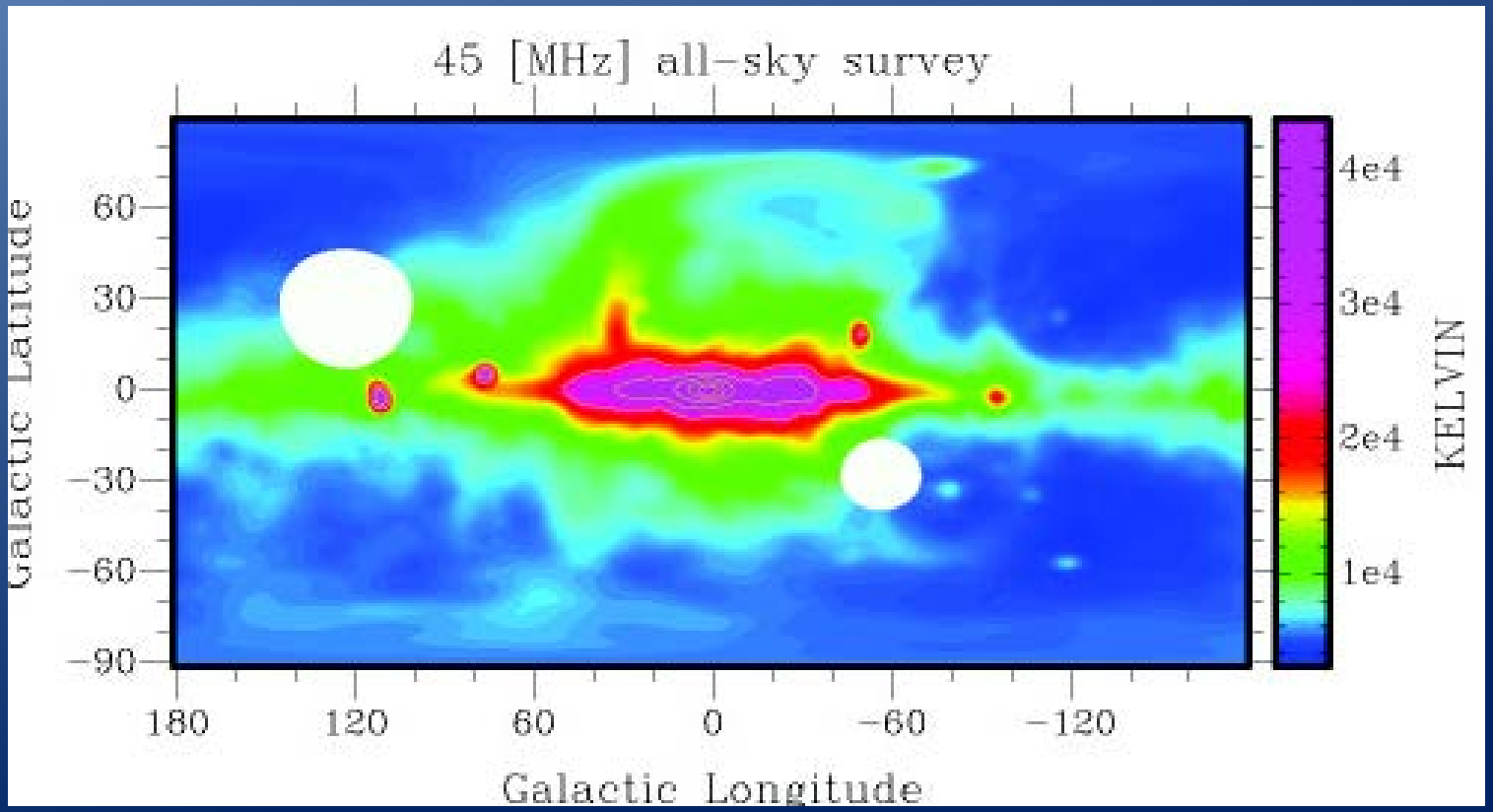
Astronomical Instrumentation at Universidad de Chile: The Mm-Wave Laboratory

Leonardo Bronfman

SOME HISTORY

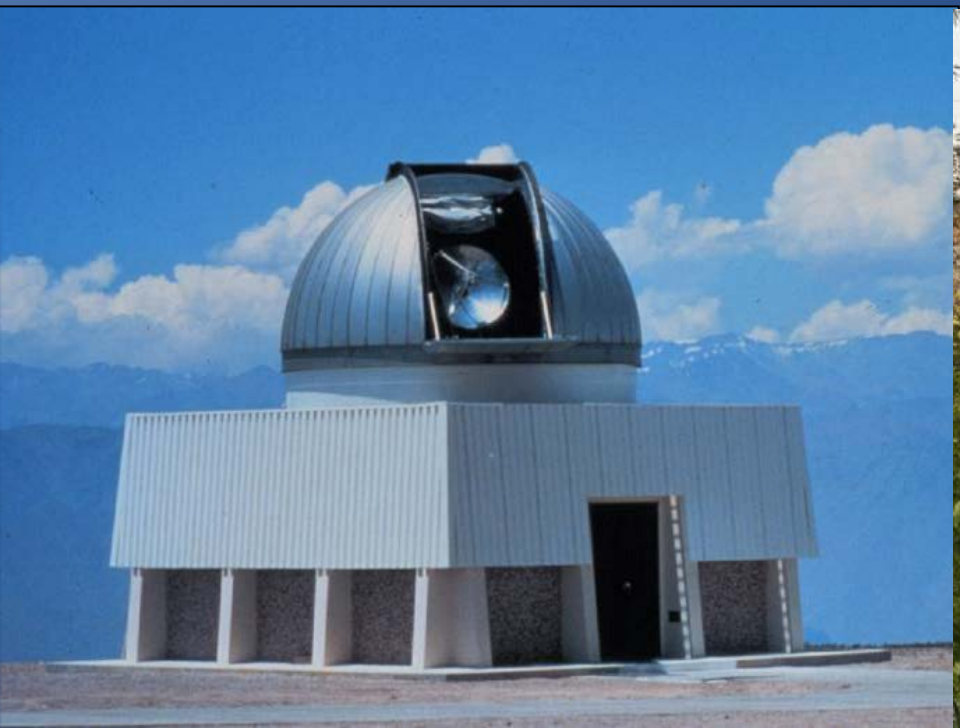
Maipú Radio Observatory (45 MHz, 1959-2000)
First in South America, model for ALMA radio band protection.

- Complete map of the sky at 45 MHz
- N. Hemisphere observed from Japan (K. Maeda, Hyogo U.)
- Lowest frequency full-sky map (Guzmán, May et al. 2011)

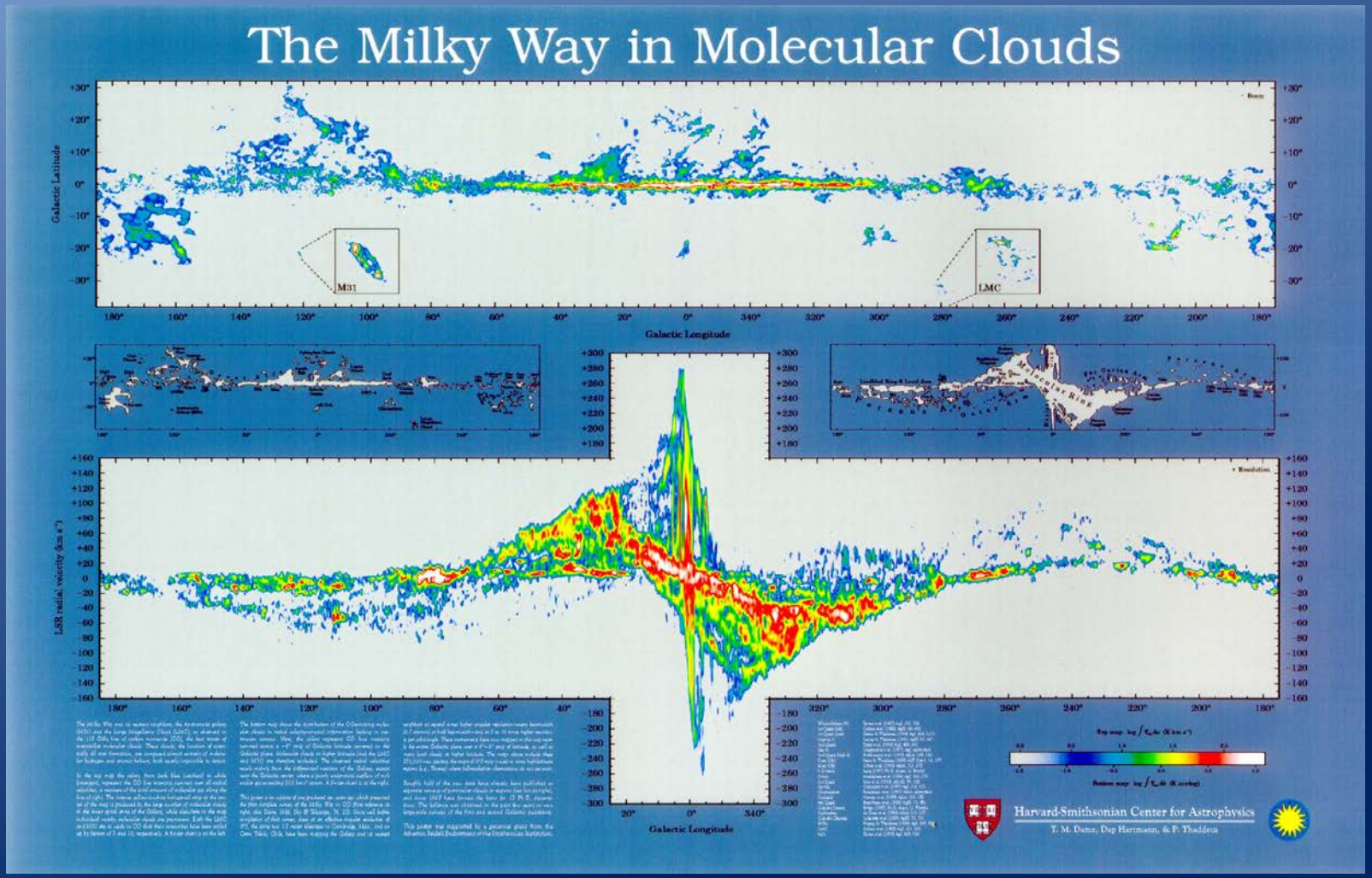


1.2 m Southern Mm-wave Telescope (86 -115 GHz)

- Columbia U. / U. de Chile (Cerro Tololo 1982).
- First dedicated mm-wave telescope in the Southern Hemisphere
- Moved to Cerro Calán, U. Chile campus (2009)



First complete CO survey of the Galaxy



The U. Chile Millimeter Wave Laboratory (2005)
Center for Astrophysics and Assoc. Technologies (2008)

- Joint effort of Astronomy and Electrical Engineering Departments at the National Astronomical Observatory in Cerro Calán.
- Development of receiver front-end and digital back-end technology
- Innovation and technology transfer
- Training of undergrad and grad students (joint PhD program)
- International collaboration in state-of-the-art projects: ALMA

THE PEOPLE

Leonardo Bronfman
Professor

Patricio Mena
Associate Professor

Ernest Michael
Associate Professor

Nicolas Reyes
Assistant Professor

Ricardo Finger
Assistant Professor

Walter Max-Moerbeck
Assistant Professor

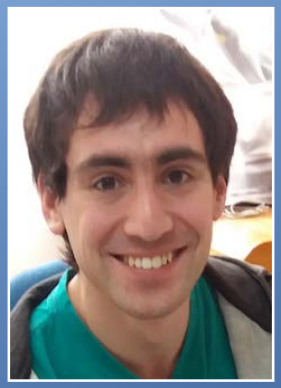
Claudio Jarufe
PhD

Rocío Molina
MSc

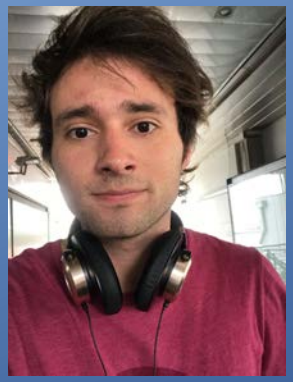
Daniel Montofré
PhD Student

Jose Pizarro
Sr. Mehanical Engineer

Diana Cubillos
PhD Student



Franco Curotto
MSc



Roberto Aguirre
MSc Student

Catalina Medina
MSc Student

David Monasterio
Engineer

Pablo Astudillo
Engineer

Camilo Avilés
Mech. Engineer

Christopher Muñoz
Eng.

VALERIA TAPIA
(The Netherlands)

RAFAEL RODRIGUEZ
(UdeC)

PABLO ZORZI
(ALMA)

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THE FACILITIES:

MM-WAVE LAB AND MACHINE SHOP:

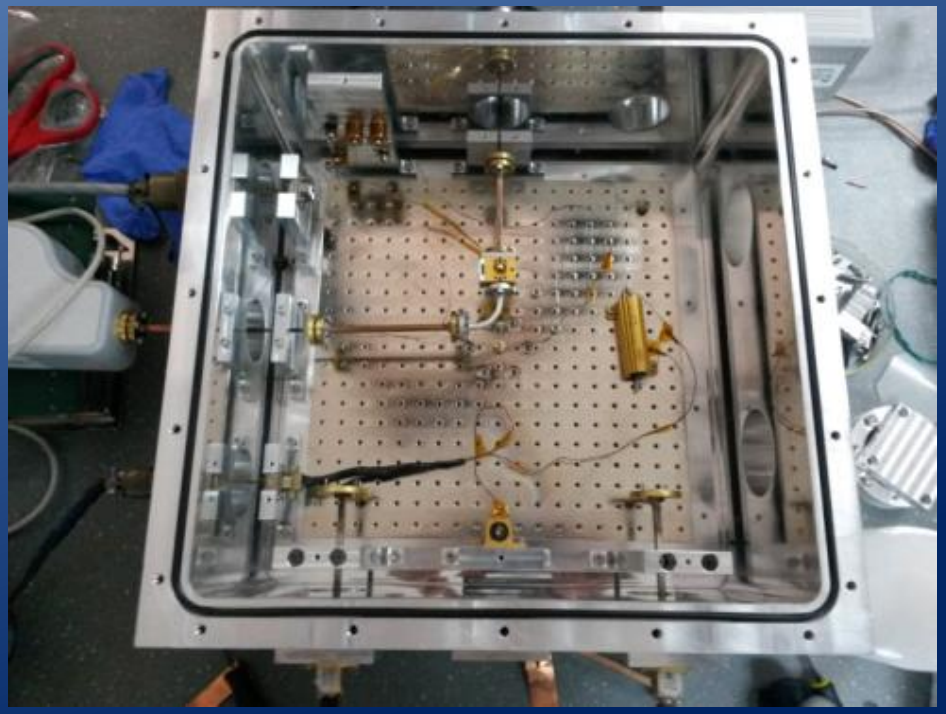
ORIGINAL CATA INVESTMENT USD 600.000
QUIMAL, AIC27, FONDEQUIP USD 600.000
ALMA, ESO, GEMINI (CONICYT)

ALSO:PHOTONICS LAB. AT FCFM

QUIMAL 2015

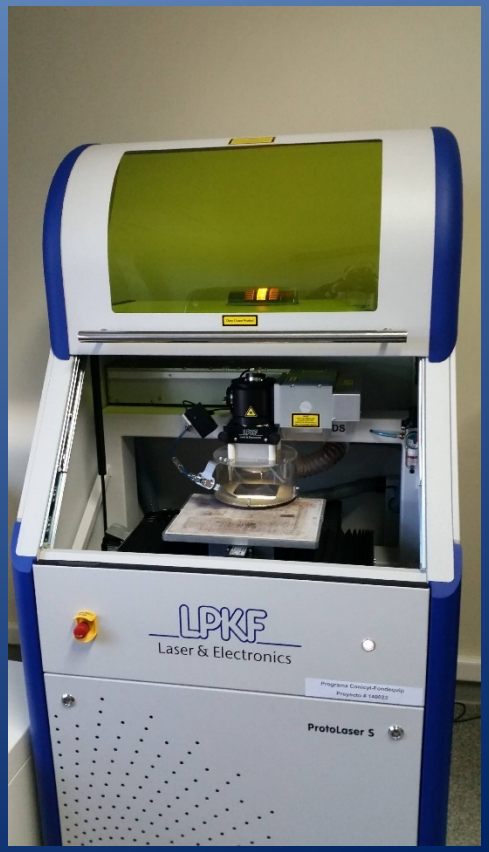
Mm-Wave Laboratory-Cryogenics

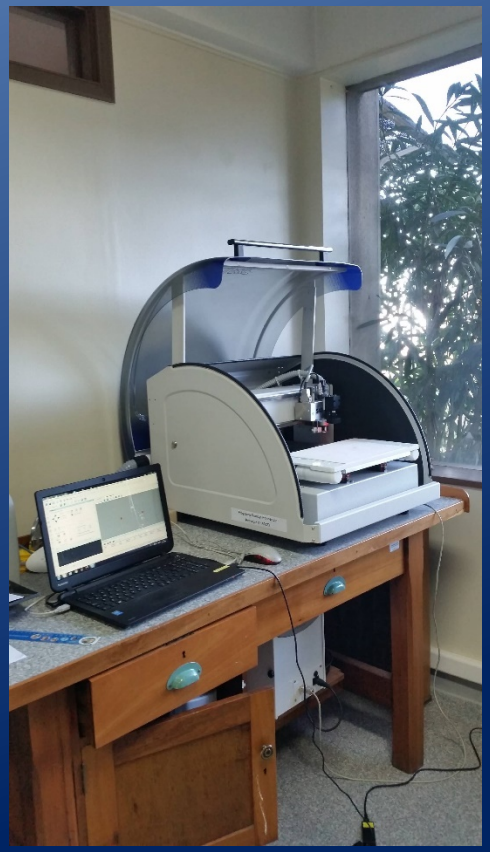
ALMA compatible cryostat (NAOJ)



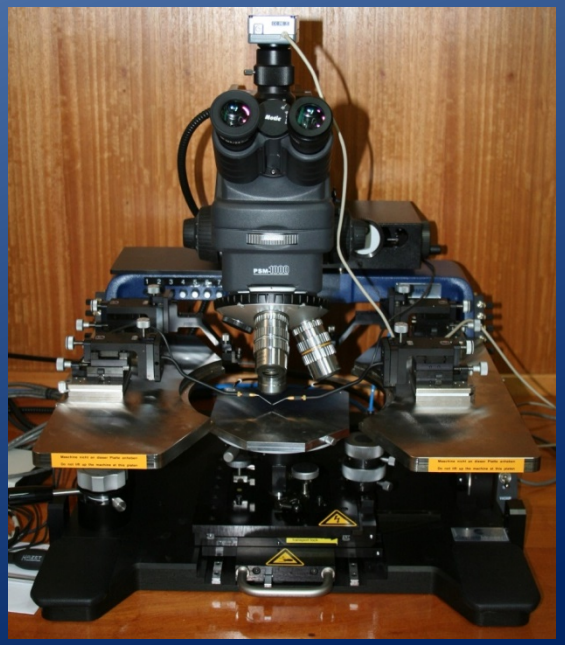
Homemade cryostat for component testing

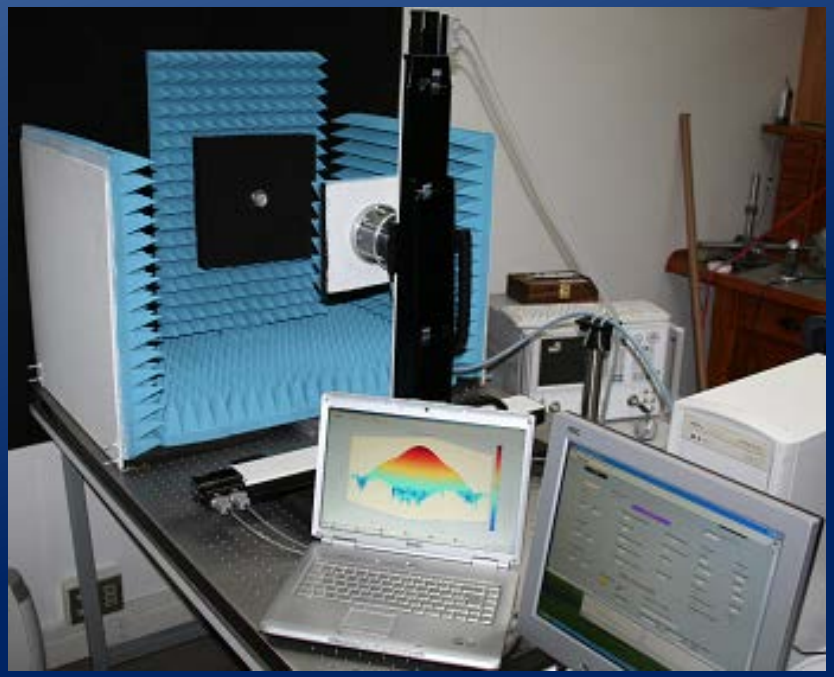
- Electronic workshop for circuit fabrication and assembly





- Well assorted components and test sources up to 110GHz.
- Vector Network Analyzer up to 50 GHz
- Probe station for MMIC characterization
- Beam pattern scanner (30-110GHz)





Main Current Projects

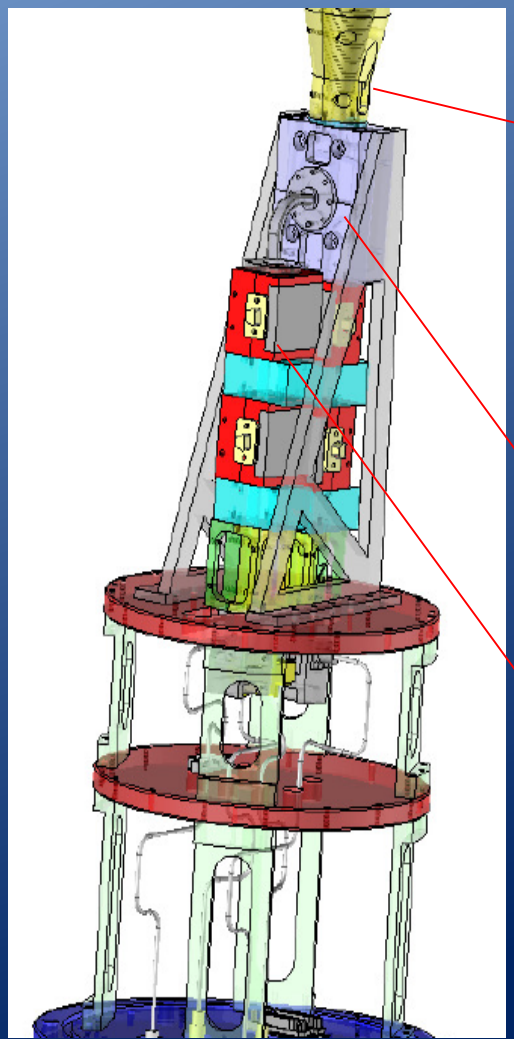
1. ALMA Band 1 Optics full design and fabrication
2. ALMA Band 2+3 Optics design and prototype
3. Development of Sub-mm detectors (Shanghai Obs.)
4. CCAT-P Holography
5. FPGA-based Digital Signal Processing (ALMA Band 9, SRON; Band 7+8, NAOJ; FAST 500 m, CAS)
6. Innovation and technology transfer

1.- ALMA Band 1 (35-52 GHz) Receiver: Flagship project

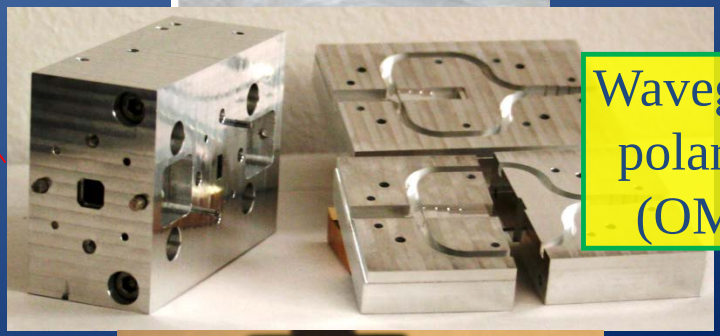
- Phase 1: Receiver prototype (CATA 2008-2012)
- Phase 2: Design and Production of 77 receivers (Taiwan; Japan; Canada; US)
- **Chile WP: Optics**

CONSTRUCTION APPROVED BY ALMA BOARD ON 23 MAY 2016

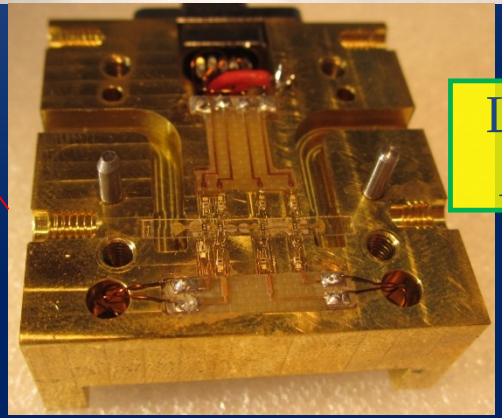
- We developed a receiver prototype for ALMA Band 1 (35-50GHz).



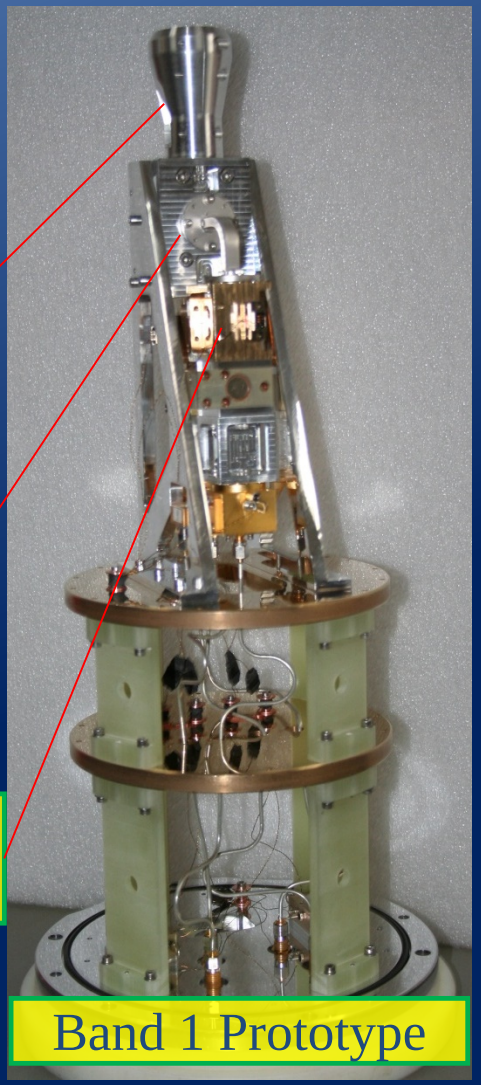
Horn antenna



Waveguide polarizer (OMT)



Low Noise Amplifier



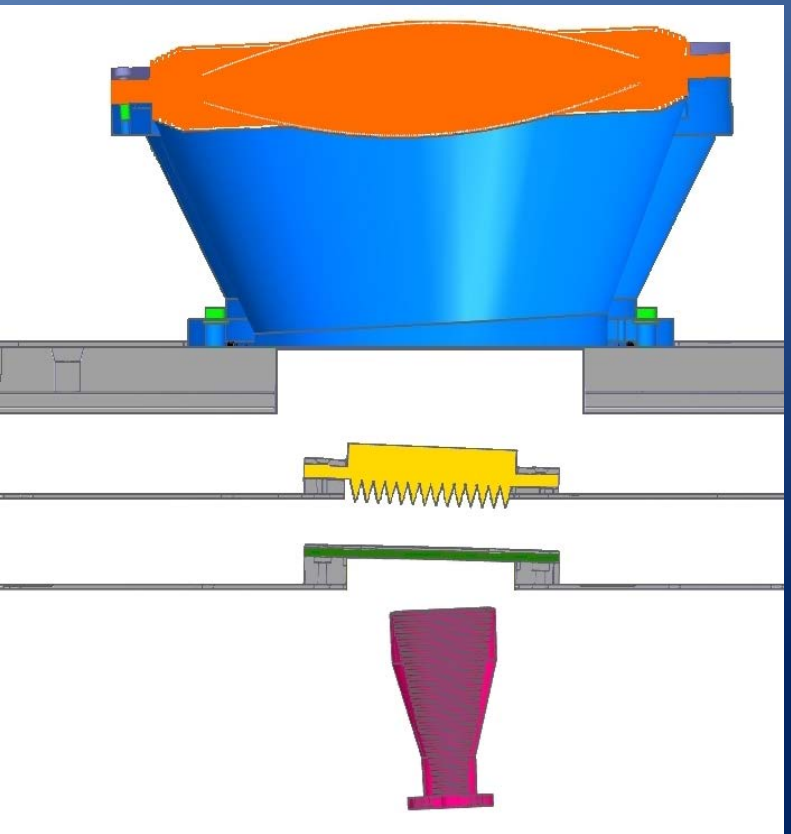
Band 1 Prototype

ALMA Band 1

“High efficiency wideband refractive optics for ALMA Band-1”;

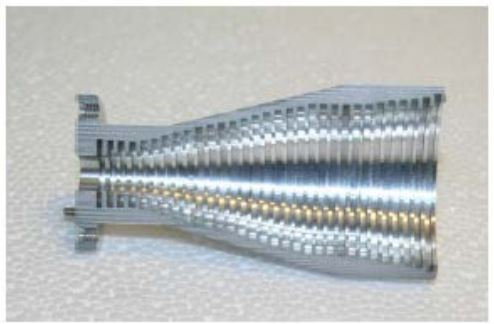
Tapia et al. 2017, J Infrared Mm and Teraherz Waves

77 units of the ALMA Band 1 (35-52 GHz) optical system are being built by U. Chile after own prototype design.



Bi-hyperbolic zoned Fresnel lens

Optimized-profile corrugated horn



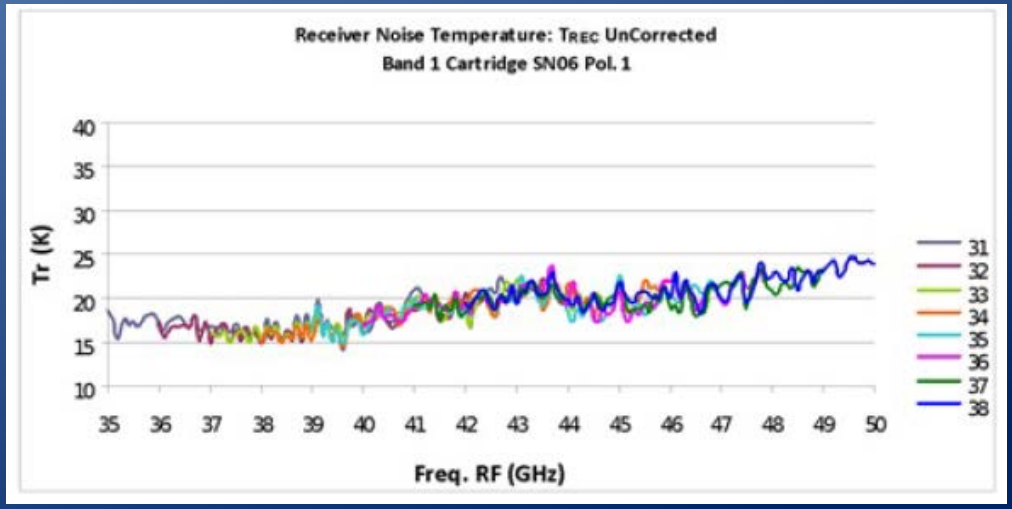
ALMA Band 1 Optics Production at U. Chile

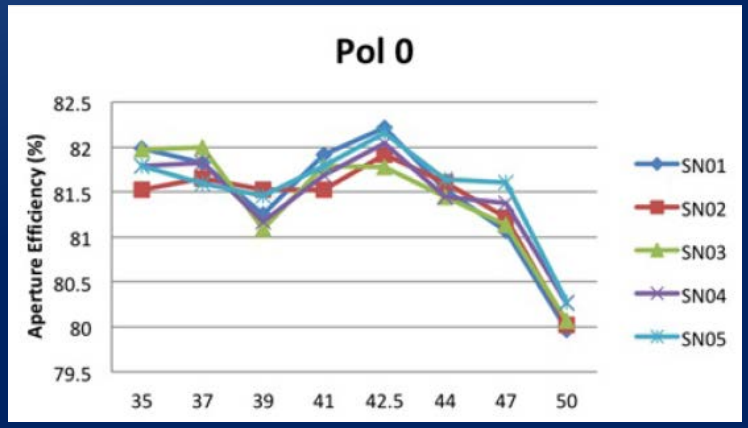
Bi-hyperbolic zoned Fresnel lens

Optimized-profile corrugated horn

ALMA Band 1

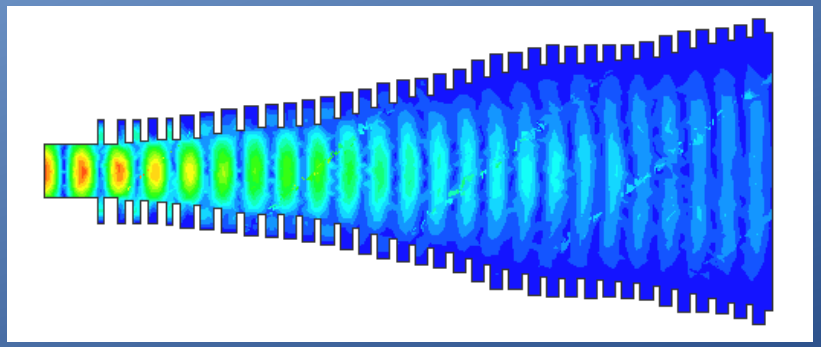
- Assembly is running at Academia Sinica in Taiwan
- Tnoise~25K
- Optical efficiency >80%



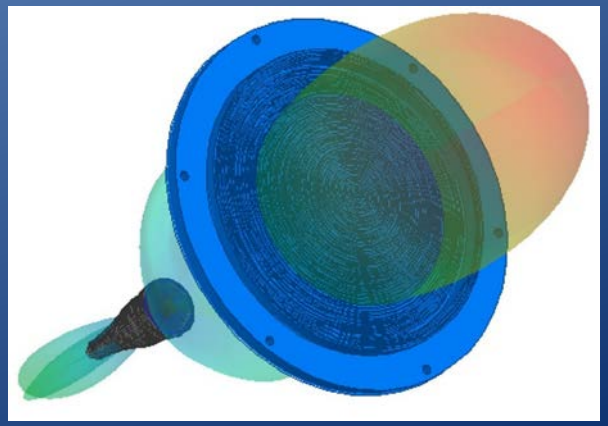


2.- ALMA Band 2+3 (67-116 GHz Wide Band):

Development of a prototype within consortium: ESO, IRAM, Manchester, Arcetri, NAOJ, U. Chile (Optics)

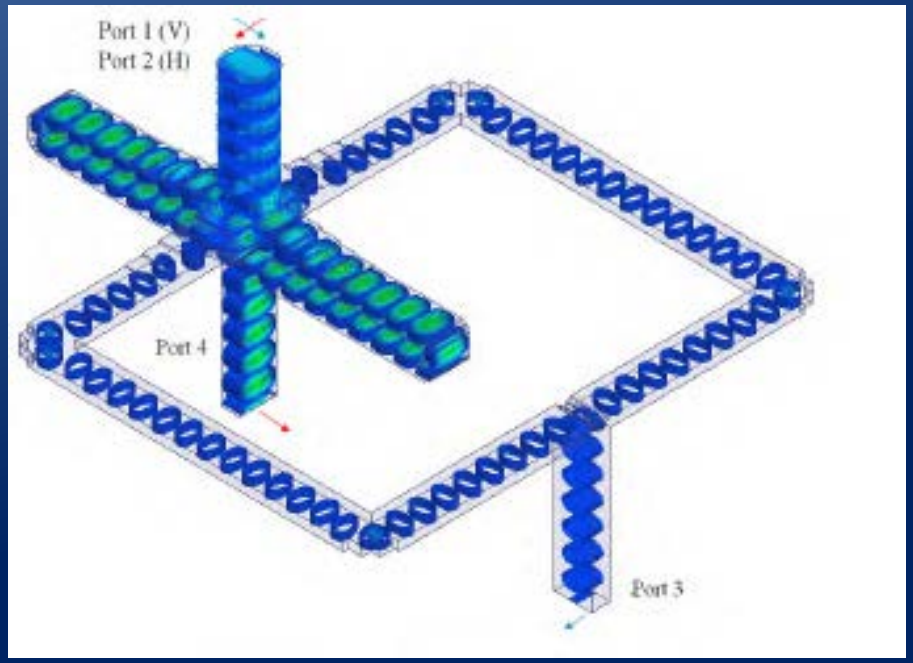


Horn



Lens

- Design



Polarizer

Optics for ALMA Band 2+3 (67-116 GHz)

Valeria Tapia et al. ”Systematic study of the cross polarization introduced by broad-band anti- reflection layers at microwave frequencies” Applied Optics 2018

Horn

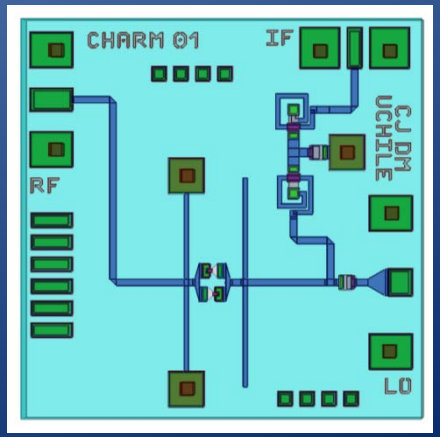
Lens

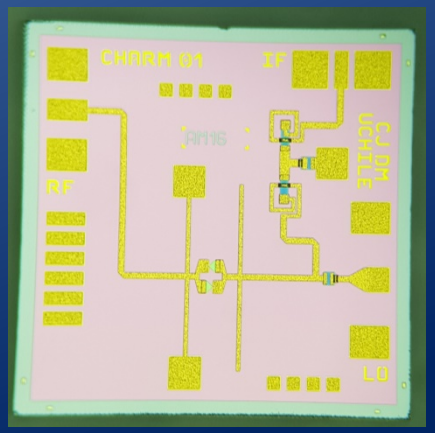
- Construction

Polarizer

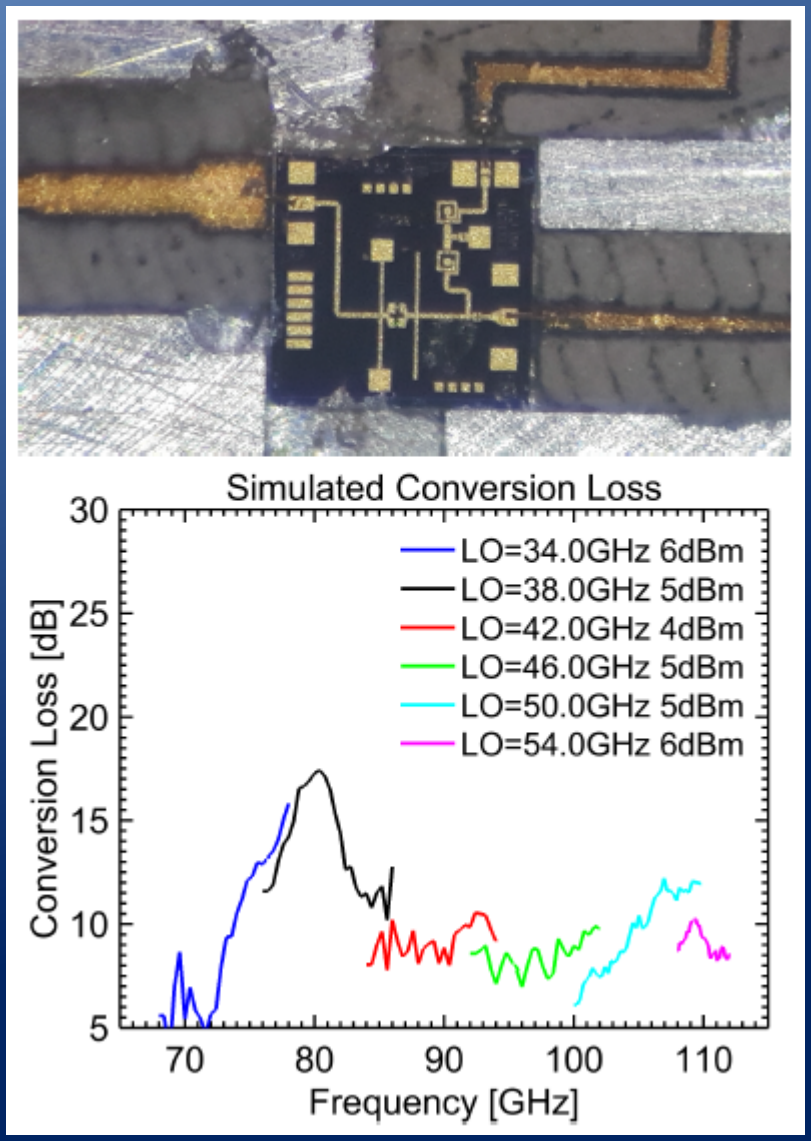
3.- MMIC Development

- We are developing broadband mixers using MMIC technology.
- Collaboration with Shanghai Observatory
- RF range: 67-116GHz
- IF range: 2-12GHZ
- Step 1(2018): single harmonic mixer



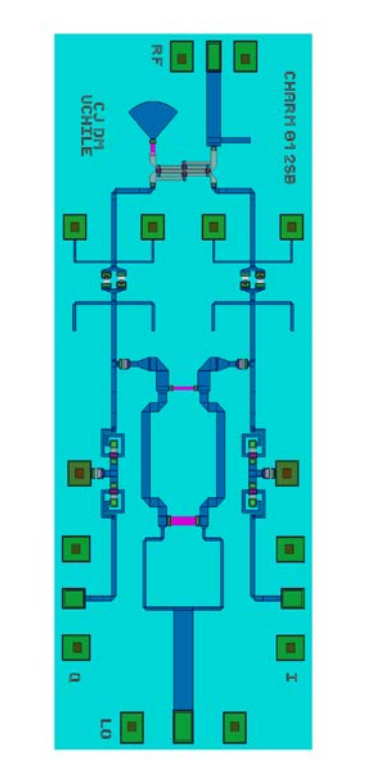


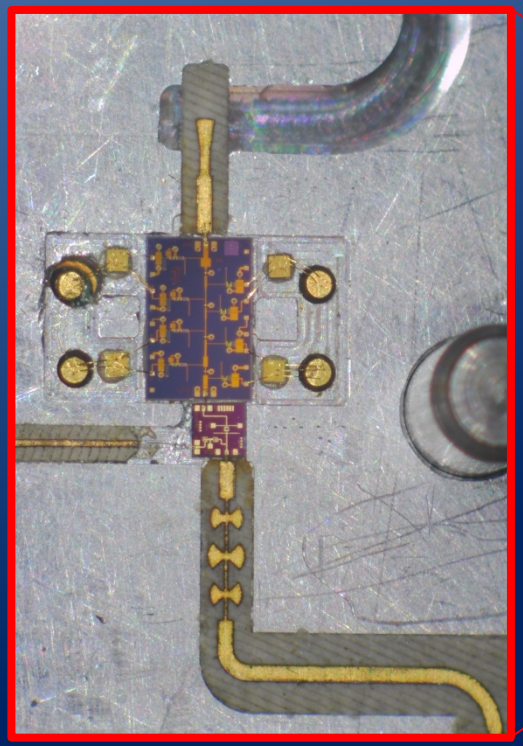
Chip size is 1.4 X 1.4 mm2

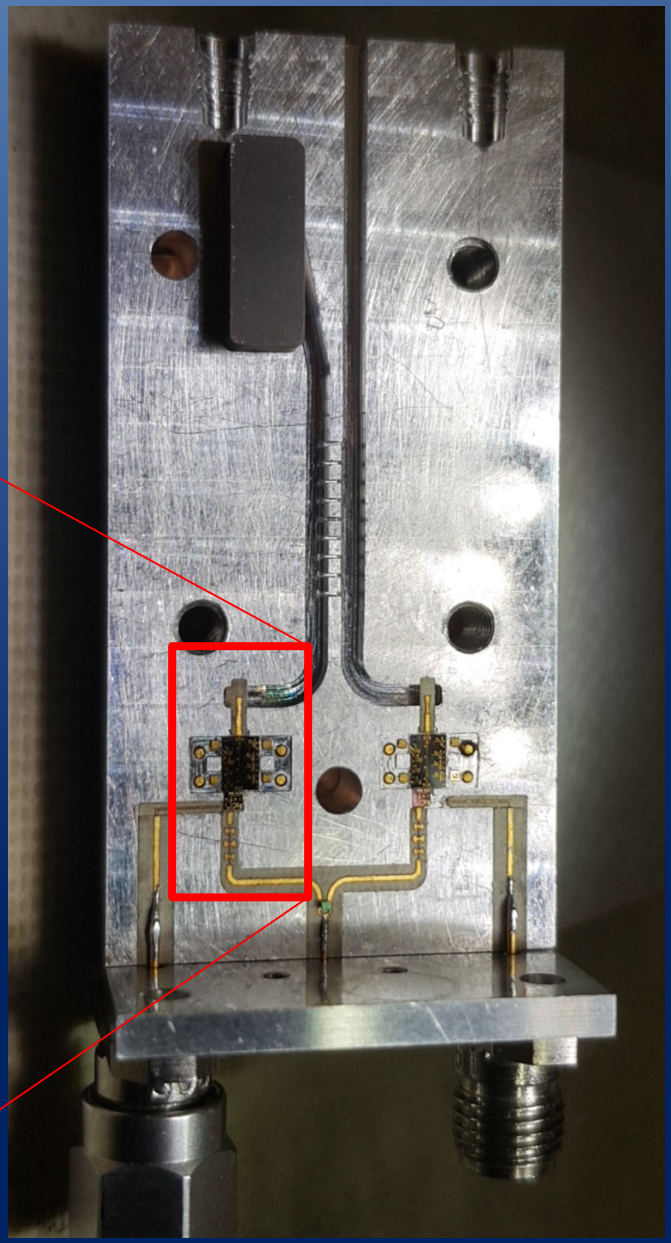


MMIC Development

- Now: Integration of the mixers in a sideband separation down-converter module.
- Design of new MMIC for sideband rejection.

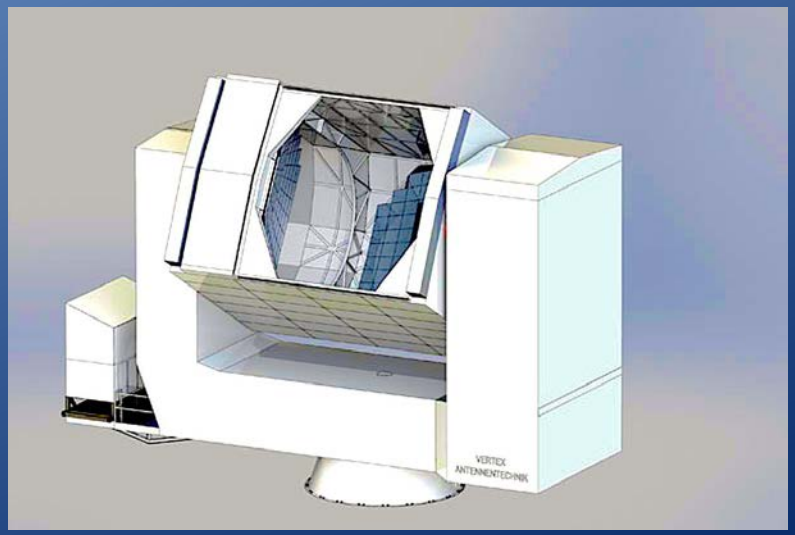






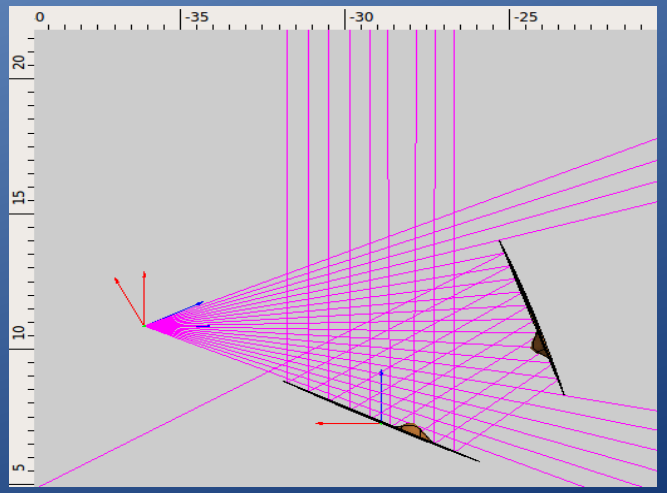
4.- CCAT-p

- 6 meter sub-millimeter Telescope with large field of view.
- Atmospheric conditions allow observations up to 1THz
- Surface accuracy: 7μm RMS (goal)



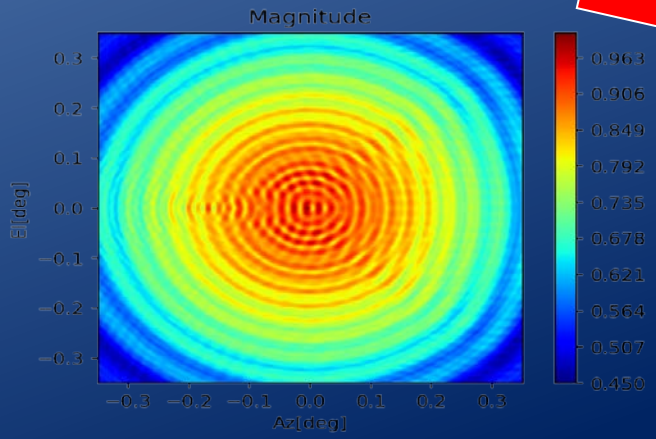
CCAT-p

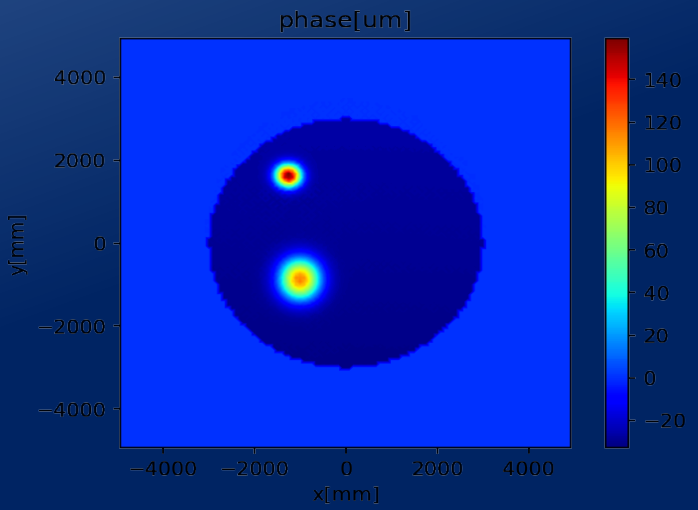
- We are developing a holography solution at 300GHz to achieve this measurement accuracy.



GRASP Simulation

Simulated Near field Data (300m)

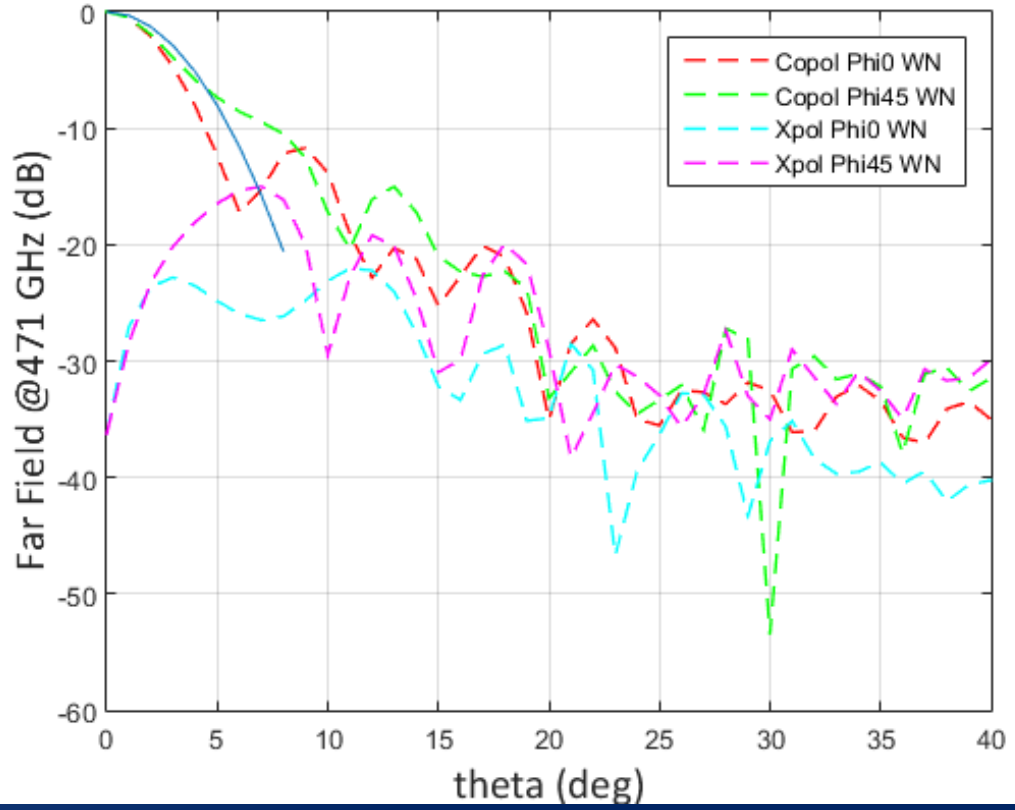




Aperture phase error

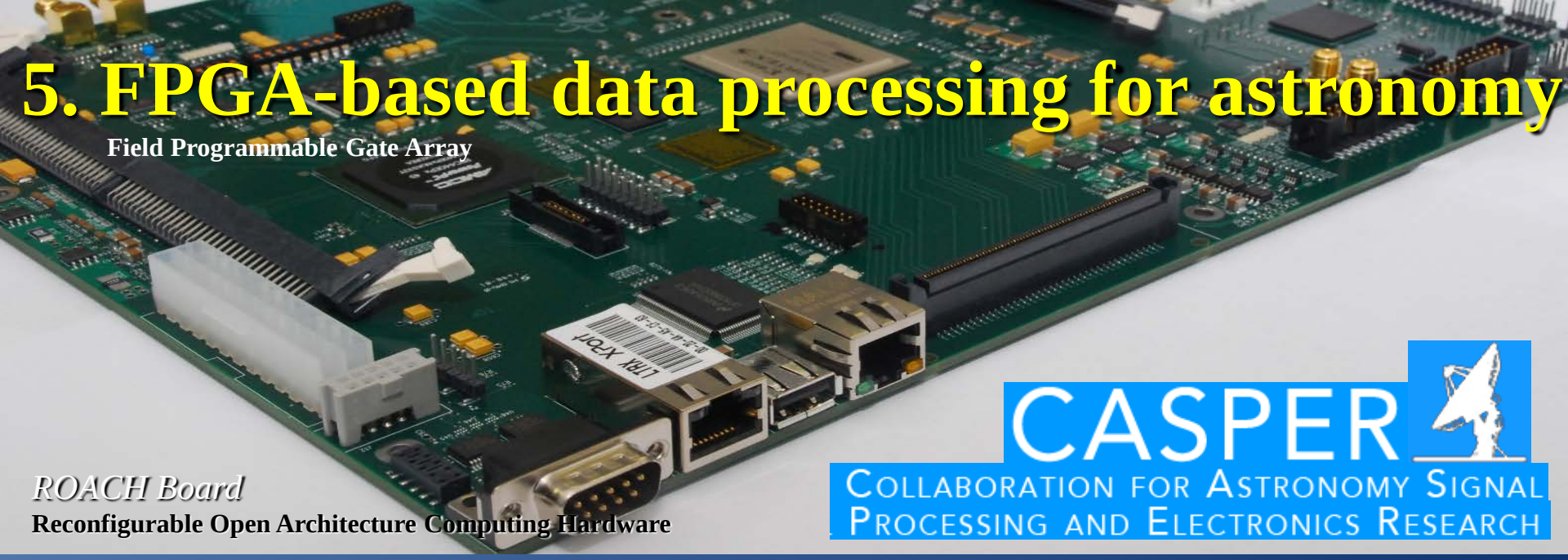
CCAT-p

- Research on large aperture horn antenna for dense arrays.



5. FPGA-based data processing for astronomy

Field Programmable Gate Array



ROACH Board

Reconfigurable Open Architecture Computing Hardware

CASPER

COLLABORATION FOR ASTRONOMY SIGNAL PROCESSING AND ELECTRONICS RESEARCH

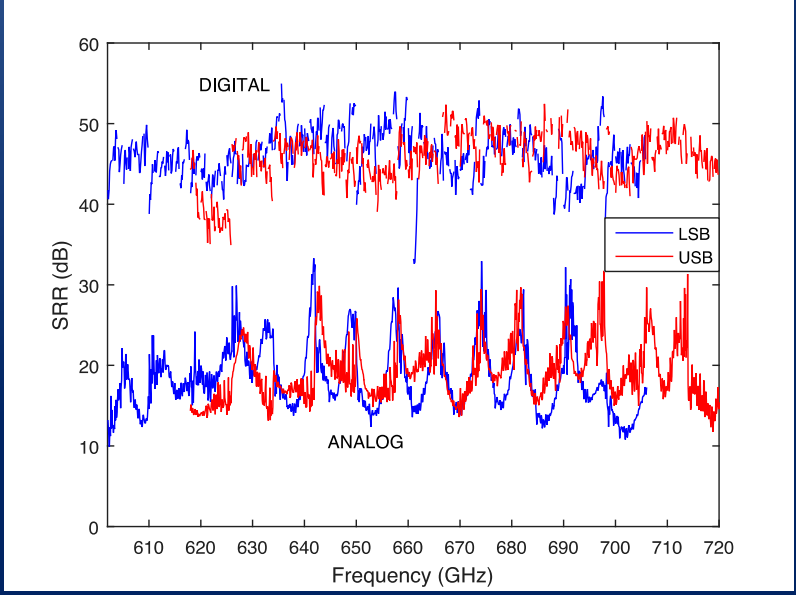
- Field Programmable Gate Arrays: Novel way to process astronomical signals digitally.
- Digital Sideband separation (ALMA Band 9, SRON; Band 7+8, NAOJ)
- Real Time Radio Frequency Interference Mitigation (FAST 500 m Telescope, CAS)

DIGITAL SIGNAL PROCESSING HIGHLIGHTS

"Ultra-pure digital sideband separation at sub-mm wavelengths".
Finger et al. 2015, A&A; Rodriguez et al. 2014, PASP

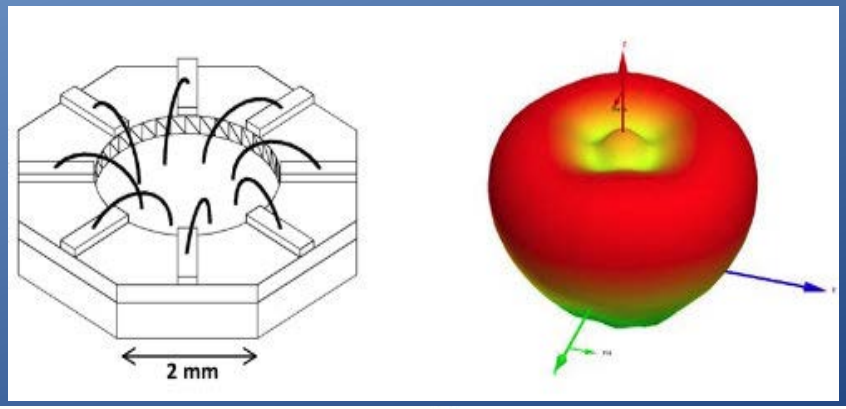
- ALMA Band 9 (602–720 GHz) currently double sideband (DSB)
- Analog Side-band separating prototype receiver built at SRON, Netherland
- CATA FPGA 2SB digital back-end interfaced with SRON prototype.

• SB rejection ratio 1000 times better using CATA digital backend

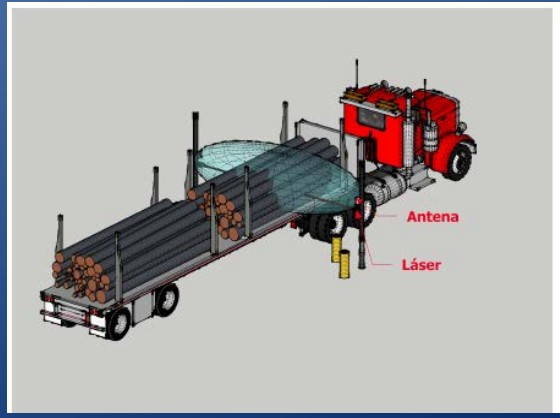


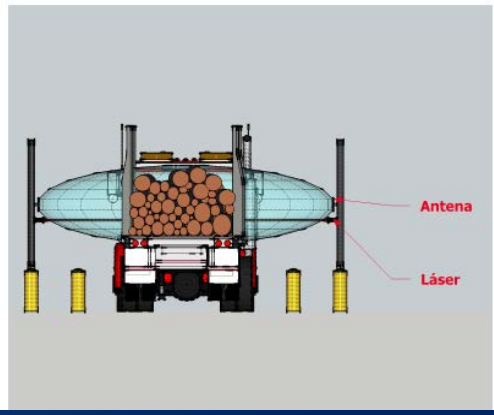
6.- INNOVATION AND TECHNOLOGY TRANFER

Bond wire array antenna prototype for in-door 60 GHz communications

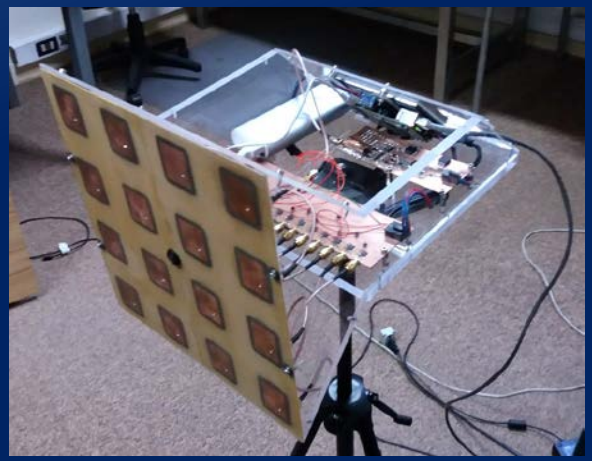


Measurement of wood moisture content using microwave transmission



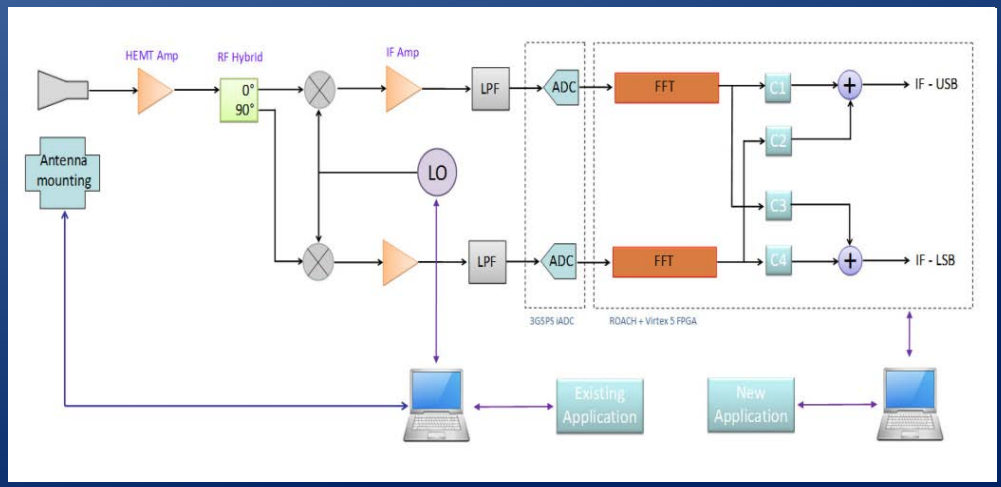


Radio-Vision: portable camera allowing localization of mobile phones. Prototype already working.



Training facility:
1.2 m Southern Mm-wave Telescope (Mini)

- Hands-on training for students of engineering and astronomy courses.
- Test bench for new technologies.
- Many engineering degrees and 2 PhD theses.
- Front-End and digital Back-End upgrades.



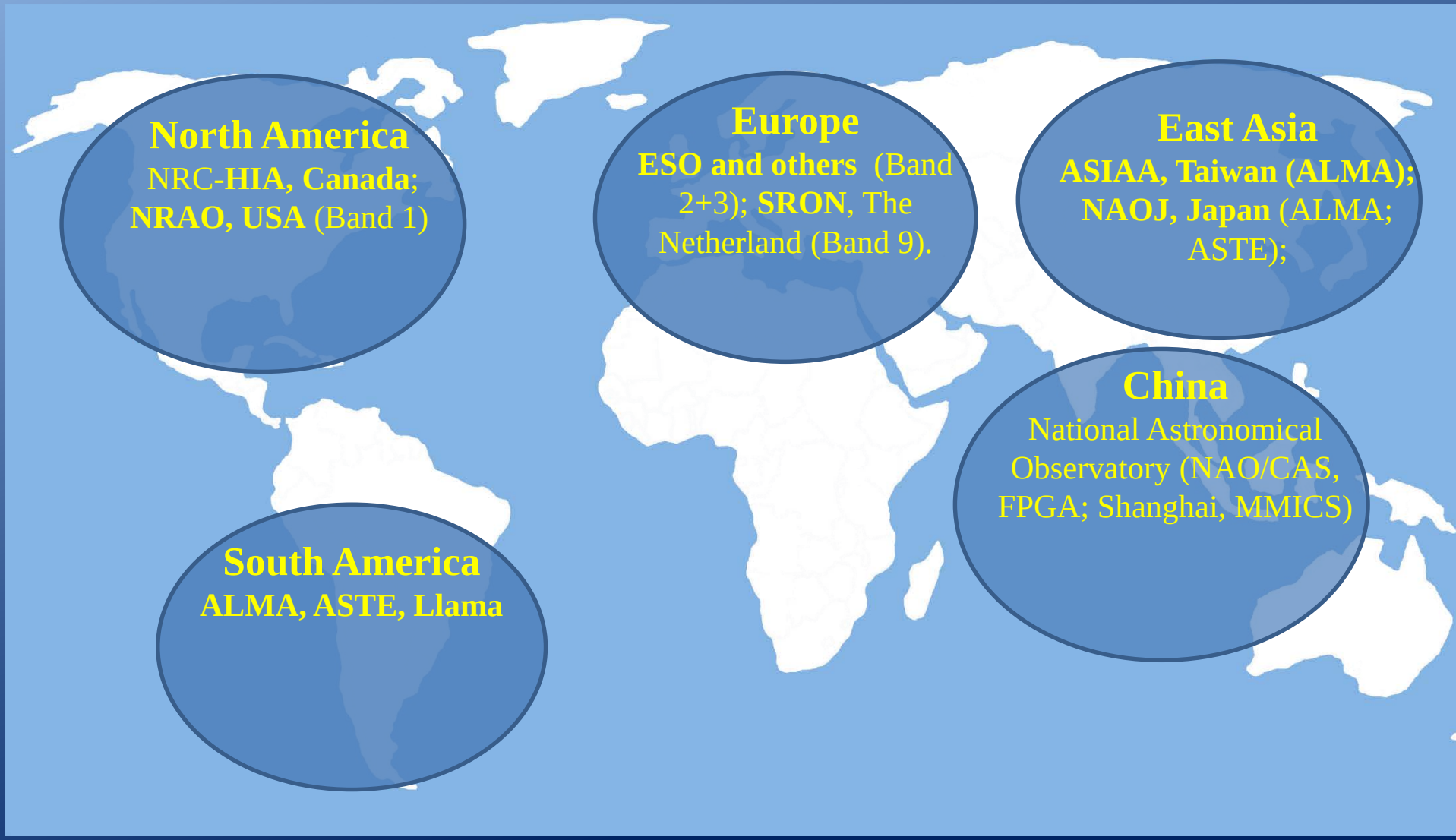
Digital sideband separating receiver using FPGA technology (ROACH).

R. Rodriguez et al. ”A Side-band-Rejection Ratio Compensation of a complete 2SB sub-millimeter Receiver using a Digital Spectrometer” PASP 2018

U. Chile Astronomical Instrumentation in numbers

Aspect	Baseline	CATA U. Chile outcome
Graduate students	No graduate program in Astronomical Instrumentation	Joint PhD (DAS-DIE): 6 PhD graduated, 3 ongoing, 5 MSc graduate, 6 ongoing
Undergraduate Students	No Major in Astronomical Instrumentation	16 Undergraduates theses (EE, Mec.E, Chem.E); 2 ongoing
Publications	20 years since last paper in Astronomical Instrumentation	15 ISI papers since 2011, > 20 conference papers
Internships in Chile	---	7 Internships completed (Argentina, Ecuador, France, The Netherlands, Japan, China; 1 ongoing The Netherlands)
Internships abroad	---	All graduate students perform international internships
New professors	3 professors	2 new assistant professors (Faculty of Phys. and Math. Sciences, (2013) 1 new assistant professor(2018)

International Collaborations



Thanks!

In memory of Prof. Jorge May (1936-2011)