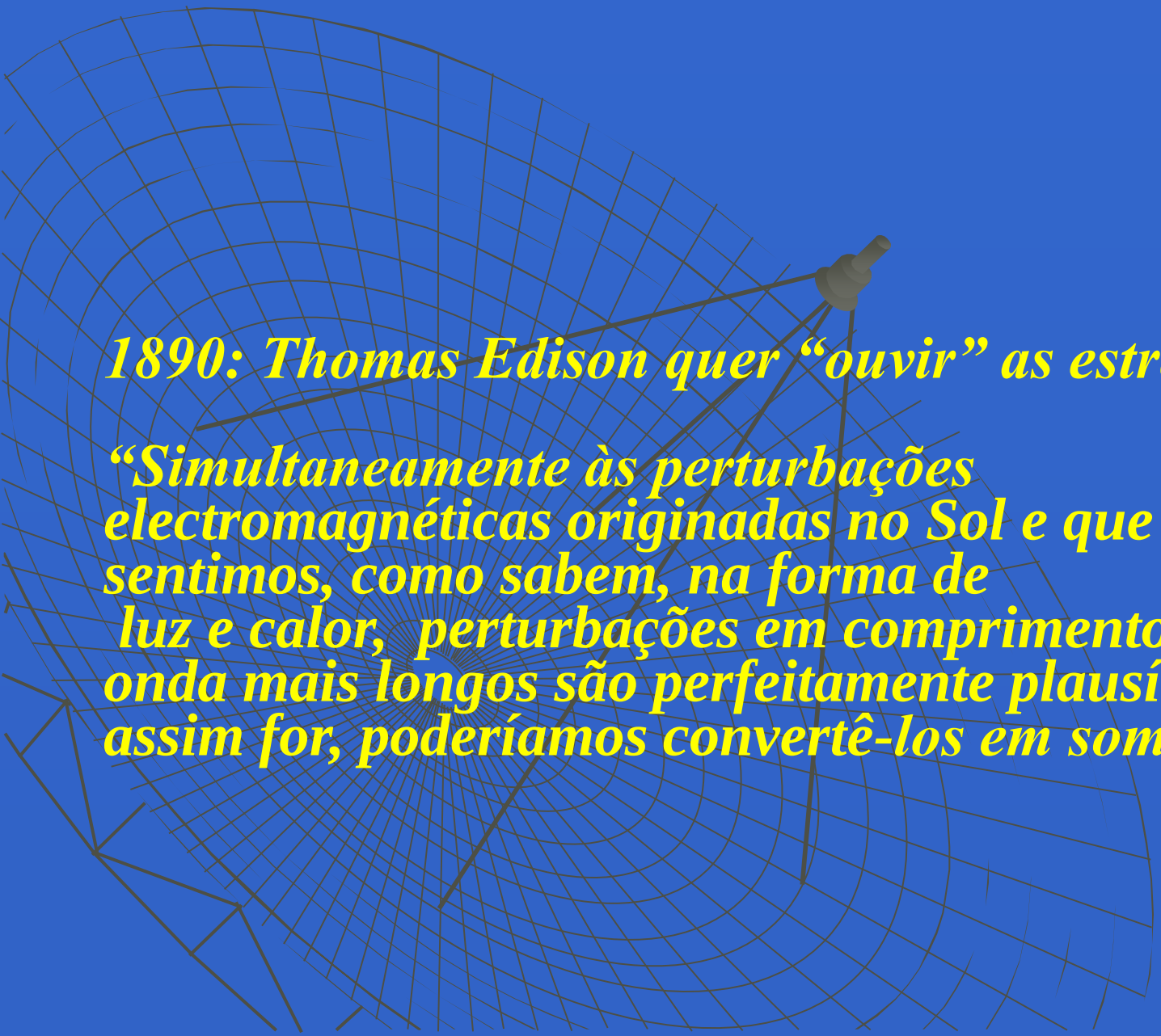
Status of Galactic Emission Mapping project @ Portugal : *from CMB to cosmic-rays*

(http://www.av.it.pt/gem/)

by
Domingos Barbosa

Grupo de Radioastronomia
Basic Sciences & Enabling Technologies
Instituto de Telecomunicações - Aveiro

FCT- POCI/CTE-AST/57209/2004
FCT- PDCT/CTE-AST/65925/2006
GEM NSF Grant

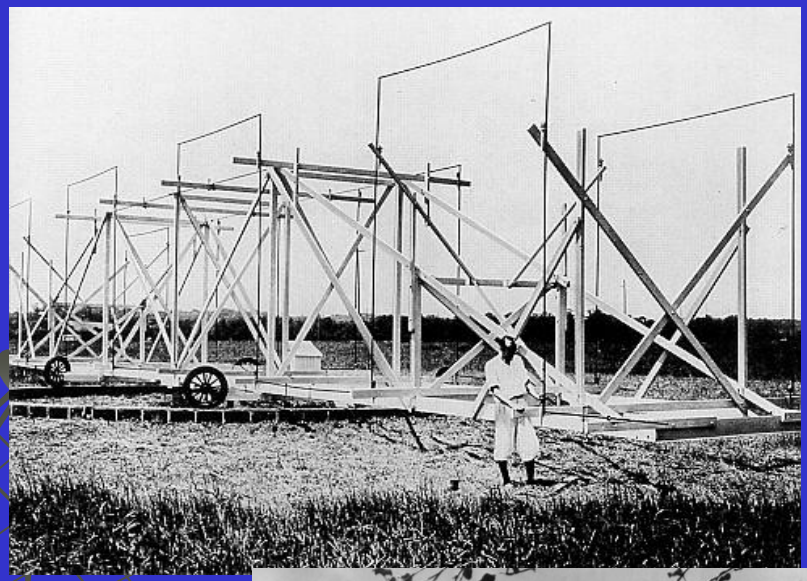


1890: Thomas Edison quer "ouvir" as estrelas.

"Simultaneamente às perturbações electromagnéticas originadas no Sol e que sentimos, como sabem, na forma de luz e calor, perturbações em comprimentos de onda mais longos são perfeitamente plausíveis. Se assim for, poderíamos convertê-los em som."

TICs/Radioastronomia: começo acidental

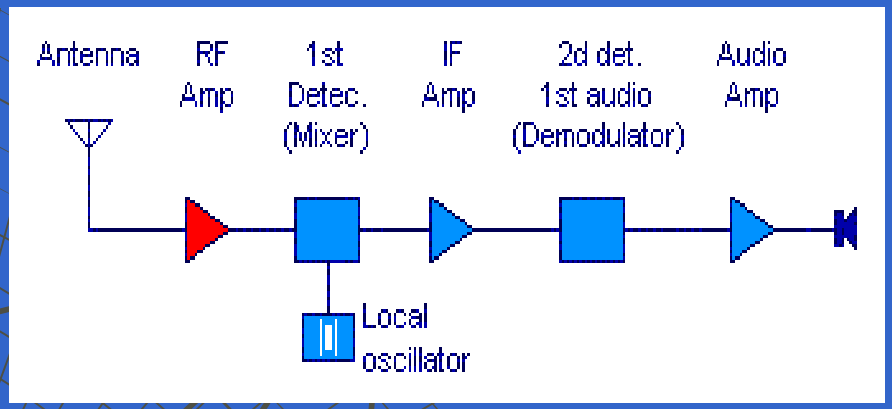
1931-1935 Karl Jansky
(Bell Telephone Labs)



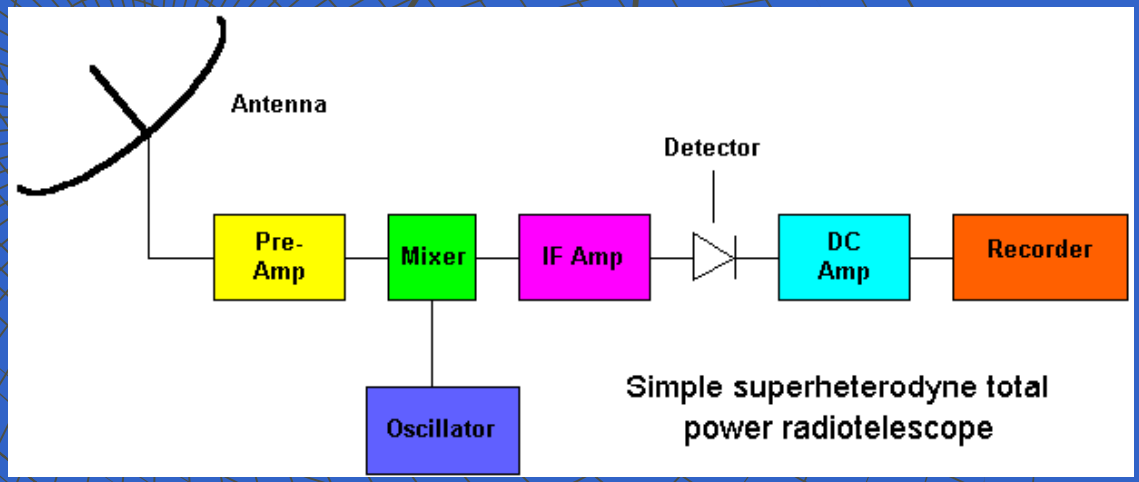
Estudo de estática durante tempestades @20MHz-
- Centro da Via Láctea

1940 Grote Reber - receptor VHF/UHF @ 160 Mhz (*ultra-alta freq.*) – **encontra Júpiter, o Sol, the Sun e fontes rádio cósmicas**

Rádio como grande negócio :um receptor superheterodínico de 1930

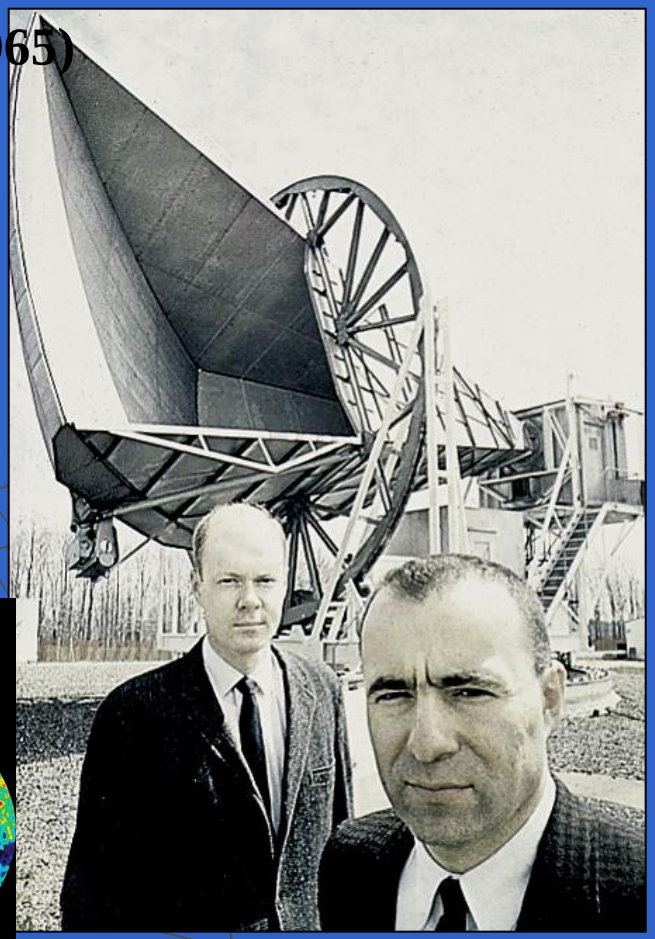


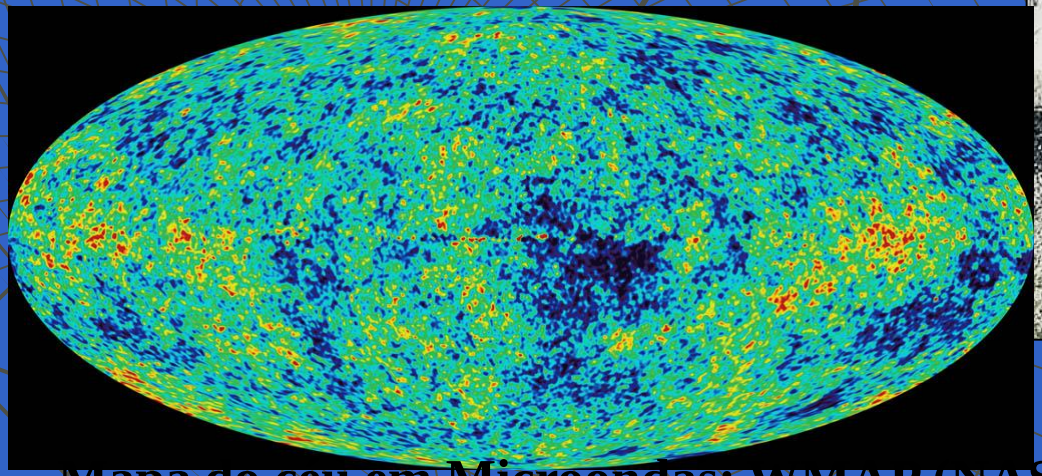
Os modernos radiómetros no espaço/ radiotelescópios



Os 5 Prémios Nobel da RadioAstronomia : setup-das técnicas experimentais

- **Fundo de Radiação Cósmica em Microondas (1965)**
  - **Nobel para Penzias e Wilson**
    - **Bell Telephone Labs**
  - **Descoberta fortuita, possibilitada pela Tecnologia**



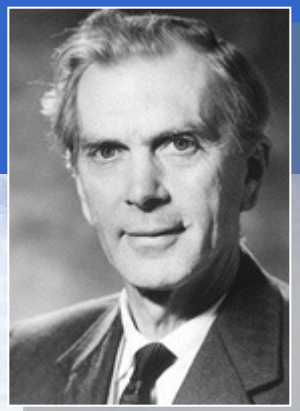


Mapa do ceu em Microondas: WMAP (NASA)

Os 5 Prémios Nobel da RadioAstronomia : setup-das técnicas experimentais

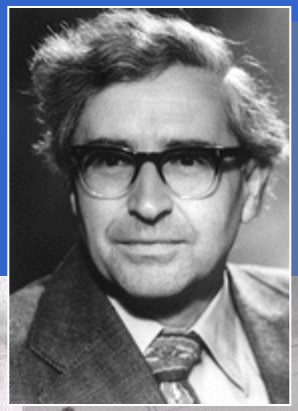
- **Fundo de Radiação Cósmica em Microondas (1965)**
  - **Nobel para Penzias e Wilson**
    - **Bell Telephone Labs**
  - **Descoberta fortuita, possibilitada pela Tecnologia**

- **Evolução Cósmica**
  - **Síntese de abertura**
  - **Martin Ryle (1974)**



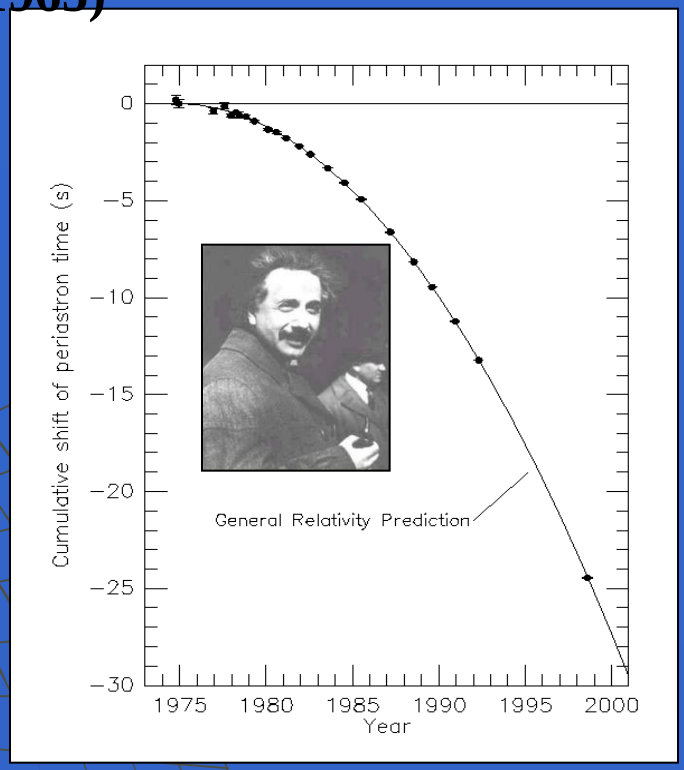
Os 5 Prémios Nobel da RadioAstronomia : setup-das técnicas experimentais

- **Fundo de Radiação Cósmica em Microondas (1965)**
  - **Nobel para Penzias e Wilson**
    - **Bell Telephone Labs**
  - **Descoberta fortuita, possibilitada pela Tecnologia**
- **Evolução Cósmica**
  - **Síntese de abertura**
  - **Martin Ryle (1974)**
- **Descoberta de estrelas de neutrões**
  - **radio pulsações (pulsars)**
  - **Tony Hewish (1974)**



Os 5 Prémios Nobel da Radio Astronomia

- Fundo de Radiação Cósmica em Microondas (1965)
  - Nobel para Penzias e Wilson
    - Bell Telephone Labs
  - Descoberta fortuita, possibilitada pela Tecnologia
- Evolução Cósmica
  - Síntese de abertura
  - Martin Ryle (1974)
- Descoberta de estrelas de neutrões
  - radio pulsações (pulsars)
  - Tony Hewish (1974)
- Verificação das previsões de Einstein's da Relatividade Geral
  - Desaceleração da rotação de um pulsar
  - Taylor and Hulse (1993)



As redes multi-antenas de observação:
Interferometria : resolução de miliarsec !!!!!!
Imbatível

Very Large Array, USA

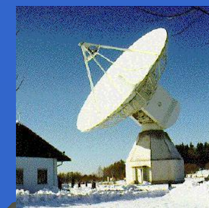
+ VSOP

Global Very Large Baseline Interferometer

VSOP (36000 Km baseline)

European Radio Astronomy





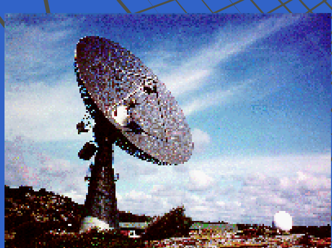






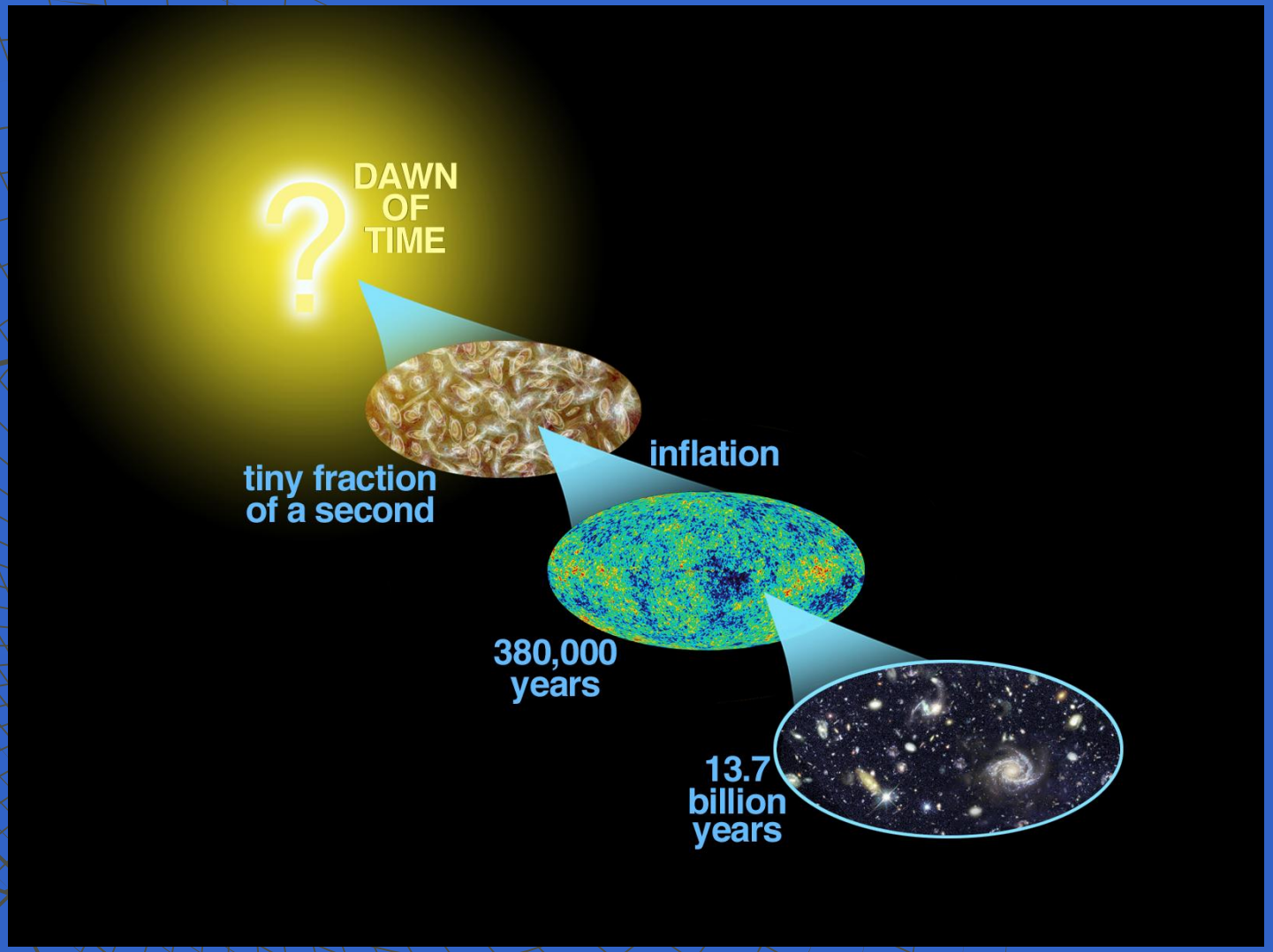




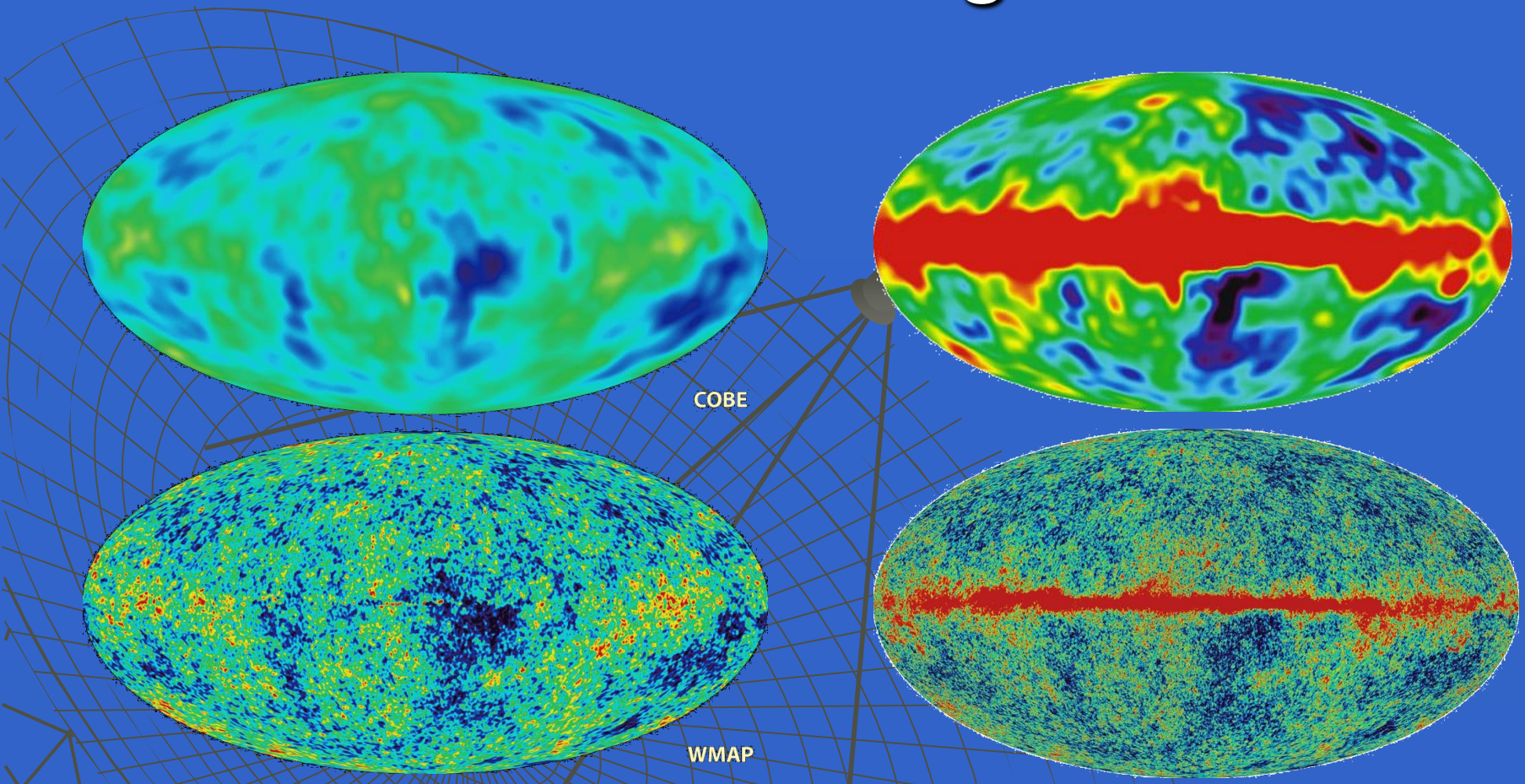


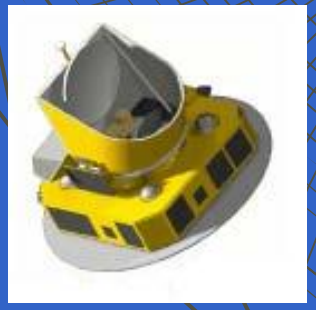

CMBR – Cosmic Microwave Background Radiation



Courtesy of the NASA-WMAP / ESA-Planck

CMB and Foregrounds





Polarization, the future paradigm!

Planck Surveyour (ESA 2009)

Courtesy of the NASA/WMAP Science Team

GEM-P Team Colaboration

- **Team**
  - Domingos Barbosa (PI)
  - Dinis Santos
  - Luís Cupido
  - Rui Fonseca
  - Miguel Bergano
  - Francisco Fernandes
  - David Macário
  - Ana Mourão
  - **George Smoot**
  - Camilo Tello
  - Graça Rocha
  - Marco Bersanelli
  - Andrew Jaffe
  - Marco Tucci

- **Colaborators**
  - Aníbal Costa
  - Francisco Queirós de Melo
  - Rui Martins
  - Vasco Lagarto
  - Thyrso Villela
  - Ivan Ferreira
  - Luis Reitano
  - Dietmar Wagner
  - James Bartlet
  - Nazareno Mandolesi
  - Luca Valenziano

- **Institutions**

- **IT-Aveiro** – Instituto de Telecomunicações - Portugal
- **CENTRA** – Centro Multidisciplinar de Astrofísica, IST - Portugal
- **LBNL** – Lawrence Berkeley National Laboratory – EUA
- **INPE** – Instituto Nacional de Pesquisas Espaciais – Brasil
- **UNIMI -** Università di Milano, Dipartimento di Fisica - Italy
- **IASF - Bologna** – Instituto di Astrofisica Spaziale e Fisica Cosmica – Italy
- **CMdPS** - Câmara Municipal de Pampilhosa da Serra - Portugal

---

- CFN – Centro de Fusão Nuclear, IST - Portugal
- DEMUA – Departamento de Eng. Mecânica da UA - Portugal
- DECUA – Departamento de Eng. Civil da UA - Portugal
- Max Planck-Institut für Plasmaphysik - Germany
- Imperial College – London Planck Analysis Center - UK
- Université de Paris VII & College de France - France
- Caltech - USA

Constraining Inflation

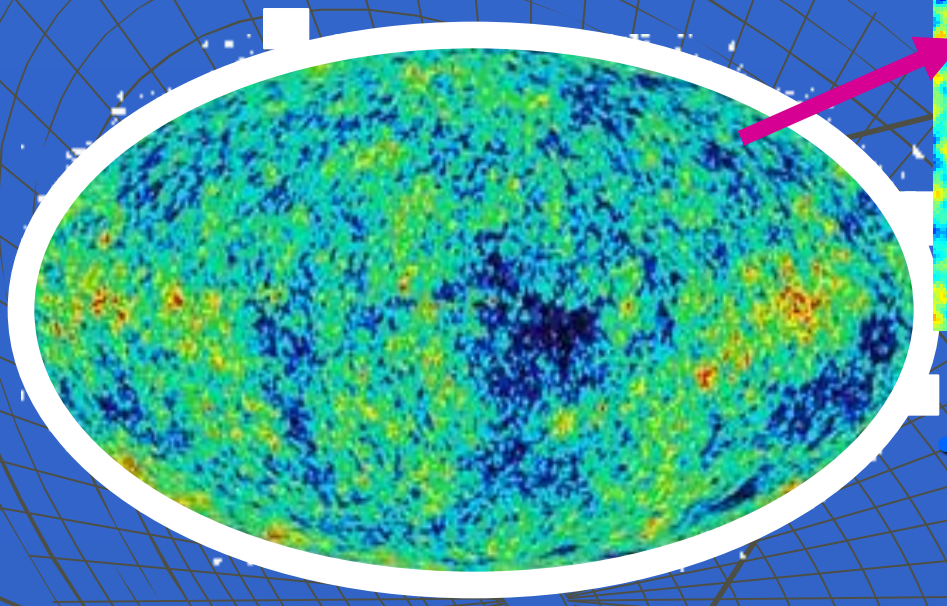
- Accurate measurement of the CMB can constrain the nature of the inflationary potential, at 10^{-35} sec after Big-Bang

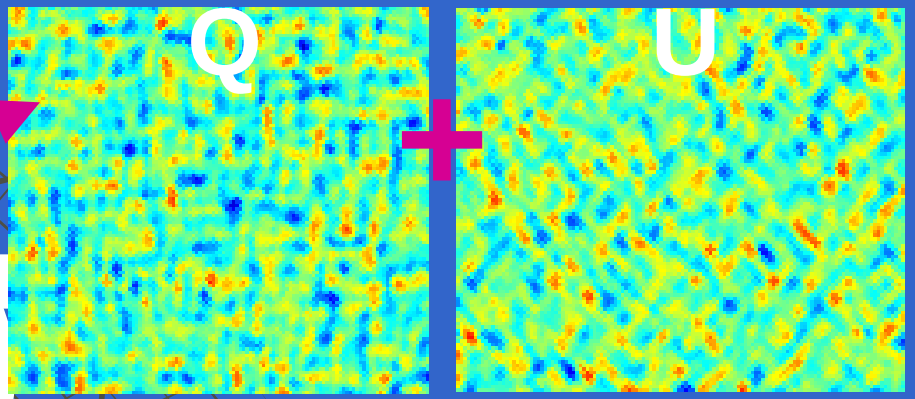
- in particular the ratio of scalar to tensor fluctuation amplitude $r=T/S \sim V^{1/4}/m_{pl}$

- and the *slope* n of the assumed power-law spectrum P(k) of fluctuations:

Polarisation of the CMB

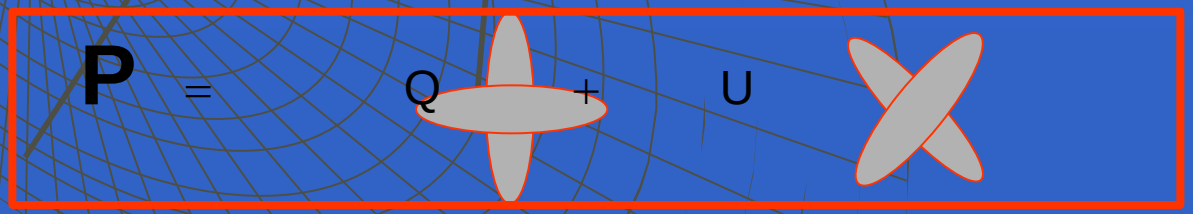
Temperature





- Generated by Thompson scattering off electrons in quadrupolar motion.

Polarisation Matrix:

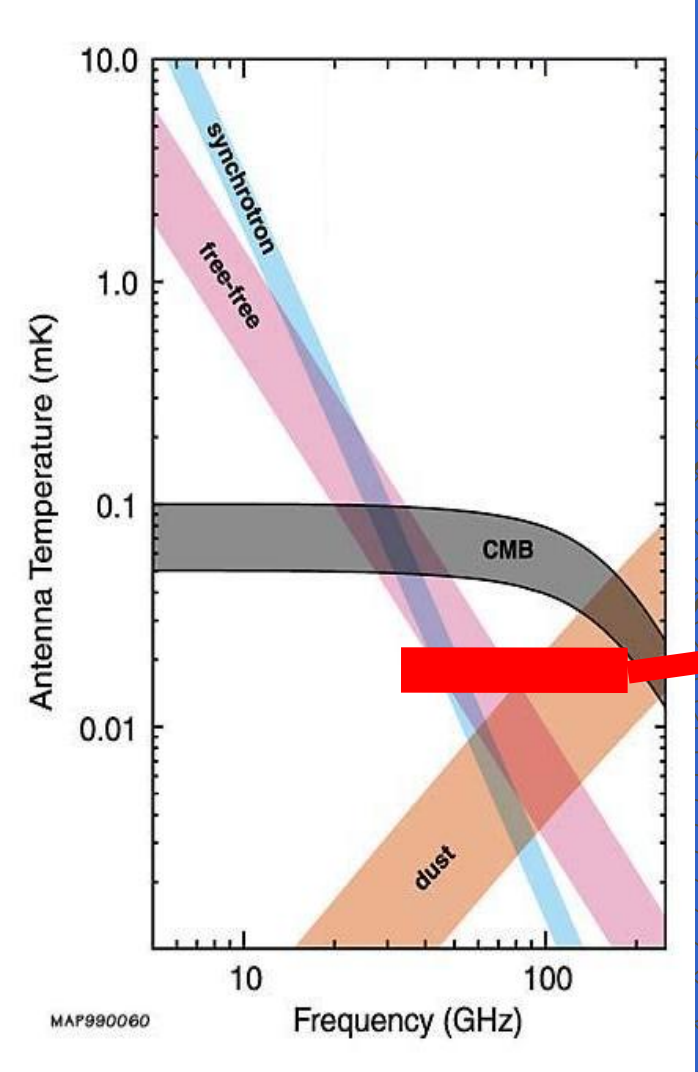


Perpectives

- Theorist:
  - B modes are fashionably great!
  - Science Maximust!
    - Improve all other observations
    - Only way to see tensor modes
    - Already confident in E-modes predicted
  - Much more Theoretical Development needed
    - Read - many more papers soon to be!
- Experimenter: Polarization is the Frontier
  - E-modes are there !
  - B-modes - much more difficult and lower level
    - More sensitivity required
    - Lower systematics required
    - Foreground removal required
    - ????

G.Smoot 2004

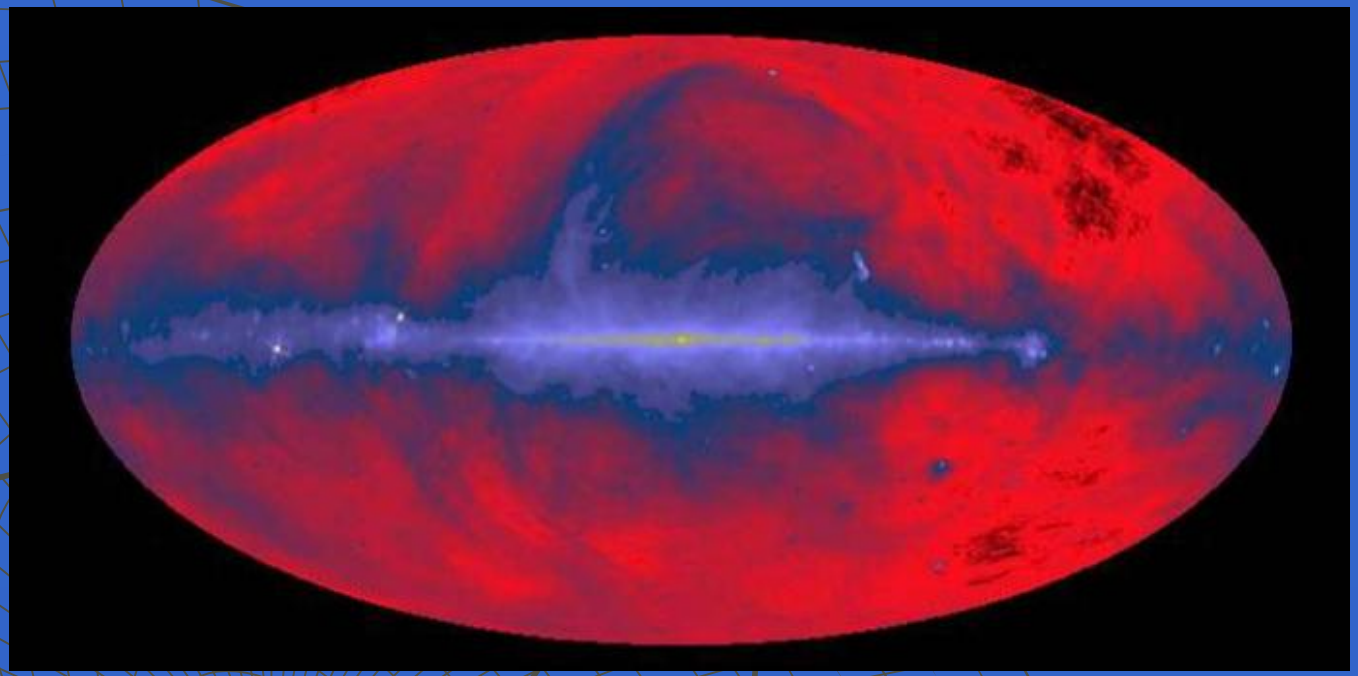
Foregrounds: Diffuse Galactic Emission



- Synchrotron: Cosmic-ray Relativistic electrons gyrating in interstellar magnetic fields
- Free-free: Thermal Bremsstrahlung from electrons produced in interstellar gas by the galactic UV radiation field
- Dust: Emission arises from thermal re-radiation of absorbed stellar light
- At low frequencies (1Ghz-15GHz) synchrotron prevails
- ***Present and future = Polarization***

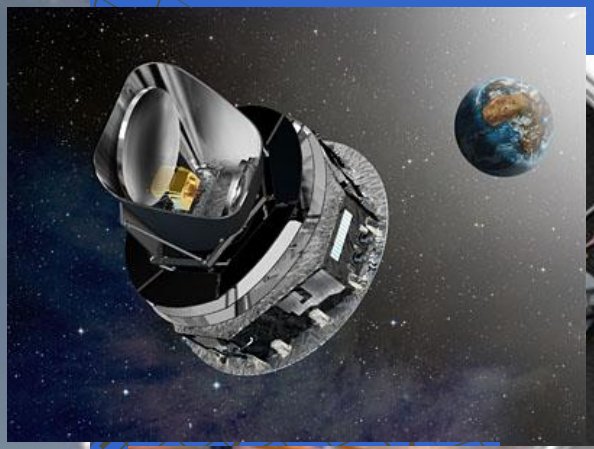
- Non existent all sky synchro. maps
- No polarization templates @ low freq.
- Minimal Faraday depol. @ 5GHz
- Maximum ~60% of polarization

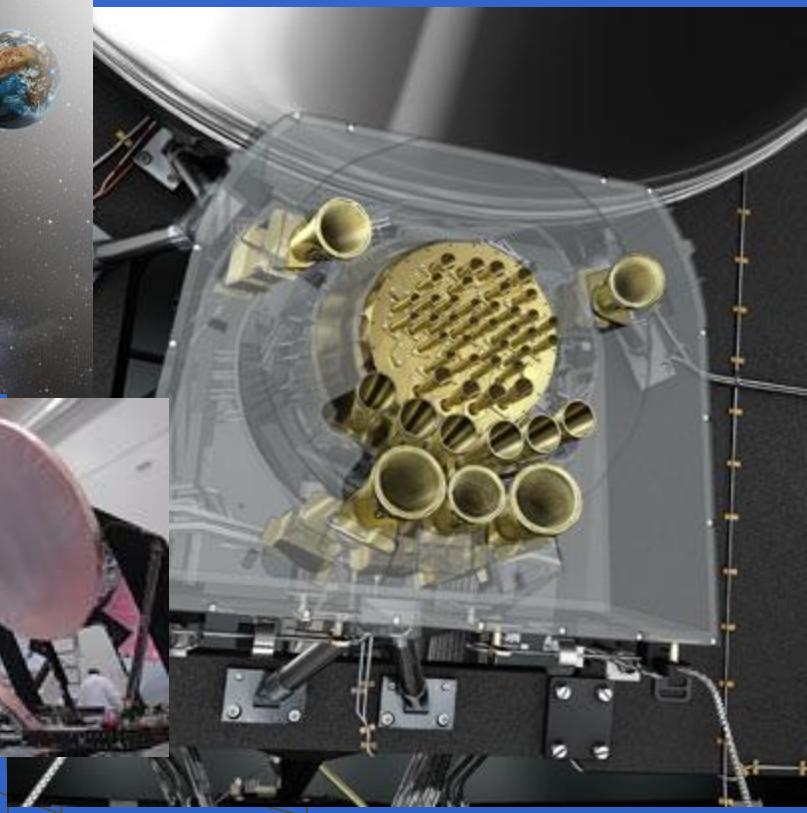
Low Frequency Sky Surveys



- The Only existing Full sky map is the 408 MHz survey by Haslam et al. (1982)
- Although it has a good angular resolution (0.85º), zero levels (±3K) and gain uncertainty (10%) make extrapolation to higher frequencies lack precision
- Comparable maps at a different frequencies are needed for extrapolation that accounts for spectral index variations

Planck Surveyor ;
30-850 GHz (Temp : 100 mK)

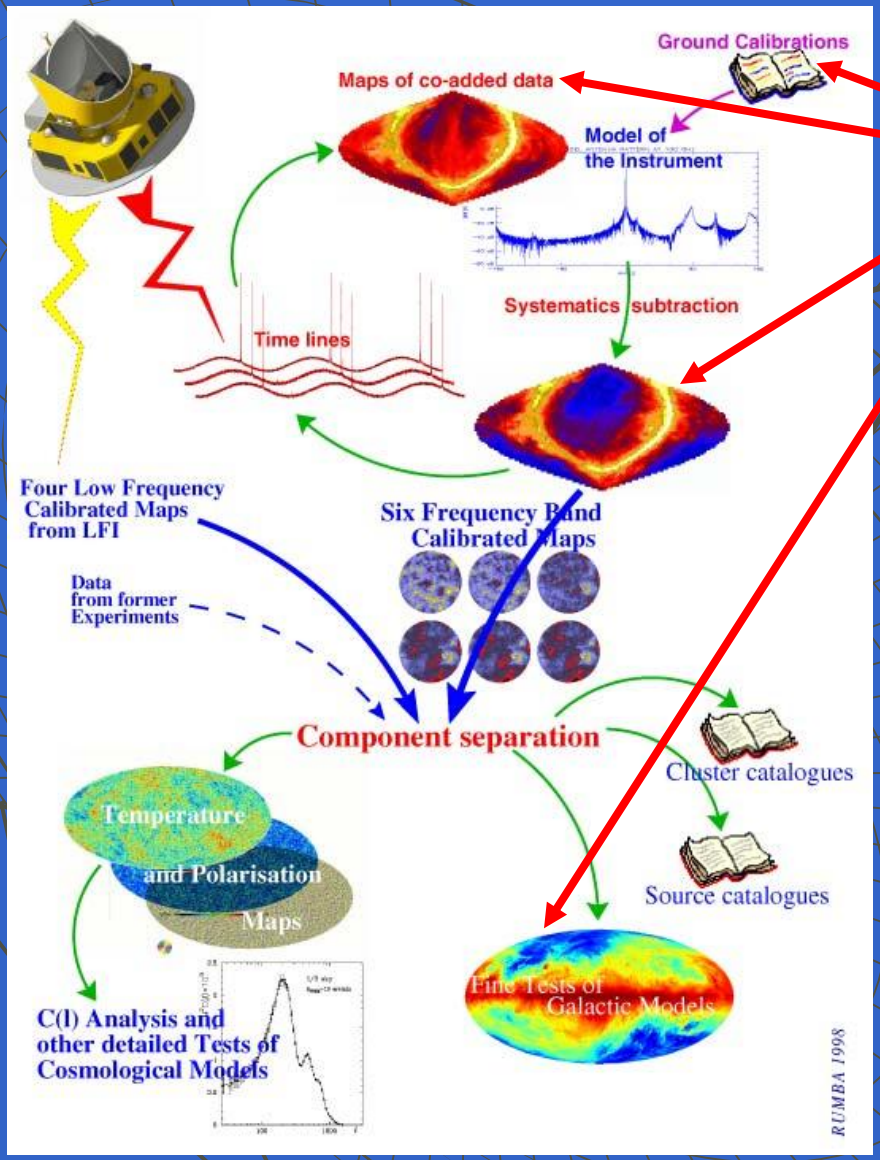




Planck Surveyor ; 30-850 GHz (Temp : 100 mK)

- COBRAS (Mandolesi, Bersannelli, Smoot) – 1994 **(-> LFI)**
- SAMBA (Puget et al.)- 1994 **(->HFI)**
- Merged in 1996 (COBRAS/SAMBA Phase A ESA red book (Barbosa et al.,1996 pilar for SZ WG5)
- It became Planck; see the legacy effect

Planck Data Pipeline

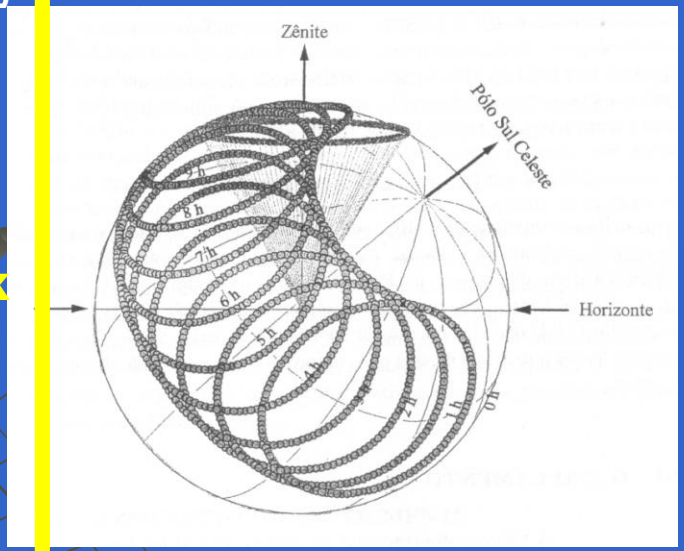


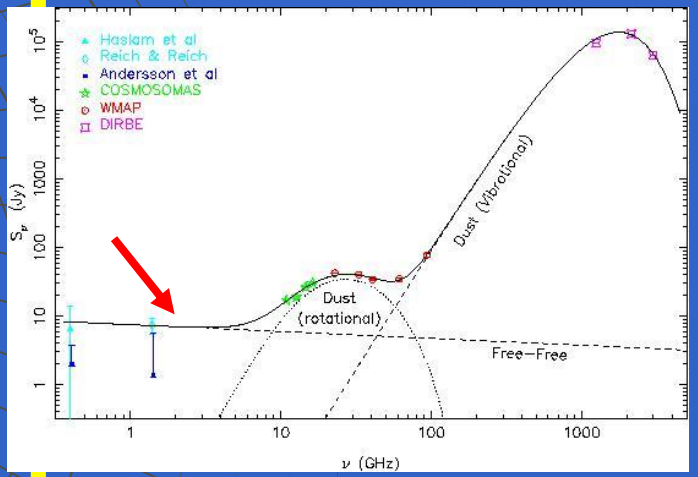
GEM

- **Planck foreground removal is an important issue**
- **Need absolute ground calibrations at low frequencies**
- **Absolute co-added data**
- **GEM templates will feed Planck data pipeline with low frequencies absolute calibrations**
- **GEM importance for Planck Survey – Working Group 2,7**

GEM – Galactic Emission Mapping

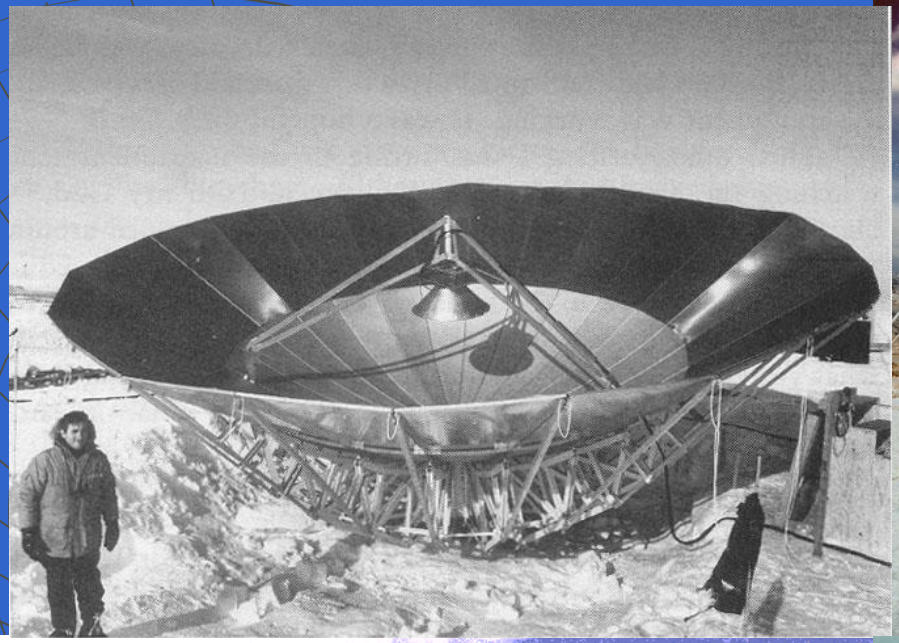
- **Synchrotron polarization survey @ 5, 10 GHz+2.3GHz I**
- **North and South Hemispheres 80% sky coverage**
- **Same scanning strategy of Planck Surveyor Mission**
  - **1 rpm azimuthal rotation**
  - **Avoid HEMT 1/f noise and atmospheric noise drifts**
- **Test for spinning dust (in col. With IAC) Cosmosomas 5,10 GHz Perseus scan**
- **Resolution @5GHz, 32 arc min, <0.5 mK sensitivity**
- **Elevation "jitter" – similar to nutation/precession in satellites**



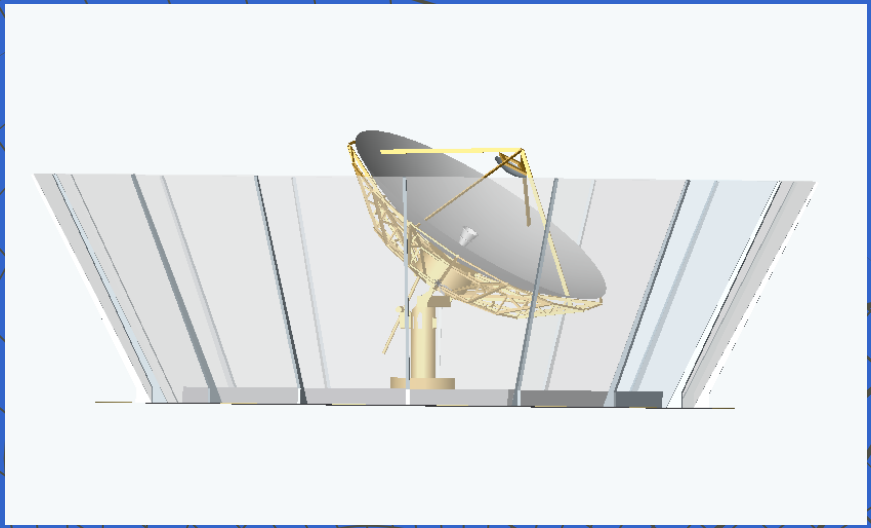


Observation sites

GEM



Portugal and Brazil

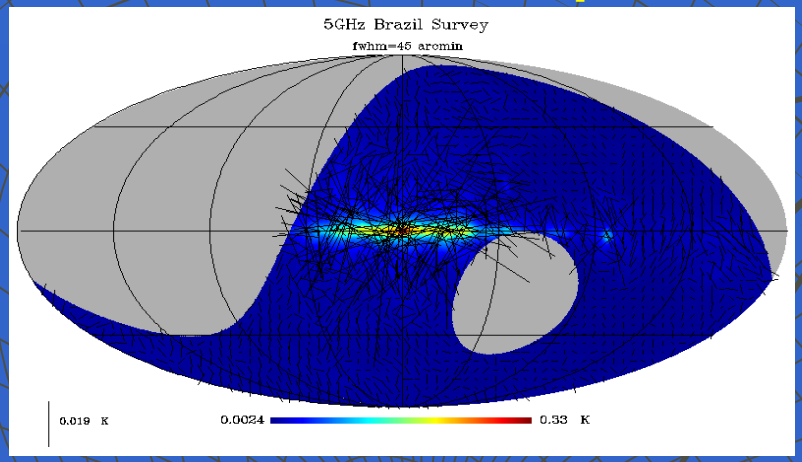


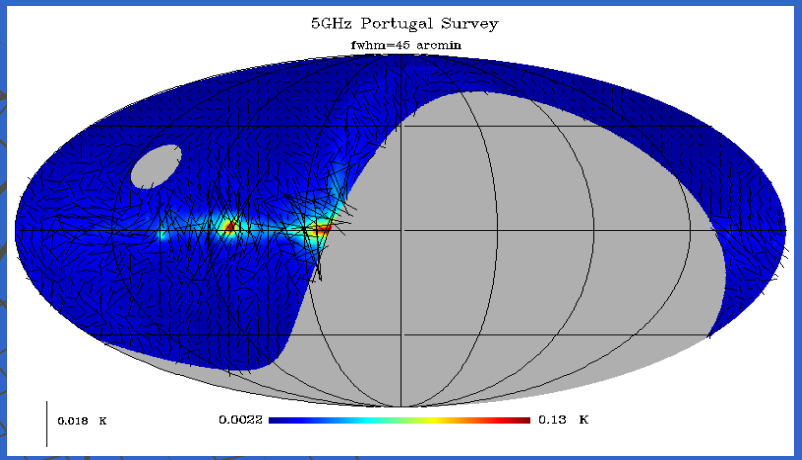
- Digital correlator receiver
- 9 m diameter dish (offered by PT)
- In commissioning!
- First results expected in 2009

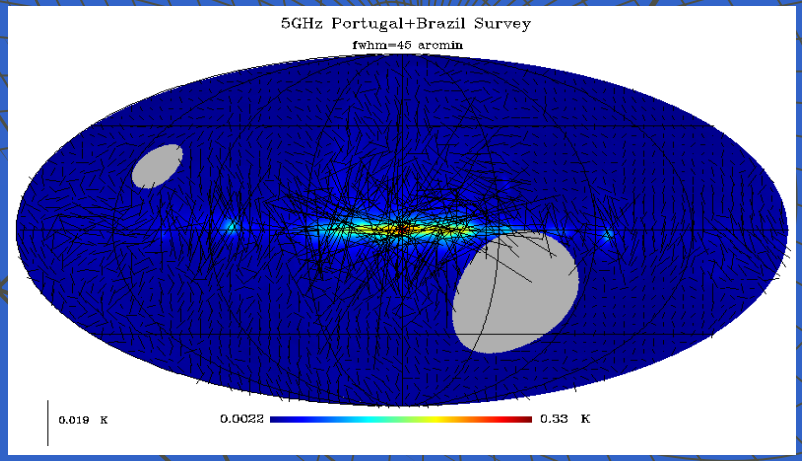
- Pseudo correlator receiver
- 5.5 m diam. dish (extended to 9 m)
- Already first light
- First results in 2008

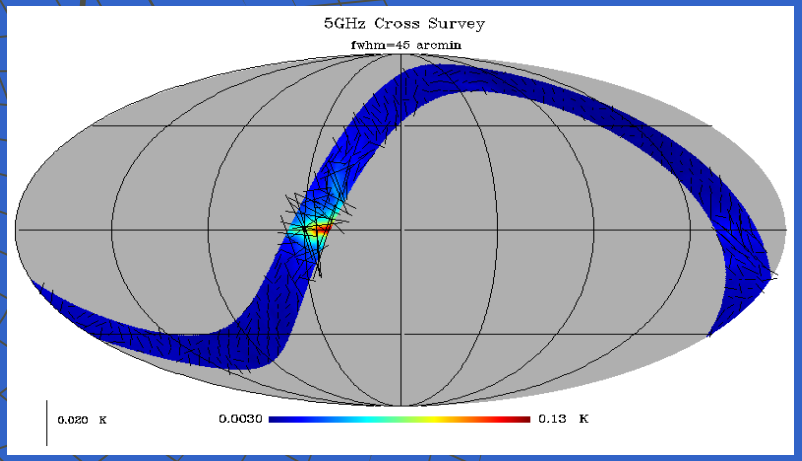
5 GHz Portugal and Brazil Surveys

The Galactic Emission Mapping project aims to accurately determine the absolute intensity and polarization state of the radiation emitted by the Milky Way at several frequencies in the radio and Microwave spectrum

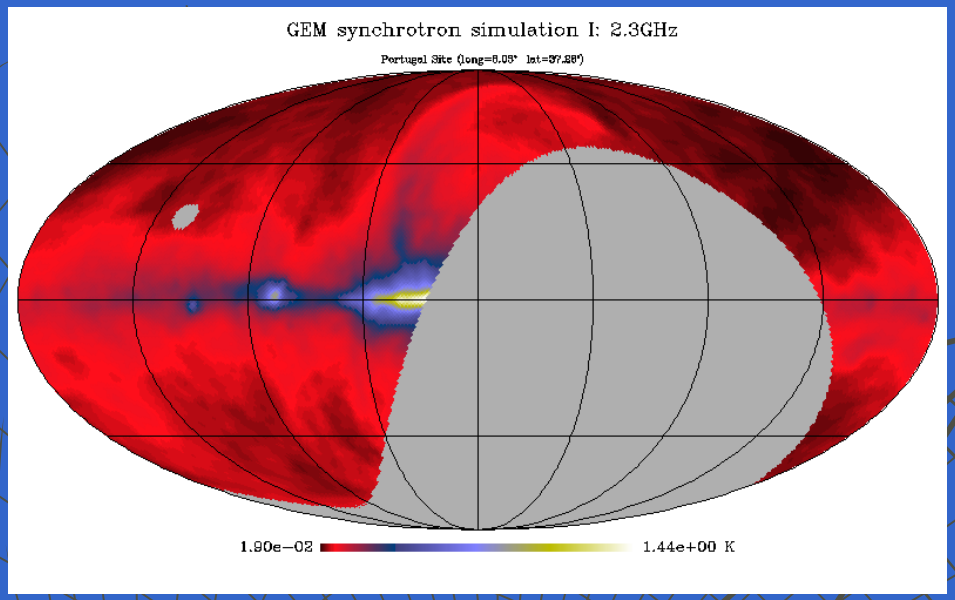






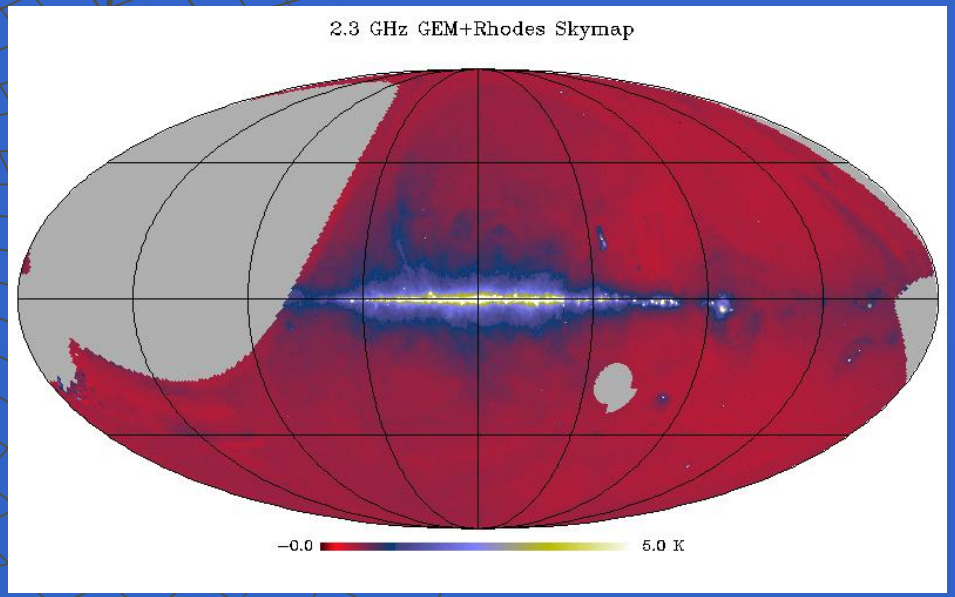


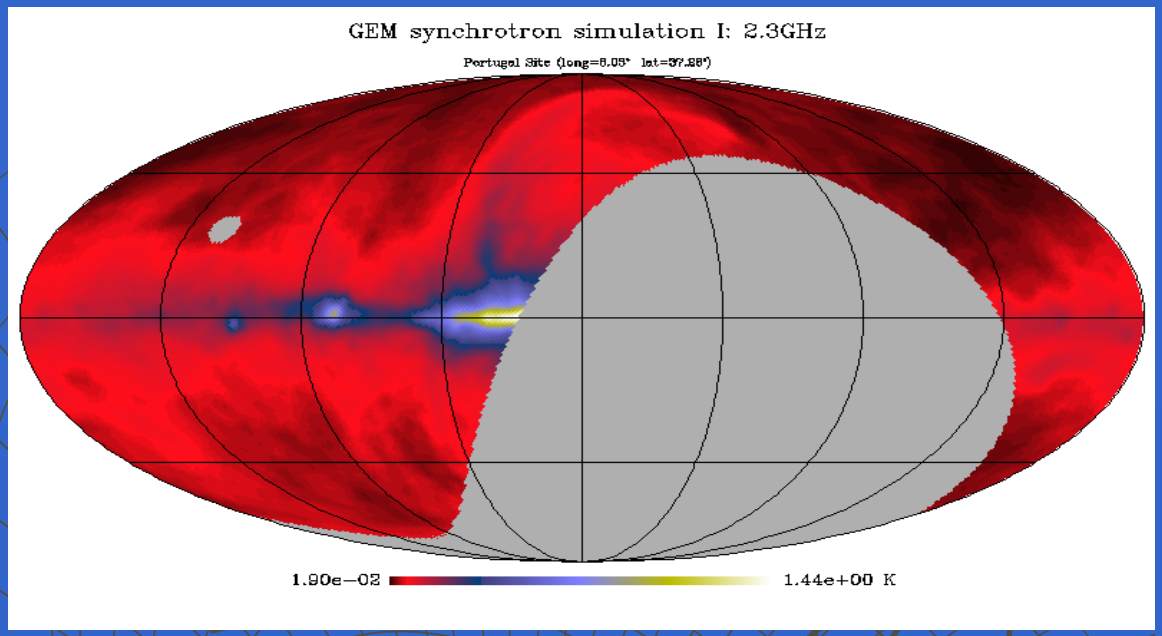
2.3 GHz Survey

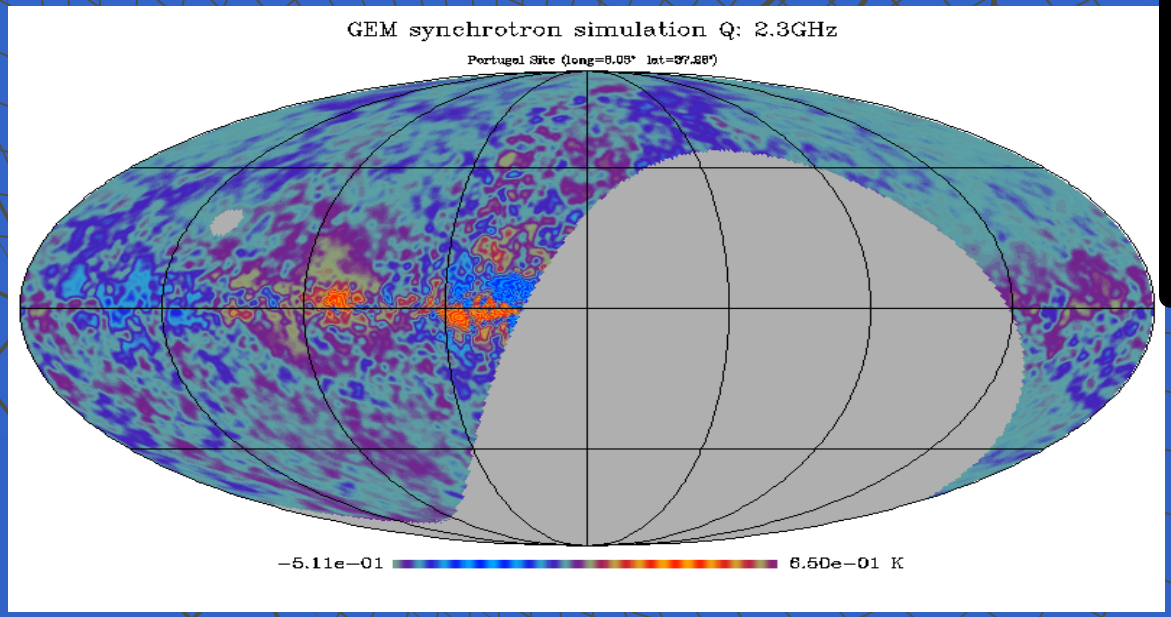


- Expected north Hemisphere coverage
- 2 weeks integration time
- Total power radiometer (M. Bersaneli)
- Mid 2009

- Current 2.3GHz south hemisphere
- GEM + Rhodes
- "A 2.3GHz map of the sky: a new synchrotron template", Tello, Villela, Smoot, Bersanneli, Barbosa, Cingoz, Ferreira, Lamb, Perez-Becker, Smoot, Carrivan, A&A, astro-ph







Single-pixel code :

Using Planck Simulated reference sky:

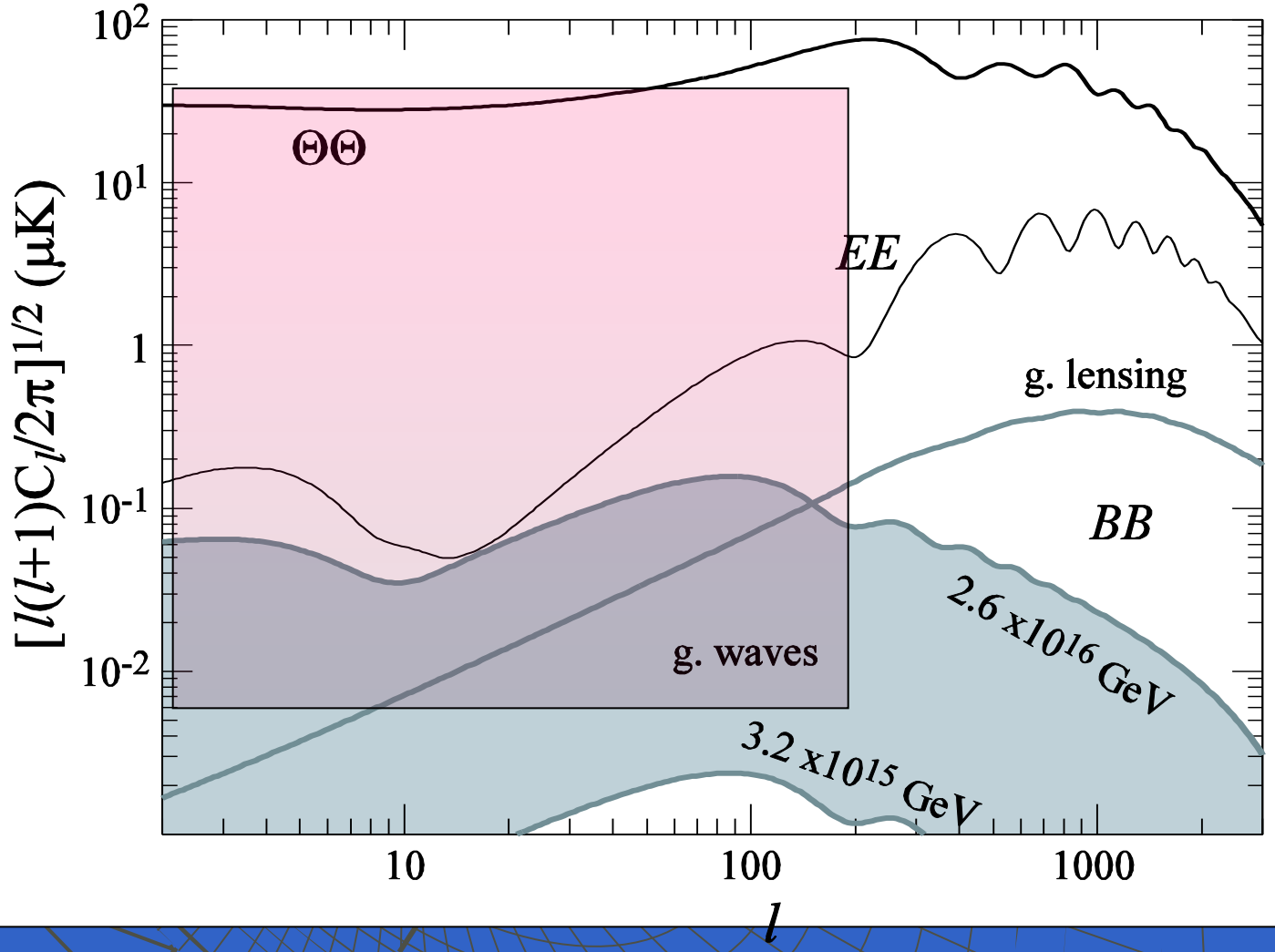
GEM+Planck:

@ synchro amp : 50% better

@synchro index: 3x better!

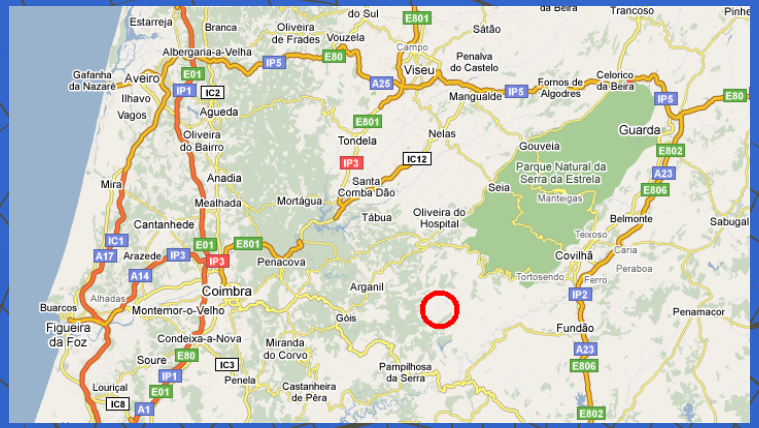
MoU with ESA !

GEM-P coverage : l~200 (fwhm~32')

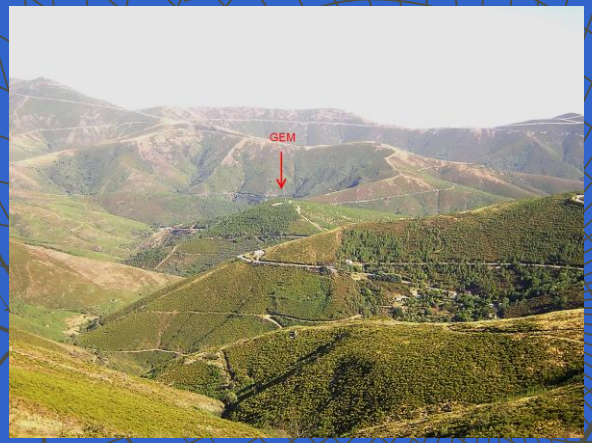


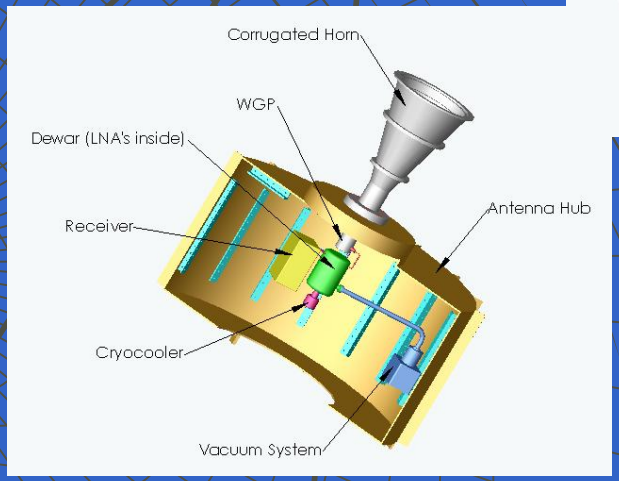
Sensitivity ~300uk (@5GHz)

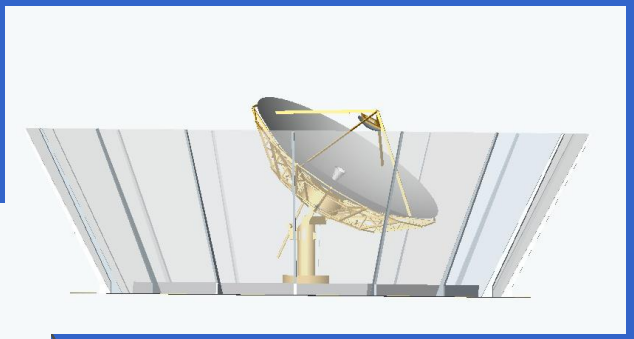
GEM-P



- Digital correlator receiver
- 9 m diameter dish (offered by PT)
- In installation
- First results by 2009/2010

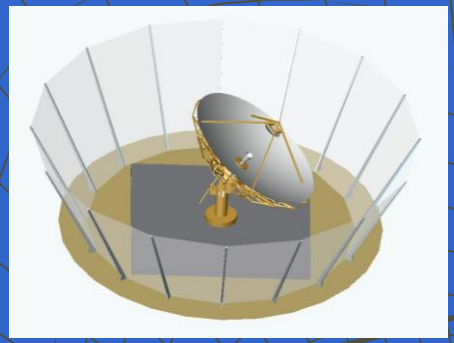


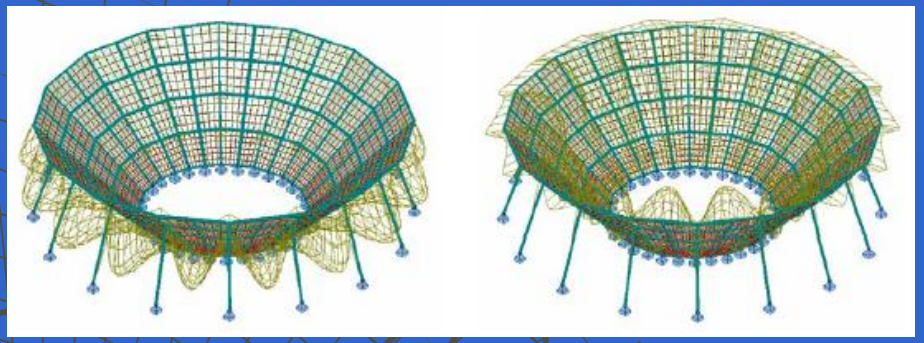


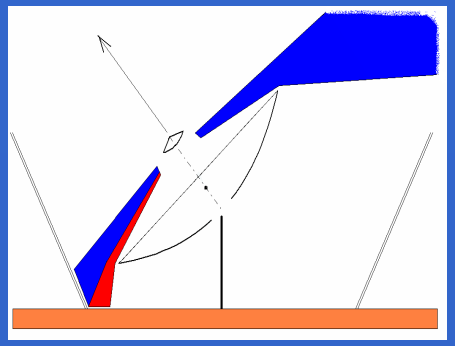


- Fajão, Concelho de Pampilhosa da Serra
- 840m altitude (RFI tested – Fonseca et al., 2006)

Antenna – Foundations and Ground Screen







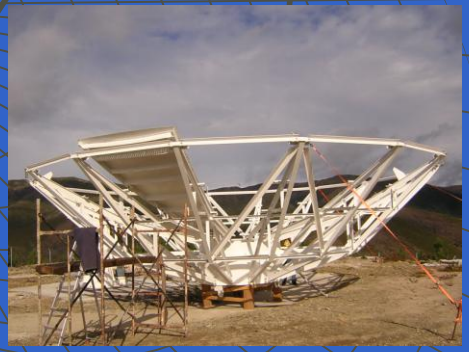
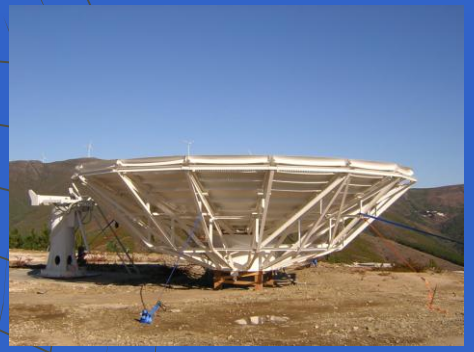
- Protect from ground pick-up
- Spillover & ground shielding (20 dB atten.)
- Mechanical simulations to check compliance with antenna and wind requirements
- Ground Screen awaiting for implementation (funding)

Antenna – Site & Assembly





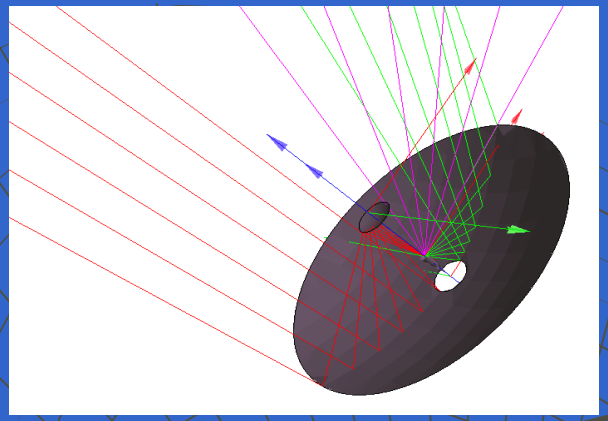


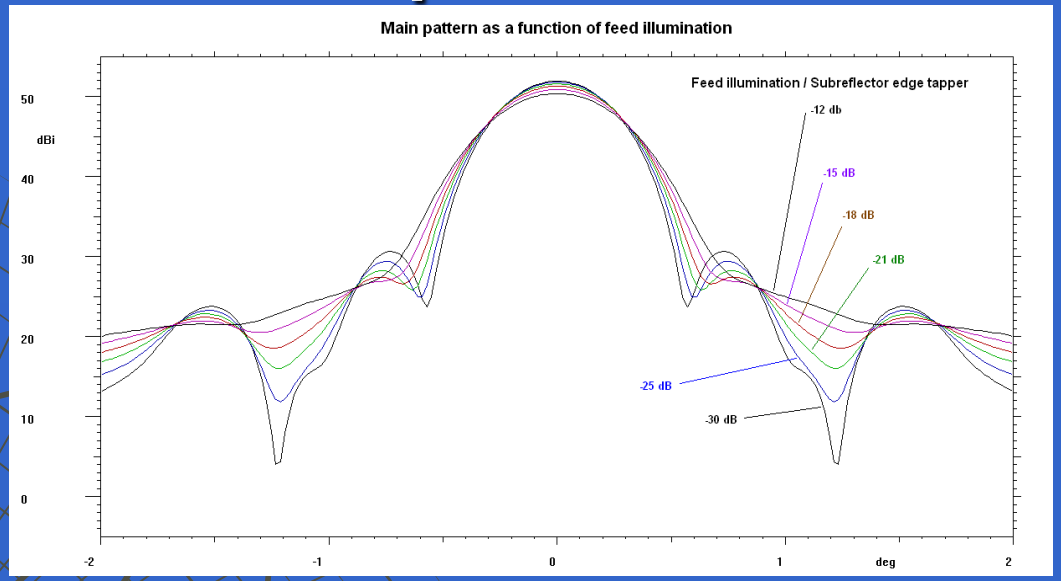




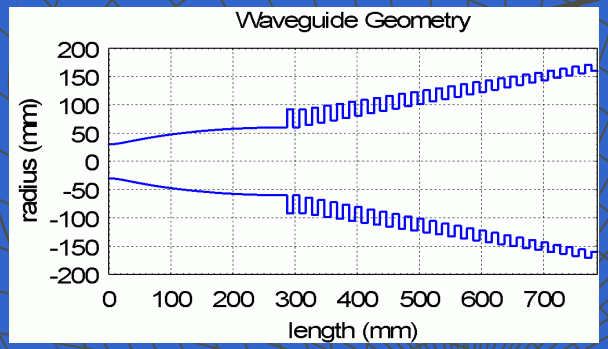
Antenna - Assembly

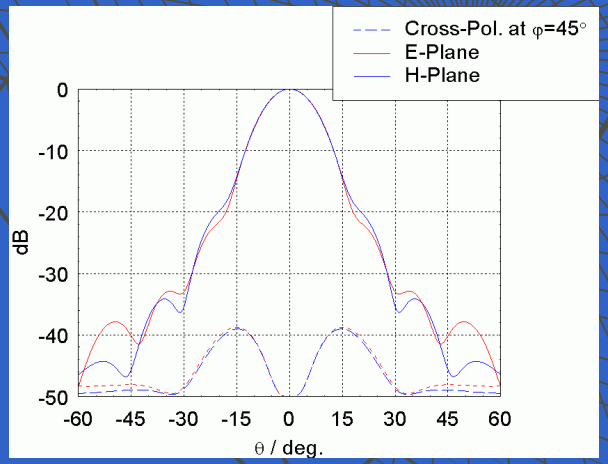
- ***Problems : undesired visit of metal scrap robbers; serious dmage+ 6-9 month delay.2nd dish assembly***

Antenna - Optics



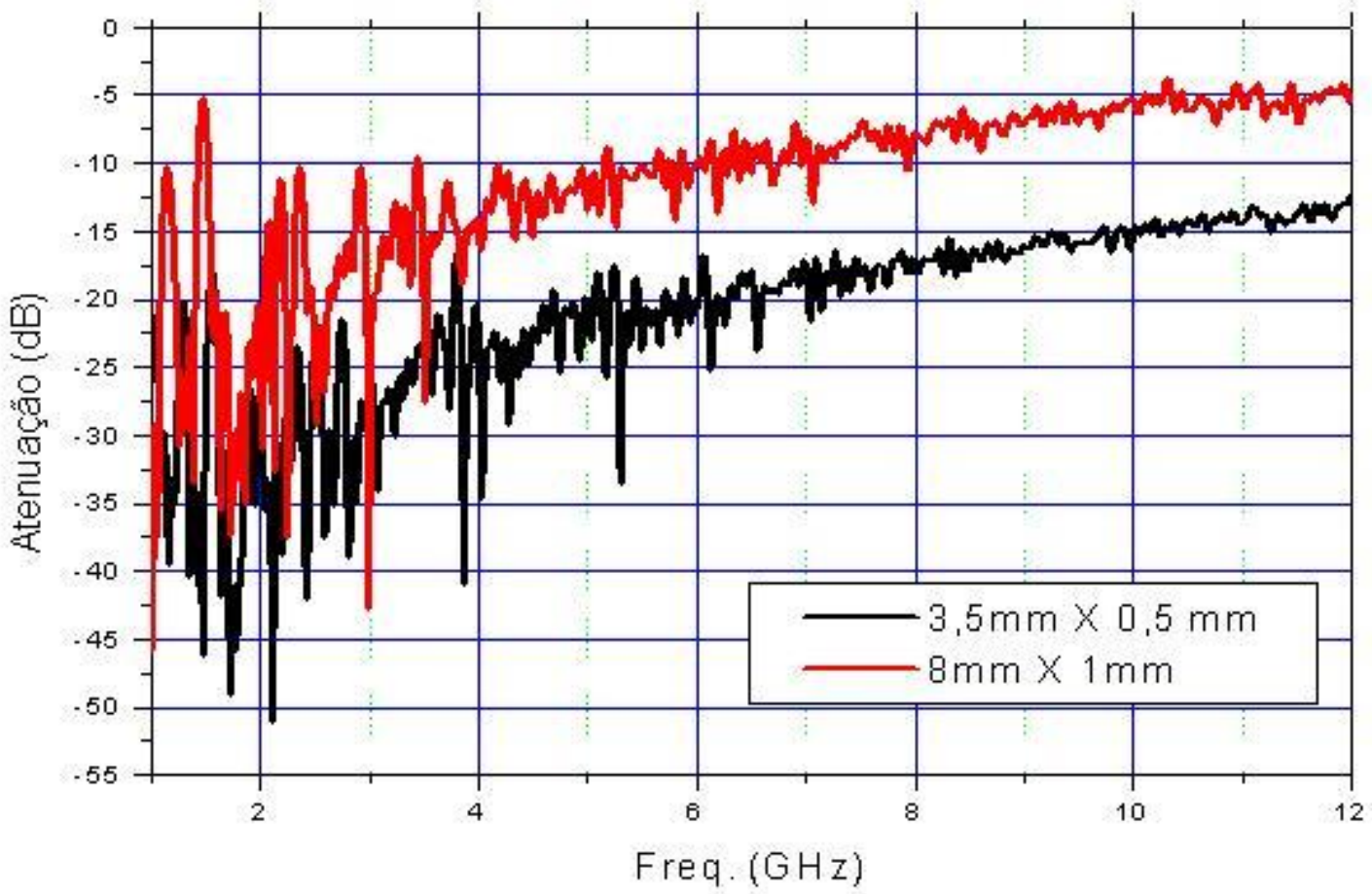


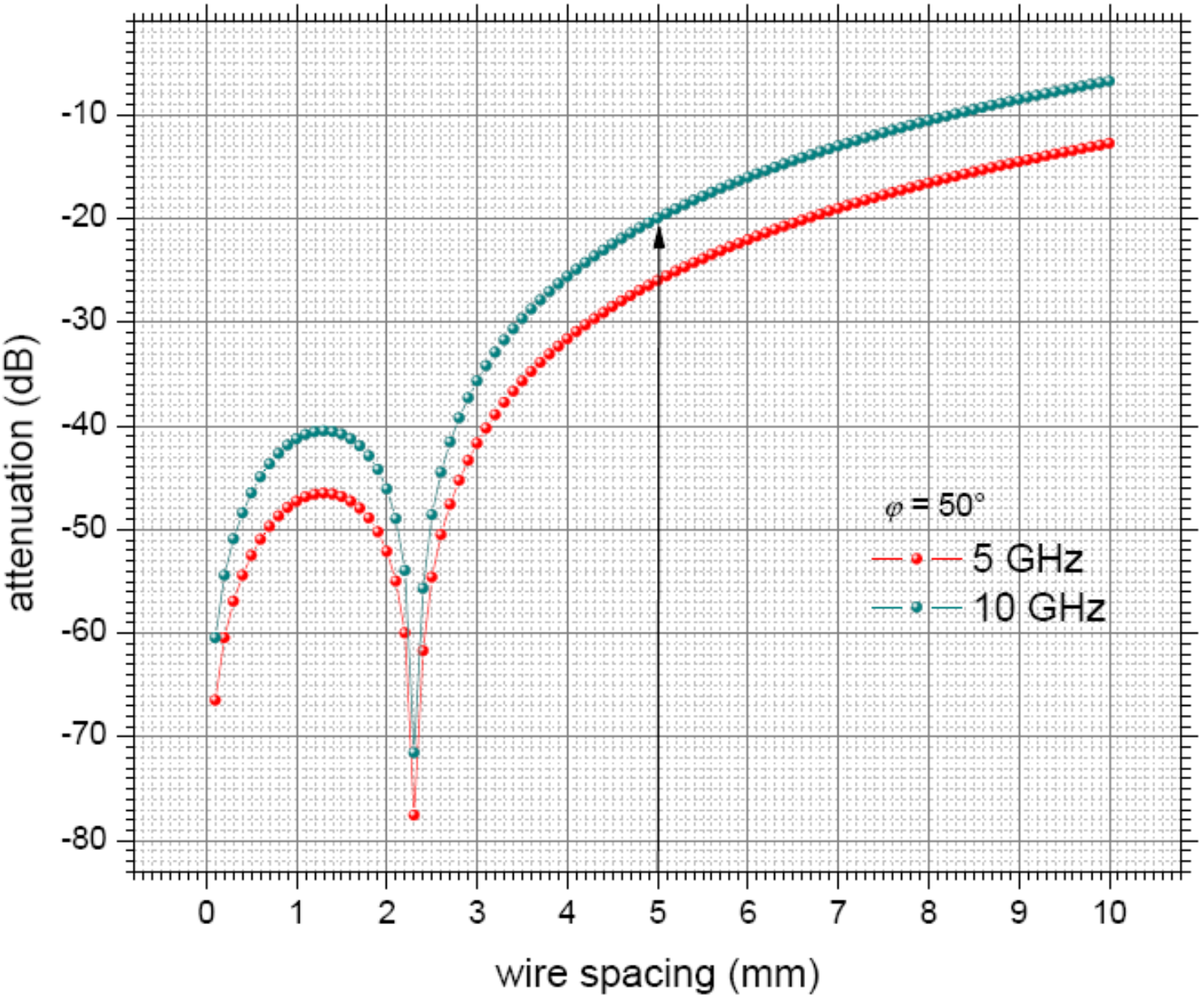




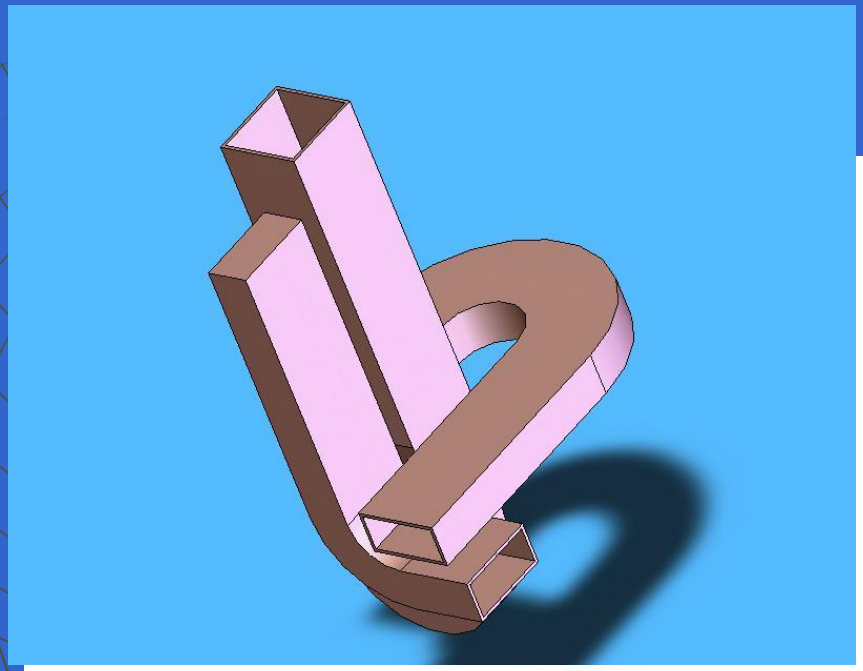
- **Optimize antenna response (G/T~40 dB/K), GRASP, HFSS, Planck IDIS Level S:**
- Cassegrain focus configuration
- New feed (corrugated horn)
- Main dish illumination (edge taper > 20dB)
- Spillover & ground shielding (20dB)
- Guarantee low cross-polarization.

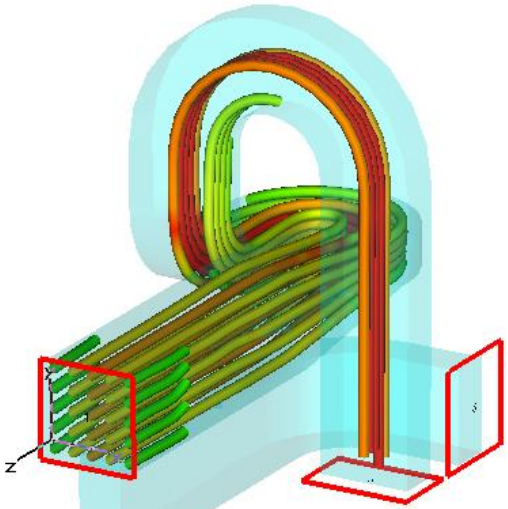
Atenuação da tela (Ferreira et al.)



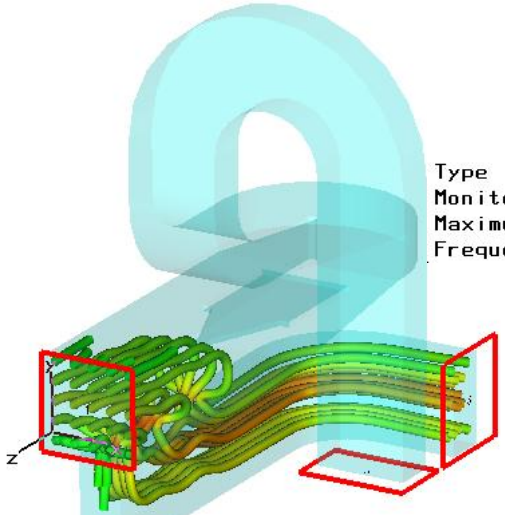

attenuation (dB)
-10
-20
-30
-40
-50
-60
-70
-80
0
1
2
3
4
5
6
7
8
9
10
wire spacing (mm)
φ = 50°
5 GHz
10 GHz

Brasil : OMT





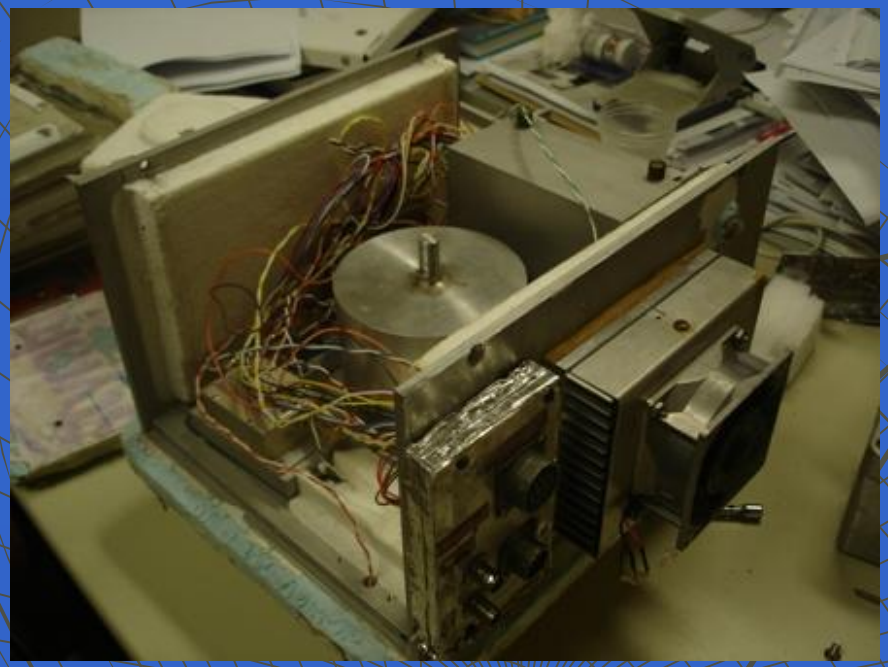
Type = Powerflow (peak)
Monitor = power (f=5) [2(1)]
Maximum-3d = 2098.53 VA/m^2 at -38.8107 / 8.68125 / -320.343
Frequency = 5



Type = Powerflow (peak)
Monitor = power (f=5) [3(1)]
Maximum-3d = 5119.24 VA/m^2 at -2.84 / -25.775 / -97.5303
Frequency = 5

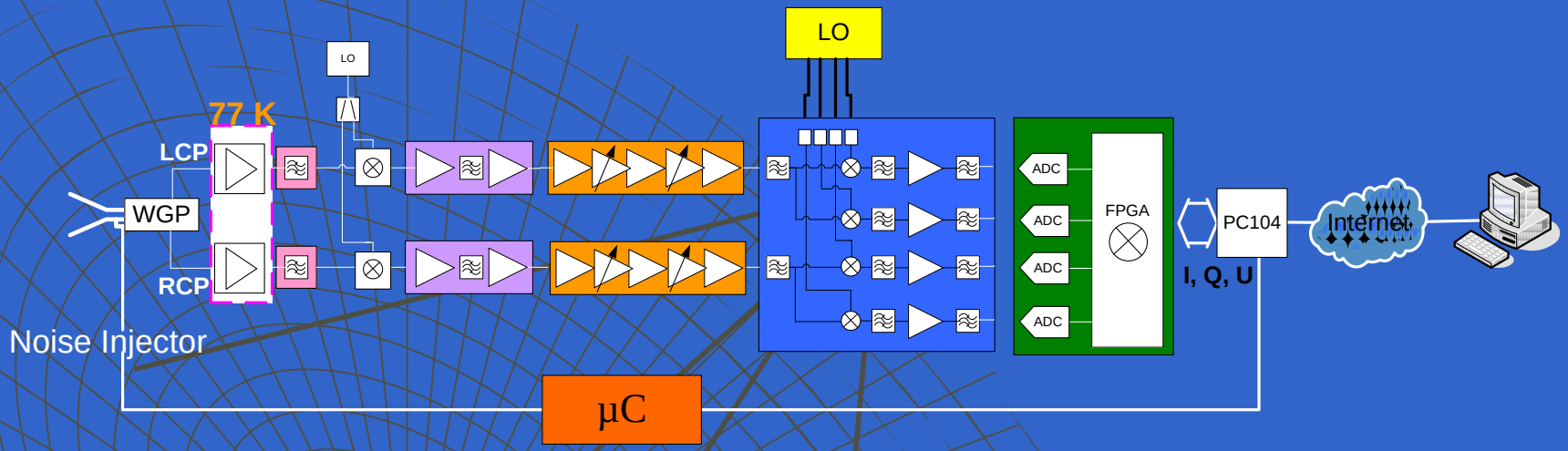
Rui Fonseca initiated
IEEE Wireless let. (sub)
Ferreira et al.

Receiver 2.3GHz



Done !! Instalation soon ! Tested in the field already !

Superheterodyne 5GHz Receiver (Base-band Complex Correlator)



Novel approach to digital correlators!

The radiometer/polarimeter gain budget:

Antenna	LNA	Passive Filter	Mixer	IF Pre Amplifier	IF Amplifier	Converter	ADC
Input (dBm)	26	-4	-7	31	56	2	Output(dBm)
-105,6	-79,6	-83,6	-90,6	-59,6	-3,6	-1,6	-2

Receiver sensivity

$$\Delta T_{min} = \sqrt{\frac{k^2 T_{sis}^2}{\Delta\nu\tau} + T_{off}^2 \left(\frac{\Delta G}{G}\right)^2 + \Delta T_{off}^2},$$

$$\Delta T_{min} = \sqrt{2}\frac{T_{sis}}{\sqrt{\Delta\nu\tau}}.$$

$$T_{sis} = T_a + \frac{T_b}{G_a} + \frac{T_c}{G_a G_b} + \frac{T_d}{G_a G_b G_c} + \cdots$$

$$T_a = T_{amb}(1 - F_a)$$

Sensitivity : 2 mK $sec^{1/2}$

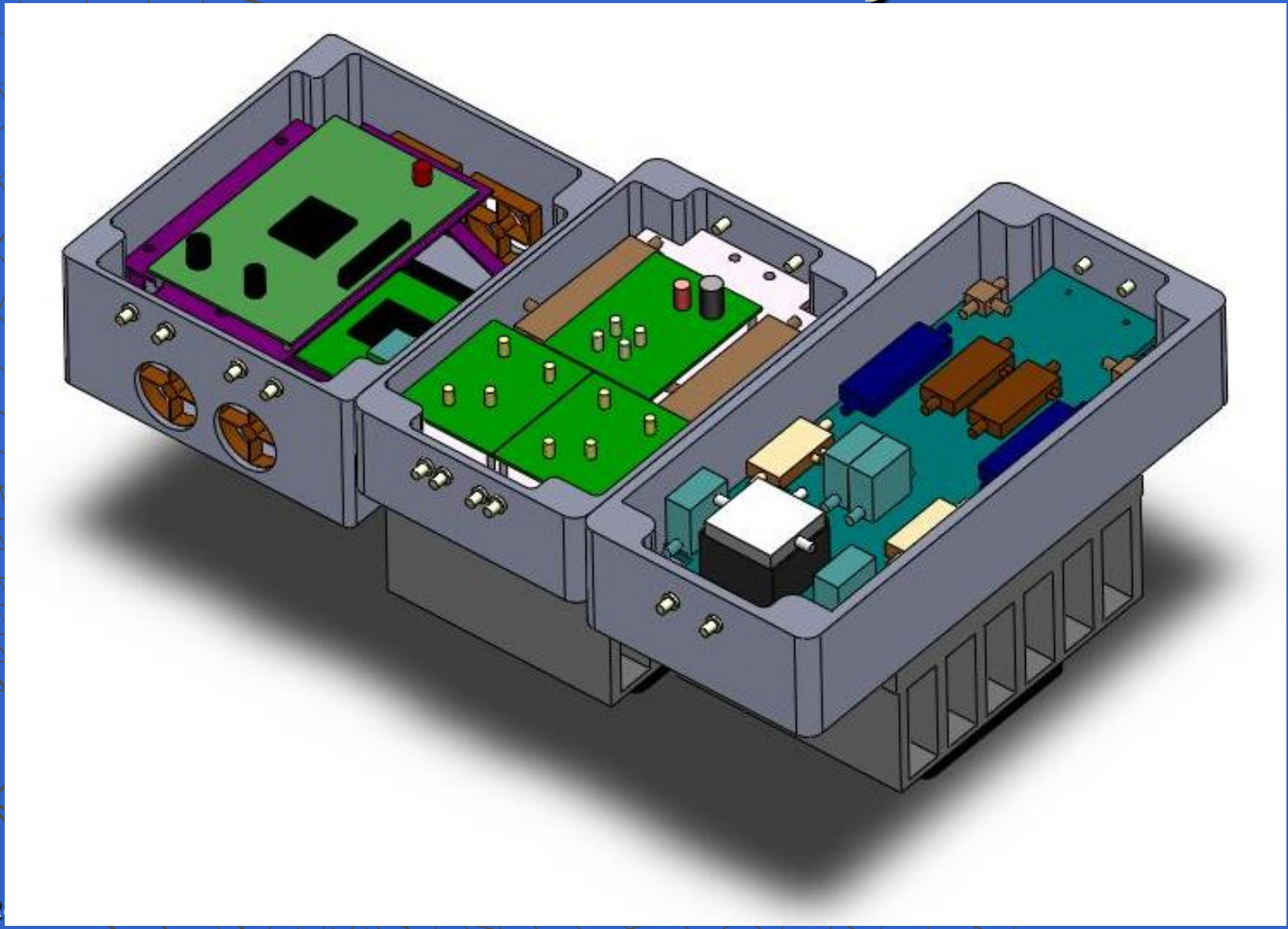
Conclusion : Radiometer facts

- Tsys < 20 K; B = 200 MHz; 104 dB gain
- High-performance IF strip
- Latest RF tech+ microstrip design + MMIC

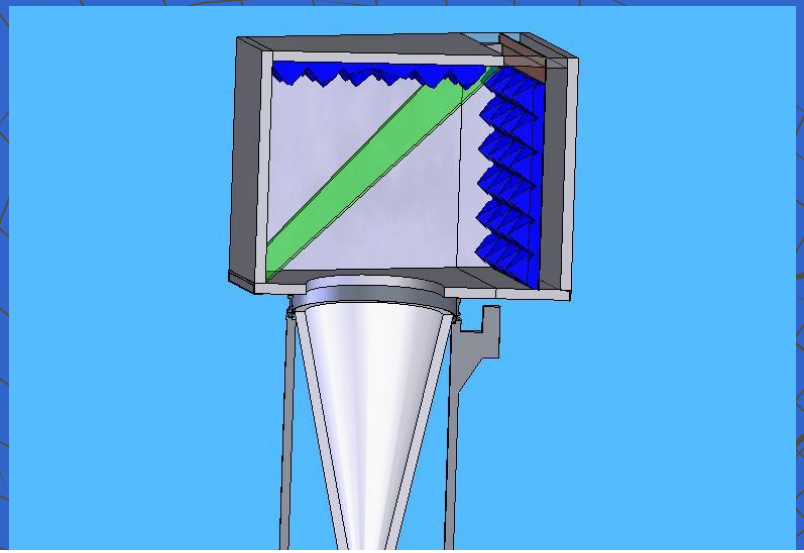
New Radioastronomy Design:

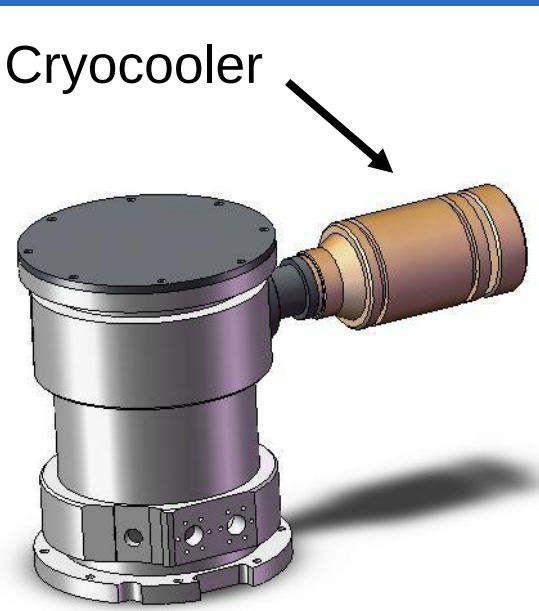
- Zero-IF Converter + I,Q modulation
- Digital Correlator : 4-channel, FPGA implemented!
- Dynamic Range: Total=20dB, Instantaneous=80dB
- Suitable for state of the art radioastronomy applications.

Mechanical Layout



Frontend cryogenic assembly in design + external calibrator

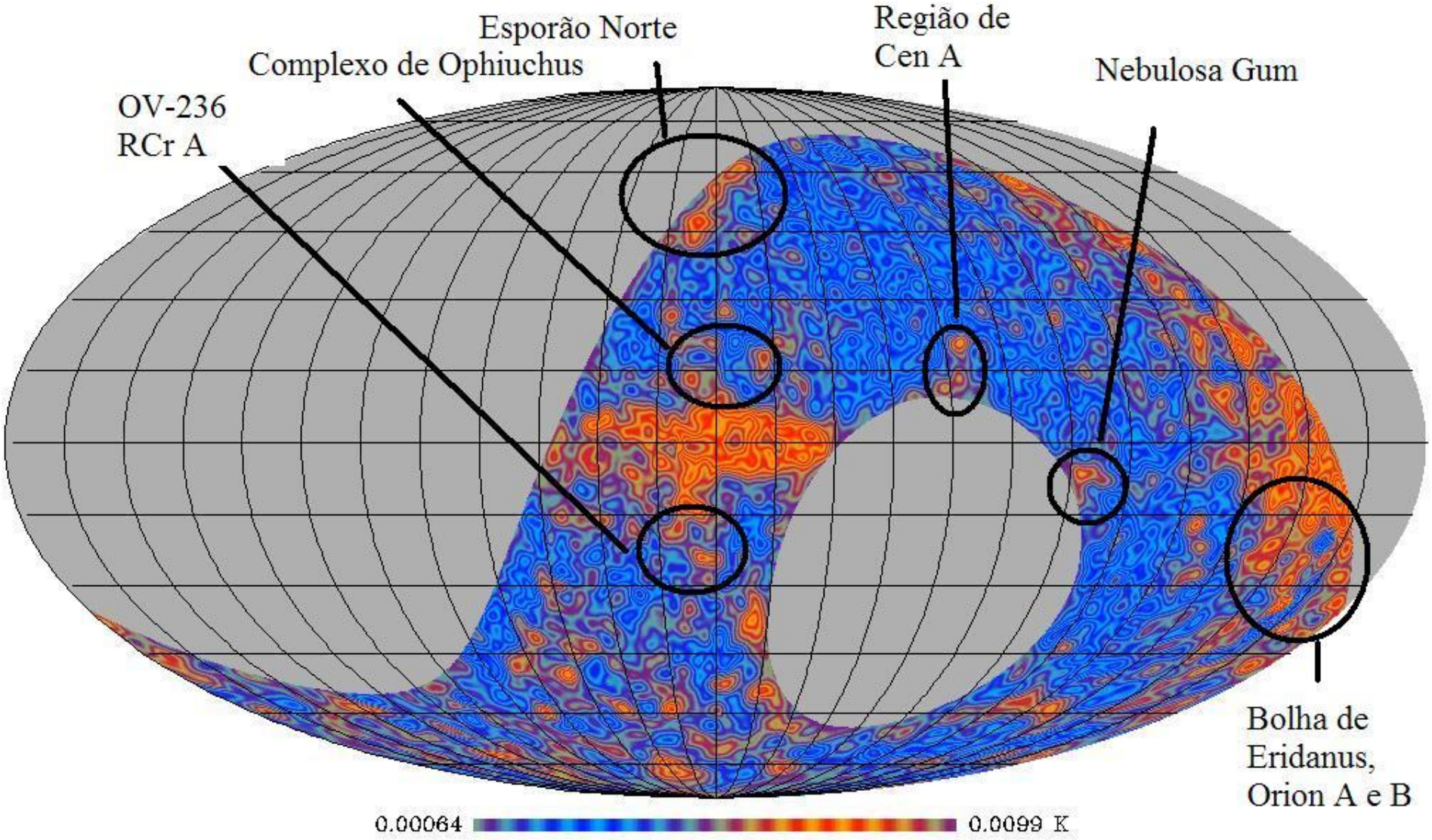




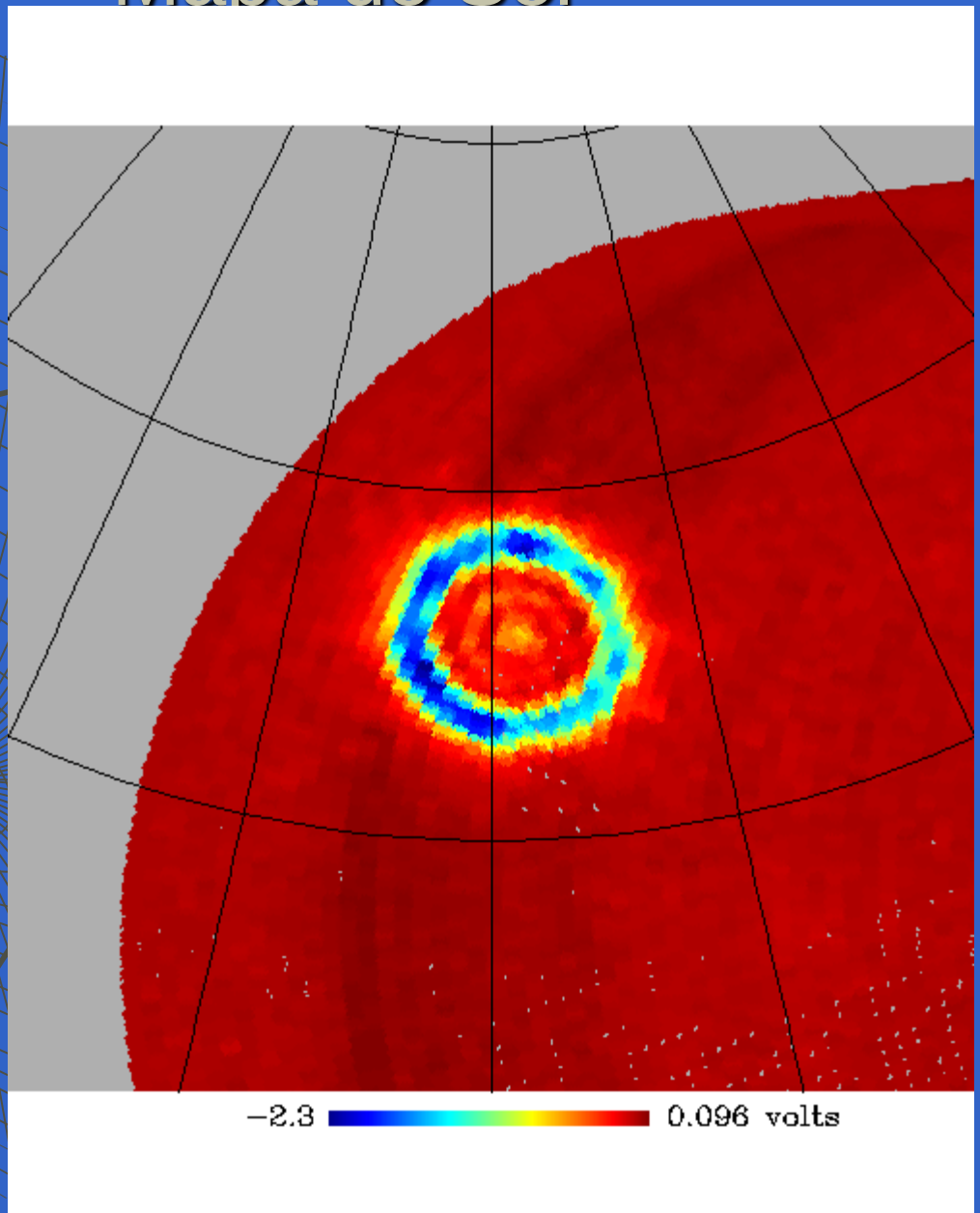
$$I_x = T_f + (T_q - T_f)R_{TE} + (T_p - T_f)\epsilon_{TE};$$
$$I_y = T_f + (T_q - T_f)R_{TM} + (T_p - T_f)\epsilon_{TM};$$
$$Q = (T_q - T_f)(R_{TE} - R_{TM}) + (T_p - T_f)(\epsilon_{TE} - \epsilon_{TM});$$
$$U = 0.$$

It means high effciciency on integration time – no LN leaks. Cryocooler bought by our lab (own funds)!

Results from GEM-South - Pol



Mapa do Sol



Modelling: inputs

Line-of-sight integration of emissivity and Faraday rotation, e.g. synchrotron:

$$I(\nu) \propto \int_{LOS} n_{CRE} B_{perp}^{2} \, d\,l$$

to create total and polarised intensity as well as RM maps needs:

- magnetic field model including large-scale/regular and small-scale/random
- 3D dust emissivity model
- 3D CRE density and spectral model (*galprop* by Strong et al.)
- 3D thermal electron density model
- integration code
- MCMC model selection?

Future

- Planck: full sky polarised dust and synchrotron emission (free-free also useful);
- CBASS and GEM: full sky Stokes at 5 GHz;
- GALFACTS: RMs over Arecibo sky at 1.4 GHz;
- Extensions to IGPS (more RMs);
- Parks Galactic Meridian Survey (PGMS);
- ....

GEM Goals

- **Biggest synchrotron polarization template (2.3GHz , 5GHz) – NEW EMISSION DISCOVERIES/MAPPING**
- **Foreground control of CMB space probes + galactic science (absolutely calibrated maps): Planck Surveyor WG7 proposals, MoU (this week) with ESA**
- **Probe ensitivity target for ESA Cosmic Vision Polarization Probe 2015-2025 (CMB B-mode): priority defined for next generation of Einstein Probes (NASA Microwave Task Force)**
- **Calibration of radiometers for planetary missions (JUNO-Jupiter Polar Orbiter / NASA-JPL 2010+). Aproved !**
- **Acquisition/testbed of needed R&D for radioastronomy / space science instruments : Low power digital microwave radiometers.**
- **Recently: SKA testing and foreground control (Prep-SKA FP7 member) + ARENA-Antarctica CMB exp.**

Summary

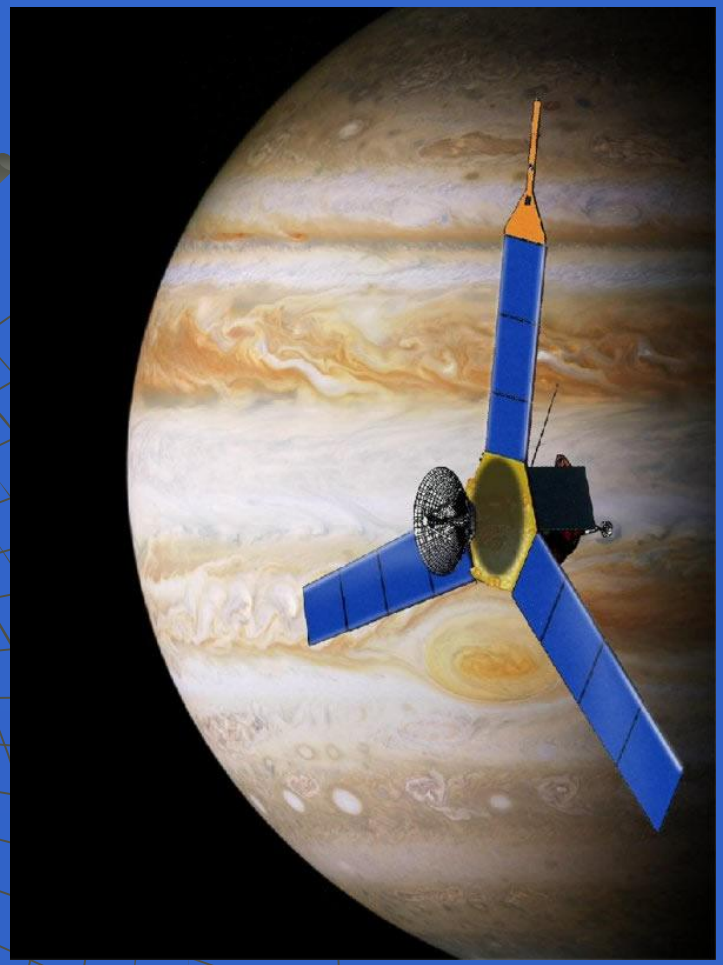
- There is much to learn from synchrotron emission
  - Traces major energy component of ISM (cosmic rays)
  - Major synchrotron features may be stranger than we thought
  - Current spectral data extremely shaky
  - Major progress possible soon due to dramatic increase in spectral range (esp. for polarization) and calibration reliability.
- Synergy with γ-ray observations of diffuse emission, especially with GLAST
  - Bremsstrahlung (same electron energy as microwave synch.)
  - Inverse-Compton (~2 orders of magnitude higher energy)
  - Deflexion charts for UHECR !

Pathfinder to :

- **Experiments probing the 10-20GHz spectrum (similar to QUIJOTE – Spain)**
- Exploit the band (with INSCAF) 20-50GHz for polarized foreground, with coherent receivers – in Antarctica or high dry site.
- Sub-orbital / small concept satellite for <50GHz without optics : high-bandwidth 2-beam differencing pair of radiometers in 10 years.
- Inclusion on B-Pol/CMBPOl science and R&D

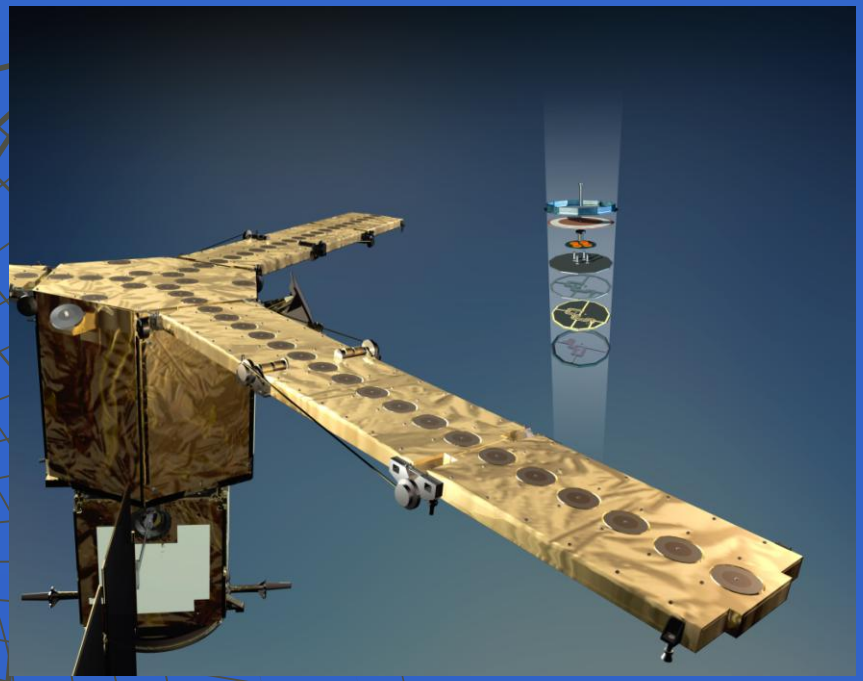
Calibration of space radiometers

- **Juno (NASA)– launch in 2010 to Jupiter;**
- **MWR – probes Jupiter athmosphere (600MHz-30GHz)**
- **Calibrate when MWR sees deep space**
- **PIs:Steve levin,Paul Janssen**



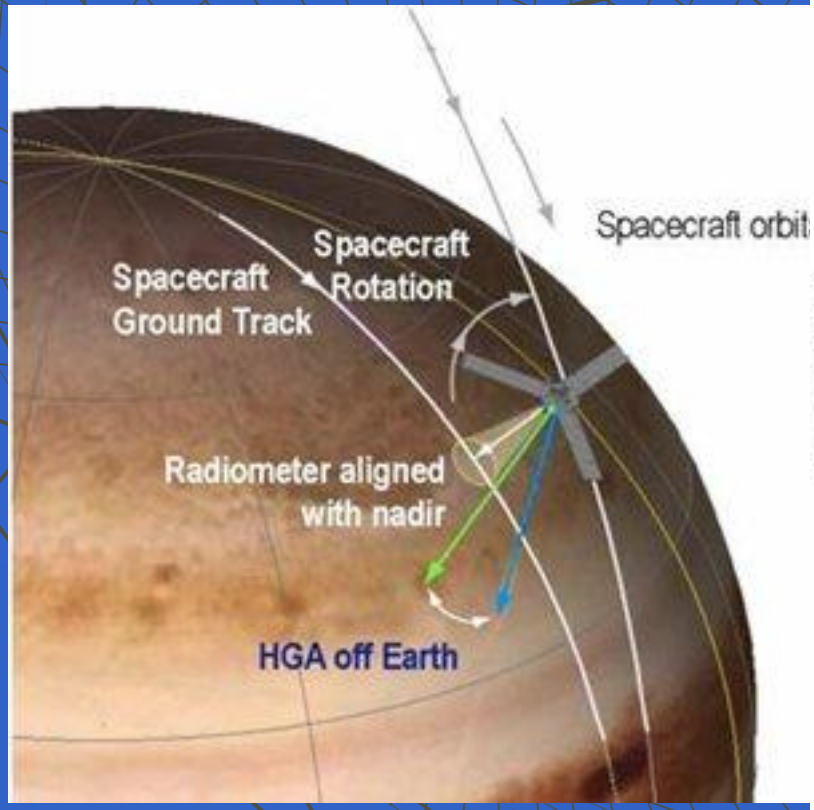
Sky template for Earth Observation/remote sensing

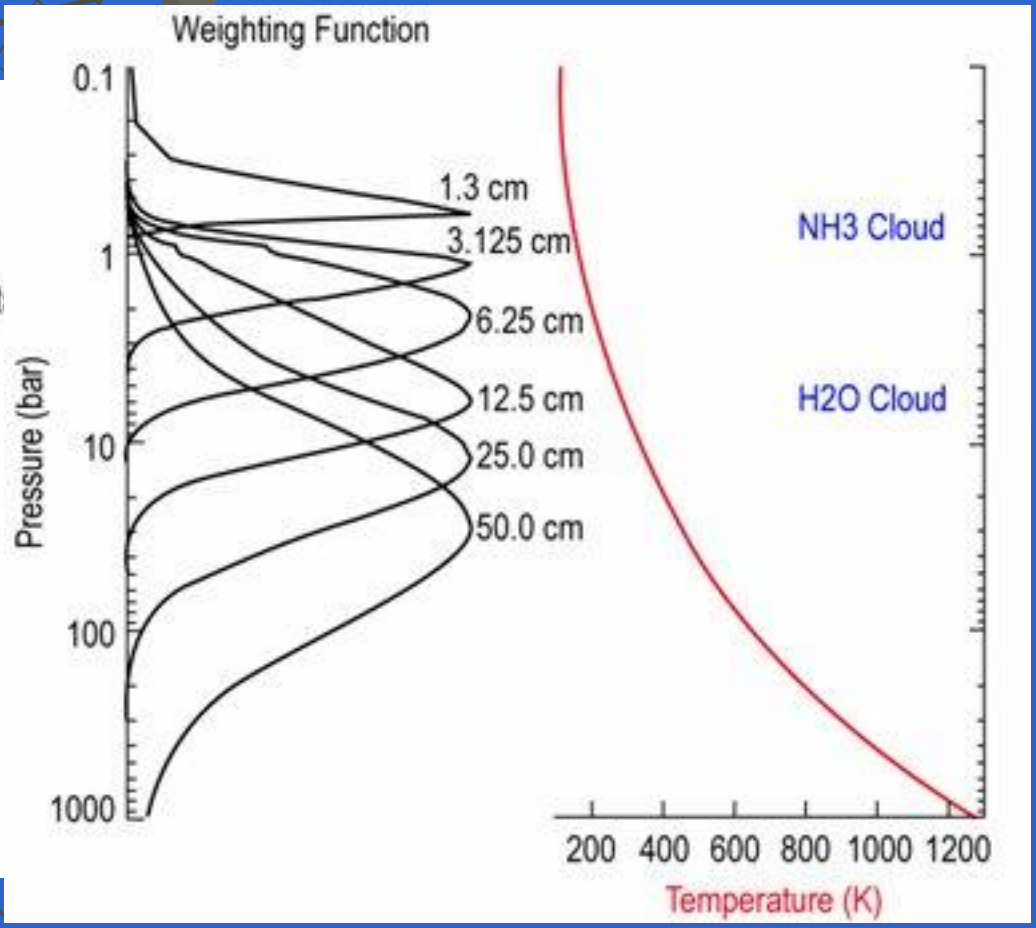
- **Satellites use in their software packages for calibration.**
- **Ex. SMOS (CMB and galaxy account for most of deep space flux)**



Calibration of space radiometers

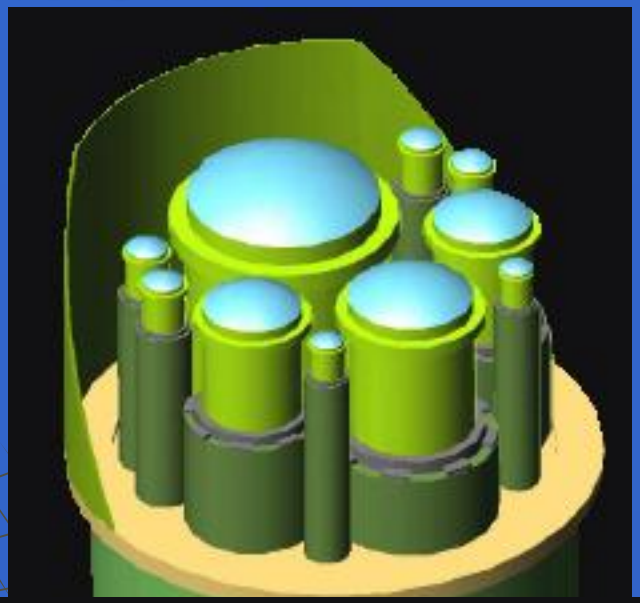
- Jupiter's chemistry





Science Pathfinder for CMB 4th space generation

- Polarization needs 100x gain in sensitivity
- Thus, space is mandatory
- On ESA, NASA future roadmaps
- Specs dependent on Planck and R&D maturing
- GEM on Foreground WG (with IT and IST)




Estação Radioastronómica
de Porto da Balsa
instituto de
telecomunicações
tmn
até já.