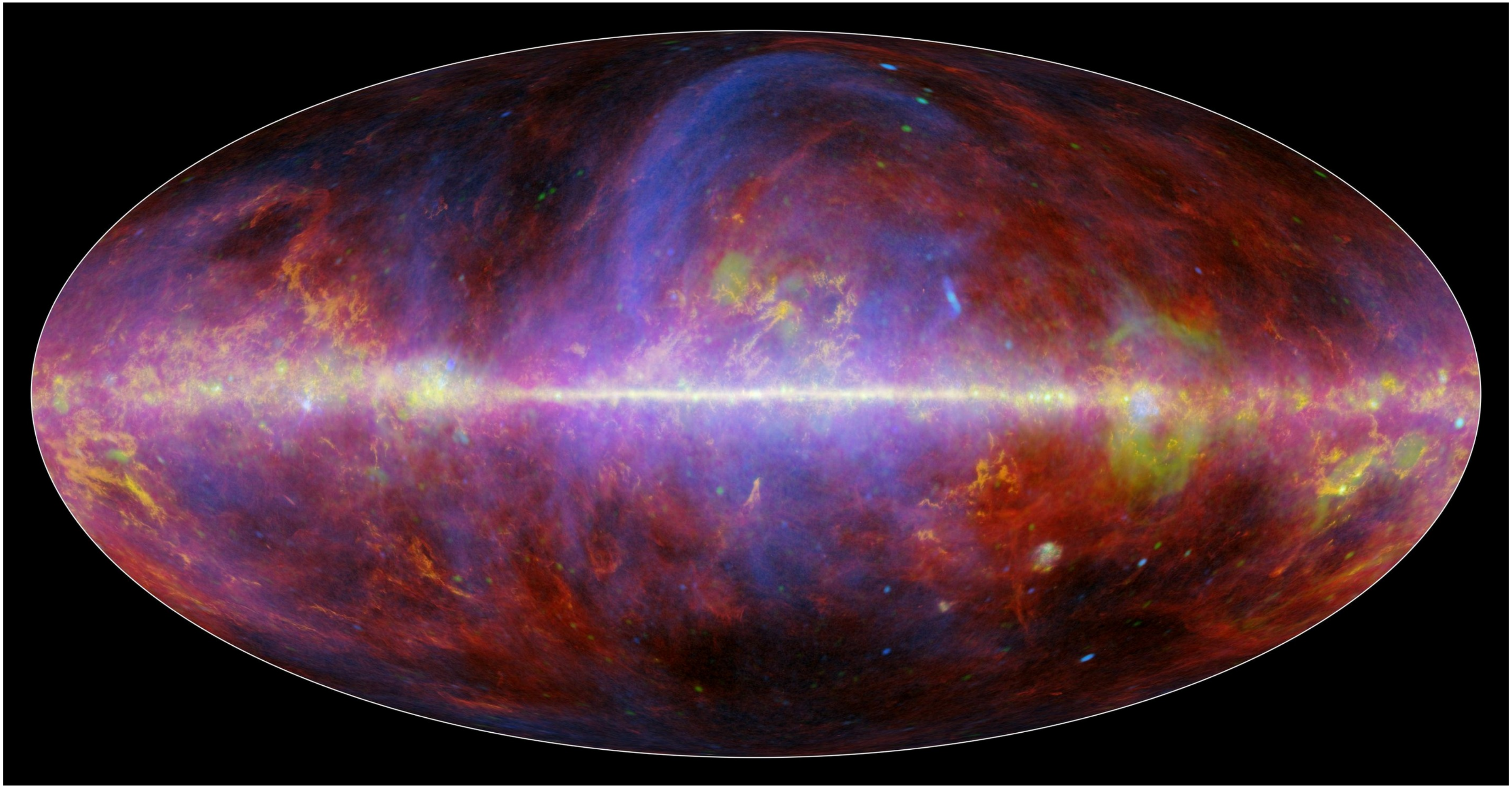
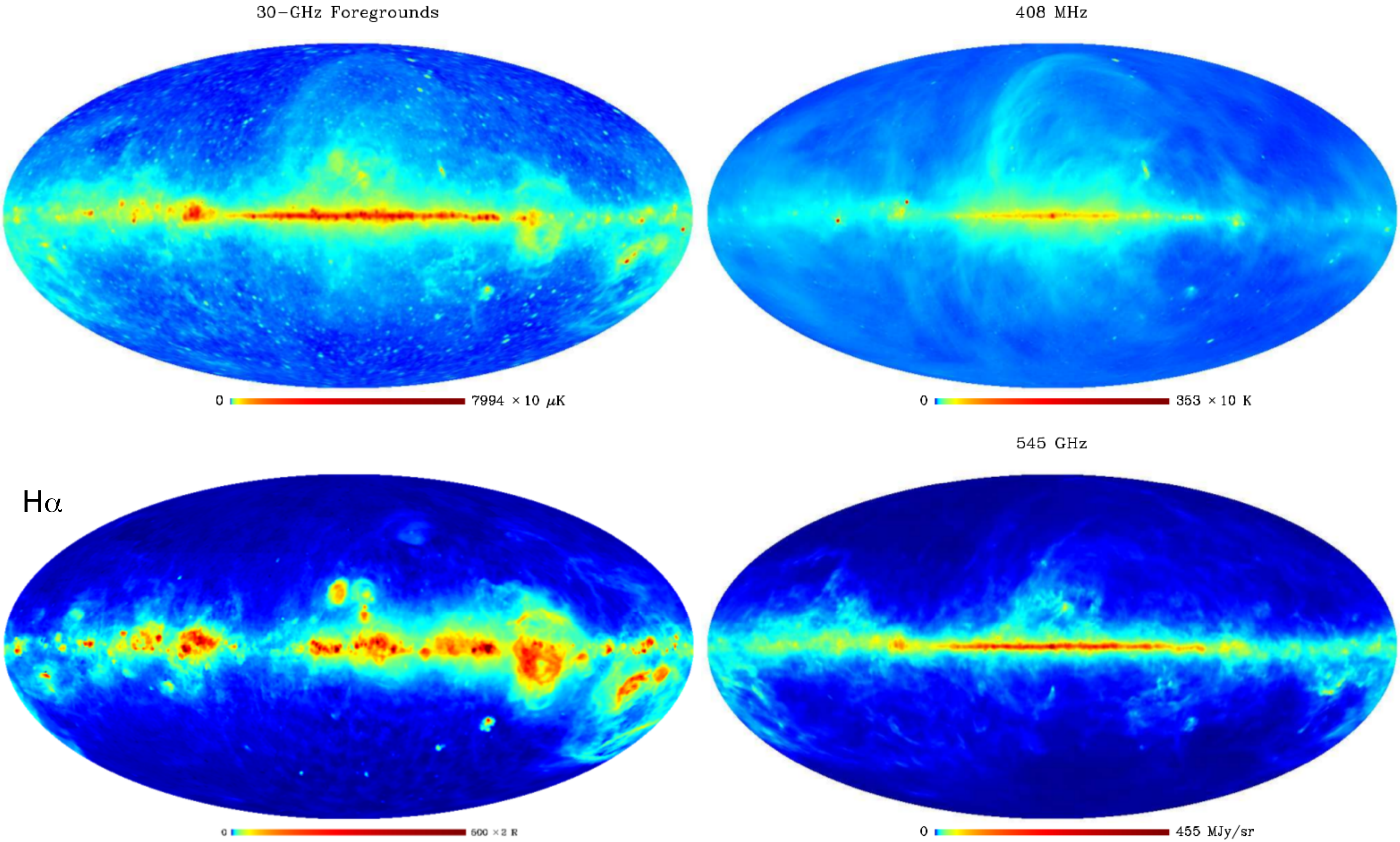
Large scale Synchrotron and Loop I



Matías Vidal
Universidad de Chile

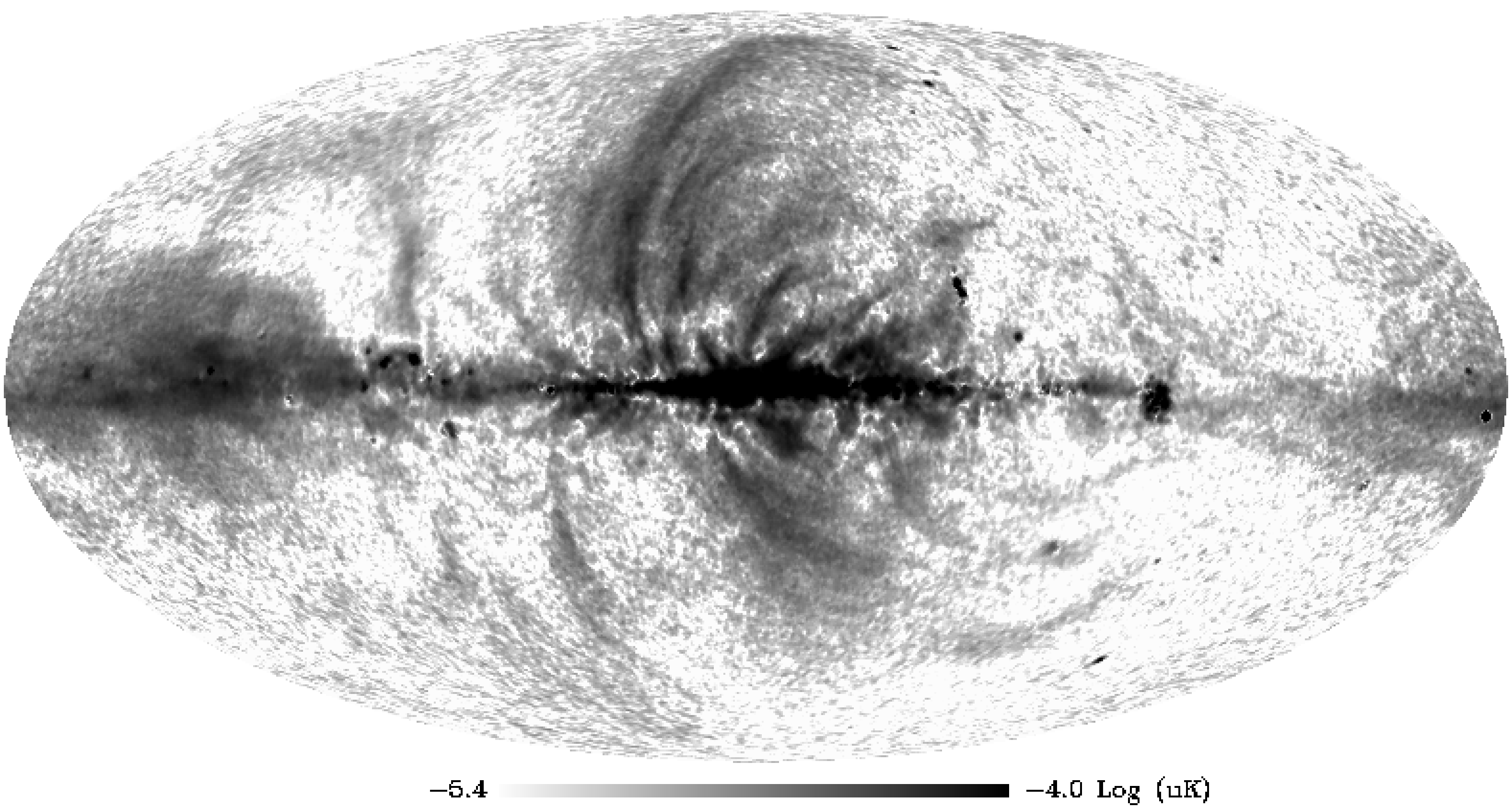
With Clive Dickinson, Paddy Leahy, Mike Peel and Rod Davies.

CMB subtracted 30 GHz sky, a combination of different components



Planck 2015 results. XXV

In polarisation, 30 GHz sky is dominated by filamentary structures



Can we trust P ?

Polarisation noise bias

- Polarisation amplitude measurements suffer from a positive bias.

$$P = \sqrt{Q^2 + U^2}$$

- When $\sigma_Q = \sigma_U$, a popular estimator is proposed by Wardle & Kroberg (1974):

$$\hat{p}_{WK} \approx \sqrt{P^2 - \sigma^2}$$

- In *WMAP* and Planck data, the polarisation uncertainties are correlated, $\sigma_Q \neq \sigma_U$ so a different estimator is required.

$$p(P|Q', U') = \frac{1}{2\pi\sigma_Q\sigma_U\sqrt{1-\rho^2}} e^{\left(-\frac{1}{2(1-\rho^2)}\left[\frac{(Q-Q')^2}{\sigma_Q^2} + \frac{(U-U')^2}{\sigma_U^2} - \frac{2\rho(Q-Q')(U-U')}{\sigma_Q\sigma_U}\right]\right)}$$

Montier et al. 2014a,b gives a nice review on this general case. But all estimators based exclusivelly on observed Q’, U’ values have a significant bias at low SNR...

However, at Planck/WMAP frequencies, the observed polarisation angle $\chi \approx \chi_0$, due to the almost zero Faraday rotation. If the polarisation angle is known, then the bias dissapear, and the p.d.f for P is normal.

With some algebra, the maximum likelihood debiased estimator is:

$$\hat{p}_{\chi_0} = \frac{\sigma_U^2 Q' \cos 2\chi - \sigma_{QU}(Q' \sin 2\chi + U' \cos 2\chi) + \sigma_Q^2 U' \sin 2\chi}{\sigma_U^2 \cos^2 2\chi - 2\sigma_{QU} \sin 2\chi \cos 2\chi + \sigma_Q^2 \sin^2 2\chi}$$

And its variance is:

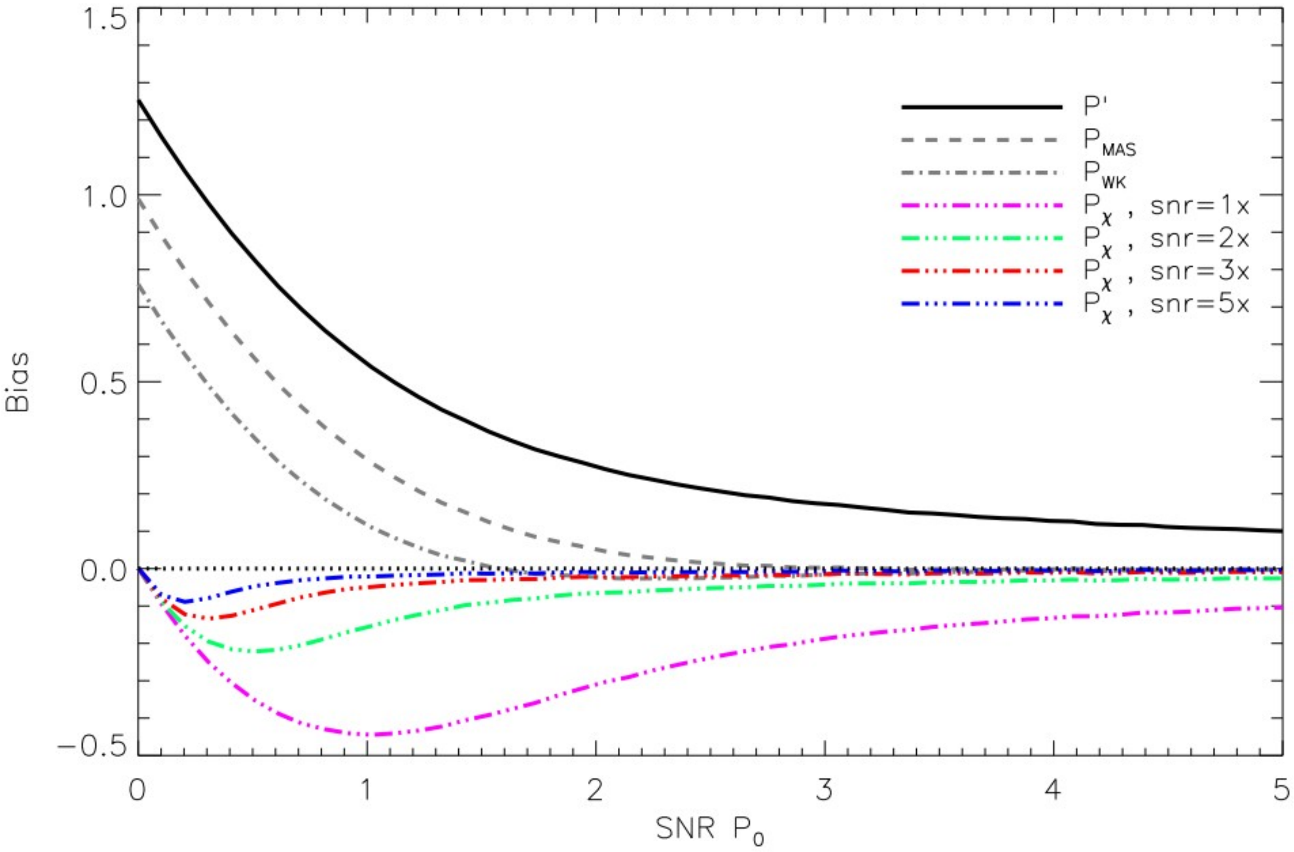
$$\sigma^2_{\hat{p}_{\chi_0}} = \frac{\sigma_Q^2 \sigma_U^2 - \sigma_{QU}^2}{\sigma_U^2 \cos^2 2\chi - 2\sigma_{QU} \sin 2\chi \cos 2\chi + \sigma_Q^2 \sin^2 2\chi}$$

Given a good template for the pol. Angle, the “known angle estimator” performs excellently in the low SNR regime.

e.g. use WMAP 23GHz pol. Angle to debias WMAP 44GHz Pol. Intensity map

See Vidal, Leahy and Dickinson 2016

Performance of estimators

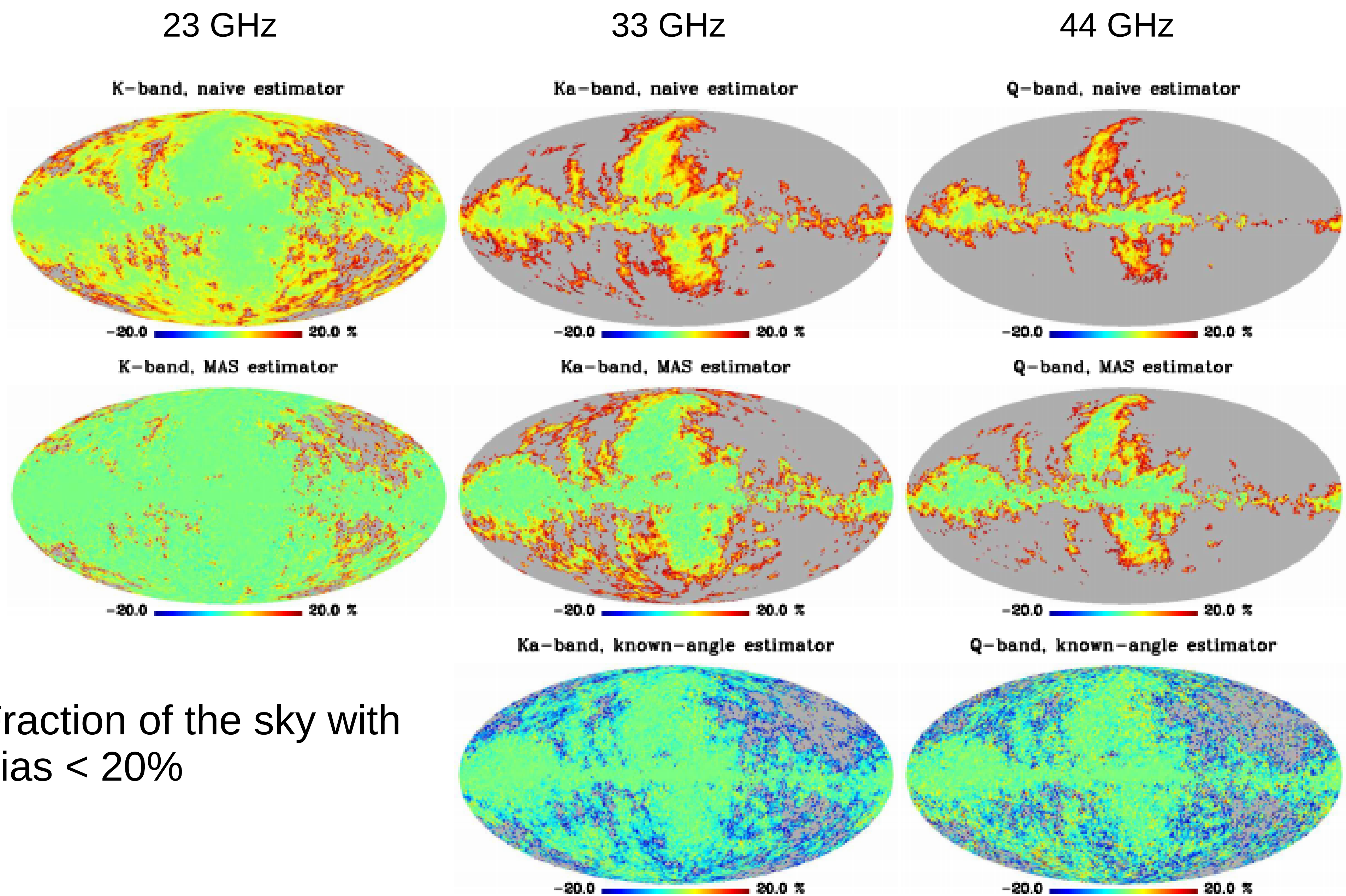


Using a simulated sky, with the noise properties of the WMAP data, we measured the residual bias from 3 estimators over the entire sky.

The estimator using the polarization angle performs much better.

See Vidal, Leahy and Dickinson 2016

Performance of estimators



Fraction of the sky with bias < 20%

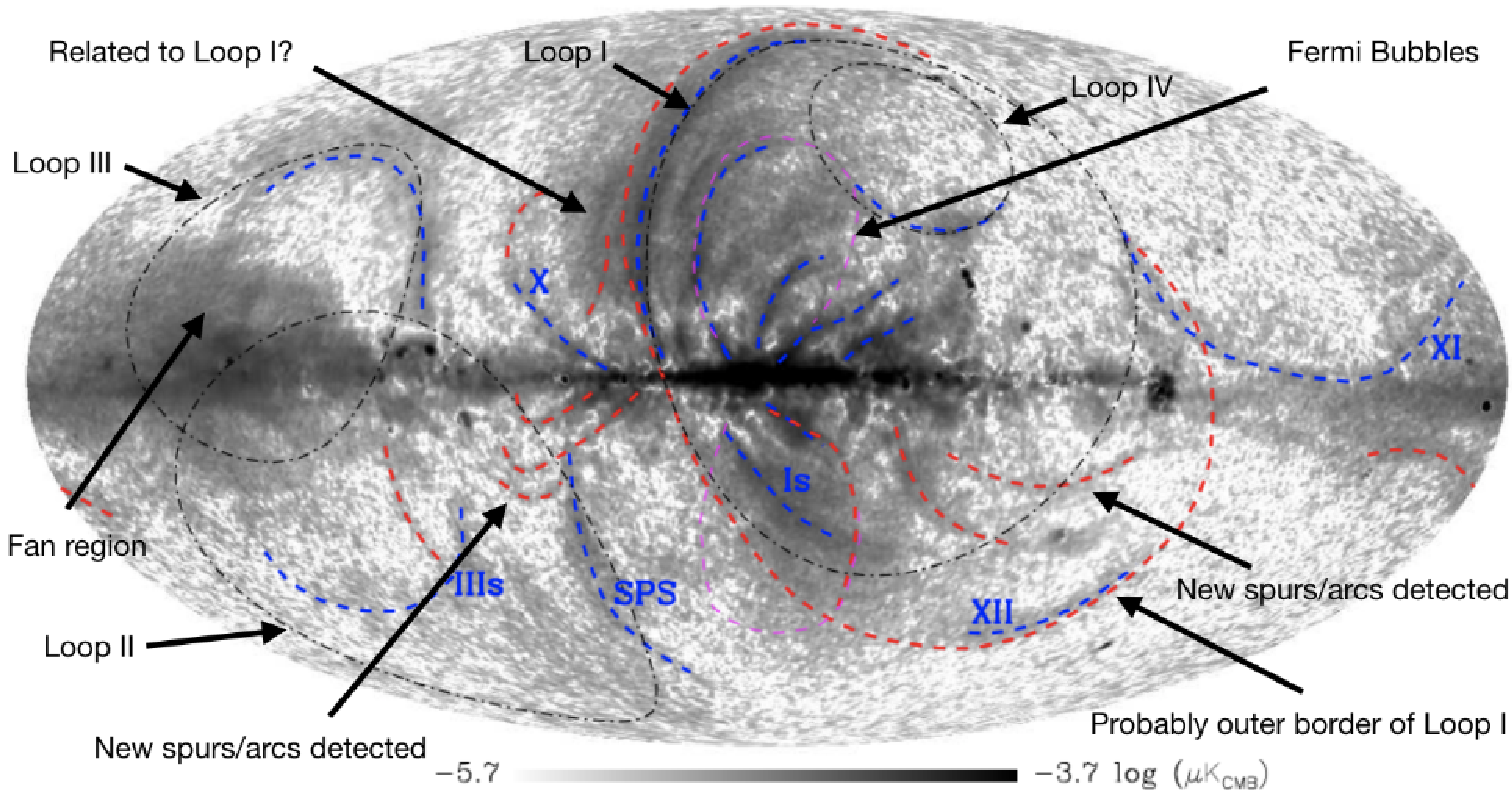
See Vidal, Leahy and Dickinson 2016

Known angle estimtor

- Corrects for the bias when a good template for pol. Angle is available
- Analytical form for the estimator, variance and residual bias due to uncertainties in the pol. Angle template
- Performs great in the low SNR regime.
- Useful in multi-frequency datasets with different SNR (optical-ingrared-radio)

See Vidal, Leahy and Dickinson 2016

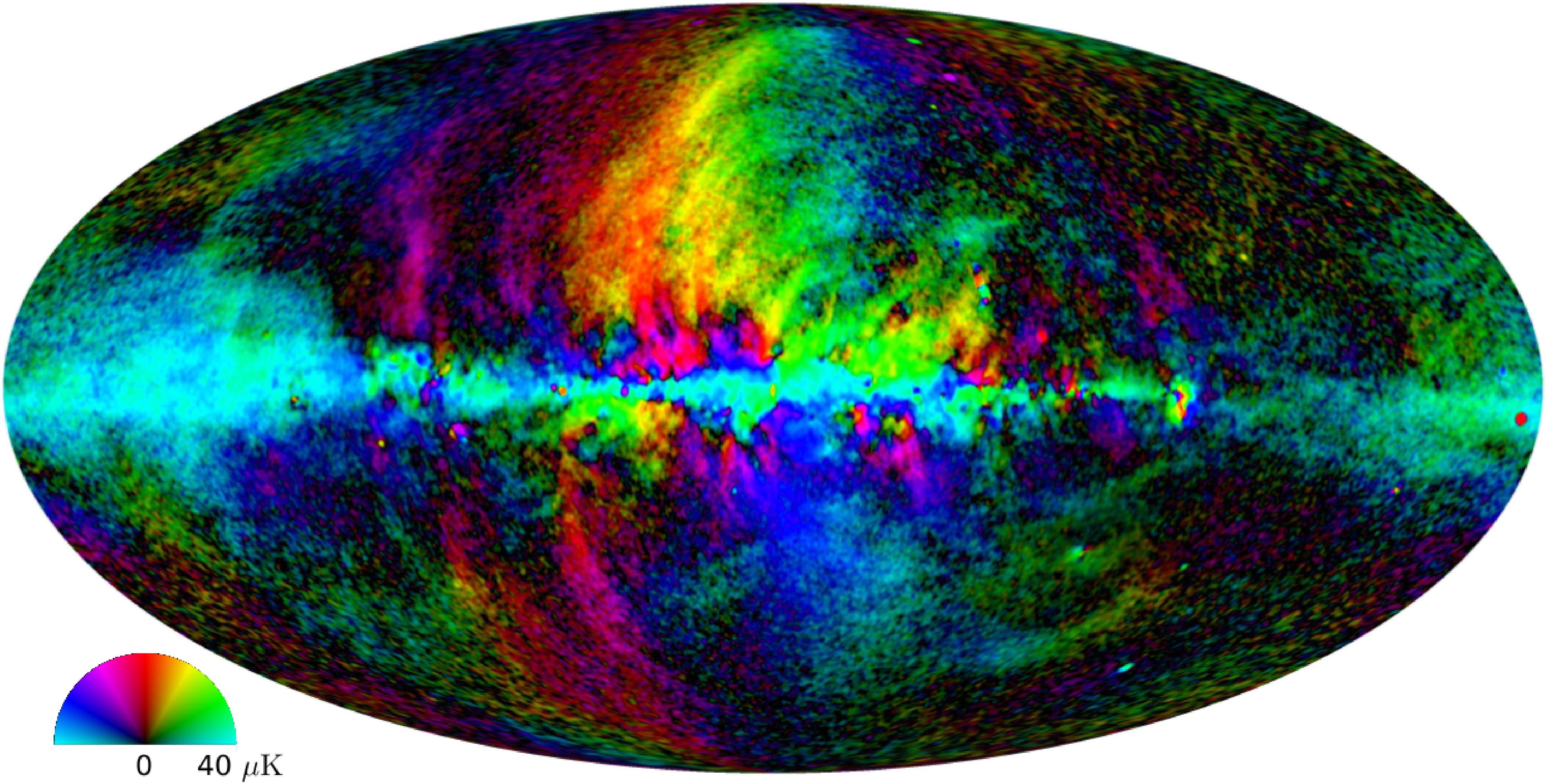
Planck + WMAP 30GHz polarization intensity



Planck 2015 results. XXV

What is the origin of these structures?

Polarized synchrotron emission mostly comes from large scale filamentary structures with coherent magnetic fields



Planck 2015 results. XXV

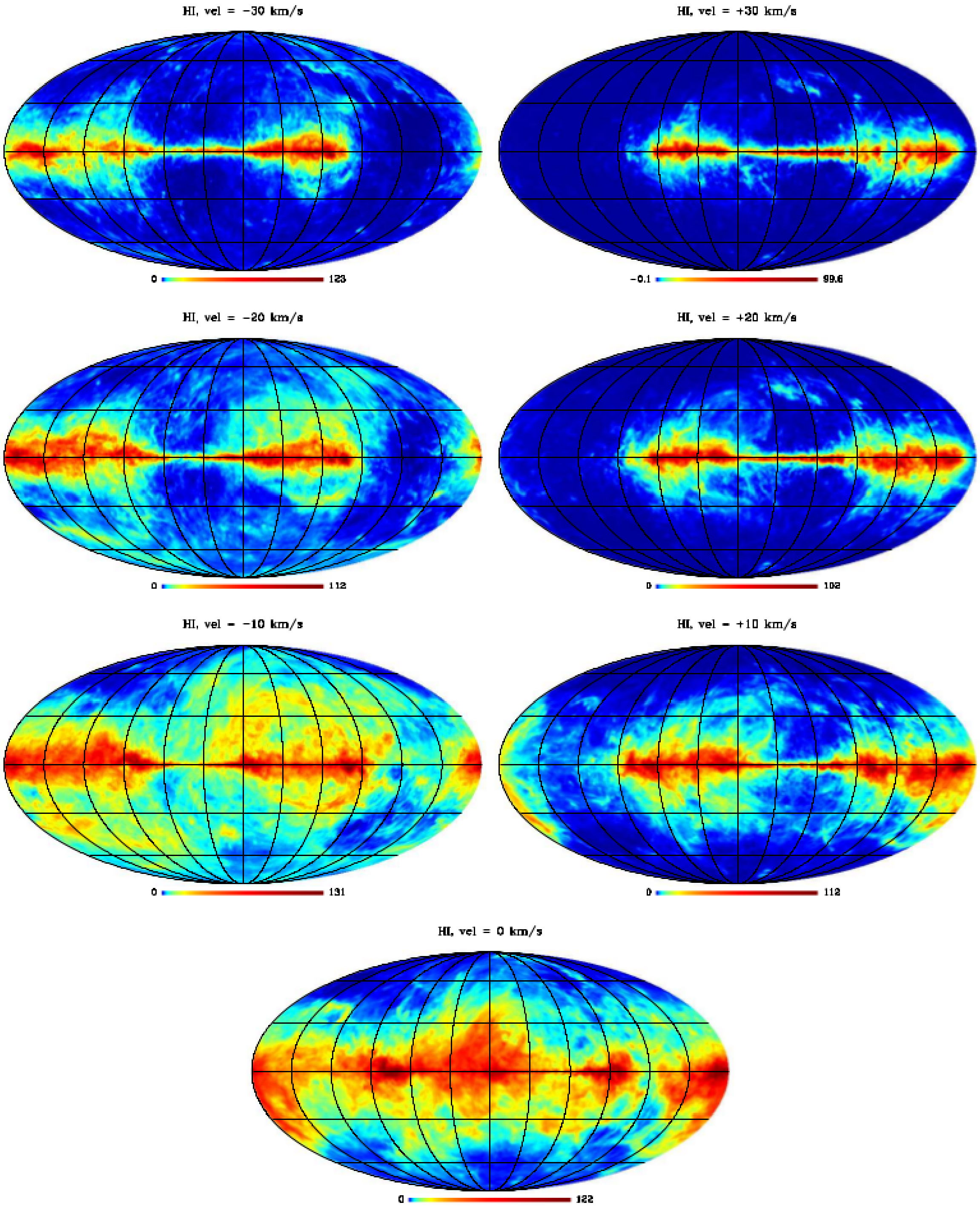
What is the origin of these structures?

Filaments origin

There have been a number of hypothesis about the origin of the filaments and loops:

- Outflow from Galactic Centre (Sofue, 1977; Bland-Hawthorn & Cohen, 2003, Carretti et al., 2013)
- Bubbles/shells powered by OB associations (Egger, 1995; Wolleben, 2007).
- Old and nearby supernova remnants (Berkhuijsen et al., 1971; Spoelstra, 1973) and magnetic field loops illuminated by relativistic electrons (Heiles, 1998).

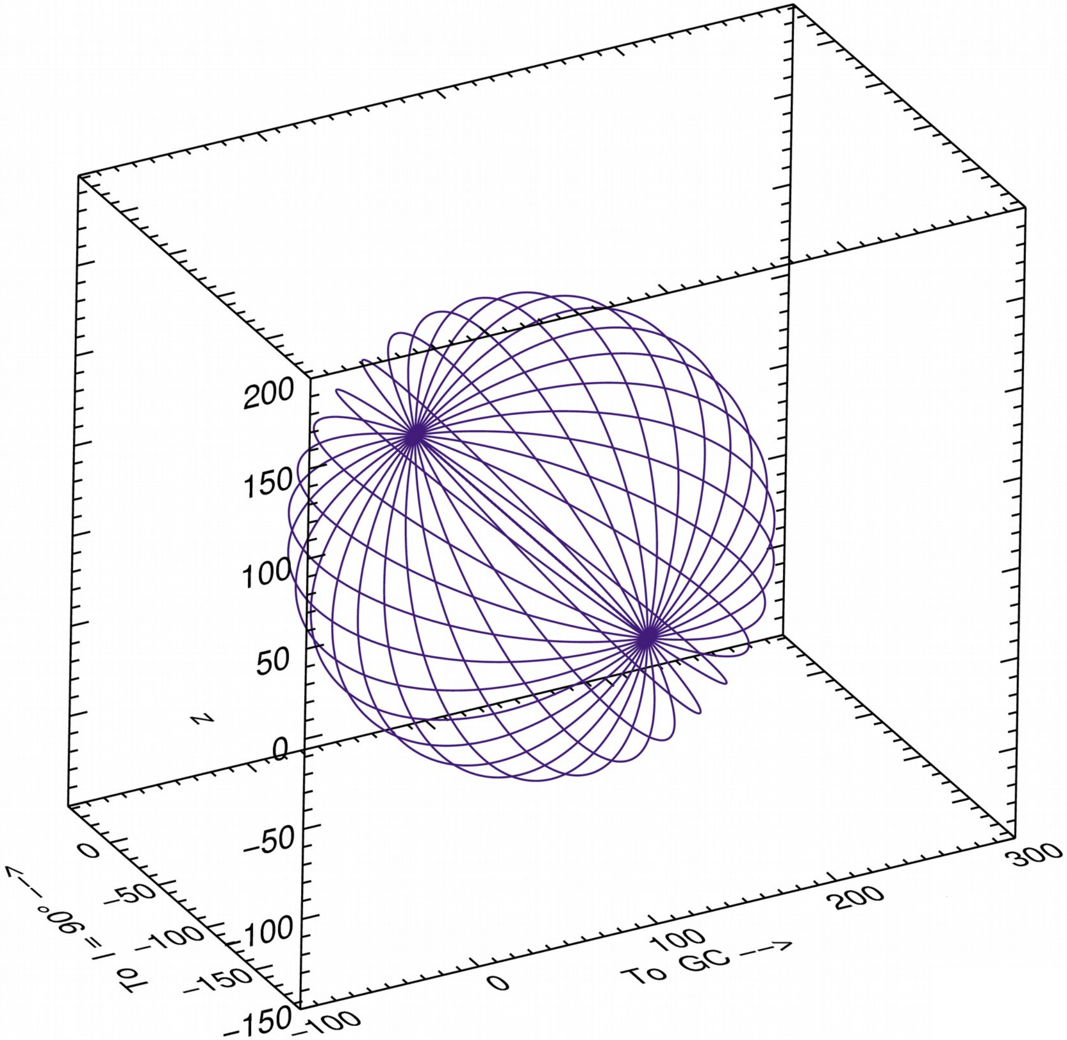
The unknown distance is a major problem.



HI velocity maps show an expanding bubble centred at l=320 deg. This is known as the Sco-Cen Super-shell. (Weaver, 1979; Heiles et al., 1980).

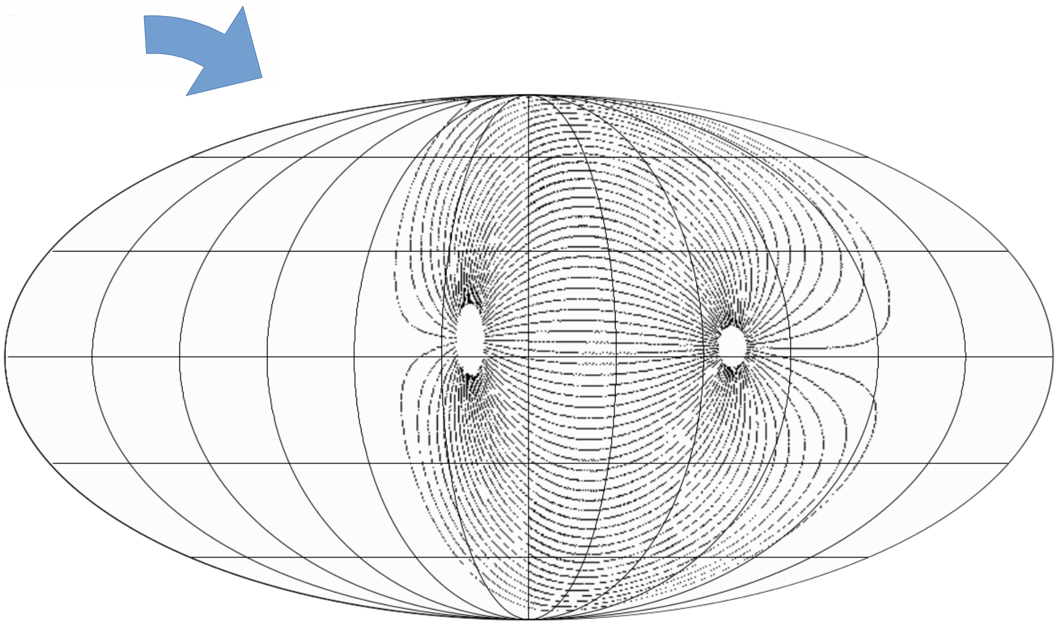
Formed by a number of SNe explosions ocurred less than 10 Myr ago.

Heiles, 1998 proposes that this expanding cavity will deform the local interstellar magnetic field.



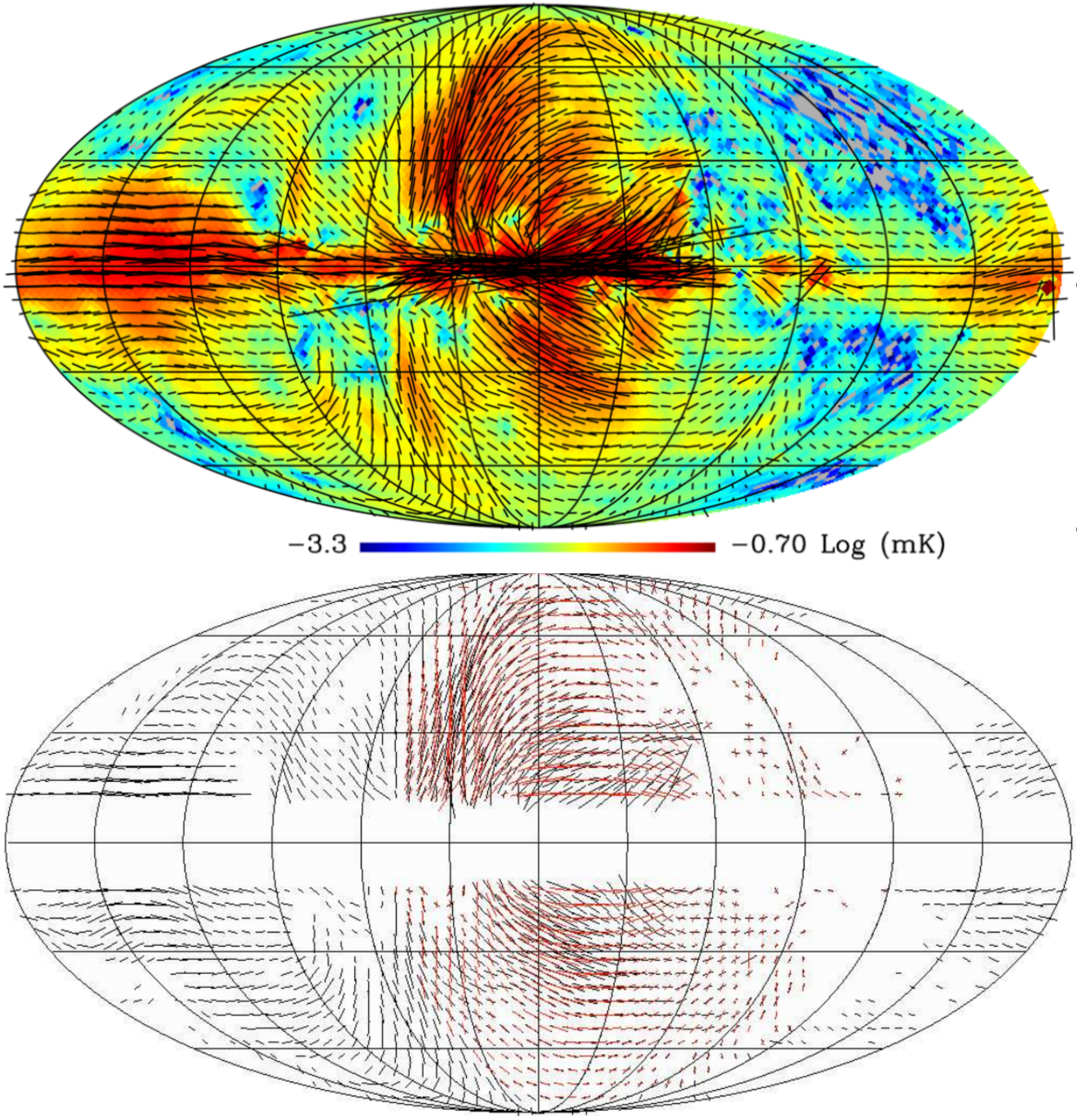
Assuming an initial ordered magnetic field parallel to the Galactic plane, a spherical expanding shell will deform the field in a simple manner.

CR originated in the SNe will produce synchrotron radiation while spiraling these field lines.



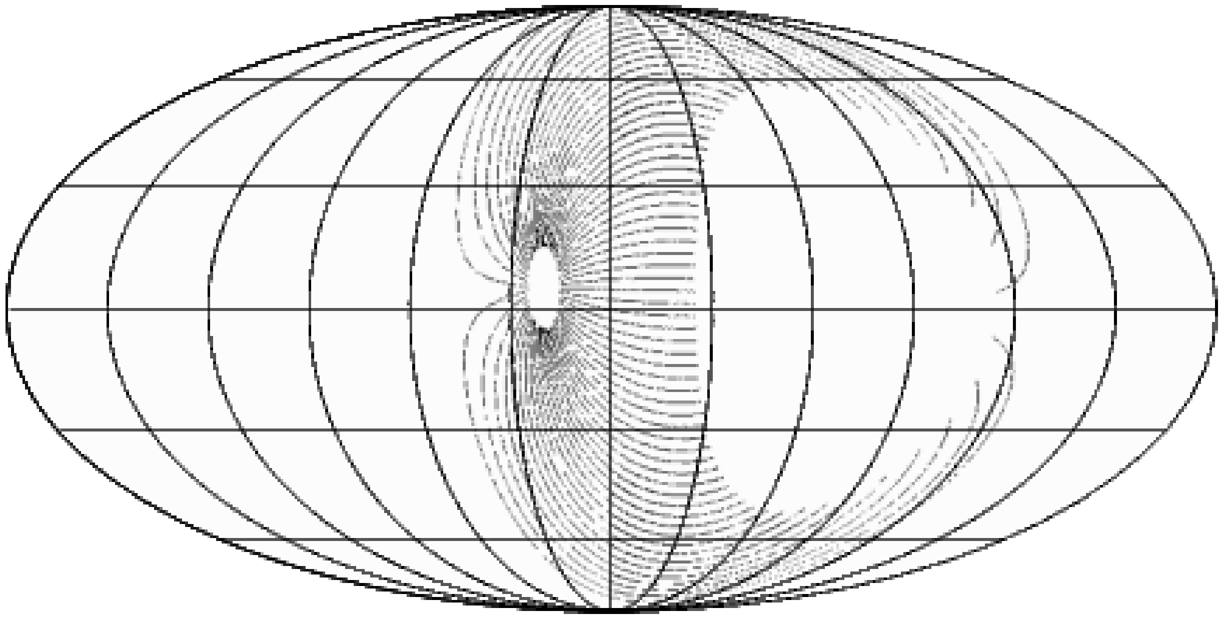
The shell will be illuminated in sychrotron by succesive SNe

Locating the center of the bubble at 120 pc towards the Sco-Cen shell we can project the field lines as seen from our vantage point.

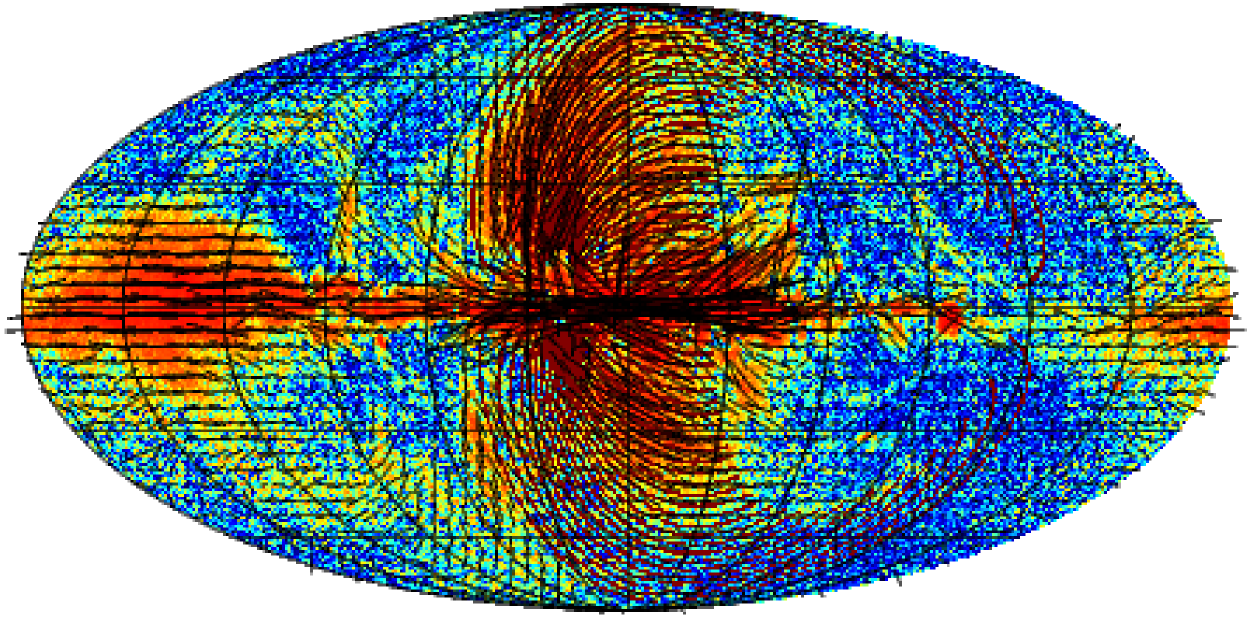


- This simple model qualitatively explains large scale polarisation structures.
- The emission is compatible with a nearby origin.

See Vidal et al. 2015

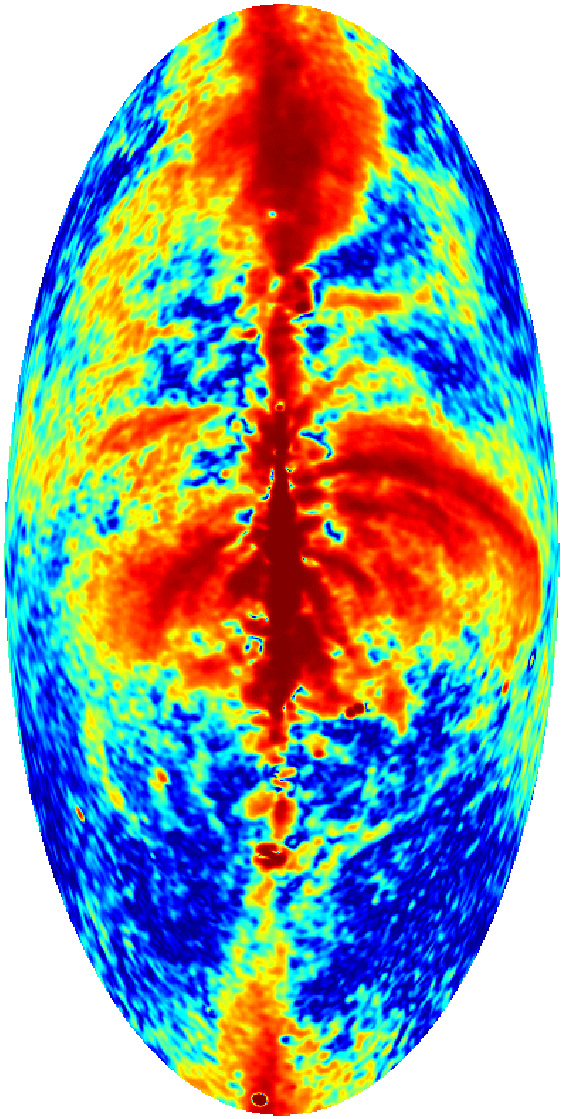


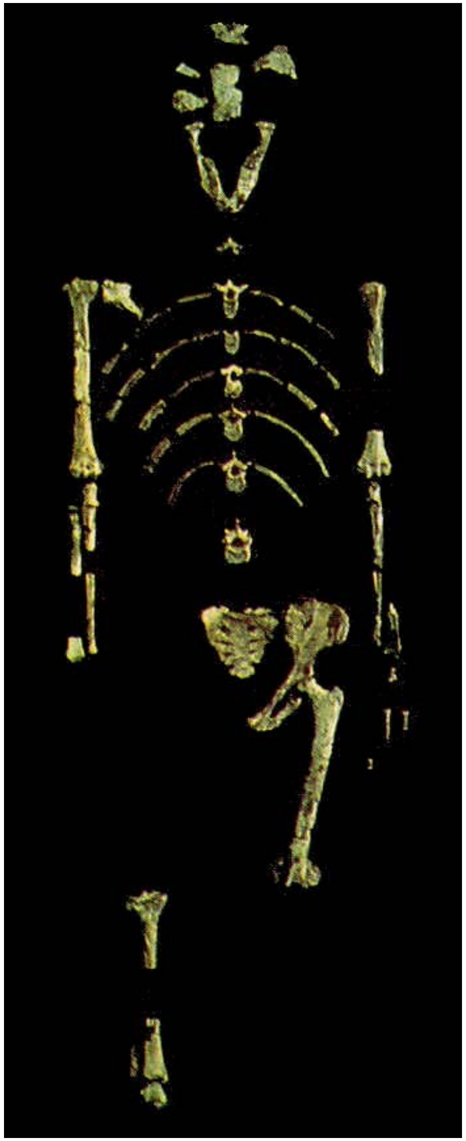
Magnetic field lines from near side of the shell



See Bob Watson's talk for new model!!

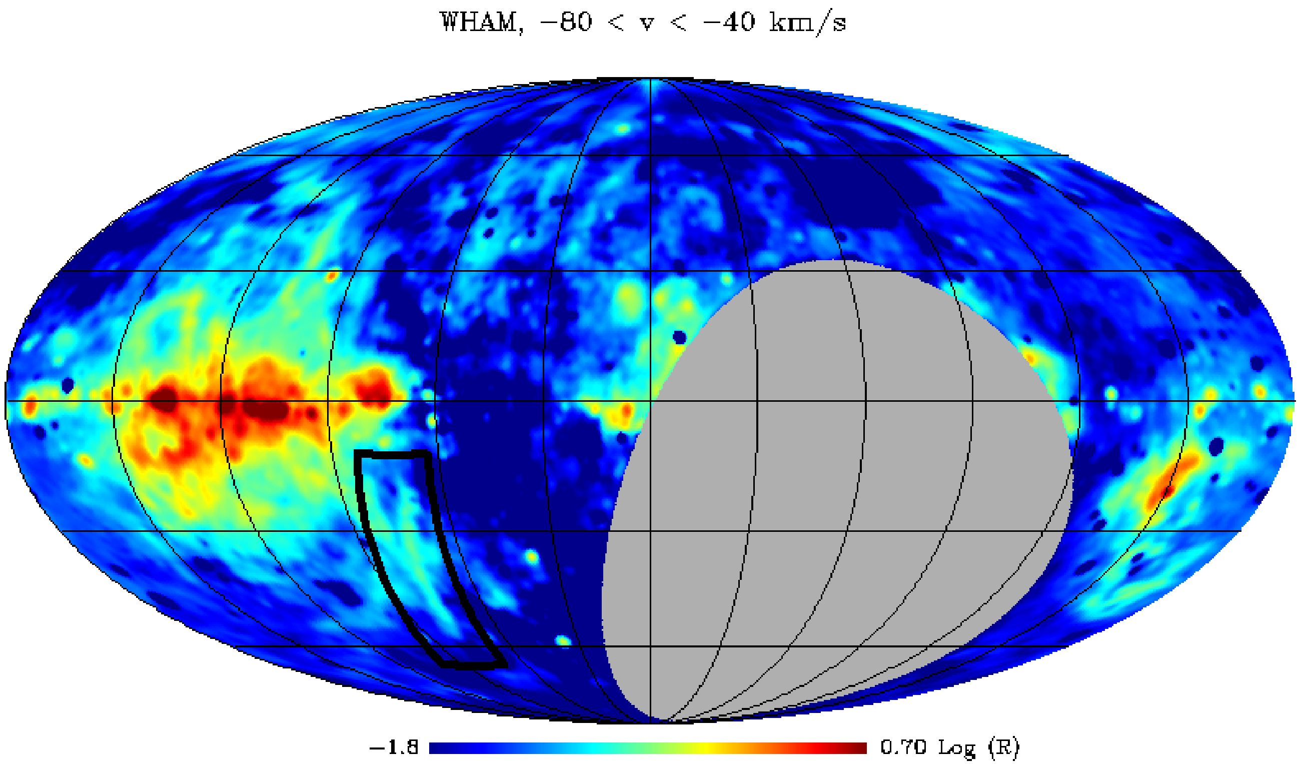
Maybe about the same age??





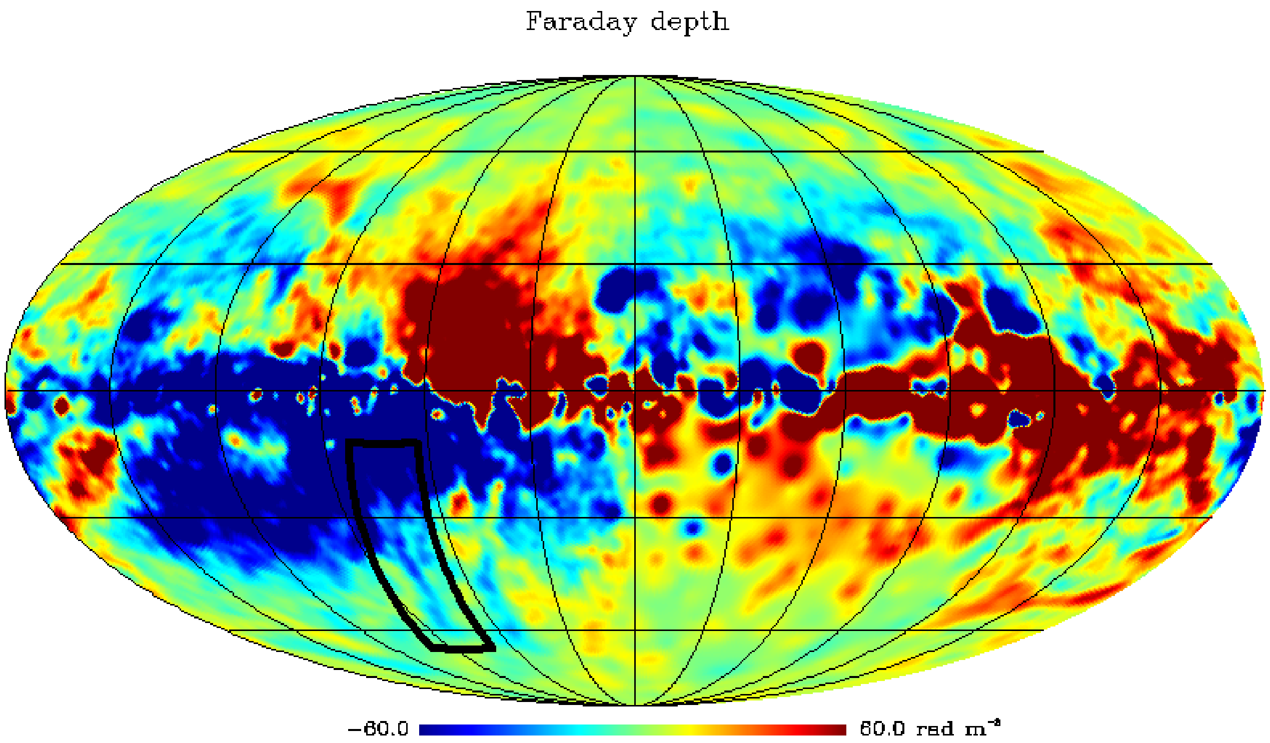
Lucy, ~3.2 Myr old.

Hα–synchrotron anti correlation



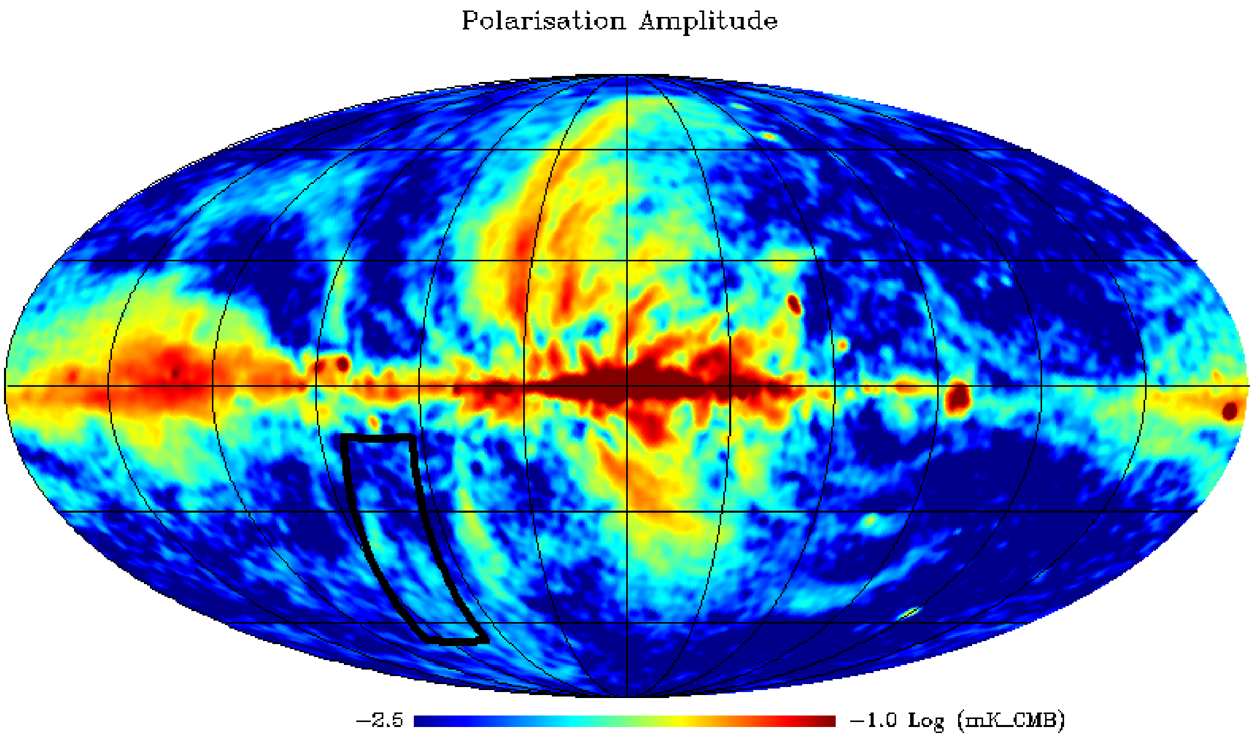
Narrow (unresolved at 6') Hα filament visible at negative radial velocities.

Hα–synchrotron anti correlation



Visible in the Faraday depth map from Oppermann et al. 2012

Hα–synchrotron anti correlation



The filament anti-correlates with the polarised map at 30GHz.

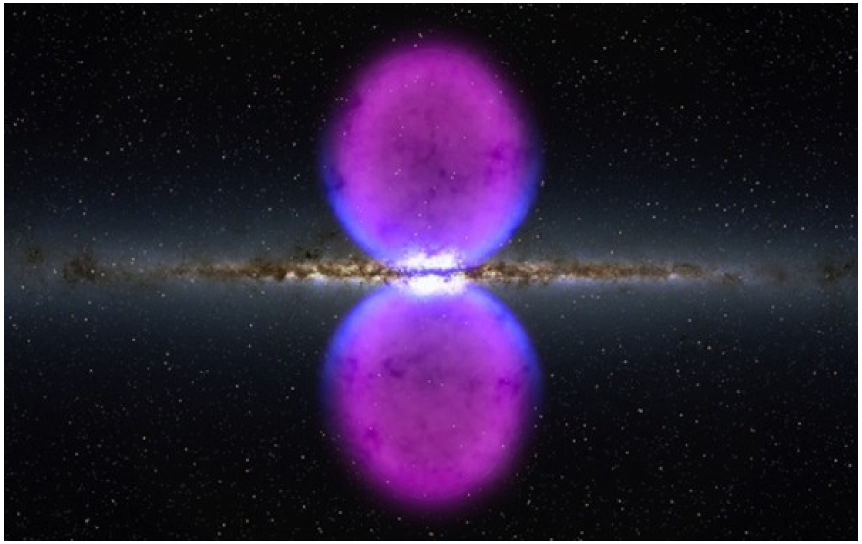
- Depolarization by Far. Rotation?? → should be lower than 0.3° at 23 GHz
- Strong coherent B-field parallel to the line of sight along the filament?
- Synchrotron from the filament is weakly polarised → disordered B-field
- Radial velocity correspond to Perseus arm of the Galaxy. If the filament lies there, it would imply that the diffuse synchrotronn emission has d > 2kpc

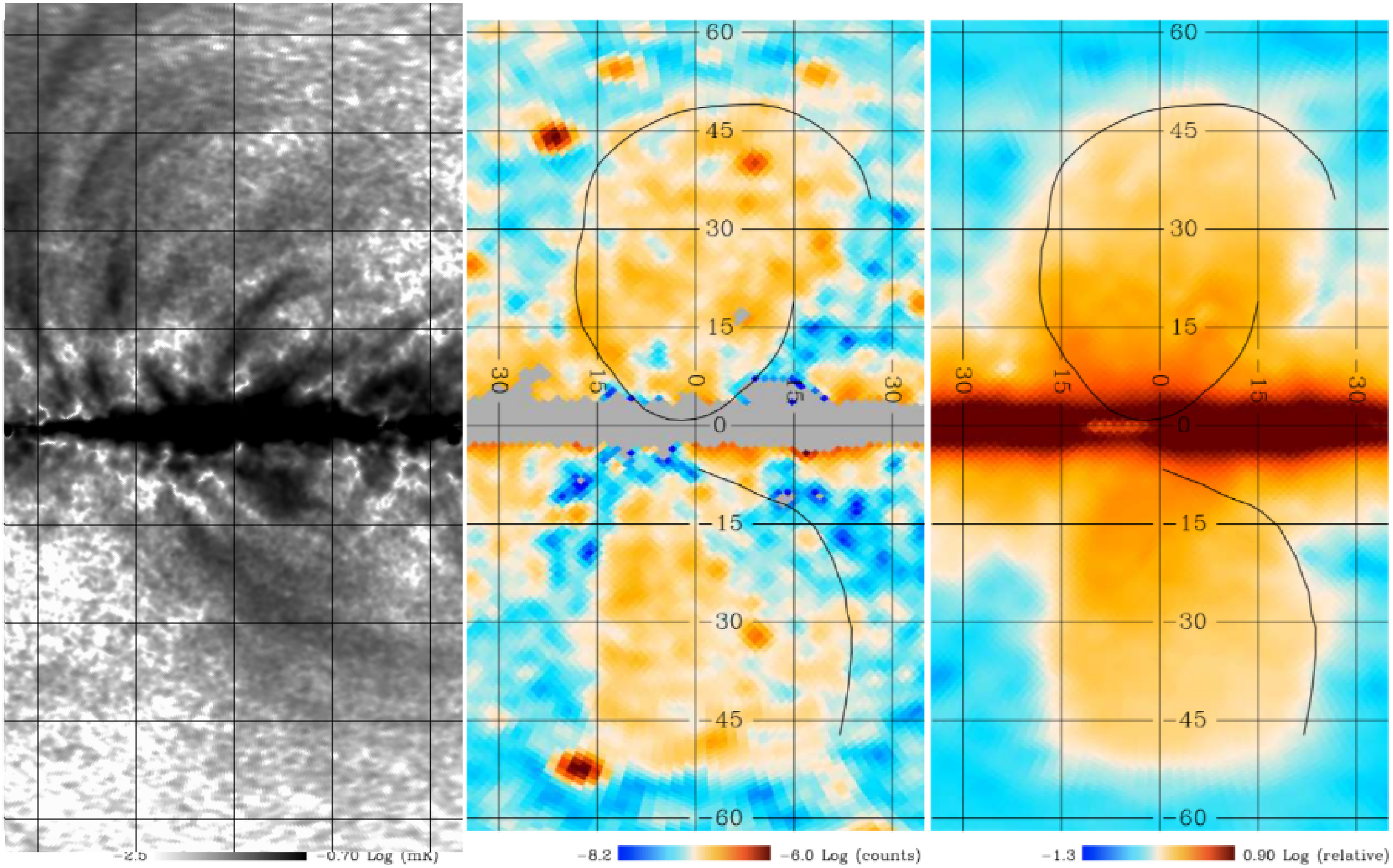
Fermi Bubbles

- Giant γ ray emitting structure that extend up to b=55 deg

- Believed to be formed by ejected gas during an accretion event from Sag A* between 6-9Myr ago. (Bordoloi et al. 2017)

- Polarised emission that traces the outer edge of the bubbles





Along the filament,
$\beta = -2.54 \pm 0.16$

Much flatter than most of the diffuse syncrotron.

Identical to microwave haze spectrum:

β Haze = -2.54 ± 0.05

Summary

- Polarised emission reveals large filamentary structures (“loops and surs”) with well ordered B field.
- There is a new way to correct for polarisation bias when the angle is well known.
- A simple model for Loop I, placing it at a distance of ∼ 100–200 pc with a similar diameter, can reproduce much of the large-scale geometry of polarization angles.
- New Hα-synchrotron anti correlation → interesting magnetic structures?
- Some emission however can be traced to Galactic Centre distances as it seems to be associated with the Fermi bubbles.