Understanding Galaxy Formation and Evolution: Stellar Mass Growth, Metallicity Enrichment and Quenching of Early-Type Galaxies

ETG12

Paolo Saracco
Osservatorio Astronomico di Brera

Program
2018 - 2025

Based on PRIN-INAF-2019
1.05.01.85.11

Outline

- Team
- Science and Planning
- Funds
- Results
- Critical issues and prospects

ETG12 - Aims, Methods, Team

Aim - Reconstructing the mass assembly history of massive ($M^*>5\times10^{10}\ M_\odot$) ETGs and constraining the different processes responsible for their formation and mass growth.
Why massive ETGs? - Their presence at increasingly high redshift severly constrains galaxy formation models and the process of mass growth.

Methods
1) Tracing the properties of massive ETGs over the widest redshift range achievable with the current instrumentation;
2) Linking them accross time by also updating the state-of-the-art models with observed variations in some of their basic ingredients (e.g. IMF).

Team
- Personale TI INAF: 7
- Personale Ass. INAF: 2
- Post-doc: 1

+ Collaboratori esterni #

FTE 2021-2023 5.8

Strutture INAF coinvolte
- OA Brera
- OA Capodimonte
- OA Arcetri
- OA Trieste

Altre strutture
- FINCA - University of Turku, Finland
- University of Heidelbergh, Germany
- Oxford University - UK

Team and expertise

Name	Institute	Position
Paolo Saracco	OA Brera	Ricercatore
Fabio Fontanot	OA Trieste	Ricercatore
Mario Nonino	OA Trieste	Ricercatore
Francesco La Barbera	OA Capodimonte	Ricercatore
Crescenzo Tortora	OA Capodimonte	Ricercatore
Anna Gallazzi	OA Arcetri	Ricercatrice
Stefano Zibetti	AO Arcetri	Ricercatore
Roberto De Propris	Ass. OA Brera	Ricercatore
Anna Pasquali	Ass. OA Capodimonte	Prof. Ass.
Chiara Spiniello	Ass. OA Capodimonte	Post-doc
External collaborators		
M. Annunziatella	CSIC-INTA, Spain	Post-Doc
A. Gargiulo	INAF-IASF	Ricercatrice
D. Marchesini	Tufts University, USA	Full Prof.
N. Napolitano	OA - Capodimonte	Ric/Congedo
S. Toft	Cosmic Dawn Center, DN	Full Prof.

The team has an excellent expertise in extragalactic astronomy and in galaxy evolution study.

It provides both observational and theoretical skills suited to cover the needs of the project.

Project Planning

GAUSP
S. Zibetti

LEGA-C
A. Gallazzi

SHARP
P. Saracco
RSN5

IMF-UP
F. La Barbera

WP1 - (P. Saracco)
Stellar populations, dynamical properties and fundamental relations at different redshifts.

WP2 - (F. La Barbera)
A detailed study of the IMF-sigma relation, implications on the Dark Matter fraction.

WP3 - (R. De Propris)
Constraints on the nature of the UV up-turn: probing the existence of helium rich stars.

WP4 - (F. Fontanot)
SAMs of galaxy formation with a varying IMF and predictions of chemical abundances.

GAEA
G. De Lucia

DATA

ID	Survey/Tel	Redshift	Description
1	SDSS	z~0	SPIDER sample (La Barbera et al. 2010) - a large database of local massive ETGs best suited to establish local reference quantities and relations. About 400 galaxies also have MANGA-DR15 IFU spectroscopy available.
2	VLT-Xshooter	z~0	**Proprietary** - High S/N (~100) spectra of 7 high-mass ETGs suited to study radial variations of UV-NIR stellar population properties. (F. La Barbera)
3	VLT-Xshooter	0.2<z<0.5	**Proprietary** (ESO on-going large-programme) – High S/N (~70) spectra of 64 ultra-compact massive galaxies (UCMGs) (C. Spiniello)
4σ	BOSS-II	z<0.7	Public – Spectra of luminous red galaxies at intermediate redshifts (0.3<z<0.7).
5	LEGA-C	z<1	Public ESO-survey. Deep spectroscopy of thousands galaxies at 0.6<z<1 including massive ETGs. A. Gallazzi and S. Zibetti are involved in the survey.
6	VANDELS	0.9<z<1.4	Public ESO-survey. Deep low-resolution spectroscopy of hundreds galaxies at z>1. We have already selected a sample of ~70 ETGs at 1<z<1.4.
7	LBT-MODS	z~1.2	**Proprietary** - Spectroscopy of 7 massive ETGs in XLSS0223 cluster at z=1.22, and 8 additional cluster ETGs from Jorgensen+14 at z=1.27.
8	VLT-FORS	1.2<z<1.9	**Proprietary** - Spectroscopy of 5 massive ETGs at 1.2<z<1.9 from the MUNICS survey (Gargiulo+2016).
9	VLT-Xshooter	z~2	**Proprietary** – Spectroscopy of 15 massive quiescent galaxies at 1.9<z<2.5 (Stockman et al., submitted)
10	LBT-LUCI	z~3.35	**Proprietary** - Near-IR spectroscopy of a massive ETG at z=3.35, suited to measure stellar velocity dispersion, age and metallicity at such high redshift.
11	ULTRA-Vista	z>3	Public - Multiwavelength (22 bands) photometric data best suited for SED fitting of ETGs at redshift unreachable with current spectroscopic facilities.

Funds

PRIN-INAF-2019 **52 kE** granted (~140 kE requested)

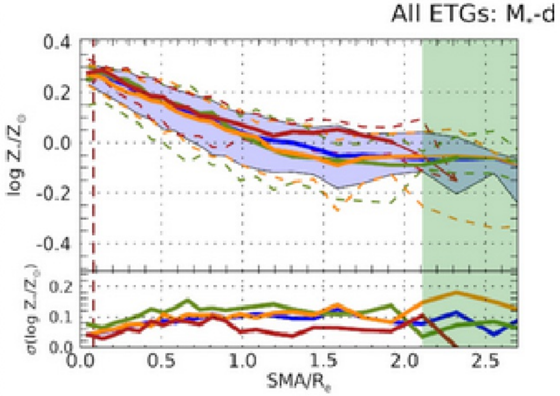
#	Provenienza	Certi 2021 (k€)	Certi 22 (k€)	Certi 23 (k€)	Presun. 2021 (k€)	Presun. 22 (k€)	Presun. 23 (k€)	Totale Certi (k€)	Totale Presunti (k€)
1	PRIN-INAF-2019	26	26	0	0	0	0	52	0

F.O.	Descrizione
1.05.01.85.11	ETG's twelve - Stellar population and dynamical properties of massive early-type galaxies over the last 12 Gyr: testing hierarchical galaxy formation (ref. P. Saracco)

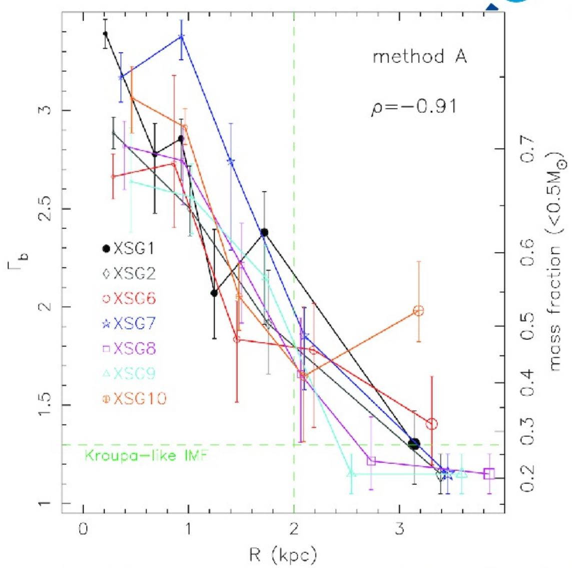
~65% used to co-fund
Dottorato di Ricerca Universita' degli Studi dell'Insubria (Como) - Ciclo XXXVI -
Candidate selection expected in September 2021

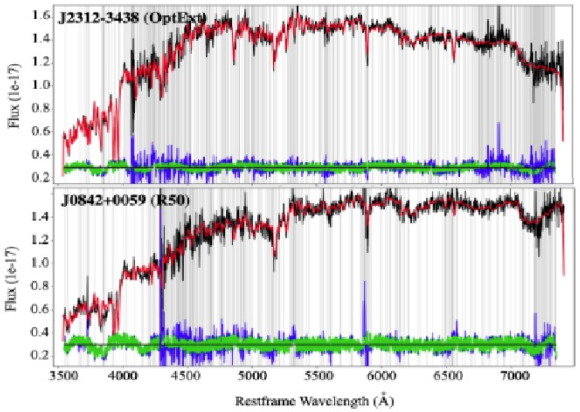
Possible funding sources for the next future
PRIN-INAF
PRIN-MUR

Some Results

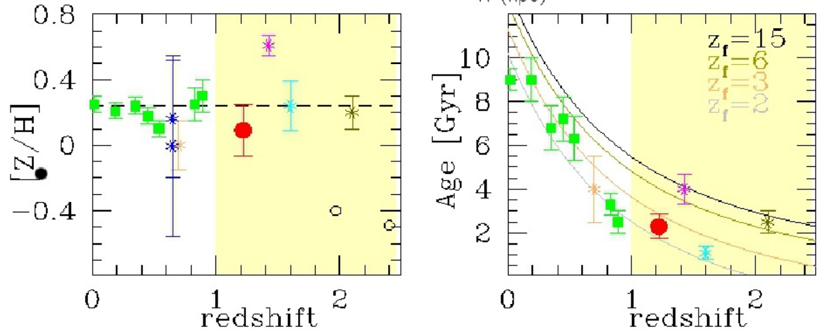


Radial variation of:
- **stellar metallicity**, higher toward the center (left, Zibetti+21);
- **IMF**, excess of low-mass stars toward the center (right; La Barbera+19).





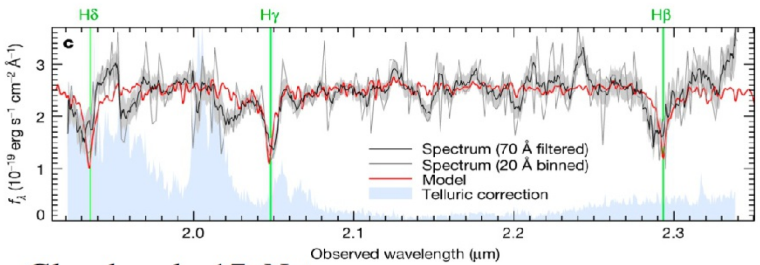
INSPIRE - pPXF full spectrum fitting example for a massive compact galaxies. (Spiniello+2021)



No significant metallicity evolution up to z~2 (Saracco+2019)

Leadership? The challenge

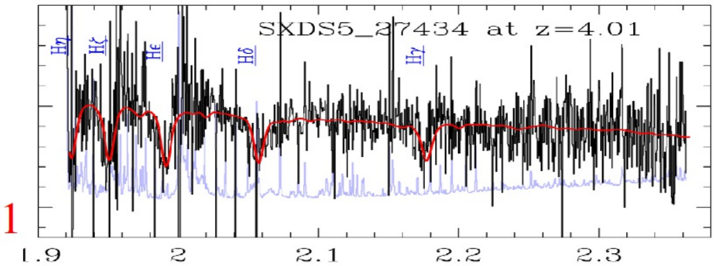
MOSFIRE@Keck
demonstrates the presence of massive ETGs at z>3
Universe younger than 1.8 Gyr



Spectroscopic confirmation

z=3.7

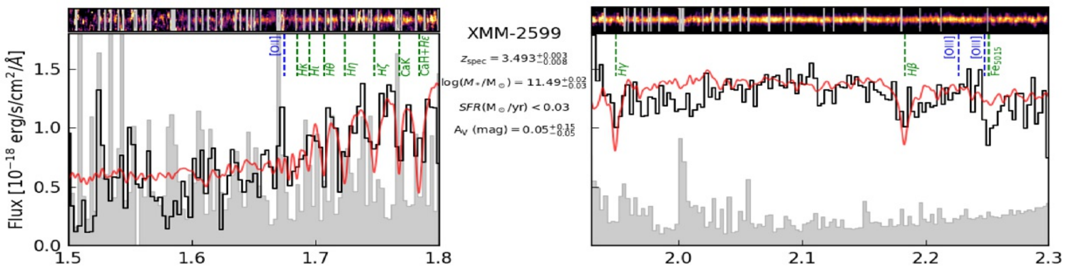
z=4.01



Glazebrook+17, Nature

Stellar velocity dispersion 270∓60 km/s

Tanaka+20



Forrest+20

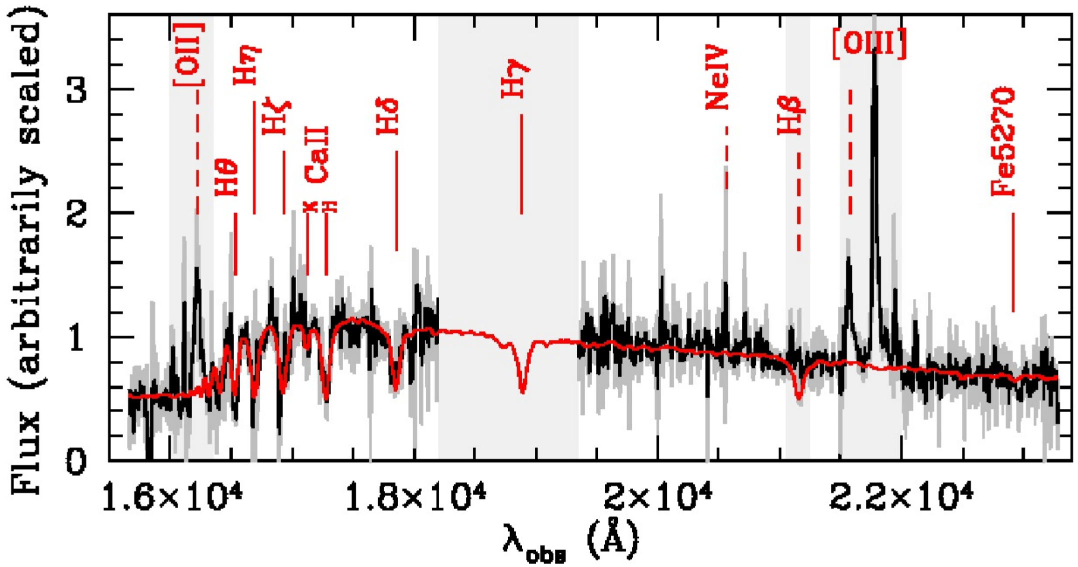
Spectroscopic confirmation

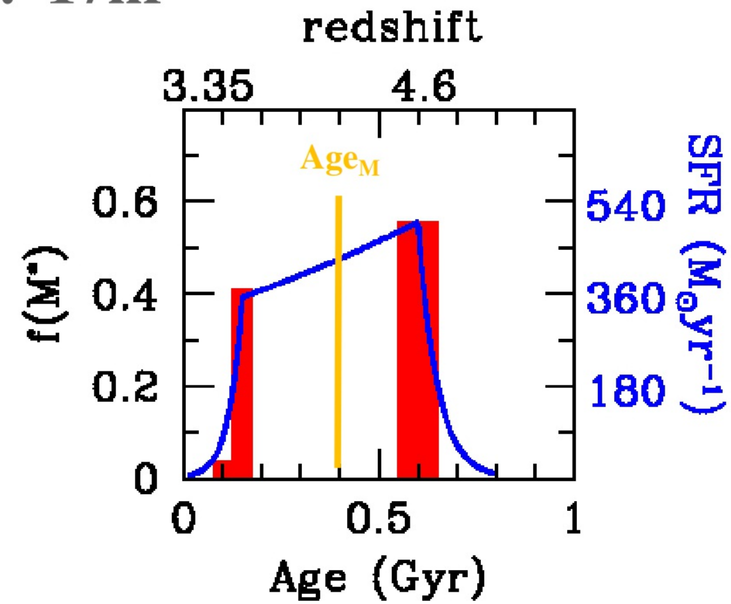
z=3.49

K-band observations
λ>1.8 μ

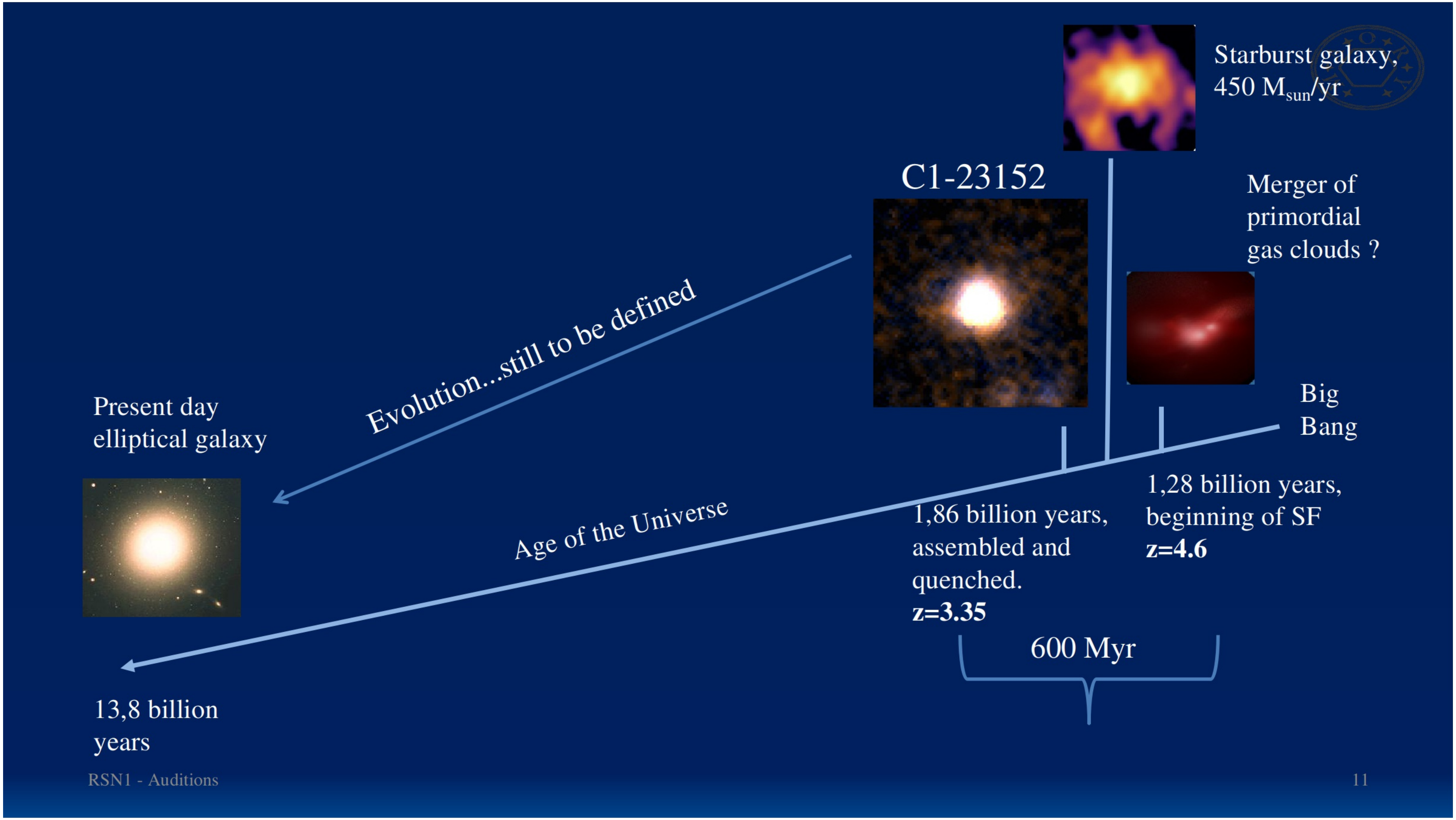
C1-23152 - A massive ETG at z=3.35

LBT-LUCIs Obs. 17hr





Assembly timescale	**< 600 Myr**	**Stellar metallicity**	**$\log(Z/Z_{sun})$=[0.25-0.15]**
Star formation timescale	≤ 450 Myr	Mean Age	400∓50 Myr
Quenching timescale	< 150 Myr	Dynamical mass	$2.2(\mp0.4)\times10^{11}\ M_\odot$
Average SFR	≥ 440 $M_\odot\ yr^{-1}$	Stellar mass	$2.0(\mp0.7)\times10^{11}\ M_\odot$
Stellar velocity dispersion	**409∓60 km/s**	**DM Fraction**	$M_{dyn}/M_{*}\sim1$


Starburst galaxy,
450 M_{sun}/yr
C1-23152
Merger of
primordial
gas clouds ?
Evolution...still to be defined
Present day
elliptical galaxy
Big
Bang
1,28 billion years,
beginning of SF
z=4.6
1,86 billion years,
assembled and
quenched.
z=3.35
Age of the Universe
600 Myr
13,8 billion
years

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Giant Galaxies from the Universe's Childhood Challenge Cosmic Origin Stories

Large galaxies are thought to form gradually, across billions of years of cosmic time. So why... astronomers keep finding them in the youthful early universe?

By Robin George Andrews on January 27, 2021

AAS NOVA Research highlights from the journals of the American Astronomical Society

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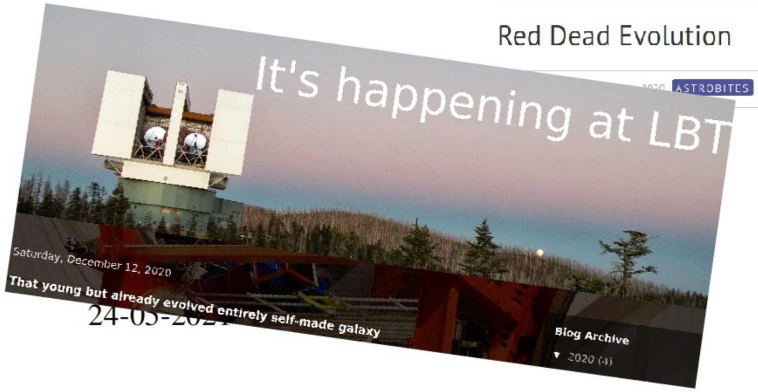

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Critical issues and prospects

1. **Small scale issue**: relevant to the project only
2. **Large scale issue**: relevant to the community

Small scale issue

Timing and rapidity are fundamental in hot and frontier research topics.

Post-doc positions fully dedicated to the project would have accelerated the project dramatically, increasing the international competitivity and leadership.

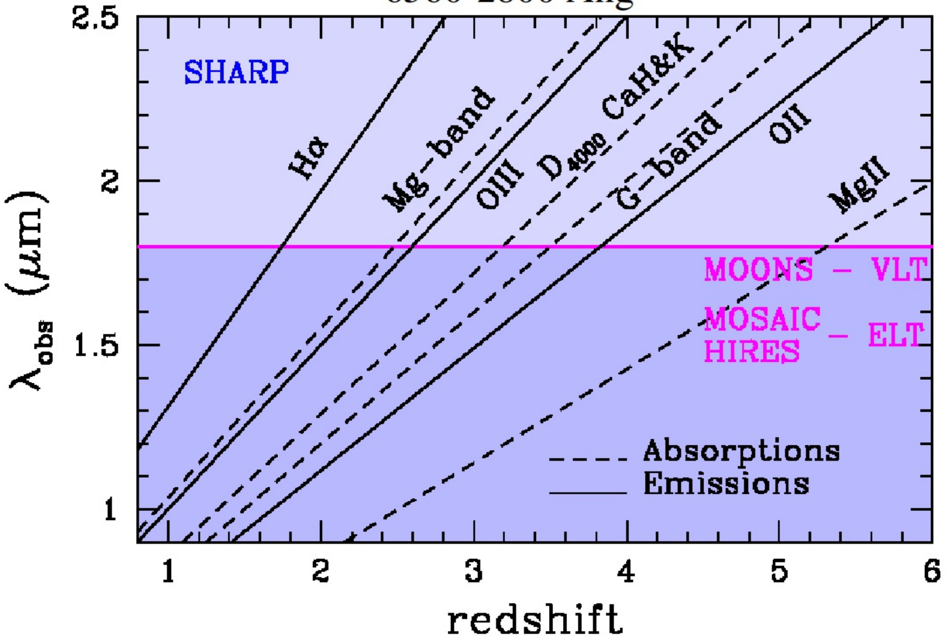
The lack of them due to the cut (63%) in the funds granted with PRIN-INAF affects significantly timing and rapidity.

Large scale issue and prospects

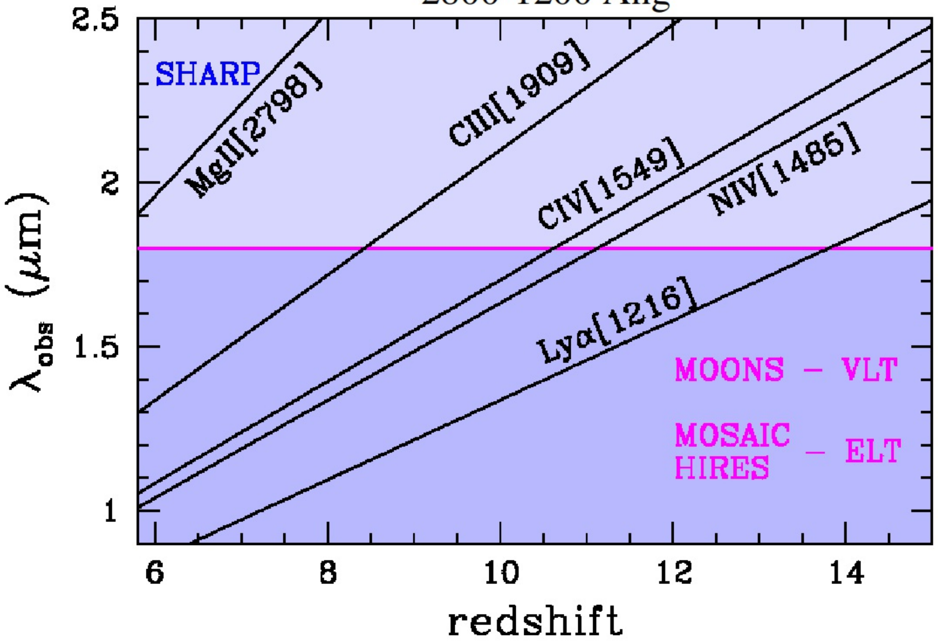
To study stellar and gas component in galaxies at z>1.5-2 near-IR observations at λ>1.8 μ are needed.

- Current ESO instruments not competitive: no AO, KMOS low sens. + issues; Xshooter long-slit, low-sens;
- Upcoming and future ESO instruments limited to **λ=1.8 μ**
- LBT-LUCI (+AO) is the only competitive facility to probe high-z galaxies till >2031 (at least).

6560-2800 Ang



2800-1200 Ang



We are cut off from the study of high-z galaxies.
Are we fully aware of this?

SHARP

A near-IR suite for VLT

(RSN5)

Near-IR Imager,
Multi-Object Spectrograph and IFU with
MCAO capabilities

A short document summarizing the rationale and the main features of the instrument can be found at

https://drive.google.com/file/d/1f2LO5GRij1hxlHKMiwDQTrEKDG-iErkp/view?usp=sharing

Thank you!

SHARP

A near-IR suite for VLT

VESPER

MCAO Unit

SHARP Main Unit

Imager/MOSpectrograph
~7'x7' (1'x1' AO)

NEXUS

Integral Field Unit
>15''x15'' (7.5''x7.5'' AO)

ELT first light

SHARP

15. Team Summary

15. Personale INAF coinvolto

Numero di partecipanti INAF al progetto: 32

Struttura	Nfte	N0	TI 21	TI 22	TI 23	TD 21	TD 22	TD 23	Nex	Extra
O.A. BRERA	1	4	0.30	0.00	0.00	0	0	0	0	0.00
O.A. PADOVA	0	4	0.00	0.00	0.00	0	0	0	0	0.00
OAS BOLOGNA	0	6	0.00	0.00	0.00	0	0	0	0	0.00
O.A. CAPODIMONTE	0	5	0.00	0.00	0.00	0	0	0	0	0.00
O.A. ARCETRI	0	3	0.00	0.00	0.00	0	0	0	0	0.00
IASF MILANO	0	5	0.00	0.00	0.00	0	0	0	0	0.00
O.A. ABRUZZO	0	1	0.00	0.00	0.00	0	0	0	0	0.00
O.A. ROMA	0	2	0.00	0.00	0.00	0	0	0	1	0.10
O.A. TRIESTE	0	1	0.00	0.00	0.00	0	0	0	0	0.00
Totali	1	31	**0.30**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	1	**0.10**

SHARP

Table 3 - Summary of observing capabilities of SHARP in **imaging mode**

Imaging mode	pixel scale "/pix	f.o.v.	λ range µm	Mag-limit(1) AB
Imaging	0.1"/pix (0.125"/pix)	7'x7' (8.5'x8.5')	0.95-2.5	J>24.8, H>23.9, K>24.2
Imaging+AO	0.015"/pix (0.02"/pix)	60"x60" (80"x80")	0.95-2.5	

(1) Indicative values taken from HAWK-I as reference

Table 4 - Summary of the observing capabilities of SHARP in **spectroscopic mode**.

Spectroscopic mode	Band	R λ/Δλ	λ range width µm	dispersion Å/pix	F.o.v.
Long-slit & Mask MOS	Y, J, H, K YJ, HK, YJHK	5000/6000 2000/2500 300/500	0.2/0.3 0.5/0.6 1.5	≤1 1-1.5 ~5	7'x7' no-AO 60"x60" MCAO

Table 5 Summary of the main properties of **IFU.**

Mode	Band	R λ/Δλ	λ range w µm	dispersion Å/pix	pixel scale	F.o.v.
IFU & IFU+AO	Y, J, H, K YJ, HK, YJHK	5000/6000 2000/2500 300/500	0.2/0.3 0.5/0.6 1.5	≤1 1-1.5 ~5	0.1" 0.05"	**TBD** (15"x15") (7.5"x7.5")

Table 1 - Summary of the observing modes of SHARP and comparison with the near-IR instruments currently operating at VLT (in blue) and with those soon available (in green).

Modes	**SHARP**	HAWK-I	KMOS	X-SHOOTER	MOONS	ERIS
Imaging	7'x7'	7.5'x7.5'				
Imag+AO	60"x60"	X (GLAO)**				27"x27"
Long-slit	X			X		
MOS #	X*		24		≤1000	
IFU	15"x15"		3"x3"	1.8"x4"		X
IFU+AO	"7.5x7.5"***					0.8"x0.8"

*The MOS capability depends on the spatial distribution of the sources and slitlets length. **Ground Layer AO: according to the performances of GRAAL on ESO web pages, the worst the seeing the higher the improvement. For best seeing conditions (~0.3") the improvement is a factor 1-1.3. ***The IFU f.o.v. is TBD (see Sec. 3.2, *IFU*).

Tab. 2 Comparison of the observing capabilities of SHARP with those of the main near-IR (1-2.5 μm) instruments at the other 10m-class telescopes.

Modes	**SHARP**	LUCI @LBT	Flamingos GSAOI @Gemini	MOSFIRE OSIRIS @Keck	NIRC2 NIRSPEC @Keck	MOIRCS IRCS @Subaru	EMIR @GTC
Imaging	7'x7'	4'x4'	6'x6'	X	20"x20"	4'x7'	7'x7'
Imag+AO	60"x60"	30"x30"	85"x85"	40"x40"	20"x20"	20"x20"	
Long-slit	X	X	X	X	X	X	X
MOS	X	X	X	X		X	X
IFU	X			X		X	
IFU+AO	X			X			