The impact of SKA on Galactic Radioastronomy continuum observations

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#GalacticSKA
Large area surveys:

- Statistical studies of different populations of radio emitting Galactic Objects.

✓ All-sky survey
✓ Deep survey

The place where you look at makes the difference: most of the Galactic sources localised in/close the GP

Deep pointed observations:

- More detailed studies of particular classes of Galactic object;
- Variabilities studies;

All the estimates in the talk are based on Dewdney et al., 2013 and Braun 2013
SKA All-sky survey

SKA\textsubscript{1} Reference Surveys @ Band 2 (Full BW)
SKA1\_SUR (rms 2\(\mu\)Jy/b, 2") 2yr, All-sky

Much deeper and higher resolution than any other survey

✓ The most complete catalogue of the Galactic Plane to date

Continuum Galactic Studies: try some commensality with other surveys:

SKA\_MID Deep survey @ 4.8 GHz for H\(_2\)CO,
Continuum (rms 0.4 \(\mu\)Jy/b, 0.3")
500 hrs, 200 deg\(^2\)

See Mark’s talk
SKA1-All-sky will bridge the gap in sensitivity and resolution between available GP surveys:

- High angular resolution, limited areas:
  - CORNISH (Purcell and Hoare, 2010) 6cm, 1-6 arcsec, ≈100 deg², few mJy
  - MAGPIS (Helfand+ 2006) 20/6cm “”

- Lower angular resolution, wide areas:
  - CGPS (Taylor+ 2006), 20cm, arcmin, several 100 deg², few mJy
  - SGPS (McClure-Griffiths+ 2005) “”

EMU (Norris+, 2012): ASKAP, 1.4 GHz, 50μJy (5σ), 10 arcsec
MeerGAL (Pis- Thompson and Goedhart ): MeerKAT, 14 GHz, 30μJy (5σ), 0.8 arcsec

Results from EMU will help with:
- Issues from complex continuum structures associated with GP
- Variability
Synergy with multi-frequency Galactic Plane surveys

For several classes of Galactic objects robust classification is possible only by combining radio and IR information

| Survey     | Wavelength | Beam (′) | \(l\) Coverage  | \(b\) Coverage | Probe                        | Reference               |
|------------|------------|----------|------------------|----------------|------------------------------|-------------------------|
| IPHAS      | \(\text{H}\alpha\) | 1.7      | \(30^\circ < l < 210^\circ\) | \(|b| < 5^\circ\) | Nebulae & stars              | Drew et al. (2005)      |
| UKIDSS     | JHK        | 0.8      | \(-2^\circ < l < 230^\circ\) | \(|b| < 1^\circ\) | Stars, Nebulae               | Lucas et al. (2008)     |
| VVV        | ZYJHK      | 0.8      | \(-65^\circ < l < 10^\circ\) | \(|b| < 2^\circ\) | “                           | Minniti et al. (2010)   |
| GLIMPSE    | 4-8 \(\mu\)m | 2        | \(-65^\circ < l < 65^\circ\) | \(|b| < 1^\circ\) | Stars, Hot Dust              | Churchwell et al. (2009)|
| MSX        | 8-21 \(\mu\)m | 18       | All               | \(|b| < 5^\circ\) | Warm Dust                    | Price et al. (2001)     |
| MIPS GAL   | 24,70 \(\mu\)m | 6, 20    | \(-65^\circ < l < 65^\circ\) | \(|b| < 1^\circ\) | “                           | Carey et al. (2009)     |
| AKARI      | 50-200 \(\mu\)m | 30-50    | All sky           | \(|b| < 1^\circ\) | Cool Dust                    | White et al. (2009)     |
| Hi-GAL     | 70-500 \(\mu\)m | 10-34    | All               | \(|b| < 1^\circ|^{\text{a}}\) | “                           | Molinari et al. (2010)  |
| JPS        | 450,850 \(\mu\)m | 8-14     | \(10^\circ < l < 60^\circ\) | \(|b| < 1^\circ\) | “                           | Moore et al. (2005)     |
| ATLAS GAL  | 850 \(\mu\)m | 19       | \(-60^\circ < l < 60^\circ\) | \(|b| < 1.5^\circ\) | “                           | Schuller et al. (2009)  |

Hi-GAL (Molinari+ 2010)  \(345^d<l<330^d\)  
\(R=350\mu m; \ Y=160\mu m; \ B=70\mu m\)
About 400 “bubbles” found in MIPSGAL (24 µm)
Carey et al., 2009, Mizuno et al 2010

Possibly related to late stages of Stellar evolution
only 10% have been identified

Radio observations:
- Morphological
- Spectral index
- Polarization
to discriminate
LBV, PN, WR (thermal)
from SNR (non-thermal)

Ingallinera+ 14
SKA results will address several science topics:
(list not exhaustive!)

**Massive stars formation**

- A census of the early stage of massive stars formation in the GP
- Giant HII and interaction with their environments: triggered star formation

**Evolved stars**

- Detection of SNRs
- Detection of PNs

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To derive accurate space density and rate formation
Radio needed for robust identification

**Radio Stars**

**Serendipitous discoveries**
Access to all stages of the evolution of HII regions

Earliest stages of HII development:
• Ultra-compact (UCHII) \( d > 0.02 \) pc
• Hyper-compact (HCHII) \( d < 0.02 \) pc
• Angular dimension < 1” ( @ 1kpc)

Turnover frequency function of the EM

HCHII
• Missed at 5 GHz
• Examples serendipitously detected

Courtesy of M. Thompson
Massive star formation: the birth of a HII region

✓ Access to all stages of the evolution of HII regions

Earliest stages of HII development:

- Ultra-compact (UCHII) $d > 0.02$ pc
- Hyper-compact (HCHII) $d < 0.02$ pc

Need high frequency:
Frequencies $< 5$ GHz select against dense plasma ($n_e \geq 10^5$ cm$^{-3}$)
Against the youngest and densest objects

Kurtz, 2005
Late stages of stellar evolution: Unveiling the missing population of PNe

• PNe: late stage of stellar evolution of stars with mass 0.8-8 $M_{\text{Sol}}$

1. MISSING POPULATION
   • Estimated population of PNe 23000 (Zijlstra and Pottash, 1991)
   • Only 3000 known (Frew and Parker, 2010)
   • Very bright in radio: $\approx 700$ in NVSS

   Important for stellar evolutionary models

2. ORIGIN OF IONIZED EJECTA
   • Optical HST images reveal bi-polar morphologies
   • Shaping agent? B?
Late stages of stellar evolution: Unveiling the missing population of PNe

2 ORIGIN OF IONIZED EJECTA
• Shaping agent?

Consistent with a Synchrotron jets
Need to investigate for larger sample
-SED

Radio continuum map of IRAS 15445-5449 @22 GHz (ATCA)
Perez-Sanchez +13
420 radio detected stars (mostly VLA) (Gudel, 2002)

$L_{\text{radio}}$ a small ($10^{-12}$ Sun) fraction of $L_{\text{tot}}$

Radio probes astrophysical phenomena non detectable by other means:

- B and its topology in flares stars, RS CVn
- HII region in dust enshrouded sources
- Winds-winds interactions....

Important for:

- Stellar evolution
- Physical processes in a wider context.
**Stellar radio emission**

$$S_v = \frac{T_B}{1960} \cdot \frac{\theta_1 \theta_2}{\lambda_{cm}^2} \text{ Jy}$$

The brightest stellar radio emission associated with:

- **small $T_B$**
  - Large emitting surface
  - Thermal radio source
  - Bremsstrahlung
  - Not variable

- **high $T_B$**
  - Small emitting surface
  - Non-thermal radio source
  - Synchrotron / Gyrosynchrotron
  - Variable
Stellar winds and nebulae around massive stars (LBVs)

free-free from stellar winds

Physical quantities from Radio Observations

\[ S_\nu \approx \nu^\alpha \quad \alpha = 0.6 - 2 \]

Mass-loss rate
\[ \dot{M} \propto S^4 \nu D^2 \]

Mion = mass of the ionized nebula

VLA-A, 5 GHz (6cm)

VISIR 12.25 μm

IRAS 18576+0341
Buemi+, 2012

Umana +, 2005
The brightest stellar radio emission associated with:

- Solar-type, non-thermal phenomena ($high \ T_B$): gyrosynchrotron, related to a strong and (often) variable stellar $B$

Magnetically active stars and binary systems (Flares stars, RS CVns, Algols)

- **Gyro-synchrotron** quiescent periods - slowly varying flux density, up to several mJy
- Active periods - series of strong outburst, up to 1Jy

![Graphs showing flux density vs frequency for HR 1099]
Active binary systems

- Not clear relation between quiescent and flaring periods.

- Not clear origin for quiescent emission.

- Both quiescent and active periods are related to solar-type magnetic activity (observed also in other spectral ranges)

Radio flares in large magnetic structures (loops); in binaries could be intersystem: 

\textit{Algol} 

(Mutel +., 2009)
Stellar radio flaring emission

Coherent events (usually observed in addition to gyrosynchrotron)
- Modelled as electron cyclotron maser emission (ECME)

Astrophysical environments
  common ingredient strong B and energetic particles

Active stars and stellar systems (Osten + 2004; Slee + 2008..)

Ultra Cool Dwarf (Hallinan +2008, Route and Wolszczan, 2012)

CPs stars (Trigilio + 2000, 2008, 2011; Ravi + 2010)

General Characteristics
  Polarization up to 100%
  Frequency structure
  Narrow bandwidth
  Short duration (time)

Emission frequency scales with the local magnetic field strength
CPs stars

CU Vir

- Coherent bursts are still present after 10 yrs (Trigilio et al., 2008, 2012, Ravi et al., 2012) (steady phenomenon)

- Little delay in phase modelled as a spin-down of CU Vir $\Delta P \sim 1$ sec ($P=0.52$ days)

Perfect template for stellar magnetospheres?

CPs stars, Strong magnetic fields Mainly dipolar Steady
The actual knowledge of stellar radio emission suffers of:

- **limited sensitivity:**
  Radio star with radio luminosity similar to the quiescent Sun detected only very recently.
  JVLA Villadsen+14 (detection of solar-type stars)
  few $\div \mu$Jy, $S/N = 5,6$

- **selection bias:**
  based on targeted observations aimed at addressing specific astrophysical problems

However, starting from some information on radio luminosity

| Objects                        | References                                      |
|-------------------------------|-------------------------------------------------|
| Flares stars (and late-M)     | Seaquist, 1993; Gudel 2002; Berger + 2005       |
| PMS                           | Gudel, 2002                                      |
| Active binary systems         | Moris and Mutel, 1988, Umana +., 1993            |
| OB-WR                         | Seaquist, 1993; Bieging +, 1989                  |
| CP                            | Leone +., 1992; Trigilio + 1994                  |
SKA detection forecast

Schematic radio continuum spectrum of classes of radio emitting stars. Assumed distances are: 10pc flare stars, 100pc RS and PMS, 500pc CP, 1kpc OB and SG

SKA1 and SKA2 performances as in Dewdney 2013 and Braun 2013

1 hr sensitivity

| Thermal Stellar winds OB, WR |
| Non-therm RS, flare stars, PMS |
| Flares from a Sun-twin at 10pc |

SKA1 will detect a solar analog (at 10pc) BUT only at band 4 and 5
SKA forecast

SKA1 all WR, and OB stars of the Galaxy will detect CP, PMS, RSCNS and SG up to the GC

SKA2 All of the above classes of stars in the Galaxy and in the nearby Galaxies Solar analog up to 50pc
The SKA Radio HR Diagram

A real REVOLUTION in Stellar Astrophysics

No more biased, targeted observations
But real Population Studies
Several areas of stellar Radioastronomy will particularly benefit from SKA

- Studies of magnetic activity in active stars and stellar systems
  *Solar-stellar connection*

- Search for coherent events in different classes of star

- Mass-loss from massive stars (Mass-loss archeology)

List is NOT exhaustive
The impact of SKA on stellar coronae

The Solar-stellar connection

SKA1, 10m sensitivity, will detect all kinds of known non-thermal emitting stars up to few kpc
SKA2, 10m sensitivity, will detect them all over the Galaxy

- Identify radio coronae across wide range of stellar type
- Identify radio flares (multi-epoch observations?)
  - typical behaviour (occurrence rate, duration..) from a statistical study of a larger source population
    (ranges of mass and evolutionary stages)
- Comparison with solar-type magnetic activity
Detailed studies of a large number of stellar coronae:

- understanding of energy release in upper atmospheres of stars with different ages and masses.

- Study the correlation with the hot local plasma (x-ray)

Common energy reservoir for particles acceleration and plasma heating?

Gudel and Benz, 1993, Benz and Gudel 1994
Variability Studies:

SKA1: Detailed studies of a large number of stellar coronae

SKA1_MID: 5 sec $\approx$ 20 $\mu$Jy
A solar-type weak flare (0.1mJy @ 1.3 pc)
observed with $\Delta t=5s$ with $S/N=5$

- Addressing the problem of coronal heating by microflares
  (quiescent radio corona maintained by series of small flares)

- Evidence for rotation modulation?

Long-term monitoring could uncover magnetic activity cycle
The impact of SKA on coherent events

- Detection of coherent emission from a larger source populations
  - Implication for magnetic activity and dynamos studies
  - Emission mechanisms.

- Detailed studies of stellar magnetospheres
  - Modelling coherent radio emission from CP, UCDs and Active binaries
    - Modelling coherent radio emission from CP, UCDs and Active binaries
    - B, N_{non-thermal} and spectral energy distribution

- If CE is stable (CU Vir): timing the star rotation
The impact of SKA on stellar winds

For two values of stellar wind:
\[ V_1 = 100 \text{ km/sec} \]
\[ V_2 = 1000 \text{ km/sec} \]

SKA1 and SKA2 performances as in Dewdney 2013

\[ \dot{M} \propto S^4 \nu \Delta^2 \]

In 10 m, SKA will detect very small \( (10^{-7} M_{\odot}/\text{yr}) \) mass-loss at the GC

Studies of large population of massive stars (in all stages of evolution) will be performed in massive cluster located in GC (Central Cluster, Arches and Quintuple)

Assumed distance 8 kpc
The impact of SKA on stellar winds

Studies of large population of massive stars (in all stages of evolution) could be performed in nearby Galaxy (i.e. LMC)

Now limited only to very high mass-loss objects (Agliozzo +, 2013)

LMC as seen by Herschel (red 250 µm, green 100 µm) and Spitzer (blue 70 µm)
Credit: ESA/NASA/JPL-Caltech/STScI
Massive star formation: the birth of a HII region

Courtesy of R. Cesaroni
Active binary systems

Different activity diagnostics are phase modulated

Active structures spatially correlated

Coronal loop

Photospheric spot