MINISTÉRIO DA CIÊNCIA, TECNOLOGIA, INOVAÇÕES E COMUNICAÇÕES
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

The BINGO radio telescope current status

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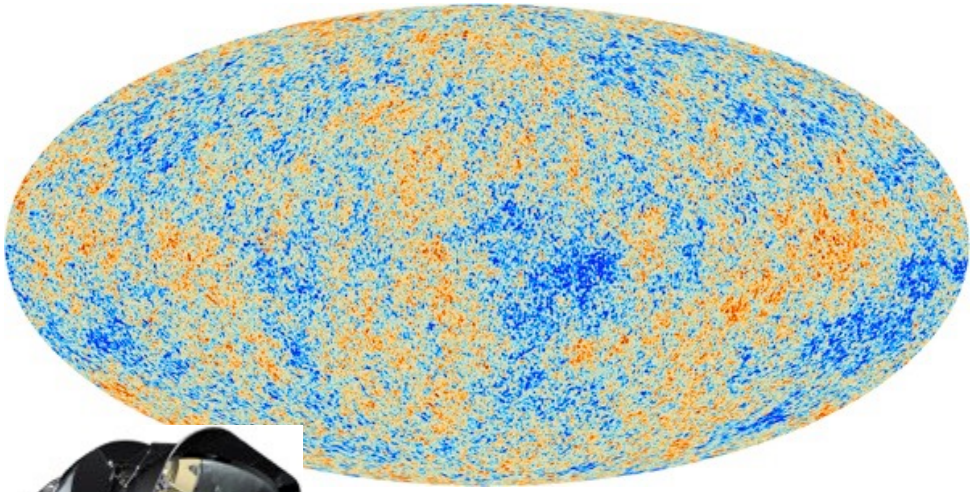
Tremendous Radio Arrays, July 2018

Era of precision cosmology

- Cosmology is now in a golden area (Planck, SDSS, DES and other large surveys) but there are still a few key questions to be answered!
  - Inflation ($t<10^{-32}$ s) – maybe CMB with B-mode polarization results
  - Dark energy – DES, e-BOSS, EUCLID, HETDEX and others?



CMB map from Planck collaboration et al. (2016)

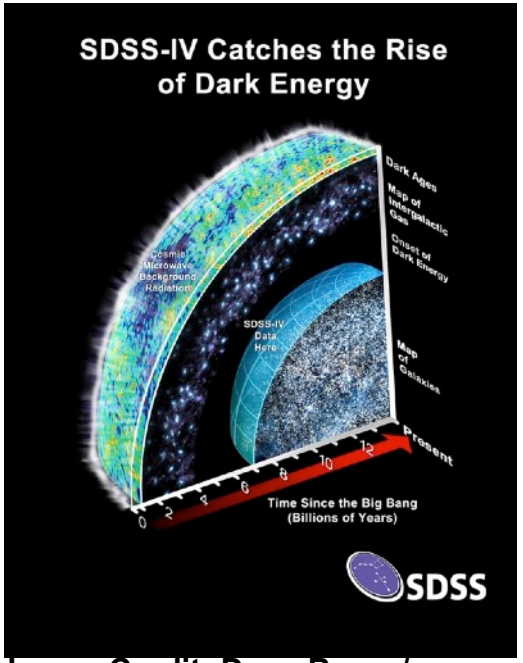
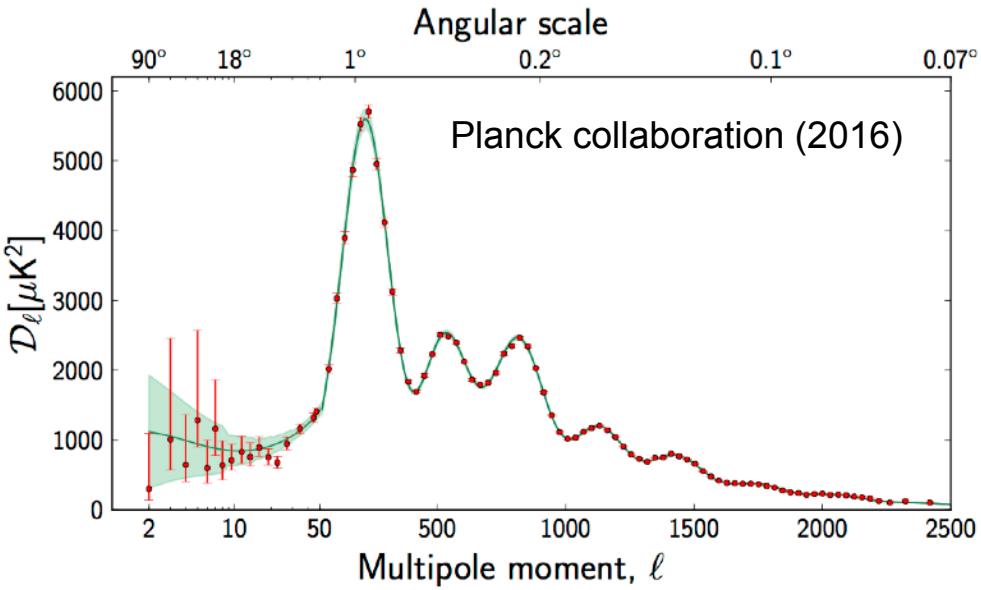
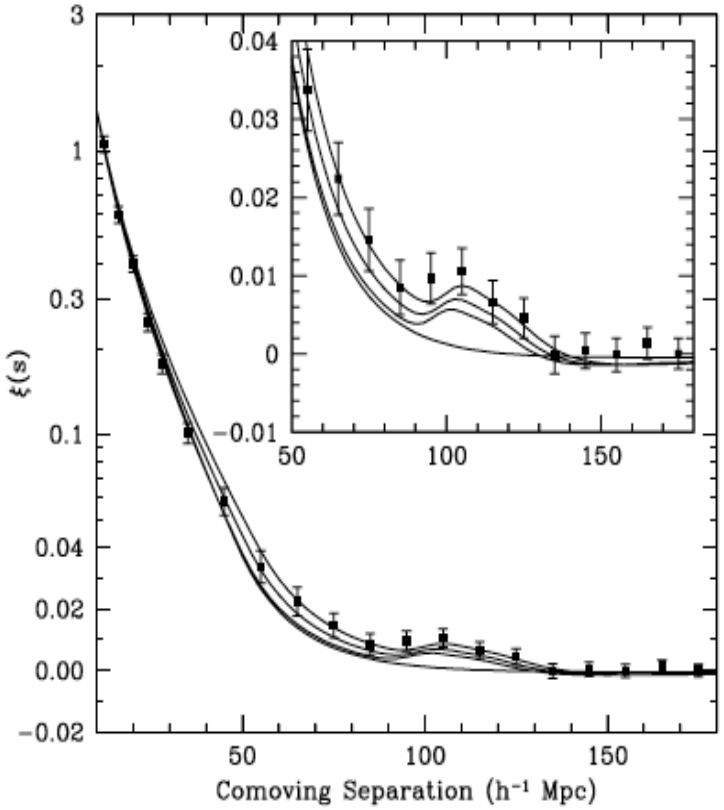


Image Credit: Dana Berry / SkyWorks Digital Inc. and the SDSS collaboration.

Baryon Acoustic Oscillations (BAOs)



Eisenstein et al. (2005)



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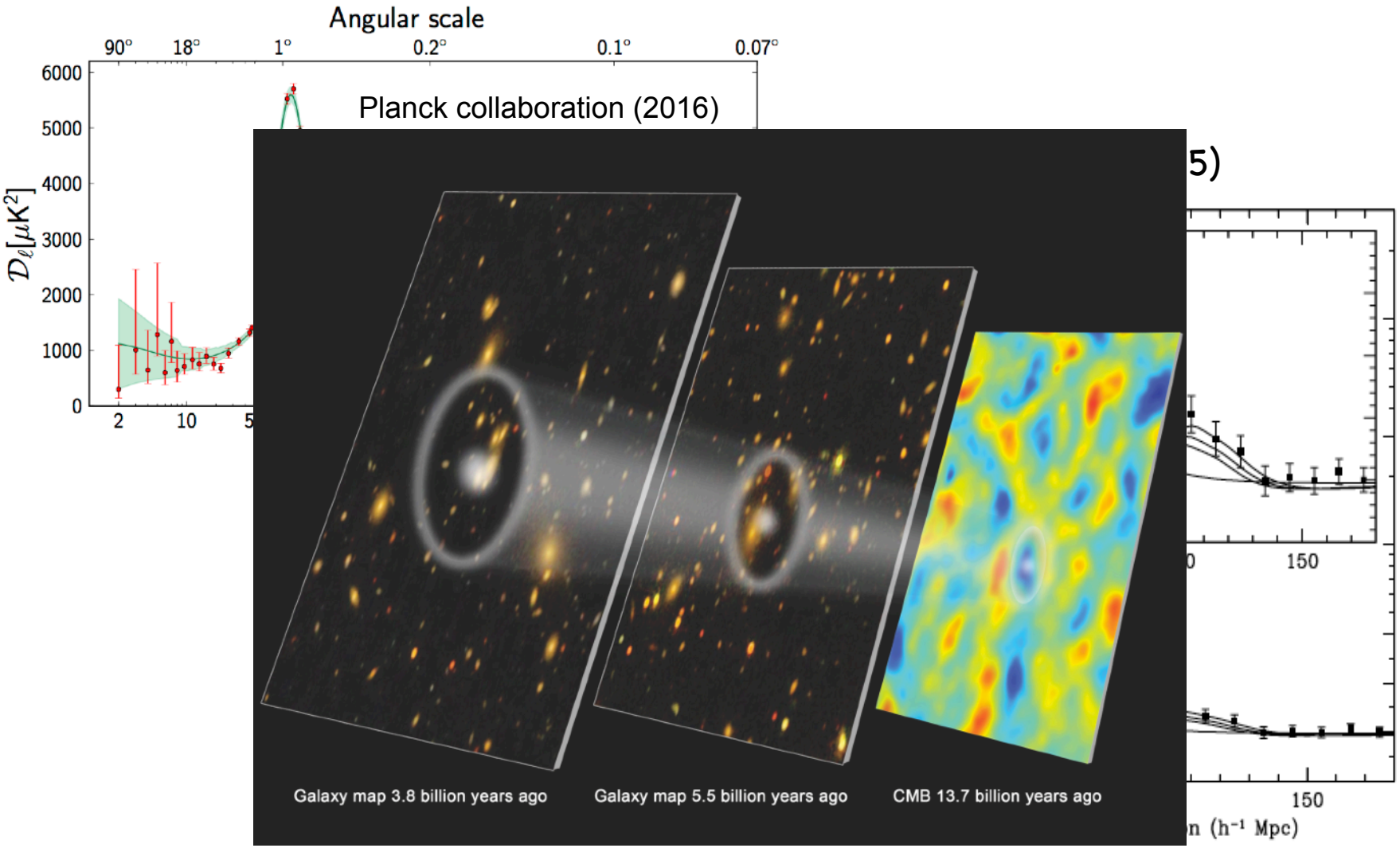
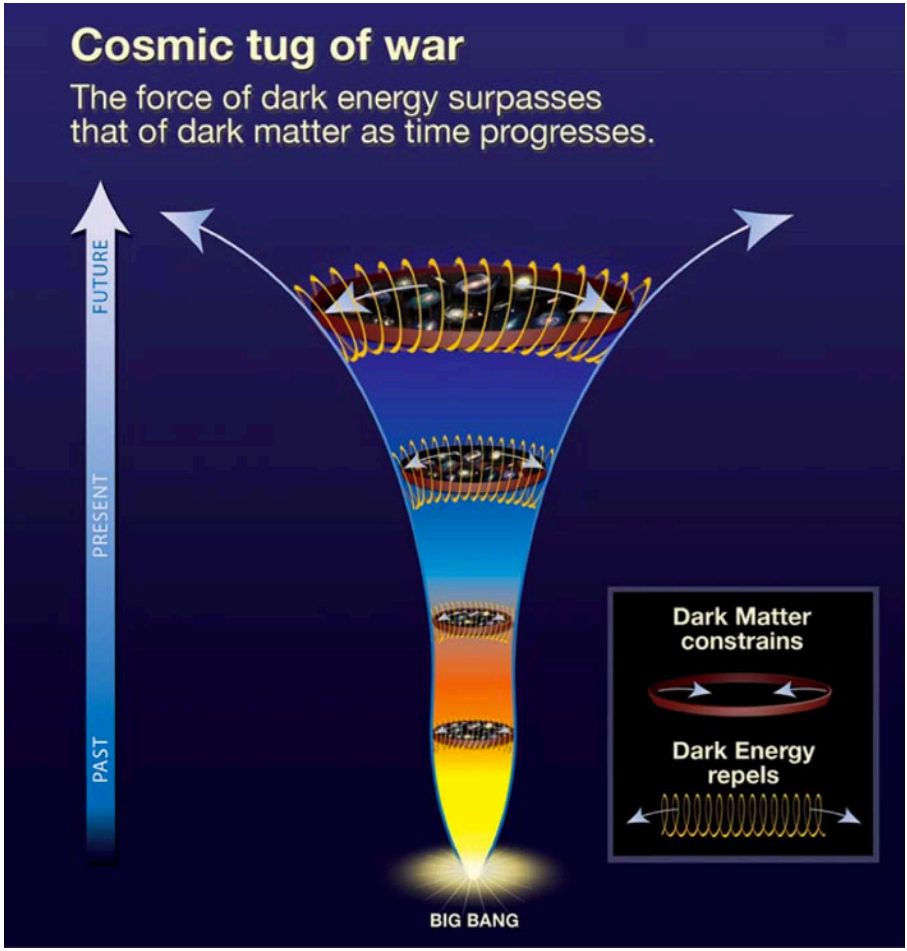


Credit: Eric Huff, the SDSS-III team, and the South Pole Telescope team. Graphic by Zosia Rostomian

The science – main case

- Measure BAOs on top of the 21 cm Hydrogen spectrum => intensity mapping in radio
- Redshift interval BINGO will reach starts right after DE starts dominating the Universe => possible to set constraints on its properties
- HI intensity mapping can be used as mass tracer, probing distortions in redshift space
- Complementary to large optical surveys

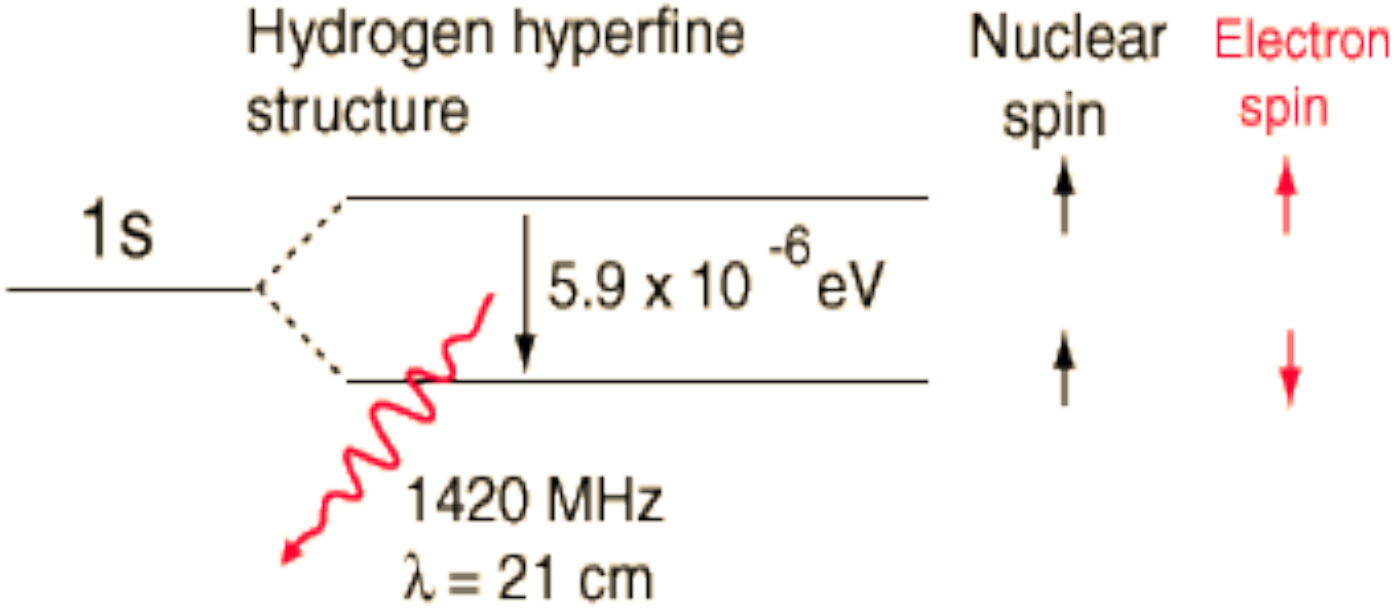


- Similar to CMB:

$$\Delta T_{CMB} = \Delta T_{CMB}(\theta, \phi, z = 1100)$$

$$\Delta T_{HI} = \Delta T_{HI}(\theta, \phi, z)$$

Why BAO in radio?

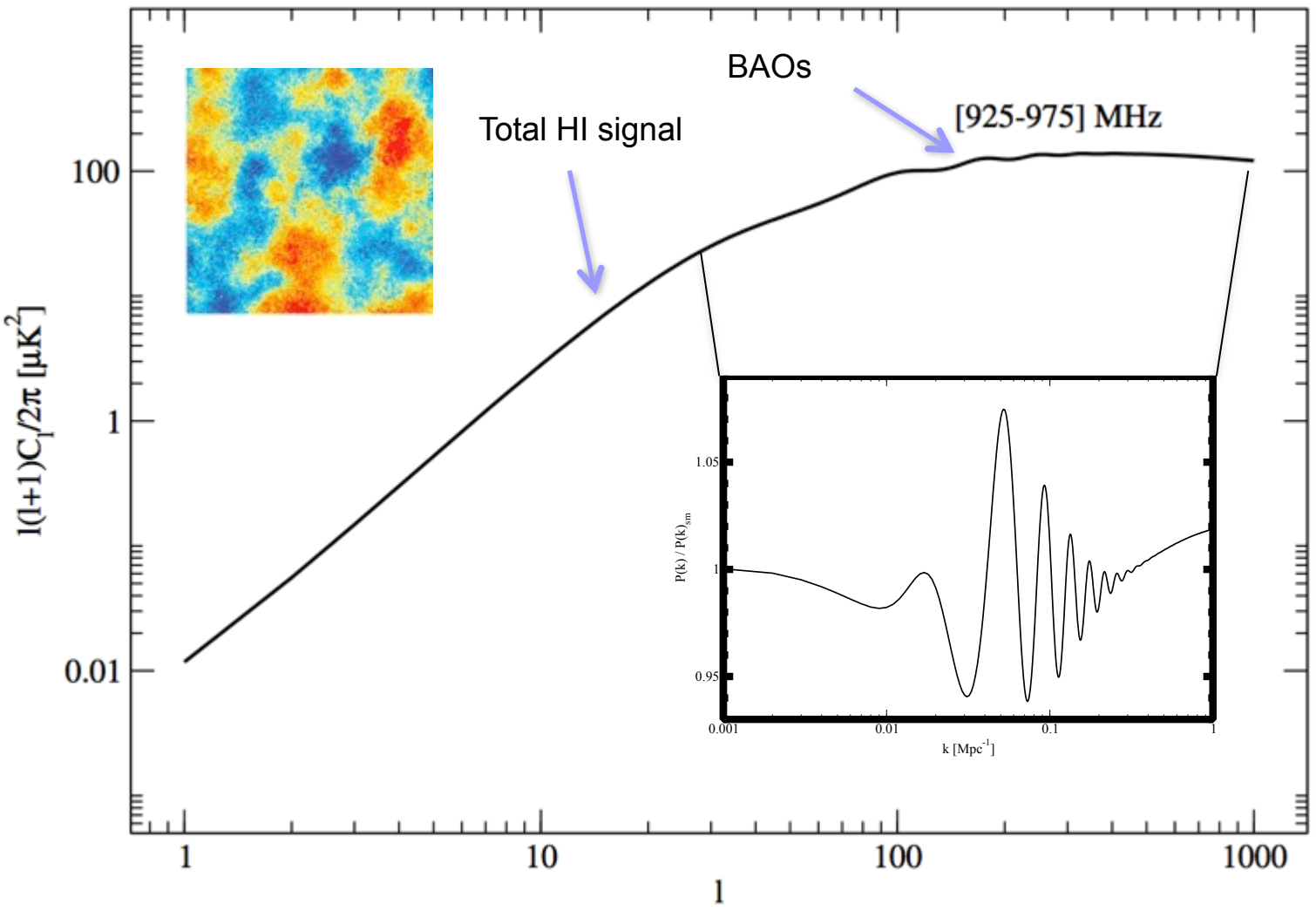


Why BAO in radio?

- Complementary to optics, different systematics
- Decay time of HI hyperfine transition is ~ 10^{15} seconds, but 75% of visible matter in the Universe is made of H…
- Efficient alternative for measuring a large number of galaxies individually (plus integrating the signal “alla” CMB allows for the reutilization of a large background experinece in instrumentation and data analysis)
- Interferometers are excellent instruments for these measurements, but are expensive and hard to operate and maintain
- Approach: single-dish, many horns X single horn per dish

The HI signal power spectrum

Cosmological HI signal is weak! (≈100 μK rms) and on degree scales



l≈(200/θ) degrees

The HI signal power spectrum

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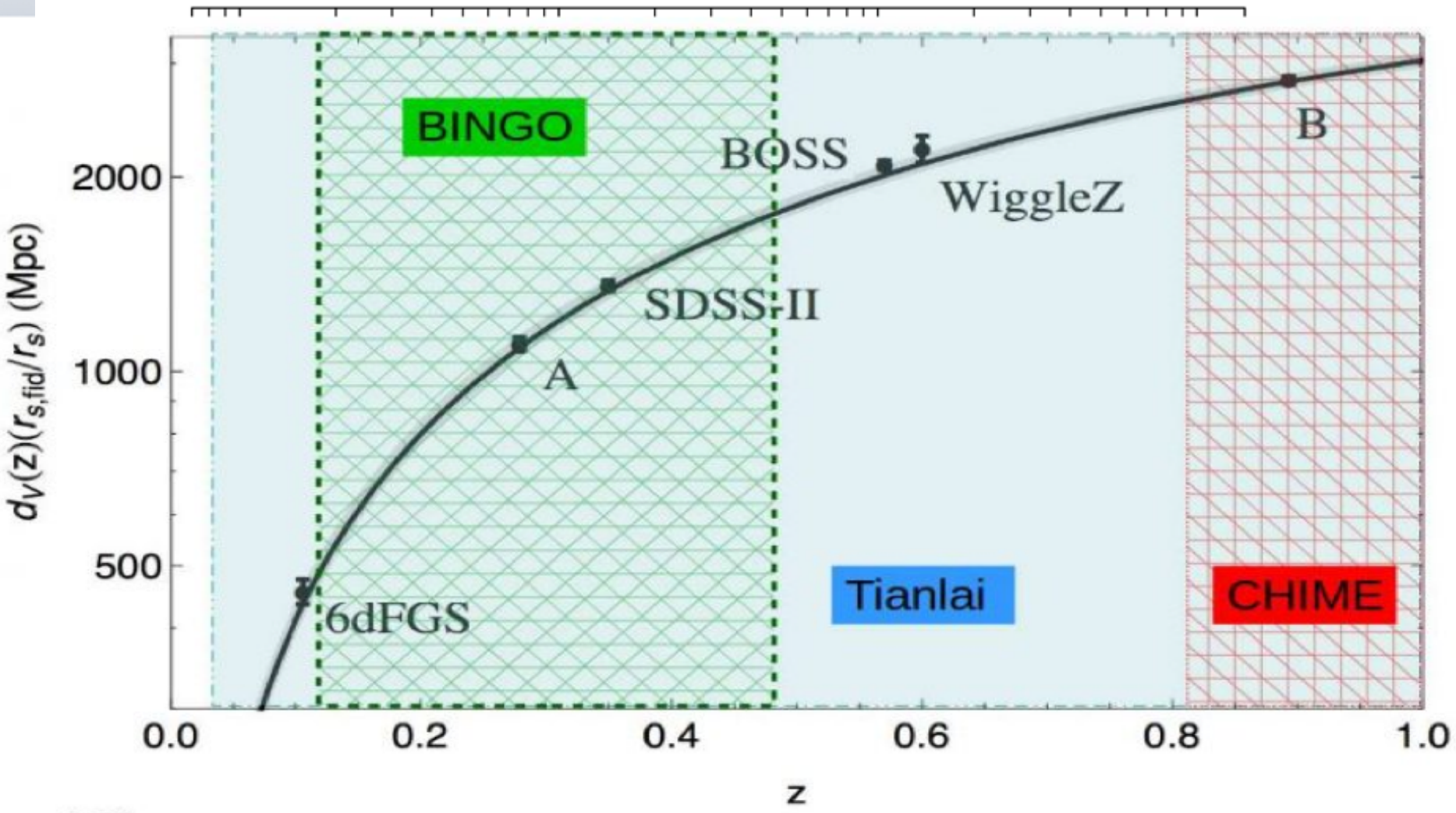


l≈(200/θ) degrees

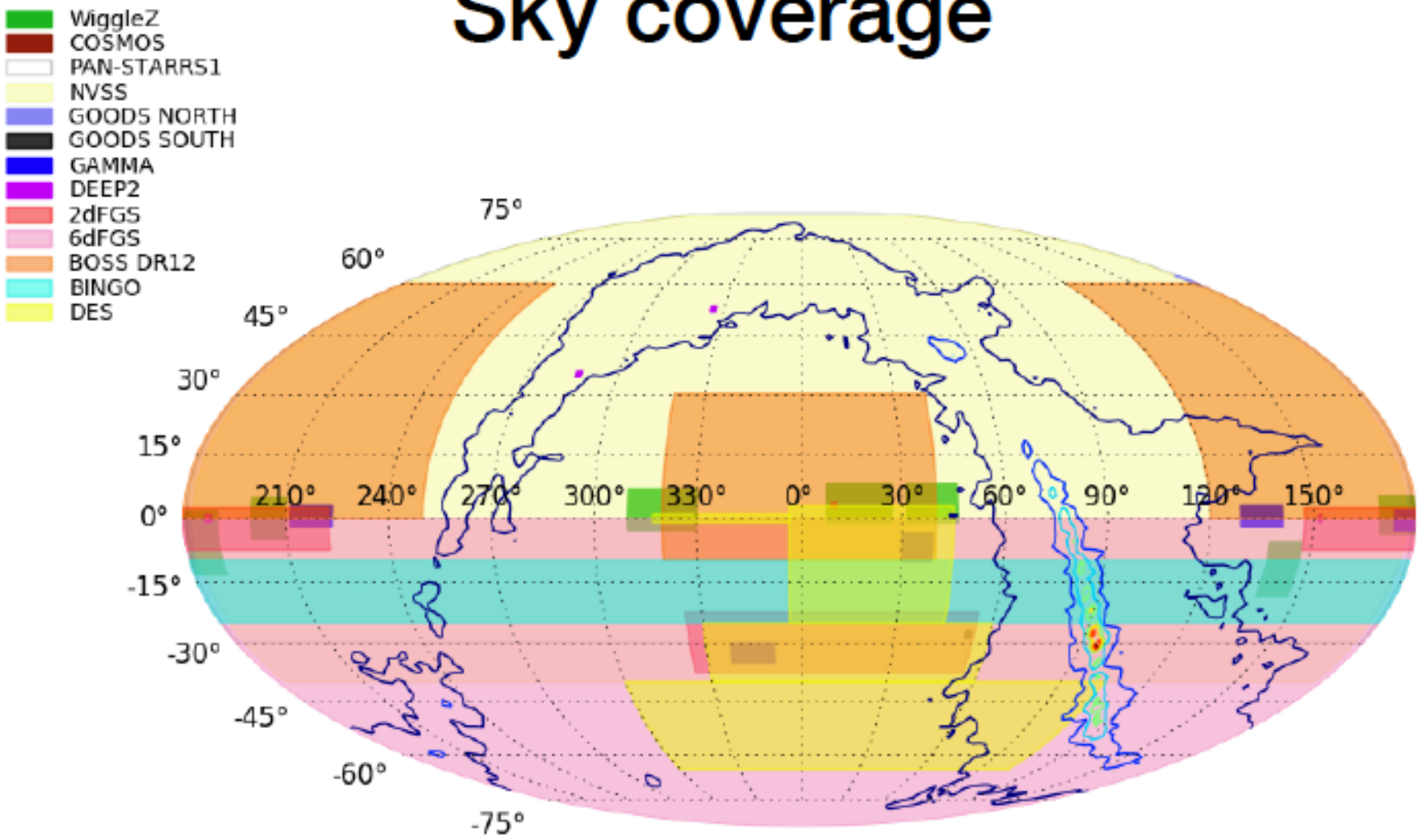
Foreground budget

Table 2. Summary of foregrounds for HI intensity mapping at 1 GHz for an angular scale of $\sim 1^\circ$ ($\ell \sim 200$). The estimates are for a 10°-wide strip at declination $\delta = +45^\circ$ and for Galactic latitudes $|b| > 30^\circ$.

Foreground	$\bar{T}$ [mK]	δT [mK]	Notes
Synchrotron	1700	67	Power-law spectrum with $\beta \approx -2.7$.
Free-free	5.0	0.25	Power-law spectrum with $\beta \approx -2.1$.
Radio sources (Poisson)	–	5.5	Assuming removal of sources at $S > 10$ mJy.
Radio sources (clustered)	–	47.6	Assuming removal of sources at $S > 10$ mJy.
Extragalactic sources (total)	205	48	Combination of Poisson and clustered radio sources.
CMB	2726	0.07	Black-body spectrum, ($\beta = 0$).
Thermal dust	–	$\sim 2 \times 10^{-6}$	Model of Finkbeiner et al. (1999).
Spinning dust	–	$\sim 2 \times 10^{-3}$	Davies et al. (2006) and CNM model of Draine & Lazarian (1998).
RRL	0.05	3×10^{-3}	Hydrogen RRLs with $\Delta n = 1$.
Total foregrounds	~ 4600	~ 82	Total contribution assuming the components are uncorrelated.
HI	~ 0.1	~ 0.1	Cosmological HI signal we are intending to detect.

- From Battye et al. (2013)
- Need to recalculate this budget for current BINGO concept

Sky coverage



BINGO concept (as of June 2018)

Instrument characteristics

- Dish diameter : 45m and 38m
- Resolution (°): ~ 0.67
- Horn opening (°): ~ 25
- Frequency range (MHz): 960 – 1260
- Channel resolution ~ 1 MHz
- Z interval: 0.13 - 0.48

Instrument characteristics

- Number of feeds : 50 (dual pol.)
- Horn largest diameter: 1.9m
- Horn length: 4.3m
- Focal plane size: 19m x 9,5m
- Estimated scan area: ~ 5000□
- No cryogenics : $T_{sys} \approx 50K$

Fixed wire-mesh parabolas

No moving parts

Transit telescope

Most components "off-the-shelf"

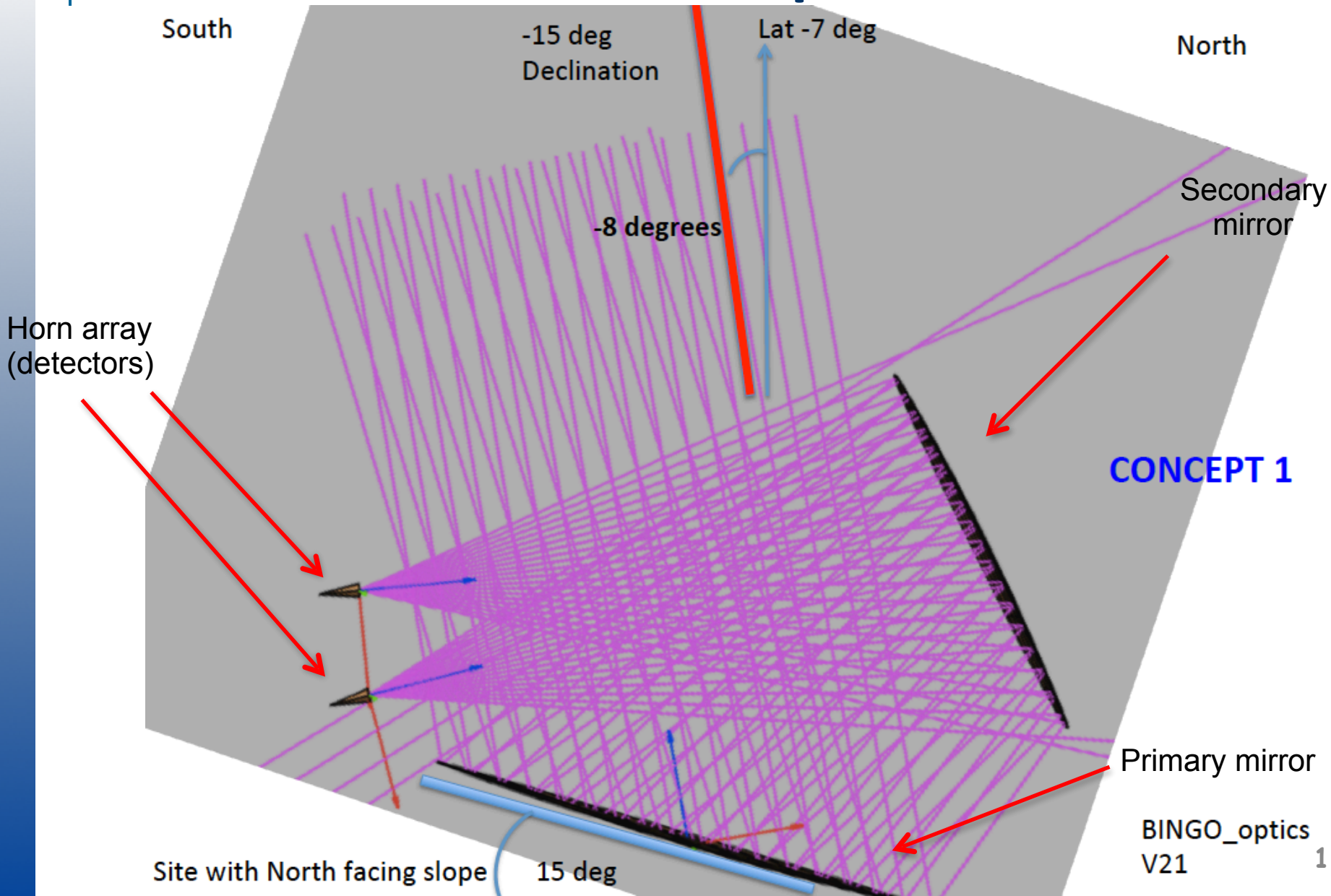
Guiding principle : simplicity !

Project status

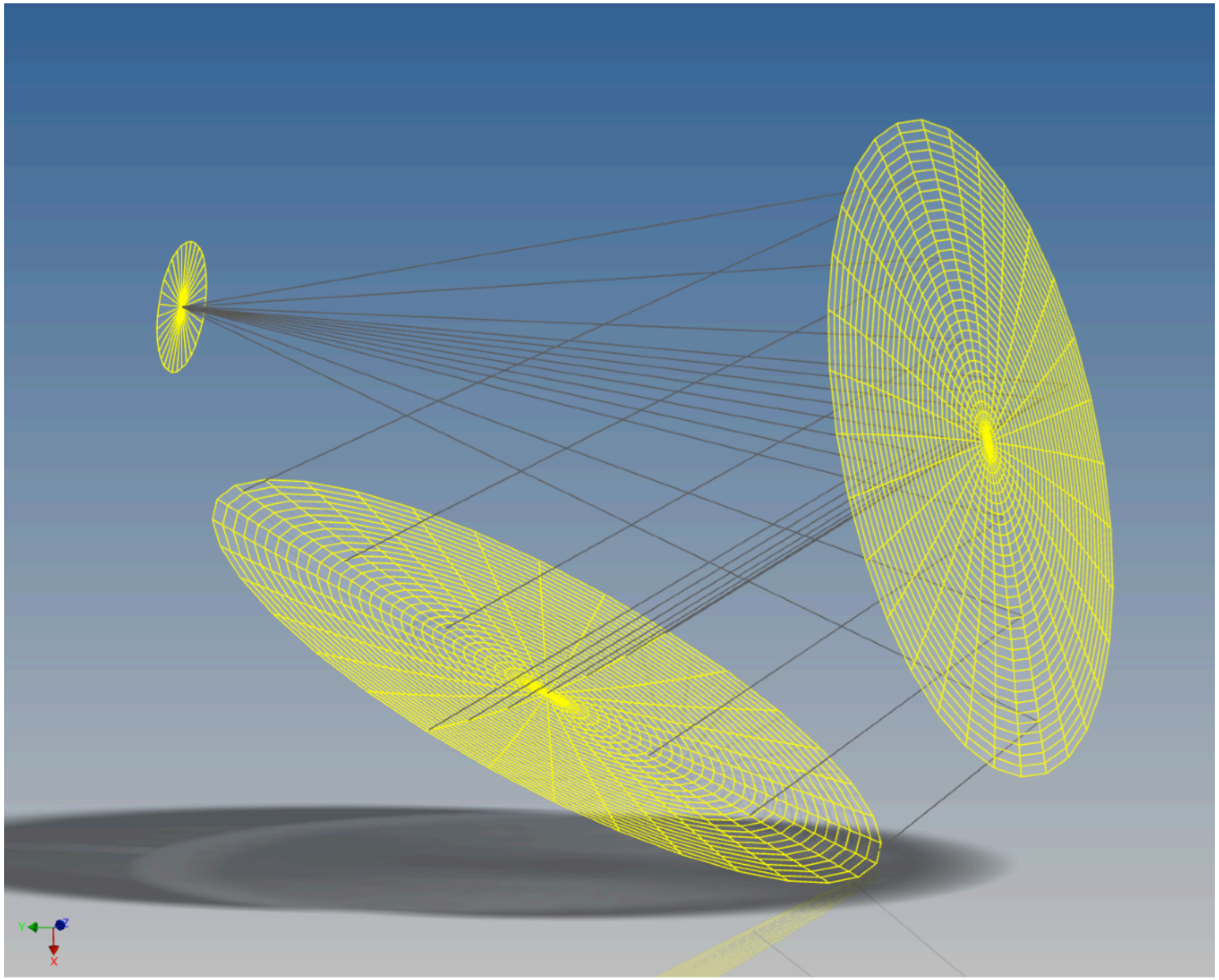
- BINGO is under construction
  - horn prototype completed
  - transitions, polarimeter, transitions and magic tee prototypes going to fabrication
  - receiver waiting for components to arrive
  - RFI initial measurements on site completed => permanent monitor received from Swiss to be installed on site
  - Topography sorted out => optical design in preparation
  - Legal issues regarding property, electrical power, roads and silence protection zone being handled by collaborators in Paraiba
- About 80% completely funded
  - (total ~ R$ 17.5 M => ~ US$ 4,25 M)

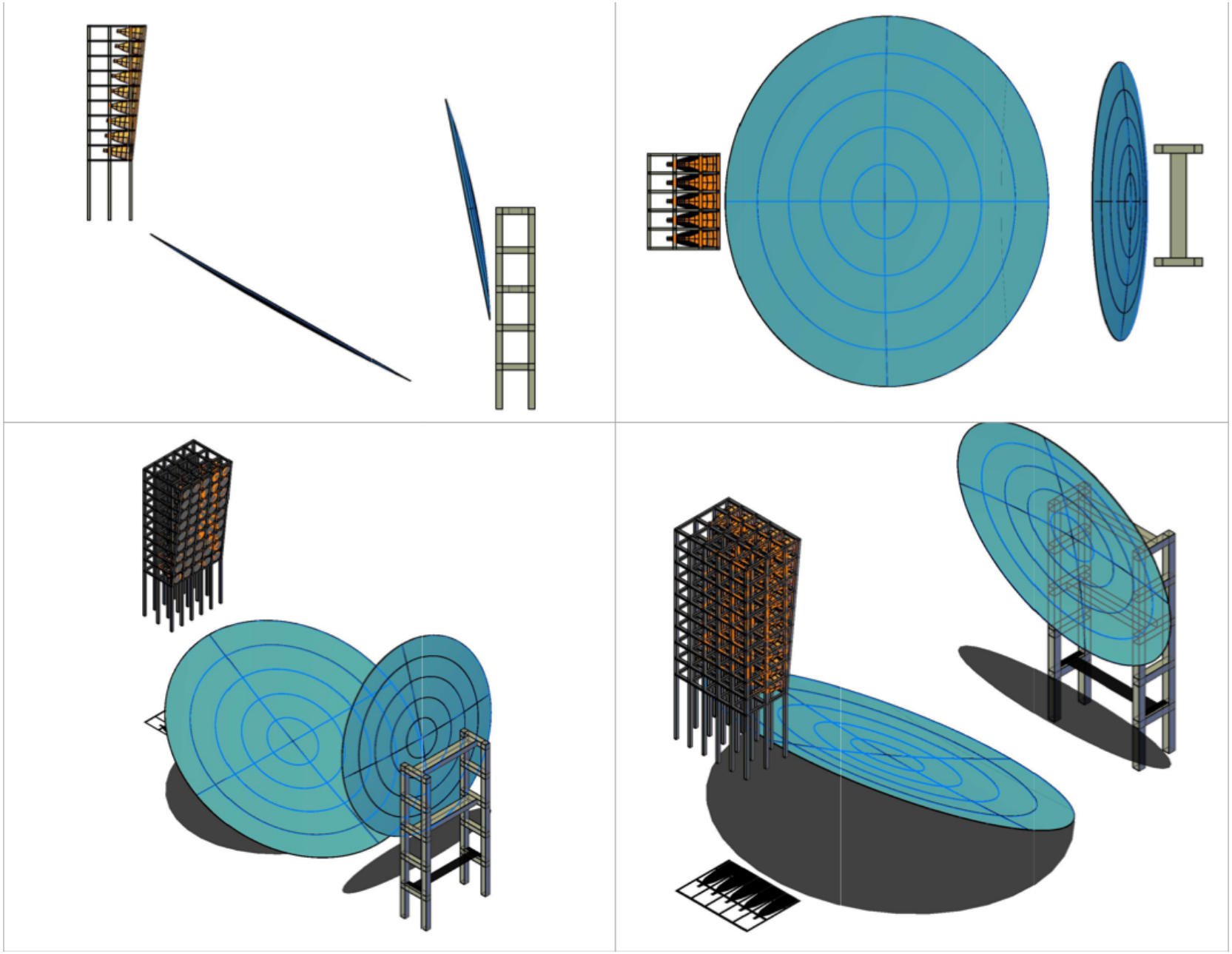
Sketch of 3-D model of optics

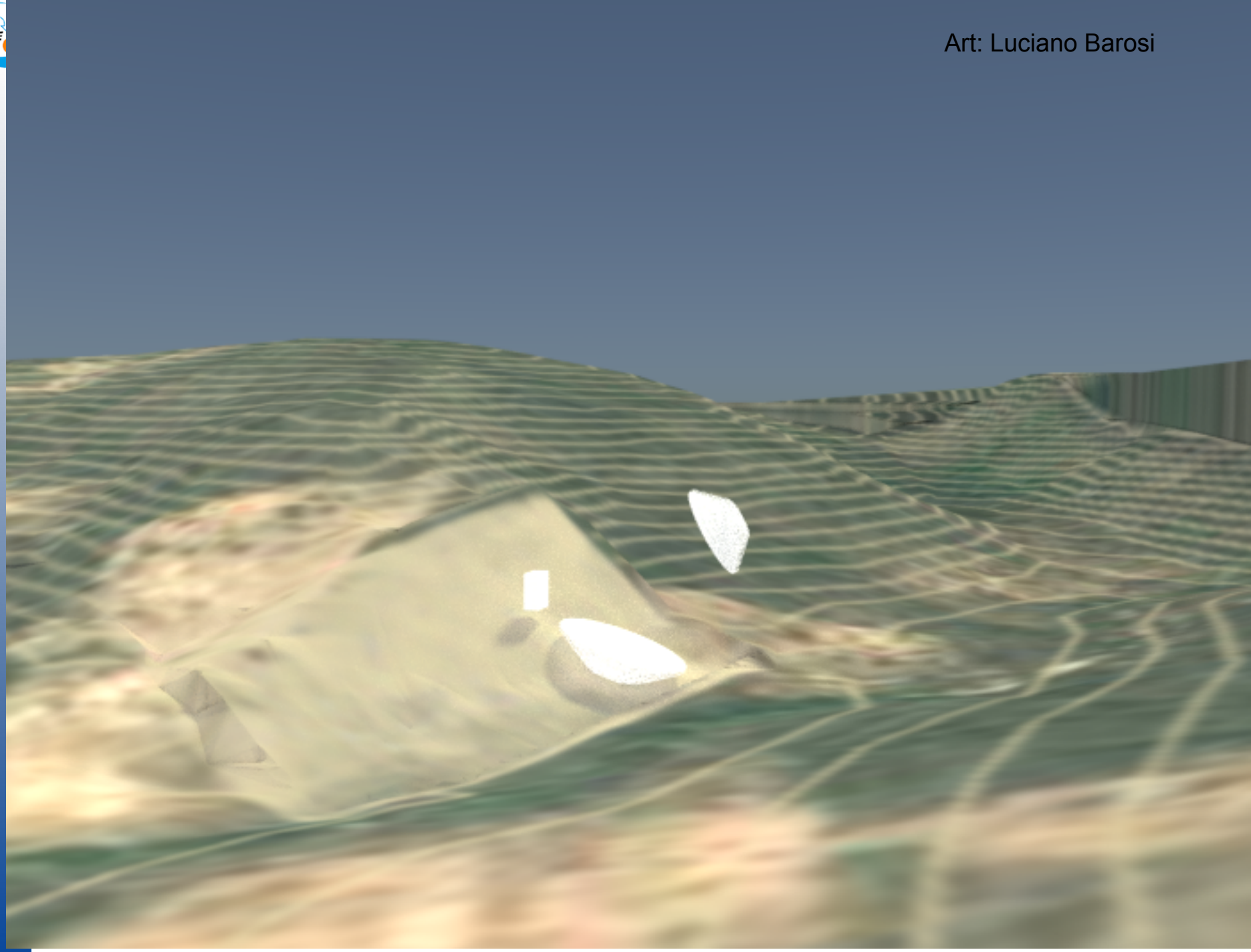
Picture by Bruno Maffei



Optics schematics

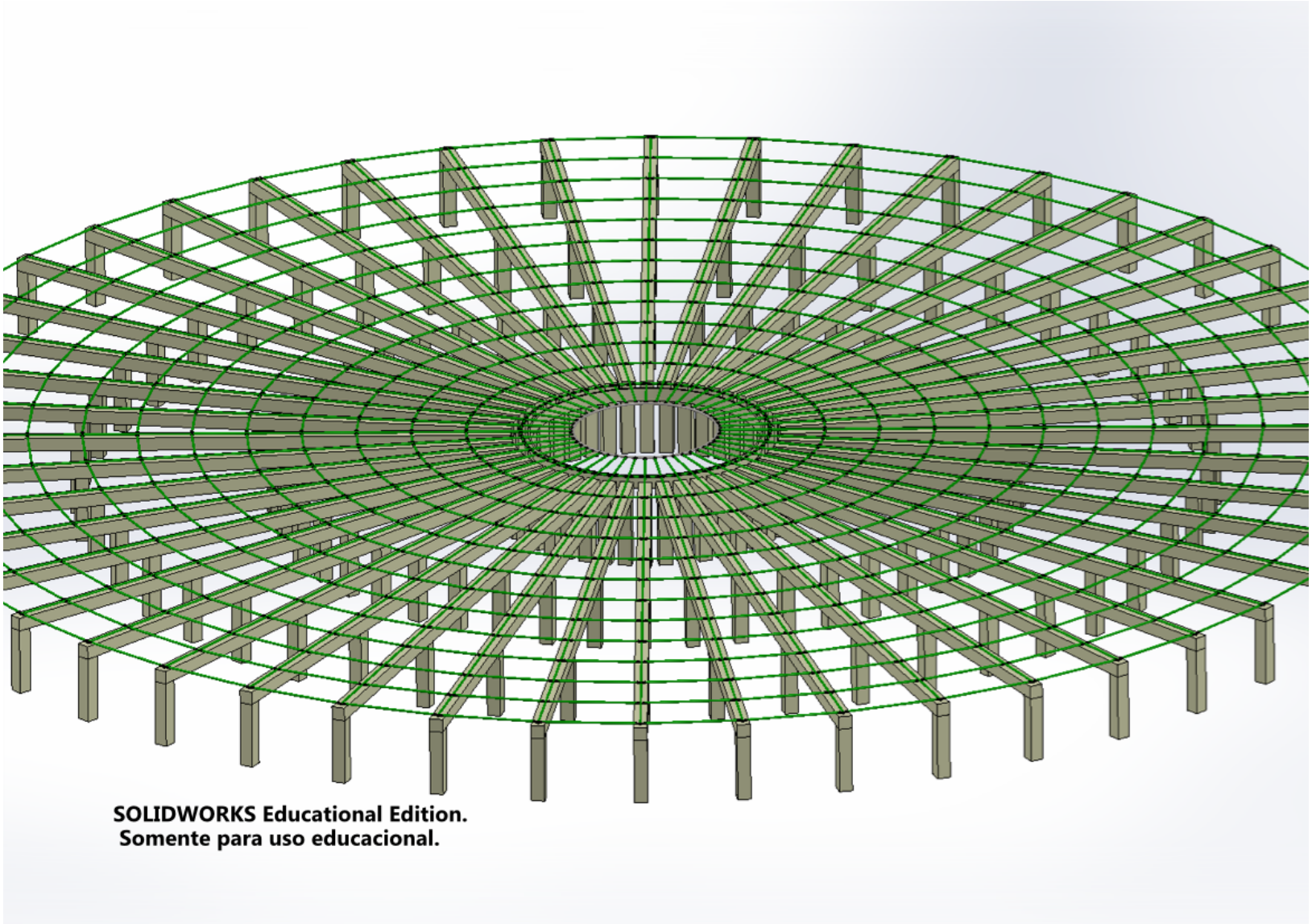





Art: Luciano Barosi

Espelhos

Crédito: L. A. Reitano



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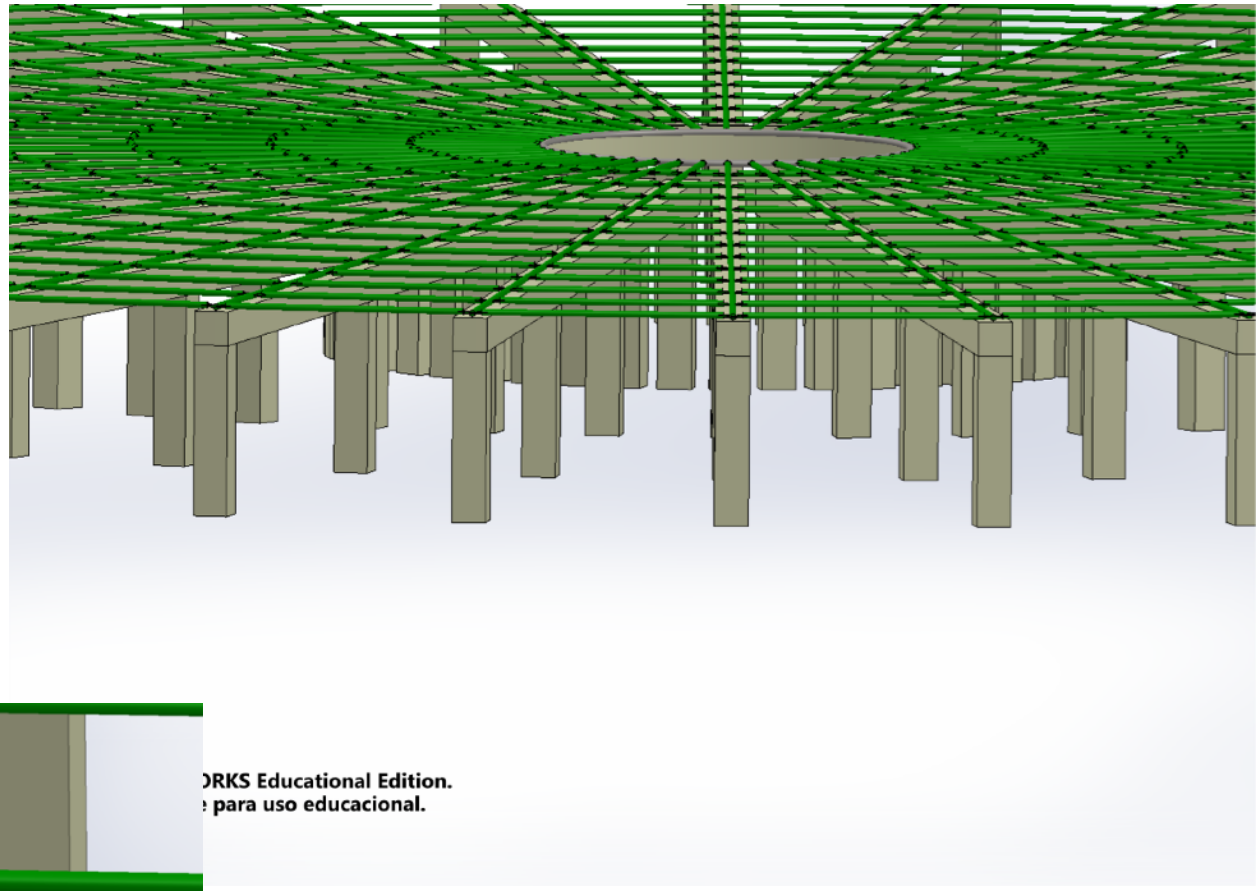
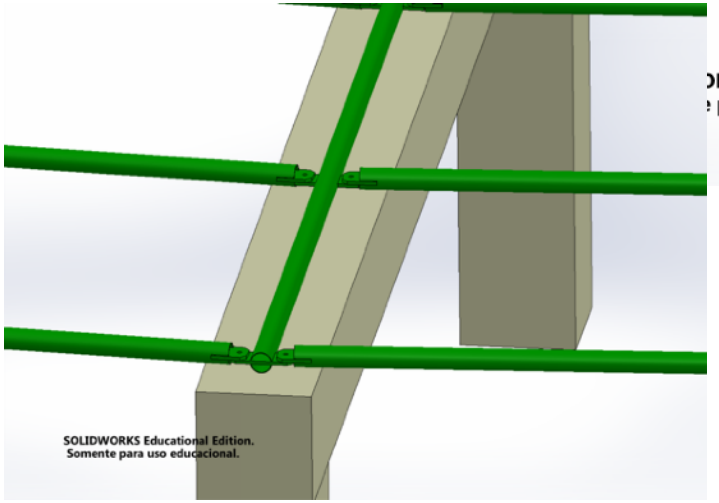
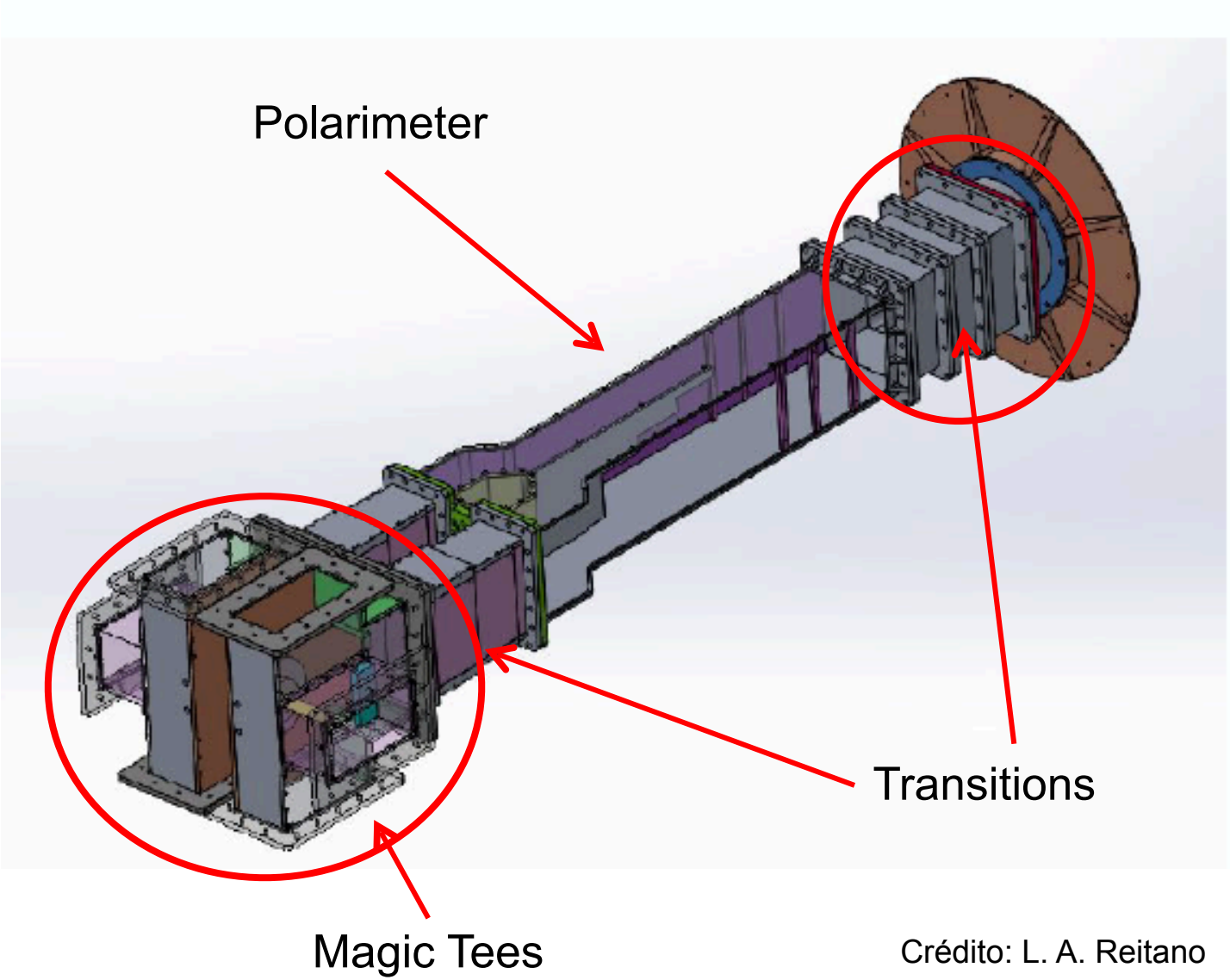




ORKS Educational Edition.
para uso educacional.

Polarimeters, transitions and magic tees



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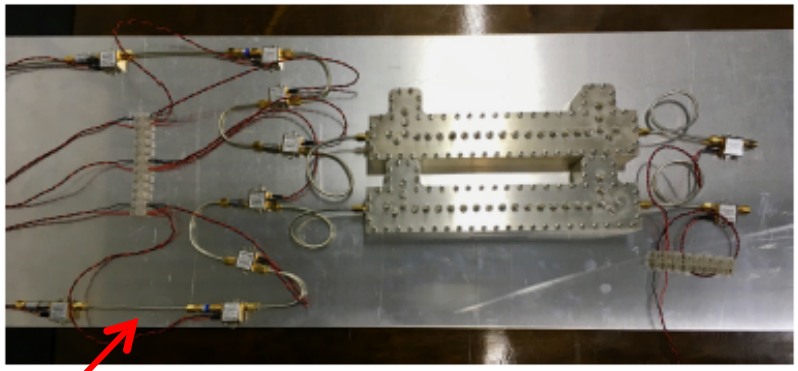
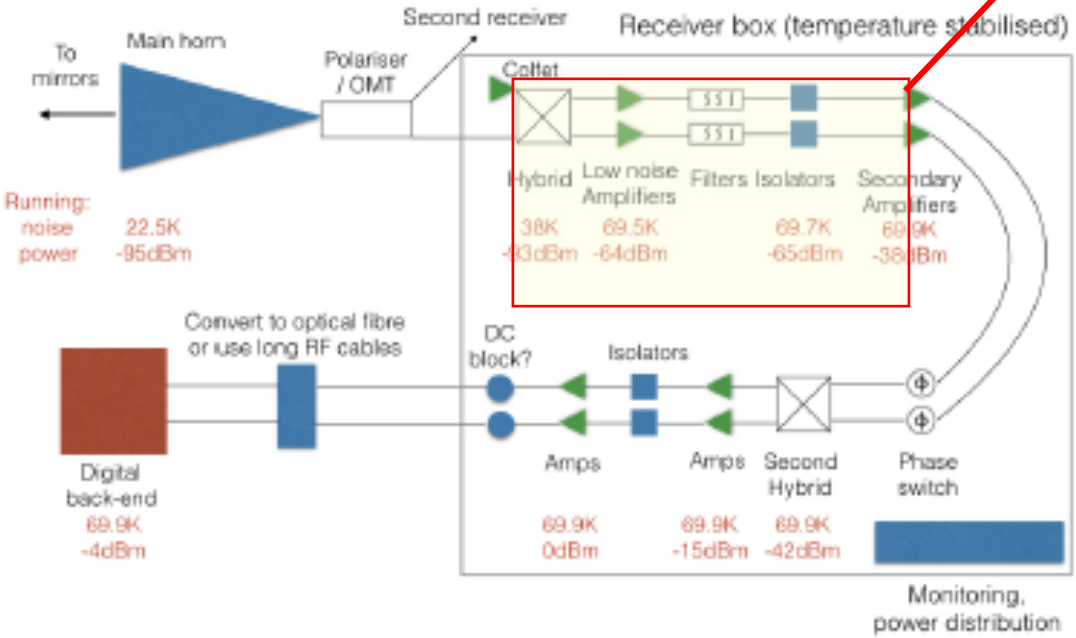
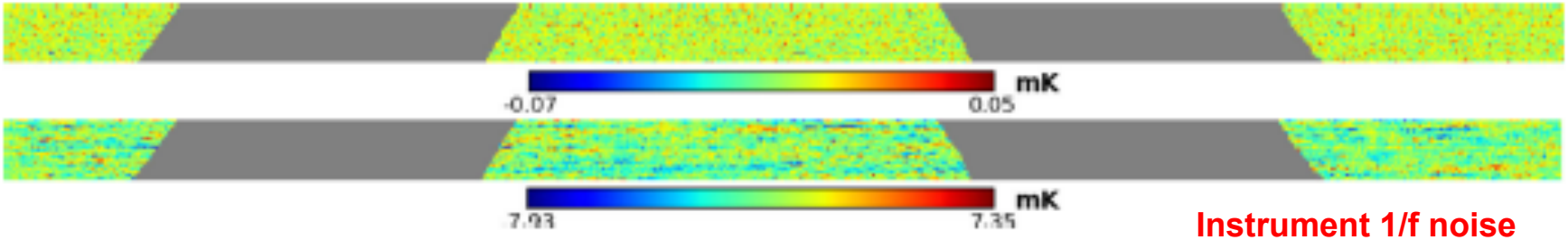
Receiver status





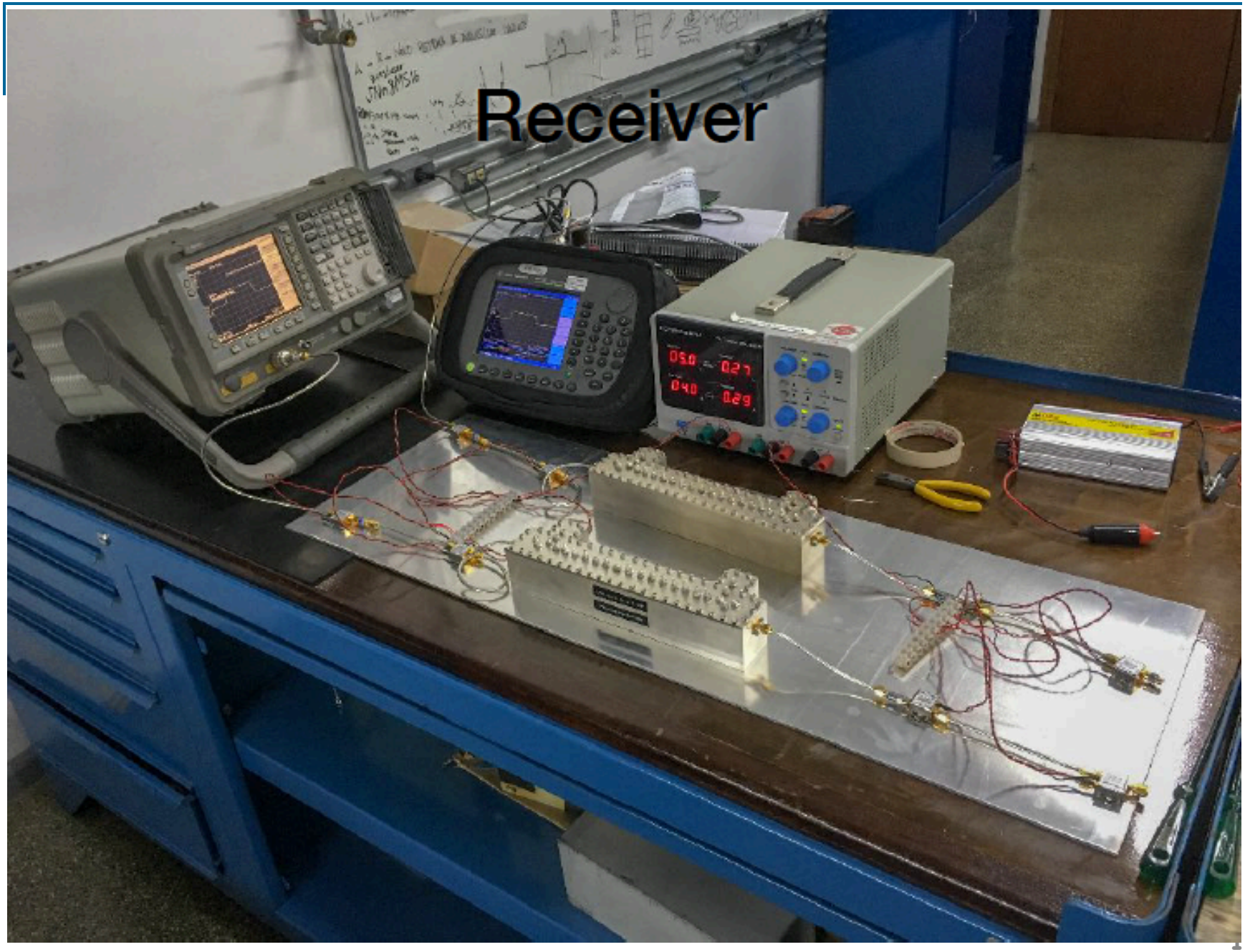
SIMULATIONS

Instrument (thermal) noise



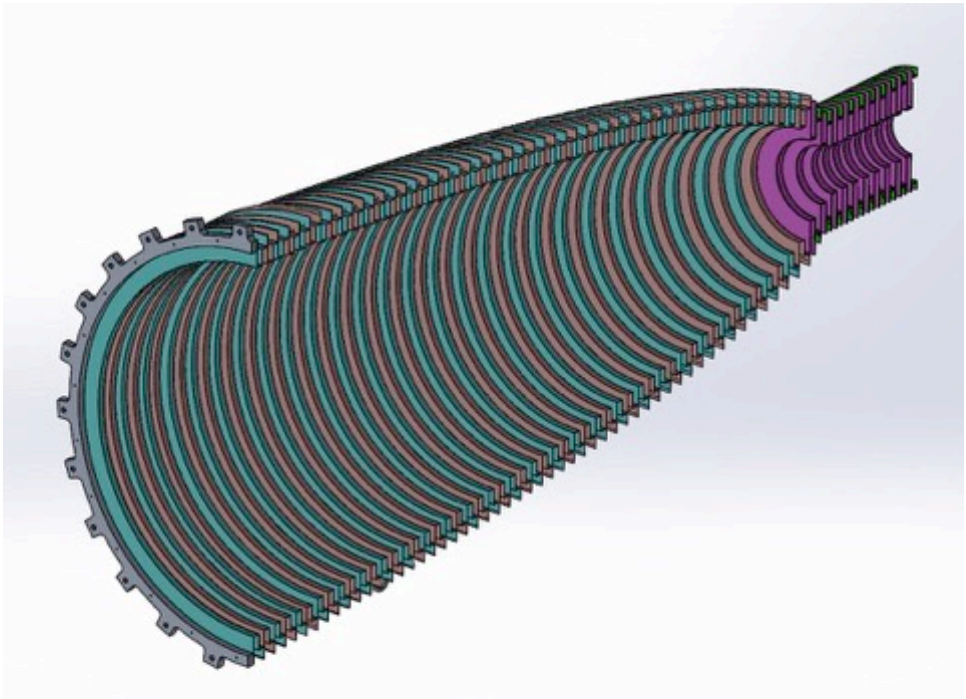
Instrument 1/f noise

Receiver



Horn status

- Aluminum horns (6060 T4 alloy)
  - Mass: 347 kg, not including screws and bolts, which may add ~ 30 kg to the unit
  - Number of rings (sectors): 127
  - Length: 4318 mm
  - Mouth: 1900 mm
  - Throat: 250 mm



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ROMI
GL 350M


ROMI
GL 350M


ROMI
GL 350M

Horn tests

"BINGO: Horn design, fabrication and testing" (Wuensche et al. 2018, in preparation)

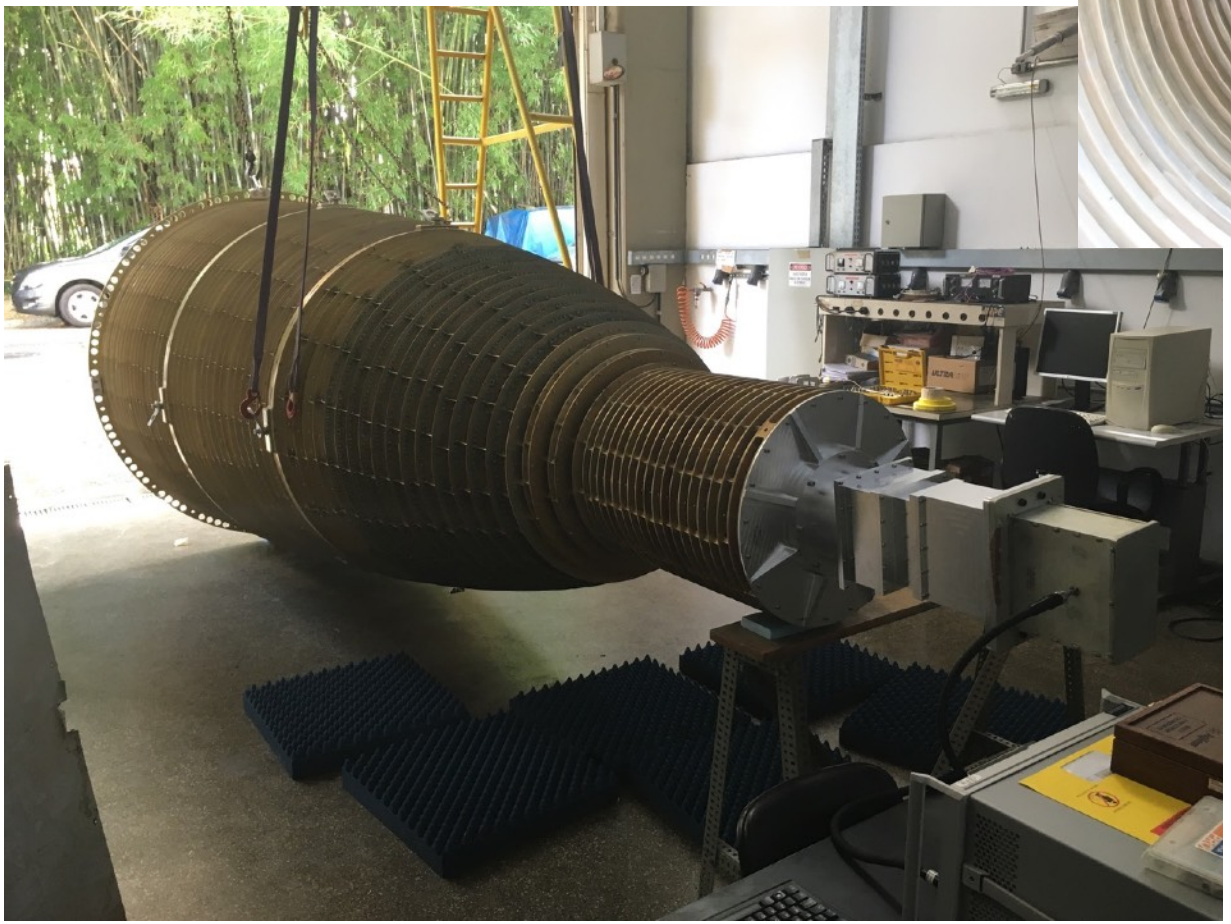
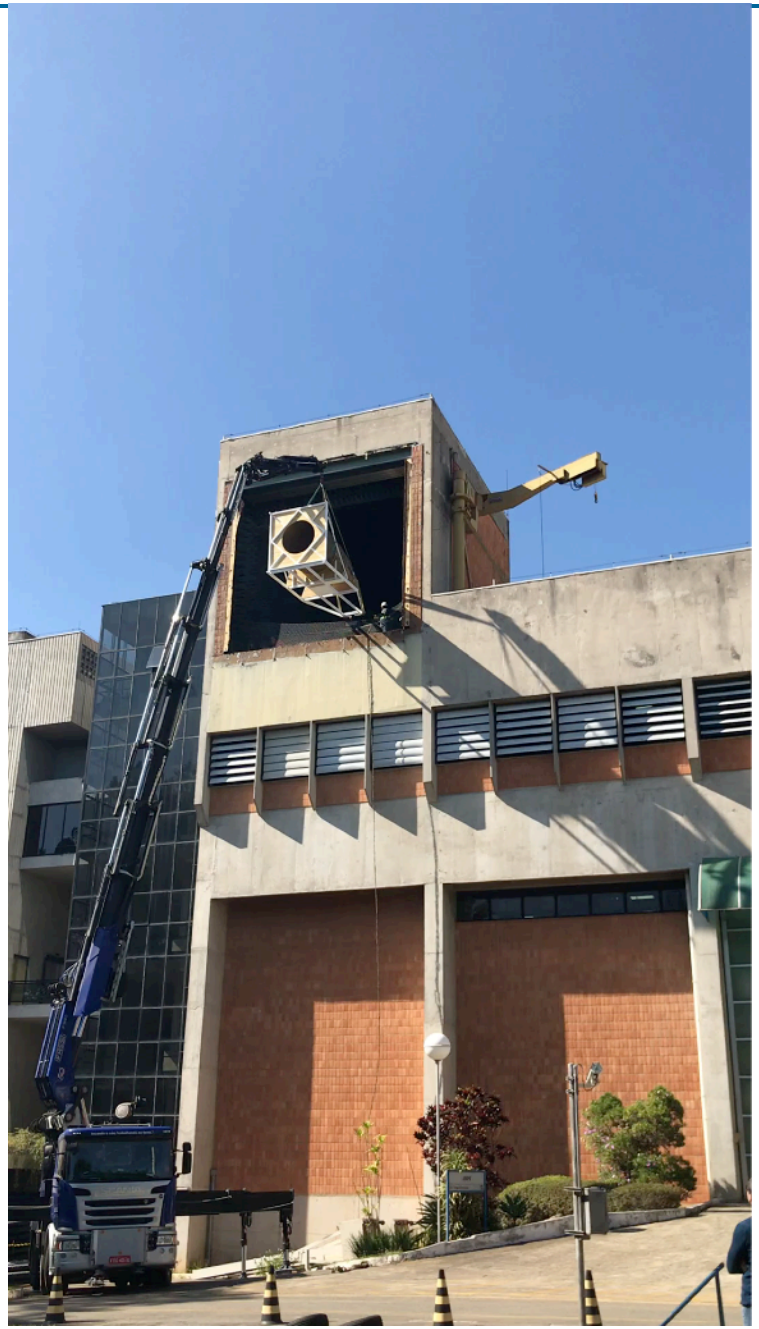
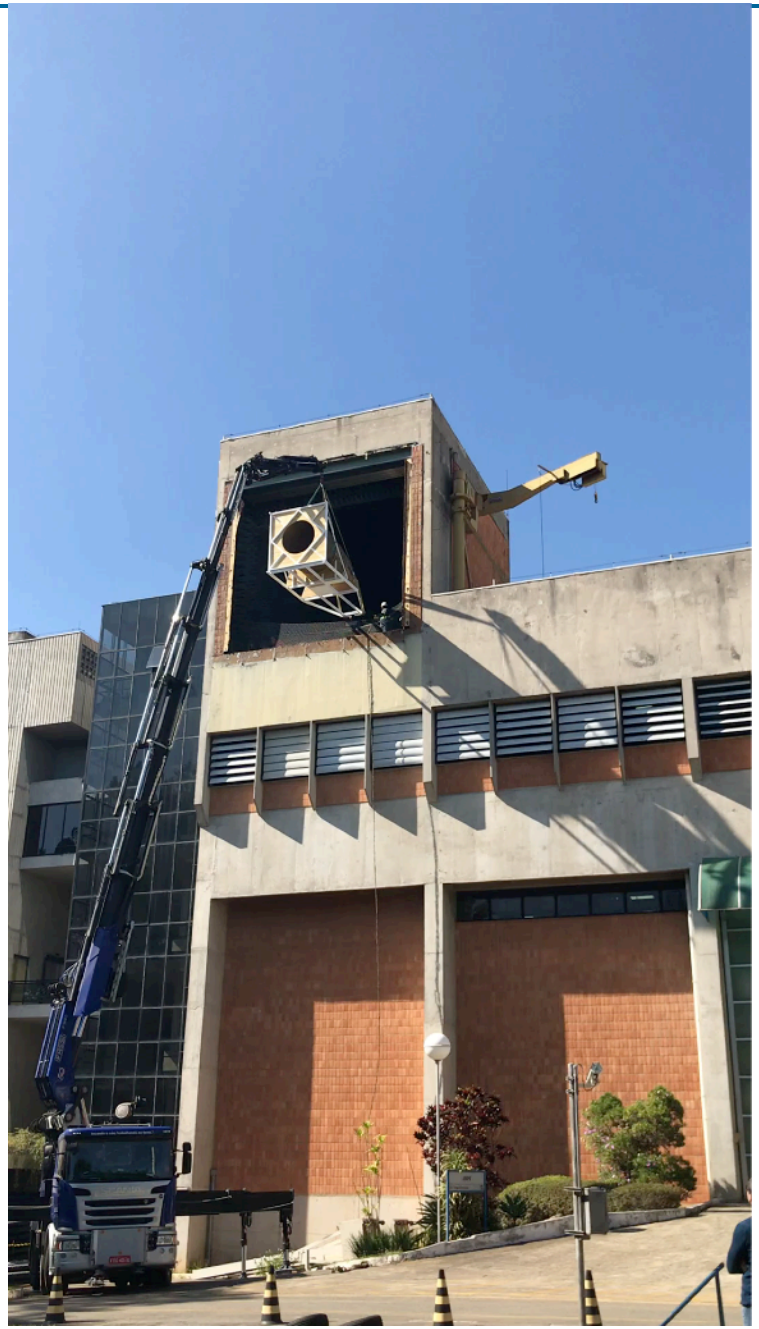
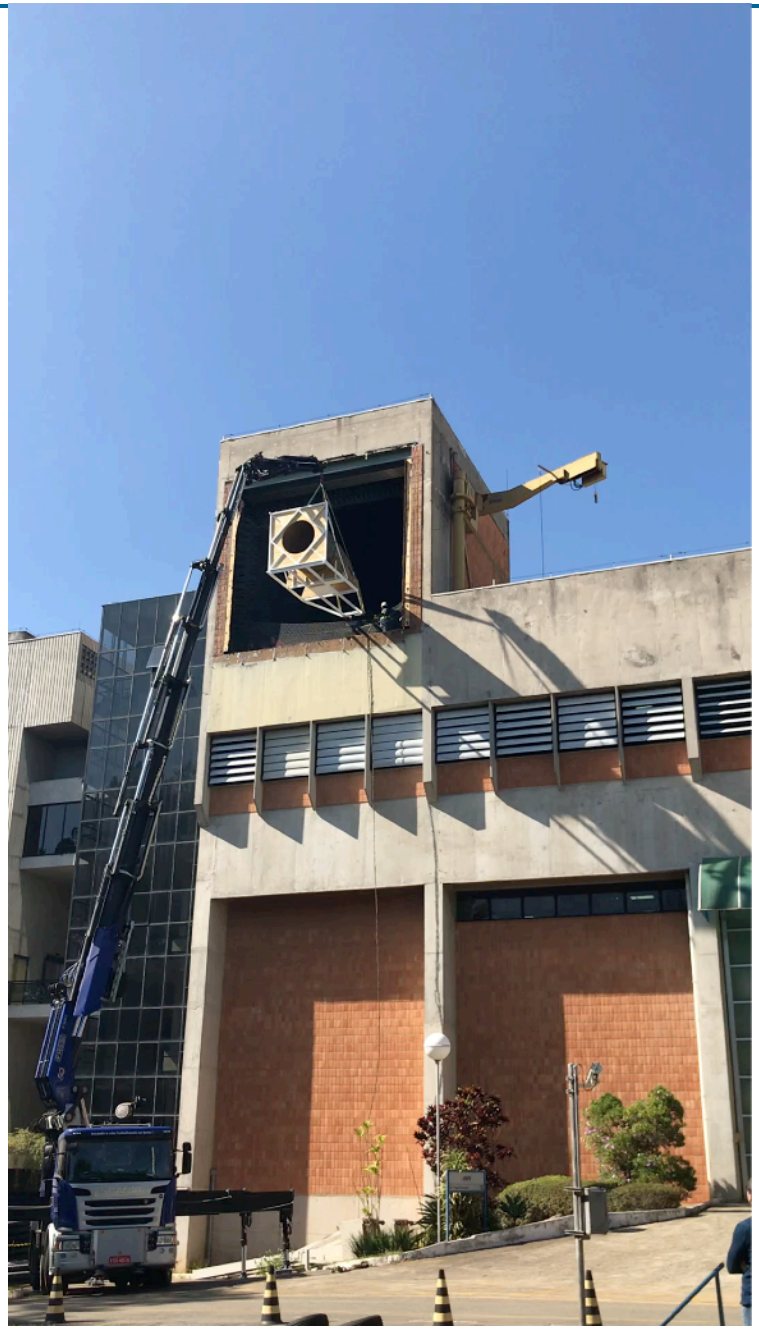
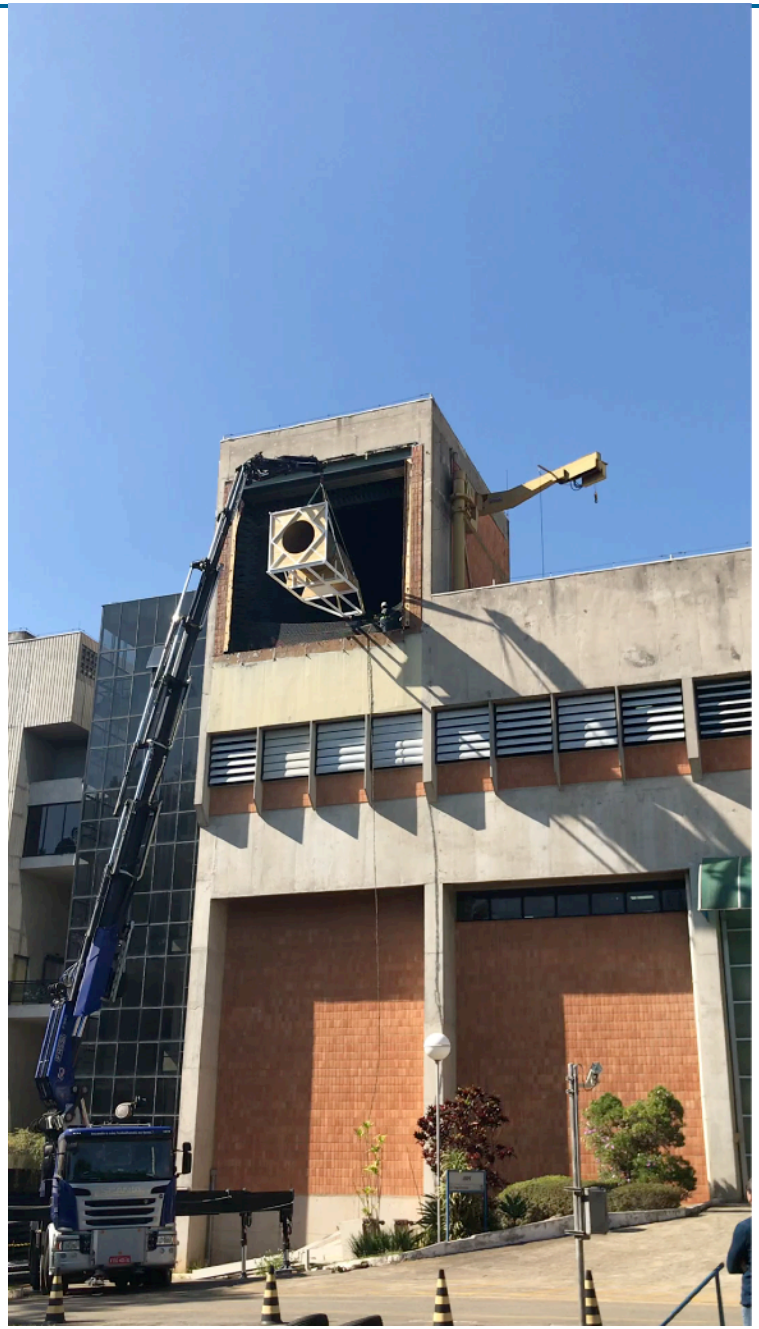


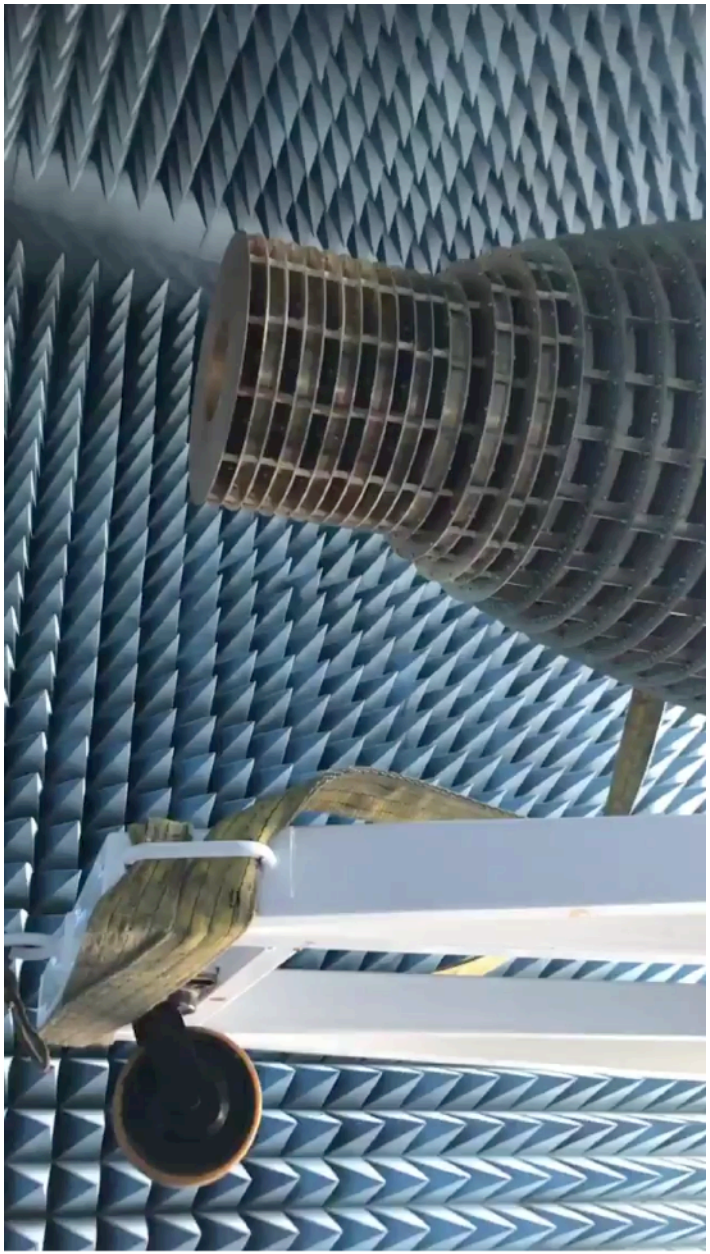
Foto: M. Peel

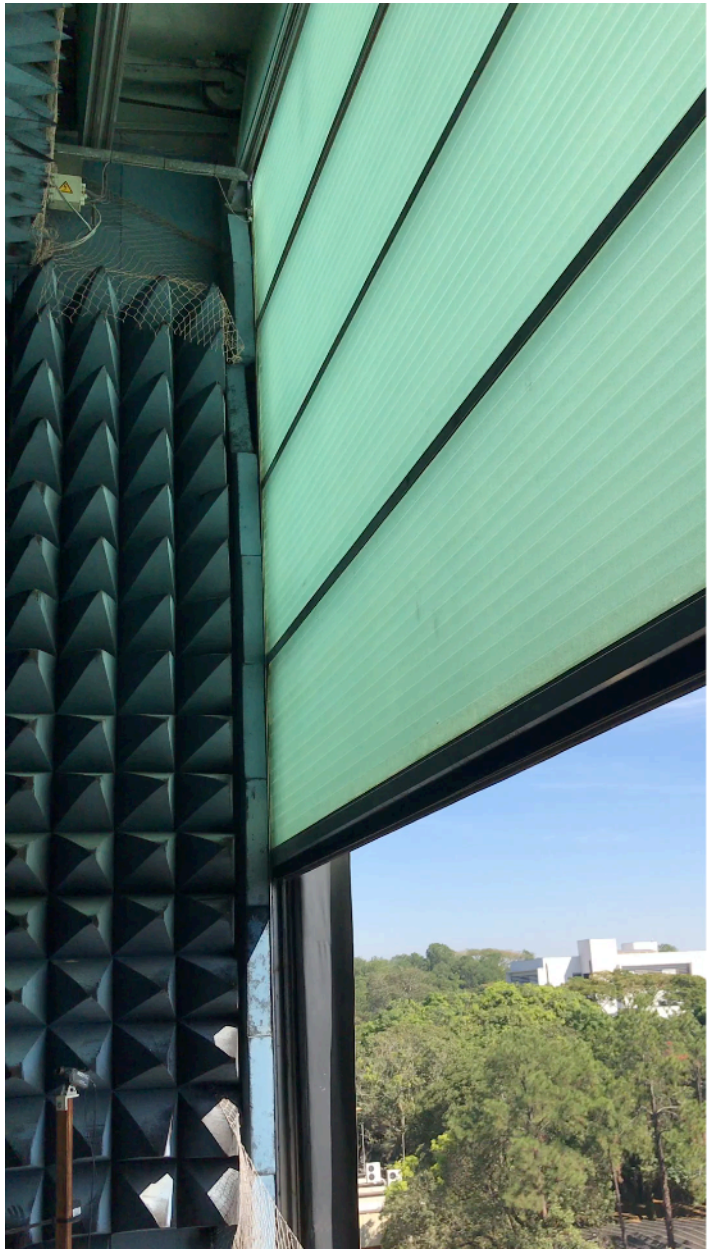


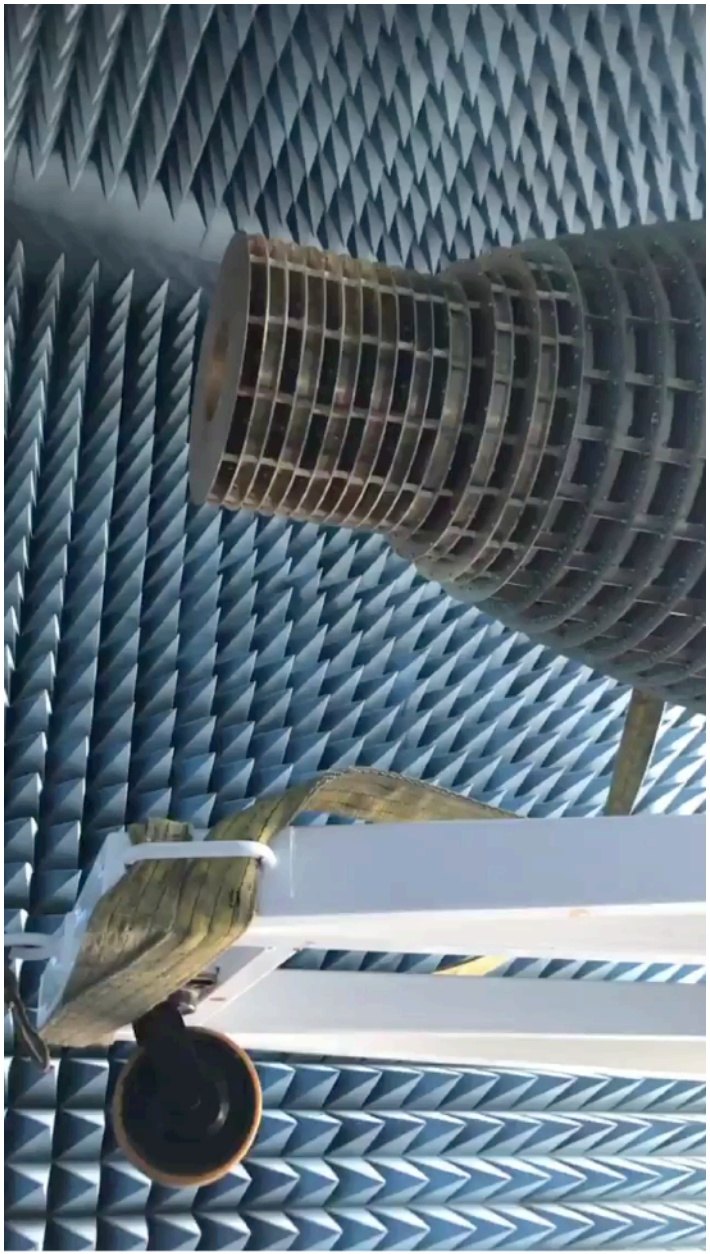


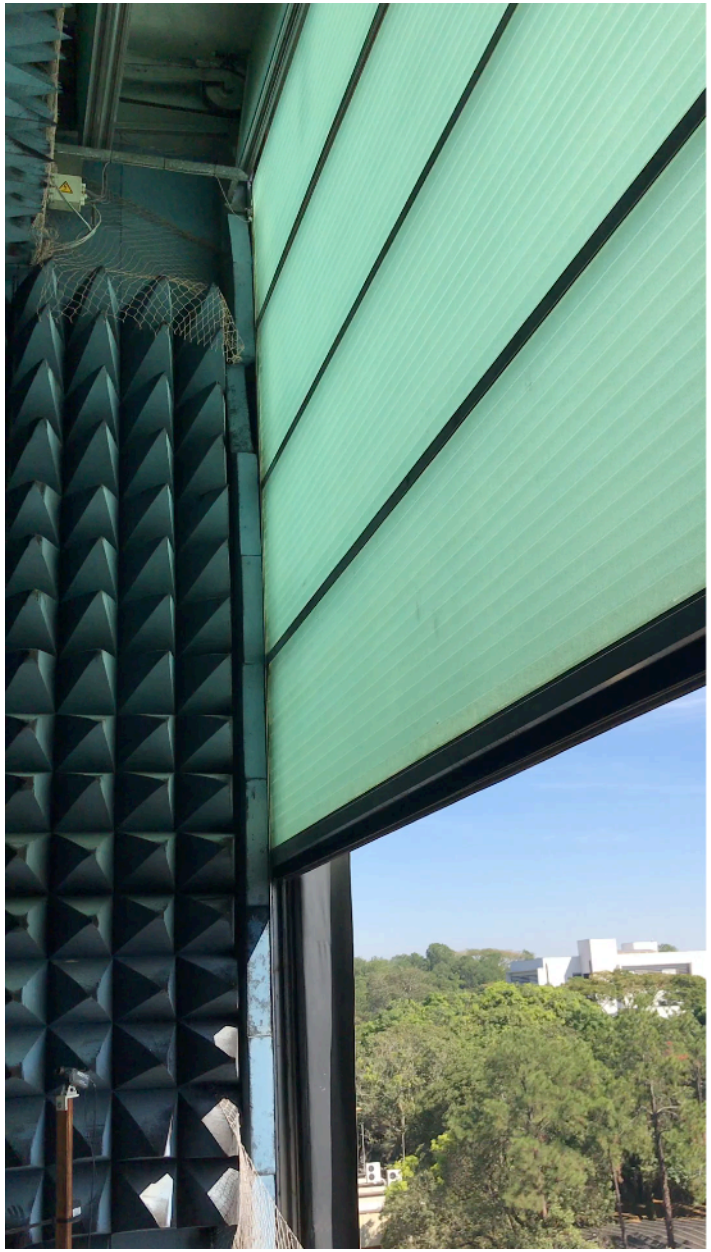


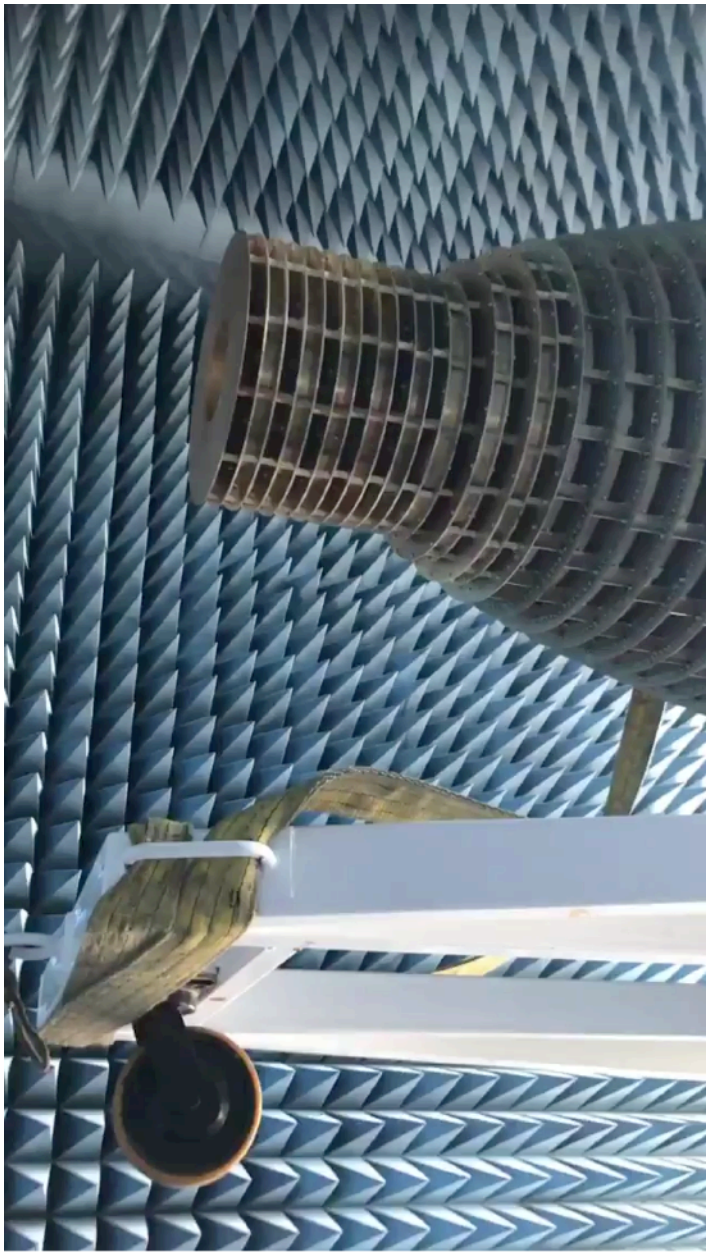


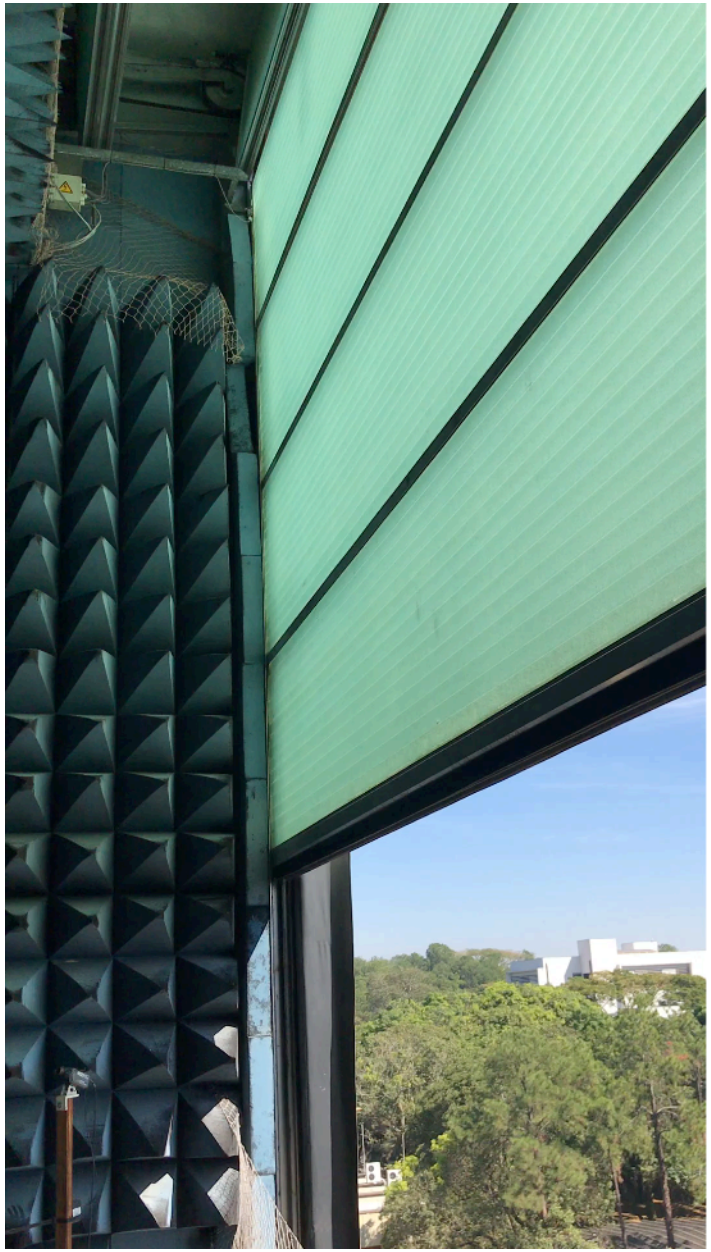


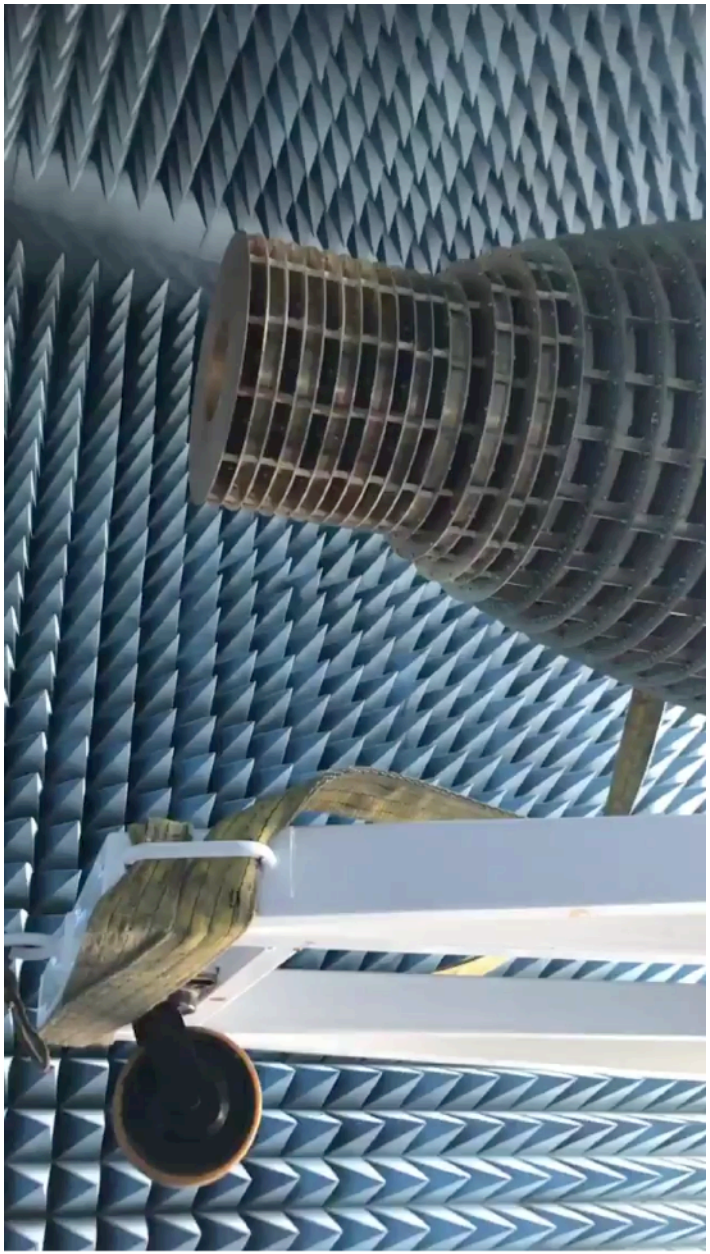


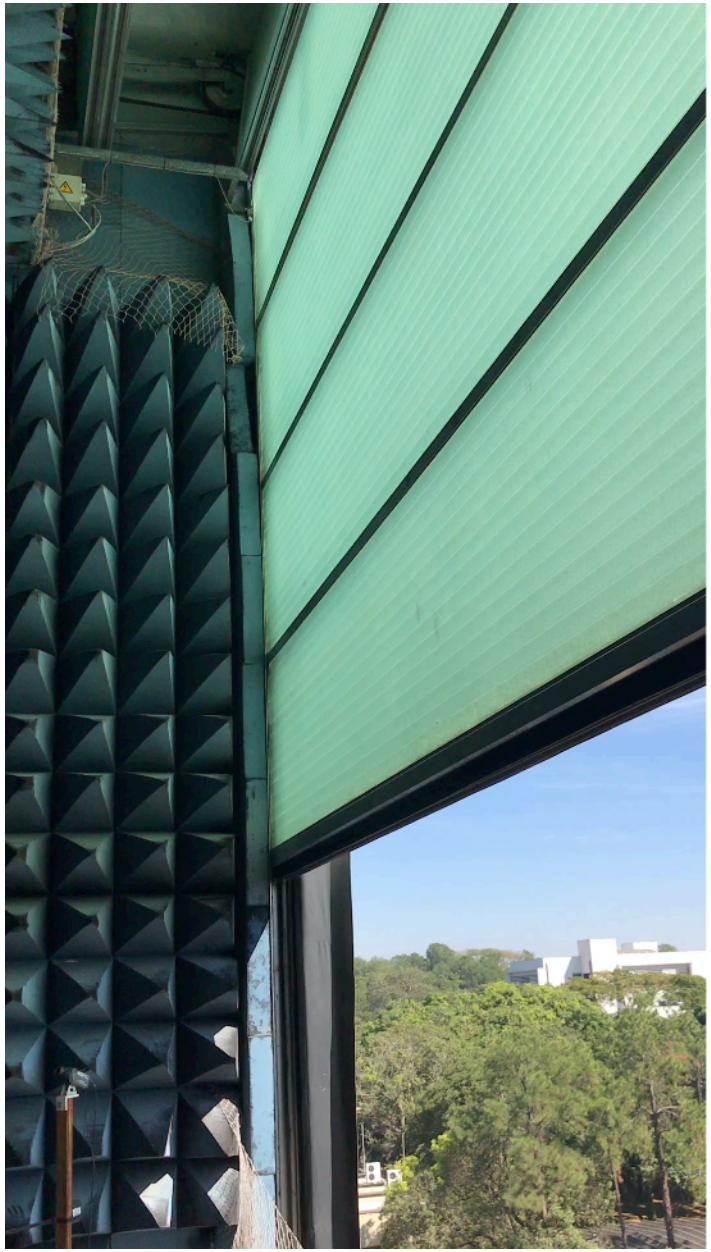




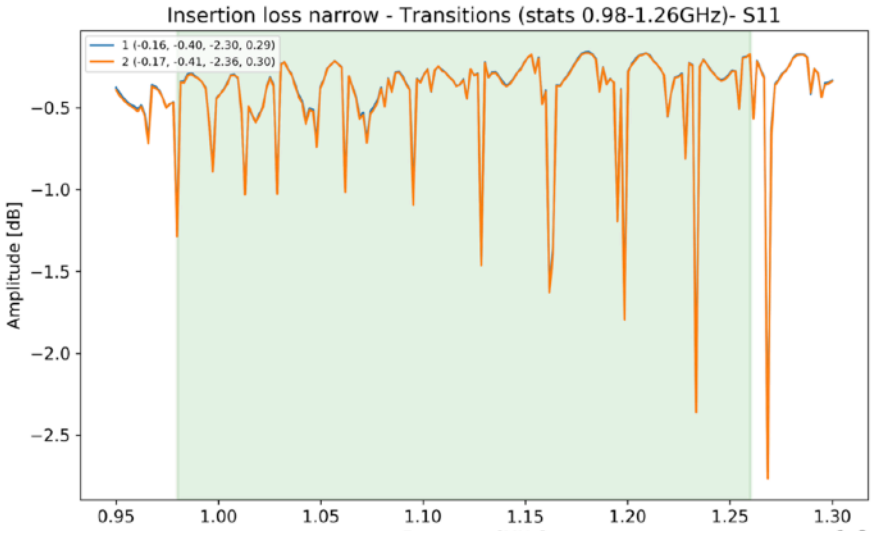








Horn prototype tests



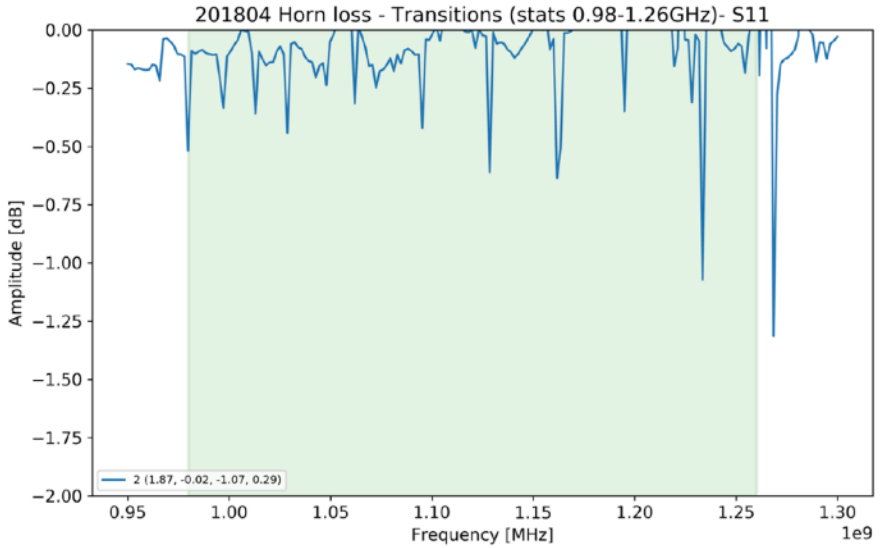
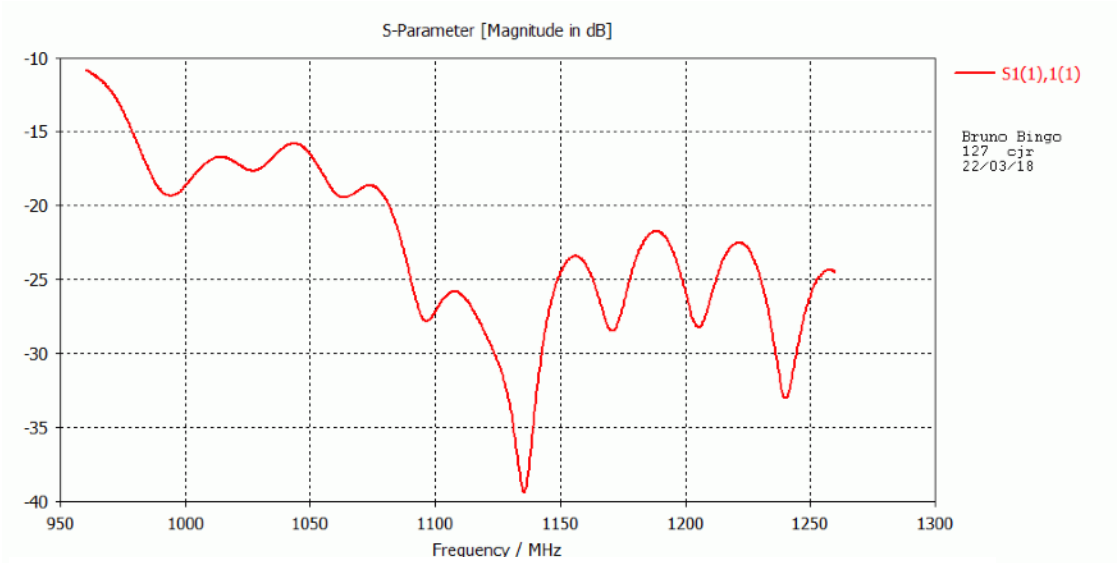


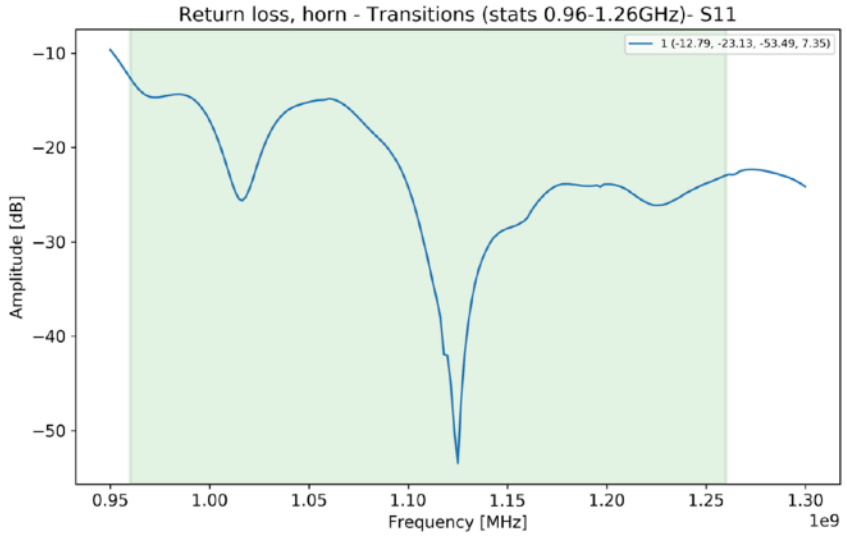
Foto: M. Peel

- Return loss (measured, metal circle covering the mouth).
- The repeating pattern may be standing waves created due to covering the mouth with reflective surface

Horn prototype tests

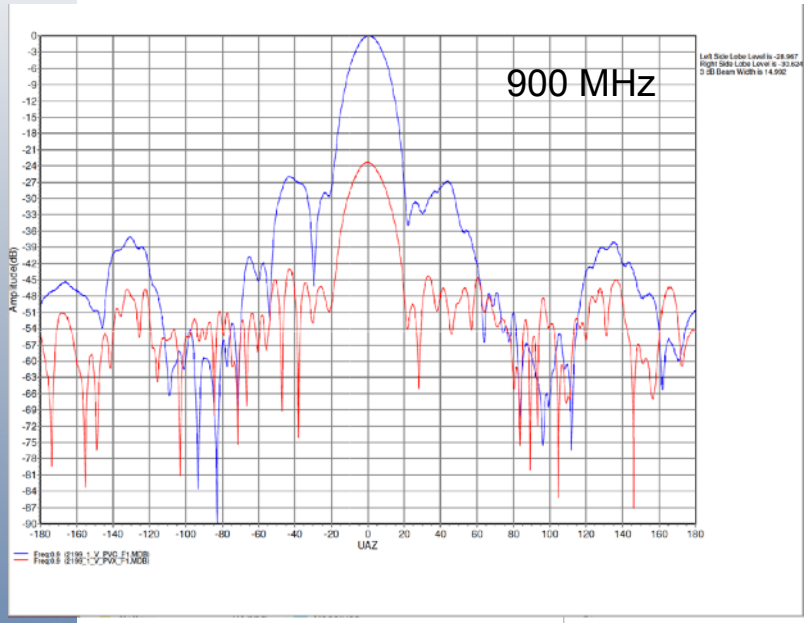


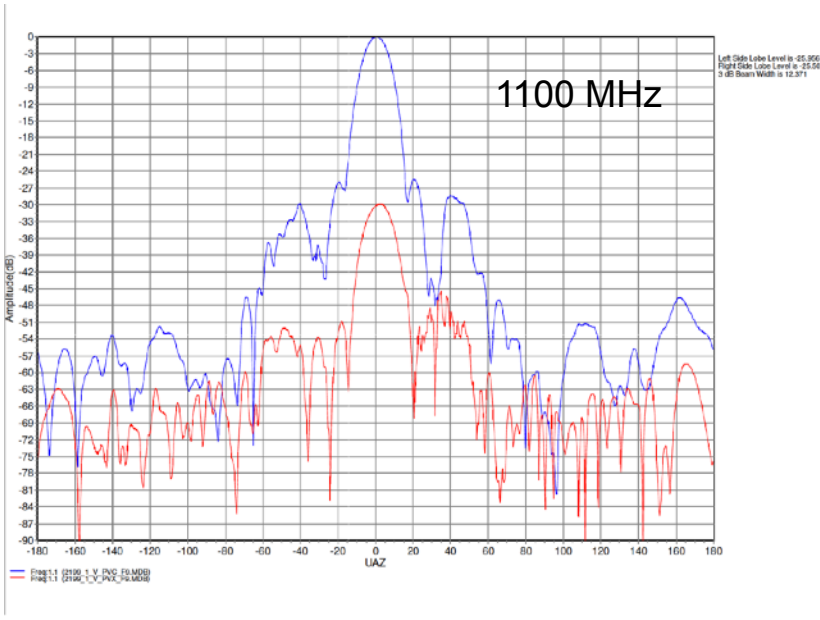
Return loss (simulated)

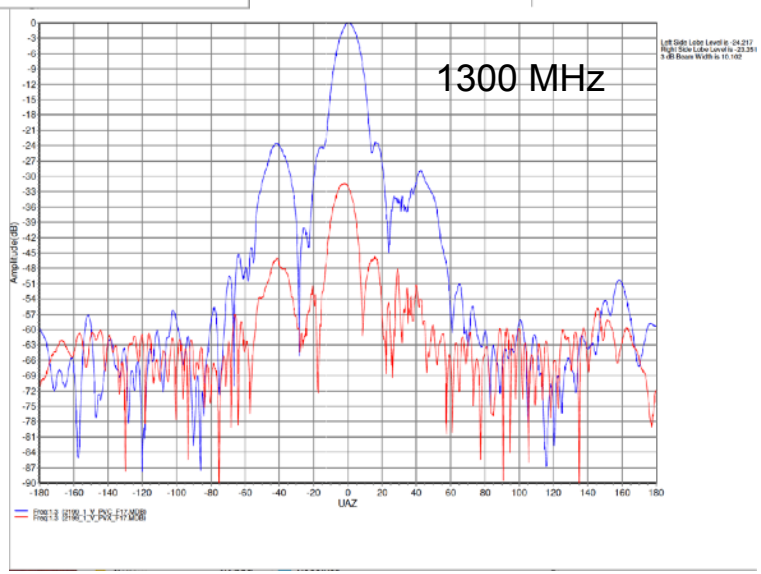


Return loss (measured, ecossorb covering the mouth)

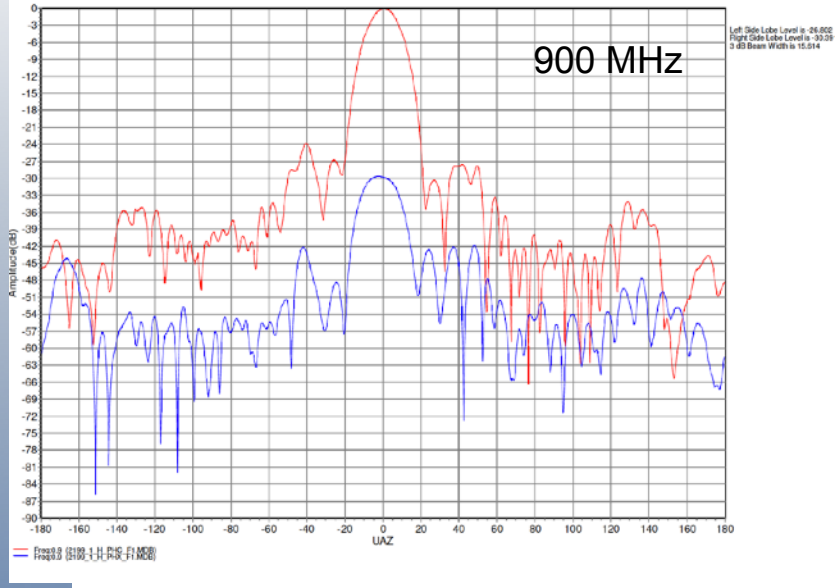
Horn testing results – Vertical polarization

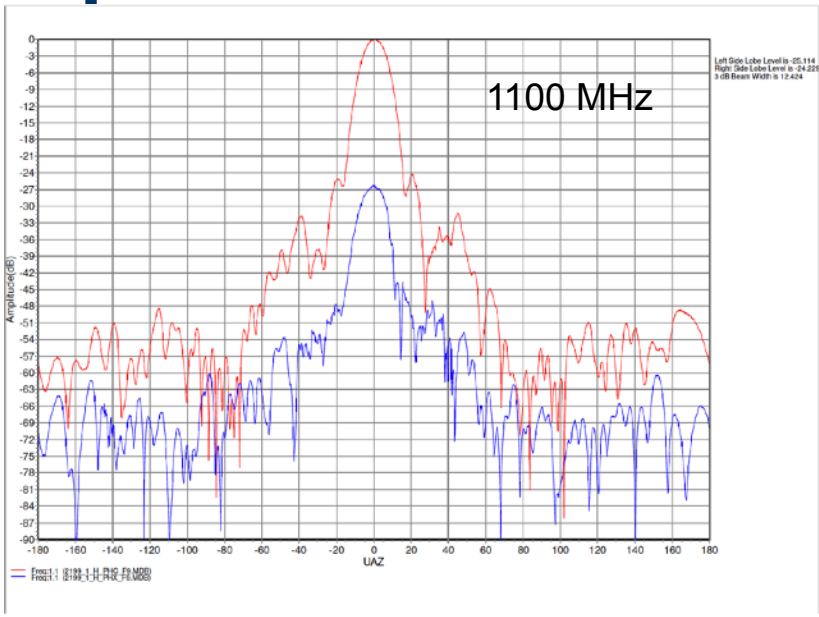


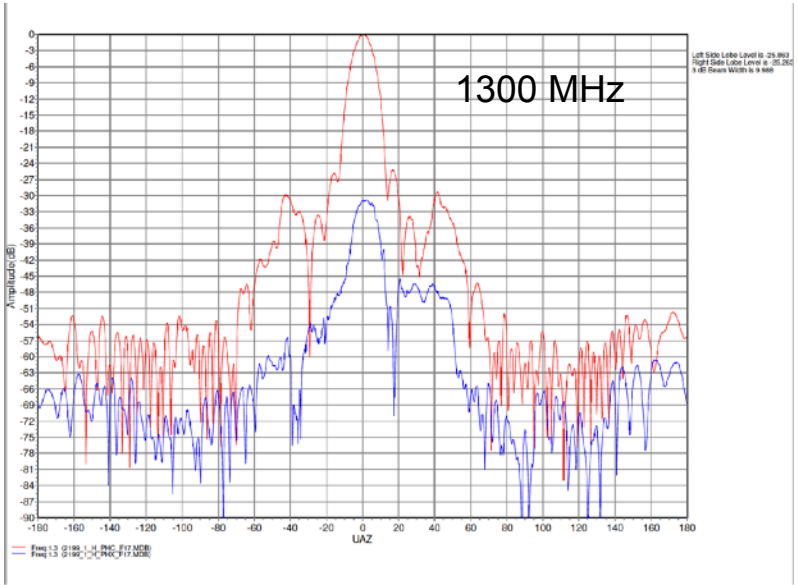




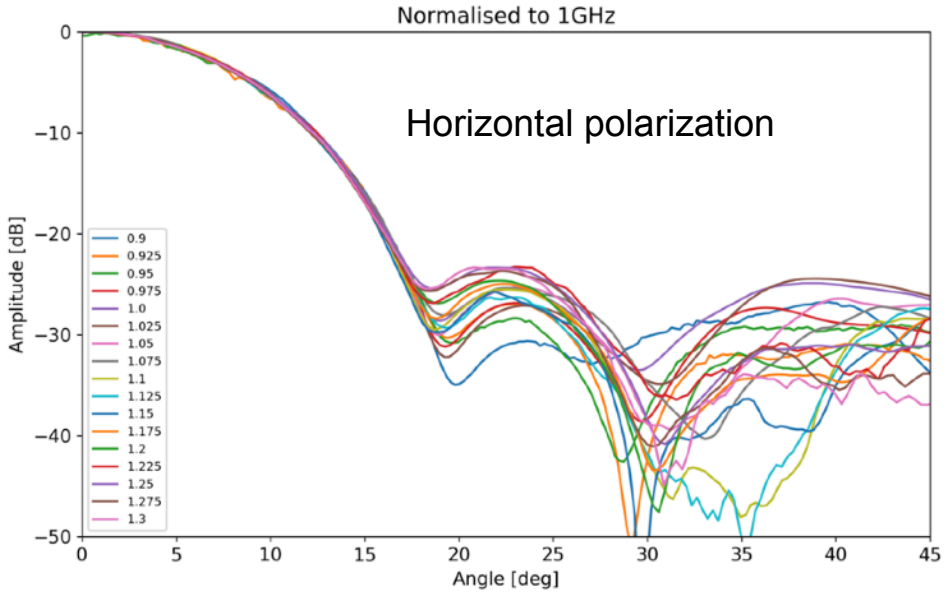
Horn testing results – Horiz polarization

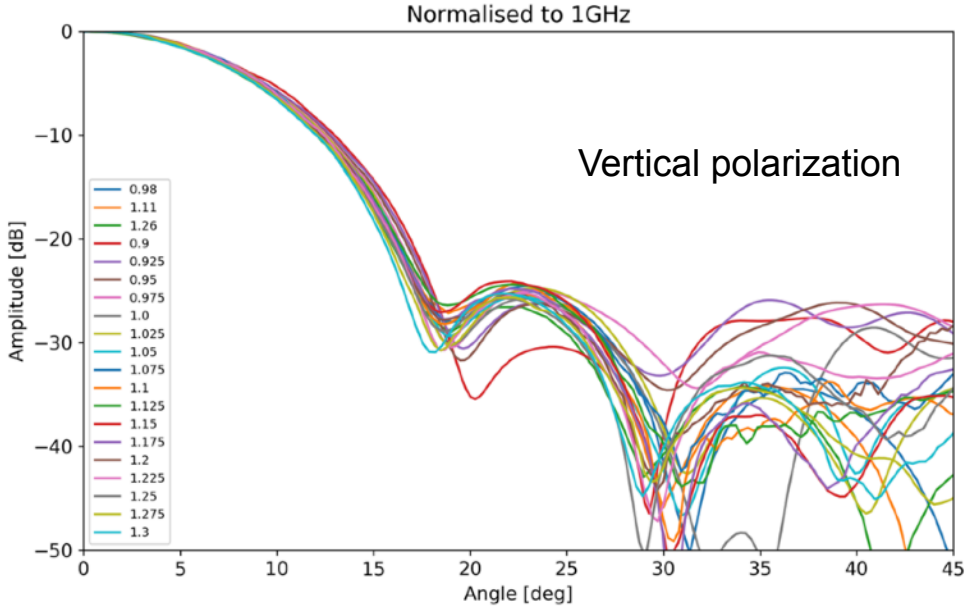




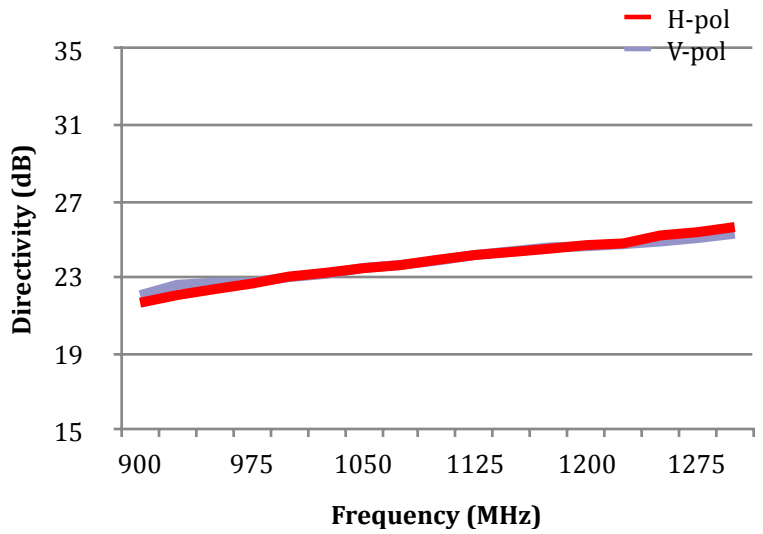


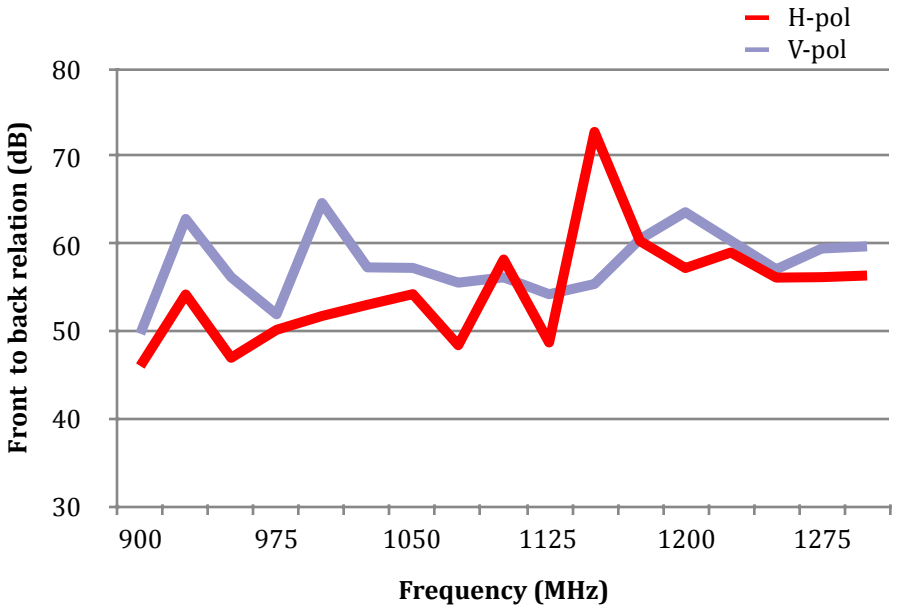
Horn testing results – Combination of all freqs.

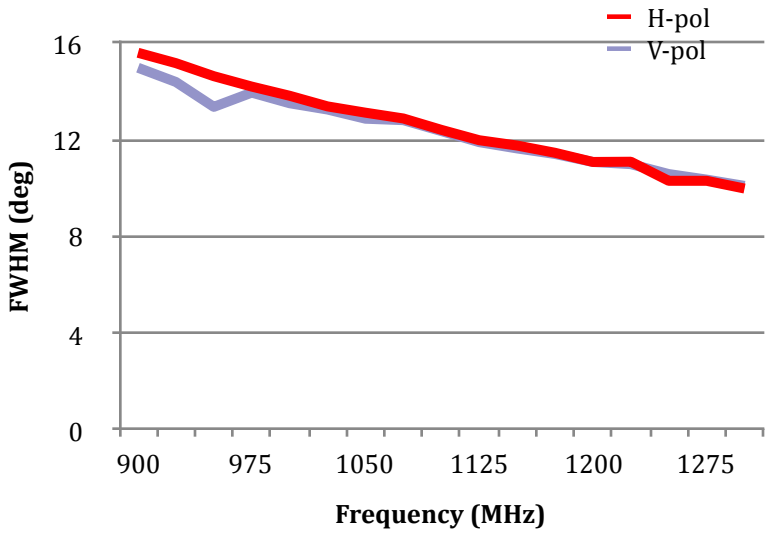




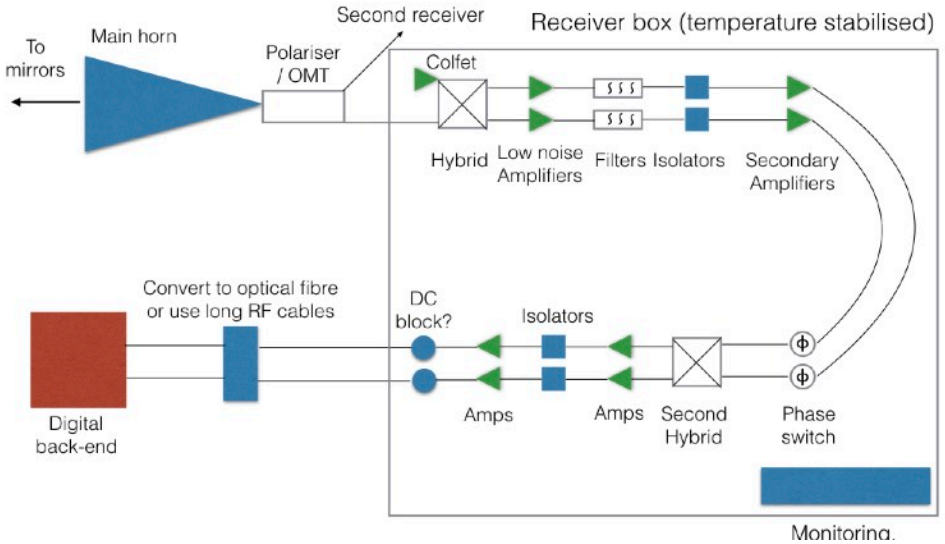
Horn testing results



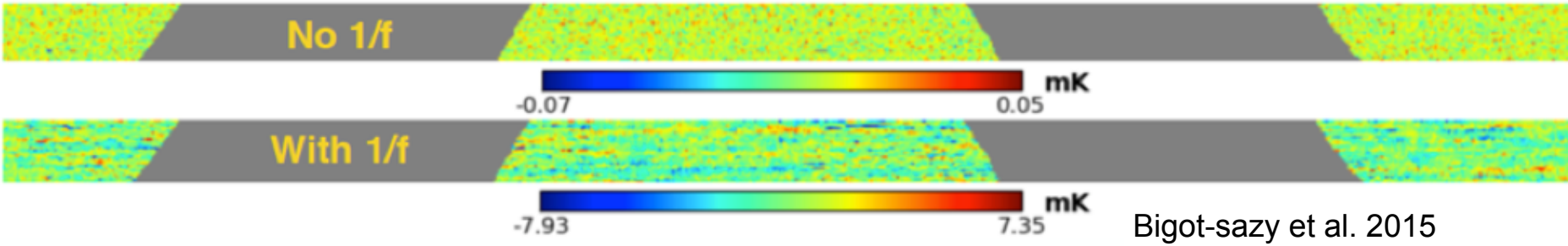




Correlation receiver



- 1/f knee frequency of typical receivers is ≈1 Hz
- To achieve 1mHz we need :
  - Input matching to < 3%
  - Hybrid accurate to < 1.5%
- Probably go with digital backend after 1st LNA

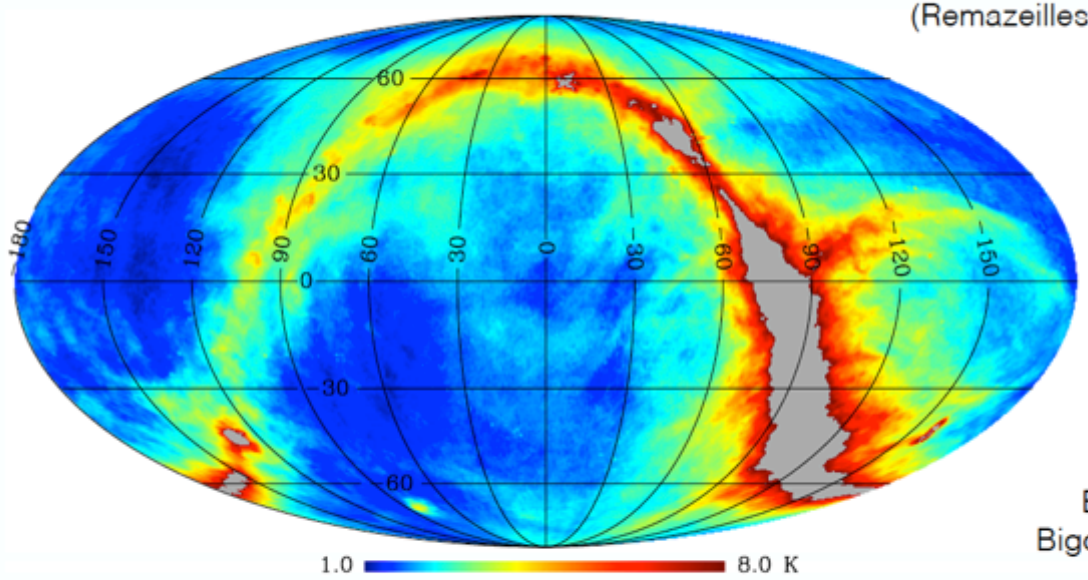


Bigot-sazy et al. 2015

Foreground contamination

- Diffuse Galactic continuum radiation - synchrotron and free-free radiation
- Spectrum expected to be smooth (should allow for it to be subtracted)
- Mean ~5K at 1 GHz
- Fluctuations on degree scales **~70mK**
- Note: HI signal ~ 0.1 mK !

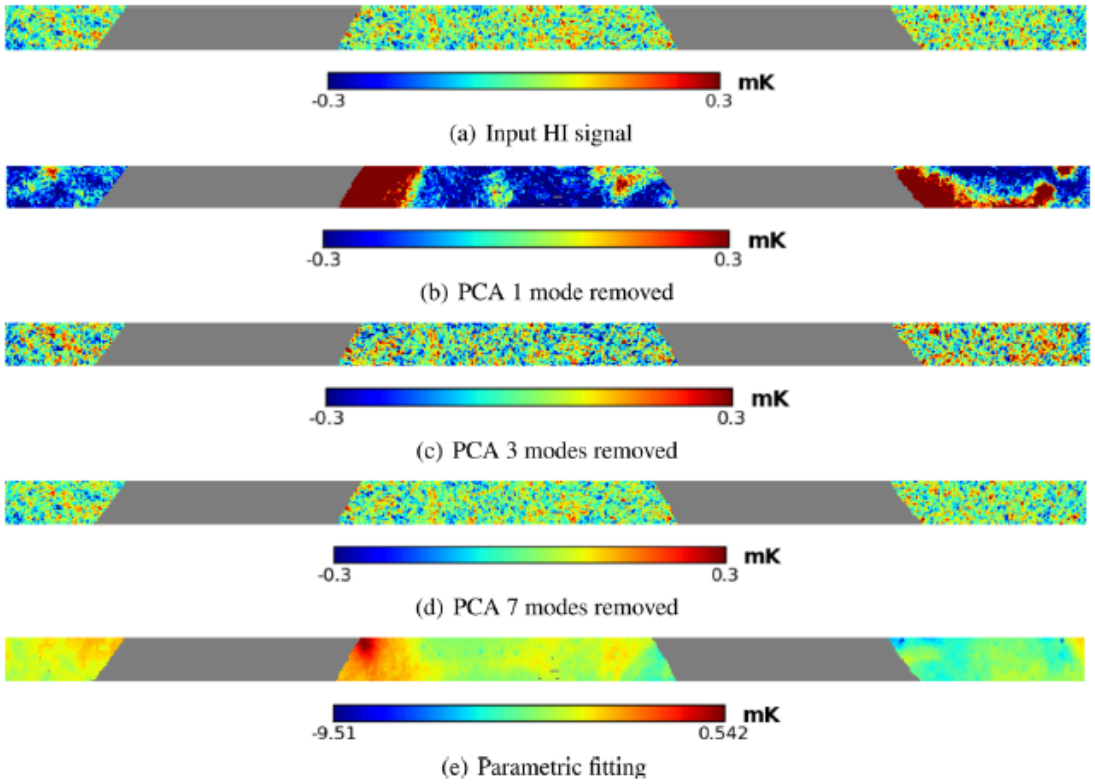
Improved 408 MHz Haslam map now available
(Remazeilles et al. 2015)



Battye et al. (2013);
Bigot-Sazy et al. (in prep.)

Component separation

- Dominant foregrounds are expected to be spectrally smooth
- HI signal fluctuates in frequency, allowing for it to be extracted
- Simple PCA can do a remarkable job by removing the first few eigenmodes of the freq-freq covariance matrix
  - Caveat: assumes calibration is PERFECT
- New methods using frequency and spatial info can be found in Olivari et al. (2015)

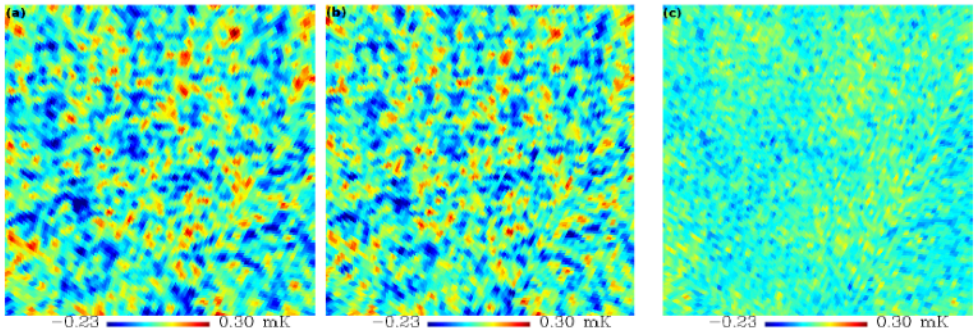


Bigot-Sazy et al. 2015

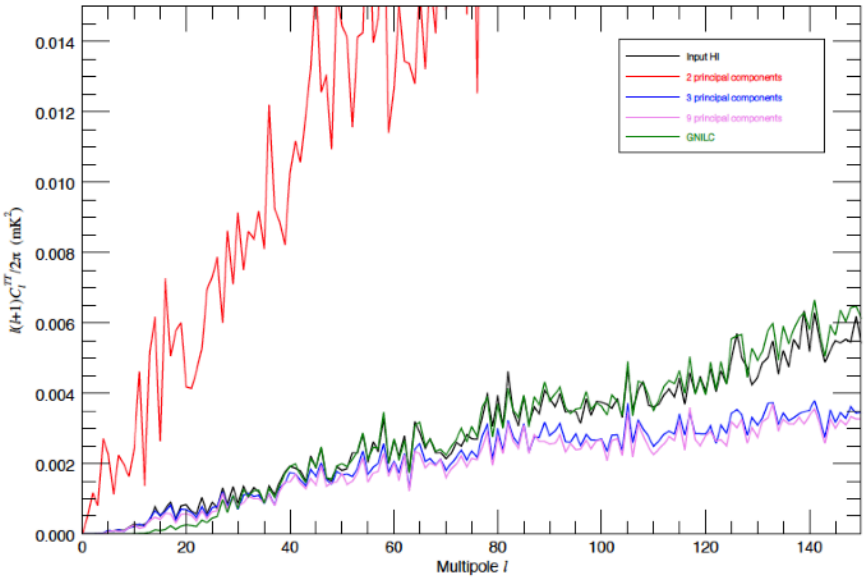
Data analysis efforts

- HI power spectrum reconstruction (Olivari et al., 2015)
- Cosmological parameters forecast (Olivari et al. 2017)

Parameters	
Redshift range $[z_{\min}, z_{\max}]$	[0.13, 0.48]
Bandwidth $[\nu_{\min}, \nu_{\max}]$ (MHz)	[960, 1260]
Number of feed horns n_f	80
Sky coverage $\Omega_{\rm sur}$ (deg^2)	21000
Observation time $t_{\rm obs}$ (yrs)	1
System temperature $T_{\rm sys}$ (K)	50
Beamwidth at the first channel (arcmin)	40



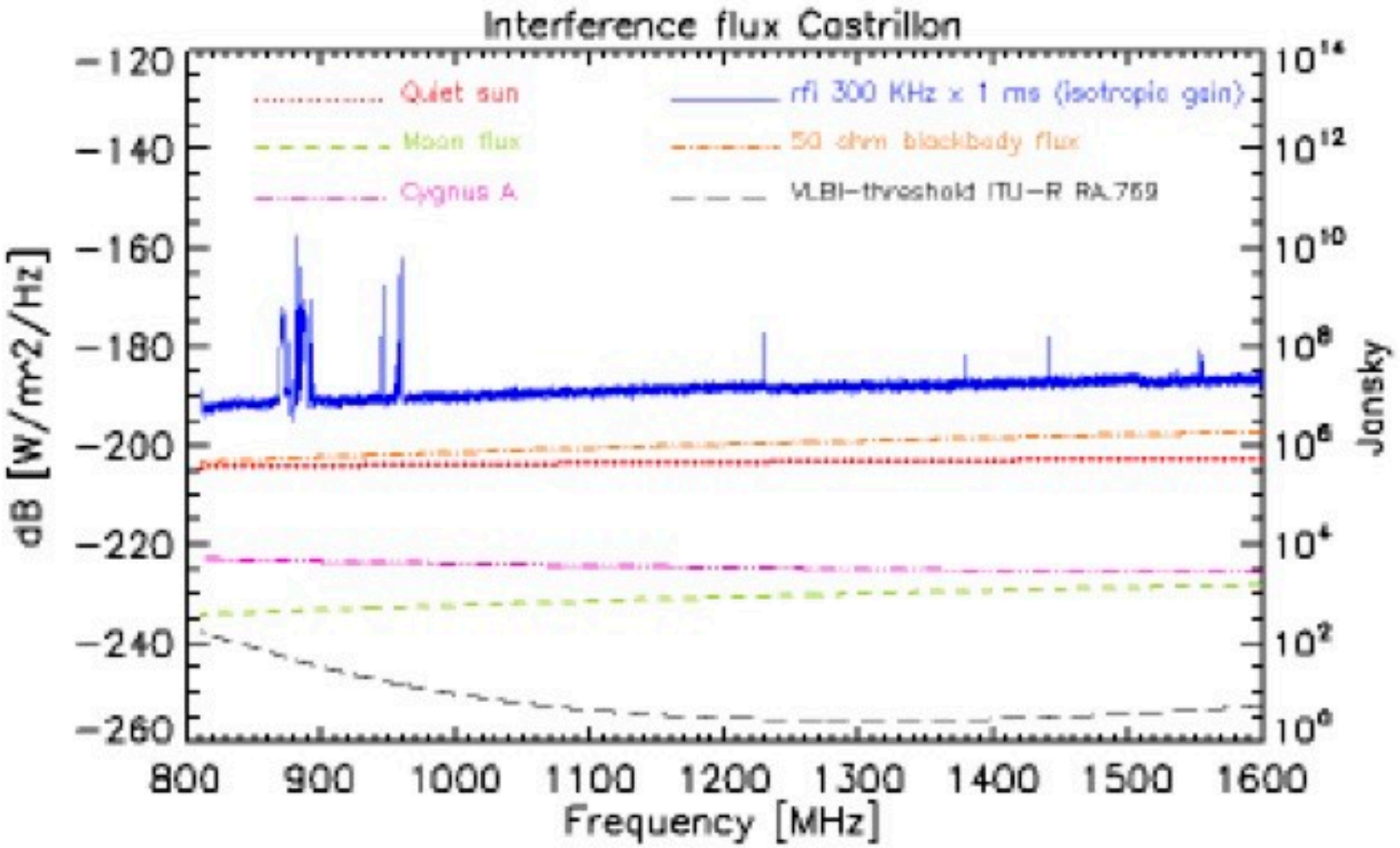
HI input HI reconstructed Noise



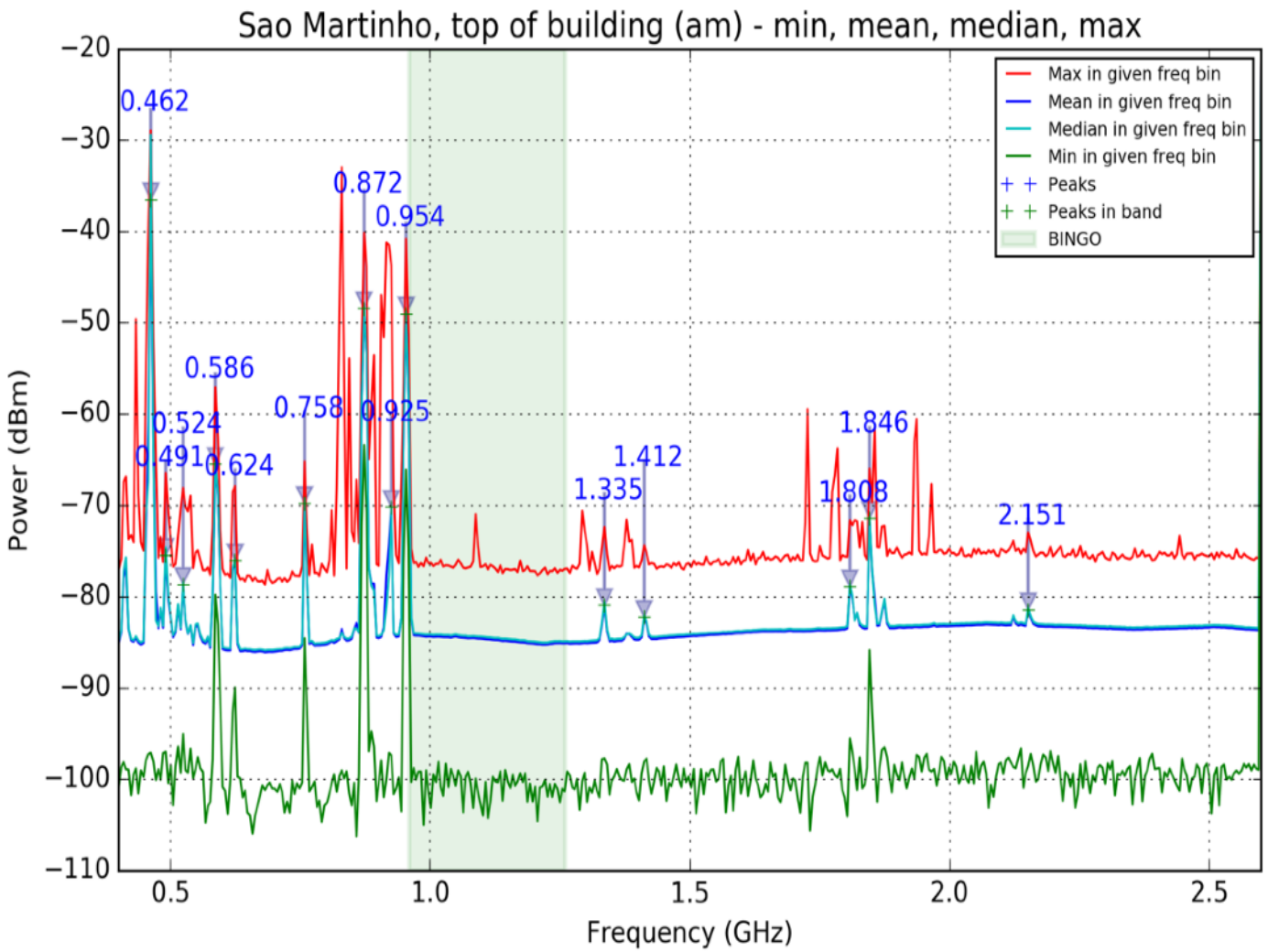
Short version of a 6 month RFI campaign for site selection....


Nicarágua
Venezuela
Guiana
Colômbia
Suriname
RR
AP
Equador
AM
PA
MA
RN
PB
PI
PE
AL
SE
AC
Brasil
TO
RO
Peru
MT
BA
GO
Bolívia
MG
ES
MS
2.000,00 km
SP
RJ
Paraguai
PR
Chile
SC
RS
3.325,70 km
Uruguai
Argentina
INPE Headquarters

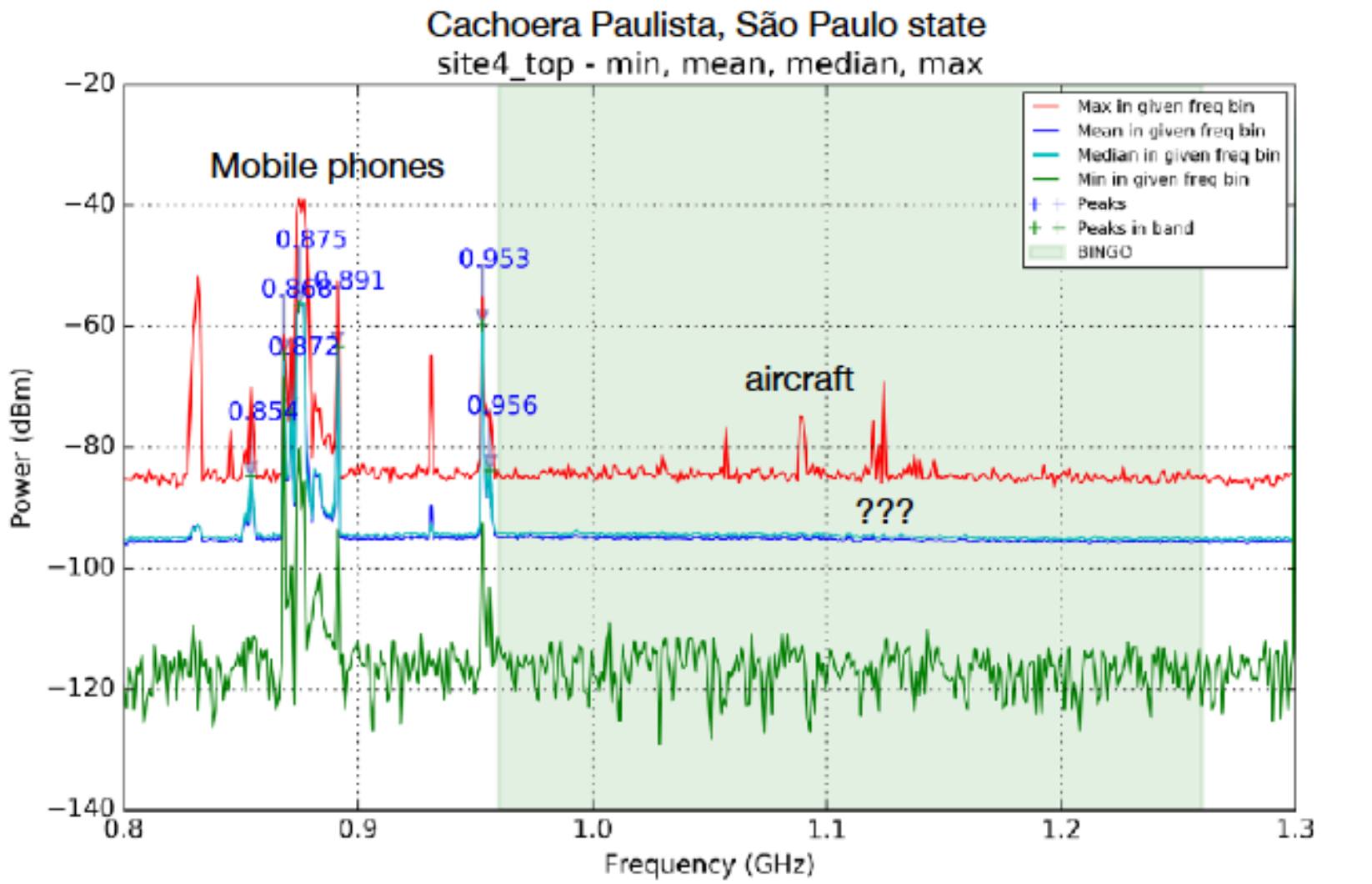
Uruguay sites



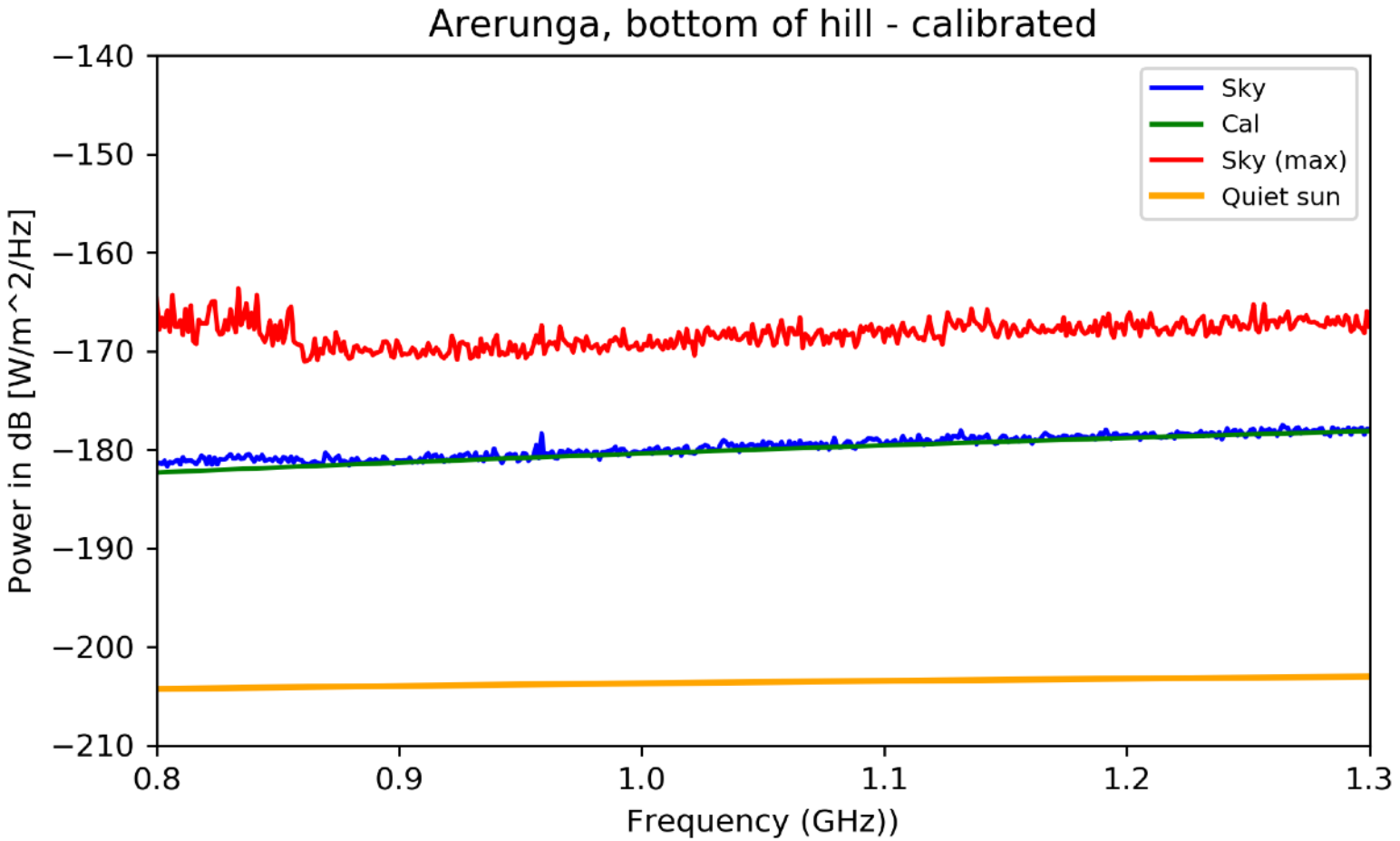
S. Martinho, INPE's center, South of Brazil



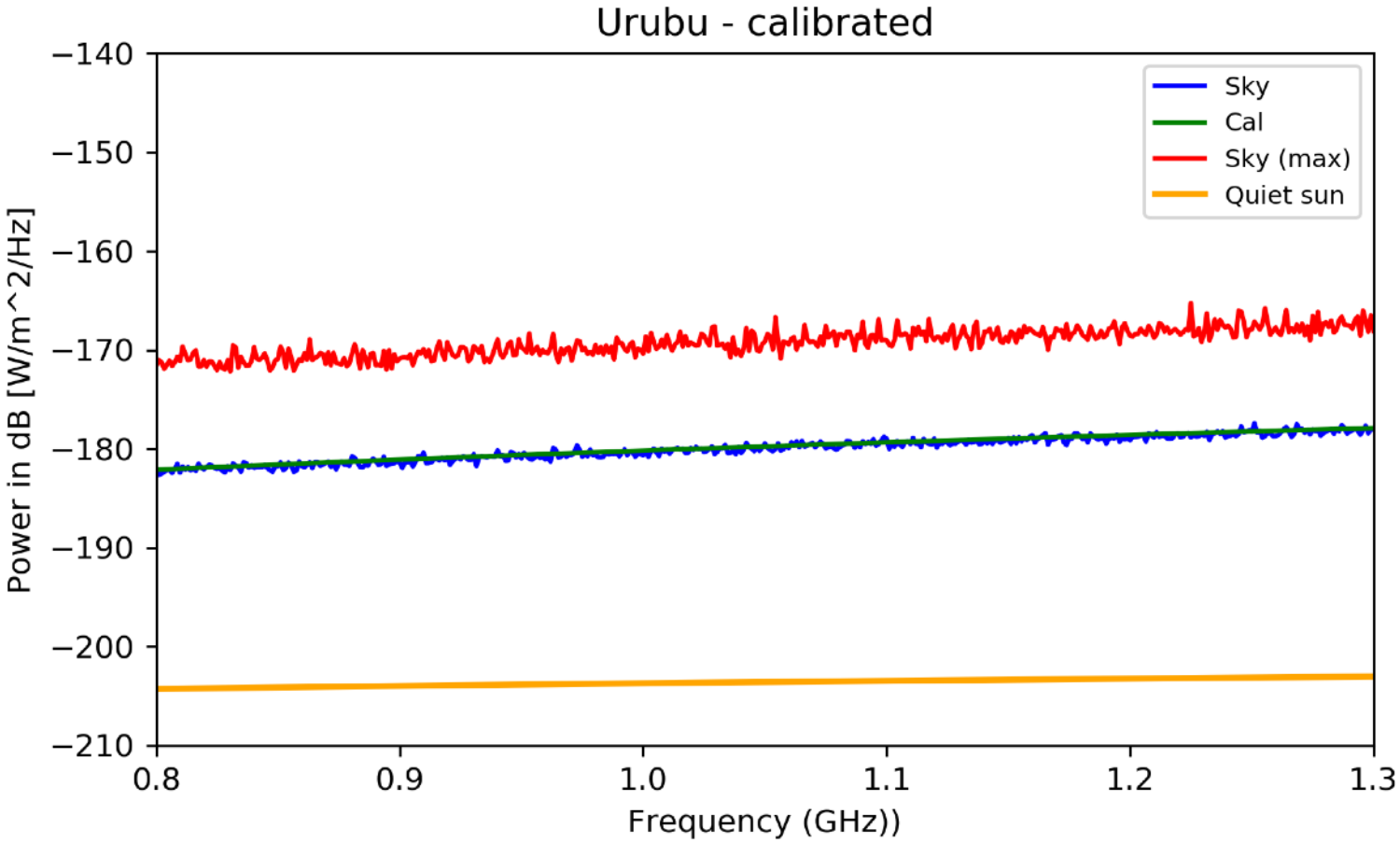
Cach. Paulista, INPE's center, near S. Paulo



Uruguay sites

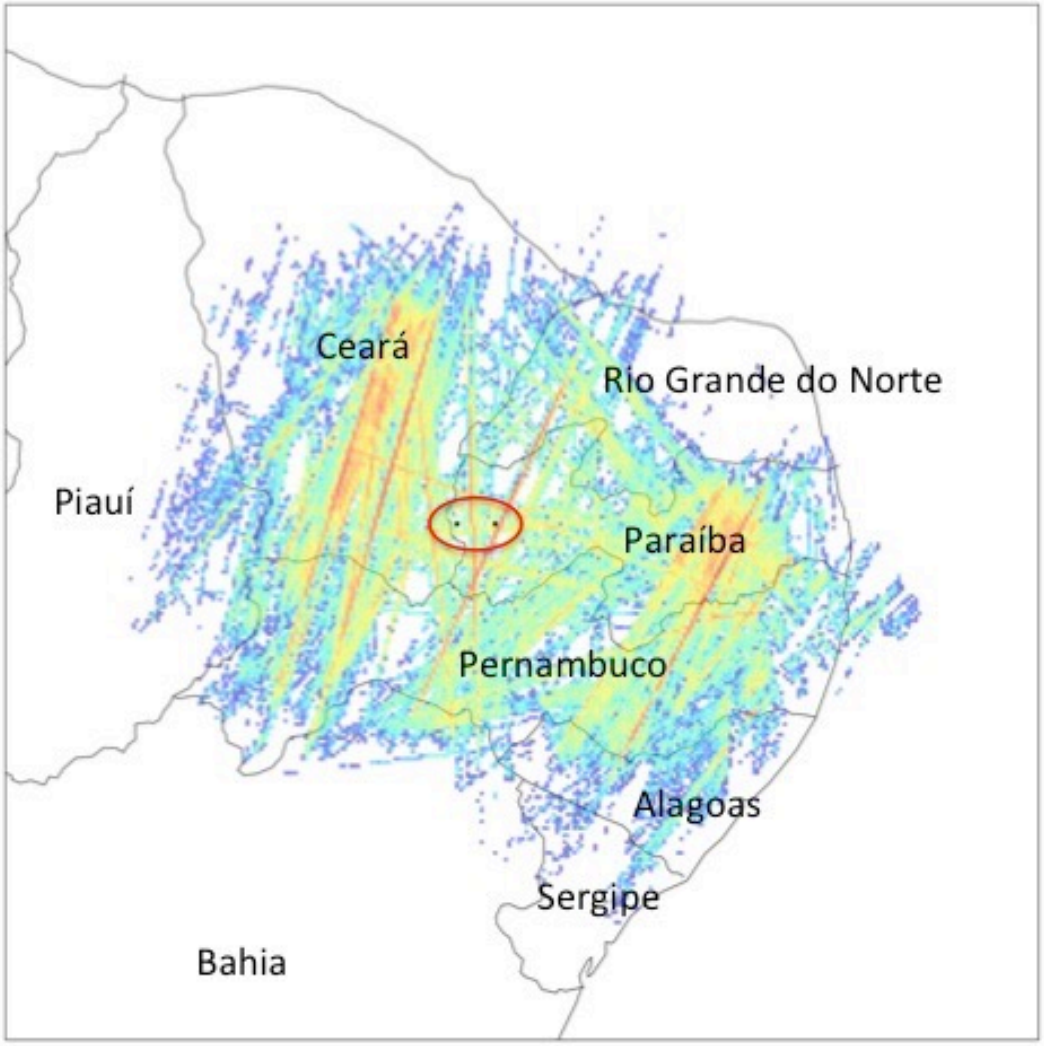


Paraíba sites



Still concerns about airplane coverage...

"BINGO: RFI measurements and site selection" (Peel et al. 2018, submitted)



And satellites....

Harper & Dickinson, arXiv:1803.06314

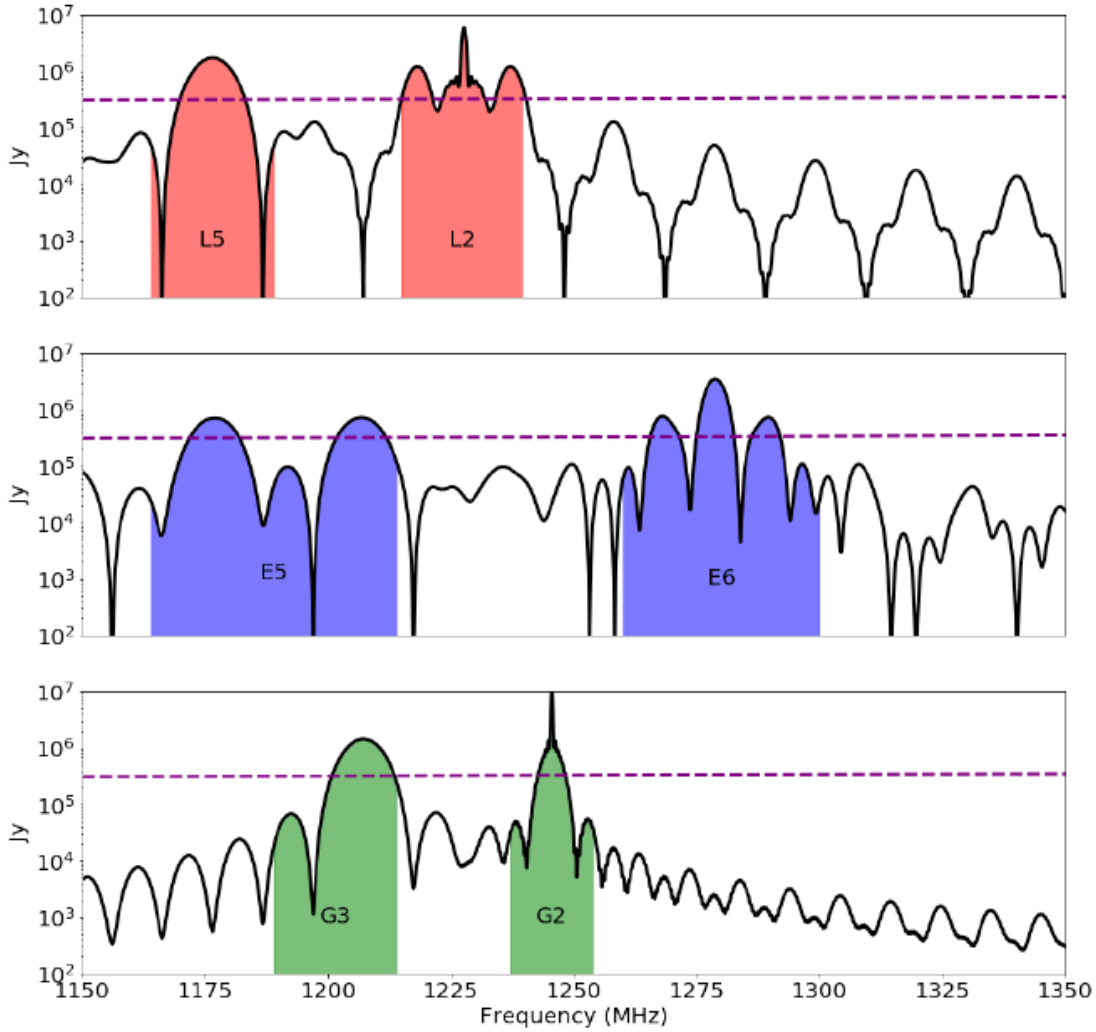
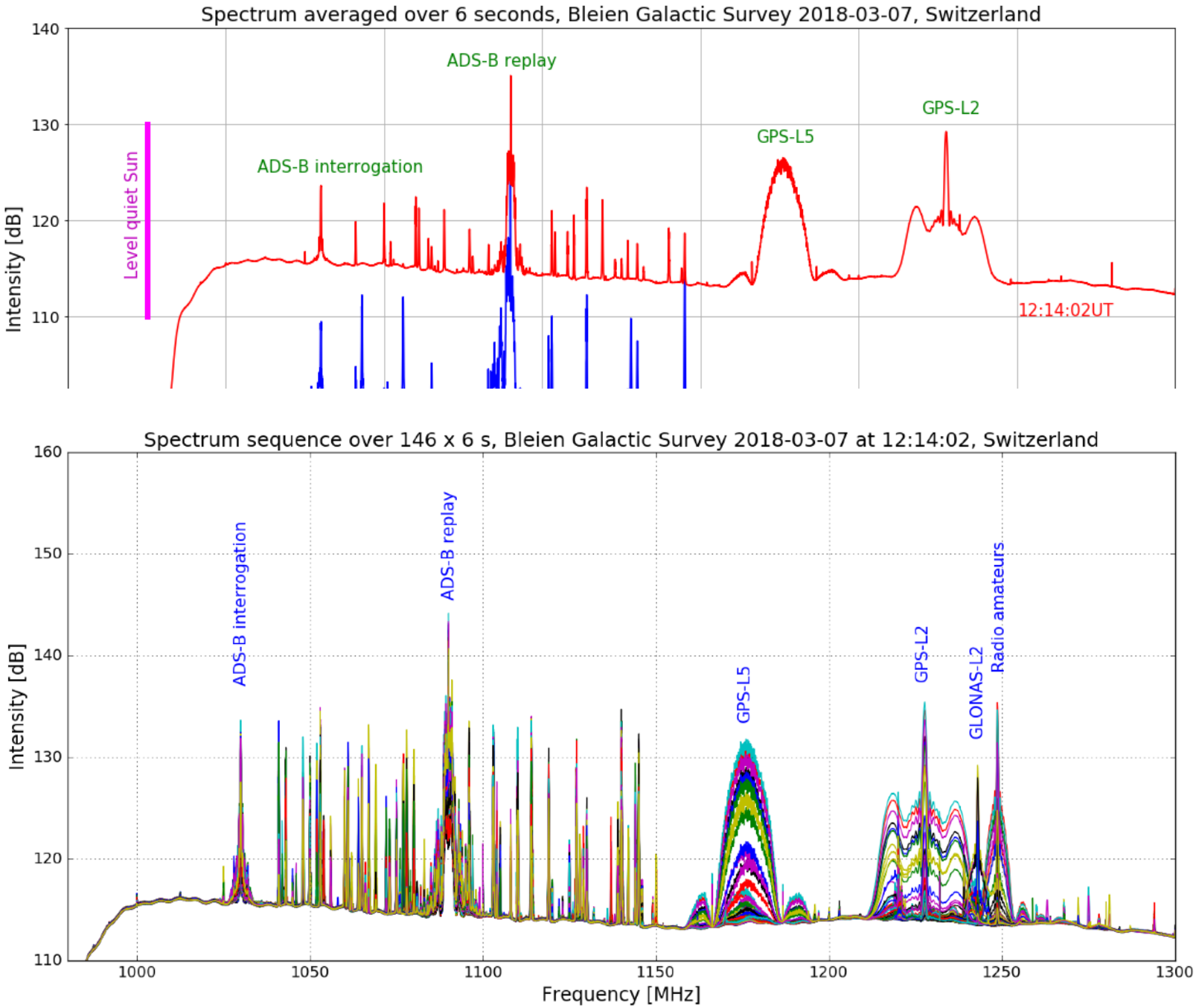


Figure 3. Typical spectral energy distribution as measured from the Earth of GNSS transmissions at frequencies less than 1410 MHz. The *top* plot shows the SED for GPS, the *middle* plot shows Galileo, and the *bottom* shows GLONASS. Highlighted regions in the SEDs represent the nominal frequency allocations for each service and service designation. GPS services are highlighted in *red*, Galileo in *blue* and GLONASS in *green*. Unhighlighted regions in the SED are the predicted out-of-band transmissions. The *dashed purple* line shows the expected integrated flux density of the quiet Sun for reference.

- Hard to get software solutions (no smooth spectrum)
- Hardware possible solutions:
  - cross-correlating data from auxiliary telescopes that are tracking GNSS satellites (Galt 1991)
  - hardware simulated GNSS signals (Ellingson et al. 2001) with data from the primary observing
  - phased array feeds (PAFs) can perform spatial filtering
  - to adaptively suppress transmissions from GNSS satellites (Hellbourg et al. 2012, 2014)
  - building a bespoke HI IM experiment and designing in strict requirements on beam sidelobe suppression such as with the BINGO telescope (Battye et al. 2013).

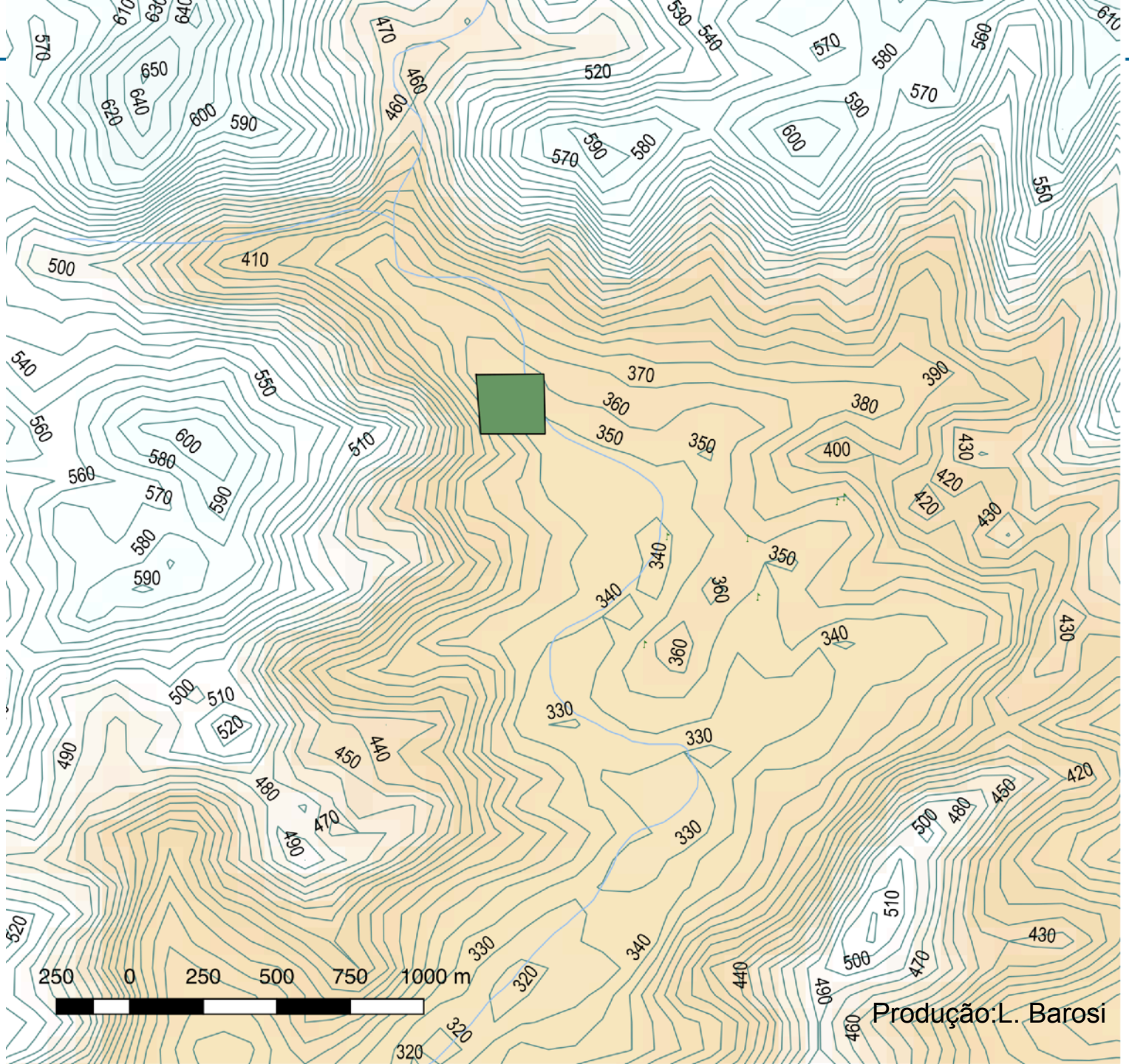

Spectrum averaged over 6 seconds, Bleien Galactic Survey 2018-03-07, Switzerland
Intensity [dB]
Level quiet Sun
ADS-B interrogation
ADS-B replay
GPS-L5
GPS-L2
12:14:02UT
Spectrum sequence over 146 x 6 s, Bleien Galactic Survey 2018-03-07 at 12:14:02, Switzerland
Intensity [dB]
ADS-B interrogation
ADS-B replay
GPS-L5
GPS-L2
GLONAS-L2
Radio amateurs
Frequency [MHz]

Serra da Catarina, Vale do Piancó (PB)
Lat: 07° 02’ 57.1” S
Long: 38°15’ 46"W

Crédito: M. Peel

Foto: M. Peel

Foto: M. Peel



Produção:L. Barosi

VÉRTICE	LONGITUDE	LATITUDE
V1	38° 15' 59,244" W	7° 2' 30,611" S
V2	38° 16' 3,998" W	7° 2' 35,068" S
V3	38° 16' 10,689" W	7° 2' 27,944" S
V4	38° 16' 5,935" W	7° 2' 23,488" S

Universidade Federal de Campina Grande

Legenda
- Poligonal
- Curvas secundárias
- Curvas mestras
- Vértices
- Cerca

Localização da Área

LEVANTAMENTO PLANIALTIMÉTRICO

Local: Zona Rural do Município de Aguiar UF: PB - Área: 6,00 ha	Prancha: 01/01	Data: 09/07/2018
Resp Técnico: Alexandre Ferreira da Silva Técnico em Cartografia SIAPE: 2377572	Escala: 1:1.500	Sistema de Coordenadas Geográficas DATUM: WGS84

LONGITUDE	LATITUDE
38° 15' 59,244" W	7° 2' 30,611" S
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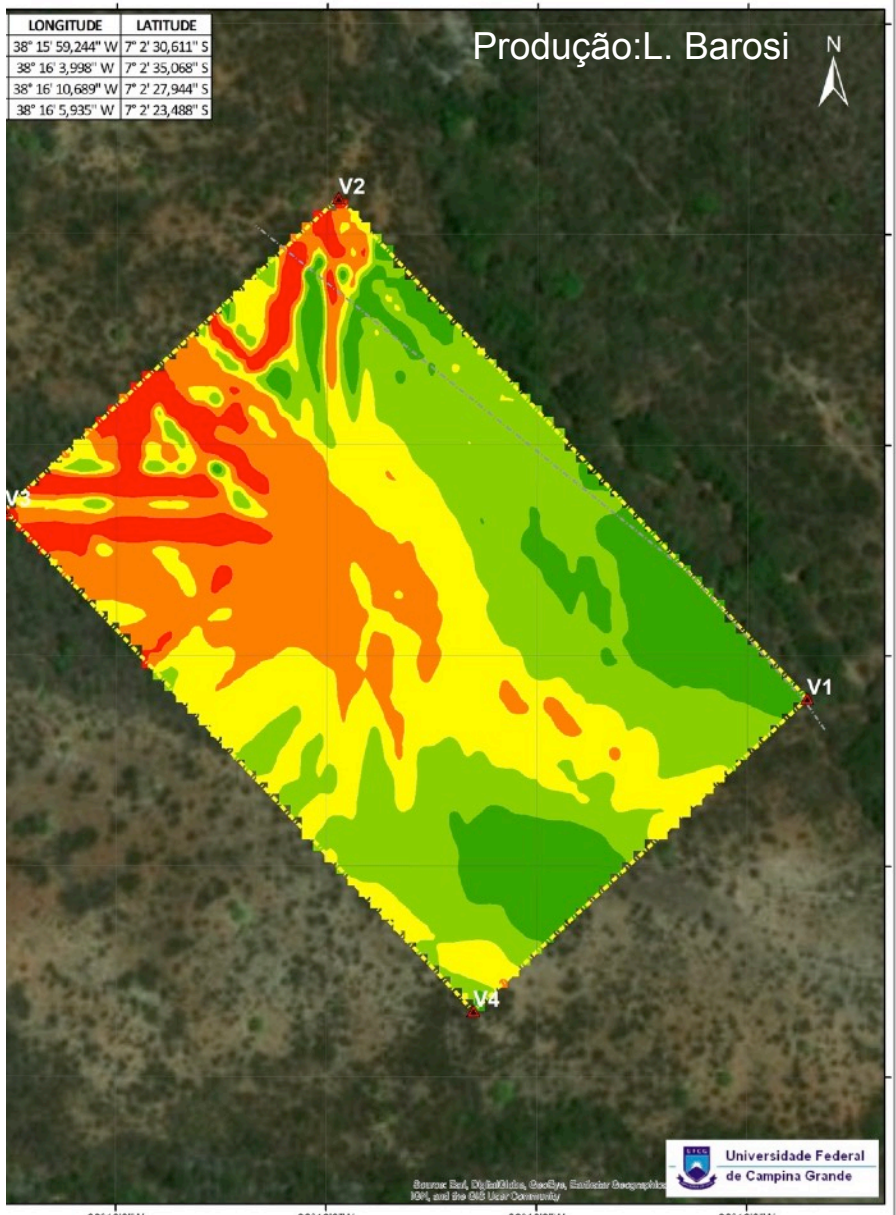

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Graus

Localização da Área

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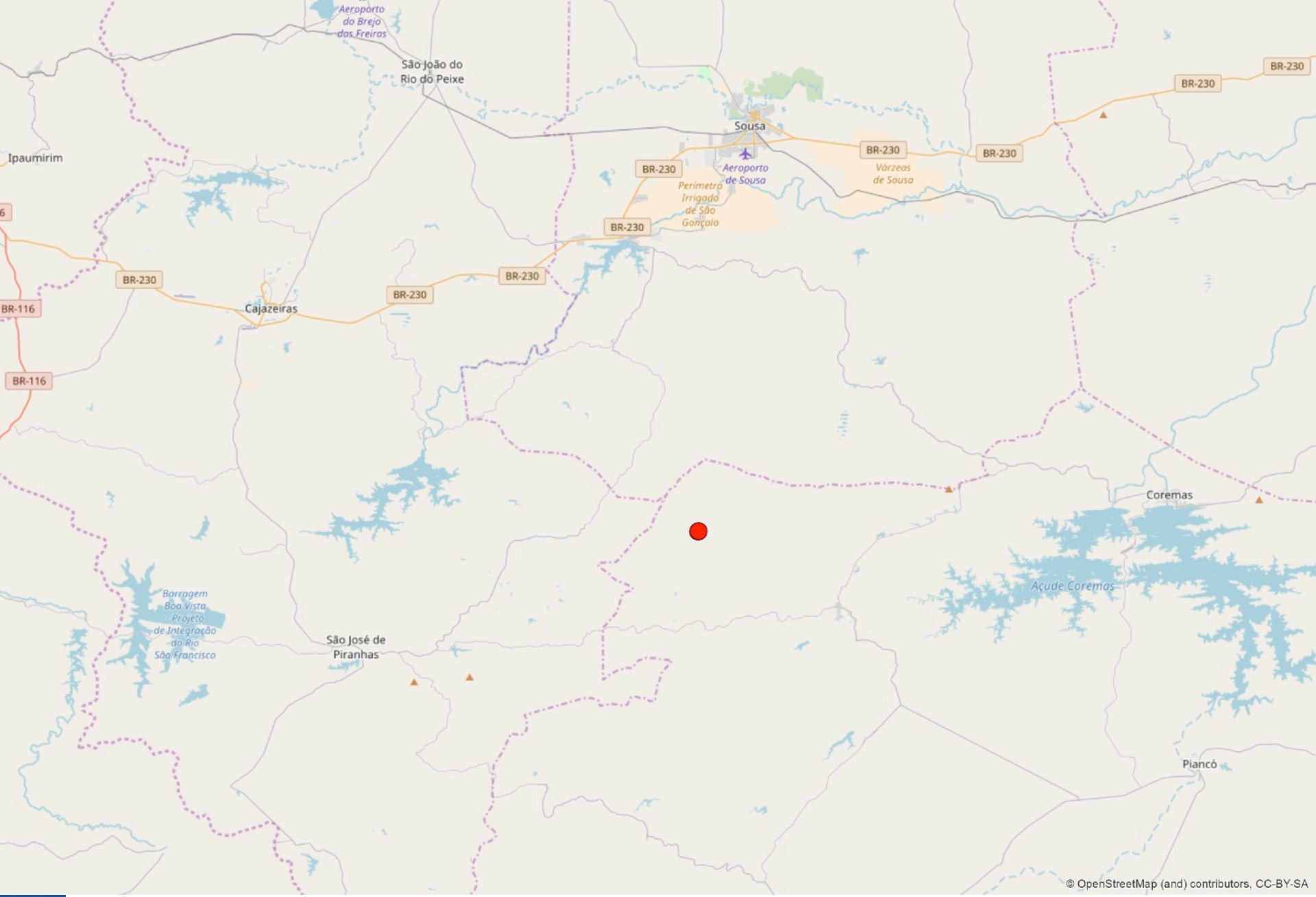
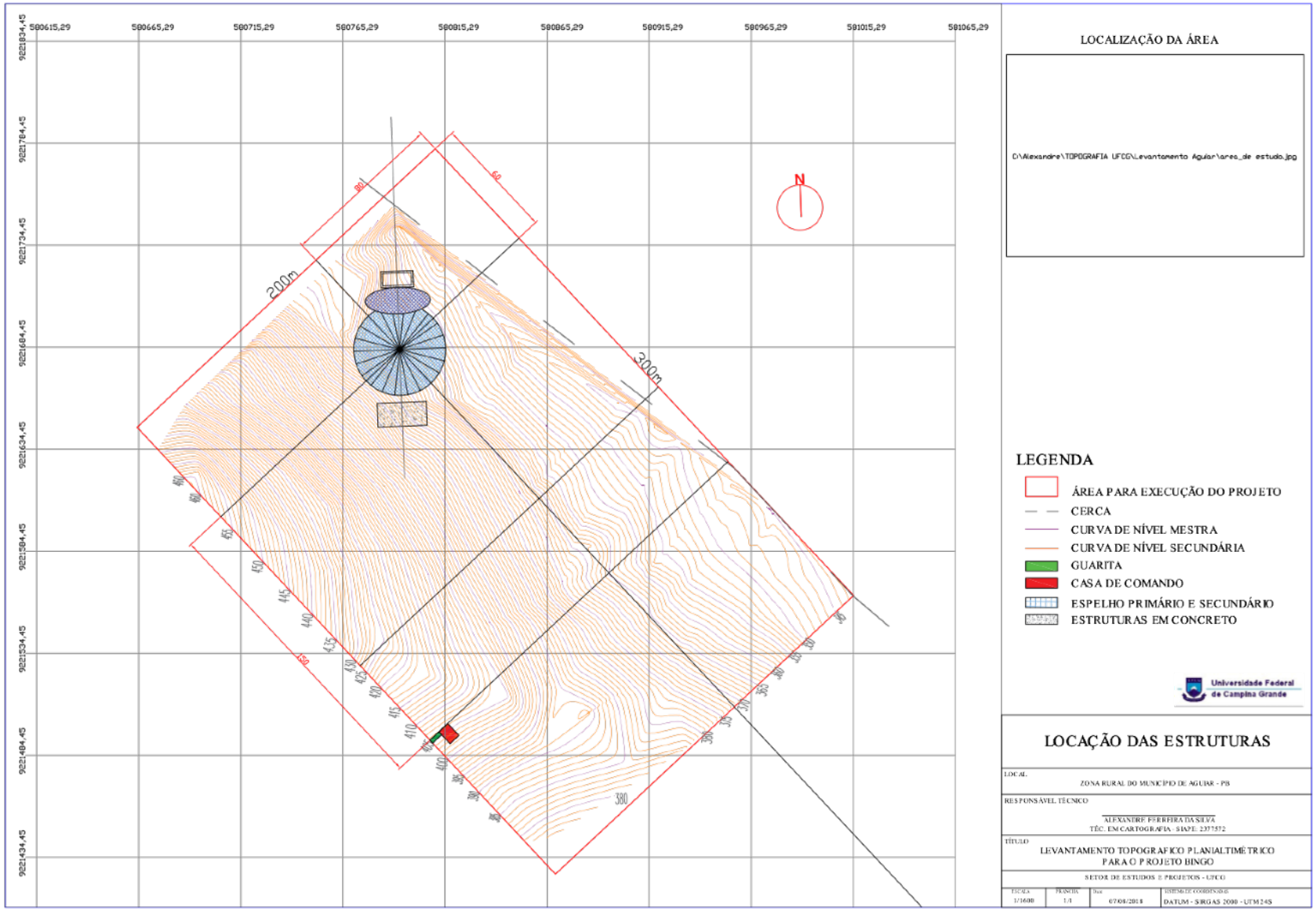


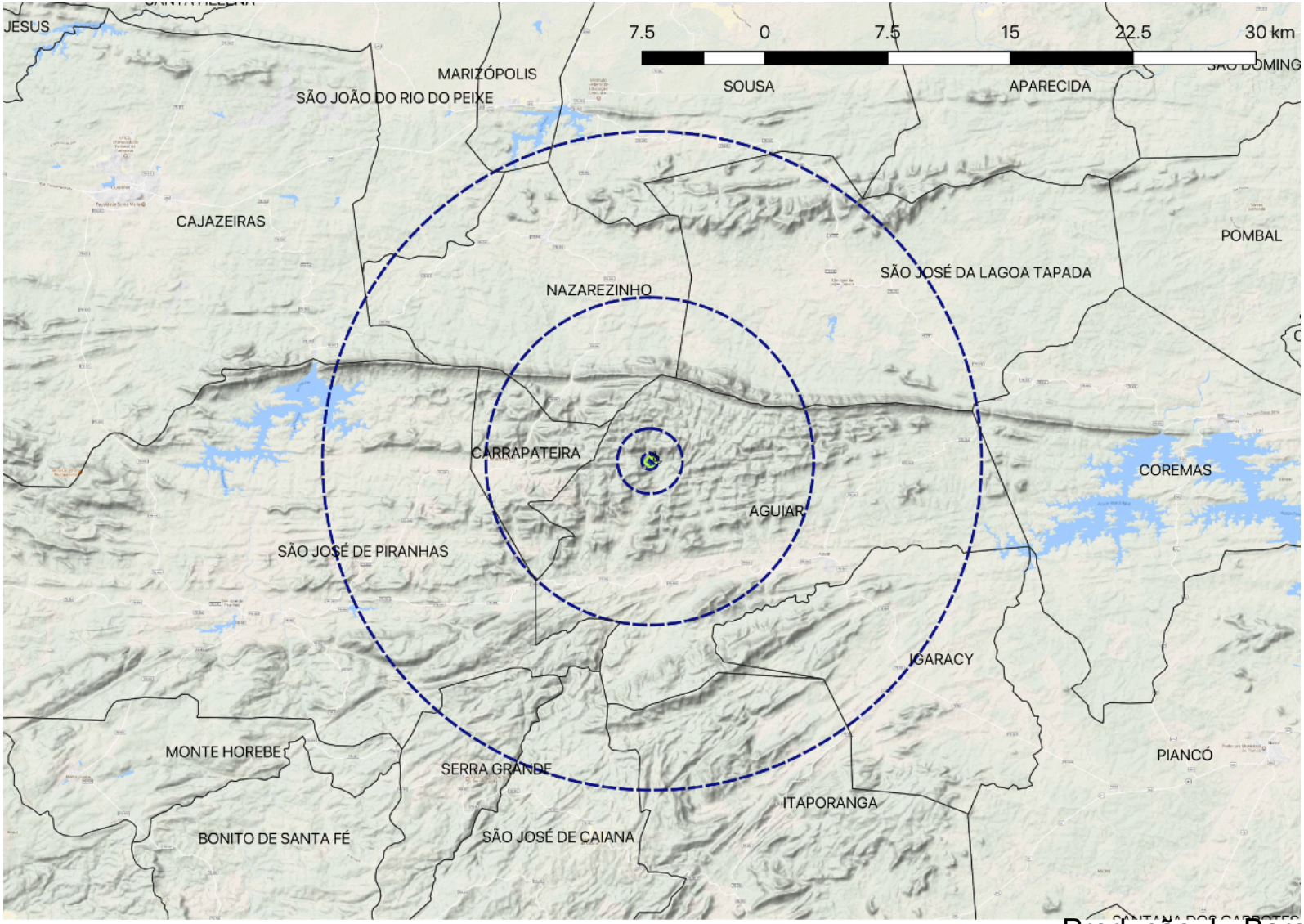
Produção:L. Barosi



PRODUCED BY AN AUTODESK STUDENT VERSION

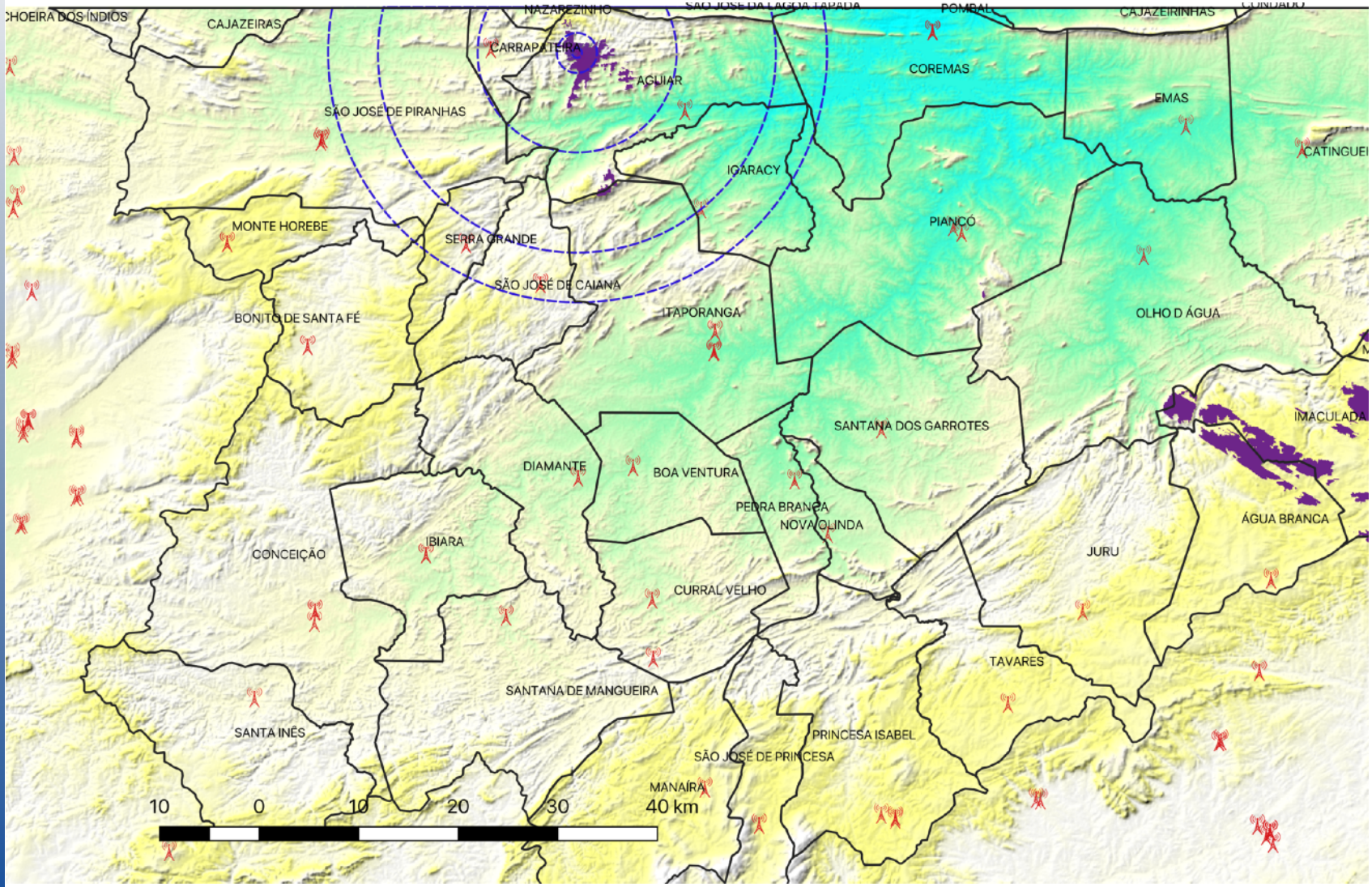
Produção: Andreia Souza

Silence zone requests



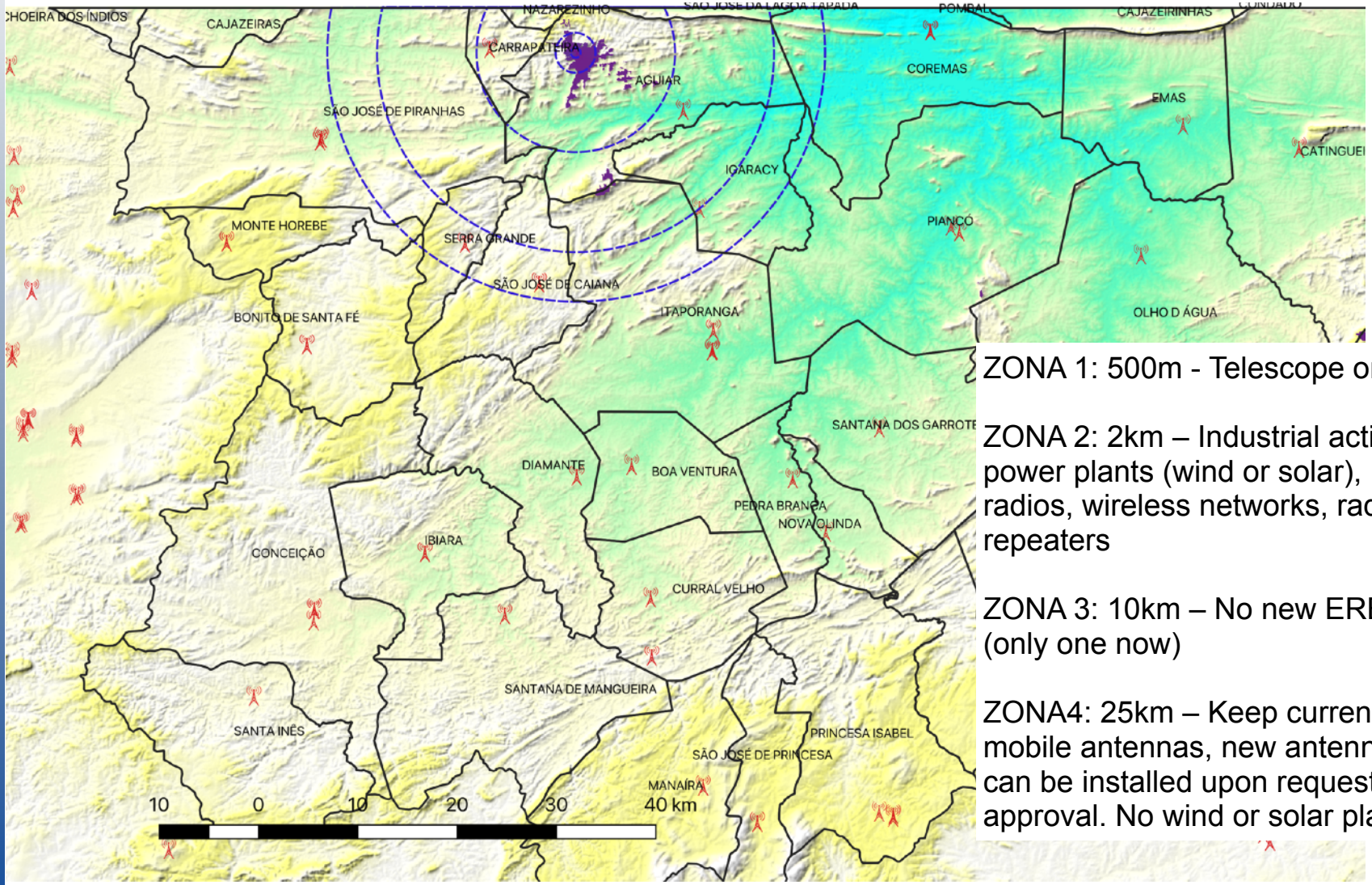
Produção: L. Barosi

Silence zone proposal



Produção:L. Barosi

Silence zone proposal



ZONA 1: 500m - Telescope only

ZONA 2: 2km – Industrial activities, power plants (wind or solar), radios, wireless networks, radio repeaters

ZONA 3: 10km – No new ERB (only one now)

ZONA4: 25km – Keep current mobile antennas, new antennas can be installed upon request & approval. No wind or solar plants.

Produção:L. Barosi

Potential science with BINGO IM data

- Primordial non-gaussianity constraints (e.g., arXiv:1701.00221v1)
- HI tomography and cosmological constraints from cross-correlations (e.g. arXiv;1511.07377, arXiv:1512.04189v1, arXiv:1610.04189v2,)
- Modified gravitation testing (e.g., arXiv:1511.05927v2)
- Late time cosmology forecasting with HI Intensity Mapping (e.g., arXiv: 1405.1452) – likelihood of good measurements with upcoming experiments:
  - Cosmological observables (the expansion rate, growth rate, and angular diameter distance) and
  - Cosmological parameters (the densities of DE/ DM, spatial curvature,DE equation of state, etc.)
- Fast Radio Bursts
  - New transient sources discovered (35 as of July 19) and one repeater (121102)
  - Still to be understood…
  - BINGO is an ideal survey instrument (1 detection/week estimated)
  - BINGO phase-2 may add outriggers and do astrometry (need funding and another RFI-clear zone)

Main difficulties – as of July 2018

- Large telescope → **need to find a company to fabricate the dishes**
- Large horns → **fabrication process understood, need to reduce costs for 50**
- 1/f noise → **Correlation receiver (needs to be reduced)**
- Radio Frequency Intereference → **Mobile quiet zone has been already requested to the state authorities**
- Bright foreground emission→ **Component separation techniques (alla Planck)**
  - **Diffuse Galactic radio emission**
  - **Extragalactic point sources**
- Calibration and stability → **use Moon and planets for additional calibration**
- Sidelobe pick-up → **careful optical design (horn testing showed quite good rejection for 1st/2nd lobe and front/back lobe rejection**
- Atmospheric fluctuations → **much smaller than thermal noise (but Paraiba is one of the most stable regions in South America in terms of cloud coverage and seasonal weather changes)**

BINGO

BAOs from Integrated Neutral Gas Observations

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INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

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UNIVERSIDAD DE LA REPÚBLICA URUGUAY

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

Yangzhou University

Thank you!

Please visit us at http://www.bingotelescope.org