Galactic Science

The impact of SKA on Galactic Radioastronomy

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SKA1 Continuum Science Assessment Workshop
Manchester Sep. 2013

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;

SKA all-Sky/Deep survey:
The most complete catalogue of the Galactic Plane to date

Much deeper and higher resolution than any other survey

SKA1_SUR (3.7 μJy (1 hr), 0.9")
SKA1_MID (0.7 μJy (1 hr), 0.22")

Dewdney et al., 2013

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 deg^2, few mJy
MAGPIS (Helfand et al., 2006) 20/6cm " "

✓ Lower angular resolution, wide areas:

CGPS (Taylor et al., 2006), 20cm, arcmin, several 100 deg^2, few mJy
SGPS (McClure-Griffiths et al., 2005) " "

EMU (Norris et al. 2012): ASKAP, 50μJy (5σ), 10 arcsec

SKA results will address several science topics:

(list not exhaustive!)

Massive stars formation

- A complete 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

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

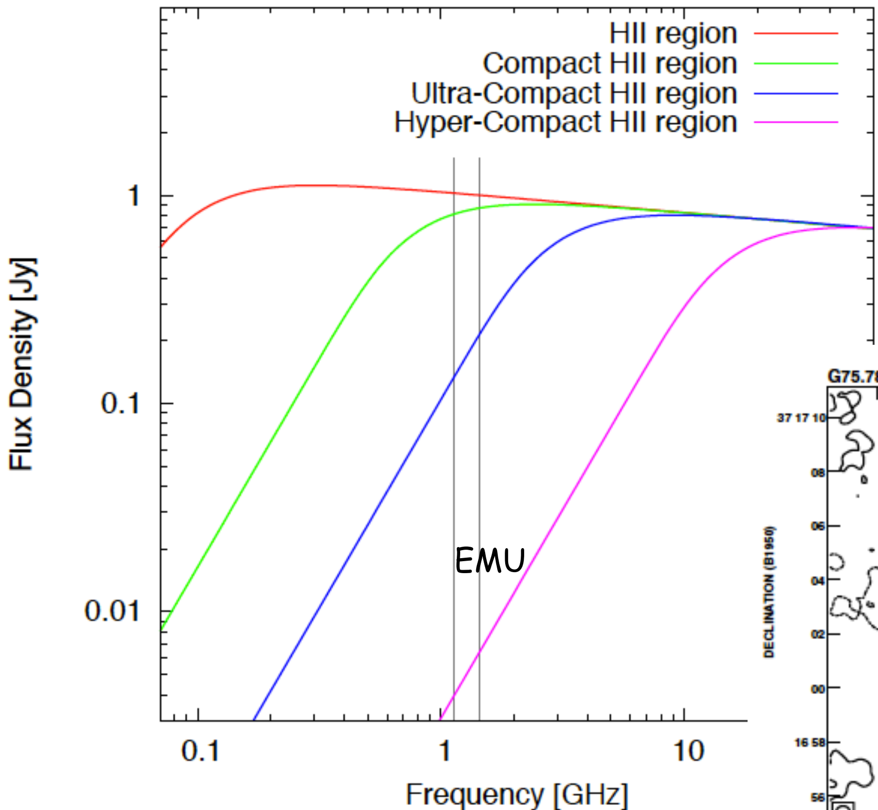
Radio Stars

Serendipitous discoveries

Massive stars formation

SKA will trace one of the major component of the Galaxy: The ionized gas

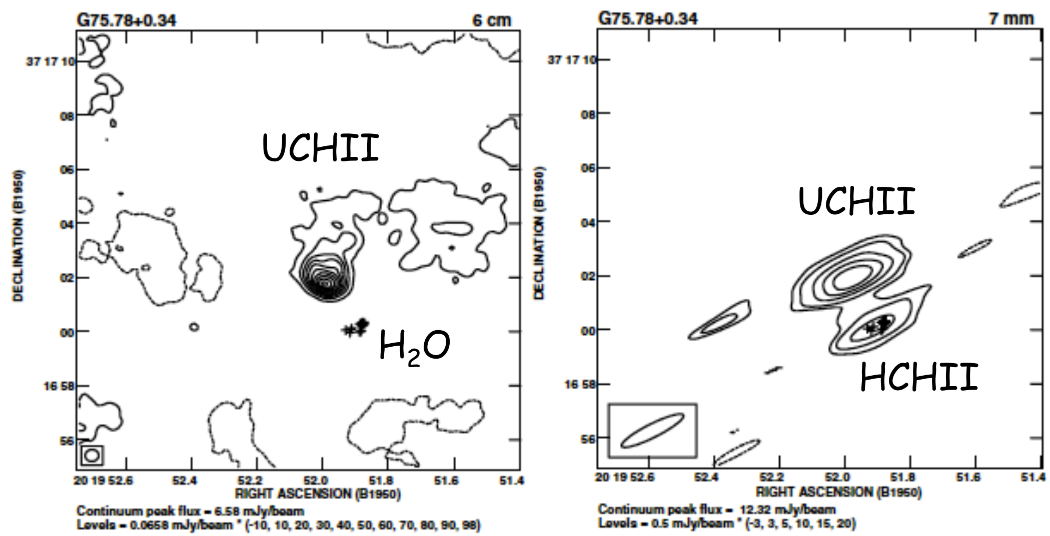
- ✓ Access to all stages of the evolution of HII regions



d>0.02 pc
d<0.02 pc

Not clear if they constitute an evolutionary sequence

← Turnover frequency function of the EM



Kothes, 2012

Kurtz, 2005

Massive stars formation

SKA will trace an of the major component of the Galaxy: The ionized gas

✓ Access to all stages of the evolution of HII regions

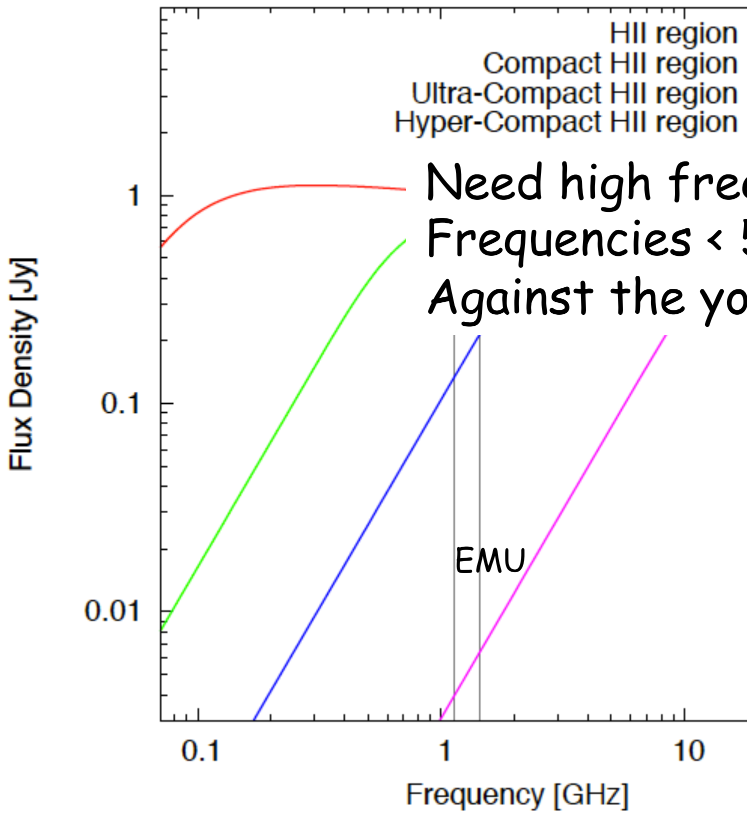
Ultra-compact d>0.02 pc

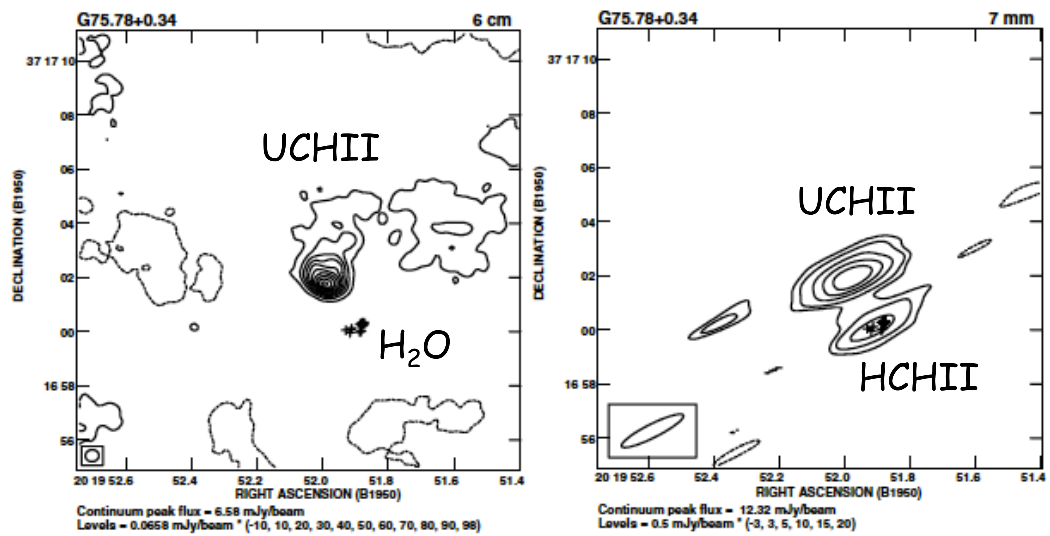
Hyper-compact d<0.02 pc

Need high frequency:

Frequencies < 5 GHz *select against dense plasma* (ne ≥10^5 cm^{-3})

Against the youngest and densest objects





Kothes, 2012

Kurtz, 2005

Late stages of stellar evolution

SKA will allow a complete census of evolved stars (with extended atmospheres):

PNe (0.8-8 MSol)

Estimated population of PNe
23000 (Zijlstra and Pottash, 1991)
Only 3000 known (Frew and Parker, 2010)

Possible cause: a strong bias
towards bright, not extincted objects

Missing populations:
- Compact, young
- Located very close to the GP

SNR (>8 MSol)

Estimated population of SNRs
1000 (Helfand et al., 2006)
Only 274 known (Green, 2009)

Possible cause: a strong bias
towards bright, extended objects

Missing populations:
- Compact, young SNRS
- Low surface brightness

✓ Complete samples of PNe and SNRs will constrain their density and distribution in the Galaxy.

✓ Implications for models of both solar-type and massive stars evolution.

The impact of SKA on Galactic Science

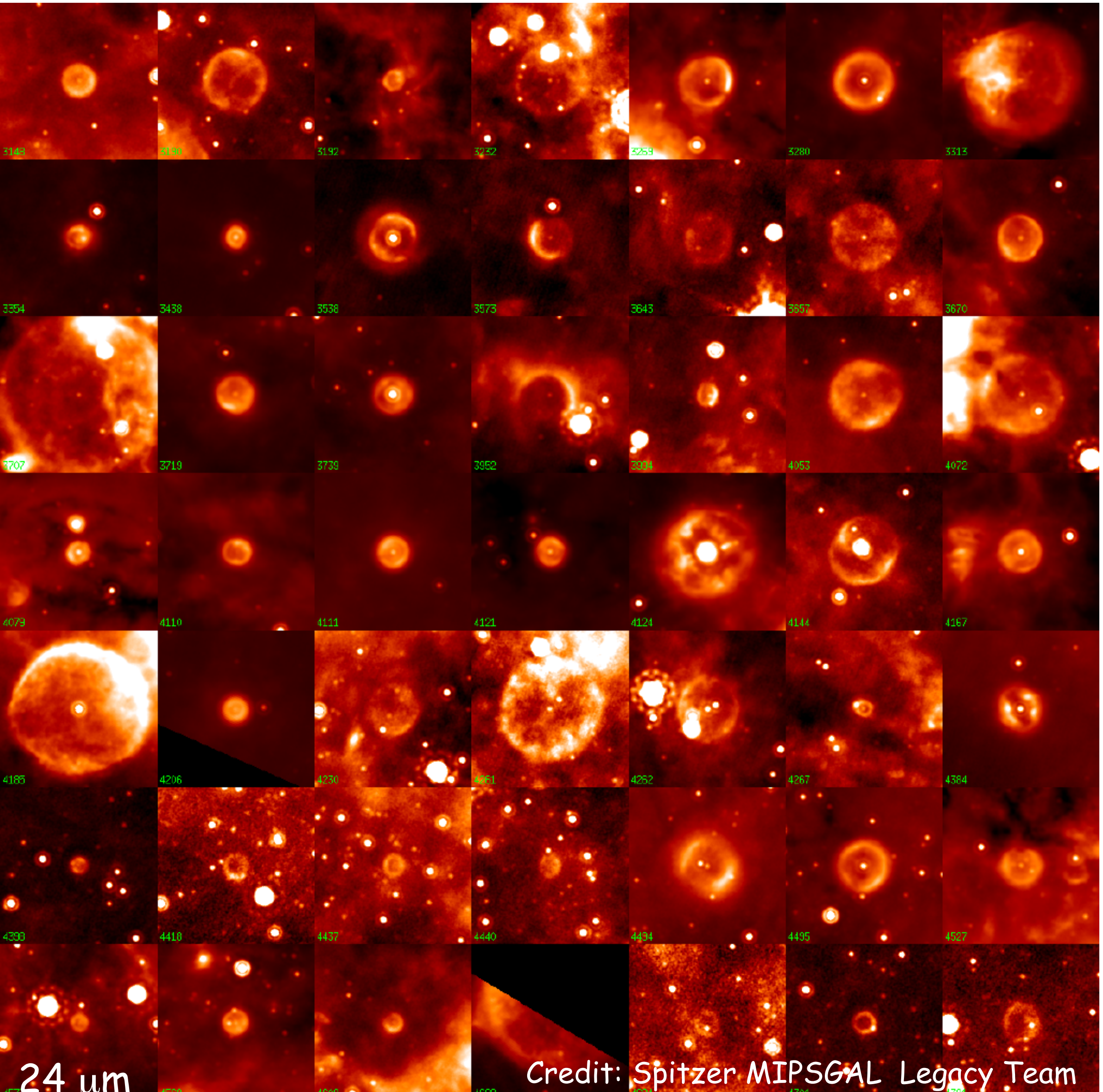
Particularly important for synergy with new generation GP surveys

Adapted from Hoare et al., 2012

Survey	Wavelength	Beam ($''$)	l Coverage	b Coverage	Probe	Reference
IPHAS	Hα	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 μm	2	$-65^{\circ} < l < 65^{\circ}$	$\|b\| < 1^{\circ}$	Stars, Hot Dust	Churchwell et al. (2009)
MSX	8-21 μm	18	All	$\|b\| < 5^{\circ}$	Warm Dust	Price et al. (2001)
MIPSGAL	24,70 μm	6, 20	$-65^{\circ} < l < 65^{\circ}$	$\|b\| < 1^{\circ}$	“	Carey et al. (2009)
AKARI	50-200 μm	30-50	All sky		Cool Dust	White et al. (2009)
Hi-GAL	70-500 μm	10-34	All	$\|b\| < 1^{\circ a}$	“	Molinari et al. (2010)
JPS	450,850 μm	8-14	$10^{\circ} < l < 60^{\circ}$	$\|b\| < 1^{\circ}$	“	Moore et al. (2005)
ATLASGAL	850 μm	19	$-60^{\circ} < l < 60^{\circ}$	$\|b\| < 1.5^{\circ}$	“	Schuller et al. (2009)

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

Recent discovery from GP mid-IR survey:
The *BUBBLING* Galactic Plane

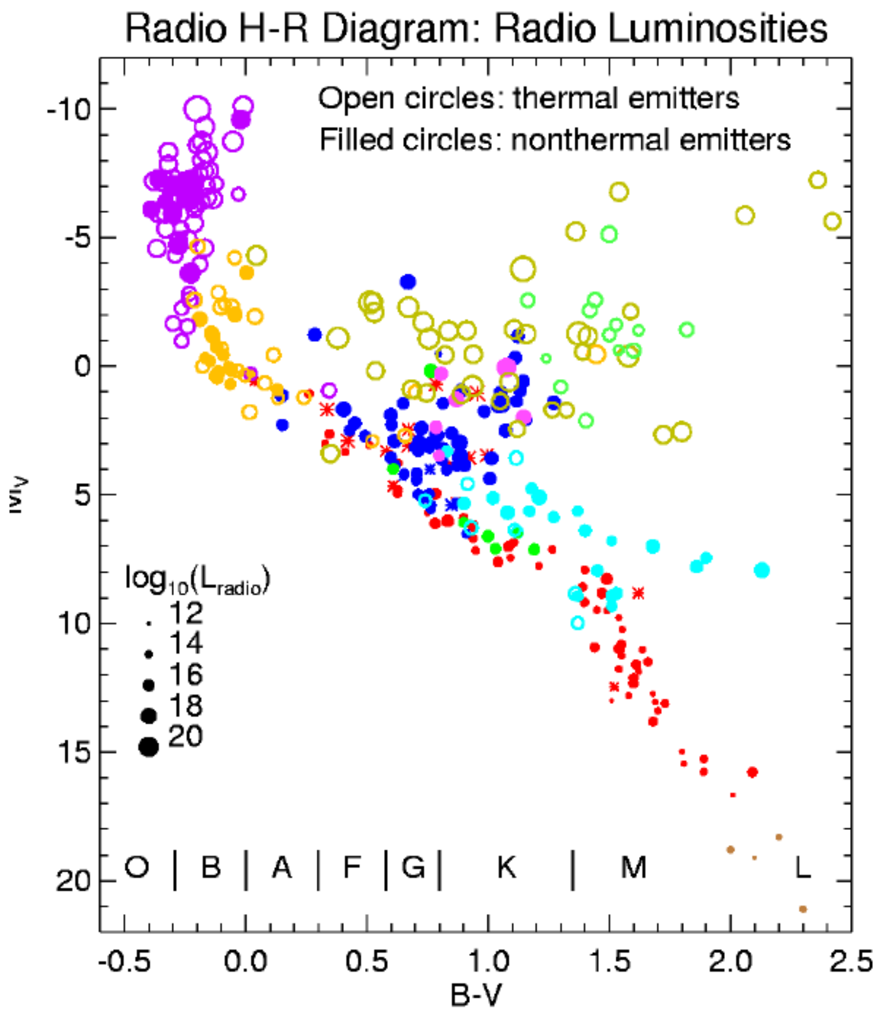


About 400 "bubbles" found in MIPSGAL (24 µm)
Carey et al., 2009, Mizuno et al 2010

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)

HR diagram for the 420 radio detected stars (mostly VLA)
(Gudel, 2002)



-L_{radio} a small (10^{-12} Sun) fraction of L_{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

The brightest stellar radio emission associated with:

-Large mass-loss (*large emitting surface*): free-free from stellar winds (OB, WR)
$S_\nu \approx \nu^\alpha$ $\alpha = 0.6-2$

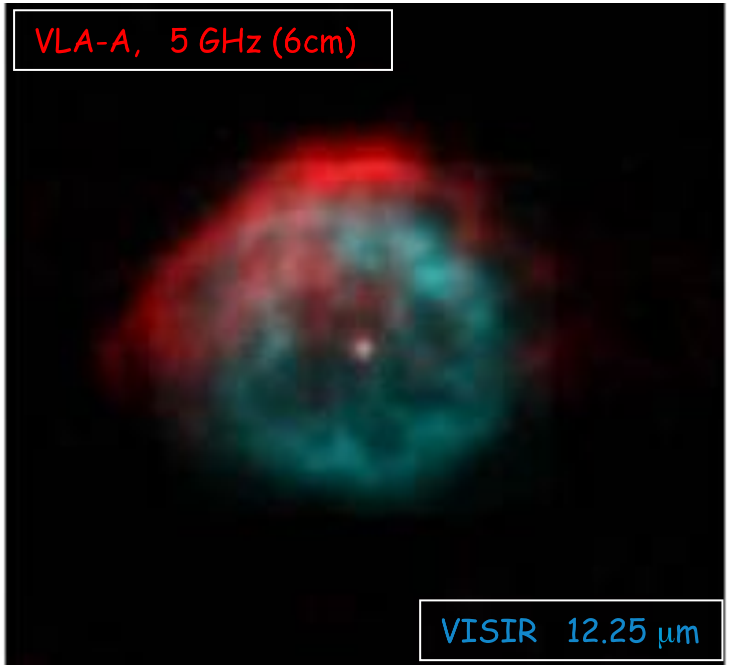
-Solar-type, non-thermal phenomena (*high* T_B): gyrosynchrotron, related to a strong and (often) variable stellar B

The brightest stellar radio emission associated with:

-Large mass-loss (*large emitting surface*): free-free from stellar winds (OB, WR)

$S_\nu \approx \nu^\alpha \quad \alpha = 0.6-2$

$$\dot{M} \propto S^{\frac{3}{4}} v D^{\frac{3}{2}}$$



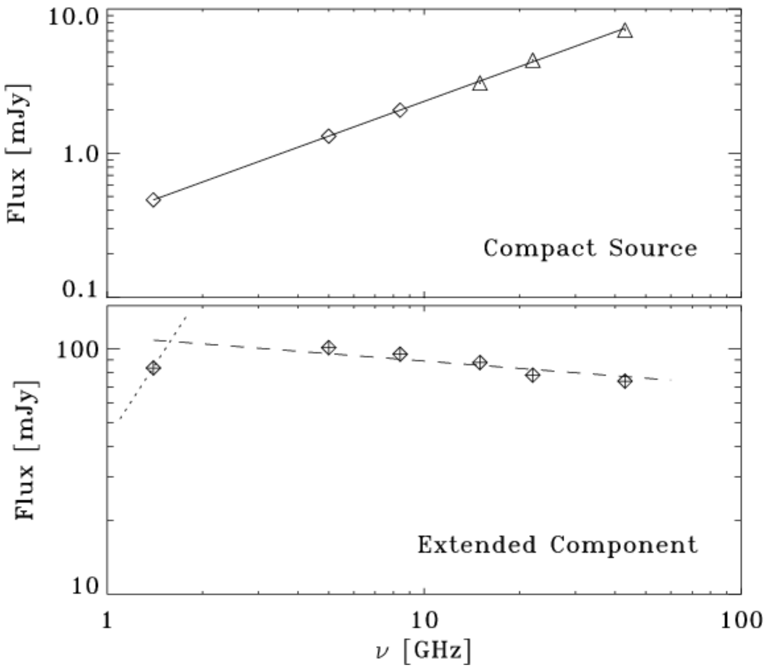
IRAS 18576+0341

Buemi et al., 2012

Current day mass-loss
$3.7\ 10^{-5}\ M_\odot yr^{-1}$

$M_{ion} \sim 2\ M_{Sun}$

B0-B0.5 I,
$T_{eff} \sim 2.6\ 10^4$ K



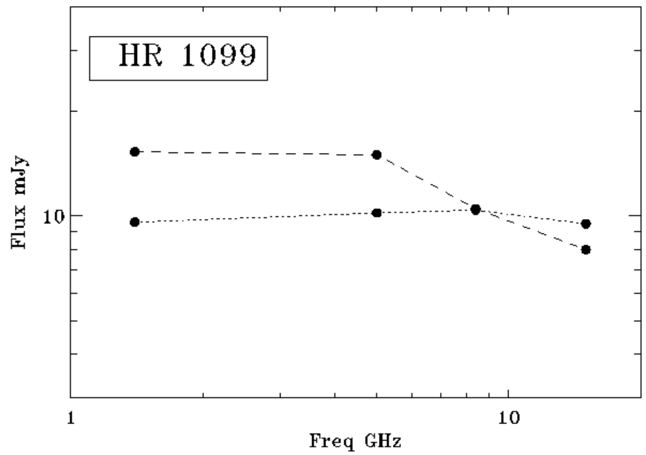
Umana et al., 2005

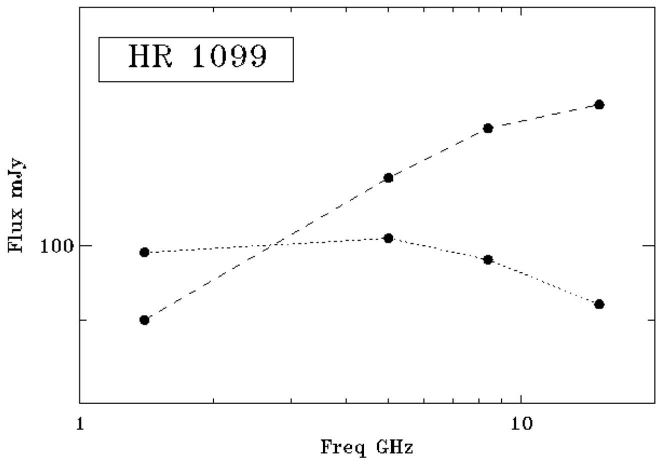
The brightest stellar radio emission associated with:

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

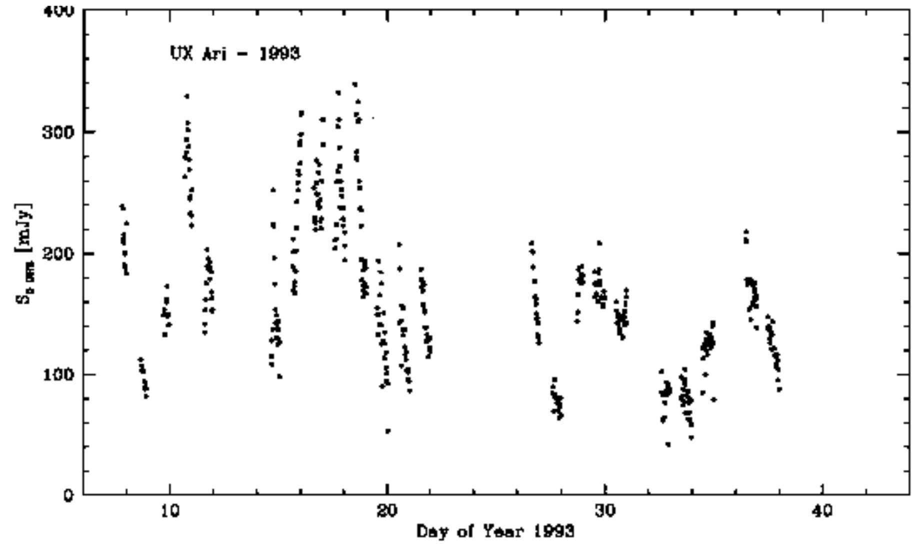
- Gyro-synchrotron (Active stars and stellar systems):
  quiescent periods -slowly varying flux density, up to several mJy
  active periods -series of strong outburst, up to 1Jy

Variable



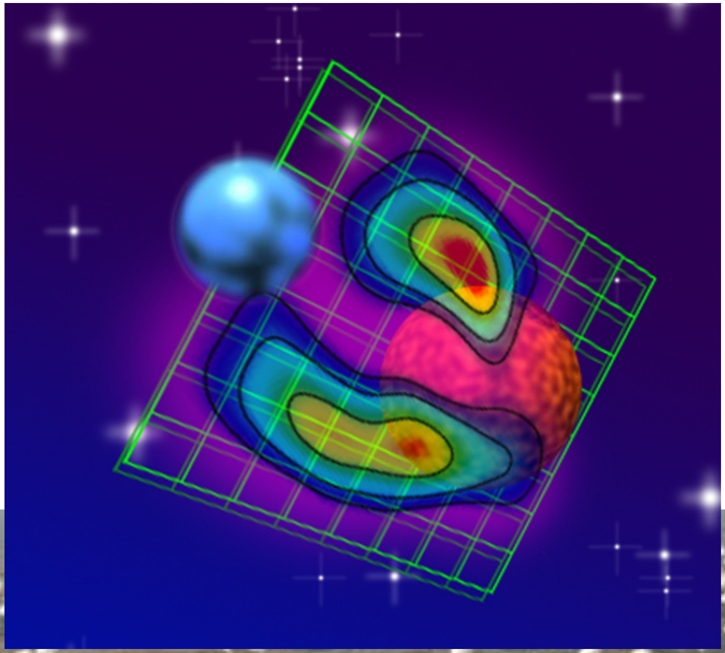


- ✓ **Both quiescent and active periods are related to solar-type magnetic activity** (observed also in other spectral ranges)



Noto 6cm monitoring- 23 days/ up to 12 hrs coverage

- ✓ **Active periods can last several months**



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

Algol (Mutel et al., 2009)

Coherents events (usually observed in addition to gyrosynchrotron)

- Modelled as electron cyclotron maser emission (ECME)

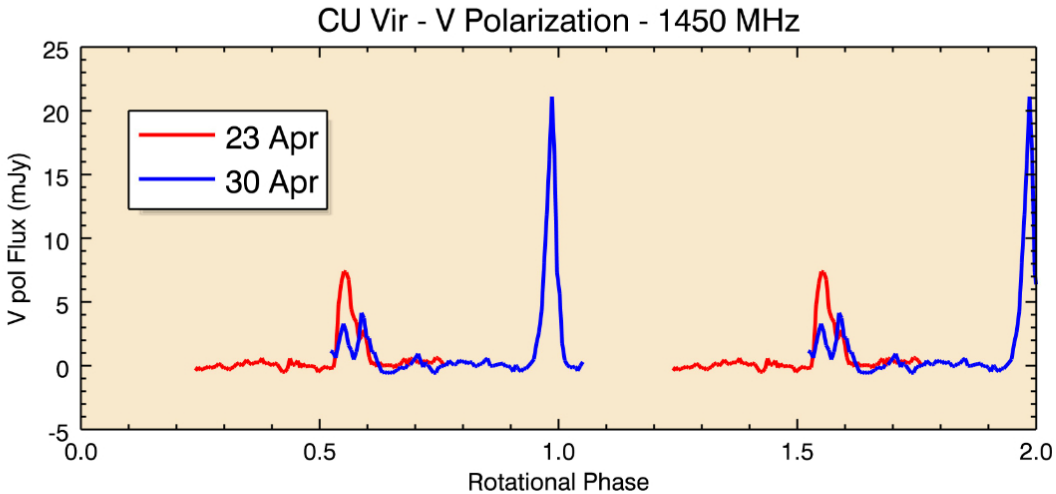
<u>Astrophysical environments</u>

common ingredient strong B and energetic particles

Active stars and stellar systems (Osten et al., 2004; Slee et al., 2008..)

Ultra Cool Dwarf (Hallinan et al., 2008; Route and Wolszczan, 2012)

CPs stars (Trigilio et al., 2000; Trigilio et al., 2008, 2011)



Polarization up to 100%
Frequency structure
Narrow bandwidth
Short duration (time)
Usually observed at low frequency

Trigilio et al., 2011

Stellar radio emission: SKA forecast

The actual knowledge of stellar radio emission suffers of:

-*limited sensitivity:*

No radio star with radio luminosity similar to the quiescent Sun ($L_{6cm} \approx 10^{10.7}$ erg sec^{-1} Hz^{-1}) detected yet.

-*selection bias:*

based on targeted observations aimed at addressing specific astrophysical problems

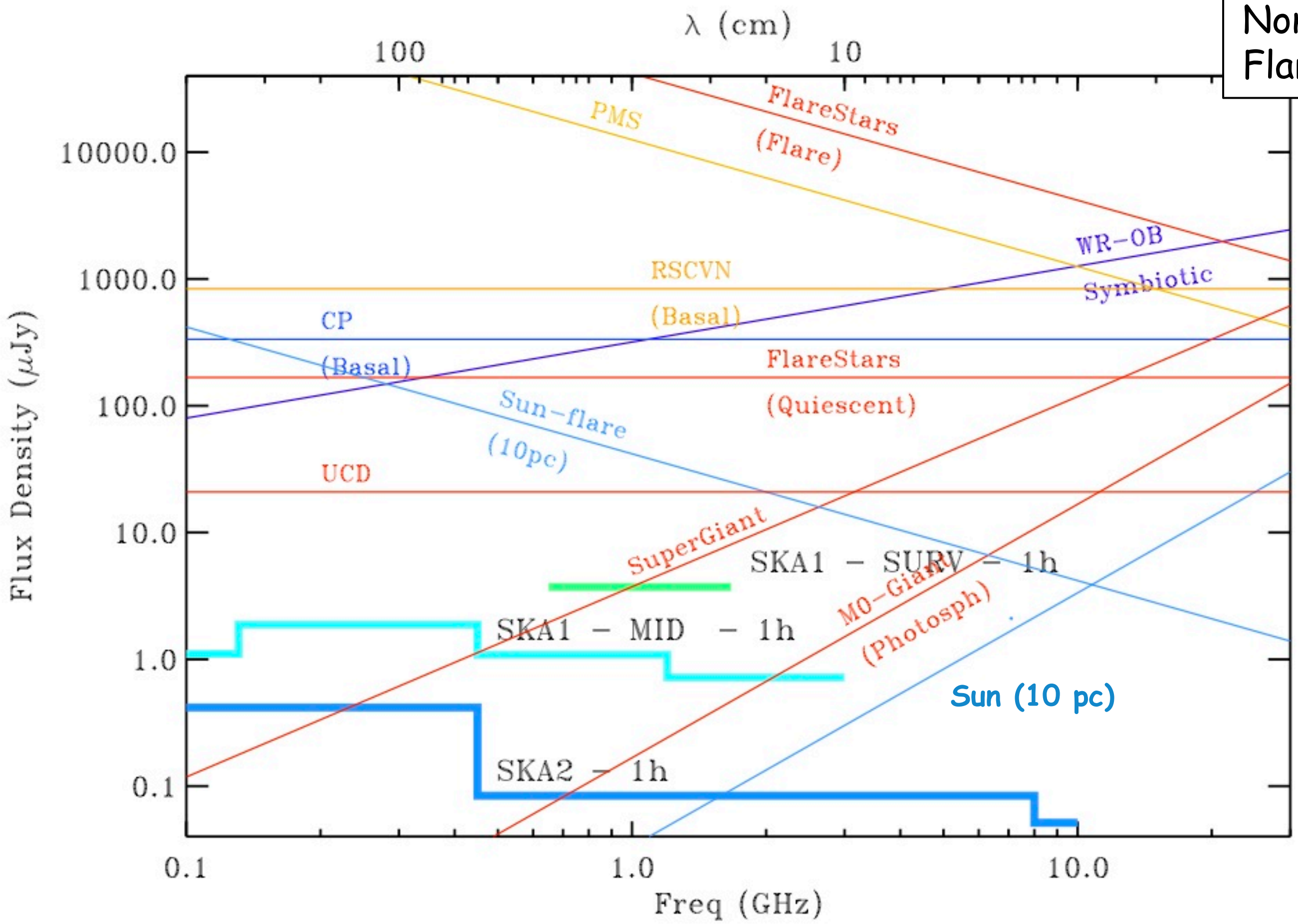
However, starting from some information on radio luminosity………

Flares stars (and late-M)	Seaquist, 1993; Gudel 2002; Berger et al. 2005
PMS	Gudel, 2002
Active binary systems	Moris and Mutel, 1988, Umana et al., 1993
OB-WR	Seaquist, 1993; Bieging et al., 1989
CP	Leone et al., 1992; Trigilio et al., 1994

SKA forecast

Schematic radio continuum spectrum of classes of radio emitting stars.

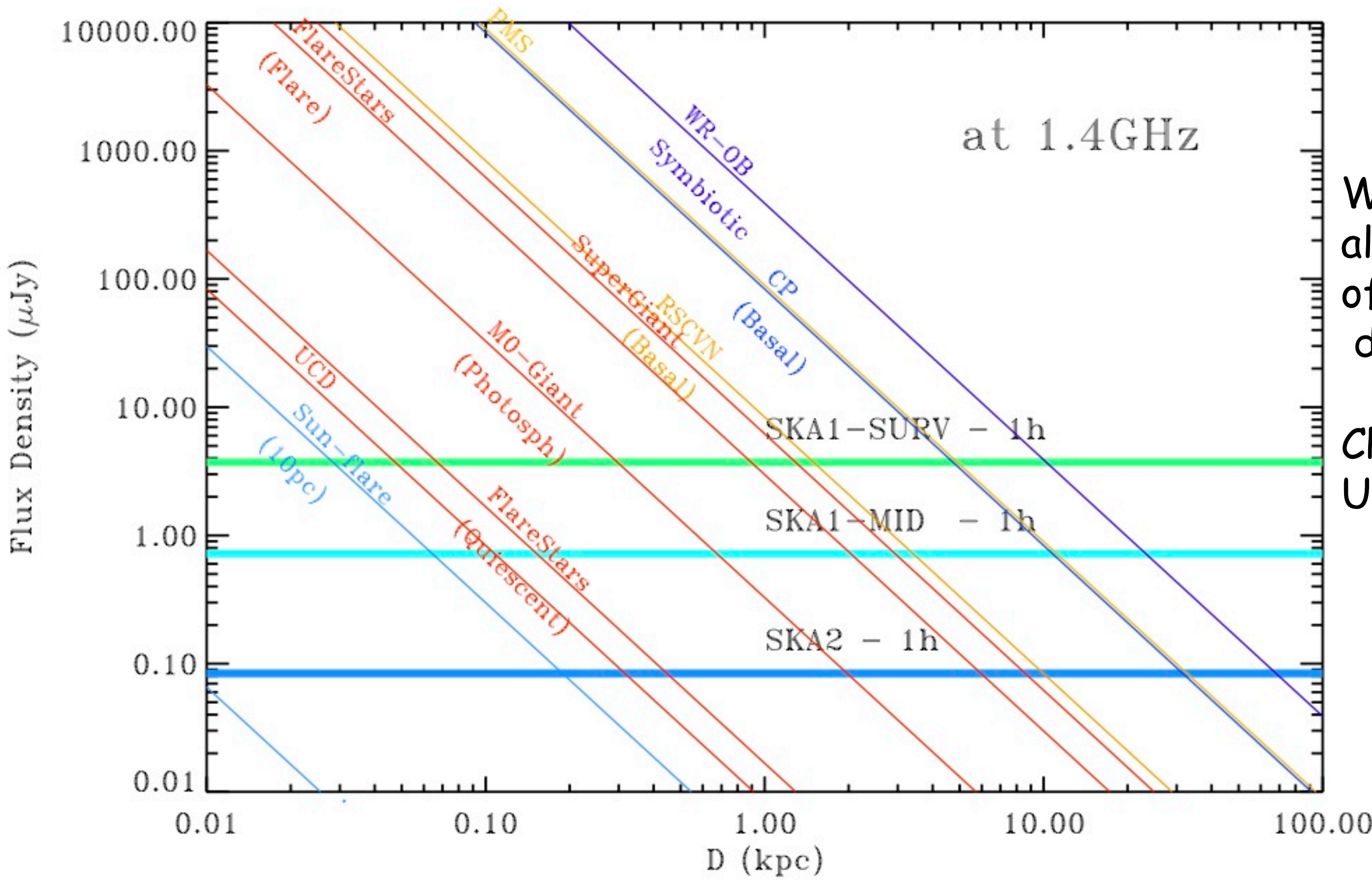
thermal Stellar winds OB, WR
Non-therm RS, flare stars, PMS
Flares from a Sun-twin at 10pc



Non-thermal and strong winds easily detected!

Assumed distances are: 10pc flare stars, 100pc RS and PMS, 500pc CP, 1kpc OB and SG

SKA forecast



With SKA1_MID
all WR, and OB stars
of the Galaxy will be
detected

CP, PMS, RSCNS nd SG
Up to the GC

Stellar radio emission

Key question:

How many stars, at sub-mJy level, we can expect to detect in one square degree of sky?

Not obvious answer

1) the presence of stars belonging to classes thought to be radio emitter is a necessary but not sufficient condition to detect them. Need sufficient B and Nrel (non-therm) or mass-loss rate and UV field (therm)
   detection rate: OB 20%, CP 25%, 30-40% RS

2) Distance plays a role

3) Non-thermal radio emission is variable

Can large field radio survey help?
NVSS, too shallow and low angular resolution for stellar work
FIRST, ATLAS,…designed for extragalactic➔ High Galactic Latitude

Stellar radio emission in the SKA era:

the SCORPIO project

2 x 2 deg^2 l=343, b=1.0

Grazia Umana INAF-OAC

C. Trigilio, R. Norris, T. Franzen, A. Ingallinera, C. Agliozzo
P. Leto, C. Buemi, E. Budding, B. Slee, G. Ramsay, G. Doyle, M. Thompson, J.C. Guirado,
S. Keller, J.D. Bunton, J. Lazio, F. Leone, G. Hallinan, M. Johnston-Hollit, G. Hobbs,
M. Mao

The SCORPIO project

Expected outcomes- Science

- Enlarge the stellar radio emitting population, with no selection bias

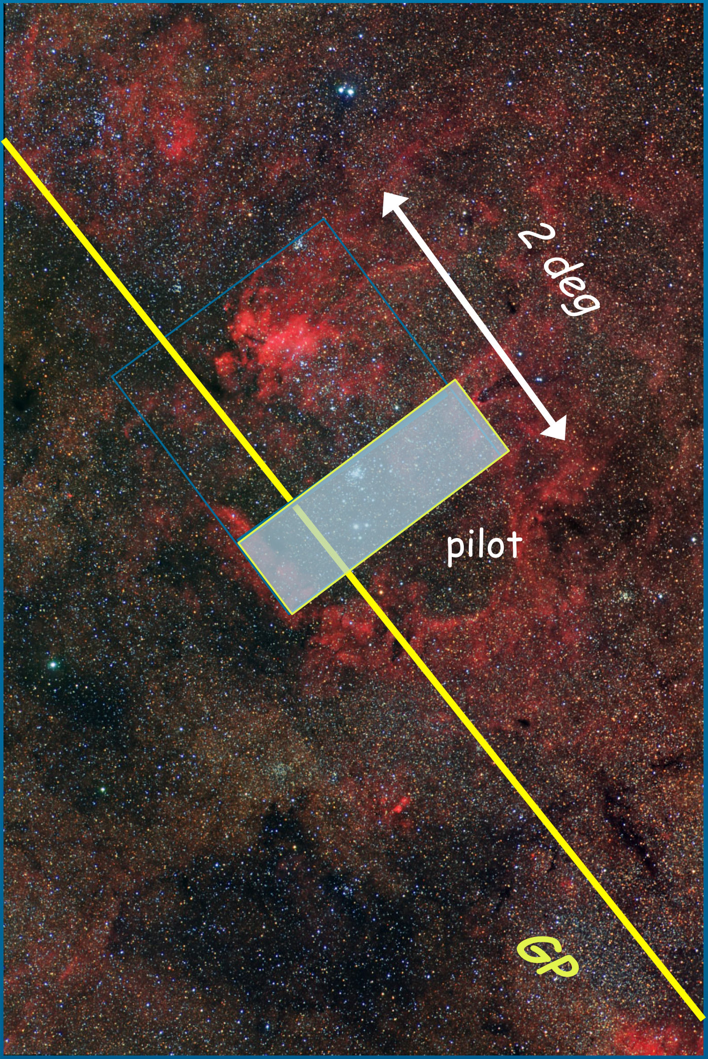
Expected outcomes- Planning the EMU project

- Dynamic range from sources complexity: issues related to complex, extended structure in the GP

- Dynamic range from source variability: issues related to the presence of variability in most of non-therm sources

- Source extractions: what is the most appropriate method for sources embedded in the diffuse emission in the Galactic Plane

A deep radio survey with the ATCA (200 hrs)



Observed in *MOSAIC* mode

The SCORPIO project: the pilot

Observed in mosaic mode with ATCA
38 pointings, 8.8 arcmin spacing hexagonal grid

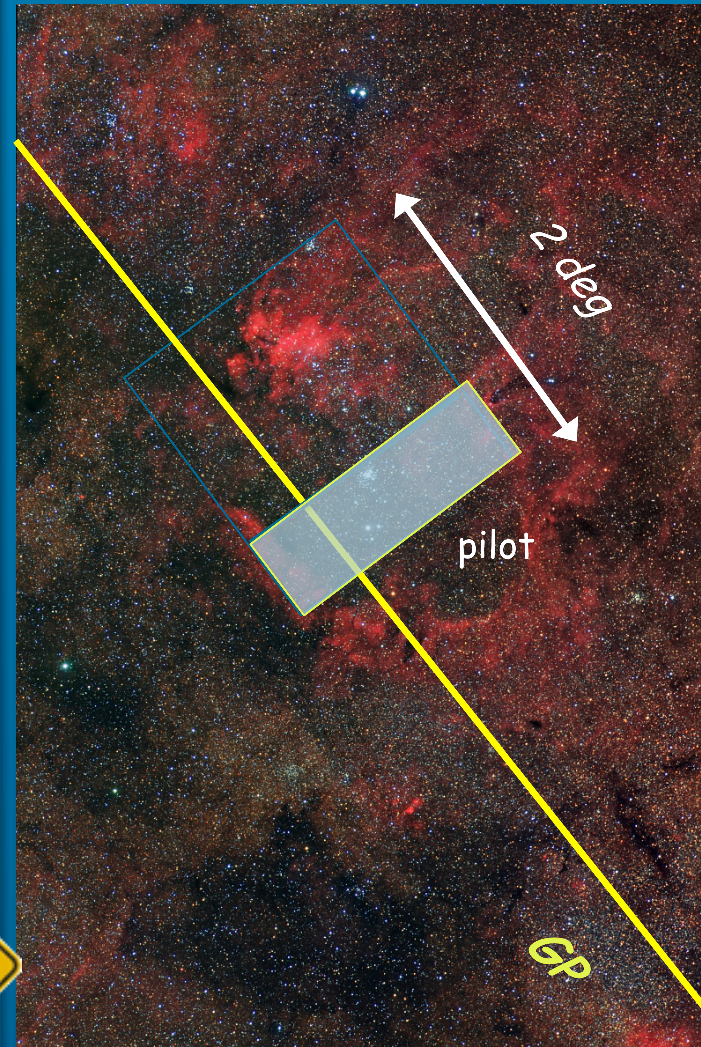
Duty cicle=1min/pointing +cal
total integration time/pointing   1.2 hr
Total observing time= 50 hrs

C2515
6A, 6B
Δv= 1.1-3.1 GHz
CABB: 2048 chs, 1 MHz each

Preliminary results are encouraging:
reaching 40μJy rms

But map needs more work!

A deep radio survey with the ATCA (200 hrs)



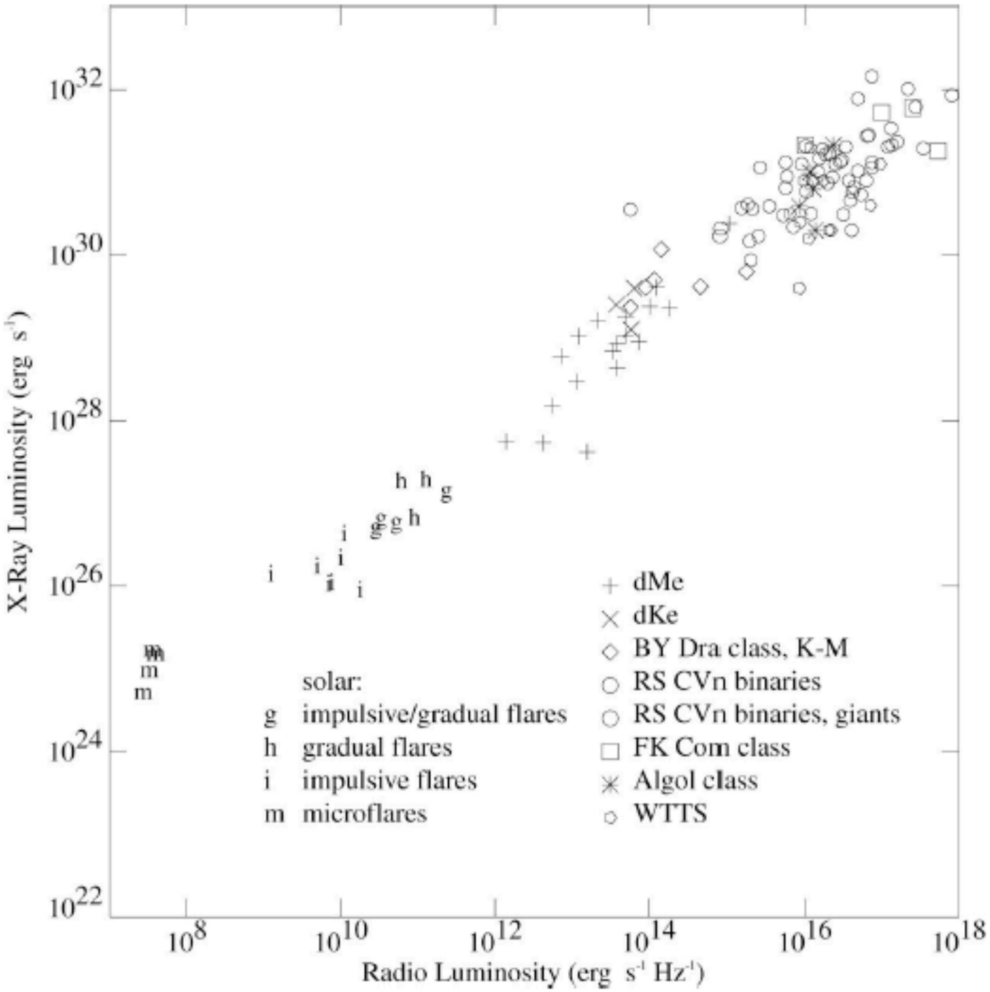
Observed in *MOSAIC* mode

The impact of SKA on stellar coronae

The Solar-stellar connection

SKA1_SURV: 1 hr sensitivity will allow to detect all kinds of known non-thermal emitting stars

- ✓ Identify radio coronae across wide range of stellar type
- ✓ Identify radio flares (multi-epoch observations?)
- typical behaviour (occurance 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

SKA1_MID: Detailed studies of a large number of stellar coronae

Variability studies:

SKA1_MID: 5 sec $\approx$ 20 μJy

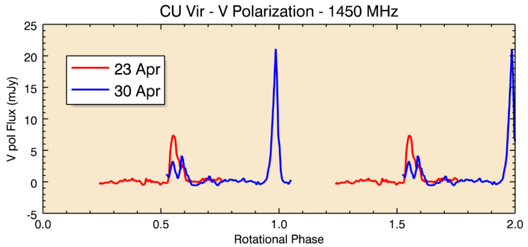
A solar-type weak flare (0.1mJy @ 1.3 pc) observed with $\Delta t=5$s with S/N=5

-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

B, $N_{non\text{-}thermal}$ and spectral energy distribution

-If CE is stable (CU Vir): timing the star rotation

The impact of SKA on Galactic Science

This is what we can prospect based on what we know today, just a taste....

Imagine what we will able to do once the "main course" will come along...