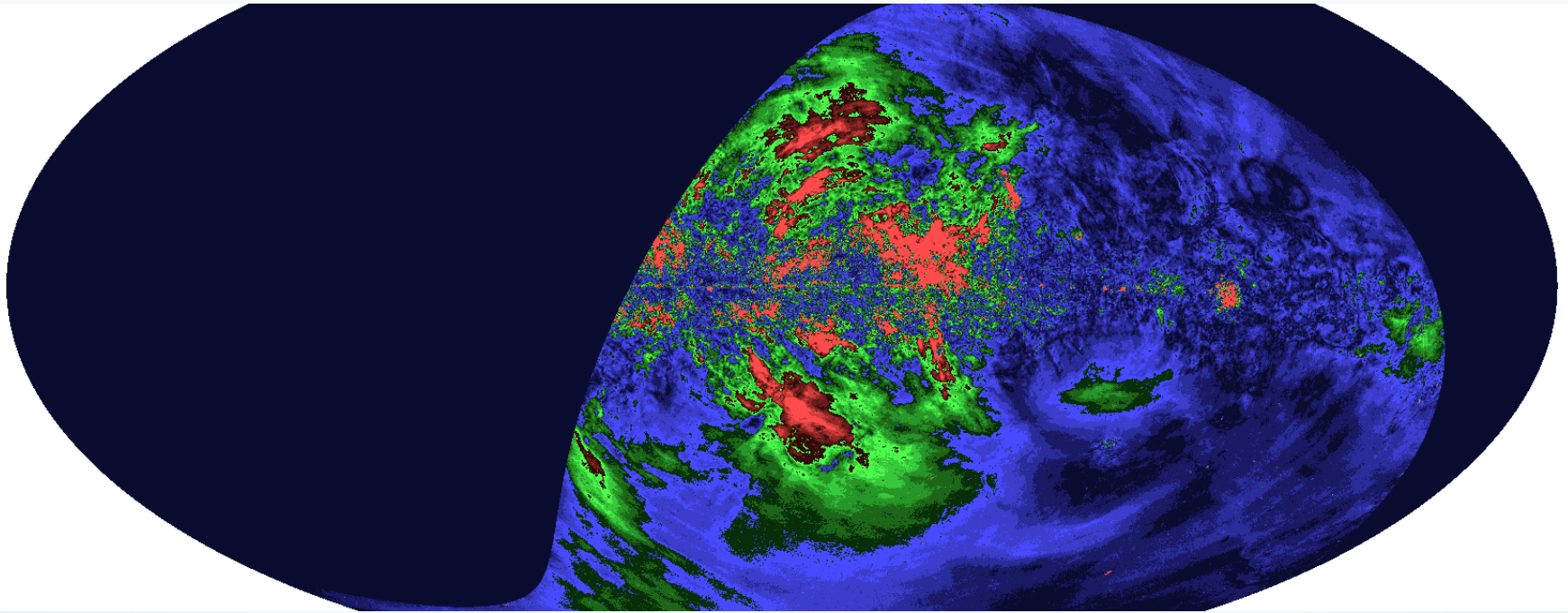


# S-PASS (S-band Polarisation All Sky Survey)

## A new view of the polarised sky



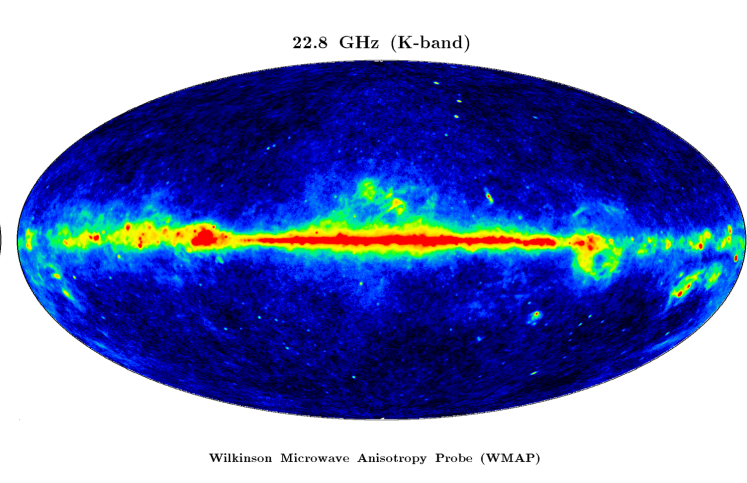
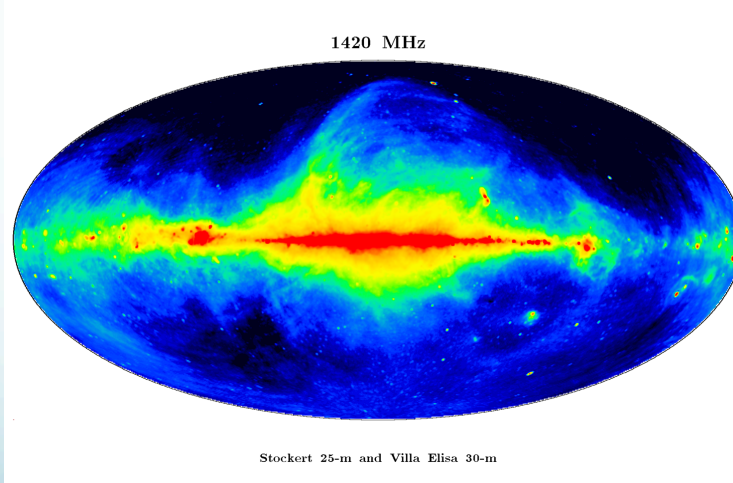
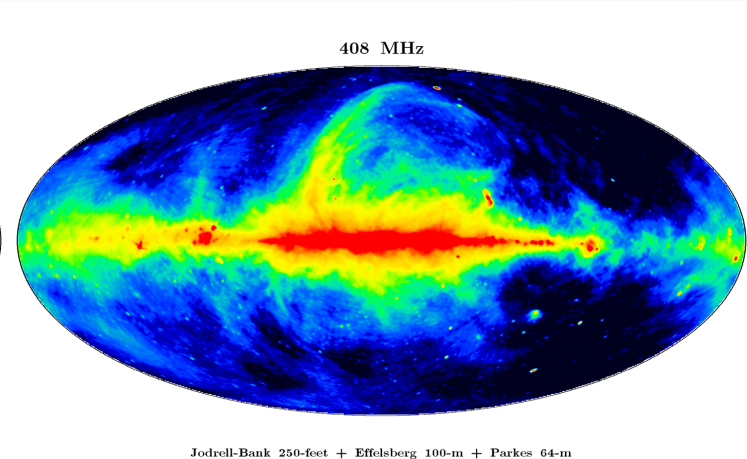
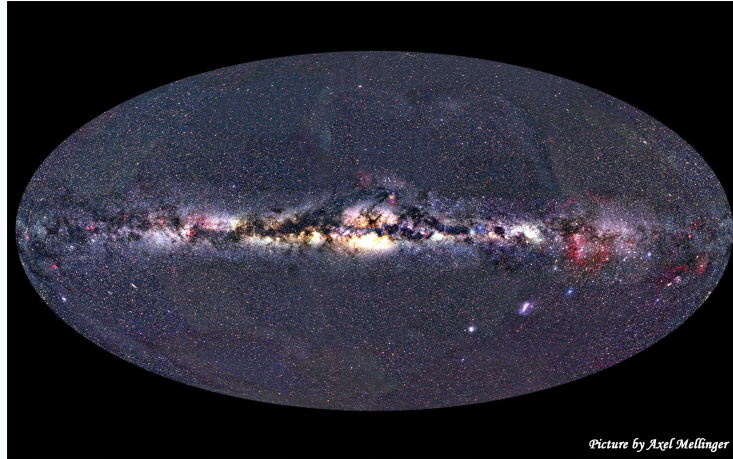
**E. Carretti**

INAF Istituto di Radioastronomia  
Presented by: **Carlo Baccigalupi**

# Outline

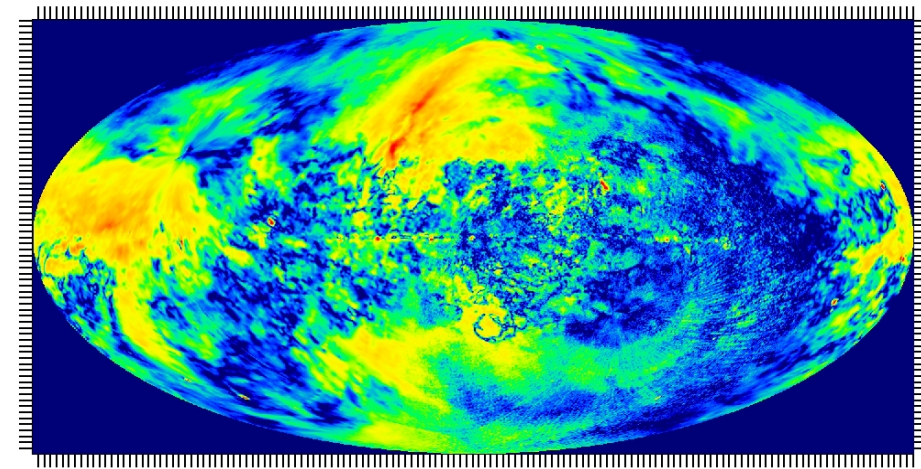
- Radio polarisation surveys
- Why S-PASS at 2.3 GHz?
- S-PASS: The project, observation strategy, and maps.
- Science results so far

# Radio unpolarised emission – total magnetic field



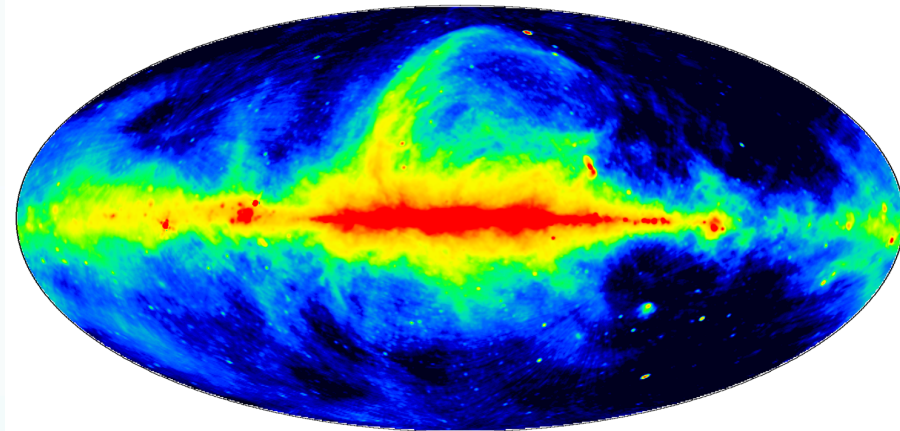


# Polarised radio emission

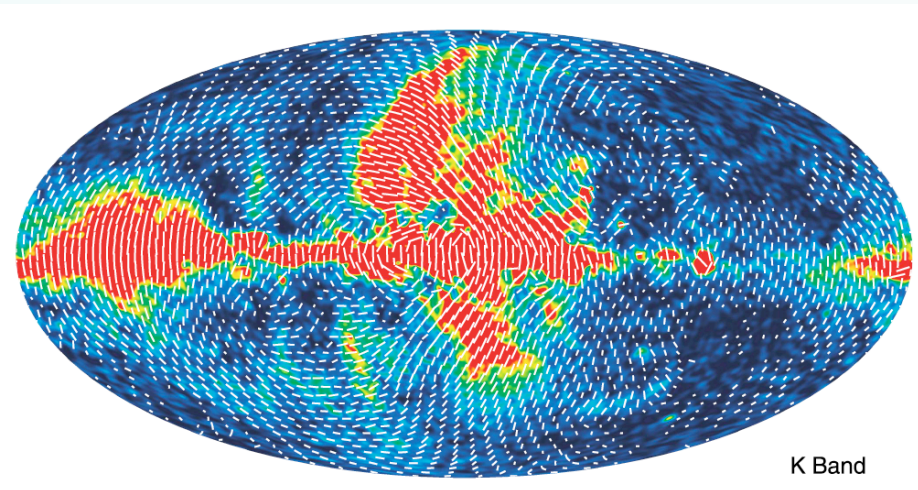


UNPOLARISED

408 MHz



Jodrell-Bank 250-feet + Effelsberg 100-m + Parkes 64-m



K Band

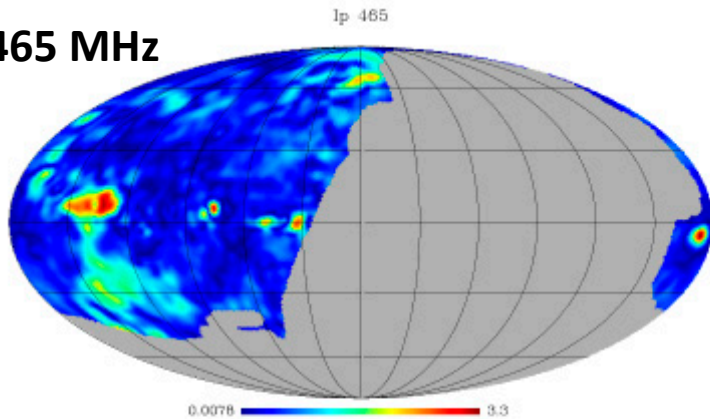


# Why 2.3 GHz?

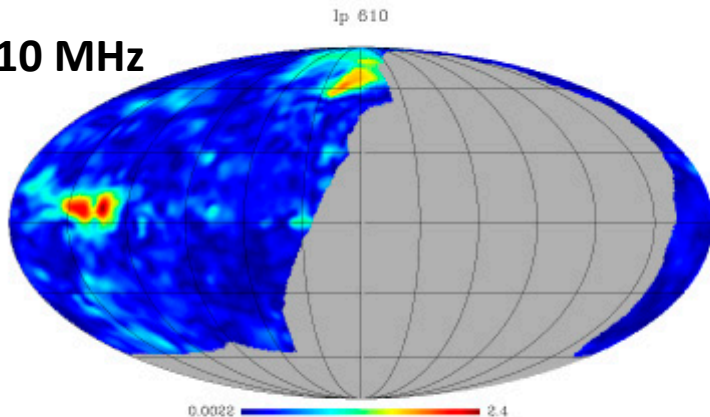
## Low frequency: obscured polarised emission

- Signal mostly obscured at low frequency
- Signal gradually reappears at high frequency

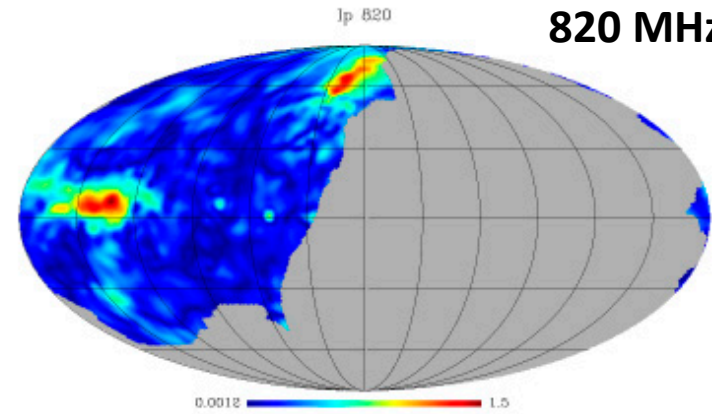
465 MHz



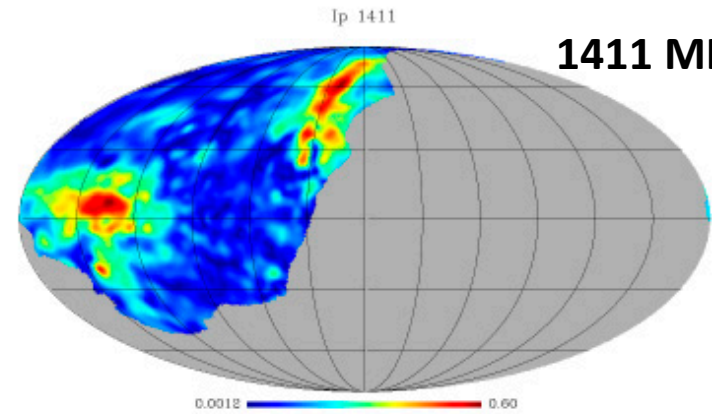
610 MHz



820 MHz



1411 MHz



Carretti et al., 2005, MNRAS, 358,

1

# Polarization surveys: 1.4 GHz

- ALL SKY maps at **1.4 GHz**
- Galactic Disc obscured at  $|b| < 30^\circ$  (depolarisation by Faraday Rotation)

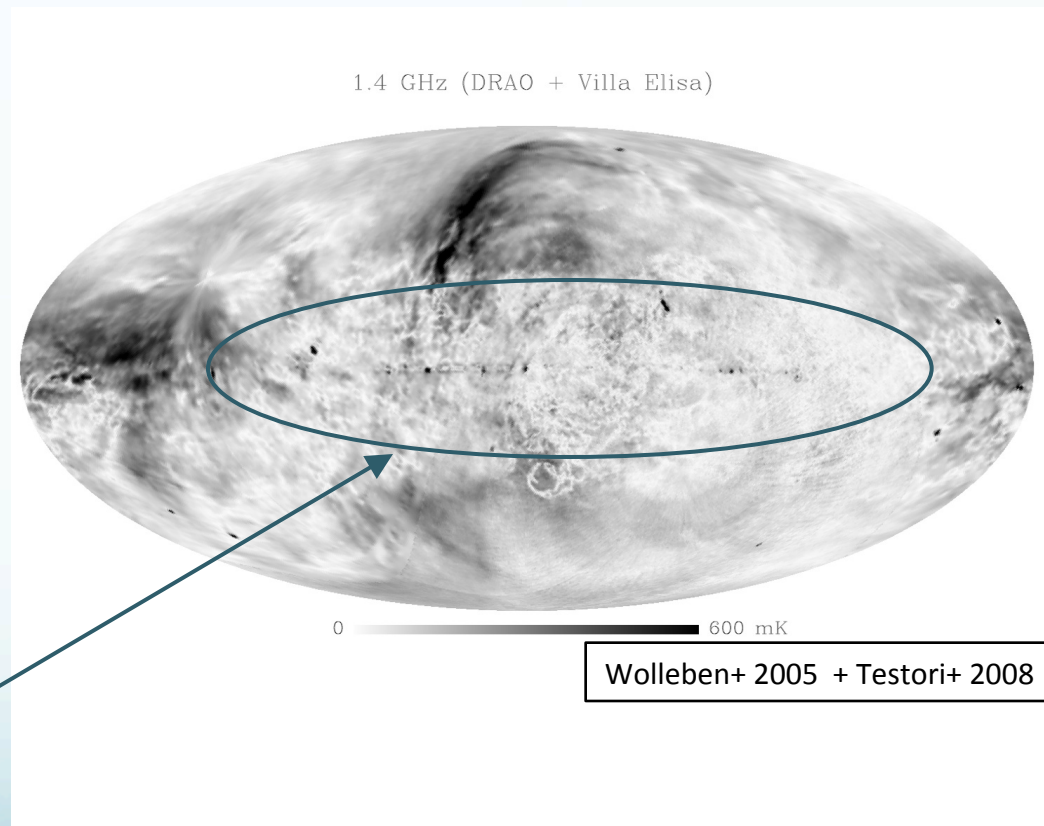


- **1.4 GHz: not sufficient**



**Higher frequency!!**

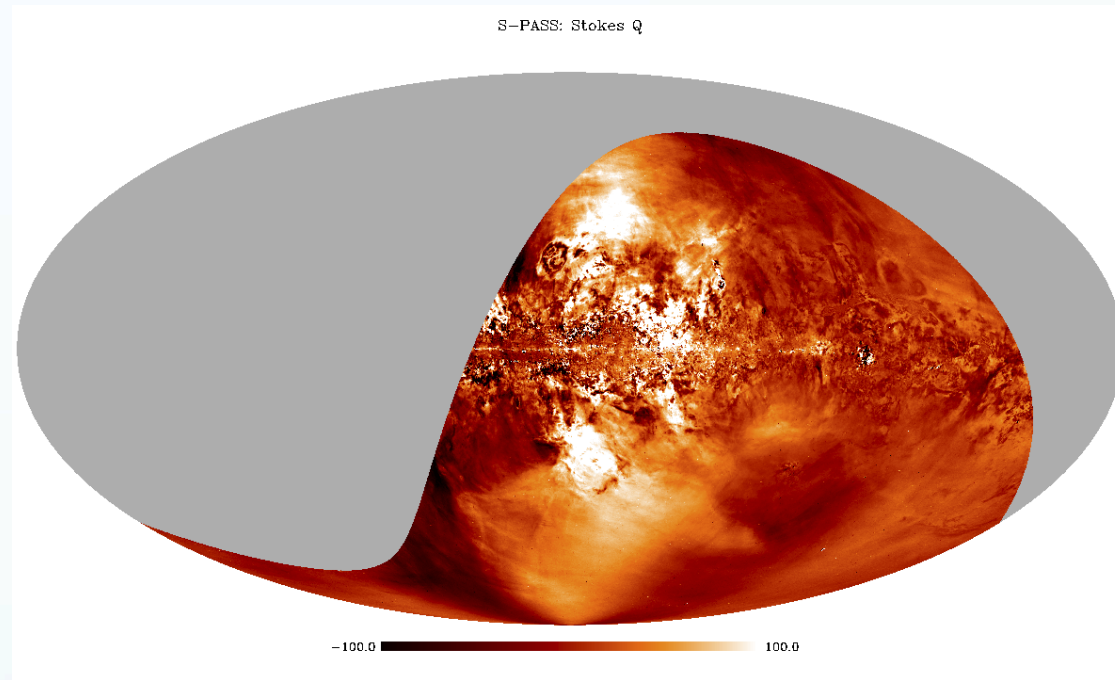
depolarization



# S-PASS: S-band Polarization All Sky Survey

- To survey the polarized emission of the entire southern sky at 2.3 GHz

- Dec  $< 0^\circ$ ;
- PARKES (64m): 2.3 GHz ;
- 224 MHz BW (100+ ch);
- FWHM = 9' ;
- $\sigma_{\text{beam}} < 1.0$  mK;
  
- 2000 h
- 175 nights in 2.5 yrs (!)



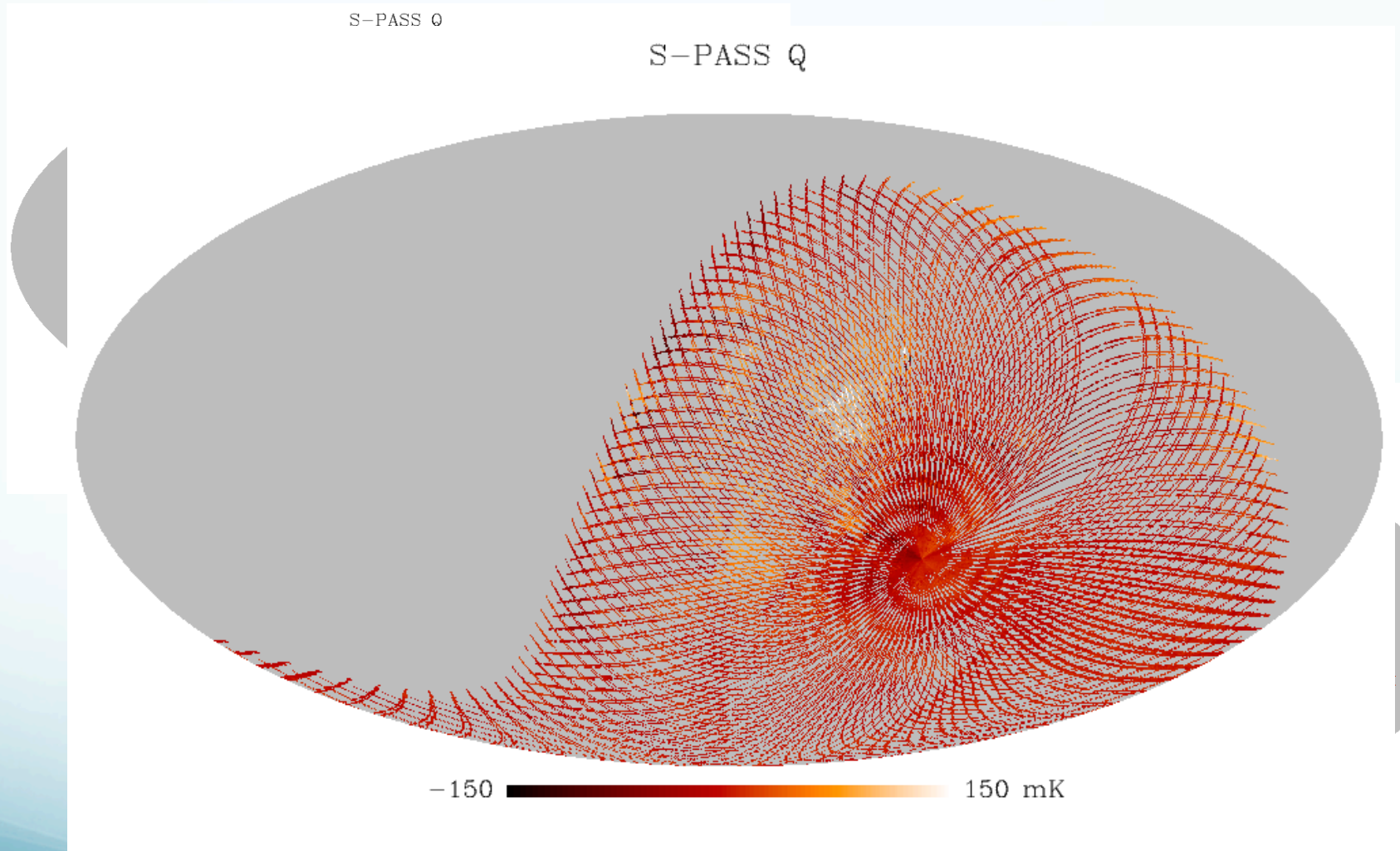
- Started Oct 07, **completed in January 2010**
- **Goals:**
  - **synchrotron emission, Galactic magnetic field, CMB foregrounds**



# Mapping: long AZ scans

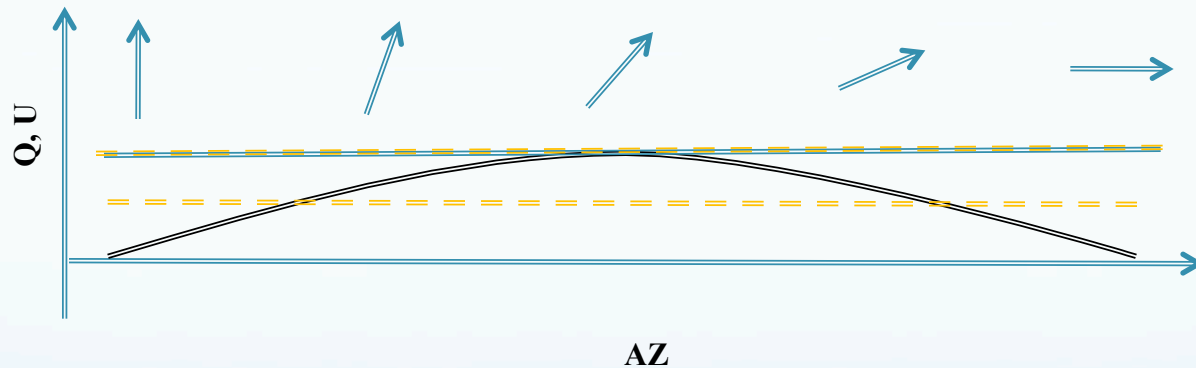
- small area basket weaving: **not an option for S-PASS**
  - ground emission contamination (EL dependant)
  - high speed requires significant overhead for short scans ( $10^{\circ}$ - $20^{\circ}$ )
  - short scans: mean emission on area scale is lost
  
- **non-standard scanning strategy** has been developed for S-PASS
  - **AZ scans**
  - Long AZ scans at South Pole EL to cover all Dec each scan ( $\sim 115^{\circ}$ )
  - Sky rotation to observe all RA 24 hrs.
  - Each night a zig-zag track is observed in the sky
  - one zig-zag per night: accurate start timing is required

# Basket weaving with AZ scans



# Absolute Calibration

- Long scans and basckeweaving: recover signal up to the size of the map
- **Not sufficient!**
- **The idea is to use the parallactic angle modulation of Q and U**
- parallactic angle modulates even a constant Q, U signal

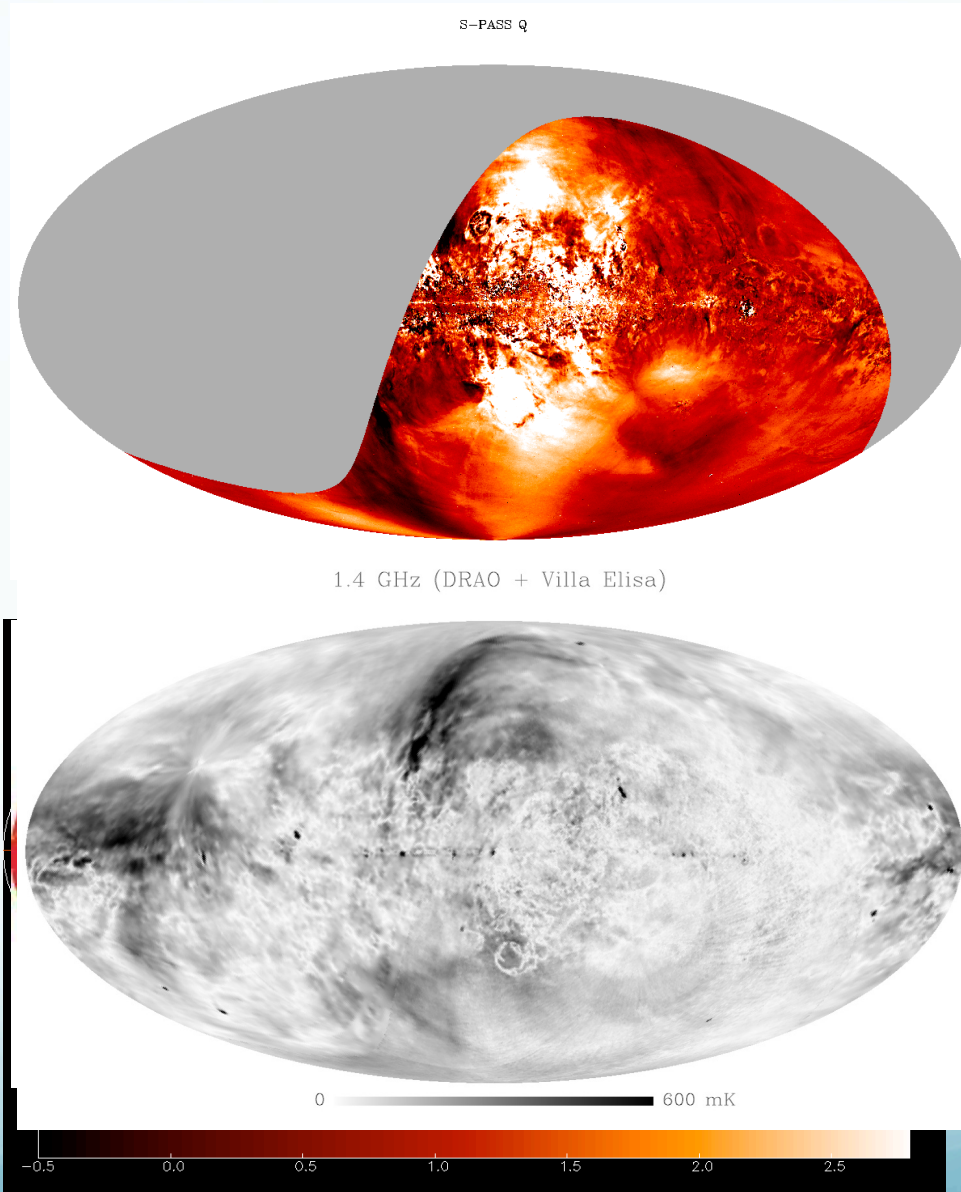


- **Mean signal is not fully lost: the baseline subtraction does not fully remove it (long scans essential)**
- It can be reconstructed (M-L inversion problem).



# S-PASS: polarization maps

# S-PASS and other data sets



SHASSA:  $H_{\alpha}$

WMAP 22.8 GHz

# Science Results



# Science Results

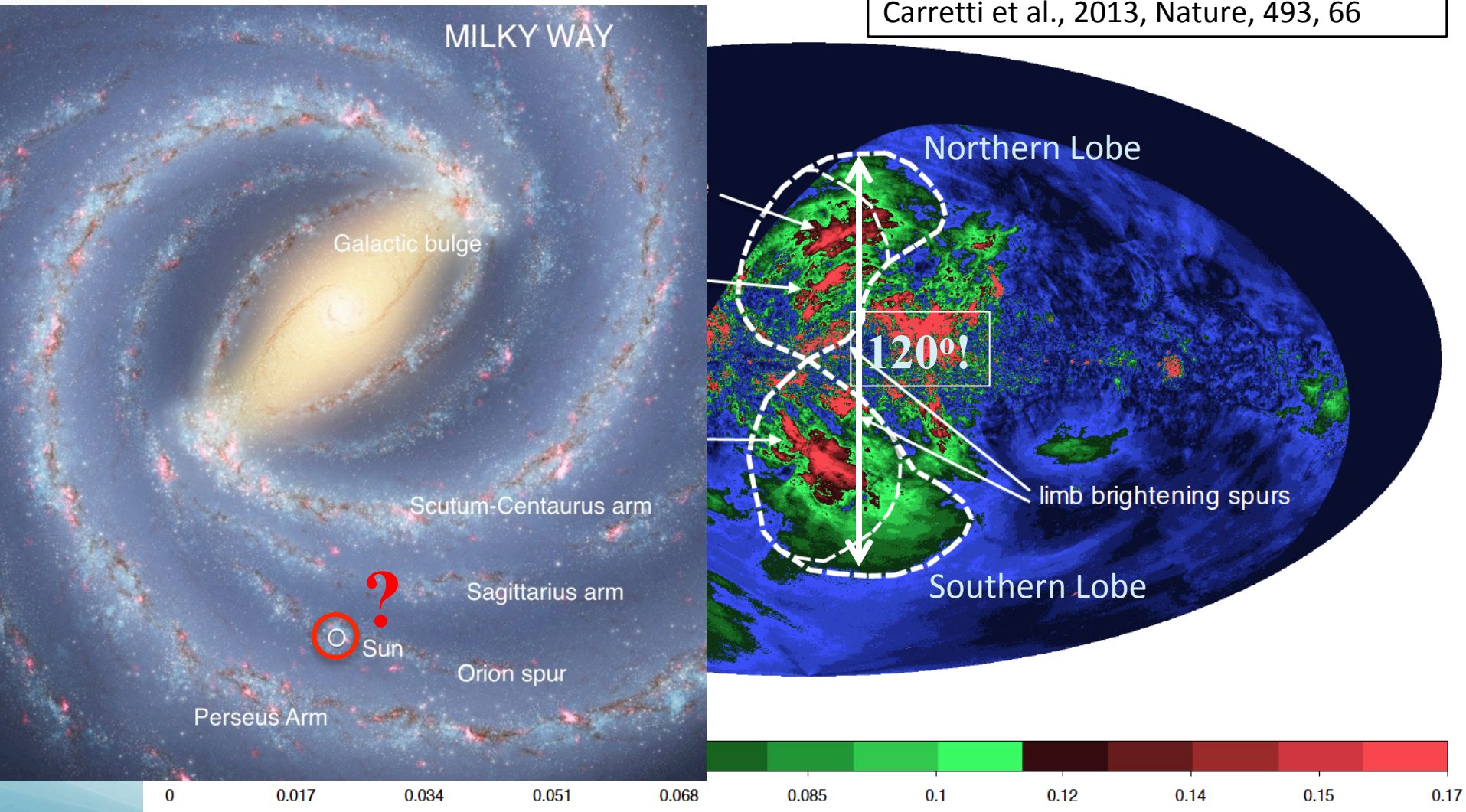
- S-PASS science is diverse
- Milky Way, galaxy clusters, cosmic web, CMB
  - Galactic Magnetic field
  - Fermi Bubbles and Galactic structure
  - ISM turbulence
  - ISM clouds, cavities, and supershells (e.g. Gum Nebula)
  - ICM of galaxy clusters
  - Extragalactic source properties
  - Synchrotron Cosmic Web
  - RM catalogue
  - CMB foregrounds
  - ....

# Science Results

- **16 papers**, to date (and counting)
- A selection

# 1. Milky Way lobes => Fermi Bubbles

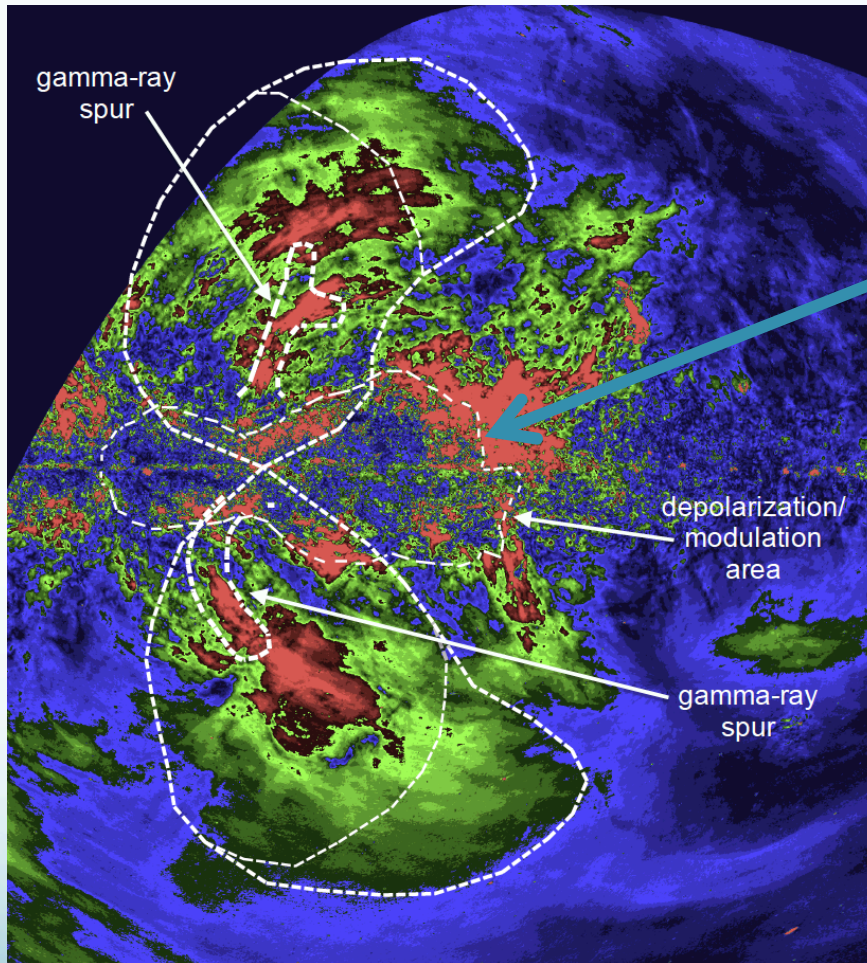
Carretti et al., 2013, Nature, 493, 66





# Galactic scale structure

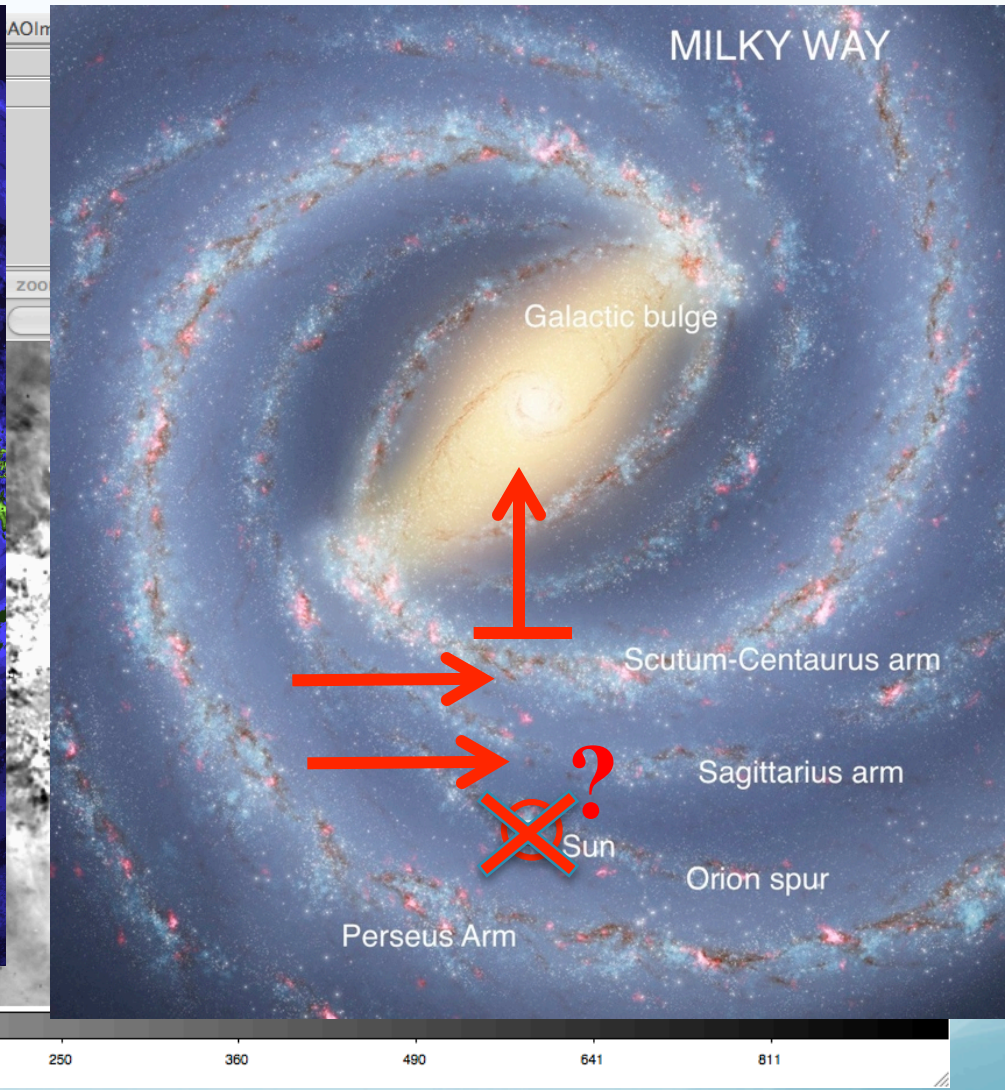
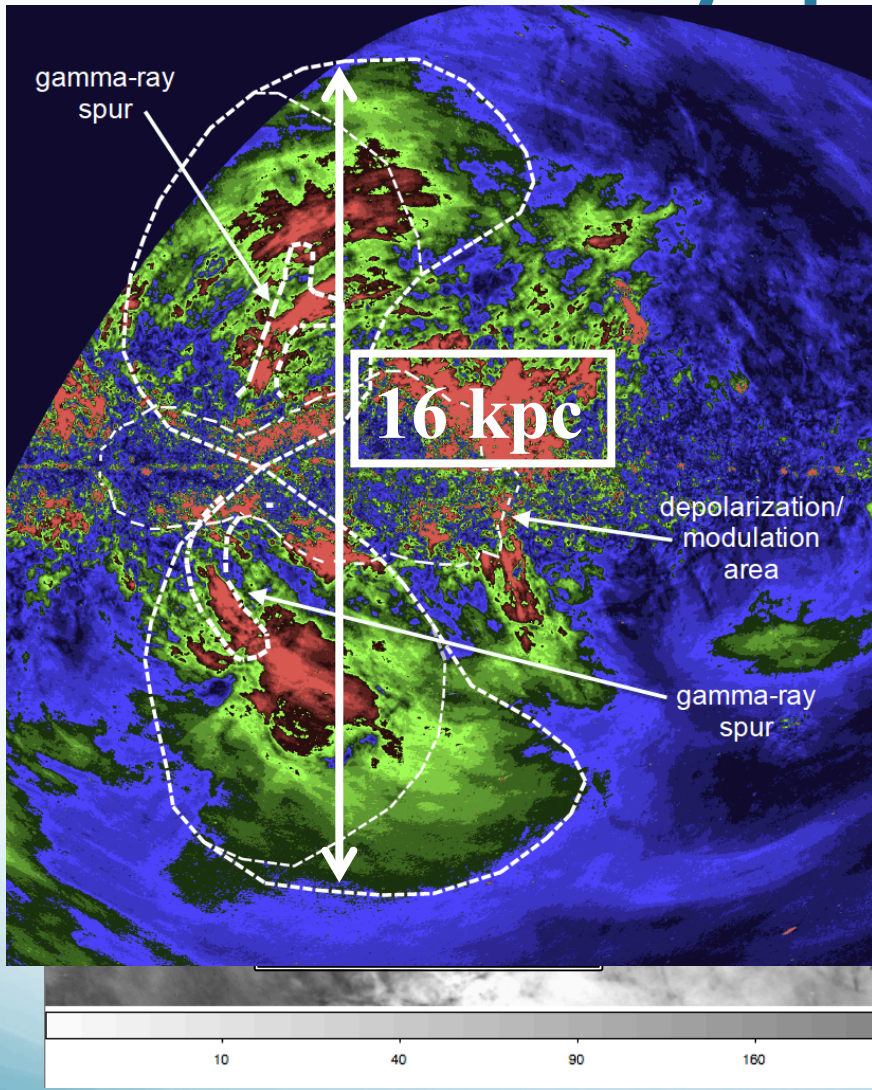
Carretti et al., 2013, Nature, 493, 66



Depolarisation

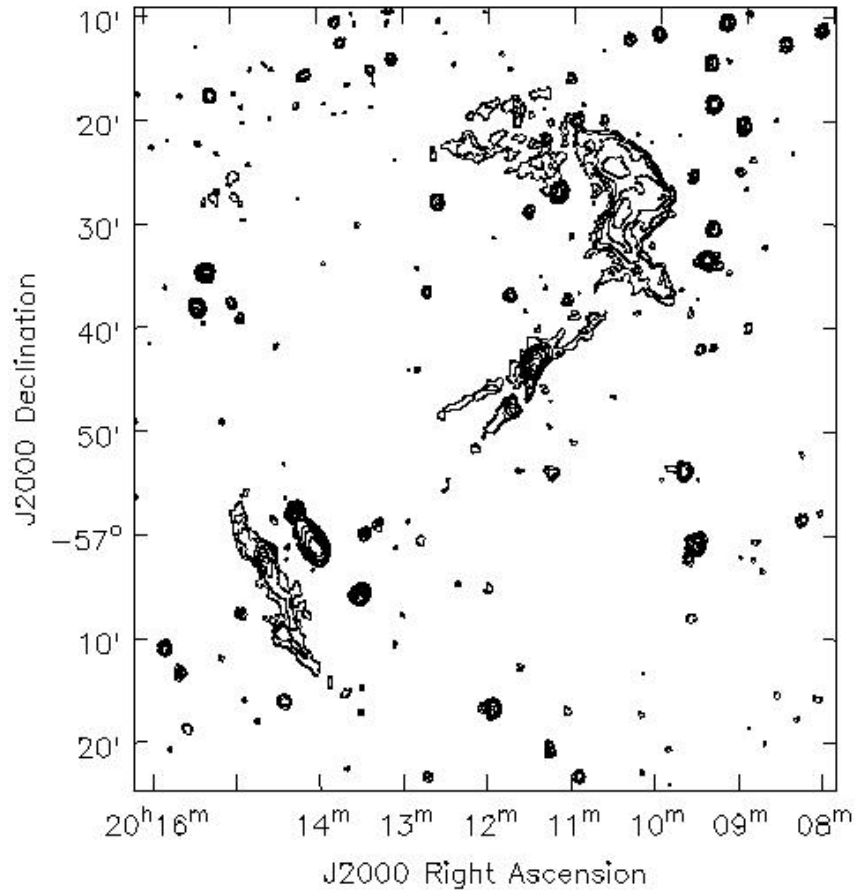


# Extinction by Spiral Arms: Not local!



## 2. Galaxy clusters: Abell 3667

- Galaxy cluster A3667
- Post major merger cluster
- Two relics supposed to be outgoing front shocks
- No ICM extended emission

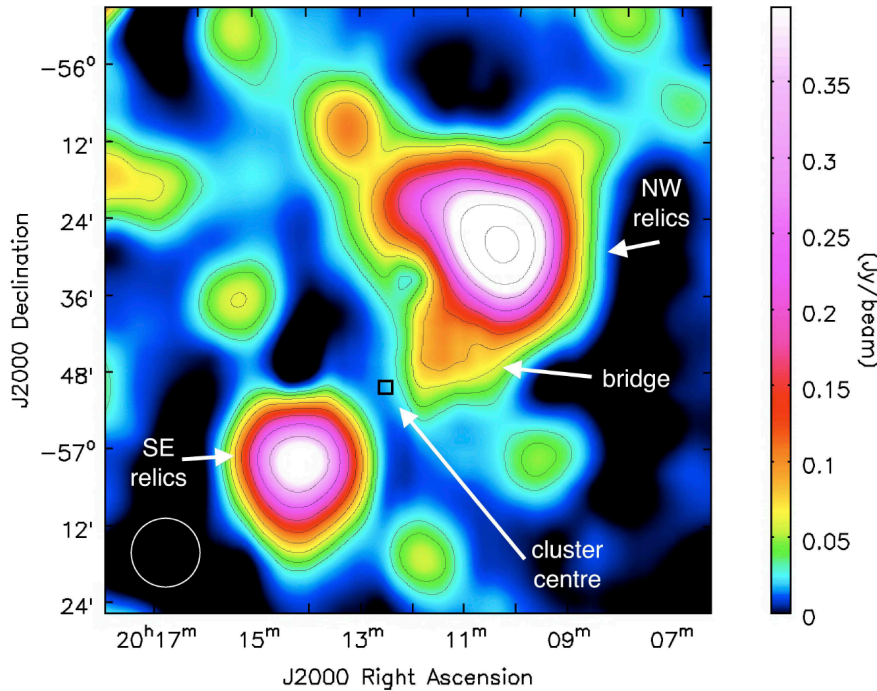


SUMSS image (843 MHz)

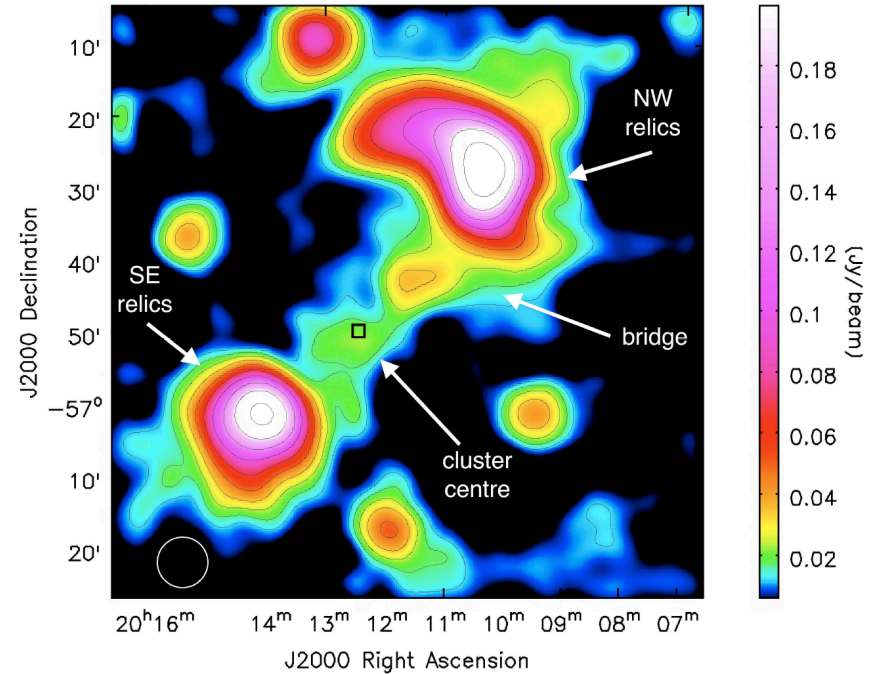


## 2. Bridge in A3667: Parkes images

Carretti et al., 2013, MNRAS



2.3 GHz S-PASS



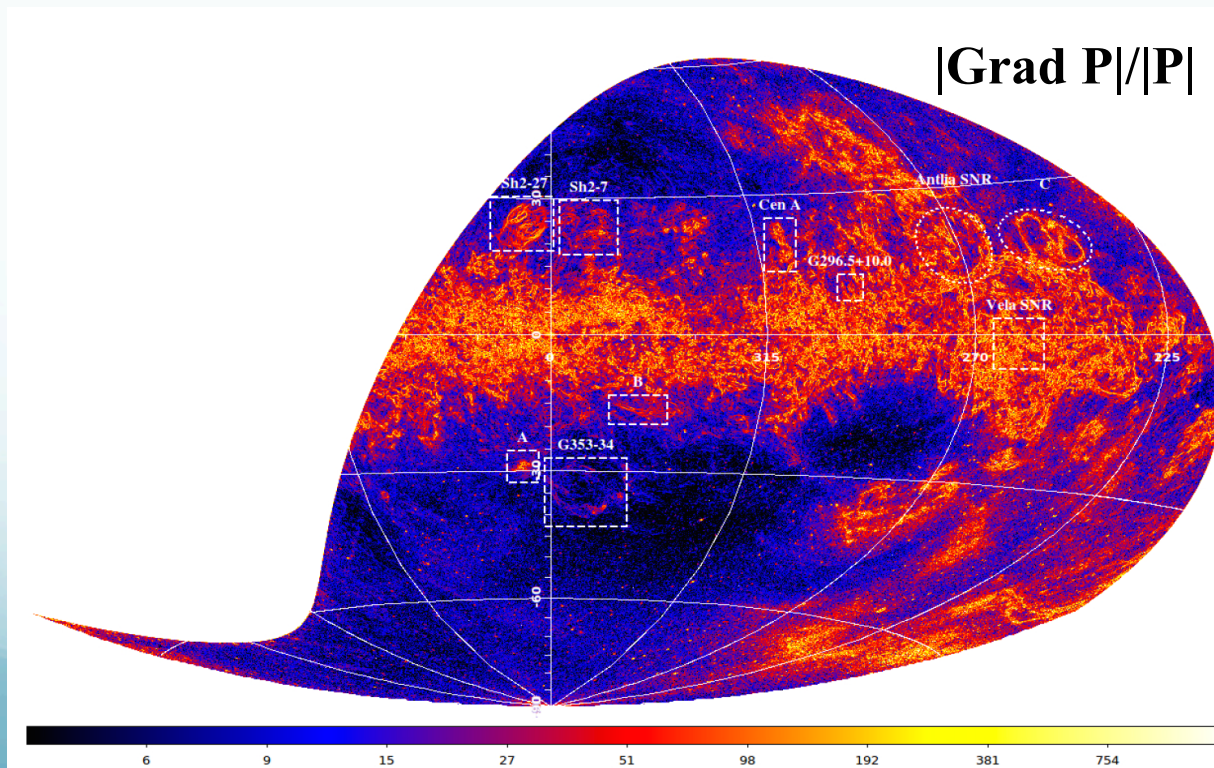
3.3 GHz (Parkes)

- Large scale emission revealed by S-PASS and Parkes obs.
- Wake of outgoing post-merger shock missed by interferometric observations
- Large single-dish telescope essential to reveal it

# 4. ISM Turbulence

- Grad P map (polarisation gradient)
- **First all sky (class) ISM turbulence map**
- S-PASS map and turbulence simulation comparison
- ISM in transonic regime ( $1 < \mathcal{M} < 2$ )

Iacobelli et al., 2014, A&A

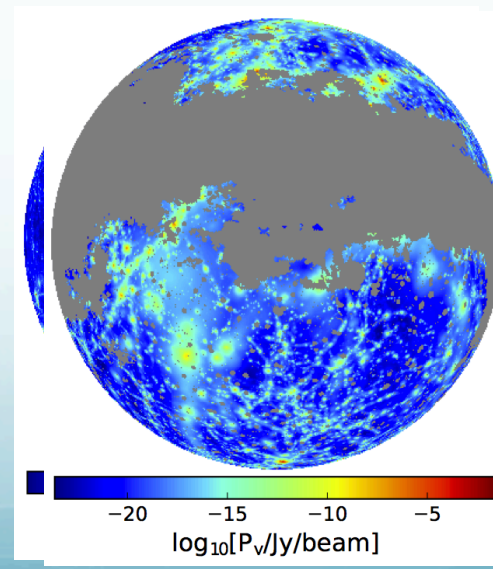
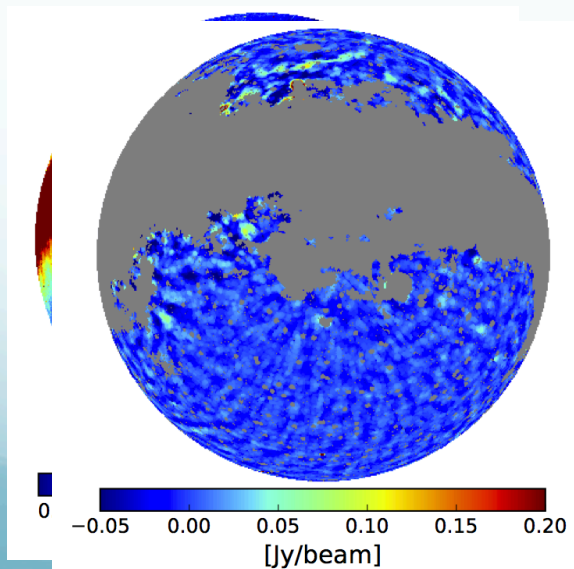




# 6. S-PASS and Synch Cosmic Web

- Search for Synchrotron Cosmic Web
- from Cosmic Web filaments (B field and CRs)
- S-PASS ideal: S-PASS beam matches well filament cross-section
- Statistical search: cross-correlation S-PASS and cosmic web tracers (simulation reproducing the real cosmic web)
- **New deep upper limit: Synch emission  $<0.04 \mu\text{Jy}/\text{arcsec}^2$  ( $3\sigma$ )**
  - **B  $< 30$  nG ( $3\sigma$ )  $\Rightarrow$  primordial MF  $< 1$  nG**

Brown et al., 2017, MNRAS, accepted,  
arXiv:1703.07829



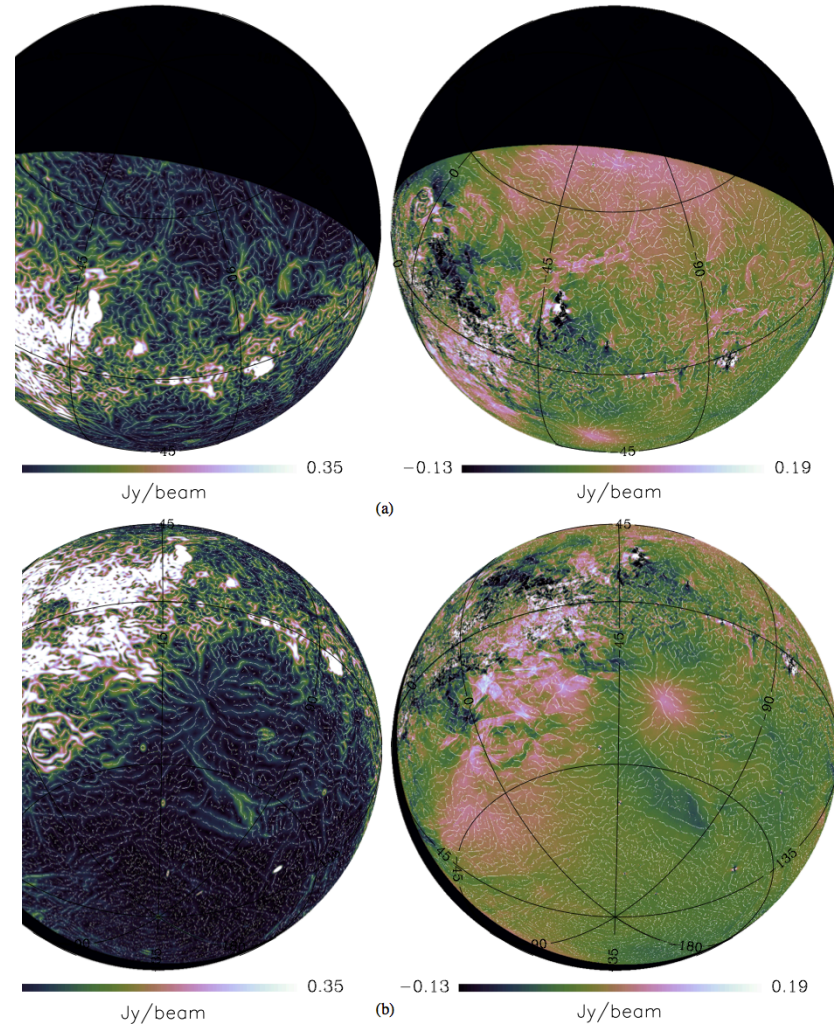
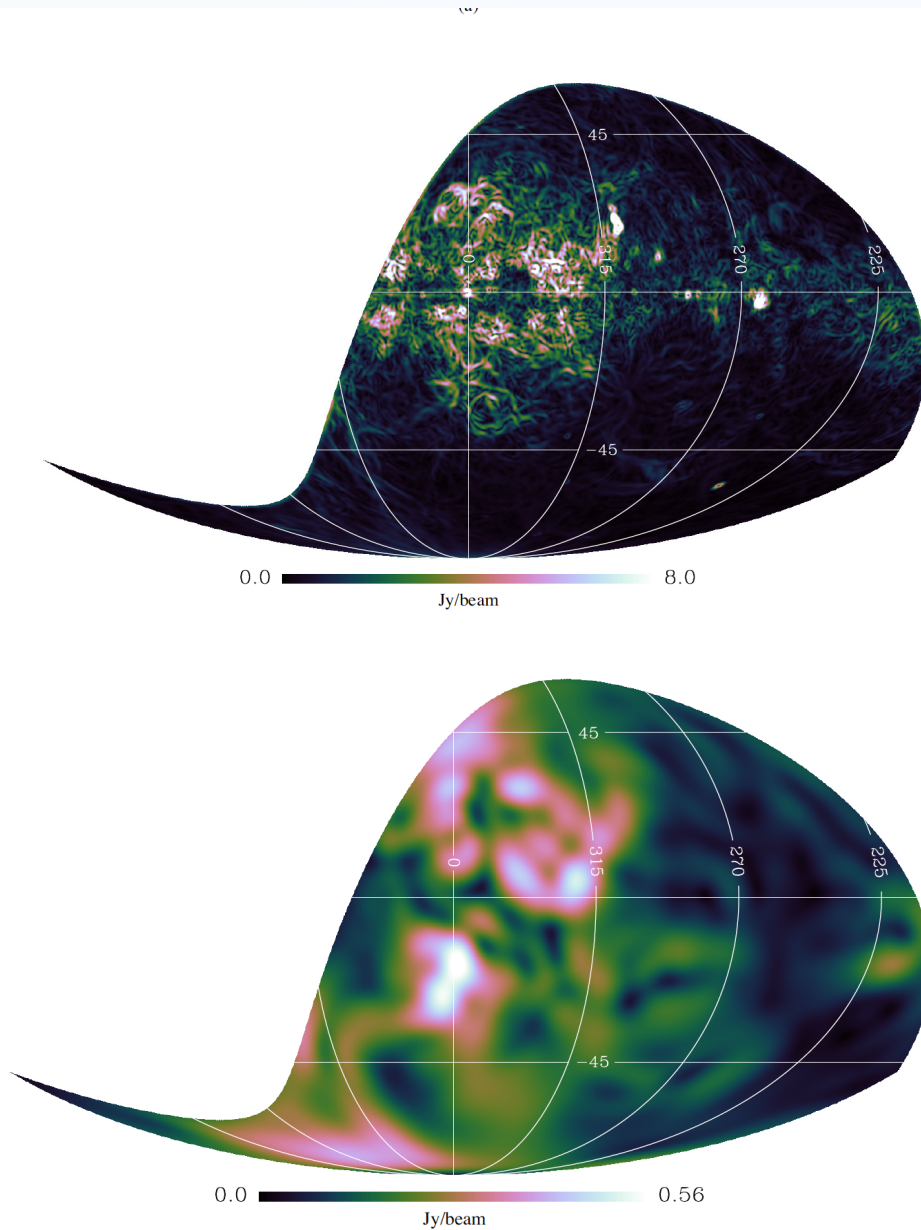
# 7. S-PASS bright polarisation sources catalogue

Lame'e et al., 2016, ApJ, 829, 5

- Polarisation properties of compact Extragalactic sources
- Bright sample of 533 sources with
  - Stokes I > 420 mJy
  - Dec > -40°
  - Counterpart at 1.4 GHz (NVSS)
- Depolarisation(D) between 1.4 and 2.3 GHz
- Correlation with a number of properties (L, z, pol frac, RM, ...)
- Major outcomes:
  - Flat spectrum sources are neither depolarised nor repolarised (on average)
  - Depolarisation depends on the source env, not on the Galactic screen
  - First (weak) evidence of z-evolution of D => magnetic field evolution with z

# 9. ISM Multi-Scale Turbulence

Robitaille et al., 2017, MNRAS, accepted,  
arXiv:1703.04469

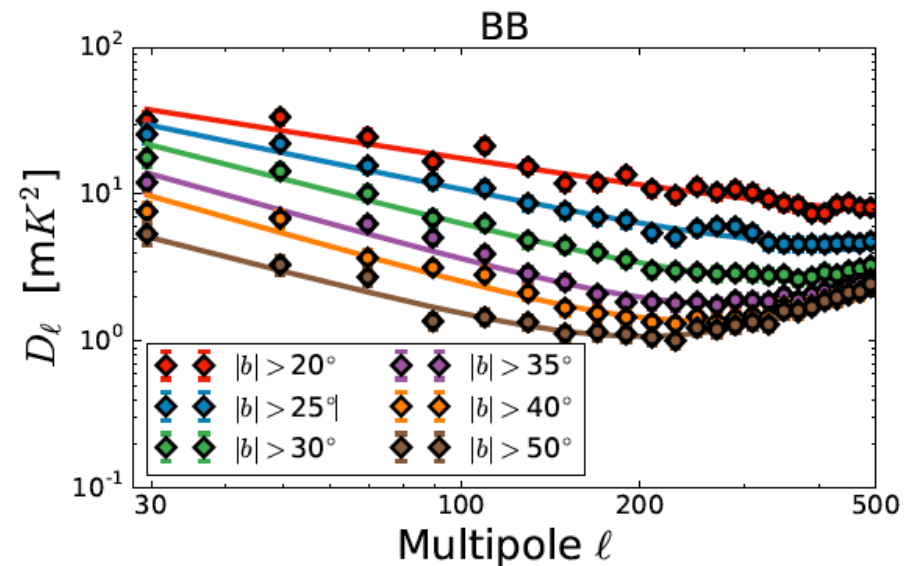
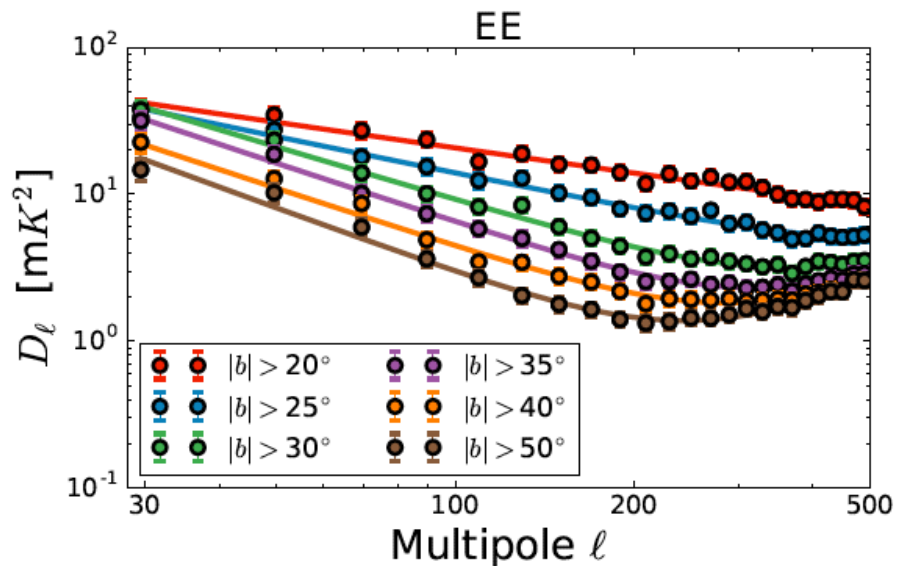


# 10. S-PASS and CMB foregrounds

- Synchrotron component
- Very preliminary results
- Several sky cuts ( $|b| > 20$  deg  $\Rightarrow$   $|b| > 50$  deg)

Krachmalnicoff et al., A&A, accepted,  
arXiv:1802.01145

## • SEE NICOLETTA'S TALK

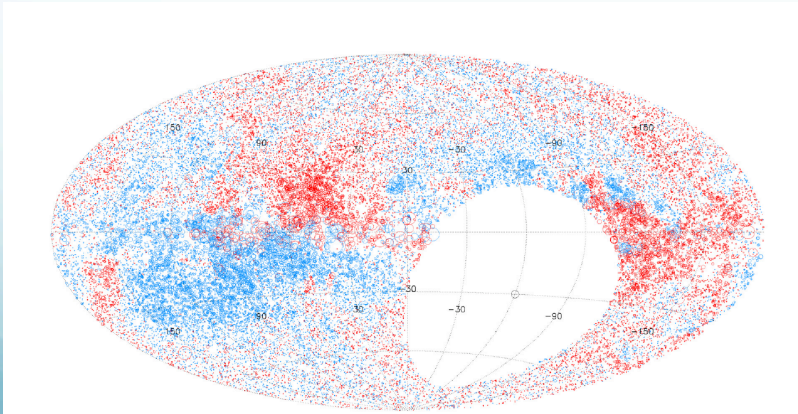




# 13. S-PASS Compact Source RM Catalogue

Schnitzeler et al., 2018, MNRAS, submitted

- Polarisation compact source catalogue (Dec < 0°)
- Sample of ~5000 pol sources identified in S-PASS maps
- Follow-up with ATCA, 1.1-3.1 GHz, broad band
- Filling the Southern Hemisphere gap of Taylor et al. (2009)
- Large Scale magnetic field modelling, EGS magnetic field analysis, ...





# Work in progress

14. Advance diagnostic to study linearly pol em Herron et al., 2018, ApJ, 855, 29
15. New Local ISM cavity with outflows into the halo Robitaille et al., 2018, A&A, 617, 101
16. Survey paper **Carretti et al., MNRAS, submitted**
17. Large radio loops
18. New SNRs
19.  $\zeta$  Oph region
20. Combination GMIMS-S-PASS (RM-synthesis (Faraday Tomography) on 300-2400 MHz)
21. And counting...

# Future Plans

- S-PASS-North with SRT (same size as Parkes)
- 7-beam receiver in S-Band

# Take home messages

- S-PASS: absolutely calibrated polarisation maps.
- **Polarised signal detected down the Galactic disc**
- **Diverse science:** Galactic, Extragalactic, galaxy clusters, cosmology
- Analysis for CMB B-Mode foregrounds (**See Nicoletta's talk**)
- **High accuracy, high S/N foregrounds maps essential for CMB B-mode Detection ( $r=0.01-0.001$ ) (all sky => strong synch contamination)**

**THANK YOU!**

