

# Studying gas flows in the SUNBIRD starburst galaxies and LIRGs

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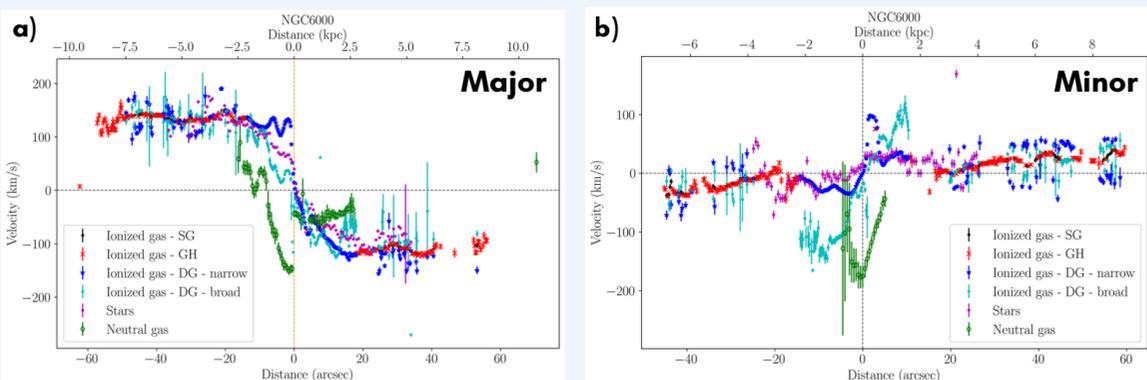
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## 1. Introduction

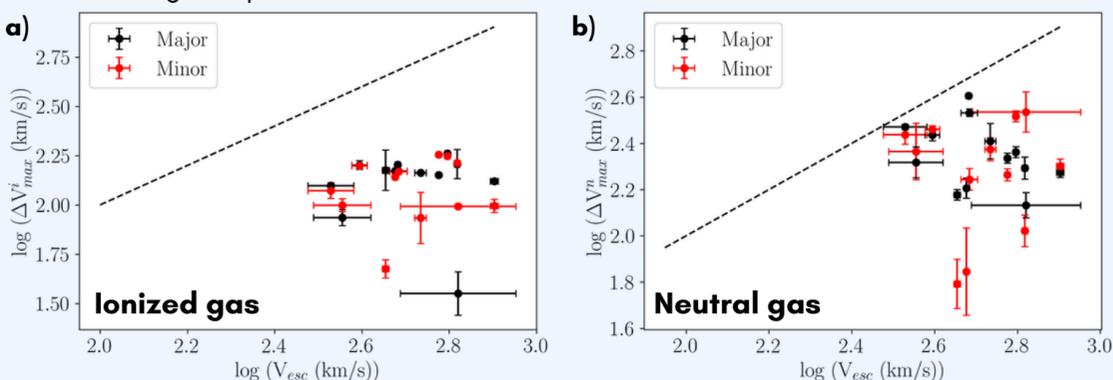
- Gas flows are important to consider in feedback and the regulation of star formation in galaxies.
- Star formation can be enhanced or quenched depending on the inflow and outflow of gas, respectively (e.g., Veilleux et al., 2005; Tumlinson et al., 2017).
- Nearby starburst galaxies and luminous infrared galaxies (LIRGs) provide an extreme environment where gas flows, feedback and the changes due to it can be studied in great detail, giving insight into galaxy evolution.

## 4. Results & Discussion

We found non-circular ionized and neutral gas flows in all 12 starburst galaxies and LIRGs (see Fig. 5 for an example of the rotation curves). These non-circular gas flows can be inflows, outflows or extraplanar gas. The non-circular gas flow velocities of the 12 galaxies range between 35–182 km/s for the ionized gas and 61–403 km/s for the neutral gas and originate from the nucleus for most of the galaxies. We found that the strongest non-circular gas flows are due to galaxy interactions or the presence of a possible AGN. We also found that if we assume the non-circular gas flows is outflowing gas, that none of the ionized or neutral gas can escape the galaxy (see Fig. 6). The neutral and ionized gas will therefore flow to the halo and could possibly cool down to form more stars, without the star formation being quenched. This supports the galactic fountain model.



**Figure 5.** The rotation curves for galaxy NGC 6000 along its major (a) and minor (b) axes. The x-axis shows the distance from the centre and is indicated in arcseconds (bottom axis) and kpc (top axis). The velocity is shown in km/s on the y-axis. The black dashed lines at 0''/0 kpc and 0 km/s indicate the optical photometric centre of the galaxy and the velocity at the photometric centre of the galaxy, respectively. The dashed orange line indicates the kinematic centre. The velocities of the ionized gas are shown in blue (narrow) and cyan (broad) points for the double Gaussian (DG) model, red plus signs for the Gaussian-Hermite (GH) model and black crosses for the single Gaussian (SG) model. The velocities of the neutral gas are shown as green diamonds and the velocities of the stars are shown as magenta points.



**Figure 6.** Escape velocity against the ionized (a) and neutral gas (b) offset velocities. The major axis observations are shown in black and the minor axis observations in red. The straight line shows  $v_{esc} = \Delta V$ . If we assume that the offset velocity is the outflow velocity, none of the gas in the galaxies will be able to escape the galaxies' potential well.

## 2. Research Questions

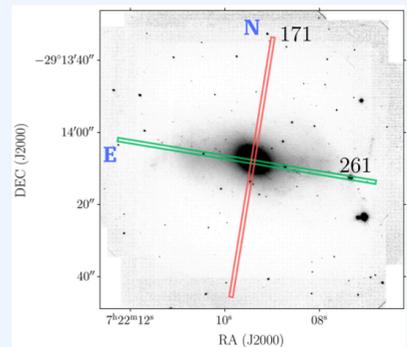
- Are there multi-phase non-circular gas flows (inflows, outflows, extraplanar gas) in the starburst galaxies and LIRGs?
- If there are multi-phase non-circular gas flows, what are the properties of the gas, does it originate from the nucleus or disk and is the gas flow due to star formation or an AGN?
- What is the fate of the gas and what do the gas flows tell us about how the systems will evolve?

## 3. Methodology

We studied the gas flows in 12 starburst galaxies and LIRGs with the Southern African Large Telescope (SALT; Buckley et al., 2006; O'Donoghue et al., 2006) Robert Stobie Spectrograph (RSS, Burgh et al., 2003; Kobulnicky et al., 2003). The galaxies form part of the SuperNovae and starBurst in the InfraReD (SUNBIRD) survey (Väisänen et al., 2014). The galaxies were studied with long-slit spectroscopy along mainly the major and minor axes (Fig. 2). We traced the ionized gas along each slit by modelling the H $\alpha$  emission line with a single Gaussian, double Gaussian (Fig. 3) and Gaussian-Hermite profile (Fig. 4) and sodium-D (NaD) absorption

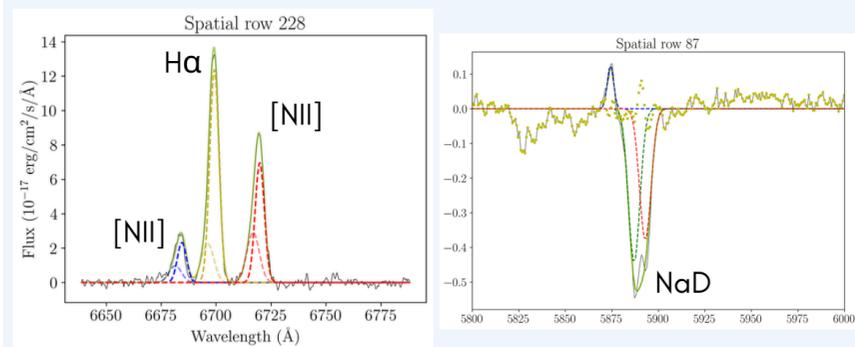


**Figure 1.** Southern African Large Telescope in Sutherland, South Africa.



**Figure 2.** The SALT RSS observations of galaxy ESO 428-G023 showing the two slit positions in red and green. The image is a near-infrared observation of the galaxy with the VLT/NACO (Randriamanakoto et al., 2022).

doublet with a single Gaussian on each line (Fig. 4). To obtain the stellar kinematics, we modelled the stellar continuum using a Penalized Pixel-Fitting method (pPXF, Cappellari & Emsellem, 2004; Cappellari, 2016). The stellar and gas kinematics were compared to identify non-circular multi-phase gas flows.



**Figure 3.** Double Gaussian model of the H $\alpha$  emission line (yellow) to trace the ionized gas along each spatial row. A double Gaussian was also fitted to the two adjacent [NII] lines (blue and red).

**Figure 4.** Single Gaussian model on the NaD absorption lines (red and green). The blue line modelled the He emission line.

## 5. Future work

- Study these nearby starburst galaxies and LIRGs with optical and near-infrared integral field units (IFUs) on SALT to study the gas flows across the entire galaxy disk.
- Use telescopes such as MeerKAT, ALMA and JWST for a detailed multi-wavelength study of these galaxies.

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