GeoSTAR
A New Approach for a Geostationary Microwave Sounder

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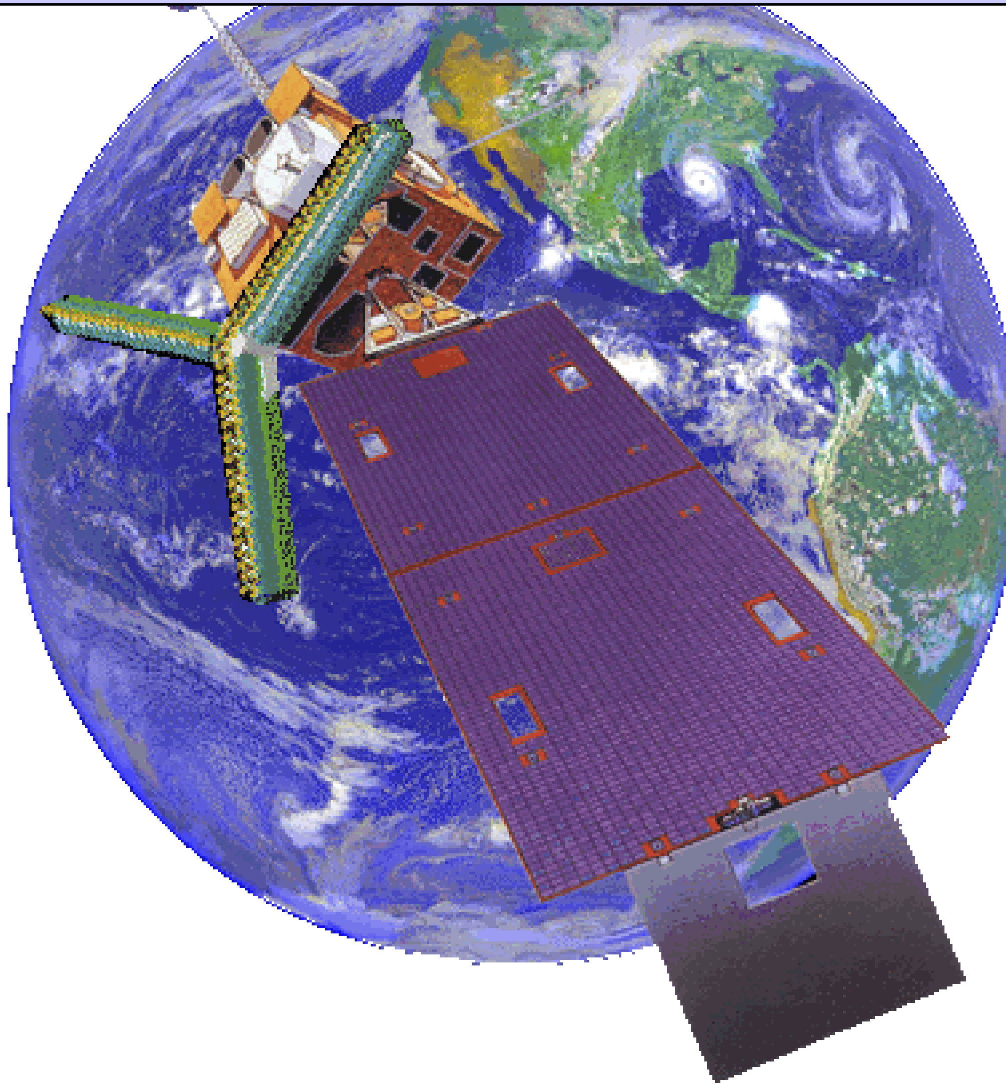

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Credits

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Summary

- **GeoSTAR is a microwave sounder intended for GEO deployment**
  - Also suitable for MEO
- **Functionally equivalent to AMSU**
  - Tropospheric T-sounding @ 50 GHz with ≤ 50 km resolution
    - Primary usage: Cloud clearing of IR sounder
    - Secondary usage: Stand-alone soundings
  - Tropospheric q-sounding @ 183 GHz with ≤ 25 km resolution
    - Primary usage: Rain mapping
    - Secondary usage: Stand-alone soundings
- **Using *Aperture Synthesis***
  - Also called Synthetic Thinned Array Radiometer (STAR)
  - Also called Synthetic Aperture Microwave Sounder (SAMS)

Why?

- **GEO sounders complement LEO sounders**
  - LEO: Global coverage, but poor temporal resolution; high spatial res. is easy
  - GEO: High temporal resolution and coverage, but only hemispheric non-polar coverage; high spatial res. is hard
  - Requires equivalent measurement capabilities as now in LEO: IR + MW
- **Enable full sounding capability from GEO**
  - Complement primary IR sounder with matching MW sounder
    - Until now not feasible due to very large aperture required (~ 4-5 m dia.)
  - Microwave provides cloud clearing information
    - Requires T-sounding through clouds
    - Must reach surface under all atmospheric conditions
- **Stand-alone IR sounders are only marginally useful**
  - Can sound down to cloud tops (“clear channels”)
  - Can sound in clear areas (“hole hunting”)
    - Clear scenes make up < 2% globally at AMSU resolution (50 km)
    - As clear criteria are relaxed, retrieval errors grow
  - Both exclude active-weather regions & conditions
    - In particular: The all-important boundary layer is poorly covered

Functionality & Benefits of GeoSTAR

- **Soundings**
  - Full hemisphere @ ≤ 50/25 km every 30-60 min (continuous) - initially, but easily improved
  - Cloudy & clear conditions
  - Complements any GOES IR sounder
  - Enables full soundings to surface under cloudy conditions
- **Rain**
  - Full hemisphere @ ≤ 25 km every 30 min (continuous) - initially, but easily improved
  - Measurements: scattering from ice caused by precipitating cells
  - Real time: full hemispheric snapshot every 30 minutes or less
- **Synthetic aperture approach**
  - Feasible way to get adequate spatial resolution from GEO
  - Easily expandable: aperture size, channels -> Adaptable to changing needs
  - Easily accommodated: sparse array -> Can share real estate with other subsystems
  - Above all: *No moving parts* -> Minimal impact on host platform & other systems

Background

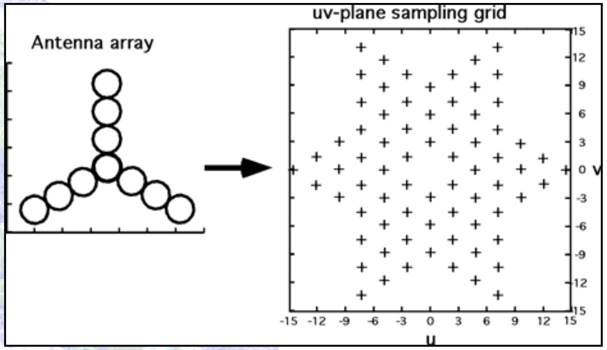
- **GeoSTAR based on GEO/SAMS (1999):**

  One of 4 innovative concepts selected for NMP/EO-3 Study

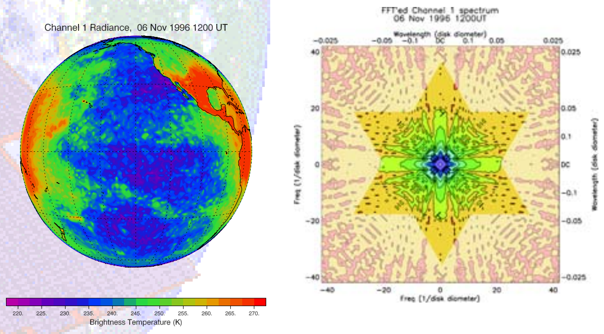
  Medium-scale space demo @ 50 GHz, T-sounding only
  - Phase A completed (cost $0.75M) - 9/99
  - Projected mission cost: $87M (with reserves)
  - Projected payload development cost: $36M (with reserves)
  - Not selected for implementation (GIFTS selected instead)
- **Proto-GeoSTAR: Ground demo now being developed**
  - Sponsored by NASA’s Instrument Incubator Program (IIP)
  - Similar to GEO/SAMS: small-scale proof-of-concept *ground demo* @ 50 GHz
  - Projected cost: ~$3M
  - JPL teaming with GSFC (Piepmeier) & U. Mich. (Ruf)

GeoSTAR System Concept

- **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, 3λ wide (2 cm @ 50 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



Receiver array ➔ Resulting uv samples



Example: AMSU-A ch. 1

Aperture Synthesis Is Not New

Very Large Array (VLA) at National Radio Astronomy Observatory (NRAO)

In operation for many years

Others Are Developing STAR for Space

ESA's Soil Moisture and Ocean Salinity (SMOS)

L-band system under development - Launch in 2006-2008

What GeoSTAR Measures

- **Visibility measurements**
  - Essentially the same as the spatial Fourier transform of the radiometric field
  - Measured at fixed uv-plane sampling points - One point for each pair of receivers
  - Both components (Re, Im) of complex visibilities measured
  - Visibility = Cross-correlation = Digital 1-bit multiplications @ 100 MHz
  - Visibilities are accumulated over calibration cycles —> Low data rate
- **Calibration measurements**
  - Multiple sources and combinations
  - Measured every 20-30 seconds = calibration cycle
- **Interferometric imaging**
  - All visibilities are measured simultaneously - On-board massively parallel process
  - Accumulated on ground over several minutes, to achieve desired NEDT
  - 2-D Fourier transform of 2-D radiometric image is formed - *without scanning*
- **Spectral coverage**
  - Spectral channels are measured one at a time - LO tunes system to each channel

Calibration

- **GeoSTAR is an *interferometric* system**
  - Therefore, *phase calibration* is most important
  - System is designed to maintain phase stability for tens of seconds to minutes
  - Phase properties are monitored beyond stability period (e.g., every 20 seconds)
- **Multiple calibration methods**
  - Common noise signal distributed to multiple receivers —> complete correlation
  - Random noise source in each receiver —> complete de-correlation
  - Environmental noise sources monitored (e.g., sun's transit, Earth's limb)
  - Occasional ground-beacon noise signal transmitted from fixed location
  - Other methods, as used in radio astronomy
- **Absolute radiometric calibration**
  - One conventional Dicke switched receiver measures "zero baseline visibility"
    - Same as Earth disk mean brightness temperature (Fourier offset)
  - Also: compare with equivalent AMSU observations during over/under-pass
  - The Earth mean brightness is highly stable, changing extremely slowly

GeoSTAR Data Processing

- **On-board measurements**
  - Instantaneous visibilities: high-speed cross-correlations
  - Accumulated visibilities: accumulated over calibration cycles
  - Calibration measurements
- **On-ground image reconstruction**
  - Apply phase calibration: Align calibration-cycle visibility subtotals
  - Accumulate aligned visibilities over longer period —> Calibrated visibility image
- **On-ground image reconstruction**
  - Inverse Fourier transform of visibility image, for each channel
  - Complexities due to non-perfect transfer functions are taken into account
- **On-ground geophysical retrievals**
  - Conventional approach
  - Applied at each radiometric-image grid point

Technology Development

- **MMIC receivers**
  - Required: Small (2 cm wide ‘slices’ @ 50 GHz), low power, low cost
  - Status: Receivers off-the-shelf @ < 100 GHz; Chips available up to 200 GHz
- **Correlator chips**
  - Required: Fast, low power, high density
  - Status: Real chips developed for IIP & GPM; Now 0.5 mW per 1-bit @ 100 MHz
- **Calibration**
  - Required: On-board, on-ground, post-process
  - Status: Will implement & demo GEO/SAMS design in Proto-GeoSTAR
- **System**
  - Required: Accurate image reconstruction (Brightness temps from correlations)
  - Status: Will demonstrate capability with Proto-GeoSTAR
- **Related efforts: Rapidly maturing approach & technology**
  - European L-band SMOS now in Phase B; to be launched ~2006-8
  - NASA X/K-band aircraft demo (LRR): candidate for GPM constellation
  - NASA technology development efforts (IIP, etc.); various stages of completion

GeoSTAR vs. Real-Aperture Approach

Feature	GeoSTAR	Real-Aperture
Aperture size	Any size	Limited
Scanning	No scanning	Mechanical scanning
Spatial coverage	Full disk	Limited
Spectral coverage	One array: one band	One antenna: all bands
Accommodation	Easy	Difficult
Power consumption	Now: high; Soon: med.	Moderate
Platform disturbance	None	High

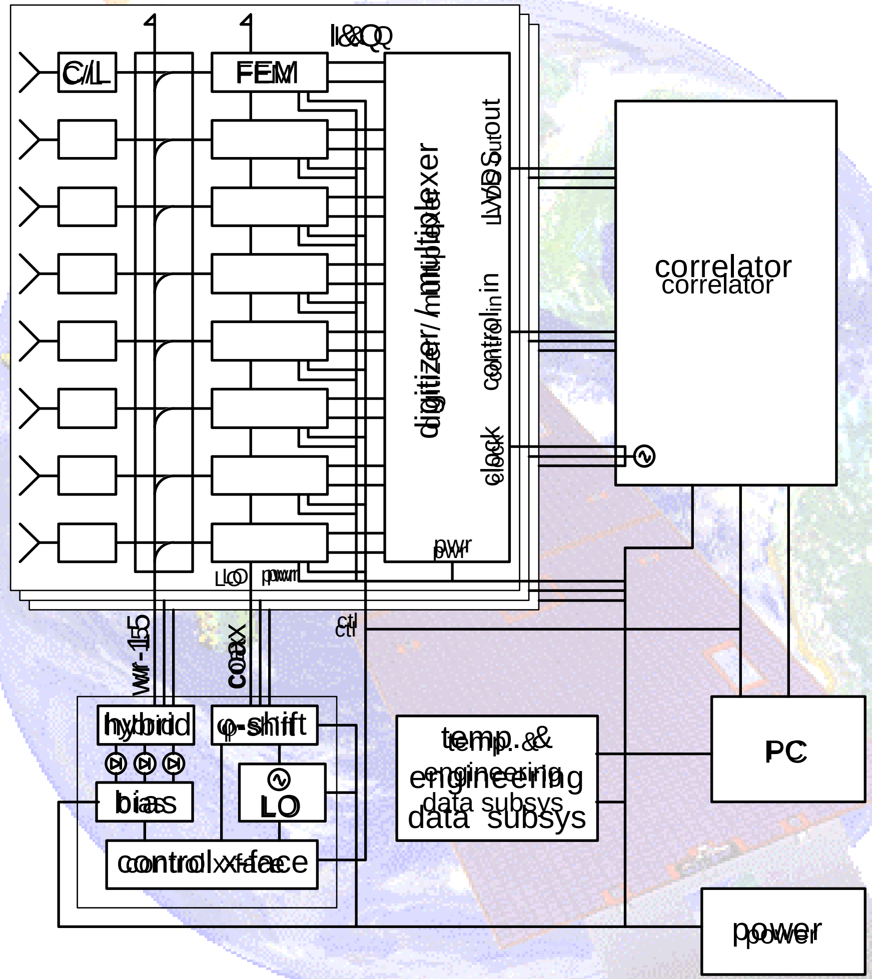
Science & Algorithms

- **Rain: New methodology @ sounder frequencies**
  - Requires 1 band @ 183 GHz; additional sounding bands are advantageous
  - Advantage: High freq. ⇒ High res. @ small aperture
  - Algorithms being developed for EOS Aqua/AIRS by Staelin (MIT)
  - Not yet mature - expect mature in ~ 1-2 yrs
  - Being considered to complement GPM
  - Measures snowfall as well as rain: unique capability
- **Soundings: Existing methodology**
  - Tropospheric T-sounding requires 1 band @ 50 GHz (4-5 AMSU channels)
  - Full T/q-sounding requires 2 bands @ 50 + 183 GHz (+ windows)
  - Use algorithms developed for AMSU
  - Mature - little further development needed

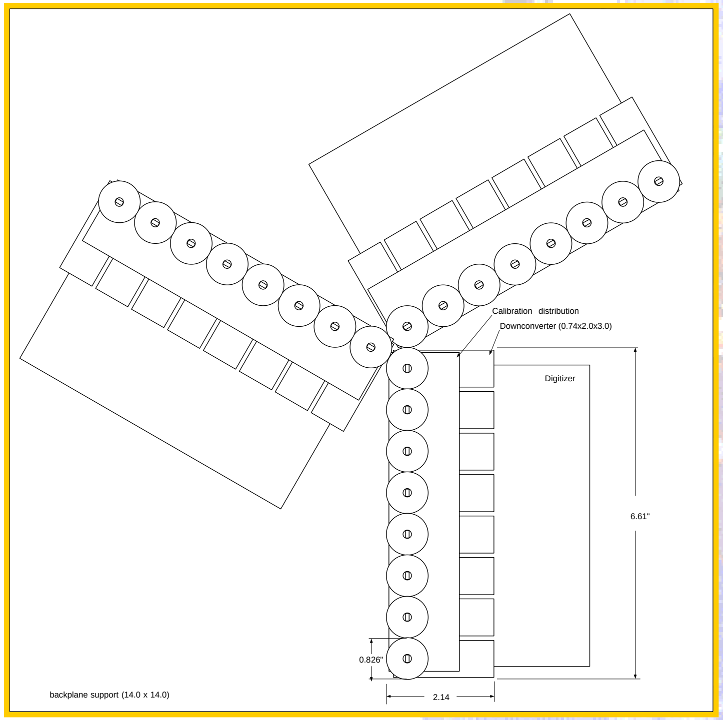
GeoSTAR Prototype Development

- **Objectives**
  - Technology risk reduction
  - Develop system to maturity and test performance
  - Evaluate calibration approach
  - Assess measurement accuracy
- **Small, ground-based**
  - 24 receiving elements - 8 (9) per Y-arm
  - Operating at 50-55 GHz
  - 4 tropospheric AMSU-A channels: 50.3 - 52.8 - 53.71/53.84 - 54.4 GHz
  - Implemented with miniature MMIC receivers
  - Element spacing as for GEO application (3 λ)
  - FPGA-based correlator
  - All calibration subsystems implemented

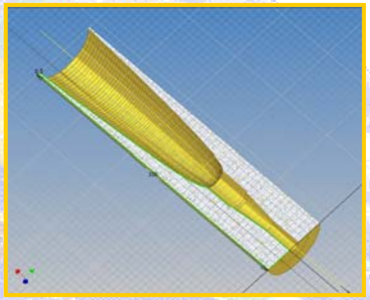
GeoSTAR Prototype Development



Proto-GeoSTAR Antenna Array



Y-Array of 24 Horns



Parabolic Potter Horn

Gold Plated Copper
Knife Edge (0.5 mm)
Waveguide transition to WR-15

Prototype 50-GHz Receiver

Calibration Error Budget

Individual errors causing equal contribution to overall image-NEDT of 1.0 K

Array size	delta-T $= T_{sys}/\sqrt{B\tau}$				
50x50	0.0076	0.32	0.19	1.7	0.17
200x200	0.0019	0.32	0.19	3.5	0.17

Additive noise needs to be smaller for larger arrays (same goes for null offsets).

Gain and phase tolerances are relaxed for larger spacings, so large arrays have ~ same requirements as small array.

Antenna pattern tolerances are not changed by array size.

Roadmap

- **Prototype: 2003-2006**
  - Functional system expected ready in < 1 year
  - Fully characterized in < 2 years
- **Further technology development: 2005-2008**
  - Develop efficient radiometer assembly & testing approach
  - Migrate correlator design & low-power technology to rad-hard ASICs
    - Expect power consumption to reach 0.1 mW per correlator in this time frame
    - Overall power consumption is then trivial: < 100 W for the entire T/q-sounding correlator
  - Develop signal distribution, thermal control & other subsystems.
- **Space demo: 2008-2012**
  - Ready for Phase B in 2008
  - Ready for launch in 2012

The GeoSTAR Team

Bjorn Lambrigtsen (JPL)	Principal Investigator
William Wilson (JPL)	Task Manager
Todd Gaier (JPL)	MMIC radiometers
Alan Tanner (JPL)	System Engineer
Chris Ruf (U. Mich.)	Correlators & electronics
Jeff Piepmeier (GSFC)	Correlator subsystem & testing

Shyam Bajpai (NOAA)	Science advisory board
James Shiue (GSFC)	Science advisory board