Surveying the magnetic field of the Milky Way with SKA1

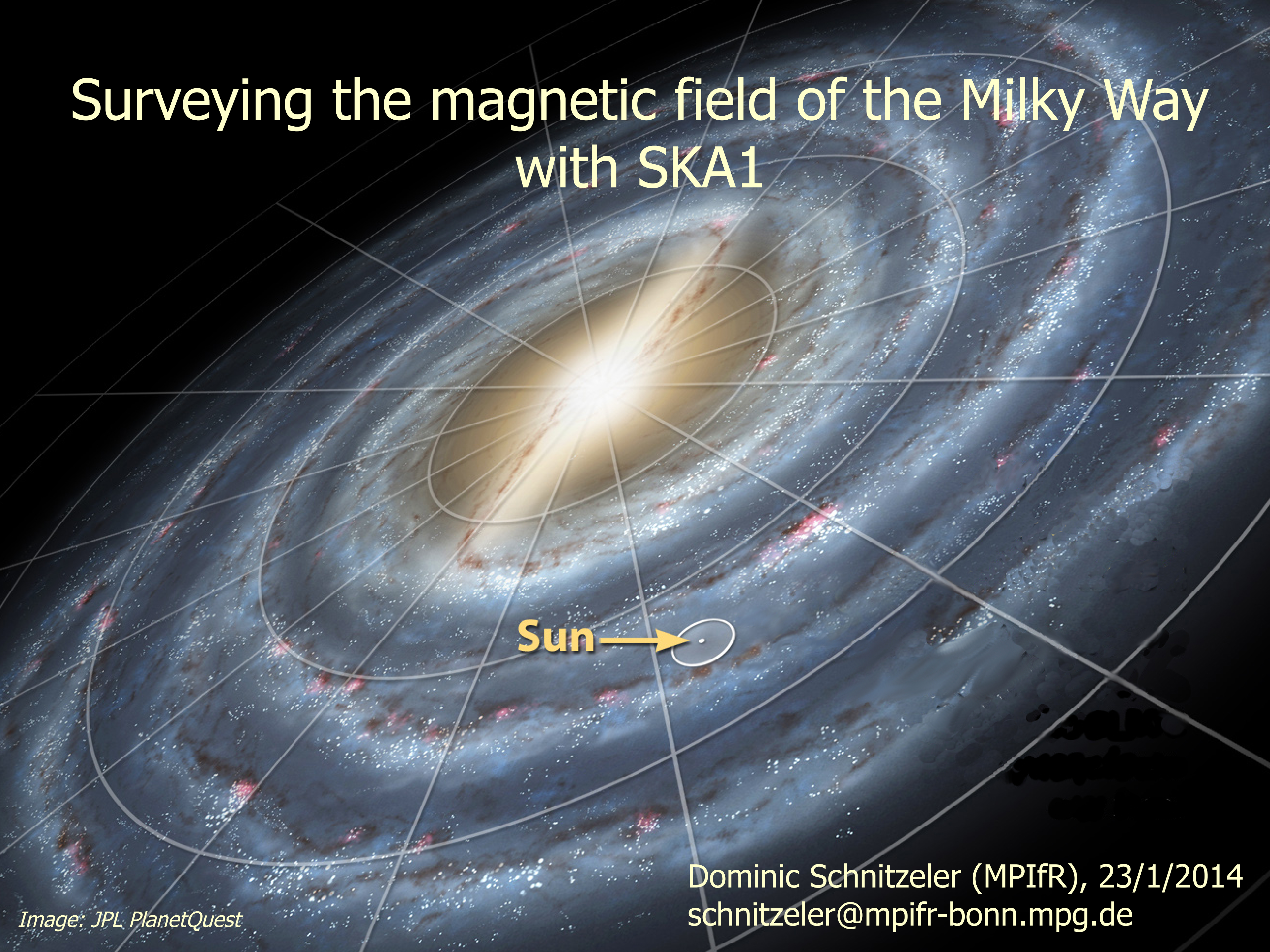


Image: JPL PlanetQuest

Dominic Schnitzeler (MPIfR), 23/1/2014
schnitzeler@mpifr-bonn.mpg.de

Overview

What are the hot topics?

Which tools do we have at our disposal?
What are their pros and cons?

Can we use these tools with SKA1?
Which potential pitfalls are there?

Key science questions

Which (micro)physical processes generate magnetic fields on galaxy scales?

What is the origin of ultra-high energy cosmic rays?

How is energy dissipated in the turbulent cascade?

What is the structure of the magnetic field close to the centre of the Milky Way?

Get rid of these nasty foregrounds! I want to study the CMB/cosmic web/clusters/AGNs (strike through)

Ways of surveying B in the Milky Way

- Pulsars
- RM grid of extragalactic sources
- The polarized diffuse emission from the Milky Way
- Masers and Zeeman splitting

These methods are highly complementary

1. Pulsars

2300 pulsars have been discovered so far;

SKA1 will discover ~ 20,000 pulsars (Smits+09) with 30m int.

Pros

Distances from observed DM

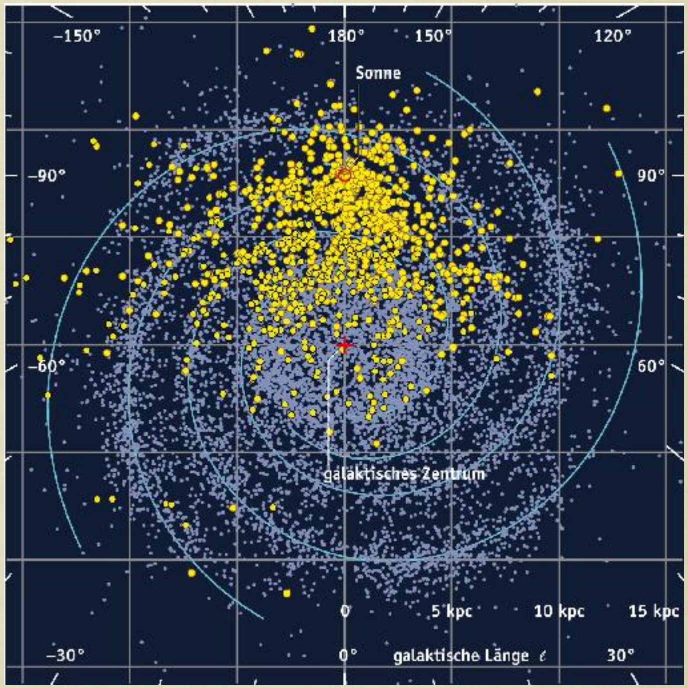
Comparing nearby (in 3D) PSR allows for tomography of the magnetized ISM

Constrain electron density models of the Milky Way → derive $B_{||}$ from RM

Cons

Most PSRs lie close to the Galactic plane

(h = 330 pc – 1 kpc Lorimer+ 2006, 2012)



Cordes+ (Sterne & Weltraum)

1. Pulsars: technical issues

Pulsar searches can start as soon as the central core has been deployed; polarization calibration is an integral part of the pulsar KSP from the very start.

Hardware-wise, pulsar searching requires very narrow frequency channels (20-51 kHz) and very high time resolution (50 μs).

Storing the data is not possible → need real-time processing. Pulsar searching is very time consuming and requires vast quantities of computing power!

10 TFlops/s puts it in the top-5 of supercomputers in 2013.

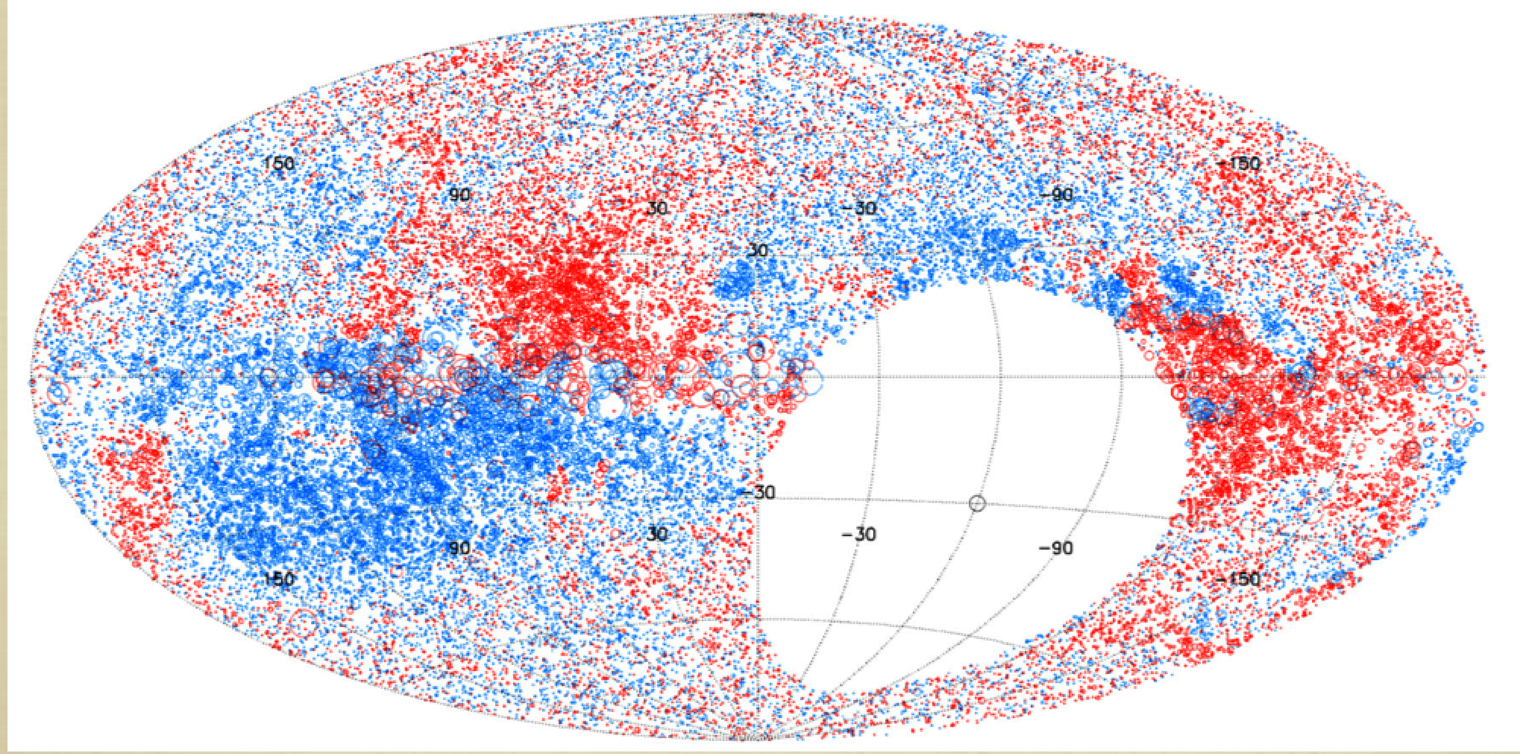
Need good instrumental polarization performance across the field of view **(this is the case for all tracers of Galactic B fields!)**.

The first science results from SKA1 will in all likelihood come from pulsars.

2. RM grid of extragalactic sources

Taylor et al. (2009): RM grid of 37,543 src above DEC=-40^{o}

Re-processed NVSS polarization data, fitted RM to data at 1.365 and 1.435 GHz



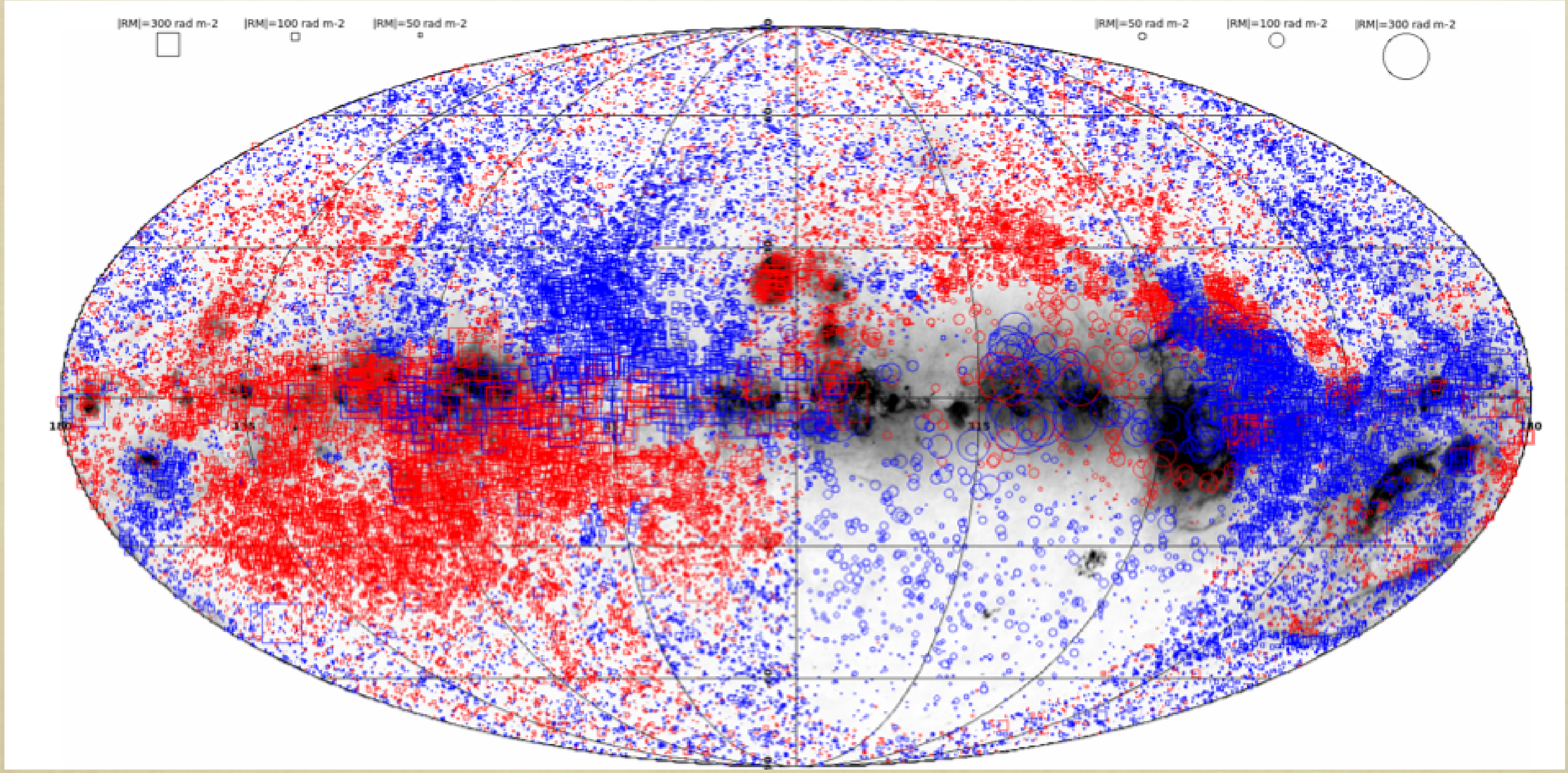
Red = RM > 0, Blue = RM < 0 rad/m^2

2. RM grid of extragalactic sources

NVSS RMs + S-PASS RMs (Schnitzeler et al.)

4600 target sources with DEC < 0^{o} / err_RM < 1.5 rad/m^2

BROAD-BAND: 1.3-3.1 GHz



Red = RM < 0, Blue = RM > 0 rad/m^2. Greyscale: Hα intensity (figure courtesy of M. Iacobelli)

2. RM grid of extragalactic sources

Use the RM grid to:

Derive the large-scale structure of the Galactic magnetic field (and how it got there) Brown et al. (2007), Sun & Reich (2008), Jansson & Farrar (2012), Jaffe et al. (2011)

RMs are accumulated all along the line of sight → Measure the RM signature of clusters (e.g., Johnston-Hollitt et al. 2003, Clarke 2004, Govoni et al. 2010) and the cosmic web (e.g., Akahori & Ryu 2011)

Study the structure of the jets and lobes for NN sources, and how magnetic fields in these sources evolve with redshift (Hammond et al. 2013)

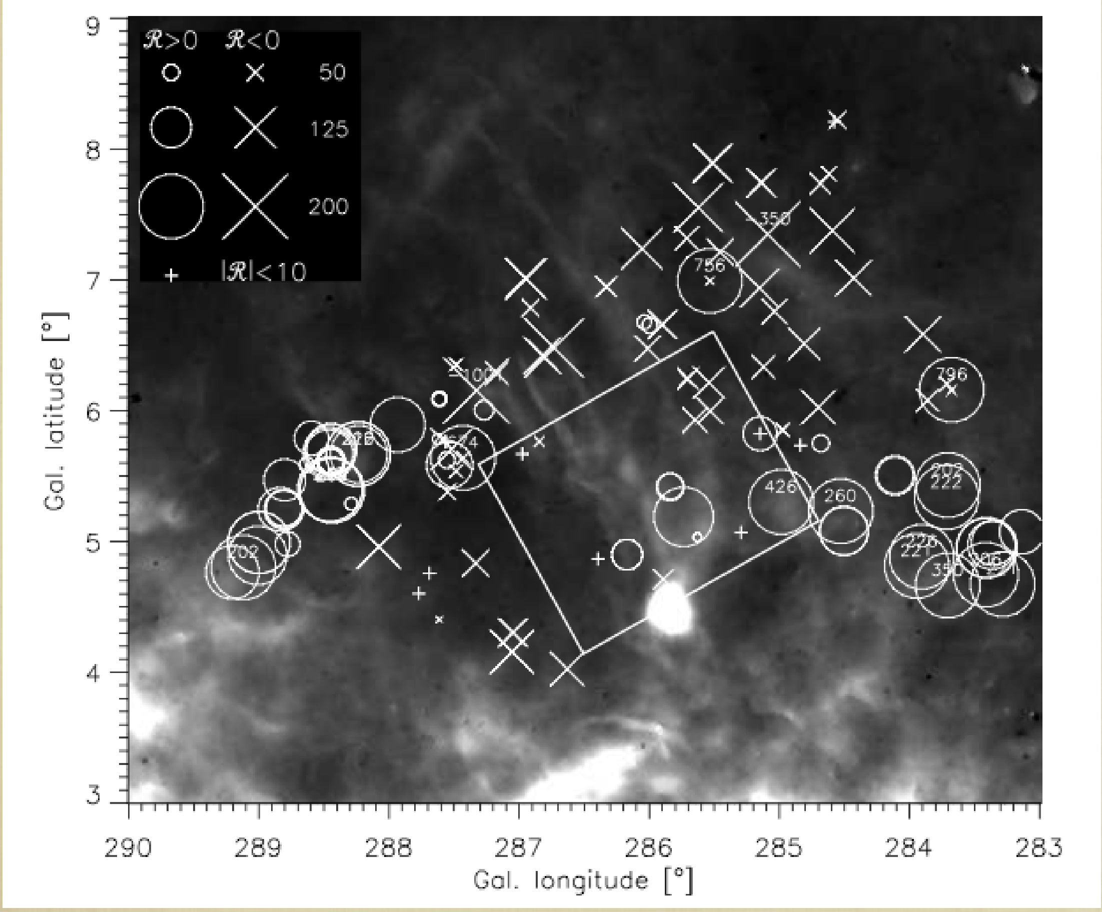
But:

Need a dense grid over a wide area to separate Galactic from extragalactic structure (e.g. Wolleben 2010).

Extragalactic sources have sigma_RM = 6 rad/m^2 (Leahy 1987, DS 2010);
the Galactic RM variance is at least as large as this, at all Galactic latitudes.

2. RM grid of extragalactic sources

High-resolution RM grid and Galactic foregrounds:



Observations with the Australia Telescope Compact Array/CABB (Schnitzeler, McClure-Griffiths & Dawson)

Background:
Hα intensities from the SHASSA survey (Gaustad et al. 2001), corrected for extinction. Linear grey scale that ranges from 10 – 200 Rayleigh.

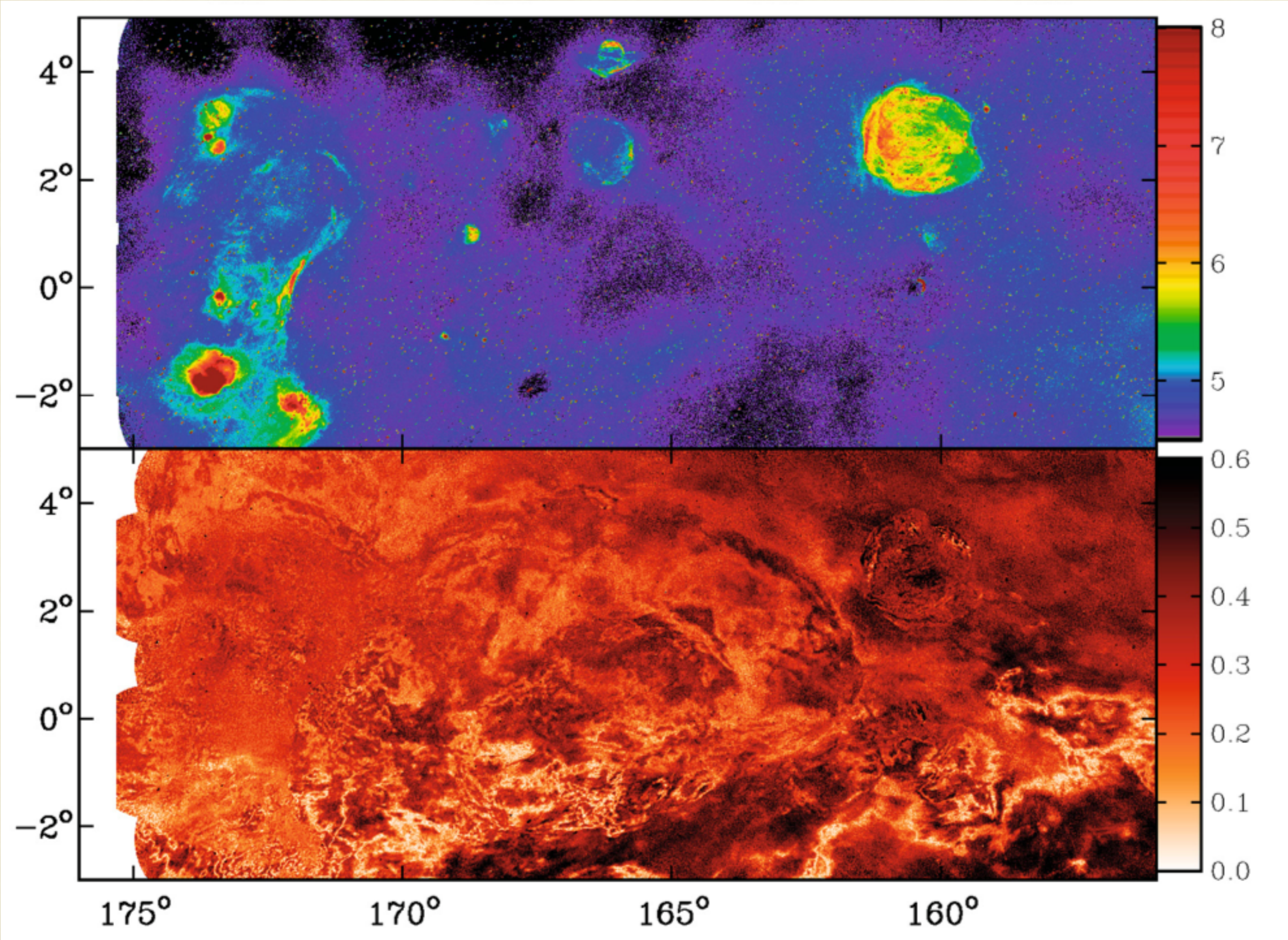
2. RM grid: technical issues

Requires angular resolution <~ 20”: if the angular resolution is poor, only a small number of polarized sources will be detected (Bernardi+2013, Emil's and Rainer's presentations on Wednesday).

Learn from pathfinder experiments how to extract information from wide-band data.

3. Polarized diffuse emission

Projects: IGPS, GMIMS, S-PASS, GALFACTS, Sino-German 6cm, ..

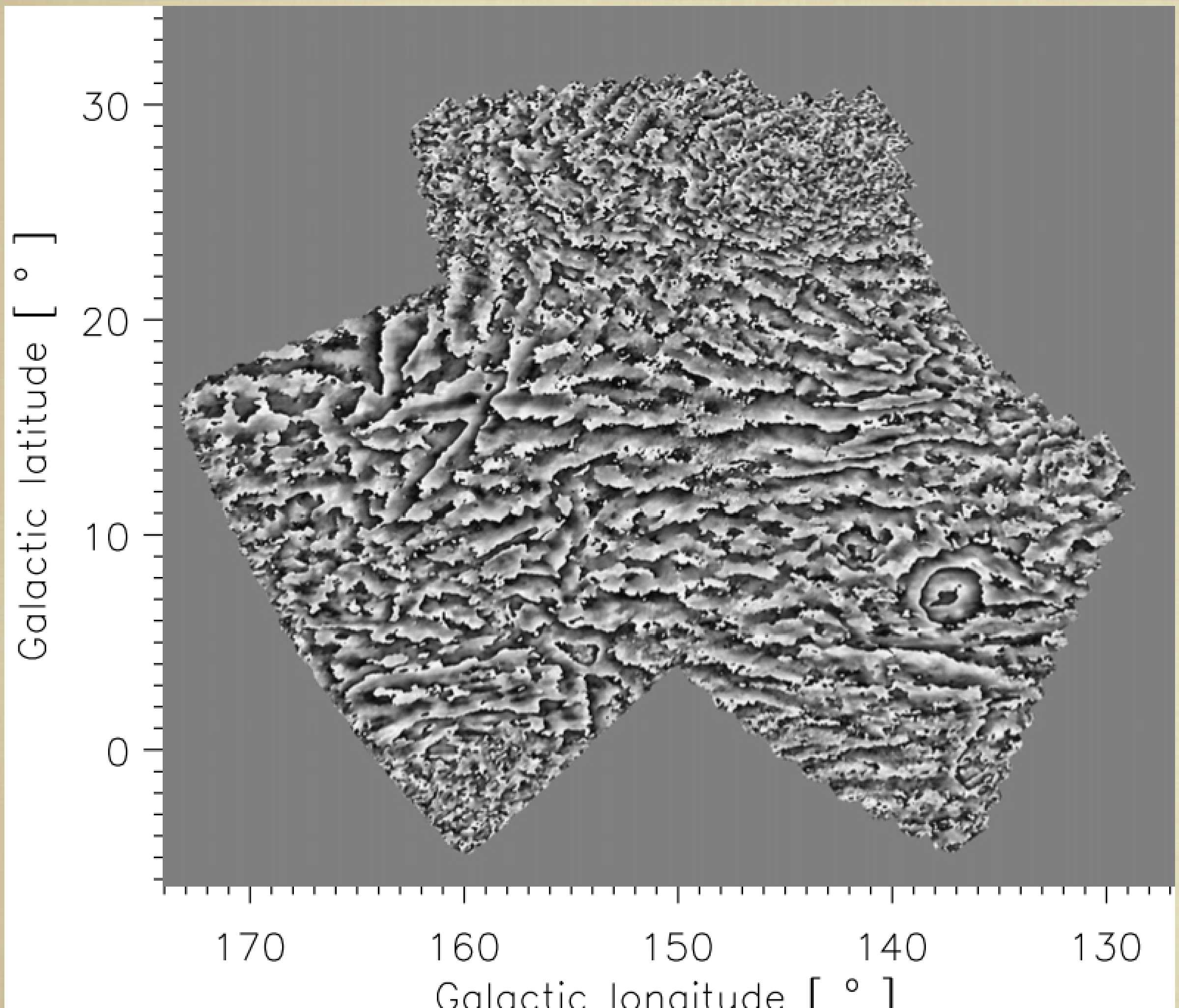


TI

PI

CGPS survey @ 1.4 GHz Landecker+10

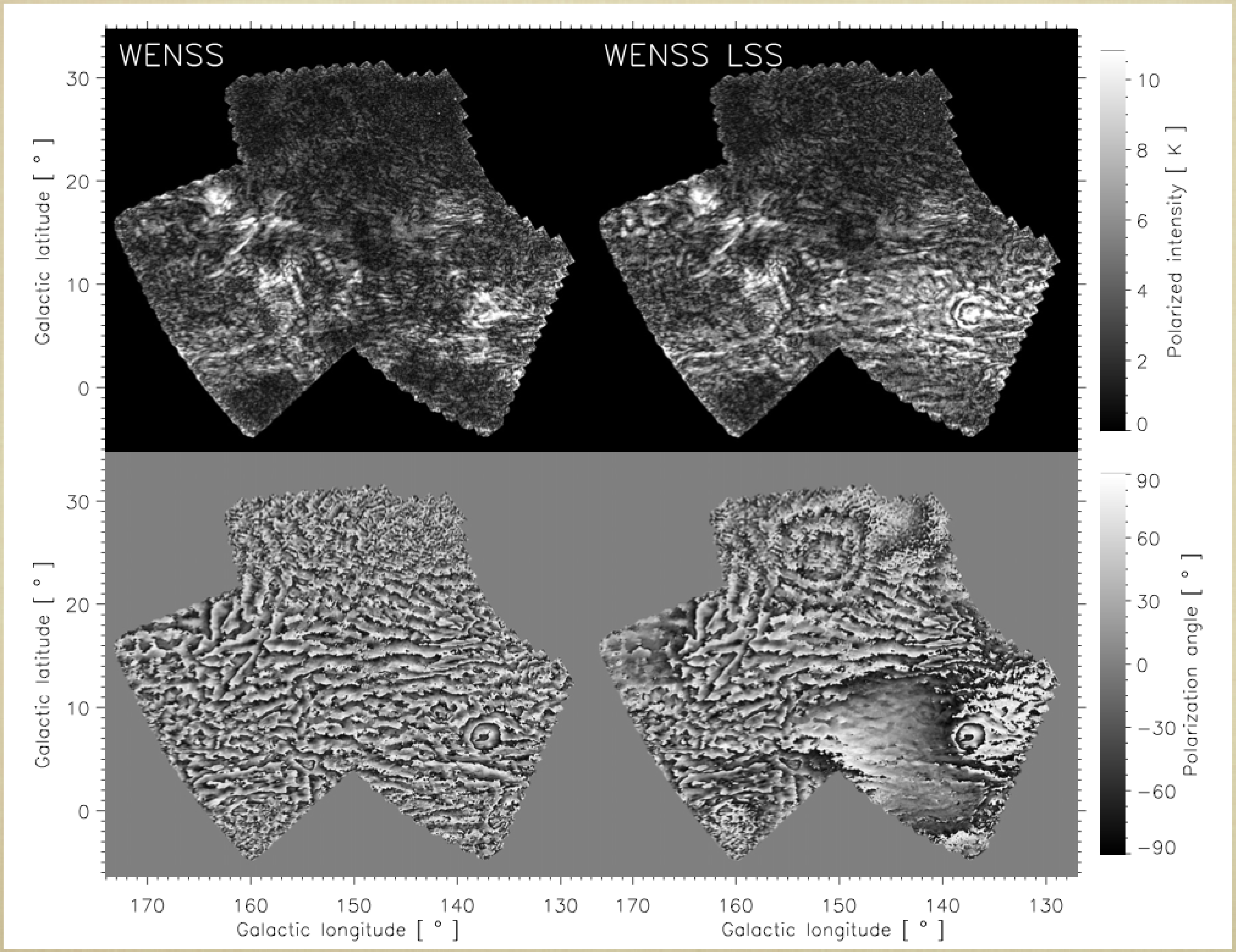
Observing polarized diffuse emission with an interferometer: WENSS (WSRT @ 325 MHz, 36m shortest baseline)



The interferometer picks up the average PI across the field of view if there is a sufficiently large RM gradient in the foreground: 2 rad/m^2 per degree at 350 MHz for a 25m baseline (DS+2009)
= 1 wrap per 1.6^o

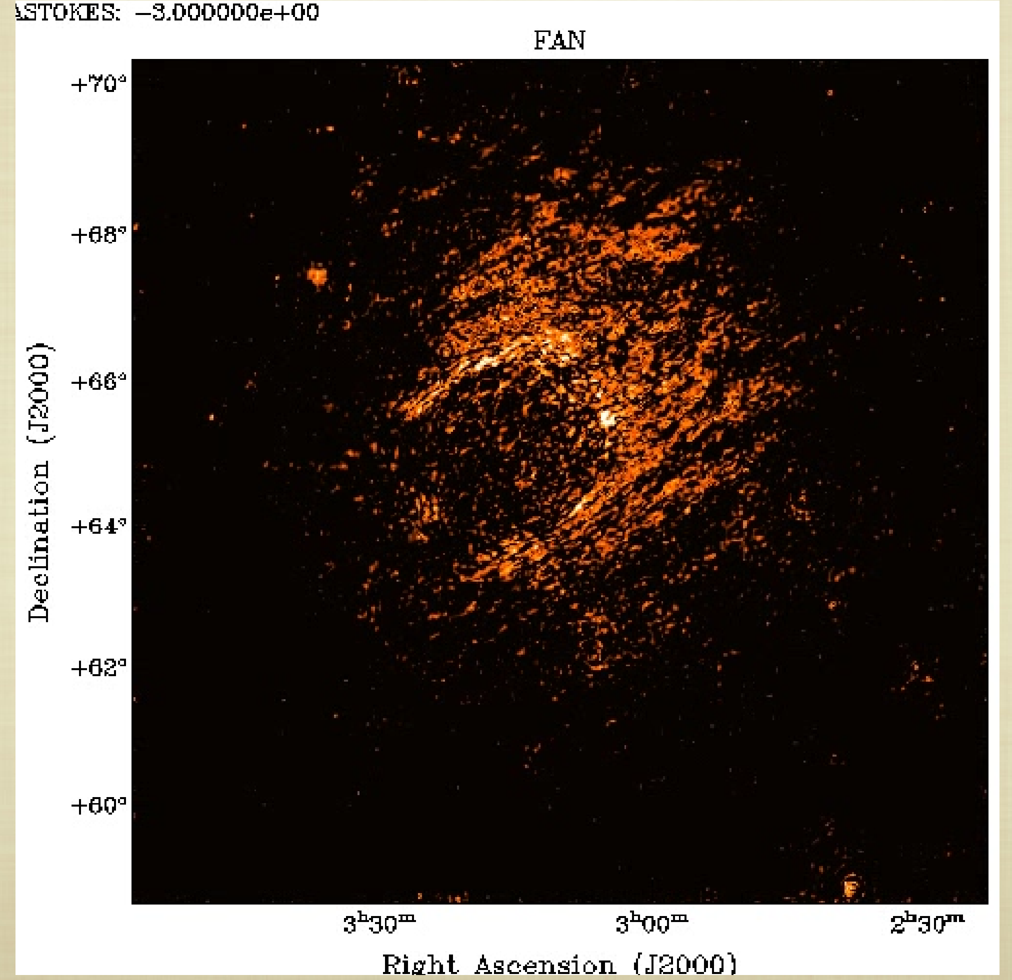
WENSS position angle map from DS+ 2007

The effect of missing short baselines

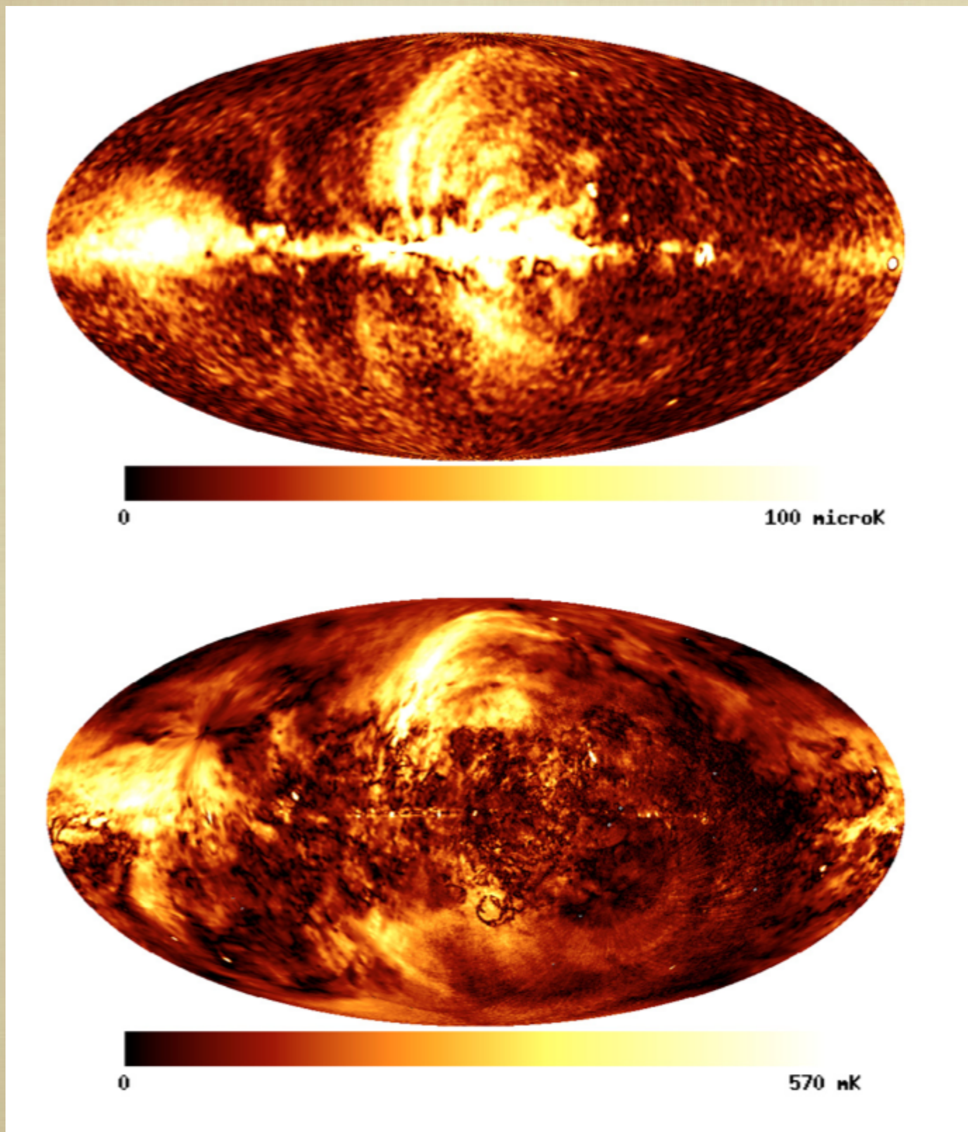


RM synthesis of the polarized diffuse emission

RM synthesis towards the Fan region (l,b) = 137°,7° (Iacobelli+13)
WSRT data between 139 and 155 MHz, 10 kHz channels



Frequency-dependent depolarization



WMAP 23 GHz PI (Page+ 07)

1.4 GHz single-dish PI
North: Wolleben+06
South: Testori+04

Image taken from Sun & Reich (2008)

3. Polarized diffuse emission

Pros

Map structure along each line of sight

Study Faraday-thin and Faraday-thick regimes

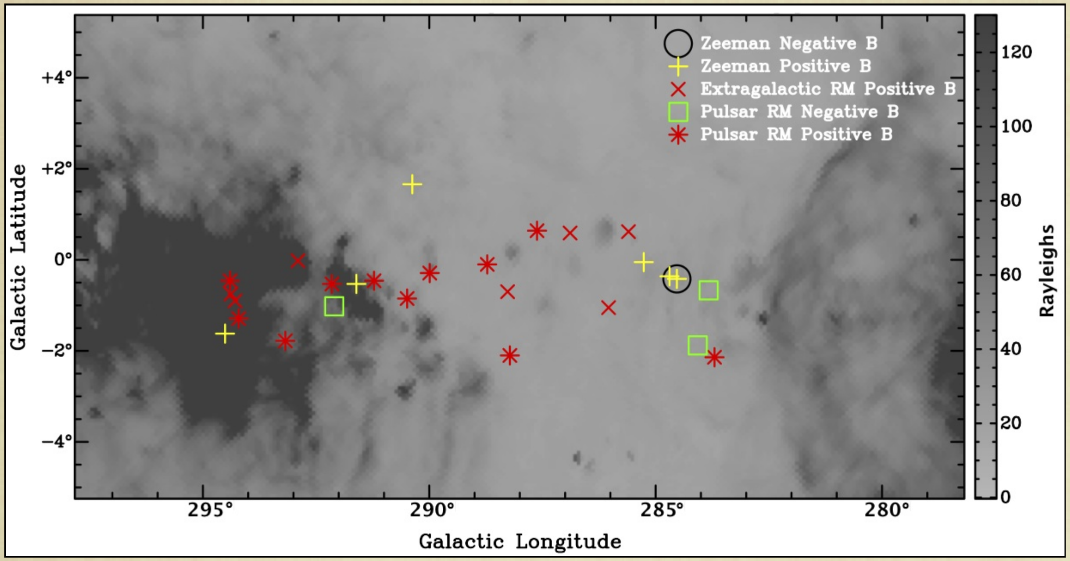
Derive 3D structure of the magnetized ISM (Faraday tomography)

Cons

Limited uv coverage → missing short baselines
Depolarization across the beam and along the line of sight
How do we know the distance to the diffuse *polarized* emission?
Option 1: look for depolarization holes left by HII regions.
Option 2: compare to pulsar RMs (but: B reversals along the line of sight!)

4. Zeeman splitting of maser lines

Zeeman splitting of maser lines allows in-situ measurements of the magnetic field



MAGMO Green et al. (2012)

Pros

Derive distance to sources from Doppler shift of the spectral lines

Tomography by comparing magnetic field strengths between sightlines

Warning!

Probe cold neutral medium, not WIM; confined to the Galactic plane

Summary: critical issues

- All observing tools require very good pol. performance across the field of view (-35 dB over the HPBW – Peter's talk)
- To suppress beam depolarization (RM grid) we need good angular resolution (~ a few arcseconds, Larry's talk)
- Mapping the diffuse emission requires short baselines (intra-station baselines?)
- Need to understand how stable antenna leakages and bandpasses are over time (and leakages: with frequencies)