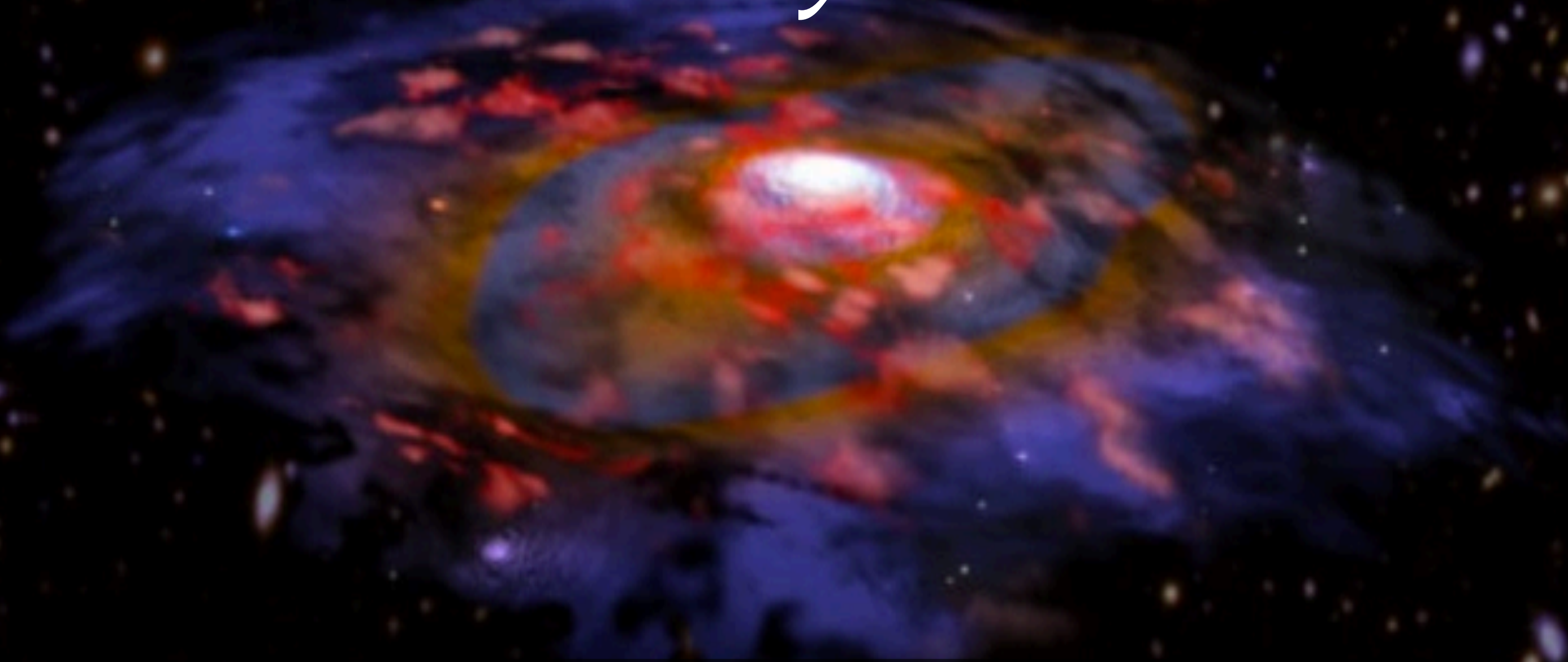
Obscured Star-Formation in the Early Universe



Carlotta Gruppioni

INAF OAS BOLOGNA

Submillimetre and Millimetre Astronomy, Moscow, 2021 April 12-16

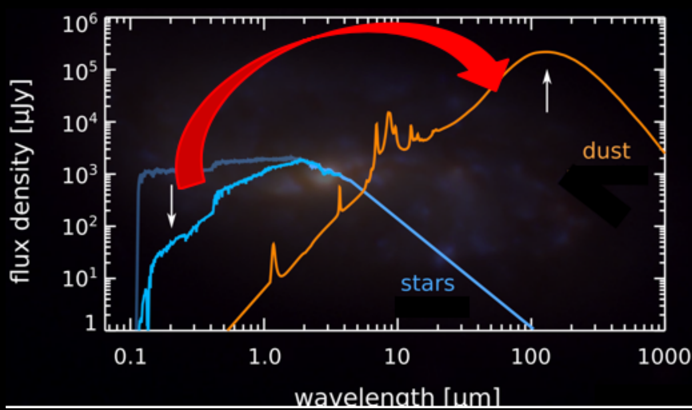
Main questions

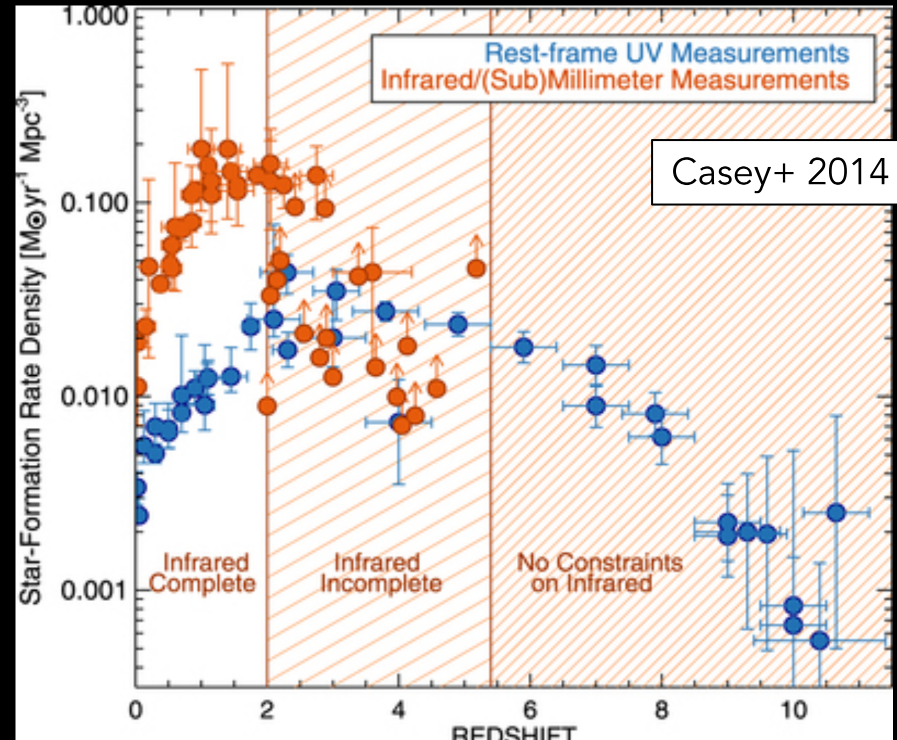
- How did galaxies form in the early Universe?
- How were they? ISM, dust, metals?

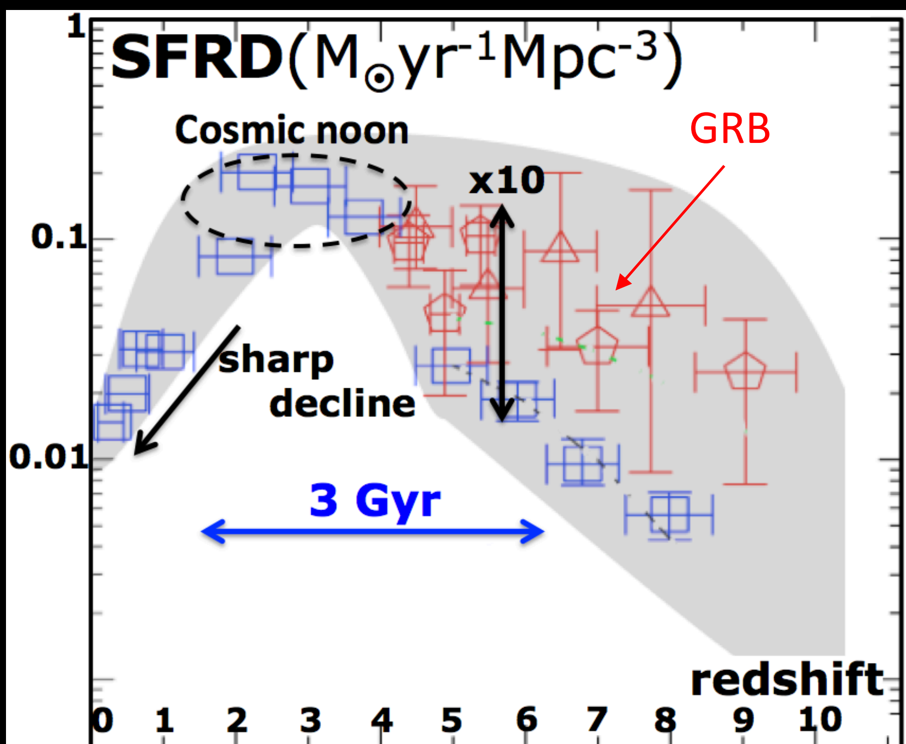
⇩

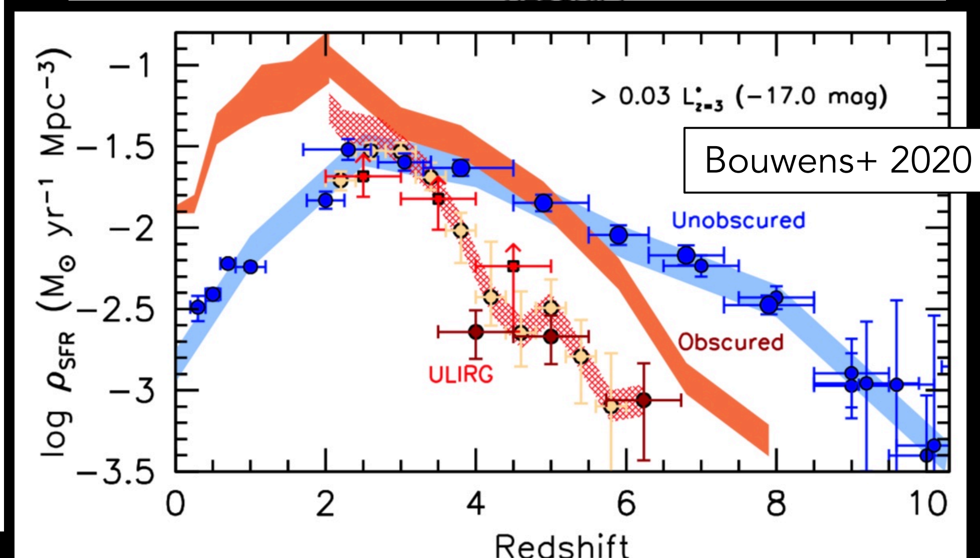
- Cosmic star formation rate density
  BUT: only from UV/optical at z>3
- we still miss an important piece in the puzzle of galaxy formation and evolution: high-z massive dusty galaxies

Our current (lack of) knowledge of the z>3 SFRD



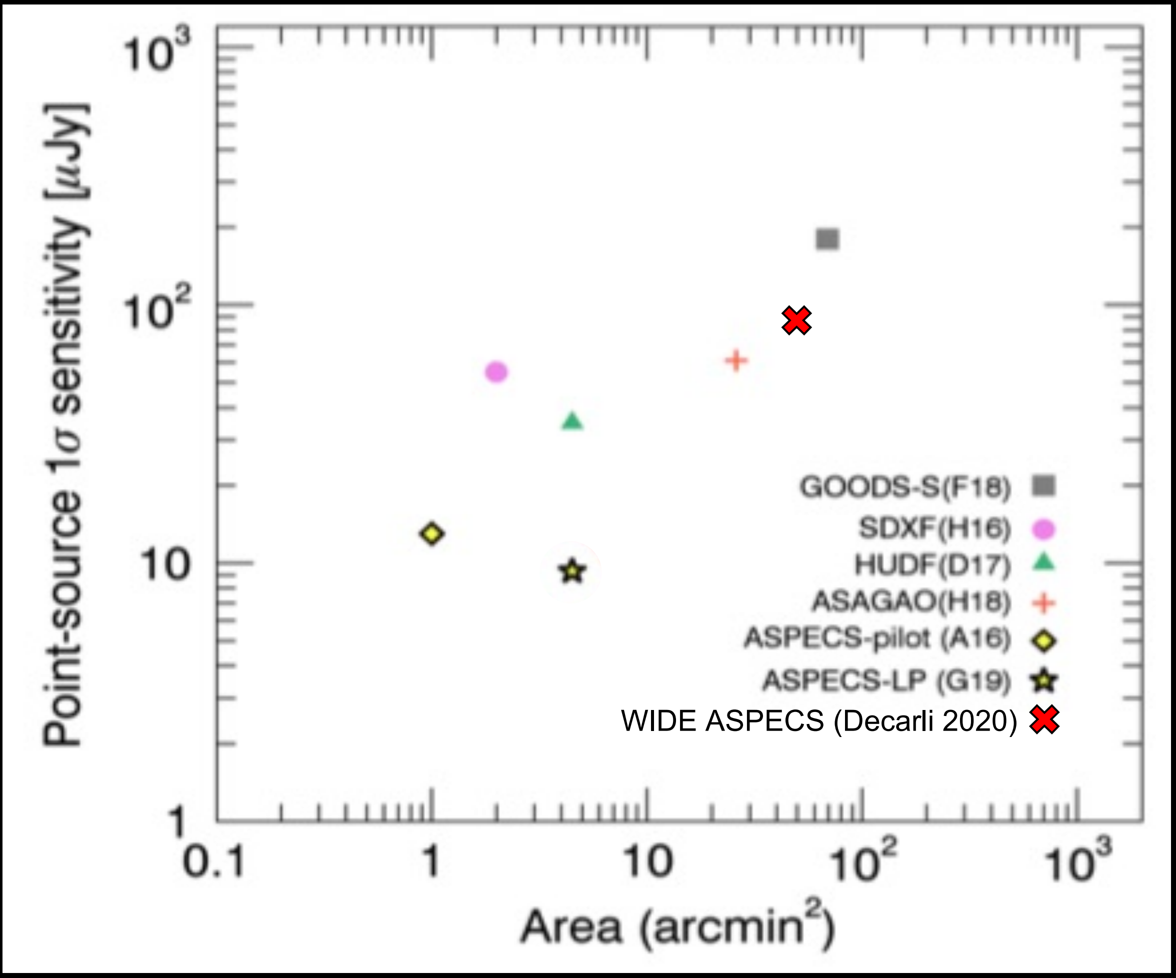






Search for high-z dusty luminous galaxies with ALMA

ALMA search for dusty luminous galaxies at high redshift



ALMA HUDF
1.3 mm, 4.5 arcmin^2, 120 μJy
16 sources *[Dunlop+ 17]*

ALMA-GOODS
1.1 mm, 69 arcmin^2, 700 μJy
20 sources *[Franco+ 18]*

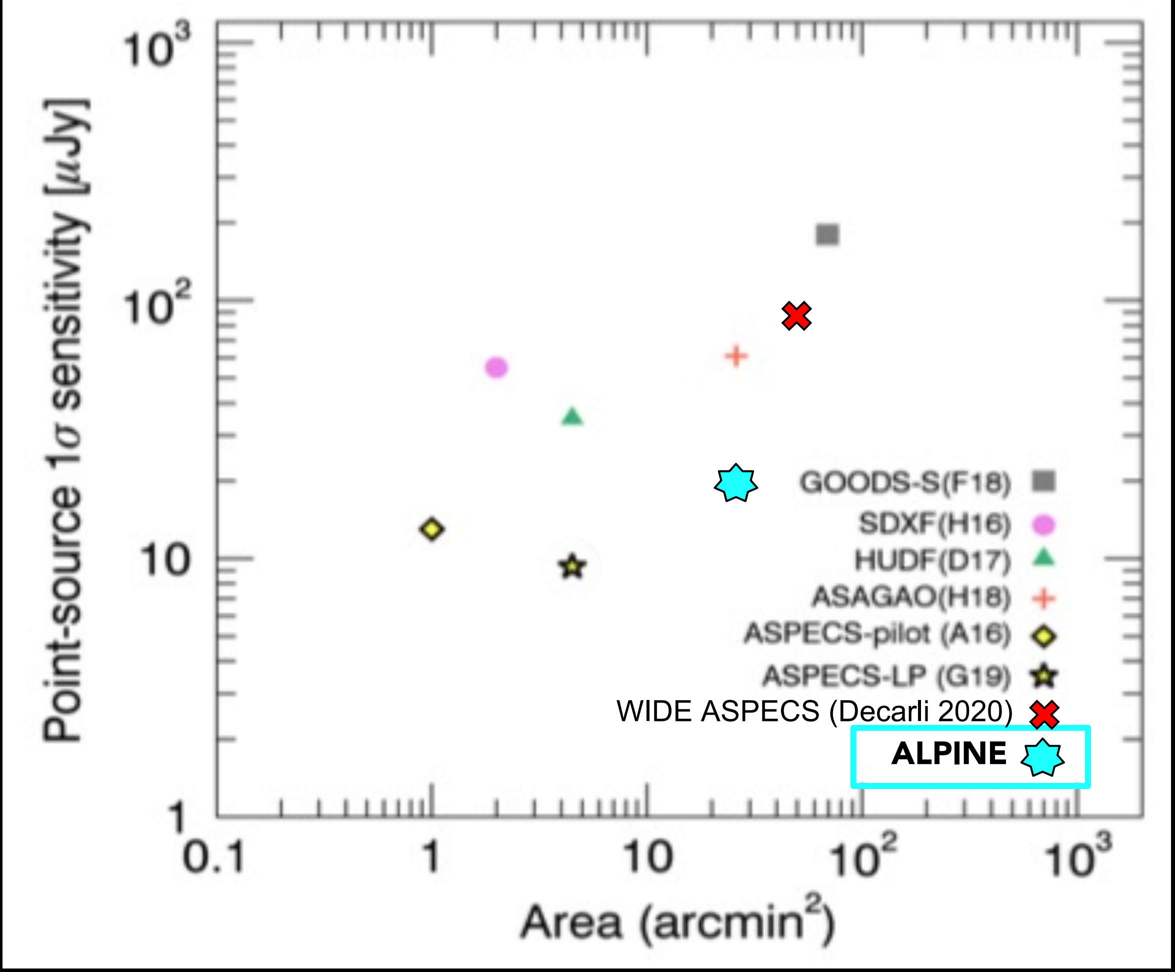
ASAGAO
1 mm, 26 arcmin^2, 135 μJy
25 sources *[Hatsukade+ 18]*

ASPECS pilot + LP
1.2 (+ 3 mm), 1 + 4.5 arcmin^2, 46 + 33 μJy,
9 + 32 (+6) sources *[Aravena+ 16, González-López+ 19]*

WIDE ASPECS
3mm, 52 arcmin^2 -> shallower
[Decarli+ in preparation]

ALPINE
0.86-1 mm, 25 arcmin^2 (118 points), to ≈100-300 μJy
56 sources *[Bethermin+ 19]*

ALMA search for dusty luminous galaxies at high redshift



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The ALMA Large Programme to INvestigate CII at Early Times (ALPINE)

A2C2S | ALMA ALPINE [CII] Survey

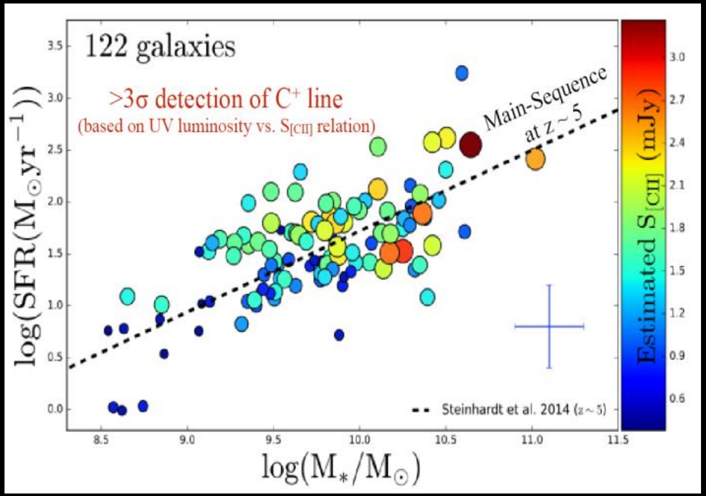
PI O. Le Fèvre

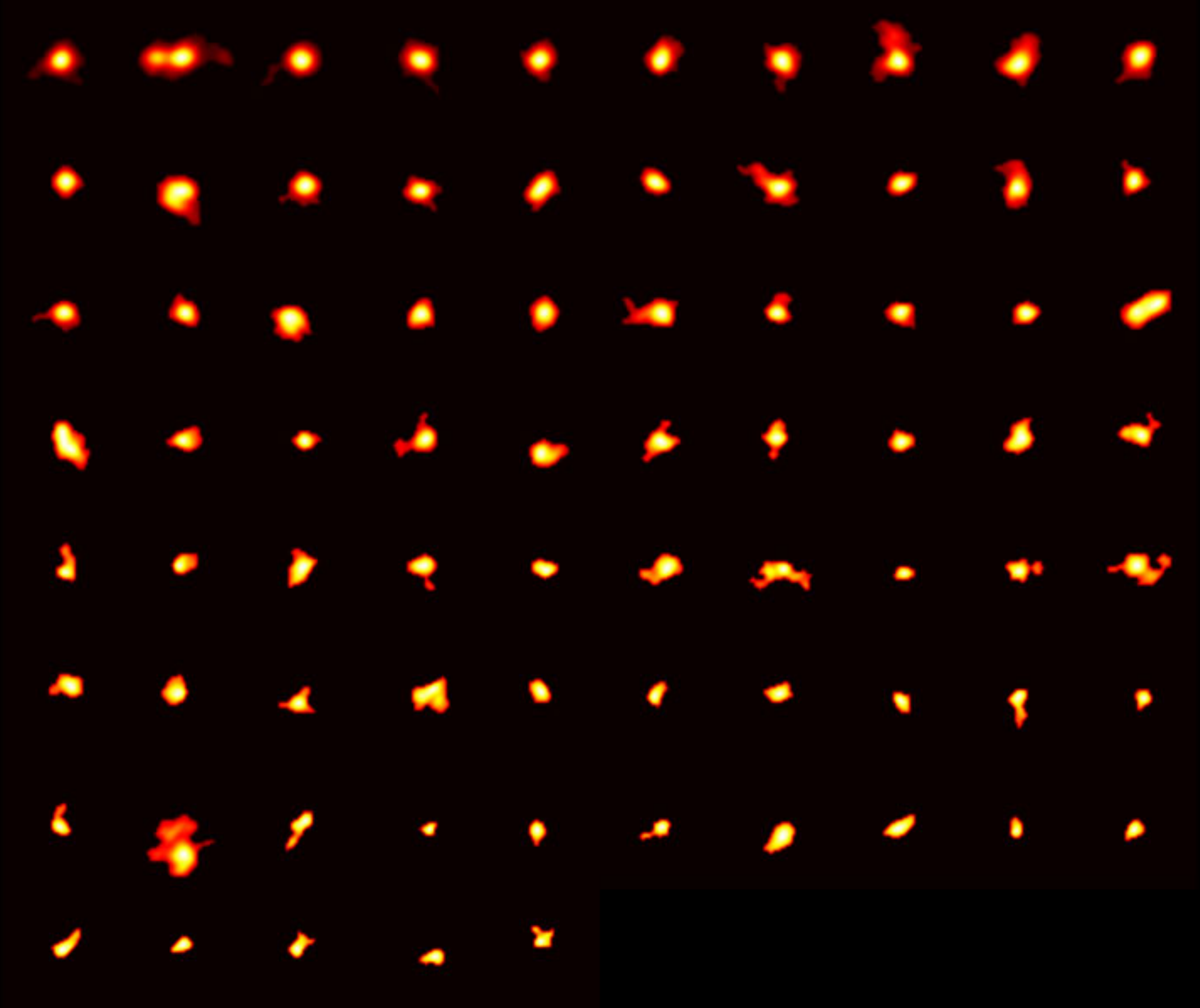
Co-PIs:
- Andreas Faisst, Caltech, USA
- Lin Yan, Caltech, USA
- Peter Capak, Caltech, USA
- John Silverman, University of Tokyo, Japan
- Matthieu Béthermin, Laboratoire d'Astrophysique de Marseille, France
- Paolo Cassata, University of Padua, Italy
- Daniel Schaerer, University of Geneva, Switzerland

Targeted survey on 118 galaxies with known $4<z_{spec}<6$

+ serendipitous sources

- C+ and FIR measurements
- Total SFRD, incl. hidden star formation
- Dynamical masses
- Mergers

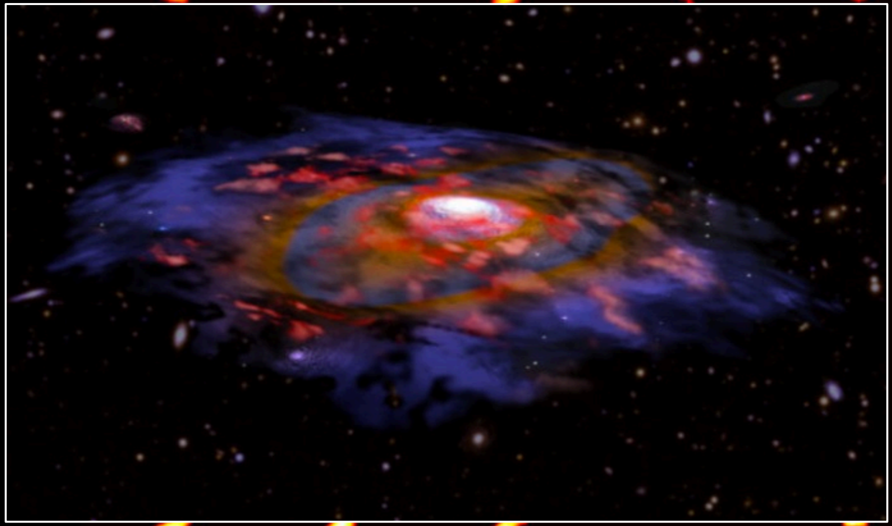


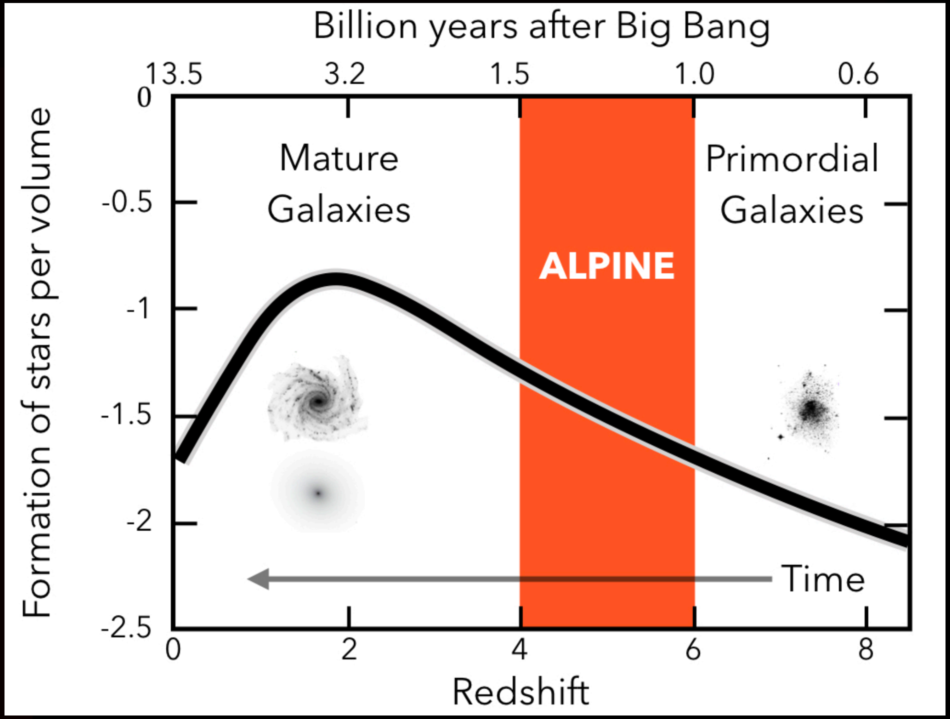


The ALPINE ALMA [C II] Survey

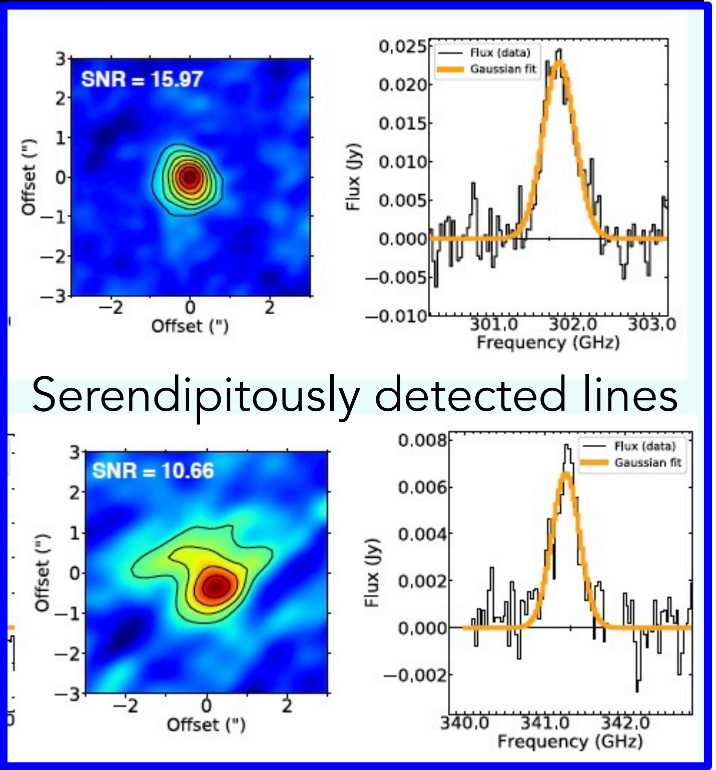
ALPINE galaxies were already much more mature (i.e., containing a significant amount of dust and metals) in the early universe than expected *(e.g., Faisst+ 2020; Ginolfi+ 2020; Fujimoto+ 2020; Fudamoto+ 2020; Schaerer+ 2020).*

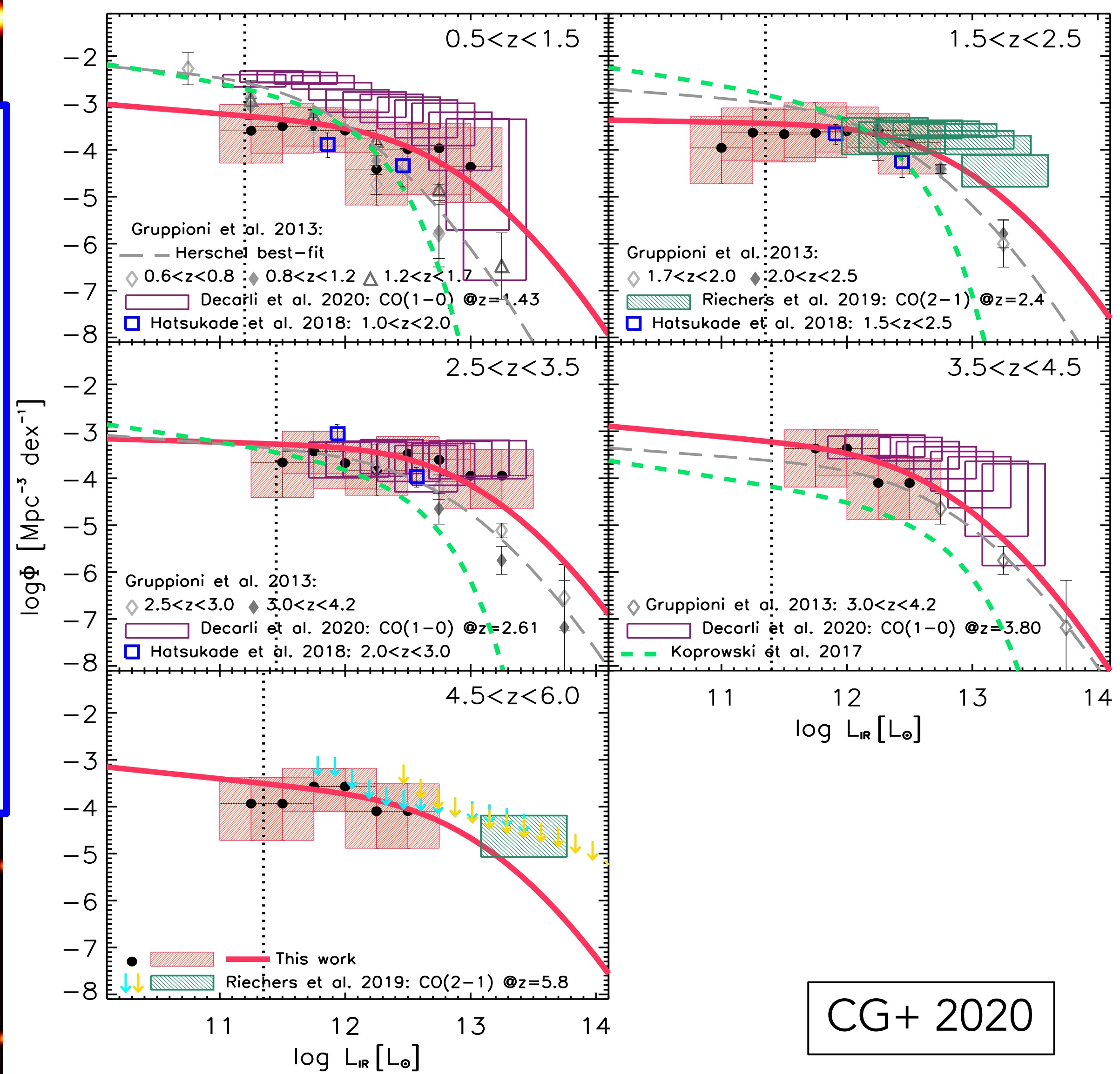
The galaxies were also relatively grown-up showing the first signs of rotationally supported disks *(e.g., Le Févre+ 2020; Jones+2021)*



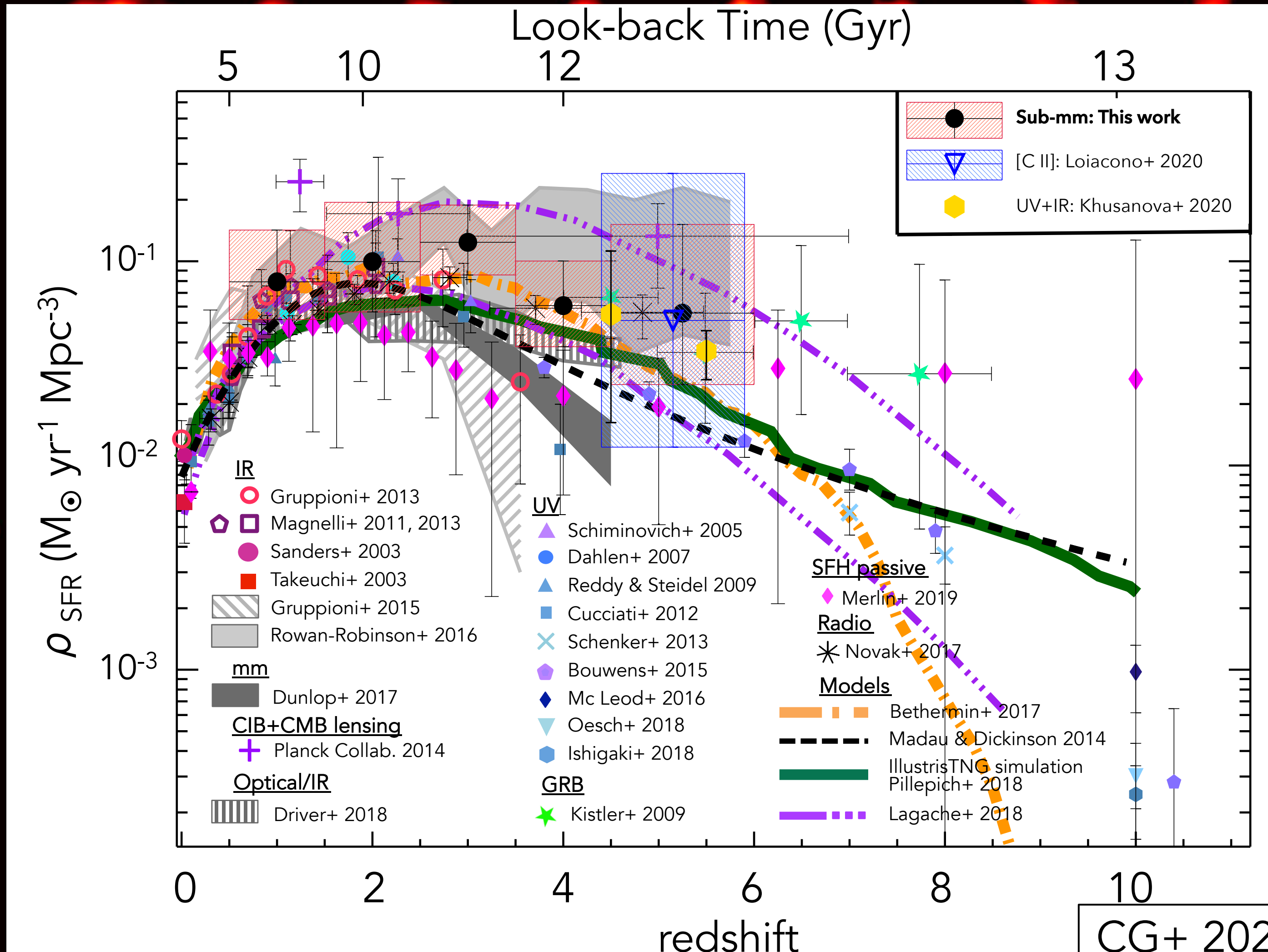


Besides the main targets, in the ALPINE pointings a blind search for serendipitous line and/or continuum emitters has been performed in a total area of 24.9 arcmin^2





CG+ 2020



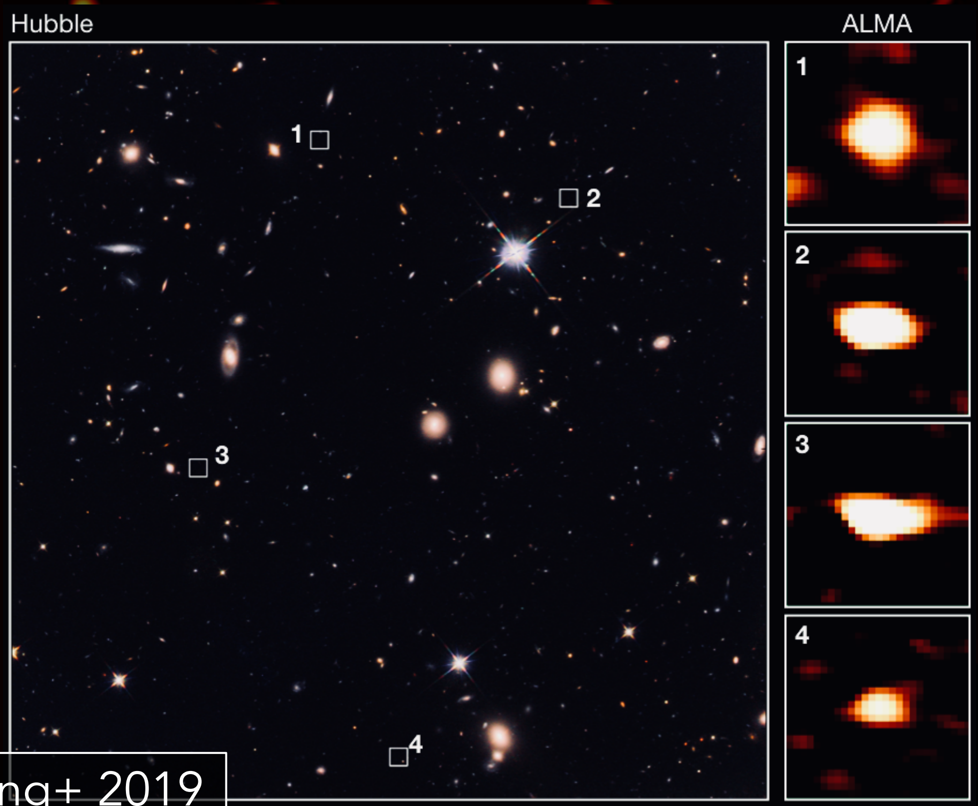
CG+ 2020

The SFRD remains almost constant from cosmic noon to z~6 (5-8× higher than the optical/UV estimates)

ALMA discovers a population of optically dark galaxies

ALMA is revealing a population of optically and near-IR dark galaxies with number density exceeding predictions from current theoretical models and and hydrodinamical simulations.

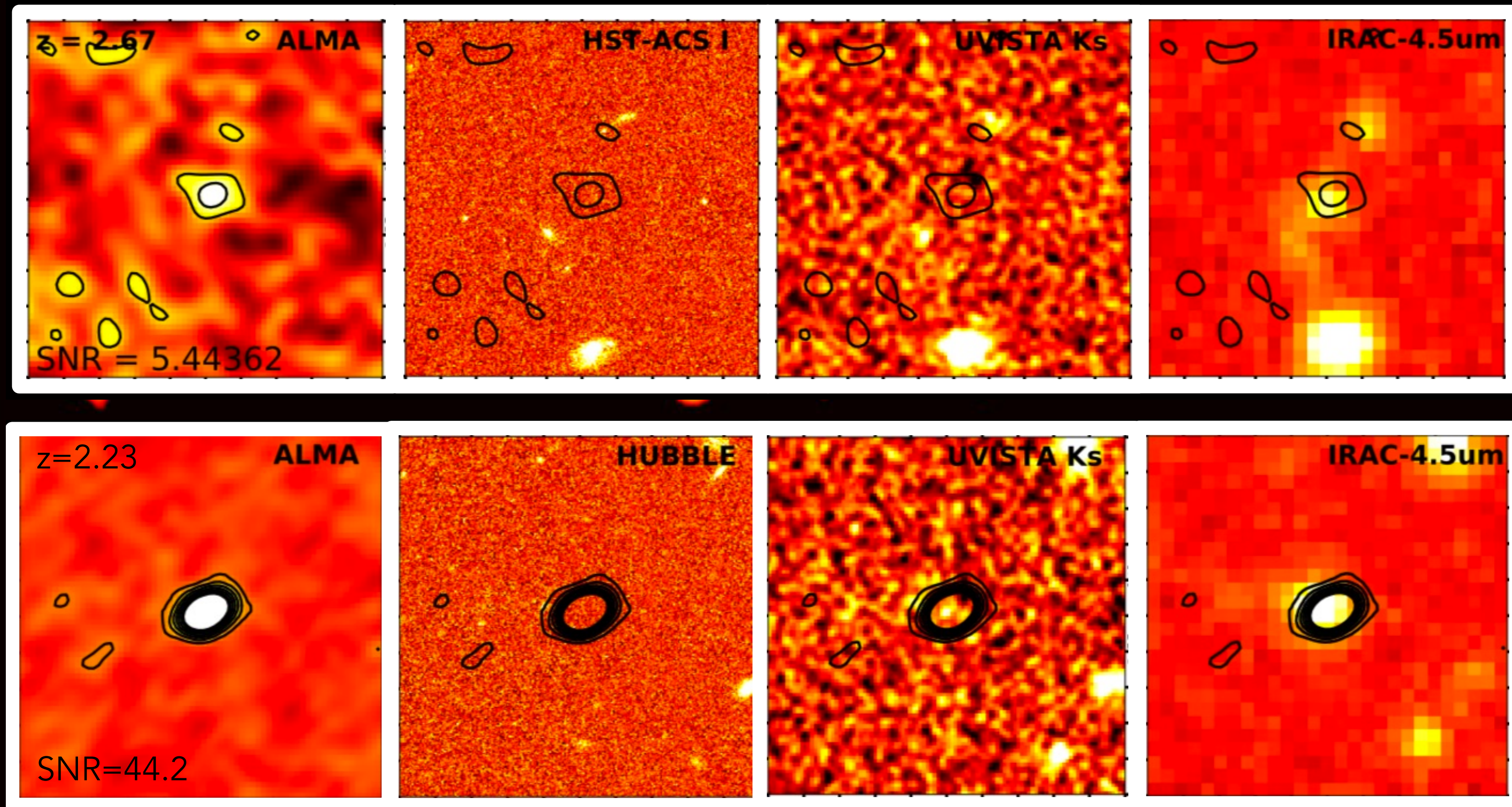
For state-of-the-art models is challenging to build a large number of massive objects in such an early phase of the Universe.



Wang+ 2019

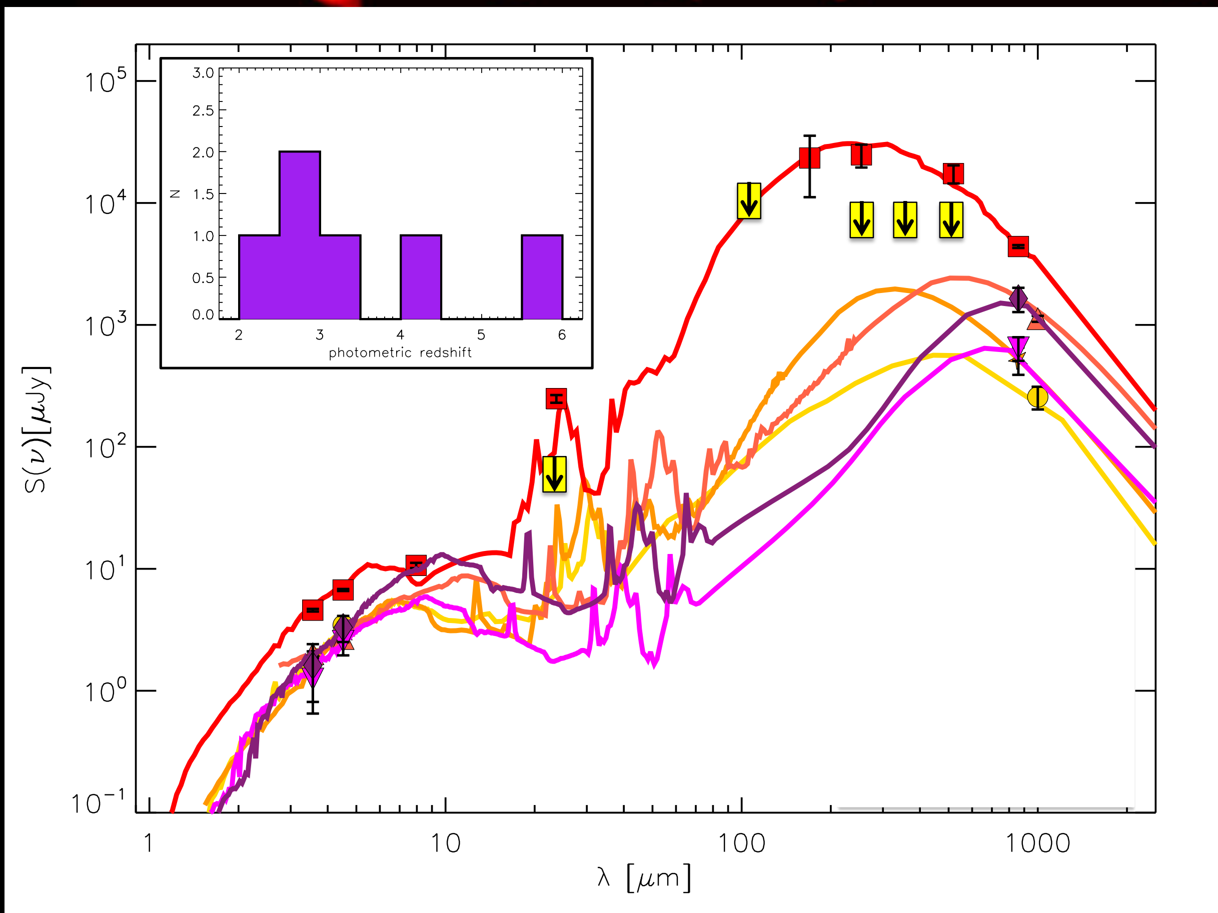
These ALMA results challenge our current understanding of the evolution of the Universe.

ALMA HST-dark galaxies in ALPINE



14-20% of all the sources serendipitously detected in continuum are HST and near-IR dark

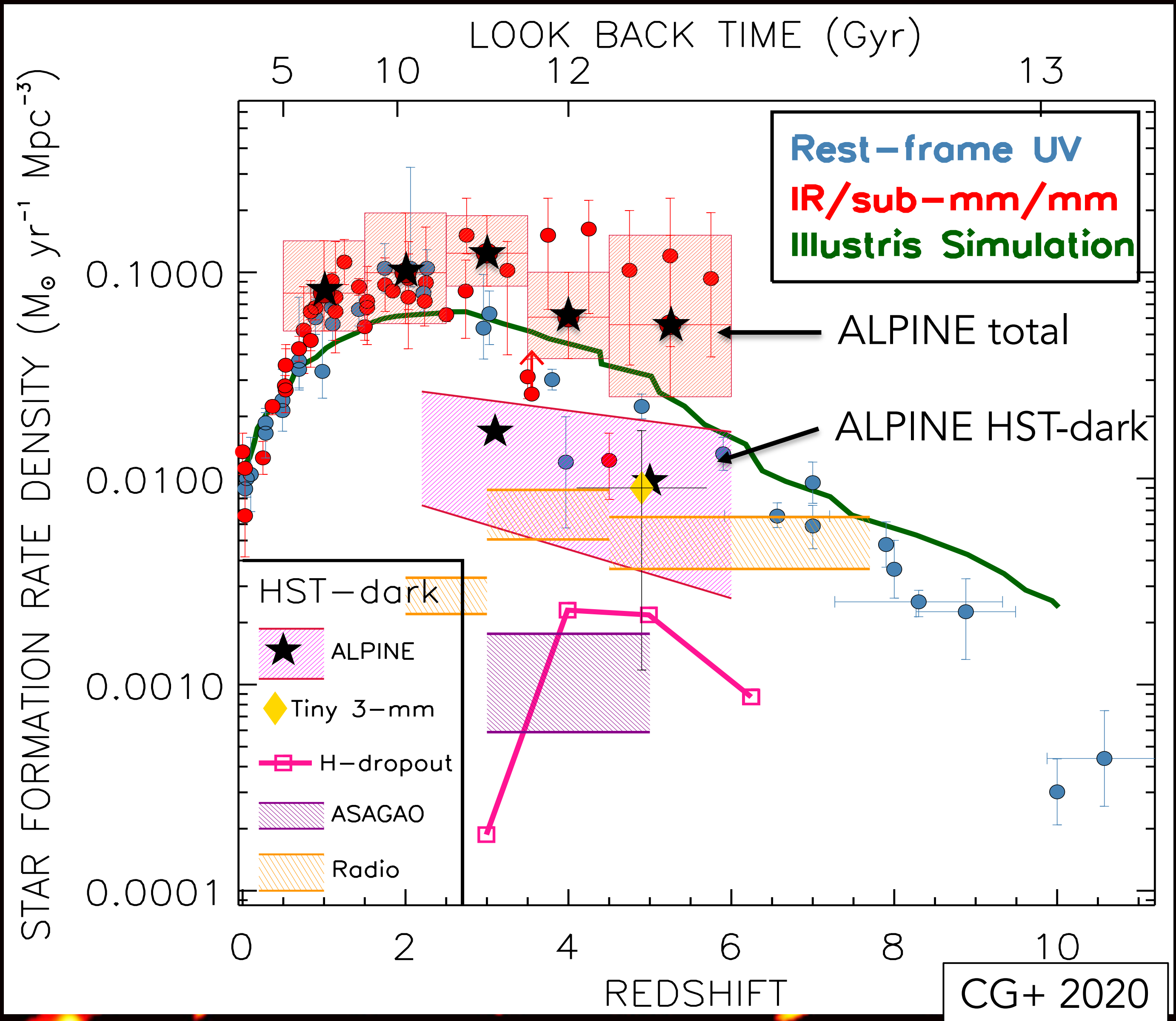
Spectral Energy Distribution and photo-z of ALPINE HST+near-IR dark galaxies



Only two/three data points (ALMA+IRAC) + upper limits from UV to sub-mm

All @z>2.2 (in the range 2.2-5.85):

$< z > \sim 3.5$



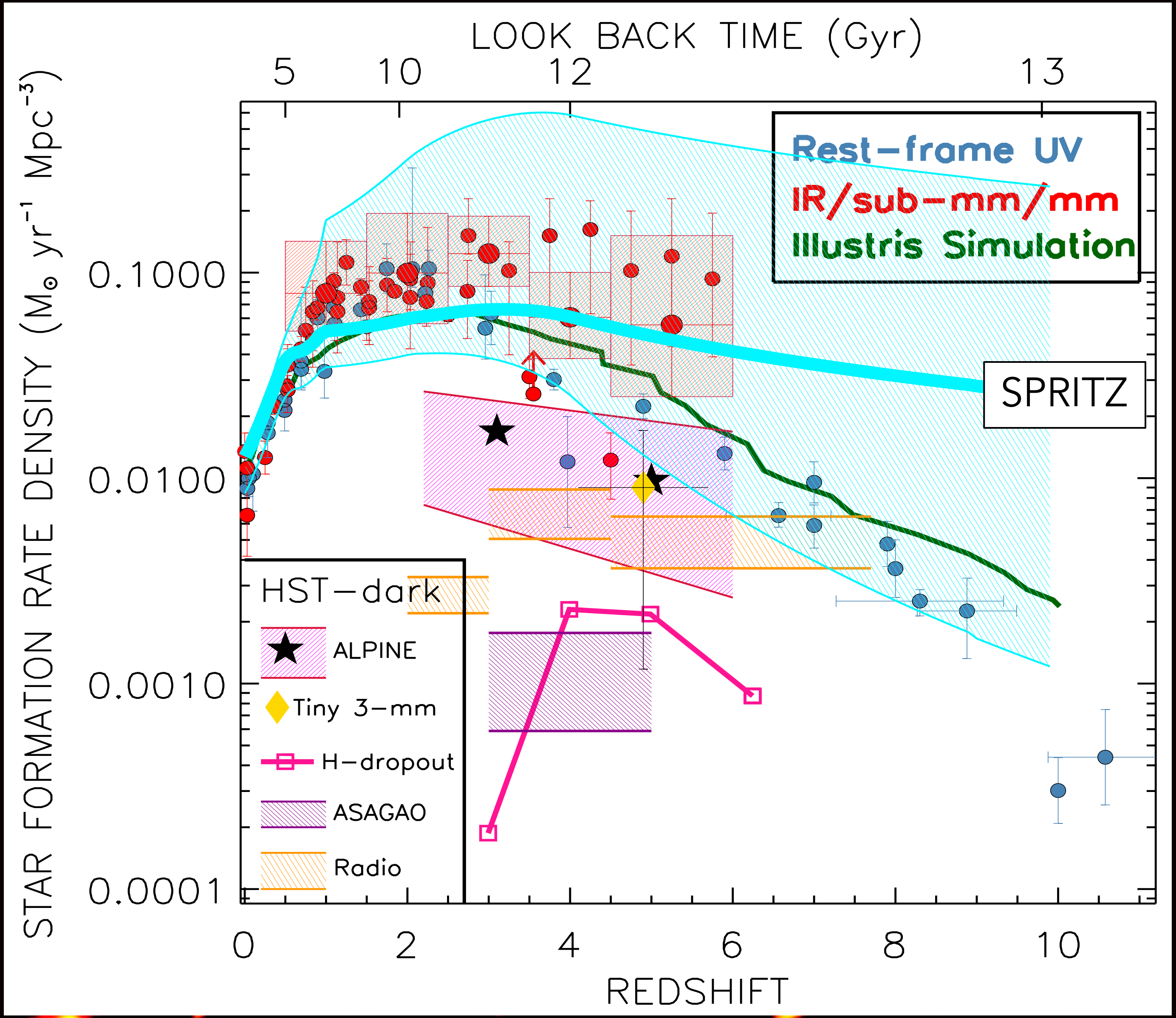
HST+near-IR dark sources are found to contribute for ~17% of the total SFRD at z~5

Simulating the Infrared Sky with a SPRITZ

→ To plan surveys with future IR facilities we built a phenomenological evolution model: **SPRITZ** (**S**pectro-**P**hotometric **R**ealisations of **I**nfrared-selected **T**argets at all-**Z**) based on Herschel results and constrained by all the currently available multi-λ data

("Simulating the IR sky with a SPRITZ", Bisigello, Gruppioni et al., A&A in press)

see Laura Bisigello's talk!



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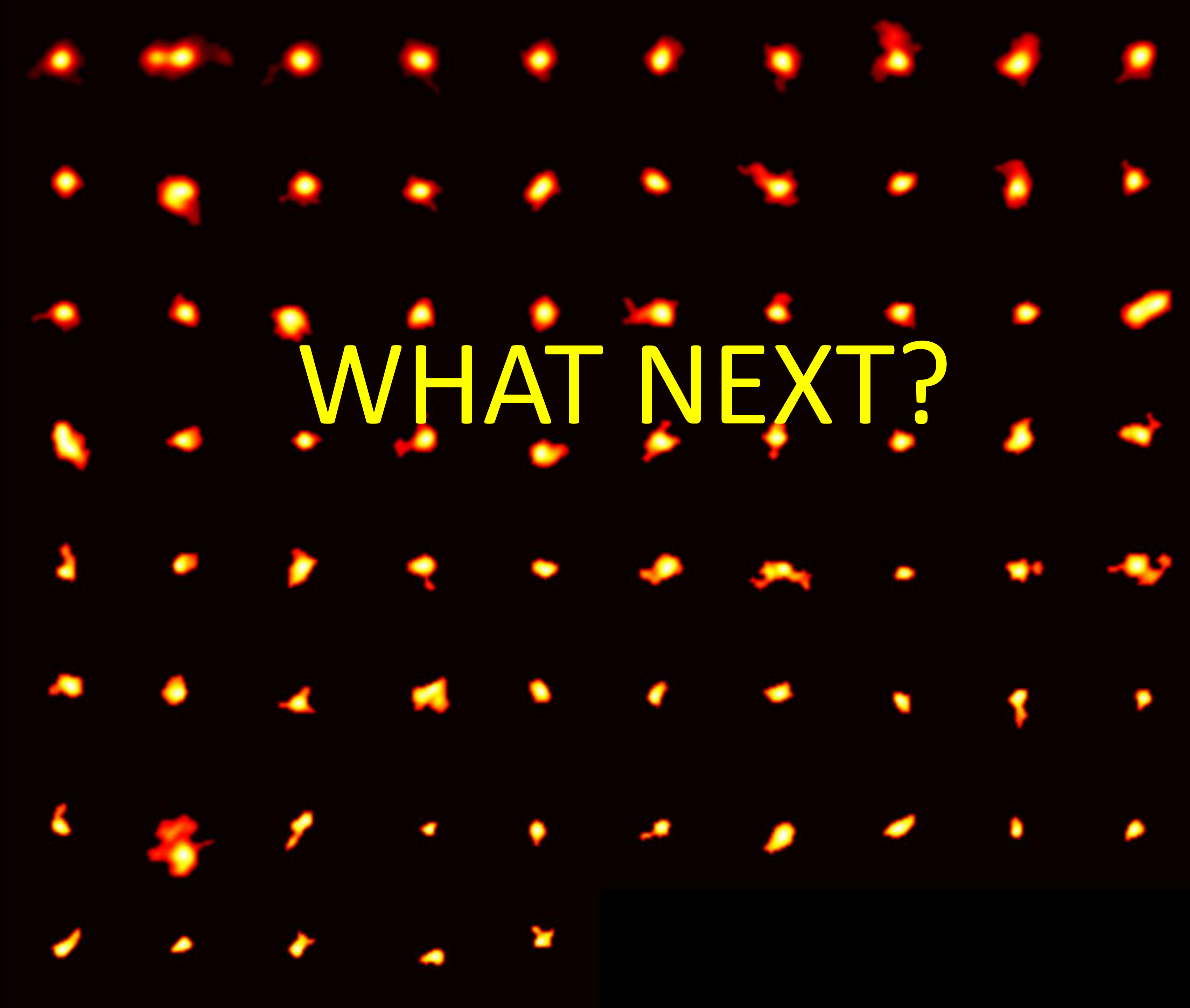
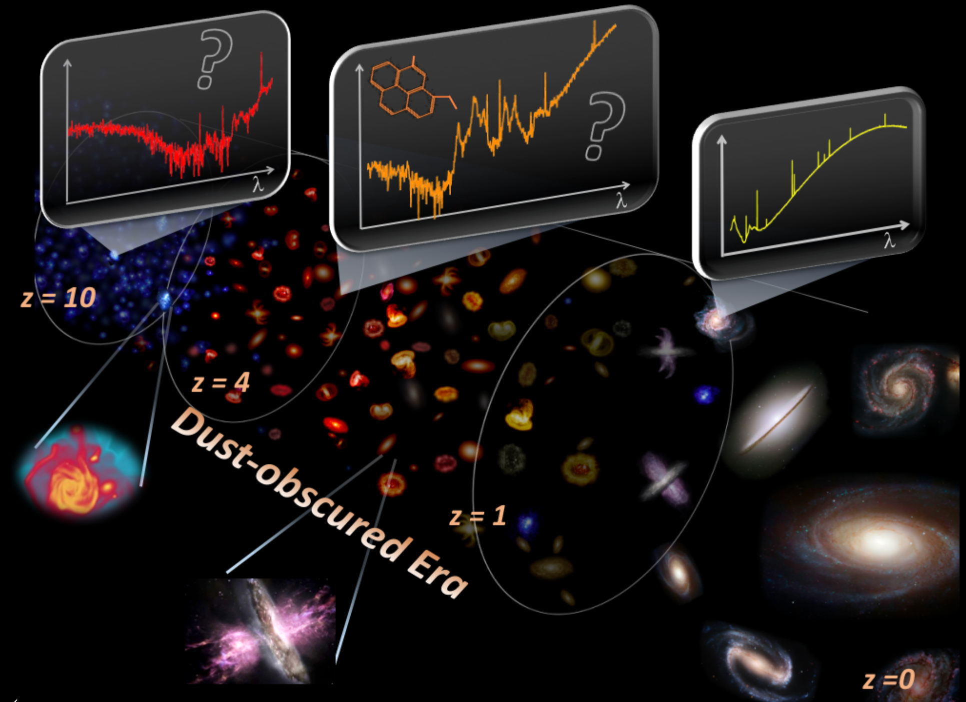
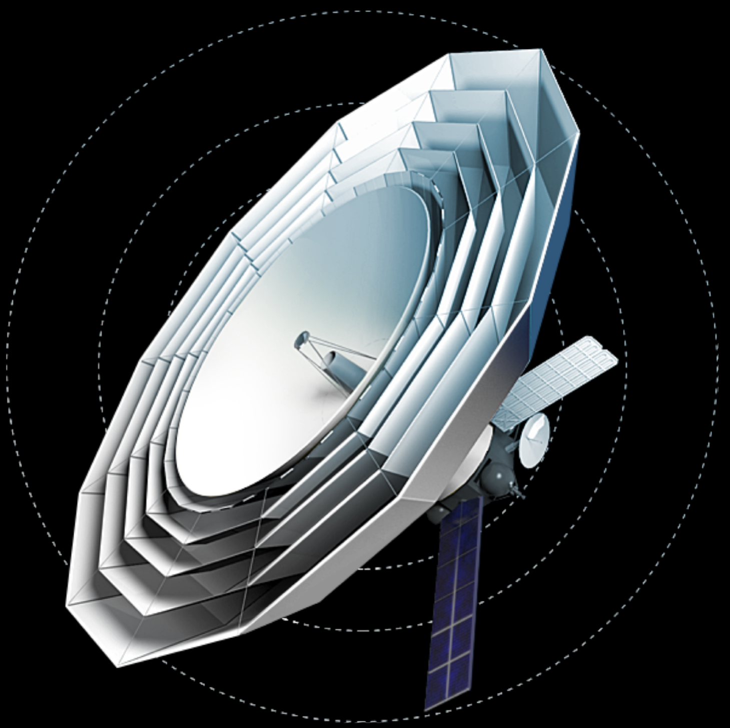

WHAT NEXT?

Need for a cooled/sensitive space telescope observing the Universe at far-IR/sub-mm/mm wavelengths



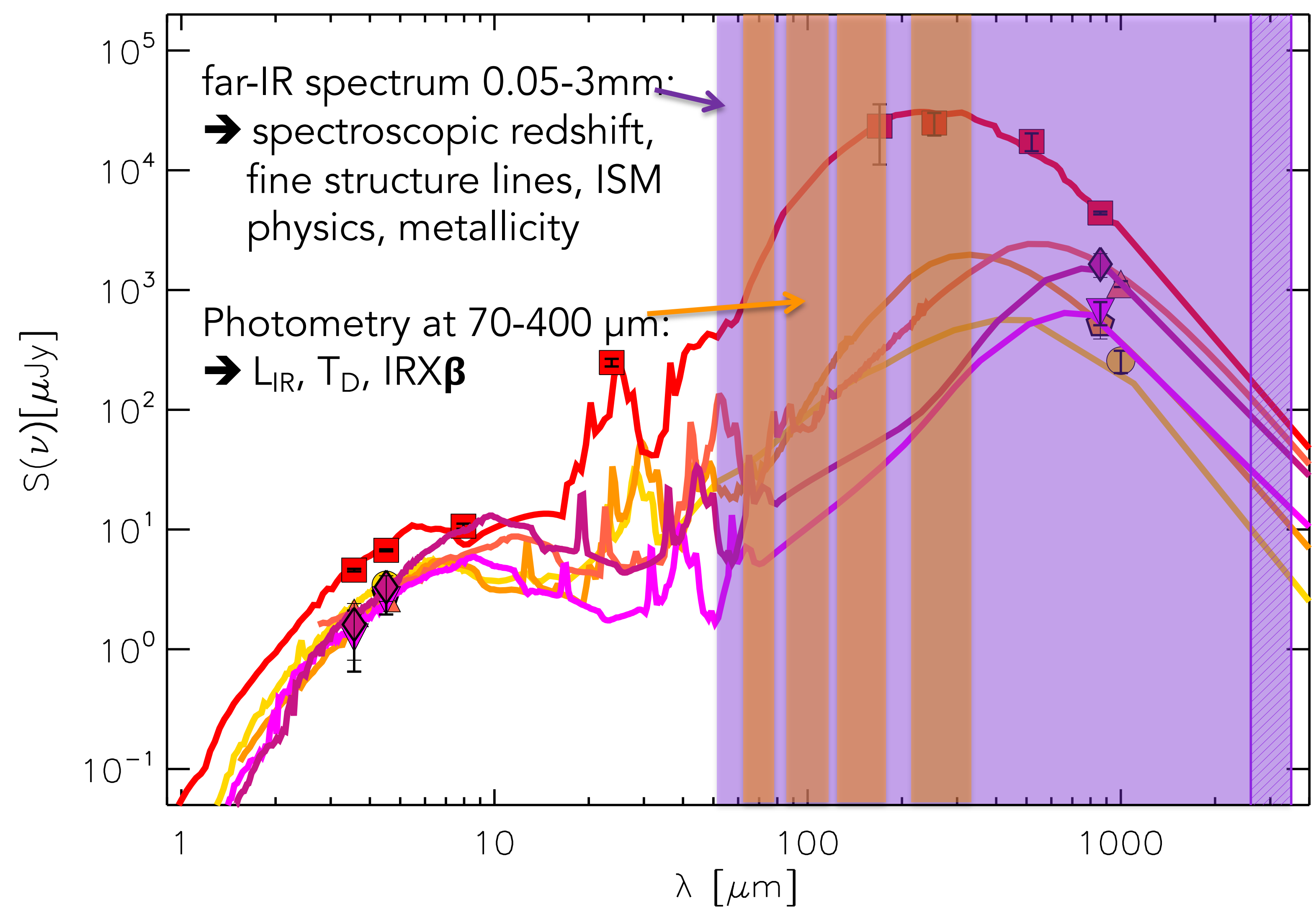
(Credit : JAXA / Nagoya University)



➔ Need to reveal how galaxies have formed and evolved in the history of universe from an unbiased view unaffected by dust obscuration

Census of massive dusty galaxies in the very early Universe (are they the progenitors of nowadays ellipticals?), understand how they did form, study their main physical properties, search for sold grains and metals, …

Need for:
Deep and wide-band far-IR photometric capability
Sensitive far-IR spectrometry



Millimetron will reveal and characterise thousands of optically-dark sources

Conclusions

- Herschel measured the SFRD up to z~3 revealing a large fraction of obscured activity at cosmic noon
- ALMA allows us to observe SFRD in more normal galaxies at much higher redshifts, revealing a population of totally obscured sources
- We would need a far-IR facility like Millimetron to study the physics of dusty galaxies at early epoch and make a complete census of the obscured activity