SWIRP: Compact Submm-Wave and LWIR Polarimeters for Cirrus Ice Properties

IIP-16 Project

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(GSFC CODE 613)

Co-Is (GSFC)

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Other key personnel

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- Antenna: Cornelis Du Toit /567
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- Electrical: Carlos Duran /564

Co-Is:

William Deal (NGAS)
- 220 GHz polarimeter (V,H)
- 680 GHz polarimeter (V,H)

William Gaines (NGC)
- BAPTA

Russell Chipman (U of Arizona)
- LWIR polarimeter (V,H)

Ping Yang (TAMU)
- Ice microphysics simulation

Background and Motivations

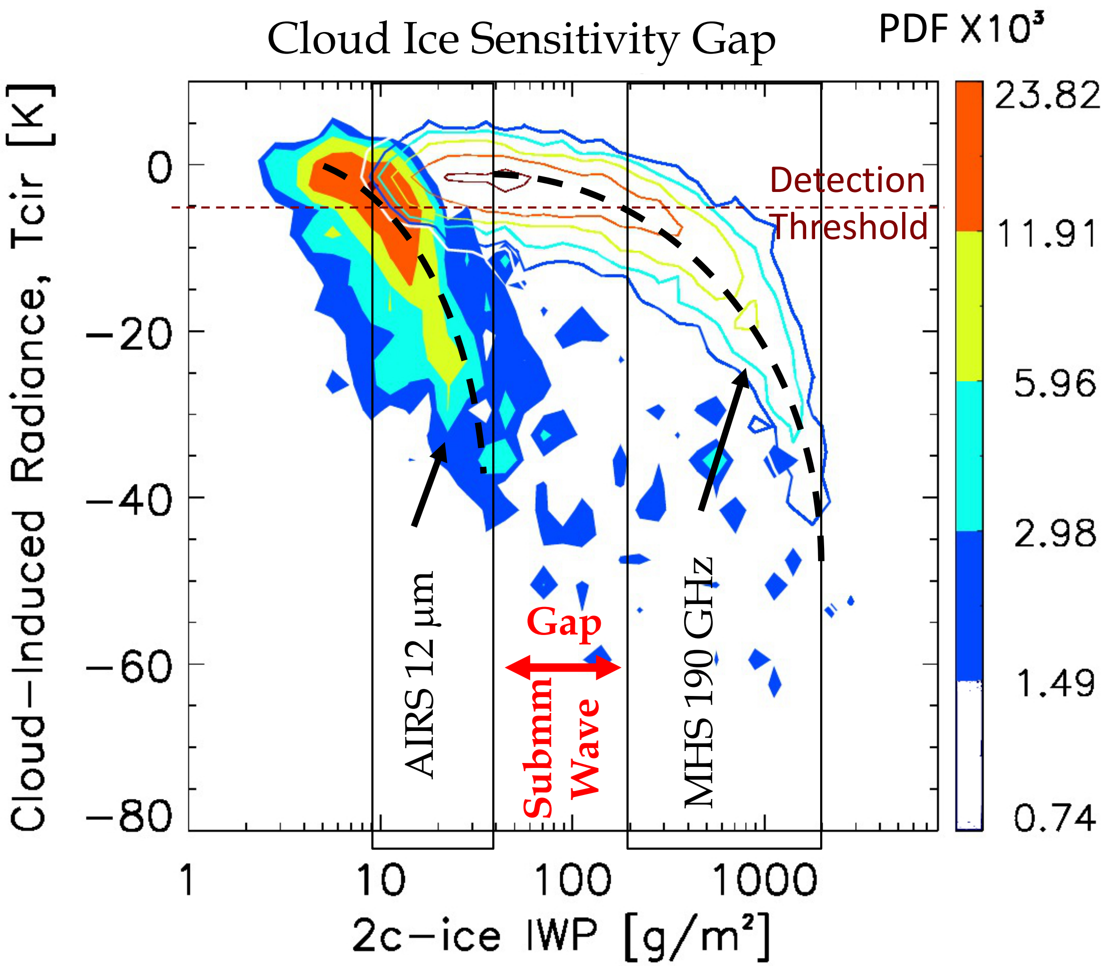
Clouds, ice clouds in particular, remain a major source of uncertainty in climate models

Needs for accurate cloud ice measurements highlighted in the Decadal Survey (DS) mission: Aerosol, Cloud and Ecosystem (ACE), which recommended submm and LWIR radiometers for cloud ice measurements.

Cloud microphysical properties (particle size and shape) account for ~200% and ~40% of measurement uncertainty, respectively.

Combined submm and LWIR polarimeters to provide the sensitivities needed for cloud ice and microphysical property (particle size and shape) measurements

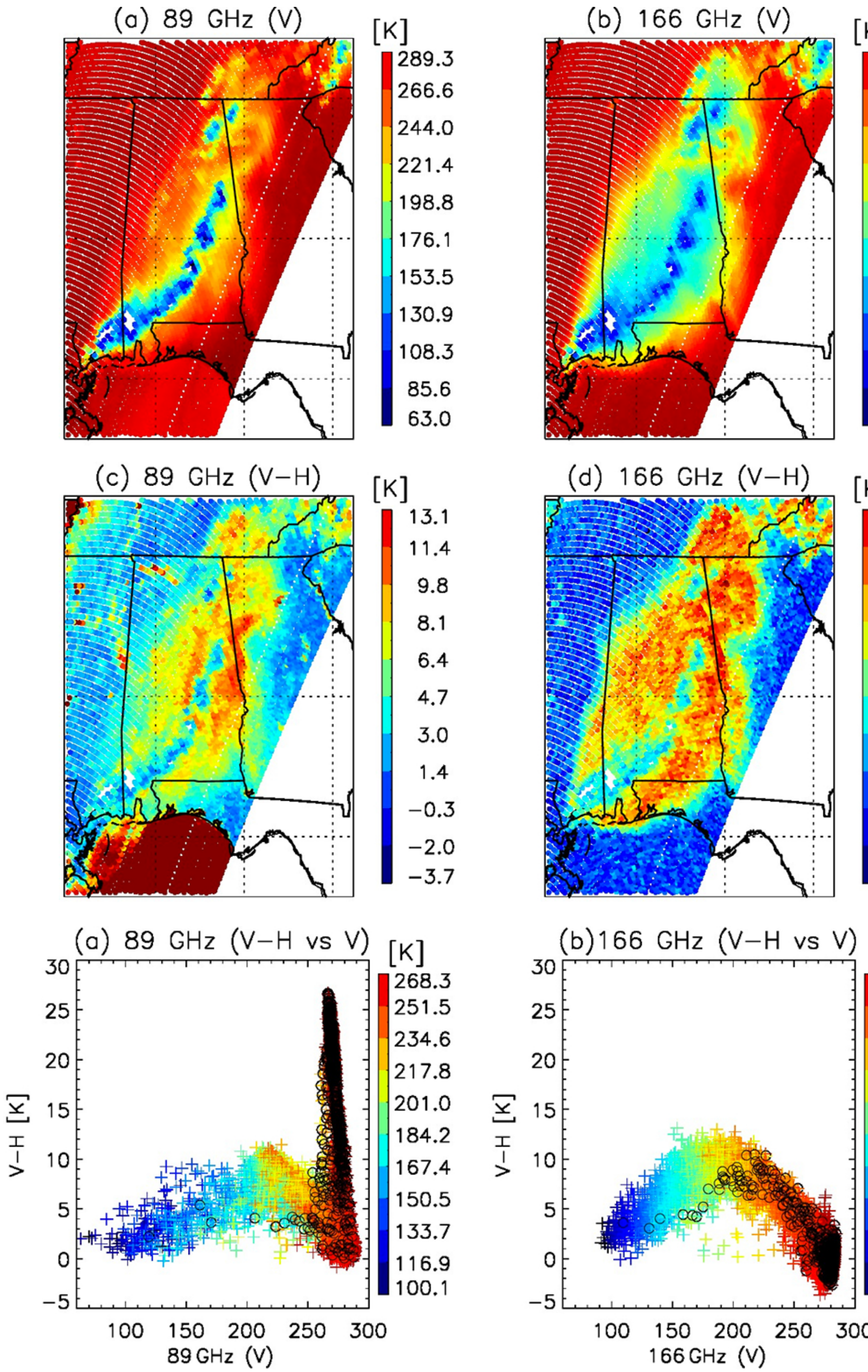
$$T_{cir} = T_b - T_{b\_clear}$$



Ice Water Path (IWP) from CloudSat/CALIOP

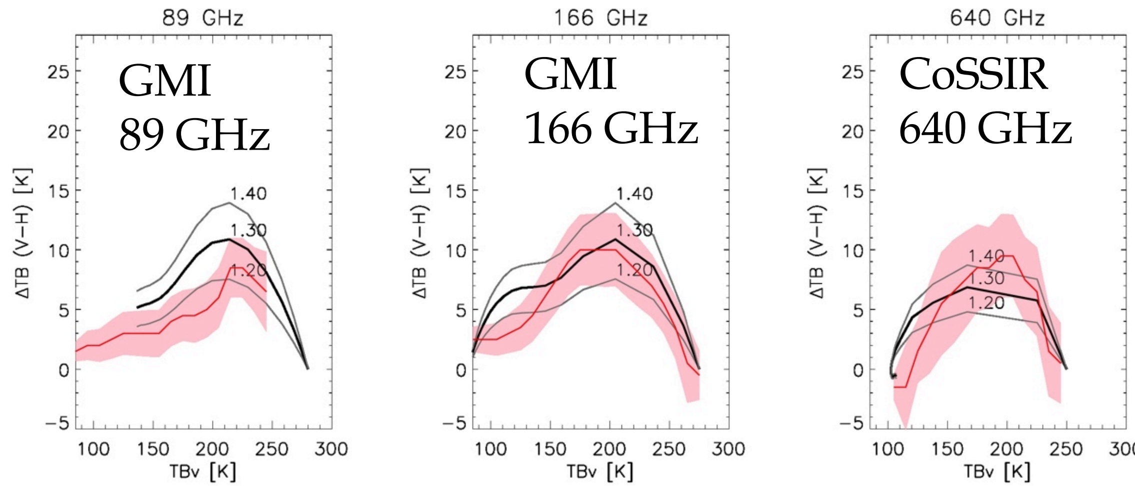
GMI 89 and 166 GHz Observations

- Strong surface polarization contributions at 89 GHz, compared to 166 GHz, resulting large TB differences between land (weak V-H) and ocean (large V-H)
- "Bell-Shape" in the TB vs V-H relationship, as a result of reduced V-H at large TB depressions
- Similar magnitudes (~10 K) of V-H at 89 and 166 GHz
- V-H differences account for 10-30% cloud scattering signals at TB=200-270K

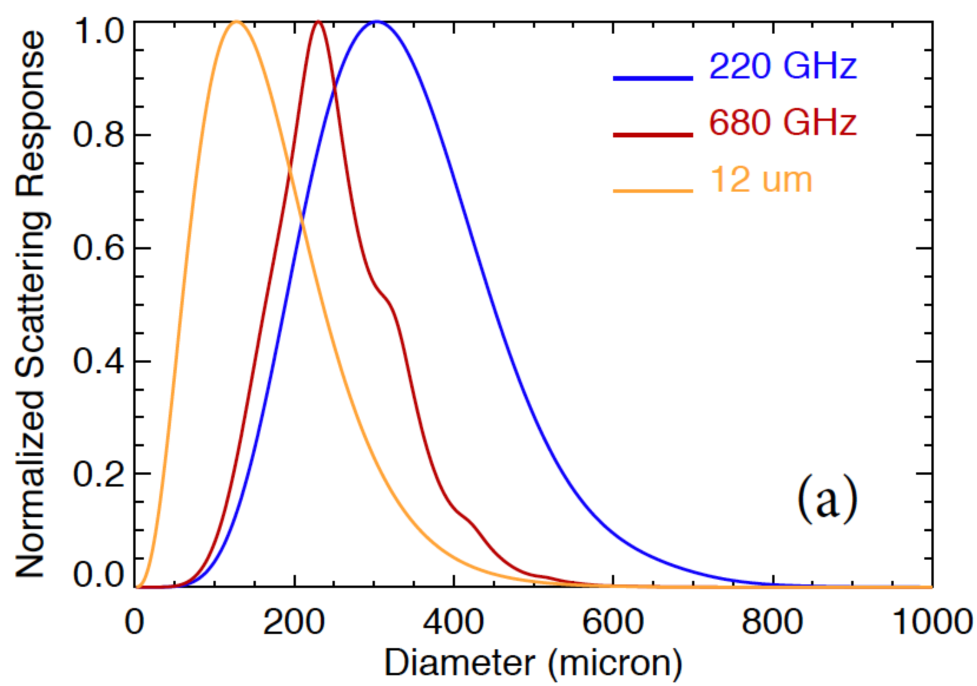


Polarization Signals in Cloud Ice Measurements

Cloud-induced radiances (Tcir, from ice particle scattering) at 220, 680 GHz and 12 μm bands provide the wide dynamic range in sensitivity needed for measuring IWP > 5 g/m^2 and Deff > 30 μm.



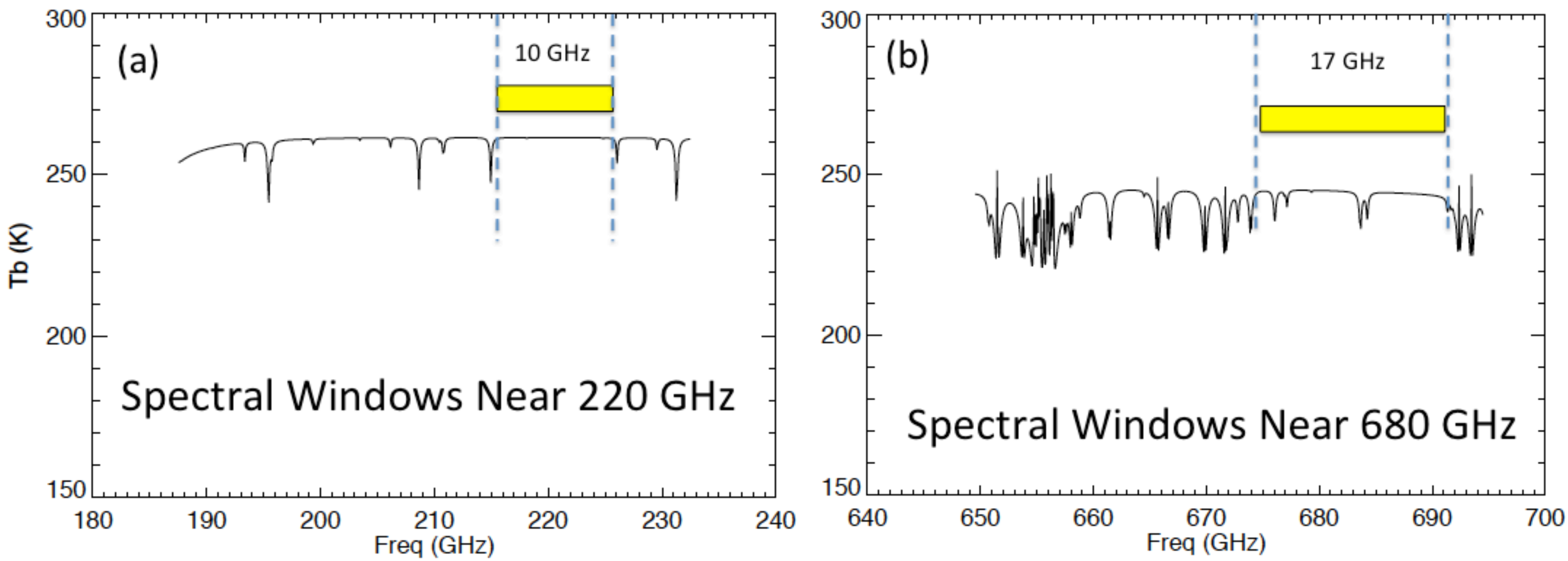
Polarimetric measurements at these bands determine bulk particle shape, which is characterized by the aspect ratio from H- and V-pol differences and can be measured to 5% or better.



Previous studies show that cloud ice particles appear to have an aspect ratio between 1.2 (89 GHz), 1.3 (166 GHz), and 1.4 (640 GHz).

No LWIR polarimetric cloud observations were made from space.

Spectral Windows at 220 and 680 GHz



Overview of Proposed SWIRP Developments

- Key Subsystems and Responsibility
  - 2x 680 GHz Polarimetric Receivers (NGC)
  - 1x 220 GHz Polarimetric Receivers (NGC)
  - 1x LWIR Polarimeter and Cal Targets (U of Arizona)
  - Bearing and Power Transfer Assembly (BAPTA) (NGC)
  - Structure, Submm Reflectors and Cal Targets (GSFC)
  - Power Distribution Unit (GSFC)
  - Instrument Control and Data Acquisition, or CDA (GSFC)
- Instrument Integration (GSFC)
- Instrument Performance Evaluation and Testing (GSFC)
  - Bench testing
  - Environmental testing
  - Rooftop testing
- Goal: System TRL 3 -> 5

SWIRP Parameters and Requirements

Flight altitude 400km; Swath 700 km

Conical scan rate: 17.6 rpm

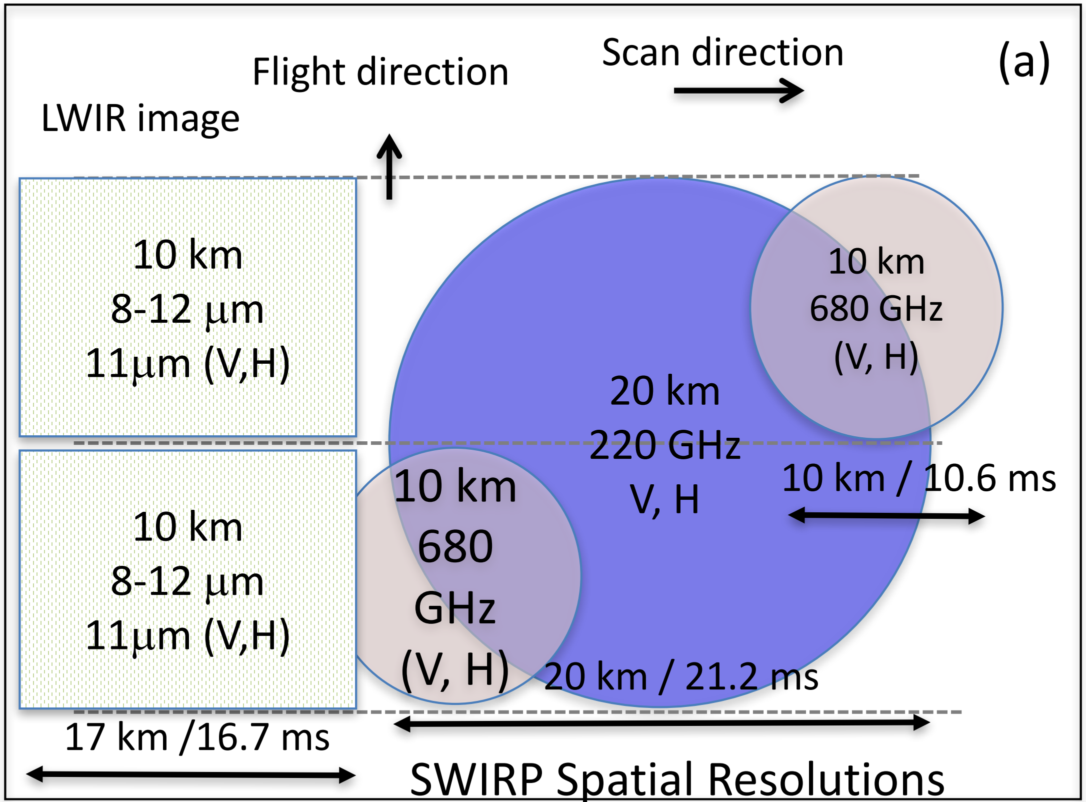
Integration time: 21.2 ms (220 GHz), 10.6 ms (680 GHz), 2.7 ms (11 μm)

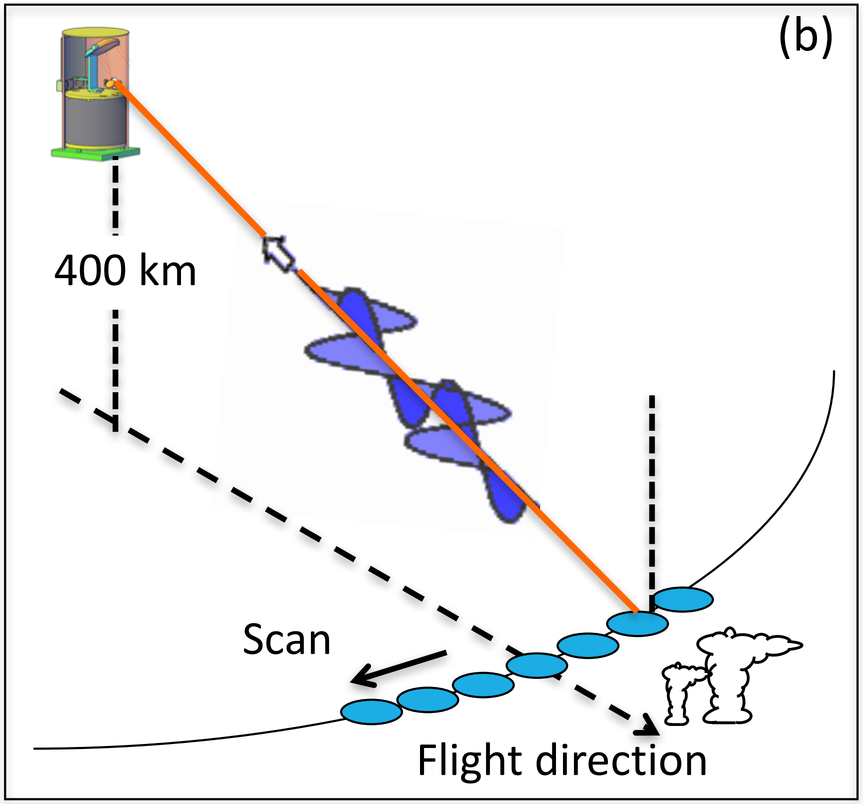
Footprints/FOVs: 220 GHz (20 km /1.6°), : 680 GHz (10 km /0.8°), 11 μm (2.5 km/0.2°)

Submm polarimetric receivers:
- 680 GHz (V, H), 2x: direct detection (baseline), or heterodyne detection (backup)
- 220 GHz (V, H), 1x direct detection

LWIR polarimeter:
- 3-band (8.6, 11, 12μm) channeled spectropolarimeter (baseline), or 2-band (11, 12μm) microgrid polarimeter (backup)
- Demonstration with 60-Hz FLIR detector

Data rate: 22.3 kbps





SWIRP Development Challenges

Volume constraints

Submm dual-polarized receivers

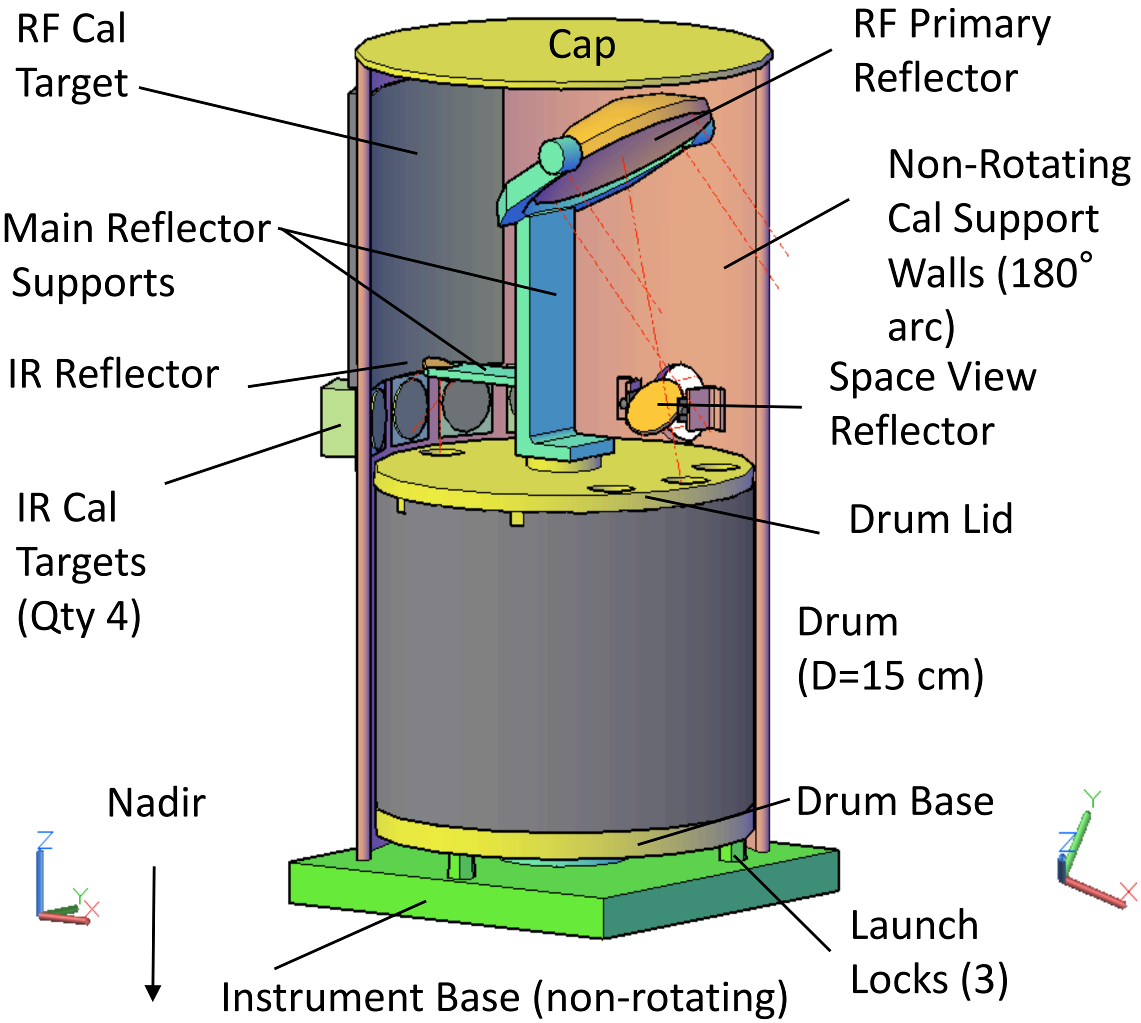
- Packaging
- Alignment to preserve V and H pol
- FOV collocation

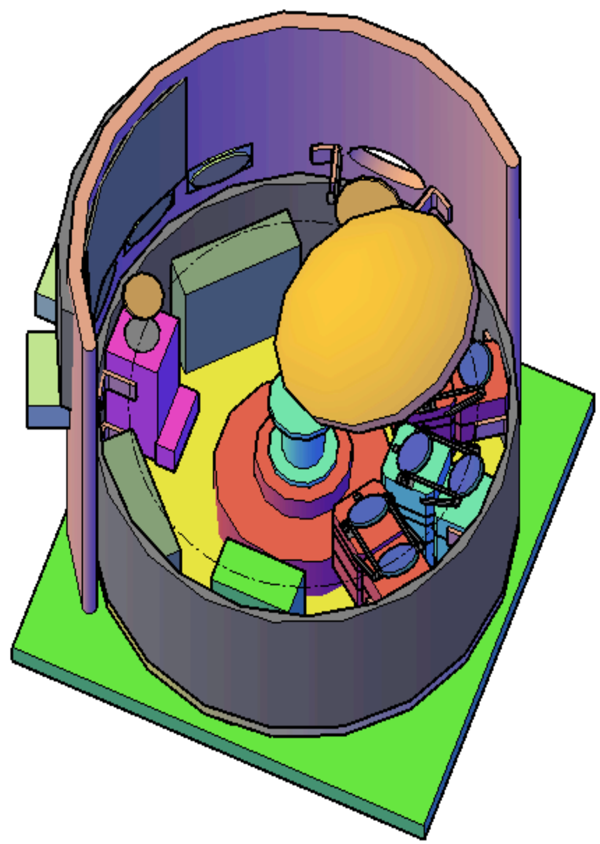
IRCSP (LWIR polarimeter)

- Thermal noise
- Calibration

BAPTA dimensions and data rate

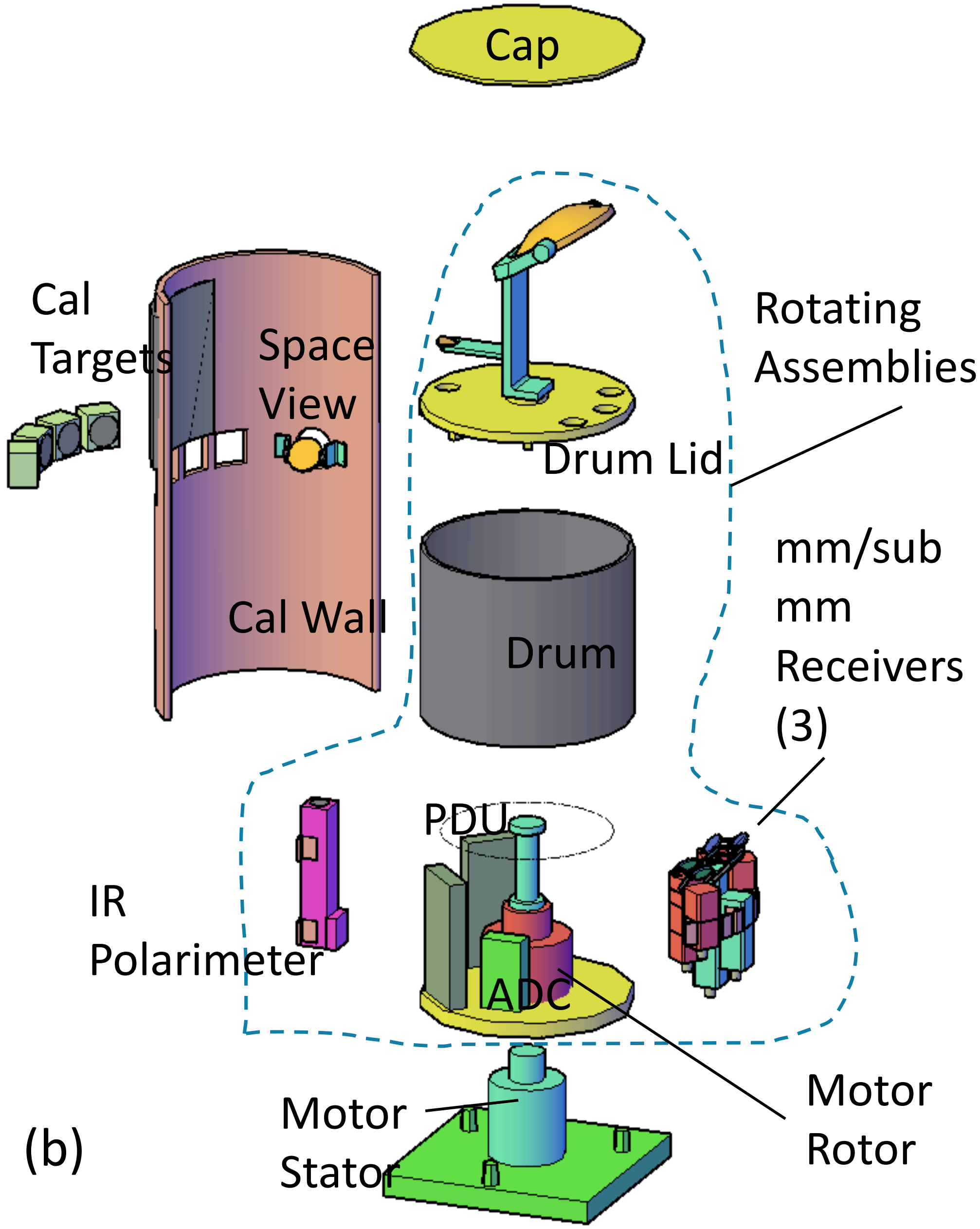
SWIRP Instrument Conceptual Drawing





Assembly view with cap, Drum Lid, and main reflector support removed.

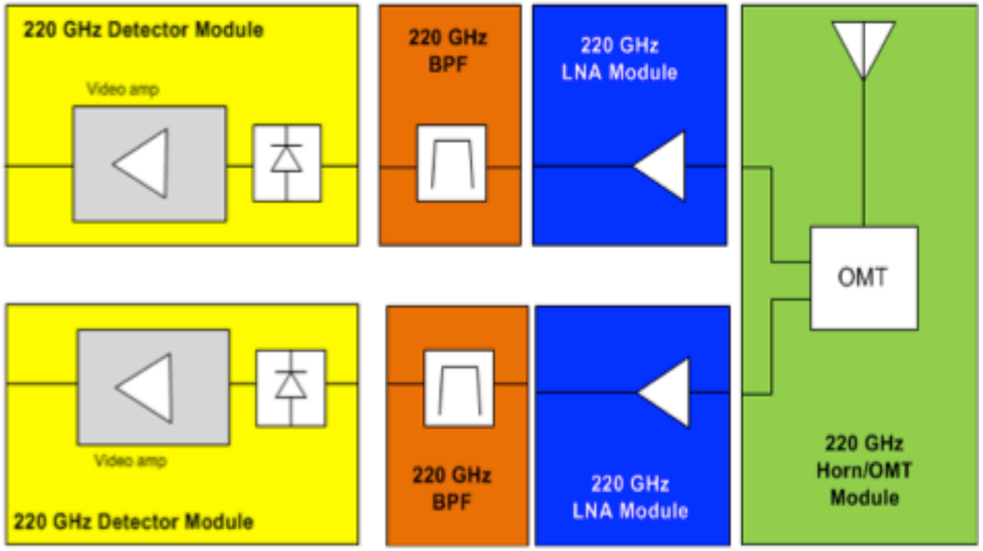
Instrument Concept Exploded View

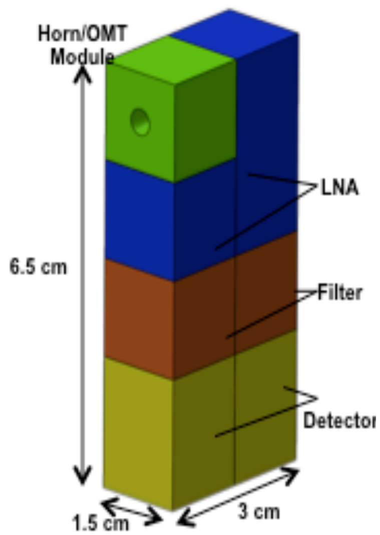


NGAS 220 GHz Direct Detection Receivers

- Compact dual-polarized receivers (H, V)
  - 1 unit
  - Mass <0.44 kg
  - Power < 1.3 W
  - Vol: 2x3x6.5 cm

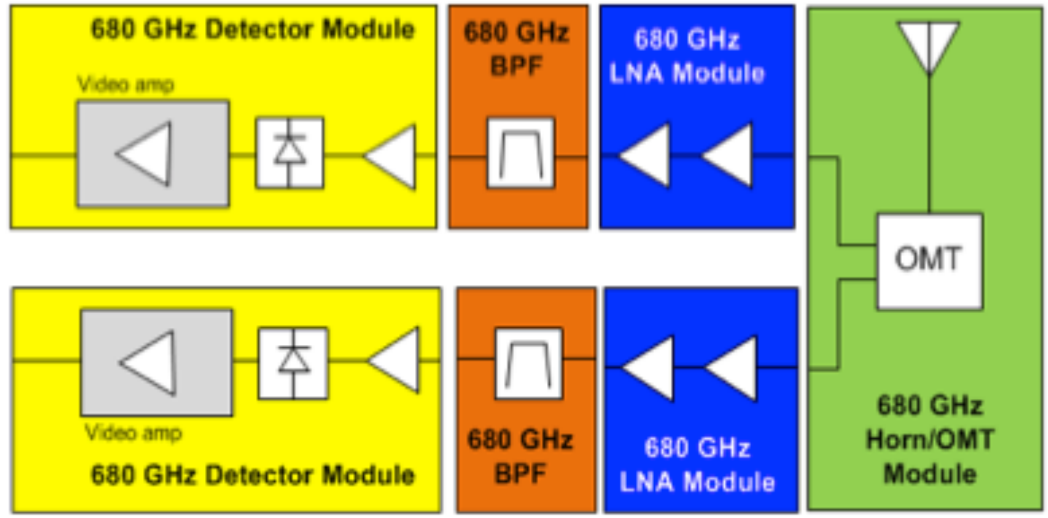
- Interfaces with SWIRP
  - Horn block (reflector)
  - Video output (CDA)
  - Power supply (PDU)

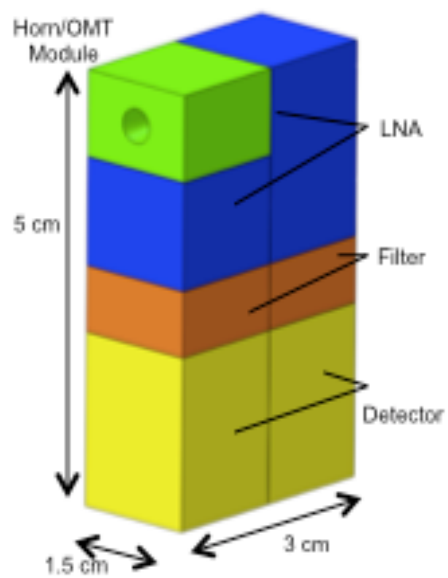




NGAS 680 GHz Direct Detection Receivers

- Compact dual-polarized receivers (H, V)
  - 2 units total
  - Mass <0.35 kg
  - Power < 1.7 W
  - Vol: 2x3x5 cm
- Interfaces with SWIRP
  - Horn block (reflector)
  - Video output (CDA)
  - Power supply (PDU)

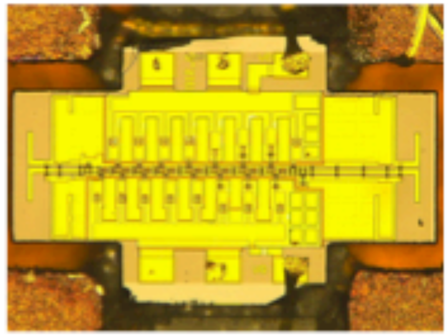


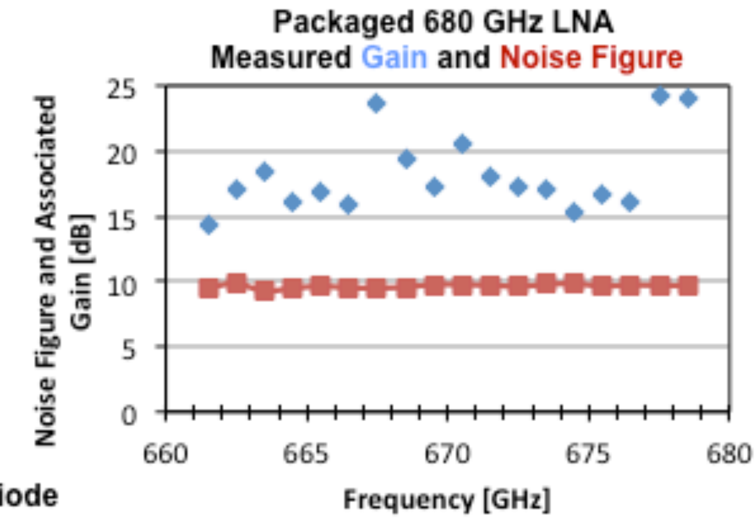


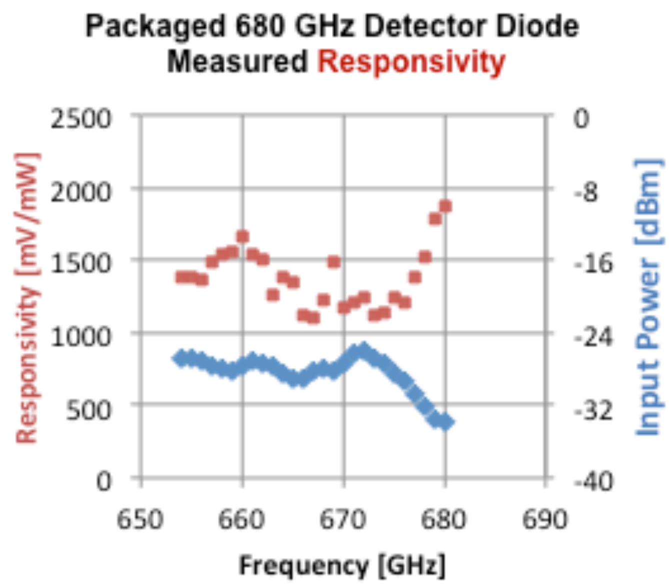
NGAS Advanced Receiver Technology

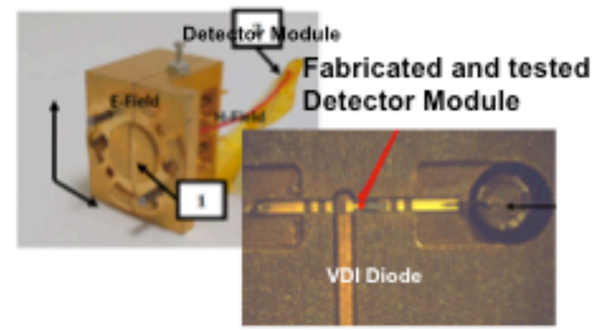
- Technology: 25 nm InP HEMT low-noise amplifier (LNA) that operates up to 800 GHz, enabling SWIRP compact direct detection receivers at 220 and 680 GHz;
- Heritage: IIP-13 TWICE project (220 and 670 GHz)
- Experience: Frequency-scaled packaging techniques for micromachined waveguides, wafer level assembly, monolithic integration of receiver sub-systems

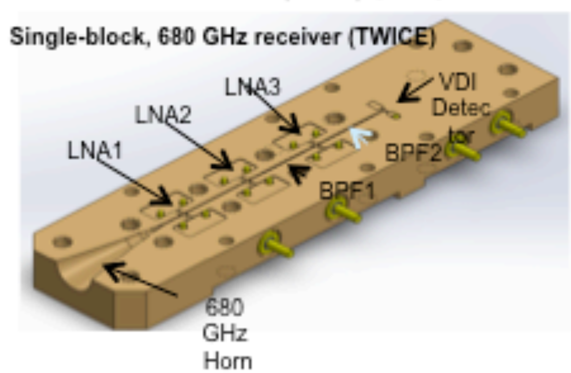
Packaged LNA TMIC

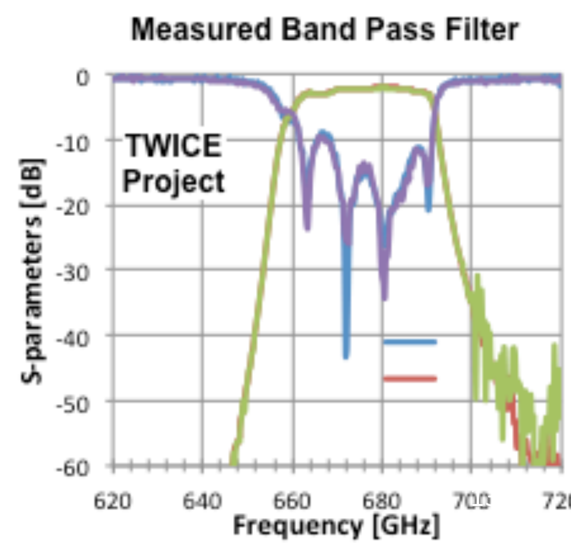






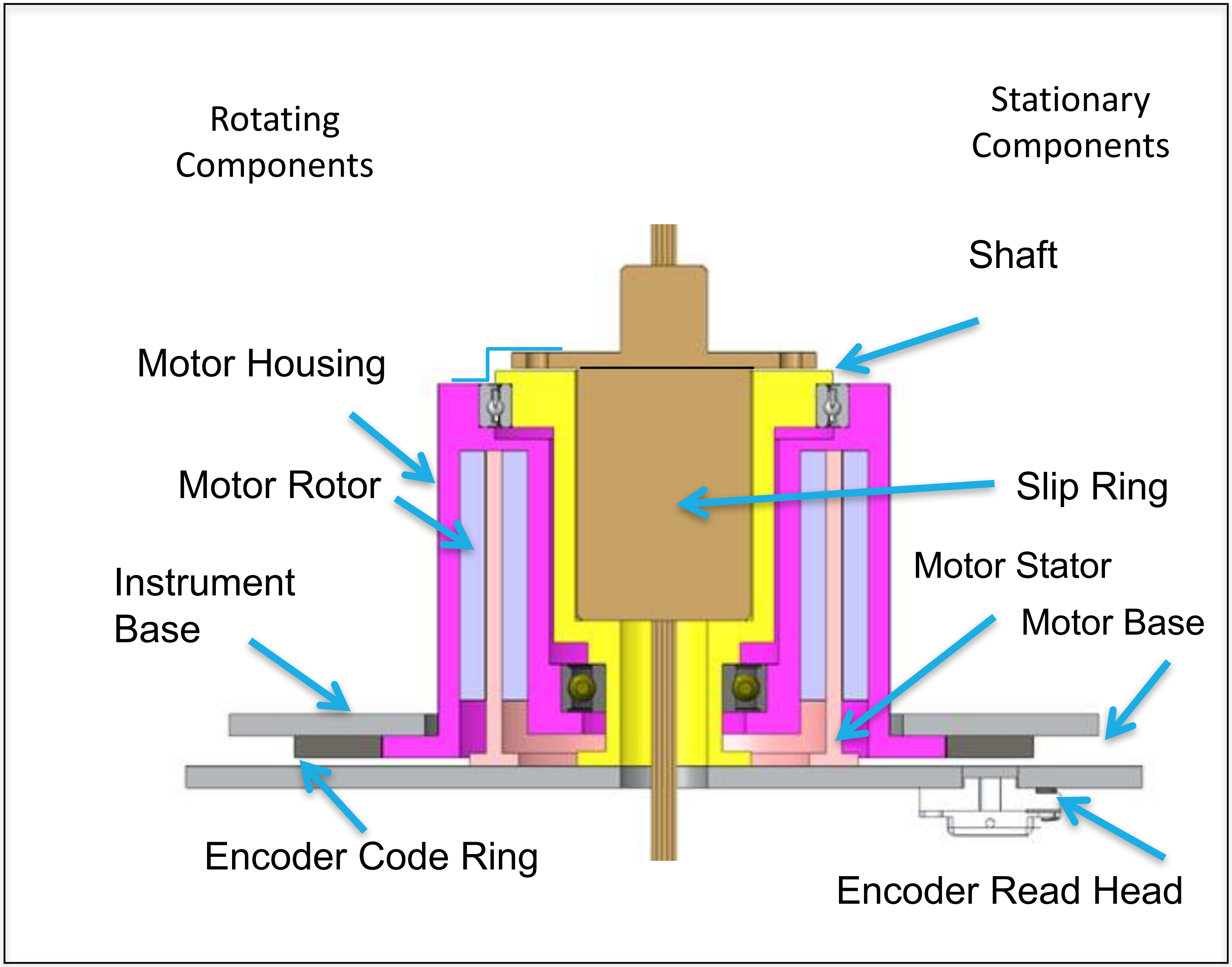






Mini-BAPTA Design

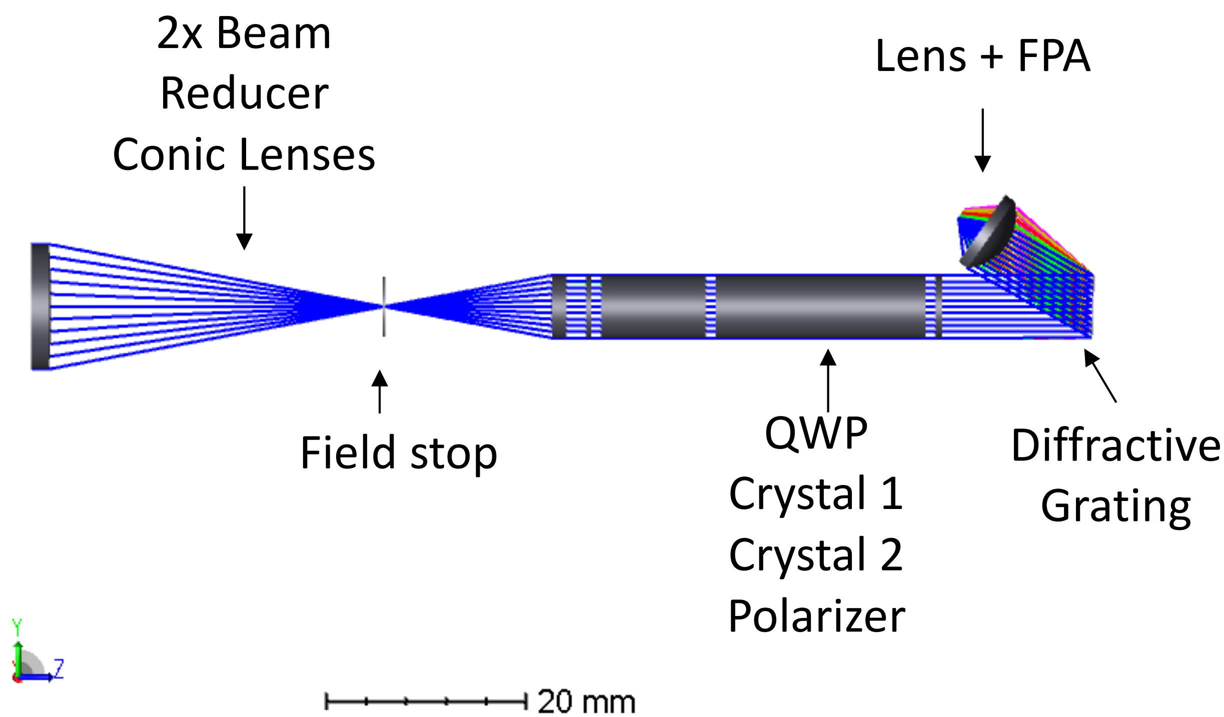
- Heritage:
  SSMIS design
- COTS parts
- Power ~ 2W
- Data rate goal: 400 kbps



SpectroPolarimeter Design

Key optical subassemblies:

1. single lens telescope
2. field stop/entrance slit and collimator
3. polarimeter with quarter wave retarder (QWR), high order retarder (HOR) and linear polarizer (LP)
4. diffraction grating/spectrometer
5. imaging lens, and
6. focal plane with two rows of microbolometer pixels.



Crystal assembly and polarizer modulate polarization as a function of wavelength

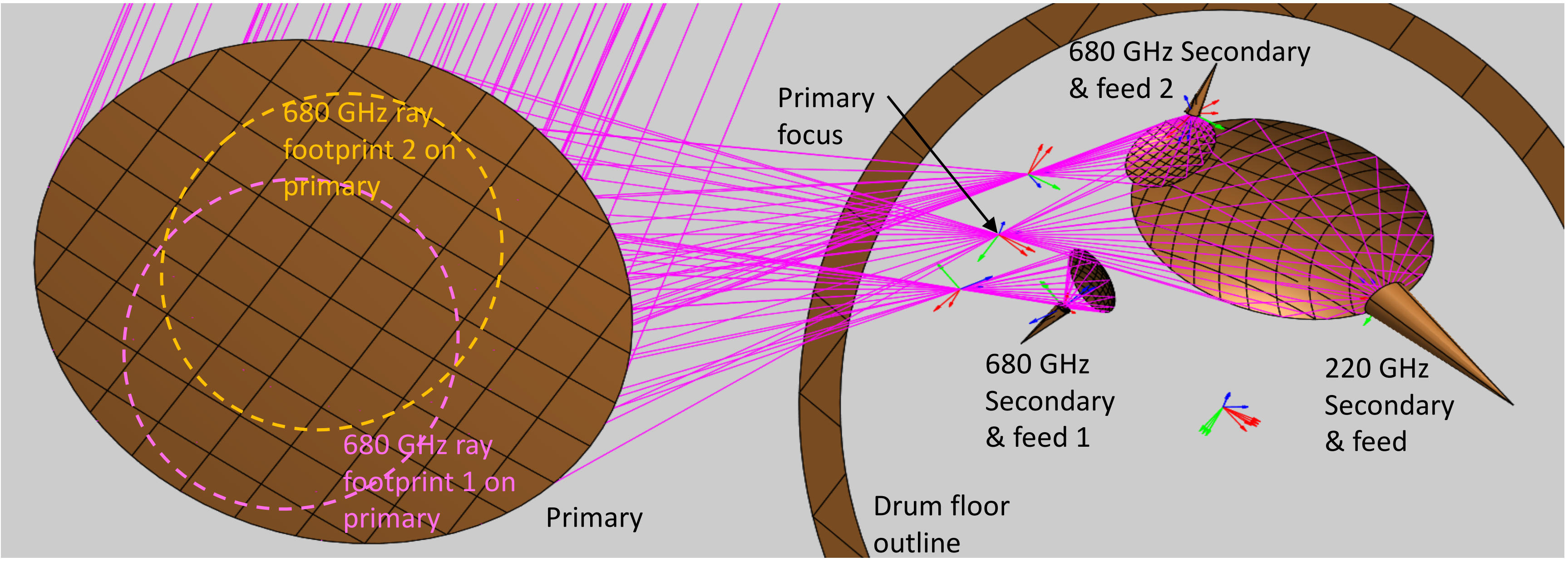
When light is unpolarized, spectrum is unmodified

When light is fully polarized spectrum is co-sinusoidally modulated, at one frequency for Q (0° and 90°) and twice the frequency for U (45° and 135°)

Antenna Optics

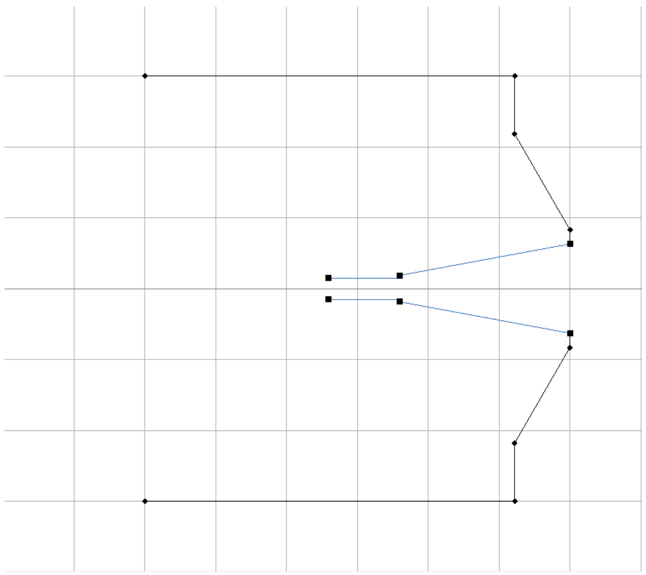
Currently under development

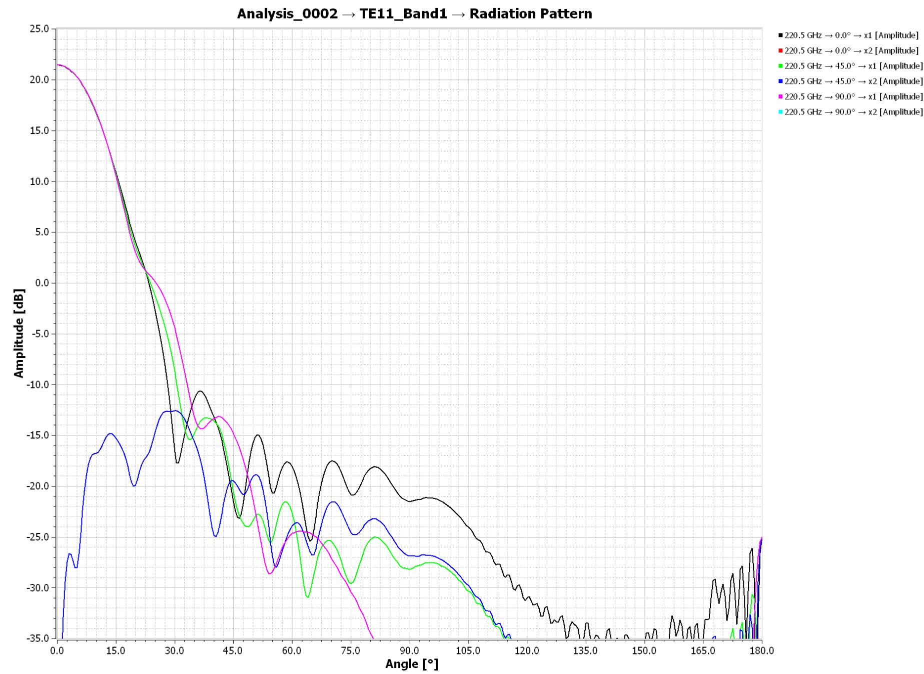
Beam efficiencies expected to be > 92%



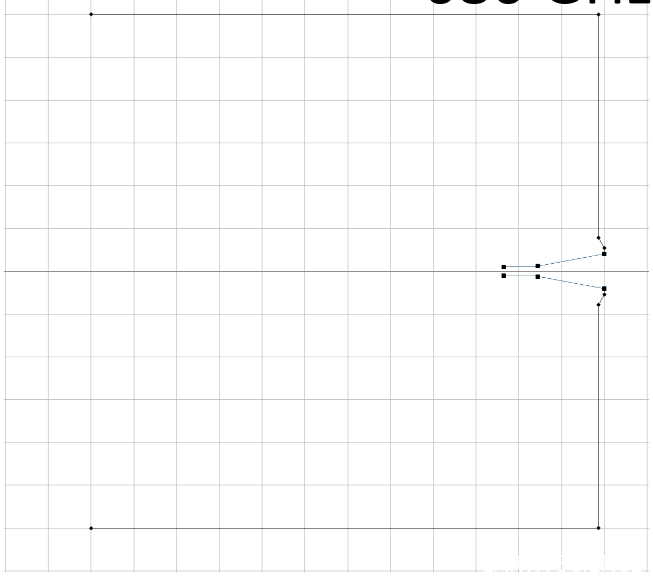
Antenna Feeds Preliminary Design

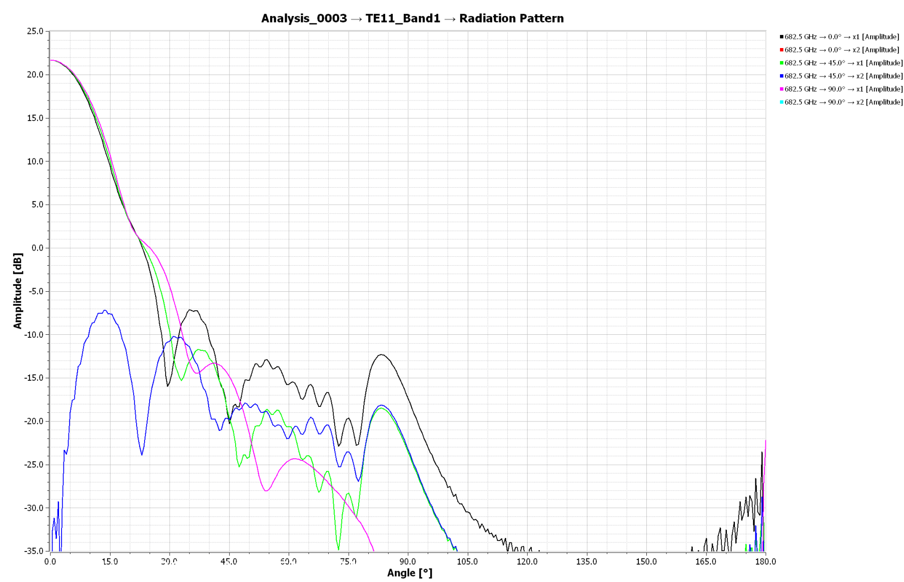
220 GHz



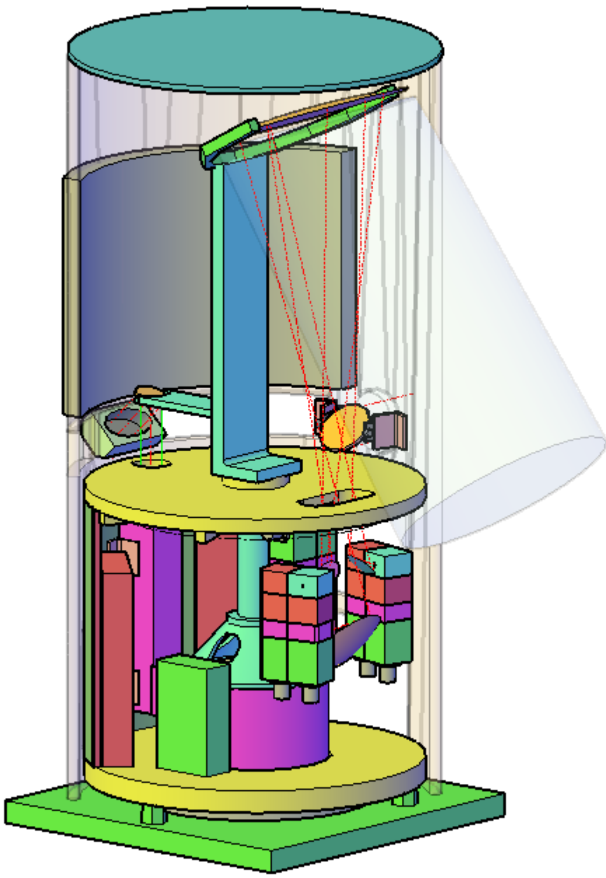


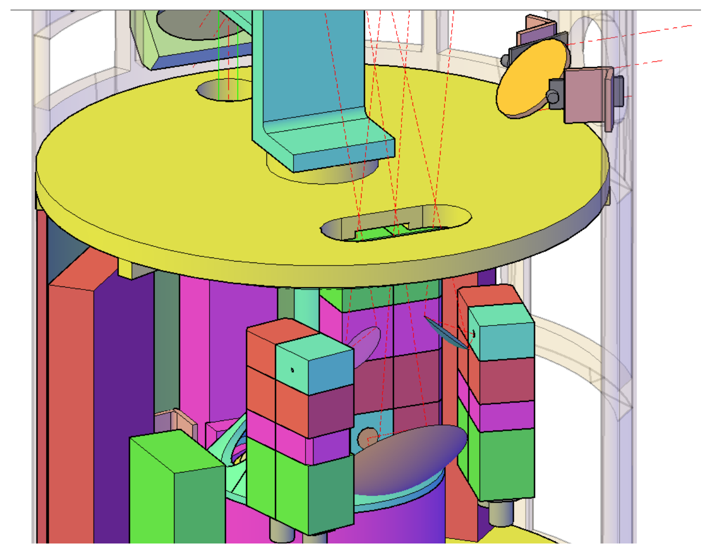
680 GHz





Updated Views with Optics





Thank you!