Thesis subject

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Subject's title: **Deciphering the dusty star formation in the early Universe**

Subject description:
Among the potentially most important results of cosmology over the last 20 years has been the discovery of the importance of dust obscured star formation. While dusty galaxies are rare in the local Universe (~1%), they are 10 to 100 times more numerous at higher redshift (z>1). For these galaxies, a large fraction of the light produced by stars reaches us in the range 100-2000 microns, after being reprocessed by dust. These galaxies become so important that they dominate the census of star formation in the Universe at 1<z<3.5. At higher redshift (z>4), and despite recent progress, the contribution of dust-obscured galaxies to the young Universe remains unknown. Today, most measurements at high redshift (z>4) rely on the UV emission emerging from galaxies. However, these observations trace the unobscured star formation and thus do not allow direct measurements of star formation from dust-obscured galaxies. Importantly, recent observations by the JWST seem to show that heavily obscured sources exist up to z~13.

To probe the dust-obscured galaxies, deep surveys in the (sub-)millimeter domain are mandatory. To reach this goal, we are conducting a large observing program (called N2CLS, Bing+2022) at 1.2 and 2 mm with the NIKA2 camera which is installed on the IRAM 30-meter telescope. We are observing two emblematic cosmological fields, GOODS-N and COSMOS. The observation campaigns started in Oct 2017 and will end in Feb 2023 (only 12% of observations are missing as of beginning of January). They are covering an unprecedented range of parameters, in terms of luminosity reached and area observed.

COSMOS-NIKA2 is covering an area of ~1400 Sq. Arcmin and is by far the deepest and largest survey ever made at those wavelengths. We are detecting hundreds of galaxies obscured by dust during their intense star formation episodes in the young Universe. Getting the redshift for such dusty sources is a real challenge. In an analysis with the first 20% of data, we cross-matched the NIKA2 sources with existing ancillary data and found 35% were z>4 candidate galaxies. From this z>4 sample, 38% of them were already confirmed high-z galaxies using blind spectral-scans with ALMA in the millimetre. On the remaining 62%, 81% are optically-dark galaxies. For these kinds of sources, upcoming JWST data will be of unique value and will allow us to pinpoint the location of these galaxies, and thus get their multi-wavelength data (including the new Meerkat data) and consequently study their cosmic evolution. For JWST, these dusty galaxies (which appears very “red” for optical/near-IR data) could be posing as extremely high-redshift galaxies (Zavala+2023).

The thesis objectives are to:

- obtain a complete view of the star formation rate (SFR) at high redshift by both measuring the dust-obscured SFR (NIKA2) and disentangling between very high-z dust-poor galaxies and very obscured z~3-5 galaxies (rest-frame optical data, JWST);
- bring new constraints on the evolution of galaxies by probing for example the star formation in “normal” galaxies at high-z (using both NIKA2 and radio data) and determining if these galaxies follow the main sequence of star formation seen in the Universe at z<2 or if the starburst activity induced by galaxies interaction and fusion play an important role;
- measure the distribution of star formation in large-scale structures with environment measurements thanks to our large-area survey.

These are also key science drivers of the SKA. Several important results are guaranteed, among which the discovery of obscured galaxies in the very young Universe.

The successful PhD candidate will contribute to the final data processing and analysis. She/he will extract the sources using multi-wavelength source extraction codes. Novel extraction techniques could also be explored, such as image segmentation based on Deep Learning algorithm. Using counterparts of detected millimeter sources from ancillary data, she/he will analyze their spectral energy distribution to measure stellar masses and star formation rate. Once the observations and galaxy detections are fully characterized, she/he will directly use them to constrain the history of dusty star formation by fitting for example our evolutionary model of galaxy evolution. She/he will also help us to define the best strategy for follow up observations, especially with the NOEMA and ALMA interferometers, to measure the redshift and gas mass of the most representative galaxies. Such measurements, combined with JWST and Meerkat, will be used to relate the star formation efficiency to other galaxy properties (mass, merger state, kinematics), to learn what regulates their star formation. Finally, she/he will be involved in the study of the environment/clustering of these objects, that will put strong constraints on models for the evolution of large-scale structure, giving the link between star formation and dark mater halos mass.

This thesis offers the unique opportunity to participate to a pioneering observational project, within a dedicated team (the N2CLS collaboration). Members of the NIKA2 deep field surveys include M. Béthermin, V. Buat and D. Burgarella at LAM, N. Ponthieu and F.-X. Désert at IPAG, in addition to many others over the globe.

<u>Bibliography:</u>

“Searching for high-z DSFGs with NIKA2 and NOEMA”, Bing et al. 2022 (ArXiv:2111.00090).
“Dusty starbursts masquerading as ultra-high redshift galaxy in JWST CEERS observations”, Zavala et al. 2023, ApJL in press (ArXiv 2208.01816).