



The 10-15 GHz radio continuum survey of the Galactic Plane with SKAO

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Star formation emerges from the complex interplay between gravity, turbulence, magnetic fields, and stellar feedback, all of which vary across spatial scales and Galactic environments. Over the past decades, extensive multiwavelength surveys of the Galactic Plane have progressively unveiled this complexity. Far-infrared and sub-millimetre surveys have identified and characterized tens of thousands of star-forming regions, revealing their mass, temperature, and evolutionary stage. Complementary molecular-line surveys, spanning several CO transitions and isotopologues, have mapped the gas kinematics from giant molecular clouds down to sub-parsec structures. The advent of interferometers such as ALMA has revolutionized this field, enabling systematic studies of gas dynamics, fragmentation, and collapse in dense clumps at scales of a few thousand astronomical units.

At the same time, mid-infrared and radio surveys at frequencies $0.8 \lesssim \nu \lesssim 5$ GHz have traced ionised gas associated with the earliest and latest phases of massive-star evolution, including thermal radio jets, hypercompact and ultracompact H II regions, supernova remnants, planetary nebulae, and evolved massive stars. Yet, a uniform, Galaxy-wide census of ionised structures and feedback processes remains elusive.

A transformational leap forward requires a sensitive, high-resolution radio survey of the Galactic Plane at 10–15 GHz, capable of resolving physical scales smaller than 0.05 pc at distances up to 20 kpc. This is precisely the goal of the SKA-Mid Galactic Plane survey, which will, with its unprecedented sensitivity, angular resolution, and mapping speed, provide the first panoptic view of ionised gas and stellar feedback across the Milky Way.

1 Introduction

Star formation is the outcome of a complex, hierarchical process that operates across multiple spatial scales — from hundreds of parsecs-scale molecular clouds down to parsec-scale clumps and thousands of AU dense cores (Motte et al., 2018; Beuther et al., 2025). At each scale, the interplay of gravity, turbulence, magnetic fields, and feedback determines the morphology, fragmentation, and dynamical evolution of the gas (Vázquez-Semadeni et al., 2019, 2025; Padoan et al., 2020; Traficante et al., 2018b, 2020; Peretto et al., 2023). Understanding the interplay between these processes across various spatial scales is crucial for resolving a decades-old enigma in star formation theory: what regulates the star formation rate (SFR) in our Galaxy. The total mass of molecular hydrogen (H_2) in Galactic molecular clouds is estimated to be $\approx 10^9 M_\odot$ (Miville-Deschênes et al., 2017). If this gas was fully gravitationally bound and allowed to undergo global gravitational collapse, it would do so on a free-fall timescale of roughly $\approx 10^7$ years. This scenario would imply a Galactic SFR of about $200 M_\odot/\text{yr}$. However, the SFR stands among the most precisely constrained quantities in astrophysics, with concordant determinations spanning tracers from the cosmic microwave background to the far-infrared and X-ray regimes, all converging at a value near $2 M_\odot/\text{yr}$ (Elia et al., 2022, and references therein).

While gravity remains the fundamental driver of collapse across all spatial scales, promoting the formation of filamentary networks and dense hubs (Kumar et al., 2020; Hacar et al., 2023), supersonic turbulence can either inhibit or promote this collapse by generating local overdensities within the gas. Magnetic fields further modulate this interplay by regulating angular momentum transport and influencing filament alignment (Pattle et al., 2023). Crucially, both small- and large-scale feedback processes inject energy and momentum into the interstellar medium (ISM), thereby shaping its evolution. In particular, feedback from massive stars, through mechanisms such as ionising radiation from emerging H II regions, stellar winds, outflows, and supernova explosions strongly impact the surrounding medium (Grudić et al., 2022). They all drive turbulence and influence the balance between suppression and triggering of subsequent star formation on scales of tens of parsecs from their natal sites. Understanding the impact of these feedback across different spatial scales and Galactic environments is crucial for identifying the mechanisms that substantially suppress the Galactic SFR. What all of these mechanisms (except the supernovae) have in common is that they ionise the surrounding medium and generate thermal bremsstrahlung (free-free) emission.

The scientific motivation for conducting a Galactic Plane (GP) survey in the 10–15 GHz range is to investigate feedback mechanisms spanning across many different Galactic environments and in a vast range of spatial scales. These high-frequency radio observations are in fact particularly sensitive to free-free emission, and are less contaminated by synchrotron emission or anomalous microwave emission than that at lower radio frequencies. Supernovae explosions generate gyrosynchrotron emission, but it is very likely that in some of these regions even at these radio frequencies this is still the dominant form of radiation. These higher radio frequencies, required to study ionized gas, remain vastly unexplored.

In this chapter, we present the scientific framework of a GP survey with the Square Kilometre Array Observatory (SKAO), discuss the key science goals, outline the main survey design requirements and highlight the transformative potential of such an effort in addressing long-standing questions

on the interplay between massive stars and the ISM.

First, in Section 2 we review the state-of-the-art of the GP surveys at various range of wavelengths: infrared and sub-mm (Section 2.1), CO and other molecular lines (Section 2.2), optical and X-ray (Section 2.3), mm high-resolution surveys with interferometers (Section 2.4) and radio surveys at low ($\nu \lesssim 5$ GHz) frequencies (Section 2.5, concluding the Section with the needs for a new survey of the GP in the radio frequencies enabled by SKA-Mid in Band 5b ($\sim 8.3 - 15.3$ GHz, Section 2.6). In Section 3 we outline the diverse range of science cases enabled by the proposed GP survey with SKA-Mid. The primary goal will be the investigation of feedback from H II regions (Section 3.1), since such a survey will uniquely enable statistical studies of their physical properties, morphologies, evolutionary states, and impact on subsequent generations of star formation throughout the GP. Beyond this primary goal, the proposed survey will allow the detection and characterisation of thousands of different objects across a broad range of evolutionary stages, including radio jets from deeply embedded protostars (Section 3.2), supernova remnants (SNRs, Section 3.3), planetary nebulae (PNe, Section 3.4) and other evolved stellar processes (Section 3.5). In Section 4 we discuss new models that can improve the interpretation of our data: how the contribution of synchrotron emission can still influence the free-free emission even at the band 5b frequencies (Section 4.1), and we introduce a novel approach to post-process and model the free-free emission seen by SKA-Mid at $\sim 10 - 15$ GHz following the approach of the Rosetta Stone project (Lebreuilly et al. 2025; Tung et al. 2025; Nucara et al. 2025, Section 4.2). In Section 5 we outline the most significant synergies that the proposed radio continuum survey will provide with other projects achievable with SKAO, such as the study of star-forming regions towards radio recombination lines (Section 5.1) or methanol masers (Section 5.2, as well a detailed study of the most extreme region in our Galaxy, the Galactic Center (Section 5.3). In Section 6 we present the observational strategy and the technical requirements to realize the GP survey in band 5b with SKA-Mid and finally in section 7 we draw our conclusions and final remarks.

2 Galactic Plane Surveys: Legacy, Achievements, and Limitations

Surveys of the GP have long played a fundamental role in advancing our understanding of the structure, content, and evolution of the ISM and star formation processes in the Milky Way, allowing statistically significant census of Galactic structures and their characterization in different environments. A number of large-scale surveys have been carried out in the past two decades across a broad range of wavelengths, each contributing to a progressively more complete view of the gravitational content and the turbulent gas dynamics of the various regions across the Galaxy. As discussed in detail in the following sections, these surveys span a wide range of spatial scales and sensitivities but they are nevertheless highly complementary, tracing different phases of the interstellar medium or emphasizing specific physical aspects of the same phase. These surveys include far-infrared (FIR) and sub-mm continuum surveys of the cold dust reservoirs, large-scale CO surveys tracing molecular gas kinematics, optical and X-ray surveys aimed to identify thousands of young stellar objects (YSOs) and a series of radio continuum and spectral line surveys at cm wavelengths. Together, they have enabled the identification and characterisation of tens of thousands of Galactic objects, including massive star-forming regions, SNRs, compact H II regions and the

more diffuse gas components such as HI, molecular complexes and ionised gas.

In the next sections we will summarize the major results obtained from these surveys in the past years and we highlight how the synergy between these surveys and the proposed GP survey in band 5b will finally allow us to advance towards a comprehensive, panoptic theory of the star formation process in our Galaxy.

2.1 Infrared and sub-mm Surveys

Far-infrared and sub-mm surveys have mapped the thermal dust emission associated with cold molecular gas, offering essential constraints on column density, dust temperature, and mass distribution across the GP. These surveys are pivotal in identifying the earliest phases of star formation, including pre-stellar cores and filamentary cloud structures. In particular, the Herschel Hi-GAL survey from 70 – 500 μm (Molinari et al., 2010) covered the entire Galactic plane. The 870 μm ATLASGAL (Schuller et al., 2009) and ≈ 1.1 mm Bolocam Galactic Plane Survey (BGPS, Aguirre et al., 2011) focused on the inner region of the Galaxy. Together, these surveys identified and characterized the physical properties of more than 30000 filamentary structures (Li et al. 2016; Schisano et al. 2020) and more than 2×10^5 star-forming parsec-scales clump (Contreras et al., 2013; Csengeri et al., 2014; Svoboda et al., 2016; Elia et al., 2021) across the Galaxy.

While they do not trace ionised gas directly, they are essential for placing H II regions and other feedback-driven structures within the broader molecular cloud environment. For example, they allowed for a detailed evolutionary classification of star-forming clumps across the Galaxy based on the widely used luminosity over mass (L/M) indicator (Molinari et al., 2008, 2016; Duarte-Cabral et al., 2013; Merello et al., 2019; Traficante et al., 2018a; Urquhart et al., 2022) and in synergy with radio observations have been crucial to recognize that clumps with $L/M \geq 10$ are the best candidates to be associated with newly formed H II regions (Urquhart et al., 2013b; Cesaroni et al., 2015).

There have been a large number of GP surveys also in the mid-infrared. The most relevant for characterising the star formation sites are the *Spitzer* surveys: the Galactic Legacy Infrared Mid-Plane Survey Extraordinaire (GLIMPSE, Benjamin et al., 2003) from 3 – 9 μm and the MIPS GAL survey at 24 μm (Carey et al., 2009). Together, these surveys have allowed the identification and classification of thousands of young star forming clouds seen in absorption against the mid-infrared background, the so-called infrared dark clouds (IRDCs, Peretto and Fuller 2009). And, in combination with the Hi-GAL survey we were able for the first time to identify, classify and characterize thousands of young, massive clumps associated with IRDCs (Traficante et al., 2015).

At these wavelengths, surveys of the GP have also uncovered a significant number of young stellar objects with outflow candidates and H II regions. For example, more than 300 outflow candidates have been identified thanks to the extended emission in the 4.5 μm GLIMPSE maps (the so-called Extended Green Objects; Cyganowski et al. 2008). The GLIMPSE survey has also been fundamental to identify ~ 600 bubbles candidate to be formed by newly born H II regions (Churchwell et al., 2006, 2007, 2009).

The Wide-field Infrared Survey Explorer (WISE) telescope in the mid-IR regime has also yielded a notable sample of H II regions. Thanks to its full-sky survey, a deep investigation of the emission

at 12 μm and 22 μm allowed the identification of ≈ 8000 H II and candidate H II regions across the GP (Anderson et al., 2014). This has been mainly possible through the lens of PAH emission features, which are excited by the UV radiation field of massive stars in photodissociation regions (PDR, Tielens, 2023), and due to the emission by heated dust at a few tens of microns. While PAH emissions demarcate the boundary of the PDR, radio continuum observations will help in delineating the ionization content in a given region, with the presence of heated dust emission within the front as an added indicator. The synergy between IR and radio surveys will help to understand morphological structures and the strength of the feedback mechanisms, which are often needed to constrain star formation scenarios of different complex regions.

2.2 CO and Molecular Line Surveys

Extensive surveys of CO and their isotopologues (e.g., ^{13}CO , C^{18}O), as well as higher-density tracers such as HCN and HCO^+ , have been conducted across large portions of the GP using various facilities, providing insights into the distribution, kinematics, and turbulent properties of molecular gas. The CfA 1.2 m survey provided the first comprehensive map of ^{12}CO (1–0) emission across the entire Milky Way disk, laying the foundation for subsequent studies (Dame et al., 2001). The FUGIN (FOREST Unbiased Galactic plane Imaging survey with the Nobeyama 45m telescope) survey, using the Nobeyama 45 m telescope, delivered high-resolution maps of ^{12}CO , ^{13}CO , and C^{18}O (1–0) lines over the inner Galaxy (Umemoto et al., 2017). The Galactic Ring Survey (GRS) focused on ^{13}CO (1–0) to study the molecular ring structure (Jackson et al., 2006), while the Mopra CO survey extended such efforts into the southern plane with observations of ^{12}CO , ^{13}CO , and C^{18}O J=1–0 lines (Burton et al., 2013). Similar longitudes, but extended latitude ranges have been covered in multiple CO (1 – 0) isotopologues by the Three-mm Ultimate Mopra Milky Way Survey (ThRUMMS, Barnes et al. 2015). Higher-excitation transitions have been targeted by CHIMPS (CO Heterodyne Inner Milky Way Plane Survey; ^{13}CO and C^{18}O J=3–2) and COHRS (CO High-Resolution Survey; ^{12}CO J=3–2) using the JCMT, revealing the distribution of warmer and denser gas (Rigby et al., 2015; Dempsey et al., 2013). The SEDIGISM (Structure, Excitation, and Dynamics of the Inner Galactic Interstellar Medium) survey complements these by mapping ^{13}CO and C^{18}O J=2–1 emission over a wide longitude range with the APEX telescope, enabling detailed studies of the physical and dynamical structure of the inner Galactic disk (Schuller et al., 2017; Schuller et al., 2021). The Outer Galaxy High-Resolution Survey (OGHReS; Colombo et al. 2021; Urquhart et al. 2024, 2025) is a highly complementary APEX CO survey of the 3rd quadrant outer Galaxy ($180^\circ < \ell < 280^\circ$) allowing the study of molecular clouds and star formation to lower density, pressure and metallicity environments. The Forgotten Quadrant Survey (FQS, Benedettini et al., 2020, 2021) has mapped a portion of the 2nd quadrant ($220^\circ < \ell < 240^\circ$) and $-2.5^\circ < b < 0^\circ$) in both ^{12}CO (1–0) and ^{13}CO (1–0) to identify and to study the kinematics of ≈ 250 molecular clouds in this poorly explored region of our Galaxy.

Complementing the CO-based surveys, targeted observations of dense gas tracers have also been conducted across the GP. The most extensive among them is the MALT90 (Millimeter Astronomy Legacy Team 90 GHz, Jackson et al. 2013) survey, which used the Mopra 22-m telescope to observe 16 molecular transitions – including HCN(1–0) and HCO^+ (1–0) (Rathborne et al. 2016) – toward over 2000 dense clumps identified by the ATLASGAL submillimeter continuum survey (Contreras

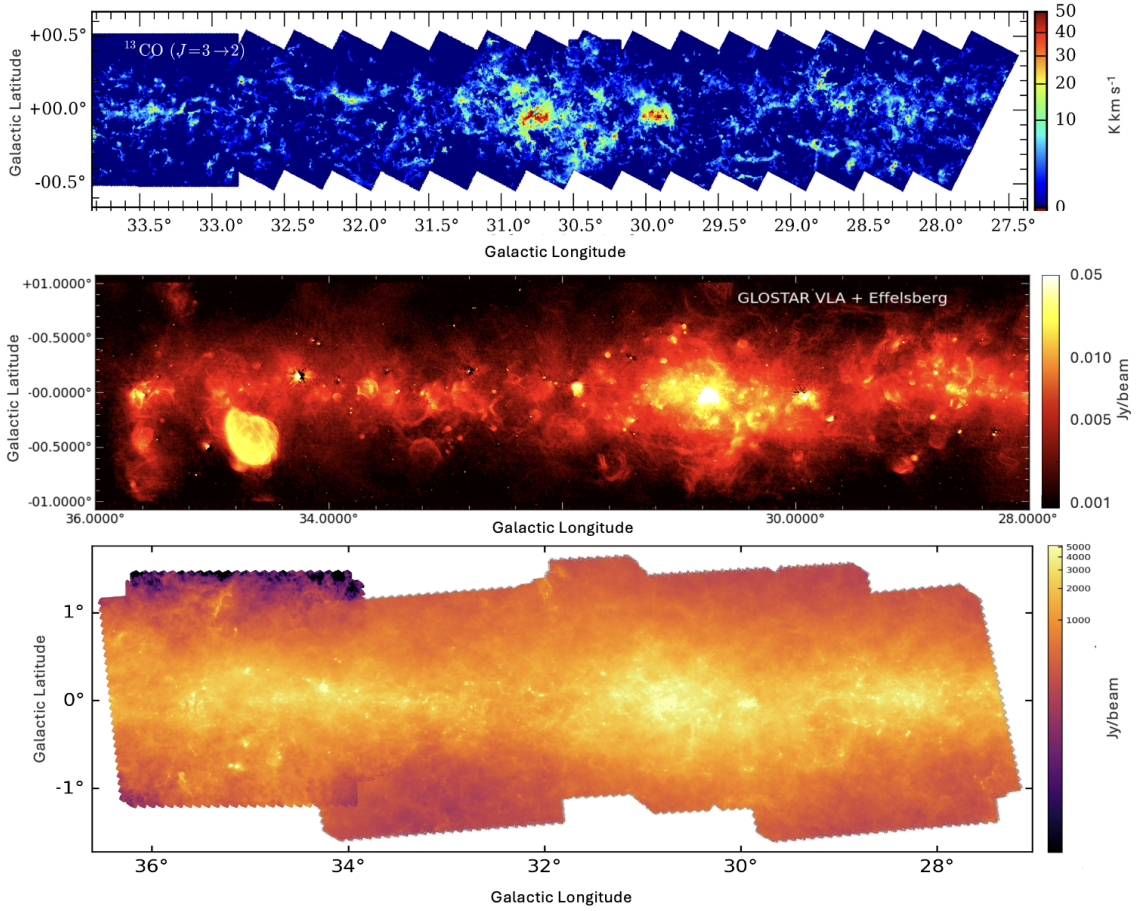


Figure 1: Example of GP surveys at different wavelengths. *Top panel:* ^{13}CO (3–2) emission image from CHIMPS (adapted from Rigby et al. 2015). *Middle panel:* 5 GHz image from GLOSTAR (adapted from Brunthaler et al. 2021). *Bottom panel:* Hi-GAL 250 μm emission (adapted from Traficante et al. 2011 and Molinari et al. 2010).

et al., 2013; Urquhart et al., 2014a). The CHaMP (Census of High- and Medium-mass Protostars) survey also employed Mopra to map HCO^+ (1–0) emission across a section of the southern GP ($\ell \sim 280^\circ - 300^\circ$), focusing on high- and intermediate-mass star-forming regions (Barnes et al., 2011). More recently, the JCMT’s MAJORS (Massive, Active, JCMT-Observed Regions of Star formation) program has begun targeting HCN (3–2) and HCO^+ (3–2) emission toward a mass-selected sample of star-forming regions (Urquhart et al. 2014b), including sources in the GP and the Central Molecular Zone (Eden et al., in preparation).

All these surveys are essential for determining the physical conditions of the molecular clouds that give rise to massive stars (Miville-Deschênes et al., 2017), and for constraining the gravitational and turbulent balance of star-forming clumps (Traficante et al., 2018a), filaments and clouds (Duarte-Cabral et al., 2021). However, they do not directly trace the ionised gas or its spatial connection with feedback-related structures.

2.3 Optical / X-ray Surveys

Optical and X-ray surveys give an opportunity to identify objects like YSOs and flaring stars (and in general, stars) in our solar neighborhood and beyond. The former helped to reveal more evolved YSOs, while X-ray surveys are efficient at detecting embedded sources and, in particular, at disentangling foreground stars from younger pre-main sequence objects. Observations at these wavelengths are providing a complementary view of physical mechanisms in stars detected in a GP survey, such as magnetic activity, wind emission, aurorae. For example, the Gaia space observatory provides an all-sky survey for about 2 billion sources (mainly stars in our Galaxy, with about 10 million extragalactic sources; [Gaia Collaboration et al. 2023b,a](#)) in the optical (G band and sub-bands BP and RP , including spectro-photometry), allowing for precise position, distance, and kinematic measurements up to several kpc, and provides mid spectral resolution spectra (and thus radial velocities) for millions of bright sources in the near-infrared (845–872 nm). Gaia, furthermore, scans the sky repeatedly, offering a window into the time domain variability, and thus, classification of variable stars (e.g., about 10 million variables in DR3, and 80k young stars across the Galaxy, [Eyer et al., 2023](#); [Rimoldini et al., 2023](#); [Marton et al., 2023](#)). The Vera Rubin Observatory (VRO/LSST) has recently started its observations and will observe repeatedly a large portion of the GP in different filters. Similarly, in the X-ray regime, all-sky surveys including the GP were done by eROSITA (e.g., 230k sources in DR1 for the Western Galactic Hemisphere, i.e., Galactic longitudes $0^\circ - 180^\circ$, [Merloni et al., 2024](#); [Salvato et al., 2025](#)), ROSAT (e.g., 145k sources across all sky, among them 18.8k bright X-ray sources and 28k identified as stars, [Voges et al., 1999](#); [Freund et al., 2022](#)), and by XMM-Newton or Chandra (e.g., 427k sources detected in the 4XMM-DR14s catalogue of serendipitous sources, [Traulsen et al. 2019, 2020](#); 408k sources detected in the Chandra Source Catalog Release 2.1, [Evans et al. 2024](#)).

All these surveys probe the large-scale structure, gas dynamics and stellar population distribution across the Galaxy. However, they do not provide information about the future population of stars in star-forming regions. This is what we will describe in the following Section.

2.4 ALMA/NOEMA surveys of star-forming regions

The investigation of the dense, cold star-forming regions down to thousands of AU scales have been recently made possible thanks to mm/sub-mm observations with powerful interferometers such as ALMA and NOEMA. These observations provide unprecedented spatial and spectral resolution studies of all evolutionary stages, from the cold starless clump/core stage in IRDCs up to the Hot Molecular Core and the H II region stages, wherein the H II region itself matures from a hypercompact to ultracompact to compact to classical form.

The earliest stages of star formation have been studied in different ALMA surveys ([Svoboda et al., 2019](#); [Anderson et al., 2021](#)), including the ASHES (The ALMA Survey of 70 μm Dark High-mass Clumps in Early Stages; [Sanhueza et al., 2019](#)) program, which together have mapped tens of 70 μm massive dark clumps. At the more evolved phases, the NOEMA CORE survey ([Beuther et al., 2018](#)), together with the ATOMS (ALMA Three-millimeter Observations of Massive Star-forming regions; [Liu et al., 2020](#)), QUARK (Querying Underlying mechanisms of massive star formation with ALMA-Resolved gas Kinematics and Structures; [Xu et al., 2024b](#)), ASSEMBLE (ALMA

Survey of Star Formation and Evolution in Massive Protoclusters with Blue Profiles; Xu et al., 2024a) or the DIHCA (Digging into the Interior of Hot Cores with ALMA; Ishihara et al., 2024) surveys have covered hundreds of evolved star-forming regions at the hot core or UC/HC H II region stages both in continuum and molecular lines and investigate the fragmentation properties and the gas dynamics in regions strongly affected by early feedback mechanisms. Other surveys have been also specifically designed to investigate the complex chemistry during the hot core stage of the massive star formation (Complex Chemistry in hot Cores with ALMA (CoCCoA); Chen et al., 2023). Few surveys have instead mapped clumps at different evolutionary stages with the aim of investigating the evolution of the accretion rates in globally collapsing clumps (Star formation in QUIescent And Luminous Objects (SQUALO); Traficante et al., 2023) or the fragmentation properties across bright, luminous objects (Tracing Evolution in Massive Protostellar Objects (TEMPO); Avison et al., 2023).

The ALMA telescope has also allowed a fundamental step forward in our understanding of the fragmentation properties in massive star forming regions thanks to large surveys of the GP aimed to explore in a statistically significant way the fundamental role of the environment in the hierarchical, multi-scale star formation mechanism. The ALMAGAL survey (Molinari et al., 2025), an ALMA large program at $\lambda \simeq 1.3$ mm has mapped more than 1000 dense clumps – spanning the full evolutionary range from the IRDCs to H II regions – with a minimum resolution of ~ 1000 AU, and provided the first characterization of the fragmentation properties at these scales on a Galaxy-wide survey (Coletta et al., 2025), as well as the first characterization of the morphology of different molecular line emissions across these massive clumps at various evolutionary stages (Mininni et al., 2025). The ALMA-IMF large program (Motte et al., 2022) has characterised the molecular and ionized gas environment of 15 massive protoclusters on the GP, investigating the core populations in different protoclusters (Pouteau et al., 2022; Nony et al., 2023; Armante et al., 2024) as well as providing a sample of $\simeq 1000$ gravitationally bound cores with ~ 2000 AU, radii and well-constrained properties: prestellar or protostellar, mass, protostellar luminosity, association with hot cores and ionized gas (Bonfand et al., 2024; Galván-Madrid et al., 2024; Louvet et al., 2024; Motte et al., 2025).

The picture that is emerging is consistent with the family of models defined as "clump-fed" scenario, in which the fragmentation is very dynamical and involves a multi-scale process where the gas from the parent parsec-scale clump (and likely the larger scales filament) participate at the collapse and formation of the inner cores (Vázquez-Semadeni et al., 2019, 2025; Padoan et al., 2020). The mass of observed cores has a direct relation with that of the parent clump, and the distribution of fragments within each clump seems to evolve with the clump evolution (Traficante et al., 2023; Xu et al., 2024b). The question of how this gas flows at various scales to produce the observed fragmentation properties, however, remains still elusive. At what scales the dynamics is dominated by the gravitational collapse, the turbulent motions or the feedback mechanisms is still unclear. The multi-scale gas dynamics in different environments has now started to be investigated with ALMA surveys in IRDCs (Traficante et al., 2020; Peretto et al., 2023) and in massive clusters at various phases with ALMA-IMF (Sandoval-Garrido et al., 2025; Koley et al., 2025). The first large survey of multi-scale gas dynamics in different Galactic environments, combining cloud-scales information down to thousands of AU core scales is now going to be carried out thanks to the ALMA Large

project PANTA REI (PIs: N. Peretto; A. Traficante; S. Clark; M. Merello). This project will map the 3-mm emission associated with 259 clumps already observed at the tens of parsec scales with CO surveys such as SEDIGISM (Duarte-Cabral et al., 2021) or OGHReS (Colombo et al., 2021) and, at the few thousands of AU scales with ALMAGAL (Molinari et al., 2025), filling the gap between these scales and allowing a comprehensive study of the interplay between turbulence and gravity in different Galactic environments. Furthermore, by observing molecular tracers such as SiO (2-1) or HCO⁺ (1-0) PANTA REI will allow a statistically significant investigation of outflows (Duarte-Cabral et al., 2014; Traficante et al., 2017) and their impact on the gas dynamics at all spatial scales.

However, we are still not able to predict how much the environment and the feedback mechanisms contribute to the formation of one, or many fragments within each star forming regions. As shown in an example in Figure 2, all these mm surveys mainly traces the cold dusty envelopes of the star-forming regions. Only the synergy between ALMA, NOEMA and radio surveys will lead us to a comprehensive understanding on the interplay between gravity, turbulence and feedback at various scales, thanks to the mapping of the ionized gas that traces newly formed massive protostars, which are likely to be the main source of feedback in these star forming regions.

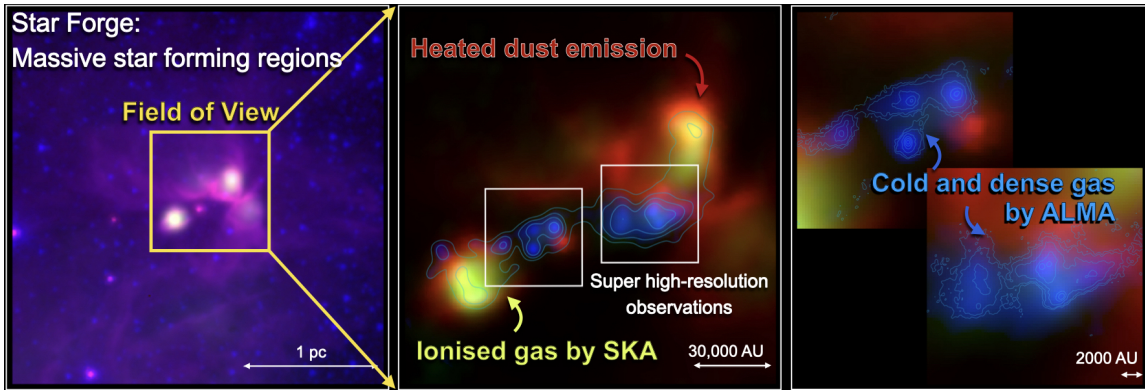


Figure 2: The concept of synergy between SKA-Mid and ALMA GP surveys. *Left panel:* the Spitzer 3.6 μm and 8 μm and MeerKAT 1.28 GHz composite image shows the overview of a massive star-forming region. *Center panel:* The ionized gas is traced by the MeerKAT 1.28 GHz and ALMA 3-mm images. *Right panel:* With the help of ALMA-QUARKS data, we can even trace the cold and dense gas which are the site of new generation of star formation.

2.5 Low-Frequency Radio Continuum Surveys ($\nu \lesssim 8$ GHz)

A number of GP radio continuum surveys have been carried out below 5 GHz. The most relevant in terms of sensitivity and angular resolution are: MAGPIS (≈ 1.4 and 5 GHz), CORNISH (5 GHz), THOR (1–2 GHz), GLOSTAR (4–8 GHz) and SMGPS (L-band). These surveys have delivered extensive catalogs of compact and extended radio sources, including H II regions, SNRs, and PNe, with increasingly improved angular resolution and sensitivity.

The Multi-Array Galactic Plane Imaging Survey (MAGPIS) were acquired in about 22 years of Karl G. Jansky Very Large Array (VLA) observations in seven out of the eight possible configurations (White et al., 2005). The 1.4 GHz survey covered ≈ 331 deg² in the Galactic longitude range

$-20^\circ < \ell < 120^\circ$ (and variable latitude range between $\pm 0.8^\circ$ and $\pm 2.7^\circ$) with a 90% sensitivity completeness level of ~ 14 mJy. The 5 GHz survey mapped the GP region $-10^\circ < \ell < 42^\circ$, $|b| \leq 0.4^\circ$ with a 90% sensitivity completeness level of ~ 2.9 mJy. These programs have identified ~ 5000 compact sources at 1.4 GHz and ~ 2700 sources at 5 GHz. Furthermore, an extension of the 1.4 GHz survey covered a portion of the first Galactic quadrant ($5^\circ < \ell < 48.5^\circ$), achieving an improved sensitivity of $\sim 1\text{--}2$ mJy using the VLA in B, C, and D configurations, which led to the detection of over 3000 compact sources and approximately 400 extended sources, including ~ 50 candidate supernova remnants (Helfand et al., 2006).

CORNISH is a 5 GHz survey of the northern region of the inner GP ($295^\circ < \ell < 350^\circ$, $10^\circ < \ell < 65^\circ$, $|b| \leq 1^\circ$). The northern part of the survey ($10^\circ < \ell < 65^\circ$) was carried out using the VLA in B and BnA configurations (Hoare et al., 2012; Purcell et al., 2013). This yielded an angular resolution of $\sim 1.5''$ and a 1σ sensitivity better than 0.4 mJy beam $^{-1}$. The survey was optimized to detect emission on scales smaller than $14''$, targeting the earliest phases of H II region evolution. The southern part of the survey used the Australia Telescope Compact Array (ATCA) in its 6A configuration (Irabor et al., 2023). The ATCA observations provided an angular resolution of $2.5''$ and a 1σ sensitivity of 0.11 mJy beam $^{-1}$. The CORNISH-North catalog, that is 90% complete at a level of 3.9 mJy, detected ~ 2600 reliable sources above a 7σ detection limit, of which 288 and 170 are classified as H II regions and planetary nebulae (PNe) respectively. The CORNISH-South survey detected a total of ~ 4700 sources above 7σ . In total, these surveys have classified ~ 800 H II regions and ~ 450 PNe.

The HI/OH/Recombination line survey of the Milky Way (THOR; Beuther et al. 2016b) and the Global View of Star Formation in the Milky Way (GLOSTAR; Brunthaler et al. 2021) used the upgraded WIDAR correlator of the VLA. In addition to providing a much larger continuum bandwidth, the surveys employed “zoom” modes to study selected spectral lines such as maser lines of OH and methanol, formaldehyde and various radio recombination lines (RRLs). The wide continuum bandwidth also enabled determination of the spectral index for bright sources. The THOR survey covered the GP with $14.5^\circ \leq l \leq 67.4^\circ$ and $|b| \leq 1.25^\circ$ from 1–2 GHz with the VLA in its C-configuration, yielding an angular resolution of 10-20'' depending on the frequency. The data products include continuum images and data cubes for HI, the four OH maser lines and stacked hydrogen recombination lines. More than 10000 continuum sources have been classified as reliable detections (Wang et al., 2018) including hundreds of H II regions, SNRs and 164 PNe in the Milky Way. THOR continuum data have been also used to identify new Galactic SNR candidates (Anderson et al., 2017), whereas the line data (RRLs and OH) have been used to study massive star feedback (Rugel et al., 2019, 2025).

The GLOSTAR survey covers the GP in the range $-2^\circ < l < 60^\circ$, $|b| < 1^\circ$ in addition to the Cygnus-X complex at a range $76^\circ < l < 83^\circ$, $-1^\circ < b < 2^\circ$ from 4–8 GHz. The unique aspect of the GLOSTAR survey is its utilization of data from interferometers in multiple configurations to achieve both good angular resolution and sensitivity to emission on large angular scales. The VLA was used in the D and B configurations, providing angular resolutions of $\sim 18''$ and $\sim 1.5''$, respectively. The GLOSTAR survey included observations from the 100-m Effelsberg telescope to obtain zero spacing information. The final data products include radio continuum images from D-

and B-configurations individually, combined D- and B-configuration images, Effelsberg images, and those from combining Effelsberg and VLA D-configuration data. In addition, spectral line data for formaldehyde at 4.8 GHz, methanol masers at 6.7 GHz, and hydrogen RRLs (six lines stacked together) are also available. Using the B-configuration GLOSTAR data, [Dzib et al. \(2023\)](#) and [Yang et al. \(2023\)](#) identified more than 300 H II region candidates, including ~ 120 new ones and ~ 40 variable UCH II regions ([Yang et al. 2025](#)). Using the D-configuration GLOSTAR data, hundreds of large-scale structures, large-scale structures such as star forming complexes and supernova remnants were also identified ([Medina et al., 2019, 2024](#)). Measuring the spectral index by combining the GLOSTAR and THOR surveys and comparing the radio continuum emission with the emission properties at other wavelength regimes from far to mid-infrared, these surveys together allowed the identification and classification of more than 700 H II regions. As with the THOR survey, polarization data have been used to identify SNRs ([Dokara et al. 2021, 2023](#)). In addition, the RRL data have been used to study the properties of 244 individual Galactic H II regions in addition to studying the Galactic electron temperature gradient that arises from the gradient in the chemical composition of the Galactic disk ([Khan et al., 2024](#)).

Finally, the recently released SRAO MeerKAT GP survey (SMGPS; [Goedhart et al. 2024](#)) has mapped a large portion of the visible GP ($2^\circ < \ell < 60^\circ$, $252^\circ < \ell < 358^\circ$, $|b| \leq 1.5^\circ$) in L-band ($\sim 0.89\text{-}1.68$ GHz). With an angular resolution of $8''$ and a theoretical sensitivity of $\simeq 10 - 20 \mu\text{Jy}/\text{beam}$ this survey is the largest, most sensitive and highest angular resolution survey of the GP at ~ 1 GHz to date. From this survey it has been delivered a first catalogue of extended radio sources which includes ~ 4000 known objects such as H II regions, planetary nebulae, supernovae remnants, luminous blue variables and Wolf-Rayet stars ([Bordiu et al., 2025a](#)). A complementary compact source catalogue containing almost $\sim 500\,000$ objects of the same region has recently become available ([Mutale et al. 2025](#); in press).

In Table 1 we summarise the main parameters of these radio surveys and we include also for completeness the main observational parameters of other radio surveys of the GP at lower resolution and sensitivity, including the surveys performed with the Australian SKA pathfinder, ASKAP (adapted from [Bordiu et al. 2025a](#)). In Figure 3 we visualize the GP coverage of all the radio surveys performed to date as described in Table 1.

2.6 The need for a survey of the Galactic Plane at 10-15 GHz

Despite the rich legacy of these ancillary surveys, critical gaps remain in our ability to trace the full continuum spectral energy distribution (SED) of ionised sources, and to distinguish between emission mechanisms. In particular: free-free emission from H II regions becomes increasingly dominant at higher frequencies ($\gtrsim 10$ GHz), while synchrotron emission steeply declines. Ultra- and hyper-compact H II regions, deeply embedded in dense gas, often become optically thin only above ~ 10 GHz. These are crucial phases for studying the onset of massive star feedback and their role in disrupting natal environments. Planetary nebulae and evolved stars often show a mix of optically thin thermal emission and recombination lines; their detection and characterization benefit from higher-frequency sensitivity, especially when embedded in complex fields. For SNRs, while typically dominated by synchrotron emission, high-frequency observations enable better background discrimination and separation from overlapping H II regions or PNe.

Table 1: Main parameters of radio continuum surveys covering the GP in the frequency range 0.8–8.0 GHz. Adapted from Bordiu et al. (2025a).

Survey	Instr.	l Coverage (deg)	b Coverage (deg)	Quadrant	Freq. (GHz)	Bandwidth (MHz)	FWHM (arcsec)	rms (μ Jy/beam)	LAS (arcmin)	Ref.
MAGPIS (1.4 GHz)	VLA	$-10 < l < 42$	$ b < 0.4$	I, IV	5.0	50	6	179	–	1
	VLA+Effelsberg	$5 < l < 48.5$	$ b < 0.8$	I	1.4	95	6	897	$-^a$	2
MAGPIS (5 GHz)	VLA	$-20 < l < 120$ $-10 < l < 40$ $100 < l < 105$	$ b < 0.8$ $ b < 1.7$ $ b < 2.2^e$	I, IV I, IV I	1.4	$-^b$	6	897	–	1
	VLA	$10 < l < 65$	$ b < 1.1$	I	5.0	25	1.5	400	2	3
CORNISH	VLA	$295 < l < 350$	$ b < 1$	IV	5.5	2000	2.5	110	–	4
GLOSTAR	VLA	$-2 < l < 60$	$ b < 1$	I	4–8	2×1024^c	1.5, 18 ^c	123	4	5
		$76 < l < 83$	$-1 < b < 2$							
THOR	VLA	$14 < l < 67.4$	$ b < 1.25$	I	1.42	128	18.1×11.1 to 12.0×11.6	300–1000	2	6
SMGPS	MeerKAT	$2 < l < 60$	$ b < 1.5$	I	1.284	792	8	30	27	7
		$252 < l < 358$	$ b < 1.5$	III, IV						
MGPS	MOST	$245 < l < 365$	$ b < 10$	III, IV	0.843	3	45×45 csc δ	1000	25	8
RACS-low ^d	ASKAP	$\delta \leq 41$ (34,240 deg ²)		full sky	0.887	288	15–25	200–400	10 ~ 30	9
RACS-mid		$\delta \leq 49$ (36,449 deg ²)			1.367	144	≥ 8	150–400	~ 5	10
VGPS	VLA+GBT	$18 < l < 46$	$ b < 1.3$	I	1.4	1.866	60	$-^e$	$-^f$	11
		$46 < l < 59$	$ b < 1.9$							
		$59 < l < 67$	$ b < 2.3$							
SGPS	ATCA + Parkes	$253 < l < 358$	$ b < 1.5$	III, IV	1.4	128	132	<1000	$-^g$	12
		$5 < l < 20$	$ b < 1.5$	I			198			
CGPS	DRAO Synth. Tel.	$74.2 < l < 147.3$	$-3.6 < b < 5.6$	I, II	1.42	35	60×60 csc δ	300	40	13

Notes. ^(a) Without Effelsberg data, the quoted LAS of VLA D-configuration is ~ 16 arcmin. ^(b) Bandwidth variable across different observations, from 40 to 200 MHz. ^(c) Final mosaic obtained by integrating 8 sub-band images formed from two 1-GHz wide bands centred at 4.7 and 6.9 GHz. Angular resolution is 18'' and 1.5'' for D- and B-configuration respectively. ^(d) First data release. ^(e) Noise level ~ 0.3 K. ^(f) Without Green Bank Telescope data, the quoted LAS of VLA D-configuration is ~ 16 arcmin. ^(g) Without Parkes data, the theoretical LAS of ATCA smallest baseline configuration is ~ 23 arcmin.

References. (1) White et al. (2005); (2) Helfand et al. (2006); (3) Hoare et al. (2012); (4) Irabor et al. (2023); (5) Brunthaler et al. (2021); (6) Beuther et al. (2016a); (7) Goedhart et al. (2024); (8) Murphy et al. (2007); (9) McConnell et al. (2020); (10) Duchesne et al. (2023); (11) Stil et al. (2006); (12) McClure-Griffiths et al. (2005); (13) Taylor et al. (2003).

The spectral index (α) across the radio SED provides a direct probe of source optical depth, geometry and internal physical structure. Measurements based solely on low-frequency surveys can misclassify compact sources or miss optically thick components. A dual-frequency SKA-Mid survey centred at ~ 10 and ~ 15 GHz is optimal for isolating the thermal component and it would provide two well-separated SED points, enabling robust spectral index estimation even for unresolved sources and improving classification of jets, winds, and ionised bubbles.

Finally, none of the existing surveys provide uniform, wide-area coverage of the GP at frequencies above 8 GHz. As showed in Figure 4, a high-frequency radio continuum survey with arcsecond resolution and sub-mJy sensitivity would uniquely fill this gap, enabling a statistically robust, morphologically resolved census of ionised sources throughout the Galaxy. Its legacy value lies not only in expanding the known population of H II regions, jets, SNRs, and PNe, but in providing the critical continuum anchor points needed to interpret the physics and evolution of these objects in synergy with molecular and FIR data.

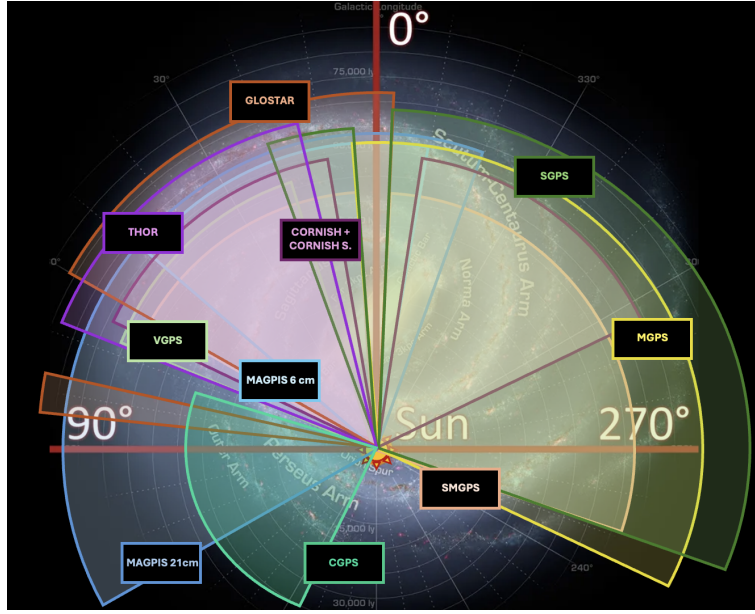


Figure 3: Spatial coverage of the main GP radio surveys in the frequency range $0.8 \lesssim \nu \lesssim 8$ GHz. The RACS survey is not displayed, as it provides full-sky coverage. The detailed observational parameters of each survey are summarized in Table 1.

3 The new science unveiled with a SKA-Mid GP survey at 10-15 GHz

In this Section we highlight more in detail all the new science that can be unveiled with observations of the GP at 10-15 GHz, with particular emphasis on the advantages of performing a GP survey in terms of statistics and coverage of different environments, ranging from H II regions (Section 3.1), to radio jets (Section 3.2), SNRs (Section 3.3), PNe (Section 3.4), and evolved massive stars (Section 3.5).

3.1 H II regions

Massive O and B stars ($M_* \geq 8 M_\odot$) have a profound impact on their surrounding medium all along their life through their radiation and wind. During the formation process they produce copious amounts of ultraviolet photons ($E \geq 13.6$ eV) that ionize their surroundings, forming bubbles of hot ionized gas known as H II regions. These regions expand rapidly, driving ionization fronts that launch shocks into the ambient medium. Recent JWST-MIRI images of nearby galaxies, such as that of the Phantom galaxy (NGC 628), show how important their impact is in shaping the surrounding molecular medium (Watkins et al., 2023). The effect of early radiative feedback on the distribution of molecular material has also been demonstrated in a larger sample of the nearby galaxies sampled by PHANGS, ALMA, and MUSE (Zakardjian et al., 2023) on a spatial scale of 100 pc, providing important constraints on the efficiency of radiative feedback produced by intense and sudden bursts of star formation. This is indeed a critical parameter in galaxy evolution models (Hopkins et al., 2020). However, the impact that such feedback might have on star formation at the resolved scales of few thousands of AU up to few pc is highly debated, despite dedicated observation programs such as FEEDBACK (Schneider et al., 2020). Some numerical simulations suggest that this feedback is

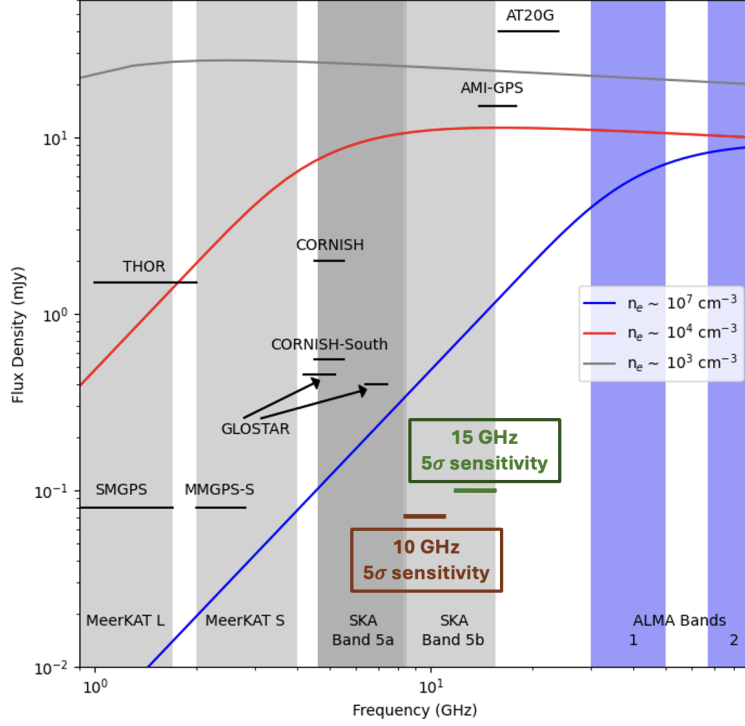


Figure 4: Sensitivity and frequency coverage of selected radio surveys, overlaid with the SEDs of H II regions characterized by different average electron densities: $n_e \sim 10^7 \text{ cm}^{-3}$ (blue curve), $n_e \sim 10^4 \text{ cm}^{-3}$ (red curve), and $n_e \sim 10^3 \text{ cm}^{-3}$ (grey curve). The figure illustrates that the target sensitivity of the proposed GP survey at 10–15 GHz ($20 \mu\text{Jy}$ at 15 GHz; see Section 6) will enable the detection of even the faintest H II regions across the Galaxy with more than 5σ sensitivity ($100 \mu\text{Jy}$).

destructive (Walch et al., 2013; Geen et al., 2015b), but it is still quite debated. Other numerical simulations indicate that, under certain conditions, feedback may instead trigger star formation before the cloud dispersal (Suin et al., 2024). Several observations support the triggering scenario, favouring the formation of a new generation of high-mass stars observed at the edges of ionized (H II) regions in the GP (Deharveng et al., 2010; Thompson et al., 2012; Palmeirim et al., 2017; Zhang et al., 2021; Saha et al., 2024). More generally, the impact of feedback from H II regions depends on several factors, including the strength of the magnetic field in the surrounding molecular cloud, as well as the spatial configuration and total mass of the ionising sources driving the feedback (Suin et al., 2025).

The complex nature of this early radiative feedback and its influences requires deeper investigation and a statistically significant analysis of young massive star forming regions across various Galactic environments. Young H II regions can be identified and characterised using a well-defined set of observational diagnostics.

The earliest phases are characterized by the formation of hypercompact (HCH II), then ultracompact (UCH II), and finally a classical H II regions. Each phase is characterized by distinct physical conditions: HCH II regions represent the very youngest phase of ionized gas, typically with diame-

ters less than about 0.05 pc, high emission measures ($EM > 10^{10}$ pc cm $^{-6}$) and electron densities exceeding 10^6 cm $^{-3}$ (Kurtz, 2005). They are also characterized by extremely broad radio recombination lines (RRL), with typical $\Delta V = 40 - 50$ km s $^{-1}$, and in some cases up to ≈ 100 km s $^{-1}$ (Jaffe and Martín-Pintado, 1999; Sewilo et al., 2004).

As the ionized region expands, it quickly evolves into an UCH II region, with typical scales of ≈ 0.1 pc, electron densities of 10^4 – 10^5 cm $^{-3}$, emission measures $EM \sim 10^7$ – 10^9 pc cm $^{-6}$ and $\Delta V = 25 - 30$ km s $^{-1}$ (Wood and Churchwell, 1989). UCH II regions are often associated with masers and hot molecular cores (Hoare et al., 2007).

With time, they expand into larger, classical H II regions—ionized zones extending up to several parsecs, with densities (> 100 cm $^{-3}$), and visibly shaping their natal molecular clouds (Anderson et al., 2014).

Another crucial diagnostic of the different evolutionary phases is provided by the radio spectral energy distribution (SED), in particular the turnover, or “knee,” frequency where the spectrum transitions from being optically thick ($S_\nu \propto \nu^2$) to optically thin $S_\nu \propto \nu^{-0.1}$ free-free emission. This frequency is strongly dependent on the emission measure and electron density of the ionized gas, and it therefore shifts systematically as the H II region evolves. In HCH II regions, the combination of extremely high electron densities and emission measures pushes the turnover to very high frequencies, often ≥ 20 GHz (Kurtz (2005), see also Figure 4). As the ionized gas expands and densities decrease in the ultracompact phase, the knee frequency correspondingly shifts downward, typically into the 5 – 15 GHz range, while still reflecting significant optical depth at centimeter wavelengths (Yang et al., 2019). In the more extended, evolved classical H II regions, the densities are low enough that the emission becomes optically thin already at frequencies below ~ 1 GHz, producing the nearly flat free–free spectra that characterize mature ionized nebulae (Anderson et al., 2014). Although the evolution of H II regions is more accurately described as a continuum rather than discrete phases, distinguishing different stages remains valuable for capturing key evolutionary moments, particularly the earliest phase of HCH II region formation. This initial phase is critical, as the emerging ionization front begins to significantly influence the star formation process.

Nevertheless, a comprehensive and statistically significant study of HCH II regions (along with a thorough radio characterization of UCH II regions) remains lacking. This is primarily due to the rarity of these objects and the considerable challenges inherent in their identification. The extreme compactness of the HCH II phase (size below ≈ 0.05 pc), which requires angular resolutions better than $\approx 0.5''$ to be resolved at distances up to 10 kpc, combined with the high optical depth at frequencies around 1–8 GHz, where most surveys have been conducted to date, and their relatively short lifetimes ($< 10^5$ years; González-Avilés et al. 2005; Sabatini et al. 2021), have made their detection and detailed study exceedingly difficult.

As a result, the identification of HCH II regions has remained limited to ~ 50 , with most discoveries occurring serendipitously (Yang et al., 2019, 2021). However, this number has increased significantly in recent years by the Search for Clandestine Optically Thick Compact H II Regions (SCOTCH) program (Patel et al., 2023, 2024, 2025). This program systematically mapped the positions of ~ 500 class II methanol masers located in the fourth quadrant and between $2^\circ \leq \ell \leq 20^\circ$

longitude range. These methanol masers are embedded in dense, high-mass clumps (Urquhart et al. 2013a, 2015) and are known to be exclusively associated with high-mass star formation (Pandian et al. 2010; Breen et al. 2013). These sources were observed with the ATCA at frequencies up to 24 GHz and an angular resolution reaching $0.5''$ and have resulted in the identification of 33 new HCH II regions, more than doubling the number previously known (Patel et al., 2025).

The slightly larger size and extended lifetime of UCH II regions have allowed the identification of several hundreds of such objects. Their characterization primarily relies on observations at ≈ 5.5 GHz, with confirmed near- and mid-infrared counterparts, achieved at an angular resolution of $2.5''$ (Irlabor et al., 2023), corresponding to ≈ 0.1 pc at a distance of 10 kpc. These UCH II regions are often physically associated with large-scale diffuse ionized emission, as demonstrated in recent GP radio surveys such as MAGPIS, THOR, and GLOSTAR (see Section 2.5). However, the exact mechanisms behind the formation of such structures are still unclear. A simulation by Wood et al. (2005) indicates that these extended envelopes may have been produced by the leakage of ionizing photons selectively through low-density regions within the boundary of UCH II regions. On the other hand, Williams et al. (2000) indicates that the hierarchical nature of molecular clouds may lead to the clumpy, non-uniform density structures seen in UCH II regions as ionizing photons permeate these clouds. A recent study (Dey et al., 2024) involving UCH II regions with extended emission reveals electron densities (n_e) are within the range of 40 to 260 cm^{-3} , with a median value of 97 cm^{-3} , which is much different than what has been measured in the "standard" warm ionized medium (WIM; $n_e \sim 0.1 \text{ cm}^{-3}$) and typical UCH II regions ($n_e \sim 10^4 \text{ cm}^{-3}$). Similarly, in another study, Goldsmith et al. (2015) reported n_e of 10–100 cm^{-3} with a mean of 29 cm^{-3} within the GP using [N II] fine structure line surveys. Numerous hypotheses are suggested in the literature to explain these intermediate n_e values, including multiple density components within the WIM, and the extended low-density envelopes of H II regions interacting with the large-scale ISM. However, the exact physical processes that could lead to these intermediate n_e values remain elusive.

Although the number of identified HCH II and UCH II regions has become significant, these surveys lacked the sensitivity and angular resolution required to probe the far edges of the Galaxy and to uniformly sample a large population of massive star-forming clumps across different Galactic environments, where extremely young H II regions may still remain undetected. As a result, neither a systematic and unbiased census of HCH II regions on Galactic scales nor a statistically significant characterization of the radio SEDs of HCH II, UCH II, and H II regions across a vast portion of the Galactic Plane has yet been carried out. As illustrated in Figure 4, the proposed GP survey in band 5b will represent a transformative advancement in our understanding of the feedback mechanisms produced by ionised emission from recently formed H II regions. This survey will uniquely cover the $\sim 10\text{--}15$ GHz frequency range, essential for constructing the radio SEDs of H II regions across various evolutionary stages. Thanks to the unique capabilities of SKAO in its AA4 configuration, this GP survey will have a resolution as high as $\approx 0.08''$, a factor of ≈ 10 better than the actual radio surveys across candidate HCH II regions, which will allow us to resolve HCH II regions up to distances of 20 kpc away from us. With the proposed sensitivity of $\approx 0.08 \mu\text{Jy}/\text{beam}$ (see Section 6) it will be possible to probe UCH II regions down to electron densities of the order 850-3000 particles $/\text{cm}^3$ (at a distances of 1 and 12 kpc, respectively, following the calculations in Schmiedeke et al. 2016), almost one order of magnitude lower than typical UCH II regions densities (Yang et al.,

2021).

More details about the role of SKAO in unveiling the physics of H II regions and their feedback are presented in the chapter "The Impact and Environment of Massive Stars and Stellar Clusters" (Anderson et al., 2026).

3.2 Radio Jets from massive regions

In low-mass protostars, accretion is facilitated by the removal of angular momentum via highly collimated, fast-moving jets ($\sim 100 \text{ km s}^{-1}$), which in turn generate molecular outflows, as well as through magneto-hydrodynamic (MHD) disc winds (Frank et al., 2014; Tabone et al., 2020). Investigations in this context (e.g. Skretas et al., 2023; Maud et al., 2015, and references therein) reveal that properties such as outflow mass, momentum, and the entrainment rate of surrounding gas correlate with the luminosity of the star-forming region. In contrast to their low-mass counterparts, massive protostellar jets are typically located at greater distances and within highly complex, clustered environments (e.g., Li et al., 2020, 2022; Izumi et al., 2024; Lin et al., 2025). Although decades of observational studies (e.g., Purser et al., 2016; Li et al., 2019; Rosero et al., 2019; Karska et al., 2025) and numerical simulations (e.g., Grudić et al., 2022; Oliva and Kuiper, 2023; Gardiner et al., 2024; Lebreuilly et al., 2024; Hennebelle and Grudić, 2024; Neralwar et al., 2024) have underscored the pivotal role of jets and outflows as feedback mechanisms in galactic regions of high-mass star formation (e.g. Beuther et al., 2025, and references therein), their precise physical nature remains far from fully understood. For this reason, expanding the currently limited sample is essential for advancing our understanding of the complete physical process: from how these massive jets are launched and propagate into their surrounding environments to how they regulate star formation efficiency.

The proposed SKA-Mid GP survey in Band 5b ($\sim 10\text{-}15 \text{ GHz}$), with its unprecedented cm-continuum sensitivity of $20\text{-}30 \mu\text{Jy beam}^{-1}$, will enable, for the first time, a systematic, sensitive, and unbiased census of ionized jets from massive protostars across the Galaxy. To estimate the impact of this sensitivity, we first consider typical radio jet properties. Literature reports that typical flux densities of radio jets and knots in HH-objects at cm-wavelengths ($\sim 10 \text{ GHz}$) are in the range of ~ 0.1 to a few mJy (e.g., Anglada et al., 2018). Given that the spectral index in this frequency range is usually flat (median ~ 0.45), we can assume these radio luminosities are representative for the SKA-Mid GP survey frequencies ($\sim 9.5 \text{ GHz}$ to 14 GHz). We use the radio luminosity to bolometric luminosity ($L_R - L_{\text{bol}}$) correlation from Anglada et al. (2018), reads as:

$$\left(\frac{S_\nu d^2}{\text{mJy kpc}^2} \right) = 10^{-1.90} \left(\frac{L_{\text{bol}}}{L_\odot} \right)^{0.59}. \quad (1)$$

Based on this linear correlation, we can derive the minimum detectable bolometric luminosity ($L_{\text{bol, min}}$) as a function of source distance (d), using a 3σ detection limit ($\approx 60 \mu\text{Jy}$ for the survey):

$$\log_{10}(L_{\text{bol, min}}) = 3.2 + 1.7 \log_{10}(0.06 d^2). \quad (2)$$

Equation 2 yields the following L_{bol} estimates: at $d = 100 \text{ pc}$, the detection limit is $\sim 0.006L_\odot$ (meaning virtually all YSOs across the full range of protostellar masses with associated radio-jets

would be detectable), while YSOs with $L_{\text{bol}} \gtrsim 14 L_{\odot}$ will be detected at $d = 1$ kpc. In terms of angular resolution, the SKA-Mid GP survey, with a proposed beam size of 80 mas, corresponds to ~ 10 au at 140 pc or ~ 80 au at 1 kpc. Given that emission in radio-jets is dominated by the central optically thick region at these scales, we anticipate that most sources will remain unresolved at this survey resolution. For a comprehensive overview of this topic, readers may refer to the chapter “Jets and outflows in young stellar objects with the SKAO” (Sabatini et al., 2026).

3.3 SNRs

The emission from SNRs is dominated by synchrotron emission arising by their relativist electrons. The typical averaged power-law spectrum of such emission is $S(\nu) \propto \nu^{\alpha}$, with values of α in the range $-1.1 \leq \alpha \leq 0.0$ (Green, 2025), although there is increasing evidence that the power spectrum of an SNR can vary within its interior due to different distribution of the electrons, with variations of α across each SNR (Loru et al., 2024). The synchrotron emission dominates the spectrum at frequencies below the ones provided by our GP survey at 10-15 GHz where, instead, the free-free emission is usually the dominant mechanism of emission. However, it is very likely that in some cases even at these radio frequencies the dominant radiation is the synchrotron one generated by relativistic electrons, as predicted from theoretical models, at least at the shock fronts of H II regions (Padovani et al., 2019). In addition, it is yet unclear if the spectral index of SNRs remains constant up to such high frequencies and, in particular, if some variations may be expected locally across specific electron distributions within a given SNR. This is because only few studies of SNRs have been carried out at radio frequencies $\gtrsim 10$ GHz, and those that exist to date, and they are usually limited to single-dish telescopes.

The expected number of SNRs in our Galaxy is also still debated: despite being among the brightest radio sources in the sky, there is a severe discrepancy between known and expected Galactic SNR numbers, likely due to observational problems related to a lack of sensitive radio data and confusion in the GP (Brogan et al., 2006).

A high-frequency radio survey of SNRs would be invaluable both for identifying new SNR candidates and for conducting detailed spectral index analyses (see Figure 5). This SKA survey of the GP has the potential to uncover hundreds of previously unknown Galactic SNRs. Currently, there exist over 300 SNR candidates (e.g., Anderson et al., 2017; Dokara et al., 2021; Anderson et al., 2025), primarily identified through observations with the JVLA and MeerKAT, which require spectral index measurements to confirm their nature as true SNRs. High-frequency radio observations will provide the key measurements to constrain the spectral energy distribution of both confirmed and candidate SNRs (Figure 5). Moreover, the exceptional angular resolution achievable with SKAO in its final AA4 configuration will enable the resolution of individual SNRs up to distances of 20 kpc, achieving a spatial resolution of approximately 1500 AU (see Section 6). This capability will allow a detailed characterization of the local spatial variation in spectral indices across different regions of each SNR within the 10–15 GHz frequency range. A comprehensive overview of the science that SKA can unveil for SNRs can be found in the chapter , readers may refer to the chapter "Supernova remnants in the new radio astronomy era" (Ingallinera et al., 2026)

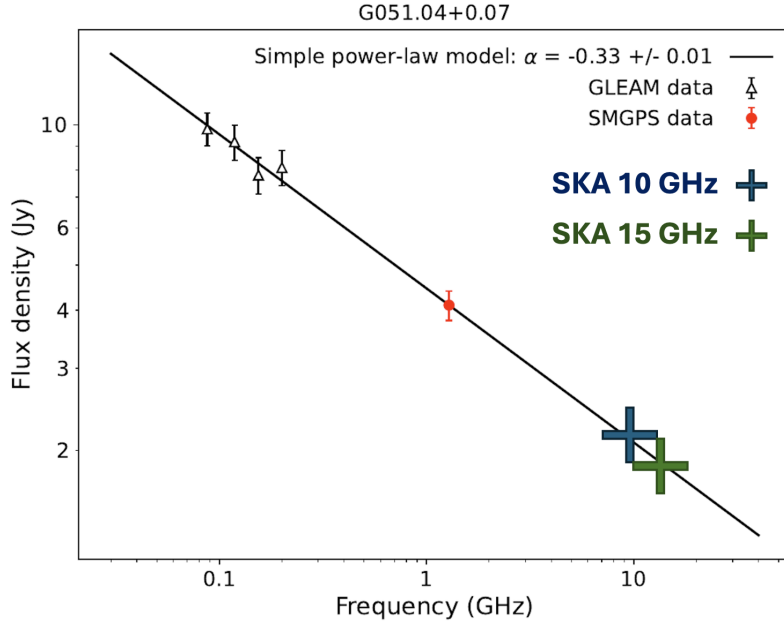


Figure 5: SED of the SNR G051.04+0.07 reported by Loru et al. (2024). This is a typical example of a SNR for which only a few measurements are available, and high-frequency observations, in particular in the 10-15 GHz will give strong constraints.

3.4 PNe

PNe represent one of the final evolutionary stages of stars with (ZAMS) masses between 0.08 and $8M_{\odot}$. After leaving the main sequence, these stars evolve first as red giants and then as AGB stars. In this phase, the stars eject part of their outer layers, which form a circumstellar envelope. After this phase, the stellar wind velocity increases by about an order of magnitude (while its density simultaneously decreases), and the star enters the post-AGB phase. In this stage, the star begins to expose increasingly hotter internal layers until what remains of the initial star reaches a surface temperature high enough to ionize the previously ejected circumstellar material, conventionally marking the birth of a PN.

PNe play a fundamental role in understanding stellar evolution, the chemistry of the interstellar medium, and even some fundamental physical processes related to magnetohydrodynamics. The final stages of the lives of these stars represent a critical moment when the products of nuclear reactions that occurred within them are expelled and alter the chemical composition of the interstellar medium. Understanding these phenomena provides general insights into cosmic abundances and, consequently, the formation of rocky bodies and even life. The origin of the various morphologies of PNe is still debated, but strong indications point to the influence of possible companion stars and interaction with magnetic fields.

For all these reasons, a systematic study of PNe is of fundamental importance, particularly of Galactic ones, which can be studied in greater detail. It is therefore necessary to have the largest possible sample. In fact, it is widely accepted that the number of known Galactic PNe (about 3000) is at least one order of magnitude less than expected. Estimates vary from just over 6000 to more

than 40,000 depending on the method used to calculate the number (see, for example, [Sabin et al. 2014](#)). This discrepancy likely stems, especially in the optical and IR, from the limited sensitivity of current surveys in the GP and from the fact that in these sky regions, the presence of dust absorbs radiation at short wavelengths and re-emits it in the mid- and far-infrared. In this context, radio observations can have a major impact in the search for the missing PNe across the Galaxy because they penetrate the dust, allowing us to observe regions inaccessible in other bands. This task will be fully addressed by future Galactic surveys conducted with SKAO. This potential has already been demonstrated by MeerKAT. Thanks to the SMGPS, 176 new PNe candidates have been identified by visual inspection. When compared with known PNe with the same angular sizes lying in the area covered by the survey, the new candidates show a distribution with a clear peak around Galactic latitude $b = 0^\circ$, while the known PNe are approximately evenly distributed at $b < |1^\circ|$ ([Goedhart et al., 2024](#)). New radio surveys will hence further fill in the gap between known and expected PNe.

As the work with the SMGPS demonstrated, to assess the impact of SKAO, it is essential to consider not only sensitivity limits but also the ability to resolve sources: even if a PN is detected by these radio surveys, identifying it as such may be difficult if it appears point-like, as, for example, its SED might be confused with other source types. The exceptional resolution offered by SKA-Mid will then be fundamental to identifying new possible PN candidates where other probes (like H_α) fail. Furthermore, the synergy with IR surveys such as GLIMPSE, MIPS GAL, WISE or Hi-GAL will enable a robust discrimination between radio emission associated with planetary nebulae and that arising from compact or bright H_{II} regions ([Hoare et al., 2012](#); [Anderson et al., 2012](#); [Yang et al., 2023](#)).

In particular, the proposed survey at 10–15 GHz opens a new avenue for studying the whole population of PNe at global scales in the Galaxy. Above 5 GHz, PNe become optically thin, allowing meaningful morphological analyses and assessments of flux and variability. Assuming a standard spectral index of -0.1 for their thermal free-free spectra allows cross-frequency evaluations on both morphology and flux variability. The SKA-Mid survey will dramatically enhance our ability to track PNe over decades, and though few have attempted this, a striking example is the long-term radio monitoring of NGC 7027, where changes in flux density and stellar temperature over a 25-year period have been measured ([Zijlstra et al., 2008](#)). These changes provided direct insight into the nebula’s expansion and the evolution of its central star.

3.5 Evolved massive stars

The evolution of massive stars remains a challenging topic in modern astrophysics, particularly concerning their late evolutionary phases ([Langer, 2012](#)). It is well established that massive stars undergo a series of short-lived stages before the final core collapse, characterised by widely different spectrophotometric features (e.g., Red Supergiants (RSGs), Luminous Blue Variables (LBVs), Wolf Rayet stars (WRs) and related objects). The occurrence and duration of these phases are influenced by several weakly constrained factors, such as initial stellar mass, rotation, and the mass-loss rate.

In the last decades, radio continuum observations have become an essential tool to investigate massive star mass-loss processes, being highly complementary to infrared observations. The potential of the radio window is threefold: first, observations at \sim GHz frequencies provide independent

diagnostics of the current mass-loss rate (Umana et al., 2005), by means of the direct detection of thermal stellar winds, with a radio spectrum of the form $S_\nu \propto \nu^{0.6}$. Radio observations probe deeper within the wind than shorter wavelength observations; therefore, the resulting mass-loss rate estimates are less affected by the effects of wind structure and clumping. Second, radio observations allow for reconstructing the mass-loss history of the stars, through the detection of circumstellar shells or nebulae (Umana et al., 2010; Buemi et al., 2017). These structures, typically characterised by a flat radio spectrum ($\alpha \sim -0.1$), trace the extended ionised remnants of past mass-loss episodes. The characterisation of these structures contributes to more robust estimates of the total mass-loss budget over the lifetime of stars, which is a crucial piece of information for stellar evolution models. Last but not least, radio observations can also reveal more complex interaction phenomena, such as wind-wind collisions in massive binaries, characterised by non-thermal spectral indices, or bow shocks around runaway evolved massive stars, such as RSGs or WRs (Van den Eijnden et al., 2022).

While targeted observations of single stars have advanced our understanding of these topics, population-sized studies have been hindered by the technical limitations of existing wide-area radio continuum surveys. However, SKAO precursors like ASKAP and MeerKAT are revolutionising the field, allowing for the first time for targeting large samples of radio-emitting massive stars. The transformative potential of these facilities is already evident, with surveys like the SMGPS (Goedhart et al., 2024) detecting a vast number of LBV and WR stars with a plethora of circumstellar structures around them (Umana et al., in prep., Buemi et al., in prep.), clear bow-shocks around cooler RSGs (Buemi et al., in prep.), and even allowing for the identification of new massive star candidates through the detection of circumstellar shells around unclassified variable stars (Bordiu et al., 2025b). Additionally, radio studies of massive stellar clusters are now possible at unprecedented angular resolution and sensitivity. Observing these coeval populations minimizes uncertainties in distance, metallicity, and formation conditions, providing a controlled environment to investigate the effects of the collective feedback from the cluster members.

SKAO will constitute an even larger leap forward, beyond the limitations of current facilities. The increased resolution will allow for disentangling the central stellar sources from the circumstellar envelope in the most compact objects, which appear as blended structures in current interferometric images; the increased instantaneous bandwidth will yield robust estimates of spectral indices, key to verifying the thermal or non-thermal nature of the emission of the stellar and nebular components; and the exceptional sensitivity will reveal faint, extended structures around known evolved massive stars and lead to the discovery of new candidates across the Milky Way. Specifically, a sensitive wide-area survey at 10-15 GHz would be particularly valuable; at these frequencies, the thermal emission from stellar winds is stronger, enabling the measurement of current-day mass-loss rates for nearly entire populations of evolved massive stars. Furthermore, it will allow us to directly monitor their variable radio emission, allowing for the study of the wind instabilities that characterise the final stages of massive star evolution.

The role of SKA in understanding the physics of evolved objects is detailed in the chapter "Evolved massive stars and their impact on their environment" (Buemi et al., 2026).

4 Insights from modelling and simulations

4.1 Modelling free-free and synchrotron emissions

Radio emission from Galactic H II regions comprises both thermal and non-thermal components. [Meng et al. \(2019\)](#) analyzed VLA observations of Sgr B2(DS) between 4 and 12 GHz and identified an expanding H II region showing non-thermal emission all along the expanding shock. [Padovani et al. \(2019\)](#) introduced a model attributing this emission to synchrotron radiation generated by relativistic electrons accelerated at the shock front formed by the expansion of ionized gas. Modelling such emission through direct comparison with radio spectra and morphology constrains key physical quantities, including volume density, magnetic field strength, temperature, and flow velocity in the shock reference frame. The GLOSTAR survey confirmed the presence of non-thermal emission in both compact and extended H II regions across the Galaxy ([Yang et al., 2023](#)), finding that a significant fraction of sources exhibit negative spectral indices in the 4-8 GHz range. These results indicate that synchrotron radiation, although not the dominant emission mechanism, is emitted during the evolution of massive star-forming regions and is associated with the local acceleration of relativistic electrons and with the intensity of the magnetic field, which increases due to compression caused by the expanding shock.

At higher frequencies, such as the ones proposed for this survey, free-free emission by ionized gas is expected to dominate. Nevertheless, residual synchrotron contributions, especially in young or rapidly expanding H II regions, may still influence observed spectra and polarization. Integrating synchrotron modelling into the analysis framework will enable a more comprehensive assessment of the thermal and non-thermal emission balance and facilitate the identification of regions where active particle acceleration and magnetic field amplification occur. Even when non-thermal emission is weak, establishing upper limits will refine constraints on magnetic field strengths, shock energetics, and the transition from ionized to molecular phases in massive star-forming complexes throughout the GP.

4.2 Feedback mechanisms from H II regions in post-processed numerical simulations

The classification of H II regions based on their observed properties (Section 3.1) is further complicated by the tight coupling of the H II region evolution with the properties of the local medium ([Kim and Koo, 2001](#)). In fact, several HCH II and UCH II regions have shown rapid variations of a few percent per year in both luminosity and size ([Franco-Hernández and Rodríguez, 2004](#); [Rodríguez et al., 2007](#); [Galván-Madrid et al., 2008](#); [Gómez et al., 2008](#); [De Pree et al., 2014a](#)). However, it is unfeasible to obtain a detailed overview of the evolution of H II regions and the interaction with their environments solely through observation.

Numerical simulations provide a powerful tool to investigate the temporal evolution of H II regions and of their environmental conditions. In the last few decades, these studies have highlighted how the expansion of the ionised bubble can be delayed, confined, or even reversed. Local flows and turbulence ([Peters et al., 2010a,b](#); [Tanaka et al., 2016](#)), gravitational confinement ([Keto, 2003](#); [Geen et al., 2015a](#)), or pre-main sequence evolution ([Klassen et al., 2012a,b](#)) may explain why some bubbles do not expand monotonically but exhibit a “flickering” behaviour instead ([De Pree et al., 2014b](#)). Simulated regions showed good agreement with observational results, reproducing the

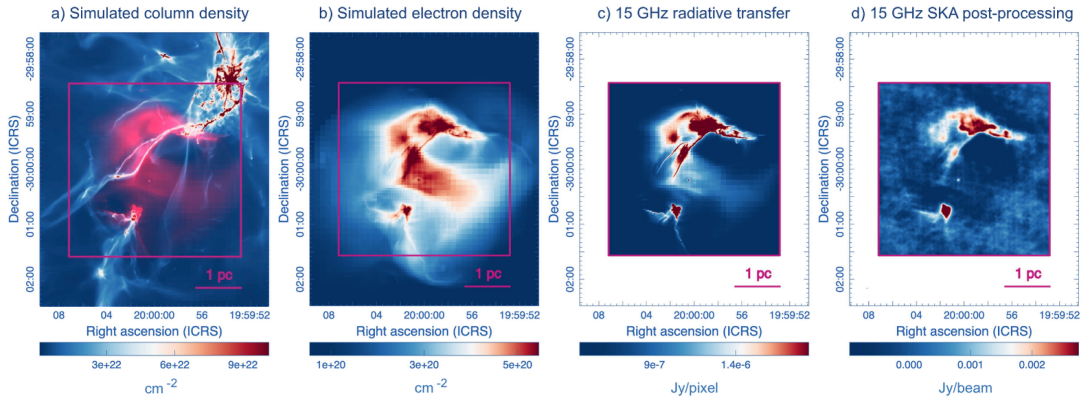


Figure 6: Rosetta Stone step-by-step production of SKA-Mid synthetic observations. *Panel a:* Simulated column density (N_H) obtained with RAMSES for a collapsing $10^4 M_\odot$ cloud. Superimposed in magenta is the 15 GHz emission. *Panel b:* Simulated electron density (n_e) obtained with RAMSES. *Panel c:* Radiative transfer at 15 GHz performed with POLARIS. *Panel d:* SKA-Mid-like post-processing obtained with a tailored CASA routine.

observed flux variations of several percent per year (Peters et al., 2010a), and matching the lifetime of the ultra compact phase ($\gtrsim 10^5$ yr) derived from statistical samples (Peters et al., 2010a; Klassen et al., 2012a; Geen et al., 2015a).

Nonetheless, significant uncertainties remain. Even with the most advanced simulations, it remains infeasible to simultaneously resolve the inner stellar scales of the assembling protostars (tens of AU and below) and track the larger-scale dynamics of the H II region (from a few hundredths to tens of parsecs). Therefore, the codes have to rely on subgrid models to schematically reproduce the formation of the massive star. Furthermore, while some simulations achieve compact lifetimes consistent with observations, in some cases the compact phases lasted up to an order of magnitude longer (Geen et al., 2015a). In such extreme environments, the uncertainties associated with the theoretical models are large, and different approaches may yield quantitatively different results (Klassen et al., 2012a).

This hinders the interpretation of the numerical results, and the physical origin of flickering is still debated. It remains unclear whether the H II regions variability is mainly driven by changes in the protostar itself (Franco-Hernández and Rodríguez, 2004; Klassen et al., 2012a) or by changes in the environment – intermittent accretion flows (Peters et al., 2010a), local turbulence and outflows (Tan and McKee, 2003; Tanaka et al., 2016), or shielding from clumpy structures (Peters et al., 2010b).

Therefore, tighter constraints are essential to disentangle the relative contributions of the various physical processes at play. Observations conducted at radio frequencies enable the examination of these processes through measurements of key local parameters such as electron density, ionisation structure, and gas kinematics. These diagnostics provide important benchmarks for numerical simulations, enabling direct comparison between model predictions and observed quantities.

As recently demonstrated with the Rosetta Stone project (Lebreuilly et al. 2025; Tung et al. 2025; Nucara et al. 2025), such comparison may be misleading, unless the simulations are post-processed

in order to reproduce the observational patterns with the highest level of fidelity. To this end, and in preparation for this future survey of the GP with SKA-Mid, we are developing the first complete end-to-end framework to post-process a suite of simulations as if it was observed with SKA-Mid at 10-15 GHz. For our test case, we considered three-dimensional magnetohydrodynamic (MHD) simulation of a $10^4 M_{\odot}$ collapsing cloud developed with the RAMSES code (Teysier, 2002). Such cloud is in global collapse, it forms several cores and the most massive one develops an H II region after 3.65 Myr.

The simulation has been post-processed using a novel implementation of the POLARIS code (Reissl et al., 2016), specifically developed for this study, now incorporating free-free emission (Reissl et al., in prep.).

Following the Rosetta Stone approach, we have simulated the post-processed ideal sky with a pipeline designed in the CASA software (McMullin et al., 2007) to reproduce the SKA-Mid array configurations and the integration time of our survey (see Section 6). The final product presents with the highest level of confidence how the simulated star-forming region would be seen through the SKA-Mid at 10-15 GHz. The RS framework steps are presented in Figure 6. The time-step corresponding to ~ 0.4 Myr after the formation of the H II region, is shown in Figure 6 (a) with its associated electron density in (b). In Figure 6 (c) we show the POLARIS post-processed map simulating the sky at 15 GHz. In Figure 6 (d) is the post-processed map as seen with SKAO using the configuration of our GP survey at 15 GHz, assuming a pixel size of $0.02''$ and an integration time of 20 seconds per pointing (Section 6).

The synergy between SKAO observations and simulations will provide an accurate framework for exploring the first stages of the interaction between massive stars and their natal environments, and enable a robust test for the competing theories of massive star formation and H II region evolution.

5 Synergies with other SKAO science cases

In this Section, we provide a detailed discussion of the synergies between this survey and other proposed SKAO science cases. As already presented in Section 3, the data from this GP survey at 10-15 GHz will be instrumental in advancing our understanding of the physics underlying radio emission processes in diverse environments, such as H II regions, radio jets, SNRs, PNe and evolved massive stars. Furthermore, this survey will serve as a extremely valuable complementary dataset in other science cases, as discussed in the following.

5.1 RRLs

Radio recombination lines (RRLs) provide complementary information on the physical properties of atomic/ionised gas originating from radio-bright continuum sources detected as part of the GP survey. They can be used to constrain the temperature and density of ionised gas (Luisi et al., 2019), the hardness of ultraviolet radiation (Roshi et al., 2012), and metallicity (Méndez-Delgado et al., 2022). In addition, they may serve as a tracer of gas kinematics, contributing to the understanding of physical processes as well as determining the distances (Anderson and Bania, 2009).

Table 2: The main maser transitions observable in the $\sim 10 - 15$ GHz spectral window.

Molecule	Transition	Freq (GHz)	Occurrence	Ref
CH ₃ OH	$9_{-1} - 8_{-2}$ E($v_t=0$), class I	9.936202	low	Slysh et al. (1993)
CH ₃ OH	$2_1 - 3_0$ E($v_t=0$), class II	12.1786	high	Batra et al. (1987)
H ₂ CO	$2_{1,1} - 2_{1,2}$	14.48848	low	Chen et al. (2017)

As discussed in the Chapter "Spectroscopic surveys with the SKA probing the ionised and molecular Milky Way" ([Karska et al., 2026](#)), there are 17 H α RRLs alone available band 5b, accompanied by the weaker He and C RRLs. The predicted sensitivities of RRLs are sufficient to detect, among other sources, compact H II regions at their earliest stages (see Section 3.1). While the pressure broadening might limit the utility of RRLs at lower frequencies, this is not expected to be the issue in Band 5b, where lines tracing lower density gas are located. Nevertheless, combining survey data at Band 5b with lower frequencies would provide a full census of H II regions spanning the range of properties and evolutionary stages.

5.2 Methanol masers

Within the $\sim 8-15$ GHz range of SKA-Mid band 5b, at least three known maser transitions are present, two methanol masers and one formaldehyde maser (see Table 2). These three transitions have been detected all towards star-forming regions. The most widespread one amongst these, and thus also best studied, is the 12.2 GHz CH₃OH (methanol) maser. It is thought to be excited mainly by warm dust emission, closely connected to the YSO luminosity. In fact, the 12.2 GHz methanol maser is found to be more sensitive to variability in the radiative pumping mechanism, making it an interesting tracer of accretion flares in high-mass stars (see, for example, the case of NGC 6334I [MacLeod et al., 2018](#)). [Breen et al. \(2010\)](#) observed 113 6.7 GHz methanol maser bearing sources with the Parkes 64-m telescope and detected 12.2 GHz CH₃OH towards 68 of these sources, out of which 30 were new detections. The 9.9 GHz class I CH₃OH masers and the 14.4 GHz H₂CO masers are both relatively rare; both are potentially excited in shocked regions, such as where molecular outflows impact the ambient ISM or the expanding H II region.

Just as blind GP surveys have increased the number of known 6.7 GHz CH₃OH masers (e.g., [Pandian et al., 2007](#); [Green et al., 2009](#); [Breen et al., 2015](#); [Nguyen et al., 2022](#)), including the 12.2 GHz line in the SKA-Mid GP survey will find new detections also for this transition. The complete characterization of these masers, together with information of ambient feedback guaranteed by the continuum survey at 10-15 GHz will help to understand better the initial stages of high-mass star formation. A complete description of the maser science enabled with SKA-Mid can be found in the dedicated chapter "Cosmic Rulers: Masers as Tools for Probing Structure in the Galaxy and Beyond, from au to kpc" ([Rygl et al., 2026](#)).

5.3 The Galactic Center

The SKA-Mid GP survey will provide a complementary view of the Galactic Center (GC) to the one provided by the SKAO GC survey (see the chapter "The nearest galactic nucleus: Studying the Galactic Centre with SKA MID", [Schoedel et al. 2026](#)). The SKAO GC survey will cover an

area of $2.0^\circ \times 0.4^\circ$ (equivalent to $290 \text{ pc} \times 60 \text{ pc}$), centered on the massive black hole Sagittarius A* (Sgr A*) using SKA-Mid in Bands 2, 5a and 5b. This survey will perform 1-hour snapshots per pointing achieving continuum sensitivities of $5.3 \mu\text{Jy}/\text{beam}$ at 1.36 GHz, $0.7 \mu\text{Jy}/\text{beam}$ at 6.6 GHz, and $0.8 \mu\text{Jy}/\text{beam}$ at 11.9 GHz. Therefore, the SKAO GC survey will cover a smaller area than that proposed in this chapter (see below), but it will reach a higher sensitivity per pointing (by at least a factor of ≥ 4) compared to the $20 \mu\text{Jy}/\text{beam}$ sensitivity requested for the SKA-Mid GP survey. In addition, in the SKAO GC survey multi-epoch observations over a time-span of 10 years will be carried out toward the Nuclear Stellar Cluster (NSC) and comparison fields, to uncover the dark cusp around SgrA*.

Although with a more limited spatial extent than the SKA-Mid GP survey, the higher sensitivity of the SKAO GC survey will unveil the population of the faintest stellar remnants, massive stars and pulsars in the GC, and it will allow studies of the properties and physics of the large-scale magnetic field, the origin of non-thermal filaments (unveiling the morphology and distribution of the faintest ones) and of the Galactic chimney. The molecular line emission detected within the SKAO GC survey will also enable studies of the present day star formation (not only in the Central Molecular Zone, but also at the intersection with the dust-lane), as well as the discovery of prebiotic molecules such as simple sugars (Schoedel et al., 2026). Note that the SKAO GC survey will not provide any intra band spectral index, as it will be provided by the SKAO GP survey, and hence the GP survey will provide complementary data on the SED of the objects that are detected by both surveys.

6 The 10-15 GHz SKA-Mid GP survey design

We aim to map a large portion of the GP visible from the SKA-Mid site, in South Africa, for a total of 630 deg^2 of the GP. This field of view includes the inner part of the I quadrant the II and the IV quadrant, including the Galactic Center ($-180^\circ < \ell < 30^\circ$, $|b| \leq 1.5^\circ$).

Thanks to the SKAO correlator, we can simultaneously observe the GP around 10 and 15 GHz using two spectra windows with bandwidths of $\sim 2.5 \text{ GHz}$ each. Since Band5B receivers will cover the range of frequencies $8.3 \leq \nu \leq 15.3 \text{ GHz}$, we will center the rest frequency of the two spectral windows to approximately 9.5 GHz and 14.0 GHz respectively. We will perform the calculation at 14.0 GHz, which is the band with the smaller field of view and the longest integration time to reach the desired sensitivity.

The SKAO AA4 standard configuration includes 133 antennas with a dish size of 15 m. According to the official SKAO specifications, at the reference frequency of 14 GHz, the AA4 configuration corresponds to a field of view (FoV) of each pointing of $\sim 6.0'$, a synthesized beam of $\approx 0.07''$ (assuming natural weighting), and the largest recoverable scale is $\sim 2'$.

With such FoV, in order to map the entire 630 deg^2 of the proposed survey we would need in principle a total of $210^\circ \times 3^\circ / (6.0' \times 6.0' / 3600) = 63000$ pointings. We also assumed a factor 1.96 due to the mosaicking to reach the desired sensitivity. This factor has been derived to guarantee the necessary degree of overlaps to reach uniform sensitivity across the entire GP. Combining all these parameters, we obtain a final number of $210^\circ \times 3^\circ / (6.0' \times 6.0' / 3600) \times 1.96 \sim 124000$ pointings. The sky coverage and survey strategy are showed in Figure 7.

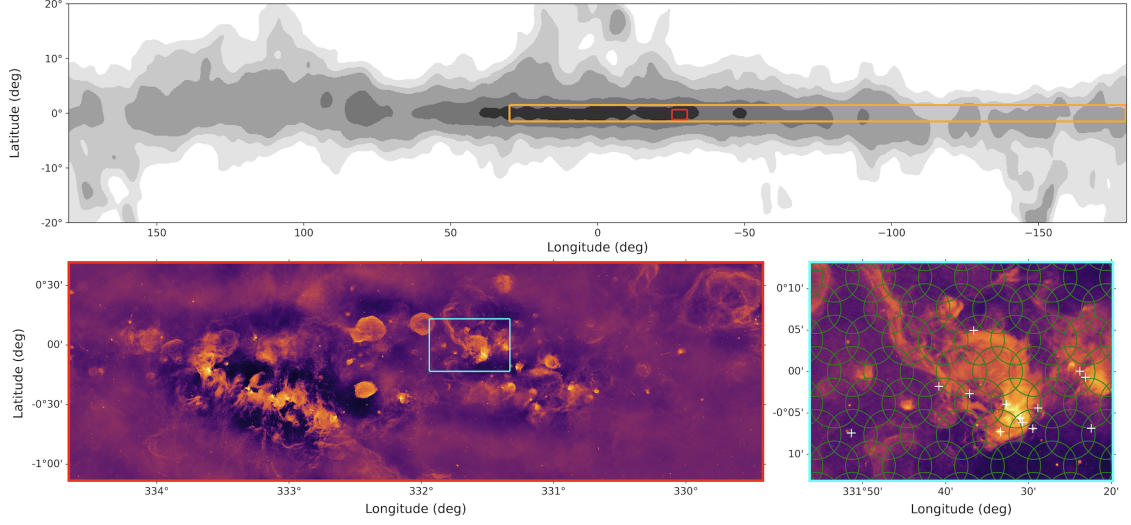


Figure 7: *Top panel:* greyscale image of the Galaxy with overlaid the sky coverage of the SKA-Mid GP survey (orange box). *Bottom left panel:* zoom-in on the Galactic region $330^\circ \lesssim \ell \lesssim 334^\circ$ observed at 1.3 GHz (Goedhart et al., 2024). This representative portion of the GP contains at least 3 confirmed supernova remnants, 4 additional SNR candidates, 5 PNe candidates, and ~ 80 ALMAGAL sources. *Bottom right panel:* a detail of the region with the sky coverage of the proposed mosaic survey at 15 GHz, with a FoV per pointing of $6'$.

The exquisite sensitivity of the SKAO telescope allows us to reach a sensitivity of $20 \mu\text{Jy}/\text{beam}$ with only ~ 20 s of integration time per pointing at 14 GHz (which is equivalent at $\sim 14 \mu\text{Jy}/\text{beam}$ per pointing at 10 GHz). This value does not take into account the increase in sensitivity achieved in mosaic mode due to the overlapping of the FoV of different pointings. We estimated this increase using the MeerKAT Mosaic calculator to look at the ratio of sensitivity achieved inside the area of a simulated mosaic with respect to the sensitivity achieved at the edge of the same simulated mosaic, where there is not the effect of the overlapping FoV. The ratio found with the MeerKAT Mosaic simulator is an increment in sensitivity of ~ 1.17 thanks to the mosaicking. Therefore, we can reach the required sensitivity of $20 \mu\text{Jy}$ with a reduction of the integration time of a factor $(1/1.17)^2 \simeq 0.73$. The integration time therefore becomes $20 \times 0.73 \simeq 14.5$ s per pointing. Finally, we also consider a possible overhead factor of 20%.

Altogether, the SKA-Mid survey of the GP at 10-15 GHz carried out in AA4 configuration requires a total time of $14.5 \text{ s} \times 124000 \times 1.2 \simeq 600 \text{ h}$.

The unparalleled combination of angular resolution and sensitivity achievable only with the SKAO in its AA4 configuration enables observations of sources extended up to 10 pc with a resolution of $\simeq 1500$ AU at a distance of 20 kpc, sufficient to resolve the earliest stages of UCH II region formation and to detect and characterize radio jets up to $\simeq 10$ kpc away, while its sensitivity ensures the identification of even the faintest UCH II regions with electron densities exceeding 10^7 cm^{-3} (Figure 4). Remarkably, all these results are achievable with only ~ 600 h of observation time, making the proposed GP survey fully feasible.

If we assume the AA* array configuration, the time requested to complete the GP survey at the same sensitivity of $20 \mu\text{Jy}$ increases by a factor $\simeq 3.1$, therefore the total time requested will be $\simeq 1800$ h. At the same time, the synthesised beam will decrease from an average FWHM of $\simeq 0.07''$ to $\simeq 0.16''$. Such survey will still be transformational for our understanding of the feedback mechanisms across the GP and it will allow to resolve UCH II regions and radio jets up to $\simeq 10$ kpc and $\simeq 5$ kpc away from us, while missing the most distant objects within the GP.

Finally, we want to stress the importance to complement the SKA-Mid observations in band 5b with single-dish data. Every interferometer filters out spatial scales above a frequency-dependent threshold, the so-called Largest Angular Scale (LAS), which can be approximated as $\theta_{\text{LAS}} \sim \lambda/b_{\text{min}}$, where $\lambda = c/\nu$ is the observation wavelength and b_{min} the interferometer’s shortest baseline. Sources with an extension comparable to, or greater than the LAS are difficult to recover. From MeerKAT observations we can infer a LAS for SKA-Mid at ~ 1 GHz of about half a degree (Loru et al., 2024). In band 5b, zero-spacing problems may arise for sources of the order of a few arcminutes. The combination of interferometer data with single-dish telescope can mitigate this limitation. A single-dish telescope with a diameter $D > b_{\text{min}}$ can be used, to recover the missing information from the inner part of the uv -plane. In the southern hemisphere, the only suitable single-dish telescope is currently Parkes, which is planned to mount a new high-frequency receiver (UWH), expected in 2027, covering SKA-Mid bands 5A and 5B. Even if all-sky surveys with this new receiver are impractical, interesting portion of the sky may be imaged and combined with the data of the SKA-Mid GP survey in order to properly study sources more extended than the SKAO LAS.

7 Conclusions

The proposed 10–15 GHz SKA-Mid survey of the GP will represent a decisive step forward in our understanding of the ionised Milky Way. By bridging the gap between existing low-frequency radio surveys and the FIR and millimetre domain, it will provide the first comprehensive, high-resolution census of ionised structures, ranging from HCH II to UCH II regions, radio jets, PNe, SNRs, and evolved massive stars across the entire GP. This survey will take fully advantage of the spectacular sub-arcsec angular resolution, sub-mJy sensitivity, and wide-area coverage that SKAO in AA4 configuration can offer. With ~ 600 h of observations in Band 5b we will be able to map a total of 630 deg^2 of the GP, including the Galactic Center ($-180^\circ < \ell < 30^\circ$, $|b| \leq 1.5^\circ$). Our survey will allow us to resolve feedback processes from massive stars and protostars over scales from a few hundred AU to several pc across a vast range of different Galactic environments.

The resulting dataset will constitute a legacy resource for decades to come, offering essential synergy with ALMA, MeerKAT, JWST, and future optical and IR surveys, and serving as the cornerstone for multi-scale analysis of star-formation feedback and its interplay with gravity and turbulence.

Ultimately, the 10–15 GHz SKA-Mid GP survey will not only complete the continuum view of our Galaxy but will also establish a benchmark for future studies of ionised feedback in other galaxies, thereby advancing one of the central goals of modern astrophysics: to understand how stellar feedback governs the life cycle of baryons from the birth of stars to the assembly of galactic structure.

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