Design of ALMA Band 1, 2, and 2+3 receiver optics at NAOJ

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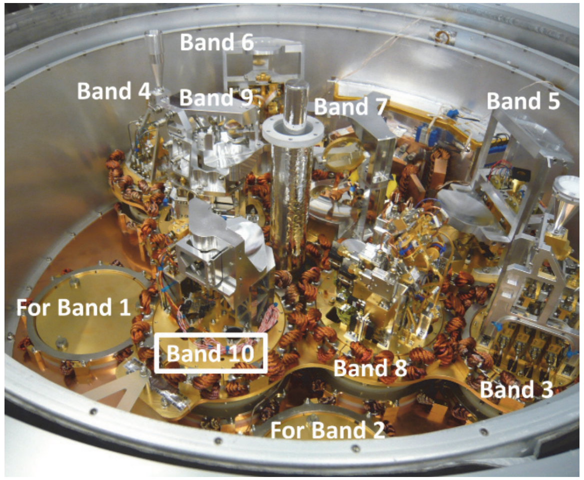
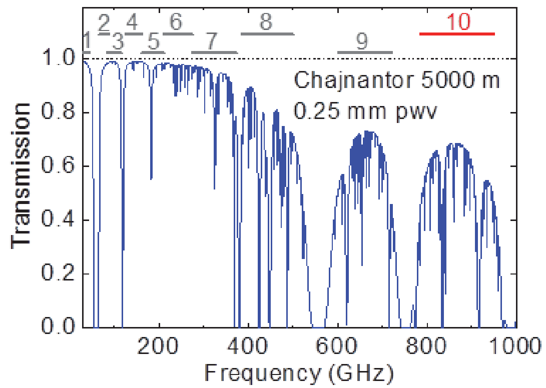
ALMA bands

Band 1	EA	Band 6	
Band 2		Band 7	
Band 3		Band 8	
Band 4		Band 9	
Band 5		Band 10	

- ALMA radio telescope: 66 12m/7m Cassegrain antennas with 10 frequency bands covering from 35 to 950 GHz

- The first two bands 35-50 GHz and 67-90 GHz are not implemented into the array yet!





ALMA band 1 receiver

- ALMA band 1 covers the first mm-wave atmospheric window in ALMA: 35-50 GHz/ 52 GHz if possible (35.9% / 39.8% fractional BW)
- The design of the ALMA 1 receiver is currently on-going as a joint international effort (CDR – Jan16)
- ALMA band 1 consortium:
  - ASIAA (Taiwan): Project Leader + warm LNA + down-converters
  - NAOJ (Japan): Optics + Management Support
  - NRAO (USA): cold LNA + WCA (warm cartridge assembly)
  - HIA (Canada): OMT
  - Universidad de Chile (UdC) (Chile): Optics

ALMA band 2 receiver

- ALMA band 2 rx is not an official ALMA project yet
- Two different initiatives to develop a receiver for this band:
  - Band 2 (67-90 GHz): NRAO with NSF funding
  - Band 2+3 (67-116 GHz): consortium (INAF, NAOJ, Univ. Chile, RAL, Univ. Manchester) led by ESO
- NAOJ has provided optical design and studies for both projects
- NAOJ contributed to measurement campaign and data analysis of band 2+3 optics at ESO in Dec ’15
- Optics for band 1, 2 and 2+3 are similar: HDPE lens used as cryostat window

ALMA Specifications NAOJ

- Efficiencies at secondary:
  - Aperture efficiency > 80%, as product of
    - Spillover Eff x Amplitude Eff x Phase Eff x Polariz Eff x Defocus Eff
    - Desired: freq. independent performance and high quality beams
  - Polarization efficiency > 99.5% (integ. XsP on sec < -23 dBc)
- Receiver noise:
  - Optics are the first element in the receiver
  - Losses affect the noise contribution of all other elements
    - Friis formula of noise

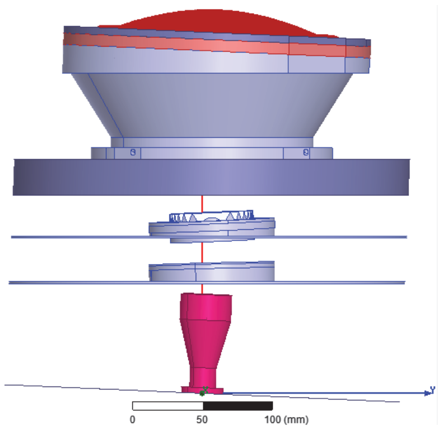
$$T_{eq} = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1 G_2} + \ldots$$

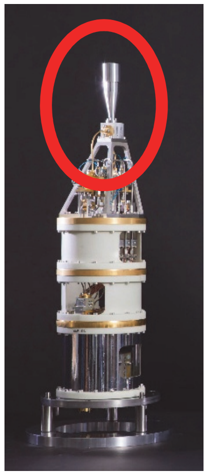
- Spillover noise:
  - radiation from optics terminated at different temperatures
  - Possible diffraction at secondary can end up at the ground

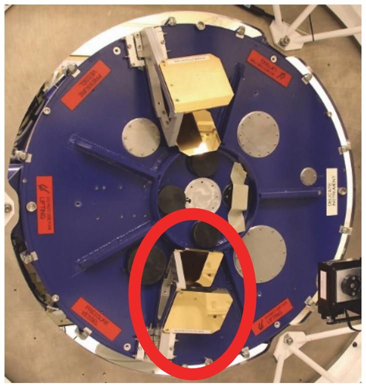
Design principles

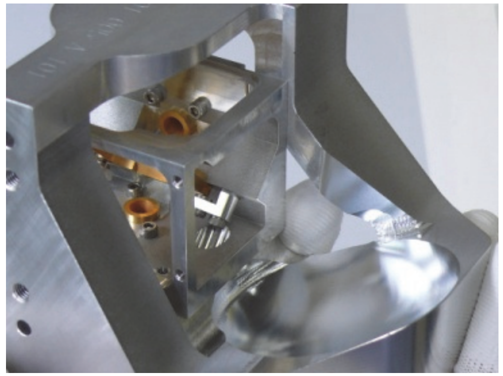
- Corrugated horns + focusing elements + OMT
- Frequency coverage is larger in terms of fractional BW

1. Different sizes of components -> proportional to λ
    - Upper bands (5-10) with optics inside cryostat (less loss)
    - Lower band optics do not fit inside
        - Band 1 and 2: Horn in 15K stage, dielectric lens used as window
        - Band 3 and 4: Horn in 4K stage, warm mirrors on top of cryostat





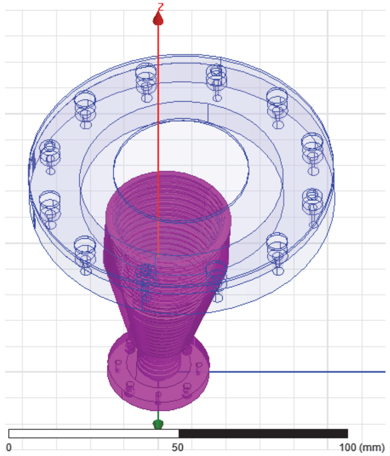


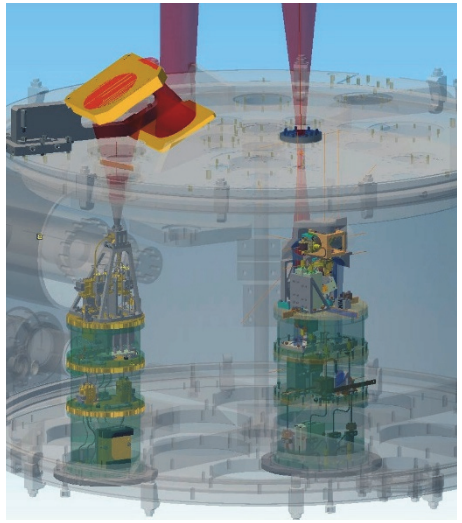


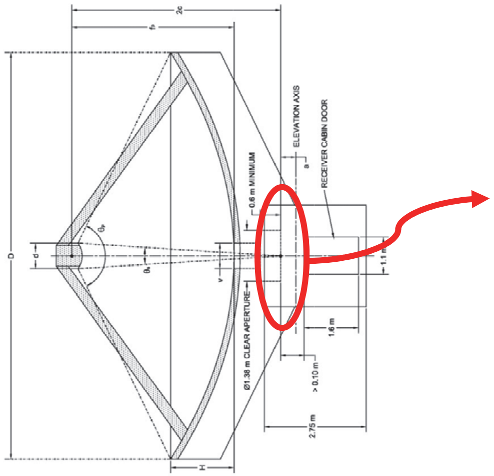
A. Gonzalez, 36th ESA Antenna WS, 2015

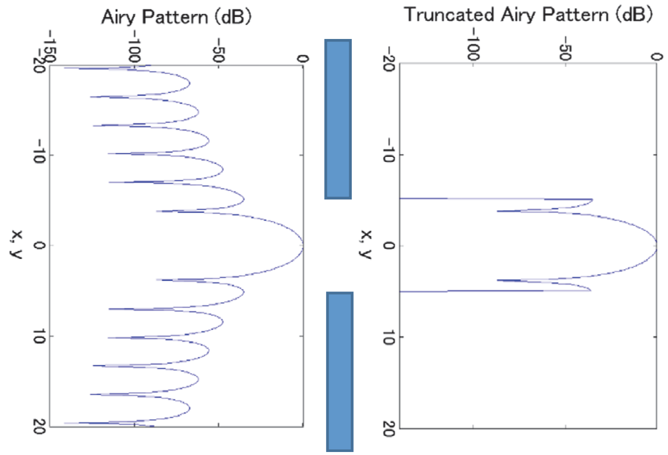
Design principles

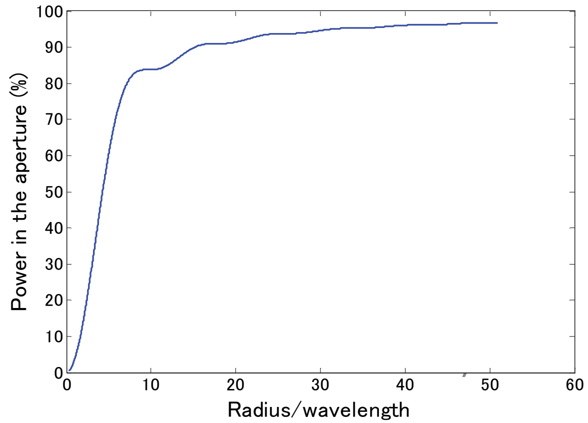
2. Truncation at cryostat apertures
   - Smaller beams at higher freqs suffer less truncation at cryostat shields and windows
   - Truncation at cryostat window
     - Limits the maximum aperture efficiency! -> Problem at lower bands









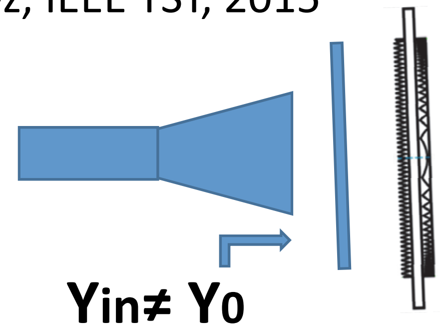


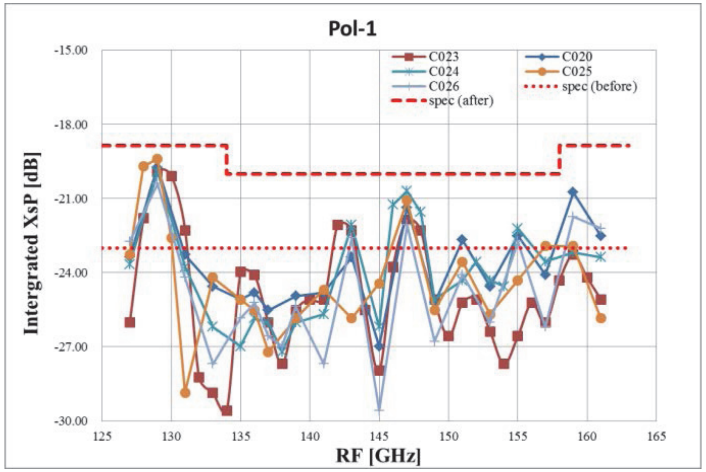
Common principles

3. Methods for Electro-Magnetic Analysis:
   - Quasi-optics and Physical Optics validation for upper bands
   - Careful Method of Moments calculations for lower bands
     - Truncation, diffraction, impedance couplings…

4. Negative effects due to IR filters and rims
   - Impedance coupling on horn aperture currents (discovered for the ALMA band 4 receiver)

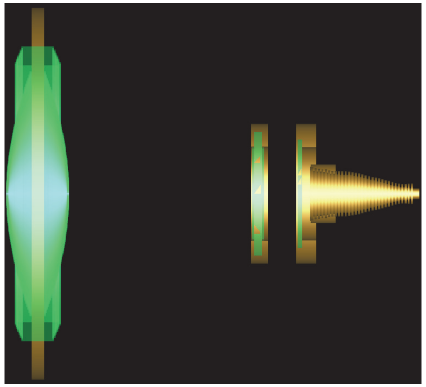
Gonzalez, IEEE TST, 2015

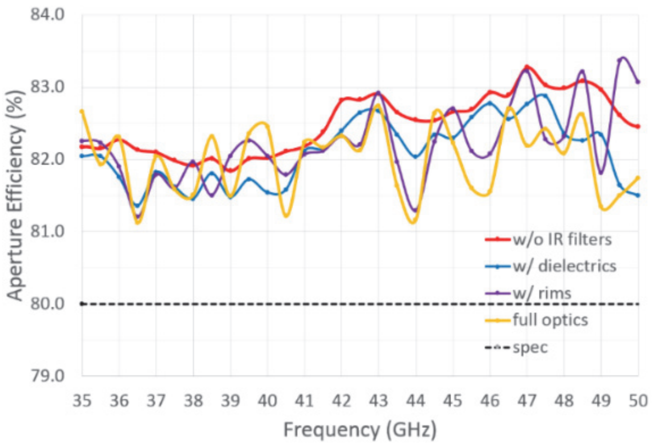


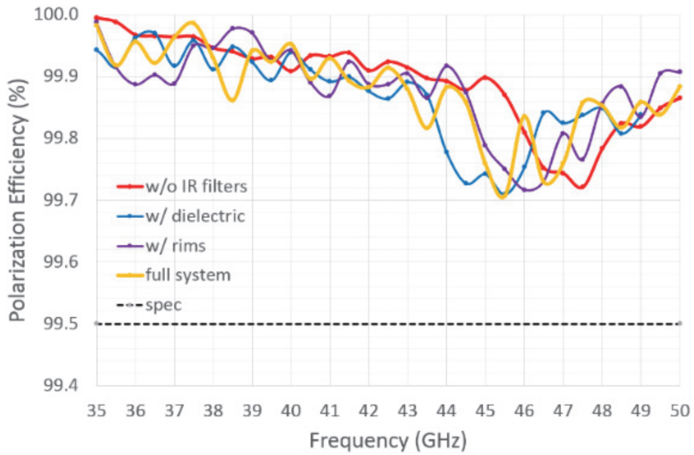


Common principles

- All these bands have the horn aperture next to IR filter
  - Same as band 4 but with worse consequences
  - Effects on CoP patterns are important (more than on XsP)
  - Effects on noise temperature too due to truncation…



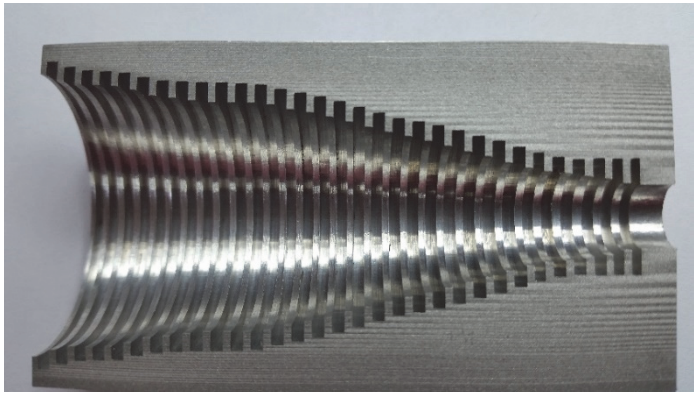


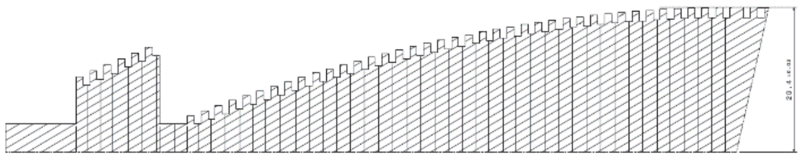


A. Gonzalez et al,
IEEE APS ‘16

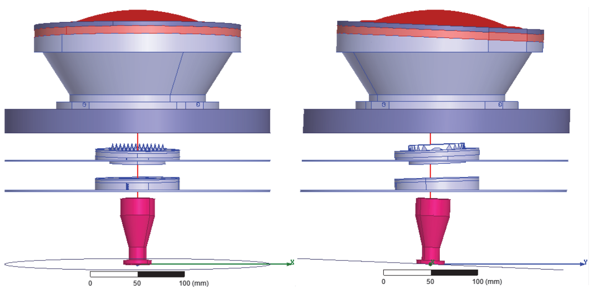
Band 1 (35-50 GHz)

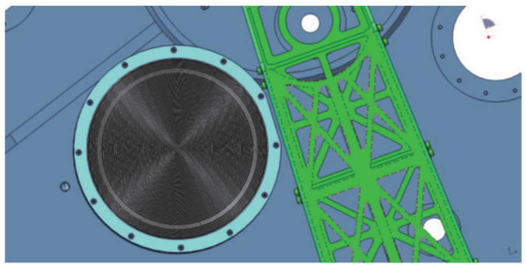
- Project led by ASIAA (Taiwan) with room temp. measurement at UdC and cold beams at Taichung
- Optics based on lens (NAOJ) and profiled horn (UdC)

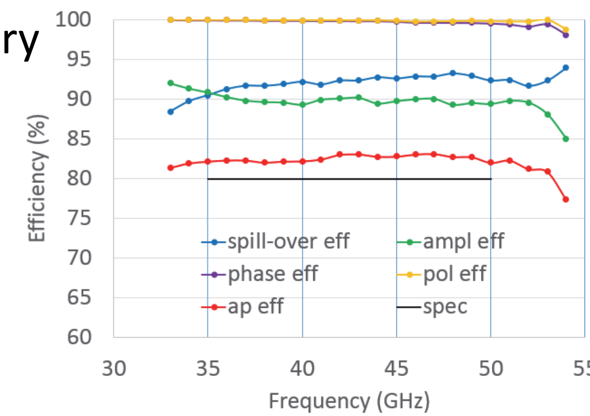




Max Ap. Eff from Airy pattern < 84.1%!





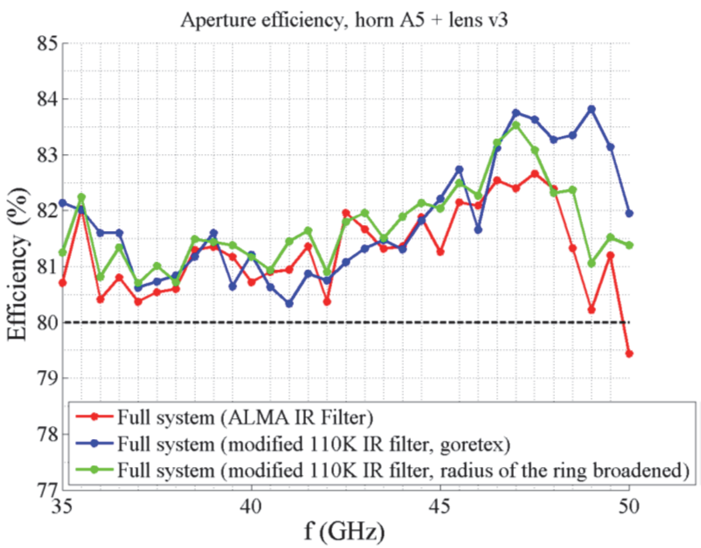


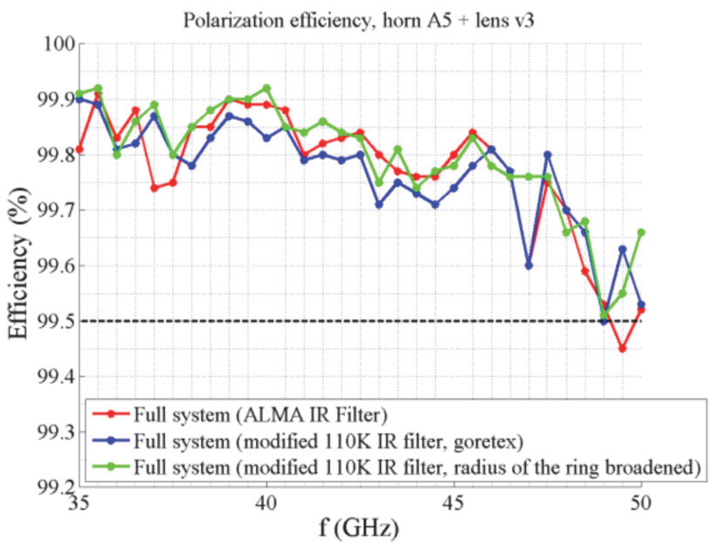
A. Gonzalez, 9th EuCAP, 2015

Band 1 (35-50 GHz)

- Measurement results
  - Room-temp measurements in Chile, cold meas. in Taiwan
  - Still some work to be done in understanding the connection between the two kind of measurements
  - CDR review panel praised the design results!

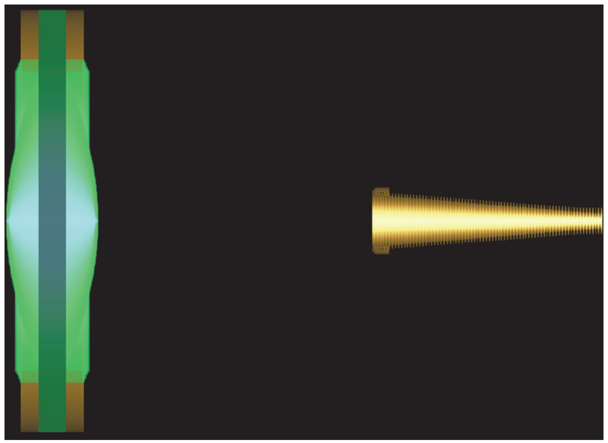
Measurements done by UdC - unpublished

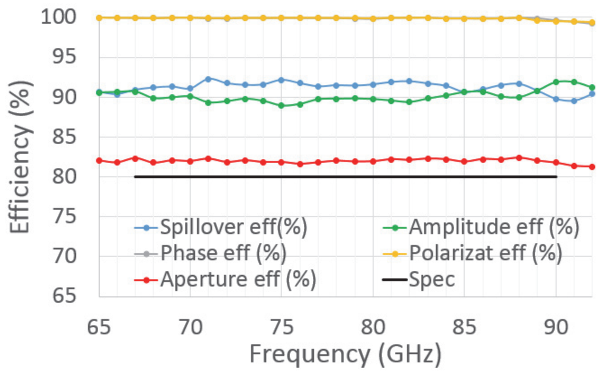




Band 2 (67-90 GHz)

- NRAO project -> NAOJ contributes the rx optics design
- Lens just on top of cryostat to refocus the fields from a long conical horn (designed by NRAO / S. Srikanth)
- Maximum aperture eff from Airy pattern considerations is only 83.8%!
- Measurements being done at NRAO

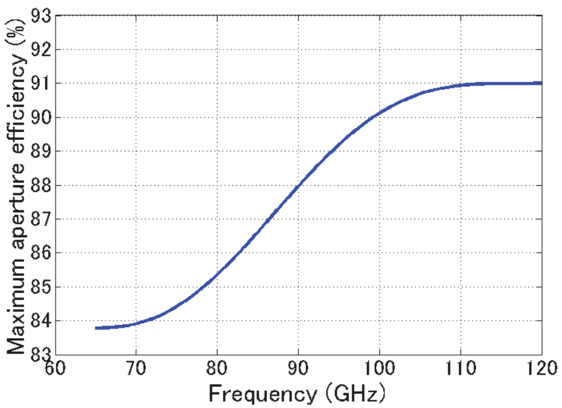


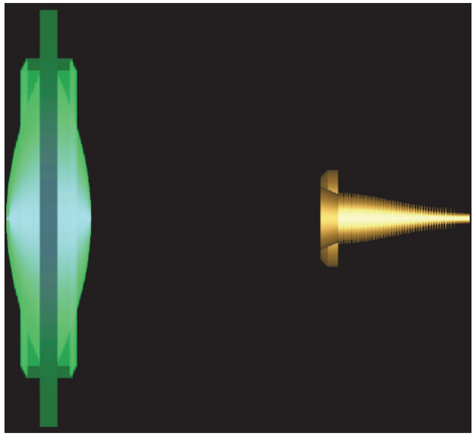


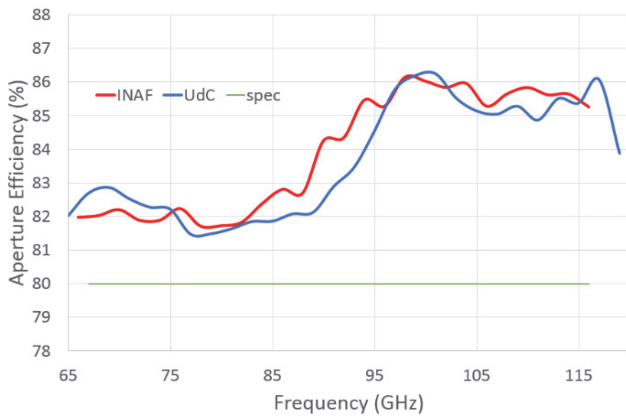
Preliminary measurement results in S. Srikanth, A. Gonzalez, AT-RASC 2015

Band 2+3 (67-116 GHz)

- Optics collaboration by NAOJ, UdC, INAF, and led by ESO
- Horns designed by INAF and UdC
- Optical designs with both horns done by NAOJ
  - Based on zoned lens just on top of cryostat top plate
- Maximum aperture eff changes with frequency



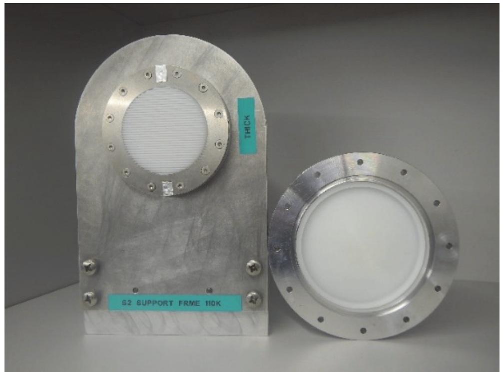


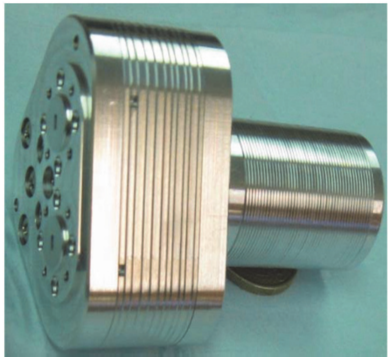


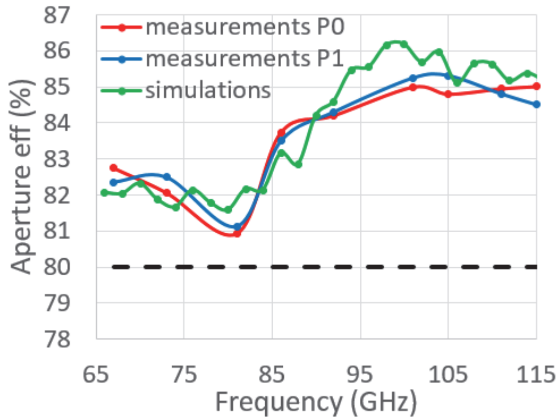
To be presented in APS 2016

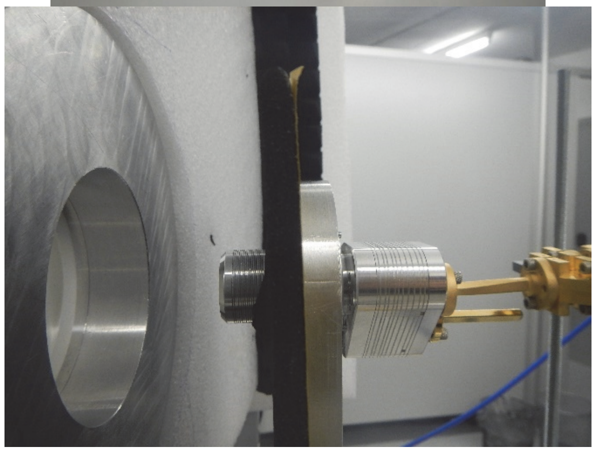
Band 2-3 measurements

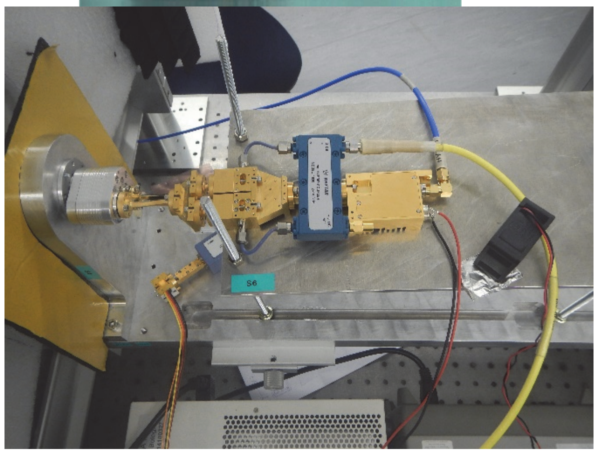
- Measurement campaign at ESO in Dec. 15
  - I contributed automatic acquisition software development and analysis of results (far field transformation, Gaussian beam fitting, aperture efficiency calculations…)

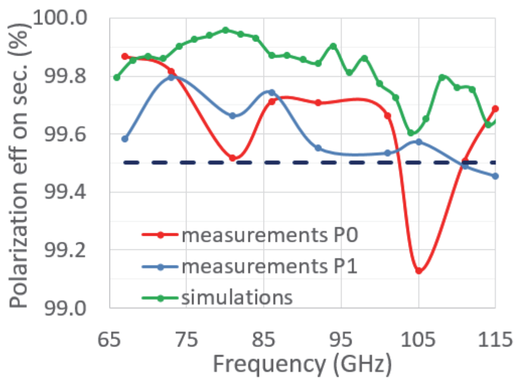












Thank you for your attention!