UNIVERSITÄT BIELEFELD

Max-Planck-Institut für Radioastronomie

MAX-PLANCK-GESELLSCHAFT

The S-Band Polarization Survey with the SKA-MPG Prototype

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Universität Bielefeld

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Outline

- The SKA-MPG prototype telescope
- Full Southern-sky survey
- Broadband spectro-polarimetry and its synergy
  - CMB foreground measurements

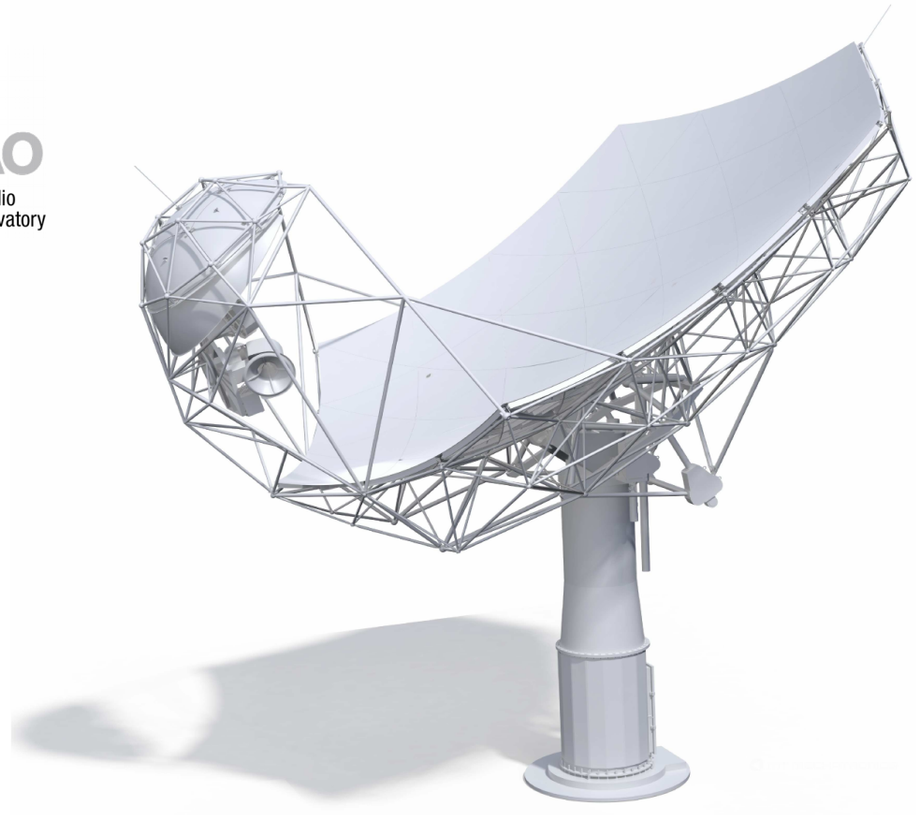
The SKA-MPG prototype telescope

Max-Planck-Institut
für Radioastronomie

MT MECHATRONICS GmbH

NRF National Research Foundation | SARAO South African Radio Astronomy Observatory

First dish of the SKA-MID
(Karoo, South Africa)



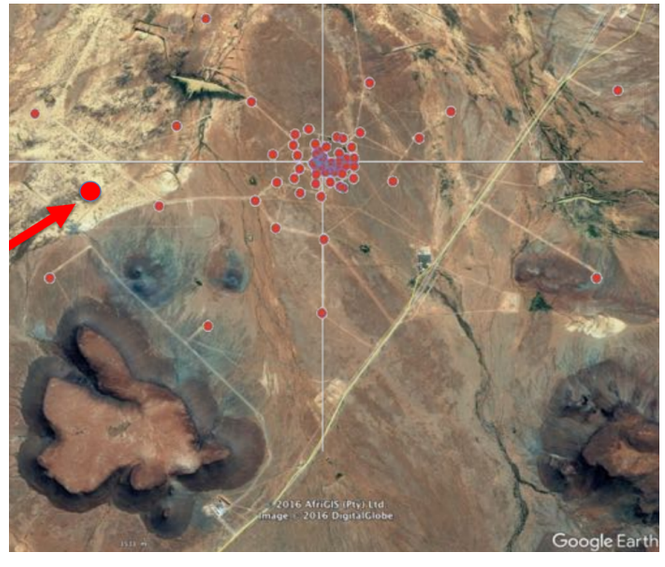
Diameter: **15 m.** (surface rms <300 μm)

T_{sys}/η: **< 20 K.**

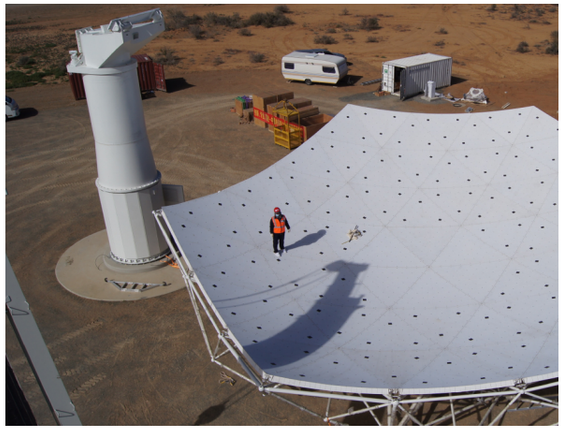
Frequency: **1.7—3.5 GHz** (S-band). **BW 1.75 GHz.**

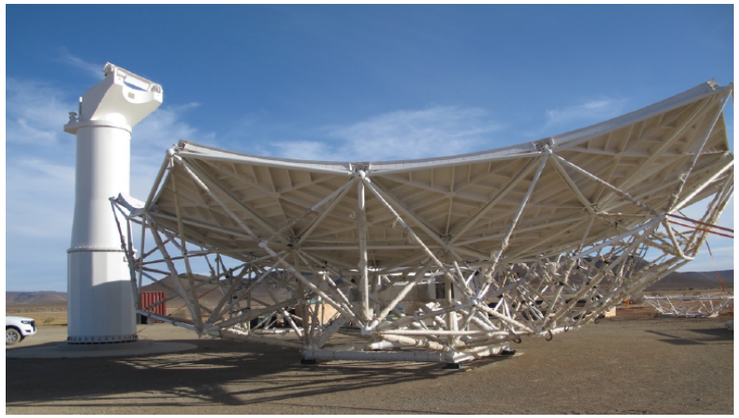
Resolution: **50–25 arcmin** (~30 arcmin.)

Confusion noise: ~300–70 mJy (Stokes I)
~60 μJy (Pol int.)



Construction status





Picture credit: MPIfR, SKAO

Arrived in South Africa
(August 2018)

Max-Planck-Institut
für Radioastronomie

NRF
National Research
Foundation

SARAO
South African Radio
Astronomy Observatory

May 2019: Dish lifted on the pedestal.

On-going: Pointing tests.

End-October 2019: Handover to the MPIfR
(Holography, RF tracking, S-band Receiver tests,...)

April 2020: Science observations and data verifications.

Full polarization Southern sky survey

Capabilities of the SKA-MPG telescope

Excellent survey instrument:

Highly sensitive to polarized emission (rms ~ 0.3 mK/10 MHz channel)

Fast slewing (Azimuth 3°/sec; Elevation 1°/sec)

Extremely stable receiver gains over the entire 1.75-GHz bandwidth.

Gain: **<0.03% *rms* gain**; tested on a MeerKAT dish

Polarization: < -35 dB cross-coupling (circular polarization)

Beam: -24 dB (first side-lobe); -32.8 dB (second side-lobe)

Full Southern sky survey can be performed in:

300 hours (confusion limited total intensity) => 1 month!

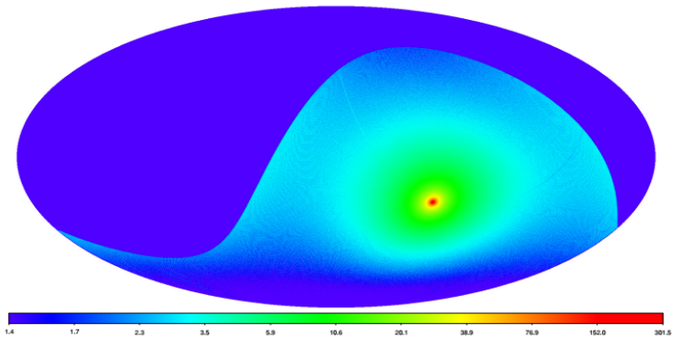
6000 hours (polarized intensity) => ~24 months!

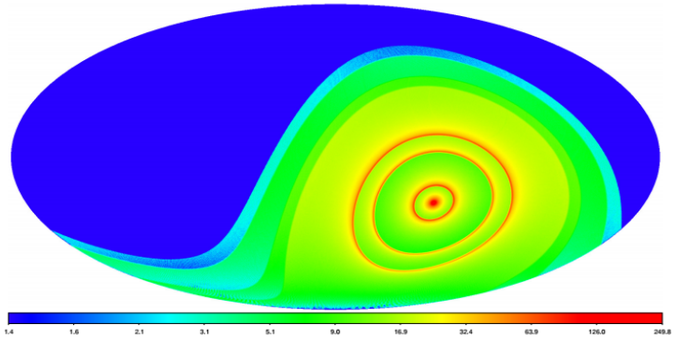
(**3–4 years with overheads & quality checks**)

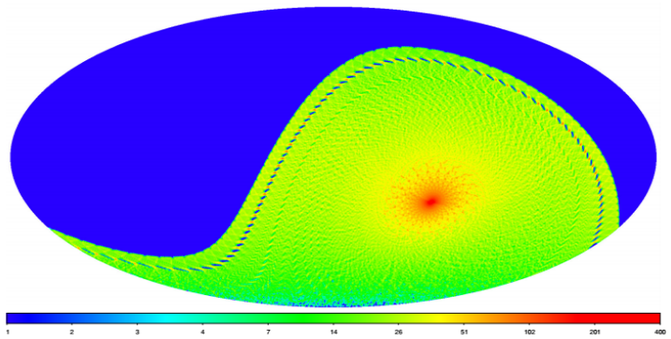
Survey strategy and designing: On-going

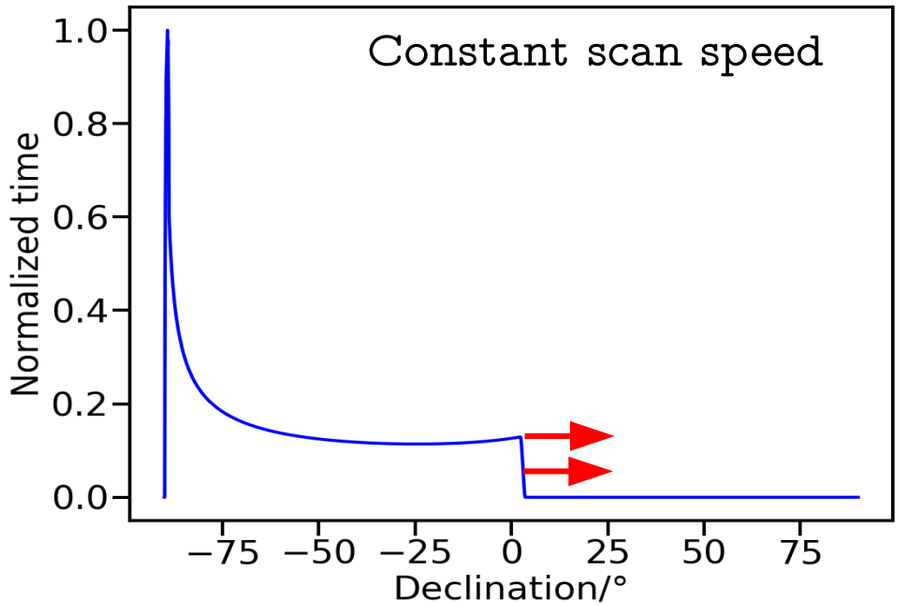
Master thesis: Ferdinand Jünemann.

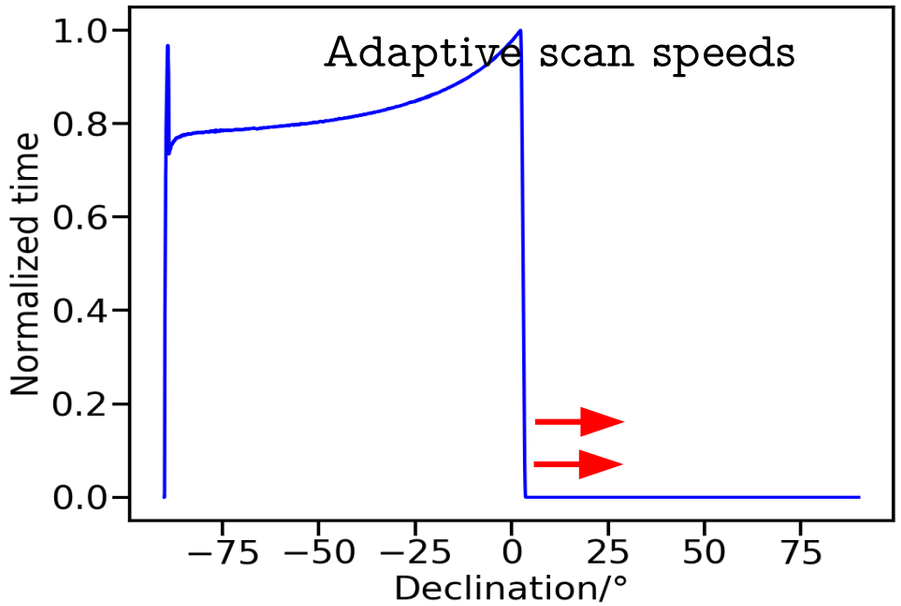
Homogenize sky integration
(reduce scanning artefacts and correlations)











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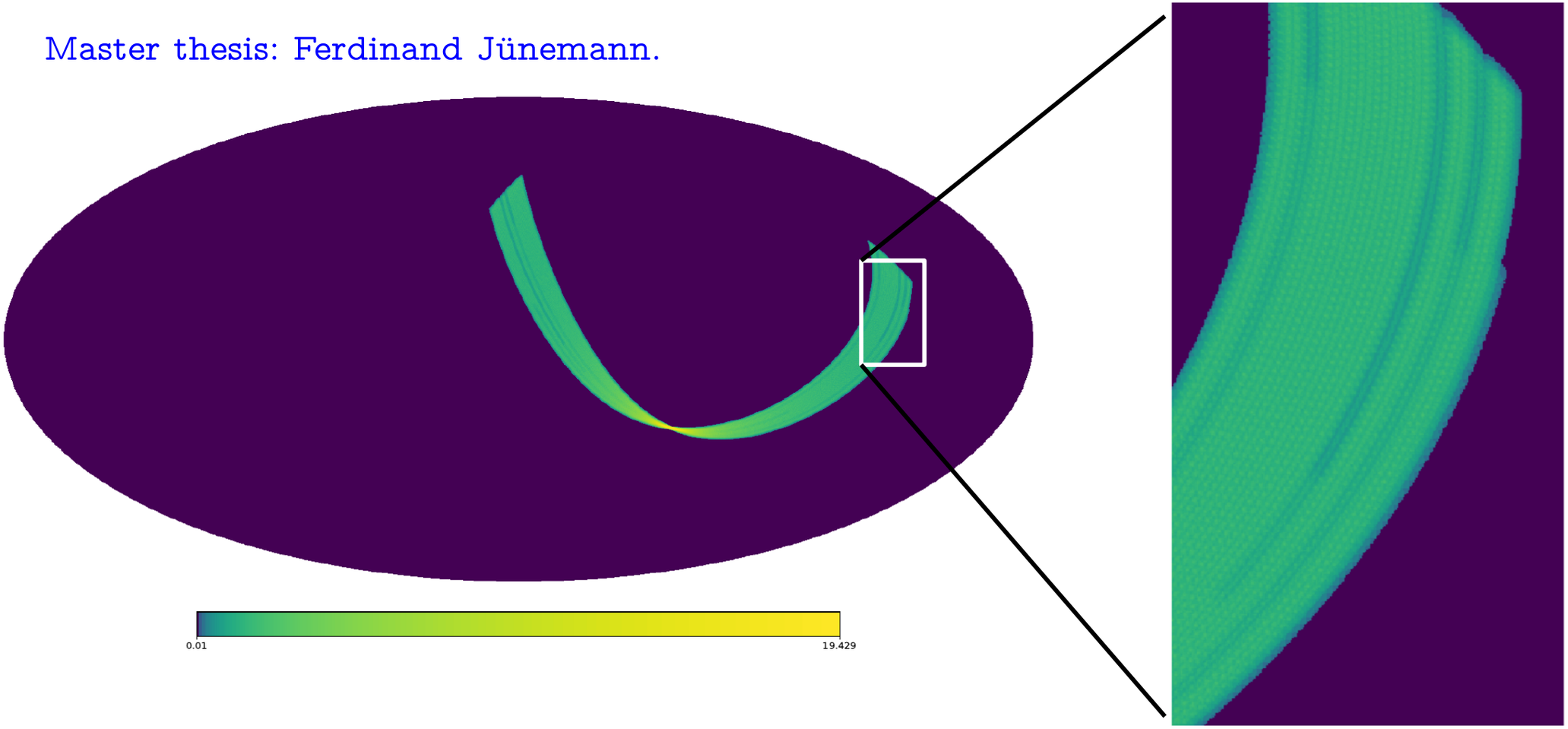


Automatic calibration and tracking intelligence

Development of a fully automatic "remote" telescope manager for the survey.

Manual input as minimal as: Yes/No!

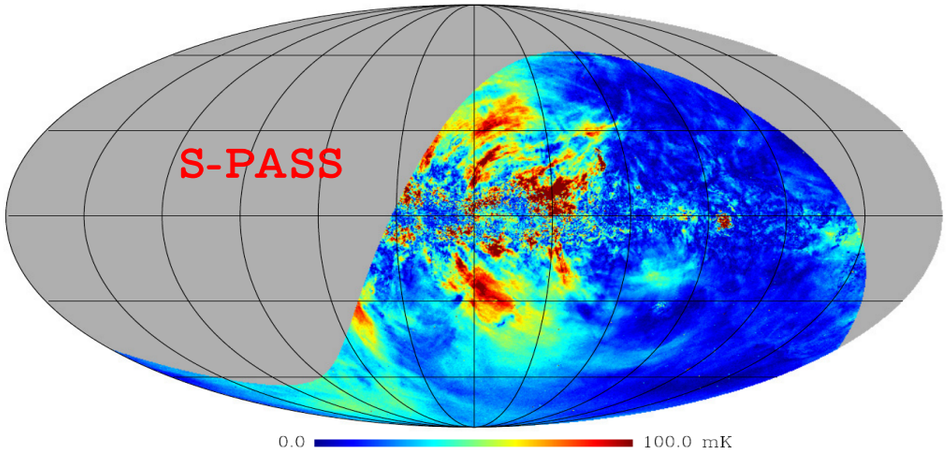
Stokes Q, U, I Deciphering Survey (SQUIDS)

A broadband spectro-polarimetric survey of the Southern sky.

Sky area: ~21,000 deg^2

Freq.: 1.7–3.5 GHz (S-band)
2048 channels

Target sensitivity: 0.3 mK/10 MHz
(in Stokes *Q*, *U*)



Carretti, et al., 2019, MNRAS

~20× 300-hr confusion-limited sky mapping.

SQUIDS

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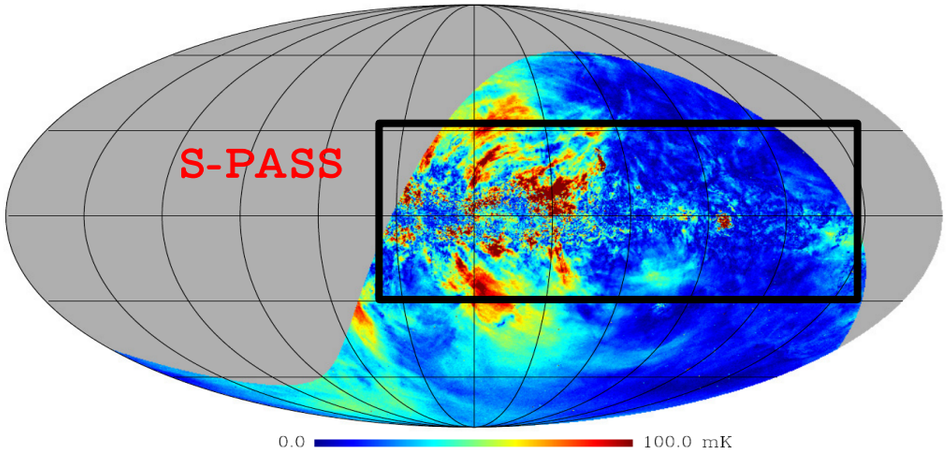
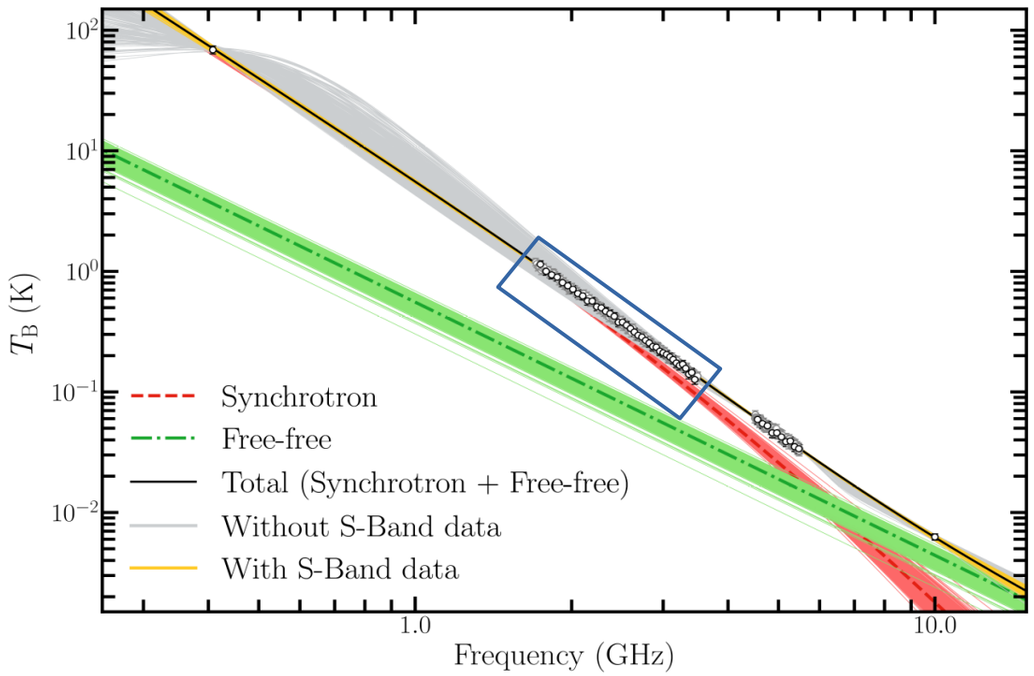


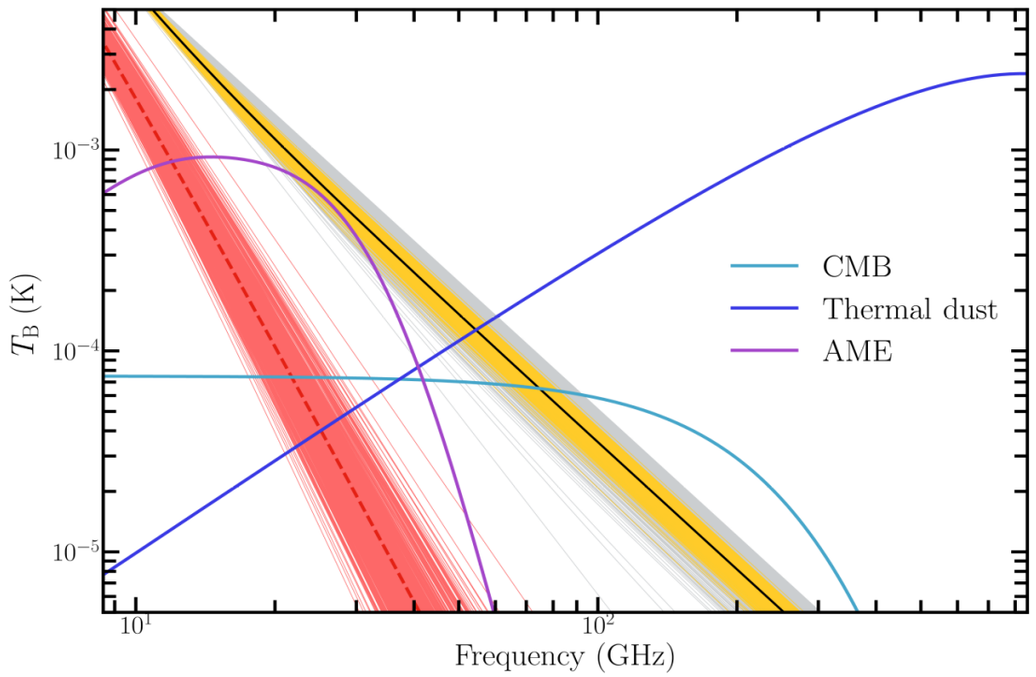
Carretti, et al., 2019, MNRAS

~20× 300-hr confusion-limited sky mapping.

Clean up the low- to mid-latitude region in polarization.

Synchrotron + Free—free foregrounds



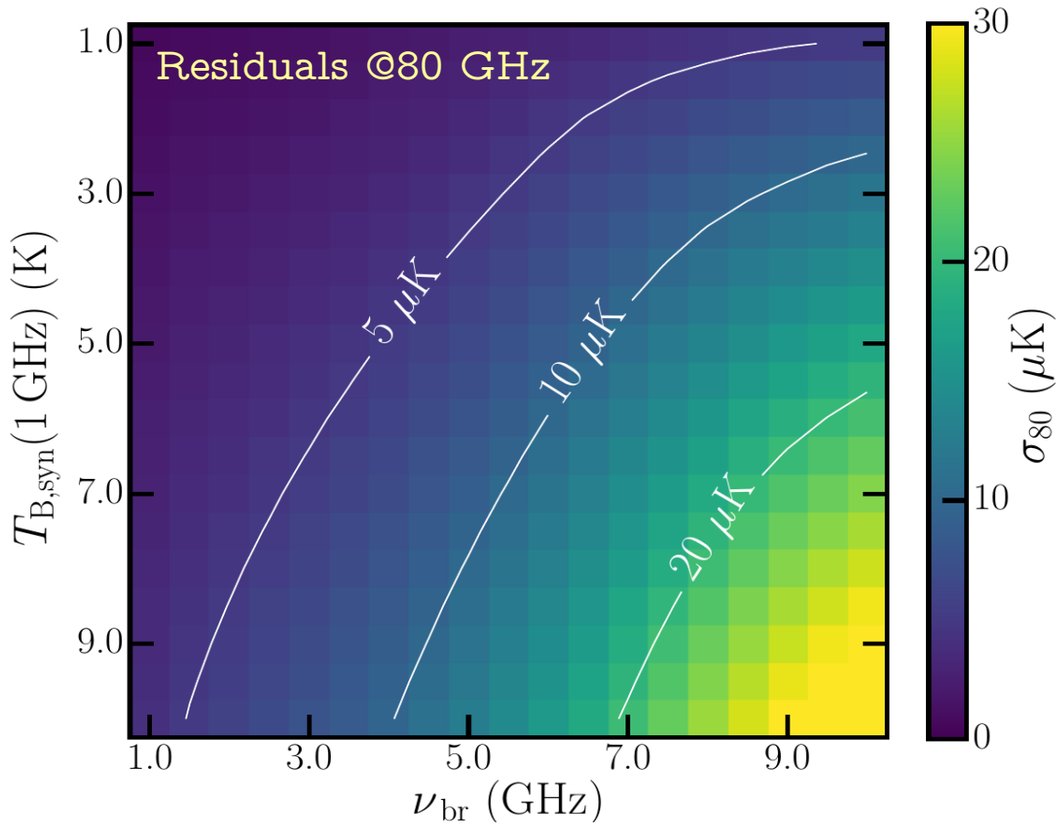


Constrain synchrotron + free—free emission from low frequencies alone!

$$T_B(\nu) = T_{\rm syn,0}\,\frac{(\nu/\nu_0)^{\beta_{\rm syn}}}{[1+(\nu/\nu_{\rm br})^{\gamma}]}\,e^{-(\nu/\nu_c)} + T_{\rm ff,0}\,(\nu/\nu_0)^{-2.1}$$

Basu, Schwarz, Klöckner, von Hausegger, Kramer, Wieching, Burkhart, 2019, MNRAS. arXiv:1906.04788

Synchrotron + Free—free foregrounds



Total intensity brightness temp. rms < 10 μK per 1 deg^2.

Constrain synchrotron + free—free emission from low frequencies alone!

$$T_B(\nu) = T_{syn,0}\,\frac{(\nu/\nu_0)^{\beta_{syn}}}{[1+(\nu/\nu_{br})^{\gamma}]}\,e^{-(\nu/\nu_c)} + T_{ff,0}\,(\nu/\nu_0)^{-2.1}$$

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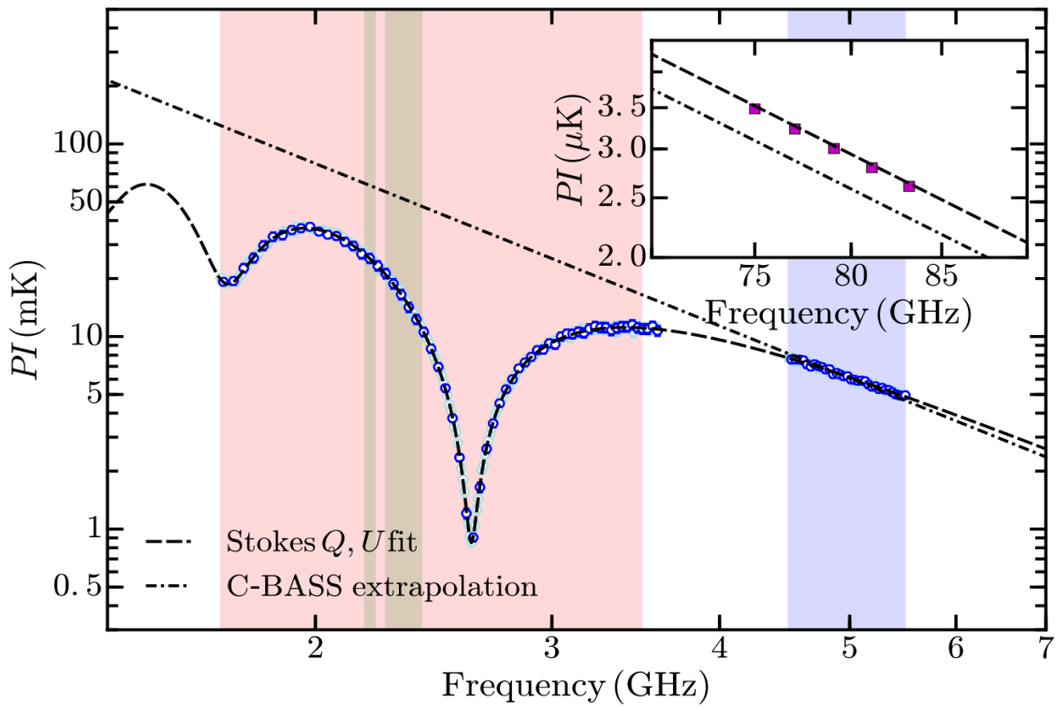
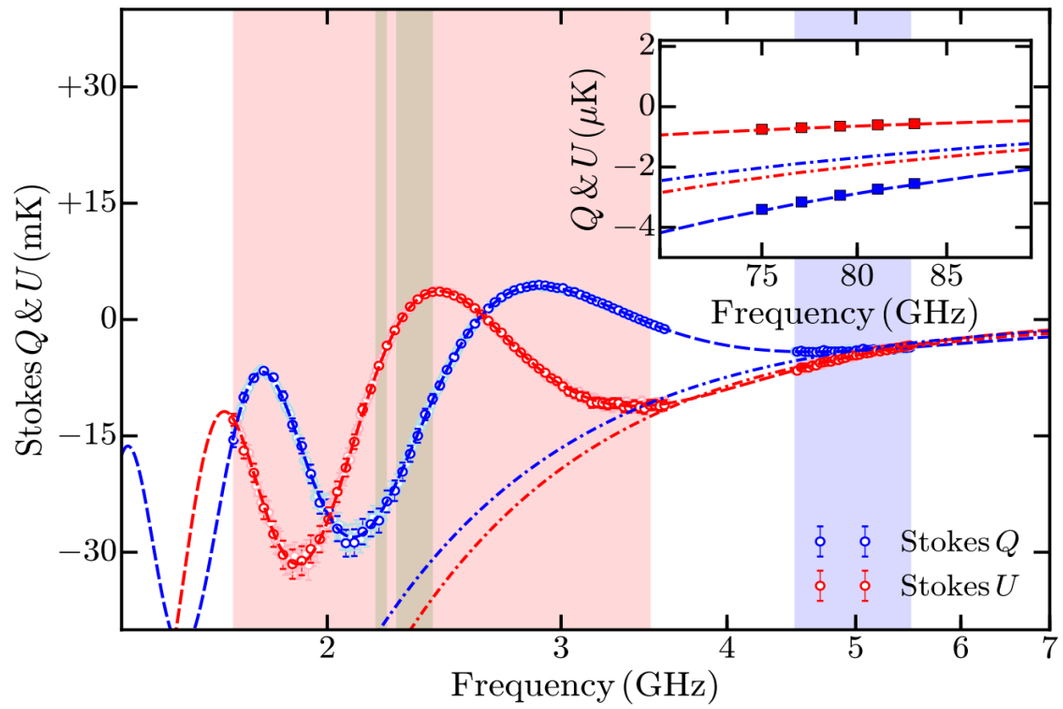
Stokes Q,U fitting & Faraday depolarization





SQUIDS

C-BASS

S-PASS

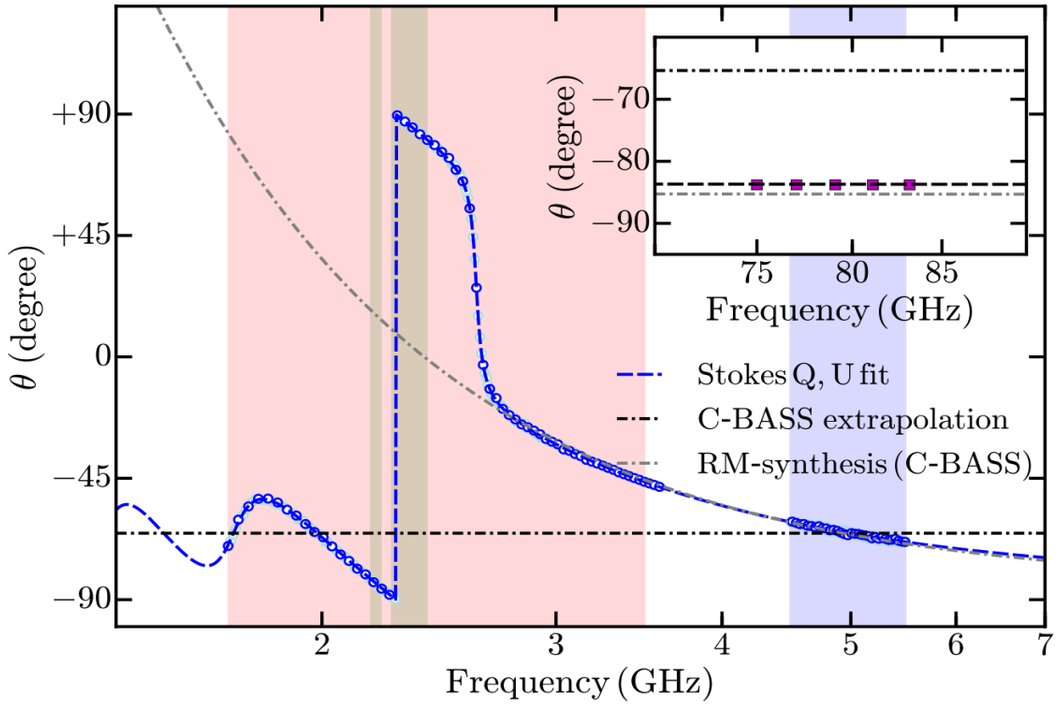
Synthetic observations:
MHD simulation of sub-sonic, isothermal, compressible turbulence in the ISM.

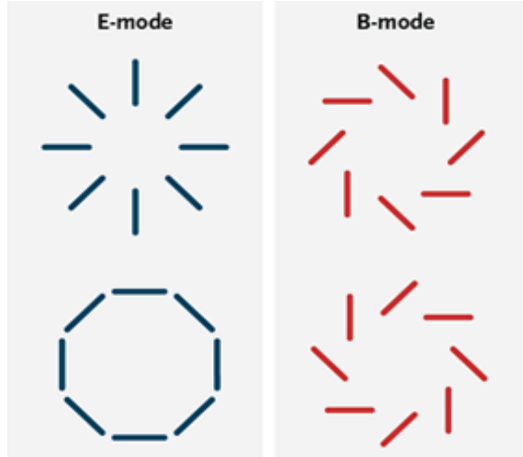
Gaensler et al., 2011, Nature

Burkhart et al., 2009, ApJ

Stokes Q,U parameter fitting will allow to reach rms(PI)@100 GHz < 5 nK/deg^2

Stokes *Q*,*U* fitting & Faraday depolarization





SQUIDS

C-BASS

S-PASS

Precise angle measurement is critical to avoid mixing!

Stokes *Q*,*U* parameter fitting will allow to reach rms(*PI*)@100 GHz < 5 nK/deg^2

$\Delta\theta_0$ < 0.1 degree (most parts of the sky).

Summary

– The SKA-MPG prototype telescope will provide state-of-the-art measurements of the polarized synchrotron foreground and crucial insights into Galactic magnetic fields.

Expected to be completed by 2024–2025 (preparation for LiteBIRD)

– New techniques of analyzing the polarized emission, such as, Stokes Q,U fitting, needs to be incorporated into CMB analysis pipelines.

– The Southern-sky survey at S-band (1.7–3.5 GHz) will enable us to determine the total and polarized synchrotron emission using physically motivated models.

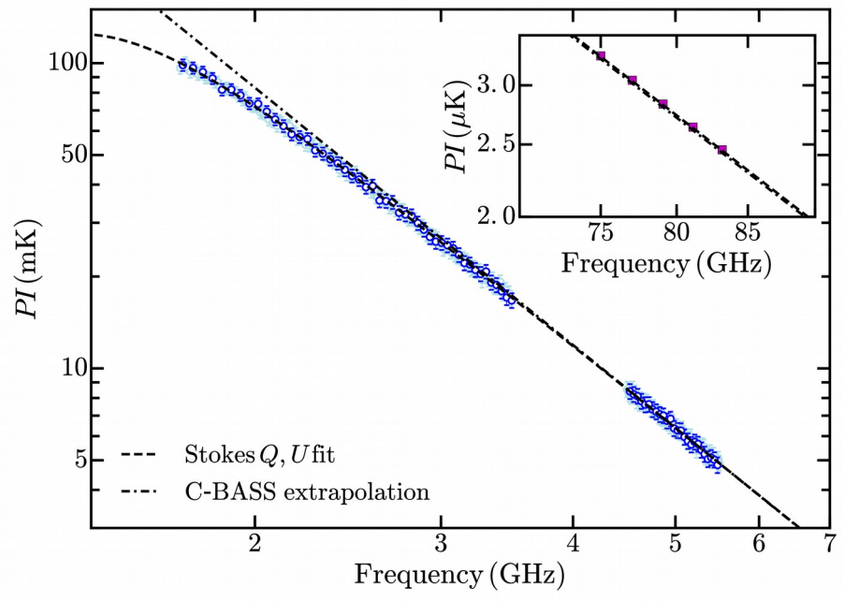
Pol. Intensity rms @100 GHz $\lesssim$ 5 nK per 1 deg^2. (Expected B-mode rms ~10 nK for $r = 10^{-3}$)

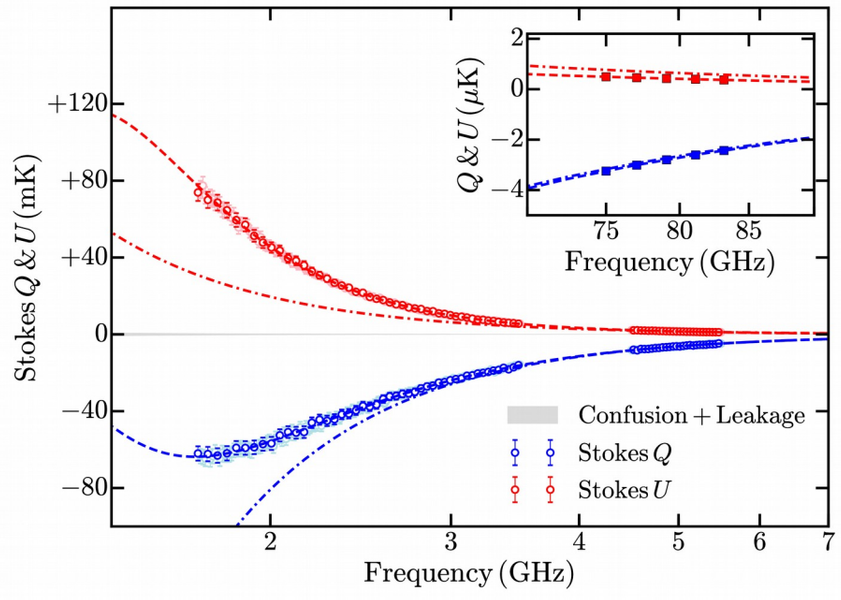
Tot. Intensity rms $\lesssim$ 10 μK per 1 deg^2.

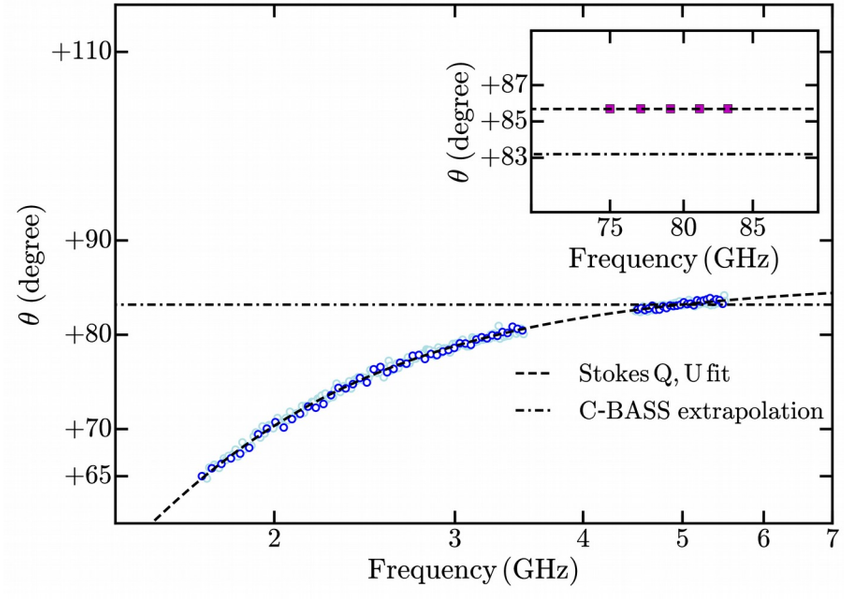
– Open up a large fraction of the sky for power spectrum analysis at the largest angular-scales.

– **Adding another receiver in the 12 to 18 GHz frequency range is possible (4 to 7 arcmin angular resolution)**

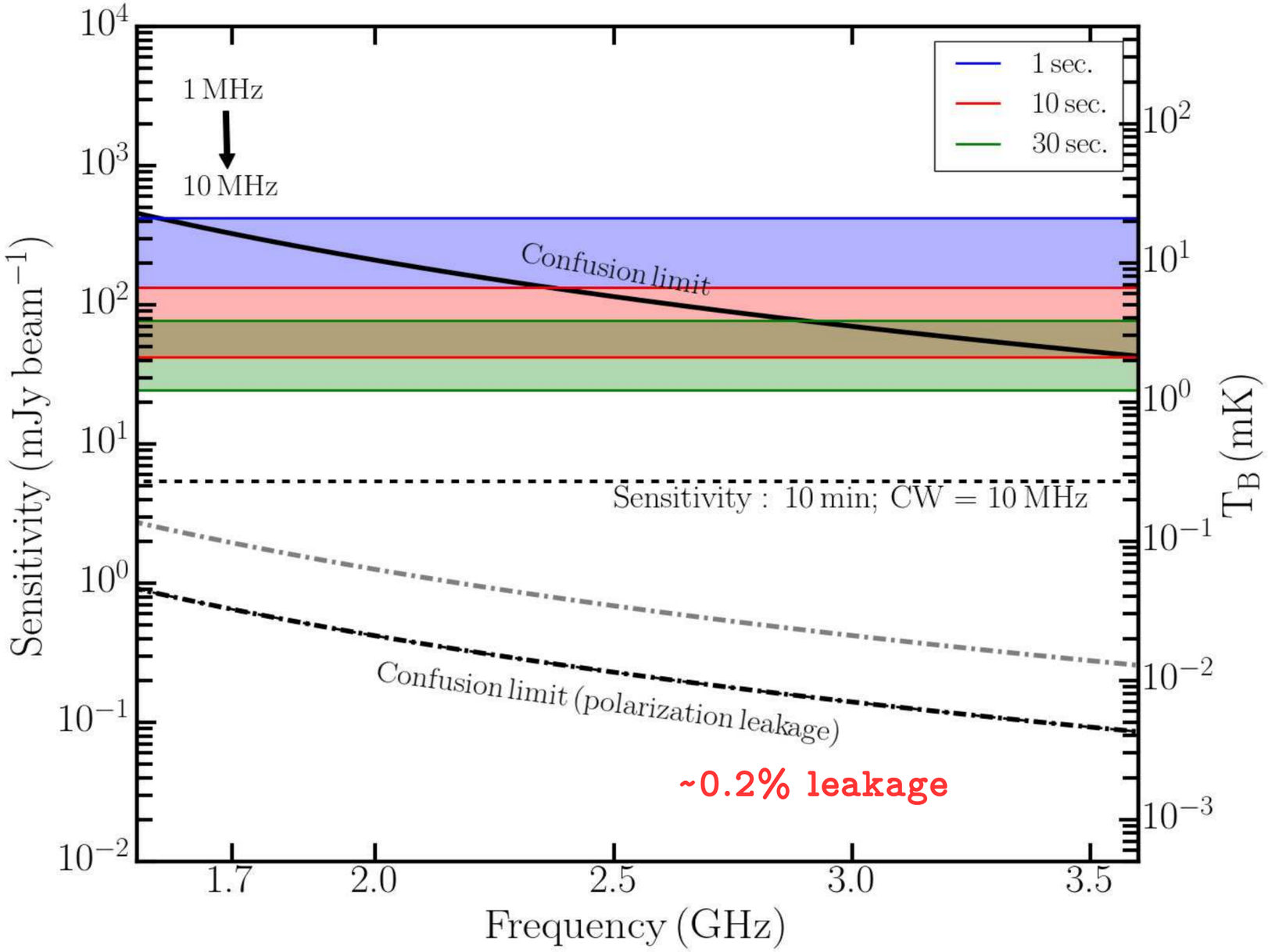
Low depolarization (high Gal. Lat.)





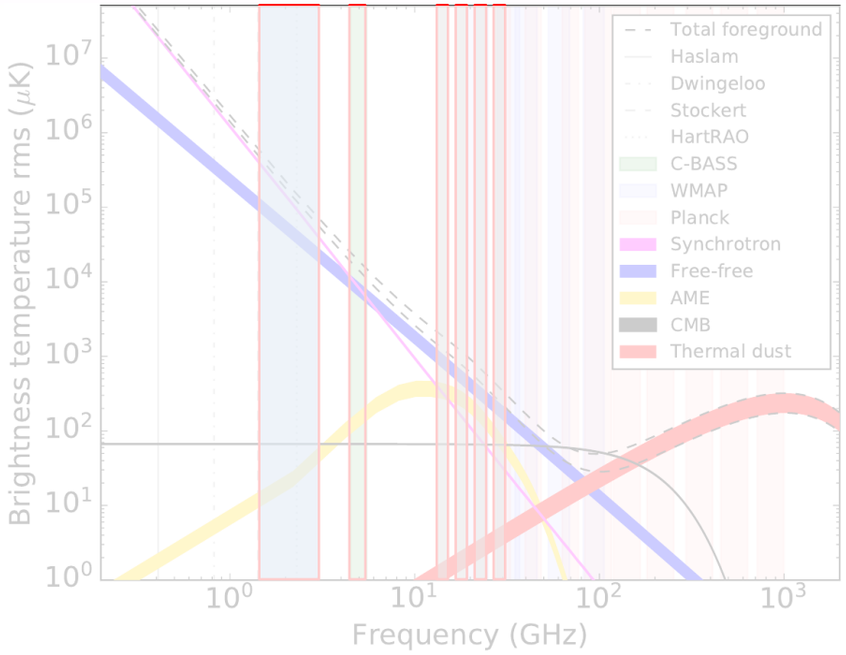


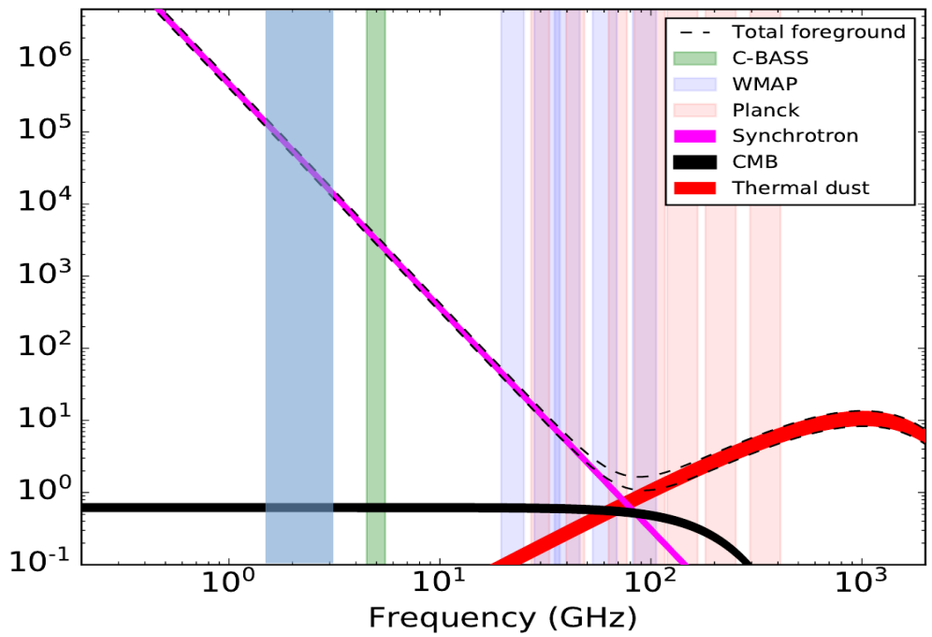
Expected sensitivity



Synchrotron polarization

Fig. from C-BASS, MNRAS, 2018





Total Intensity

$$T_{\mathrm{B}} = T_{\mathrm{B,syn}}\, \nu^{\alpha + C\, \log(\nu/\nu_{\mathrm{br}})}$$

Kogut, 2012, ApJ

Polarized Intensity

$$T_{\mathrm{B,pol}} = p\, T_{\mathrm{B,syn}}\, \nu^{\alpha + C\, \log(\nu/\nu_{\mathrm{br}})}$$

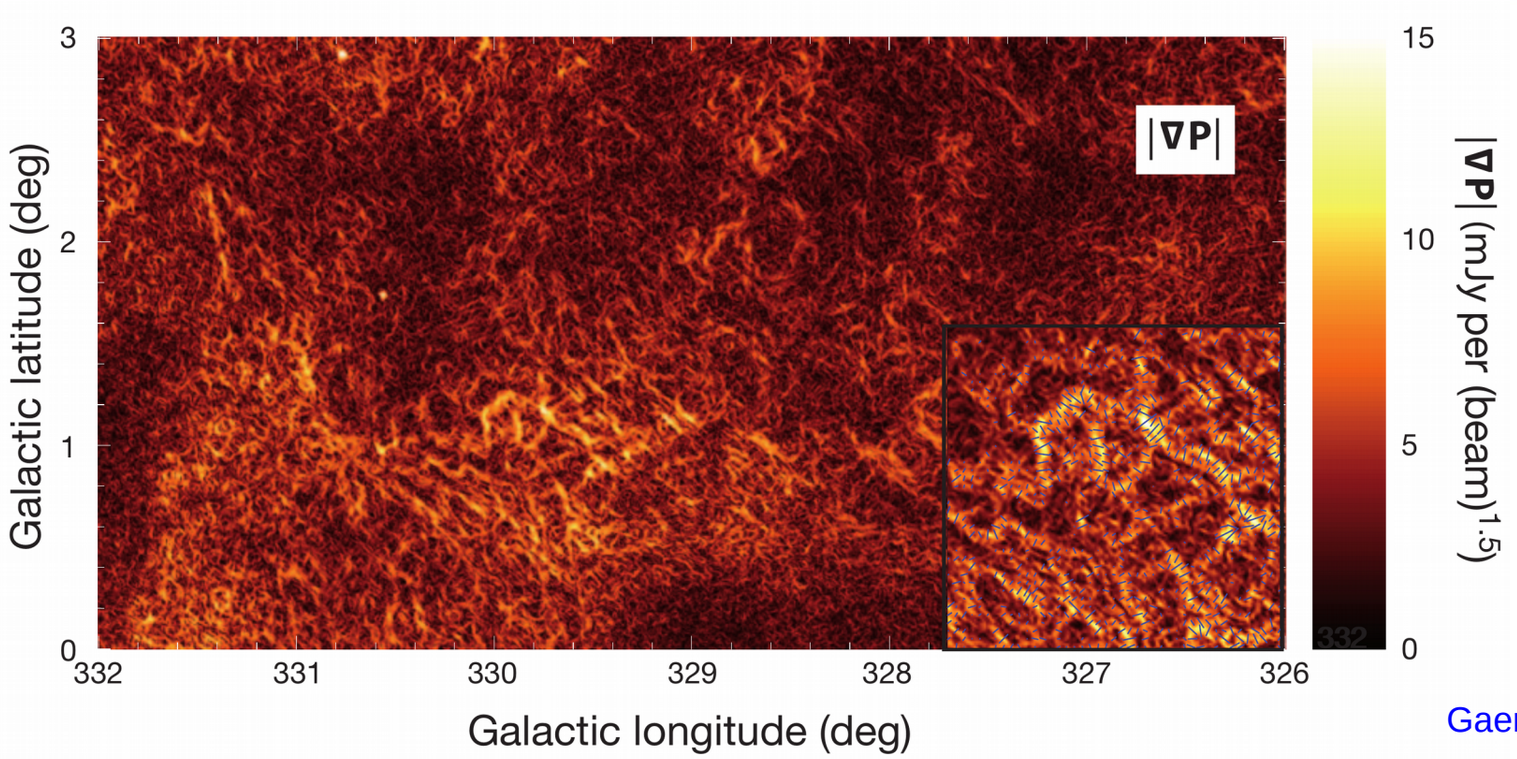
$$p(\lambda) = p_0\, \frac{\sin \mathrm{FD}\, \lambda^2}{\mathrm{FD}\, \lambda^2}\, \mathrm{e}^{2\, i\, (\theta_0 + \frac{1}{2}\, \mathrm{FD}\, \lambda^2)}.$$

$$p(\lambda) = p_0\, \mathrm{e}^{2\, i\, \theta_0} \left(\frac{1 - \exp[-(2\, \sigma_{\mathrm{FD}}^2\, \lambda^4 - 2\, i\, \mathrm{FD}\, \lambda^2)]}{2\, \sigma_{\mathrm{FD}}^2\, \lambda^4 - 2\, i\, \mathrm{FD}\, \lambda^2} \right).$$

$$p(\lambda) = p_0\, \mathrm{e}^{-2\, \sigma_{\mathrm{FD}}^2\, \lambda^4}\, \mathrm{e}^{2\, i\, (\theta_0 + \mathrm{FD}\, \lambda^2)}.$$

Sokoloff et al., 1998, MNRAS

Synthetic observations



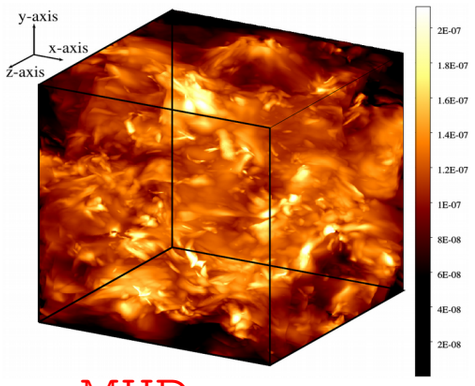
Gaensler et al., 2011, Nature

Burkhart et al., 2009, ApJ

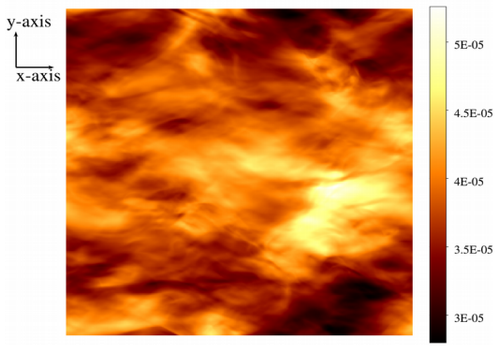
Koley & Roy, 2019, MNRAS

Synthetic observations:

MHD simulation of sub-sonic, isothermal, compressible turbulence in the ISM.

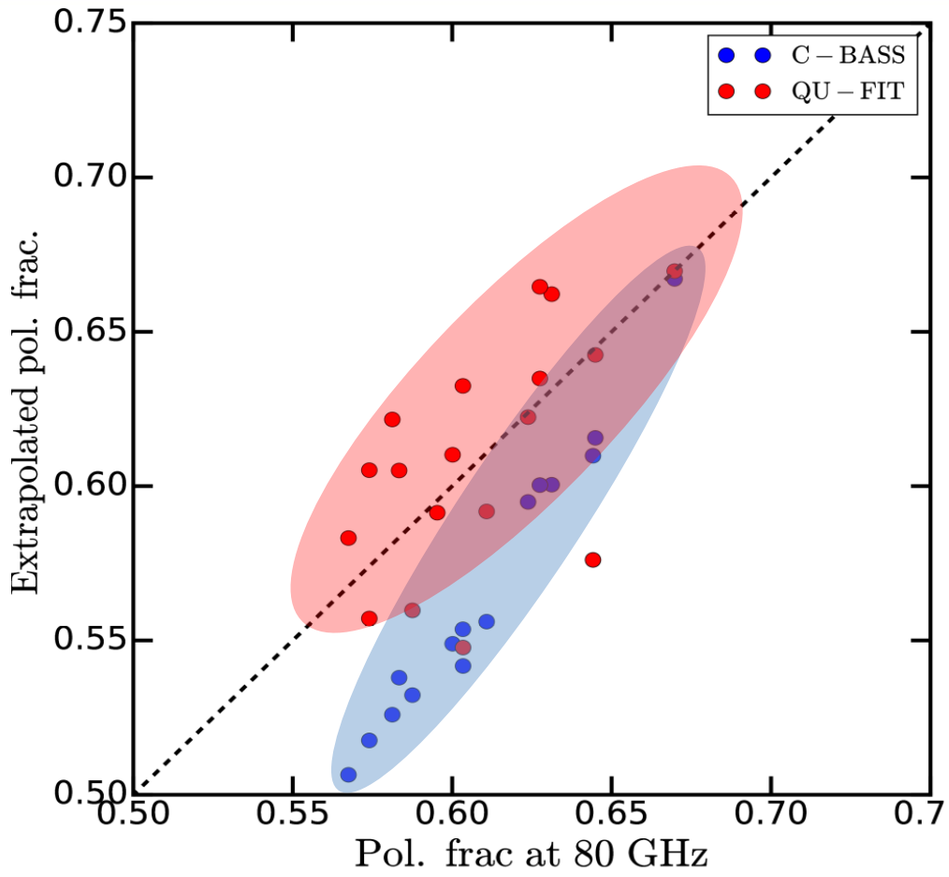


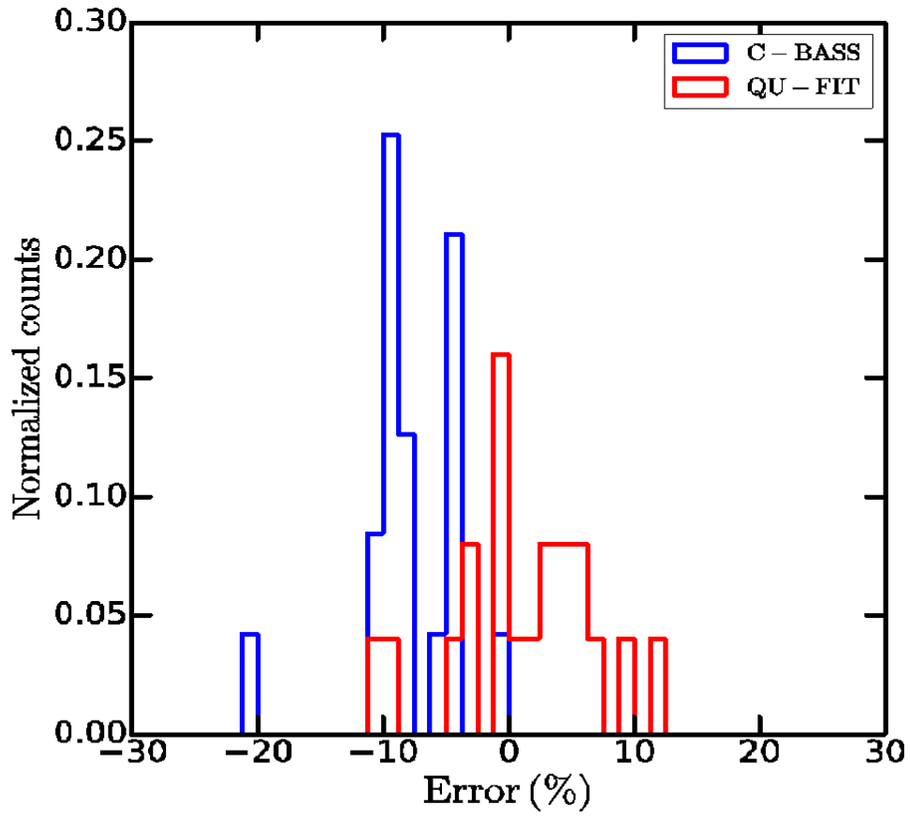
MHD



Polarized intensity

Extrapolation to CMB



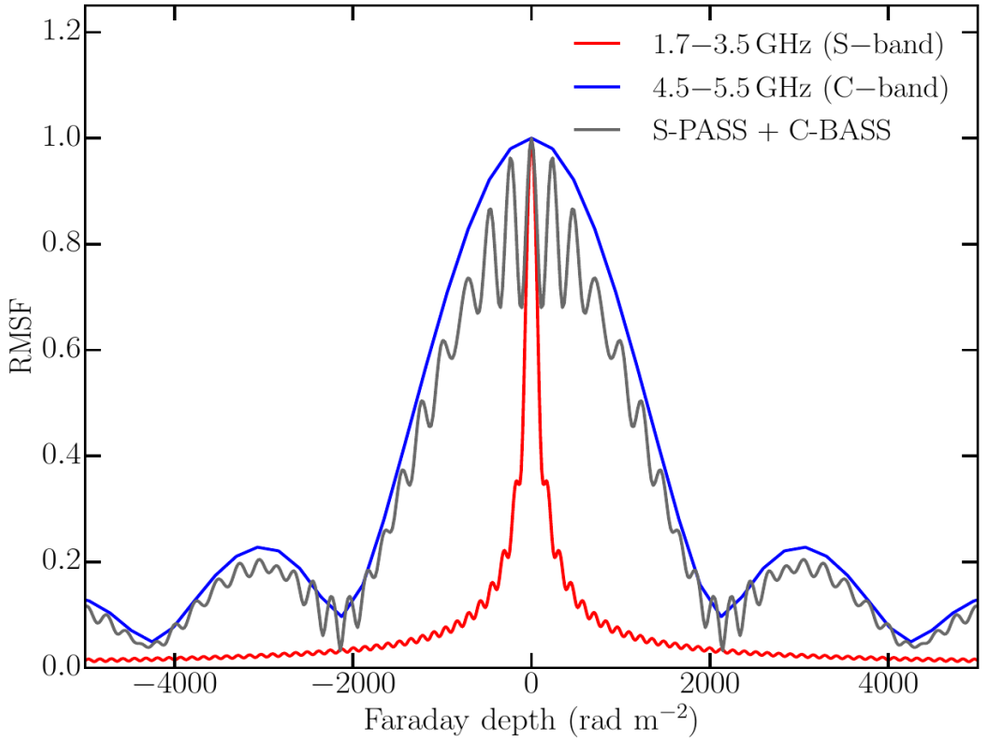


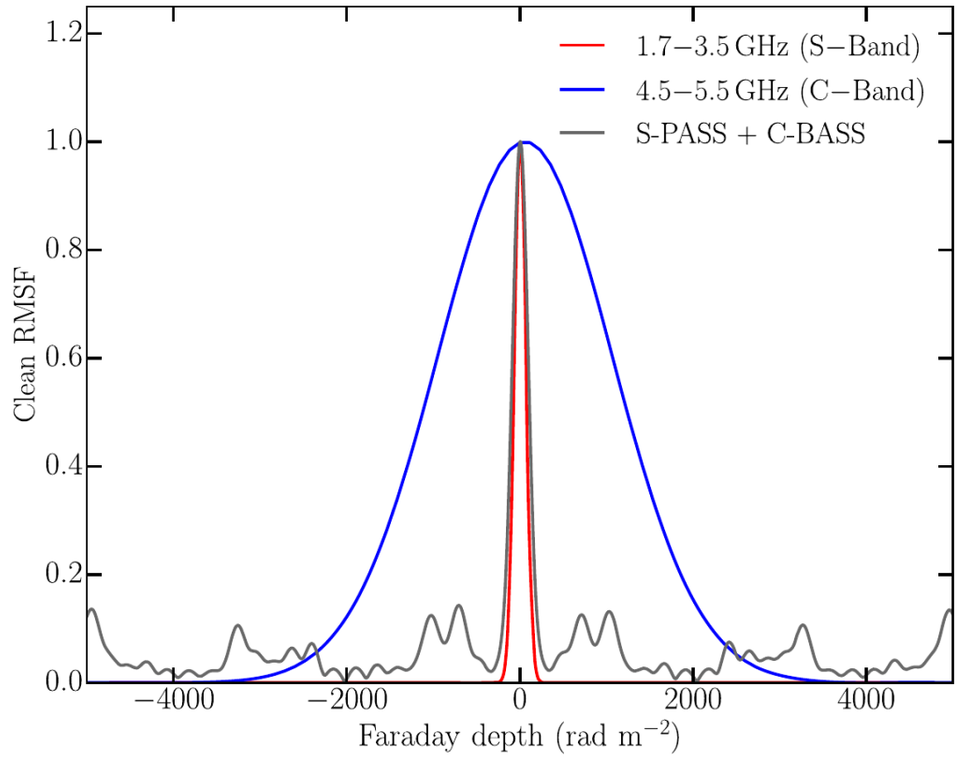
Stokes Q, U fitting provides estimates at $\lesssim 5\%$.

PI brightness temperature rms $\lesssim$ 10 nK per 1 deg^2.

Basu, Schwarz, Klöckner, von Hausegger, Kramer, Wieching, Burkhart, 2019, MNRAS.

RMSF



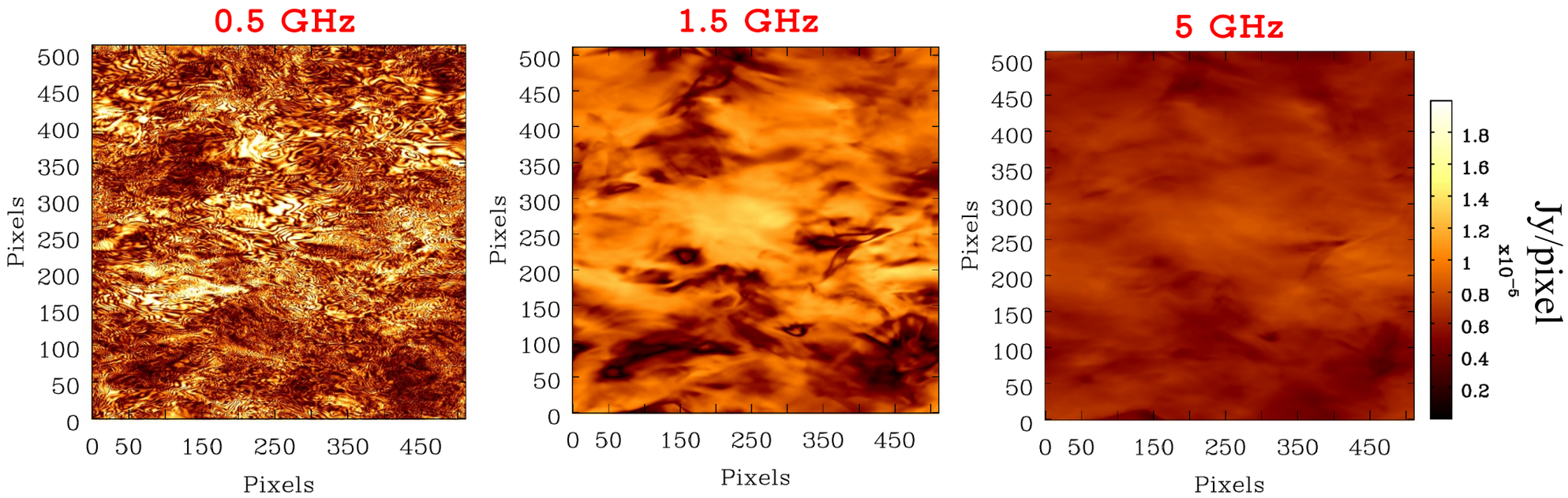


FD resolution:

SQUIDS **~ 150 rad m^{-2}**

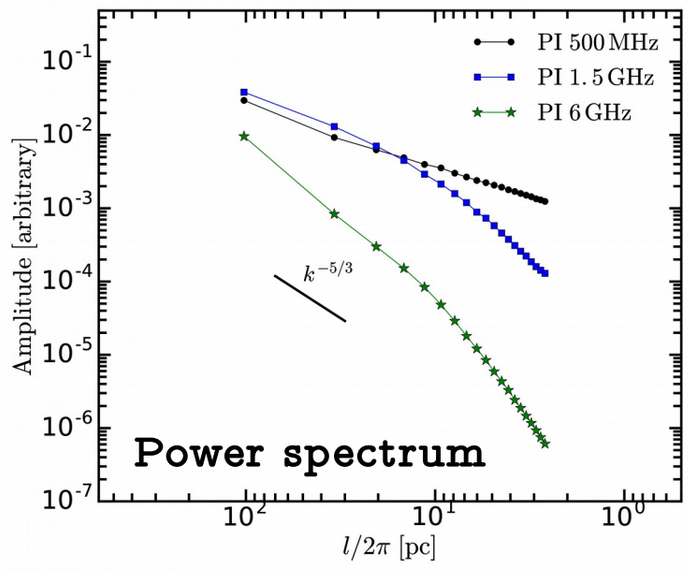
C-BASS ~ 2500 rad m^{-2}

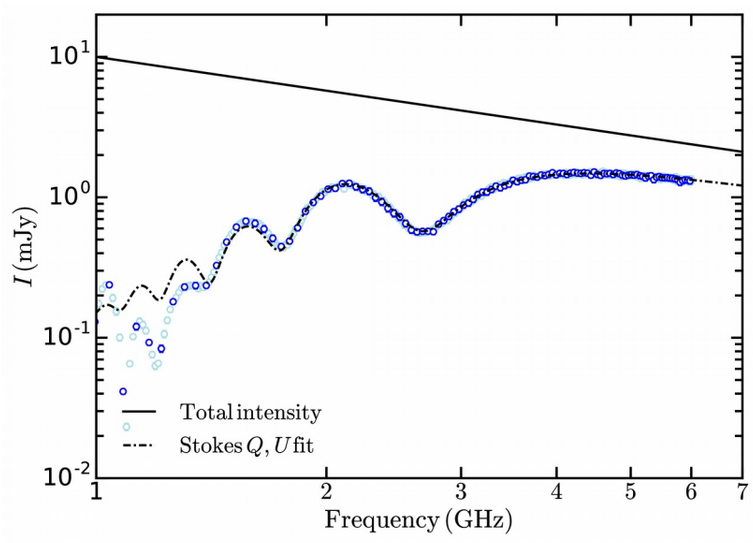
Faraday depolarization



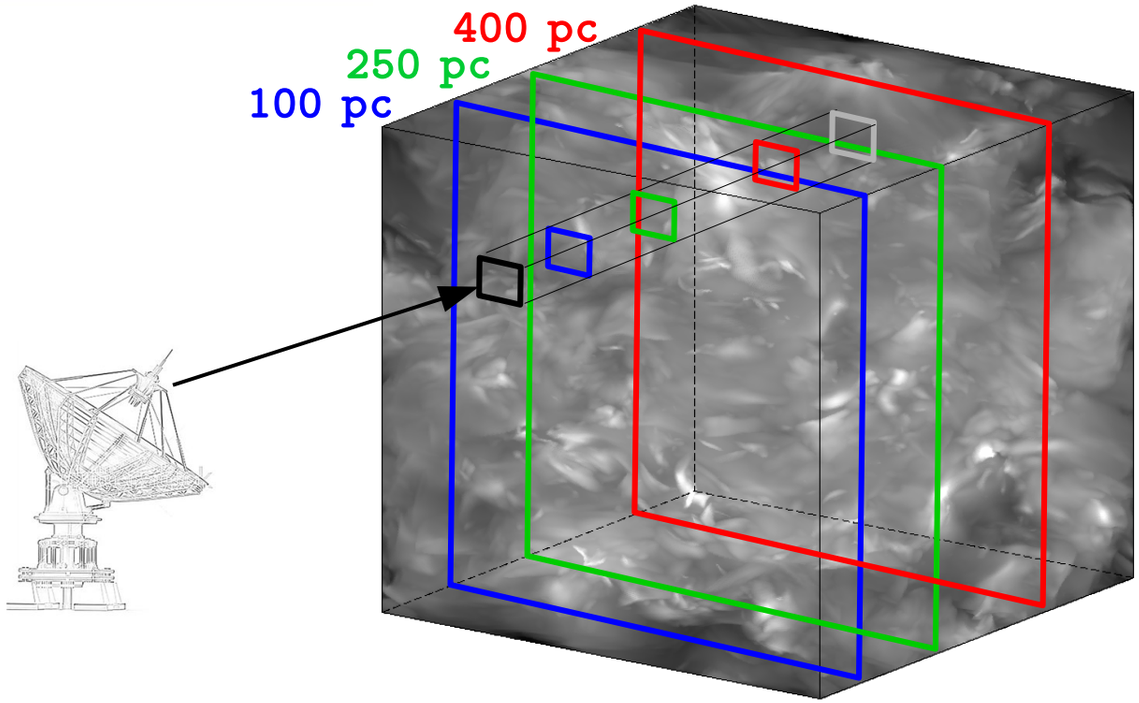
L_c < 2 pc

L_c ~ 60 pc





Polarization horizon



Basu et al. (in prep.)