GENeration and Evolution of Structure in the InterStellar medium

GENESIS

Image: Cygnus X region (Herschel) ESA/HOBYS

Molecular cloud assembly and filament formation with SKA observations

L. Bonne[(1)], S. Bontemps[(2)], N. Schneider[(3)]

(1) SOFIA Science Center, USRA, NASA Ames Research Center, (2) Laboratoire d'Astrophysique de Bordeaux, (3) I. Physik. Institut, University of Cologne

SOFIA Stratospheric Observatory for Infrared Astronomy

The filamentary interstellar medium

The filamentary nature of the interstellar medium (ISM) has become increasingly evident over the last decades. This consists of star formation in dense molecular filaments (André et al. 2014), atomic (HI) low-density filaments (e.g. Clark et al. 2014) and kpc filaments in the galactic spiral structure (e.g. Goodman et al. 2014). This ubiquitous filamentary structure is an imprint of the physical processes during galactic evolution that drive the assembly of molecular clouds and initiate star formation. Following the dynamics and cooling of these filamentary structures will provide a deeper understanding of galactic evolution.

A universal scenario for molecular cloud assembly and dense filament formation?

Combining molecular line and low-resolution HI observations towards the nearby Chamaeleon-Musca complex, we unveiled systemic kinematic anisotropies for denser gas from large (i.e. >50 pc) down to small (i.e. 0.1-1 pc) scales (Bonne et al. 2020). Currently, the only available model to explain all the observations is filament formation by the collision of two CO-dark clouds/flows. In this collision, denser regions, that are compressed, bend the magnetic field during the interaction with the colliding lower-density atomic medium, see Fig. 1. This magnetic field curvature creates an apex where the filament will form and then continuously accrete mass along the magnetic field lines (Inoue et al. 2018).

Analyzing the kinematics around the massive DR21 filament in Cygnus-X with HI, the [CII] fine-structure line and molecular line observations, we found the same kinematic anisotropies as for the relatively low-mass Musca filament. This strongly suggests the same formation mechanism for DR21 as for Musca, but with a higher collision velocity (Schneider et al. to be subm.; Bonne et al. to be subm.). That a low-mass filament like Musca and an extremely massive filament like DR21 appear to have formed through the same mechanism hints at a potentially universal scenario for molecular cloud and dense filament formation in the Milky Way. This universality would fit with magnetic field studies of several nearby molecular clouds using Faraday rotation observations that unveiled curved magnetic fields around dense filaments and signs of collisions (e.g. Tahani et al. 2019; Bracco et al. 2021). This could also fit with non-isotropic turbulence statistics in molecular clouds that were unveiled with improved multifractal analysis tools (Yahia et al. 2021).

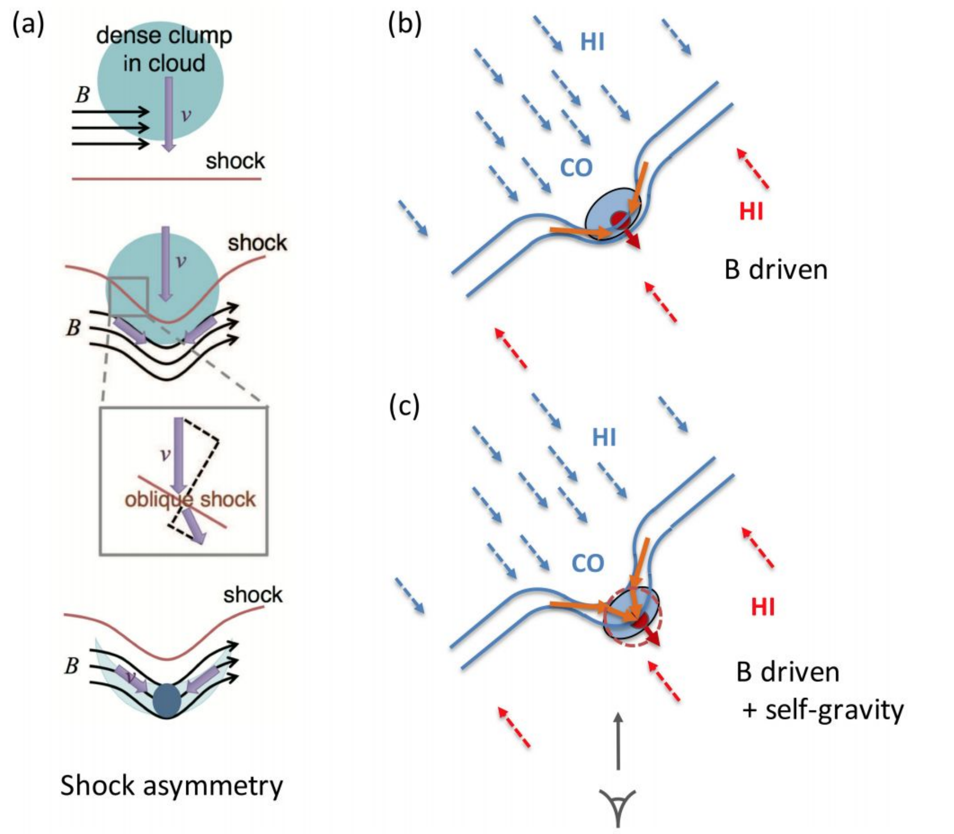

Fig. 1: (a) A schematic representation of magnetic field bending around an overdensity from the simulations by Inoue et al. (2018). (b) & (c) A schematic view of the colliding, mostly atomic, flows with overdensities bending the magnetic field which explains the observations towards the Musca filament.

Molecular cloud assembly with SKA precursors such as ASKAP

A potentially universal scenario for molecular cloud and simultaneous dense filament formation by large (> 50 pc) scale colliding flows is thus proposed. This opens up several questions e.g., Is this indeed the dominant mode of cloud assembly in the Milky Way? What are the physical conditions in these colliding flows? What drives and sets the physical conditions of these colliding flows on the galactic scale?...
HI observations with a high spatial and spectral resolution of a statistical molecular cloud sample in the Milky Way are necessary to address these questions. The GASKAP-HI survey (Dickey et al. 2013) with ASKAP, and complementary molecular line surveys at a similar resolution such as SEDIGISM (Schuller et al. 2017) and GASKAP-OH will provide the necessary datasets to address these questions. New HI analysis tools such as ROHSA (Marchal et al. 2019) will then be necessary to characterize the velocity structure in these rich datasets to provide a detailed view on the physical structure of these colliding flows e.g., in nearby clouds such as Chamaeleon-Musca (see Fig. 2).
Another large survey with ASKAP, i.e. POSSUM, will provide a large number of Faraday rotation measurements which will allow to study the (3D) magnetic field morphology (combined with Planck) in an increased sample of nearby clouds and thus investigate the potential universality of curved magnetic fields around dense filaments.

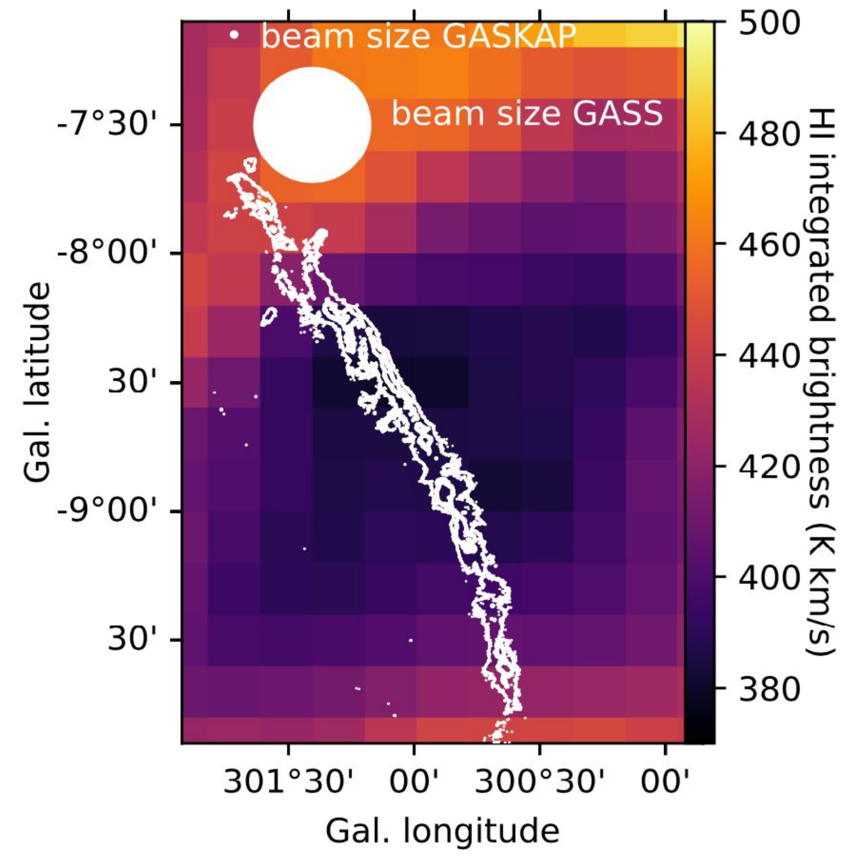

Fig. 2: The velocity integrated HI map from the currently available GASS survey towards the Musca filament with the associated beam size. The GASKAP beam size is also indicated, showing it will provide a well-resolved view of nearby molecular cloud.

Towards nearby galaxies and a more detailed magnetic field morphology with SKA

It is difficult to resolve molecular clouds in nearby galaxies with the HI 21 cm line using currently available facilities while this is now possible for CO lines with ALMA (e.g. Fig. 3; Henshaw et al. 2020). Observations at ALMA resolution with SKA will allow to extend our understanding of molecular cloud assembly in the Milky Way to nearby galaxies. The PHANGS consortium has already created large publicly available datasets from UV to submm wavelengths. Adding HI observations will be central to better understand molecular cloud assembly in galactic ecosystems.
The SKA sensitivity will also significantly increase the number of Faraday rotation measurements, which is currently still limited, and will thus provide a more detailed view on the magnetic field morphology and allow to study a larger molecular cloud sample. This work could be highly complementary e.g. with the far-infrared (FIR) probe that should be launched by NASA, based on decadal survey recommendations, either around 2030 or 2040. Very sensitive FIR observations of the [CII], [OI], high-J CO,... lines with this probe can unveil the cooling associated with the colliding flows. In addition, if the probe is equipped with a polarimeter it could provide a ~20"-30" resolution view on the plane-of-the-sky magnetic field morphology over entire molecular clouds which would be very complementary to the SKA Faraday rotation measurements.

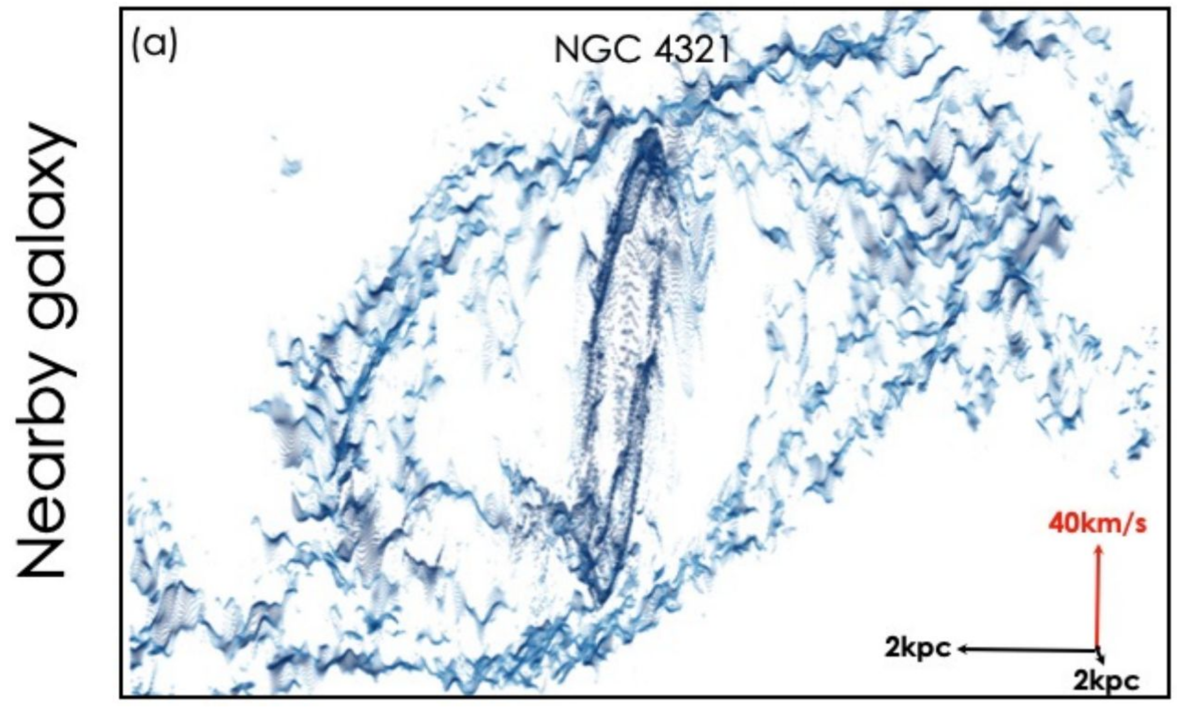

Fig. 3: The resolved velocity structure of the nearby galaxy NGC 4321 from Henshaw et al. (2020) based on ALMA CO(2-1) observations. It unveils a wealth of oscillatory motions. Comparing the CO dynamics with HI data will provide a new perspective on the assembly of giant molecular clouds (GMCs).

Contacts

lbonne@usra.edu

sylvain.bontemps@u-bordeaux.fr

nschneid@ph1.uni-koeln.de