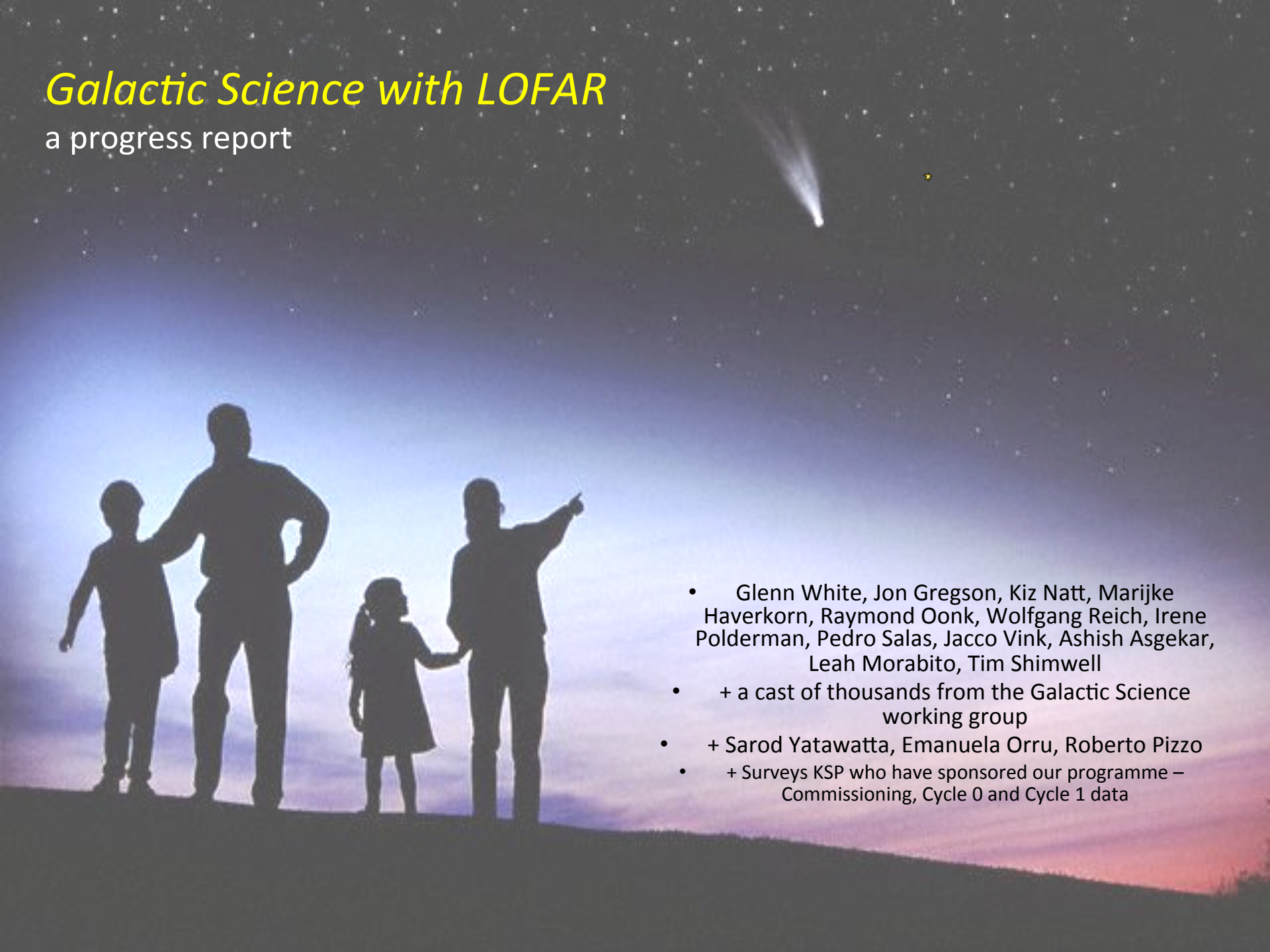
Galactic Science with LOFAR

a progress report



- Glenn White, Jon Gregson, Kiz Natt, Marijke Haverkorn, Raymond Oonk, Wolfgang Reich, Irene Polderman, Pedro Salas, Jacco Vink, Ashish Asgekar, Leah Morabito, Tim Shimwell
- + a cast of thousands from the Galactic Science working group
- + Sarod Yatawatta, Emanuela Orru, Roberto Pizzo
- + Surveys KSP who have sponsored our programme – Commissioning, Cycle 0 and Cycle 1 data

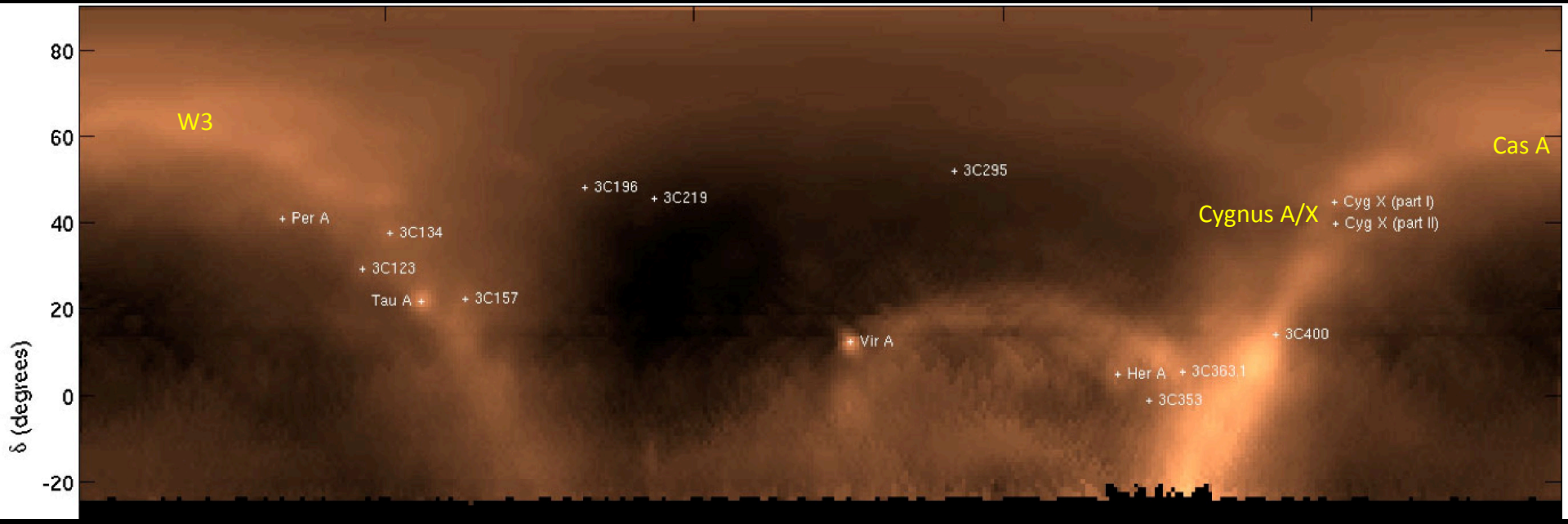
Observing the Galactic Plane is ~~fun~~ challenging:

- Highly structured bright diffuse background – source models tricky to make
- Many bright point-like and resolved sources – psychedelic moving sidelobes
- No useful sky models – no clear solutions
- Very difficult to efficiently demix extended emission
- System temperatures depend on background – calibration difficult
- Ringing/negative bowls around bright sources - lack of zero spacings
- HII region source fluxes drop as ν^2 below ~ 1000 MHz: flux/100
- Cleaning is very difficult requiring multi-scale approaches
- HII regions opaque - self absorption likely to be present – τ ~ 10 - LBA and HBA may differ
- Variety of Observing strategies, and different data reduction solutions

Nil desperandum – pas de problem !!!

….. 3 years later !!!

- *HII regions*
  - W3 / W4 / W5 – high mass star forming complex at 2.3 kpc
  - 4 beam LBA mosaic in commissioning – SAGECAL based data reduction
  - Relatively low background – absorption of the diffuse Galactic Synchrotron emission not likely



W3 - LBA

High mass star forming complex at 2.3 kpc

- HII regions
- Chimneys, shells, bubbles
- SNRs
- Bright extragalactic sources

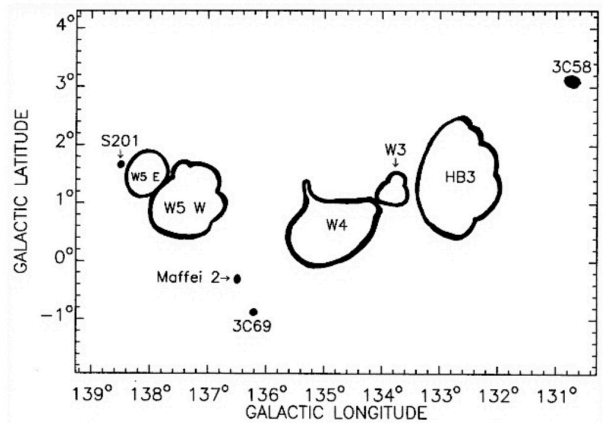


Figure 1.1: Sketch of the W3/W4/W5 complex and SNR HB3 with the main regions of continuum emission outlined. SNR 3C 58 and 2 strong extra-galactic sources 3C 69, and Maffei 2 are also shown (Normandeau et al. 2007).

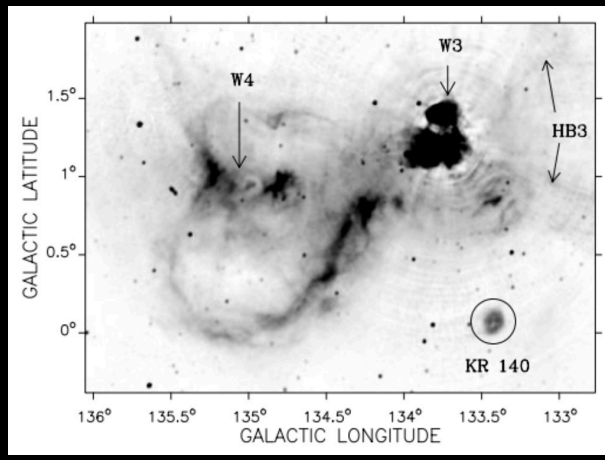
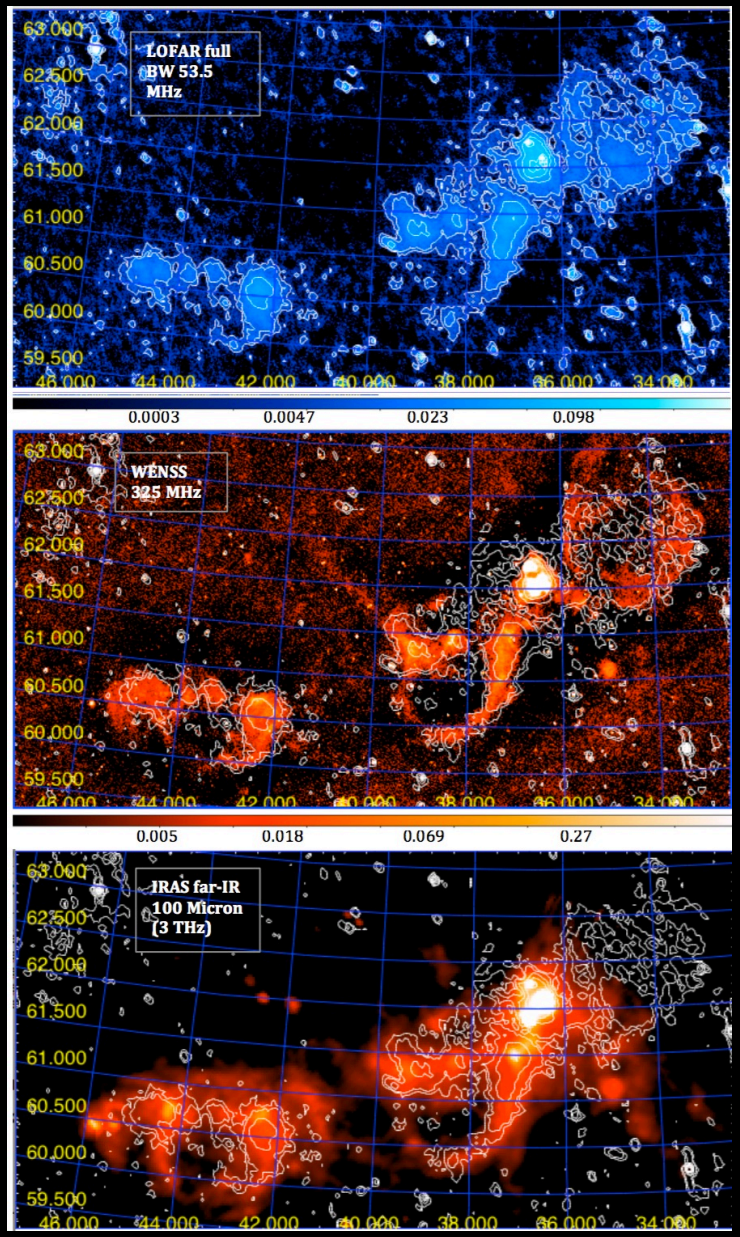
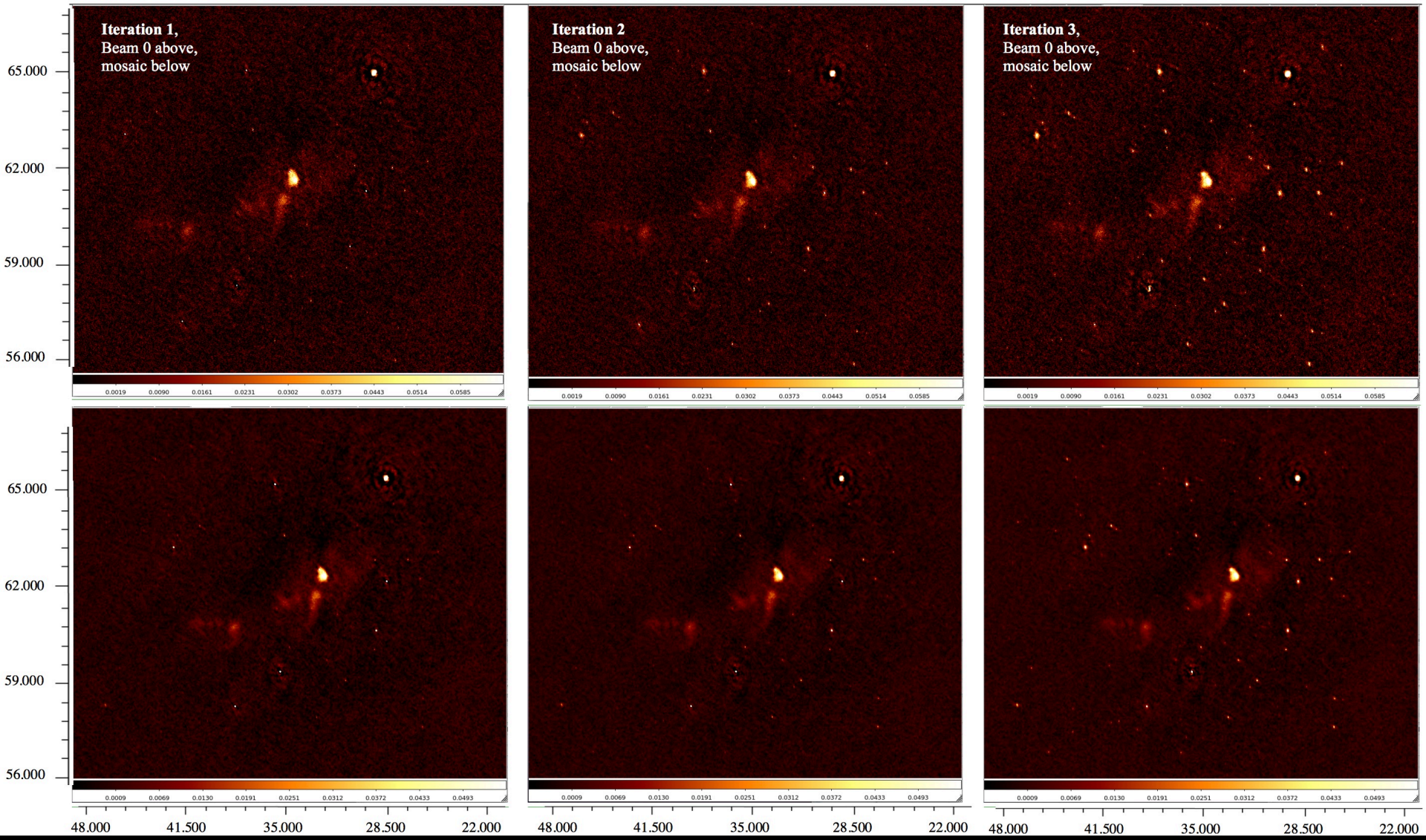


Figure 1.2: 1420 MHz ontinuum image of the W3/4 star-forming region and the HB3 supernova remnant (Ballantyne, Kerton & Martin 2000).



W3 LBA – 3 Sagecal iterations

(All W3 work taken from Kiz Natt's 2015 PhD Thesis)



W3 – LBA – main HII region

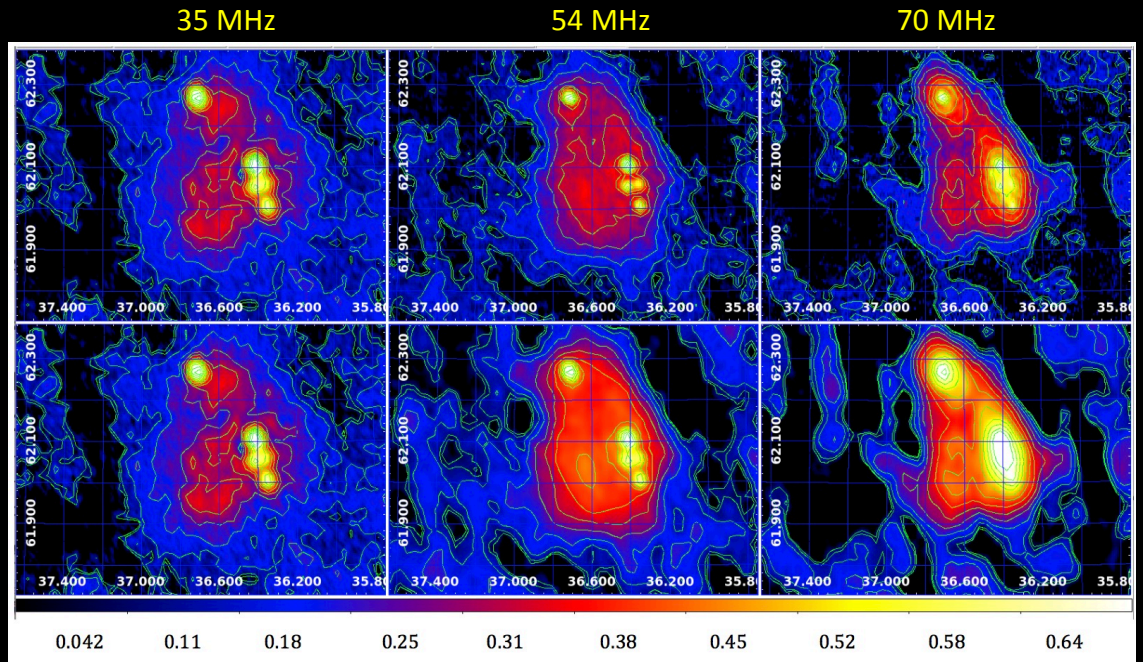
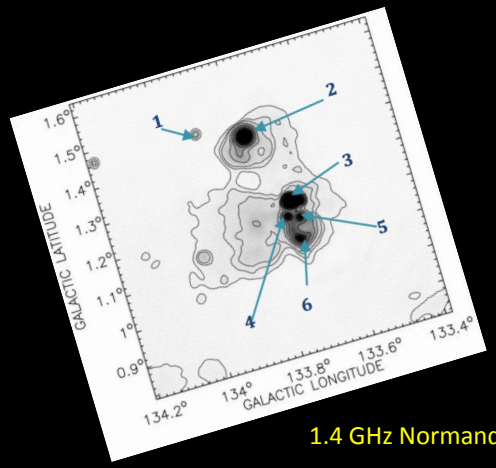
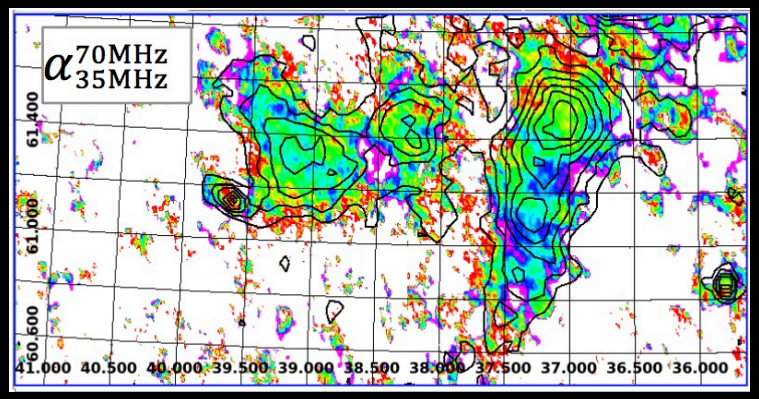


Figure 4.23: W3 maps at 35.2 MHz, 54.4 MHz and 69.9 MHz from right to left. The angular resolution at 35.2 MHz, 54.4 MHz and 69.9 MHz (major x minor axis) is 130″ x 110″, 96″ x 93″ and 95″ x 83″ respectively. The bottom row displays the same data convolved to a common angular resolution of 130″ x 110″ (PA = 9◦). Map units are in Jy/beam. Contours are plotted from -0.025 to 0.613 Jy/beam in 14 linear levels. The same intensity scale is used such that the intense emission from W3 is saturated in the display at 69.9 MHz.



1.4 GHz Normandeau et al 2007

Spectral indices – diffuse emission



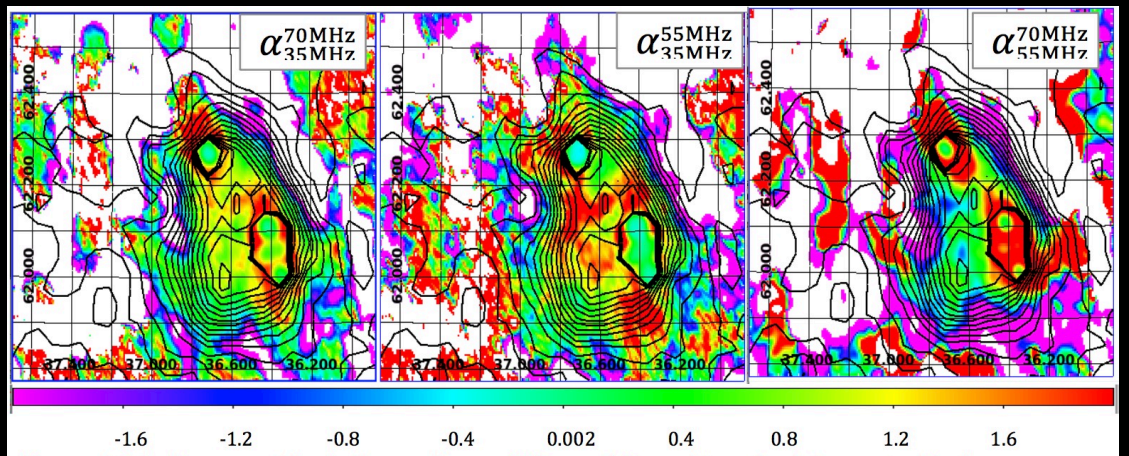
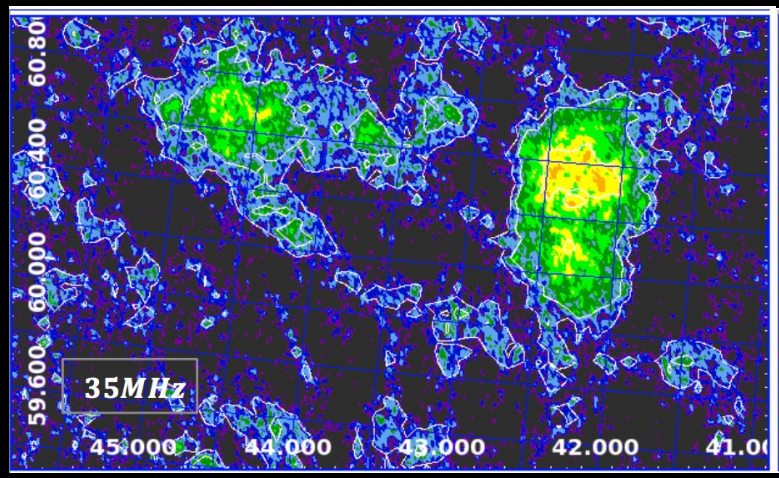
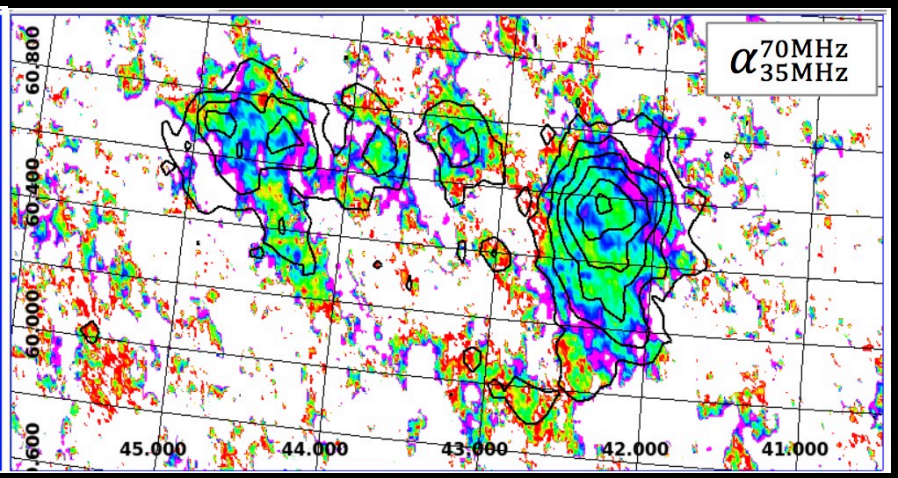


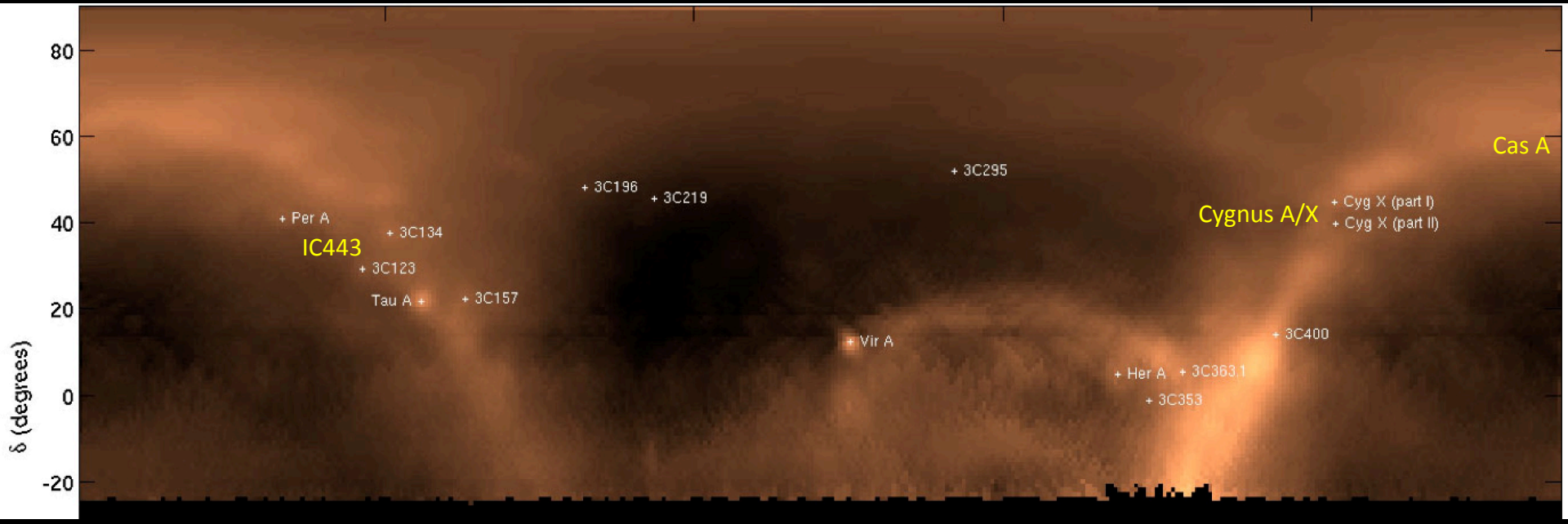
Figure 4.24: Beam matched observations of Figure 4.2 used to calculate spectral index maps. The contours indicate the full bandwidth radio emission centred at 53.5 MHz (beam smoothed to that at 35.2 MHz) at 16 levels from 180 mJy to 2200 mJy/beam.





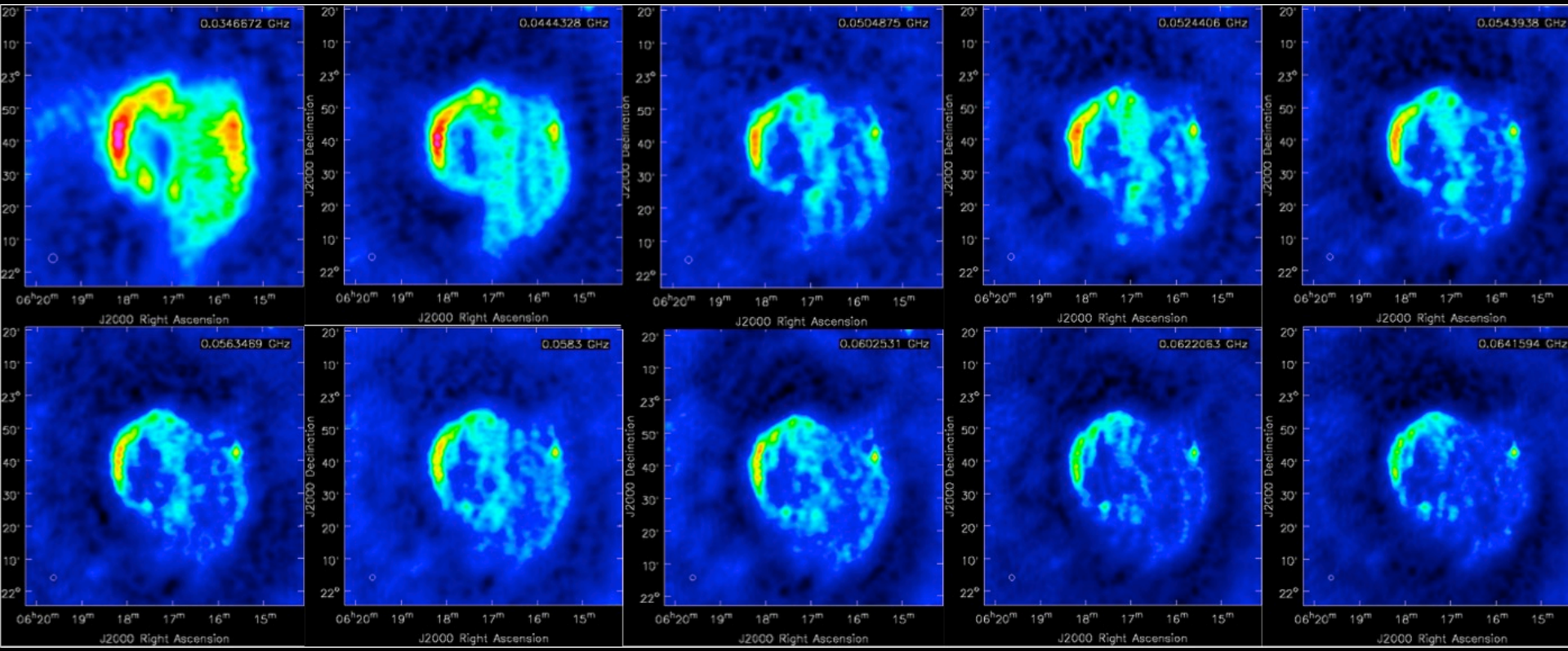
Well behaved HII region, no clear HII region absorption

- Supernovae
  - IC443, σupernova remnant at 1.5 – low background of diffuse Galactic emission in the former, high background in the latter
  - γ Cyg , 3C58, G84.8-0.2, HB3 – outer fields



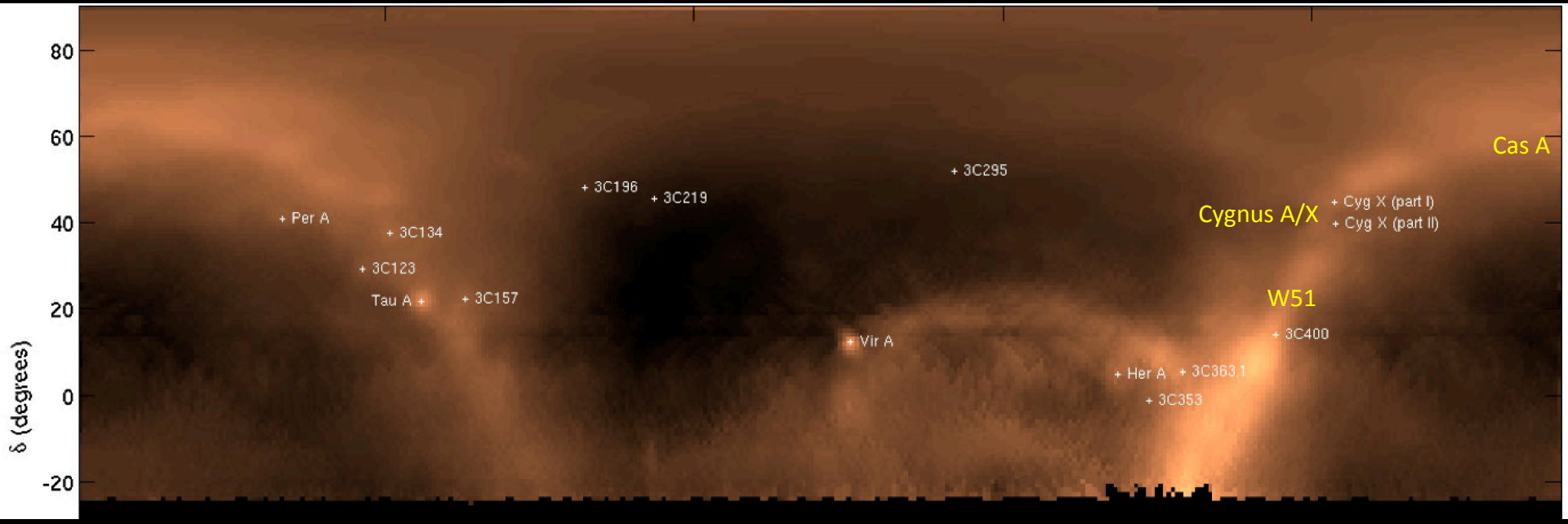
IC443

IC443 – Supernova remnant



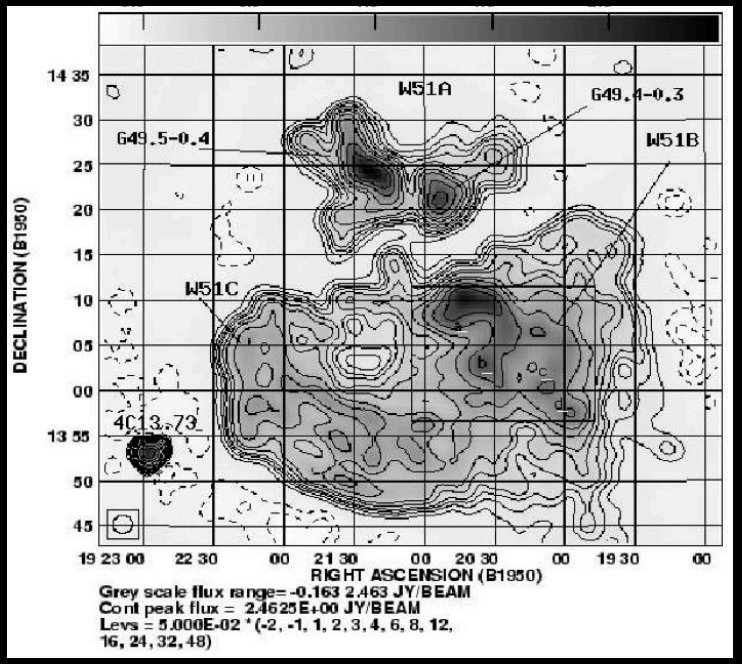
- The flattest spectral components (-0.25< α <0.0) coincide with the brightest parts of the SNR at the eastern edge
- Fast dissociating J-type shock ionising the gas (seen in molecules – White et al 1987)
- Steeper spectral index (α ~ -0.8) towards centre/western edge
- IR/atomic/molecules destroyed in fast J-shock in eastern rim
- Veritas γ-rays from west, suggest thermal absorption

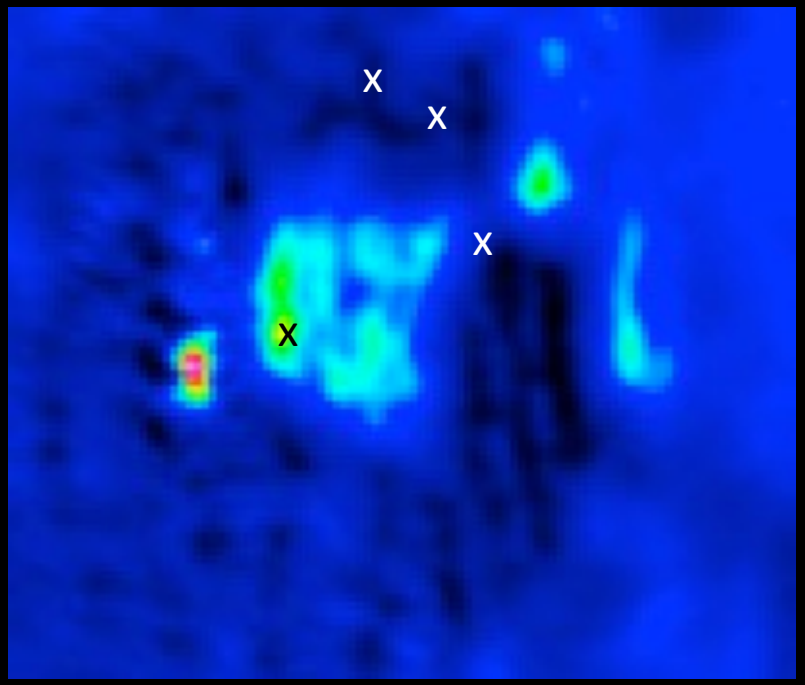
- HII regions
  - W51 – high mass star forming region at 4.5 – 7 kpc
  - HII regions seen against diffuse background non-thermal synchrotron emission
  - HII regions optically thick below 1 GHz, detection of absorption constrains the brightness temperature of cosmic ray synchrotron emission from behind the HII regions -> with enough HII regions with known distances could map out the 3D cosmic ray emissivity throughout the Galaxy



W51

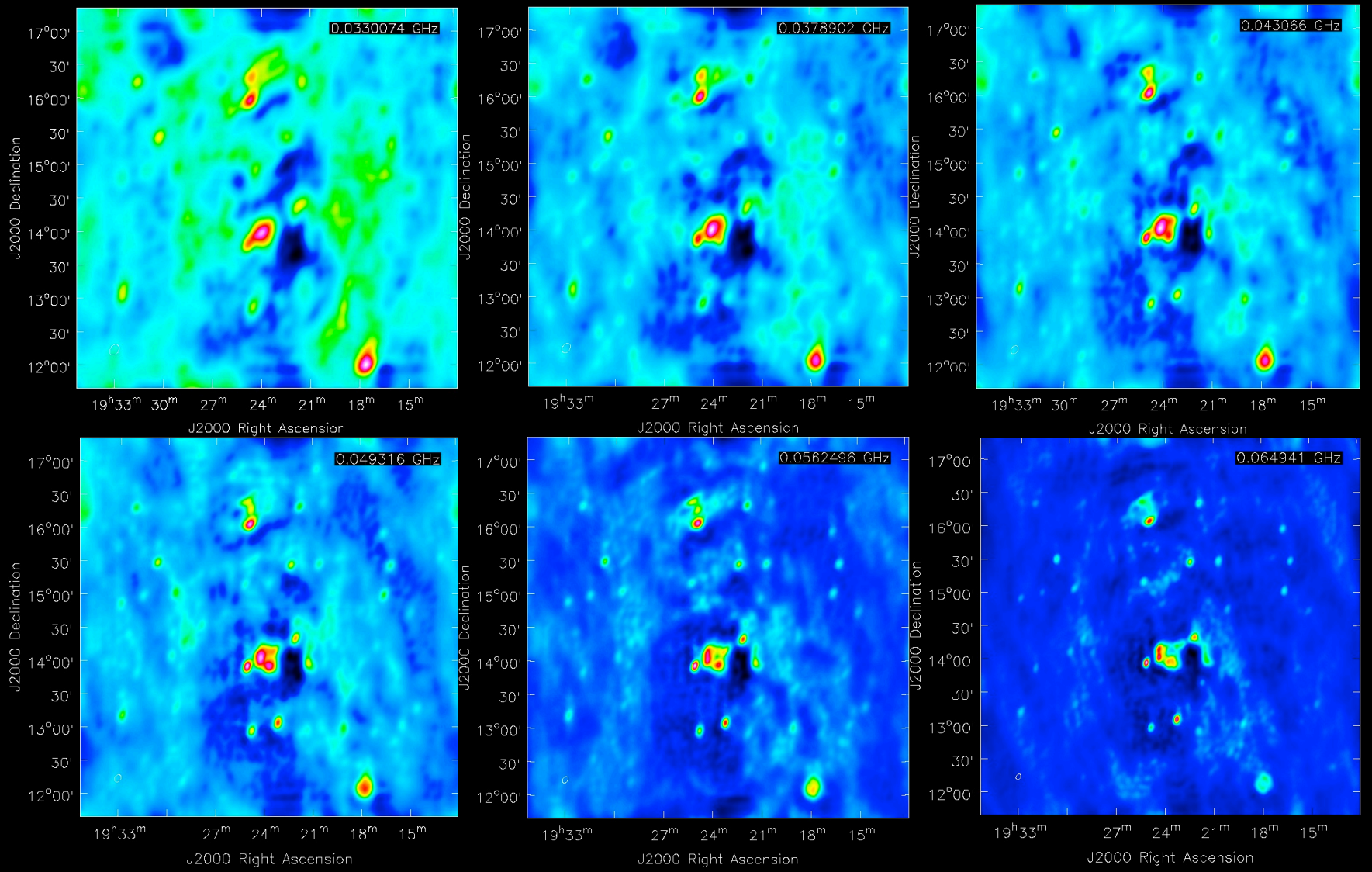
- Giant HII complex / massive SF region along the tangent to the Sagitarius arm 5.4 – 7 kpc
- Many HII regions dominated by W51A, B, plus W51C SNR in the SE



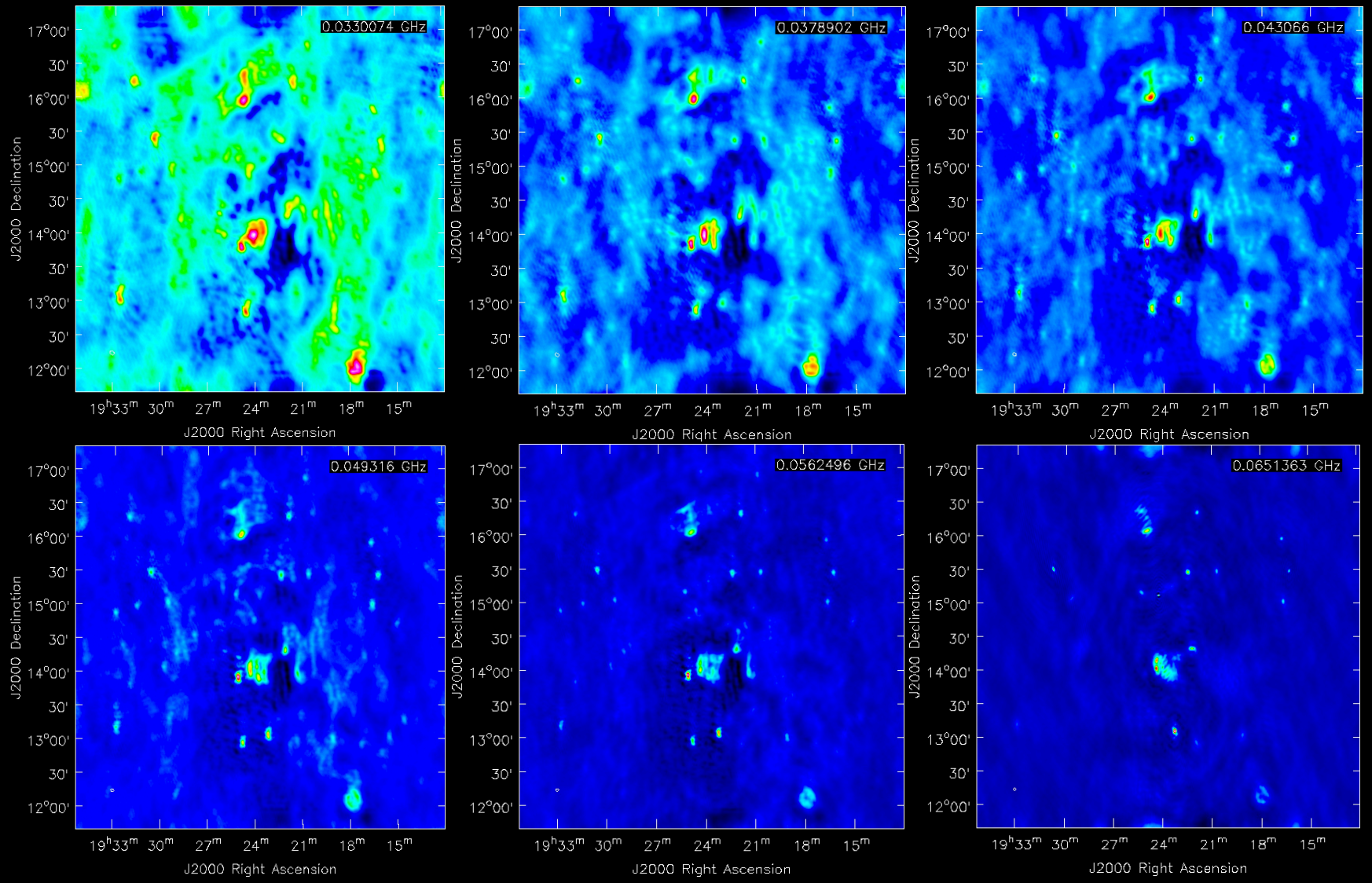


GMRT 240 MHz, 2’ beam
Srivastava and Rao 2013

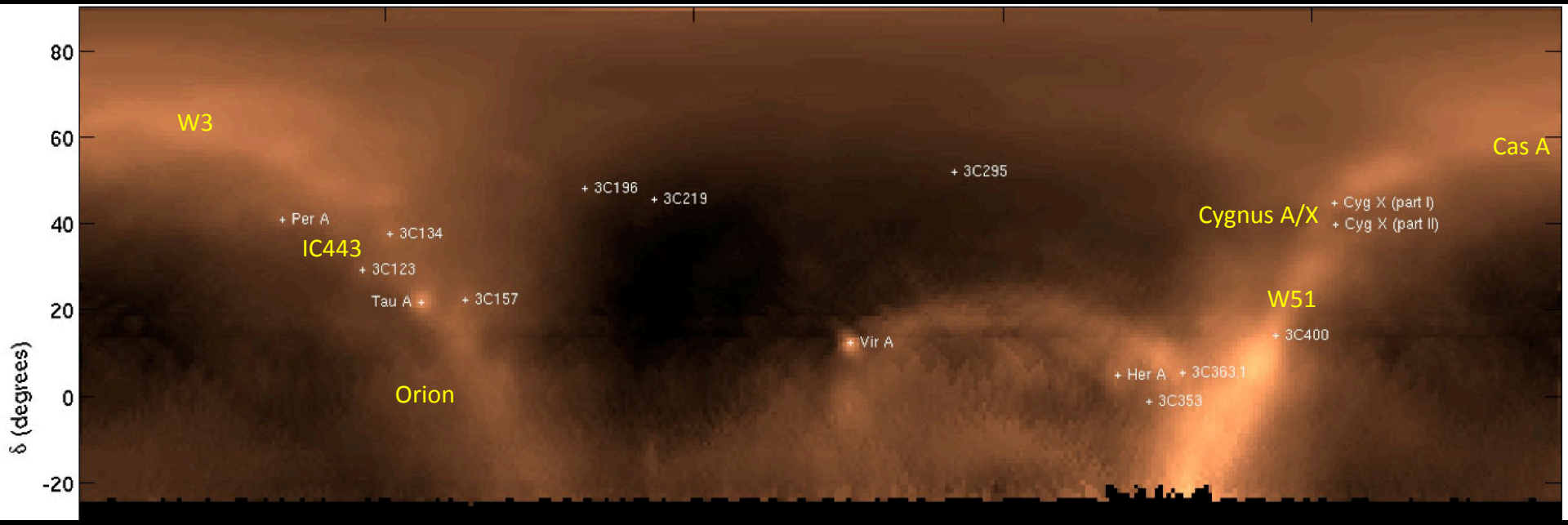
W51 LBA – blank skymodel

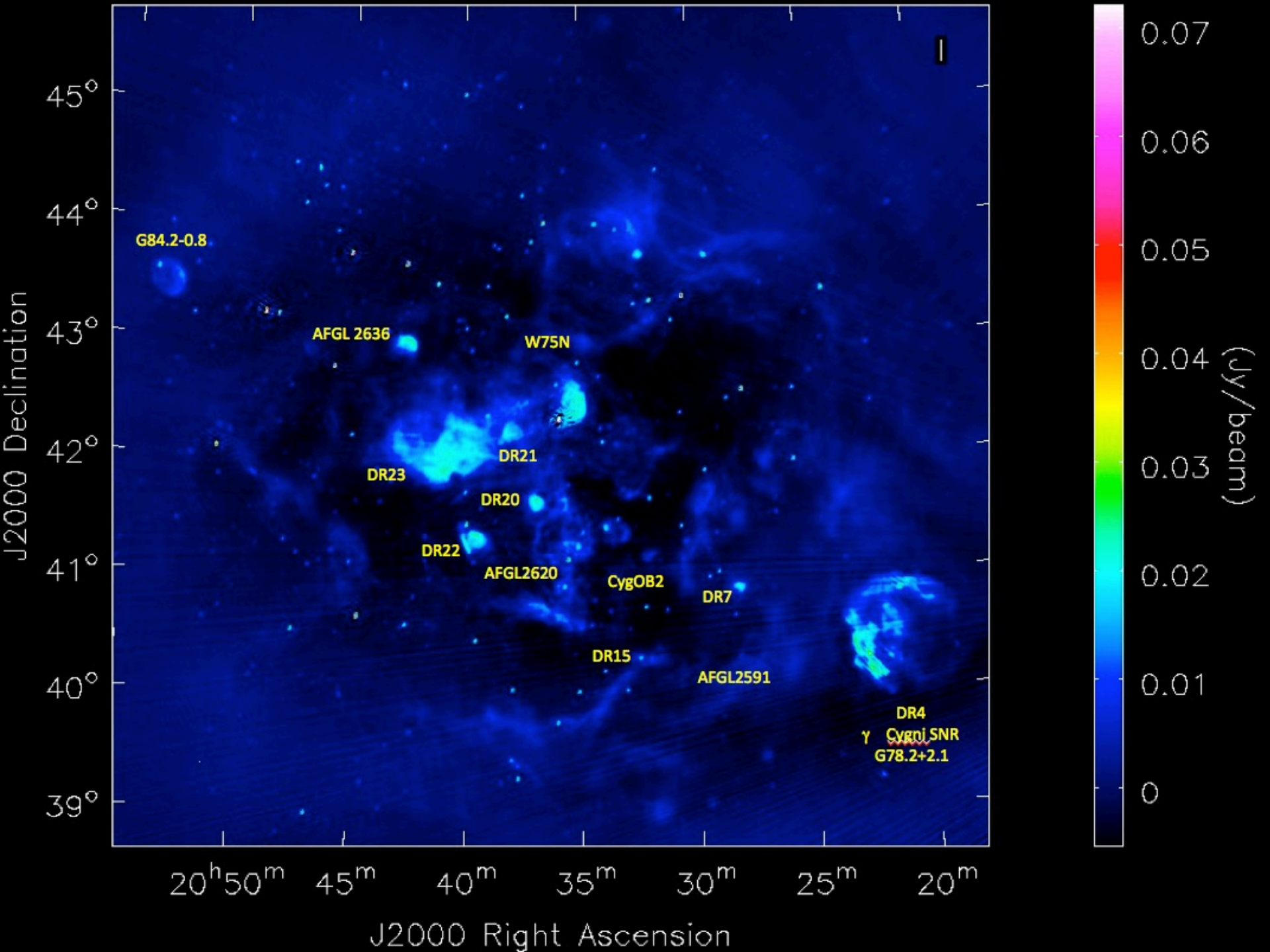


W51 LBA – selfcal skymodel

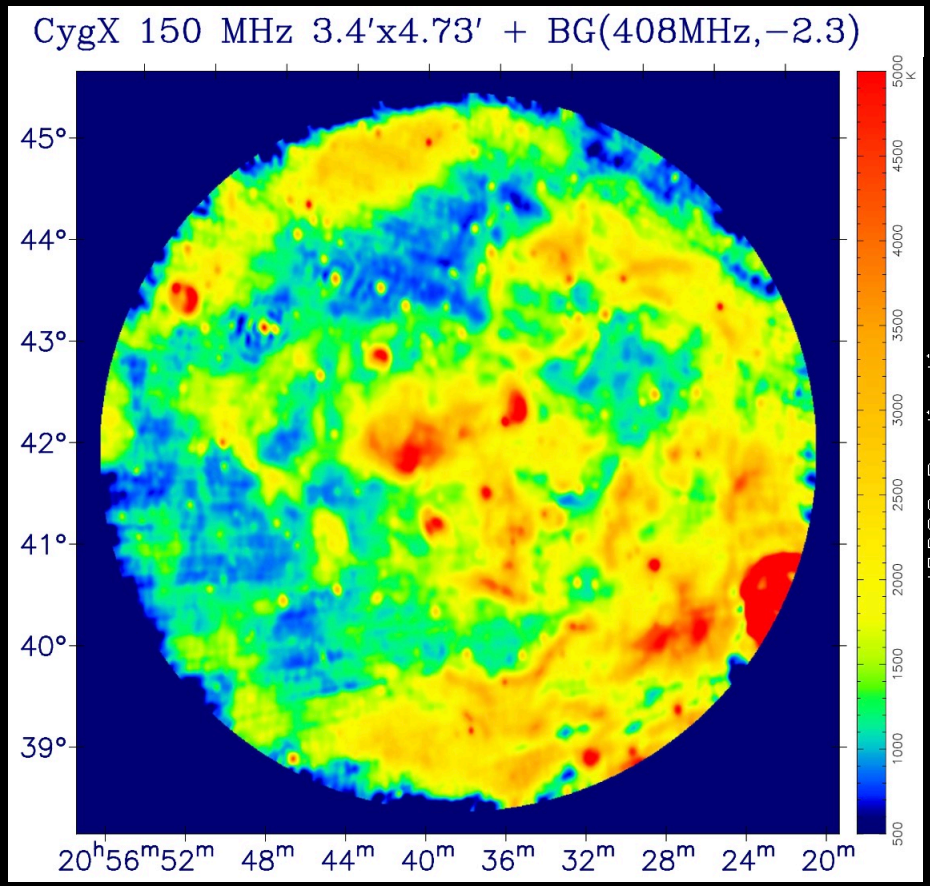


- HII regions
  - Cygnus X – massive high mass star forming region – looking down a spiral arm
  - 9 degrees from Cygnus A – 2 beam - phase and amplitude cal from CygA/ 3C197

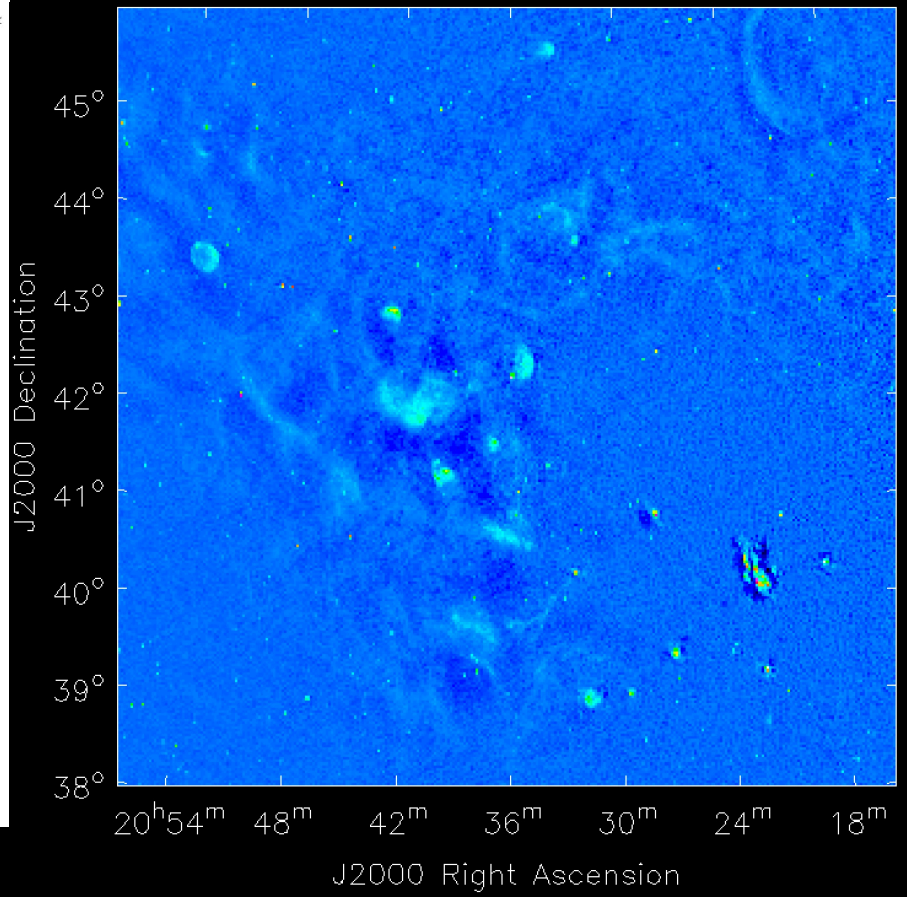



I
G84.2-0.8
AFGL 2636
W75N
DR21
DR23
DR20
DR22
AFGL2620
CygOB2
DR7
DR15
AFGL2591
DR4
γ Cygni SNR
G78.2+2.1
45°
44°
43°
42°
41°
40°
39°
J2000 Declination
20h50m
45m
40m
35m
30m
25m
20m
J2000 Right Ascension
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
(Jy/beam)

Simulating zero spacings – preliminary work from Wolfgang Reich

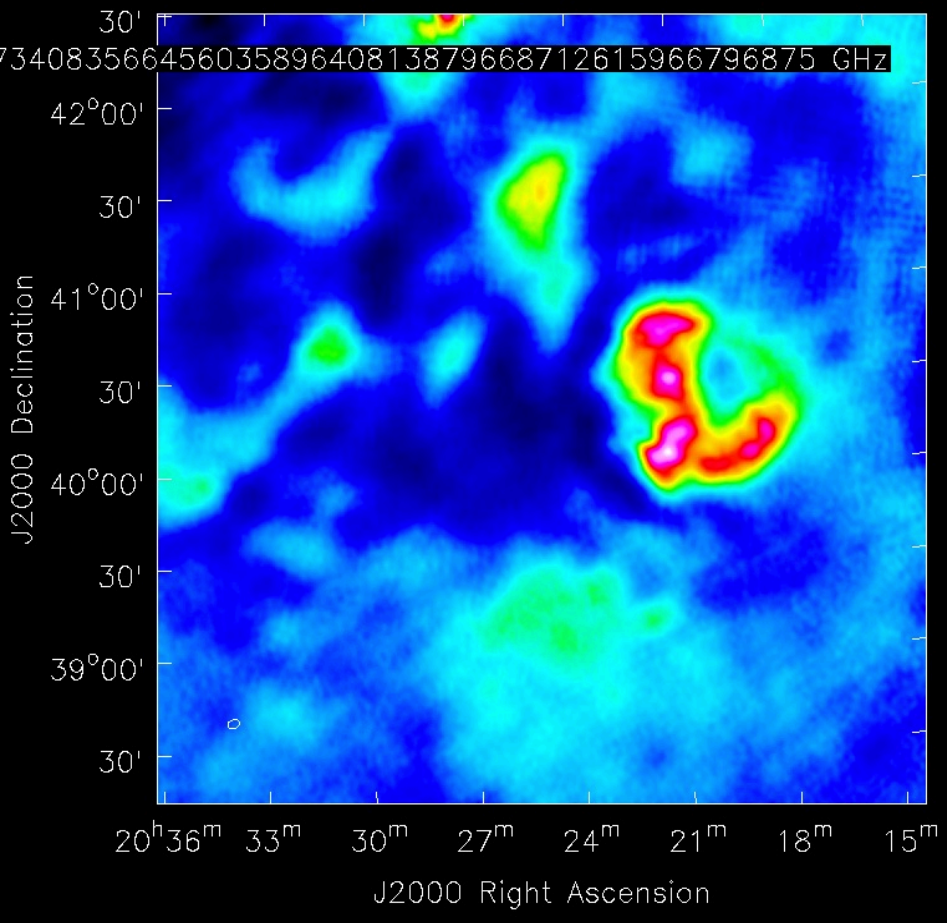


WENSS 330 MHz

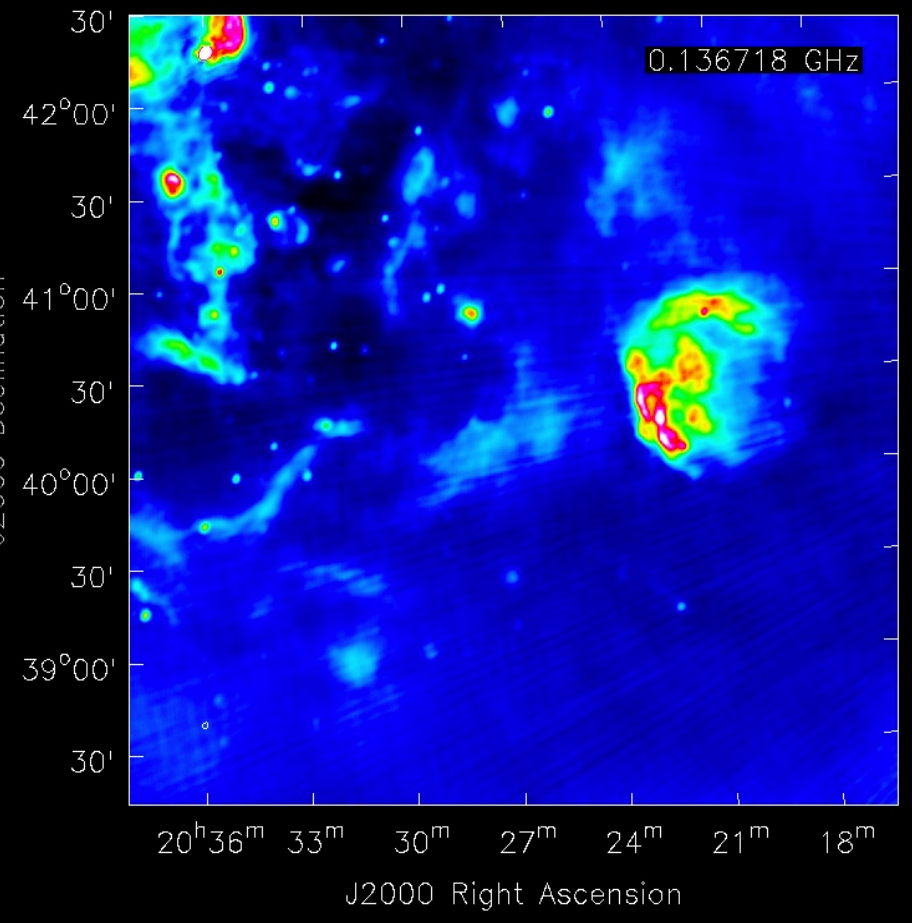


CYGNUS X

LBA

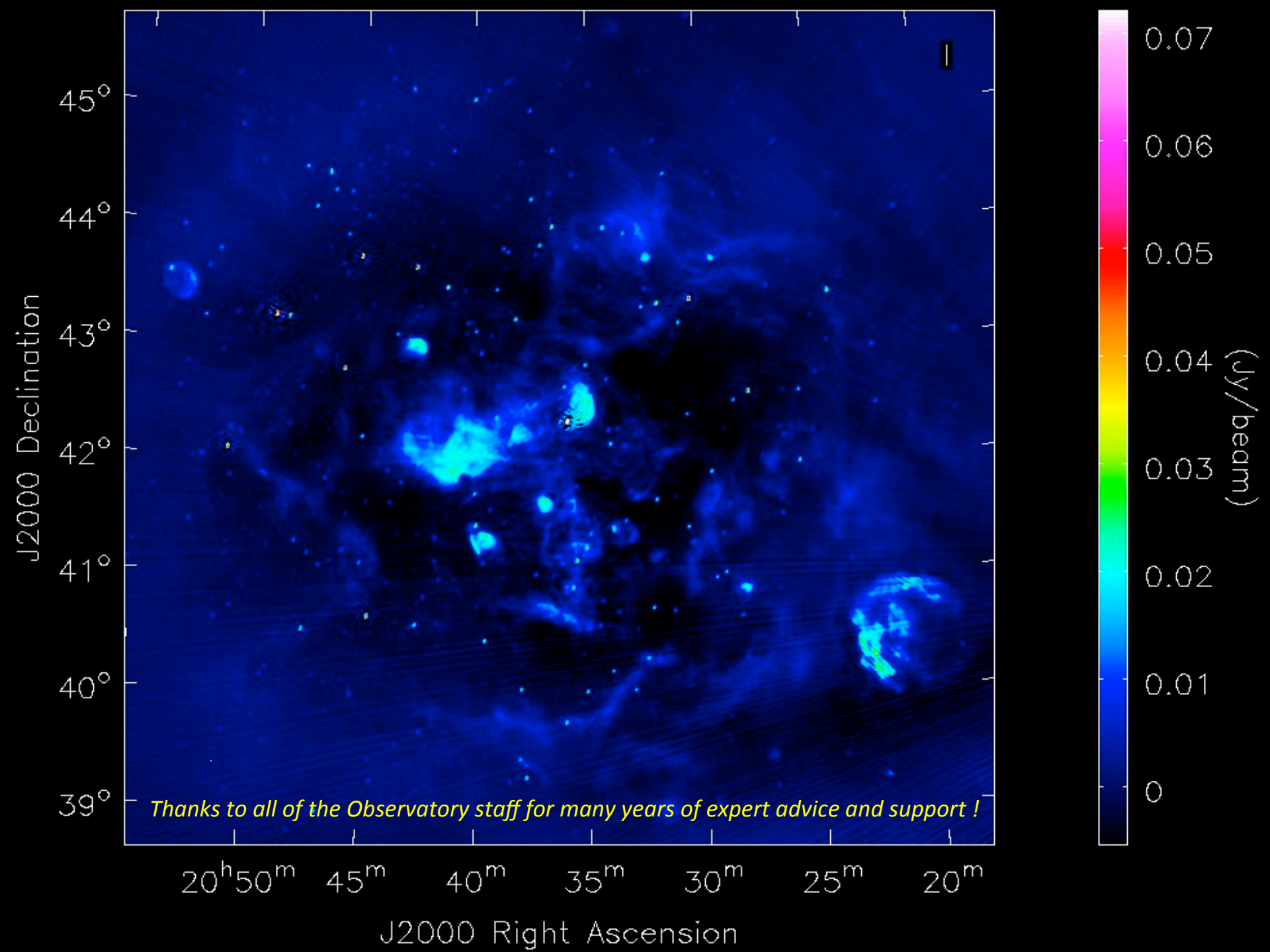


HBA



A few conclusions

- LOFAR is a superb instrument to observe the Galactic Plane
  - It has taken a lot of time to solve, and requires a different approach to normal to reduce data
- Supernova remnants dominate the low frequency Galactic emission and are easy to detect
  - Strong spectral index variations seen – information on the shock physics
  - Fluxes continue to increase into the LBA regime
- HII regions are widespread along the Galactic Plane, but difficult to detect due to the flux declining
  - Diffuse emission is difficult to detect using standard prescriptions – use blank skymodels
  - Calibration is very difficult – best approach remains to scale from a field calibrator
  - Lack of short baselines can be a problem – can we use single stations to help – extrapolation ?
  - LBA and HBA images may be the inverse of each other – don't assume LBA structure from HBA
  - RRLs are detectable – although have major implications for data processing and storage
  - W3/W4/W5 and Orion are well behaved HII regions with classic spectral indices as per theory
  - The W51 and Cygnus X regions show very strong HII region self-absorption (in LBA images)
  - The self-absorption will allow 3D tomographic sensing of the Galactic CR emissivity


45°
44°
43°
42°
41°
40°
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J2000 Declination
20h50m
45m
40m
35m
30m
25m
20m
J2000 Right Ascension
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
(Jy/beam)
Thanks to all of the Observatory staff for many years of expert advice and support !

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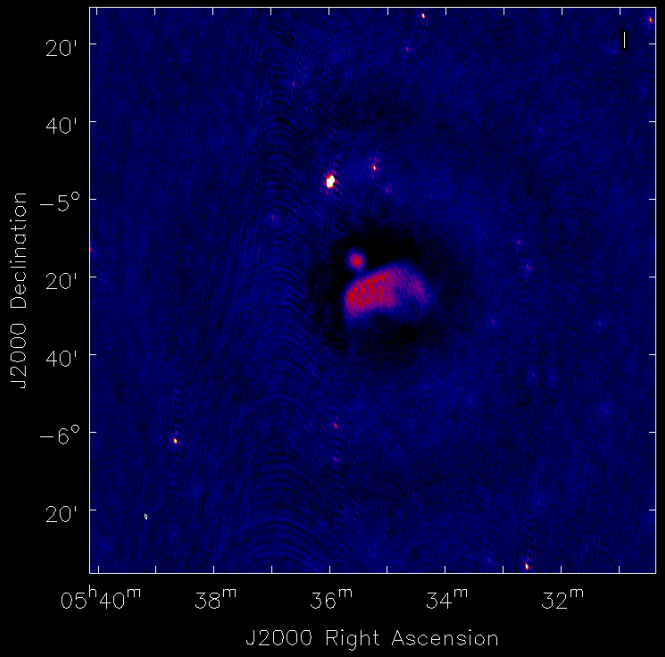

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