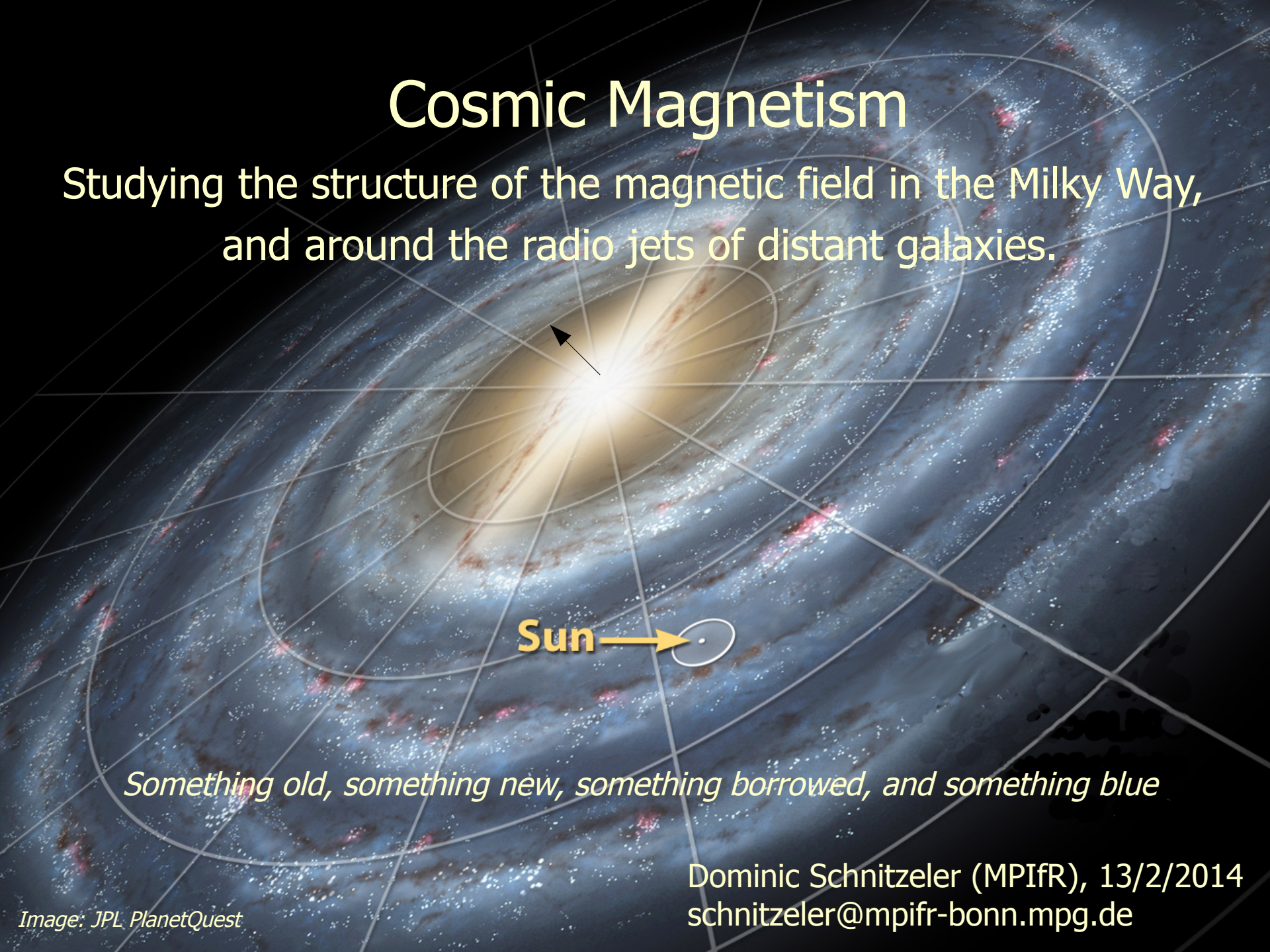
Cosmic Magnetism

Studying the structure of the magnetic field in the Milky Way, and around the radio jets of distant galaxies.



Something old, something new, something borrowed, and something blue

Dominic Schnitzeler (MPIfR), 13/2/2014
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Image: JPL PlanetQuest

The Milky Way: Key science questions

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

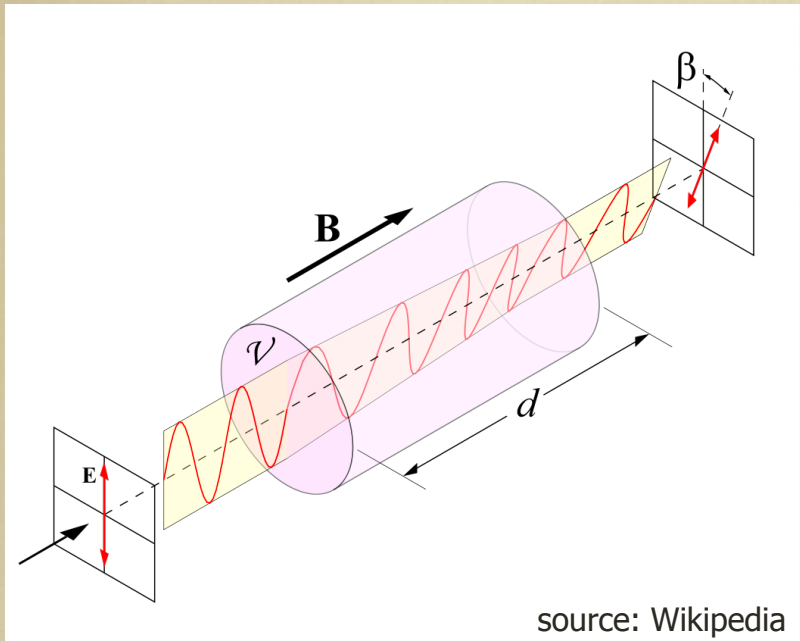
What is the origin of ultra-high energy cosmic rays?

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)

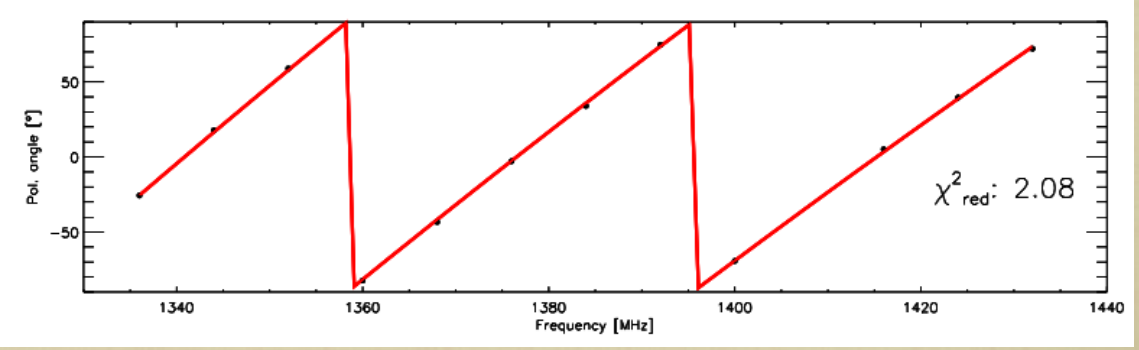
Answering these questions depends on knowing the strength and structure of the Galactic magnetic field!

Faraday rotation



source: Wikipedia

$$\mathrm{RM} = 0.81 \int_{\mathrm{there}}^{\mathrm{here}} n_{\mathrm{e}} B_{\parallel} dl$$



ATCA calibrator PKS 1352-63: RM= -1226 rad/m^2

1. Pulsars

2300 pulsars have been discovered so far;
SKA1 will discover ~ 20,000 pulsars with 30m integrations (Smits+09)

Pros

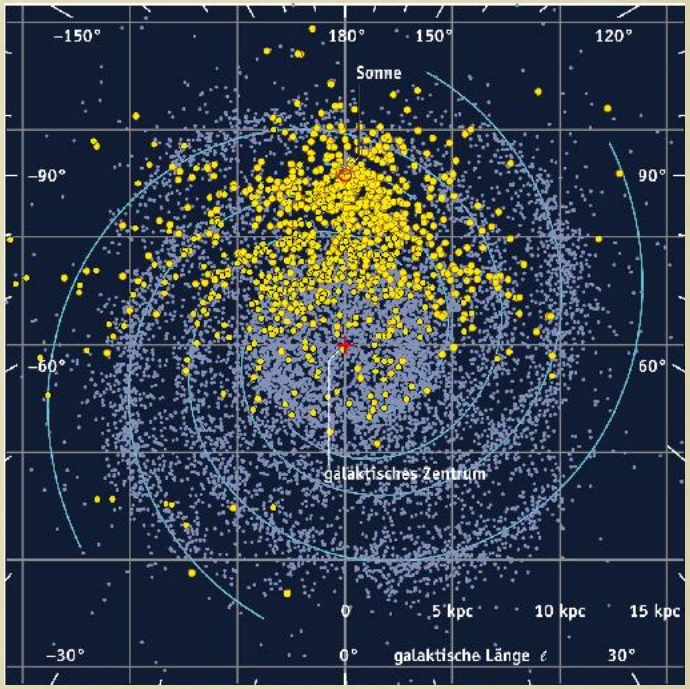
Distances from observed DM

The ratio between RM and DM is proportional to $\langle B_{||} \rangle$ (Noutsos et al. 2008)

Constrain electron density models of the Milky Way → derive $\langle B_{||} \rangle$ from RMs of extragalactic sources.

Cons

Most PSRs lie close to the Galactic plane (h = 330 pc – 1 kpc Lorimer et al. 2006, 2012)

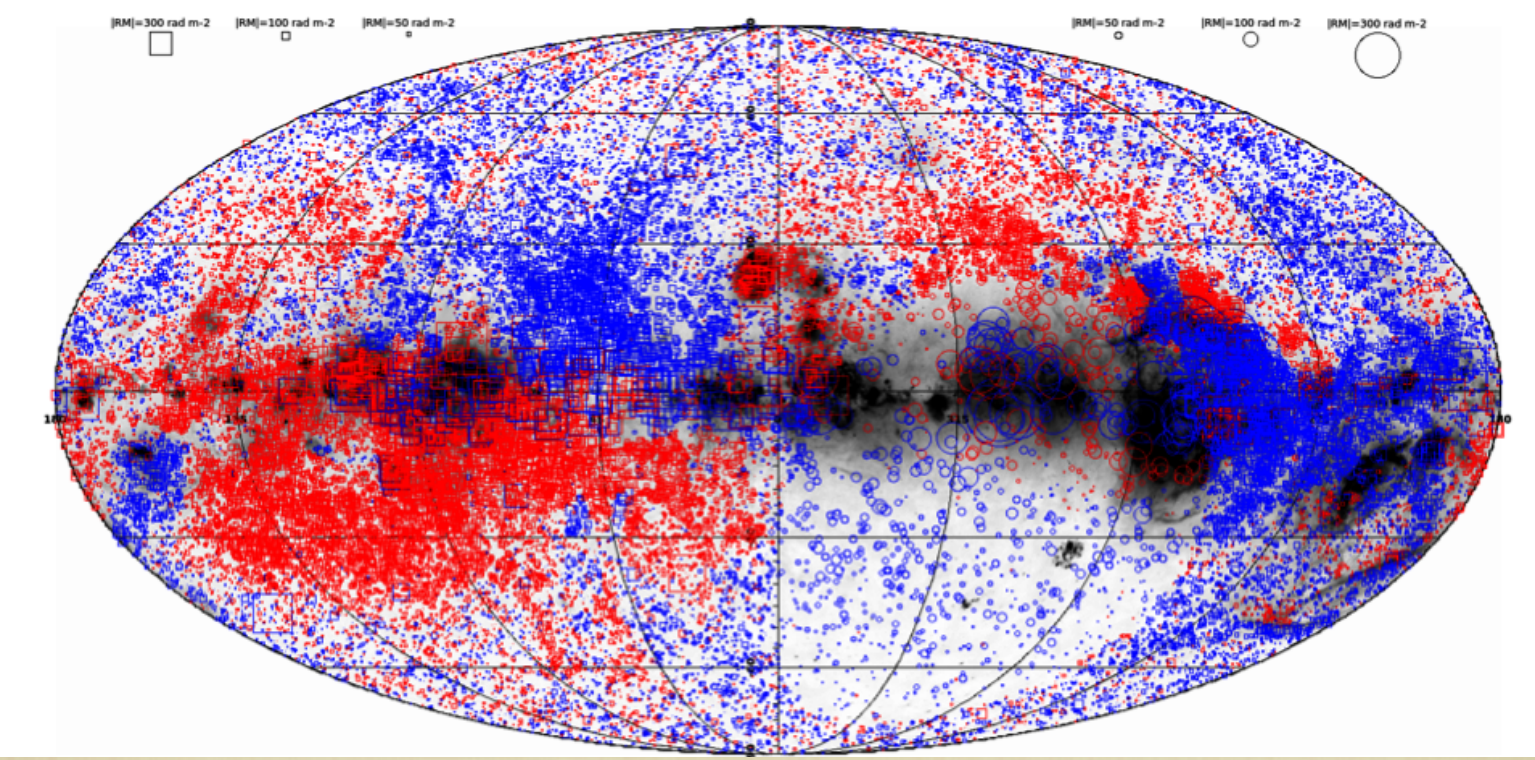


Cordes+ (Sterne & Weltraum)

2. RM grid of extragalactic sources

37,543 NVSS RMs (above DEC=-40°; Taylor et al. 2009)

+ 2,610 S-PASS RMs (DEC < 0°; Schnitzeler et al., in prep.)



Red = RM < 0, Blue = RM > 0 rad/m^2. Greyscale: Hα intensity (Finkbeiner 2003)
(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)

Measure the RM signature of clusters and the cosmic web
Johnston-Hollitt et al. 2003, Clarke 2004, Govoni et al. 2010, Akahori & Ryu 2011

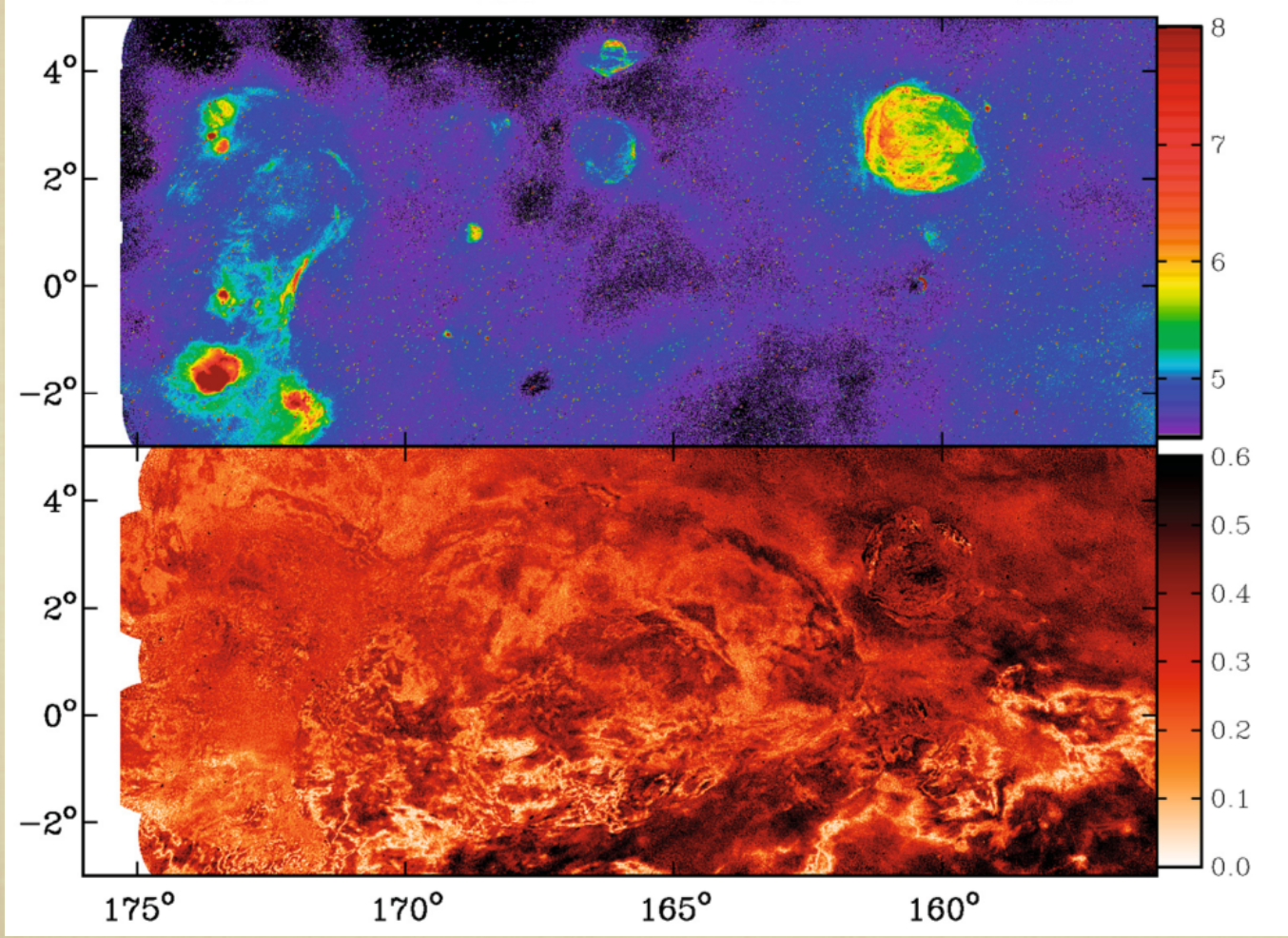
Study the structure of the jets and lobes for NN sources, and how magnetic fields in these sources evolve with redshift
Hammond et al. 2012

But:

Need a dense grid over a wide area to separate the Galactic and extragalactic RM contributions (Leahy 1987, DS 2010).

3. Polarized diffuse emission

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



T_b

P_b

CGPS survey @ 1.4 GHz Landecker+10

3. Polarized diffuse emission

Pros

Measure polarized flux density and RM in any direction on the sky

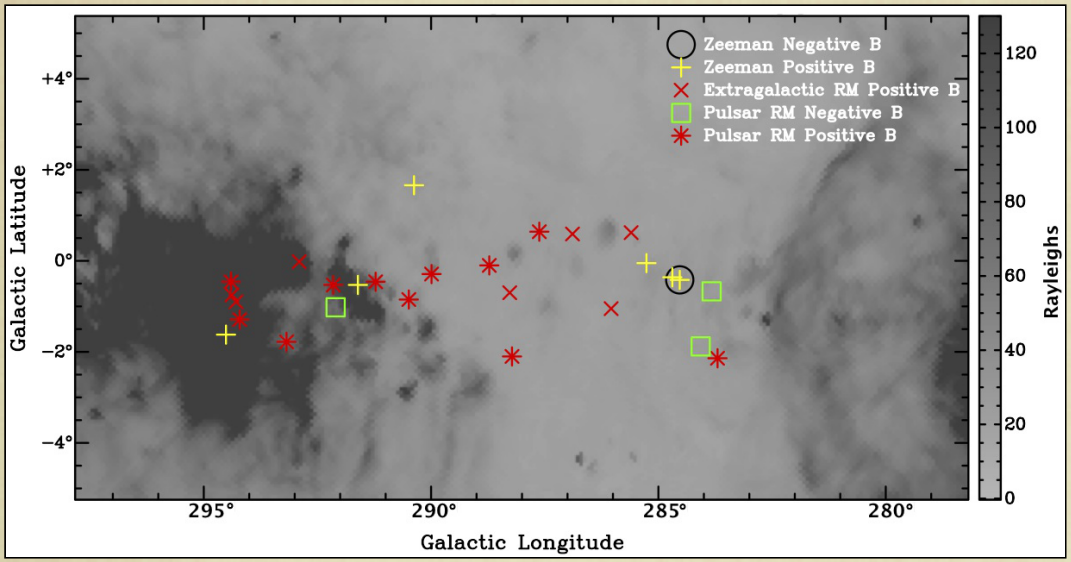
Cons

Limited uv coverage → extended emission missing from maps

Summing polarization vectors across the beam and along the line of sight produces signal loss (depolarization)

4. Zeeman splitting of maser lines

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



MAGMO Green et al. (2012)

Pro: Derive distance to sources from Doppler shift of the spectral lines

Con: Galactic masers have a small scale height (10s of pc)

Warning! Zeeman splitting probes the cold neutral medium,
Faraday rotation probes the warm ionized medium

Ways of surveying B in the Milky Way

Measure the amount of *Faraday rotation* of

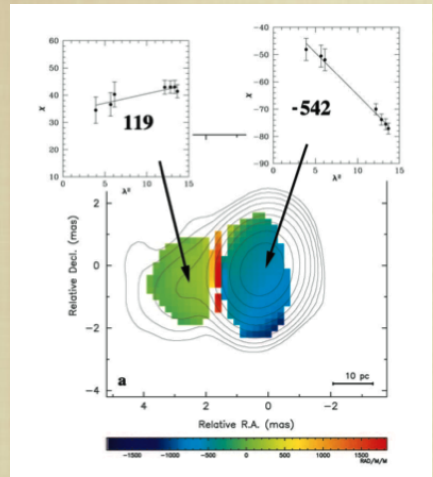
- Pulsars
- Extragalactic sources
- The polarized diffuse emission from the Milky Way

Measure *Zeeman splitting* of masers lines

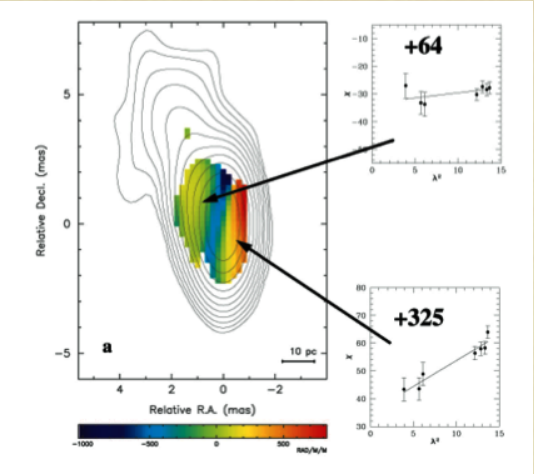
These methods are highly complementary!

Magnetic fields in jets of distant galaxies

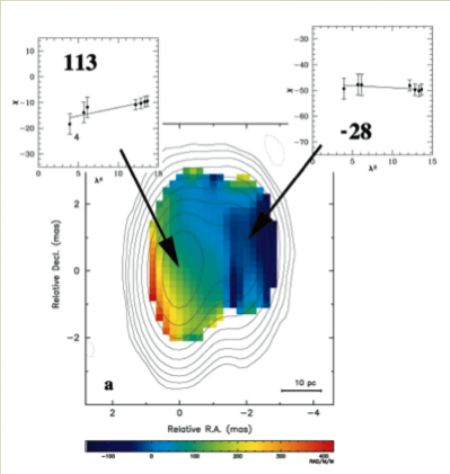
Examples from VLBI observations: (Zavala & Taylor 2003)



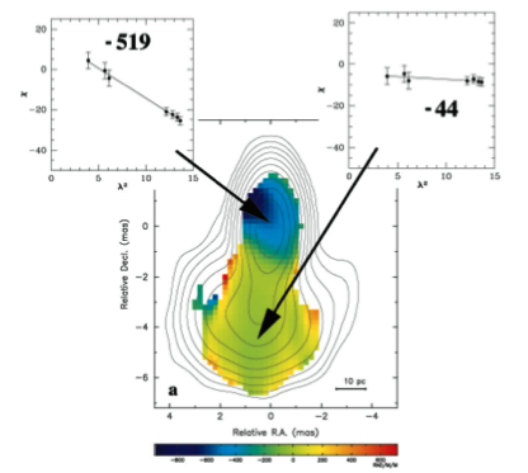
0212+735



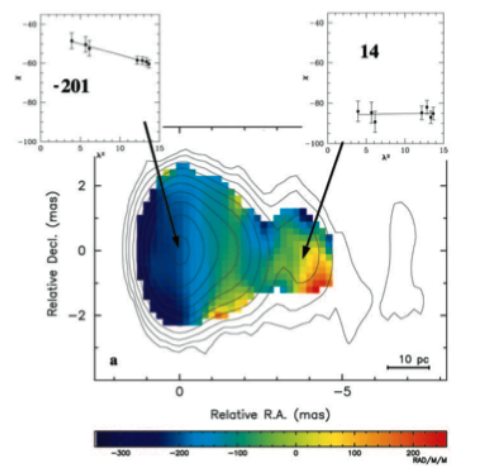
0528+134



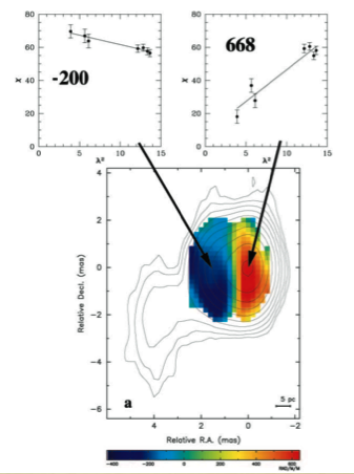
1308+326



1611+343



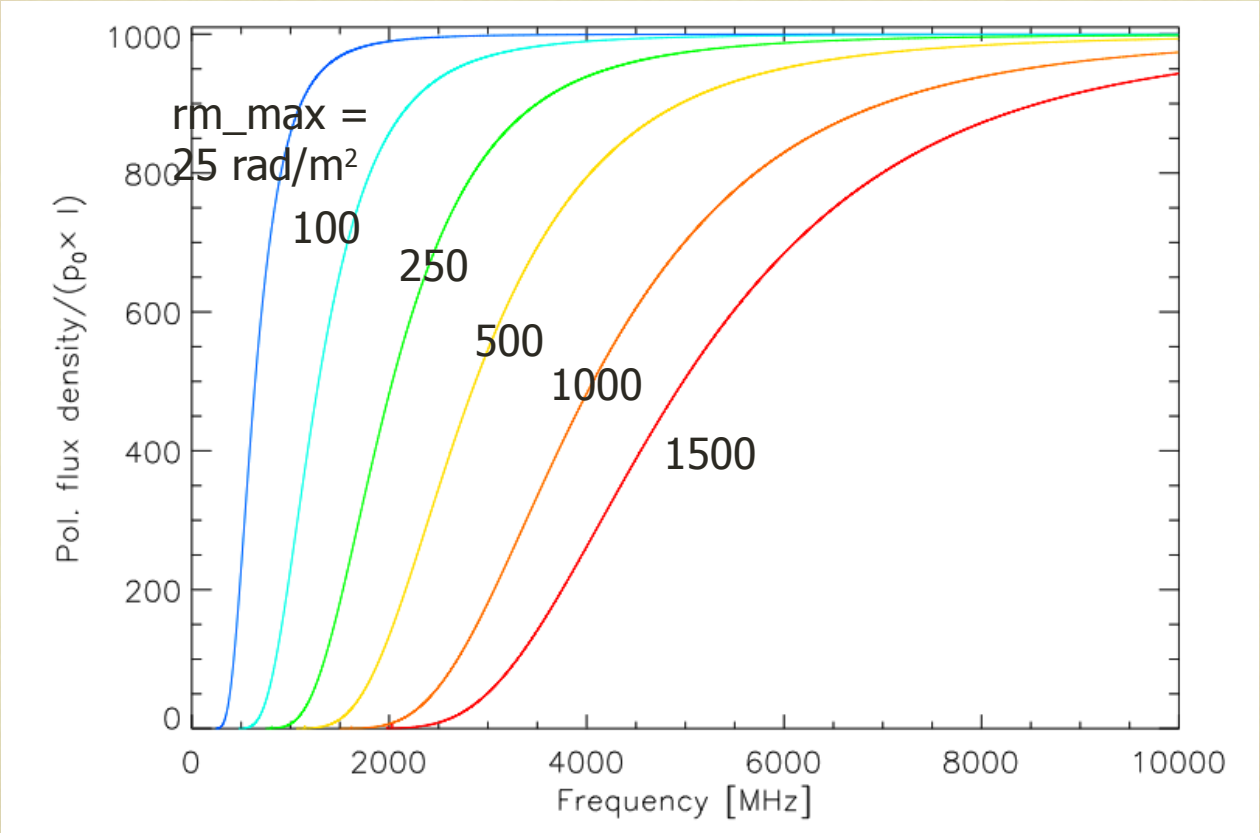
1803+476



2005+403

Broad-band spectra of unresolved sources

Model the polarization signatures for different configurations of Faraday-rotating and synchrotron-emitting layers



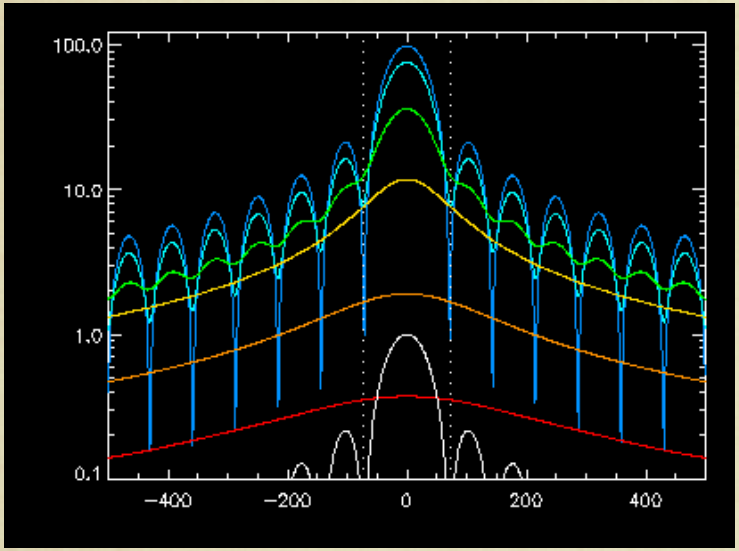
Thin cylinder with a wrapped-around magnetic field that emits polarized flux in the range -rm_max, +rm_max

Model RM spectra

Separate emission at multiple RMs using 'RM synthesis'

Example: observations between 1.3 and 3.1 GHz (ATCA)

measured pol. flux



RM (rad/m^2)

Blue → red = jets that emit at RMs between +/- 25, 100, 250, 500, 1000, and 1500 rad/m^2

White = scaled instrumental response (-30dB)

Vertical dotted lines: expected position of the first minimum if the source emits at a single RM

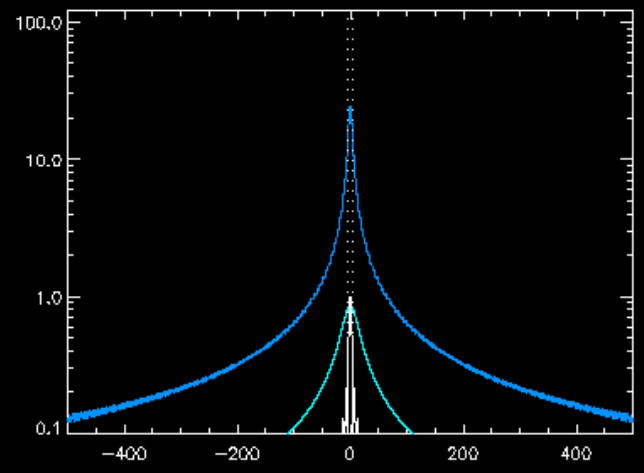
Over this frequency range:

Jets that emit over the narrowest RM range (blue, cyan) are not resolved.

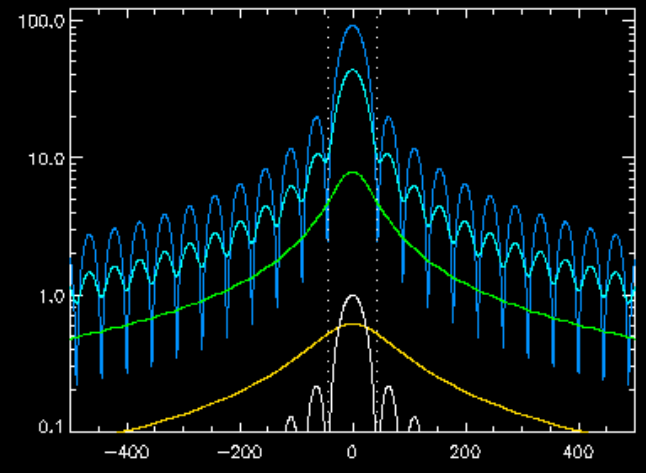
Jets that emit over a wide range of RMs (orange, red) are resolved, but faint.

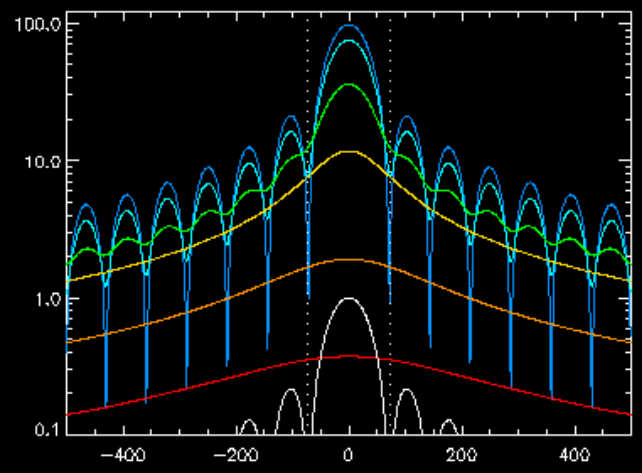
Model RM spectra at different frequencies

SKA band 1 (350-900 MHz)

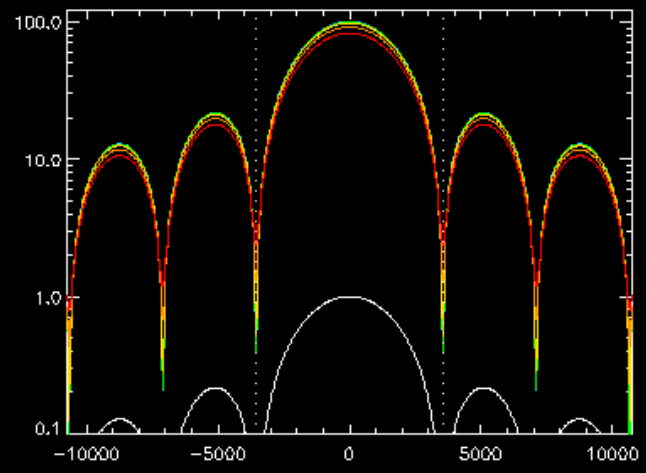


SKA band 2 (950-1760 MHz)





ATCA (1300-3100 MHz)



ATCA / JVLA (6500-8500 MHz)

Summary

With broad-band receivers, and ultimately the SKA, we can

reconstruct the properties of the large-scale magnetic field of the Milky Way with unprecedented accuracy

*** NEW ***

study extragalactic sources that emit at multiple RMs, and learn about the strength and structure of their magnetic field