Abstract

Spiral galaxies are composed of stars and interstellar medium (ISM) residing in a dark matter halo. They are very much dynamically active and are the playgrounds for the ISM to give birth to stars. The large scale distribution in dark matter halo, differential galactic rotation, interaction with satellite galaxies, star formation and its feedback, all give rise to isotropic and anisotropic density and velocity structures in the ISM. The interstellar medium acts as a compressible fluid with turbulent flows that later give rise to scale invariant density and velocity structures. The density structures give rise to fragmentation in the gas helping it to collapse. On the other hand, the turbulent dynamics raise the pressure and at small clumps, collapses are lengthened. Such scale invariant structures in both velocity and density have been seen observationally in our Galaxy and its satellites at scales of the order of a few astronomical units to a few hundreds of parsec (Crovisier and Dickey, 1983; Green, 1993). Recent observations in nearby spiral galaxies have established the existence of scale invariant coherent density structures at the scales of a few kiloparsecs, almost at the scale of the galactic discs (Dutta et al., 2013). The observed structures in our galaxy at scales of a few hundreds of parsec and lower are attributed to compressible fluid turbulence generated by the supernovae feedback. However, related dynamics and the generation mechanism of the large scale structures probed recently in external spiral galaxies are now well established. In this thesis, we design and implement various statistical estimators and use them to investigate the large scale structure and dynamics of the ISM in these spiral galaxies. We comment on the driving mechanism behind the large scale structures based on our observations and access their relation to star formation.

We use radio interferometric observation of H I 21-cm emission line as a tracer of the ISM. Radio interferometers measure visibility function, roughly the Fourier transform of

the sky brightness distribution. The visibilities are measured only at discrete points in the baseline plane, the Fourier conjugate to the angular separation in the sky. To probe the structure and dynamics of the ISM, we need to estimate the large scale dynamics and morphology of the gas. The imprint of turbulence can be traced through the two-point statistics of the density and velocity, like their spatial power spectrum. The limited measurements of visibility create challenges to estimate various statistics of the density and velocity unbiasedly. In this thesis, we first use simulation of radio interferometric observations of external spiral galaxies to investigate the efficacy of estimation of the column density distribution from the reconstructed images from visibilities. We also compare the image based and visibility based column density power spectrum estimators to access their relative merits in this context. We find that the Natural weighting scheme in the CLEAN deconvolution algorithm unbiasedly estimates the large scale distribution of the H I , whereas to estimate the power spectrum direct use of visibilities gives an unbiased result.

Turbulence is a stochastic random process which creates scale invariant structures in density and velocity that can be quantified through the spatial power spectrum measurements of density and velocity. The power spectrum of turbulence generated structures follows a power law, with its slope indicating the nature of turbulence. Combined knowledge of density and velocity power spectrum lets us infer the energy supply and driving mechanism. Following the idea of Dutta (2016) we develop and implement Visibility Moment power spectrum Estimators (VME) of H I column density and line of sight velocity power spectrum directly from the observed visibilities. We measured the column density and the line of sight velocity power spectrum of spiral galaxies NGC 5236 and NGC 6946. We present here the evidence of large scale energy cascade in these galaxies observed in more than one decade of length scales between $\sim$ 100 parsecs to 15 kiloparsecs. We find that the compressive forcing is responsible to drive the turbulence cascade at the scales of kiloparsec and higher in NGC 5236. While a combination of solenoidal and compressive force acts a generating mechanism for the turbulence in NGC 6946. The cascade brings down energies to the scales of 100 pc which is comparable to the energies injected by supernovae feedback.

We review the instability of a star-forming disc in presence of turbulence (Leroy et al., 2008). The instabilities are assessed through modified Toomre criteria of two fluid disc models incorporating effects of turbulent generated log-normal H I density distribution. We choose a sample of three galaxies, NGC 4736, NGC 3351 and NGC 5236 with similar stellar and gas mass and velocity dispersions but different disc scale length and star formation rates per unit area. We find that the H I is unstable at scales greater than a few kiloparsecs in the regions with high H I column density, at smaller scales the correlation between high H I column density and instability dies down indicating conversion of H I to the molecular cloud. At small scales, we also see more fragmented regions of instabilities commensurate with the high star-forming regions. We observe that for NGC 3351, even at small scales the high ISM column density regions do not form stars effectively. Comparing the column density power spectrum slopes in these three galaxies we conclude that turbulent fragmentation has a significant role in inducing instabilities which eventually seed the star formation.

Several dynamical effects like interaction with satellite galaxies, accretion of the intergalactic medium, tidal effects etc create bending waves in the galactic discs. Observationally these are traced as corrugation in edge-on discs for density and in the face on stellar disc for velocity mostly in optical or infrared (Narayan et al., 2020; Sánchez-Gil et al., 2015). In this thesis, we investigate the corrugation in gas density and velocity using 21-cm observations of the galactic discs. With a sample of six nearby spiral galaxies, we estimate the multipole moments of the column density and line of sight velocity corrugation. We see all these galaxies are vertically perturbed indicating that corrugations or bending is a common phenomenon. We also see that $m = 2$ is the dominant mode that forms around 50% of the identified modes in both density and velocity space. This probably suggests that $m = 2$ mode may be long-lived than the higher modes. Most of the anisotropies are also found near the $0.6R_{25}$ of the corresponding galaxies suggesting the likely cause of these structures is the gravitational interaction of the gas with the stellar disc.

This thesis establishes the origin and role of large scale turbulence cascade in the disc galaxies and explores vertical corrugations in the spiral galaxies. Some of the results presented here had indications in recent simulations of the discs, others need further theoretical study.