"First results at sub-kpc scale in local LIRGs with ALMA"

Authors: Enrica Bellocchi[1], Miguel Pereira-Santaella[2], Álvaro Labiano[1], Luís Colina Robledo[2], María Sanchez García[2]

1) Centro de Astrobiología (CSIC-INTA), Camino Bajo del Castillo s/n, Urb. Villafranca del Castillo, Villanueva de la Cañada, E-28691 Madrid, Spain
2) Centro de Astrobiología (CSIC-INTA), Cra. de Ajalvir Km. 4, 28850 - Torrejón de Ardoz, Madrid, Spain

ABSTRACT

In this work we present the preliminary results obtained for the dust and molecular gas derived for NGC3110, ESO264-G036 and ESO267-G030 which belong to a representative sample of 23 local LIRGs observed with ALMA at ~80 pc spatial resolution. We aim at combining the emission from the spatially resolved cold molecular gas CO(2-1), the dust (at 230 GHz or 1.3 mm), and the SF regions (HST Pa-alpha imaging) to estimate the range of gas-to-dust ratios and dust temperatures compatible with the observations. The comparison between the radial extension obtained for the dust and the molecular emissions with those derived for the stellar and ionized gas (Hα) emissions as a function of the L_{IR}, activity and morphology will be analyzed.
We also plan to test how reliable are previous dust-to-molecular gas mass conversion methods (e.g., Scoville+14) when using one single continuum observation in the millimeter band.

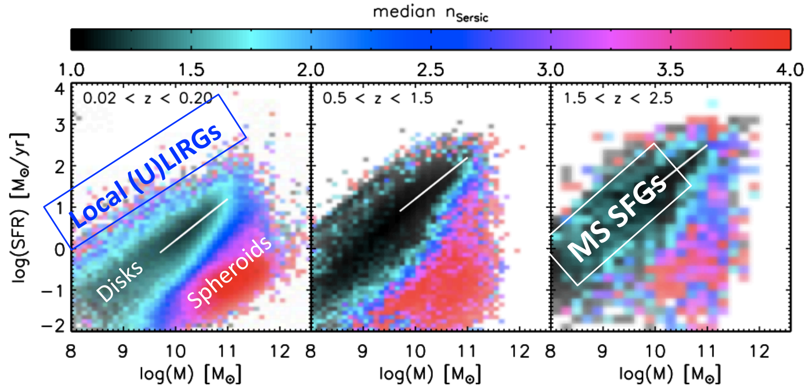
The cold molecular gas phase in local LIRGs

The cold phase of the interstellar medium (ISM) has a central role in galaxy growth and evolution, consisting of clouds of neutral and molecular gas dominated in mass by atomic and molecular hydrogen (HI and H_2). Molecular gas is the ISM phase that is most directly linked to the star formation process (Leroy et al. 2008). Carbon monoxide (^{12}CO), the second most abundant molecule after H_2, is the most convenient tracer of the bulk of molecular gas in large galaxy samples, thanks to its bright low-*J* transitions at millimeter wavelengths that are easily excited down to gas temperatures of T~10 K (Carilli & Walter 2013).

The strong correlation between the star formation rate (SFR) and the cold molecular gas content in galaxies is usually referred to as the star formation (SF) law (or Kennicutt-Schmidt relation). Many studies of the resolved sub-kpc SF laws in nearby galaxies have appeared (Leroy et al. 2008; Casasola et al. 2015) finding a bimodal SF law when main sequence (MS) and starbursts (SB, with higher specific SFR than MS galaxies for a given z) are considered (Daddi et al.2010; García-Burillo et al. 2012). Most of these sub-kpc studies are focused on very nearby (d < 20 Mpc) spiral galaxies and active galactic nuclei (AGN).

Low-z (U)LIRGs cover a similar star formation rate (SFR) range than high-z normal star-forming galaxies (SFGs). Therefore, local (U)LIRGs offer a unique opportunity to study, at high linear resolution and signal-to-noise ratio (S/N), extreme SF events and compare them with those observed at high-z.

The characterization at sub-kpc scales of their molecular gas content using ALMA observations will allow us to explore in more detail the consequences for the relation between *gas and dust masses with the IR luminosities and SFRs when considering different galaxy populations* (SFGs at low- and high-z).



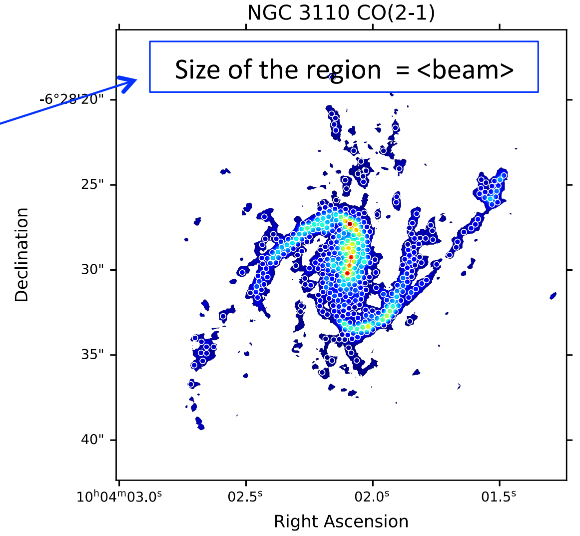
Molecular gas mass and dust temperature at sub-kpc scales

From the CO(2-1) flux map:

- We first select the emission >5σ over which we identify several circular regions (see top figure)

→ for the analysis we use the best spatial resolution achieved for each galaxy;

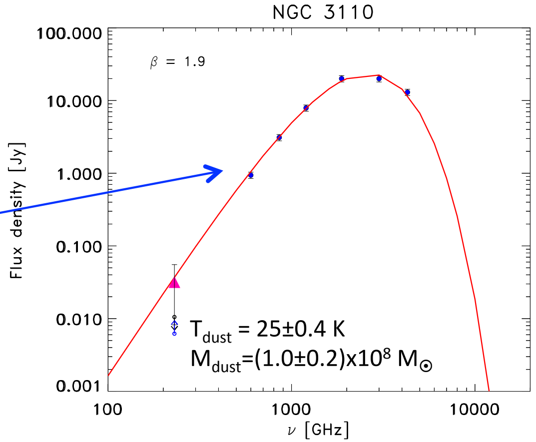
- For each clump we get the CO flux which is transformed to molecular gas mass according to fundamental relations (Solomon 1997: $\alpha_{CO} = 4.3$ [$M_{\odot}$ (K km/s pc^2)$^{-1}$]; Bolatto+2013: $<r_{21}> = 0.8$);
- Assuming a GDR = $M_{mol}/M_{dust} = 100$ we obtain the → *dust mass M_{dust}*



From the continuum 1.3 mm map:

Once obtained the M_{dust}, we can derive the T_{dust} in each clump from the relations:

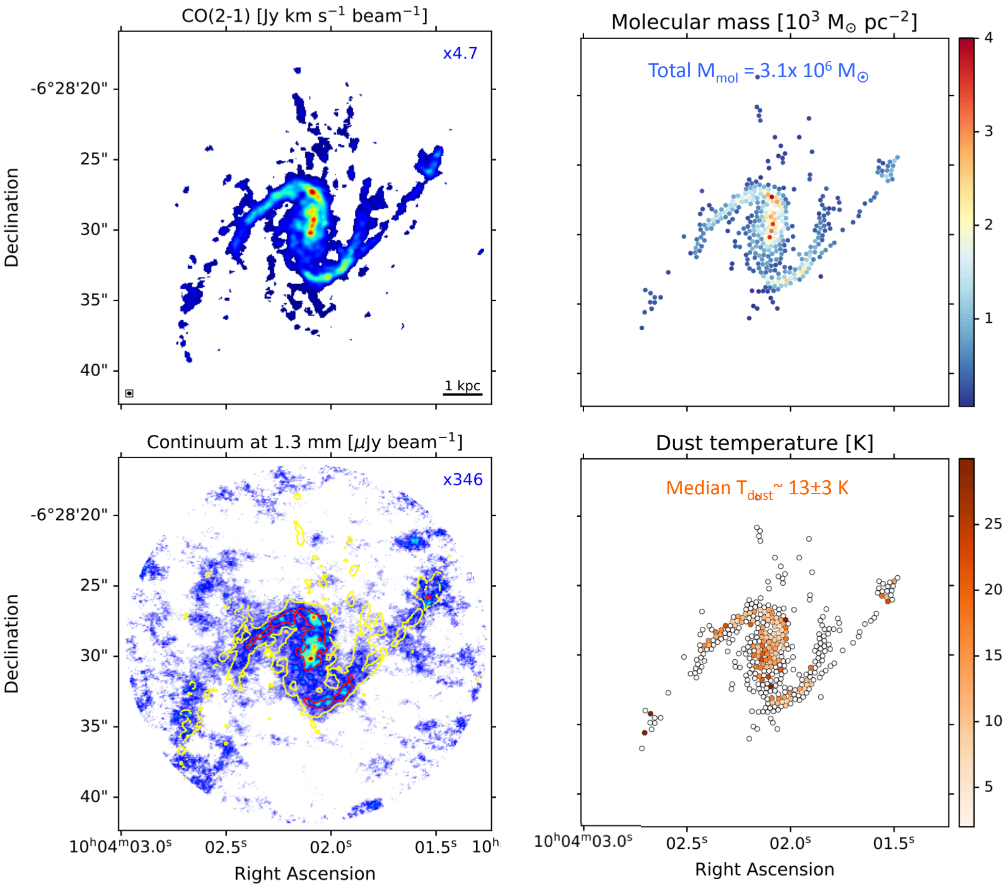
- $\tau = k(\nu)/(\Omega_{source} \times D_L^2) \times M_{dust}$
- $k(\nu) = 0.04 \times (\nu/\nu_0)^{\beta}$; $\nu_0 = 250$ GHz (see Weiss08)
- β = 1.9 from SED fitting using SPIRE and PACS data (e.g., fluxes from Pereira et al. 2015)

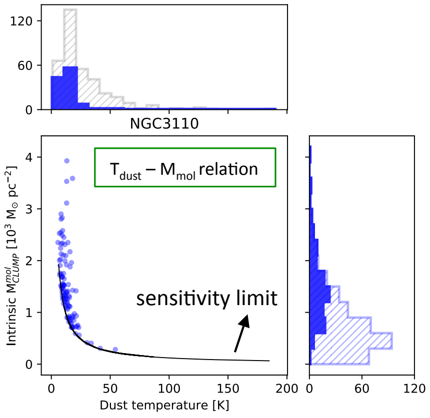


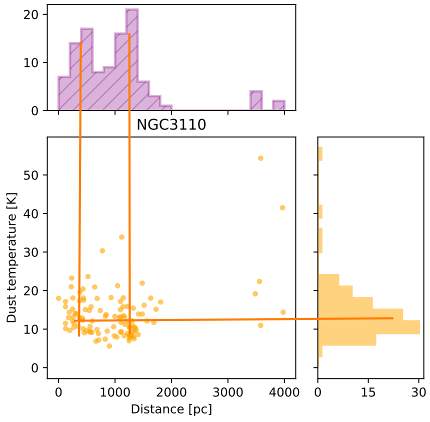
→ $T_{dust} = S^{1.3mm}_{dust} \times c^2/2h\nu^2 \times D_L^2/k(\nu) \times M_{dust}^{-1}$

First results:

NGC 3110







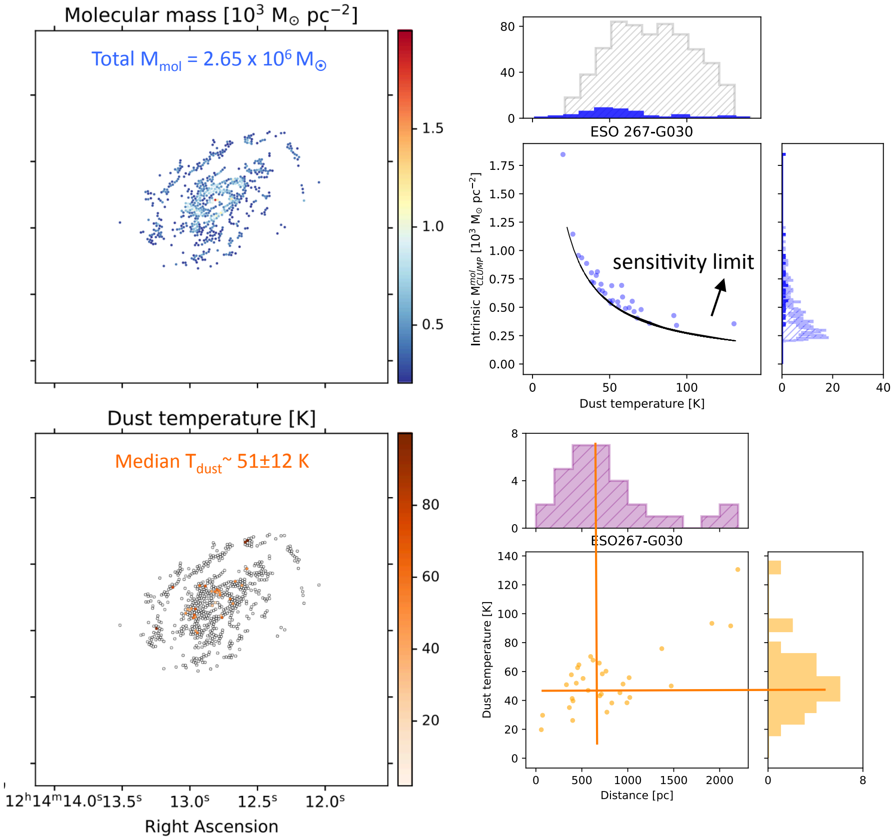
- Small scale offset between the CO(2-1) and 1.3 mm continuum peak emissions: gas and dust are maybe heated by different mechanisms (e.g., see Cao et al. 2018);

- More massive clumps are found in the center and towards the north: their corresponding T_{dust} is low (5-13 K);

- Higher T_{dust} (18-25 K) value are found around the nucleus (0.5-1.5 kpc)

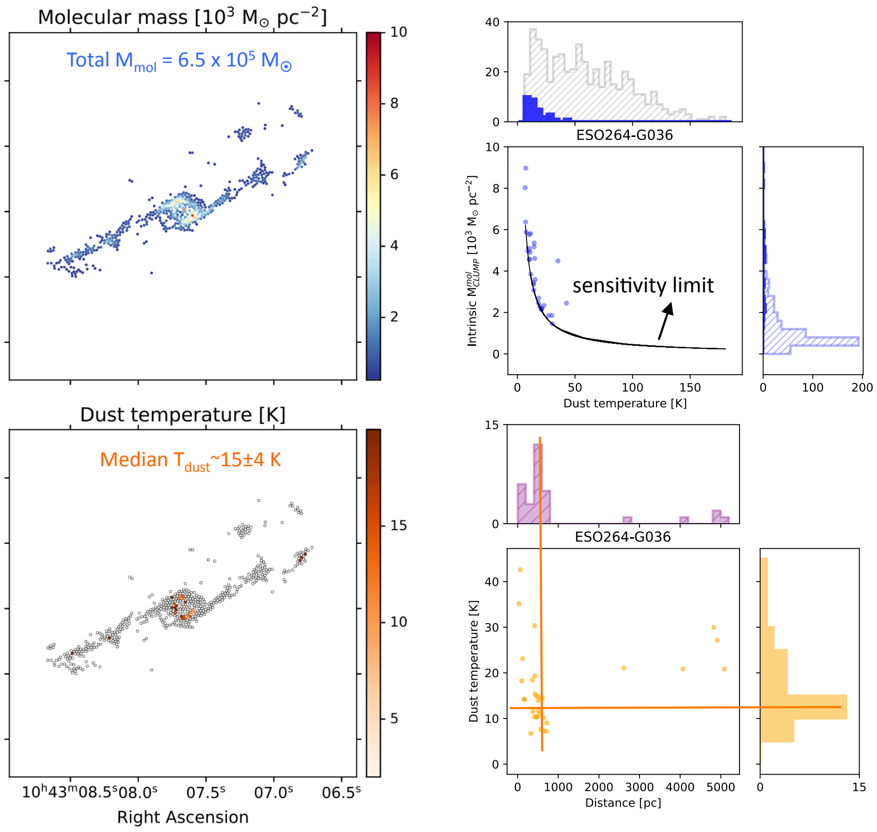
More results:

ESO267-G030



- Hotter dust with large T range (20-80 K) placed at <1 kpc

ESO264-G036



- Dust emission mainly found around the center (<1 kpc)

Future work: finding scaling relations in our sample (23 local LIRGs)

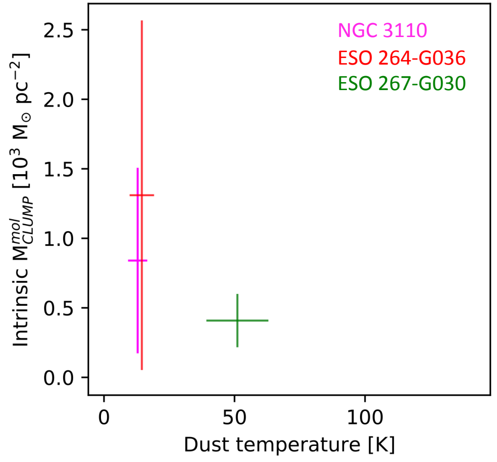
1) Characterization of the <u>effective radius</u> of the different gas components (molecular, ionized, star and dust):

NGC 3110: R_{CO} = 1.1 kpc *versus* $R_{2MASS\ (K)}$ = 3.2 kpc (Bellocchi et al. 2013)

$R_{1.3mm}$ = 0.9 kpc *versus* $R_{H\alpha}$ > 2.7 kpc (Arribas et al. 2012)

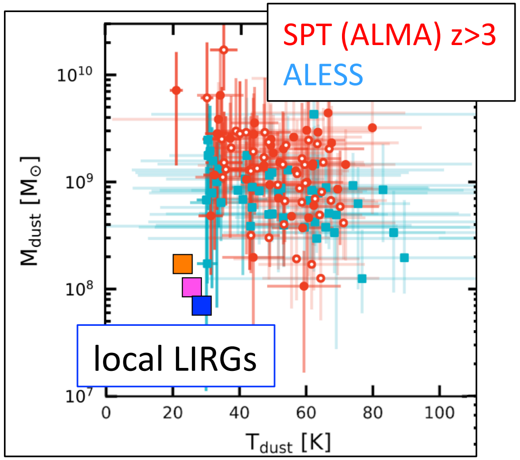
2) Looking for relation with respect to the <u>ionization type</u> and <u>dynamical phases</u>

3) Relation between the dust and molecular gas: T_{dust} -- M_{mol}



4) Compare our results with those obtained for local ULIRGs and nearby spirals

5) Comparison with *high-z* galaxies → Dusty SFGs at z~4 (Reuter et al. 2020) characterized by L_{IR}~10^{13} $L_\odot$, a factor of 100 higher than local LIRGs (L_{IR}~10^{11} $L_\odot$)



high-z → SPT (ALMA):
T_{dust} = 51±12 K
M_{dust}=(2.0±2.4)x10^9 $M_\odot$

local LIRG → NGC 3110:
T_{dust} = 25±0.4 K
M_{dust}=(1.0±0.2)x10^8 $M_\odot$

High-z SFGs are hotter and more massive than local LIRGs …?

To be continued… Stay tuned!