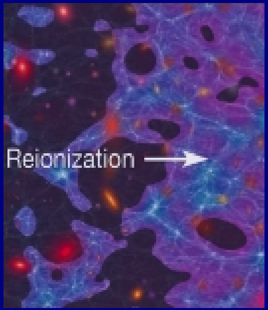
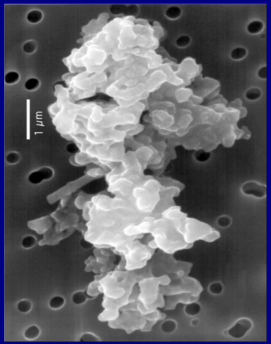


Signatures of early structure formation at FIR/sub-mm wavelengths



María Emilia De Rossi

Instituto de Astronomía y Física del Espacio (CONICET-UBA), Argentina

&

Volker Bromm

Department of Astronomy, University of Texas at Austin, USA

DSU2019, Buenos Aires, Argentina, 2019

INTRODUCTION

Mini-halos (~10^6 $M_\odot$) at z>20

First stars (Pop III)
e.g. Bromm 2013

Reionization | **First metals** | **Dust Formation**

Strong negative feedback

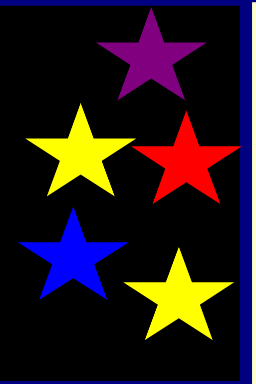
Atomic cooling halos (~10^7 – 10^8 $M_\odot$) at z~20-6
e.g. Bromm & Yoshida 2011

First long-lived stellar systems

First galaxies might have been composed of Pop II stellar systems, surrounded by mixed phase of gas and dust.

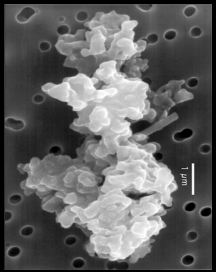
Interconnection FIR/sub-mm Radiation and First Galaxies

Primordial stellar populations



- *Imprint on the NIR (peaking at λ~1μm) (e.g. Bromm 2013).*
- *Widely studied in the literature.*
- *NIR-EBL excess suggests a significant contribution from early epochs (e.g. Kashlinksky 2005).*

Dust emission



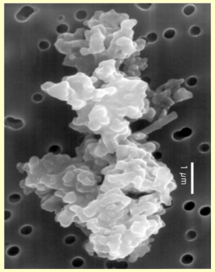
- *UV radiation from primordial stars heated interstellar dust.*
- *Re-radiated dust emission contributes to the FIR/sub-mm part of the spectrum.*
- *Role of first galaxies as possible FIR/sub-mm sources poorly explored.*

We ask to what extent the first galaxies may have contributed to the observed FIR/sub-mm radiation through redshifted dust emission. ?

Brief overview of dust model (De Rossi & Bromm 2017)

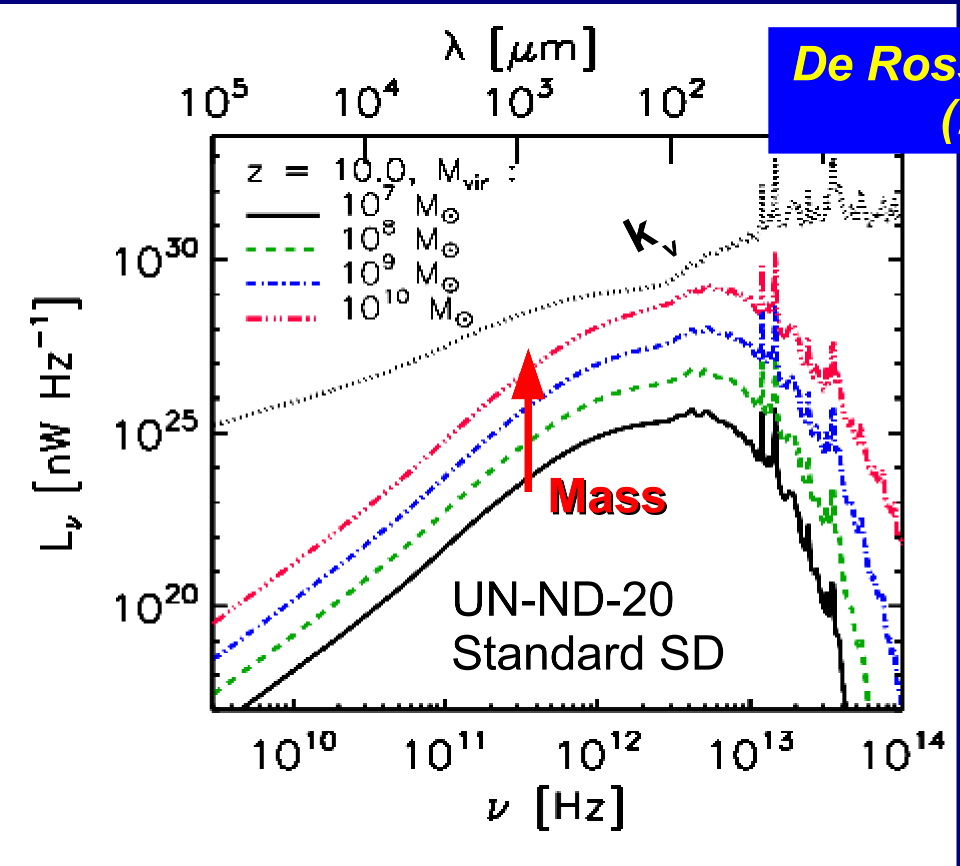
Model galaxy: *dark matter halo hosting a central cluster of Pop II stars, surrounded by a mixed phase of gas and dust.*

- *Different density profiles for the gas (e.g. isothermal power law).*
- *Spectral energy distribution associated to stars: YGGDRASIL model grids (Zackrisson+2011).*
- *Silicon-based dust models (Cherchneff & Dwek 2010).*
- *Grain-size distributions used in Ji et al. (2014): "standard" (Pollack+1994) and "shock" (Bianchi & Schneider 2007).*
- *Dust temperature (T_d) was determined assuming thermal equilibrium.*
- *Dust emissivity was estimated by applying the Kirchhoff's law for the T_d profile.*

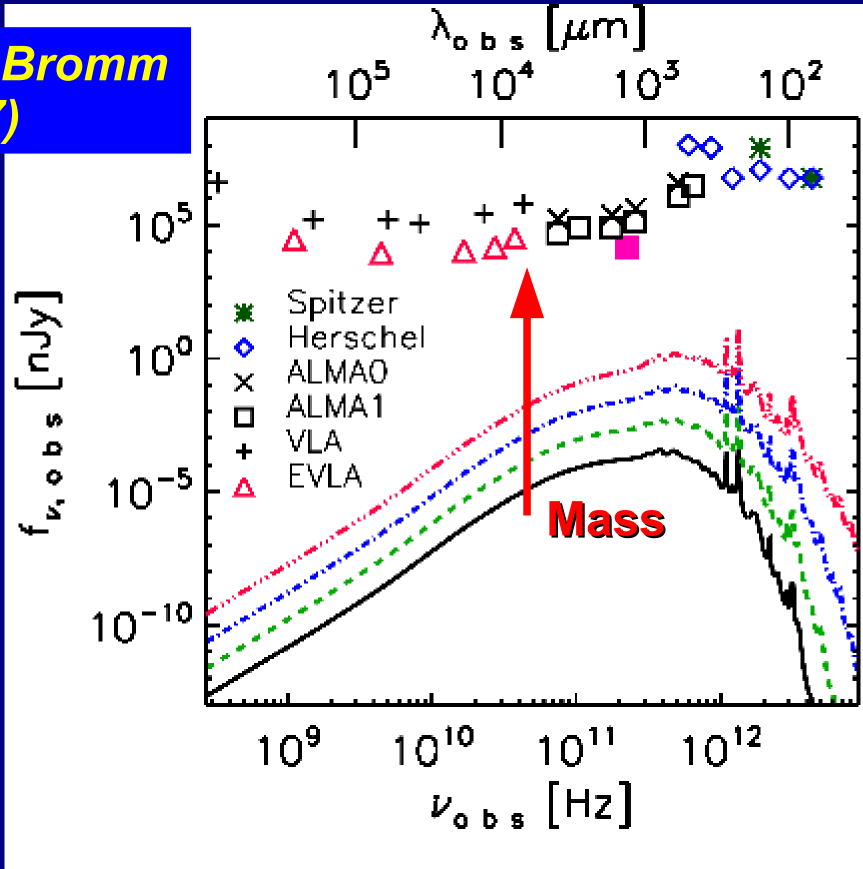


☆ ***Fiducial model**: dust-to-metal mass ratio $D/M=5\times 10^{-3}$, gas metallicity of $Z_g=5\times10^{-3}Z_\odot$ and a star formation efficiency of $\eta = 0.01$.*

Dust emission from a model source at z=10



De Rossi & Bromm (2017)



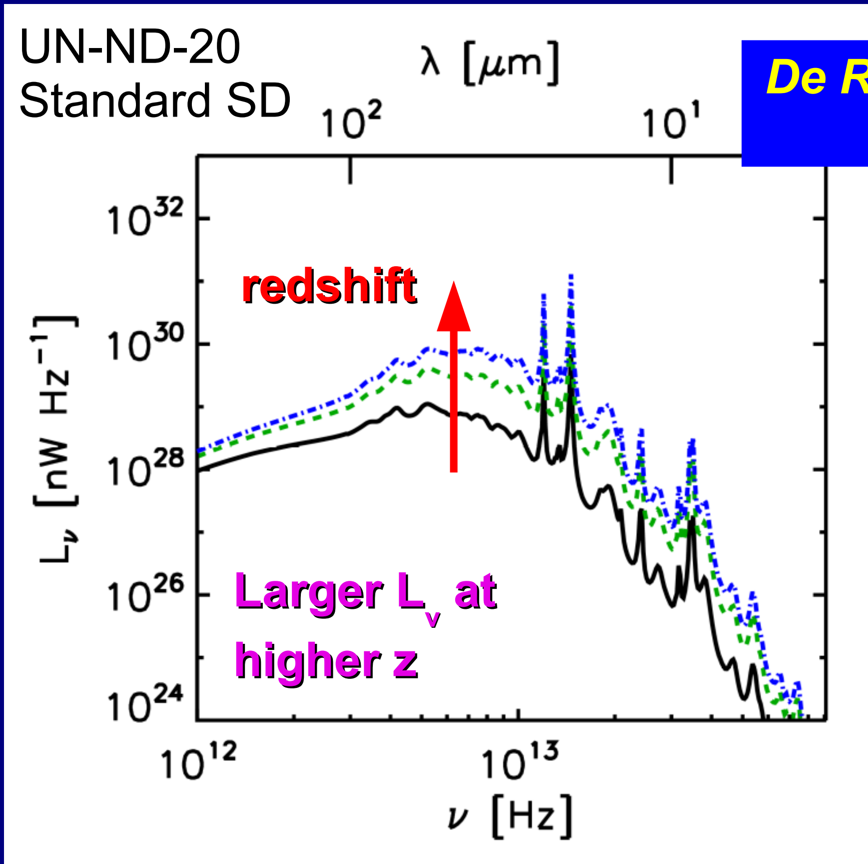
Peak at $\lambda \sim 50\mu m$ or $\lambda_{obs} \sim 500\mu m$.

Rare massive systems ($M_{vir} > 10^{14} M_\odot$, $L_d > 10^{12} L_\odot$) detectable but statistically difficult to find.

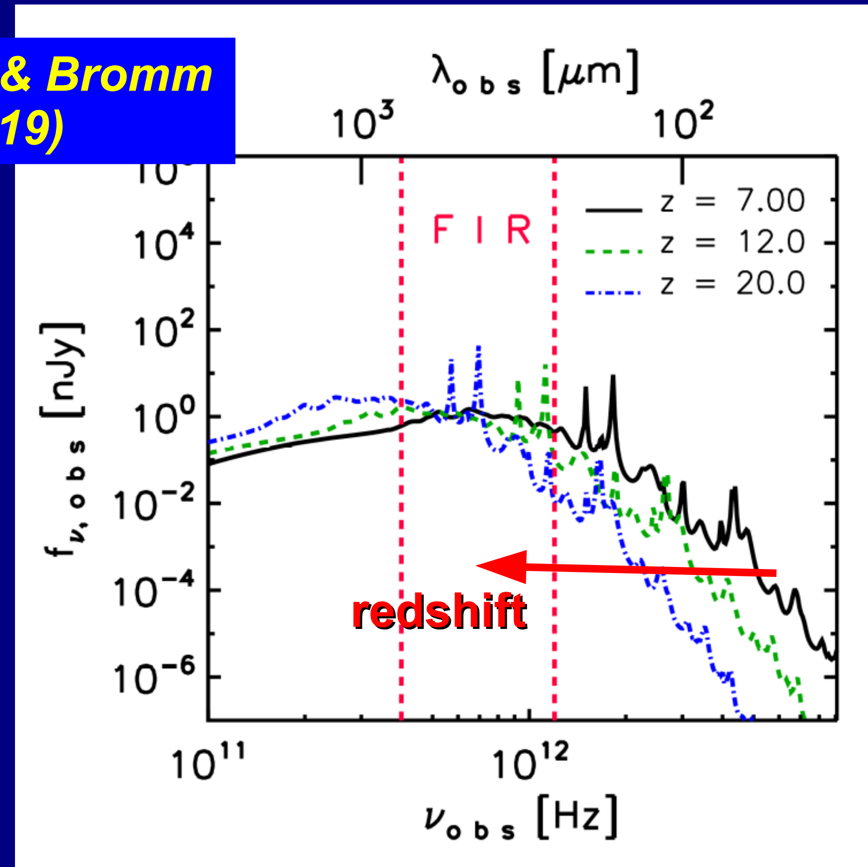
Point source sensitivities of current instruments not sufficient to allow detection.

An increase of D/M, Z_g or η and the use of the shock SD would increase dust emission.

Dust emission from a model source with $M_{vir}=10^{10}M_{\odot}$



De Rossi & Bromm (2019)



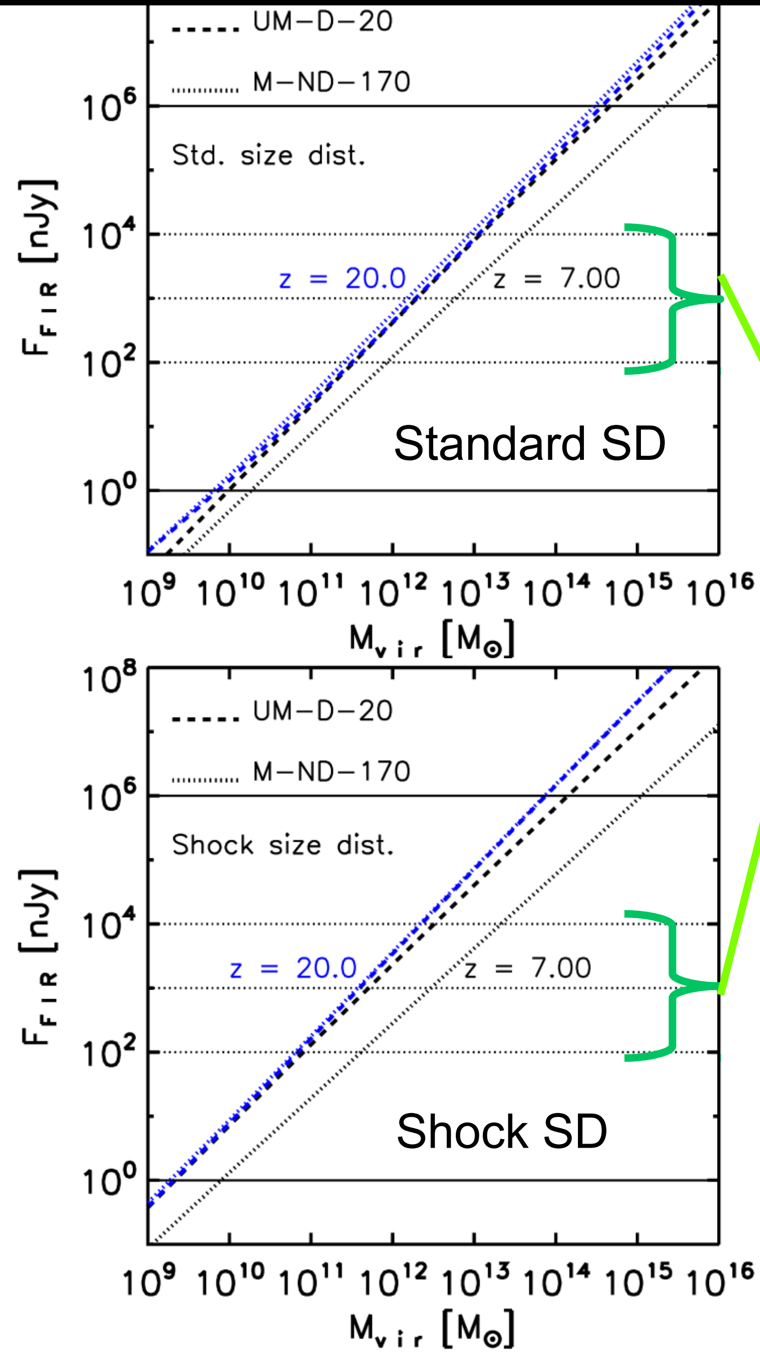
High-z systems, more concentrated. → **Enhancement of heating efficiency associated with stellar radiation.**

Higher temperature floor set by the CMB. → **Increase in dust temperature.**

FIR/sub-mm sources at z > 7 experience a strong negative K-correction

Observations in the FIR also sensitive to spectral features

De Rossi & Bromm (2019)



FIR flux vs Mass at z = 7-20

Contrary to expectations, systems with similar masses brighter at higher z.

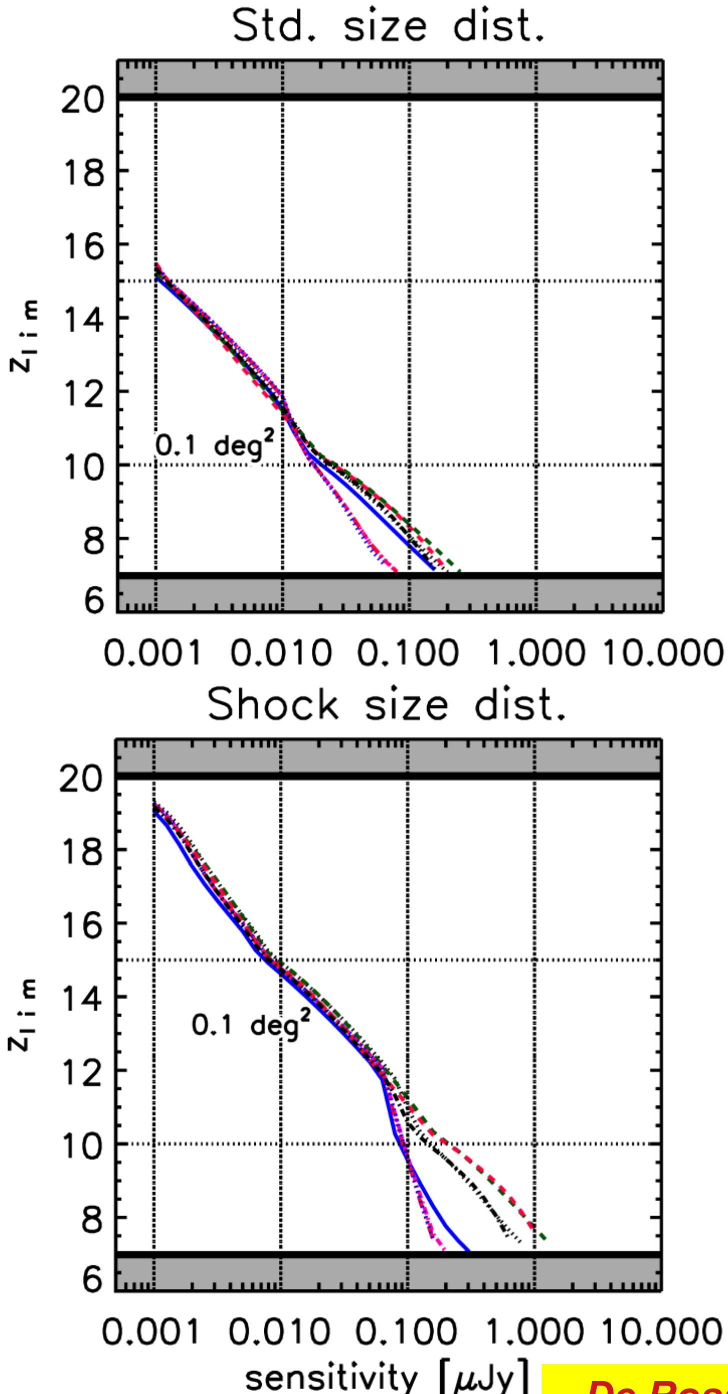
Strong negative K-correction

Characteristic sensitivity values covering the scope of future FIR surveys.

$M_{min} \sim 10^{11} - 10^{12}\ M_\odot$ ($M_{min} \sim 10^{13} - 10^{14}\ M_\odot$) required to reach sensitivity limits of S ~ 0.1 μJy (S ~ 10.0 μJy), with the exact value depending on dust properties.

$M_{vir} > M_{min}$ far from typical, highly biased overdensities.

Detection difficult with blind surveys.



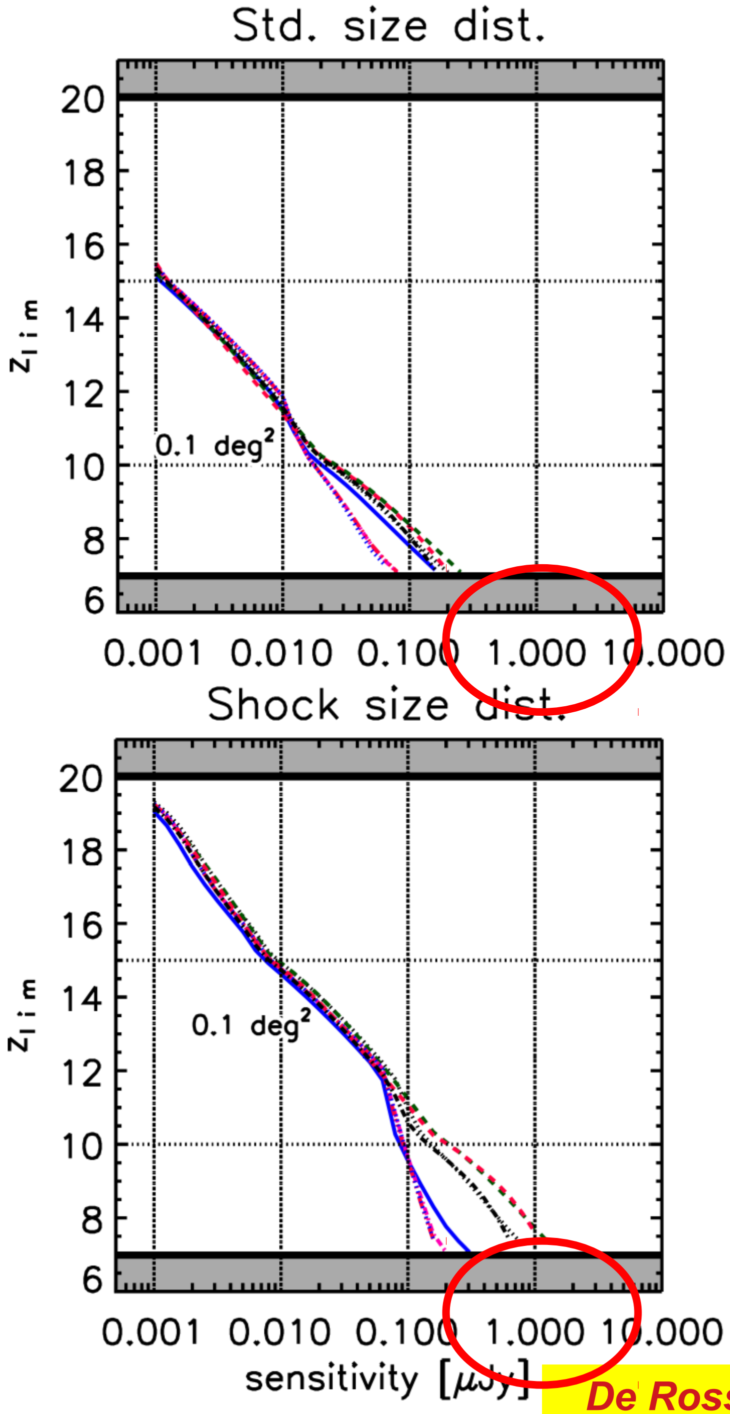
The Redshift Horizon

For a given **sky area (ΔΩ)**, z_{lim} is defined as the highest z above which the **projected number of sources** above the **sensitivity limit** is N ≤ 1.

At $z_{lim} > 12$:

$$z_{lim} = -4 \log_{10}(S/\mathrm{nJy}) + z_{lim}(S = 1\ \mathrm{nJy})$$

De Rossi & Bromm (2019)



The Redshift Horizon

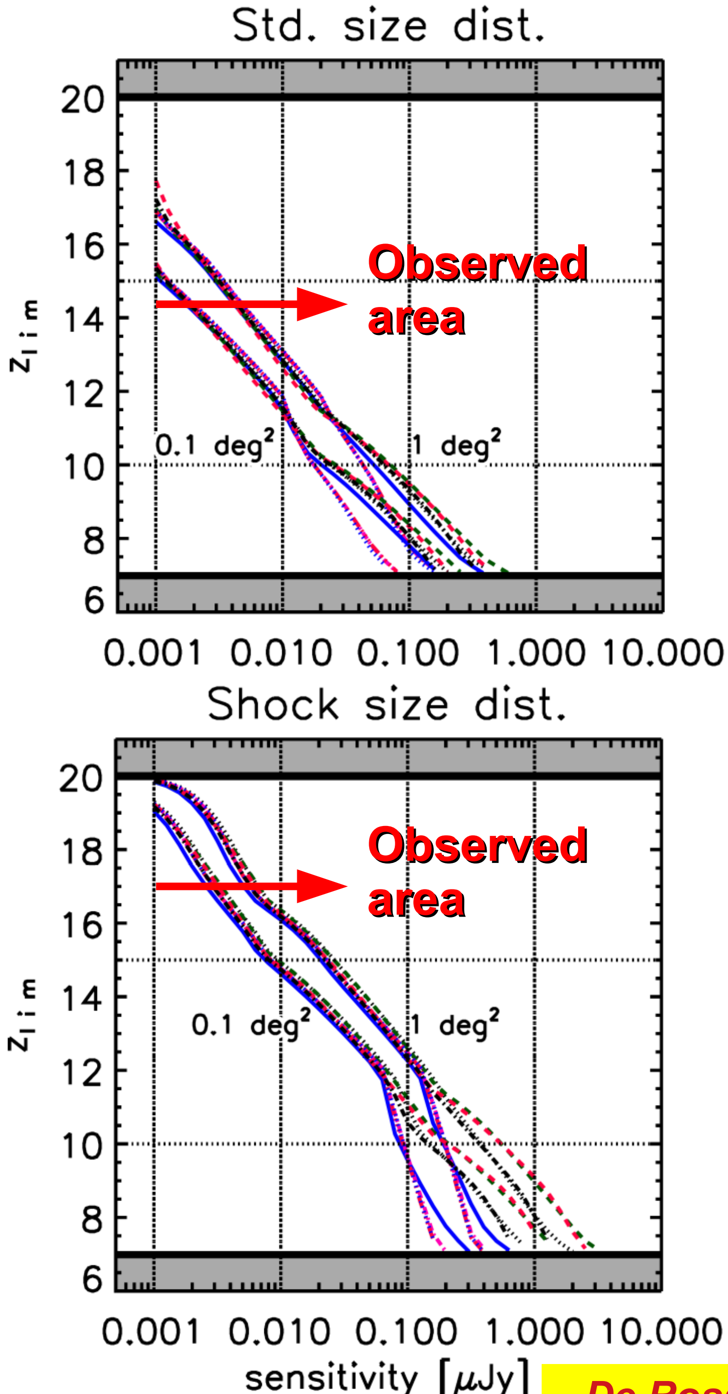
For a given sky area ($\Delta\Omega$), z_{lim} is defined as the highest *z* above which the projected number of sources above the sensitivity limit is $N \leq 1$.

At $z_{lim} > 12$:

$$z_{lim} = -4 \log_{10}(S/\mathrm{nJy}) + z_{lim}(S = 1\ \mathrm{nJy})$$

Probability of detecting typical first galaxies in blind surveys (FIR/sub-mm): *very challenging, given the extreme sensitivities required.*

De Rossi & Bromm (2019)



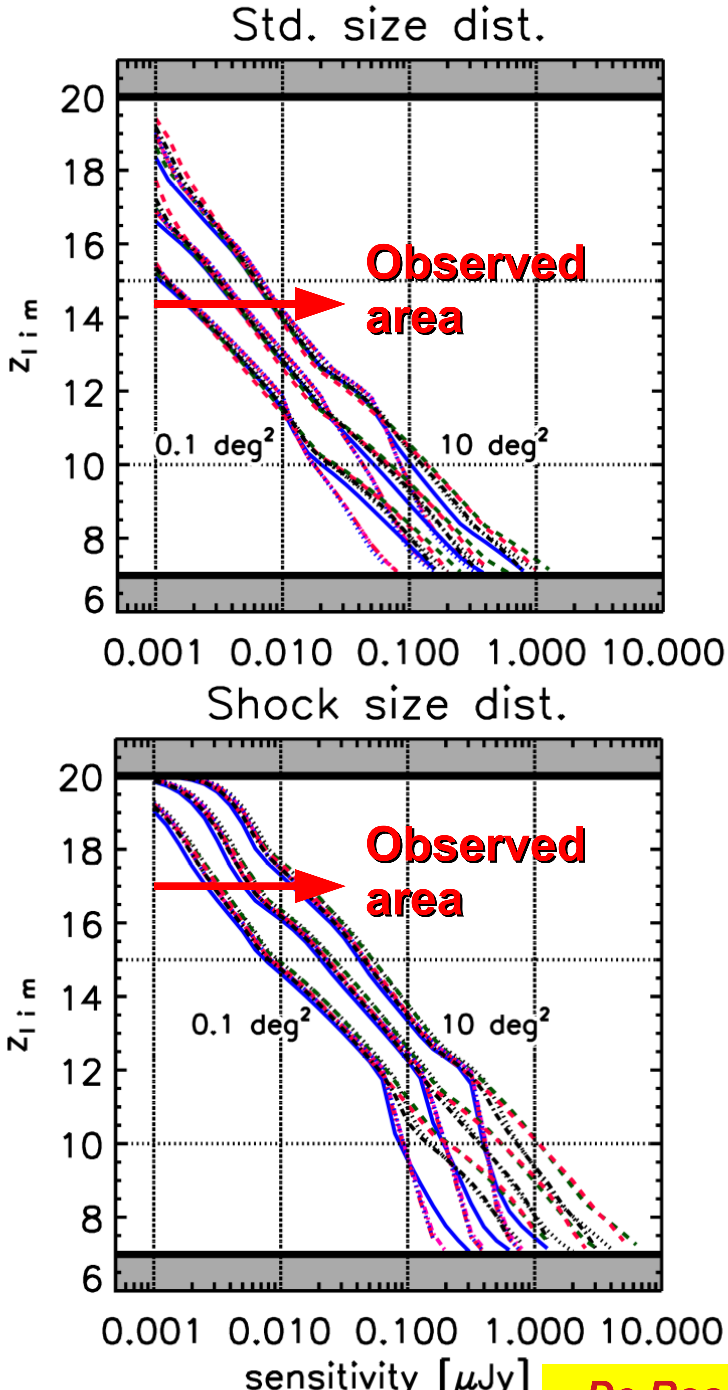
The Redshift Horizon

For a given **sky area ($\Delta\Omega$)**, z_{lim} is defined as the highest *z* above which the **projected number of sources** above the **sensitivity limit** is **$N \leq 1$**.

Probability of detecting one individual source: dependence on instrument sensitivity and survey area.

De Rossi & Bromm (2019)

The Redshift Horizon



For a given sky area (ΔΩ), z_{lim} is defined as the highest *z* above which the projected number of sources above the sensitivity limit is N ≤ 1.

Probability of detecting one individual source: dependence on instrument sensitivity and survey area.

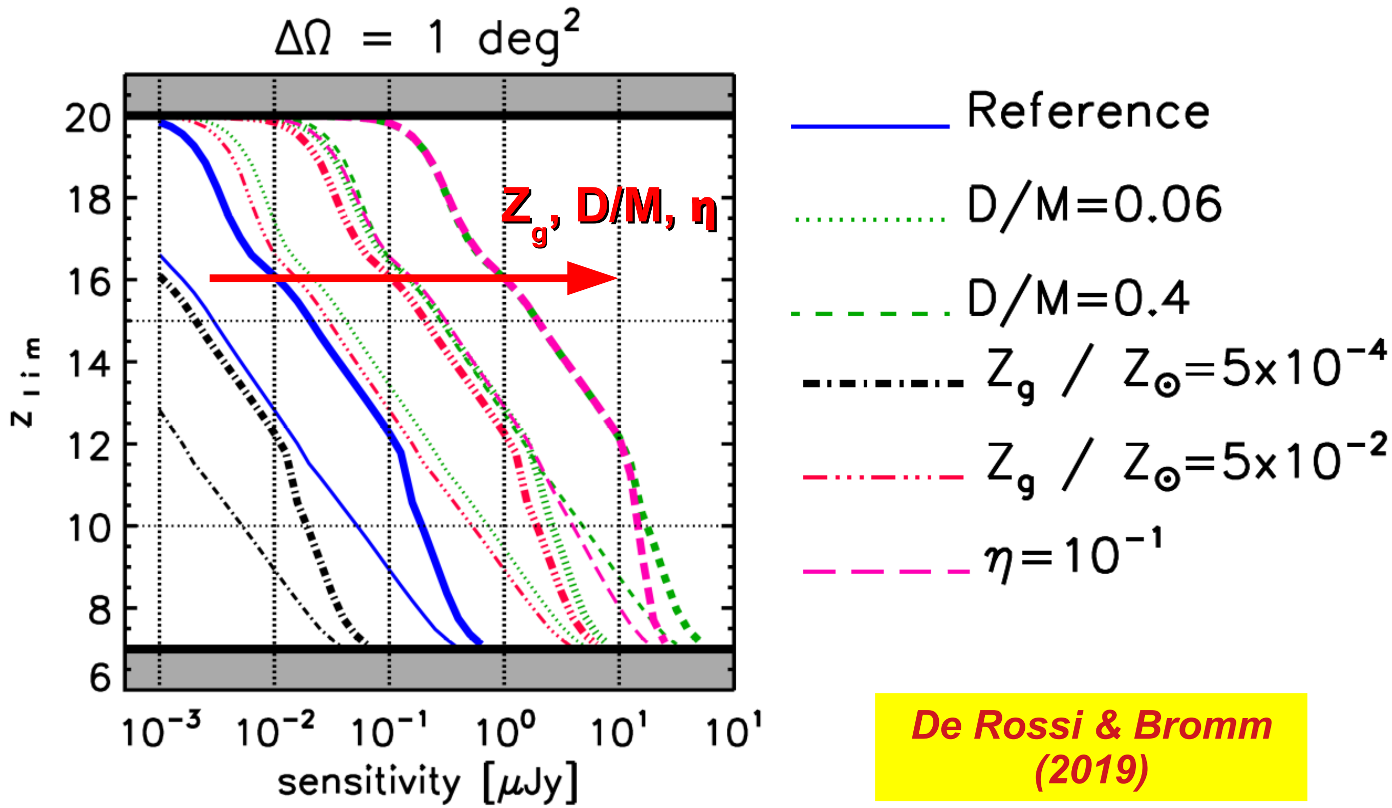
Nature of primordial galaxies still uncertain. Observational prospects increase significantly with star formation efficiency, metallicity and dust-to-metal ratio.

De Rossi & Bromm (2019)

Parameter sensitivity

Reference parameters

- ***Dust-to-metal mass ratio $D/M=5\times 10^{-3}$***
- ***Gas metallicity $Z_g=5\times10^{-3}Z_\odot$***
- ***Star formation efficiency $\eta = 0.01$***

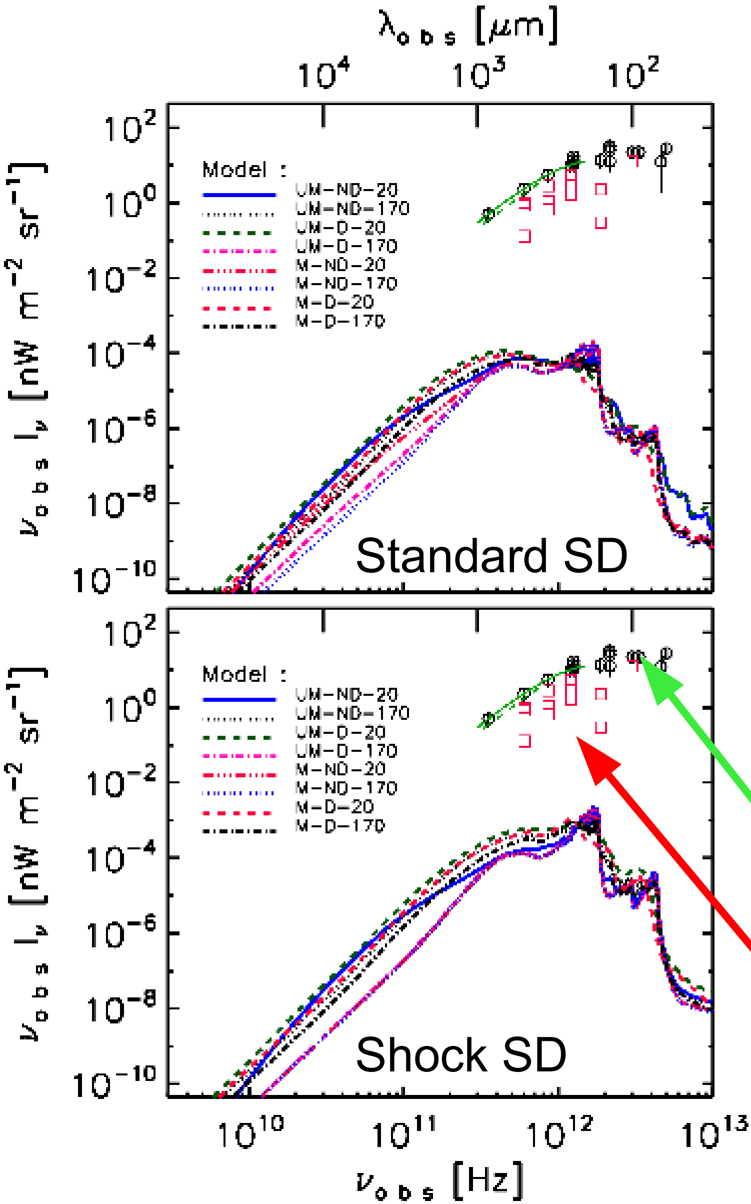


De Rossi & Bromm (2019)

An increase by one order of magnitude of Z_g, η or D/M , relaxes the sensitivity limit for detection to similar order of magnitude.

Similar trends obtained if adopting survey areas of 0.1 and 10 deg^2 .

Cosmic FIR Background



De Rossi & Bromm (2017)

$$I_\nu(\nu_{\rm obs}) = \frac{c}{4\pi} \int_{z_{\rm min}}^{z_{\rm max}} \epsilon_\nu(\nu, z) \left| \frac{{\rm d}t}{{\rm d}z} \right| {\rm d}z,$$

* ε_ν : specific luminosity per comoving volume

⟶ Sheth-Tormen MF **+** dust luminosities predicted by our model.

Peak: ~500 μm

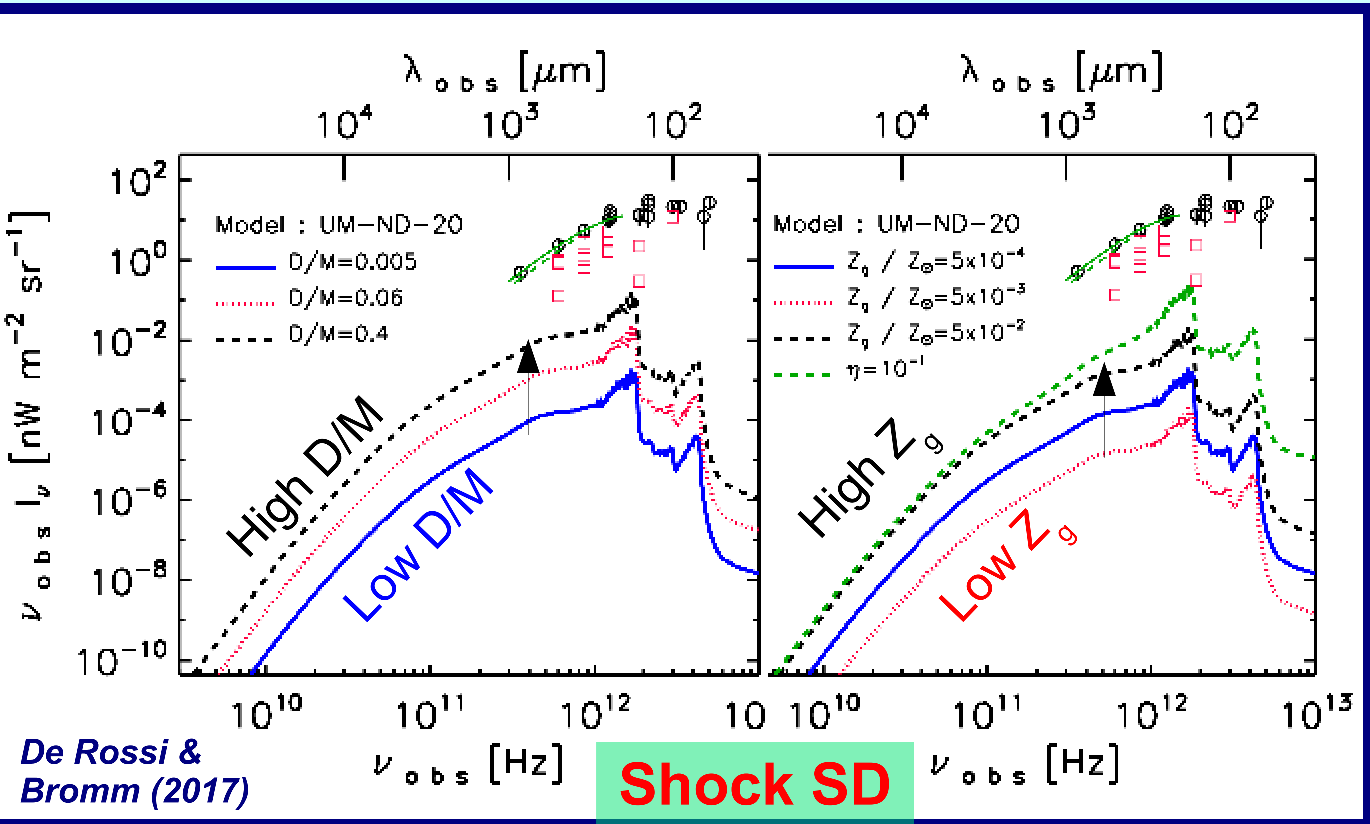
Maximum intensities: ~10^{-4} and ~10^{-3} nW m^{-2} sr^{-1} for the standard and shock SD, resp.

Below the measured background by ~3–4 orders of magnitude.

Below average source-subtracted EBL by ~2–3 orders of magnitude.

Dust chemical composition does not significantly affect the main trends.

Impact of model parameters



Standard parameters

- ***Dust-to-metal mass ratio $D/M=5\times 10^{-3}$***
- ***Gas metallicity $Z_g=5\times10^{-3}Z_\odot$***
- ***Star formation efficiency $\eta = 0.01$***

Radiation intensity increases with D/M. For extreme D/M, ~1% of measured flux and ~100% of SS EBL.

Radiation intensity increases with *η*. For extreme *η, model EBL reaches the averaged observed* EBL excess.

⇒ D/M and Z_g are degenerate parameters.

SS EBL only reached if extremely high values are assumed for model parameters.

CONCLUSIONS

- We analysed the FIR/sub-mm signatures of first galaxies by implementing an analytical model for dust emission.
- Sources at z>7 experience a strong negative K-correction.
- Dust emission from dwarf galaxies at $z \sim 10$ would peak at $\sim 500\mu m$, with observed fluxes below the capabilities of current observatories.
- For survey areas of 0.1 deg^2 and 10 deg^2, the redshift horizon would be above $z \sim 7$ for sensitivities <0.1 − 0.5 μJy and <0.5 − 3.0 μJy, respectively, with the exact values depending on the nature of dust.
- The FIR/sub-mm EBL peaks at $\sim 500\mu m$ and it would not represent a significant percentage of the total observed EBL.
- Because the FIR/sub-mm radiation shows a strong dependence on D/M, Z_g and η, its study could help to constrain these quantities at early times.

For more details, see: https://doi.org/10.1093/mnras/stw2971 or ArXiv: 1610.05407

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS **465**, 3668–3679 (2017) doi:10.1093/mnras/stw2971
Advance Access publication 2016 November 17

Contribution of the first galaxies to the cosmic far-infrared/sub-millimeter background – I. Mean background level

María Emilia De Rossi[1,2]★ and Volker Bromm[3]

[1] *Consejo Nacional de Investigaciones Científicas y Técnicas, Av. Rivadavia 1917, C1033AAJ, Buenos Aires, Argentina*
[2] *Instituto de Astronomía y Física del Espacio (IAFE, CONICET-UBA), CC 67, Suc. 28, 1428 Buenos Aires, Argentina*
[3] *Department of Astronomy, University of Texas at Austin, 2511 Speedway, Austin, TX 78712, USA*

Accepted 2016 November 15. Received 2016 November 13; in original form 2016 April 11

De Rossi & Bromm (2017)

ArXiv: 1903.02512

Draft version March 7, 2019
Typeset using LaTeX **twocolumn** style in AASTeX62

De Rossi & Bromm (2019)

Redshift Horizon for Detecting the First Galaxies in Far-Infared Surveys

María Emilia De Rossi[1,2] and Volker Bromm[3]

[1] *Universidad de Buenos Aires, Facultad de Ciencias Exactas y Naturales y Ciclo Básico Común, Buenos Aires, Argentina*
[2] *CONICET-Universidad de Buenos Aires, Instituto de Astronomía y Física del Espacio (IAFE), Buenos Aires, Argentina*
[3] *Department of Astronomy, University of Texas at Austin, 2511 Speedway, Austin, TX 78712, USA*

(Received M D, 2019; Revised M D, 2019; Accepted M D, 2019)

Submitted to ApJ

¡ MUCHAS GRACIAS !

mariaemilia.dr@gmail.com