Resolving the Rise and Fall of Star Formation in Galaxies
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Extended neutral hydrogen filamentary network in NGC 2403

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Abstract. We present new neutral hydrogen (H I) observations of the nearby galaxy NGC 2403 to determine the nature of a low-column density cloud that was detected earlier by the Green Bank Telescope.

We find that this cloud is the tip of a complex of filaments of extraplanar gas that is coincident with the main disk. The total H I mass of the complex is 2×10^7 M$_\odot$ or 0.6% of the total H I mass of the galaxy. The main structure, previously referred to as the 8-kpc filament, is now seen to be even more extended, along a 20 kpc stream.

Keywords. Galaxies: evolution, Galaxies: interactions, Radio lines: galaxies, Techniques: interferometric

1. Introduction

Neutral hydrogen (H I) is the fuel of the star formation processes, but there is not enough of it in galaxies to sustain star formation over the age of the Universe (Sancisi et al. 2008; Madau & Dickinson 2014). Hence, there must be accretion of H I onto galaxies and we believe most of it comes from the Inter Galactic Medium (IGM) (Somerville & Davé 2015; Danovich et al. 2015); yet no unambiguous evidence has been found (Barnes et al. 2001; de Blok et al. 2002; Pisano et al. 2004; Giovanelli et al. 2007; Walter et al. 2008; Heald et al. 2011). We combined new and archival (Fraternali et al. 2002; Walter et al. 2008) 21-cm observations of the nearby galaxy NGC 2403 taken by the Very Large Array to better study an accreting cloud candidate observed with the Green Bank Telescope (GBT) (de Blok et al. 2014) and explored its connection with the previously reported 8 kpc anomalous velocity H I filament found in the galaxy (Fraternali et al. 2002).

2. Results

The combination of the new and archival data allowed us to reach a column density sensitivity of 1.8×10^{18} cm^{-2} with a spatial resolution of 52×49 arcsec (1.04×0.98 kpc). The GBT cloud is detected as being the tip of the 8 kpc filament, which is now seen as a 20 kpc long stream. Two 10 kpc long H I filamentary structures have also been detected close to the 20 kpc filament (see right panel of Fig. 1). The filaments have a collective mass of 2×10^7 M$_\odot$.

3. Discussion

One of the questions we tried to answer is whether the GBT cloud and the filaments are formed due to a gas accretion event. However, other explanations for these features are possible. For example, the structures could be the result of a galactic fountain that

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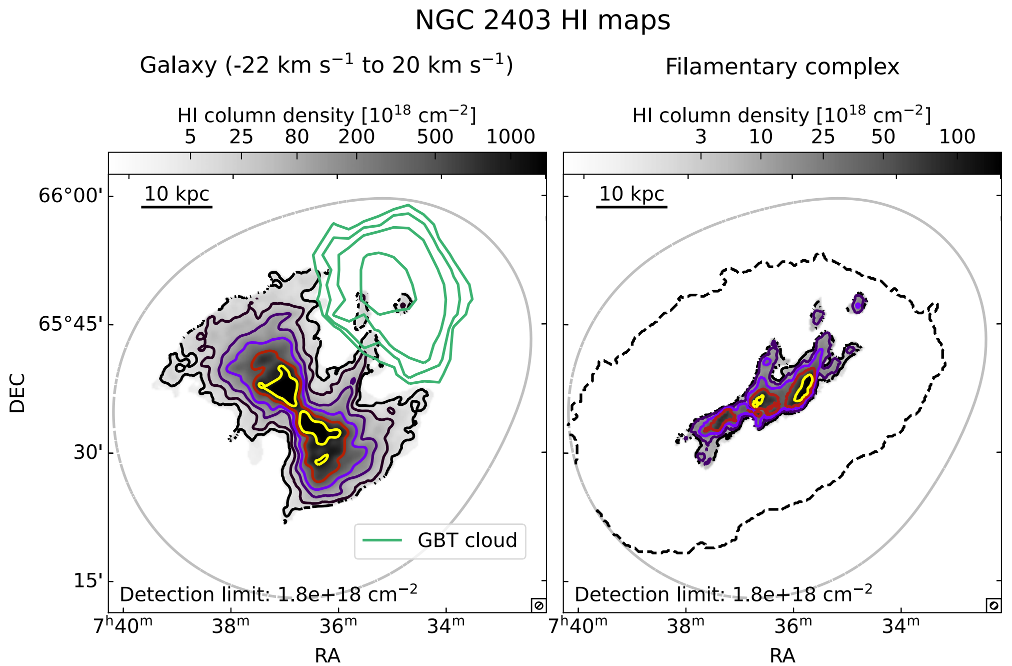

Figure 1. *Left panel*: primary beam corrected H I column density map of NGC 2403 (in reversed grey-scale colormap) overlaid with the the GBT cloud candidate (green) from de Blok et al. (2014). The map was produced by integrating over the channels from -22 km s^{-1} to 20 km s^{-1} w.r.t. the systemic velocity. This range corresponds to the one used by de Blok et al. (2014) to computing the candidate GBT cloud moment 0 map. Grey-scale contours levels are from 5×10^{18} cm^{-2} to 1×10^{21} cm^{-2}. Intermediate levels are given above the colorbar. The 3σ 1-channel column density limit is reported at the bottom. The beam of the interferometric data is shown in the bottom right, while in the top-left corner we show a 10-kpc scale for reference. The green contours, instead, define the (6.25, 12.5, 25, 62.5) $\times 10^{17}$ cm^{-2} column density in the GBT data. The light-gray line denote the 20% cut-off threshold of the primary beam response. *Right panel*: primary beam corrected H I column density map of the filamentary network. Grey-scale contours levels are (3, 10, 25, 50, 100) $\times 10^{18}$ cm^{-2} column density. The spatial scale is the same as in the left panel, as well as the definition of the light gray line. We indicate the galaxy edge with the dashed-black contour.

ejects gas from the disk. Yet, it is difficult to form a straight 20 kpc long filament in a pure galactic fountain model, as the gas ejecta reach distances of at most 10 kpc even with extremely high kick velocities (Fraternali & Binney 2006, 2008; Marasco et al. 2019).

The origin of the filamentary complex might be also a galactic interaction. In the event of a merging or disrupting dwarf, one might expect to see a disturbed stellar population from the dwarf, most likely coinciding with or near the filaments. Barker et al. (2012) performed an in-depth study of the stellar properties in NGC 2403 but did not identify any peculiarities in the distribution of the stars and concluded that the galaxy has evolved in isolation with no significant recent merging event. Those information, available at the time of the IAU General Assembly 2022, brought us to the conclusion that the filaments are likely the result of accretion from the IGM.

However, recent re-reduction of deep optical wide-field data presented in Carlin et al. (2019) reveal a ~ 50 kpc long stellar stream originating from the NGC 2403 dwarf satellite DDO 44 and connecting with the NW part of the stellar disk of NGC 2403 at the location of the northern tip of the 20 kpc filament. Thus, the most plausible explanation for the

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origin of the H I filaments in NGC 2403 is now a previous interaction with the dwarf satellite DDO 44.

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