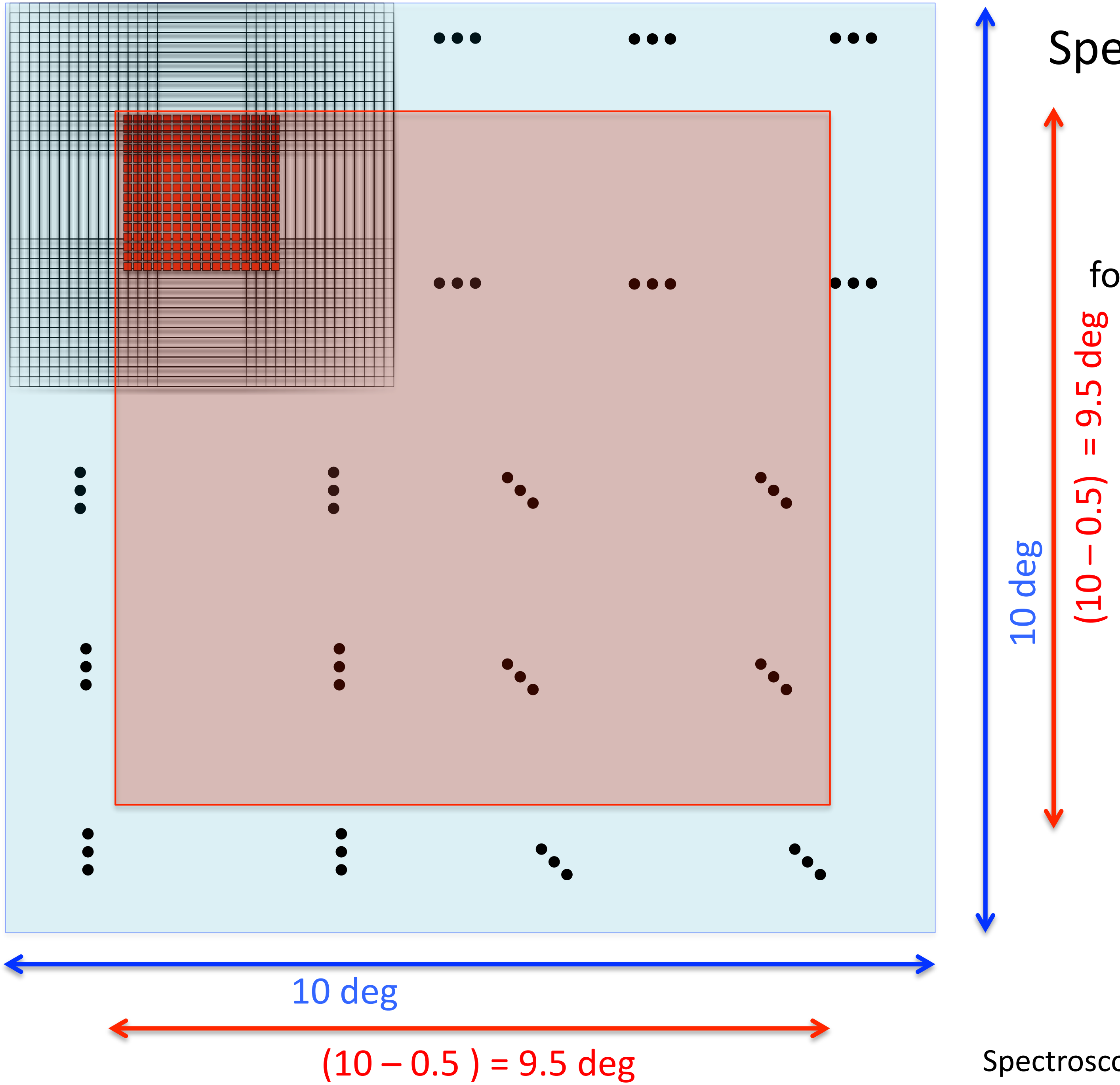



http://www.mpa-garching.mpg.de/galform/virgo/millennium/
$z = 5.7$, $H_0 = 70$ km s^{-1} Mpc^{-1}, $\Omega_M = 0.3$ & $\Omega_\Lambda = 0.7$
125 Mpc/h
COSMOS HST IMAGING
1.4 X 1.4 = 2 DEG^2
WISH/IFU SPECTROSCOPIC SURVEY
(NON CONTIGUOUS) 1.0 DEG^2
WISH/IFU SPECTROSCOPIC SURVEY
(NON CONTIGUOUS) 10 DEG^2
WISH UDS PHOTOMETRIC SURVEY 100 DEG^2
WISH UWS PHOTOMETRIC SURVEY 1000 DEG^2 (FRAME NOT PLOTTED HERE)


http://www.mpa-garching.mpg.de/galform/virgo/millennium/
z = 5.7, H0 = 70 km s-1 Mpc-1, ΩM = 0.3 & ΩΛ = 0.7
WISH/IFU SPECTROSCOPIC SURVEY (CONTIGUOUS) 90 DEG2
125 Mpc/h
COSMOS HST IMAGING
1.4 X 1.4 = 2 DEG2
WISH/IFU SPECTROSCOPIC SURVEY (NON CONTIGUOUS) 1.0 DEG2
WISH/IFU SPECTROSCOPIC SURVEY (NON CONTIGUOUS) 10 DEG2
WISH UDS PHOTOMETRIC SURVEY 100 DEG2
WISH UWS PHOTOMETRIC SURVEY 1000 DEG2 (FRAME NOT PLOTTED HERE)

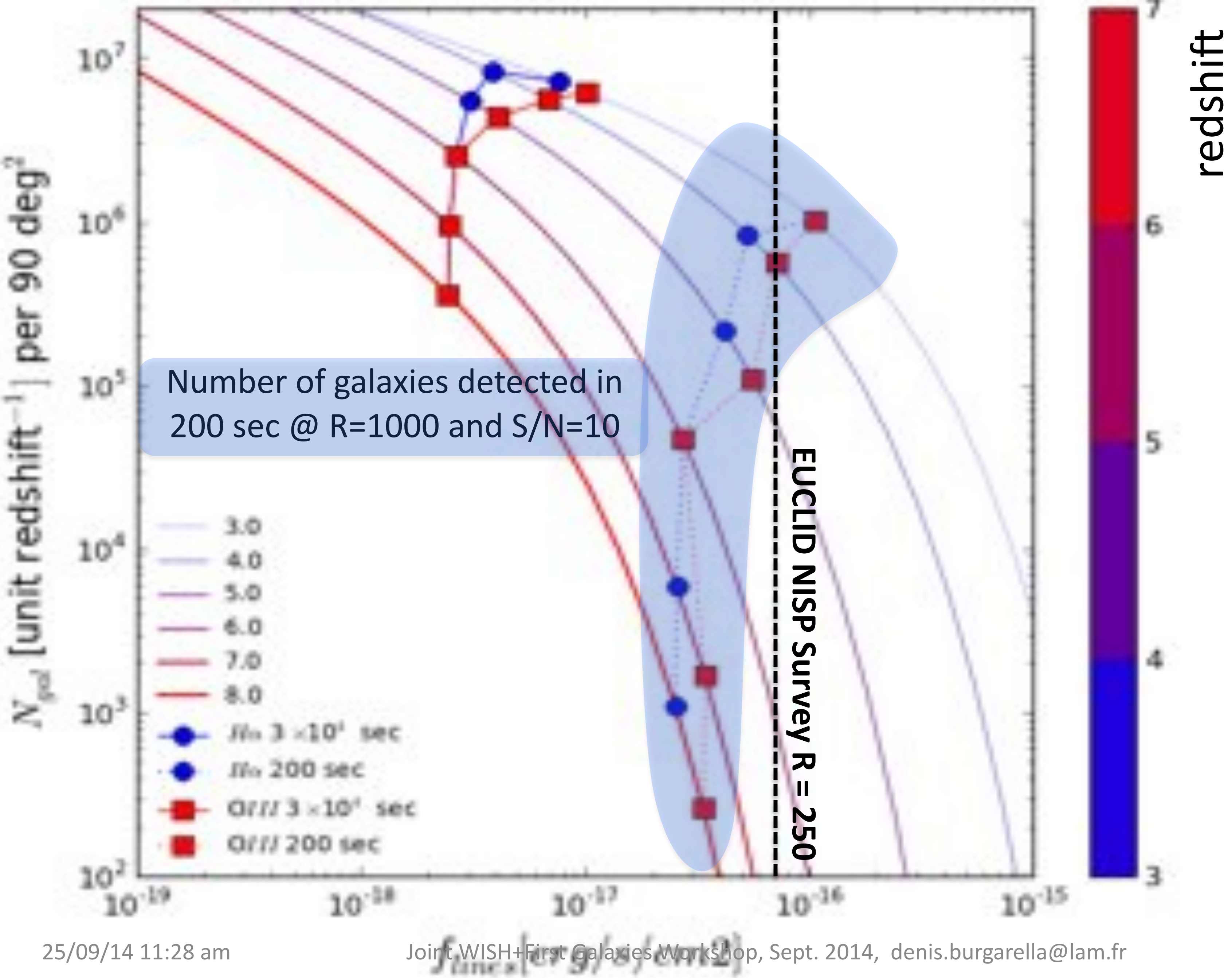
Spectroscopic Survey option 2 over ~ 90 deg^2

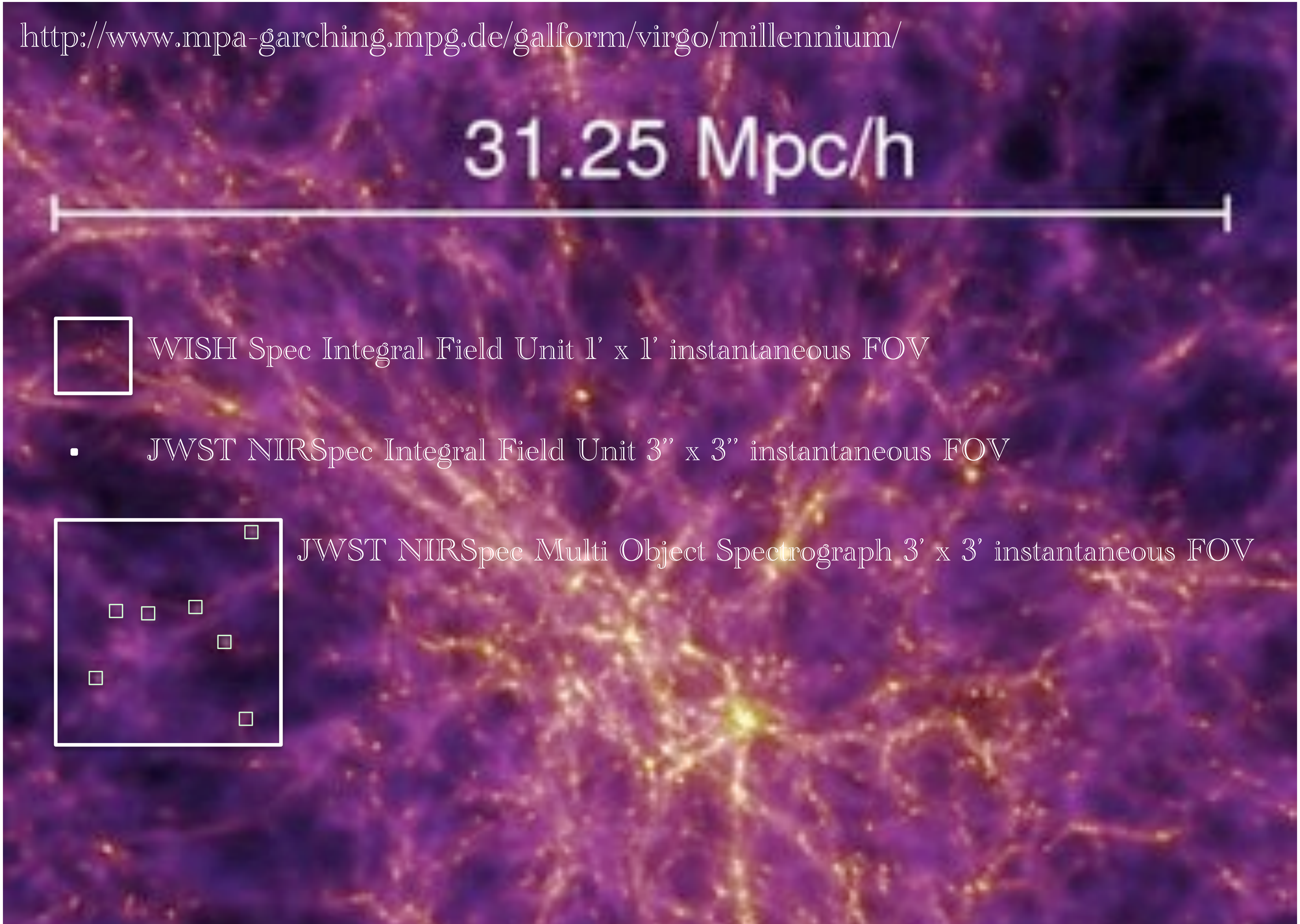
The exposure time for each FOV is 200 sec



Spectroscopic instantanenous FOV = 1'x1'

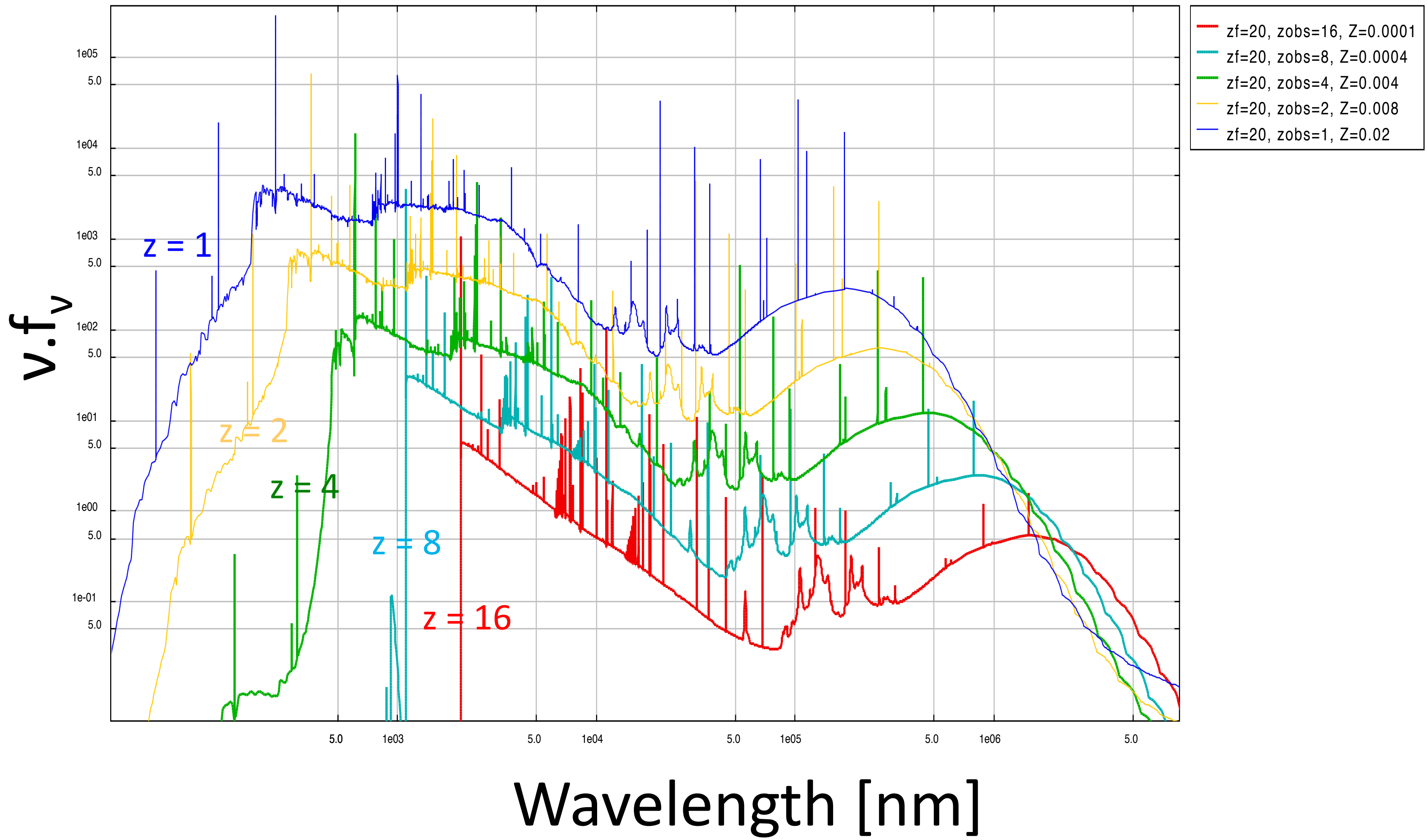
Spectroscopic Survey – Option 2 over 90 deg^2




http://www.mpa-garching.mpg.de/galform/virgo/millennium/
31.25 Mpc/h
WISH Spec Integral Field Unit 1' x 1' instantaneous FOV
JWST NIRSpec Integral Field Unit 3'' x 3'' instantaneous FOV
JWST NIRSpec Multi Object Spectrograph 3' x 3' instantaneous FOV

More simulations are now needed to constrain WISH-Spec

We have developed a code (*CIGALE*) able to fit observe SEDs but also to model the emission of galaxies (http://cigale.lam.fr) that allows to predict (assuming any SFH, metallicity, dust, IGM attenuation, AGN fraction, emission lines, etc.) the spectra of galaxies at any redshift and their evolution.

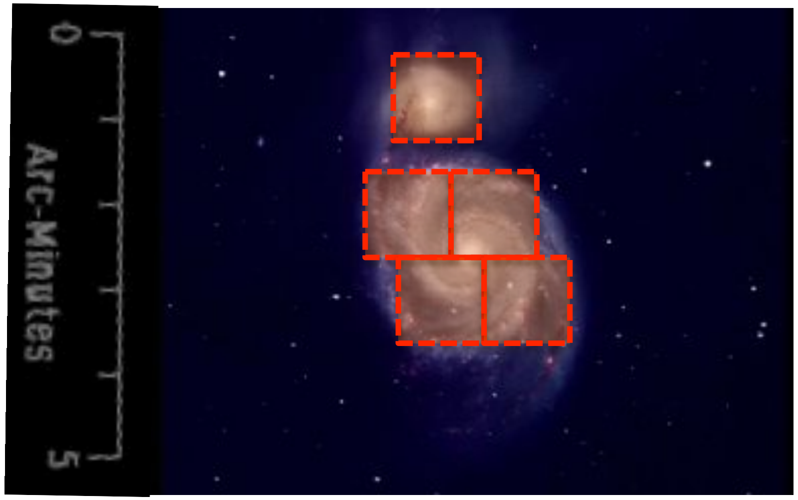


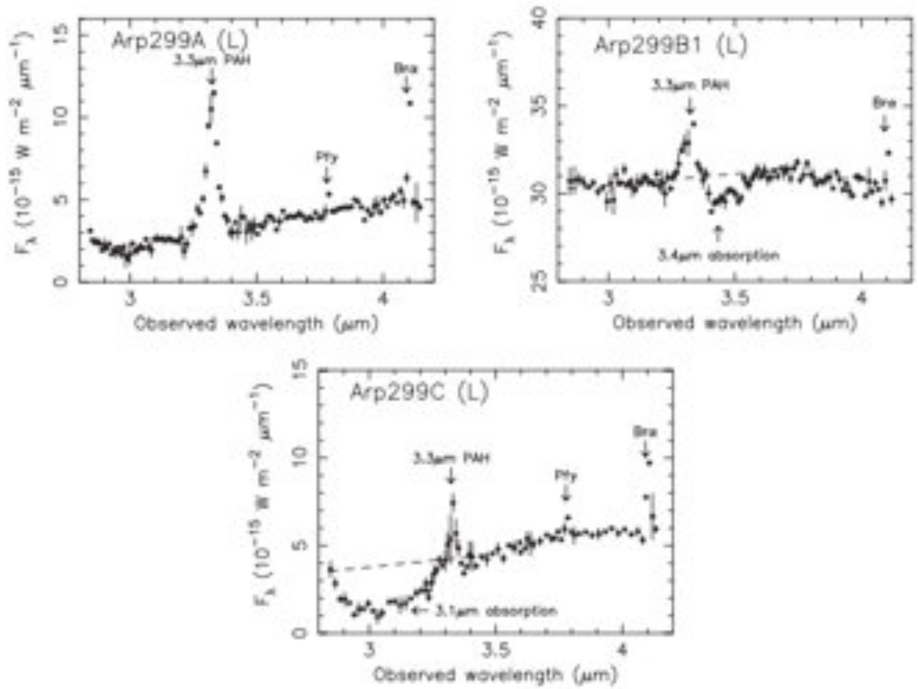
zf=20, zobs=16, Z=0.0001
zf=20, zobs=8, Z=0.0004
zf=20, zobs=4, Z=0.004
zf=20, zobs=2, Z=0.008
zf=20, zobs=1, Z=0.02
z = 1
z = 2
z = 4
z = 8
z = 16
ν.f_ν
Wavelength [nm]

Science cases outside Dark Ages and First Galaxies?

How much is a 1-arcmin^2 IFU?

(some of you will say 60 x 60 arcsec^2)

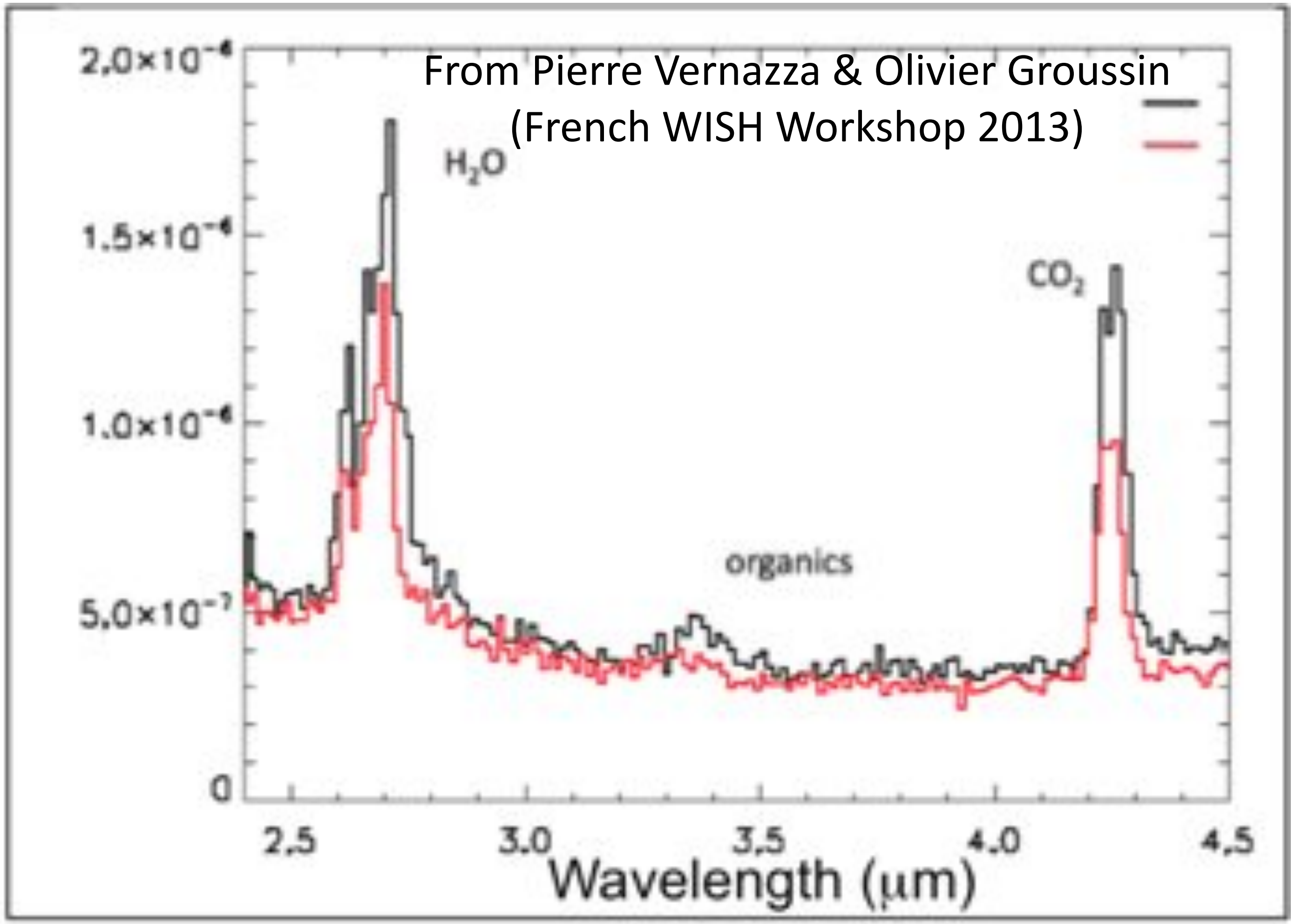




Imanishi & Nakanishi (2006)

Good size for studying local galaxies

Observing solar system objects



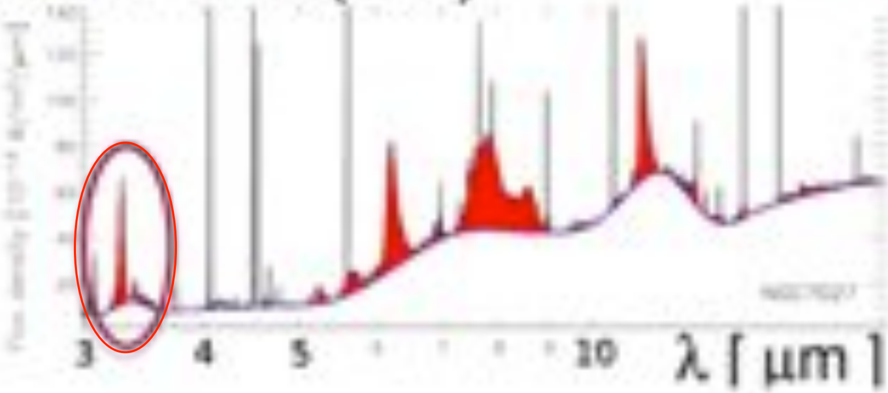
Two near-infrared spectra of the comet 103/Hartley 2 taken by the HRI-IR instrument onboard the Deep Impact spacecraft (Feaga et al. 2012)

The aromatic infrared bands and the PAH hypothesis

From Julien Montillaud
(French WISH Workshop 2013)

AKARI 9 μm: ubiquitous mid-IR emission
PAH = carriers of the AIBs (in this talk)

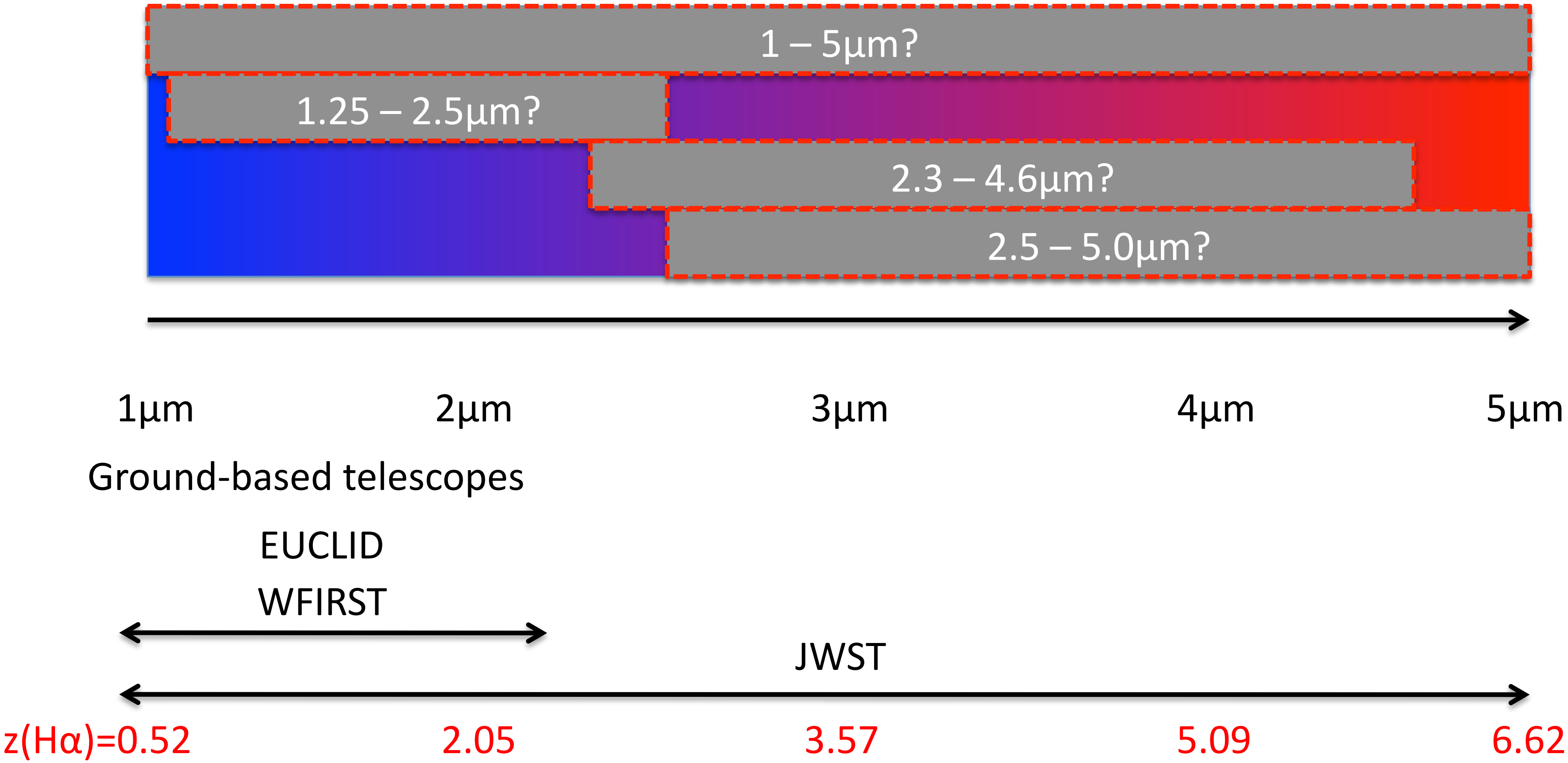
"Astrophysical PAHs": aromatic infrared bands (AIBs)



Adapted from Peeters et al. 2002

The 3.3 - 3.4 μm band:
C-H stretching mode **ONLY**

One important question to address during this workshop: What is the wavelength range that we need? Please give us your opinion.

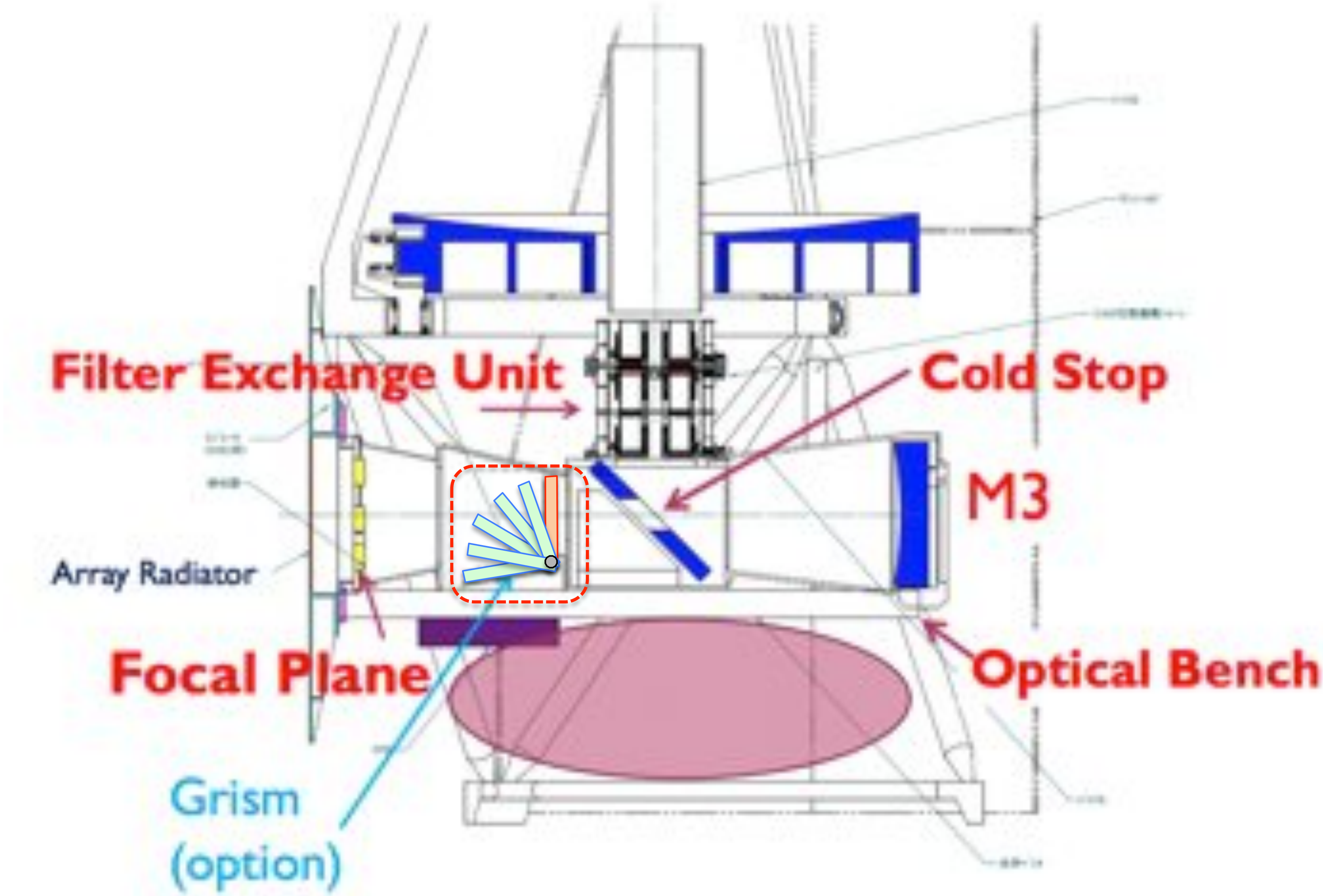


Other possible (than WISHSpec) French contributions

Test the 1.5m M1: LAM's AIT/V technical facilities will be upgraded in 2013 with the ERIOS cryo-vaccum chamber. This large 90 m^3 (45 m^3 useful) tank benefits from an ultra-high stability optical bench for high angular resolution measurement and tests can be carried out at temperatures as low as 77K for the full volume (i.e. the entire M1) and locally down to 4K. This option could be selected whether or not the M1 will be procured by LAM or by an industrial.

A downling antenna furnished by CNES: WISH needs to download the data to Earth and an additional downlink antenna would be useful to improve the rate. This point was initialy raised by the Japanese PI. It is possible to use one of the CNES stations for downlink. Several ones are available at Kourou, Aussagel and on the Kerguelen islands. Two other stations can be used through a colaboration with international partners at Hartebeeshoek (South Africa), Kiruna (Sweden) and possibly at Inuvik (Canada). Presentely band S is used but an upgrade including the possibility to use band X in on-going. The details of the use of the CNES antenna would be discussed later on but such a possibility does exist.

Grism in the main optical path



Several studies funded by CNES for SNAP (LAM) and IRSIS (Paris Obs.) could be used for WISH.

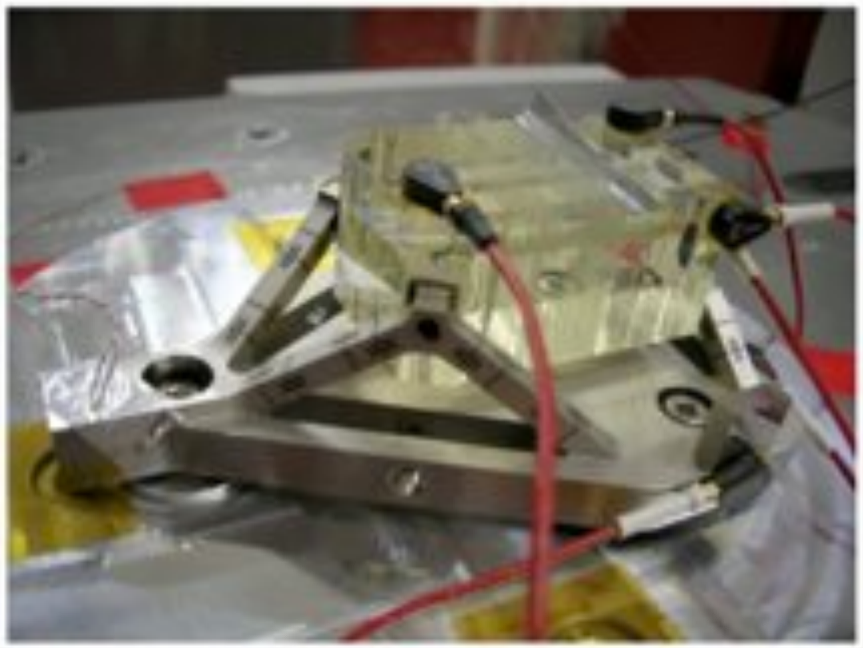
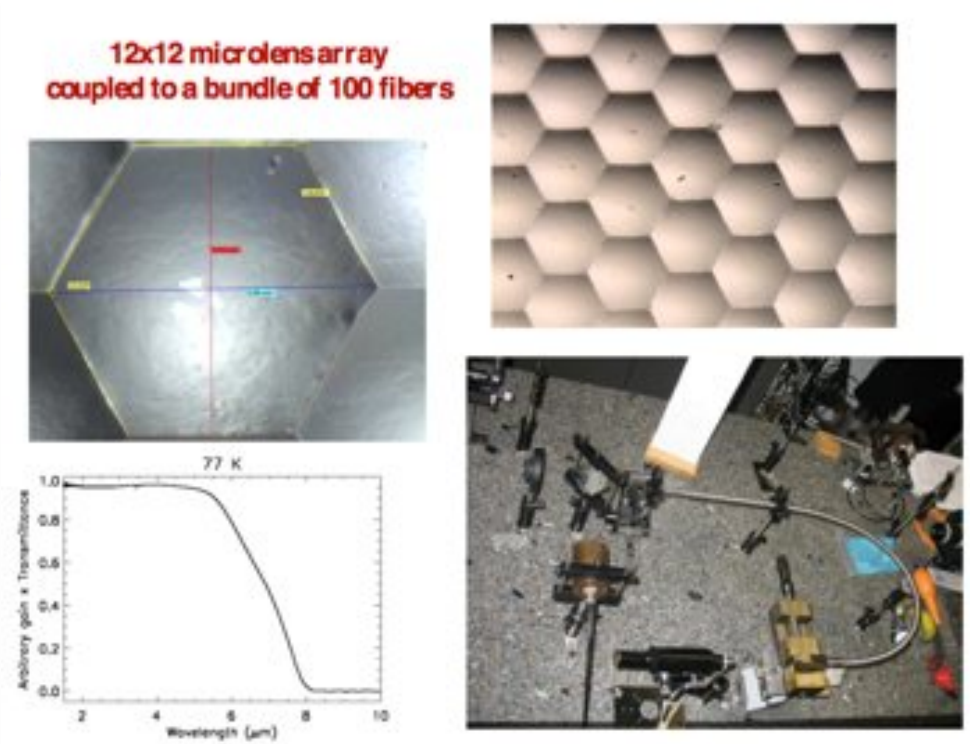
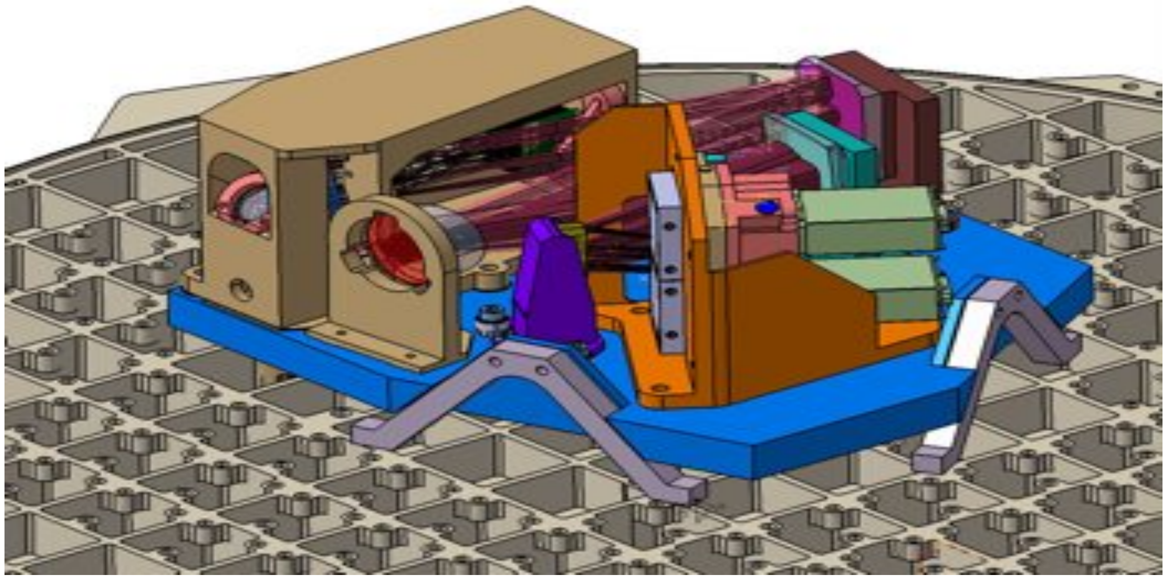


Image slicer prototype (TRL5 validation) for the SNAP project.



Micro-lenses array from the IRSIS project

• First optical design from WISH-Spec based on SNAP. It fits in a (large) shoe-box.
• Technology is ready and we only need to adapt it to WISH.
• Small and light spectrograph.
• Simple design that does not add complexity to WISH.



A bit of politics...

Which team to study and develop WISHSpec?

- The French space agency (CNES) noted that the **addition of spectroscopy to WISH would multiply scientific possibilities** of the mission, in particular allowing a detailed study of the properties of galaxies during the reionization and this for a very large number objects.
- CNES defined as one of its priorities: "**Understanding the end of the Dark Ages and study the formation of the first objects**" in the Near-IR through a mission of opportunity. This would match the requirements for an IFU spectrograph for the Japan-led WISH project.
- However, it is certainly interesting to **open up the project to a wider community** (Europe, USA, Canada and more?).
- Specifically for Europe, we envisage to apply to **ESA « Collaborative Missions »** like for AKARI, Suzaka, Hinode, ASTRO-H

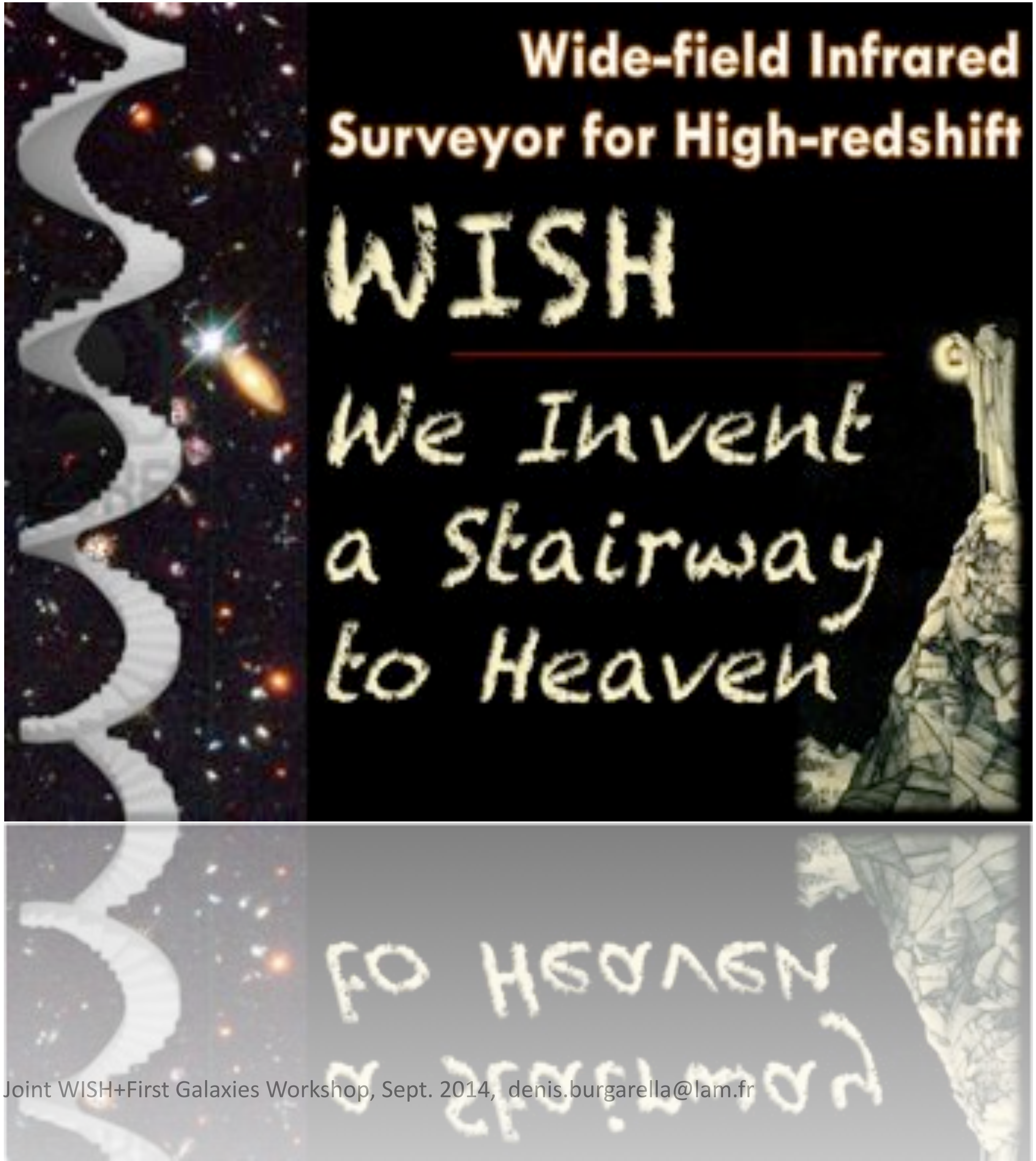
=> **enlarge the team in Europe**

Priorities underlines by the French Space Agency CNES

Méthode d'observation	Cadre de réalisation	Priorité	R&T associée	Thème scientifique
Observer l'Univers dans le domaine des rayons X	L2 (ESA)	P0	Chaîne de détection et cryogénie	- Comprendre la fin des âges sombres et étudier la formation des premiers objets - Comprendre les mécanismes d'échange de matière et d'énergie aux différentes échelles, des étoiles aux trous noirs et aux galaxies
Observer les modes B de la polarisation du fond diffus cosmologique	M (ESA) ou Opportunité (NASA/JAXA)	P0	Chaîne de détection et cryogénie	- Comprendre la phase d'inflation de l'Univers primordial
Observer l'Univers lointain dans l'infrarouge lointain ou l'Univers proche dans l'ultraviolet	M (ESA) ou Opportunité (NASA)	P1		- Comprendre les mécanismes d'échange de matière et d'énergie aux différentes échelles, des étoiles aux trous noirs et aux galaxies
Observer par spectrophotométrie les atmosphères des exoplanètes	M (ESA) ou Opportunité	P1		- Caractériser les exoplanètes et chercher les biosignatures
Observer l'Univers dans le domaine du MeV	M (ESA) ou Opportunité	P2	Chaîne de détection	- Comprendre les explosions stellaires, la physique des objets compacts. - Comprendre l'origine des rayons cosmiques galactiques.
Observer les étoiles dans l'ultraviolet	M (ESA) ou Opportunité	P2	Spectro-polarimètre	- Comprendre la formation et l'évolution des étoiles et des planètes.
Observer l'univers lointain dans l'infrarouge proche	Opportunité	P2		- Comprendre la fin des âges sombres et étudier la formation des premiers objets

Phase 0 également demandée pour « Observer les étoiles dans l'ultraviolet ».

Merci


Wide-field Infrared
Surveyor for High-redshift
WISH
We Invent
a Stairway
to Heaven