The Inter-stellar medium

Master in Astrophysics and Cosmology

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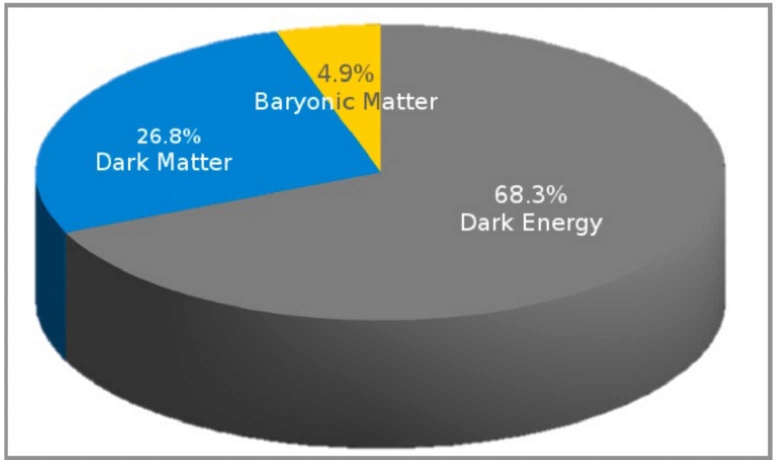
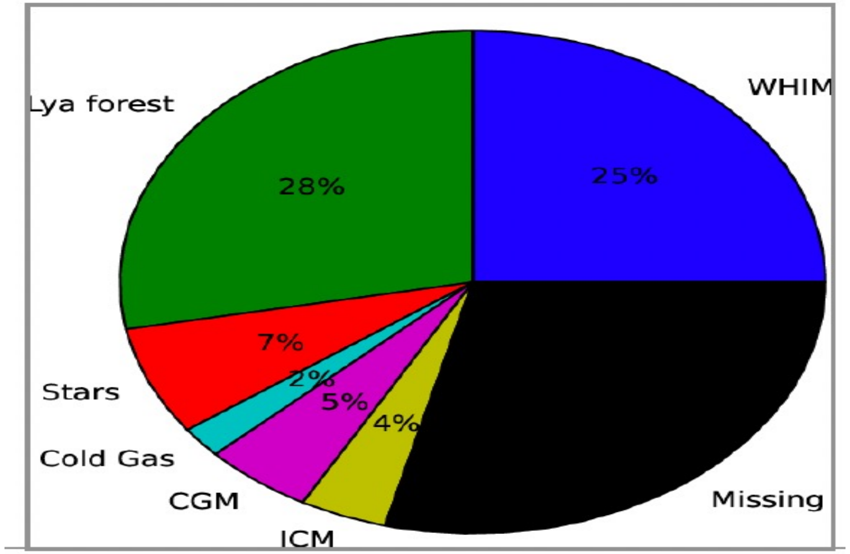
and contribution from Roberto Decarli of the
OAS/INAF Institute

Why we care?



Mass budget of the Universe.



Most of the Universe has an unkown mass

The ISM (cold Gas) is only 2 % of the Baryon mass

The Baryon cycle

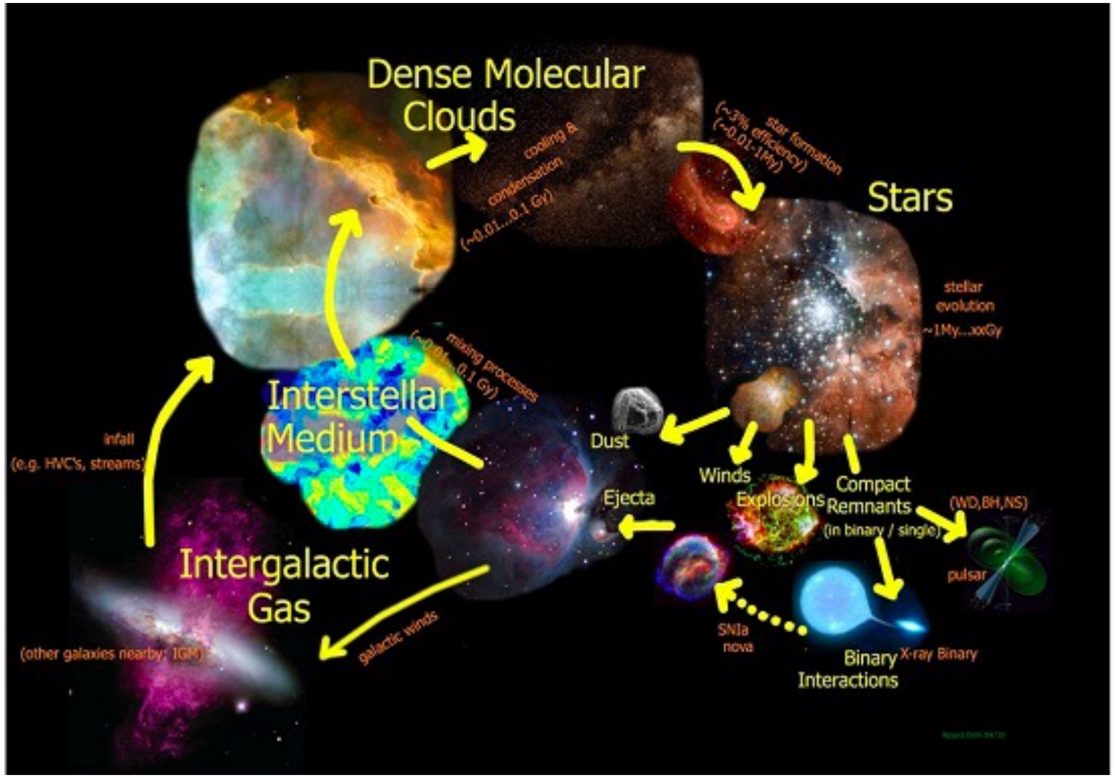


Fig. 1. The **baryon cycle** is due to gas flows within a galaxy (bottom left corner) and their interplay with the environment. The gas accreted from the intergalactic medium fuels star formation. Stellar evolution leads to mass loss and SNe, seeding the ISM with dust, metals and molecules. Starburst winds and jets from AGN provide feedback and launch outflows (even out of the galaxy). Metal-enriched and pristine halo gas eventually cool and accrete in the disk to form new stars and feed the central black hole, starting the cycle again (credit R. Diehl).

A complex interplay is therefore expected among these processes as a function of galaxy properties, environment and cosmic time. Hence, understanding the evolution of the baryon cycle has become a key question of current astrophysics.

Program

I. Introduction to the ISM and main constituents (ionized, atomic, and molecular gas; dust; magnetic fields; cosmic rays; EM radiation)

II. Level population and line formation.
Radiative transfer equation

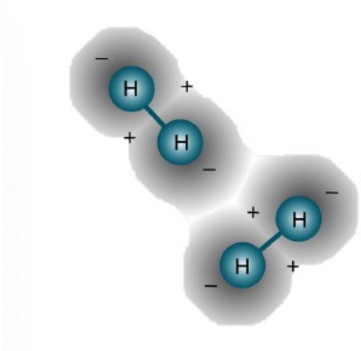
III. Dust processes (extinction, emission, chemical models)

IV. State of the art of the research:
ISM in galaxy/AGN from the local up to the high-z Universe
Lessons from Dott. Roberto Decarli from the INAF Institute

I. The ISM and its main constituents

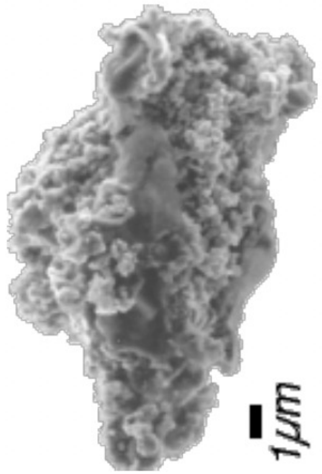
Composition

Gas



~99 % of the ISM
Composed by: 74% H, 24% He, 2% others
Different phases, **ionized, atomic, molecular**

Dust



~ 1% of the ISM
Composition: by small grains of solid material, **silicates** (namely sand, e.g. mostly olivine) and carbonaceous (**graphite** or agglomerates of graphite) grains.
Average radius: 0.1 μm
Despite the relatively small mass, dust has an immense impact on the physical and chemical status of the ISM.

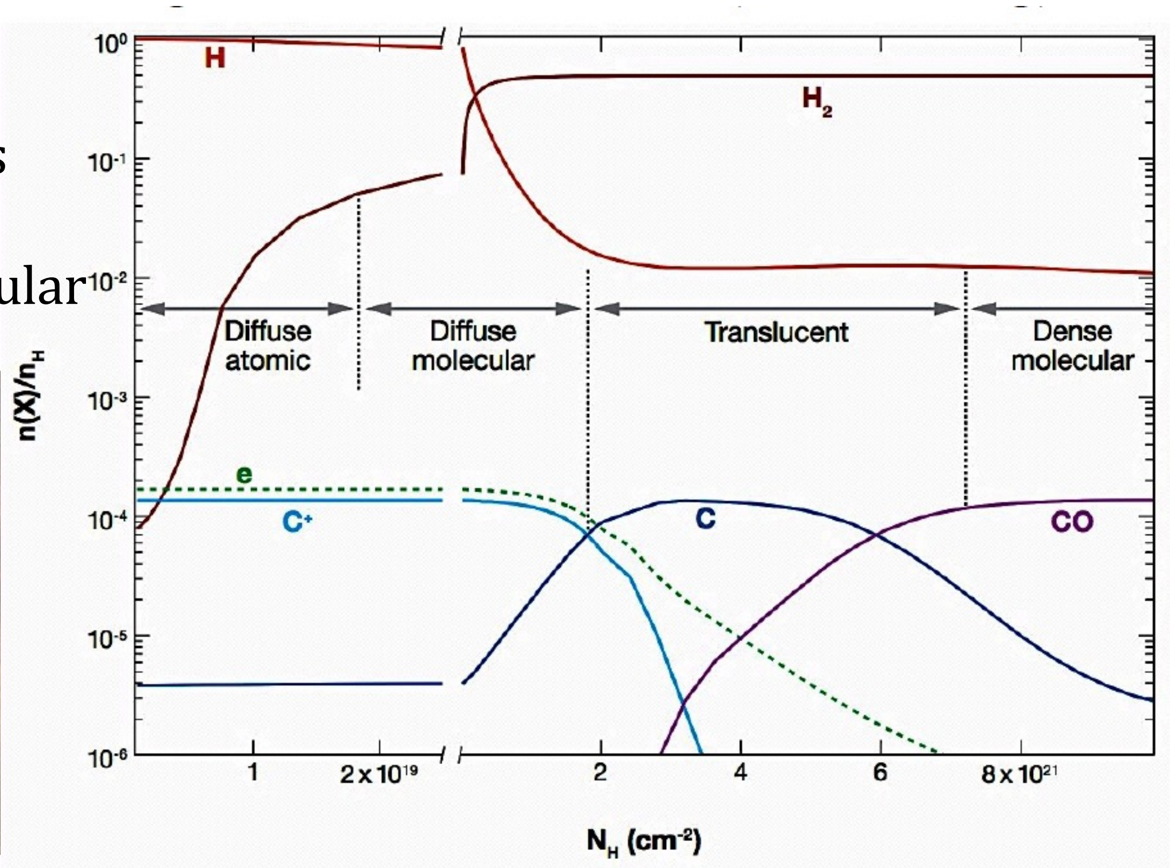
I. The ISM and its main constituents

Properties

Extremely Rarefied: <n> ~ 1 atom cm^{-3}
(pression at sea level ~10^{19} cm^{-3})

Inhomogeneous: Diffuse matter, Clouds

Gas Phases : ionized → atomic→ molecular

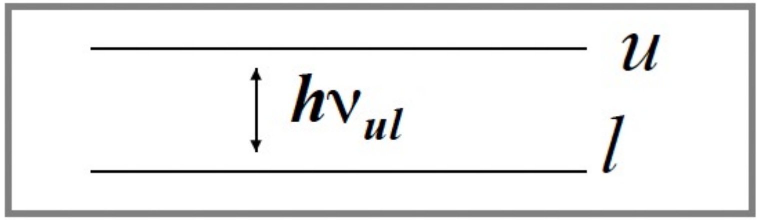


II. Level population and line formation

(see also Radiative processes course)

The only way we have for studying the ISM is to interpret the information coming from photons emitted or absorbed.
The goal is to provide the tools for understanding the formation of a line spectrum and extracting the information it brings

Statistical equilibrium equation



At equilibrium, the rate of excitation of the level *l* is equal to the rate of de-excitation of the level *u*.

$$n_l n_{coll} \gamma_{lu} + n_l B_{lu} J_\nu = n_u nc_{oll} \gamma_{ul} + n_u A_{ul} + n_u B_{ul} J_\nu$$

- γ_{lu} and γ_{ul} :excitation and de-excitation collisional coefficients
- n_{coll} is the number density of the collisors
- B_{lu}, B_{ul} and A_{ul} are the Einsteins coefficients;
- J_ν the intensity at frequency ν_{ul}
- n_l and n_u are the number density of the level *l* and *u*

Importance of LTE approssimation, critial density

III. Dust processes (extinction, emission, chemical models)

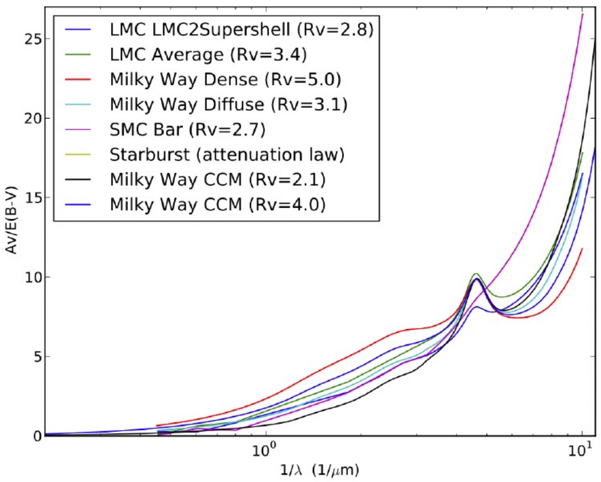
a. The effects of dust

Dust extinction: Draine theory (microphysics: MieTheory)

$$A_\lambda = 1.086\pi L \int a^2 Q_{ext}(a) n(a) da$$

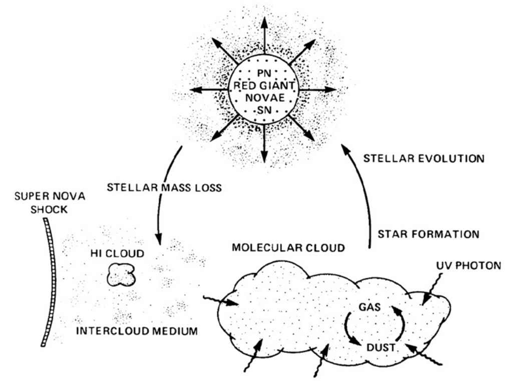
Dust emission: Radiative transfer equation

$$S_\nu = \Omega B_{BB}(\nu)(1-e^{-\tau})$$



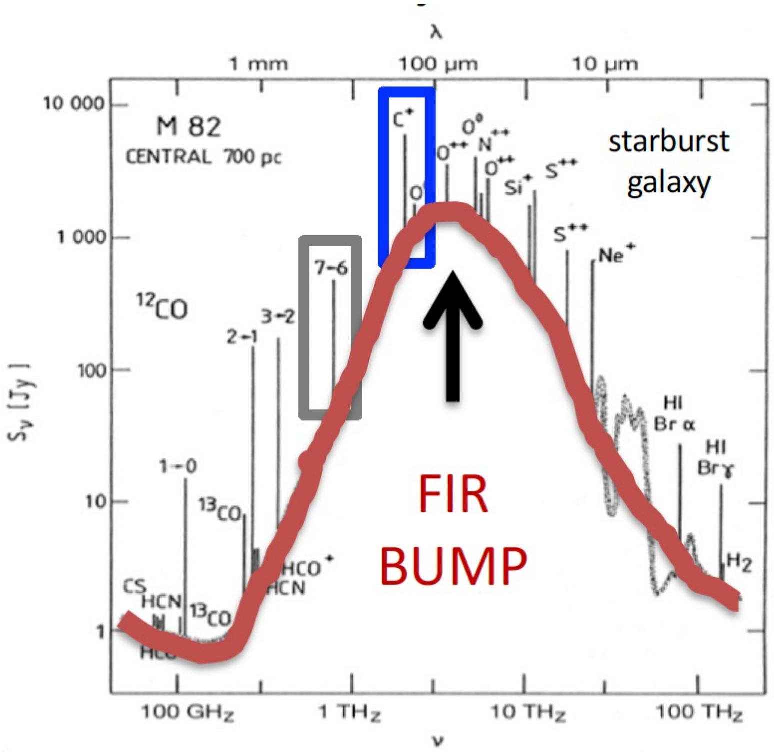
b. Chemical models

$$\frac{dM_d}{dt} = \int_m^{100M_\odot} ([m - m_R(m)]Z(t-\tau_m)\delta_{AGB} + my_z\delta_{dus}$$
$$\cdot \Psi(t-\tau_m)\Phi(m)dm - (\frac{M_d}{M_g})\Psi(t)$$
$$- M_d\delta_{dest}(t) + M_d\delta_{grow}(t) + (\frac{M_d}{M_g})I(t)$$
$$- (\frac{M_d}{M_g})O(t)$$



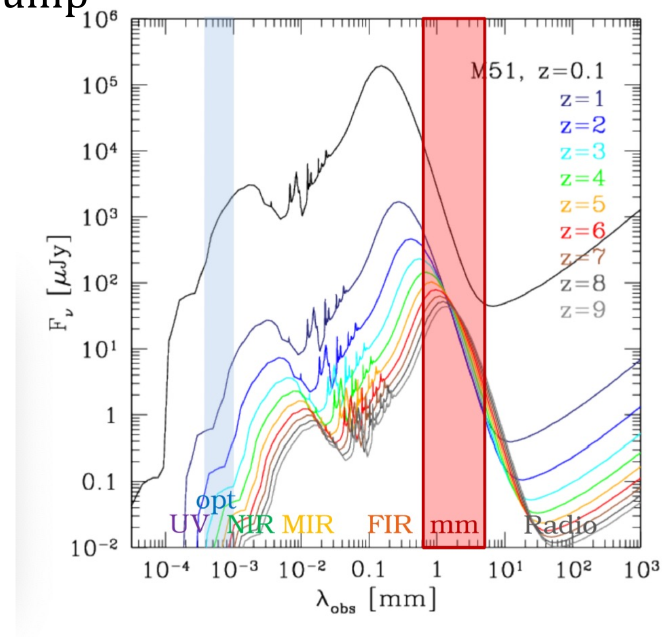
IV. ISM in galaxy/AGN from local up to the **high-z Universe**

Golden age for ISM studies



(e.g. Stacey 1993)

Fine structure lines from heavy elements
(e.g. [CII] @158μm)
Rotation transition from molecules
Ie.g. CO (J-J-1)@ Jx115 GHz)
on the top of the IR bump



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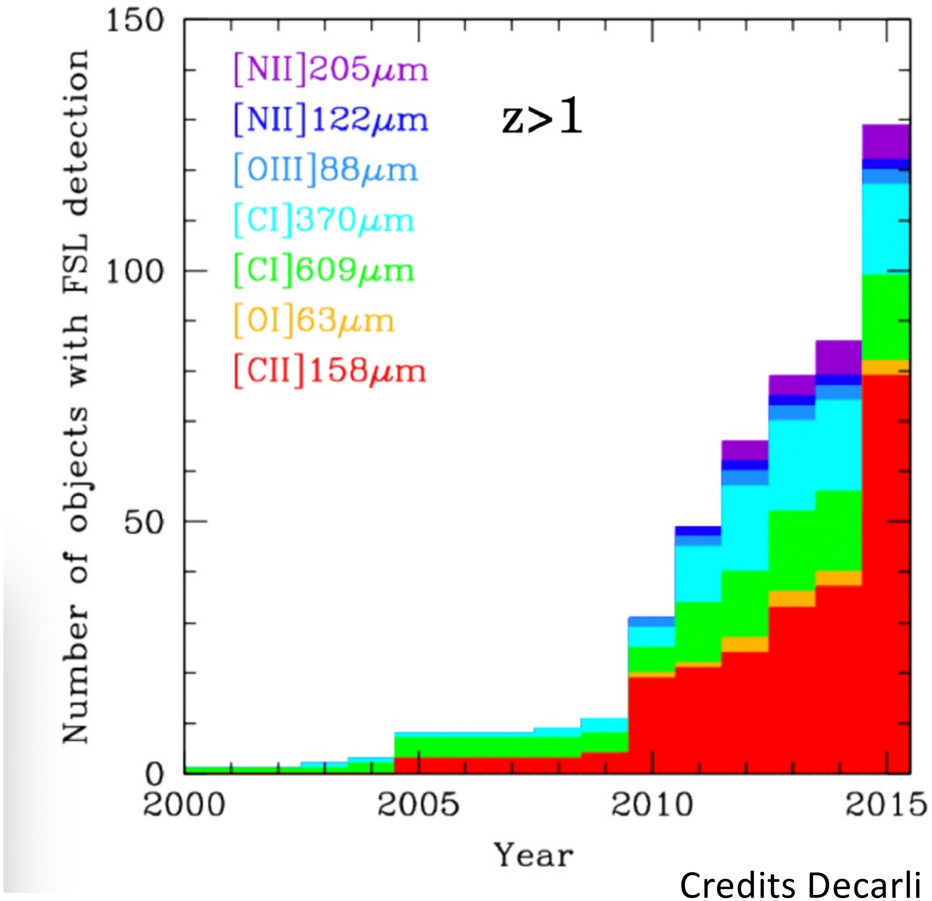
IV. ISM in galaxy/AGN from local up to the **high-z Universe**

Golden age for ISM studies

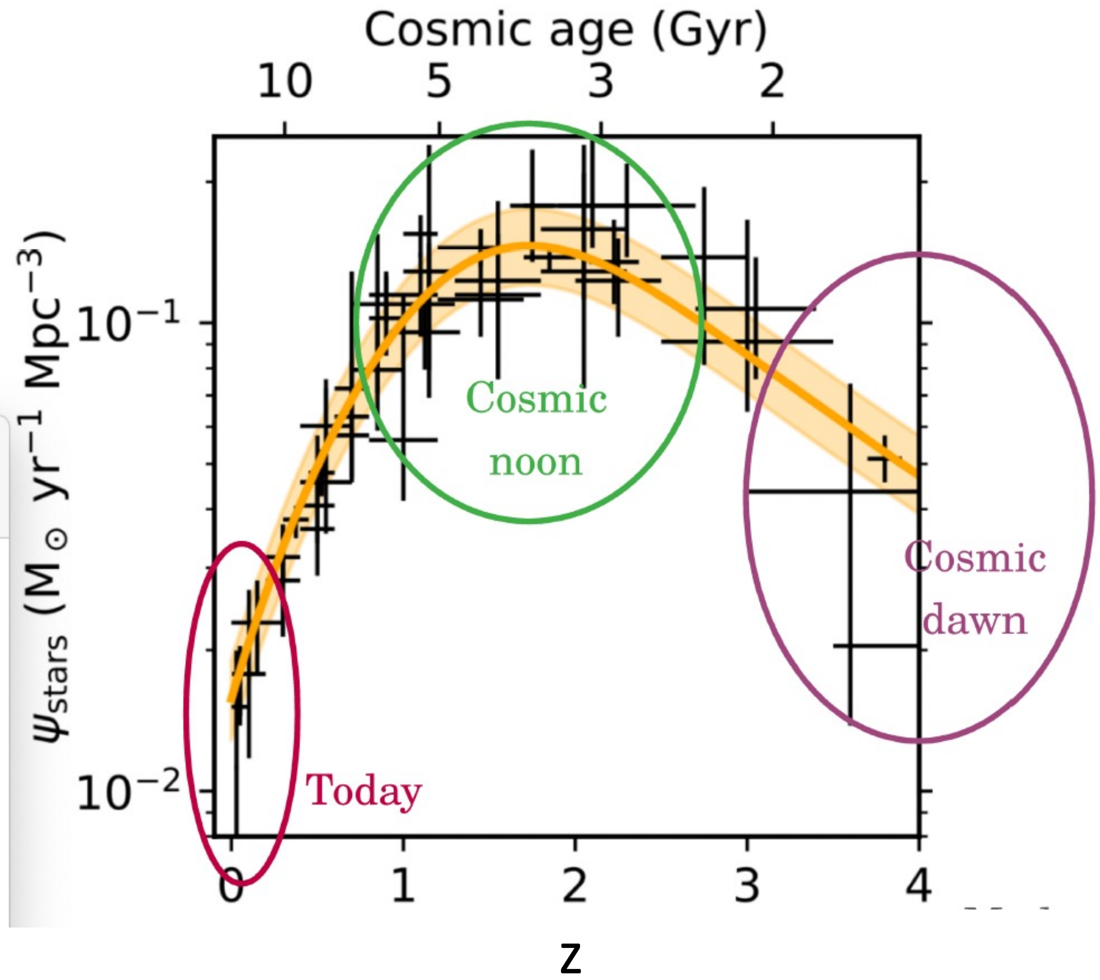
ALMA

Noema



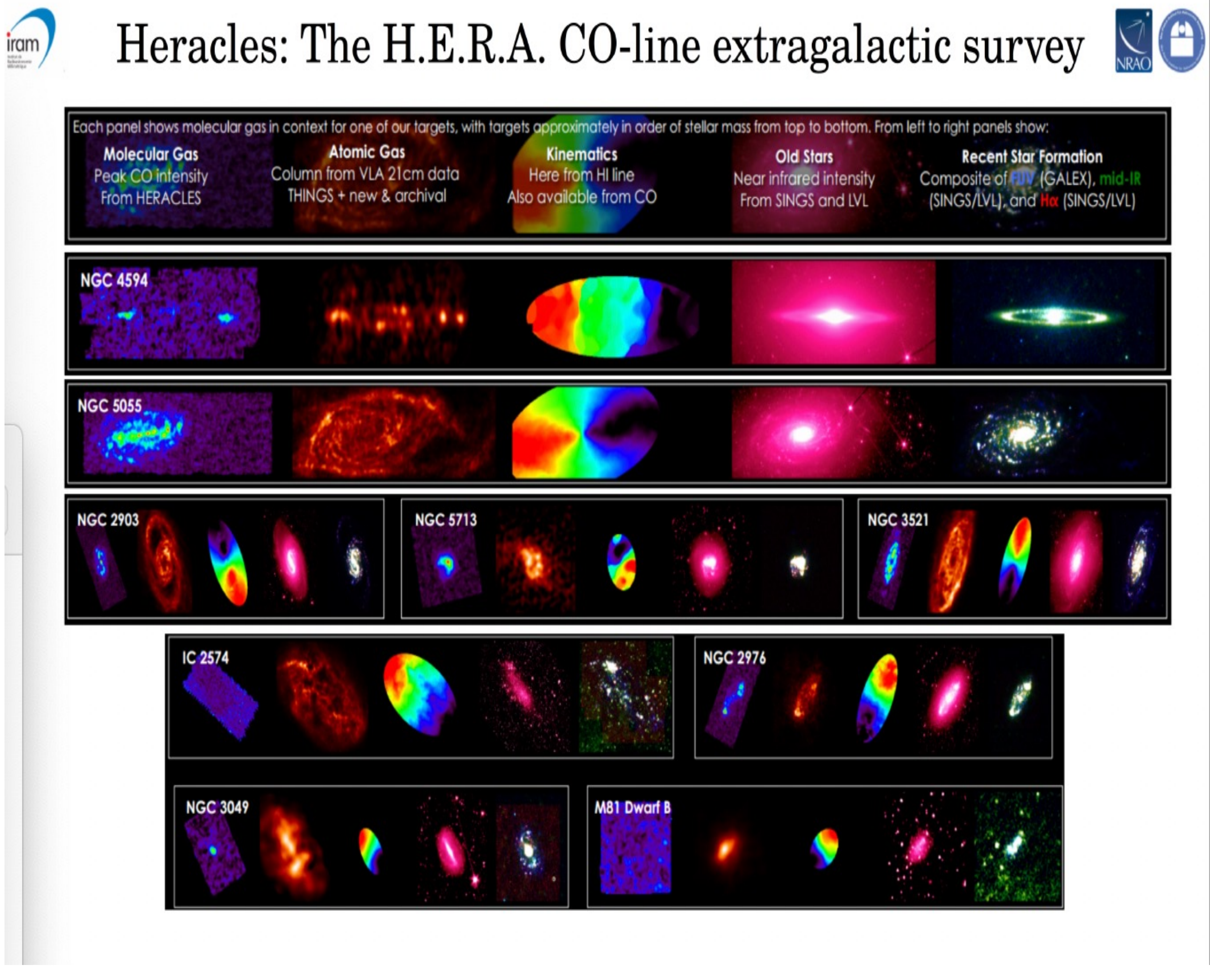
Credits Decarli

IV. ISM in galaxy/AGN from local up to the **high-z Universe**



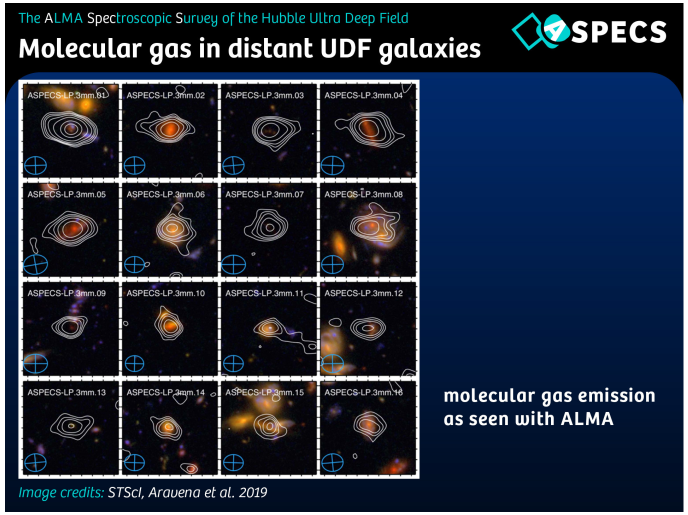
IV. ISM in galaxy/AGN from local up to the **high-z Universe**

Heracles: Local Universe(Leroy+08)

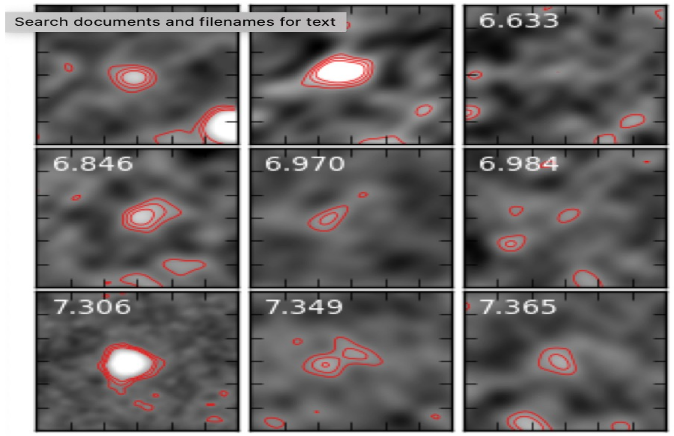


Leroy +2008

ASPECS 0<Z<5 (Decarli+19)



REBELS, z> 6(Bowens+2021)



IV. ISM in galaxy/AGN from local up to the **high-z Universe**

Key questions

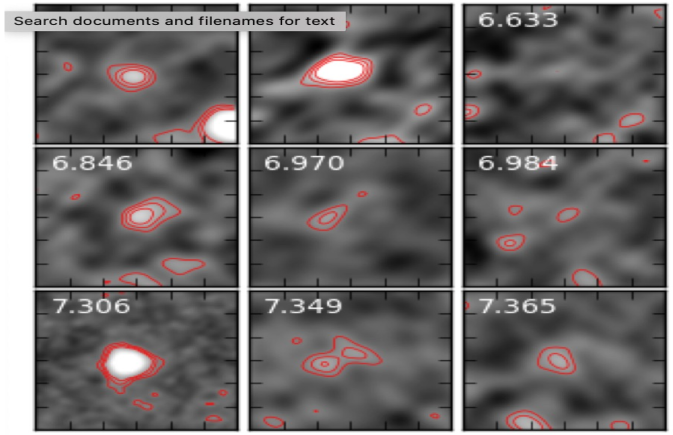
- ❖ How gas is converted into stars?
  (i.e. SK relation $\boldsymbol{\Sigma}_{mol} \Leftrightarrow \boldsymbol{\Sigma}_{SFR}$)

- ❖ SFRD obscured and not obscured

- ❖ Does the AGN impact on the ISM and on the galaxy evolution?

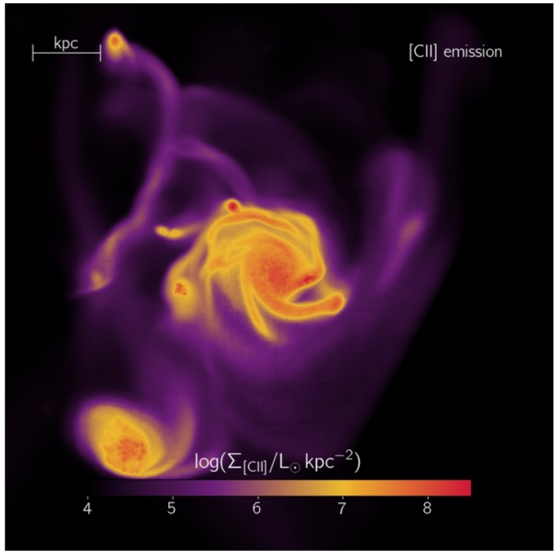
- ❖ Which is the total content in baryon mass as a function of z and how is in comparision with cosmological models?

Data



Bowens+2021

Simulations



Palottini, Ferrara+2020