On the oxygen and nitrogen chemical abundances and the evolution of the "Green Pea" galaxies

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Outline

I. Introduction: What are the "green pea" galaxies ?
II. Oxygen and nitrogen chemical abundances
III. The mass-metallicity relation
IV. Discussion:
   a) Outflow/inflow scenario
   b) Hints on the evolutionary status
V. Summary and final remarks

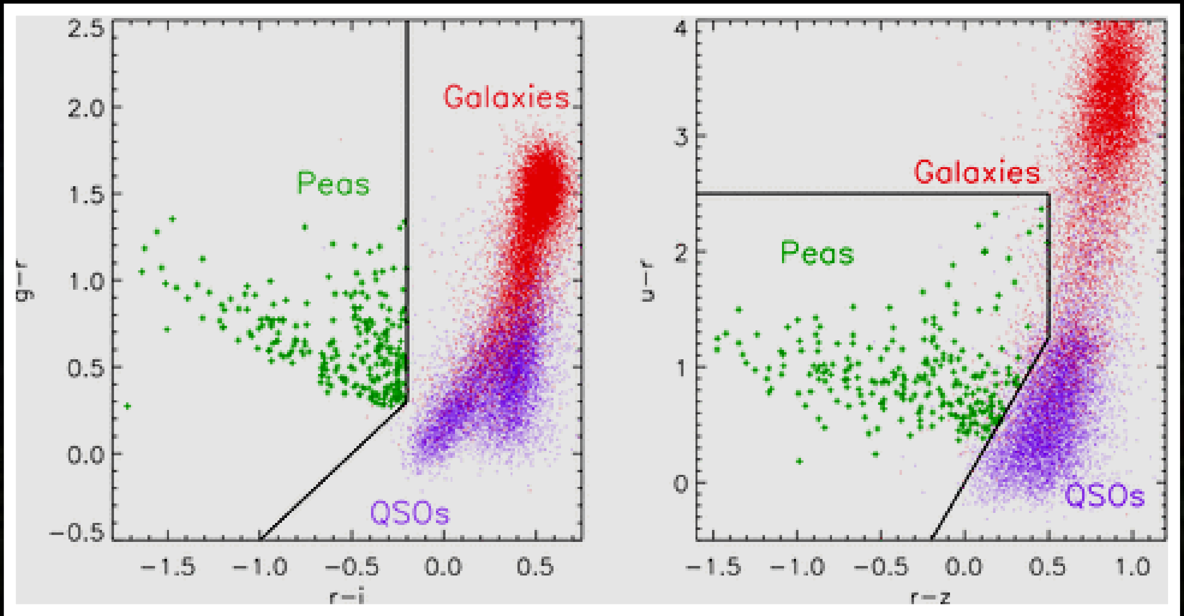
Discovering the “green peas”

- First noticed by the > 200000 volunteers of the “Galaxy Zoo project” (Lintott et al. 2008)
  - Visual inspection of 10^6 galaxies in *ugr* SDSS images
    - Unresolved
    - Mostly classified as stars, but with galaxy-like spectra
    - Green colour driven by powerful [OIII]λ5007Å that increase the *r*-band luminosity relative to the *g* and *i* bands
      - This implies redshifts $0.11 < z < 0.36$

- First report in the literature by Cardamone et al. (2009)

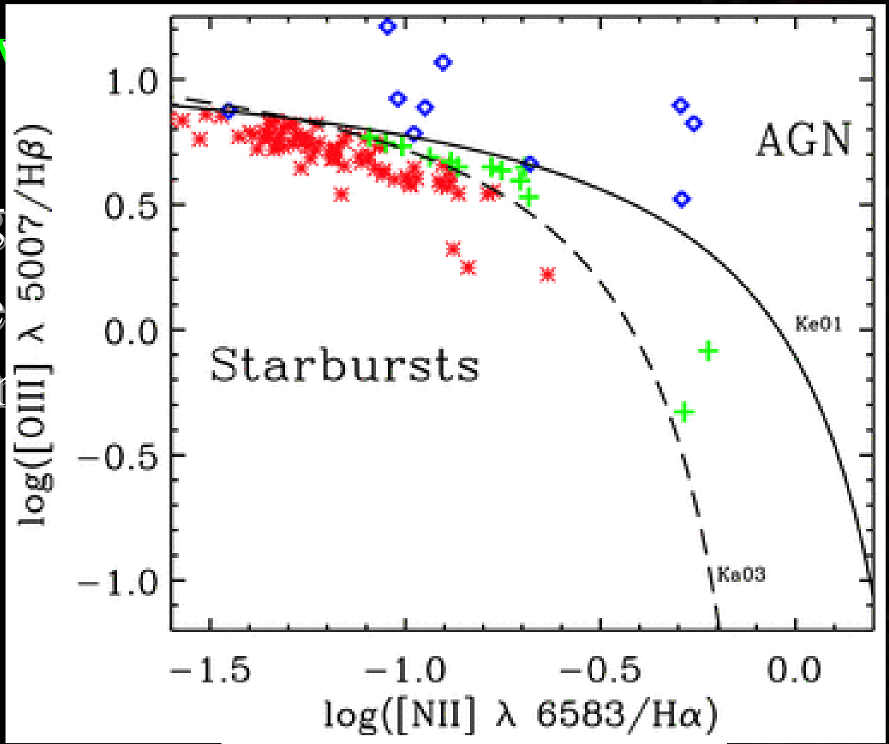
Discovering the "green peas": sample selection (Cardamone et al. 2009)

- SDSS-DR7 spectroscopic targets in the range $0.112 < z < 0.360$
  - (strong [OIII] λ5007Å emitters falling in the r-band)
- Colour criteria: *ugriz* SDSS broad-bands
  - Comparison with star-forming galaxies (SFGs) and QSOs at the same redshifts



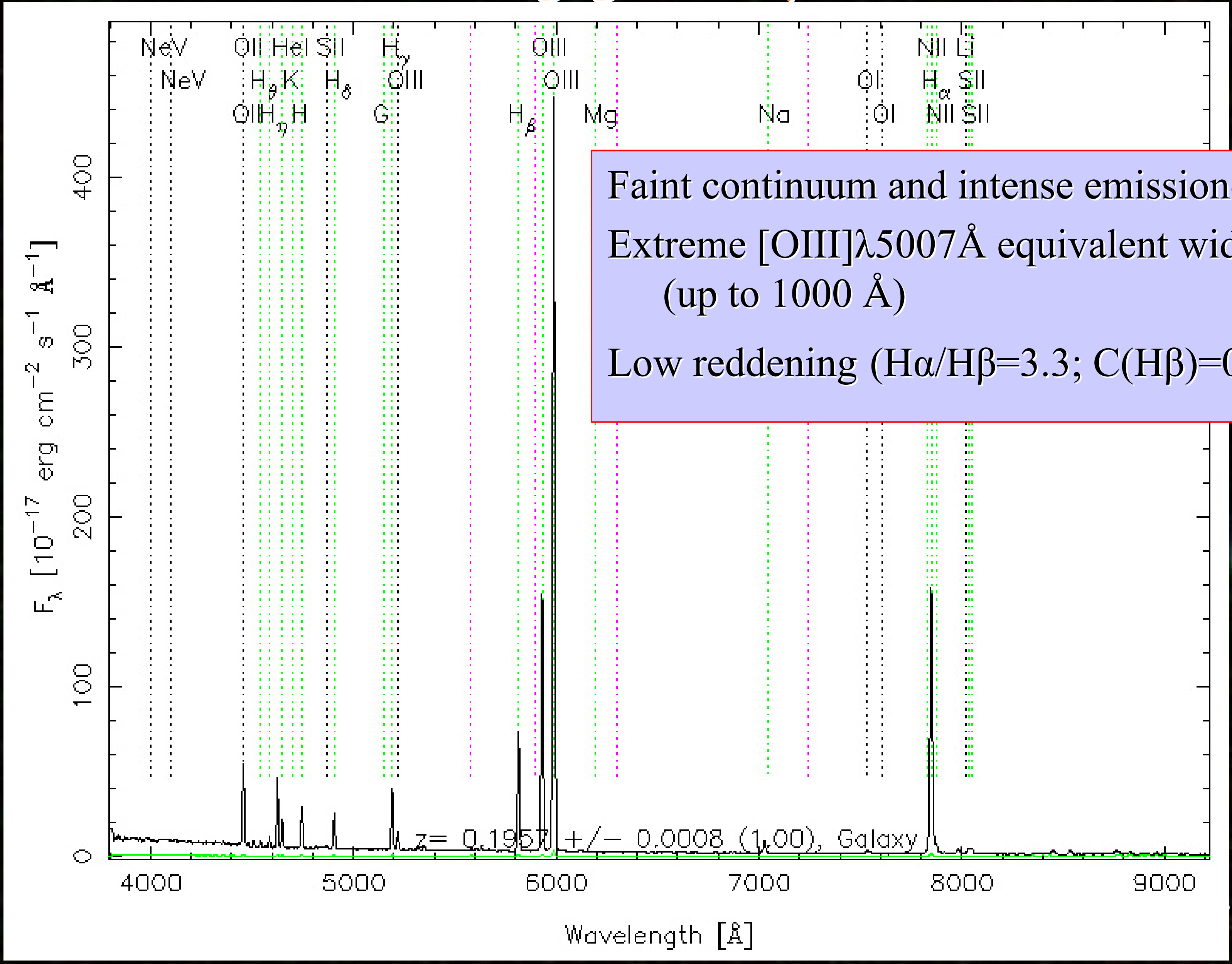
Discovering the "green peas": general properties

- Extremely compact. Not resolv
  $R_{petro} < 2'' \rightarrow R_e < 5$kpc
- Rare objects: ~ 2 per deg² brig
- Environment: lower density re galaxies of the same i-band lur
- Spectral classification:
  - Star-forming galaxies (80)
  - Narrow-line Seyfert 1s (8)
  - Narrow-line AGNs (10)
  - Broad-line AGNs (1)
  - "Transition" (mix of SF and AGN) objects (13)



Cardamone et al. (2009)

Star-forming green peas (GPs)



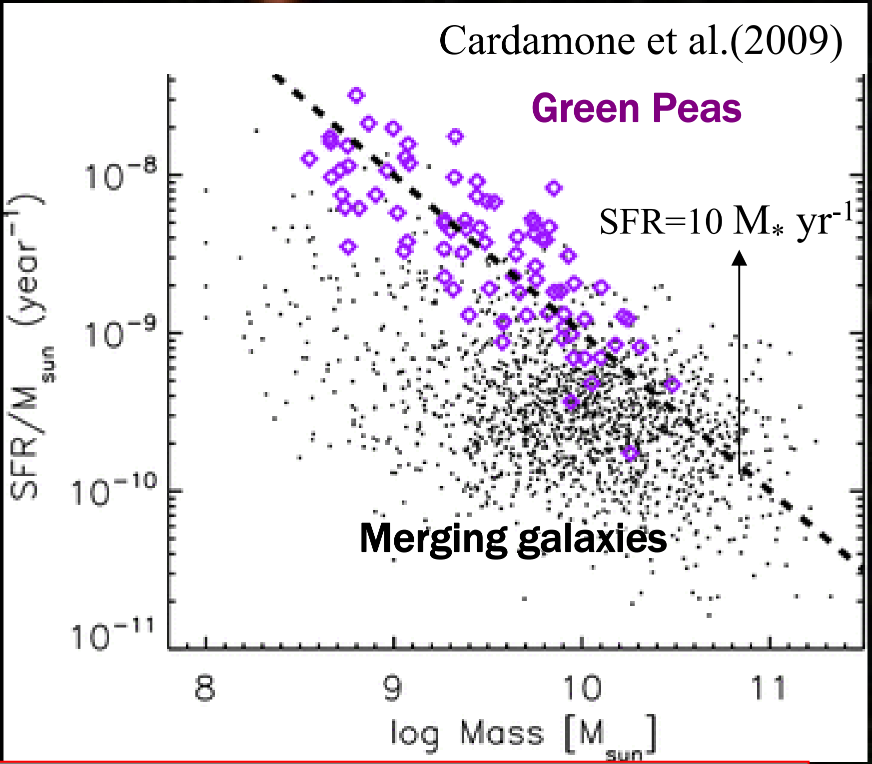
Faint continuum and intense emission-lines

Extreme [OIII]λ5007Å equivalent widths (up to 1000 Å)

Low reddening (Hα/Hβ=3.3; C(Hβ)=0.23

Star-forming green peas

- *g*-band luminosity:
  - $-19 < M_g < -21.5$
- *FUV* luminosity:
  - $L_{FUV} \sim 3\times10^{10}\ L_{sun}$
- Stellar masses:
  - $8.5 < \log(M_*/M_{sun}) < 10.5$
- High star formation rates:
  - $3 < SFR\ [M_*\ yr^{-1}] < 35$



Specific star formation rates unusually high for galaxies at z ~ 0.2 (Brinchmann et al. 2004, Bauer et al. 2005)
At these SFR the GPs can double its stellar mass in timescales between 100 Myr and 1Gyr !!!

SIMILAR OBJECTS IN THE LITERATURE ?

1- [OIII]-selected galaxies with L* at redshift 0.29-0.42 from the KISS galaxy survey (Salzer et al. 2009)

2- Luminous UV-selected galaxies, so-called "Lyman-break analogs"or LBAs, (Heckman et al 2005, Overzier et al. 2008, 2009a,b). Especially those at lower masses

THEY SEEM TO SHARE MOST OF THEIR KNOWN PROPERTIES INCLUDING: redshift, morphology and sizes, spectral features, stellar mass, extinction, UV/H luminosities and SFRs

BUT... WHAT ABOUT METALLICITIES ?

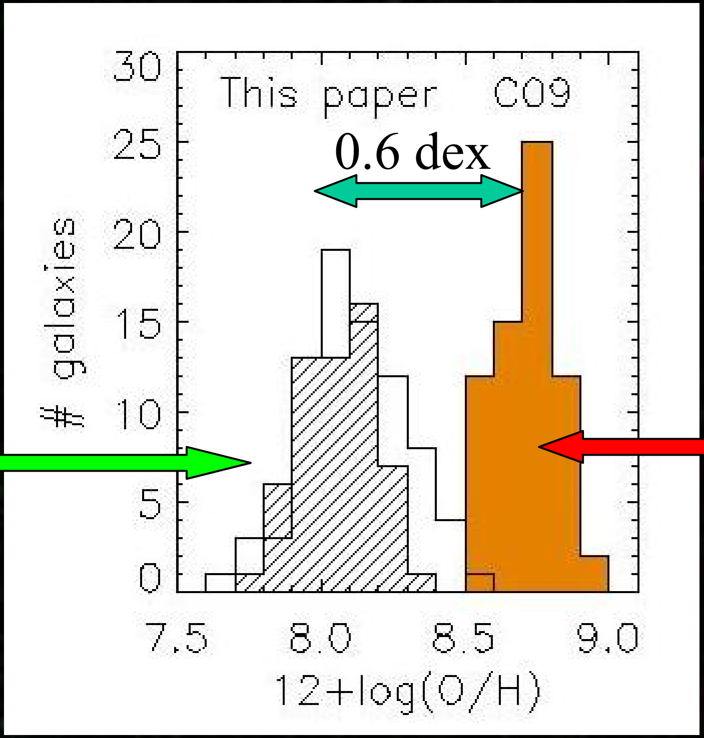
[OIII]-selected galaxies and LBAs of the same mass were found to be metal-poor (12+log(O/H) < 8.2)

Cardamone et al. found striking results: the green peas apparently have roughly constant solar metallicities (median 12+log(O/H)=8.7)

→ strong constraint to the nature and evolutionary status of the green peas

Green pea´s chemical abundaces: oxygen

- We measured the emission-line fluxes from SDSS spectra for the 80 SF green peas:
- Direct O/H and N/O measurements using T_e [OIII] λ4363Å for 70%
- N2-method for the full sample
- The agreement is below 0.1 dex



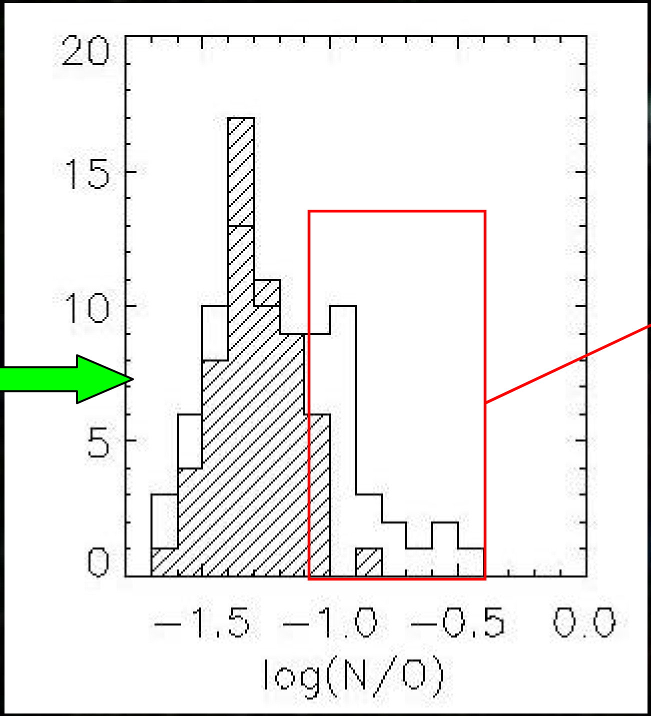
Cardamone et al. (2009)

using the [NII] λ6584Å / [OII] λλ3726,3729Å ratio and the theoretical calibration by Kewley & Dopita (2002)

The green peas are a genuine population of metal-poor ($Z \sim 0.2\ Z_{sun}$) starburst galaxies

Green pea´s chemical abundaces: nitrogen

- Direct N/O measurements using T_e [OIII] λ4363Å for 70%
- Empirically using the N2S2 index for the full sample. Less dependence with reddening or flux calibration (Perez-Montero et al. 2009)
- The agreement is quite good



High N/O values

Addditional data

1- Reference Sample

Local Star-Forming Galaxies (SFGs) with 0.03 < z.< 0.37

Emission-line galaxies from the MPA/JHU catalogue of SDSS/DR7

• Only spectra with high signal-to-noise ratio (S/N>5) in the relevant emission lines

We used the same emission line indexes and calibrations to derive O/H and N/O

2- Comparison Sample

"Lyman-break analogs" (LBAs): super compact UV-selected galaxies with 0.1 < z < 0.3

• 30 galaxies. Line ratios from Overzier et al. (2009).

• Less massive LBAs include 3 galaxies also classified as GP

• Most massive LBAs are morphologically different and host dominant (massive) central objects

N/O vs. O/H

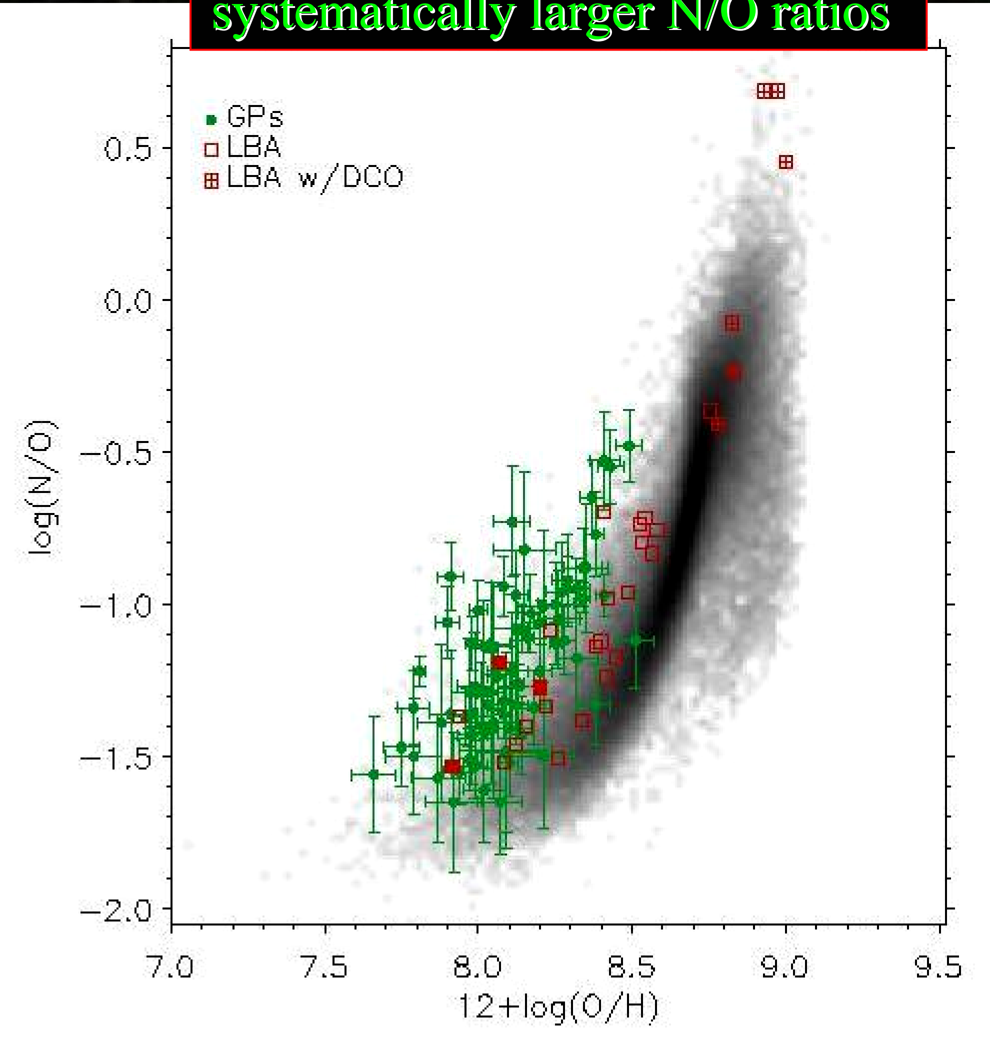
Possible reasons:

a) Extra production of primary nitrogen coming from low-intermediate stars ? (Renzini & Violi 1981; Gavilán et al. 2006; Mollá et al. 2006)

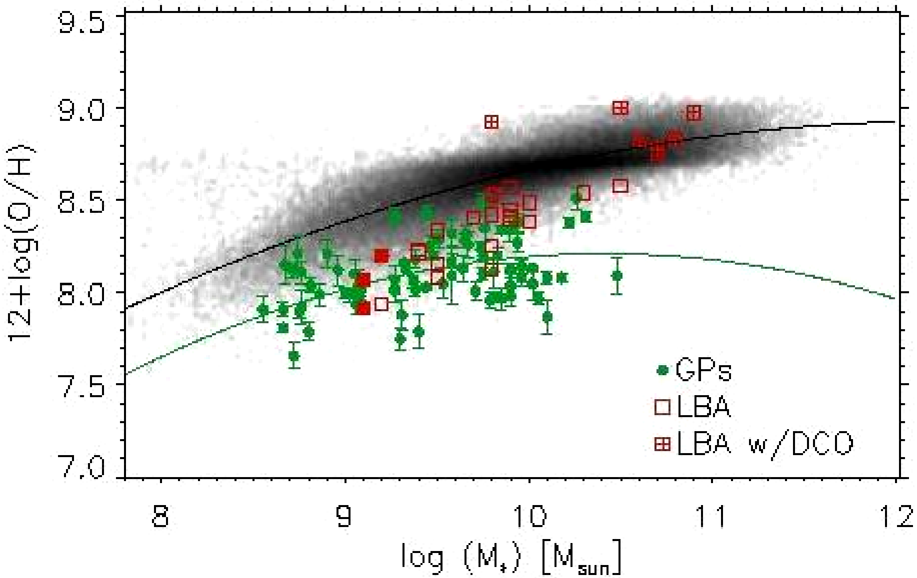
b) hydro-dynamical effects involving gas outflow and/or inflow ? (van Zee et al. 1998; Köppen & Hensler 2005)

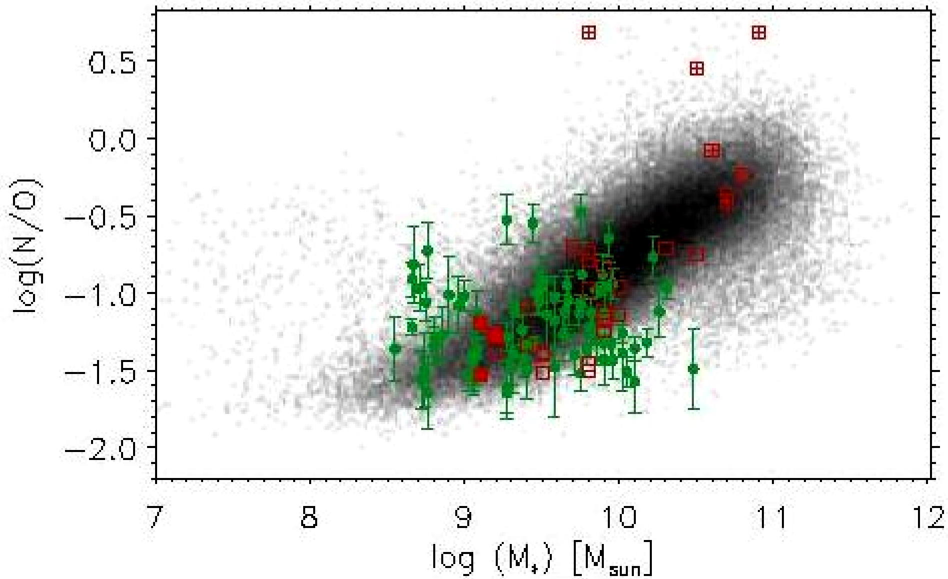
Explain different metallicity estimates relative to Cardamone et al.: Large N/O can enhance the N2 value (Pérez-Montero & Contini 2009) Kewley & Dopita calibration does not take into account the dependence on N/O.

Overall, the GPs display systematically larger N/O ratios



Stellar mass vs. O/H and N/O





The green peas follow a parallel relation. They lie > 0.3dex below the relation for SFGs: *at a fixed stellar mass GPs are systematically more metal-poor than normal SFGs*

Agreement at lower masses with LBAs

LBA behaviour agree with previous findings (Hoopes et al. 2007; Overzier et al. 2009)

More massive objects evolve more quickly. Agreement with previous findings (Pérez-Montero & Contini 2009)

Overall, the green peas follow the relation of normal SFGs. No clear offset is observed

Discussion: shaping the MZR

1. Star-formation efficiency: dwarf galaxies are less evolved than large galaxies (e.g. Lequeux et al. 1979; Brooks et al. 2007; Calura et al. 2009)
2. Outflow/Inflow
   - Models (e.g. Larson 1974; Kobayashi et al. 2007; Finlator & Davé 2008)
   - Observations (e.g. Garnett 2002; Tremonti et al. 2004)
3. Variable IMF (Köppen et al. 2007)
4. Different amounts of dark matter (Dekel & Silk 1986)

Discussion: shaping the MZR of GPs

1) Could these rare galaxies still be converting a large amount of their cold gas reservoirs into stars?

Green Peas have much higher SSFRs compared to other SFGs of similar mass.

Recent studies (e.g. Tremonti et al. 2004; Ellison et al. 2008) have shown that galaxies with higher SSFRs or larger half-light radii for their stellar mass have systematically lower abundances.
GPs being high SSFR have greater underabundances and are extremely compact…

Star-formation efficiency? We do not have information about cold gas. HI observations are needed

Discussion: shaping the MZR of GPs

2) Are green peas experiencing outflows?

Some models show that in highly concentrated low-mass galaxies, galactic winds induced by a large SF are strong enough to scape from their weak potential wells (e.g. Finlator & Davé 2008)

However, subsequent star formation potentially removes the outflow effects in metallicity (Dalcalton et al. 2007)

SPH+N-body simulations have shown that low star-formation efficiencies, regulated by supernova feedback, could be primarily responsible for the behaviour of low-mass SFGs in the MZR (Brooks et al. 2007)

The offset in the MZR is constant, therefore supporting an explanation via the selective metal-rich gas loss driven by supernova winds (e.g. Erb et al. 2006)

Discussion: shaping the MZR of GPs

3) Are green peas experiencing inflows?

Metal-poor gas massive inflows either from the outskirts of the galaxy or beyond can dilute metals in the galaxy centres, thus explaining the offset in the MZR (e.g. Mihos & Hernquist 1996; Barnes & Hernquist 1996; Finlator & Davé).

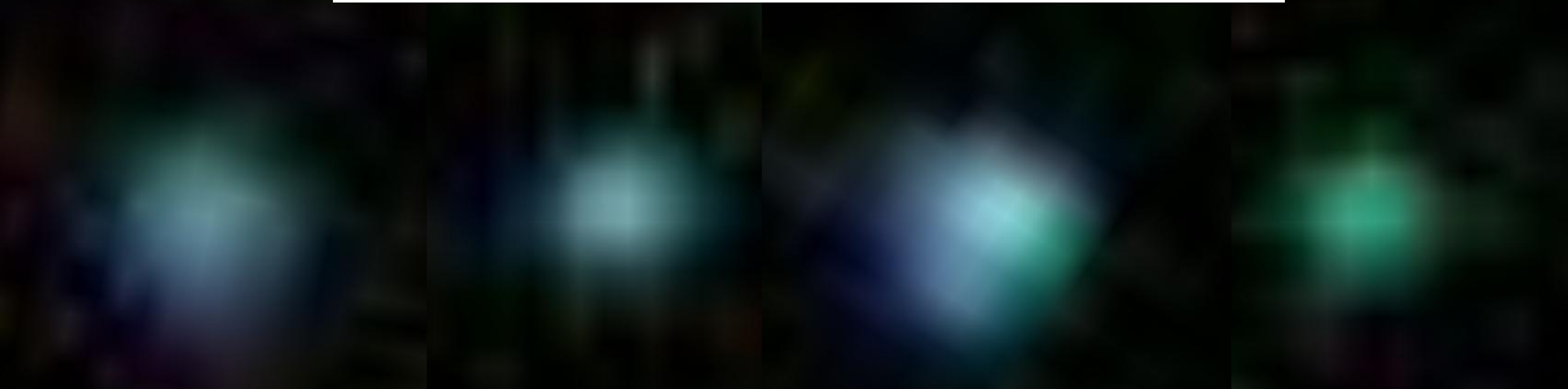
Dilution due to an inflow can be restored by SF depending on the dilution-to-dynamical timescale: galaxies with smaller radius are expected to take longer time to enhance their metallicity to the MZR values (Finlator & Davé 2008; Ellison et al. 2008)

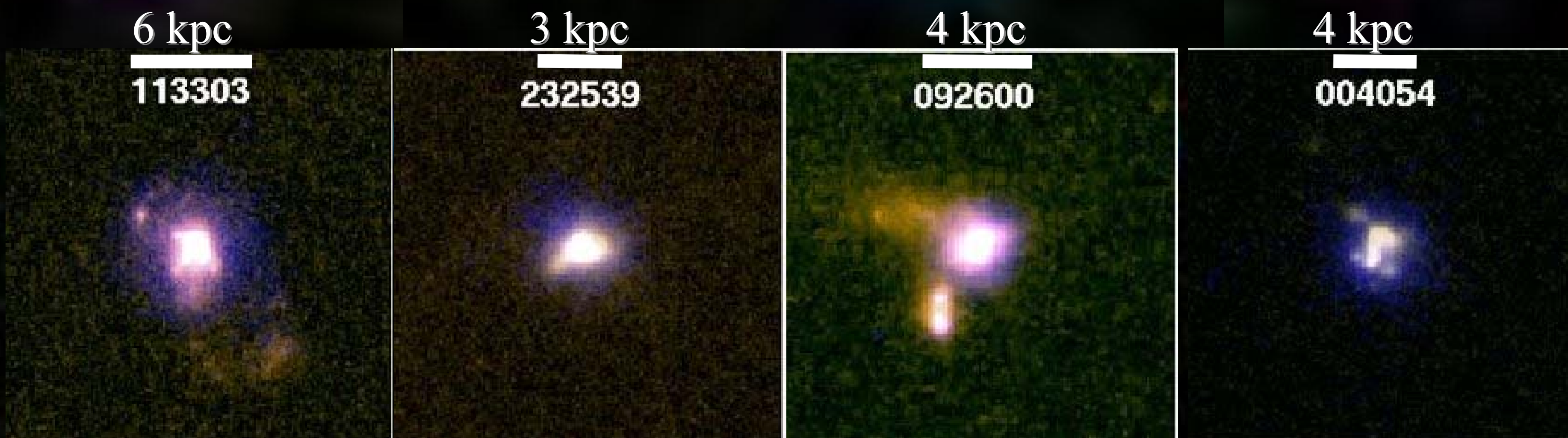
Cold gas accretion driven by interactions or mergers eventually increases the gas surface density and the star formation. SPH+N-body simulations show that major interactions drive starburst and gas inflow from the outskirts of progenitor HI disks (e.g. Cox et al. 2006; Rupke et al. 2010).

Similar offset in the MZR has been observed in central regions of SFGs with signs of tidally-induced large.scale inflow to the centres (e.g. Kewley et al. 2006; Michel-Danseac et al. 2008; Peeples et al. 2009)

Morphology: GPs / LBAs

6′′x 6′′ SDSS-DR7 (seeing limited) *ugriz* composition





6′′x 6′′ HST (FWHM=0.1′′) blue/purple=FUV; yellow/red=optical. Overzier et al. (2009)

Some hints for the evolution of GPs

1. Are green peas luminous Blue Compact Galaxies (LBCGs) ?
   - Several similarities but GP´s metallicities are quite lower for the same luminosity.
   - If so, an underlying old stellar component should be detected at low surface brightness. The host galaxy is present in virtually all BCDGs (e.g. Papaderos et al. 1996, Cairós et al. 2001, Amorín et al. 2009 among others).

2. Are green peas, LBAs and KISS OIII-selected galaxies sharing evolutionary pathways?
   - Metallicity is an additional evidence. Deep and systematic studies are needed to elucidate this.
   - Even if not, their properties suggest that these galaxies are *snapshots* of an extreme and short phase in their evolution. *Relics* of a mode of star formation more common at high-z. Excellent local laboratories to study the extreme properties of starburst at higher redshifts (e.g. Lyman-break galaxies).

Summary and final remarks

1) The green peas are a genuine population of metal-poor star-forming galaxies, with mean oxygen abundances ~ 20% solar.
2) At a given metallicity, they display systematically large N/O ratios compared with normal galaxies
3) The stellar mass-metallicity relation of the green peas is offset >0.3 dex to lower metallicities compared to normal SFGs.
4) The presence of an interaction-induced inflow of metal-poor gas, possibly coupled with a selective gas loss driven by supernova winds, may explain our findings and the know properties of the green peas.
5) These properties seem to be not common in the local universe. Therefore, the green peas may allow us to study in great detail many processes, such as starburst/feedback and chemical enrichment, under physical conditions approaching those taking place at higher redshift
6) Future plans include: optical imaging and spectroscopy with OSIRIS/GTC; NIR imaging with 4m-8m class telescopes, and 21 cm HI observations with GMRT or VLA.