GRBs and Host Galaxies Studies, The Need for Deep Ancillary Multi-λ Data

Denis Burgarella (Laboratoire d’Astrophysique de Marseille, France)
Outline of this talk

• Introduction
• Detecting galaxies in the early Universe
• Studying the Interstellar Medium of galaxies in the early Universe
• Conclusion
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A major goal of contemporary astrophysics and cosmology is to achieve a broad understanding of the formation of the first collapsed structures (Pop III and early Pop II stars, black holes and galaxies) during the first billion years in the life of the universe.”

This is one of the main points in ESA’s Cosmic Vision program and will very likely remain after Voyage 2050, the next planning cycle of the ESA Science Programme.

Most related science presented before
First Stars, First Galaxies: a Brand-New World to Study

Timeline For The Universe is a photograph by Nicolle Rager Fuller, National Science Foundation/science
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Detecting galaxies in the early Universe

When and How Did Galaxies Form?

- The expected density of these galaxies at \( z > 14 \) is estimated to be \( \sim 1 \text{ deg}^{-2} \) at \( m_{AB} = 28 \).
- JWST will build surveys HST-like surveys with a detection bias based on spectral features like the Lyman break.

Number of galaxies to \( z = 14 \), detected in the three JWST surveys over 1deg\(^2\), 0.1 deg\(^2\) and 0.01 deg\(^2\) (as defined in Mason et al. 2015). The combined depth / area gives about the same number of objects for each of the JWST surveys.
Detecting galaxies in the early Universe

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Alvarez-Marquez et al. (2016)
Detecting galaxies in the early Universe

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• JWST will build surveys HST-like surveys with a detection bias based on spectral features like the Lyman break.

• We need to use other probes to build galaxy sample with different biases to understand the variety of their properties.
Detecting GRBs in the early Universe

Simulations suggest that THESEUS will add up high redshift GRBs, which means we will gain access to a notably different selection.

Yearly cumulative distribution of GRBs with redshifts as a function of redshift for Swift and THESEUS. The THESEUS predictions of >10 times more high redshift GRBs than Swift are conservative (i.e. they reproduce the current GRB rate). THESEUS can detect a median-luminosity GRB (Eiso ~10^{53} erg) to z = 12.
Specifications (1):

• Unique detection of sources in the early Universe via GRBs:
  ➢ \( \gamma \)-ray facility
Identifying galaxies in the early Universe

• The optical – near-IR range will be needed to estimate the redshift of the detected GRBs and their galaxy host via some of the main spectral features.

• VRO’s LSST (Legacy Survey of Space and Time) catalogue of 20 billion galaxies with an information on shapes, variability, environment, etc.)
Specifications (1):

• Unique detection of sources in the early Universe via GRBs:
  ➢ Theseus γ-ray facility

• Deep optical - NIR observations:
  ➢ Theseus IRT
  ➢ Wide and deep survey from VRO/LSST
  ➢ 10m-class and ELTs
Physics of galaxies in the early Universe

- Once the galaxies have been detected and their redshift measured (spectro or photo), analyses are necessary to understand their properties.
- Given the number of expected targets, JWST could “easily” follow them on and get spectra and use the bright rest-frame optical lines (i.e. observed NIR+MIR) that will provide an information on the stellar population and on the gas properties.

![JWST simulations of MACS1149-JD1 @ z=9.11](image)

*Fig. 5. Simulated medium-deep (10ks) MIR observation of MACS1149-JD1 at a redshift of 9.11. It illustrates the simulated spectrum with metallicities of 0.02Z⊙ (blue), 0.04Z⊙ (green), and 0.2Z⊙ (red). The main emission lines are shown as dashed lines, and their derived integrated fluxes can be found in Table 4.*

Alvarez-Marquez et al. (A&A 629, A9 2019)
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- Deep spectroscopic + imaging observations to study the physics of the host galaxies:
  - *JWST suite of instruments*
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Extinction & Attenuation Curves in the early Universe

THESEUS will add up high redshift GRBs, in the Epoch of Reionization. GRBs are bright point sources that allow to study the line of sight in the ISM of the host galaxy, and also in the IGM.
Extinction & Attenuation Curves in the early Universe

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Extinction & Attenuation Curves in the early Universe

The properties and physical mechanisms shaping the dust extinction in front of a point source and attenuation curves in galaxies is one of the fundamental questions of extragalactic astrophysics, with a great practical significance for deriving the physical properties of galaxies, such as the star formation rate and stellar mass.

• The wavelength-dependence of the dust extinction and spectral features in extinction curves are useful for constraining the size distribution of dust grains and revealing the dust chemical composition.

• Attenuation curves result from a combination of dust grain properties, dust content, and the geometry of dust and stellar populations.

• Studying both simultaneously provides a unique and very powerful tool.
Attenuation & extinction laws in galaxies

Salim & Narayanan 2020ARA&A..58..529S

Figure 1
Schematic summarizing the difference between extinction and attenuation. The former encapsulates absorption and scattering out of the line of sight, while the latter folds in the complexities of star-dust geometry in galaxies, and may include scattering back into the line of sight, varying column densities/optical depths, and the contribution by unobscured stars.
Attenuation & extinction laws in galaxies

Attenuation in a galaxy, stars and dust are mixed

Both can be measured in GRB hosts

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From the GRB
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From the GRB Host

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Best model for 080607 at z = 3.04. Reduced $\chi^2 = 0.7$
Extinction curves measured in galaxies hosting $\gamma$-rays bursts

Zafar+18

The afterglow is modelled by a single or double power-law: any deviation due to dust extinction
Specifications (2):

• Points sources, especially at high redshifts: $\gamma$-ray facility
What do we know today on the topic?

Locally, extinction versus attenuation curves in nearby galaxies: Radiative transfer

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Locally, extinction versus attenuation curves in nearby galaxies: Radiative transfer

What do we know today on the topic?

For more distant galaxies (especially in the EoR), there are attenuation curves but no extinction curve.
Rest-frame UV range is crucial to discriminate between different extinction curves (and good spectral resolution). For objects in the EoR, this means that we need a near-IR facility.
With spectroscopic observations ($R > \text{a few 100}$) of the afterglow: slope and bump for the extinction law.
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• Dust extinction / attenuation laws:
  ➢ *rest-frame UV* $\Rightarrow$ *observed NIR & R* $\sim 500$ (directly from Theseus IRT but better from ground-based large telescopes (10m-class and ELTs)

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We use the photometric data for the host galaxies to measure the shape of the attenuation law with the code CIGALE (Boquien et al. 2019)

Best model for 120119A at $z = 1.72$. Reduced $\chi^2=0.32$

Best model for 061121 at $z = 1.314$. Reduced $\chi^2=0.74$

Steep attenuation Curve
Steeper than Calzetti

Flat attenuation Curve
Flatter than Calzetti
When dealing with dust properties, we must use data in the rest-frame far-IR (and in radio).
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• Dust emission to constrain the amount of dust attenuation:
  - Rest-frame FIR \(\Rightarrow\) observed sub-mm (ALMA, NOEMA maybe Origins?)
  - Radio \(\Rightarrow\) SKA will be very useful
Summary* of the multi-\( \lambda \) specifications useful to study GRB hosts in the early Universe\( \dagger \)

- Unique detection of sources in the early Universe via GRBs:
  - *Theseus \( \gamma \)-ray facility*
- Deep optical - NIR observations:
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  - *Wide and deep survey from VRO/LSST*
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- Deep spectroscopic + imaging observations to study the physics of the host galaxies:
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  - *Rest-frame FIR* \( \rightarrow \) *observed sub-mm* (ALMA, NOEMA maybe Origins?)
  - *Radio* \( \rightarrow \) SKA will be very useful

\( \dagger \) AGNs but also SF \( \rightarrow \) Athena

* Non exhaustive
Merci
The SKA, expected to be fully operating in the 2030s, will enable an ideal technique to study the evolution of cosmic reionization via the measurement of the 21 cm radiation from neutral hydrogen atoms (due to the hyperfine structure of the triplet and the singlet levels of the hydrogen ground state). The 21 cm sky contains fluctuations around the mean (“global”) signal, which encode information on the physical state of hydrogen, largely representative of all baryons, in the Dark Ages and in the Epoch of Reionization.