LOFAR Cosmic Magnetism and Its Relationship With the Surveys KSP

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On behalf of LOFAR
and the MKSP
and Rainer, who is busy at a different meeting

Max-Planck-Institut für Radioastronomie

MAX-PLANCK-GESELLSCHAFT

Updating Project Plan and Observation Plan

Studying Cosmic Magnetism in the Nearby Universe with LOFAR

LOFAR Key Science Project

Project Plan

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Main Science Aspects of MKSP

- Milky Way
- Spiral Galaxies
- Perturbed Galaxies
- Dwarf Galaxies
- Giant Radio Galaxies
- Stellar and AGN Jets
- Intergalactic Magnetic Fields
- Pulsars

Rotation Measure Synthesis

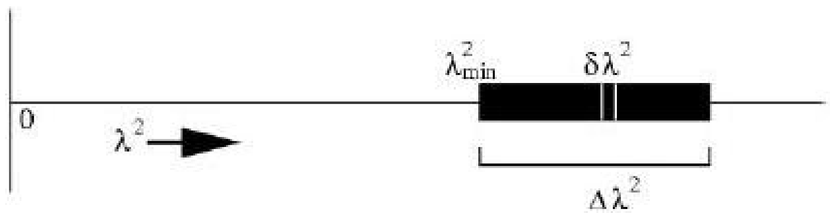


Figure 1: Three instrumental parameters determine the output of a Faraday rotation observation in λ^2 space: the minimum wavelength λ^2_{min}, the resolution $\delta\lambda^2$, and the total range $\Delta\lambda^2$ (from Brentjens & de Bruyn 2005).

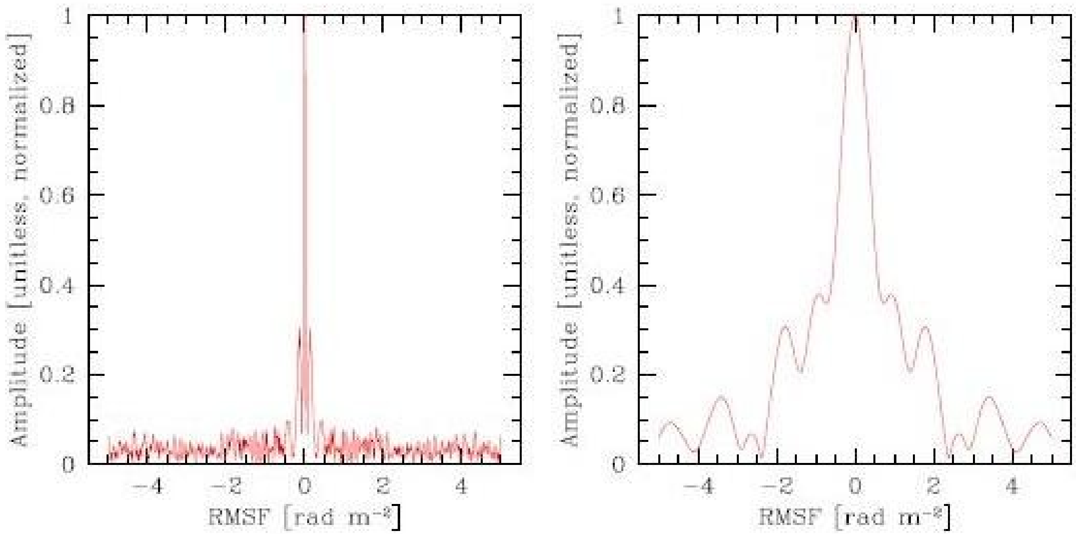
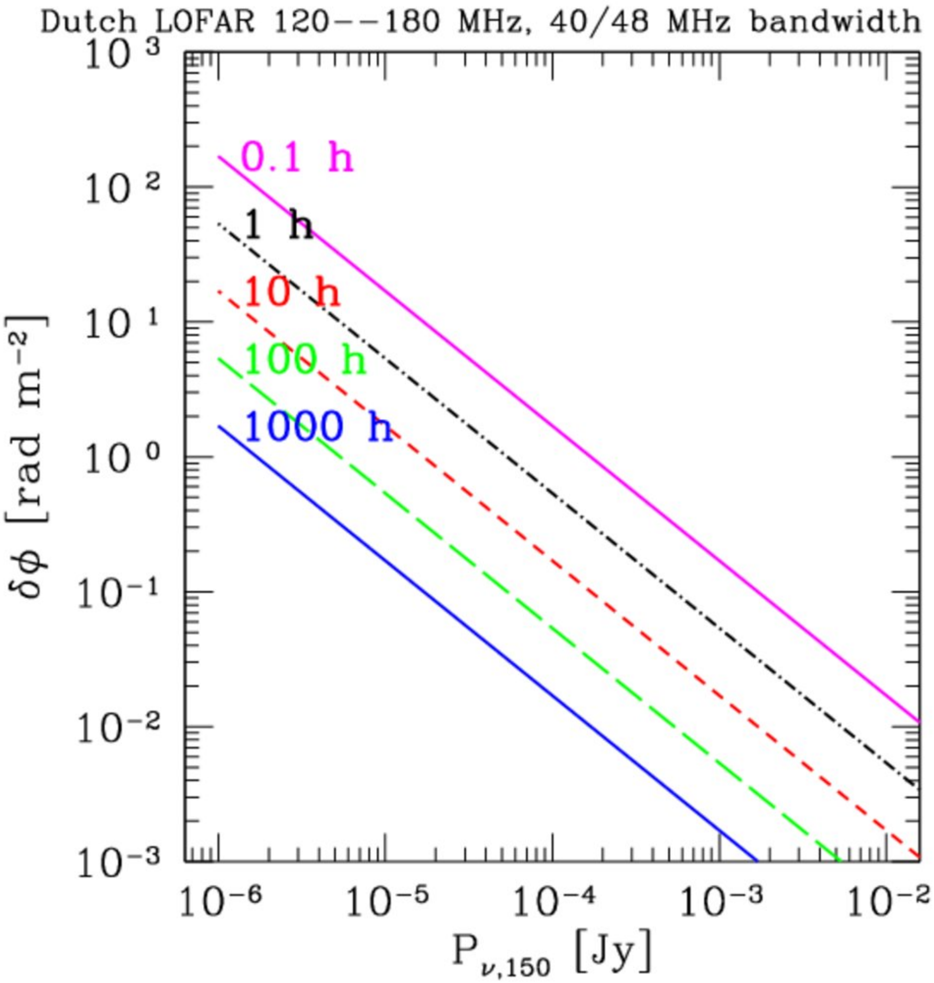
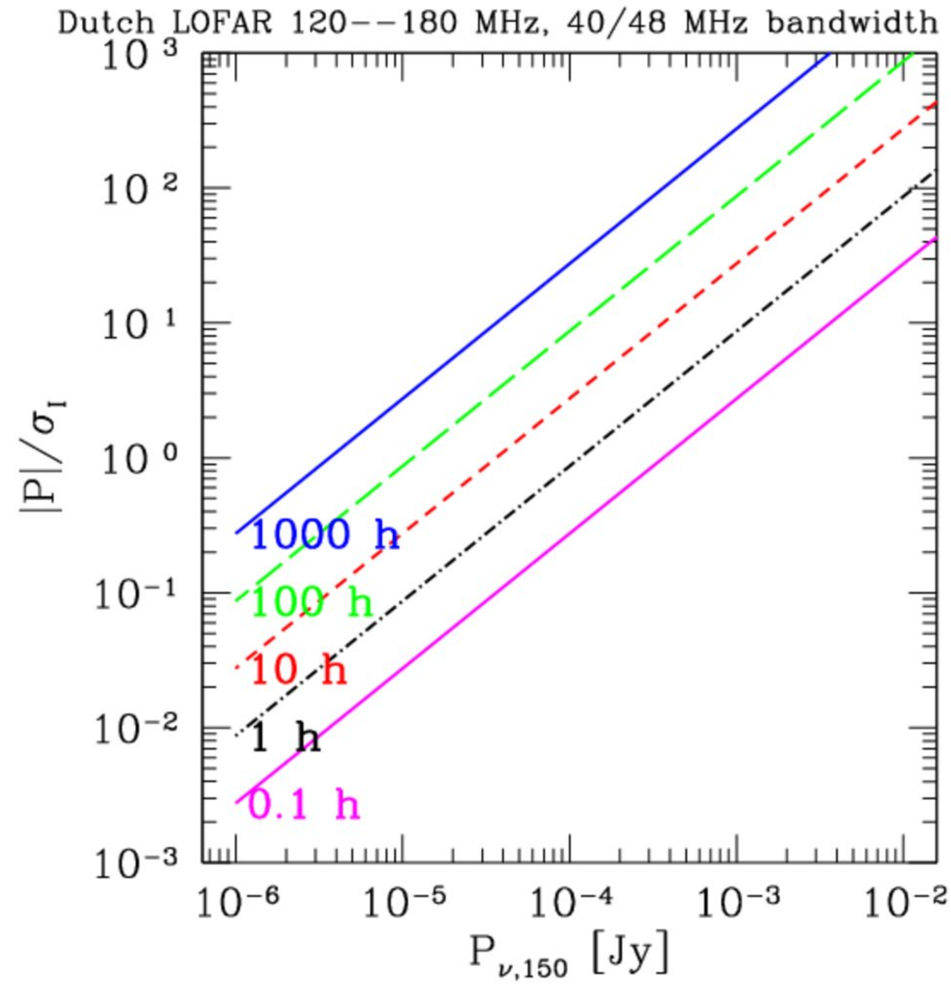


Figure 2: Rotation measure spread function (RMSF) for LOFAR survey observations (according to the plans of the Surveys Key Science Project) in the lowband at 30–50 MHz plus 60–80 MHz (left) and in the highband at 120–150 MHz plus 180–210 MHz (right), both with a total bandwidth of 16 MHz. The resolutions $\Delta\phi$ in Faraday depth are 0.05 and 1.0 rad m^{-2}, the maximum observable Faraday depths ϕ_{max} are 19 and 1200 rad m^{-2}, and the maximum widths in Faraday depth $L_{\phi,max}$ are 0.2 and 1.5 rad m^{-2}, respectively (from Heald 2009).

- Faraday rotation plays a major role in studying magnetic fields in the MKSP
- Key point for LOFAR magnetic field research is precision RM measurements, down to 0.01 rad m^{-2} level
- At this precision, we expect to see multiple Faraday components, or depths of individual components for individual lines of sight
- Rotation measure synthesis key to unraveling the emission processes

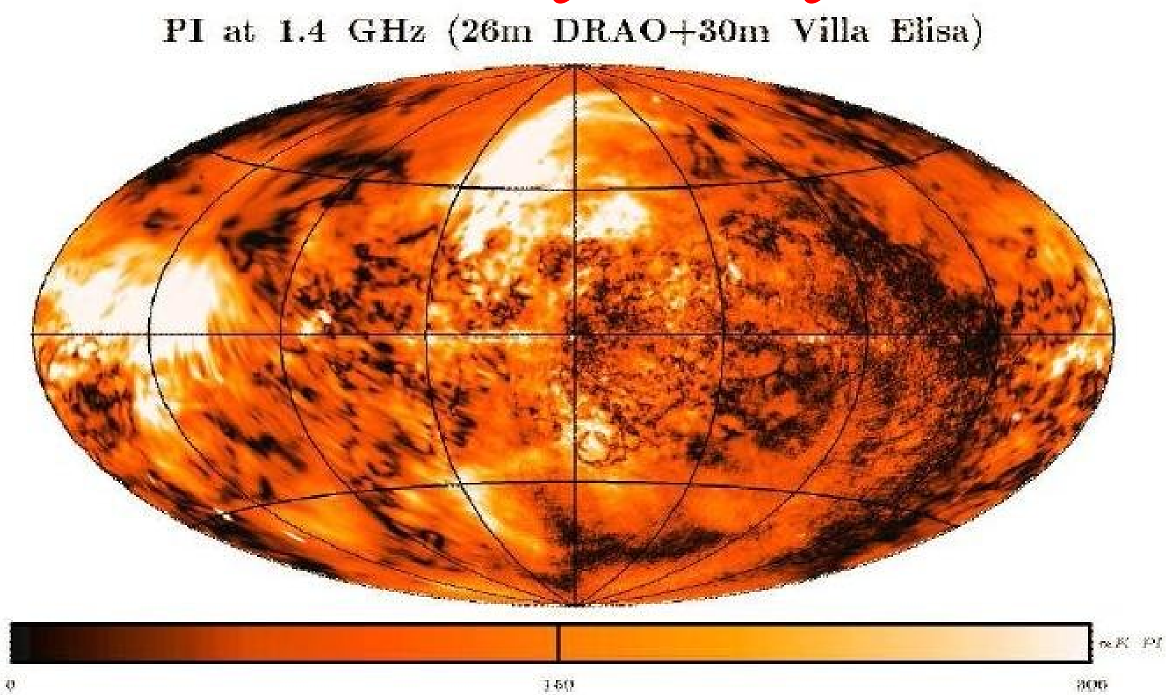
LOFAR Performance





- Wide frequency coverage key to RM precision
  - Approximately inversely linear to $\Delta\lambda^2$
- Can reach 0.1 or 0.01 rad m^{-2} for (sub-)mJy polarized emission

Milky Way



- All (2π) survey, polarization, rotation measures, and Stokes I
- Need Remote and International baselines to identify and subtract (background) point sources
- Polarized background sources also of interest, providing precision RM points through Galaxy
- Need to add in intrastation baselines

Nearby Galaxies

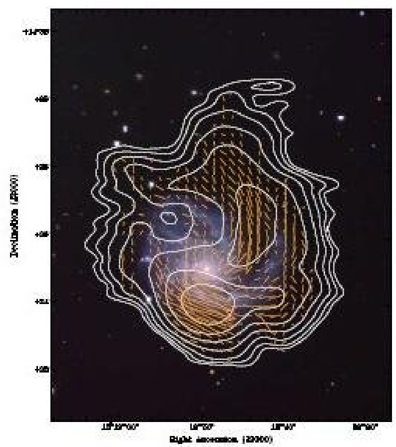


Figure 8: Contours of polarized flux (at 60″ resolution) and B-vectors (corrected for Faraday rotation) overlaid on the optical image of NGC 4254 (image courtesy of Robert Gendler). The 18 cm and 22 cm radio data shown here are from the WSRT–SINGS survey (Heald et al. 2009). Vector lengths are proportional to the polarized flux. The spiral pattern extends far to the north of the optical disk.

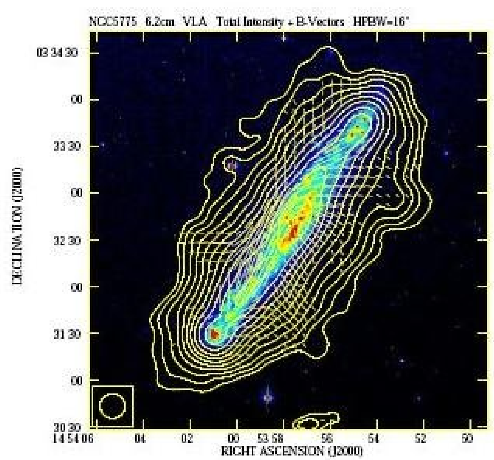


Figure 9: Total radio emission (contours) and apparent B-vectors of NGC 5775 at 4.8 GHz (16″ resolution), observed with the VLA. Vector lengths are proportional to the polarized intensity (from Tüllmann et al. 2000). Note that the vector orientations in this and all following figures are not corrected for Faraday rotation, which is small at frequencies of 4.8 GHz and higher.

- ~60 galaxies to be observed together with the Surveys KSP (see K Chyzy)
- RM analysis key
  - Need large frequency coverage
- Medium depth (50 μJy RMS)
- Currently plan HBA-only observations
- **Need to figure out what to do with other 3 or more beams for 4 bit mode operation**
  - Typically only 1 galaxy per HBA tile beam

Nearby Galaxies 2

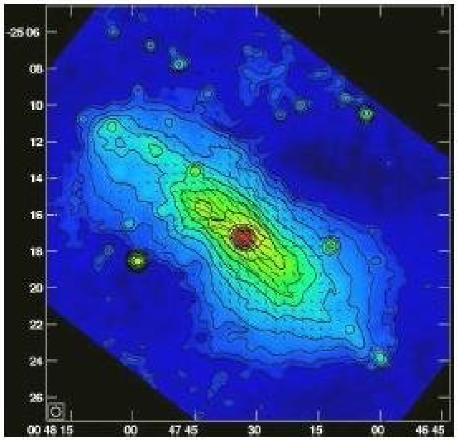


Figure 10: Total radio emission at 6 cm wavelength (30″ resolution) and B-vectors of the almost edge-on spiral galaxy NGC 253, combined from observations with the VLA and the Effelsberg 100m telescope (from Heesen et al. 2009a,b).

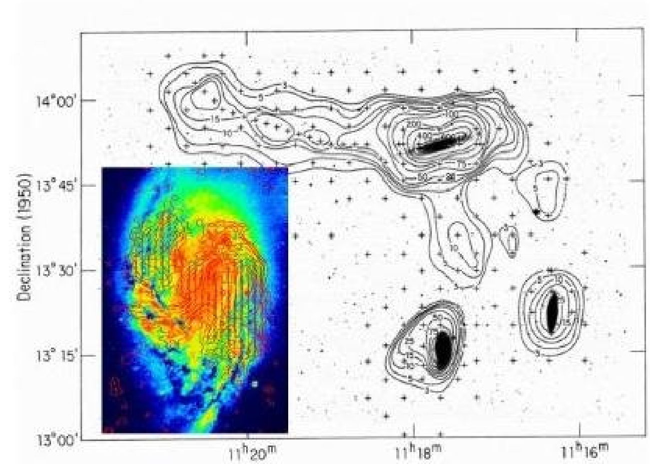


Figure 12: Large image: Contours of extended HI emission around the Leo Triplet, overlaid onto the optical emission (from Haynes et al. 1979). Small image: Contours of polarized emission and B-vectors of the spiral galaxy NGC 3627, observed at 8.46 GHz with the VLA, overlaid upon the DSS blue image. Vector lengths are proportional to the polarized intensity (from Soida et al. 2001).

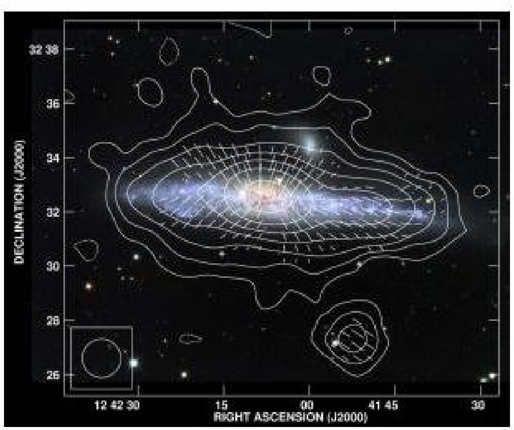


Figure 11: Total radio emission (contours) and B-vectors of NGC 4631 at 8.35 GHz (70″ resolution), observed with the Effelsberg 100m telescope. Vector lengths are proportional to the polarized intensity (from Krause 2008).

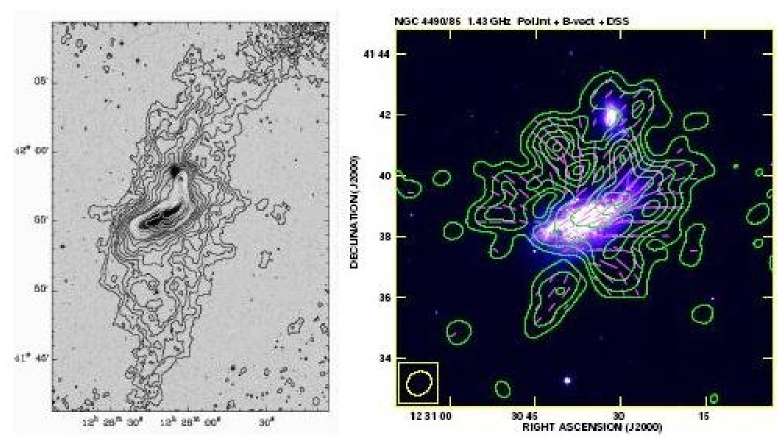


Figure 13: Left: Contours of extended HI emission around the interacting galaxy pair NGC 4490/85, overlaid onto the optical emission (from Clemens et al. 1998). Right: Contours of polarized radio emission at 1.4 GHz with B-vectors. Vector lengths are proportional to the polarized intensity (VLA data, from Knapik et al. in prep.).

Nearby Galaxies 3

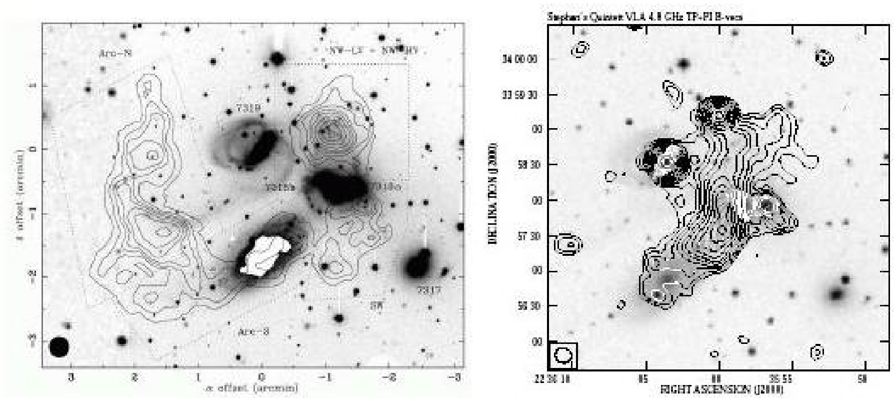
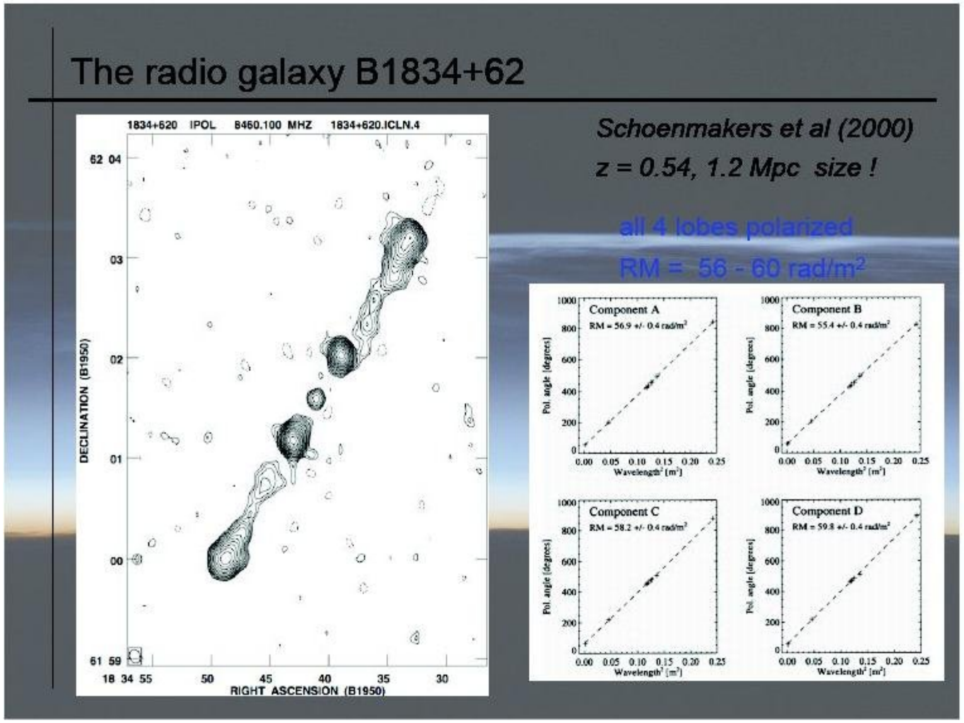


Figure 17: Left: HI tail around Stephan's Quintet (from Williams et al. 2002). Right: Contours of the total power and B-vectors of Stephan's Quintet observed with the VLA at 4.86 GHz, overlaid upon the blue DSS image. Vector lengths are proportional to the polarized intensity (from Soida et al. in prep.).

- Go very deep (7 μJy RMS) on 10 fields, plus 6 more fields with Surveys KSP
- RM mapping
- Background RM grid
  - Hope to find many background polarized sources to study Faraday rotation in galaxy halos
- Need to include International stations for background source resolution
- Again, have to figure out what to do with other beams in HBA tile beam

AGN Polarization



- Also important for use as probes of magnetic fields in other objects

- MKSP plans to observe many AGNs
  - Giant radio galaxies in addition to standard AGN jets and lobes
- Some direct science projects for polarization and magnetic field aspects of AGNs
- Also will observe many AGNs as polarization calibrators for other MKSP projects
  - Will provide some medium depth observations of AGNs and fields with good (u,v) coverage

Major Areas of Overlap: Science

- Milky Way research and all-sky surveys
  - Milky Way projects want access to polarization information from all-sky surveys to learn about Milky Way
  - Milky Way group needs to contribute short spacings, with dedicated observations for intrastation and superterp data
- Catalog of polarized sources and all-sky survey
- Joint nearly galaxies observations of ~60 galaxies
- Deep mapping of selected galaxy targets
  - 4 bit mode provides far more sky coverage, but does not contribute significantly to MKSP nearby galaxies studies.
  - Useful for Surveys KSP, Milky Way background probes, intergalactic magnetic field grid

Major Areas of Overlap: Technical Details

- High dynamic range imaging, for all Stokes
- Deep observations and getting the noise down
- Long baseline observations for high resolution
- Full field of view imaging
  - But MKSP will often only image individual sources with long baselines
- Some mosaicking aspects in common
  - Mostly for the Milky Way, but also M31, ...
- Many details can only be decided after commissioning observations demonstrate the actual behavior of LOFAR
- ...

Differences

- MKSP needs as wide of frequency coverage as possible
  - MKSP RM signal to noise improves better than linearly with frequency span
  - Surveys wants to minimize frequencies in surveys to have largest beams and therefore survey speeds
  - Talk to G Heald
- Additional calibration requirements for polarization calibration
- Milky Way research needs fields at many different Galactic latitudes, while Surveys KSP gets best signal to noise when observing in regions of lowest Galactic emission
- MKSP needs to process data in small frequency slices for RM synthesis, Surveys KSP will keep things in larger frequency chunks
  - MKSP will also want MFS of Stokes I too, so not a major problem

Concluding Thoughts

- Things are coming together for the two KSPs relatively well
- Many of the details will eventually be decided by the instrument, rather than what we think we want now
- Lots of commissioning work to share
- Hopefully lots of data to keep ourselves busy with in the future

The End