Birth and physical properties of giant star forming clumps at redshift $1 \leq z \leq 2$

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Saclay, 1st July, 2015

Education

Osservatorio di Asiago

Università di Padova

PhD: CEA - Saclay

Master Thesis: Università di Padova and University of Minnesota

Bachelor Thesis: Università di Padova

University of Minnesota

Nearby and far-away galaxies

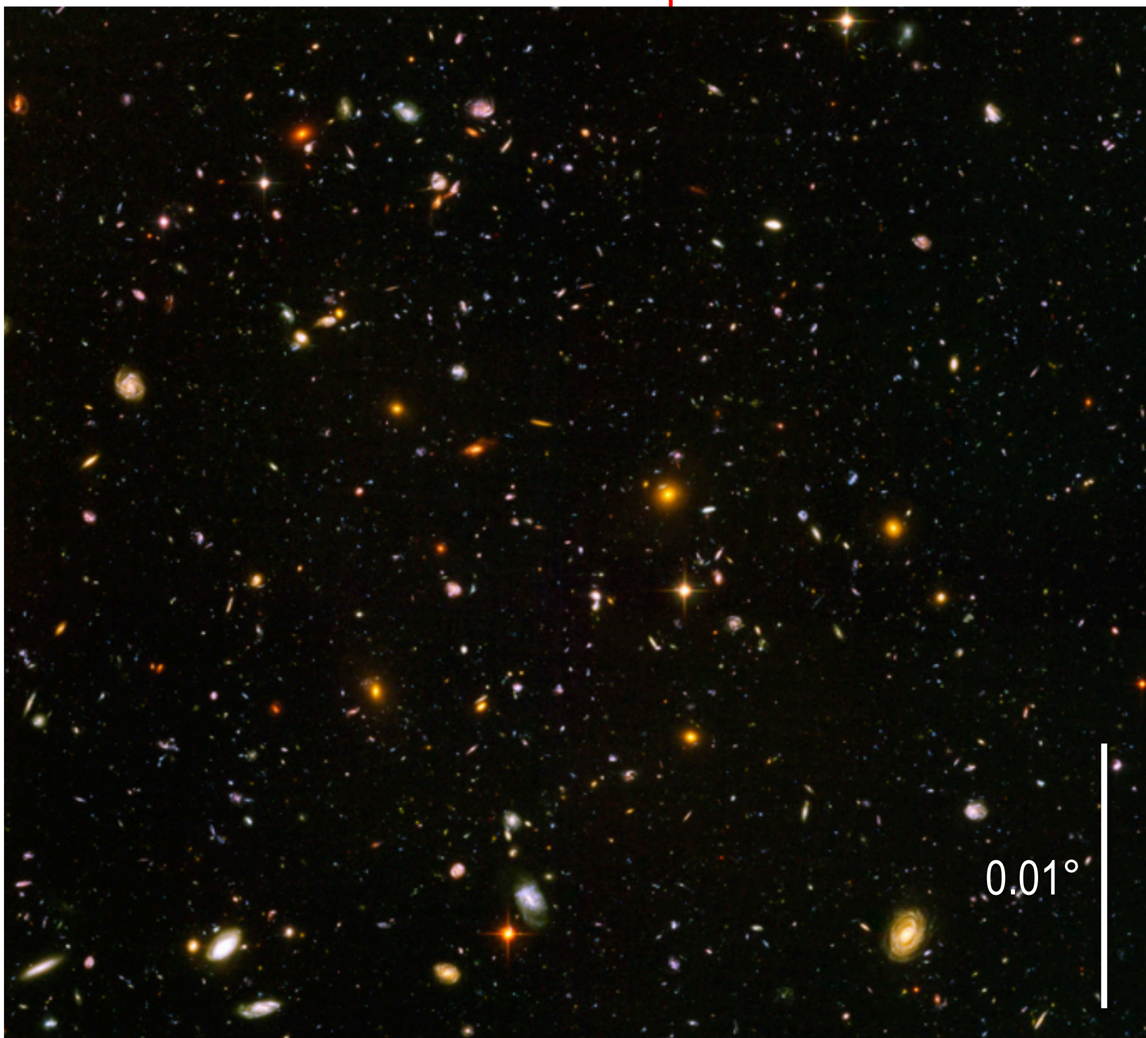
Big Bang theory: Universe has finite age
→ far-away (young) galaxies are different with respect to nearby (old) ones

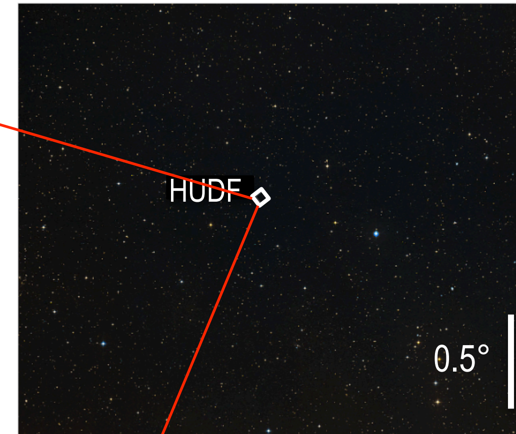
Sep 2003 – Jan 2004:
Hubble Space Telescope observed a **small region** in the Fornax constellation that appeared to be **completely dark**

HUDF size:
1/10th diameter of full moon observed from Earth

Nearby and far-away galaxies

Hubble Ultra Deep Field

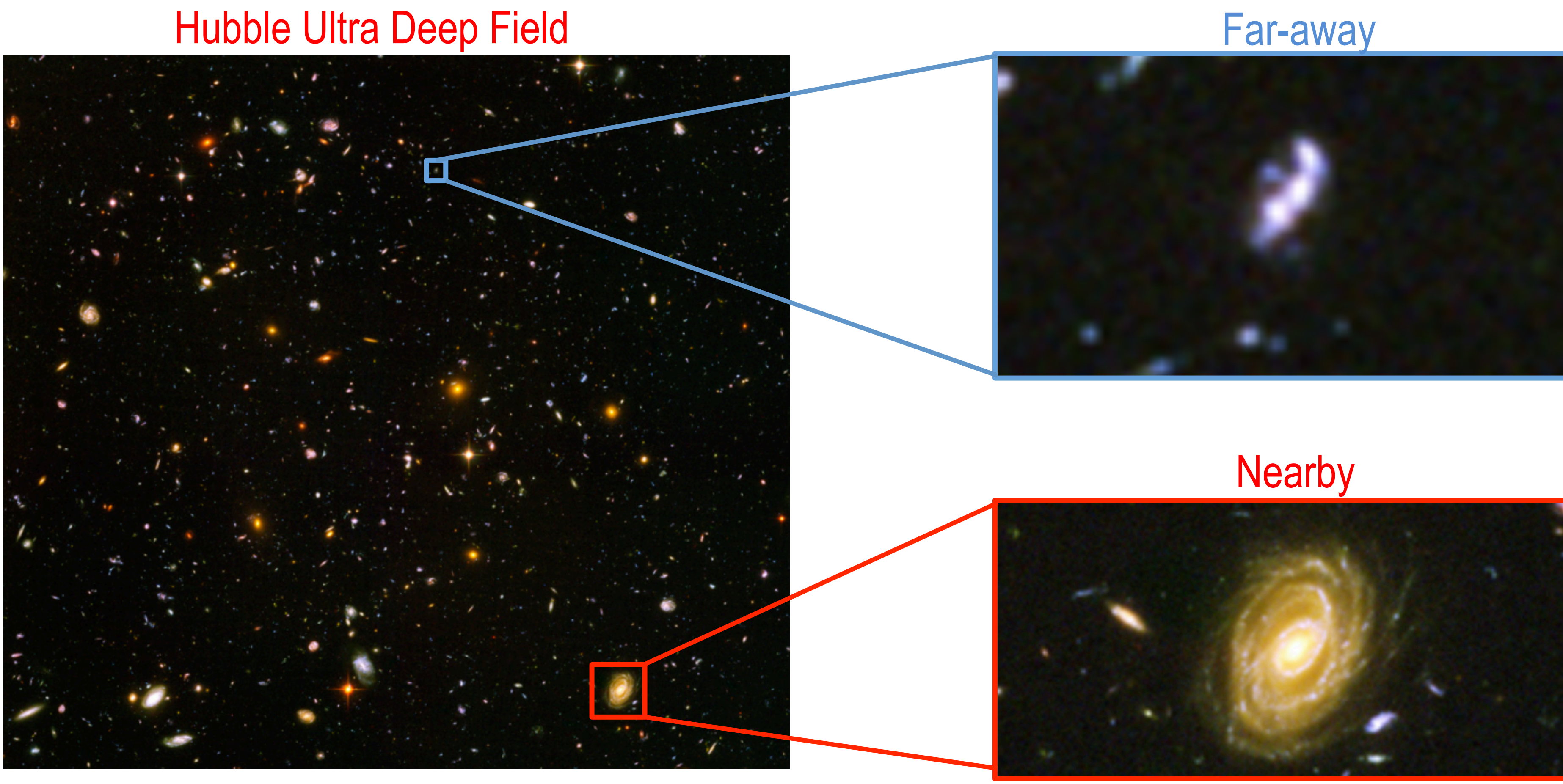




HUDF is our deepest image of the Universe: looking back ~ 13 billion years

→ more than 10,000 galaxies

Nearby and far-away galaxies



Are far-away galaxies different with respect to the nearby ones?

Nearby galaxies

Pinwheel galaxy

NGC 1300

Nearby galaxies

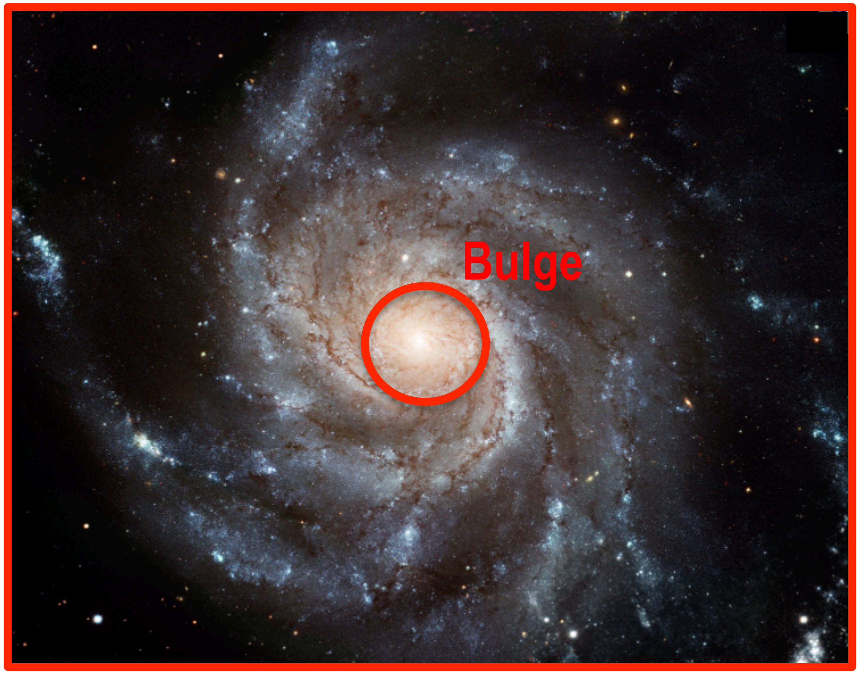
Pinwheel galaxy

NGC 1300

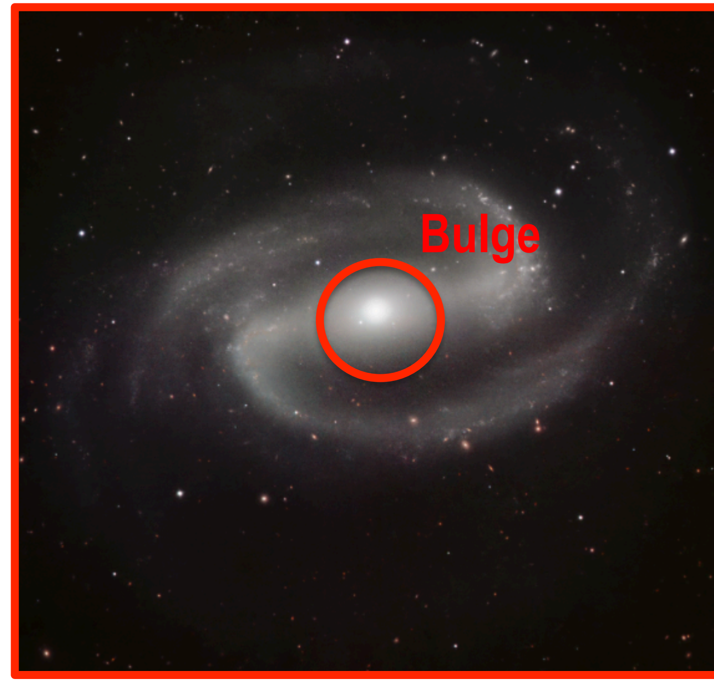
Regular shape (spiral morphology)

Nearby galaxies

Pinwheel galaxy



NGC 1300



Regular shape (spiral morphology)

Bulge with super massive black hole

Nearby galaxies

Pinwheel galaxy

NGC 1300

Regular shape (spiral morphology)

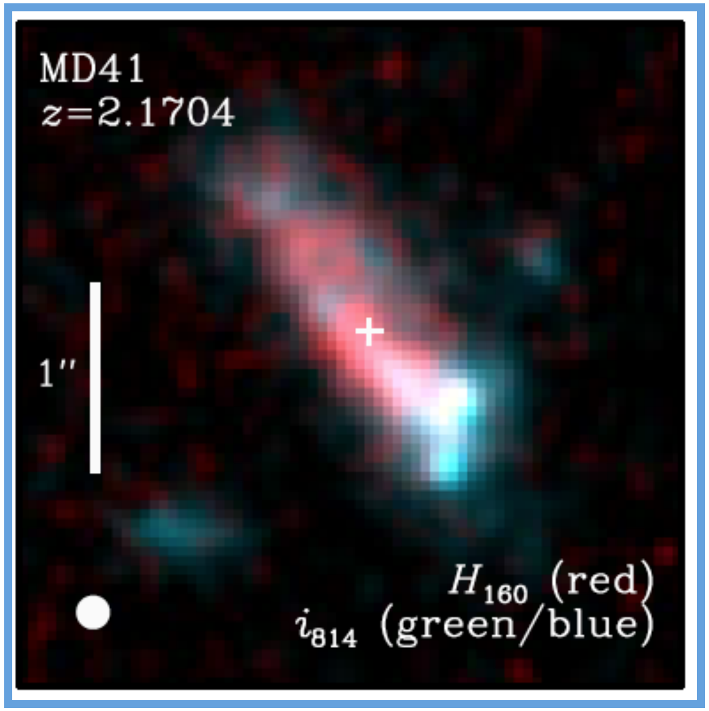
Bulge with super massive black hole

Low gas fraction

Low star formation rate

Far-away galaxies

MD41



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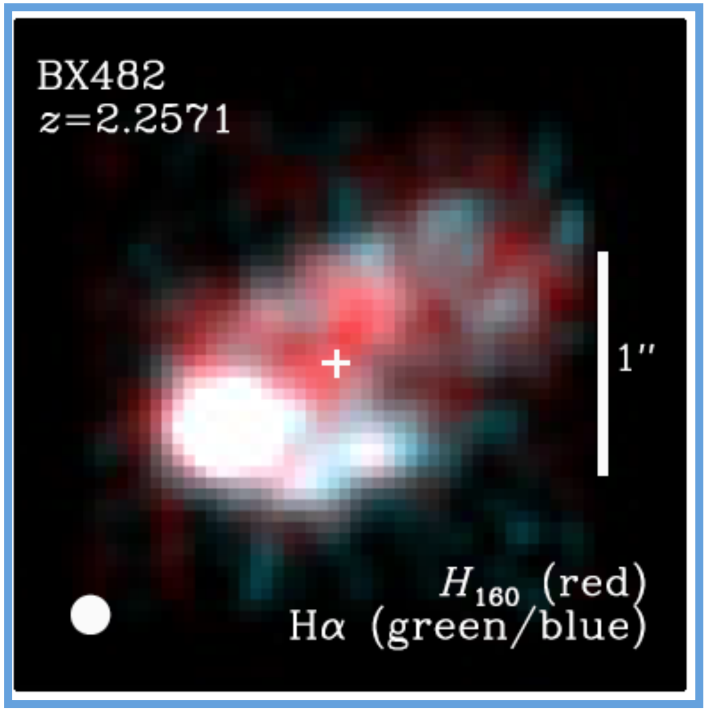
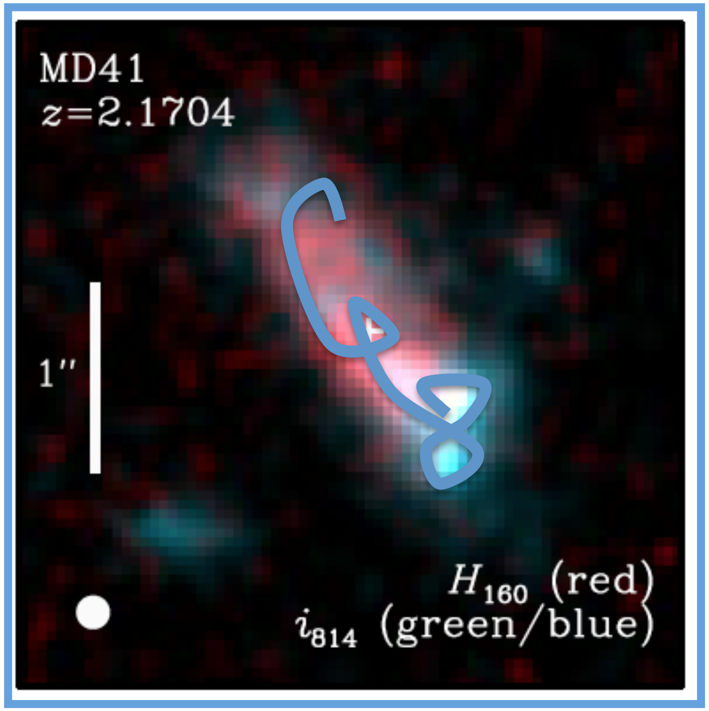


Far-away galaxies

MD41



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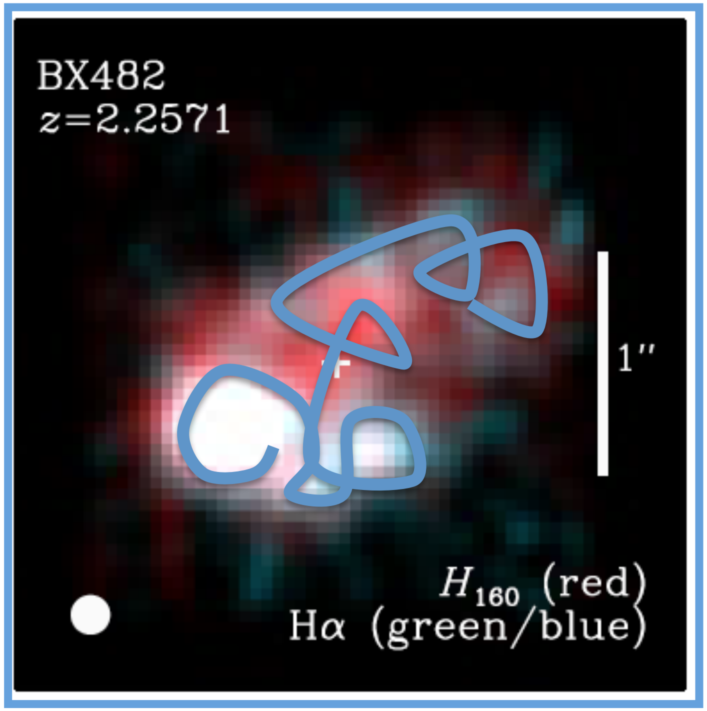
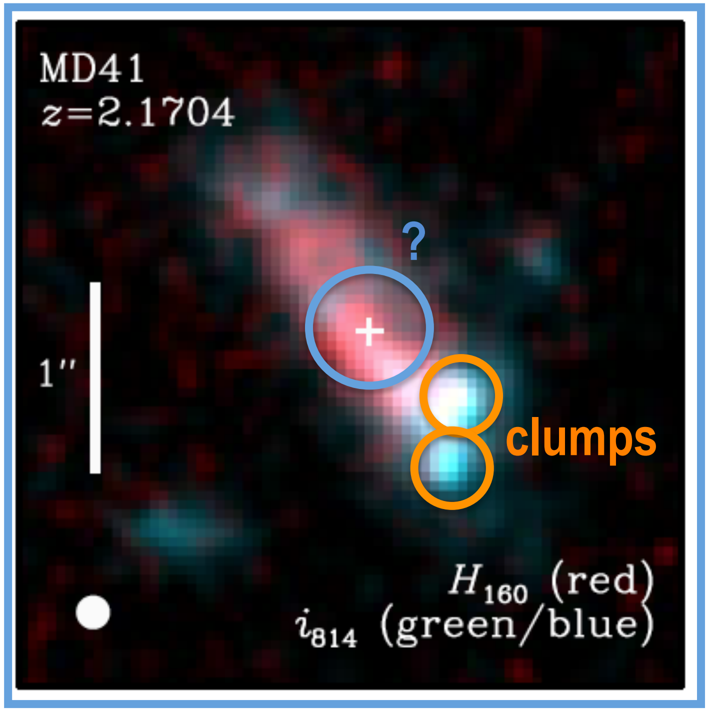


Irregular shape (clumpy morphology)

Far-away galaxies

MD41



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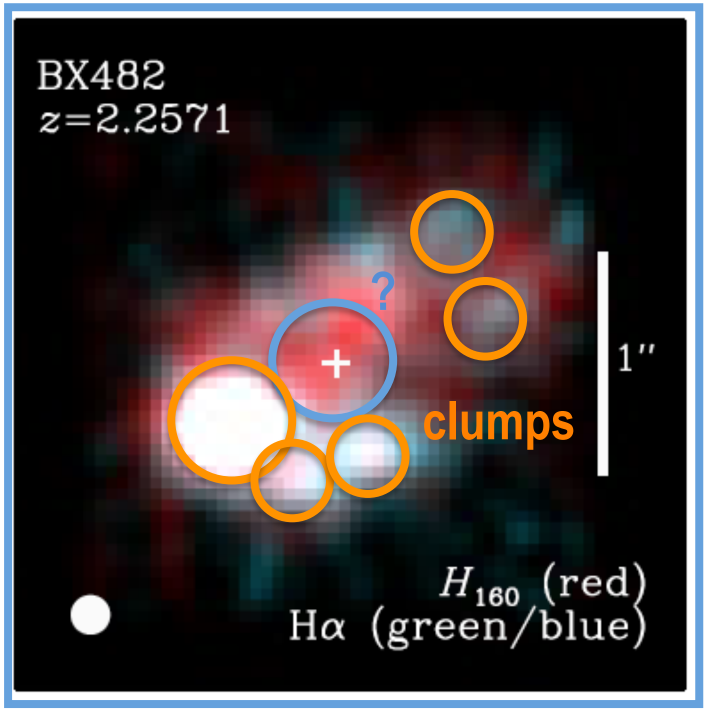
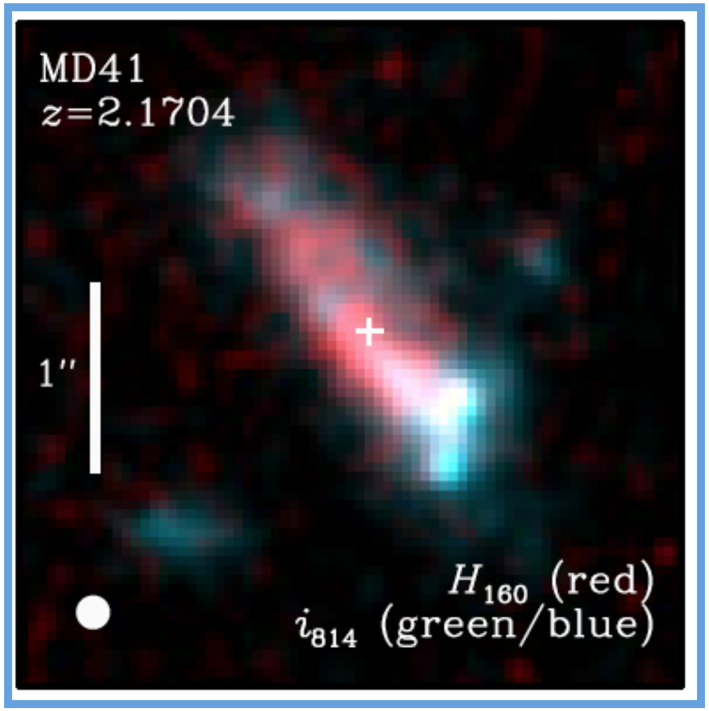


Irregular shape (clumpy morphology)

No bulge

Far-away galaxies

MD41



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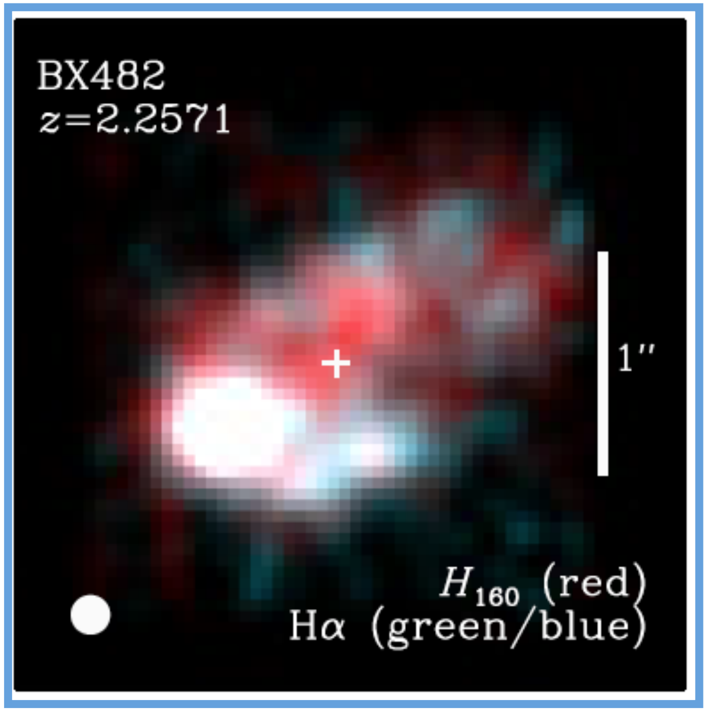


Irregular shape (clumpy morphology)

No bulge

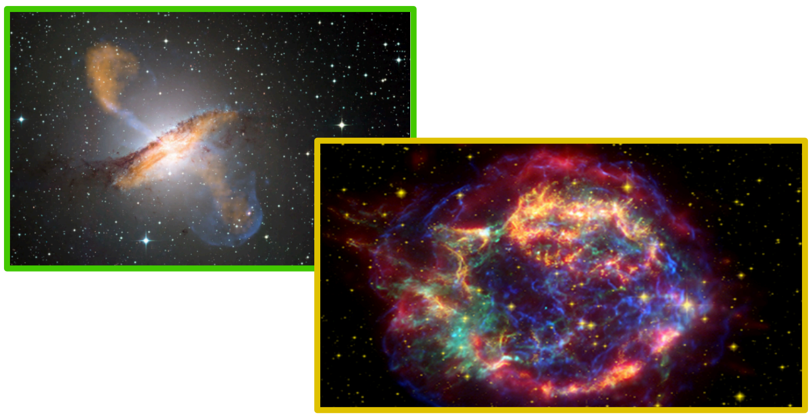
High gas fraction

High star formation rate

Open questions

Why do galaxies in the nearby and far-away Universe have different morphologies?

How is the bulge formed?



How are super massive black holes formed?

Which is the role of stellar winds (feedback)?

How are stars formed in the early Universe?

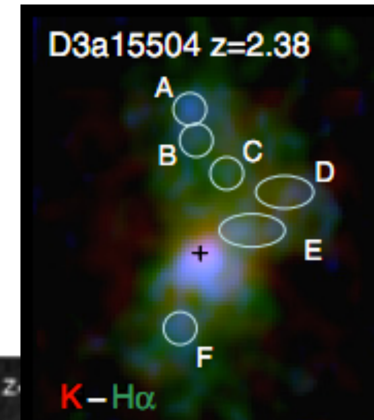
How are galaxies quenched?

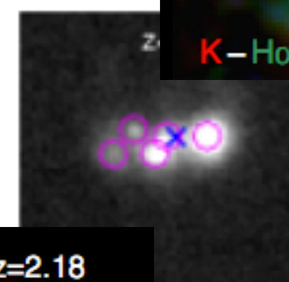
Giant clumps: why studying them?

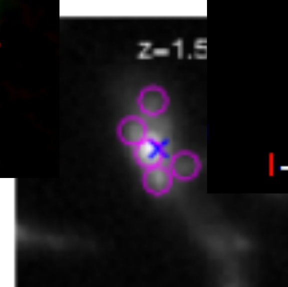
Giant clumps seem to be a **common characteristic** of distant galaxies

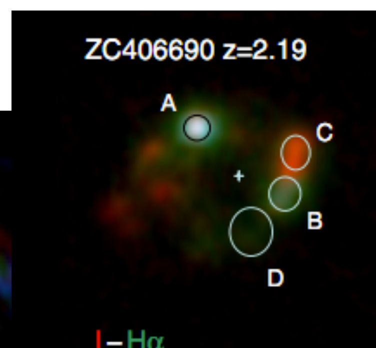
They could: strongly **influence galaxies evolution**
crucially **determine star formation** mechanisms
play a role in **super massive black holes growth**

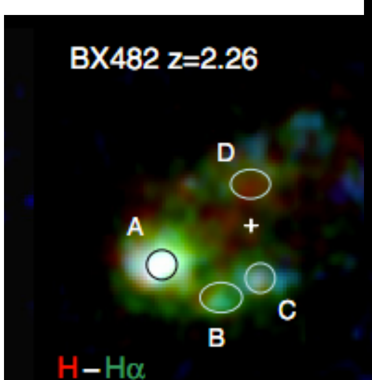
However, still little is known about **clumps formation**
physical properties
fate







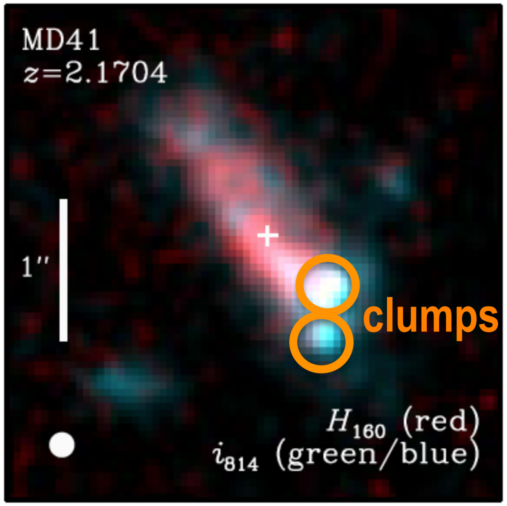


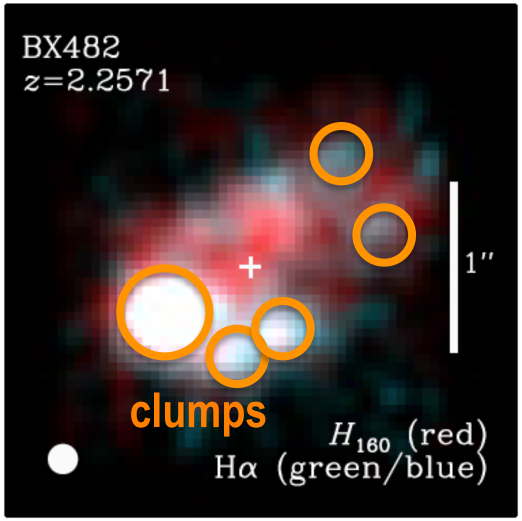


Giant clumps: observations

Clumps in far-away galaxies:

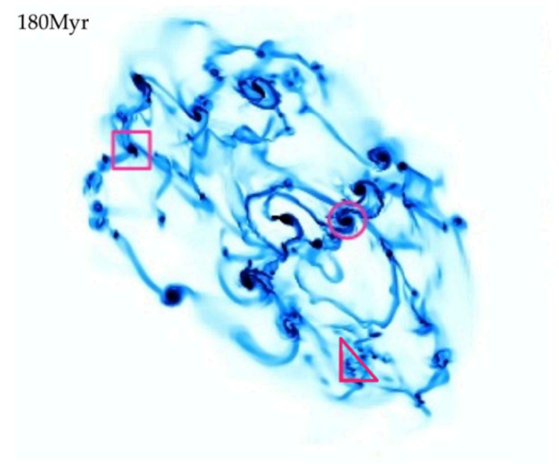
- mostly identified in Hubble Space Telescope UV images
- have total masses ~ $10^{8\text{-}9}$ $M_{\odot}$
- size ~ 1 kpc
- have SFR ~ 20 - 50% of the total SFR of the galaxy





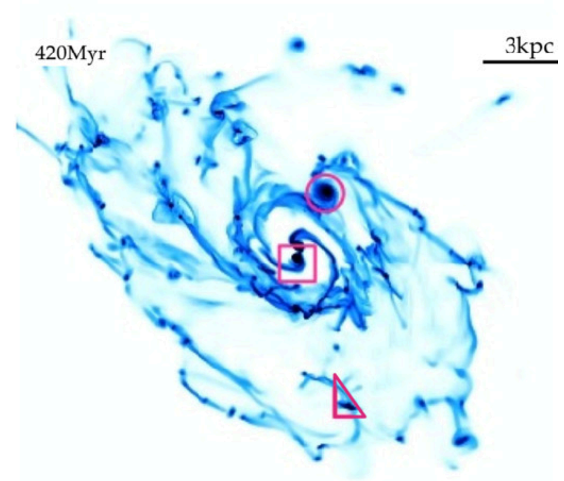
Giant clumps: simulations

- Far-away galaxies are fed with gas by large scale gas inflows
- Due to high gas fraction, violent disk instability fragments disks into giant clumps



But which is the fate of giant clumps?

- Do they migrate inward and form the **galaxy bulge**?
- Are they disrupted by stellar **feedback** in short **timescales?**



Giant clumps: this thesis

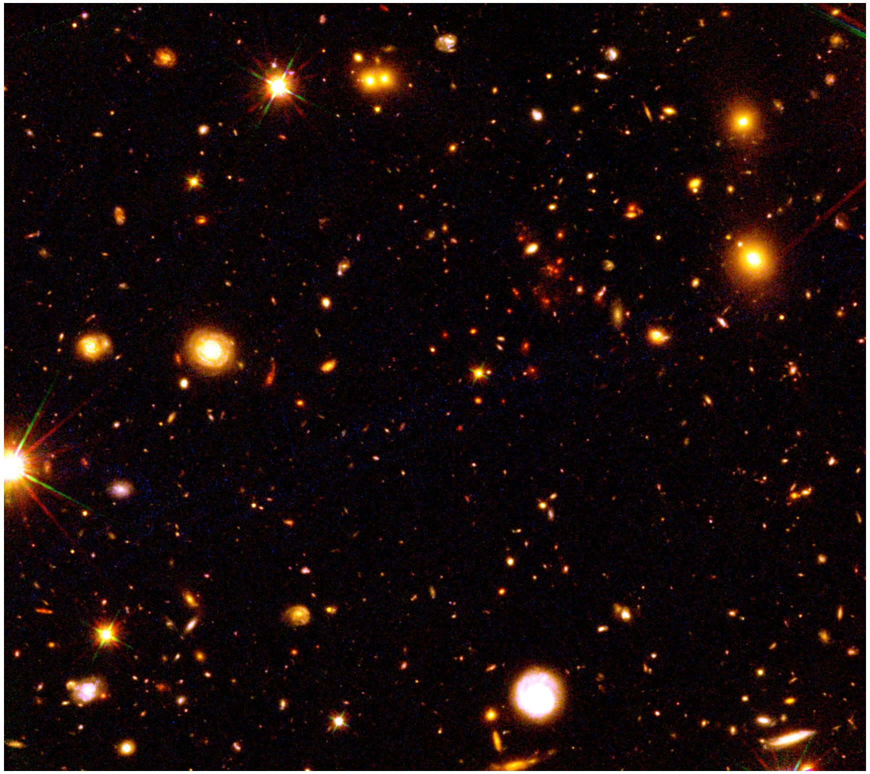
[OIII] emitting galaxies at $1 \leq z \leq 2$

Observations: WFC3 on board HST

Slitless spectroscopy
Imaging: near-IR, UVIS

→ Spatially resolved emission line maps:
first study of SFR-selected clumps

Pointed at CL J1449+0856 cluster



Gobat+ 13

A special galaxy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NATURE | LETTER

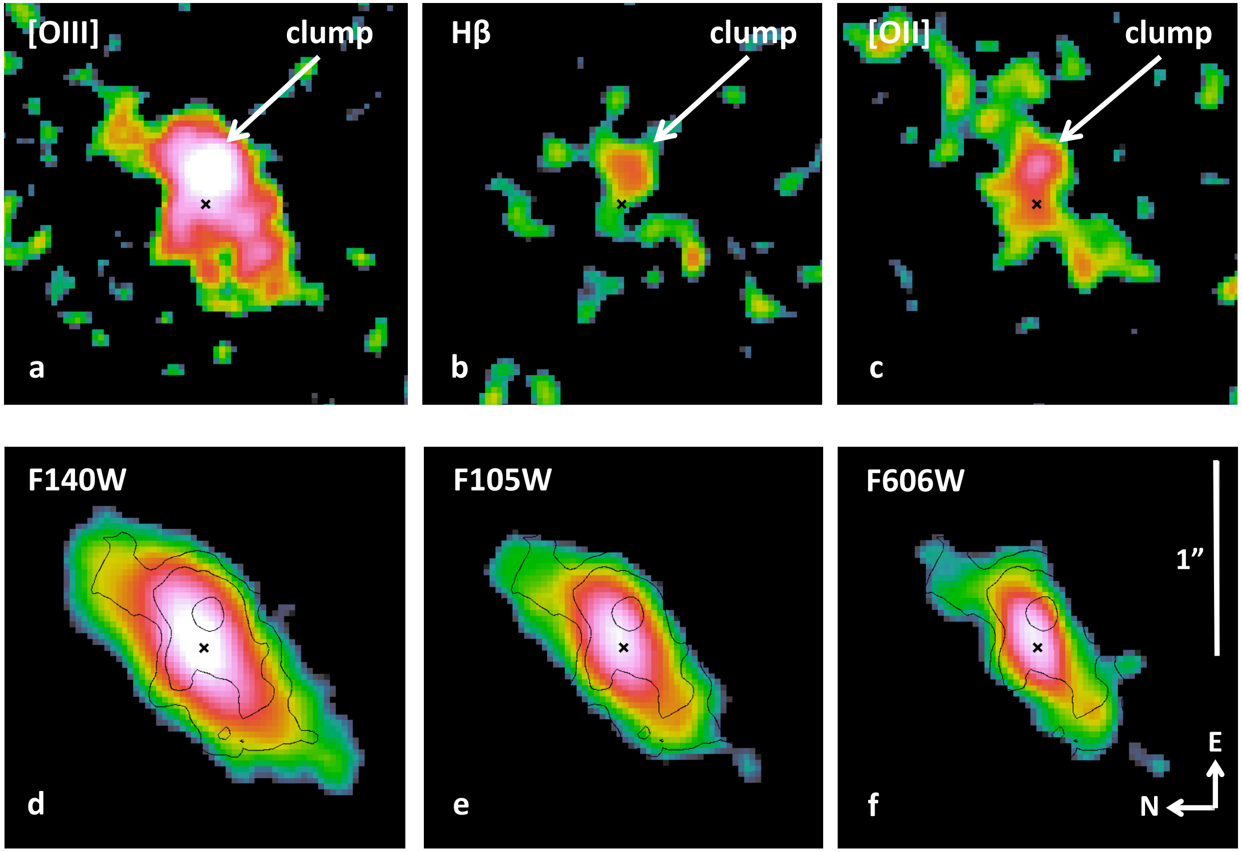
日本語要約

An extremely young massive clump forming by gravitational collapse in a primordial galaxy

A. Zanella, E. Daddi, E. Le Floc'h, F. Bournaud, R. Gobat, F. Valentino, V. Strazzullo, A. Cibinel, M. Onodera, V. Perret, F. Renaud & C. Vignali

Zanella et al., **Nature**, 2015

A star forming clump caught at birth



Emission line maps

SFR indicators

Continuum images

$M_\star$ indicators

Bright o**ff-nuclear** [OIII], Hβ and [OII] emissions with no continuum detection:
an **extraordinary young** star forming clump (age < 10 Myr)

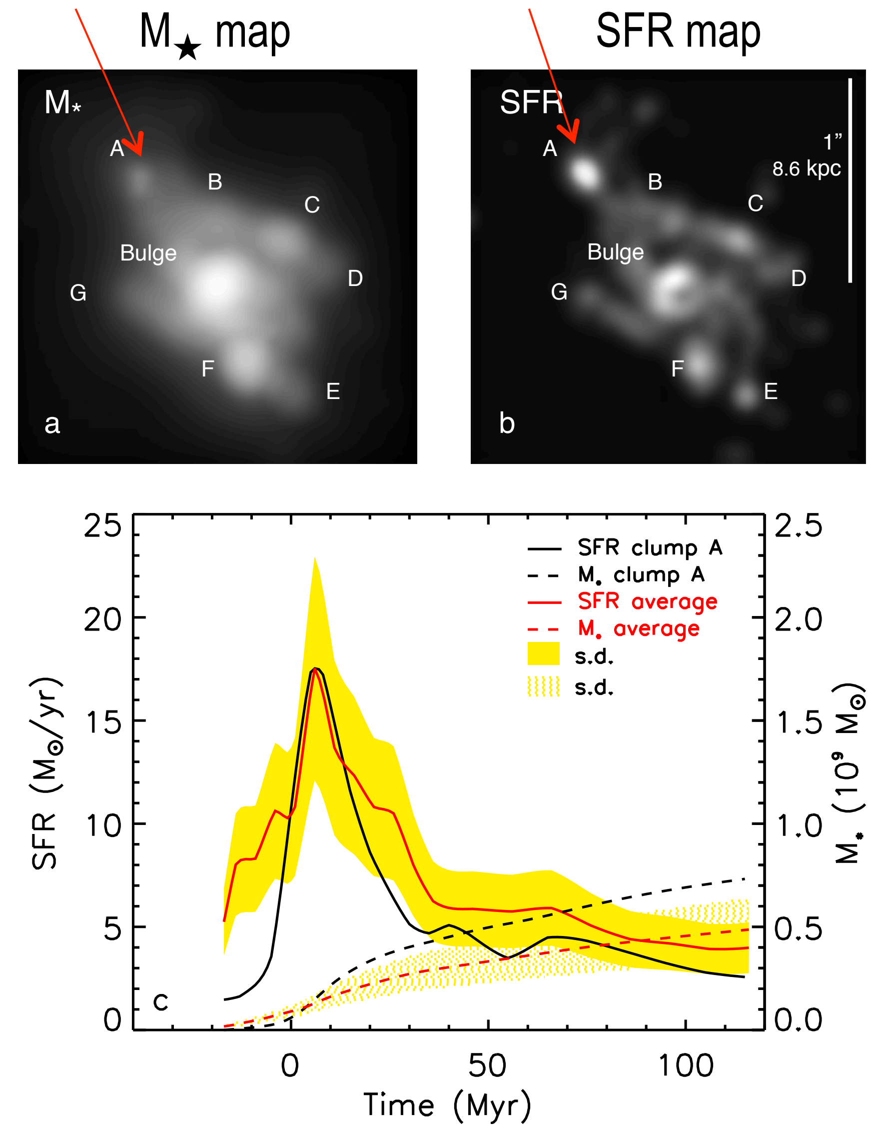
Interpreting the results with simulations

(from F. Bournaud's group)

t = 0 birthtime clump A

t = 12 Myr observed time for the $M_\star$ and SFR map

other clumps are older (100 – 300 Myr)

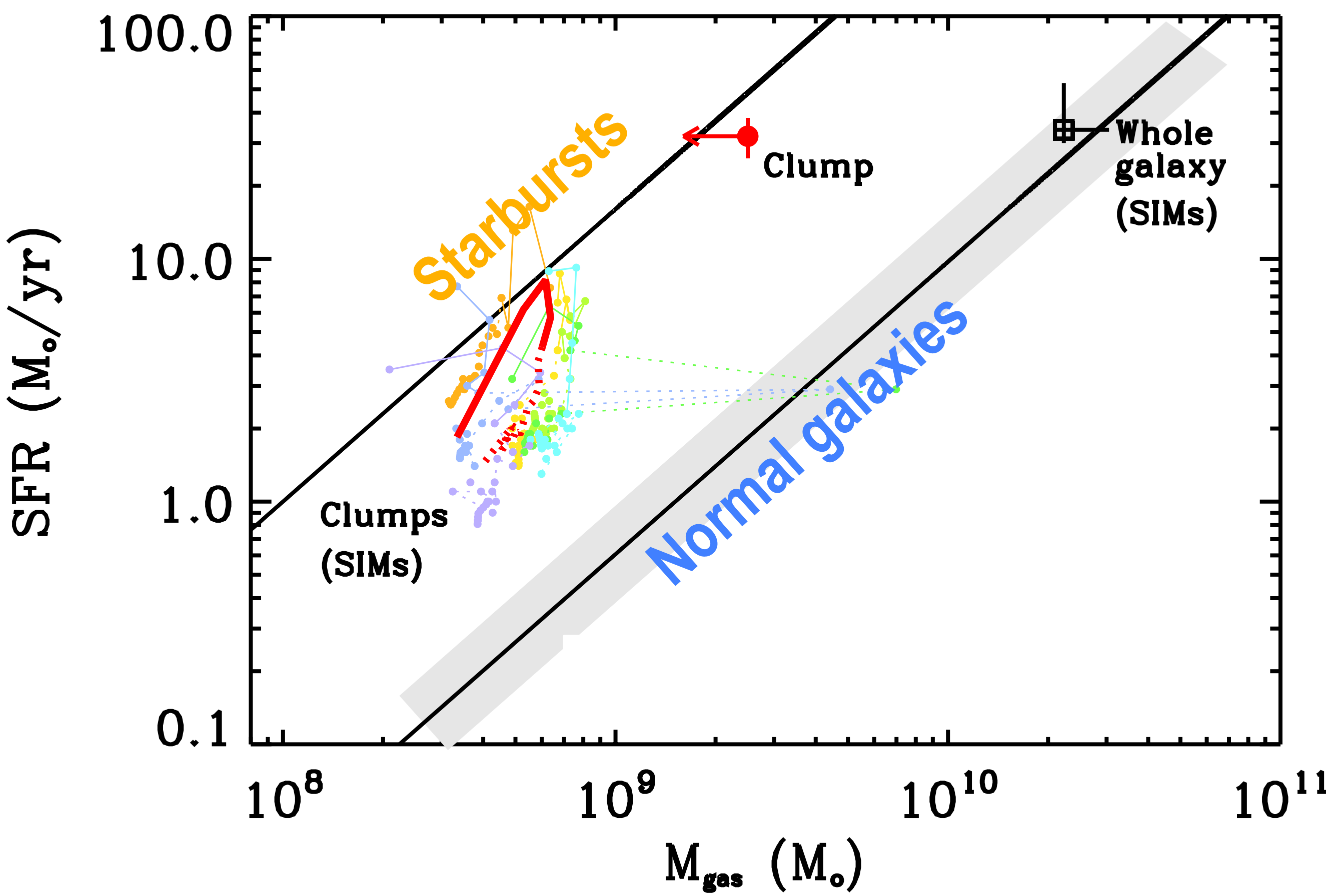


Initial burst of star formation confirmed by observations

Newly born clumps behave like mini-starbursts

Young clumps behave like **starbursts**:

they form stars with **higher efficiency** than normal galaxies



Clumps formation rate

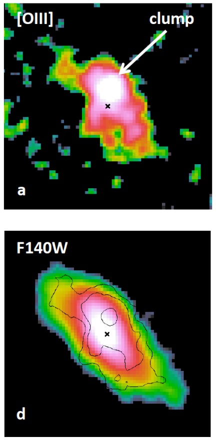
Constraints on **clumps formation rate** (CFR):

$$\mathrm{CFR} = \frac{N_{\mathrm{young}}}{t_V N_{\mathrm{gal}}}$$

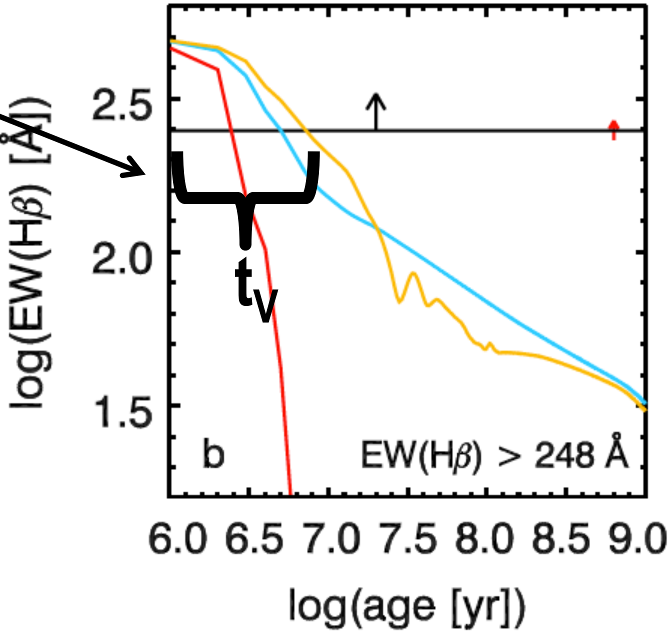
N_{young} → # of young clumps = 1

N_{gal} → # of sample galaxies = 57

t_V → Visibility window = 7 Myr

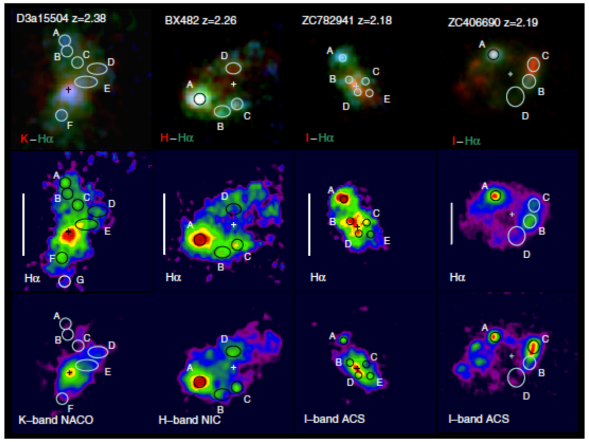


ID568

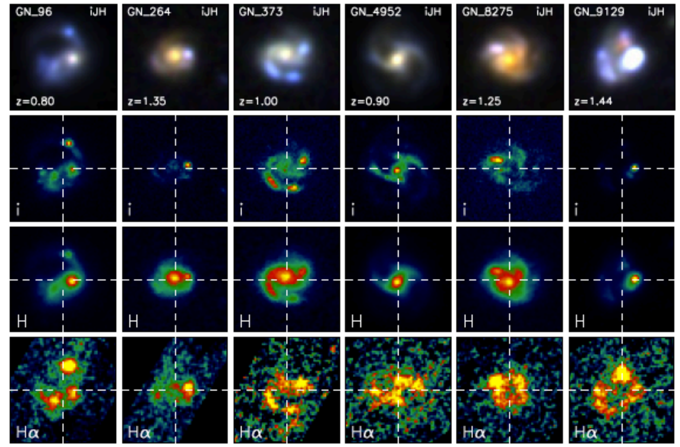


CFR ~ 2.5 clumps/galaxy/Gyr

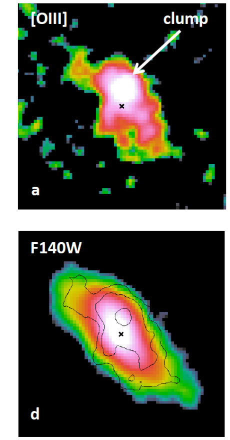
Clumps lifetime



Genzel+ 11



Wuyts+ 13



ID568

Constraints on **clumps lifetime** (LT):

$$\mathrm{LT} = \frac{\mathrm{N}_{\mathrm{cl/gal}}}{\mathrm{CFR}}$$

→ # of clumps/galaxy with $M_{tot} \geq 2.5 \times 10^9\ M_\odot$

LT ~ 500 Myr → clumps seem to **survive stellar feedback** and participate to **bulge formation**

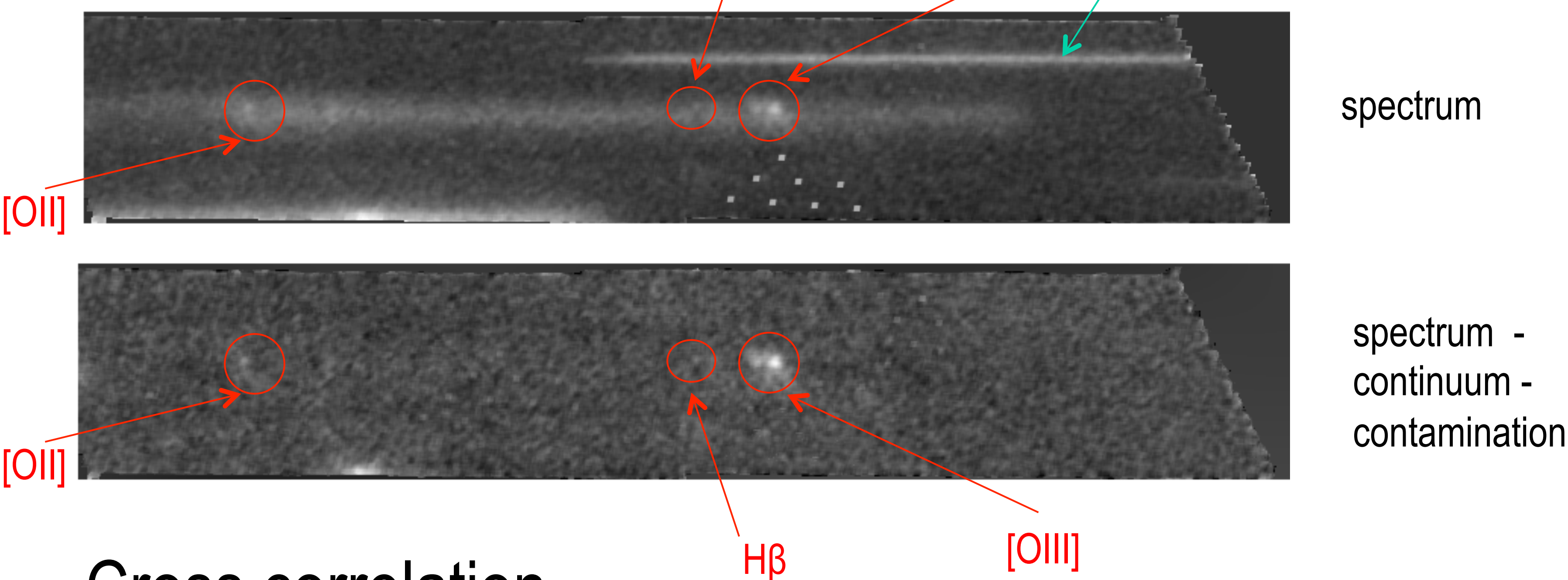
A full statistical sample of clumps

Zanella et al., in preparation

Emission line maps

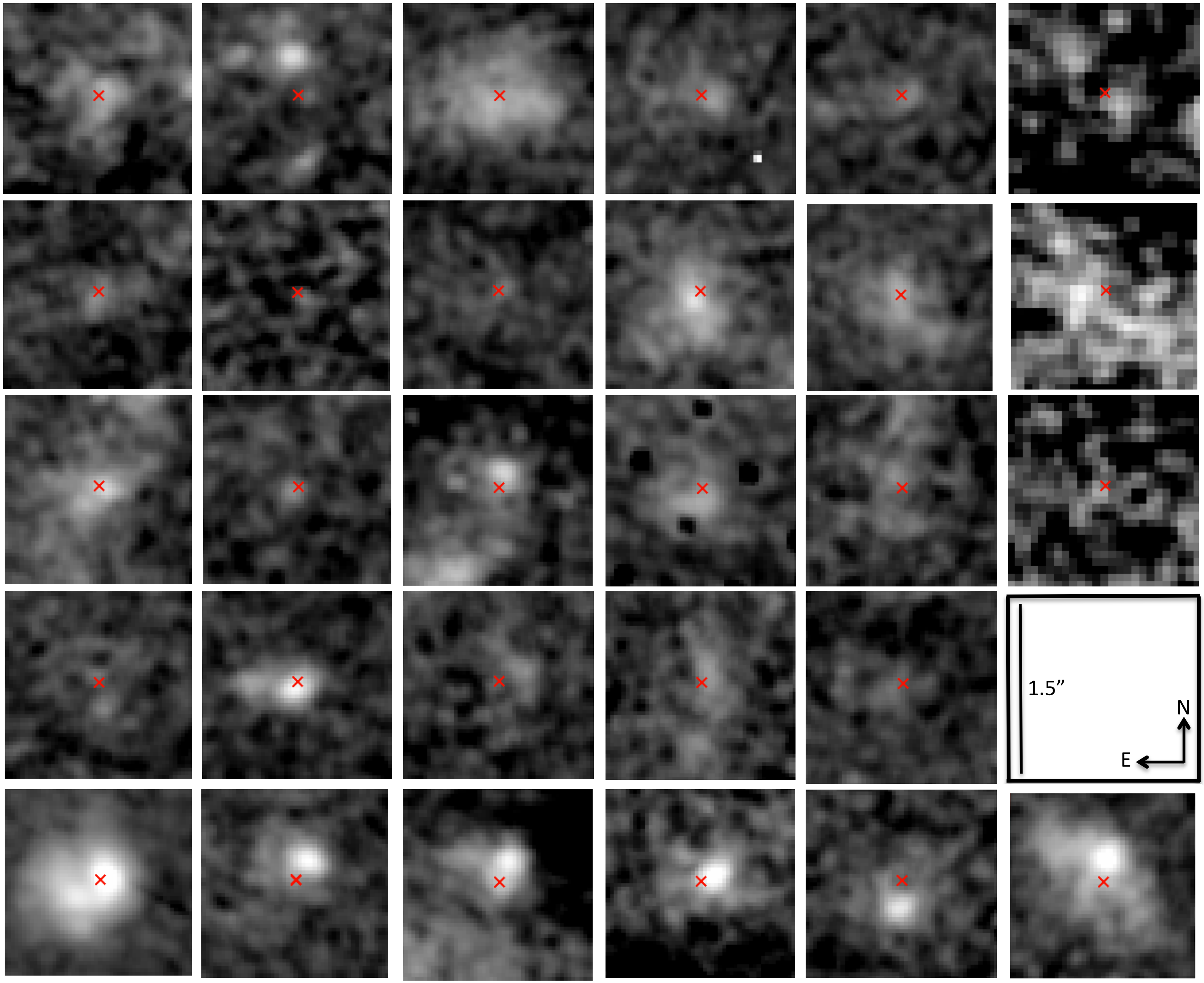
Contamination correction

Continuum subtraction

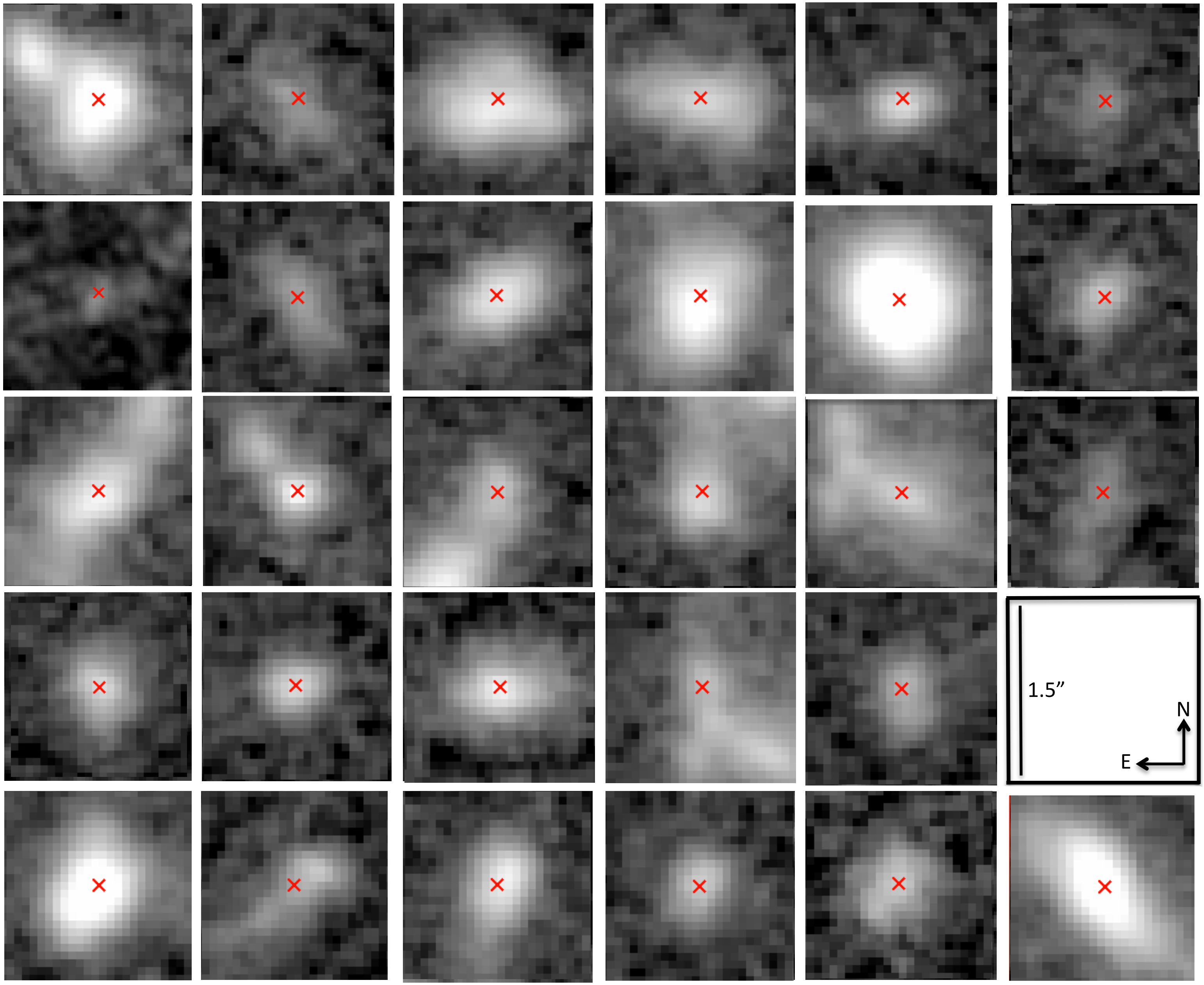


Cross correlation

[OIII]
emission
line
maps



F140W
direct
images



Forthcoming work

With a **statistical** sample
of **spatially resolved** emission line maps:

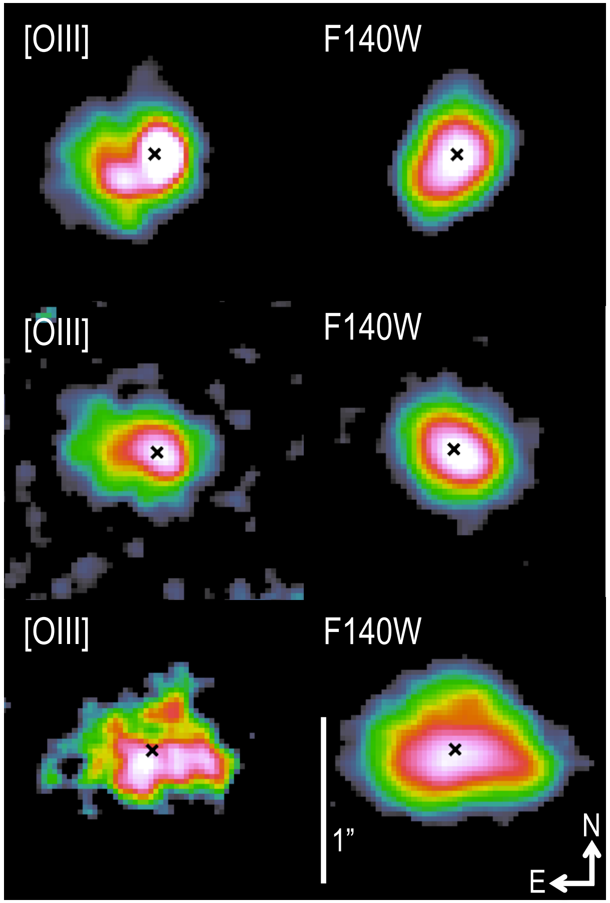
galaxies clumpiness → galaxies gas fraction?

sSFR vs age → feedback role?

SFR vs age → clumps SFH?

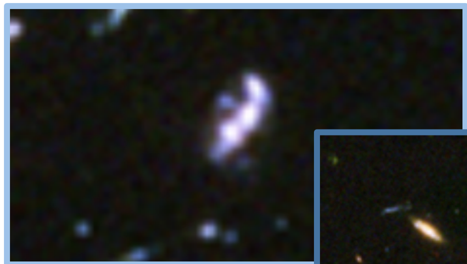
CFR → clumps' lifetime

age gradient? → clumps migration



Towards the end of the thesis and beyond

Goals




Which is the role of clumps migration in the morphological transformation of galaxies with cosmic time?
Which is the relevance of galaxy mergers instead?

Do giant clumps form in situ due to high gas fraction and turbulence?

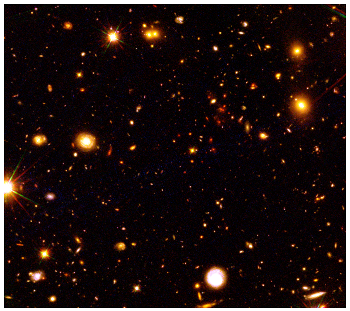

Do seeds of super massive black holes form inside giant clumps?

Which is the role of stellar feedback?
Is it strong enough to destroy giant clumps?


Are giant clumps the main cradles of young stars in the far-away Universe?

Are clumps responsible for bulge formation?
Bulge formation and disk stabilization are responsible for star formation quenching?

Data

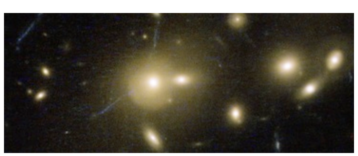


CL J1449+0856 CLUSTER

HST imaging
HST slitless spectroscopy
Subaru longslit spectroscopy
Chandra, XMM imaging
ALMA CO+850μm continuum

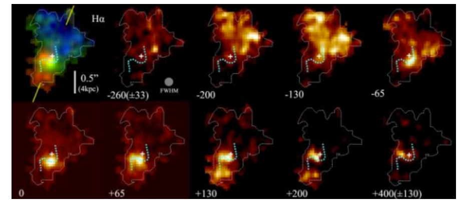
3D-HST + CANDELS

HST imaging
HST slitless spectroscopy



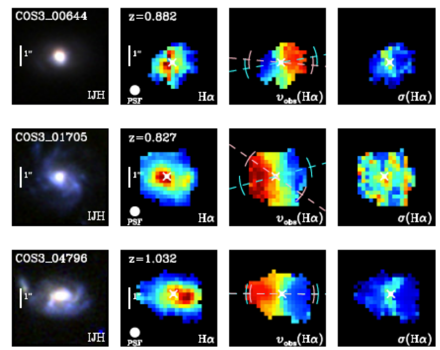
FRONTIER FIELDS

HST imaging
HST slitless spectroscopy



SINS SURVEY

Sinfoni IFU spectroscopy
HST imaging
LUCI multi-slit spectroscopy



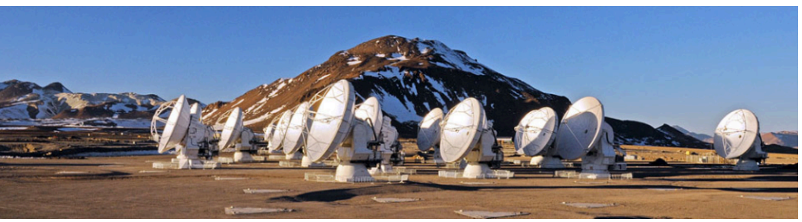
KMOS^{3D} SURVEY

KMOS IFU spectroscopy
HST imaging

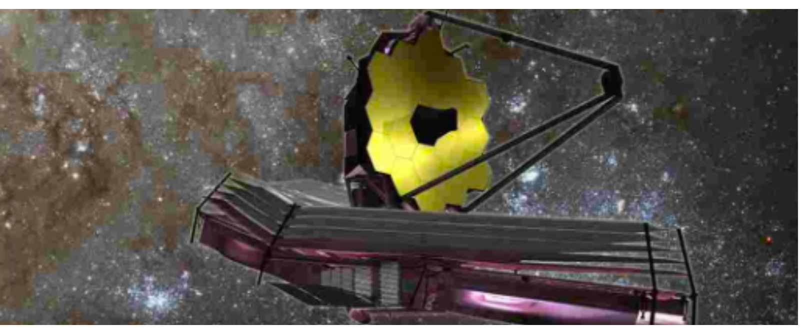
Additional new data for ID568:
SINFONI accepted proposal (Hα)
KMOS IFU data (OII)
MUSE UV spectrum
ALMA submitted proposal (CO4-3)

Instruments

SINFONI@VLT and **KMOS@VLT**
IFU spectroscopy of large samples of giant clumps
(velocity and dispersion fields, dynamical mass, feedback)



ALMA telescope
Systematic study of giant clumps with the complete ALMA
(gas mass, dust mass, velocity width)

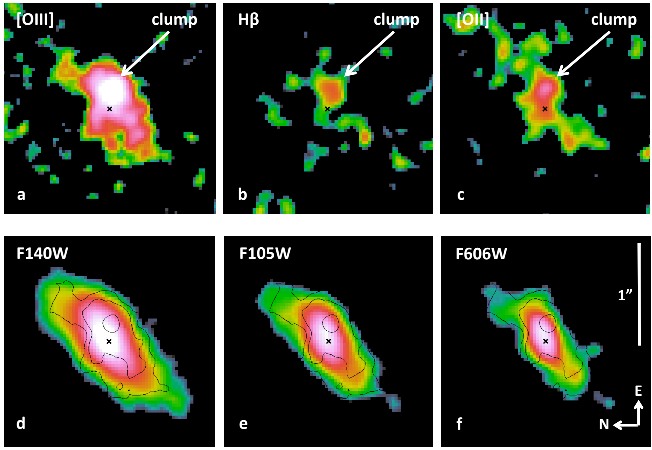


James Webb Space Telescope and EELT
Systematic study of giant clumps in the IR
(emission line maps, clumps size, SFR, $M_{\star}$)

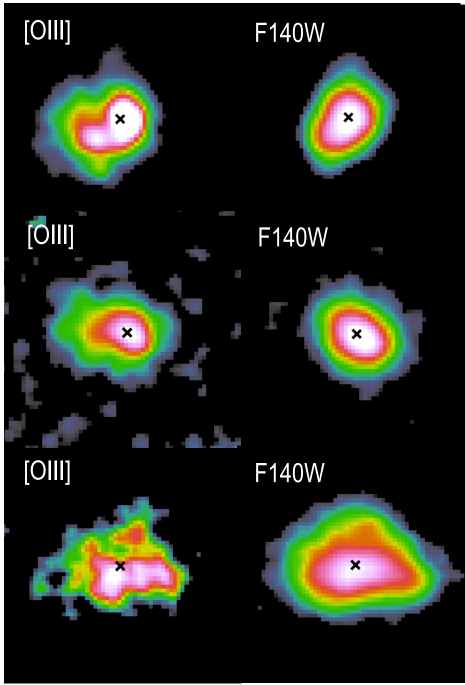
Square Kilometer Array
Systematic study of giant clumps in the radio continuum
(no bias due to dust)

Summary

- **The birth of a star forming clump:**
  - The case of ID568:
    bright off-nuclear [OIII] without continuum counterpart
  - It is an **extremely young star forming clump**:
    first study of clumps formation phase
  - **Young clumps behave like mini-starbursts**
  - It supports the scenario where **clumps survive stellar feedback**



- **A statistical study of giant star forming clumps**
  - Creation of emission line maps: first SFR-selected sample
  - Constraints on stellar feedback, bulge growth,
    clumps star formation history, clumps lifetime



- **More to come in the future**

Backup slides

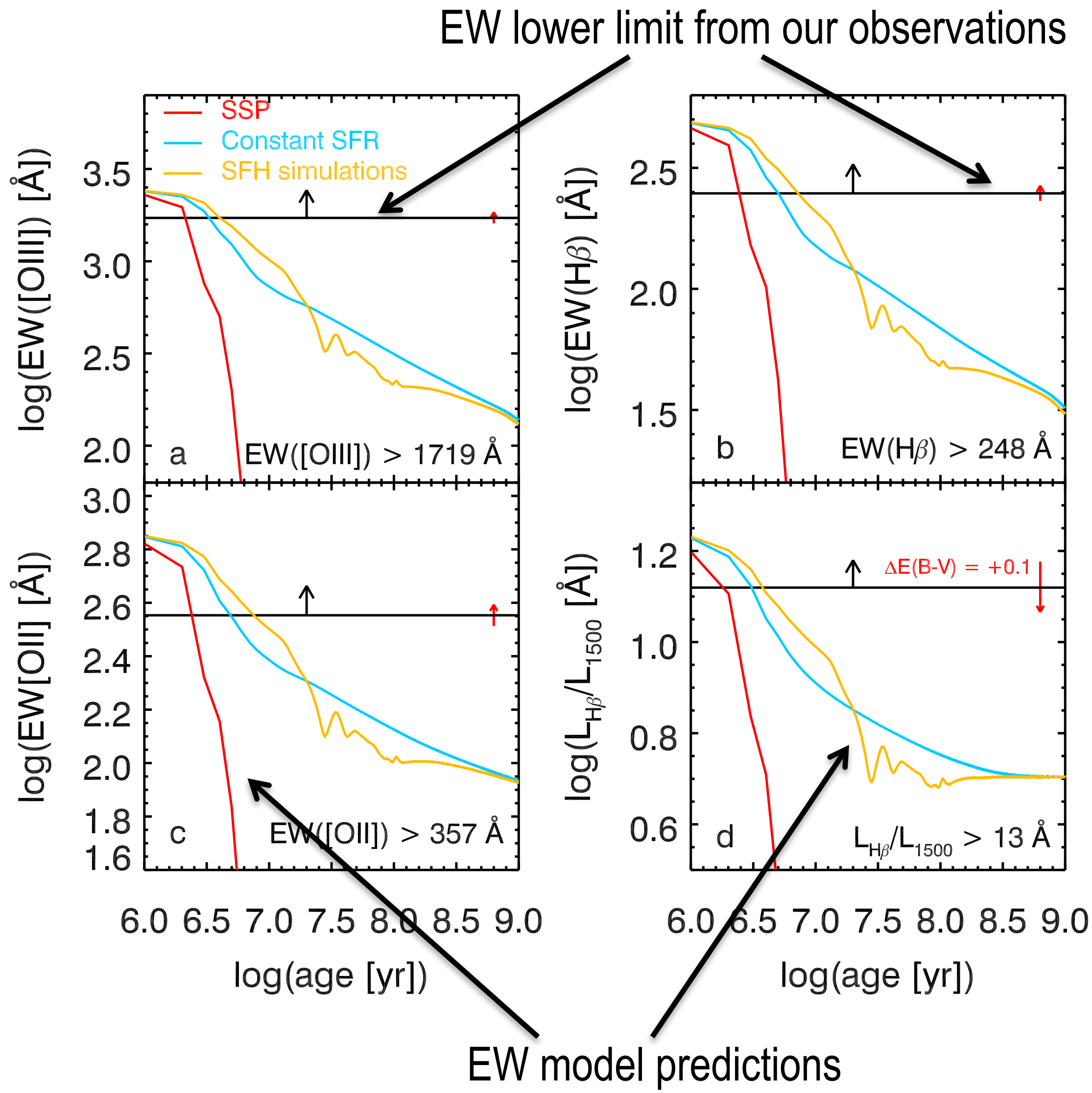
An extremely young star forming clump

The **equivalent width** (EW) changes with the **age** of the stellar population

$$EW = \frac{F_{line}}{F_{continuum}}$$

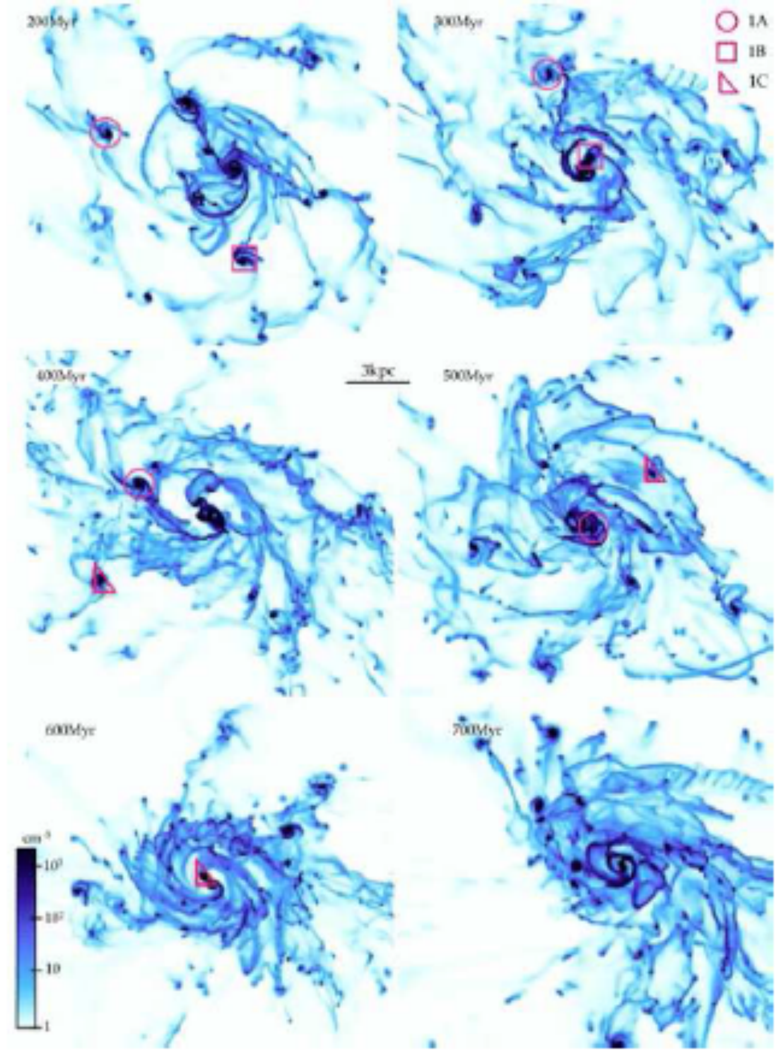
Age < 10 Myr

First time robust **age** estimate comparable to the **free fall time** in a gas-rich turbolent disk



Simulations

High resolution hydrodynamical simulations:
simulation of a dynamical system of particles
under the influence of physical forces
(**pressure** and **gravity**)



Bournaud+ 14