Radio Frequency Interference Working Group

May 2022 update

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CMB-S4

RFI and CMB-S4 - Overview

- CMB-S4 is seeking to dramatically increase sensitivity in frequency bands that are largely unprotected, and are being increasingly utilized for telecommunications.
- Our remote sites are especially vulnerable to satellite transmissions, which are dramatically increasing in frequency (how often, as large constellations are launched) and frequency (GHz, as lower bands ‘fill up’).
- Nothing that exists today is a major concern to CMB-S4, but it is an extremely complex and evolving situation.
    - This is not entirely new - we also have significant experience in understanding and mitigating RFI.
    - Other fields of astronomy have even more complicated concerns.
    - Background reading: Astro2020 Ch 3.4.2, JASON Report from 2020
    - Join our working group if you want to learn more!

RFI working group

Charge:

- Study the RFI environment relevant to CMB-S4 now, and that expected over the life of the project, for South Pole and Chilean sites.
- Consider ground-based and satellite transmitters, and regulatory constraints.
- Assess the potential impact on CMB-S4 observations.
- Produce a report summarizing findings and recommendations

Email: rfi@cmb-s4.org

Google Drive: https://drive.google.com/drive/folders/1es8Kce8slN0Q0vWV6tnz96FfpOJGX7OV

Confluence:
https://cmb-s4.atlassian.net/wiki/spaces/XPI/pages/275513374/Radio+Frequency+Interference

Meetings are currently Fridays, 3:30-4pm EDT

Defining RFI

- In-band
  - Ka-band satellite transmissions
  - Harmonics of microwave or millimeter-wave transmitters
- Out-of-band
  - RFI from lower-frequency emissions: UHF radios, microwave comms, WiFi
- Directly coupled
  - Absorbed in detectors, producing bolometric response
- Indirectly coupled
  - RFI pickup in readout system

Recent efforts by RFI group

Several efforts with widely varying audiences

- (*In progress*) CMB-S4 RFI draft report
- Recommendations for IceCube on wireless communications in Dark Sector
- (*In progress*) Bolometer document for ITU
- (*In progress*) SPIE presentation and proceedings on potential impacts of RFI on CMB-S4
- (*In progress/upcoming*) Identifying important areas of study for CMB-S4 related to RFI, and starting more detailed studies

RFI draft report

- Detailed internal document for CMB-S4
- Work-in-progress, including relevant calculations and recommendations
- https://docs.google.com/document/d/1vRD9Sm88K-YSxBhlARh34x2ch3zbJVWwdMG38eaW6hY/edit#heading=h.i0ji8db57ghi
- Current recommendations
  - Coordinate with sponsoring agency spectrum managers
  - Coordinate at site level with local spectrum management efforts
  - Coordinate with broader efforts within astronomy on RFI
  - Conduct a data risk assessment
  - Implement site monitoring to detect and identify local RFI
  - Implement data monitoring for early identification of interference

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In Progress

Recent work: IceCube comms in Dark Sector at Pole

- RFI group talked with members of IceCube collaboration on options for communication for IceCube Gen2
- Were considering communication options to the extended array (located in Dark Sector), including wireless and wired
    - Need > 800 MHz to avoid contaminating their own signal, were considering an 850 MHz LTE network
- RFI group provided historical information on power levels for **out-of-band** harmful interference at 450 MHz and 2-15 GHz, and calculations for power levels for proposed LTE deployment relative to known interference levels

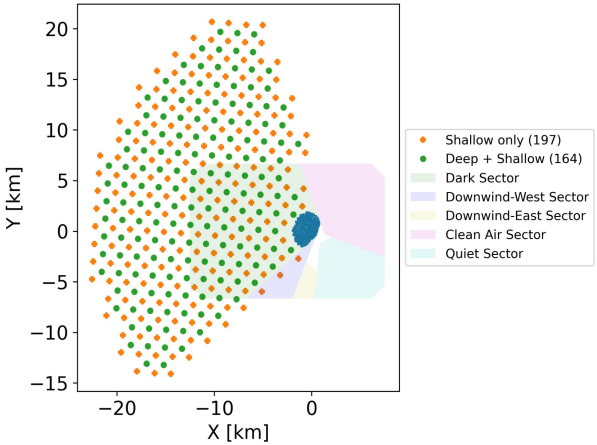
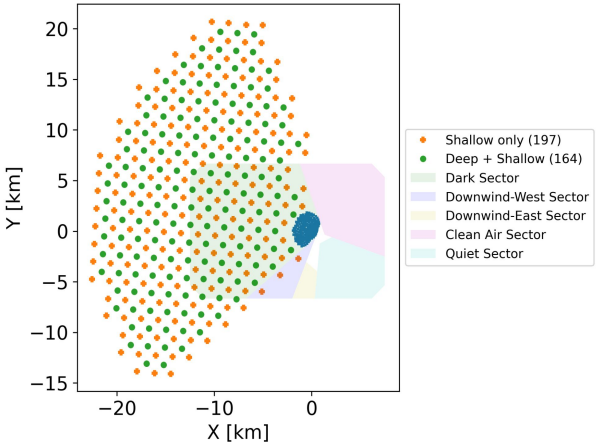


Figure from IceCube team with potential layout of Gen2 array

Recent work: IceCube comms in Dark Sector at Pole

- **Conclusions**
  - Proposed network would significantly exceed interference threshold informed by past experience.
  - IceCube will pursue other options, including wired (probably necessary for power anyway).
  - IceCube team is now aware of susceptibility of CMB instruments to out-of-band interference.



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Bolometer Document for WP7D

- Developed a document describing CMB instruments and established observing sites for Working Party 7D on radio astronomy
- **Part of a larger US effort on engaging more astronomers in this process**
- Group includes government, radio astronomers and industry
- Document first introduced at September 2021 ITU meeting
- Accepted as working document at September 2021 and April 2022 meetings

Intentionally narrow scope

Documenting existence and characteristics of **broadband bolometer instruments** operating at **established observing sites** with **exceptionally good millimeter-wave atmospheric transmission**
(i.e. South Pole, Chajnantor)

Radiocommunication Study Groups

Received: 18 April 2022

Source: Annex 8 of 7D Chairman's Report (7D/120)

Document 7D/153-E
19 April 2022
English only

United States of America

UPDATES TO WORKING DOCUMENT TOWARD A PRELIMINARY DRAFT NEW REPORT

Technical and operational characteristics of bolometers operating in the millimeter-wave regime

Introduction

Bolometric detectors see use in many astronomical instruments conducting cutting-edge research, including investigation of the Cosmic Microwave Background, which is a blackbody peaking at 160 GHz. Bolometers are thermal detectors that incoherently detect incident power, and thus are inherently sensitive to all incident radiation. When millimeter-wave bolometric detectors are cooled to sub-Kelvin temperatures, their noise performance is limited only by the unavoidable photon noise from Earth's atmosphere. Therefore, to reach the sensitivity necessary for astronomical surveys, these bolometric receivers operate with years-long integration times from dry, high-altitude sites, with broad frequency bandwidths designed to fit within atmospheric transmission windows. Suitable observing sites for these instruments have historically been limited to exceptionally dry sites in extremely geographically remote areas, including the South Pole and the Chajnantor plateau in the high Atacama Desert in Chile.

CMB measurement bands and key observables

CMB measurement band *	RAS allocations and identifications	Scientific observable	Typical band-integrated atmospheric power [pW]**	Typical atmospheric noise equivalent power [aW $Hz^{-1/2}$]**
21.5-30 GHz	22.01-22.21 GHz, 23.07-23.12 GHz (**5.149**) 23.6-24 GHz (Primary **5.340**)	Galactic synchrotron; CMB blackbody	0.6	10
30-47.5 GHz	31.2-31.3 GHz (**5.149**) 31.3-31.8 GHz (Primary **5.340**, **5.534A**) 36.43-36.5 GHz (**5.149**) 42.5-43.5 GHz (Primary **5.149**, **5.551H**, **5.551I**)	Galactic synchrotron; CMB blackbody	2.6	30
72 -118 GHz	76-77.5 GHz (Primary **5.149**) 77.5-79 GHz (Secondary **5.149**) 79-86 GHz (Primary **5.149**) 86-92 GHz (Primary **5.340**) 92-94 GHz (Primary **5.149**) 94-94.1 GHz (Secondary **5.562A**) 94.1-100 GHz (Primary **5.149**) 100-102 GHz (Primary **5.340**) 102-105 GHz (Primary **5.149**) 105-109.5 GHz (Primary **5.149**, **5.562B**) 109.5-111.8 GHz (Primary **5.340**) 111.8-114.25 GHz (Primary **5.149**, **5.562B**) 114.25-116 GHz (Primary **5.340**)	CMB blackbody; Galactic synchrotron	3	40
122-180 GHz	123-128.33 GHz (Secondary US211) 128.33-128.59 GHz, 129.23-129.49 GHz (Secondary **5.149**) 129.49-130 GHz (Secondary US211) 130-134 GHz (Primary **5.149**, **5.562S**) 134-136 GHz (??) 136-148.5 GHz (Primary **5.149**) 148.5-151.5 GHz (Primary **5.340**) 151.5-158.5 GHz (Primary **5.149**) 164-167 GHz (Primary **5.340**) 168.59-168.93 (**5.149**) 171.11-171.45 GHz (**5.149**) 172.31-172.65 GHz (**5.149**) 173.52-173.85 GHz (**5.149**)	CMB blackbody; Sunyaev-Zeldovich (SZ) effect decrement	6	50

Values for
pwv = 0.5 mm
elevation = 50 deg.

Bolometer Instruments at South Pole Dark Sector

Telescope or Project Name	Instrument, Years of Operation Detector Count	Band Center [GHz]	Fractional Bandwidth	Antenna beamwidth [deg.]	Directivity gain [dBi]	Instrument Field of View [deg.]	Primary Aperture [m]	Unshielded Aperture [m]
BICEP/Keck	BICEP1 2006-2008 98 detectors	95 150 220		0.93 0.6 0.42			0.25	0.25
	BICEP2 2010-2012 512 detectors	150					0.26	0.26
	Keck Array 2012-2019 1824 detectors	95 150 220 270		0.72 0.5 0.35 0.28			0.26	0.26
	BICEP3 2015-current 2560 detectors	95		0.4			0.52	0.52
	BICEP Array 2020-current 32,724 detectors	30 40 95 150 220 270	0.27	1.27 0.95 0.4 0.25 0.18 0.15			0.52	0.52

Help us fill in these tables!

https://docs.google.com/spreadsheets/d/1wHQ5naSTYBENNYsI2yaZ74GkH6ULKQN2KKg4w1ptYmc/edit#gid=1535144499

SPIE proceedings on RFI and CMB-S4

- **Title**: “Assessing Potential Impacts of Radio Frequency Interference on the CMB-S4 Cosmic Microwave Background Survey”
- Author list and abstract
- **Goal**: Describe the unique vulnerability of CMB instruments to RFI, and current and historical efforts to mitigate impacts.
- Discuss specific concerns for baseline design of CMB-S4, and aspects of instrument design where we expect to do better than prior experience
    - Areas where design improves include smaller window apertures, staggered MF bands, better shielding, better sidelobe performance
- Discuss potential mitigation strategies and impacts on survey sensitivity

Identifying important areas of study for CMB-S4 related to RFI

- Recommendations from RFI report
  - Coordinate with sponsoring agency spectrum managers
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Identifying important areas of study for CMB-S4 related to RFI

- Recommendations from RFI report
  - Coordinate with sponsoring agency spectrum managers
    - See today's talk by **Ashley Vanderley** and **Jonathan Williams**
  - Coordinate at site level with local spectrum management efforts
    - Showed recent example with IceCube
    - Draft updates for South Pole ASMA-5 Dark Sector RFI Spectrum Management regulations
  - Coordinate with broader efforts within astronomy on RFI
    - Participation in Working Party 7D on Radio Astronomy
    - Participation in workshops on RFI issues, and events organized by new *IAU Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference*
    - Our next speaker, **Mike Peel**, is also engaged in many of these broader efforts
  - Conduct a data risk assessment
    - Progress on initial steps in today's talk by **Ian Birdwell**
  - Implement site monitoring to detect and identify local RFI
    - Have experience with BICEP/Keck RFI monitor, duplicating setup for Chajnantor
  - Implement data monitoring for early identification of interference