3D spectroscopic surveys: Spatially resolved properties of high-z galaxies

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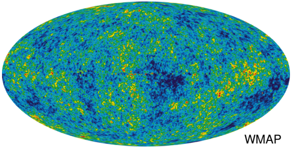
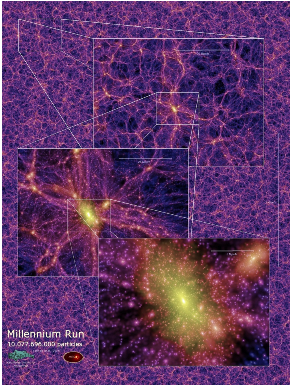
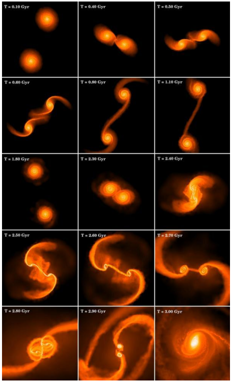
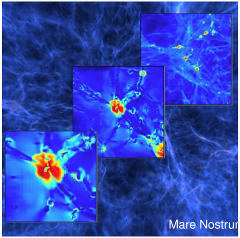
Galaxy formation and evolution processes





Physics of baryons



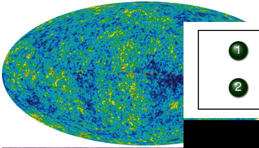


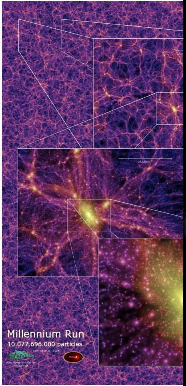
Galaxy mergers	VS	Diffuse gas accretion
	&	
Secular evolution	VS	Environmental effect

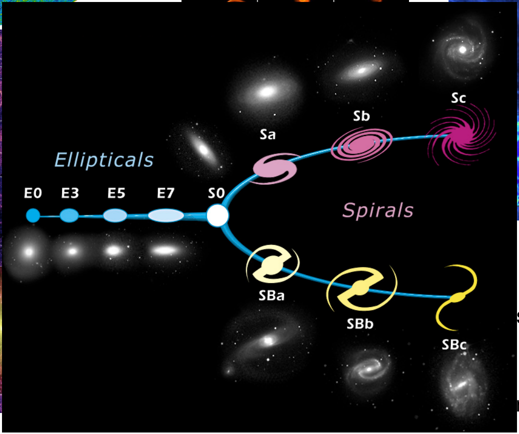
Galaxy formation and evolution processes

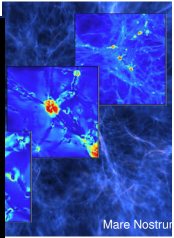
Physics of baryons

1. **Contribution of these processes**
2. **Hubble sequence build-up**









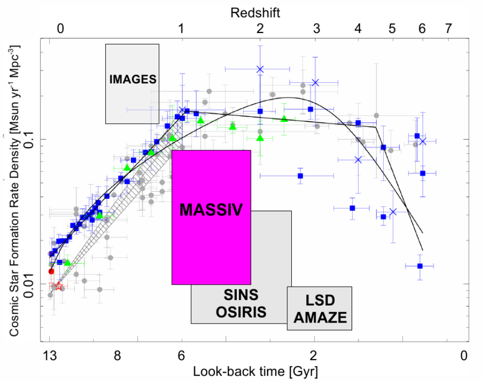
se gas accretion

ronmental effect

3D spectroscopy surveys

Samples at $0.5 < z < 3$

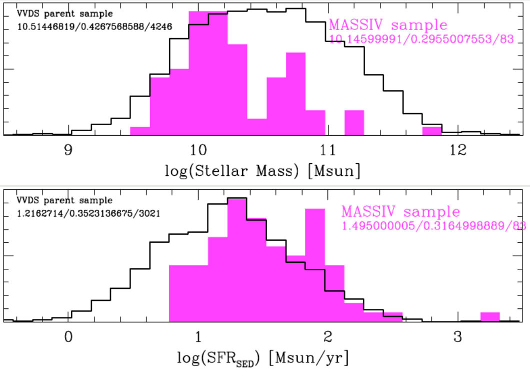
- Peak of cosmic star formation activity
- Morphological transition
- Only emission lines can be studied due to current instrument sensitivity
- Surface brightness dimming : $\propto (1+z)^4$
- Various observational setups
- Various selection functions



Contini et al. (2011) – adapted from *Hopkins (2006)*

Samples vs parent samples : representativeness

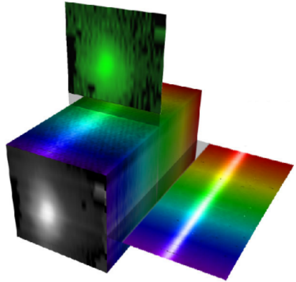
MASSIV ($0.9 < z < 1.8$), built from VVDS, a complete sample down to $I_{AB} \sim 24.5$

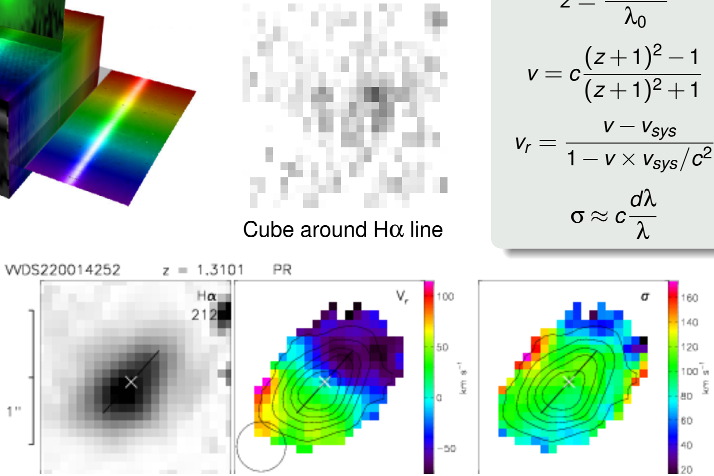


Contini et al. (2011)

- Not massive galaxies
- **Representative of star-forming galaxies**

From 3D-spectroscopy observations to kinematic maps





Cube around Hα line

Doppler-Fizeau

$$z = \frac{\lambda - \lambda_0}{\lambda_0}$$

$$v = c\frac{(z+1)^2 - 1}{(z+1)^2 + 1}$$

$$v_r = \frac{v - v_{sys}}{1 - v \times v_{sys}/c^2}$$

$$\sigma \approx c\frac{d\lambda}{\lambda}$$

Hα flux map   Hα velocity field   Hα velocity dispersion

Resolution vs. sensitivity

$0.7 < z < 4$: small variation of the physical scale (~ 8.5 kpc/")

Seeing limited vs. AO

- Seeing limited : $\sim 0.6 - 1.0$"
- AO : $\sim 0.1 - 0.4$"

Higher sampling with AO $\Longrightarrow$ Lower sensitivity (extended sources)

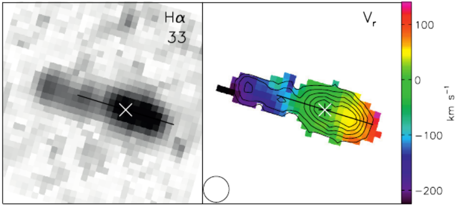
Current solution : lensed surveys

- Spatial magnification
- Flux magnification

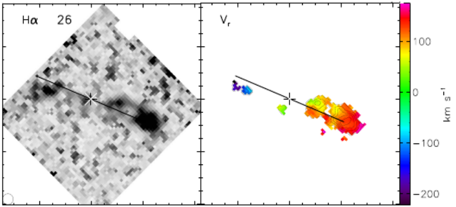
$\Longrightarrow$ Can target smaller and fainter sources + use AO

BUT difficulties to build statistical samples (*Stark et al., 2008 ; Jones et al., 2010*)

Seeing limited : resolution $\sim$ 6 kpc



AO : resolution $\sim$ 2 kpc



Contini et al. (2011)

$z = 1.27$

$M_* \sim 5.5 \times 10^{10} M_\odot$

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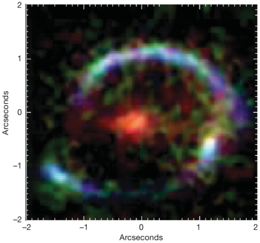
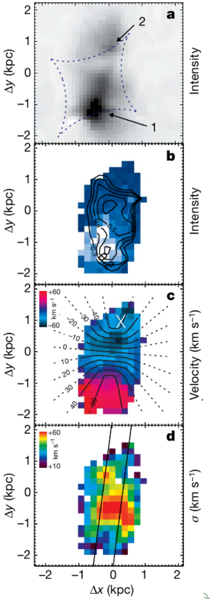
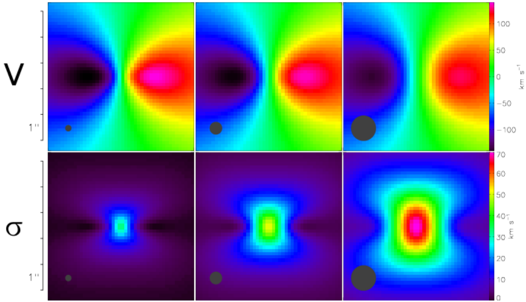


Stark et al. (2008)
$z = 3.07$
resolution $\sim$ 100 pc
$M_* \sim 6 \times 10^9 M_\odot$



Effect of beam smearing on kinematical maps



Epinat et al. (2010)

Simulation of a rotating disk

- Seeing increasing from 0.125″ to 0.5″
- Null local velocity dispersion

Results

- Velocity gradient decreases
- Velocity dispersion has a peak

Rotating disk modeling

- Gas in rotation in a plane : $V_{los} = V_{sys} + V_{\theta} \cos\theta \sin i$
- Modeling allows to recover the parameters (e.g. Epinat et al. 2010 ; Davies et al. 2011)

Kinematics classifications

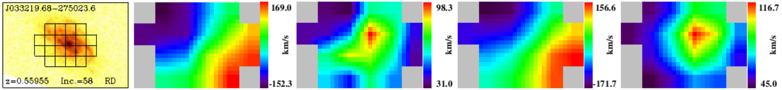
Goals

- Which galaxies are regular rotating disks (gas expected in a plane)
- Merger rate
- Rate of galaxies with other kinematics (irregular, non rotating galaxies, dispersion dominated disks, etc.)

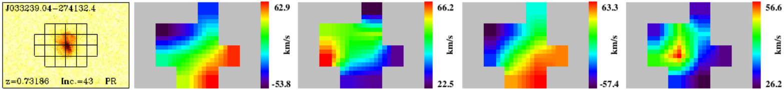
IMAGES classification

Based on the position of the velocity dispersion peak (*Flores et al., 2006, Yang et al., 2008*)

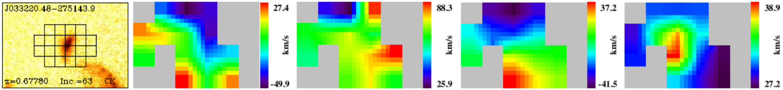
Rotating Disk



Perturbed rotation



Complex kinematics

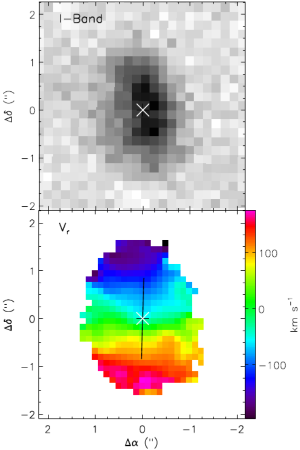


HST VF-obs σ-obs VF-model σ-model

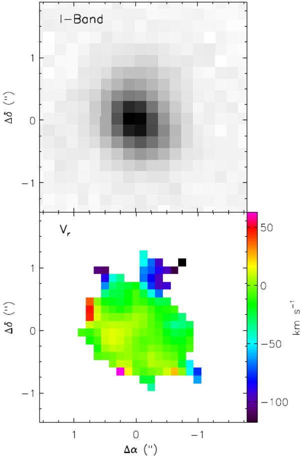
MASSIV classification

Based on agreement between morphology and kinematics

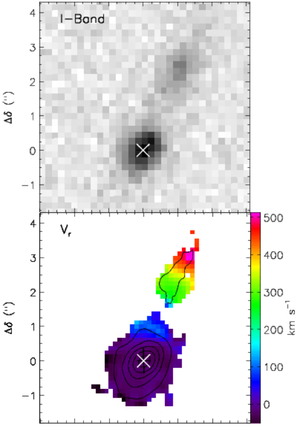
Rotators



Non-rotating galaxies



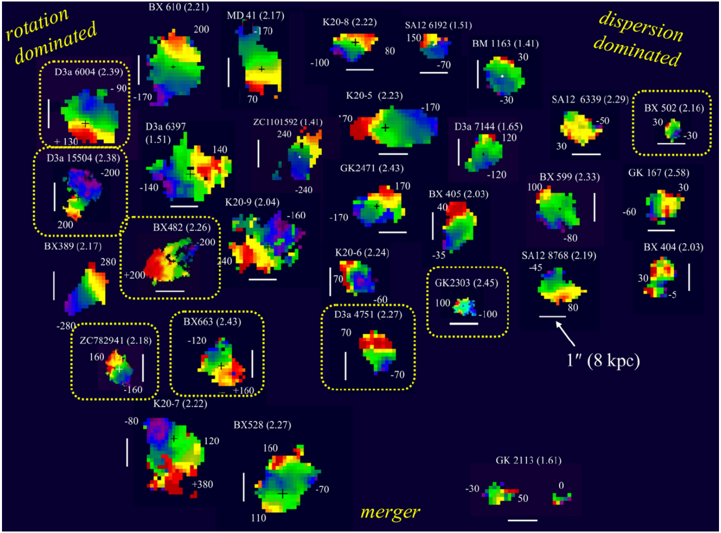
Interacting galaxies



Epinat et al. (2011)

SINS classification

Based on a kinemetry analysis (*Shapiro et al., 2008*)



Classification comparison

Classification results and interpretations

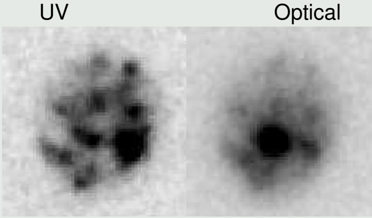
- $z \sim 0.6$ (IMAGES) : anomalous kinematics in at least 41% of the galaxy population
  $\Rightarrow$ rapid evolution of kinematics most probably induced by merging
- $z \sim 1.3$ (MASSIV) : at least 30% of interacting galaxies (mainly minor mergers)
  + at least 35% of dispersion dominated objects or with no rotation
  + some stable disks similar to low-z disks
  $\Rightarrow$ Still several processes in action at $z > 1$ in contrast with $z \sim 0.6$
- $z \sim 2$:
  SINS : Evidence for cold gas accretion due to 1/3 of dispersion dominated disks
  + Significant fraction of mergers ($\sim 1/3$)
  OSIRIS (*Law et al., 2009*) : non rotating objects support cold gas accretion

Coherent scenario can be built but a consensus is not reached on the interpretation of the kinematics.

One clear evidence : high redshift galaxies have higher local velocity dispersion on average

Clumpy galaxies : which processes are responsible ?

Intermediate redshift : interactions ?

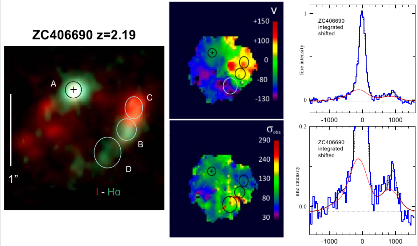


Puech (2010)

- $\sigma \sim 30$ km/s
- Half compatible with major mergers
- Cold gas accretion not efficient at $z \sim 0.6$ (*Kereš et al., 2009*)

$\Rightarrow$ **In favour for interactions as the main driver of clump formation**

$z \sim 2$: cold gas accretion ?



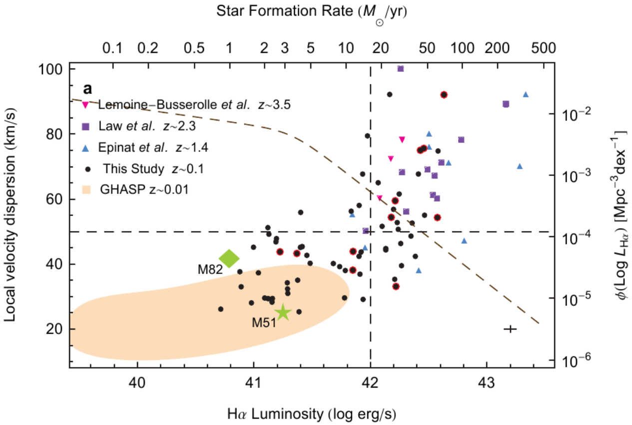
Genzel et al. (2010)

- $\sigma > 60$ km/s
- Compatible with rotating disks
- Cold gas accretion is efficient at $z \sim 2$

$\Rightarrow$ **In favour for cold gas accretion for clump formation**

High velocity dispersions at high-z

- Local galaxies are not in the same star formation regime than high-z galaxies
- *Green et al. (2010), Gonçalves et al. (2010)* found local counterparts with both high σ and SFRs



Green et al., 2010

Gaseous velocity dispersion may be powered by star formation (e.g. Lehnert et al. 2009)

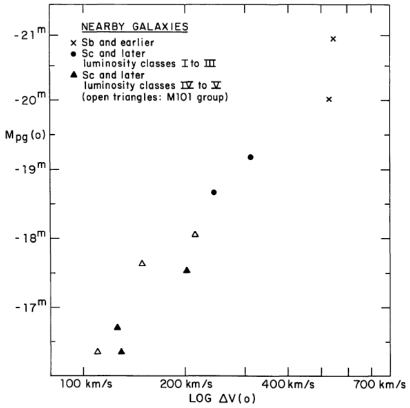
Evolution of the Tully-Fisher relation

Original TF relation in the local Universe

- Link between magnitude and rotational velocity
- Distance estimator (*Tully & Fisher, 1977*)

TF at high-z

- Difficulty : magnitude has to be in rest-frame to be compared
  $\Rightarrow$ use SEDs to derive stellar masses
- If gas content is constrained : baryonic TF relation



Tully & Fisher (1977)

Stellar mass Tully-Fisher relation evolution at high redshift

IMAGES : $z \sim 0.6$ (*Puech et al., 2009*)

- Evolution of the zero point : $M_{star} \times 2$
- Scatter due to perturbed kinematics

MASSIV : $z \sim 1.3$ (*Vergani et al., in prep*)

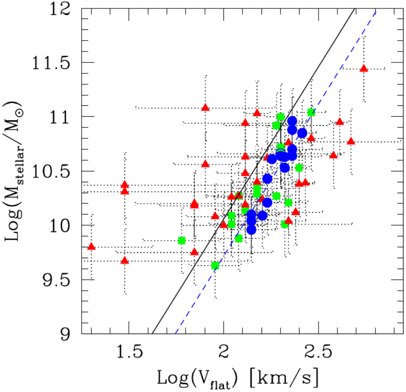
- No significant evolution from $z = 0$
- Large scatter

SINS : $z \sim 2.2$ (*Cresci et al., 2009*)

- Evolution of the zero point : $M_{star} \times 2.5$
- Small scatter

LSD/AMAZE : $z \sim 3$ (*Gnerucci et al., 2010*)

- Evolution of the zero point from $z = 2.2$
- Large scatter



Puech et al. (2009) : z ~ 0.6

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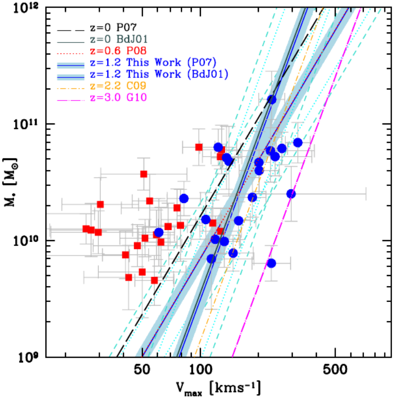

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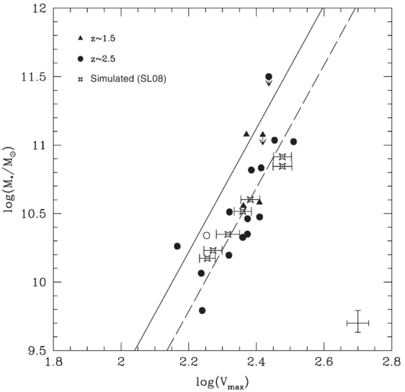

Cresci et al. (2009) : $z \sim 2.5$

Stellar mass Tully-Fisher relation evolution at high redshift

IMAGES : $z \sim 0.6$ (*Puech et al., 2009*)

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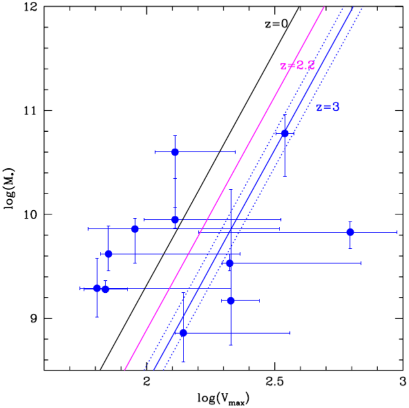


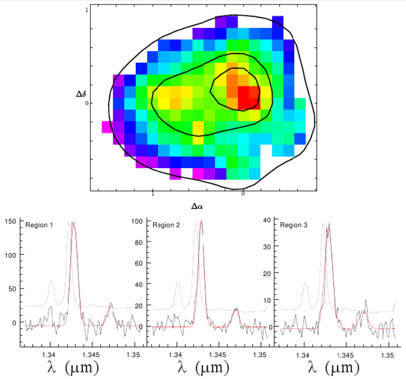
Gnerucci et al. (2010) : $z \sim 3$

Abundance estimators

MASSIV

Calibration by *Pérez-Montero & Contini (2009)* :

$12 + \log \frac{O}{H} = 9.07 + 0.79 \times \log \frac{[N\textsc{ii}]}{H\alpha}$

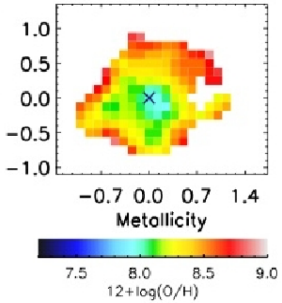


Queyrel et al. (2011)

LSD/AMAZE

Three diagnostics (from SINFONI data) :

- $[O\textsc{iii}]\lambda5007/H\beta$
- $[O\textsc{iii}]\lambda5007/[O\textsc{ii}]\lambda3727$
- $[Ne\textsc{iii}]\lambda3870/[O\textsc{ii}]\lambda3727$



Cresci et al. (2010)

Positive metallicity gradients

MASSIV

Study of abundance gradients in 29 galaxies at $z \sim 1.3$:

- Positive abundance gradients in half the sample
- 7 unambiguous positive gradients : majority of interacting galaxies

Interpretation : Fresh gas accreted in the center due to interaction tidal tails

Queyrel et al. (2011)

LSD/AMAZE

Discovery of positive abundance gradients in 3 rotationally supported galaxies at $z \sim 3$
Interpretation : Cold flows along cosmic filaments toward the center

Cresci et al. (2010)

Conclusions

Different mass assembly mechanisms

$z \sim 0.6$ **: merging main driver (IMAGES)**

- Kinematics analysis + Clumpy galaxies + Baryonic Tully-Fisher relation (gas content is already there)

$z > 2$ **: cold gas accretion substantial driver (SINS, LSD/AMAZE, OSIRIS)**

- Existence of dispersion-dominated disks + Positive abundance gradients in disks + Clumpy galaxies

Transition around $z \sim 1 - 2$ **(MASSIV, OSIRIS)**

- Positive abundance gradients in merging systems + High fraction of interacting galaxies
- Stable disks in place
- But also dispersion dominated disks : cold gas accretion ?

Need for numerical simulations

- Signatures of mergers, gas rich disks, spheroids, etc.
- How can we explain non-rotating galaxies ?
- Origin of high gaseous velocity dispersion
- Impact of strong star formation
- Explain evolution of scaling relations (e.g. Tully-Fisher) + scatter around these relations
- Can inverse metallicity gradient be explained by merging ? Cold flows ?

Need to convert simulations into “pseudo-observed” datacubes : same methodological biases.

Neutral and molecular gas observations of high-z galaxies

Need to constrain molecular and neutral gas content in high-z galaxies : existence of gas reservoirs ? continuous gas accretion ?

First observations : Plateau de Bures Interferometer

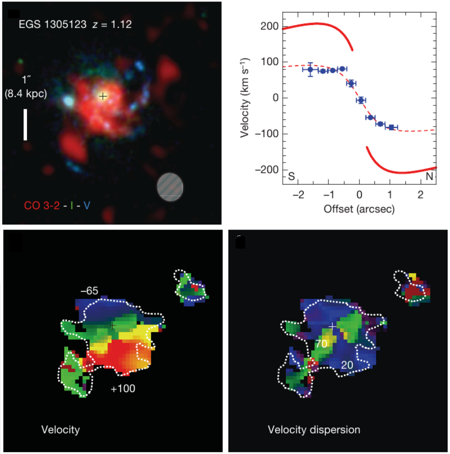
- CO observations of 3 ULIRGs : Bothwell et al. (2010)
- CO observations of 4 + 19 $z \sim 1.2$ & $z \sim 2.5$ galaxies : Taconni et al. (2008, 2010)

The future

- ALMA
- E-VLA
- SKA + precursors (ASKAP, MEERKAT)

$\Longrightarrow$ **Improved sensitivity, resolution and field**

Molecular gas content + kinematics



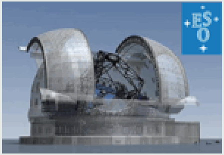
Tacconi et al. (2010)

New generation of optical and infrared 3D spectrometers

Need for better sensitivity and statistics

New instrumentation

- Large IFU in optical : MUSE/VLT
- Multi-IFU in IR : KMOS/VLT
- HARMONI/E-ELT



Future projects

- Explore new redshift ranges
- Effect of environment
- Target specific populations (most massive galaxies, less massive galaxies, AGN hosts, etc.)