Impact of metal enrichment on the fraction of ionizing radiation leaking from the interstellar medium

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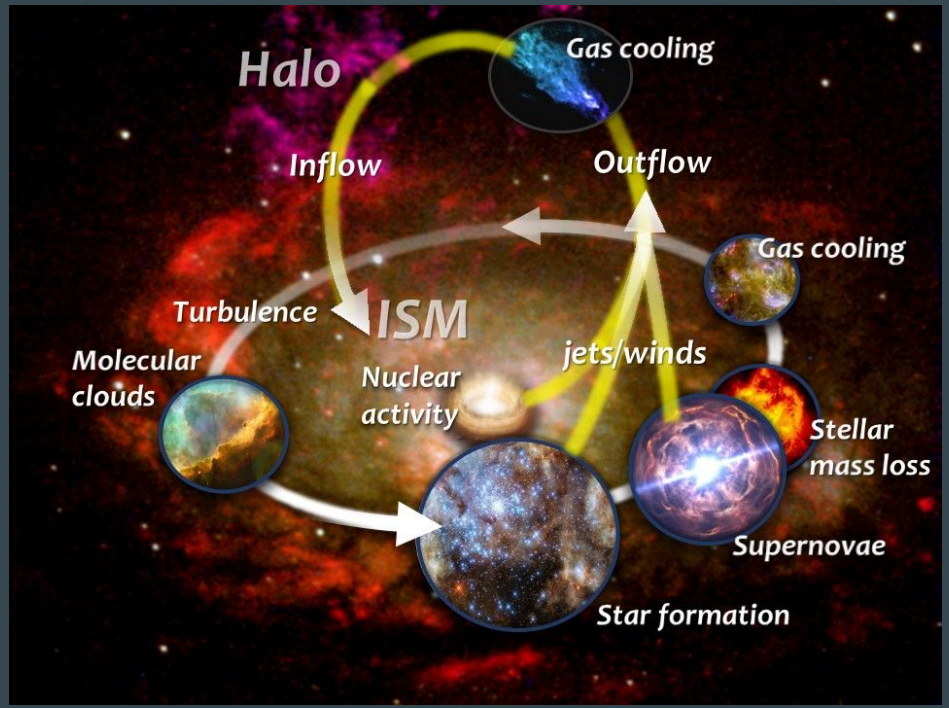
I- Some keywords

#1: ISM = InterStellar Medium

ISM = mostly gas (89 % d'H + 9% He + 2% metals) + dust

Birthplace of stars (gravitational instability, turbulence)
⇒ **Energy injection** (feedback, chocs, ejecta)
⇒ **Energy conversion** (thermal processes)
⇒ **Re-emission of energy** (spectral emission lines)

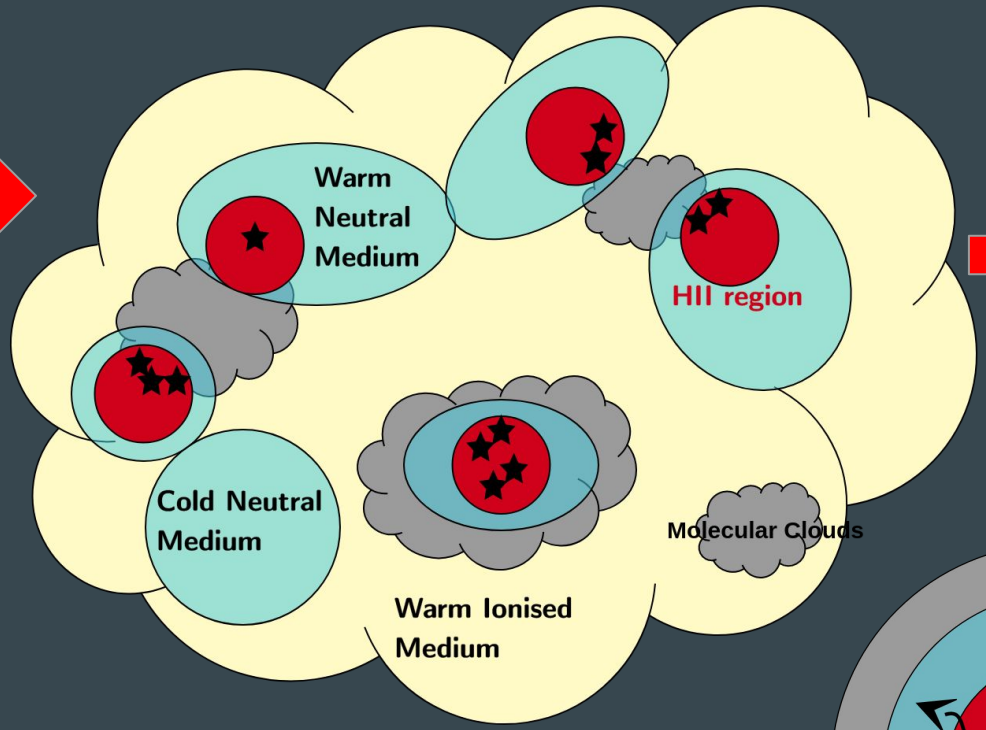


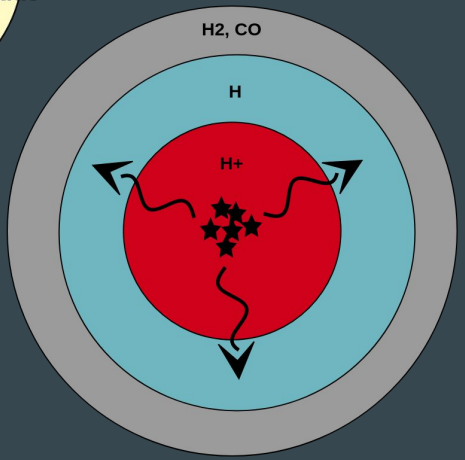
from SRON website

I- Some keywords

#1: ISM = InterStellar Medium

#2 multi-phase topology





Complex structure of the ISM! often **spatially unresolved**
⇒ topology = representative model of the contribution of each phase

I- Some keywords

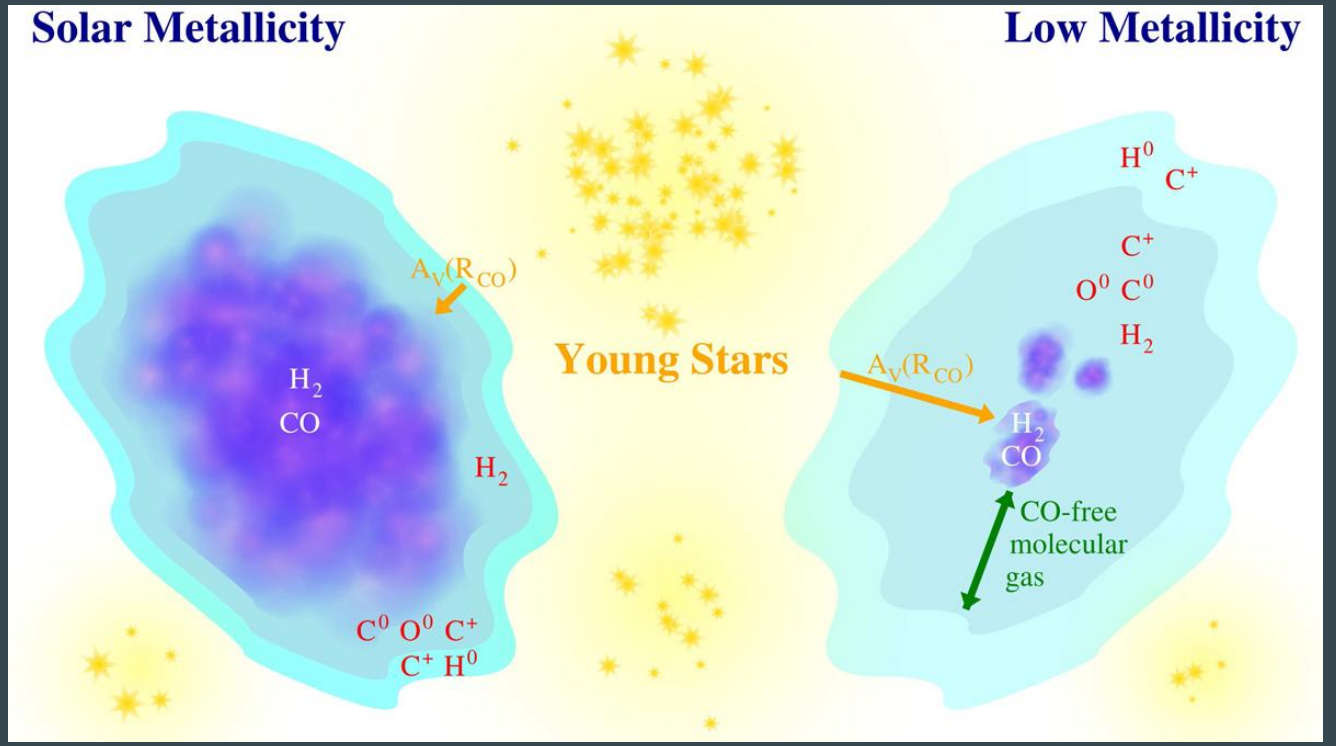
Primitive= chemically unevolved, **metal-poor and dust-poor**
(XMP: Extremely Metal-Poor galaxies → below 1/10 solar metallicity)

⇒ strong impact on the **ISM properties and gas reservoirs**

#1: ISM = InterStellar Medium

#2 multi-phase topology

#3: primitive galaxies



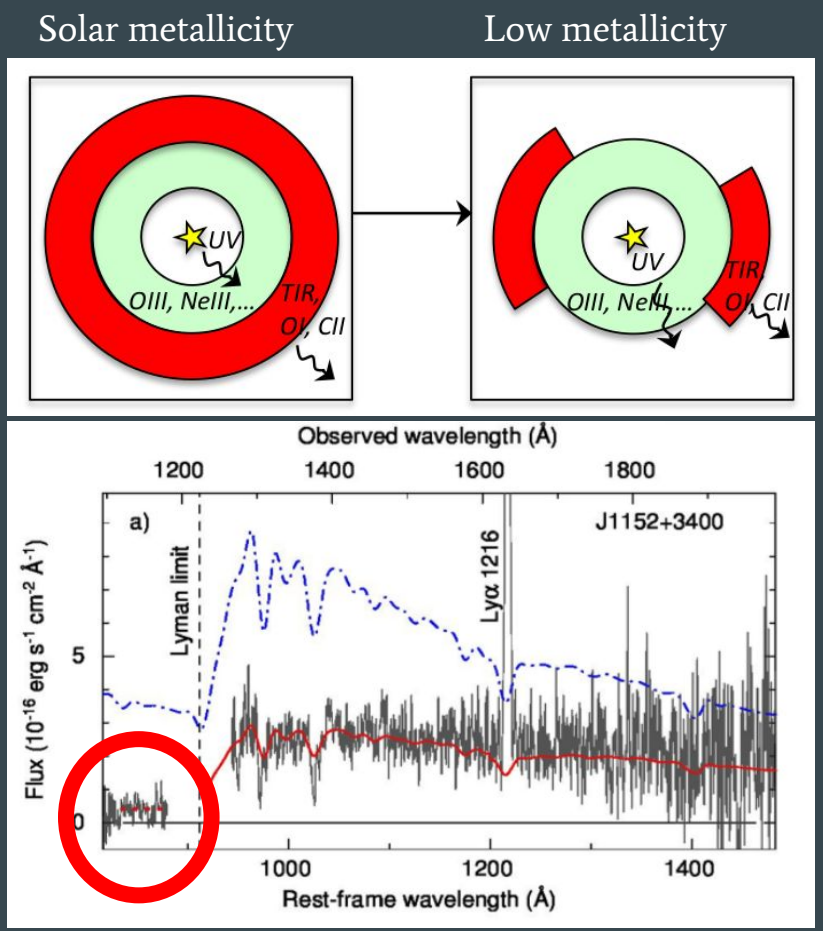
Madden et al. 2020

What's special about the ISM topology of primitive galaxies?

II- What's special about the ISM topology of primitive galaxies?

From local observations (z~0)
⇒ clumpy distribution of molecular gas: sometimes undetected! (Grenier+05, Madden+20)
⇒ high star formation rate + luminous and numerous X-ray sources (quote)
⇒ increased porosity of the ISM (Cormier+19)

From intermediate redshift observation (z~0.3 up to z~6)
Few detections of UV escaping photons → **"leakers" or "leaking galaxies" → ~1 to 72%** of the intrinsic flux produced by stars! (e.g. Izotov et al. 2016,2018, Vanzella et al. 2016)
⇒ multi-sectors approach needed to model leakers (Ramambason+20)



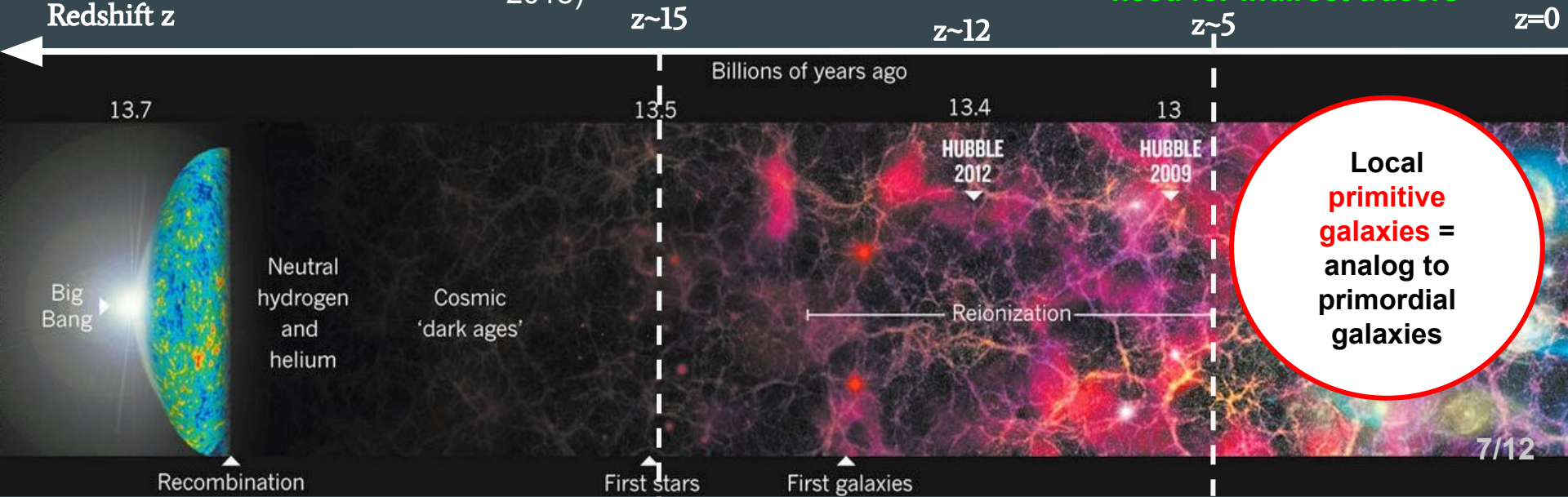
III- Implication for galaxies in the Epoch of Reionization (z>5)

Are primordial leaking galaxies responsible for the reionization of the universe ?

From simulations: possible if $<f_{esc}> \sim$ 10-20 % (Ouchi et al. 2009)

other candidates? active galactic nuclei ⇒ to few luminous one above z>4 (Robertson et al. 2015, Mitra et al. 2018)

observational confirmation? very difficult… (absorption, line of sight variations)
⇒ need for indirect tracers



IV- Using emission lines to constrain the ISM topology

New bayesian code (Lebouteiller & Ramambason in prep.)

INPUTS:
-grid of models
-configuration
-list of observed emission lines + uncertainties + detection upper limits
-priors if any

MULTIGRIS
A multi-component probabilistic grid search

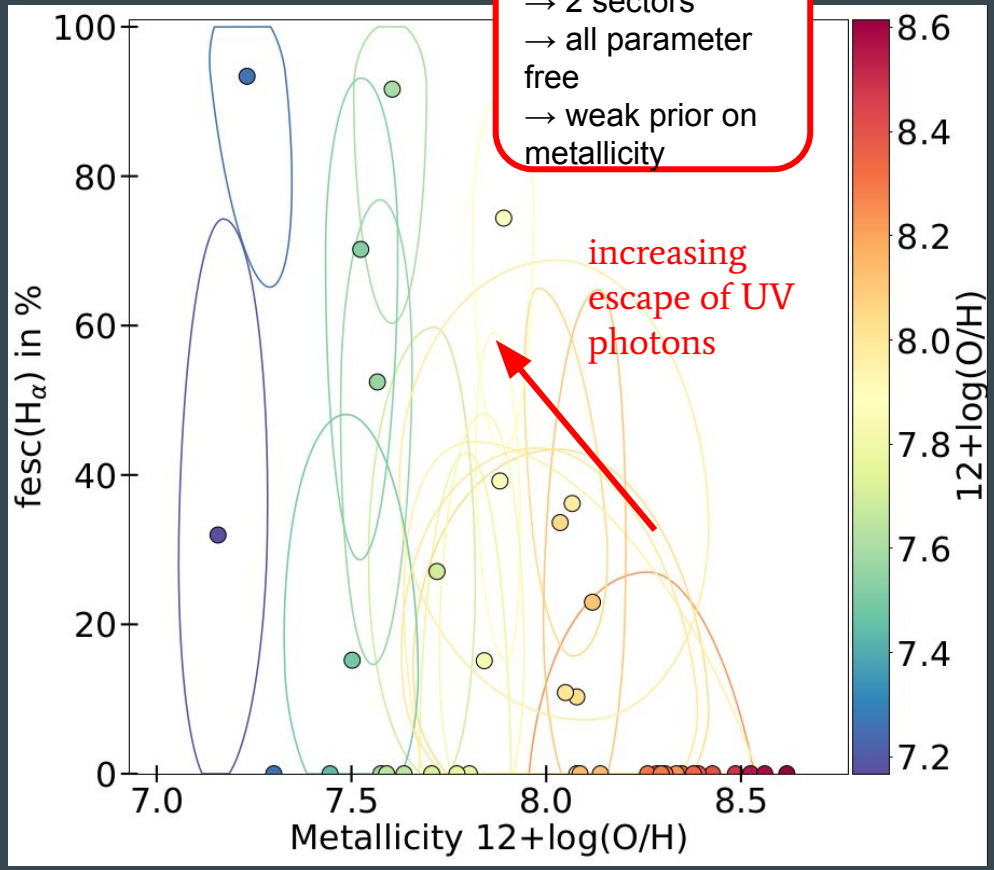
OUTPUTS:
-posterior probability density functions of each parameter, predicted emission lines
+other model observables (e.g escape fraction)

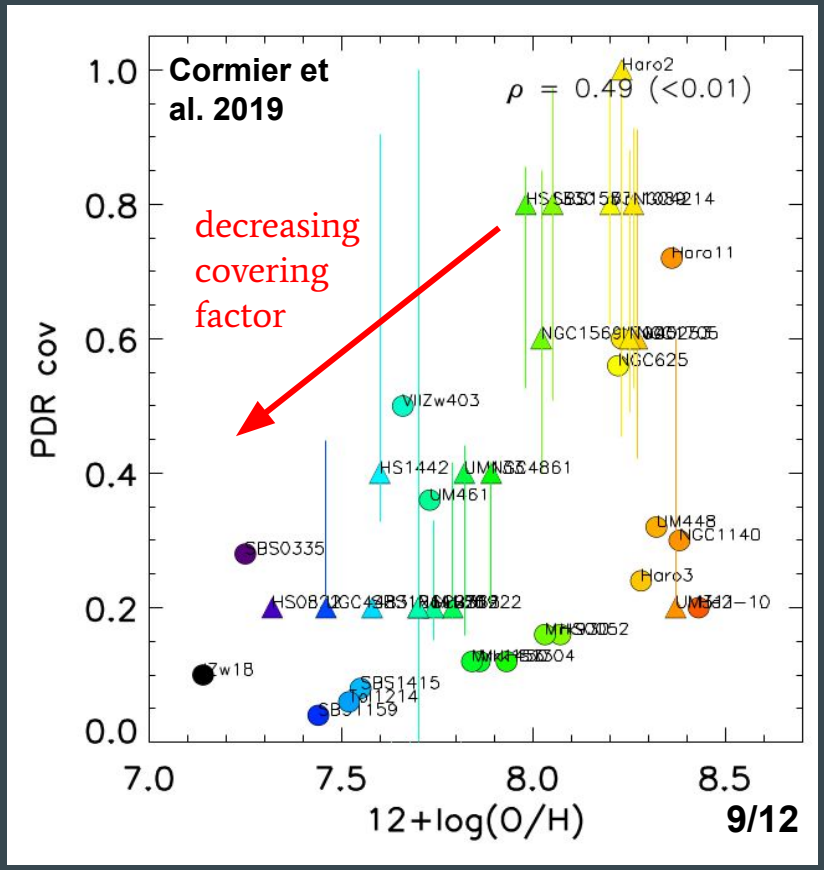
Dwarf Galaxy Survey (Madden et al. 2013)

- 40 local galaxies (<200Mpc)
- **low metallicity** (½ $Z_\odot$ →1/50 $Z_\odot$)
- ~20 **infrared emission lines** from Spitzer

V- 1rst application: inferring f_{esc} in the Dwarf Galaxy Survey

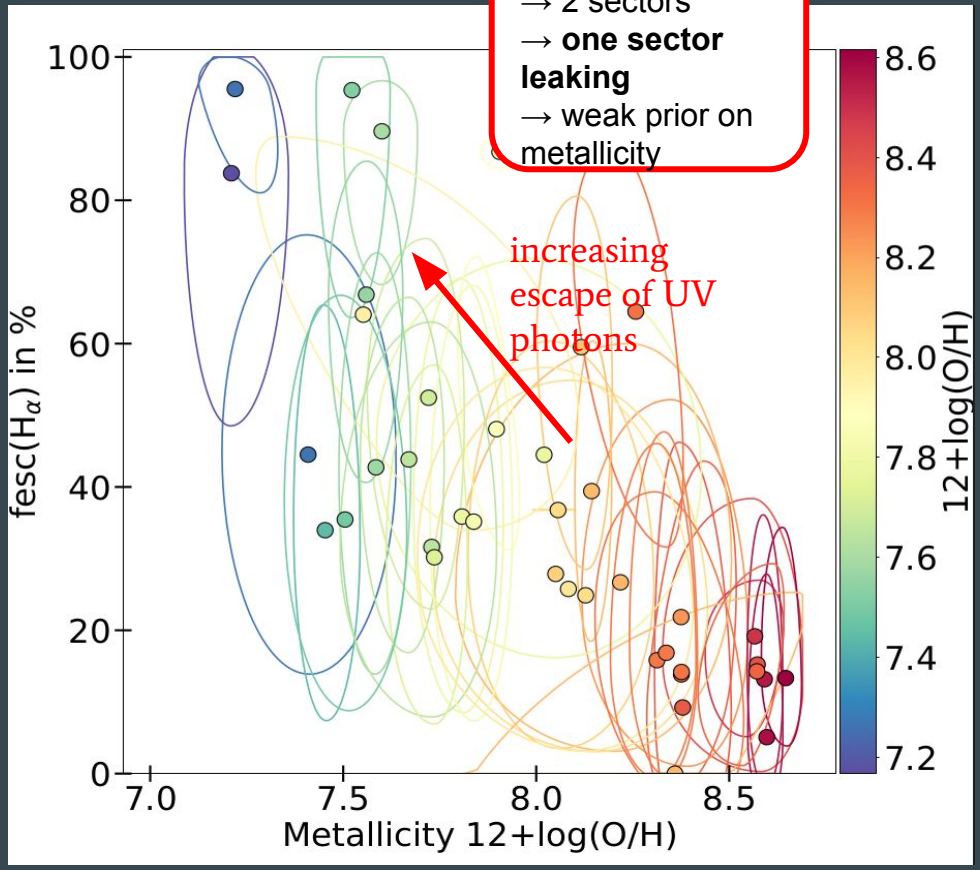
Configuration 1:
→ 2 sectors
→ all parameter free
→ weak prior on metallicity

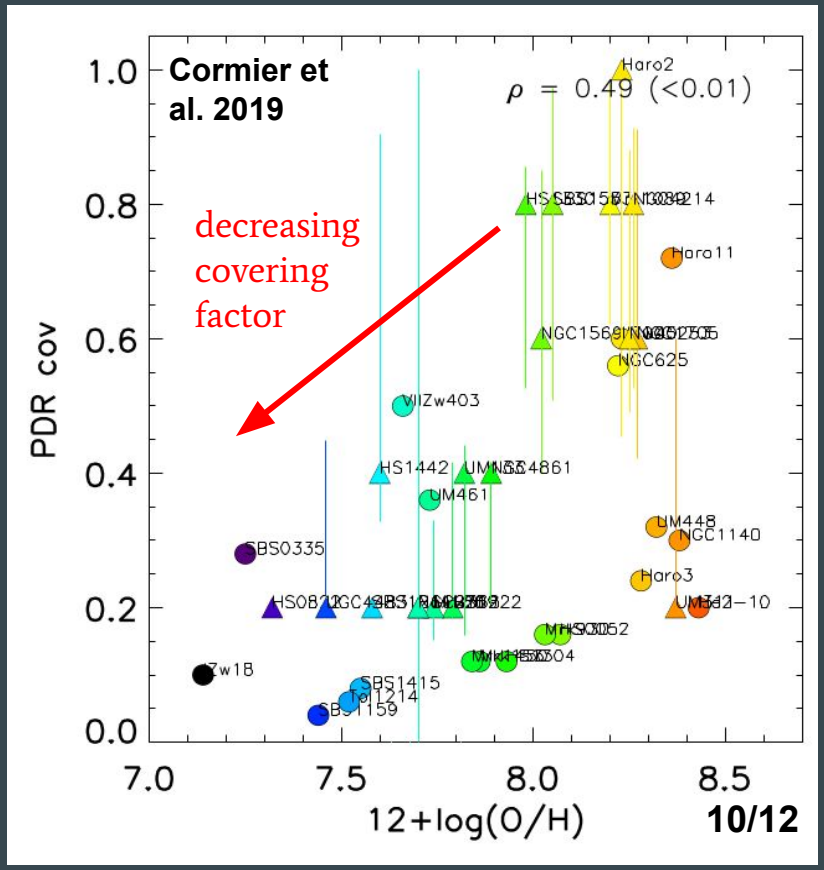




V- 1rst application: inferring f_{esc} in the Dwarf Galaxy Survey

Configuration 2:
→ 2 sectors
→ **one sector leaking**
→ weak prior on metallicity





VI- Analysis and next steps

Why do the porosity of the ISM increases at low metallicity?

Recent hydrodynamical simulations from Yoo et al. 2020

⇒ stars **disrupt their birth cloud** much faster a low metallicity

⇒ less time enshrouded in gas

⇒ greatest fraction of ionizing flux remains unabsorbed and escape

BUT: complex dependencies of the escape fraction (age of the stars, halo mass, geometrical effects…)

Next steps

⇒ explore **secondaries dependencies**

⇒ correlation with **known spectral tracers** ? (important for high-z with ALMA, JWST)

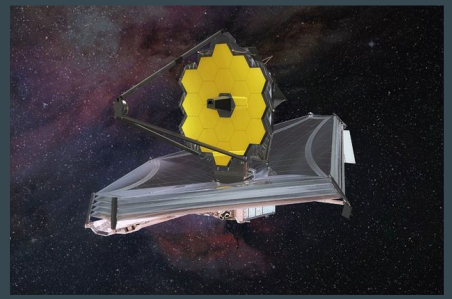
⇒ test other configurations (number of sectors, addition of a diffuse ionised gas component) **+ quantifying & compare the quality of agreement with the obs**

⇒ Include **dust attenuation** treatment to use optical lines

⇒ New refined grid: tailored abondances, dust, PAH, X-ray spectrum

Take away messages

- **low metallicity increases the ISM porosity sometimes leading to** UV photons **escaping in the intergalactic medium**
- Photons escaping from **primordial galaxies** may be the **main contributors to the reionization of universe**
- **Emission lines** = great tools to **probe the ISM topology**
- **Complex models are needed** to interpret current observation of local and intermediate redshift galaxies and **future high-z ones** (e.g. ALMA, JWST)



ANNEXES

V- 1rst application: inferring f_{esc} in the Dwarf Galaxy Survey

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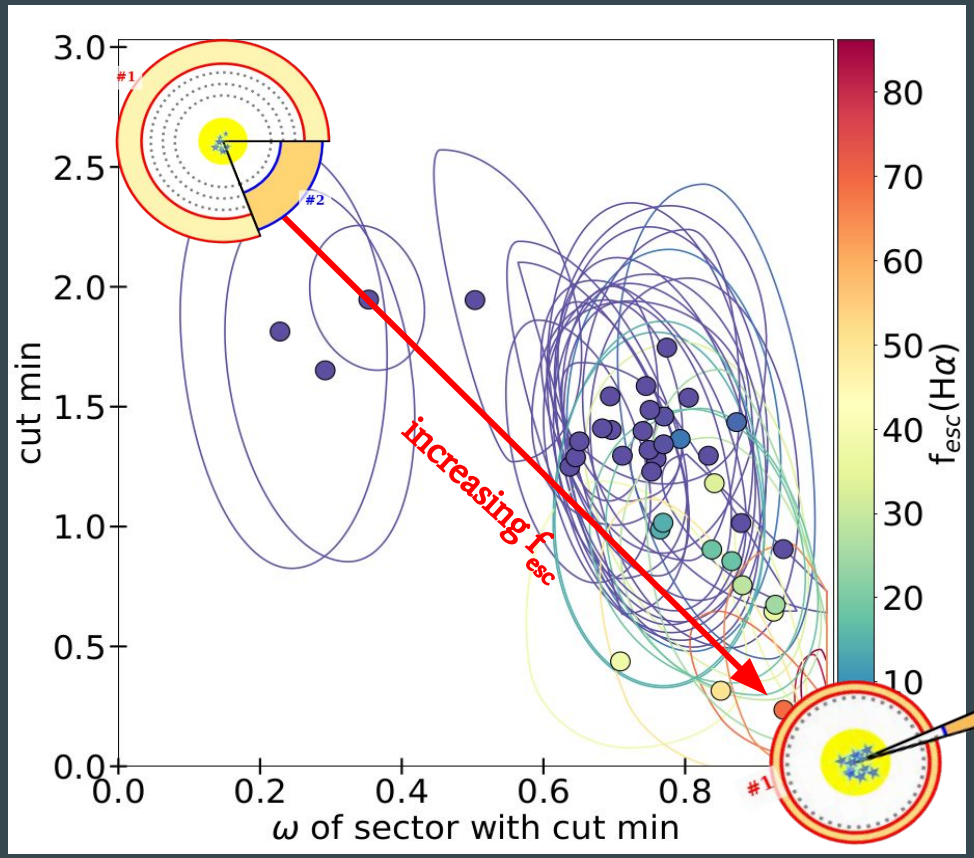
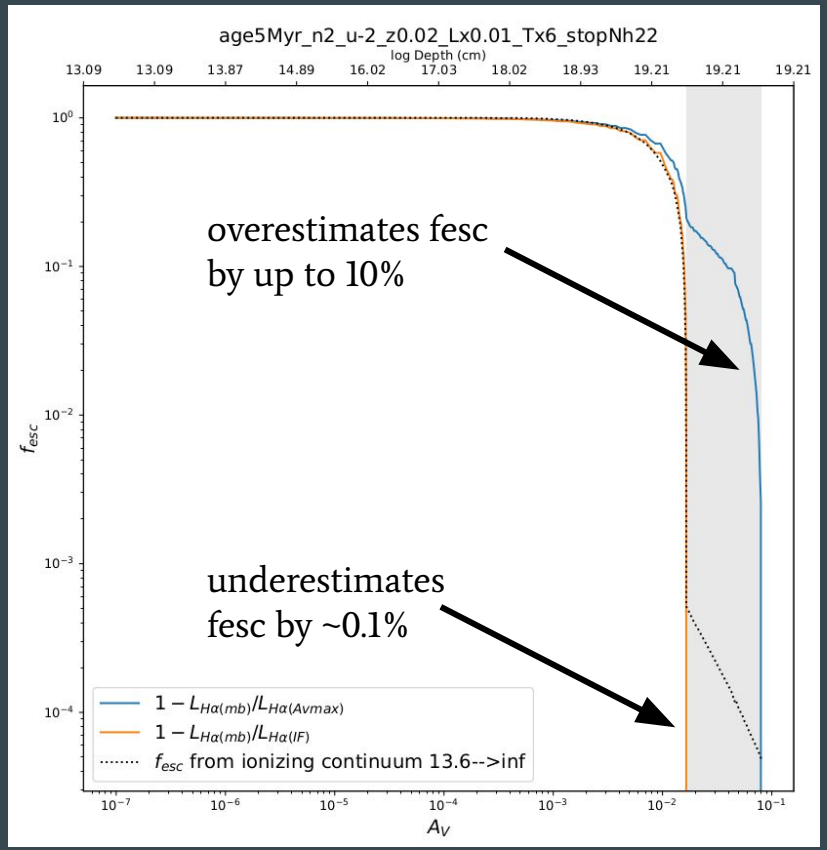
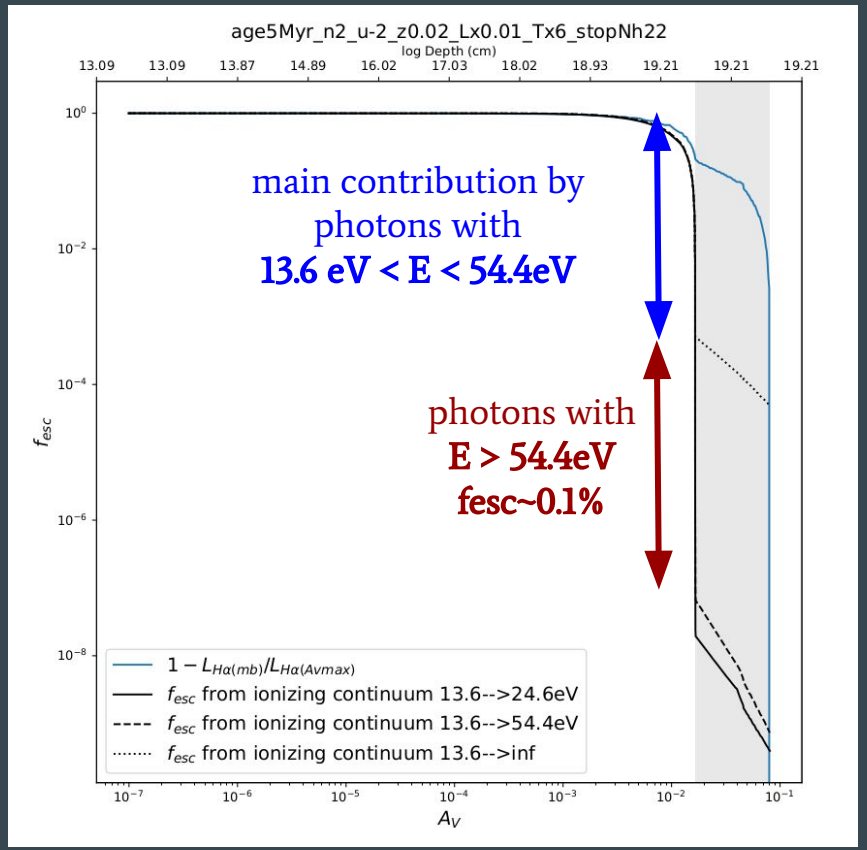
$$f_{esc} = \sum f_{esc}^{\,i},\ i \in [\![1; n_{sectors}]\!]$$

$$f_{esc}^{\,i}(H\alpha) = [1 - H\alpha^i(R_{cut})/H\alpha^i(R_{IF})] \times \omega_i \propto (1 - cut_i) \times \omega_i$$

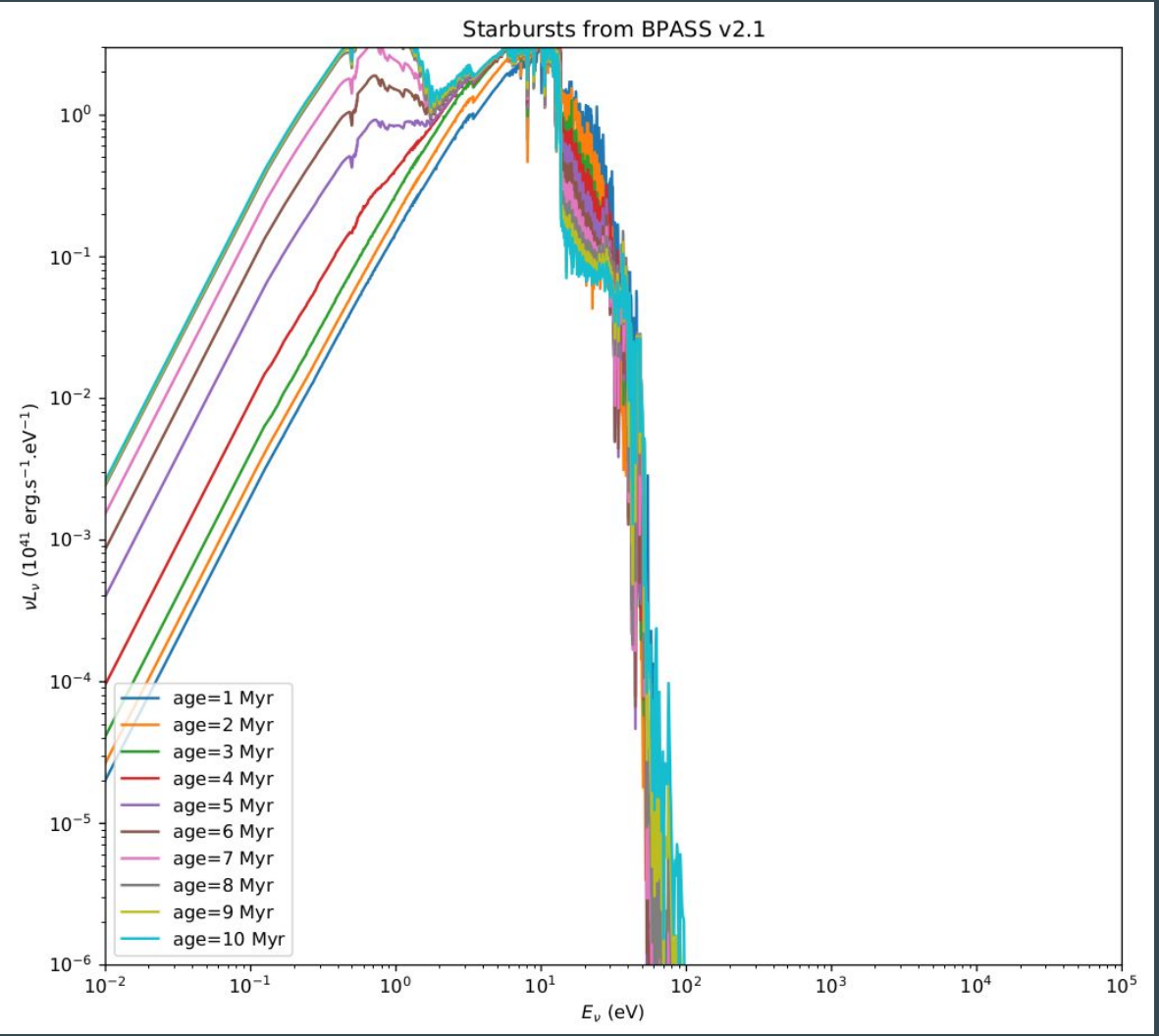


Using Hα to estimate fesc of ionizing photons

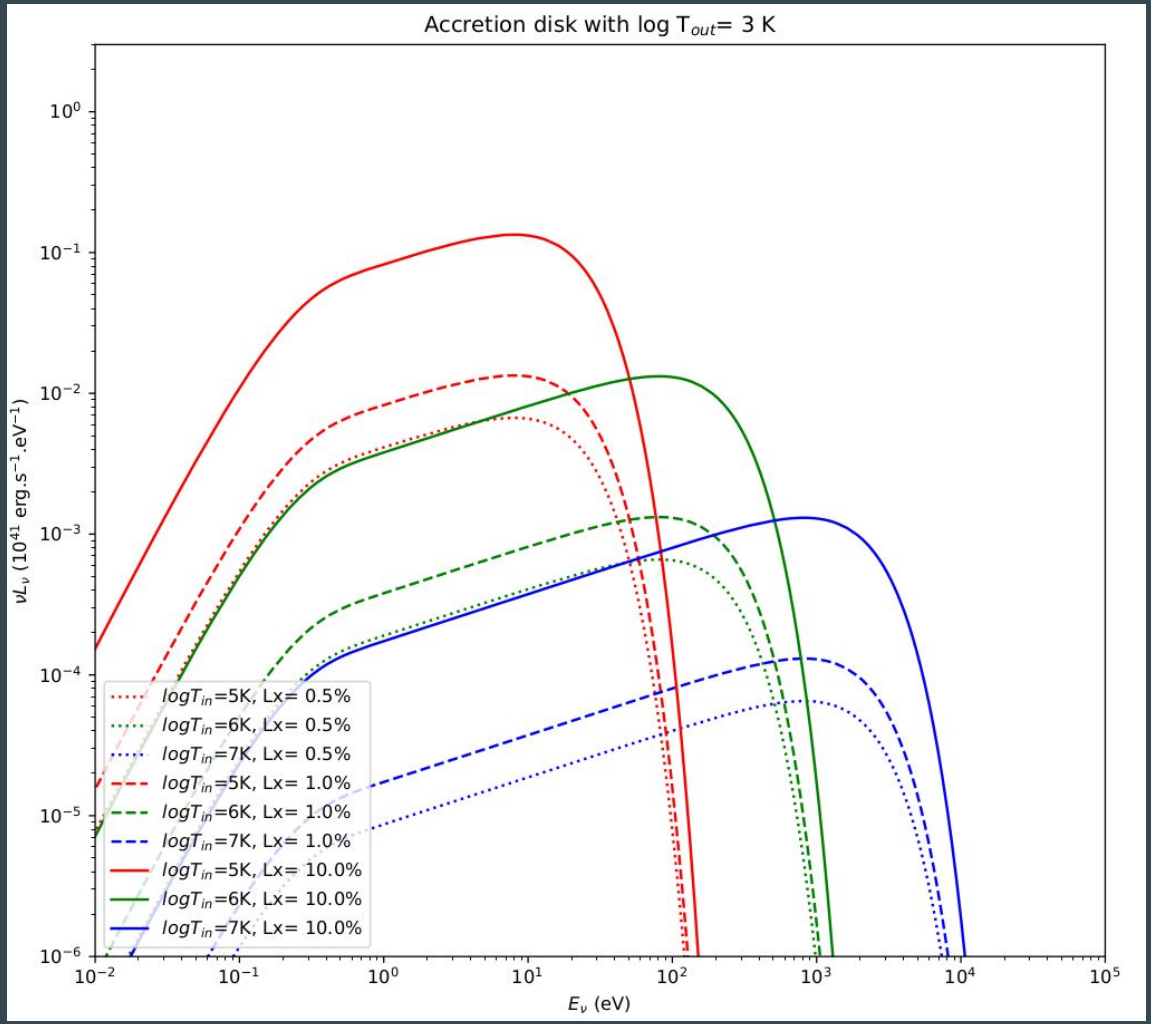




STELLAR SOURCE SPECTRUM



X-RAY SOURCE SPECTRUM



Using MULTIGRIS to estimate metallicity?