Go with the Flow: Measuring the Physical Properties of the Magellanic Stream

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Background

Our neighboring galaxy, the Large Magellanic Cloud (LMC), has a prominent, outflowing gaseous stream, called the Magellanic Stream (MS). The MS spans ~140 degrees across the sky (Nidever et al. 2010) and has a mass of about one billion Sun's worth of neutral hydrogen gas (Putman et al. 2003).

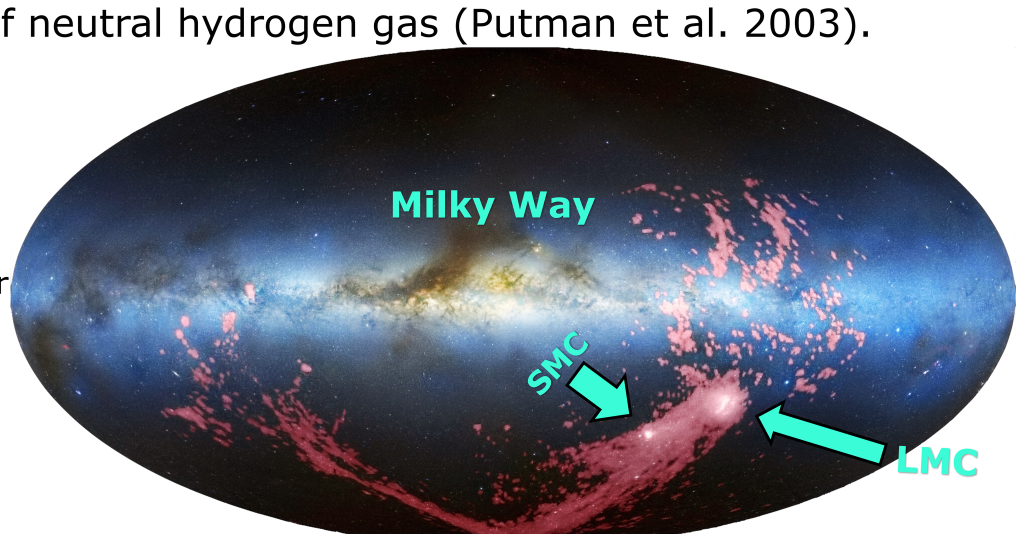


Figure 1: Radio and optical observation map of our galaxy, our neighboring galaxies, and the Magellanic Stream.

Credit: David Nidever, NRAO/AUI/NSF and Mellinger, Leiden/Argentine/Bonn Survey, Parkes Observatory, Westerbork Observatory, and Arecibo Observatory

A unique characteristic of the MS is that it is divided into two filaments that vary in velocity space, spatial orientation and chemical composition (Nidever et al. 2008; Richter et al. 2013; Fox et al. 2013). One filament contains more metals than the other. The filament with more metals appears to originate from an active starburst region inside the LMC (Nidever et al. 2008). **We measure the properties of this filament near its proposed origin.**

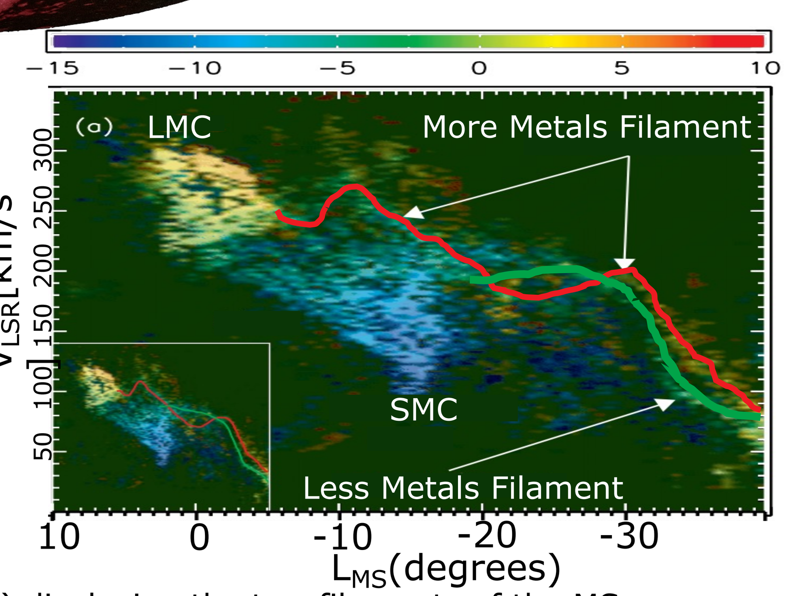
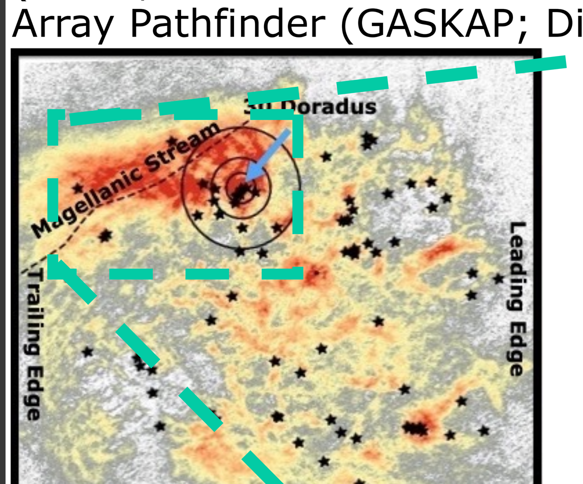


Figure 2: A modified reprint from Nidever et al. (2008) displaying the two filaments of the MS.

Data & Observations

We utilized both absorption-line observations from the Hubble Space Telescope's (HST) Ultraviolet Legacy Library of Young Stars as Essential Standards (ULLYSES) program, and neutral hydrogen emission data, from the Galactic All-Sky Survey (GASS; McClure-Griffiths et al. 2009) and the Galactic Australian Square Kilometre Array Pathfinder (GASKAP; Dickey et al. 2013) survey to probe the MS.



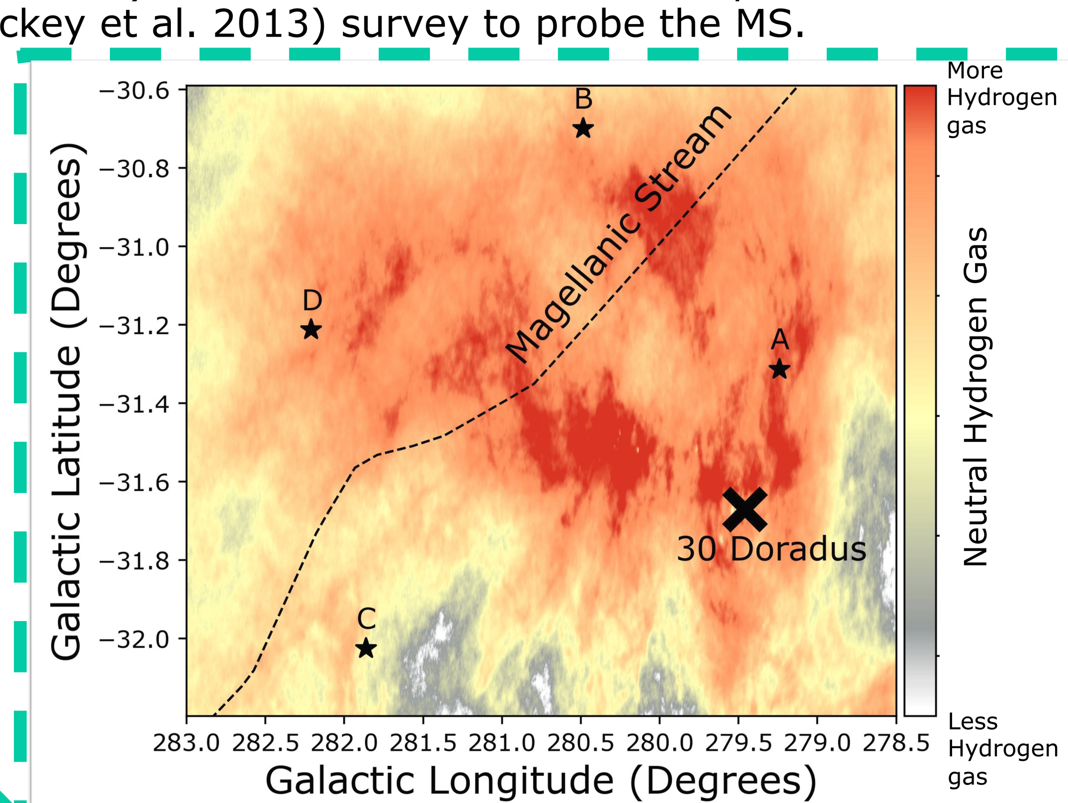


Figure 3: Neutral hydrogen emission map from the GASS (smaller image) and GASKAP (larger image) observations. The predicted location of the MS in velocity space from Nidever et al. (2008) is highlighted with the black dashed line. The sightlines in our study are marked with a star and the location of the proposed origin of the MS, 30 Doradus, is shown with an 'X'.

GASS detects the faint, diffuse MS material (McClure-Griffiths et al. 2009) and GASKAP has a beam size which more closely aligns with the pencil beam resolution of the HST observations (Dickey et al. 2013).

Connecting the LMC and MS

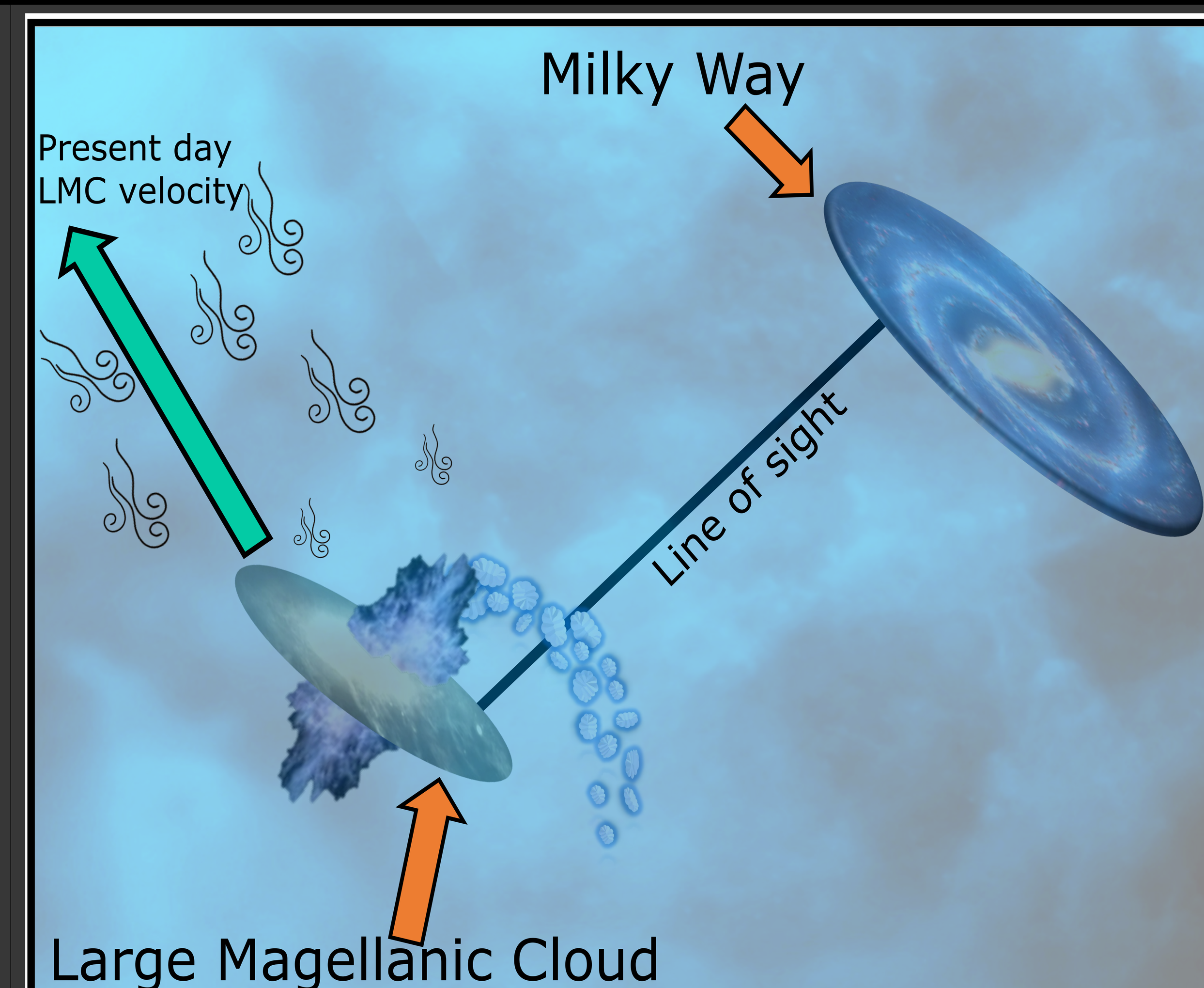


Figure 4: Supernovae explosions and stellar activity launch gaseous debris outside the LMC's disk exposing that debris to processes in the environment. As the LMC moves through the Milky Way's hot, dense halo, the gas on the outskirts is swept away and can form a stream of gas flowing from the galaxy.
Image Credit of Milky Way Galaxy: NASA/JPL-Caltech/R. Hurt (SSC/Caltech)
Image Credit for neighboring galaxy: NASA, ESA, and M. Kornmesser (HEIC)

Powerful, energetic processes inside a galaxy, such as supernovae explosions, stellar winds, and active galactic nuclei, can launch gaseous debris outside the galaxy's disk forming a galactic wind. The galactic wind material is more vulnerable to close galaxy interactions which sweep away the debris and can form a tail of gas flowing behind the galaxies. An example of such outflows is the MS.

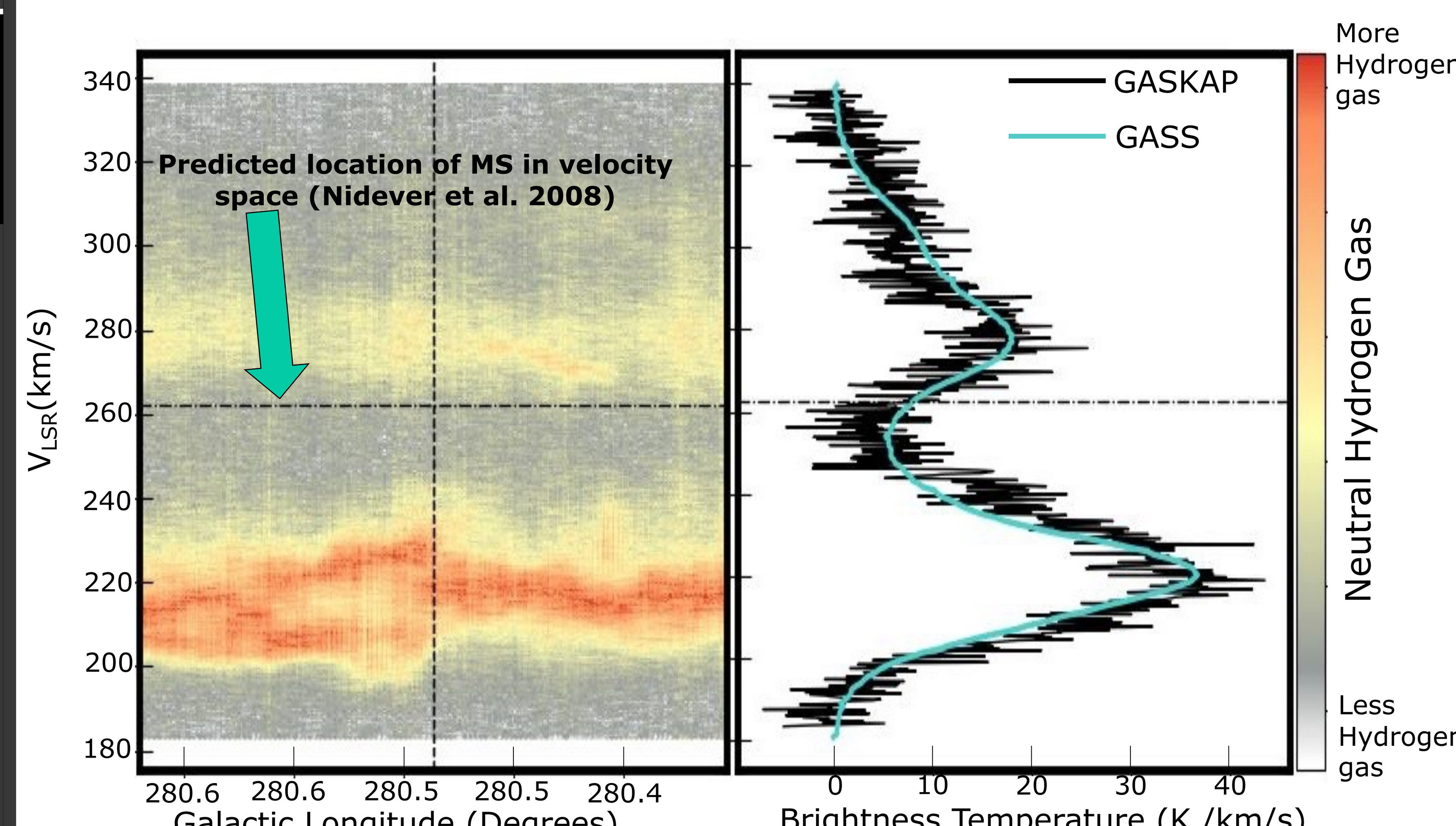


Figure 5: The left panel is a position-velocity map of the neutral hydrogen gas in the LMC's disk and MS. The right panel is the neutral hydrogen emission profiles for both the GASS and GASKAP observations. There are two peaks in the emission profiles that align with the two bands of neutral hydrogen gas in the position-velocity map.

We created position-velocity maps for each sightline to observe the small-scale kinematic variation of the neutral hydrogen gas in the LMC's disk and the MS. We determined the average velocity bounds of both the LMC's disk and the MS by fitting the emission profiles with Gaussians and by doing a by eye estimate. With these kinematic boundaries, we examined the absorption spectra from HST to see if we could identify the MS within these velocities.

Physical Properties of the MS

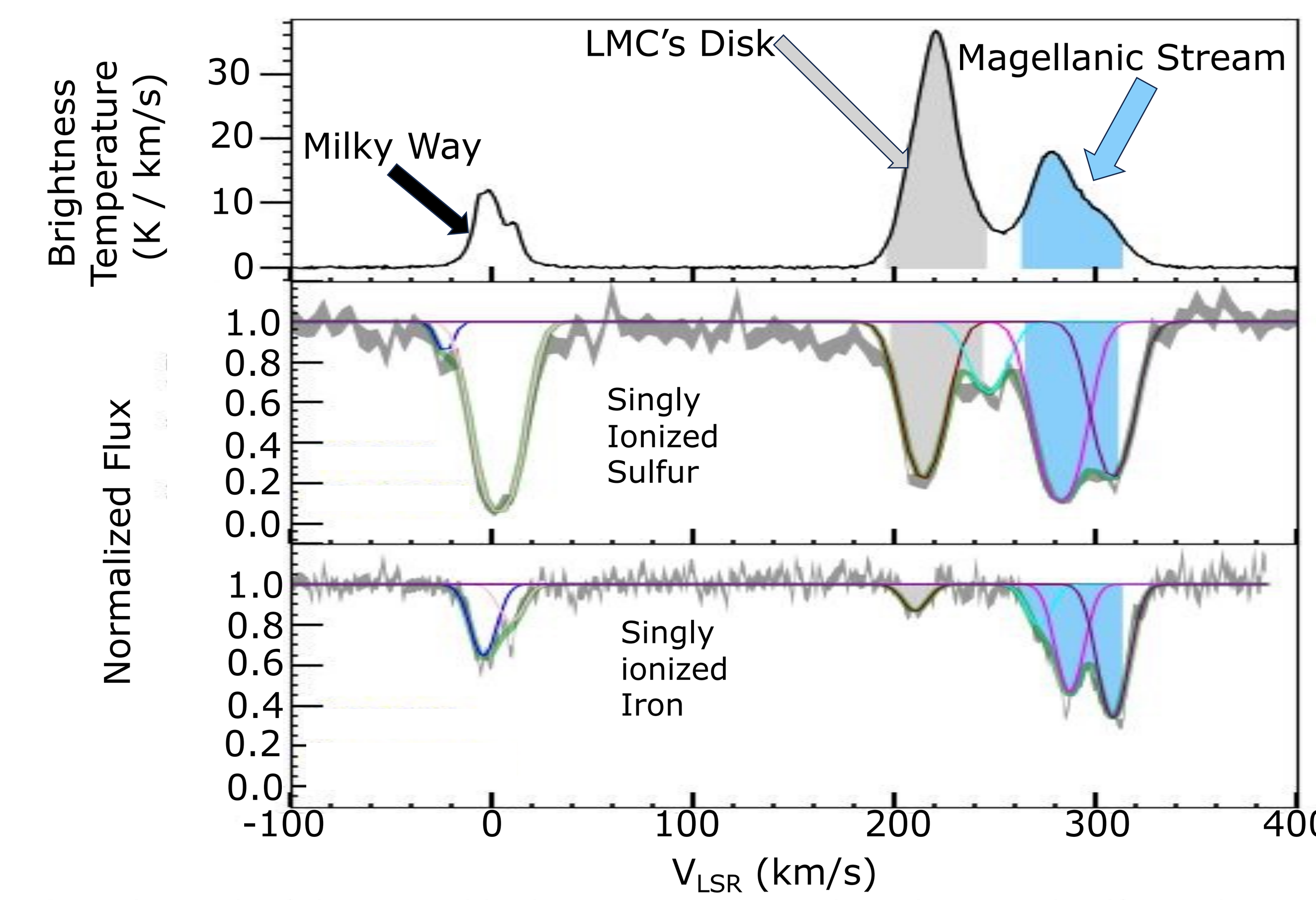


Figure 6: A plotstack of the neutral hydrogen emission and singly ionized sulfur and iron transitions. Signatures of the MS can be identified: highlighted by the light blue region (centered around +285 km/s). The gray shaded region (centered around +210 km/s) is the velocity boundary of the LMC's disk. The various colored lines are the individual components in the total Voigt profile that were fit using the *VoigtFit* Python software (Krogager 2018).

To measure the physical properties of the MS, we fit the absorption features with a Voigt profile. These fits provide information on how much gas is present, its temperature, and how fast it is moving. We find components of the MS on the nearside of the LMC in velocity space between $+235 \leq v_{LSR} \leq 350$ km/s.

Future Work & Acknowledgements

We will incorporate additional sightlines along the MS into our study. We will perform the same analysis on these new sightlines and compare our findings to the original four.

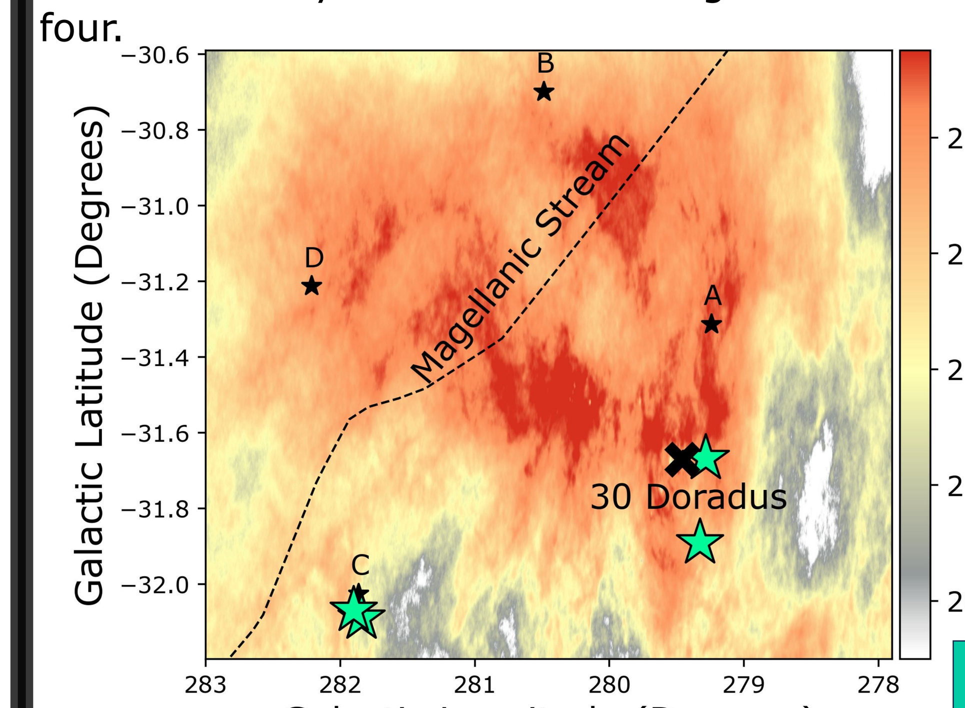


Figure 7: The additional sightlines we are planning to include in our project are marked by the larger green stars.

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When massive stars die, they explode creating fast-moving gas clouds that can escape a galaxy and form an outflowing stream. In the night sky, there is a prominent feature known as the Magellanic Stream that flows out of one of our neighboring galaxies. We study the MS by using light from background stars shining through it. This technique helps us measure the properties of the gas like how much is present, its temperature, and how fast it moves. The physical properties help us understand the processes forming the MS.

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