Detecting molecules in high-z mergers with ALMA

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➡ Formation and evolution of galaxies

1. Starbursts: increase as a function of z

factor 10 between z=0 et 1

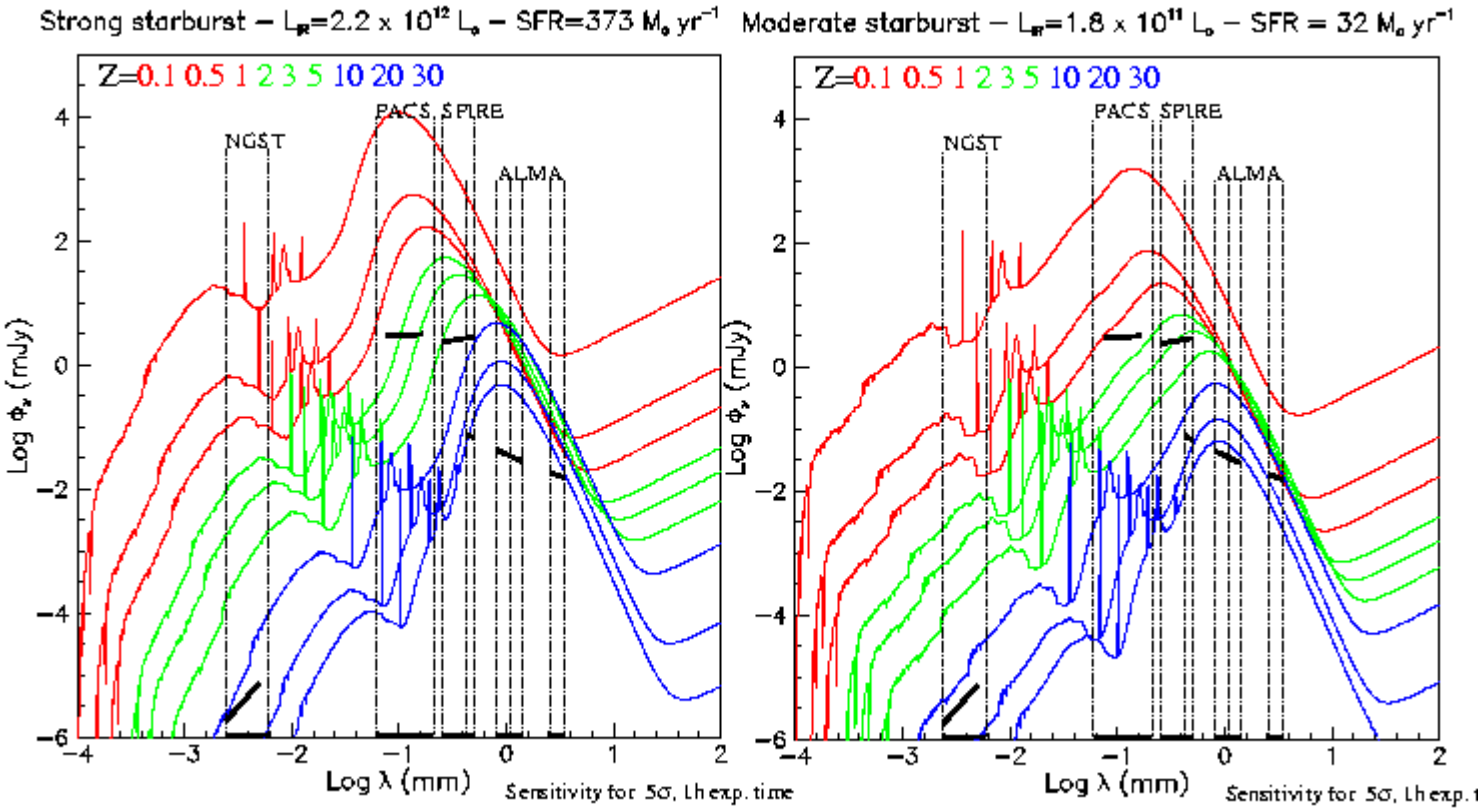
2. Dust and extinction:

the most active starbursts are the most obscured (at z=0)

-> at high z, more affected

Star formation rate highly underestimated
LIR/LB varies from 0.1 to 1000 !

3. Negative K Correction

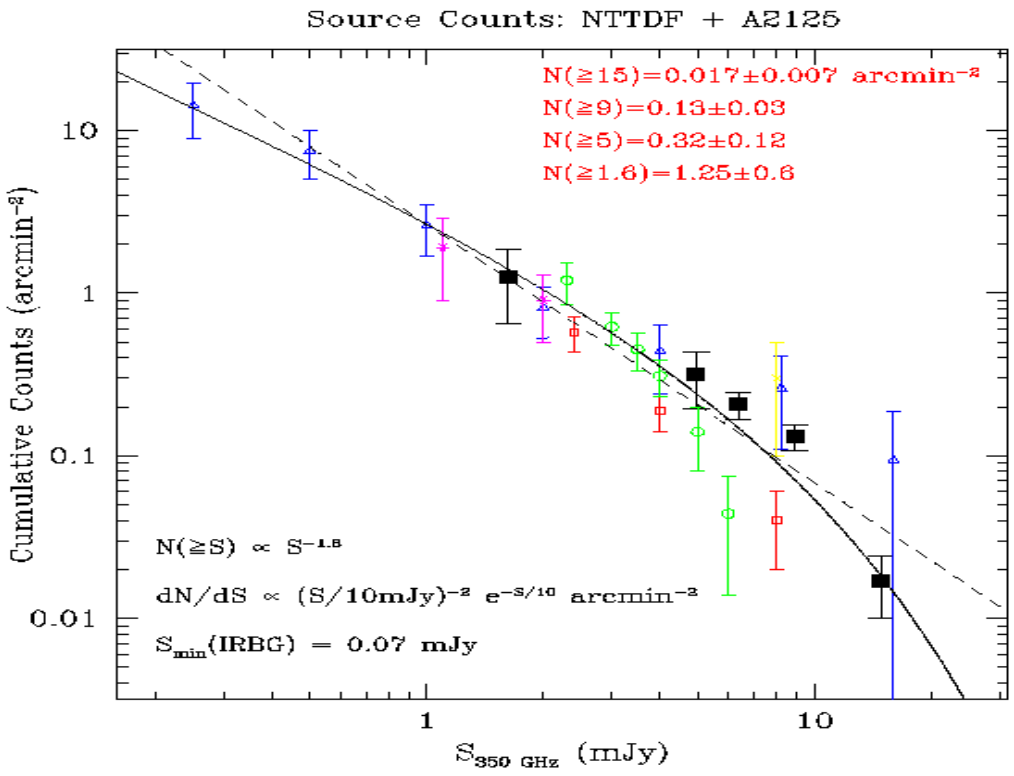


SED for strong and moderate starbursts, at various redshifts, compared with NGST, FIRST/Herschel and ALMA sensitivities, for 1h integration time (Melchior et al. 2001).

PRESENT SURVEYS

JCMT-SCUBA, IRAM-MAMBO at 0.850 -1.2 mm
(Smail et al 97, Barger et al 98, Carilli et al 00)

1-2 sources/ arcmin2
above 1 mJy (e.g. Carilli et al. 2001)



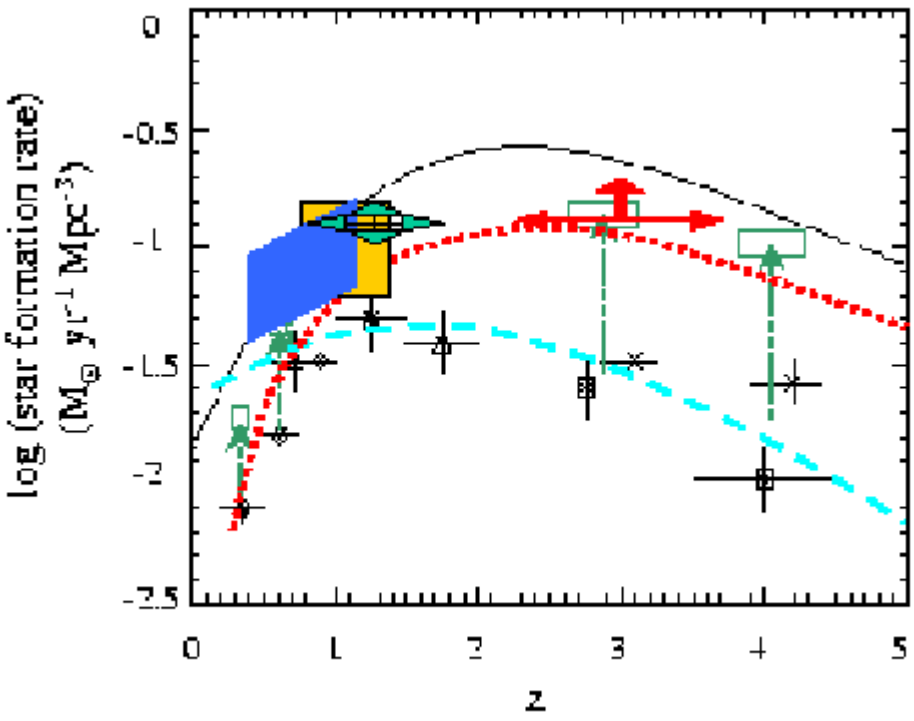
Source number counts, for sub-mm sources, from Carilli et al (2001, astro-ph/0009298)

Problems:

- Identification of sources
- Confusion (also SIRTF, ASTRO-F, Herschel)
- Contribution of AGN?
- How to get redshifts?

By molecular lines (redshift machine)
LMT, GBT, ALMA...

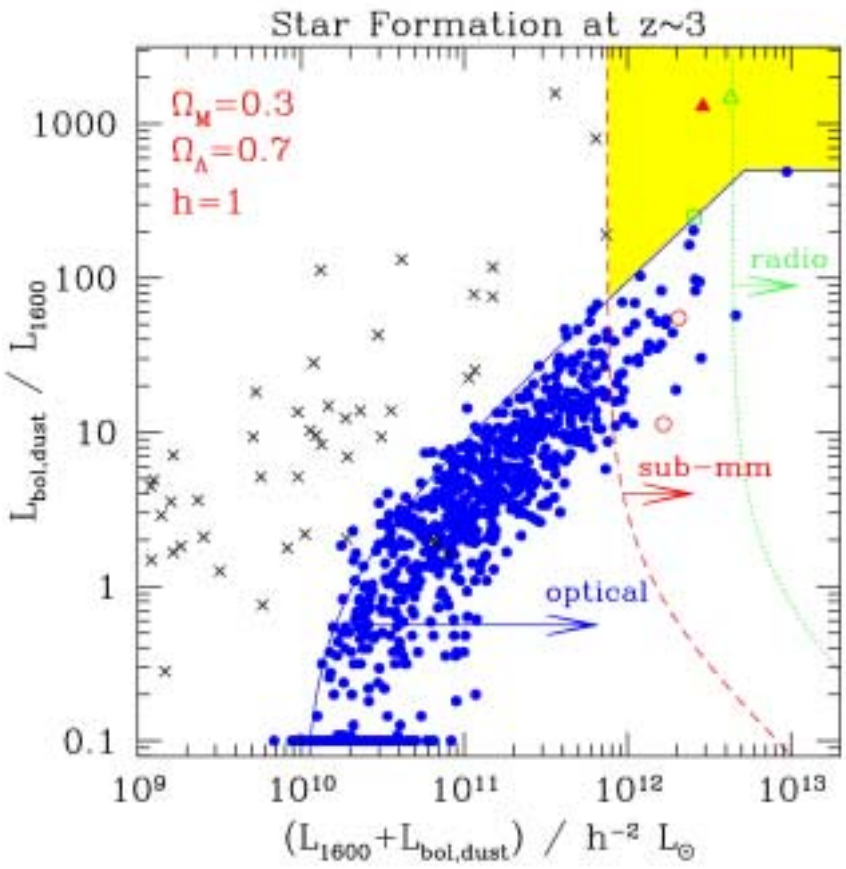
Extinction corrections applied to vis/UV results correspond (x 3)



From Genzel & Cesarsky, 2000
Blue losange = ISO
Black squares: without reddening
Green squares: After reddening correction, by a factor 3
Red error bars: SCUBA results
Blue dashed curve: no ULIRG
Red dashed curve: with ULIRG
Black full line: CIBR limits, from COBE

No confusion with ALMA:
spatial resolution better than 0.1"
Possible detection of non ULIRGs
for ex. LBGs: Lyman-Break Galaxies
(Steidel et al 1996, Adelsberger & Steidel 2000)
their density is 150/arcmin2 for z=2.5-3.5

100 times more objects than today



Colour-magnitude diagram (from dust emission and 1600 Angstrom luminosity), for starbursts at z=3, from Adelberger & Steidel (2000, ApJ 544, 218). The x-axis can be viewed as the star formation rate, and the y-axis as the obscuration rate. The blue dots are Lyman-break galaxies, the red and green points are detected sub-mm sources. The black crosses are starbursts at z=0, for comparison. The limit of detection for optical sources is the blue full line, for sub-mm sources is the dash-red line, and for radio sources the dot-green line. The yellow region indicates where very obscured sources can only be detected by their sub-mm or radio emission. With ALMA, the dash-red line will shift to the left by 2 orders of magnitude, and all Lyman-break galaxies will be detected

Counts compared to theory:

Semi-analytic models, based on the hierarchical scenario
Numerous free parameters

- either parameters are fixed through "realistic" laws (Granato & Silva 2001)
- either best fit is searched, with a restricted set of parameters (Blain 2000)

One can deduce the evolution (z) of the fraction of baryons transformed in energy by mergers

Much more efficient at high z shorter tdyn?

How to know the molecular gas fraction ?

Molecular lines: favored also at high z but no negative K correction

Highly depend on excitation, density, temperature..
ULIRGs: observed in excited CO lines
J=8-7, 9-8, etc..

PANORAMA in mm & sub-mm

Tel	Area	min wavelength	Resol
IRAM-30m	707 m^2	1mm	10"
IRAM-PdB	883 --> 1060m^2	1mm	0.5"
NRO	6x10m=509m^2	1mm	0.5"
OVRO	6x10m= 509 m^2	1mm	0.5"
+BIMA	10x6m=282 m^2	1mm	0.5"
=CARMA	791 m^2	1mm	0.5"
SMA	7x6m = 200 m^2	0.3mm	0.1"
GBT	100m = 7854 m^2	2.6mm	7"
LMT	50m = 1963 m^2	1mm	6"
ALMA	64x12=7238 m^2	3-0.3mm	0.1-0.01"
E-VLA	35x25m=17200m^2	6mm	0.004"

MOLECULES AT HIGH REDSHIFT

CO EMISSION

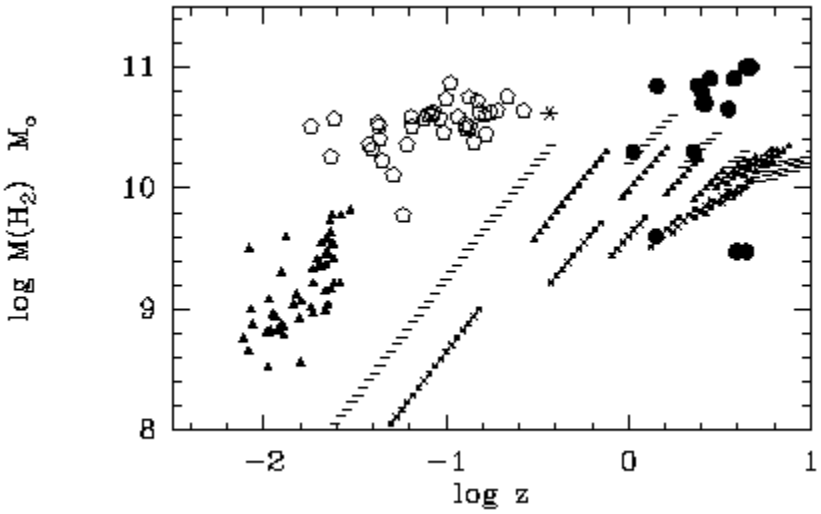
First detection: Faint IRAS Source
F10214+4724 at z=2.3
(Brown & van den Bout 1992, Solomon et al 1992)

Table 1. CO data for high redshift objects

Source	z	CO line	S mJy	ΔV km/s	MH_2 10^{10} $M_\odot$	Ref
SMM 02399-0134	1.062	2-1	3	500	2*	1
0957+561	1.414	2-1	3	440	0.4*	2
HR10	1.439	2-1	4	400	7	3
F10214+4724	2.285	3-2	18	230	2*	4
53W002	2.391	3-2	3	540	7	5
H 1413+117	2.558	3-2	23	330	2-6 *	6
SMM 14011+0252	2.565	3-2	13	200	5*	7
MG 0414+0534	2.639	3-2	4	580	5*	8
SMM 02399-0136	2.808	3-2	4	710	8*	9
6C1909+722	3.532	4-3	2	530	4.5	10
4C60.07	3.791	4-3	1.7	1000	8	10
APM 08279+5255	3.911	4-3	6	400	0.3*	11
BR 1335-0414	4.407	5-4	7	420	10	12
BR 0952-0115	4.434	5-4	4	230	0.3*	13
BR 1202-0725	4.690	5-4	8	320	10	14

* corrected for magnification, when estimated
Masses have been rescaled to $H_0 = 75$km/s/Mpc. When multiple images are resolved, the flux corresponds to their sum
(1) Kneib et al. (2000); (2) Planesas et al. (1999) (3) Andreani et al. (2000); (4) Solomon et al. (1992), Downes et al. (1995); (5) Scoville et al. (1997b); (6) Barvainis et al. (1994); (7) Frayer et al. (1999); (8) Barvainis et al. (1998); (9) Frayer et al. (1998); (10) Papadopoulos et al. (2000); (11) Downes et al. (1999); (12) Guilloteau et al. (1997); (13) Guilloteau et al. (1999); (14) Omont et al. (1996)

CO data for high redshift objects



H2 mass as a function of redshift. Black triangles: normal galaxies. Empty pentagons: ULIRGs. Asterisks: high-z CO-detected objects. Dotted lines: IRAM sensitivity for various CO lines.

Triggered the search: hyper-luminous objects, quasars..

15 between z= 1.0 and 4.7 (in 2001)
most of them amplified gravitationally

Strategy:

- Search in FIR or sub-mm continuum
- Search in CO emission with interferometers

(z known from optical observations)

MODELING

Starburst modeling, from z=0 ULIRGs
size 1kpc, mass 6 10^{10} Mo

2 extreme models:

- 2-components clouds: 30 and 90K at z=0

  densities 10^4 and 10^6 cm-3

- Homogenous sphere at T=50K,

  density 10^3 cm-3
  N(H2) = 3.5 10^{24} cm-2

Assuming the same energy comes from stars

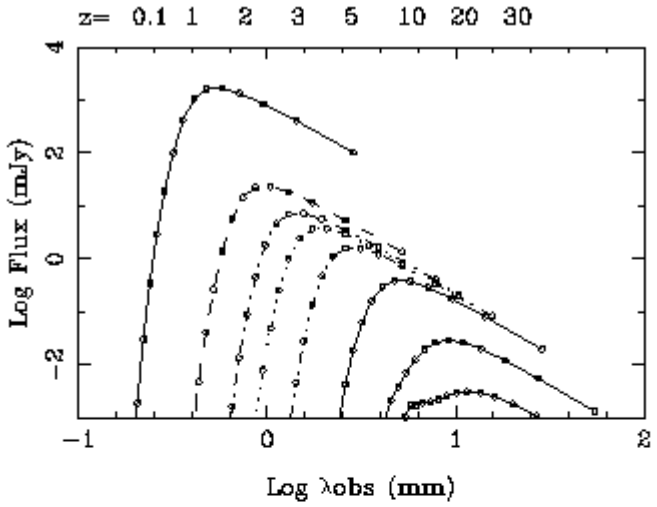
- either a black-body

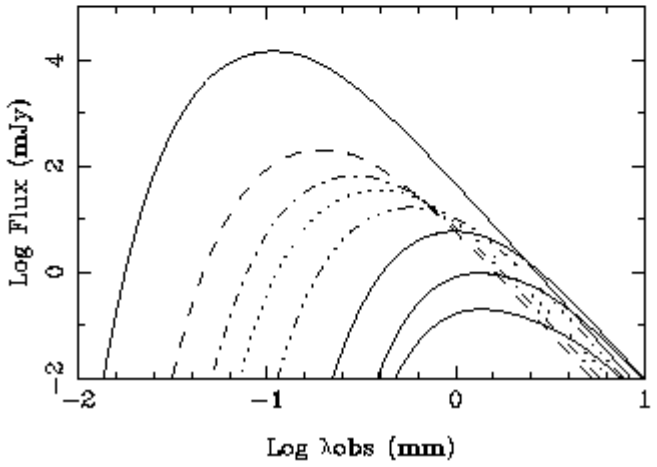
  $T_{dust}^4 - T_{bg}^4 = cste$

- or an optically thin dust

  $T_{dust}^6 - T_{bg}^6 = cste$

Transfer: LVG model



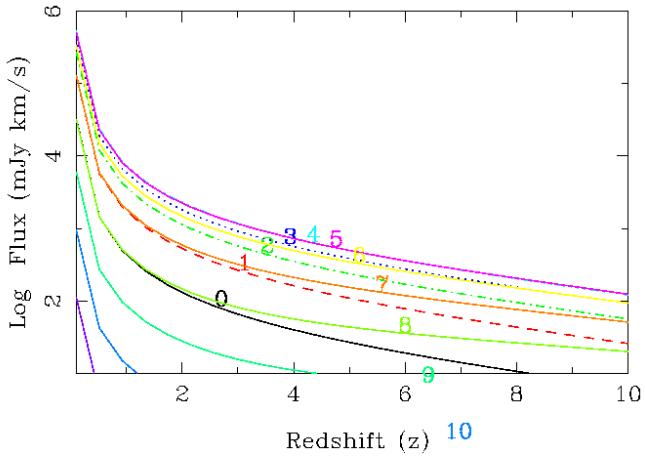


Result of the LVG model, for the homogeneous case at T=50K. Top: CO lines; Bottom: continuum as a function of redshift.

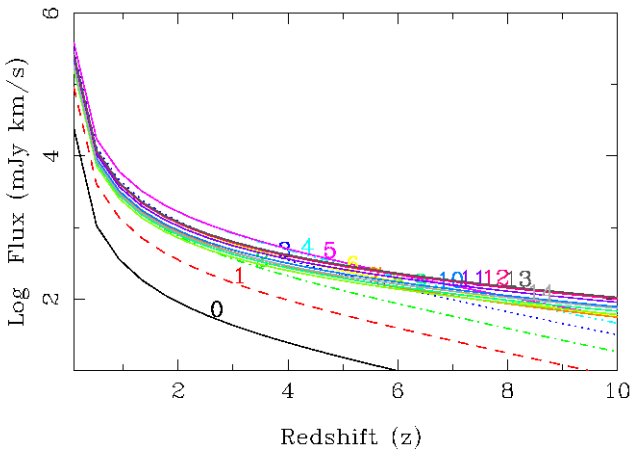
Starbursts at high z could be different from ULIRGs at z=0

In particular, the molecular density could be less, and the rotational levels of CO not excited until J=9-10..

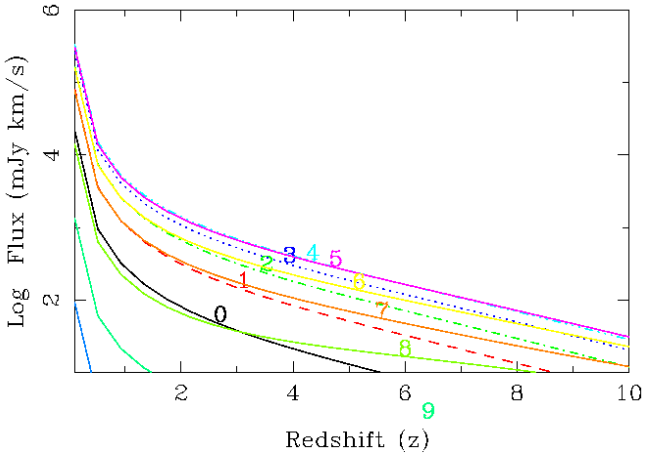
T=50K



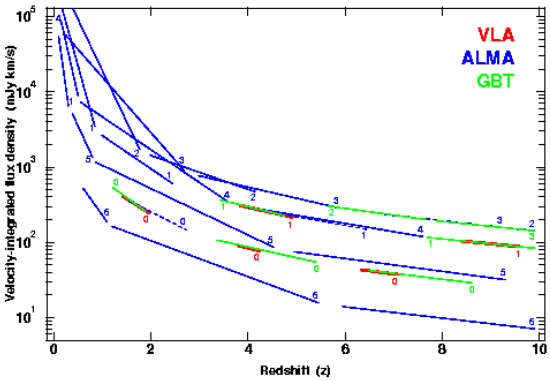
T=30K & 90K



T=30K

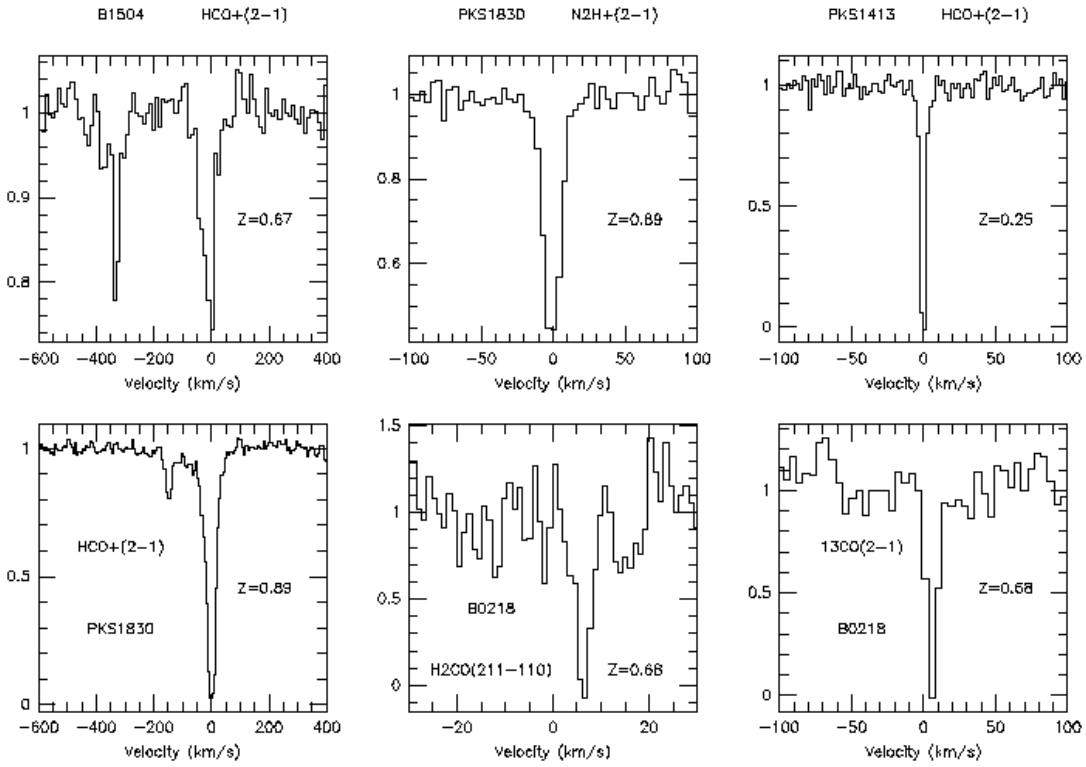


HR10, Papadopoulos & Ivison 2001



Molecular absorption in front of quasars will be also a useful tool to determine the chemistry as a function of z, with ALMA

Several examples of molecular absorption in front of quasars, at various redshift (Wiklind & Combes)

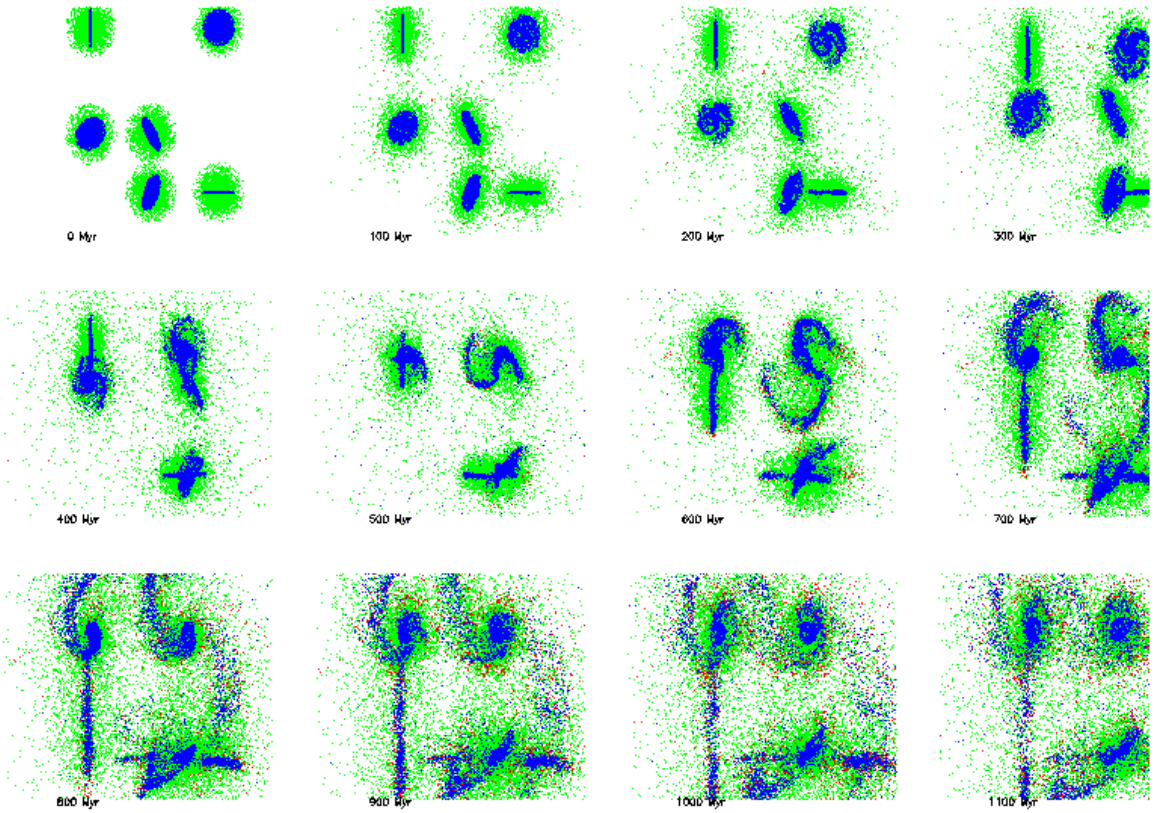


STARBURST DYNAMICAL SIMULATIONS

Melchior & Combes (2001)

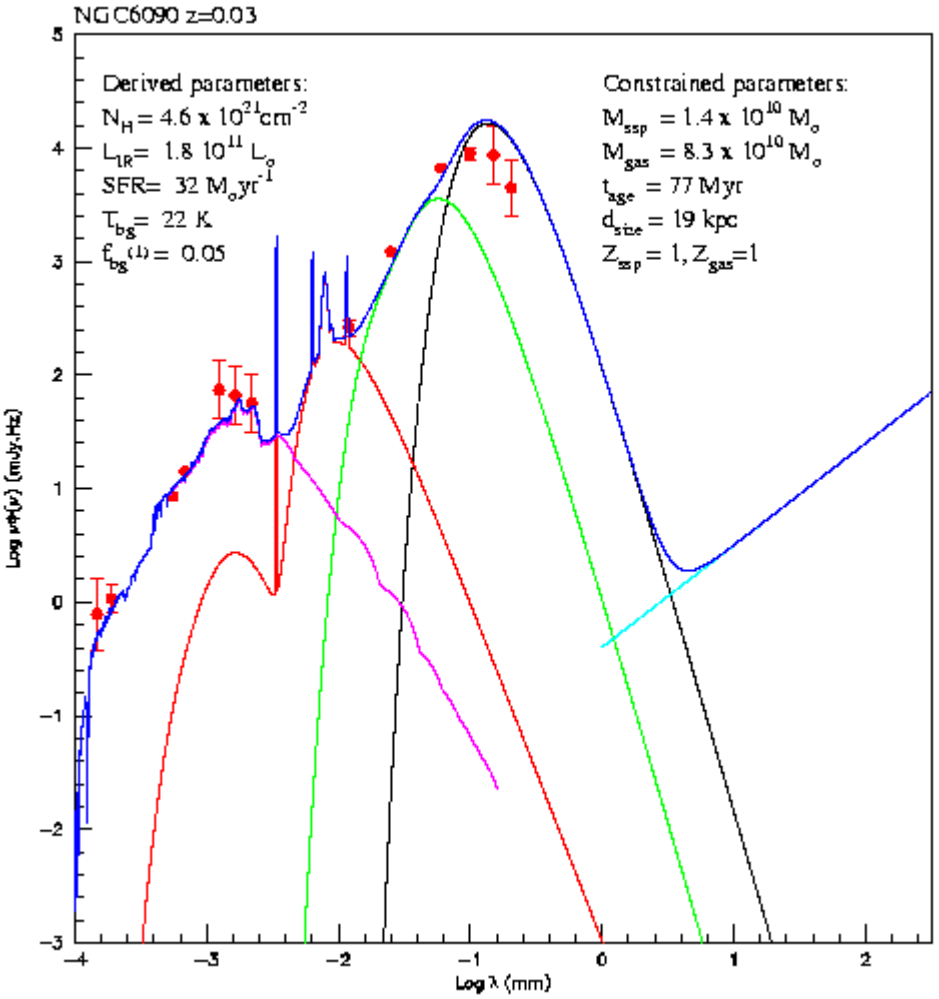
Chemo-dynamical simulations of galaxy collisions at high z

N-body Tree-SPH
with spectral modelisation coupled to dynamics



One of the first simulations, with in green the dark matter, in red the stars, and in blue the gas particles. Three projections are given at each epoch.

In the frame of large-scale cosmological simulations
N-body (Colombi et al)
+ semi-analytical (Guiderdoni et al)



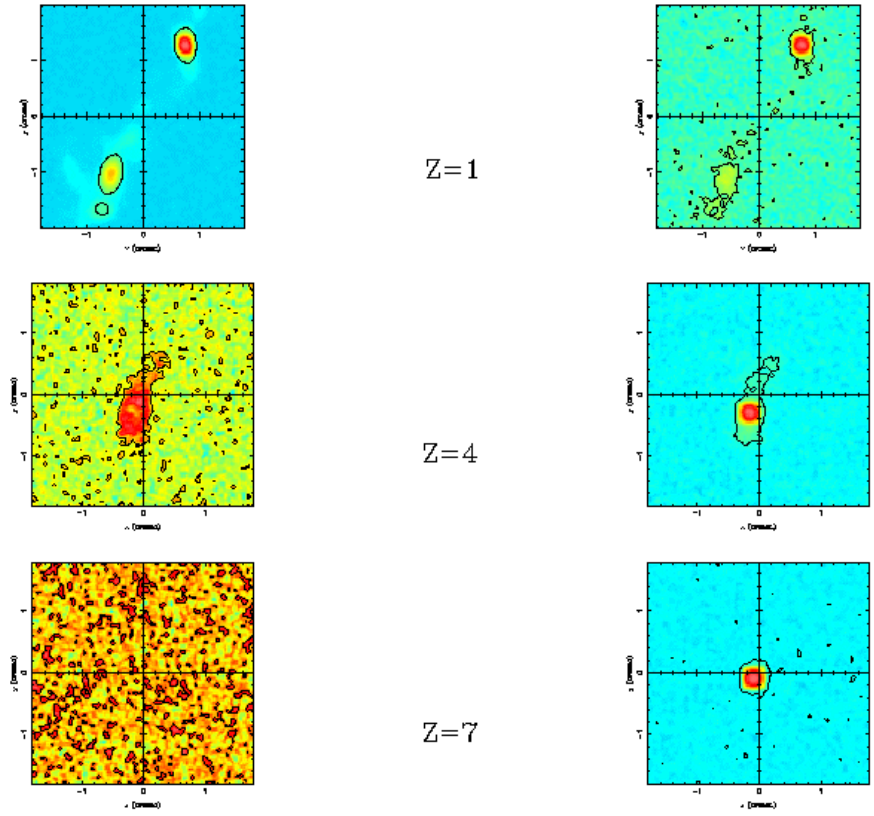
Modeling of the SED: three types of dust particles are considered PAH, small and big grains
A population synthesis model is used from the stars formed in the simulation, their light is absorbed by the gas in the same line of sight, within any resolution element, and is re-radiated by the dust (from Melchior et al. 2001).

Library of merging galaxies:
the missing link, baryons
star-formation and feedback
disks and angular momentum
dynamical friction..

Observations of the objects:
toward predictions for NGST, ALMA, FIRST-HERSCHEL
and before, GBT, LMT..

Continuum and lines

"Observation" of the simulated galaxies at different redshifts.
Left with NGST
Right with ALMA



CONCLUSIONS

Opening of the ALMA "window"

- how galaxies are formed
- star formation history
- merger efficiency to transform baryons in energy, reprocessed by dust
- history of gas enrichment
- formation of bulges, disks, etc..