Universität Bielefeld Fakultät für Physik

Max-Planck-Institut für Radioastronomie

MAX-PLANCK-GESELLSCHAFT

Low frequency efforts in Germany

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Universität Bielefeld

With: Dominik J. Schwarz (Univ. Bielefeld),
Hans-Rainer Klöckner (MPIfR),
Michael Kramer (MPIfR),
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04th March 2019, COSMOS workshop, Milan

Outline

The SKA-MPG prototype telescope

Prospects of the SKA-MPG prototype telescope

– *Stokes Q, U, I Deciphering Survey (SQUIDS)*

Broadband spectro-polarimetry and its synergy

– CMB foreground measurements

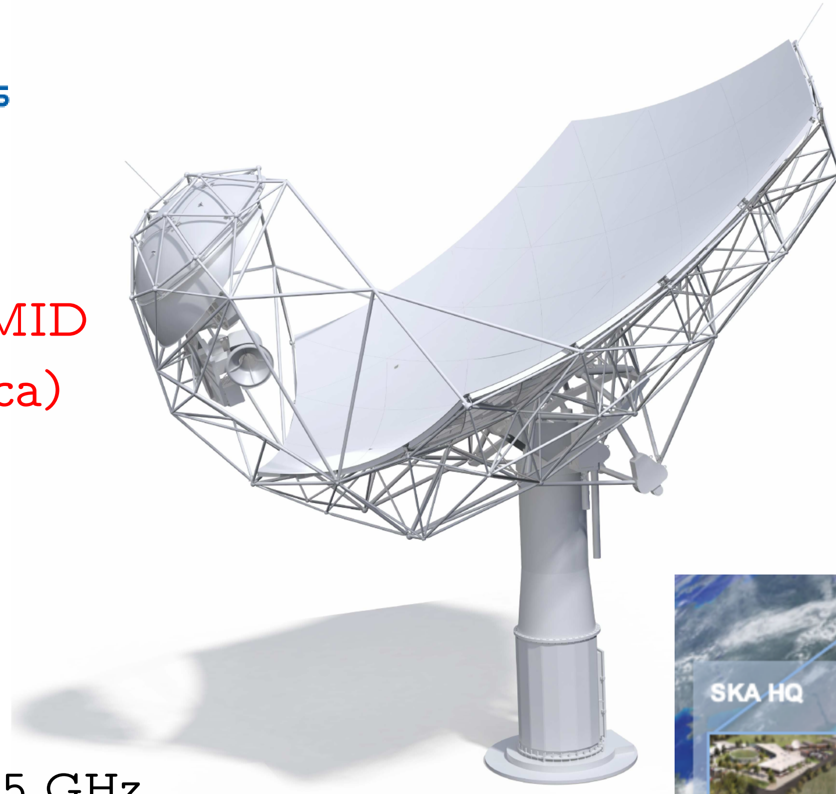
Future scopes!

The SKA-MPG prototype telescope

Max-Planck-Institut für Radioastronomie

MT MECHATRONICS GmBH

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



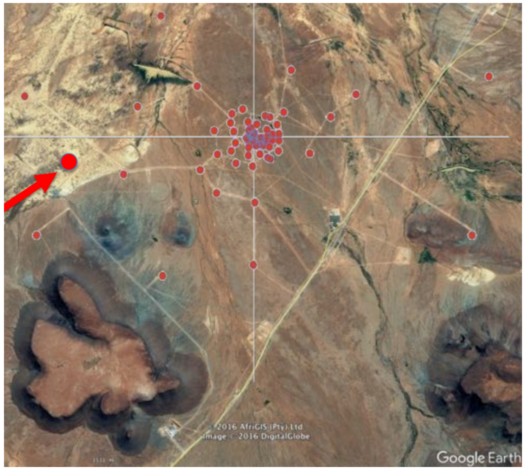
Diameter: 15 m. (surface rms <300 μm)

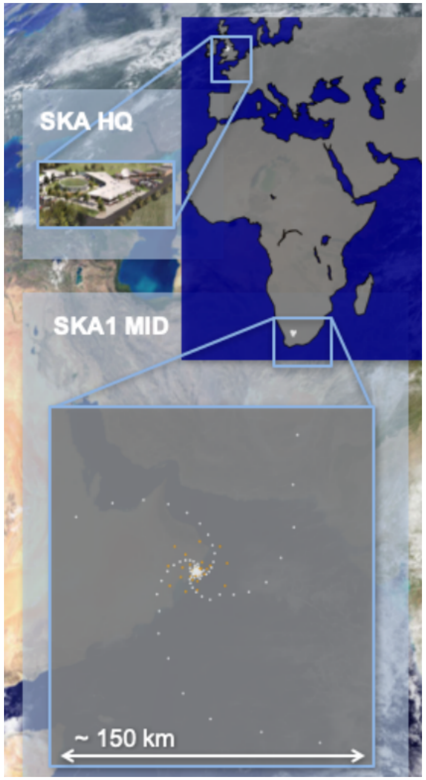
T_{sys}/η: < 20 K.

Frequency: 1.7—3.5 GHz (S-band). BW 1.75 GHz.
Novel receiver designing and digitizer by the MPIfR

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)

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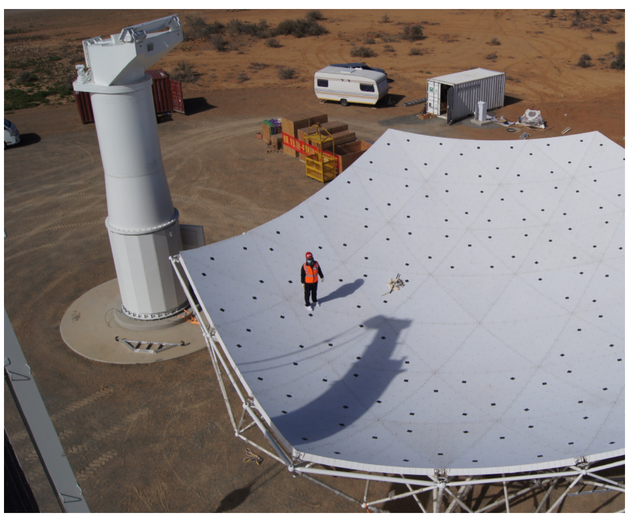

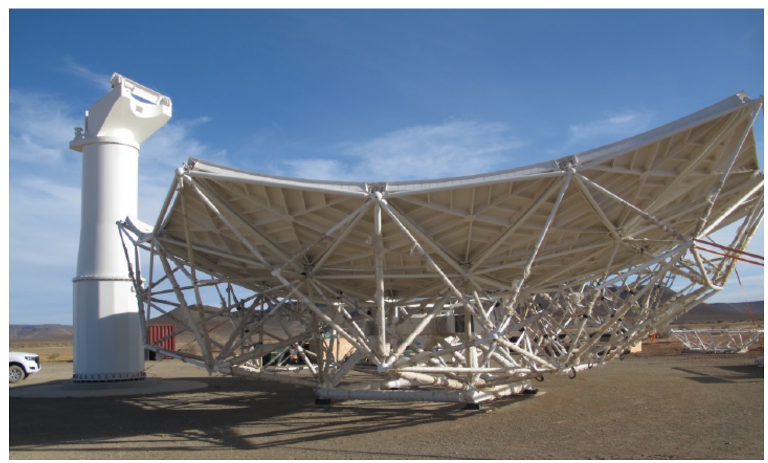

Soon to be lifted on the pedestal

Construction status

Picture credit: MPIfR, SKAO

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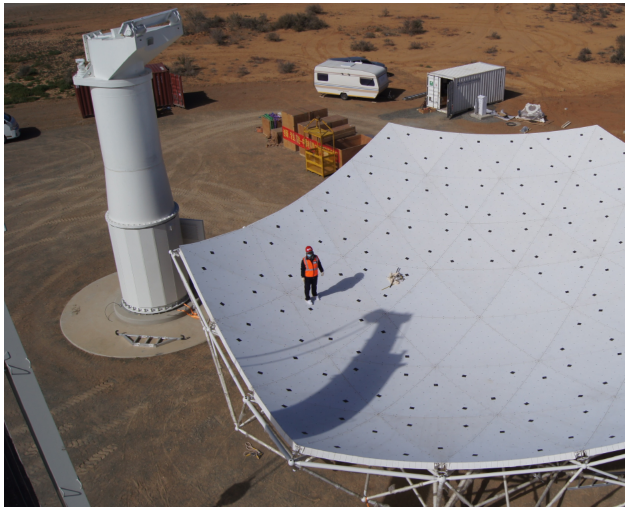
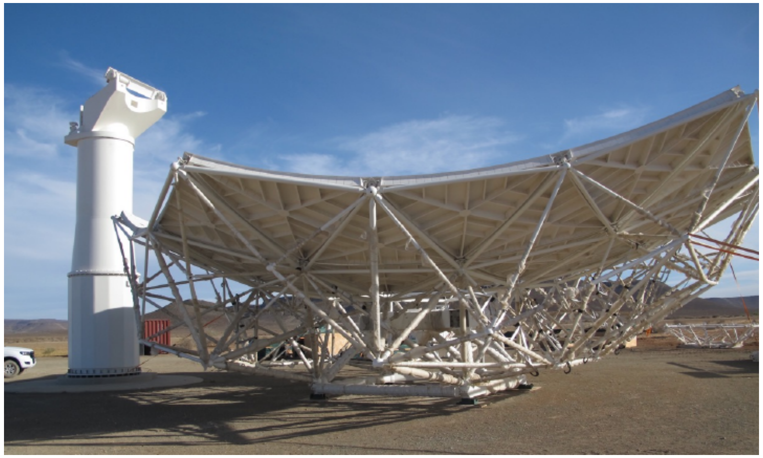


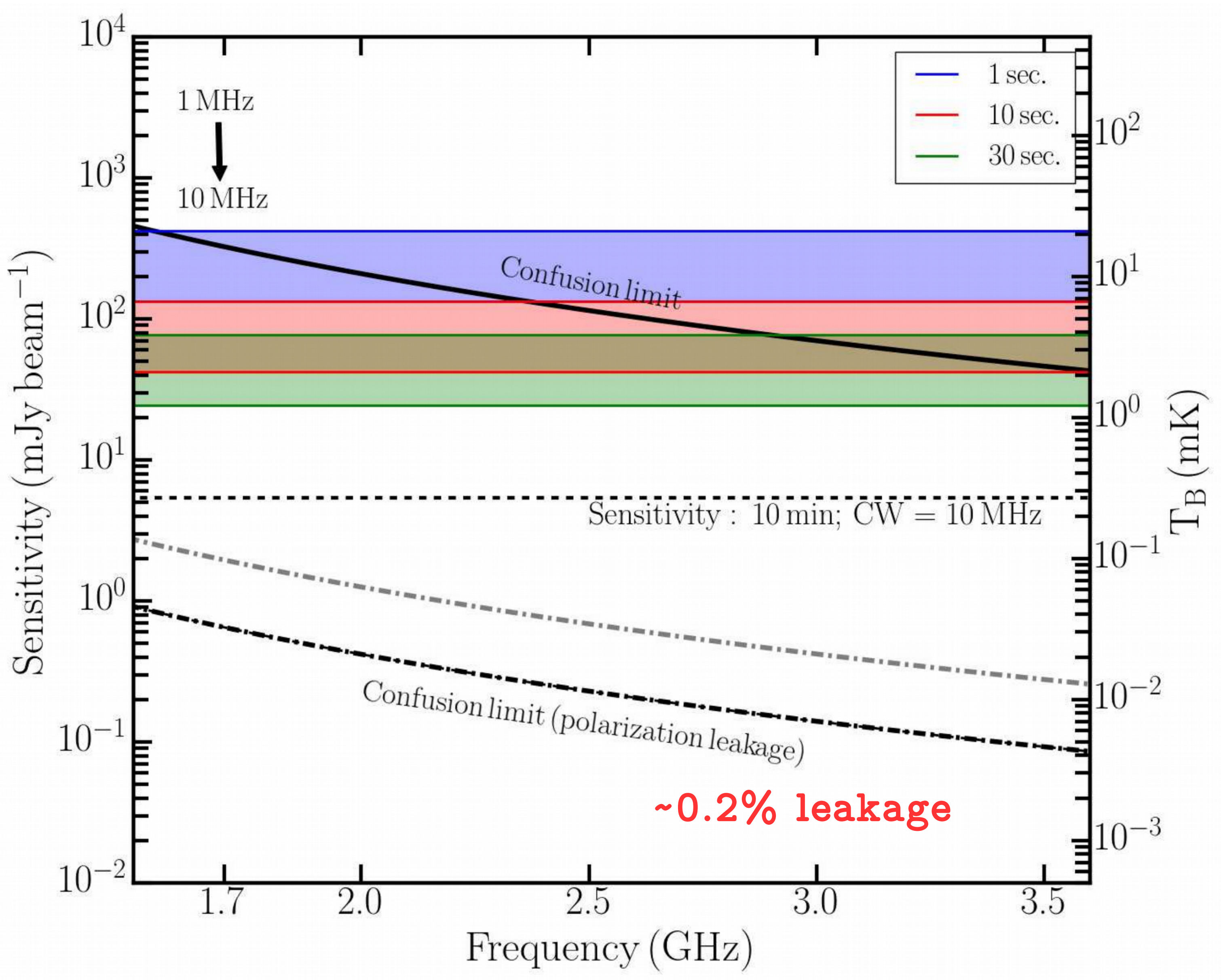


Soon to be lifted on the pedestal

April 2019: Handover to the SKAO for Critical Design Review.

August/September 2019: Science commissioning and observations.

Expected sensitivity



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.

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**)

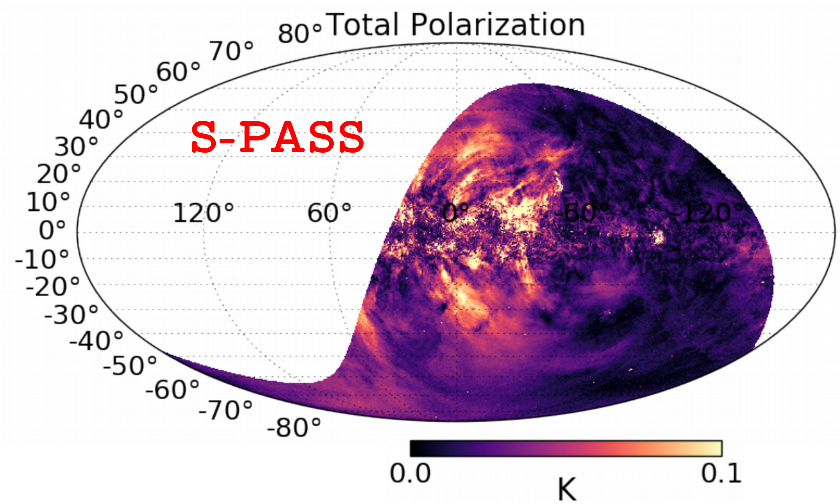
Stokes Q, U, I Deciphering Survey (SQUIDS)

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*)

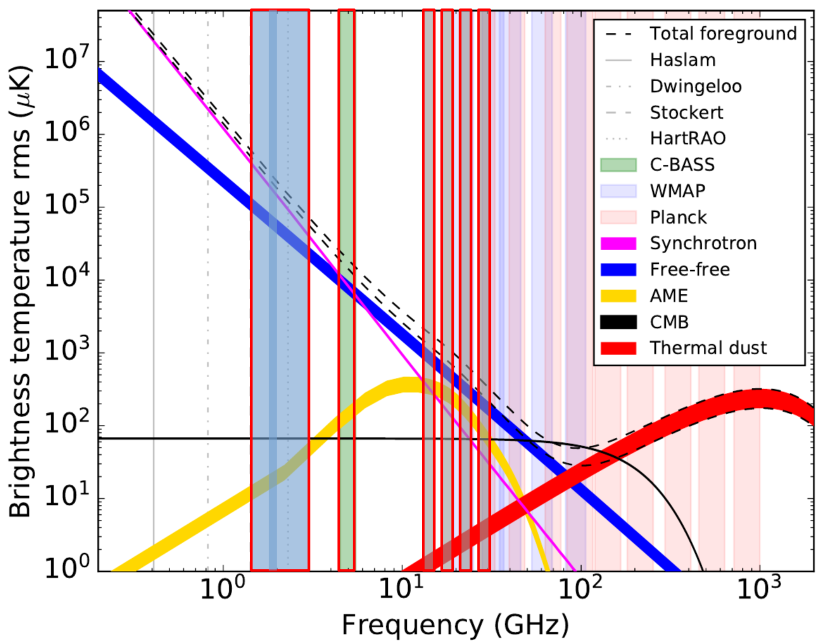


Krachmalnicoff, et al., 2018, A&A

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

Synchrotron + Free—free foregrounds

Fig. from C-BASS, MNRAS, 2018



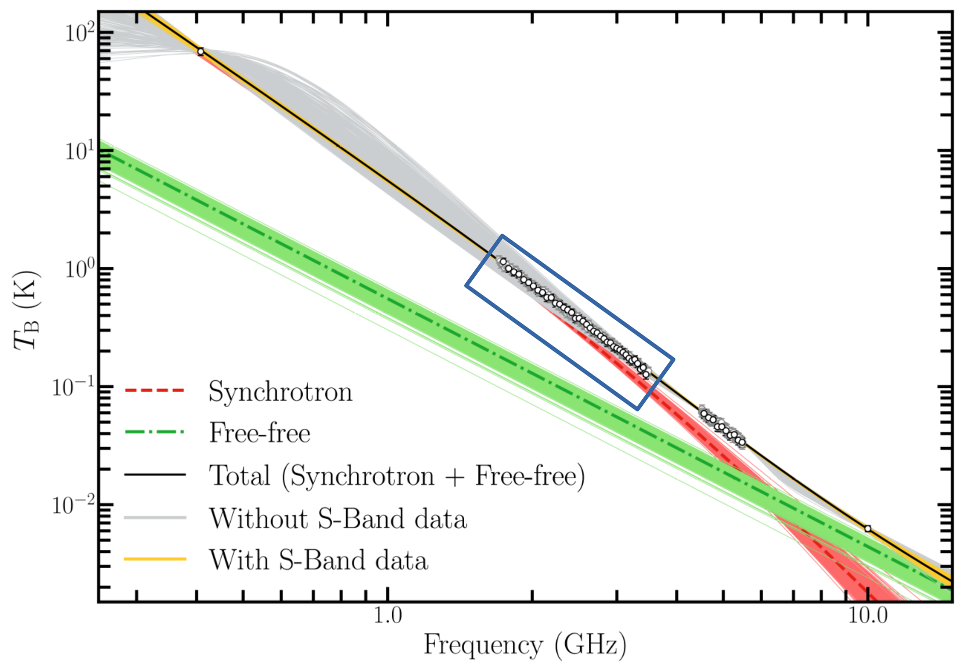
Total Intensity

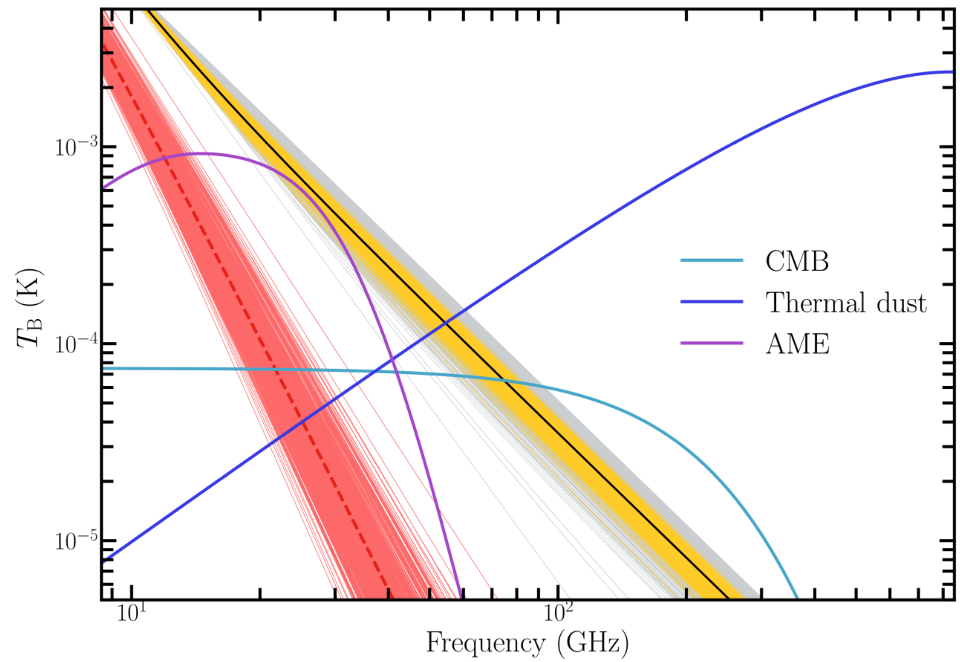
Synchrotron $T_{\mathrm{B}} = T_{\mathrm{B,syn}}\, \nu^{\alpha + C\, \log(\nu/\nu_{\mathrm{br}})}$

Kogut, 2012, ApJ

Free-free **Template @33 GHz or Hα**

Synchrotron + Free—free foregrounds



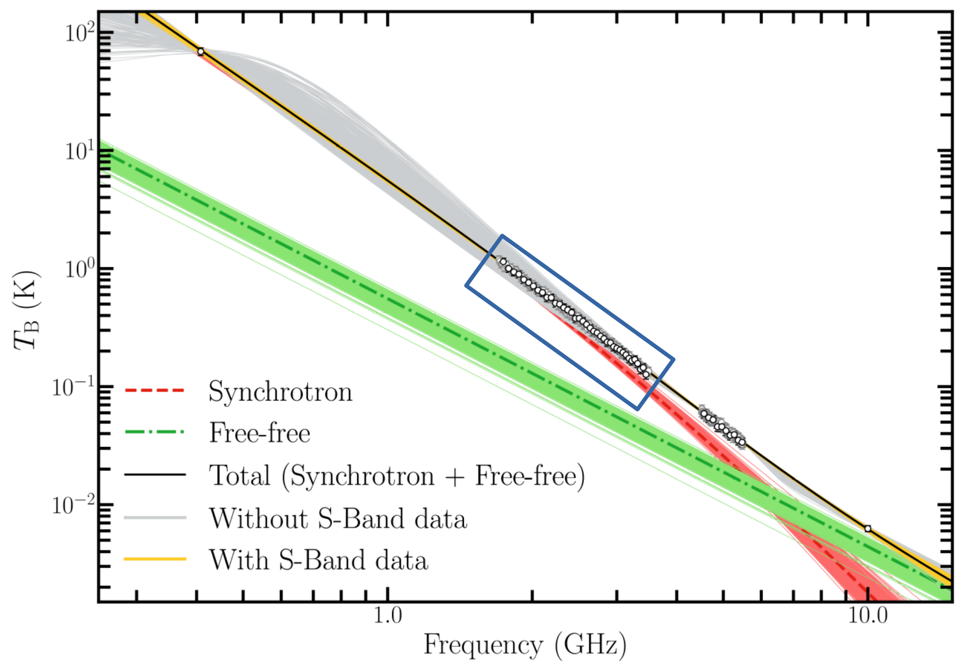


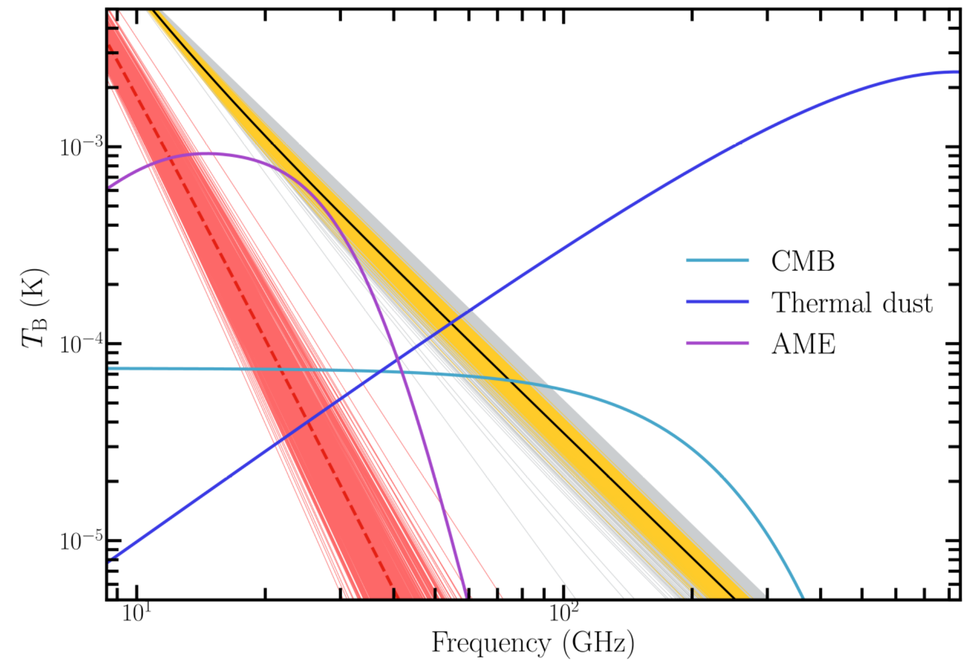
Constrain synchrotron + free—free emission from low frequencies alone!

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

Basu, Schwarz, Klöckner, von Hausegger, Kramer, Wieching, Burkhart, MNRAS, *under review*

Synchrotron + Free—free foregrounds





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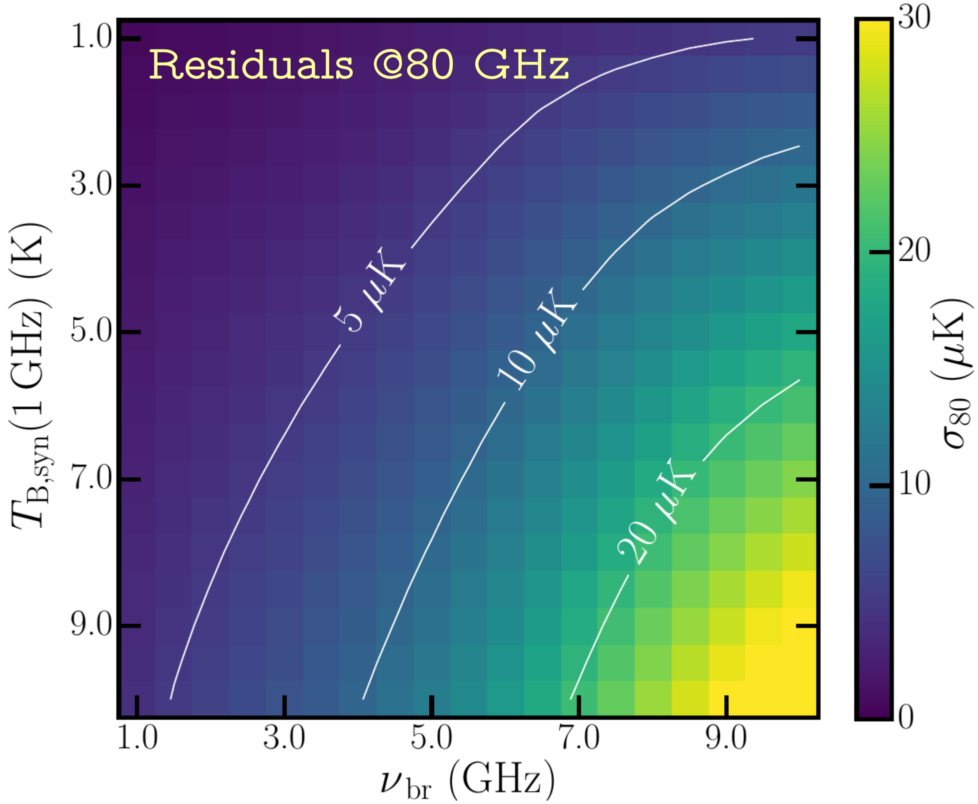
D ~ 10^{28} cm^2/s

L ~ 1–2 kpc, B ~ 10 μG → ν_{br} ~ 3–10 GHz.

Basu, Schwarz, Klöckner, von Hausegger, Kramer, Wieching, Burkhart, MNRAS, *under review*

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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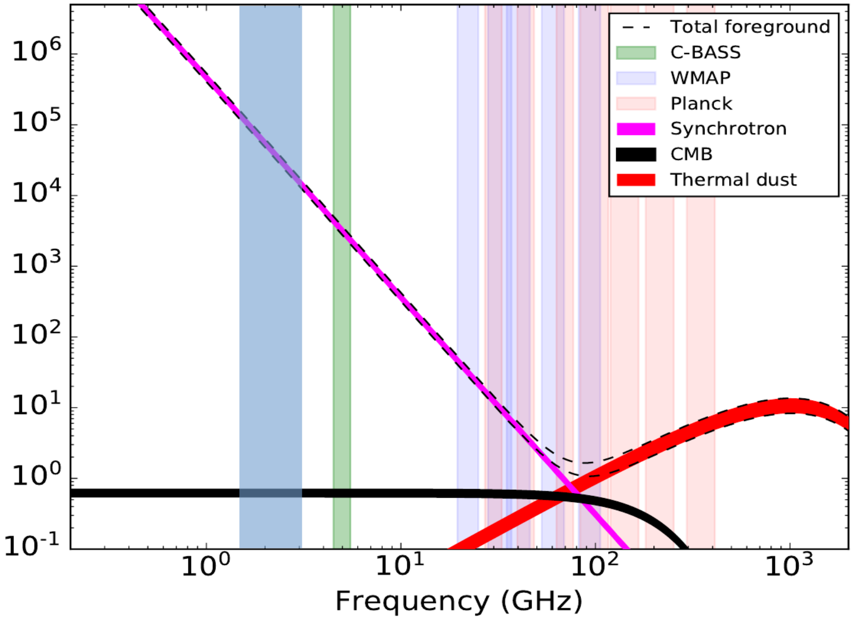
Synchrotron polarization

Fig. from C-BASS, MNRAS, 2018



Total Intensity

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

Kogut, 2012, ApJ

Polarized Intensity

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

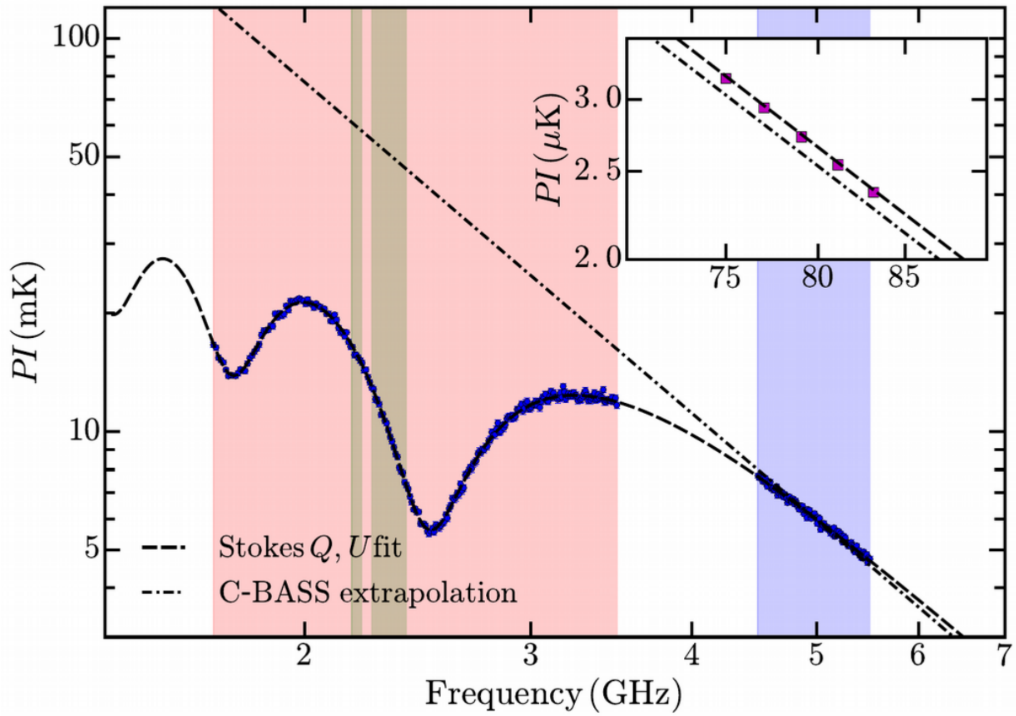
$$p(\lambda) = p_0 \frac{\sin \mathrm{FD}\,\lambda^2}{\mathrm{FD}\,\lambda^2}\, e^{2\,i\,(\theta_0 + \frac{1}{2}\,\mathrm{FD}\,\lambda^2)}.$$

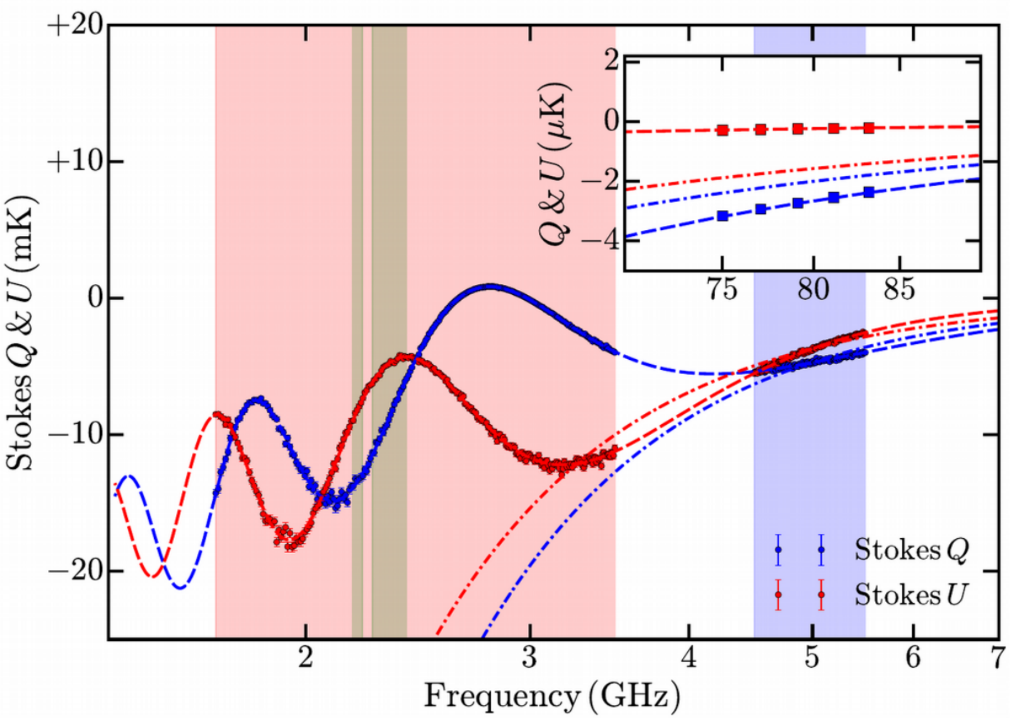
$$p(\lambda) = p_0\, e^{2\,i\,\theta_0} \left(\frac{1 - \exp[-(2\,\sigma_{\mathrm{FD}}^2\,\lambda^4 - 2\,i\,\mathrm{FD}\,\lambda^2)]}{2\,\sigma_{\mathrm{FD}}^2\,\lambda^4 - 2\,i\,\mathrm{FD}\,\lambda^2} \right).$$

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

Sokoloff et al., 1998, MNRAS

Stokes Q,U fitting & *SQUIDS*





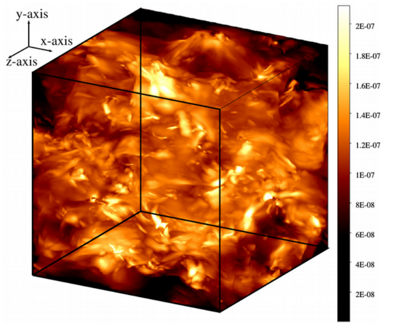
SQUIDS

C-BASS

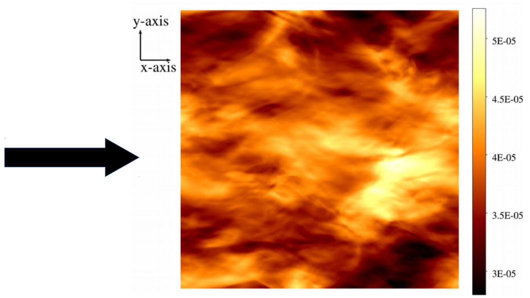
S-PASS

Synthetic observations:

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



MHD



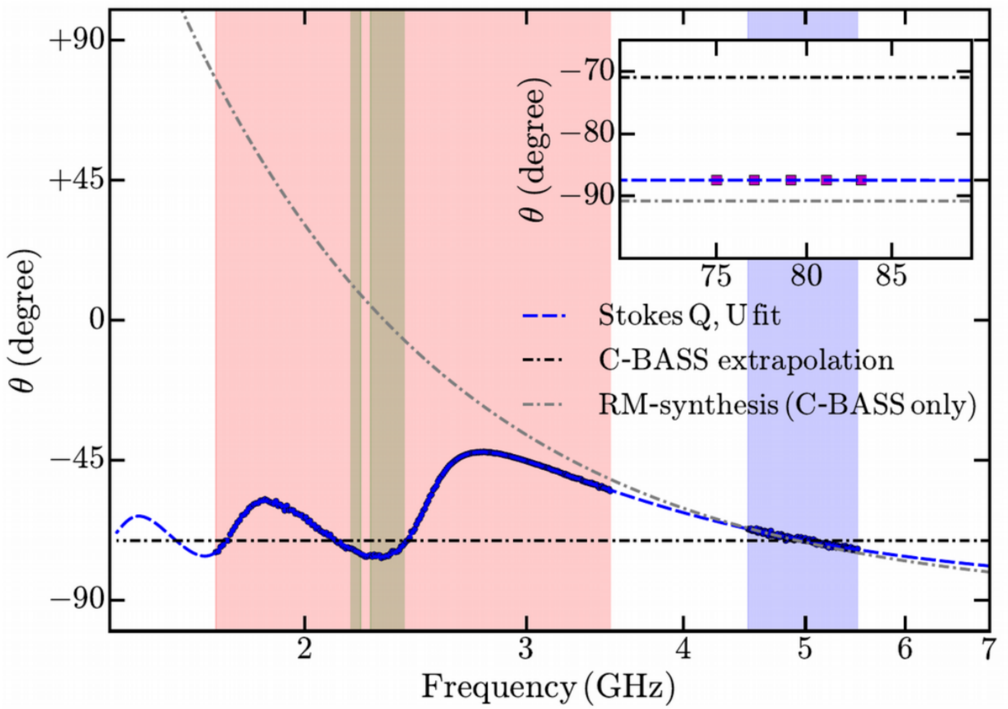
Polarized intensity

Gaensler et al., 2011, Nature

Burkhart et al., 2009, ApJ

Koley & Roy, 2019, MNRAS

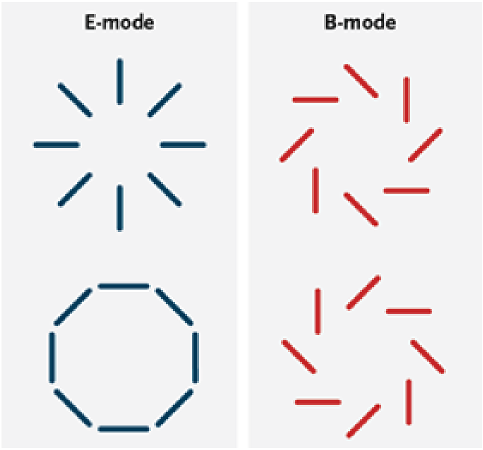
Stokes Q, U fitting & *SQUIDS*



SQUIDS

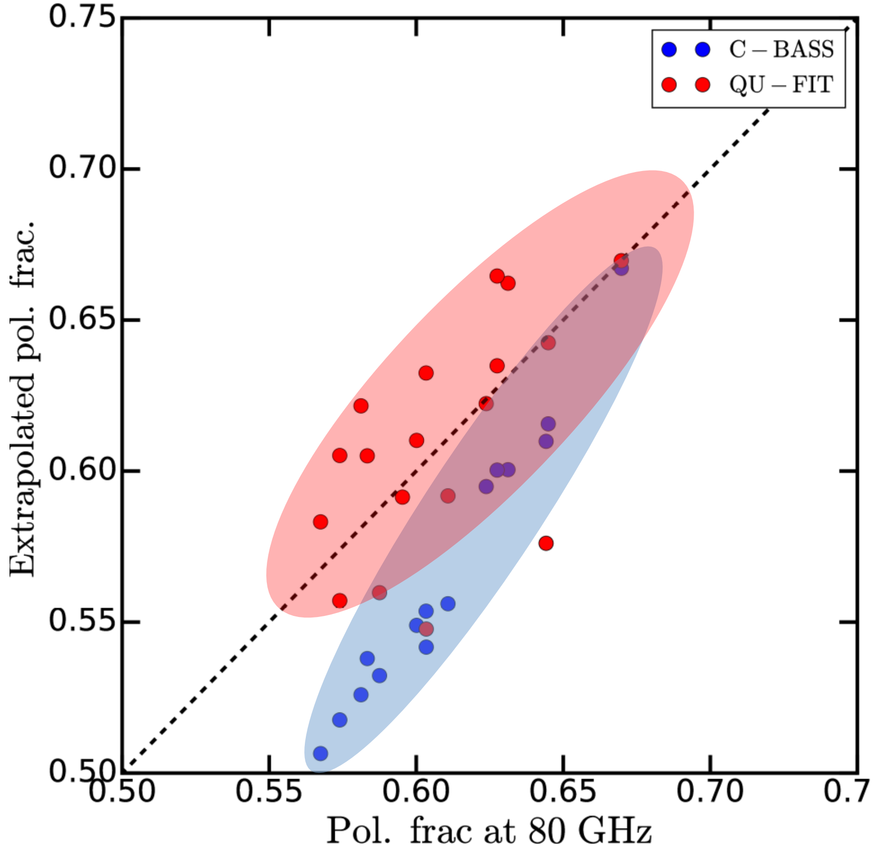
C-BASS

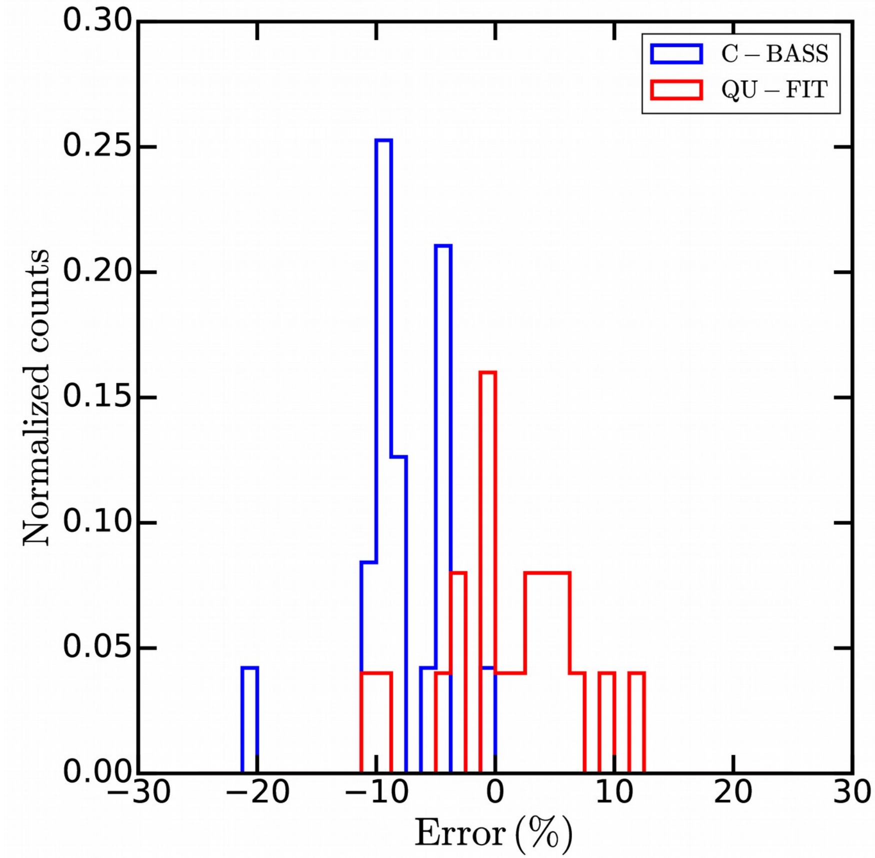
S-PASS



Precise angle measurement is critical to avoid mixing!

Extrapolation to CMB





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

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

Basu, Schwarz, Klöckner, von Hausegger, Kramer, Wieching, Burkhart, MNRAS, *under review*

Summary

– *SQUIDS* will provide state-of-the-art measurement of the the polarized synchrotron foreground and crucial insights into Galactic magnetic fields.

– New techniques of analyzing the polarized emission, such as, Stokes Q,U fitting, is essential for proper estimation of foreground contribution to the CMB.

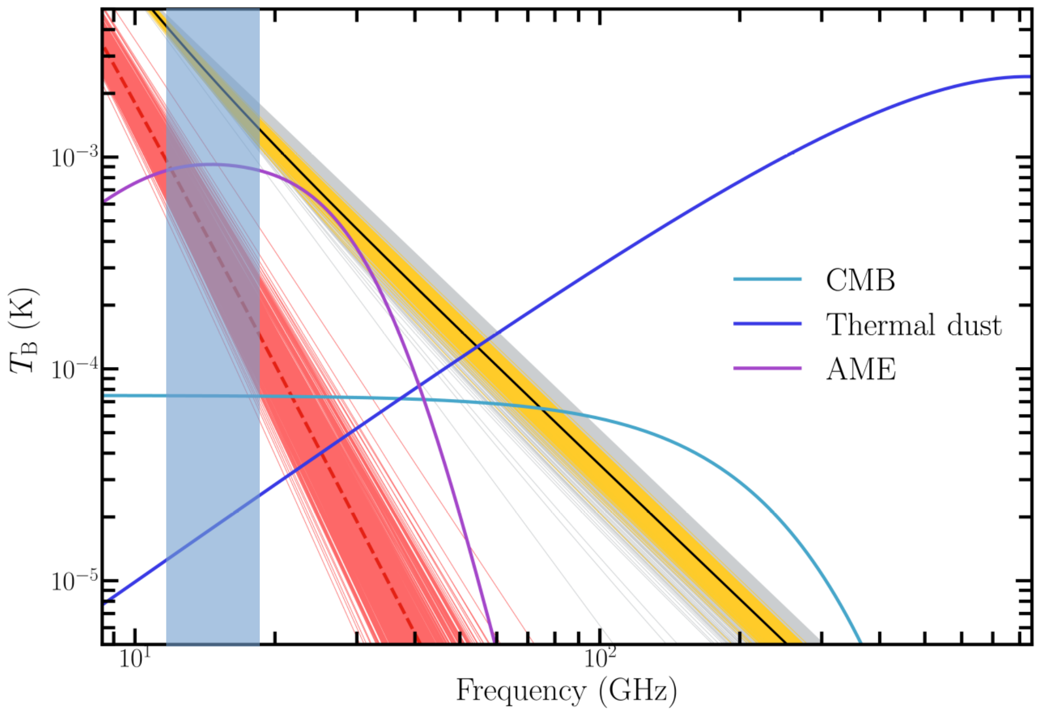
– *SQUIDS* at S-band (1.7–3.5 GHz) will enable us to determine the total and polarized synchrotron emission using physically motivated models.

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

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

– *SQUIDS* will open a large fraction of the sky for power spectrum analysis at the largest angular-scales.

Future: Scientific



Ku-band receiver covers the 12–18 GHz range

Cryogenically cooled; Single pixel feed

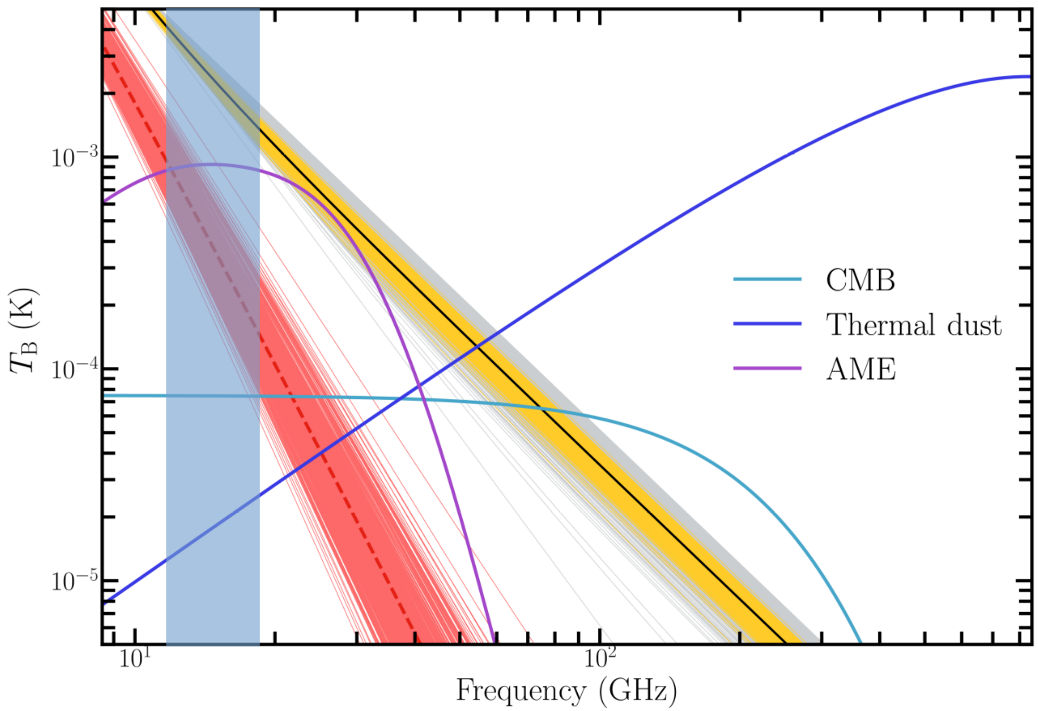
Perform QUIJOTE-like counterpart of the Southern sky.

Tracer of AME!

Resolution: 4.5–7 arcmin!

Compliment South Pole Telescope at low frequencies!

Future: Technology development



Ku-band receiver covers the 12–18 GHz range
Cryogenically cooled; Single pixel feed

→ Multi pixel feed
(Phased Array Feed)

↓

R&D and feasibility studies
for single dish application!

Full sky survey: ~120 000 hours!

Future: Resources

GPU based backend programming [high priority!]

Data rate: 4 Stokes × 1.75 GHz BW sampling × 12-bit digitizer

~ 21 GB/sec @ Nyquist [Raw dump]

Data transfer

Uncalibrated data rate:

4 Stokes × 2048 channels × 256 ms sampling × 64-bit float

~ 1 GB/hour + Metadata => **2.3 Mbps internet connection**

Data archive

Raw data: 23 PB/survey run

Uncalibrated data products/survey run:

~ 0.3 TB + Metadata

Total: 6 TB × 5 (analysis overheads) = 30 TB

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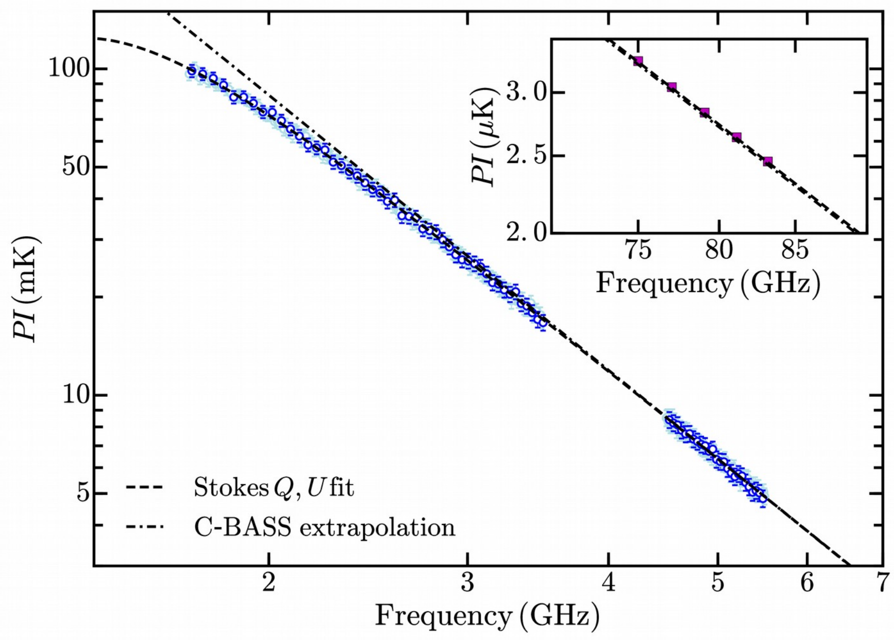
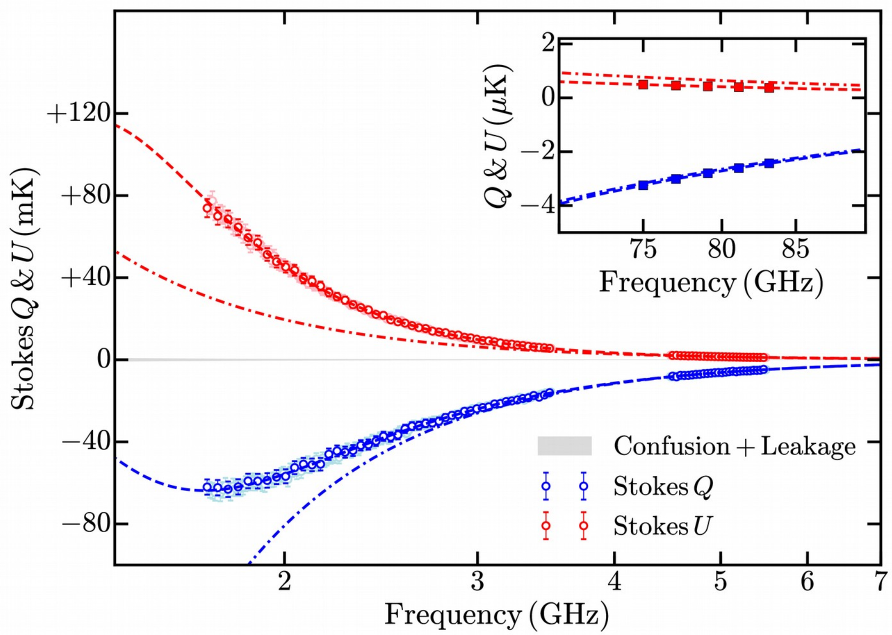
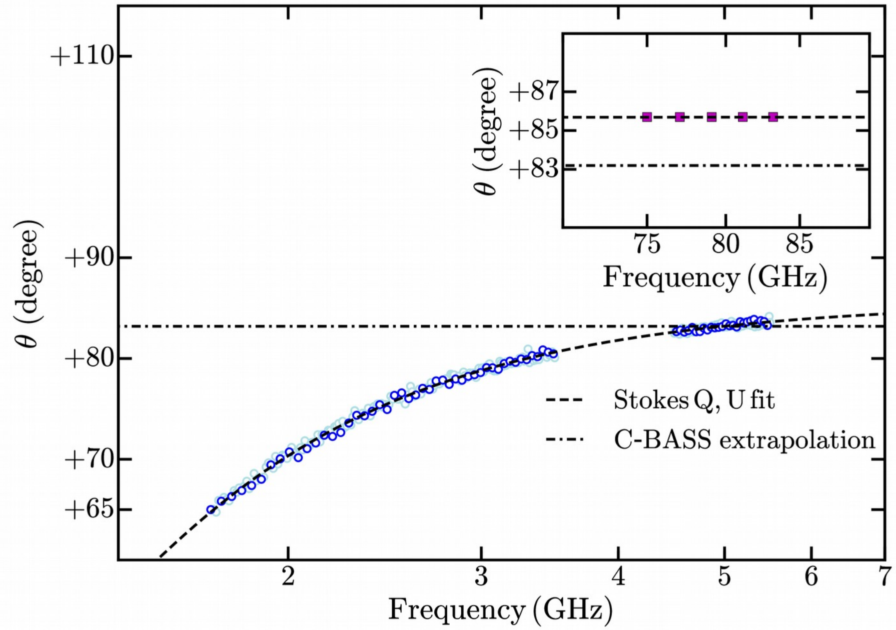
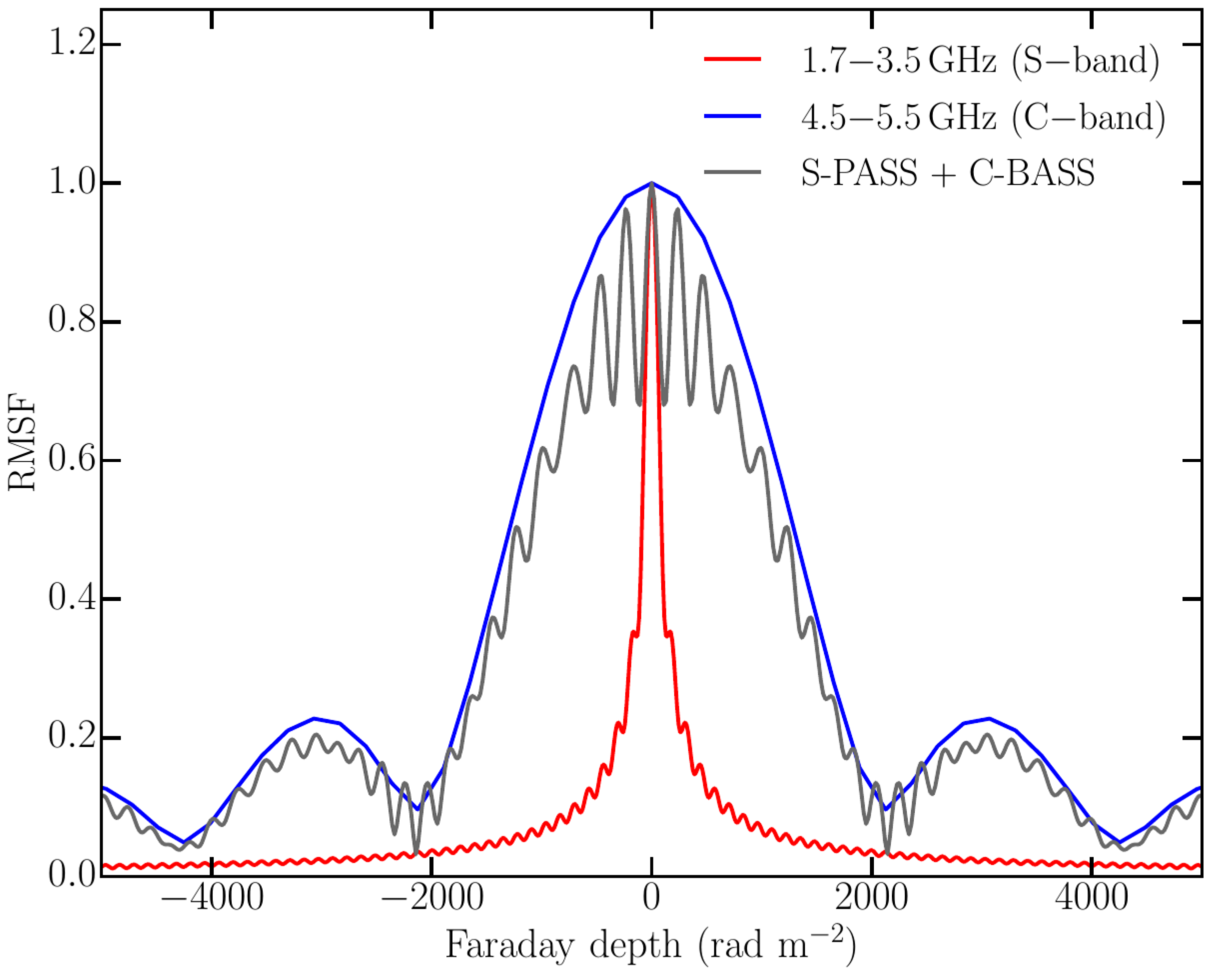
Low depolarization (high Gal. Lat.)







RMSF



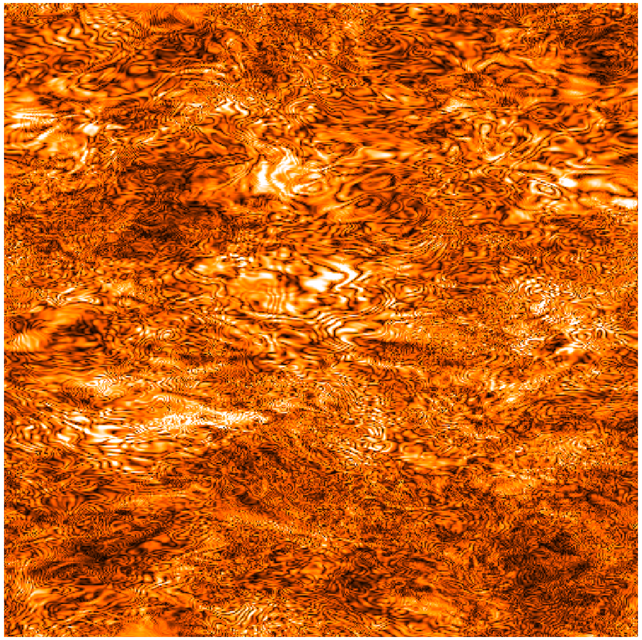
FD resolution:

SQUIDS ~ 150 rad m^{-2}

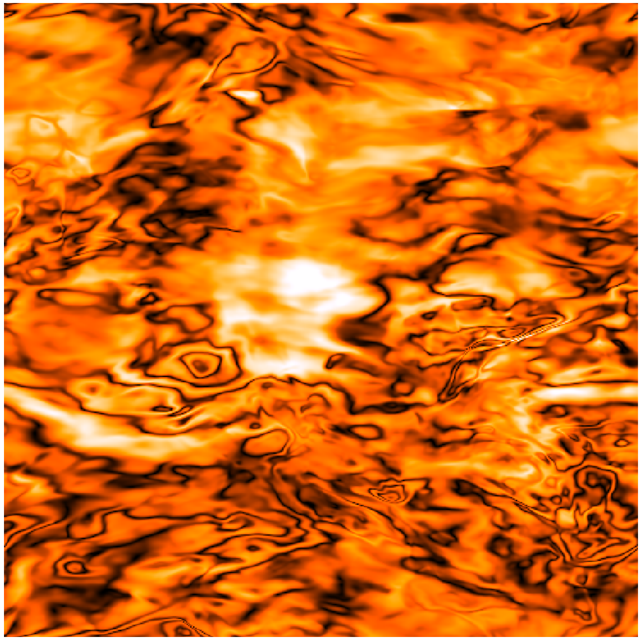
C-BASS ~ 2500 rad m^{-2}

Faraday depolarization

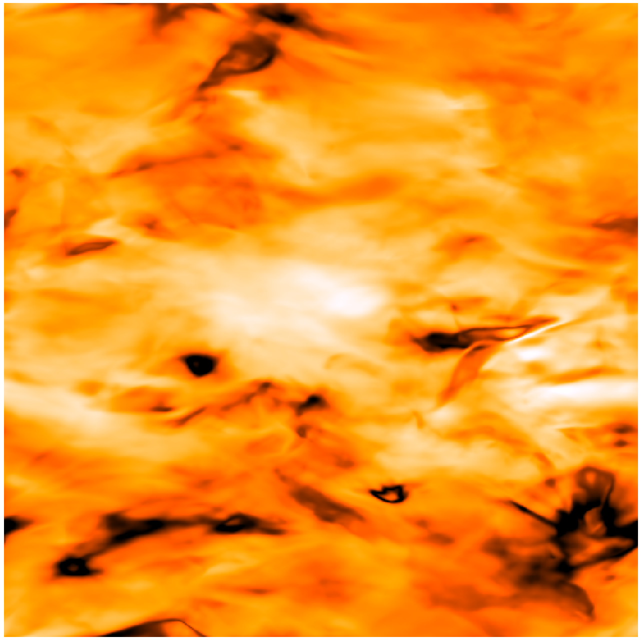
500 MHz



1.5 GHz

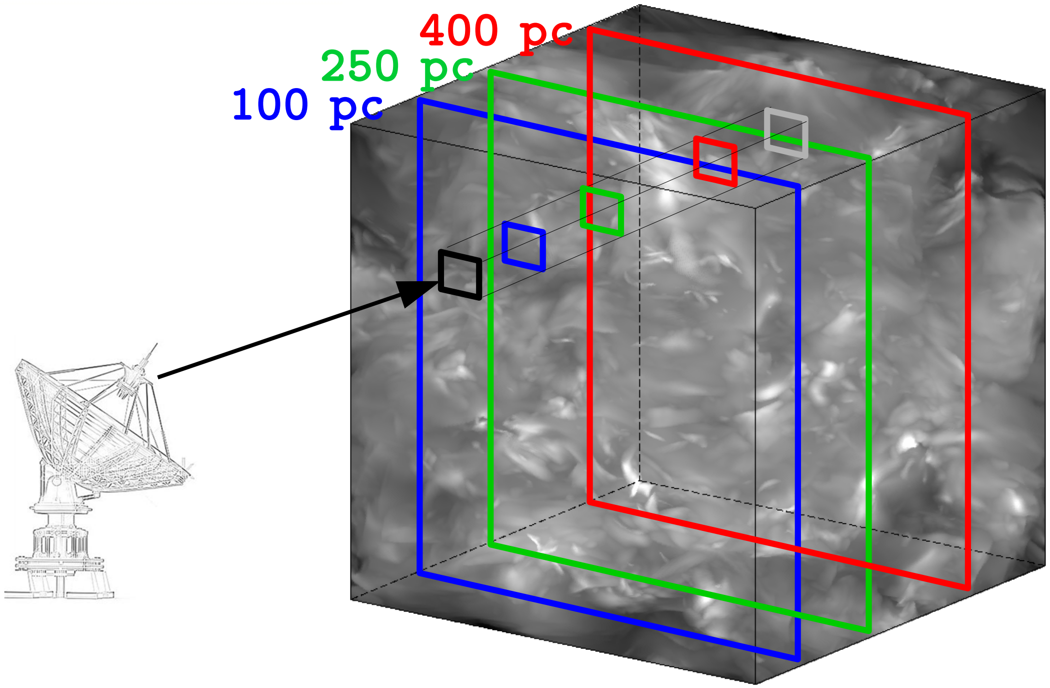


3 GHz



Basu et al. (in prep.)

Polarization horizon



Basu et al. (in prep.)