Searching for Extremely Metal Poor Galaxies and their Physical Origin

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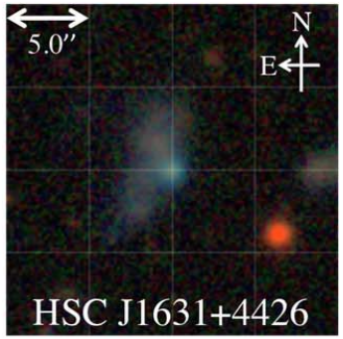
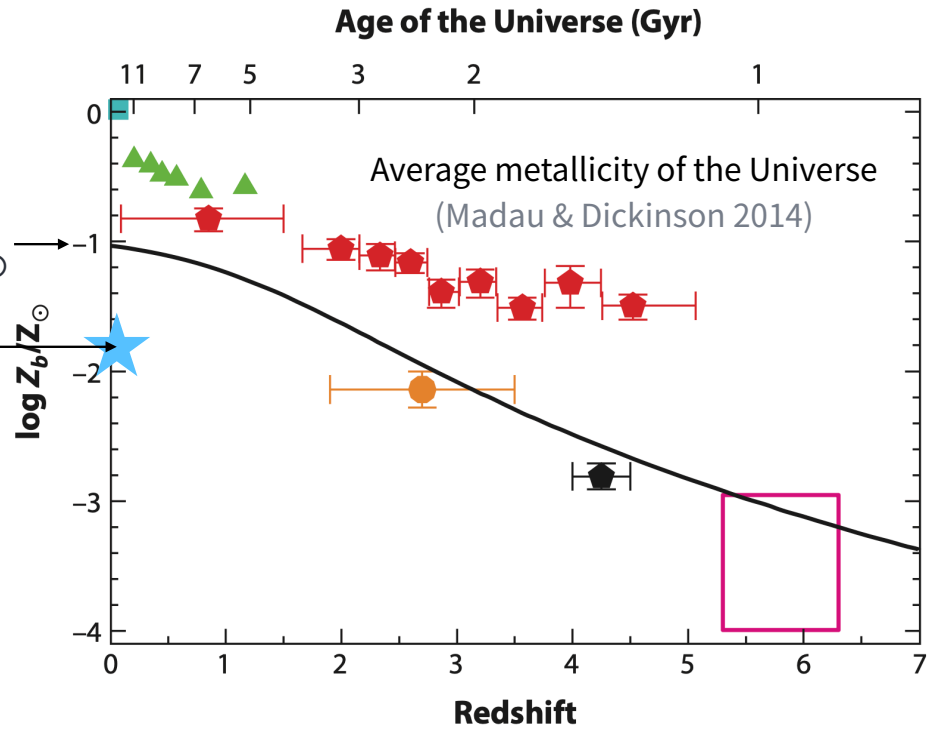
Extremely metal poor galaxies (EMPGs) in the local universe

EMPGs: with metallicity $Z < 0.1\ Z_\odot$



the most metal poor galaxy;
0.016 $Z_\odot$, redshift = 0.031 (Kojima+20)

IGM average $\simeq 0.1 Z_\odot$

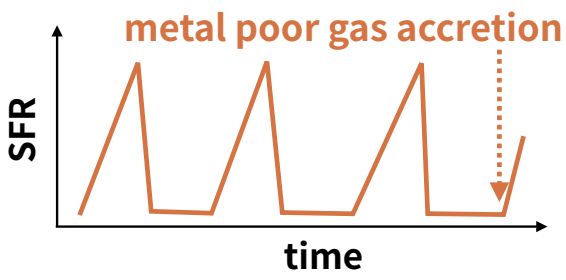


<u>What is the physical origin of EMPGs?</u>

Possible Scenarios

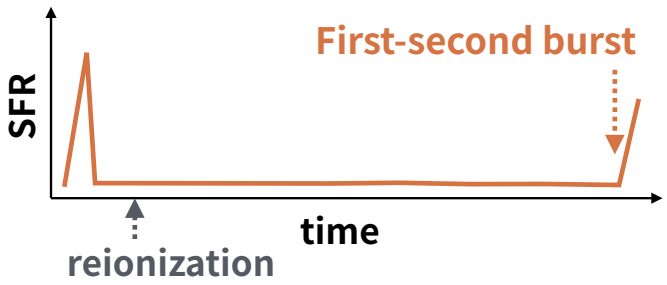
1. Intermittent star-formation history scenario:

EMPGs have the intermittent star-formation history just like the typical star-forming galaxies.



2. First-second burst of star-formation scenario:

EMPGs are truly primordial galaxies.



Searching for EMPGs

Method

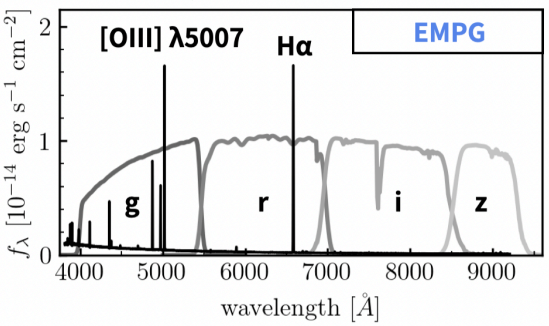
Selection using machine learning

model spectra of EMPGs and other populations

-> classifying EMPGs in SDSS photometric colors

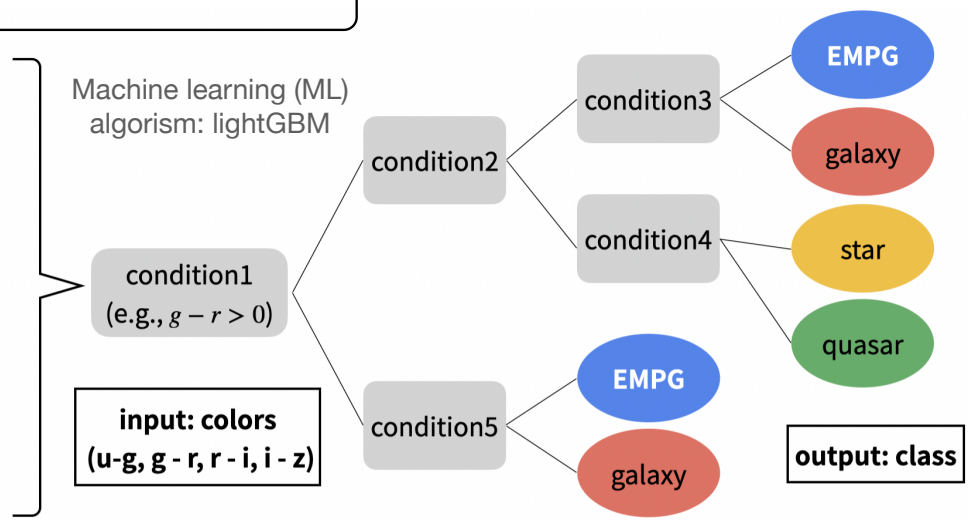
Characteristic features of galaxies
in the early phase of star formation

- large $\mathrm{EW}_0([\mathrm{OIII}]\lambda5007)$ & $\mathrm{EW}_0(\mathrm{H}\alpha)$
- $[\mathrm{OIII}]\lambda5007 \lesssim \mathrm{H}\alpha$



+ photometry of other populations
(typical SFGs • stars • quasars)

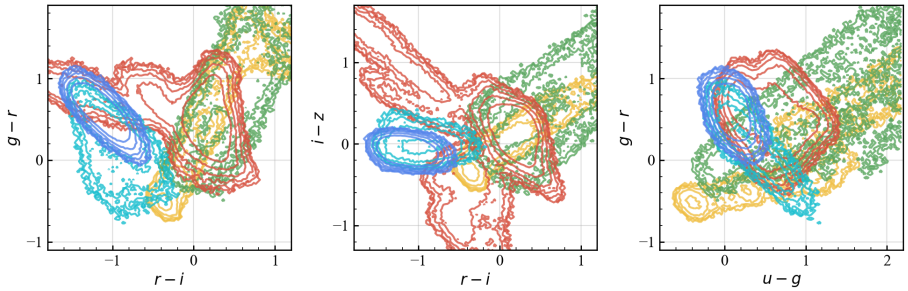
Machine learning (ML)
algorism: lightGBM



input: colors
(u-g, g - r, r - i, i - z)

output: class

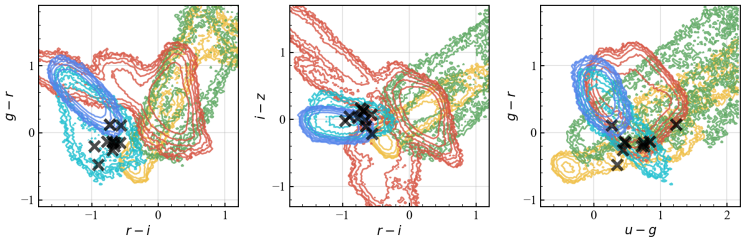
color-color diagram of the model spectra

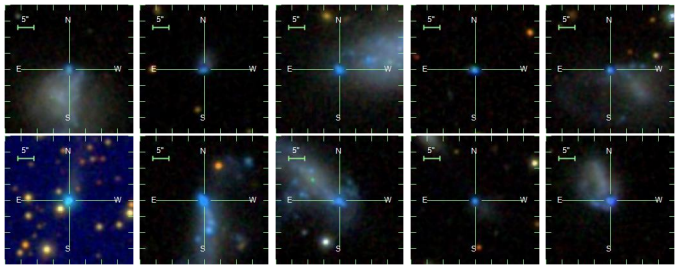


xEMPG ($Z < 0.01\ Z_\odot$)
EMPG ($Z = 0.01 - 0.1\ Z_\odot$)
Galaxy ($Z > 0.1\ Z_\odot$)
QSO
Star

Spectroscopic follow-up observation

Applying to our method to SDSS photometric data (N~570,000)

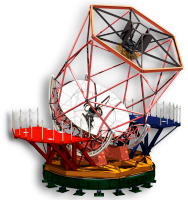




SDSS image

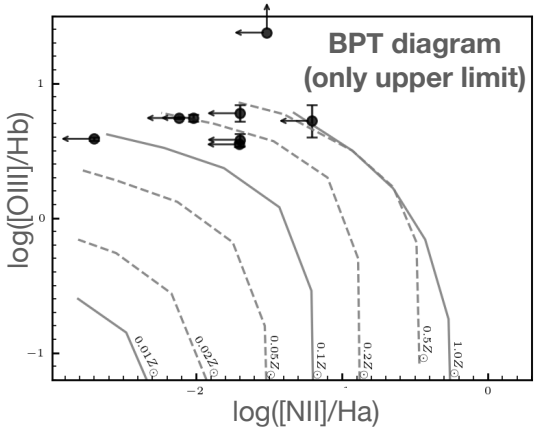
→ 134 candidates

Spectroscopic follow-up with Seimei/KOOLS, Nayuta/MALLS
（Dec. 2020 - Feb. 2021）



Seimei (3.8m)

Nayuta (2m)



→ **10** candidates

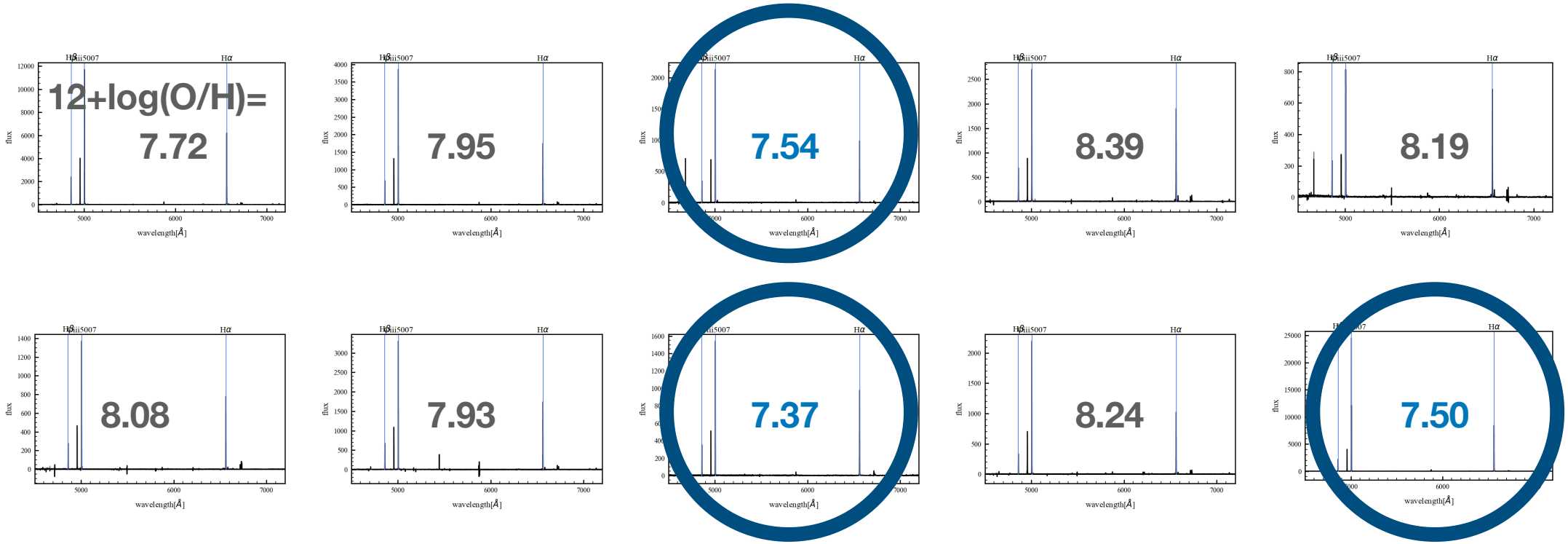
Follow-up
with Magellan/MagE
(July. 2021 - Apr. 2022)

Magellan (6.5m)

Result

MagE observation

MagE spectra of 10 candidates



Environment

Environment — Cross correlation function

$$\xi(r,\pi) = \frac{D_1D_2 - D_1R - D_2R + RR}{RR}$$

$$\omega(r) = 2\int_0^{\pi_{\max}} d\pi\ \xi(r,\pi)$$

Zehavi+05

DD: Number of galaxy-galaxy (different sample) pairs at distance (r,π)

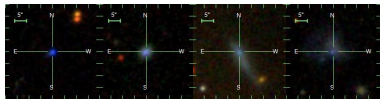
DR: Number of galaxy-random pairs at distance (r,π)

LSS catalog (Reid+16)

- galaxy (N= 30,757)
- random (N=745,628)

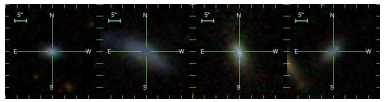
- **EMPG**: spec-confirmed EMPGs (N=221)

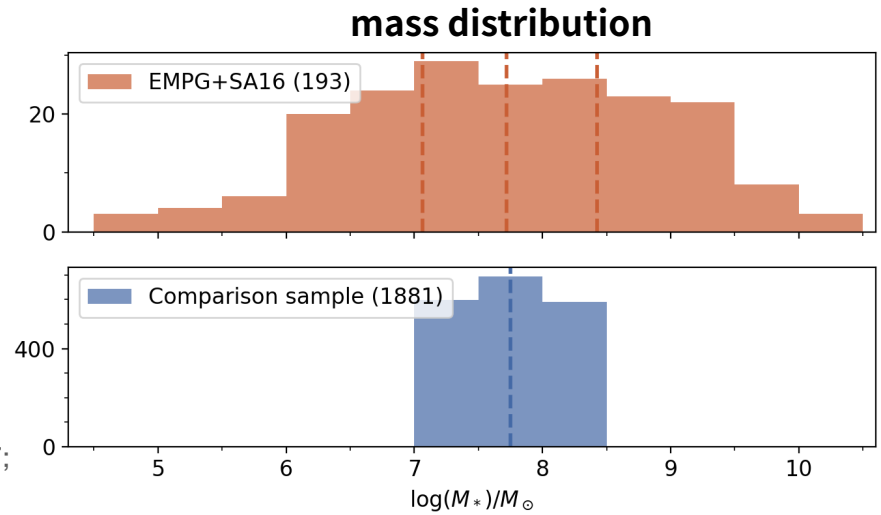
  literature* + SanchezAlmeida+16



- **Comparison sample**:

  galaxies from SDSS spec (N=1881)

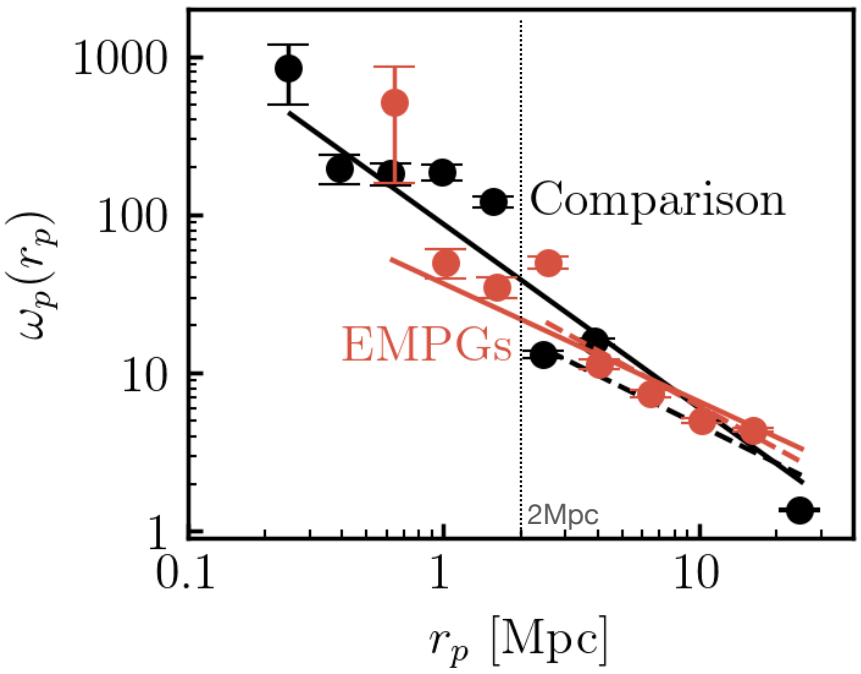




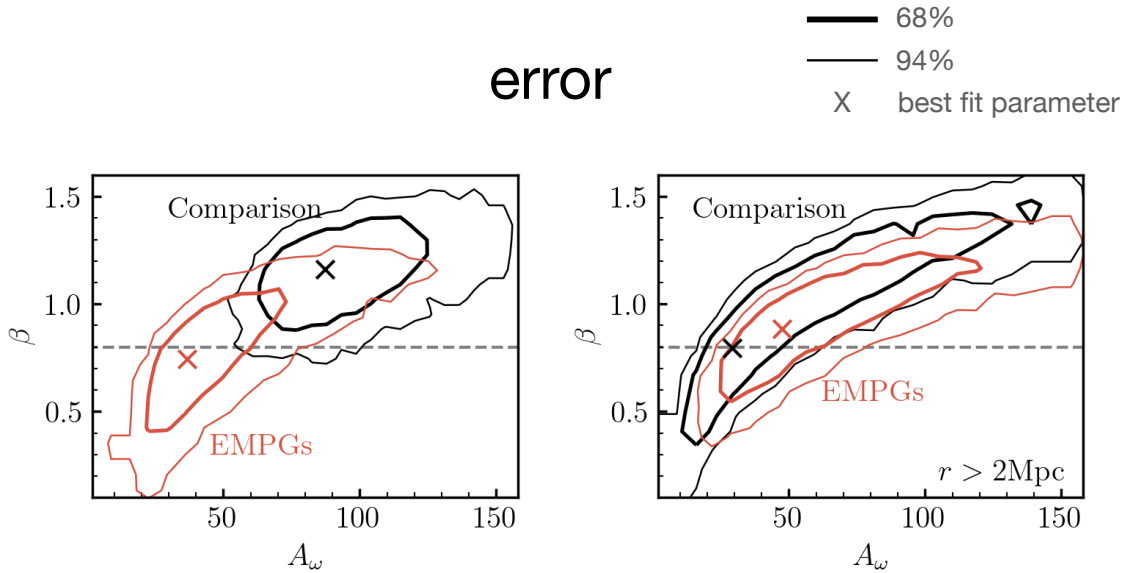
* Kniazev+03; Thuan&Izotov+05; Skillman+13; Hirschauer+16; Sanchez Almeida+16; James+17; Hsyu+17; Senchyna&Stark 19; Kojima+20; Isobe+21; Xu+22; Izotov+06;09;12;18;19;20;21

Environment — Cross correlation function

CCF ($\omega_p = A_\omega r_p^{-\beta}$)



error



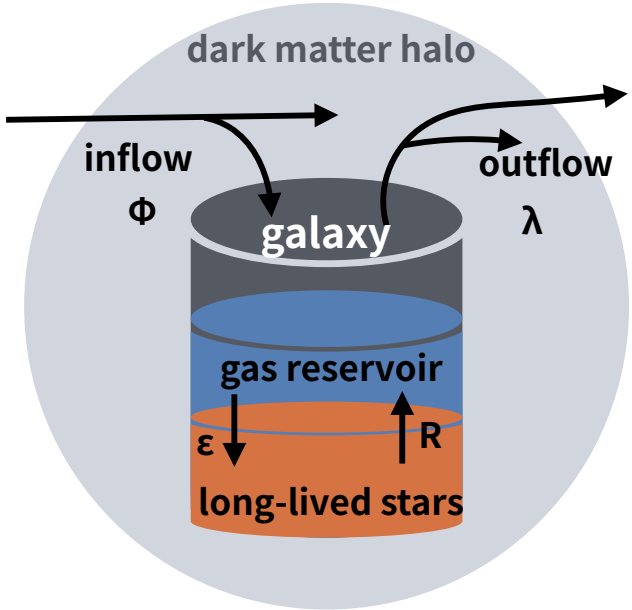
to eliminate the effect of "1 halo term"

Clustering of EMPGs is consistent with that of comparison sample.

Chemical properties

The “equilibrium” model

- Analytical chemical evolution models (e.g., Lilly et al. 2013) can reproduce the observed MZR & FMR and its evolution.
- Establishing a balance between gas flows and star-formation.



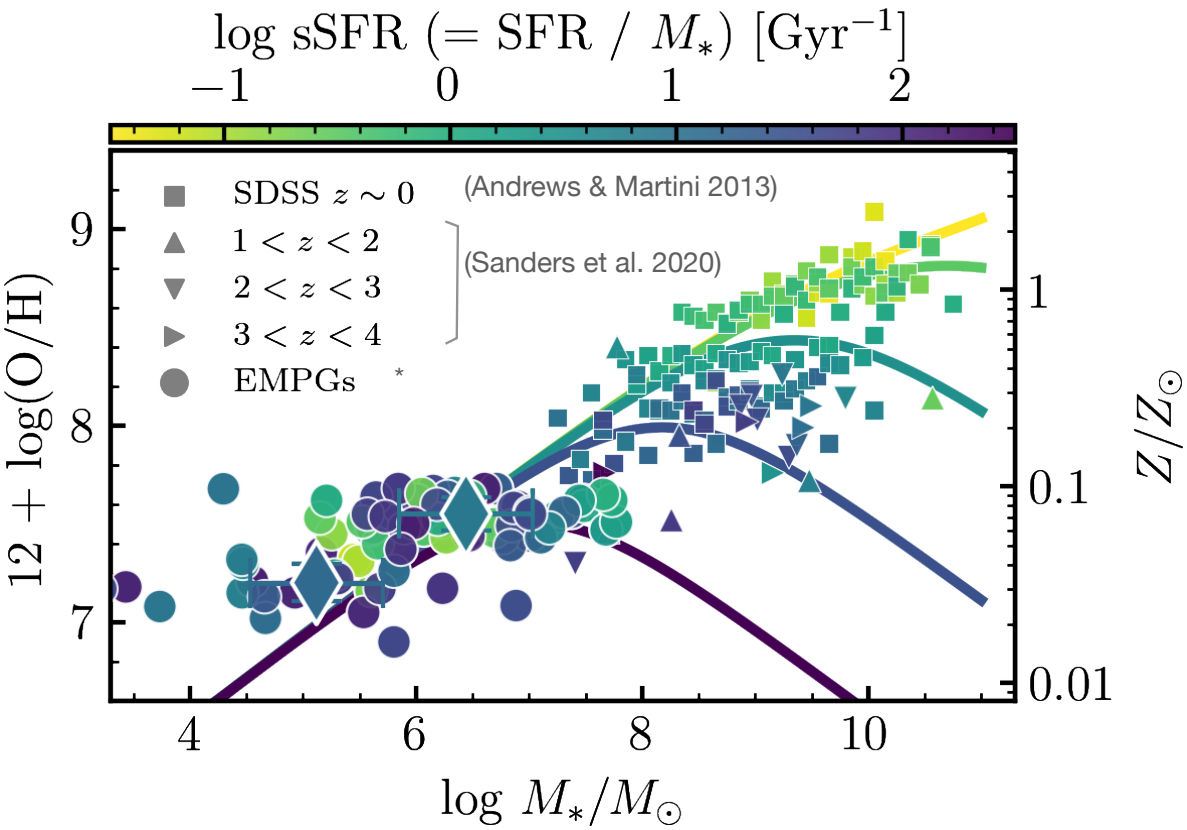
$$\Phi = (1 - R) \cdot \mathrm{SFR} + \lambda \cdot \mathrm{SFR} + dm_{\mathrm{gas}}/dt$$

metallicity at equilibrium:

$$Z_{\mathrm{eq}} = Z_0 + \frac{y}{1+\lambda(1-R)^{-1}+\varepsilon^{-1}\left((1+\beta-b)m_{\mathrm{star}}^{-1}\cdot\mathrm{SFR}-(1-R)^{-1}\frac{1.2}{t}\right)}$$

Lilly et al. 2013

Fundamental metallicity relation (FMR) of EMPGs



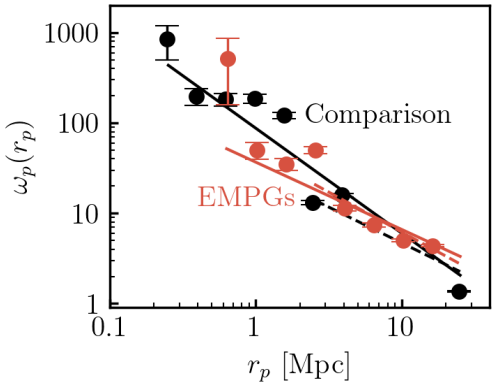
→ EMPGs are in equilibrium between inflow and outflow, on average.

* Kniazev+03; Thuan&Izotov+05; Skillman+13; Hirschauer+16; Sanchez Almeida+16; James+17; Hsyu+17; Senchyna&Stark 19; Kojima+20; Isobe+21; Xu+22; Izotov+06;09;12;18;19;20;21+ this work

Discussion

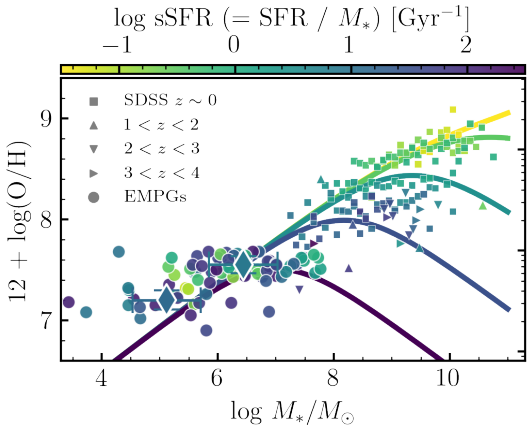
Physical origin of EMPGs

Environment

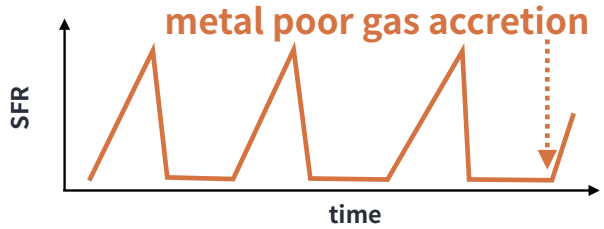


→ EMPGs have the same clustering as metal richer galaxies.

Chemical properties



→ EMPGs are in equilibrium between inflow and outflow.



EMPGs can be explained by the intermittent star-formation history.

Summary

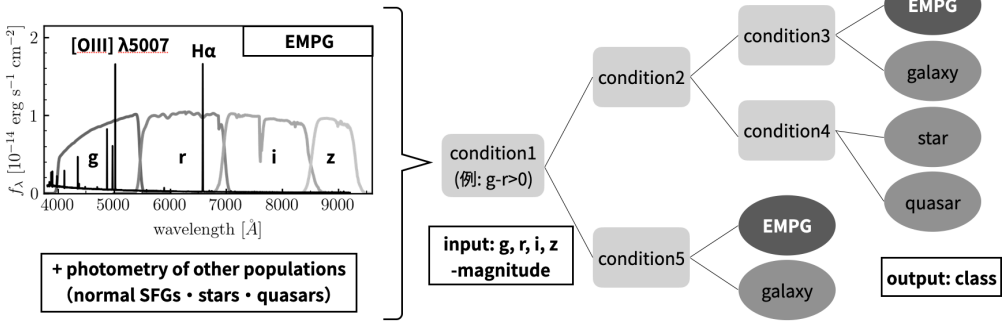
- Searching for new extremely metal poor galaxies (EMPGs) :
  - Selected from SDSS photometric data using machine learning technique
    -> Screening with Nayuta & Seimei spectroscopy
    -> Follow-up spectroscopy with MagE
    -> 3 new EMPGs
- Environment:
  - EMPGs have the same clustering as metal richer galaxies with similar mass
- Chemical properties:
  - EMPGs are in equilibrium between inflow and outflow, on average.

→ **EMPGs may have the intermittent star-formation history, just like typical star-forming galaxies.**

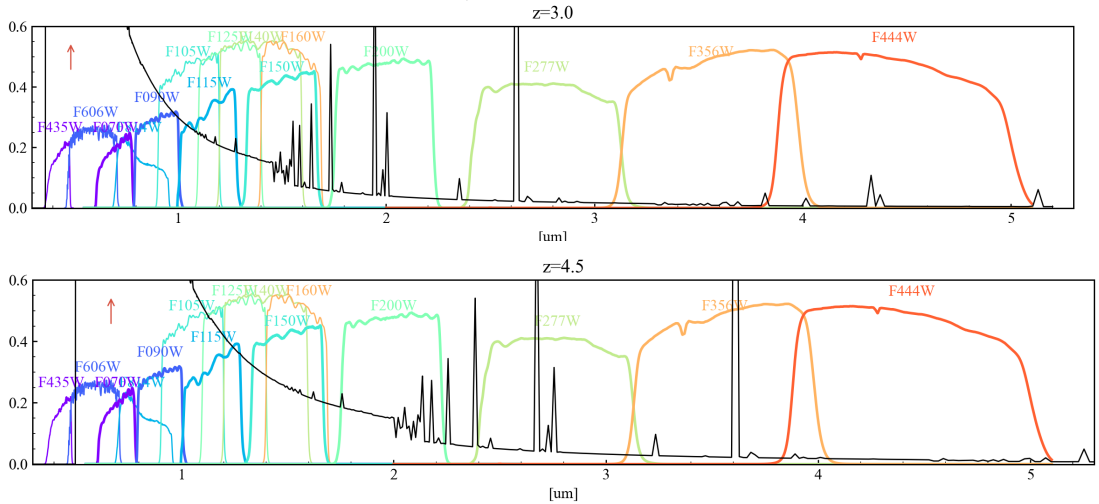
Future Work

Searching for high-z EMPGs with JWST

z~0 EMPGs with SDSS filters



z~3.0 & 4.5 EMPGs with NIRCam filters



Searching for the first galaxies
at z~3.0 and 4.5 using NIRCam data
follow-up with NIRSpec