UNIVERSITY OF SÃO PAULO

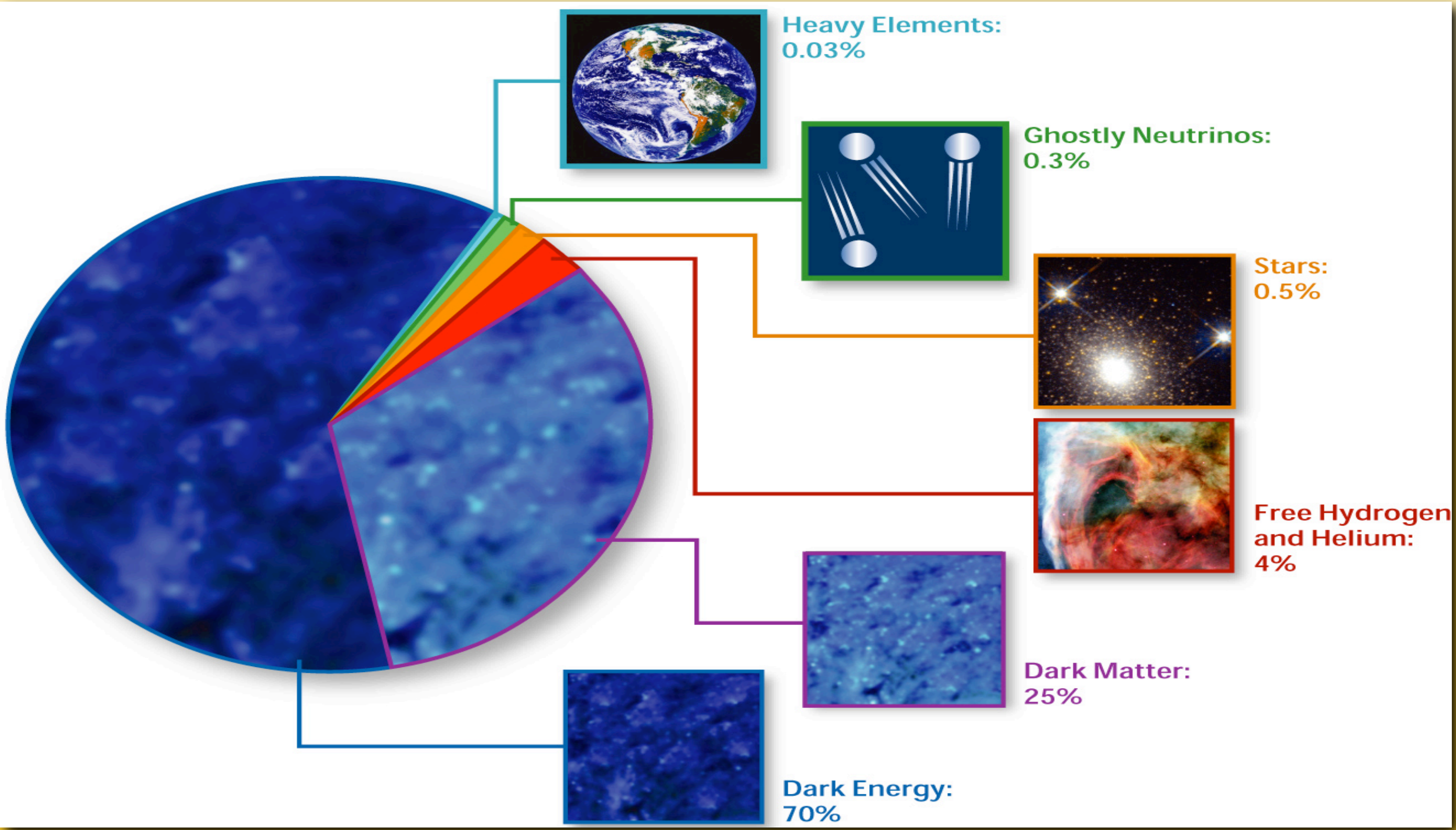
Whispers of the Universe: theoretical and observational developments in the BINGO project.

I present the theoretical developments expected in the construction of the BINGO (BAO In Neutral Gas Observations) observatory, which is being supported by a consortium led by Brazil including China, UK, South Africa, France and Switzerland.

Elcio Abdalla

2019

Standard Cosmological Model
Composition of the Universe



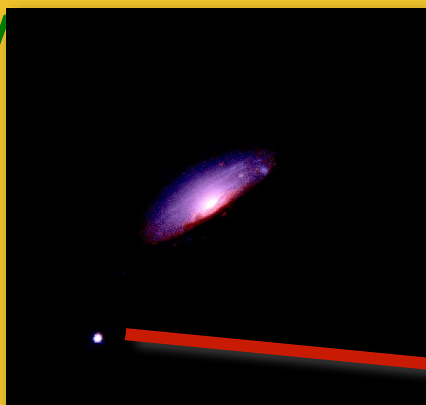
http://en.wikipedia.org/wiki/Image:Cosmological_composition.jpg source and rights]

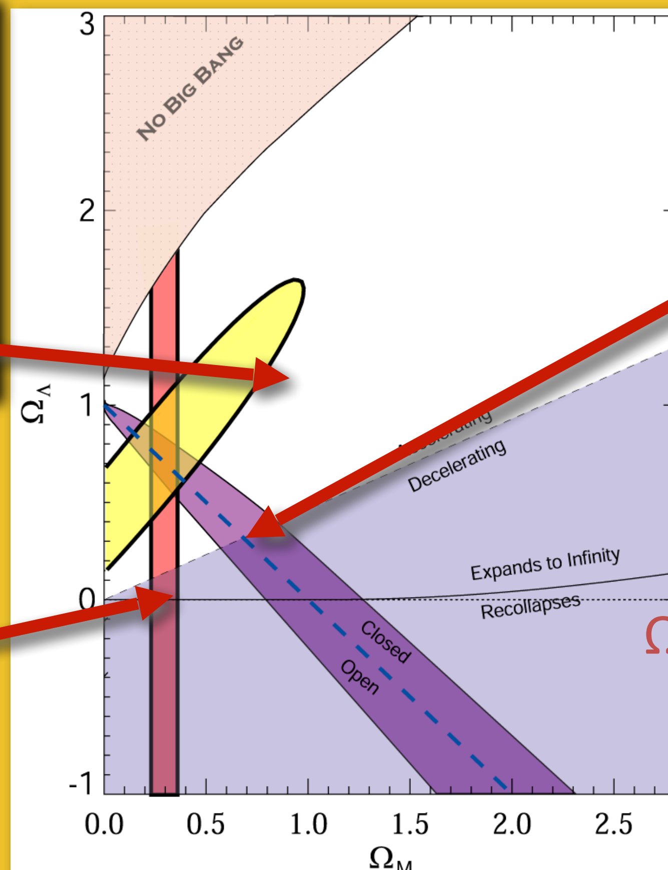
What is Dark Energy?

The Evidence:

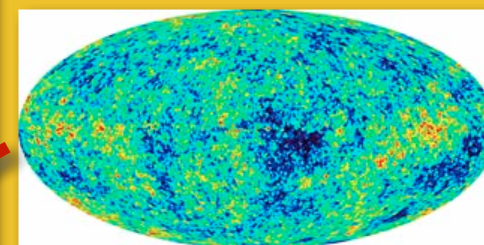
98's: The universe is expanding in an accelerated way

SNe Ia





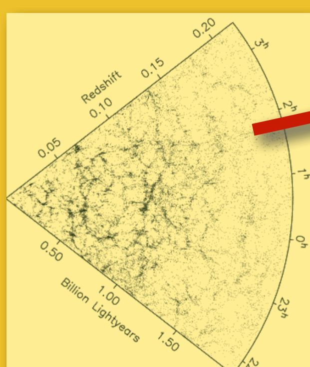
CMB



Ω_{DE}=0.721±0.025 (WMAP)

WMAP

LSS



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

Ω_{DE}=0.685±0.013 (Planck)

What is causing the acceleration?

From the Friedmann equations:

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

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

Source: de Rahm & Tolley, 2008

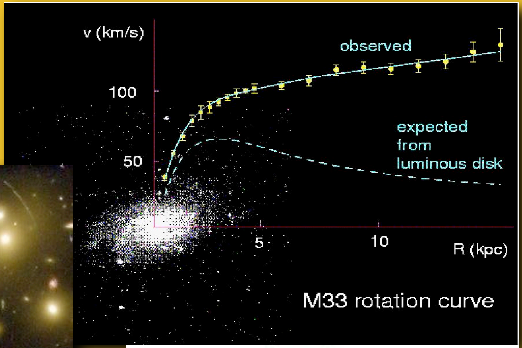
What is Dark Matter?

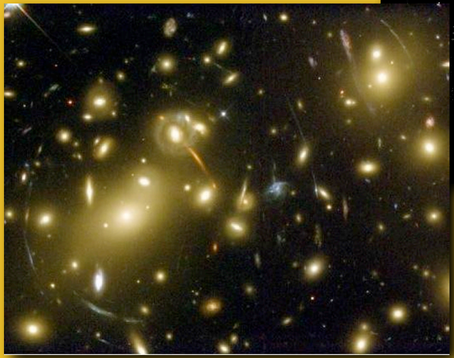
Evidences for Dark Matter

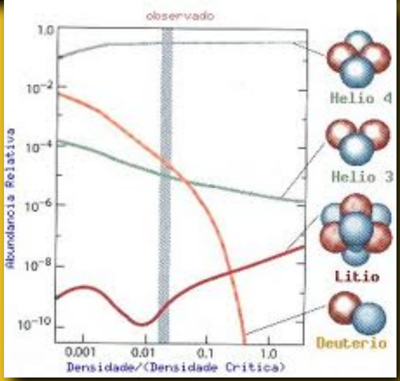
- Huge amount of evidences indicating that dark matter exists. One of the biggest unsolved, but very well measured, problems in physics.

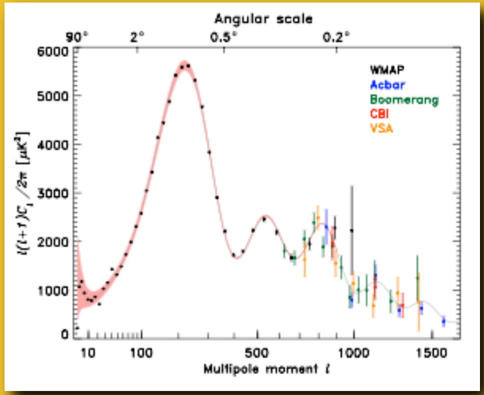
- Observations indicate that DM interacts mainly gravitationally.

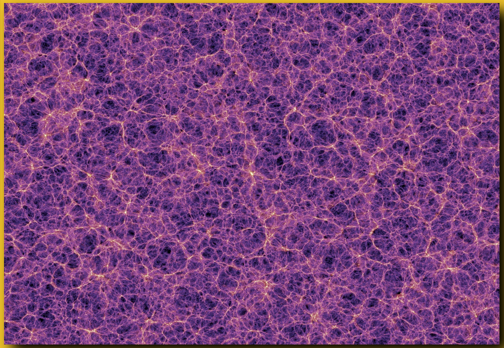
- So far, we have no (non-contradictory) observations that DM was detected by any non-gravitational mechanism.











Candidates

- Neutralinos (higgsino, 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, …

Supersymetric

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, Attrio 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:

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

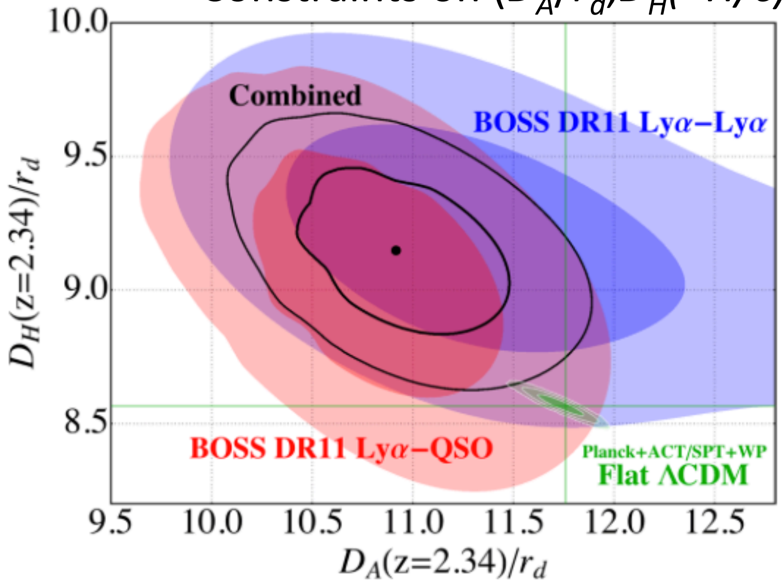
$$D_A(z=2.34) = (1662 \pm 96\,\mathrm{Mpc}) \times \frac{r_d}{147.4\,\mathrm{Mpc}},$$

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

- Values differ: 1.8σ from Planck+WP;

  1.6σ from WMAP9+ACT+SPT

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



Conclusion: Approximately 2σ below the value of D_H

And 2σ above the value of D_A

compared to the ΛCDM prediction.

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

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

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

~2.5σ difference from the expected from ΛDCM!

Parameters from Planck+WMAP for ΛDCM

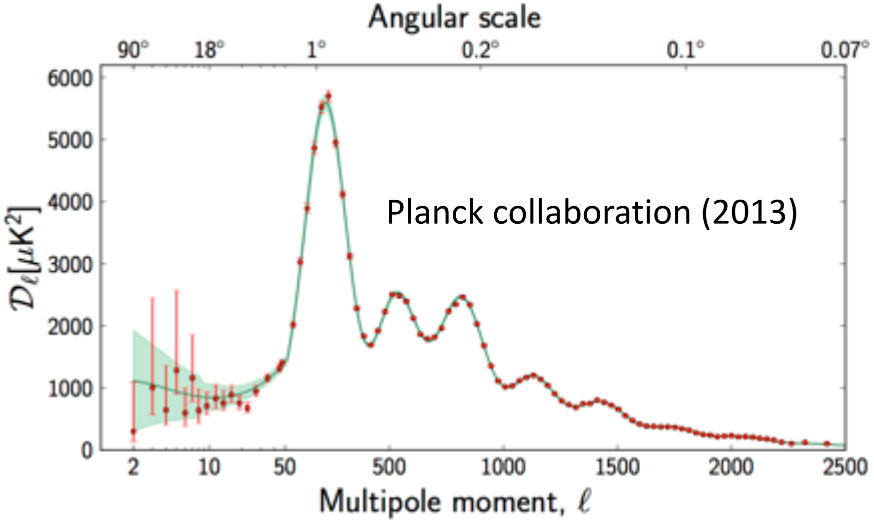
Parameter	Bestfit	σ
h	0.706	0.032
$\Omega^0_{DM}h^2$	0.143	0.003
Ω^0_{DE}	0.714	0.020
$\Omega^0_b h^2$	0.02207	0.00033

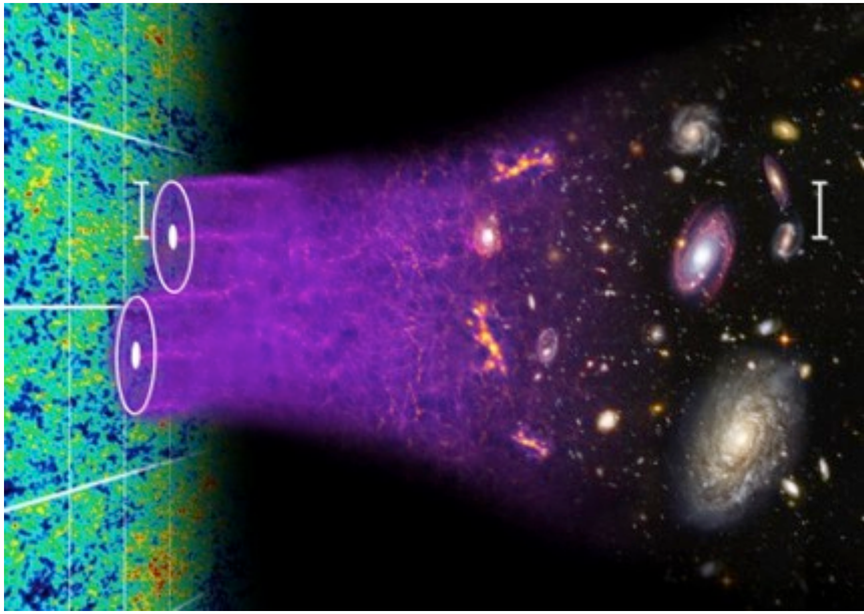
Interacting dark energy

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

Baryon Acoustic Oscillations (BAOs)

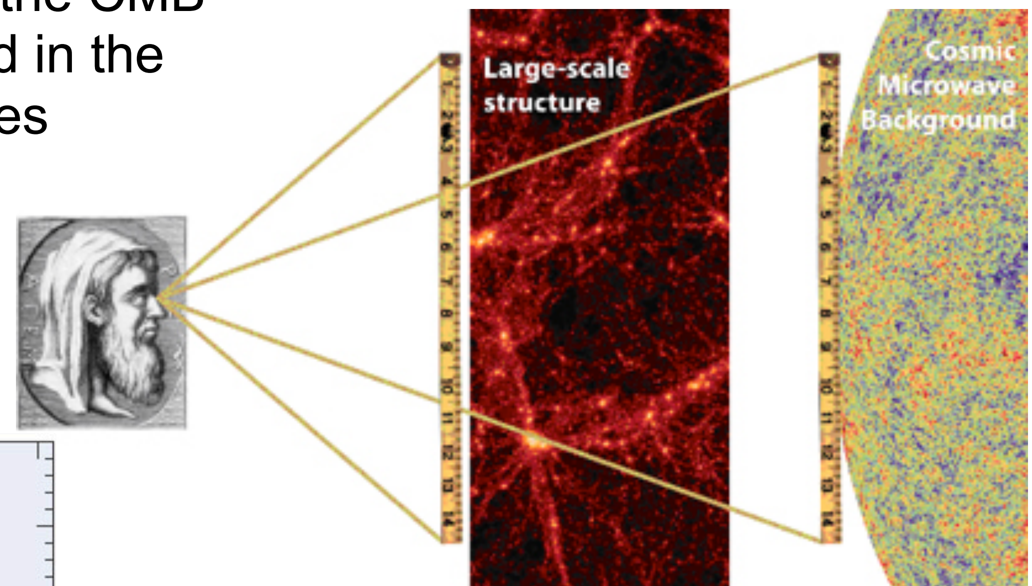
- Acoustic waves imprinted on CMB 380,000 years after Big Bang
- Acoustic scale set by distance light travelled at that time
  - Known precisely from CMB power spectrum
  - D=149 ± 0.6 Mpc
- BAO scale imprinted on all matter in the Universe
  - Use as a “standard ruler”



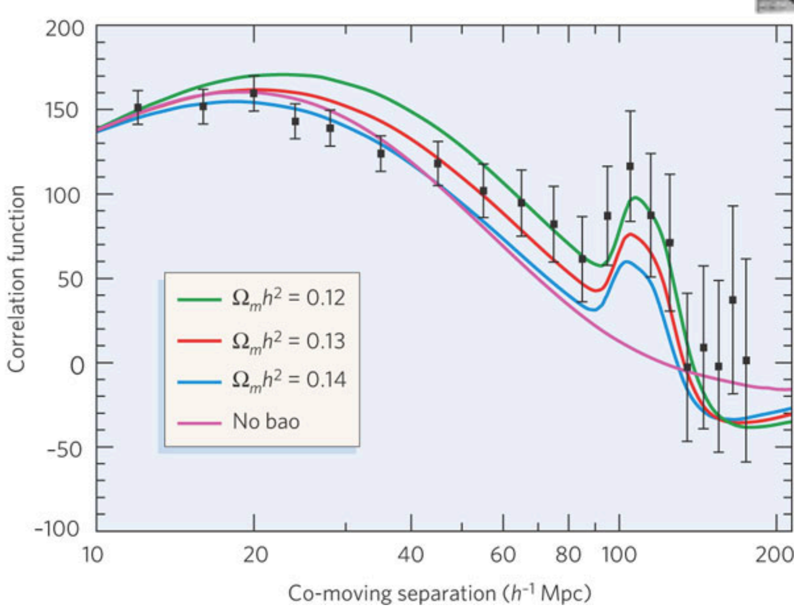


Baryon Acoustic Oscillations (BAOs)

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



Credit: EUCLID website (ESA)

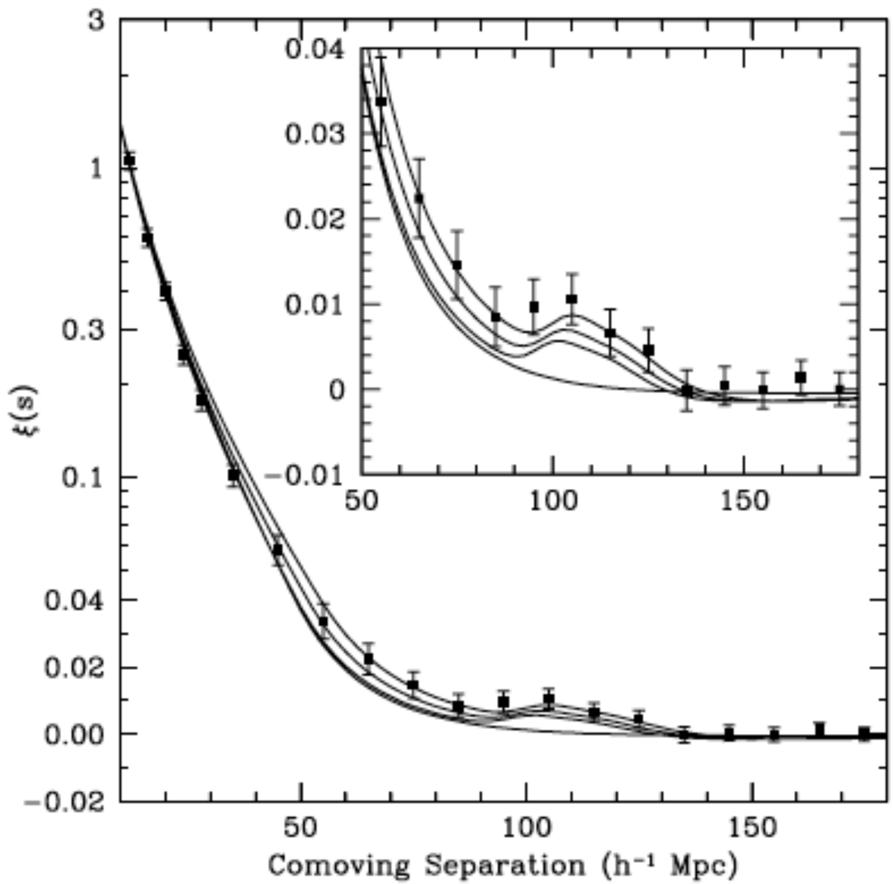


Credit: Bennett, *Nature* (2006)

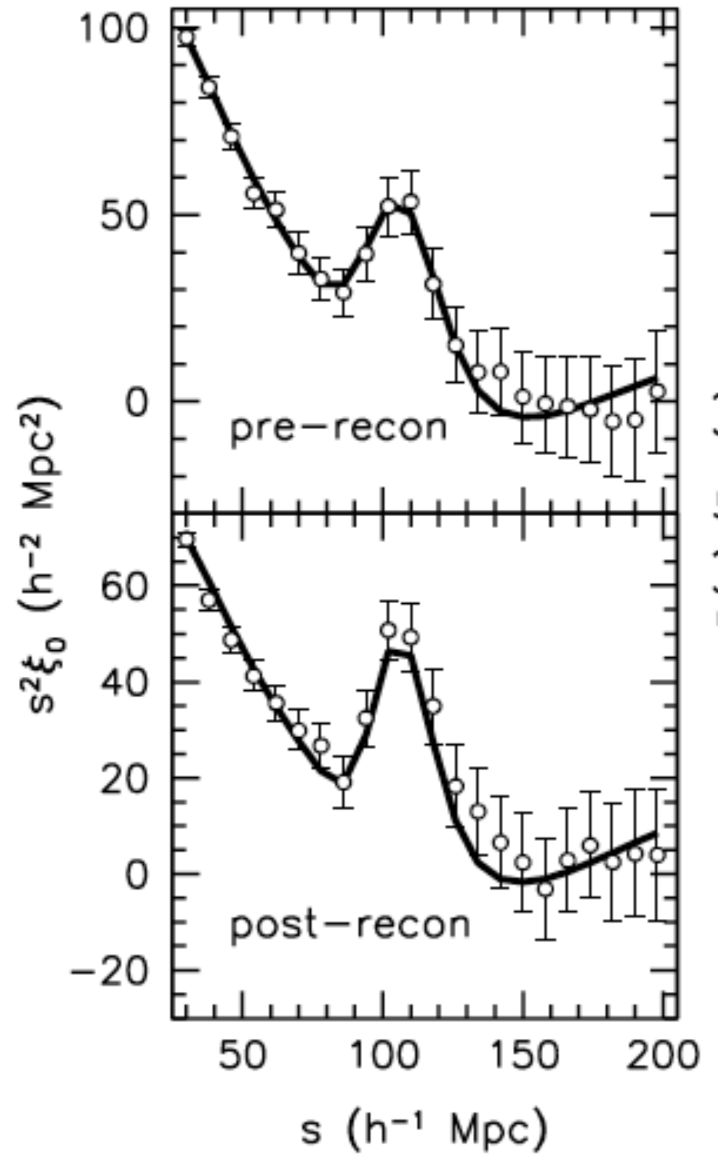
- The acoustic peak gives the ratio of the distances to *z*=.35 and *z*=1,100 to 4% fractional accuracy.
- absolute distance to *z*=0.35 is determined to 5% accuracy.
- co-moving sound horizon scale 150 h^{-1} Mpc.

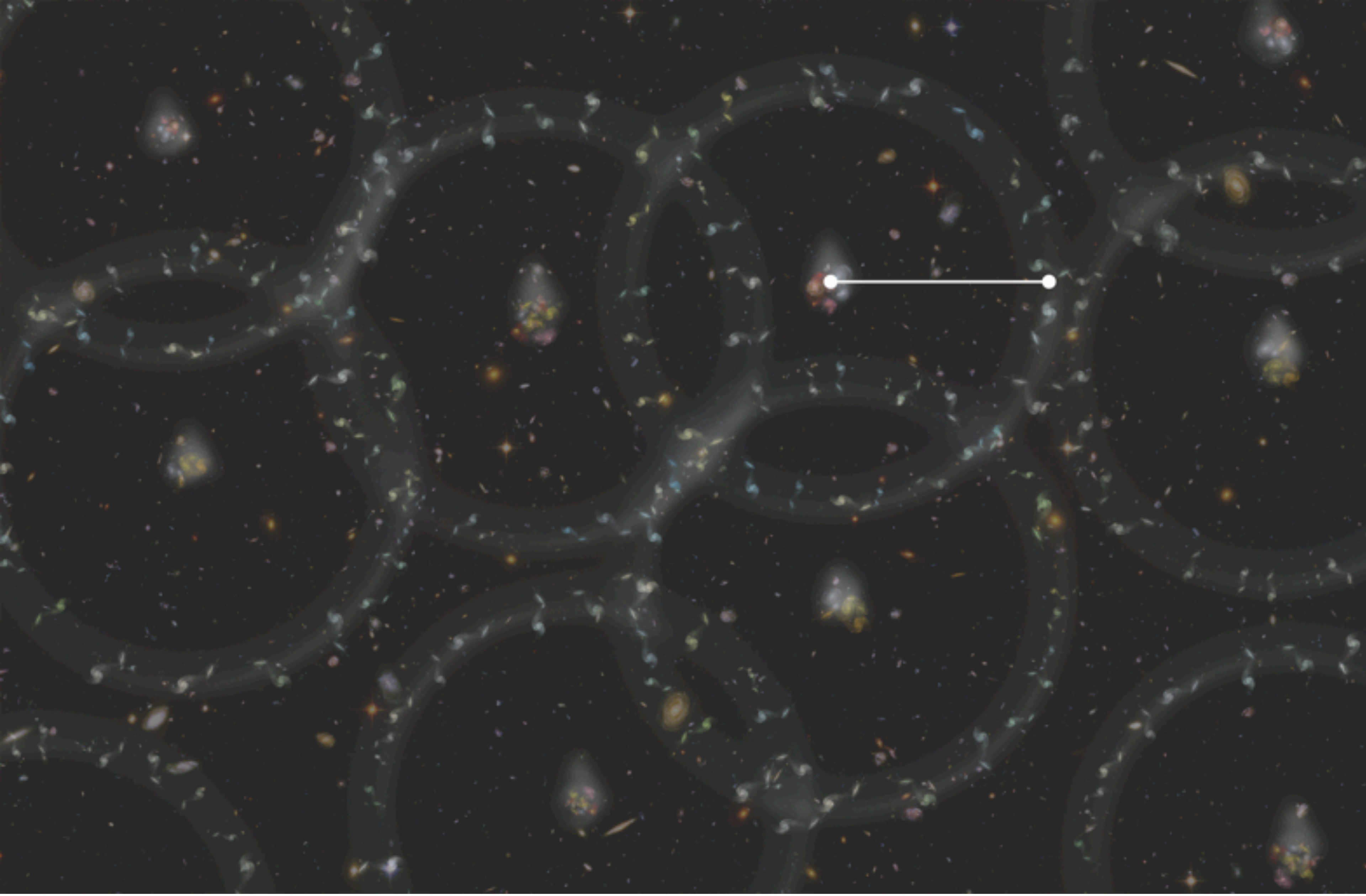
Optical BAOs

Eisenstein et al. (2005)



Anderson et al. (2014)



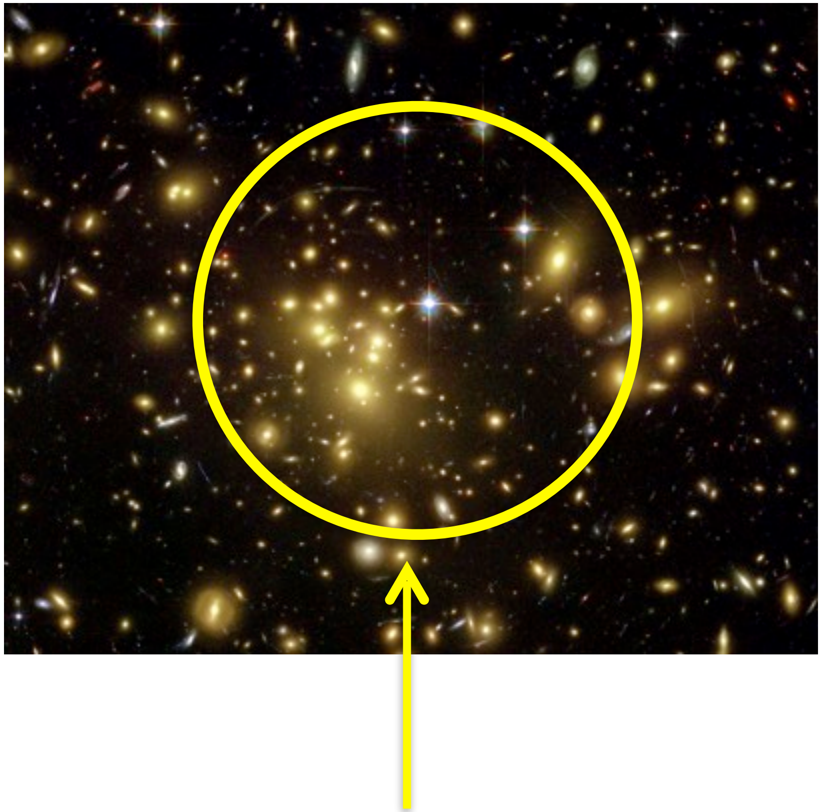


Alternative: HI Intensity mapping

- HI intensity mapping
  - Use relatively large beam on the sky
  - Measure HI *fluctuations*

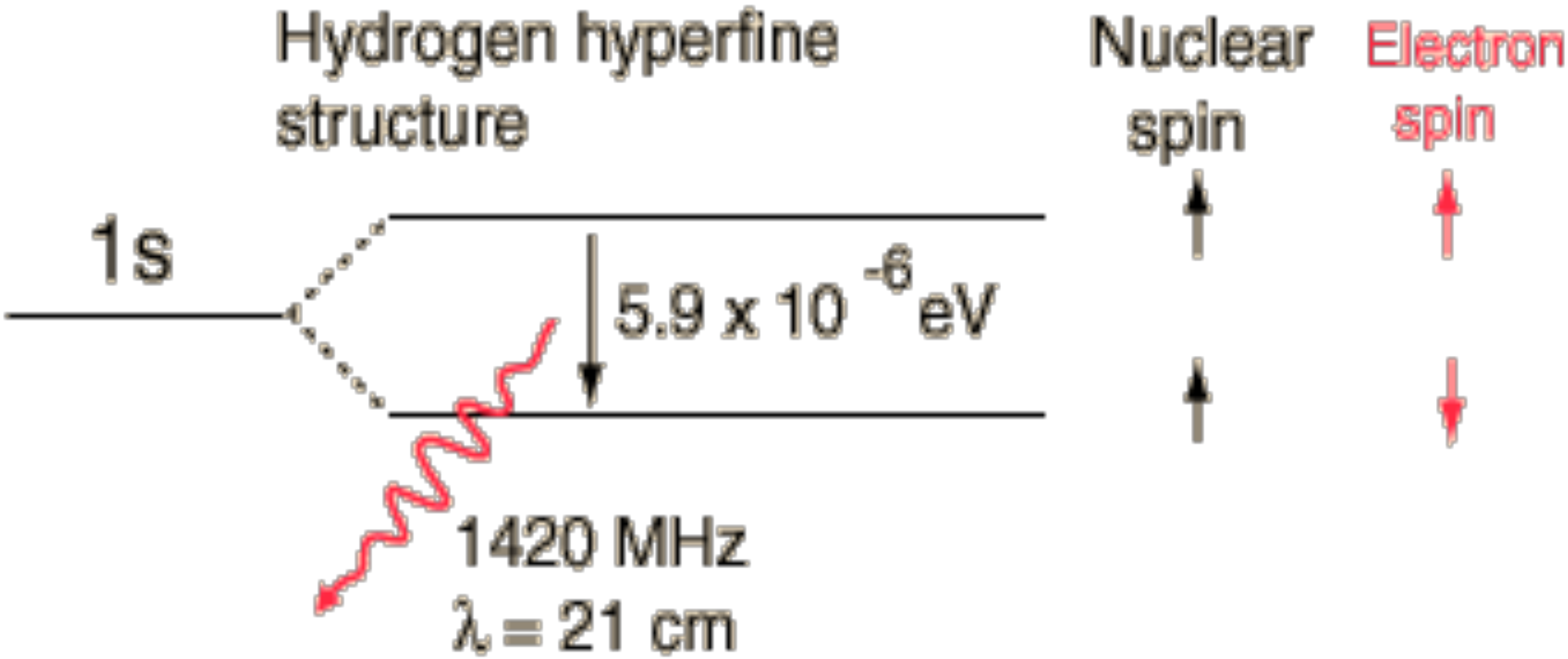
- Proposed single dish radio experiment: **BINGO**
  - No competition in the radio!
  - Complementary to large optical surveys

Battye, Browne, Dickinson, Heron, Maffei, Pourtsidou 2013 MNRAS, 434, 1239 [arXiv:1209.0343]



Large beam on the sky (≈1 deg) contains many galaxies

Baryonic Acoustic Oscillations



The BINGO radio telescope and 21 cm Cosmology

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*
- *Also other astrophysical phenomena*
- *HI intensity map at $0.13 < z < 0.48$*
- *Constraints on cosmological parameters (particularly DE)*

What is Bingo?

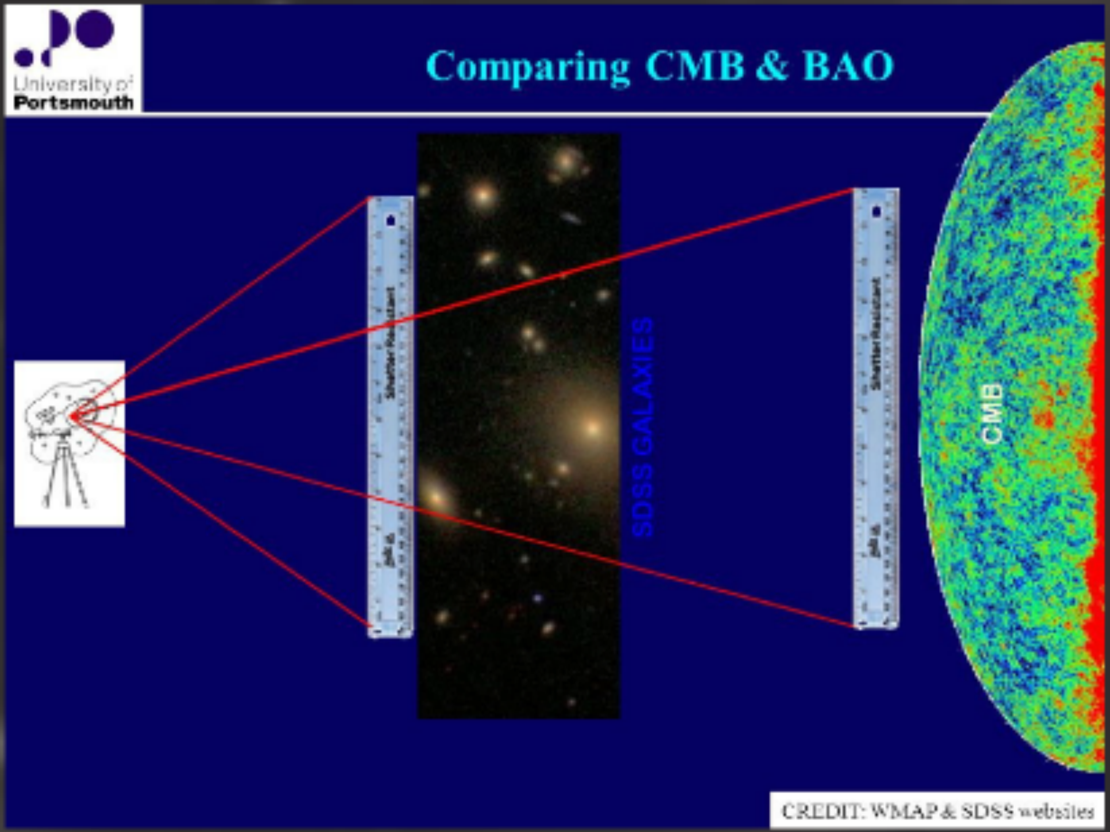
- *50 Horns (1.8 m wide, 4.8 m long)*
- *System Temperature 50 K (up to now, we have 70K)*
- *Site in "Serra do Urubu" (Vulture heights) in Paraíba, Brazil*

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

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



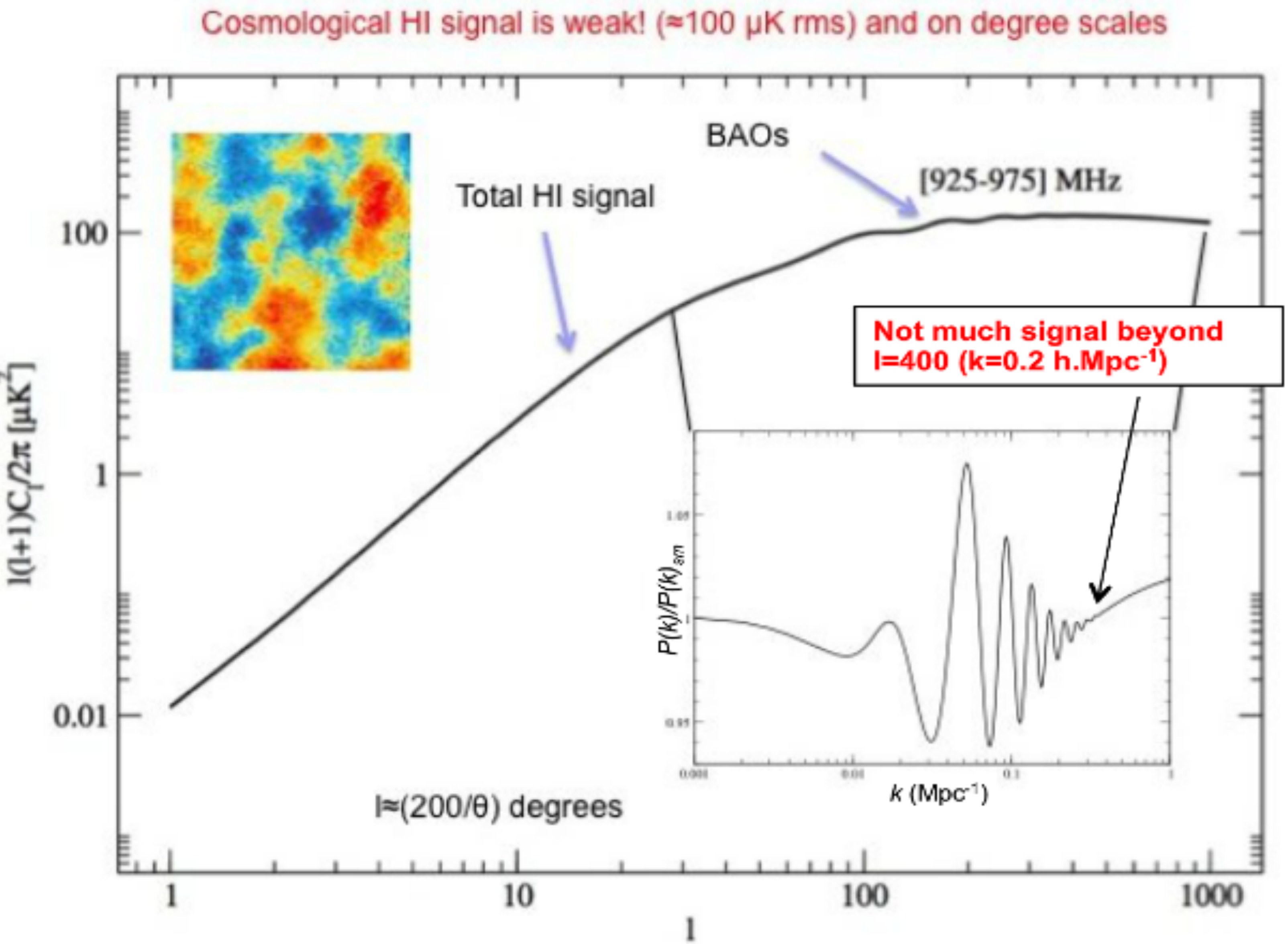


Figure 4: *HI power spectrum, obtained from 2D neutral HI distribution. Subplot highlights the BAO oscillations.*

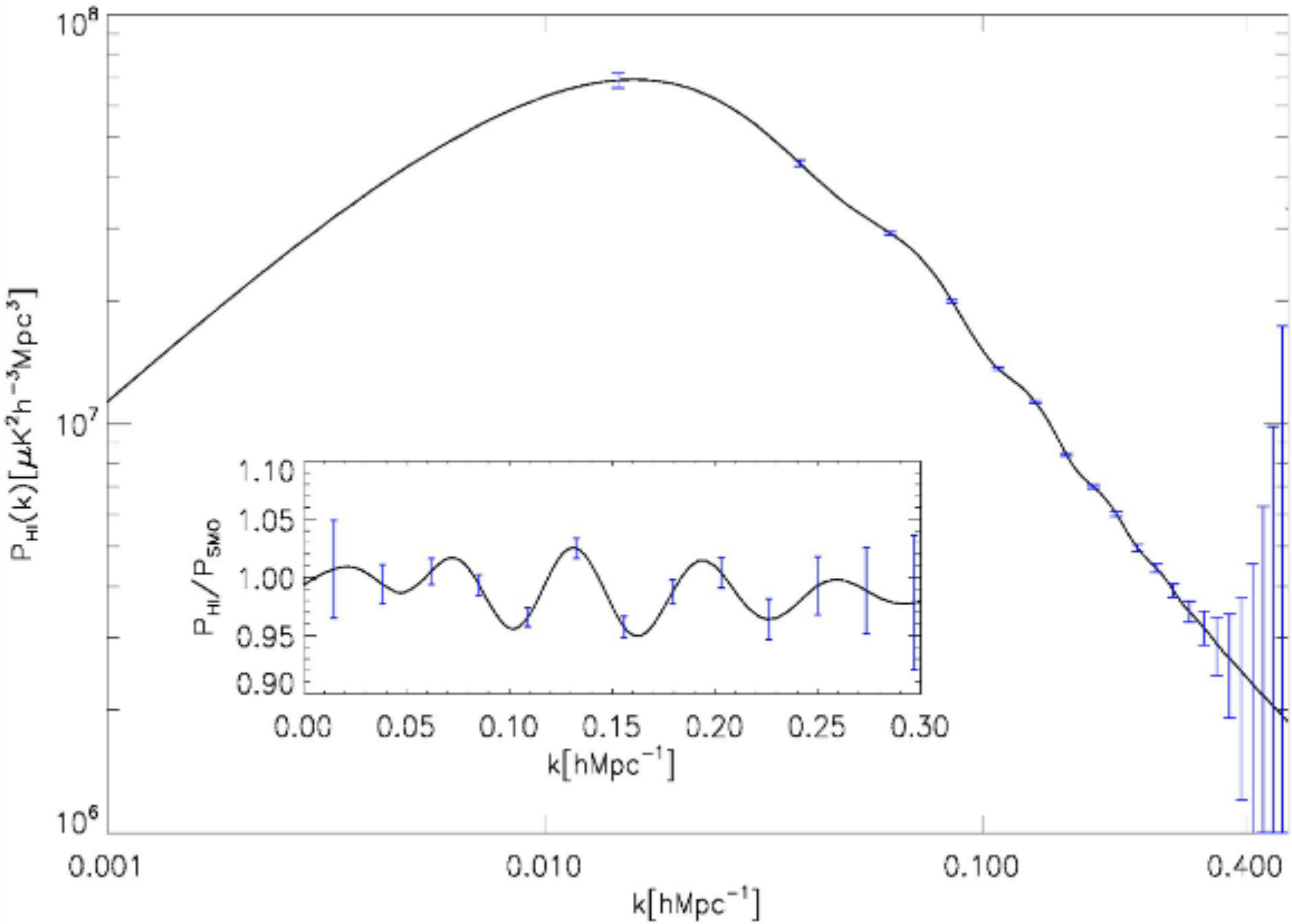
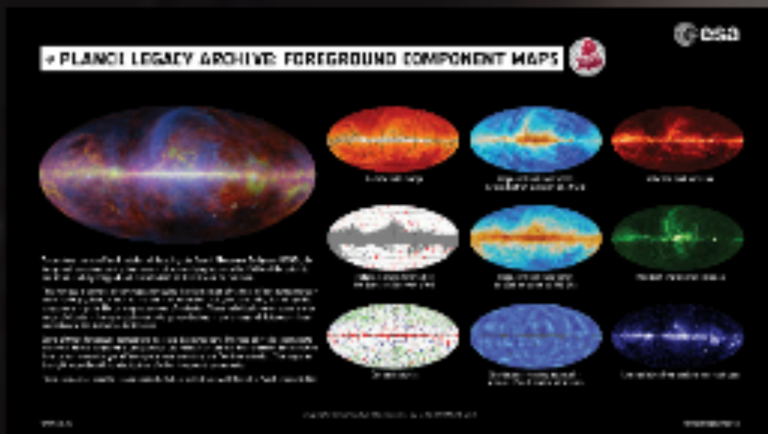


Figure 5: *Projected power spectrum sensitivity for a full 1-year of BINGO observations, with 50 horns and 15° FOV (Battye et al. 2016). The subplot highlights the BAO features after dividing out the smoothed spectrum.*

Some scientific challenges

Foregrounds ~ 10000 stronger than BAO signal!!!!



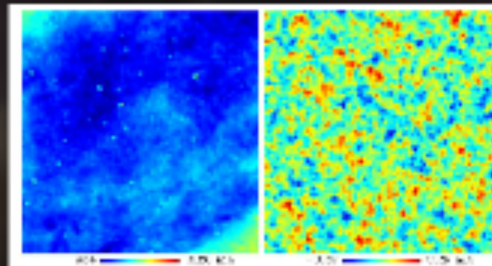
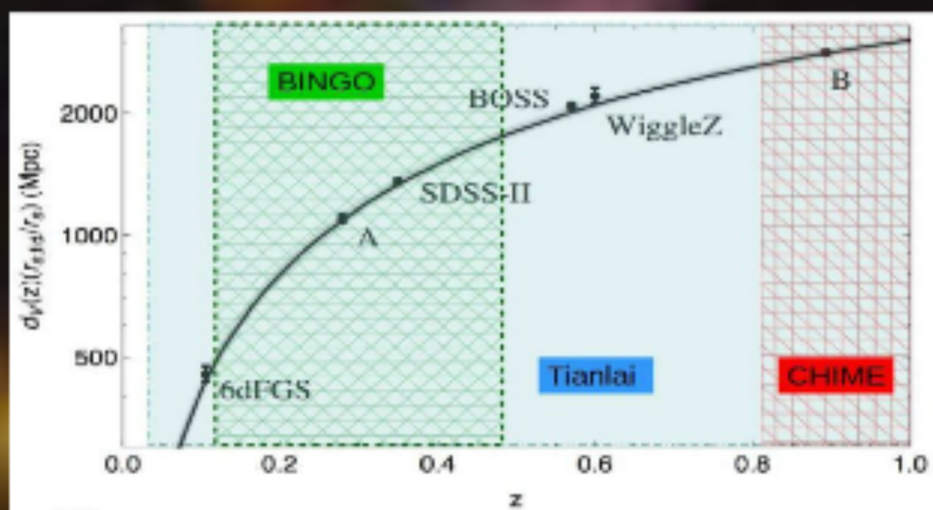


Figure 6: . Astrophysical emissions (Galactic synchrotron, Galactic free-free, and extragalactic point sources) (left) and HI emission (right), at 1 GHz. The maps are centred at Galactic coordinates (30, 120). The maps resolution is 40 arcmin. Astrophysical emissions are ~ 10^4 brighter than HI emission.



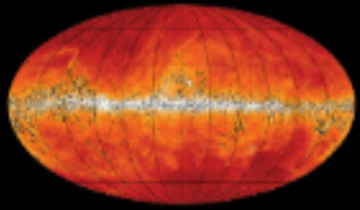
→ PLANCK LEGACY ARCHIVE: FOREGROUND COMPONENT MAPS

To complete the core Planck mission of detecting the Cosmic Microwave Background (CMB), the foreground emissions arising from cosmic structures lying between the CMB and the satellite had to be carefully mapped and characterised so that it could be removed.

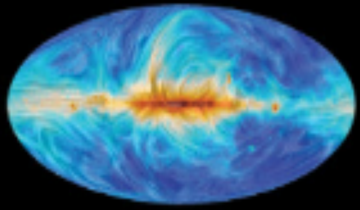
This resulted in several all-sky maps portraying the distribution of various diffuse components in our Milky Way galaxy, as well as in a series of extensive catalogues containing lists of specific components – point-like or compact sources of emission. These individual sources cover a wide range of objects – from pre-stellar cores to galaxy clusters – and a range of distances – from our Galaxy to the distant early Universe.

Some of these foreground component maps are displayed here. The map above is a composite of several diffuse components that pervade the Milky Way: thermal dust emission, line radiation from carbon monoxide gas, diffuse synchrotron emission, and free-free emission. The maps on the right show the all-sky distribution of other foreground components.

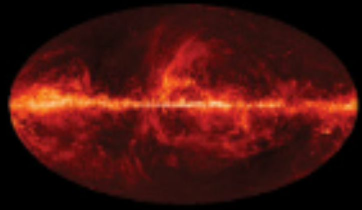
These maps are among the mission products that are publicly accessible from the Planck Legacy Archive.



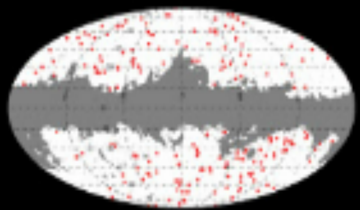
Galactic cold clumps



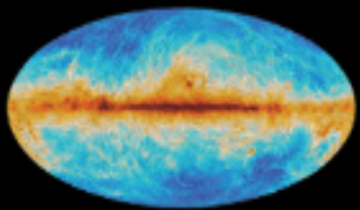
Magnetic field lines traced by synchrotron radiation at 30 GHz



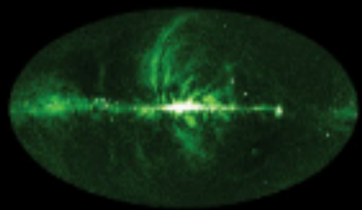
Polarised dust emission



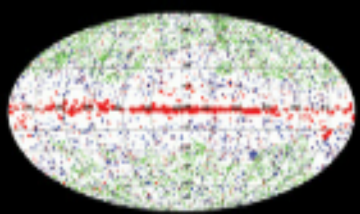
Galaxy clusters detected by the Sunyaev-Zeldovich effect



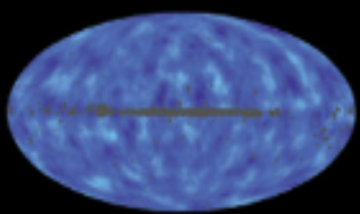
Magnetic field lines traced by dust emission at 353 GHz



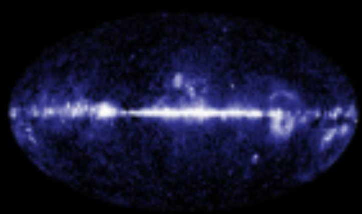
Polarised synchrotron emission



Compact sources



Gravitational-lensing potential – a tracer of dark matter structures



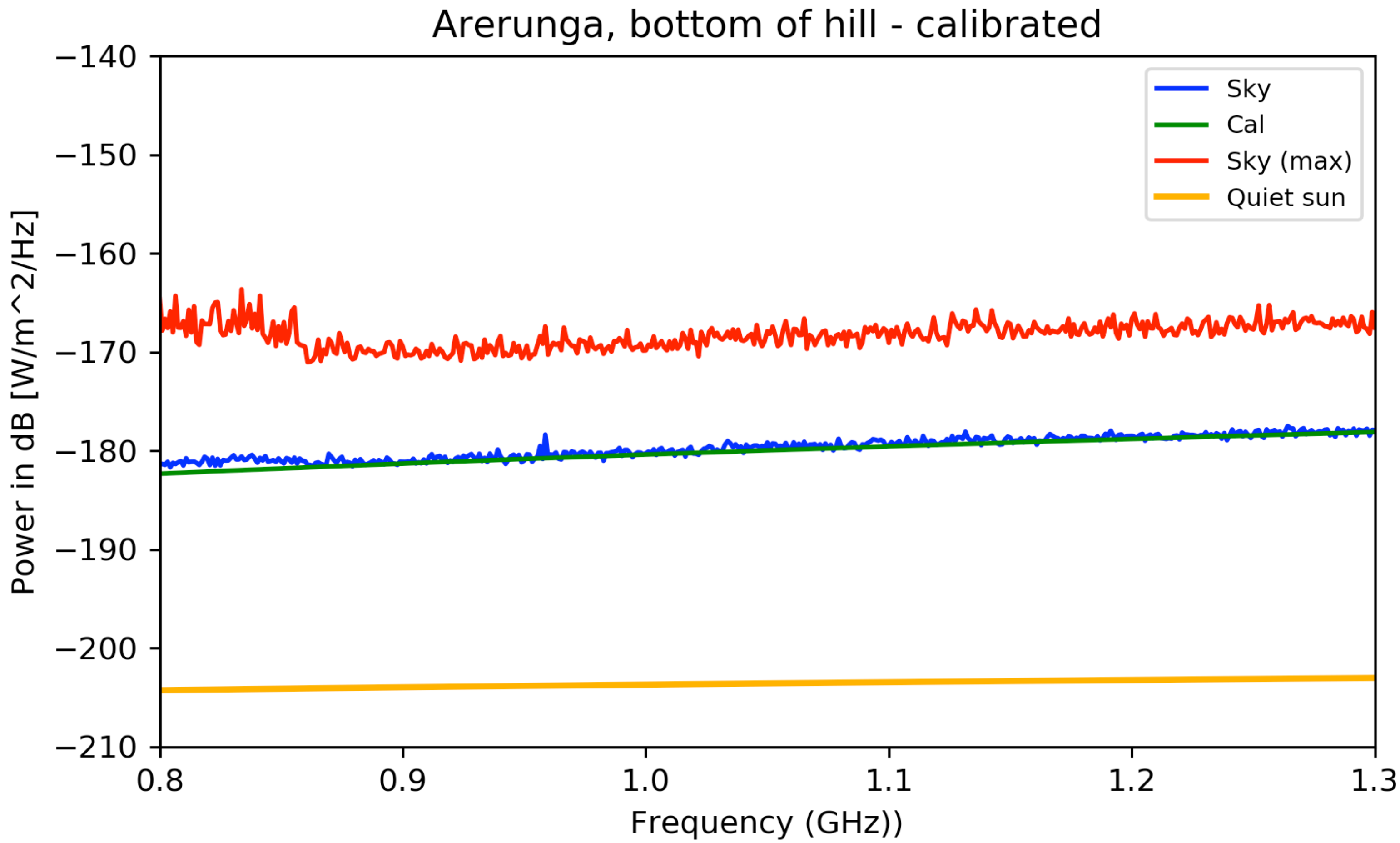
Line radiation from carbon monoxide gas

Technological challenges

Some of the challenges BINGO will have to deal with:

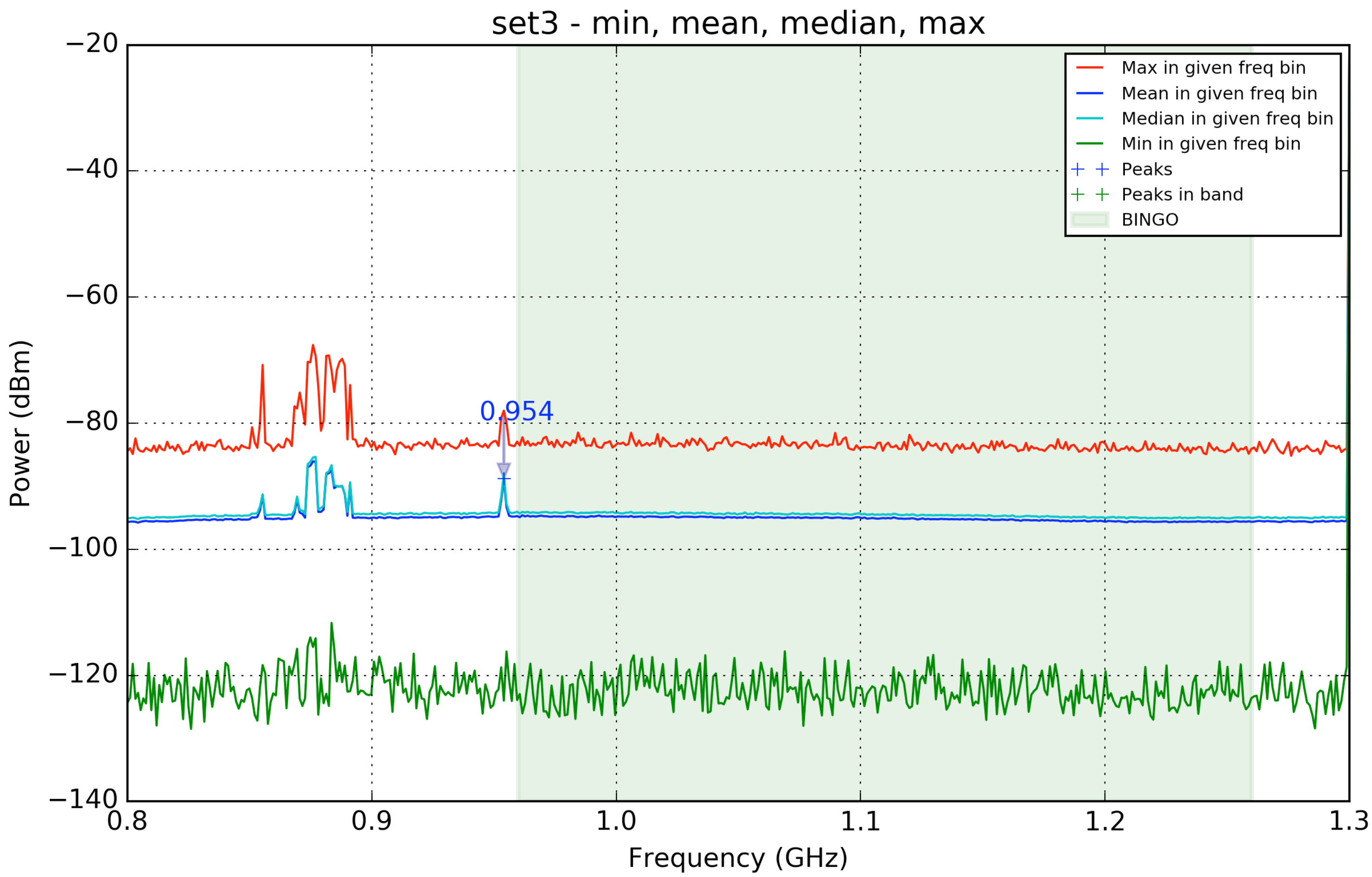
- Build the 50, ~ 4.8 x 1.8 m, horns to a 0.5 mm precision
- Transport to and build the 2, ~ 40 m dishes in "Sertão da Paraíba"
- Same thing for the horns
- Data stewardship of the 50 horns
- RFI from mobile phones, airplane routes, radio links and microwave ovens are a permanent threat to the quality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

Uruguay

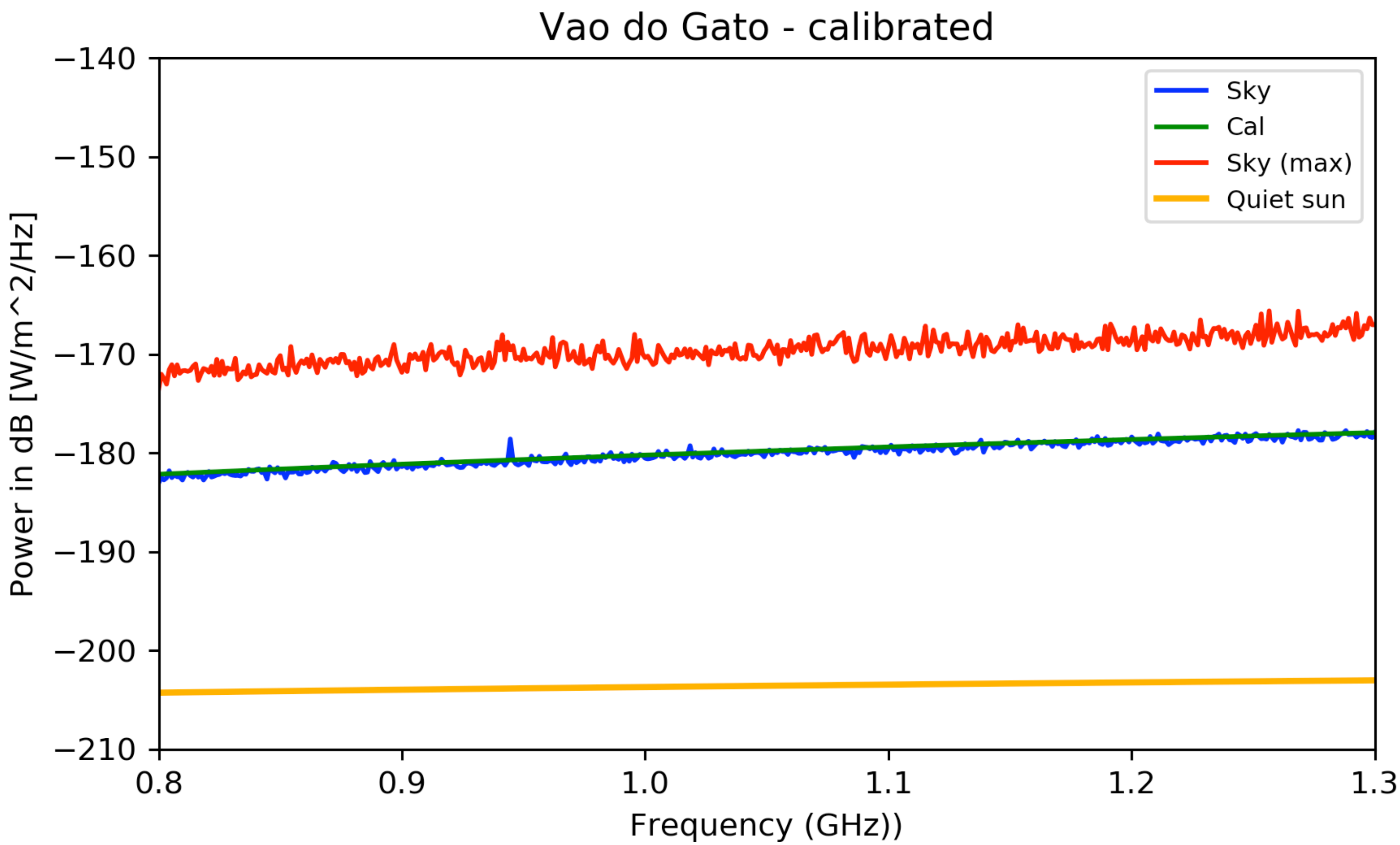


Arerunga, bottom of hill - calibrated
Power in dB [W/m^2/Hz]
−140
−150
−160
−170
−180
−190
−200
−210
0.8
0.9
1.0
1.1
1.2
1.3
Frequency (GHz))
Sky
Cal
Sky (max)
Quiet sun

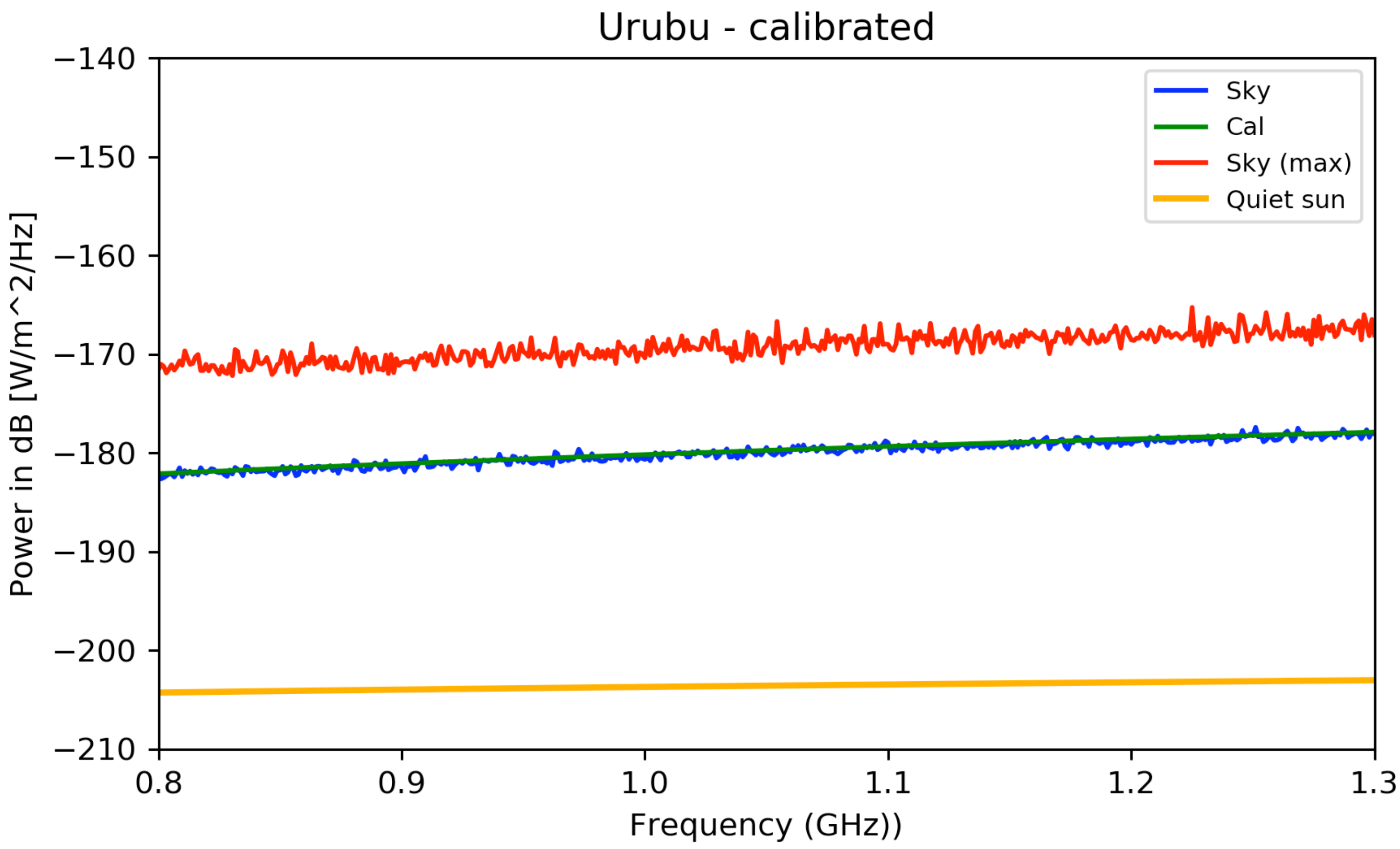
Cachoeira Paulista (SP)



Vão do Gato (Cat's den) Paraíba



Urubu (Vulture), Paraíba



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)

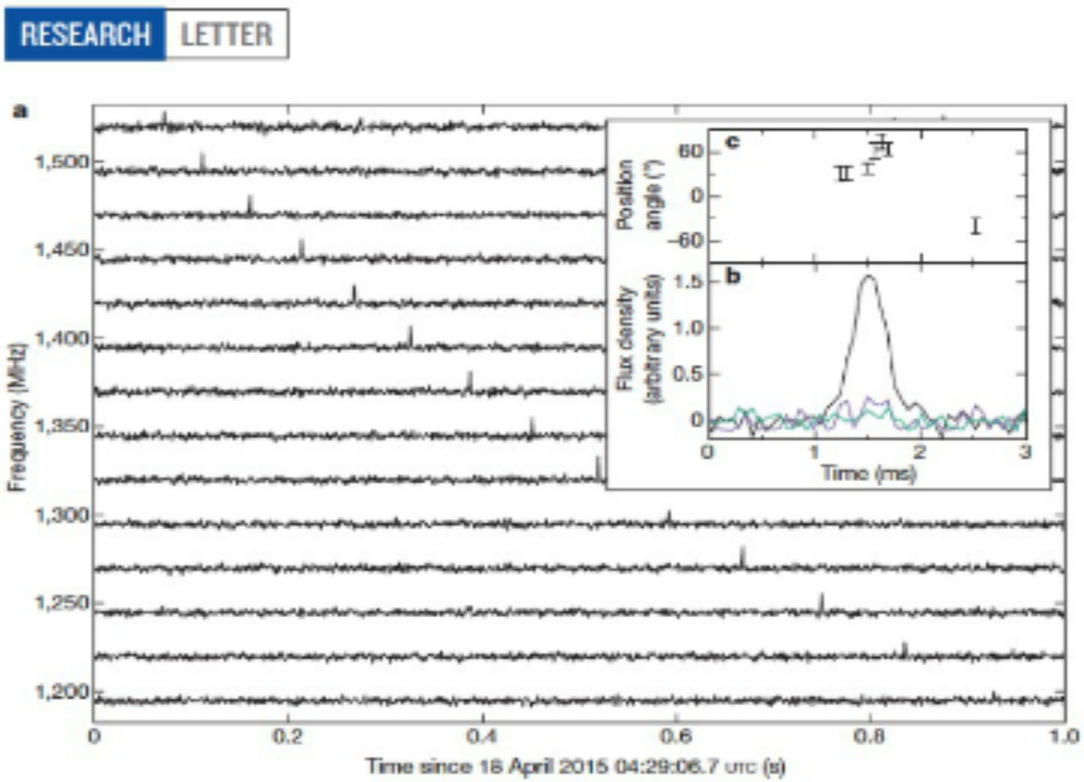
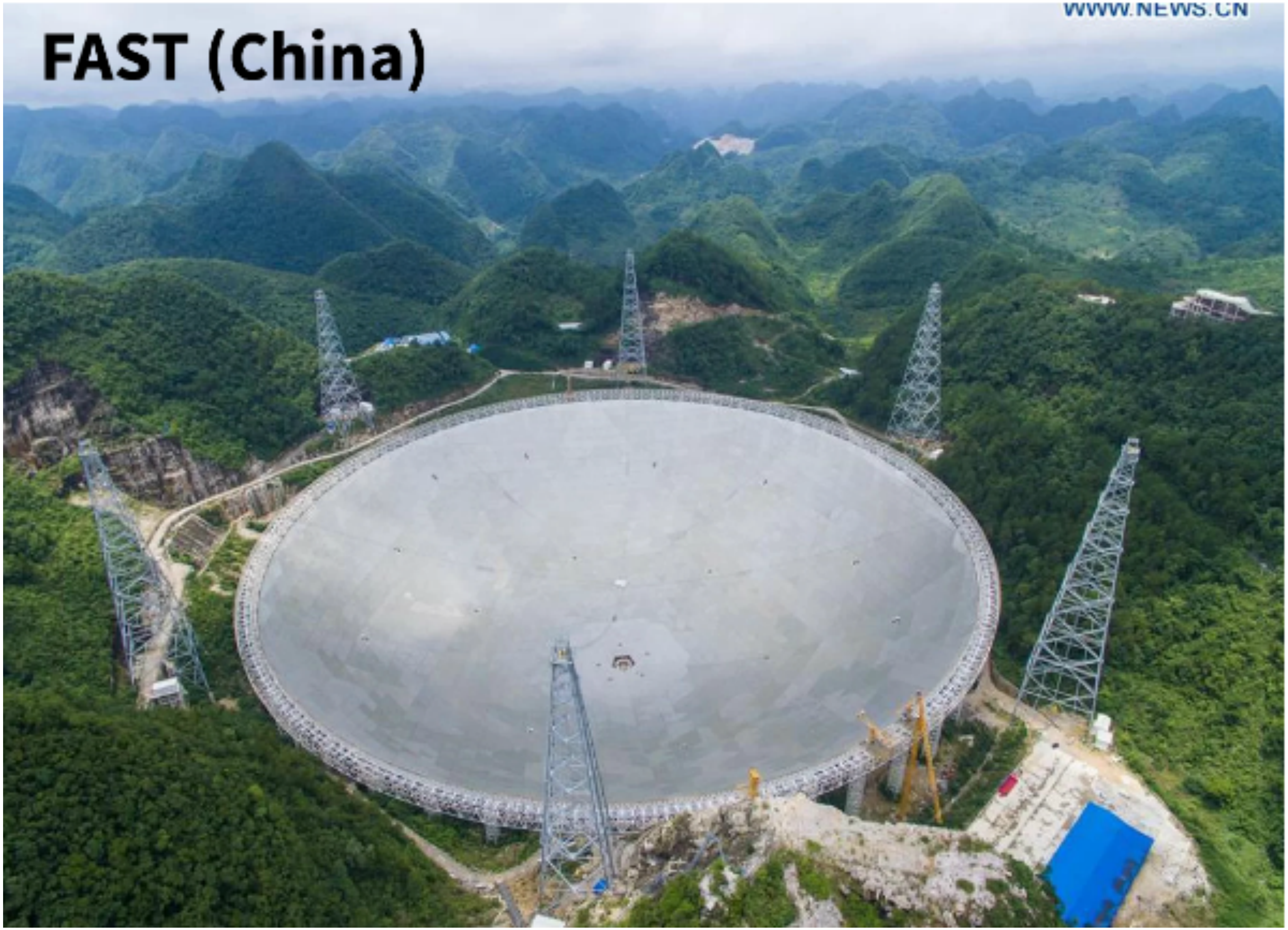


Figure 1 | The FRB 150418 radio signal. **a**, A waterfall plot of the FRB signal with 15 frequency sub-bands across the Parkes observing bandwidth, showing the characteristic quadratic time–frequency sweep. To increase the signal-to-noise ratio, the time resolution is reduced by a factor of 14 from 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.

Other Projects

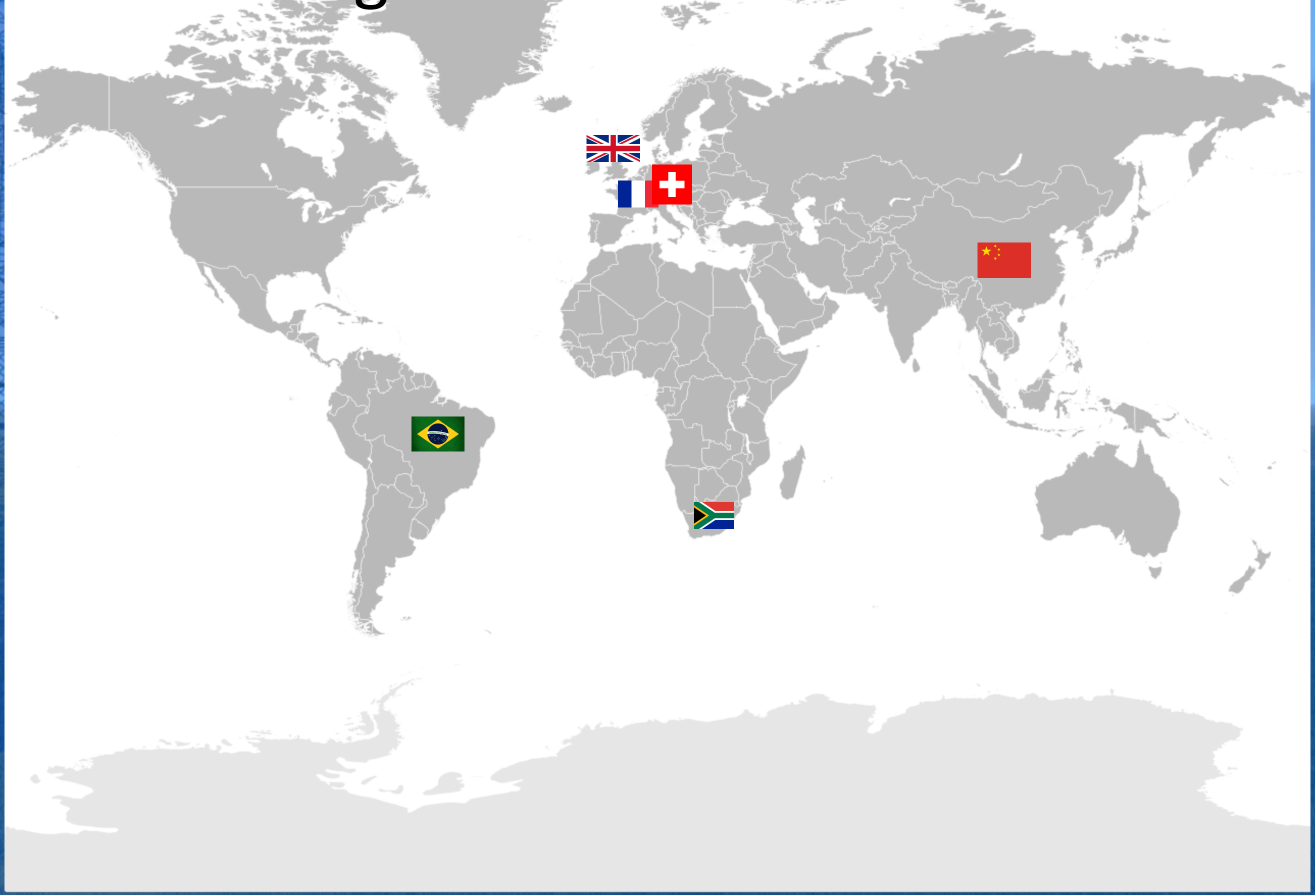

WWW.NEWS.CN
FAST (China)


Chime (Canada)


Not before ~ 2022, though...
SKA (South Africa/ Australia)

BINGO

BAOs from Integrated Neutral Gas Observations



BINGO

s from Integrated Neutral Gas Observations

Instituto de Física da USP

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Elisa Ferreira
Andreia de Souza
Michael Peel
Ricardo Landim
Many students

Instituto Nacional de Pesquisas Espaciais

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Luis Reitano	Cesar Strauss
Vincenzo Licardo	Karin Fornazier
Alan Cassiano	Renato Branco
Thyrso Vilela	Many students

Universidade Federal de Campina Grande

Luciano Barosi
Francisco Brito
Amilcar Queiroz
Many students

BINGO

Os from Integrated Neutral Gas Observations

University College London

Filipe Batoni Abdalla
Students and post docs

The University of Manchester

Ian Browne
Richard Battye
Clive Dickinson

BINGO

BAOs from Integrated Neutral Gas Observations

Bruno Maffei

Yin-Zhe Ma

Bin Wang

Larissa Santos

Jie Zhu

Haiguang Xu

Alex Refrigier
Christian Monstein

BINGO

BAOs from Integrated Neutral Gas Observations

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Women in Science

- *in Bingo*
- *Karin Fornazier*
- *Andreia de Souza*
- *Elisa Ferreira*
- *Graciele Oliveira*
- *Priscila Gutierres*
- *Christianne Morais*
- *Larissa Santos (in China with Bin Wang)*
- *Isabela Carucci (UCL with Filipe Abdalla)*
- *Sonia Anton (Portugal)*
- *not in Bingo (in my research group)*
- *Bertha Cuadros Melgar*
- *Cecilia Chirenti*
- *Diana Taschetto*