National Aeronautics and Space Administration

The development of a U.S. Geostationary Microwave Sounder

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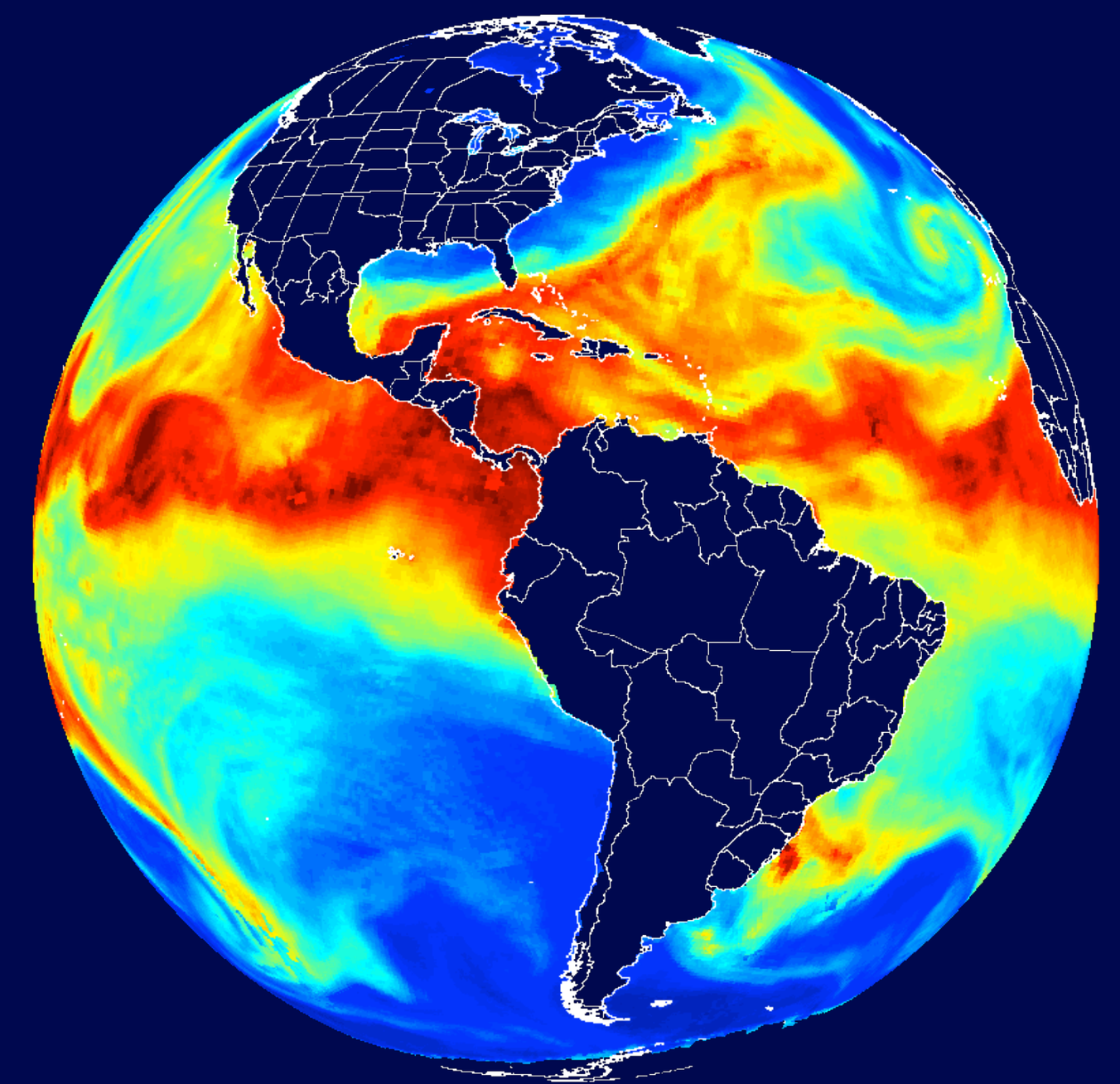
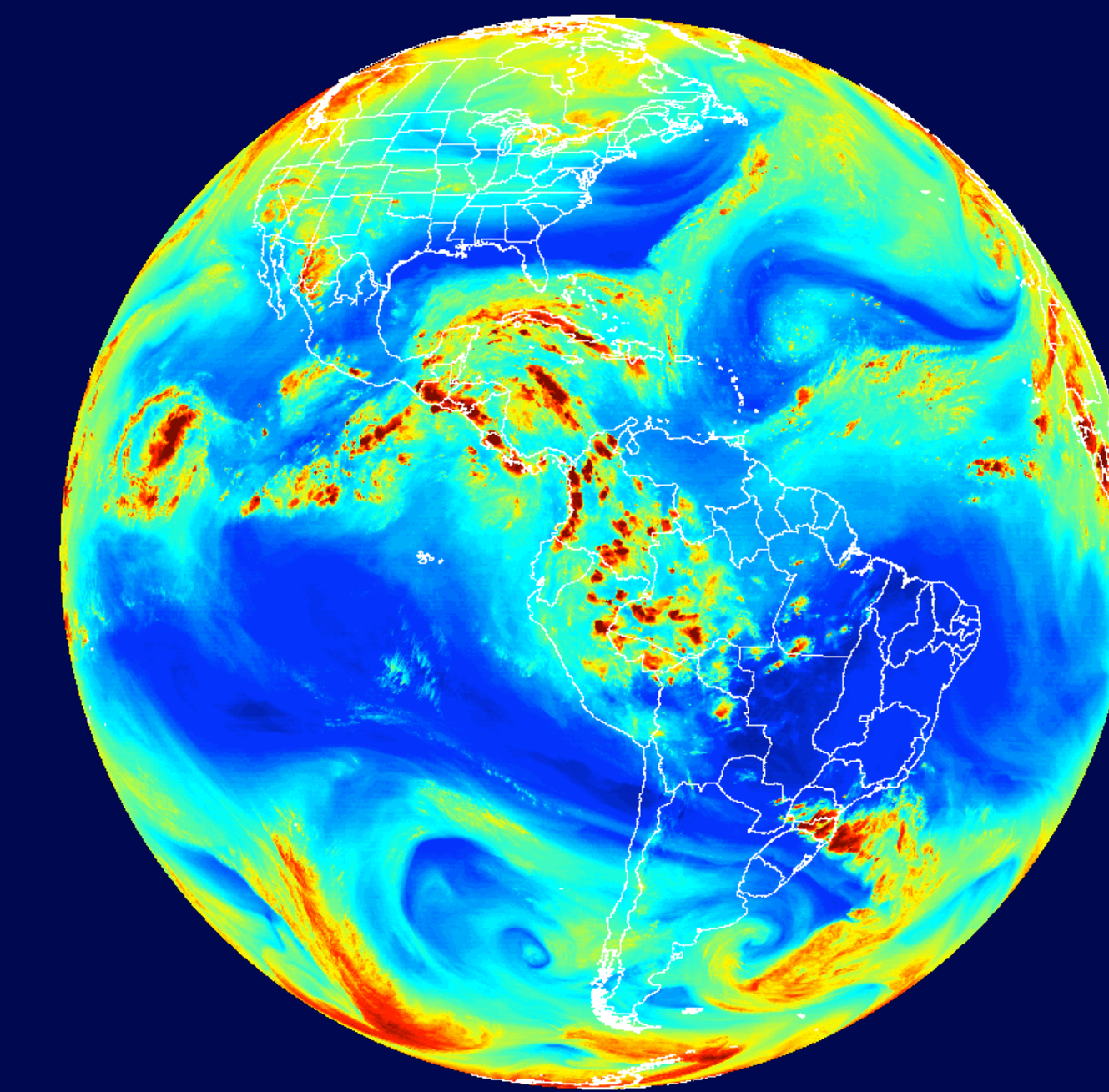


MW view of water vapor: total column (AMSU, 10/15/15)



IR view of water vapor: mid-trop only (GOES, 10/15/15)

A geostationary microwave sounder, capable of providing temperature, water vapor, clouds, precipitation, and wind vectors in the presence of clouds and precipitation, will add tremendously to our ability to observe dynamic atmospheric phenomena, such as hurricanes and severe storms, monsoonal moisture flow, atmospheric rivers, etc. Such a sensor is now feasible, enabled by technology that has been developed under NASA's Instrument Incubator Program. The Jet Propulsion Laboratory has led that development in partnership with the University of Michigan. A prototype, the Geostationary Synthetic Thinned Aperture Radiometer (GeoSTAR), is essentially an "AMSU in GEO", i.e. it has similar capabilities as AMSU would have if it were operating on a geostationary satellite, including similar spatial resolution. GEO orbits are almost 50 times higher than the LEO orbits that current AMSUs operate from, and the corresponding scaling of aperture size required to maintain spatial resolution has stymied the development of such a sensor for many decades. The aperture synthesis approach implemented with GeoSTAR finally overcomes that obstacle, and the large number of microwave receivers and associated electronics required is made possible with the new technology that has now been developed. This development also enables the decadal-survey Precipitation and All-weather Temperature and Humidity (PATH) mission, and it is possible that NASA will elevate PATH from a low-priority "third-tier" mission to a higher priority first or second tier. In the meantime, a low-cost demonstration mission implementing a subset of the PATH objectives is feasible and has been proposed as a hosted payload on a commercial communications satellite, through the NASA EV-I Venture program. The objective of such a mission is to advance our understanding and modeling of storm processes that control rapid or explosive intensification of hurricanes, mesoscale convective systems, and extratropical cyclones. Retrieval of temperature and water vapor profiles is possible even in the presence of moderate precipitation, and with the ability to derive horizontal wind vectors by tracking water vapor features, a rich set of parameters measuring the thermodynamics, dynamics and convection, sampled every 15 minutes, will enable significant progress in storm science.

Motivation for a GEO/MW sounder (PATH)

Overarching

Significant portions of the atmospheric branch of the hydrologic cycle are poorly understood and therefore poorly modeled and predicted

Examples

- Convective storms – hurricanes, mesoscale convective systems, thunderstorms – are major mechanisms for transport of moisture and energy in the atmosphere, but inadequate models have difficulties predicting intensity
- Mid-latitude frontal systems provide much of continental precipitation, but their interaction with other atmospheric systems & processes is a modeling challenge
- Atmospheric rivers provide 30-50% of California's annual rainfall, but are poorly understood and predicted
- Monsoons are mechanisms for transportation of moisture from ocean to continents but also not well modeled

Common threads

- Processes evolve on hourly timescales
- Thermodynamics, dynamics, microphysics all play a role
- Multiscale interactions: stormscale–mesoscale-largescale

We need to improve:

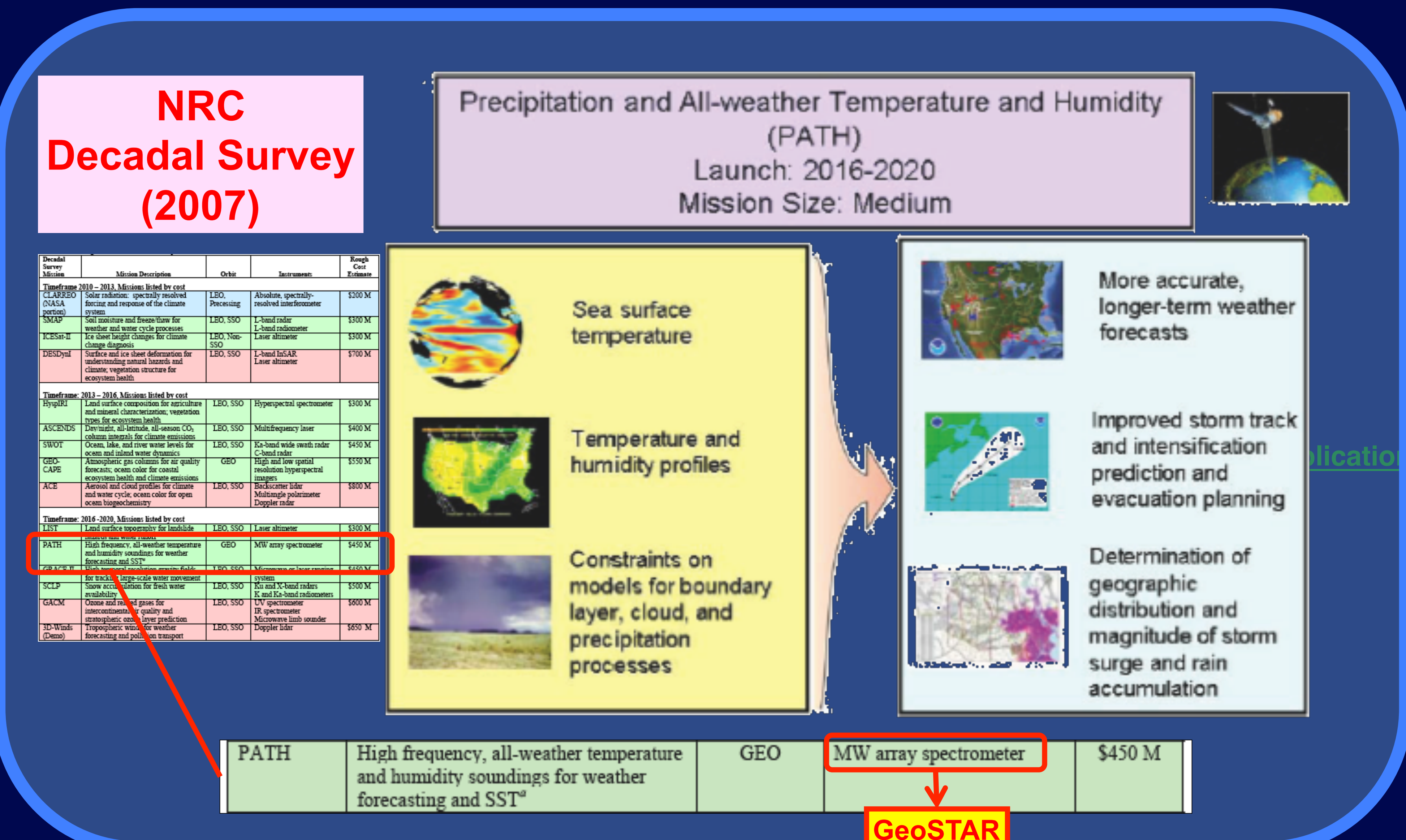
Observations → Understanding → Models → Predictions

Observational needs

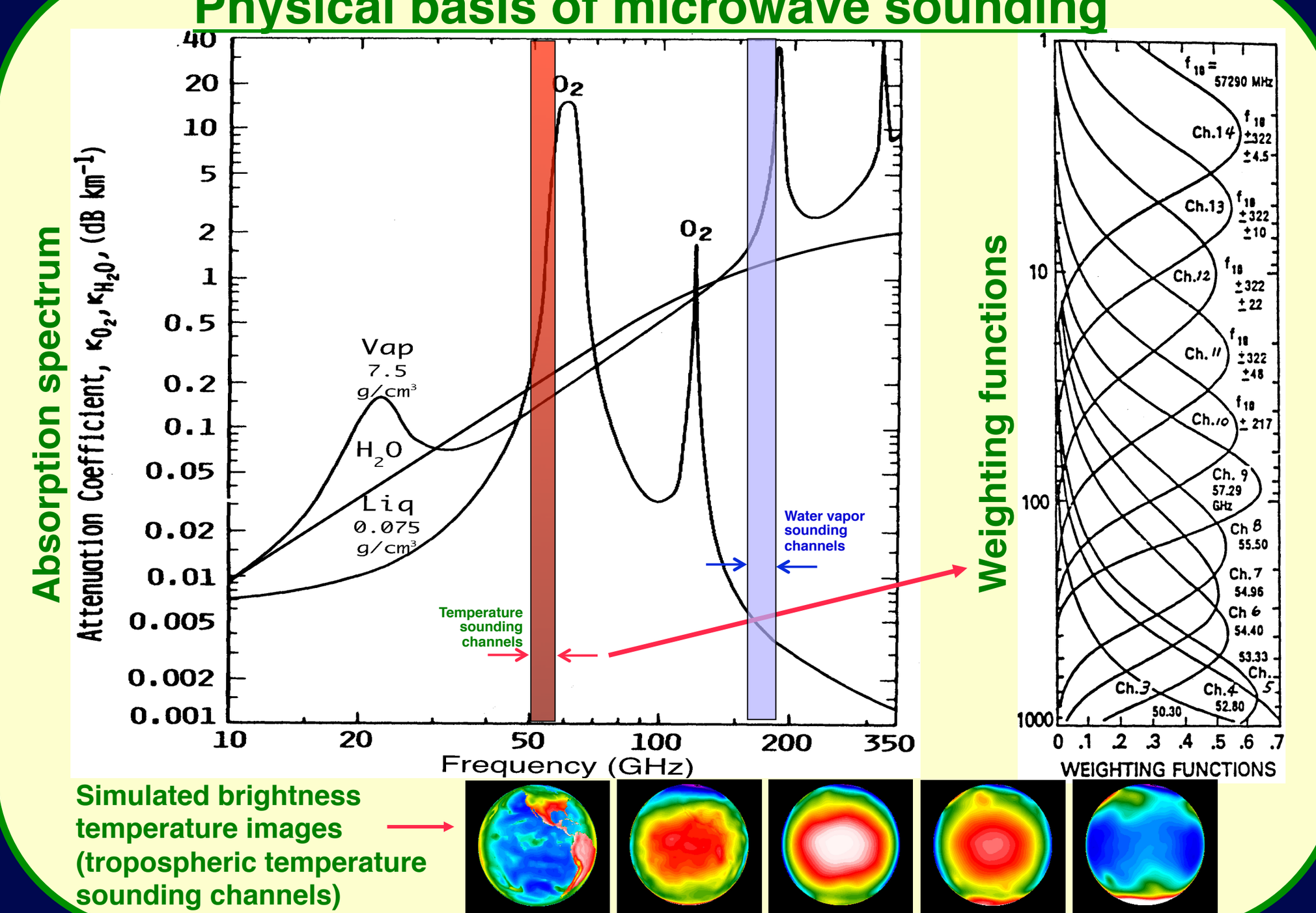
- Observations under cloudy/precipitating conditions
- Better temporal resolution of dynamic processes
  - — cloud formation; convective initiation; precipitation
  - — storm propagation & intensification
- Simultaneous observation of all key variables in 3D
  - — thermodynamics: temperature & humidity
  - — dynamics: wind vectors
  - — microphysics: clouds & precipitation

Solution

- Microwave observatory in geostationary orbit
- Sounder with AMSU-like capabilities: "AMSU in GEO"



Physical basis of microwave sounding



Data products

Mature products:

Parameter	Horizontal	Vertical	Temporal	Accuracy
Tb (50 GHz)	50 km	(6 channels)	3 min per ch.	= AMSU-A
Tb (183 GHz)	25 km	(4 channels)	5 min per ch.	= AMSU-B
Temperature	50 km	2 km	30 min	1.5-2 K
Water vapor	25 km	2 km	30 min	25%
Liquid water	25 km	3 km	30 min	40%
Stability index	50 km	N/A	30 min	N/A
TPW	25 km	N/A	30 min	10%
LWC	25 km	N/A	30 min	20%
SST	100 km	N/A	1 hour	0.5 K

Evolving experimental products:

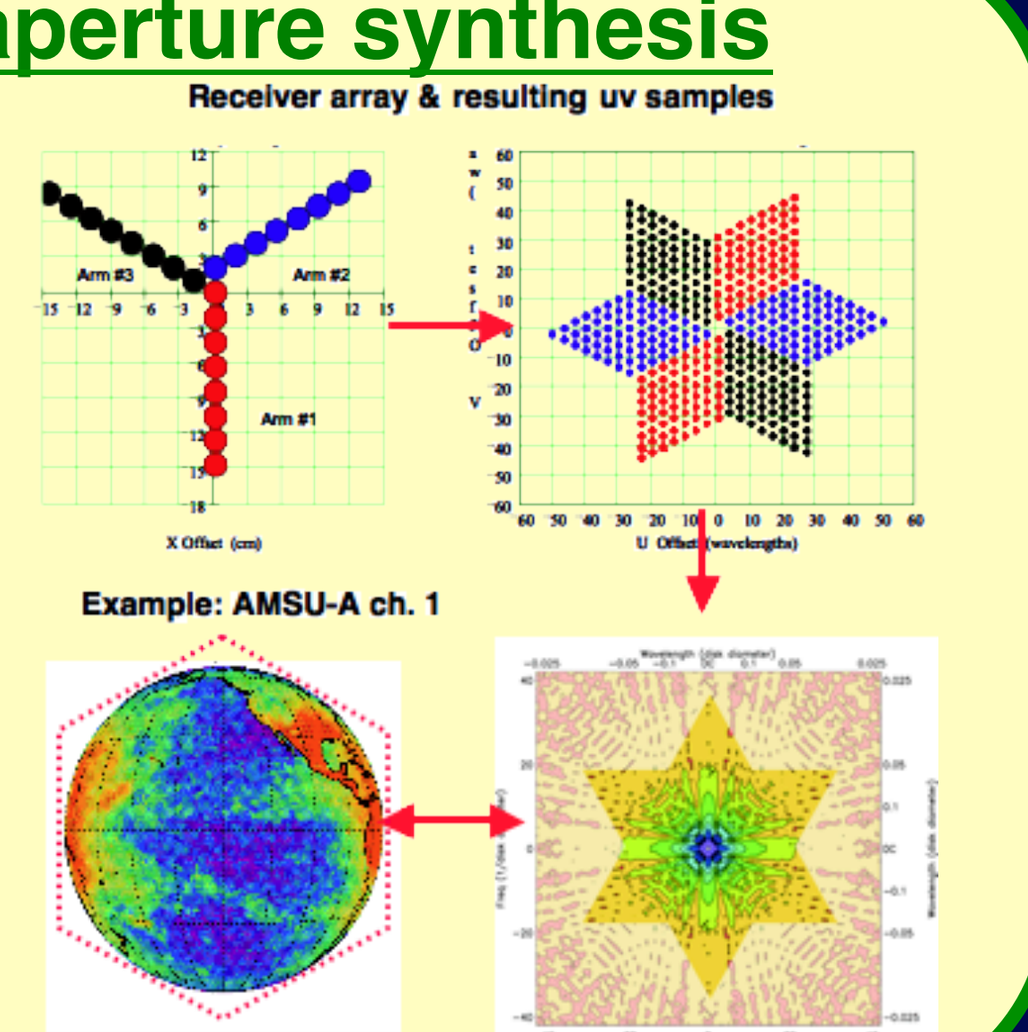
Parameter	Horizontal	Vertical	Temporal	Accuracy
Rain rate	25 km	N/A	30 min	2 mm/hr
Reflectivity.	25 km	1-2 km	30 min	4-6 dBZ
IWC	25 km	N/A	30 min	30%
Wind vector	25 km	2-3 km	30 min	TBD

GeoSTAR: "MW array spectrometer" technology developed at JPL through NASA/ESTO Instrument Incubator Program, 2003-2015

Principle of aperture synthesis

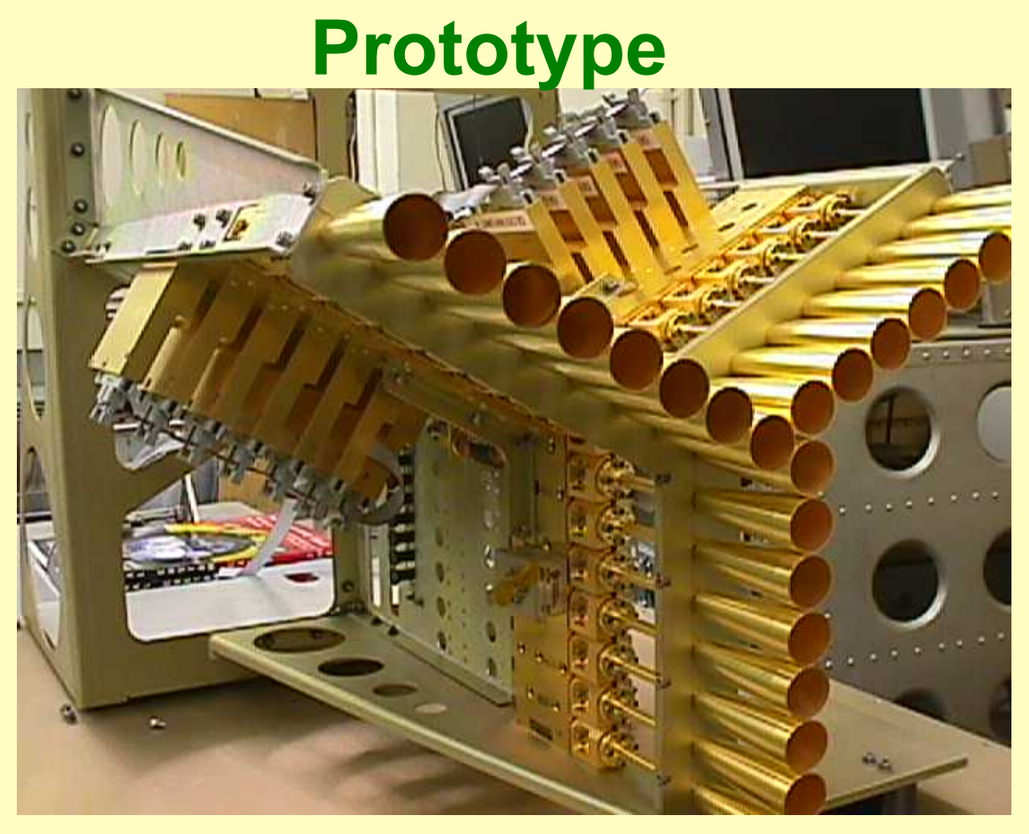
- **Aperture-synthesis concept**
  - Sparse array employed to synthesize large aperture
  - Cross-correlations -> Fourier transform of Tb field
  - Inverse Fourier transform on ground -> Tb field
- **Array**
  - Optimal Y-configuration: 3 sticks; N elements
  - Each element is one I/Q receiver, 3.5λ wide (2.1 cm @ 50 GHz; 6 mm @ 183 GHz!)
  - Example: N = 100 ⇒ Pixel = 0.09° ⇒ 50 km at nadir (nominal)
  - One "Y" per band, interleaved
- **Other subsystems**
  - A/D converter; Radiometric power measurements
  - Cross-correlator - massively parallel multipliers
  - On-board phase calibration
  - Controller: accumulator -> low D/L bandwidth

Bonus: **No moving parts!**



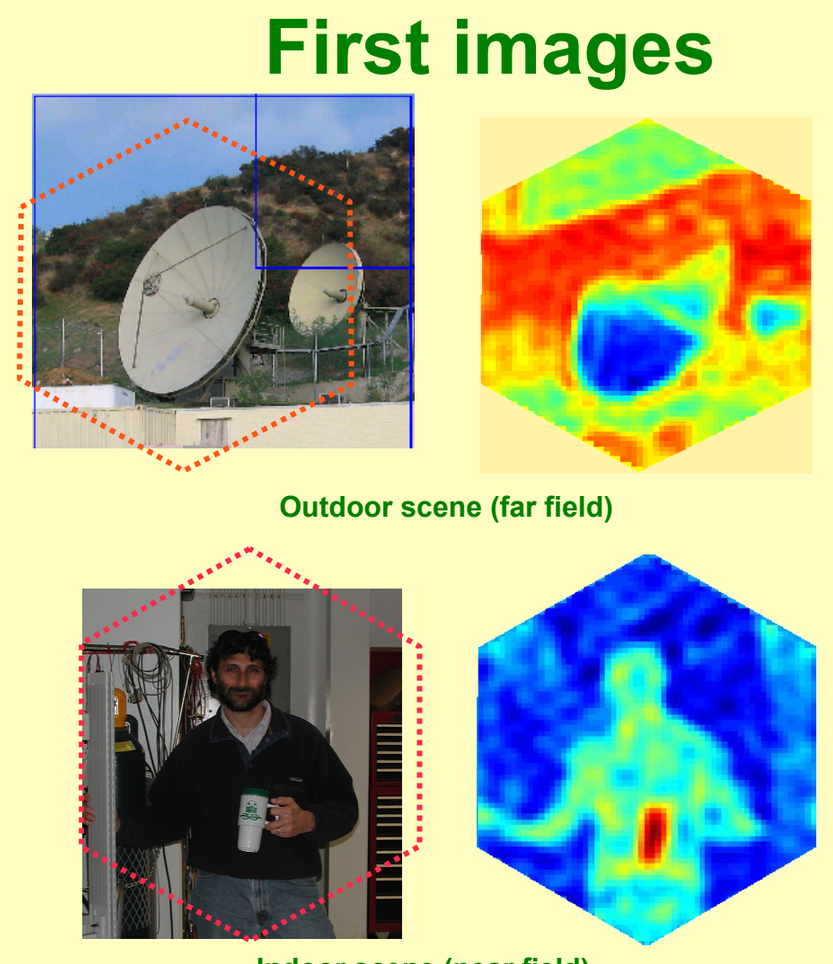
Concept development

Prototype

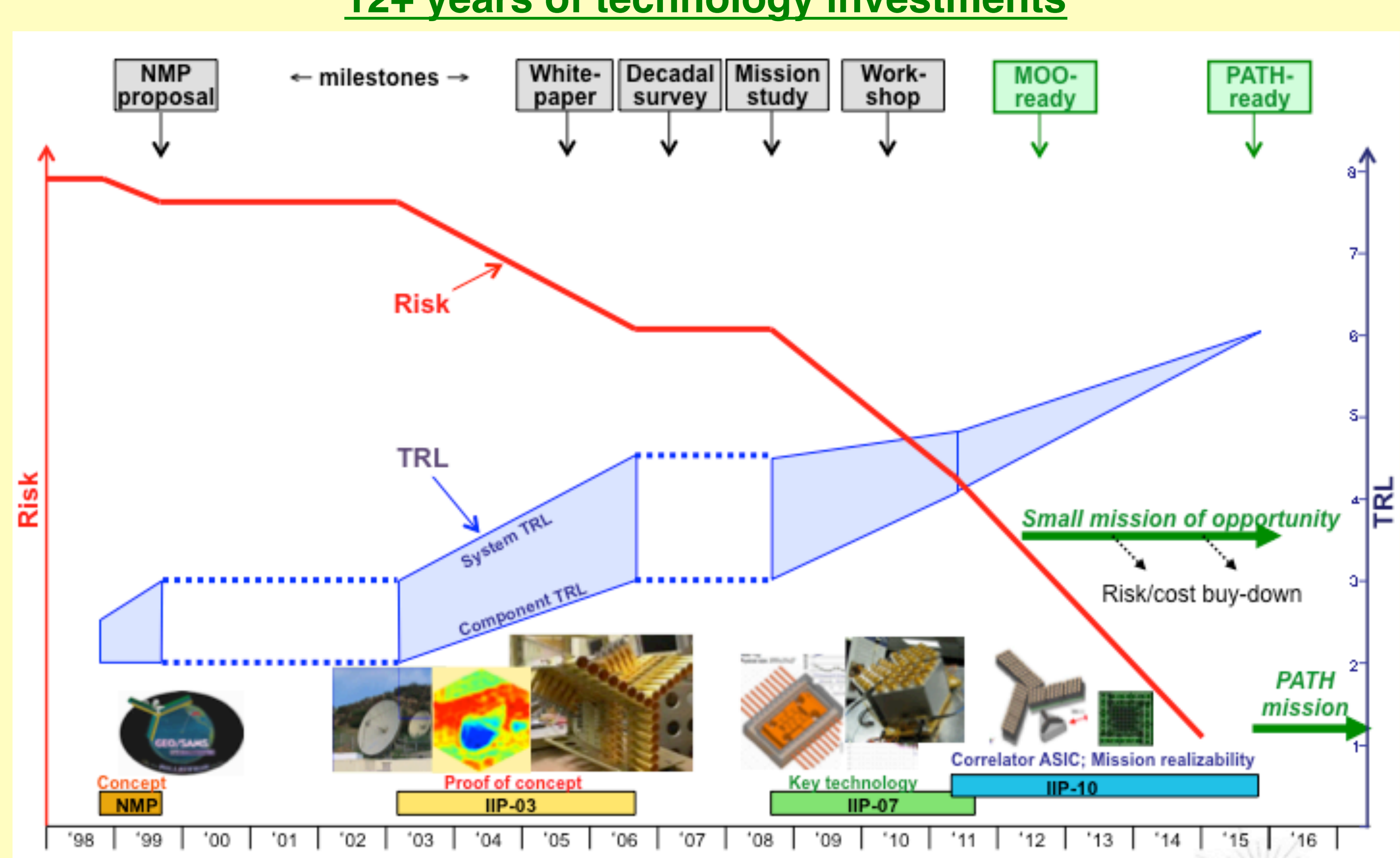


Proof-of-concept prototype demonstrated in 2005

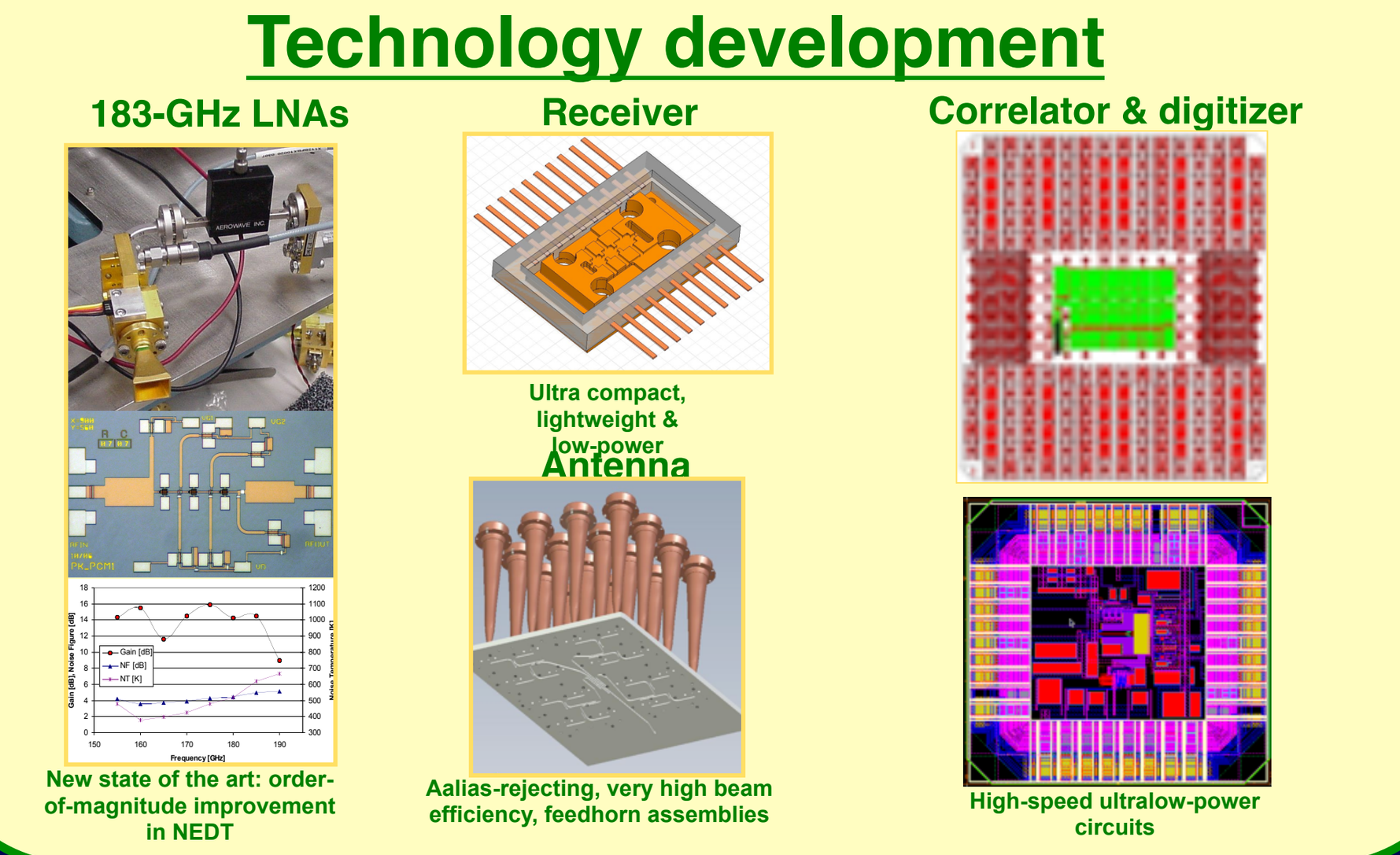
First images



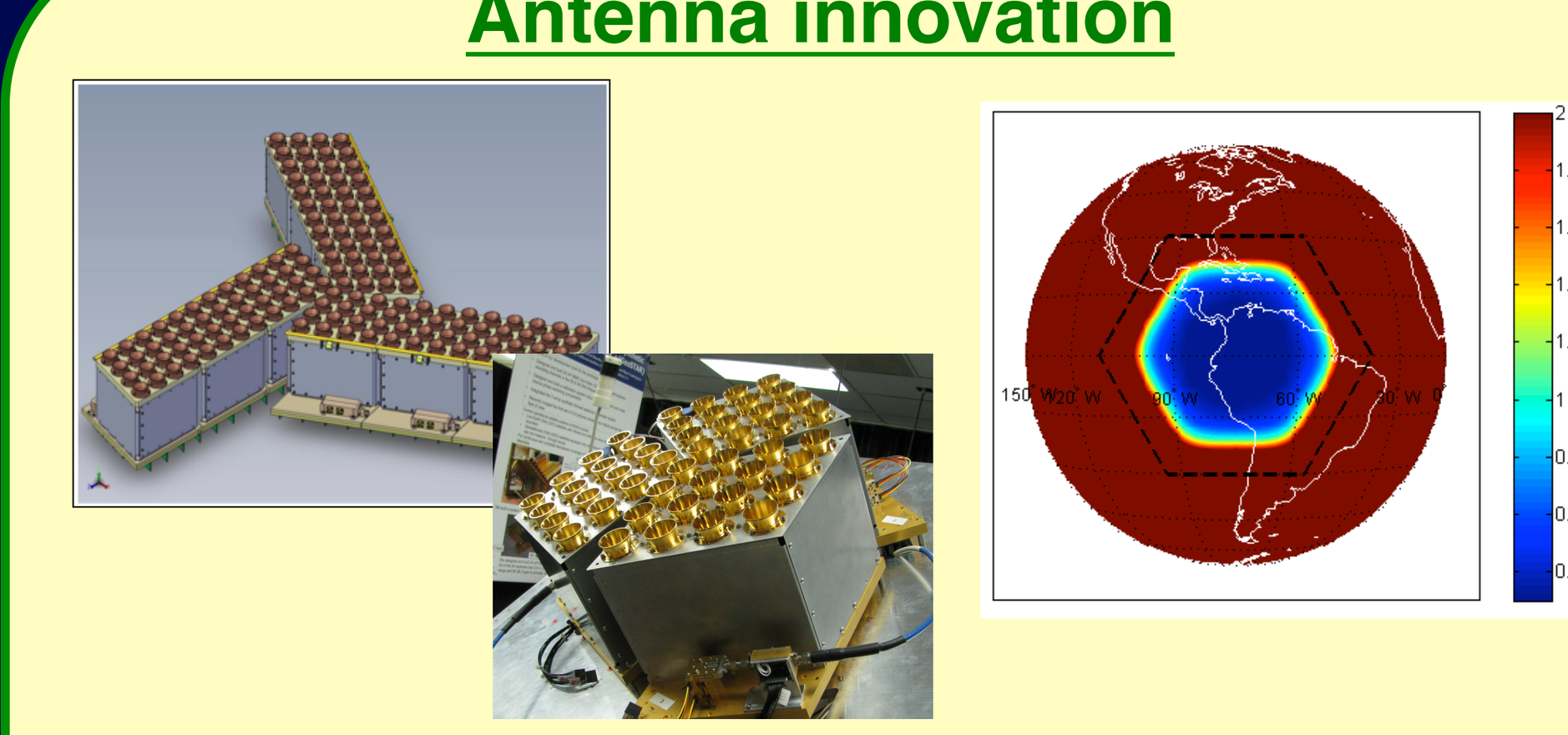
12+ years of technology investments



Technology development



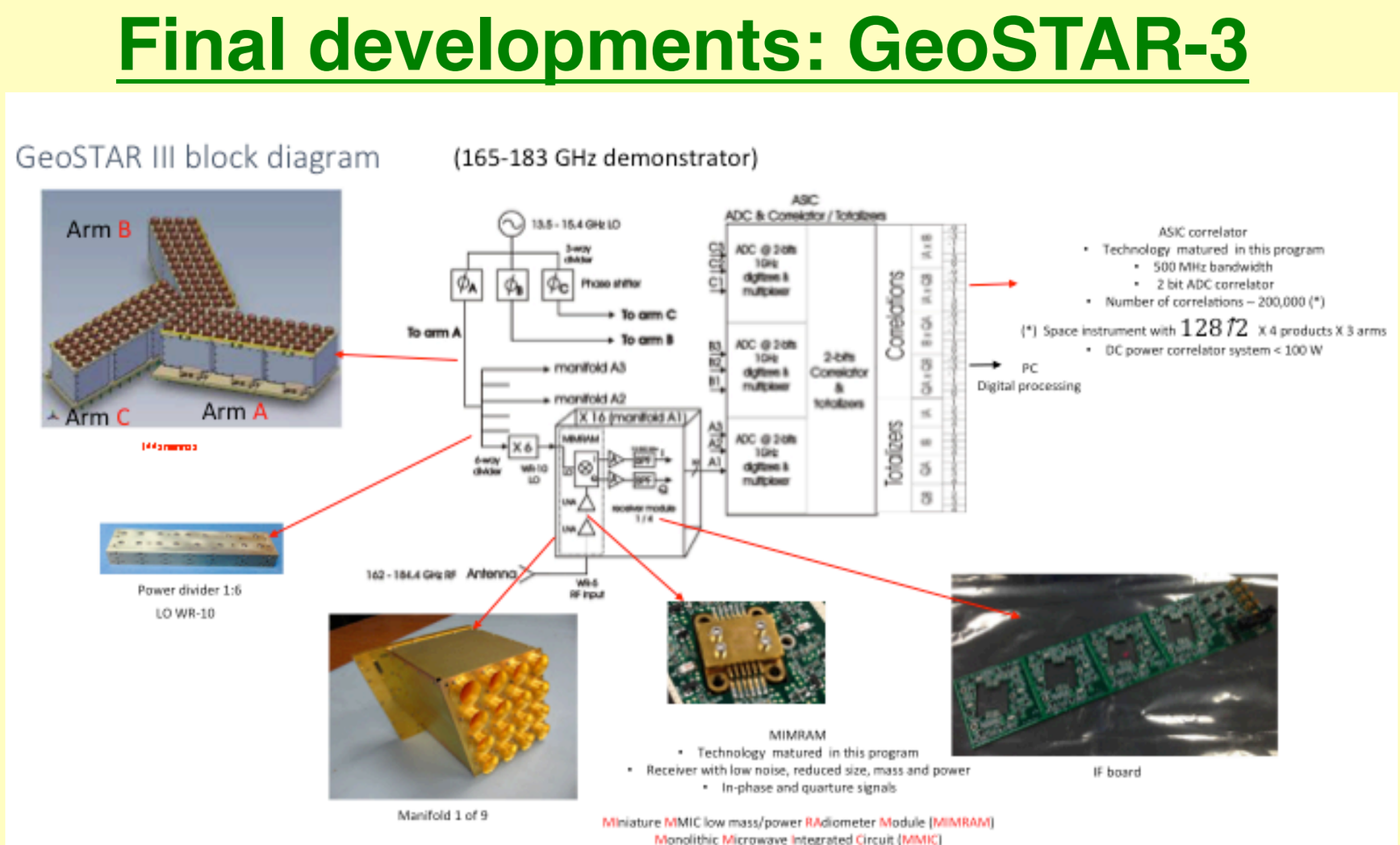
Antenna innovation



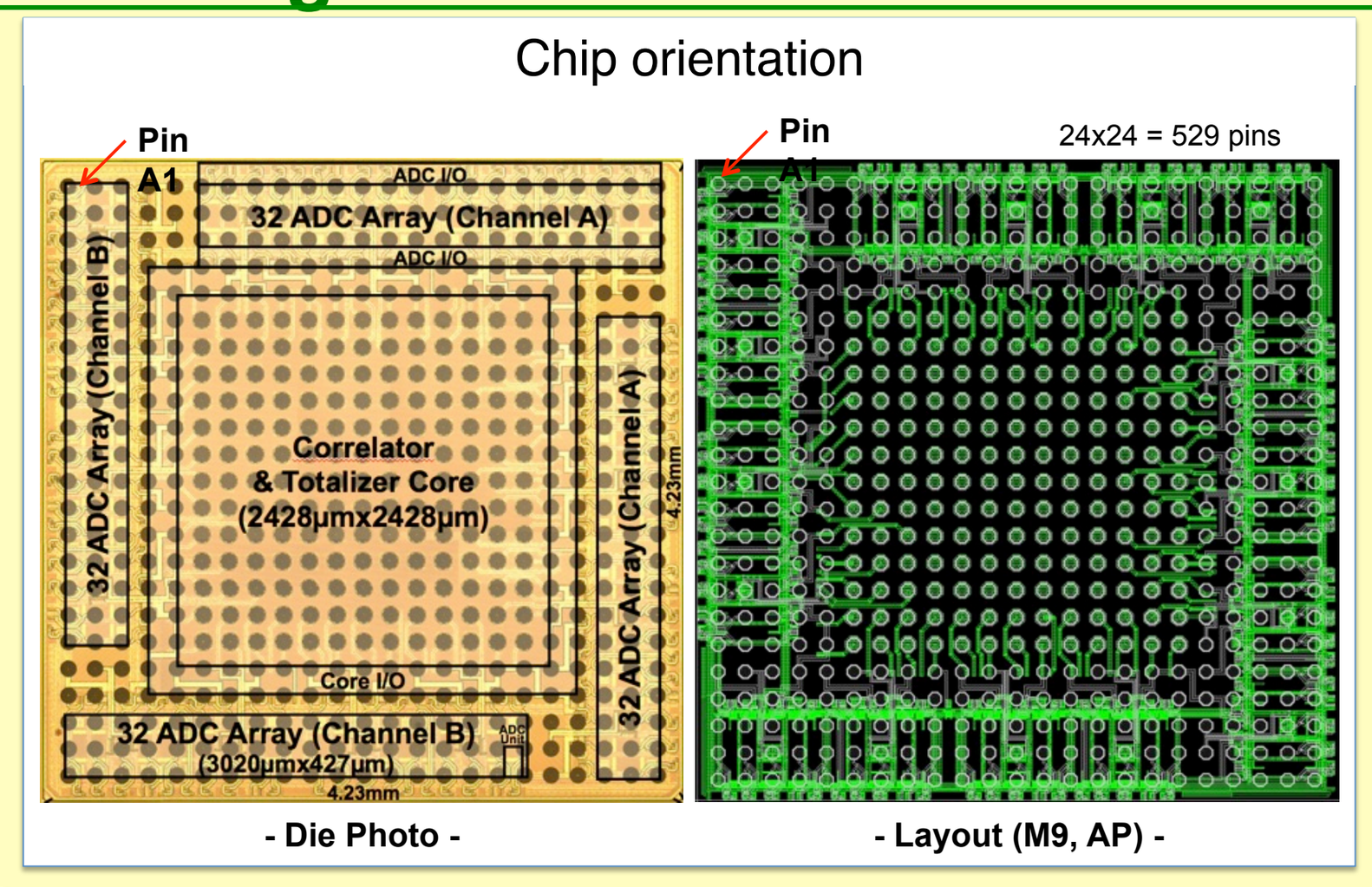
Multiple-row antenna design maximizes the antenna beam efficiency and radiometric sensitivity and makes it possible to synthesize non-gaussian antenna patterns to limit aliasing. This makes it possible to focus the imaging area on a small region of interest using a small number of large-diameter feedhorns. The resulting field-of-view (blue) can be pointed at regions of interest

With the completion of GeoSTAR-3 all key technology for a GEO/MW is now in place

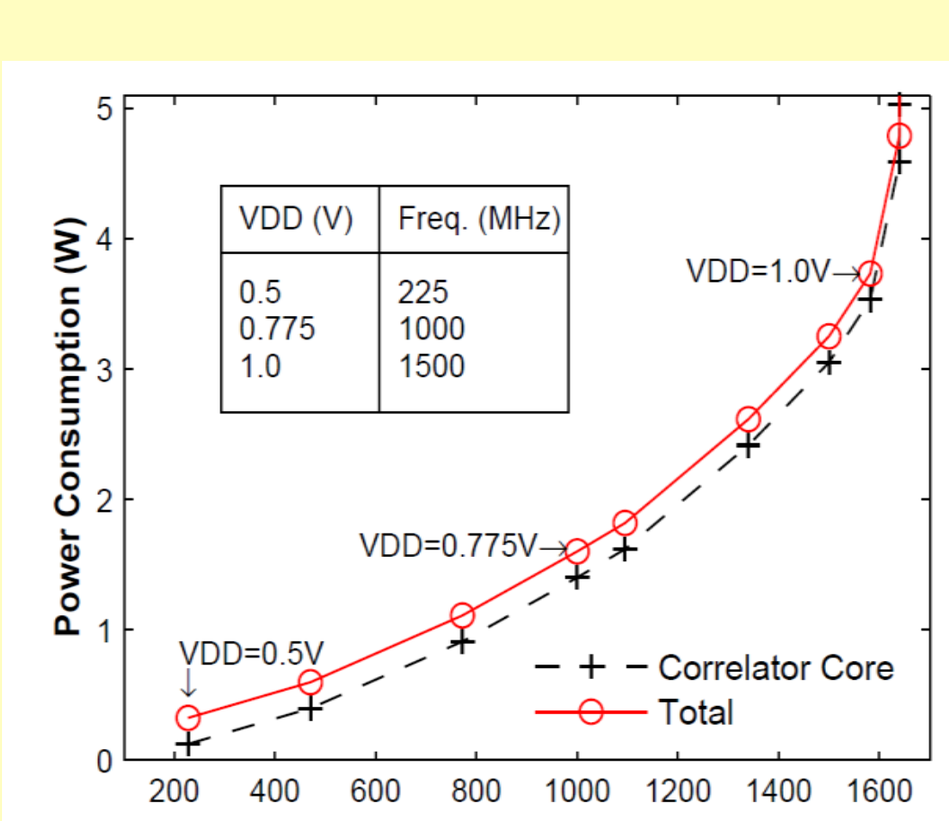
Final developments: GeoSTAR-3



Crowning achievement: Correlator ASIC



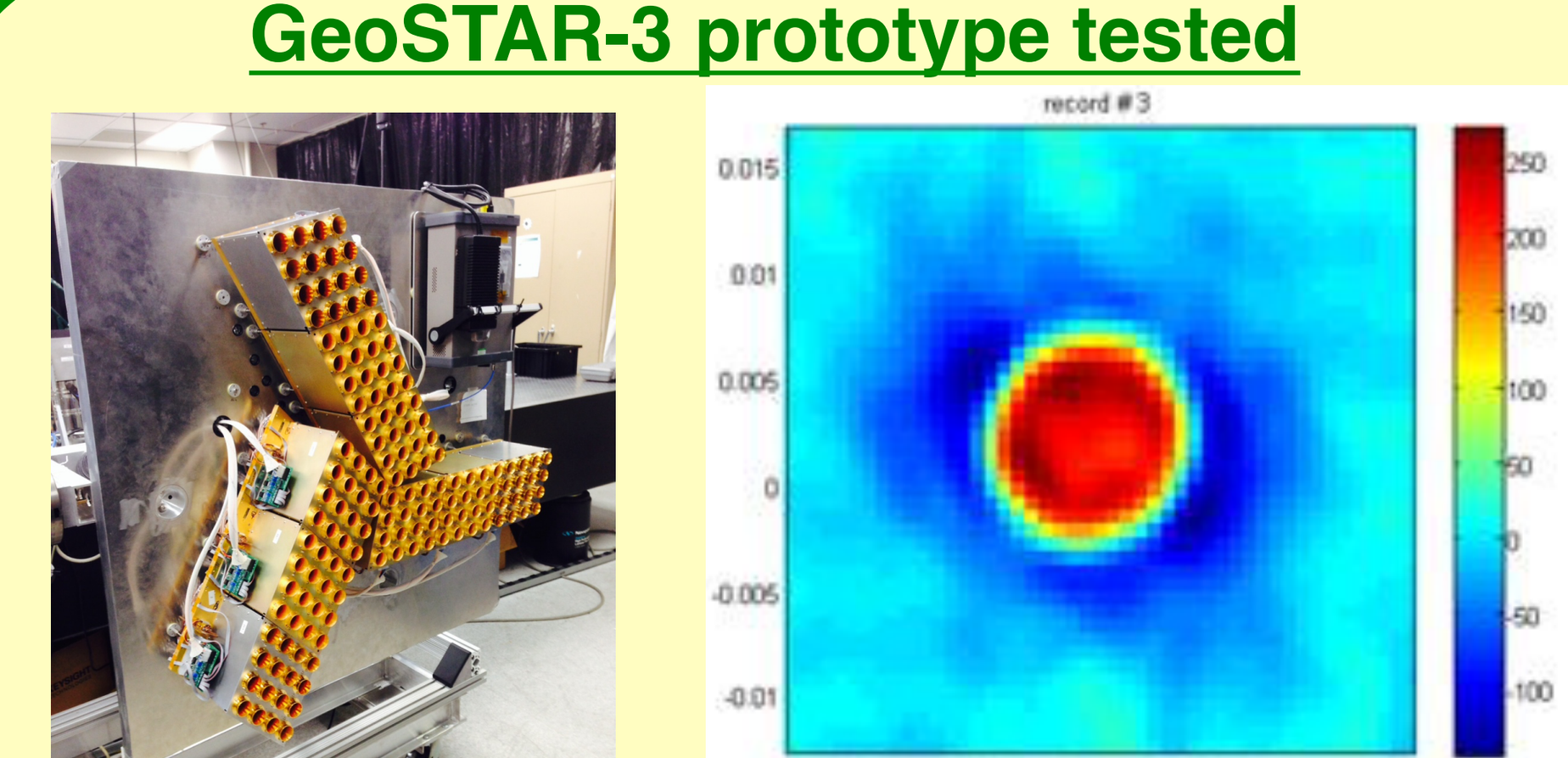
Correlator chip: Phenomenal performance



	This work
# of Channels	128
# of Correlators	4096
Channel Bitwidth	2
On-Chip ADCs	yes, 128
Logic Family	static
Correlation Efficiency (%)	>90% @ >30dBm
Isolation (dB)	-42.4
Technology	65nm
Total Power (W)	1.44 @775mV, 1GHz 3.73@1V, 1.5GHz
Energy per Correlation (pJ/correlation/cycle)	0.35 @775mV, 1GHz 0.61 @1V, 1.5GHz (2b corr + ADC)
Core Area (mm^2) Chip Area (mm^2)	5.9 17.9
Max Performance (T correlation/s)	6.14 @1V, 1.5GHz

a: a 1-bit correlation is just XOR

GeoSTAR-3 prototype tested



First-light visibility image of the sun (uncalibrated)

This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology under a contract with the National Aeronautics and Space Administration.