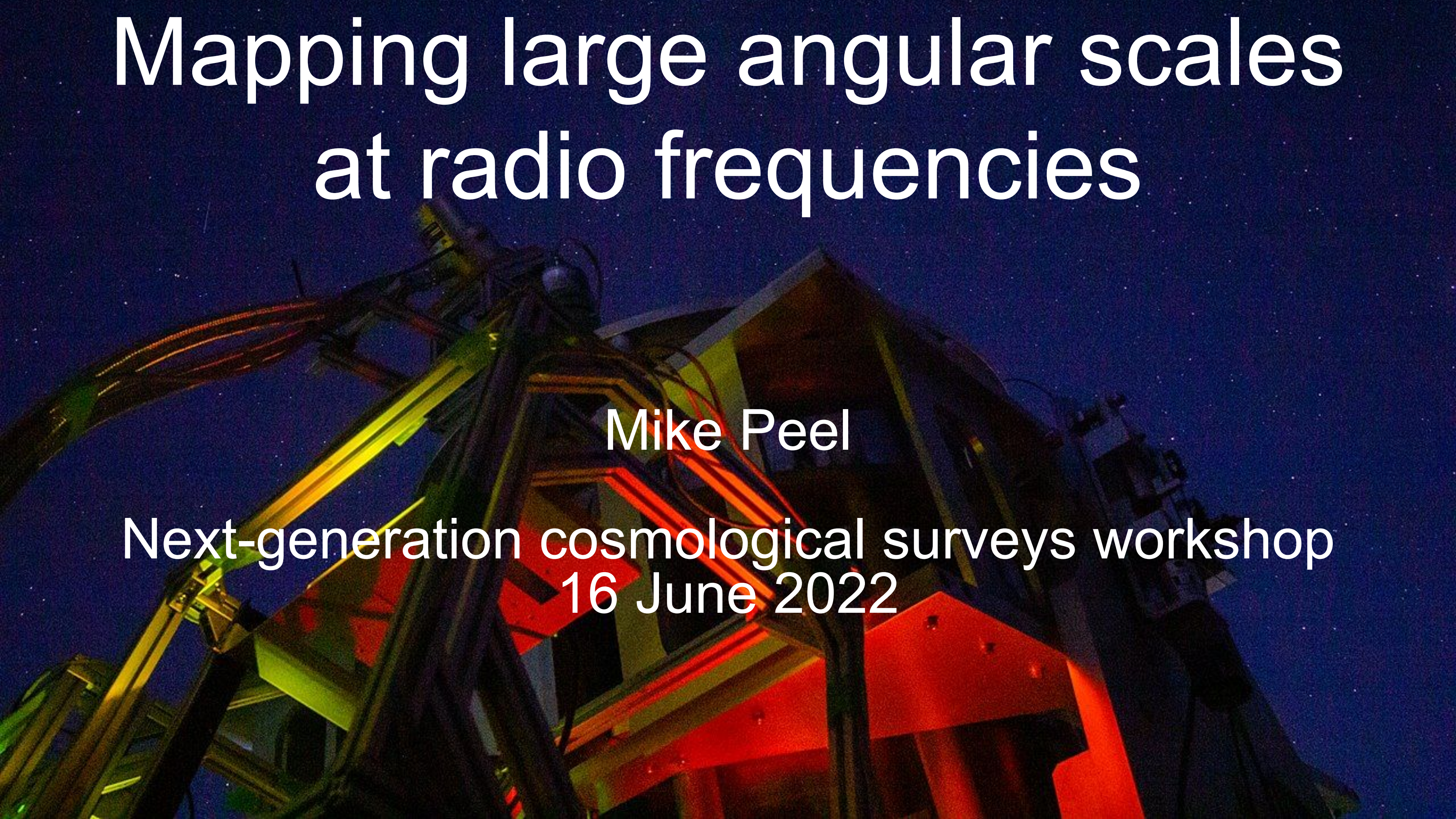
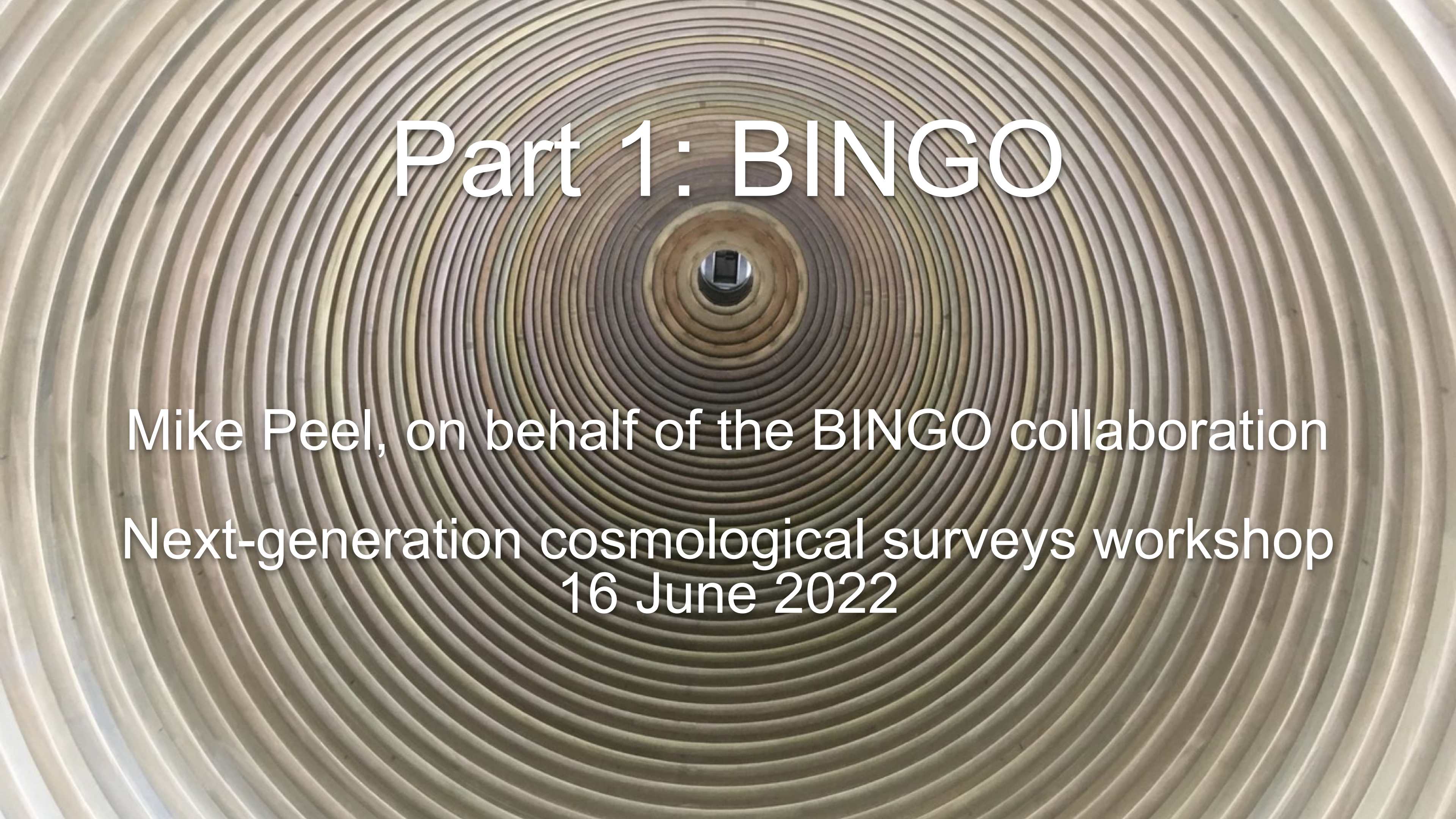
Mapping large angular scales at radio frequencies



Mike Peel

Next-generation cosmological surveys workshop
16 June 2022



Part 1: BINGO

Mike Peel, on behalf of the BINGO collaboration

Next-generation cosmological surveys workshop
16 June 2022

Collaboration (Brasil, UK, China + others)

University of São Paulo, Brazil
- Elcio Abdalla [Professor, Core (P.I.)]
- Elisa Ferreira [Professor, Builder]
- Alessandro Marins [PhD., Builder]
- Andreia Pereira de Souza [Technician, Support]
- Carlos Otobone [Undergrad., Team]
- Gustavo B. Silva [MSc., Team]
- Jordany Vieira [PhD., Team]
- Juliana F. R. dos Santos [Undergrad., Team]
- Karin Fornazier [Pos-doc, Builder]
- Pablo Mota [PhD., Team]
- Rafael M. G. Ribeiro [MSc., Team]

Instituto Nacional de Pesquisas Espaciais, Brazil
- Carlos Alexandre Wuensche [Professor, Core]
- Thyrso Villela [Professor, Core]
- Camila Paiva Novaes [Pos-doc, Builder]
- Cesar Strauss [Technician, Team]
- Eduardo Mericia [PhD., Team]
- Frederico Vieira [PhD., Team]
- Luiz Reitano [Technician, Support]
- Telmo Machado [Technician, Support]
- Vincenzo Liccardo [Pos-doc, Builder]

Universidade Federal de Campina Grande, Brazil:
- Luciano Barosi [Professor, Core]
- Amilcar Queiroz [Professor, Core]
- Francisco Brito [Professor, Core]
- Alexandre Jean René Serres [Professor, Team]
- Edmar Candeia Gurjão [Professor, Team]
- João Rafael Lucio dos Santos [Professor, Team]
- Marcelo Vargas dos Santos [Professor, Builder]
- Victor I. Afonso [Professor, Team]

University College London, UK
- Filipe Abdalla [Professor, Core]

University of Manchester, UK
- Chris Radcliffe [Technician, Team]
- Clive Dickinson [Professor, Team]
- Ian Browne [Professor, Team]
- Mathieu Remazeilles [Pos-doc, Team]
- Richard Battye [Professor, Team]
- Stuart Harper [Pos-doc, Team]

Technische Universität München, Germany
- Ricardo Landim [Pos-doc, Builder]

Max Planck Institute, Germany
- Elisa Ferreira [Professor, Builder]

Instituto de Astrofísica de Canarias, Spain
- Mike Peel [Pos-doc, Team]

University of Roma, Italy
- Giancarlo de Gasperis [Professor, Team]

Laboratoire AstroParticule et Cosmologie, France
- Jacques Delabrouille [Professor, Team]

Institut d'Astrophysique Spatiale, France
- Bruno Maffei [Professor, Team]

ETH Zurich, Switzerland
- Christian Monstein [Professor, Team]

Center for Gravitation and Cosmology, Yangzhou University, China
- Bin Wang [Professor, Core]
- André Costa [Professor, Builder]
- Larissa Santos [Professor, Builder]
- Xue Zhang [Professor, Team]
- Yu Sang [Professor, Team]

School of Physics and Astronomy, Shanghai Jiao Tong University, China
- Bin Wang [Professor, Core]
- Chenxi Shan [PhD, Team]
- Haiguang Xu [Professor, Team]
- Linfeng Xiao [PhD, Team]
- Yongkai Zhu [PhD, Team]
- Zhenghao Zhu [PhD, Team]

University of Science and Technology of China
- Cheng Feng [Professor, Team]

Liao Ning Normal University, China
- Weiqiang Yang [Professor, Team]

CTPU Institute for Basic Science, Korea
- Jiajun Zhang [Pos-doc, Builder]

bingotelescope.org

Publications at bingotelescope.org/results/

Science goals

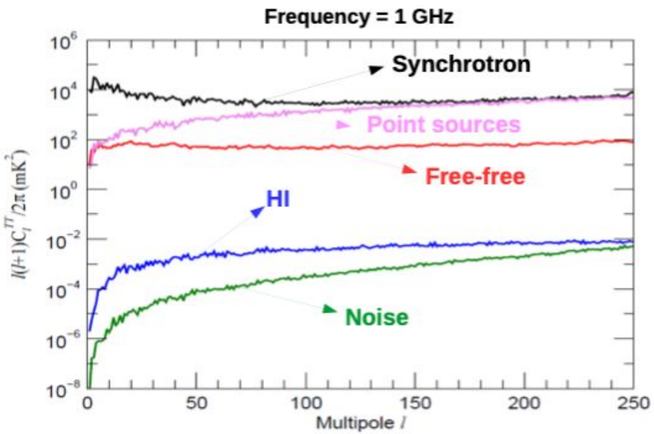
Use Intensity Mapping to statistically detect galaxies

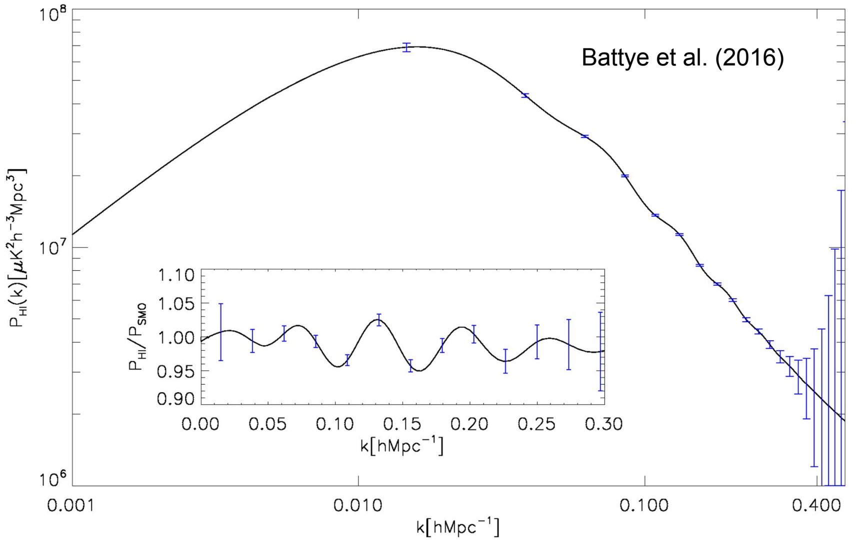
Measure Baryon Acoustic Oscillations from H1 21cm line

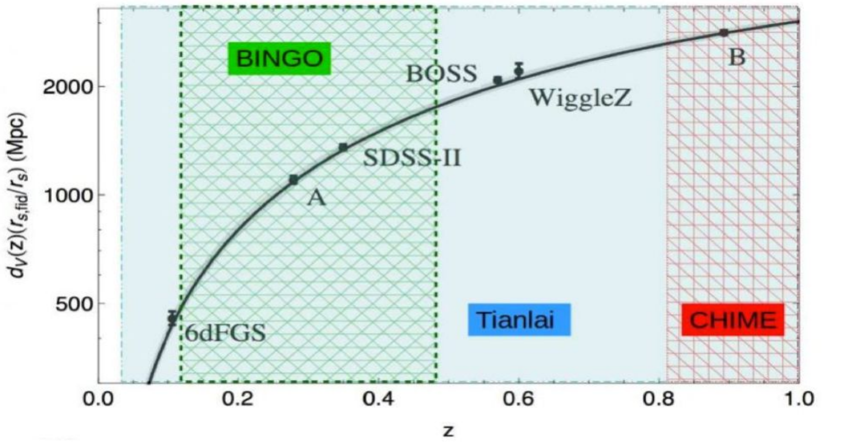
Constrain cosmological parameters, particularly dark energy, in the redshift range 0.1-0.5

(Also measure a lot of foreground emission - but want to subtract that!)

(See Tianyue's talk earlier at this meeting!)







Design

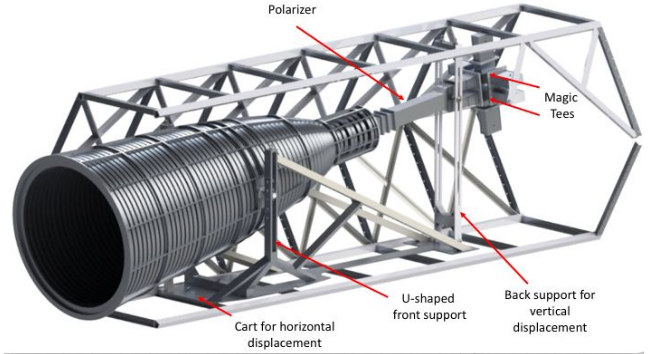
40m-class crossed-dragone radio telescope (original design on the right)

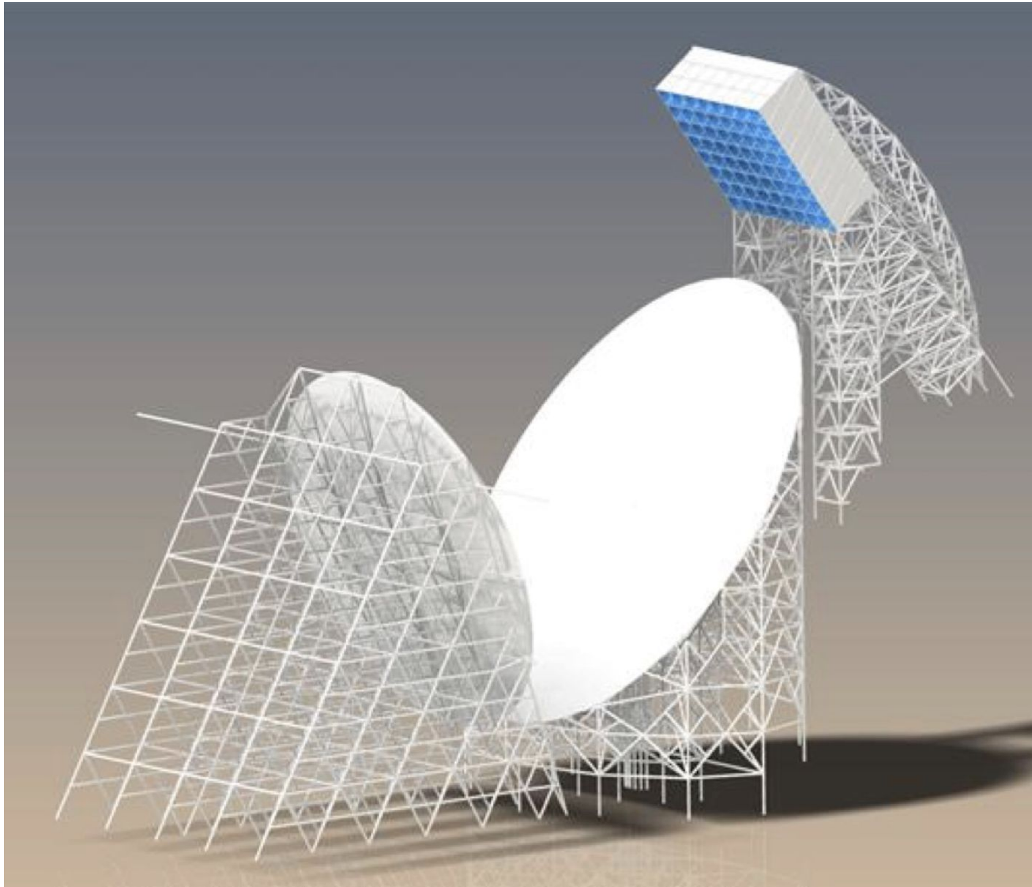
Very clean optics - necessary for accurate foreground separation

~0.5° resolution on the sky
(optimal resolution - like CMB telescopes)

Large focal plane (~15x15°)

Huge horns: 1.8x4.7m feed





Scan strategy

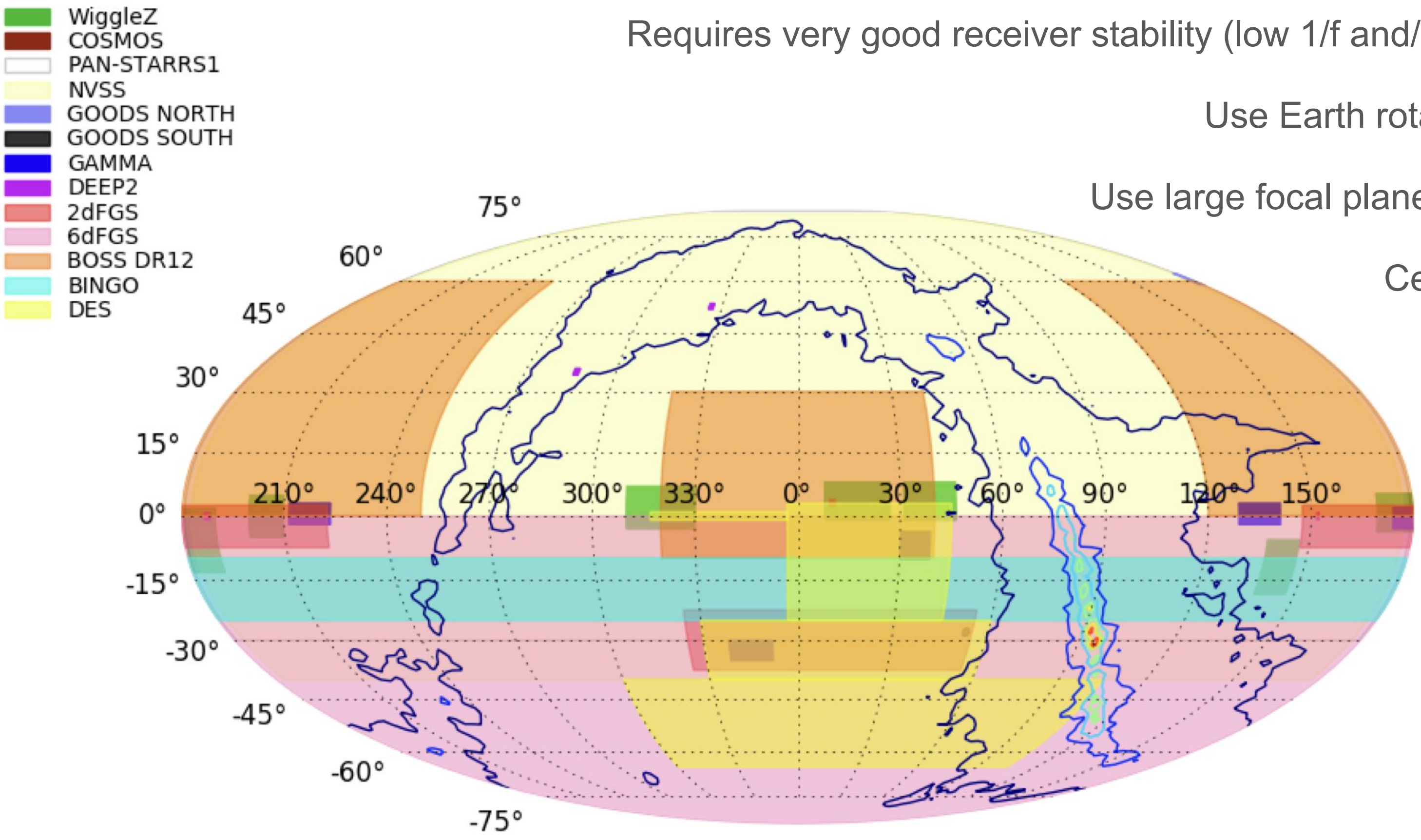
Completely static telescope! (a lot cheaper + fewer systematics)

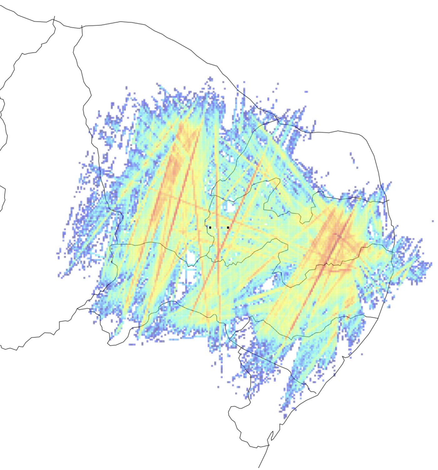
Requires very good receiver stability (low 1/f and/or correlation receivers)

Use Earth rotation to map 360° in RA

Use large focal plane to get ~15° declination

Centered around -15° dec





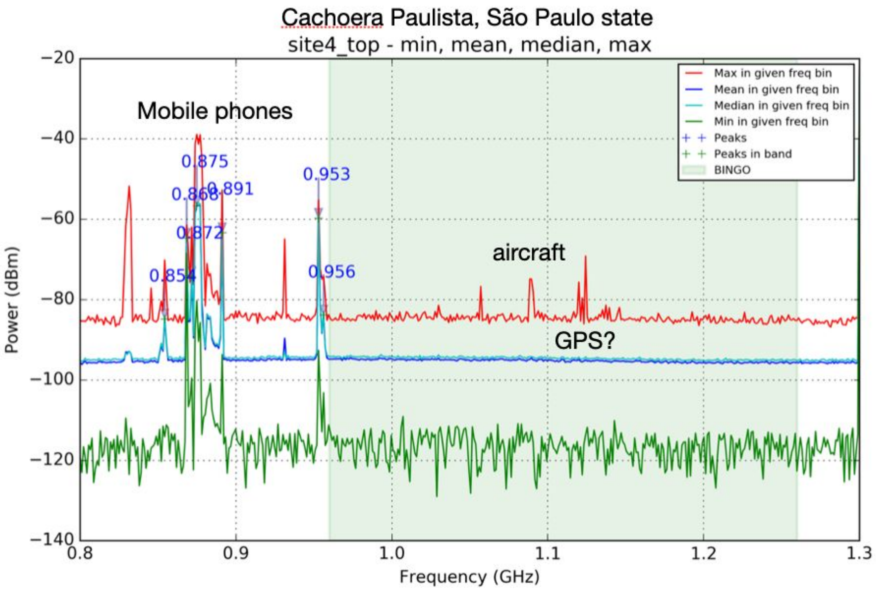
Site selection

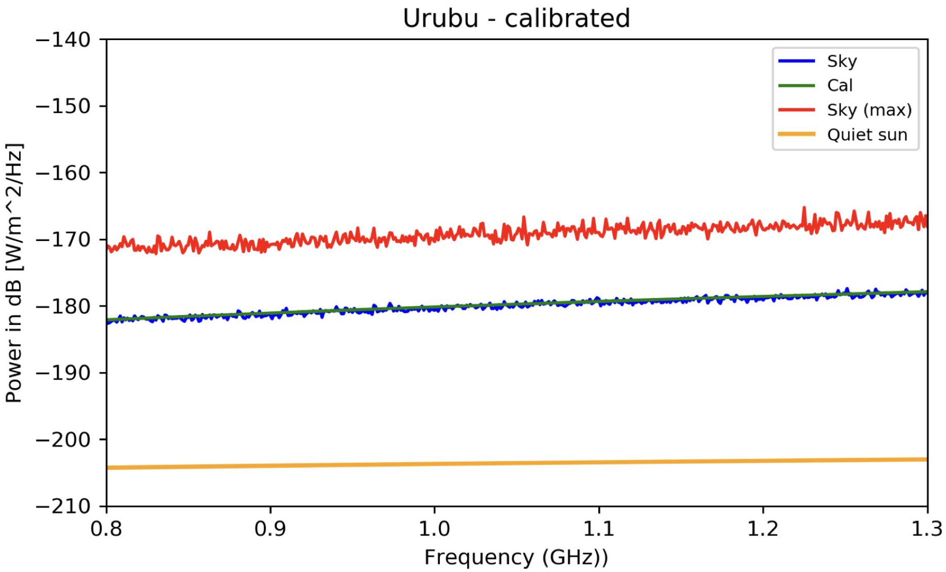
Requires very low RFI - far away from everyone!

Mobile phone signal covers a lot of brazil!

Can't avoid aircraft or GPS satellites...

(Peel et al. 2019)





Timeline

2012: Project conception (Battye et al.)

2016: Project funded (FAPESP)

2018: Site selected

2019: Site clearance started

2020: horn/front end production

2021: Mirrors funded (Paraíba)

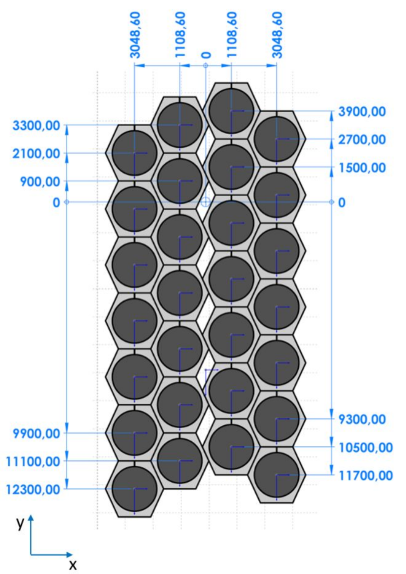
2021: Outrigger in operation

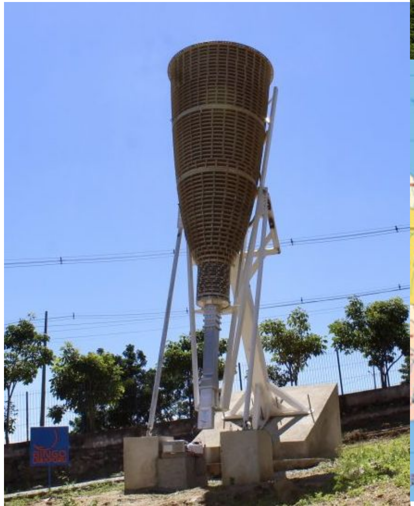
2022: Construction funded (FINEP)

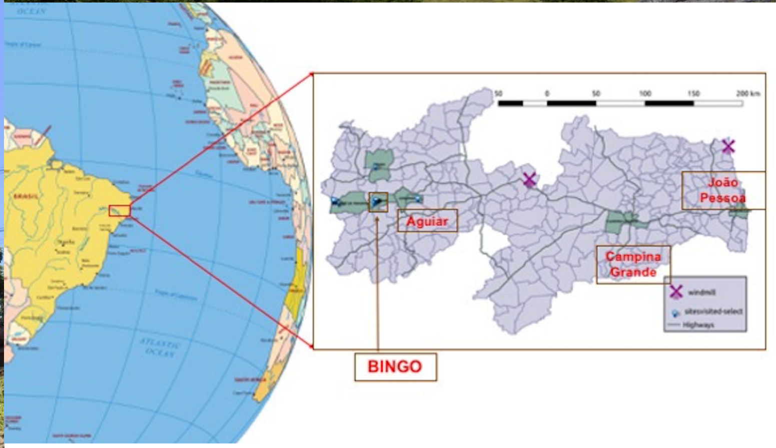
2022: Start of construction

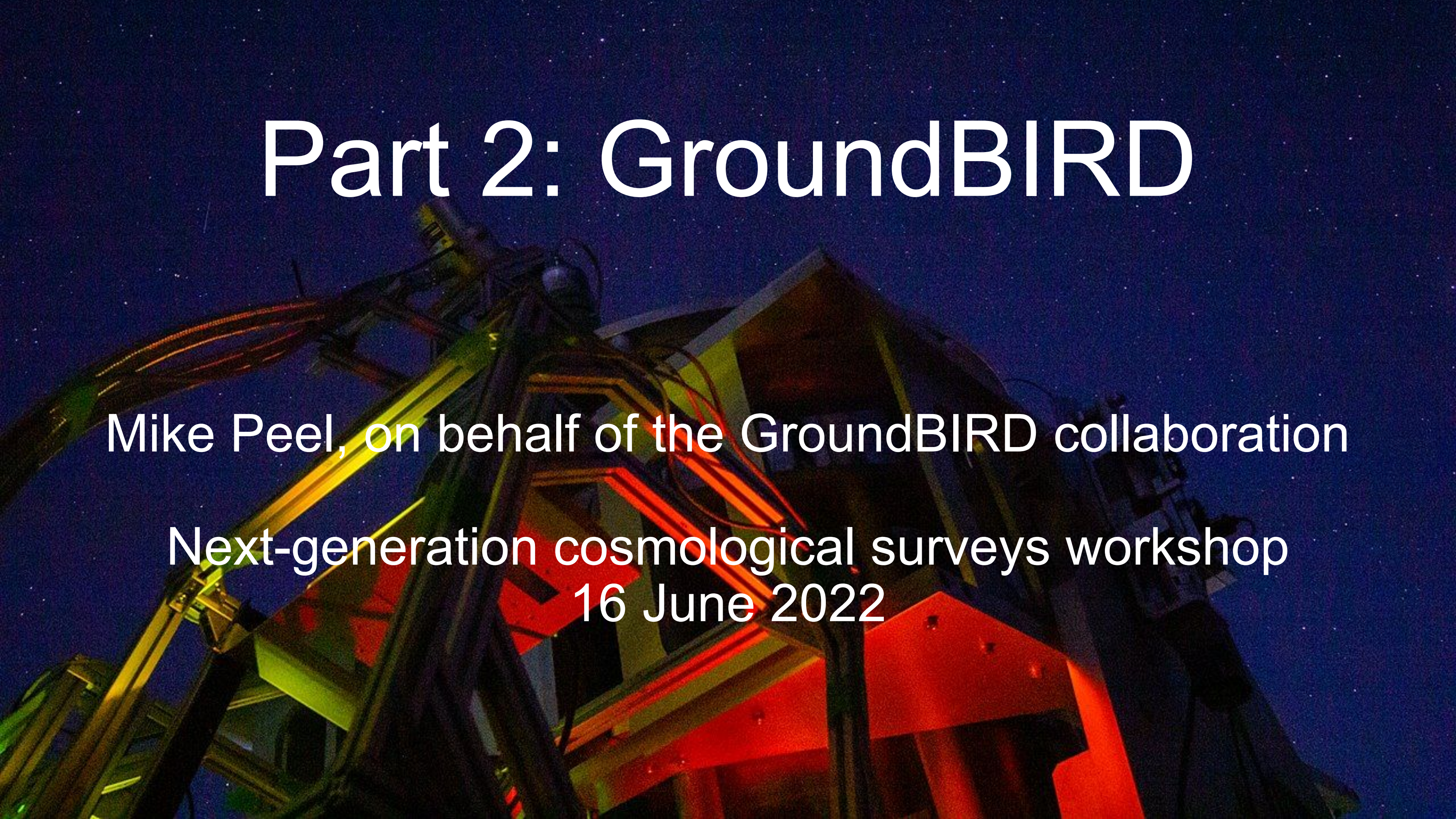
2023: Commissioning

2023-2028: Survey (phase 1)









Part 2: GroundBIRD

Mike Peel, on behalf of the GroundBIRD collaboration

Next-generation cosmological surveys workshop
16 June 2022

Collaboration (Japan, Korea, Spain, Netherlands)

RIKEN: Chiko Otani (PI), Satoru Mima, Shugo Oguri (now at JAXA), Hiroki Kutsuma

Kyoto University: Osamu Tajima, Takuji Ikemitsu, Junta Komine, Junya Suzuki, Yoshinori Sueno, Soichiro Takeichi

KEK: Masashi Hazumi, Hikaru Ishituka, Tomohisa Uchida, Mitsuhiro Yoshida, Taketo Nagasaki

NAOJ: Makoto Nagai, Yutaro Sekimoto (now JAXA)

Tohoku University: Makoto Hattori, Tomonaga Tanaka, Miku Tsujii

University of Tokyo: Kenji Kiuchi, Makoto Minowa, Nozomu Tomita, Hidesato Ishida, Yuta Tsuji

Saitama University: Ryo Koyano, Masato Naruse, Munehisa Semoto, Toru Taino

Korea University: Eunil Won, Kyungmin Lee, Yonggil Jo, Hoyong Jeong

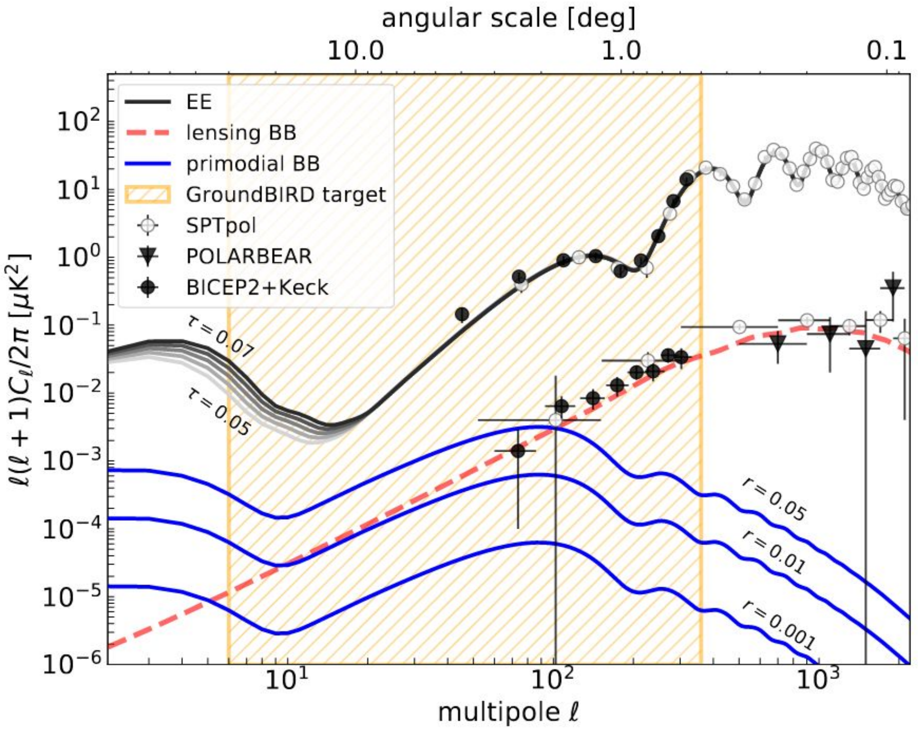
KASI: Jihoon Choi

SRON: Kenichi Karatsu

IAC: Ricardo Génova-Santos, Mike Peel, Rafael Rebolo, José Alberto Rubiño-Martín, Victor Gonzalez Escalera, Shunsuke Honda (now at University of Tsukuba)

Science goals

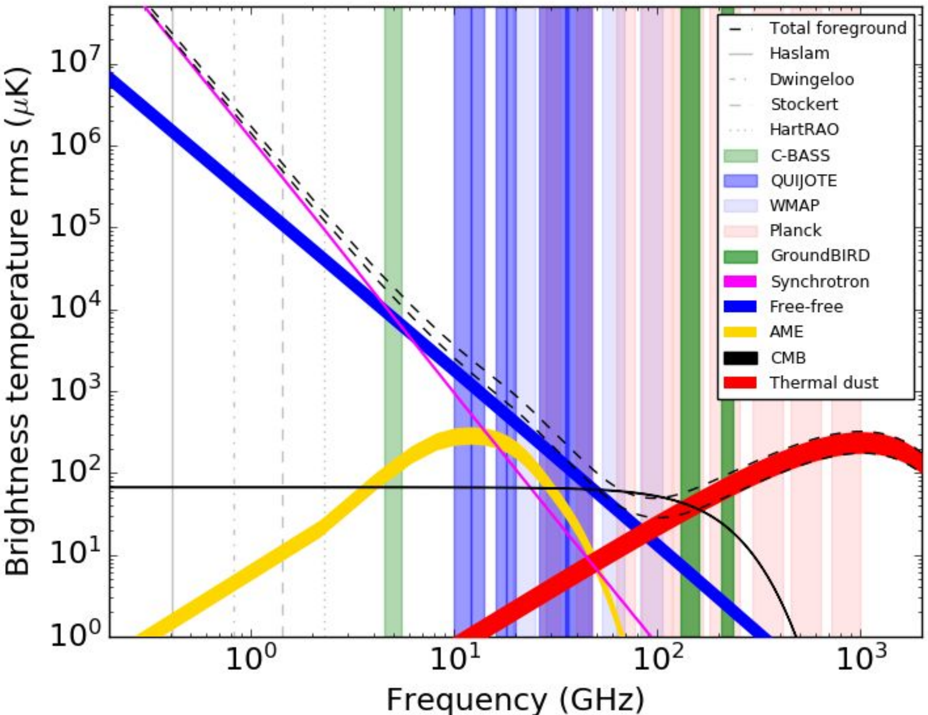
- High sensitivity measurements of largest angular scales from ground (ℓ = 6–300)
- B-modes: tensor-to-scalar ratio, *r, to* σ_r < 0.01 (Current best limit from BICEP <0.036 2σ)
- E-modes: optical depth to reionisation, τ, to σ_τ < 0.03 (gives the epoch at which the universe became ionised: higher value = earlier - known to 0.0073 from Planck but systematics?)
- Polarised thermal dust emission amplitude + spectral properties
- Northern hemisphere observations
    - Complementary to South observations
    - Understanding full sky foregrounds is important for satellite observations

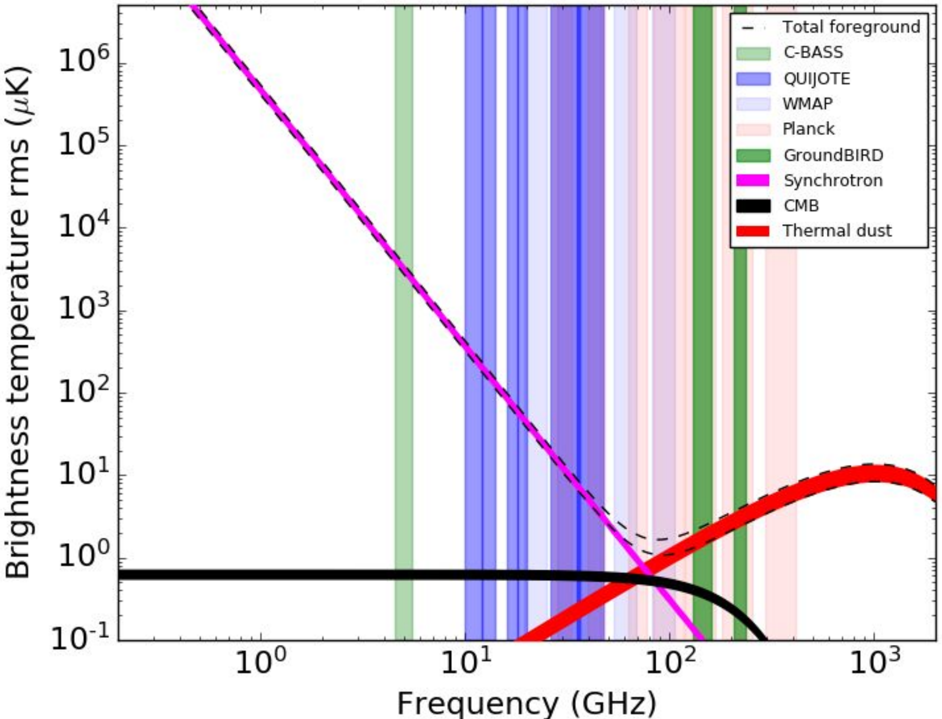


From Honda et al. (2020) (Mike: explain this!)

Foregrounds

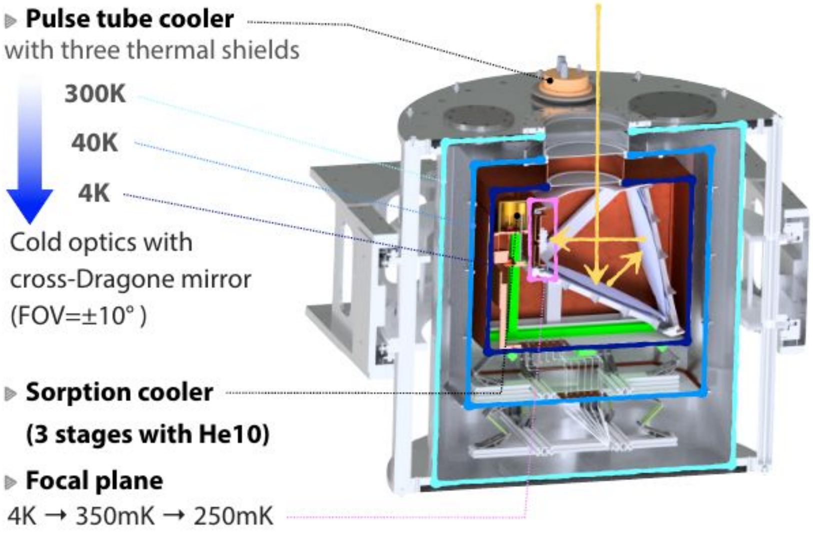
- GroundBIRD sees CMB + thermal dust (intensity + polarisation)
- cf. QUIJOTE seeing CMB + synchrotron (I+P) + free-free + AME
- Need multi-frequency analysis to accurately remove foregrounds + extract CMB

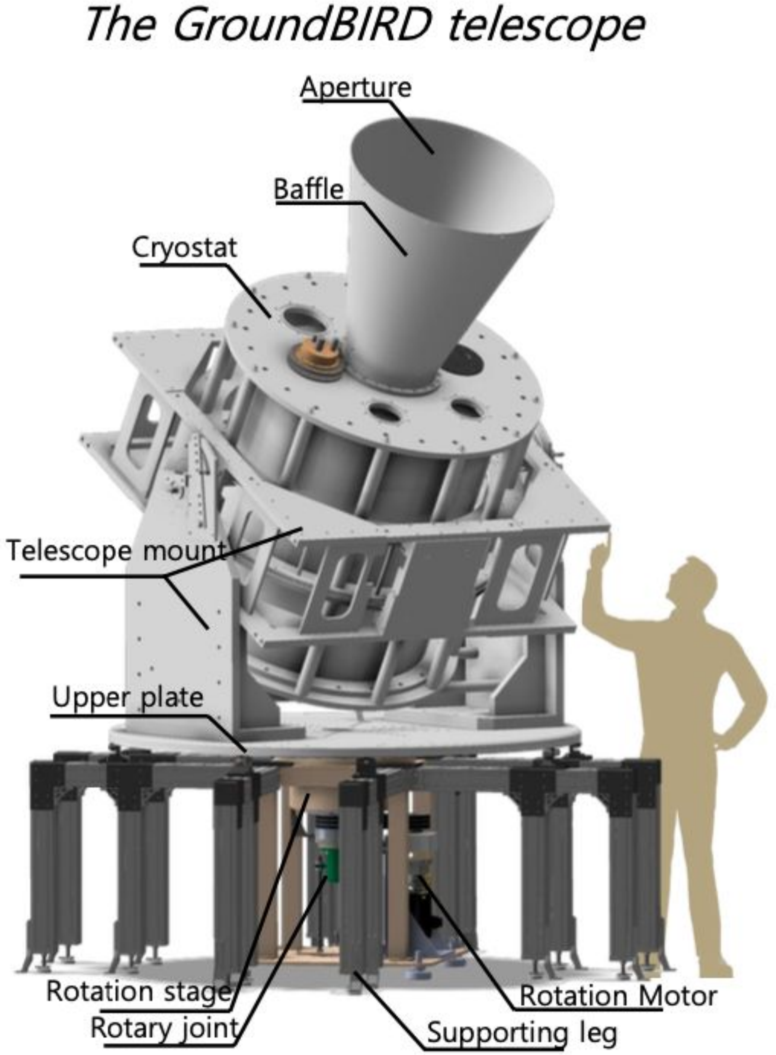




Specifications

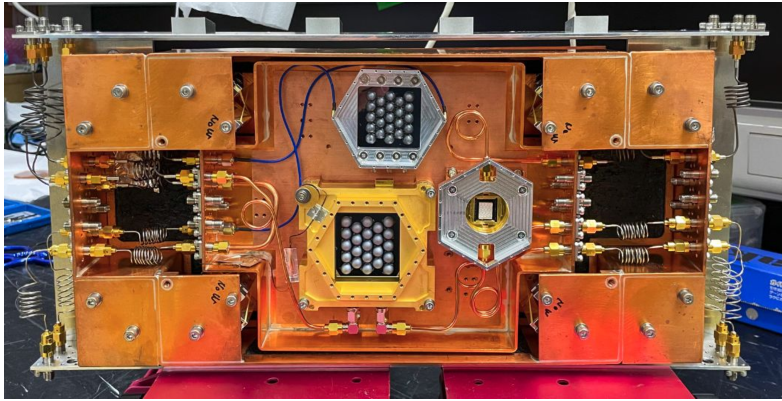
- Focal plane at <0.3 K (sorption cooler, PTC)
- KIDS detectors at 145 GHz, 220 GHz
    - 7 x 23 pixel array: 161 total
    - 6 x 150 GHz arrays, 1 x 220 GHz array
- 40 cm cooled (4 K) cross-dragone mirrors
- Resolution around 0.5°/0.3° (145/220 GHz)

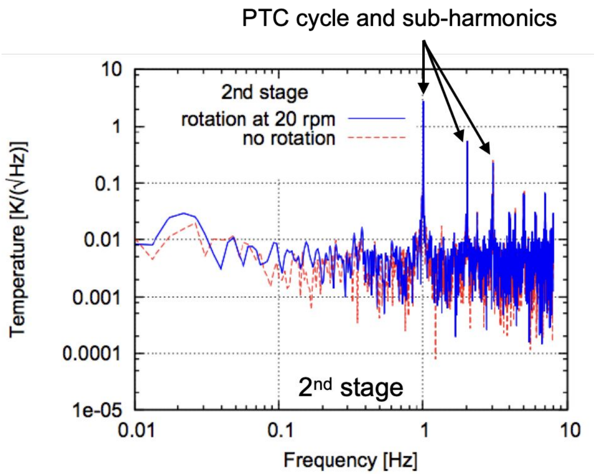




Stability for large angular scales

- Large angular scales → need to minimise 1/f
- Continuous very fast spin: 20r.p.m. at fixed elevation (~60-90°)
    - Cuts out any 1/f on timescales longer than 3 seconds (360° rotation) or better (destriping)
- Fast MKID detectors
- Lots of magnetic shielding around cryostat
    - (MKIDs can be affected by Earth's magnetic field)
- Very stable cryo temperatures during operations
    - (exception being daily regeneration of sorption cooler for ~3 hours)
- Humidity in dome controlled
- Dome inside ground shield
    - (sheltered from weather, ground radiation)

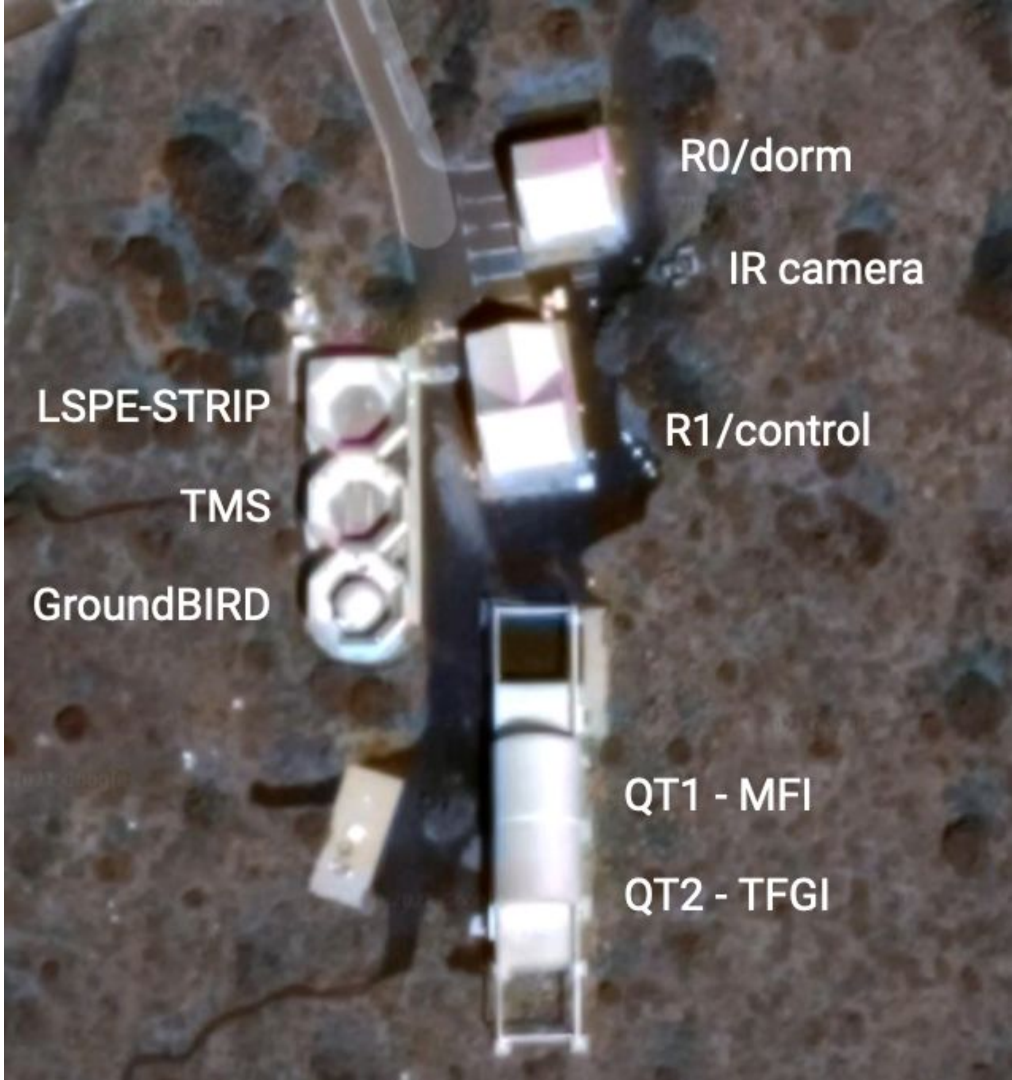




From Jihoon Choi (PhD thesis)

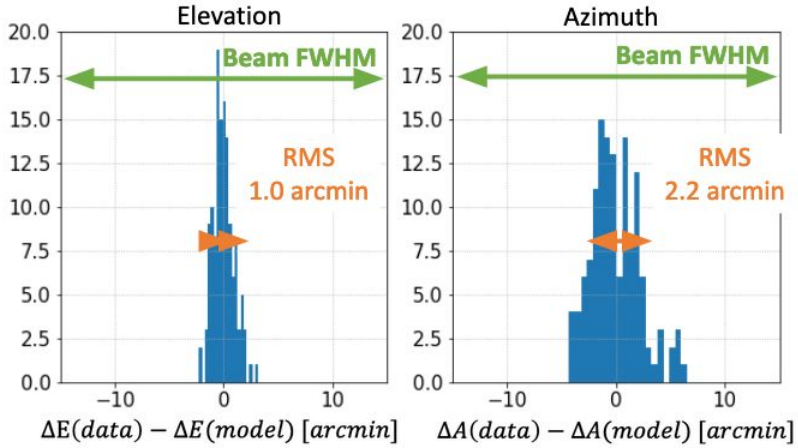
Observations

- CMB area at Teide Observatory (in use since 1984!)
- Installed next to QUIJOTE (see Alberto's presentation)
- New dome inside former Very Small Array enclosure
- 2400m, median PWV 3.8mm
- (Cloud level is mostly ~1500m)
- 28.3°N, 60° elevation → declinations -1.7° to +58.3°
- Instantaneous field of view ~10x10°
- Using Earth rotation, will map ~50% of the sky

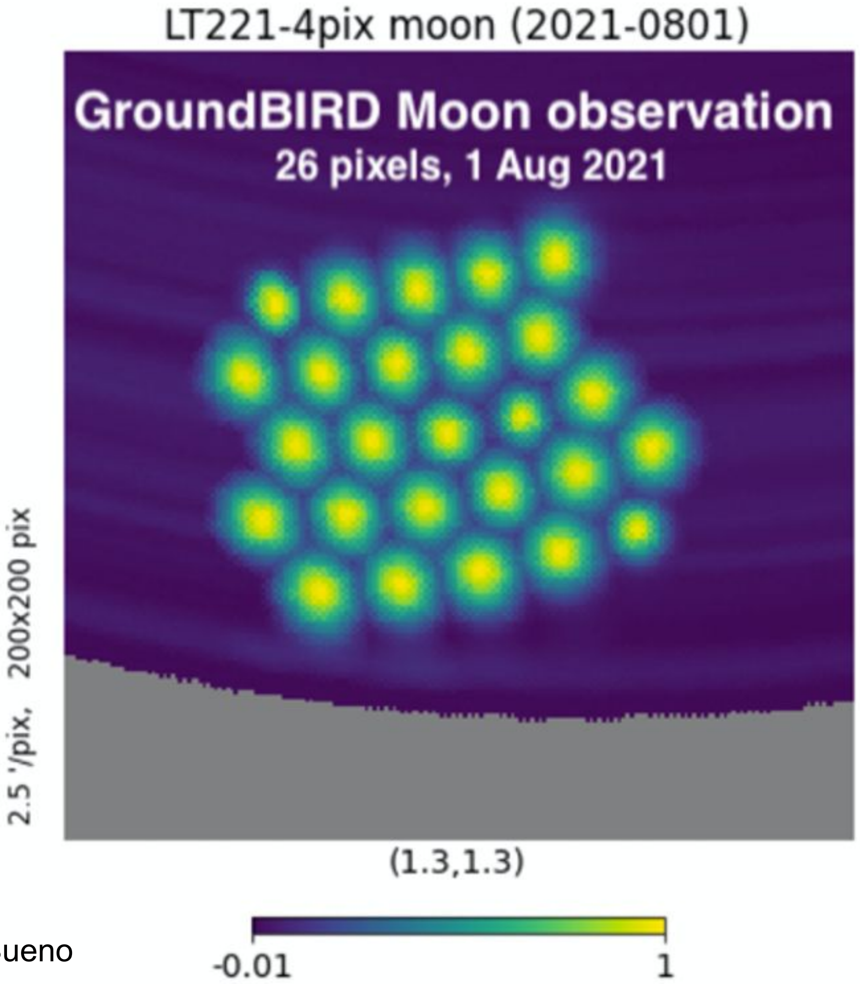


Calibration - moon observations

- Moon: bright calibrator, easy to observe
- Observe when rising/setting at fixed elevations (normally 70°)
- Example plot on the right!
- Using SRON 145 GHz detector
- (22 only antennas, 4 + lenslets)
- + telescope pointing (looking good!)

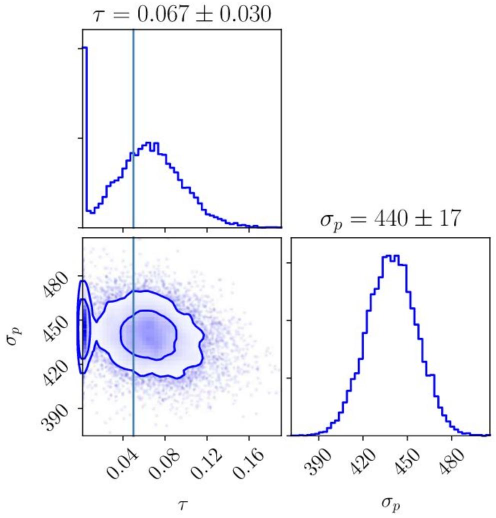


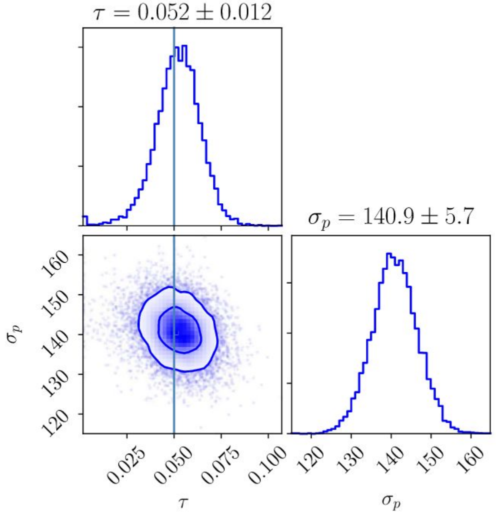
Thanks to
Yoshinori Sueno



Forecast of cosmological parameters

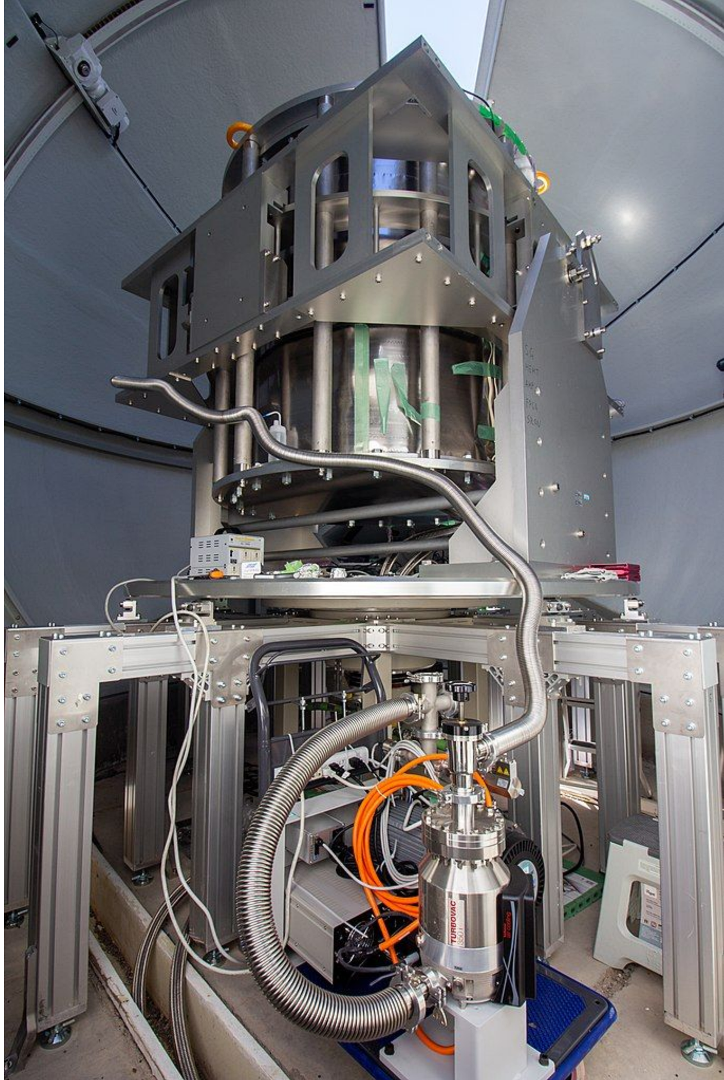
- Lee et al., "A forecast of the sensitivity on the measurement of the optical depth to reionization with the GroundBIRD experiment",
  ApJ, 915, 88, arXiv:2102.03210
- (See CosmoGlobe talk last year for details!)
- Forecast sensitivity: 110 uK arcmin at 150 GHz, 780 uK arcmin at 220 GHz
- Uncertainty on τ of 0.03 with GB only
- Reduces to 0.012 including QUIJOTE
- (Complicated bit is foregrounds!)





Current status

- Fully remote observations started!
    - Automatic dome open/close, rotation start/stop
    - (lots of work to automate + make safe/secure)
- Currently observing at 70°
    - (need to tweak helium pipes to go to lower elevation, can to to 60° in principle - limited by PTC/sorption cooler tilt angles.)
- (Actually, we broke an elevation axis during crane work last month ... currently fixing, plan to resume observations in July/August!)

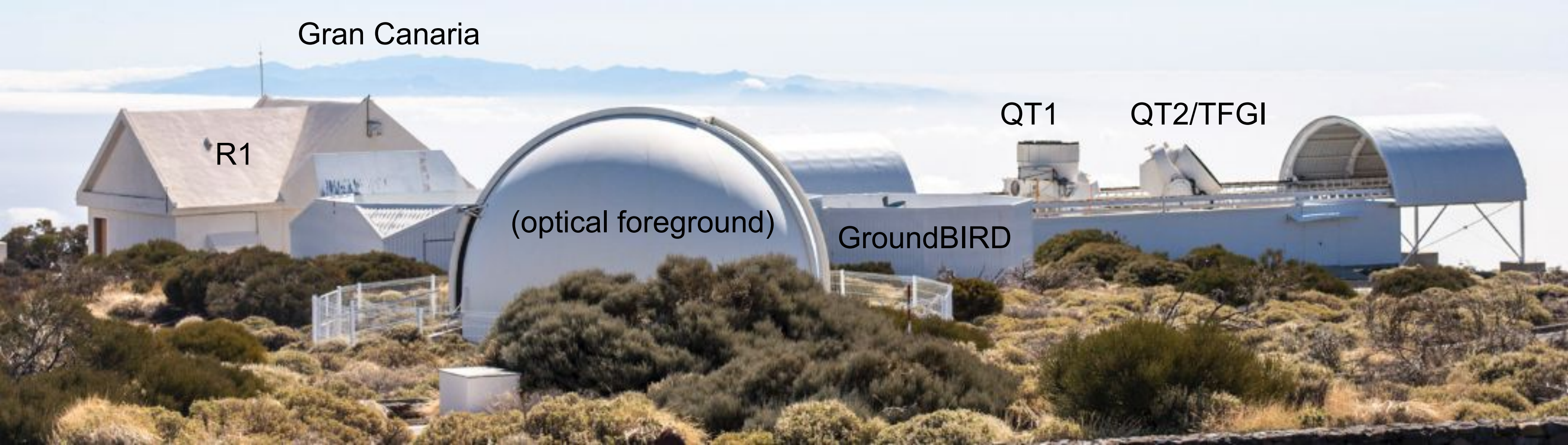


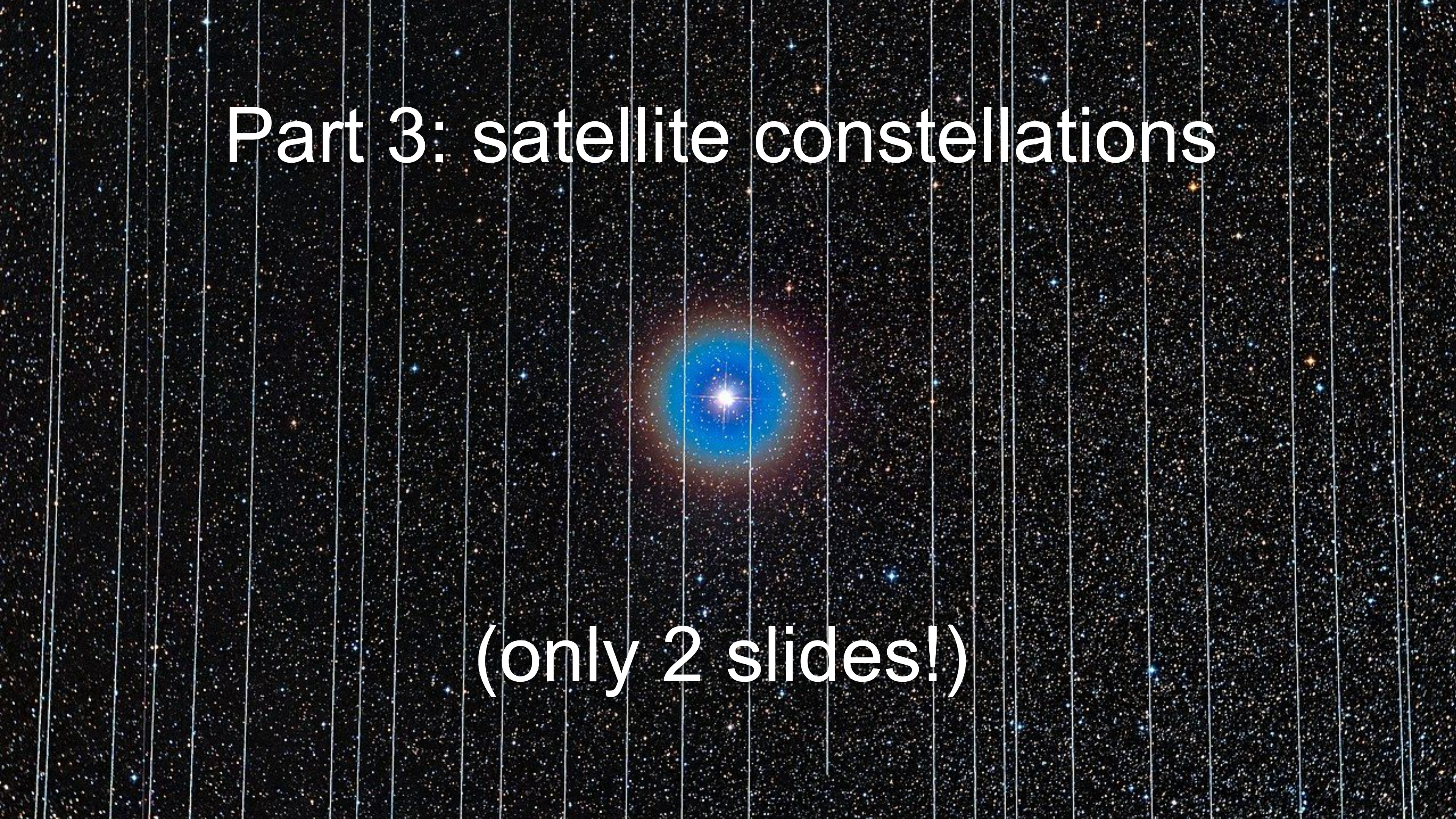
Timeline

- 2018: dome installed
- 2019: instrument installation, first light September
- (2020-2021: covid slowdown...)
- 2021: resume initial observations, calibration with moon and wire
- 2022: 2x23 pixel wafers installed, remote observations prepared
- July/August 2022: start of science observations with two wafers
- March 2023: upgrade to full set of 7 wafers
- Continuous survey observations until ~2025

Conclusions

- GroundBIRD is fully installed and prepared for remote observations
- Starting routine science observations shortly!
- Aim is ~110 uK arcmin at 150 GHz in the Northern hemisphere - complementary to Southern obs!
- Will constrain τ with an uncertainty < 0.03, r with an uncertainty < 0.01




Part 3: satellite constellations
(only 2 slides!)

Increasing impact of satellite constellations

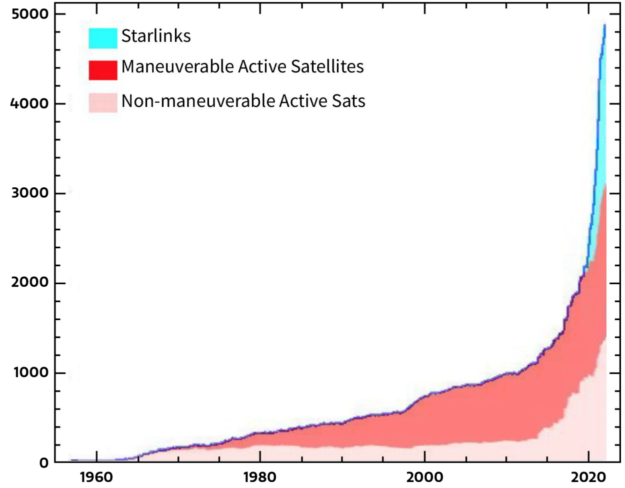
Satellites launching in their thousands as part of constellations like Starlink.
Major optical issues from sunlight reflection causing streaks in optical survey data.
Also, transmission at Ku-Ka band frequencies, V-band planned! (+ octaves...?).
Also, increasing geostationary satellites (Ku full, people now launching Ka!).

New IAU centre to coordinate astronomical response.
Open to participation very soon! Led by NOIRlab (USA) and SKAO (UK).

Four hubs: Sathub (I'm co-lead), Industry, Community, Policy.
More info now published!: cps.iau.org

Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference
CPS

IAU NOIRLab SKAO



Constellation	Use	Start (GHz)	Stop (GHz)	Instruments affected
Starlink Ku-Ka	User downlink	10,7	12,75	MFI, TMS
	Gateway downlink	17,8	18,6	MFI, TMS
	Gateway downlink	18,8	19,3	MFI, TMS
	Gateway downlink	19,7	20,2	MFI, TMS
Starlink V band	Gateway downlink?	37,5	37,75	FGI
	User downlink?	37,5	42,5	FGI, LSPE-STRIP
OneWeb Ku-Ka	User downlink	10,7	12,7	MFI, TMS
	Gateway downlink	17,8	18,6	MFI, TMS
	Gateway downlink	18,8	19,3	MFI, TMS
Kuiper Ka	User/GW downlink	17,7	18,6	MFI, TMS
	User/GW downlink	18,8	19,3	MFI, TMS
	User/GW downlink	19,3	19,4	MFI, TMS
	User/GW downlink	19,7	20,2	MFI, TMS

Active radio transmissions

QUIJOTE observes the **oldest light in the universe**, and **our Galaxy on the largest angular scales.**

Geostationary satellites are **brighter than the Sun** (even in 2012) - we mask ~10° around dec=0 as a result.

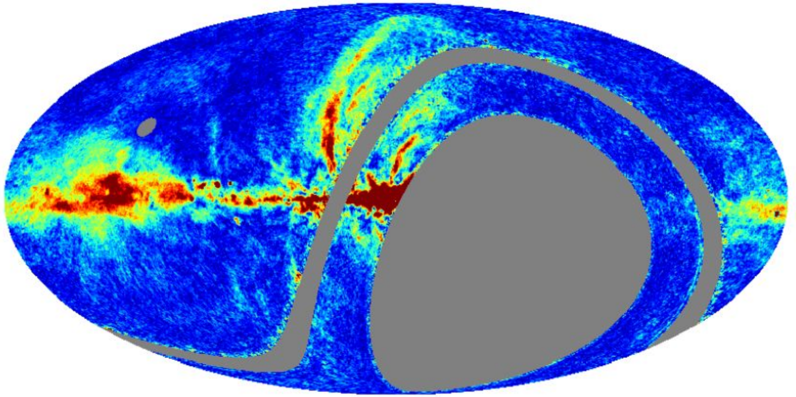
A bigger problem: **Sidelobes** can be seen **well away from the position the telescope is pointing**.

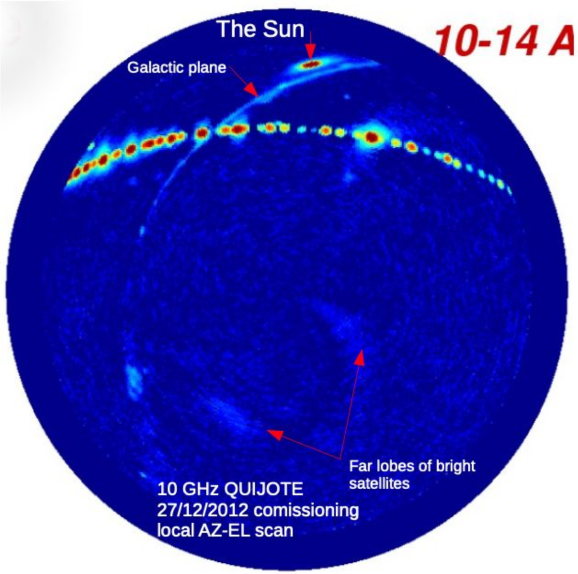
This **significantly affects large angular scale observations**.

Even though we use **special radio telescopes that minimize sidelobes** at the 99% level. Extra baffles helped, but won't solve the problem completely.

Except now, **satellites are everywhere**, plus moving fast, difficult to predict impact. Can no longer depend on quiet zones + distance from people to minimise impact!

SKA (>€1bn) will also see these. Maybe **CMB S4** (~€1bn)? Also many other telescopes, such as the Sardinia Radio Telescope, Yebez, ... - any observing at these frequencies!





Thanks for listening!