MetEvol

The Evolution of Metallicity in the Universe

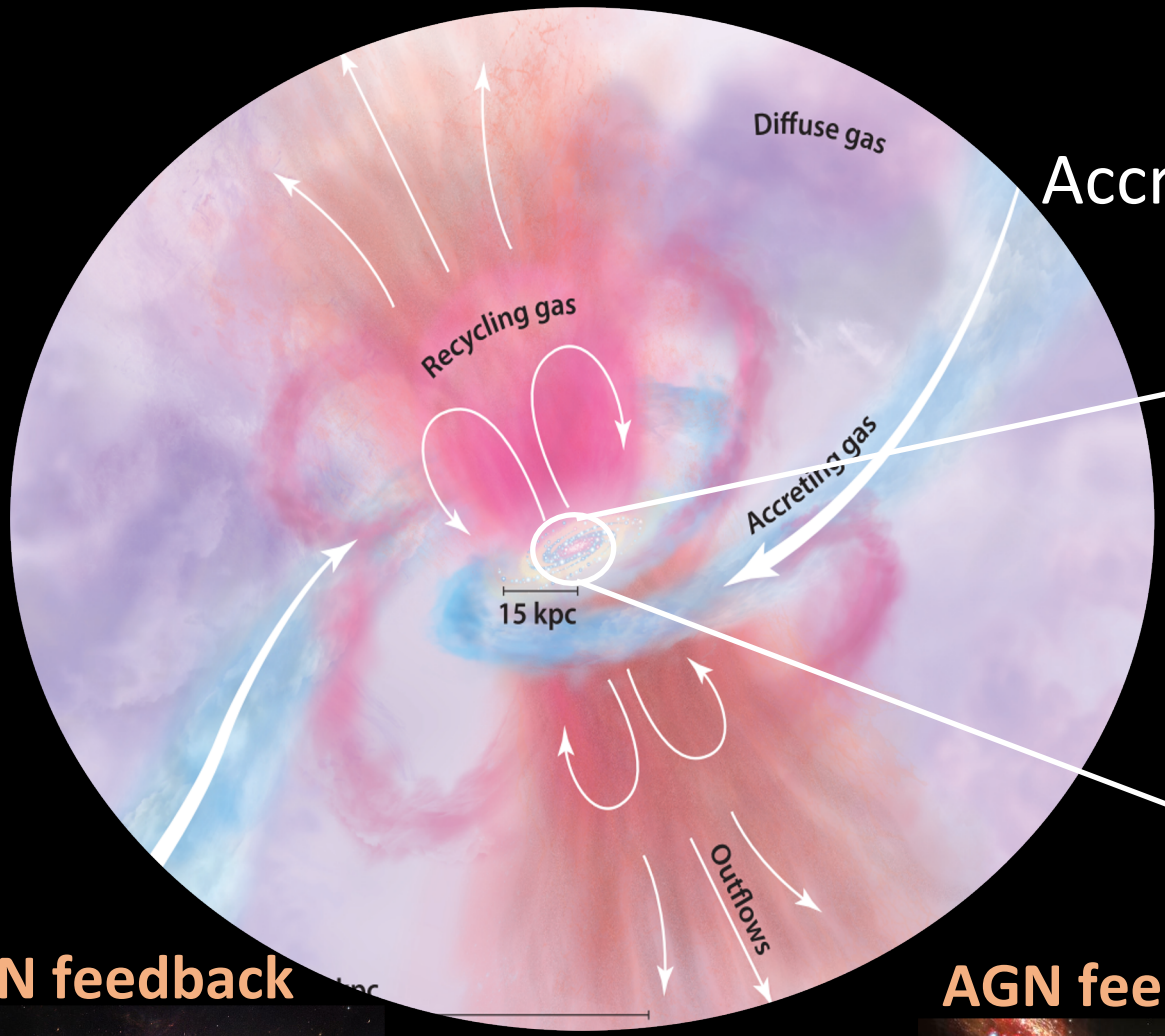
Coordinator: Filippo Mannucci

Presented by
Francesco Belfiore

INAF – Arcetri Astrophysical Observatory

INAF ISTITUTO NAZIONALE DI ASTROFISICA
OSSERVATORIO ASTROFISICO DI ARCET

Galaxies in their cosmic environment



Accretion

Outflows

SN feedback

AGN feedback

Cycling of matter in the ISM

H_2, GMCs

HII regions

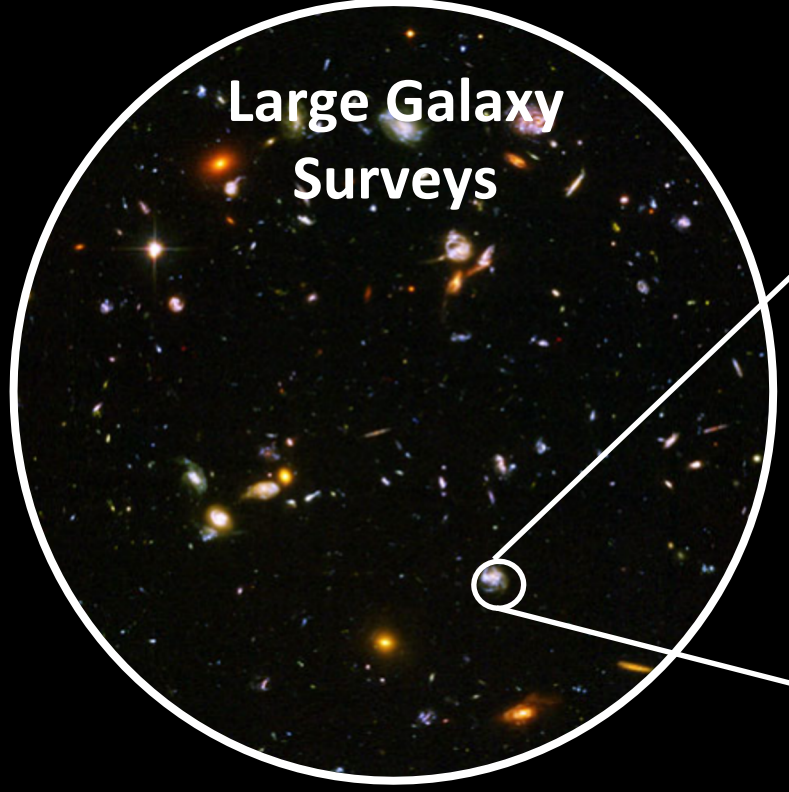
HI

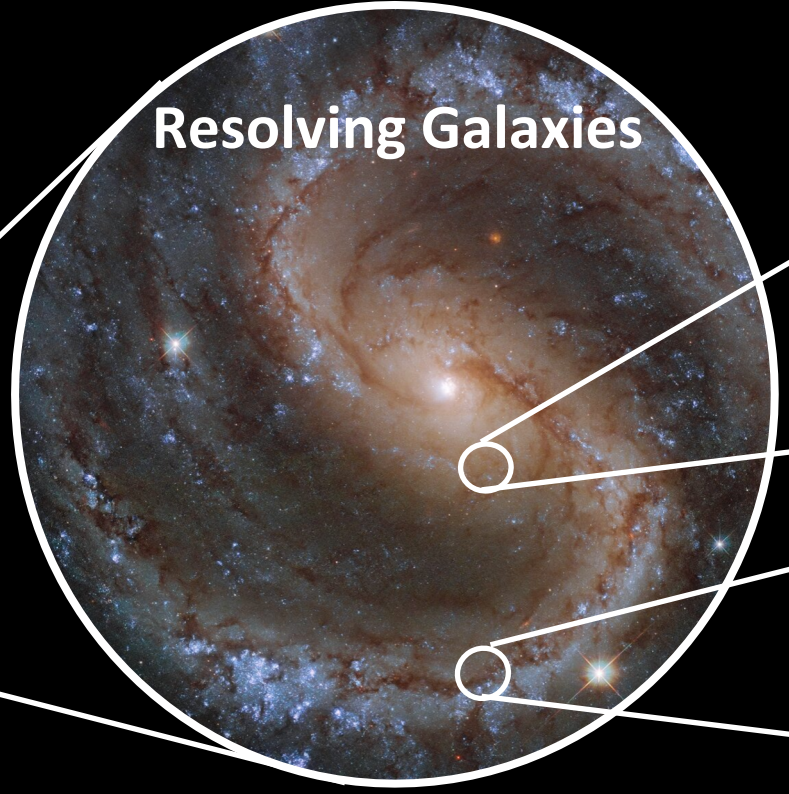
Ejecta

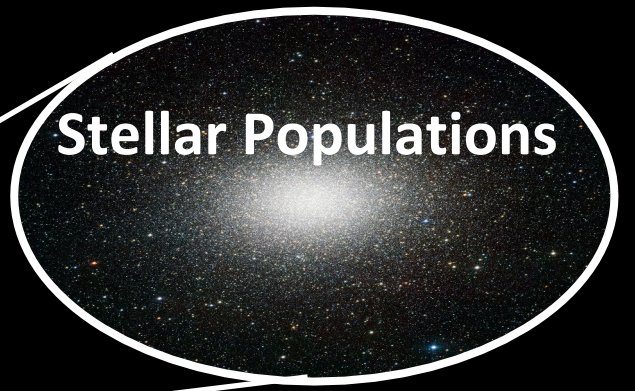
Star clusters

Our goal in one sentence:

Determine the chemical evolution history of the Universe







How and when did galaxies produce their metals?

Scaling relations between metallicity, SFR, $M_\star$, gas content, [O/Fe], environment, redshift evolution

How do discs grow?

Metallicity gradients, relation to dynamical support, inside-out growth, outflows

How do we measure metallicity?

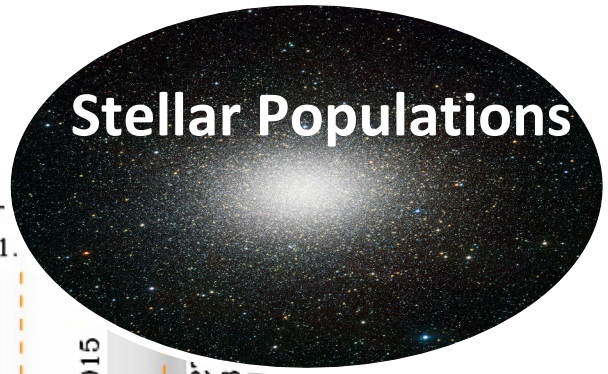
ISM: Metallicity calibrations, photoionisation models,
Stars: optical/UV absorption indices

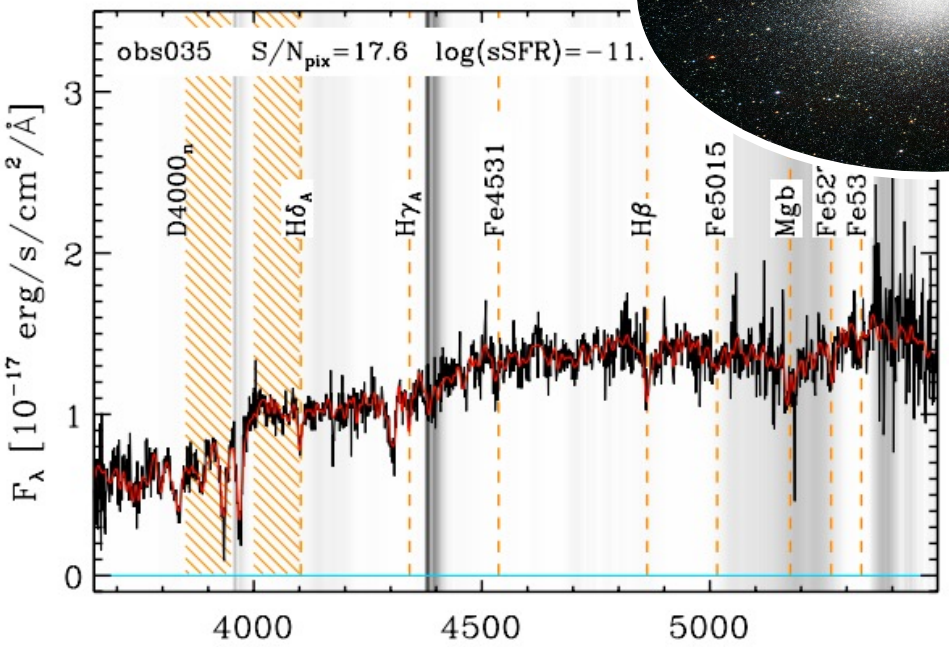
Key Results: How do we measure metallicity?

Deep Spectroscopy!

Stellar metallicities

Absorption lines in the Opt./UV,
New Bayesian modelling

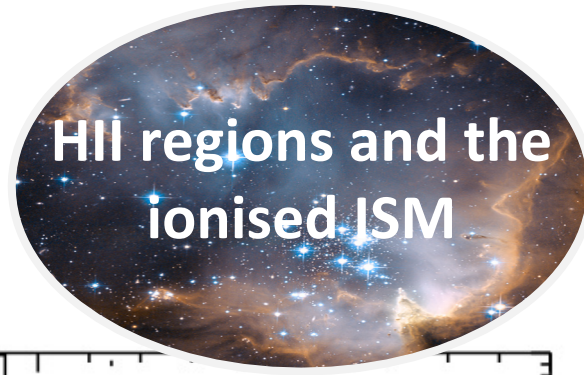


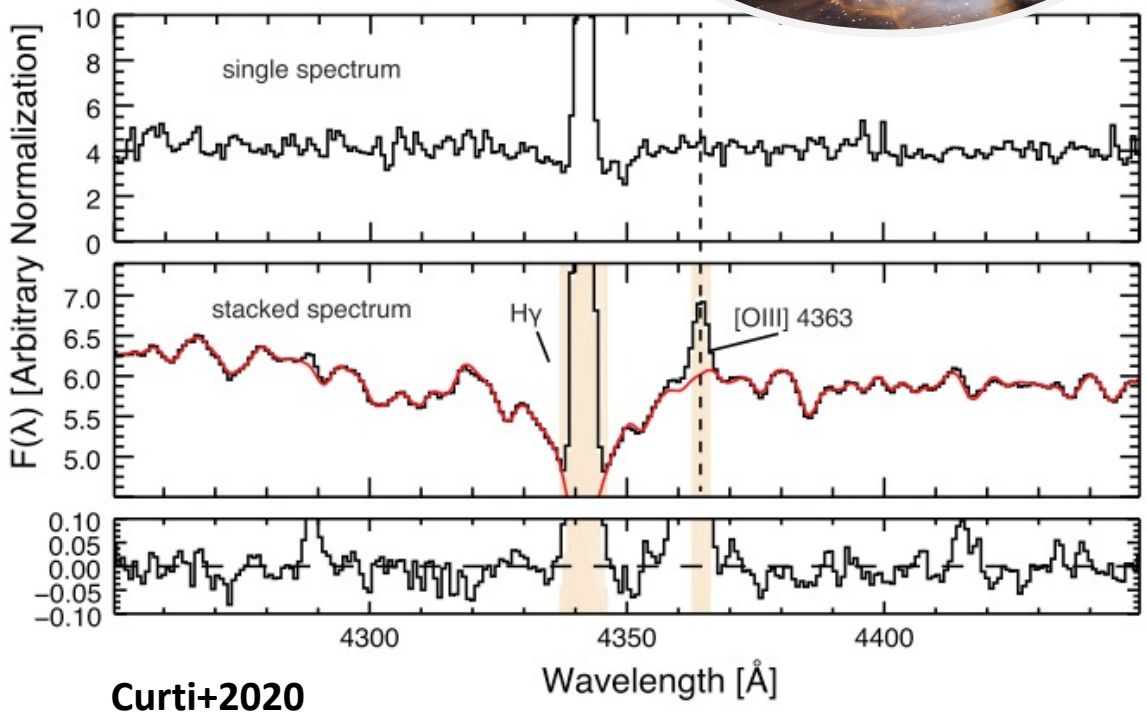


Gallazzi+2014

ISM metallicities

New calibrations,
Photoionsiation models,
Bayesian fitting



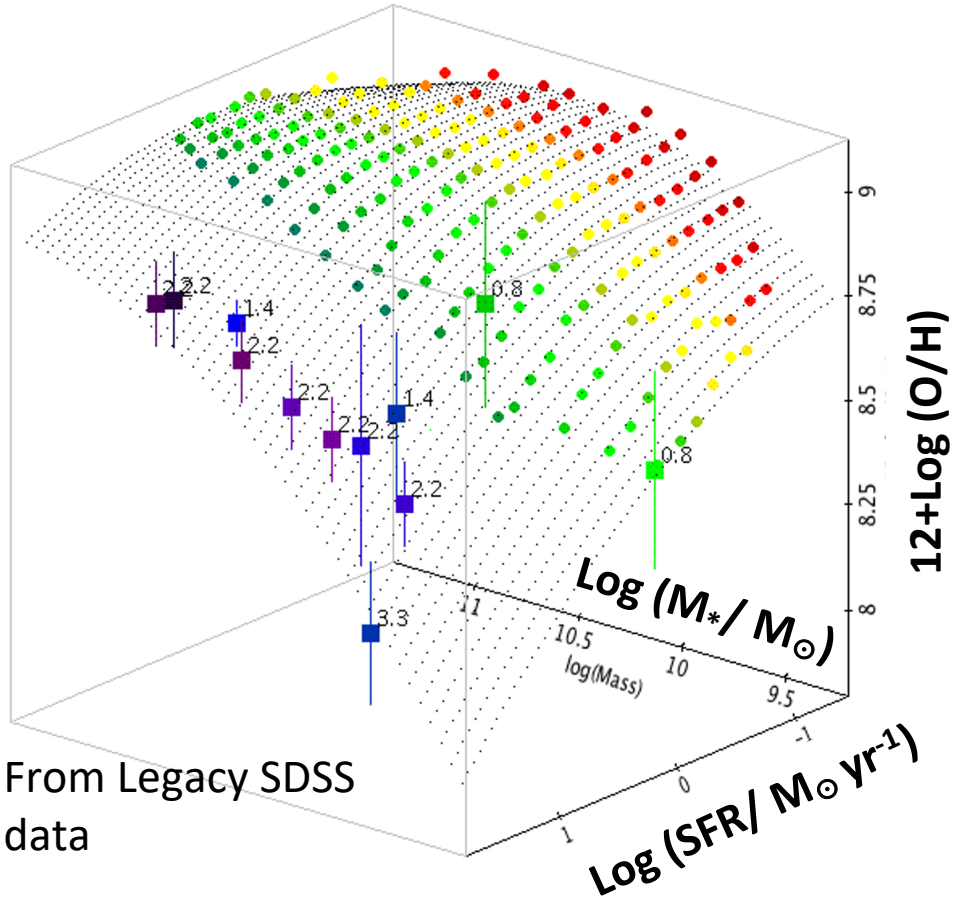


Curti+2020

Key links with:
GAUSP (Stellar populations, Zibetti)

Key Results: How and when did galaxies produce their metals?

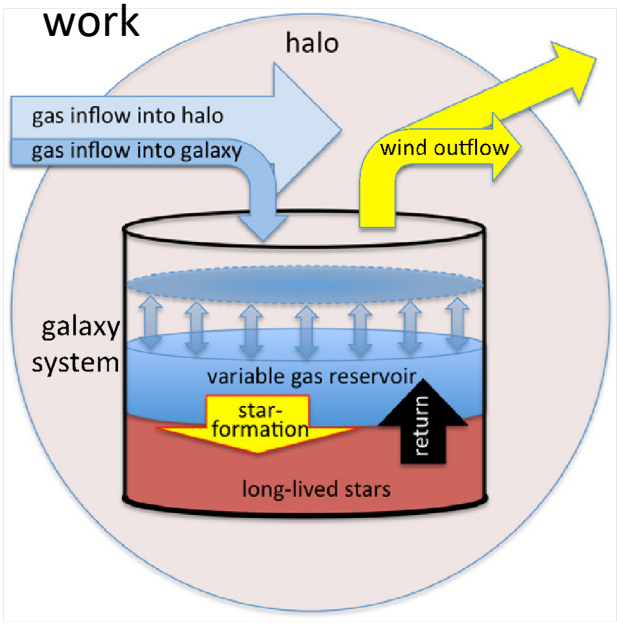
A 3D relation between log(O/H) – $M_\star$ – SFR:
The "fundamental metallicity relation"



From Legacy SDSS data

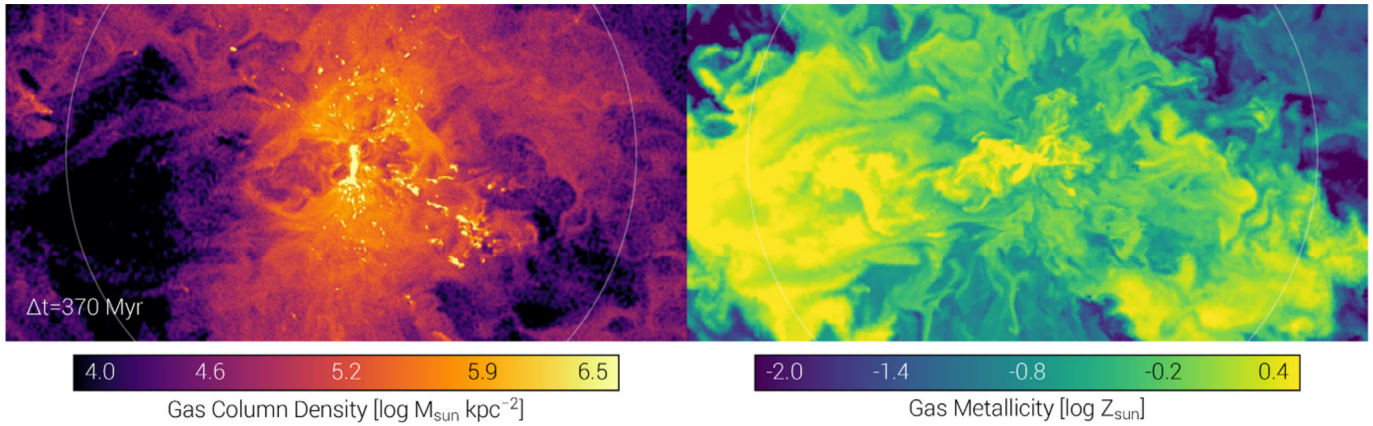
Mannucci+2010
Hunt+2016ab, Cresci+2019, Curti+2020

Extensive (semi)-analytical modelling work



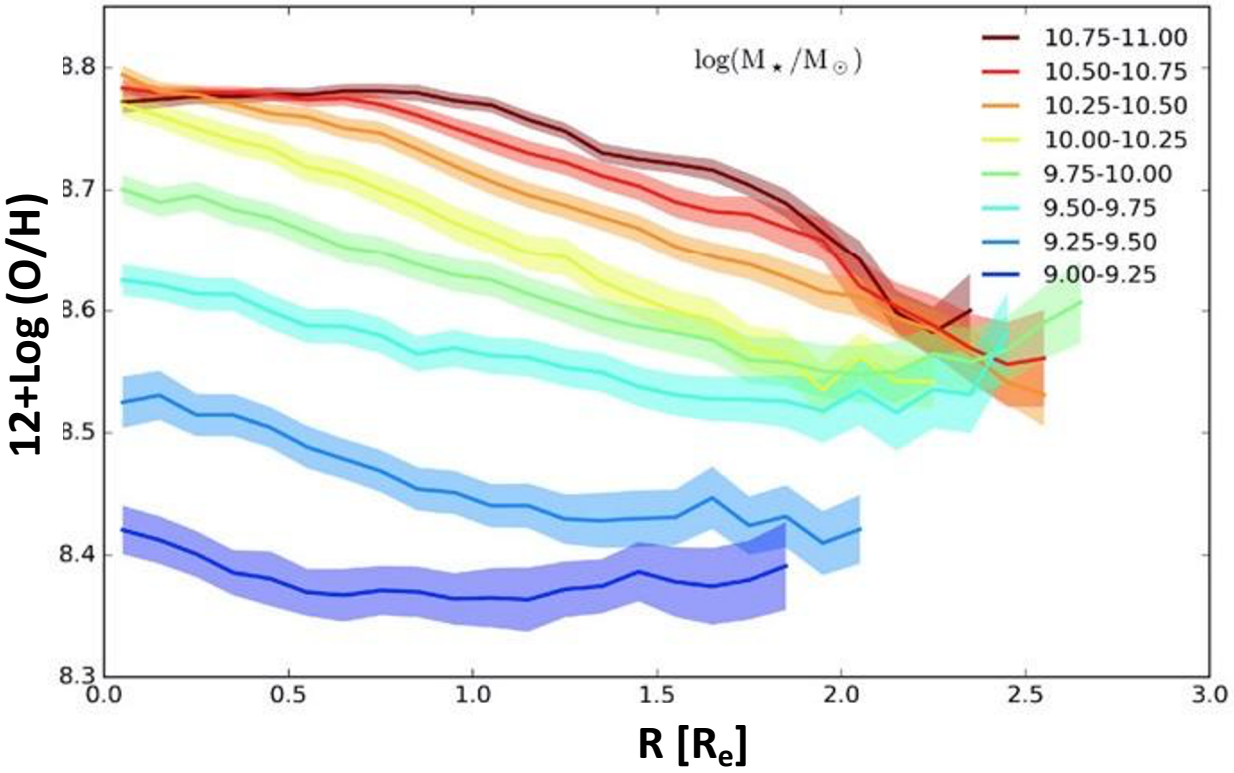
Key links with:
BaryonCycling
(Hunt)

… and in hydrodynamical simulations of galaxy formation and evolution



Key Results: How do discs grow?

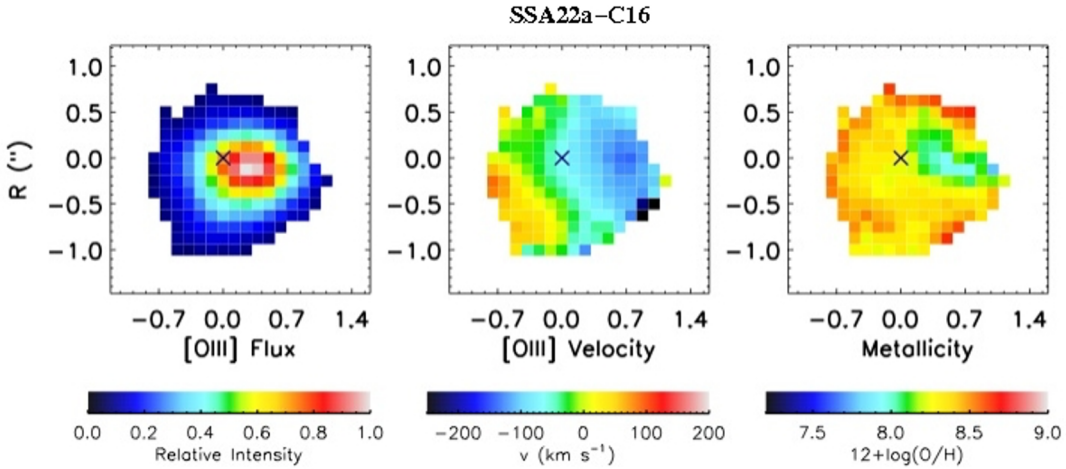
Metallicity gradients in star forming galaxies in the local Universe from large IFS surveys (SDSS IV, MaNGA)



Belfiore+2017

See also Belfiore+2019, Mingozzi+2020

Inverted metallicity gradients in high-redshift (z~2) galaxies



Cresci+2010

See also Curti+2020a

+ Metallicity gradients in Local Early Type galaxies

Zibetti+2020

Detailed studies of local galaxies/HII regions

PHANGS, DWARFS (PI: Belfiore, Cresci)

MUSE@VLT, ~20 galaxies, resolution <100 pc, Detailed physics of the ionised ISM/HII regions

Statistical study of z~0 galaxies at ~kpc resolution

z~1-2 galaxies at ~kpc resolution

KLEVER (following on AMAZE-LSD)

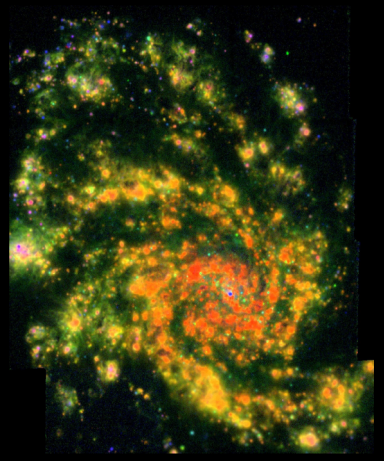
KMOS@VLT (seeing-limited), + SINFONI (AO), multi-band IR survey

Rest-frame UV metallicities

Key links with: BaryonCycling VANDELS, GAUSP

Lookback time

D < 20 Mpc | **z ~ 0.02** D ~ 100 Mpc | **z=0.6-1** 6-8 Gyr ago | **z =1.2-2.6** 9-11 Gyr ago | **z=2.0-5.0**



MaNGA, CALIFA

IFS for 10^3 -10^4 local galaxies, kpc resolution, ISM + stellar metallicities

LEGA-C (Survey Sci.: Gallazzi)

Deep opt. spectroscopy with VIMOS@ VLT of 3000 K-band selected galaxies, stellar metallicity

VANDELS (PI: Pentericci)

VIMOS @VLT optical (rest-frame UV) ultra-deep spectra, UV metallicity of young stars

INAF Leadership: A global Outlook

”The Californians”

e.g. Shapely (UCLA) & Steidel (Caltech),
High-redshift ISM (Keck MOSFIRE)
e.g. Kriek (UCB),
High-redshift stars

McLure (Edinburgh), VANDELS
McLeod (Durham), MUSE-DWARFS
Van der Wel (Ghent), LEGA-C
Maiolino (Cambridge), MaNGA, KLEVER, MOONS, JWST
Schinnerer (MPIA), PHANGS
Cirasuolo (ESO), KLEVER, MOONS

Sanchez (UNAM, Mexico)
Local Galaxies (CALIFA, MaNGA, SAMI)

MetEvol (INAF)

Belfiore, Calabrò, Castellano, Cresci, Corbelli, Feruglio, Gallazzi, Hunt, Longhetti, Mannucci, Marasco, Pentericci, Santini, Zibetti
+ 2 PhD students (Tozzi, Amiri)
+ associated staff/postdocs (Carniani, Curti, Marconi, Venturi)

>230 papers, >21K citations, h=72

”The Australians /Astro3D”
Local galaxies (SAMI)
High-redshift (Keck IFUs, MAVIS)
Photoionisation models

We believe our program is unique because it includes:

- **ISM + stars;**
- **Large surveys and detailed IFU studies;**
- **Low + high redshift**

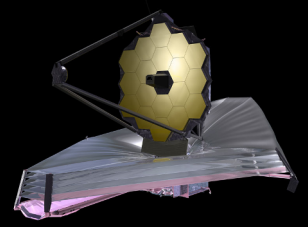
INAF Leadership: the near future

Key links with:
MOONS-VLT-0
ERIS
4MOST-StePS

MOONS

(WG Lead: Mannucci, Pentericci)

Multi-fibre (1000 fibres) IR spectroscopy @ VLT, 0.8 -1.5 µm,



JWST

(GTO: Cresci, Carniani, GO: Curti)

Unprecedented capability for ultra-deep near-IR (resolved/MOS) spectroscopy of high-redshift galaxies

The Local Universe → **Lookback time**

z = 0.3-0.7	z = 0.9-2.5	z ~1-2.5	z>2.5
3-6 Gyr ago	7-11 Gyr ago	9-11 Gyr ago	

WEAVE-Steps

(Core Team: Gallazzi, Zibetti, Longhetti)

Multi-fibre optical spectroscopy
1000 fibre @ WHT,
Upcoming **GTO**,
25000 galaxies with SNR=10

ERIS

(Science Team: Mannucci, Cresci, Longhetti)

AO-assisted IR IFU (upgrade of SINFONI) @VLT

VLT MOONS

MOS: 1000 fibers, 0.6-1.8µm

ISM Work Package Lead: Mannucci

200 GTO nights (coordinated galaxy survey)

- Systematic survey of galaxies 0.9<z<2.5
- ~100 K ISM metallicities
- ~10 K stellar metallicities

~SDSS @ z=1-2!

Science Teams:
Long-term Involvement

- Definition of science cases
- Top level requirements
- Management of tradeoff
- Instrument characterisation
- Definition of GTO
- Data reduction pipelines
- Commissioning

VLT ERIS

IFU+AO, 1-2.5 µm,
resol~50mas,
high sky coverage

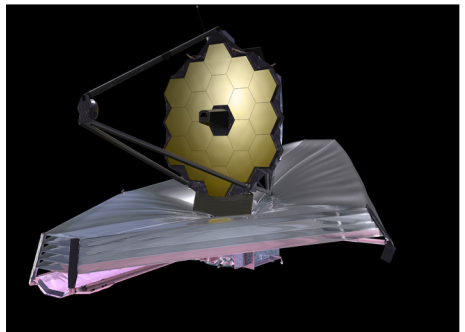
~60 GTO nights:

- Resolved ISM metallicities
- Feedback and baryonic flows

JWST

A GO program to measure accurate metallicities at Cosmic Noon (PI: Curti)

Our group was awarded the deepest JWST spectroscopic data in the entire cycle 1 (40hr integrations, sensitivity 10^{-19} erg/s/cm^2)



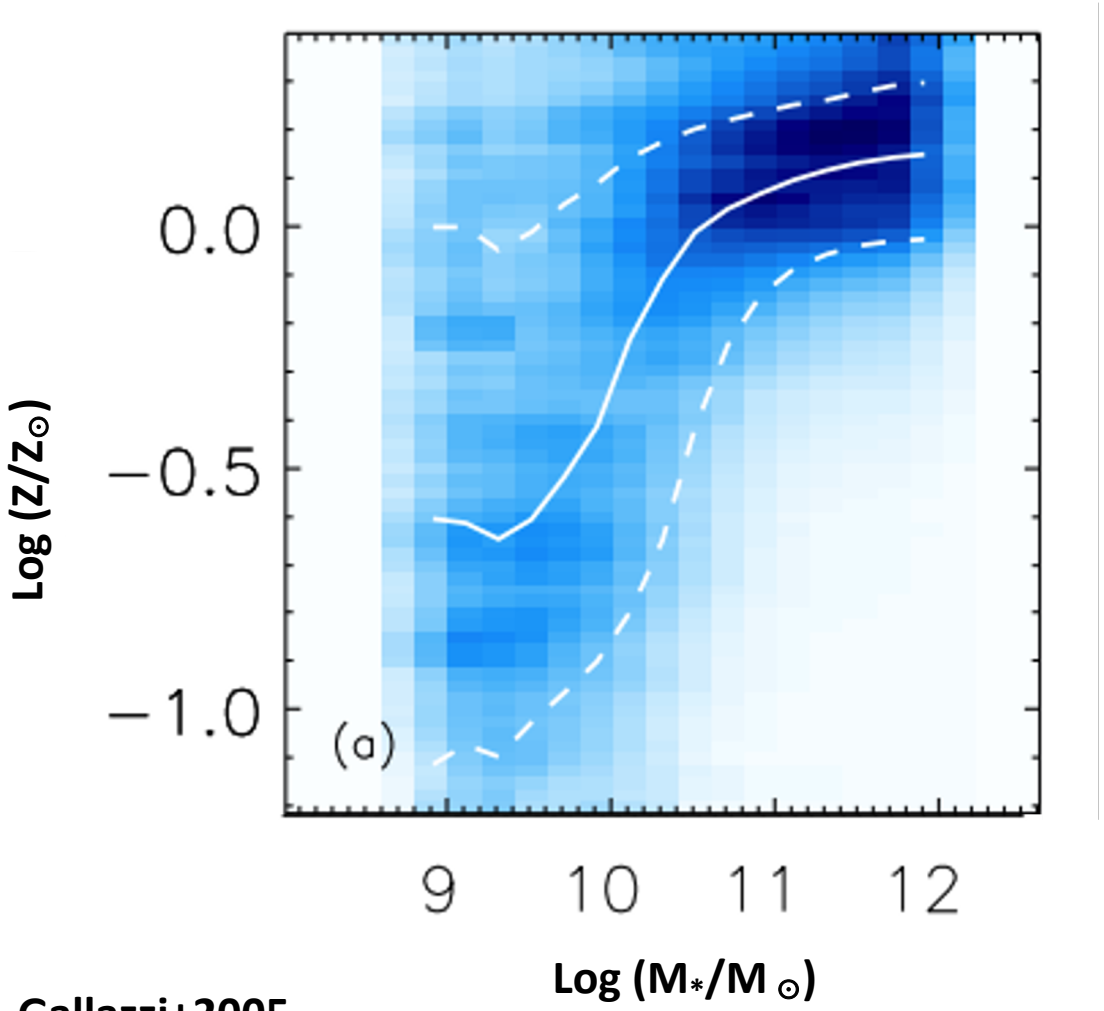
Near-IR MOS with the NIRSpec Multi-shutter array
40 hr in the G140H grism, 1-1.9 µm
55 – 60 galaxies between 1.6 <z< 3.16

MetEvol: Conclusions

- Our Program is well-placed on the world stage. We span expertise in: ISM + stellar metallicity, large surveys and resolved galaxies & low + high redshift.
- We have secured access to competitive world-class facilities (e.g. ESO, JWST)
- In the farther future, we are keen to exploit planned ELT instrumentation: HIRES, MOSAIC and MAVIS @ VLT
- INAF support to science teams of key instruments: it will be important to secure funding for science!

Key Results: How and when did galaxies produce their metals?

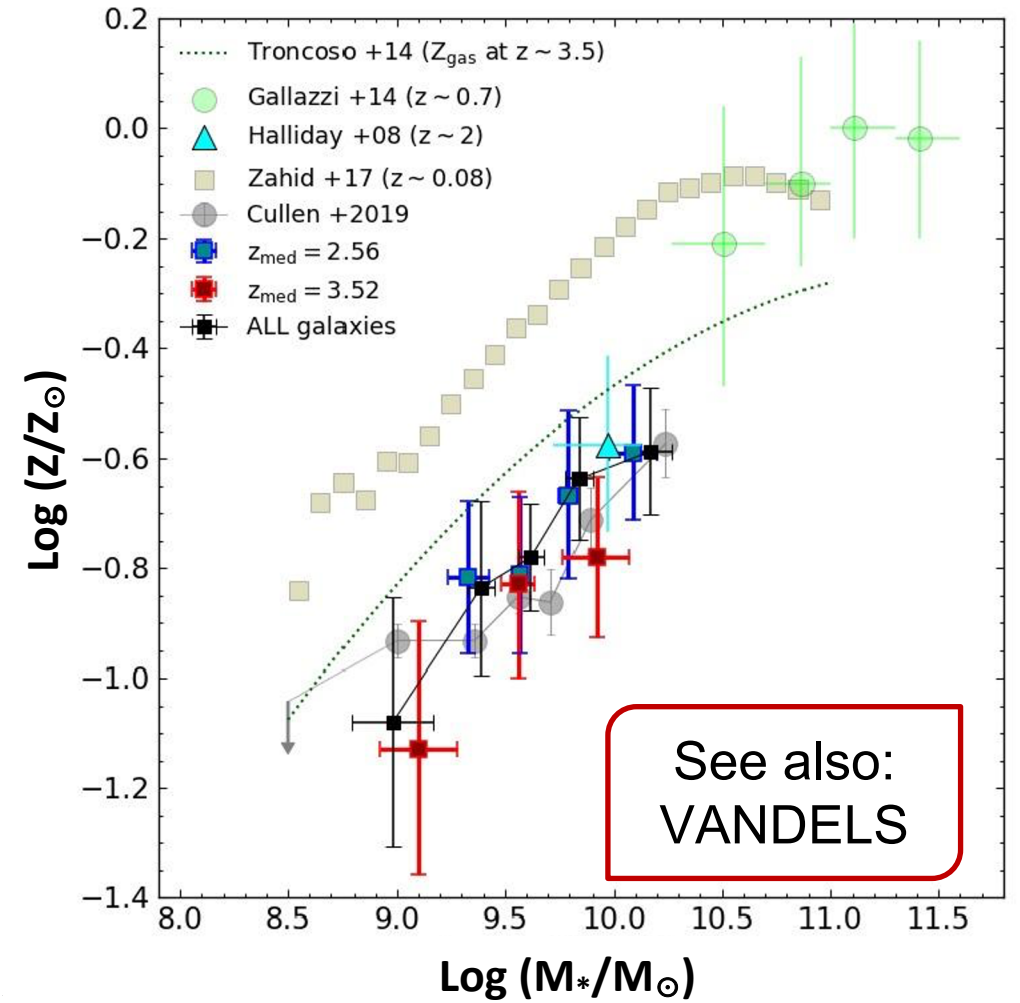
The Mass-stellar metallicity relation at z~0



Gallazzi+2005

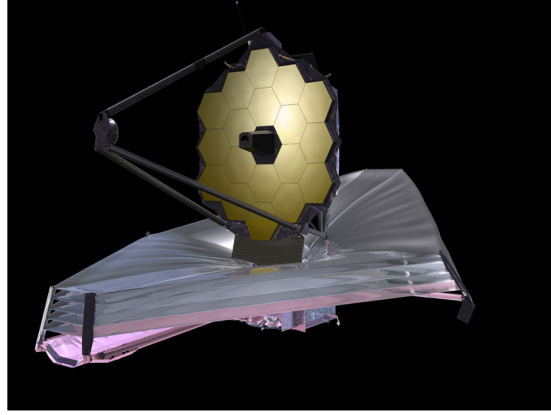
See also Gallazi 2014, Gallazi 2021

… and its redshift evolution



Calabrò+2021

JWST



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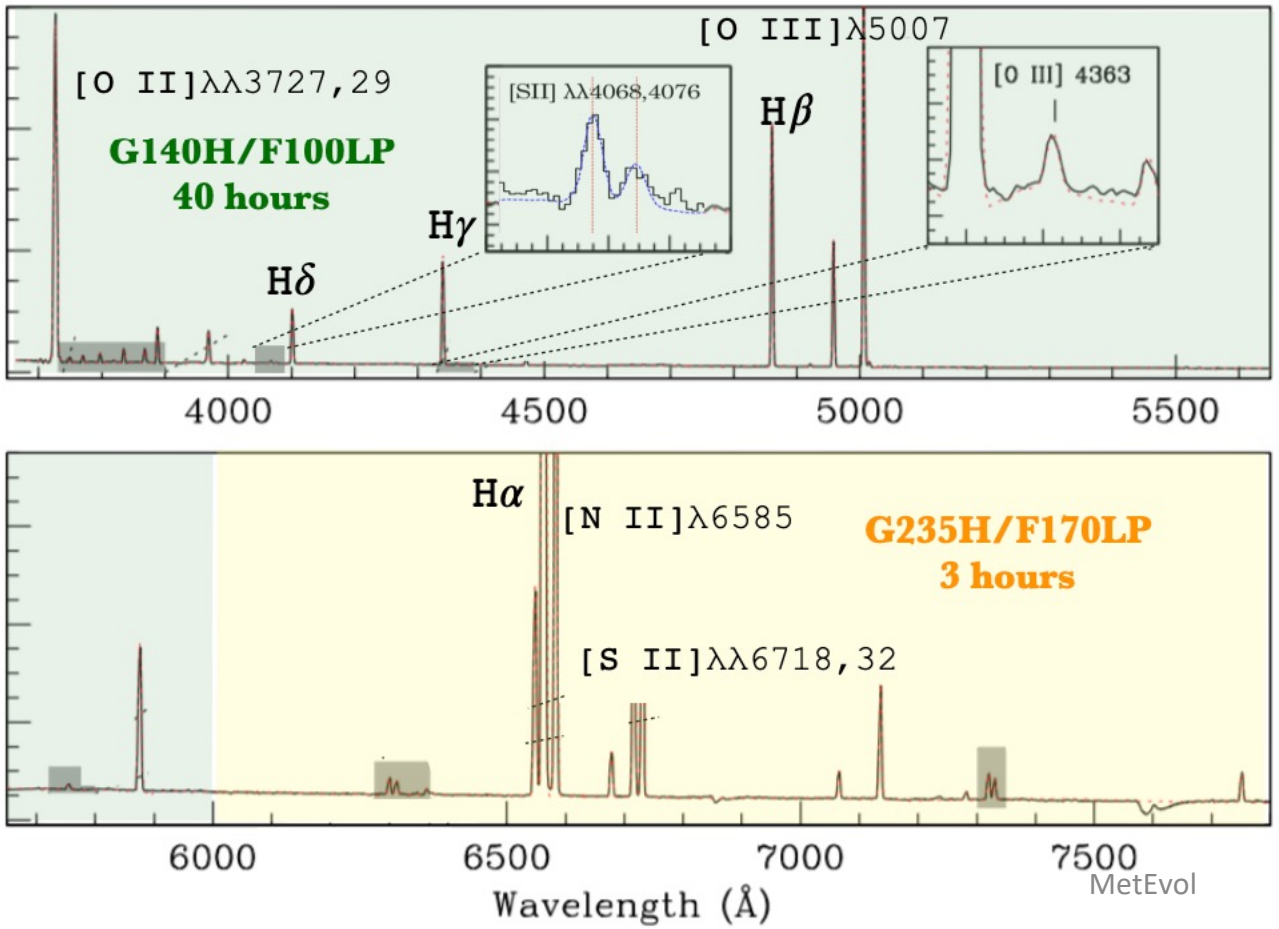
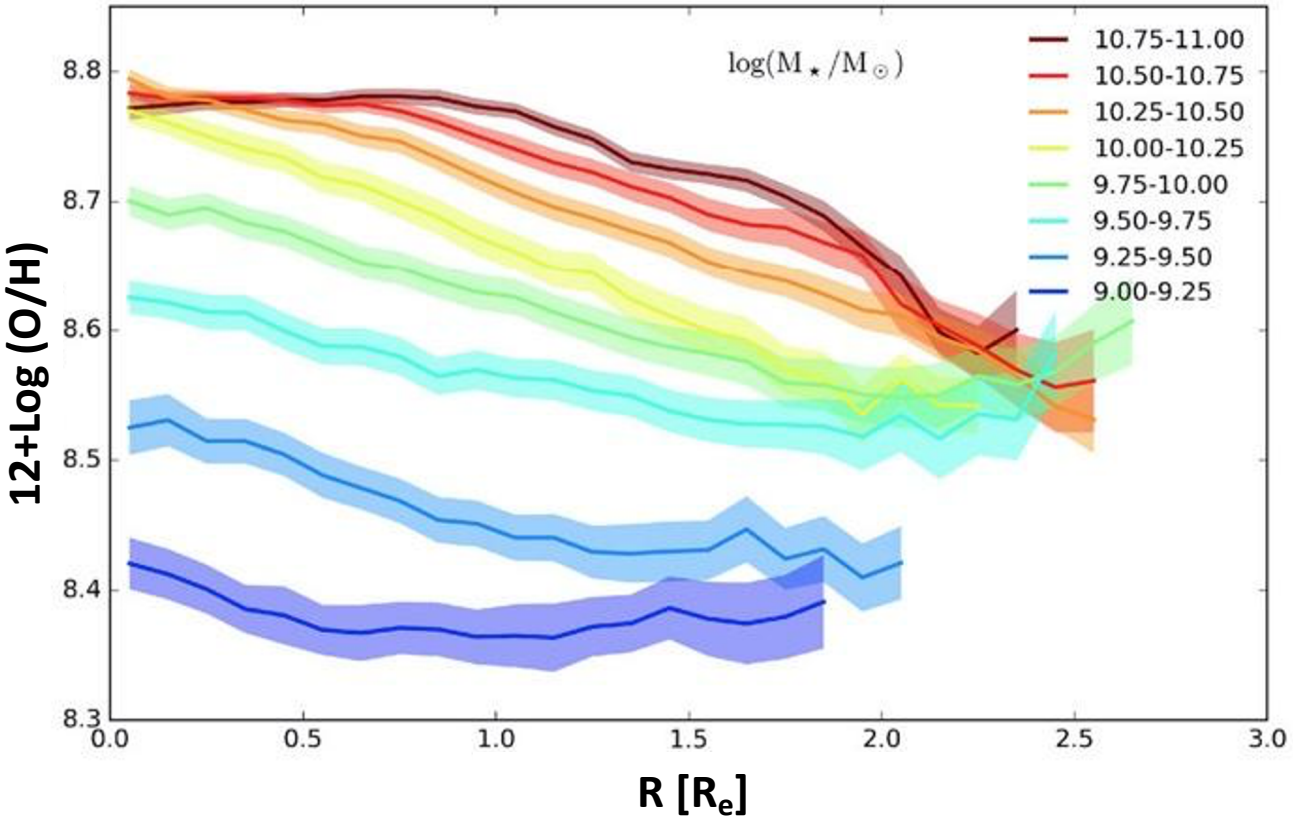


Near-IR MOS with the NIRSpec Multi-shutter array
40 hr in the G140H grism, 1-1.9 μm
55 – 60 galaxies between 1.6 <z< 3.16
Will detect weak temperature-sensitive lines (e.g. [OIII]4363) to determine accurate metallicities

+ We are involved in several ERS and GTO programs

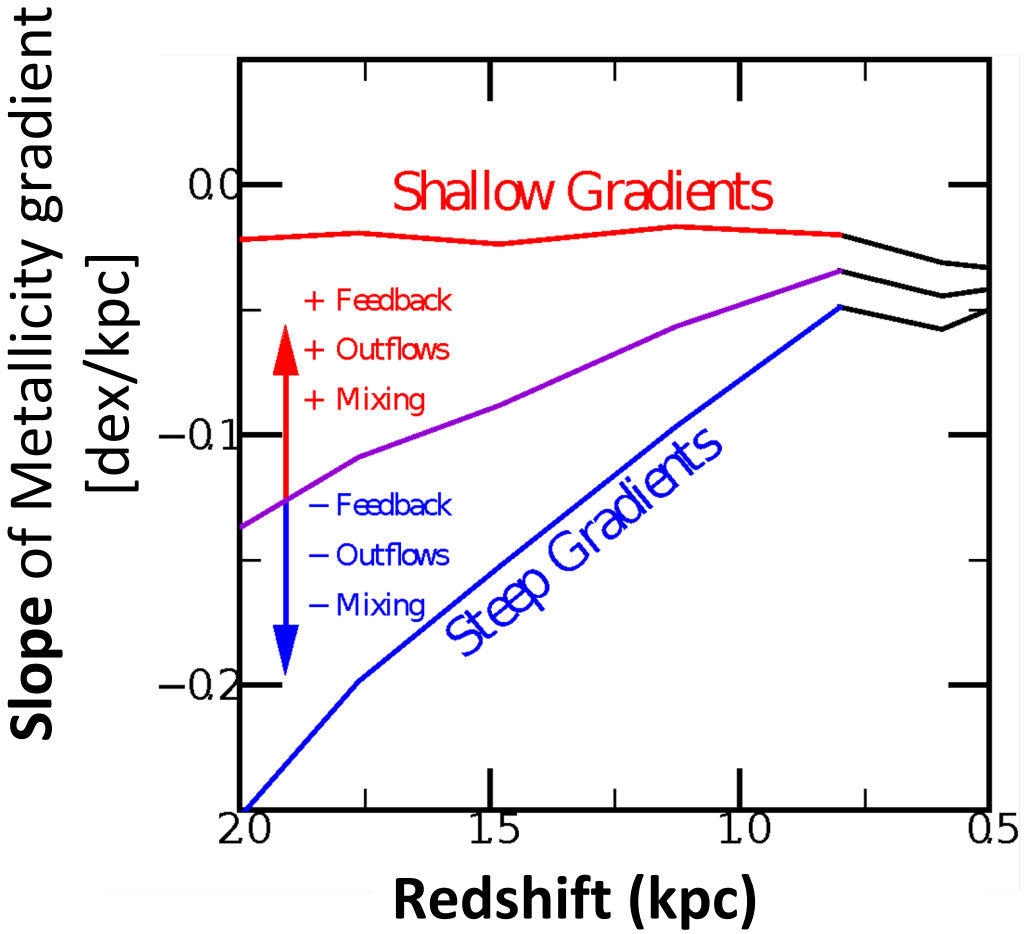
Key Results: How do discs grow?

Metallicity gradients in the local Universe from large IFS surveys (SDSS IV, MaNGA)



Belfiore+2017

See also Belfiore+2019, Mingozzi+2020



Maintaining leadership in an evolving landscape