# Characterizing the CGM and IGM of galaxies with MAAT: two practical cases at two extreme redshifts

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# Outline

- Gas accretion in cosmological simulations
  Science Case

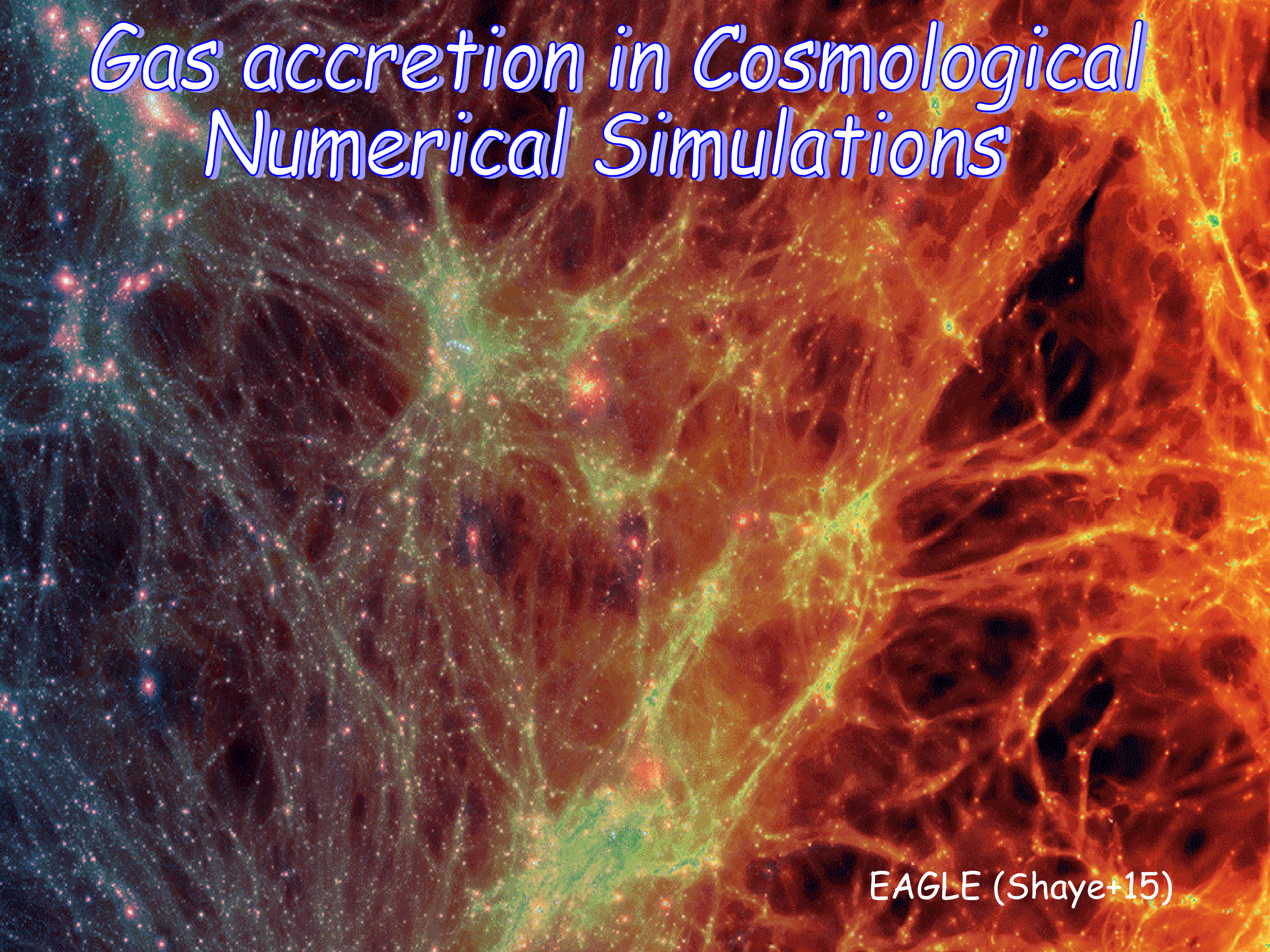
- Observational evidence for cosmological accretion

- z=0 The HI plume of Izw18

- z=3.18 Gigantic Lya nebula dynamics, and so, its nature

- Summary: take-home message

# Gas accretion in Cosmological Numerical Simulations



EAGLE (Shaye+15)

Cosmological numerical simulations of galaxy formation predict that accretion of metal-poor gas from the cosmic web fuels star formation in disk galaxies (e.g., Dekel & Birnboim06, Dekel+09, Silk & Mamon12, Genel+12 ...)

This process occurs at all redshifts, when the physical conditions are given, this gas accretion occur though a particularly fast via called cold-flow accretion: the Dark Matter halo mass has to be below a threshold, typically, of the order of

$$M_{halo} \leq 10^{12} M_{\Theta}$$

Model galaxies tend to reach a subtle **stationary state** where the gas accretion rate balances the star-formation rate (SFR), once outflows are properly taken into account (*Finlator & Dave 2008; Bouché+10; Schaye+10; Fraternali & Tomassetti+12; Dave+12; Dekel+13; Bothwell et al. 2013; Feldmann 2013; Altay+13; Forbes+14, Sanchez Almeida+14*).

gas accretion rate

1D model (bathtub) -->

$$\mathrm{SFR}(t) \simeq (1 - R + w)^{-1}\, \dot{\mathrm{M}}_{\mathrm{in}}(t),$$

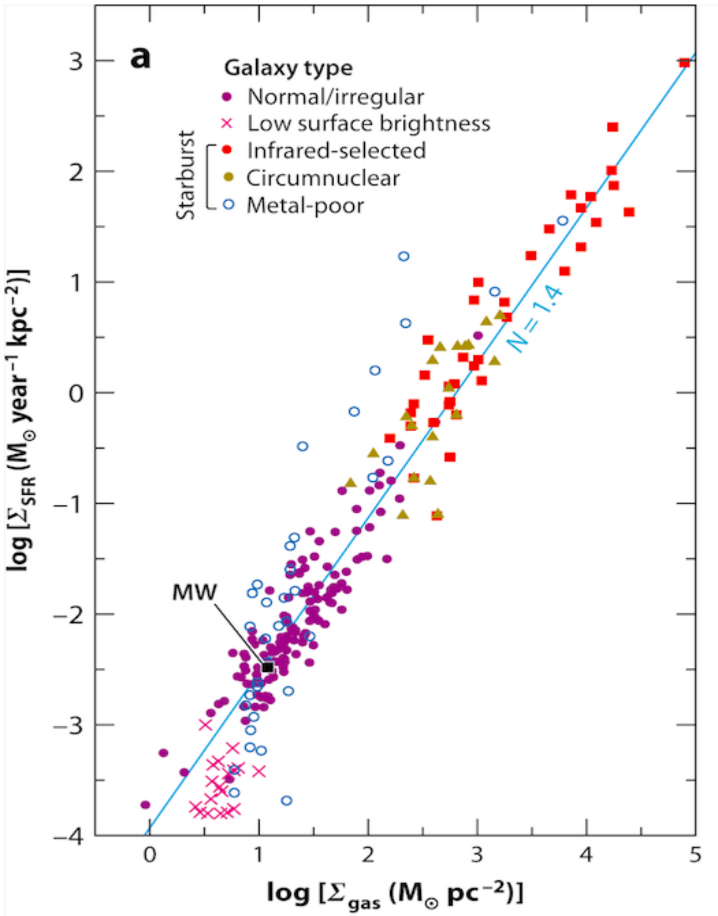
$$\mathrm{M_g}(t) \simeq \tau_{\mathrm{g}}\, \mathrm{SFR}(t) \simeq \frac{\tau_{\mathrm{g}}}{1 - R + w}\, \dot{\mathrm{M}}_{\mathrm{in}}(t).$$

Why is gas accretion so important?

It is like 'the one ring' of 'the lord of the rings'

One  ring to rule them all

# Short gas-consumption time-scale




Kennicutt RC Jr, Evans NJ II. 2012.

Kennicutt-Schmidt (KS)-like law

$$\mathrm{SFR} = \epsilon\,\mathrm{M_g} = \frac{\mathrm{M_g}}{\tau_{\mathrm{g}}}.$$

The star formation rate (SFR) is proportional to the mass of gas available to form stars, with a (gas consumption) time scale smaller than the rest of the important timescale,

$\tau_g < 1$ Gyr

... and decreases with increasing z

# Properties of the emitting gas

Gas accretion is expected to: e.g.:SA+14, A&ARev

- be extremely hard to detect because of the low density

- have low metallicity (but > 0.01 $Z_{\odot}$)

- be important in low-mass haloes (< $10^{12}$ $M_{\odot}$), i.e., in most galaxies at high redshift, and in dwarfs of the local Universe.

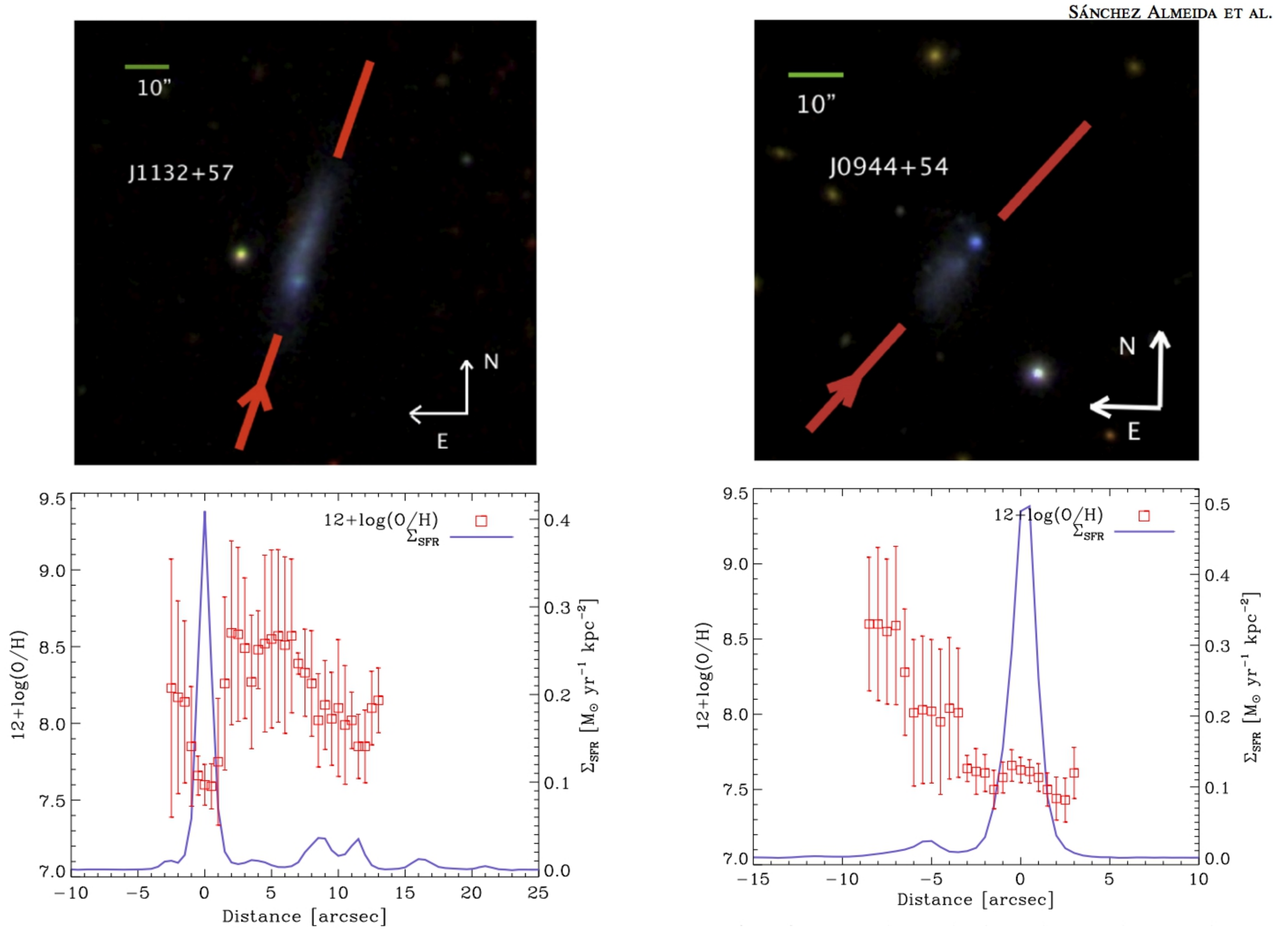
- be clumpy

- be accreted in the outskirts of the disks, so that they have to be transported inward to produce stars.

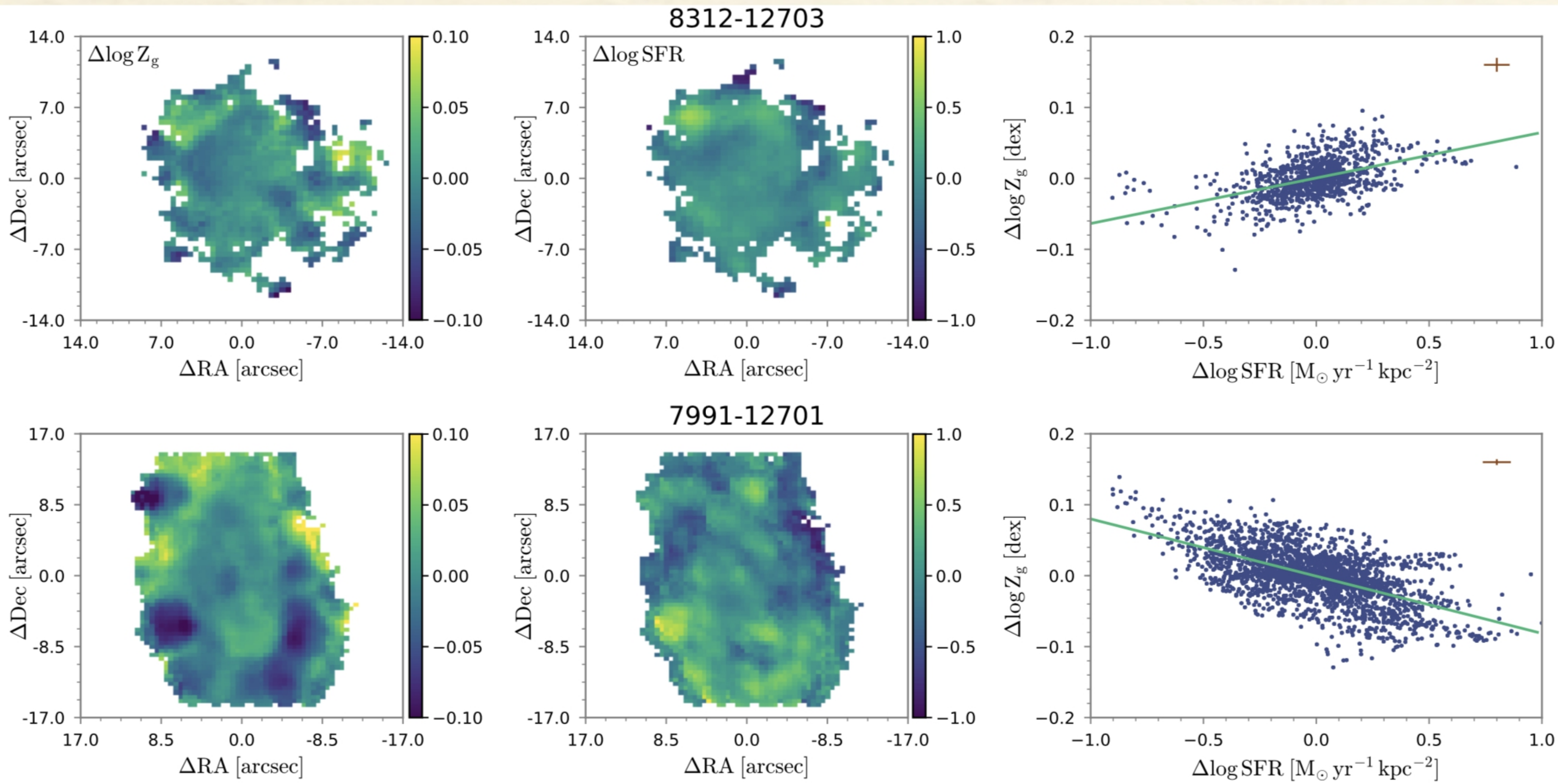
- produce chemical inhomogeneities in the disks (e.g., Ceverino+16)

- emit in H lines, including Ha, with a surface brightness at a level of around $10^{-17}$-- $10^{-18}$erg/s/cm$^2$/arsec$^2$ (e.g., Olmo-Garcia, Thesis, 19)

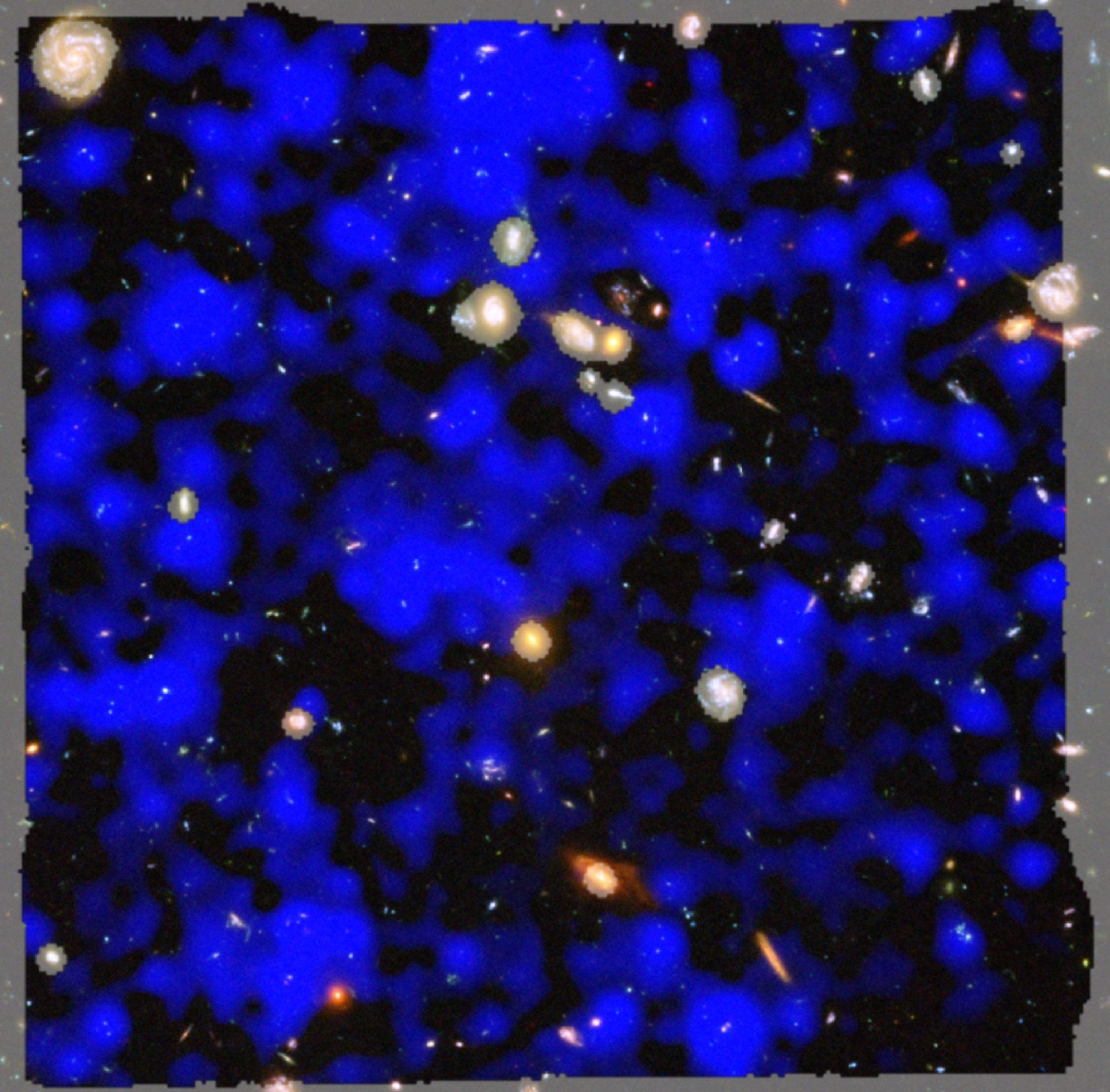
Extremely metal poor (XMPs) do present metallicity inhomogeneities so that the larger the SFR the more metal poor (SA+15, ApJL)



Inhomogeneities related with the SFR present in most star-forming galaxies of the local Universe (as portrayed by MaNGA: Sánchez-Menguiano+19, ApJ, SA&Sánchez-Menguiano 19, ApJL)




- radial gradients of SFR and Zg are removed from the 2D maps.
- some 800 galaxies



- HUDF + **MUSE**

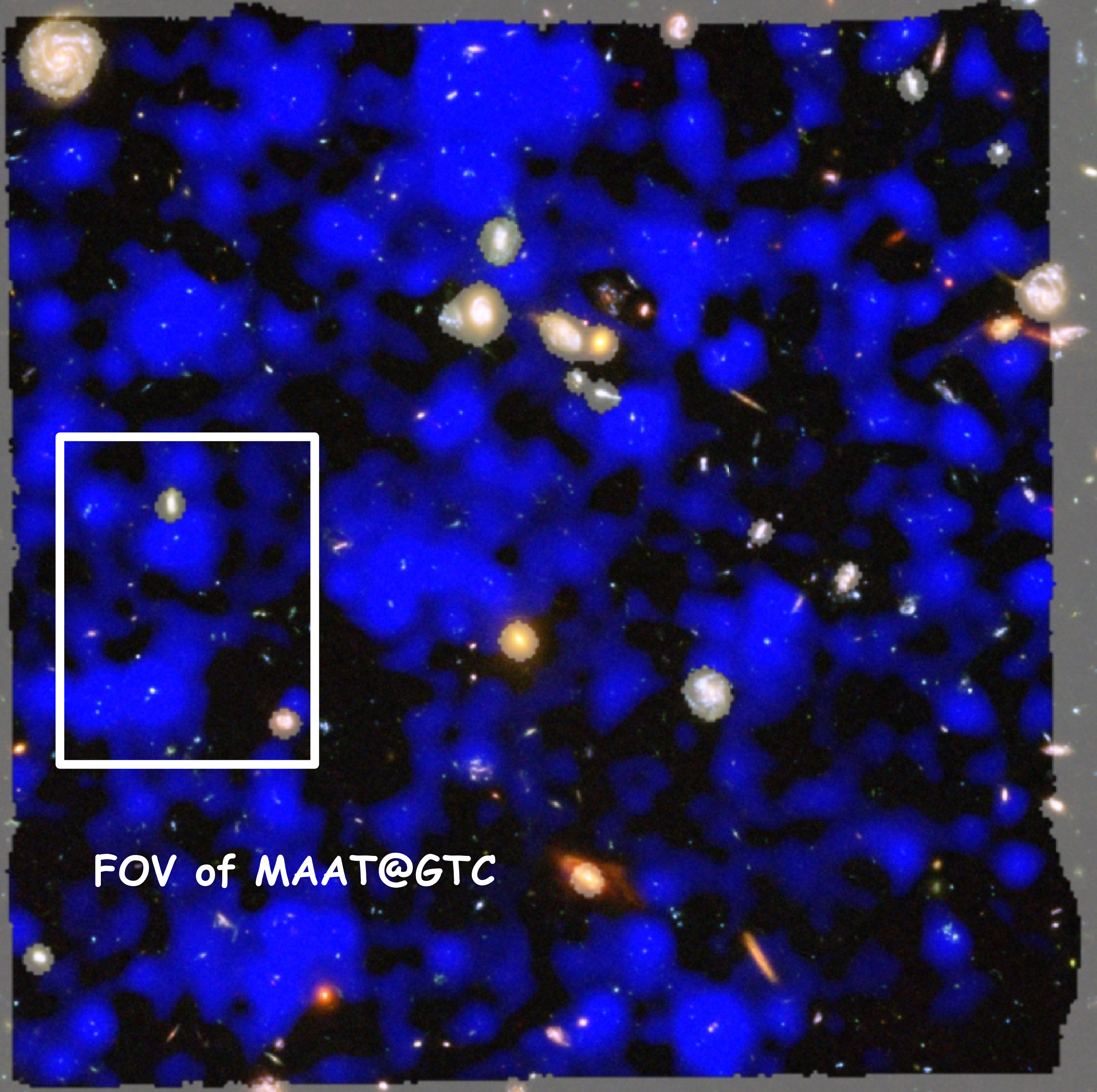
- Lya emission in Blue

- Any LOS pierces a Lya emittinng clump

- redshift 3 to 6

- min signal at $10^{-19}$ erg/s/cm$^2$/arsec$^2$

Wisotzki+18, Nat

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Wisotzki+18

MAAT is not the instrument for discovering new diffuse emission around galaxies (circum galactic medium, **CGM**, and inter-galactic medium, **IGM**).

However, it may be ideal for follow up studies of known emission to determine:

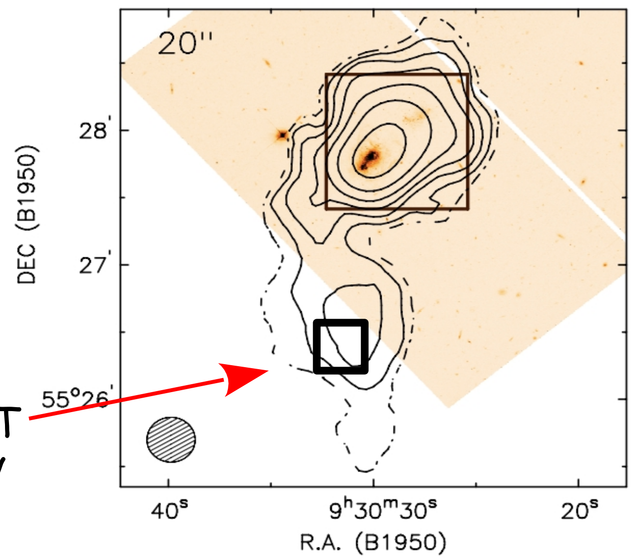
- relative velocities (good spectral resolution)

- metallicity (good spectral coverage)

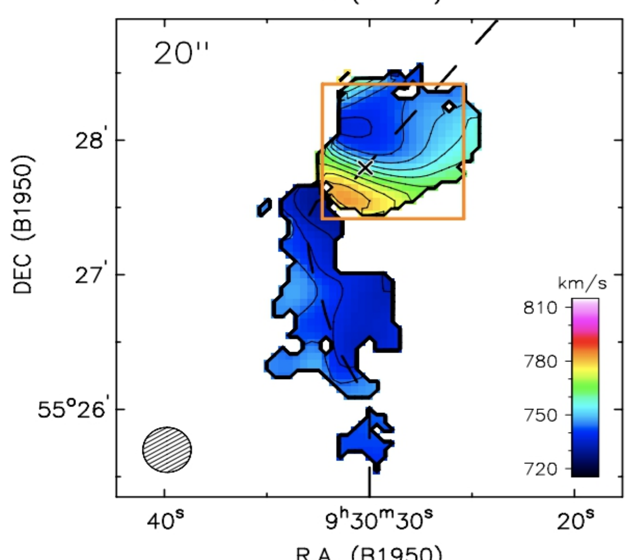
- ionization mechanisms?

- other physical properties of the gas (and stars if existing)

# The gas around local primitive galaxies: Halpha emission in the large HI plume of IZw 18




MAAT FOV




Lelli+12 A&A

- Izw18 is one of these XMP galaxies, that seem to be undergoing a cosmological gas accretion event at present.

- HI shows a large plume that may be evidence for this cosmological gas accretion.

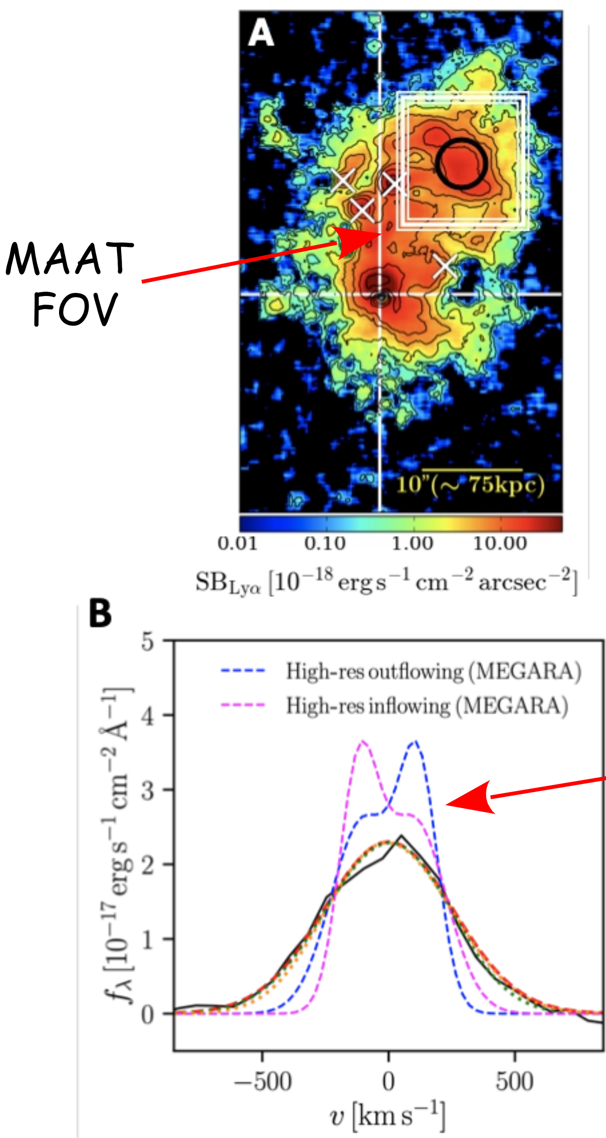
- Can we measure the metallicity? Is its even lower than the HII region metallicity? (as expected).

- Relative velocity with respect to the galaxy?

- Physical conditions? Excitation? Source of ionization the UV background or gravitational energy?

# A high spectral resolution map of a z~3 enormous Lyman-alpha nebula: confirming gas infall from the IGM

(idea: Arrigoni-Battagia+20)




- Gigantic Lya nebula at z = 3.14. What is going on? Cosmological gas accretion episode? Should be ...

- Proto cluster? 1 QSO illuminates the nebula, and then there are 2 AGNs and 2 Lya emmiters, all within 100kpc

- Huge SFRs ... gas supply is needed

- The shape of Lya can be used to distinguish between gas infall and gas outflows

- MAAT may provide a handle on relative motions.

# Summary

MAAT could be a good instrument for characterizing the physical properties of the diffuse emission of the CGM and IGM around galaxies. It is timely!

Pros:
- good spectral coverage
- good spatial resolution, good for high-z studies
- good spectral resolution, independent of seeing

Cons:

- small FOV

Extra:

I have emphasized gas accretion, but accretion comes together with outflows and winds, which also play a regulatory role in the evolution of galaxies (whether they are driven by AGN or star-formation).

Flammarion woodcut