Mem. S.A.It. Suppl. Vol. 25, 55

Memorie della
Supplementi

Lopsidedness in disc galaxies

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Abstract. Observations of the stellar and gaseous components in disc galaxies often reveal asymmetries in the morphology and kinematics, called 'lopsidedness'. Lopsidedness can have strong influences on the evolution of galaxies, e.g. on the formation of discs, the star formation and the dynamics. Here, we present an investigation based on harmonic decomposition of the HI distribution of disc galaxies in the WHISP survey to address questions like the origin of lopsidedness, its dependence on environment and the connection between kinematic and morphological lopsidedness. We measure lopsidedness to unprecedented large distances of about four optical disc sizes, and find that at these distances the lopsided amplitude shows saturation. This could prove important clues for its origin.

Key words. galaxies:disc galaxies

1. Introduction

Since the early 80's it has been known that the discs of galaxies show large-scale asymmetry with a $cos\phi$ dependence, where the disc is more extened in one half of the galaxy, so-called lopsidedness (Baldwin et al. 1980). From thereon, several investigations concentrating on the stellar discs have been carried out, e.g., Rix & Zaritsky (1995). They found that at least a third of the galaxies are significantly lopsided. Stellar discs, however, cannot easily be traced out to large scalelength, where distortions of the halo and the disc are more pronounced. Thus, studies of the gas component were done by Richter & Sancisi (1994). They investigated asymmetries in global HI profiles to characterise lopsidedness of the gas discs. This method, however, cannot distinguish between a lopsided gas mass distribution and an irregular velocity field.
Today, the new class of radio interferometers allows high resolution imaging of galactic gaseous discs in a very efficient way. Here, we present the first systematic study of a large sample of detailed HI maps (van Eymeren et al. 2011a; van Eymeren et al 2011b).

Deviations from a perfectly smooth and symmetric disc can be quantitatively described using a Fourier decomposition of the surface brightness distribution (Rix & Zaritsky 1995):

$$\sigma(r,\Phi) = a_0(r) + \sum a_m(r)cos(m\Phi - \Phi_m(r)) \quad (1)$$

Here, the first order of the harmonic coefficients represents lopsidedness, while e.g., the second order characterises spirals or bars.

The m=1 mode is of particular relevance for galaxy evolution, since unlike the much

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better known m=2 mode there is no inner Lindblad resonance for m=1, which means that this mode can lead to the transportation of matter to the inner region of a galaxy. This has a significant influence on (nuclear) star formation, the fueling of active nuclei and the dynamics in general.

1.1. Scenarios

The origin of lopsidedness is not yet understood. Clearly, since it occurs so often, it plays an important role for galaxy evolution. There are several scenarios which can lead to lopsidedness:

- Tidal interaction or merger with a small companion (Bournaud et al 2005)
- Asymmetric gas accretion: e.g., gaseous filaments (Bournaud et al 2005; Mapelli et al. 2008)
- Ram pressure stripping (Mapelli et al. 2008)
- Disc lopsidedness arising due to a lopsided dark matter halo (Jog 1999)
- density waves: perturbed spiral arms can induce long-lived m=1 mode (Emsellem 2002)

Ideally, observations will disentangle the different possible scenarios. In reality, this is very complex since the results often look the same. However, in some cases the influence on the gaseous and the stellar disc are different and correlations with e.g., the environment depend on the trigger mechanism.

2. Lopsidedness in WHISP galaxies

The Westerbork HI survey of Spiral and Irregular Galaxies (Swaters et al. 2002) is very well suitable to carry out a systematic study of a large sample of gas discs. We used a subsample selecting all galaxies within the inclination range of $20° \leq i \leq 75°$. Furthermore, to guarantee a sufficient spatial resolution, only galaxies with a diameter $d_{Hi} \geq 10$ in the $30''$ resolution maps were included. That resulted in a sample of 76 galaxies which are well distributed within the B magnitude, morphology and size space.

As a first step, we derived rotation curves for all galaxies to calculate the main structural parameters. For the lopsidedness analysis we carried out a Fourier decomposition analogue to Rix & Zaritsky (1995) (Equ. (1)). In addition to that, we investigated the perturbation potential

$$\epsilon_1 = \frac{A_1(r)}{(2(r/R_{HI})^2 - 1)} \quad (2)$$

with R_{HI} the Gaussian scale length, and the kinematic lopsidedness:

$$\epsilon_{lop} = \frac{v_{receding} - v_{approaching}}{2v_c} \quad (3)$$

2.1. Rotation curves

To search for deviations in the dynamics, we derived rotation curves both for the receding and the approaching side individually. The behaviour of these rotation curves can be classified into five groups:

- Receding and approaching side are symmetric (20%)
- Constant offset between both sides (32%)
- Rotation curves differ at large radii only (14%)
- Rotation curves differ at small radii only (11%)
- Rotation curves cross (23%)

2.2. Morphology

In general, we found various behaviours of the lopsidedness amplitude with increasing radius. In some cases, the amplitude remains constant, in others we found a constant increase, indicating that lopsidedness is in particular induced in the outer discs. We also found short-scale variations which can be related to sub-structures within the discs. A few galaxies show a large random-like scatter which is not obviously reflected in the surface brightness distribution.

Overall, the phase of the amplitude remains constant with radius, which means that lopsidedness is a global mode and not a local phenomenon.

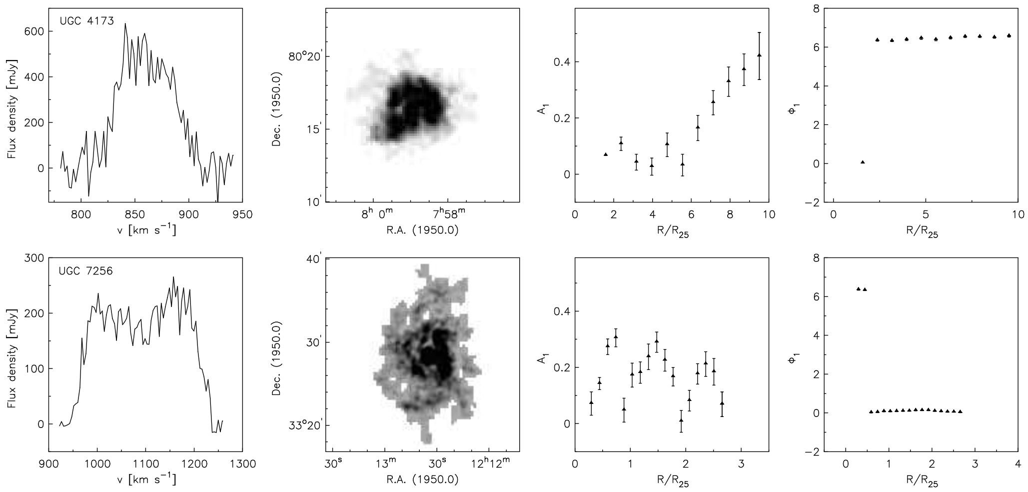

Fig. 1. Two example galaxies of our sample. From left to right: global HI profile; integrated HI distribution; lopsided amplitude A_1 as a function of radius; phase ϕ_1 as a function of radius. The upper example shows a clear case of lopsidedness, the lower example shows dominating structures within the disc (adopted from van Eymeren et al 2011b).

Figure 1 shows typical results for two examples of lopsided galaxies. UGC 4173 represents those galaxies with an increasing lopsided amplitude at large radii. The radial amplitude profile of UGC 7256 is dominated by sub-structures within the disc, leading to wiggles in the profile.

2.2.1. Environment

So far, there are indications that lopsidedness occurs more often in high density environments, likely due to galaxy interaction (Angiras et al. 2007, 2006). Since the WHISP sample includes galaxies in all kind of environments, it is very well suitable to test this hypothesis. To quantify the effect of tidal forces, we used the tidal parameter as defined in Bournaud et al (2005):

$$T_p = \log\left(\sum_i \frac{M_i}{M_0}\left(\frac{R_0}{D_i}\right)^3\right), \quad (4)$$

with M_i the mass of each companion, M_0 the mass of the main galaxy, R_0 the scale length and D_i the distance to each companion. The mass ratio was estimated from the ratio of absolute blue magnitudes.

In Fig. 2 the tidal parameter is plotted against the mean lopsidedness amplitude. Clearly, our dataset does not show any correlation with the presence of potential interaction partners.
It is, however, not so easy to calculate the tidal parameter in a proper way, since not always all relevant data of companion galaxies are available in the literature. Furthermore, it cannot ruled out that there might be faint galaxies missing. Also, the tidal parameter does not take into account the interaction history of the main galaxy and its companions, i.e. the time-scale and the geometry of the orbits. It rather gives a stationary description of a system.

2.2.2. Morphology type

In Fig. 3 we show the mean lopsidedness amplitude as a function of the galactic type. There is a weak trend that early spirals can be stronger lopsided than late-type spirals, in agreement with the results of (Angiras et al. 2007). Since galaxy interaction drives a galaxy towards earlier types, our findings indicate that these interactions can trigger long-lived lopsidedness.

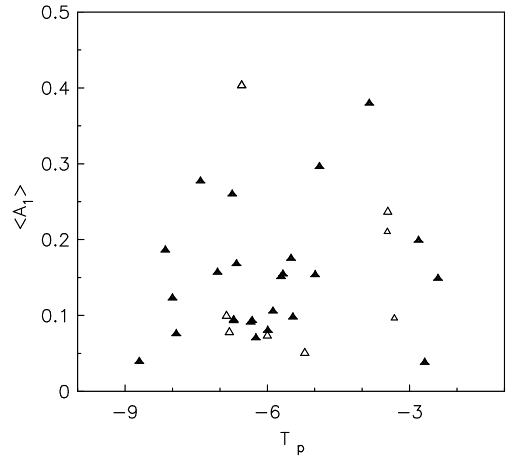

Fig. 2. The lopsidedness amplitude averaged over the full radius range *vs*. the tidal parameter (open triangles: lower limit due to lack of data of the companions) (adopted from van Eymeren et al 2011b).

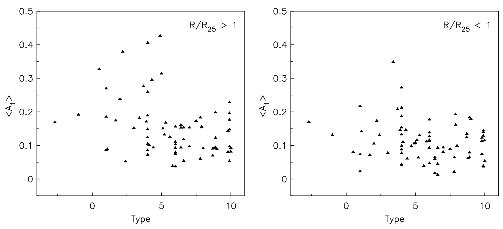

Fig. 3. The lopsidedness amplitude averaged over the full radius range *vs*. galactic type for large (left) and small radii (right) (adopted from van Eymeren et al 2011b).

2.3. Kinematic lopsidedness

Lopsidedness does not only occur in the distribution of matter, but also in their dynamics. If we assume that lopsidedness is caused by a distorted halo, e.g., due to interaction, we can estimate the lopsided perturbation potential to characterize kinematic lopsidedness ϵ_{lop}. We found that generally morphological and kinematic lopsidedness are correlated.

3. Conclusions

We have carried out a systematic study of lopsidedness in HI discs using the WHISP catalog. We confirmed that a large fraction (at least 50%) of galaxies have lopsided discs. Furthermore, we also see asymmetries in the dynamics of the gas, which is typically correlated with a lopsided gas distribution.
Lopsidedness can occur in all sorts of environments which indicates that lopsidedness is a long-lived phenomenon if it is tidally triggered. We found hints that lopsidedness is more common in early spirals, which has to be further investigated.

3.1. Outlook

As a next step, we will investigate the stellar distribution of our sample using optical and near-infrared data. This will be the first direct comparison of lopsidedness in the stellar and gaseous discs. The analysis of infrared data from the Spitzer Survey of Stellar Structure in Galaxies (S^4G, Sheth et al. (2010)) is currently ongoing.
Furthermore, the upcoming HI surveys going to be obtained with the next generation of radio telescopes such as Askap, Meerkat or the upgraded WSRT will significantly improve the available database and thus are ideal to shed more light on the nature of lopsidedness.

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