Identifying Cold and Warm Neutral phases in the Interstellar Medium of Galaxies

Astronomy Lab II experiment

1 Objective

1. Identify Cold Neutral Medium (CNM) and Warm Neutral Medium (WNM) in the Interstellar Medium (ISM) of galaxies using multi-component Gaussian Decomposition.
2. Estimate the amount of cold and warm gas and their distribution.
3. Determine the kinetic temperature distribution.

2 Tools and data required

1. Multi-component Gaussian fitting routine `'multigauss'`
2. High quality HI spectral cube (interferometric observation)

3 Overview

The Interstellar Medium (ISM) of galaxies is a crucial component that significantly influences the galaxy formation and evolution processes. For example, ISM regulates the star formation activity, which in turn decides the course of evolution. In particular, the neutral component of the ISM is of paramount importance. This is the long-term fuel reservoir for star formation. Not only that, this component extends to the farthest in a galaxy tracing the kinematics at radii where no other tracer can reach. Hence, tracing this ISM phase (i.e., neutral gas) is critical in understanding the galaxy evolution process.

Stars are born out of molecular beds. The cold molecular gas clouds collapse under gravity and form stars. Thus, the molecular gas is the immediate precursor to star formation, and it is the raw fuel for immediate star formation activities. However, in local galaxies, observationally, it is found that the molecular gas depletion time scale is $\sim 1 - 1.5$ Gyr (for a typical spiral galaxy). That is, given the observed molecular gas mass and current star formation rate, all the molecular gas will be consumed by the depletion timescale. This depletion timescale is much smaller than the lifetime of a spiral galaxy. Hence, it is clear that for sustainable star formation over the lifetime of a galaxy, the neutral gas must be converted continuously into molecular gas.

In that sense, the neutral gas acts as a long-term fuel reservoir for star formation. It should be noted here that the neutral gas also should be replenished over time as it gets converted to molecular gas. The neutral phase of the ISM in galaxies is dominated by neutral Hydrogen (HI). The processes by which this HI gets converted into molecular gas are not fully understood to date. It is believed that the molecular gas forms out of the cold neutral gas with low kinetic temperatures. This phase is typically known as the Cold Neutral Medium (CNM). The CNM in galaxies could act as a precursor to the molecular phase. Hence, identifying this phase and investigating its distribution can provide critical clues influencing the star formation process.

The HI in galaxies also exist in a much warmer phase than the CNM. This phase is called the Warm Neutral Medium (WNM). The CNM typically has kinetic temperatures between 100-500 K, whereas the WNM has kinetic temperatures ranging from 5000-8000 K. This phase of the ISM is more ubiquitous and contains the bulk of the neutral gas. A detailed thermal balance in the ISM shows that the HI will exist in these two distinct phases, i.e., CNM and WNM (Wolfire et al. 1995). Any gas having kinetic temperatures in between will quickly suffer a thermal runaway process and move to one of these two phases.

The fraction of the CNM and WNM in a galaxy reveals the ISM conditions and processes that govern the conversion of gas into stars. For example, a galaxy having a higher cold gas fraction will likely have higher star formation and vice versa. Hence, tracing these two phases of the neutral ISM is crucial in understanding the galaxy evolution process. We will identify the CNM and WNM in a given galaxy and understand several properties of these two phases.

4 Detection technique

As discussed above, the CNM and the WNM have very different kinetic temperatures. The width of a spectrum is decided by the kinetic temperature of the gas it is originating from. Thus, the kinetic width of the spectrum due to CNM would be different than it would have been for WNM. In galaxies, the CNM is mostly embedded into WNM as they are in pressure balance. Due to this, any line-of-sight (LOS) will contain both the CNM and WNM. Hence, the final observed spectrum along a LOS will have a signature from both these phases.

In a settled disk, the CNM and the WNM can be considered to be in Local Thermodynamic Equilibrium (LTE). Such as, an individual spectrum originating from any of these clouds would have a Gaussian profile. Thus the total spectrum coming from a LOS would be a superposition of multiple Gaussian components. We emphasize here that there could be multiple clouds (both CNM and WNM) with different physical properties along a LOS. A multi-component Gaussian decomposition can then be performed on the observed spectrum to recover the ISM phases along a LOS.

We will use a multi-component Gaussian decomposition routine `multigauss′ to decompose line of sight HI spectra from an HI spectral cube and identify these two phases of the ISM. The details of the decomposition algorithm and its characterization can be found in Patra et al. (2016b).

5 Setup and method

The `multigauss′ routine is a stand-alone code in python. However, one needs to install a few python modules to run it. This code runs on python-2.7. The required modules are listed below.

- numpy, pyfits, lmfit, scipy, matplotlib

For parallel processing ‘pprocess’ routine should be imported, ′pprocess.py′ code will be provided.

6 Result and discussion

- Decompose the given line-of-sight spectrum using the ′multigauss′ routine and identify how many components are required to fit the spectrum best.
- Show that the residual of the fit behaves like a Gaussian distribution.
- Estimate the kinetic temperatures of the ISM clouds as obtained by the fitting.
- Run `multigauss′ routine on the given HI spectral cube and answer the following.
  - What is the amount of cold gas in the galaxy?
  - Overplot the cold and warm gas distribution on the total HI map and interpret the result.