FIR line emission from high-z galaxies

Livia Vallini, Simona Gallerani, Andrea Ferrara, Sunghye Baek
Scuola Normale Superiore, Pisa, Italy

SCUOLA NORMALE SUPERIORE

1 AIM

By combining high resolution, radiative transfer cosmological simulations of a $z \approx 6$ galaxy with a sub-grid multi-phase model of its interstellar medium (ISM) **we derive the expected intensity of several far infrared (FIR) emission lines**.

2 COSMOLOGICAL SIMULATION

- Gadget-2 SPH simulation
- **Number of particles:** 2×512^3 baryonic + DM
- **Simulated volume:** $(10\ h^{-1}\ \mathrm{Mpc})^3$ comoving

We select a **snapshot at z=6.6** and we identify the **most massive halo**: $M_h = 1.17 \times 10^{11}\ M_\odot$ $r_{vir} \approx 20$ kpc

We post-processed UV radiative transfer using LICORICE.

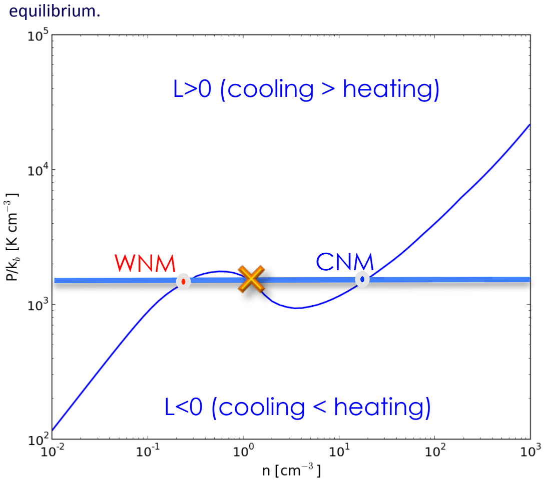
We assume that stars form in cells characterized by a gas density $\rho>1$ cm^{-3}. **The properties are comparable to that of Himiko, the most luminous Lyman Alpha Emitter (LAE) at z=6.6.**

3 ISM MULTIPHASE MODEL

We adopt a sub-grid scheme based on the model by **[1]** and **[2]**, in which ISM thermal equilibrium is set by the balance between **heating (cosmic rays, X-rays, and photo- electric effect on dust grains)** and **cooling (H, He, collisional excitation of metal lines, recombination on dust grains)** processes **[3]** :

$$L(n,xe,T) = n^2\Lambda - n\Gamma = 0$$

where $n\Gamma$ ($n^2\Lambda$) is the heating (cooling) rate per unit volume and n is the total gas density. The ISM can be described as a two-phase gas in which the cold (CNM) and the warm neutral medium (WNM) are in pressure equilibrium.



4

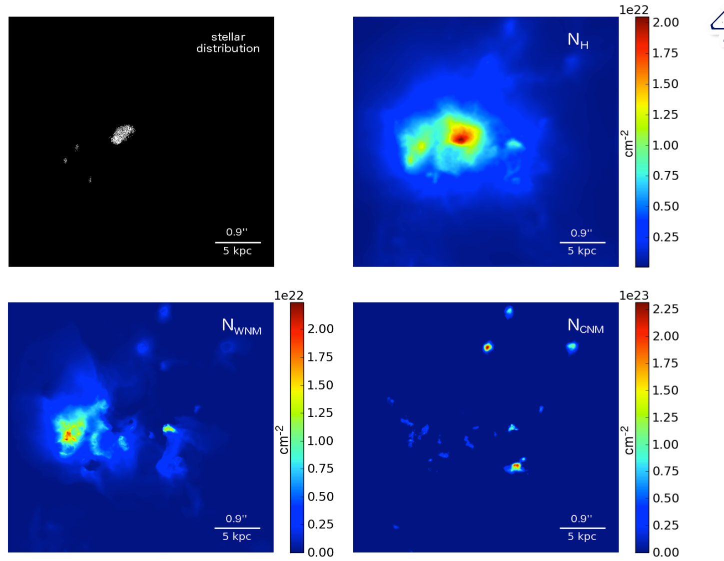


Fig. 1 - Upper panels: Projected stellar distribution (left) and hydrogen column density (right). Lower panels: warm (left), and cold (right) neutral medium column density. The distribution of WNM is more diffuse compared to that of CNM which is predominantly found in small (D~2 kpc) clumps far from SF regions.

5

For each cell we estimate the line luminosities $L_i = \epsilon V_{cell}$, where the emissivity, is given by:

$$\epsilon(n,T) = \Lambda^H \chi_i n^2 + \Lambda^{e^-} \chi_i x_e n^2$$

where n and T are the density and temperature of the WNM/CNM, Λ^H (Λ^{e^-}) is the specific cooling rate due to collision with H atoms (free electrons) taken from **[3]** and χ_i is the abundance of the i-th species.

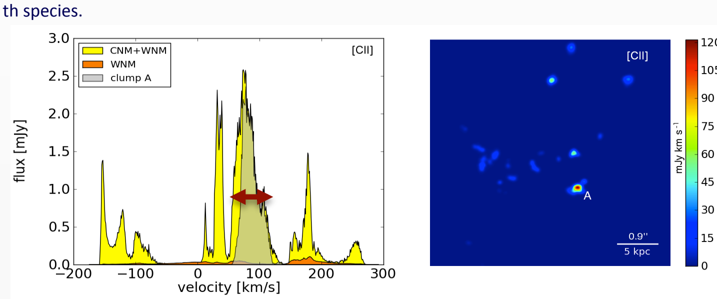


Fig. 2 - Left: Total (CNM+WNM) and WNM only (orange) spectrum of [CII] binned in 1.0 km/s channels. Right: [CII] maps in mJy km/s with resolution of 0.1 arcsec and integrated over the entire spectral velocity range. The contribution of clump A to the [C II] spectrum is plotted in gray. The FWHM (red arrow) of the line is ~50 km/s consistent with the marginal detection of [CII] in high-z LAEs **[5]**.

6

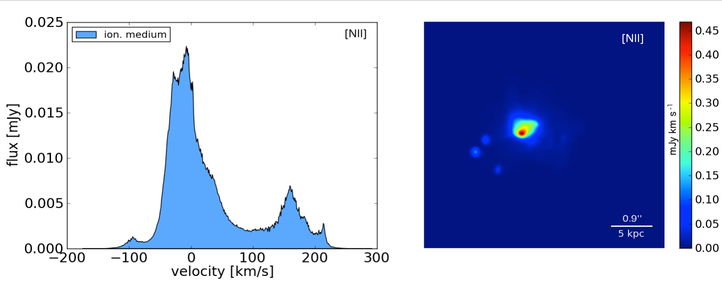


Fig. 3 - Left: Spectrum of [N II] from the ionized medium, binned in 1.0 km/s channels. Right: [N II] maps in mJy km/s with resolution of 0.1 arcsec and integrated over the entire spectral velocity range.

We evaluate also the [N II] line luminosity which provides a complementary view of the ISM with respect to the [C II] line.
Indeed, [N II] traces only the ionized medium since its ionization potential (14.5 eV) exceeds 1 Ryd.
[N II] cooling rate due to collisions with free electrons is:

$$\epsilon_{NII}(n,T) = A\, h\nu\, (g_u/g_l)\ [(g_u/g_l + 1)\ (n_e/n_c)]^{-1}\, x_e$$

where $A = 7.5 \times 10^{-6} s^{-1}$ is the Einstein coefficient, ν is the frequency for the $^3P_2 \rightarrow {}^3P_1$ transition, h is the Planck constant, g_u/g_l is the ratio of the statistical weights in the upper and lower levels, and $n_c = 300$ cm^{-3} is the [N II] critical density for $T = 10^4$ K.

The [C II] emission line is detectable with the ALMA full array in $1.9 < t < 7.7$ hr in star forming, high-z galaxies with $Z_\odot > Z > 0.5\ Z_\odot$. We note that the predicted fluxes are sensitive to the actual value of Z, implying that a [C II] line detection can strongly constrain the LAE metallicity.

References: [1] Wolfire et al. 1995, [2] Wolfire et al. 2003, [3] Dalgarno & McCray 1972, [4] Walter et al. 2012, [5] Carilli et al. 2013

Work presented here: Vallini L., Gallerani S., Ferrara A., Baek S., MNRAS, 2013. **Email:** livia.vallini@sns.it