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Studying the Galactic magnetic field with the CGPS

Joern Geisbuesch

HIA-DRAO, CGPS team

National Research Council Canada | Conseil national de recherches Canada

Canada

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The Canadian Galactic Plane Survey

Facts

- Part of International Galactic Plane Survey
- Coverage: $190 > l > 55$, $-3.5 < b < 5.5$
- Largest effort of its kind so far (1.5×10^7 data points and 1208 square degrees)
- First extensive polarization survey with arcminute resolution
- Radio continuum and HI observations with the DRAO Synthesis Telescope (other wavelengths as well)
- Some extensions into the halo (ongoing efforts)

See also Landecker et al. 2010

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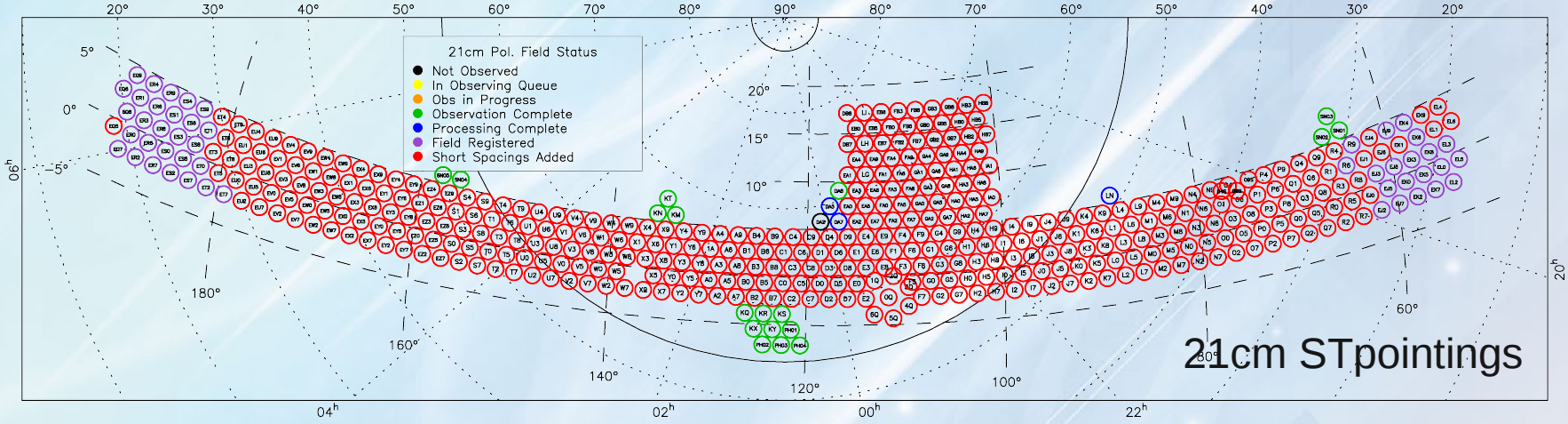
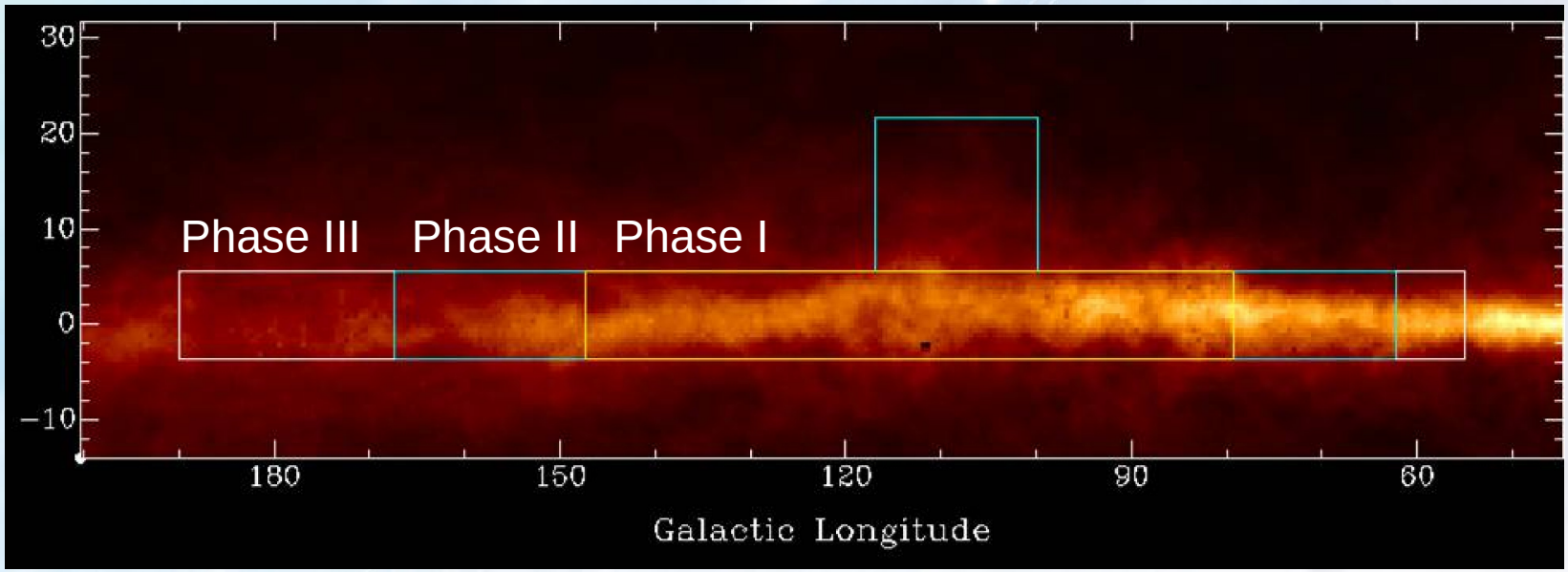
CGPS area coverage





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The Canadian Galactic Plane Survey

Frequencies and Bands

DRAO Synthesis Telescope:

408 MHz	Continuum Stokes I	Ionized gas, Magnetic fields
7.5 MHz at 1407 MHz (A)	Continuum I, Q, U and V	
7.5 MHz at 1414 MHz (B)	Continuum I, Q, U and V	
256 channels of 4 MHz at 1420 MHz	HI	Atomic hydrogen
7.5 MHz at 1427 MHz (C)	Continuum I, Q, U and V	Ionized gas, Magnetic fields
7.5 MHz at 1435 MHz (D)	Continuum I, Q, U and V	

Accompanied by observations at other wavebands and matching resolutions (far-IR, ^{12}CO survey and X-ray etc.)

Dust Molecular gas Ionized gas

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Motivation

Complex processes in the Galactic plane and in the planes of other galaxies:
→ Understand these ecosystems (star formation, cloud formation, astro-chemistry, in- and outflows)
→ Understand the Interstellar Medium

In polarization:
→ Understand the generation of magnetic fields in the plane, their transport and transition into the halo (radio polarization very suitable; however observations at other wavelengths needed to disentangle information)

CGPS polarization → resolve structure and understand generation of field (high fluxes and easily resolved)

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CGPS polarization processing

Recent and ongoing work

Reanalysis of parts of the polarized emission of the survey:

- Using updated analysis tools developed at DRAO for instrumental leakage correction from total power (Stokes I) into linear polarization (Stokes Q and U) and directional dependent effects (Meq, Jones E from voltage pattern measurements)

Analysis of extensions of the survey (in latitude):

- New data collected off the Galactic plane to study plane halo transition

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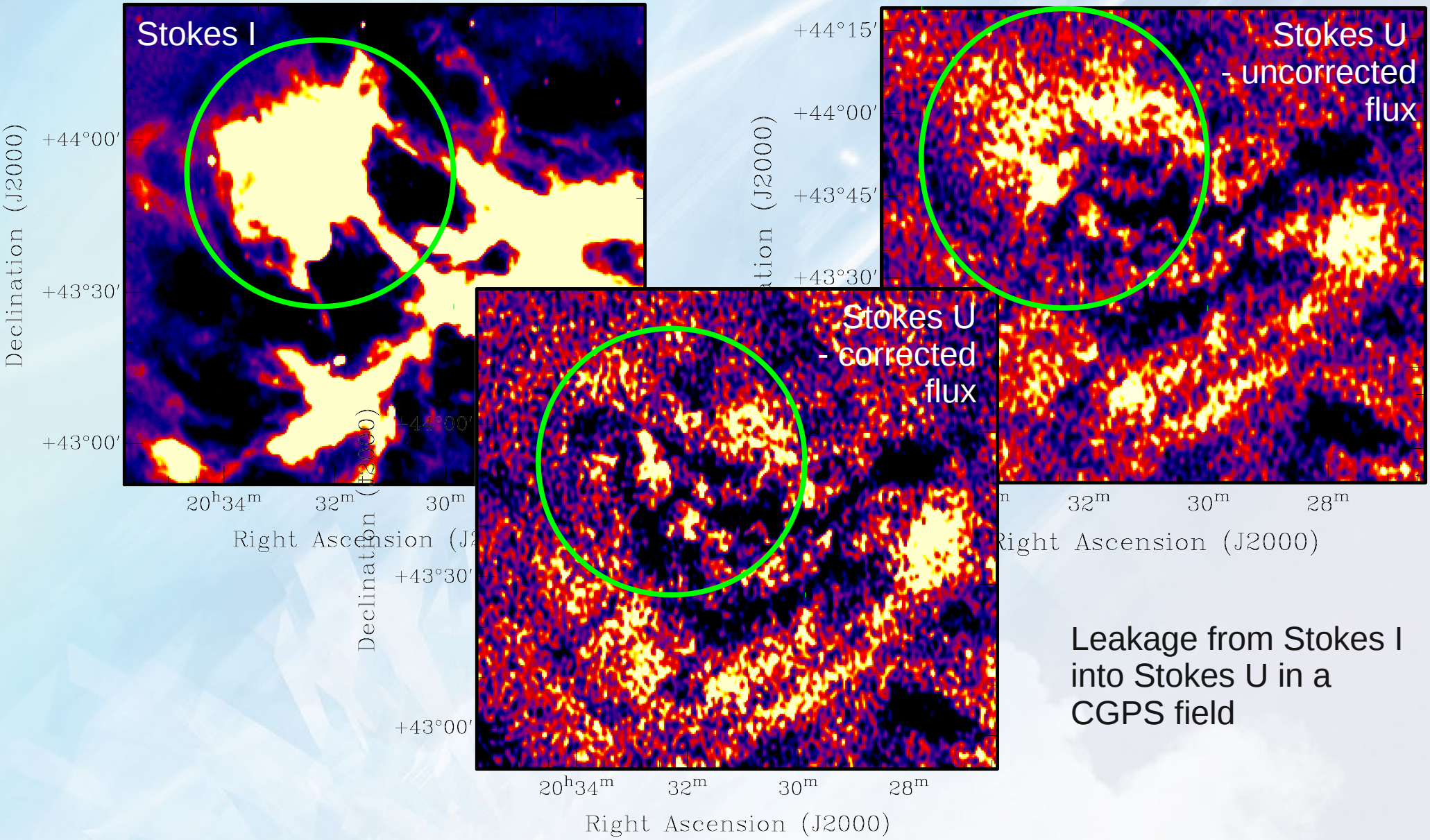
Polarization leakage correction example



Leakage from Stokes I into Stokes U in a CGPS field

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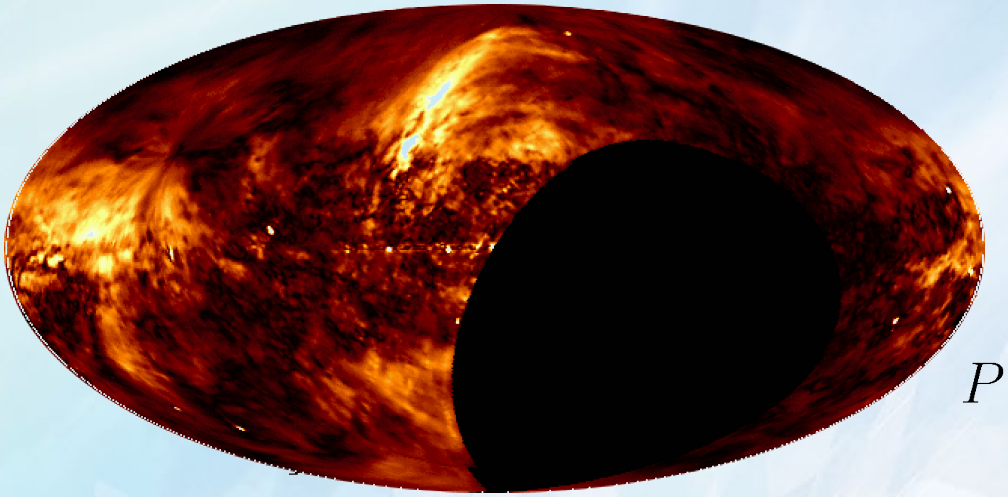
CGPS polarization data

DRAO ST as interferometer only sensitive to emission on scales ≤ 1 degree (lacks information about largest structures)

Short spacing information obtained from DRAO 26m and Effelsberg 100m dishes (Effelsberg Medium Latitude Survey which includes the DRAO Northern Sky Polarization Survey; see Reich et al. 2004, Wolleben et al. 2006).



- $I_{tot} = I_{drao} + I_{emls}$
- $Q_{tot} = Q_{drao} + Q_{emls}$
- $U_{tot} = U_{drao} + U_{emls}$

$$PI_{tot} = \sqrt{(Q_{drao} + Q_{emls})^2 + (U_{drao} + U_{emls})^2}$$

$$\neq PI_{drao} + PI_{emls}$$

$$PA_{tot} = 0.5\, atan\left(\frac{U_{drao}+U_{emls}}{Q_{drao}+Q_{emls}}\right)$$

$$\neq PA_{drao} + PA_{emls}$$

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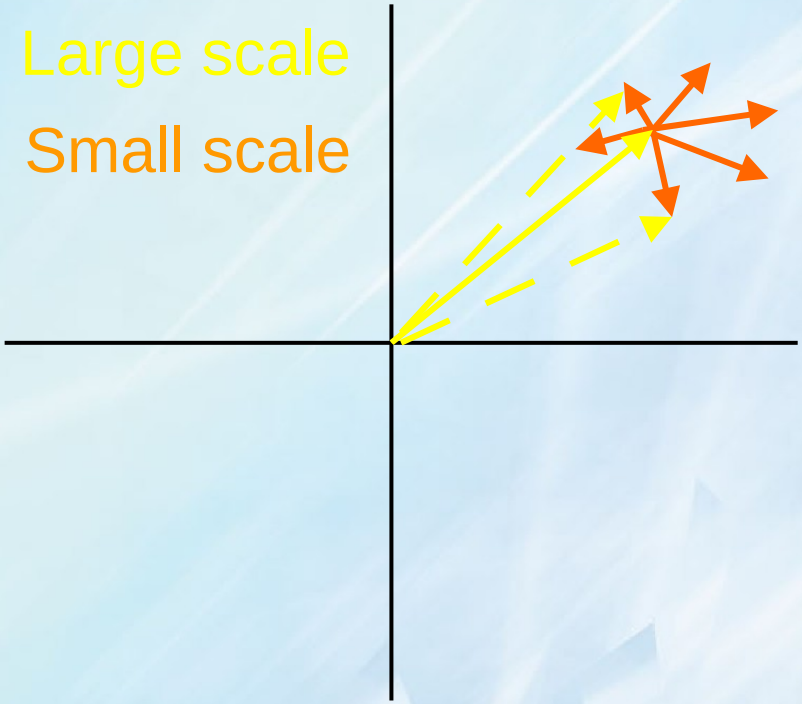
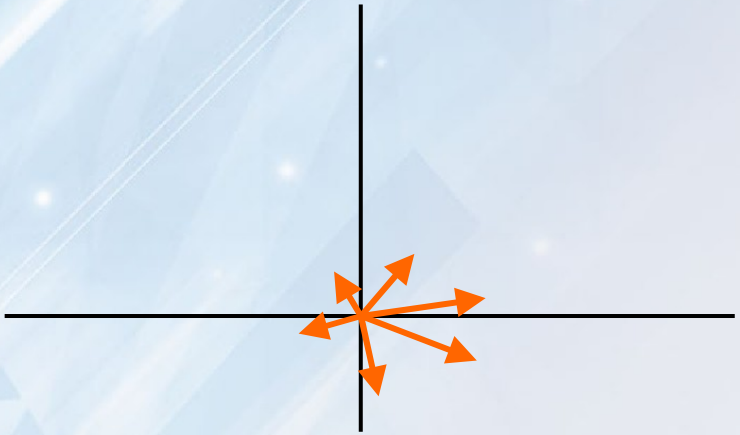
CGPS polarization data

Large scale

Small scale



What an aperture synthesis telescope sees:



Large scale missing ➔ angles wrong
Angles wrong ➔ affects RM calculation
Derived RM incorrect ➔ physical interpretation incorrect

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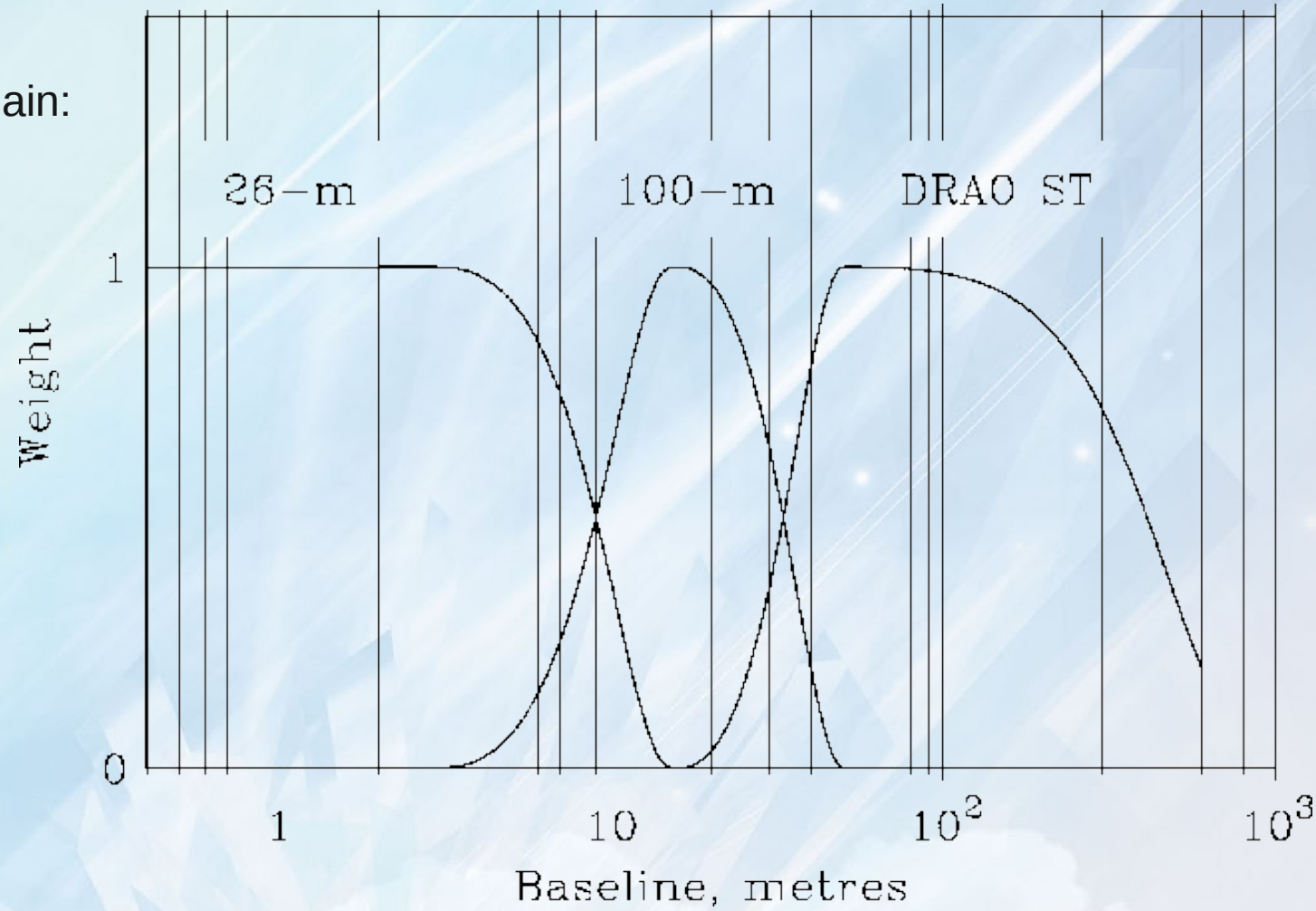
Polarization

Short spacings addition

Filtering in Fourier domain:



Combining data from DRAO 26m and Effelsberg 100m with the ST data

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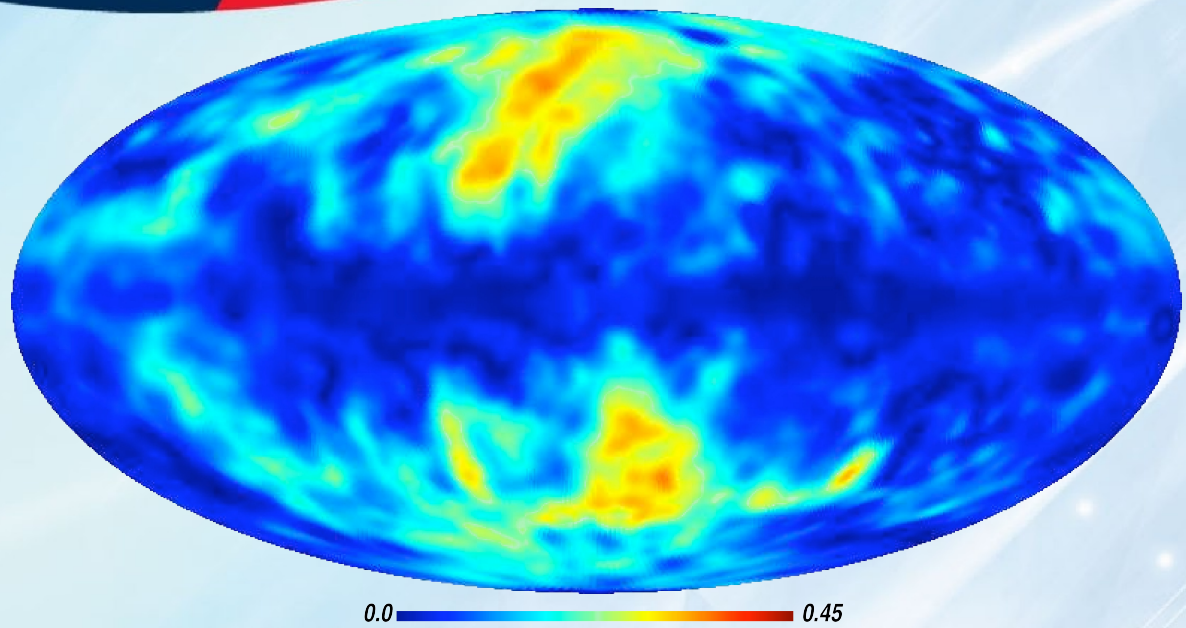
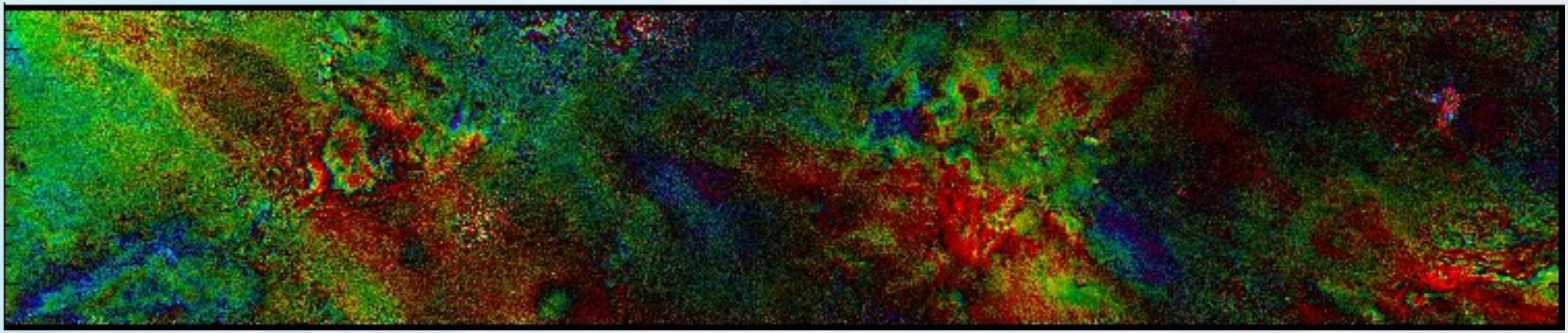
Polarization

Structures on large scales



WMAP derived polarization degree (assumes magnetic field model; see Miville-Deschenes et al. 2008)



CGPS polarization angle (color) vs polarized intensity (brightness)

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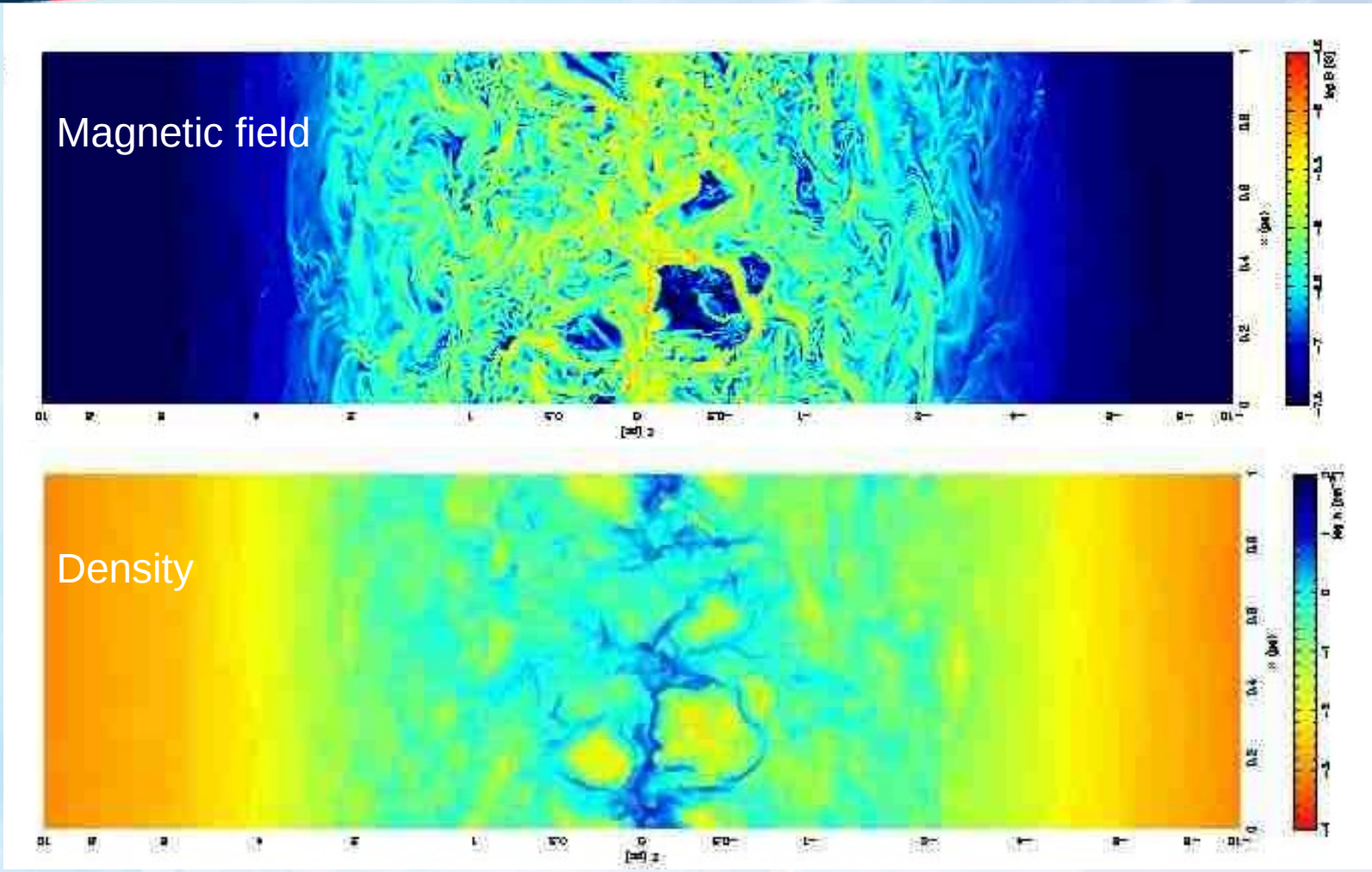
Polarized emission

Structures on small scales



MHD simulations of supernova induced turbulence by Avillez & Breidtschwerdt.
The galactic plane inhabits a anisotropic distribution of turbulent fields → Study properties and distribution → CGPS very suitable.

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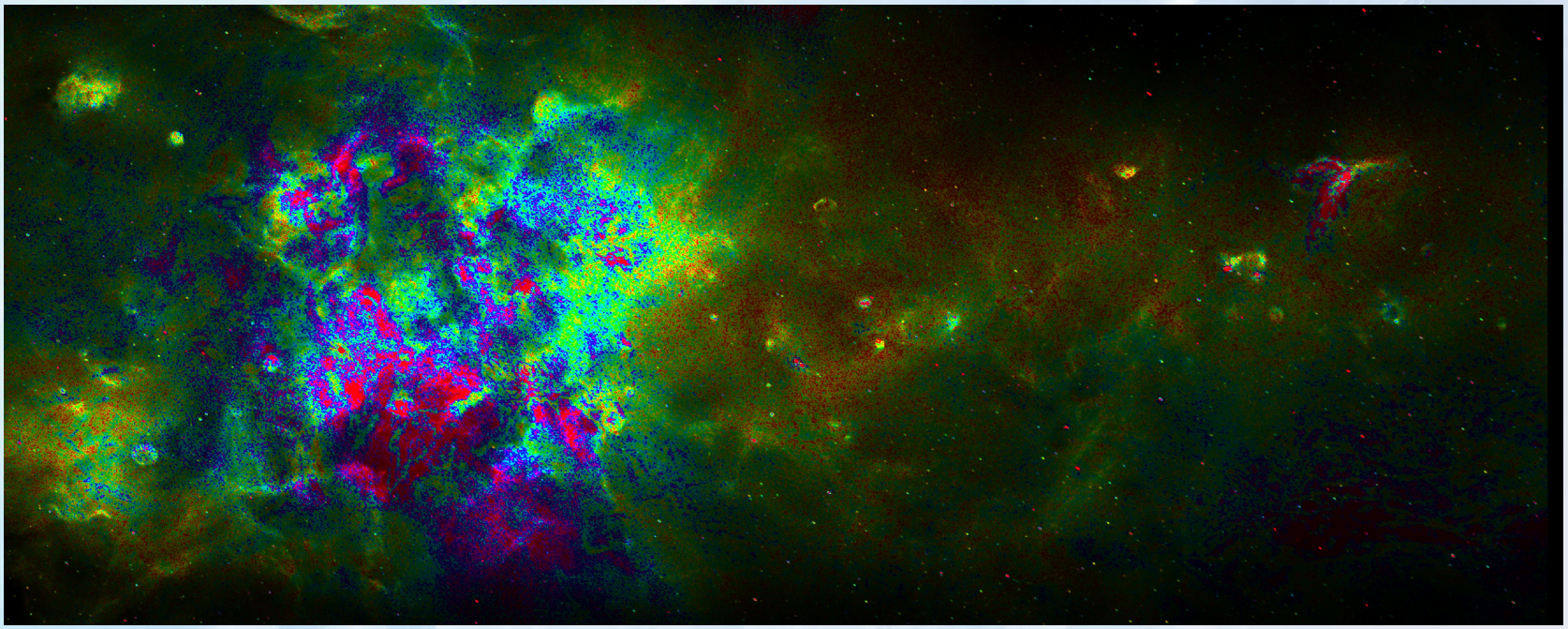
Polarized emission

Polarized intensity vs total intensity

Cygnus X region



Brightness: total intensity (the brighter the plotted area, the stronger the emission)
Color: polarized intensity (purple/blue → high; yellow/red → low)

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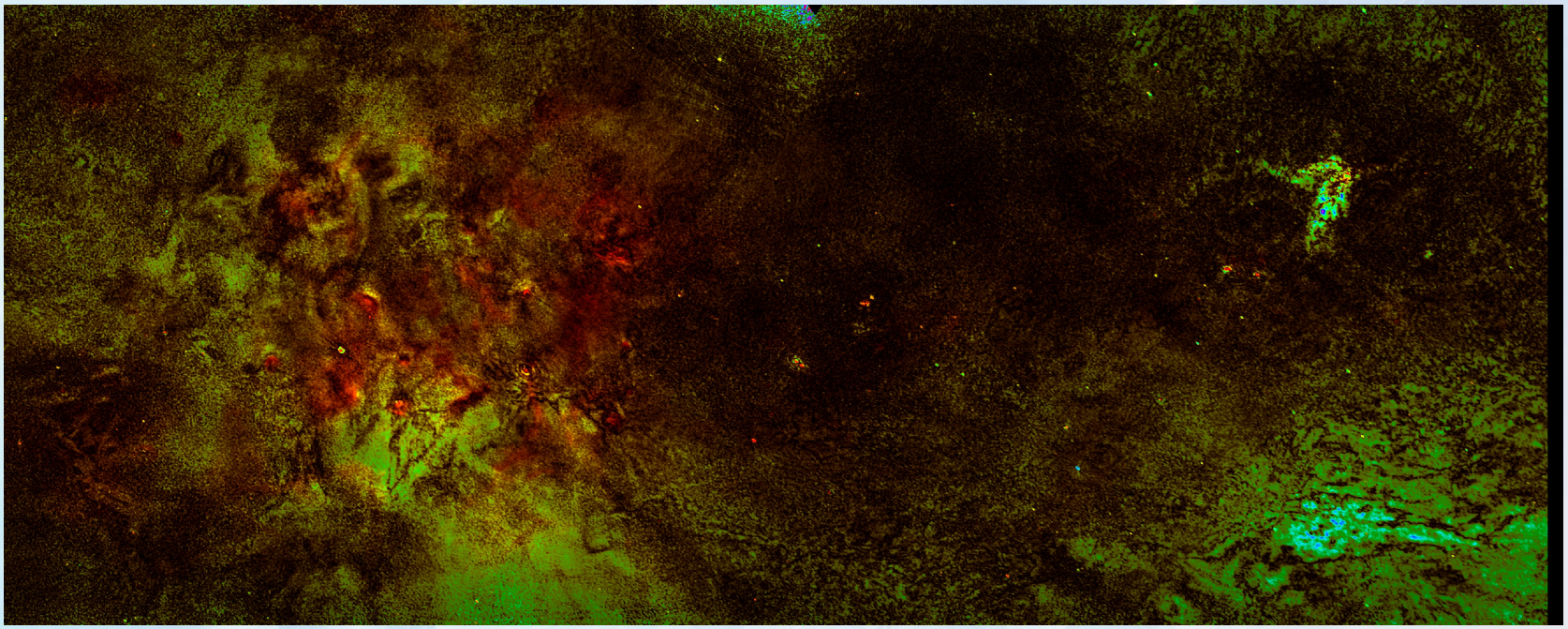
Polarized emission

Polarization degree vs pol. intensity

Cygnus A



Brightness: pol. intensity (the brighter the plotted area, the stronger the emission)
Color: polarization degree (blue/green → high; yellow/red → low)

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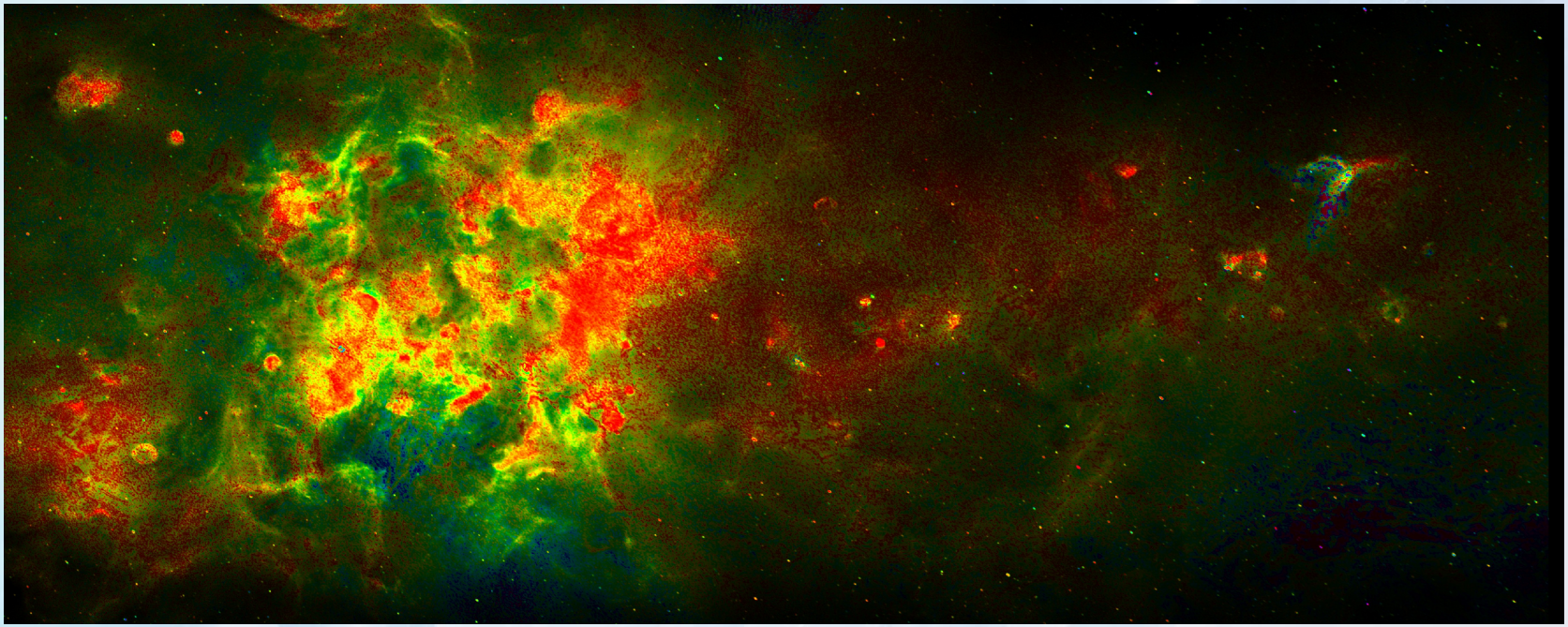
Polarized emission

Polarization degree vs total intensity

Cygnus A



Brightness: total intensity (the brighter the plotted area, the stronger the emission)
Color: polarization degree (blue/green → high; yellow/red → low)

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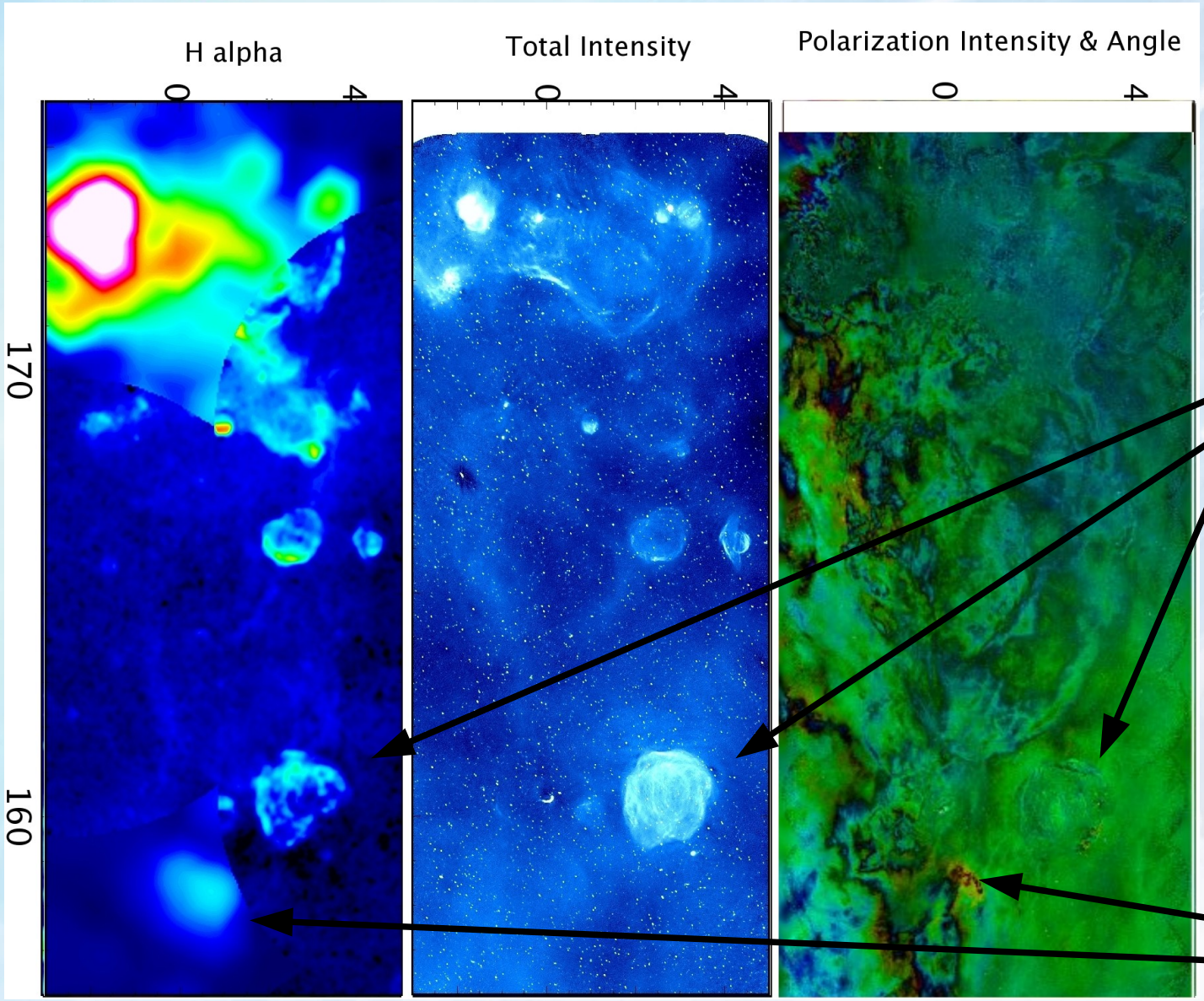
Interpretation



Complex structures seen in polarized emission → to get a handle start with the known

Supernova remnants (see papers by Kothes et al.)

Planetary nebulae (see Ransom et al. 2008, 2010)

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Interpretation

Structure and Statistical data examination

- Structure functions
- Polarization gradient maps

  ↳ Polarization: Study turbulence of ISM (e.g. depolarization canals and filaments in polarized intensity maps, transfer of power to smaller scales due to Faraday rotation)

- Pattern recognition algorithms

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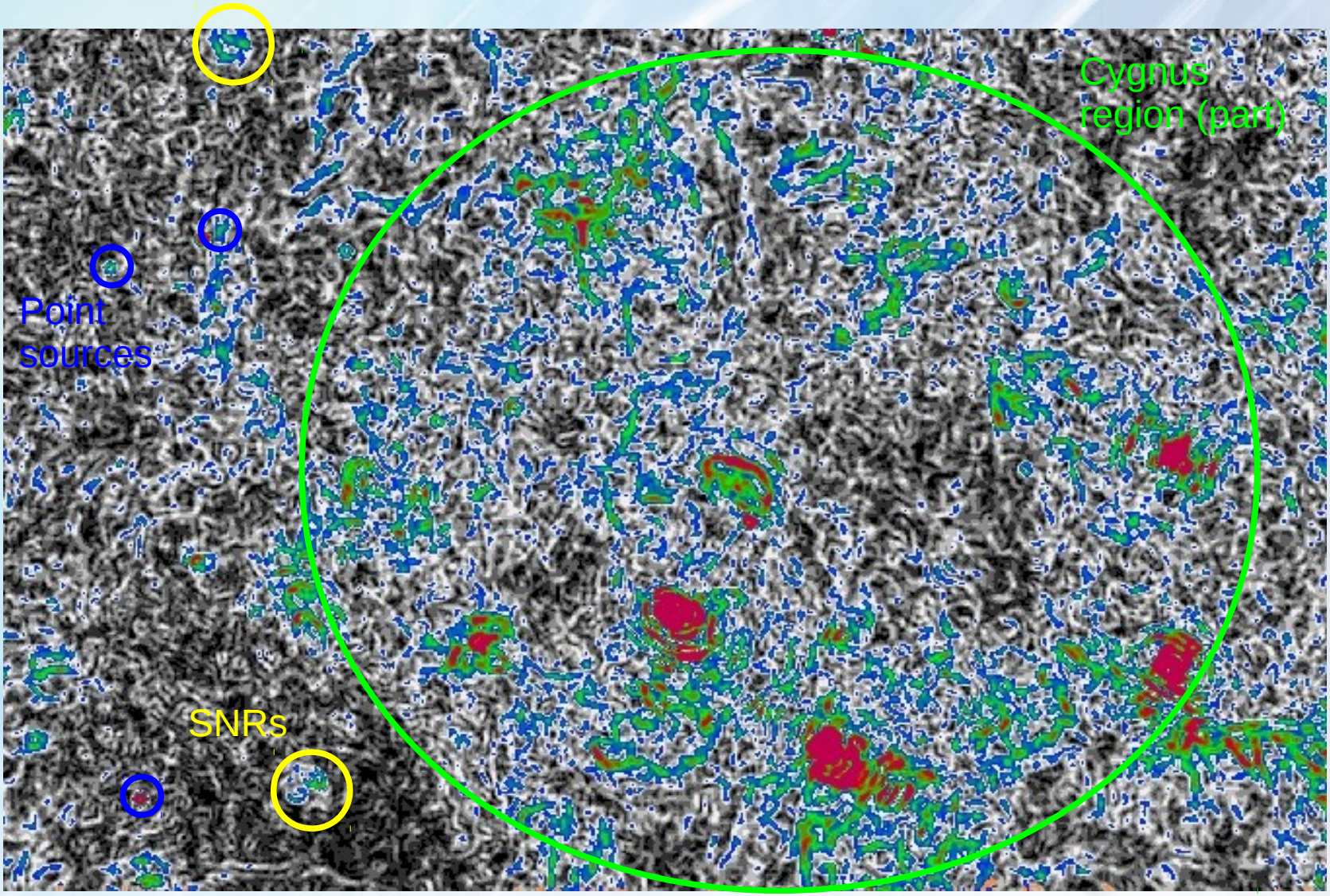
Interpretation

Example of Polarization gradient map



See also Gaensler et al. 2011 for interpretation of structures in polarization gradient maps.

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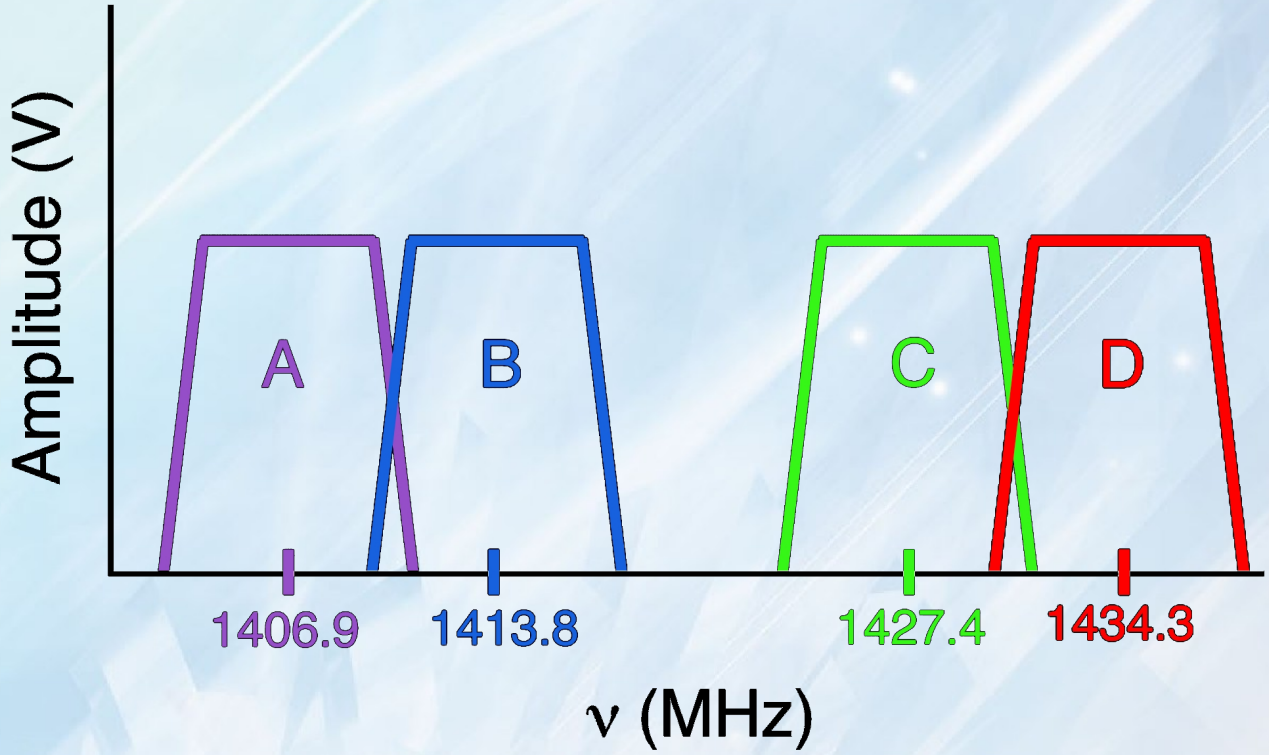
Rotation measure mapping

DRAO ST 21 cm continuum band structure:



Even though the RM resolution is rather coarse, we can use bands to derive RM grid from polarized point source emitters (under assumptions: possible to derive RM distribution of diffuse emission).

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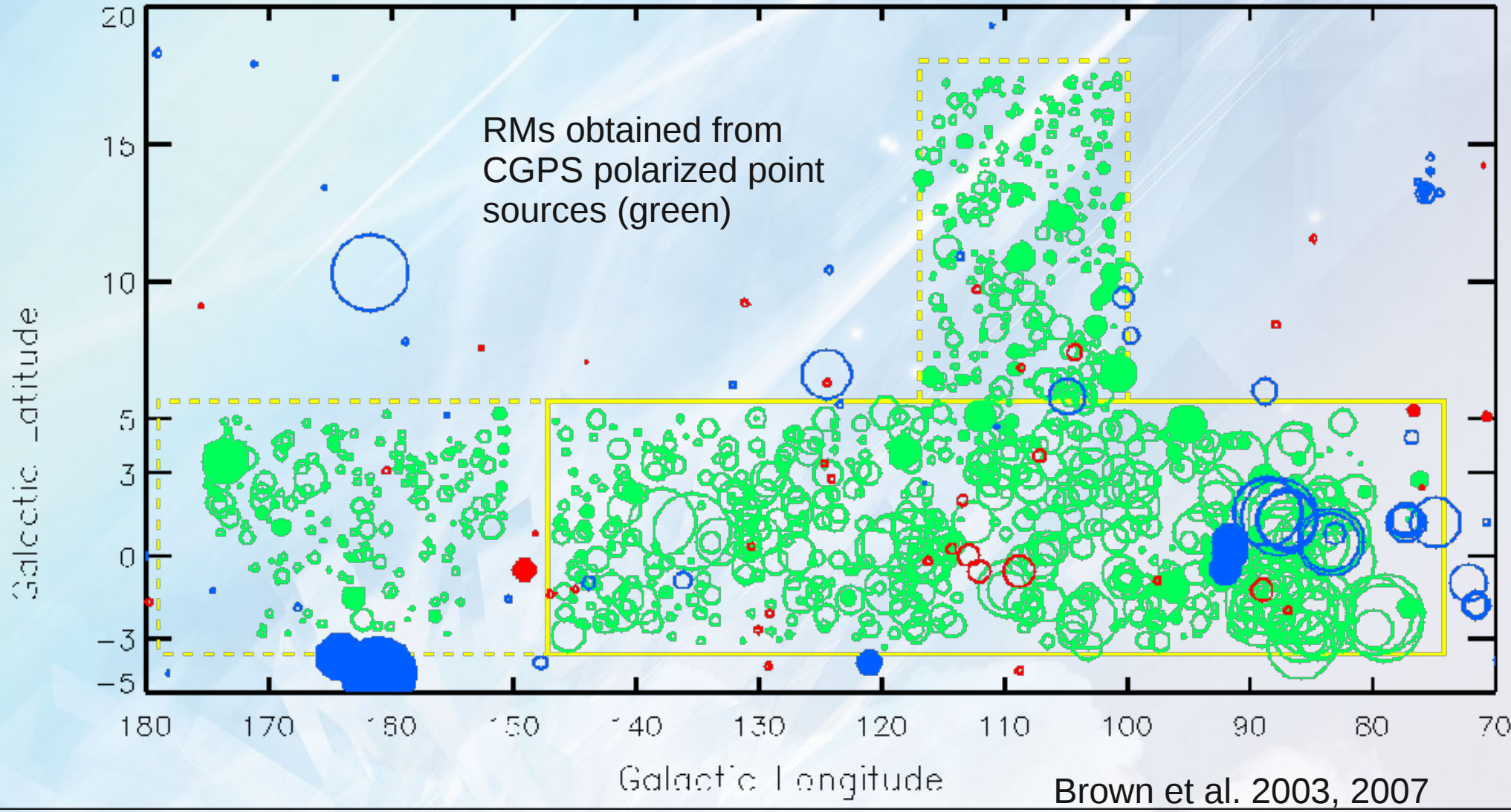
RM point source grid



Brown et al. 2003, 2007

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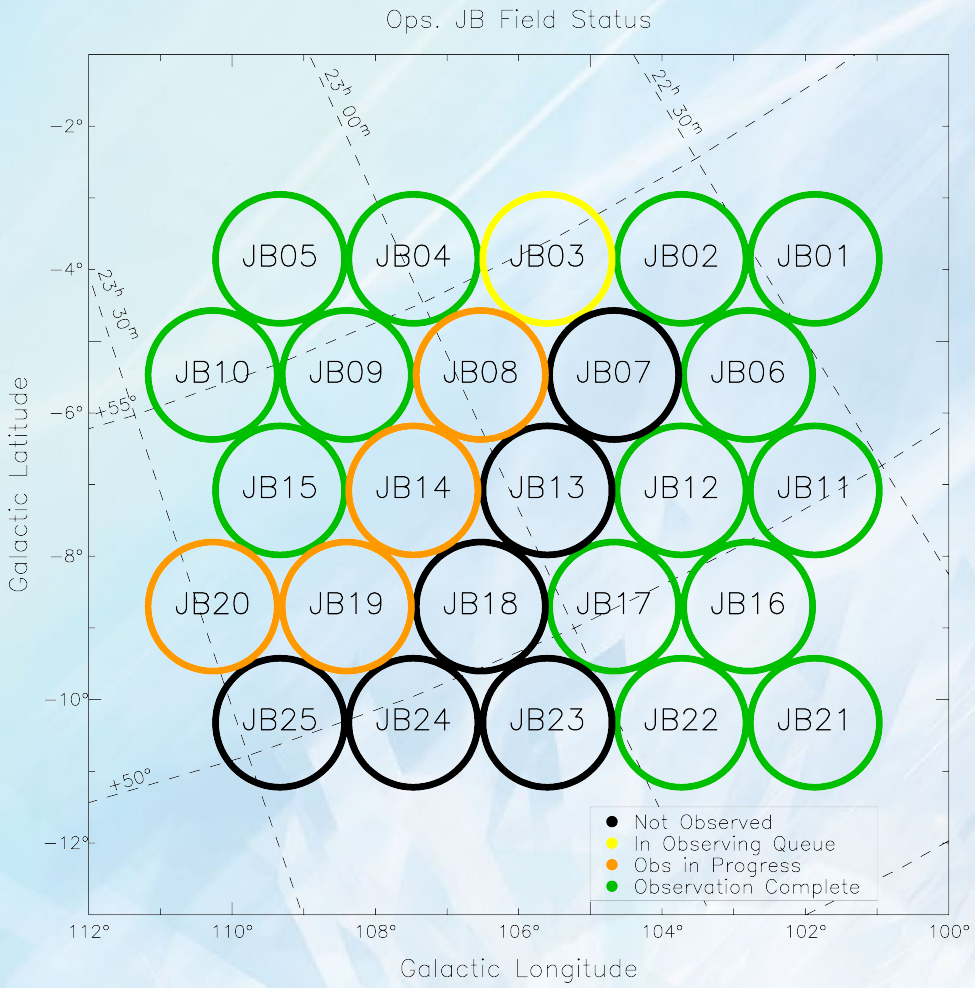
Recent Extension to the CGPS



So far: CGPS studies polarized emission within the plane

Ongoing: Extension to lower galactic latitudes to study transition of magnetic field from plane into the halo

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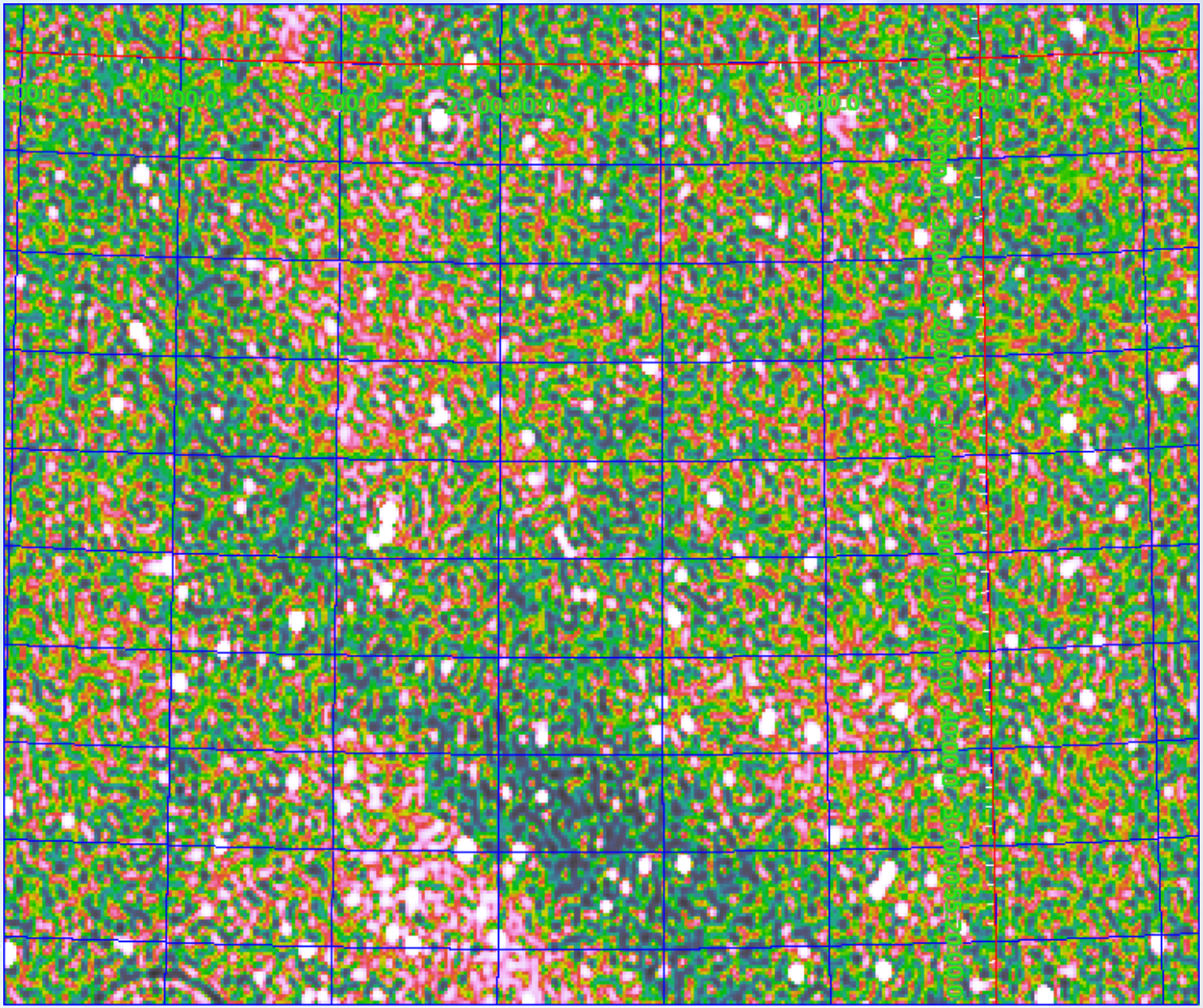
Result preview

Stokes I of JB04

Point sources and extended structures are visible in total intensity at 1.4 GHz



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Conclusions

- The diffuse polarized emission can reveal magnetic fields in action in the ISM.
- Single-antenna **+** aperture-synthesis data set to give complete picture of structure over “all” scales
- Data on other ISM tracers is essential
- High angular resolution is essential
- RM grid density within the Galactic plane has been strongly increased by the CGPS
- CGPS has given and will give major insights of ISM and its magnetic field (structure)