The Dark Sector of the Universe and the BINGO/ABDUS project.

I present the observational and theoretical developments concerning the cosmological structure since the Discovery of a Dark Sector comprising the overwhelming majority of cosmological matter constituents.

I especially argue in favour of the construction of the BINGO (BAO from Integrated Neutral Gas Observations) observatory, which is being supported by a consortium led by Brazil and China and its second phase, with high resolution, the ABDUS Project, Advanced Bingo Dark Universe Studies.

Elcio Abdalla

João Pessoa 2024

TEAM

- Management: Elcio Abdalla, A. Queiroz, Bin Wang, F. Abdalla and others
- Builders: JiaJun Zhang, Chang Feng, Ricardo Landim, Alessandro Marins, João Rafael, Edmar Gurjão
- Members (USP): Jordany Vieira de Melo, Pablo Motta, Gabriel Hoerning, Eveling Costa and others.
- Other members: UFCG, INPE and others (Brazil), China (many Universities and companies), France, UK, Italy.
- Total: more than 80 members

Support

- FAPESP
- Paraiba Government
- FINEP
- MCTI
- Chinese Government
- Others

Open Problems in the Study of the Cosmos

- What is Dark Energy
- What is Dark Matter
- Gravity in Cosmology
- Fast Radio Bursts
- Pulsars

The Dark Matter Question: brief history

- Speculations about Dark, unknown Matter exist since XIX century (see wikipedia)
- Observations by Oort in 20´s point to excess of Matter, however not really established until further observations Much later by himself and Babcock.
- The first real indication came with Zwicky, 1933, observing the Coma Cluster. In spite of the wrong used value of the Hubble constant this was the first real indication of Dark Matter
- Further observations of Galaxy rotation curves little by little confirm the Dark Matter existence

The Dark Matter Question: establishing facts

- Further observations in Green Bank and Jodrel Bank in the 70´s
- Large Scale structure observations.
- CMB observations (more later).
- Today: Further observations from lensing, cosmological parameters fixing via precision observations
- Distant Supernovae (more about that for Dark Energy)
- Redshift Space Distortion
- Baryon Acoustic Oscillations

The Dark Matter Question: conclusion

- Dark Matter is a reality
- It roughly corresponds to 27% of the energy budget of the Universe.
- Interaction with visible matter is either inexistente (except for gravity) or very weak

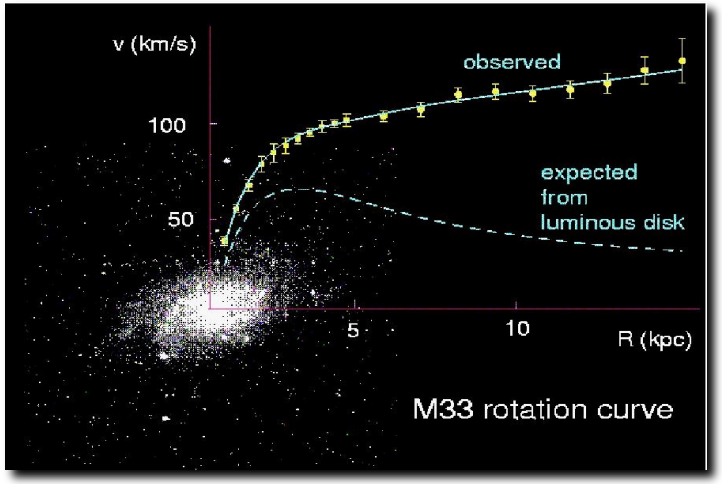
What is Dark Matter?

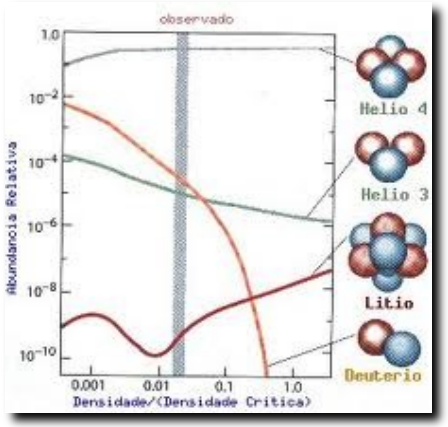
Evidences for Dark Matter

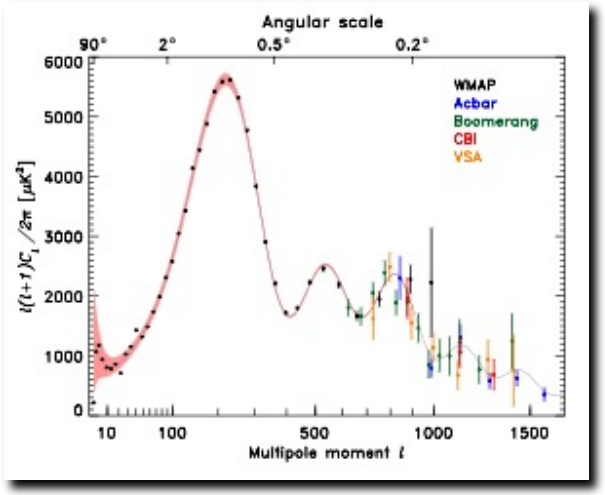
Huge amount of evidences indicating that dark matter exists. One of the biggest unsolved, but very well measured, problems in physics.

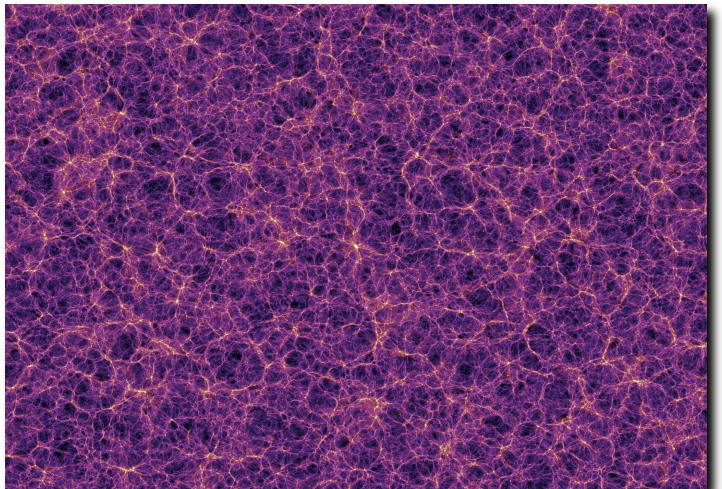
Observations indicate that DM interacts mainly gravitationally.

So far, we have no (non-contradictory) observations that DM was detected by any non-gravitational mechanism.









Candidates

Neutralinos (higgsino, binos, winos, singlinos)
Axinos
Gravitinos
Sneutrinos
Axions
Sterile neutrinos
4th generation neutrinos
Kaluza-Klein photons
Kaluza-Klein gravitons
Brane world dark matter/D-matter
Little higgs dark matter
Light scalars
Superheavy states (ie. “WIMPzillas”)
Self-interacting dark matter
Super-WIMPs
Asymmetric dark matter
Q-balls (and other topological states)
CHAMPs (charged massive particles)
Cryptons, …

Supersymetric

The Flatness problem and a Dark Sector

- Friedmann Equation:

$$\frac{3H^2}{8\pi G} = \rho - \frac{3kc^2}{8\pi G a^2}$$

$$ds^2 = -dt^2c^2 + \frac{dr^2}{1-kr^2} + r^2 d\Omega^2$$

$$\rho_c = 3H^2/8\pi G$$

The Flatness problem and a Dark Sector

$$\Omega = \rho / \rho_c$$

$$(\Omega^{-1} - 1)\rho a^2 = -3kc^2/8\pi G$$

$$\rho \sim 1/a^3 \text{ (matter dom)} \quad 1/a^4 \text{ (rad d.)}$$

The Flatness problem and a Dark Sector

$$\Omega^{-1} = 1 - \frac{3kc^2}{8\pi G} a^{1+3w}$$

$p = w\rho$

$$\rightarrow \begin{matrix} +\infty \\ \equiv 1 \\ -\infty \end{matrix} \longrightarrow \rho \equiv \rho_c$$

$\Omega \equiv 1$

!

The Flatness problem and a Dark Sector

- Therefore, k=0 (critical density) is highly unstable!!!
- Critical density near 1 now means near 1 around nucleosynthesis with 20 digits certainty!!!
- Thus better we have critical density as a result of inflation.
- All contributions should add up to the critical density!
- Dark Matter + Visible Matter (Baryons) +

[something else](Dark Energy) = critical mass!

The Dark Energy Question

- Type 1A Supernovae are the result of a binary system
- One of them is a subcritical White dwarf that acretes from its companion.
- Upon accretion, it becomes critical and ignites
- Its mas and constitution are know
- Thus they are standard candles
- Have (and are) been used to caracterize the Hubble relation

The Dark Energy Question

- Type 1A Supernovae observation and use of Hubble relation imply that the Universe is in accelerated expansion!!!
- A model for the expansion is a cosmological constant, positive, equivalent to a mass density of the order of 69% of the critical mass
- Together with previous figures, the Universe is flat.
- This constitutes the ΛCDM Standard Model, or Concordance model of Cosmology

The Cosmological Question

- The ΛCDM Standard Model is flat, contains Dark Matter (27%), 4% Baryonic Matter (including “minorities”). And today´s data are almost well described

- Nothing can describe the Cosmological constant, whose size, compared to Elementary Particle Standard Model is 120 times smaller. Weinberg pointed that out long ago and it constitutes the Cosmological Constant problem

The Cosmological Question

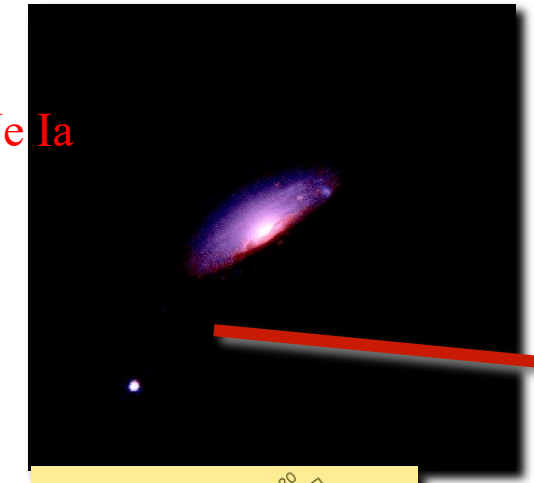
- Moreover, Dark Matter and Dark Energy are of the same order of magnitude today, although DE is constant and DM decays with the cube of the scale fator.
- This is known as the coincidence problem
- Together with the fact that as for today the Dark Sector does not communicate (except for gravity) with the visible Sector, we are in a position of total lack of knowledge about circa 95% of the matter contente of the Universe

What is Dark Energy?

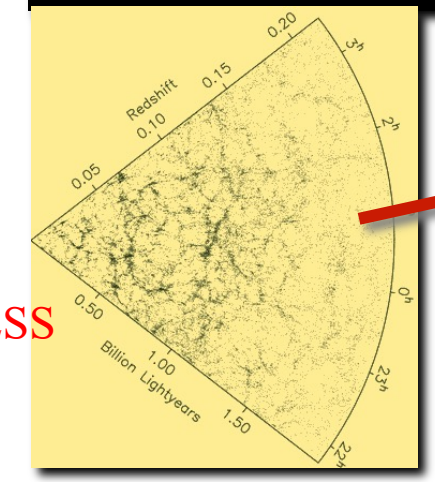
The Evidence:

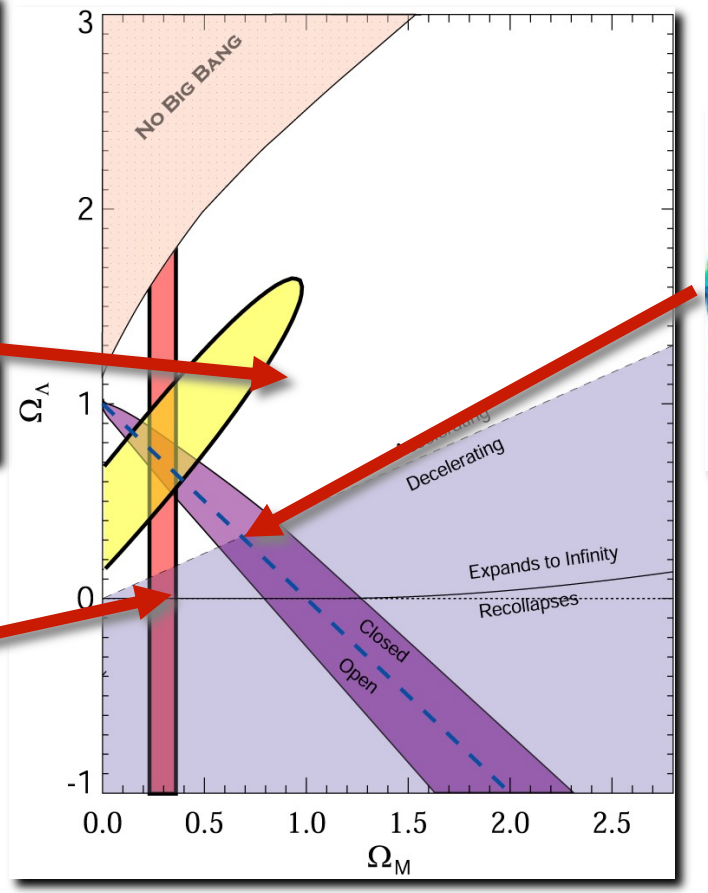
98's: The universe is expanding in an accelerated way.

SNe Ia

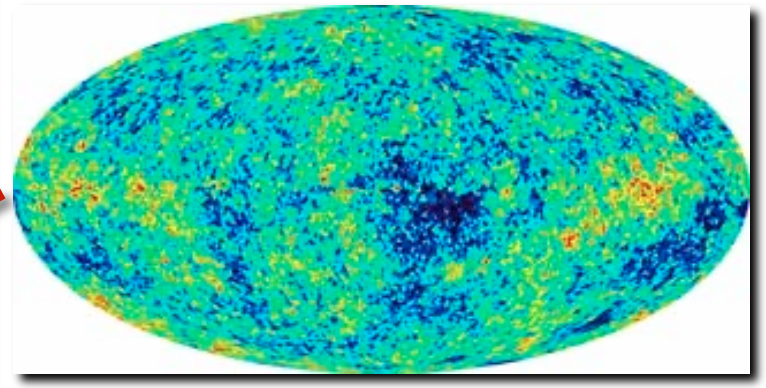


LSS





CMB



Ω_{DE}=0.721±0.025 (WMAP)

WMAP

Ω_{DE}=0.685±0.013 (Planck)

Source: S. Tsujikawa, "**Dark Energy and Modified Gravity**"

What is causing the acceleration?

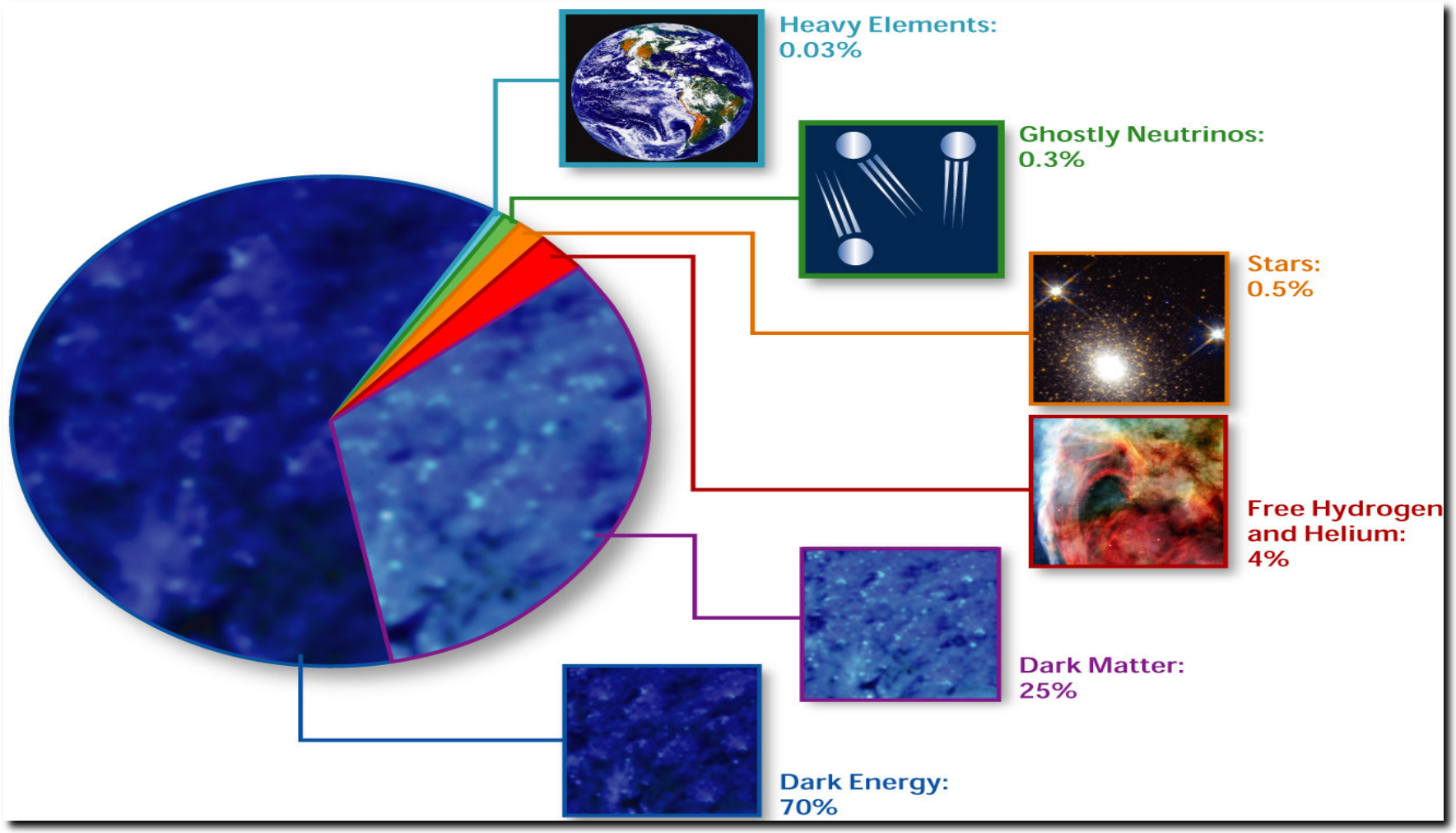
Source: de Rahm & Tolley, 2008

$$\frac{\ddot{a}}{a} = \frac{-4\pi G}{3}(\rho + 3p)$$

$$p < -\frac{\rho}{3} \rightarrow \omega < -\frac{1}{3}$$

Standard Cosmological Model

Composition of the Universe



http://en.wikipedia.org/wiki/Image:Cosmological_composition.jpg source and rights]

The Dark Sector Structure

- There is no established model for the Dark Sector based on Field Theory
- Dark Matter, up to now, is seen as inert matter, na inert transparente liquid oblivious to touch (no electromagnetism)
- Dark Energy is just a cosmological constant.

The Dark Sector Structure

- Possibilities already considered
- 1. DM as a fluid with zero pressure
- 2. DE as a fluid with pressure equal to minus the density (Cosmo Const)
- 3. DE as a fluid with negative pressure. Equation of state

- $p=-\omega\rho$, where ω is also called equation of state parameter. For $1/3<\omega<1$ the gravitational solution is in accelerating expansion

Precision Cosmology

- The way to establish facts is via Precision Cosmology.

$$g_{\mu\nu} = g^{(0)}_{\mu\nu} + h_{\mu\nu}$$

$$\Phi = \Phi^{(0)} + \varphi \quad \text{etc}$$

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi G\, T_{\mu\nu} \longrightarrow$$

$$\Box h_{\mu\nu} = \gamma\, \varphi \quad \text{etc}$$

Precision Cosmology

- That is, Einstein Equation is perturbed, we also use Boltzmann Equation to describe the perturbed fluids in interaction and the perturbed field equations. All become linear and can be solved by sophisticated numerical methods.

- We compute correlators in the sky also called
- 1. power spectrum (two point correlators
- 2. Bispectrum (three point correlators)
- 3. We obtain temperature variations in the sky

Precision Cosmology

- Observing Sky Radiation we have results with high precision, the

- Precision Cosmology

DE/DM Interaction

Each component is not conserved alone anymore.

Cosmological equations:

$$\dot{\rho}_m + 3H\rho_m = -Q,$$

$$\dot{\rho}_\phi + 3H(1+w_\phi)\rho_\phi = Q,$$

Many many models in the literature:

Phenomenological (For a classification see Koyama, Maartens, Song, 0907.2126; see also Wang, Abdalla, Atrio Barandela, Pavon Rep. Prog. Phys. 2016)

- Interaction depending on DM or DE

Constant coupling or Time varying coupling

Coupling must be small : constraints from observations!

In general no analytic solution!

Evidence Against ΛDCM?

Baryon Acoustic Oscillations in the Lyα forest of BOSS DR11 quasars.
T. Delubac et al. [BOSS Collaboration] – A&A 574, A59 (2015), arXiv: 1404.1801

- From adjusting the BAO peaks and combining with the ΛCDM fiducial values from Planck+ WMAP:

$$H(z = 2.34) = (222 \pm 7\,\mathrm{km\,s^{-1}\,Mpc^{-1}}) \times \frac{147.4\,\mathrm{Mpc}}{r_d}$$

$$D_A(z = 2.34) = (1662 \pm 96\,\mathrm{Mpc}) \times \frac{r_d}{147.4\,\mathrm{Mpc}},$$

$$r_d = 147.4\ \mathrm{Mpc}$$

- Values differ: 1.8σ from Planck+WP;

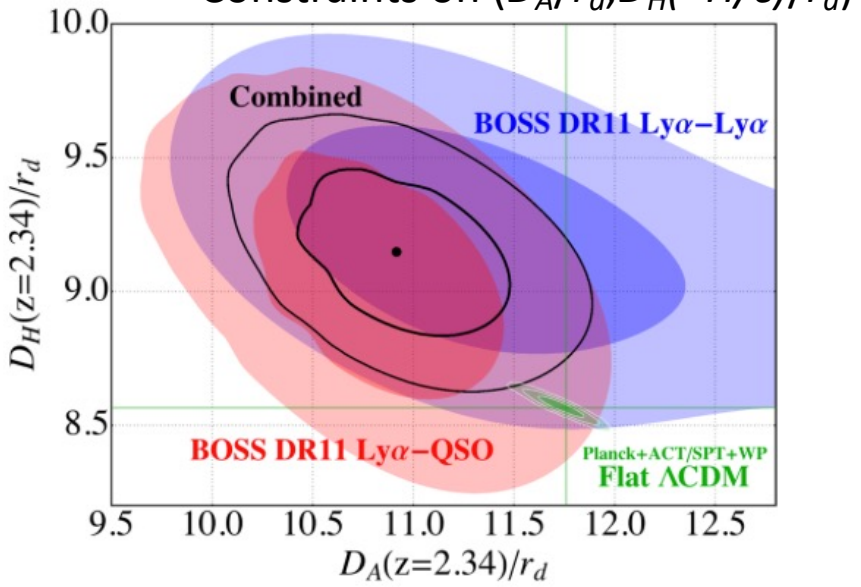
  1.6σ from WMAP9+ACT+SPT

Conclusion: Approximately 2σ below the value of D_H

And 2σ above the value of D_A

compared to the ΛCDM prediction.

Constraints on $(D_A/r_d, D_H(=H/c)/r_d)$



Evidence Against ΛDCM?

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$$\frac{8\pi G}{3}\rho_{\rm de}(z) = H^2(z) - H_0^2\Omega_M(1+z)^3 \ .$$

$$\frac{\rho_{\rm de}(z=2.34)}{\rho_{\rm de}(z=0)} = -1.2 \pm 0.8 \ .$$

~2.5σ difference from the expected from ΛDCM!

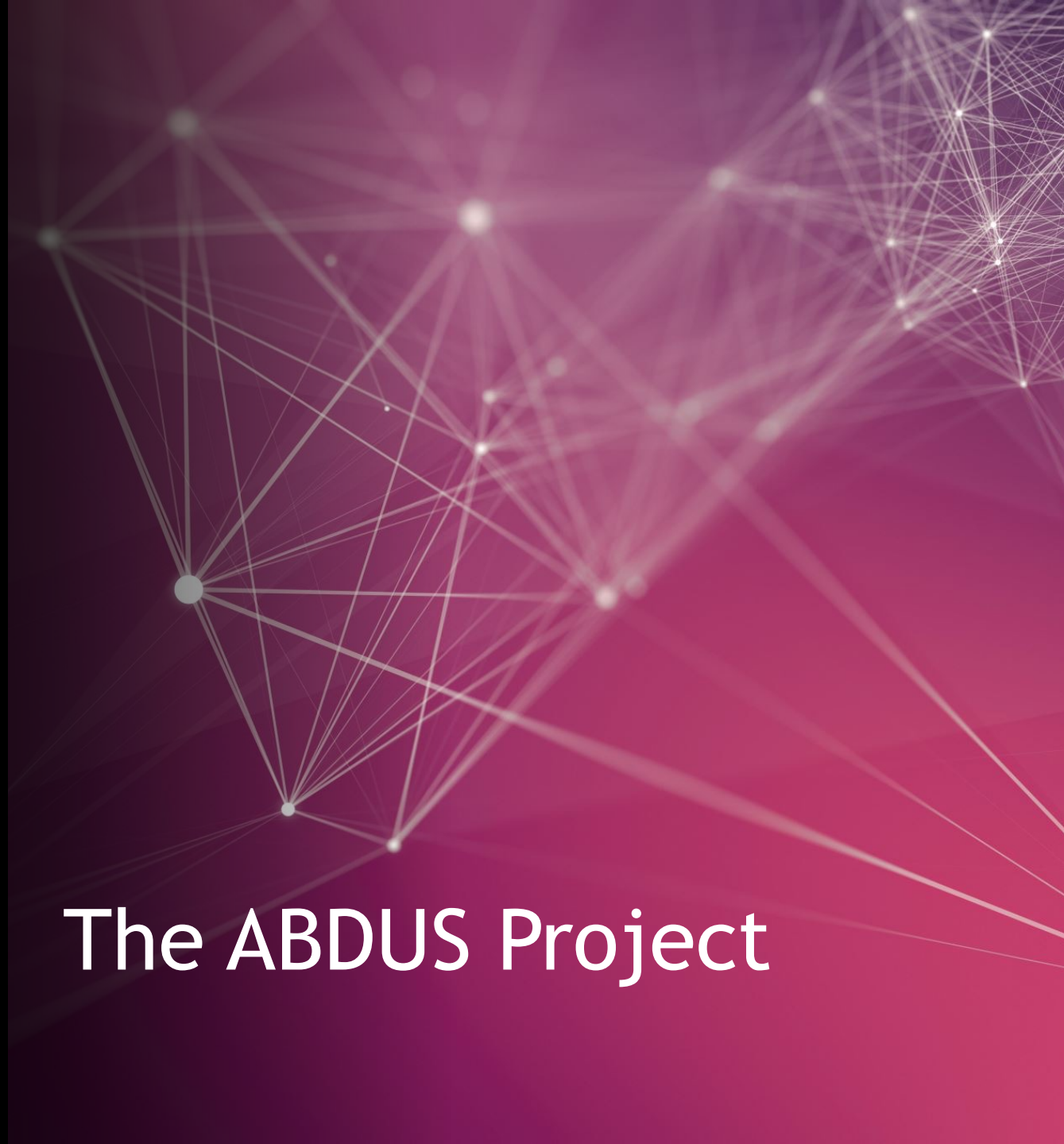
Parameters from Planck+WMAP for ΛDCM

Parameter	Bestfit	σ
h	0.706	0.032
$\Omega^0_{DM}h^2$	0.143	0.003
Ω^0_{DE}	0.714	0.020
$\Omega^0_b h^2$	0.02207	0.00033

Interacting dark energy?

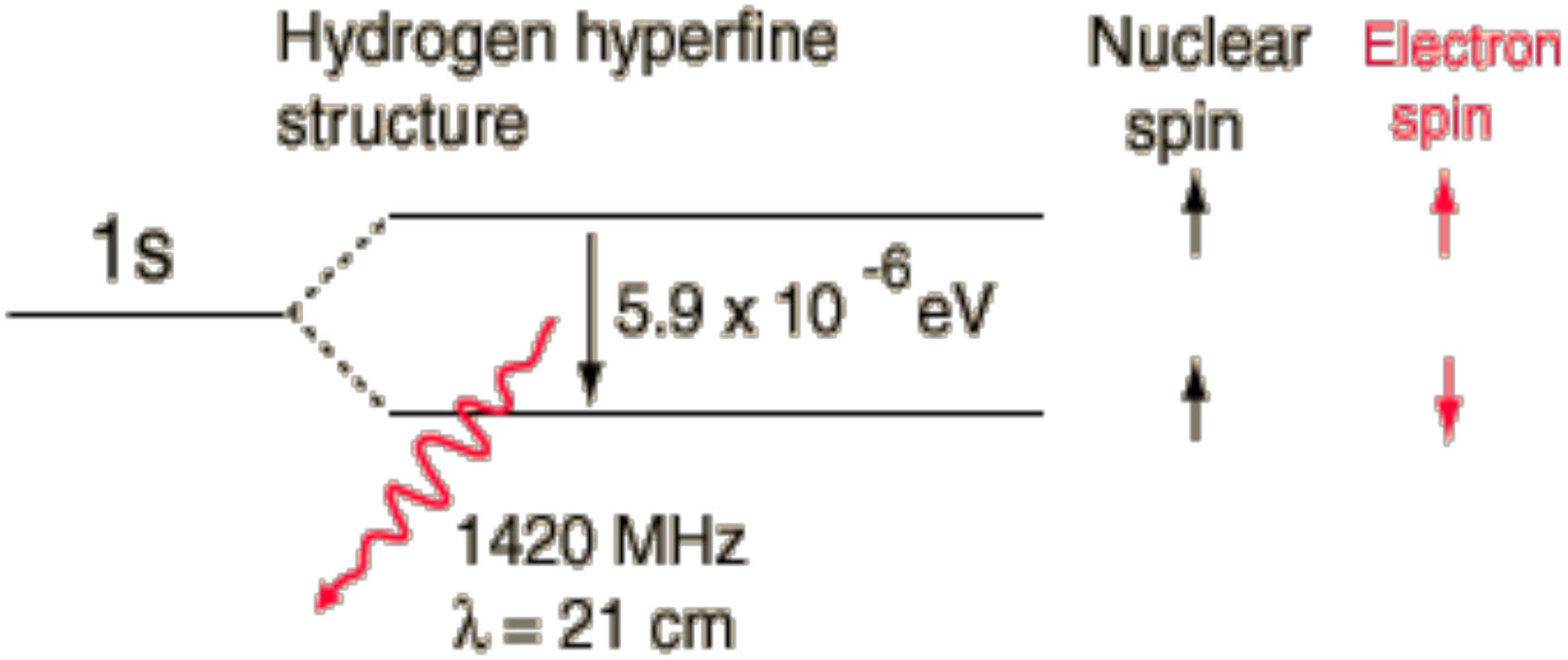
Review Rep. Progr. Phys.: Wang, E.A., Atrio-Barandela, Pavon

Whispers of the Universe: the BINGO project



The ABDUS Project

21 cm Physics – The Hyperfine Structure



BINGO TELESCOPE

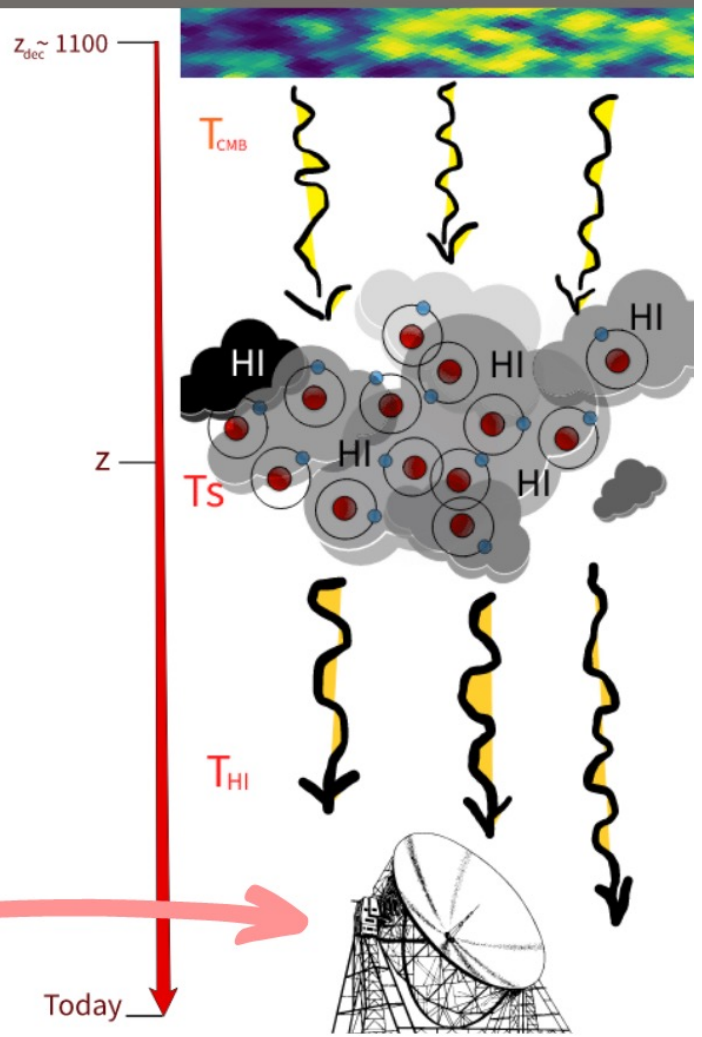
21cm Cosmology

- Used to trace the distribution of matter at radiofrequency
- Gives information between CMB and the Local Universe
- Informs about several astrophysical process at high-z
- Sensitive to the dynamics of the Universe
- Informs about the ionization state of hydrogen

Brightness Temperature HI

$$T_{\rm HI}(z) = \left(\frac{9hc^3A_{10}}{256\pi^2 G k_{\rm B}\nu_{10}^2 m_{\rm HI}}\right)\frac{\Omega_{\rm HI}(z)}{(1+z)^2}\frac{H_0^2}{\|dv_\parallel/d\chi\|}$$

$$\delta T_{\rm HI}(z,\hat{n}) = \delta_{\rm n} - \frac{1}{\mathcal{H}}\hat{\mathbf{n}}\cdot(\hat{\mathbf{n}}\cdot\nabla\hat{\mathbf{v}}) + \left(\frac{\rm d}{{\rm d}\eta}\ln\left(a^3\bar{\rm n}_{\rm HI}\right) - \frac{\dot{\mathcal{H}}}{\mathcal{H}} - 2\mathcal{H}\right)\delta\eta + \frac{1}{\mathcal{H}}\dot{\Phi} + \Psi$$



INTENSITY MAPPING

- No Search for particular emission
- Search instead for general Hydrogen emission
- Large clouds

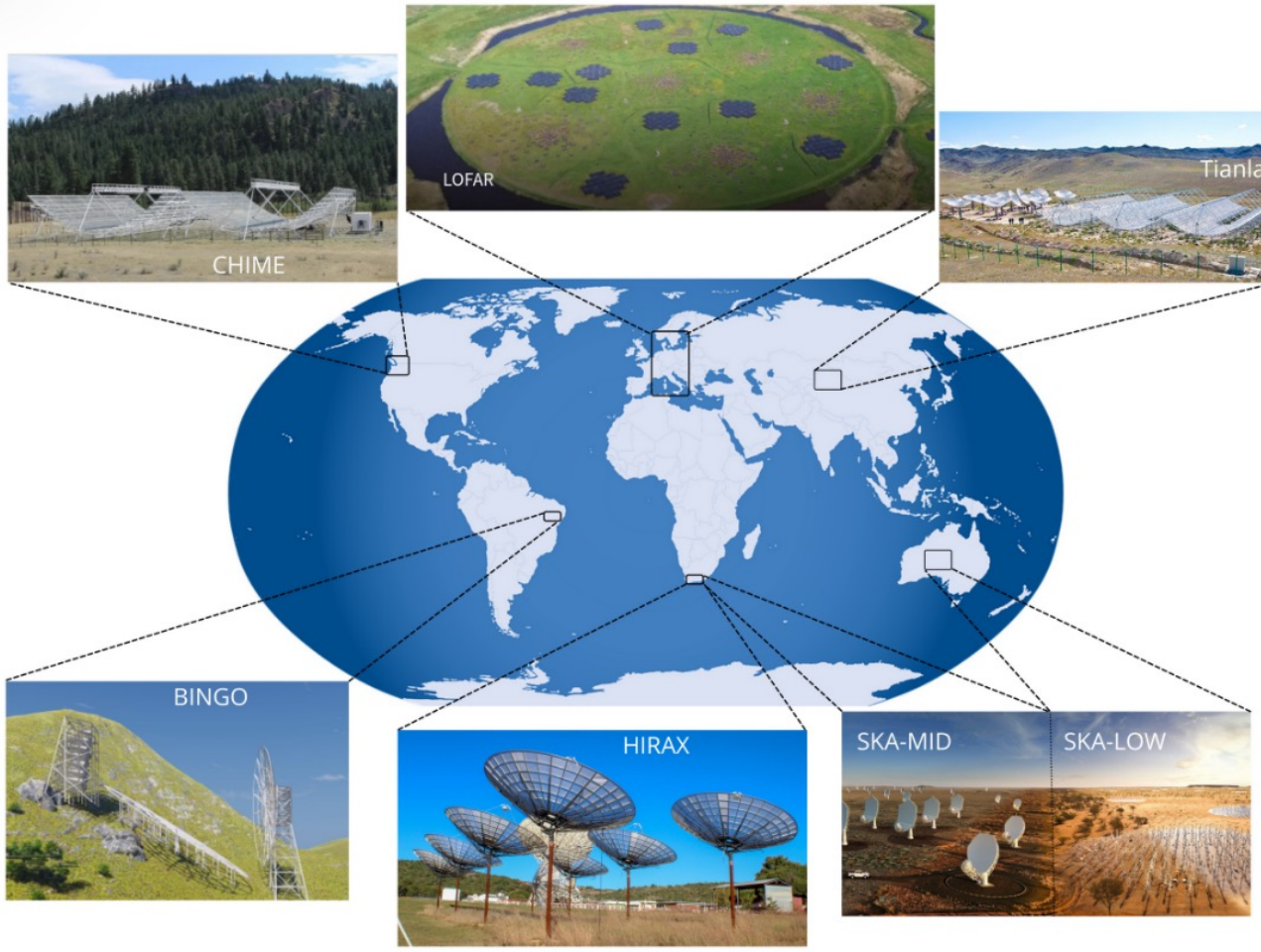
BINGO TELESCOPE

21cm intensity mapping projects

Some IM projects

- BINGO
- CHIME
- FAST
- MeerKAT
- Tianlai
- NenuFAR
- HIRAX
- MWA
- SKA
- HERA
- EDGE
- LOFAR

Projects in the image on the right



BINGO


The BINGO radio telescope and 21 cm Cosmology

Bingo´s aims

- ***B**AO for **I**ntegrated **N**eutral **G**as **O**bservations*
- *Large scale structure and constraints on Cosmological parameters (particularly DE)*
- *HI intensity map at $0.127 < z < 0.448$*
- *Astrophysical phenomena: Fast Radio Bursts and Pulsars*

What is Bingo?

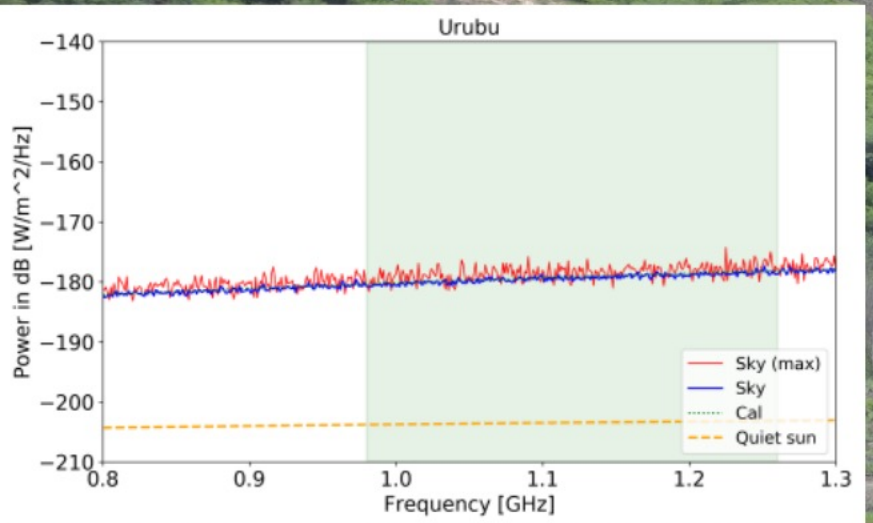
- ***B**AO for **I**ntegrated **N**eutral **G**as **O**bservations*
- *A single/double dish multiple Horns Radio Telescope, mainly to measure BAO*
- *Short scale phenomena (we can pinpoint short lumps)*

The Instrument

- *Two dishes (40 and 39 meters)*
- *28 Horns (1.8 m wide, 4.8 m long)*
- *System Temperature 50 K (up to now, we have 70K)*
- *Simple off the shelf electronics in phase 1*
- *Phased arrays in bingo 2*
- *Site at “Serra do Urubu” (Vulture heights) in Paraíba, Brazil*

THE SITE

BINGO TELESCOPE

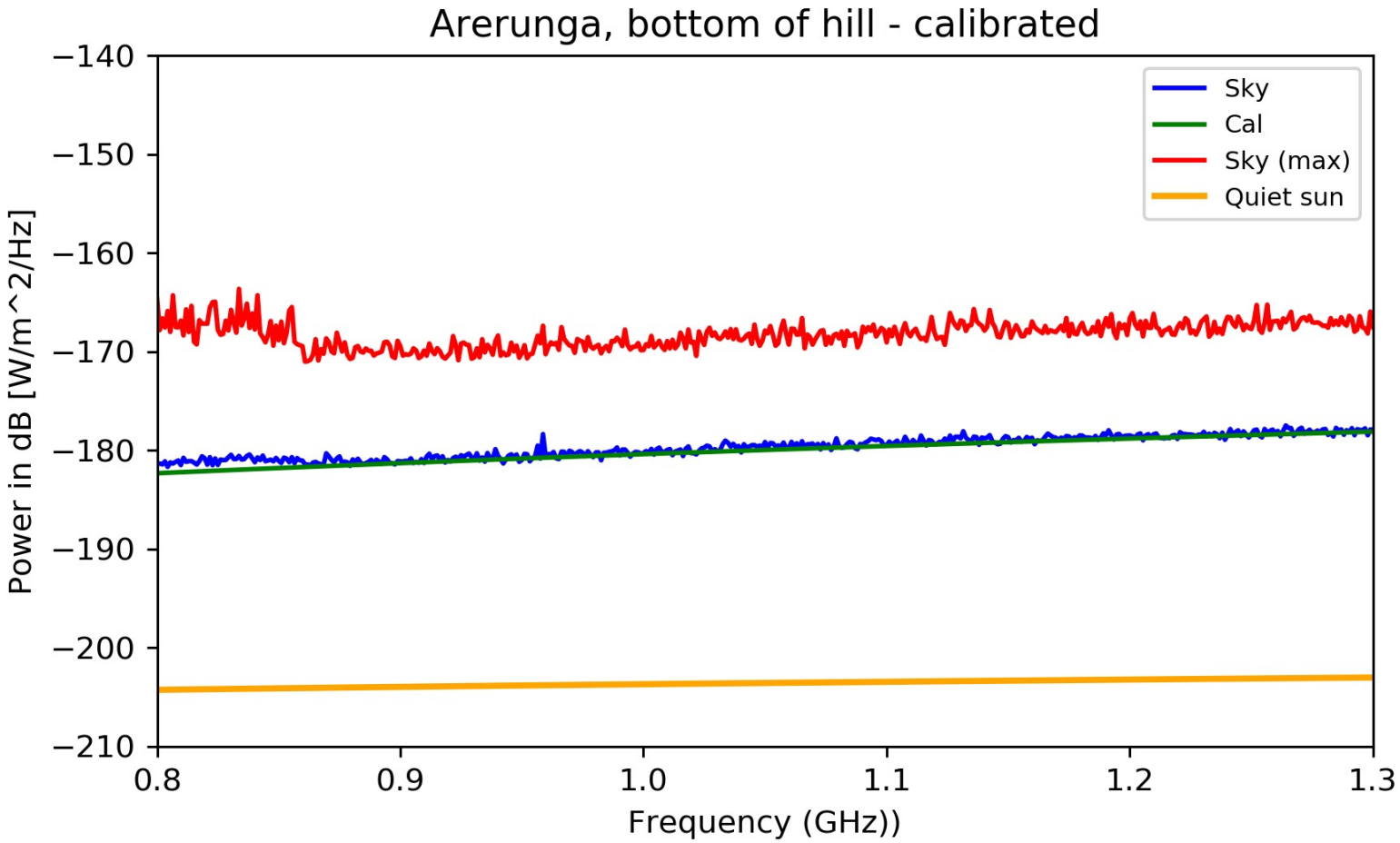


RFI measurements on the Serra do Urubu (BINGO site)

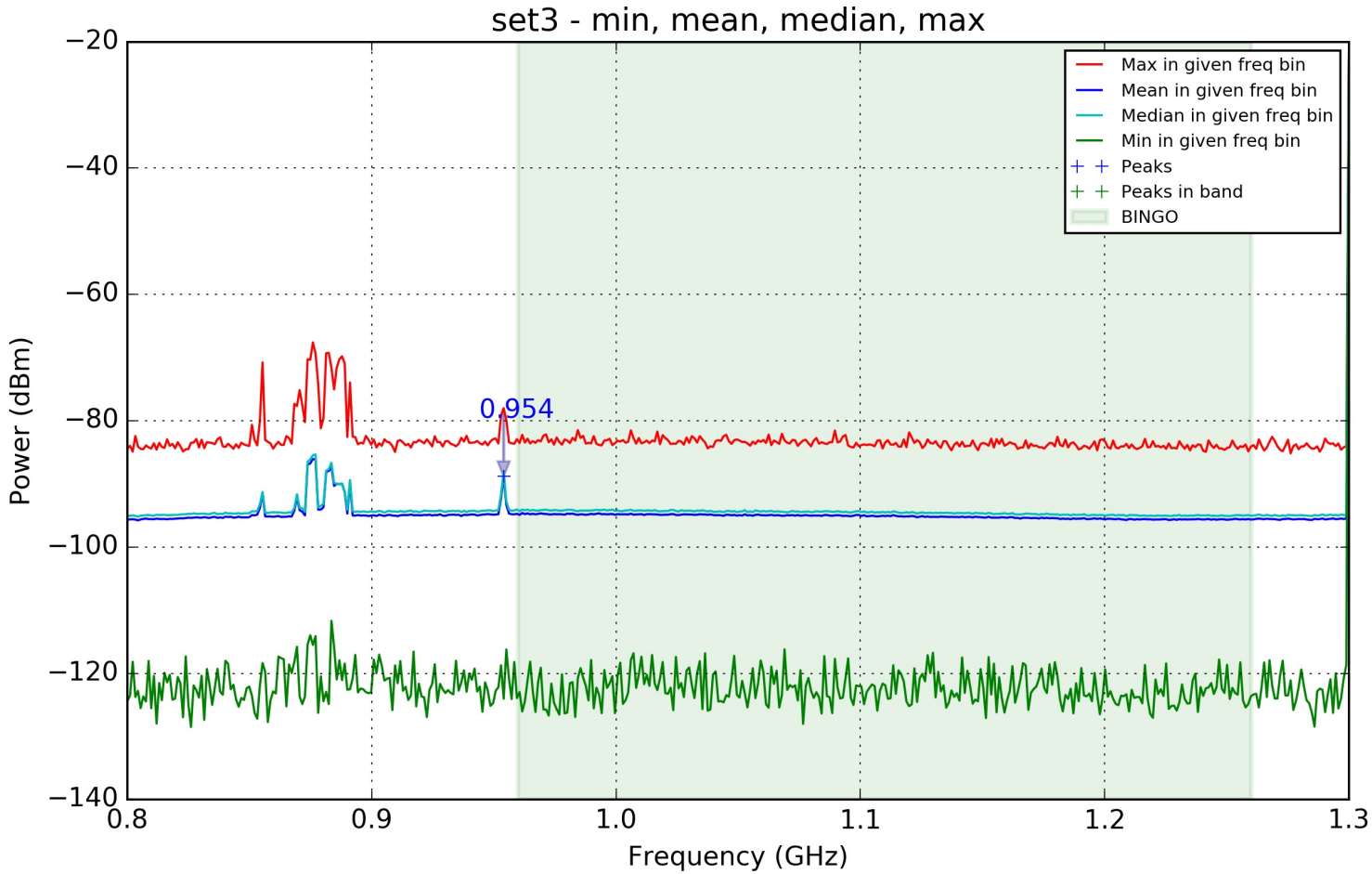
Fonte: Peel, M., et al. 2019

BINGO TELESCOPE

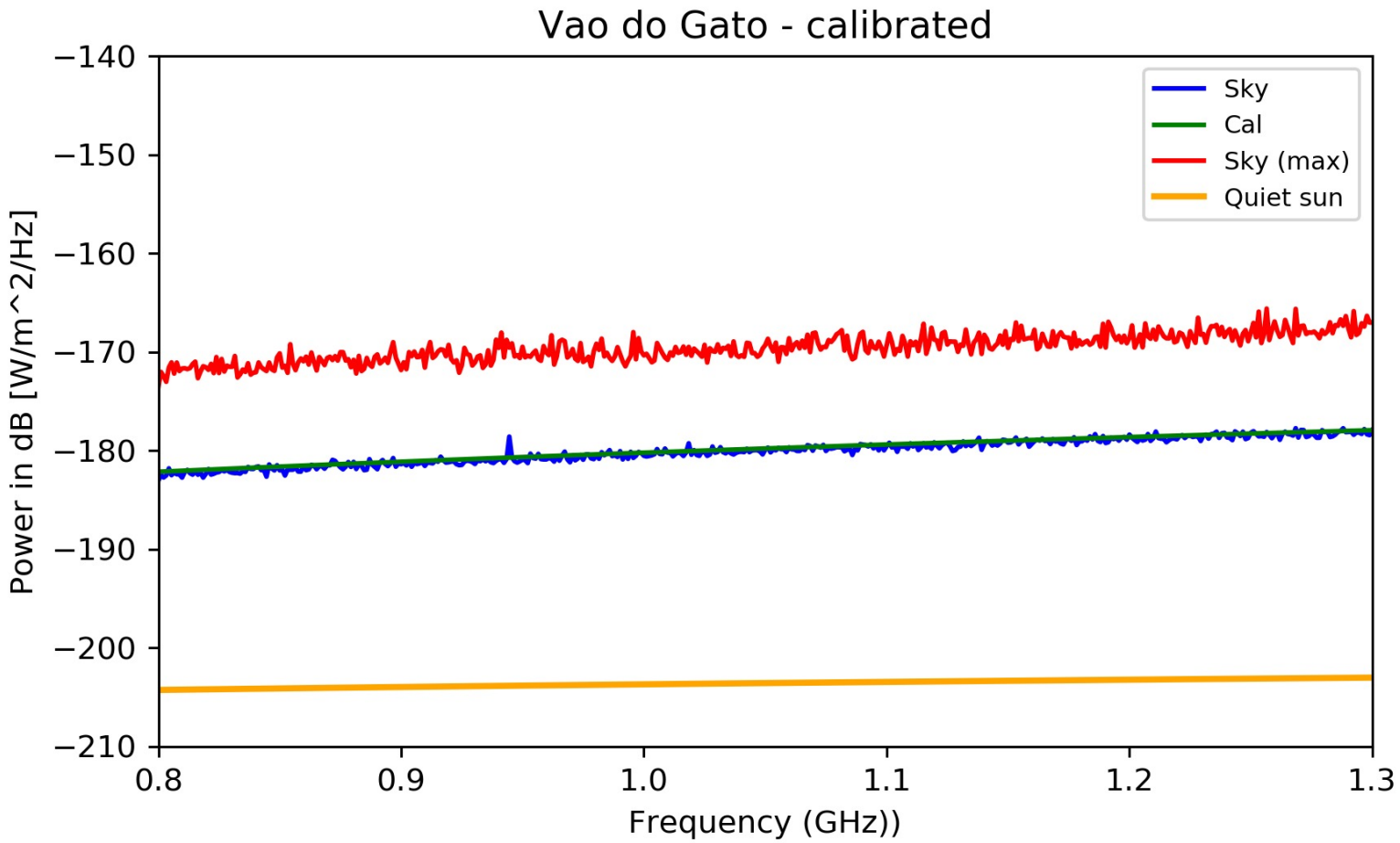
Uruguay


Arerunga, bottom of hill - calibrated
Power in dB [W/m^2/Hz]
−140
−150
−160
−170
−180
−190
−200
−210
0.8
0.9
1.0
1.1
1.2
1.3
Frequency (GHz))
Sky
Cal
Sky (max)
Quiet sun

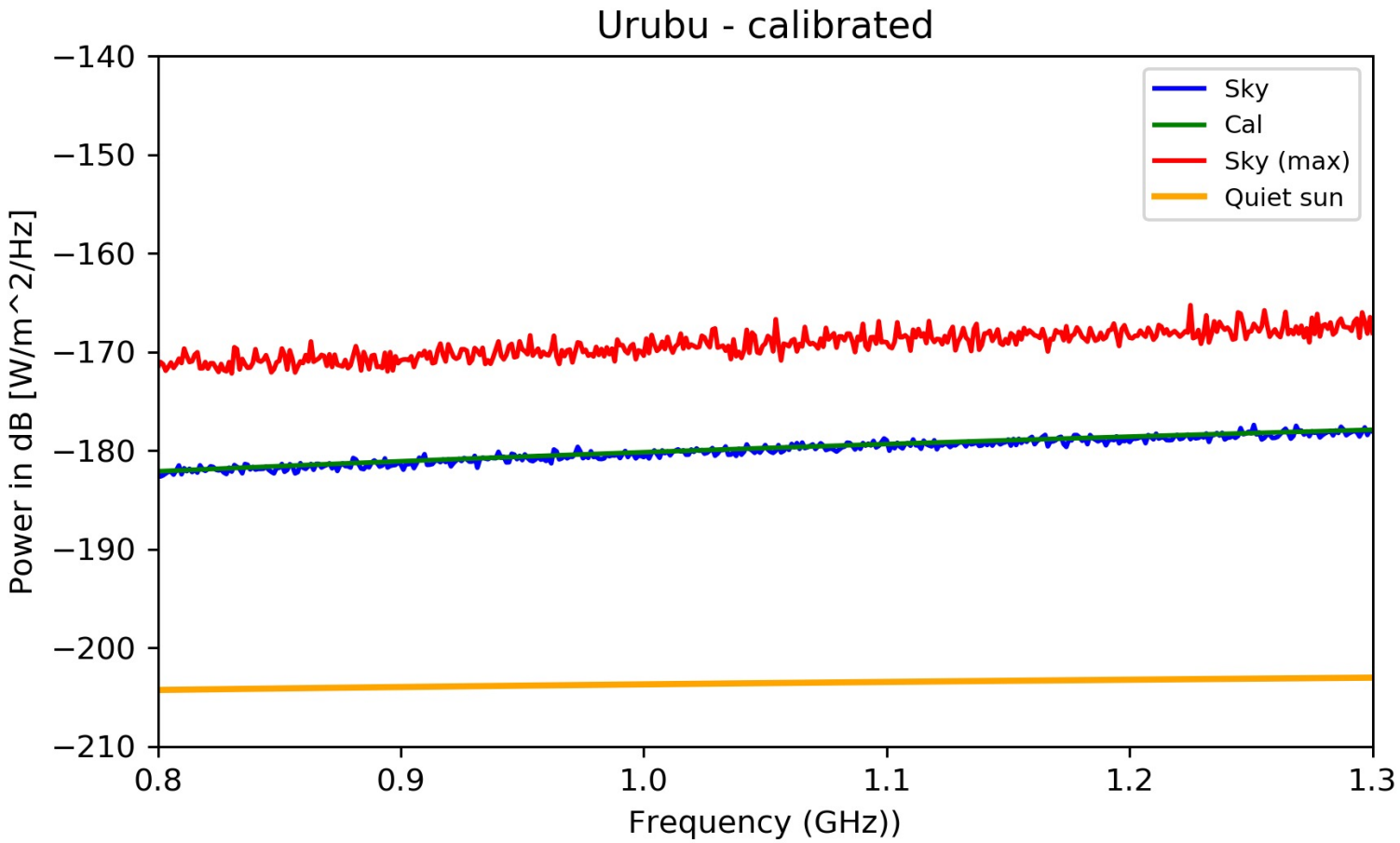
Cachoeira Paulista (SP)



Vão do Gato (Cat's den) Paraíba



Urubu (Vulture heights), Paraíba

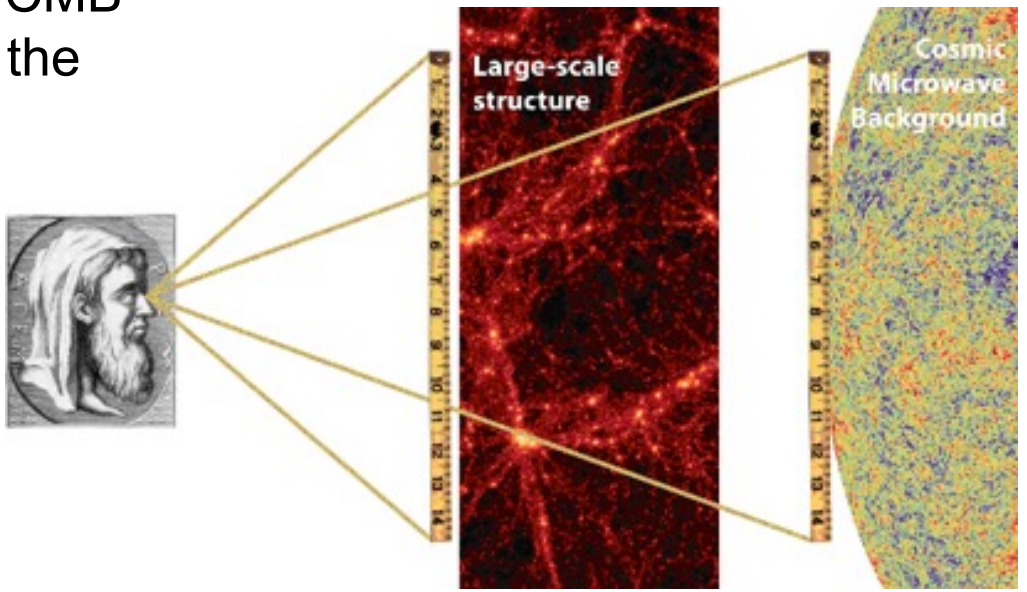


Motivations for BINGO

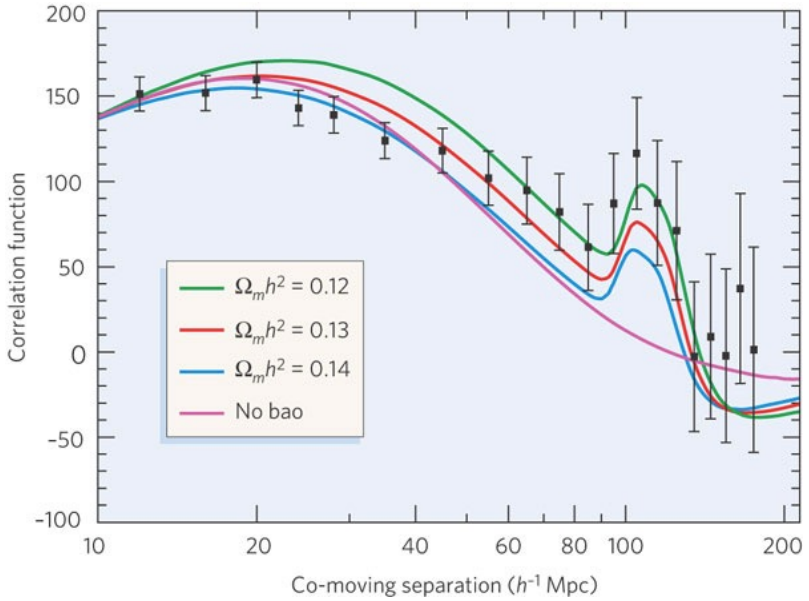
- HI intensity mapping to measure BAO
- Structure formation
- Dark Sector properties (last half history of the Universe)
- Static telescope, excellent for looking after transient phenomena
- Fast astrophysical phenomena:
- Pulsar properties
- Fast Radio Bursts

Baryon Acoustic Oscillations (BAOs)

- Baryon oscillations seen in the CMB distribution can be observed in the spatial distribution of galaxies



Credit: EUCLID website (ESA)

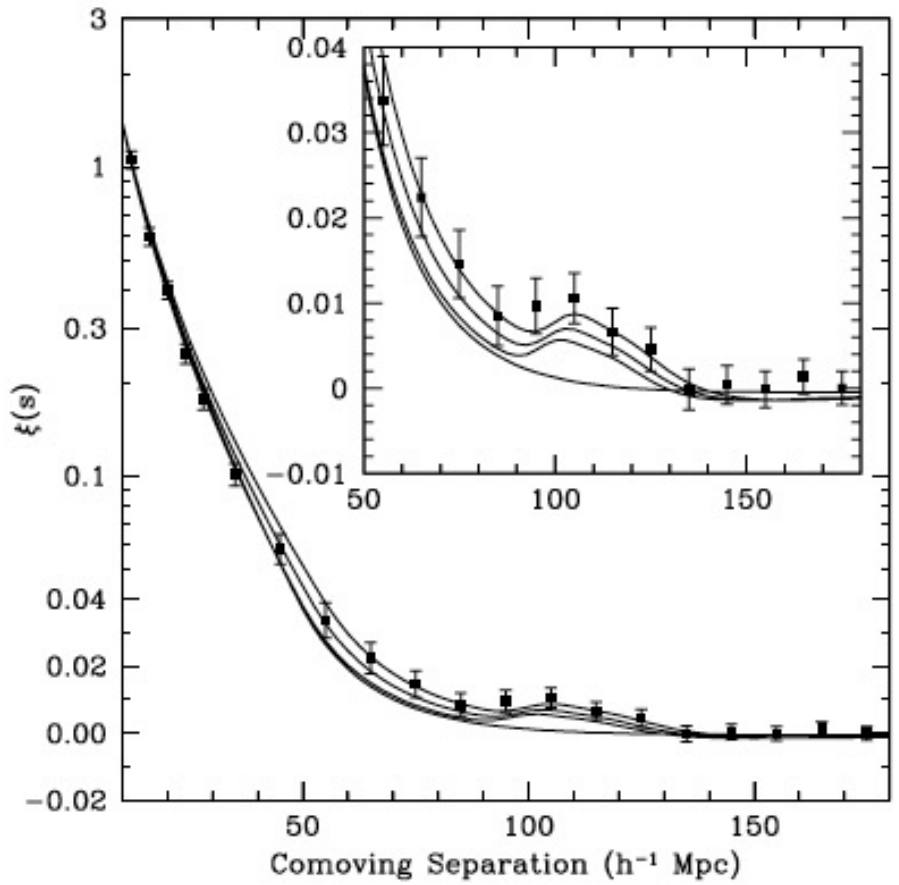


Credit: Bennett, *Nature* (2006)

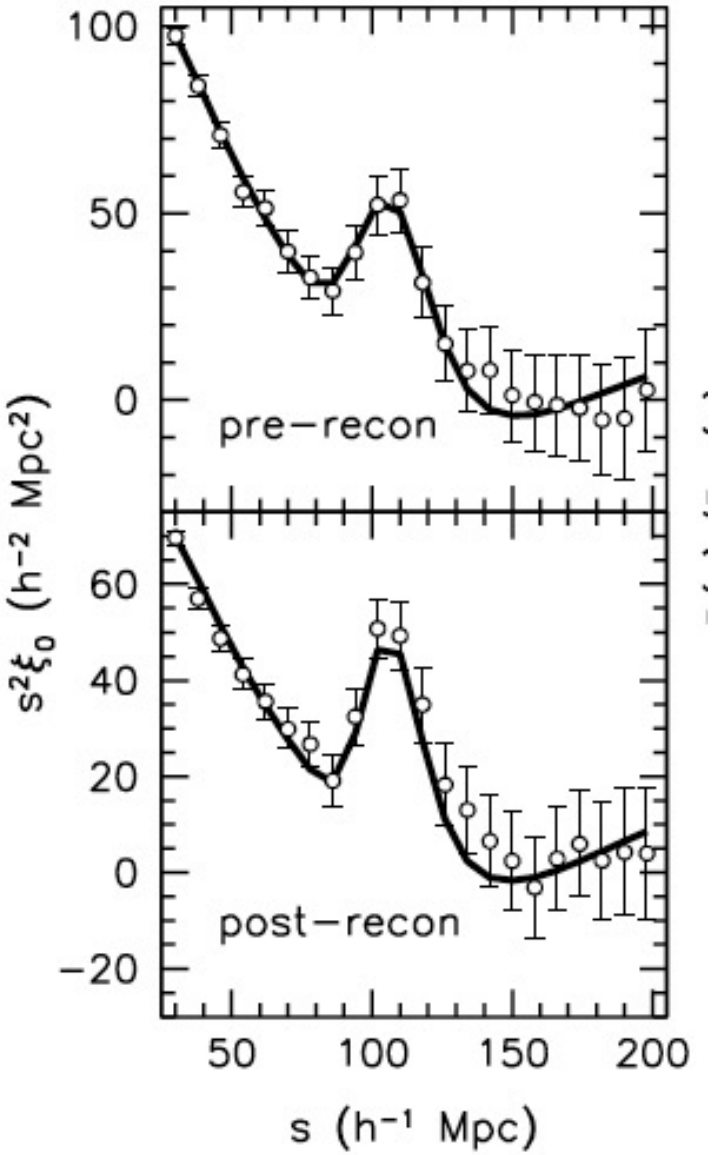
- The acoustic peak gives the ratio of the distances to z=.35 and z=1,100 to 4% fractional accuracy.
- absolute distance to z=0.35 is determined to 5% accuracy.
- co-moving sound horizon scale 150 h^{-1} Mpc.

Optical BAOs

Eisenstein et al. (2005)



Anderson et al. (2014)



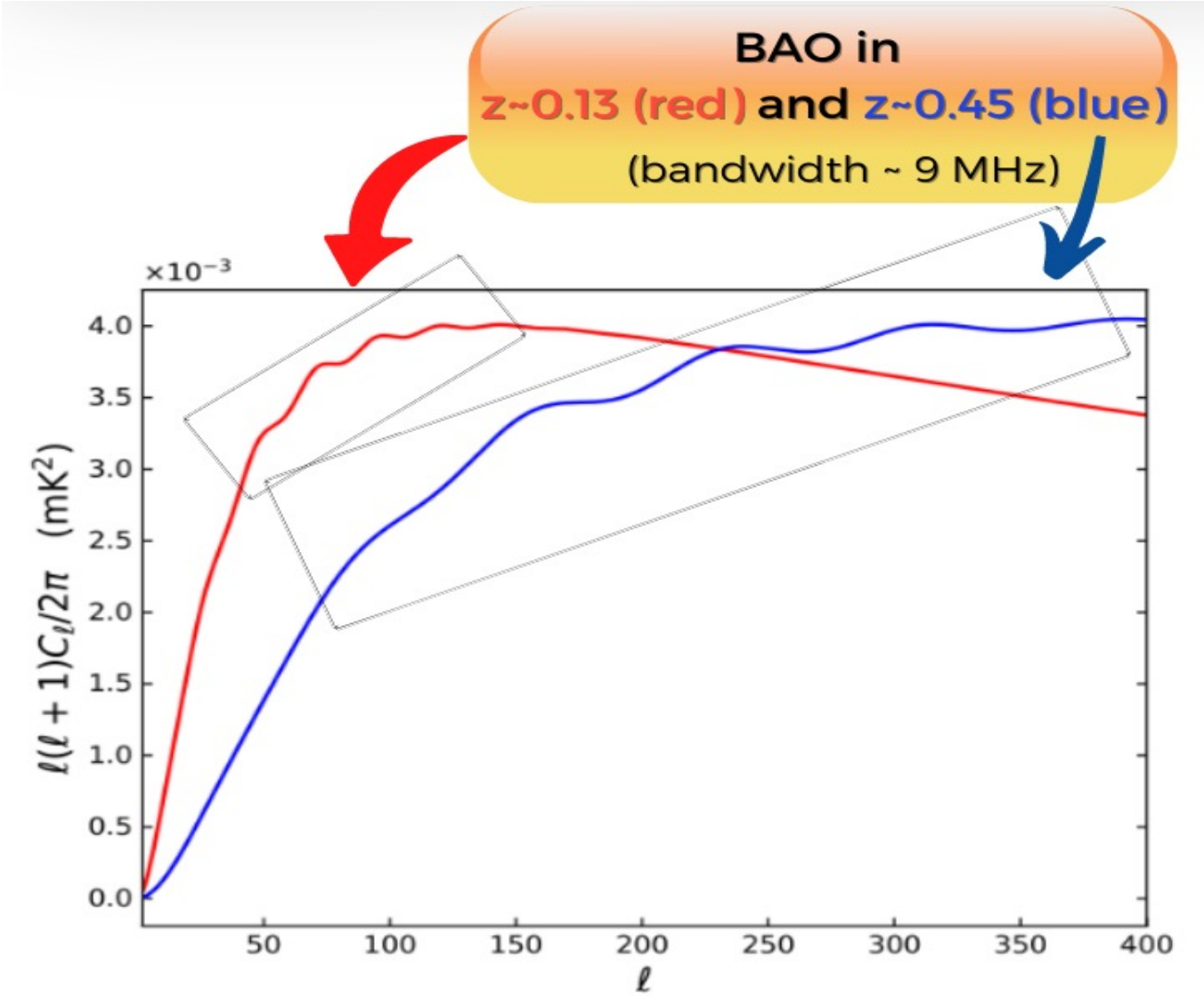
C.A. Wuensche (2016)

Baryon Acoustic Oscillations (BAOs)

- Acoustic waves imprinted on CMB 380,000 years after Big Bang

- Acoustic scale set by distance light travelled at that time
  - Known precisely from CMB power spectrum
  - D=149 ± 0.6 Mpc

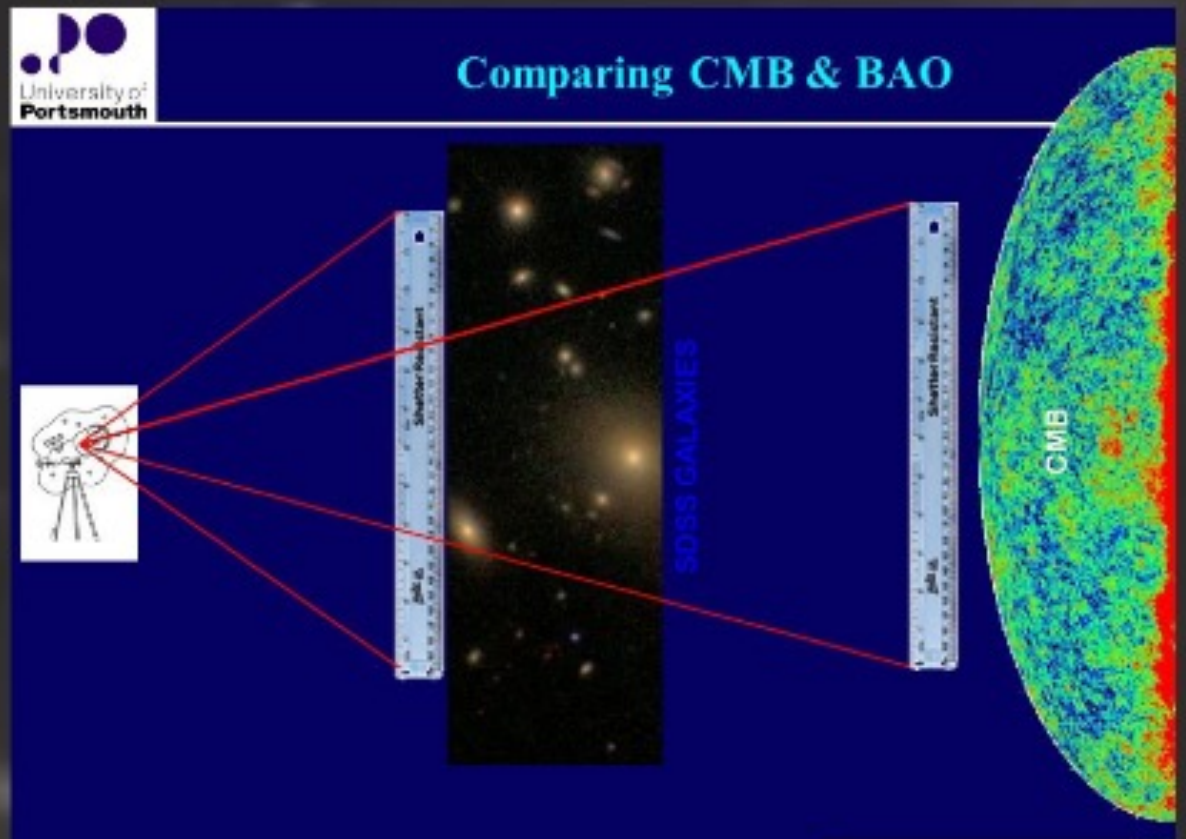
- BAO scale imprinted on all matter in the Universe
  - Use as a “standard ruler”



Fonte: Abdalla, E. et al 2021

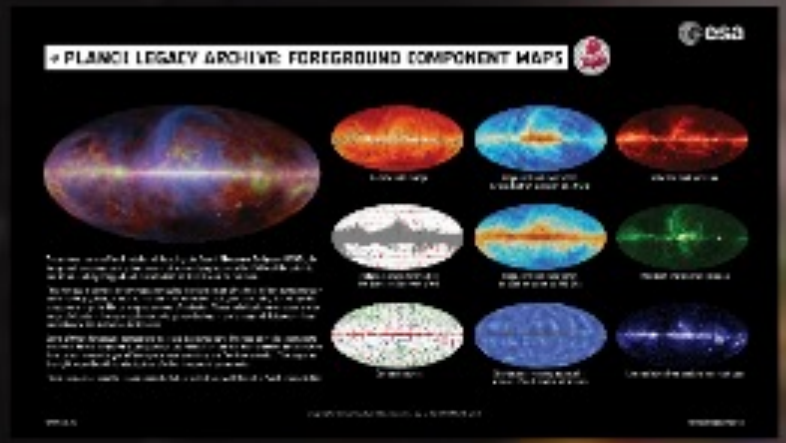
The Science

- Acoustic waves imprinted on CMB 380,000 years after Big Bang
- The acoustic scale is set by distance light travelled at that time
- Known precisely from CMB power spectrum: D=149 ± 0.6 Mpc (Planck 2015)
- BAO scale imprinted on all matter in the Universe, use as a “standard ruler”
- HI intensity mapping, measure HI FLUCTUATIONS, using a ~ 0.7 deg beam on the sky



Some scientific challenges

Foregrounds ~ 10000 stronger than BAO signal!!!!



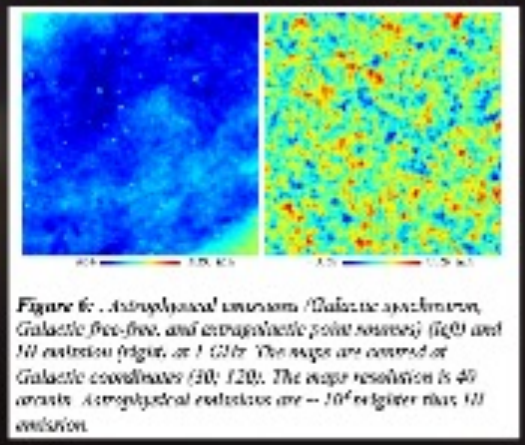
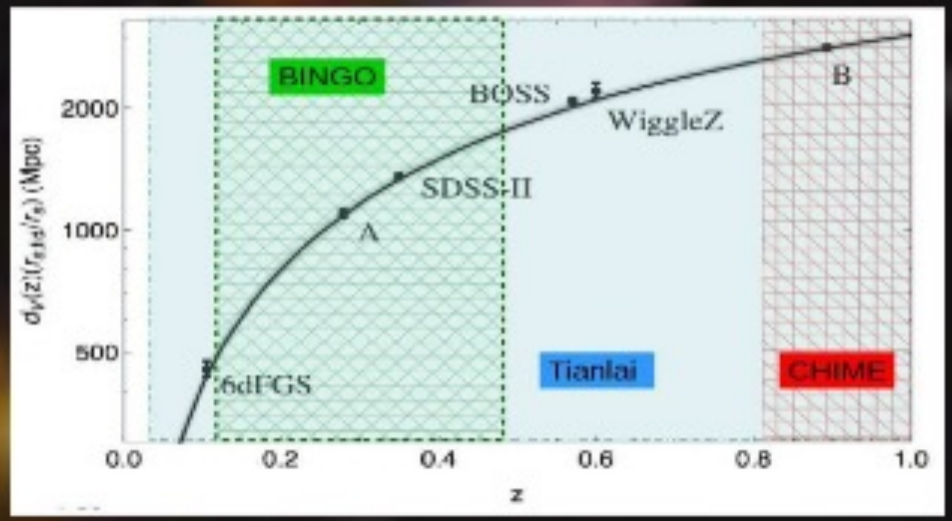
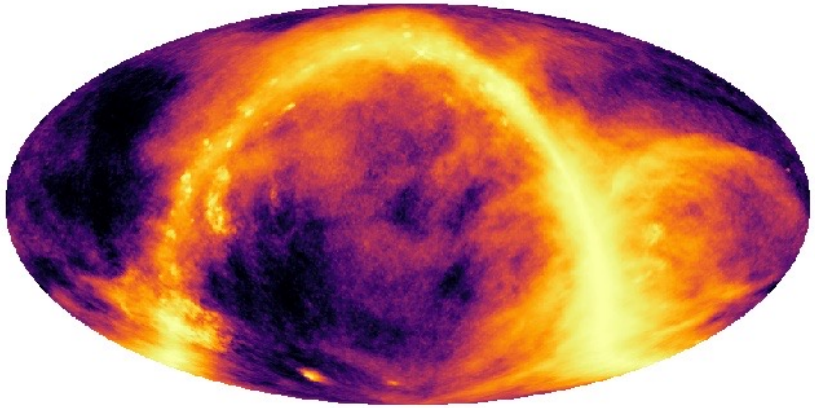


Figure 6: Astrophysical emissions (Galactic synchrotron, Galactic free-free, and extragalactic point sources) (left) and 3D emission (right, at 1 GHz). The maps are centred at Galactic coordinates (30, 120). The maps resolution is 40 arcmin. Astrophysical emissions are ~ 10^4 brighter than 3D emission.

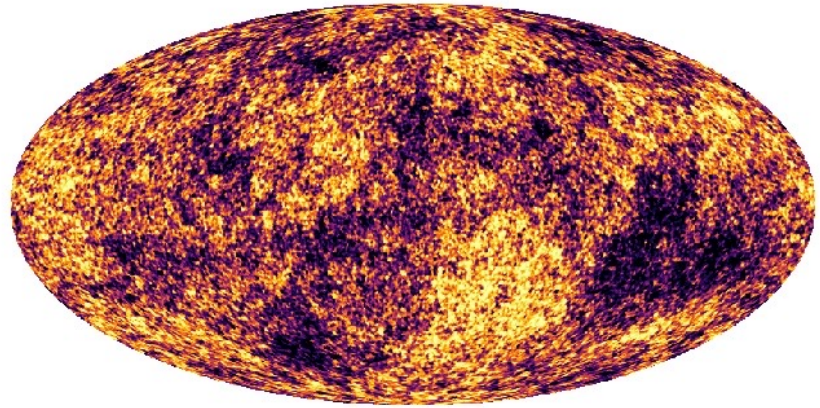


TOTAL



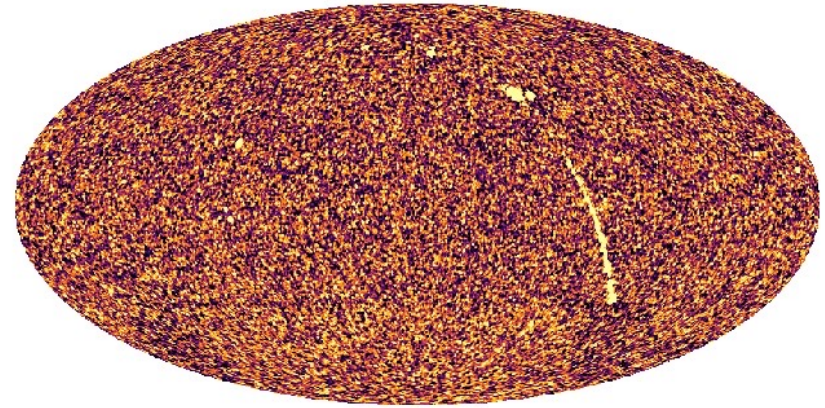
301.403 mK 165476

CMB



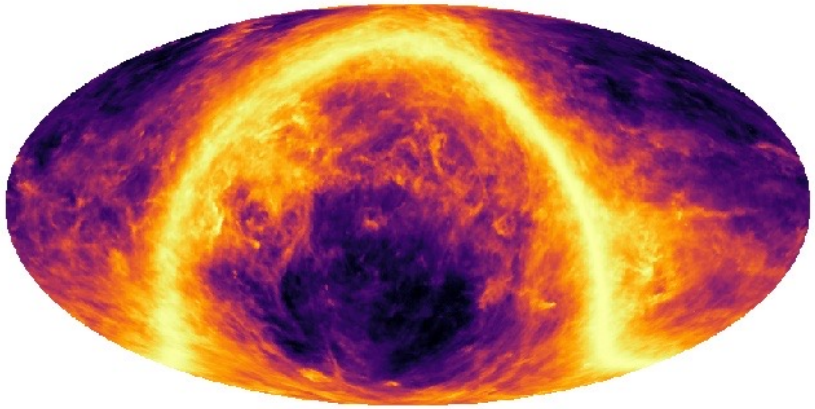
-0.348303 mK 0.383637

POINT SOURCES



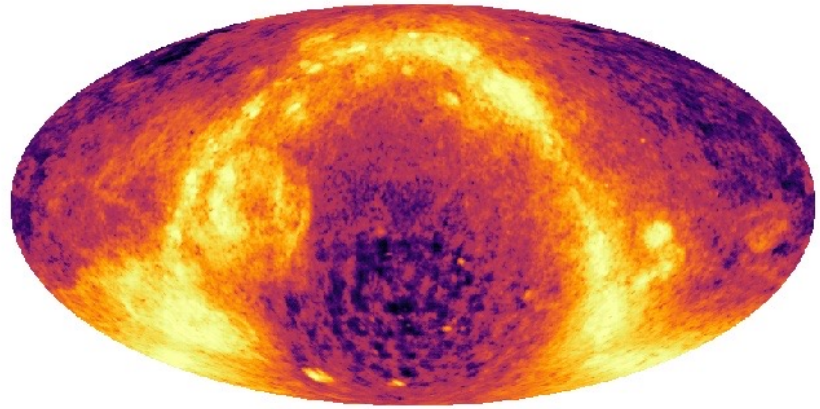
36.3582 mK 1269.76

AME



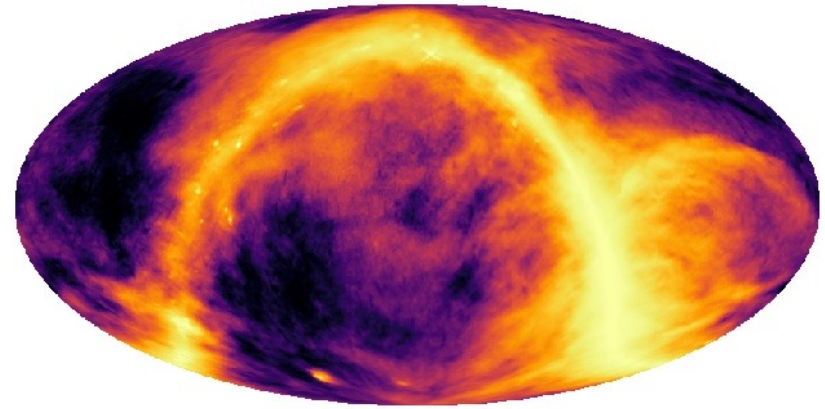
0.000909162 mK 1.75552

FREE-FREE



-0.13996 mK 51424.5

SYNCHROTRON



232.101 mK 164817

Technological challenges

Some of the challenges BINGO will have to deal with:

- Build the 50, ~ 4.8 x 1.8 m, horns to a 0.5 mm precision
- Transport to and build the 2, ~ 40 m dishes in "Sertão da Paraíba"
- Same thing for the horns
- Data stewardship of the 50 horns
- RFI from mobile phones, airplane routes, radio links and microwave ovens are a permanent threat to the quality of BINGO data!!!!
- Continuously monitor the radio environment around BINGO

Additional Science

- Life history of HI
- Fast Radio Bursts
- Pulsar timing
- Recombination lines
- Galactic science

Fast Radio Bursts

- First detected in 2007 (Lorimer et al., Science 2007)
- Duration: ~ millisecs to ~ 10s of millisecs
- Extragalactic origin, unknown causes (magnetar flares, short GRB bursts)

RESEARCH LETTER

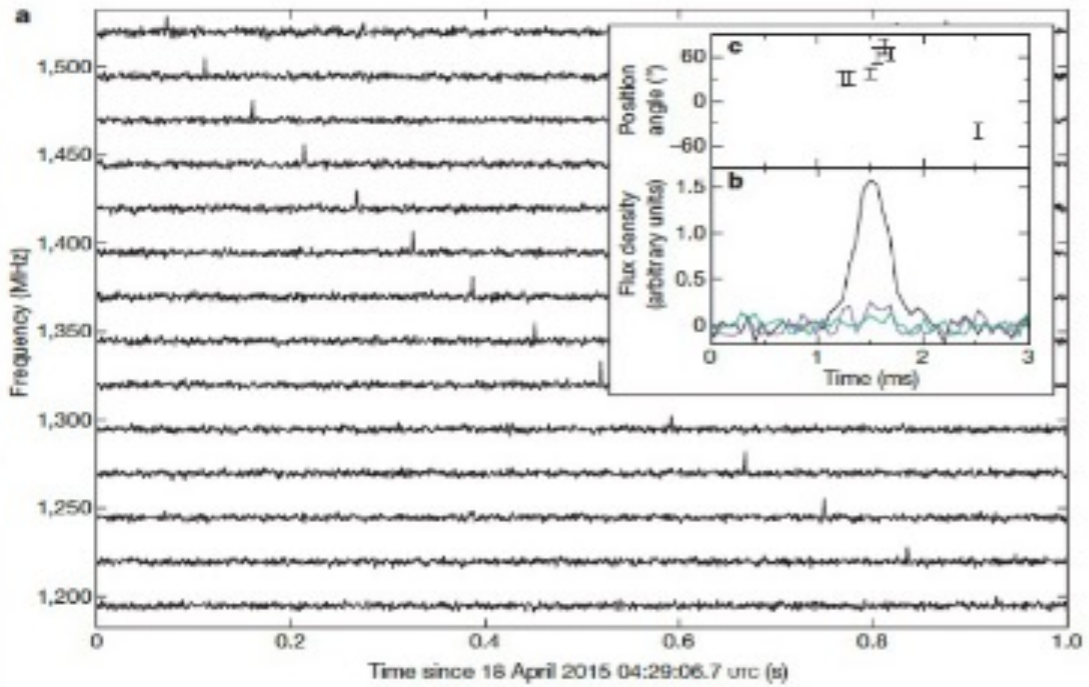
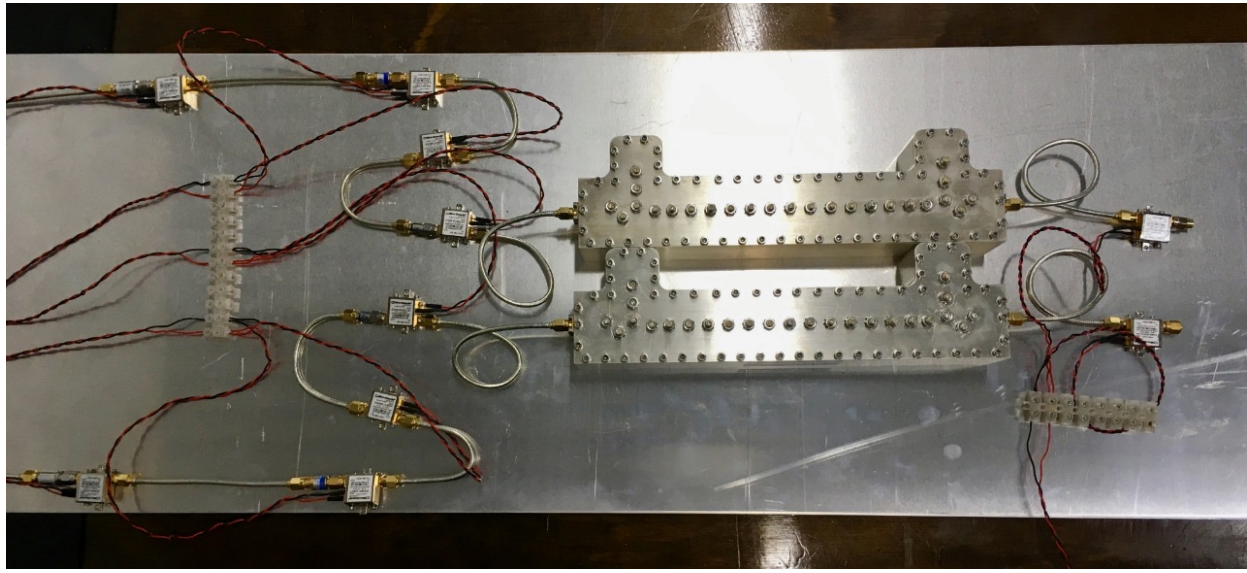


Figure 1 | The FRB 150418 radio signal. **a**, A waterfall plot of the FRB signal with 15 frequency sub-bands across the Parkes observing bandwidth, showing the characteristic quadratic time–frequency sweep. To increase the signal-to-noise ratio, the time resolution is reduced by a factor of 14 from the raw 64-μs value. **b**, The pulse profile of the FRB signal with the total intensity, linear and circular polarization flux densities shown as black, purple and green lines respectively. **c**, The polarization position angle is shown with 1σ error bars, for each 64-μs time sample where the linear polarization was greater than twice the uncertainty in the linear polarization.

THE VARIOUS STAGES

Stage 0

- The Instrument:
- Horns (basically done)
- Receiver (already projected, now in series)

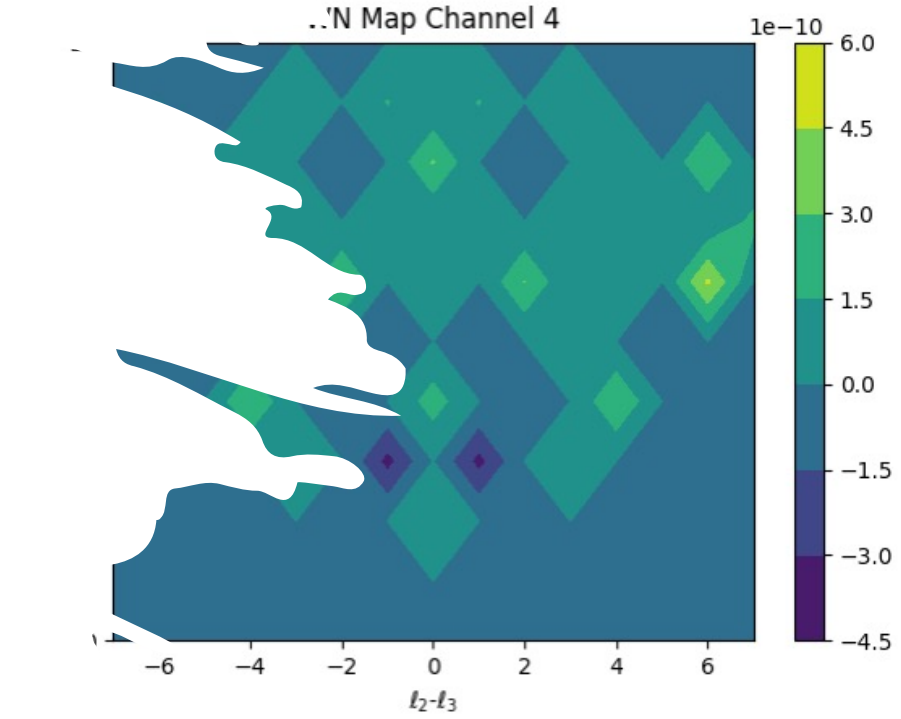


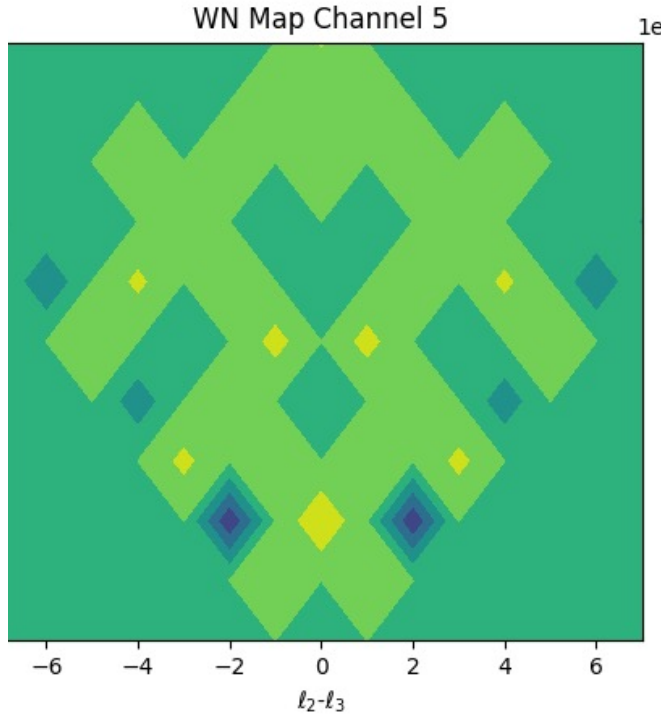
Stage 1

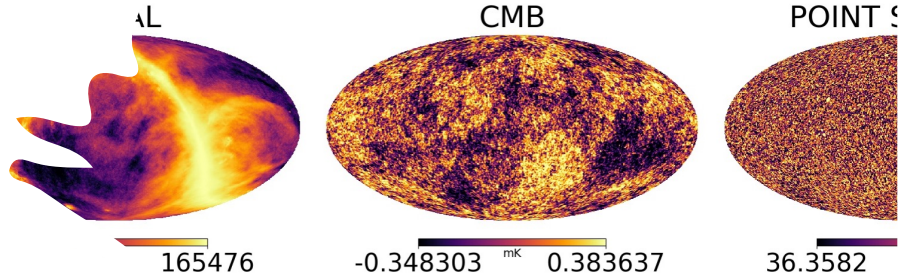
- Raw data
- FRB´s
- Outriggers (Uiapuru in Campina Grande University campus, Paraiba)

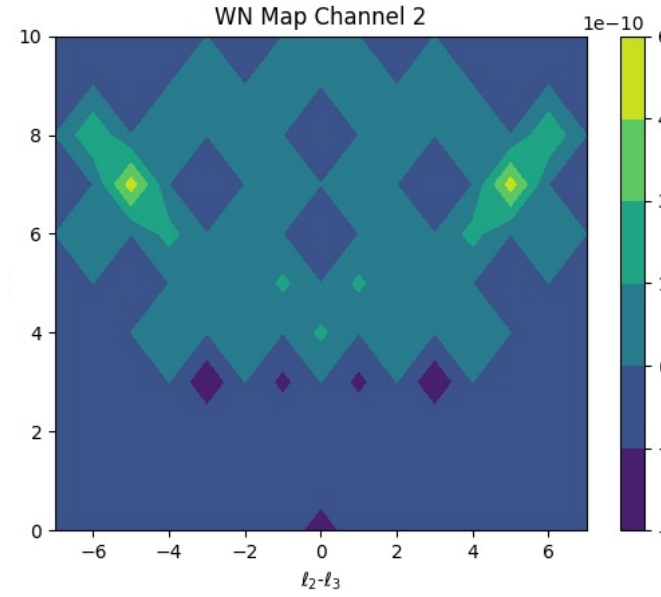
Stage 2

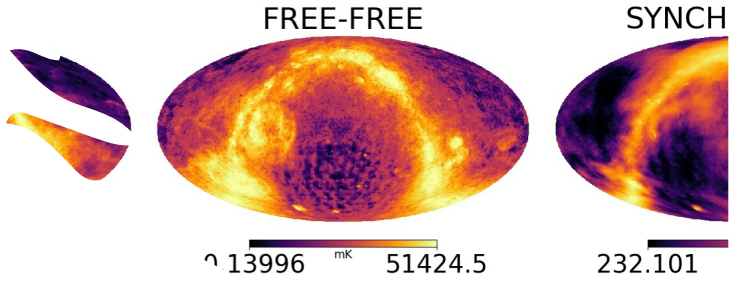
- Component Separation
- Noise analysis
- Bispectrum





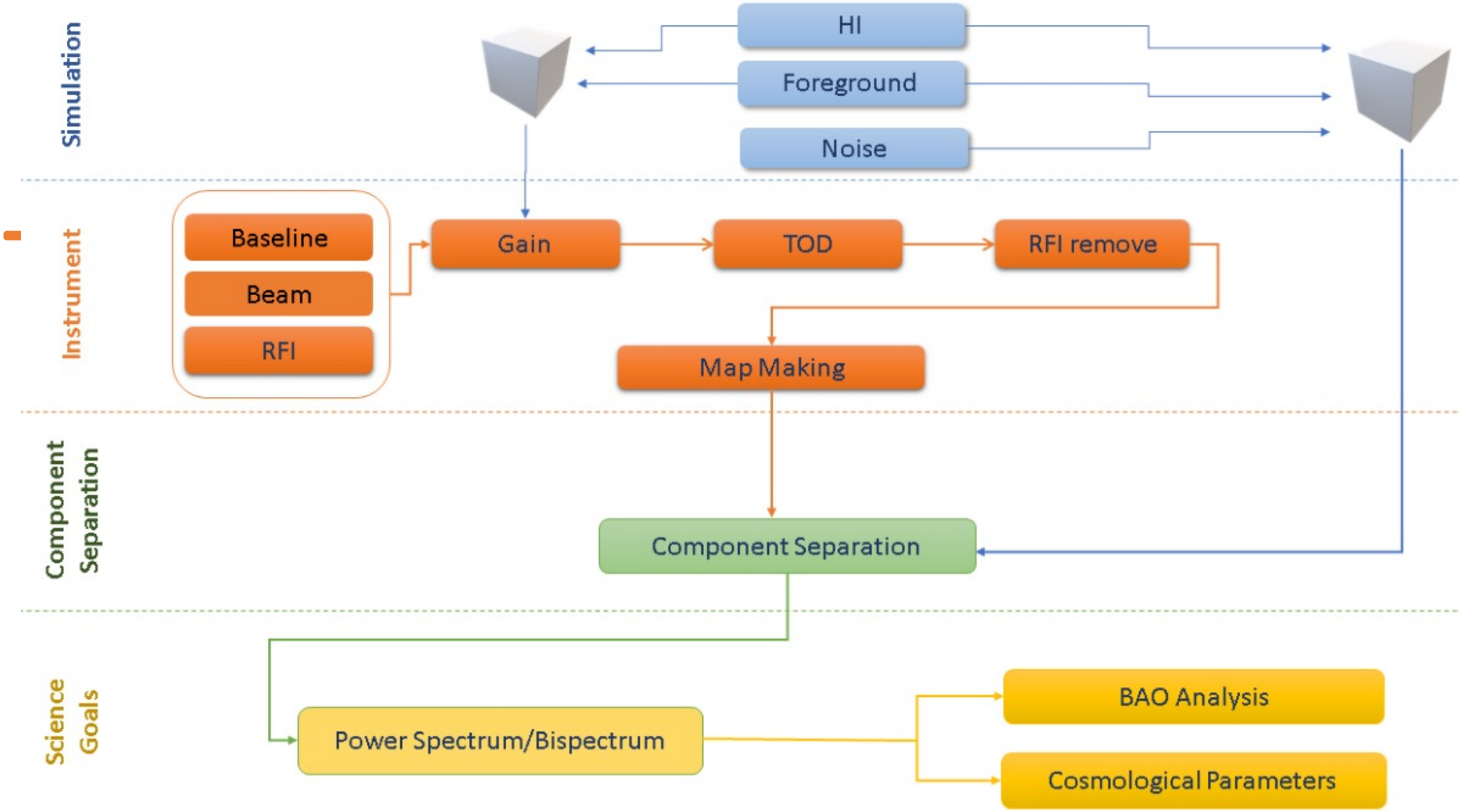






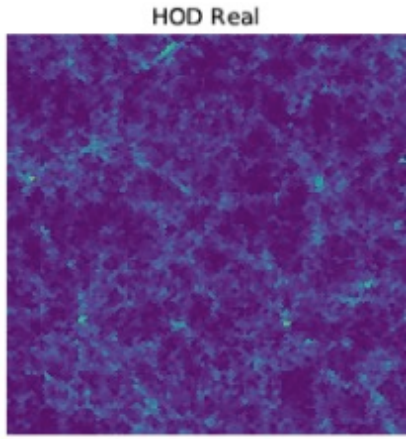
STAGE 2

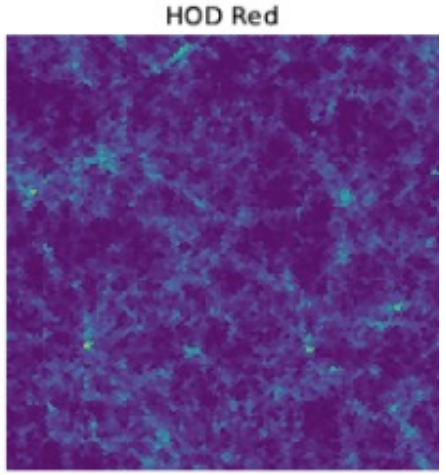
- Component Separation: power spectrum, BAO, Cosmological Parameters

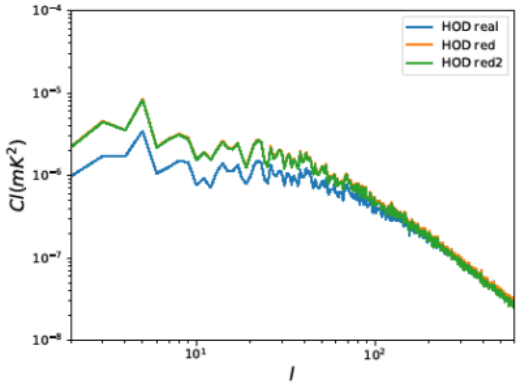


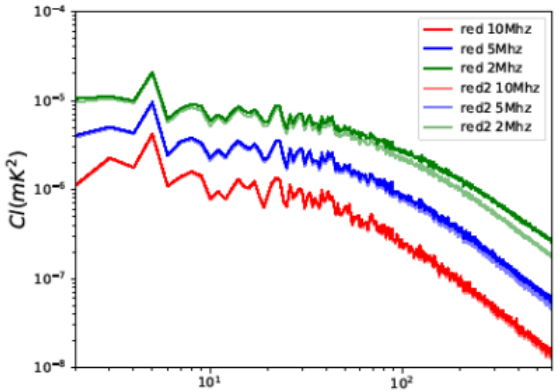
STAGE 3

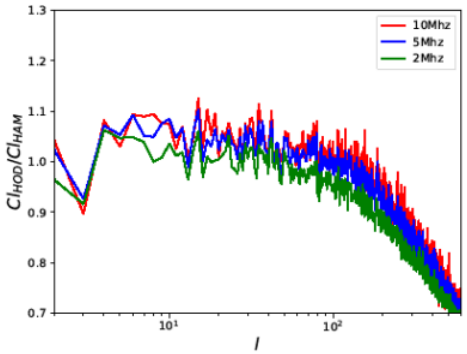
- Mocks

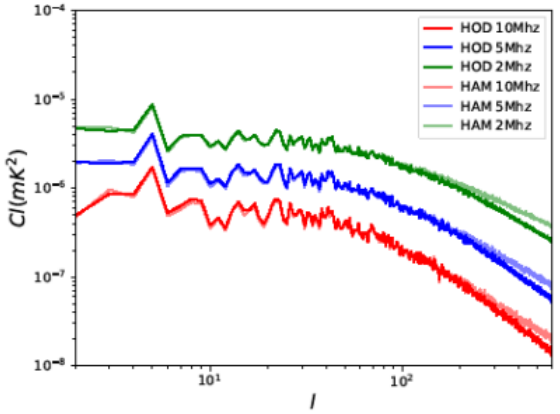






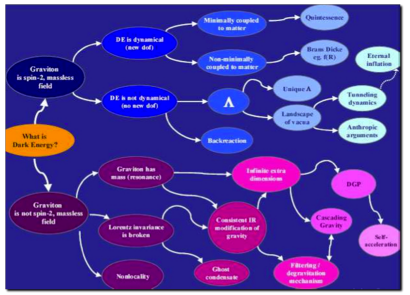






STAGE 4

- Theory



Equações Cosmológicas

- *Seja ρ(t) a densidade média de matéria do Universo, e p(t) a pressão correspondente.*

Equações de Einstein:

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi G T_{\mu\nu}$$

onde

$$T_{\mu\nu} = \begin{bmatrix} \rho & 0 & 0 & 0 \\ 0 & -p & 0 & 0 \\ 0 & 0 & -p & 0 \\ 0 & 0 & 0 & -p \end{bmatrix}$$

Candidates

- Neutralinos (higgsino, bins, winos, singlinos)
- Axinos
- Gravitinos
- Sneutrinos
- Axions
- Sterile neutrinos
- 4th generation neutrinos
- Kaluza-Klein photons
- Kaluza-Klein gravitons
- Brane world dark matter/D-matter
- Little higgs dark matter
- Light scalars
- Superheavy states (ie. "WIMPzillas")
- Self-interacting dark matter
- Super-WIMPs
- Asymmetric dark matter
- Q-balls (and other topological states)
- CHAMPs (charged massive particles)
- Cryptons, ...

THEORY

- Structure of Dark Sector
- cosmological parameters
- DE/DM interactions
- Models of DM/DE
- FRB´s and cosmological parameters/consequences
- Mass distribution
- Pulsars
- Flaring stars
- Astrophysical signs and consequences
- .....

CONSTRUCTION

- Ongoing construction operations

OUTREACH AND EDUCATION

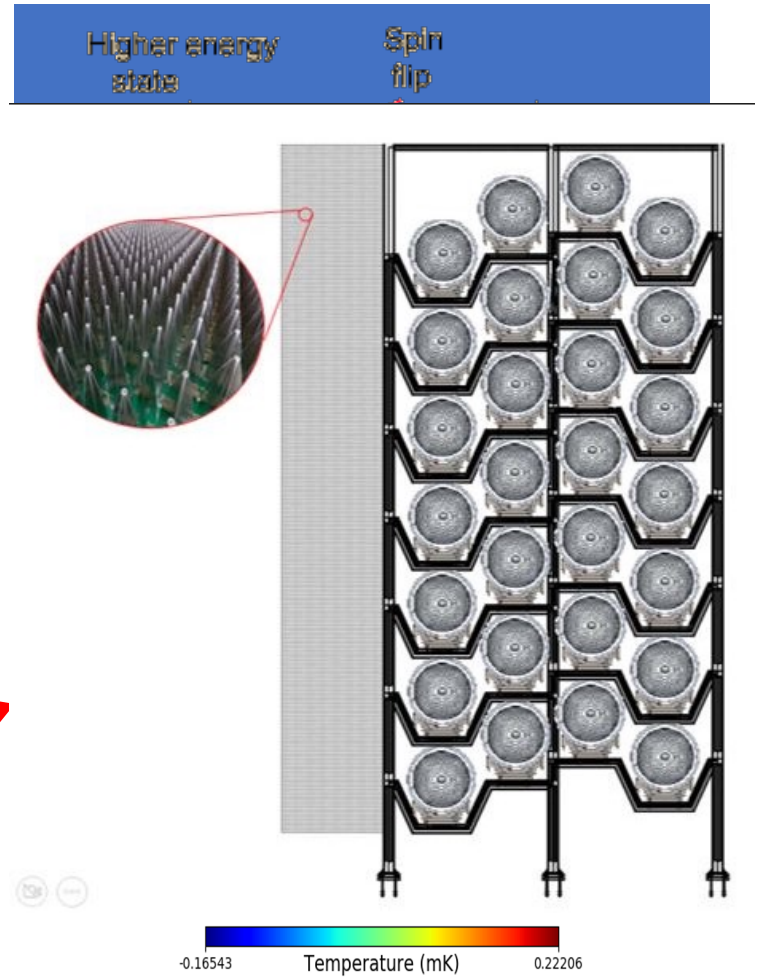
OUTREACH AND EDUCATION

- Work with local population and support from local Secretary of education from the Paraiba State

BINGO HIGH RESOLUTION
THE ABDUS PROJECT

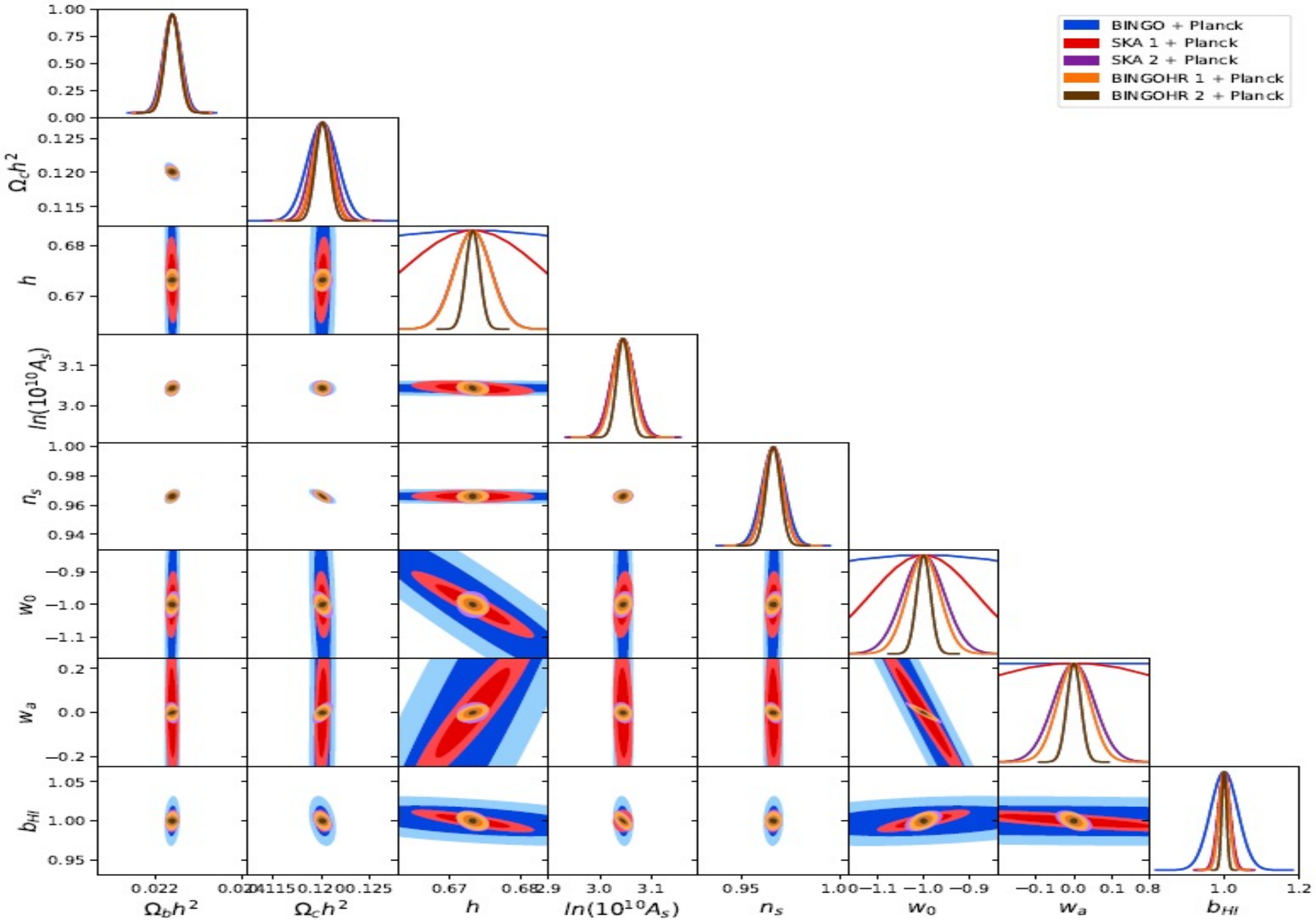
Filipe Abdalla, Amilcar Queiroz, Elcio Abdalla, Bin Wang

- 450 – 1450 MHz
- (z ~ 0 – 2.1)
- 1 MHz resolution
- 1.2 deg Resolution
- T system 40K
- Station 4500 m²



BINGO

ABDUS FORECASTS



Searching for FRBs with BINGO.

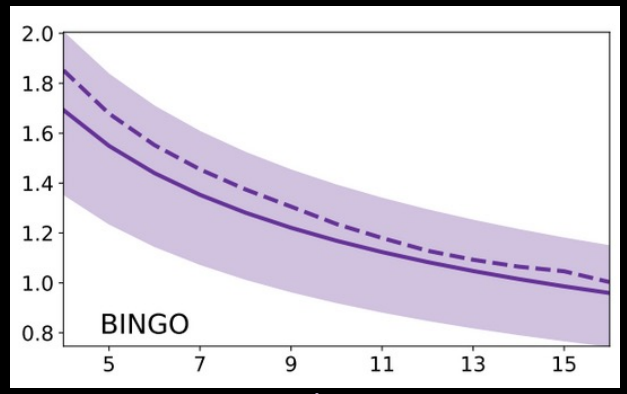
- The FRB will have an intrinsic flux, which is modelled by our mock catalogue given observed data (Luo et al 2020.)

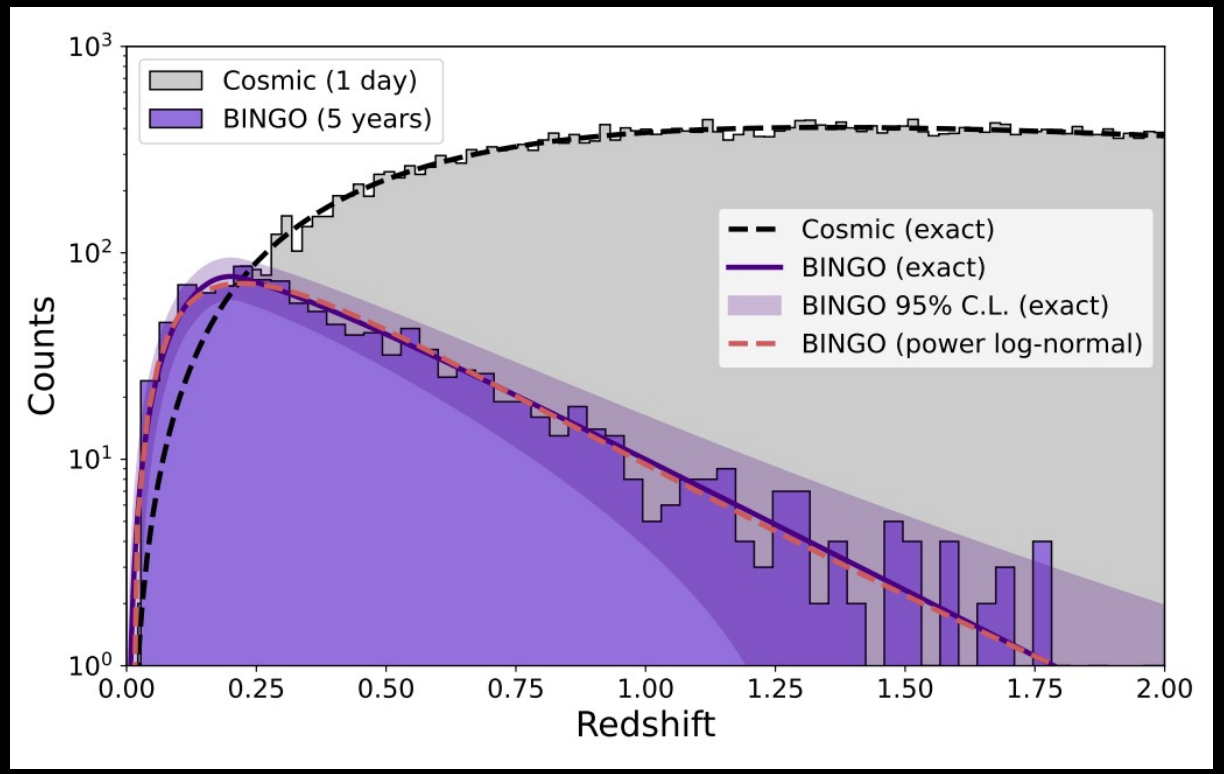
$$S_{\rm peak} = \frac{L_{\rm bol}}{4\pi d_L^2(z)} \frac{(1+z)^{\alpha+1}}{\tilde{\nu}_{\rm high}^{\alpha+1} - \tilde{\nu}_{\rm low}^{\alpha+1}} \frac{\nu_2^{\alpha+1} - \nu_1^{\alpha+1}}{\nu_2 - \nu_1}$$

- The noise is obtained given telescope and outrigger characteristics.

- A mock catalogue is created for the entire sky.

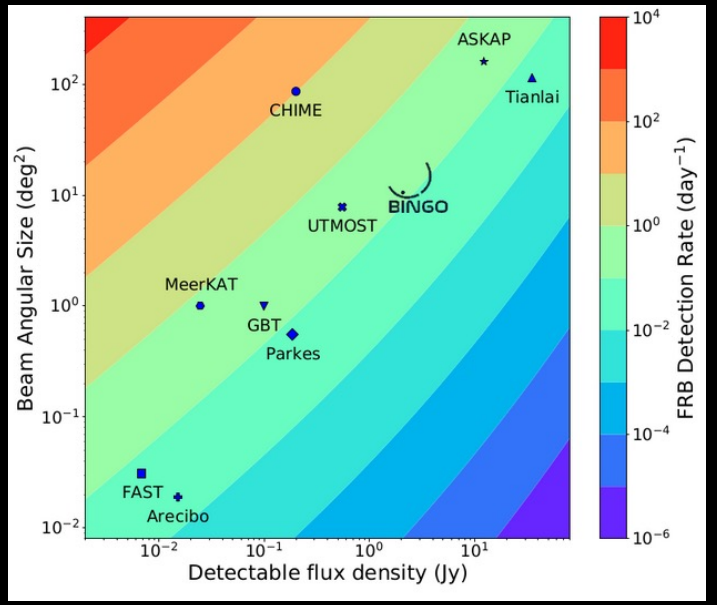
Effective maximum redshift

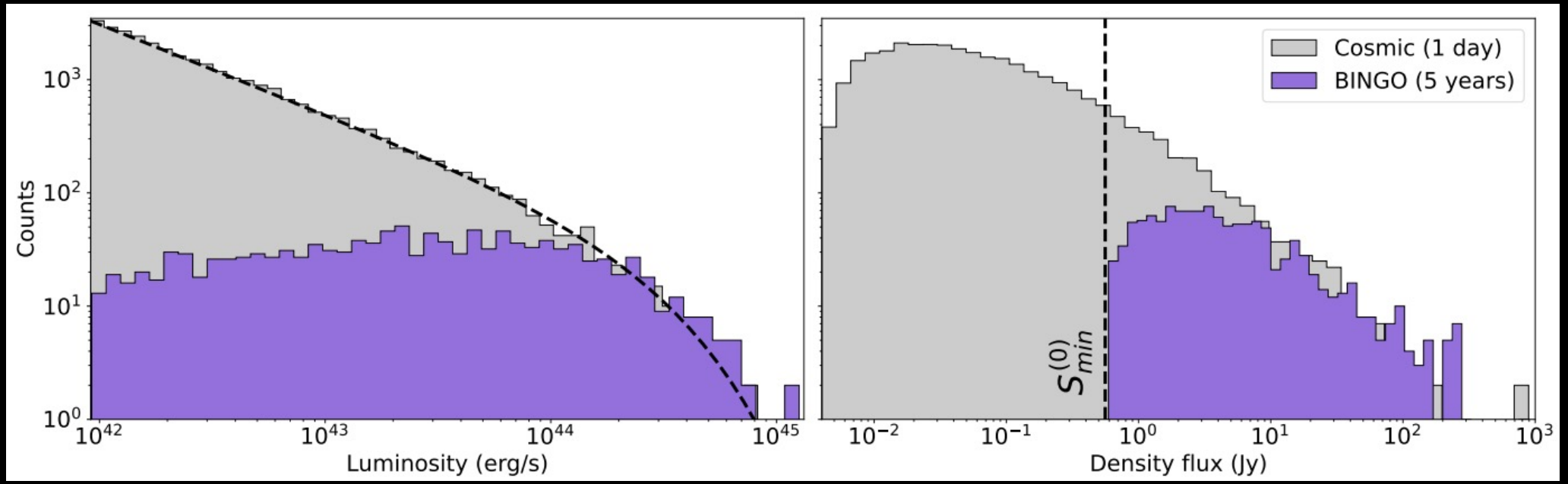




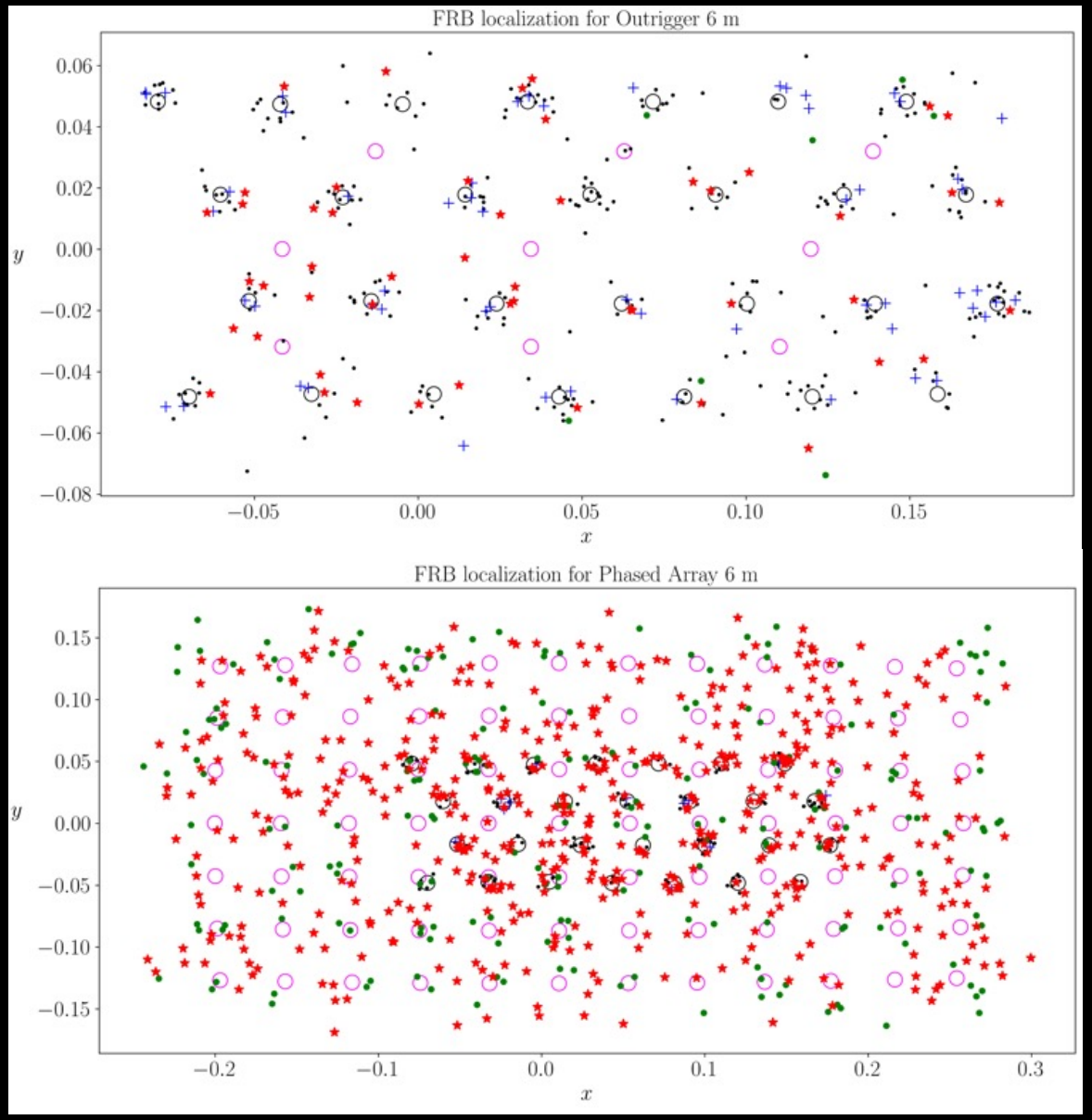
Search for FRBs with BINGO main

Several FRBs will be found, competitive with CHIMES, but no localization is possible with the main telescope only.





Using outriggers to locate the FRBs



BINGO horn
Array beams
Candidates = 369
Detected = 113
Localized in 1 baseline = 57
Localized in 2 baselines = 50

BINGO horn
Array beams
Candidates = 878
Detected = 733
Localized in 1 baseline = 720
Localized in 2 baselines = 517

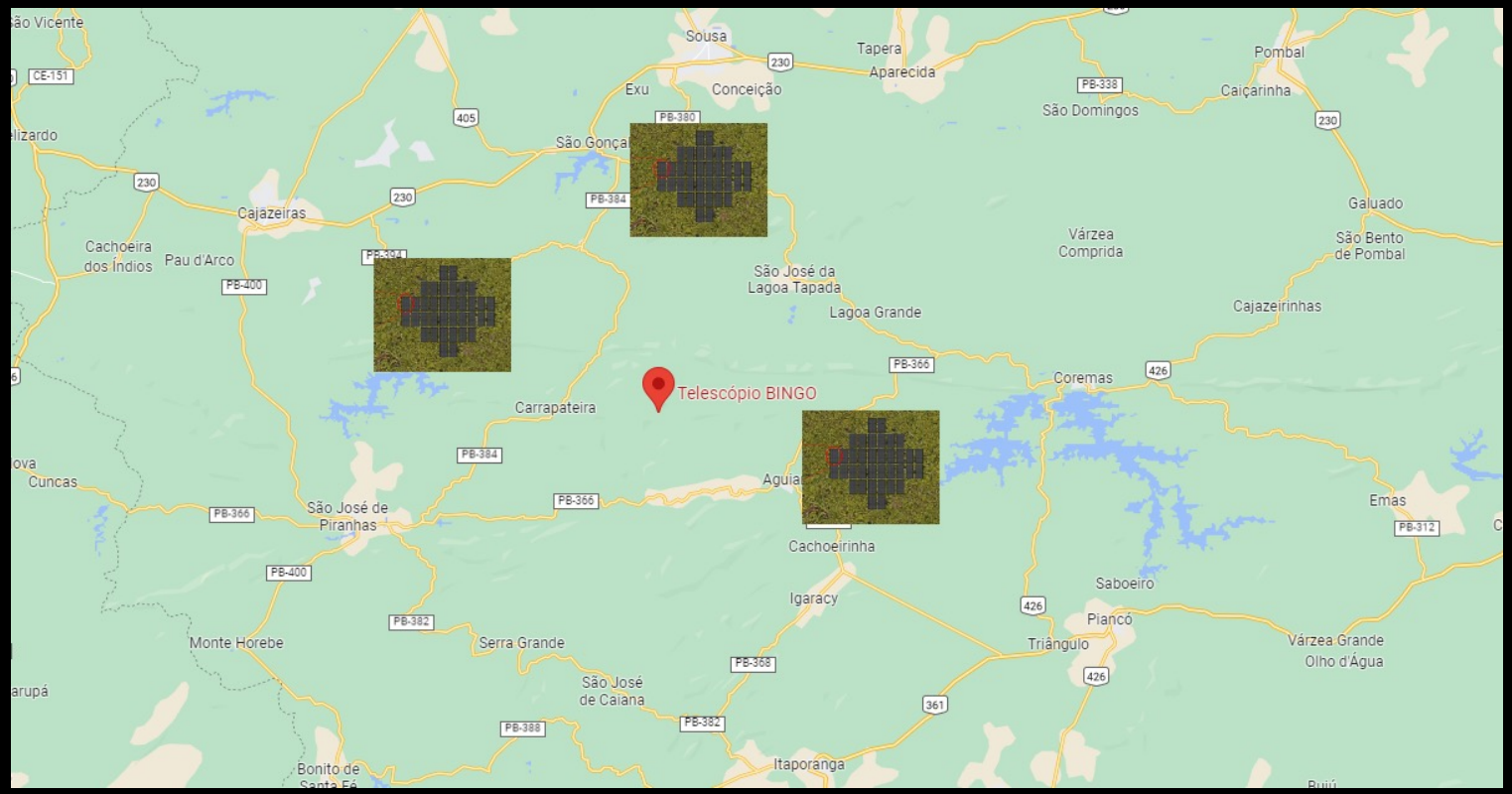
Cross Correlations

- Several stations, signal to noise given by:

$$S^{(0)}_{\min,\ i\times j} = \sqrt{\frac{S^{(0)}_{\min,i} S^{(0)}_{\min,j}}{2}}$$

$$\frac{1}{S^2_{\min}(\mathbf{n})} = \sum_{i}^{N} \frac{1}{S^2_{\min,i}(\mathbf{n})} + \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \frac{1}{S^2_{\min,\ i\times j}(\mathbf{n})}$$

- We aim to have three stations at different locations, to be able to cross correlate them.

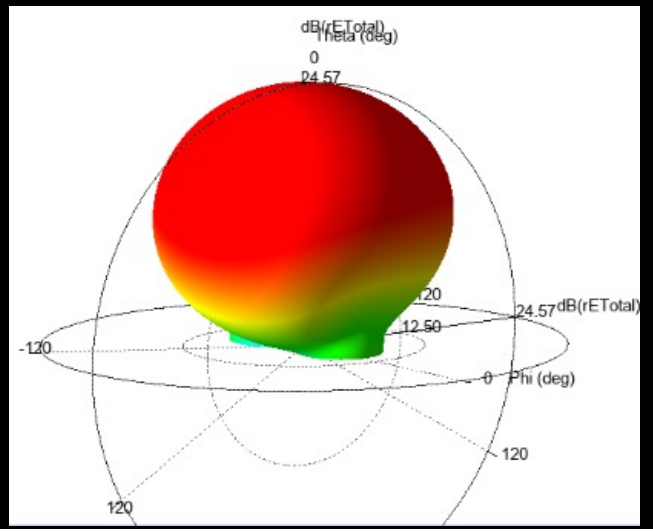


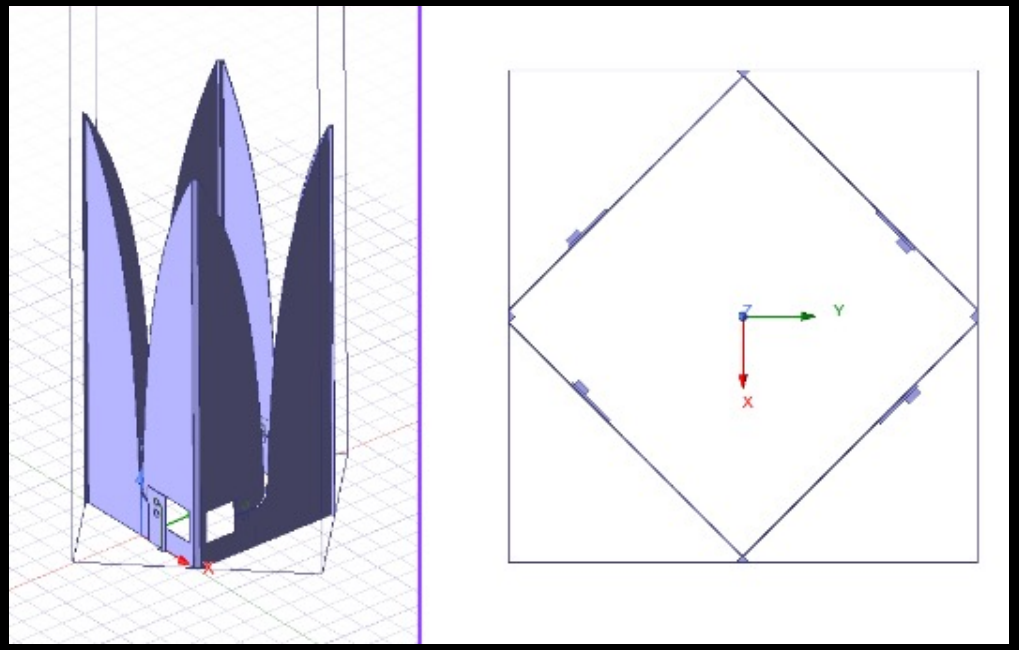
ABDUS and phased array antennas

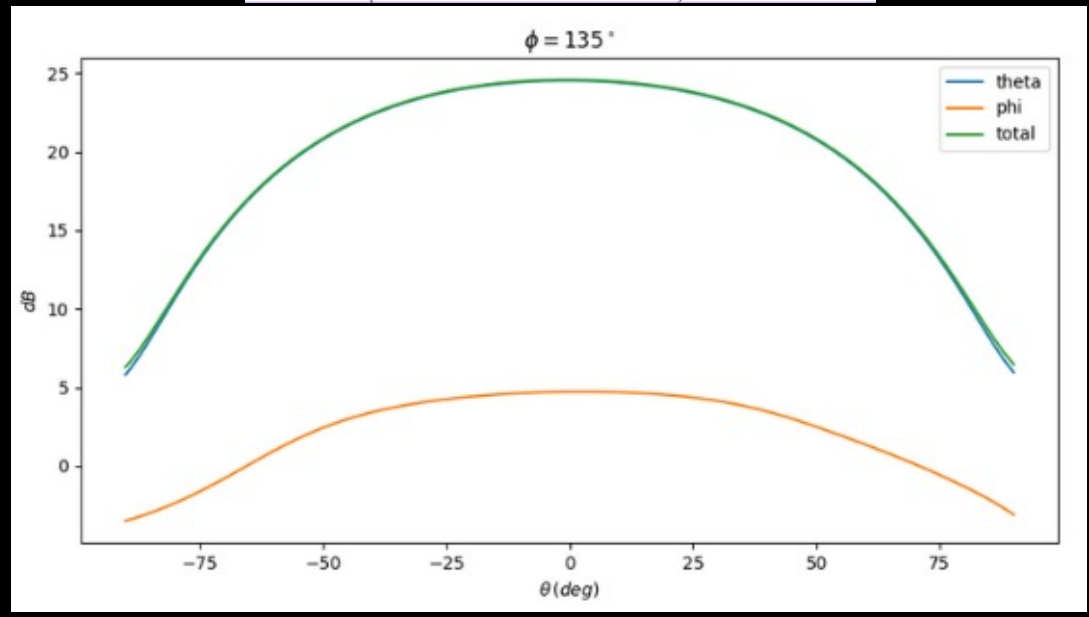
- Phased arrays consist of closely distributed antenna elements, allowing synthesis of multiple independent beams.
- ABDUS proposes the use of phased arrays to boost BINGO's capabilities.
- ABDUS-1 involves associating phased arrays with the BINGO focal plane using Vivaldi antennas and beamformers.
- ABDUS-2 includes outriggers composed of feed horns and phased-array stations 20 km away to achieve higher angular resolution.

Unit Cell simulation

- One unit cell is assumed with four antenna elements, two for each polarization.
- We excite two elements of same polarization and run EM simulations on HFSS sofware.



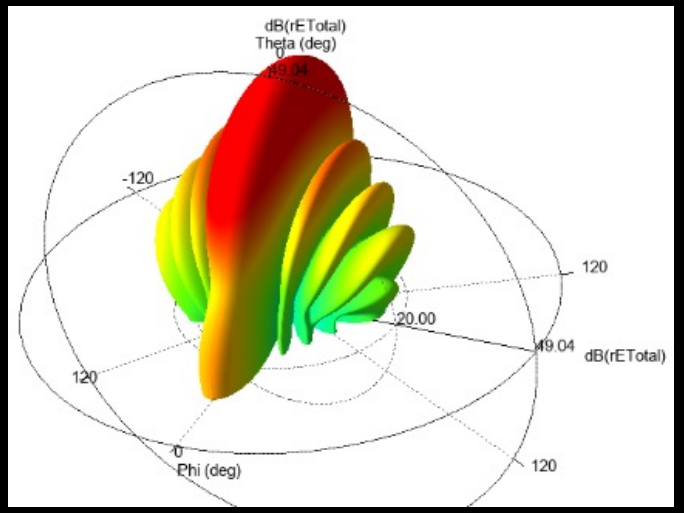


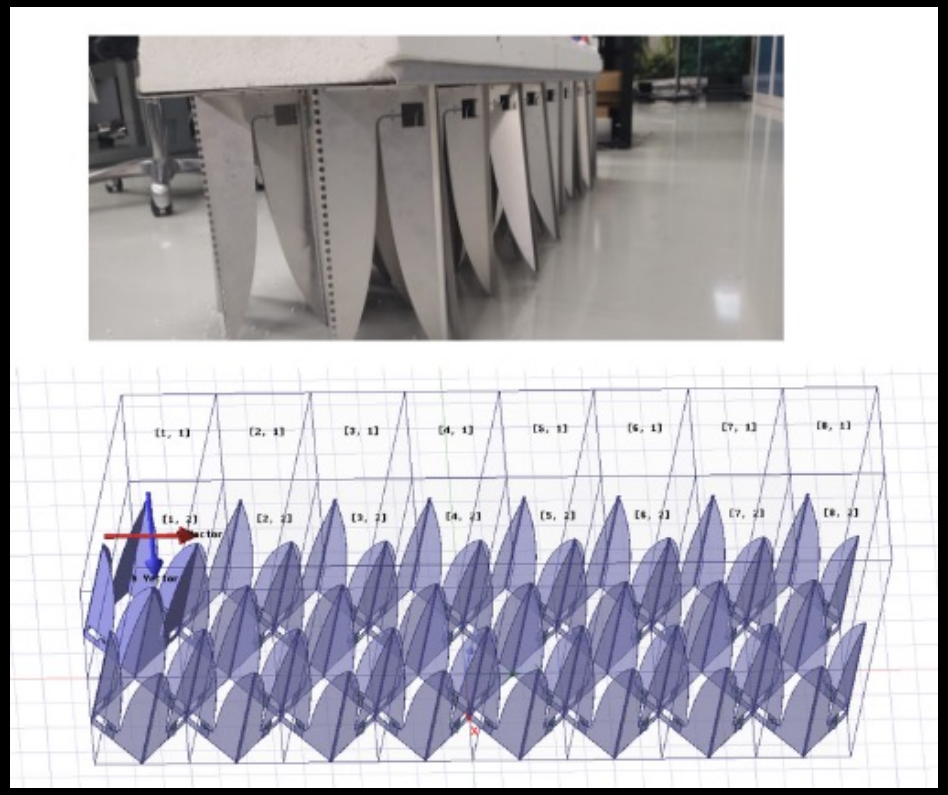


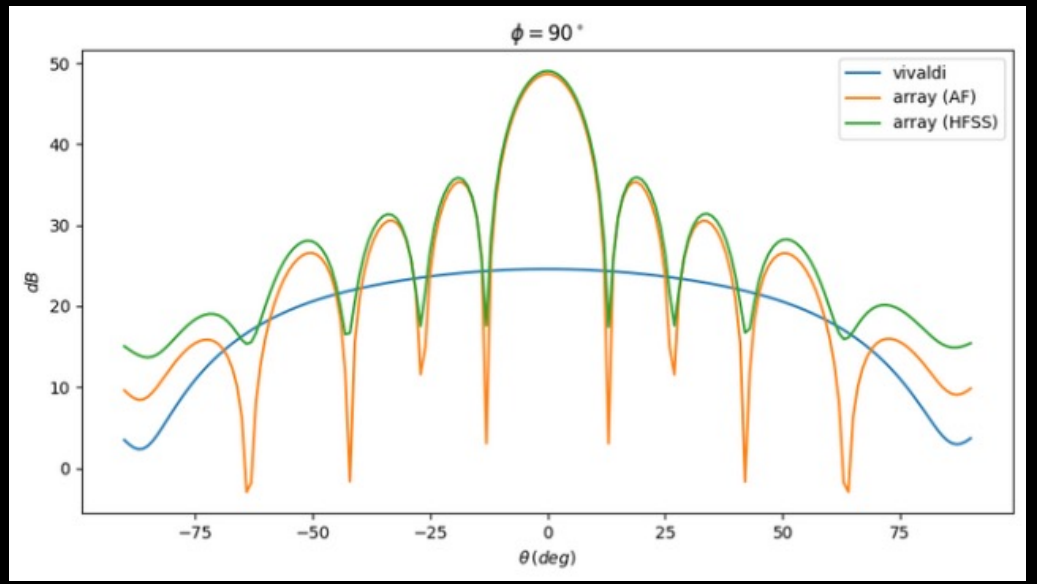
Vivaldi Tile simulation

- We simulated a 2x8 array. It correspond to a 35cm x 134 cm tile that will be used on ABDUS project.

- The tile is also under tests on ASTRON facilities and will be sent to Brazil after some measurements be finished.

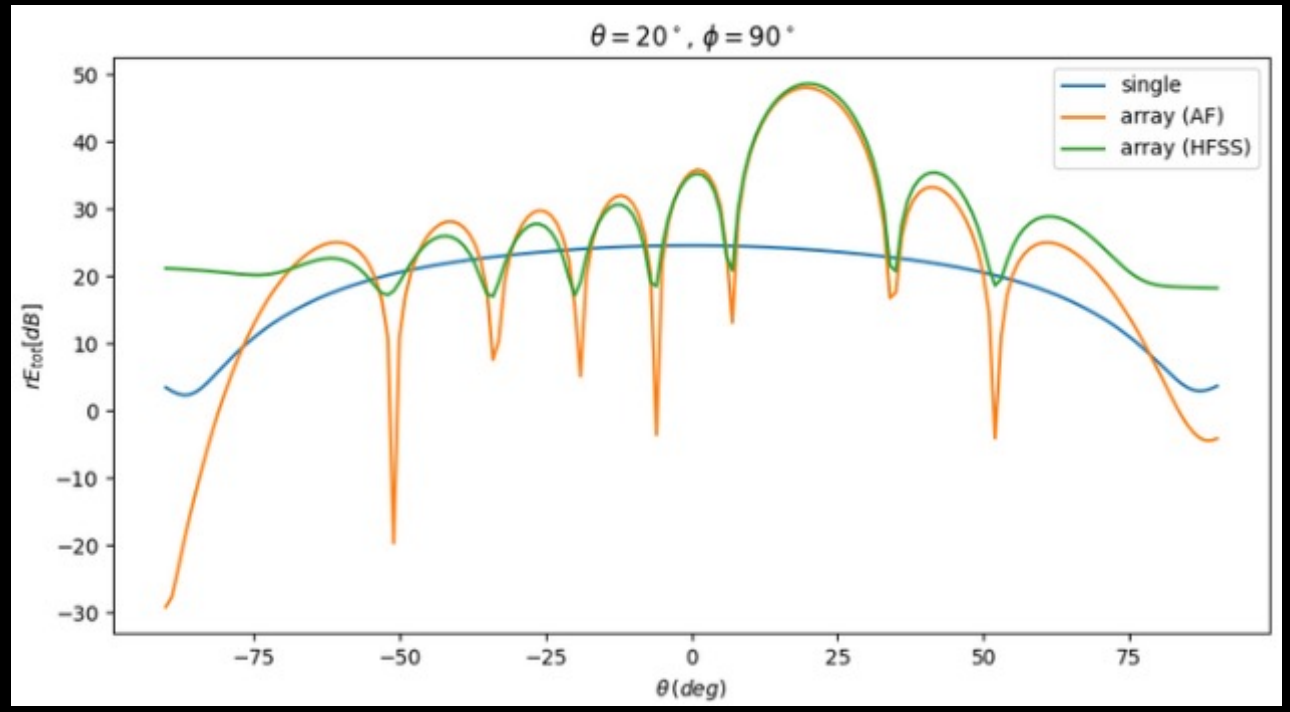


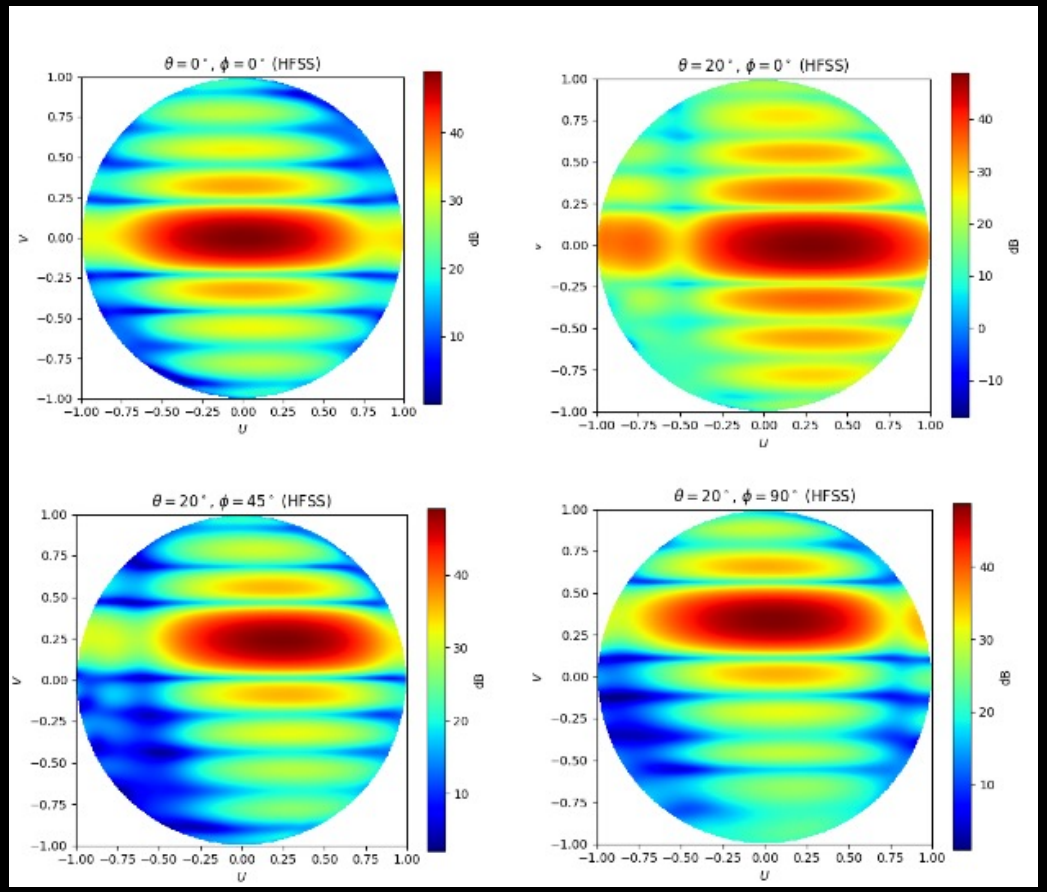




Vivaldi Tile simulation: scanning

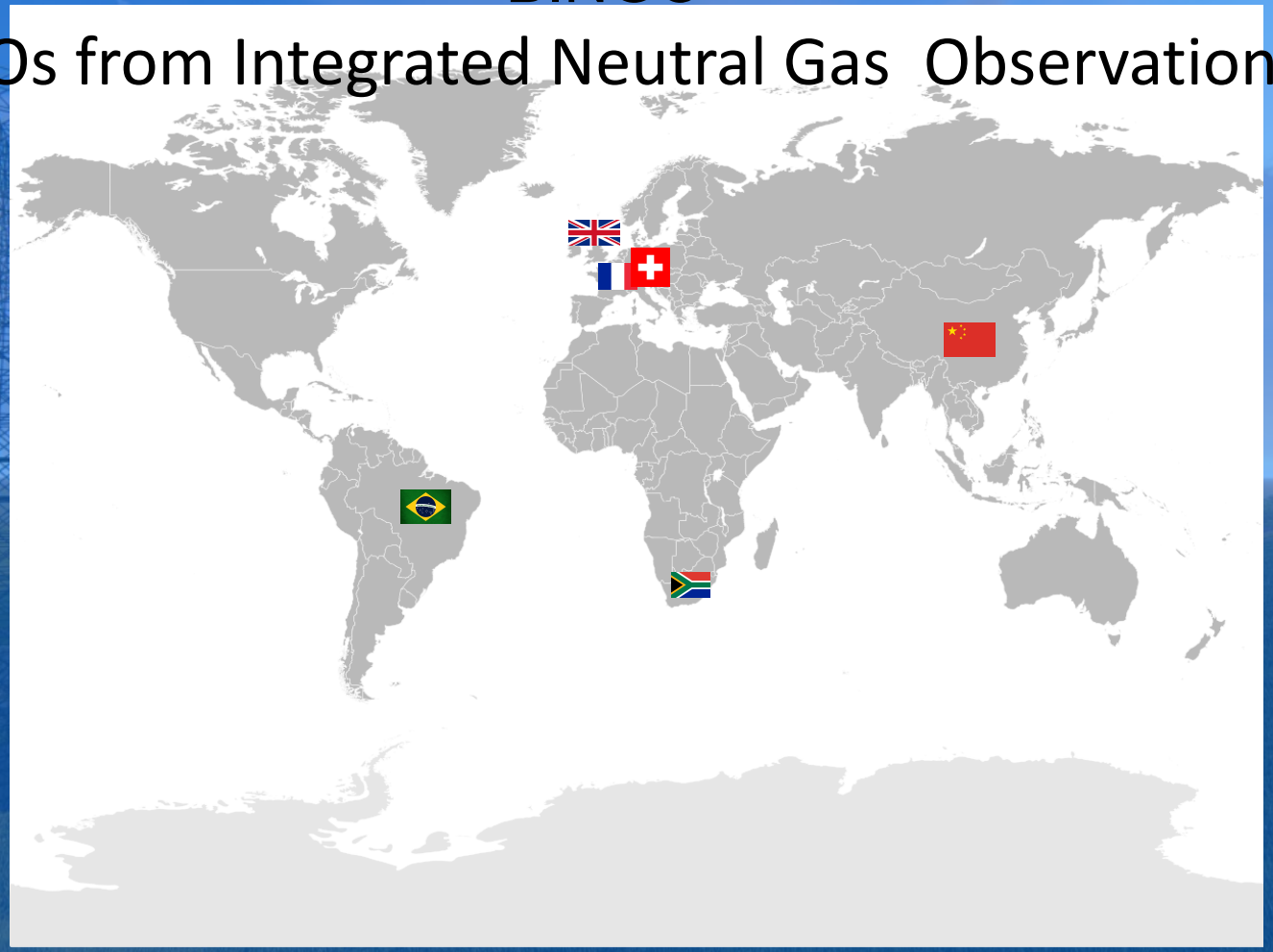
- The array can be be electronically steered to point in different directions without moving the antennas.
- We then present simulations steering in some different directions.

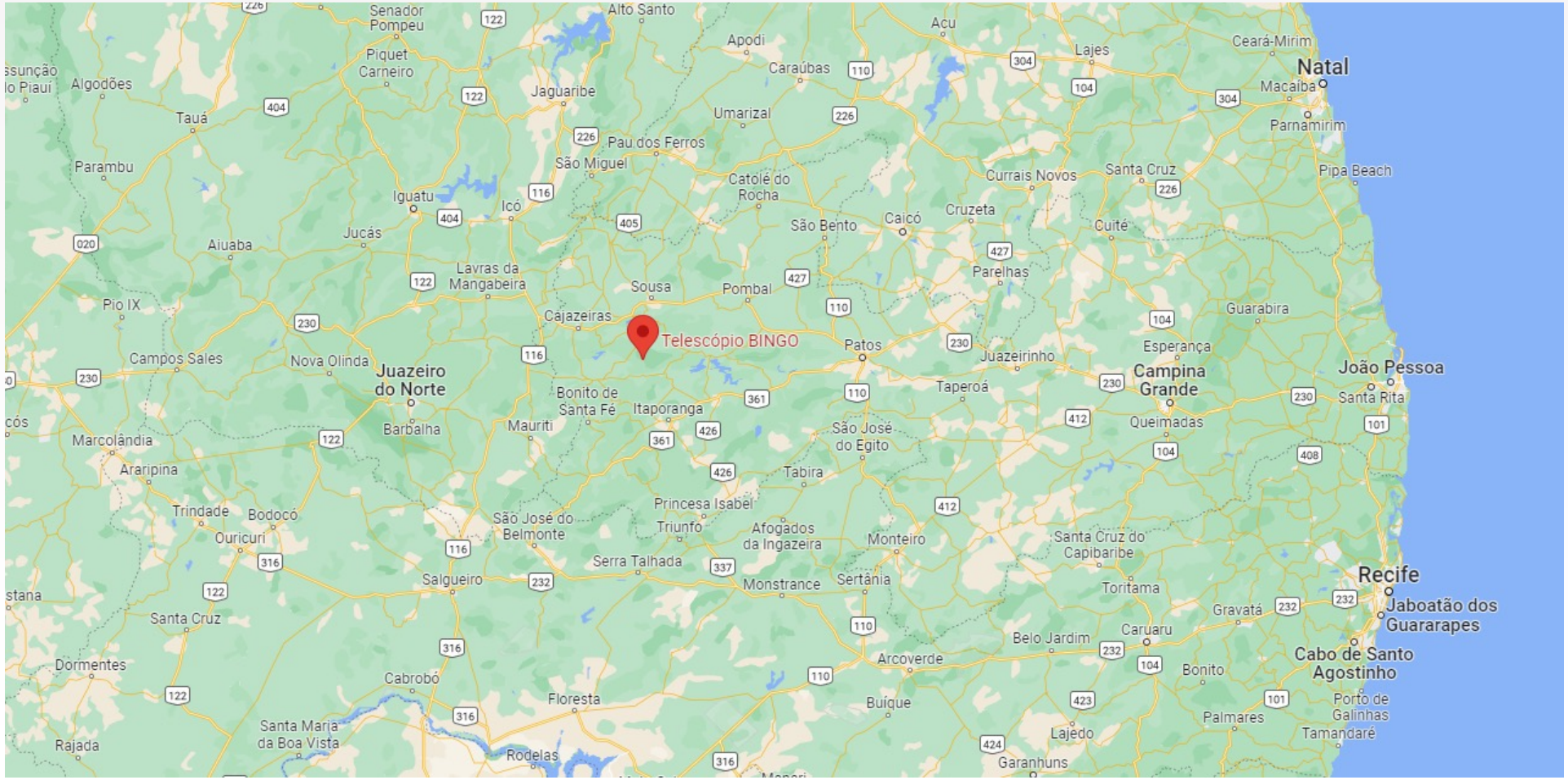




BINGO

BAOs from Integrated Neutral Gas Observations





Serra do Urubú (PB) – 07 deg 02'57.1"S, 38 deg15'46"W


ATLANTIC OCEAN
PACIFIC OCEAN
BRASIL
50 0 50 100 150 200 km
João Pessoa
Aguiar
Campina Grande
windmill
sites-visited-select
Highways
BINGO

BINGO TELESCOPE

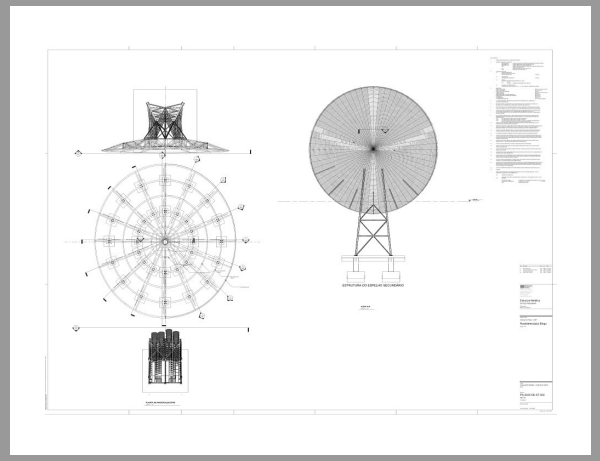
BINGO Collaboration

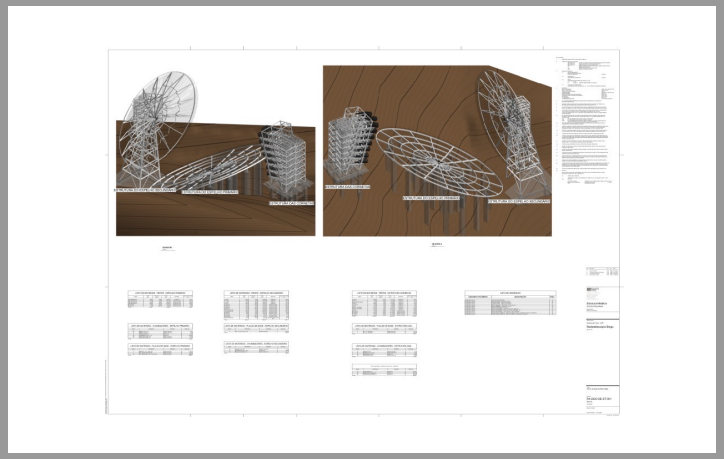
SUPPORT

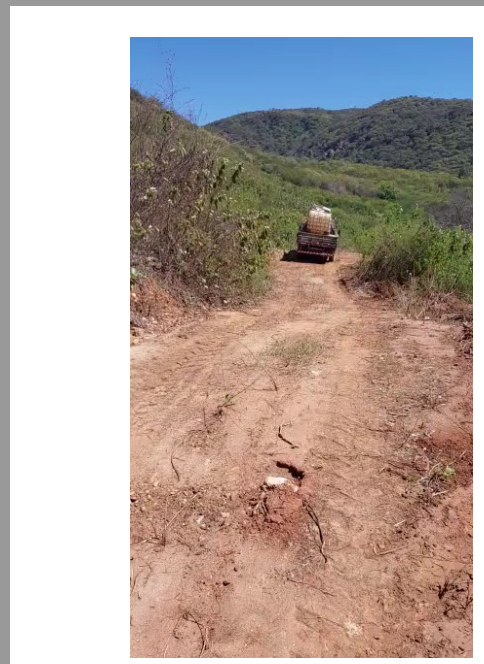
- FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo)
- Paraiba Government (João Azevedo, Claudio Furtado, Rubens Freire) *
- FINEP (Projects and Studies financing – Federal Government)
- Ministry of Science and Tecnology (Brazil)
- Federal University of Campina Grande
- University of São Paulo
- National Natural Science Foundation of China
- YangZhou University (China)
- INPE (National Institute of Space Research, Brazil)

MAIN COLLABORATING COMPANIES

- Alltec (São Paulo): metallurgy/horns
- CETC 54 (China): metal structure
- IBRTEL (Paraiba): construction
- Ponto de Apoio and GTP (projects)







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- Alltec (São Paulo): metallurgy/horns
- CETC 54 (China): metal structure
- IBRTEL (Paraiba): construction
- Ponto de Apoio and GTP (projects)

Inauguration and begining of commissioning

- Between September and November 2024

- Thanks for the attention

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