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Stellar and gas mass distributions for understanding the nature of spiral arms

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Abstract. Numerical simulations of disk galaxies with steady (long-lived) and dynamic (short-lived) spiral arms suggest that offsets between stellar and gas spiral arms depend on their nature or lifetime (Baba *et al.* 2015). Based on this theoretical study, we investigated gas-star offsets in the nearby grand-design spiral galaxy M51, and found that its two spiral arms exhibit different offset dependences against radius. One arm is consistent with a steady arm, while the other is consistent with a dynamic arm. We deduce that this difference is likely due to a tidal interaction with the companion galaxy (Egusa *et al.* 2017). For this study, a stellar mass distribution with a high accuracy at a high spatial resolution is essential, which has come to be available by applying recent SED fitting techniques to multi-wavelength images. We are now working to extend this study to other nearby spiral galaxies.

Keywords. galaxies: individual (M51 or NGC 5194, M74 or NGC 0628), galaxies: spiral, galaxies: structure

1. Introduction

In the local universe, more than half of galaxies are categorized as spiral galaxies (e.g. Delgado-Serrano *et al.* 2010). However, we do not have a conclusive answer to the very fundamental question: *"What is the nature of spiral arms?"* Table 1 lists theoretical models for spiral arms and their predictions for spiral arm properties, but these models have not been fully confirmed by observations yet.

Baba *et al.* (2015) performed numerical simulations of disk galaxies with steady (long-lived) and dynamic (short-lived) spiral arms, and found that the location of gas spiral arms (relative to stellar arms) is different between the two models (their Figure 2). For the steady models, the gas arm is found downstream to the stellar arm at inner disk, and then gradually moves upstream with increasing radius. This trend is consistent with the classical view of galactic shocks (Fujimoto 1968; Roberts 1969), and does not change depending on parameters (e.g. pitch angle, arm strength) in the steady models. On the other hand, the gas arm in the dynamic model almost coincides with the stellar arm. These results suggest that offsets between stellar and gas spiral arms (which can be observationally measured) should tell whether that spiral arm is steady or dynamic.

2. Result: a case study with M51

Based on the simulation results above, we measure spatial offsets between stellar and gas spiral arms in the nearby grand-design spiral galaxy M51 (NGC 5194). Here we

Table 1. Theoretical models for spiral arms

Model	Lifetime	Predicted spiral feature	References[1]
Density wave	>1 Gyr	2-armed?	Lin and Shu (1964)
Tidal interaction	~ 1 Gyr	2-armed	Pettitt *et al.* (2016)
Bar driven	~ 0.2 Gyr?	2-armed	Baba (2015)
Swing amplification	~ 0.1 Gyr[2]	multi-armed or flocculent?	Fujii *et al.* (2011)

Notes:
[1]Not a complete list. See Dobbs and Baba (2014) for a comprehensive review.
[2]The lifetime of each structure is this short, but spiral structures are recurrent.

describe a brief overview of our study, while the full detail is presented in Egusa *et al.* (2017).

Data. The stellar mass distribution is obtained by fitting SEDs to multi-wavelength images from optical to NIR (Mentuch Cooper *et al.* 2012). The gas mass distribution is obtained by combining an atomic gas map (from HI; Walter *et al.* 2008) and molecular gas map (from CO; Koda *et al.* 2009). Both stellar and gas mass data are smoothed to a common angular resolution of $6''$ (FWHM), and regridded to a pixel size of $2''$.

Gas-star offset versus radius. At a radial range of $30''$–$220''$, we measure locations of two spiral arms (called arm1 and arm2) at an interval of $4''$ for both stellar and gas arms and calculate their offsets. We find that offsets for only the inner part ($r < 150''$) of arm2 decrease with radius, while those for the others (inner arm1 and outer two arms) appear independent on radius (see Fig. 7 of Egusa *et al.* 2017). We conclude that only inner arm2 is consistent with the steady spiral arm, while the others are not.

The gas-star offsets in M51 suggest that the nature of spiral arms can be different even within a galaxy. In this particular case, this difference could be due to the interaction with the companion galaxy (Pettitt *et al.* 2018).

3. Work in progress

We are now working to extend this study for other nearby spiral galaxies. The very first step is to apply the SED fitting code `CIGALE` (Boquien *et al.* 2019) for multi-wavelength images including GALEX UV, SINGS optical, SDSS, 2MASS, and Spitzer NIR images of M74 (NGC 0628). This is another well-studied nearby grand-design spiral galaxy, but lacks apparent perturbers (e.g. bar, companion) which clearly contrasts to M51.

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