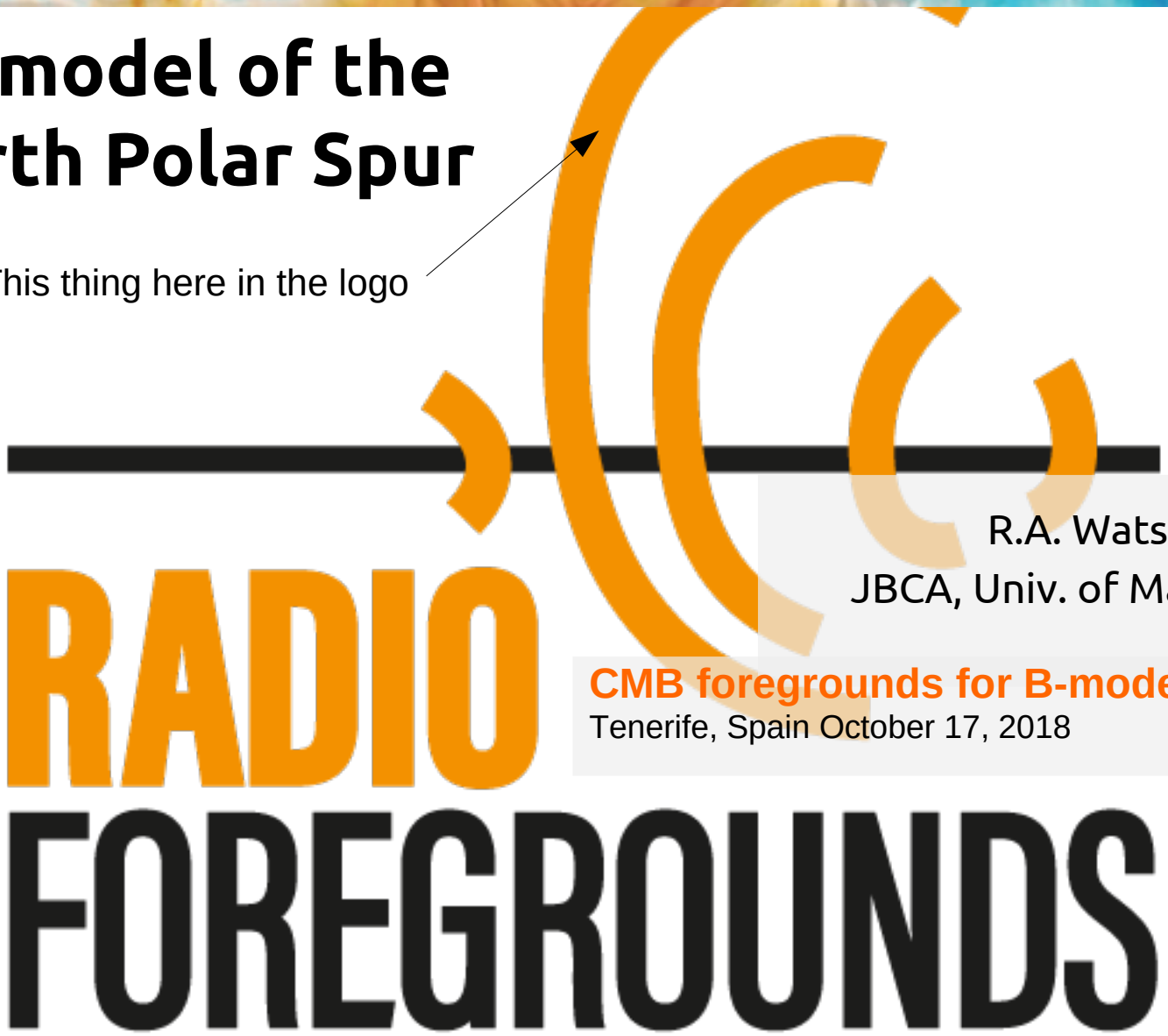
3D model of the North Polar Spur

This thing here in the logo



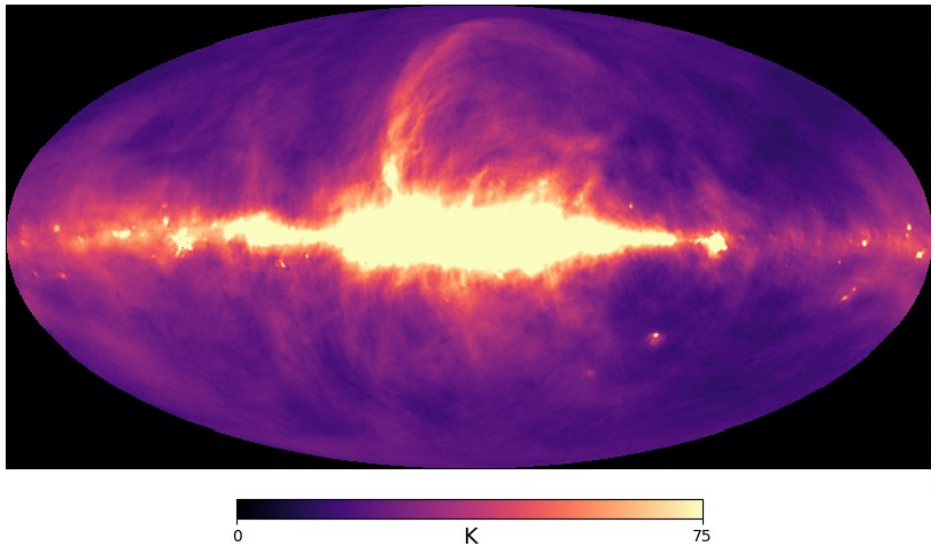
R.A. Watson
JBCA, Univ. of Manchester

CMB foregrounds for B-mode studies
Tenerife, Spain October 17, 2018

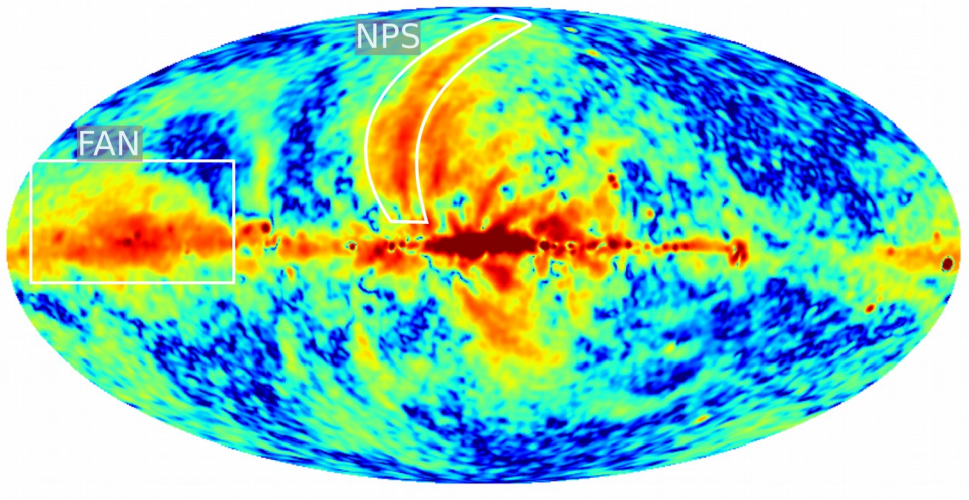
H2020 – G.A. 687312

The North Polar Spur

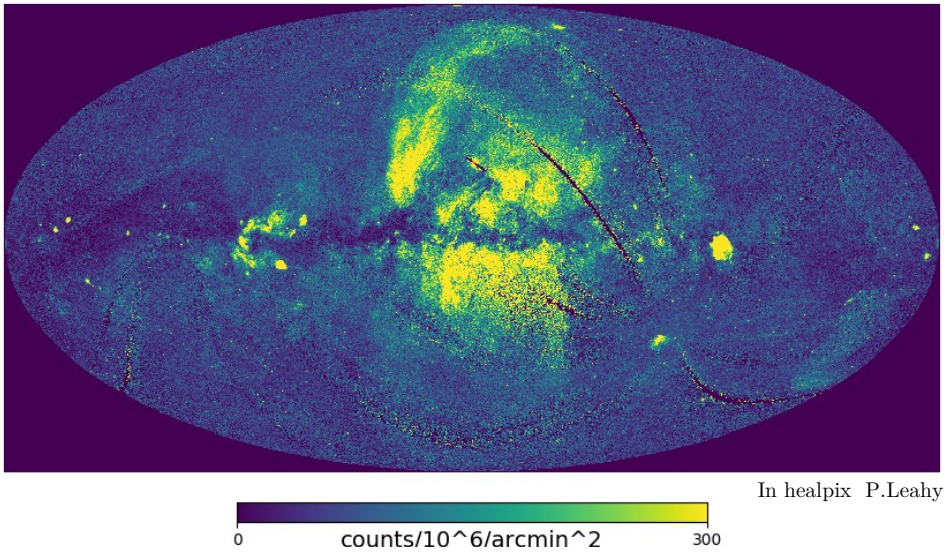
Haslam *et al* 408 MHz (reprocessed Remazeilles *et al*)



30GHz Commander Synchrotron polar intensity



X-ray *ROSAT* 0.89 kev



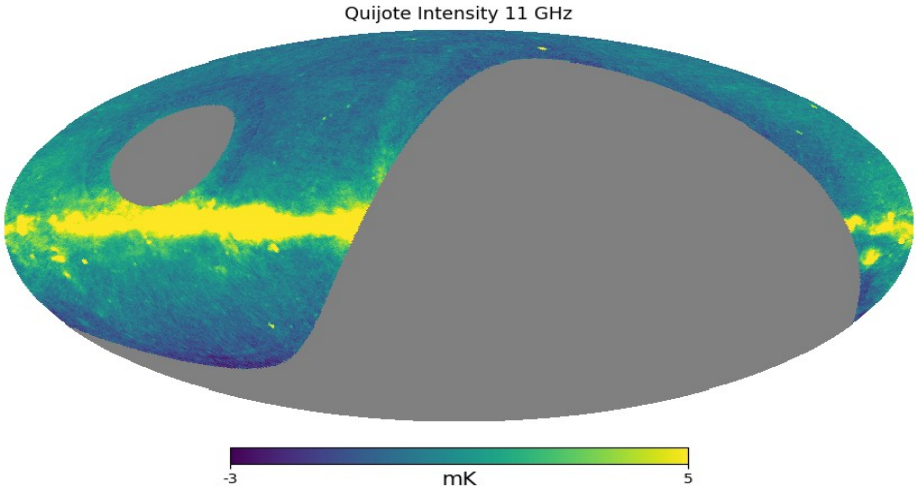
In healpix P.Leahy

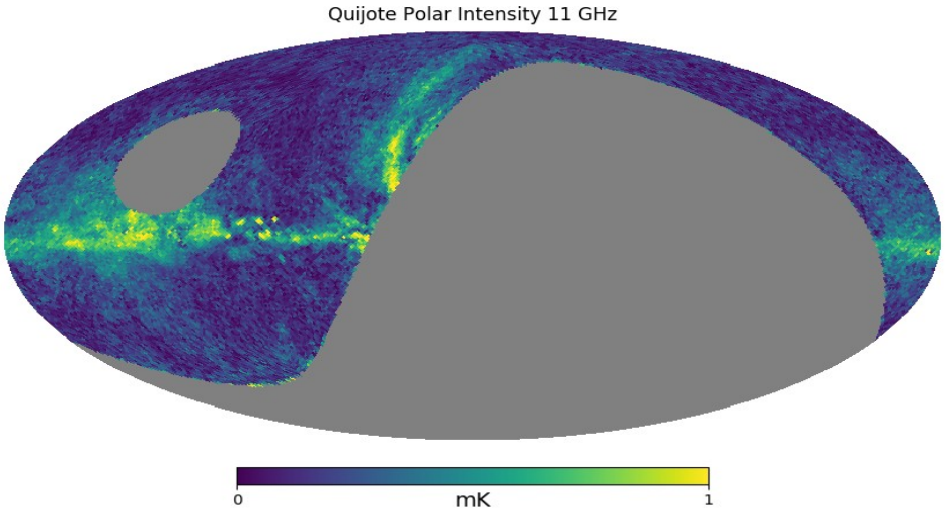
The North Polar Spur is a large feature seen in Radio and X-rays towards the galactic centre.

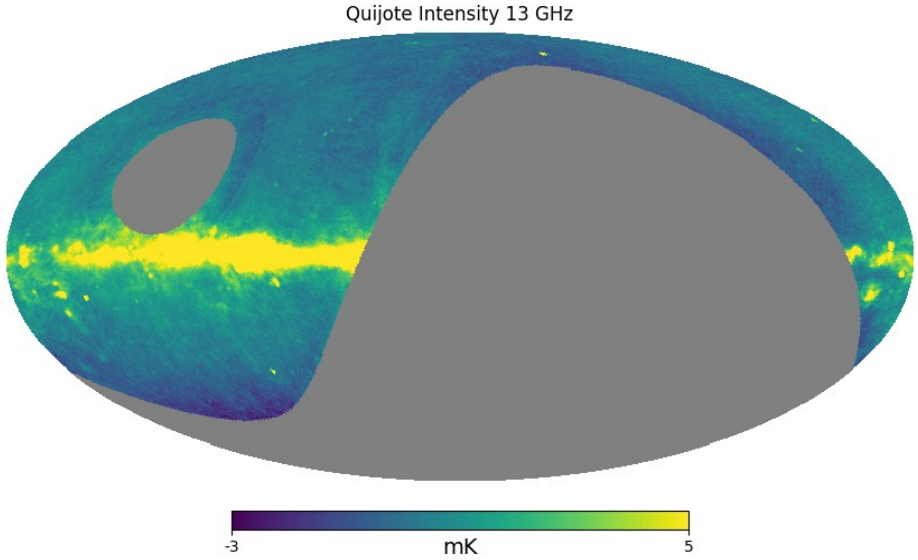
Assumed to be a nearby supernova remnant, it is a very strongly polarised synchrotron source which goes to high galactic latitudes. It's distance and nature are still debated (review Dickinson 2018)

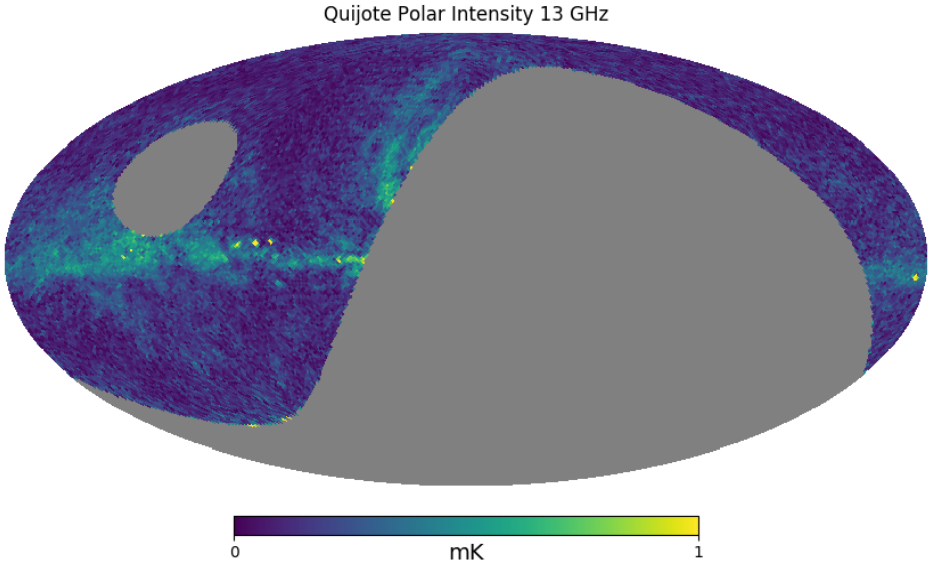
An example of the radio loops which could cause problems for future B-mode experiments.

NPS in QUIJOTE



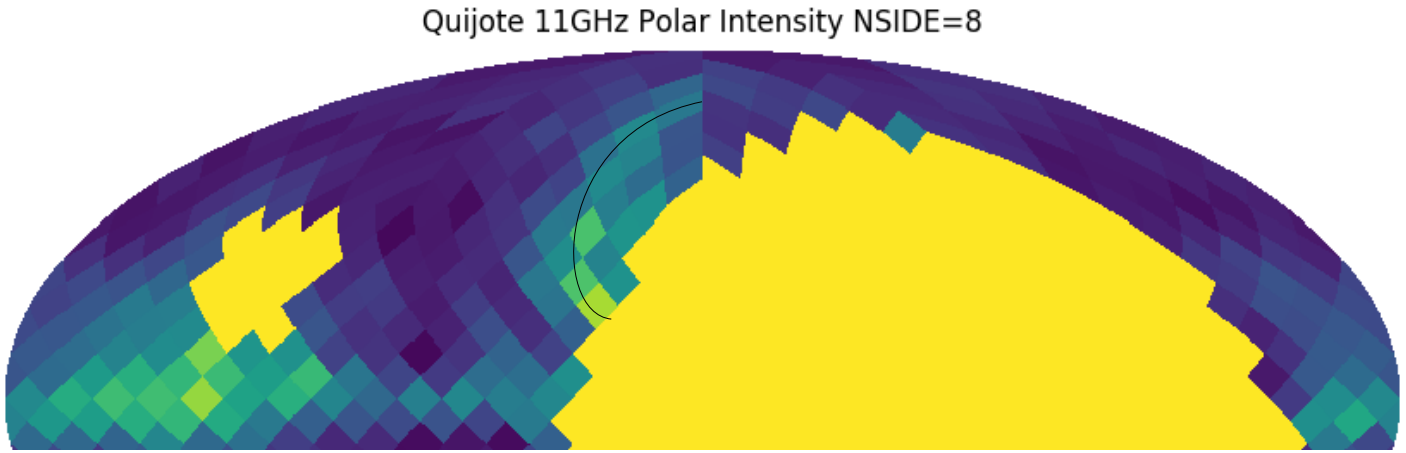






Noise ~250μK deg^{-2} Intensity & ~50μK deg^{-2} in polarization.

NPS pixels in NSIDE 8



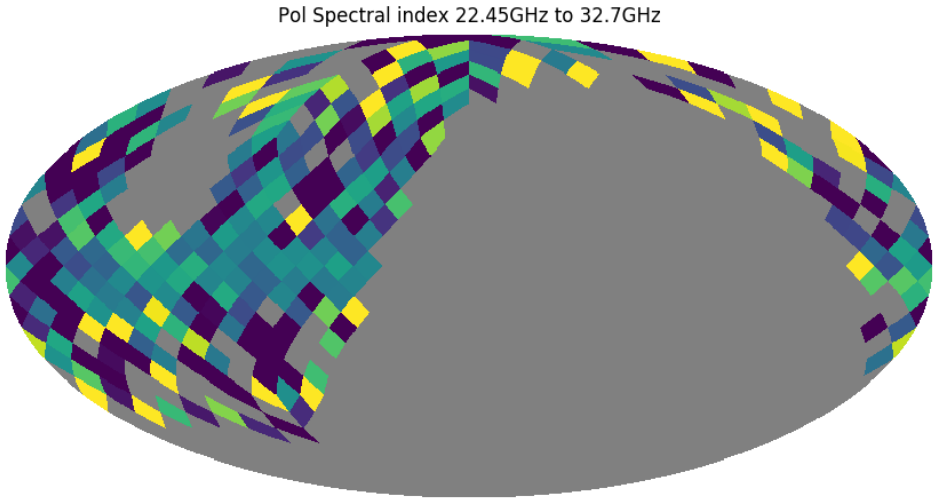
Define path of NPS in terms of NSIDE=8 pixels [211, 179, 147, 115, 86, 62, 41, 24]
Downgrade input maps to nside 32 to reduce noise bias (but still correct for it), so have 16 points per NSIDE 8 pixel for TT plot.

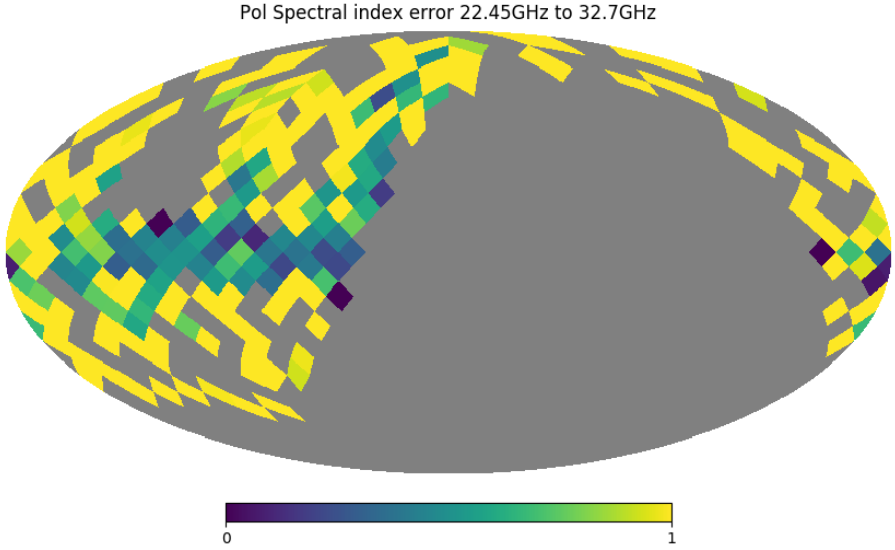
$P = \mathrm{sqrt}(Q_{64}^{2} + U_{64}^{2} - \sigma_{64}^{2})$

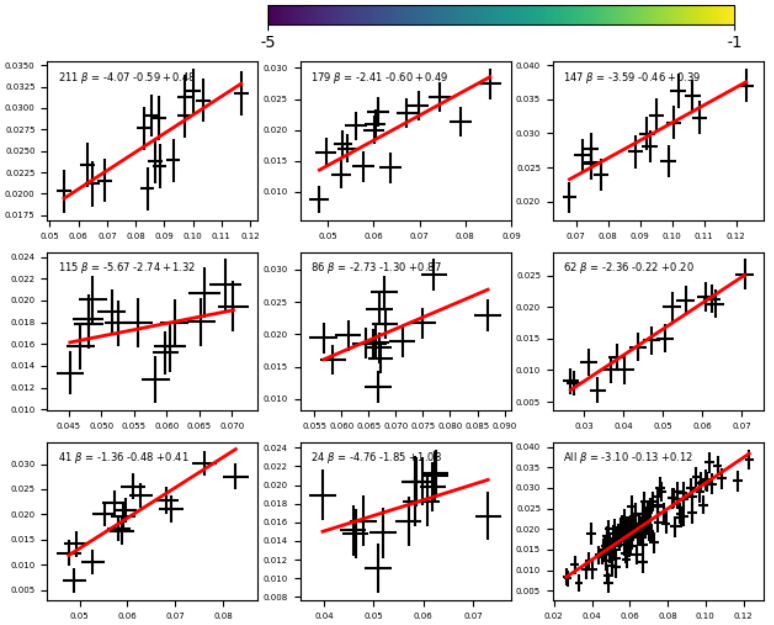
The slope of the TT plots were found using the python scipy odr routine using a linear model and errors in both x and y. So y =mx + C

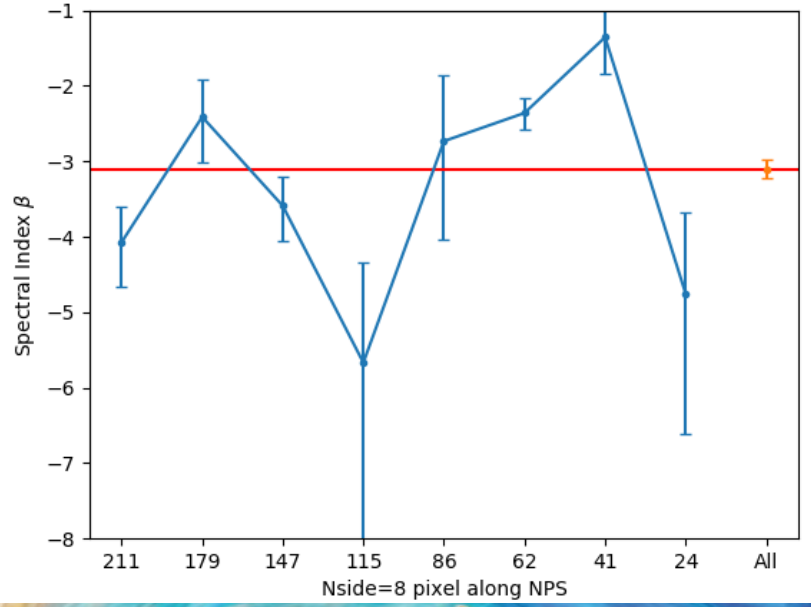
The spectral index and it's error was calculated using $\beta_{12} = \log(m)/\log(\nu_1/\nu_2)$

WMAP polar intensity TT plots



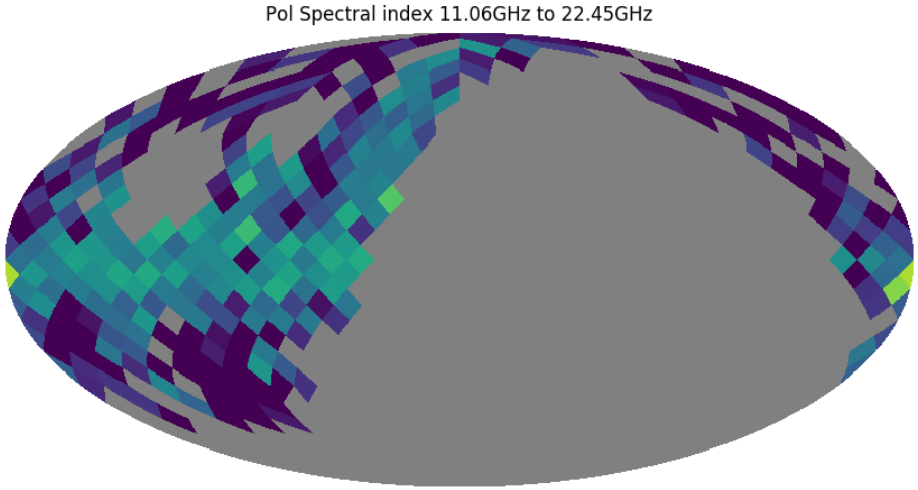


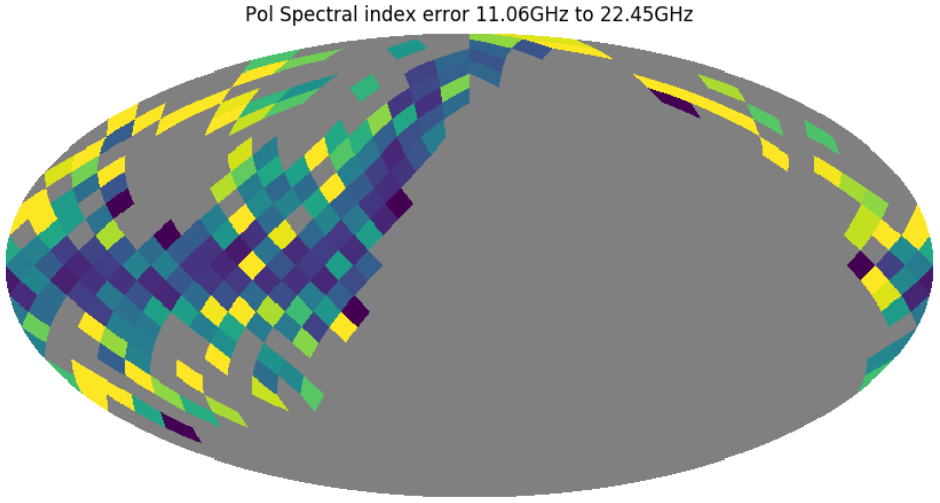


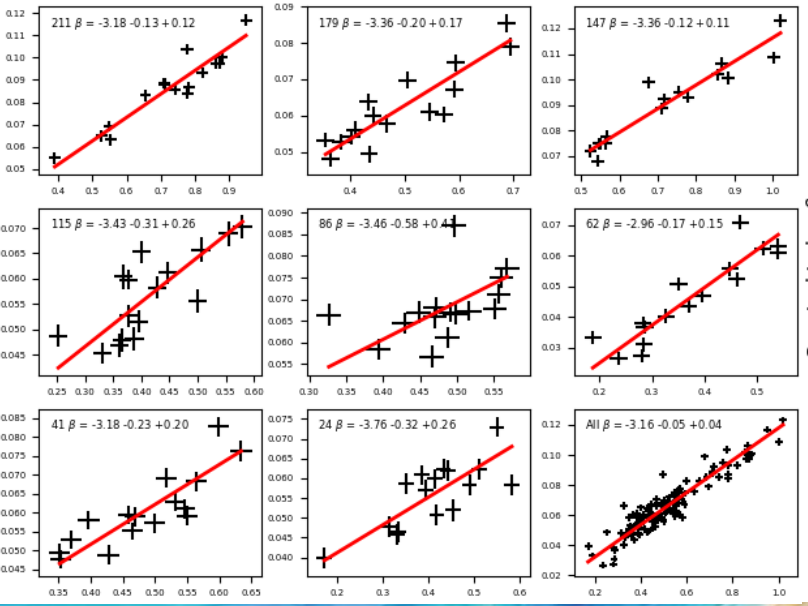


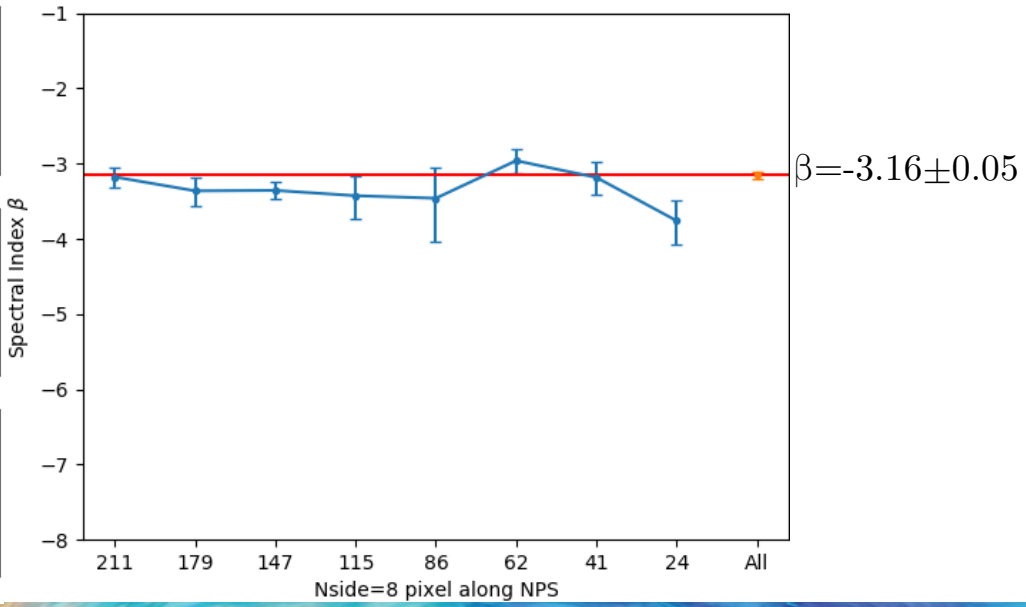
β=-3.10$\pm$0.13

QUIJOTE 11 to WMAP 23 GHz

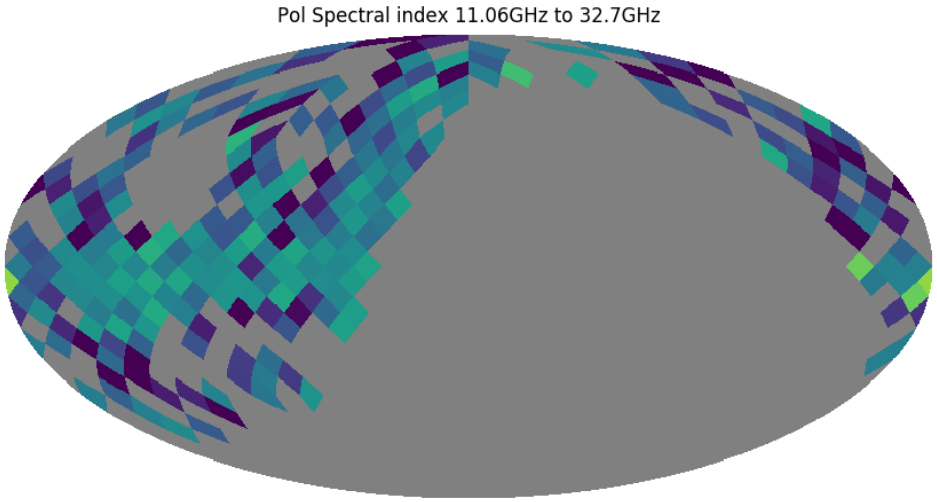


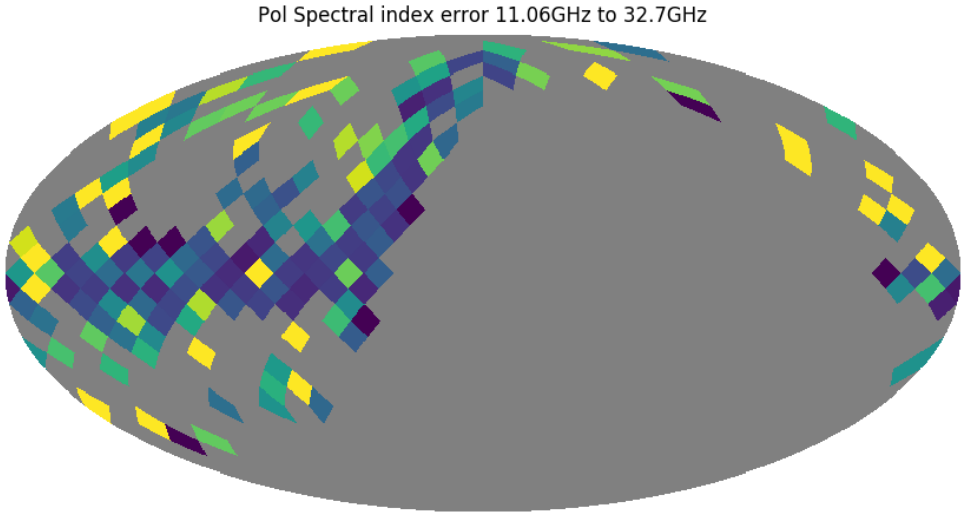


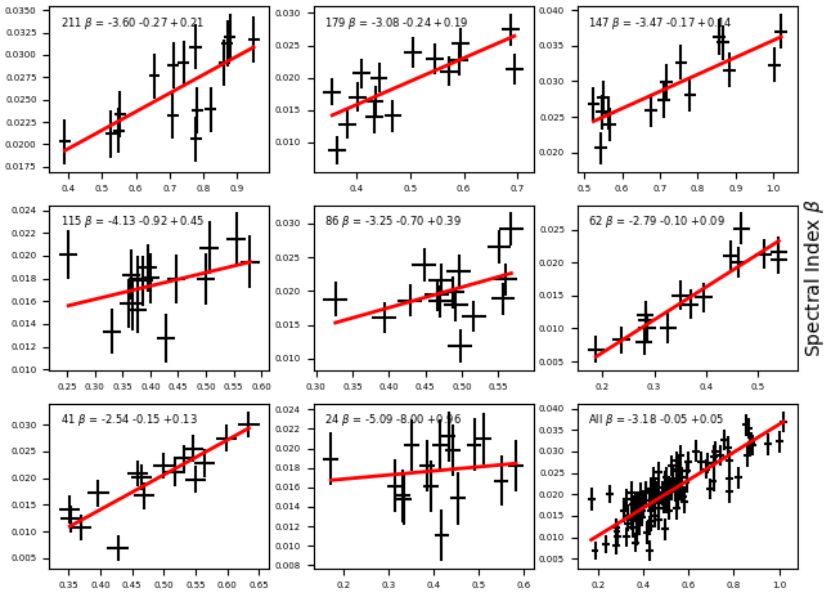


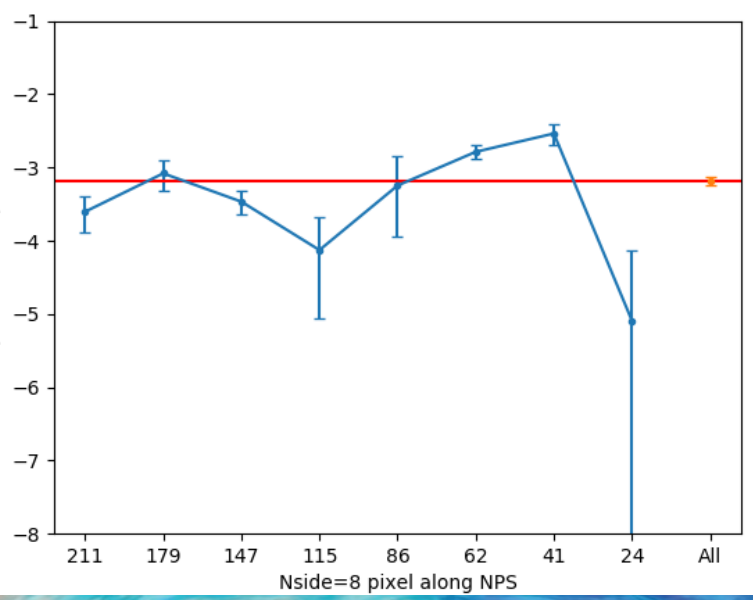


QUIJOTE 11 to WMAP 33 GHz



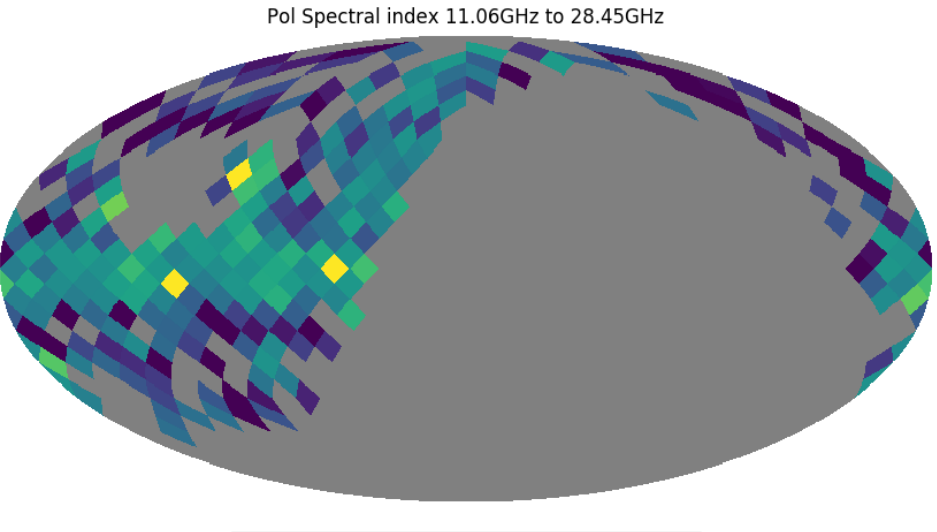


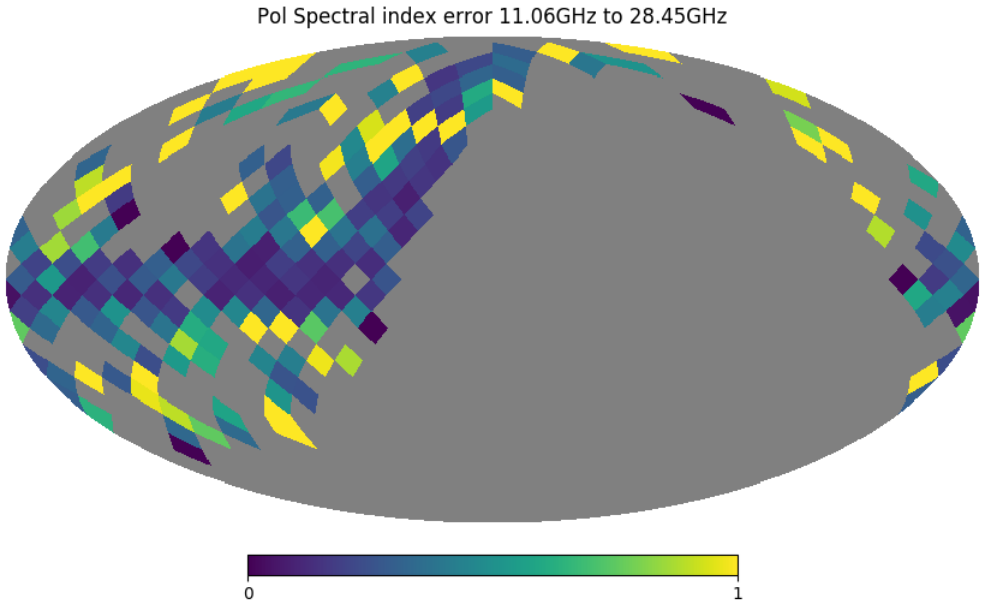


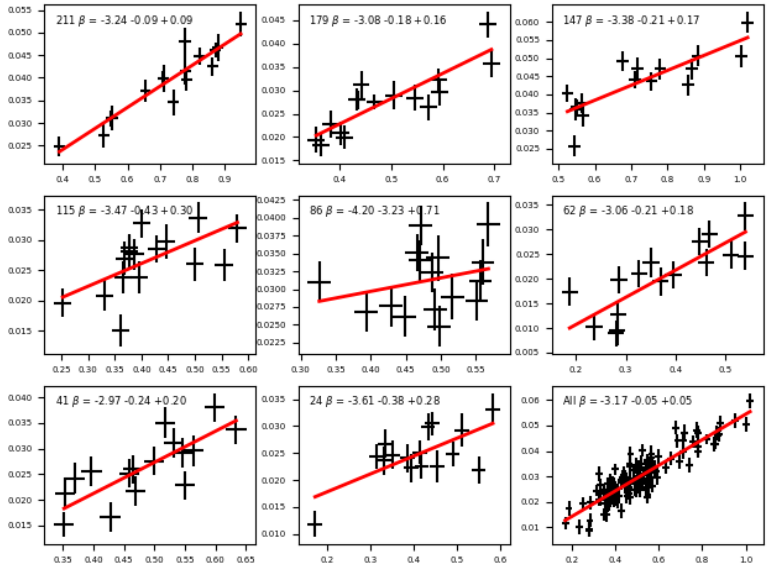


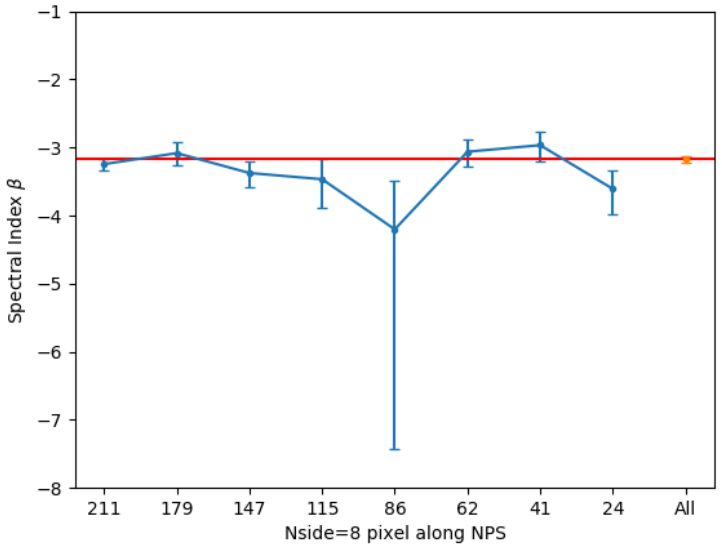
β=-3.18$\pm$0.05

QUIJOTE 11 to Planck 30 GHz



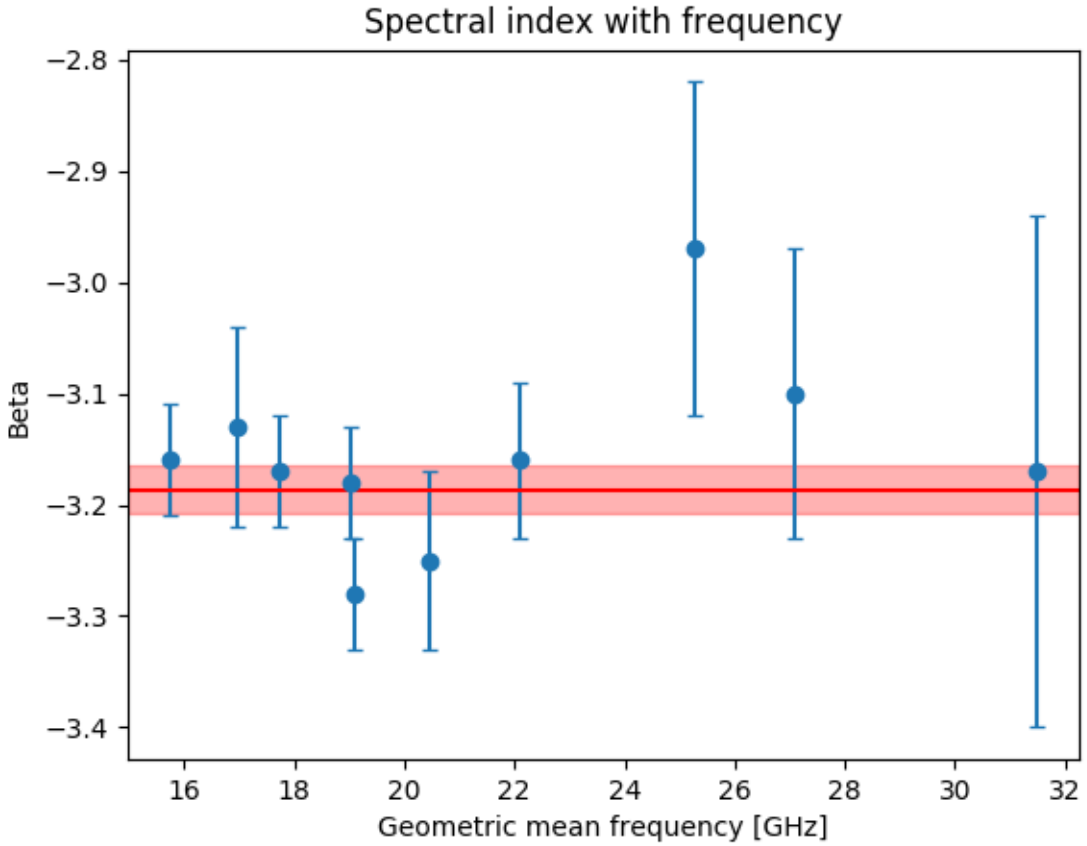






β=-3.17$\pm$0.05

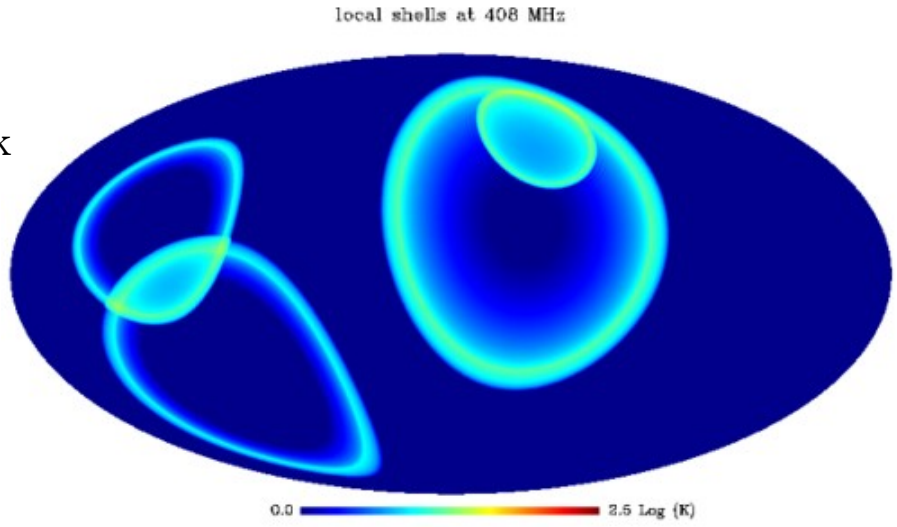
Spectral index curvature

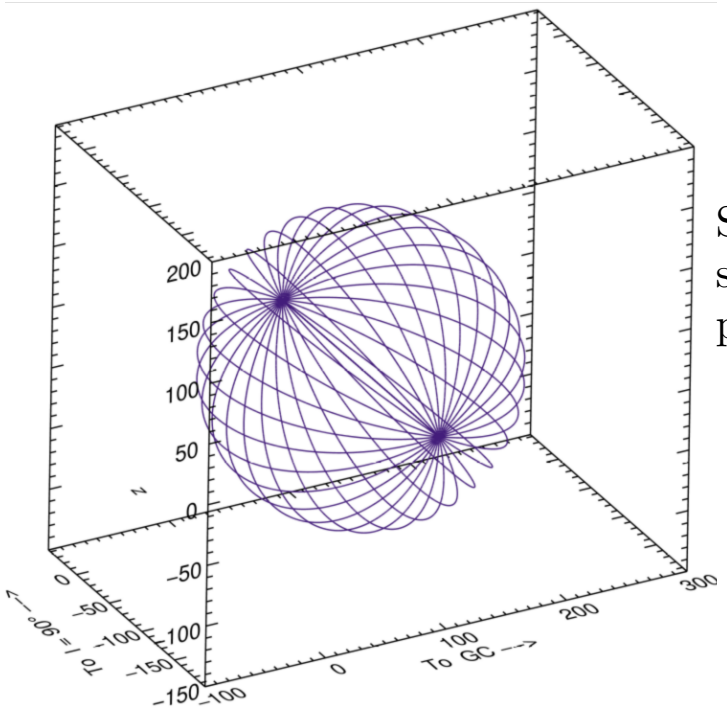


An ageing electron population should show up as a curvature in the spectral index. Taking the geometric mean of the pair of frequencies in the TT plots, there doesn't appear to be any departure from the weighted mean β -3.15$\pm$0.02.

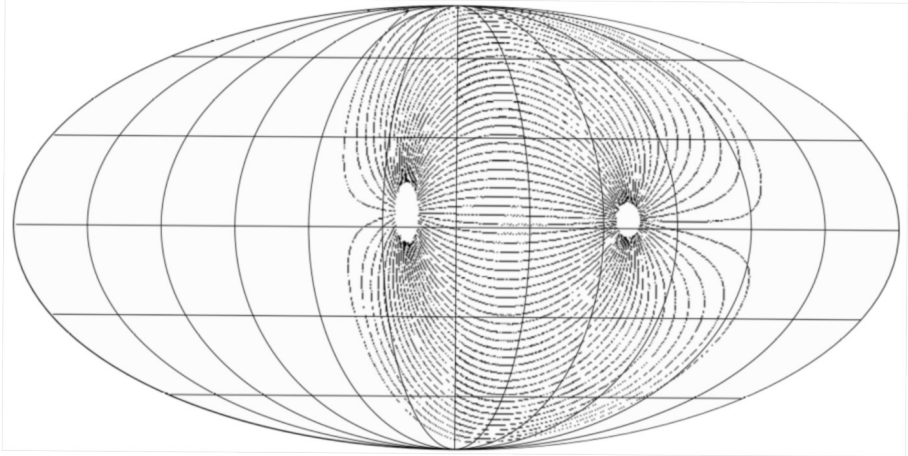
Modelling loops

Mertsch and Sarkar 2013 considered compressed B-field in shell and shock electron re-acceleration for old SNR shells.

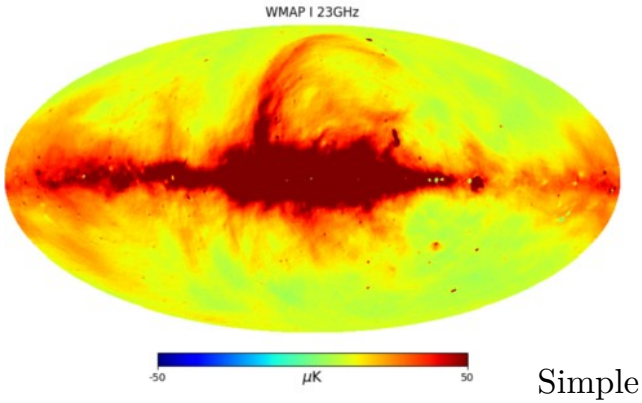


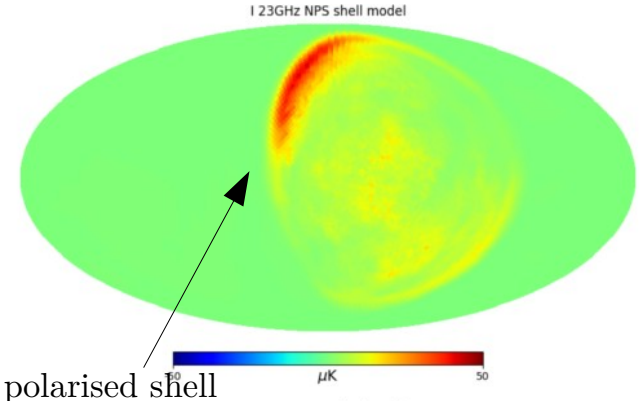


Simple model from Vidal 2015 for loop I of an expanding sphere sweeping up field lines does seem to describe polarization vectors close to observations

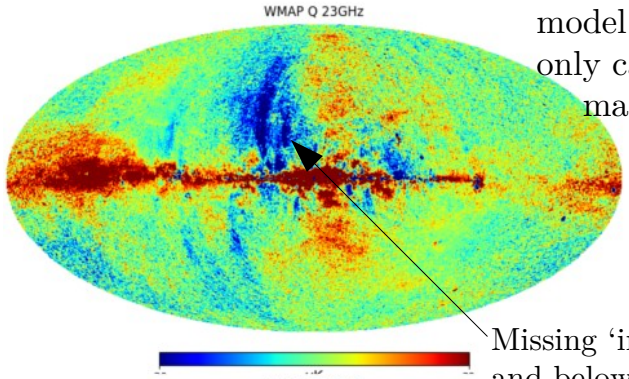


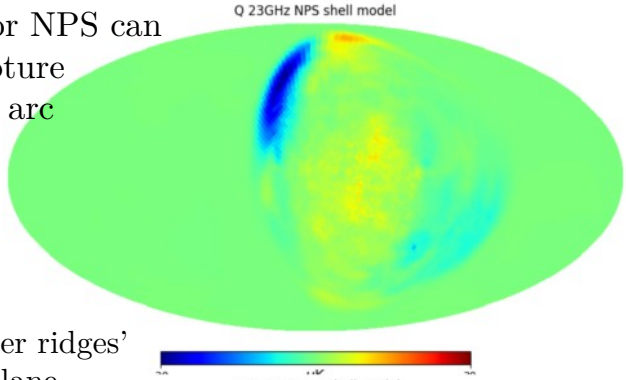
Comparison of Model North Polar spur model



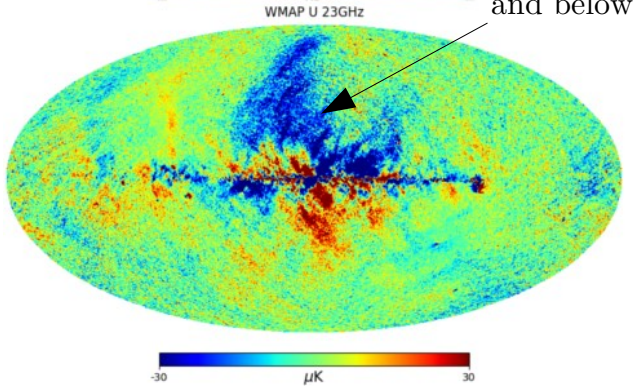


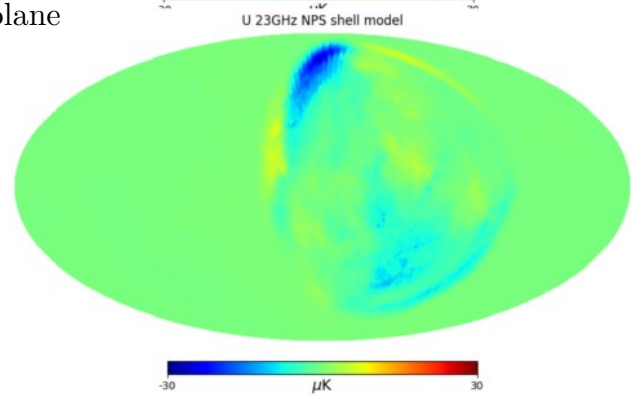
Simple polarised shell model for NPS can only capture main arc



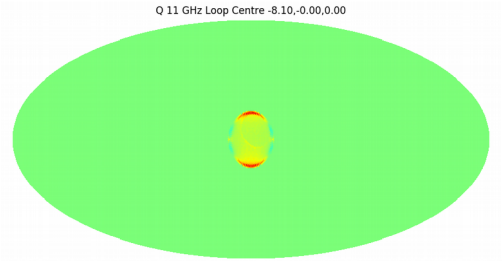


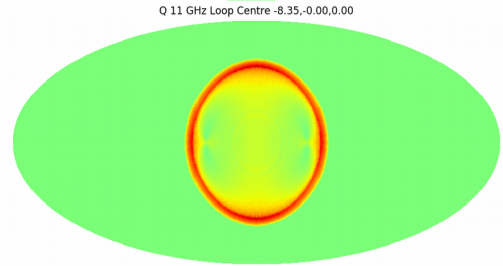
Missing 'inner ridges' and below plane

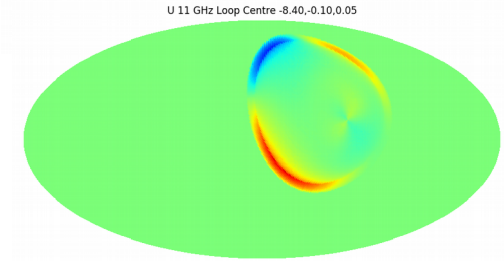




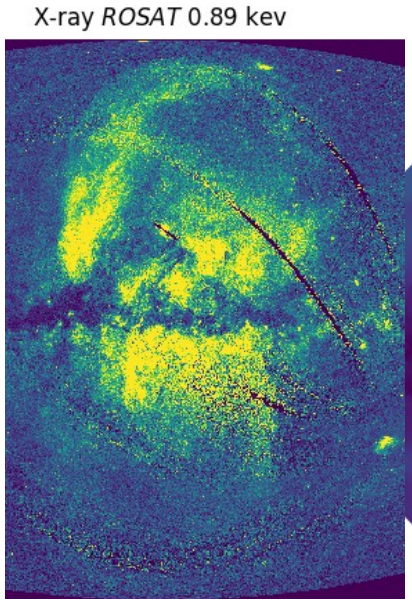
Using modified modelling code gPemPy from V.Pelgrim, I implemented Vidal's model. Move it around, a very close perspective get an asymmetric distribution due to interaction of line of sight and nodal point.

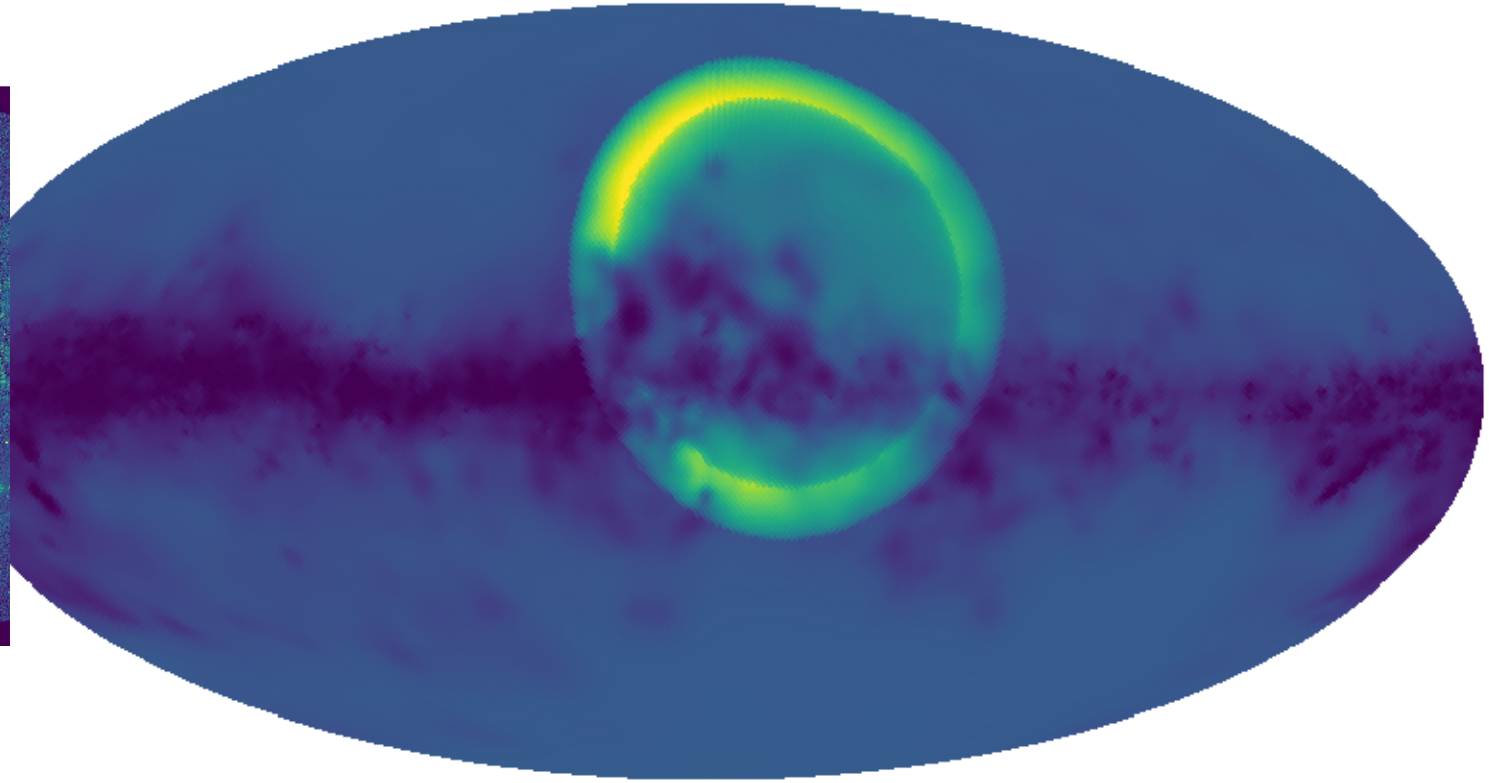




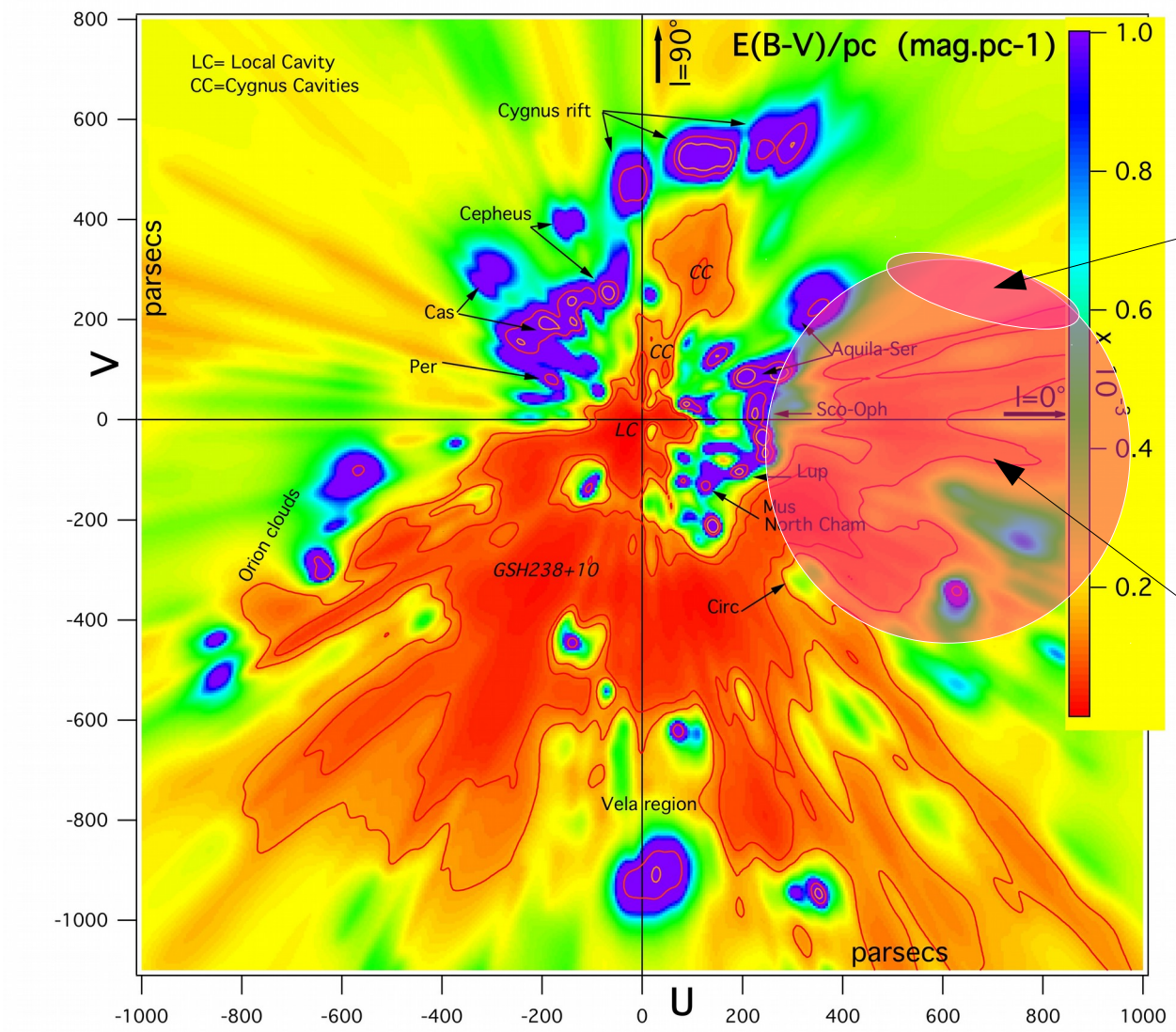


Modelling NPS in Xrays



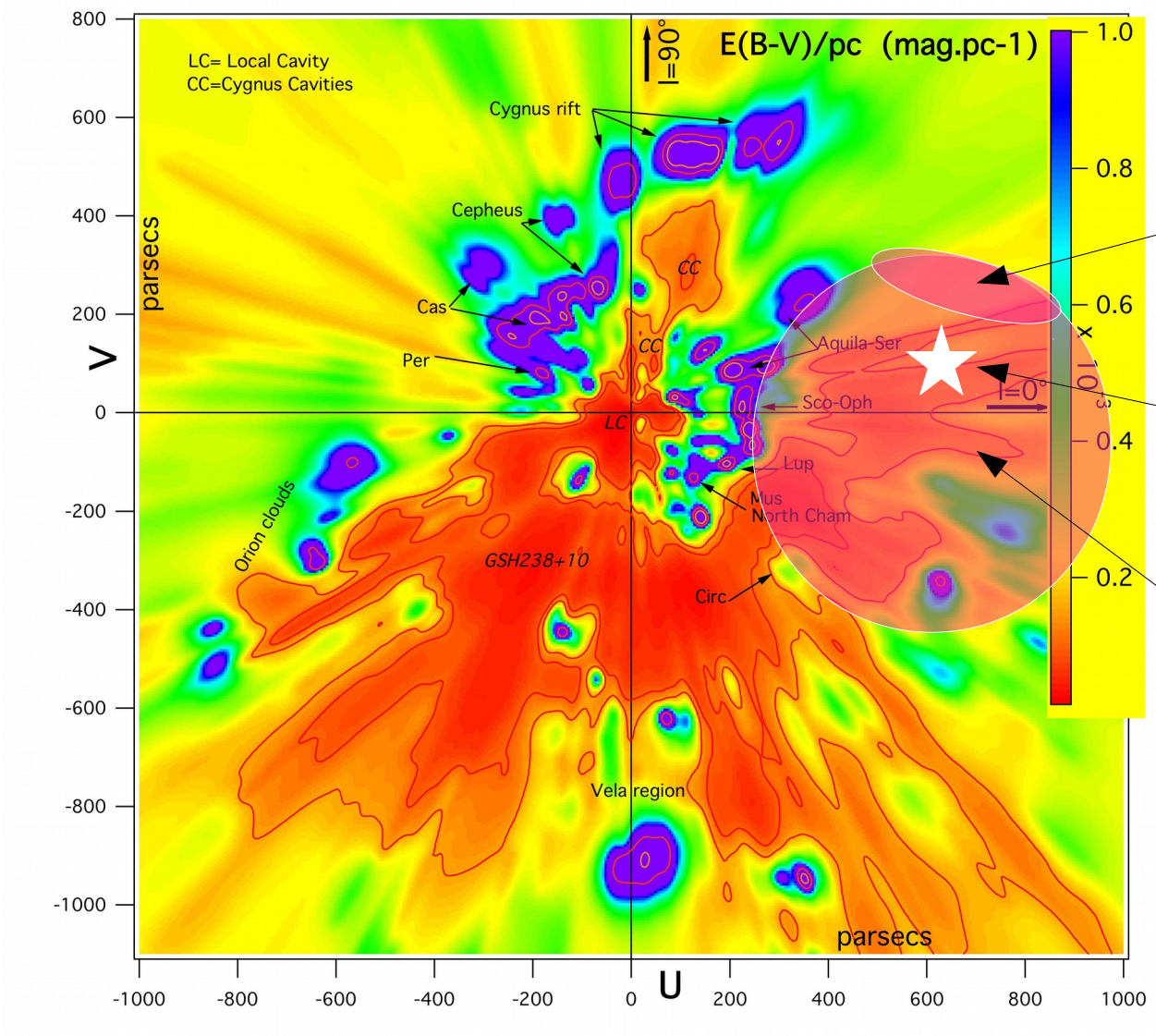


For distance to we need to use X-ray data combined with 3D opacity data. Here we have taken the Lallement et al (2018) extinction 3D cube based on Gaia, 2MASS and APOGEE-DR14 via a simple conversion of Av to N_H to X-ray opacity. Then ray traced a X-ray shell model through it. The half-shell centre must be >600pc away and also have a large factor 2 gradient across it, seems non physical – needs proper simulations



Would like most of the emission from here

NPS more or less constrained to be in this volume

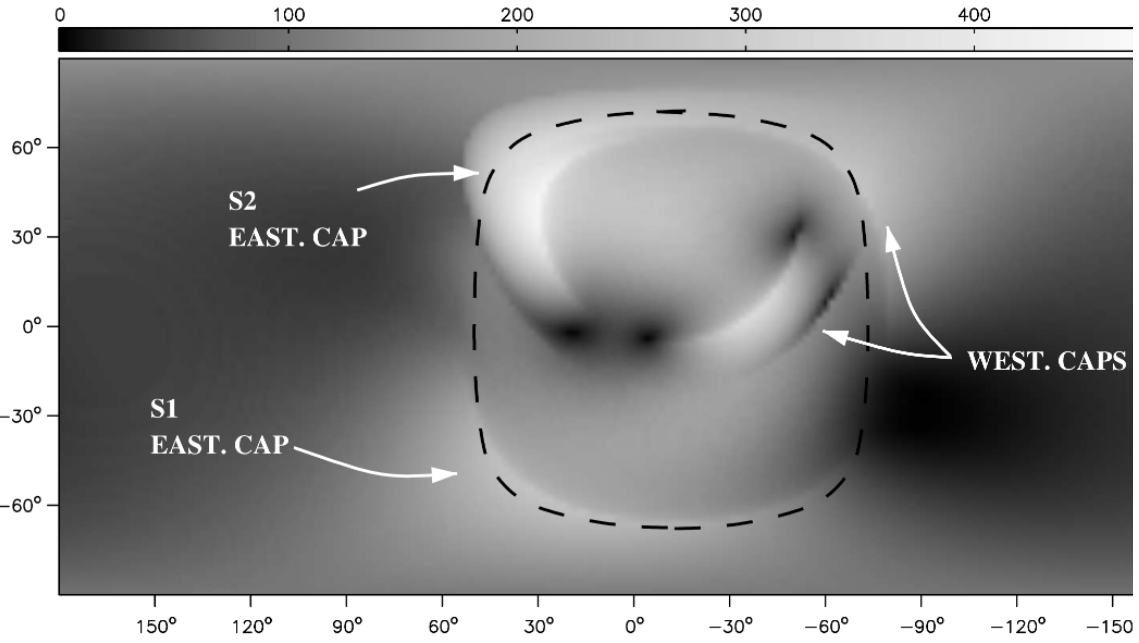


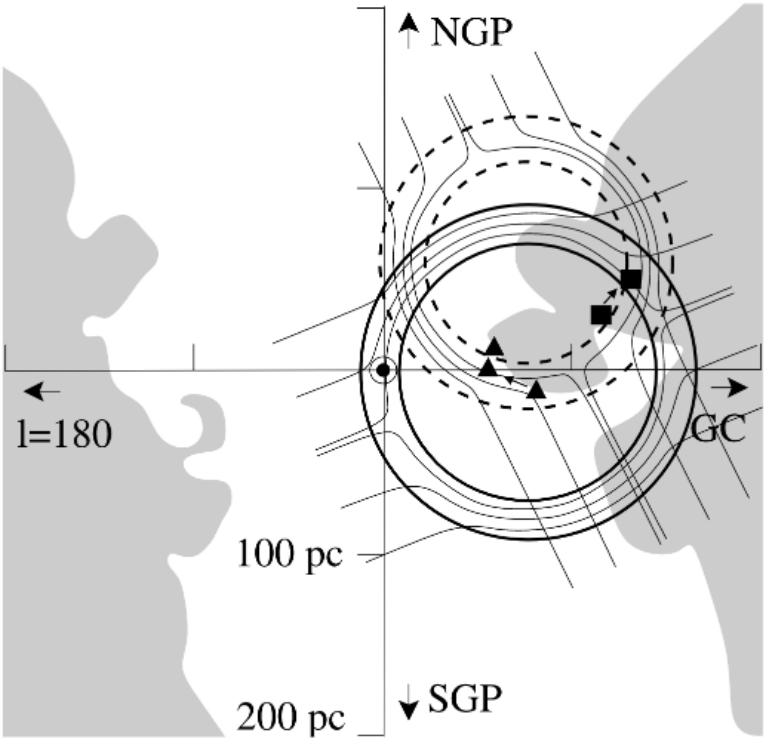
Would like most of the emission from here

So what if we had a supernova go off and interact with an already existing shell?

NPS more or less constrained to be in this volume

SNR inside old shell revisited

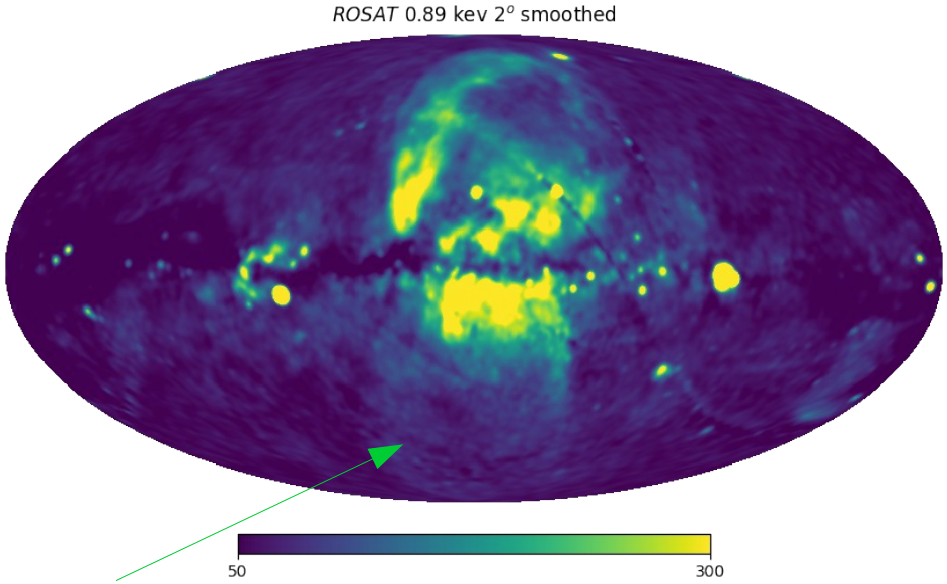


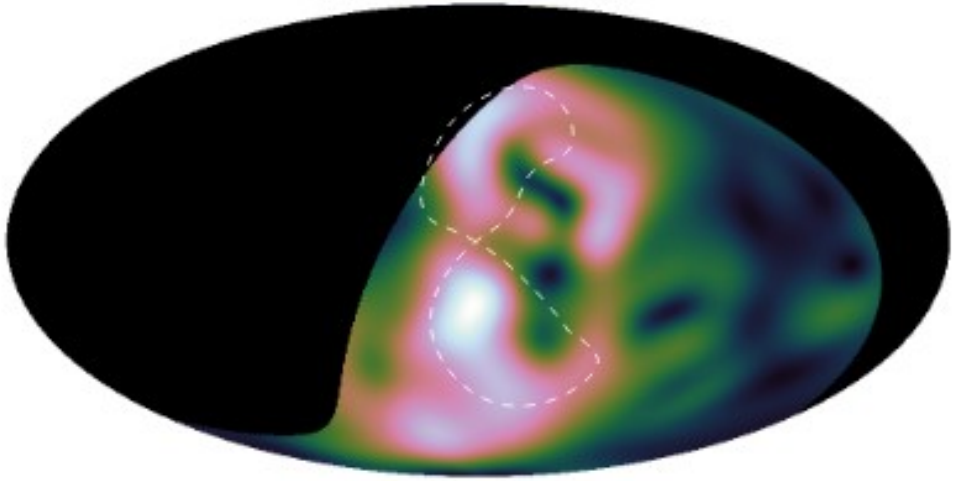


Wolleben (2007) proposed two overlapping spherical shells to explain the polarization angles and depolarization justified by a suggest by Weaver (1979) of the interaction of a supernova remnant with a much older remnant.

A SNR inside an old super-shell would explain the alignment with local B-field outside SNR and the asymmetric radio and X-ray emission

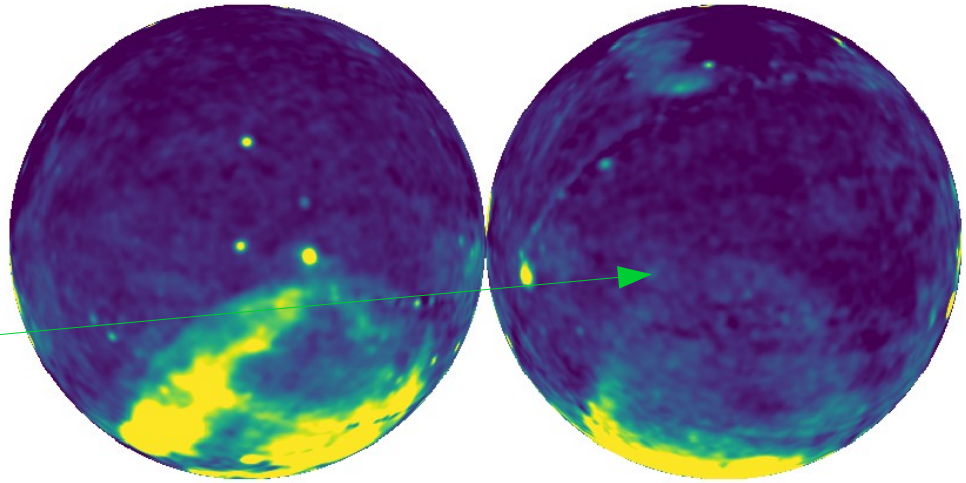
Closer look at Southern lobe





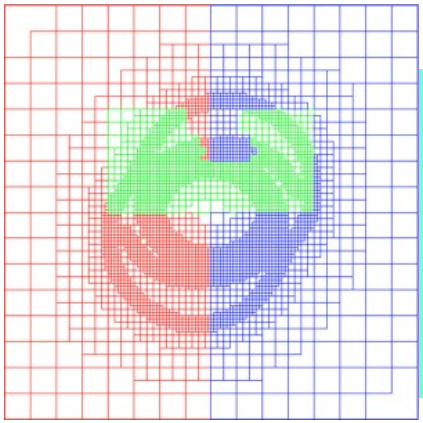
Robitaille et al 2017 fig 9 filtered $|\nabla P|$ S-PASS pulls out diffuse synchrotron on scales $> 10°$

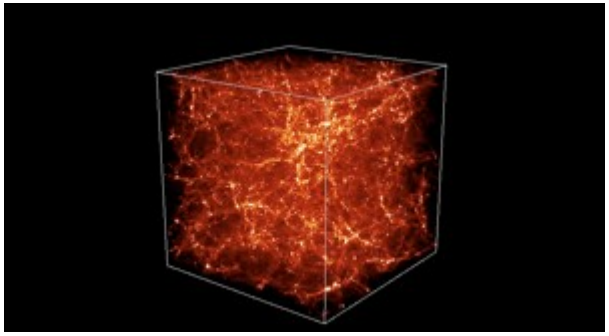
Smoothing the 0.89 kev ROSAT seems to reveal a southern X-ray lobe, which looks remarkably like super-shell S1 of Wolleben 2007



Checking the orthographic projection, the lobe really seems to be there.

MHD simulations with RAMSES



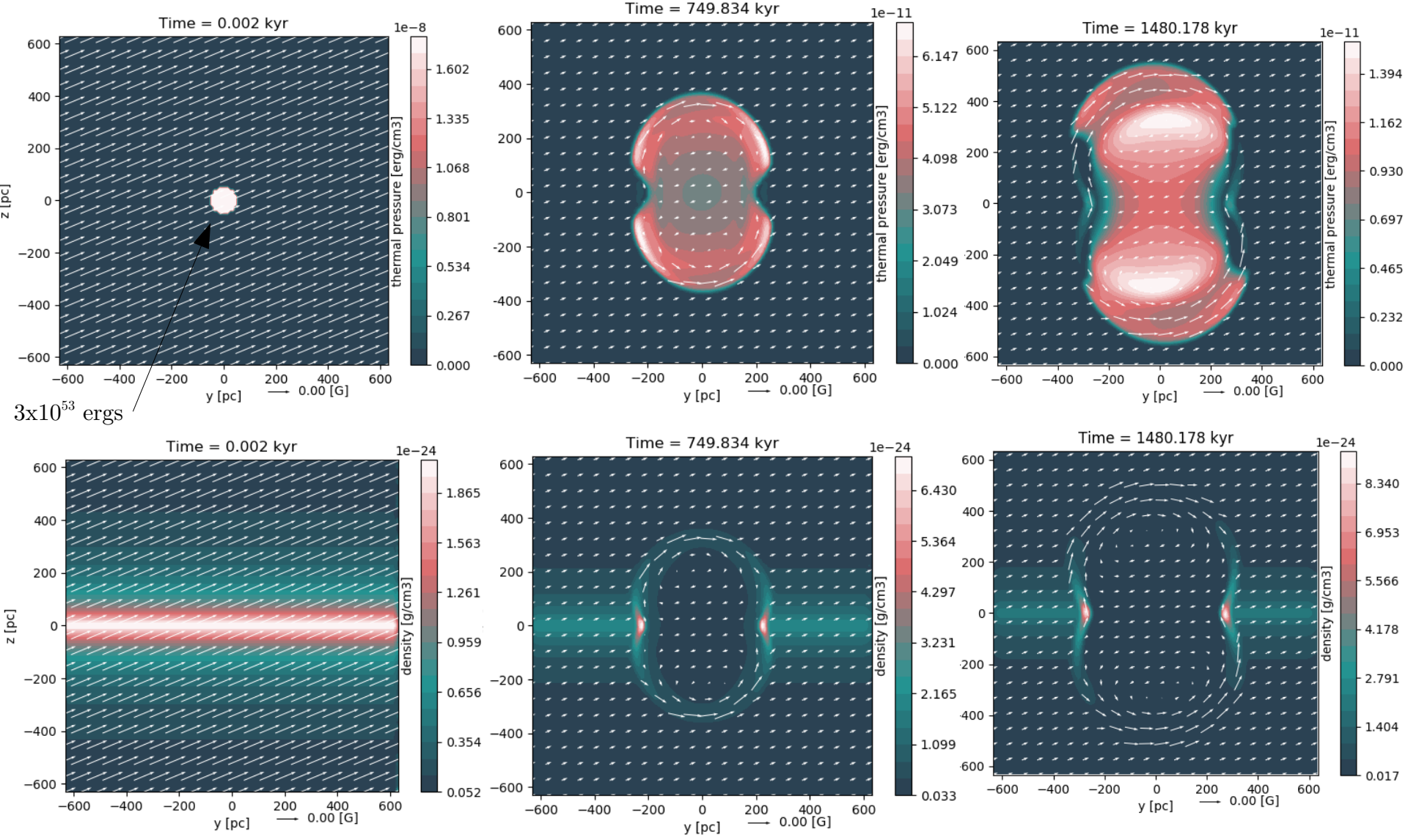


RAMSES is a open source grid-based hydro solver with adaptive mesh refinement for self-gravitating magnetized fluid written by Romain Teyssier (Teyessier 2002 & bitbucket.org/rteyssie/ramses)

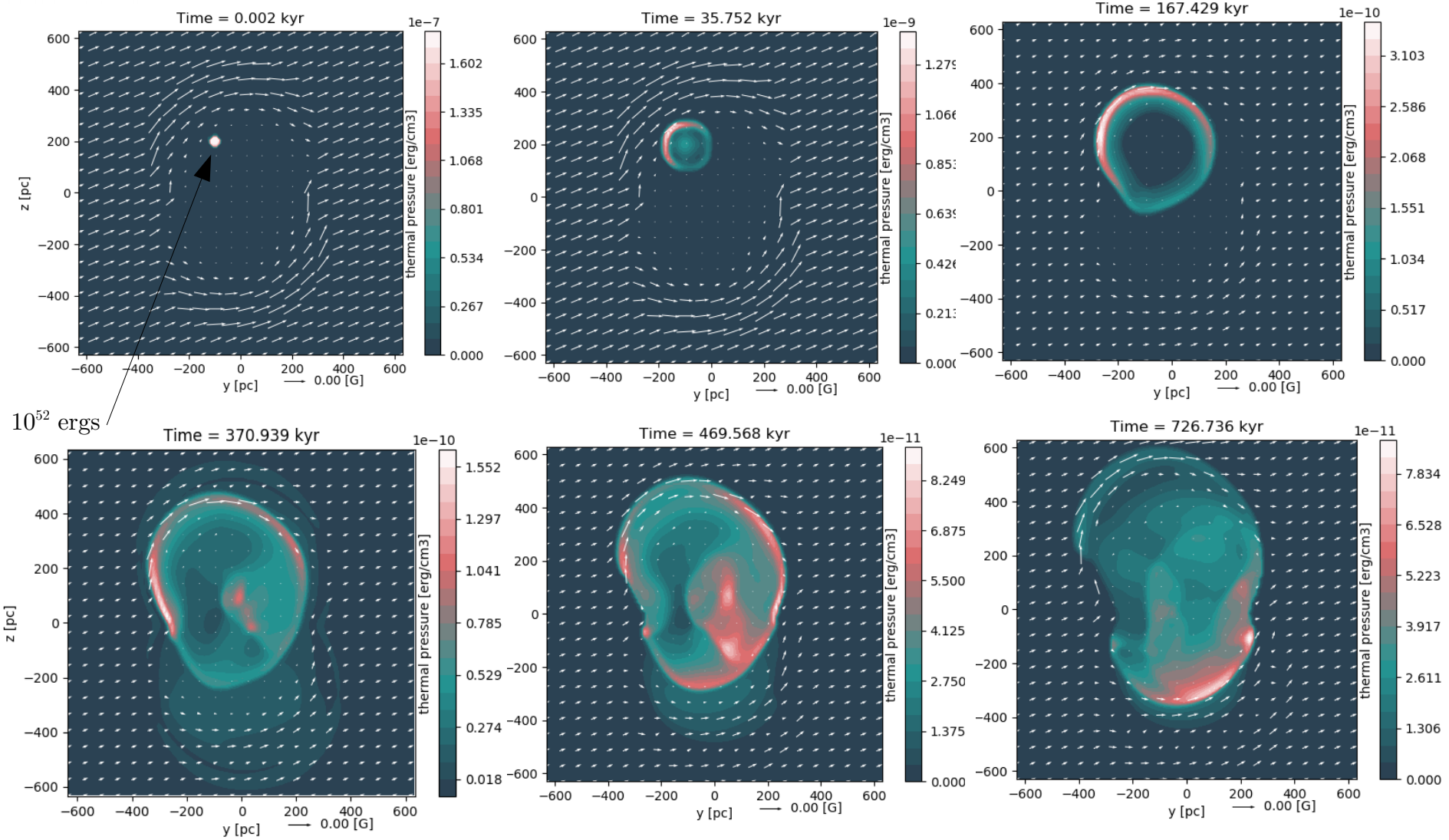
Patched to run in MHD mode with on a 128x128x128 non-refining grid 1280pc in size. The initial density and B-field grids were generated in python. Two exponential disks with N_H=0.3cm^{-3} scale height 0.35pc and 1cm^{-3} and scale height 0.08 for the dense but thinner molecular clouds.

The B-field was a constant 3μG angled like Wolleben's S1 in order to sweep up in the expected direction of the spur. The Supershell was initialized as a 3x10^{53}erg fireball.

Weaver revisited with MHD

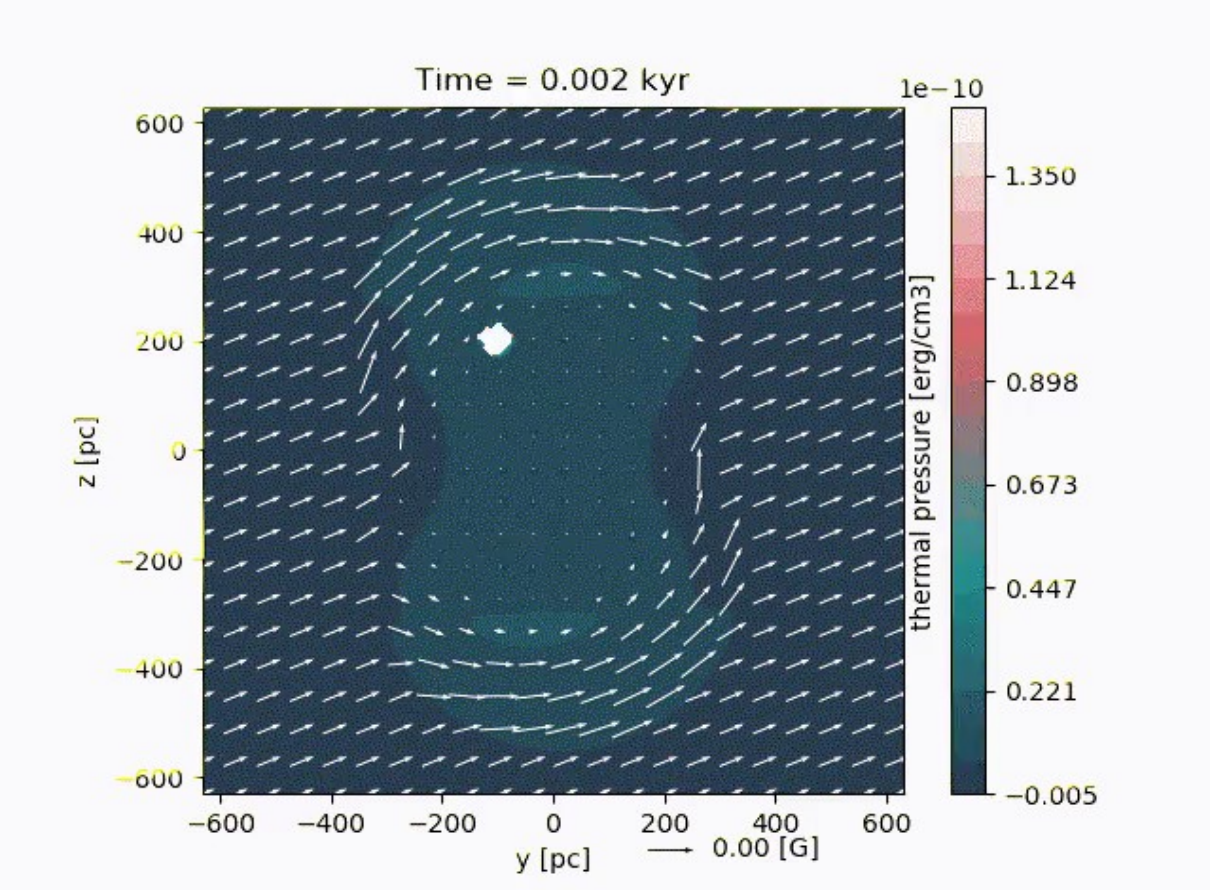


Supernova growth within a Supershell

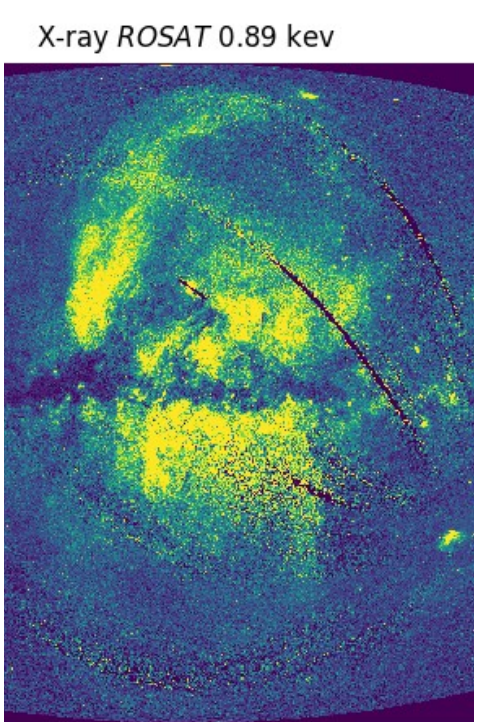


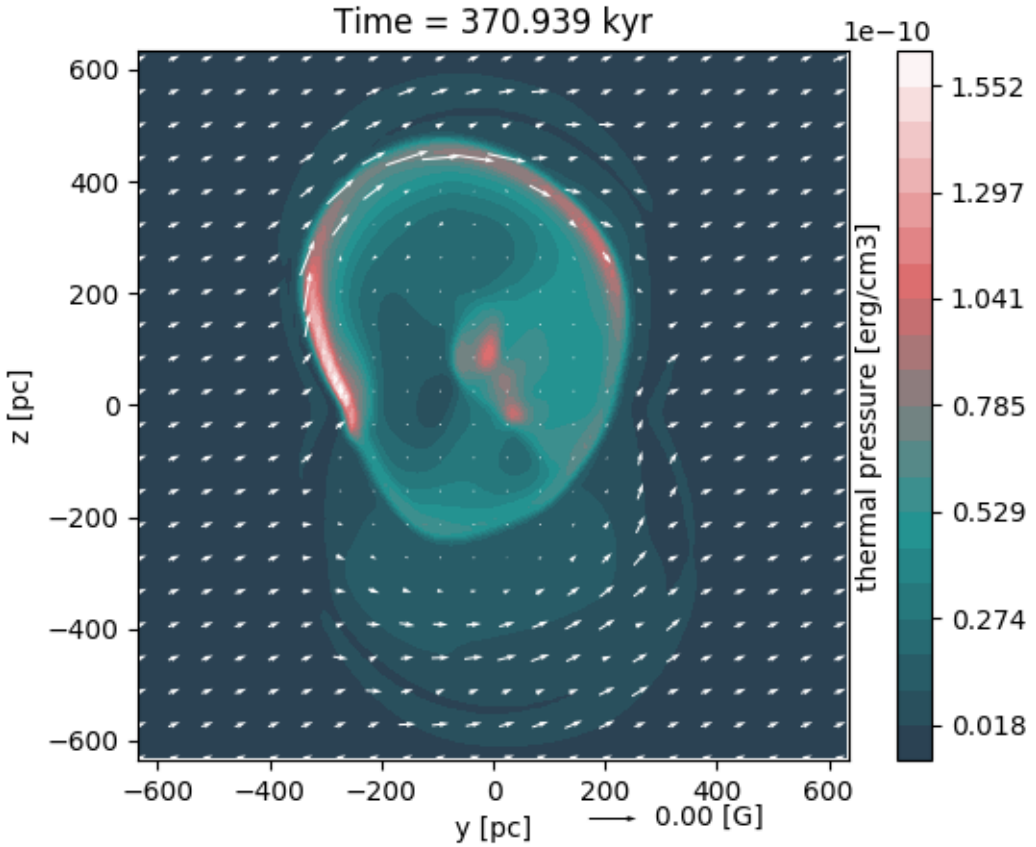
Supernova growth within a Supershell

Video

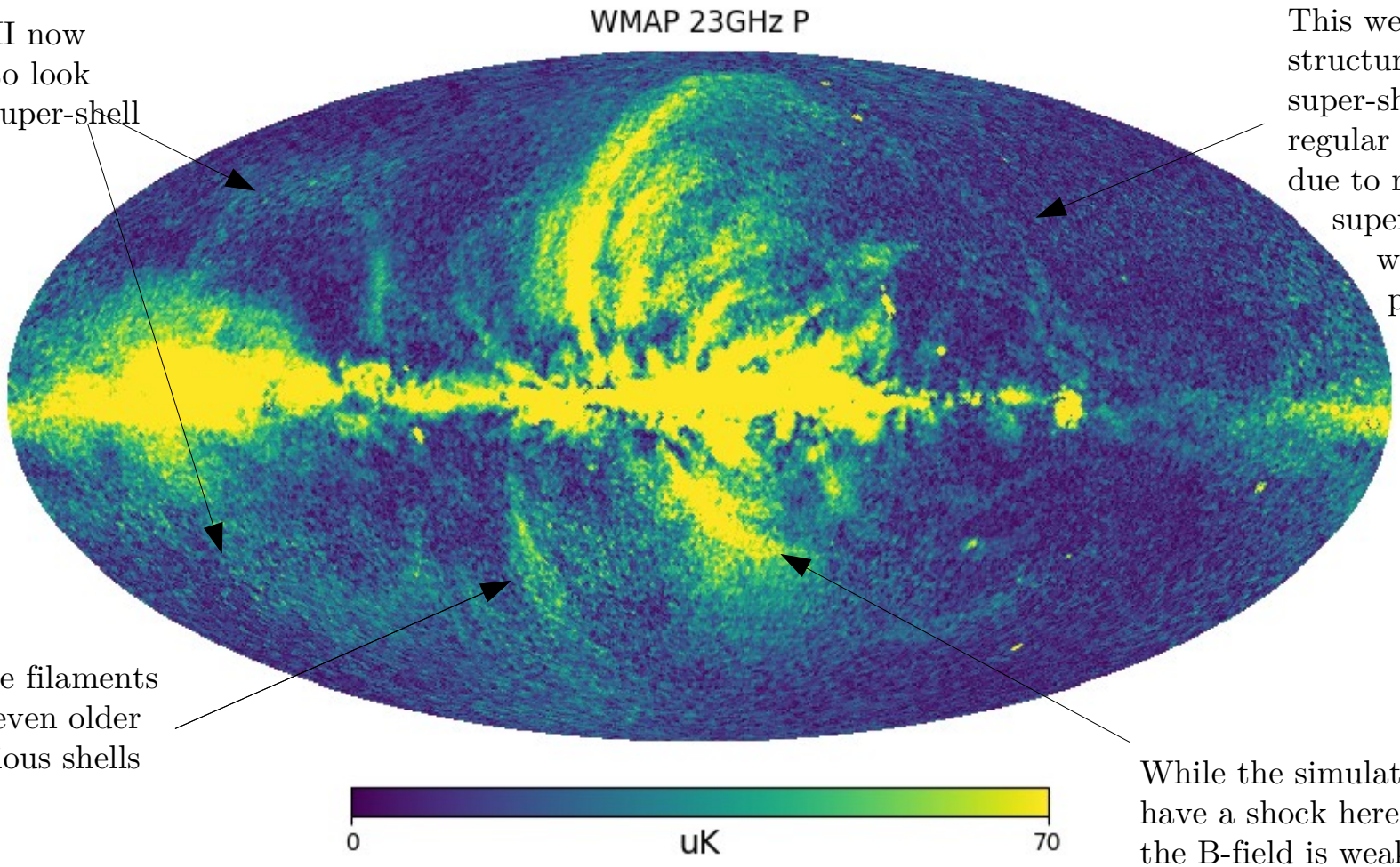


Supernova growth with supershell





With the a new supernova offset in position, the density gradients naturally guide the shape of the new shell into that of the NPS also with the recompression of the old shell field. Also the reverse shock leads to the cavity and loop IV.



Loop III now starts to look like a super-shell

This weak structure NPS super-shell has regular shape due to repeated supernova with perhaps activity shifting

These filaments like even older previous shells

While the simulations have a shock here there's the B-field is weak here suggesting we need more 'messy' initial conditions

Conclusions

Suspect the North Polar Spur is an evolved (400kyr) supernova remnant inside a super-shell (>1.5Myr).

This supernova is just the current one of those which have formed the shell in the past. Just caught as it blasts through.

It explains the age contradiction of slow moving gas (several Myr) with ~2 million K soft X-ray inside (100s kyr)

Also explains why the B-field direction is the same inside as out

The opacity of the Aquila Rift pushes the NPS >600pc.

To Do: Ray tracing of Synchrotron and X-ray and parameter estimation