GroundBIRD status

Mike Peel, on behalf of the GroundBIRD collaboration

Cosmology Jamboree, 7 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

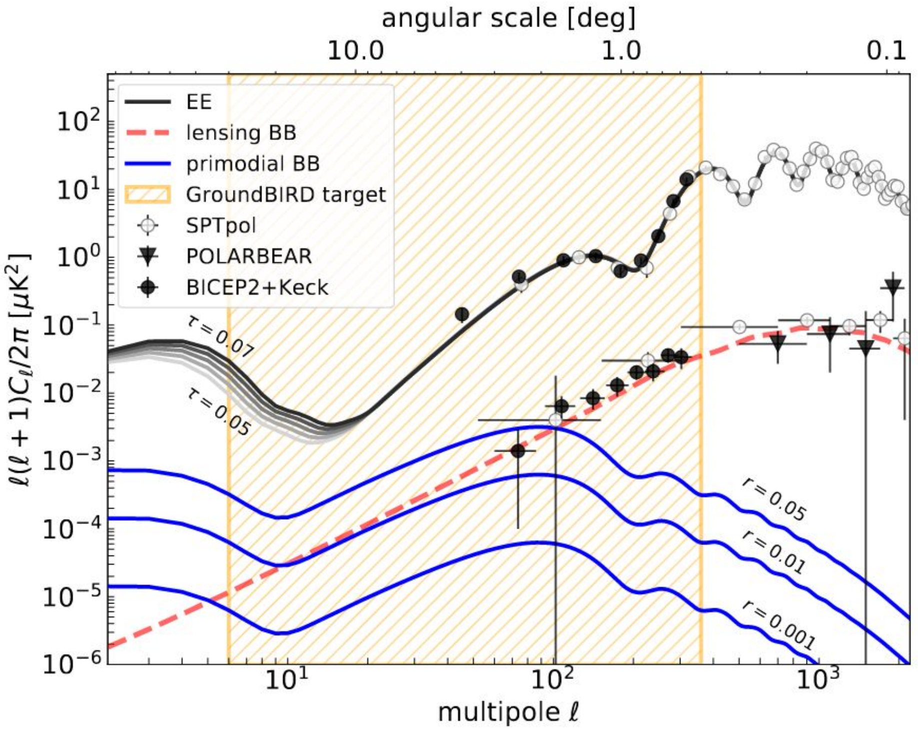
KASI: Jihoon Choi

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

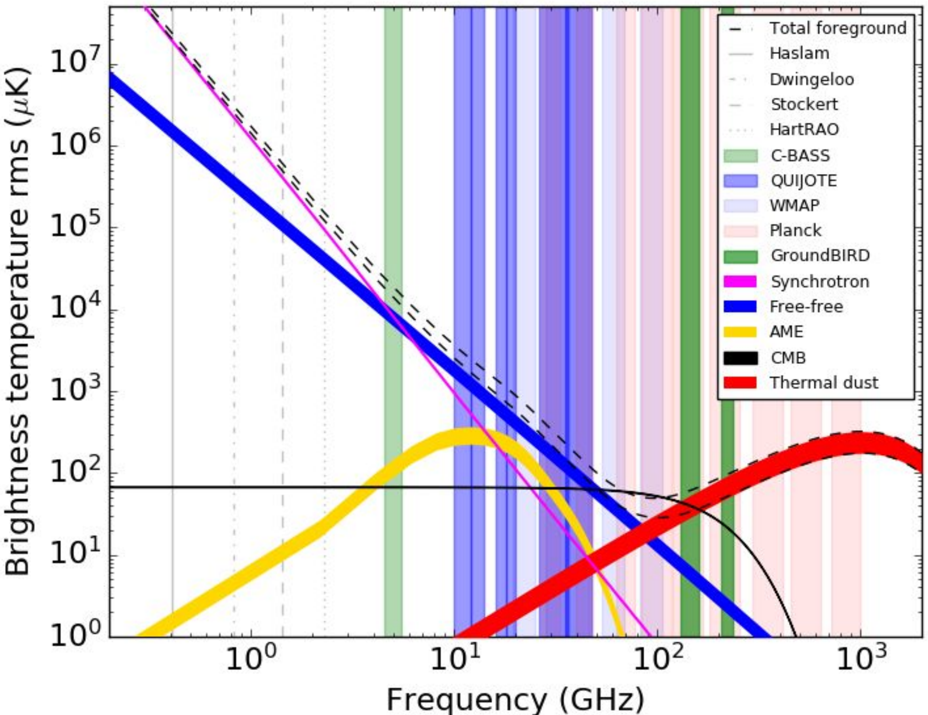
- High sensitivity measurements of largest angular scales from ground (ℓ = 6–300)
- B-modes: tensor-to-scalar ratio, *r, to* σ_r < 0.01 (Current best limit from BICEP <0.036 2σ)
- E-modes: optical depth to reionisation, τ, to σ_τ < 0.03 (gives the epoch at which the universe became ionised: higher value = 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

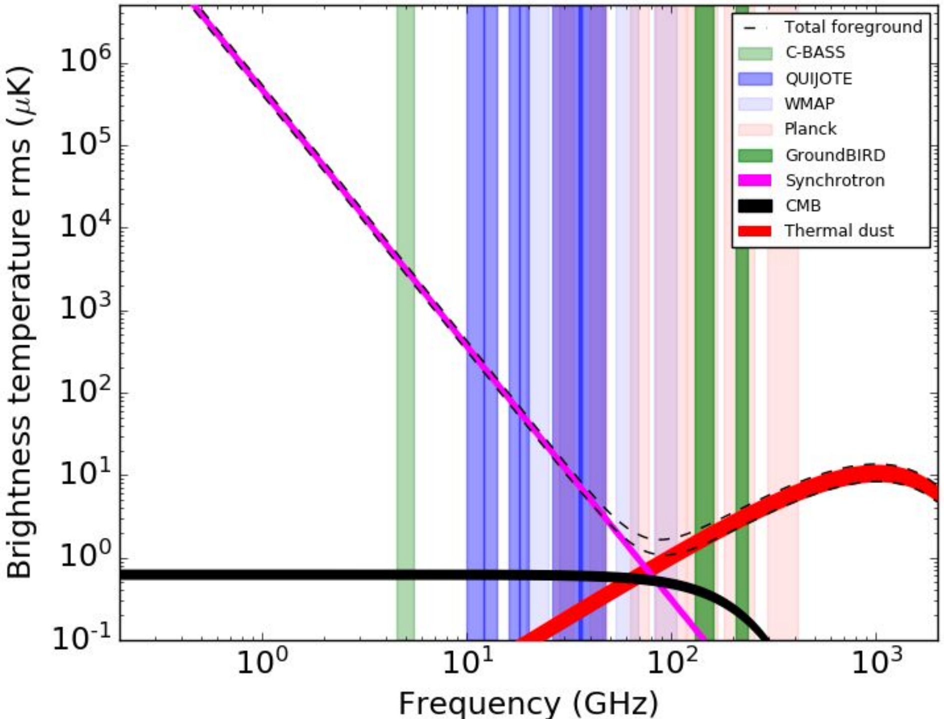


From Honda et al. (2020) (Mike: explain this!)

Foregrounds

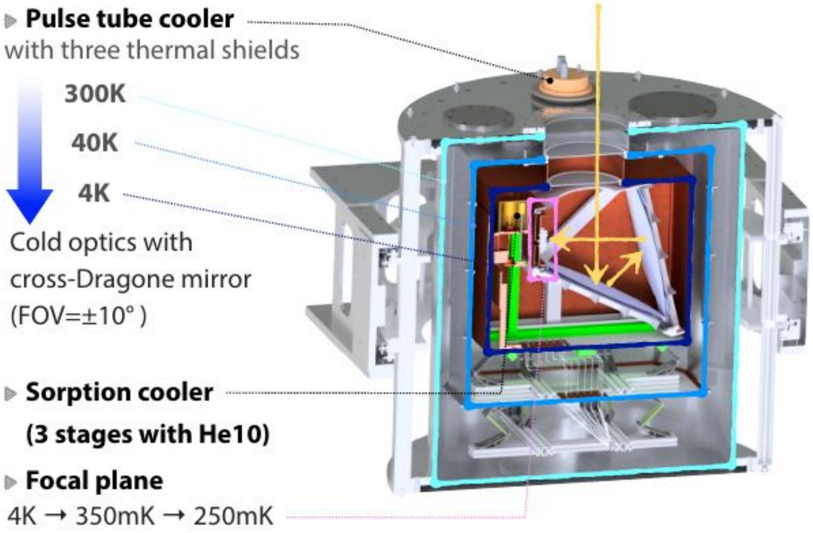
- GroundBIRD sees CMB + thermal dust (intensity + polarisation)
- cf. QUIJOTE seeing CMB + synchrotron (I+P) + free-free + AME
- Need multi-frequency analysis to accurately remove foregrounds + extract CMB

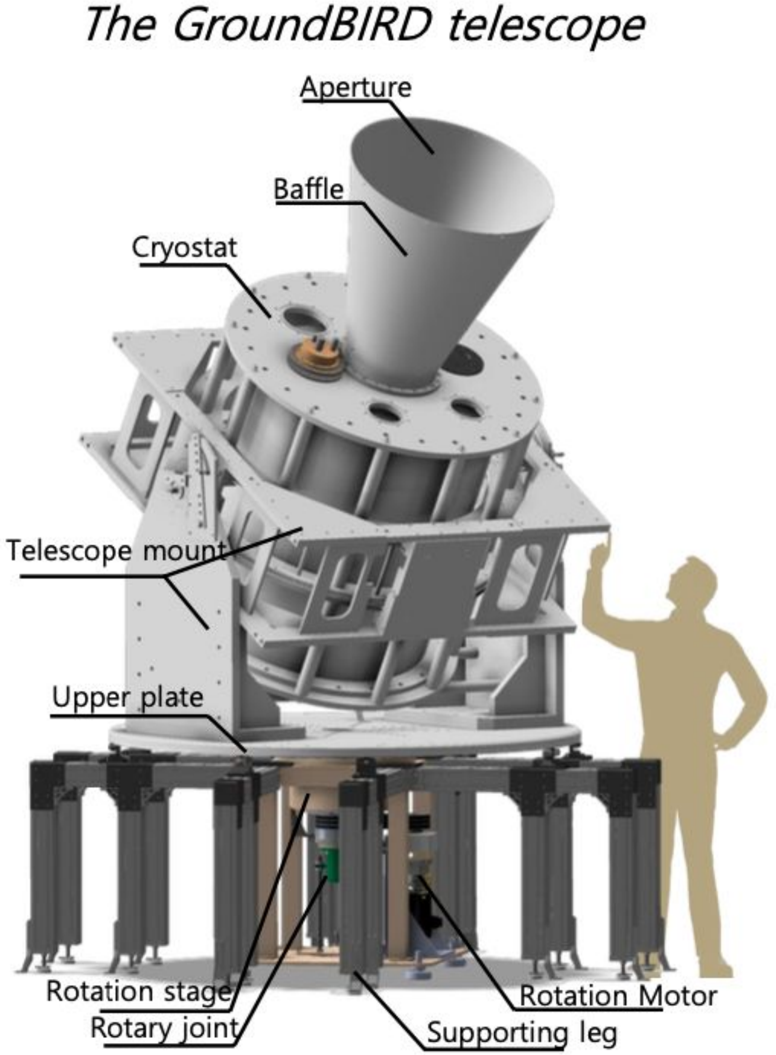




Specifications

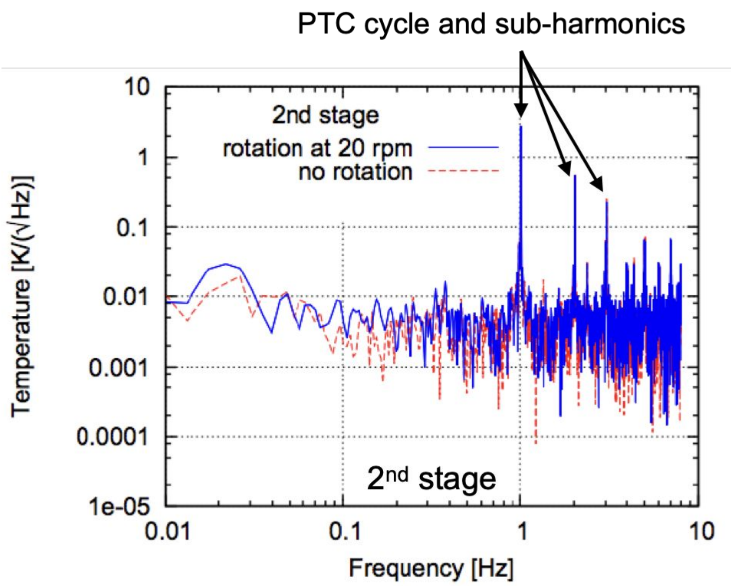
- Focal plane at <0.3K (sorption cooler, PTC)
- KIDS detectors at 145 GHz, 220 GHz
  - 7 x 23 pixel array: 161 total
  - 6 x 150 GHz arrays, 1 x 220 GHz array
- 40 cm cooled (4 K) cross-dragone mirrors
- Resolution around 0.5°/0.3° (145/220 GHz)





Stability for large angular scales

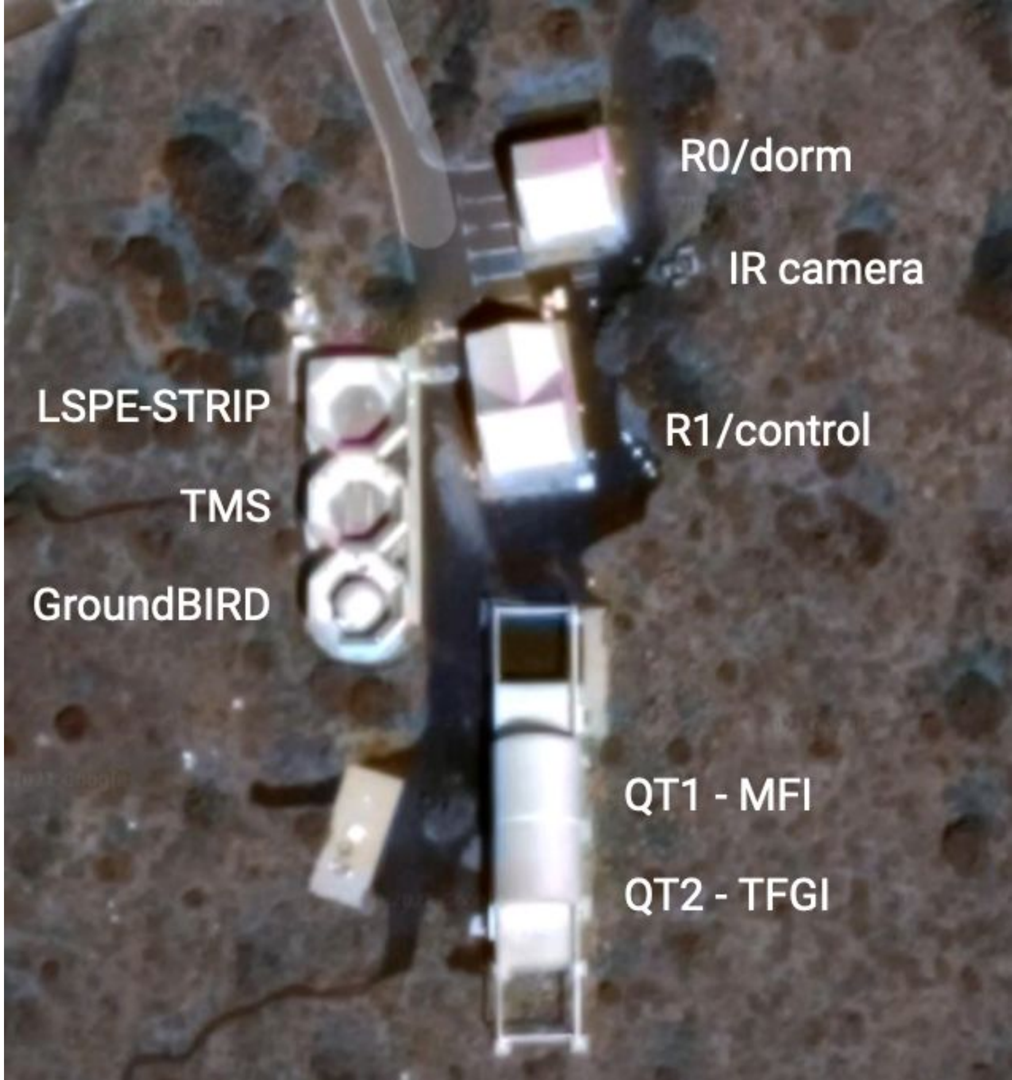
- Large angular scales → need to minimise 1/f
- Continuous very fast spin: 20r.p.m. at fixed elevation (~60-90°)
    - Cuts out any 1/f on timescales longer than 3 seconds (360° rotation) or better (destriping)
- Lots of magnetic shielding around cryostat
    - (MKIDs can be affected by Earth's magnetic 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)

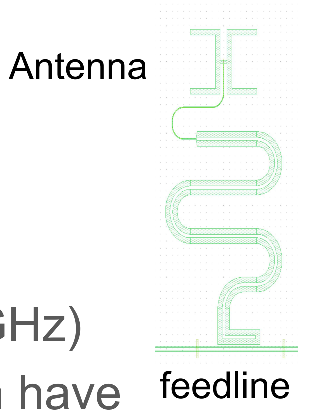
Observations

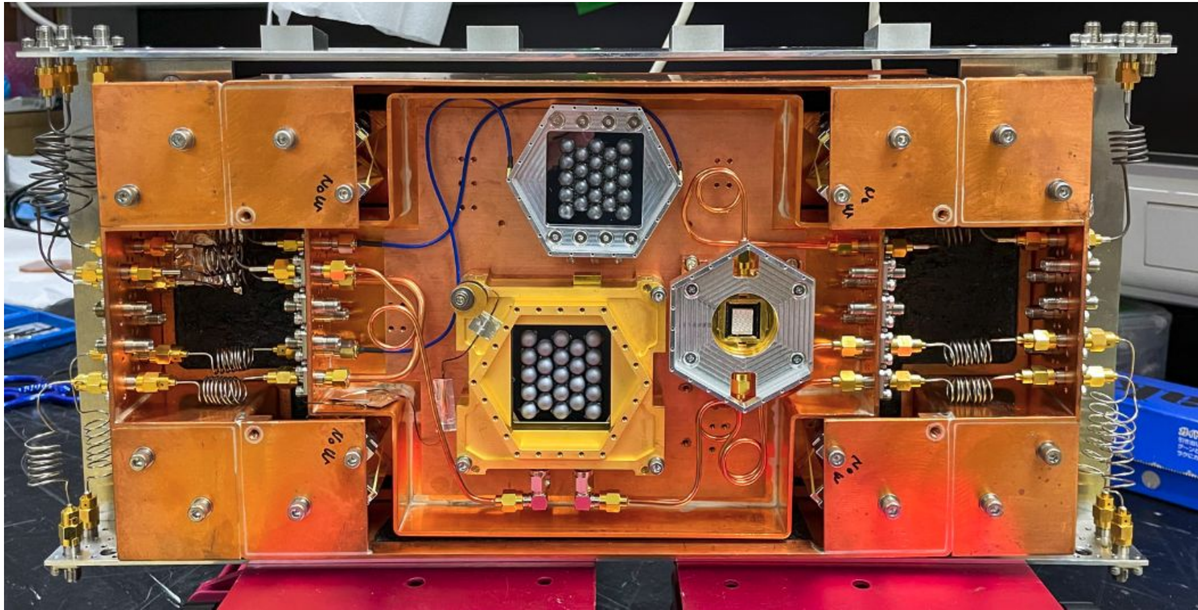
- CMB area at Teide Observatory (in use since 1984!)
- Installed next to QUIJOTE (see next presentation!)
- New dome inside former Very Small Array enclosure
- 2400m, median PWV 3.8mm
- (Cloud level is mostly ~1500m)
- 28.3°N, 60° elevation → declinations -1.7° to +58.3°
- Instantaneous field of view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



Detectors

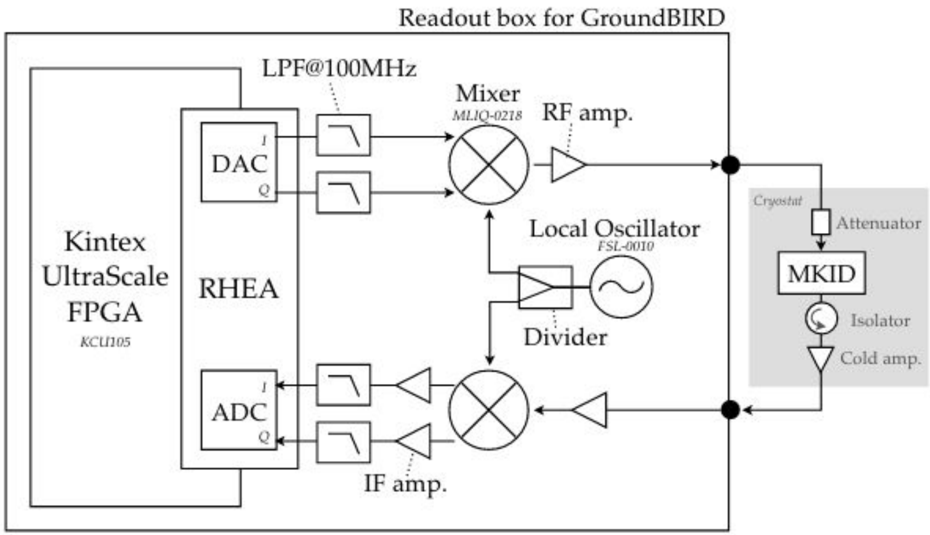
- Using MKIDs at 145 GHz (main) and 220 GHz (dust)
- Antennas coupled with optics using lenslets
- Broad bandwidth, simple construction
- Initial obs with 3-pixel 145 GHz + 14-pixel 350 GHz (filtered to 220 GHz)
- Now 23 pixel arrays. 1 from RIKEN, 1 from SRON, under test. Both have 2 polarisation directions.
- Plan is to build more from SRON with 4 polarisation directions.
- Fully populate focal plane next year (can fit 7 x hexagons, SRON holder is temporary)
- (Mike: skip this except pic?)

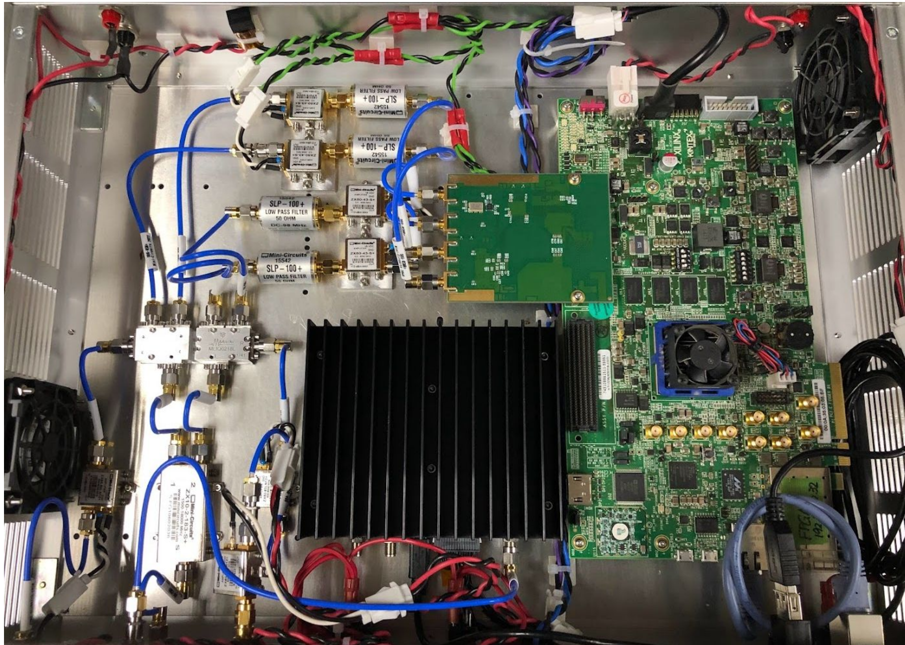




Read-out

- Input tones, read out measures change in amplitude and phase (~5GHz)
- One FPGA per wafer: reading out ~23 pixels, 250MHz bandwidth
- 1,000 samples/sec: fully sample (~5 samples) beam size with high (20 rpm) rotation speed. MKIDs have fast response, unlike e.g., some bolometers.





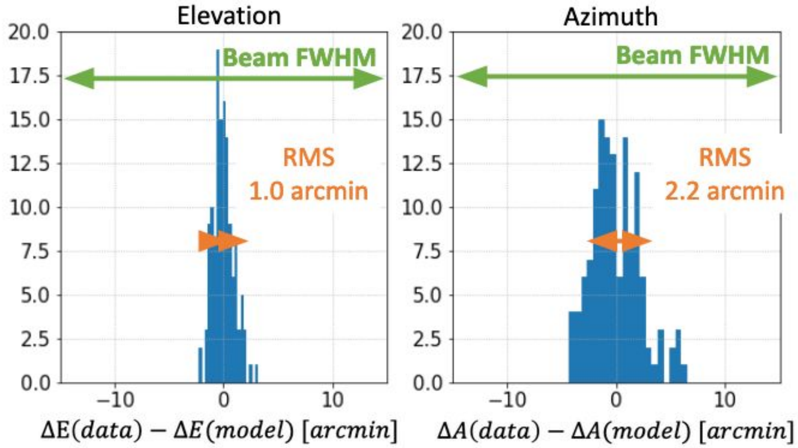
Monitoring (ancillary data)

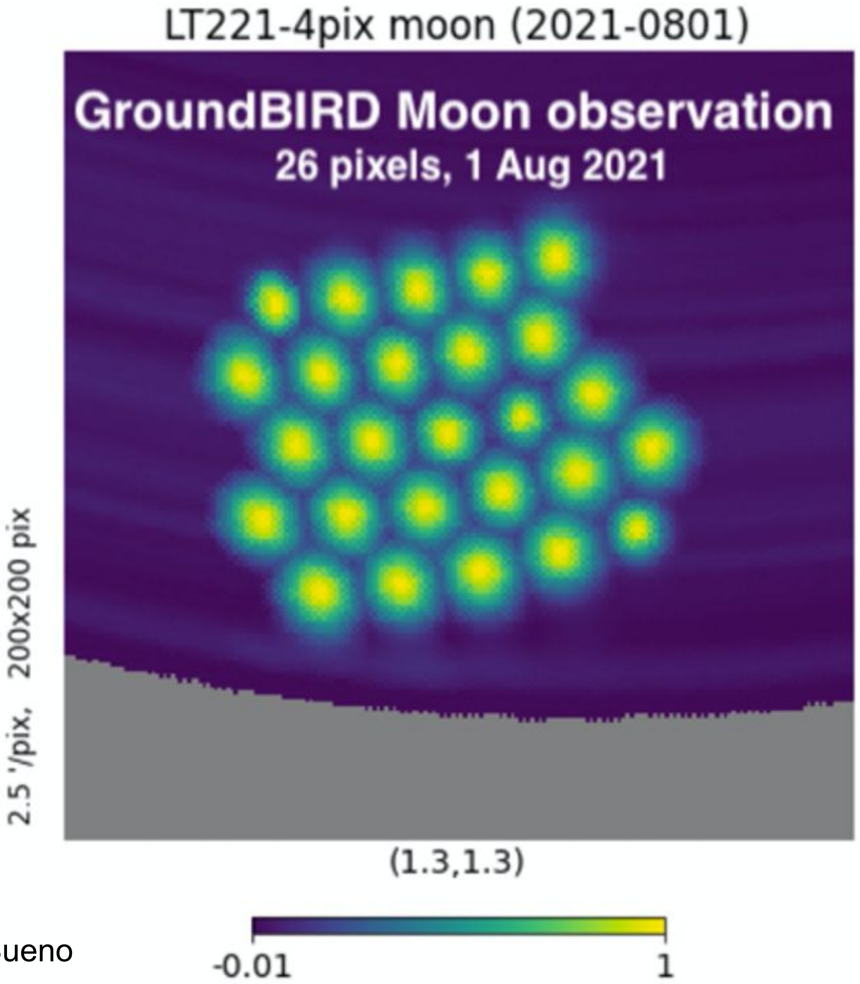
- Local weather (multiple stations, STELLA/SONG/etc.)
- Atmosphere PWV through GPS measurements (AEMet)
- Clouds through infrared camera (developed by Korea University)
- Local rain, humidity, temperature, pressure sensors
- Aircraft (ADS-B receiver)
- Webcams, thermometers, ...
- ... lots of Raspberry Pi's!

AEMet Izana
weather station

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!)

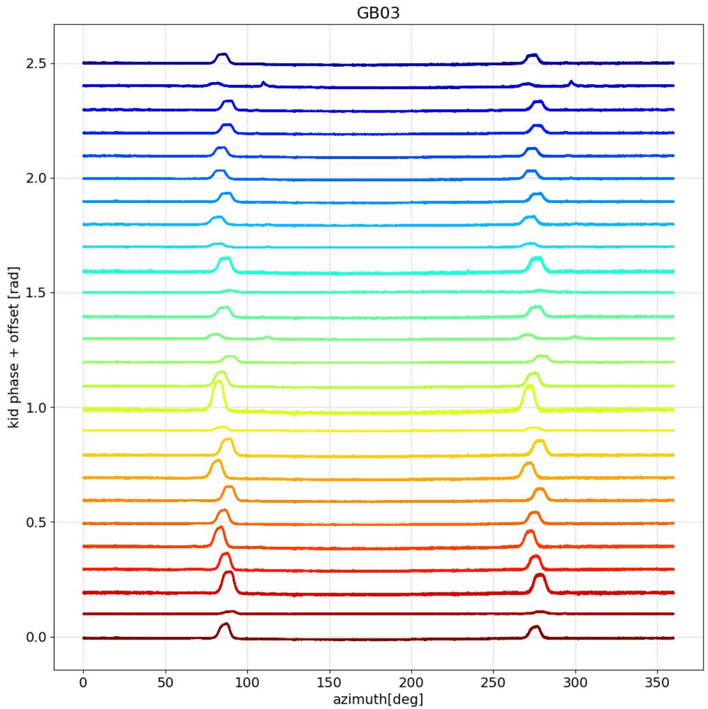


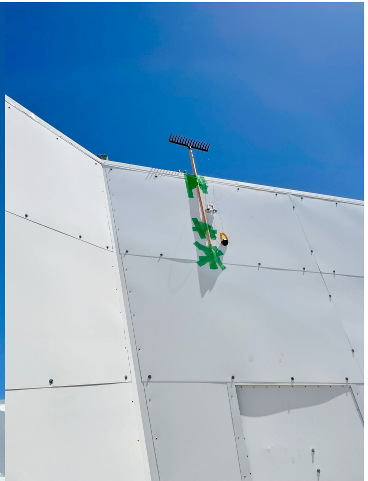


Thanks to Yoshinori Sueno

Calibration - wire observations

- Single wire suspended over telescope
- Telescope rotates underneath
- Get a peak when observing the wire
- Can use to calibrate polarisation (work in progress!)

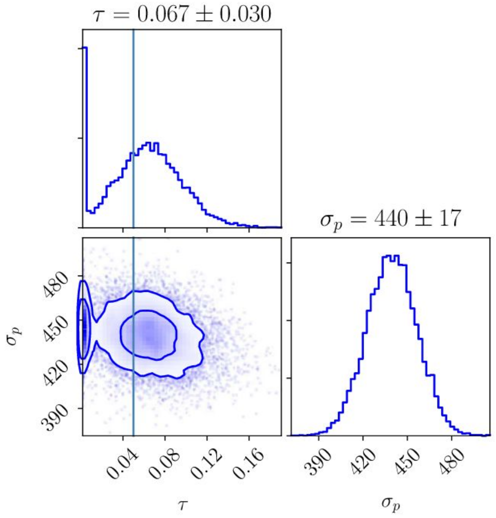


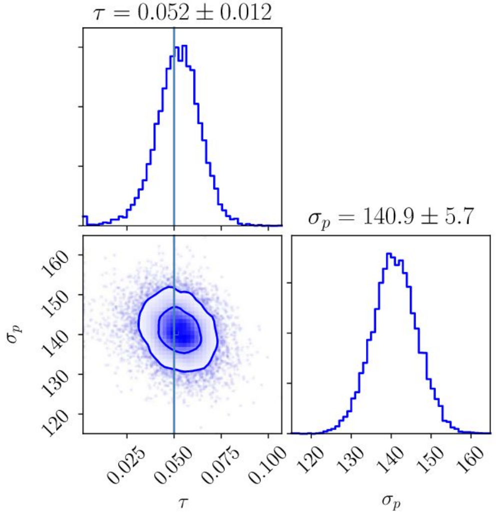


Concept from QUIET: see Tajima et al. 2012 (Journal of Low Temperature Physics, 167, 936)

Forecast of cosmological parameters

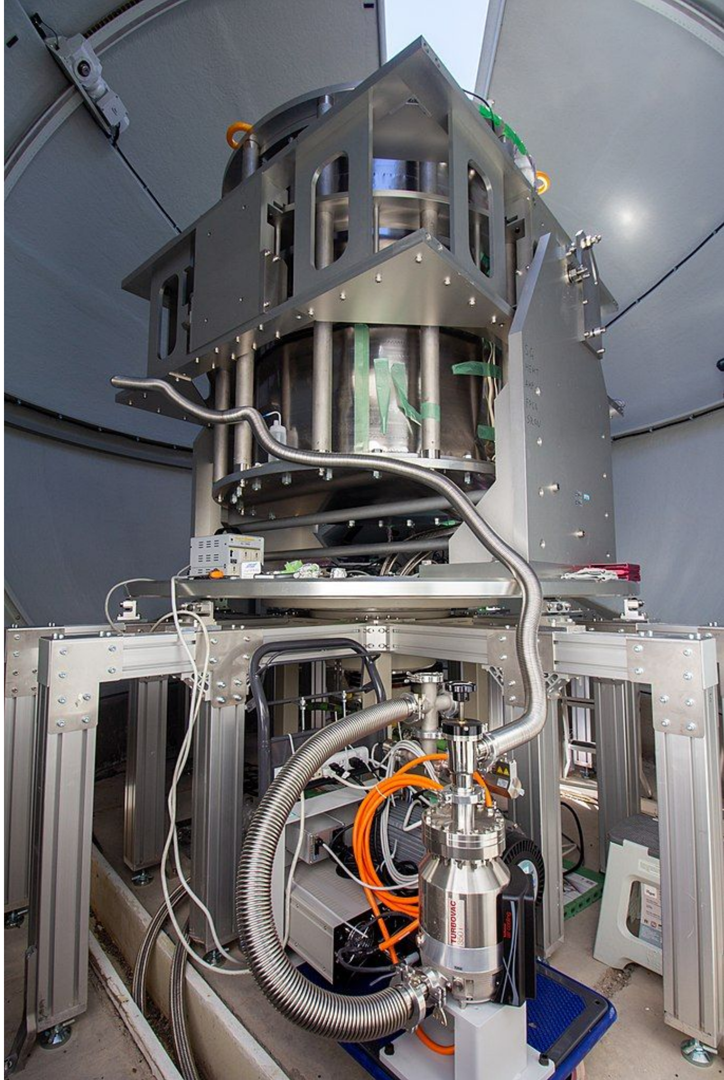
- Lee et al., "A forecast of the sensitivity on the measurement of the optical depth to reionization with the GroundBIRD experiment", ApJ, 915, 88, arXiv:2102.03210
- (See CosmoGlobe talk last year for details!)
- Forecast sensitivity: 110 uK arcmin at 150 GHz, 780 uK arcmin at 220 GHz
- Uncertainty 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!)

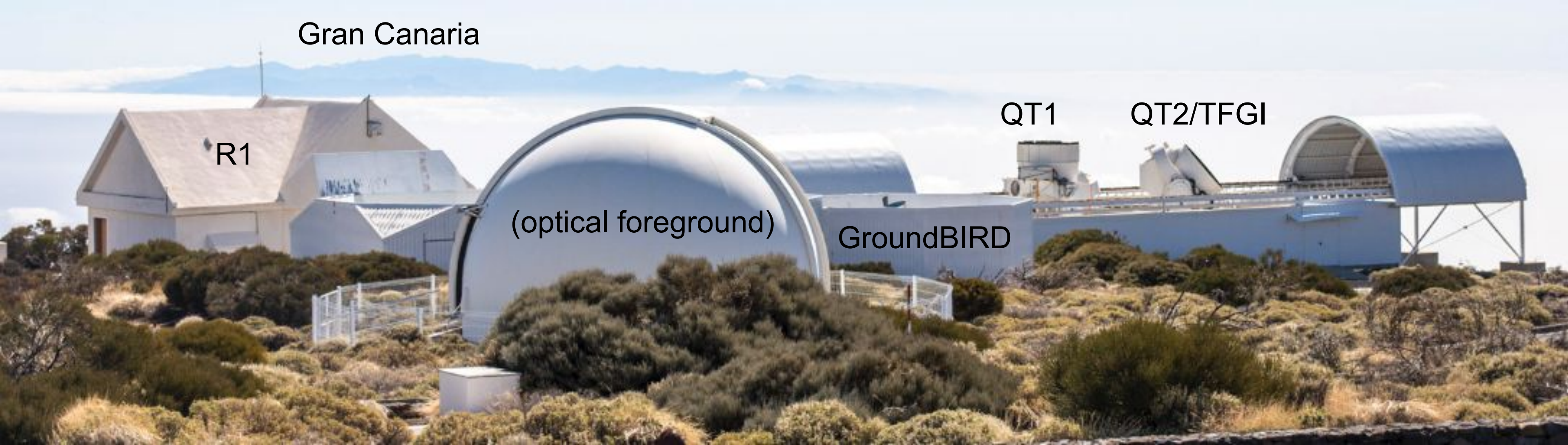


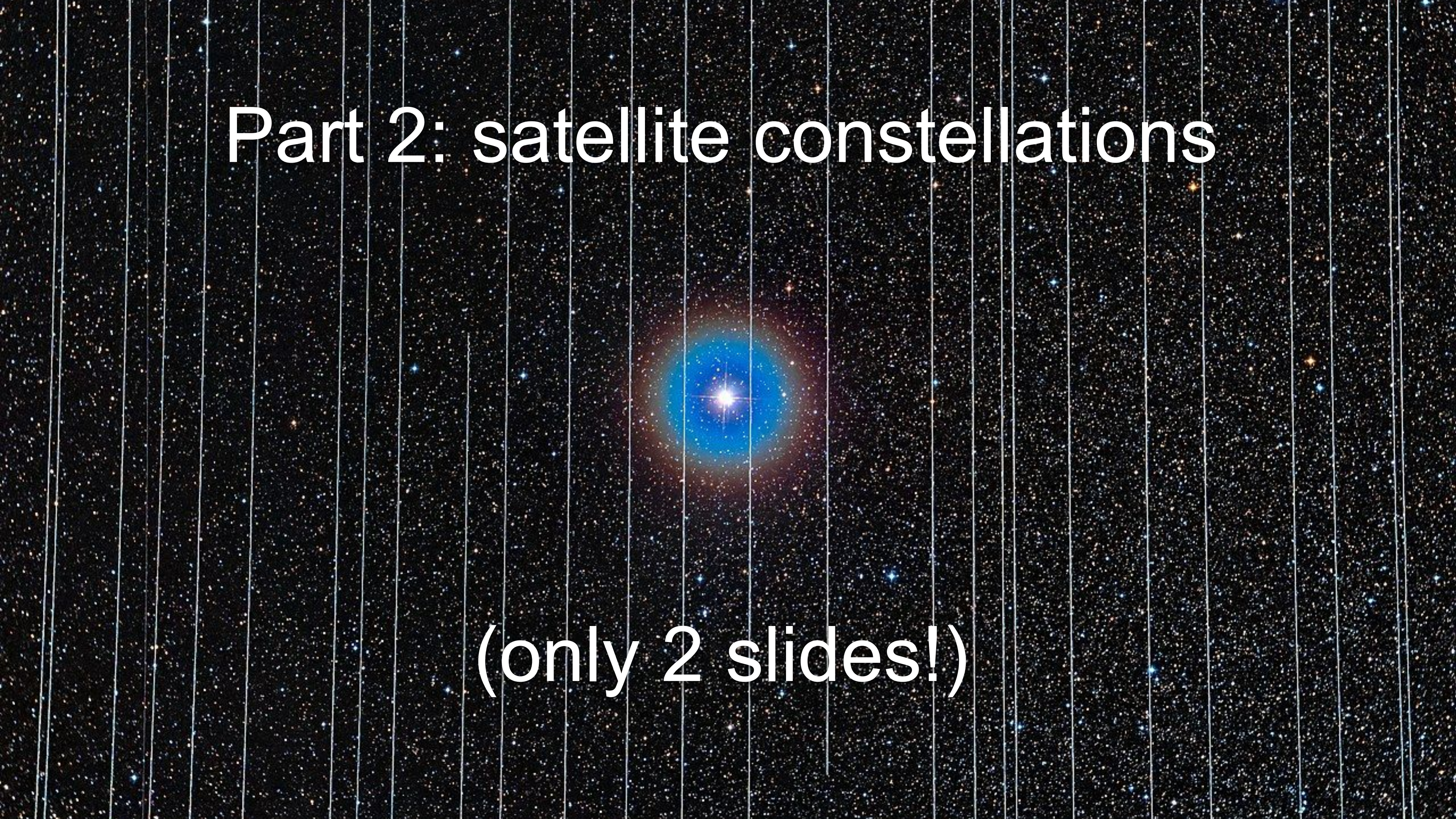
Timeline

- 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
- (TBC: change of frequency, add 90 GHz?)

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



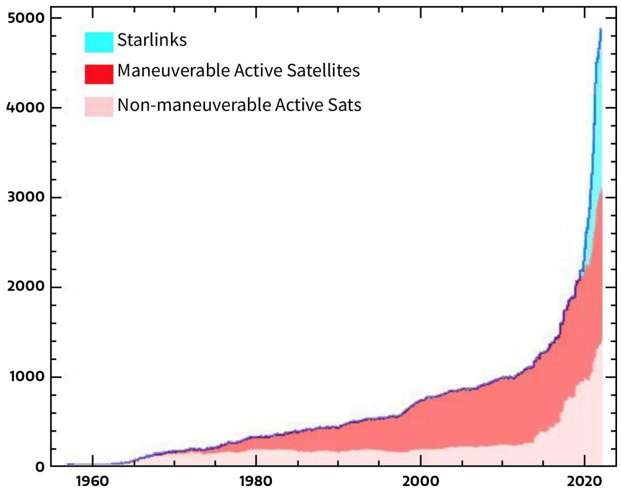

Part 2: satellite constellations
(only 2 slides!)

Increasing satellite impact? (see my DNC talk last week!)

New satellite launching in their thousands as part of constellations like Starlink. Transmit 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: **Could we formally join this?**

Could we formally register OT (and ORM?) with the ITU as a site needing special radio frequency protection? Also possible to request sats be turned off over site? (but would need >500km exclusion?)

Start monitoring the RF environment? Planning to do this asap with personal 60cm satellite dish + 10MHz receiver + Raspberry Pi. Ultimate test is when QUIJOTE MFI2 starts observing (later this year).



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.

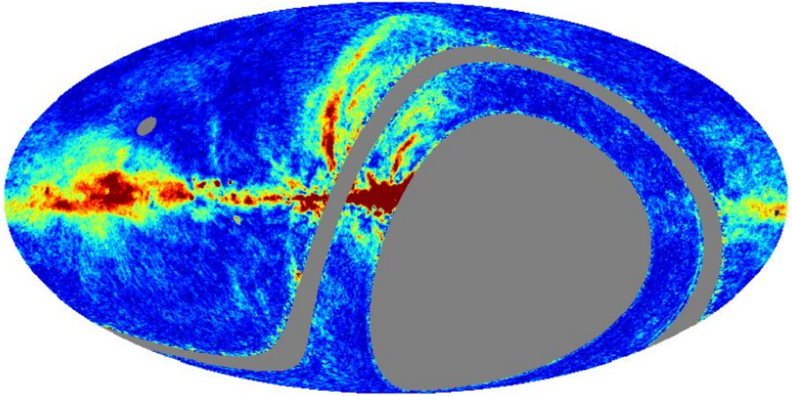
A bigger problem: **Sidelobes** can be seen **well away from the position the telescope is pointing**.

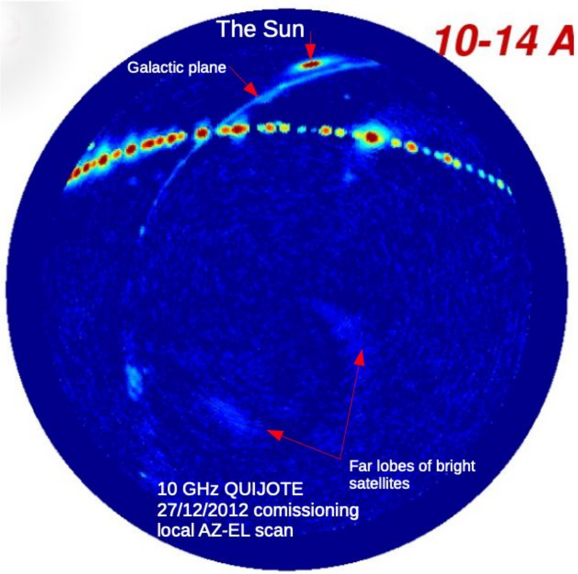
This **significantly affects large angular scale observations**.

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!