Galaxy evolution during the last 7.5 Gy with VIPERS

Miguel Figueira Sebastião
Postdoctoral fellow

Odbiory - 16th December

Collaborators: Agnieszka Pollo
Katarzyna Małek
and the VIPERS team

Narodowe Centrum Badań Jądrowych
National Centre for Nuclear Research
ŚWIERK
JRC collaboration partner

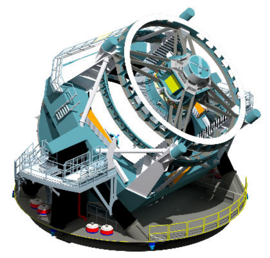
Summary

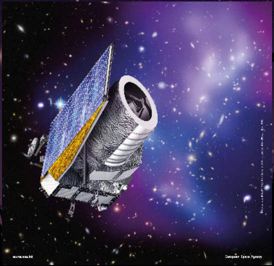
- *Introduction*
  1) The need for surveys and databases
  2) The VIPERS survey
- *Galaxy evolution with VIPERS*
  1) An overview
  2) A comparison of star formation rate calibrators [Figueira et al., 2022]
  3) The fundamental metallicity relation [Pistis et al., 2022]
- *Current work*
  1) Current studies with VIPERS
  2) Star formation in the Outer Galaxy
- *Conclusion*

Studying galaxy formation and evolution requires:

1) Statistically significant number of galaxies

- Sloan Digital Sky Survey: 230 million objects up to $z \sim 0.3 - 0.5$ (18 000 $\deg^2$ of the sky)
- Large Synoptic Survey Telescope: $\sim$15 millions galaxies up to $z \sim 2 - 3$ (18 000 $\deg^2$ of the sky)
- Euclid: $\sim$10 billion sources up to $z \sim 2$ (15 000 $\deg^2$ of the sky)





2) Observations at different wavelengths

- X-ray ⟹ Black hole/Active Galactic Nuclei/Supernovae
- Far-/Near-UltraViolet ⟹ Young high-mass stars
- Optical/Near-infrared ⟹ Stars
- Mid-infrared ⟹ Polycyclic Aromatic Hydrocarbon/Active Galacic Nuclei
- Far-infrared ⟹ Cold dust
- Radio ⟹ Free-free and synchrotron emission

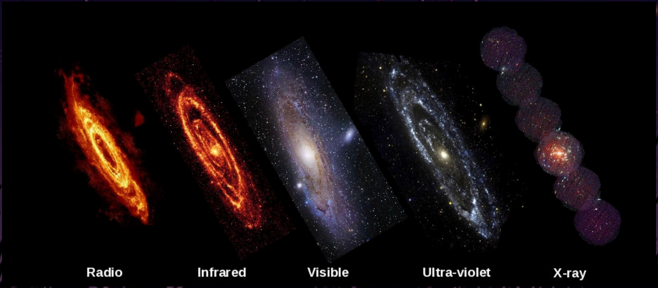


Figure: Andromeda Galaxy at different wavelengths (credits: WSRT/NASA/ESA)

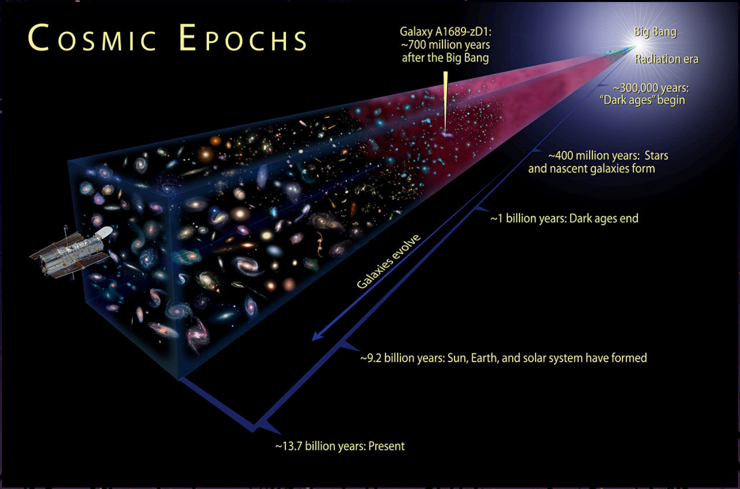


Figure: Evolution of the Universe (credits: NASA/ESA/STScI/A. Feild)

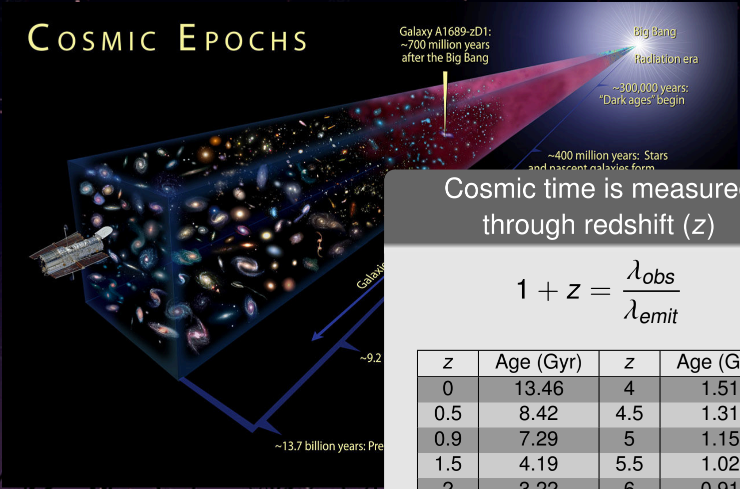


Figure: Evolution of the Universe (cr

Cosmic time is measured through redshift (z)

$$1 + z = \frac{\lambda_{obs}}{\lambda_{emit}} \qquad (1)$$

z	Age (Gyr)	z	Age (Gyr)
0	13.46	4	1.51
0.5	8.42	4.5	1.31
0.9	7.29	5	1.15
1.5	4.19	5.5	1.02
2	3.22	6	0.91
2.5	2.56	6.5	0.82
3	2.1	7	0.74
3.5	1.77	7.5	0.68

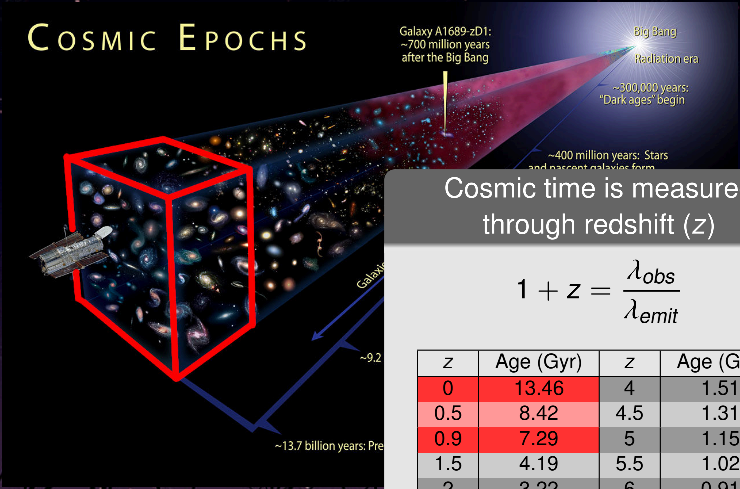


Figure: Evolution of the Universe (cr

Cosmic time is measured through redshift (z)

$$1 + z = \frac{\lambda_{obs}}{\lambda_{emit}} \quad (2)$$

z	Age (Gyr)	z	Age (Gyr)
0	13.46	4	1.51
0.5	8.42	4.5	1.31
0.9	7.29	5	1.15
1.5	4.19	5.5	1.02
2	3.22	6	0.91
2.5	2.56	6.5	0.82
3	2.1	7	0.74
3.5	1.77	7.5	0.68

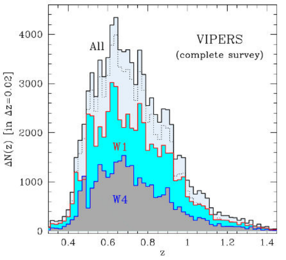
The VIMOS Public Extragalactic Redshift Survey

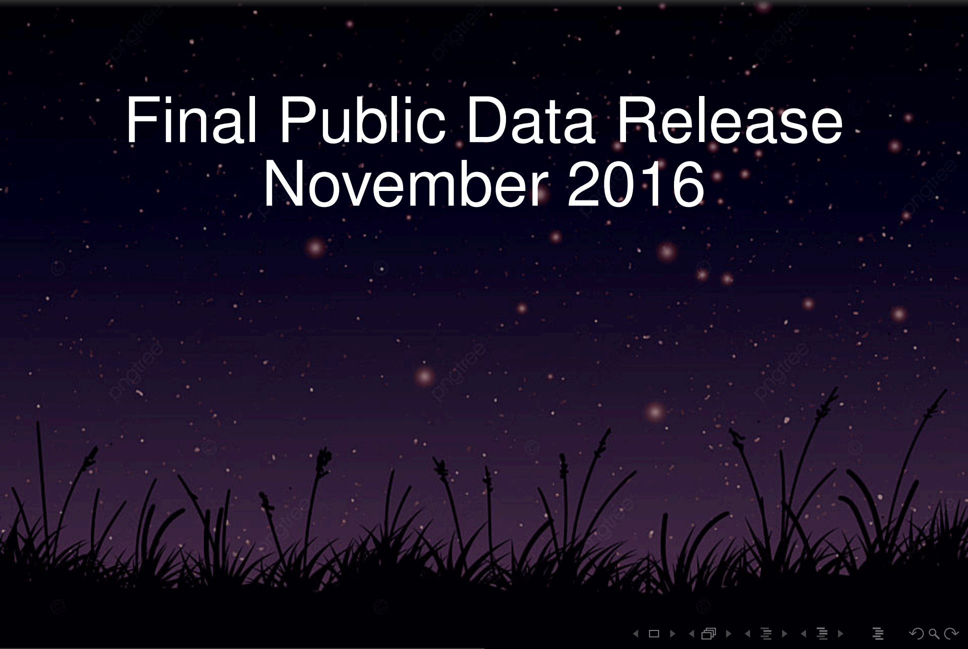
Guzzo and VIPERS Team [2013], Garilli et al. [2014], Scodeggio et al. [2018]

Spectroscopic survey of ~92 000 sources with $0.5 \leq z \leq 1.2$

- Counterpart of SDSS ($z \leq 0.3$) at intermediate redshift ($0.5 \leq z \leq 1.2$)
- Based on the Canada France Hawai Telescope Legacy Survey (fields W1 and W4)
- Color-color and magnitude selection to select galaxies in the range $0.5 < z < 1.2$ and stellar decontamination

Measured redshift	Number
All measured	91 507
Main survey, all targets	89 022
- Galaxies	86 775
- Stars, AGNs	2247
Good quality, all targets	78 586
Good quality, galaxies	76 552

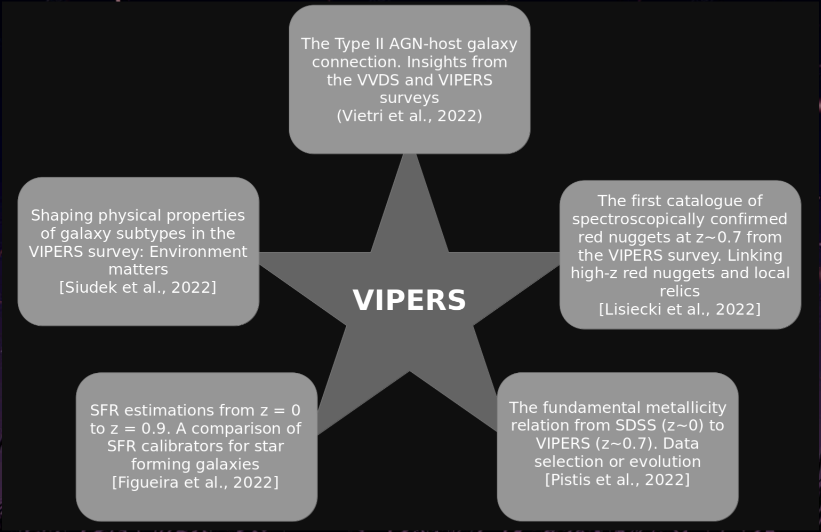




Final Public Data Release
November 2016

Final Public Data Release
November 2016

But galaxy evolution with VIPERS is still ongoing...


The Type II AGN-host galaxy connection. Insights from the VVDS and VIPERS surveys
(Vietri et al., 2022)
Shaping physical properties of galaxy subtypes in the VIPERS survey: Environment matters
[Siudek et al., 2022]
VIPERS
The first catalogue of spectroscopically confirmed red nuggets at z~0.7 from the VIPERS survey. Linking high-z red nuggets and local relics
[Lisiecki et al., 2022]
SFR estimations from z = 0 to z = 0.9. A comparison of SFR calibrators for star forming galaxies
[Figueira et al., 2022]
The fundamental metallicity relation from SDSS (z~0) to VIPERS (z~0.7). Data selection or evolution
[Pistis et al., 2022]

The Type II AGN-host galaxy connection. Insights from the VVDS and VIPERS surveys
(Vietri et al., 2022)

Shaping physical properties of galaxy subtypes in the VIPERS survey: Environment matters
[Siudek et al., 2022]

VIPERS

The first catalogue of spectroscopically confirmed red nuggets at z∼0.7 from the VIPERS survey. Linking high-z red nuggets and local relics
[Lisiecki et al., 2022]

SFR estimations from z = 0 to z = 0.9. A comparison of SFR calibrators for star forming galaxies
[Figueira et al., 2022]

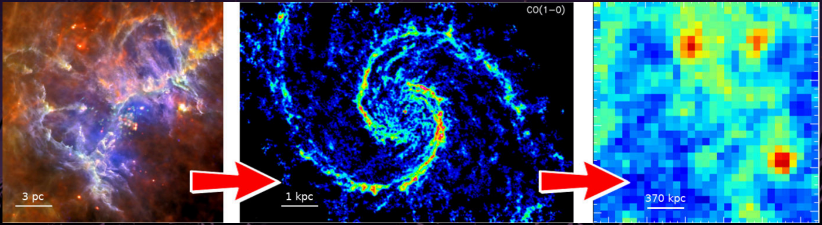
The fundamental metallicity relation from SDSS (z∼0) to VIPERS (z∼0.7). Data selection or evolution
[Pistis et al., 2022]

SFR estimations from z = 0 to z = 0.9. A comparison of SFR calibrators for star-forming galaxies [Figueira et al., 2022]

Star formation rate calibrators

Why do we need it?

- Formation and evolution of galaxies depend on the build-up of stellar mass throughout time (SFR in $M_\odot$ yr^{-1})
- More and more global surveys at higher redshift allow the study of SFR at different cosmic times (LSST, EUCLID, *JWST*, GAMA)
- SFR measurements over cosmic time gives us information about the galaxies at different epochs of the Universe



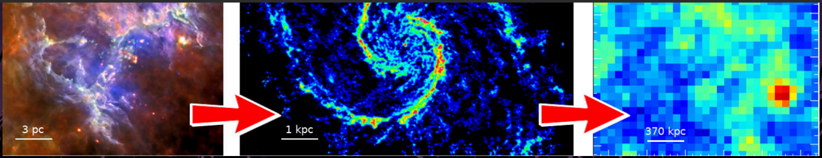
Star formation rate calibrators

Why do we need it?

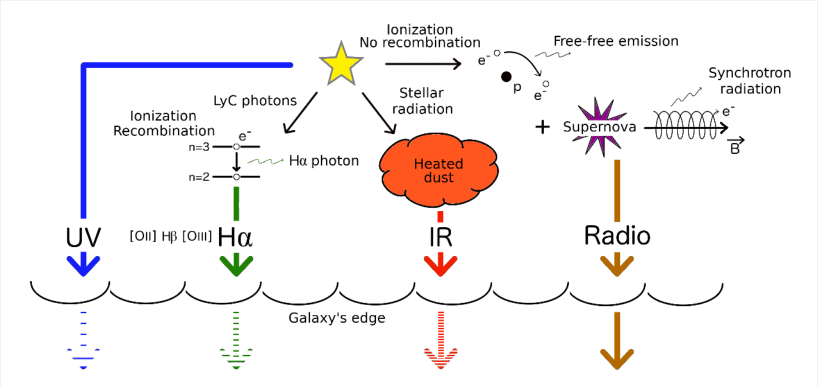
- Formation and evolution of galaxies depend on the build-up of stellar mass throughout time (SFR in $M_{\odot}$ yr^{-1})
- More and more global surveys at higher redshift allow the study of SFR at different cosmic times (LSST, EUCLID, *JWST*, GAMA)

Toolbox with several SFR indicators needed

for a large range of redshift



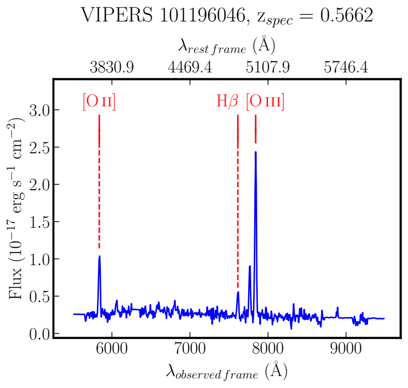
Continuum and spectroscopic bands tracing the SFR



Skąd wiadomo, ile gwiazd rodzi się w galaktyce? (Miguel Figueira, Delta, 01/11/21)

Above $z \sim 0.5$...

SFR from Hα commonly used to calibrate other bands.
At $0.5 \leq z \leq 0.9$, Hα is **shifted out** of the optical window

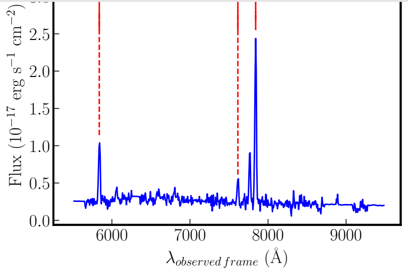


Above $z \sim 0.5$...

SFR from Hα commonly used to calibrate other bands.
At $0.5 \leq z \leq 0.9$, Hα is **shifted out** of the optical window

$$\textbf{SFR} = 7.9 \times 10^{-42} L(H\alpha)$$

$$\textbf{SFR} = A \times L(band)$$



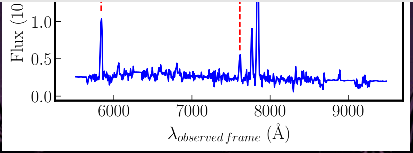
Above $z \sim 0.5$...

SFR from Hα commonly used to calibrate other bands.
At $0.5 \leq z \leq 0.9$, Hα is **shifted out** of the optical window

~~$$\mathbf{SFR} = 7.9 \times 10^{-42} L(H\alpha)$$~~

$$\mathbf{SFR} = A \times L(band)$$

How can we estimate the (true) SFR when Hα is not available?

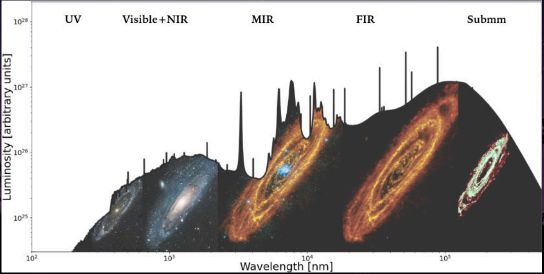


With CIGALE

Burgarella et al. [2005], Noll et al. [2009], Boquien et al. [2019]

Continuum and spectroscopic data

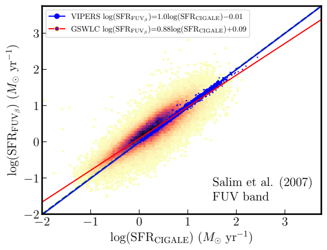
- CFHTLS ugriz K_s bands (optical/NIR part of the spectrum)
- Cross-correlation with GALEX (UV part of the spectrum)
- Cross-correlation with WISE, *Spitzer*, *Herschel* (IR part of the spectrum)
- Spectral lines: Hβ, [O II]λ3727, [O III]$\lambda\lambda$4959,5007

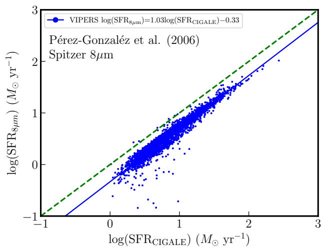


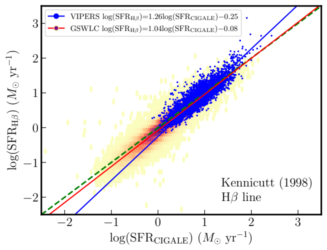
Credit: M. Hamed

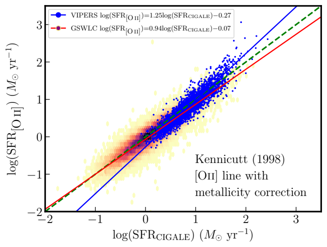
- Code Investigating GALaxy Emission (CIGALE) reconstructs the SED using the principle of energy-balance
- Estimation of SFR but also rest-frame luminosities, attenuation for each band, etc...

Comparison between CIGALE and calibrations









CCC = Pearson coefficient + Deviation from $y = x$

Reference (1)	Catalog – Band (2)	N (3)	m (4)	b (5)	Pearson (6)	Mean (7)	Scatter (8)	CCC (9)	CCC_{GV} (10)
FUV									
Brown et al. [2017]	V – (Calzetti)	3 457	1.21	−0.28	0.99	0.09	0.10	0.94	0.91
	G – (Calzetti)	91 533	0.95	−0.06	0.83	0.02	0.30	0.83	
	V – (Hao)	3 457	1.05	−0.04	0.99	0.01	0.05	0.99	0.94
	G – (Hao)	91 533	0.95	0.02	0.88	−0.02	0.25	0.88	

SFR calibrations at $0 \leq z \leq 0.9$

$$\log[\mathrm{SFR_{band}}\ (M_\odot\ \mathrm{yr}^{-1})] = A \times \log[L_{\mathrm{band}}(\mathrm{units})] + B$$

Rest-frame band	A	B	Luminosity range	Unit
FUV	1.04±0.01	−21.99±0.02	$2.1\times10^{19} < L < 4.7\times10^{23}$	$\mathrm{W\,Hz^{-1}}$
NUV	1.03±0.01	−21.81±0.01	$3.9\times10^{19} < L < 4.3\times10^{23}$	$\mathrm{W\,Hz^{-1}}$
u-band	1.11±0.0	−23.62±0.01	$8.3\times10^{19} < L < 4.5\times10^{23}$	$\mathrm{W\,Hz^{-1}}$
8 μm	0.85±0.01	−18.53±0.14	$3.9\times10^{21} < L < 4.4\times10^{24}$	$\mathrm{W\,Hz^{-1}}$
24 μm	0.81±0.0	−18.22±0.01	$7.3\times10^{20} < L < 2.6\times10^{25}$	$\mathrm{W\,Hz^{-1}}$
L_{TIR}	0.99±0.01	−9.97±0.03	$3.7\times10^{8} < L < 4.8\times10^{12}$	$L_\odot$
Hβ	0.94±0.01	−38.34±0.04	$9.3\times10^{38} < L < 1.0\times10^{44}$	$\mathrm{erg\,s^{-1}}$
[O II]λ3727	0.96±0.01	−39.69±0.07	$6.4\times10^{39} < L < 1.1\times10^{44}$	$\mathrm{erg\,s^{-1}}$
[O III]λ5007	0.89±0.01	−35.94±0.35	$4.4\times10^{38} < L < 6.1\times10^{43}$	$\mathrm{erg\,s^{-1}}$

The fundamental metallicity relation from SDSS (z∼0) to VIPERS (z∼0.7). Data selection or evolution? [Pistis et al., 2022]

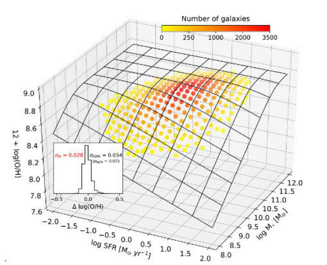
The fundamental metallicity (FMR) relation

- Relation between SFR, stellar mass (M_*) and metallicity (Z)
- It relates the chemical evolution (Z) to M_* and SFR, M_* as a proxy of the dark matter halos and SFR as a proxy of the galactic inflows/outflows
- It may be fundamental (no evolution of the shape up to $z \sim 2.5$)

Goal of the paper

How these different characteristics impact the FMR?

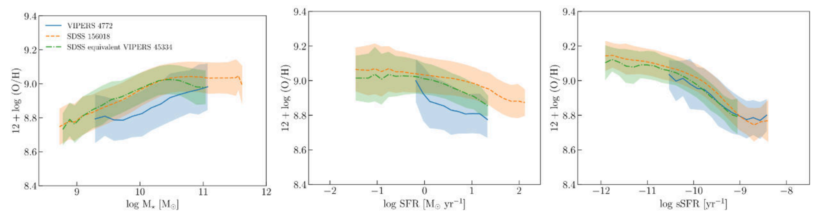
- Different intrinsic signal to noise
- Quality of spectra
- Different volume in the B−B∗ space
- Different fraction of observed blue galaxies



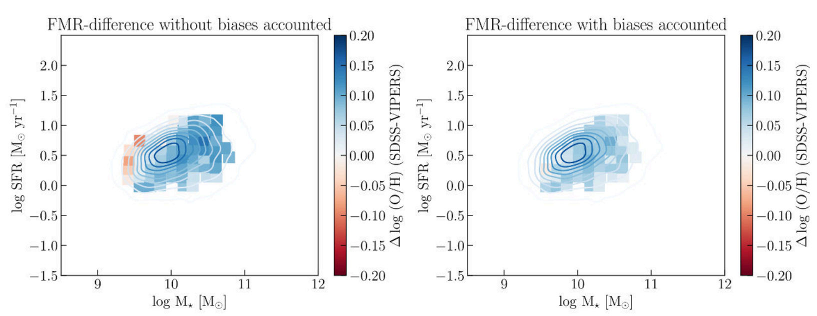
Source: Curti et al., 2020

Using the VIPERS and SDSS, we perform a comparison between:

- VIPERS sample
- SDSS sample
- SDSS sample with characteristic of the VIPERS survey



$\Longrightarrow$ Biases considered have negligible impact on the projections



$\Longrightarrow$ Biases decrease the difference mainly at high $M*$ and SFR. The median difference is ~0.08 dex, and ~0.06 dex, with and without accounting biases, respectively.

Current work
VIPERS/Milky Way

Current work with VIPERS

$\Longrightarrow$ **Environmental impact on the mass-size relation at** $z \sim 0.7$ (*Figueira et al. in prep*)

- No significant environmental impact on mass-size but also on other physical parameters (SFR, sSFR, n, D_n4000)

$\Longrightarrow$ **The fundamental metallicity relation from the perspective of methodology and galaxy evolution** (*Pistis et al. in prep*)

- No footprints from galaxy evolution and environment on the metallicity relation. Therefore, this relation may be fundamental.

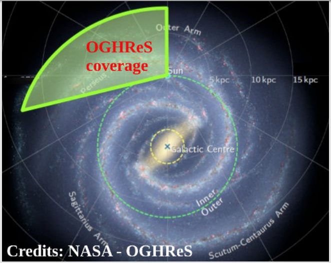
$\Longrightarrow$ **Influence of star-forming galaxy selection on the galaxy main sequence** (*Pearson et al. in prep*)

- Presence or absence of mass turn-over might be partially due to how star-forming galaxies are selected.

Star-formation in the Milky Way

The Outer Galaxy High Resolution Survey (PIs: C. König, J. Urquhart)

- ~1300hrs of observations performed with the APEX telescope
- 100deg^2 ($180^\circ < \ell < 280^\circ$)
- ^{12}CO, ^{13}CO, $C^{18}O$, SiO, DCO^+, CH_2O and CH_3OH lines
- Aims: gas and dust, physics and chemistry of star-forming regions, filamentary structures, Milky Way spiral arms, impact of metallicity



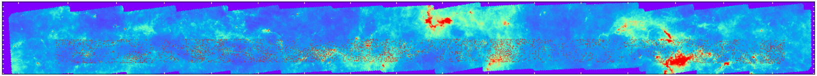


Figure: Galactic plane ($220^\circ << 250^\circ$) seen by *Herschel* at 250 μm

⟹ **Far-infrared line emission from the outer Galaxy cluster Gy 3-7 with SOFIA/FIFI-LS: Physical conditions and UV fields**
(*Le et al. submitted*)

⟹ **Carbon budget in the outer Galaxy**
(*Karska et al. in prep*)

- Effelsberg - Ammonia toward star-forming clumps in the outer Galaxy (PI: A. Karska - accepted)
- APEX - The fraction of dense gas in star-forming clumps in the outer Galaxy (PI: A. Karska - accepted)
- IRAM - Physics and chemistry of star-forming clumps in the outer Galaxy: an OGHReS-selected sample (PI: A. Karska - accepted)
- JCMT - Magnetic field observations towards dense star-forming clumps of the RCW 120 H II region (PI: D. Arzoumanian - submitted)

Conclusions

- Comparison and new SFR calibrations from $z = 0$ to $z = 0.9$
- Impact of survey's characteristics on FMR and its projections
- News studies ongoing: mass-size relation, FMR, SF main sequence
- Future works: lenticular galaxies, looking for rare objects, red nuggets as cosmic chronometers

- OGHReS observations ongoing (more than 2/3 of fields are observed)
- Studies on OGHReS and data from proposals

Thank you