What is the behavior of the ISM in the SMC?

Snezana Stanimirovic (sstanimi@naic.edu)  
Arecibo Observatory, NAIC/Cornell University, HC3 Box 53995, Arecibo, Puerto Rico 00612

Abstract. We describe quantitatively the neutral hydrogen (HI) and dust content of the interstellar medium (ISM) in the Small Magellanic Cloud (SMC), using the spatial power spectrum. The velocity modification of the HI density power spectrum is investigated and discussed.

Keywords: ISM: structure, turbulence, Small Magellanic Cloud

1. Introduction

Many observations in the past decade have challenged the traditional picture of the interstellar medium (ISM). Instead of a two-level hierarchical system, consisting of clouds uniformly dispersed in the intercloud medium, the ISM shows an astonishing inhomogeneity, with many levels of hierarchy. In order to consider real density functions in physical processes, a better understanding of the inventory and topology of the ISM is essential, as well as the processes responsible for their creation.

Having an extremely gas-rich ISM, dwarf irregular galaxies are particularly suitable for such studies. We hence here describe quantitatively, using the spatial power spectrum, the inventory of the ISM in the Small Magellanic Cloud\(^1\) (SMC) and point to several processes that may be involved in the sculpturing of its ISM.

2. HI and IR spatial power spectrum

The power spectrum of the HI emission fluctuations in the SMC was derived in Stanimirovic et al. (1999). For more information on the exact technique and the data used see Stanimirovic et al. (1999). It was shown that the 2-D power spectra can be remarkably well fitted by a power law, \( P(k) \propto k^\gamma \), over the continuous range of spatial scales \( \sim 30 \text{ pc} \) – 4 kpc, and over the velocity range 110 – 200 km s\(^{-1}\). Using the velocity slices of \( \sim 20 \text{ km s}^{-1}\), the average slope was estimated with \( \langle \gamma \rangle = -3.04 \pm 0.02 \). No change of the power law slope was seen on either large or small scale end. However, when looking at the power

\(^1\) We assume SMC to be at the distance of 60 kpc throughout this study.
The 2-D spatial power spectra of HI (asterisks) and dust (diamonds) mass column densities (in units of $M_\odot$).

Figure 1. The 2-D spatial power spectra of HI (asterisks) and dust (diamonds) mass column densities (in units of $M_\odot$).

spectrum of the HI column density distribution, after integrating along the whole velocity range, a change of the power law slope was noticed, with $\gamma$ being equal $-3.31 \pm 0.01$ (Stanimirovic et al., 2000). The power spectrum of dust column density fluctuations in the SMC was derived in Stanimirovic et al. (2000). This spectrum can be fitted by $P_d(k) \propto k^{-3.1 \pm 0.2}$. A slight change of slope on spatial scales smaller than 50 pc may be present though. Nevertheless, slopes for HI and dust column density power spectra appear to be very similar, see Fig 2.

The power law fit of both HI and dust column-density power spectra shows that the hierarchical structure organization is present within both HI and dust content of the ISM in the SMC, with no preferred spatial scales for both HI and dust clouds. Similar power law indices suggest that similar processes are involved in shaping both HI and dust content of the SMC.

2.1. Velocity modification of the HI power spectrum

The 2-D intensity fluctuations traced by the power spectra have contribution from both density and velocity fluctuations. Indeed, due to the velocity fluctuations, two clumps along the same line of sight at different distances may appear in the same velocity channel, hence doubling the measured intensity. It is therefore necessary to disentangle density from velocity influence to the power spectrum. The importance of this phenomenon was first recognized by Lazarian and Pogosyan (2000). They start with 3-D density spectrum in velocity space ($P_s \propto K^n$) and calculate, analytically and numerically, 2-D power spectrum of intensity fluctuations, in two particular cases: (a) the 3-D density spectrum is small-scale dominated ($n > -3$); and (b) the 3-D density spectrum is
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large-scale dominated ($n < -3$). One of the main results in Lazarian and Pogosyan (2000) is that the intensity statistics depends strongly on velocity slice thickness.

To test the predictions by Lazarian and Pogosyan (2000) in the case of the SMC, we have determined the power spectrum slope, $\langle \gamma \rangle$, while varying the velocity slice thickness from $\sim 2 \text{ km s}^{-1}$ to $\sim 100 \text{ km s}^{-1}$. A significant variation of $\langle \gamma \rangle$ was found, shown in Fig. 2.1, consistent with the predictions — $\langle \gamma \rangle$ decreases with an increase of velocity slice thickness. The thickest velocity slice gives $n = -3.3$ suggesting that we are in the large-scale dominated regime. Hence, the intensity spectrum is dominated by velocity fluctuations and only the thickest velocity slices must be used in order to find density fluctuations. Using the thin slices, however, we can find the slope of velocity fluctuations to be $m = 0.4$. The transition point between thin and thick slice regimes is equal to the velocity dispersion on the scale of the whole SMC ($\sim 4 \text{ kpc}$), which is $\sim 22 \text{ km s}^{-1}$. Both $n$ and $m$ are significantly shallower than for the case of Kolmogorov turbulence (where $n = -11/3$ and $m = 2/3$).

3. On the origin of the power spectrum

The hierarchical structure organization is usually ascribed to interstellar turbulence (see Elmegreen, 2000). But which processes create this turbulence is still not well understood. However, there are several possible candidates. As a large number of expanding shells was found in the SMC, the energy injection by these shells can significantly stir up the ISM. The radii of the SMC shells range from $\sim 30 \text{ pc}$ to $\sim$
2 kpc, with most of them being around 100 pc. However, no specific scales on which the energy injection happens show up in the HI power spectra. Very recently Goldman (2000) suggested a very different scenario: large scale turbulence is induced by instabilities in the large-scale flows during the last SMC–LMC encounter. In this case both dust and gas are just ‘passive markers’, they do follow turbulent field but do not feed back dynamically. Elmegreen (2000) shows that interacting, nonlinear magnetic waves can produce hierarchical density structure out of an initially uniform medium. Actually, the power spectrum of such simulated structure has a power law slope between $-2.5$ and $-3.6$, which is close to what was observed.

4. Summary

The spatial power spectrum of HI and dust content in the SMC is well fitted by a power law, with power law slopes being similar. The HI spectrum appears to be modified by velocity fluctuations. After disentangling velocity from density fluctuations, the 3-D HI density spectrum has slope of $-3.3$. This is significantly shallower than for Kolmogorov turbulence.

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