Structure, Excitation, and Dynamics of the Inner Galactic Interstellar Medium (SEDIGISM)

Abstract

We present the first data release of the **SEDIGISM (Structure, Excitation and Dynamics of the Inner Galactic Interstellar Medium)** survey, a large spectroscopic programme conducted with the **APEX 12-m telescope** to map the molecular gas in the inner Milky Way. The survey covers **~84 deg²** of the southern Galactic plane, with continuous coverage from **−60° ≤ ℓ ≤ +17° at |b| ≤ 0.5°**, and an additional **2 deg² region** between **+29° and +31° (W43)** for cross-comparison with northern surveys. The latitude range is extended in selected regions, reaching **|b| ≤ 1°** towards the **Central Molecular Zone**, **b ≤ +0.75°** towards **RCW 120**, and **b ≤ −0.75°** towards the **Nessie filament**. All observations were obtained with the **SHeFI/APEX-1 receiver** in position-switching on-the-fly mapping mode, covering the **217–221 GHz frequency range**.

The primary data products are **^{13}CO(2–1)** and **C^{18}O(2–1) spectral cubes**, complemented by additional transitions including CH_3OH, H_2CO, HC_3N, HNCO, SiO, SO_2, and SO. The final dataset consists of **78 FITS cubes**, each covering ~2° × 1° with 1° overlap, sampled at **9.5″ pixels**, **30″ angular resolution**, and **0.25 km s^{-1} velocity resolution** (0.5 km s^{-1} for ancillary lines). The typical sensitivity is **0.8–1.0 K per channel (T_{mb} scale)**.

With this release, we provide the **fully calibrated spectral cubes** and corresponding **white-light integrated intensity maps**, enabling studies of **cloud structures, chemistry, kinematics**, and the **large-scale distribution of molecular gas** in the inner Galaxy.

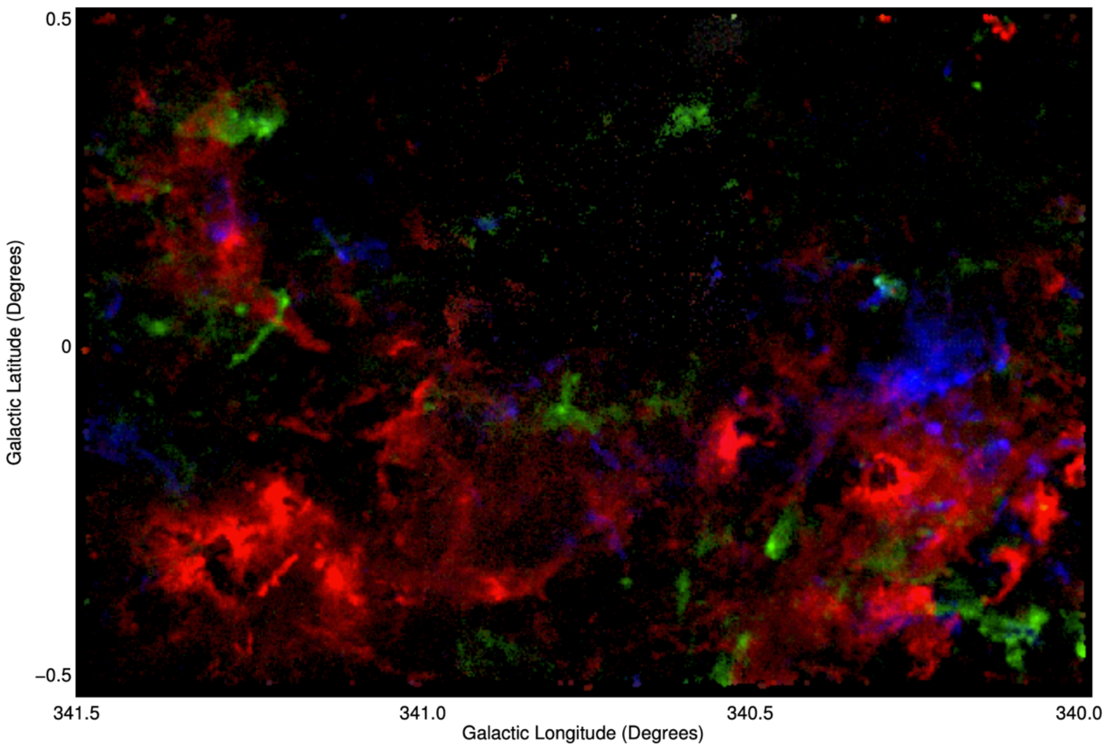

Figure 1. Three-colour ^{13}CO(2–1) maps of the SEDIGISM science demonstration field (taken from Schuller et al. 2017). The colour channels correspond to different velocity ranges: blue = −130 to −110 km s^{-1}, green = −110 to −60 km s^{-1}, and red = −60 to +5 km s^{-1}. These intervals are dominated by emission from the near sides of the 3-kpc, Norma, and Scutum–Centaurus arms, respectively.

Overview of Observations

The SEDIGISM observations were carried out between 2013 and 2017 with the 12-m Atacama Pathfinder Experiment (APEX) telescope at Llano de Chajnantor, Chile. The Swedish Heterodyne Facility Instrument (SHeFI/APEX-1) was used in single-sideband mode, connected to two wide-band Fast Fourier Transform Spectrometers (XFFTS). This setup provided 4 GHz instantaneous bandwidth, split between the two backends with an overlap of 500 MHz, covering the frequency range 217–221 GHz.

The prime targets are the $^{13}CO(2–1)$ (see Fig.1) and $C^{18}O(2–1)$ lines, which are typically optically thin and trace moderately dense gas (~10^3 cm^{-3}). The wide spectral coverage also includes transitions of other species sensitive to dense gas and shocked environments, such as CH_3OH, H_2CO, HC_3N, HNCO, SiO(5–4), SO_2, and SO(5–4).

The survey covers ~84 deg² of the inner Galactic plane (see Fig 2). The main component is a continuous strip between −60° ≤ ℓ ≤ +17° with |b| ≤ 0.5°. In addition, a 2 deg² field between +29° and +31° (W43) was mapped to facilitate comparison with northern-hemisphere surveys. The latitude coverage was also extended in selected regions: up to |b| ≤ 1° around the Central Molecular Zone, up to |b| ≤ +0.75° towards RCW 120, and down to |b| ≤ −0.75° towards the Nessie filament.

Mapping was performed in on-the-fly (OTF) mode, with each 0.25° × 0.5° tile observed in orthogonal scanning directions along ℓ and b. The spectra were calibrated to the main-beam temperature scale (T_mb) using an efficiency of 0.75, and gridded to data cubes with 9.5″ pixels, 30″ angular resolution, and 0.25 km s^{-1} velocity channels for CO isotopologues (0.5 km s^{-1} for other lines). The typical rms

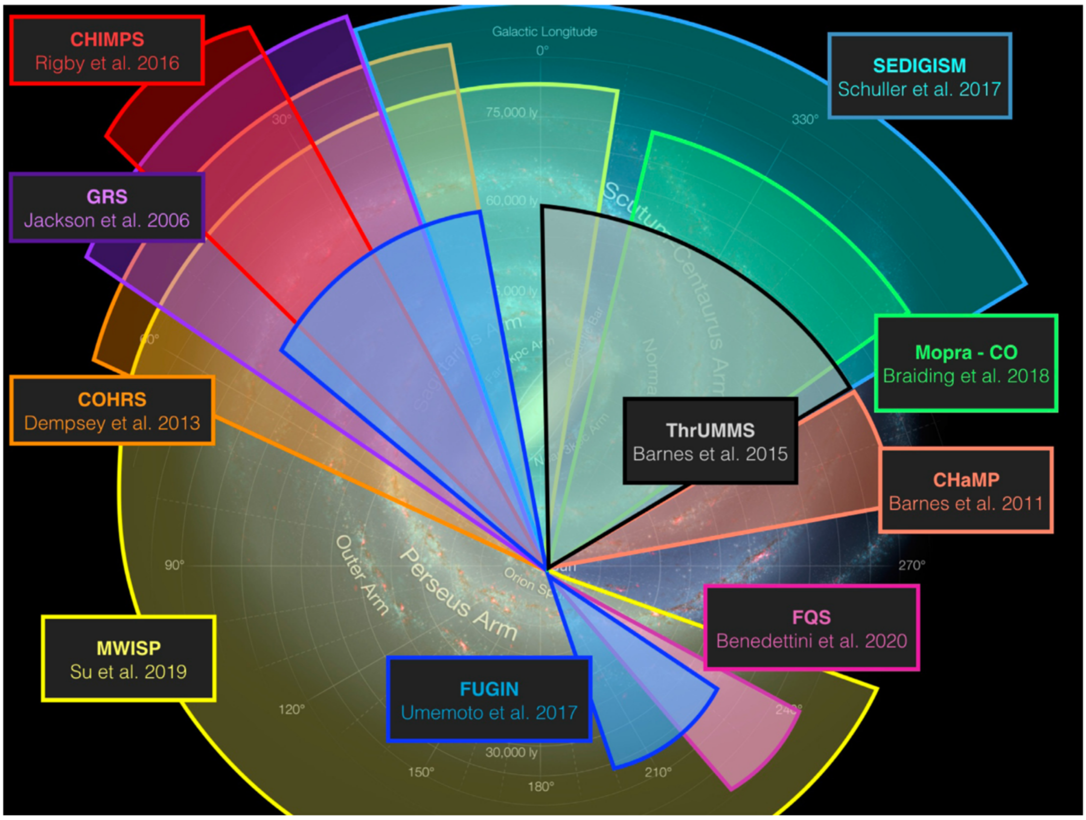

Figure 2. Milky Way coverage of recent CO surveys (see Schuller et al. 2021). The background image is a schematic of the Galactic disc as viewed from the Northern Galactic Pole [courtesy of NASA/JPL-Caltech/R. Hurt (SSC/Caltech)] showing the known large-scale features of the Milky Way, such as the spiral arms and the Galactic bar. The survey wedges emanate from the position of the Sun; their respective lengths are arbitrary and do not reflect the sensitivity of each survey.

noise per channel is 0.8–1.0 K (T_{mb}), although variations (up to 0.5 K) occur with weather conditions and elevation.

The resulting dataset provides a sensitive, uniform view of the molecular gas distribution across the inner Milky Way, including major large-scale features such as spiral arms, the Galactic bar, and the Central Molecular Zone, while resolving structures down to ~1 pc at the Galactic Centre.

Release Content

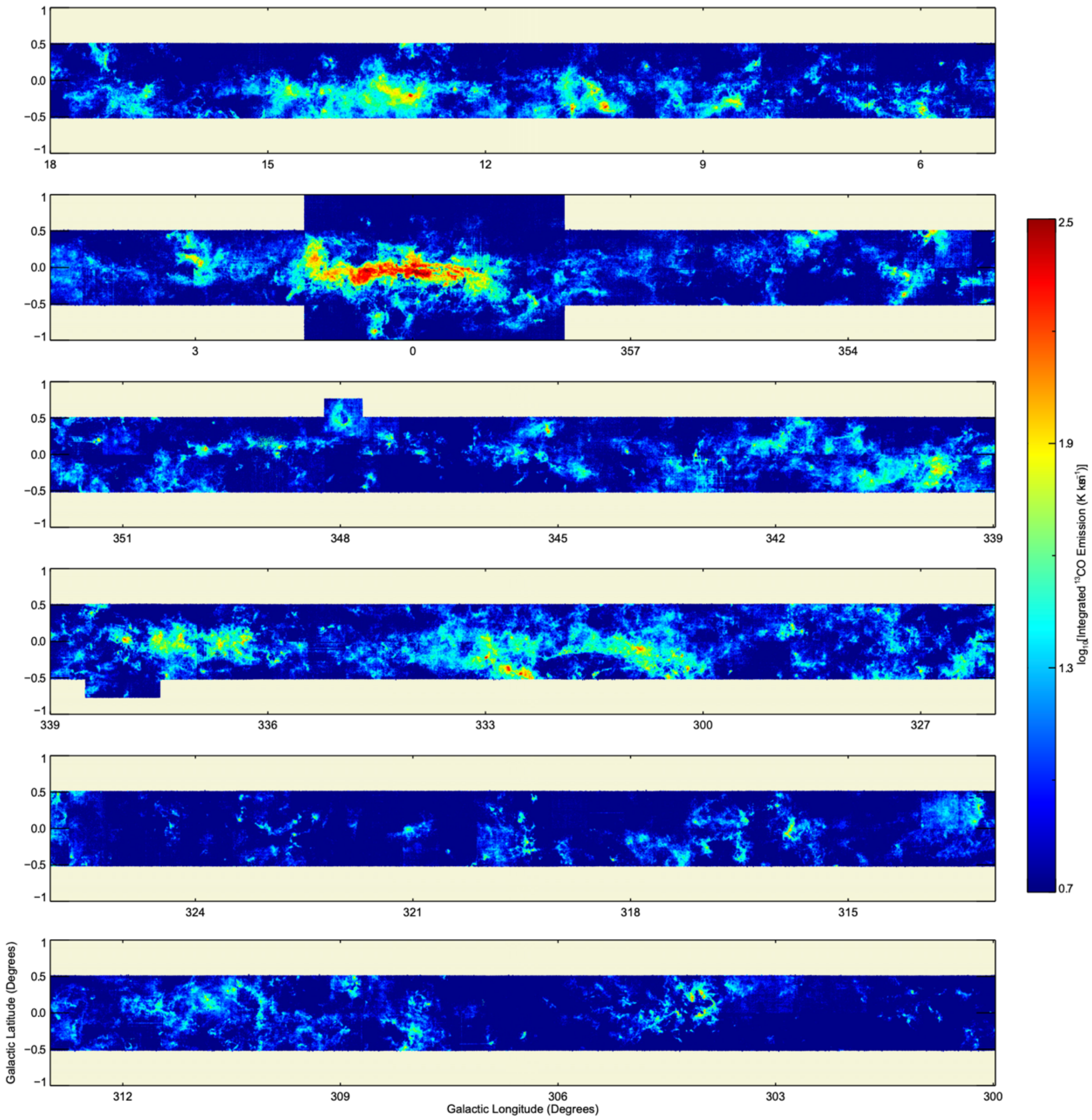

Figure 3. Integrated $^{13}CO(2–1)$ emission map for the full SEDIGISM survey (excluding the W43 extension; see Schuller et al. 2021). The map shows the emission from all spectral cubes integrated over the full velocity range (−200 to +200 km s^{-1}), providing a global view of the molecular gas distribution across the inner Galactic plane.

Spectroscopic Data Products

The core release consists of fully calibrated spectral-line FITS cubes covering the main survey area. Each cube provides uniform sensitivity and resolution, and together they form a complete dataset of the molecular gas distribution across the inner Milky Way. The main characteristics are:

Primary molecular lines: ^{13}CO (2–1), $C^{18}O$ (2–1)

Additional tracers: CH_3OH (4_2,0–3_1,0), H_2CO (3_0,3–2_0,2), H_2CO (3_2,1–2_2,0), H_2CO (3_2,2–2_2,1), HC_3N, HNCO, SiO (5–4), SO_2, SO (5–4)

- **Spectral coverage:** −200 to +200 km s^{-1}
- **Velocity resolution:** 0.25 km s^{-1} for CO isotopologues (0.5 km s^{-1} for other species)
- **Angular resolution:** 30″ (gridded to 9.5″ pixels)
- **Typical rms noise:** 1.0 ± 0.5 K per channel (T_{mb} scale)
- **Data format:** FITS spectral cubes
- **Number of cubes:** 78 tiles, each covering ~2° in longitude by 1° in latitude (with 1° overlap)

Ancillary Data Products

White-light maps: For each observed molecular transition, a single summed map is provided, obtained by integrating over the full velocity range (−200 to +200 km s^{-1}). These maps give the total emission distribution across the survey area.

The full release comprises ~2 TB of calibrated spectral-line data. Individual FITS cubes are typically **~3.6 GB** for the CO isotopologues and **~1.9 GB** for the other molecular transitions.

Release Notes

Data Reduction and Calibration

The raw spectra provided by APEX were delivered in antenna temperature scale (T^*_a) and processed with the **CLASS** package from the GILDAS suite. A dedicated SEDIGISM pipeline was developed to apply standard calibration and gridding, while also implementing additional checks for reference-position contamination and Doppler corrections.

Calibration: Spectra were converted to the main-beam brightness temperature scale ($T_{mb} = T^*_a / \eta_{mb}$) using the standard APEX main-beam efficiency η_{mb} = 0.75; see APEX efficiency tables). Observations obtained in March–June 2014 required additional scaling factors due to receiver instabilities (0.73/0.90 for XFFTS-1/2 before April 23, and 0.80/0.95 afterwards). Repeated calibrations using line-rich sources such as Sgr B2(N) and IRC+10216 show a dispersion of ≈7% in integrated ^{13}CO(2–1) fluxes, indicating an overall flux accuracy better than 10%.

Spectral resampling: Spectra were re-sampled to velocity resolutions of 0.25 km s^{-1} for the CO isotopologues and 0.5 km s^{-1} for other lines within the 217–221 GHz band. The effective velocity coverage is −200 to +200 km s^{-1} for the ^{13}CO(2–1) and $C^{18}O$(2–1) lines (±300 km s^{-1} in the raw scans).

Baseline subtraction: A critical pipeline step was the automatic detection of emission features in each spectrum, used to define windows that were masked before baseline subtraction. Channels with signal above 3σ (where σ was estimated from a smoothed version of the spectra in 80-channel sliding windows) were excluded. A third-order polynomial was typically fitted and subtracted. The same baseline windows were applied to multiple adjacent positions to ensure consistency, and spike removal was systematically applied.

Backend selection: For transitions covered by both FFTS backends, data from XFFTS-1 were preferred owing to its greater stability in varying weather conditions.

Reference position correction: Reference positions were chosen at ±1.5° in Galactic latitude from each field centre, but some showed weak ^{13}CO(2–1) emission. These were checked against more distant off-positions; when emission was detected, the reference spectrum was independently reduced and added back into each spectrum of the affected map. This correction introduced negligible additional noise (≈0.07 K rms). For DR1, an additional correction was required when on-the-fly maps and their reference positions were observed on different days: Doppler tracking offsets of up to three channels (0.75 km s^{-1}) were identified and corrected by shifting the reference spectrum before subtraction.

Scan combination and gridding: Each field was observed twice in orthogonal scanning directions (ℓ and b). Fields with higher-than-average rms were re-observed. Individual scans were calibrated and combined using Gaussian gridding onto 9.5″ pixels, with convolution kernels of one-third of the beam FWHM. This yields fully sampled data cubes with a final angular resolution of 30″. Typical rms noise in the combined data is 0.8–1.0 K per 0.25 km s^{-1} channel under PWV ≤ 3 mm conditions, though edge tiles or poor-weather scans may show slightly higher noise.

Final products: The distributed Phase 3 data products are calibrated FITS spectral cubes and derived integrated intensity (moment-0) maps for all detected transitions. No source extraction or higher-order products (e.g. cloud catalogues) are included in this release.

Spectral Reference System

- All velocities are reported in the Local Standard of Rest (LSR).
- The spectral coverage spans −200 to +200 km s^{-1}, with channel widths of 0.25 km s^{-1} for CO isotopologues and 0.5 km s^{-1} for other species.

Astrometry

- Pointing accuracy is better than 2″, based on the APEX pointing model.
- Astrometric calibration is uniform across the survey.

Flux Calibration

- Flux calibration is homogeneous to within 10%, based on repeated measurements of standard calibrators.

Data Quality

- The data exhibit uniform sensitivity across most of the survey area.
- Typical rms noise is 0.8 to 1.0 K per 0.25 km s^{-1} channel.
- Edge tiles may exhibit slightly higher noise due to shorter effective integration times.
- Comparisons with external surveys (e.g. ATLASGAL continuum maps) show good consistency.
- No significant photometric artefacts or systematic calibration offsets are present.

Known issues

Several lines of sight are blanked for specific source/transition combinations due to a failed online calibration step (with the raw data headers recording T_{sys} = 0 K). The affected fields are:

- G009_CH3OH420-310
- G009_H2CO303-202
- G009_H2CO322-221
- G009_HC3N
- G009_SiO5-4
- G010_CH3OH420-310
- G010_H2CO303-202
- G010_H2CO322-221

- G010_HC3N
- G010_SiO5-4
- G319_CH3OH420-310
- G319_H2CO303-202
- G319_H2CO322-221
- G319_HC3N
- G319_SiO5-4
- G320_CH3OH420-310
- G320_H2CO303-202
- G320_H2CO322-221
- G320_HC3N
- G320_SiO5-4
- G351_CH3OH420-310
- G351_H2CO303-202
- G351_H2CO322-221
- G351_HC3N
- G351_SiO5-4
- G352_CH3OH420-310
- G352_H2CO303-202
- G352_H2CO322-221
- G352_HC3N
- G352_SO2
- G352_SiO5-4

Previous Releases

This is the first data release (DR1) of the SEDIGISM survey.

Data Format

Data products

The release consists of calibrated FITS spectral cubes and derived white-light images for each molecular transition. The spectral cubes are three-dimensional arrays with axes corresponding to Galactic longitude, Galactic latitude, and velocity, while the white-light images are two-dimensional maps obtained by integrating each cube over the full velocity range (−200 to +200 km s^{-1}). All files follow ESO Phase 3 standards, with headers containing complete WCS information for both spatial and spectral axes. The observed transition is explicitly identified by the `LINE` keyword (e.g. 13CO21, C18O21, SO5-4), and all data values are given in main-beam brightness temperature (T_{mb}, K).

HDU structure

Each FITS file contains multiple extensions in compliance with the ESO Science Data Products (SDP) standard:

Primary HDU: header only (no data array), storing global metadata such as programme IDs, observing setup, calibration details, provenance (PROVn), and bibliographic reference.
Extension 1 (DATA_EXT): 3D science data cube with axes in Galactic longitude, Galactic latitude, and velocity (or 2D image for moment maps). Pixel units are in K (T_{mb}).
Extension 2 (STAT_EXT): error cube (or error map) corresponding to the science data, storing the rms noise, also in K.

Both extensions include consistent WCS headers: GLON-GLS and GLAT-GLS for the spatial axes, VRAD (LSRK frame) for the spectral axis, and RESTFREQ for the line rest frequency.

File naming convention

Files follow the pattern:

```
SEDIGISM_<tile>_<molecule>.fits
```

<tile> indicates the Galactic longitude range of the cube (e.g. G009, G320), corresponding to 2°-wide survey tiles with 1° overlap in ℓ.
<molecule> specifies the observed transition, e.g. 13CO21, C18O21, SiO54, H2CO303-202.

Acknowledgements

According to the Data Access Policy for ESO data held in the ESO Science Archive Facility, all users are required to acknowledge the source of the data with an appropriate citation in their publications.

Since processed data downloaded from the ESO Archive are assigned Digital Object Identifiers (DOIs), the following statement must be included in all publications making use of them:

- *Based on data obtained from the ESO Science Archive Facility with DOI: https://doi.org/10.18727/archive/102*

This data release is based on observations collected at the European Southern Observatory under ESO programme ID 097.C-0349. The SEDIGISM survey was conducted using the APEX telescope, a collaboration between the Max Planck Institute for Radio Astronomy, the European Southern Observatory, and the Onsala Space Observatory.

Users of these data are requested to cite:

Schuller, F., Urquhart, J. S., Csengeri, T., et al. 2021, MNRAS, 500, 3064

References:

- **Schuller** et al. 2017, *A&A*, 601, A124
- **Schuller** et al. 2021, *MNRAS*, 500, 3064
- **Duarte-Cabral** et al. 2021, *MNRAS*, 500, 3027