Effects of early stages of tidal interactions on the star formation law in the NGC 3110 galaxy

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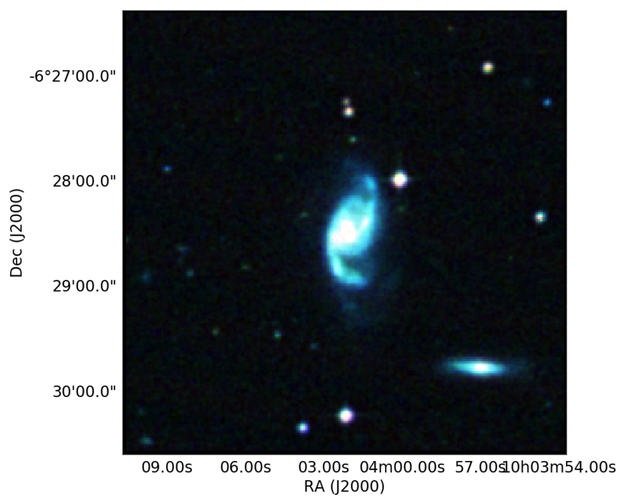
Open questions

What is the role of the environment in the evolution of galaxies? Interactions between galaxies are among the most important mechanisms modifying the properties of galaxies through their cosmological lifetime:

- What are the molecular gas properties during the early stages of mergers?
- What are the Star Formation (SF) properties during these early stages?
- High angular resolution CO observational studies at different stages of the merging process and for different mass ratios are essential to understand the response of the gas to the interaction, which have consequences on the subsequent SF activities.

NGC 3110

Figure 1: DSS2 blue, IR, red composite image



NGC 3110 is a spiral galaxy interacting with a minor companion (Fig. 1). NGC 3110 is usually classified as a SBb galaxy and is a luminous infrared galaxy (LIRG, $L_{\rm IR} = 10^{11.3}\,{\rm L}_\odot$). It is located at a distance of $D = 75.2$ Mpc, and it is interacting with a minor companion whose stellar mass is smaller by a factor of 14 at a distance of 38 kpc and velocity difference of $\Delta V = 235\,{\rm km\,s^{-1}}$, which likely contributed to the formation of its two asymmetric spiral arms and a central bar-like feature.

- It has an overall high SFR of about 20–30 $\mathrm{M_\odot\,yr^{-1}}$, as obtained from IR and Hα data, concentrated towards its center.
- The SF is fueled by a large amount of molecular gas mass, estimated to be $M_{\rm mol} \simeq 2 \times 10^{10}\ \mathrm{M_\odot}$.

Conclusions

- Tidal interactions with minor companions are common in the universe and can be an important mechanism to build large central gas concentrations triggering starbursts and feeding active galactic nuclei (AGN).
- The tidal interactions are likely the primary cause to induce in the main galaxies the formation of the spiral arms, a large molecular gas concentration, and the starburst event. Depletion times are likely higher along the molecular arms. A large population of SSCs, even in the early stages of mergers, is formed at this stage.
- Numerical simulations of interactions with minor companions agree well in terms of morphological appearance but not the SFRs.

Molecular gas

Figure 2: SMA CO(2–1) integrated intensity map

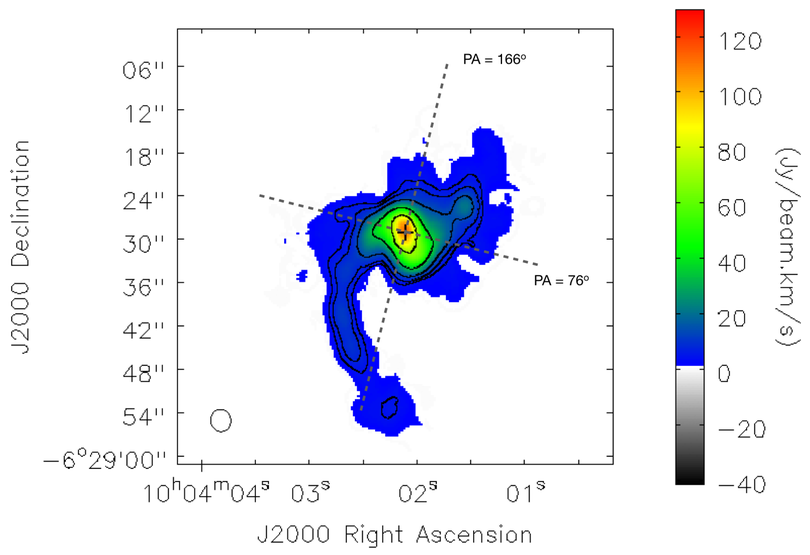
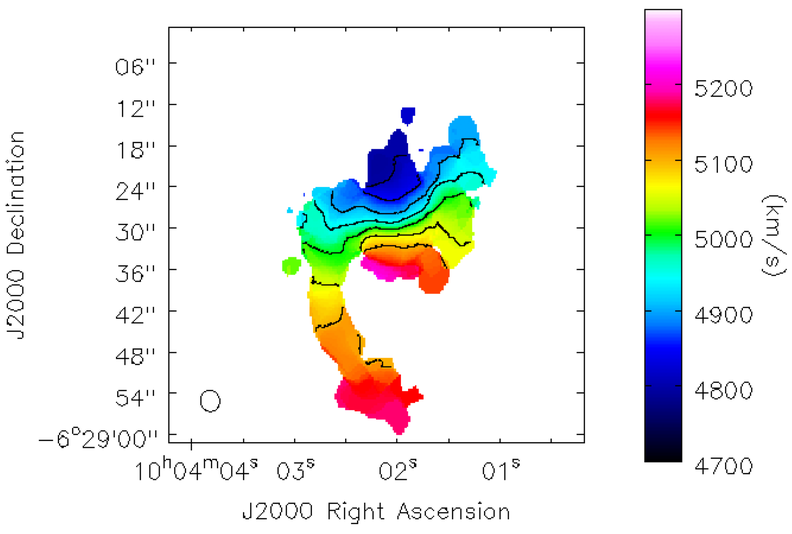
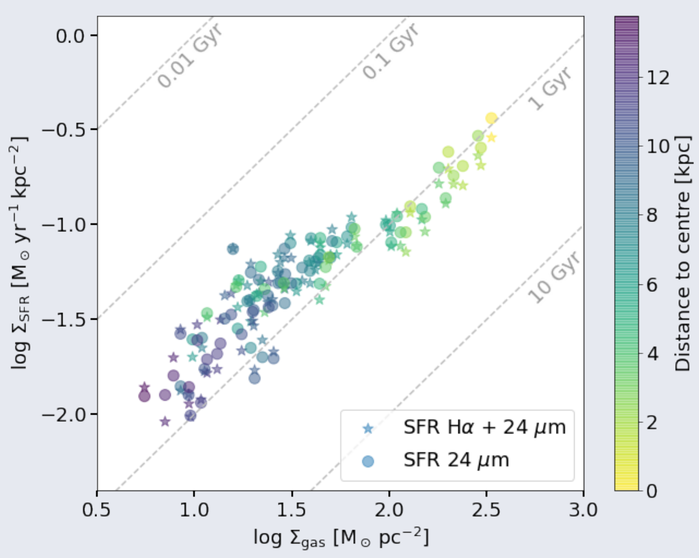


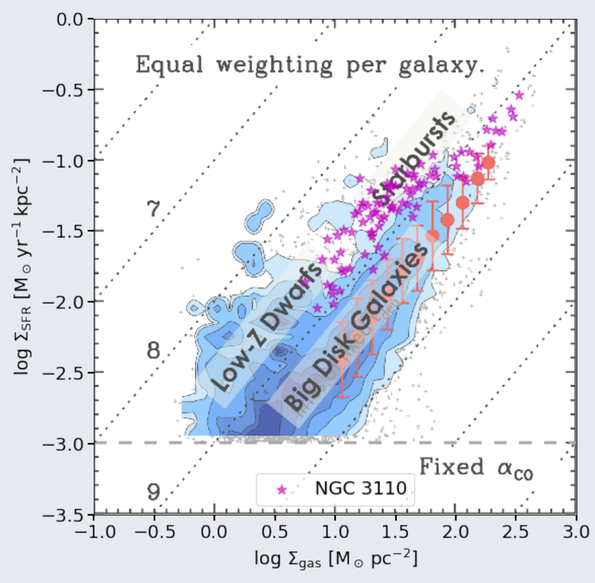
Figure 3: Intensity-weighted velocity field



We present interferometric CO(2–1) maps of NGC 3110 obtained with the Submillimeter Array (SMA) with ∼1.1 kpc resolution. It was observed for 162 min (on source) with 7 antennas in a compact configuration, to achieve a sensitivity of 14 mJy beam^{-1} in a 20 km s^{-1} channel. The contours in the integrated intensity map (Fig. 2) are at 3, 5, 10, 25, and 50 σ, where σ = 1.4 Jy beam^{-1} km s^{-1}. The contours in the velocity field (Fig. 3) range from 4750 to 5100 km s^{-1}, in bins of 50 km s^{-1}.

Spatially resolved Kennicutt-Schmidt star formation law



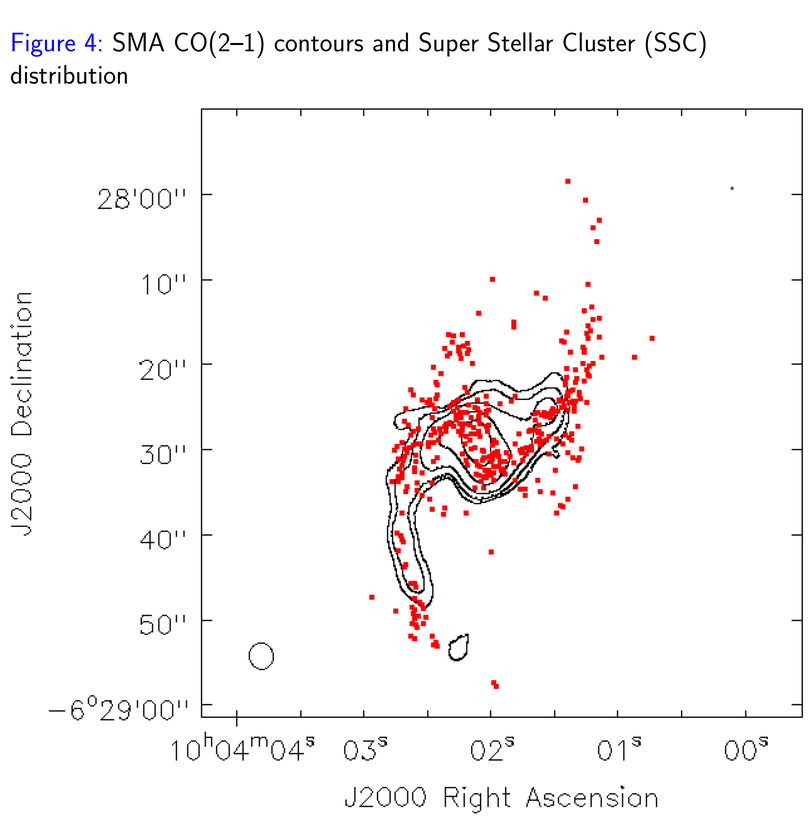


We present the spatially resolved SF law (left panel) using the SMA CO(2–1) data as a tracer of the molecular gas surface densities ($\Sigma_{\rm mol}$) and the Hα and Spitzer 24 μm maps for the SFR surface densities ($\Sigma_{\rm SFR}$):

- The derived global Star Formation Efficiency (SFE = SFR [$\mathrm{M_\odot\,yr^{-1}}$] / $M_{\rm mol}$ [$\mathrm{M_\odot}$]) is 1.3×10^{-9} yr^{-1};
- SFEs are higher along the spiral arms, assuming a constant $X_{\rm CO}$ conversion factor;
- Gas depletion times of 0.5–1 Gyr are found for the different regions, lying in between non-interacting disk galaxies and the starburst sequence (right panel, data points of NGC 3110 over Fig. 1 of Leroy et al. 2013).

Super Stellar Clusters

Figure 4: SMA CO(2–1) contours and Super Stellar Cluster (SSC) distribution



Super star clusters (SSCs) are massive (>10^5 $\mathrm{M_\odot}$) and compact (a few parsec size) star clusters, generally found in mid- and late-stage mergers. We use Ks band VLT/NACO data with ∼0.1 arcsec resolution.

- It is remarkable that more than 350 SSCs (red dots, Fig. 4) were found in NGC 3110, object in an early stage merger with a 1:14 minor companion.
- SSCs are located mostly along the spiral arms and its circumnuclear component. In general we find that molecular clumps, HII regions, and SSCs are well collocated.
- The formation of the most massive SSCs may occur preferentially in regions with high molecular gas surface densities. There are regions such as in the northern arm where gas may have been consumed by SF, and then ionized/destroyed by recently formed SSCs.