INSTITUTO DE ASTROFISICA
PONTIFICIA UNIVERSIDAD CATÓLICA DE CHILE

Centro UC
Astro - Ingeniería

A secondary dependence of the mass–metallicity relation on the metallicity gradients

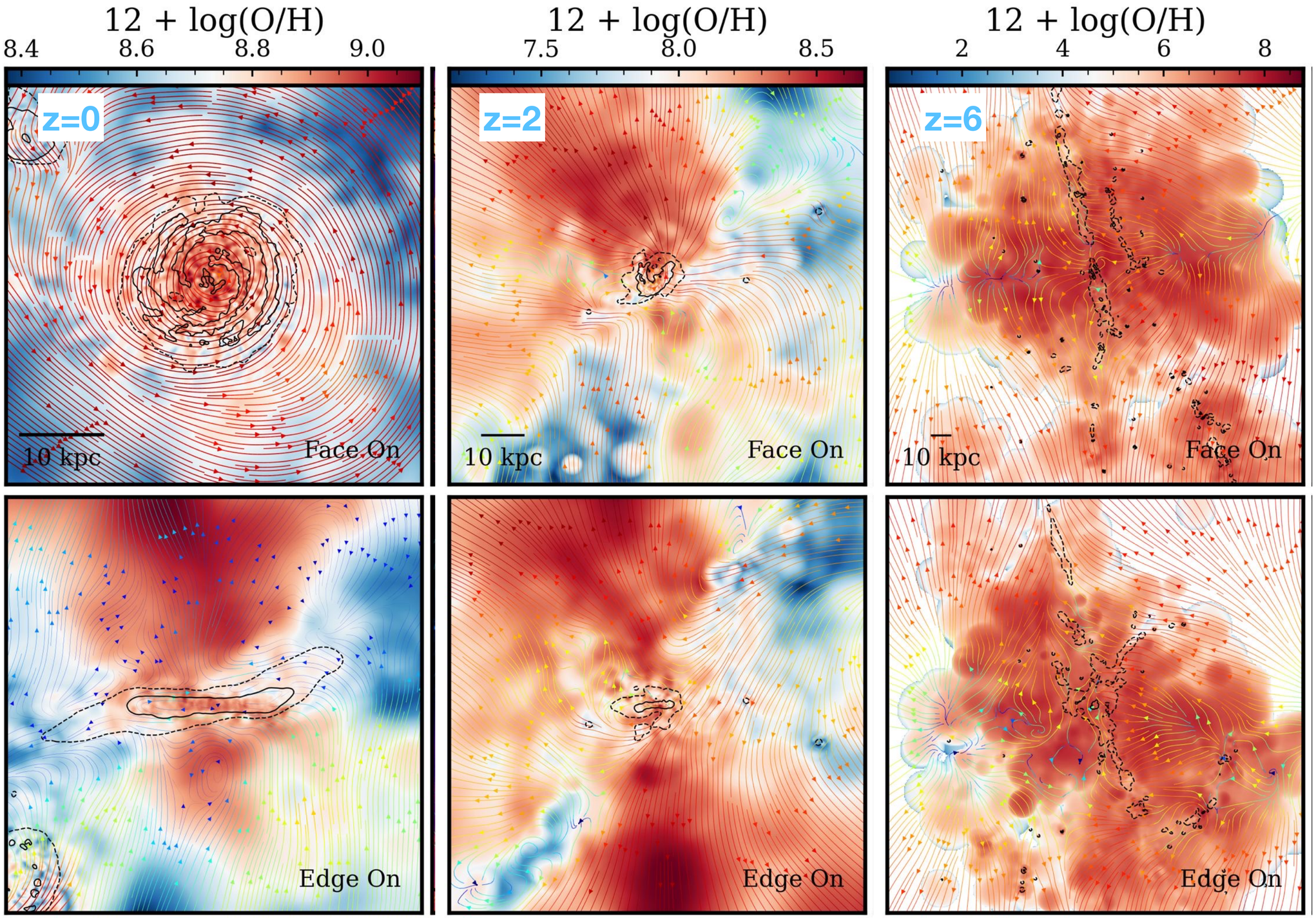
Patricia Tissera

CENTRO DE ASTROFÍSICA Y TECNOLOGÍAS AFINES

ANID Fondecyt 200703

ERIS

- Cosmological simulations + chemical evolution subgrid physics are powerful tools to study galaxy formation (e.g. Mosconi+2001, Lia+2002)



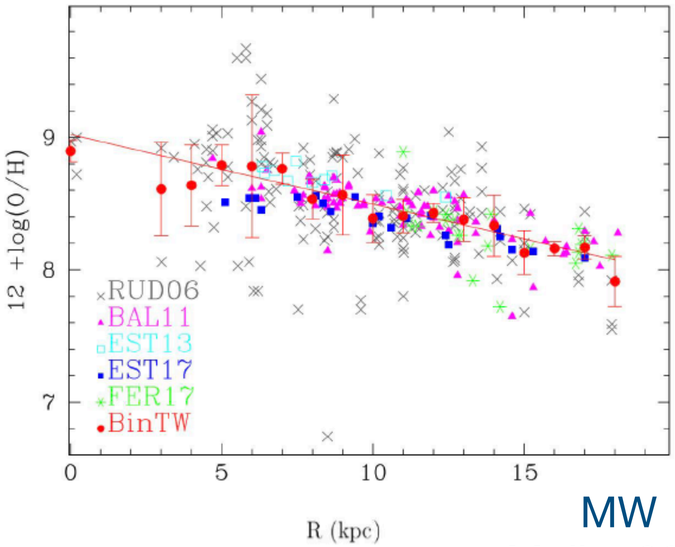
Evolution of a galaxy and its environment.

Star formation, feedback, mergers/ Interactions, gas accretion, among other environmental processes have an impact on the metallicity distributions of the ISM an stellar populations in galaxies.

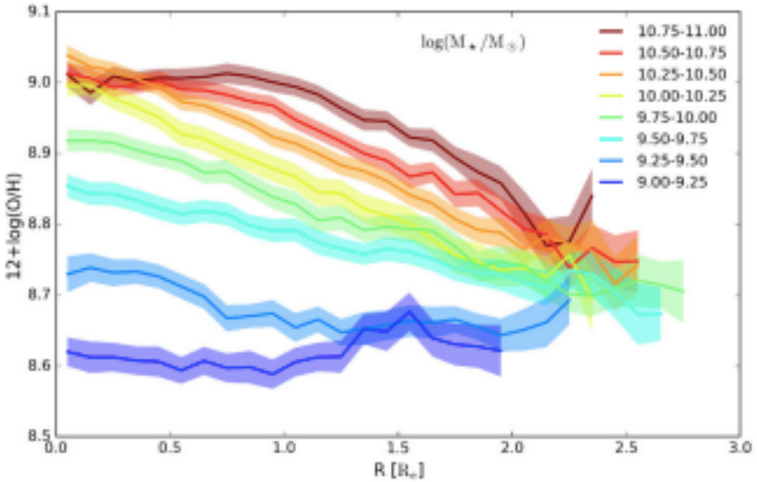
There is a coexistence of galaxies and their environment from very early stages of evolution.

Inside-out formation: Negative SF gas-phase metallicity gradients

Negative metallicity gradients are reproduced in simulations and models where the galaxies formed inside-out (e.g.Pilkington+2012; Taylor & Kobayashi 2017;Ma+2017,Tissera+2016;Hemler+2021)



MW
Molla+2018



Belfiore+2017
(MaNGA)

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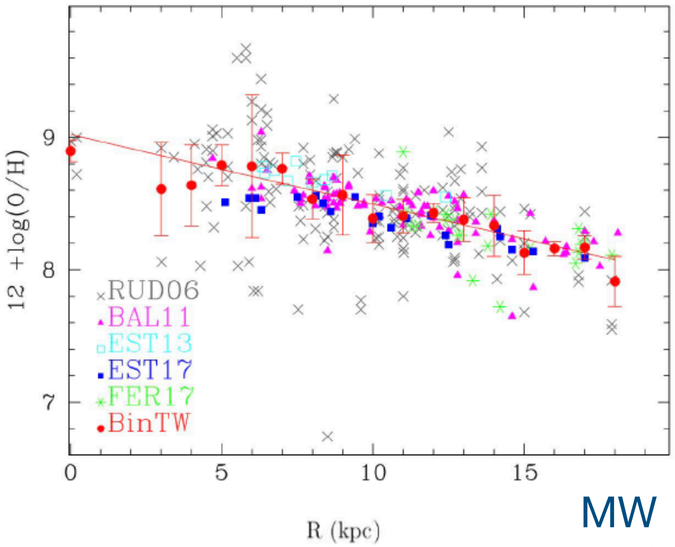

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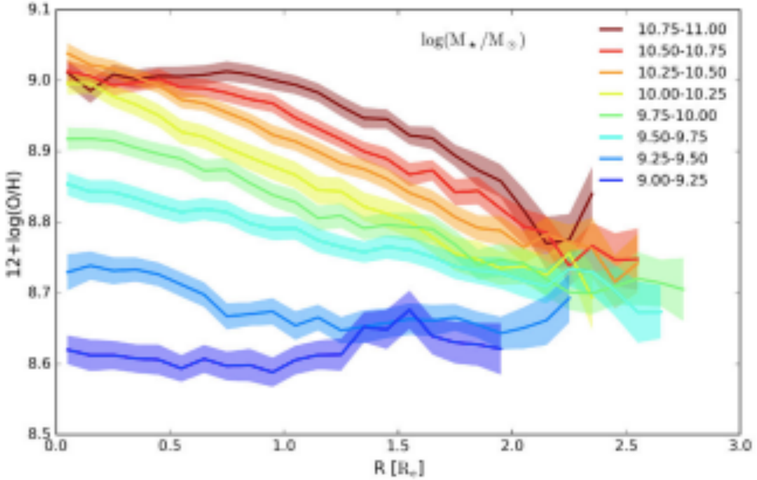

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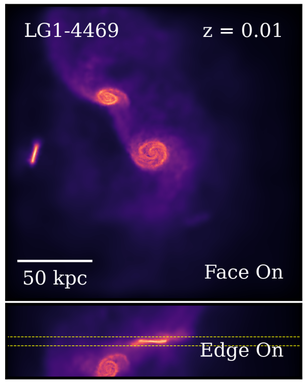
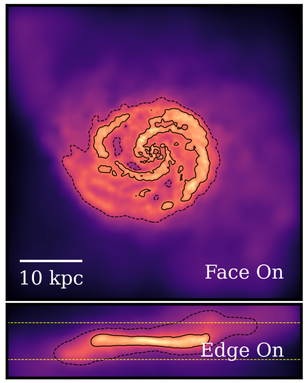
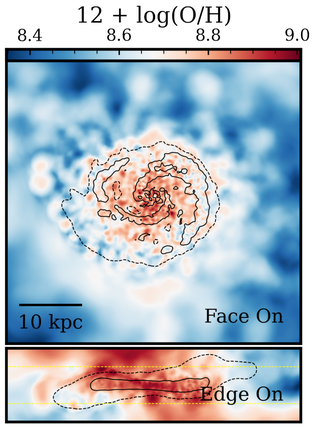
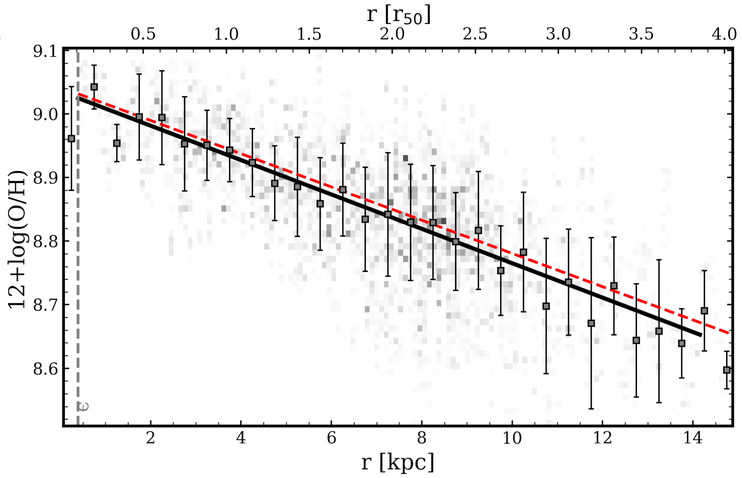


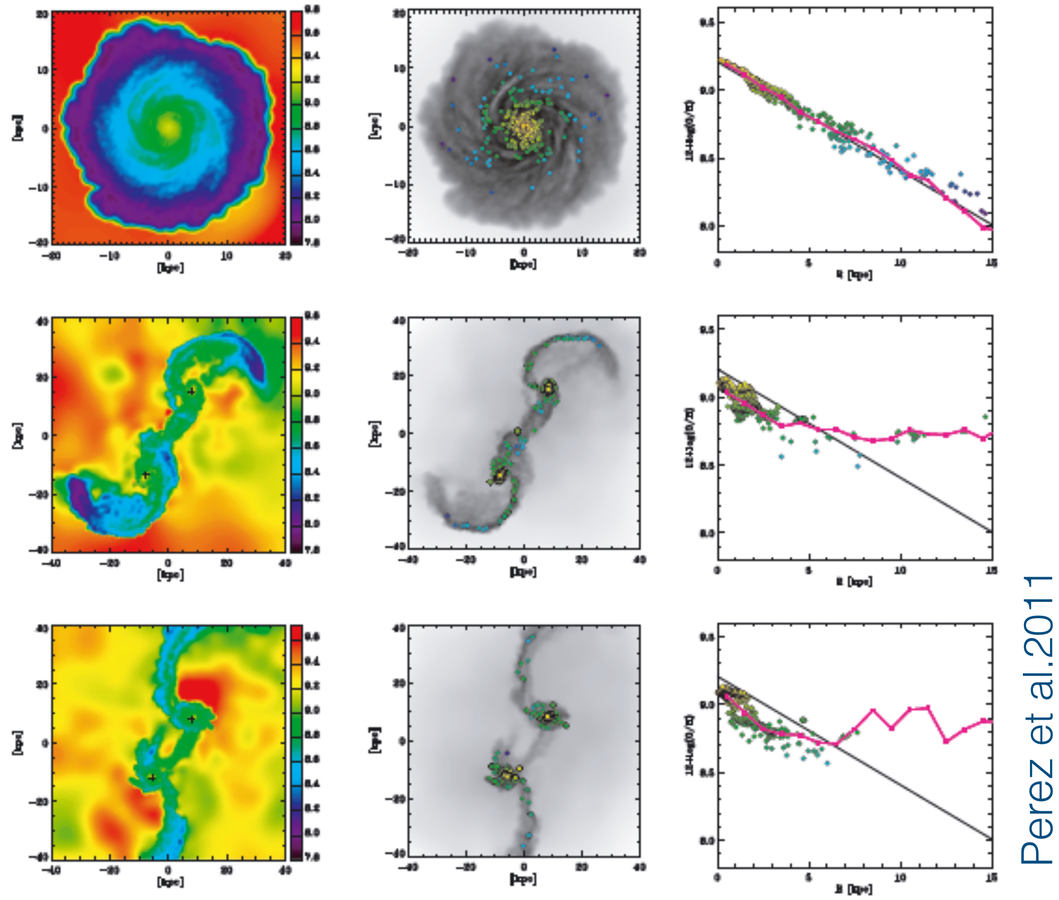






CIELO simulations;
Tapia-Contreras+2024 in prep

Evolution of the metallicity gradients during galaxy-galaxy interactions



Perez et al.2011

Mergers/Interactions shape the star formation activity and metallicity distributions depending on the gas richness, orbital parameters, mass ratio (e.g. KH91, Perez+2006; Rupke+2010;Sillero+2017; Di Matteo+2009; Moreno+2019; Bustamante+2019)

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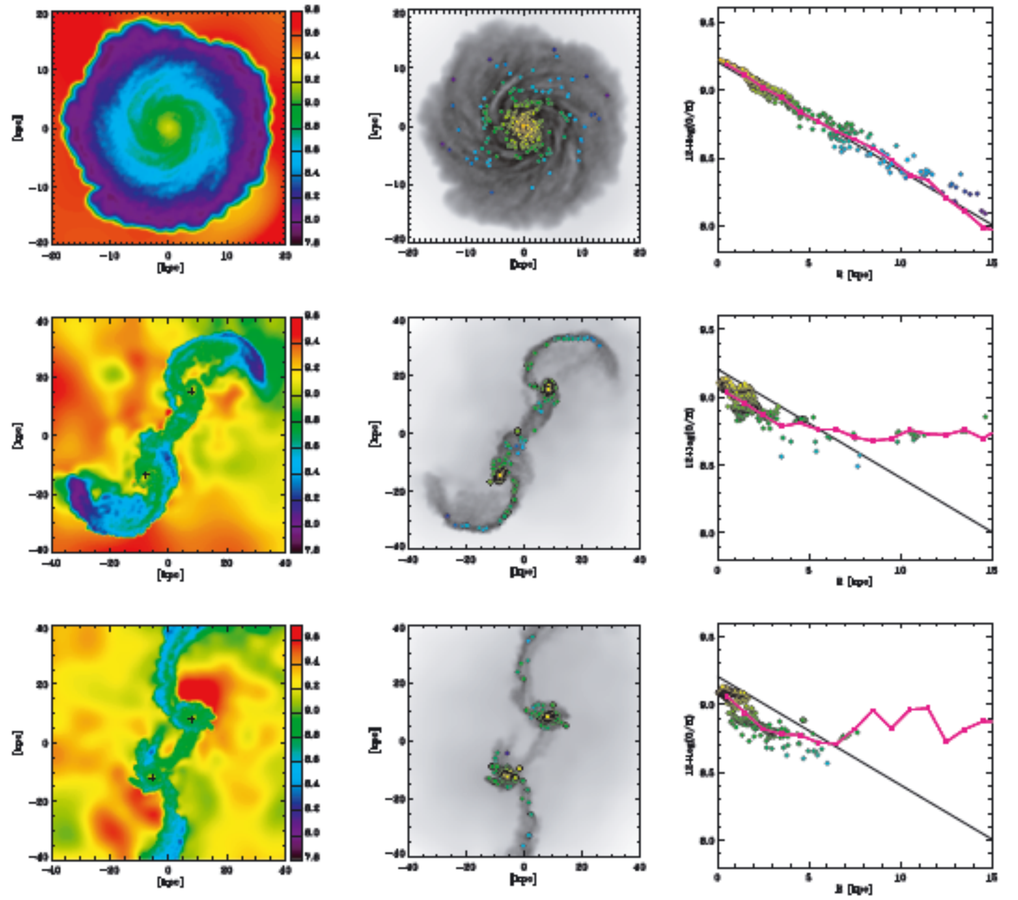

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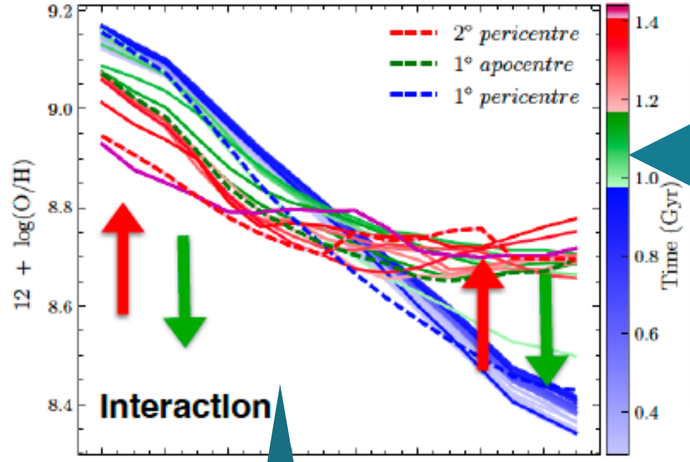


Modify the metallicity in the outer regions:

- Galactic fountain
- Disrupted material from the companion
- Stellar migration
- Gas inflows/outflows
- SFR

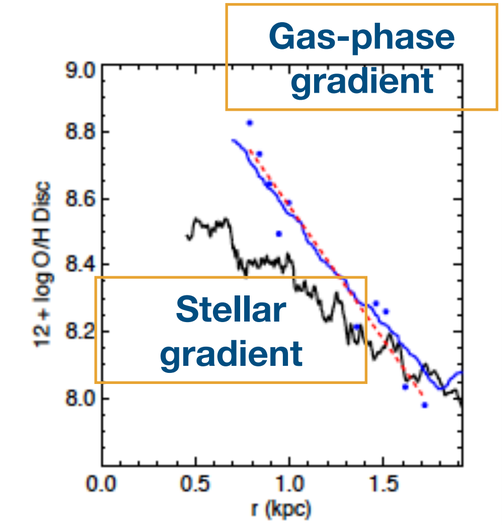
Modify the metallicity in the inner regions:

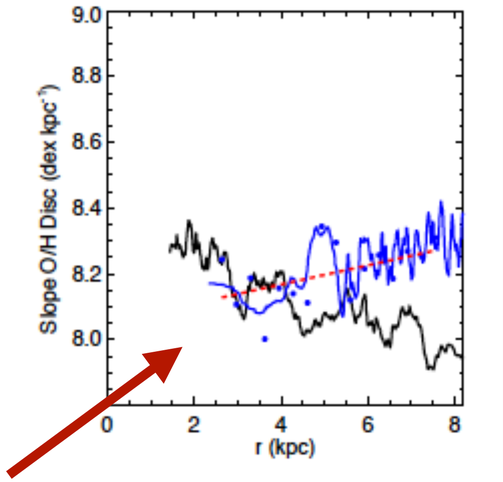
- SFR
- Secular evolution
- Galactic outflows

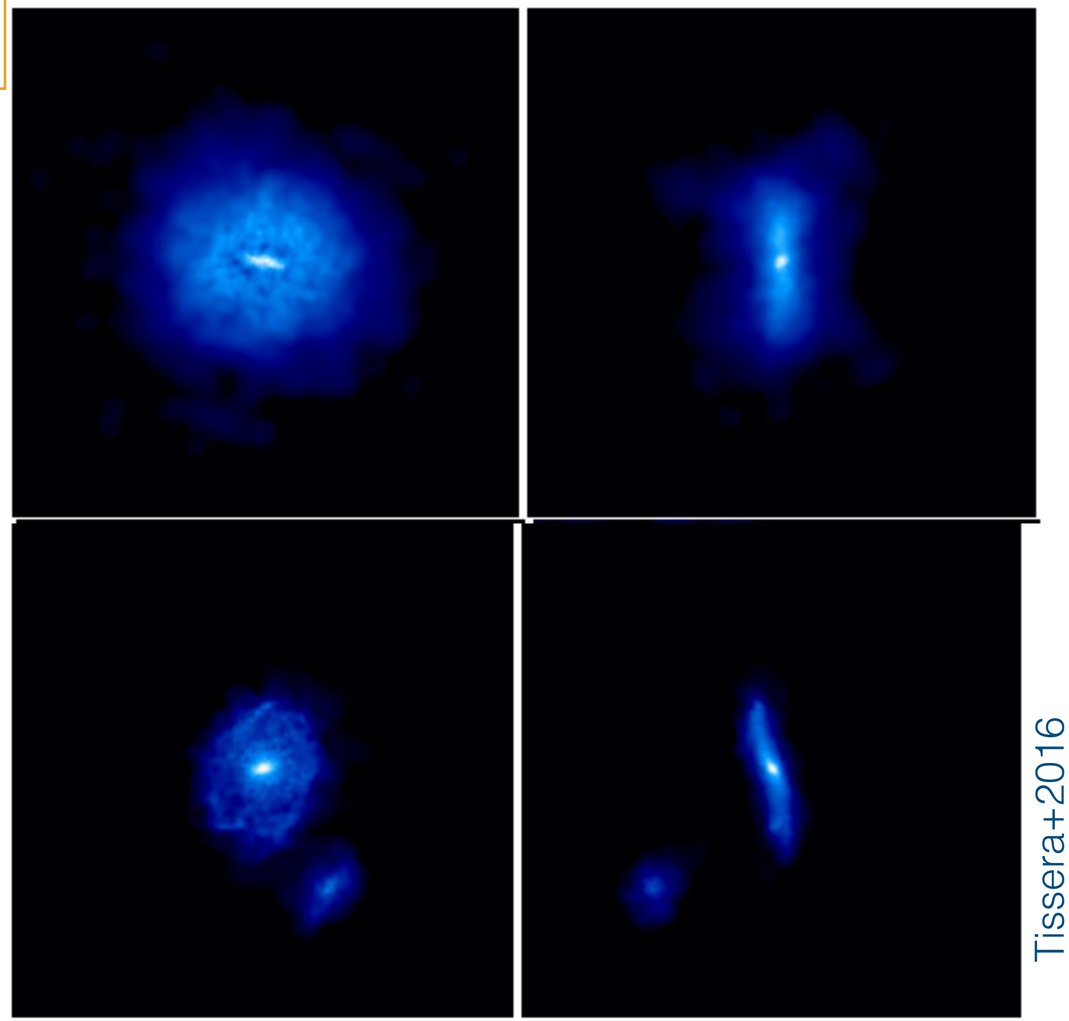
Other processes

- Gas inflows from the CGM (Ceverino 2016)
- AGN feedback

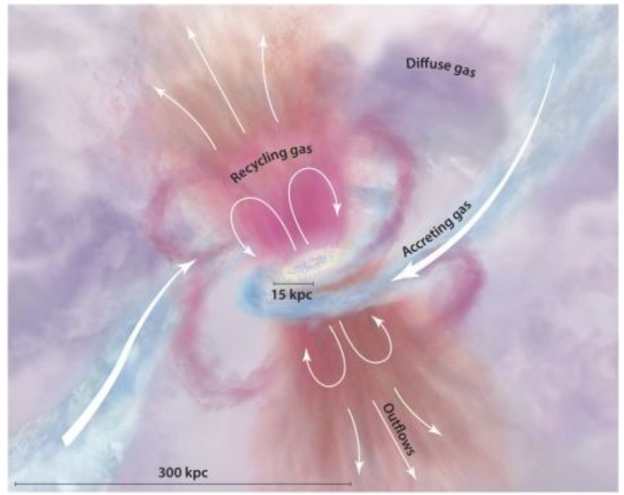
The impact of SN feedback + AGN feedback





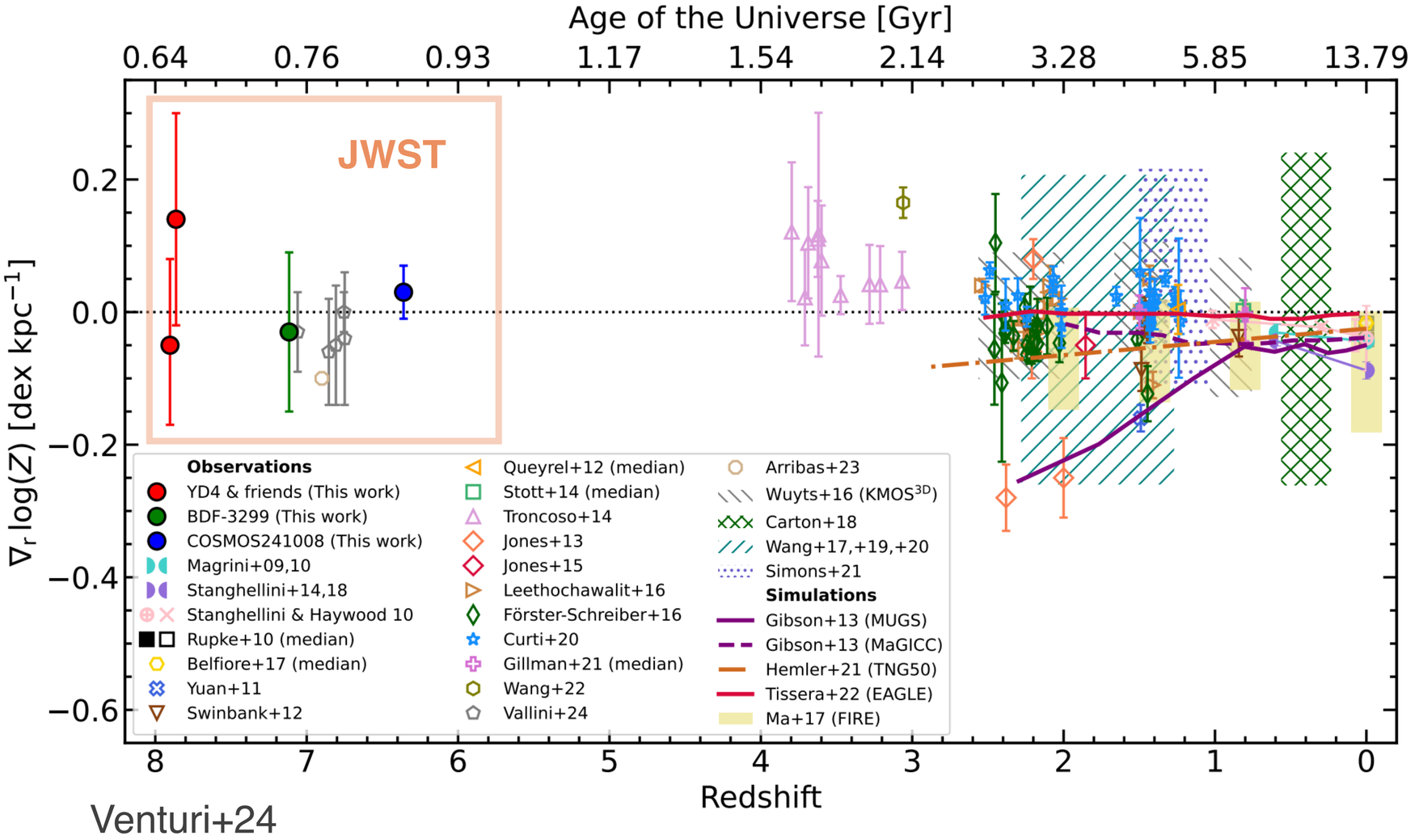


Tissera+2016



Inverted (positive) metallicity gradients can be produced by strong SN feedback and they are preferentially found in low mass galaxies (log M< ~10 Mo.

Evolution of the metallicity gradients across time



Venturi+24

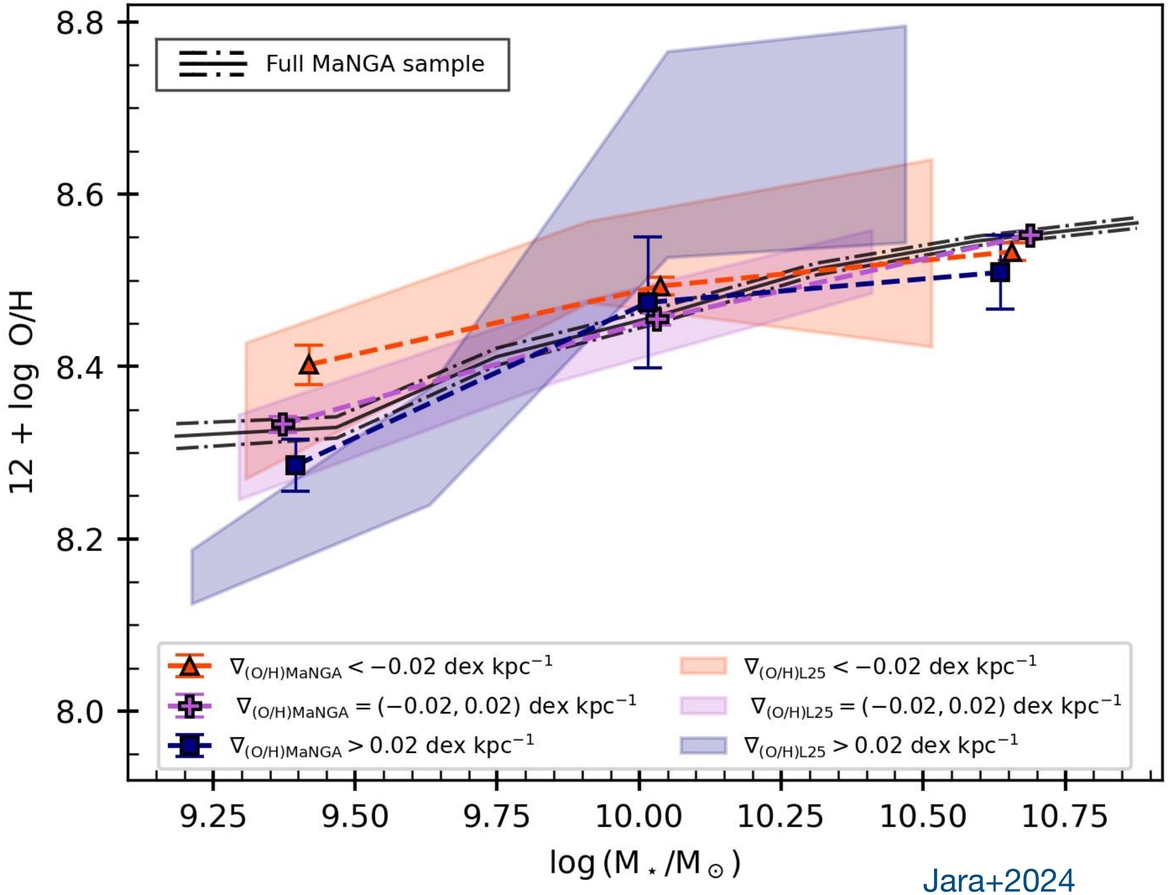
e.g. Gibson+13, Tissera+19 + 22

Positive metallicity gradients: galaxy interactions/strong gas inflows + feedback

Negative metallicity gradients are predicted by an inside-out galaxy formation scenario

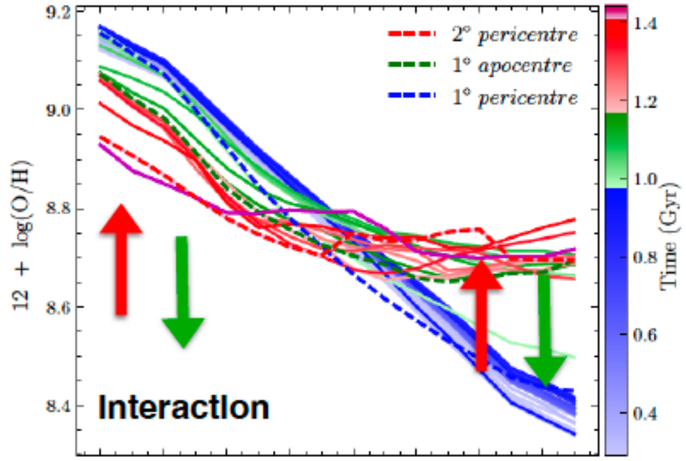
e.g. Tissera+2016,Taylor & Kobayashi +2017, Hemmler+2022.

The relation between the MZR and the metallicity gradients in EAGLE simulations and the MaNGA survey



Jara+2024

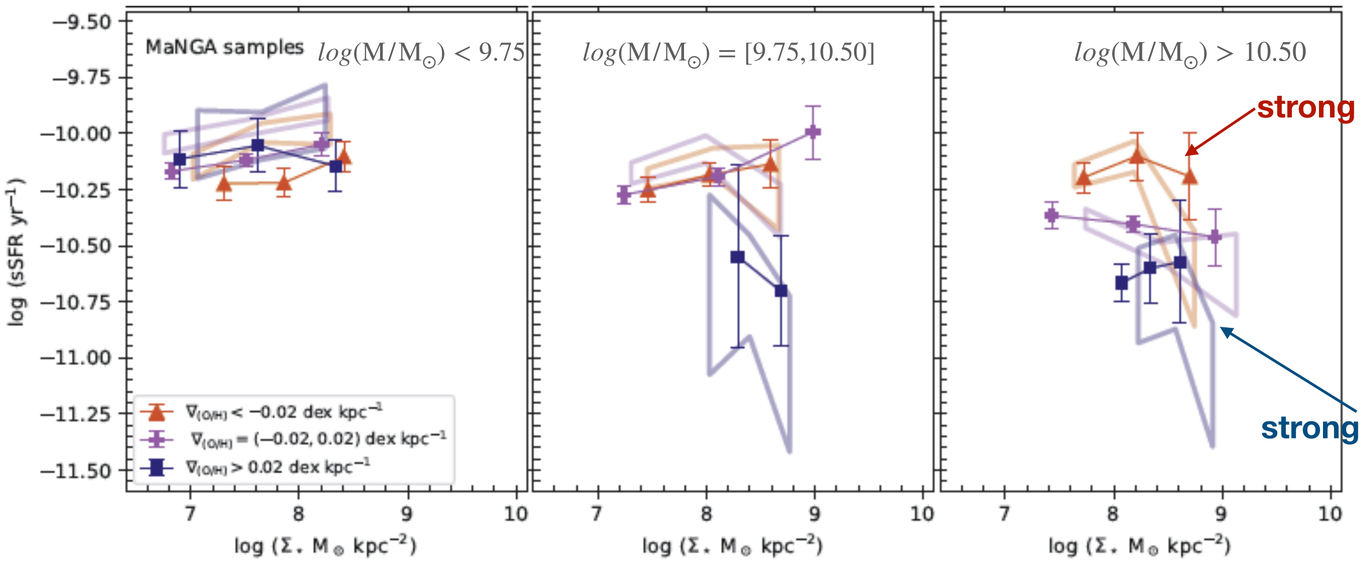
Strong negative gradients —-> recent strong SF, higher metallicity, may provide signals of outflows



Strong positive gradients —-> lower metallicity, lower SFR depending on the stellar mass, signals of outflows

Metallicity gradients, sSFR and galaxy compactness in EAGLE simulations and the MaNGA survey

MaNGA



strong negative gradients

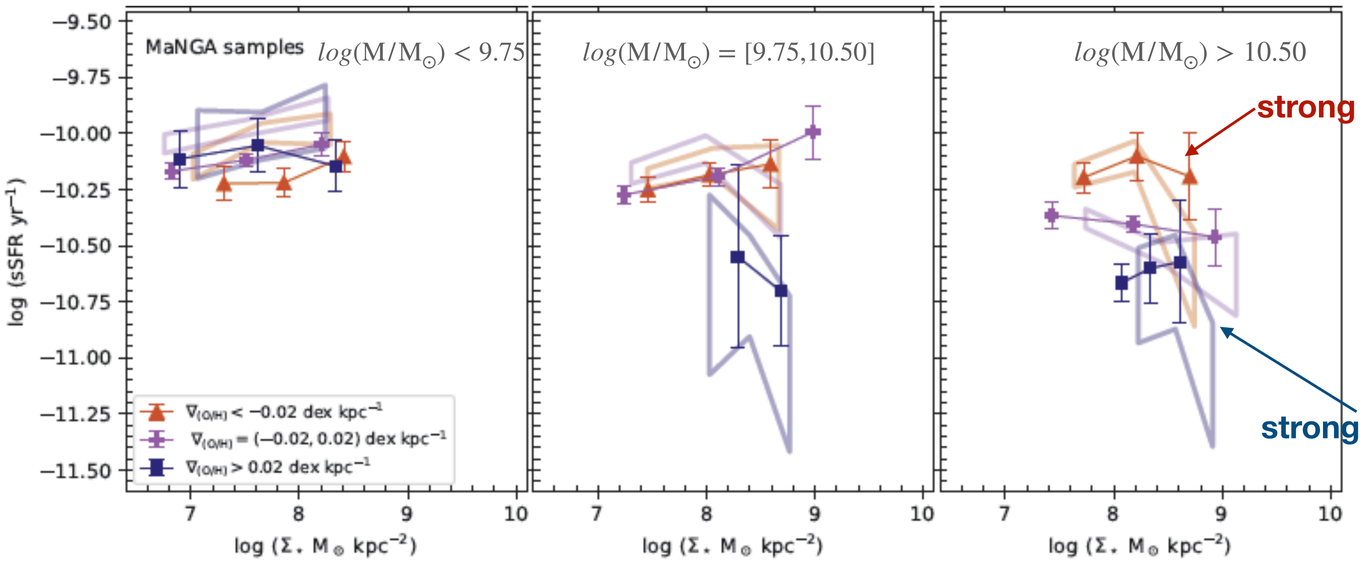
strong positive gradients

MaNGA: More massive galaxies with flat or positive gradients are less star-forming

$$\Sigma_* \propto M_*/R_{\rm eff}^2$$

Metallicity gradients, sSFR and galaxy compactness in EAGLE simulations and the MaNGA survey

MaNGA



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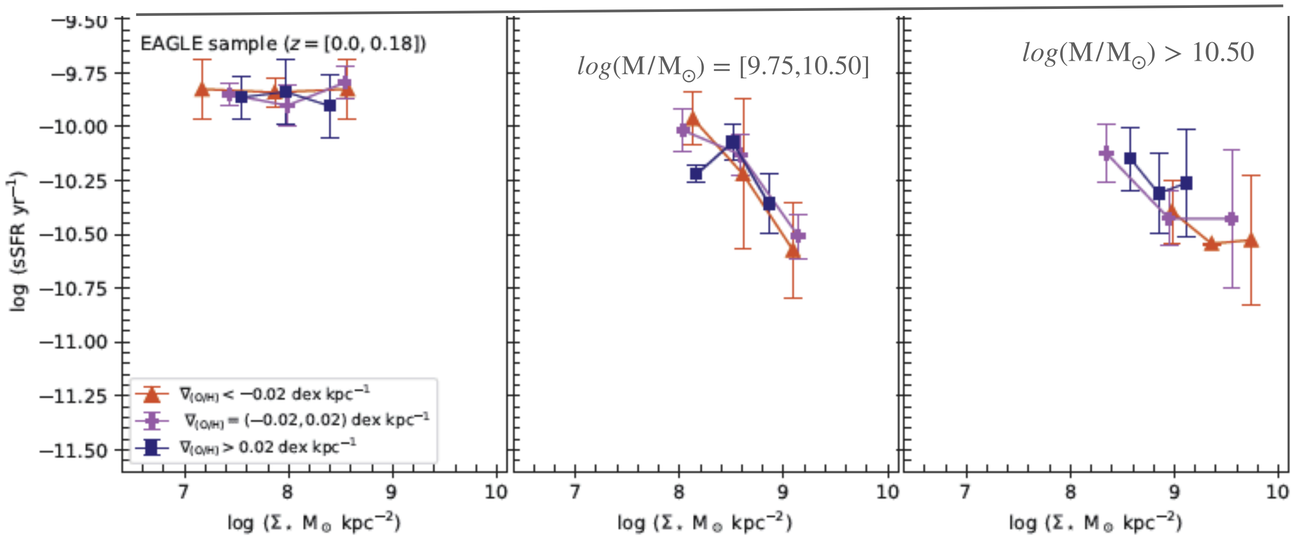
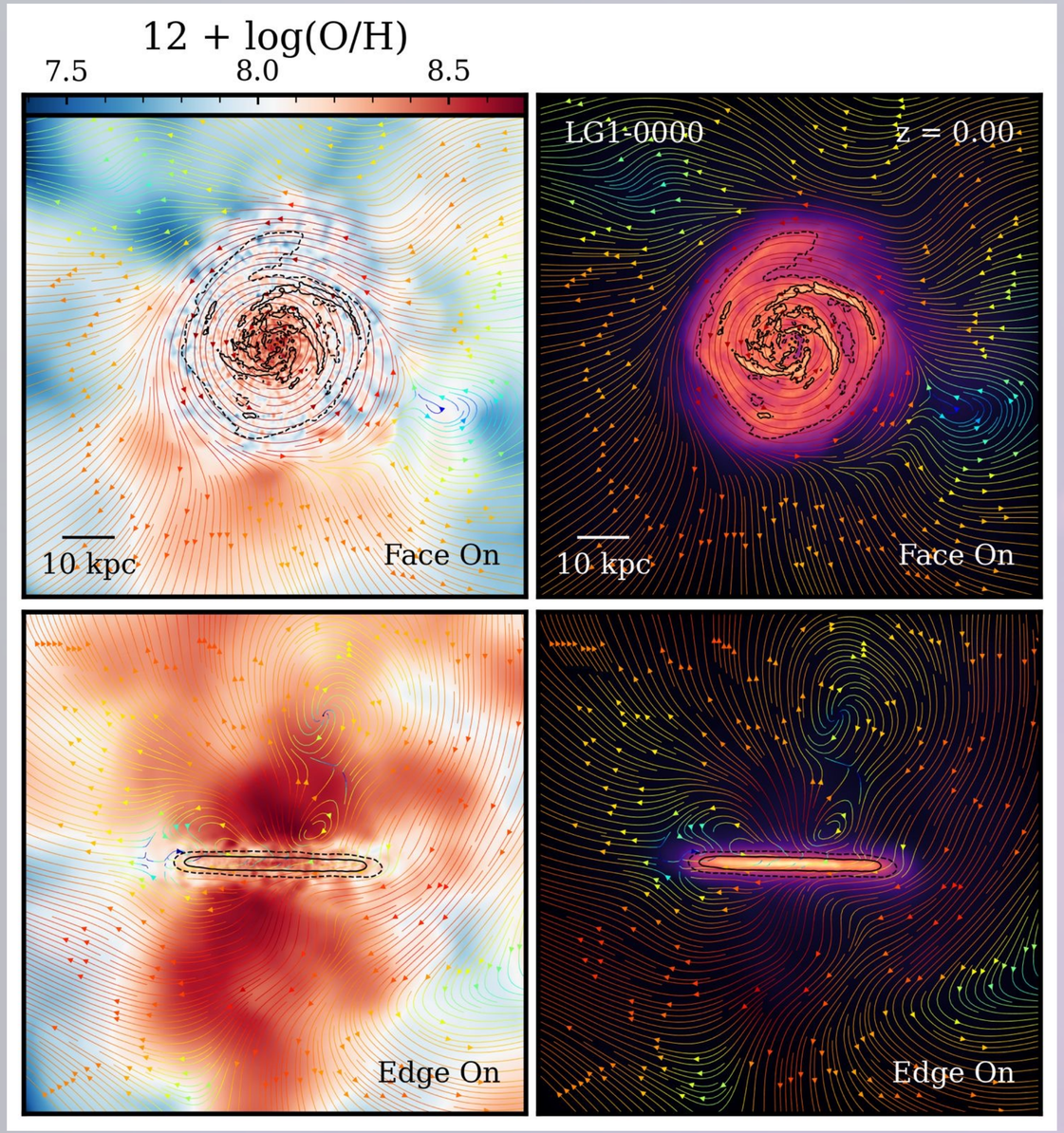
EAGLE



EAGLE: more massive galaxies show a deacrese of sSFR with galaxy compactness regardless of the metallicity gradients.

$$\Sigma_* \propto M_*/R_{\rm eff}^2$$

CIELO simulations



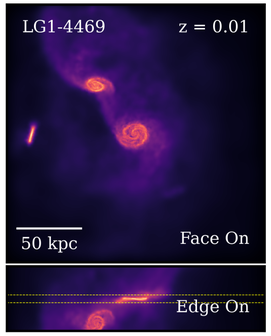
The CIELO project (Tissera et al. In prep.) aims to study galaxy formation in the field focusing on the chem-dynamical properties (collaboration: L. Bignonge, S. Pedrosa, N.Padilla, R. Dominguez, E. Sillero).

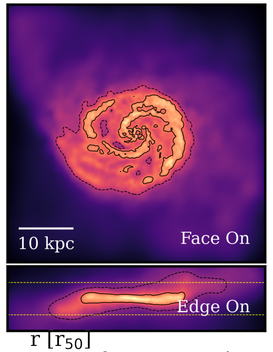
Zoom-in simulations:

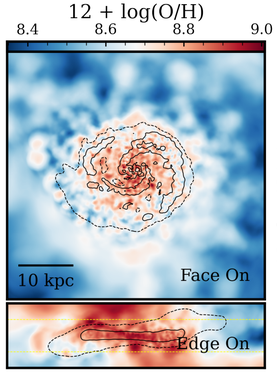
- **P-GADGET3**
- Multiphase model (Scannapieco+2006).
- **Star formation** model (based on the KS law).
- Metal-dependent cooling.
- **IMF**: Chabrier (Chabrier et al. 2003).
- **Chemical Evolution model** traces 12 elements. Includes **SN II** and **SN Ia** feedback (Mosconi+2001). New runs 22 elements + AGBs.
- See Rodriguez+2022, Cataldi+2023, Casanueva-Villavicenio+2024 for results of the CIELO Project.

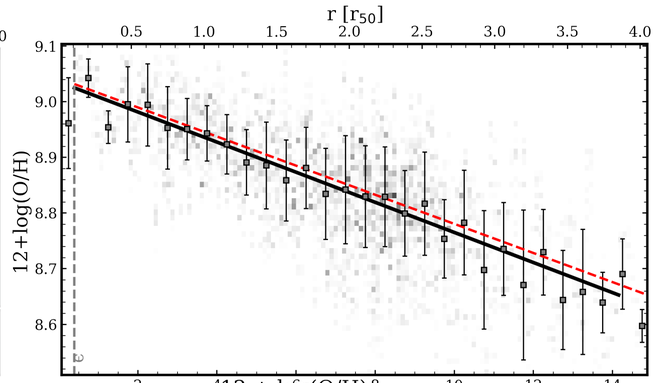
40 central galaxies: $10^{8.5}$-$10^{10.5}$ Mo

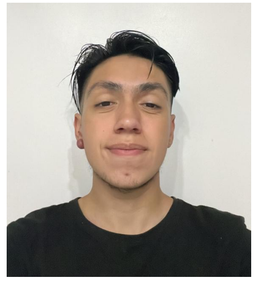
CIELO simulations



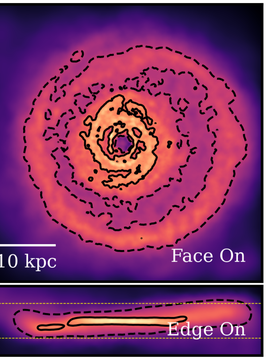


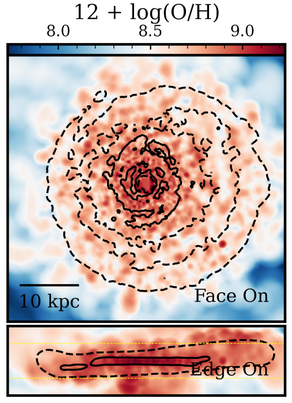


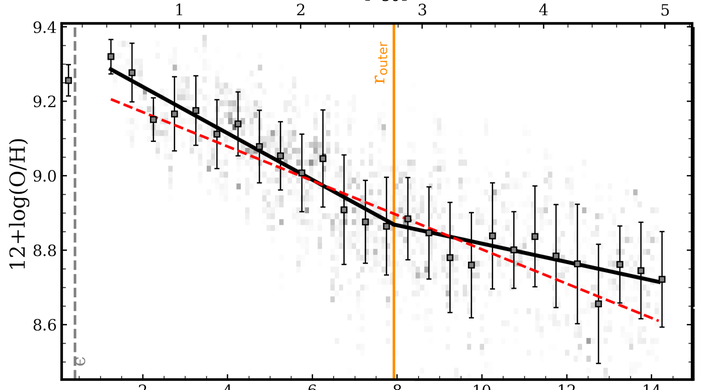


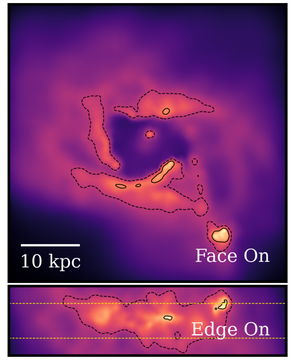


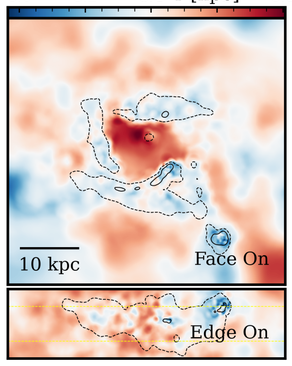
Brian Tapia

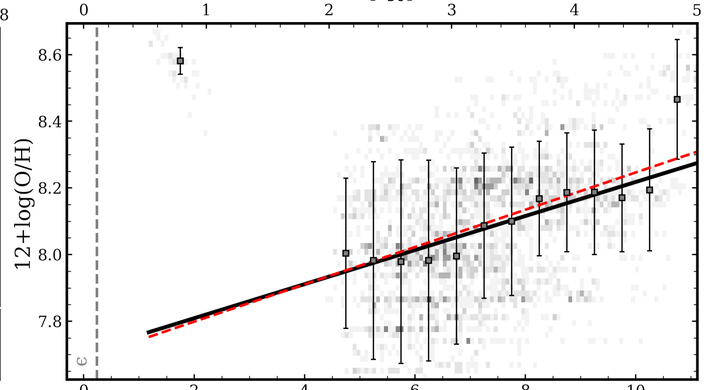


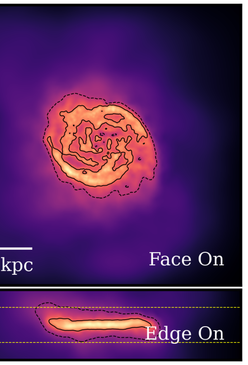


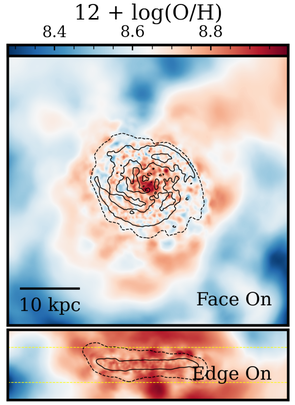


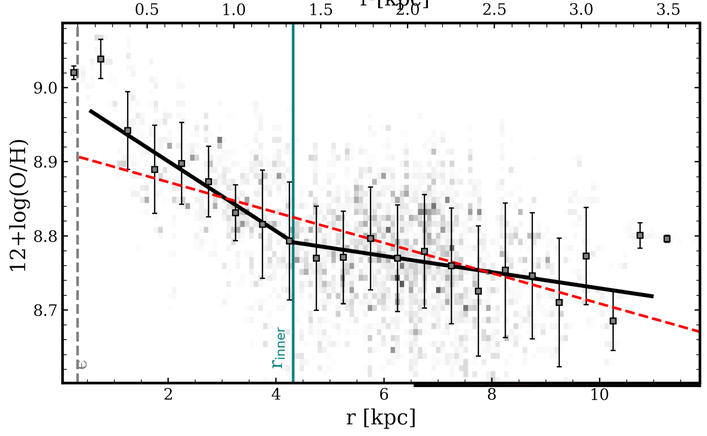


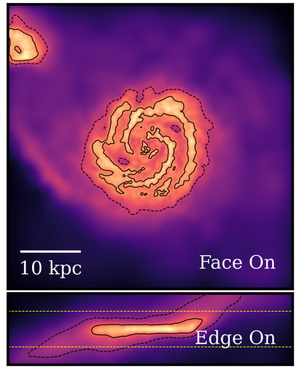


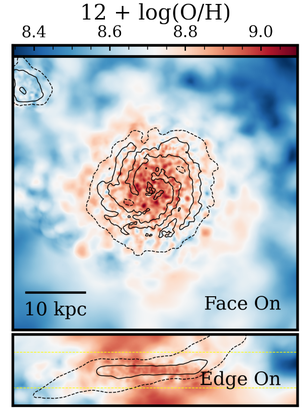


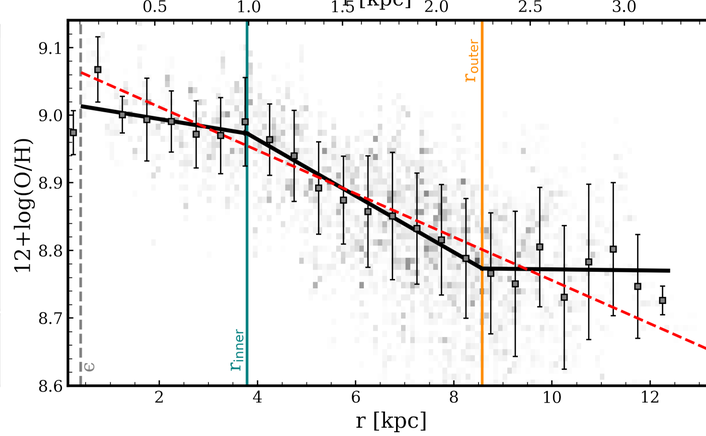












We search for the best quantification of the shape of the metallicity profiles.
At z=0, 33% linear, 41% outer-broken, 15% inner-broken, 10% double-broken profiles

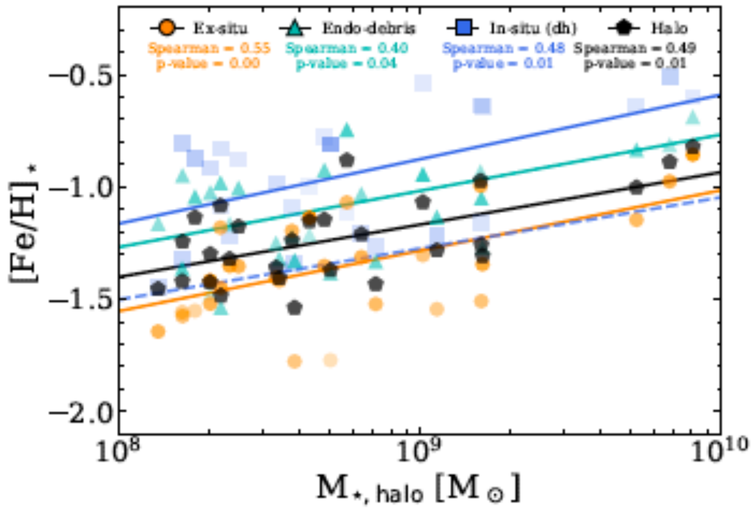
Chemical abundances to unveil formation channels In different galaxy components

Jenny Gonzalez-Jara

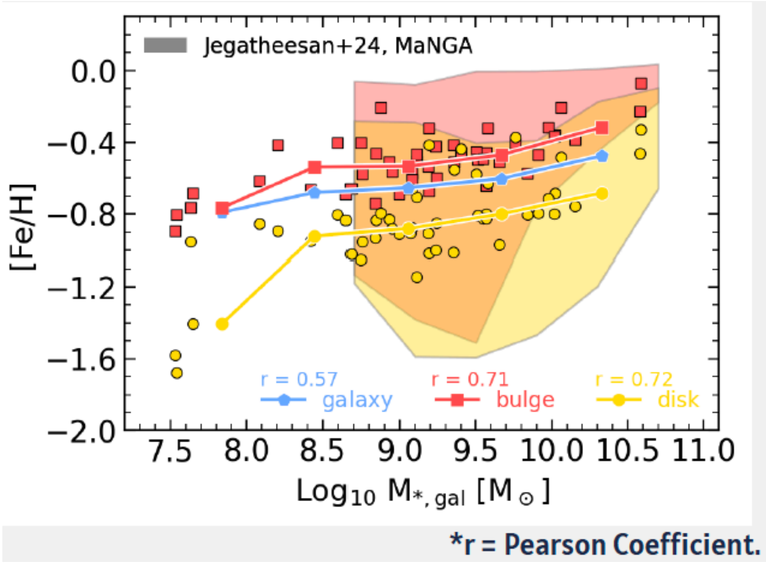
Ignacio Muñoz

Benjamin Silva

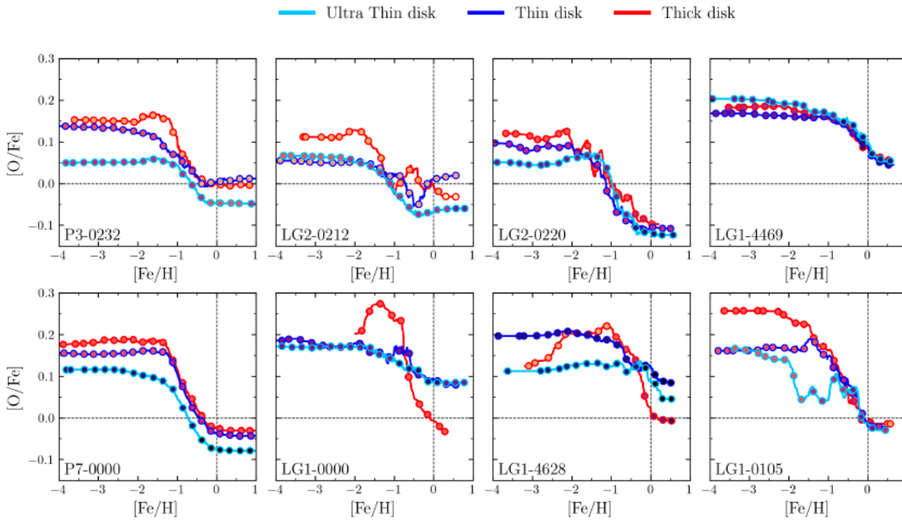
- Stellar haloes



- Bulges



- Stellar Discs



Simulated Galaxies with $M_* = [10^8, 10^{10.5}] M_\odot$ from the CIELO simulations

Conclusions

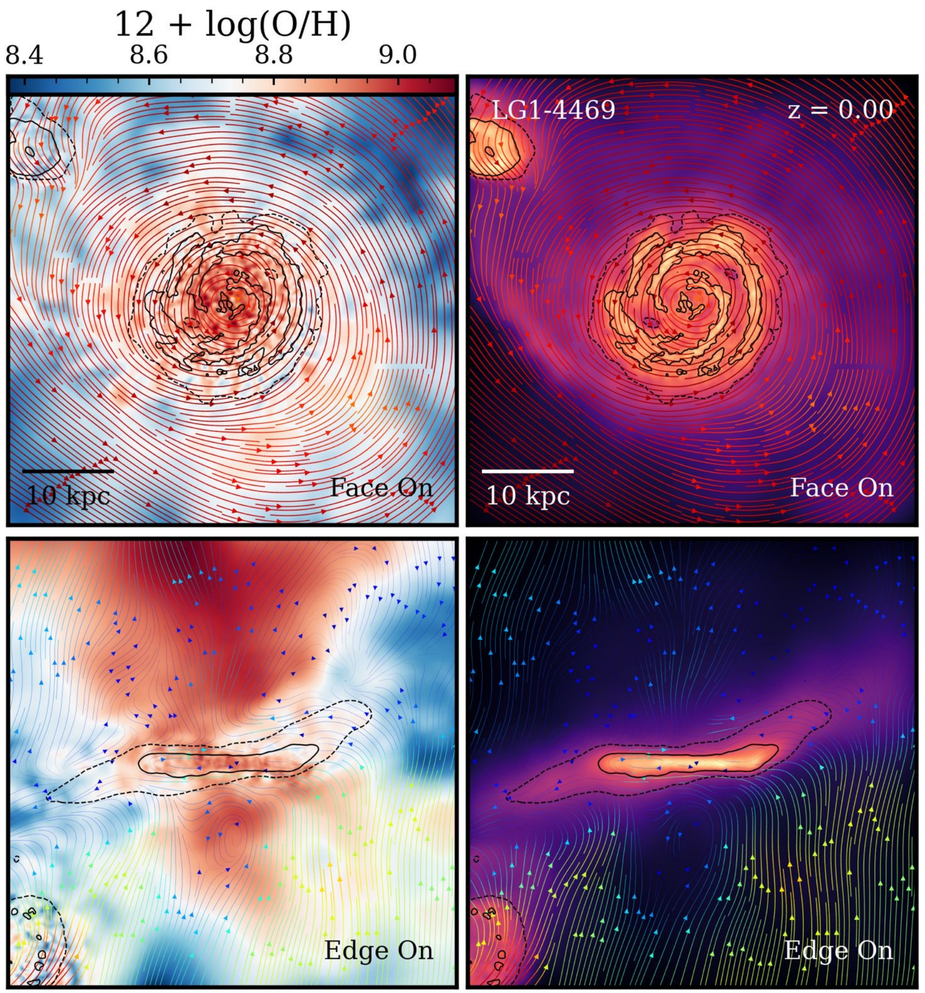
- Metallicity gradients of the star forming gas-phase are shaped by mergers, gas inflows, bars, and the environment.
- Gas-phase gradients reflect the state of the ISM within about 1-2 Gyr.
- At higher z, higher frequency of interactions, unstable gaseous discs, gas inflows, can explain higher frequency of inverted gradients and stronger negative gradients.
- Strong negative and strong positive metallicity gradients can be related to either strong accretion or galaxy interactions.

- Breaks are fingerprints of different physical rocesses, many of them highly coupled:

A. Bars and gas inflows
B. Different stages of evolution of galaxy interactions
C. Outflows
D. Galactic Fountains
E. Metal-rich/Metal-Poor Gas accretion from the CGM
F. Accreted material from companion or disrupted satellites

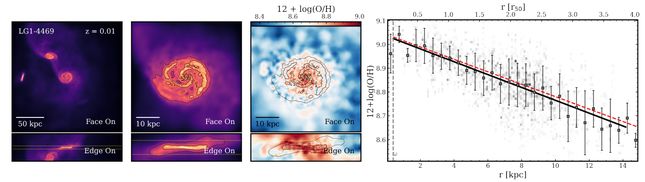
- **Are there fossil records imprinted in the chemical abundances of the stellar populations ?**

Future perspective

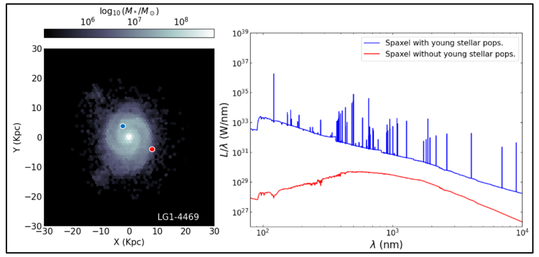


OBSERVATIONS

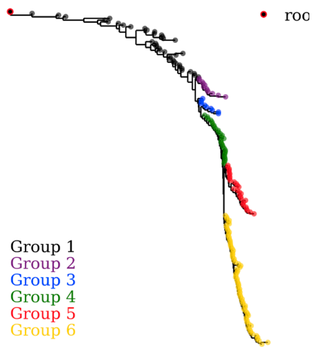
ESTIMATE OBSERVABLES

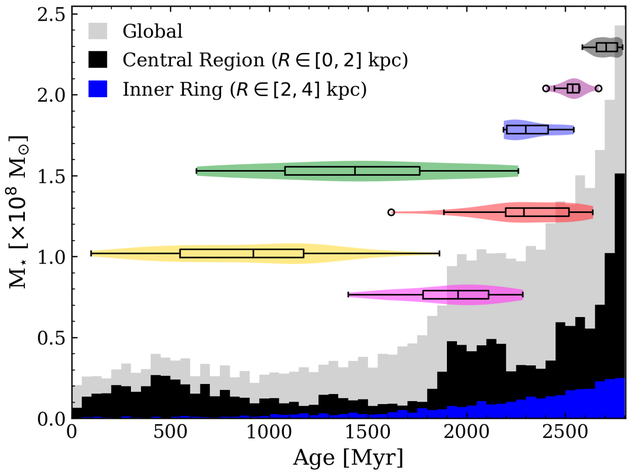


GENERATE SPECTRA
(e.g.Tissera+1997,
Nani+2022,Gang+2023,
Barrientos-Acevedo+2023;
Cornejo+2025)



GALACTIC PHYLOGENETICS





PJofre, B. Tapia, A.Rojas_Arriagada + ERIS collaboration