THE COSMIC MICROWAVE BACKGROUND
Planck Legacy Release 2018

Credit: ESA/Planck Collaboration

www.esa.int
European Space Agency
Low Frequency Instrument
Planck heritage: Expertise 1/2

- **Project System team (system engineering)**
  - Low Frequency Instrument
  - Satellite interfaces
  - NASA/JPL Sorption cooler
- **Test and Verification**
  - Radiometer Chain Assembly Test Campaign
  - Radiometer Array Assembly test Campaign
  - System level test (Instrument and Satellite level)
- **Instrument operation team**
  - Flight test and calibration campaign
  - first light
  - Support in data analysis
- **Sorption Cooler System Operation Manager**
- **Calibration and Performance Verification (CPV) Phase Manager**
Planck heritage: Expertise 2/2

- Cryogenics
  - dev. of Sorption cooler of Planck, cryo-chain of Planck, 4K reference load

- Thermal engineering

- RF/microwave engineering
  - passive components, calibrators, EM analysis,
  - amplifiers and radiometer optimization

- Telescope engineering
  - from design to qualification
  - Full Electromagnetic analysis of telescope

- 4K reference load full development

- Sorpiton cooler development @ NASA/JPL

- full development of the calibrator for system level tests

- Data analysis, pipeline development, software development
  - Foreground component separation

- Outreach
to gather competence, skills and experiences to approach all the phases of a large project (space-born and ground-based), from the conceptual design phase to the commissioning and observations.

A reference laboratory for AIV / AIT activities (Assembly Integration and Verification and Test)
Cryogenics + Microwaves = cryowaves

cryogenics and microwave technologies are tightly related one to each other

we can refer to cryowaves technologies, a science and technology branch mainly focused to develop technologies and facilities to build and operate wideband high performance radio, microwave, and mm-wave receivers and antennas to be operated in cryogenic environment
State of the art in calibrators development
Cryowaves è Bologna
the cryowaves experience

Onde millimetriche a temperature criogeniche
Viaggio illustrato dagli Appennini alle Ande
attraversando lo spazio profondo

OAS-days 17-18 Dec 2018 presented by F. Villa
Expertise mainly in experimental Physics

A. Derosa (Technician): Mechanical Engineering
F. Cuttaia (Senior researcher): RF engineering / AIV
G. Morgante (Researcher): Thermal Engineering
S. Ricciardi (Researcher): Outreach, Science, Project Control
M. Sandri (Tecnologa): Outreach, Optics, S/W
M. Terenzi (Researcher): Thermal Engineering
F. Villa (Senior researcher): PM, RF engineering, Optics
S. Mariotti (Technician, IRA): RF technical support
Competences on Instruments & experiments

- **Management of projects**
  - Program Management, System engineering, Product assurance, AIV/AIT ECSS standards and best practices.

- **Technical expertise on**
  - Cryogenics, Thermal engineering (cryostat and cooler design)
  - Microwave, mm-wavelength and RF components design and opt.
  - Low Noise Amplifier optimization
  - Electromagnetic analysis and Opt. on passive components, antennas and telescopes
  - Calibrator’s development

- **Design, development, integration, qualification, testing and calibration of microwave and mm-wave instruments and telescopes in cryogenic environment**

- **Data analysis, pipeline and software development**

- **Coding and Tinkering**
Cryo-vacuum facilities

- **Compressors house.** Dedicated house to protect compressors. The house permits to connect 4 compressors working at the same time, cooled with air or water. An automatic chiller refrigerates the water in a closed cycle.

- **Leak detector.** VS PD03 Dry leak detector with dry pump combination.

- **Vacuum instrumentation** and several lake shore instruments, pressure probes, etc. are available as support for facilities.
Cryo-vacuum facilities

- **The ‘coffin’.** The most important instrumentation for dimensions. A 1m x 2m in size x 1 m in high cryofacility with configurable thermal interfaces to cooling instrumentations down to 4 K.

- **The ‘blue barrel’.** A small cryofacility (4K) to test components such as passive components at cryogenic temperature, or to measure thermal properties of materials and pieces.

- **ALMA test Cryostat.** At present Cryowaves lab is hosting the NAOJ ALMA test cryostat to test the ALMA band 2 (+3) receiver prototype.

- **LSPE / STRIP cryostat**
<table>
<thead>
<tr>
<th>25.11.2016</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>09:03</td>
<td></td>
</tr>
<tr>
<td>( T_1 = 80.5 ) K</td>
<td>( T_2 = 10.9 ) K</td>
</tr>
<tr>
<td>( T_3 = 1.7 ) K</td>
<td>( T_4 = 2.0 ) K</td>
</tr>
<tr>
<td>( T_{pol} \phi = 83.01 )</td>
<td>( T_{pol} \varphi = 12.28 )</td>
</tr>
</tbody>
</table>
Microwave Facilities

- **Scalar network analyzer** 10 MHz - 100 GHz
  Agilent tech. 8757D + sweeper and WG setup

- **Wideband Peak Power meter.** Anritsu ML2487 A
  (100 KHz - 65GHz) equipped with standard diode sensor MA2475D 10 MHz- 50 GHz

- **BIAS Supply and data Acquisition system.** NI PXI System with 2 units NI PXIE-4140 4-CHANNEL SMU to provide 8-channel supply for LNAs biases. NI PXIe-6361, X Series DAQ (16 AI, 24 DIO, 2 AO) providing 16 analog input channels and 24 Input/Output channels.

- **3D Printer.** Additive 3D printer with printing area of 300X450X235 mm.
Software Facilities

- **GRASP.** (www.ticra.com) GRASP with mrGTD and QUAST add-ons, is the most complete and precise tool to analyze reflector antennas. Version updated until 31/01/2018.

- **SRSR-D.** Software to analyze symmetry of revolution structures like corrugated horns, lenses and reflectors. Up to date version.

- **Ansys HFSS suite.** (http://www.ansys.com) High Frequency Electromagnetic Field Simulation is the industry standard for simulating 3-D, full-wave, electromagnetic fields. Up to date version, now acquired and maintained by INAF ITC.

- **ESATAN TMS.** (www.esatan-tms.com) Thermal analysis software with thermalXL plugin. Up to date version.

- **National Instrument Labview.** (www.ni.com). Software to control lab instruments and data acquisition. Up to date version.
Cryowaves projects

- ALMA band 2(+3)
- LSPE / STRIP (G. Morgante talk)
- LiteBird (G. Morgante talk)
- Athena X-IFU filters
- Development of Calibrators
Frequency bands of receivers: When it has all 10 bands incorporated, ALMA will measure signals from 8.6 mm to 0.32 mm. The following table shows the specifications of the bands astronomers will be able to use for their observations with ALMA (available from Cycle 5, in construction, and under development):

<table>
<thead>
<tr>
<th>Band</th>
<th>Wavelength (mm)</th>
<th>Frequency (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.6 – 6</td>
<td>35 – 50</td>
</tr>
<tr>
<td>2</td>
<td>4.6 – 3.3</td>
<td>65 – 90</td>
</tr>
<tr>
<td>3</td>
<td>3.6 – 2.6</td>
<td>84 – 116</td>
</tr>
<tr>
<td>4</td>
<td>2.4 – 1.8</td>
<td>125 – 163</td>
</tr>
<tr>
<td>5</td>
<td>1.8 – 1.4</td>
<td>163 – 211</td>
</tr>
<tr>
<td>6</td>
<td>1.4 – 1.1</td>
<td>211 – 275</td>
</tr>
<tr>
<td>7</td>
<td>1.1 – 0.8</td>
<td>275 – 373</td>
</tr>
<tr>
<td>8</td>
<td>0.8 – 0.6</td>
<td>385 – 500</td>
</tr>
<tr>
<td>9</td>
<td>0.5 – 0.4</td>
<td>602 – 720</td>
</tr>
<tr>
<td>10</td>
<td>0.4 – 0.3</td>
<td>787 – 950</td>
</tr>
</tbody>
</table>

During Cycle 0 and Cycle 1, the antennas were outfitted with four bands: Band 3, Band 6, Band 7, and Band 9. Two more were added in Cycle 2: Band 4 and Band 8. Band 10 was added in Cycle 3 and 4.
ESO ALMA upgrades

- 2012 collaboration setup to study the feasibility of the band 2 (67-90 GHz) and possibly the band 2+3 (67-116 GHz) for ALMA
  - INAF (I), RAL (UK), U-MAN (UK), IRAM (F)
- Output: band 2+3 optics could be feasible, green light to go ahead with further studies
- 2015 ESO started to guide an international consortium to focus on the extreme large detector
  - ESO, INAF, U-MAN and RAL, NAOJ, U-CHILE
  - Goal to demonstrate the technology to reach the optical requirements (efficiencies) for ALMA
- Output: optical train (Lens+filters+FH+OMT) within ALMA requirement
Artistic design by S.Rini
Full functional prototype

- Developed by the consortium
- Mechanical Design by GARD, Chalmers University using Band 5 spares (Sept 2016)
- Manufactured in 2 months by the Workshop at Univ. of Milano, Physics dept. (Oct – Nov 2016)
- Assembled and tested at INAF cryowaves lab (Jan – May 2017)
- Presented by the consortium to the ALMA Preliminary Design Review, Nov. 2017
early phases up to PDR
The panel were impressed by the extensive work done by the Band 2+3 team in preparation for this review and the excellent results reported. A high degree of cooperation and a good atmosphere among the team members from the different groups was evident during the meeting. The panel appreciate the thorough and complete documentation provided for review by the Band 2+3 team, the rapid responses given to the RIDs raised, and the open discussion of issues during the meeting.
contracts & agreements

Study and Development Programme for ALMA band 2 / band 2+3 Receiver system

Contract No. 43961/ESO/11/43827/ADEL...

B23 Development Study (phase A)

B23 Development Study (phase B)

Support to PDR

Opt and Production Engineering of B23 prototype components

Support Band 2 development projects to Optimize receiver components and vacuum lens

iALMA premiale 2013

INAF funding
Consortium setup

NOVA (NL)
GARD Univ. of Chalmers (S)
INAF OAS and OAA (I)

17-18 Dec 2018
<table>
<thead>
<tr>
<th>Milestones</th>
<th>Date</th>
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<tbody>
<tr>
<td>Kick-off (KO)</td>
<td>2019-02-01</td>
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<tr>
<td>Completion of Band 2 CCA unit #1</td>
<td>2020-02-01</td>
</tr>
<tr>
<td>Band 2 CCA CDR – Delivery of review data package</td>
<td>2020-04-01</td>
</tr>
<tr>
<td>Band 2 CCA CDR – Meeting</td>
<td>2020-06-01</td>
</tr>
<tr>
<td>Band 2 CCA CDR – Completion</td>
<td>2020-07-01</td>
</tr>
<tr>
<td>Completion of Band 2 CCA unit #2-6</td>
<td>2021-03-01</td>
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<tr>
<td>Band 2 CCA and WCA (combined) Gate Review</td>
<td>2021-06-01</td>
</tr>
<tr>
<td>Band 2 CCA MRR – Delivery of review data package</td>
<td>2021-08-01</td>
</tr>
<tr>
<td>Band 2 CCA MRR – Meeting</td>
<td>2021-10-01</td>
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<tr>
<td>Band 2 CCA MRR – Completion</td>
<td>2021-11-01</td>
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<tr>
<td>Band 2 CCA unit #7-10, Provisional Acceptance on-Site (PAS)</td>
<td>2022-06-01</td>
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<tr>
<td>Band 2 CCA unit #11-20, Provisional Acceptance on-Site (PAS)</td>
<td>2022-08-01</td>
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<tr>
<td>Band 2 CCA unit #21-30, Provisional Acceptance on-Site (PAS)</td>
<td>2022-10-01</td>
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<tr>
<td>Band 2 CCA unit #31-40, Provisional Acceptance on-Site (PAS)</td>
<td>2022-12-01</td>
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<tr>
<td>Band 2 CCA units #41 - 50, Provisional Acceptance on-Site (PAS)</td>
<td>2023-02-01</td>
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<tr>
<td>Band 2 CCA units #51-60, Provisional Acceptance on-Site (PAS)</td>
<td>2023-04-01</td>
</tr>
<tr>
<td>Band 2 CCA units #61-73, Provisional Acceptance on-Site (PAS)</td>
<td>2023-06-01</td>
</tr>
<tr>
<td>Band 2 CCA spare parts</td>
<td>2023-06-01</td>
</tr>
</tbody>
</table>
ESO band 2 / band 2+3 Feasibility Study (7/6/12 - 7/3/14)

iALMA premiale INAF 25/3/14 -

ESO band 2+3 Prototype development (26/2/2015 - 15/5/2017)

ESO band 2 Optimization project (31/7/2018 - )

Band 2 73 receivers CCA production (under negotiation 2019 / 2023)
Brochure INAF on iALMA

iALMA Scienza e tecnologia per ALMA

Osservare l’universo oscuro per svelare l’origine del Cosmo e della Vita
Observing the Dark Universe to unveil the Origins of the Universe and Life

Funded by iALMA through MediaINAF
Out on Feb 2019
ALMA Band 2 Photo album

https://www.flickr.com/photos/gilas69/sets/72157677037620172
Criticalities

- Access to the Mechanical Workshop and or find a quick way to fabricate mechanical pieces and prototypes
  - Availability and access to basic tools and hardware
  - Technicians
- Software maintenance
- Upgrade of Lab instrumentation
  - Vector Network Analyzer up to 70 (116) GHz
- Upgrade of laboratory environment
  - Pressurize the laboratory
  - Clean the ducts for helium flex-lines
  - Controlled access to Laboratory for cleanliness
- Beginning of 2019 start to upgrade facilities and instrumentations to face the CDR of ALMA Band 2 (in case of funding for production)
Jan-Feb 2019 Continue the work on prototype demonstrator to consolidate the development of components and lens

April 2019 ALMA board will decide the production (CCA+WCA)

May 2019 (if approved) Kick of Meeting of Band2 CCA production up to 2023/2024

Scientific interest in OAS for Band 2 observations
Cryowaves perspectives

- Consolidate the laboratory facilities, expertise at international level
- ‘third parties’ activities to fund lab running costs and to continuously upgrade the instrumentation
- Competences for industrial grade work
  - Mechanical engineer, electronic engineer
- Continue the partnership with high tech industries
- To have students working on experimental physics and engineering
to provide, with some of the X-IFU filters proper Radio Frequency shielding in the frequency range of the satellite telemetry. Measurement and modeling at cryowaves lab.
Verification Validation and Testing: Passion and Deployment challenges in the Italian Eco-System

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Carlo Lcardi
Tetra Pak Packaging Solution
Modena Italy

Luca Stringhetti
SKA HQ
SKA Organization
Macclesfield, Great Britain

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Tinkering with the Universe

Applicare il **Tinkering** alla didattica e divulgazione delle STEAM (Science Technology, Engineer, Art, Mathematics) in campo Astrofisico
they are playing seriously
they are focus
they get frustrated
they get excited
they feel they are in power
they get engaged
they feel they belong to STEM
super inclusive (every kids feel they can play)
definition of thinkering

Ricciardi’s definition
inspired by the tinkering studio
San Francisco Exploratorium

UNO SFORZO UMANO PROFONDO
BASATO SULL'ESPERIENZA DIRETTA
(LA CONOSCENZA È COSTRUITA MENTRE UN OGGETTO FISICO PRENDE FORMA)

NON UN CURRICULUM DEFINITO
50% GIOCO 50%RICERCA
NON È LINEARE (MA) CUMULATIVO

learning happen more efficiently if the learner is engaged in building some physical object.
Collaborazioni in corso

- IC12+IC3 bologna
- convenzione Istituzione bologna musei (Museo del Patrimonio Industriale)
- collaborazione UNIBO (Dipartimento di Psicologia)
- collaborazione Università’ di Urbino (Dipartimento di Studi Umanistici)
- Cineteca di Bologna
- Associazione Hamelin
- Accademia di Belle Arti di Bologna
Representing the Universe: a Hands on Challenge
S. Varano, S. Ricciardi
Proc. of the Communicating Astronomy with the Public March 2018 in Fukuoka, Japan

Tinkering with the Universe: a primary school project
S. Ricciardi, F. Villa, S. Rini
Proc. of the Communicating Astronomy with the Public March 2018 in Fukuoka, Japan

Officina degli Errori: a Tinkering Experience in an Informal Environment
S. Ricciardi, F. Villa, S. Rini, M. Boni, S. Venturi, A. Bugini, M. Masini
Proceedings International conference New Perspective in Science Education, 2018 in Firenze

Il tinkering va al umseo
S. Ricciardi, F. Villa, S. Rini
per la rivista Scuola Officina set-dic 2018

Tinkering, la coraggiosa arte di sbagliare incontra un museo civico
S. Ricciardi, F. Villa, S. Rini
contributo al libro CCC - Città’ come cultura-
Fondazione MAXXI Roma, in press

Tinkering, ovvero la coraggiosa arte di sbagliare
S. Ricciardi
Blog topipittori