Molecular gas accreting onto massive high-z galaxies

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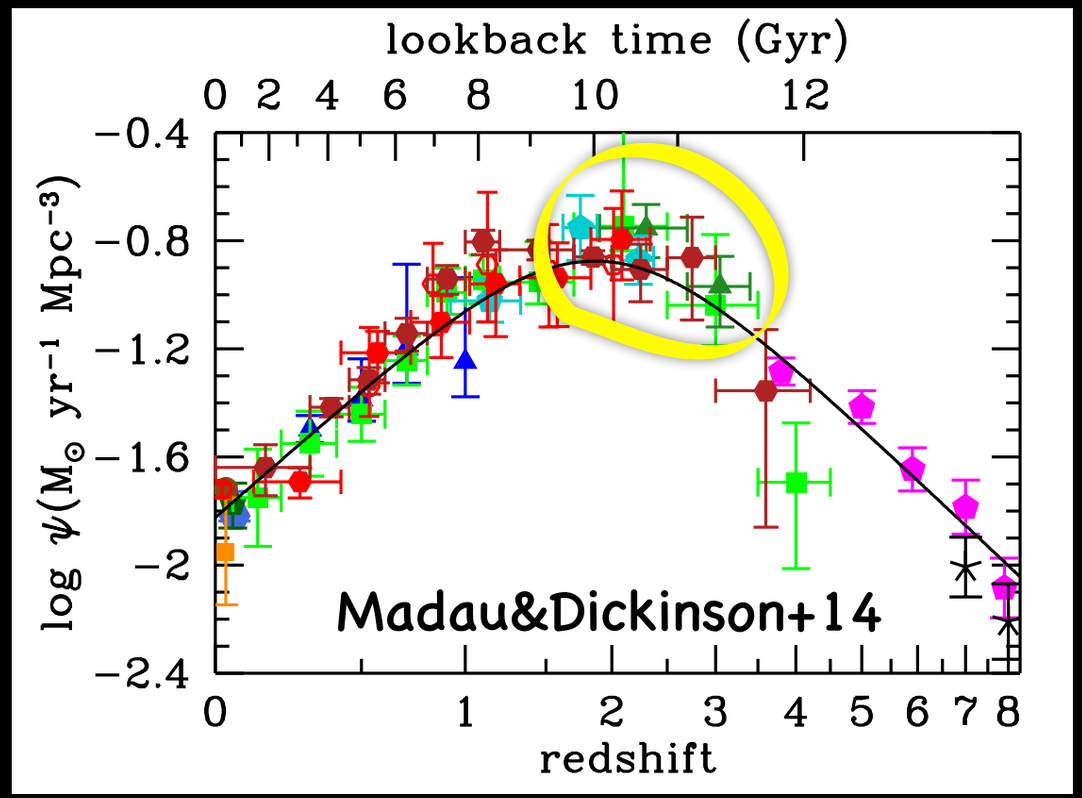
What does it fuel star formation in galaxies?



$$\mathrm{SFR} \sim 10^2 - 10^3\,\mathrm{M_\odot yr^{-1}}$$

$$\tau_{\mathrm{depl}} = \frac{\mathrm{M_{gas}}}{\mathrm{SFR}} \sim 300\,\mathrm{Myr} - 1\,\mathrm{Gyr}$$

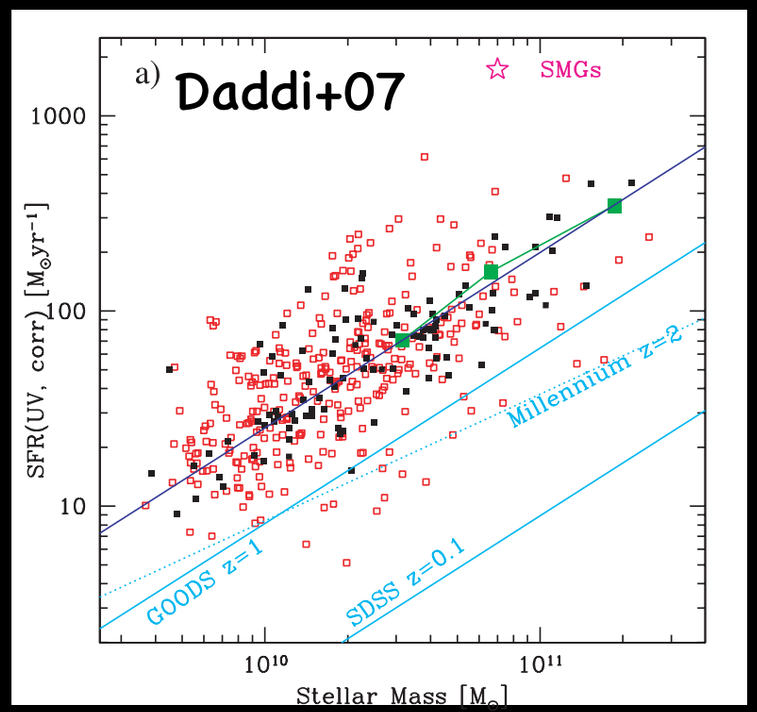
mini bibliography

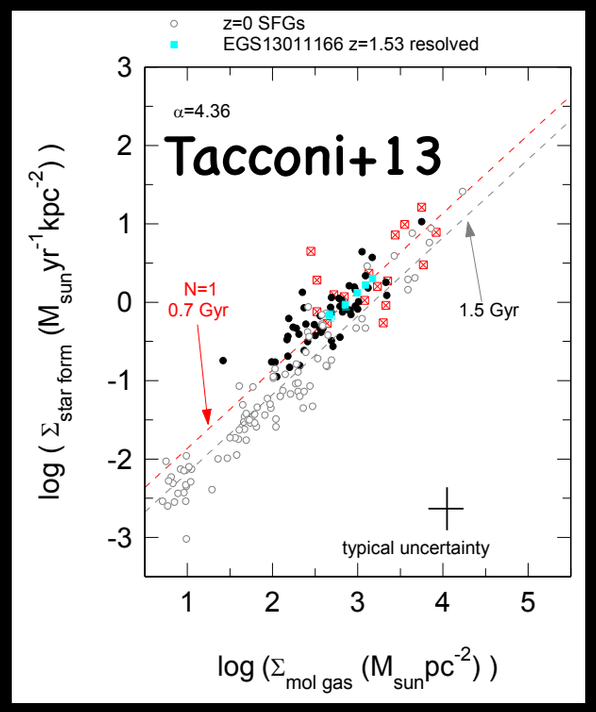
- Leroy+08
- Sancisi+08
- Cresci+09
- Genzel+10
- Tacconi+13
- Saintonge+13
- Schinnerer+16

Additional gas reservoir is needed to support (fuel) star formation!

SF occurs on longer timescale!

…star formation sequence is evident at all times…





Galaxies contain <10% of baryons, an huge reservoir is available in the IGM.

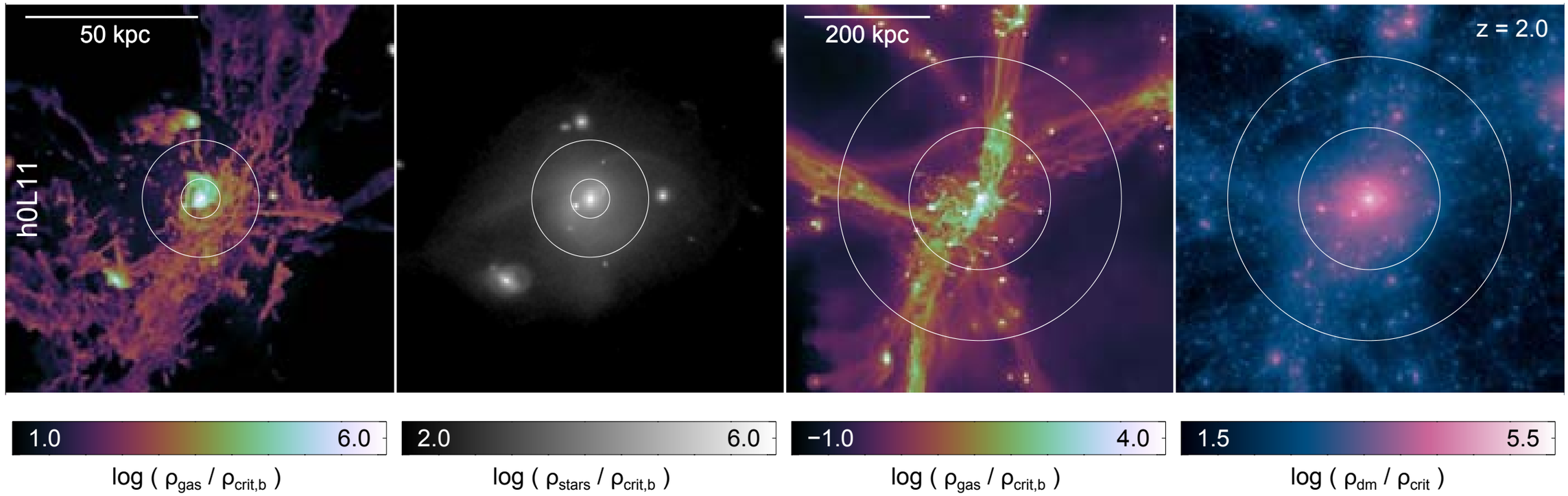
Accretion of gas from the IGM can supply galaxies at all epochs (especially at high-z)!

What we know from simulations…

- In the early Universe massive galaxies grow via accretion of gas through cosmic streams.
- Gas accretion fuel the intense star formation observed in such primeval systems.

mini bibliography

Dekel et al. 2009
Genel, Dekel & Cacciato 2012
Silk & Mamon 2012
Sanchez Almeida et al. 2014
Keres et al. 2014
Schaye et al. 2015
Nelson et al. 2015
Ceverino et al. 2016
Sanchez Almeida et al. 2017

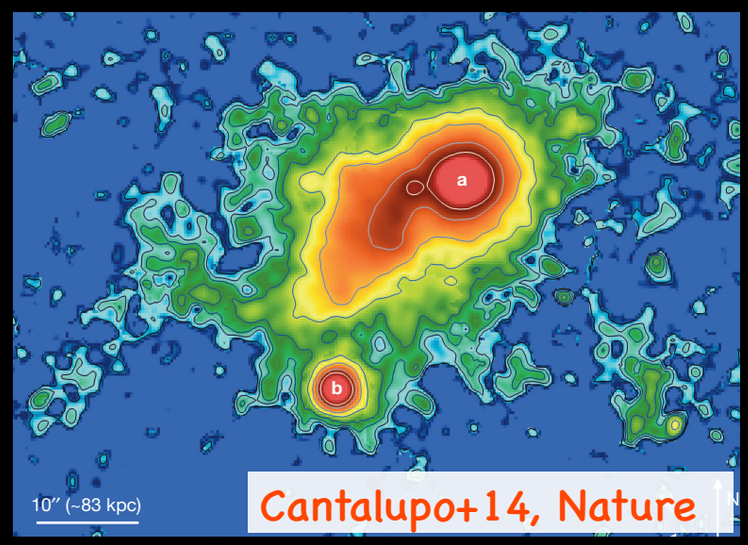


Nelson et al. 2015

Via Absorption

Bouche+12
Prochaska+15
Fumagalli+16
Bouche+16

Via Emission



Cantalupo+14; Borisova+16; Fumagalli+16; Patricio+16; Wisotzki+16; Vanzella+16; Arrigoni-Battaia+16; Vernet+17

What does it happen in massive galaxies within ***overdense regions***?

IGM/CGM enrichment is particularly enhanced in overdense regions (e.g. ***protoclusters***) due to the large presence of massive outflows (starburst and/or AGN driven)

Krishnan et al. 2017	"Enhancement of AGN Activity in Distant Galaxy Clusters"
Socolovsky et al. 2017	"Excess of Post-Starburst Galaxies in Distant Galaxy Clusters"
Hatch et al. 2017	Very good review

Under these peculiar conditions, gas flows and circumgalactic gas reservoir may be investigated exploiting other tracers, e.g., ***molecular gas***, metals, dust…

Let's try with ALMA

ALMA (CO J=4-3) of the most massive galaxy in the redshift range 3<z<4 within the 150 arcmin^2 covered by the GOODS-S field.

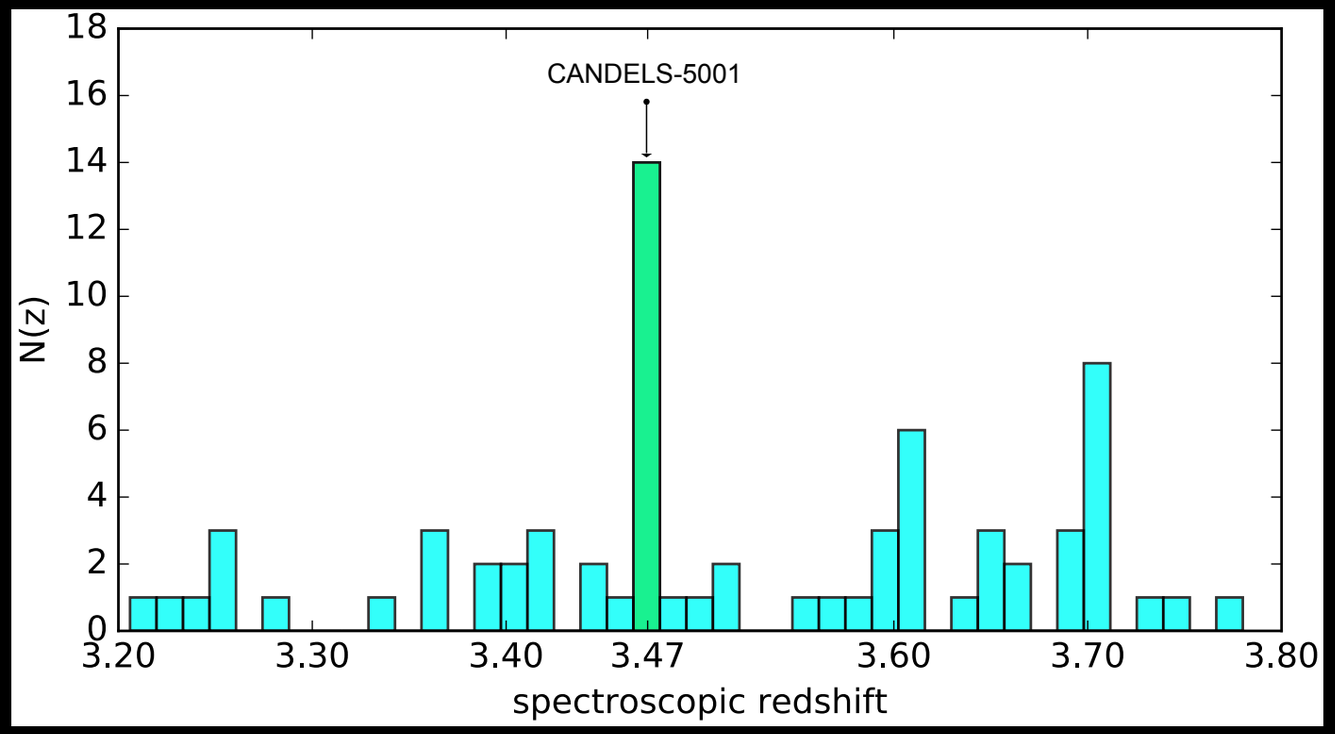
$z = 3.473$

$M_{star} \sim 1.9 \times 10^{10} M_\odot$

$Z \sim 1/2\, Z_\odot$

$SFR \sim 200 - 250\ M_\odot/yr$

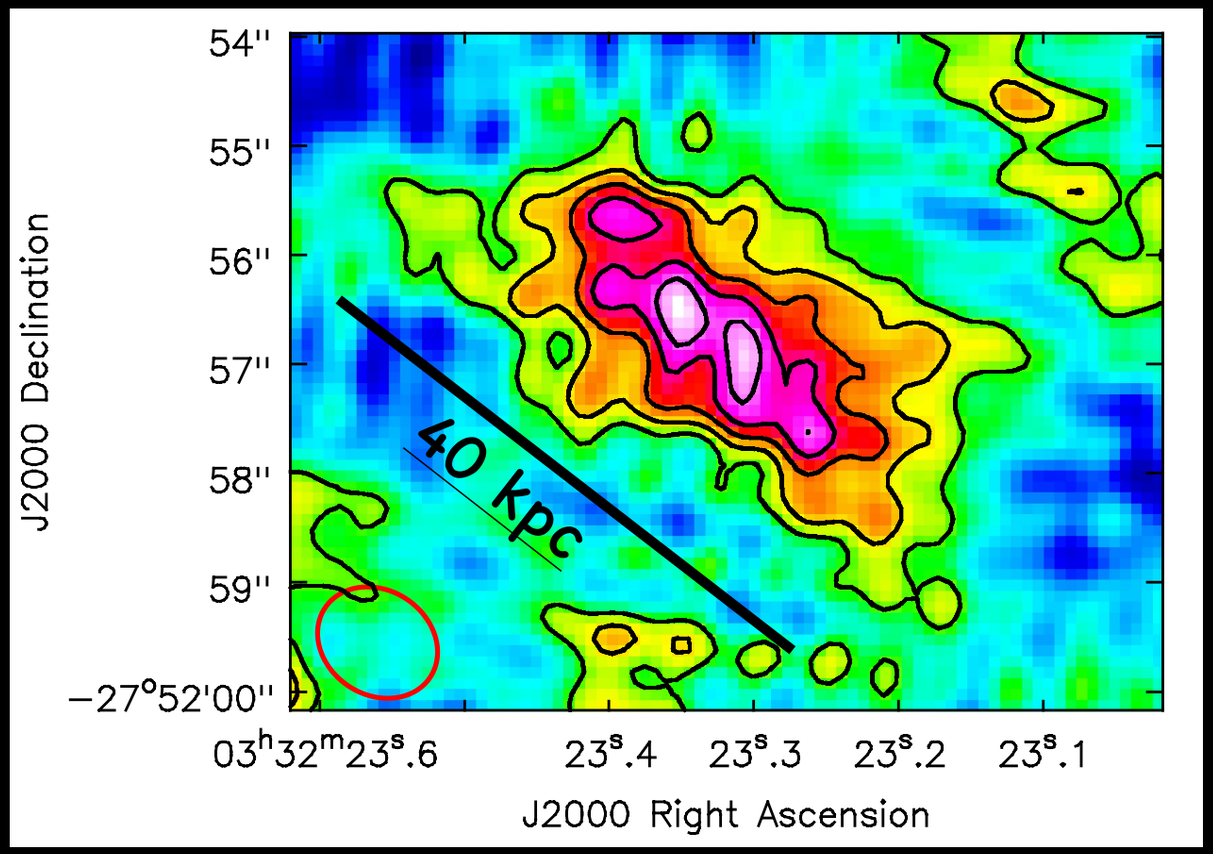
Ginolfi+17; Troncoso+14; Santini+15



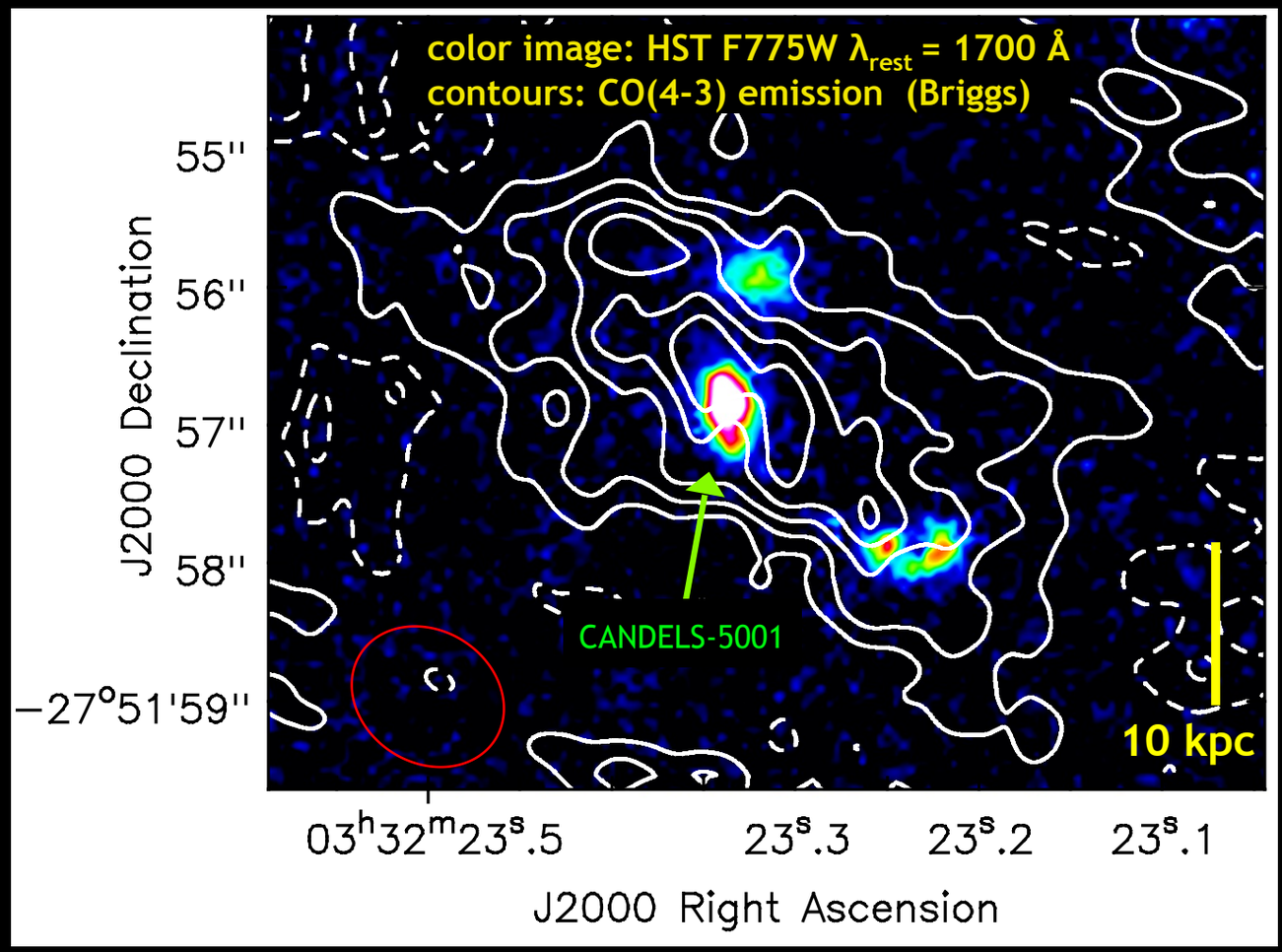
configuration tailored at detecting molecular gas down to deep sensitivity on large scales !

- Franck & McGauch 2016: based on a δ(gal) criteria
- Forrest et al. 2017: extreme [OIII] + Hβ emitters density
- Lemaux et al. (in prep): extreme overdensity of star formation and stellar mass in the density maps from the VUDS spectroscopic survey
- Len Cowie (private communication): huge excess in the 850μ flux (SCUBA-2)

Extended CO emission



Ginolfi et al., 2017, MNRAS, 468, 3468



The CO emission is extended over about 40 kpc in an elongated structure.

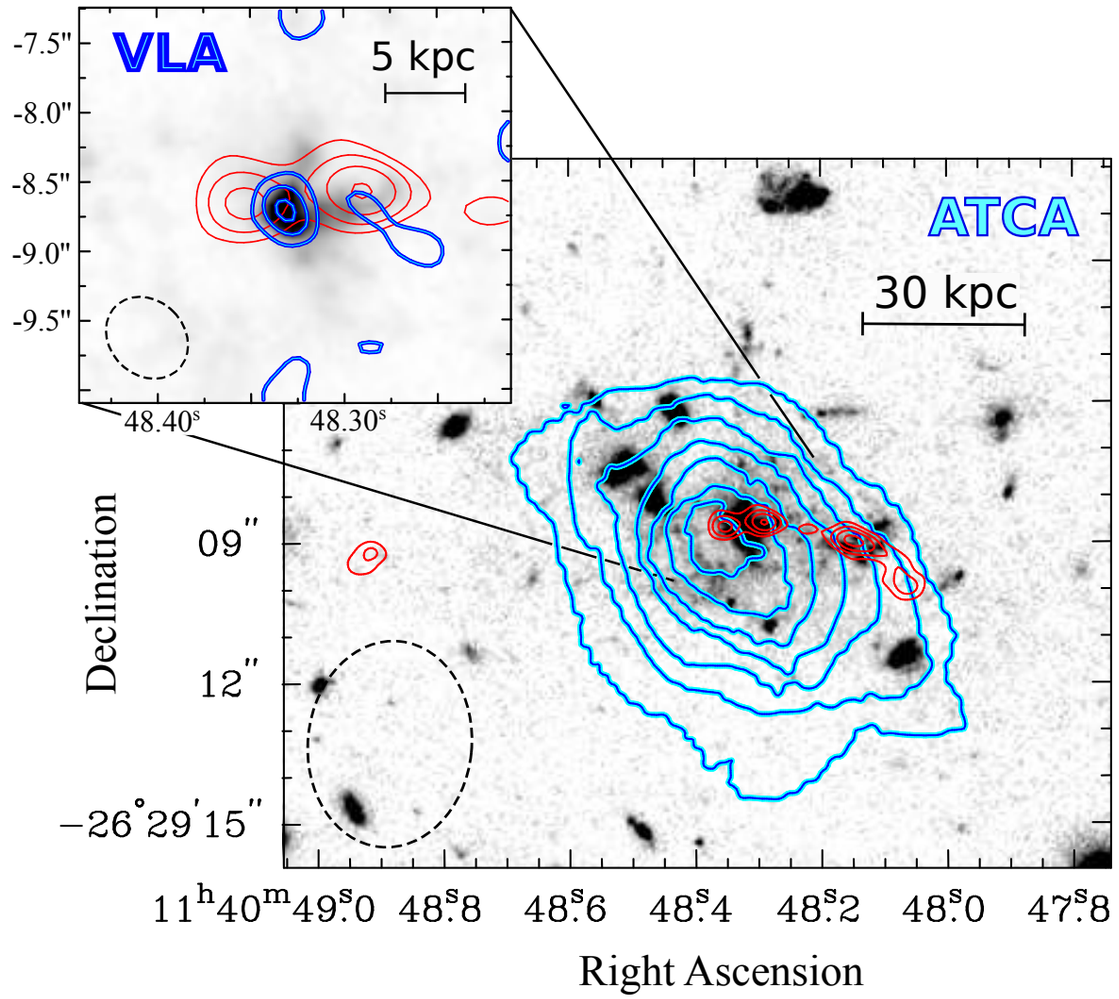
Total gas mass of the system:

$$M_{gas} \sim 1 - 6 \times 10^{11}\ M_{\odot}$$

Only the 30% of the mass is associated with the central galaxy!

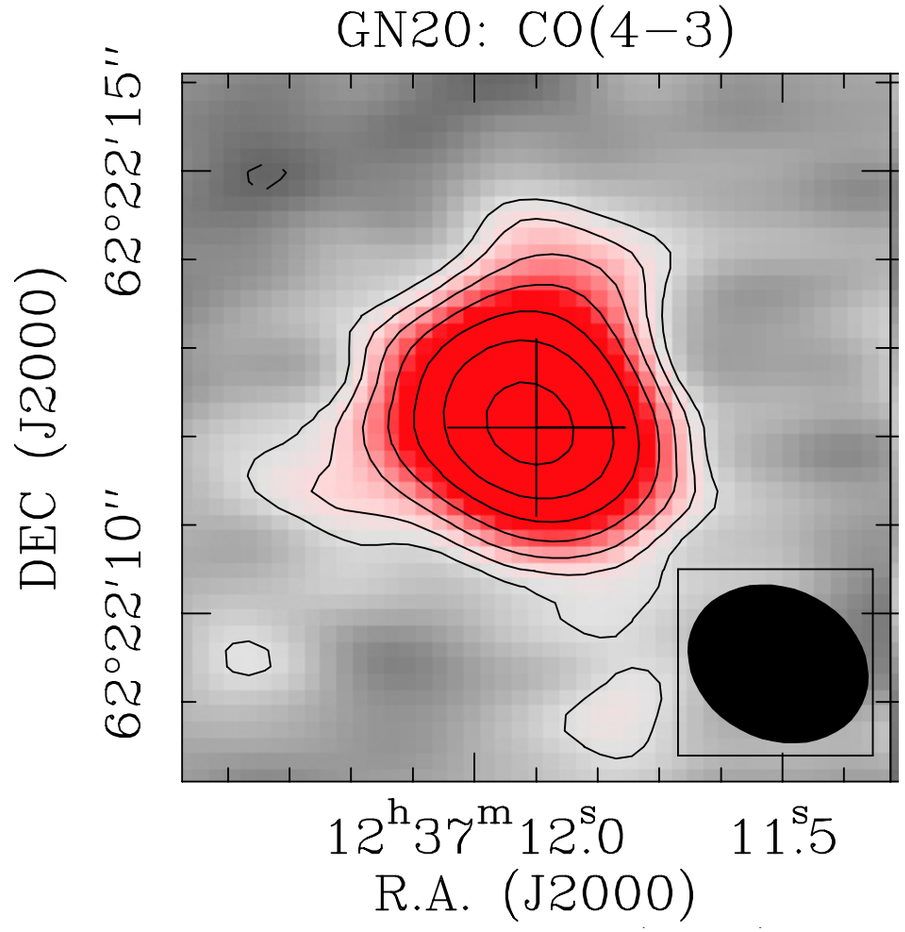
uncertainties: C0 J=4-3/CO J=1-0 and alpha_CO

something similar...



Emonts et al. 2016, Science

Spiderweb galaxy, z=2.15

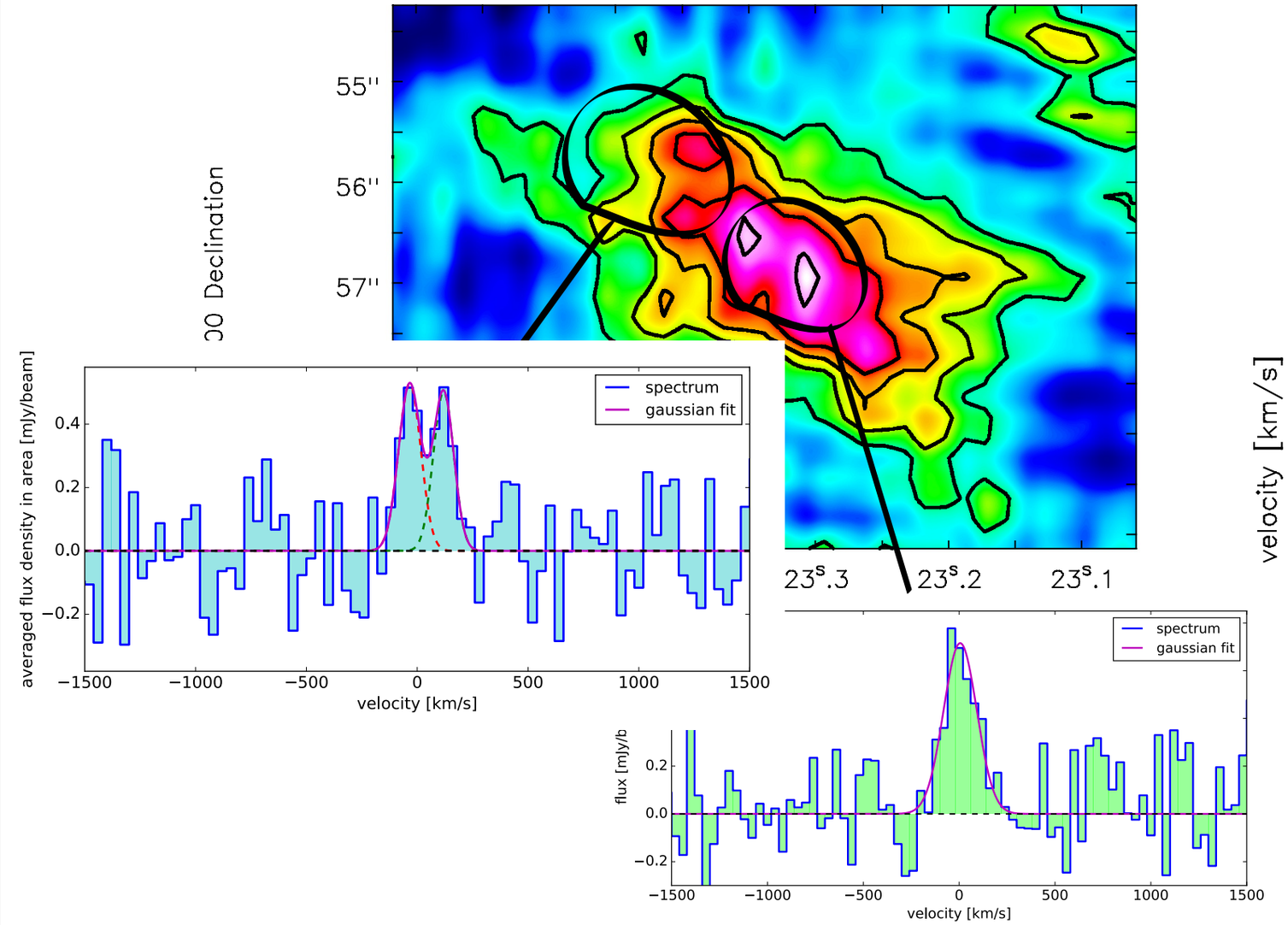


Tan et al., 2014, A&A, 569, 17

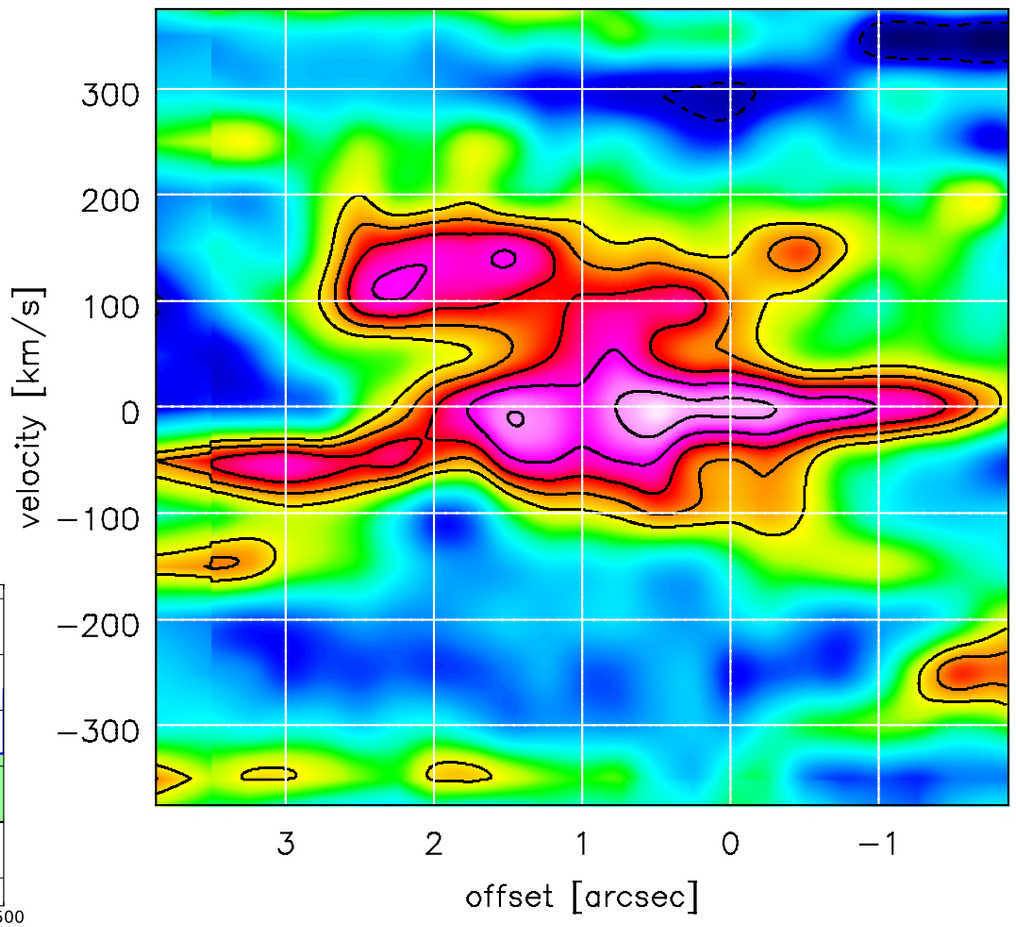
GN20, z=4

kinematics

Ginolfi et al., 2017, MNRAS, 468, 3468



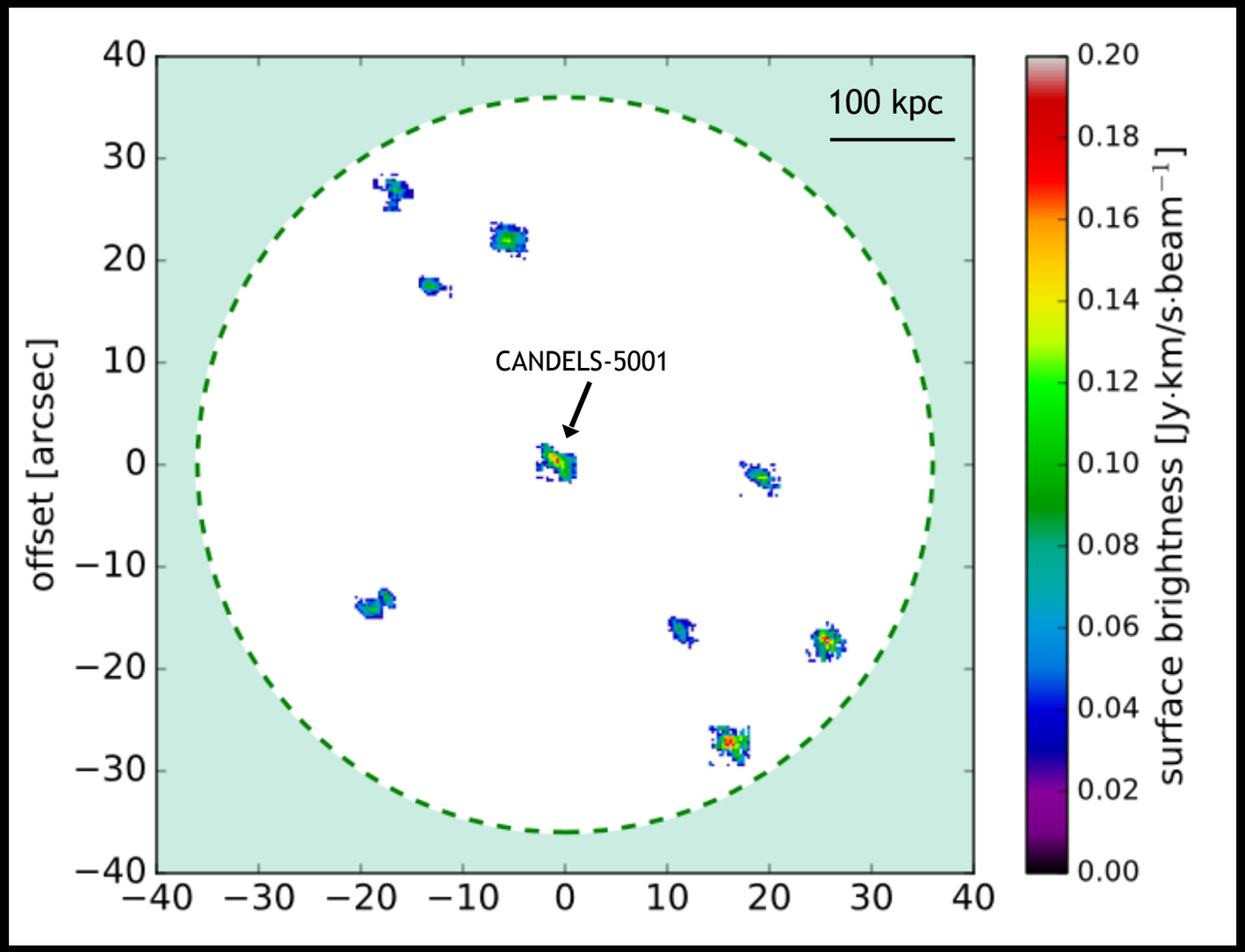
position-velocity diagram

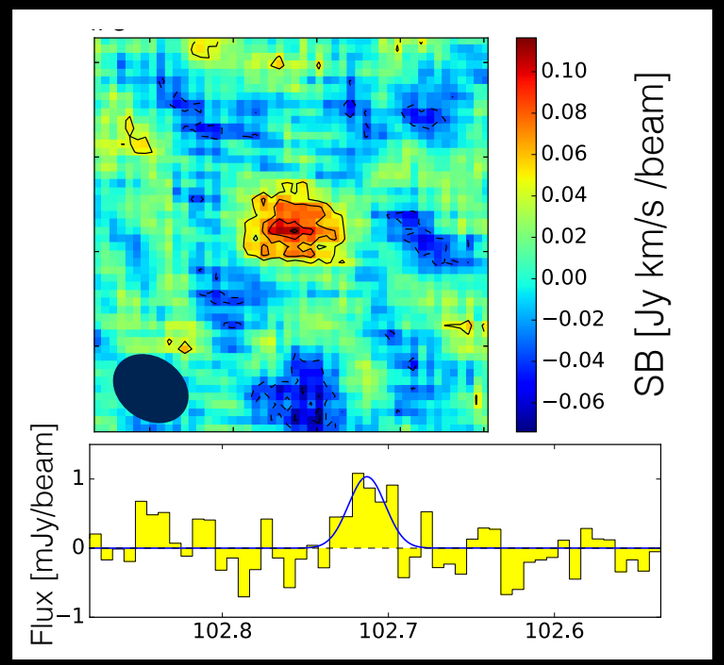


The kinematics ‘suggests’ that the gas in CGM is tracing radial streams moving towards the central massive galaxy.

on larger scales…

Ginolfi et al., 2017, MNRAS, 468, 3468



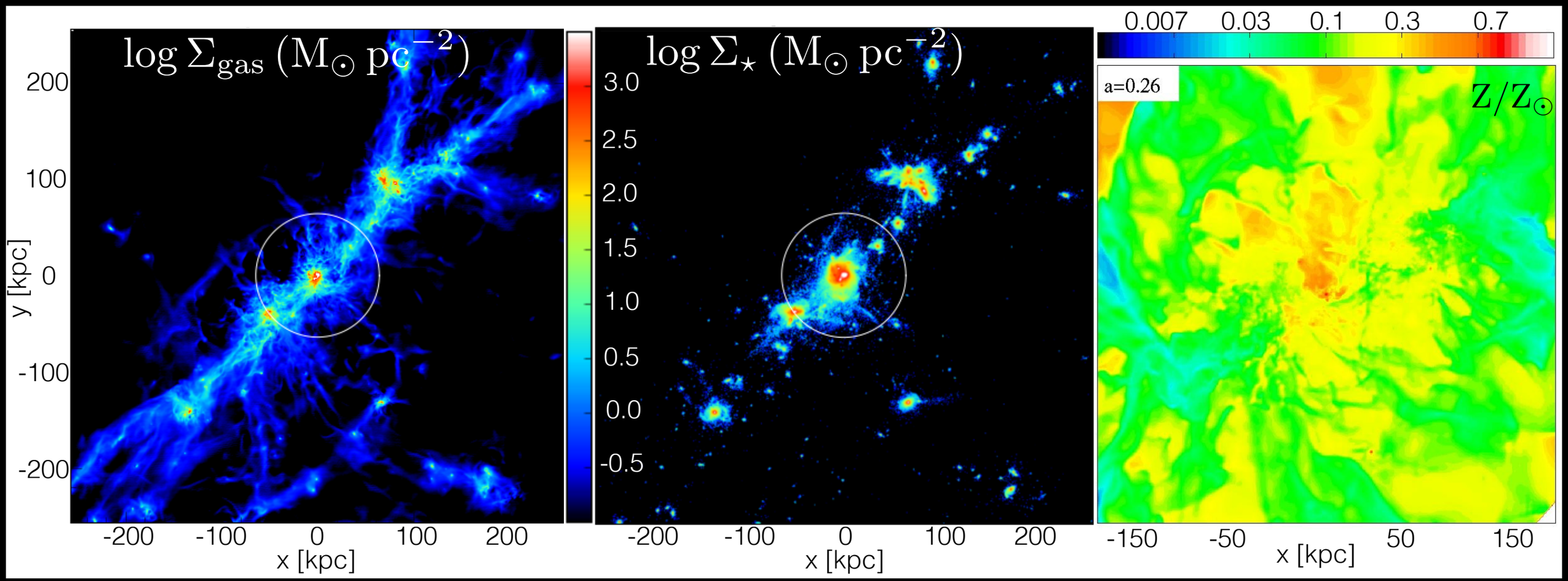


CO emitters gas masses on 250 kpc scales (>5 σ), with masses of $\mathrm{M_{gas}} \sim 10^{10}\ \mathrm{M_\odot}$

these systems may be the densest regions of the large scale accreting filaments in which gas has cooled and fragmented, in line with models expectations…

let's have a look to simulations…

Simulation tailored at reproducing the same properties of our target



Dekel, Lapiner: private communication

We reported ALMA observations tracing the molecular gas around (on CGM scales) the most massive galaxy at z~3-4 in the GOODS-S field, revealing streams of molecular gas on scales from 40 to 200 kpc accreting onto the central galaxy. (see Ginolfi+17, MNRAS)

direct observational evidence of gas flows sustaining star formation?

we need confirmation and more statistics…
We're planning deep follow-up observations (ALMA, MUSE, SINFONI) to probe the multi-phase CGM around galaxies.

Our idea:

This may be a common behaviour among massive galaxies in overdense regions (e.g. protoclusters). These are peculiar systems where it may be possible to understand gas flows and accretion by looking at the molecular gas phase.

take a protocluster

choose a massive galaxy

propose for deep (<10h) and large scale-sensitive ALMA obs.

cross you fingers

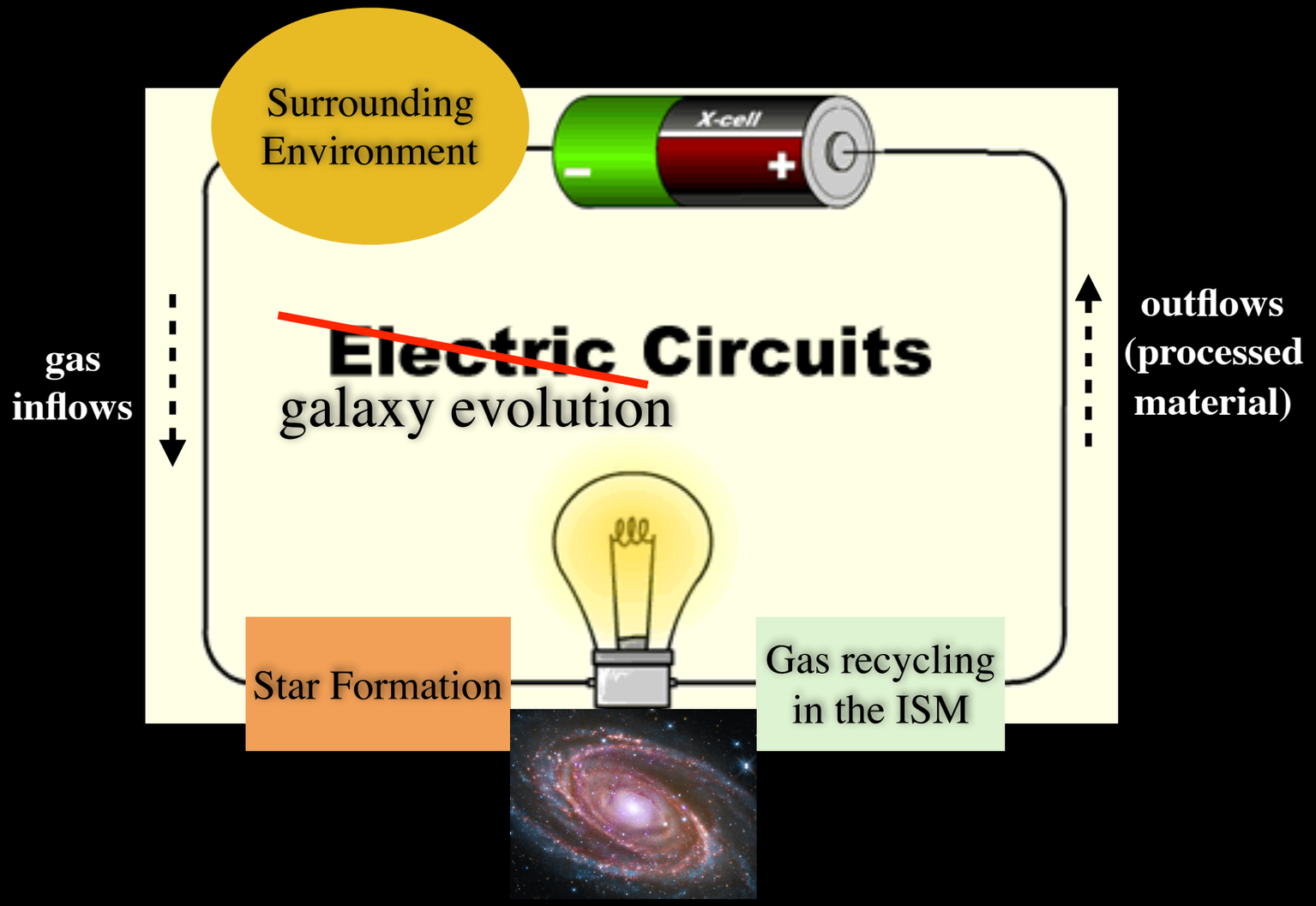
IF

not accepted

accepted

good stuff!

The galaxy baryon cycle



What does it fuel galaxies?

What does it happen in galaxies? (e.g., metals and dust evolution)

What is the imprinting of feedback on CGM?

GAMESH - our model of galaxy evolution

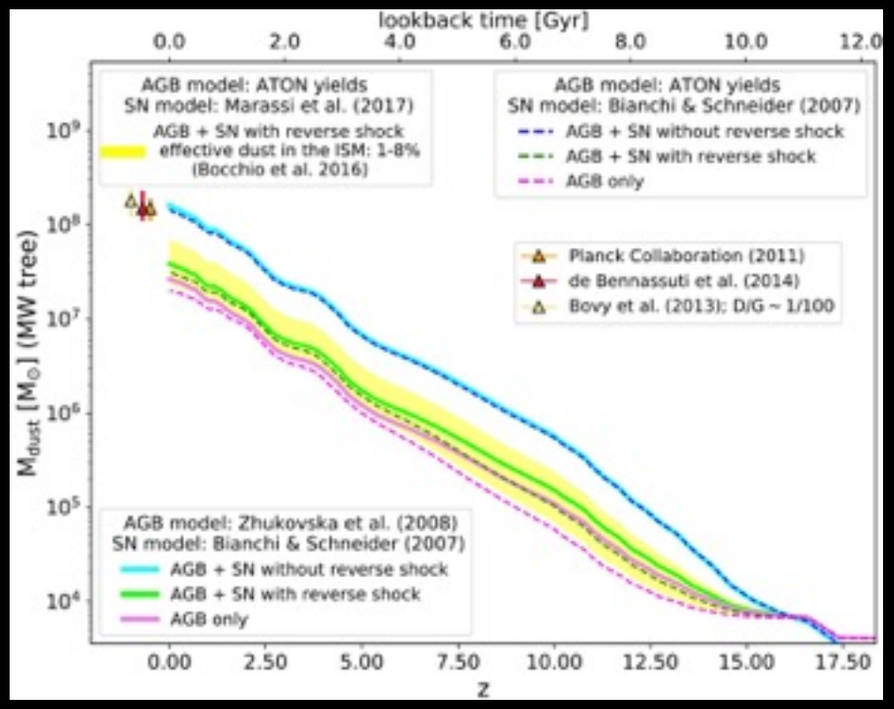
- Star Formation
- Chemical Enrichment (metals/dust)
- Pop III/Pop II transition
- SN-driven Feedback
- Galactic winds

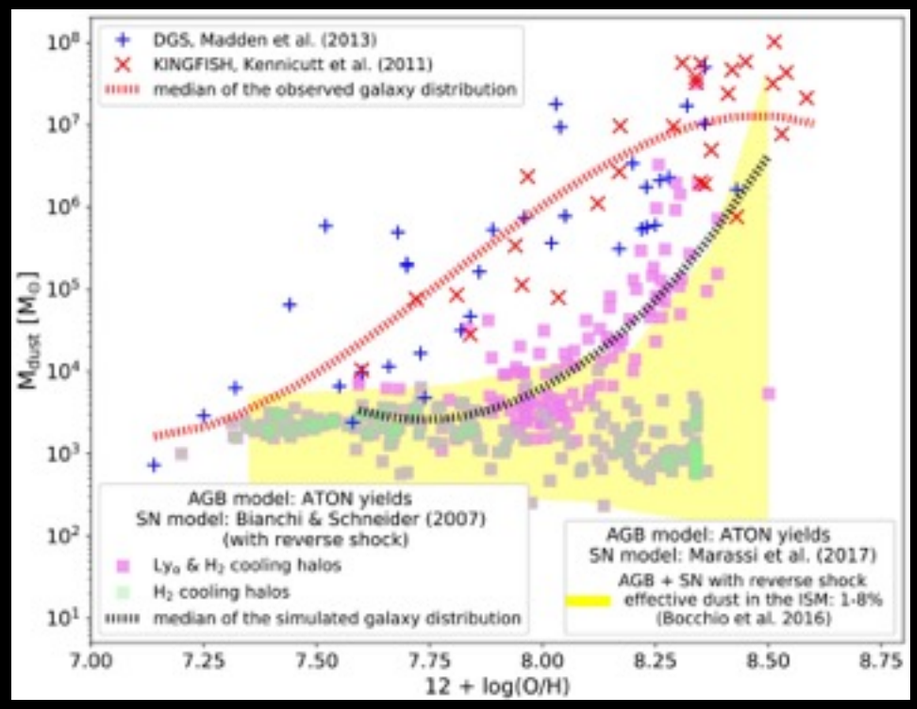
bibliography

De Bennassuti+14; Valiante+14; Graziani+15; Valiante+16; Pezzulli +16; Graziani+17; Schneider+17; Ginolfi+17

Where does galactic dust come from?

Ginolfi et al. 2017, MNRAS, stx2572, in press





local galaxies spanning a wide range of stellar masses and metallicities:

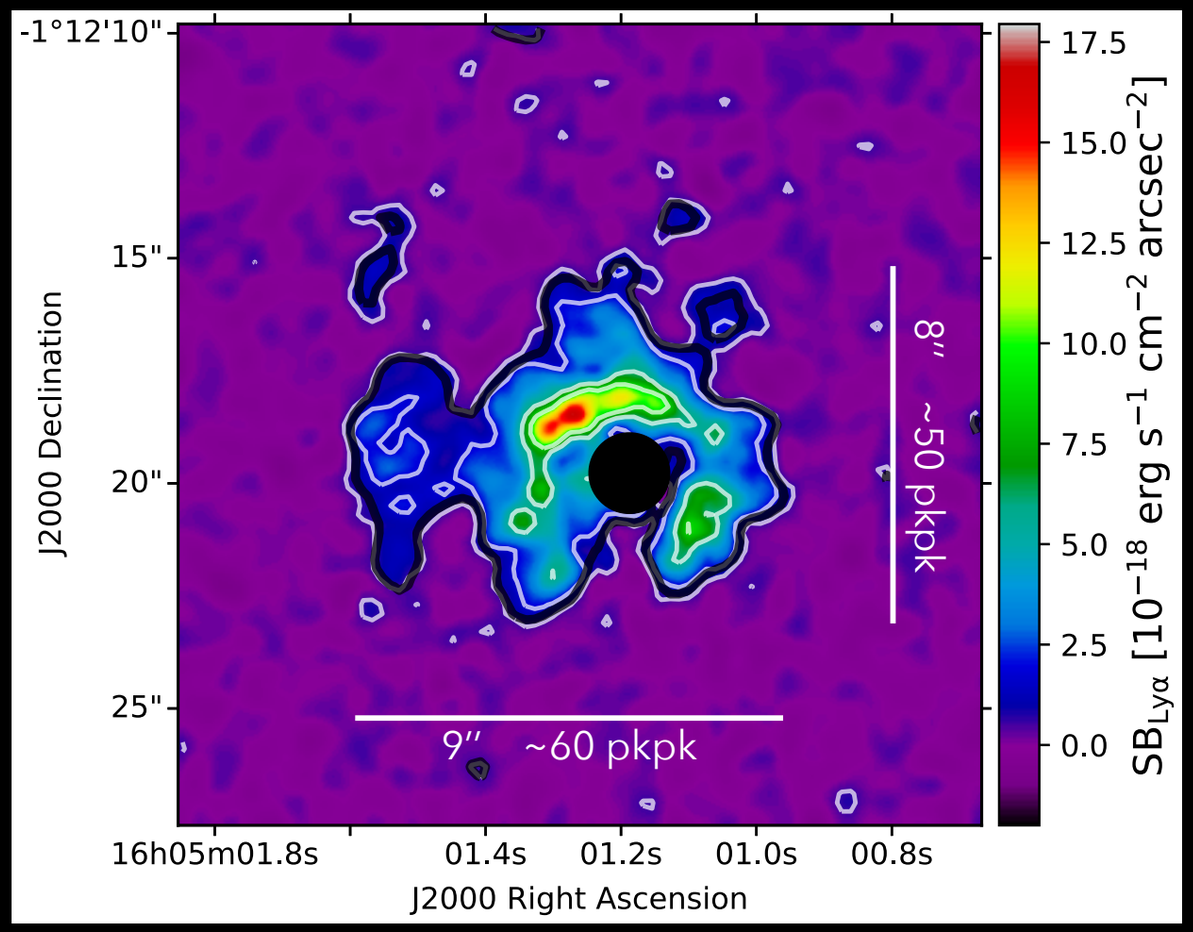
KINGFISH (Kennicutt+11) and DGS (Madden+13)

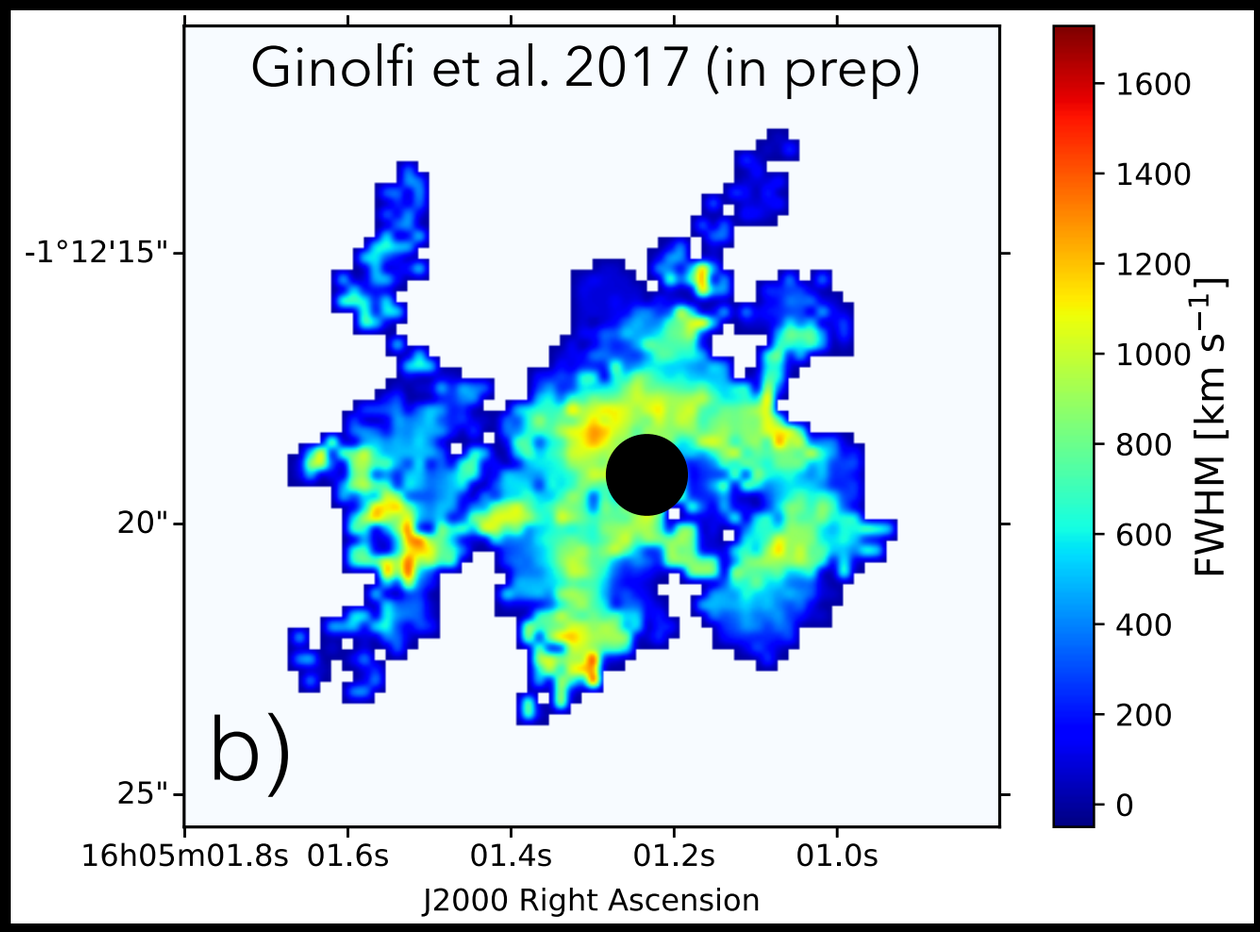
$$12 + \log(\mathrm{O/H}) = [7.14 - 8.77]$$

$$M_\star = [3 \times 10^6 - 1.4 \times 10^{11}] M_\odot$$

Stellar dust is not able to account for the available observations of local galaxies spanning a wide range of stellar masses and metallicities, independently from the adopted stellar dust yields. Additional (non-stellar) mechanisms of dust growth at play?

Lya Nebulae around quasars and **powerful outflows**





Deep MUSE observations of a BAL QSO at z~5

bibliography

Cantalupo+14; Borisova+16; Fumagalli +16; Wisotzki+16; Vanzella+16; Arrigoni-Battaia+16; Vernet+17; Farina+17

- Lya Nebula extended over ~60 kpc;
- An analysis of Lya Nebula sizes along the redshift reveals an interesting relation between sizes of Lya Halos and DM halos around QSO.
- The velocity dispersion map shows a FWHM>1000km/s in the inner regions of the CGM. Outflowing material escaping from the QSO?

Thank you for your attention

questions?

comments?

suggestions?