HC_3N vibrationally excited emission in NGC 1068

Tracing the recent star formation in the starburst ring

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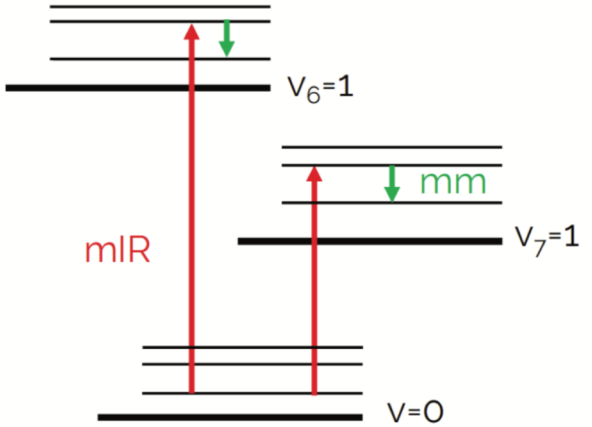
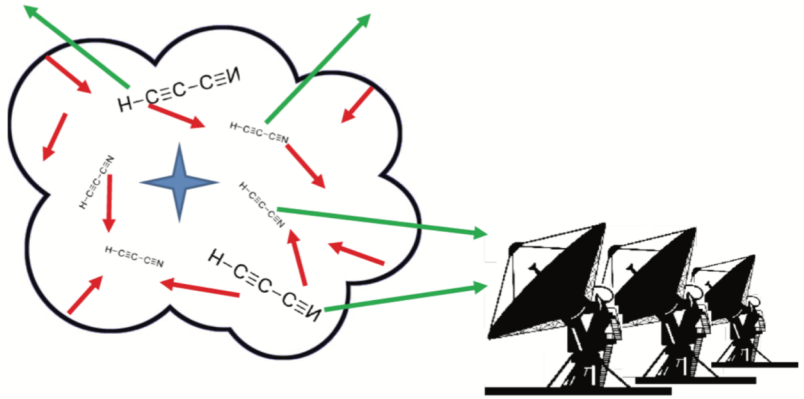
Wstudy the HC_3N and continuum emissions NGC 1068. We have detected emission from vibrationally excited HC_3N (HC_3N^*) only towards one region of the SB ring. Remarkably, HC_3N^* was not detected towards the CND. For the star forming region, we obtained a dust temperature $T_d \sim 250$ K and a luminosity of $\sim 6\times10^8$ $L_\odot$ typical of proto-Super Star Clusters (proto-SSCs) observed in NGC 253. We use the continuum emissions at 147 and 350 GHz, with CO and Pa α, to estimate the ages of another 14 SSCs in the SB ring. We find the youngest SSCs to be associated with the nuclear bar, supporting the scenario of sequential star formation triggered by gas inflow towards the bar. For the CND, our analysis yields $T_d \leq 120$ K. The very different dust temperaturas found for the CND and the proto-SSC indicates that, while the dust in the proto-SSC is being efficiently heated by the radiation from massive stars, the CND is mainly heated by X-rays and/or shocks, which basically heat the gas only at moderate densities.

AGN vs Star Formation activity and Vibrationally excited HC_3N

In many galaxies, AGN and SF activity contribute to a significant fraction of the total galaxy luminosity. Nevertheless, establishing which is the dominating heating mechastrophysicsanism in extremely obscured nuclei remains a key problem in extragalactic.

Vibrationally excited HC_3N (HC_3N^*) is very well suited for tracing energetic processes in highly obscured regions, since its vibrational levels are pumped by mid-IR.





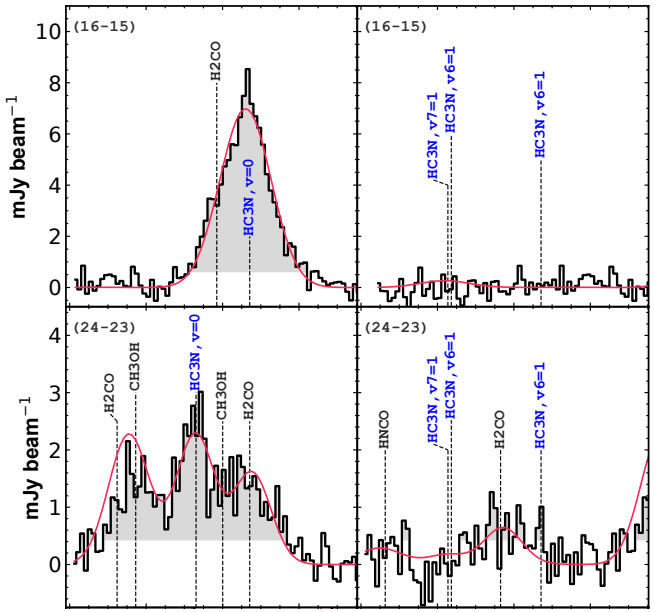
HC_3N^* has been observed in the Milky Way (deVicente2000); NGC 4418 (Costagliola2010, Costagliola2015); Arp 220 (Martin2011); and NGC 253 (Rico-Villas2020).

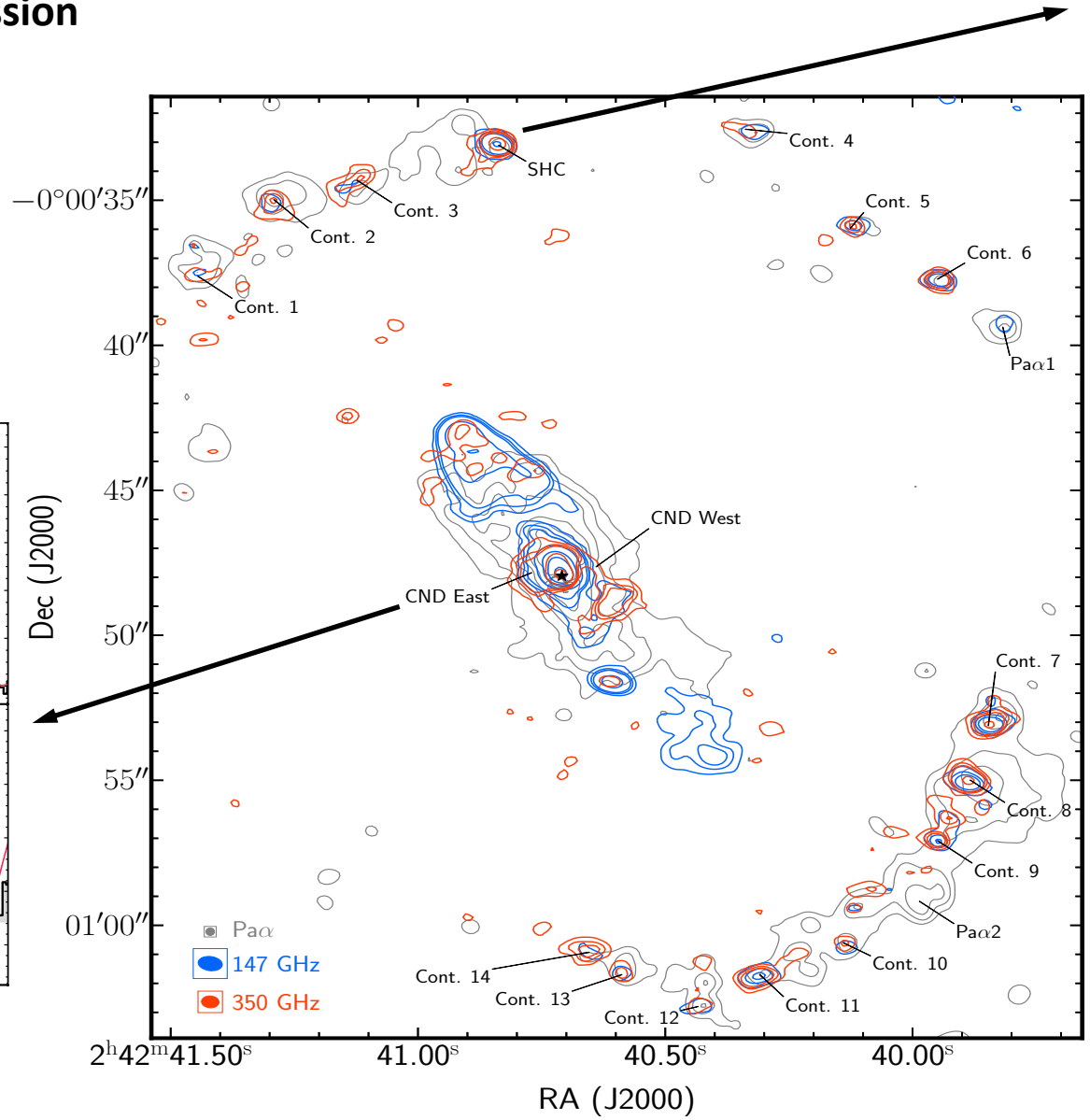
So far, all the observational data suggests that HC_3N^* emission is mainly tracing the recent brief episodes of massive star formation. However, there is no systematic study of the HC_3N^* emission in nearby galaxies with AGN and SF activity to study their effects on the excitation of HC_3N^*.

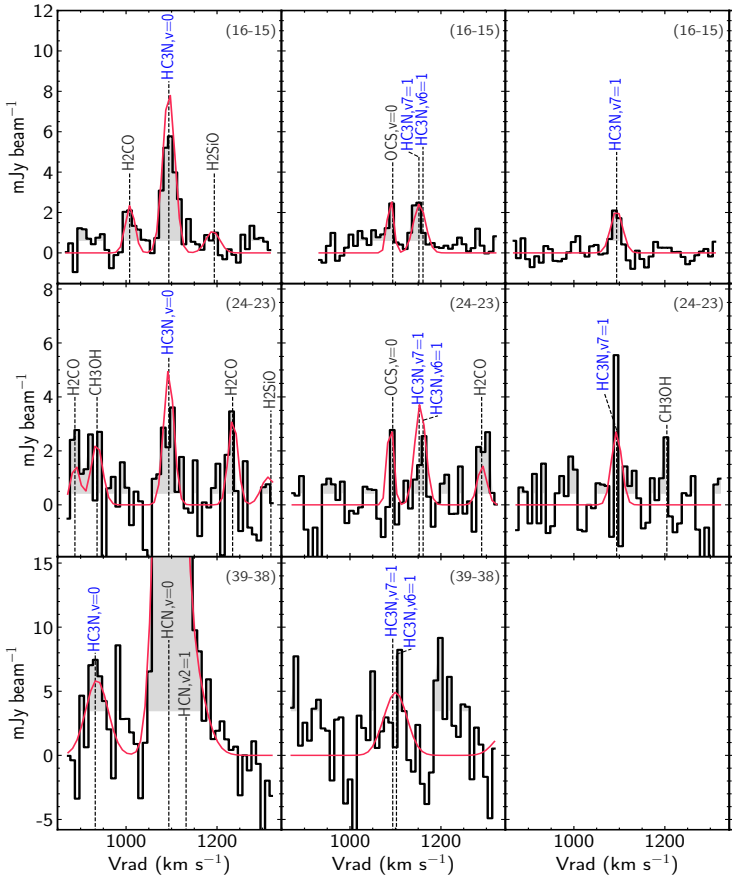
In this work we study the HC_3N emission in the CND and the SB ring of NGC 1068, one of the closest galaxies hosting spatially resolved AGN and starburst activities.

Continuum and HC_3N emission

We have used ALMA covering 85-350 GHz with the best angular resolution and sensitivity available along with Pa α from the HST NICMOS narrow-band (García-Burillo2014)







Using MADCUBA we have smoothed the continuum maps to a common resoltion to study their emission and we have extracted spectra from the data cubes in relevant positions with bright continuum emission to analyze HC_3N

Star masses from continuum and Pa α

From the Pa α and continuum emission at 147 GHz we estimated the stellar mass for the clumps in the SB ring, with $M_* \sim (1-5)\times10^5 M_\odot$ being all SSC

HC_3N LTE and non-LTE modelling

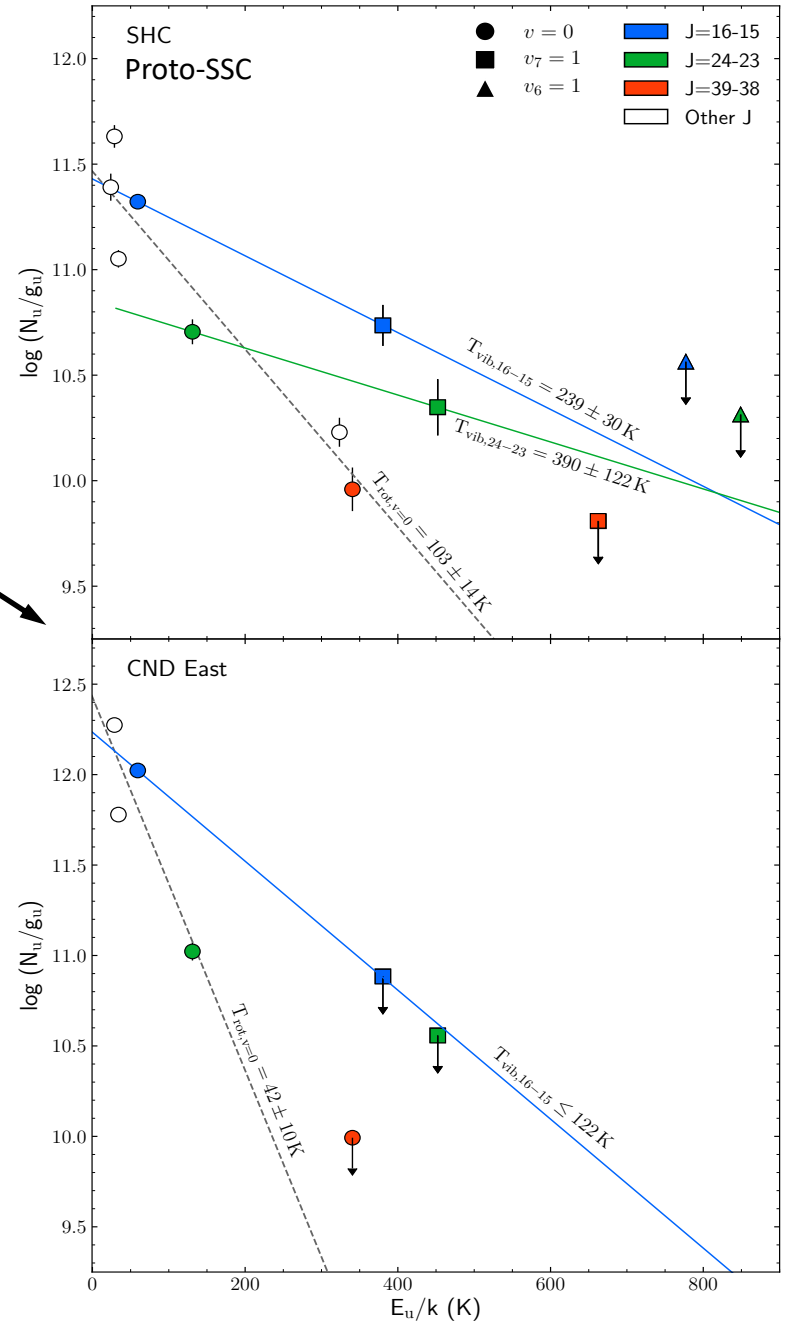
SB ring

We have only detected HC_3N^* towards one clump of the SB ring (proto-SSC). The LTE and non-LTE models give dust temperatures of $T_d \sim 250$K and densities of $n_{H_2} \sim 5\times10^5$cm^{-3}. Corresponding to an IR luminosity of $\sim 6\times10^8 L_\odot$, typical of proto-SSC observed in NGC 253. For the remaining clumps, our sensitivity is not high enough to discard the presence of the proto-SSC phase in some of them.

CND

For the CND we find from LTE and non-LTE analysis that, despite the large HC_3N column densities in the ground state $v = 0$, there is an upper limit on the dust temperature $T_d \sim 120$K, indicating a different excitation mechanism.

The very different temperatures estimated from the rotational diagram method already reveals the different excitation mechanisms between the proto-SSC and the CND



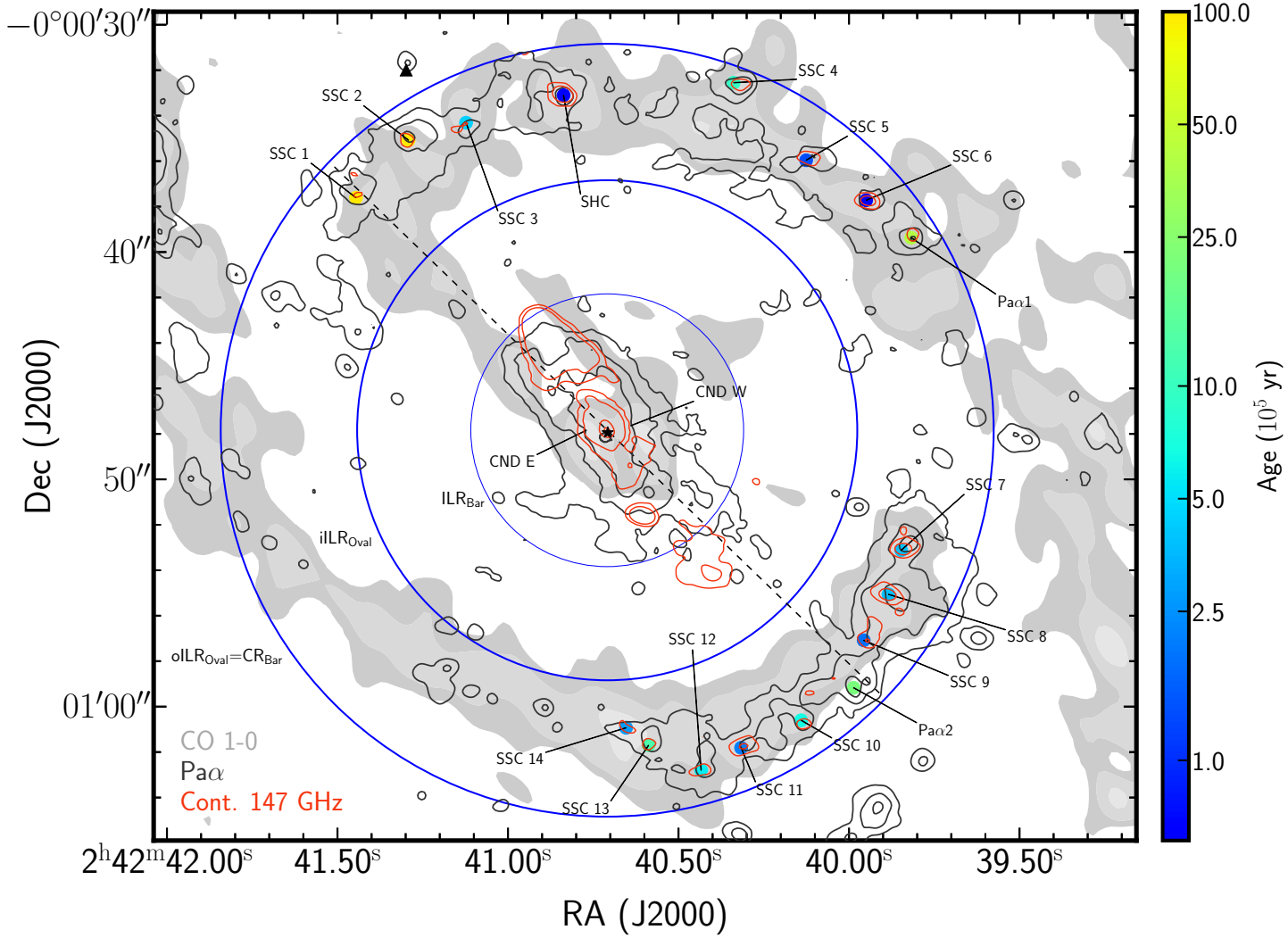
History of star formation in the SB ring

Age estimation from the star masses obtained from Pa α and the 147GHz continuum emission. SSCs ages range 10^4-10^7 yr

- The youngest SSCs (10^4-10^5 yr) are closely associated with nuclear stellar bar and the beginning of the molecular spiral arm

- The oldest population (traced by Pa α) is located on the outer part of the SB ring, the CO emission is located closest to the AGN and the recently formed SSCs are located in between.

These trends support the scenario of sequential star formation triggered by gas inflow towards the bar.



Conclusions

- HC_3N^* emission in NGC 1068 arises only from star formation in the SB ring. The dust temperature for the proto-SSC is ~ 250K.

- The trends found in the SSCs ages in the SB ring support the scenario of sequential star formation triggered by gas inflow towards the bar.

- The low dust temperatures <120 K derived towards the CND indicates heating by X-rays and/or shocks, which mainly heat the gas only at moderate H_2 densities, consistent with the expected heating by the AGN luminosity at the CND distance.

Prospects for the future

- Can the HC_3N^* emission observed in NGC 4418 and Arp 220 be used to discriminate between AGN and SF?

- The similar AGN and starburst dust profiles at large distances makes only the detection of HC_3N^* in NGC 4418 and Arp 220 not enough to discriminate between AGN and SF activity. Only the combination of spatially resolved images of several HC_3N^* images might provide the insight for the discrimination