"The multi–phase ISM in the nearby composite AGN-SB galaxy NGC 4945: large (parsecs) scale mechanical heating."

EXCELENCIA MARÍA DE MAEZTU

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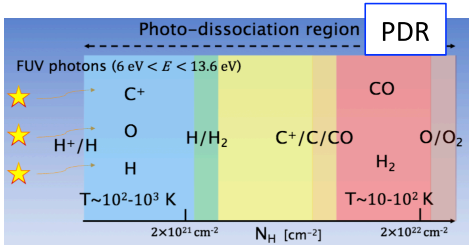
ABSTRACT

We carry out a comprehensive study of the nearby composite AGN-SB galaxy, NGC 4945, using spectroscopic and photometric data from the *Herschel* satellite. In particular, we characterize the thermal structure in this galaxy by a multi-transitions analysis of the spatial distribution of the ^{12}CO emission at different spatial scales. We also establish the dominant heating mechanism at work in the inner region of this object at smaller spatial scales (200 pc). Indeed, the thermal structure derived from the ^{12}CO multi–transition analysis suggests that mechanical heating, like shocks or turbulence, dominates the heating of the ISM in the nucleus of NGC 4945 located beyond 100 pc (>5") from the center of the galaxy. Shocks and/or turbulence are likely produced by the barred potential and the outflow, observed in X–rays. This result is confirmed by the mechanical heating models, which suggest the existence of PDRs but mainly dominated by mechanical heating (i.e., feedback from SNe) in the inner regions of NGC 4945.

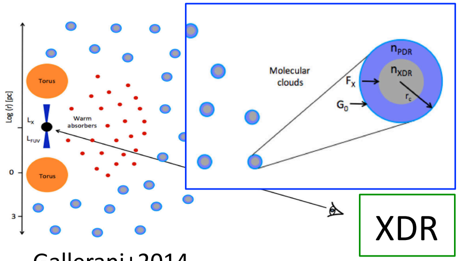
The role of the molecular gas emission in galaxies

Galaxy interactions and mergers play important roles in the formation and evolution of galaxies, able to trigger massive starburst (SB) and also feed super massive black hole (SMBH). The study of the active galactic nuclei (AGN) and starburst phenomena is a key point in order to understand the relationship between the star formation and AGN activity in galaxies.

The molecular gas plays not only a key role as fuel in the activity process but should also, in turn, be strongly affected by the activity. Depending on the evolutionary phase of the activity, *different physical processes can be involved, changing the excitation conditions and the chemistry:* strong ultraviolet (UV) radiation coming from young massive stars (i.e., photon dominated region or PDR; e.g., Wolfire et al. 2010), highly energetic X-ray photons coming from an AGN (i.e., X-ray dominated region or XDR; Meijerink et al. 2006), as well as shocks and outflows/inflows (see Flower et al. 2010). X-rays can penetrate more deeply into the ISM than UV photons (Maloney et al. 1996; Meijerink & Spaans 2005): X-rays are able to heat more efficiently the gas, but not the dust, and they are less effective in dissociating molecules (Meijerink et al. 2013). On the other hand, PDRs are more efficient than XDRs in heating the dust. For this reason, AGNs are suspected to create excitation and chemical conditions for the surrounding molecular gas that are spatially quite different from those in SB environments.



Mingozzi+2017
Hollenbach & Tielens 1999

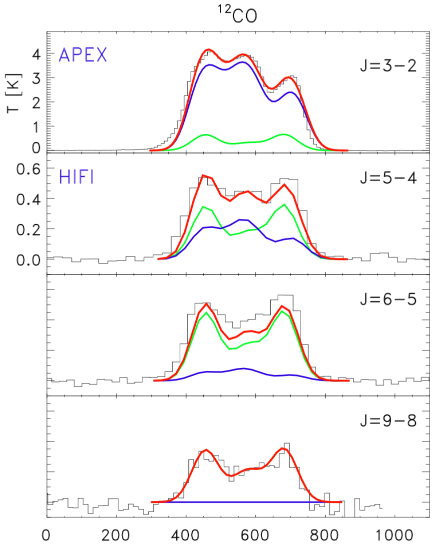


Gallerani+2014

Understanding the dominant heating mechanism in the nuclei of galaxies is crucial to understand star formation in starbursts (SB), active galactic nuclei (AGN) phenomena and the relationship between the star formation and AGN activity in galaxies. The analysis of the carbon monoxide (^{12}CO) rotational ladder versus the infrared continuum emission (hereafter, ^{12}CO/IR) in galaxies with different type of activity have shown important differences between them

NGC 4945 observed with *Herschel* and *APEX* data

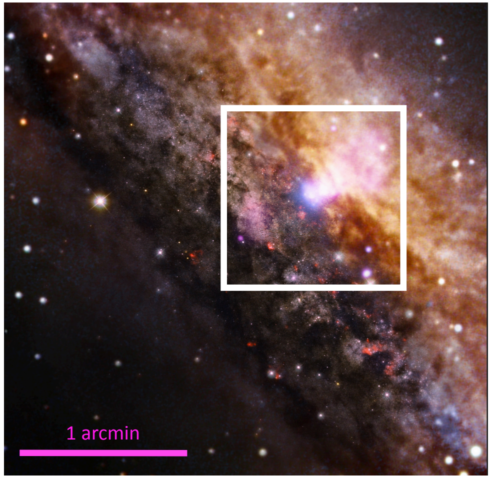
The aim of this work is to *characterize the thermal and density structures at different spatial scales in the composite AGN-SB galaxy NGC 4945*. The determination of the dominant heating mechanism and the origin of the observed heating pattern in the inner regions of this object are also discussed. Furthermore, the photometric data allow us to derive the mass of dust and the corresponding mass of gas (once assumed a specific gas-to-dust ratio) and compare with the expectations from the heating mechanisms inferred from the ^{12}CO analysis.



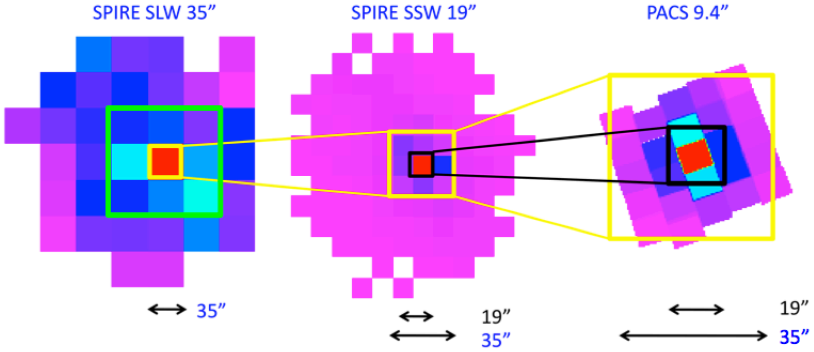
We present far-infrared (FIR) and sub-millimeter (sub-mm) ^{12}CO line maps and single spectra (from J_{up} = 4 to 20) using the Heterodyne Instrument for the Far Infrared (HIFI), the Photoconductor Array Camera and Spectrometer (PACS), and the Spectral and Photometric Imaging REceiver (SPIRE) onboard *Herschel*, and APEX.

We combined the ^{12}CO/IR flux ratios and the LTE analysis of the ^{12}CO images to derive the thermal structure of the Interstellar Medium (ISM) for spatial scales raging from 200 pc to 2 kpc.

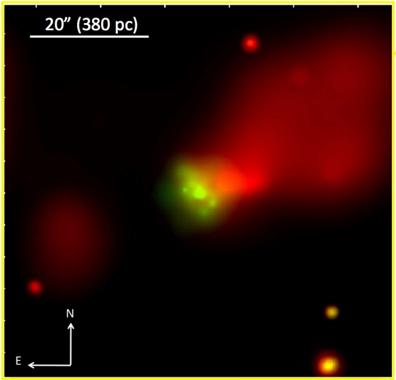
2D thermal structures from ^{12}CO at different spatial scales in NGC4945

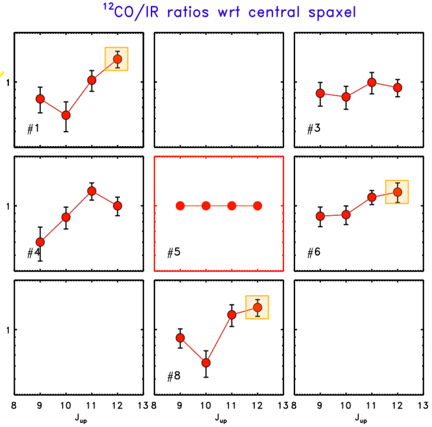


• We combine the information obtained from applying the LTE analysis (using MADCUBA) to ^{12}CO molecule using SPIRE SLW, SSW and PACS data → We derive the thermal and column density structures at different spatial scales;

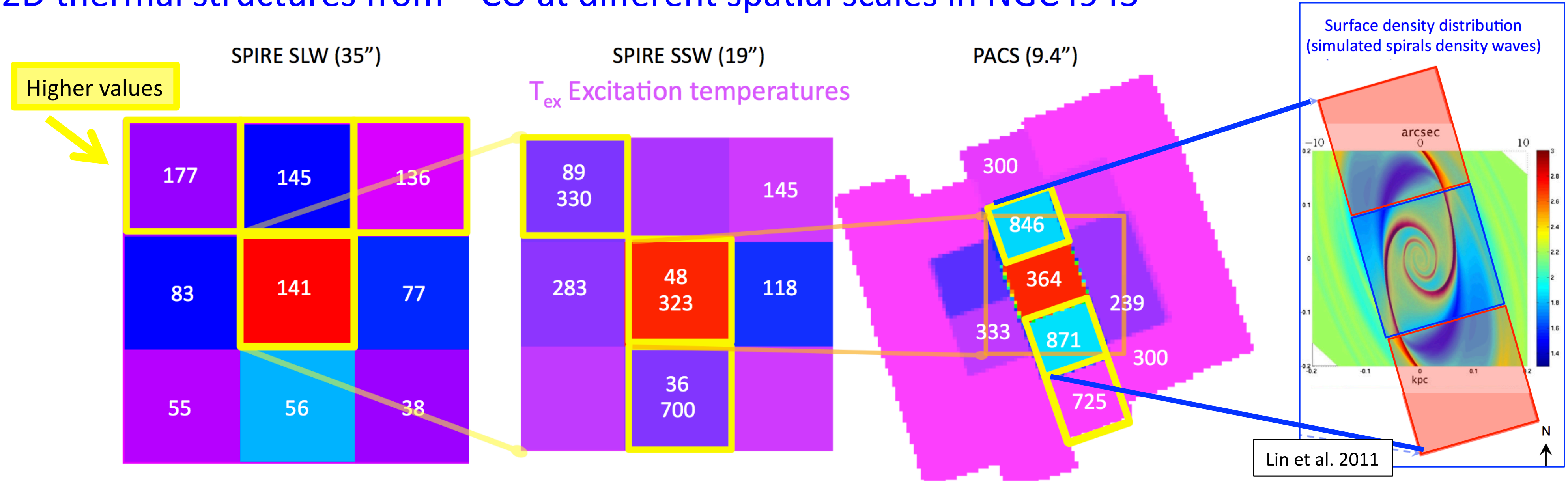


• The CO/IR flux ratios derived using SPIRE SSW data increase at J_{up}= 9 and 10 in the NW direction. This increase at higher J seems to follow the direction of the outflow observed in the X-ray band by *Chandra*. Assuming that the X-ray outflow is responsible of such an increase in these directions, we normalize the emission of each spaxel to the central one. At these spatial scales the increased emission at higher frequencies (J_{up} ≥ 11–12) suggests that other mechanisms, like shocks, could be also at work.





2D thermal structures from ^{12}CO at different spatial scales in NGC4945



Large scale (700 pc-2 kpc):

High temperatures are mainly found in the northern part of the galaxy as well as in the disk plane. This suggests the presence of the outflow might affects the T observed in the NW direction.

Intermediate scales (360 pc-1 kpc):

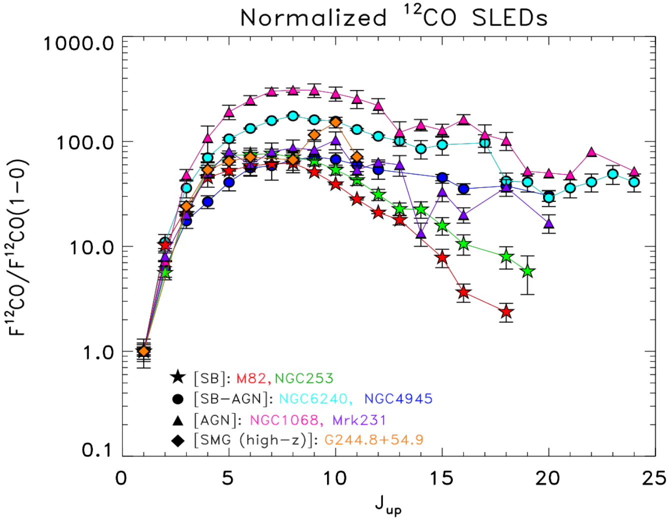
The heating is distributed along the disk plane and in the south direction too;

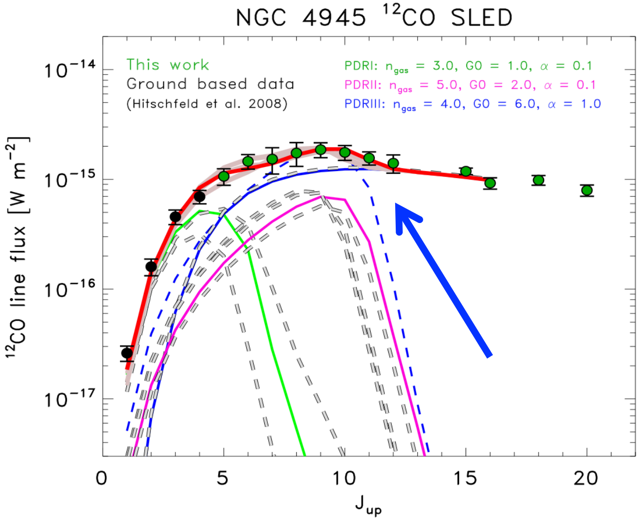
Small scales (~200 pc):

A peak in the column density is found in the central spaxel, surrounded by lower column density but higher excitation temperatures. This result is an agreement with the results derived by Lin et al. (2011) → They proposed the presence of tightly wound spirals to explain the distribution of the surface density and the related velocity field in a 20”X20” region.

Conclusions and future prospects

Results of the ^{12}CO Spectral Line Energy Distribution (SLED) of NGC 4945 from J = 1-0 through 20-19 applying the Kazandjian et al. (2015) models → mechanical heating (blue line) is needed to properly fit the higher (PACS) J





mean log G_0~5.5 ('Habing' units)
mean log n_{H2}~4.6 cm^{-3}

Our results place NGC 4945 in the region covered by local starburst galaxies (as NGC 253) and ULIRGs with similar density but characterized by higher FUV radiation.

→ In agreement with SED fitting results and LTE models.

The results obtained in this work seem to confirm that the *presence of the AGN in NGC 4945 has little impact on the thermal properties of its nuclear starburst.* IR observations at higher spatial resolution are required to characterize both the dust and molecular line emissions. Spectroscopic and photometric observations like those could be achieved by the instruments onboard SOFIA (e.g., HAWC+, CASIMIR and/or GREAT) are needed in order to characterize the physical conditions of temperature and density as well as the structure of the emission itself in the very inner regions of NGC 4945.