Vulcano Workshop 2024
Frontier Objects in Astrophysics and Particle Physics
Ischia Island (Naples, Italy)

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High-z GRBs

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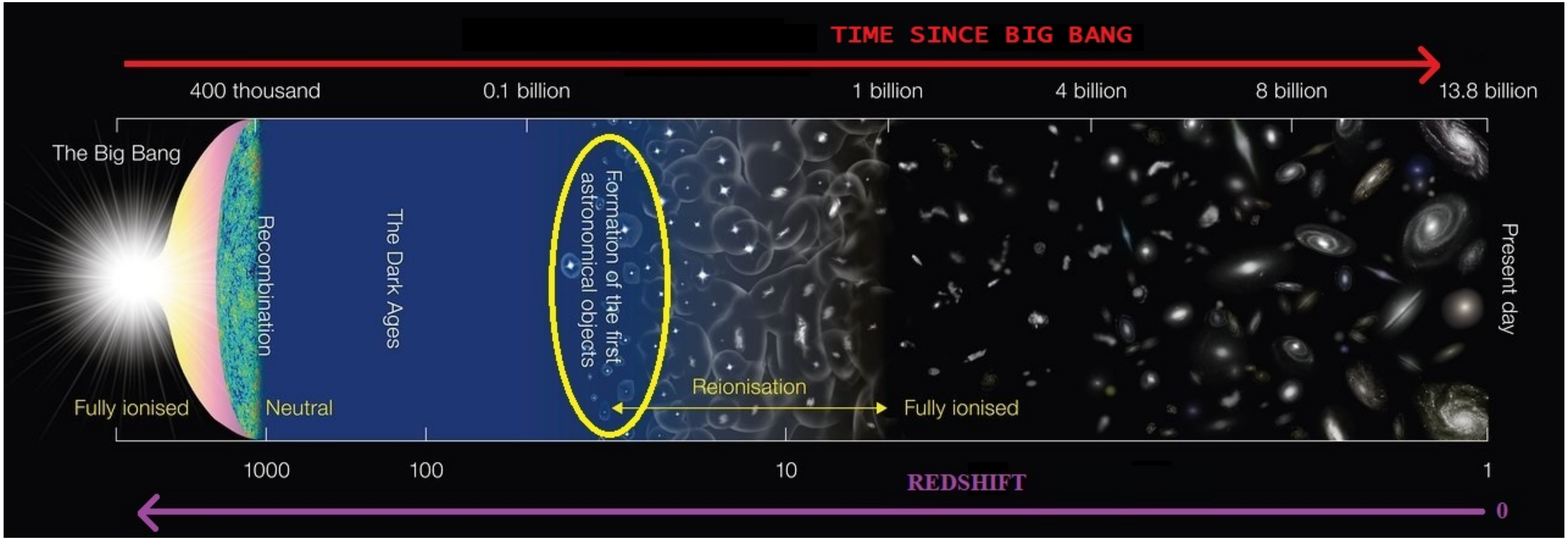
ACAV+ îledeFrance
SVOM
cnrs

Museo Archeologico di Pithecusae

The Distant Universe

Major issues of extragalactic astronomy

-What are the first objects to be formed in the Universe?
-How do galaxies form and evolve?
-What is the interplay between star formation and the inter-stellar gas?

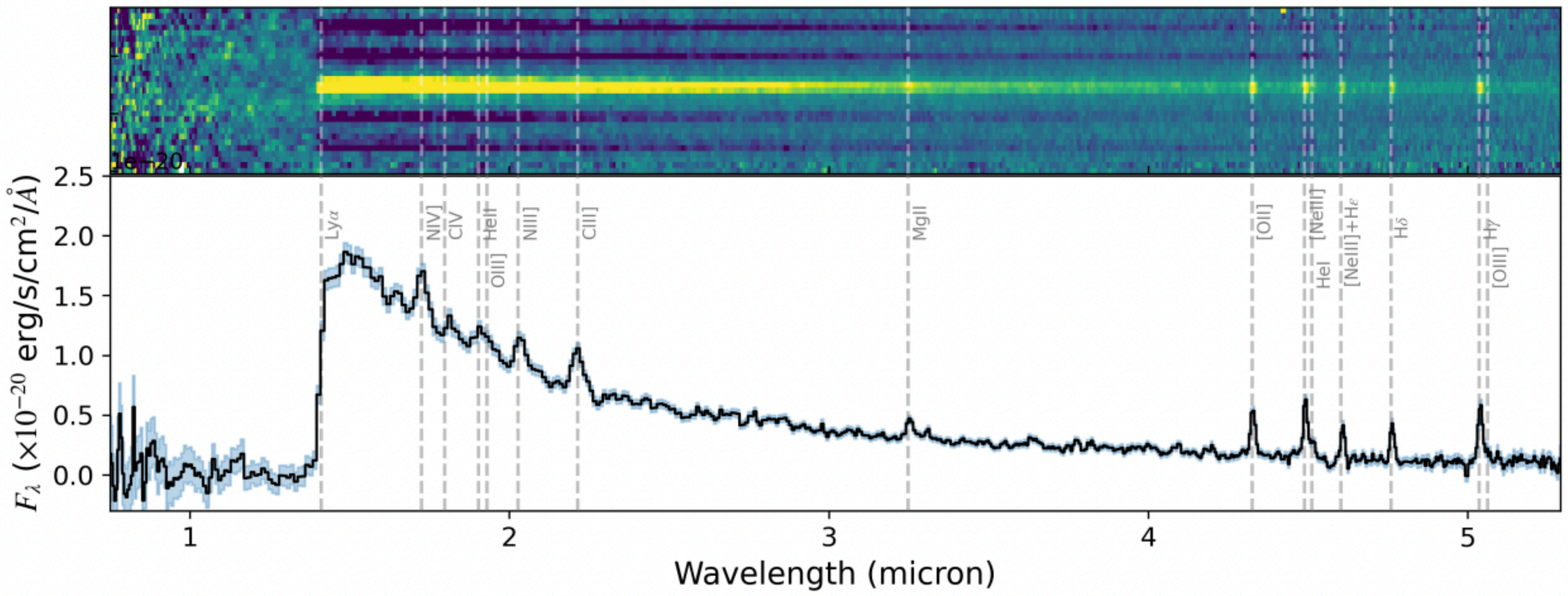


Credits: ESO

High-redshift Galaxies: *Current State of the Art*

The advent of JWST is revolutionizing the field, allowing the observation of galaxies up to a spectroscopically confirmed redshift of z~13

Bunker et al. 2023



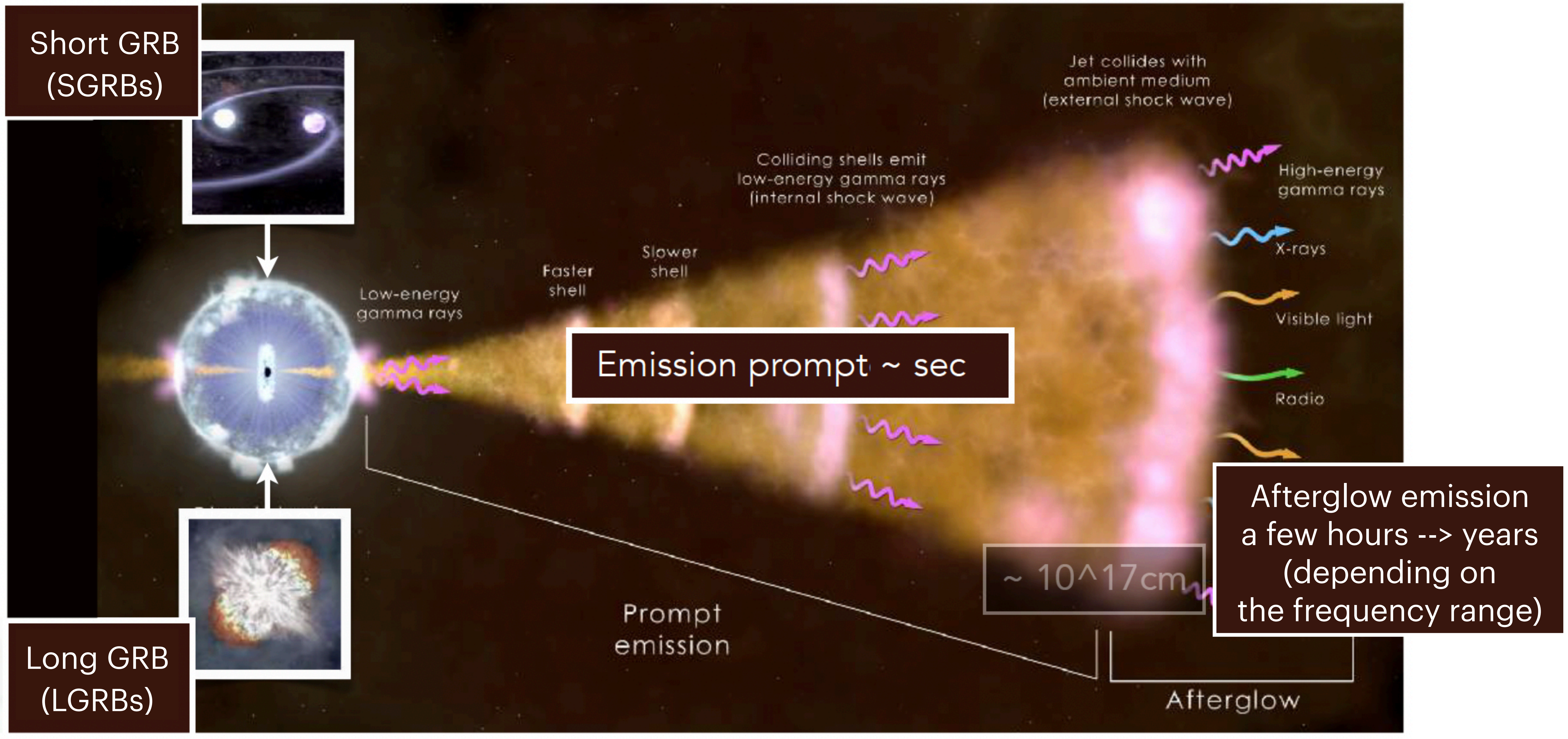
The FAINTNESS of these galaxies limits the available diagnostics even for JWST

—> FEW CONSTRAINTS ON THE NEUTRAL COLD/WARM GAS

GRBs ARE IDEAL TOOLS to explore the properties of faint high-redshift star-forming galaxies !

The GRB Phenomenon

Ultra-Relativistic Jet produced by a new-born accreting black hole



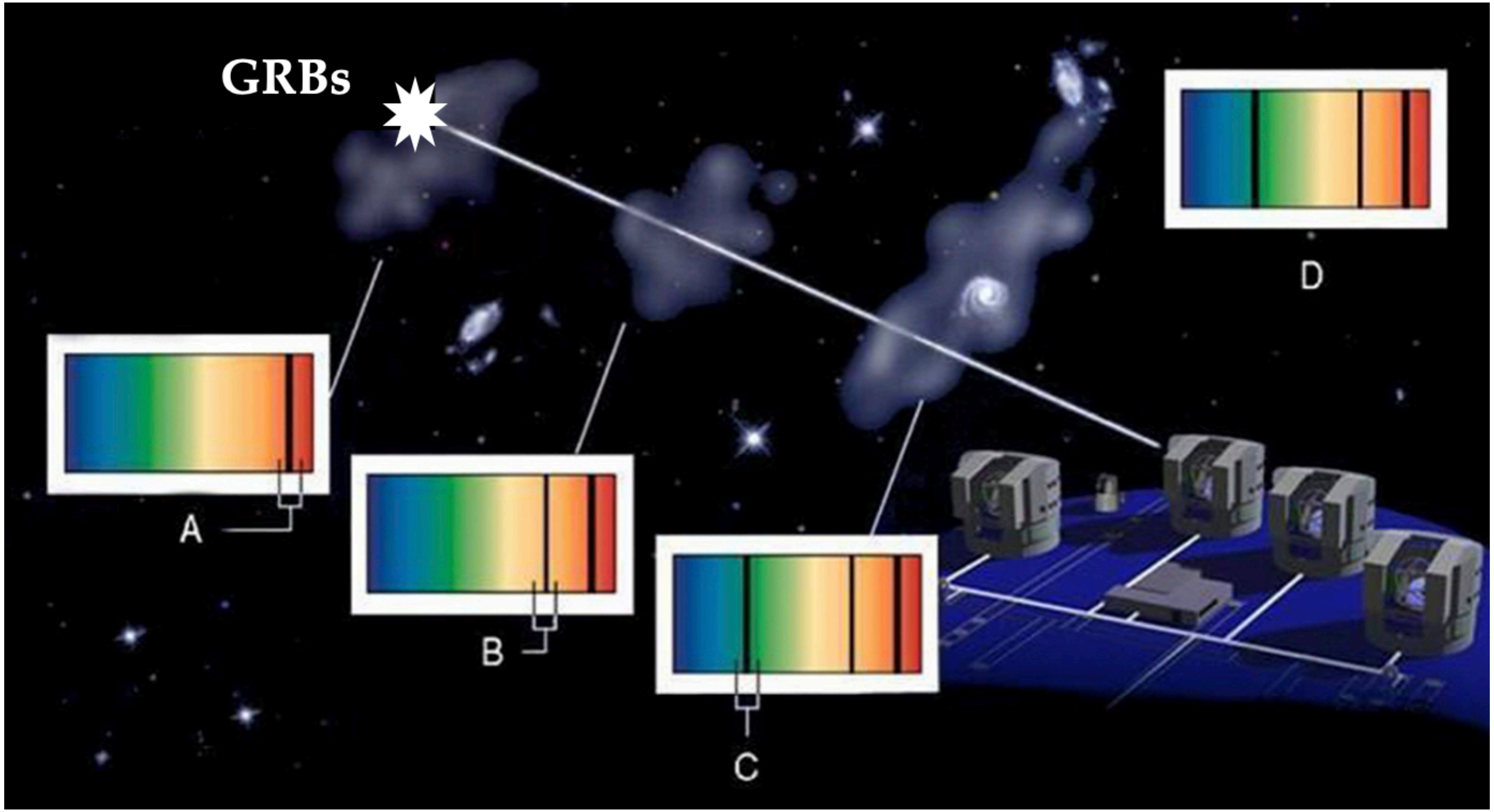
Credits: NASA

Long GRBs

1. Extremely bright at all redshift
2. Associated with the collapse of massive star
3. Trace star formation to the highest redshift
4. Afterglow emission fades

—> Study of the LGRB host (Neutral Gas + Ionised Gas)

Absorption Spectroscopy



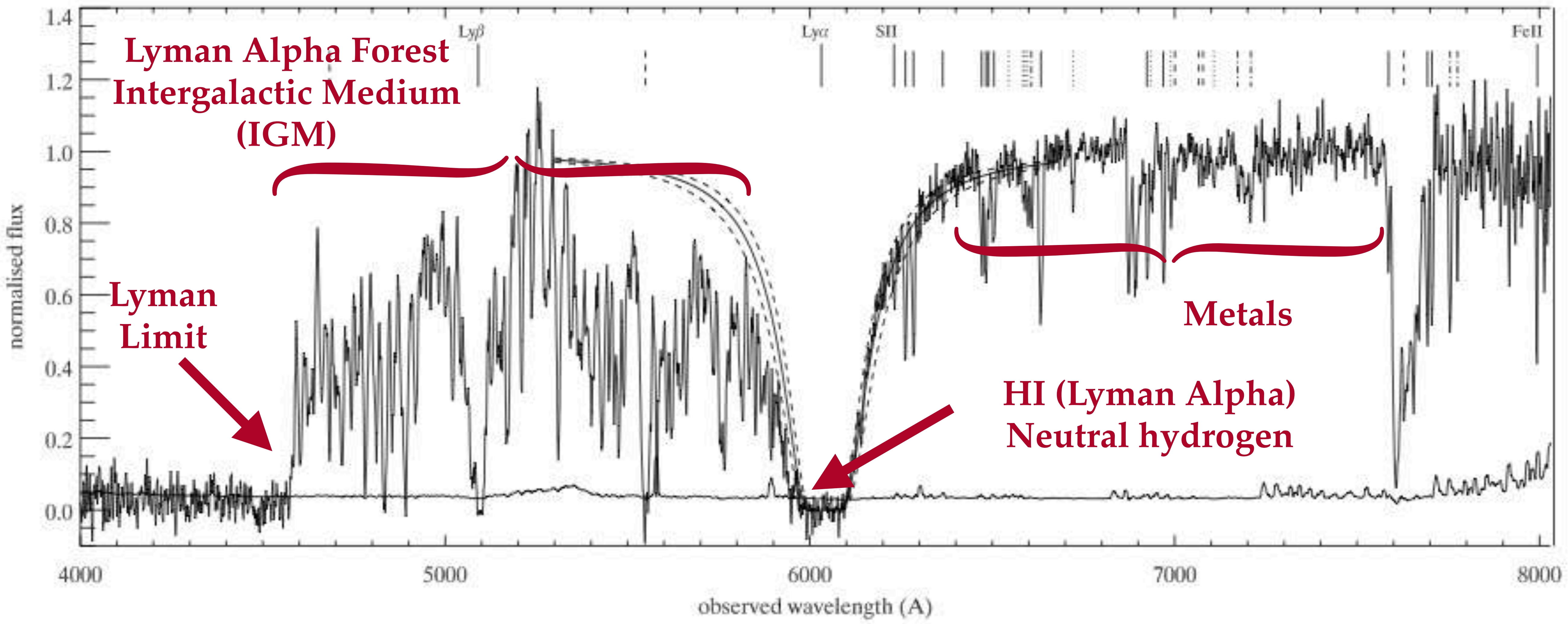
Adapted from ESO PR0813a

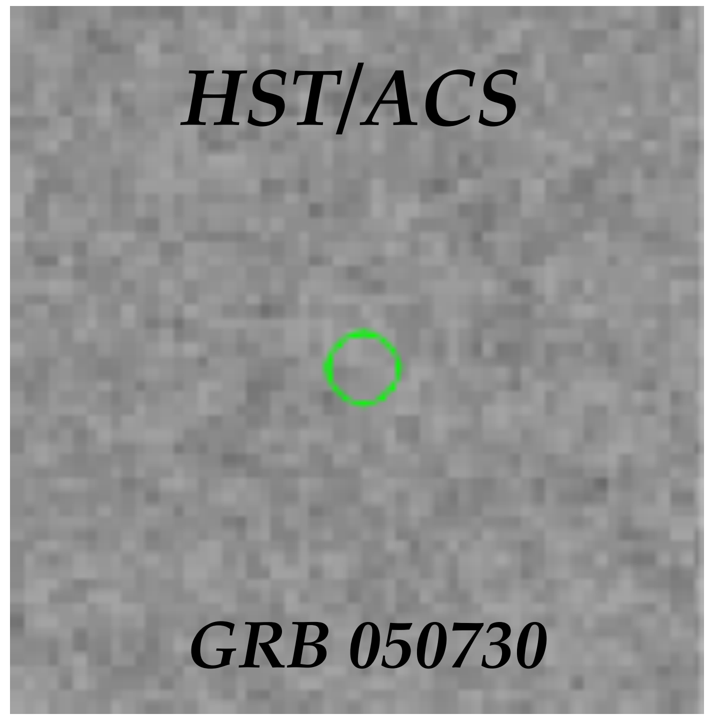
Absorption lines in the spectra of LGRBs

GRB 050730

~1h Observation

z=3.968





R>28.5

The powerful potential of LGRBs afterglow to access detailed information on the <u>neutral gas</u>

Chen et al. 2005
Nial Tanvir;
Starling et al. 2005

<u>From the analysis of the absorption lines:</u>

<u>We can measure:</u>

➡ *Redshift of the absorbers*

➡ *Column densities of the ions of different chemical elements*

<u>To study:</u>

-Metallicity and dust depletion

-The distance of the corresponding gas clouds

-Kinematic of the gas

-Chemical abundance pattern

Ground-based Follow-up

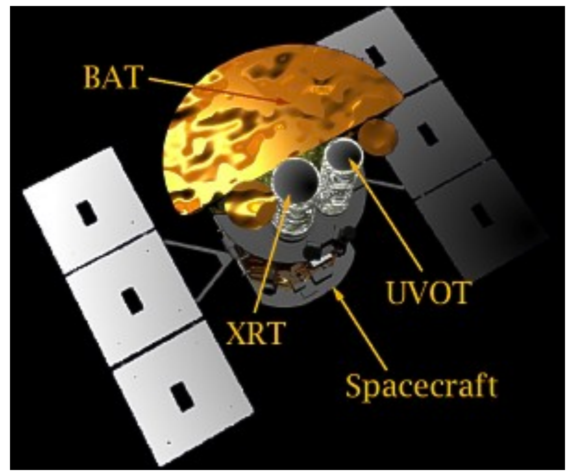
Stargate Collaboration

PIs: N. Tanvir, S.D. Vergani, D. Malesani

ESO Large Programme

GRBs Follow-up with optical-NIR telescopes

Alert



Robotic

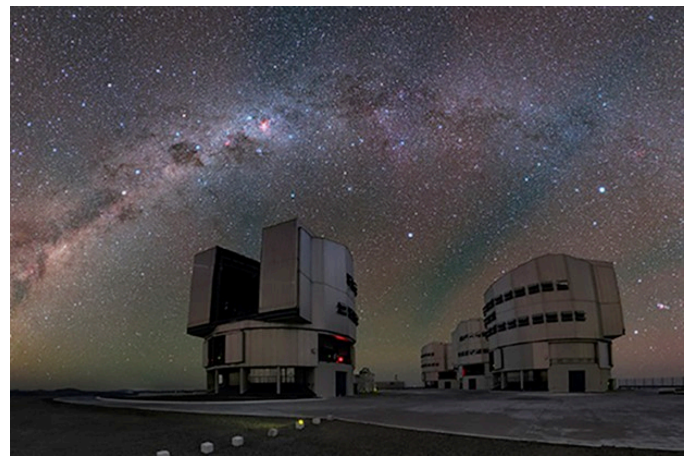
Seconds

+

Hours

ToO mode

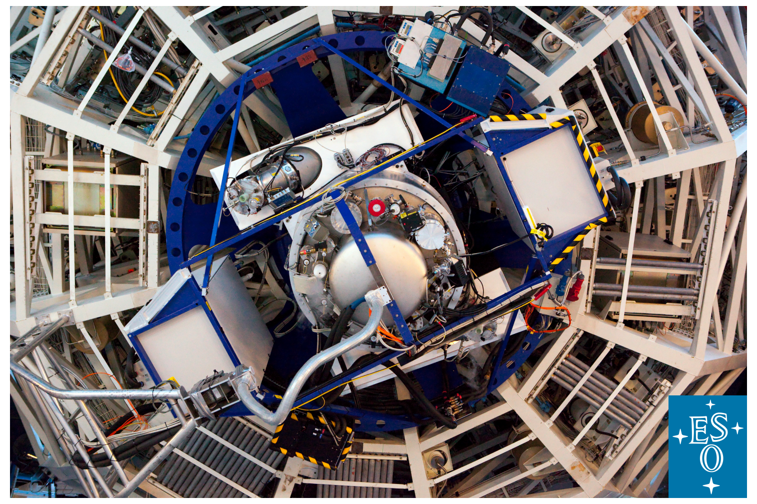
Observations

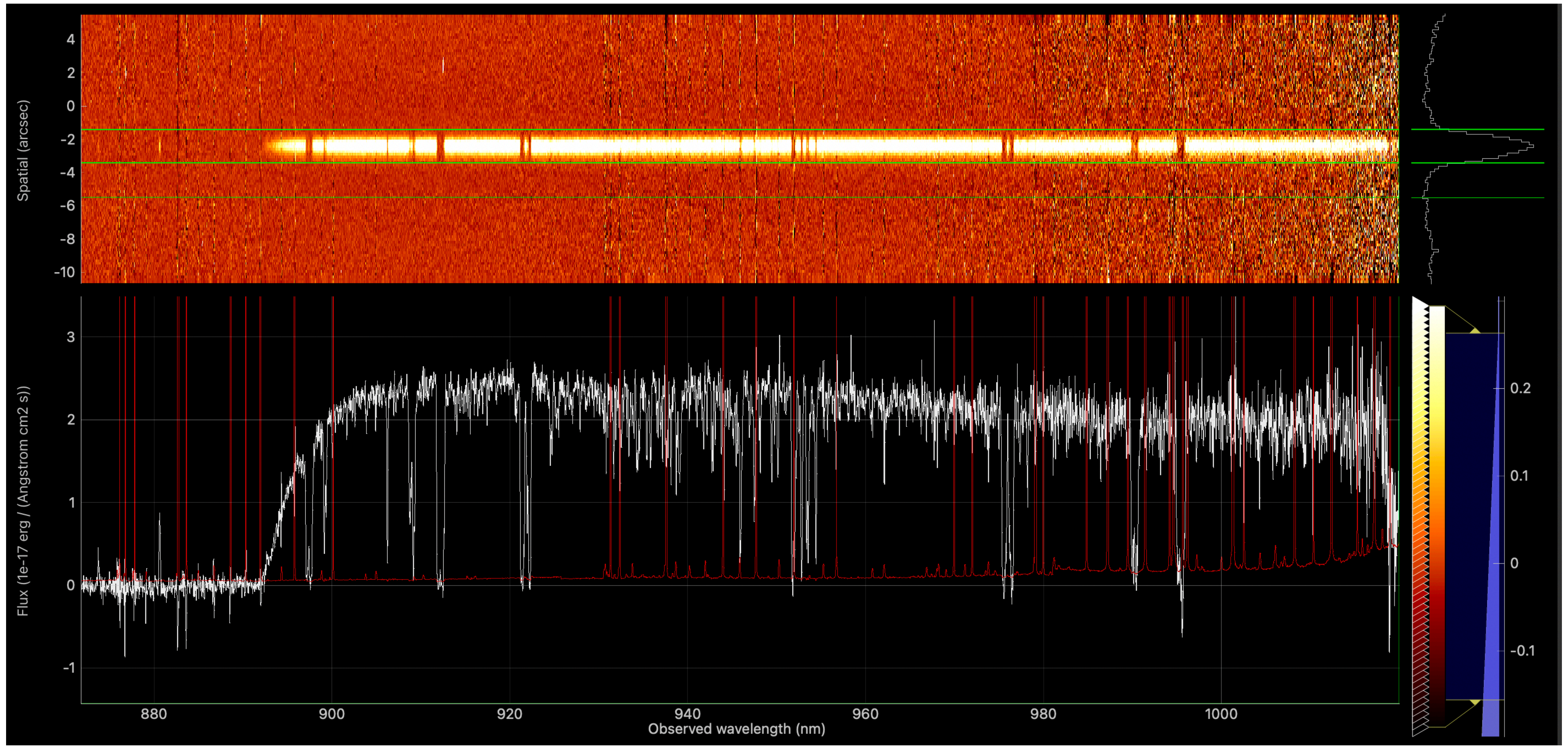


The case of GRB 210905A at z = 6.3

VLT/X-shooter spectrum

- After ~ 2.53 hours (observer frame)
- 4 exposures of 1200s (UVB,VIS,NIR)
- Wavelength range 3 000 - 21 000 Å

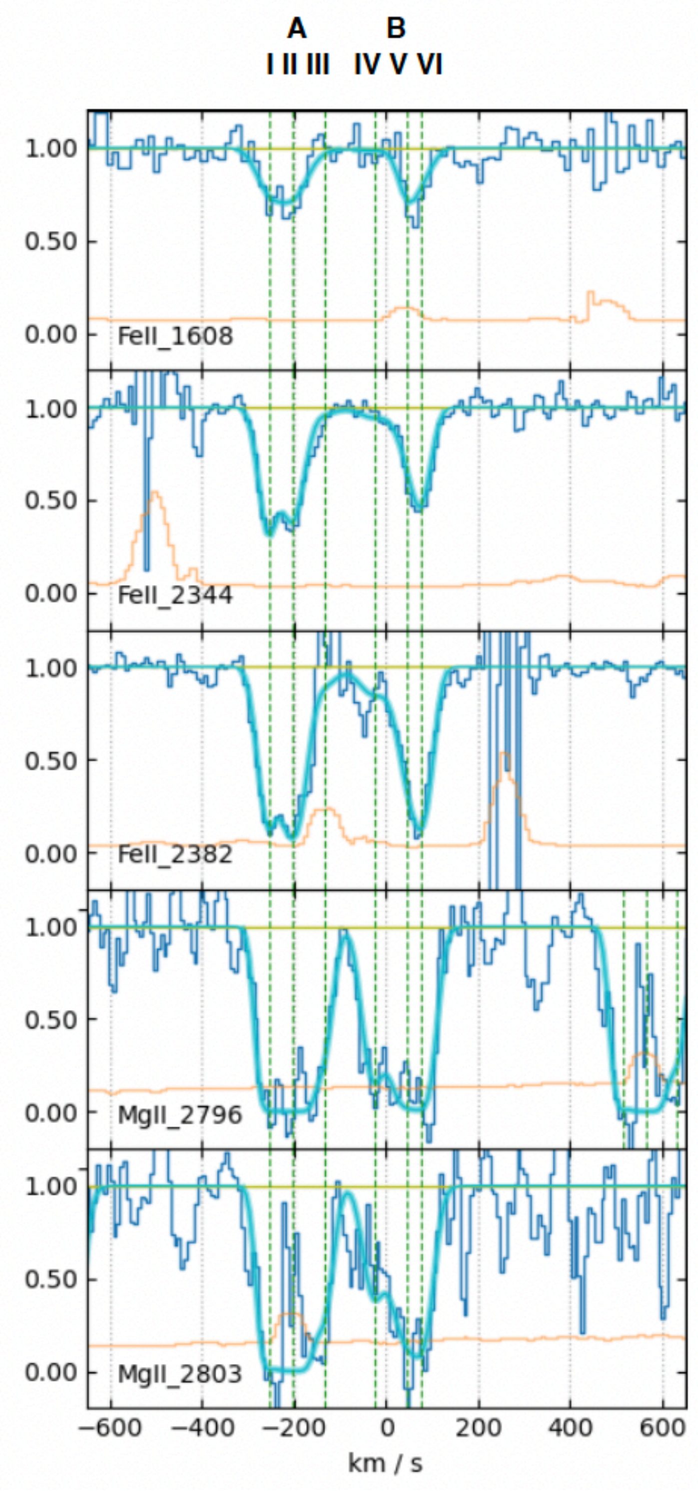


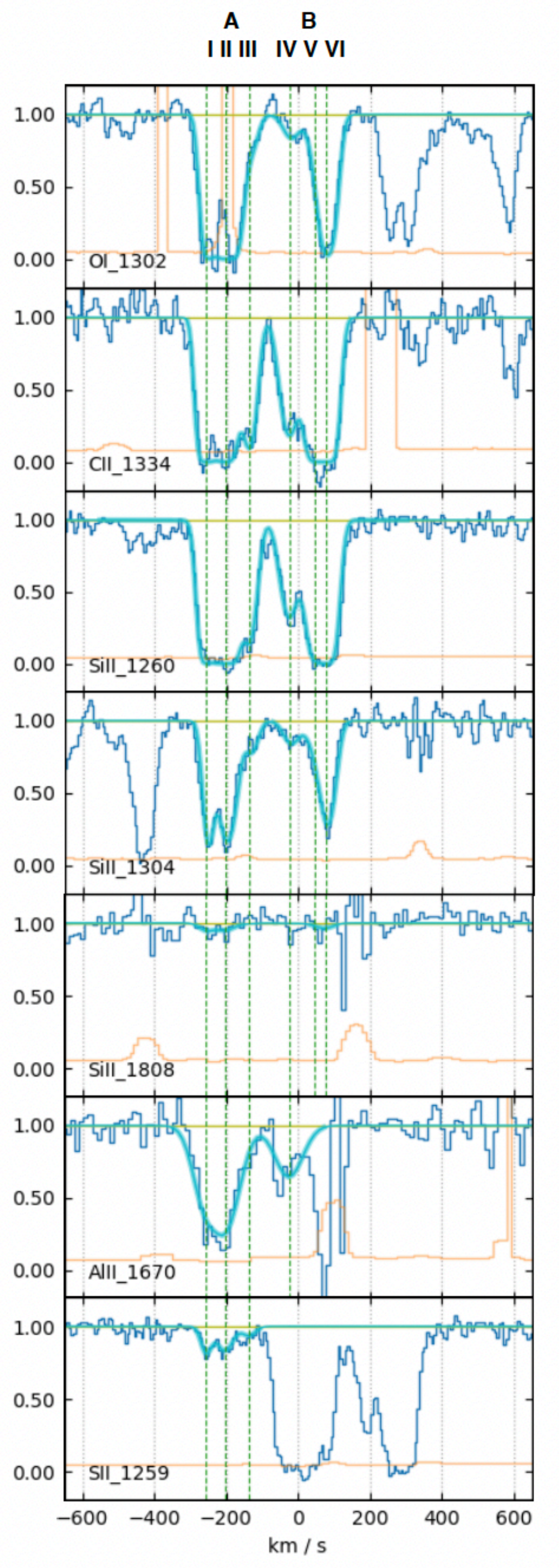


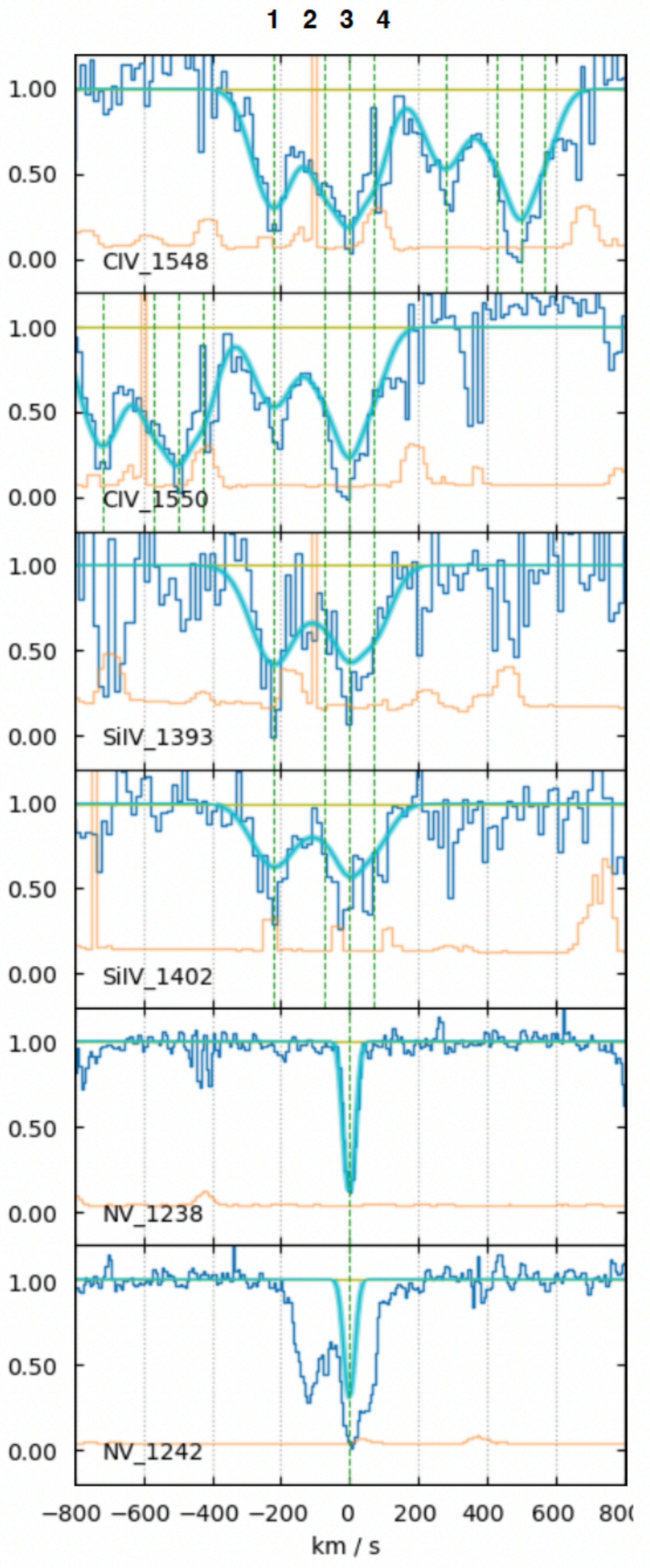
The GRB host galaxy at z ~ 6.3

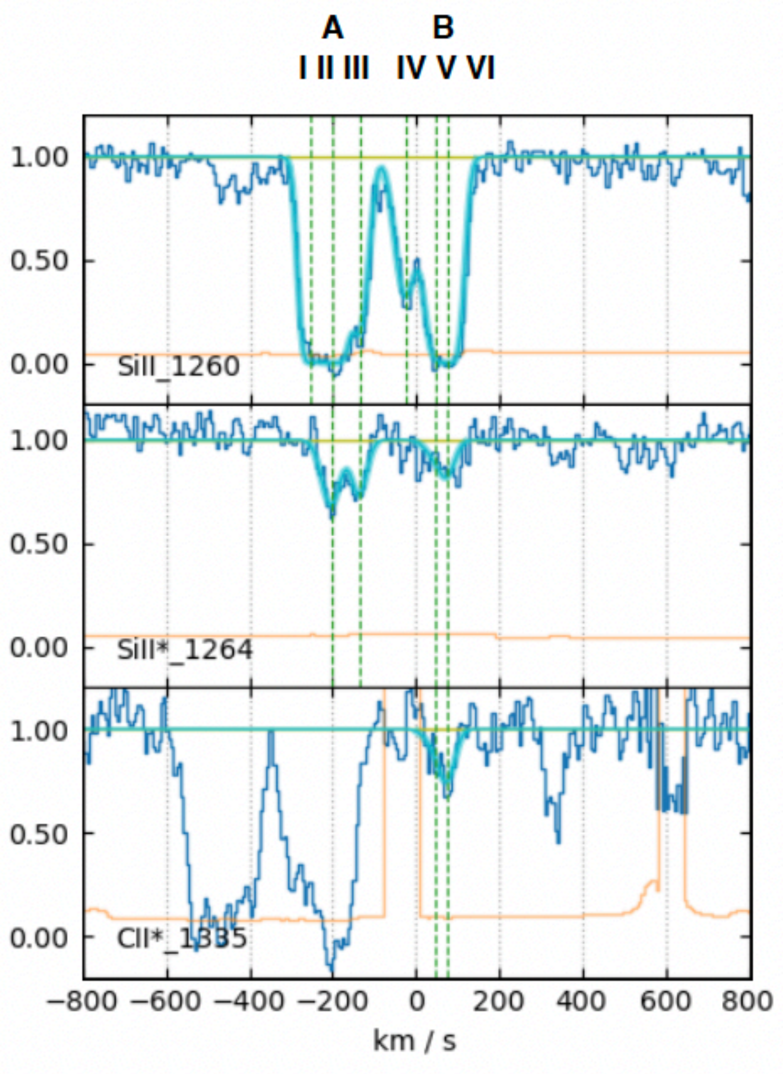
GRB210905A VLT/X-shooter Spectrum

After ~2.53h obs frame









The z = 6.3 system:

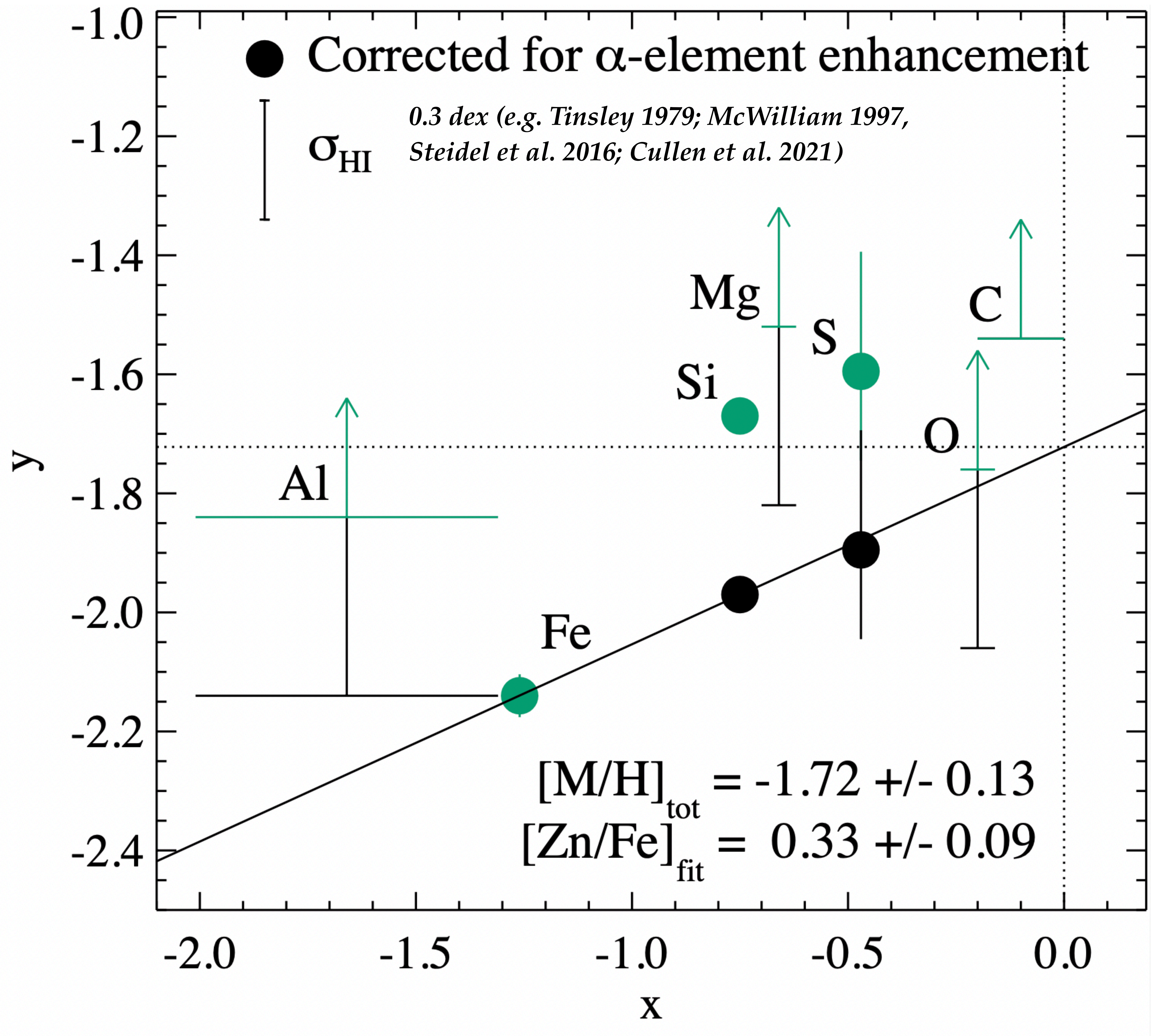
-The z~6.3 complex spans ~360 km s^{-1} and is composed of two major systems (A and B) separated by ~300 km s^{-1}, and formed by six components

-Fine-structure lines in both systems (components II, III, V, VI)

The GRB host galaxy at z ~ 6.3

We perform a detailed analysis of metallicity, chemical enrichment and dust depletion

The overall host galaxy



Following De Cia et al. 2016, De Cia et al. 2021

AXIS

X = How refractory is an element

Y = Elements abundances

FIT

Slope —> $[Zn/Fe]_{fit}$

Intercept —> $[M/H]_{tot}$

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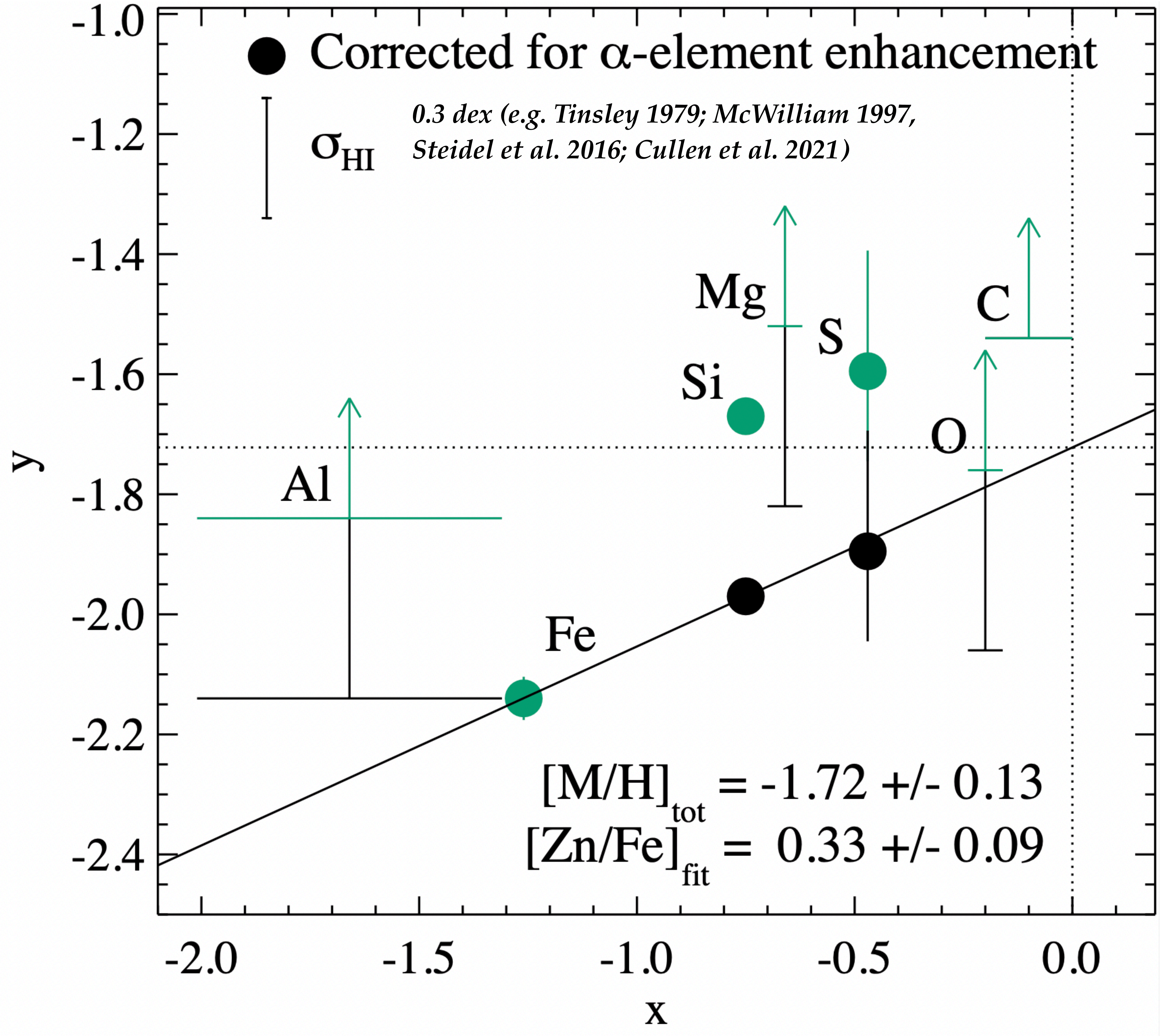
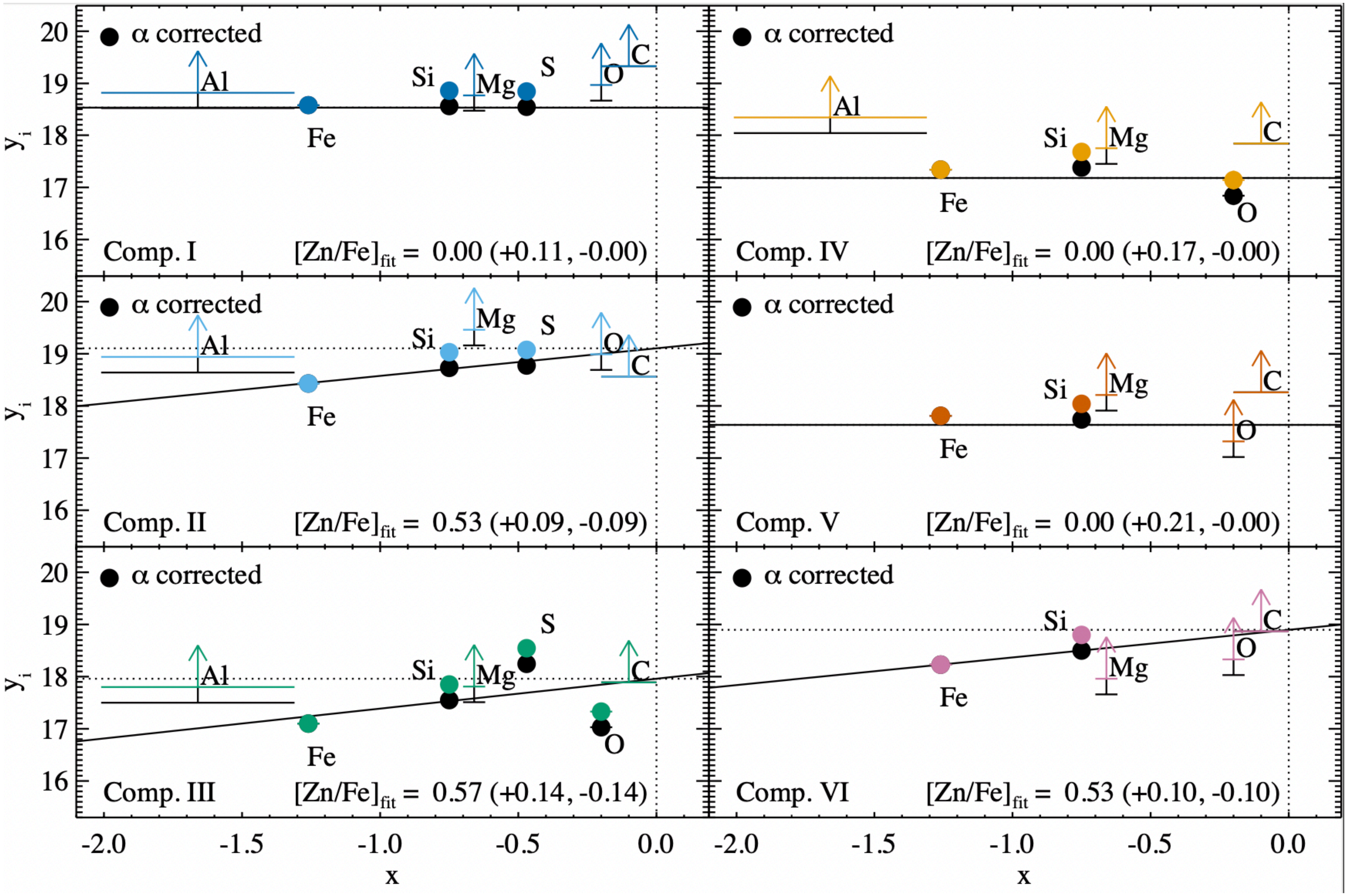


Component-by-component

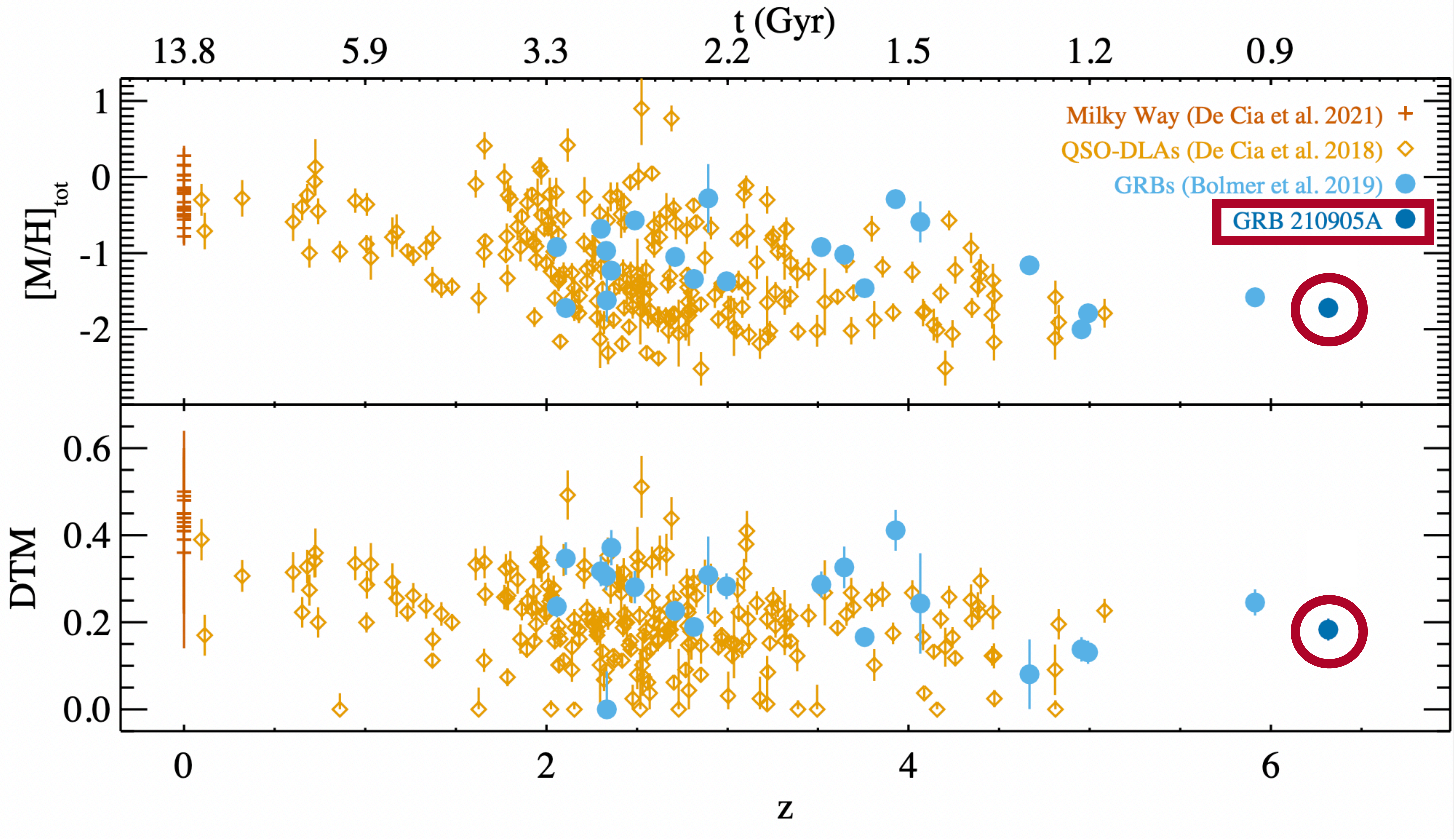


A. Saccardi, S.D. Vergani, A. De Cia et al. 2023

The GRB host galaxy at z ~ 6.3

RESULTS

-We find that the dust-corrected metallicity of the GRB host is [M/H] = -1.72 +/- 0.13 and DTM = 0.18 +/- 0.03



A. Saccardi, S.D. Vergani, A. De Cia et al. 2023

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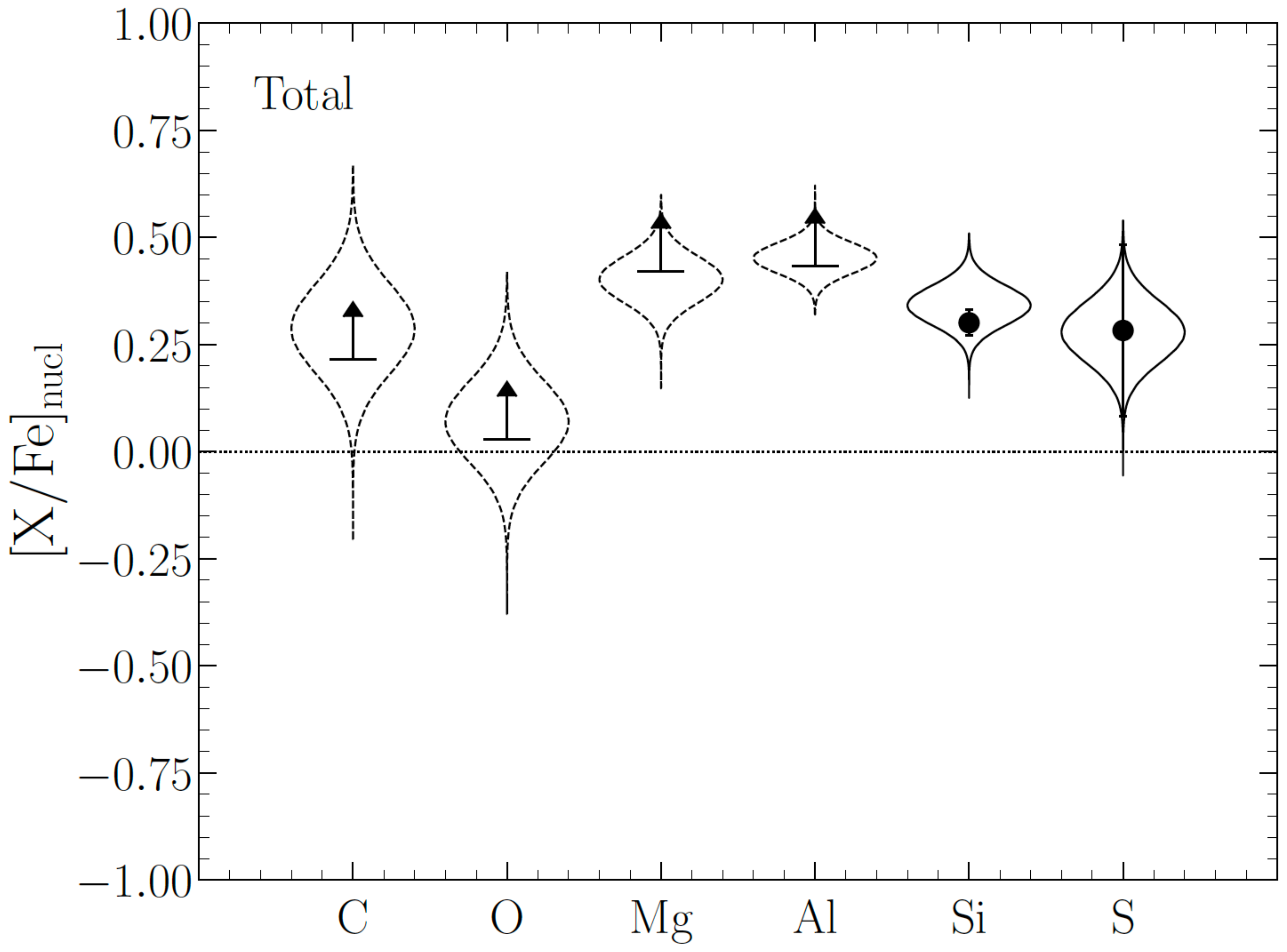
-We determine the total abundance pattern and for each component: the abundance ratios, $[X/Fe]_{nucl}$, are due to the effect of nucleosynthesis



A. Saccardi, S.D. Vergani, A. De Cia et al. 2023

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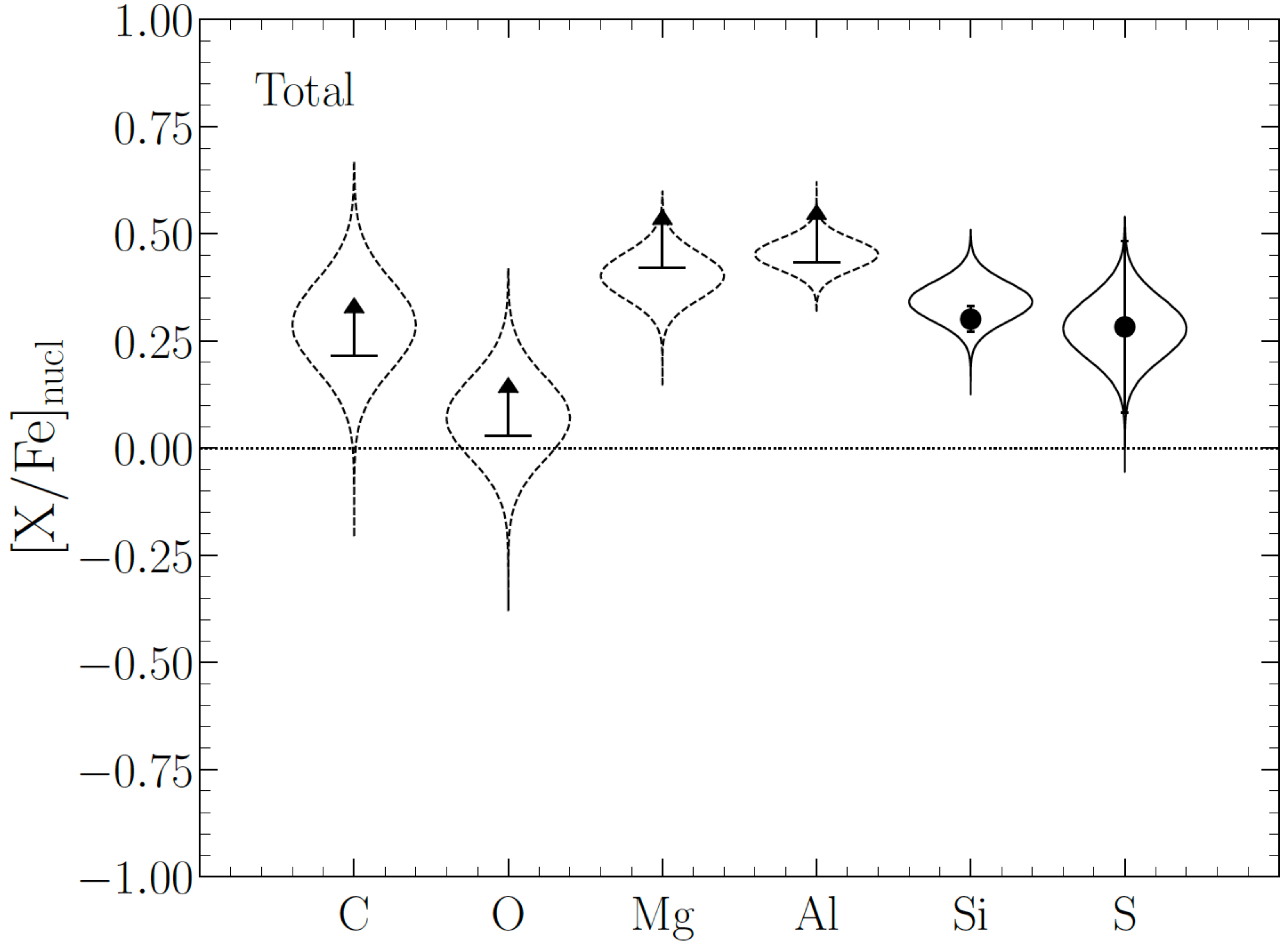

A. Saccardi, S.D. Vergani, A. De Cia et al. 2023

-Alpha element enhancement
-Nucleosynthesis due to core-collapse SNe and massive (S-)AGB stars.
(e.g., Masseron et al. 2020)

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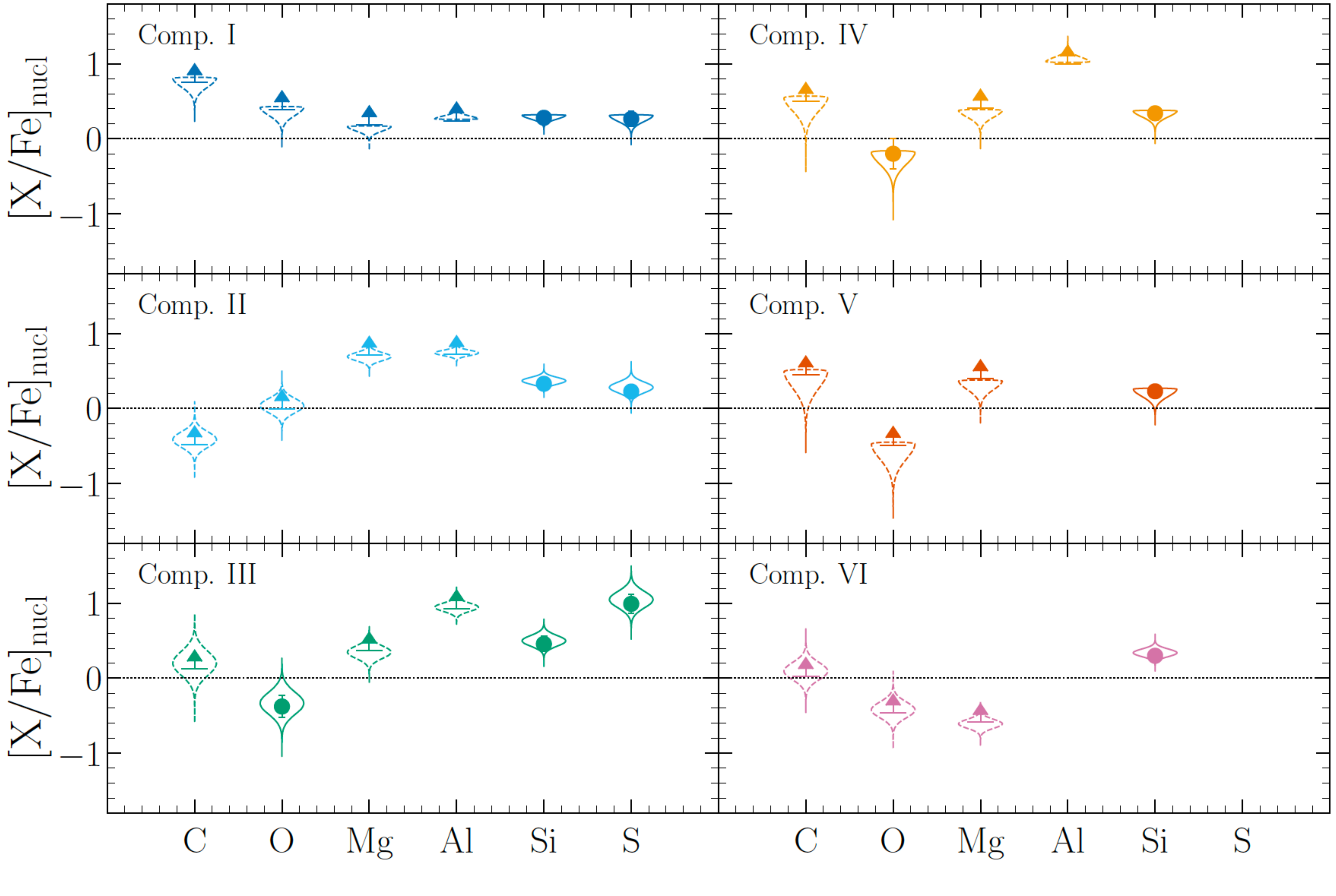

A. Saccardi, S.D. Vergani, A. De Cia et al. 2023

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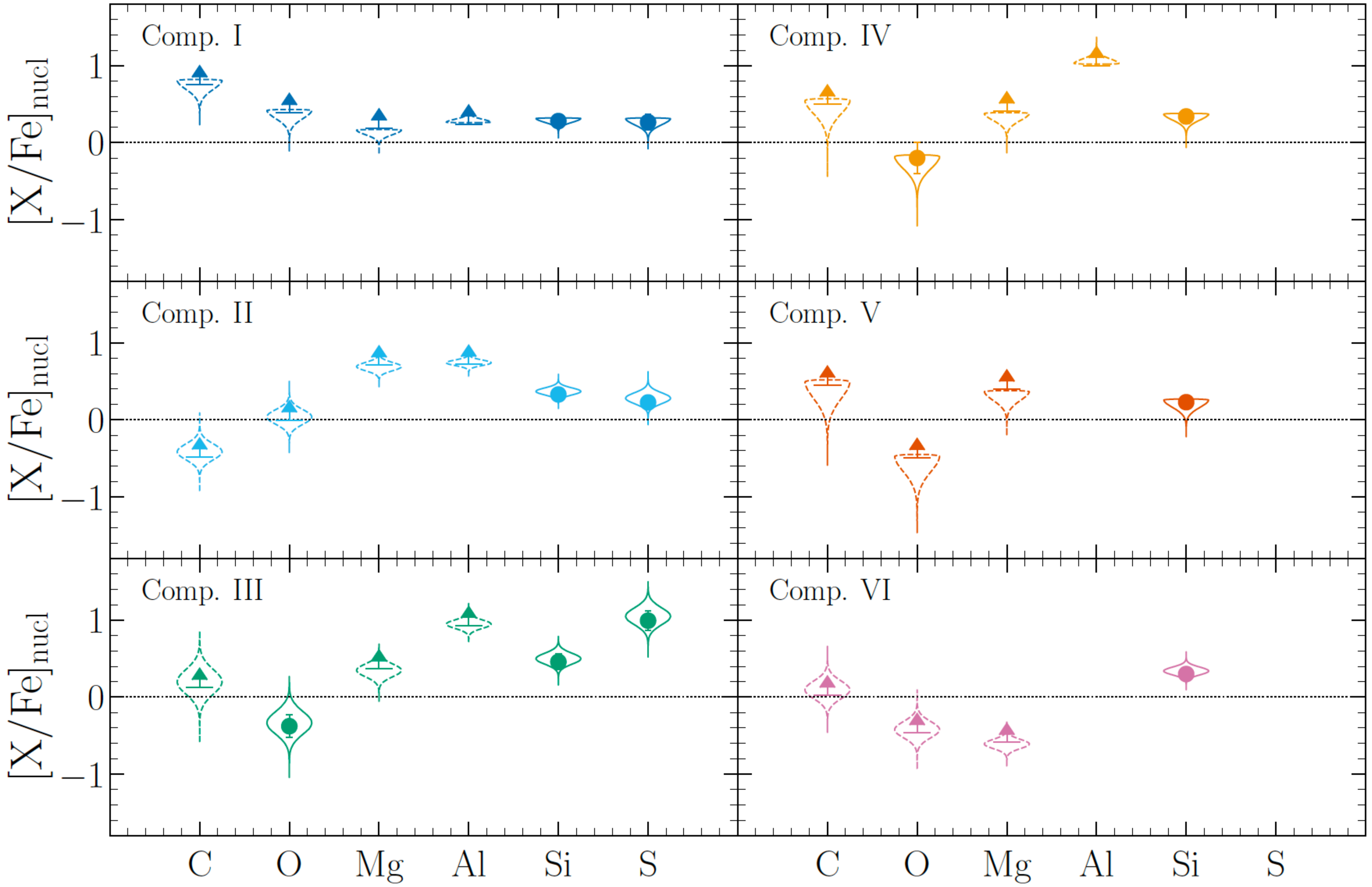


A. Saccardi, S.D. Vergani, A. De Cia et al. 2023

Over-abundance of aluminium
Under-abundance of oxygen:

-typical of some stars found in globular clusters and dwarf galaxies

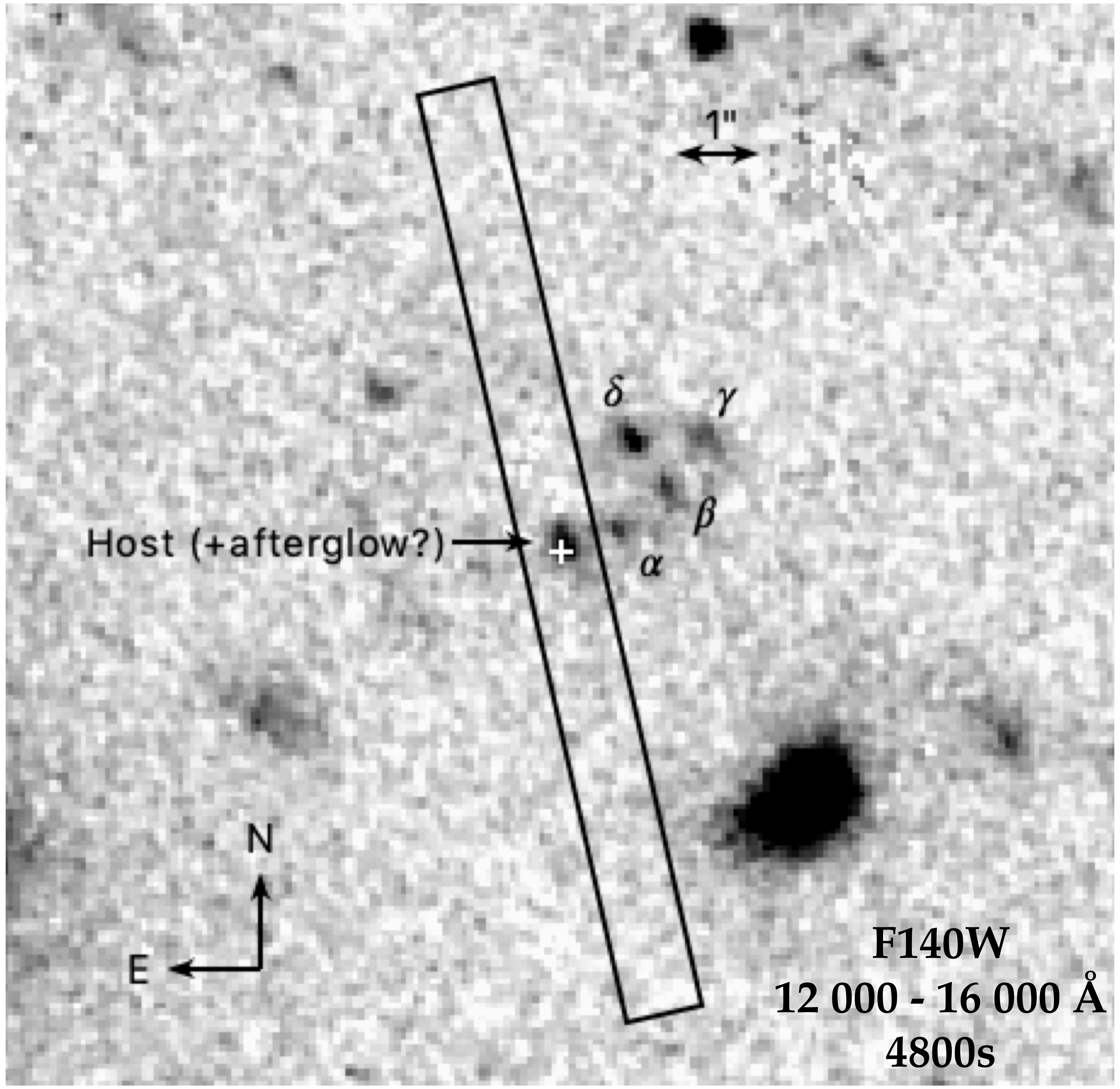
-the best candidates are massive AGB stars and fast rotating massive stars

(e.g., Prantzos et al. 2007; Fulbright et al. 2007; Alves-Brito et al. 2010)

The GRB host galaxy at z ~ 6.3

GRB210905A HST/WFC3 Image

After ~250 days obs frame



A. Saccardi, S.D. Vergani, A. De Cia et al. 2023

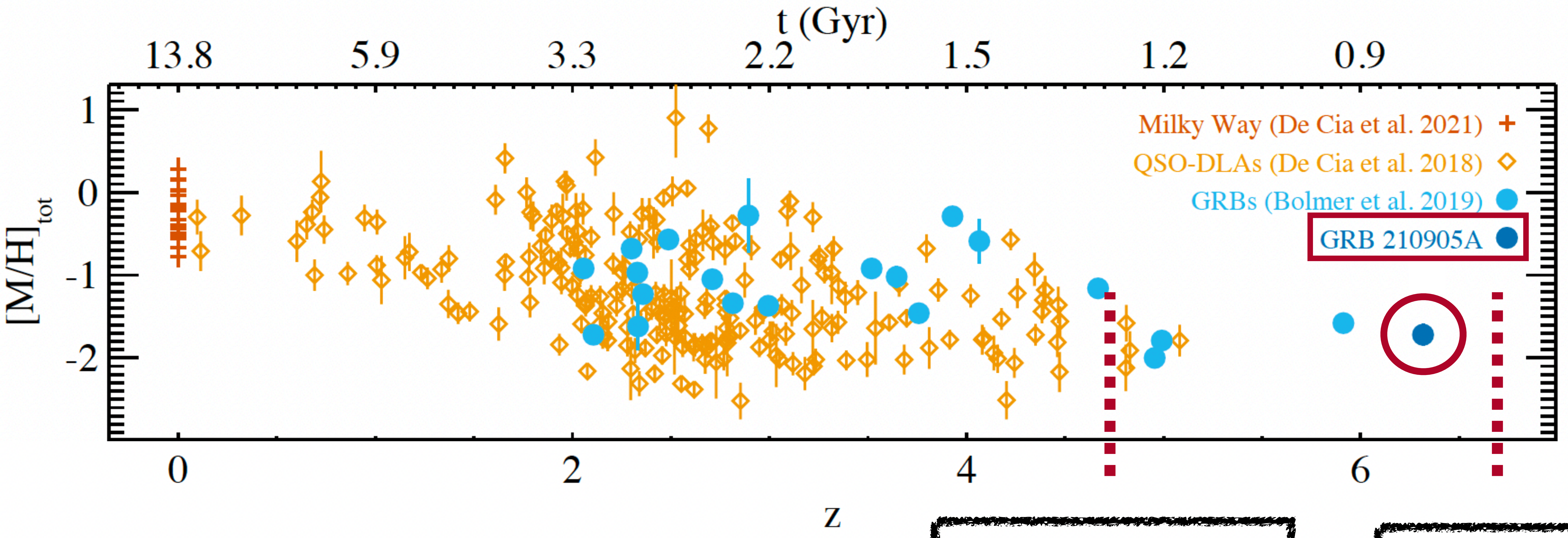
Follow-up observations

-2nd **HST** epoch in two different filters (F140W and F775W) (Executed) → δ object at lower redshift (detected in F775W filter)

-**JWST** IFU spectroscopy of the GRB host field (To be submitted) → **Detect Hα, Hβ, [OIII] λ5007 to:**
- -determine the redshift of the objects;
- -the presence of a galaxy group/clumps;
- -studying different phases and kinematics of the gas

-**ESO/MUSE** IFU spectroscopy of the GRB host field (Accepted - P113 - April/Sept) PI: A. Saccardi → **Detect Lyα emission to:**
- -determine the Lyα spatial distribution
- -look for the presence of a Lyα blobs extending over the galaxy group
- -model the Lyα emission

High-z GRBs



Adapted from A. Saccardi, S.D. Vergani, A. De Cia et al. 2023

NEW!
Einstein Probe GRB

NEW!
Swift GRB

Thanks to GRB afterglow spectroscopy we can reach the high redshift Universe and populate the reionization era (i.e. z>6)

GCN Circular 35756

Subject GRB 240218A: VLT/X-shooter redshift of z = 6.782
Date 2024-02-19T11:21:15Z (2 months ago)
From Andrea Saccardi at Observatoire de Paris <andrea.saccardi@obspm.fr>
Via Web form

A. Saccardi (GEPI/Obs. de Paris), D. B. Malesani (DAWN/NBI & Radboud Univ.), J. T. Palmerio (GEPI/Obs. de Paris & IAP), S. D. Vergani (GEPI/Obs. de Paris & IAP & INAF/OABr), E. Le Floc'h (CEA), L. Izzo (INAF/OACn & DARK/NBI), A. J. Levan (Radboud Univ. & Warwick Univ.), J. P. U. Fynbo (DAWN/NBI), P. D'Avanzo (INAF/OABr), A. Rossi (INAF/OAS), A. de Ugarte Postigo (OCA), report on behalf of the Stargate collaboration:

z = 6.782

A. Saccardi, S.D. Vergani et al. in preparation

GCN Circular 35936

Subject X-ray transient EP240315a: VLT/X-shooter spectroscopic redshift of z = 4.859
Date 2024-03-17T06:54:26Z (a month ago)
From Andrea Saccardi at Observatoire de Paris <andrea.saccardi@obspm.fr>
Via Web form

A. Saccardi (GEPI/Obs. de Paris), A. J. Levan (Radboud Univ. & Warwick Univ.), Z. Zhu (NAOC), B. P. Gompertz (U. Birmingham), S. D. Vergani (GEPI/Obs. de Paris & IAP & INAF/OABr), G. Pugliese (API), D. Xu (NAOC), D. B. Malesani (DAWN/NBI and Radboud Univ.), report on behalf of the Stargate collaboration:

z = 4.859

A. J. Levan, P. G. Jonker, A. Saccardi et al. submitted (Nature Astronomy)

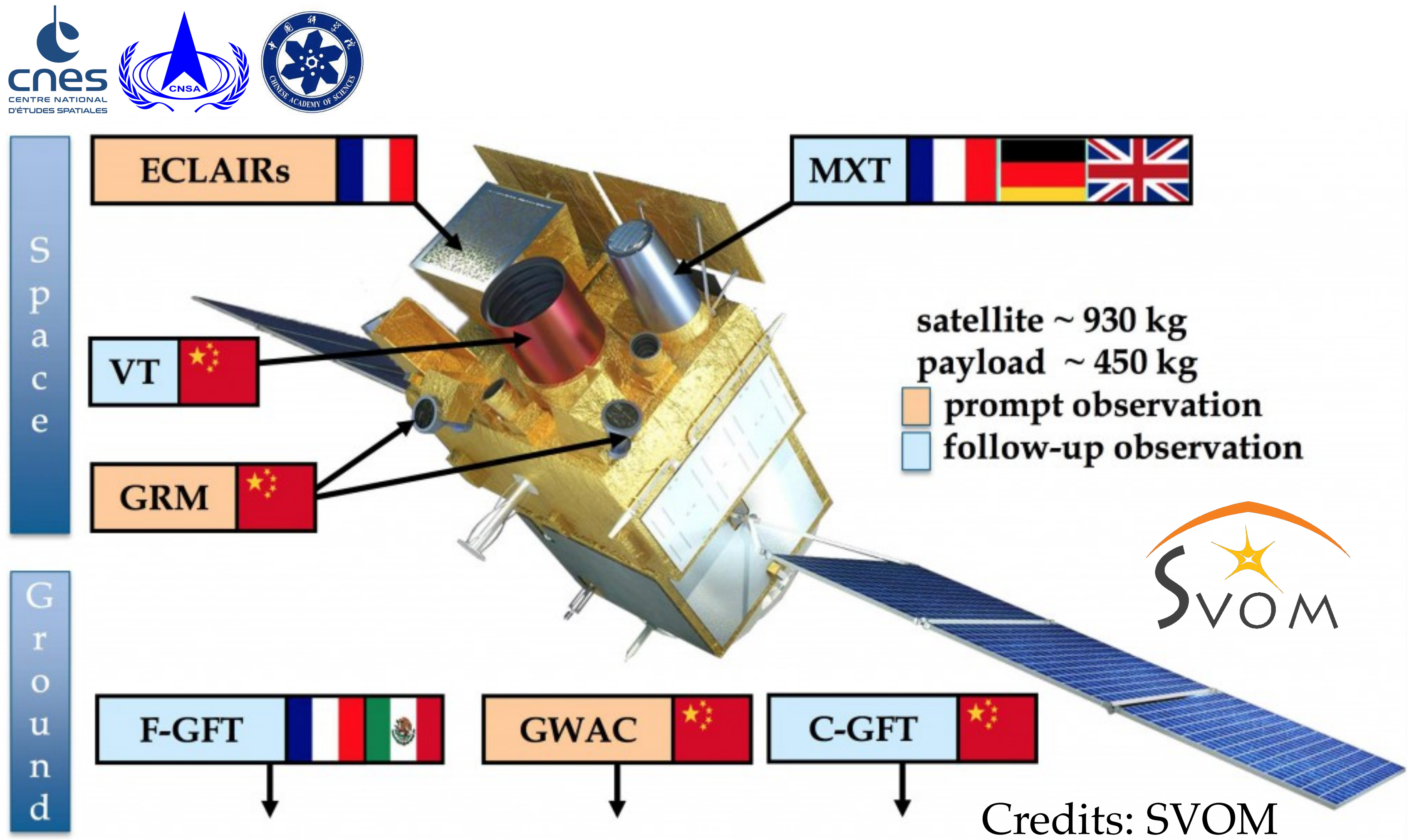
——> **Limitation**: <u>poor fraction of GRBs with an optical/NIR afterglow spectrum (20-30%)</u>

Nearby Future

SVOM

GOAL: boost to 50/60% the fraction of GRBs with redshift determination and enhance the number of high-z GRBs

Launch 24 June 2024 *https://www.svom.eu/*



Credits: SVOM

SVOM Payload

-γ-ray monitor GRM
(FoV ~ 5.6 sr; up to 5MeV)

-γ-ray telescope ECLAIRs
(< 12′; FoV ~ 2 sr; 4keV- 120keV)

-X-ray telescope MXT
(< 13″; 0.2–10 keV)

-Visible telescope VT
(~ 1″; 400–1000 nm)

How?

-An **energy threshold** of γ-ray detector at 4 keV may enable the detection of **faint soft GRBs** (e.g. high-redshift GRBs)

-A near anti-solar pointing ensuring that **SVOM GRBs are observable from earth**

-The satellite's orbit covers latitudes from +30° to -30°: **North and South follow-up**

-Good sensitivity of the on-board optical telescope: rapid identification of high-z candidates (r~22.5 (AB) in 300s)

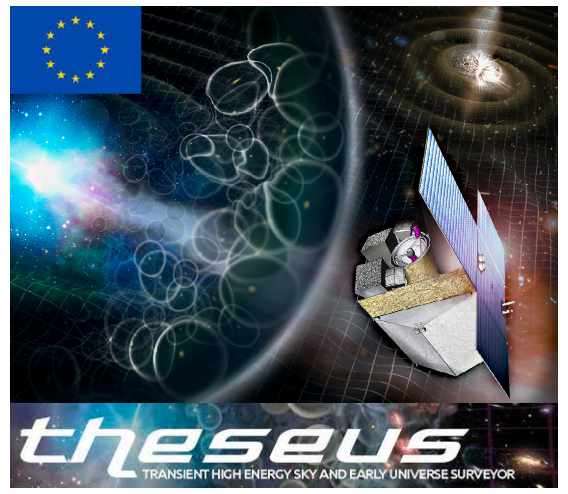
-Dedicated **NIR follow-up on the ground:** France responsible of one of the ground based telescopes (F-GFT) COLIBRI

-Agreements to obtain the **spectroscopic observations of SVOM-GRB** with large ground-based telescope

Long term Perspectives

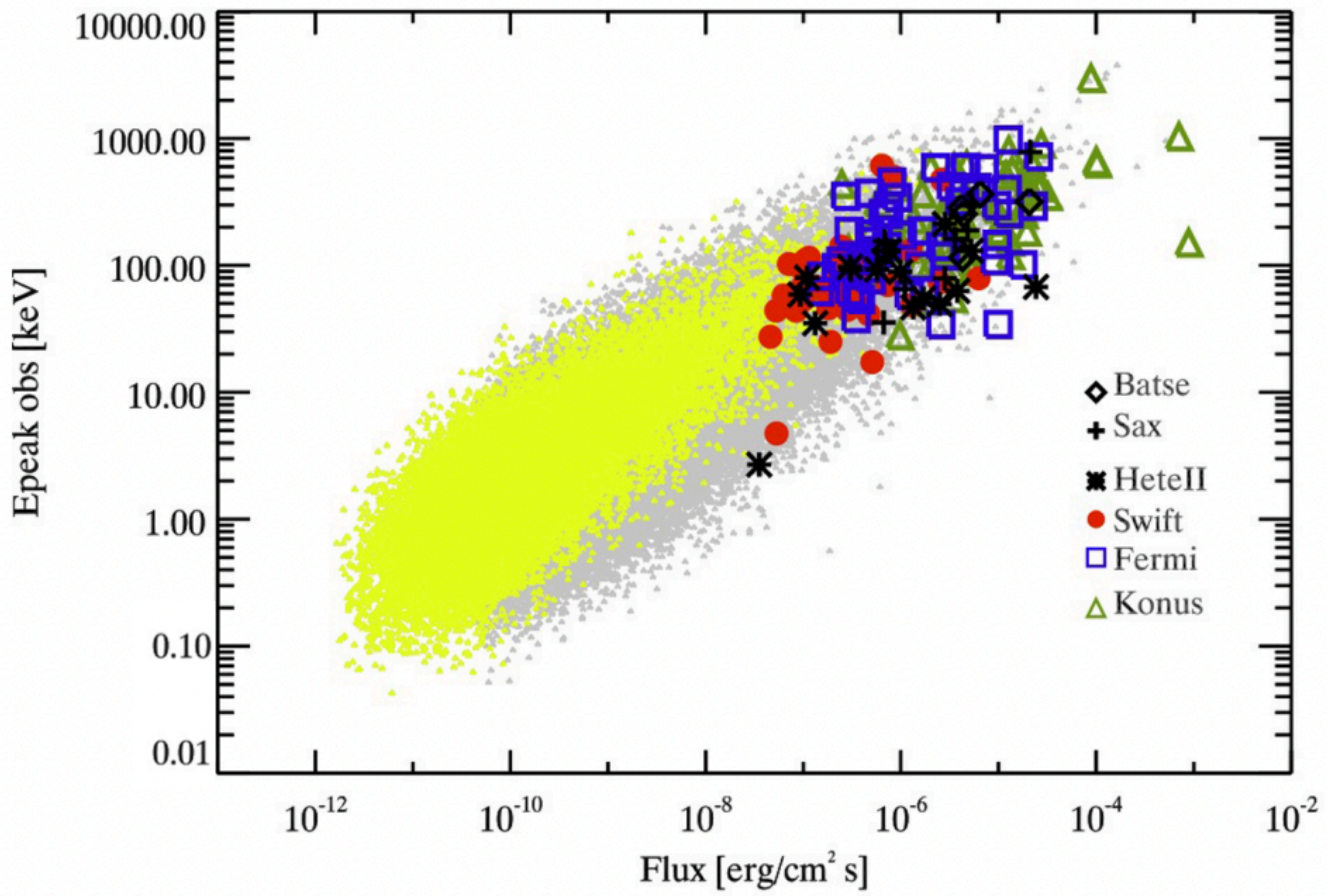
THESEUS

Selected for ESA M7 Phase-A

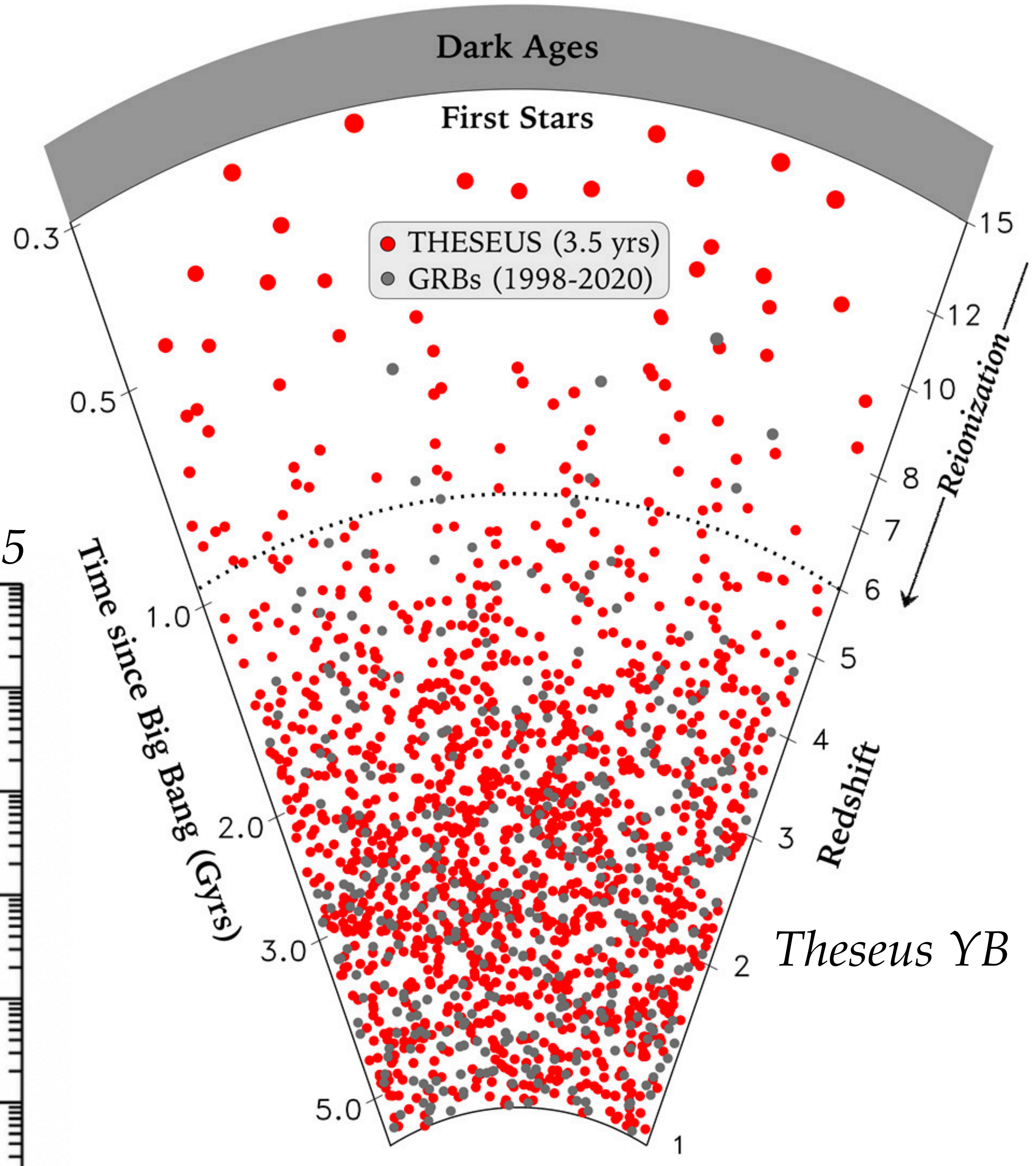


http://www.isdc.unige.ch/theseus

Ghirlanda et al. 2015



In order to efficiently detect high-redshift GRBs one needs a detector working in a softer energy band (e.g. 0.1–10 keV)



Theseus YB

THESEUS Payload

-Soft X-ray Imager (SXI, 0.3 – 5 keV)

-X-Gamma rays Imaging Spectrometer (XGIS, 2 keV – 10 MeV)

-InfraRed Telescope

(IRT, 0.7 – 1.8 μm)

ANDES

-Three fibre-fed spectrographs (UBV, RIZ, YJH)

-Spectral resolution of R~100,000

-Simultaneous wavelength coverage of 0.4-1.8 μm

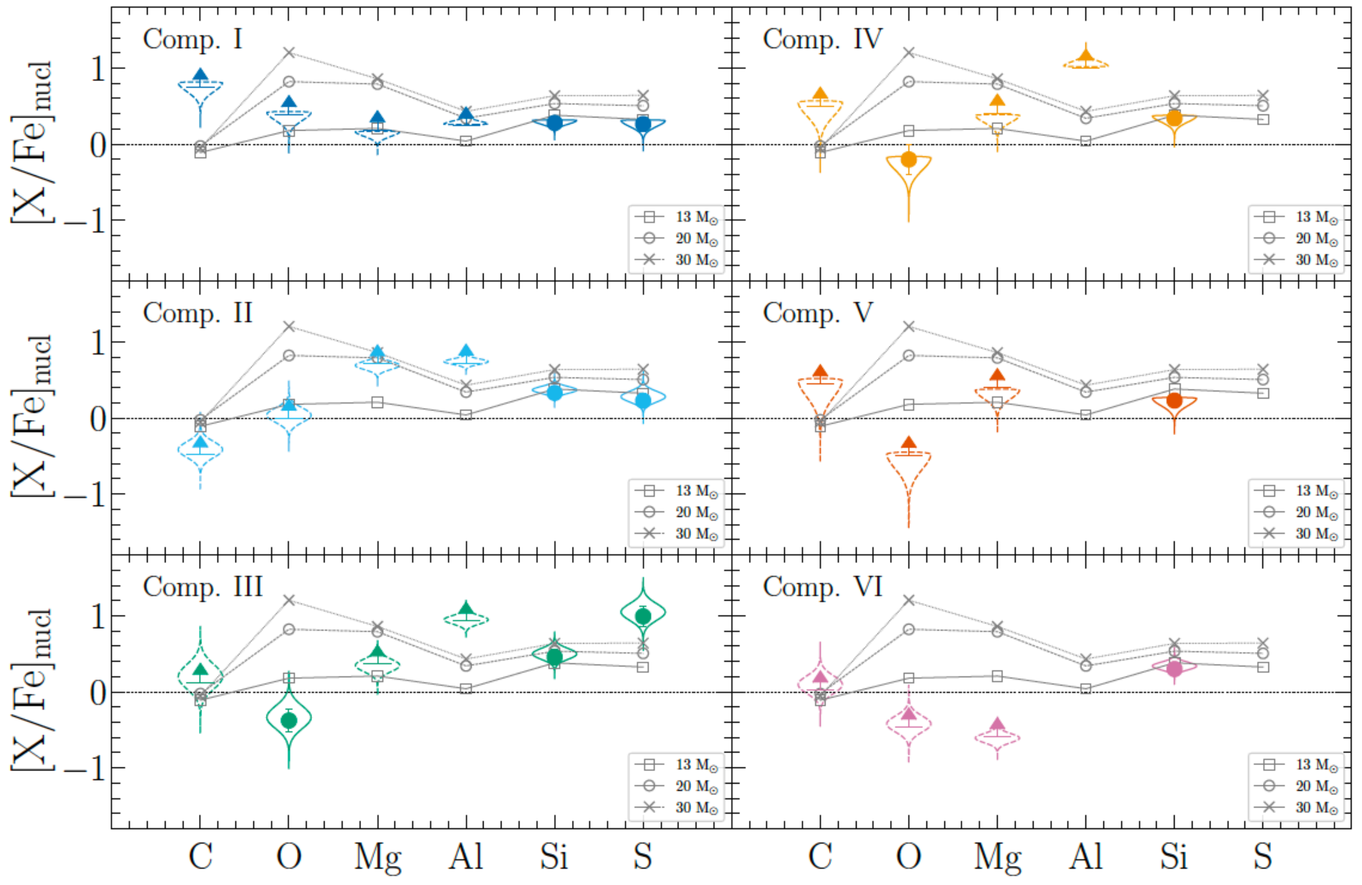
-Goal of extending to 0.35-2.4 μm (K band spectrograph)

ANDES

Marconi et al. 2022

WG3

Galaxy Formation and Evolution and the Inter-Galactic Medium



ANDES White Book

(D'Odorico et al. 2024 submitted)

Adapted from Saccardi et al. 2023a

(i) reach the SNR levels needed to study the faint high-z sources

(ii) resolve narrow absorption lines

(iii) constrain key elements column density

(iv) study relative abundances in individual gas components

Conclusions

-The investigation of high-redshift gaseous environments and their metal content can provide unique insight on the early phases of reionization.

-Bright background sources are needed to study the neutral/warm gas

-GRBs are very powerful tools to characterize faint star-forming high redshift galaxies

-Thanks to GRB 210905A we were able to obtain unique and detailed information of the neutral gas and its chemical composition for a L^* galaxy at the end of the reionization

-The future is bright thanks to new space missions such as SVOM and hopefully Theseus in synergy with ELT ground-based observations

Saccardi et al. 2023a
A&A 671, A84

Thanks for your attention

Museo Archeologico di Pithecusae

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Galaxies Étoiles Physique et Instrumentation

École Doctorale d'Astronomie & Astrophysique d'Île-de-France