

# PhD Report – Cycle XXXVI

## PhD Student: Federico Esposito

**Project title:** Characterizing the cold gas of galaxies: from the local Universe up to the Epoch of Reionization (EoR)

**Supervisor:** Prof. Francesca Pozzi

**Co-supervisor:** Dr. Livia Vallini

**Broad context** The molecular phase of the interstellar medium (ISM) is the fuel for star formation, thus it plays a crucial role in galaxy evolution. The molecular gas properties (temperature, density, pressure, turbulence, chemical composition) are affected both by star formation and, in sources hosting an active galactic nucleus (AGN), also by the accretion onto the central black hole. The two different sources give rise in the ISM, respectively, to photodissociation regions (PDRs, Hollenbach & Tielens 1997) and X-ray dominated regions (XDRs, Maloney et al. 1996). PDR and XDR heating are the main sources of molecular emission in galaxies, which is usually traced by carbon monoxide (CO) lines, since  $\text{H}_2$ , while dominant in terms of mass, is challenging to detect. The shape of the CO spectral line energy distribution (SLED) is a good proxy for disentangling PDR and XDR heating, so it can be used to understand the role of the AGN on the molecular ISM, and therefore on star formation.

**Specific aims** The main goal of my PhD is to investigate how much the AGN activity influences the molecular gas, both on a global scale and on the inner regions of galaxies. The study has an observative part, in which I analyze the gas emission (especially the CO SLED), comparing it with other observables, as the X-ray flux, or the star formation rate (SFR), for samples of active galaxies in the local Universe and at high redshift; and a theoretical part, mainly using the radiative transfer code Cloudy (Ferland et al. 2017).

**1<sup>st</sup> year: Sample selection and data analysis** During my first year I tackled the project by studying a sample of local AGN, in order to get advantage of the high-resolution and multi-band data available. After inspecting all the available works in the literature, I gathered the CO fluxes (with  $4 \leq J \leq 13$ ) for a total of 226 galaxies. I collected the X-ray data of these galaxies, and selected only the sources with intrinsic  $L_X \geq 10^{42}$  erg/s to ensure they are AGN. This resulted in a final sample of 37 galaxies. I complete CO SLEDs at low- $J$  with collected observations from ground-based millimeter telescopes, and to homogenize the data I assume a theoretical radial profile for the CO(1–0) line luminosity, from which the molecular gas mass is calculated. To put an upper limit to the size of AGN influence on the molecular ISM, I produced intensity maps of mid- $J$  CO emission from already calibrated and cleaned ALMA datacubes. I made use of Herschel/PACS images at  $70\mu\text{m}$  to calculate the star formation rate (SFR) and the FUV interstellar field: the first is needed to put my sample on the Schmidt—Kennicutt plane ( $\Sigma_{\text{SFR}}$  vs.  $\Sigma_{\text{gas}}$ ), the second to gauge the PDR heating. XDR heating is instead gauged from the X-ray flux. Finally I compare my results with numerical output from Cloudy, a radiative transfer code that takes into account PDR and XDR heating to calculate molecular spectra.

**1<sup>st</sup> year: Results** To check for an AGN influence on galactic scales, I compared my points to the Schmidt—Kennicutt relation, finding no significant difference with other literature samples of non-active galaxies. To see if there is an impact on the nuclear regions ( $r = 250$  pc), I studied the ratios of different CO lines, comparing them with FUV and X-ray fluxes (i.e. with PDR or XDR heating), and to Cloudy model clouds with different densities and radiative fields. The comparison showed that, within the central 500 pc, a mix of the two mechanisms (PDR and XDR) is necessary to explain the observed CO excitation. I am currently working on finalizing a paper on this year's work.

## **Workshops, Conferences & Meetings**

24-27 August 2021 - Institut de Radioastronomie Millimétrique (IRAM) - Remote - 50th Young European Radio Astronomers Conference

**Talk:** "AGN impact on molecular gas in the galactic centers as probed by CO lines"

## **PhD Schools**

1-5 June 2021 - Center for Astrostatistics at The Pennsylvania State University - Remote - "16th Summer School in Statistics for Astronomers"

12-23 July 2021 - CNRS/INSU (France) - Remote - International Summer School on the Interstellar Medium of Galaxies, from the Epoch of Reionization to the Milky Way

## **Internal Courses**

30 November - 2 December 2020 - Bologna, Italy - Remote - "The Interstellar Medium"

19 – 23 April 2021 - Bologna, Italy - Remote - "Gamma Ray Bursts: from observations to physical properties"

5-14 May 2021 Bologna, Italy - Remote/In presence - Writing, talking and presenting Science

## **ISA Lectures**

13 May 2021 - "Vaccini e sviluppo del farmaco tra Verità, Miti e Falsità"

6 July 2021 - "How positive pedagogy can address mental health and wellbeing of students?"

## **Publications**

Paper in preparation: "AGN impact on molecular gas in galactic centers as probed by CO lines" with Dr. Livia Vallini (second author) and Prof. Francesca Pozzi (third author).