Gas accretion from the cosmic web in the local Universe

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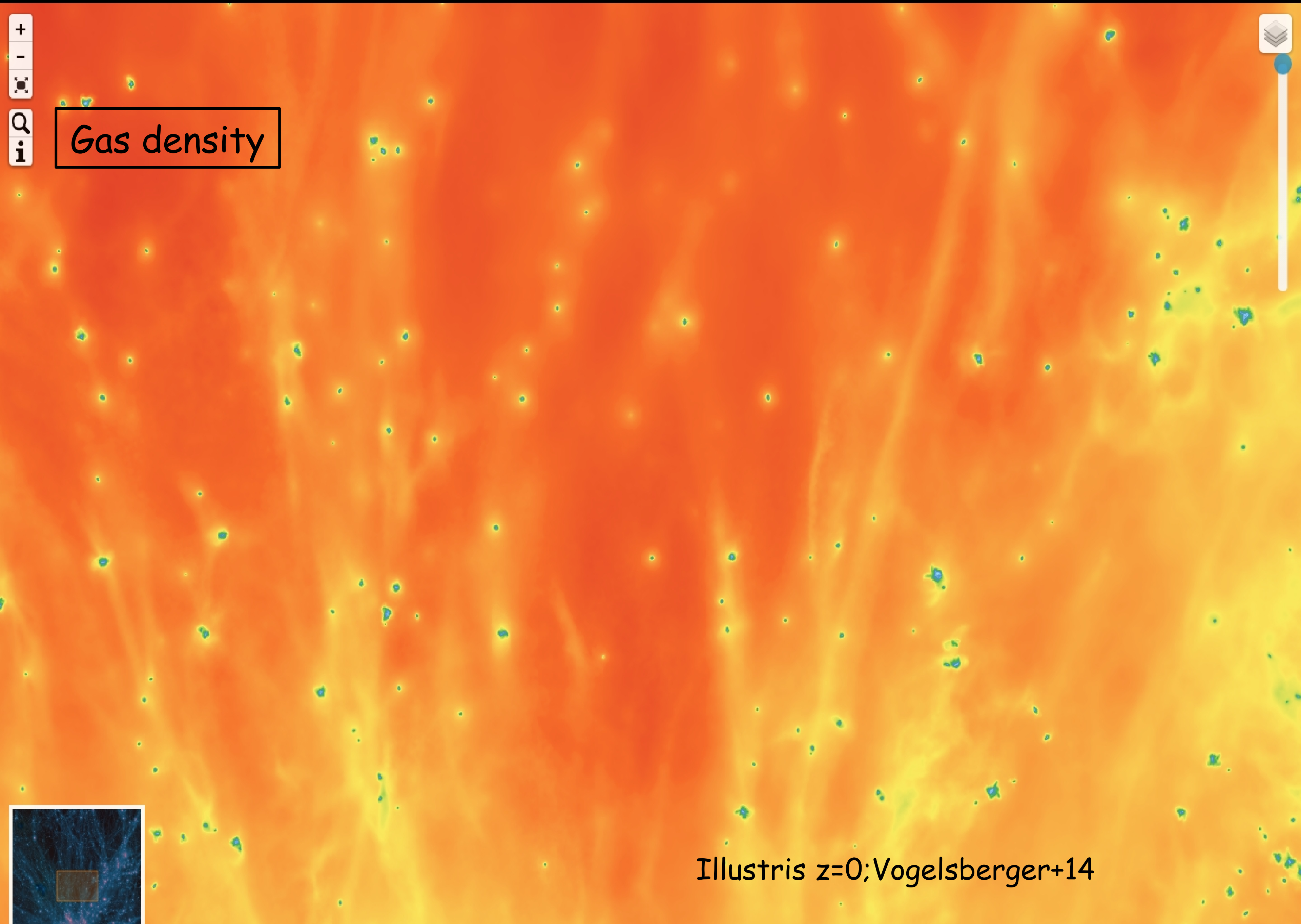
Outline

- Star formation and gas accretion
- Observational evidence of accretion in the local universe
- Evidences from eXtremely Metal Poor galaxies
- Summary: take-home message(s)


Stellar light
Illustris z=0; Vogelsberger+14


Gas density
Illustris z=0;Vogelsberger+14

Star formation and gas accretion

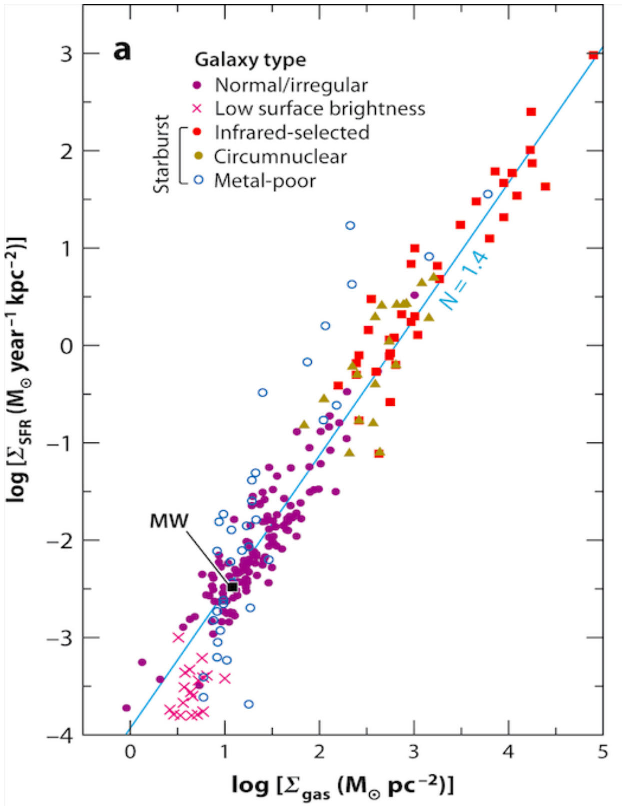
Cosmological numerical simulations of galaxy formation predict that accretion of metal-poor gas from the cosmic web fuels star formation in disk galaxies (e.g., Dekel & Birnboim06, Dekel+09, Silk & Mamon12, Genel+12 ...)

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: which provides fresh gas ready to form stars right where it is needed (Birnboim & Dekel 03)

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

- all galax at high redshift
- sub MW galaxies in the local universe

The gas accretion rate determines the star formation rate



Kennicutt RC Jr, Evans NJ II. 2012.

The reason can be pinned down to the Kennicutt-Schmidt (KS)-like law

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

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,

$$\tau_g < 1\,\mathrm{Gyr}$$

... and decreases with increasing z

gas is "instantaneously" transformed into stars

$$\frac{dM_g}{dt} \equiv \dot{M}_g = -(1-R)\,\mathrm{SFR} + \dot{M}_{in} - \dot{M}_{out},$$ mass conservation

R return fraction

$\dot{M}_{in}$ gas infall rate - the driver of the system

$$\mathrm{SFR} = \epsilon\, M_g = \frac{M_g}{\tau_g}.$$ KS law

$$\dot{M}_{out}(t) = w\,\mathrm{SFR}(t),$$ gas outflow rate

w mass loading factor

Then $$\mathrm{SFR}(t) = \mathrm{SFR}(0)\,e^{-t/\tau_{in}} + \int_0^t \dot{M}_{in}(t')\,e^{-(t-t')/\tau_{in}}\,dt'/\tau_g,$$

$$\tau_{in} = \tau_g\,/(1-R+w).$$

Since τ_g is very small $\dot{M}_{in}$ can be pulled out of the integral and

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

SFR is set the infall rate only (corrected by outflows)

Expected properties of the accreted gas

- low temperatures ($T < 50000$ K; to keep the Hydrogen neutral). Depending on the DM halo mass, mixed with hot gas ($T > 10^6$ K).

- gas infall (but infall and outflows extremely difficult to distinguish), expected to occur in the plane of the galaxy

- low metallicity (it is gas from the cosmic web gas). Due to the gas outflows, the metallicity of the accreted gas increases with decreasing redshift (becoming ~1% $Z_\odot$ at redshift zero).

- Lya forest. Produce absorption features in the spectrum of background sources typically QSO, starburst galaxies, or even GRB

- emission in Lya. The cosmic web gas is an ionized plasma undergoing recombination, and light scattering ... so it should produce an emission spectrum

- mixed with metal rich outflows ... due to stella winds, SNe and AGN feedback. Expected to be concentrated in the direction perpendicular to the galaxy disk.

(e.g., Ceverino+10; van Vort & Schaye12; Fumagalli+11,;Vogelsberger+14; Genel+14)

Observational evidence for gas accretion in the local Universe

The importance of gas infall is as clear from numerical simulation as it has being difficult to prove observationally. Many hints pointing in the direction, but no final proof given yet.

review paper collecting them: SA+14b (A&ARev)

- short gas consumption time-scale compared with the age of the stars
- pools of neutral gas, some with distorted morphology
- high velocity clouds (HVC)
- kinematical distortions (counter rotation HI components and plumes)
- metal poor HI gas around galaxies (Lebouteiler+13;Filho+13)
- the large metallicity of the quiescent BCDs
- metallicity morphology relationship
- distorted stellar kinematics (e.g., polar ring galaxies)
- organized distribution of MW satellites

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- organized distribution of MW satellites
- G-dwarf problem (in the MW and other galaxies)
- bursty SFH of dwarf galaxies
- stellar mass-metallicity-gas mass relationship
- stellar mass-metallicity-size relationship
- stellar mass-metallicity-SFR relationship, i.e., the so-called Fundamental Metallicity Relationship

Evidence from eXtremely Metal Poor galaxies

Local galaxies with a gas metallicity < 0.1 $z/z_{\odot}$ are rare (0.01% of the galax with emission lines)

(By definition, these are the XMP galaxies)

MoralesLuis+11 carried out a systematic search for XMP in SDSS-DR7 (having 10^6 galaxies). Got 32 XMPs (11 new).

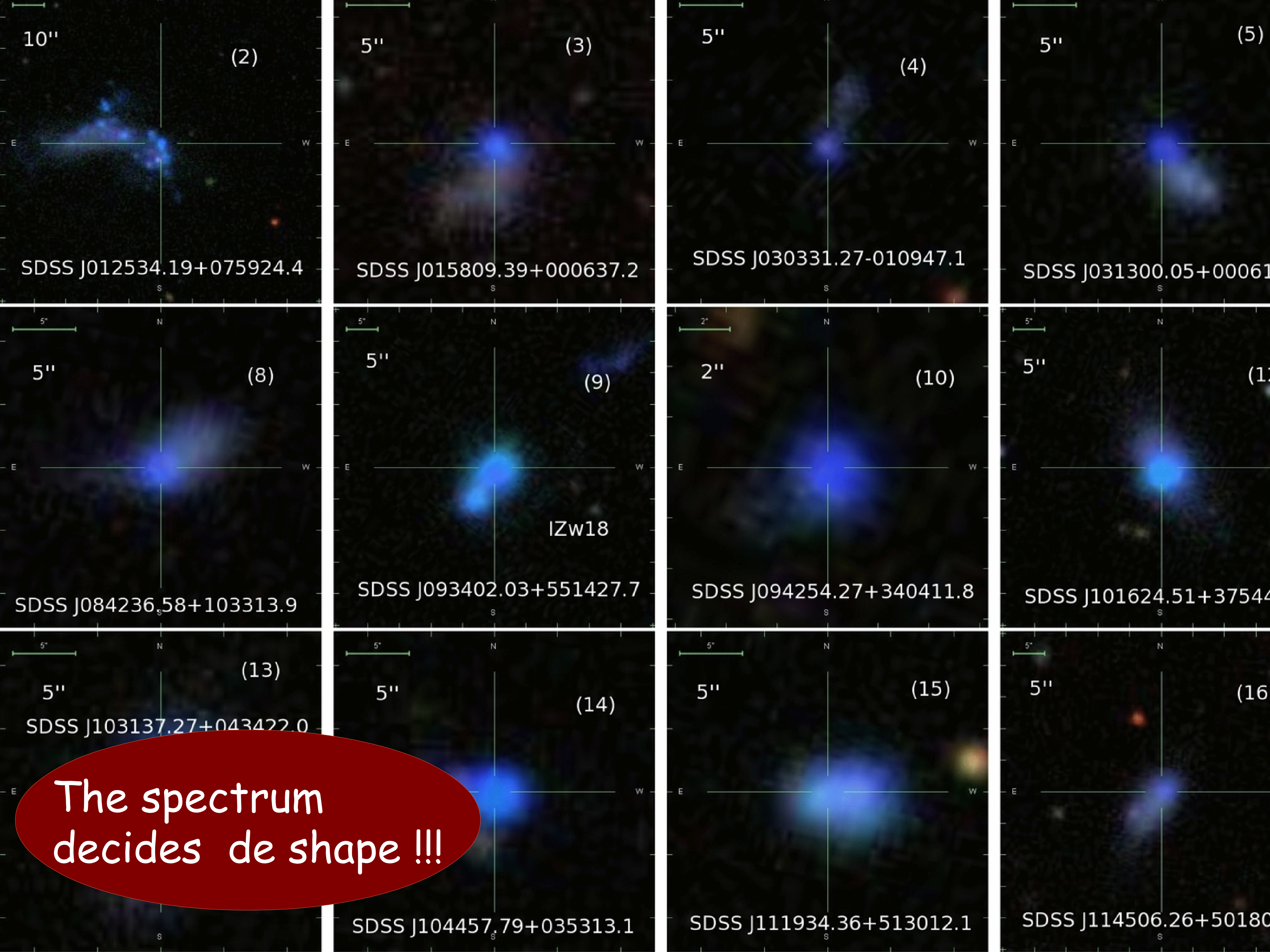
Most of them (24/32) turn out to be cometary!

Papaderos+2008 already found this association

The metallicity of the gas determines the morphology!

Tadpole-cometary morphologies are common at high redshift but rare in the local universe.

At high redshift tadpole-galaxies are associated with primitive disks


10''
(2)
SDSS J012534.19+075924.4
5''
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SDSS J030331.27-010947.1
5''
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SDSS J031300.05+00061
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(8)
SDSS J084236.58+103313.9
5''
(9)
IZw18
SDSS J093402.03+551427.7
2''
(10)
SDSS J094254.27+340411.8
5''
(1
SDSS J101624.51+37544
(13)
5''
SDSS J103137.27+043422.0
5''
(14)
SDSS J104457.79+035313.1
5''
(15)
SDSS J111934.36+513012.1
5''
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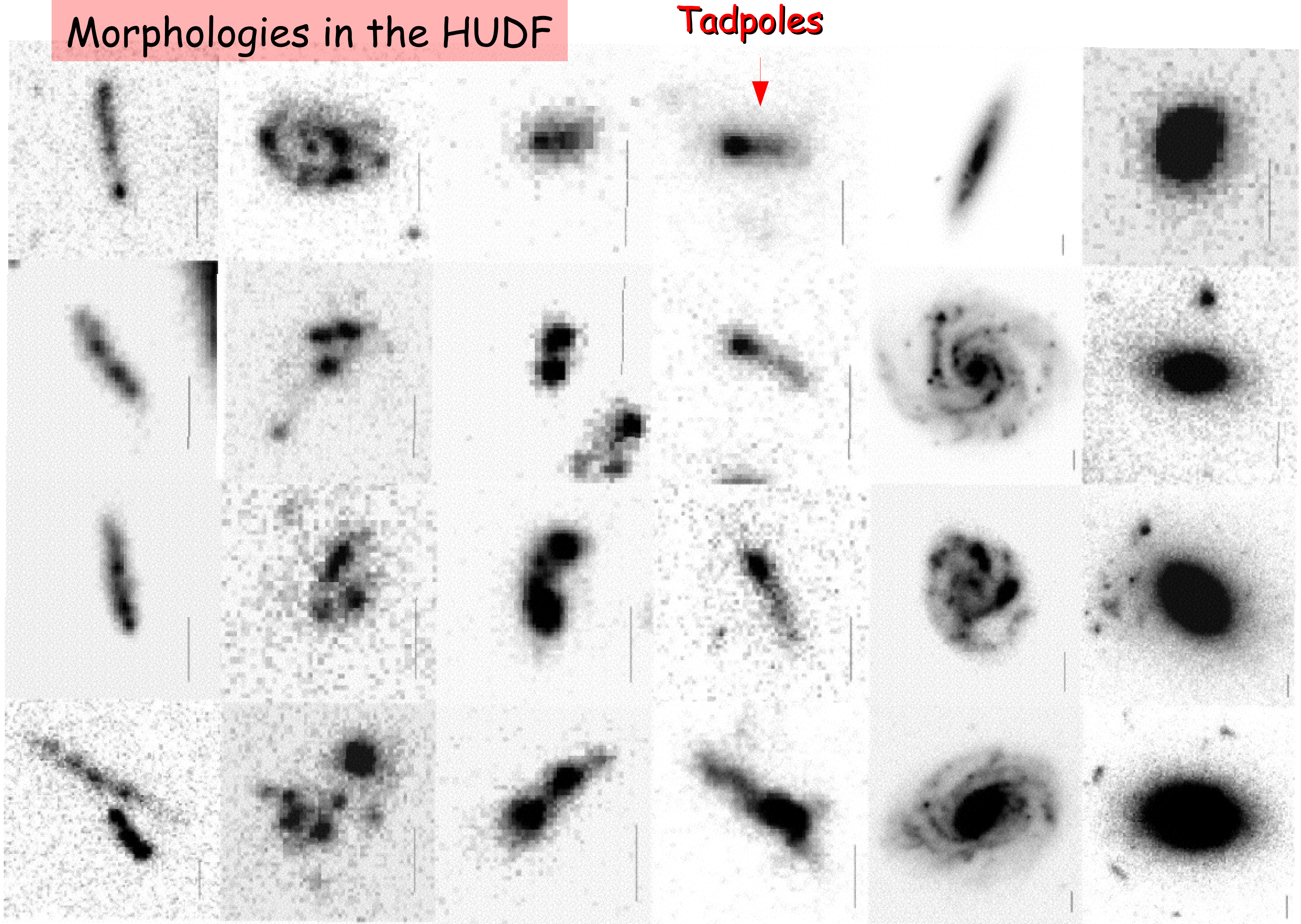
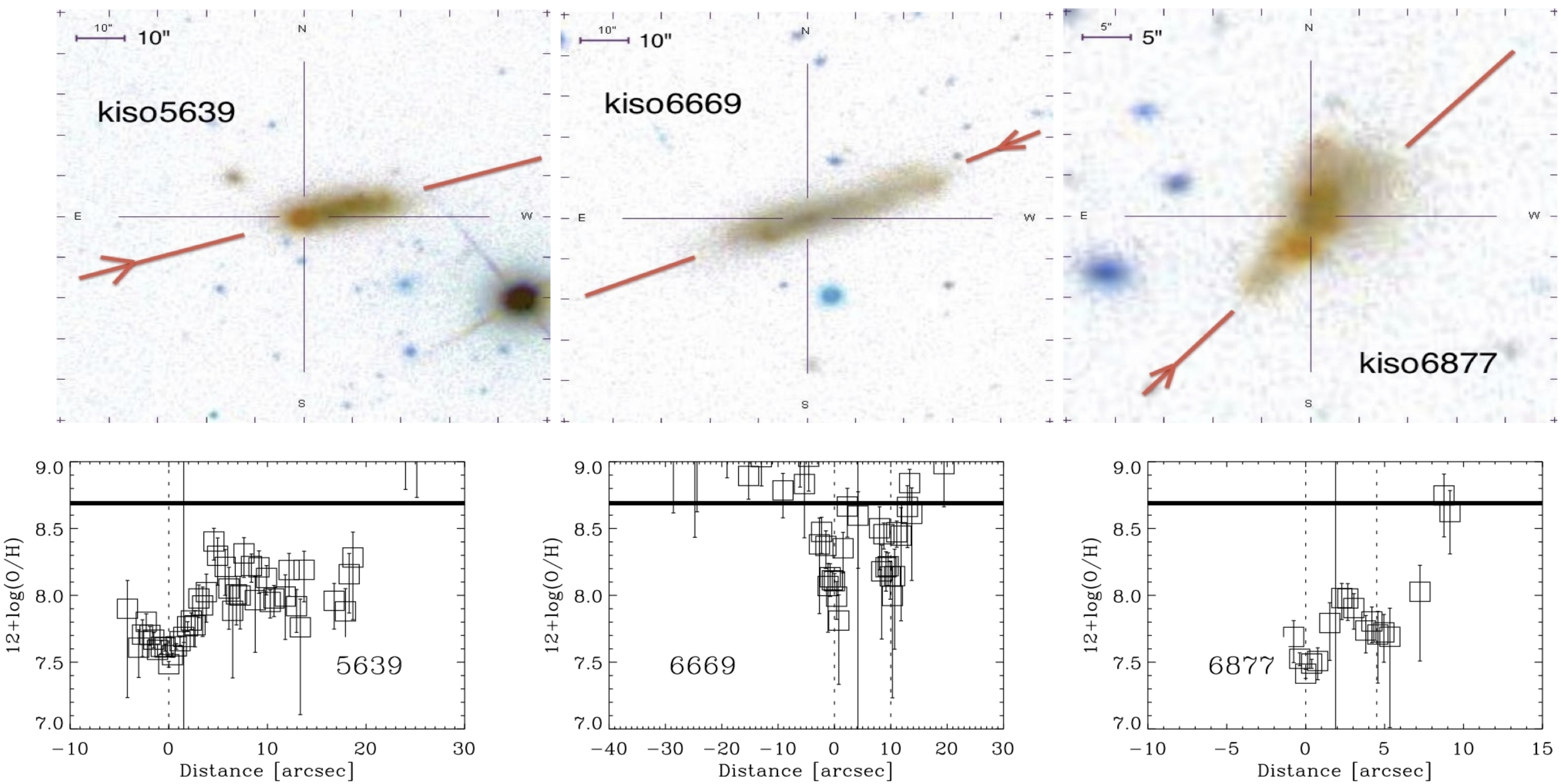
SDSS J114506.26+50180
The spectrum decides de shape !!!

Morphologies in the HUDF

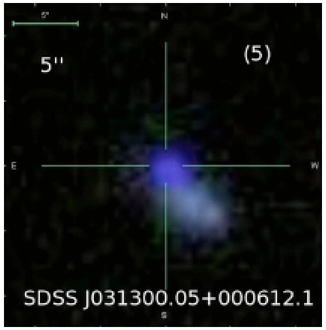


Elmegreen et al. 2005, ApJ, 361, 85 **10%**

Spectroscopic followup by SA+13ApJ and SA+14aApJ



Spectroscopic follow up of some of these targets (SA+13ApJ; SA+14aApJ) shows the following properties of the local **Tadpoles-cometary-XMP** galaxies:



- the heads are giant star-forming regions

- XMP rotate, with the heads displaced with respect to the rotation centers

- the head has a lower metallicity (~0.5dex) than the rest of the galaxy, which must be a short lived phase (ISM mixing in 100 Myr)

These observations are consistent with the heads being a star-formation episode triggered by the recent and localized inflow of pristine gas (cold-flow accretion episode).

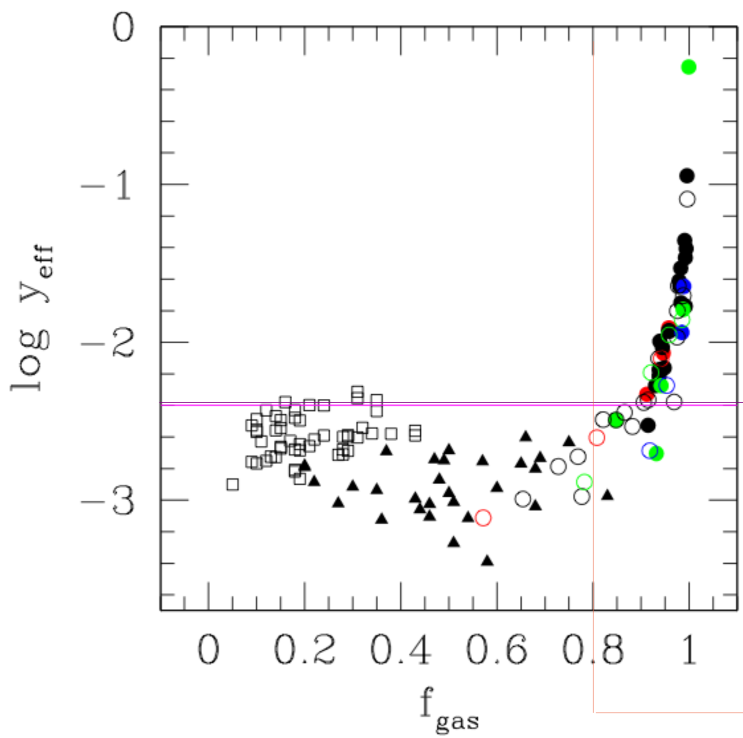
The cometary shape would be created by the bright young stars born at the head during the starburst

Filho+2013A&A Data from 130 XMPs

- Consistent with the large amounts of HI gas present in XMPs

$$\frac{M_{gas}}{M_{star}} \simeq 10$$

- The HI gas is even more metal poor than the HII



$$y_{eff} \sim \frac{M_{gas} Z_{HII}}{M_{star}}$$

$$f_{gas} = \frac{M_{gas}}{M_{star} + M_{gas}}$$

y_{theory}

$$f_{gas} \sim 1$$

$$y_{eff} \gg y_{theory}$$

XMP galaxies

The simplest way out is

$$Z_{HII} \gg Z_{HI} \left(Z_{HII} / Z_{HI} \simeq y_{eff} / y_{theory} \right)$$

Also consistent with the apparent gas metallicity threshold observed in the local universe(SA+14b)

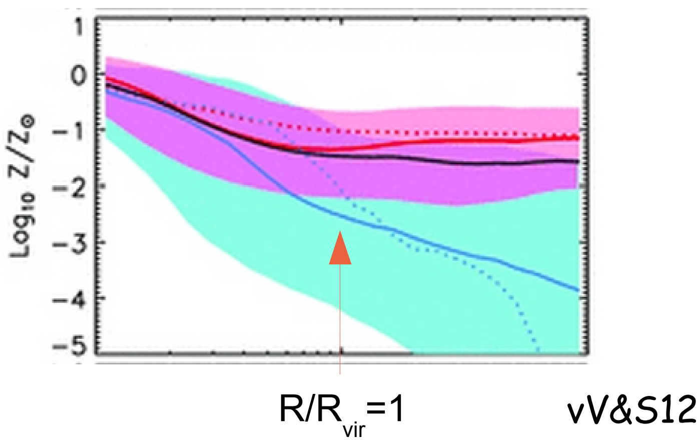
- XMP are low metallicity, but all of them have $Z > 0.01\ Z_\odot$

- This is not an observational bias. The prototype, Izw18, with $Z{\sim}0.03\ Z_\odot$, was discovered more than 40 years ago (Sargent&Searle70). Many systematic searches of XMPs have been carried out over the years (e.g., Terlevich+91;Izotov+99; Kunth & Östlin00; Morales-Luis+11), but none of the objects known so far present a metallicity lower than this value.

- Many explanations for the minimum metallicity have been put forward (self-enrichment of the HII region, abundance of the proto-galactic cloud, popIII stars contamination, technical difficulties), but none of them is fully convincing

- Natural explanation if the observed star-forming gas comes directly from the comic web, with a metallicity that has been increasing with time due to galactic winds.

- Cosmological numerical simulations predict a cosmic web gas metallicity of the order of $0.01\ Z_\odot$ at redshift zero! (e.g., van Voort & Schaye12; Oppenheimer+12)



Summary: take-home messsage(s)

1.- Most of the star-formation is driven by gas accretion from the cosmic web. Solid theoretical prediction

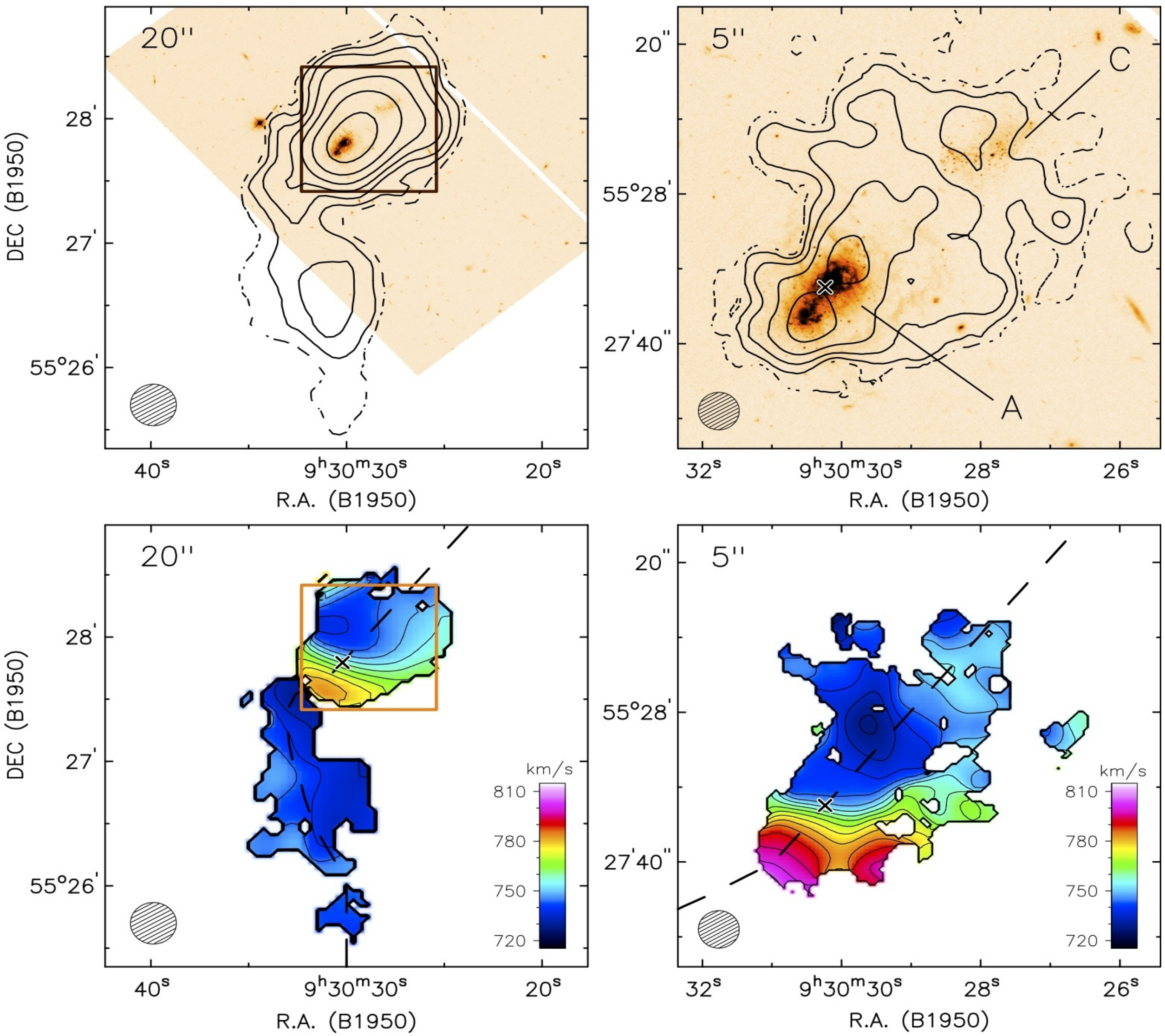
2.- This is a process that happens at all redshifts, including the local universe. Solid theoretical prediction

3.- XMP galaxies seems to be primitive disks in the process of assembling in the nearby universe, where a major cold-flow accretion episode is producing the current starburst.

4.- XMP seems to be extreme cases.There are many independent hints that gas accretion driving star-formation is a very common process in the local universe.


Flammarion woodcut
Urbi et Orbi

Accretion inferred from HI observations

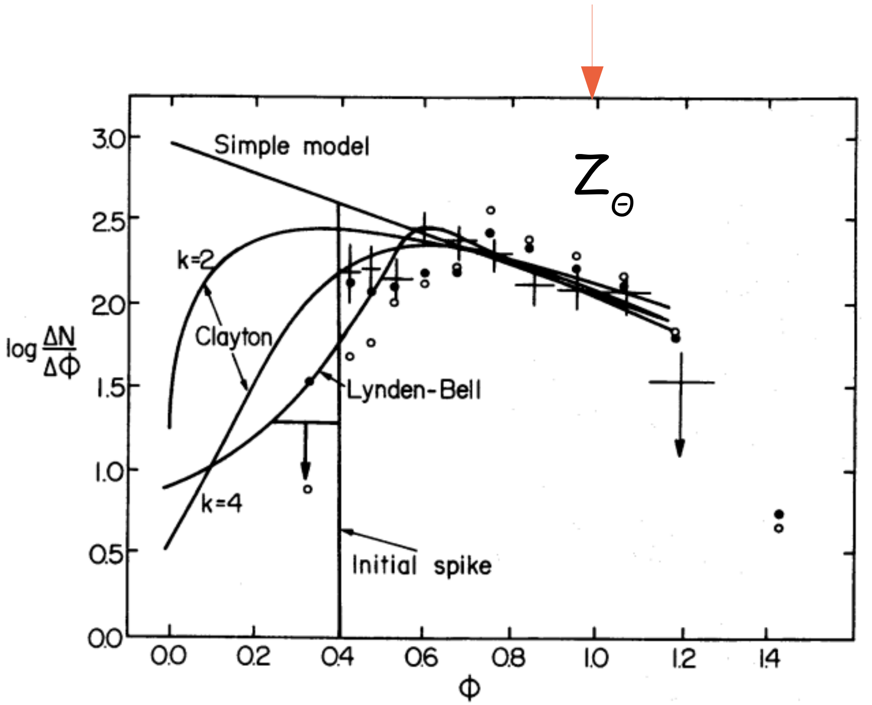


Star forming galaxies all have pools of neutral gas often with very suggestive, as the case of the extremely metal poor (XMP) IZw18

Lelli+12a

The G-dwarf problem

There is a notorious deficit of sub-solar metallicity G-dwarf stars in the solar neighborhood (van den Berg 62; Schmidt 63), as compared with the distribution expected in closed-box evolution where every new population is less numerous than the preceding one.



Φ is metallicity in linear scale

(from Rocha-Pinto & Maciel 96)

The deficit is actually and excess of G-dwarfs with solar metallicity, easy to explain in the stationary state gas infall model (Larson 72)

$$Z \simeq Z_i + y\,(1 - R)/(1 - R + w).$$

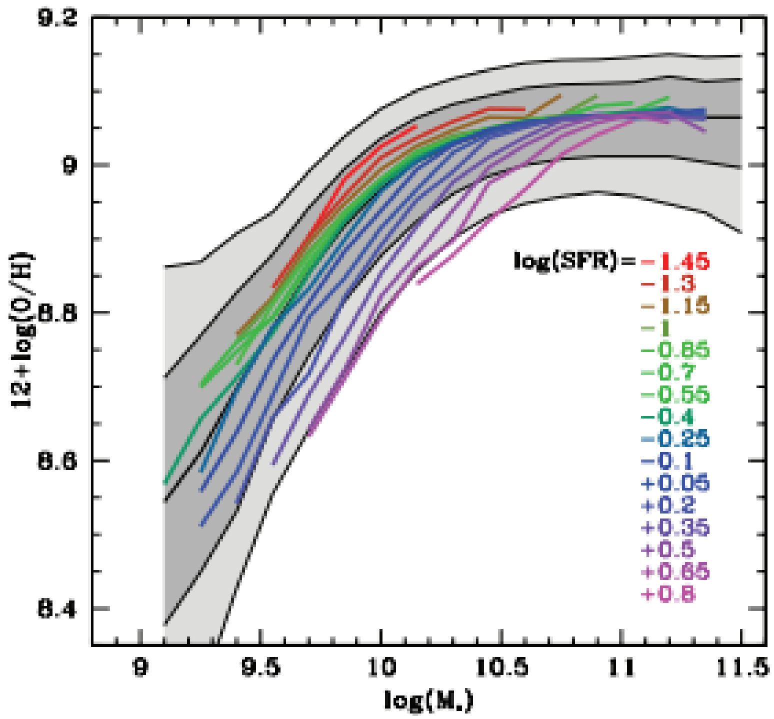
$$y \approx Z_\Theta$$

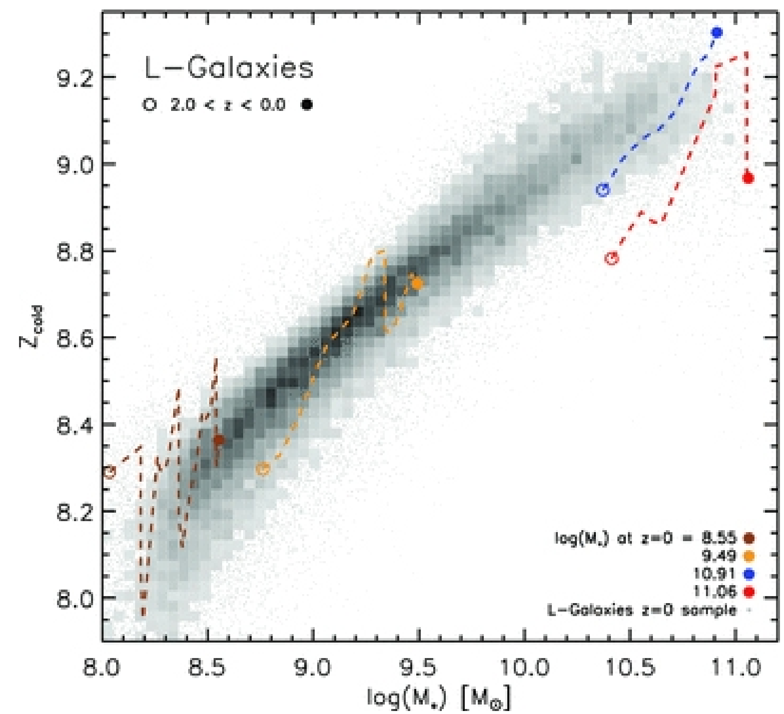
The same deficit occurs in other galaxies as well (Worthey+96)

Fundamental Metallicity Relationship

Given a galaxy mass, the metallicity decreases as the star-formation increases

Mannucci+10; Lara-Lopez+10





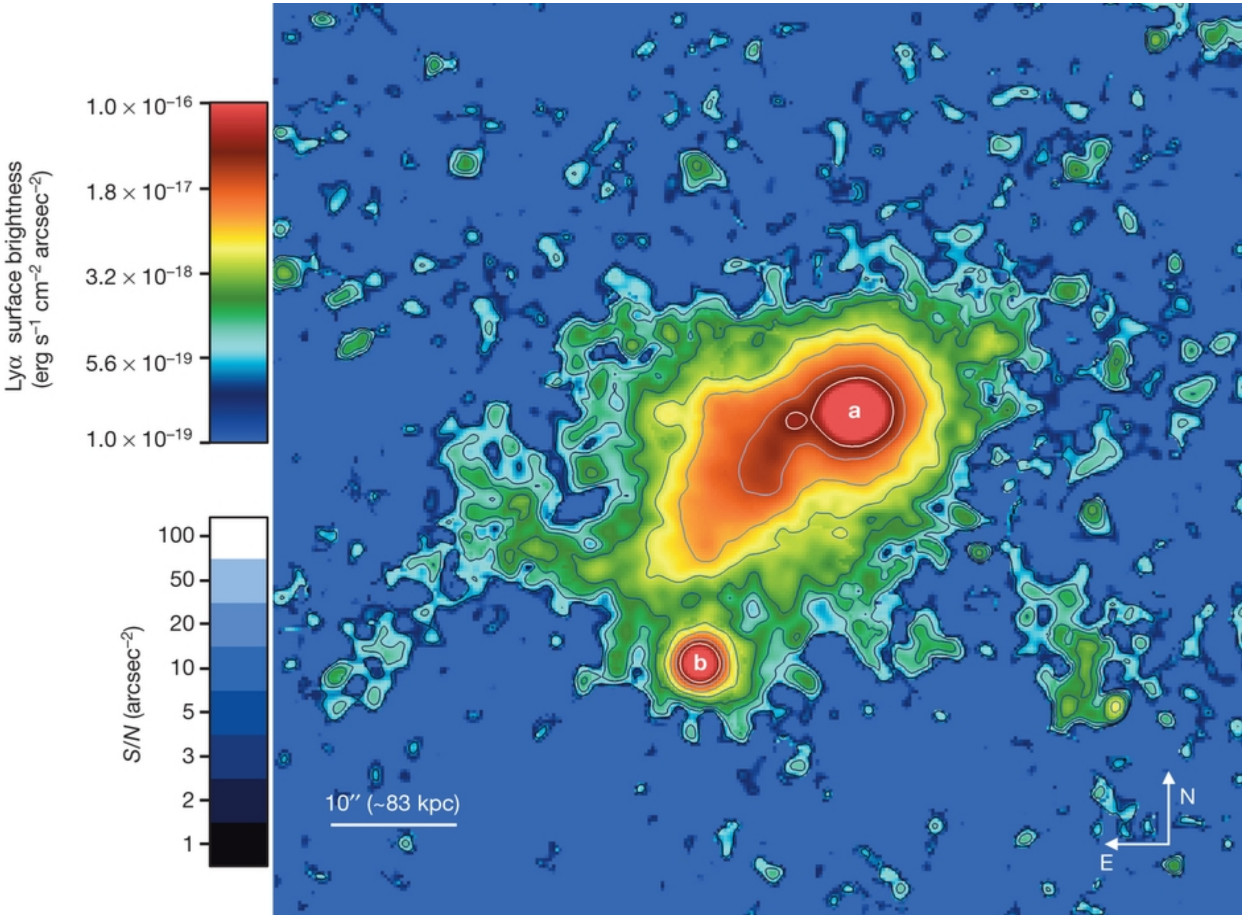
Yates+12 (semi-analytical model)

Easy to interpret if the starburst is triggered by pristine gas inflow

The cosmic web in emission

Lya emission that extends further out of the virial radius of the galaxy hosting the QSO UM287 (a). z=2.3.

Fluorescence of Lya photons originally emitted by the QSO (a)



Cantalupo+14

Flammarion woodcut