25 March 2025

GRBs as probes of the high-z Universe

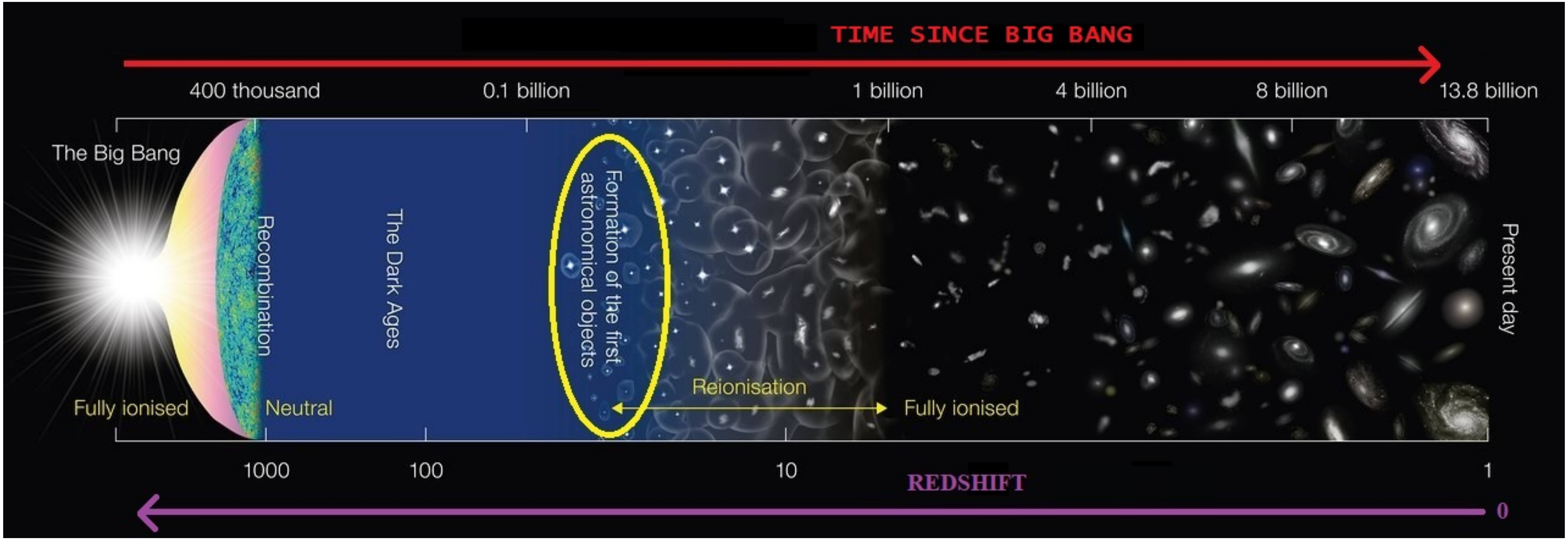
ANDREA SACCARDI
CNES Postdoctoral Fellow
@CEA/Irfu/DAp - AIM

The Distant Universe

-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?



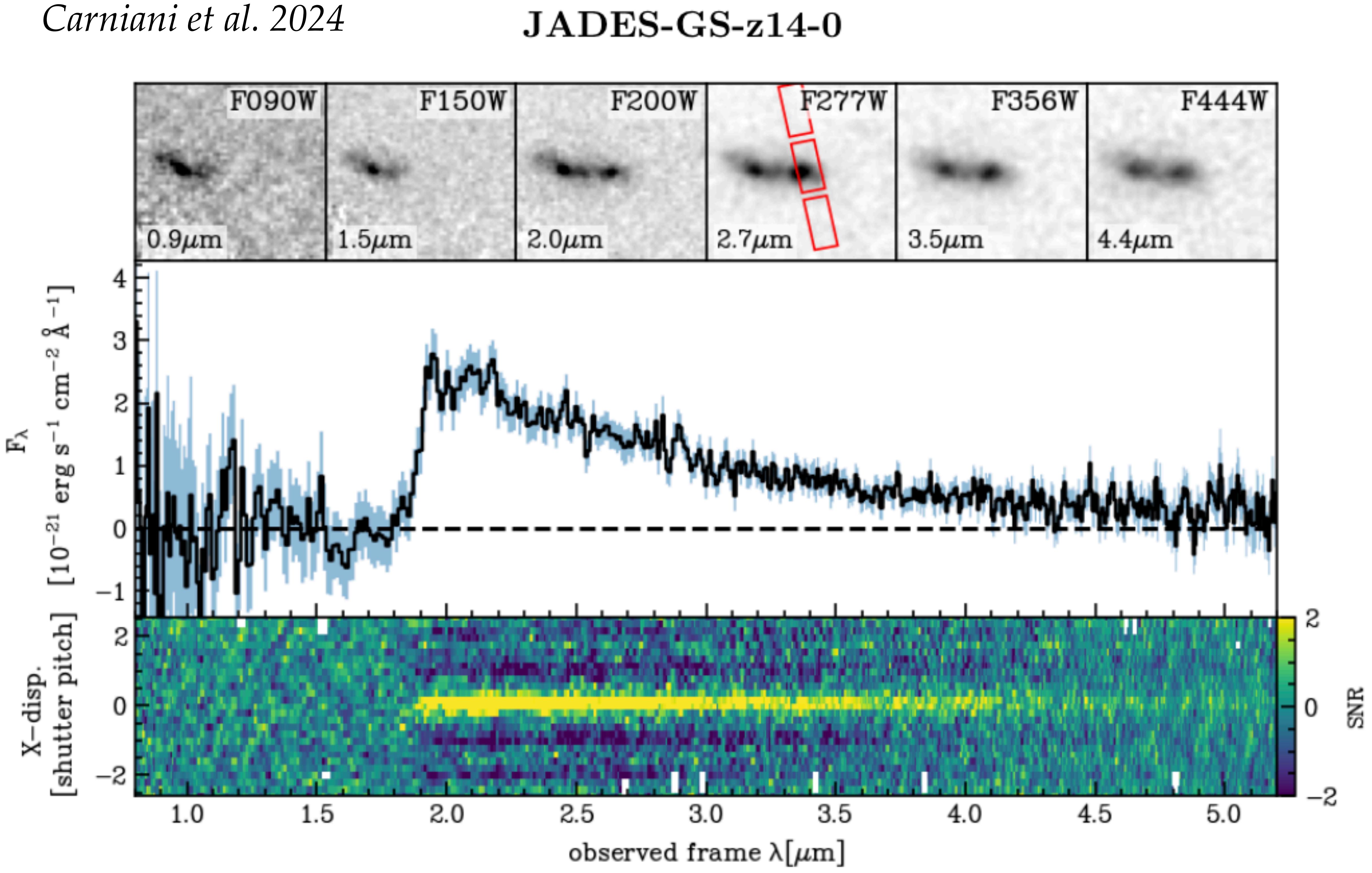
Credits: ESO

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

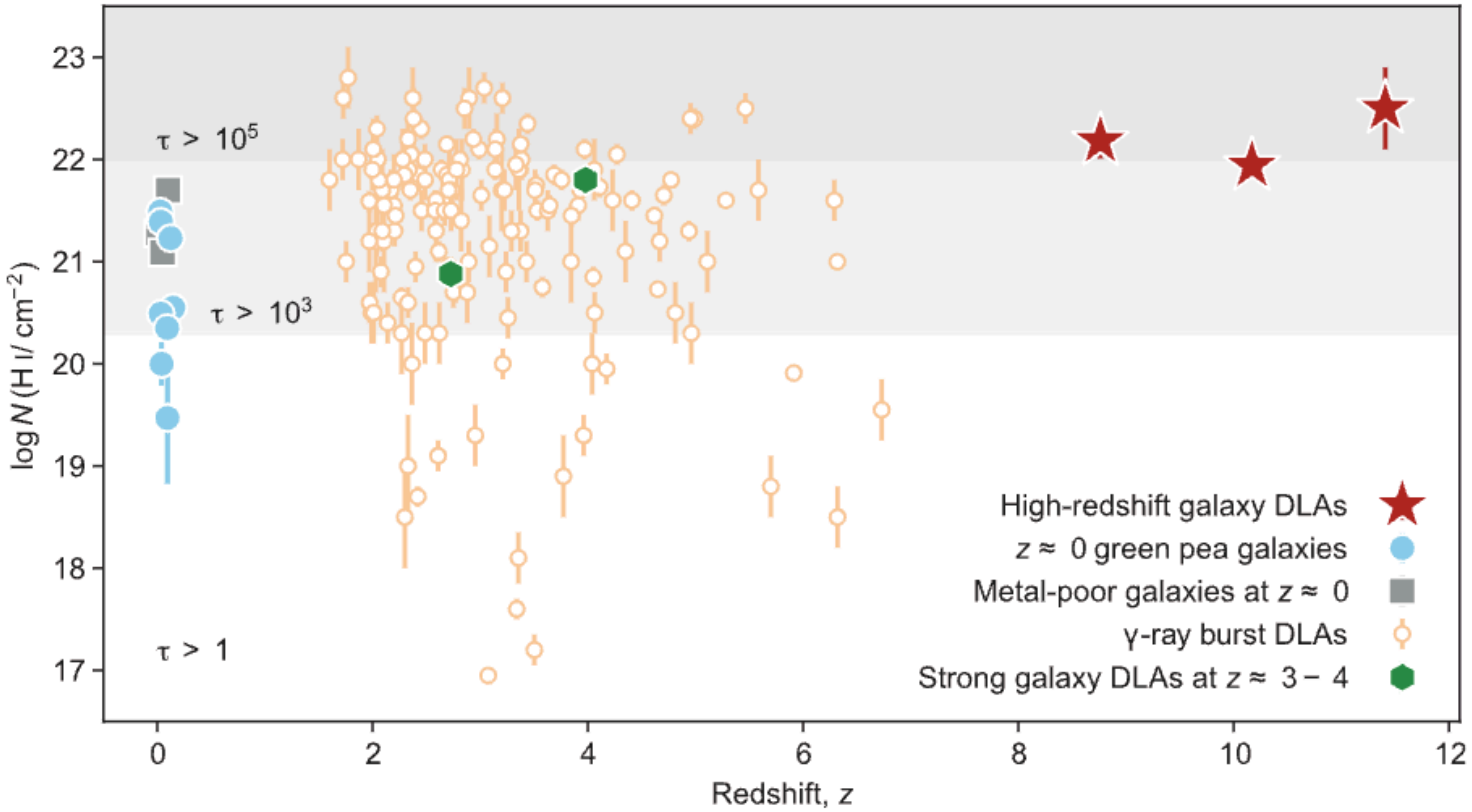
The advent of JWST is revolutionizing the field, allowing:

- The observation of galaxies up to a spectroscopically confirmed redshift of z~14

Carniani et al. 2024



Heintz et al. 2024



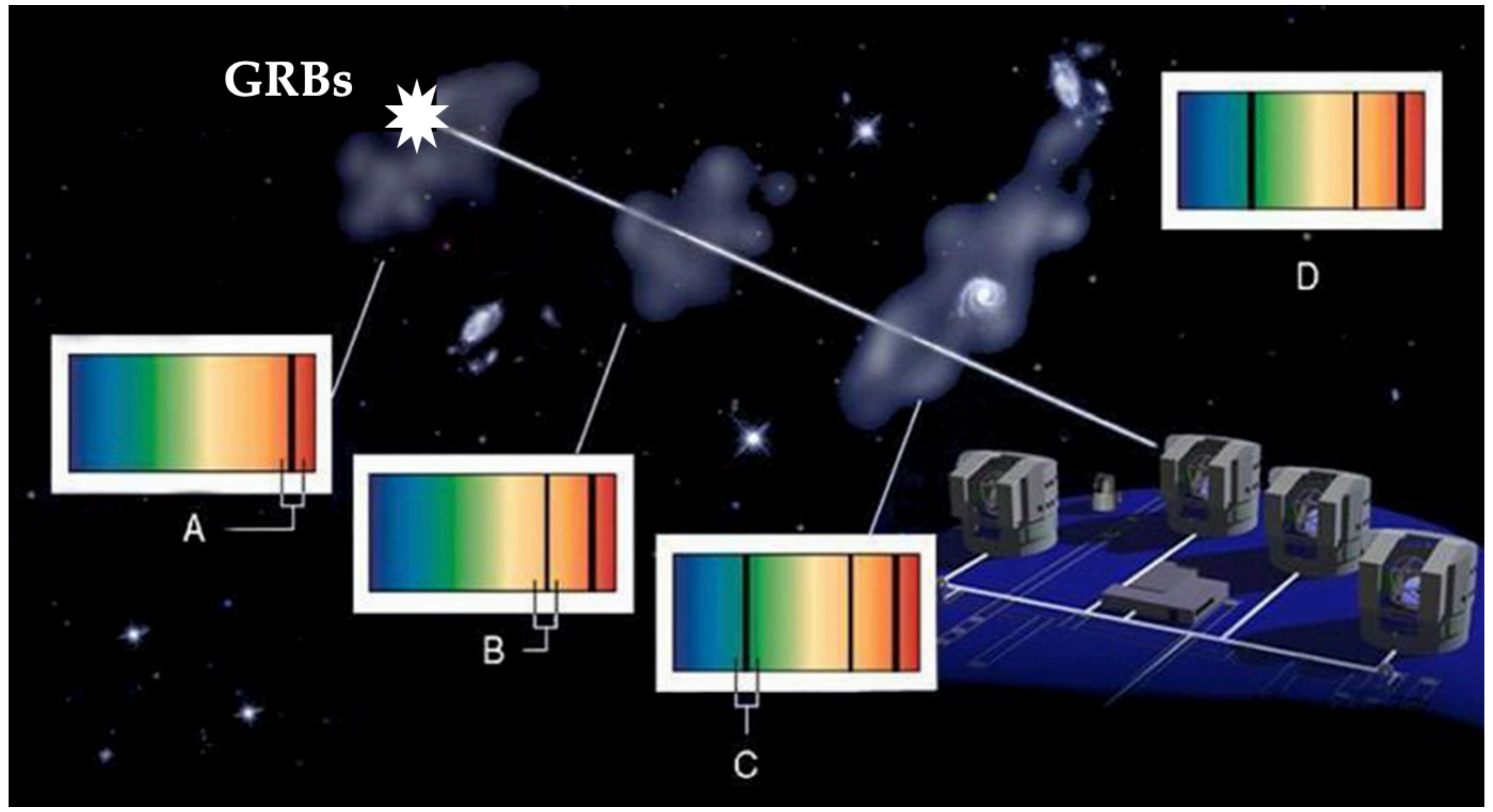
- Direct measurement of neutral hydrogen gas reservoirs in the local environments of galaxies at z > 8!

LGRBs as probes of the high redshift Universe

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

—> **FEW CONSTRAINTS ON THE PROPERTIES OF NEUTRAL COLD/WARM GAS IN GALAXIES**

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

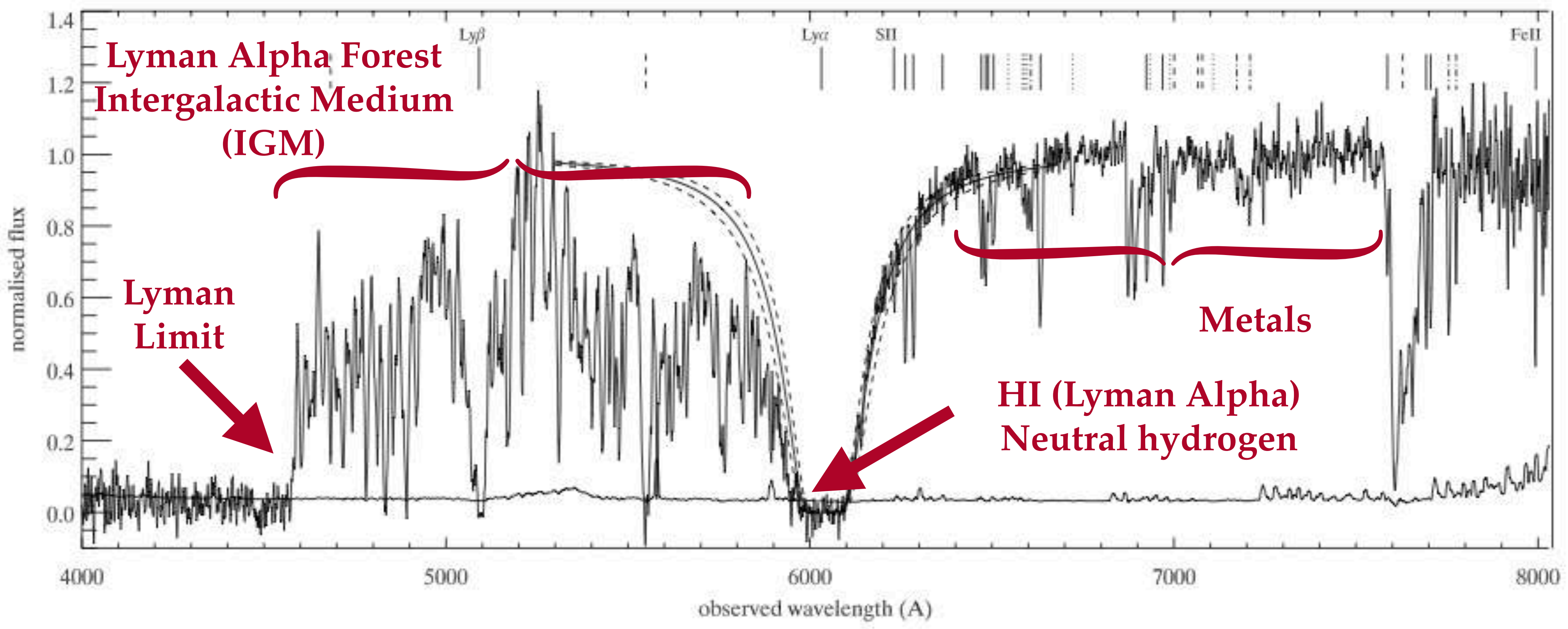


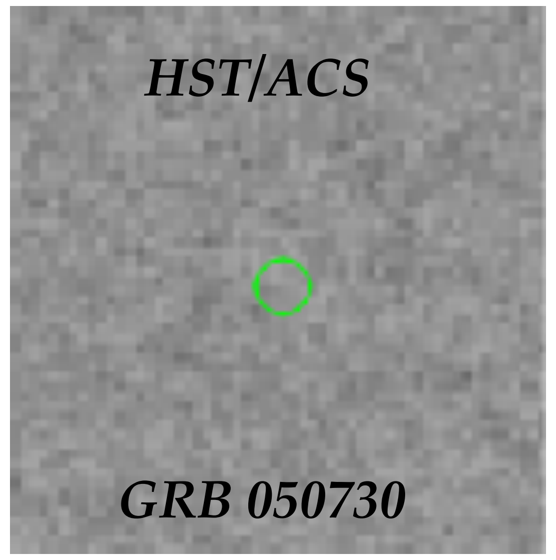
Credits: *Adapted from ESO PR0813a*

GRB 050730
z=3.968

~1h Observation

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





R>28.5

The powerful potential of LGRBs afterglow to access detailed information on the neutral gas and its components

We can measure:

- ➡ *Redshift of the absorbers*
- ➡ *Column densities of the ions of different chemical elements*

To study:

-Metallicity and dust depletion
-The distance of the corresponding gas clouds
-Kinematic of the gas
-Chemical abundance pattern

See N. Tanvir's Talk!

VLT follow-up

Stargate **Collaboration**

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

ESO Large Programme

GRBs Follow-up with optical-NIR telescopes

Credits: ESO/M. Claro

High-z GRBs


GRB 130606A
z=5.913
Lya break
Metal lines
GRB 120521C
zph~6
GRB 050904A
z=6.295
Lya break
Metal lines
GRB 210905A
z=6.312
Lya break
Metal lines
GRB 140515A
z=6.327
Lya break
GRB 080913A
z=6.733
Lya break
GRB 240218A
z=6.782
Lya break
Metal lines
GRB 250314A
z~7.3
Lya break
GRB 120923A
z=7.8
Lya break
GRB 100905A
zph~7.88
GRB 090423A
z=8.23
Lya break
GRB 090429B
zph~9.4
Redshift (z)

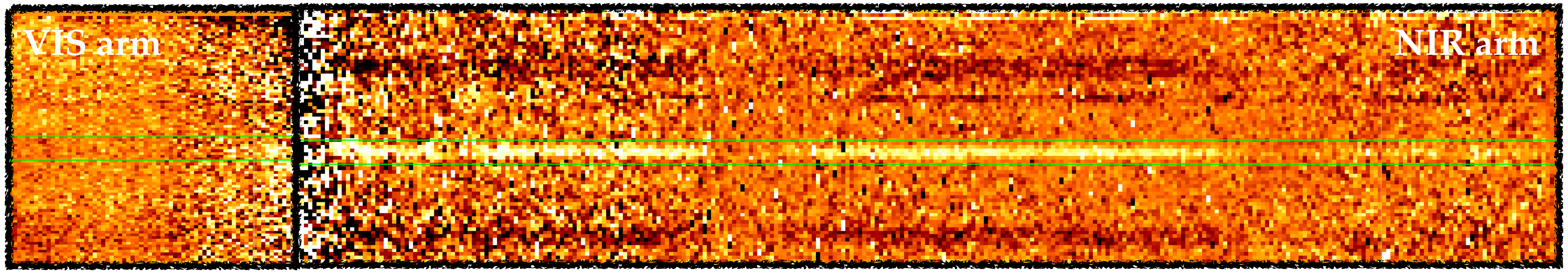
See B. Cordier's Talk!

See F. Daigne's Talk!

High-z GRBs

GRB 250314A

rebinned 2D



Credits: Stargate/A. Saccardi

Redshift (z)

z~7.3

Lya break

-High performance of VT in quickly identifying a potential high redshift candidate

-Synergy with other space satellites such as *Swift,* EP

-Powerful and successful follow-up with ground-based telescopes e.g. NOT and VLT

High-z GRBs

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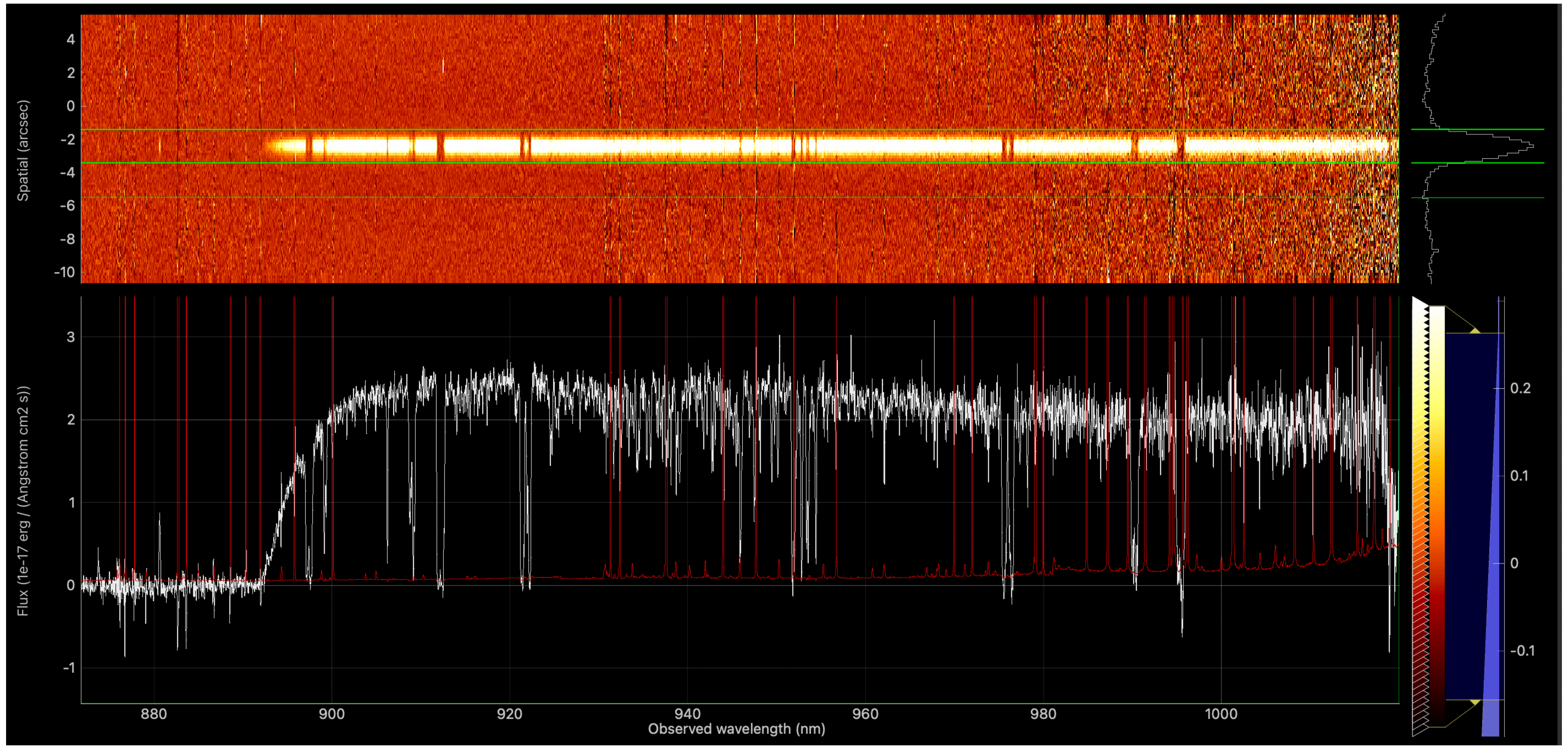
Redshift (z)

The case of GRB 210905A at z = 6.312

Dissecting the interstellar medium of a z = 6.3 galaxy.
X-shooter spectroscopy and HST imaging of the afterglow and environment of the Swift GRB 210905A

@A&A Paper - A. Saccardi et al.

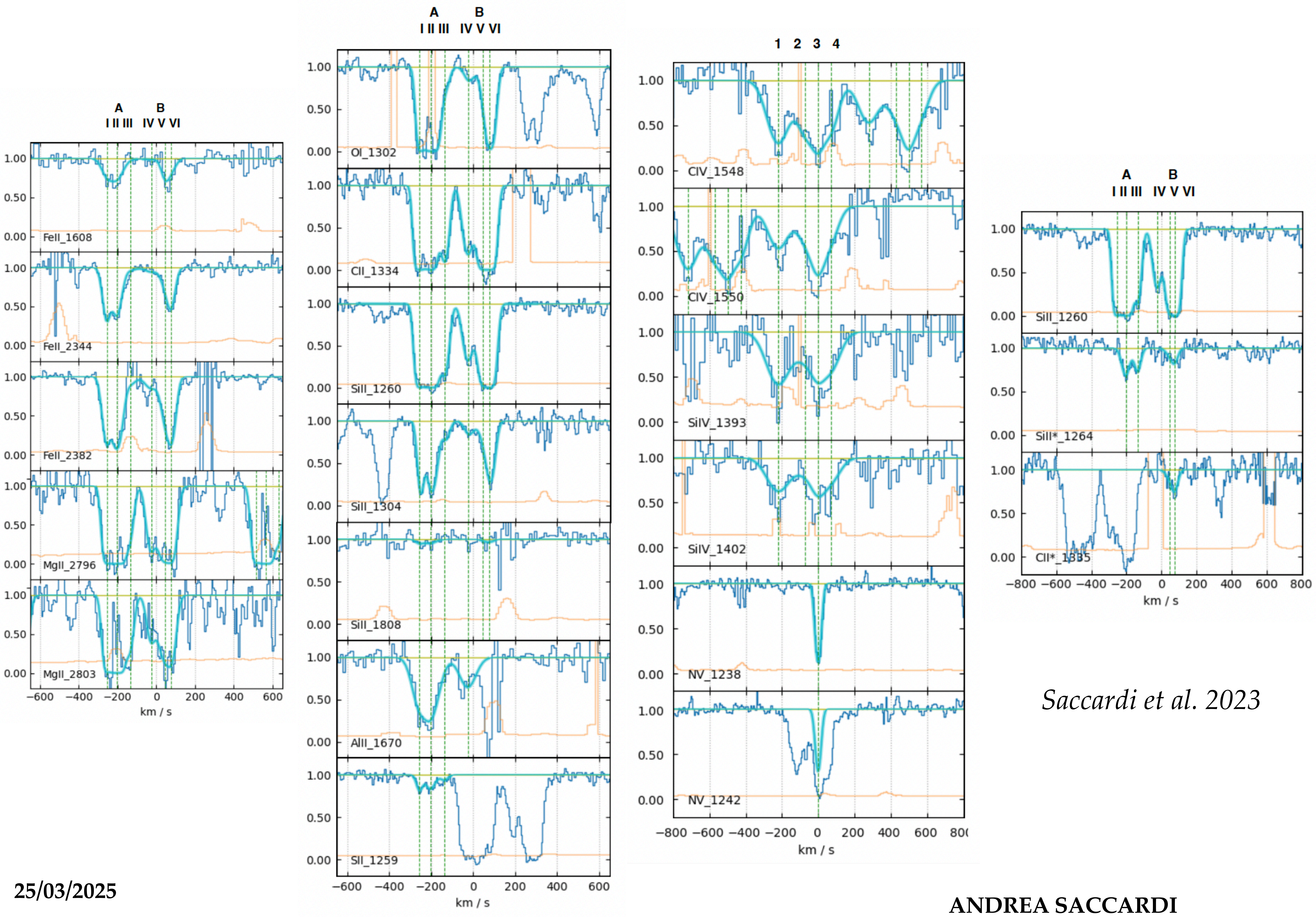
Published (2023, A&A, 671, A84, 21 pp)



Credits: Stargate/A. Saccardi

After ~2.53hr (obs frame)

GRB210905A VLT/X-shooter Spectrum



Saccardi et al. 2023

The z = 6.3 system:

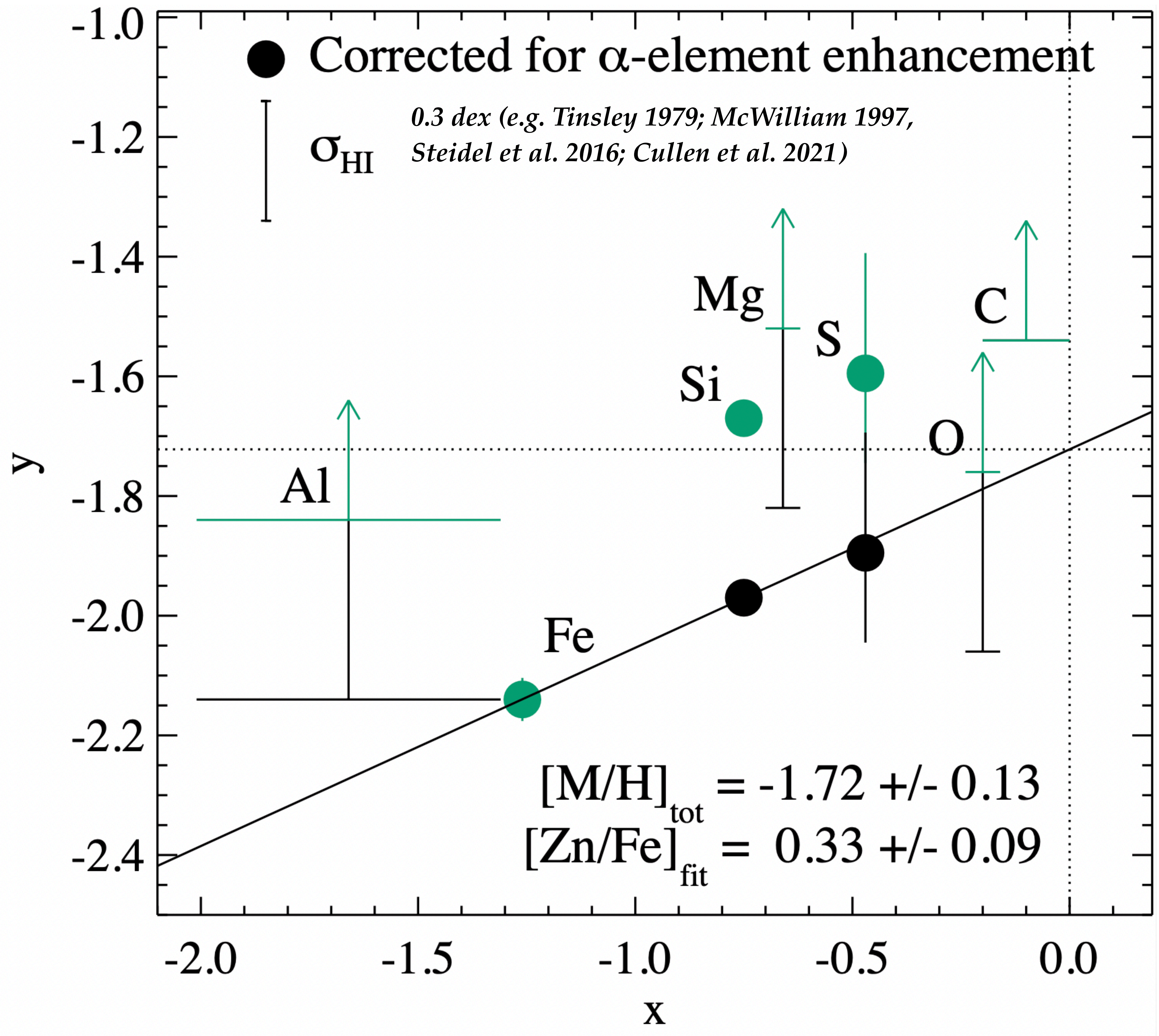
-The z~6.3 complex spans ~360 km s^{-1} and is composed of two major systems (A and B) separated by ~300 km s^{-1}, and formed by six components

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

The GRB host galaxy at z = 6.312

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

The overall host galaxy



Saccardi et al. 2023

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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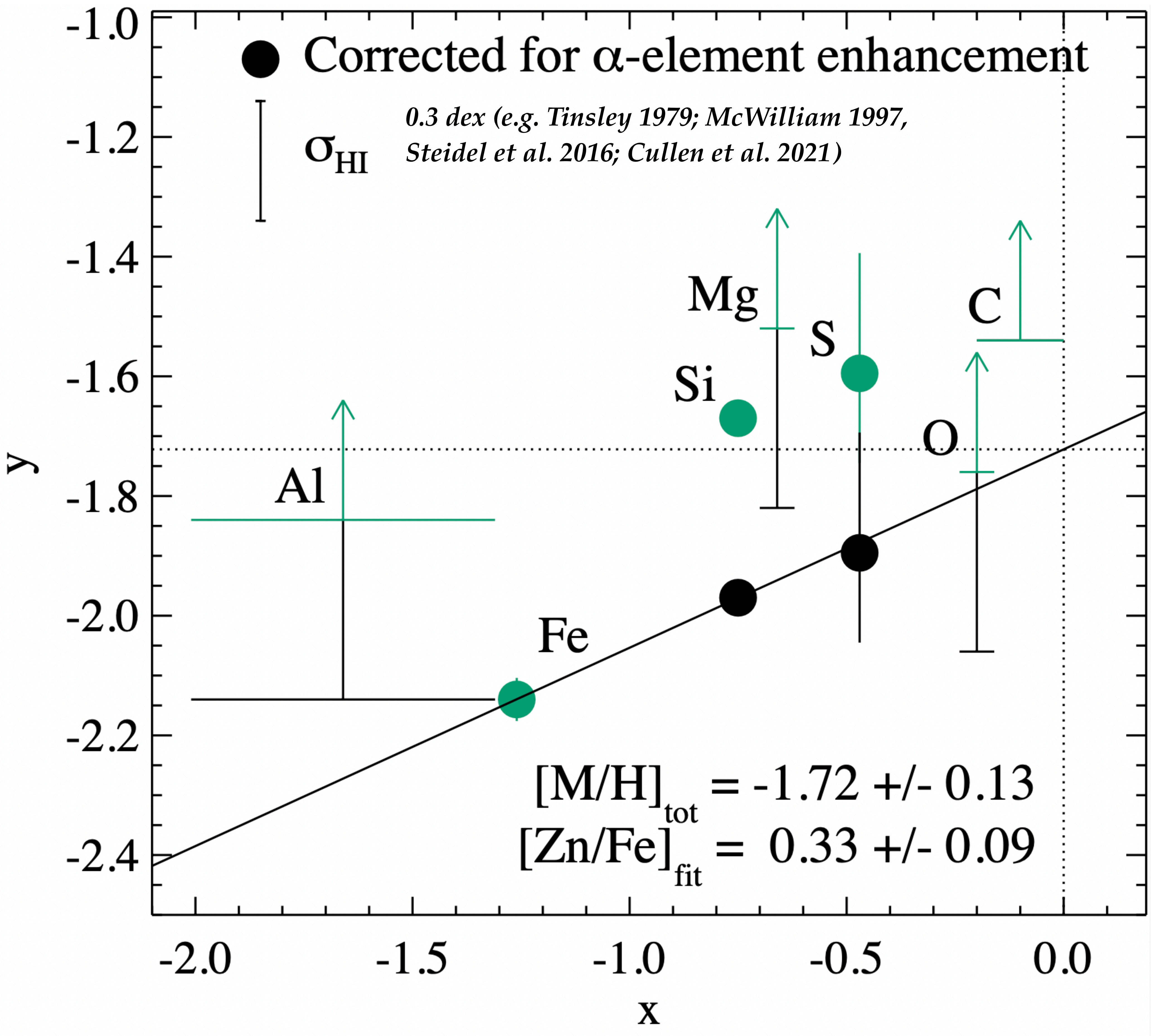
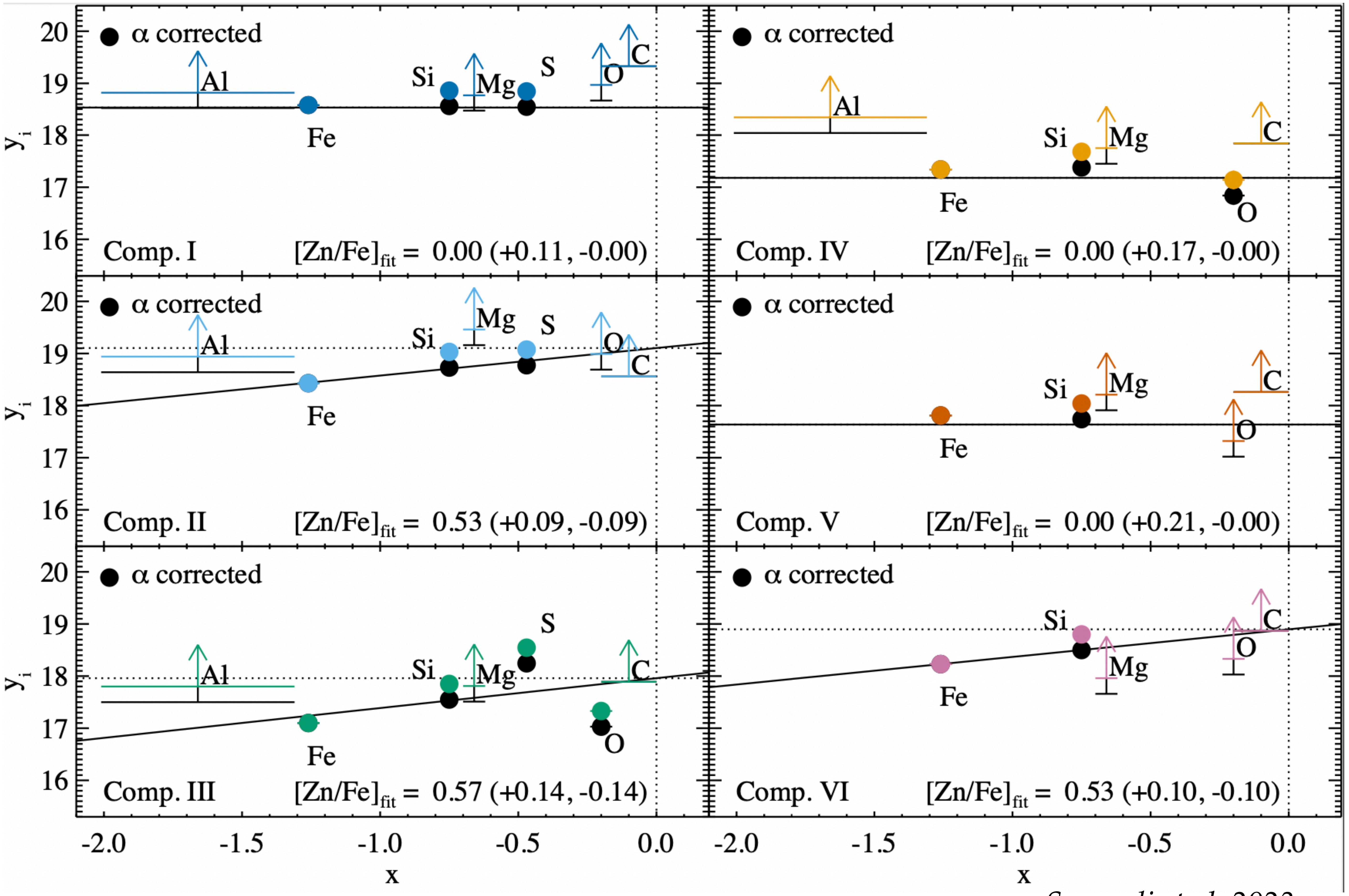
The overall host galaxy



Saccardi et al. 2023

Component-by-component



Saccardi et al. 2023

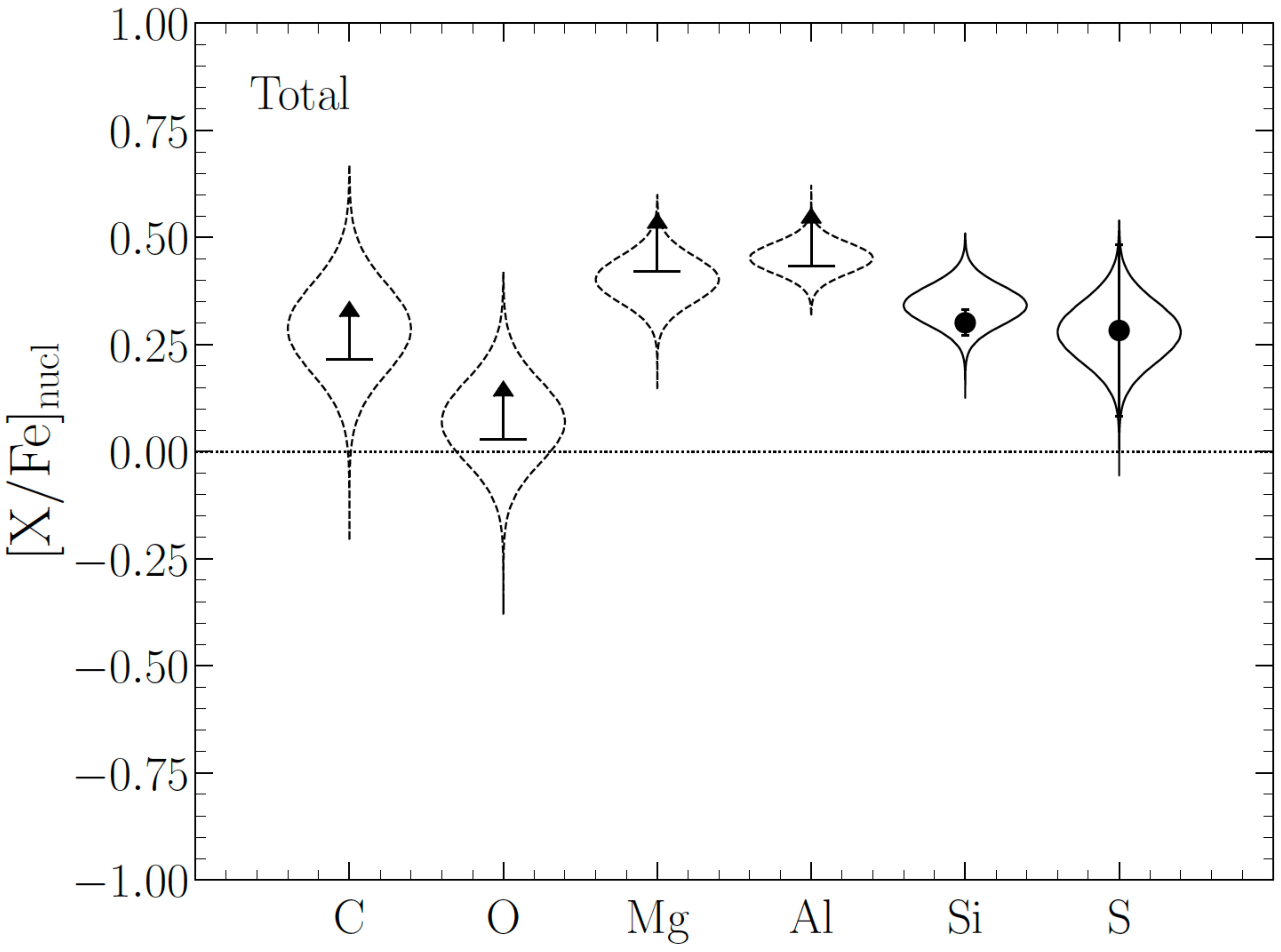
The GRB host galaxy at z = 6.312

RESULTS

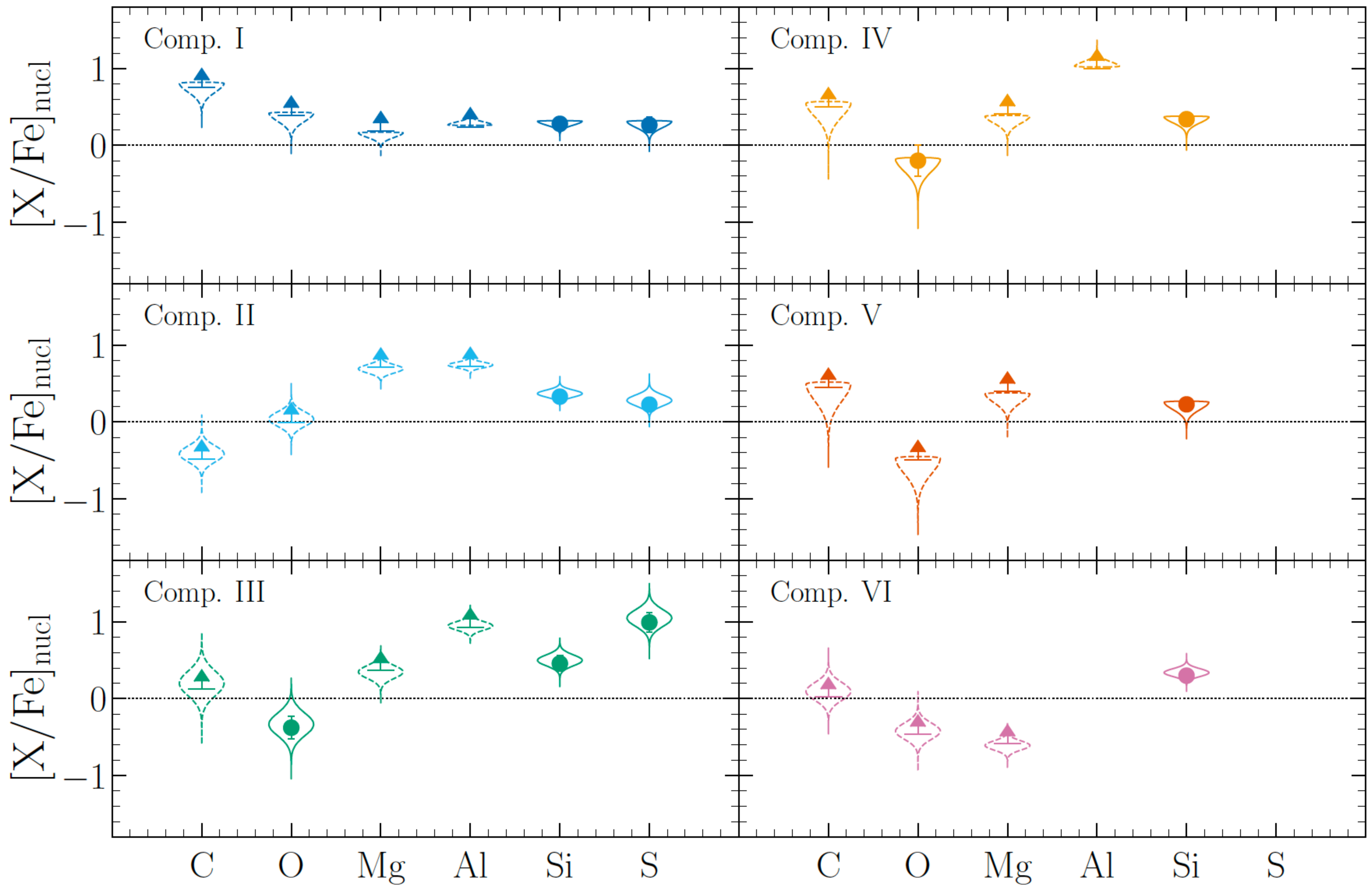
-We find that the dust-corrected metallicity of the GRB host is [M/H] = -1.72 +/- 0.13 and DTM = 0.18 +/- 0.03

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

Saccardi et al. 2023



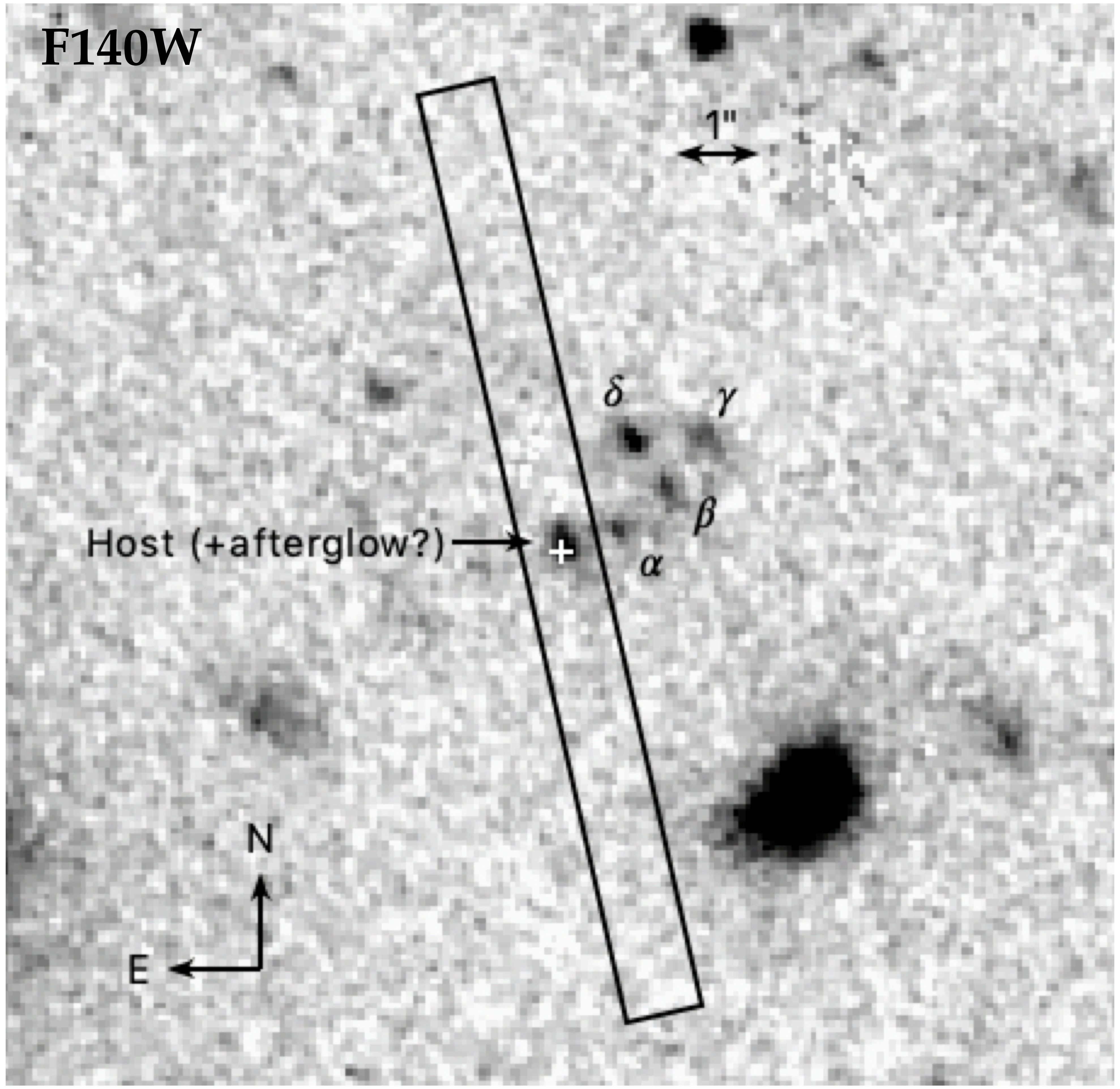
Saccardi et al. 2023



The GRB host galaxy at z = 6.312

GRB210905A HST/WFC3 Image

After ~250 days obs frame



Saccardi et al. 2023

Follow-up observations

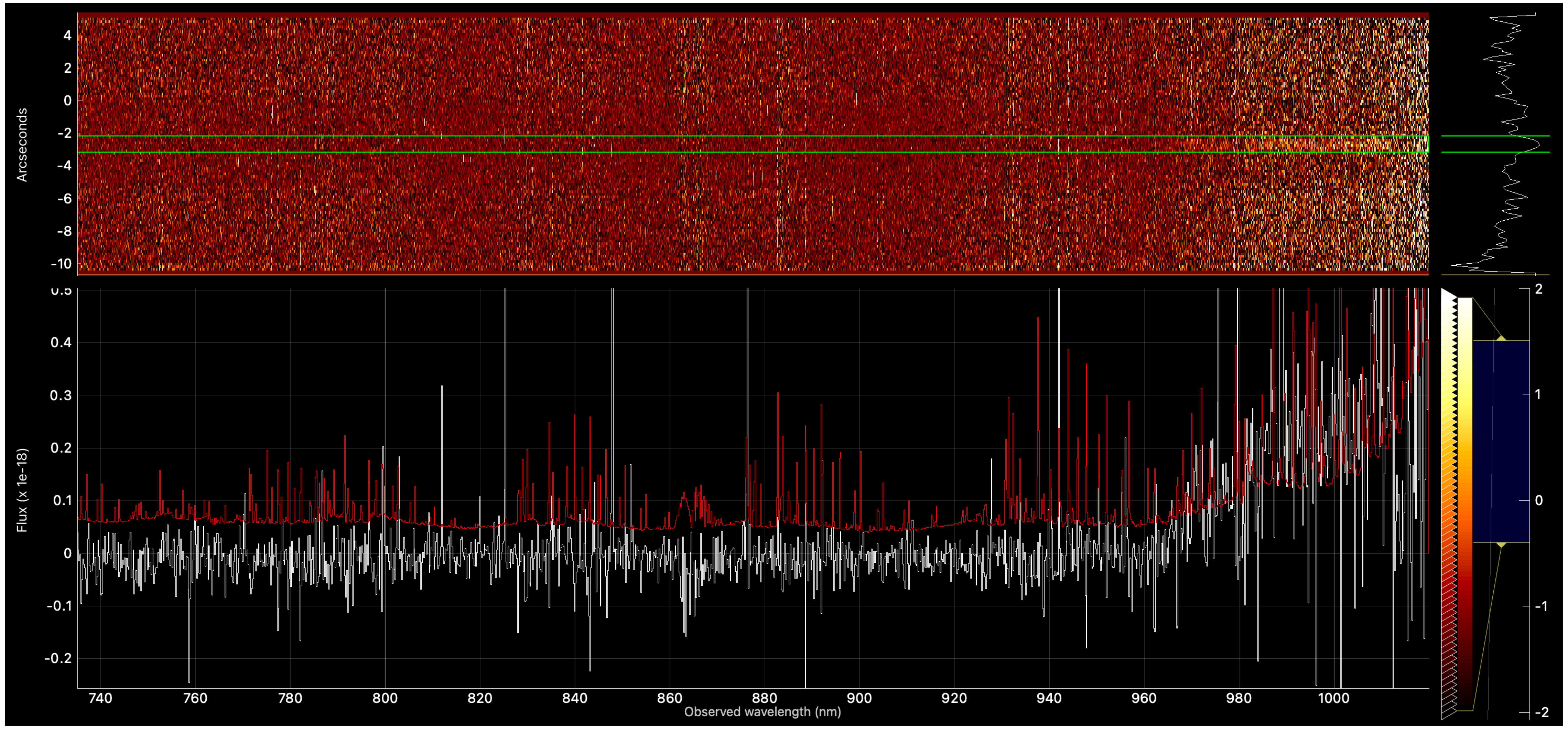
-2nd **HST** epoch in two different filters (F140W and F775W) (Executed) → δ object at lower redshift (detected in F775W filter)

-**ESO/MUSE** IFU spectroscopy of the GRB host field (Executed) PI: A. Saccardi → No sign of Lyα emission and/or presence of a Lyα blobs extending over the possible galaxy group

-**JWST** IFU spectroscopy of the GRB host field (To be re-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

The metal rich GRB240218A host galaxy at z = 6.782
@A&A Letter - A. Saccardi et al. in preparation

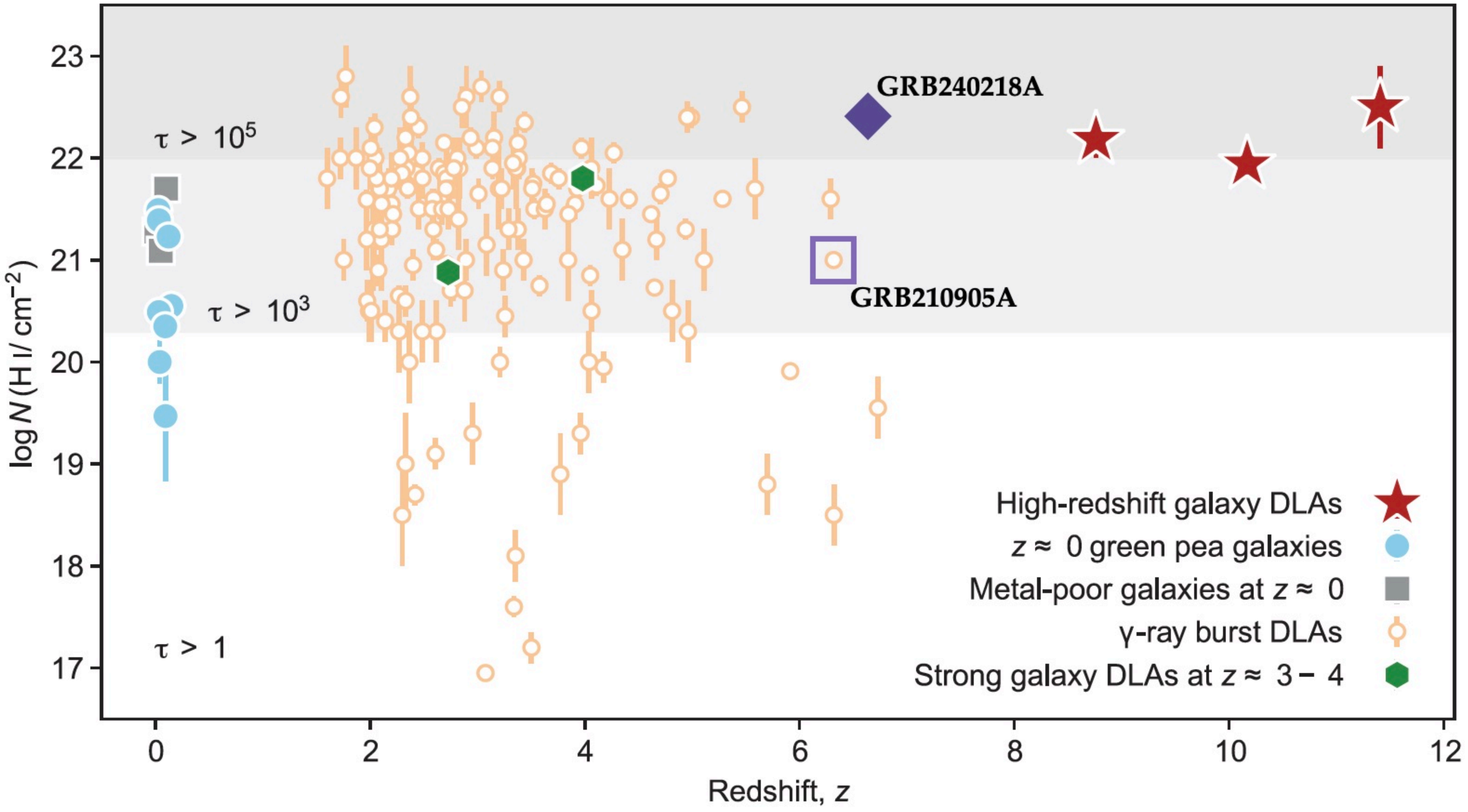


After ~26.47hr (obs frame)

Credits: Stargate/A. Saccardi

The GRB host galaxy at z = 6.782

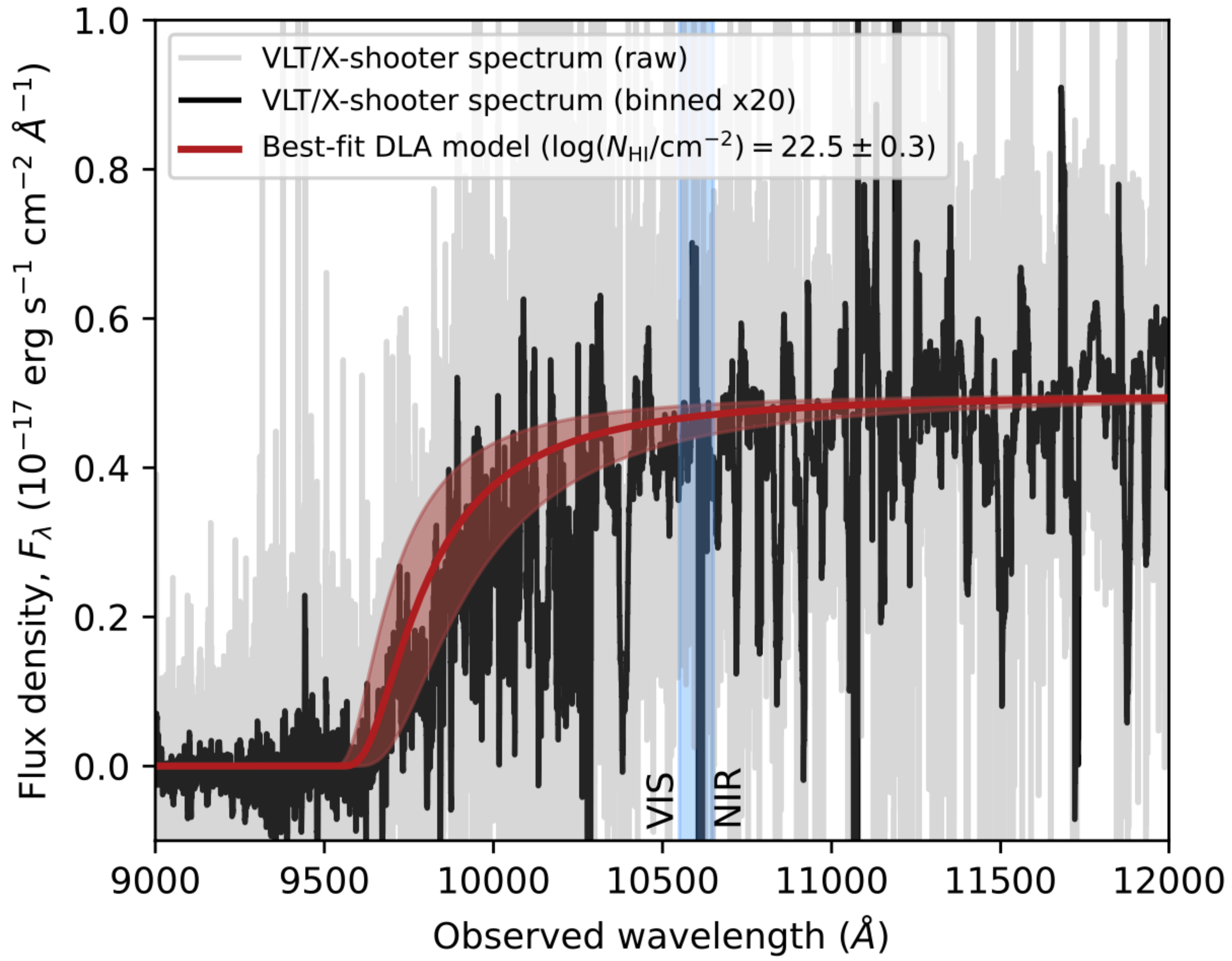
Credits: adapted from Heintz et al. 2024



GRB 240218A

z = 6.782

Credits: Saccardi et al. in prep

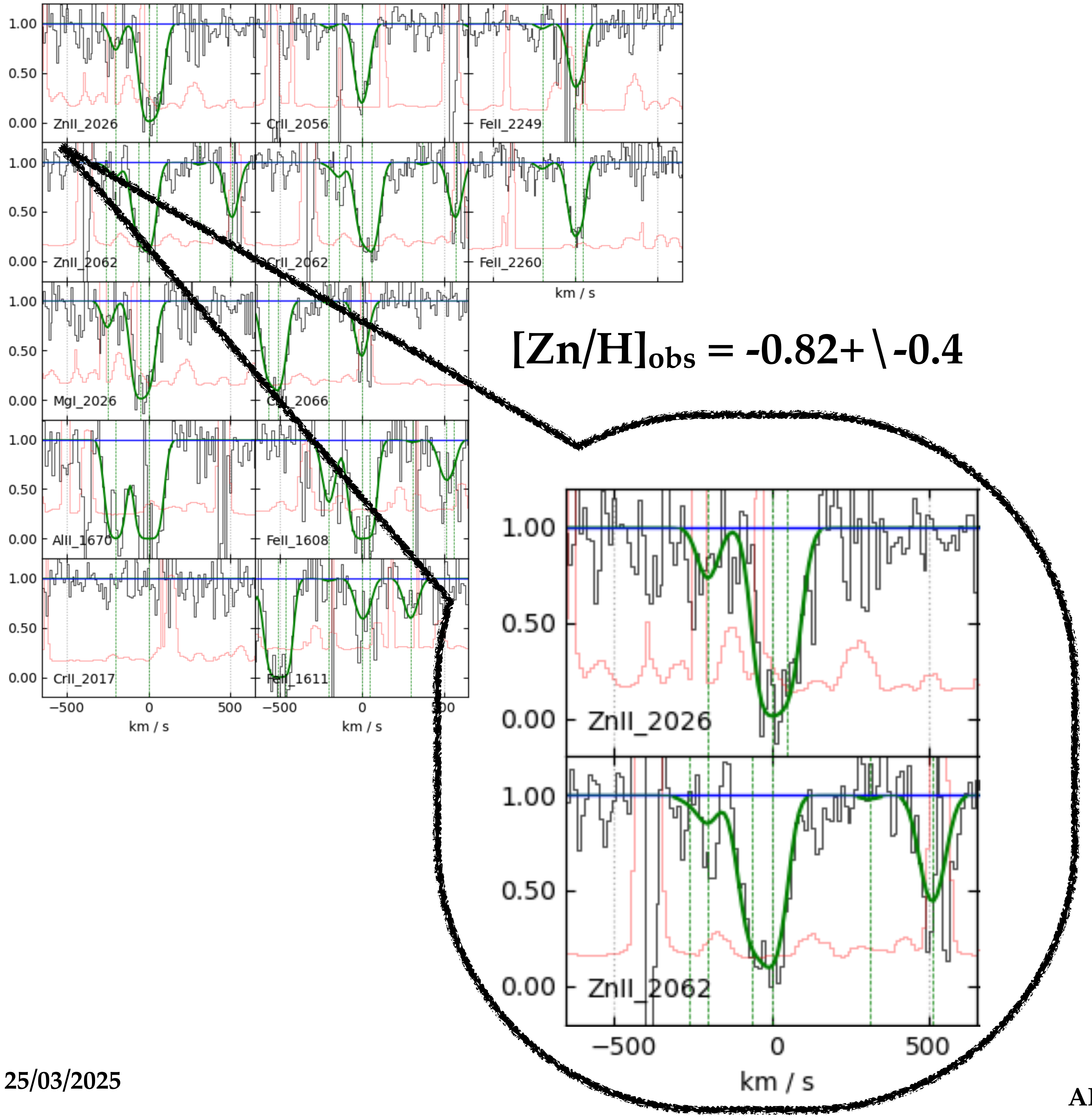


$\log(N_{HI}/cm^{-2}) = 22.5 +/- 0.3$

—-> The highest neutral hydrogen column density at high redshift!

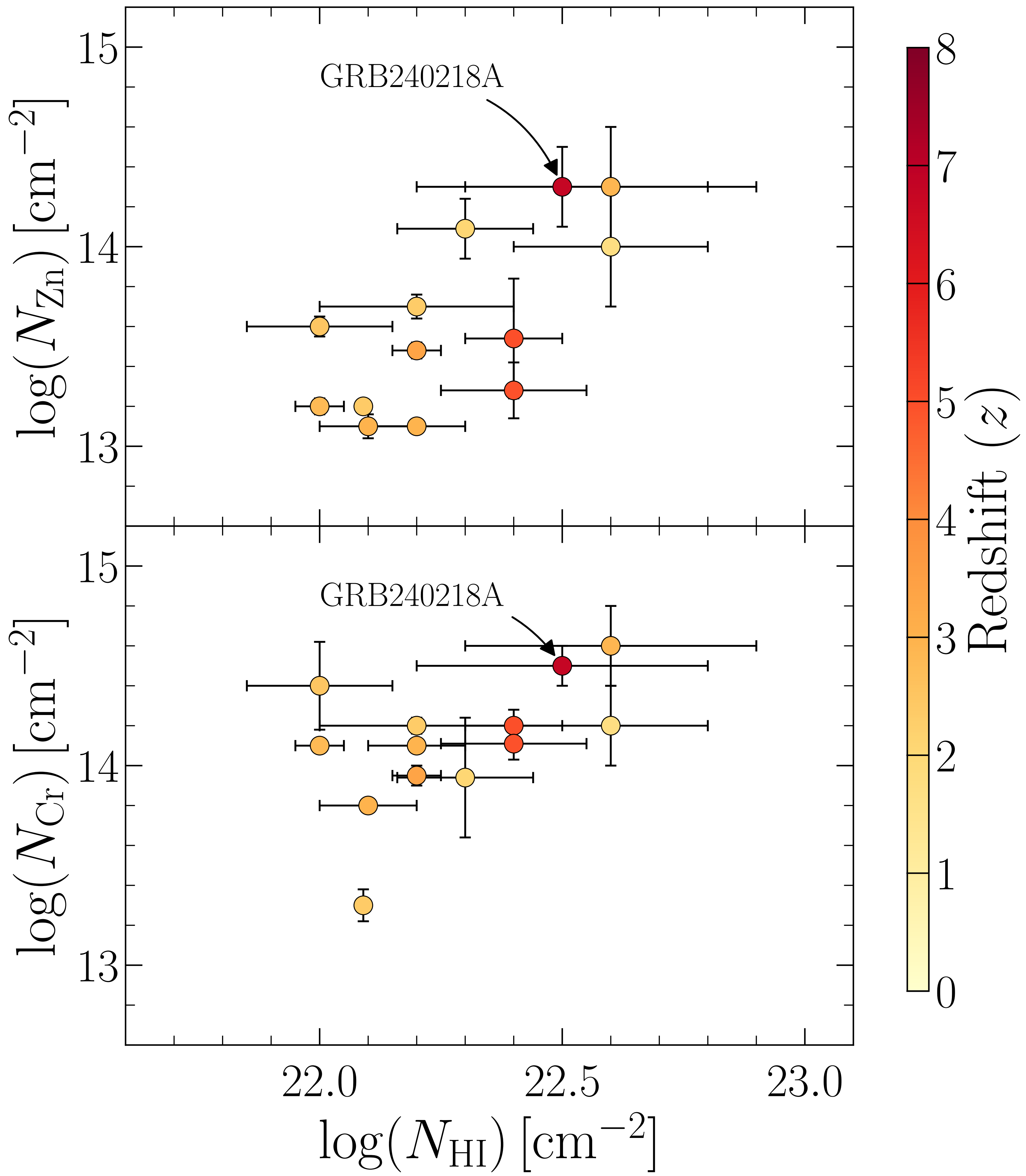
The GRB host galaxy at z = 6.782

Credits: Saccardi et al in prep



$[Zn/H]_{obs}$ = -0.82+\-0.4

Credits: Saccardi et al in prep

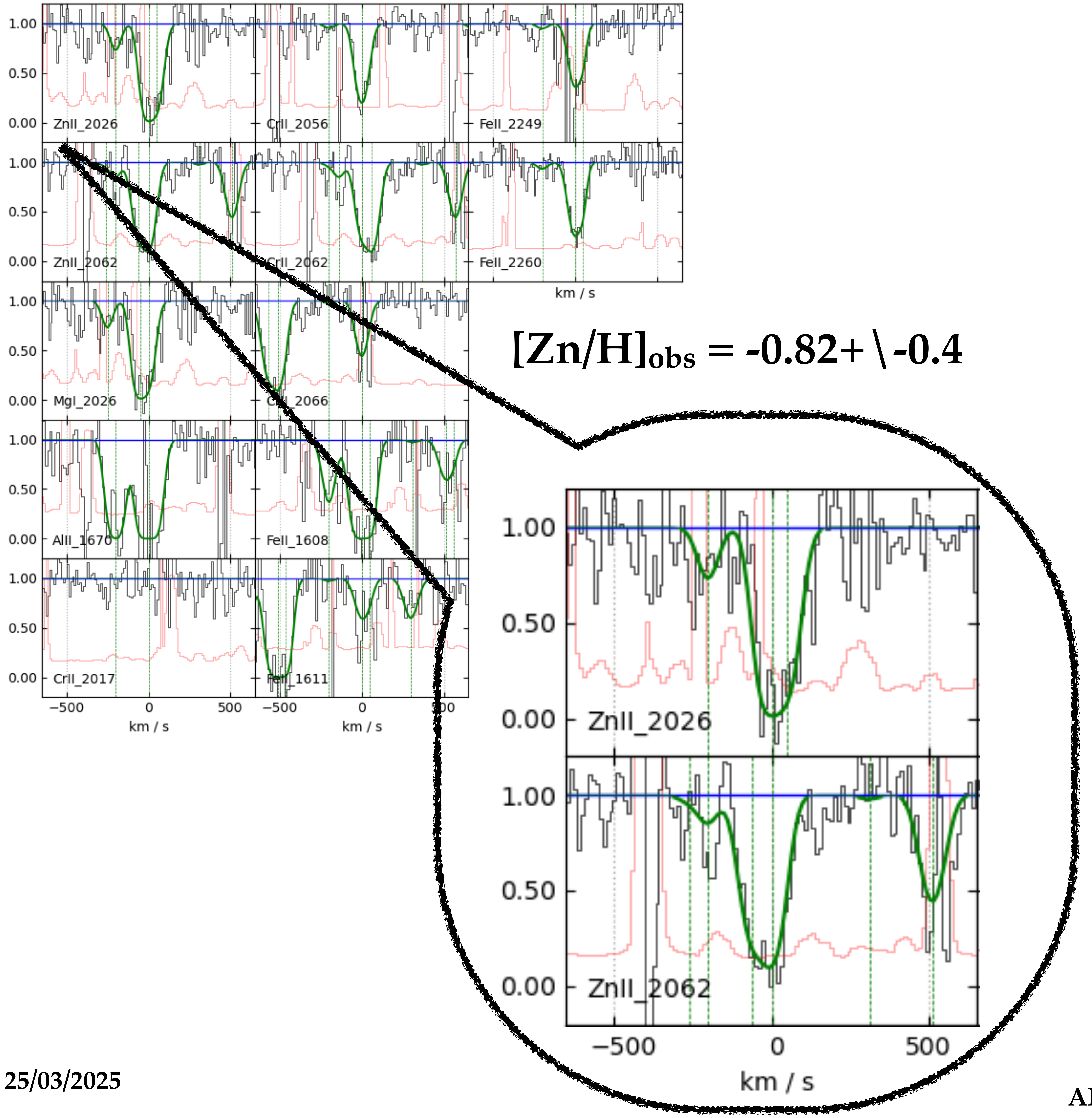


—> exception at high-z

—> large column densities less common at low-z

The GRB host galaxy at z = 6.782

Credits: Saccardi et al in prep



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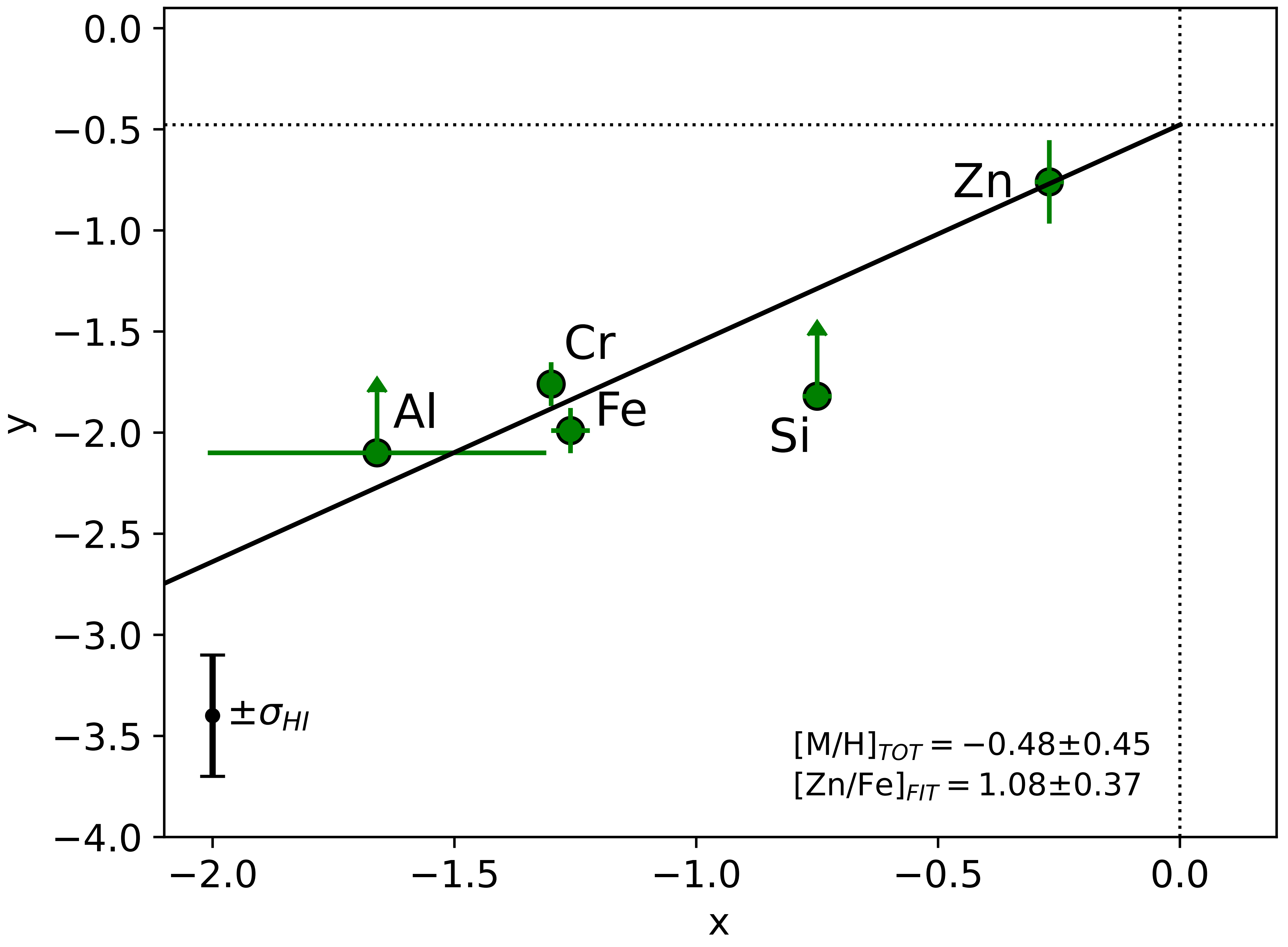
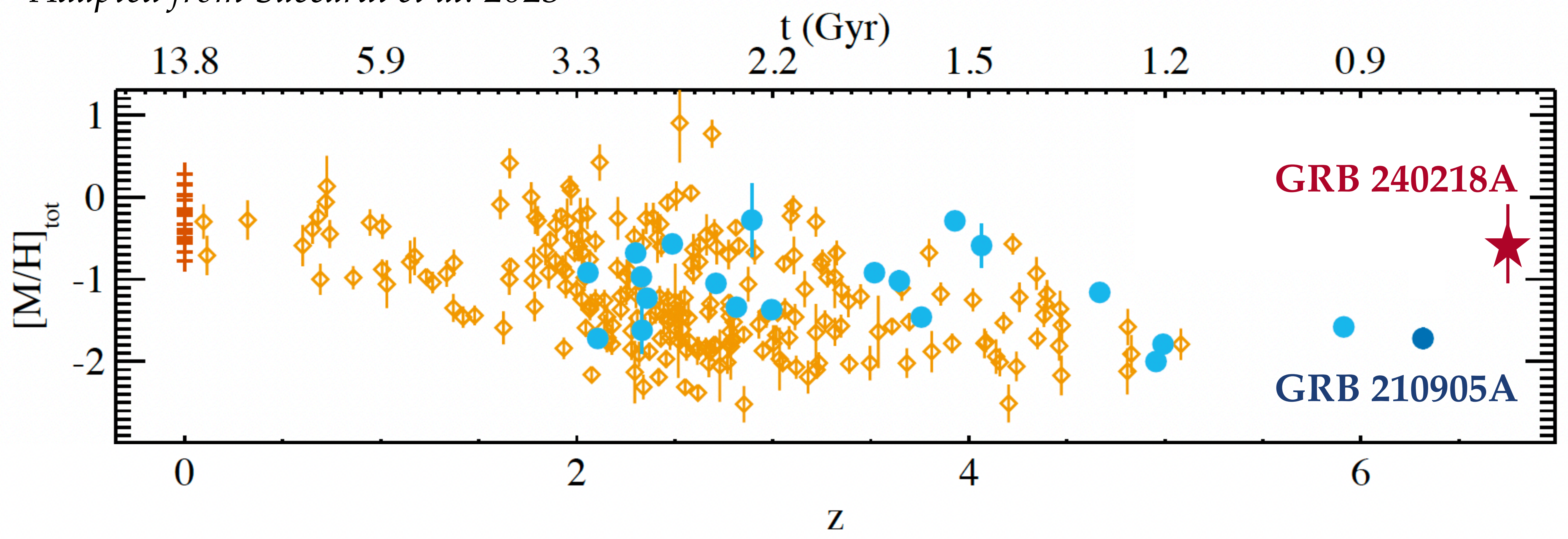


—-> Huge amount of metals and dust at high redshift !

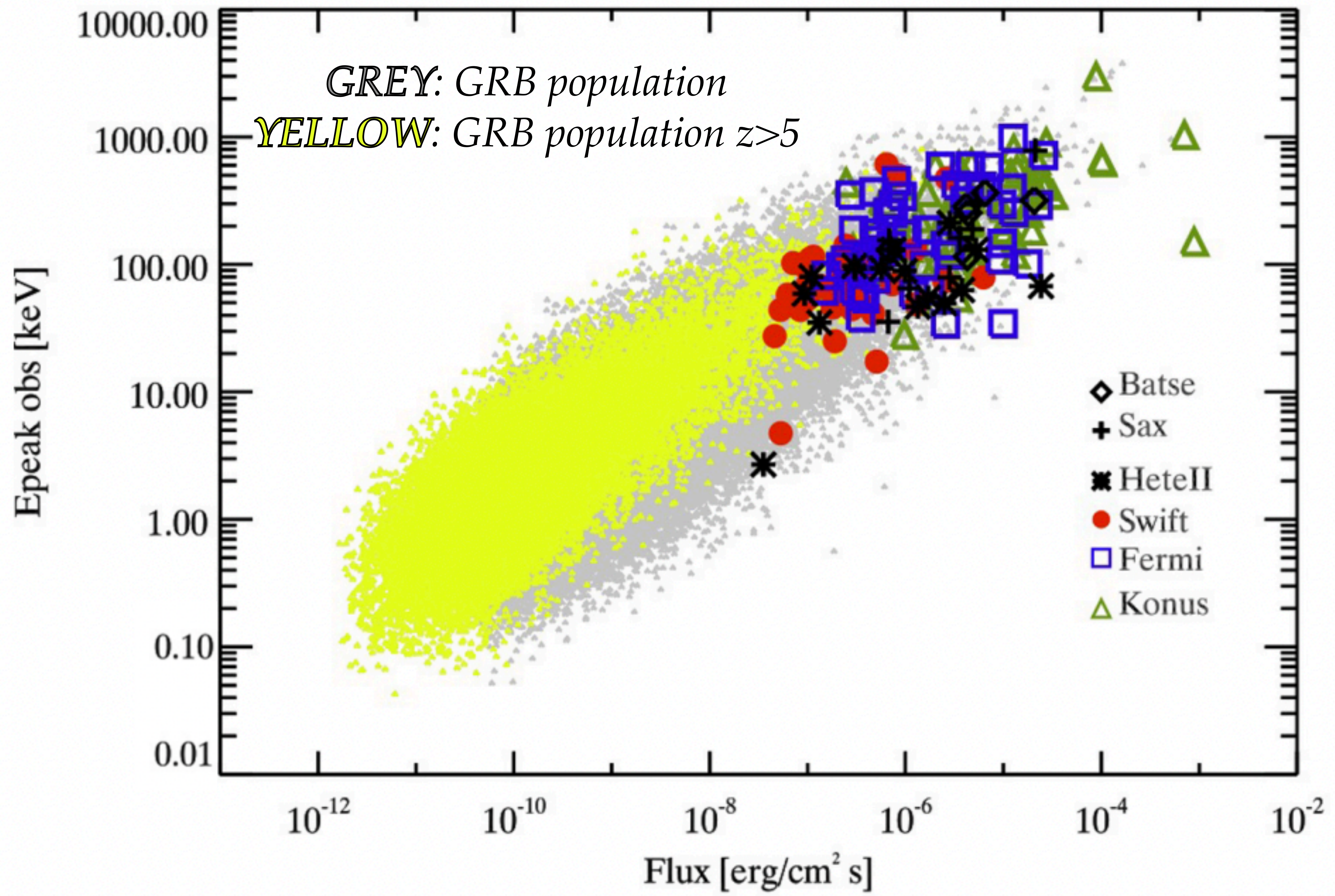
Nearby and Future Perspectives

Adapted from Saccardi et al. 2023



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

Credits: Ghirlanda et al. 2015



Limitations

(i) poor fraction of GRBs with an optical/NIR afterglow spectrum(20-30%)

(ii) lack of satellites capability to detect high-redshift GRBs

SVOM

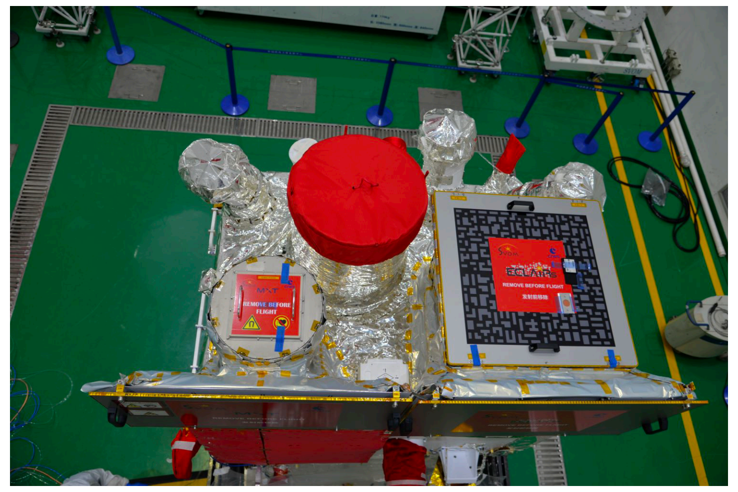
SVOM

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

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

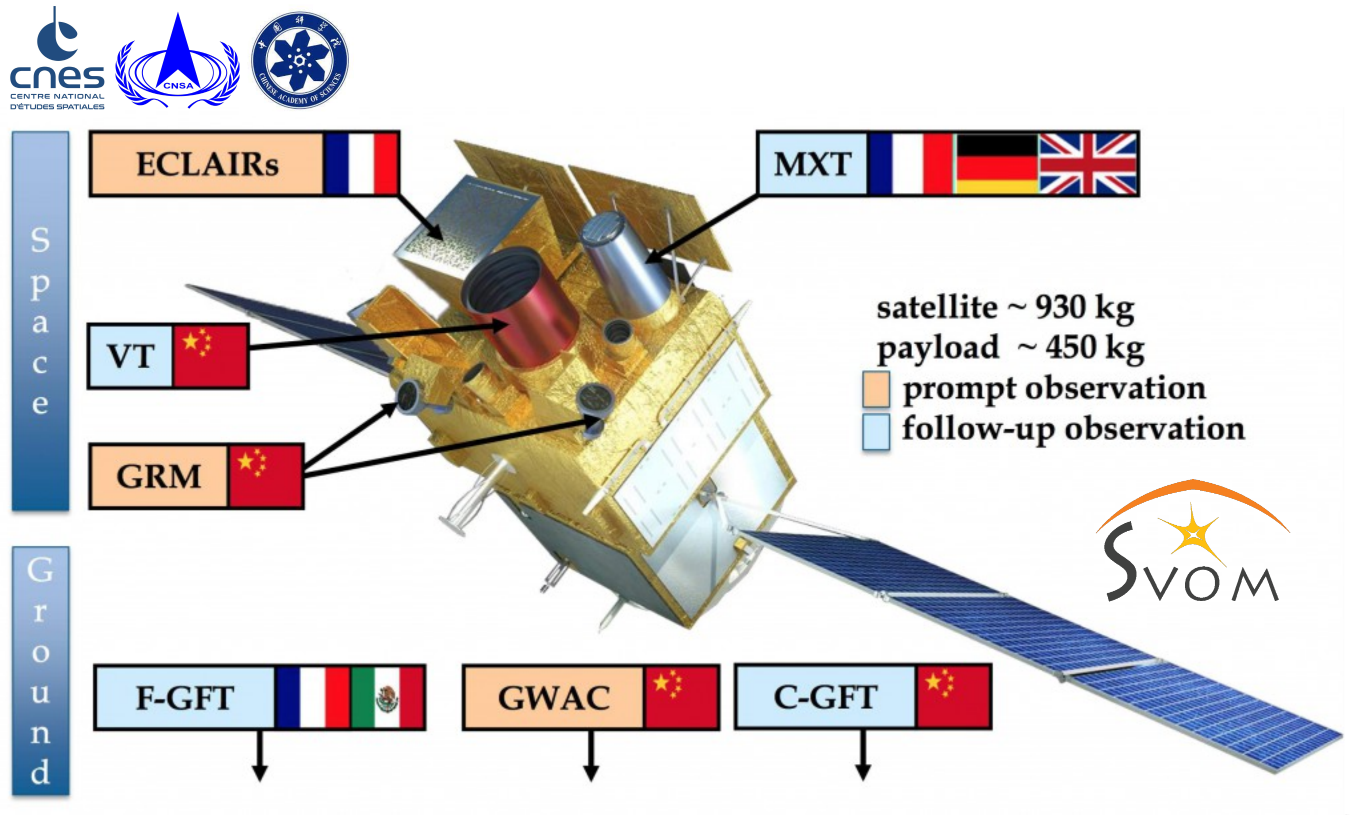
-**Good sensitivity of the on-board optical telescope:**

(i) detect and localize GRB afterglow
(ii) rapid pinpoint to high-z candidates ($r \sim 22.5$ (AB) in 300s)



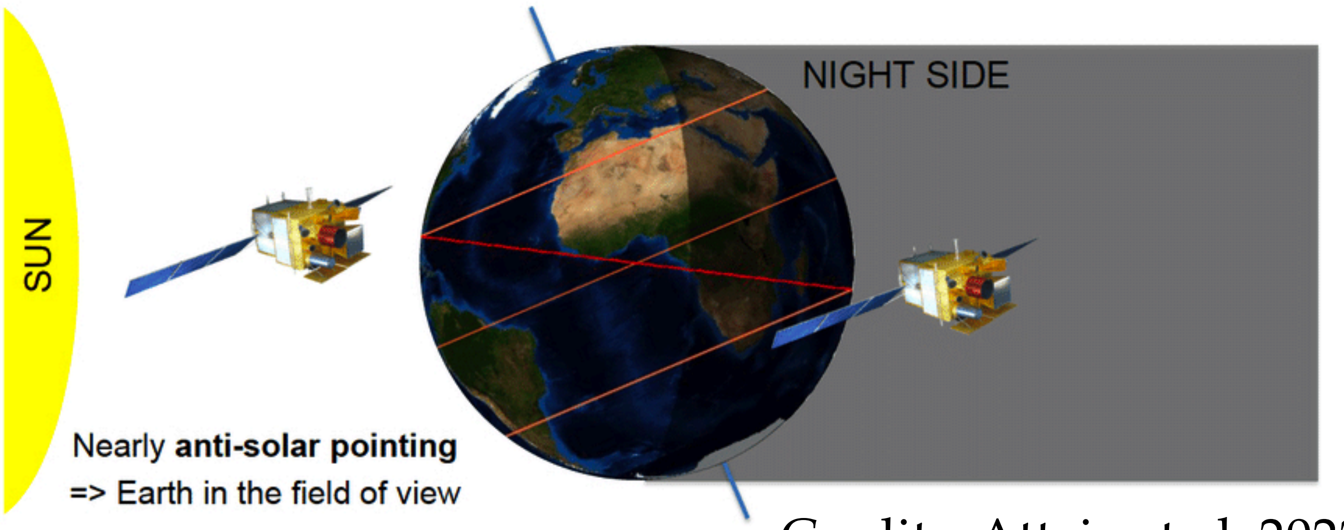
Credits: SVOM

How?



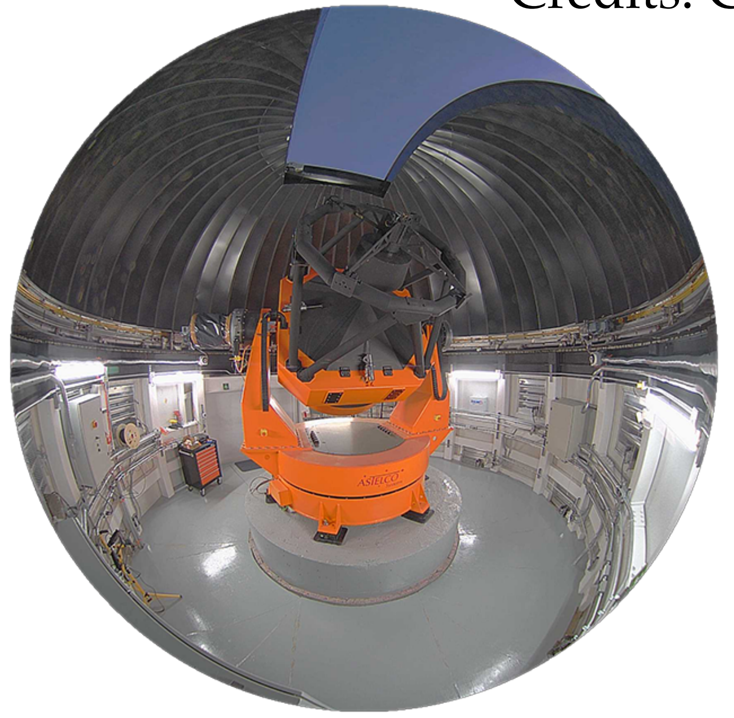
Credits: SVOM

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



Credits: Atteia et al. 2022, SVOM

Credits: COLIBRI&A. Watson, UNAM



-SVOM F-GFT

localization < 1″
mirror of 1.3 m
FoV of 26′ ×26′
400nm to 1800 nm
r = 22 mag in 300 s

-Dedicated **NIR follow-up on the ground:** i.e. ground based telescopes (SVOM/F-GFT) COLIBRI

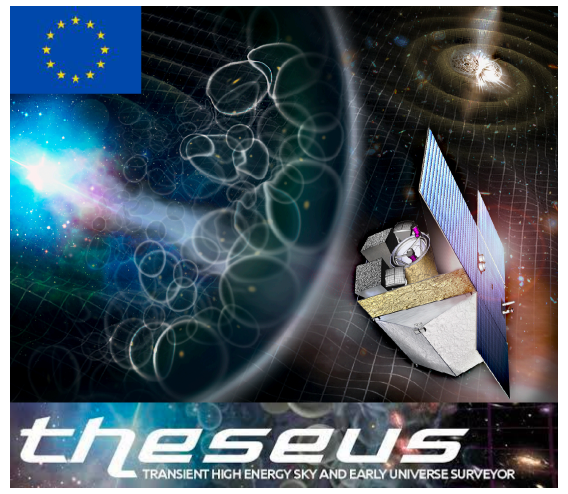
-Agreements to obtain the **spectroscopic observations of SVOM-GRB** with large ground-based telescope

See L. Amati's Talk!

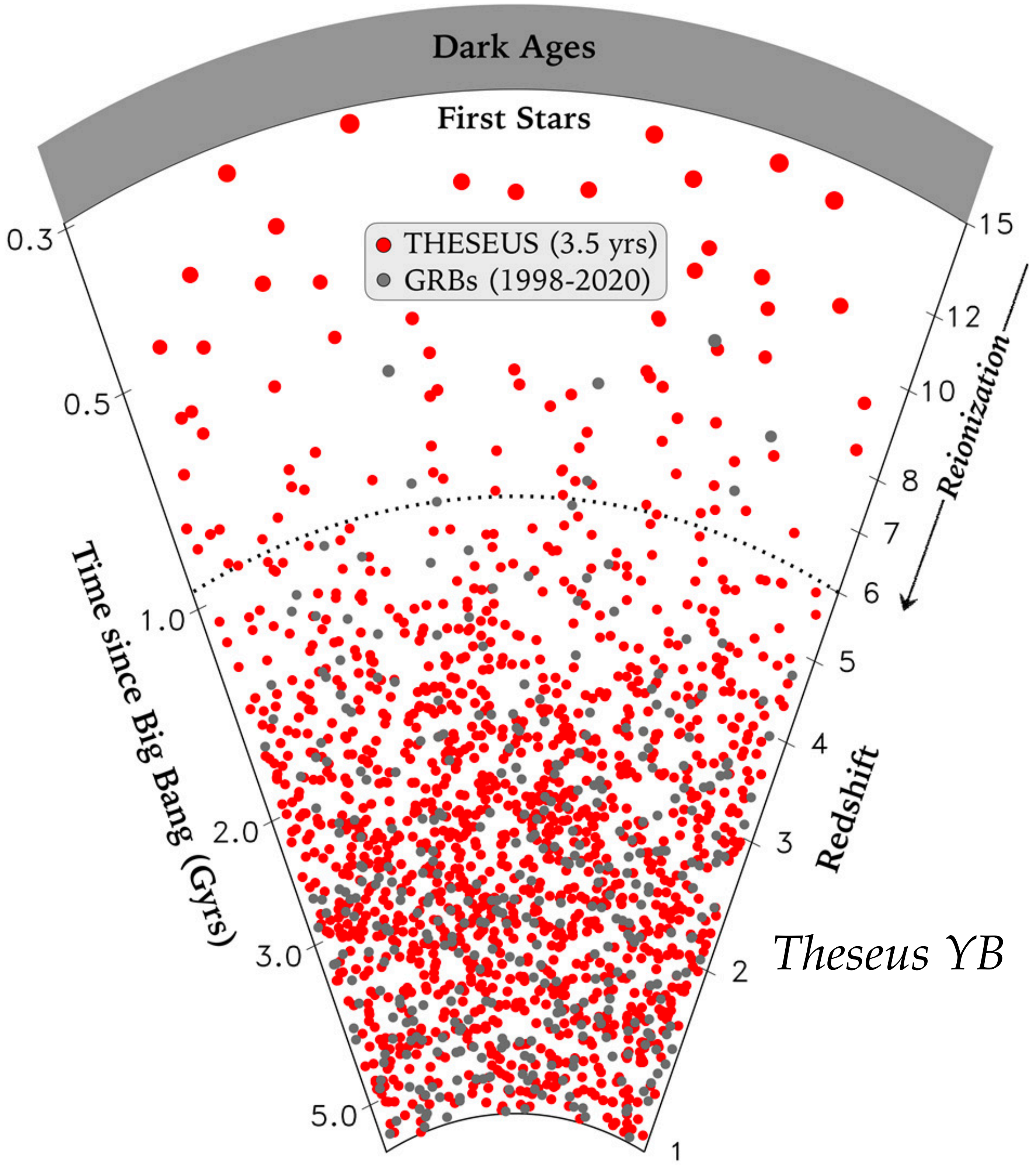
Long term Perspectives

THESEUS

Selected for ESA M7 Phase-A



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



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)

(i) X-ray large FoV (0.5 sr)
(ii) precise source localization (0.5 to 2 arc-min)
(iii) low resolution spectroscopy on-board (R~400)

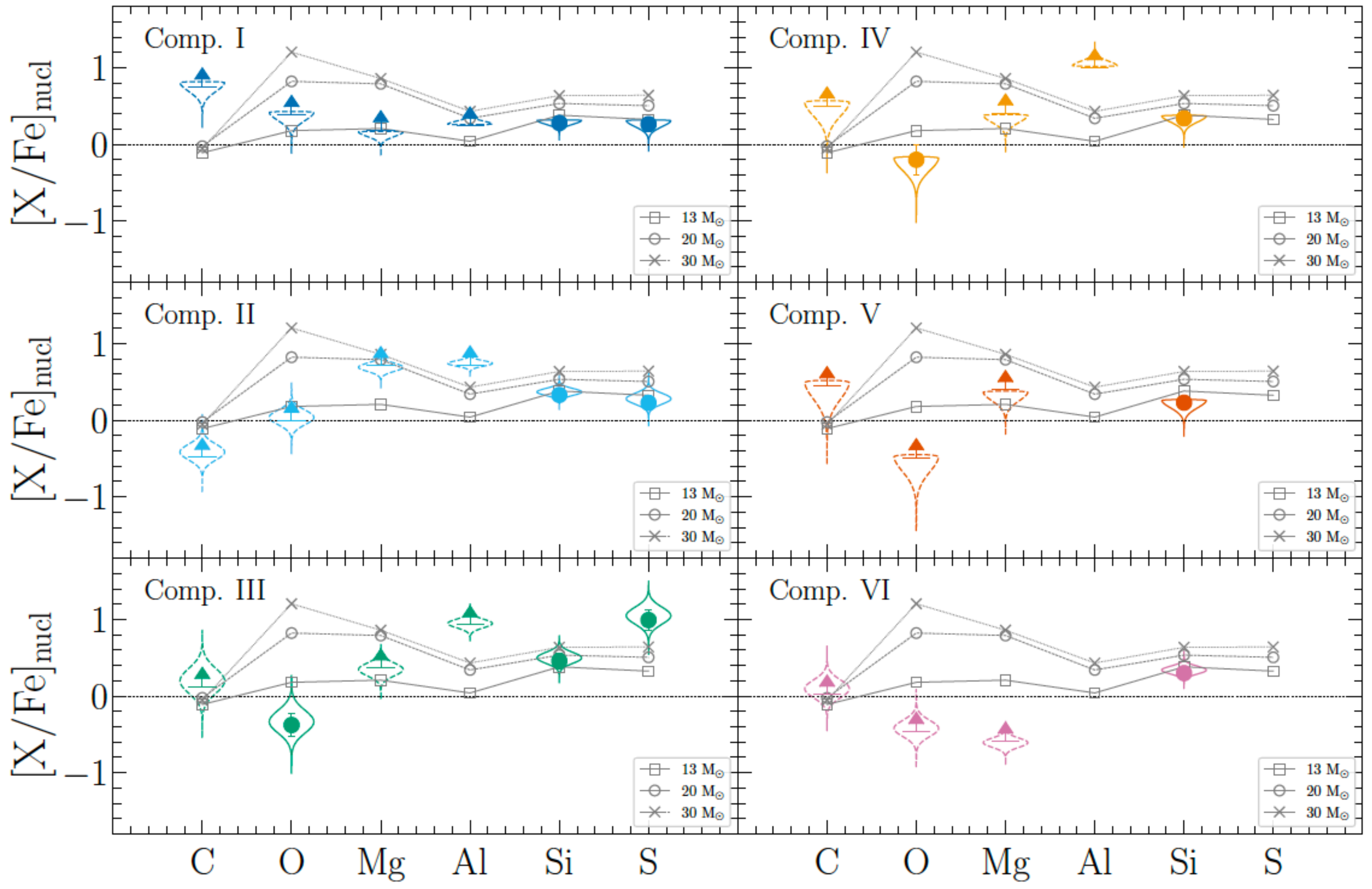
ANDES

-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)

Marconi et al. 2024

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

Thanks for your attention!

ANDREA SACCARDI
CNES Postdoctoral Fellow
@CEA/Irfu/DAp - AIM
andrea.saccardi@cea.fr

cnes CENTRE NATIONAL D'ÉTUDES SPATIALES · cea irfu · AIM · SVOM

-Unveiling galaxies at the highest redshifts and studying their chemical properties is a key objective in modern astrophysics

-Bright background sources are needed to study in detail the properties of the neutral gas

-GRBs are very powerful tools to probe the ISM of high-redshift galaxies and their metal and dust content

-Thanks to GRB 210905A and GRB 240218A we were able to obtain unique and detailed information of the neutral gas and its chemical composition

-The future is bright thanks to new space missions such as SVOM, Einstein Probe and hopefully THESEUS in synergy with ground-based observations (e.g. SOXS, ELT/ANDES)

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

Saccardi et al. 2025
In prep.

Stay Tuned!