NATIONAL CENTRE FOR NUCLEAR RESEARCH ŚWIERK

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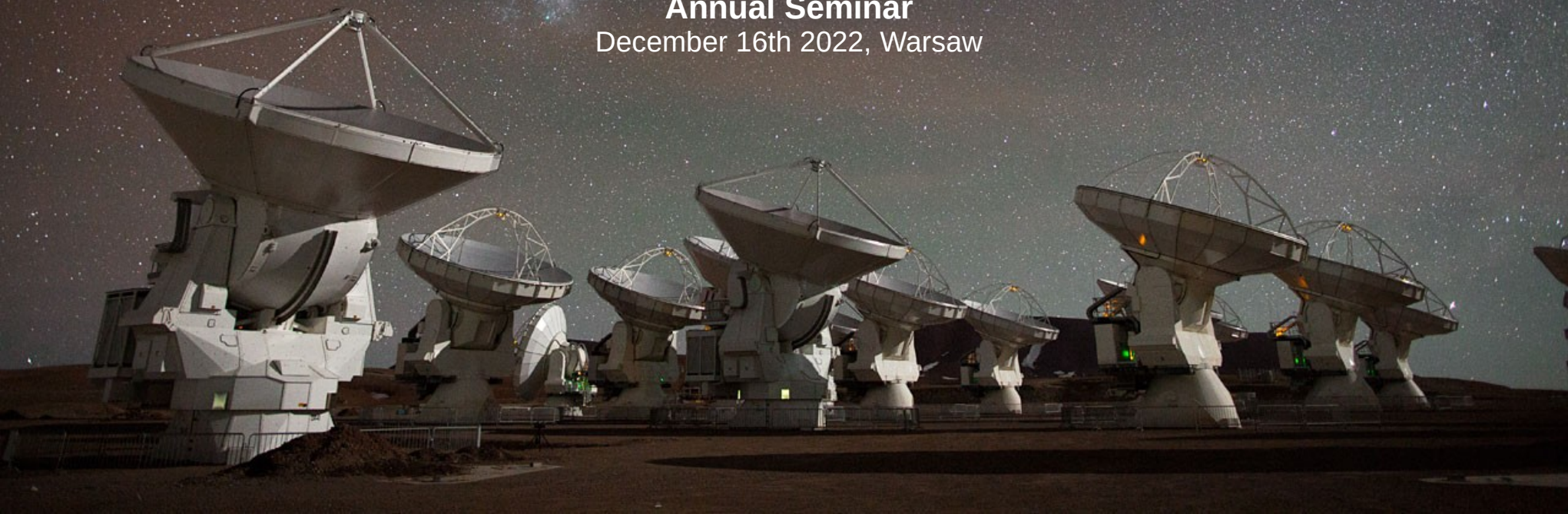
# Shedding light on the dark side of the Universe: a look at primordial galaxies with the *ALPINE* survey

**Michael Romano**[1]

[1]NCBJ, Warsaw, Poland

**Annual Seminar**

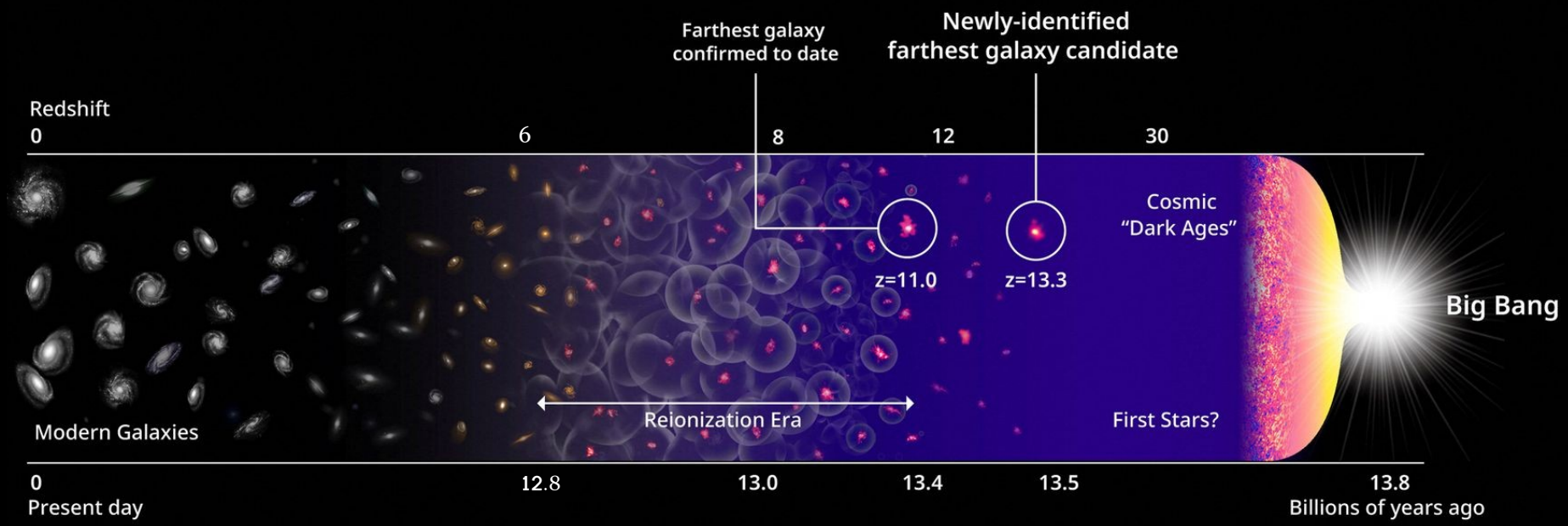
December 16th 2022, Warsaw



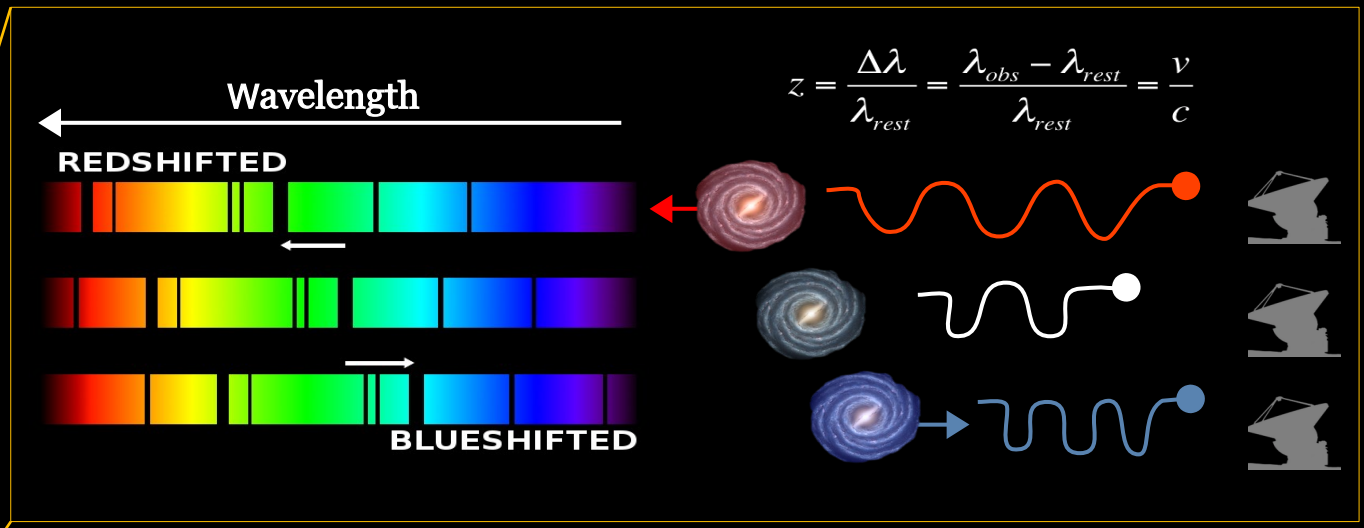
# Outline

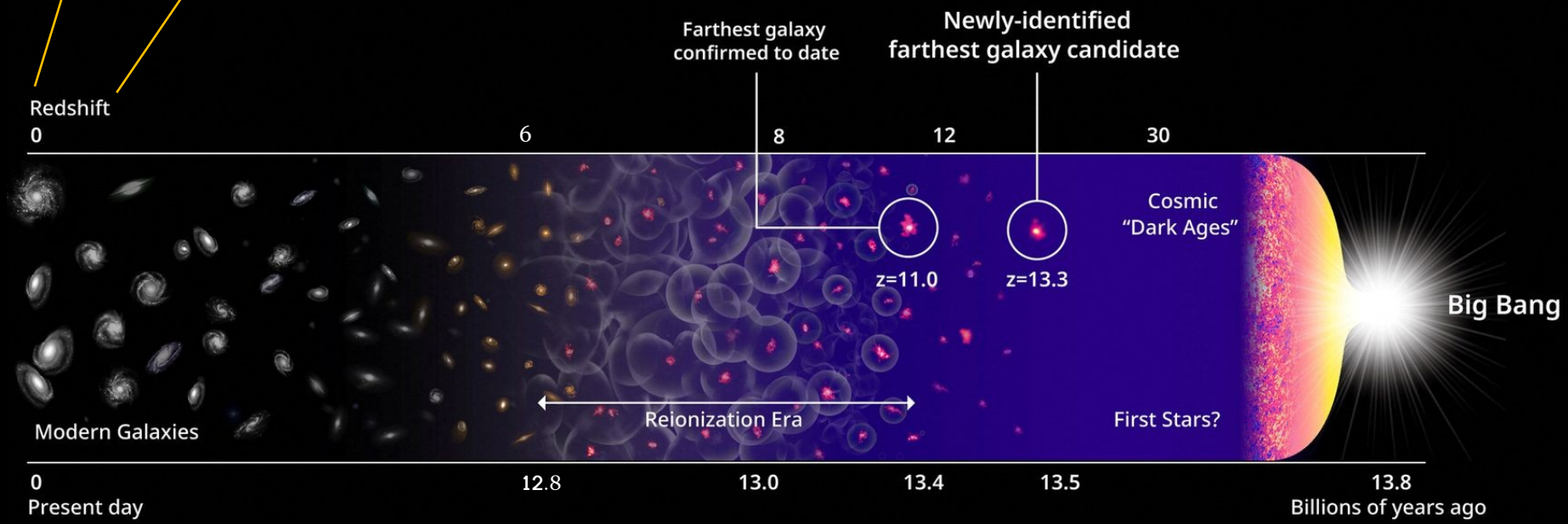
- Scientific context
- The ALPINE survey (an overview)
- Major results from ALPINE
  - Dust content
  - Morpho-kinematic diversity
  - Galaxy mass-assembly
- Future prospects

# The history of the Universe

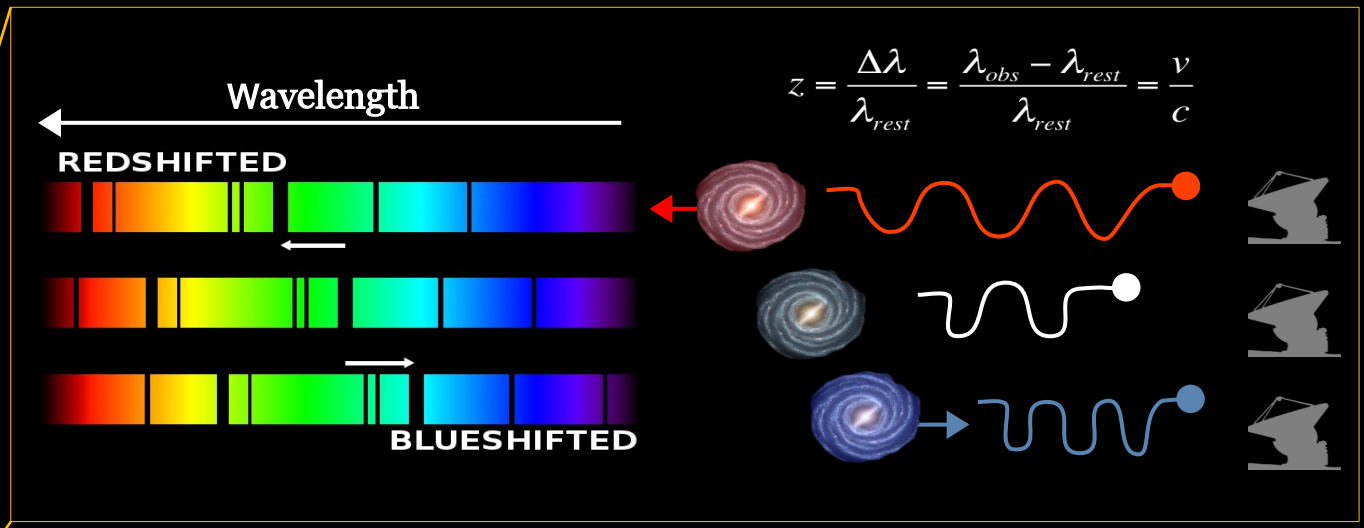


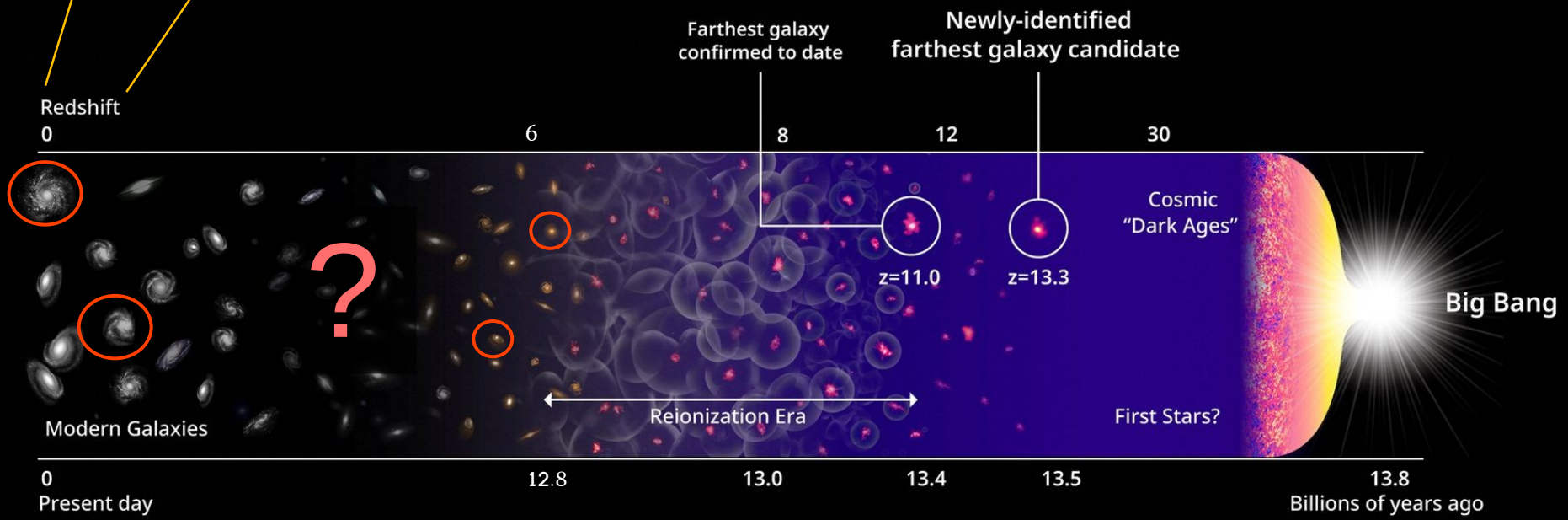
# The history of the Universe



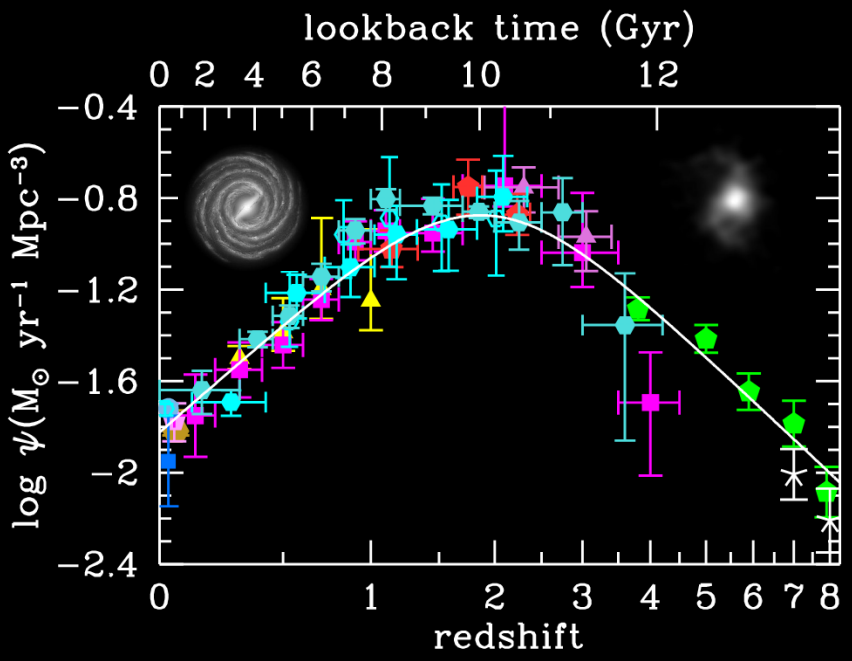



# The history of the Universe



# Star-formation history of the Universe

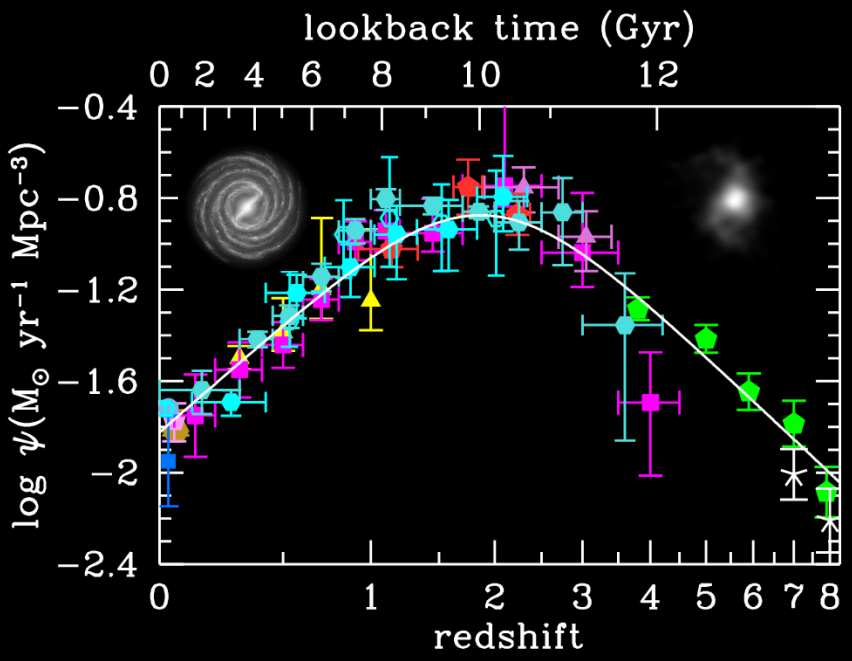



Madau & DIckinson 2014, ARA&A, 52, 415

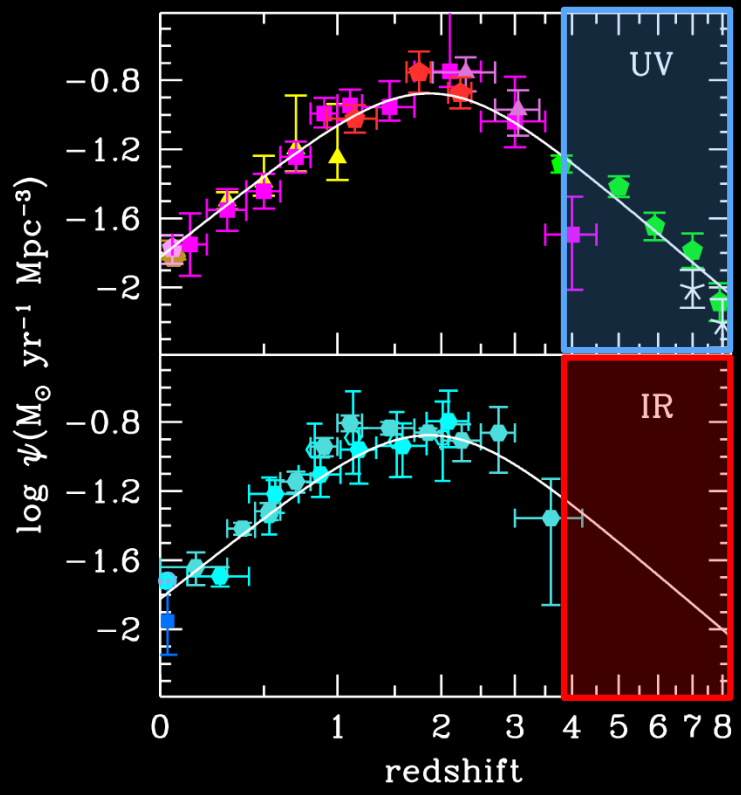
# Star-formation history of the Universe

Data at z>4 are almost exclusively based on UV measurements

IR observations are needed




Madau & DIckinson 2014, ARA&A, 52, 415



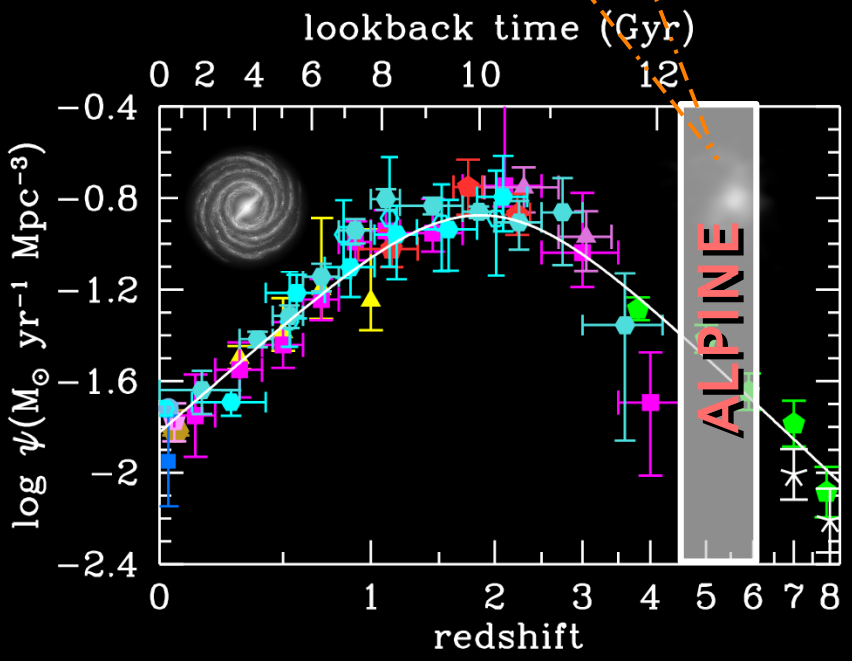

Young stars

Dust

# Star-formation history of the Universe

**What is the amount of dust-obscured star formation at z>4?**

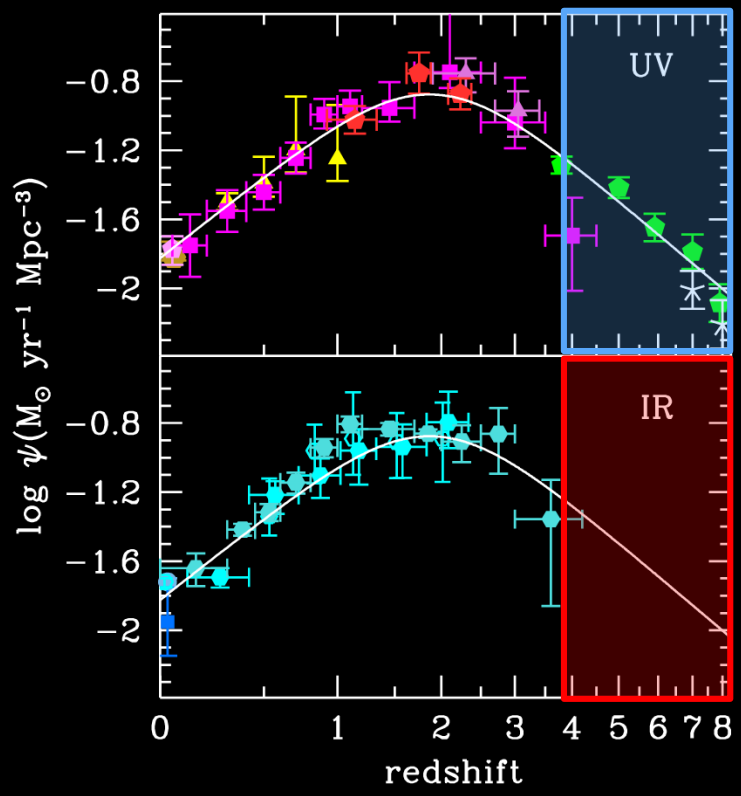
**Which are the processes molding the shape of the cosmic star-formation rate density (SFRD)?**




Madau & DIckinson 2014, ARA&A, 52, 415

**Data at z>4 are almost exclusively based on UV measurements**

**IR observations are needed**



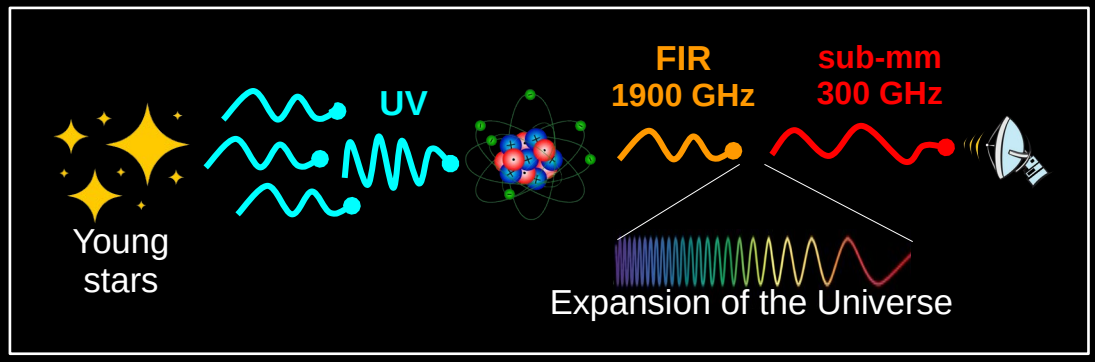

**Young stars**

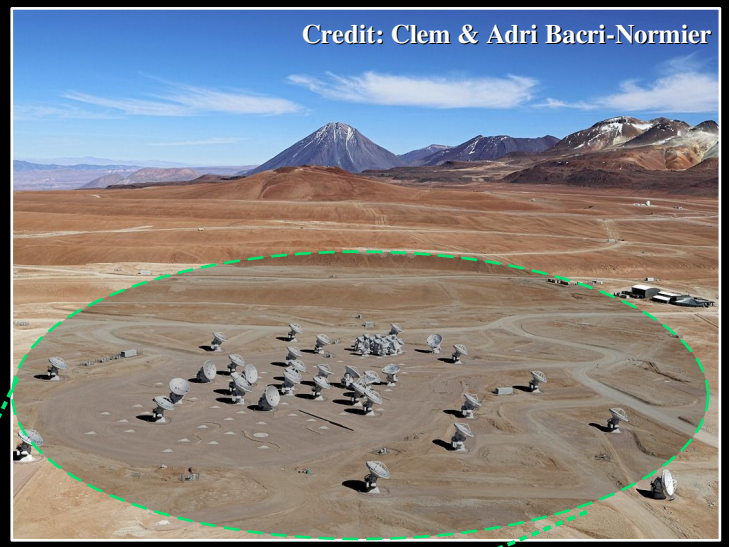
**Dust**

# ALPINE: the ALMA Large Program to INvestigate [CII] at Early times

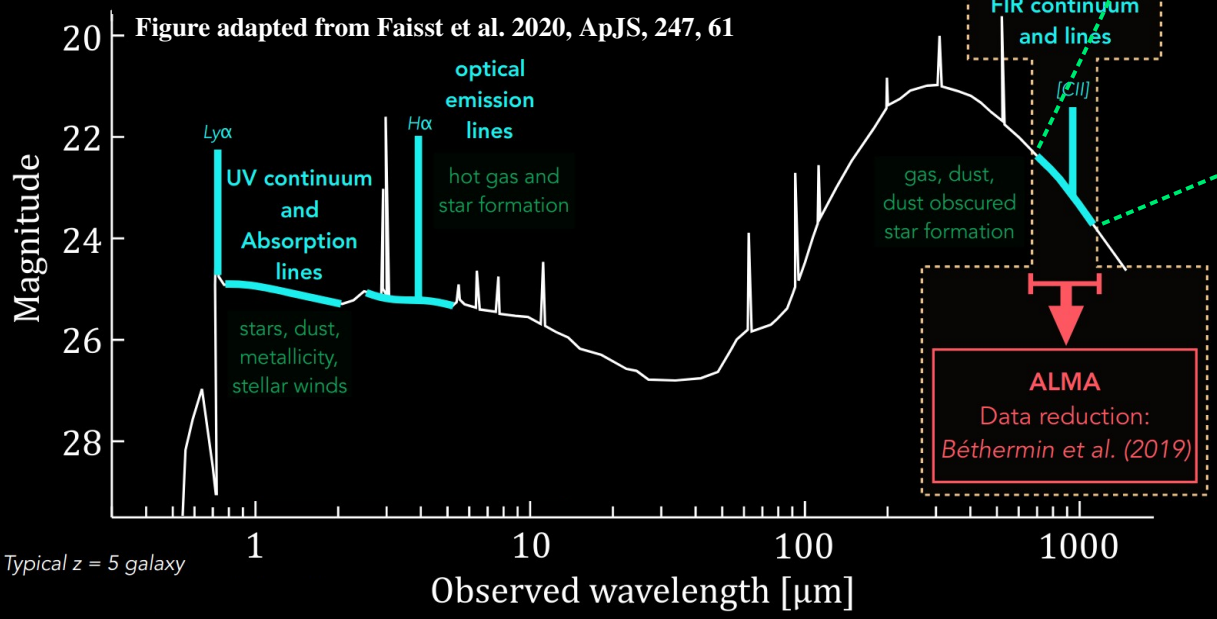
- PI: Olivier Le Fèvre
- 70h of **[CII] + continuum observations** in ALMA Band 7 (275 – 373 GHz)
- **118 normal star-forming galaxies** (SFGs) drawn from COSMOS and E-CDFS
- $4.4 < z_{spec} < 5.9$ with VUDS and DEIMOS 10K
- average galaxy population SFR > 10 $M_\odot$/yr & $9 < \log(M_*/M_\odot) < 11$

# ALPINE: the ALMA Large Program to INvestigate [CII] at Early times



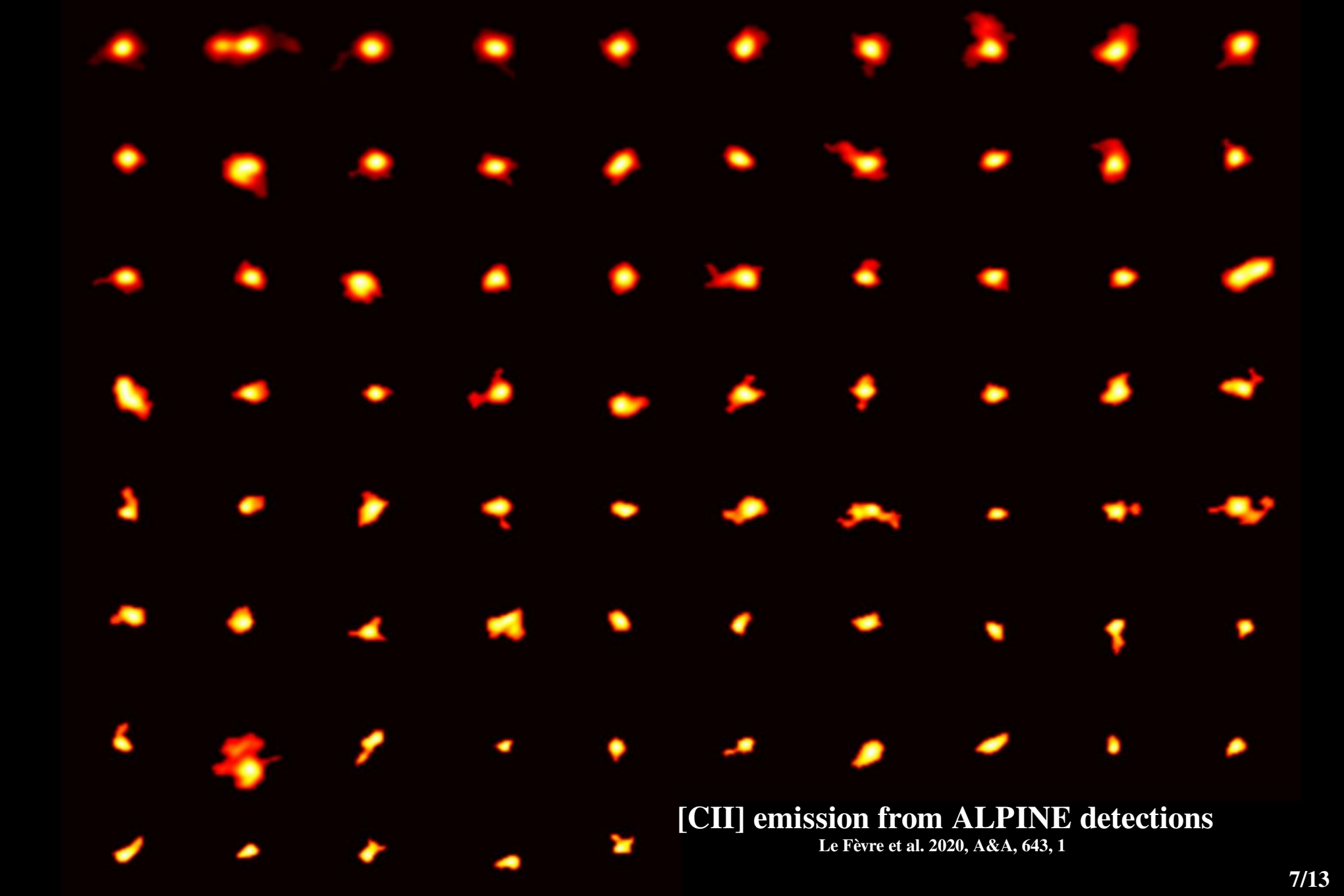




Layout of Current Data Products for *ALPINE* Galaxies



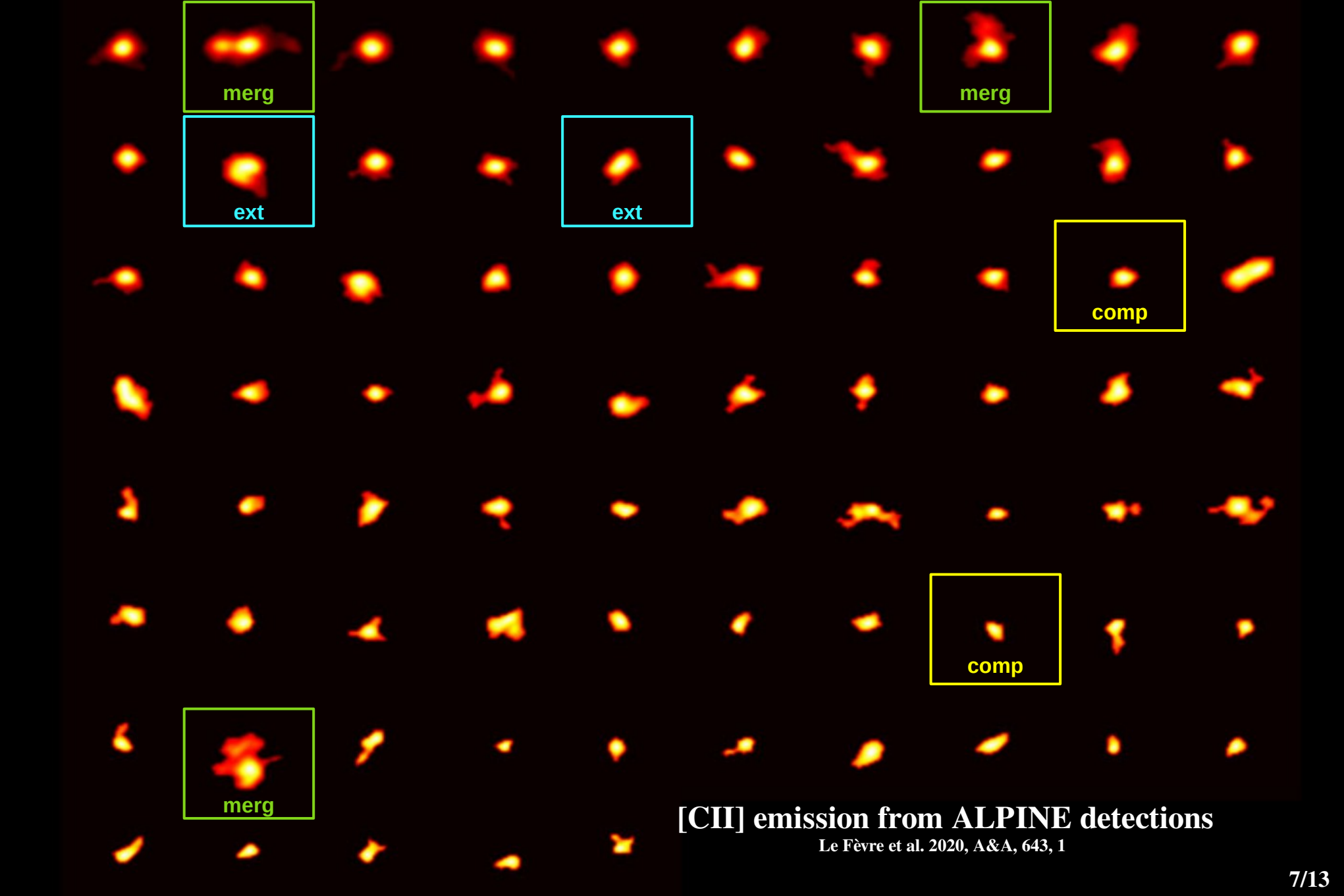

**[CII] line @ 158 μm rest-frame:**

- one of the strongest FIR line;
- mainly excited in photo-dissociation regions (PDRs);
- poorly affected by dust;
- near the peak of FIR emission



**[CII] emission from ALPINE detections**

Le Fèvre et al. 2020, A&A, 643, 1




# [CII] emission from ALPINE detections

Le Fèvre et al. 2020, A&A, 643, 1

Survey strategy
(Le Fevre et al)

Data processing
(Bethermin et al)

Multiwavelength data
(Faisst et al)

Outflows and environment
(Ginolfi et al)

Triple merger
(Jones et al)

Optically-obscured galaxy
**(Romano et al)**

Size and halos
(Fujimoto et al)

[CII]-SFR relation
(Schaerer et al)

Dust attenuation
(Fudamoto et al)

Molecular gas budget
(Dessauges-Zavadsky et al)

Lyα-[CII] offset
(Cassata et al)

Circumgalactic medium pollution
(Ginolfi et al)

Continuum luminosity function
(Gruppioni et al)

[CII] luminosity function
(Yan et al)

Serendipitous luminosity function
(Loiacono et al)

Obscured SFRD
(Khusanova et al)

Dust mass budget
(Pozzi et al)

Galaxy mass-assembly
**(Romano et al)**

Kinematic diversity
(Jones et al)

[OII]-SFR relation
(Vanderhoof et al)

Dust attenuation curves
(Boquien et al)

[CII]-undetected galaxies
**(Romano et al)**

Major results from ALPINE
(Faisst et al)

Star formation history & dust
(Burgarella et al)

Infrared-radio correlation
(Shen et al)

Double stellar population
(Barchiesi et al)

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**Under NCN SONATA BIS grant *DINGLE***

**UMO-2020/38/E/ST9/00077**
**(PI: Dr. A. Nanni)**

**Click the link if you want to know more about ALPINE:**

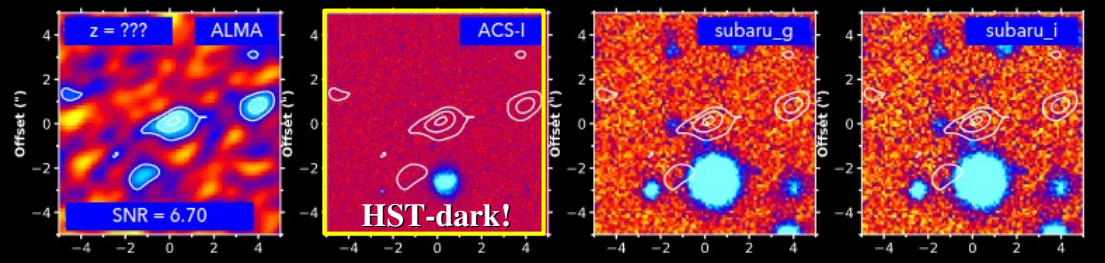
**https://cesam.lam.fr/a2c2s/**

Year

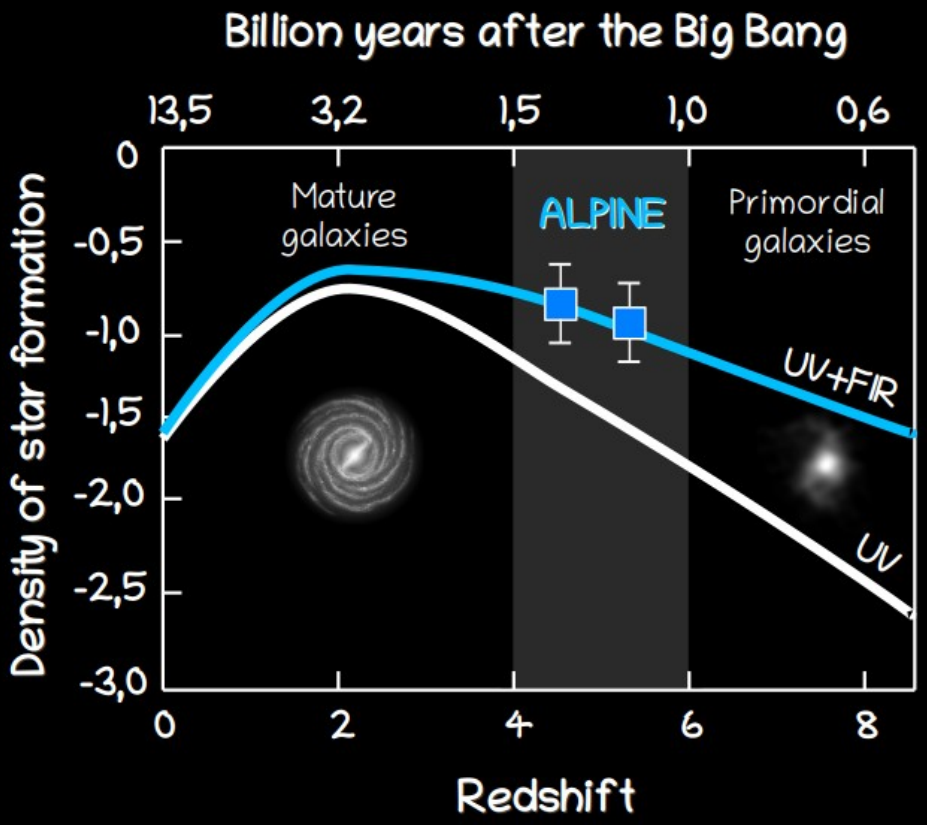
2020 2021 2022 2023

# Results: more dust than expected!

$$SFR_{TOT} = SFR_{UV} + SFR_{FIR}$$

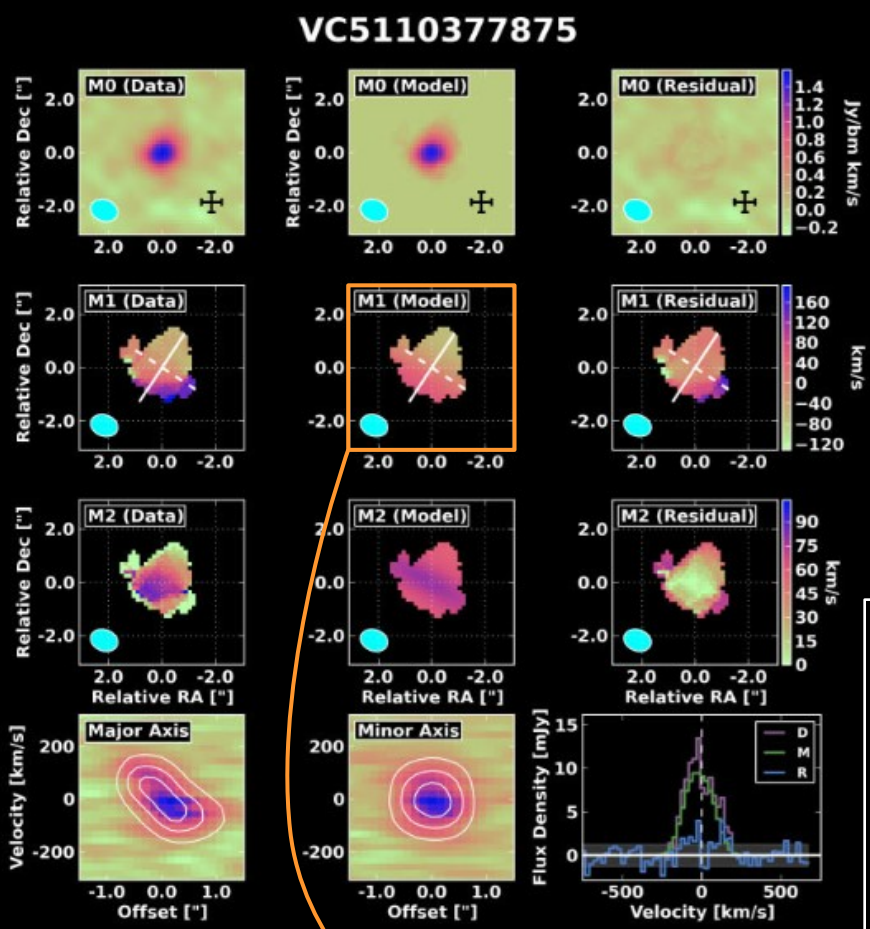



Gruppioni et al. 2020, A&A, 643, 8

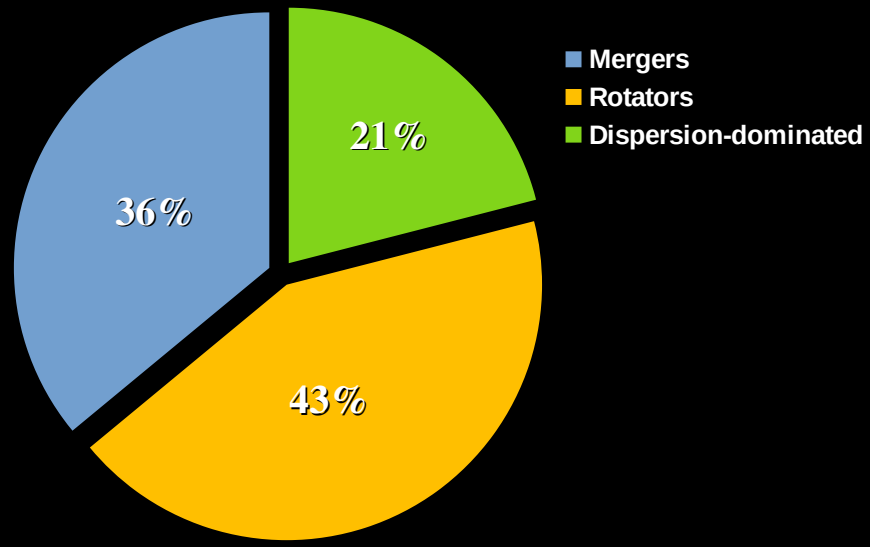


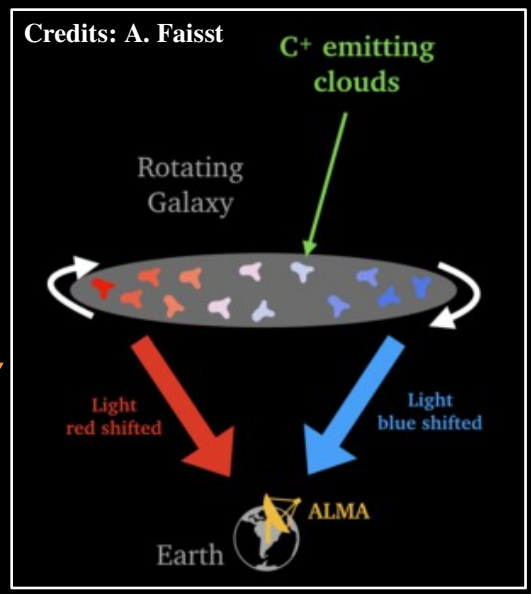

- Discovery of optically-dark galaxies missed by previous UV/optical surveys
- HST-dark galaxies contribute ~17% to the total SFRD at z>3
- SFRD almost constant between redshift 2 and 6
- Large difference between ALPINE and UV/optical data, reaching a factor of 10 at z~6
- Need to revise galaxy formation models and simulations which are not able to predict such a high amount of SFR in dusty galaxies at high-z

# Results: morpho-kinematic diversity of primordial galaxies



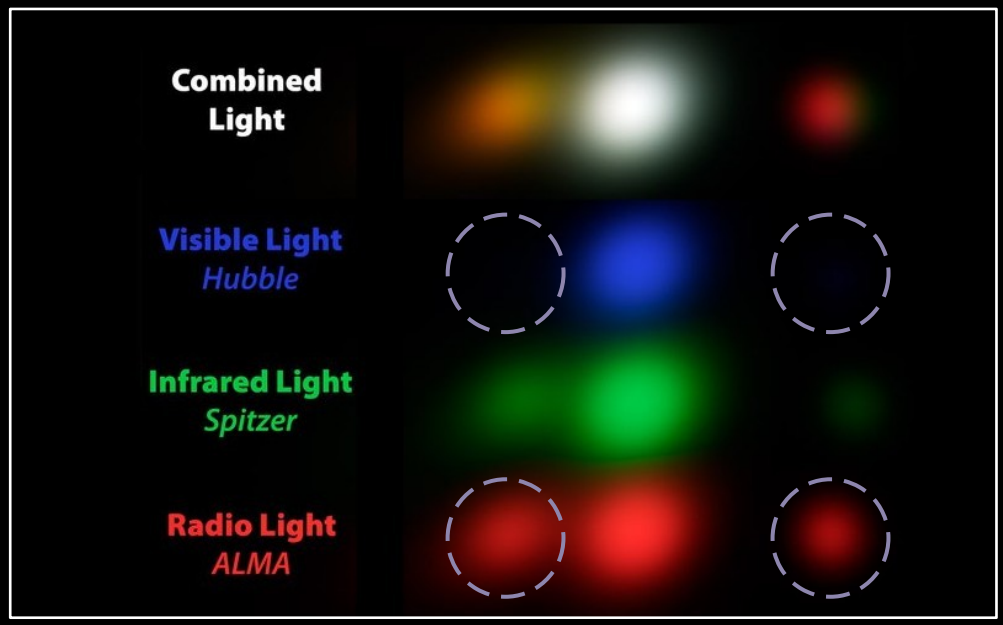

Jones et al. 2021, MNRAS, 507, 3540



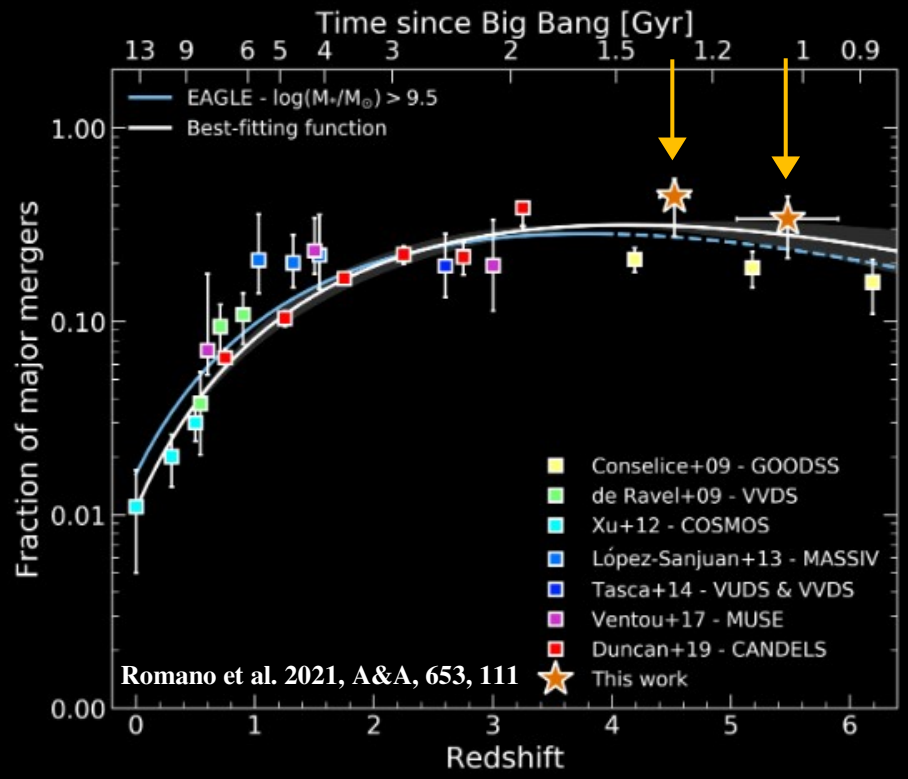




- Evidence of morpho-kinematic diversity in primordial galaxies, at only 1-1.5 Gyr after the Big Bang
- High number of mergers as compared to local Universe
- More rotating galaxies than expected

# **Results:** mergers as a mechanism of galaxy mass-assembly



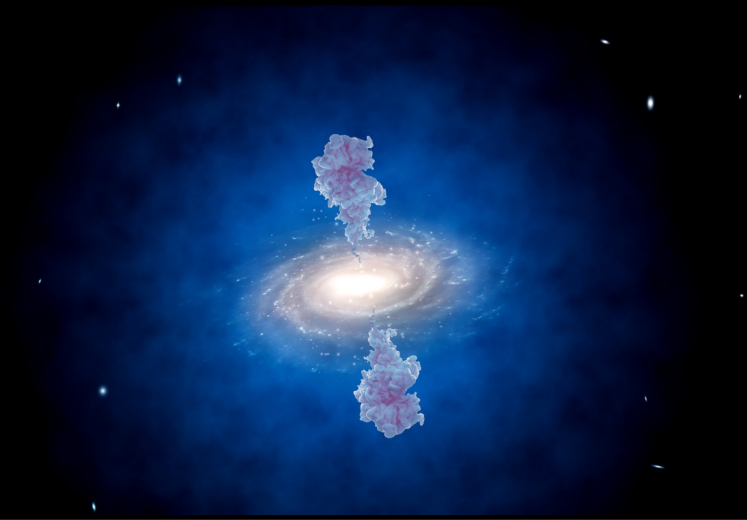

Credits: G. Jones, A. Faisst; ALMA; NASA/Stsci; Jpl-Caltech/Ipac




- A large fraction (~40%) of major mergers is found in ALPINE (two times higher than at z~2 by using optical data)
- Hints that optical survey could miss dust-obscured meerger components, which are bright in the sub-mm
- The contribution of major mergers to the cosmic star-formation rate density varies from 5% to 30%, depending on the assumed merger timescale

# Coming soon...

Further constraints on the baryon cycle and IGM enrichment of high-z galaxies by studying their analogs in the local universe, e.g. dwarf low-metallicity galaxies



*Herschel* Space Observatory

*Astronomy & Astrophysics* manuscript no. output
November 24, 2022


## Star-formation driven outflows in local dwarf galaxies as revealed from [CII] observations by *Herschel*⋆

M. Romano⋆⋆[1], A. Nanni[1], and et al.

[1] National Centre for Nuclear Research, ul. Pasteura 7, 02-093 Warsaw, Poland

Romano et al. in prep.

# Coming soon...

## APPLICATION FOR OBSERVING TIME

**Principal Investigator:** Michael Romano

**ID:** *110.2417* · **Type:** Normal · **Cycle:** P110 · **Status:** Valid

**TITLE:** **Probing the dust and metal content of primordial star-forming galaxies through rest-frame UV-to-FIR spectroscopy**

Scheduling and Feasibility Comments (per run)

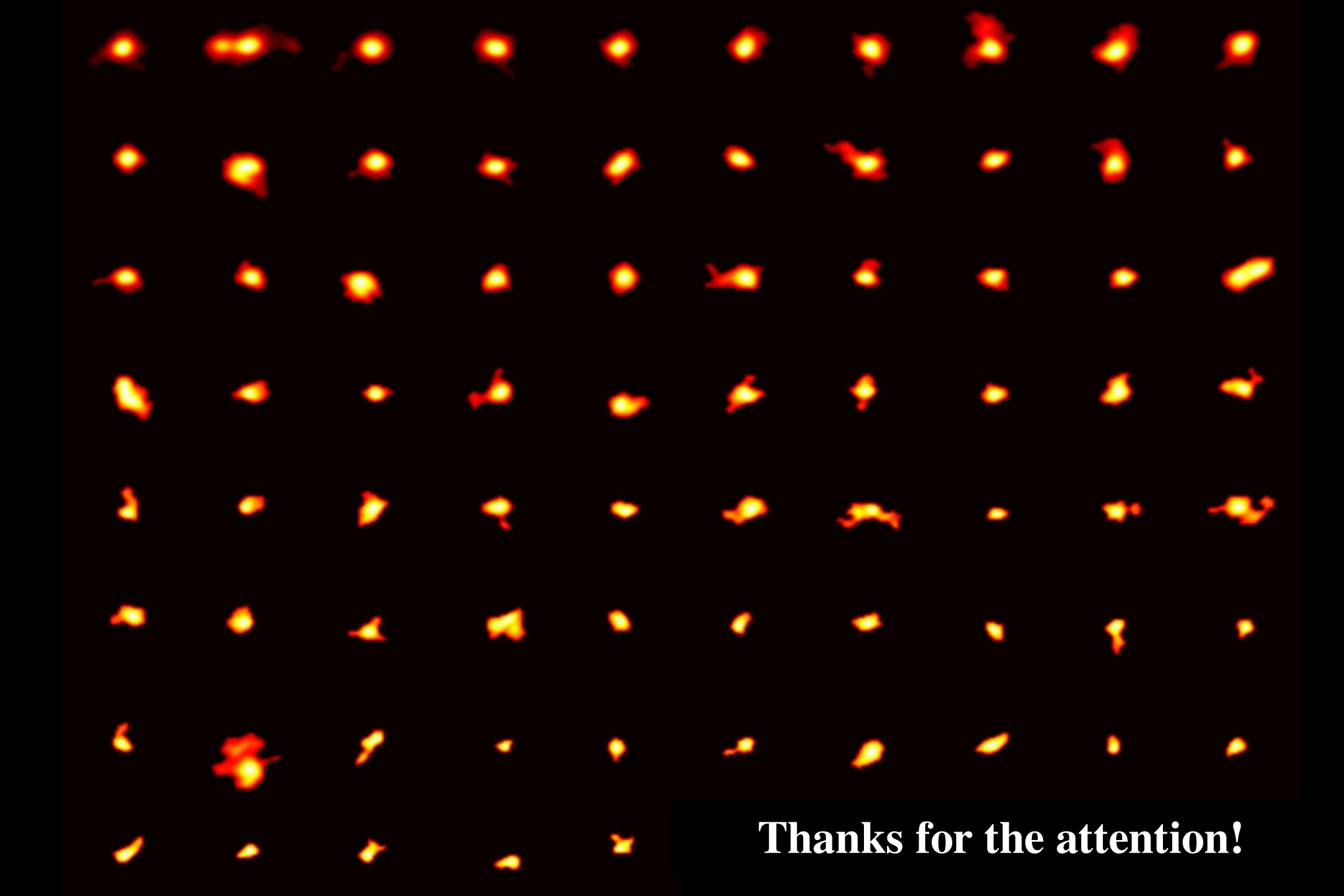
| Run | Instrument | Obs. Mode | Rank Class | From - To Noon | Feasibility Comment | Scheduling Comment | Final Outcome |
|---|---|---|---|---|---|---|---|
| Run A | KMOS | SM | B | - | | In period 110 the number of requested nights on UT1 exceeded the available time by a factor of 5.0. Ranking: This run has been ranked in the 2nd quartile of all runs at this telescope (250) and in the 2nd quartile of all non-triaged runs requested in this period (1562). | APPROVED |

[OII] observations in a sample of ~90 SFGs at z~4.5 with the K-band Multi Object Spectrograph (KMOS) at the Very Large Telescope at Cerro Paranal (Chile):

**Approved in ESO Cycle 110 (110.241; PI: M. Romano) for a total of 22 hours of observation.**

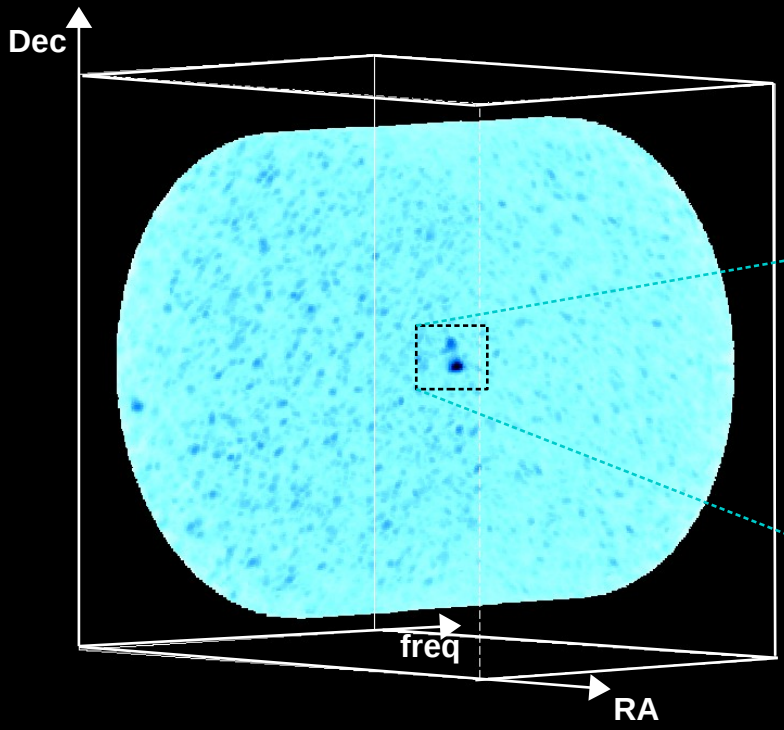
**Main objectives:**

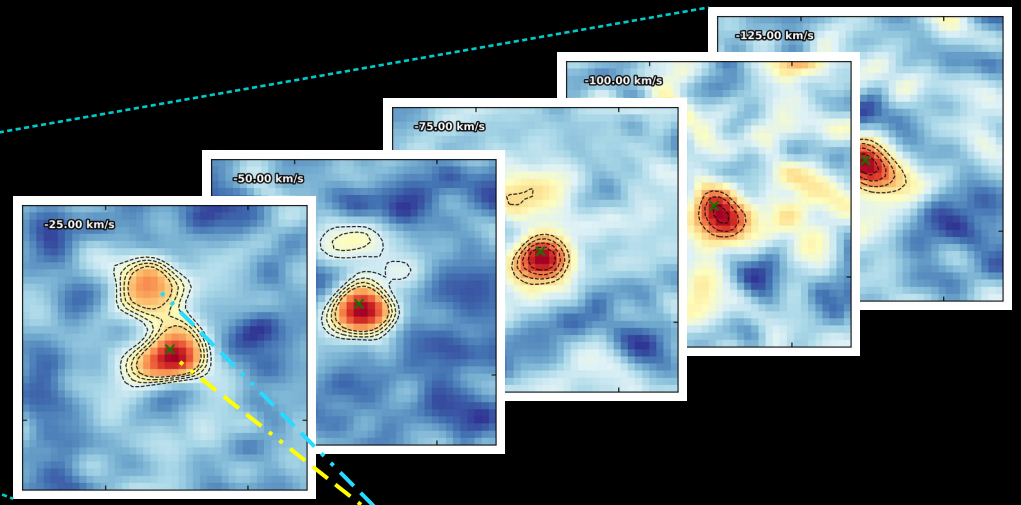
- Star formation, dust attenuation, & metal enrichment
- Systemic redshift
- Environment

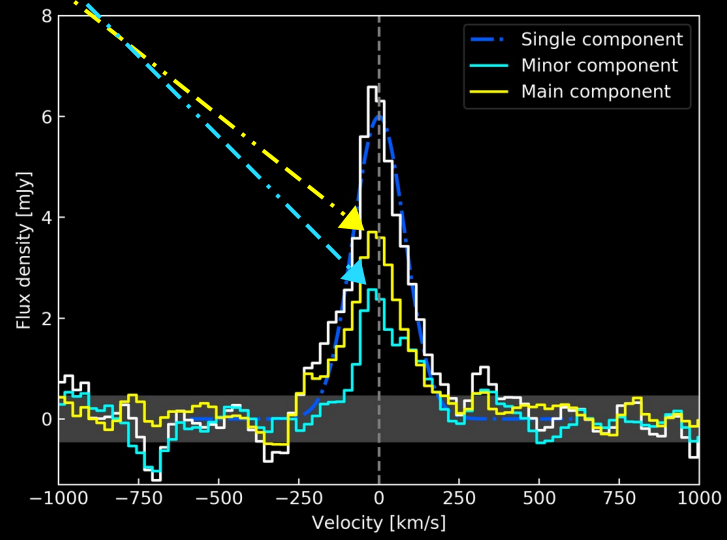

Thanks for the attention!

# EXTRAS

# ALPINE: how data look like



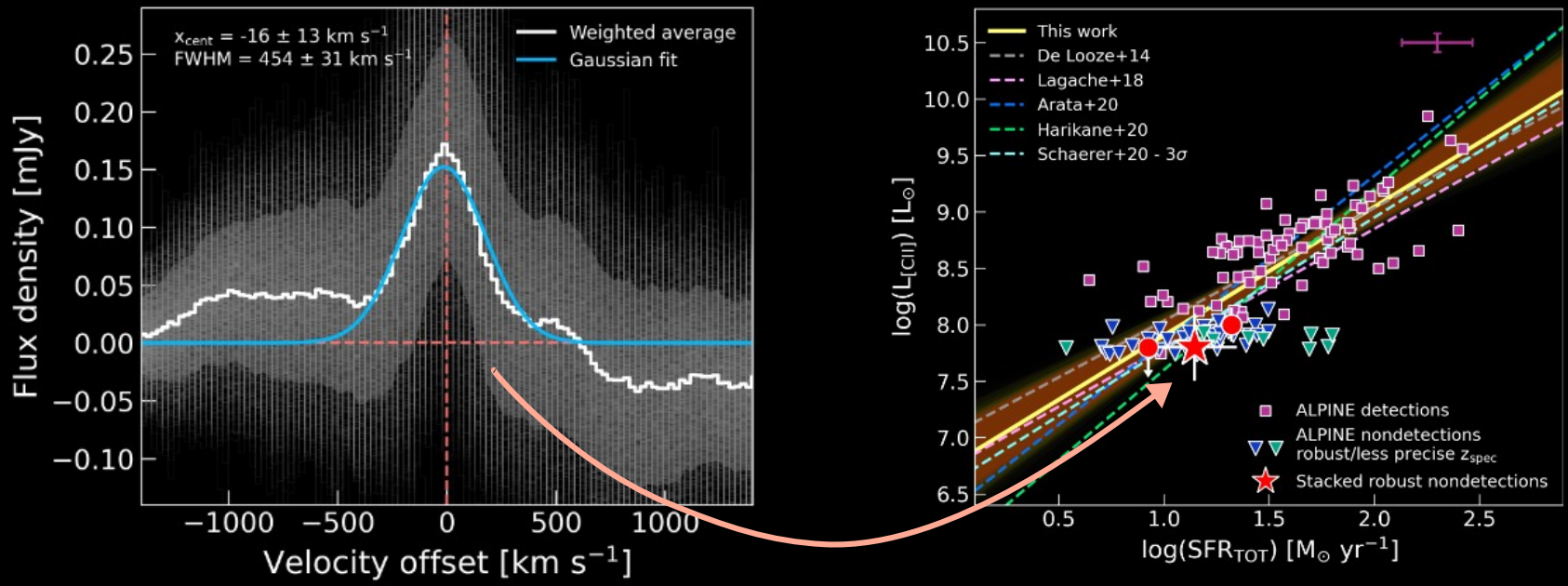

**118 ALPINE targets**

**75 [CII] detections (S/N > 3.5)**

**43 [CII] non-detections**

# ALPINE: [CII] as a tracer of star formation in the distant Universe

$$\mathbf{SFR_{TOT} = SFR_{[CII]}}$$




$$\log(L_{[CII]}/L_\odot) = a + b \times \log(\mathrm{SFR}/M_\odot\ \mathrm{yr}^{-1})$$

| Literature (1) | Sample (2) | Redshift (3) | $a$ (4) | $b$ (5) |
|---|---|---|---|---|
| De Looze et al. (2014) | HII/starburst | <0.5 | 7.06 ± 0.33 | 1.00 ± 0.04 |
| Lagache et al. (2018) | G.A.S. + CLOUDY | 4 – 6 | 6.75 ± 0.07 | 1.05 ± 0.07 |
| Arata et al. (2020) | GADGET-3 + ART$^2$ | >6 | 6.38 | 1.47 |
| Harikane et al. (2020) | LBGs/SMGs | 6 – 9 | 6.00 | 1.60 |
| Schaerer et al. (2020) | ALPINE (3$\sigma$ limits) | 4 – 6 | 6.61 ± 0.20 | 1.17 ± 0.12 |
| This work | ALPINE det + stacked non-det | 4 – 6 | 6.76 ± 0.17 | 1.14 ± 0.11 |