



# TECHNOLOGY DEVELOPMENT FOR 3-D WIDE SWATH IMAGING SUPPORTING ACE

Presentation to the ACE Science Working Group  
June 9, 2014

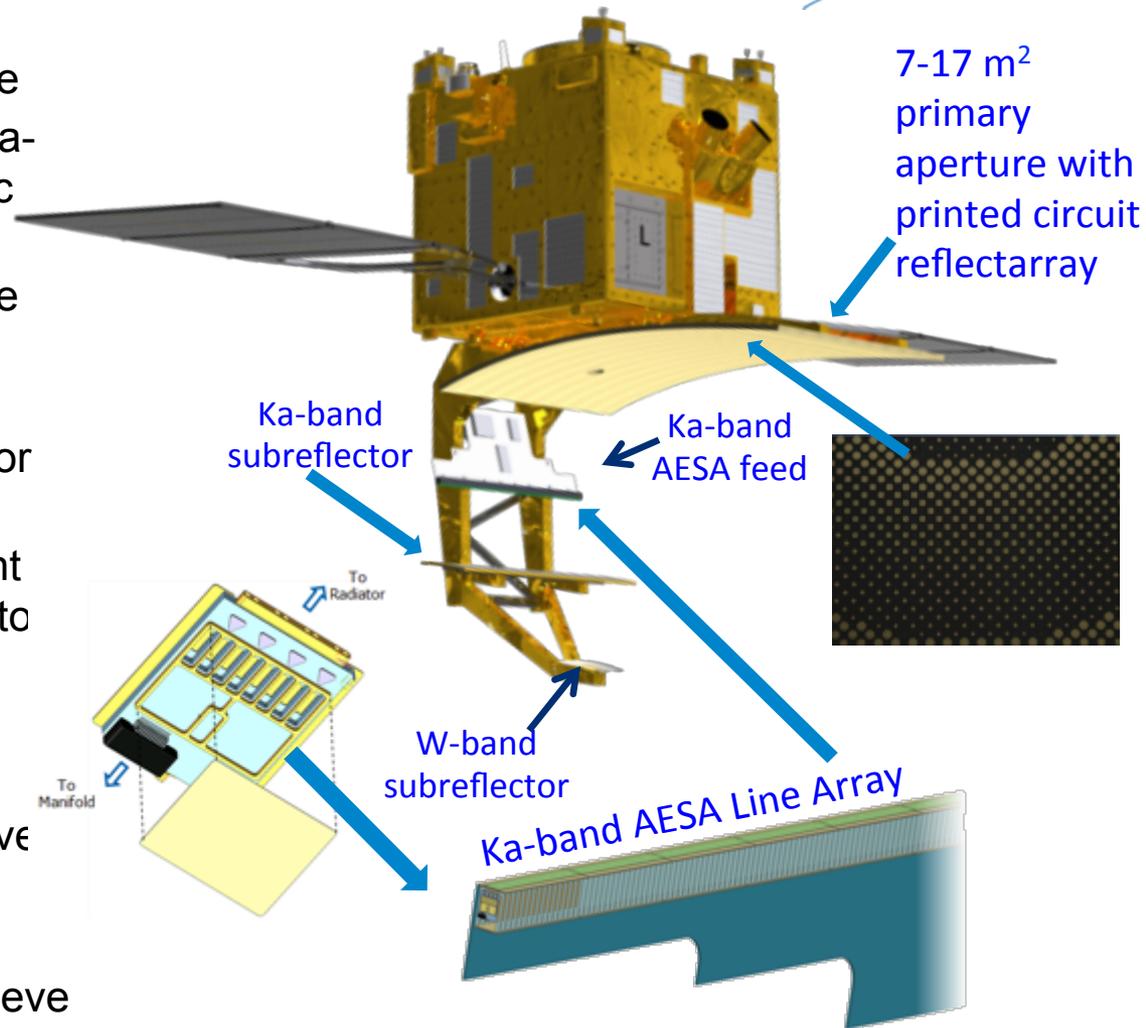
GSFC: Paul Racette • Gerry Heymsfield • Lihua Li • Matthew Mclinden  
NGES: Richard Park • Michael Cooley • Pete Stenger • Thomas Hand

- ACE Radar Introduction
- Overview of 2010 IIP objectives
- Reflectarray Development
  - IPHEX/RADEX Reflectarray Airborne Demonstration
- ACE Radar Design Study
- TRL Assessment & Technology Maturation Plan
- 2013 IIP Summary

# Introduction to Dual Band ACE Radar

## Discriminating Features

- Shared Dual-Band Primary Aperture
- Wide swath imaging ( $\geq 120\text{km}$ ) at Ka-band enabled by Azimuth Electronic Scanning (AESA Feed)
- Fixed Beam at W-Band (Compatible with CloudSat / EarthCare Beam Waveguide and Transceiver)
- Reflectarray enables tri-band and/or scanning W-band options
- Significant Payload Size and Weight Savings (Compared with two-reflecto solution)
- Leverages TRL 6+ W-band Space Radar
- Leverages HIWRAP/CRS Transceiver and Advanced Signal Processing Algorithms
- Technology Maturation Plan to achieve TRL 6 by 2017



# ACE Radar 2010 Instrument Incubator Program

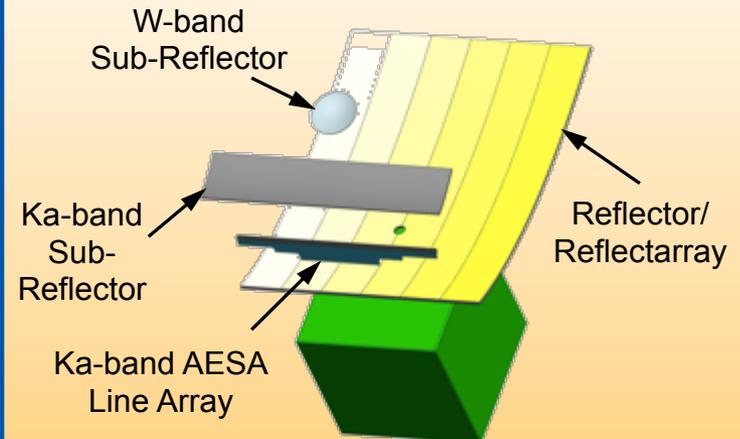


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## Project Objectives

- Develop design and analysis tools for dual-band reflectarrays. Validate tools and models using at 35 GHz (Ka-band) and 94 GHz (W-band) using test coupons. **Testing complete, Oct. 2012.**
- Develop subscale reflector/reflectarray model for dual-band range pattern testing. Integrate and test subscale model with CRS in airborne flight to demonstrate dual aperture performance. **Test flight, Apr., 2014 and IPHEX science flights, May-Jun. 2014.**
- Develop preliminary design of full scale antenna, Ka-band AESA module, and feed to identify key technology trades and drivers. **Full-scale PDR, Nov. 2012, Ka-band AESA PDR, Jan. 2013.**
- Design, fabricate, and test Ka-band MMIC front end for AESA module. **Ongoing.**

### GSFC/NGES ACE Cloud Radar using Reflector/Reflectarray Technology for wide swath Ka-band profiling



Subscale Antenna for a/c flight demo using CRS





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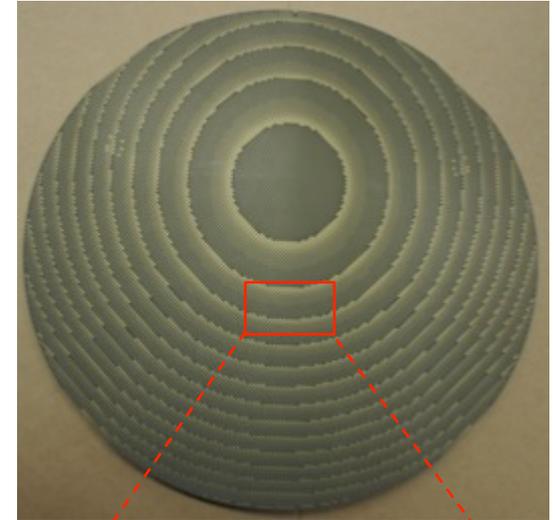
# Reflectarray Technology Development & Airborne Demonstration

# Planar Reflectarray Coupon Demonstration

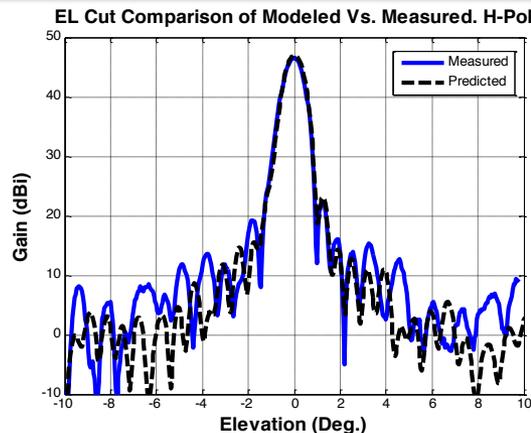
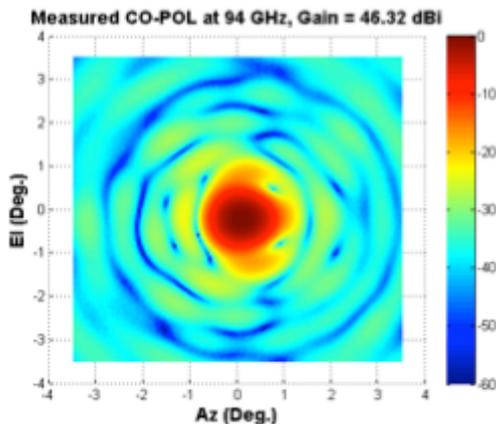


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- Flat Coupons validated reflectarray RF models
  - Reflectarray analysis/synthesis model (MATGO) and Element models
- Demonstrate manufacturability of reflectarray PCBs on candidate materials
- Demonstrate basic reflector/reflectarray functionality
  - Reflectarray focusing at W-band
  - FSS transparency at Ka-band



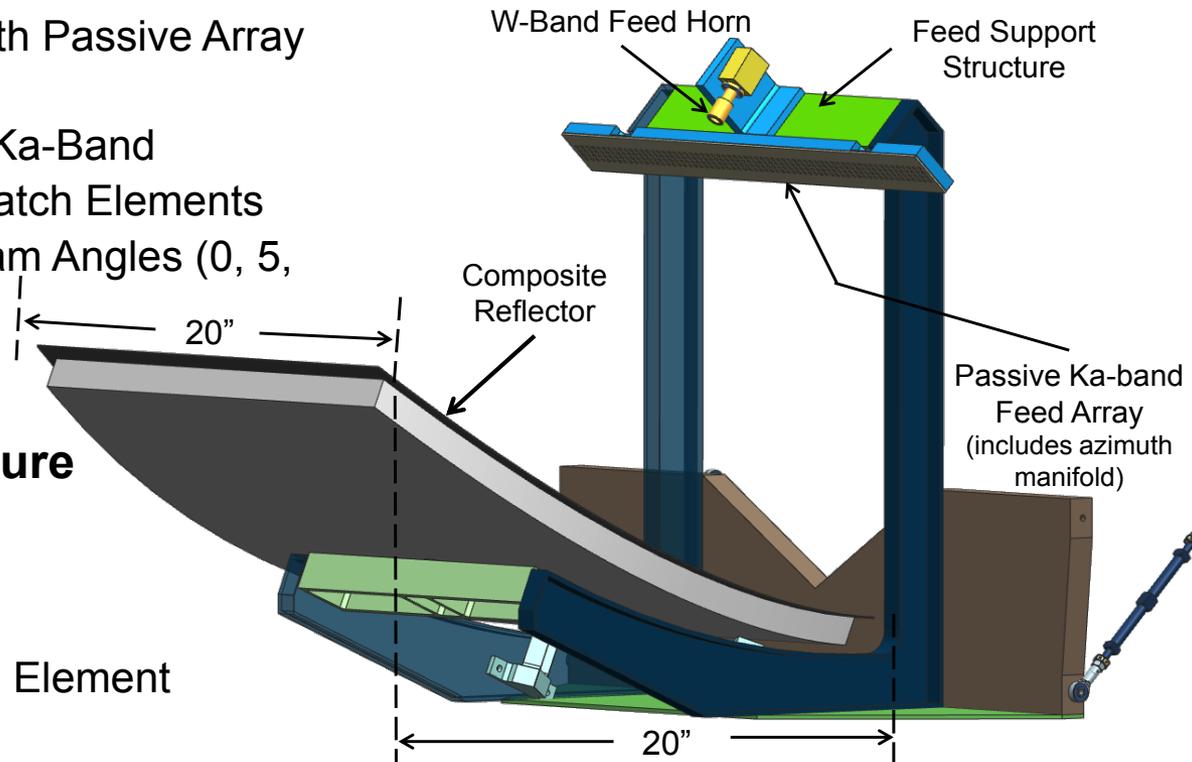
Measurements validate predicted performance



# Sub-Scale Demo Design/Architecture

## Ka-Band Antenna Architecture

- 35.5 GHz Operating Frequency
- Parabolic Cylinder Reflector with Passive Array Feed
- W-Band Reflectarray - FSS at Ka-Band
- Array Feed - Dual Pol 4 x 64 Patch Elements
- 3 Manifold Designs - Fixed Beam Angles (0, 5, 10 degs)



## W-Band Antenna Architecture

- 94 GHz Operating Frequency
- Parabolic Cylinder Surface w/ Reflectarray to Focus Beam
- Reflectarray Uses Hybrid Loop Element on Rogers 6002
- Scalar Horn Feed with OMT (Dual Linear Pol)

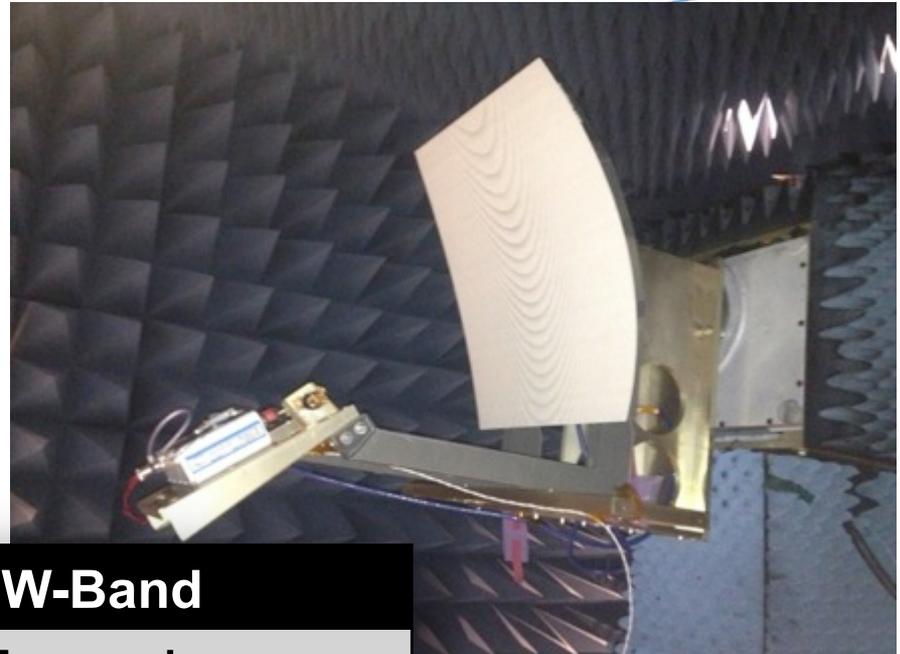
Sub-Scale antenna has been successfully tested on ER-2 with CRS and is currently flying for IPHEX/RADEX mission

# Sub-Scale Demo Design/Architecture



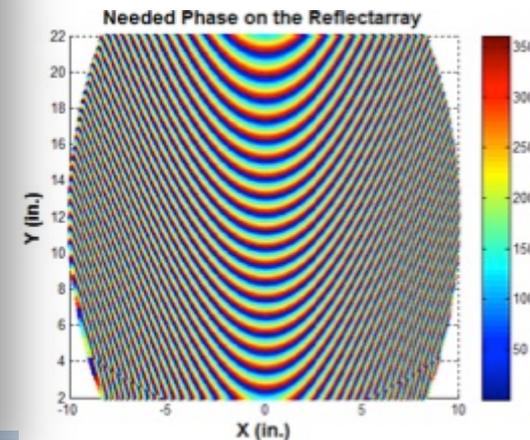
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Loss Budget for W-Band Antenna	
Aperture Directivity:	54.4 dBi
Taper Loss:	1.5 dB
Spillover:	0.4 dB
Phase Error Loss:	0.3 dB
Absorptive Loss:	0.6 dB
Gain:	51.7 dBi



## Performance Summary for W-Band

	Measured:
VPOL (Co) Realized Gain:	51.1 dBi (94.05 GHz)
HPOL (Co) Realized Gain:	50.9 dBi (94.05 GHz)
Az Beam Width:	0.45° (V) / 0.47° (H)
EI Beam Width:	0.47° (V) / 0.48° (H)
Cross-Pol (dB):	-33.2 (V) / -28.6 (H)
Peak Az Side Lobe (dB):	-28.8 (V) / -26.9 (H)
Peak EI Side Lobe (dB):	-27.2 (V) / -29.5 (H)



# The GPM Integrated Precipitation and Hydrology Experiment



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## Goddard Microwave Instruments

### ER-2 Instruments

<b>HIWRAP</b>	(Radar)	13.91/13.47 GHz, 35.56/33.72 GHz
<b>EXRAD</b>	(Radar)	9.626 GHz (nadir); 9.596 GHz (scanning)
<b>CRS</b>	(Radar)	94.15 GHz (dual-polarized)
<b>CoSMIR</b>	(Radiometer)	53 (x3), 89, 165.5, 183.3+/-1, 183.3+/-3, 183.3+/-8 GHz



### Ground-based Instruments

<b>N-POL</b>	(Radar)	2.8 GHz
<b>D3R</b>	(Radar)	13.91 GHz, 35.56 GHz
<b>ACHIEVE</b>	(Radar)	10, 24, 94 GHz
<b>DoER</b>	(Radiometer)	22 (x5), 37, 89 GHz

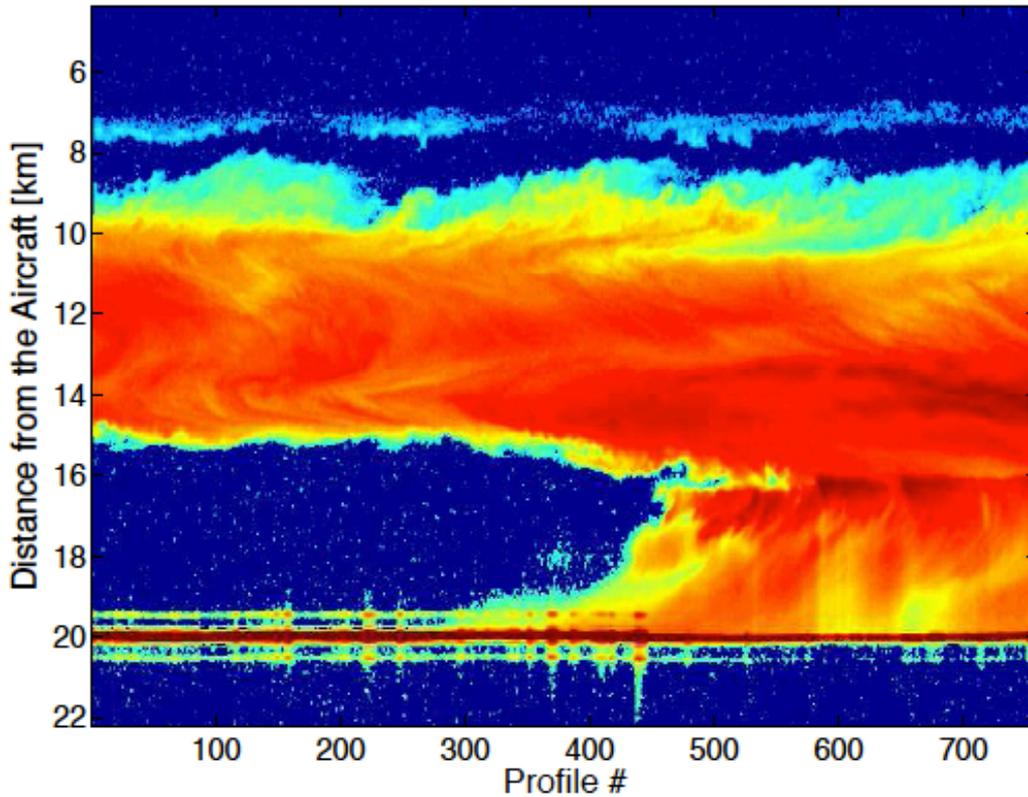
**CRS flights funded through IIP and RADEX**

# First Quick-look Imagery from CRS



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CRS Quicklook: IPHEX  
CRS-IPHEX\_20140503133636\_socket0-0009.dat



ER-2



Sub-scale antenna in CRS canister in ER-2 tail cone



SSPA installed in CRS



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# ACE Radar Design Study

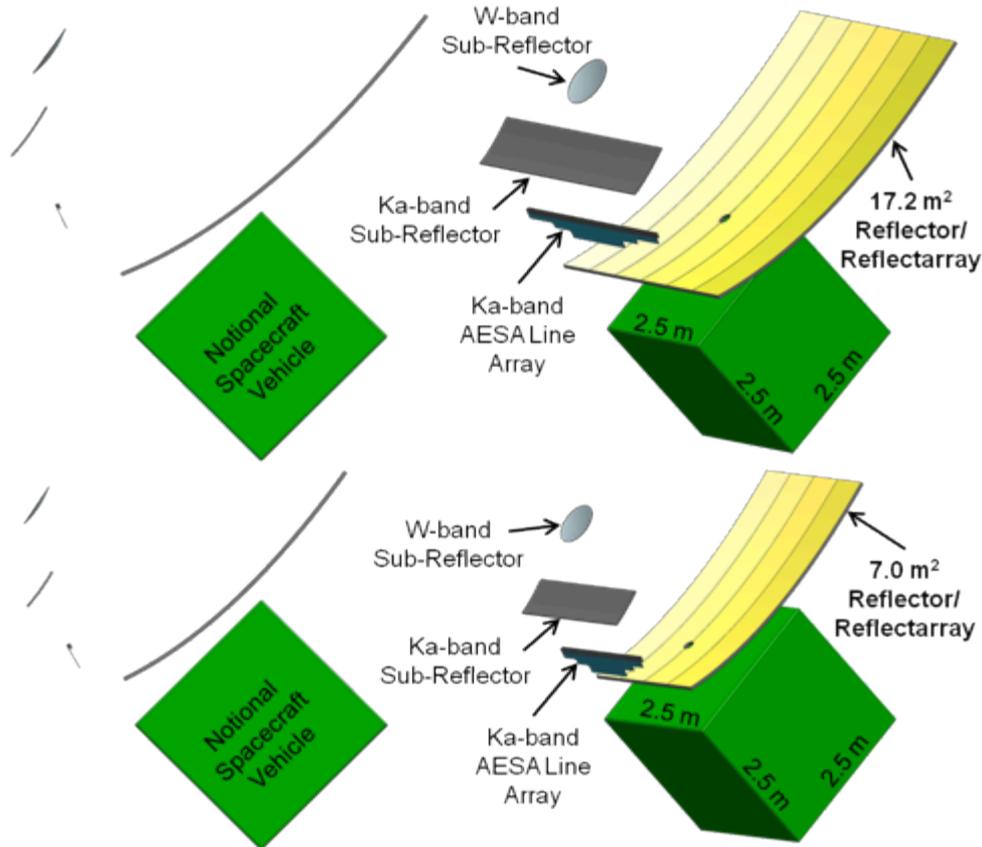


# Full-Scale Antenna Trades

## Shown Relative to Notional Space Vehicle



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**4.15 x 4.15 m<sup>2</sup> Projected Aperture:**

**Reflector/Reflectarray:  
Cassegrain Folded Optics**

**2.33x 3 m<sup>2</sup> Projected Aperture:**

**Reflector/Reflectarray:  
Cassegrain Folded Optics**

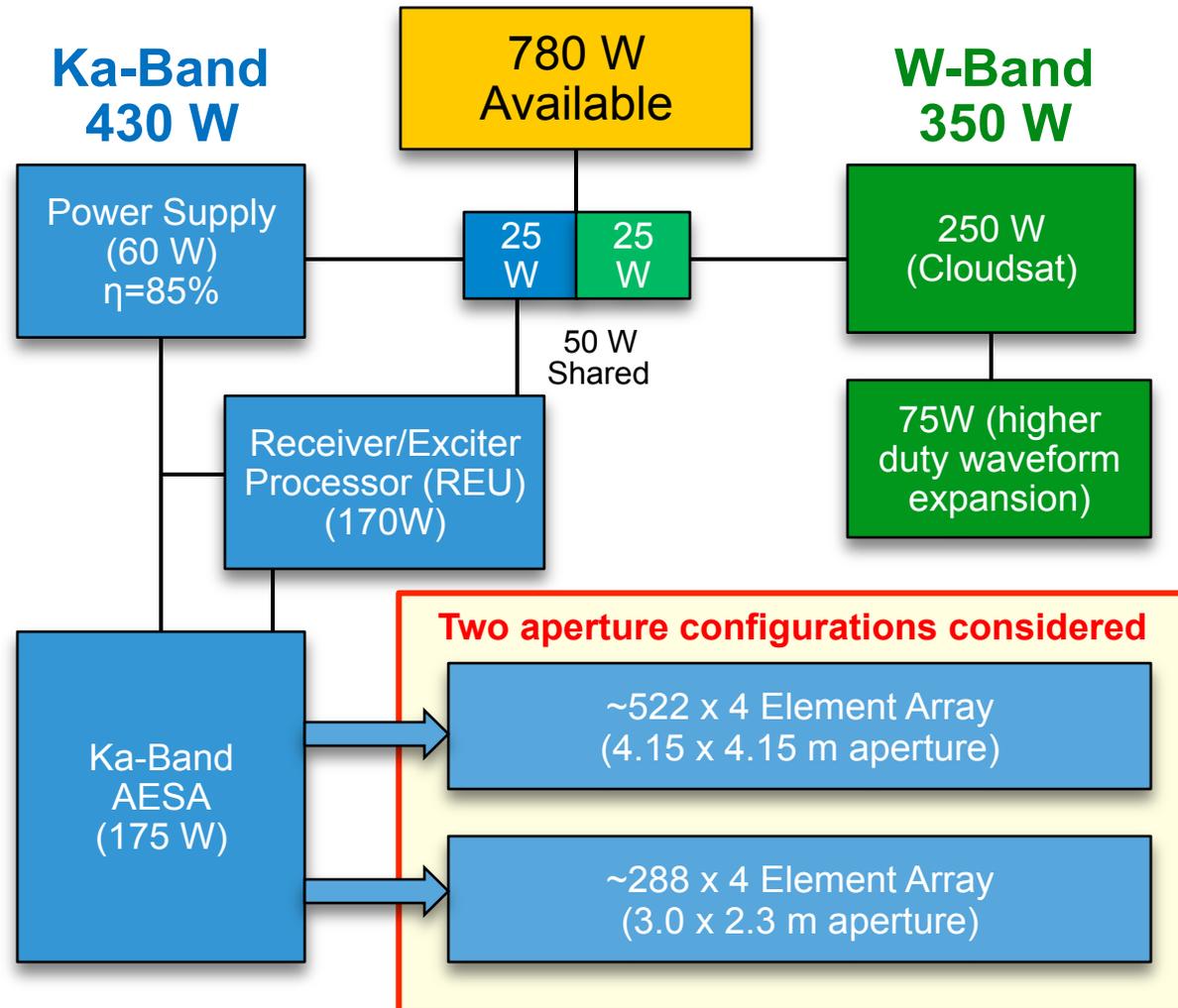
***Full-Scale Design is Modular and Scalable... It Leverages RF Design, Mechanical Design and Manufacturing Processes Developed for Coupon and Sub-Scale Designs***

# Assumed Power Allocation for Radar Design and trade studies



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- Power availability on spacecraft affects the achievable performance and influences the radar design, especially the AESA
- Selected 780W to be consistent with GPM/DPR
- Evaluated performance of two aperture sizes using the same available power
- Evaluated how design of the AESA was influenced by available prime power



# Aperture Size – Performance and Cost Driver



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Performance Trades between Two Aperture Sizes		
	7 m <sup>2</sup> Aperture	17 m <sup>2</sup> Aperture
Ka-Band Resolution	Meets Requirement	Meets Goal
Ka-Band Sensitivity (off Nadir)	-10.2 dBZ (Meets Requirement)	-13.9 dBZ (Meets Requirement)
Ka-Band Doppler	1 m/s (Meets Requirement)	0.5 m/s (Meets Goal)
W-Band Resolution	Meets Goal	Meets Goal
W-Band Sensitivity	-33.6 dBZ (Marginal to Requirement)	-37.4 dBZ (Meets Requirement)
W-Band Doppler	0.4 m/s (Meets Requirement)	0.2 m/s (Meets Goal)
Mass (Kg)	325 - 375	500 - 600

*Aperture size drives cost, performance, and spacecraft packaging*



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# TRL Assessment & Technology Maturation Plan

# Technology Maturation Plan (TMP)

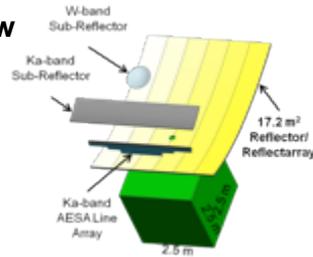
## Radar System Study & 5 Areas Addressed Keyed to Major Subsystems on Radar TRL Block Diagram



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### 0. Concept Study and System Design Review

- Requirements update
- Review major trades
- System Design Study
- Software Assessment
- System Design Review (SDR)

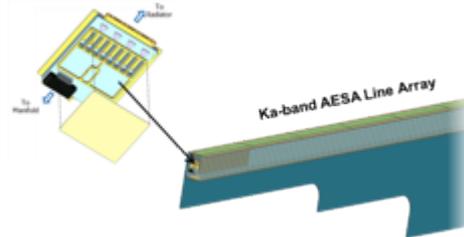


### 1. Dual Band Antenna

- Primary reflector
- Reflectarray/Frequency Selective Surface (FSS)
- W-band Subreflector
- Ka-band Subreflector
- Support structures

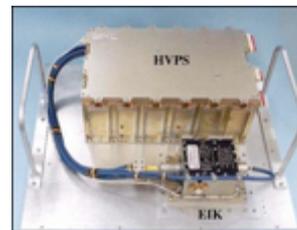
### 2. Ka-Band AESA Feed

- Passive Manifold and Radiator
- AESA Coldplate (thermal control)
- AESA Beam Steering Control
- AESA Power Supplies
- T/R Modules
- Active Feed Structure



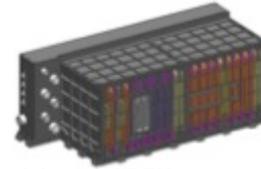
### 3. W-band Transceiver

- Transmitter – EIK baseline  
Option: SS Transmitter
- Receiver - LNA
- Quasi-optical Transmission Line (QOTL)
- Power Supplies  
Option: Active Feed & Beam Steering Control

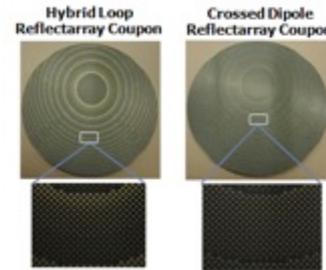


### 4. Radar Electronics Unit: RF, Waveform, and Frequency conversion

- Master Oscillator
- Reference Generator
- Waveform generator
  - Hardware
  - Algorithms
  - Firmware
- Frequency Plan
- Up/Down RF-IF Frequency Conversion
- Analog Power Supplies
- Backplane
- Chassis
- Thermal
- Form Factor



Advanced REU



### 5. Radar Electronics Unit: Signal Processing and Control

- Digital Receiver (multi-channel configuration)
- Algorithms and Firmware
- Interface & Timing
- Power Supply
- Onboard processor
  - Hardware
  - Radar control algorithms
  - Software



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# 2013 ACE Radar IIP

# Wide-swath Shared Aperture Cloud Radar (WiSCR), 2013 IIP Award



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*GSFC: Lihua Li/555 (PI), Paul Racette/555, Gerry Heymsfield/612, Matt McLinden/555*

*NGES: Pete Stenger, Tom Hand, Mike Cooley, Richard Park*

## Advance Readiness of Scanning AESA Feed - Ka-Band T/R Module Tasks

- Develop design of Space-Qualifiable Ka-band AESA T/R Module Package with (new design) Integrated RF Circulator
- Design, fabricate and test Ka-band circulator coupon
- Design, fabricate and test Ka-band T/R Module GaAs LNA, Switch and Multifunction Phase/Atten MMICs, second iteration of GaN HPA, Si ASICs for power and amp/phase control.

## Tri-band Antenna Concept (Ku/Ka/W)

- Evaluate performance of W-band fixed vs scanning feed
- Study trade between single Ku/Ka-band line feed vs. separate feeds
- Study trade, separate vs. shared subreflectors

# Wide-swath Shared Aperture Cloud Radar (WiSCR), 2013 IIP Award Tasks (Cont'd)



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GSFC: Lihua Li/555 (PI), Paul Racette/555, Gerry Heymsfield/612, Matt McLinden/555

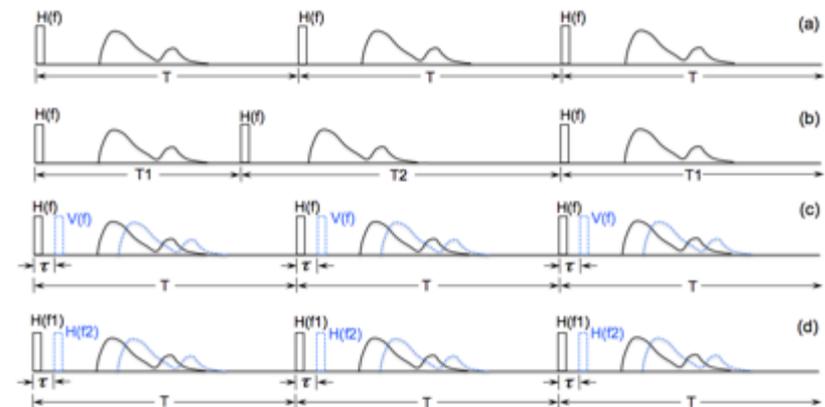
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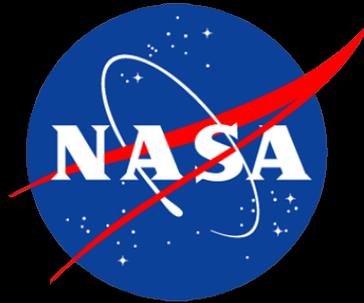
## Frequency up/down converter

- Design and fabricate Multi-channel Frequency Conversion Module (MFCM)
- Design and fabricate Multi-channel Arbitrary Waveform Generator (MAWG)
- Airborne flight demonstration of MFCM and MAWG

## Advanced Doppler Processing Algorithms

- Develop Frequency Diversity Pulse Pair (FDPP) processing
- Noise assisted I-Q data analysis
- Airborne demonstration of FDPP algorithm





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*Thank You!*