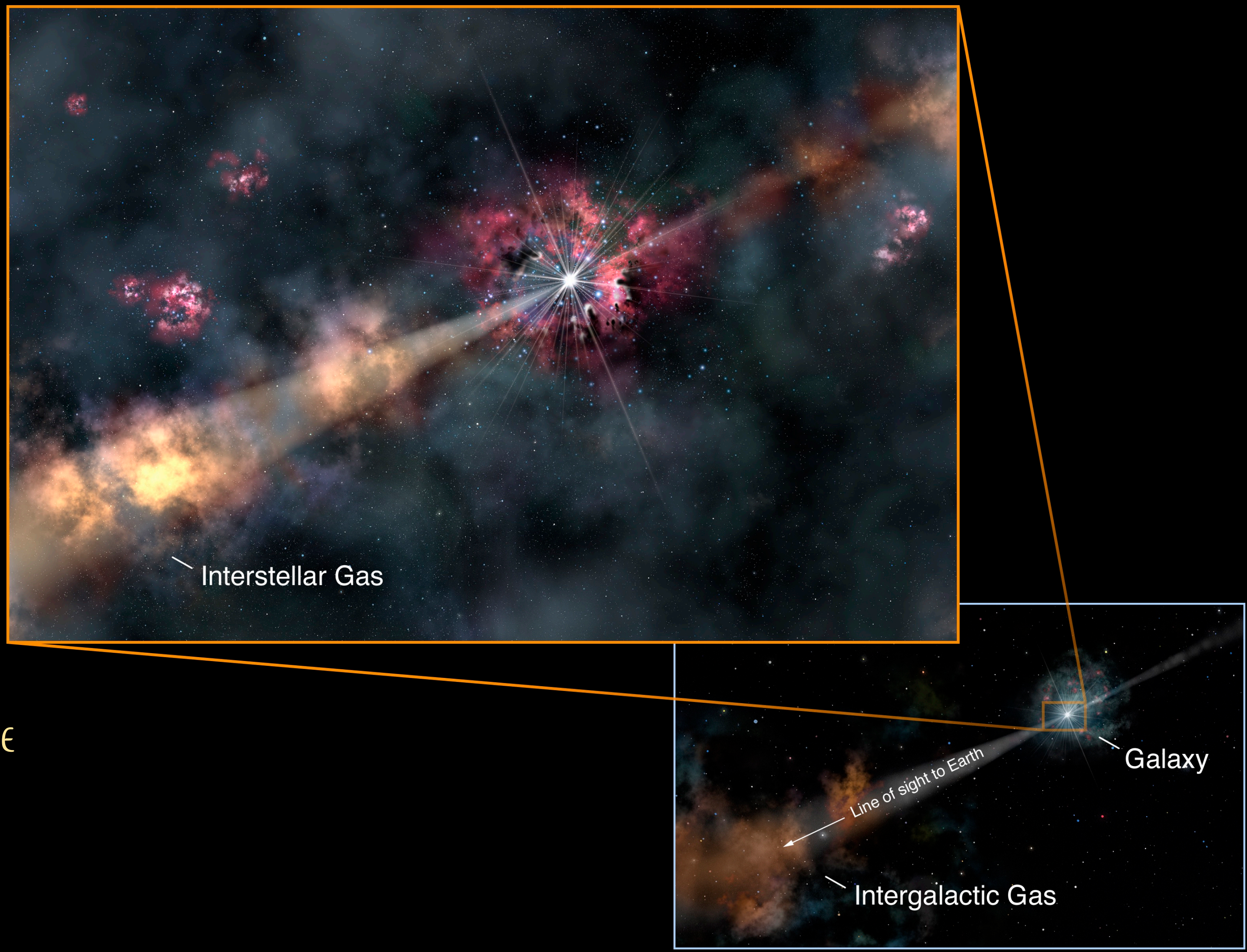
GRBs and host galaxies studies, the need for deep ancillary multi-λ data

Denis Burgarella
(Laboratoire d'Astrophysique de Marseille, France)



Credit: Gemini Observatory/AURA, artwork by Lynette Cook

Outline of this talk

- Introduction
- Detecting galaxies in the early Universe
- Studying the Interstellar Medium of galaxies in the early Universe
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Introduction (from Amati et al. 2020)

*"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

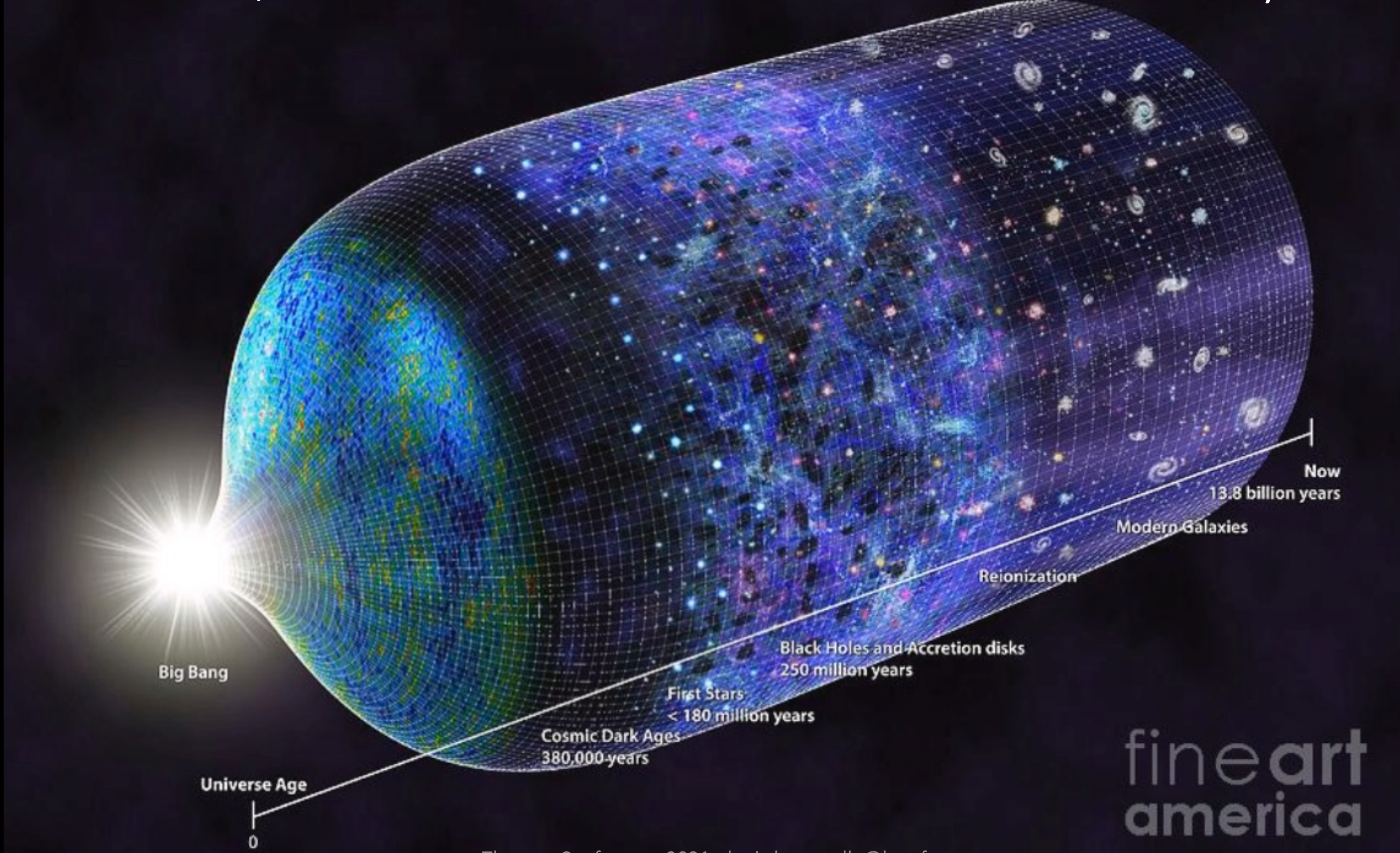
SESSION 3 - Wednesday 24 March (9:00 - 10:40)
Investigating the early Universe & cosmic evolution via GRBs (Chair Diego Götz)

GRBs in the early Universe (**Nial Tanvir**, I)
Tracing the metal-enrichment in the early universe with THESEUS (**Lise Christensen**, I)
GRBs as tracers of cosmic star formation and first galaxies (**Susanna Vergani**, I)
IRT expected science from very high redshhift GRBs (**Emeric Le Floch**, I)
General properties of optical/NIR emission of long-duration GRBs and their host galaxies (**Alberto J. Castro-tirado**, I)
Coffee Break

SESSION 4 - Wednesday 24 March (11:00 - 12:45)
Investigating the early Universe & cosmic evolution via GRBs (Chair Nial Tanvir)

Enlightening cosmic dark ages with GRBs (**Ruben Salvaterra**, I)
Assessing the detectability of optical afterglows of short gamma-ray bursts by ground-based facilities in the THESEUS era (**Lána Salmon**, C)
Population synthesis of metal-poor massive stars - How to use THESEUS' high-redshift GRB data to constrain the physics of Pop-II and Pop-III progenitors (**Dorottya Szécsi**, C)
GRBs and host galaxies studies, the need for deep ancillary multi-wavelength data (**Denis Burgarella**, C)
Measuring the cosmological parameters with Gamma-ray Bursts (**Massimo Della Valle**, I)
Investigating the early Universe & cosmic evolution via GRBs (**Ester Piedipalumbo**, I)

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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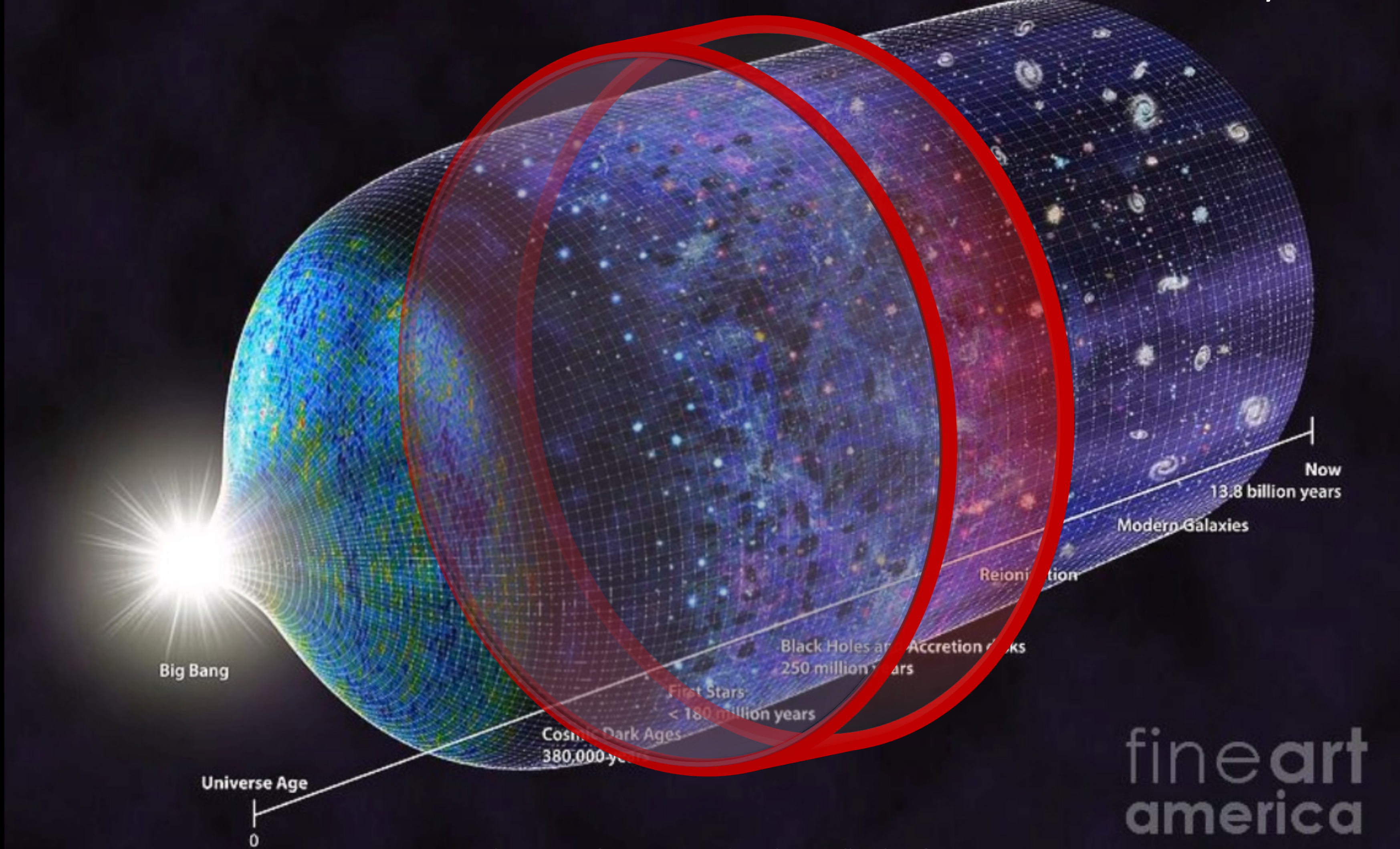

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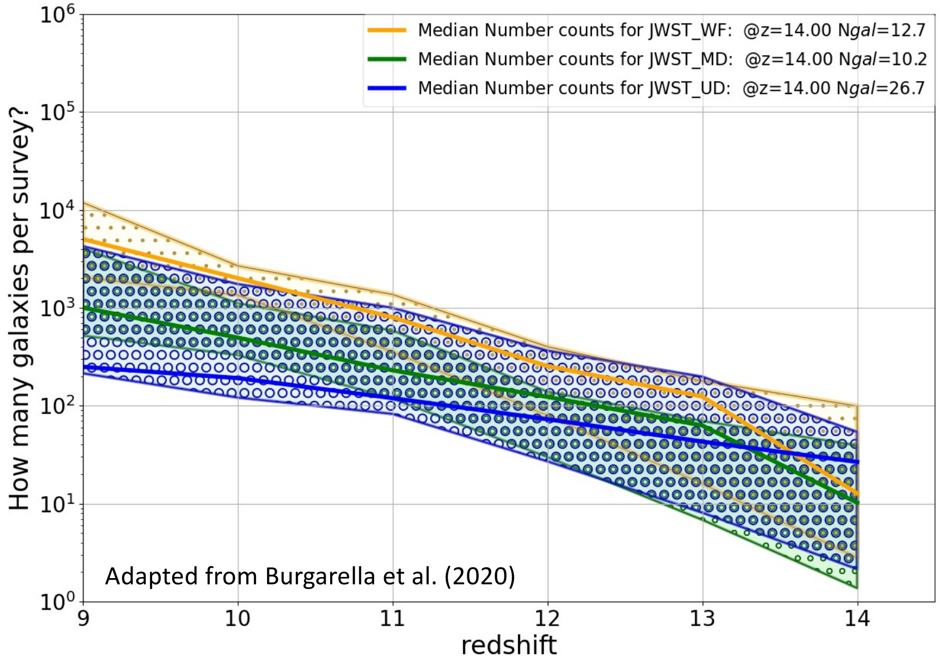
Detecting galaxies in the early Universe

When and How Did Galaxies Form?

- The expected density of these galaxies at $z > 14$ is estimated to be ~1 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 1deg², 0.1 deg² and 0.01 deg² (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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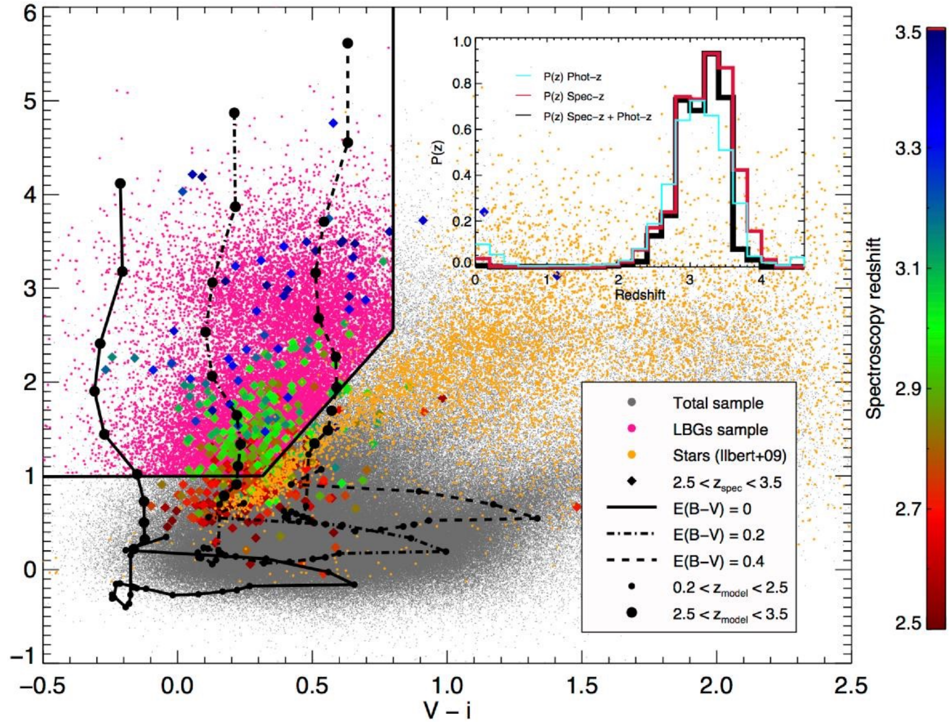
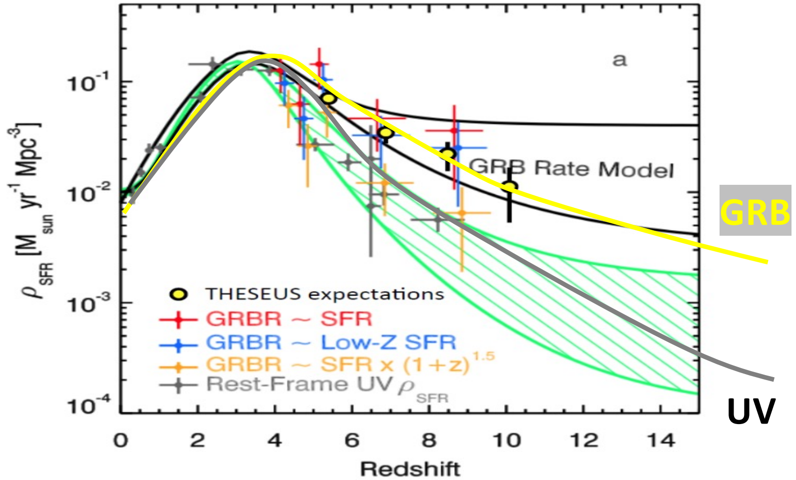


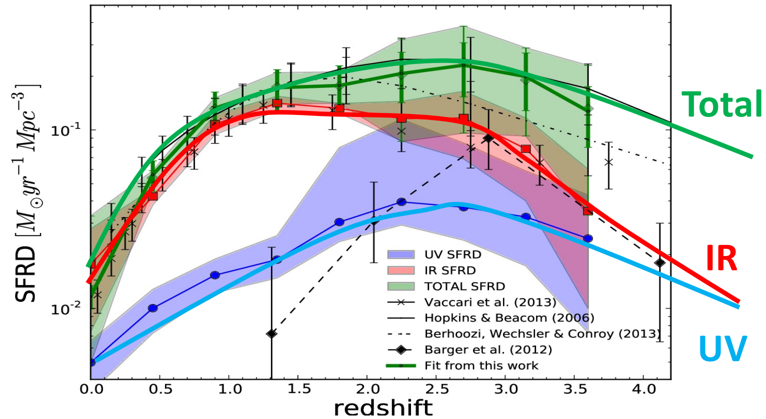
Alvarez-Marquez et al. (2016)

Detecting galaxies in the early Universe

When and How Did Galaxies Form?

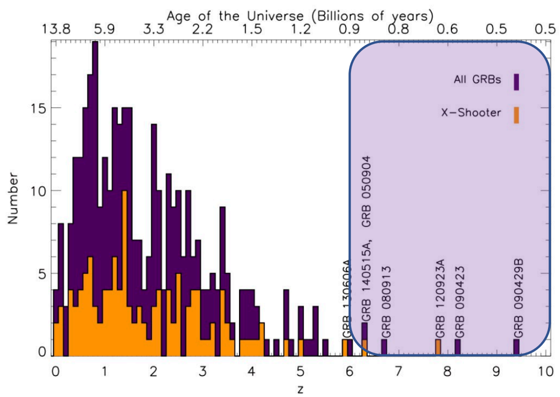
- The expected density of these galaxies at $z > 14$ is estimated to be ~1 deg^{-2} at $m_{AB} = 28$.
- JWST will build surveys HST-like surveys with a **detection bias** based on spectral features like the Lyman break.
- We need to use other probes to build galaxy **sample with different biases** to understand the variety of their properties.

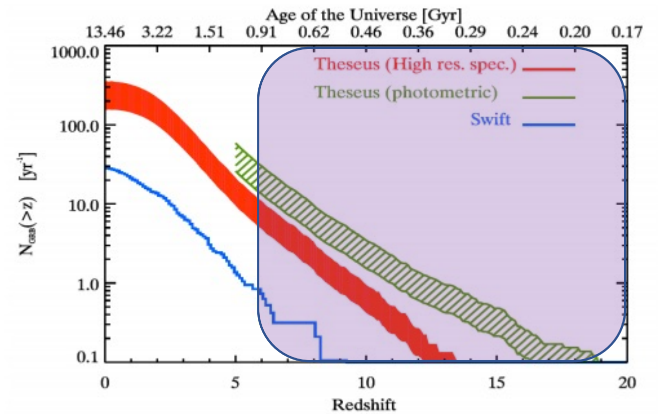




Detecting GRBs in the early Universe

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





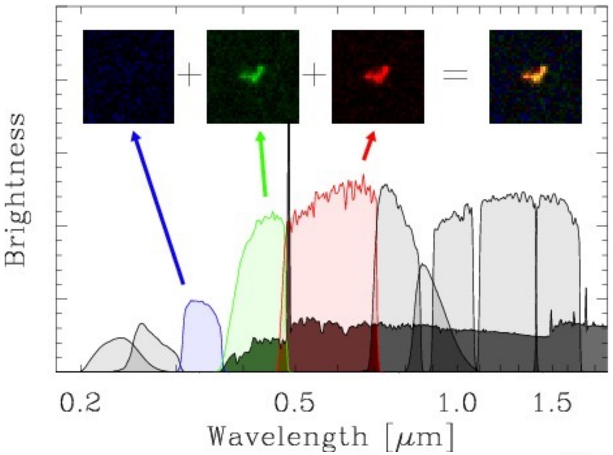
Yearly cumulative distribution of GRBs with redshifts as a function of redshift for Swift and THESEUS. The THESEUS predictions of >10 times more high redshift GRBs than Swift are conservative (i.e. they reproduce the current GRB rate). THESEUS can detect a median-luminosity GRB (Eiso ~10^{53} erg) to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

Specifications (1):

- Unique detection of sources in the early Universe via GRBs:
  - ***γ - 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.)



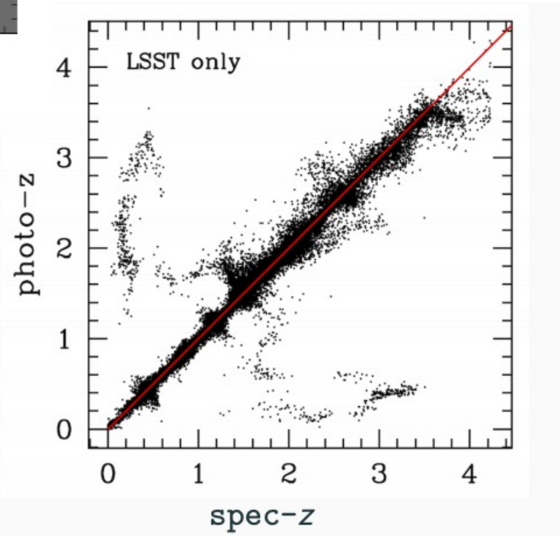


image source: Jain+15

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.**

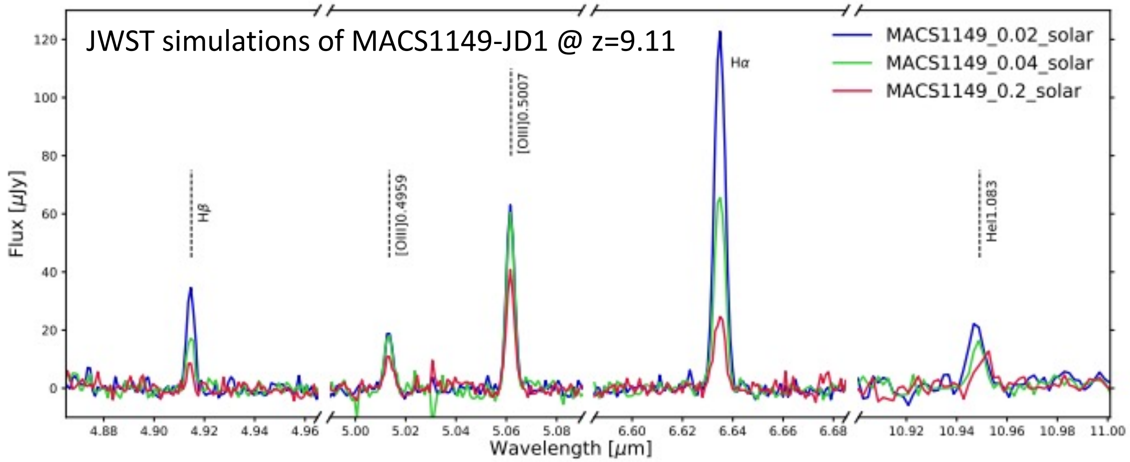
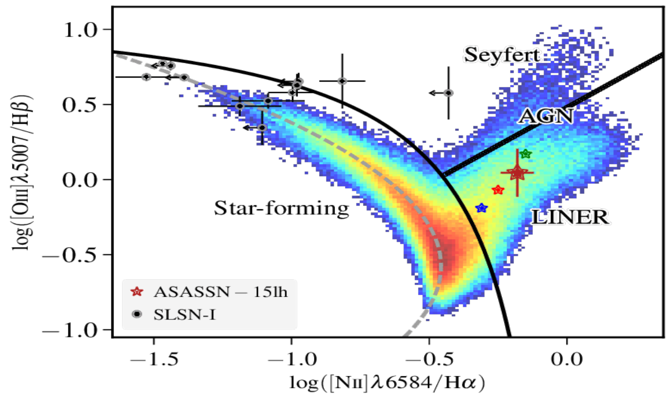


Fig. 5. Simulated medium-deep (10 ks) MRS observation of MACS1149-JD1 at a redshift of 9.11. It illustrates the simulated spectrum with metallicities of $0.02\,Z_\odot$ (blue), $0.04\,Z_\odot$ (green), and $0.2\,Z_\odot$ (red). The main emission lines are shown as dashed lines, and their derived integrated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

Alvarez-Marquez et al. (A&A 629, A9 2019)



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- 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***
- Deep spectroscopic + imaging observations to study the physics of the host galaxies:
  - ***JWST suite of instruments***

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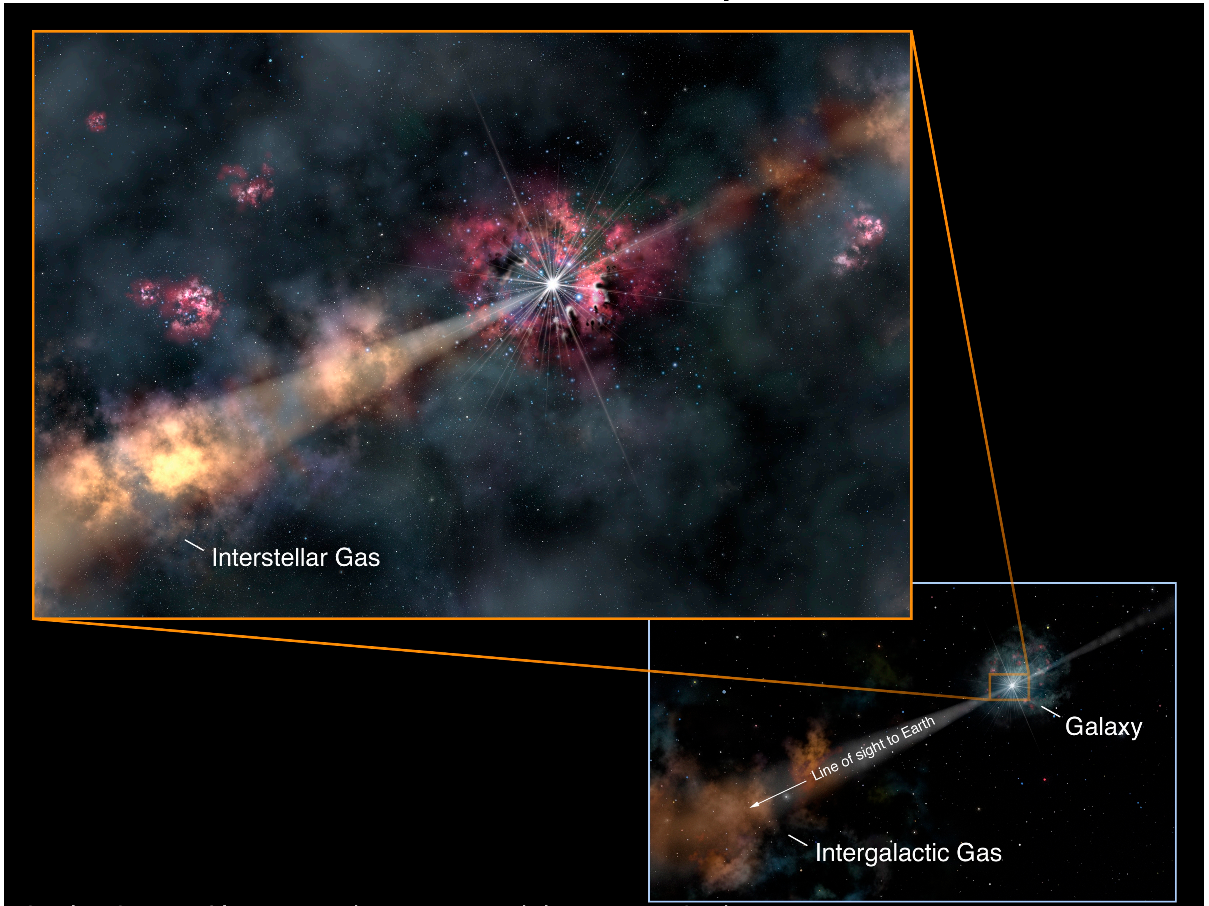
Extinction & Attenuation Curves in the early Universe

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.



Credit: Gemini Observatory/AURA, artwork by Lynette Cook

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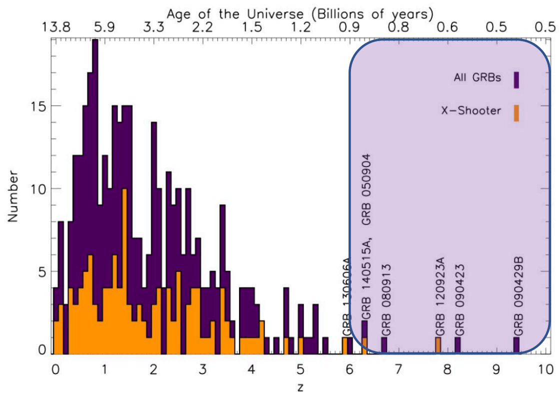
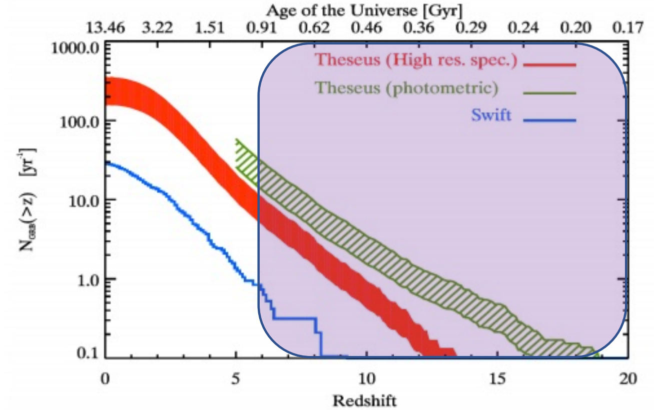




Yearly cumulative distribution of GRBs with redshifts as a function of redshift for Swift and THESEUS. The THESEUS predictions of >10 times more high redshift GRBs than Swift are conservative (i.e. they reproduce the current GRB rate). THESEUS can detect a median-luminosity GRB (Eiso ~10^{53} erg) to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

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

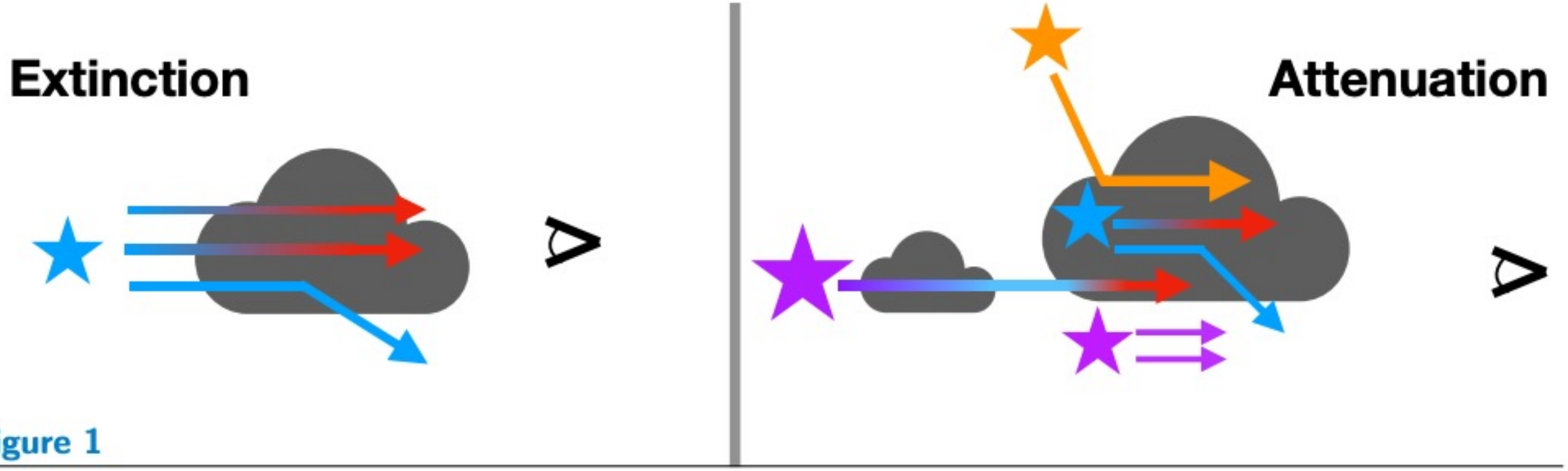


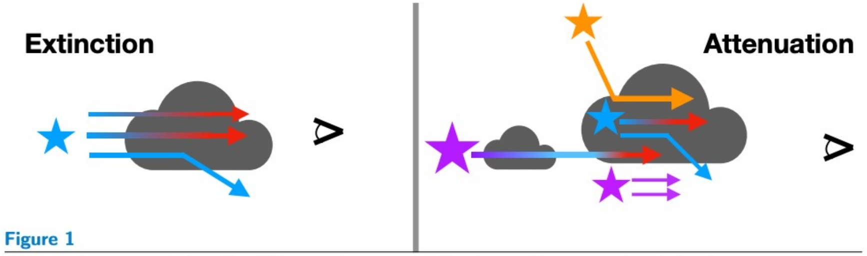
Figure 1

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 in a galaxy, stars and dust are mixed

Both can be measured in GRB hosts

Attenuation & extinction laws in galaxies



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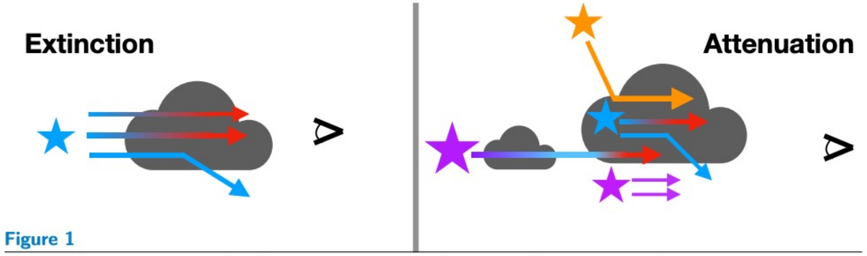

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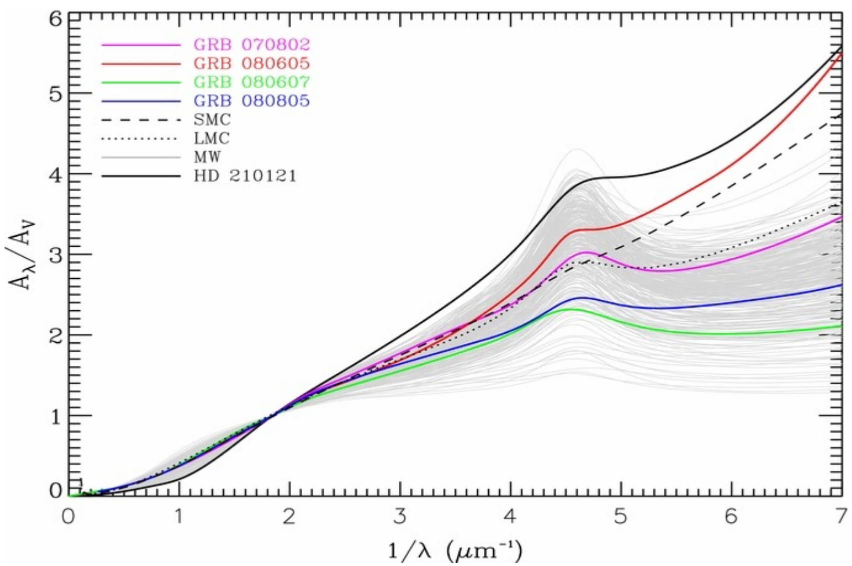
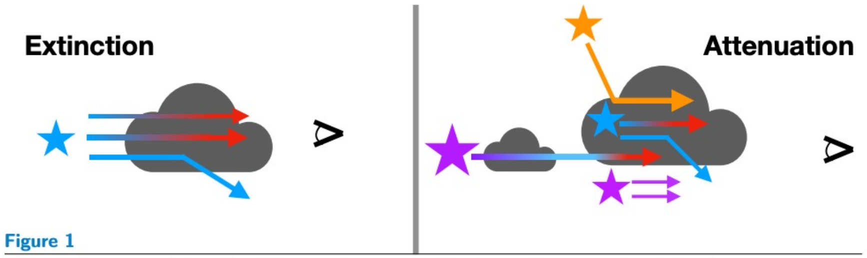


From the GRB

Attenuation & extinction laws in galaxies



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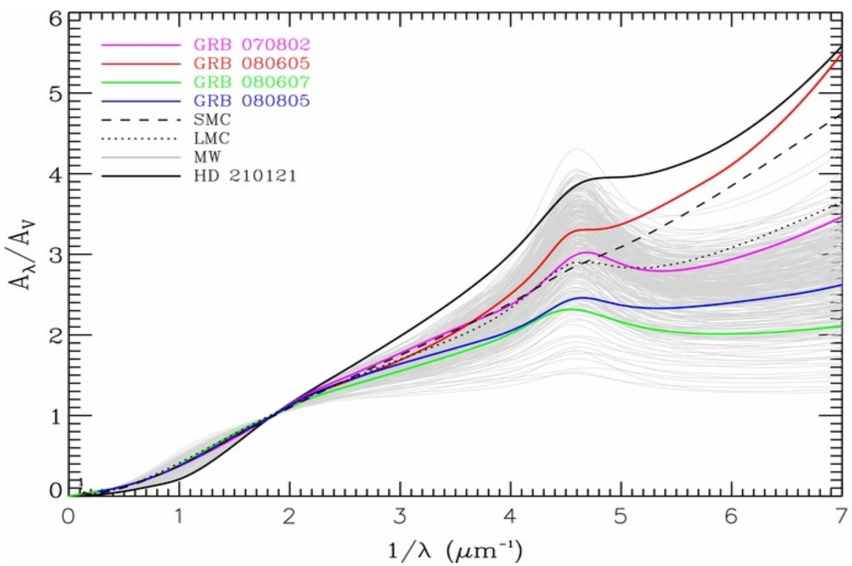
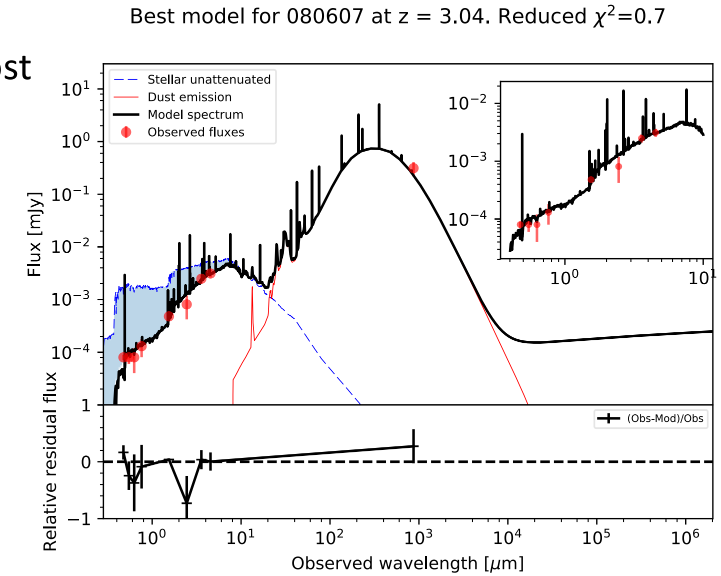


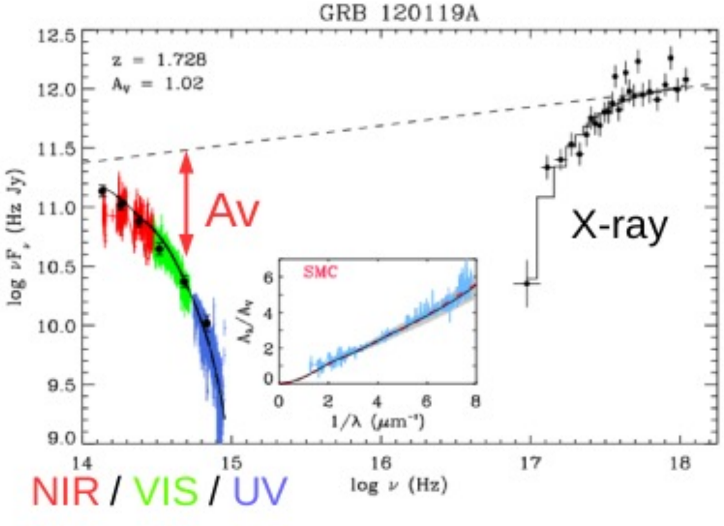
From the GRB

From the GRB Host

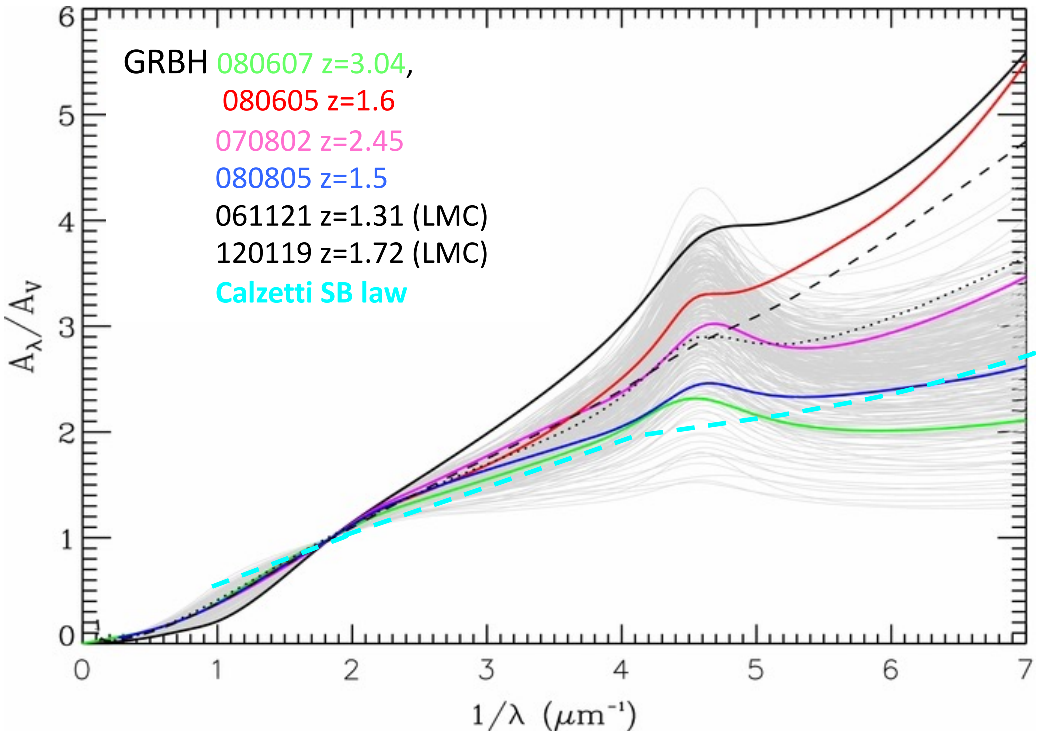


Extinction curves measured in galaxies hosting *γ-rays bursts*

Zafar+18



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

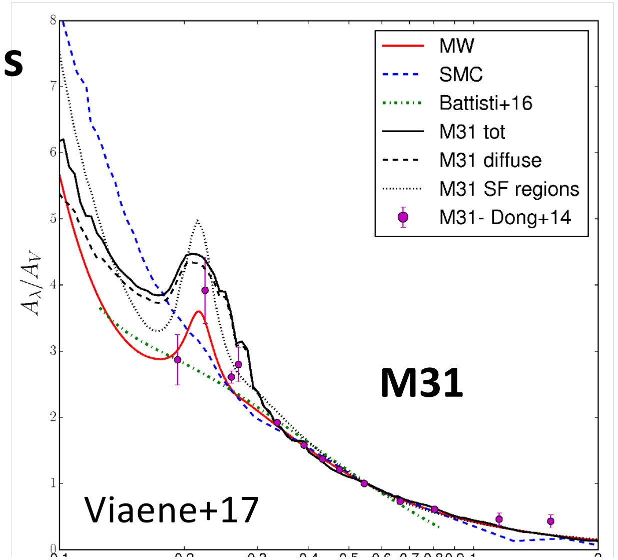


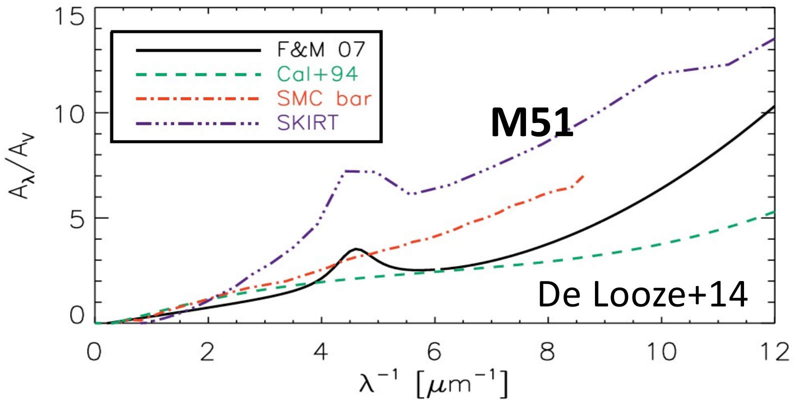
Specifications (2):

- Points sources, especially at high redshifts: ***γ - ray facility***

What do we know today on the topic?

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





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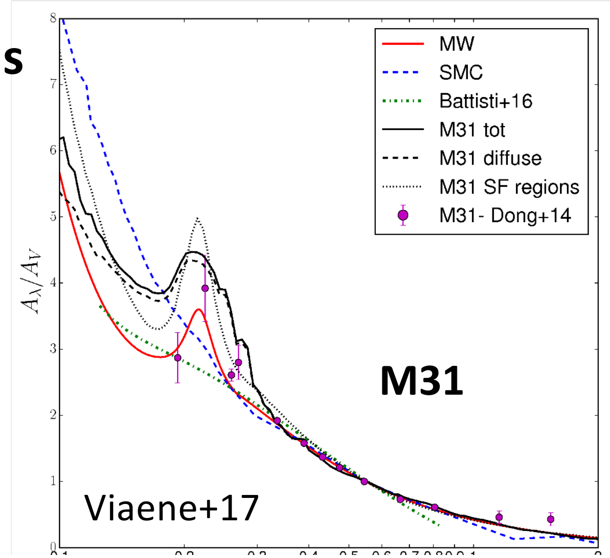
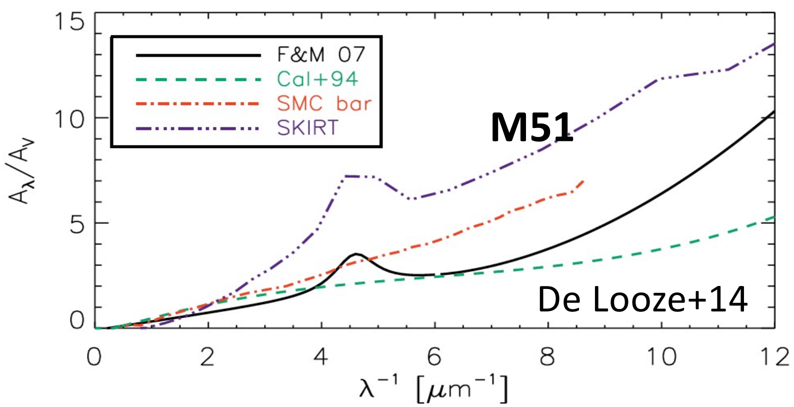
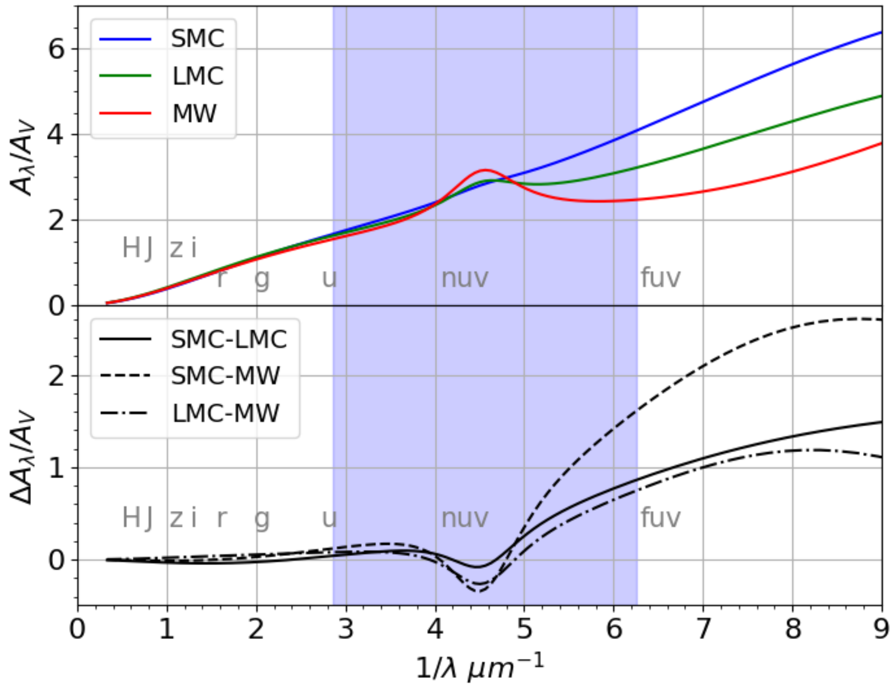


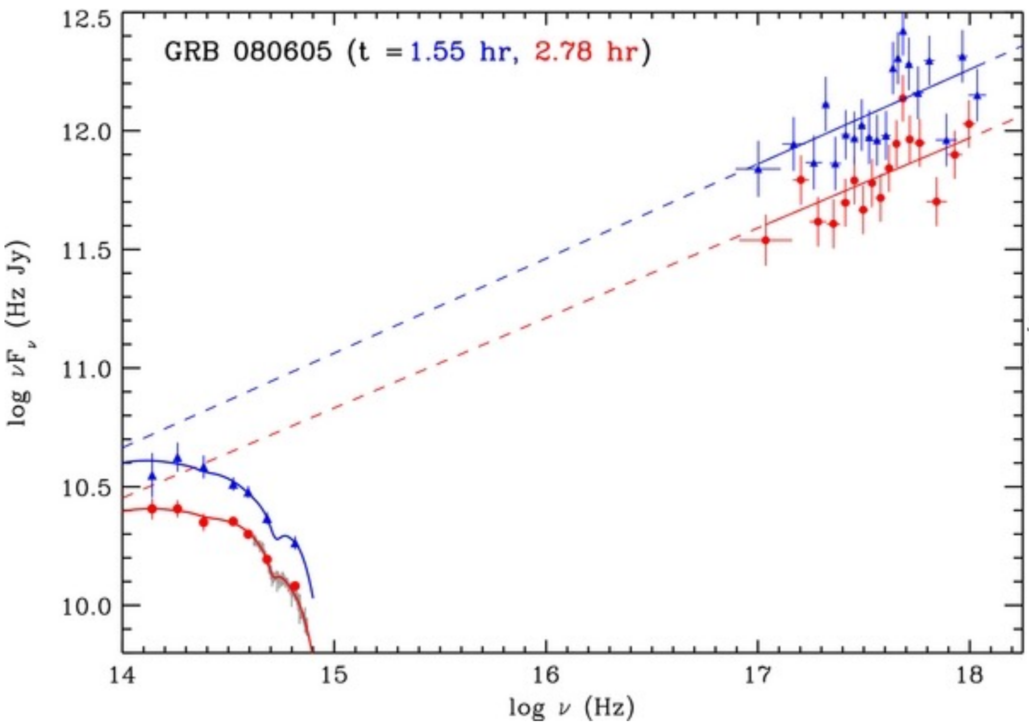


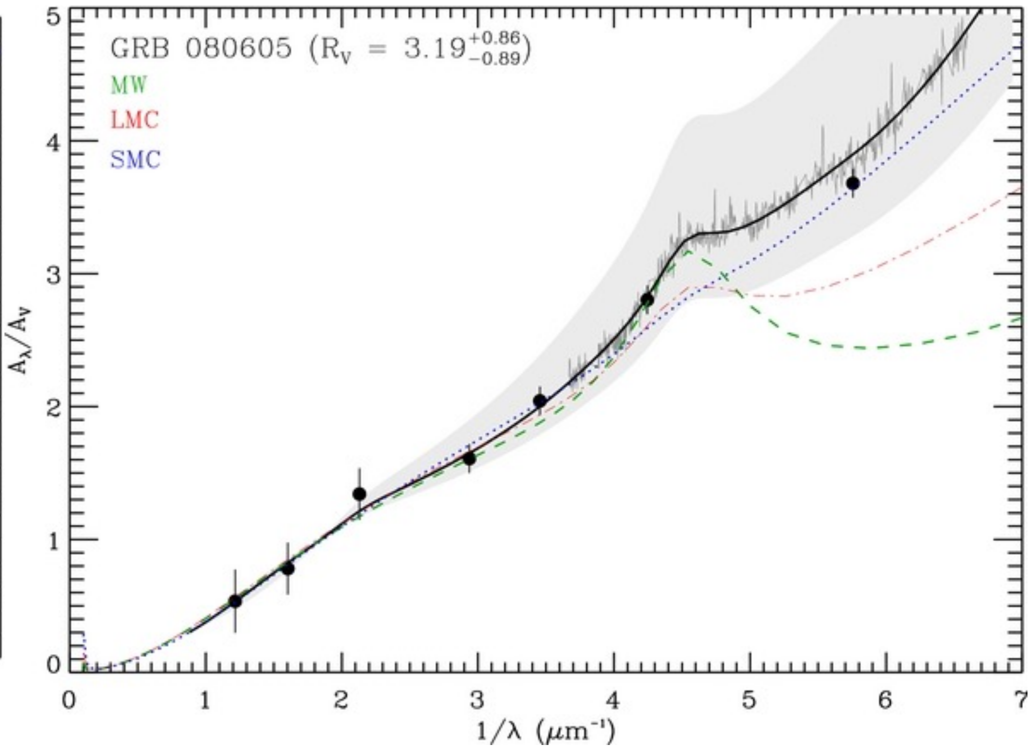
For more distant galaxies (especially in the EoR), there are attenuation curves *but no extinction curve*

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 > a few 100) of the afterglow: slope and bump for the extinction law





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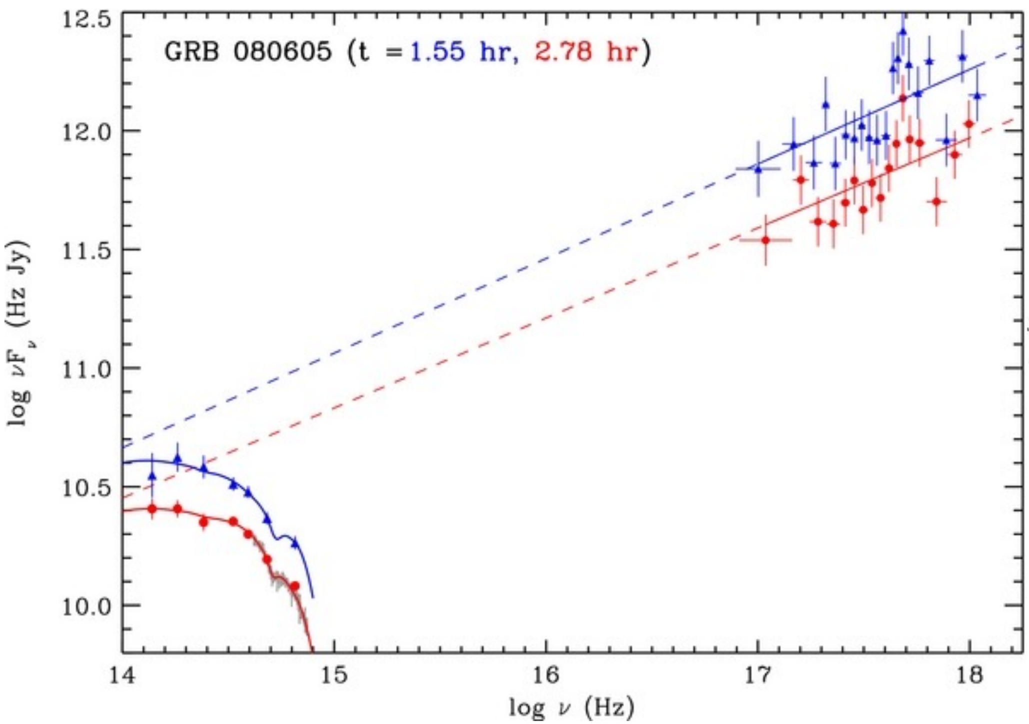

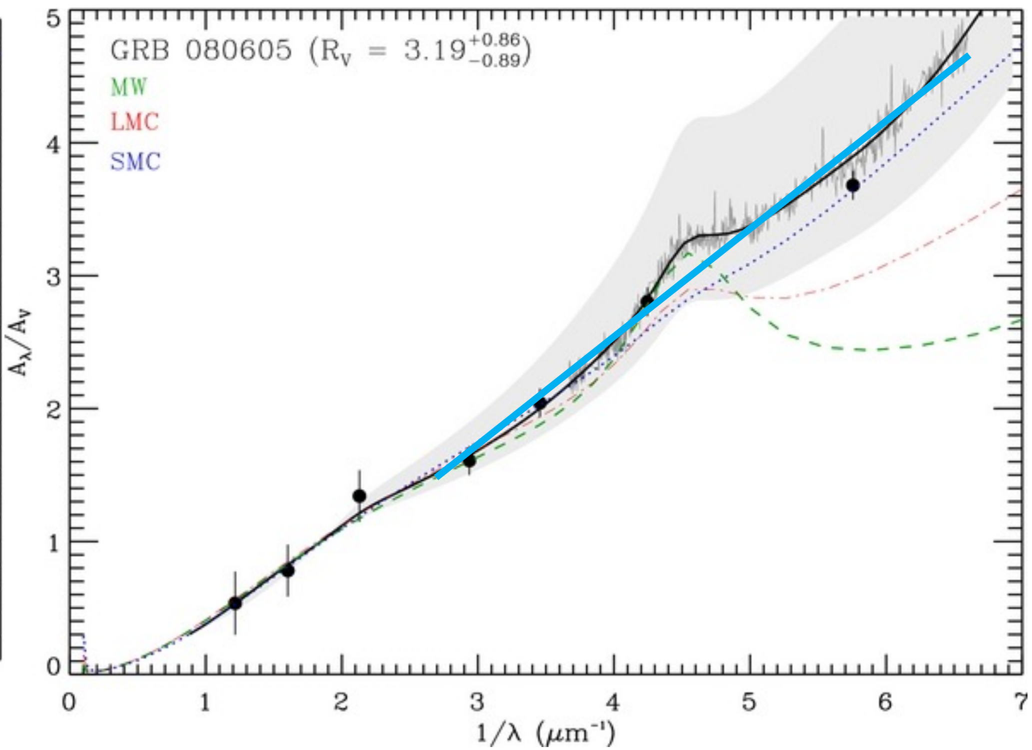

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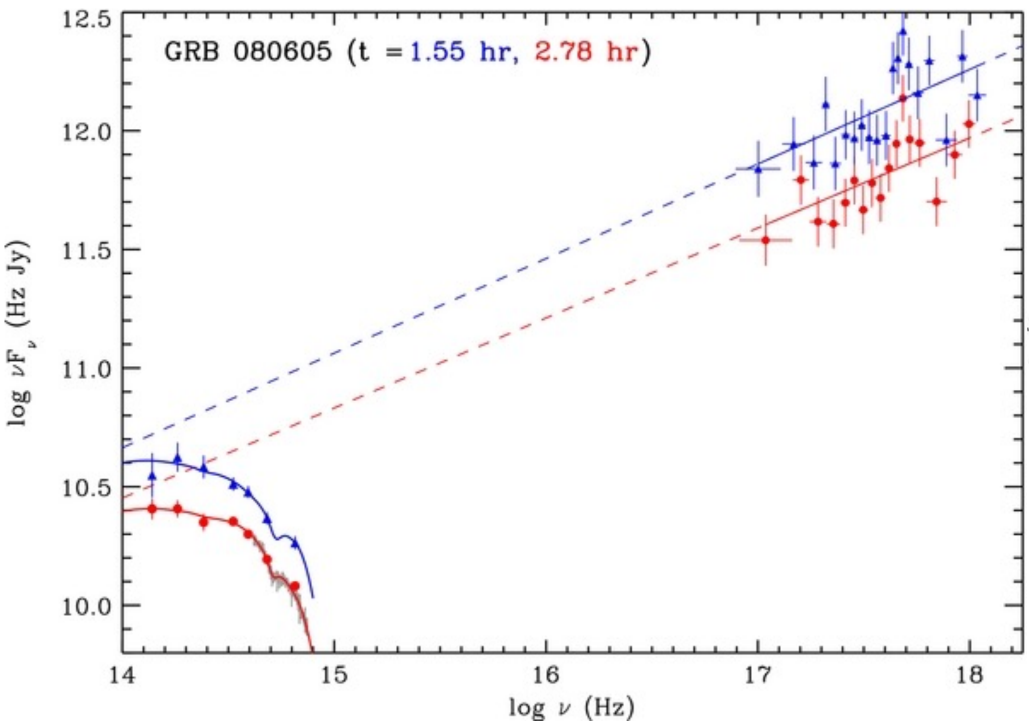
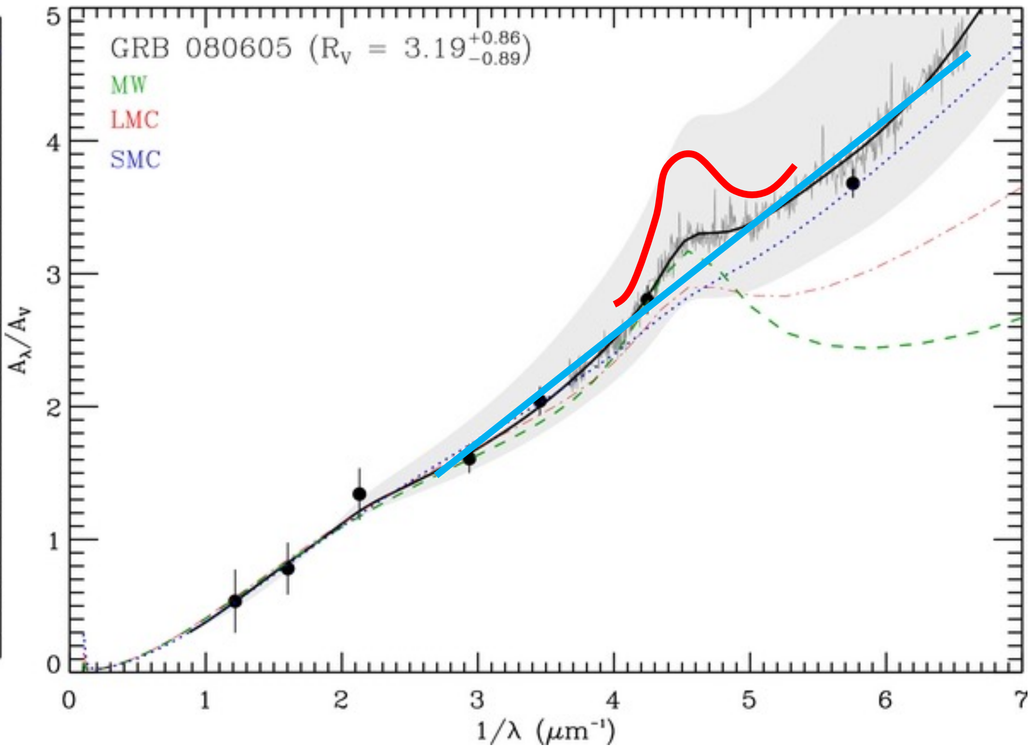


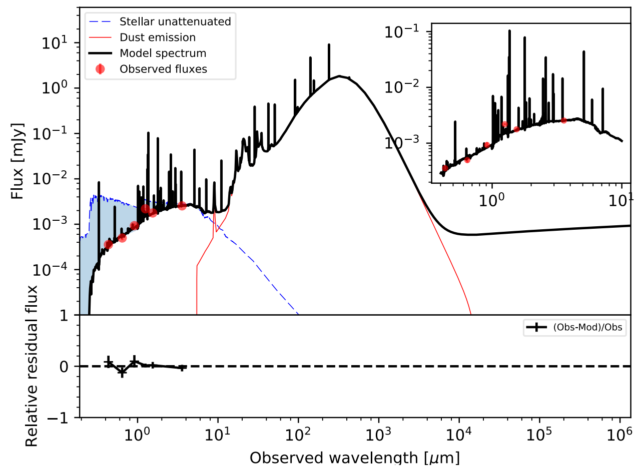


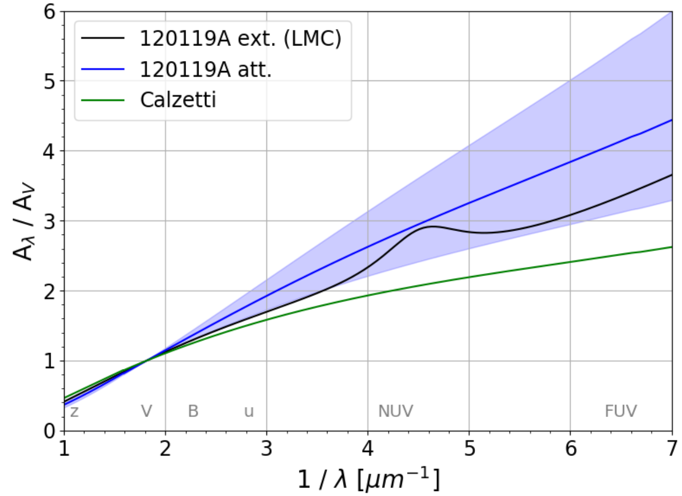
Specifications (2):

- Points sources, especially at high redshifts:
  - ***γ - ray facility***
- Dust extinction / attenuation laws:
  - ***rest-frame UV*** => ***observed NIR & R ∽ 500*** (directly from Theseus IRT but better from ground-based large telescopes (10m-class and ELTs)

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)

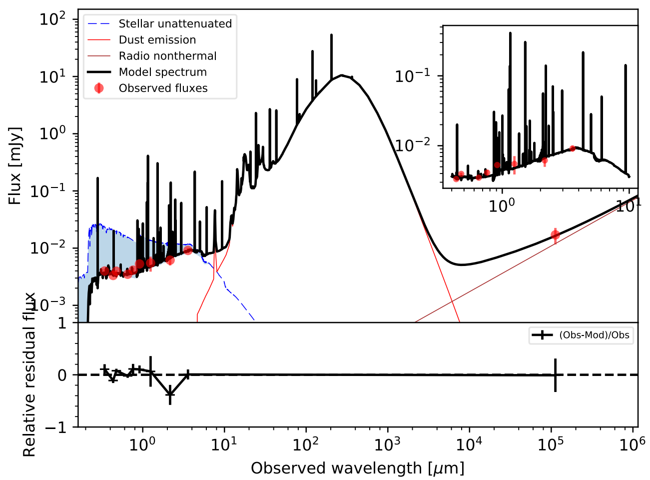
Best model for 120119A at z = 1.72. Reduced χ^2=0.32

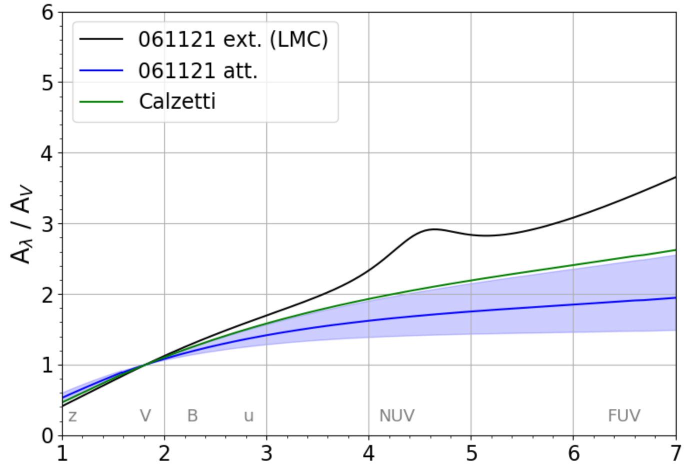




Steep attenuation Curve
Steeper than Calzetti

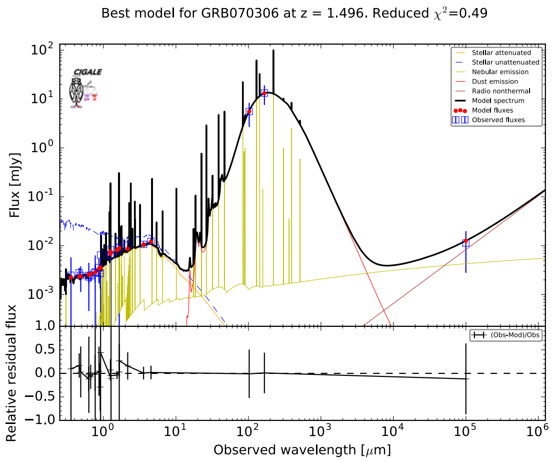
Best model for 061121 at z = 1.314. Reduced χ^2=0.74

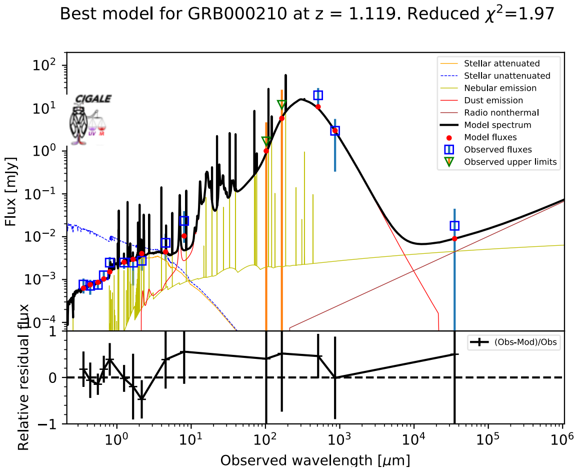


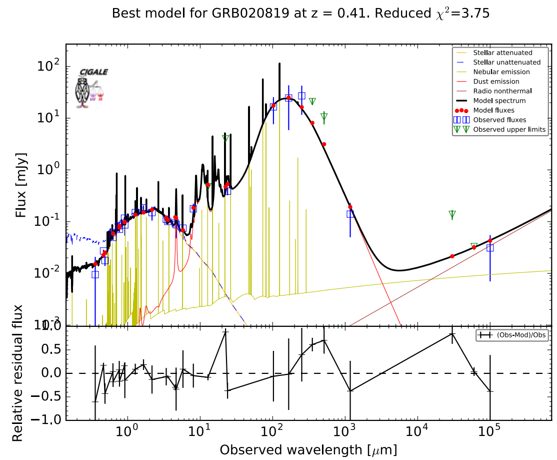


Flat attenuation Curve
Flatter than Calzetti

When dealing with dust properties, we must use data in the rest-frame far-IR (and in radio)







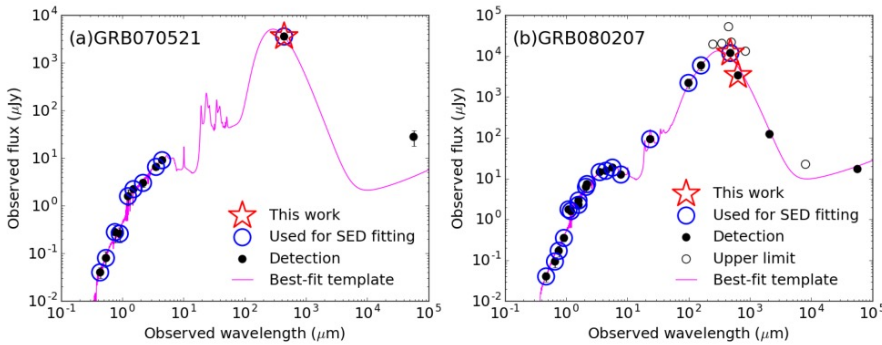
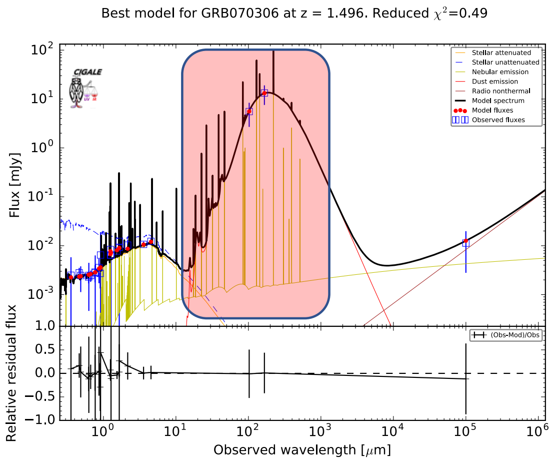
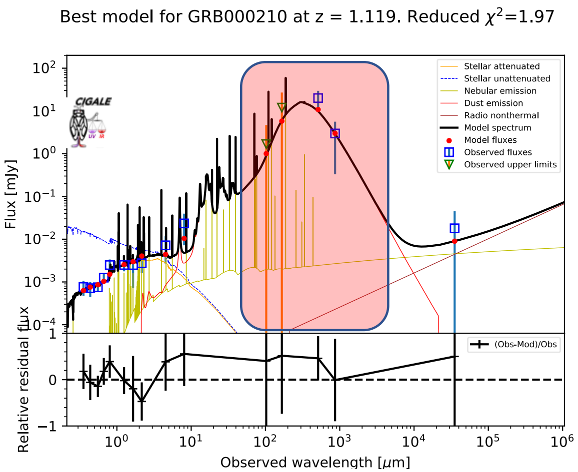
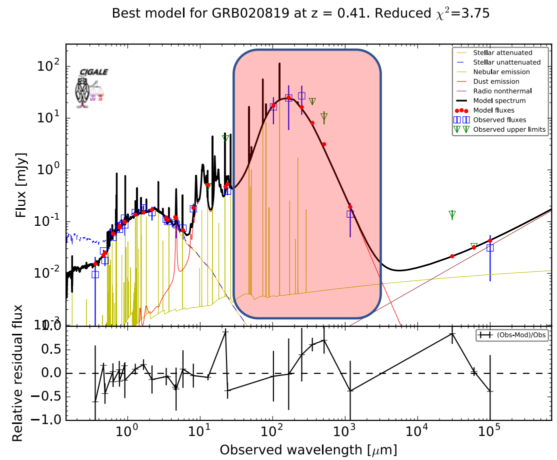


Figure 3. Spectral energy distributions of the GRB 070521 (left) and 080207 (right) host galaxies (black dots). ALMA photometry measured in this work is marked by red stars. Photometry at wavelengths longer than $\sim$500 μm was excluded from the SED fitting analysis to avoid possible contaminated flux from long-lived afterglows. Photometry used for the SED fitting analysis is marked by blue circles. The best-fitting results of the SED fitting analysis with MAGPHYS HIGHZ (da Cunha et al. 2008, 2015) are shown with magenta curves. 3σ upper limits are demonstrated by black circles. Details of the photometry are summarized in Tables 3 and 4.

When dealing with dust properties, we must use data in the rest-frame far-IR (and in radio)







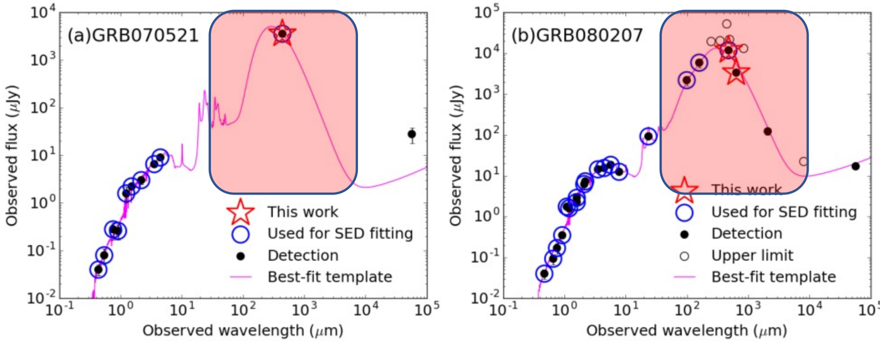
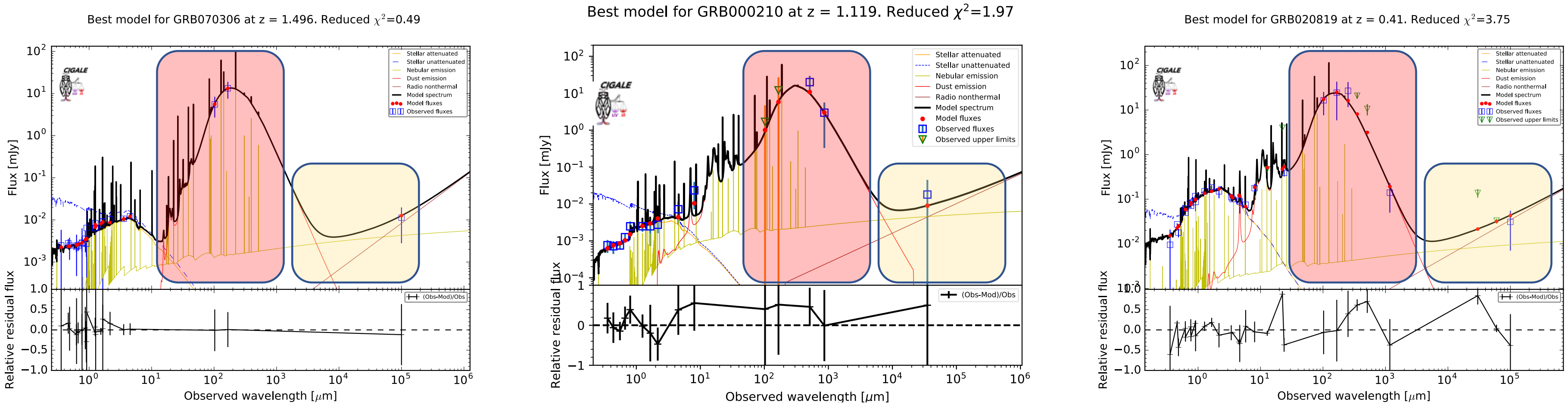
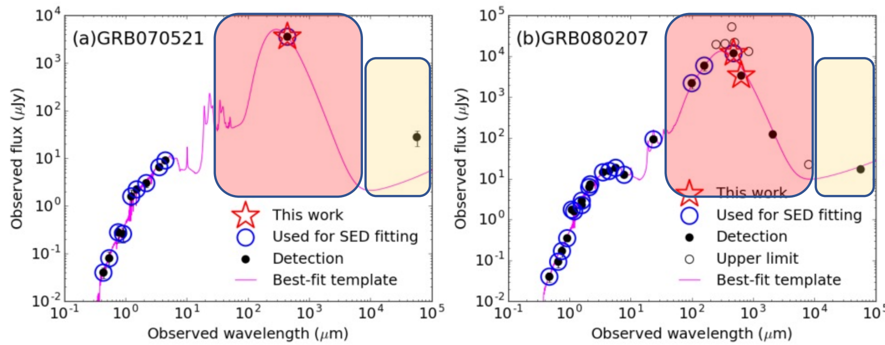


Figure 3. Spectral energy distributions of the GRB 070521 (left) and 080207 (right) host galaxies (black dots). ALMA photometry measured in this work is marked by red stars. Photometry at wavelengths longer than ~500 μm was excluded from the SED fitting analysis to avoid possible contaminated flux from long-lived afterglows. Photometry used for the SED fitting analysis is marked by blue circles. The best-fitting results of the SED fitting analysis with MAGPHYS HIGHZ (da Cunha et al. 2008, 2015) are shown with magenta curves. 3σ upper limits are demonstrated by black circles. Details of the photometry are summarized in Tables 3 and 4.

When dealing with dust properties, we must use data in the rest-frame far-IR (and in radio)





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Specifications (2):

- Points sources, especially at high redshifts:
  - ➢ ***γ - ray facility*** (from Theseus)
- Dust extinction / attenuation laws:
  - ➢ ***rest-frame UV*** => ***observed NIR & R ∽ 500*** (directly from Theseus IRT but better from ground-based large telescopes (10m-class and ELTs)
- Dust emission to constrain the amount of dust attenuation:
  - ➢ ***Rest-frame FIR*** => ***observed sub-mm*** (ALMA, NOEMA maybe Origins?)
  - ➢ ***Radio*** => SKA will be very useful

* Non exhaustive

Summary* of the multi-λ specifications useful to study GRB hosts in the early Universe÷

÷AGNs but also SF => Athena

- 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***
- Deep spectroscopic + imaging observations to study the physics of the host galaxies:
  - ***JWST suite of instruments***
- Points sources, especially at high redshifts:
  - ***γ - ray facility*** (from Theseus)
- Dust extinction / attenuation laws:
  - ***rest-frame UV*** => ***observed NIR & R $\backsim$ 500*** (directly from Theseus IRT but better from ground-based large telescopes (10m-class and ELTs)
- Dust emission to constrain the amount of dust attenuation:
  - ***Rest-frame FIR*** => ***observed sub-mm*** (ALMA, NOEMA maybe Origins?)
  - ***Radio*** => SKA will be very useful

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 ofthe 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.