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

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- 220 GHz polarimeter (V,H)
- 680 GHz polarimeter (V,H)

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- BAPTA

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- LWIR polarimeter (V,H)

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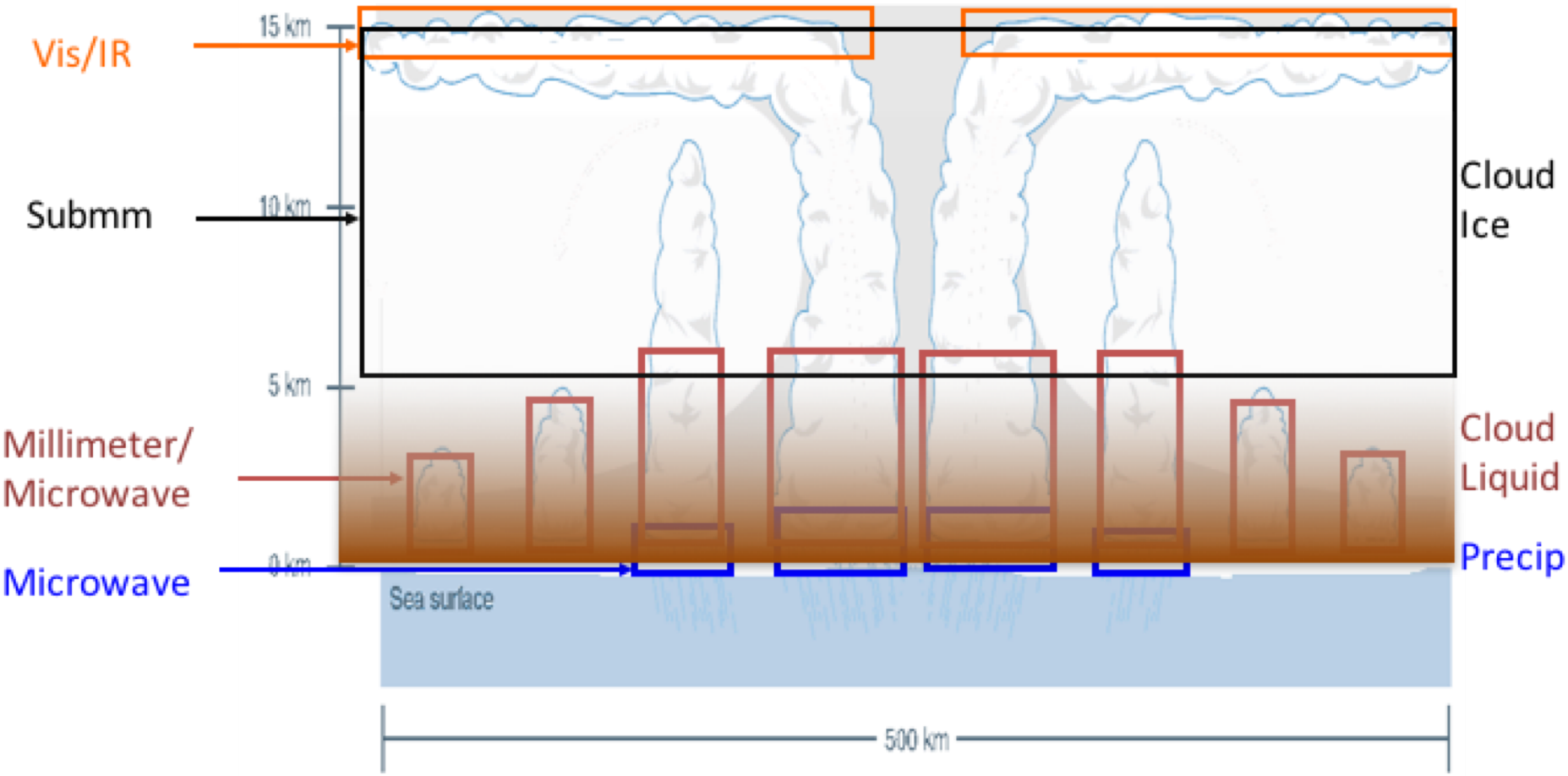
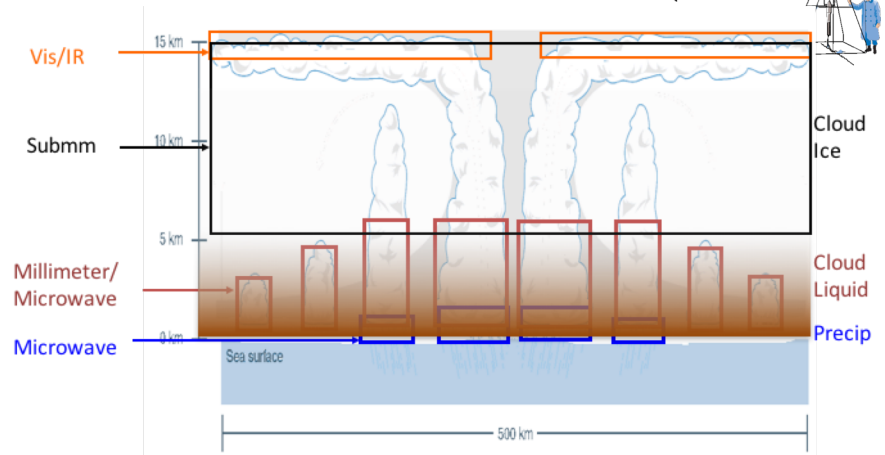
Motivation:

Ice Cloud Problem in Climate/Weather Models



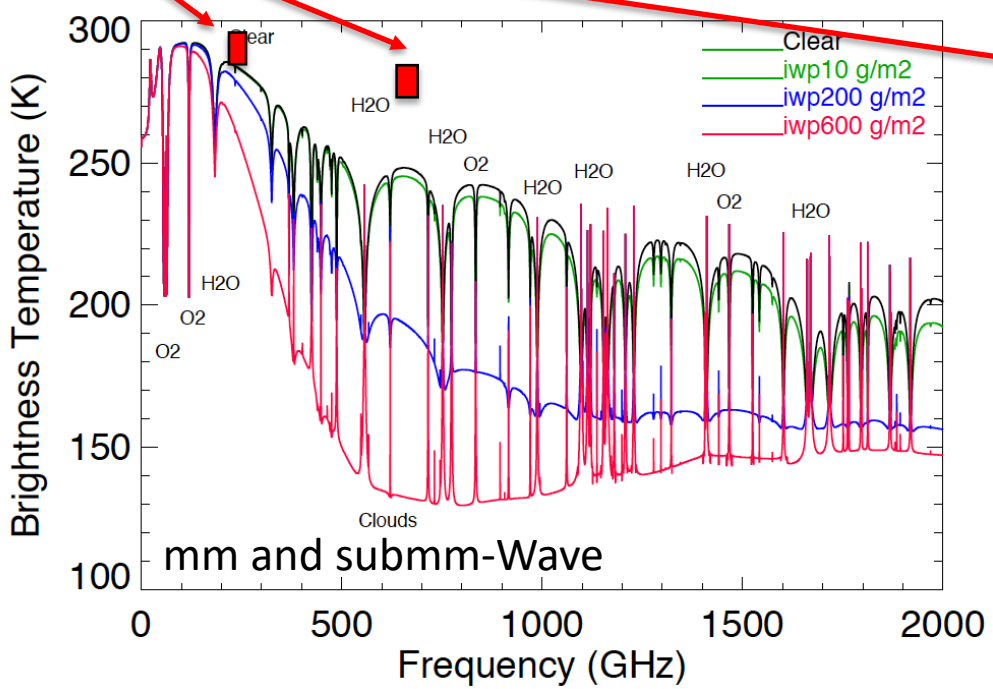
Challenges to measure ice clouds:

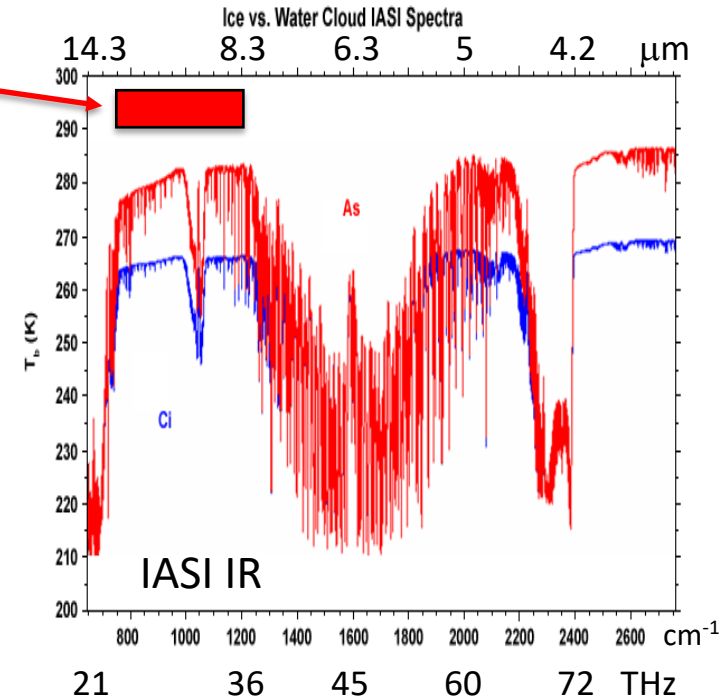
- Large dynamic range
- Complex microphysics



SWIRP

220 GHz
680 GHz
8-12 µm

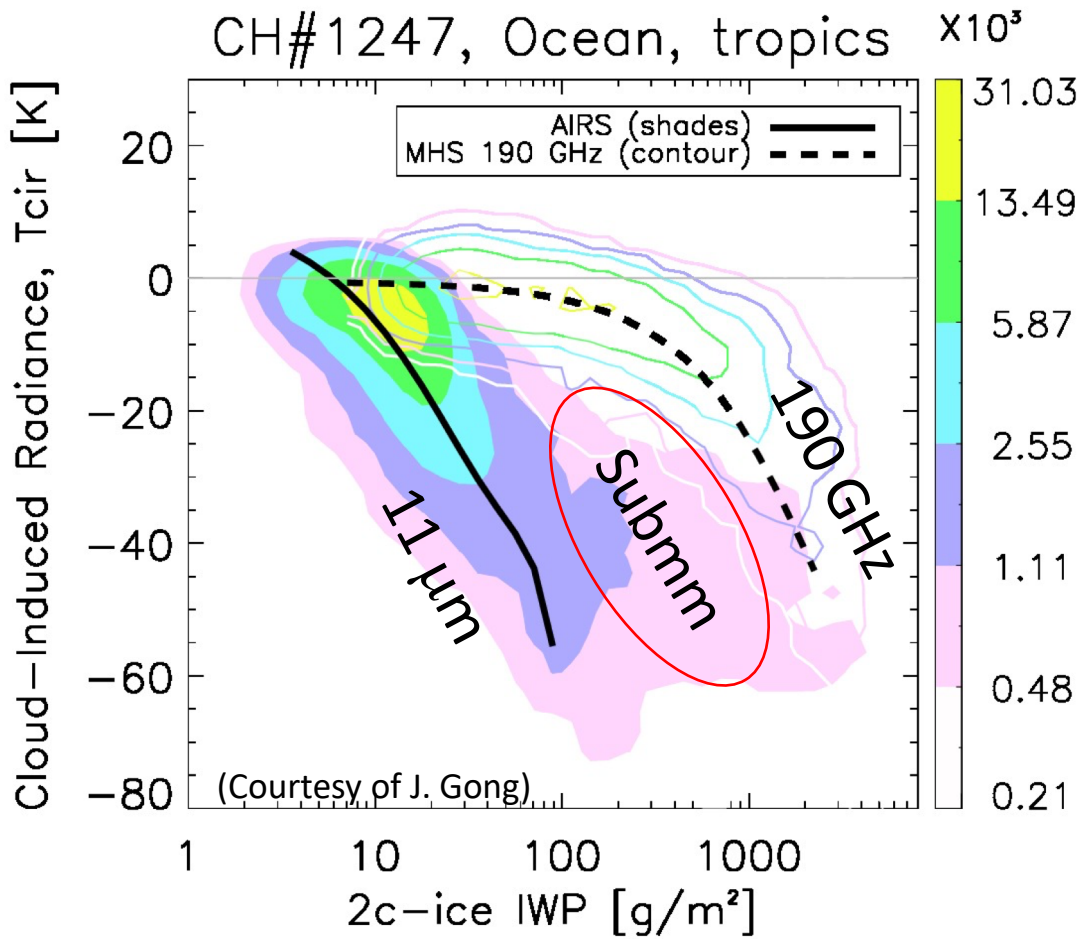




Sensitivity Gap in Cloud Ice Observations

- Clouds, ice clouds in particular, as a major source of uncertainty in climate prediction.
- Some cloud ice is not observed by microwave (MW) and infrared (IR) sensors, and need submm cloud radiometers.
- 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 over a large dynamic range.

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

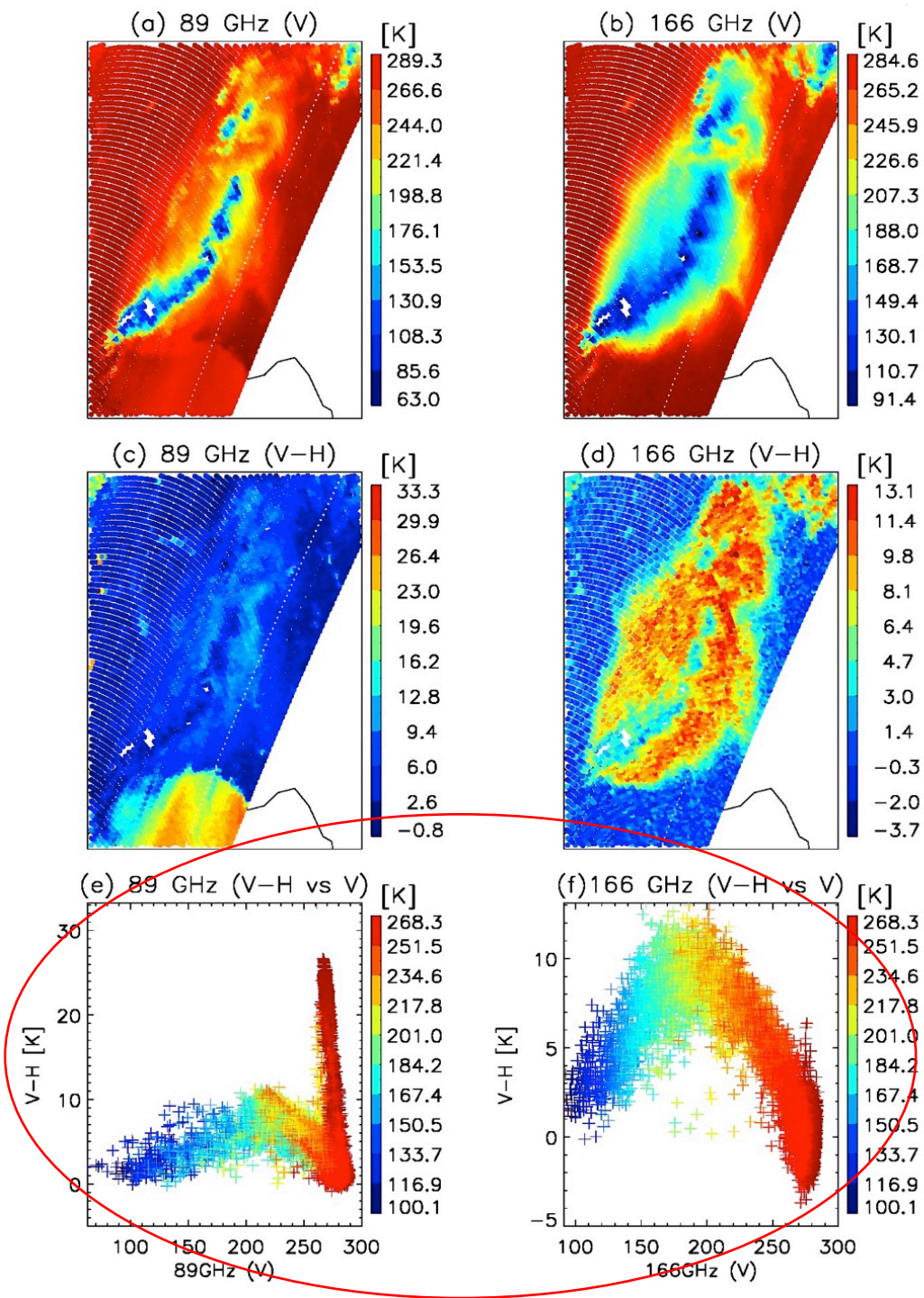


Ice Water Path (IWP) from CloudSat/CALIOP

Polarimetric Difference In GMI 89 and 166 GHz Observations

- "Bell-Shape" in the TB vs V-H relationship from cloud ice
- Larger V-H in the leading edge of squall line storms
- 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
- Stronger ocean surface polarization contributions at 89 GHz, compared to 166 GHz

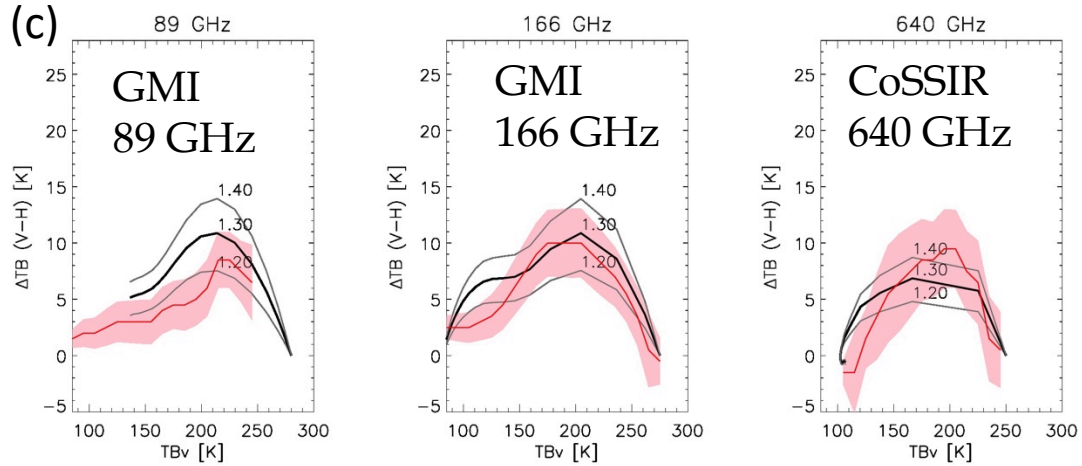
Gong and Wu (2017, ACP)



Polarization Signals at Submm-Wave

- Limited airborne observations from GSFC Compact Scanning Submillimeter Imaging Radiometer (CoSSIR) 640 GHz dual-pol radiometer

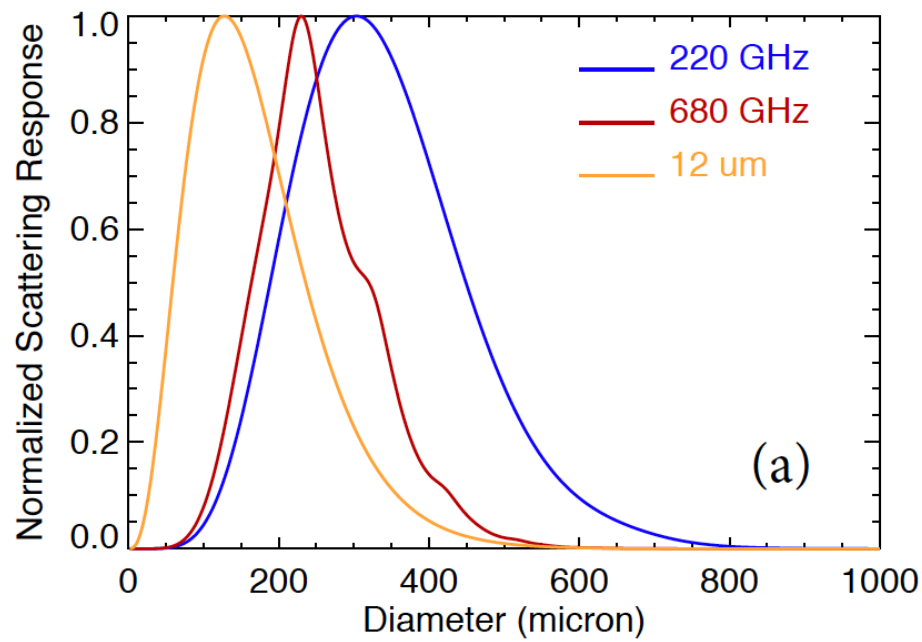
Gong and Wu (2017, ACP)



IR?

- Slightly different aspect ratios between 1.2 (89 GHz), 1.3 (166 GHz), and 1.4 (640 GHz).

- LWIR cloud scattering likely polarized, but no LWIR polarimetric measurements from space or aircraft.



Conceptual Model

$$T_J = T_{scat}\omega_0 + T_2(1-\omega_0)$$

$$PD = T_V - T_H = (T_1 - T_J)(e^{-\tau 2H} - e^{-\tau 2V})$$

$\tau 2H >> 1$

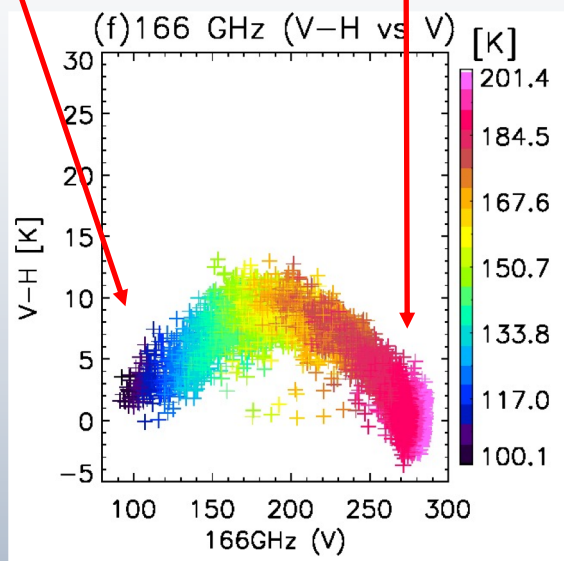
$\tau 2V >> 1$

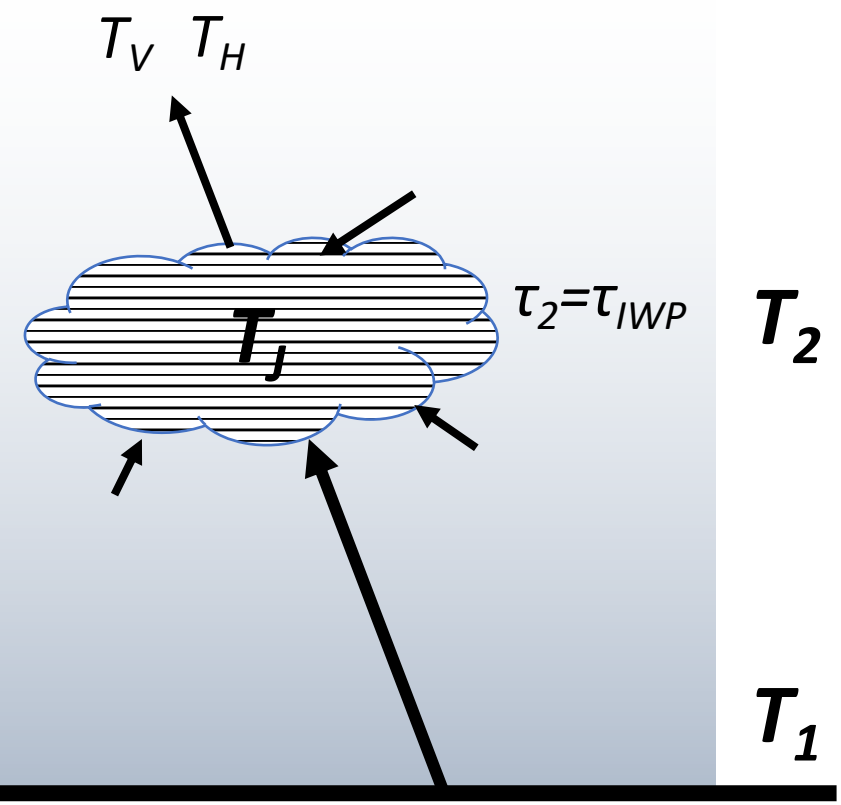
$e^{-\tau 2H} = e^{-\tau 2V} \sim 0$

$\tau 2H << 1$

$\tau 2V << 1$

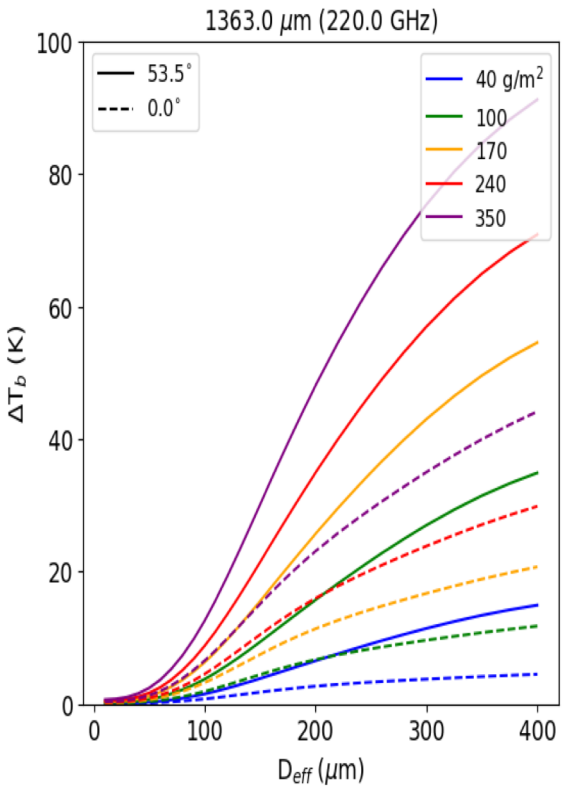
$e^{-\tau 2H} = e^{-\tau 2V} \sim 1$



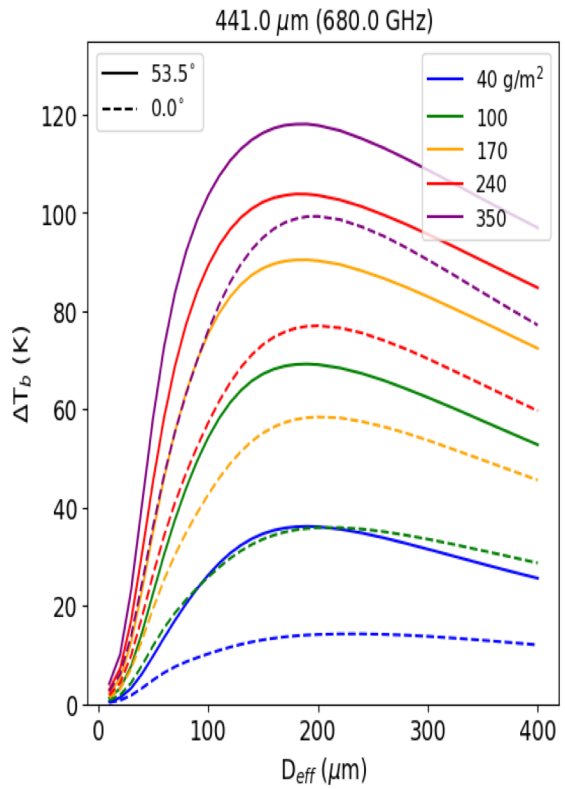


Cloud-Induced Brightness Temperature (ΔT_b) vs D_{eff}

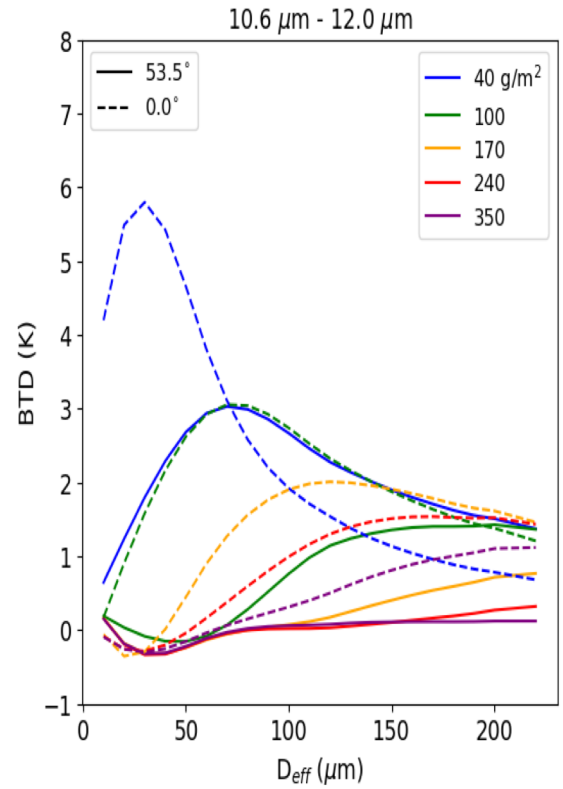
220 GHz



680 GHz



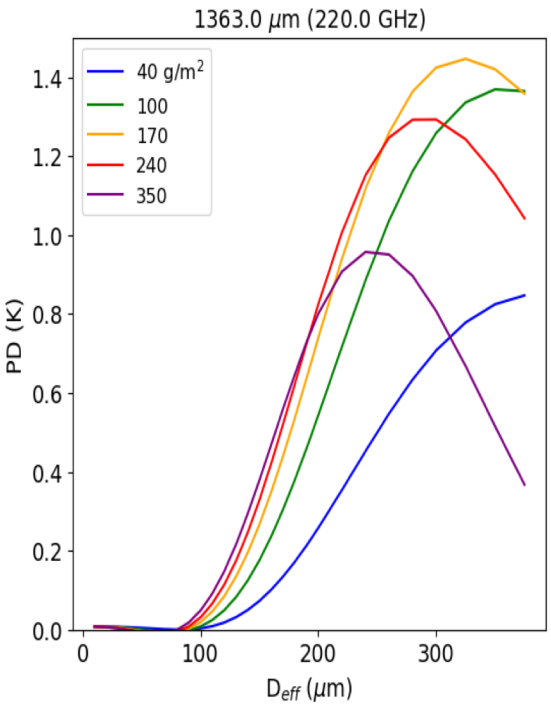
12 μm



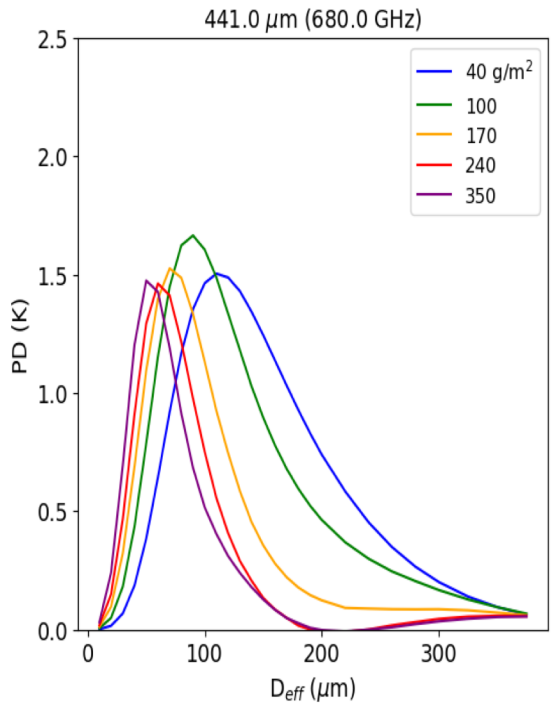
Coy, Bell, Yang and Wu (2019, submitted to JGR)

Polarization Difference (PD) vs D_{eff}

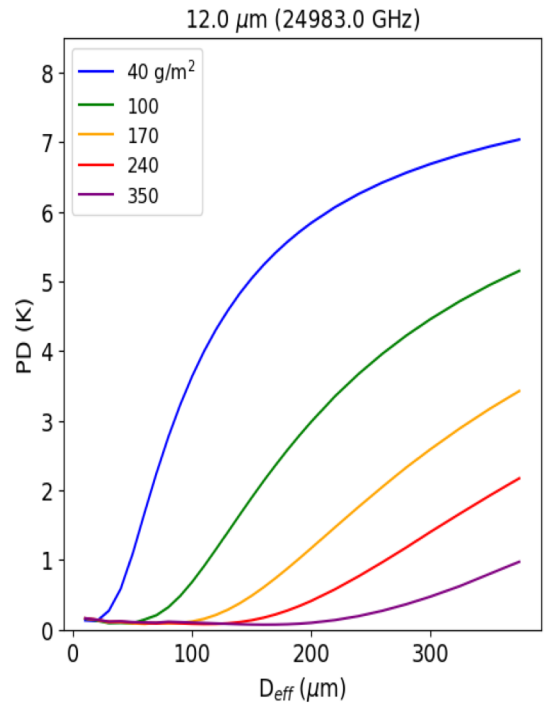
220 GHz



680 GHz



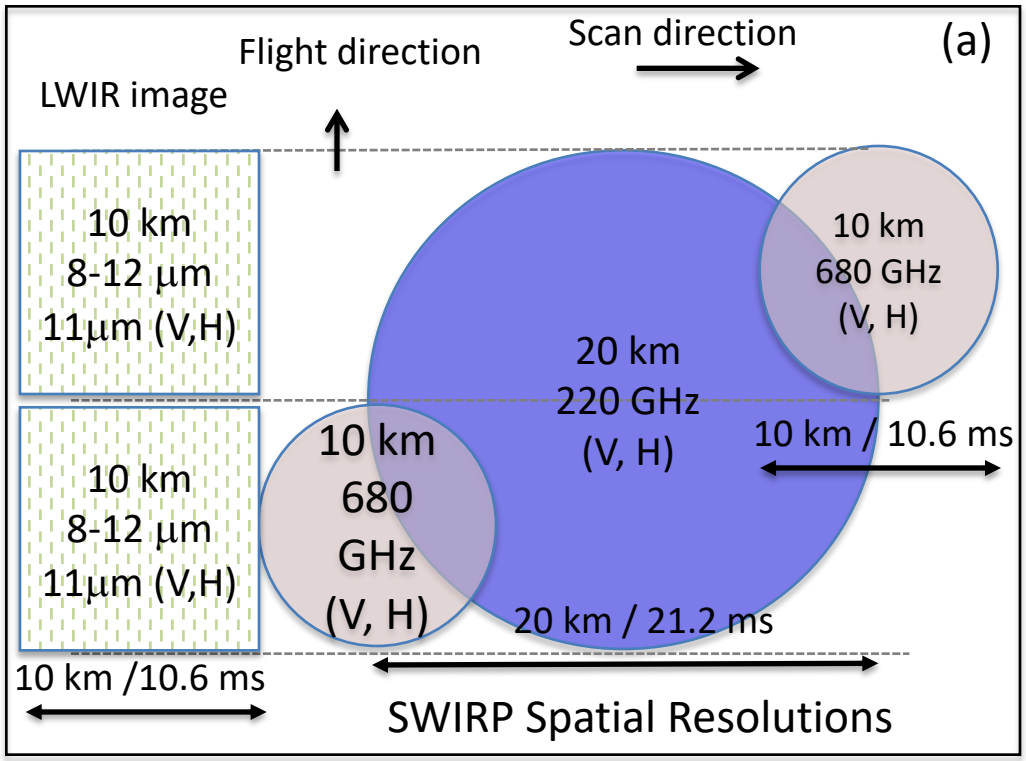
12 μm

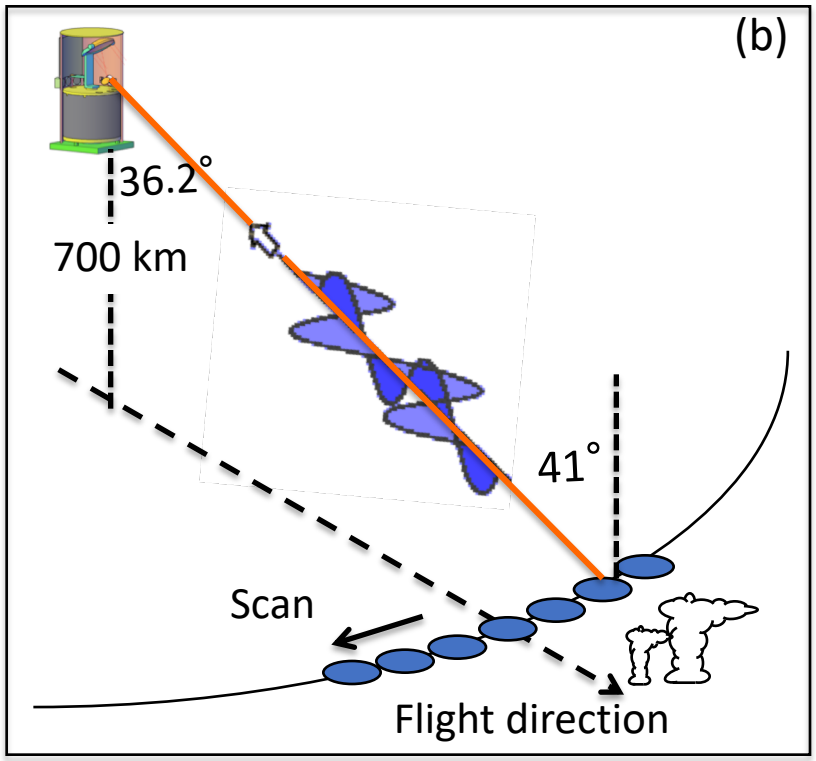


Coy, Bell, Yang and Wu (2019, submitted to JGR)

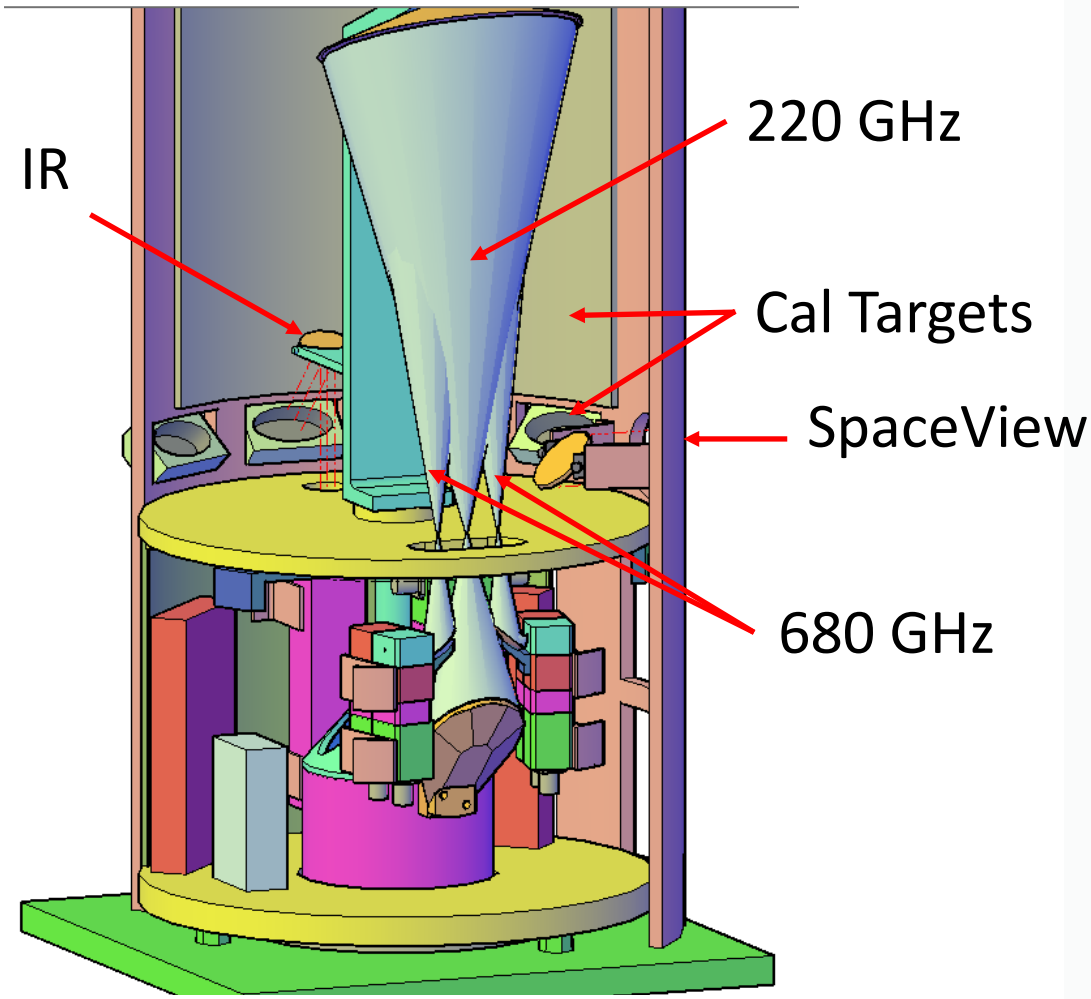
SWIRP Parameters and Requirements

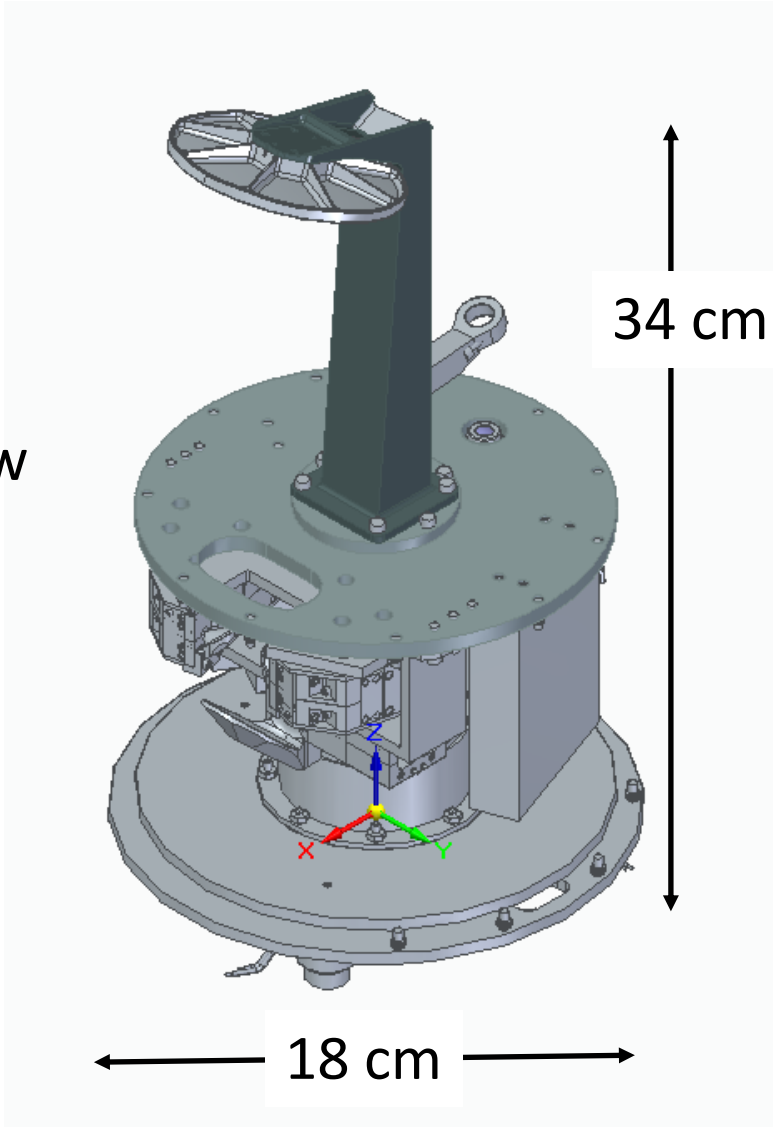
- Flight altitude 700km; Swath 1000 km
- Conical scan rate: 17.6 rpm
- Integration time: 21.2 ms (220 GHz), 10.6 ms (680 GHz), 2.7 ms (11 μm)
- Submm primary reflector 3dB diameter : 9 cm
- Footprints/FOVs: 220 GHz (20 km /1.6°), : 680 GHz (10 km /0.8°), 11 μm (2.5 km/0.2°)
- Submm polarimetric receivers:
  - 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)
- Data rate: 22.3 kbps





SWIRP Instrument Design

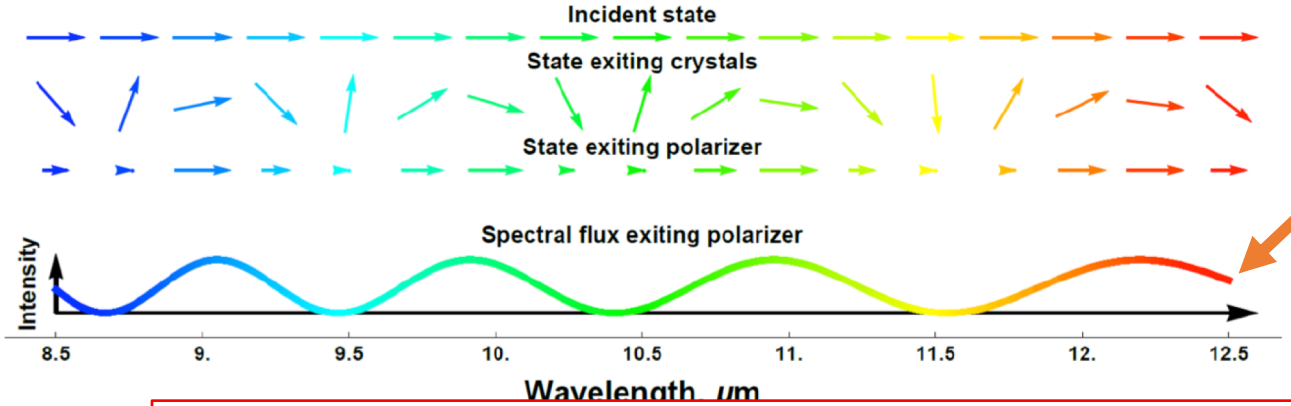




Courtesy of Michael Solly

SWIRP LWIR Polarimeters

Infra**R**ed **C**hanneled **S**pectro-**P**olarimeter (IRCSP)



Encode spectrally dependent polarization data as intensity changes

→ (I,Q,U,V)

Mueller Matrix Model

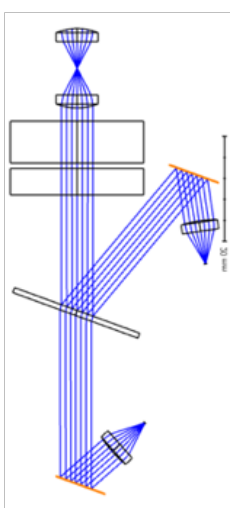
$$\frac{1}{2}\begin{bmatrix}1&0&1&0\\0&0&0&0\\1&0&1&0\\0&0&0&0\end{bmatrix}\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&cos\delta(\lambda)&sin\delta(\lambda)\\0&0&-sin\delta(\lambda)&cos\delta(\lambda)\end{bmatrix}\begin{bmatrix}1&0&0&0\\0&0&0&-1\\0&0&1&0\\0&1&0&0\end{bmatrix}\begin{bmatrix}1\\Dcos(2\theta)\\Dsin(2\theta)\\0\end{bmatrix}=\frac{1}{2}\begin{bmatrix}1+Dsin(\delta(\lambda)-2\theta)\\0\\1+Dcos(\delta(\lambda)-2\theta)\\0\end{bmatrix}$$

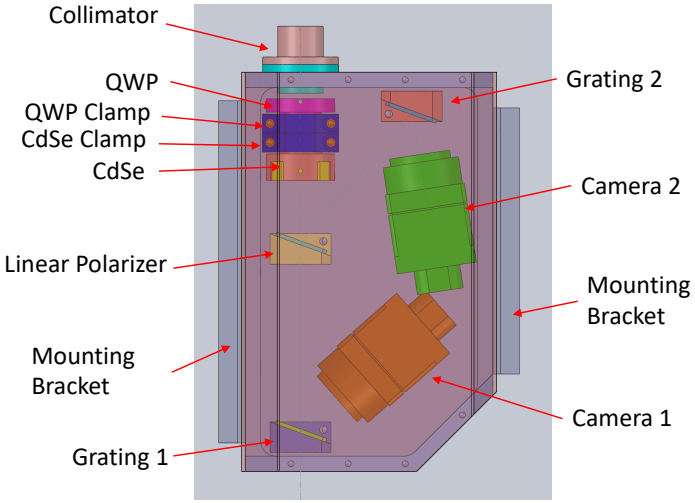
Polarization state is rotated as a function of wavelength

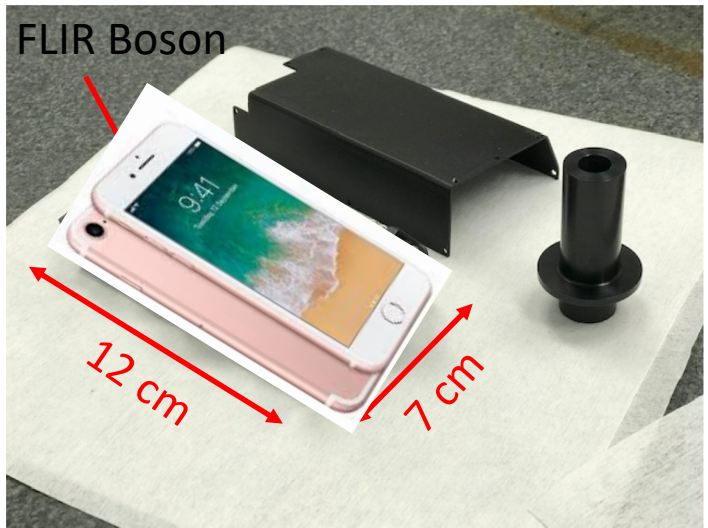
Incoming Linearly Polarized Light

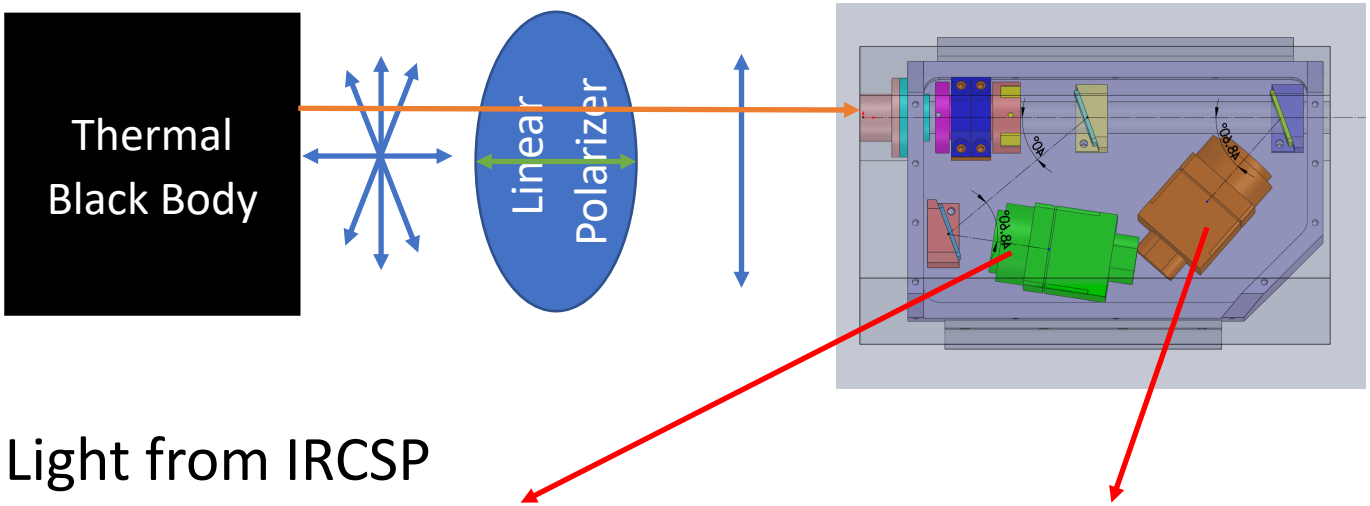
Irradiance "fringes" are produced at the detector

Optical design

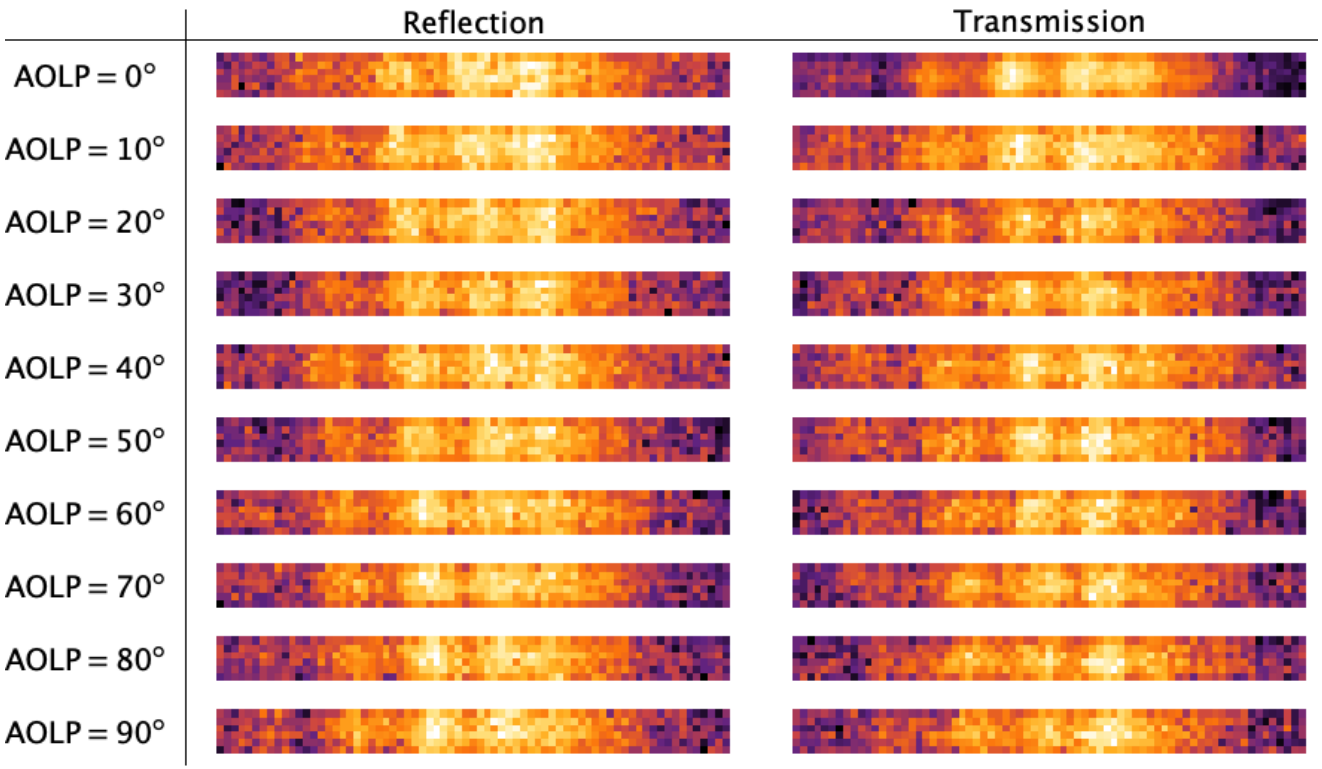




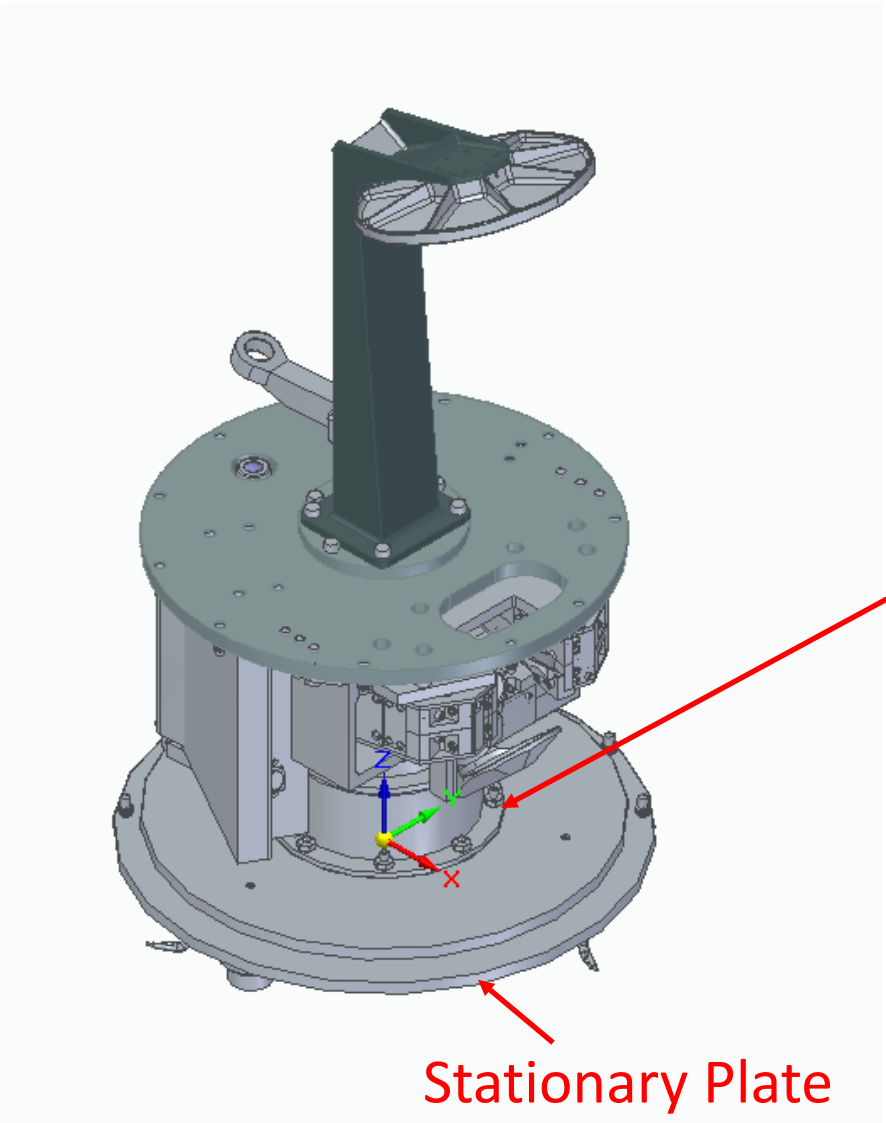


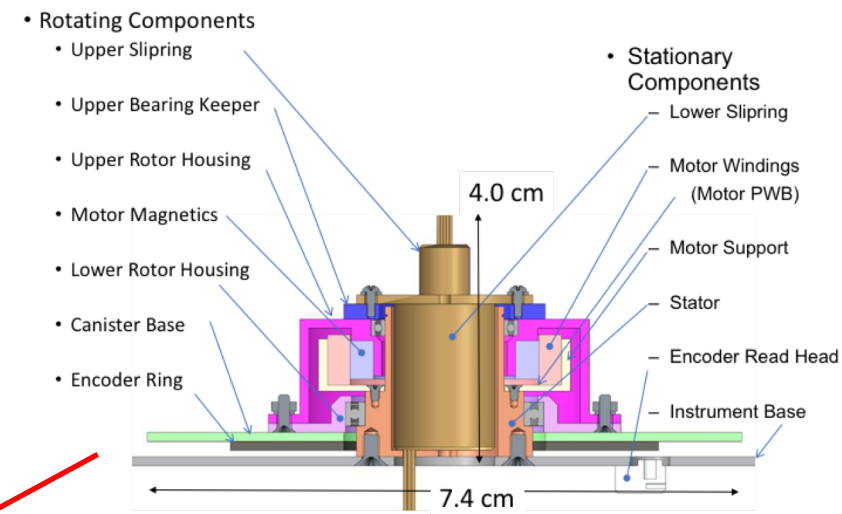


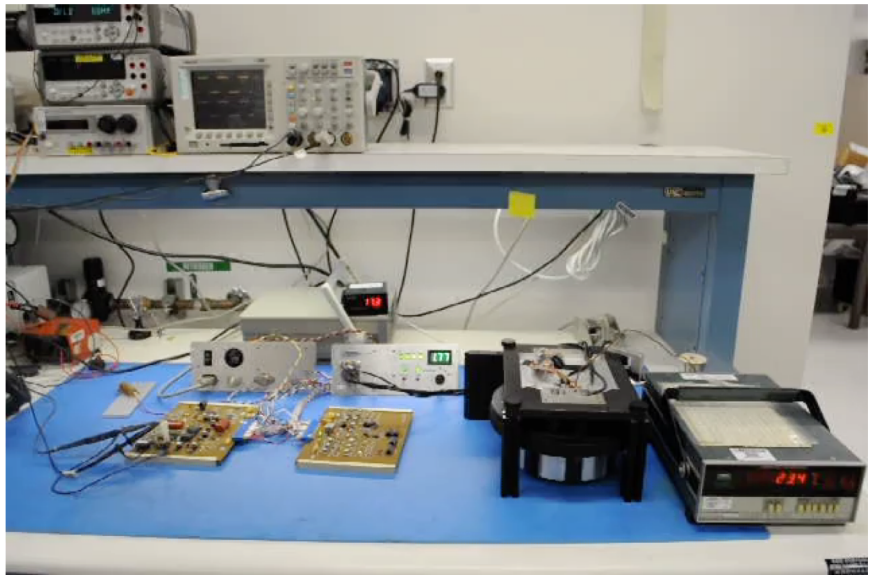
First Light from IRCSP



Miniature
Bearing and Power Transfer Assembly (BAPTA)





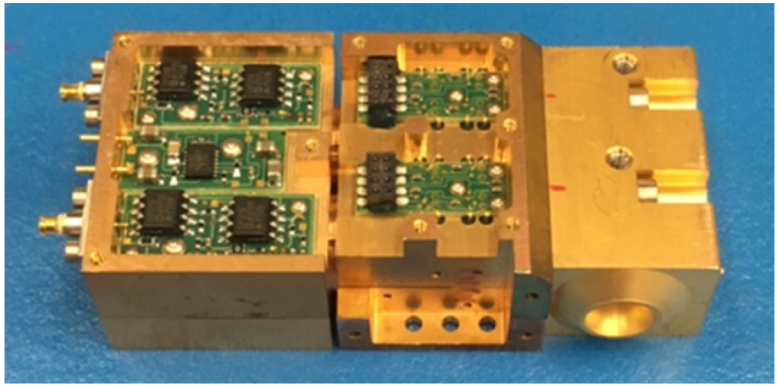


SWIRP 220 GHz Polarimetric Receiver (TRL=5)

- Final integration and burn-in completed Mar 2019
- Configured to output ~2V
- Final noise figure measured
- Two units built and characterized
- Delivered in April 2019

Receiver Output Voltage

	Receiver SN01 Output Voltage (V)	Receiver SN02 Output Voltage (V)
E-plane Channel	2.08	2.00
H-plane Channel	1.70	1.78



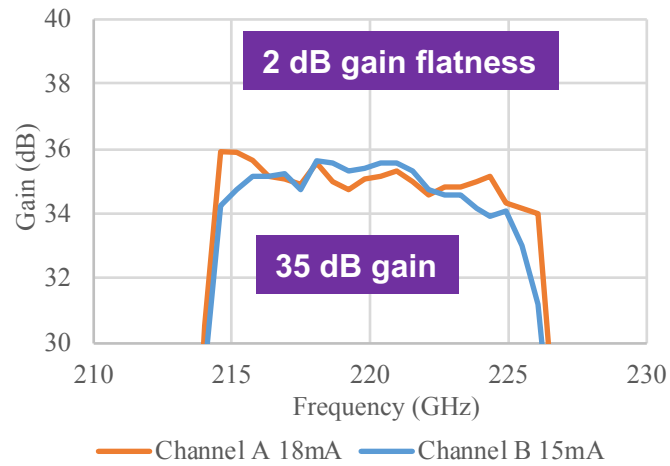
3 cm

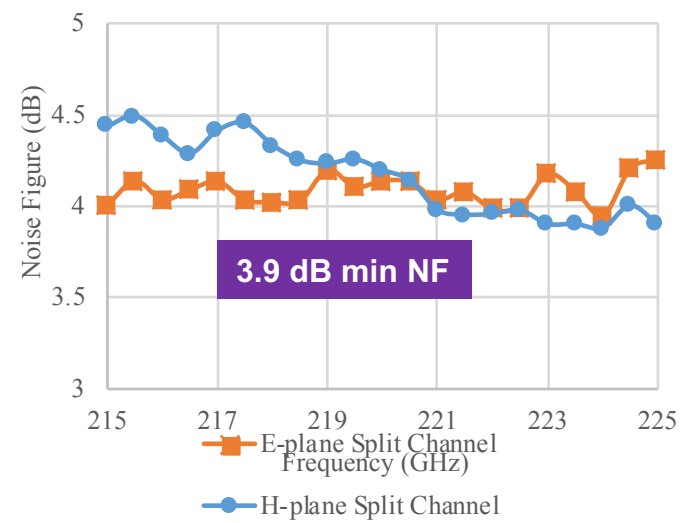
6.4 cm

200 g

0.7 W

Polarimeter gain and NF data (Rx #2)

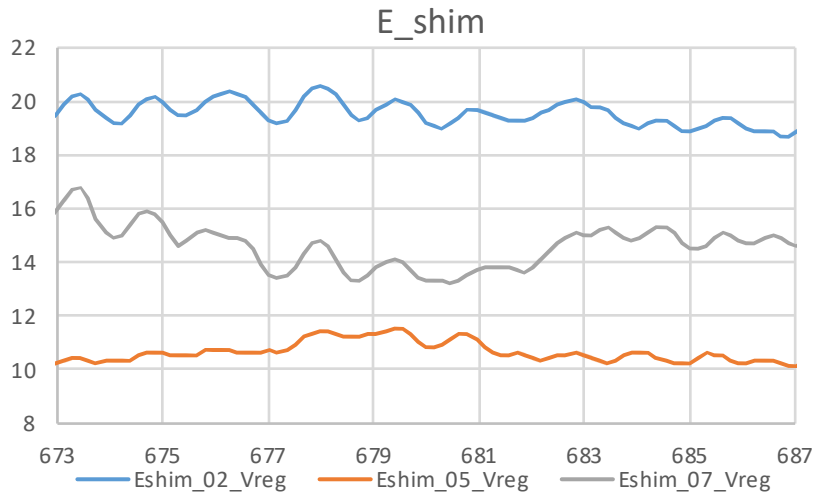




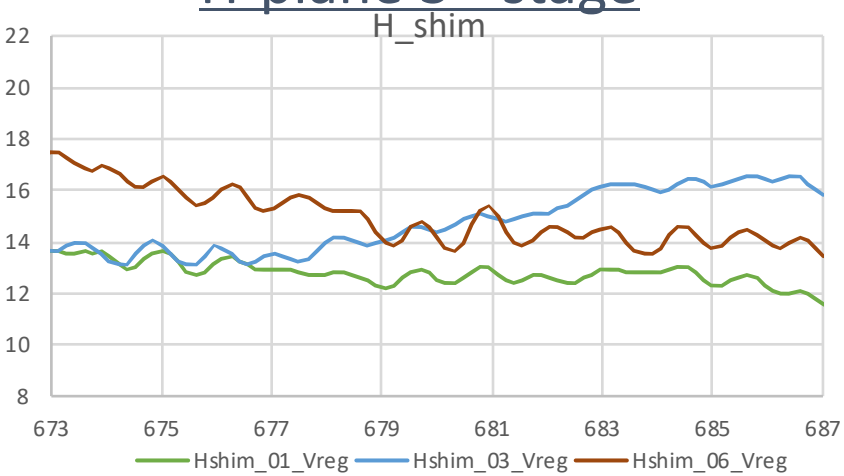
SWIRP 680 GHz Polarimetric Receivers

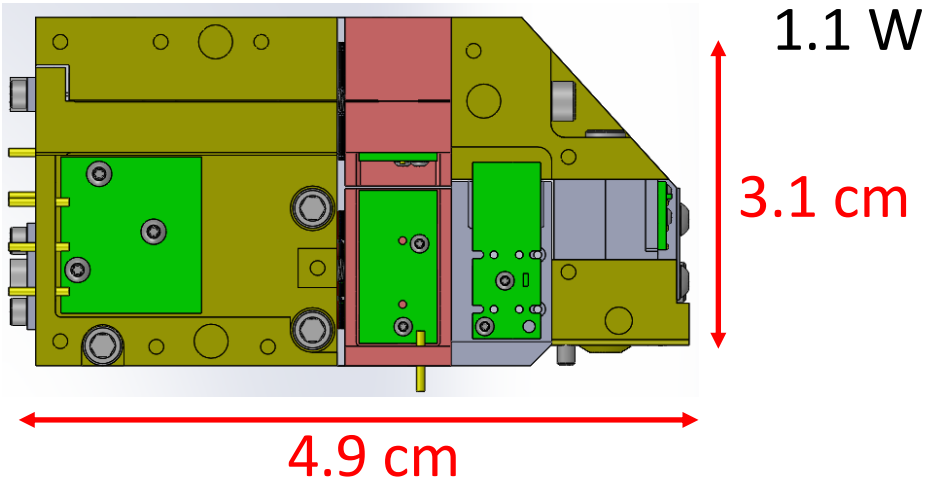
350*g
1.1 W

E-plane 3rd stage



H-plane 3rd stage

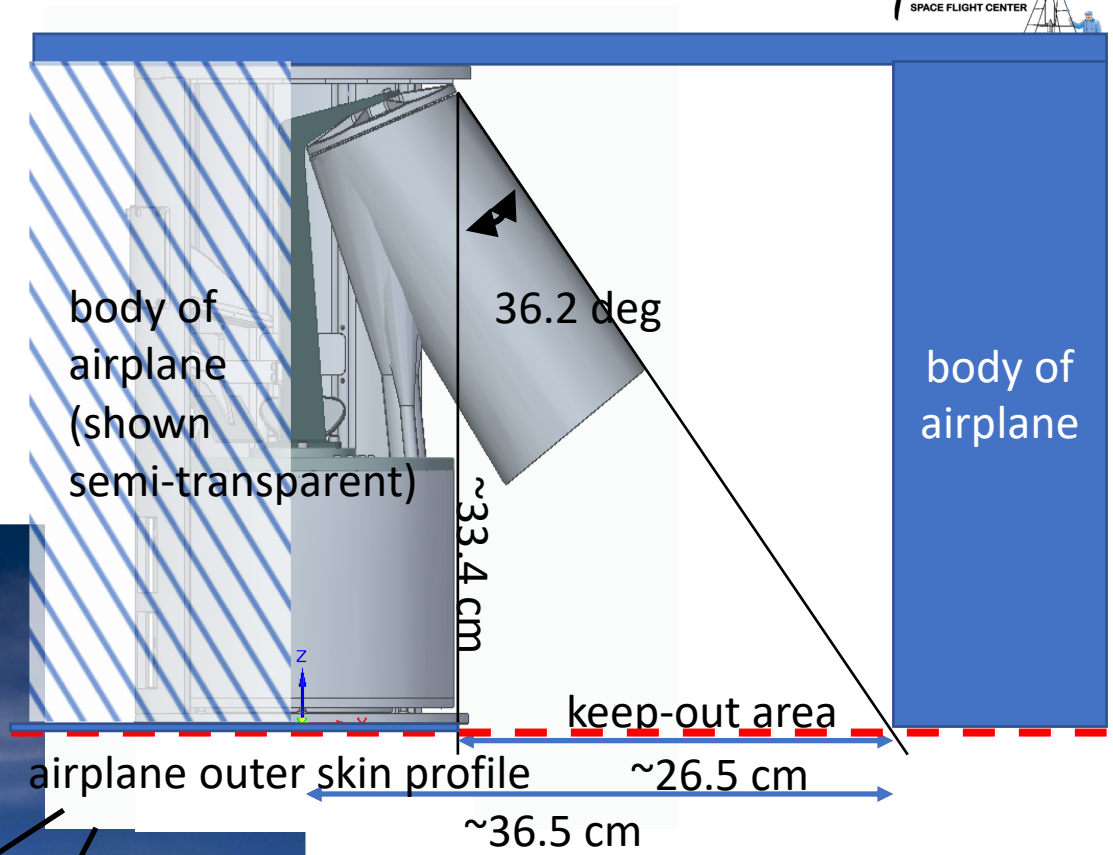


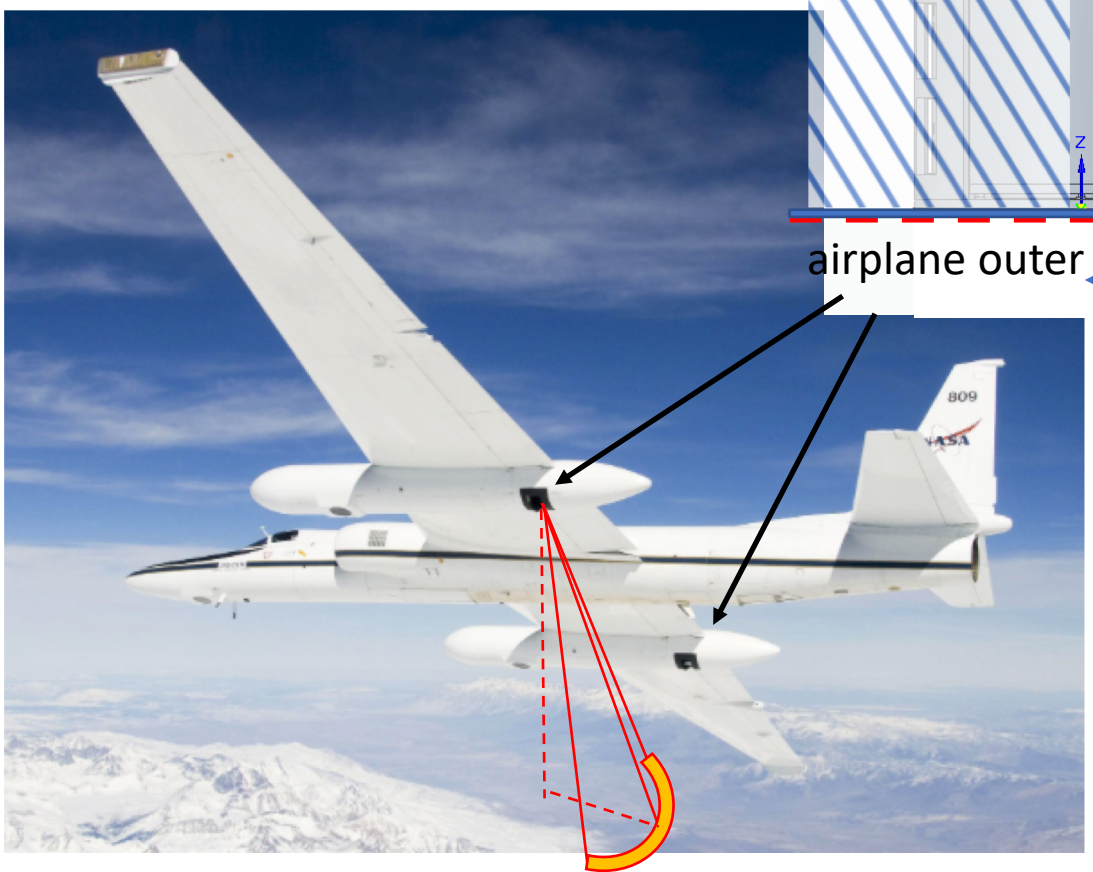


- High complexity for E- and H-Polarization intensity
- Narrow bandwidth with Polystrata filter
- 3-Stage LNA with six housings
- Packaging and I&T underway

SWIRP Demo Plan:

- High-altitude ER2 flight
- Mount inside wing pod
- Heaters near subsystems
- Power and data interfaces to ER2





CONOPS:

- Operation: -20C to 0C
- Heater-on during taking-off/landing
- Continuous conical scan
- Cloud obs from backward view
- Calibration from forward view

Summary

- Cloud ice has a large dynamic range. → SWIRP 220 GHz, 680 GHz and 12 μm to cover a broad dynamic range
- Microphysics of ice particles are complex and dynamic. → SWIRP conical-scan and polarimetric measurements to provide additional ice microphysical properties
- 2017 Decadal Survey: 'Coupled cloud-precipitation (CCP) state and dynamics' → SWIRP cloud products (220, 680 GHz, 8-12 μm); precip product (220 GHz); and info on microphysical processes