The birth of a star-forming clump in a disk galaxy at z ~ 2

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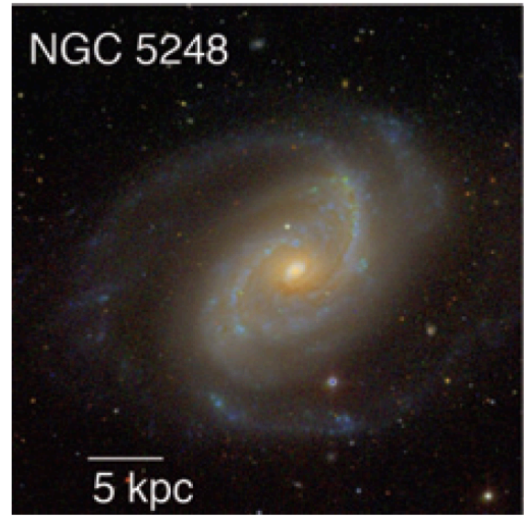
with E. Le Floc'h, E. Daddi, F. Bournaud, F. Valentino et al.

Santiago, March 23rd, 2015

Introduction: observations

Galaxies at z ~ 2:

- are gas dominated (Daddi+10, Tacconi+ 10)
- host giant star forming regions = clumps (e.g., Elmegreen+05, 09, Förster-Schreiber+ 06)



Local galaxy
d = 15.40 Mpc

(Elmegreen+ 13)

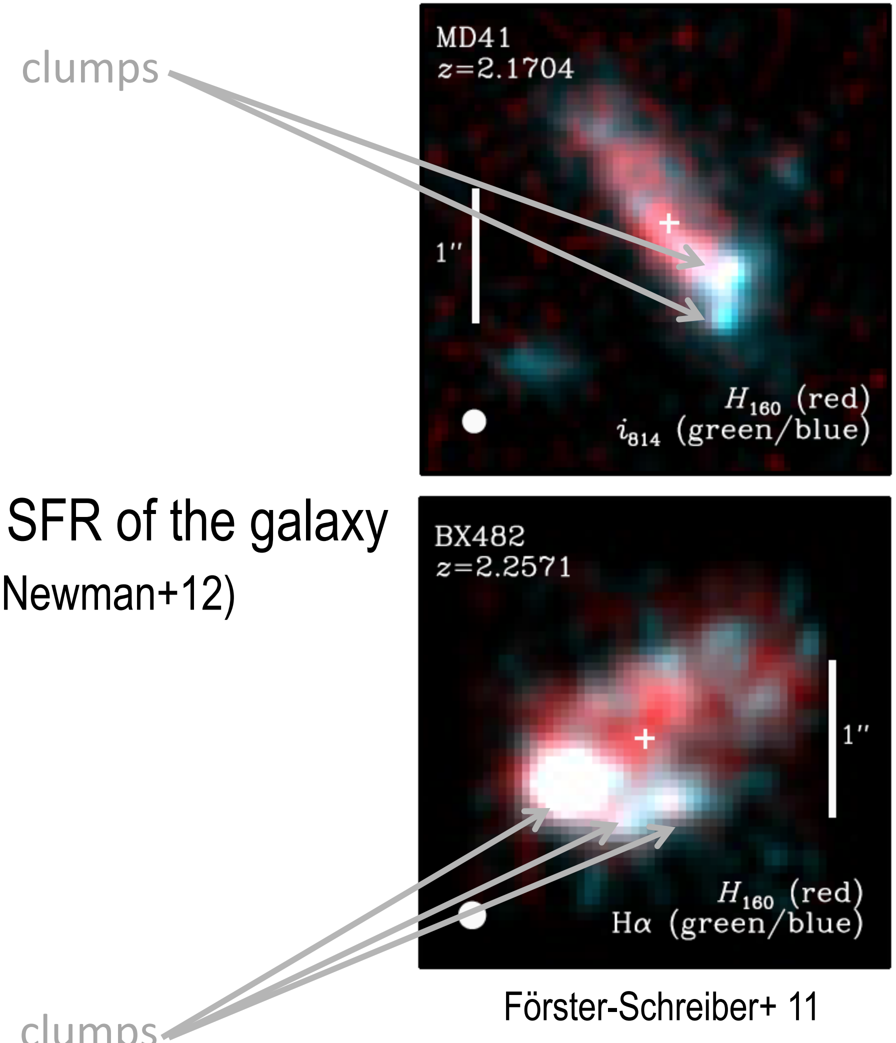
High-z galaxy
z = 2.05

(Wuyts+ 12)

Introduction: observations

Clumps in z ~ 2 galaxies:

- have total masses ~ $10^{8\text{-}9}$ $M_{\odot}$
- have SFR ~ 20 - 50% of the total SFR of the galaxy
  (e.g., Genzel+08, Förster-Schreiber+11, Newman+12)



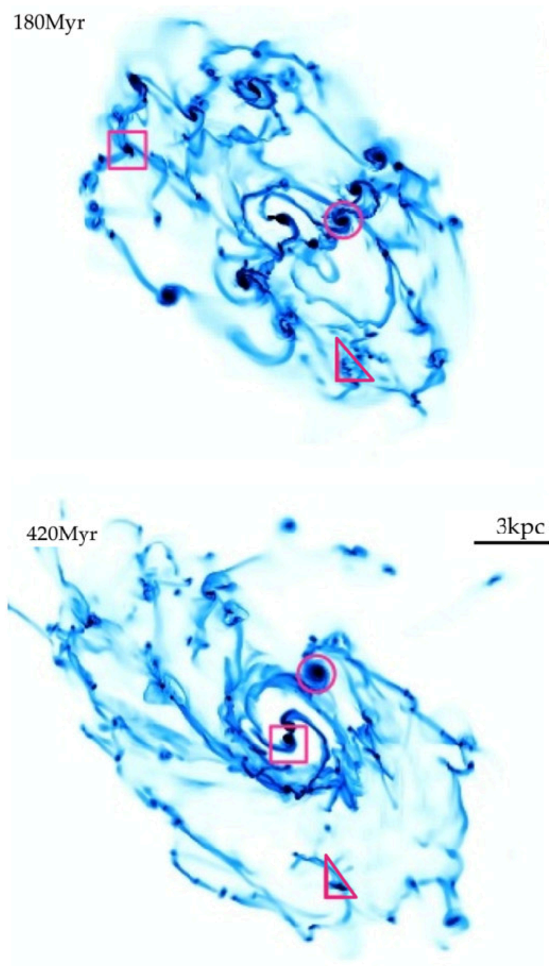
Förster-Schreiber+ 11

Introduction: simulations

- At high z: large scale gas inflows feed galaxies with gas (Keres+ 09, Dekel+ 09)
- 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**? (Dekel+ 11, Bournaud+ 14)
- Are they disrupted by stellar **feedback** in short **timescales?** (Genel+ 12, Murray+ 10) ?



Bournaud+ 14

Open questions we would like to answer…

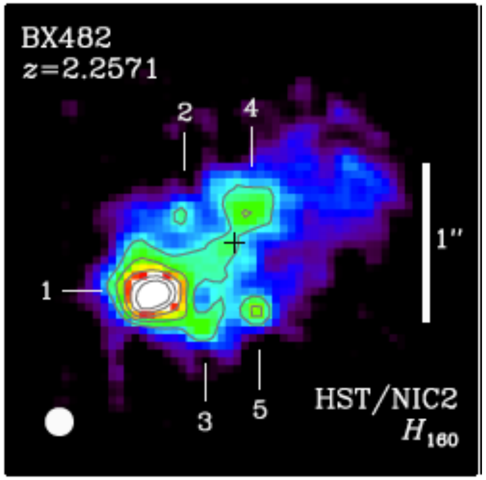
How do clumps form?

Clumps lifetime?

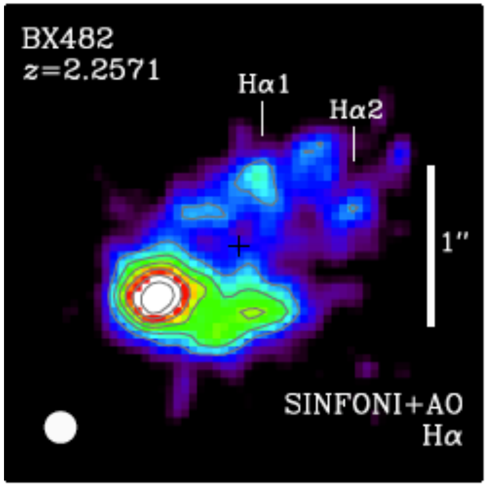
Do clumps form the bulge?

Role of stellar feedback?

Clumps SFE?



H_{160}



Hα

…key ingredients we need

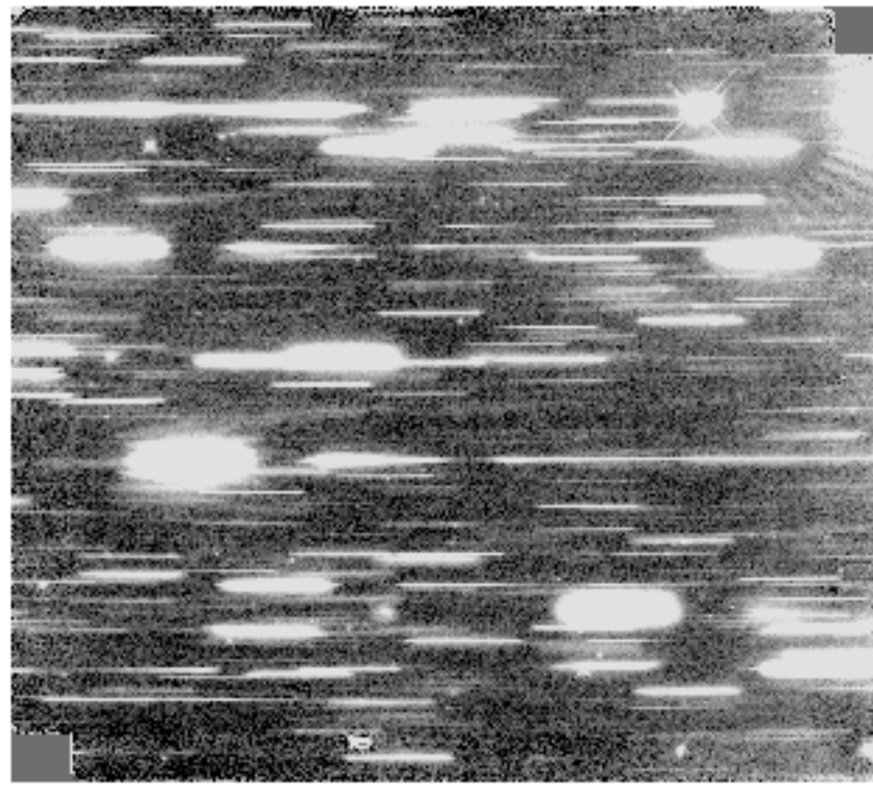
spatially resolved probe of **stellar mass distribution**
→ **imaging**

spatially resolved probe of **star formation distribution**
→ **UV, spectroscopy** (unique for young ages)

Förster-Schreiber+ 11

Sample

Pointed at CL J1449+0856 cluster (Gobat+ 13)



Slitless spectroscopy: 6.4 arcmin^2

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

Observations: WFC3 on board HST

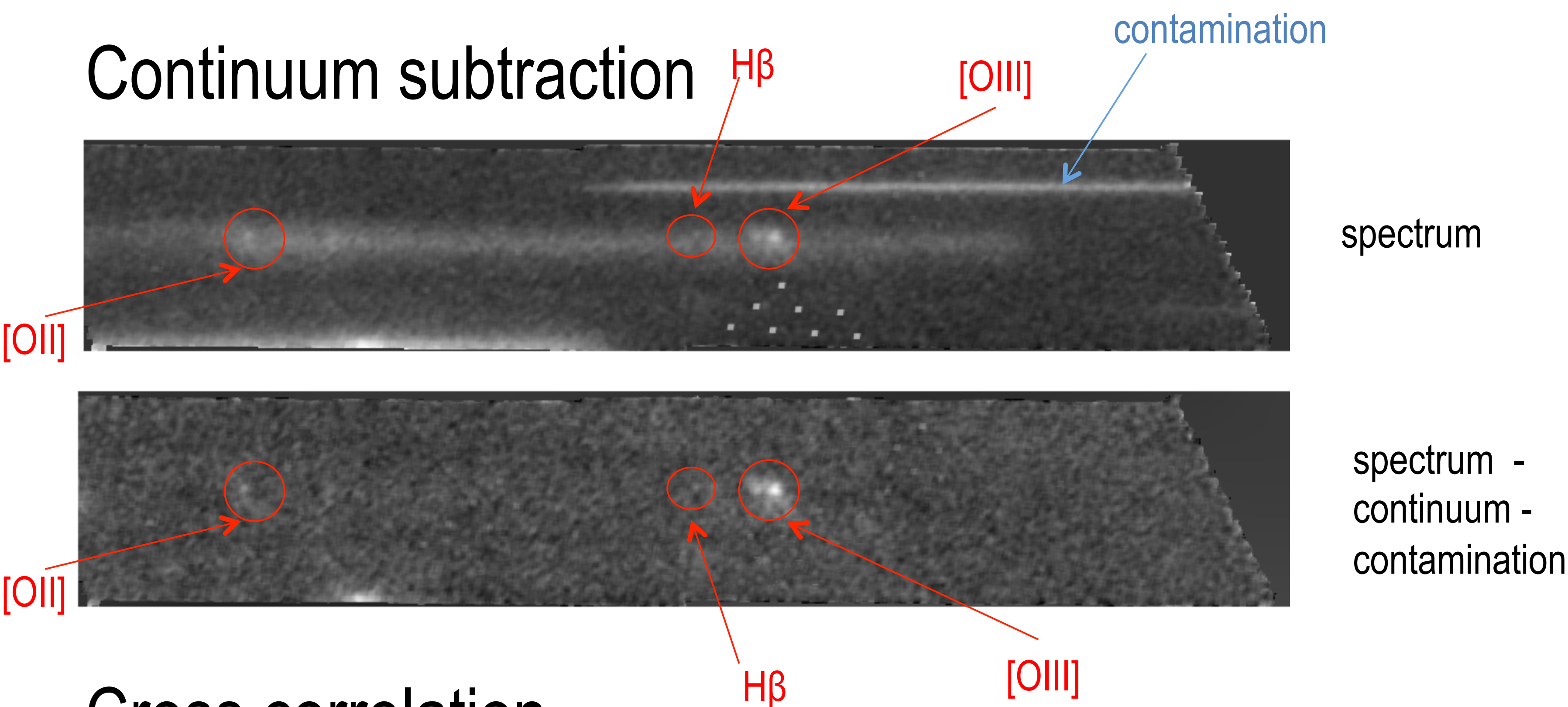
Slitless spectroscopy: G_{141} (λ = 0.8 – 1.2 μm)

Imaging: near-IR (F140W, F105W)
UVIS (F606W)

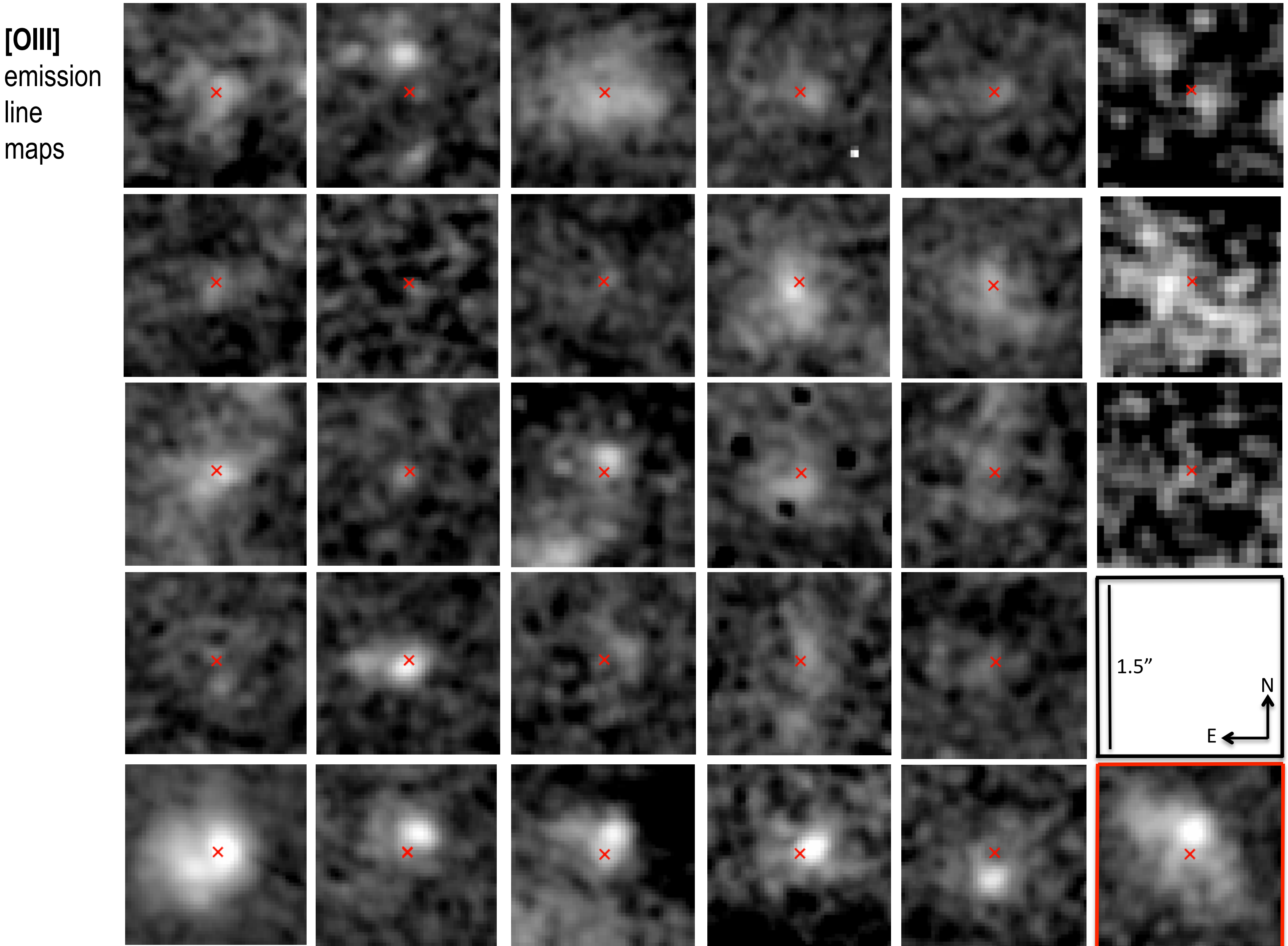
Emission line maps

Contamination correction

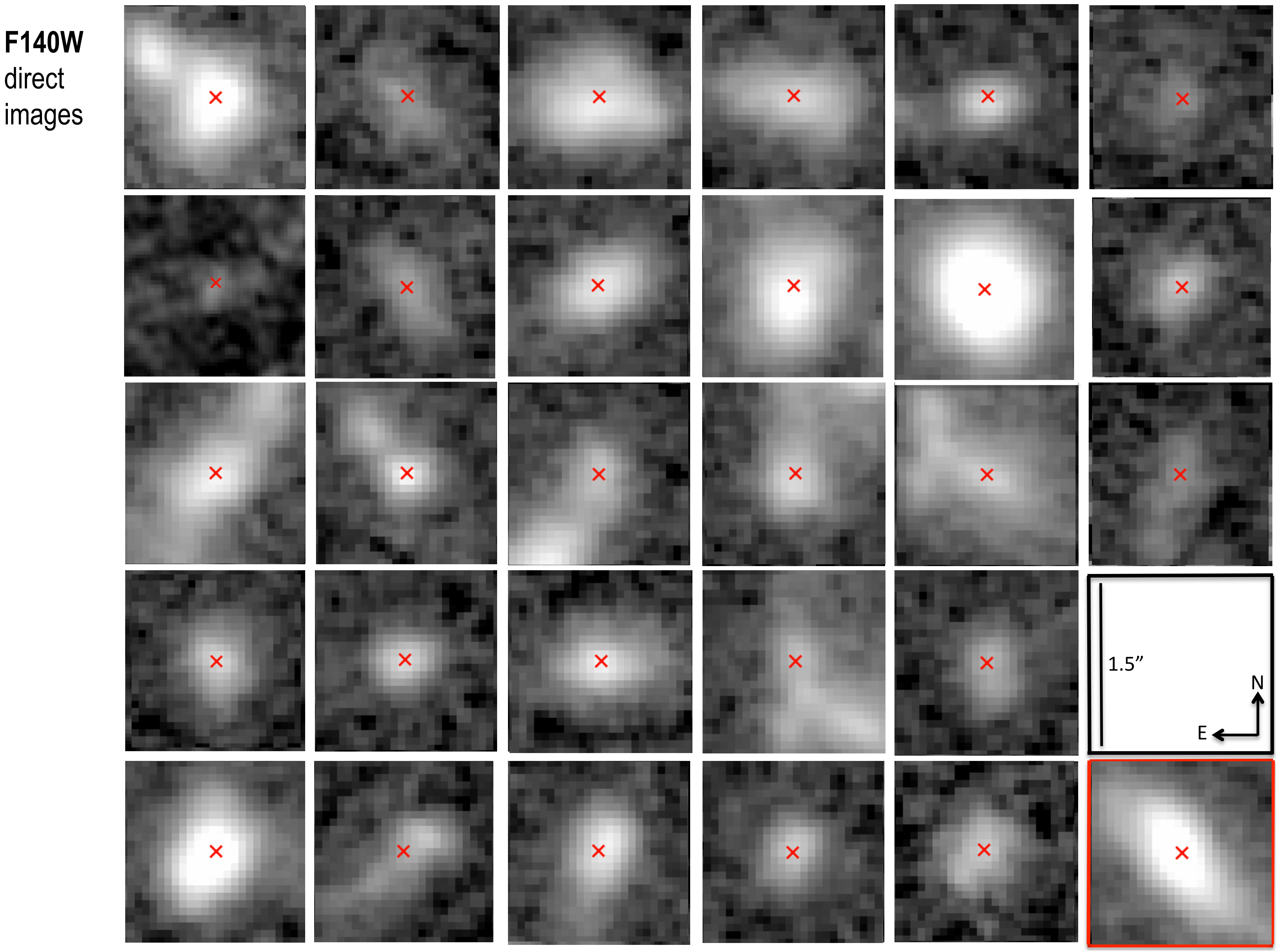
Continuum subtraction



Cross correlation

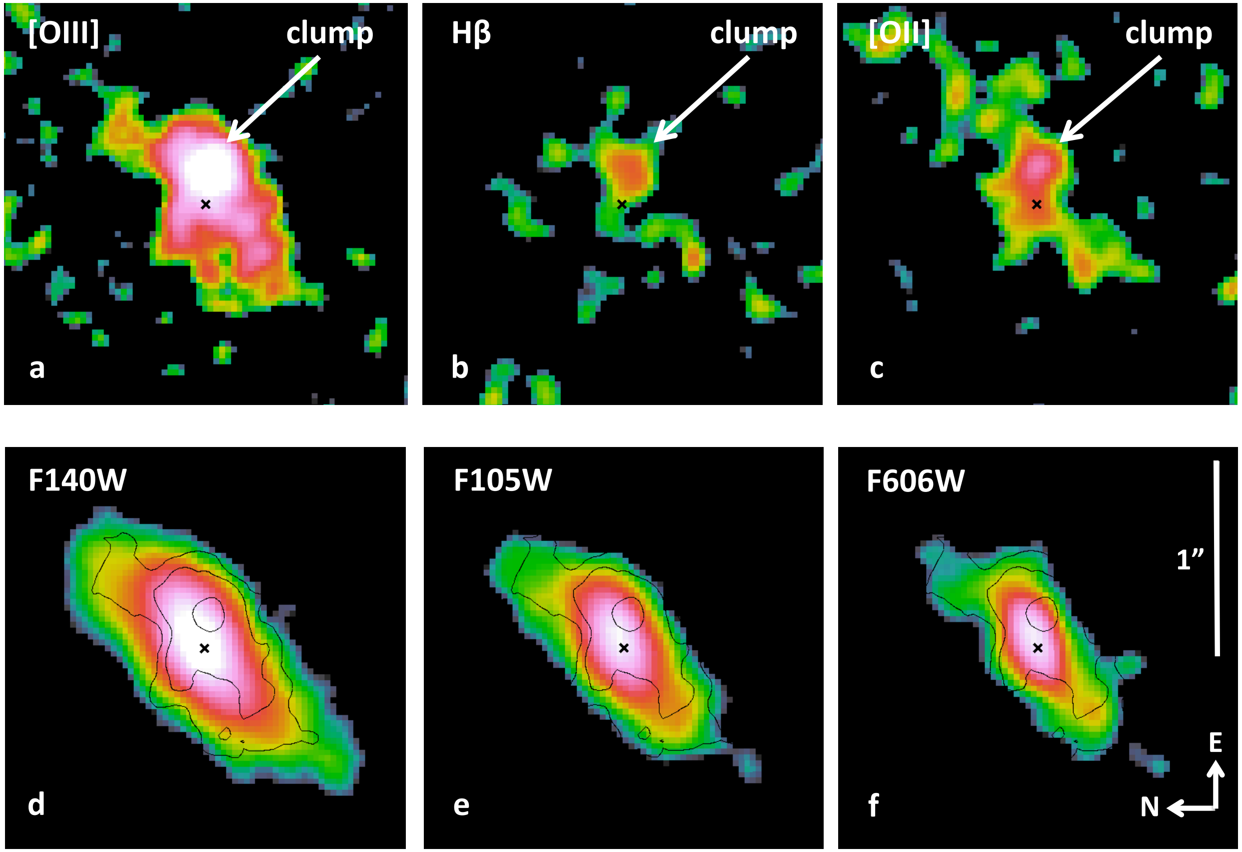


[OIII]
emission
line
maps
1.5"
N
E


F140W
direct
images
1.5"
N
E

Emission line maps

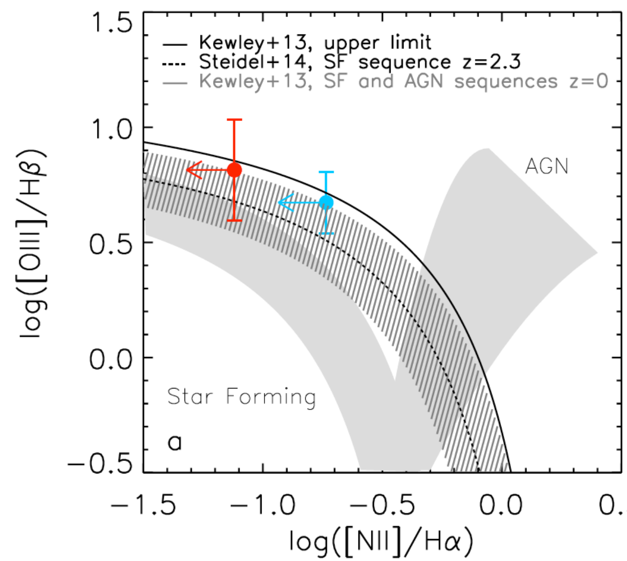
The case of ID568: **off-nuclear** [OIII], Hβ and [OII] emissions



GALFIT decomposition: diffuse **disk** + off-nuclear **clump**

Offset **significance ~ 8σ**

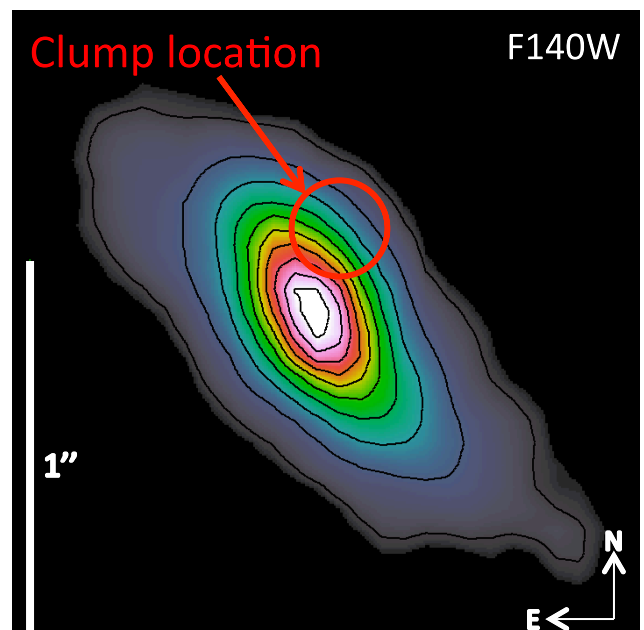
A star forming clump



1) Discarding the **AGN** hypothesis:

X RAYS: no XMM and Chandra detection

BPT (Baldwin+81): in the SF region (MOIRCS follow up)



Clump equivalent width (**EW**):

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

Upper limits on the continuum flux: simulations

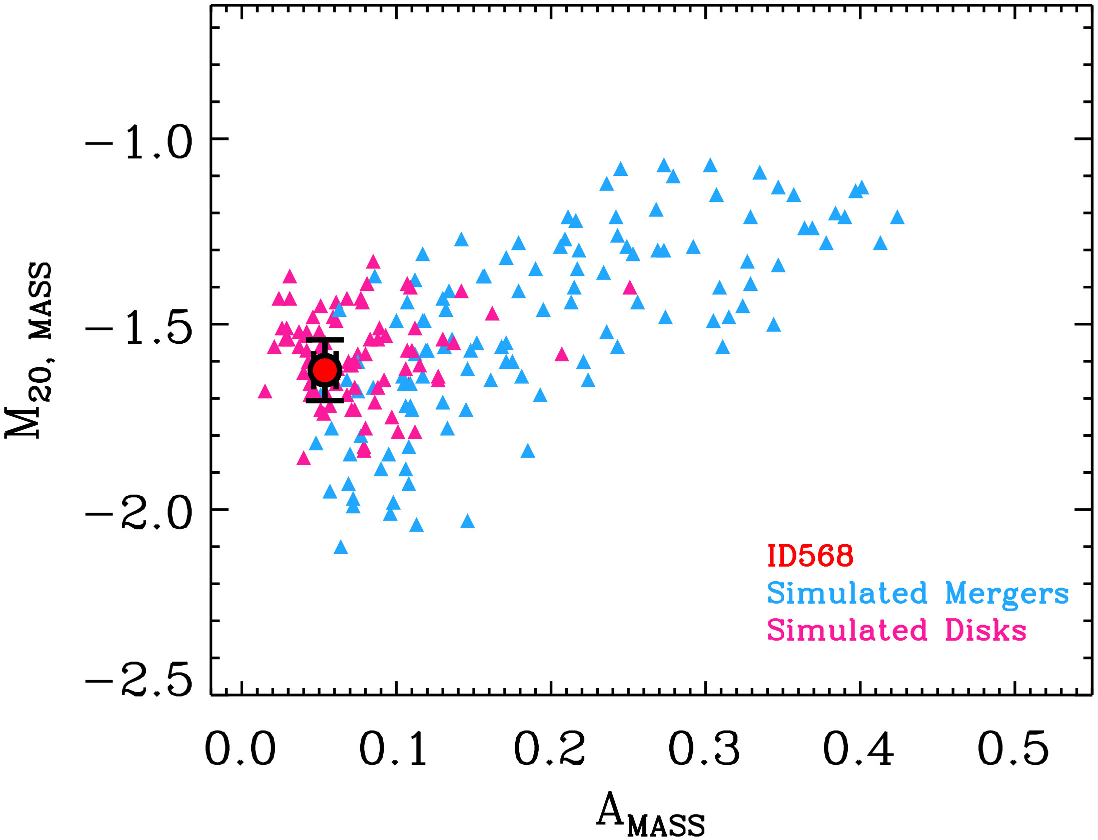
$EW_{[OIII]} \geq 1700$ Å >> typical $EW_{[OIII]}$ of AGNs

A star forming clump

2) Discarding the **merger** hypothesis

Asymmetry – M_{20} diagnostics: consistent with simulated disks

No detection in the continuum of an older stellar population



Cibinel et al., submitted

An extremely young SF clump

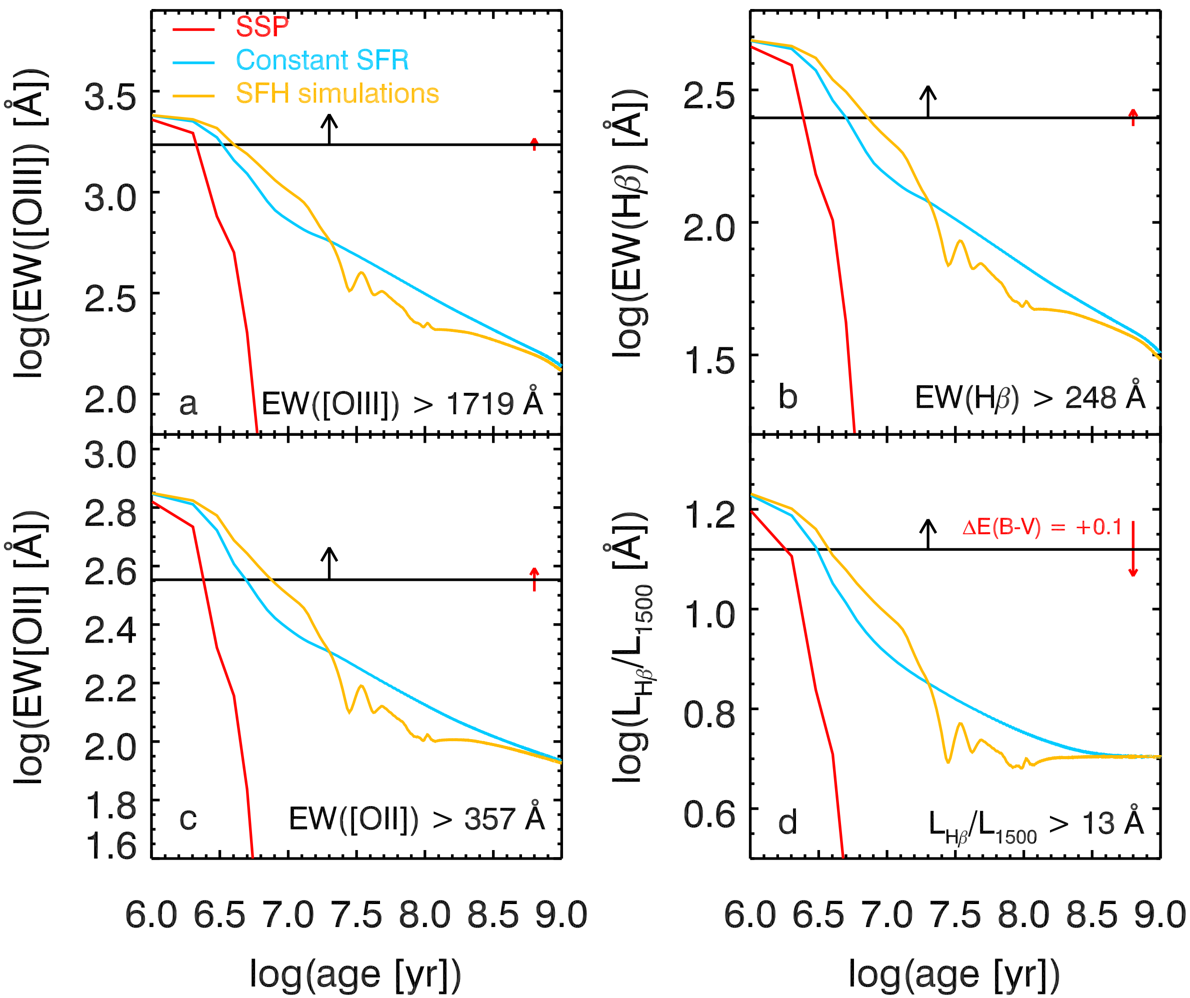
$Z \sim 0.4\, Z_\odot$

Re ≤ 0.5 kpc (unresolved)

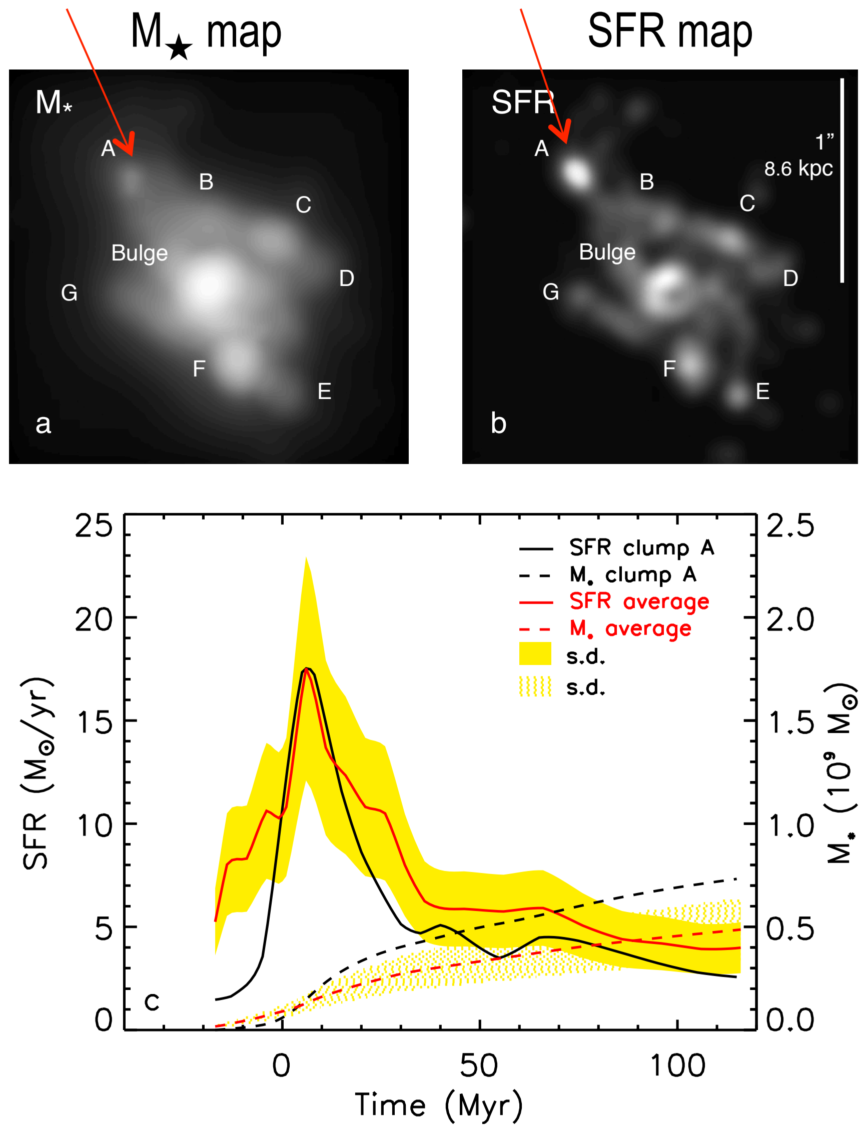
Age < 10 Myr

First time robust **age** estimate comparable to **free fall time**

Starburst99 models



Simulations



sSFR clump A = 10x sSFR other clumps

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 SF confirmed by observations

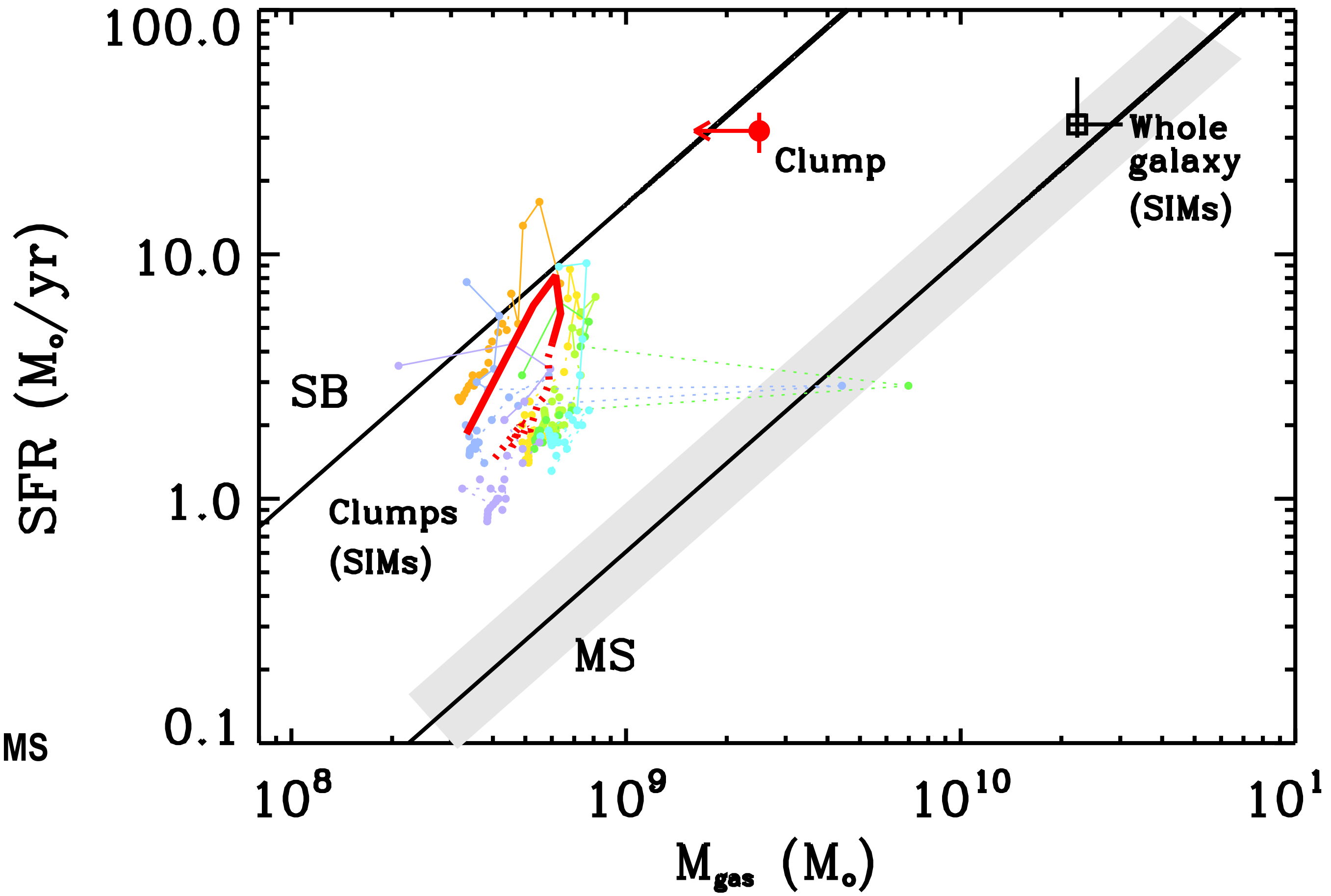
Zanella et al. 2015, Nature in press

Newly born clumps behave like mini-starbursts

SFR ~ 30 $M_\odot$/yr

$M_\star \leq 3 \times 10^8 M_\odot$

$M_{gas} < 2.5 \times 10^9 M_\odot$

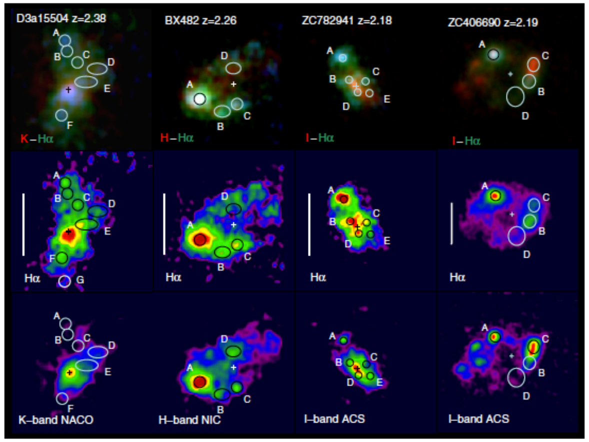


sSFR > 30x $sSFR_{gal,MS}$

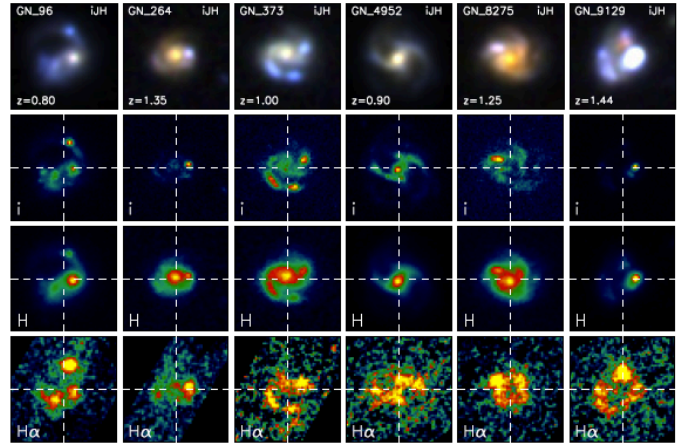
SFE > 10x $SFE_{gal,MS}$

Zanella et al. 2015, Nature in press

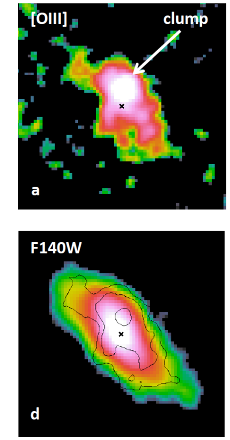
Clumps lifetime



Genzel+ 11



Wuyts+ 13



ID568

Constraints on:

clumps formation rate (~2 clumps/Gyr) ⟶ $\mathrm{CFR} = \dfrac{N_{\mathrm{young}}}{t_{\mathrm{V}} N_{\mathrm{gal}}}$

N_{young} → # of young clumps

N_{gal} → # of sample galaxies

t_{V} → Visibility window

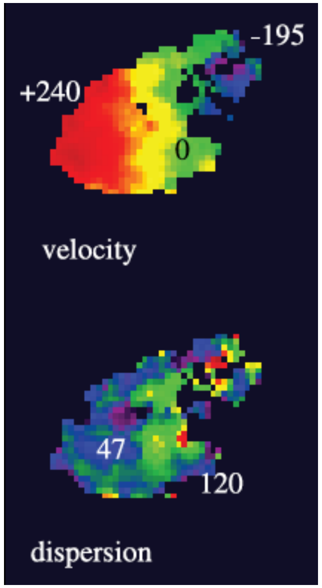
lifetimes (~ 500Myr) ⟶ $\mathrm{LT} = \dfrac{f_{\mathrm{cl/gal}}}{\mathrm{CFR}}$

$f_{\mathrm{cl/gal}}$ → # of clumps/galaxy with M_{tot}~ 2.5×10^9 $M_\odot$

→ clumps survive stellar feedback

Future developments

Kinematics constraints with **AO spectroscopy**:
accepted Sinfoni proposal (6 hr, single galaxy)

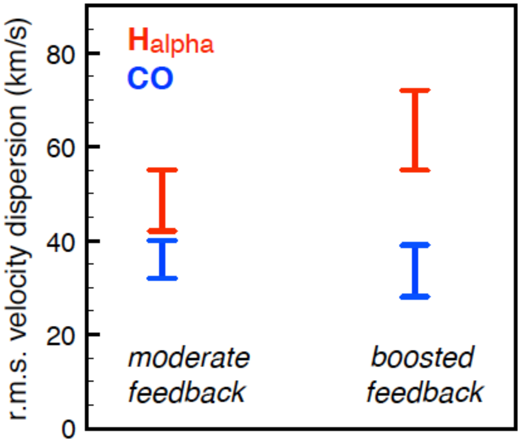


Genzel+ 08

Disk or merger? | Subgalactic infalls? | Stellar feedback processes?

Gas properties: **ALMA** proposal planned

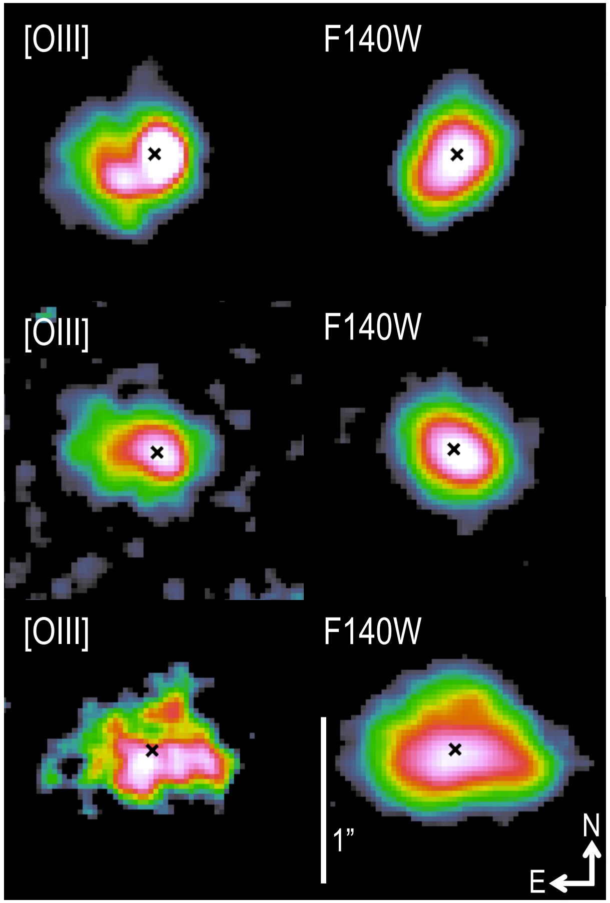
Gas mass → SFE | Feedback strength? | Dust mass



Future developments

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

- sSFR vs age → feedback role?
- SFR vs age → clumps SFH?
- CFR → clumps' lifetime
- age gradient? → clumps migration
- off-nuclear AGNs?



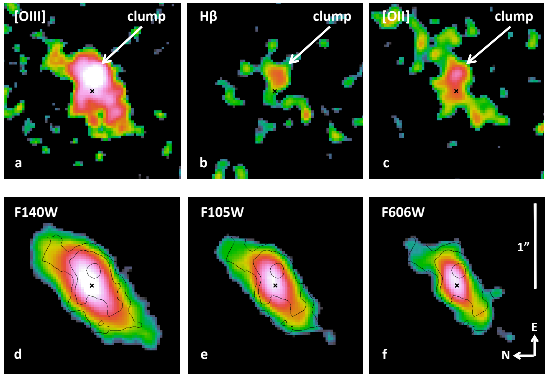
Summary

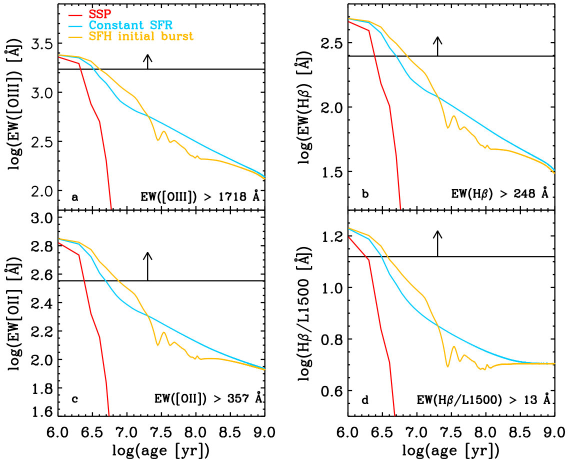
The birth of a star forming clump…

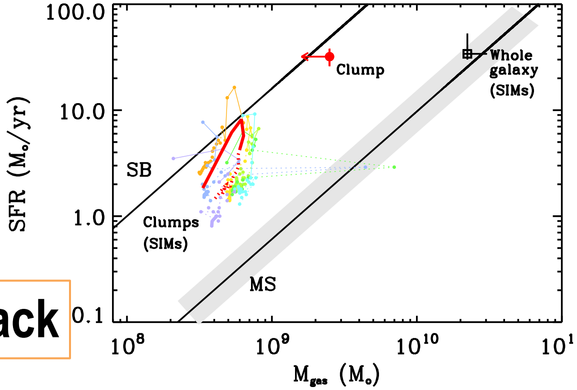
- We considered a sample of 68 [OIII] emitters at $1 \leq z \leq 2$
- We created spatially resolved emission line maps
- The case of ID568:
  bright off-nuclear [OIII] without a continuum counterpart

- The emission lines are powered by star formation
- It is an **extremely young star forming clump** likely **formed due to violent disk instability**

- It is the first direct observation of the clumps' formation phase
- **Young clumps behave like mini-starbursts** (obs. + sim.)
  Old clumps have enhanced SFE (sim.)
- It supports the scenario where **clumps survive stellar feedback**

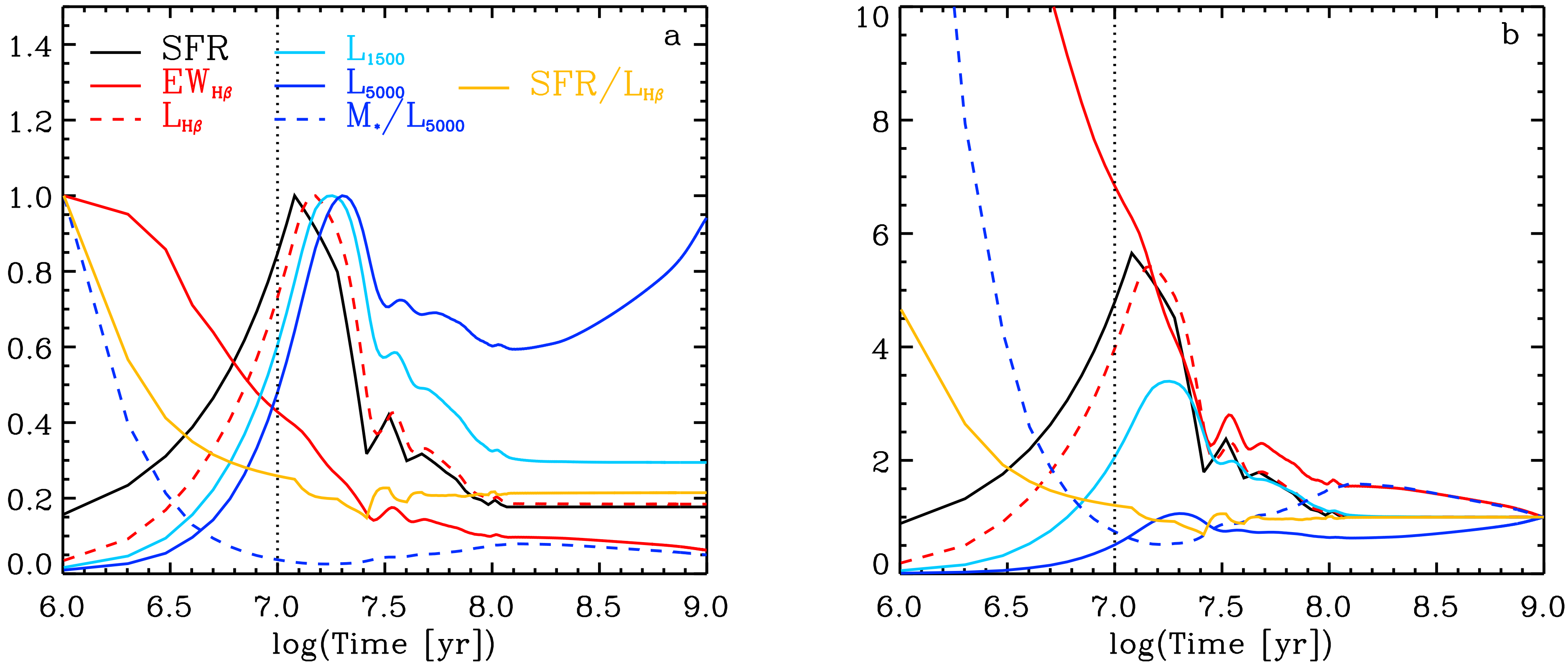






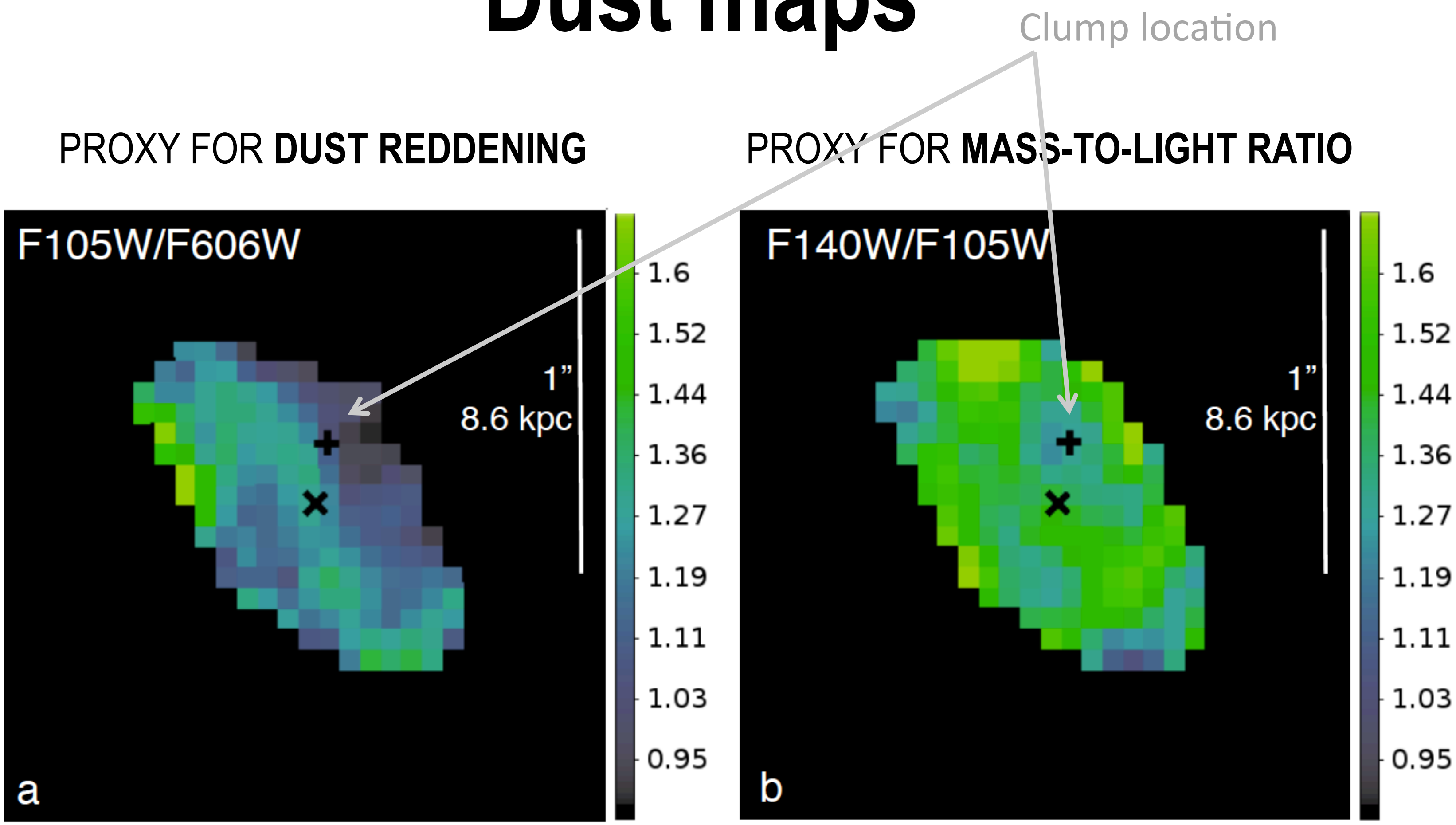
Backup slides

Physical quantities vs Age



Dust maps

PROXY FOR **DUST REDDENING** PROXY FOR **MASS-TO-LIGHT RATIO**



The clump is not a fake feature due to dust

A star forming clump

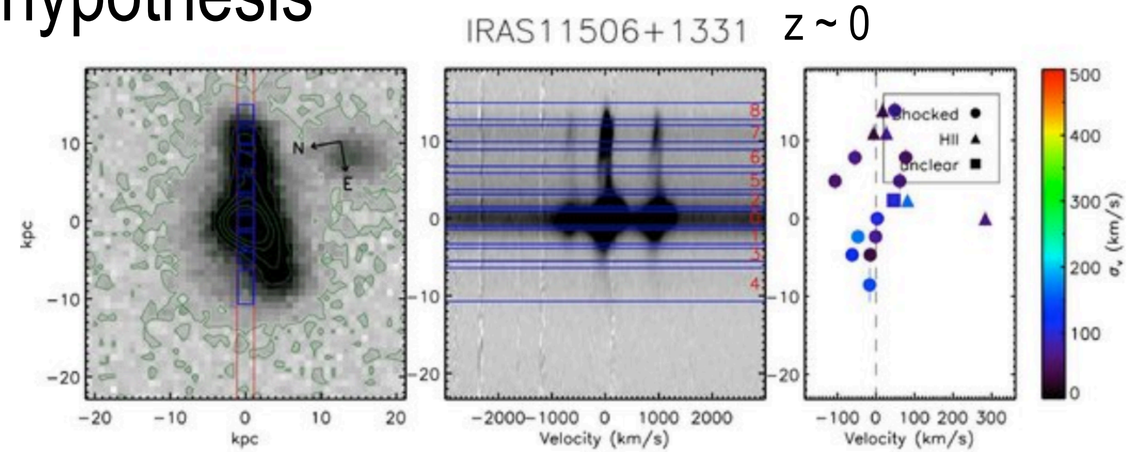
Discarding the **shock** hypothesis

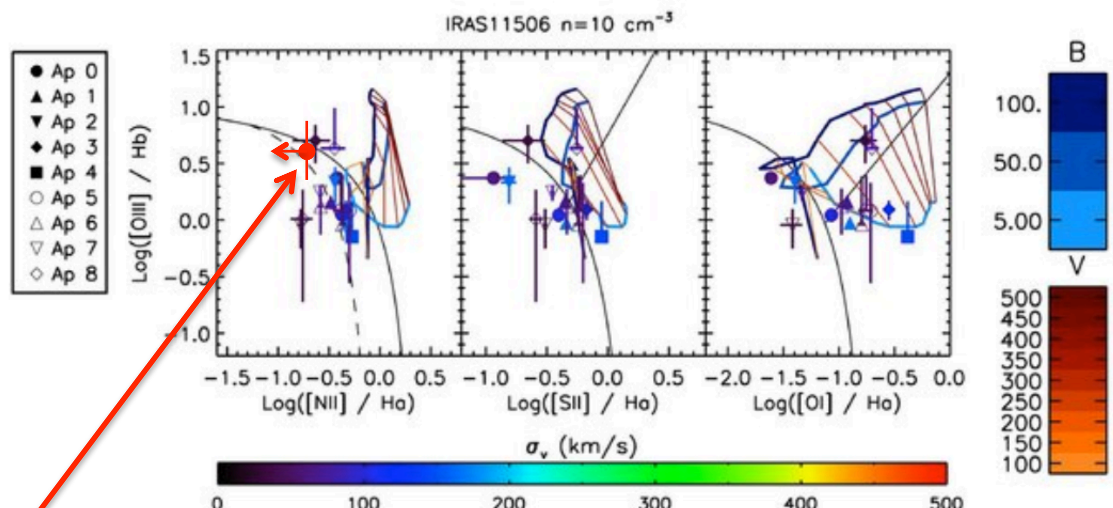
Comparable - SFR
- emission line ratios

BUT

$L_{[OIII]}$ due to shock ionization from wind outflows
~ 50 – 500x weaker than
$L_{[OIII]}$ of our clump

(calculations for z = 0 and z = 2)





Clump
z = 2

Soto & Martin 2012

Where do young clumps form?

Offset observed clump = 1.6 ± 0.3 kpc

Estimate of galaxy inclination
clump PA

→ Deprojected distance

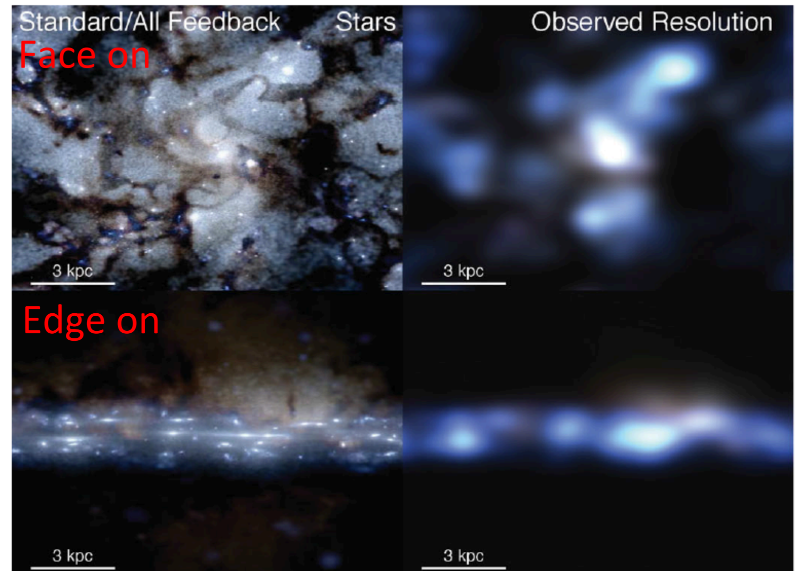
Deprojected distance from the galaxy nucleus:

1) Observed clump: 3.6 ≤ d ≤ 6.2 kpc

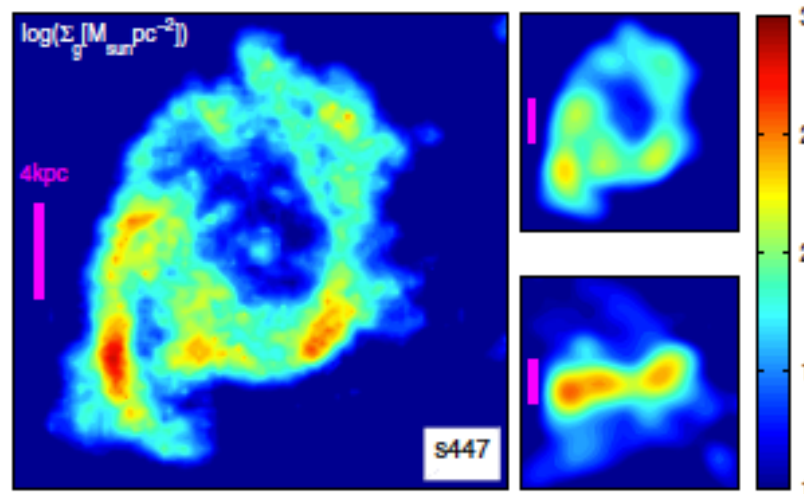
2) Our simulations: 2.1 ≤ d ≤ 7.0 kpc

3) Other simulations: 2.0 ≤ d ≤ 10.0 kpc
(e.g., Mandelker+14, Genel+12, Hopkins+12)

HST-like resolution

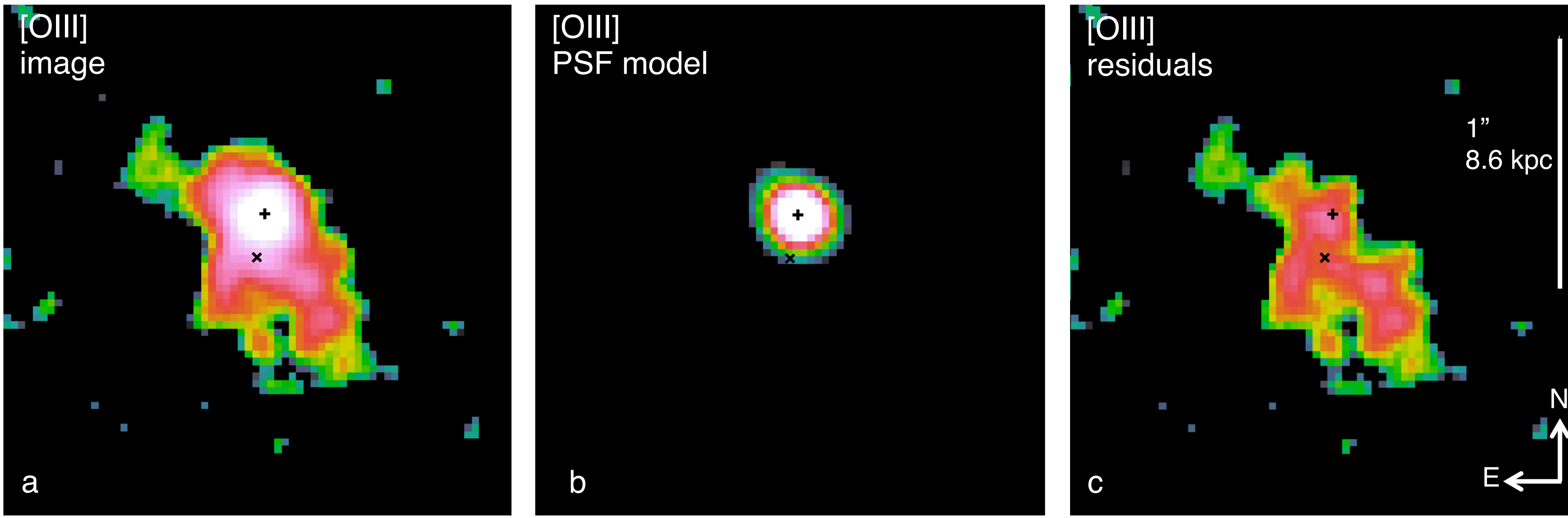


Hopkins+ 12

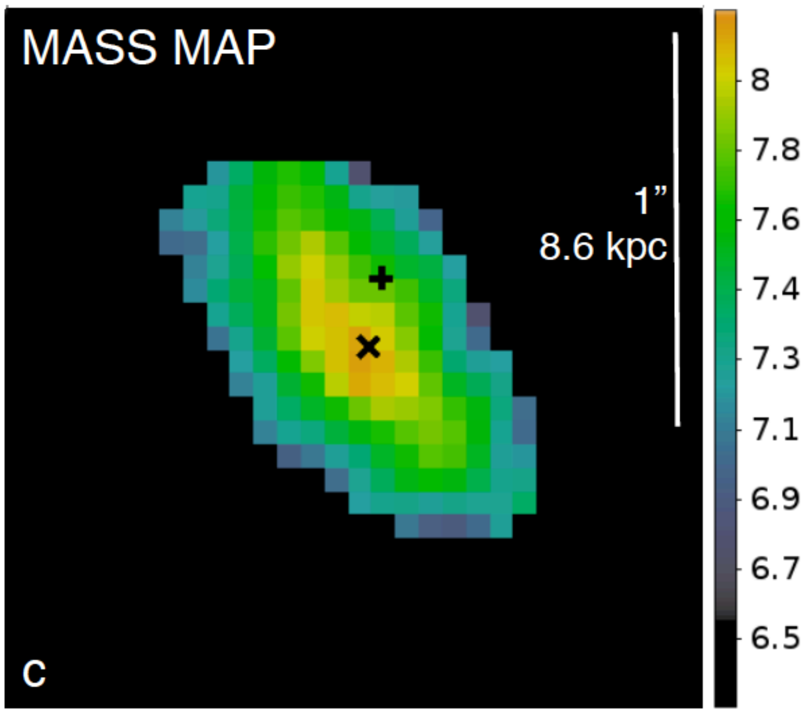


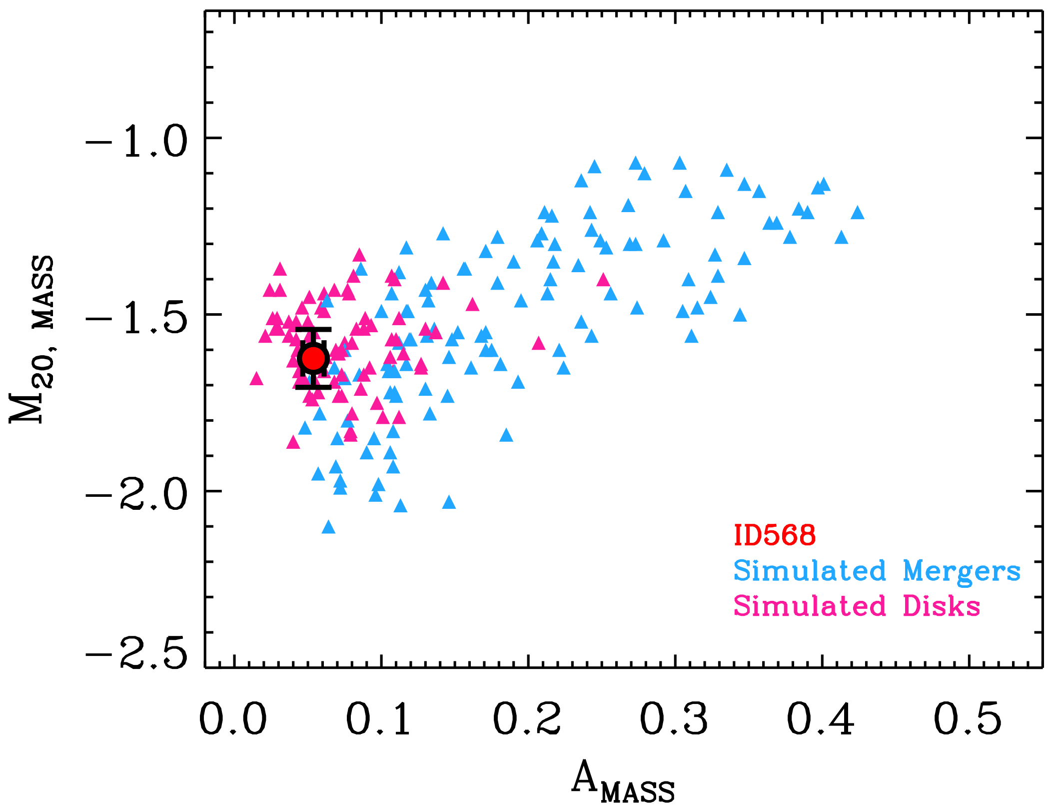
Genel+ 12

Galfit decomposition of the clump



Classification asymmetry - M_{20}

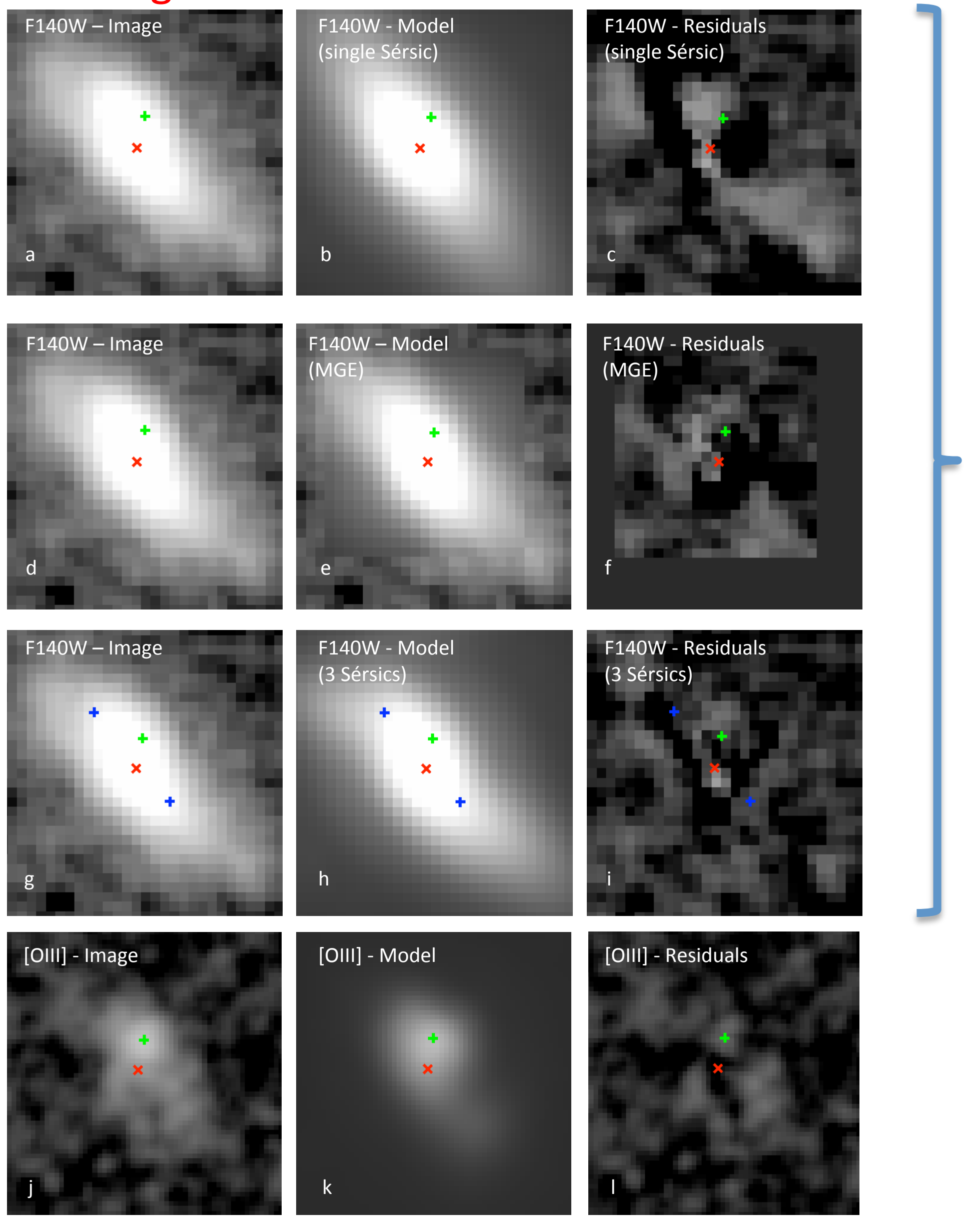




Cibinel+ 15, submitted

Galfit decomposition

Image | Model | Residuals



Galfit
1 Sérsic

Multi-Gaussian
Expansion
Parametrization

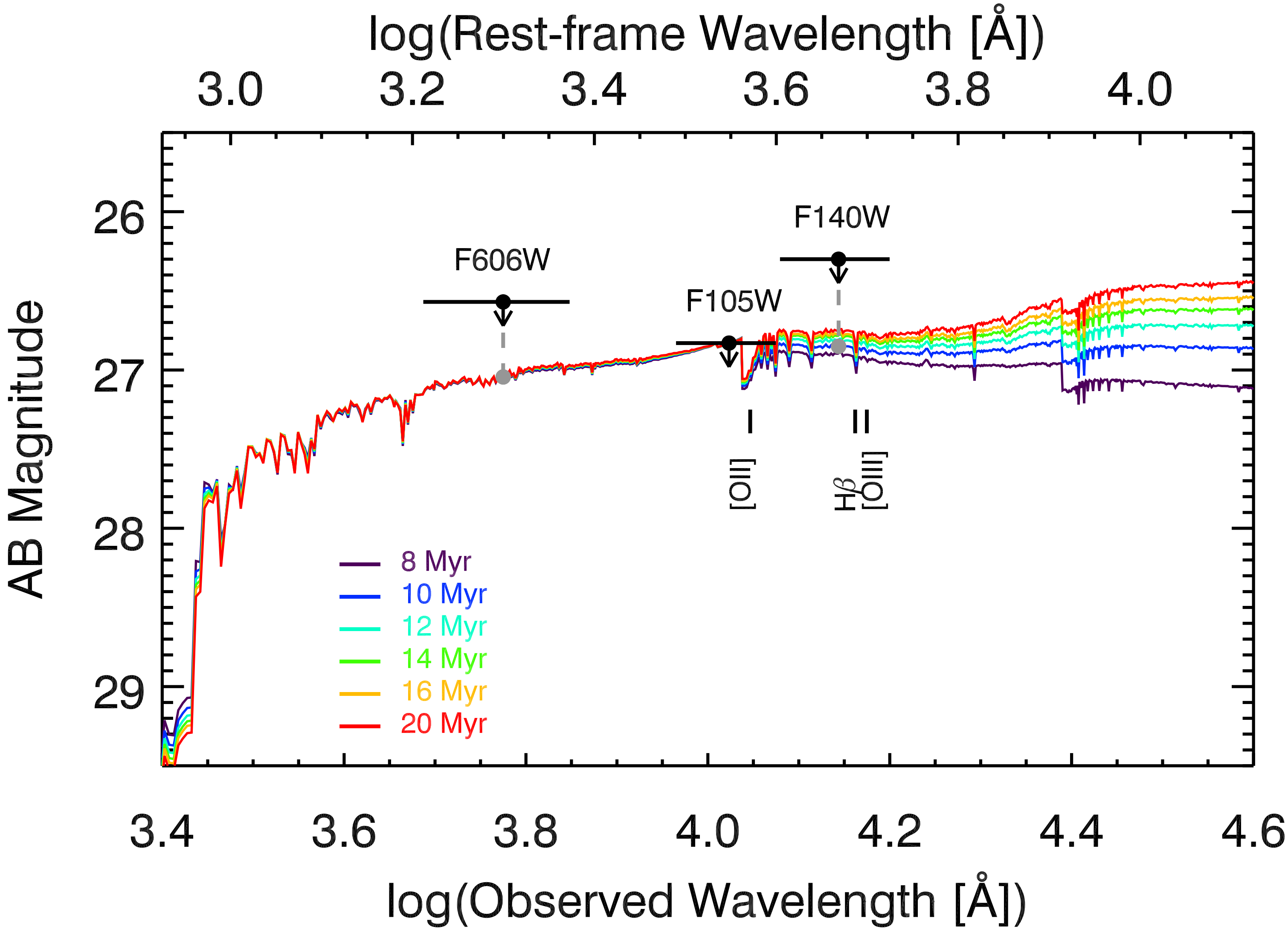
Galfit
3 Sérsic

Galfit
3 Sérsic
+ PSF

Direct image
F140W

[OIII] emisison
line map

Continuum upper limits



Properties of the galaxy and the clump

	Galaxy	Clump
$\mathbf{R_e}$ [kpc]	2.8 ± 0.4^a	< 0.5
SFR $[\mathrm{M_\odot/yr}]$	77 ± 9	32 ± 6
$\mathbf{log(M_\star/M_\odot)}$	$10.3^{+0.2}_{-0.3}$	$\lesssim 8.5$
$\mathbf{log(M_{gas}/M_\odot)}$	10.7 ± 0.2^b	$\lesssim 9.4$
Z $[\mathrm{Z_\odot}]$	0.6 ± 0.2	0.4 ± 0.2
$\mathbf{F^{obs}_{[OIII]}}$ $[10^{-17}\mathrm{erg\,s^{-1}cm^{-2}}]$	10.4 ± 0.7	4.3 ± 0.2
$\mathbf{F^{obs}_{H\beta}}$ $[10^{-17}\mathrm{erg\,s^{-1}cm^{-2}}]$	1.5 ± 0.8	0.9 ± 0.3
$\mathbf{F^{obs}_{[OII]}}$ $[10^{-17}\mathrm{erg\,s^{-1}cm^{-2}}]$	6.5 ± 1.7	1.9 ± 0.6
$\mathbf{F^{obs}_{F140W}}$ $[10^{-20}\mathrm{erg\,s^{-1}cm^{-2}\,\AA^{-1}}]$	67.5 ± 3.4^c	< 1.1
$\mathbf{F^{obs}_{F105W}}$ $[10^{-20}\mathrm{erg\,s^{-1}cm^{-2}\,\AA^{-1}}]$	89.2 ± 4.6^c	< 1.8
$\mathbf{F^{obs}_{F606W}}$ $[10^{-20}\mathrm{erg\,s^{-1}cm^{-2}\,\AA^{-1}}]$	212.3 ± 10.6^c	< 4.5