Low-resolution spectroscopic surveys with CONCERTO* at APEX

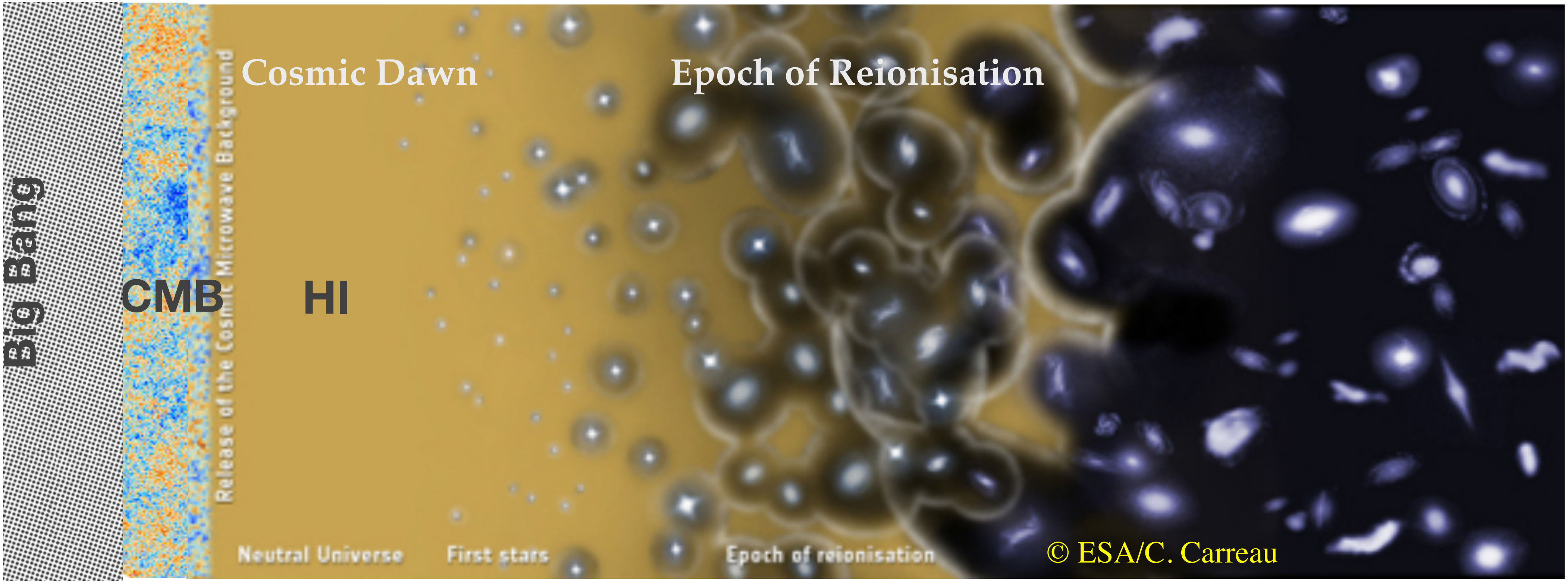
G. Lagache

Laboratoire d'Astrophysique de Marseille

* pronounce CONnnnChhhERTO + CH'TI

Cosmic dawn and the Epoch of Reionization

Redshifts 1200 20 10 8 6 3 0

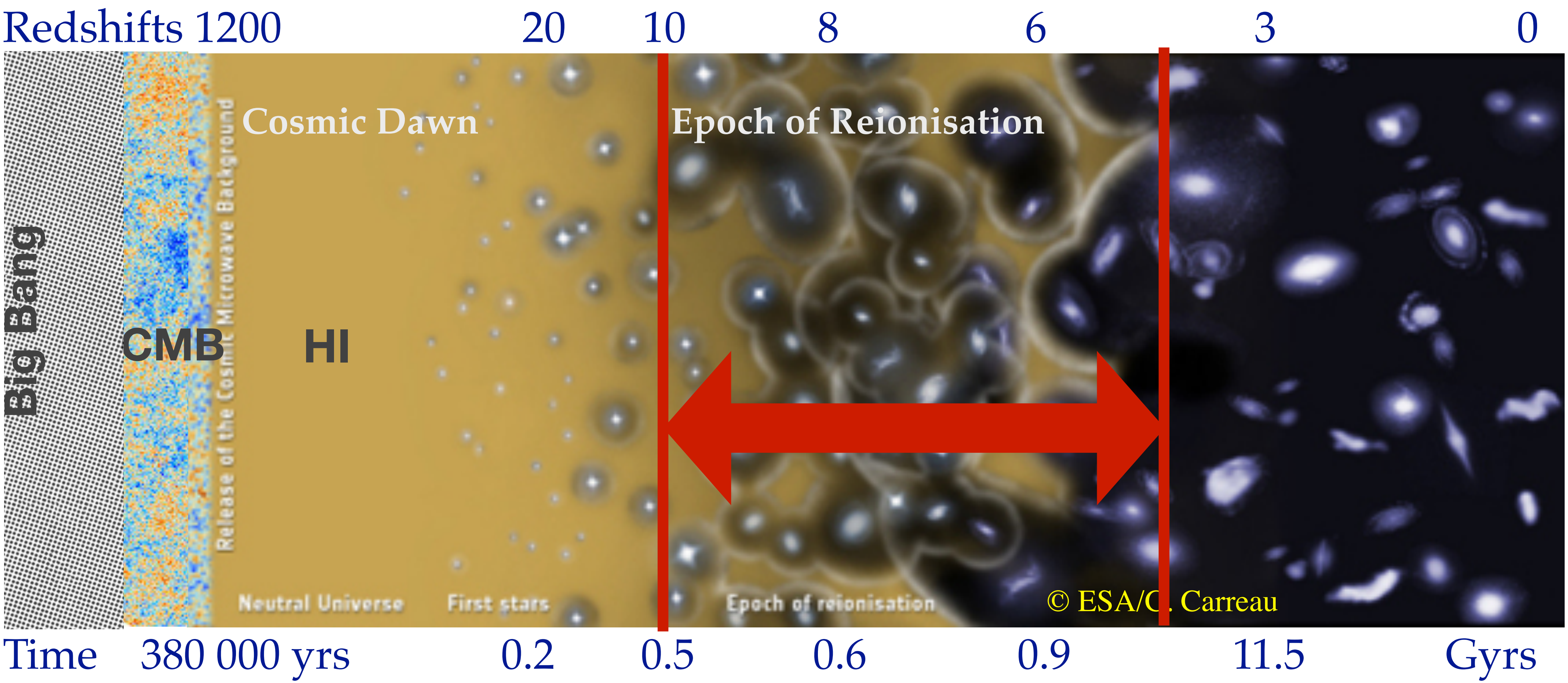


Time 380 000 yrs 0.2 0.5 0.6 0.9 11.5 Gyrs

From recombination to reionisation

… a very brief history of the Universe

Cosmic dawn and the Epoch of Reionization



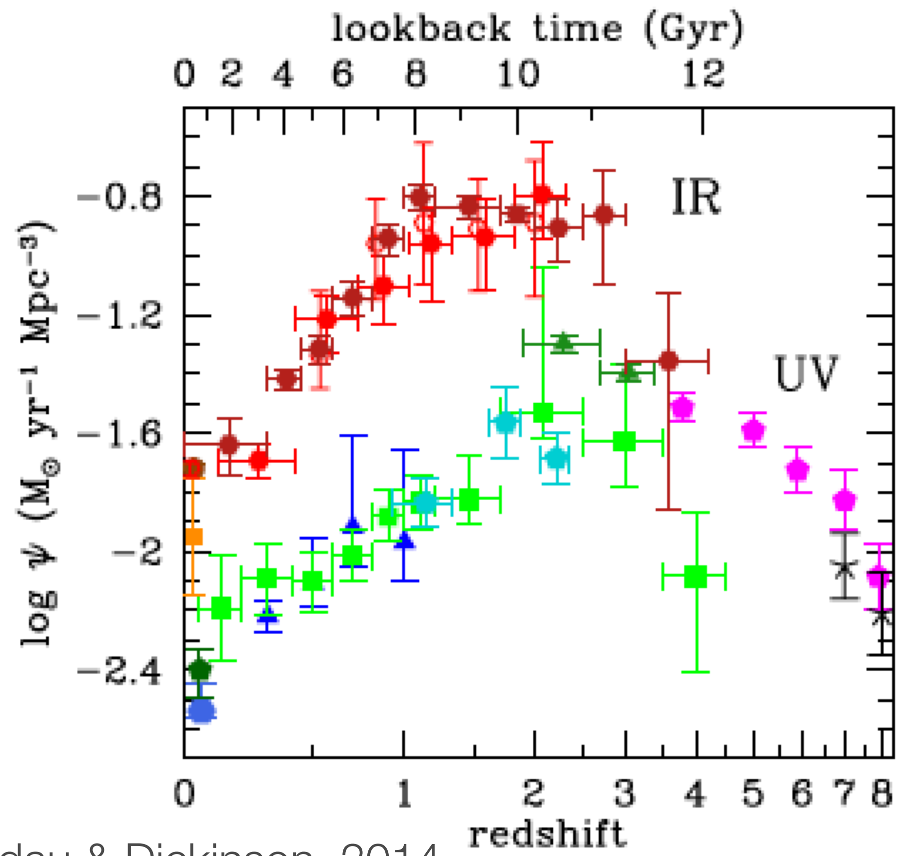
From recombination to reionisation

… a very brief history of the Universe

Dusty star formation at high redshift

- Redshifts z~4-10 :
  - An important epoch when the ISM in typical galaxies matures from a nearly primordial, dust-free state at z~8 to the dust- and metallicity-enriched state observed at z~4.

Cosmic Star Formation Rate Density



Madau & Dickinson, 2014

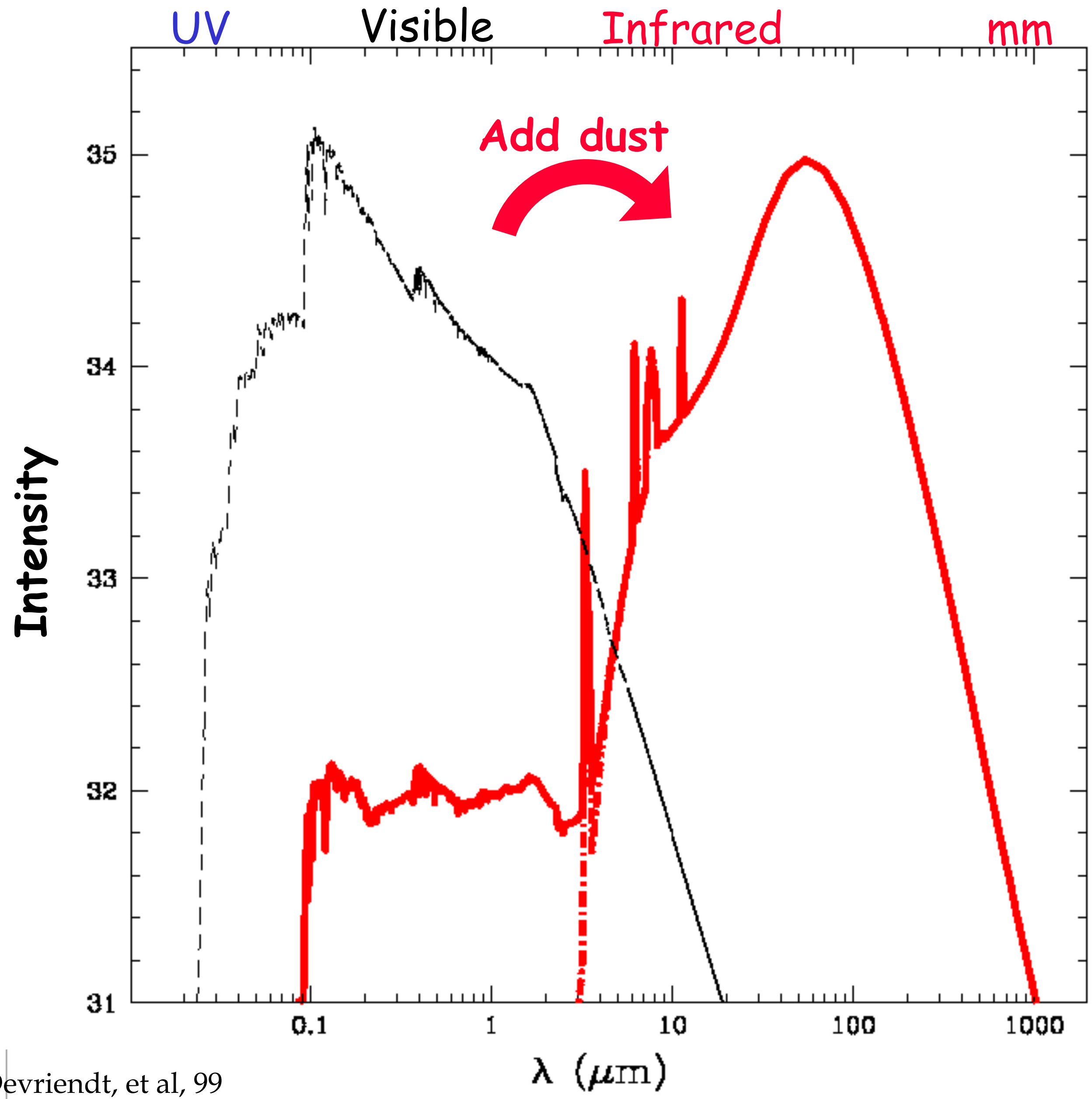
« IR » = 1- 1000 µm / 300 THz – 300 GHz

$L_{IR} > 10^{11}$ Lsol

$SFR_{IR} > 10$ Msol/yr

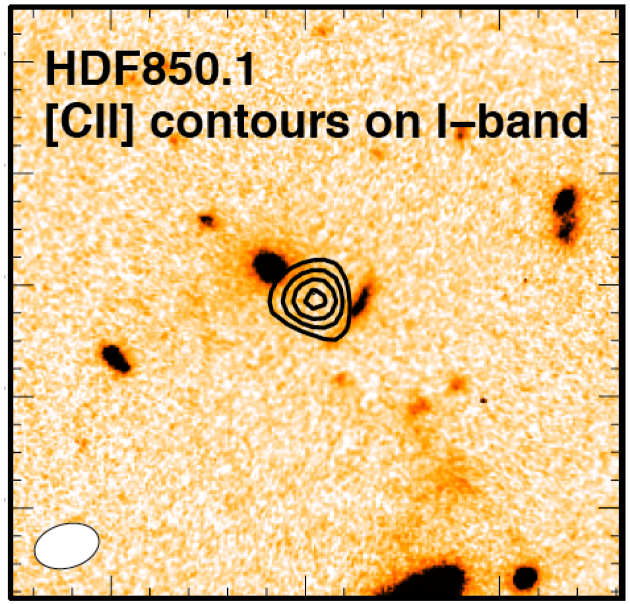
Observing the dusty star formation at z>4

You need (sub-)mm experiments !



Devriendt, et al, 99

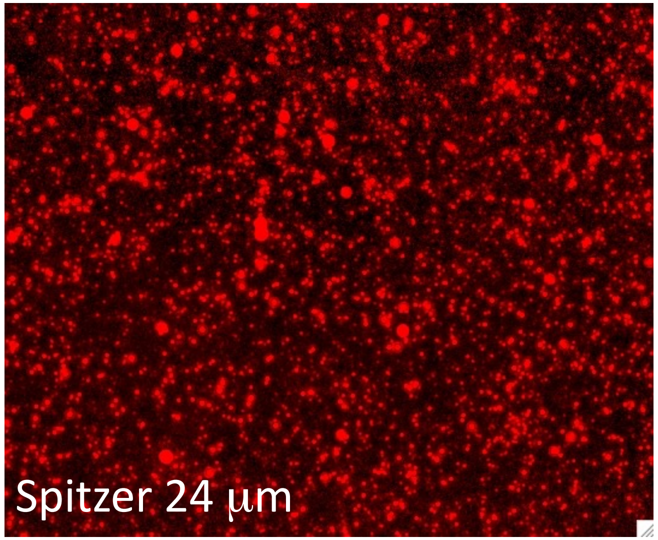
Discovered in 1998
(SCUBA surveys)
Redshift z=5.2 in 2012!

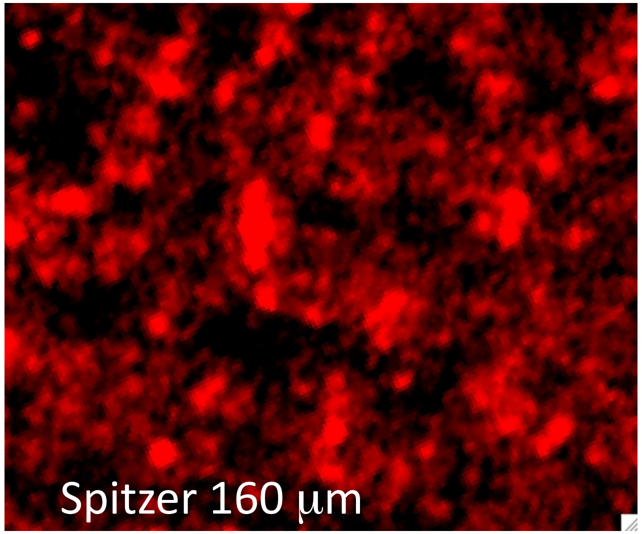


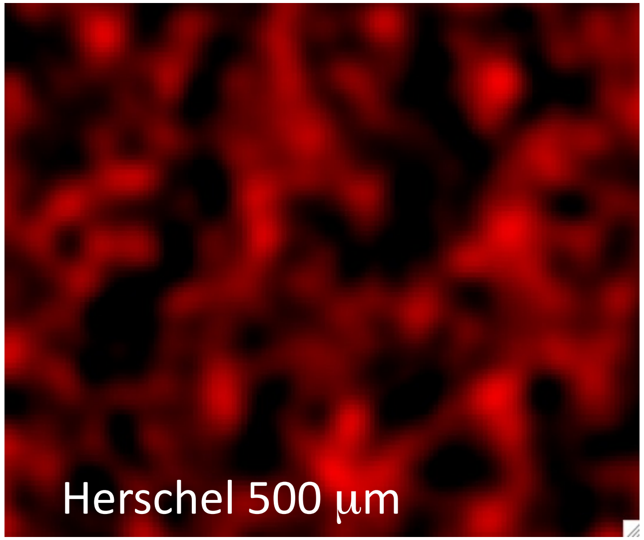
Walter et al. 2012

Observing the dusty data formation at z>4

In the (sub-)millimeter, galaxies are so faint and numerous, compared to the angular resolution achievable, that confusion plagues observations substantially.







Individual galaxies

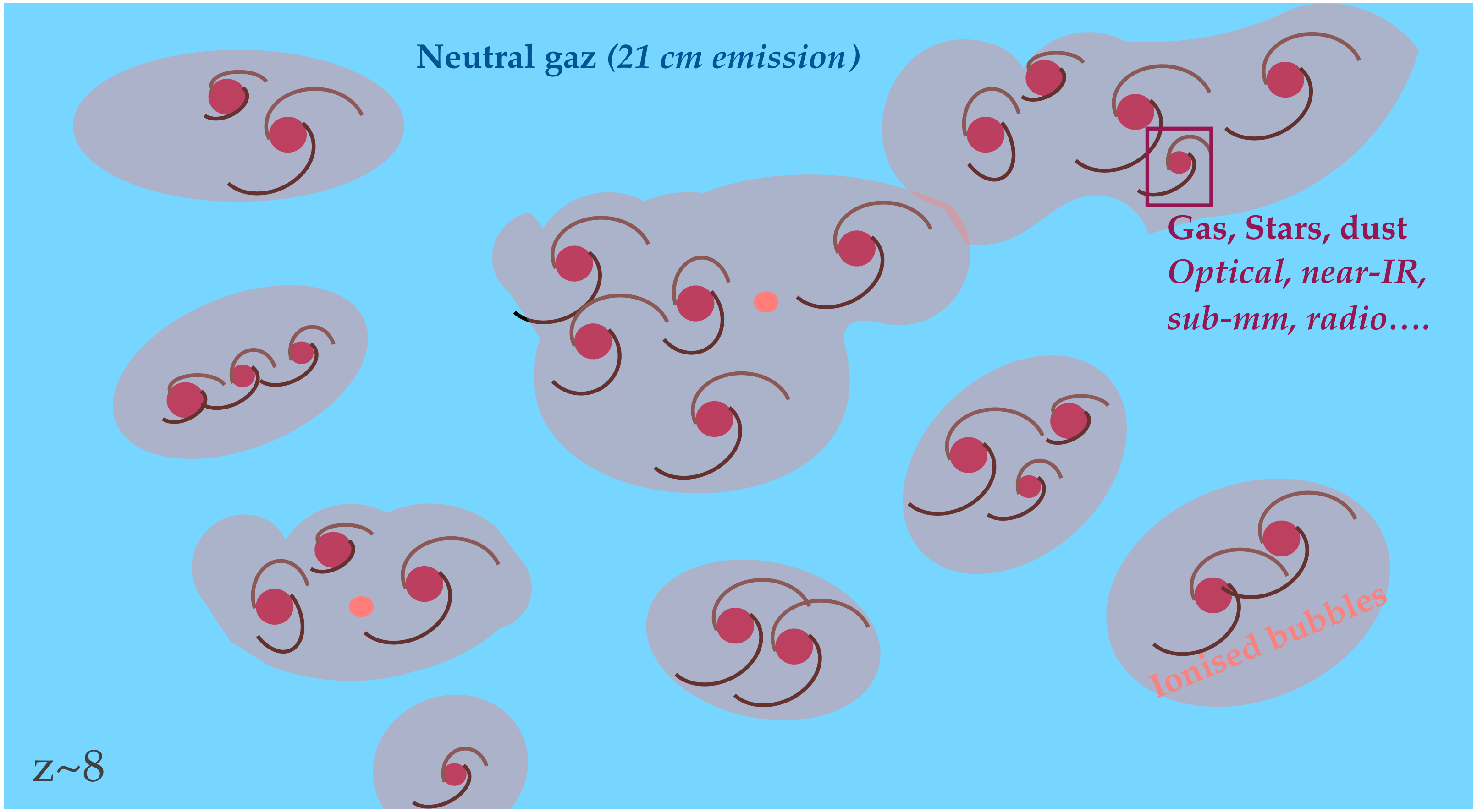
SPIRE/Herschel @ 500 microns:	35”
Laboca/APEX @ 850 microns:	18”
NIKA2/30m @ 1.2 mm:	11”
HST visible:	0.1”

CIB is resolved at ~6%

Intensity Mapping

(CIB fluctuations)

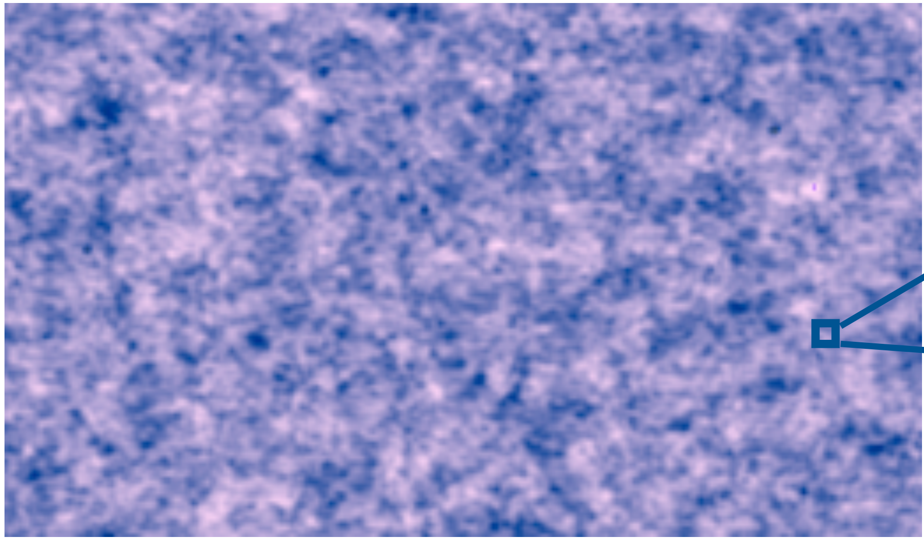
Intensity mapping: basic idea



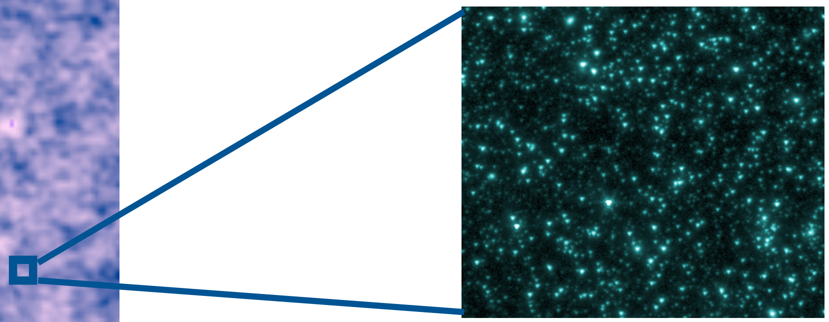
Intensity mapping: basic idea

Measuring the large-scale fluctuations in the emission from a large number of unresolved sources

Intensity mapping: basic idea



Intensity mapping
(confusion-limited surveys)

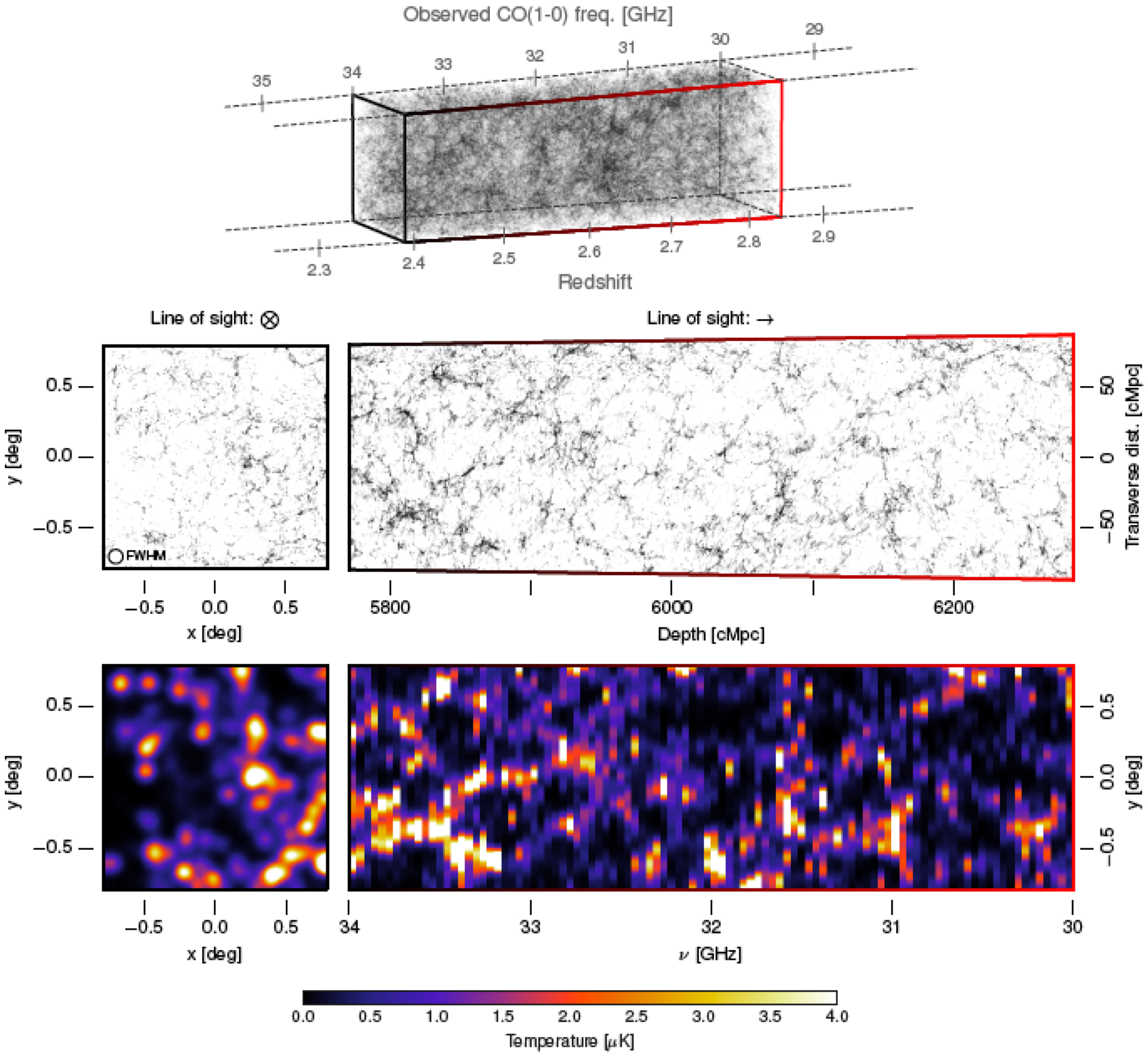


Galaxy survey (HST, Spitzer, JWST, ALMA)

<u>Intensity mapping:</u>

- measure angular fluctuations in the brightness of the sky at a particular frequency
- naturally sensitive to the radiation from faint sources and from the diffuse intergalactic medium
- basic tool : angular power spectrum; intensity fluctuations are used to reconstruct the power spectrum of matter fluctuations

Line intensity mapping (3D)



Li+2015

- Retain redshift information

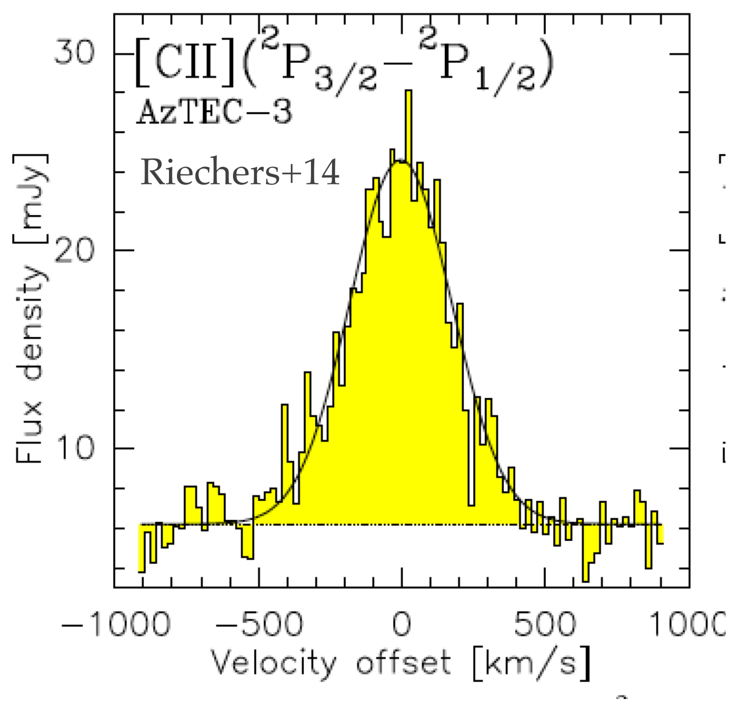
  => δν =1.5 GHz corresponds to δz=0.05 for [CII] at z=7

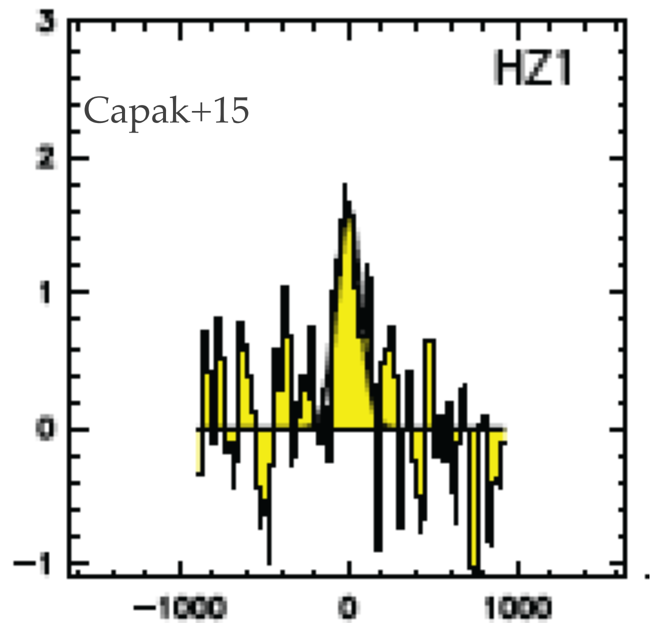
- Unique large-scale view, complementing instruments as JWST or ALMA restricted by relatively small fields of view

CII Line intensity mapping

- One of the brightest emission lines in the spectra of galaxies
- 158 microns rest-fame => Redshifted into the sub-mm and mm atmospheric windows for 4.5<z<9
  - APEX/FLASH , ALMA, NOEMA, detect [CII] at very high redshift, pointing on known objects
    - ~40 star-forming galaxies at 4.5<z<8 (LBGs and SMGs)
  - 13 blind detections at z>6 from ASPEC/ALMA
- Extinction free tracer of star formation
- One of the most valuable tracers of dusty star formation at high redshift

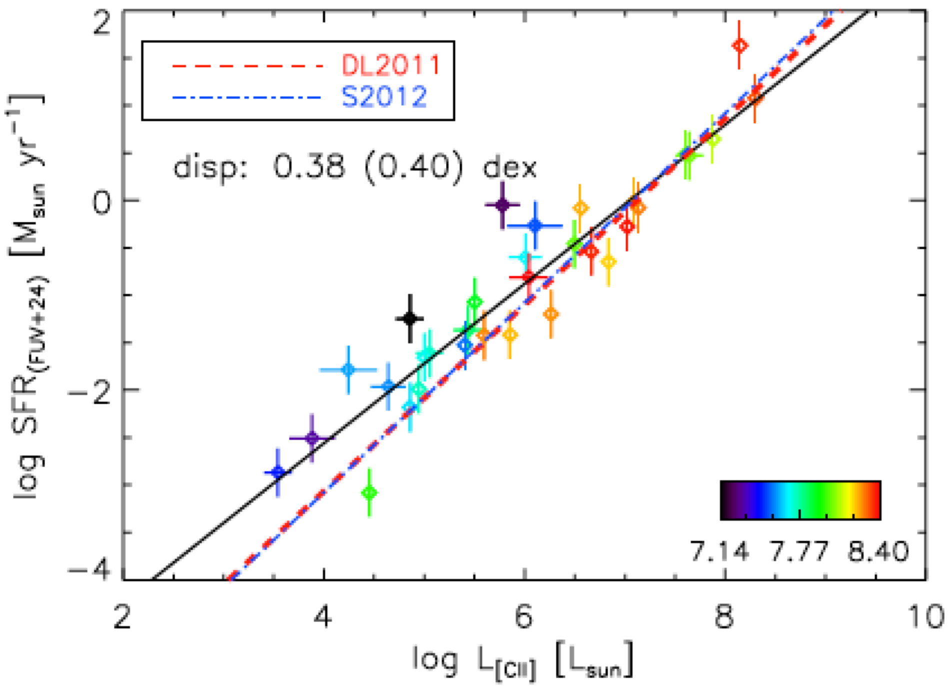
=> 3D intensity mapping of the CII line



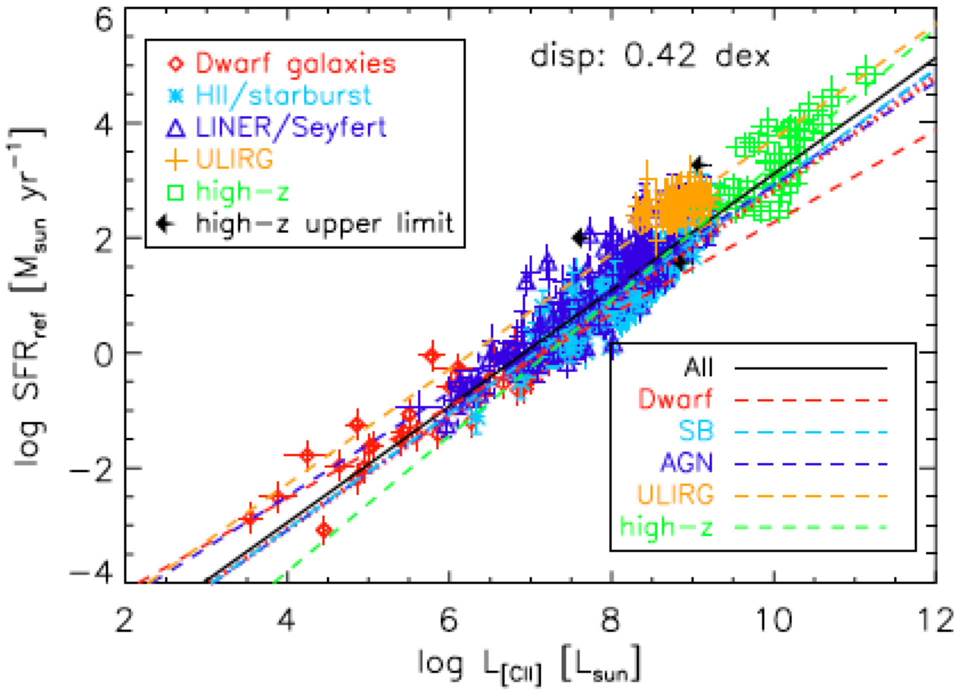


CII at high redshift: a good tracer of SFR?

Low-metallicity dwarf galaxies



Different galaxy populations

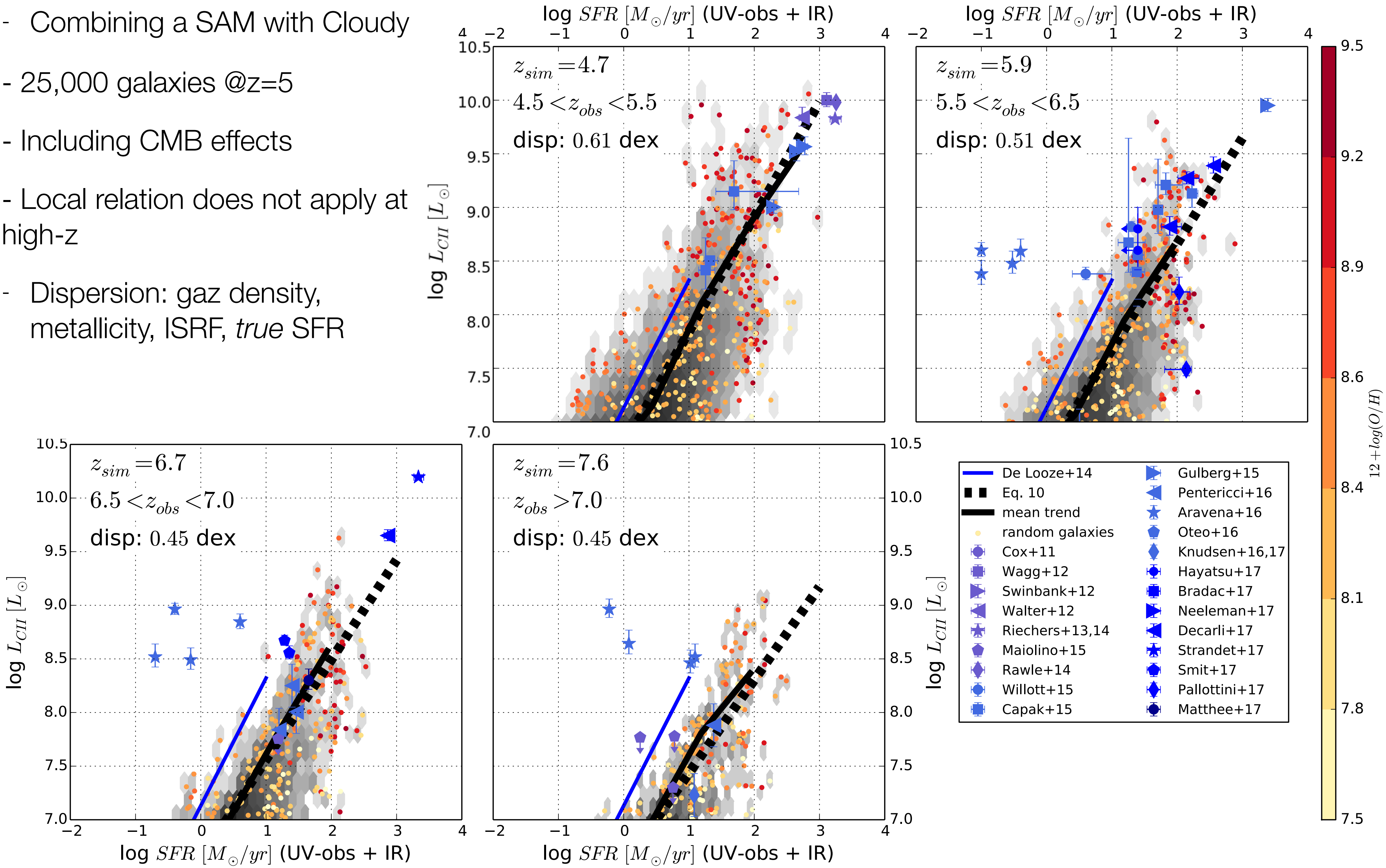


Caveat: SFR not homogeneously determined

De Looze+2014 (see also Herrera-Camus+2014)

CII at high redshift: a good tracer of SFR?

- Combining a SAM with Cloudy
- 25,000 galaxies @z=5
- Including CMB effects
- Local relation does not apply at high-z
- Dispersion: gaz density, metallicity, ISRF, *true* SFR



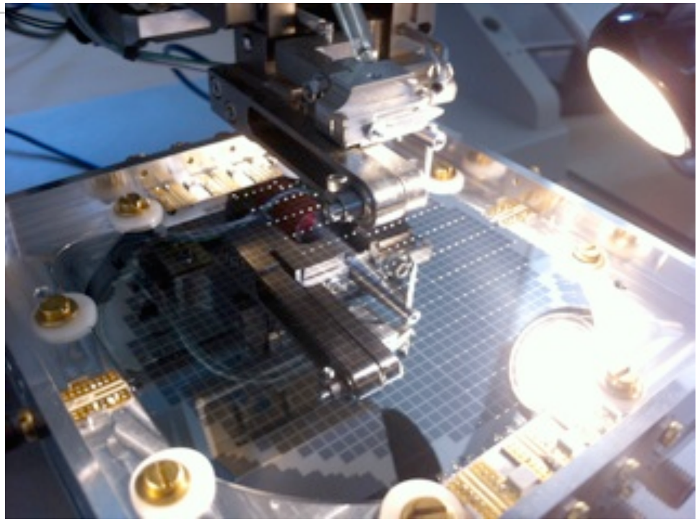
Lagache, Cousin, Chatzikos, 2018

Understanding the dusty star formation in the early Universe
and characterizing the EoR

CONCERTO

A [CII] line intensity mapping experiment

CONCERTO: instrument



- Focal plane:
  - Kinetic Inductance Detectors (KID)
  - Success of the NIKA2 IRAM camera
  - FOV D=20', fλ sampling => arrays of 2,168 pixels
- Cryostat:
  - Closed-circle ^3He-^4He dilution - 150mK
  - The 4K stage (required for initiating the ^3He-^4He dilution) is achieved using a standard two-stages pulse-tube
- Martin-Puplet interferometer (like a Michelson interferometer but with a movable mirror)
  - Outside the cryostat
  - Spectral resolution δν constant => R= ν/δν = 100 to 300
  - Perform continuously path interferograms at a frequency of few Hertz or more
  - At least one spectrum for all pixels of the matrix every second (Huge data rate!)
- A « sub-mm » antenna:
  - Frequency range: 120 - 360 GHz
  - APEX telescope (D=12m — beam size ~20" at z=5, ~30" at z=8)

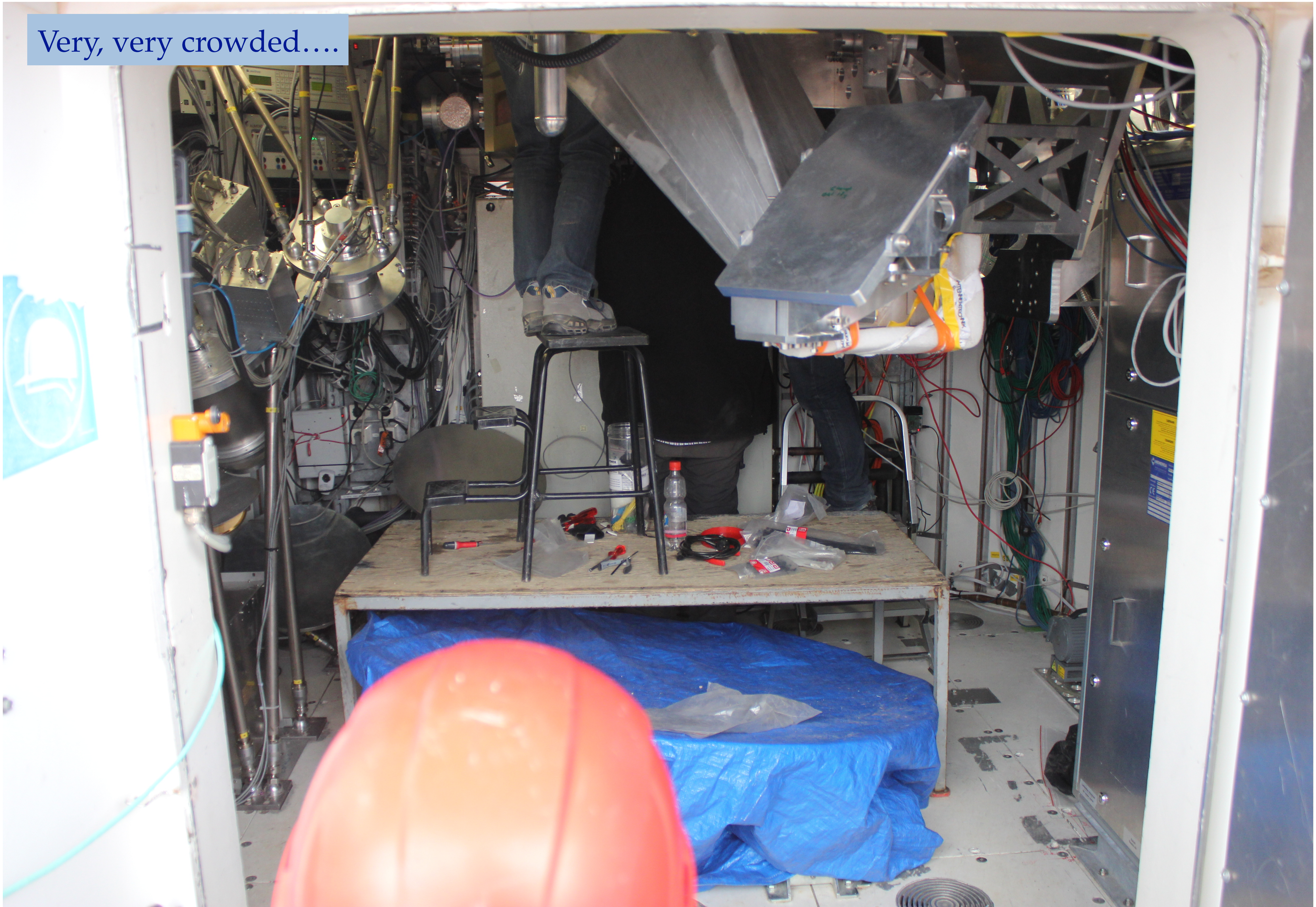
CONCERTO @ APEX

CONCERTO: project status

- KISS installation (Dec-Feb 2019) and on-going observations
  - See Alessandro's talk
- Preliminary Design Review successful (Feb. 2019)
- End of March 2019: ESO proposal (600 hours)
  - OPC in May 2019
- APEX board (May 2019): Agreement to remove LABOCA to install CONCERTO
- May 2019: CONCERTO got the ANO2 labellisation
- Critical Review Design planned for Oct 2019
- Installation at APEX: Jan 2021
- **A lot of activities!…**

Our "baby love" cryostat

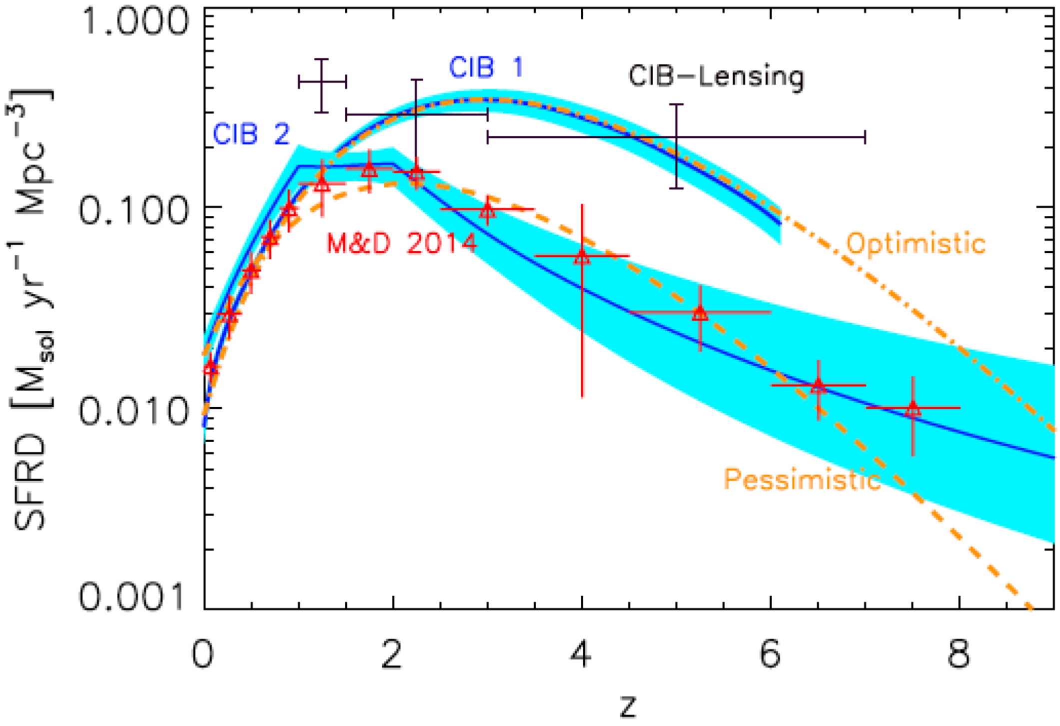
CONCERTO @ APEX

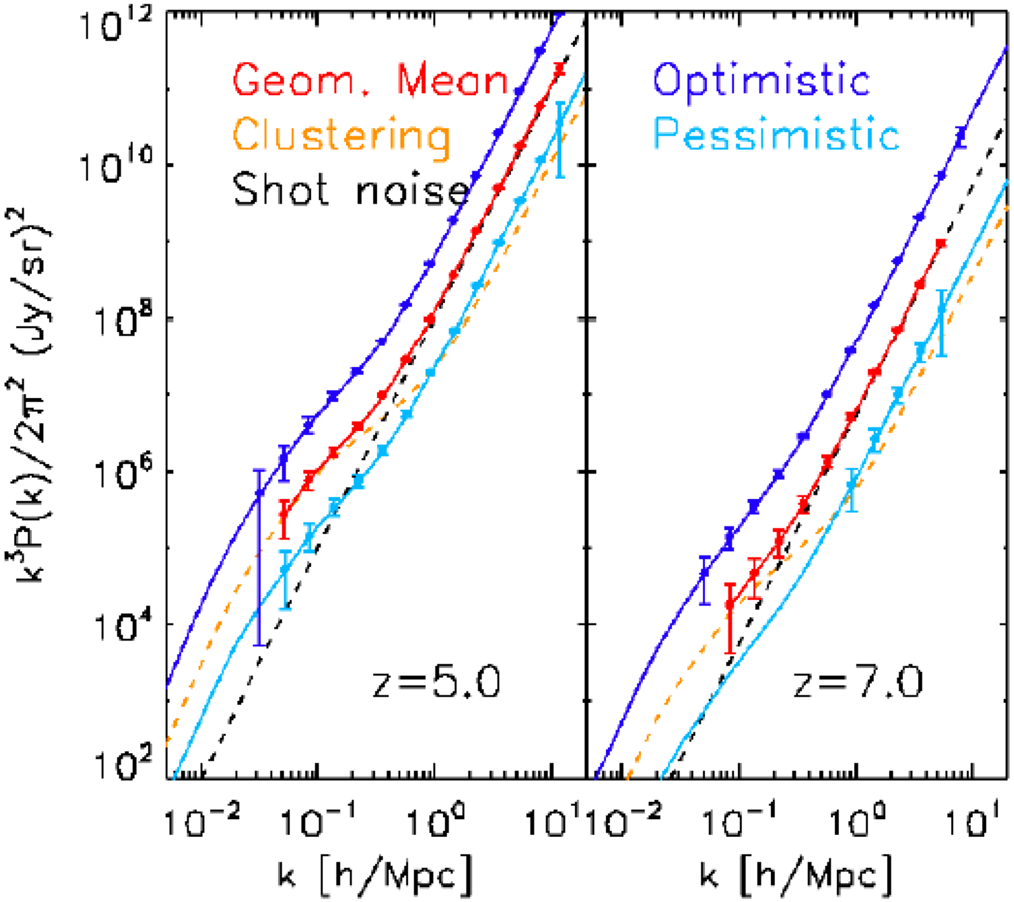


CONCERTO: … a lot of people

- **PIs:** G. Lagache & A. Monfardini
- **Instrument**
  - *Institut Néel:* E. Barria , A. Benoit, G. Bres, M. Calvo, P. Camus, G. Donnier-Valentin, O. Exshaw, A. Fasano, G. Garde, A. Gerardin, J. Goupy, M. Heigeas, P. Jeantet, J.-P. Leggeri, F. Levy-Bertrand, E. Roy, O. Tissot
  - *LPSC:* J.-L. Bouly, J. Bounmy, O. Bourrion, A. Catalano, C. Hoarau, J. Macias-Perez, M. Marton , N. Ponchant, S. Roni, S. Roudier, D. Tourres
- **Pipeline and instrument model**
  - *LPSC:* A. Catalano, J. Macias-Perez, J. Marpaud
  - *IPAG:* N. Ponthieu, F.-X. Désert
  - *LAM:* A. Beelen, Y. Cao, J.-C. Lambert
- **Scientific preparation**
  - *LAM:* A. Beelen, M. Béthermin
  - *ESO:* C. De Breuck
- **APEX**
  - *ESO:* C. De Breuck + *Staff at the telescope*
- **Administration**
  - *LAM:* L. Todorov
  - *Institut Néel:* C.Bartoli, P. Poirier
  - *LPSC:* C. Vannier

CONCERTO: predictions





Survey of 1.4 Sq. deg.
1,200 hours of observations

CONCERTO: what is expected to be learned ?

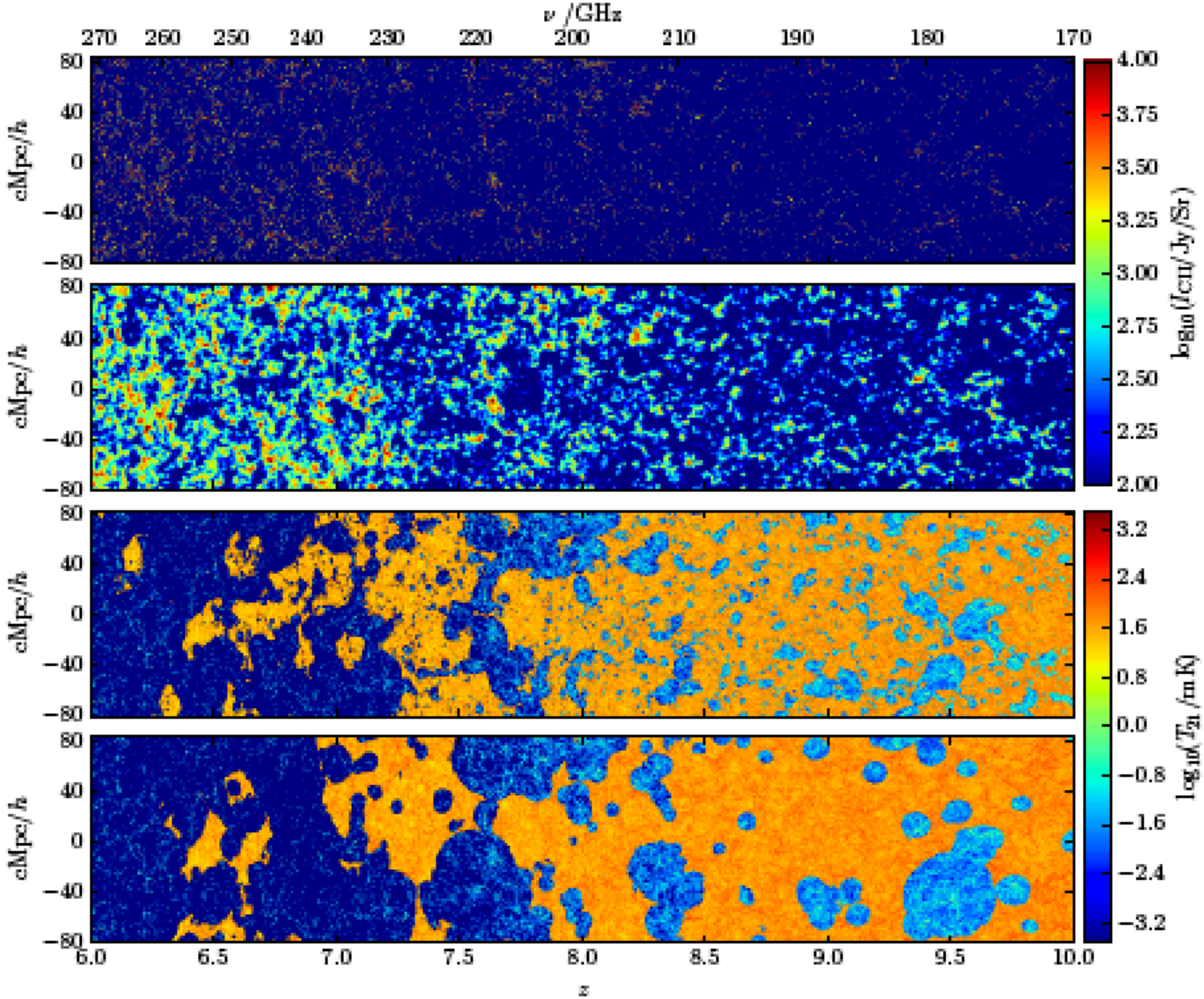
- Answer the questions of whether dusty star-formation contributes to early galaxy evolution, and whether dusty galaxies play an important role in shaping cosmic reionization
  - DSFG are critical players in the assembly of stellar mass and the evolution of massive galaxies at high redshift

- Clustering power spectra
  - «Dusty» SFRD for $z>4.5$
  - [CII] luminosity- Mh relation
  - Typical halo mass scale of SF galaxies

- Shot noise
  - Measure the weighted dark-matter halo mass integral of the [CII] luminosity function
  - Constrain number counts of [CII]-emitters as a function of redshift.

Cross-correlations

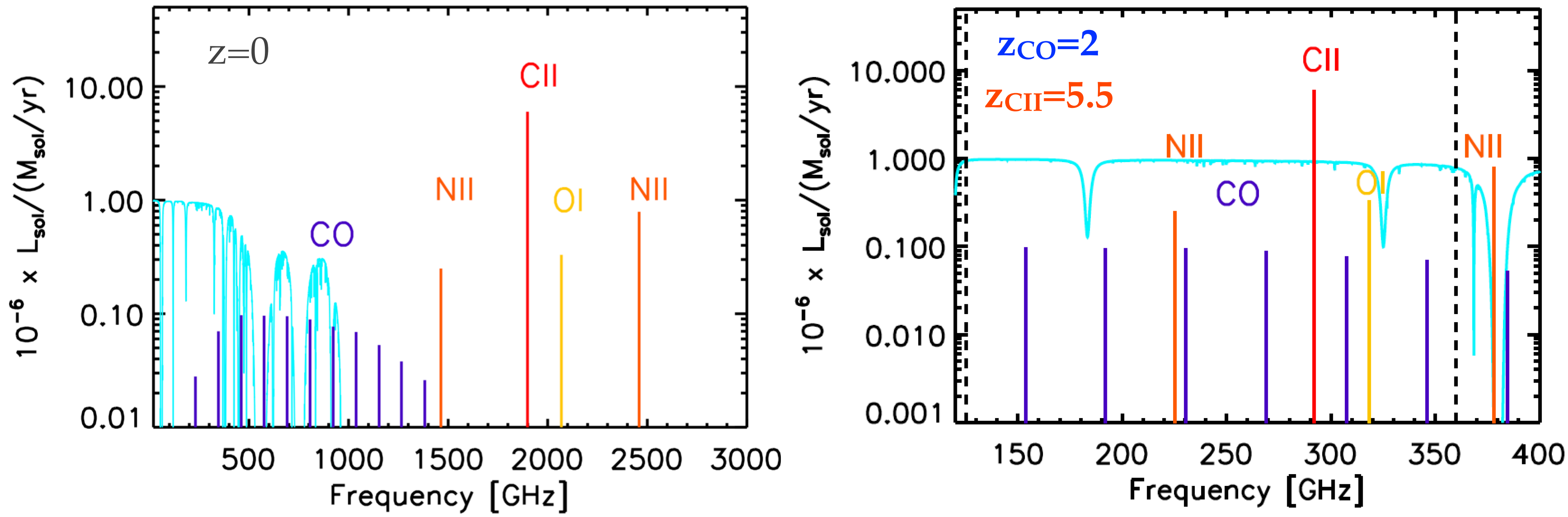
With HI (Dumitru+2019)



With NII/OI (Serra+2016), with galaxy surveys, with CIB anisotropies, etc

Intensity mapping of CO at low redshift

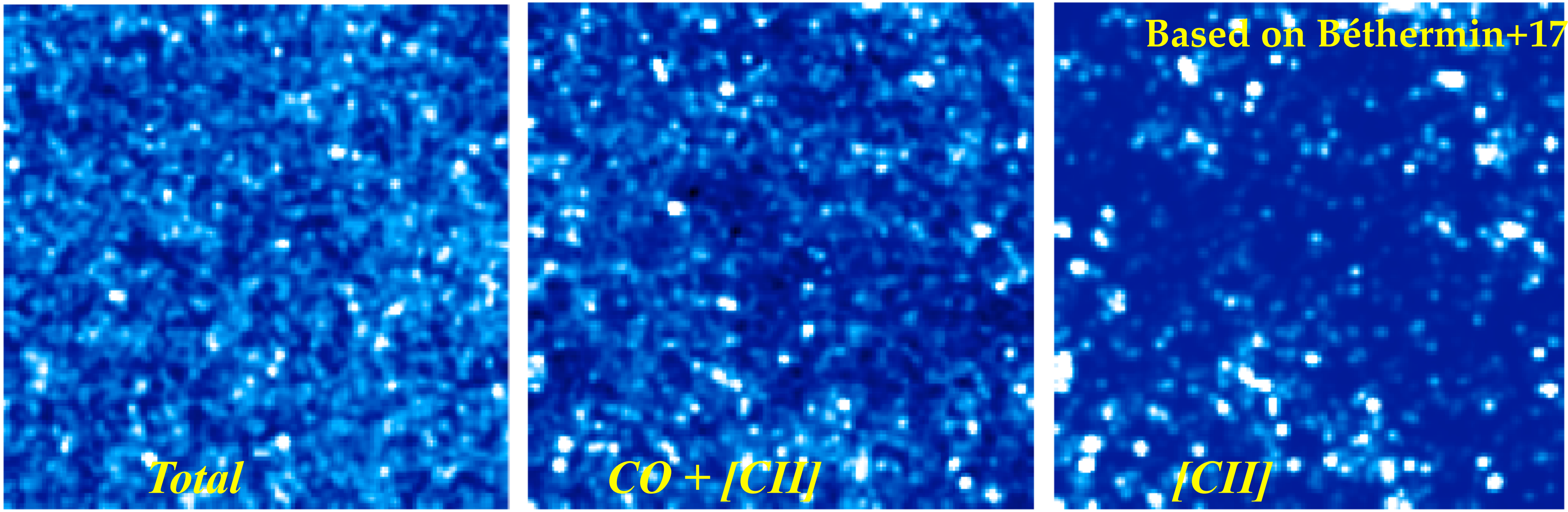
- CO emission at z<1.9 (for the rotational levels up to J=5):

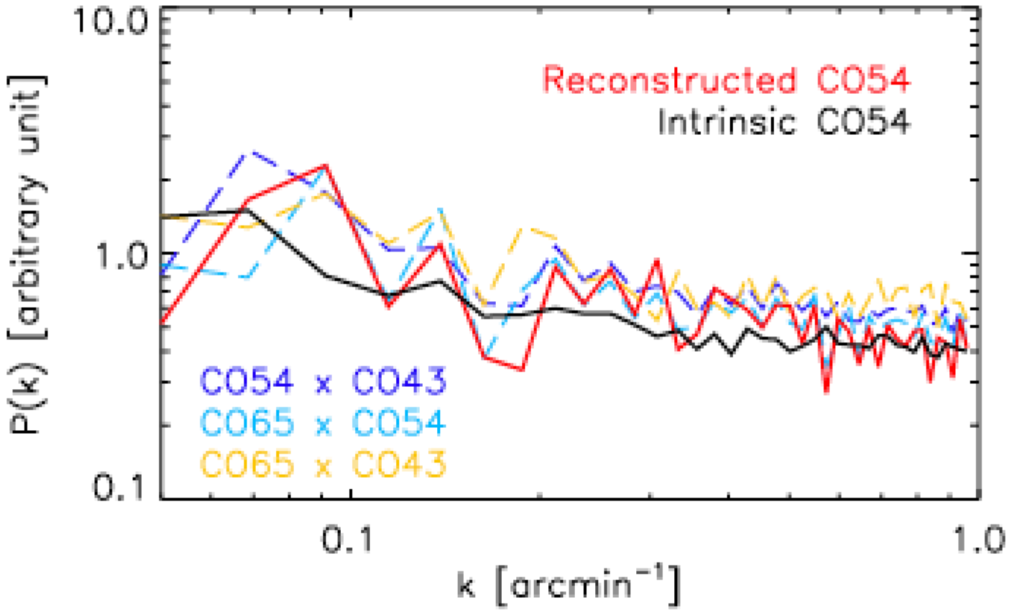


- Cross-power spectrum of two CO lines at the same redshift, within CONCERTO: A measure of the 3D clustering of undetected galaxies.
- Cross-correlating our CO signal with z~0.5-2 galaxies will also probe the molecular gas and its connection to star formation in galaxies.

CONCERTO: CO contamination

1.4x1.4 degrees CONCERTO simulated sky maps at z=5.5±0.1





A foreground for CII at z=6 :
CO(5-4) at z=[1.1-1.2]

Estimated using cross-correlations of CONCERTO maps at the frequencies of the CO(4-3), CO(5-4) and CO(6-5) lines.

CONCERTO: low resolution spectroscopic surveys

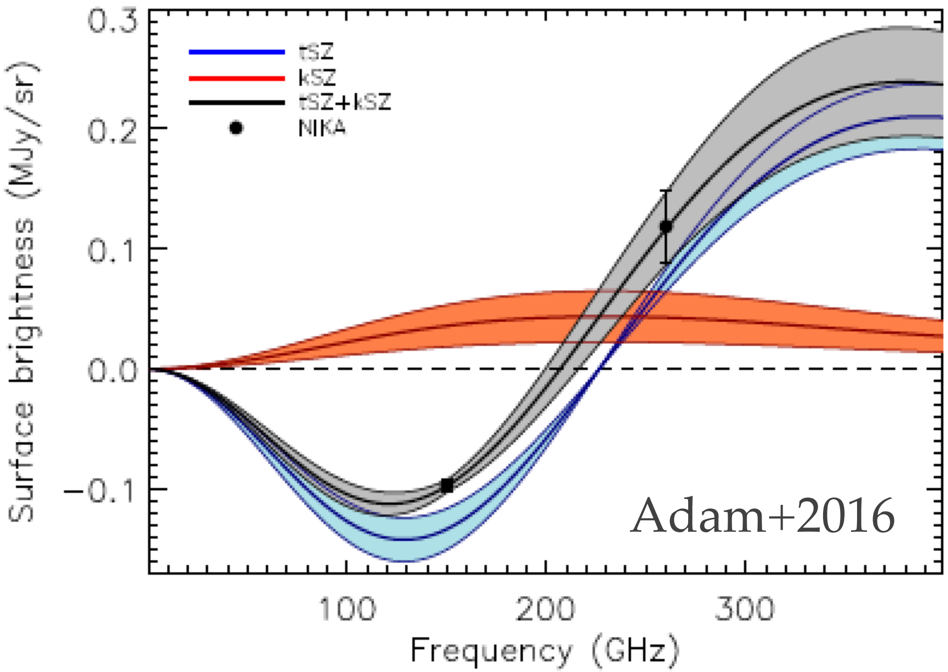
- Our goal is to offer a generic access to a large FoV and low-frequency resolution spectroscopic instrument.

- Next step after ground-based sub-mm experiments, Herschel and Planck: from broad-band photometry to spectroscopy

- A multi-purpose instrument:
  - Galaxy clusters: SZ and gravitationally lensed high-redshift galaxies
  - Local and high-redshift galaxies
  - Star-forming regions and high-latitude cirrus clouds in the MW
  - Solar system planets

Galaxy clusters (SZ)

- Kinetic and Thermal Sunyaev-Zel'dovich Effect
- The kSZ effect, due to the motion of a galaxy cluster with respect to the CMB, provides a direct, redshift-independent measurement of the velocity field of galaxy clusters
- The tSZ is proportional to the integrated line of sight electron pressure => mass proxy in cosmological studies

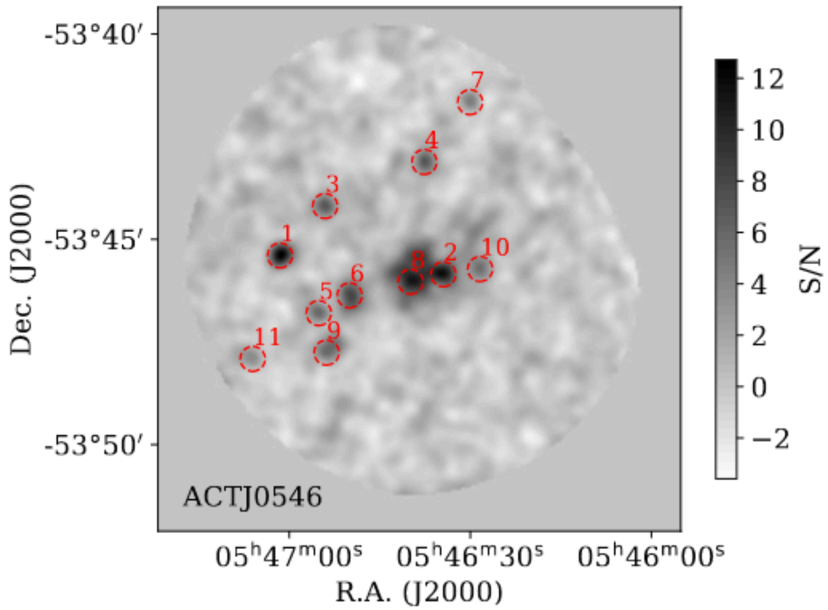


NIKA1 observations of MACS J0717.5+3745

- CONCERTO will enable an accurate separation of the tSZ, kSZ and relativistic corrections, as well as the extraction of the SZ signals from the other astrophysical components
- FOV well adapted for medium to high-z clusters & angular resolution matters (sub-structures, mergers)

Galaxy clusters & galaxies at (very-)high redshift

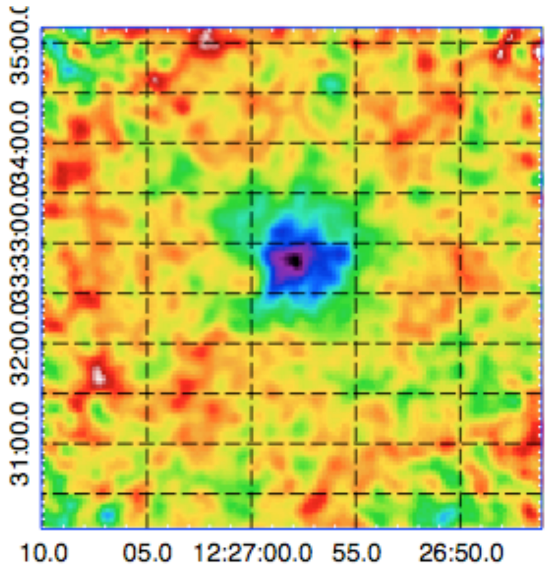
- SZ and distant galaxies at the same time!

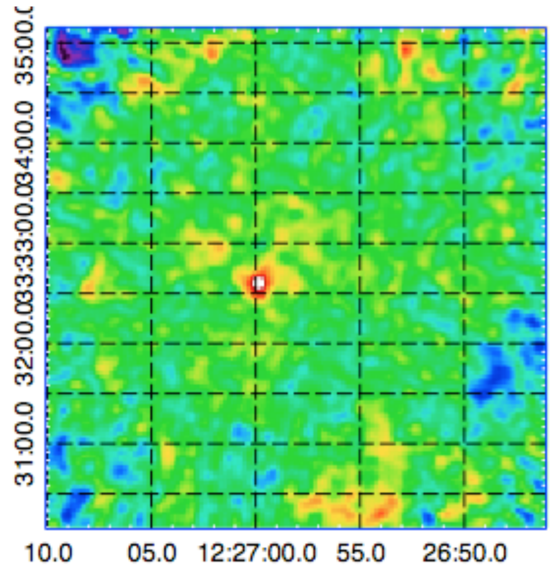


Laboca 870 microns

Aguirre+2018
Laboca follow-up of ACT/SZ galaxy clusters

NIKA 2 and 1.2 mm

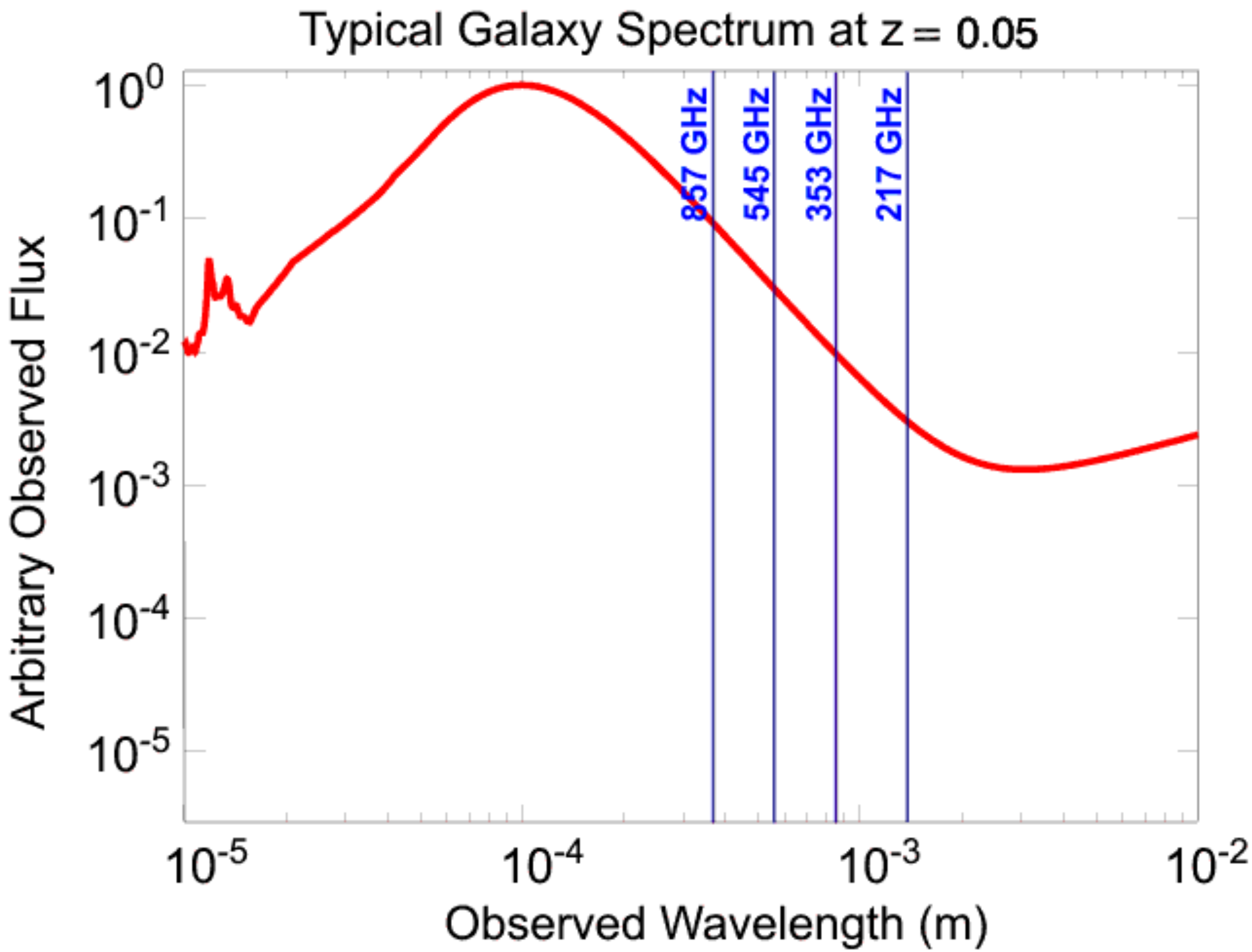




CL J1226.9+3332
An amplified galaxy at z=2.26

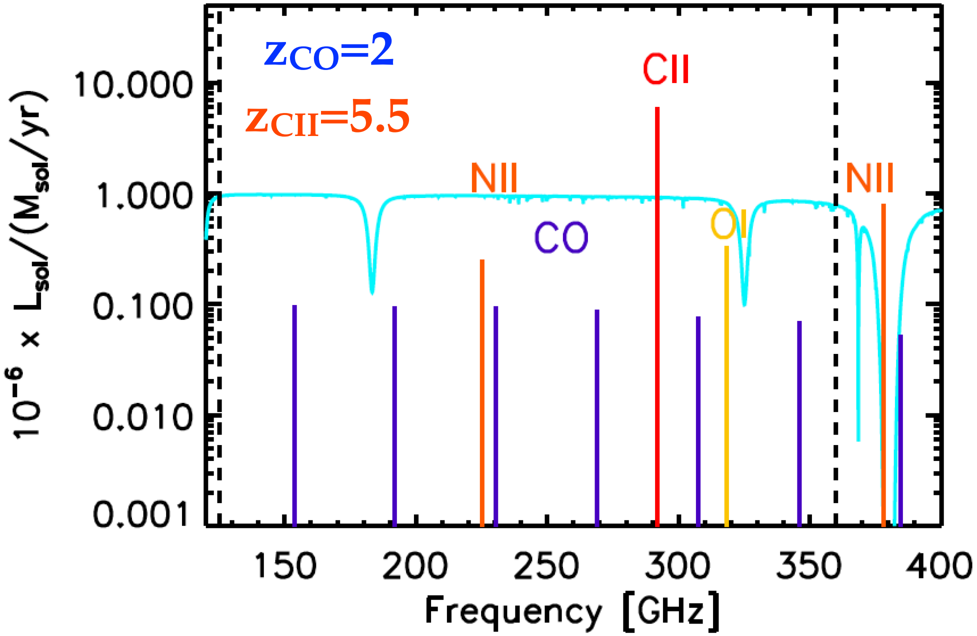
Galaxies at (very-)high redshift

- Longer wavelength probes to higher redshift



Galaxies at (very-)high redshift

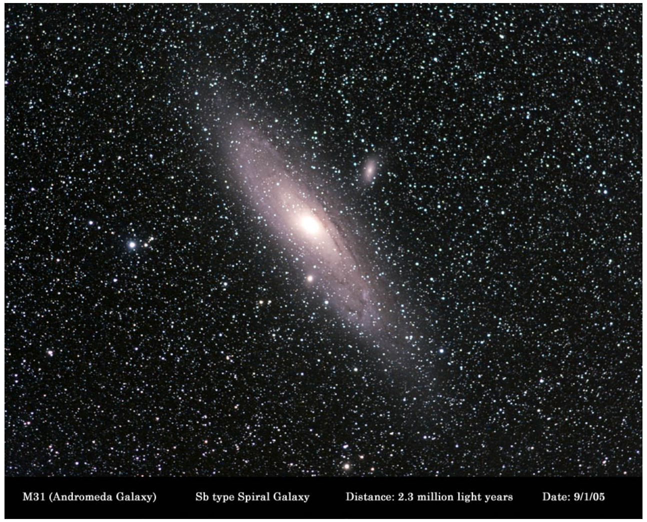
- Follow up of Herschel/Laboca/SCUBA-2 deep surveys and SPT/ACT deep fields
  - Constrain SEDs
  - Redshift identification through lines
    - At z=2:
      - CO from J4-3 to J9-8
        - SLED!
      - CI (370 and 610 microns)
    - At z=7, CII



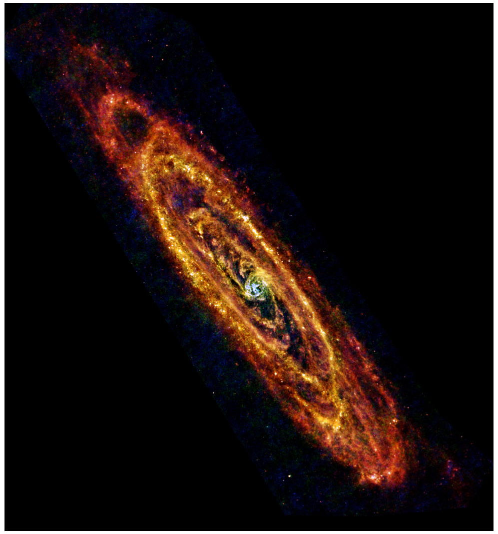
Galaxies at low redshift

- CO lines
  - Molecular gas reservoir
  - at z=0: J2-1, J3-2 , at z=1: J3-2, J4-3, J5-4, J6-5, CI

Ed Lubats



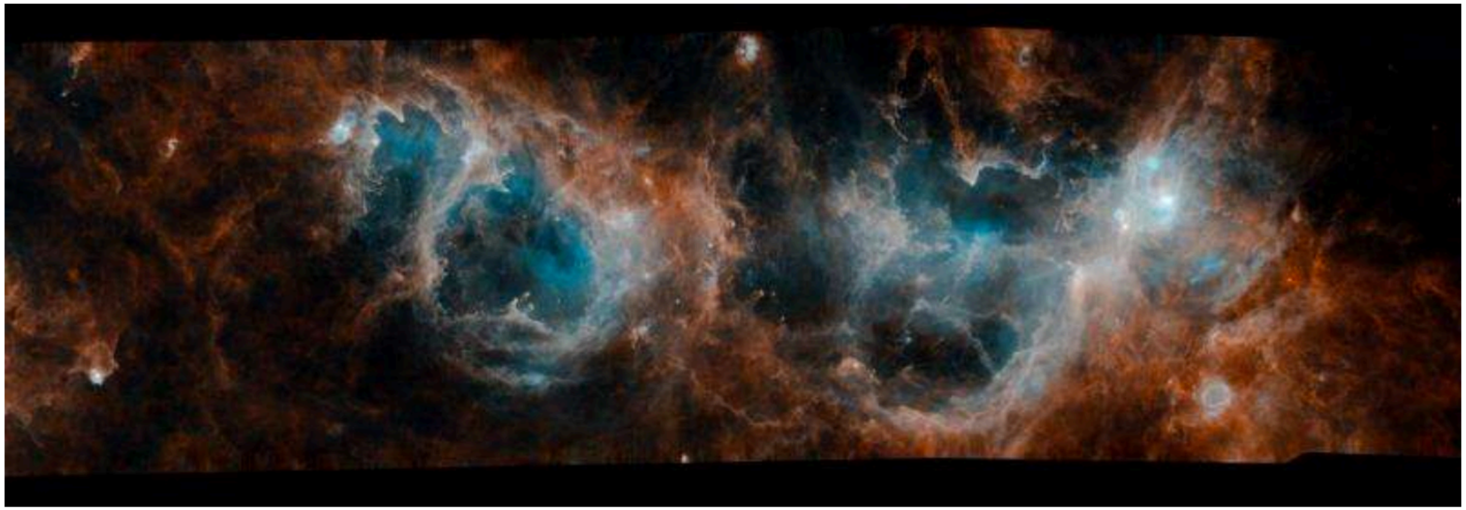
- Continuum (complementary to Herschel and LABOCA)
  - Dust (gas) mass (Scoville et al. 2016)
  - Probe the sub-mm excess (e.g. in SMC and LMC, Bot et al. 2010)
  - Follow-up of the Herschel Dwarf Galaxy survey
    - How dust properties evolve as a function of metal enrichment?



ESA/Herschel/PACS & SPIRE Consortium, O. Krause, HSC, H. Linz.

Galactic star-forming regions and high-latitude cirrus

- Dust emissivity, dust mass, dust temperature (combining with Herschel)
- Changes in dust properties related to early star formation
  - Ex: evolutionary stages of massive clumps from the youngest to the most evolved high-mass-star forming clumps (e.g., König+2017)
- Distribution of cold dust (e.g. Csengeri+2016)
- CONCERTO: dust continuum but also CO(2-1) and CO(3-2)
  - Evolution of the gas-to-dust ratio
  - CO(3-2) contamination to 870 μm broad-band surveys



Herschel's view of the W3/W4/W5 complex. Credit: ESA/Herschel/NASA/JPL-Caltech, CC BY-SA 3.0 IGO; Acknowledgement: R. Hurt (JPL-Caltech)

CONCLUSIONS

- We are constructing a low-resolution (δv =1.5 GHz) large FOV spectrometer operating between 120 and 360 GHz.

- Our main interest: map in 3D the specific intensity due to CII-line emission, a technique known as « Intensity Mapping »
  - With the CII-dedicated CONCERTO survey, we will map the star formation at z>4.5, and in the end of epoch of reionisation

- CONCERTO @ APEX is a unique combination and will allow to :
  - study galaxy cluster physics
  - probe the gaz content of galaxies (CO, CI, CII, NII, OI lines), the efficiency of star formation
  - measure the dust mass and emissivity
  - study the structure of molecular clouds