A physicist’s adventures from Medford to NASA by way of the South Pole

Todd Gaier A86

Undergraduate

- Tufts University
  - Undeclared as a freshman: Tried International Relations
  - Briefly dabbled in Engineering
  - Majored in Physics
  - Completed BS in Dec 1985

  Began doing research in Sophmore year- Optics

  Continued research in High Energy Physics Junior year- working at Fermilab summer before senior year on a neutrino bubble chamber experiment.

Graduate School

- UCSB Physics
  - Department was competitive and was a real challenge (to the breaking point)
  - Joined the Lubin Astrophysics group- new to UCSB
    - Valued hard work
    - Provided first real team experience
    - Soup to nuts experience- proposal -> technology -> instrument -> field experiment-> data analysis-> publication
      - Ideal for research or **Systems Engineering**
    - Career networking experience
  - 5 graduates from that class are now JPLers

UCSB CMB Research-South Pole

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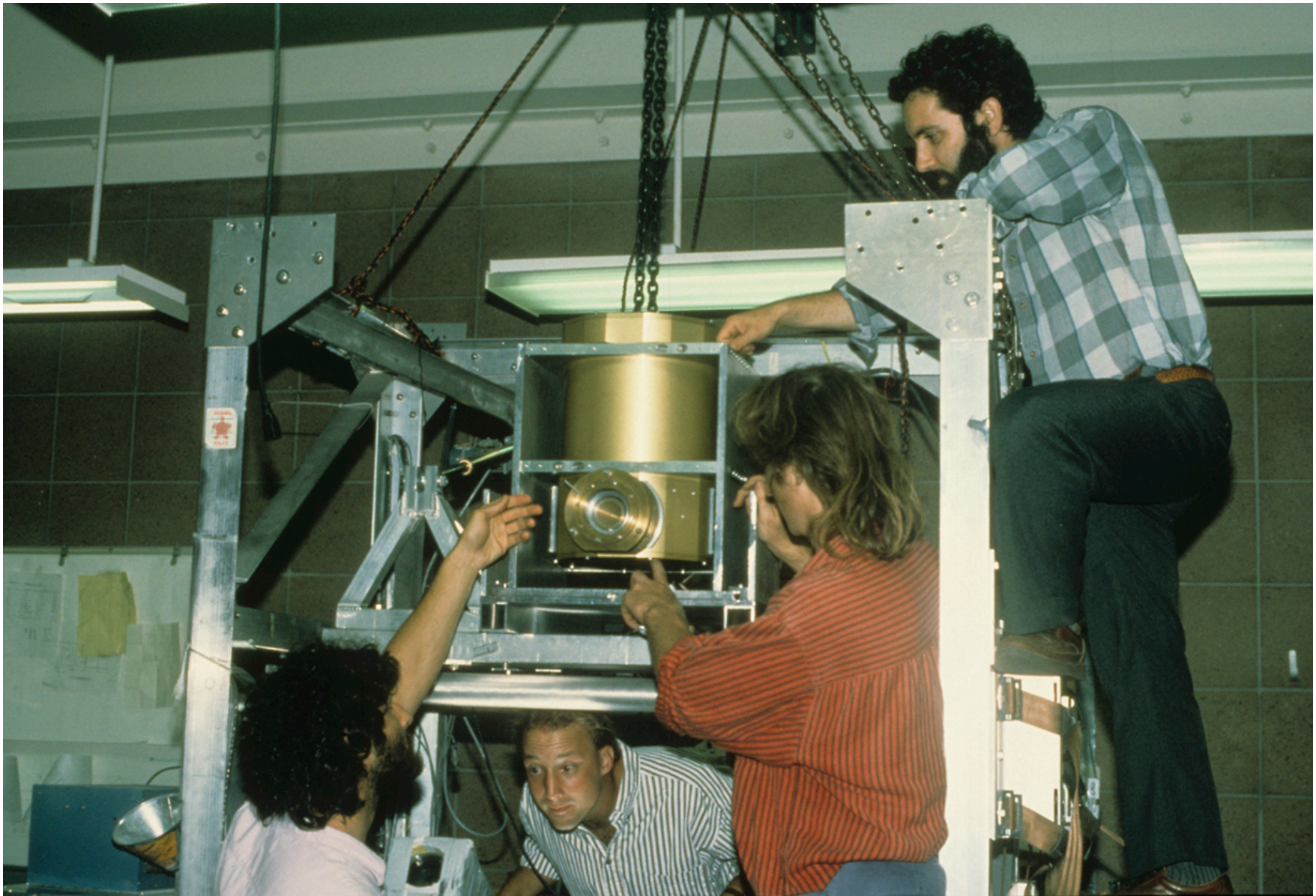
UCSB CMB Research-South Pole



UCSB CMB Research-White Mt

UCSB CMB Research-White Mt

Post-doc Work

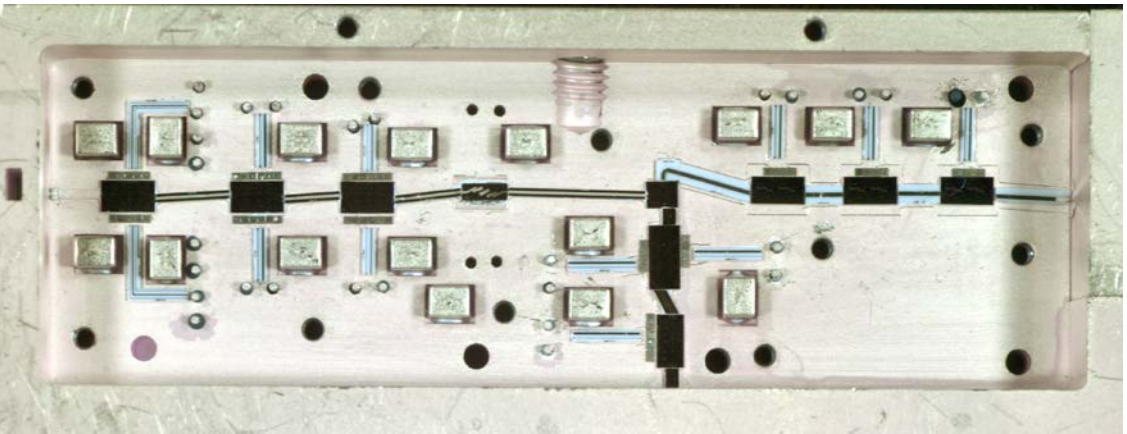
- Stayed at UCSB to work on SP94 experiment and a NASA STEDI Proposal- $4M student mission
- Offered NRC Post-doc at GSFC-declined it
- Worked instead on Primordial Spectrum Investigation MidEx proposal-led by Michael Janssen, Charles Lawrence and Gary Parks
- Took LOA after submission to work at Spacek Labs- Started amplifier product line, first close interaction with Sandy Weinreb
- Offered position at JPL

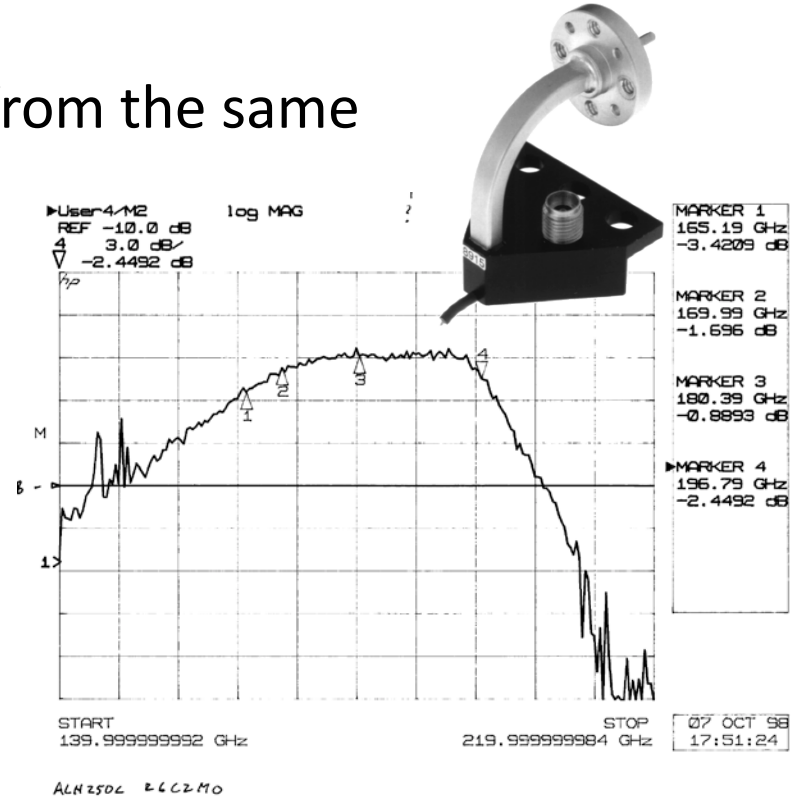
Joining JPL- Still looking up, but now down too

- Placed in an Earth Science oriented group
- Brought in to introduce astrophysics technology to Earth Science
- Established MMIC capability at JPL
- Established mm-test test capability
- Supported technical effort for the ESA Planck-Low Frequency Instrument

IMAS Development (late 1990s)

- Down converter chipsets developed for 60, 118 and 183 GHz atmospheric sounding channels
  - Never flew but the chipsets did
  - Chipset was the first of its kind above 100 GHz- 75 nm gate technology
- EOS(Aura)-MLS carries a 118 GHz receiver which is a direct result of the IMAS development
- Odin carried a cooled 118 GHz LNA from the same development

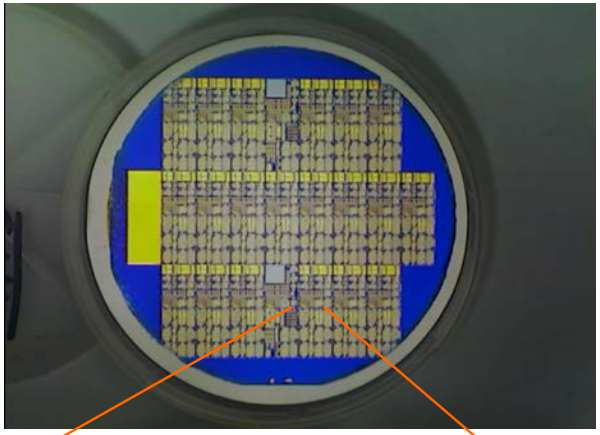




JPL- Astrophysics Group

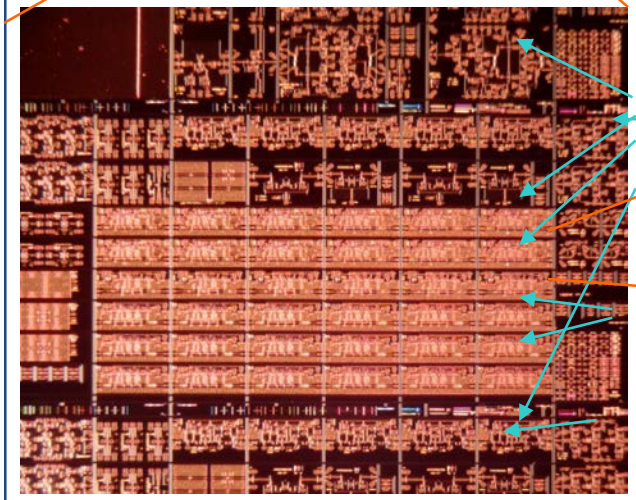
- Interdivisional group led by Charles Lawrence
  - Most members were “free agents”
  - Worked on ESA/NASA Planck LFI technology
  - PEM for NASA LFI task
    - Budget planning
    - Team leadership/management
    - Contract management
    - Reporting
    - Lots of travel
  - Developed cryogenic MMIC amplifier technologies
  - Mentored several summer students
  - First 4 hires

Cryogenic HEMT Optimization Program 0.1um InP

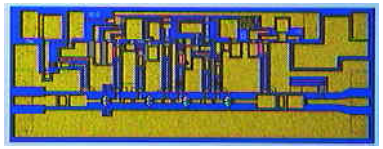


CHOP has produced thousands of low-noise InP devices which are being used for a radio astronomy including:

- UMass Sequoia Array
- 90 GHz VLBI on Effelsberg Telescope
- UCSB/JPL BEAST Telescope
- DSN
- Princeton University CMB polarization
- Planck and FIRST prototype development
- IF amplifiers for CSO, SOFIA receivers
- Amplifiers for Metsahovi Radio Obs.



75-115 GHz LNAs



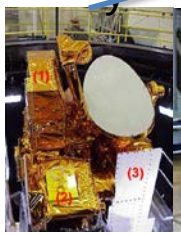
50-90 GHz LNAs

20-50 GHz LNAs

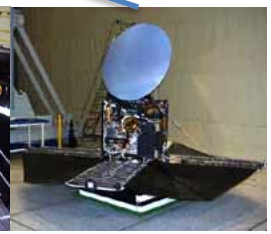
CHOP Family Tree

IMAS Technology

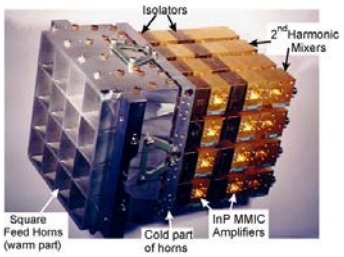
U Mass/ TRW Wafers



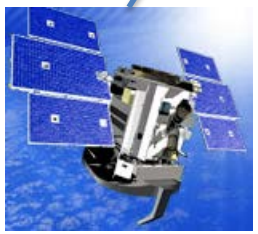
Aura-MLS



ODIN



SEQUOIA

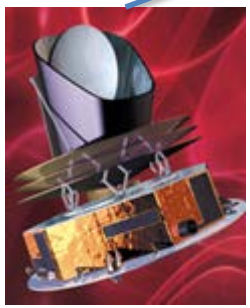


CloudSat

Herschel-HIFI

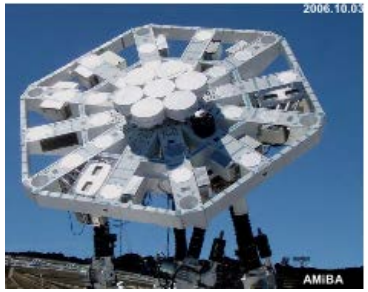
Effelsberg 100m

SZA



Planck-LFI

CAPMAP



AMiBA

QUIET

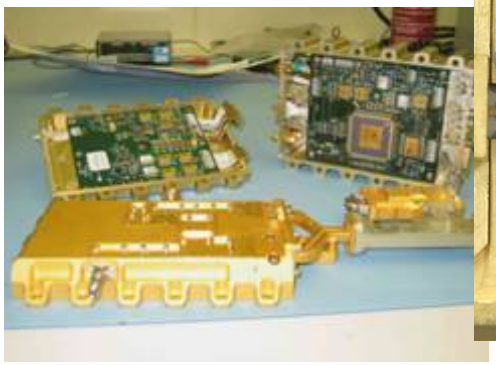
ALMA

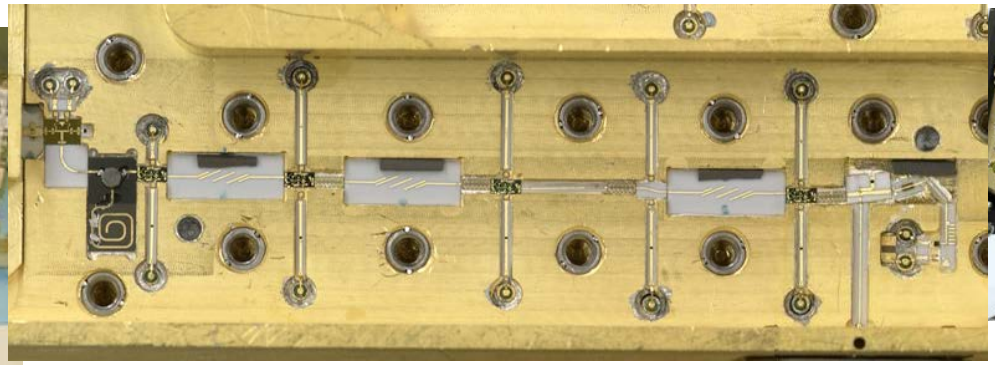
Group Supervisor- Astrophysics and Earth Science Instrumentation

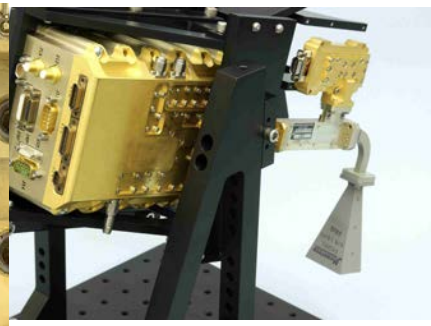
- Inherited three groups focused on airborne Earth Science, space instruments and astrophysics
- Line responsibility for Jason-II, Jason-III, COWVR, TEMPEST-D, CHARM/RACE CubeSat
- Group was key to Juno MWR
- Developed QUIET technology and receivers
- Completed GeoSTAR-I
- Managed GeoSTAR-II and III
- Co-PI and Manager for TEMPEST-D

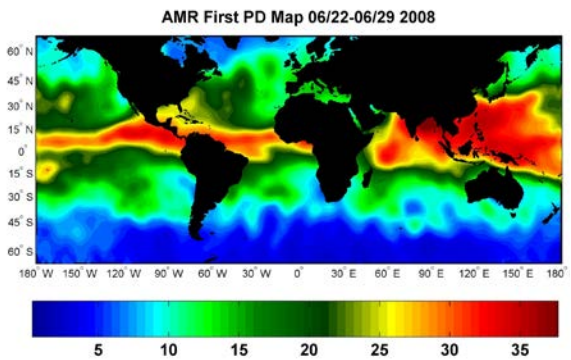
Jason-II

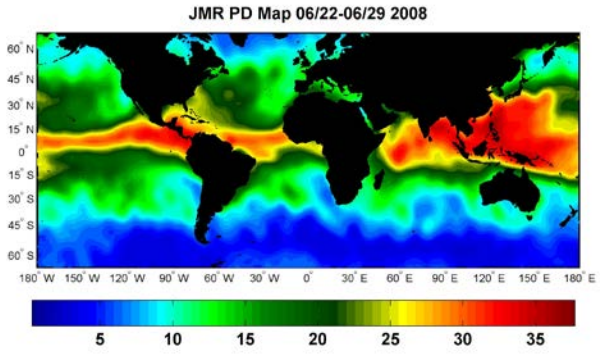
- Used commercial GaAs MMIC parts including LNAs and PIN diode switches
- Integrated noise sources reduced systematic errors
- Development was rapid









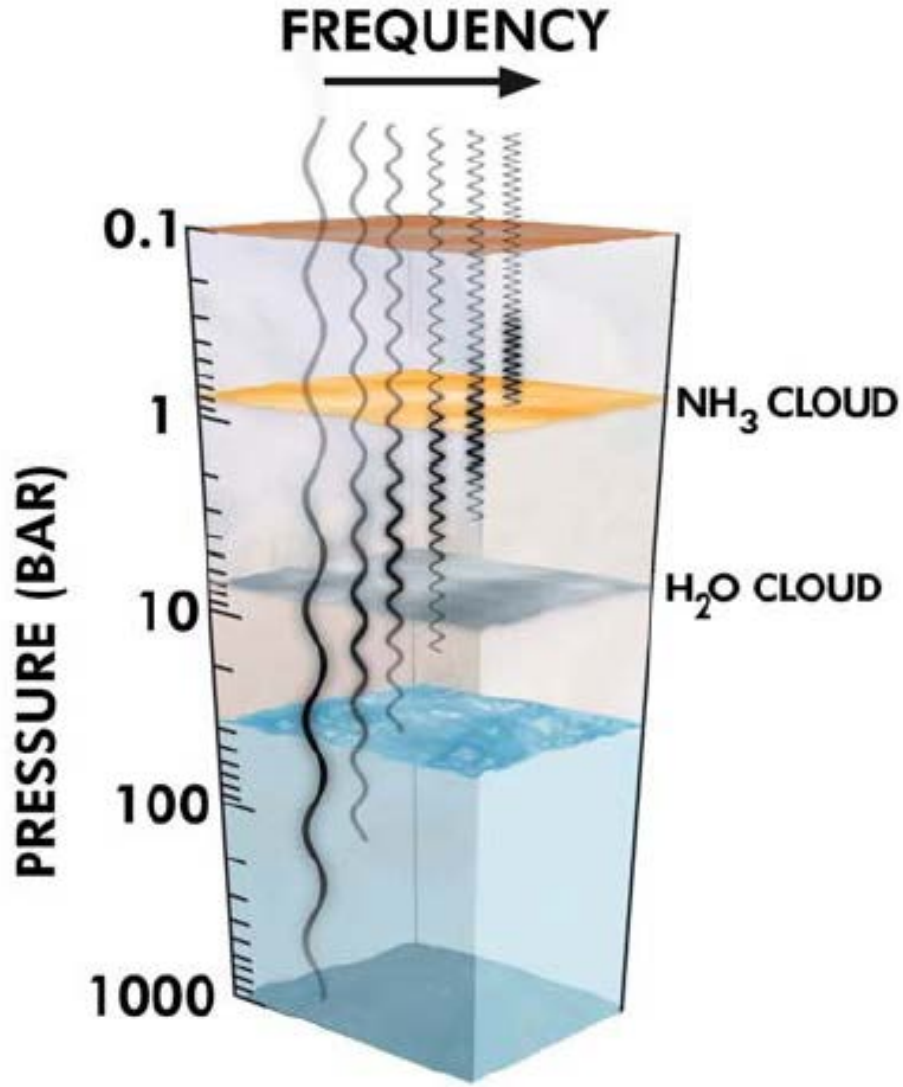


Microwave Radiometry

Radiometry sounds atmosphere to 1000 bar depth

Determines water and ammonia global abundances

6 wavelengths between 1.3 and 50 cm

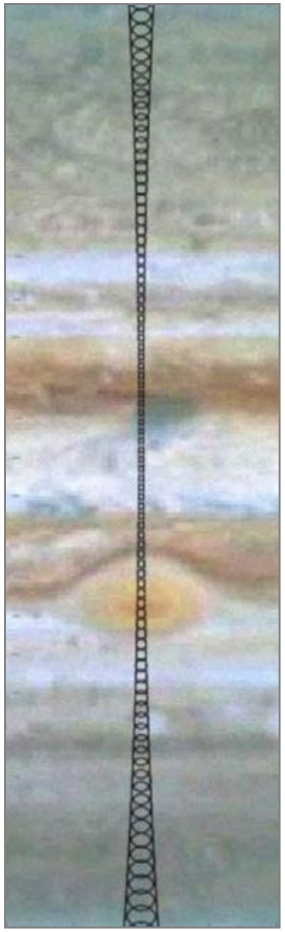


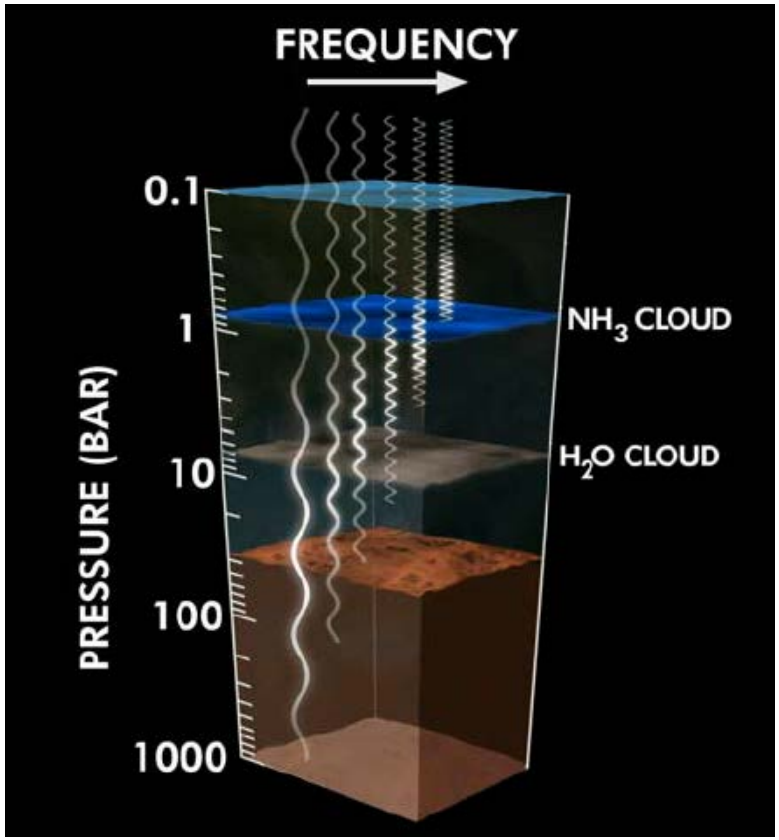
Sensing the deep atmosphere of Jupiter

Juno's Microwave Radiometer measures thermal radiation from the atmosphere

1000 atmospheres pressure (~500-600km below the visible cloud tops).

Determines water and ammonia abundances in the atmosphere all over the planet



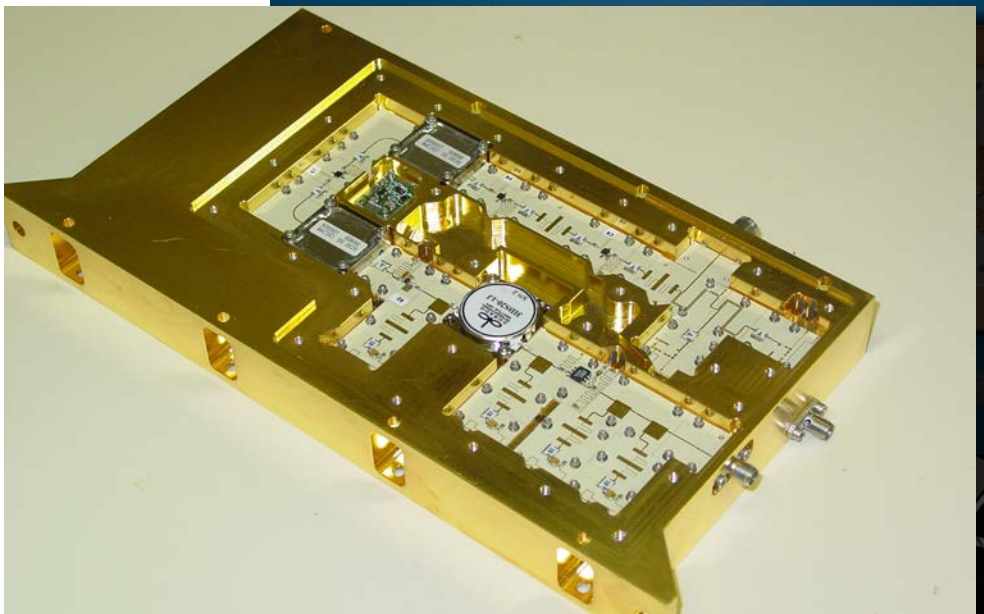


Synchrotron radio emission from the radiation belts makes this kind of measurement impossible from far away on Earth

Juno Microwave Radiometers

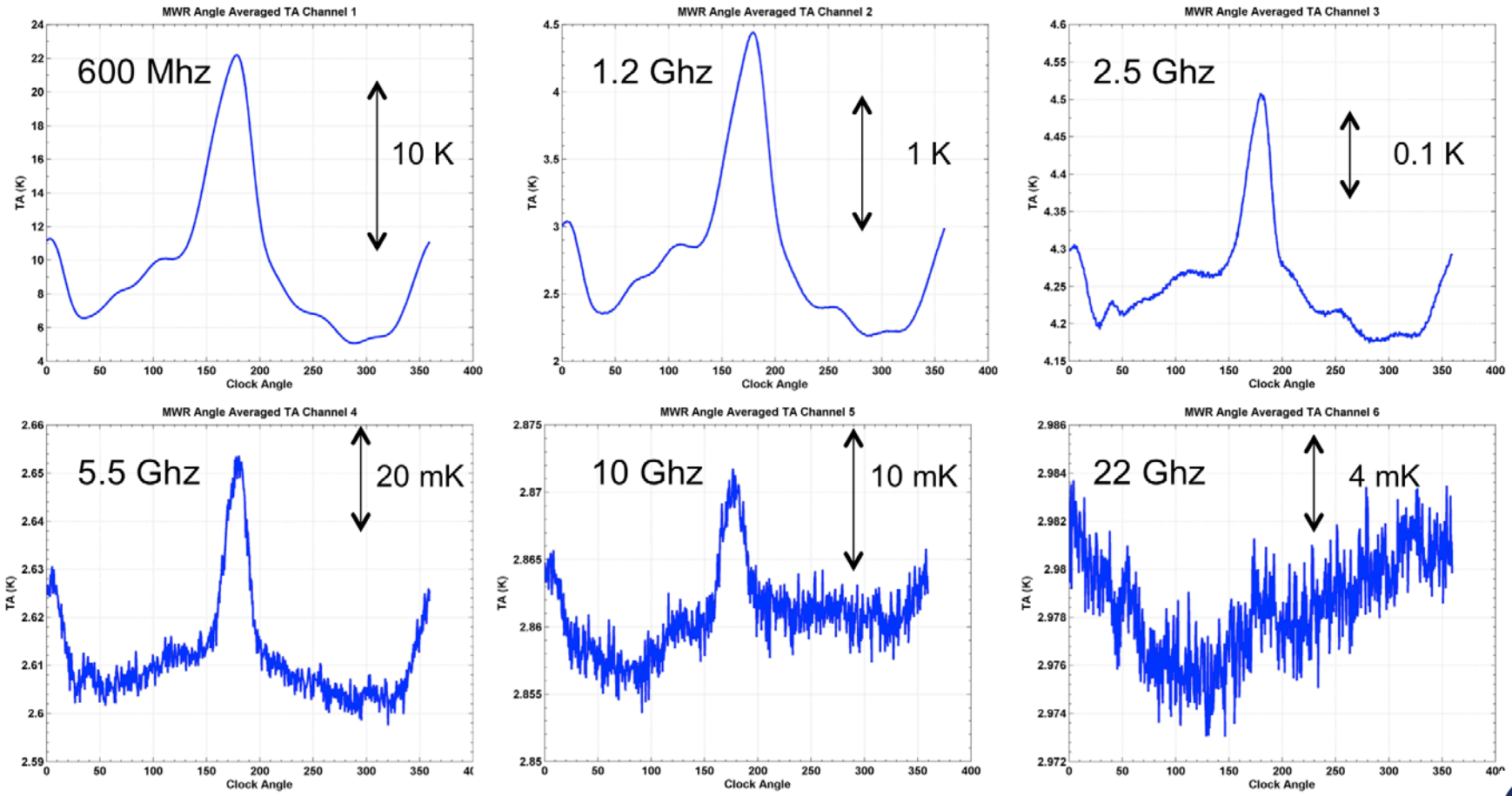
- The Juno mission required a multi-channel radiometer to probe the jovian atmosphere and measure water/ammonia mixing
  - 6 channels between 500 MHz and 22 GHz were required with a 3 year instrument development time-> enabled by the availability of chipsets at these bands

Launched August 2011



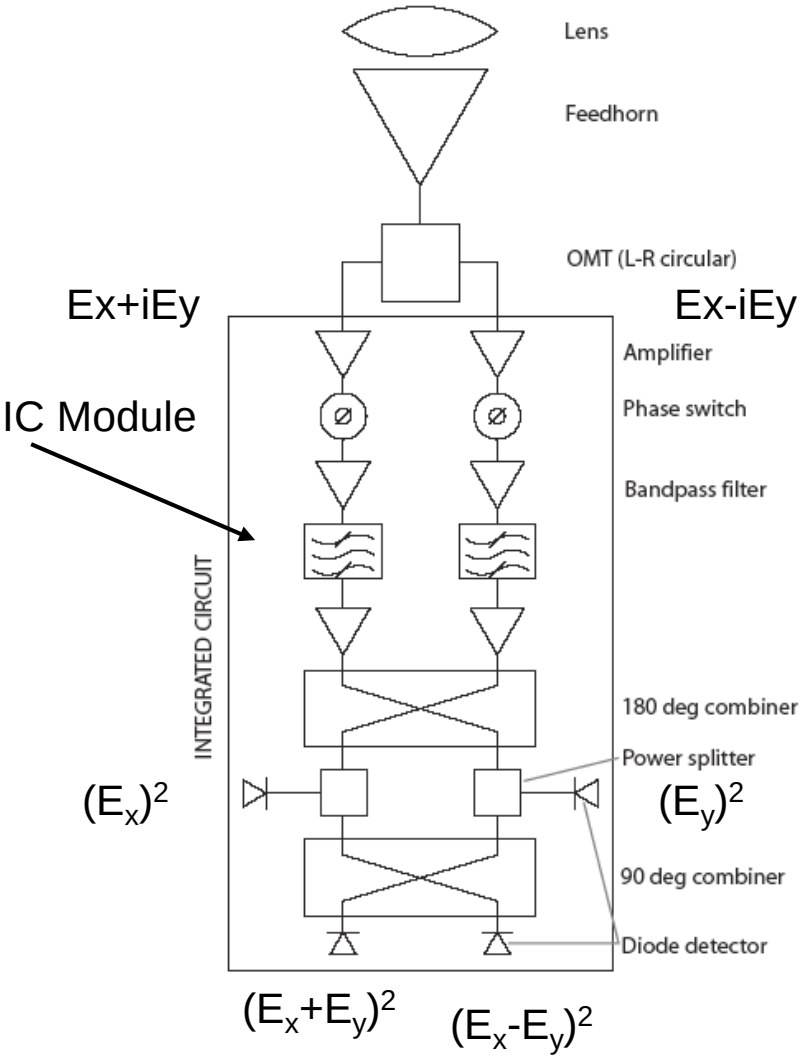
Sky Mapping with Juno

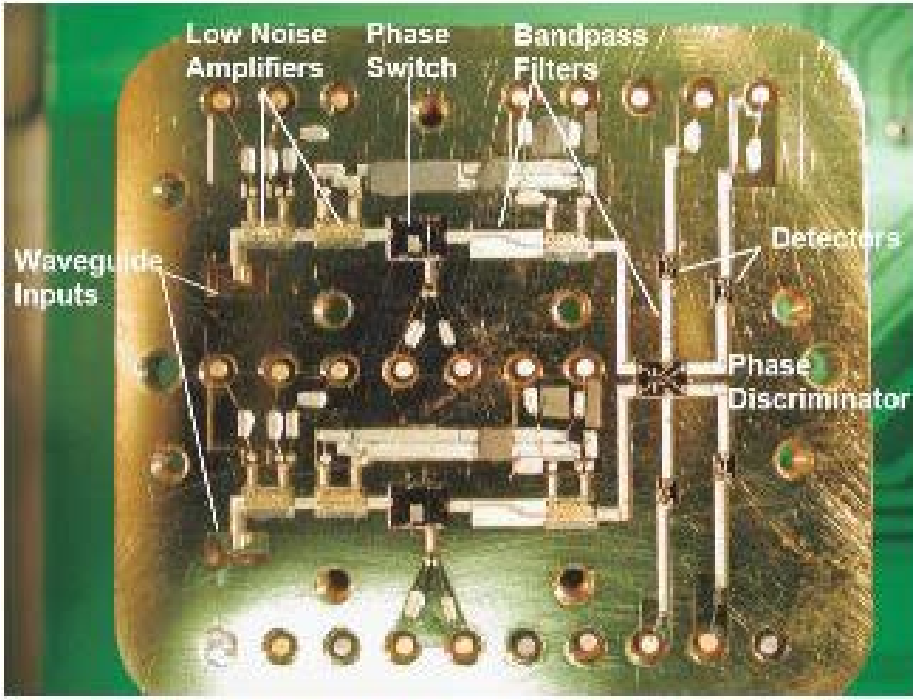
Sky scan averaged over S/C rotation for data taken in Nov-Dec 2011



Courtesy M Janssen, S Brown

90 GHz Pseudocorrelation Receiver
Used technology developed for Planck





T_{sys}=~60K at cryo temps

Receiver Arrays

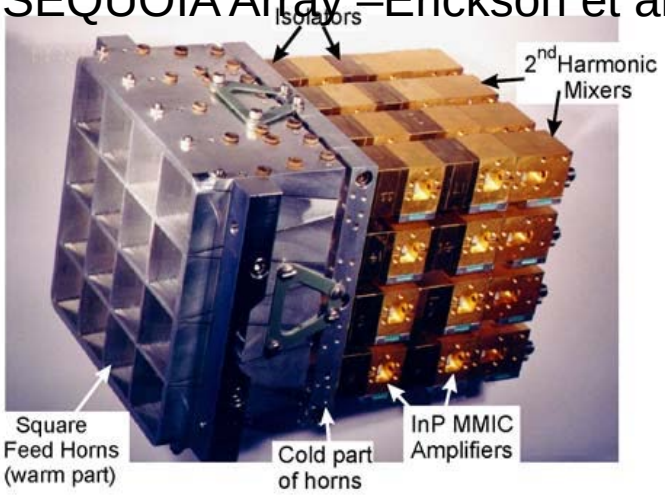
- LNAs operate above 4K
- MMICs lend themselves to higher order integration (MCMs) and arrays
- Broad instantaneous bandwidths without contribution of IF noise

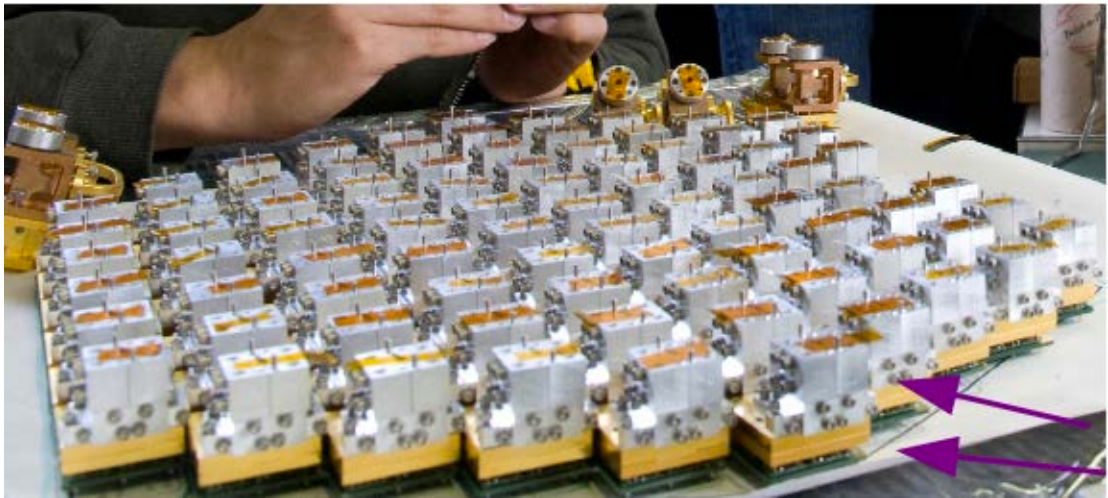
FIRST SEASON QUIET OBSERVATIONS: MEASUREMENTS OF CMB POLARIZATION POWER SPECTRA AT 43 GHZ IN THE MULTIPOLE RANGE $25 \leq \ell \leq 475$

QUIET Collaboration—C. Bischoff[1,22], A. Brizius[1,2], I. Buder[1], Y. Chinone[3,4], K. Cleary[5], R. N. Dumoulin[6], A. Kusaka[1], R. Monsalve[7], S. K. Næss[8], L. B. Newburgh[6,23], R. Reeves[5], K. M. Smith[1,23], I. K. Wehus[9], J. A. Zuntz[10,11,12], J. T. L. Zwart[6], L. Bronfman[13], R. Bustos[7,13,14], S. E. Church[15], C. Dickinson[16], H. K. Eriksen[8,17], P. G. Ferreira[10], T. Gaier[18], J. O. Gundersen[7], M. Hasegawa[3], M. Hazumi[3], K. M. Huffenberger[7], M. E. Jones[10], P. Kangaslahti[18], D. J. Kapner[1,24], C. R. Lawrence[18], M. Limon[6], J. May[13], J. J. McMahon[19], A. D. Miller[6], H. Nguyen[20], G. W. Nixon[21], T. J. Pearson[5], L. Piccirillo[16], S. J. E. Radford[5], A. C. S. Readhead[5], J. L. Richards[5], D. Samtleben[2,25], M. Seiffert[18], M. C. Shepherd[6], S. T. Staggs[21], O. Tajima[1,3], K. L. Thompson[15], K. Vanderlinde[1,26], R. Williamson[6,27], B. Winstein[1]

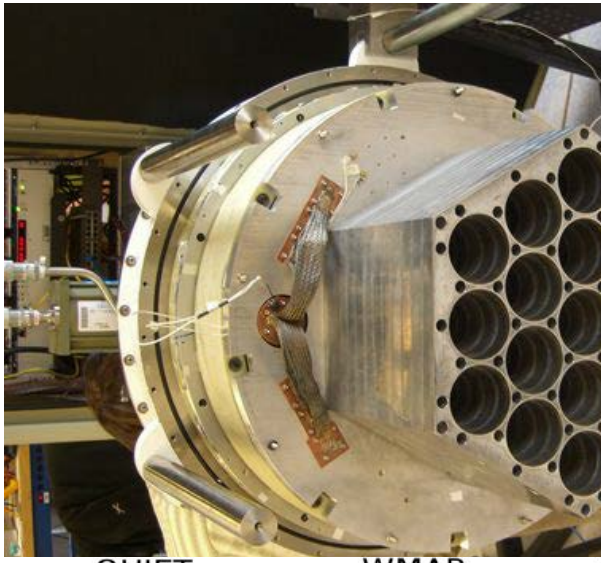
Submitted to ApJ—This paper should be cited as "QUIET (2010)"

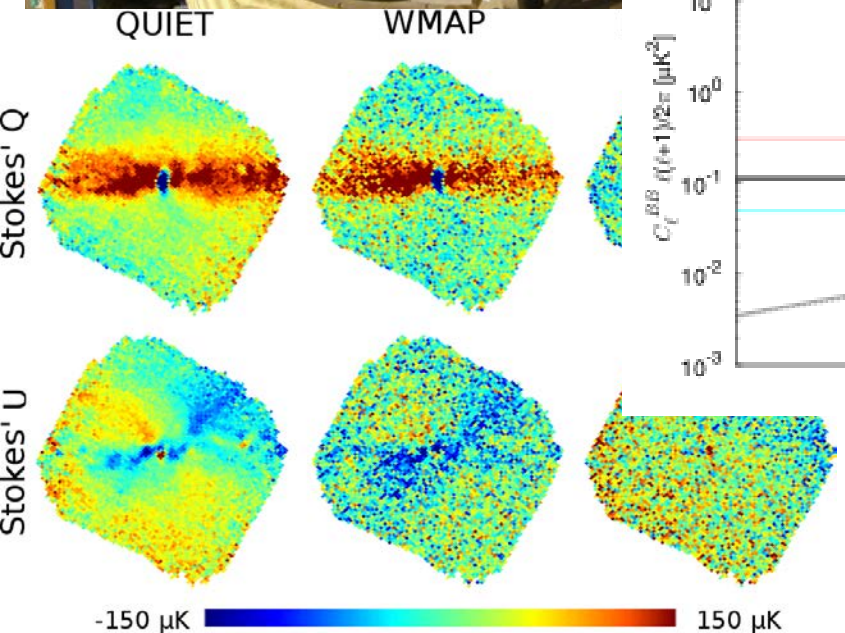
SEQUOIA Array –Erickson et al

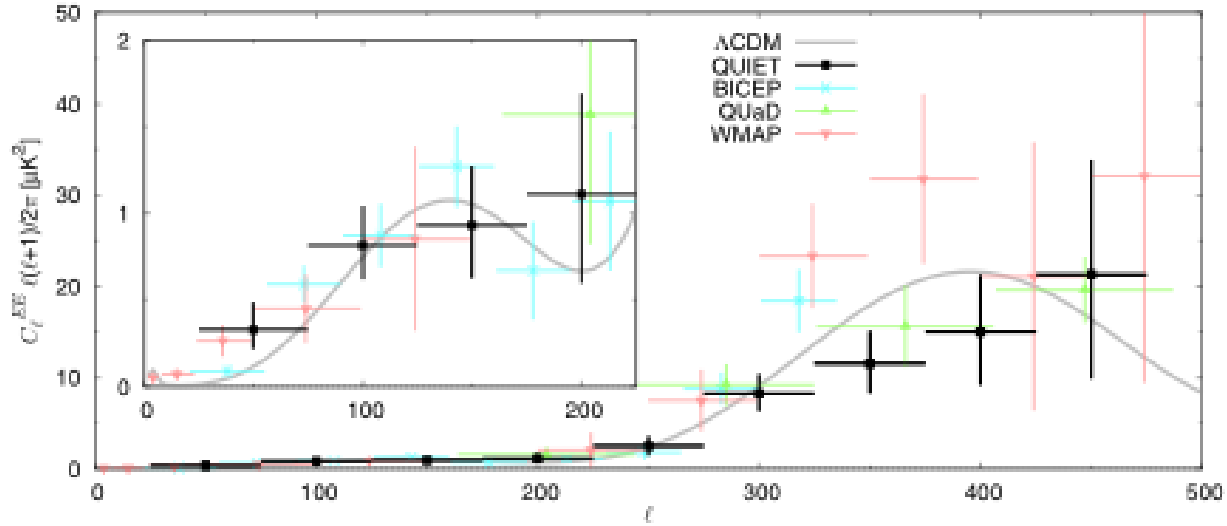


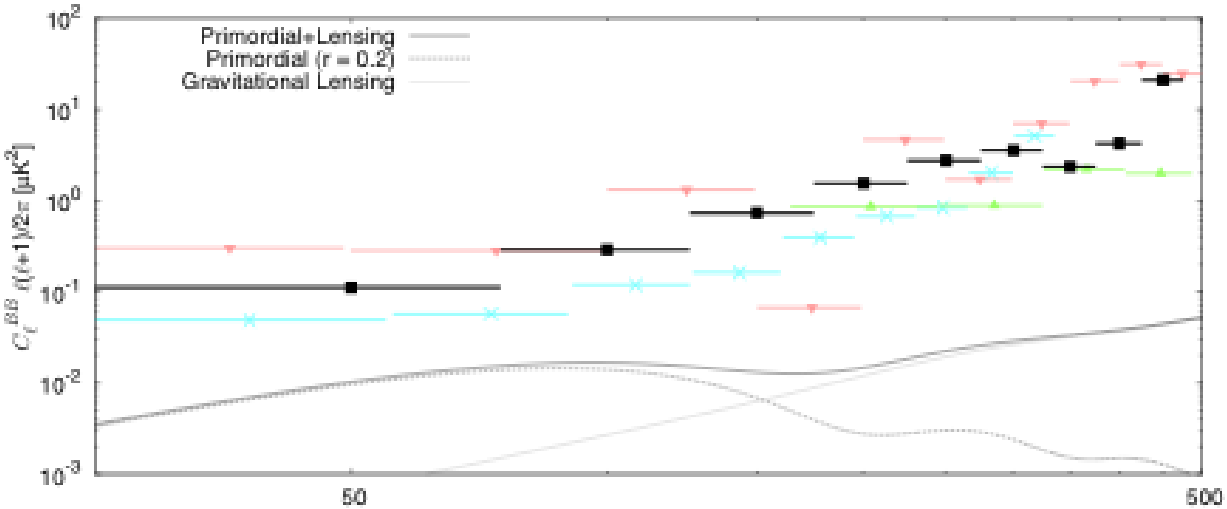


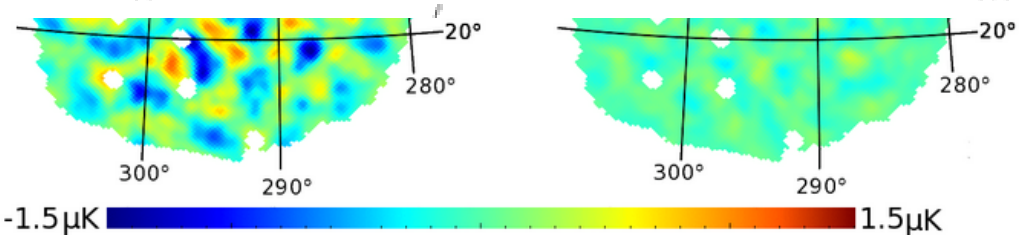
QUIET 43 GHz Result









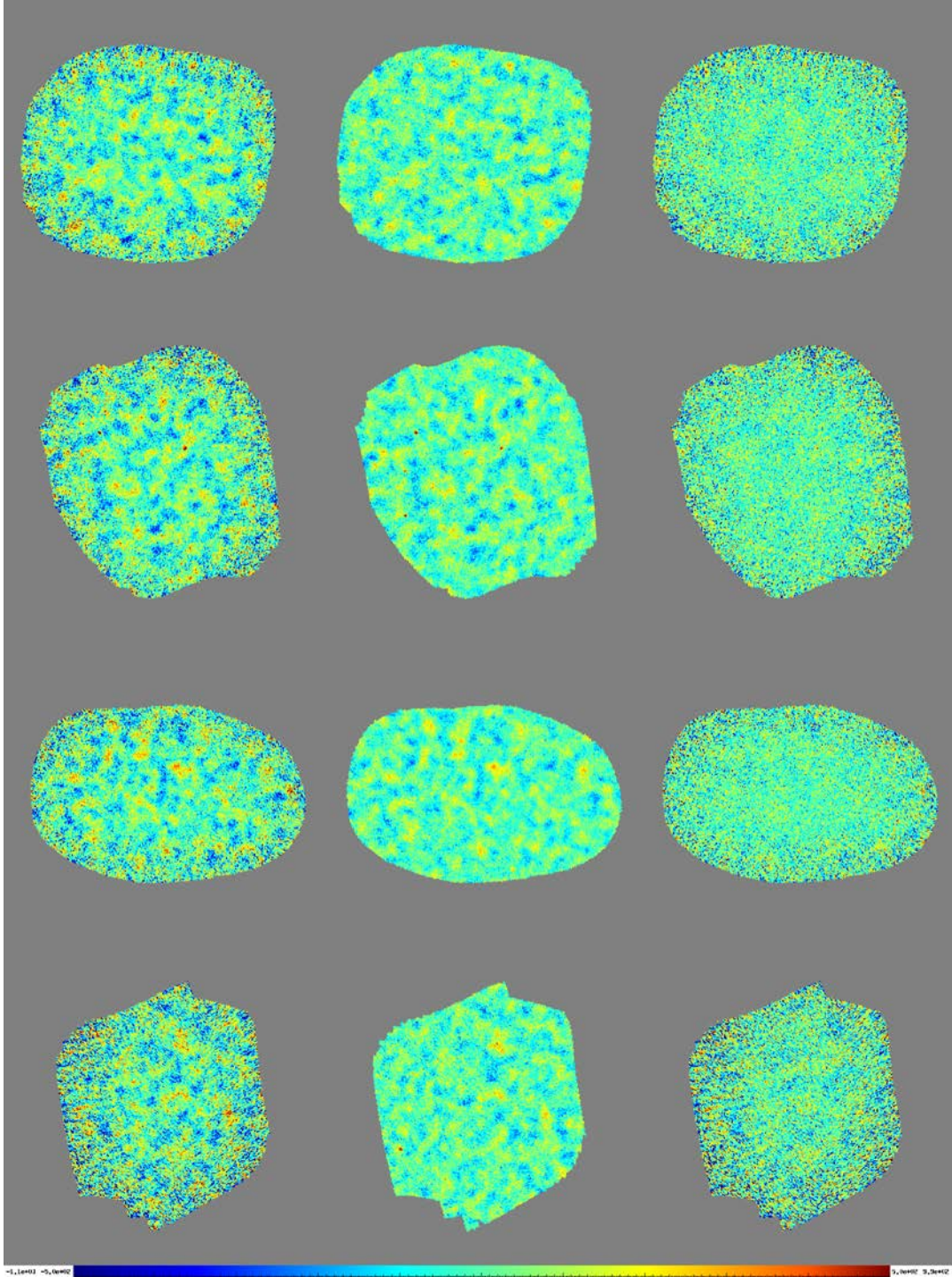


QUIET 90 GHz Preliminary Science

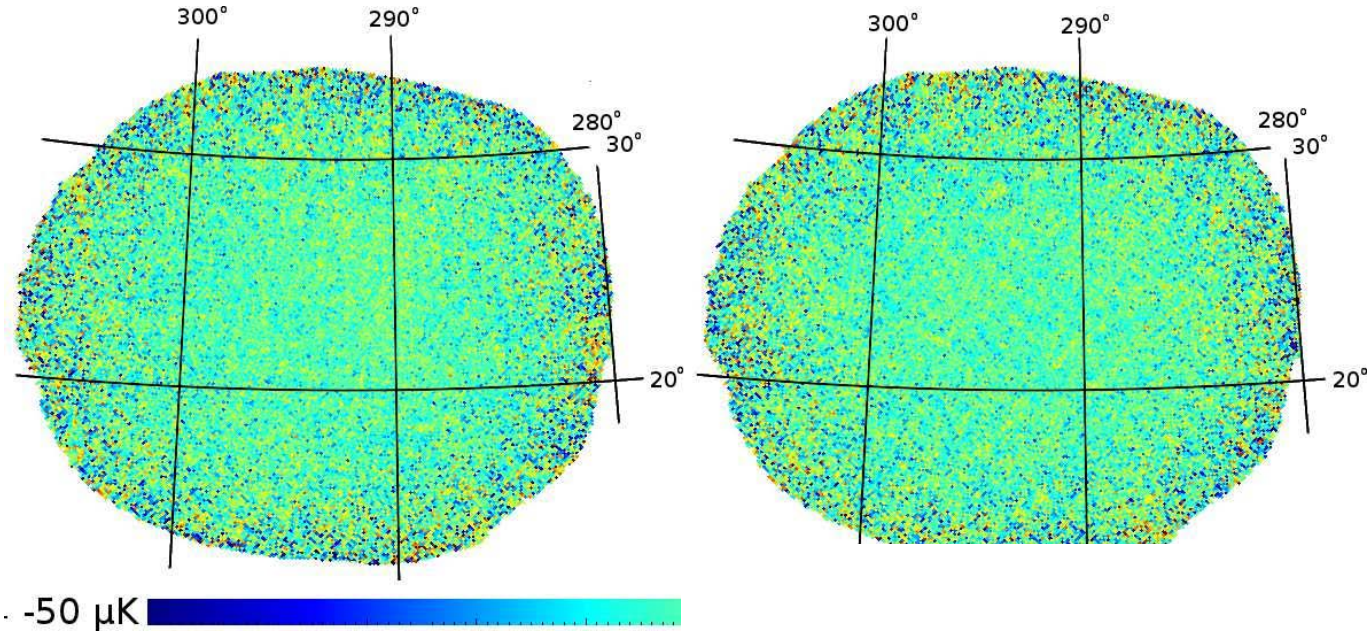
Preliminary TT results with just a few temperature pixels and 1 year obs

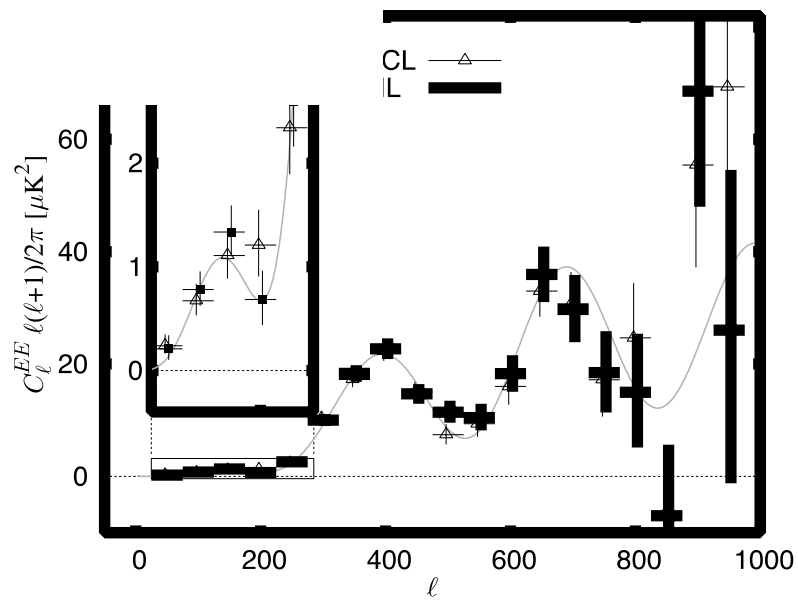
Blind analysis including calibration

There are 10 times as many polarization detectors

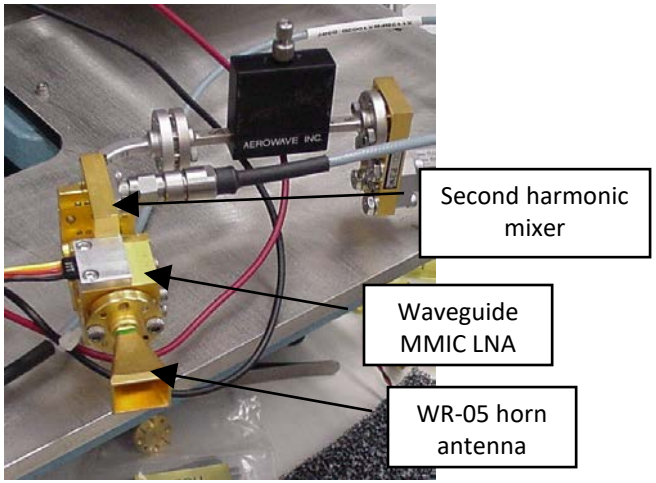


QUIET 90 GHz Results

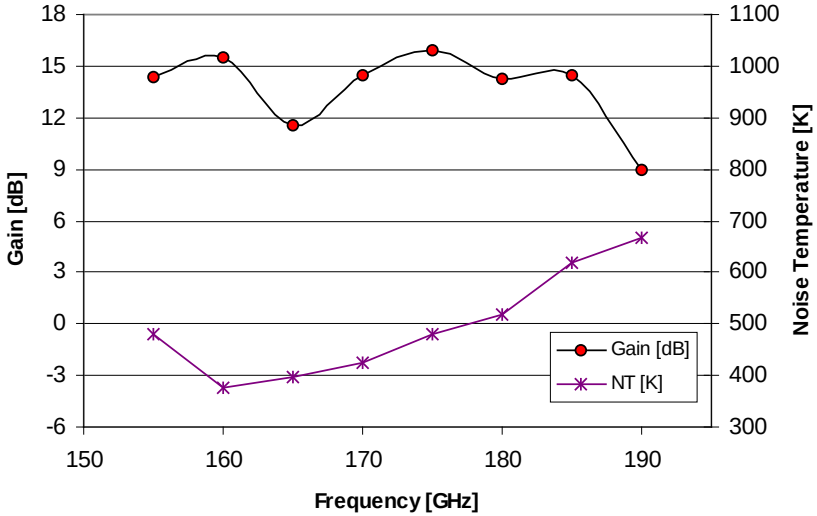


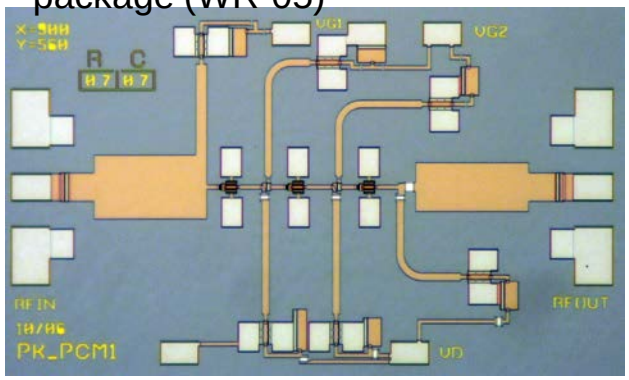


180 GHz LNA Development



Room temperature testing of the MMIC LNA in waveguide package (WR-05)





The MMIC LNA designed at JPL and processed by Northrop Grumman using their 35 nm InP technology

Measured results for the waveguide MMIC LNA. The noise is less than 500K from 165-180 GHz, a factor of two improvement

Courtesy P Kangaslahti

HAMSR Microwave Sounder on Global Hawk

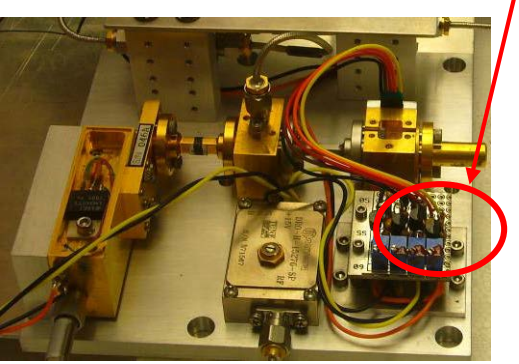
Monitor real-time evolution of tropical cyclones

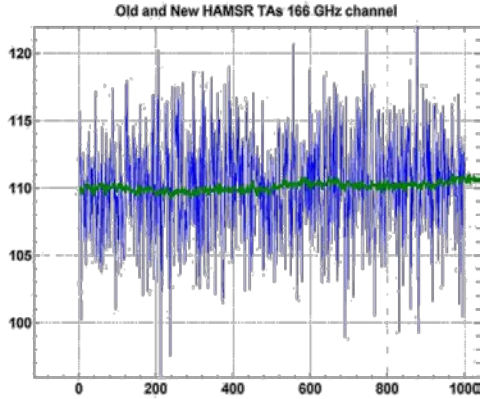
Thermodynamic and convective structure

Risk reduction for decadal-survey "PATH" mission

New receiver technology

- **183 GHz receiver upgraded with LNA developed under ESTO/ACT**
- **Noise reduced by an order of magnitude**
- **Defines new state-of-the art**

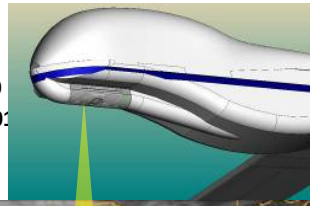


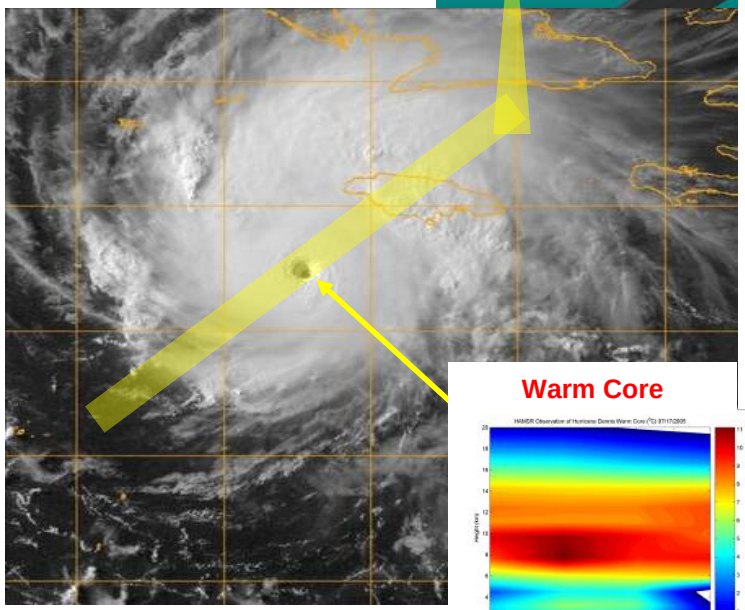


Noise reduced from 2 K to 0.2 K

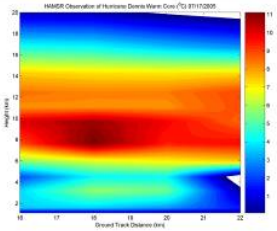
HAMSR on Global Hawk

- **Funded under AITT**
- **Ready for test flights fall 2009**
- **Ready for field deployment 201**



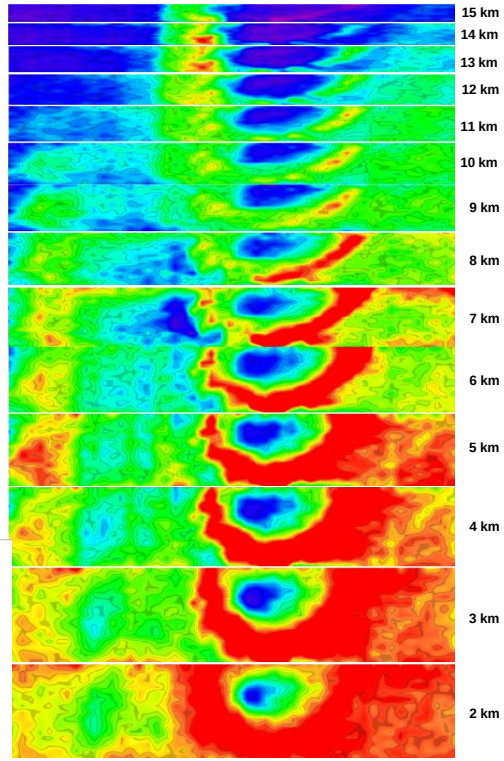


Warm Core



New science/algorithms

- **Radar-like observations**
- **3D structure of convection**
- **Enables new investigations**



3D reflectivity, Hurricane Emily (2005)

http://hamsr.jpl.nasa.gov

Background

PATH is one of 15 NASA "decadal-survey" missions

"Precipitation and All-weather Temperature and Humidity"

First *microwave sensor* in geostationary orbit

Weather & climate observations: *clouds, storms & hurricanes*

Improve models* re. the hydrologic cycle ⇒ *Improved forecasts

Improve *hurricane intensity* forecasts

GeoSTAR is the nominal sensor for PATH

"Geostationary Synthetic Thinned Aperture Radiometer"

GeoSTAR is the *first* microwave sounder for GEO

***New instrument concept* has developed/demo'd at JPL**

We have developed new cutting-edge *technology*

We are ready to proceed to a *space mission*

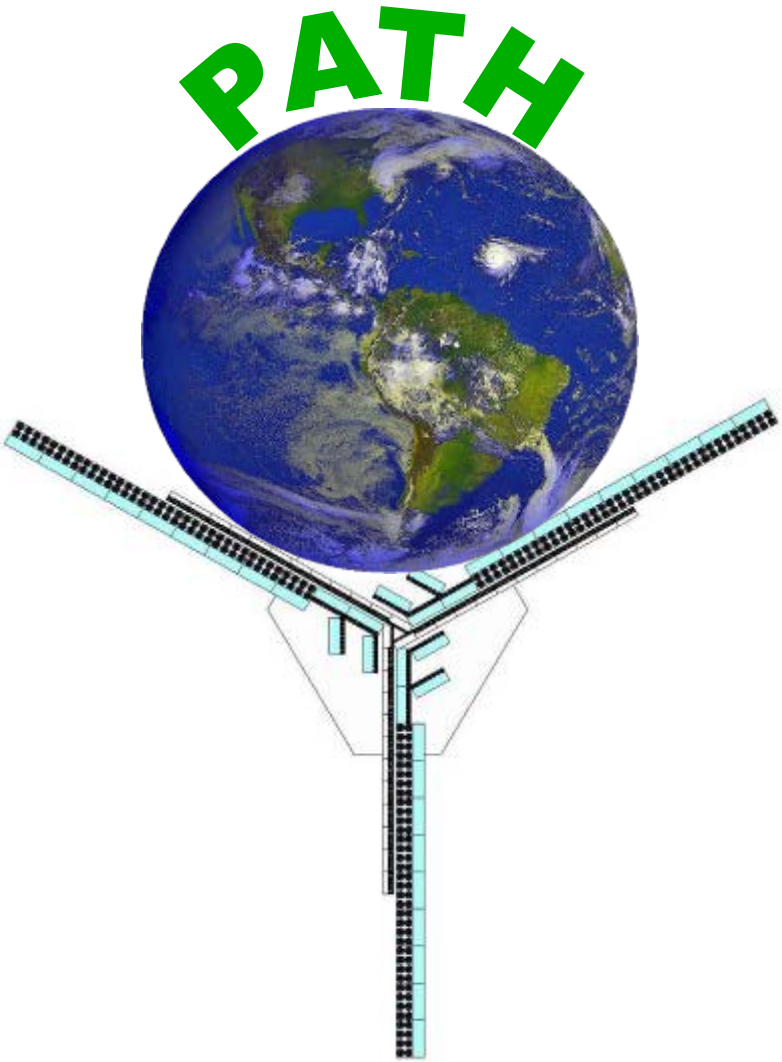
GeoSTAR is the only known "MW array spectrometer" design

This IIP will reduce PATH/GeoSTAR technology risk

Builds on previous GeoSTAR IIP-02

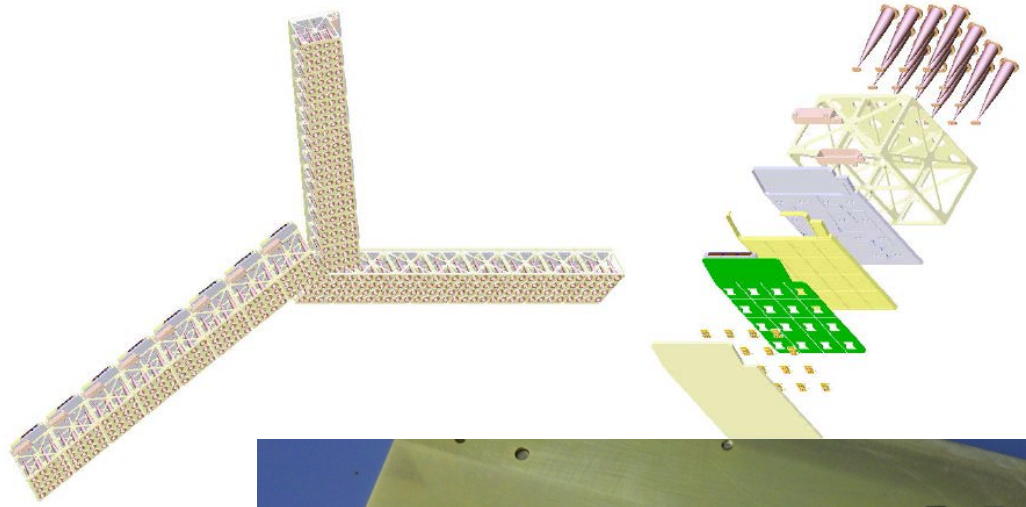
Focuses on most challenging remaining technology items

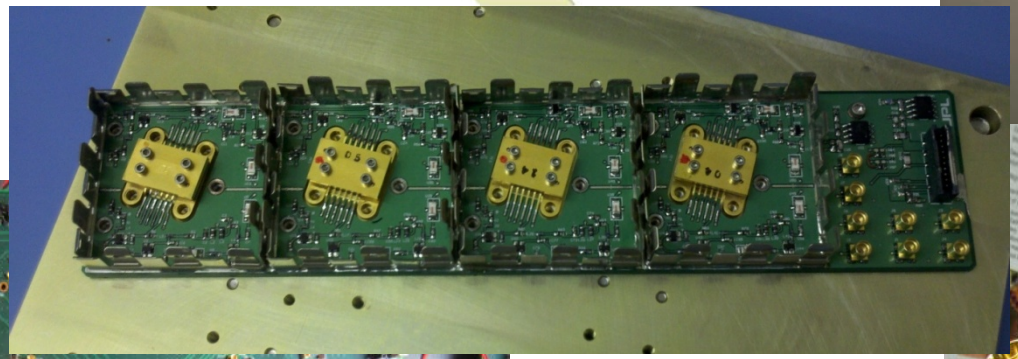
Positions GeoSTAR for fast-track PATH mission development

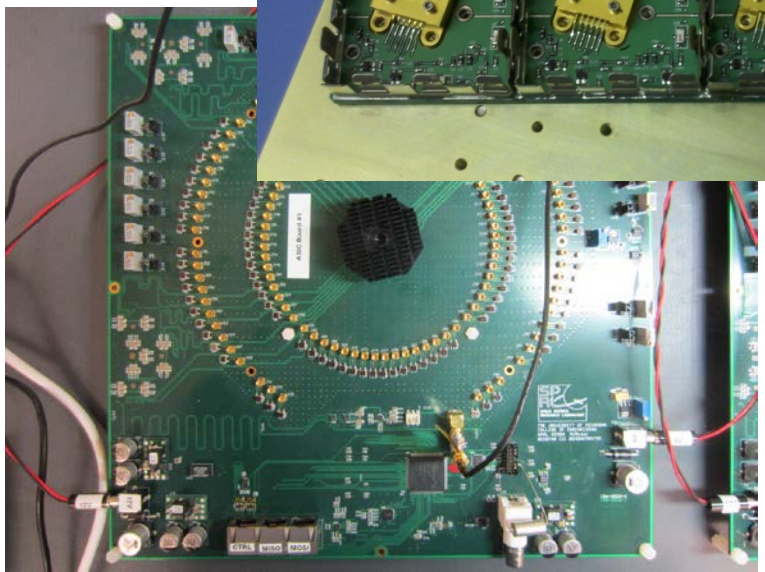


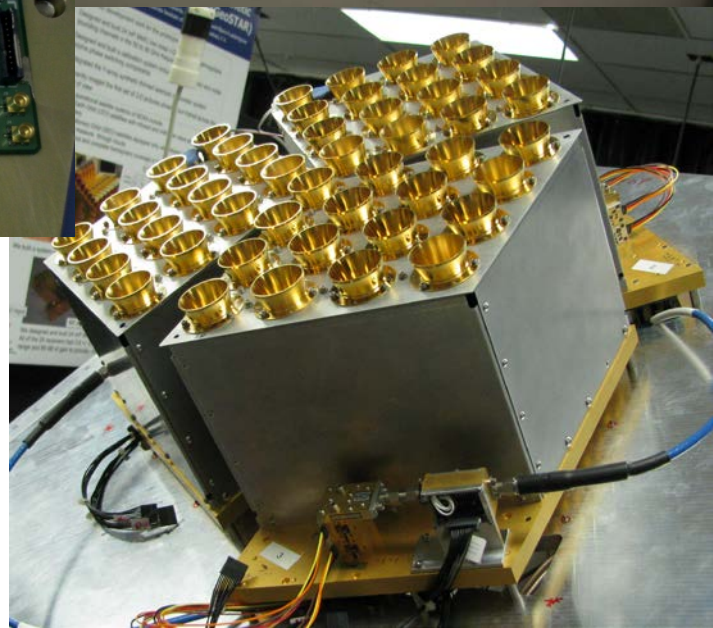
GeoSTAR Technology

>300 Receivers at 180 GHz and 60 GHz







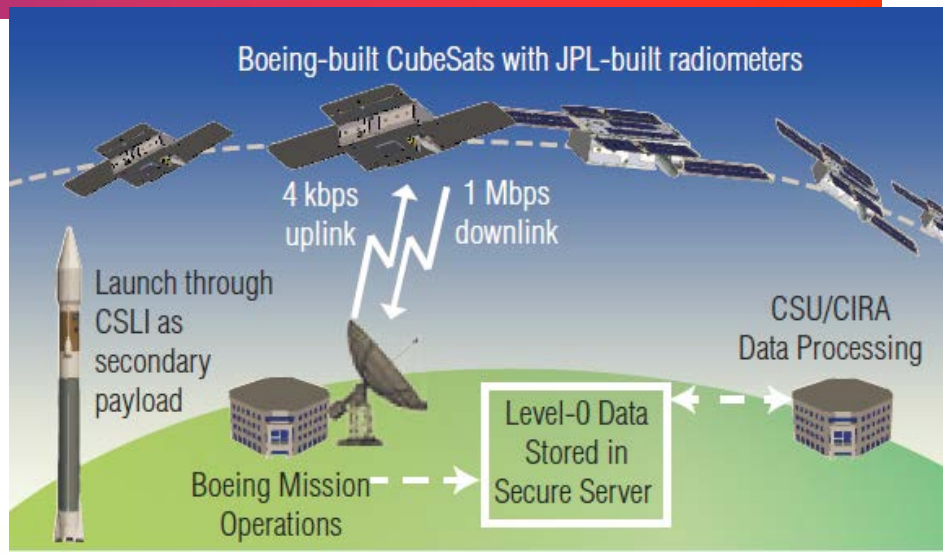


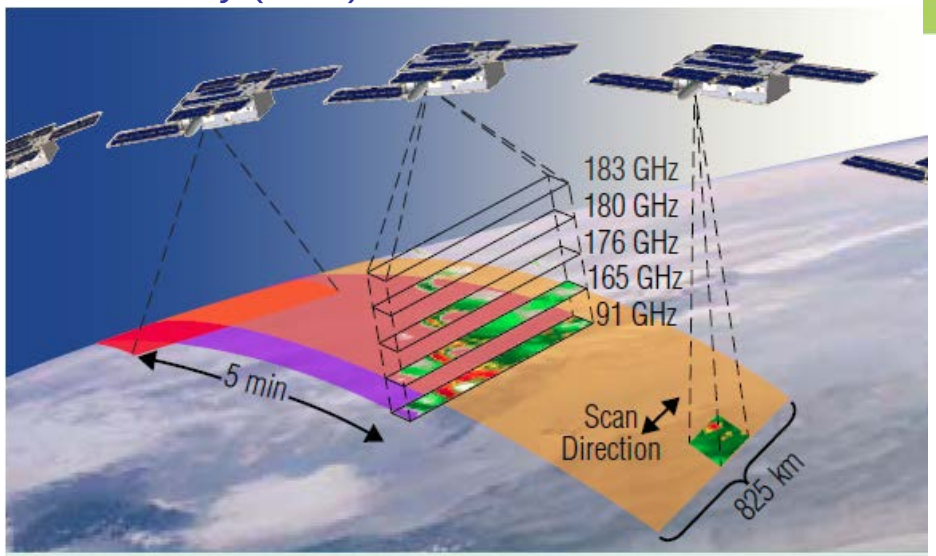
GeoSTAR-III Performance

Temporal Experiment for Storms and Tropical Systems (TEMPEST)

BENEFITS AND STRENGTHS

- First global observations of time evolution of precipitation
- Low-cost approach using 6U-Class satellites
- Unique data sets to enable improved weather and climate prediction models
- Significant impacts on agricultural forecasting, forest management and disaster preparedness
- Experienced collaborative team: Colorado State University (CSU), Caltech JPL and BCT





5 identical 6U CubeSats, each with an identical 5-channel radiometer, flying 5 minutes apart

IMPORTANCE TO NASA

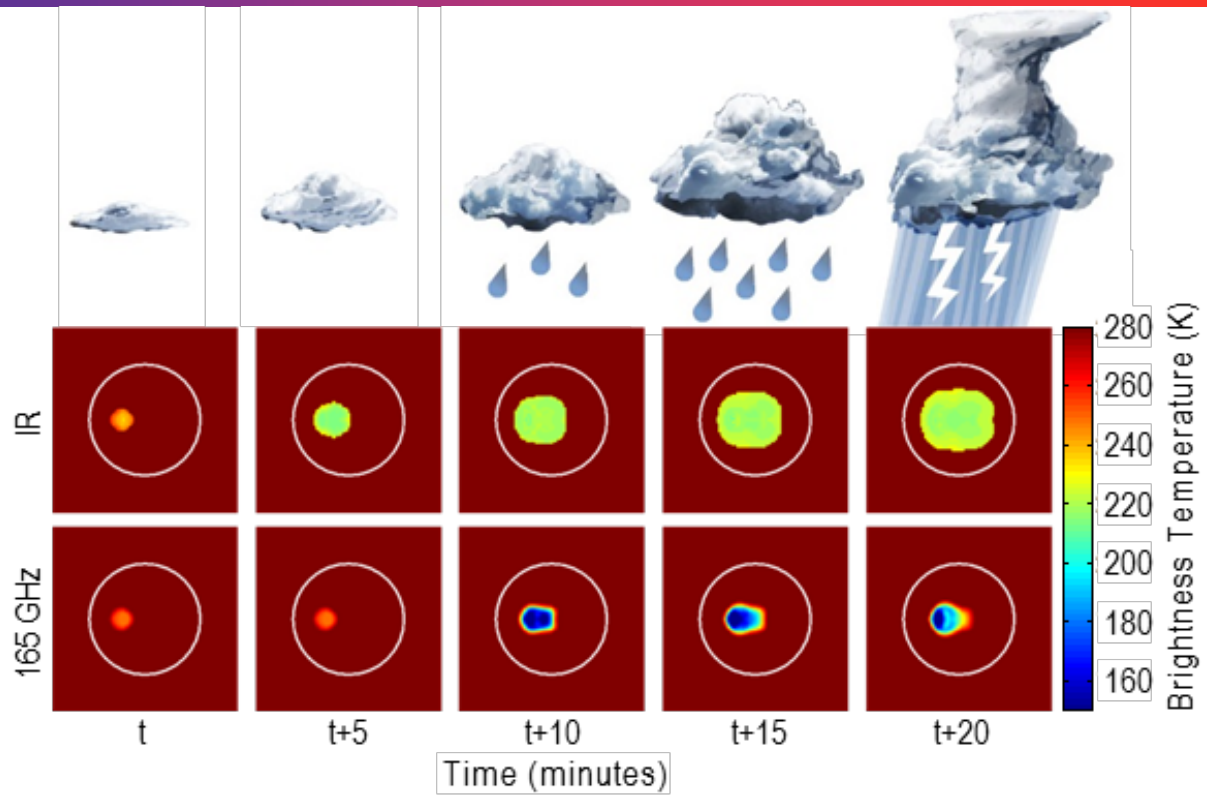
- Constrain climate models through better understanding of cloud processes, the transition from clouds to precipitation and impact on Earth's energy balance
- Provide the first characterization of the temporal variability of precipitation on a global scale to enable greater understanding of the water cycle
- Complement GPM and CYGNSS by providing a temporal context of clouds and precipitation

Observations of Transition from Clouds to Precipitation

Temporal evolution of convective system

Infrared Brightness Temperature

Millimeter-wave Brightness Temperature



The transition from clouds to precipitation is apparent at TEMPEST millimeter-wave frequencies. When observing every 5 minutes of temporal evolution of a convective system, infrared brightness temperatures show cold cloud top temperatures but do not penetrate into the cloud. Millimeter-wave brightness temperatures at 165 GHz penetrate into the clouds and detect the transition to precipitation. The largest TEMPEST spatial resolution is shown as 25-km circles.

Career Messages

- Planning is essential… plans are useless
  - Remain flexible throughout your career
- Whenever possible, surround yourself with talented people
  - JPL is ideally suited
- Networking will always pay dividends: Conferences, review panels, organizing committees, papers etc-success is both internal and external
- Sometimes there is no substitute for hard work- affects team perceptions
- Be patient with the bureaucracy, but be prepared to fight it when it prevents you from doing your job (choose your battles carefully)
- Ignore the noise