



1908 - Constraining the nature of the first stellar complexes: globular cluster precursors and Population III stellar clusters at $z \sim 6-7$

Cycle: 1, Proposal Category: GO

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JWST Proposal 1908 (Created: Thursday, July 13, 2023 at 6:00:40 PM Eastern Standard Time) - Overview

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OBSERVATIONS

<i>Folder</i>	<i>Observation</i>	<i>Label</i>	<i>Observing Template</i>	<i>Science Target</i>
PopIII				
	2	PopIII	NIRSpec IFU Spectroscopy	(5) POPIII
D2				
	3	satellite	NIRSpec IFU Spectroscopy	(6) D2
D1T1				
	4	D1T1	NIRSpec IFU Spectroscopy	(2) D1T1
T3T4				
	5	T3T4	NIRSpec IFU Spectroscopy	(4) T3T4
T2				
	6	T2	NIRSpec IFU Spectroscopy	(3) T2

ABSTRACT

The observation, down to a few parsec scale, of individual Population III star-forming complexes and Globular Cluster Precursors (GCPs) and their interaction with the hosting galaxy and environment, necessarily requires strong gravitational lensing amplification. Moreover, the role of such low luminosity ($M_{1500} > -16$) sources on the ionization of the surrounding medium is a key factor in our understanding of the cosmic reionization. We propose JWST/NIRSpec-IFU mode to map two key targets (dubbed LYA and POPIII) amplified by the Hubble Frontier Field galaxy cluster MACS J0416, currently the modeled lens with the richest number of confirmed multiple images (>180).

LYA is a strong Ly-alpha emitter (rest-frame equivalent width, $EW > 200\text{\AA}$) at $z=6.149$ in which at least 10 star-forming knots of ($<$)10-100 parsec sizes and intrinsic ultraviolet magnitudes $m_{1500}=29-33$ are secured with VLT/MUSE and HST deep observations and recognized as the ionizing sources.

POPIII is a much fainter Ly-alpha arclet straddling the caustic at $z=6.629$ with a barely detected HST counterpart down to $\text{mag}_{1500} > \sim 31$ (observed),

implying an intrinsic $m_{1500} > \sim 35$. The huge Ly-alpha EW of the Pop III arclet ($> 1000 \text{ \AA}$ rest-frame) suggests the presence of a metal-free star complex.

JWST will be a game-changer for the challenge of understanding the nature of such extremely faint and compact ionizing sources. We will blindly map, at tens of parsec scale, the key optical lines like [OIII]4959-5007 and H-alpha, and definitely identify the targets as GCPs, quantify their ionizing photon production efficiency in an unprecedented low-luminosity regime and rich environment at the tail end of the Cosmic Reionization epoch.

OBSERVING DESCRIPTION

TARGETS:

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Target 1: we aim at observing a giant Ly α arc at $z=6.149$ magnified by the galaxy cluster MACS J0416, surrounded by a group of spectroscopically confirmed star forming complexes with intrinsic magnitude and sizes in the range 29-33 and < 13 -100 parsec. Remarkably, some of them show the densest star-formation rate surface densities ever seen at these redshifts, and currently represent the best candidate globular cluster precursors in the reionization epoch.

Target 2: we aim at observing an “HST-dark” object at $z=6.629$ lying very close to the critical line with an observed (intrinsic) ultraviolet magnitude fainter than 31(35). The extremely low luminosity ($M_{1500} \sim 11.9$) and the very large rest-frame Ly-alpha equivalent width ($EW > 1000 \text{ \AA}$) makes such an object of the most interesting of candidate Pop III star complex with 10^4 solar masses illuminating a HII region straddling the caustic.

INSTRUMENTS:

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At the redshift of our targets, $z=6.149$ (Target 1) and $z=6.629$ (Target 2), the entire rest-frame optical region of the electromagnetic spectrum is redshifted at wavelengths accessible only with JWST. In particular, we will detect and spatially map with IFU the most prominent nebular emission lines like the Balmer (H-alpha, H-beta) and Oxygen ([OIII]4959-5007), all of them falling in the same grating G395H/F290LP (2.87-5.26 μ m) for Target 1, while the Prism/CLEAR will capture the entire Ly-alpha -- H-alpha interval for Target 2. The H-alpha luminosity is a primary indicator of the star-formation rate that, combined with the ultraviolet size, will provide the star-formation rate surface density, strictly related to the gas surface density (from the Schmidt law), and never explored with such details at this redshift and low luminosities.

MODES:

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We carefully calculated the expected S/N ratios by assuming both spatially compact and extended line scenarios. NIRSpec IFU with the grating G395H/F290LP is used for Target 1 and is the most suitable observing mode given the scientific objectives (see SJ), while Prism/CLEAR will explore the HST-dark MUSE region (Ly-alpha emission without HST counterparts) surrounding the Ly-alpha arclet. In both cases, the IFU mode is perfect for a proper blind spatial mapping of the most relevant lines. We tune the number of groups after performing extensive calculations with the ETC, and set the NRSIRS2RAPID readout mode, which is suitable for faint objects and provide good temporal resolution for cosmic rays rejection. The Cycling dithering with the ``SMALL" option with 8 points is also adopted. Pointing #4 on Target 2 requires the grating Prism/CLEAR, in which the IFU mode is necessary to blindly accomodate in the field of view additional emission lines like H-alpha, H-beta (or metal lines), useful to probe the undelying object, currently undetected by HST ("HST-dark").

Proposal 1908 - Targets - Constraining the nature of the first stellar complexes: globular cluster precursors and Population III stellar cl...

#	Name	Target Coordinates	Targ. Coord. Corrections	Miscellaneous
(2)	D1T1	RA: 04 16 11.4906 (64.0478775d) Dec: -24 03 43.93 (-24.06220d) Equinox: J2000		
<p><i>Comments: This IFU pointing includes four star-forming regions (D1, T1, UT1 and UT2) and the stellar stream connecting D1 with T1 and are located at the core of the giant Ly-alpha arc at z=6.149 (Target 1). The sizes span the range between 10-70 parsec.</i></p> <p><i>Category=Galaxy</i> <i>Description=[Dwarf galaxies, Emission line galaxies, Protogalaxies]</i> <i>Extended=YES</i></p>				
(3)	T2	RA: 04 16 11.7900 (64.0491250d) Dec: -24 03 47.77 (-24.06327d) Equinox: J2000		
<p><i>Comments: This IFU pointing include the star-forming regions T2 and UT3, with sizes smaller than 20 parsec. In the same IFU FoV two Ly-alpha emitters without HST counterparts are also included (dubbed EM1 and EM2 in the SJ).</i></p> <p><i>Category=Galaxy</i> <i>Description=[Dwarf galaxies, Emission line galaxies, Protogalaxies]</i> <i>Extended=NO</i></p>				
(4)	T3T4	RA: 04 16 11.3620 (64.0473417d) Dec: -24 03 41.00 (-24.06139d) Equinox: J2000		
<p><i>Comments: This pointing include two clear star-forming regions (T3 and T4) of ~ 15 and 60 parsec sizes and intrinsic magnitudes 30-31. The same IFU FoV include the Ly-alpha arc, secured with MIUSE.</i></p> <p><i>Category=Galaxy</i> <i>Description=[Dwarf galaxies, Emission line galaxies, Protogalaxies]</i> <i>Extended=NO</i></p>				
(5)	POPIII	RA: 04 16 10.9663 (64.0456929d) Dec: -24 03 36.38 (-24.06011d) Equinox: J2000		
<p><i>Comments: Pointing 5 targets the Population III star-complex candidate straddling the caustic (magnification > 40). H-alpha emission is expected at S/N~12</i></p> <p><i>Category=Galaxy</i> <i>Description=[Compact galaxies, Emission line galaxies, Lyman-alpha galaxies]</i> <i>Extended=NO</i></p>				
(6)	D2	RA: 04 16 10.3072 (64.0429467d) Dec: -24 03 25.87 (-24.05719d) Equinox: J2000		
<p><i>Comments: Pointing 6 is centered on a satellite star-forming region at z=6.149, 25 kpc way from the main system (D1+T1). This object shows a particularly narrow Ly-alpha profile and a very blue ultraviolet slope.</i></p> <p><i>Category=Galaxy</i> <i>Description=[Dwarf galaxies, Lyman-alpha galaxies, Protogalaxies]</i> <i>Extended=NO</i></p>				

Fixed Targets

Proposal 1908 - Observation 2 - Constraining the nature of the first stellar complexes: globular cluster precursors and Population III st...

Thu Jul 13 23:00:40 GMT 2023

Observation	Proposal 1908, Observation 2: PopIII Diagnostic Status: Warning Observing Template: NIRSspec IFU Spectroscopy																																			
	(Visit 2:1) Warning (Form): Overheads are provisional until the Visit Planner has been run.																																			
Fixed Targets	<table border="1"> <thead> <tr> <th>#</th> <th>Name</th> <th>Target Coordinates</th> <th>Targ. Coord. Corrections</th> <th>Miscellaneous</th> </tr> </thead> <tbody> <tr> <td>(5)</td> <td>POPIII</td> <td>RA: 04 16 10.9663 (64.0456929d) Dec: -24 03 36.38 (-24.06011d) Equinox: J2000</td> <td></td> <td></td> </tr> </tbody> </table> <p><i>Comments: Pointing 5 targets the Population III star-complex candidate straddling the caustic (magnification > 40). H-alpha emission is expected at S/N~12</i> Category=Galaxy Description=[Compact galaxies, Emission line galaxies, Lyman-alpha galaxies] Extended=NO</p>												#	Name	Target Coordinates	Targ. Coord. Corrections	Miscellaneous	(5)	POPIII	RA: 04 16 10.9663 (64.0456929d) Dec: -24 03 36.38 (-24.06011d) Equinox: J2000																
	#	Name	Target Coordinates	Targ. Coord. Corrections	Miscellaneous																															
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TA Method VERIFY_ONLY																																				
Dithers	<table border="1"> <thead> <tr> <th>#</th> <th>Dither Type</th> <th>Size</th> <th>Starting Point</th> <th>Number of Points</th> <th>Points</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>CYCLING</td> <td>SMALL</td> <td>1</td> <td>8</td> <td></td> </tr> </tbody> </table>												#	Dither Type	Size	Starting Point	Number of Points	Points	1	CYCLING	SMALL	1	8													
	#	Dither Type	Size	Starting Point	Number of Points	Points																														
1	CYCLING	SMALL	1	8																																
Pointing Verification	<table border="1"> <thead> <tr> <th>#</th> <th>PV MSA Configuration</th> <th>Filter</th> <th>PV Readout Pattern</th> <th>PV Groups/Int</th> <th>PV Integrations/Exp</th> <th>PV Total Dithers</th> <th>PV Total Integrations</th> <th>PV Total Exposure Time</th> </tr> </thead> <tbody> <tr> <td>1</td> <td></td> <td>F110W</td> <td>NRSIRS2RAPID</td> <td>5</td> <td>1</td> <td>1</td> <td>1</td> <td>87.533</td> </tr> </tbody> </table>												#	PV MSA Configuration	Filter	PV Readout Pattern	PV Groups/Int	PV Integrations/Exp	PV Total Dithers	PV Total Integrations	PV Total Exposure Time	1		F110W	NRSIRS2RAPID	5	1	1	1	87.533						
	#	PV MSA Configuration	Filter	PV Readout Pattern	PV Groups/Int	PV Integrations/Exp	PV Total Dithers	PV Total Integrations	PV Total Exposure Time																											
1		F110W	NRSIRS2RAPID	5	1	1	1	87.533																												
Spectral Elements	<table border="1"> <thead> <tr> <th>#</th> <th>Grating/Filter</th> <th>Readout Pattern</th> <th>Groups/Int</th> <th>Integrations/Exp</th> <th>Leakcal</th> <th>Dither</th> <th>Autocal</th> <th>Total Dithers</th> <th>Total Integrations</th> <th>Total Exposure Time</th> <th>ETC Wkbk.Calc ID</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>PRISM/CLEAR</td> <td>NRSIRS2</td> <td>29</td> <td>1</td> <td>false</td> <td>true</td> <td>NONE</td> <td>8</td> <td>8</td> <td>17039.824</td> <td></td> </tr> </tbody> </table>												#	Grating/Filter	Readout Pattern	Groups/Int	Integrations/Exp	Leakcal	Dither	Autocal	Total Dithers	Total Integrations	Total Exposure Time	ETC Wkbk.Calc ID	1	PRISM/CLEAR	NRSIRS2	29	1	false	true	NONE	8	8	17039.824	
	#	Grating/Filter	Readout Pattern	Groups/Int	Integrations/Exp	Leakcal	Dither	Autocal	Total Dithers	Total Integrations	Total Exposure Time	ETC Wkbk.Calc ID																								
1	PRISM/CLEAR	NRSIRS2	29	1	false	true	NONE	8	8	17039.824																										

Proposal 1908 - Observation 3 - Constraining the nature of the first stellar complexes: globular cluster precursors and Population III st...

Thu Jul 13 23:00:40 GMT 2023

Observation	<p>Proposal 1908, Observation 3: satellite</p> <p>Diagnostic Status: Warning</p> <p>Observing Template: NIRSspec IFU Spectroscopy</p>											
Diagnostics	(Visit 3:1) Warning (Form): Overheads are provisional until the Visit Planner has been run.											
Fixed Targets	#	Name	Target Coordinates			Targ. Coord. Corrections			Miscellaneous			
	(6)	D2	RA: 04 16 10.3072 (64.0429467d) Dec: -24 03 25.87 (-24.05719d) Equinox: J2000									
	<p><i>Comments: Pointing 5 is centered on a satellite star-forming region at z=6.149, 25 kpc way from the main system (D1+T1). This object shows a particularly narrow Ly-alpha profile and a very blue ultraviolet slope.</i></p> <p><i>Category=Galaxy</i></p> <p><i>Description=[Dwarf galaxies, Lyman-alpha galaxies, Protogalaxies]</i></p> <p><i>Extended=NO</i></p>											
Template	TA Method											
	VERIFY_ONLY											
Dithers	#	Dither Type		Size	Starting Point		Number of Points		Points			
	1	CYCLING		SMALL	1		8					
Pointing Verification	#	PV MSA Configuration	Filter	PV Readout Pattern	PV Groups/Int	PV Integrations/Exp	PV Total Dithers	PV Total Integrations	PV Total Exposure Time			
	1	ALLOPEN	F110W	NRSIRS2RAPID	5	1	1	1	87.533			
Spectral Elements	#	Grating/Filter	Readout Pattern	Groups/Int	Integrations/Exp	Leakcal	Dither	Autocal	Total Dithers	Total Integrations	Total Exposure Time	ETC Wbkk.Calc ID
	1	G395H/F290LP	NRSIRS2	12	1	false	true	NONE	8	8	7119.378	

Proposal 1908 - Observation 4 - Constraining the nature of the first stellar complexes: globular cluster precursors and Population III st...

Thu Jul 13 23:00:40 GMT 2023

Observation	<p>Proposal 1908, Observation 4: D1T1</p> <p>Diagnostic Status: Warning</p> <p>Observing Template: NIRSspec IFU Spectroscopy</p>											
Diagnostics	(Visit 4:1) Warning (Form): Overheads are provisional until the Visit Planner has been run.											
Fixed Targets	#	Name	Target Coordinates			Targ. Coord. Corrections			Miscellaneous			
	(2)	D1T1	RA: 04 16 11.4906 (64.0478775d) Dec: -24 03 43.93 (-24.06220d) Equinox: J2000									
	<p><i>Comments: This IFU pointing includes four star-forming regions (D1, T1, UT1 and UT2) and the stellar stream connecting D1 with T1 and are located at the core of the giant Ly-alpha arc at z=6.149 (Target 1). The sizes span the range between 10-70 parsec.</i></p> <p><i>Category=Galaxy</i></p> <p><i>Description=[Dwarf galaxies, Emission line galaxies, Protogalaxies]</i></p> <p><i>Extended=YES</i></p>											
Template	<p>TA Method</p> <p>VERIFY_ONLY</p>											
Dithers	#	Dither Type		Size	Starting Point		Number of Points	Points				
	1	CYCLING		SMALL	1		8					
Pointing Verification	#	PV MSA Configuration	Filter	PV Readout Pattern	PV Groups/Int	PV Integrations/Exp	PV Total Dithers	PV Total Integrations	PV Total Exposure Time			
	1	ALLOPEN	F110W	NRSIRS2RAPID	5	1	1	1	87.533			
Spectral Elements	#	Grating/Filter	Readout Pattern	Groups/Int	Integrations/Exp	Leakcal	Dither	Autocal	Total Dithers	Total Integrations	Total Exposure Time	ETC Wkbk.Calc ID
	1	G395H/F290LP	NRSIRS2	22	1	false	true	NONE	8	8	12954.934	

Proposal 1908 - Observation 5 - Constraining the nature of the first stellar complexes: globular cluster precursors and Population III st...

Thu Jul 13 23:00:40 GMT 2023

Observation	Proposal 1908, Observation 5: T3T4 Diagnostic Status: Warning Observing Template: NIRSpec IFU Spectroscopy											
	(Visit 5:1) Warning (Form): Overheads are provisional until the Visit Planner has been run.											
Fixed Targets	#	Name	Target Coordinates			Targ. Coord. Corrections			Miscellaneous			
	(4)	T3T4	RA: 04 16 11.3620 (64.0473417d) Dec: -24 03 41.00 (-24.06139d) Equinox: J2000									
<i>Comments: This pointing include two clear star-forming regions (T3 and T4) of ~ 15 and 60 parsec sizes and intrinsic magnitudes 30-31. The same IFU FoV include the Ly-alpha arc, secured with MIUSE.</i> <i>Category=Galaxy</i> <i>Description=[Dwarf galaxies, Emission line galaxies, Protogalaxies]</i> <i>Extended=NO</i>												
Template	TA Method											
	VERIFY_ONLY											
Dithers	#	Dither Type		Size	Starting Point		Number of Points		Points			
	1	CYCLING		SMALL	1		8					
Pointing Verification	#	PV MSA Configuration	Filter	PV Readout Pattern	PV Groups/Int	PV Integrations/Exp	PV Total Dithers	PV Total Integrations	PV Total Exposure Time			
	1	ALLOPEN	F110W	NRSIRS2RAPID	5	1	1	1	87.533			
Spectral Elements	#	Grating/Filter	Readout Pattern	Groups/Int	Integrations/Exp	Leakcal	Dither	Autocal	Total Dithers	Total Integrations	Total Exposure Time	ETC Wkbk.Calc ID
	1	G395H/F290LP	NRSIRS2	22	1	false	true	NONE	8	8	12954.934	

Proposal 1908 - Observation 6 - Constraining the nature of the first stellar complexes: globular cluster precursors and Population III st...

Thu Jul 13 23:00:40 GMT 2023

Observation	<p>Proposal 1908, Observation 6: T2</p> <p>Diagnostic Status: Warning</p> <p>Observing Template: NIRSpec IFU Spectroscopy</p>											
Diagnostics	(Visit 6:1) Warning (Form): Overheads are provisional until the Visit Planner has been run.											
Fixed Targets	#	Name	Target Coordinates			Targ. Coord. Corrections			Miscellaneous			
	(3)	T2	RA: 04 16 11.7900 (64.0491250d) Dec: -24 03 47.77 (-24.06327d) Equinox: J2000									
	<p><i>Comments: This IFU pointing include the star-forming regions T2 and UT3, with sizes smaller than 20 parsec. In the same IFU FoV two Lya emitters without HST counterparts are also included (dubbed EM1 and EM2 in the SJ).</i></p> <p><i>Category=Galaxy</i></p> <p><i>Description=[Dwarf galaxies, Emission line galaxies, Protogalaxies]</i></p> <p><i>Extended=NO</i></p>											
Template	<p>TA Method</p> <p>VERIFY_ONLY</p>											
Dithers	#	Dither Type		Size	Starting Point		Number of Points	Points				
	1	CYCLING		SMALL	1		8					
Pointing Verification	#	PV MSA Configuration	Filter	PV Readout Pattern	PV Groups/Int	PV Integrations/Exp	PV Total Dithers	PV Total Integrations	PV Total Exposure Time			
	1	ALLOPEN	F110W	NRSIRS2RAPID	5	1	1	1	87.533			
Spectral Elements	#	Grating/Filter	Readout Pattern	Groups/Int	Integrations/Exp	Leakcal	Dither	Autocal	Total Dithers	Total Integrations	Total Exposure Time	ETC Wkbk.Calc ID
	1	G395H/F290LP	NRSIRS2	22	1	false	true	NONE	8	8	12954.934	