Evidence for gas accretion from the cosmic web feeding star formation in the local Universe

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Outline

- Star formation and gas accretion
- Extremely Metal Poor galaxies (XMPs)
- Metallicity inhomogeneities in XMPs
  - Difference between gas accretion event and a minor wet merger ?
- Summary: take-home message(s)

Star formation and gas accretion

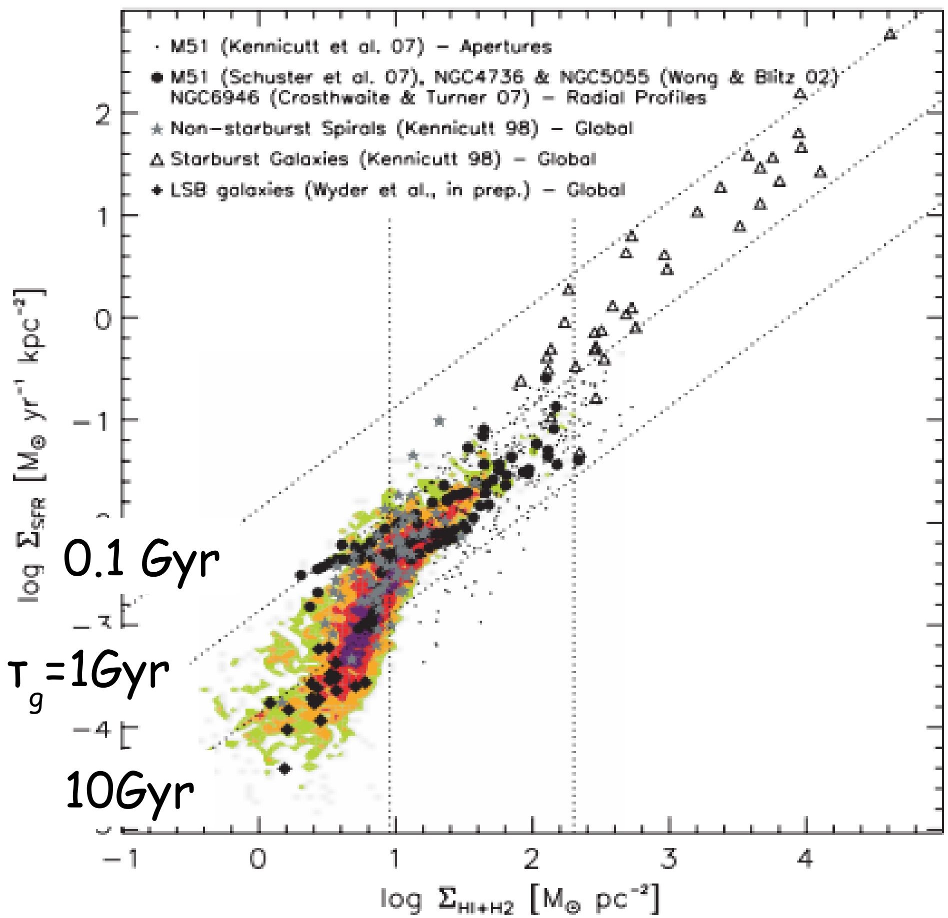
Cosmological numerical simulations produce model galaxies that, after a transit phase, enter a quasi-stationary phase were gas inflows and outflows balance the instantaneous SFR (*Finlator & Dave 2008; Schaye et al. 2010; Fraternali& Tomassetti 2012; Dave et al. 2012; Dekel et al. 2013; Bothwell et al. 2013; Feldmann 2013; Altay et al. 2013; Forbes et al. 2014*).

This process occurs **at all redshifts**, and when the physical conditions are given, the 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

Why does the gas accretion rate determines the star formation rate?



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

$$SFR = \epsilon M_g = \frac{M_g}{\tau_g}$$

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 timescales,

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

... and decreases with increasing z
... and decreases with outflows

gas is "in less than a Gyr" transformed into stars

Bigiel+08

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

EXtremely Metal Poor galaxies (XMPs)

XMPs are defined to be local galaxies with a gas metallicity < 0.1 $Z/Z_{\odot}$

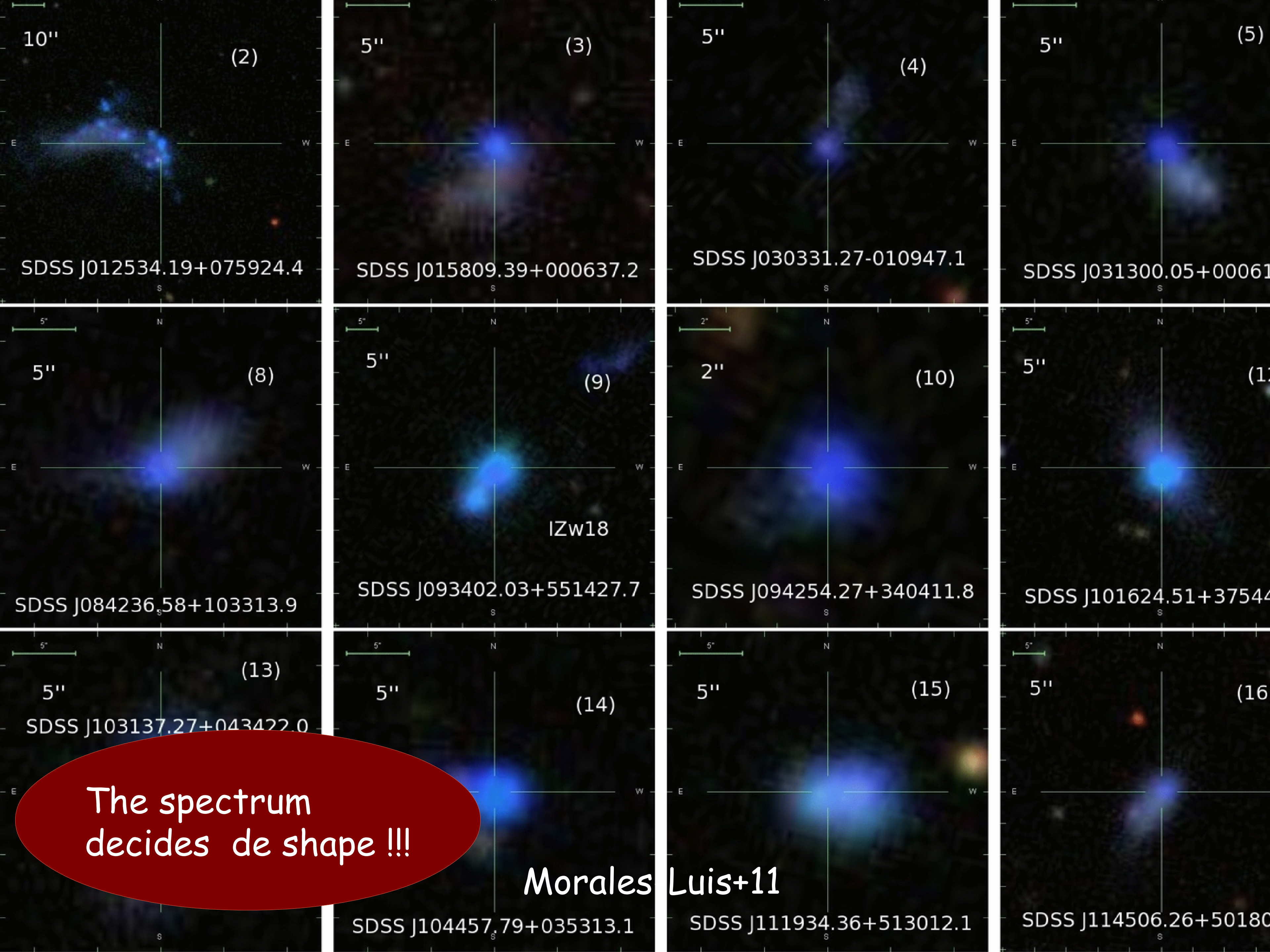
◇ XMPs are rare :1% of the galaxies in a volume (e.g., SA+15a, and much less in magnitude limited samples ...)

◇ XMPs tend to be cometary (70% in systematic searches on SDSS; e.g., Morales-Luis+11; Filho+13; SA+15a; 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 (Elmegreem+05,12).

At **high redshift, tadpole**-galaxies are associated with **primitive disks in the process of assembly**



The spectrum decides de shape !!!

Morales Luis+11

◇ XMPs tend to be Blue-Compact Dwarfs (e.g., Morales-Luis+11).

◇ XMPs are gas-rich objects $M_{HI}/M_* \approx 10$! (Filho+13)

The HI gas spatial distribution is usually asymmetric, with plumes spurs and tails (e.g., Lelli+12; Lopez-Sanchez+12)

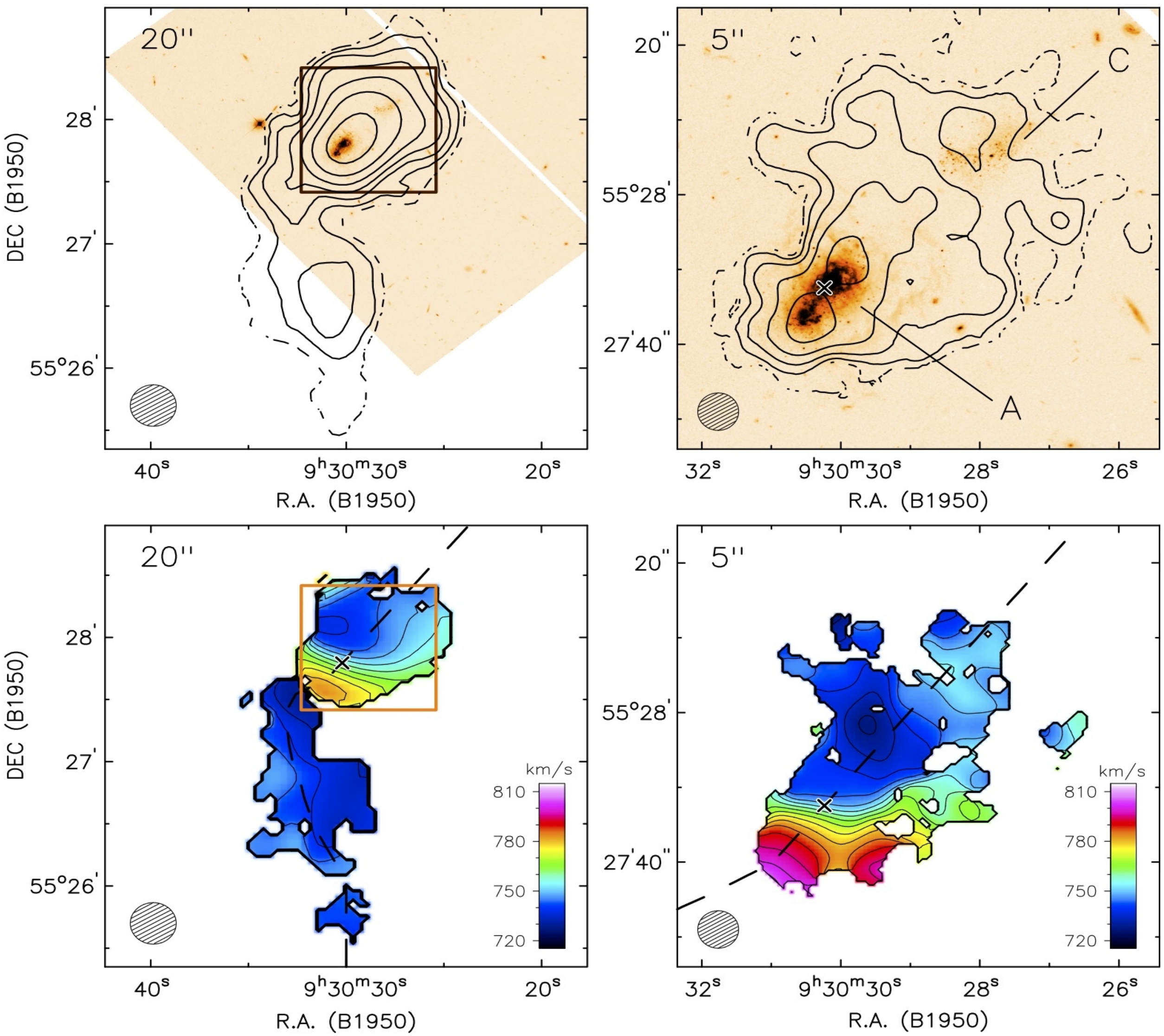
◇ XMPs often rotate, but with large velocity dispersions as inferred from the emission lines; they seem to be turbulent disks (Sanchez Almeida+13).

◇ XMPs tend to be isolated, as judged from the number of nearby companions, and they reside in voids as judged from constrained cosmological simulations (Filho+15; Nuza+14)

One also finds loose pairs (Filho+15)

No sign of ongoing major mergers

◇ There is lower limit for the metallicity $Z \geq 0.02\ Z_{\odot}$



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

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◇ XMPs show exponential light profile, aka, disk-like light profile (Elmegreen+12,15)

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Metallicity Inhomogeneities in XMP galaxies

... one additional property may be the existence of metallicity inhomogeneities associated with the starbursts

$$\mathrm{SFR}\uparrow \Leftrightarrow \mathrm{Z}\downarrow$$

We discovered them in tadpole galaxies (SA+13) and also in a couple of XMPs (SA+14).
They are similar to the kind of inhomogeneities found in high redshift star-forming galaxies (e.g., Cresci+10)

The time-scale for gas mixing in a turbulent disk is very short; of the order of the rotational period or shorter (say 200 Myr; Yang&Krumholz 12).

If metal-poor starbursts exist, then the gas undergoing the starburst has just arrived from outside the disk, providing a strong support for a gas accretion scenario

Do metallicity inhomogeneities exist? Are they common?

We carried out a systematic study of the metallicity variation along the major axes of the XMPs

- Select 10 XMPs, the magnificent 10, which represent 7% of all know XMPs at the time when the project started (2013).

- Using the 10.5m GTC (+OSIRIS), needed to measure the emission lines at the faint tail of the galaxies. Long-sligt observations provide the required spatial resolution (1 arcsec). 2 hours/object.

- Metallicities (i.e., Oxygen abundances) are obtained using the Direct Method (DM) or, more precisely, HMC (Perez-Montero 14), which is a hybrid method which agrees with the DM well within the error bars (0.15dex)

- We also have kinematic information, but its analysis is ongoing, and will not be discussed here


10m GTC, La Palma

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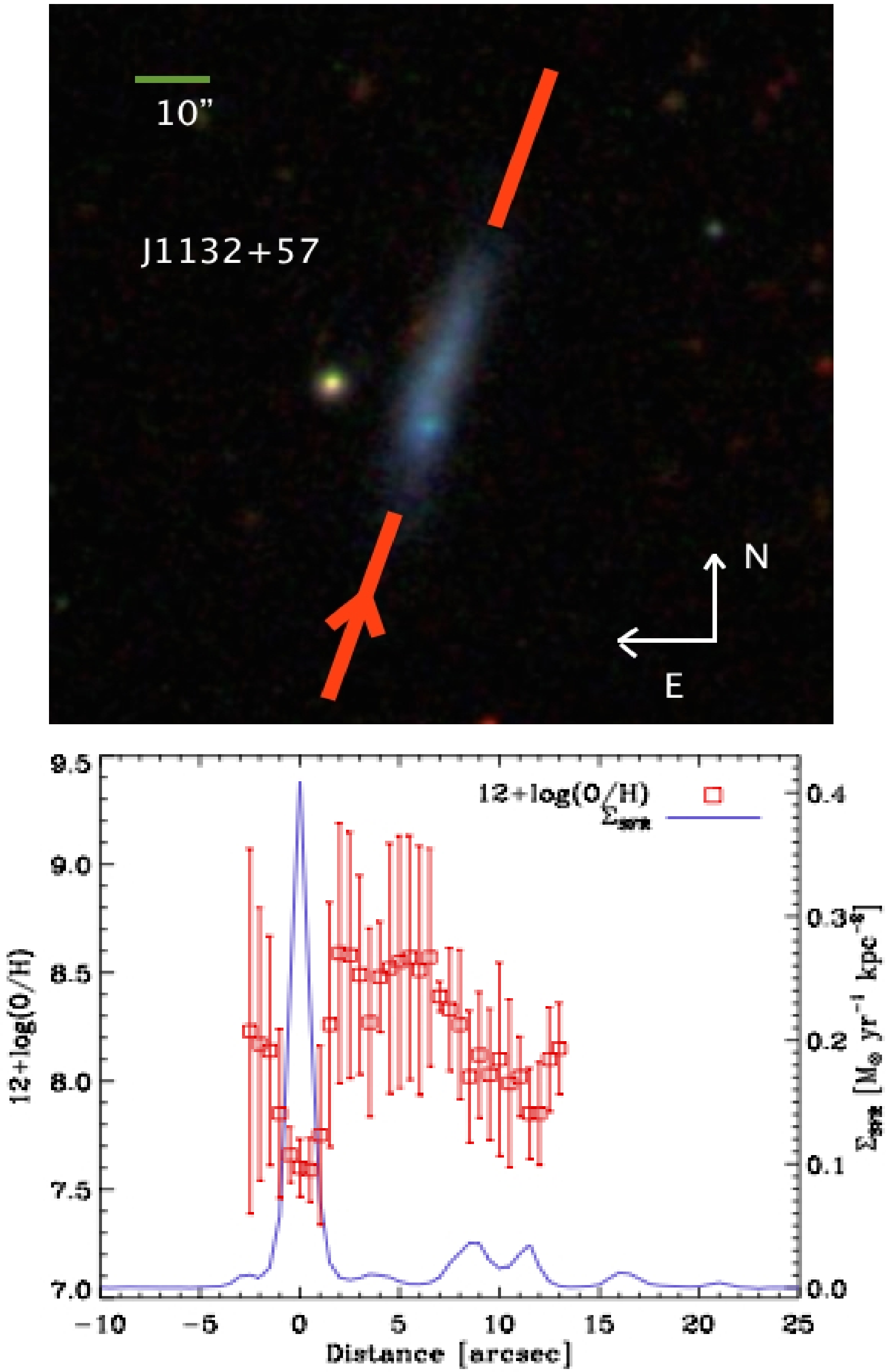
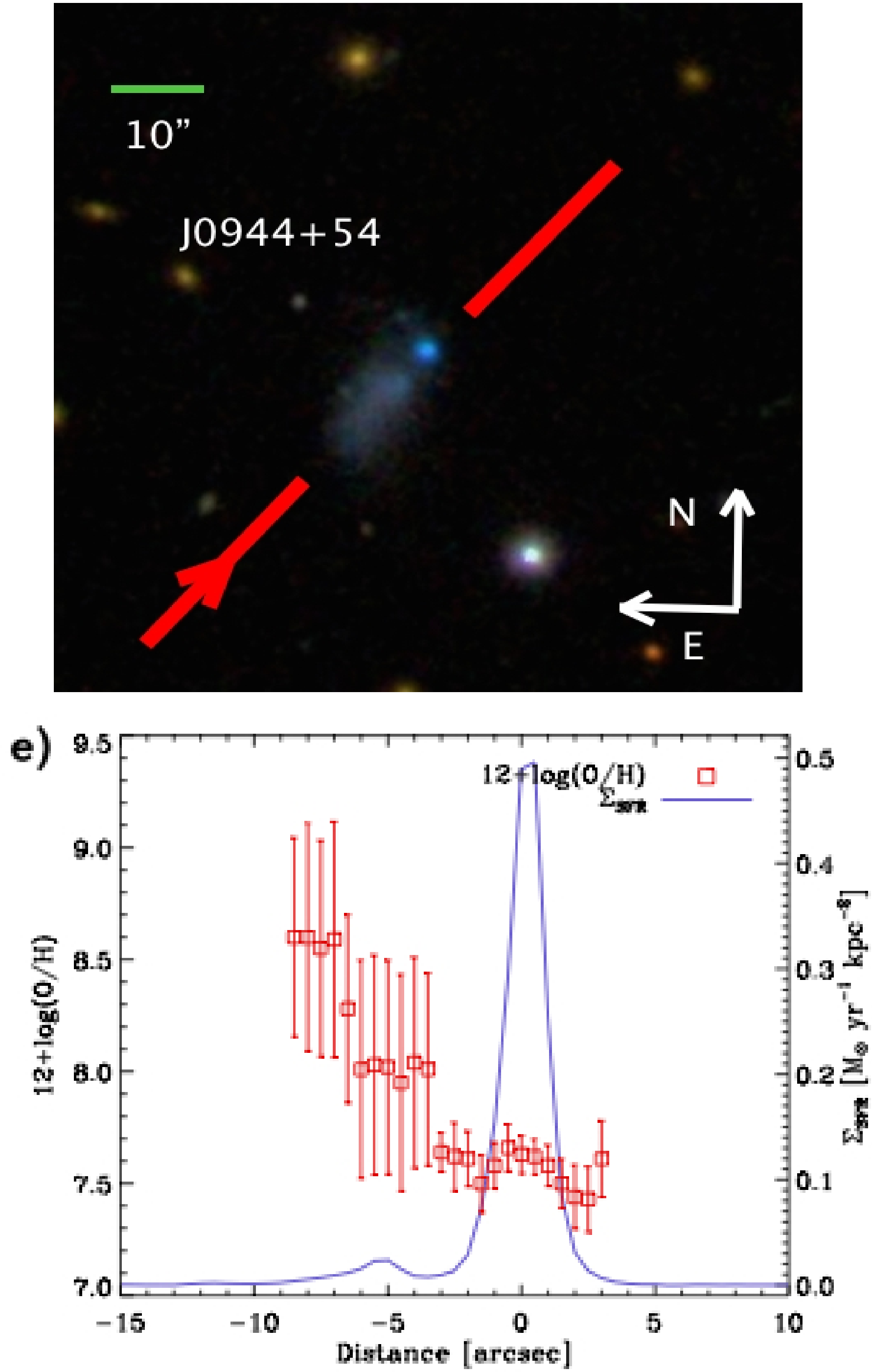
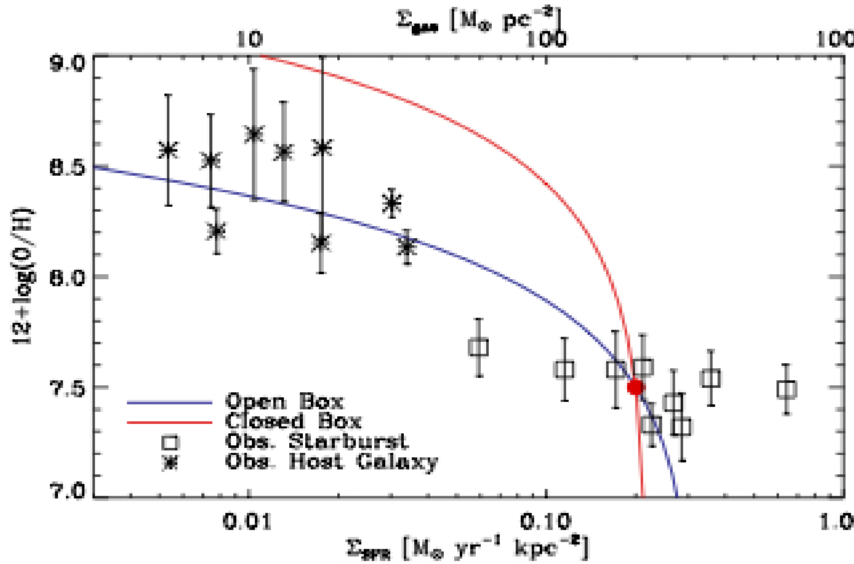


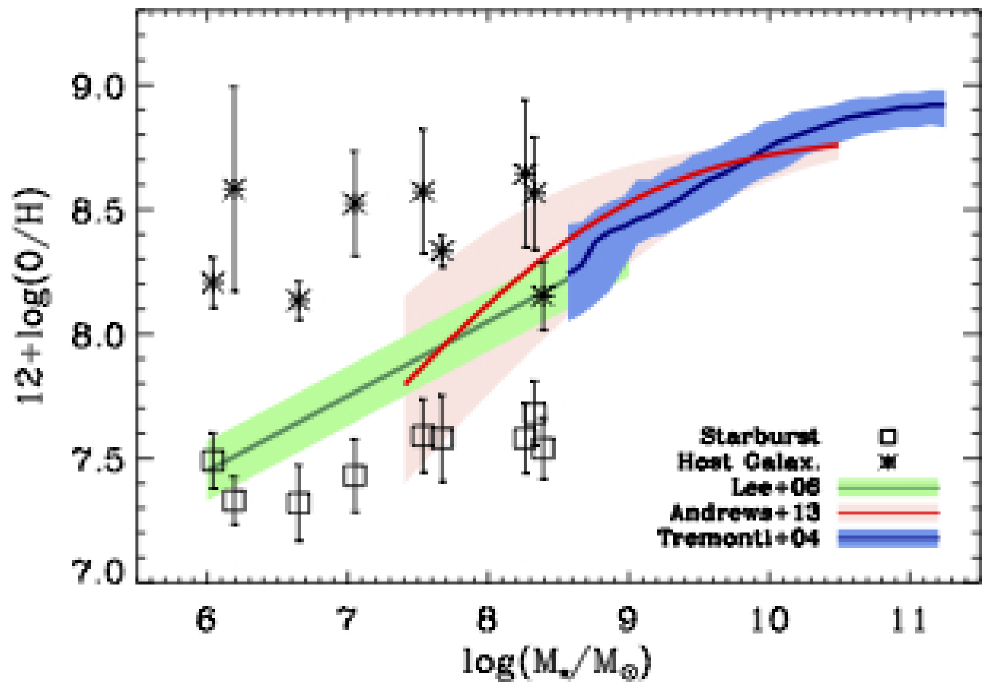
10"
J1132+57
N
E
12+log(O/H)
Σ_{SFR}
12+log(O/H)
Σ_{SFR} [$M_\odot$ yr^{-1} kpc^{-2}]
Distance [arcsec]


10"
J0944+54
N
E
e)
12+log(O/H)
Σ_{SFR}
12+log(O/H)
Σ_{SFR} [M$_\odot$ yr^{-1} kpc^{-2}]
Distance [arcsec]
9.5
9.0
8.5
8.0
7.5
7.0
0.5
0.4
0.3
0.2
0.1
0.0
−15
−10
−5
0
5
10

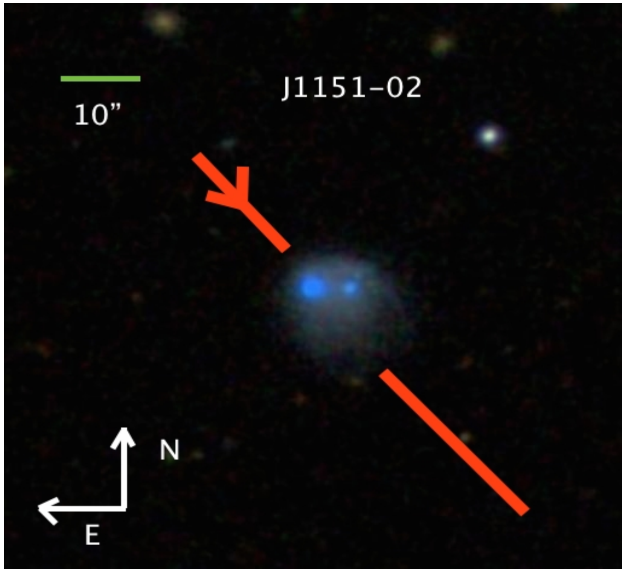


Inhogeneties are present in 9/10 cases

The underlying galaxy (i.e., the tail) has high metallicity, slightly sub-solar (~$Z_{\Theta}/2$)



So, XMPs seem to be faint solar-metallicity turbulent disks with one (or more) off-centered starburst of low metallicity



They differ in metallicity by almost one order of magnitude, and it is the starburst that give the XMP character to the XMP galaxies

Keeping in mind the short gas mixing time-scale,the observations are consistent with the heads being a starburst triggered by the recent inflow of metal-poor gas .

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

Where does the low-metallicity gas come from?

- From a gas-rich major merger?
  - isolated + voids
  - HI maps no so distorted
  - no stellar tidal streams
- From gas-rich minor merger?
  - isolated + voids
  - no tidal streams
  - no distortion in disk caused by DM clumps
- From the galaxy halo?
  - why concentrated in knots?
  - why now? Why KS-law?
  - why streams in HI
- Gas accretion from the cosmic web (cold-flow accretion)
  - may come with some stars
  - explains shape
  - explains low metallicity theshold

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

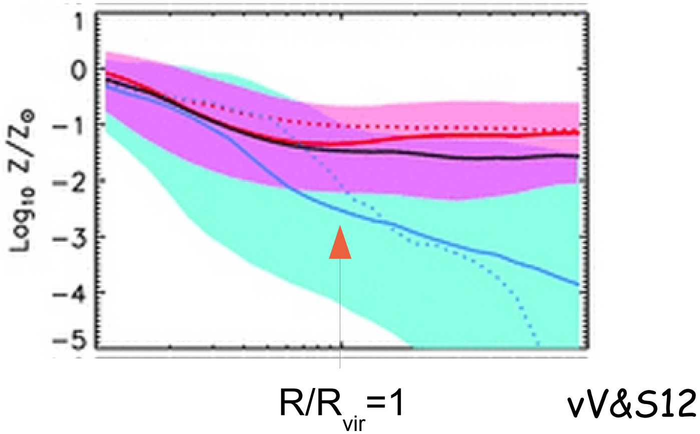
- XMP are low metallicity, but all of them have $Z > 0.02\ Z_\odot$

- 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 message(s)

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

2.- So far we only have indirect observational hints

3.- XMP galaxies show drops of metallicity coinciding with large star-forming regions

4.- The best explanation we have is that the drops are due to a gas accretion event, as predicted by the numerical models.