CYGNSS: The Cyclone Global Navigation Satellite System's CubeSat Foundations

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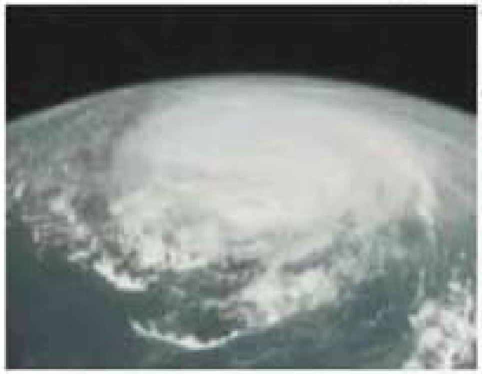
When Forecasting Goes Wrong: Katrina

Hurricane Katrina's
Storm Surge was 30 Feet Over What was Expected

Irene forecasts on track; not up to speed on wind

(A.P. wire service, August 29, 2011)



by Seth Borenstein & ChristineAmario:

Hurricane Irene was no mystery to forecasters. They knew where it was going. But what it would do when it got there was another matter. Predicting a storm's strength still baffles meteorologists. Every giant step in figuring out the path highlights how little progress they've made on another crucial question: How strong?

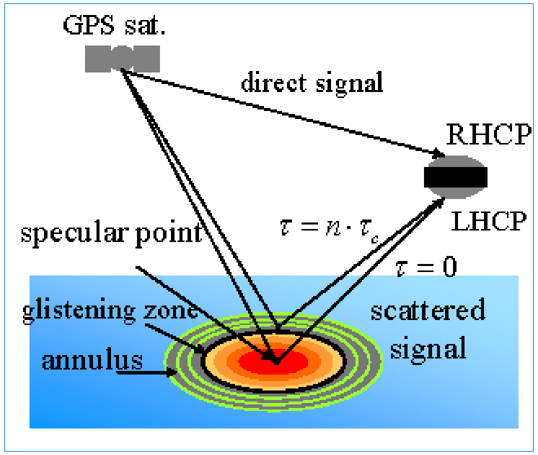
…the forecast after Irene hit the Bahamas had it staying as a Category 3 and possibly increasing to a Category 4. But it weakened and hit as a Category 1…"We're not completely sure how the interplay of various factors is causing the strength of a storm to change," [National Hurricane Center Director Bill] Read said. One theory is that a storm's strength is dependent on the storm's inner core. Irene never had a classic, fully formed eye wall even going through the Bahamas as a Category 3. "Why it did that, we don't know," Read said. "That's a gap in the science."

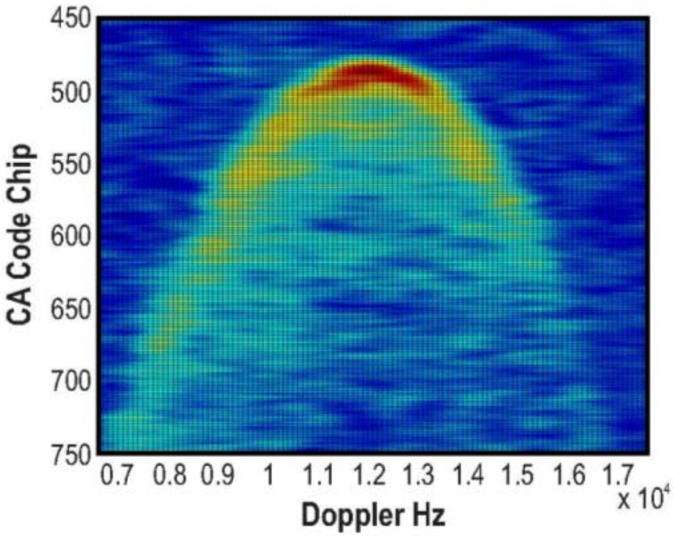
CYGNSS Science Goals & Objectives

- CYGNSS Science Goal
  - Understand the coupling between ocean surface properties, moist atmospheric thermodynamics, radiation, and convective dynamics in the inner core of a tropical cyclone (TC)
- CYGNSS Objectives
  - Measure ocean surface wind speed in all precipitating conditions, including those experienced in the TC eyewall
  - Measure ocean surface wind speed in the TC inner core with sufficient frequency to resolve genesis and rapid intensification
- Questions Answered by CYGNSS
  - How do the dynamics within TCs determine their intensity at landfall?
    - CYGNSS measures surface winds in the TC inner core with a 4 hr average revisit time, enabling the dynamics of the TC to be investigated
  - How do moist atmospheric thermodynamics, radiation and convection interact to control the development of TCs?
    - CYGNSS measures wind speed through intense rain fall, enabling researchers to better understand the complex feedback between mass and energy interchange processes

Instrument: Bi-Static Quasi-Specular Ocean Surface Scatterometry

- Bi-static scattering geometry with GPS direct signal proving reference and quasi-specular forward scattered signal containing ocean surface roughness information
- Scattering cross-section image measured by UK-DMC-1 demonstration spaceborne mission with variable lag correlation and Doppler shift enabling resolution





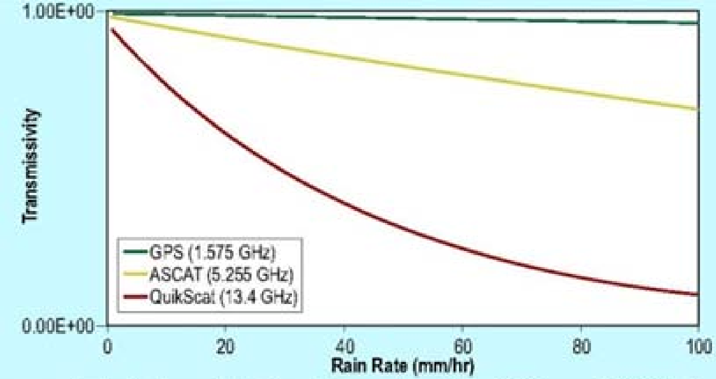
Analogy: Reflection of the Moon

Moderate wind speed

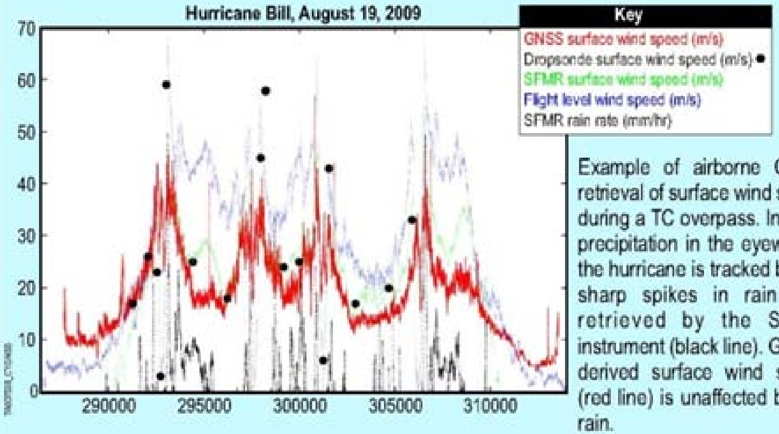
Low wind speed

Performance in Intense Precipitation

- One-way transmissivity through typical tropical storm (5 km freezing level) for: GPS (1.575 GHz), ASCAT (5.255 GHz), QSCAT (13.4 GHz)
- Airborne GNSS wind speed retrieval during overpass of Hurricane Bill on 19 Aug 2009. Strong rain bands (black) do not noticeably affect the GNSS retrieved wind (red)

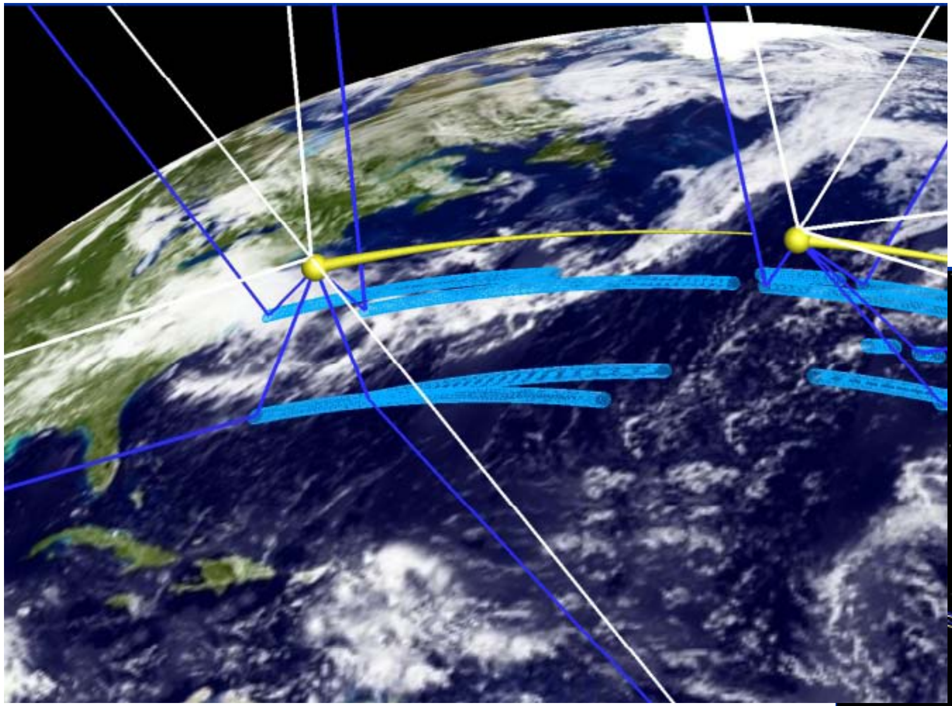


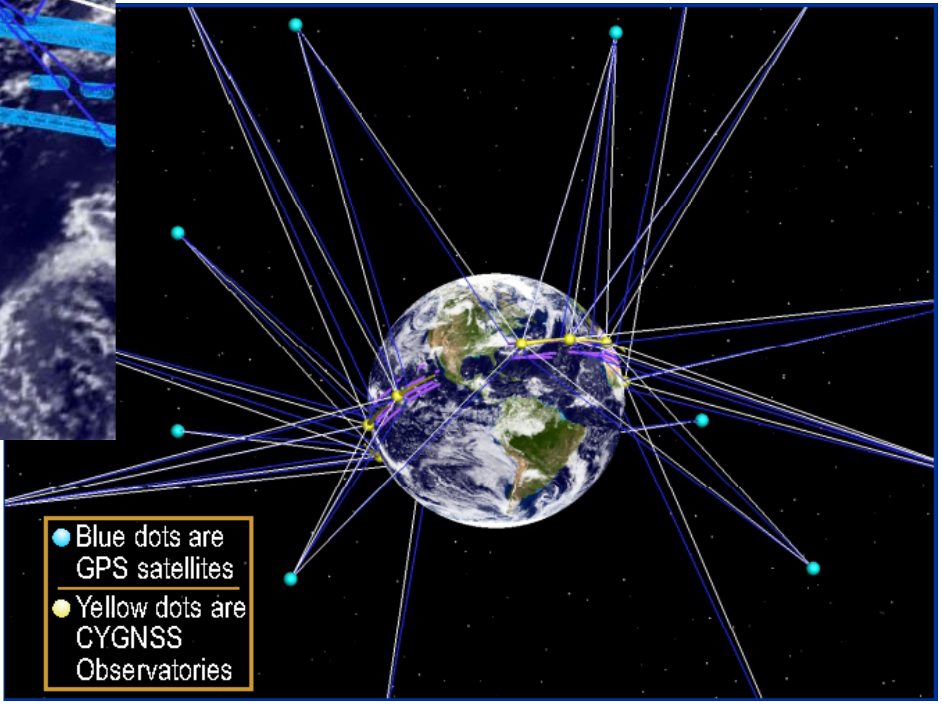
The one-way slant path atmospheric attenuation experienced by a GPS (green), ASCAT (yellow) and QuikScat (red) signal propagating through a typical tropical storm (5 km freezing level) as a function of surface rain rate. Rain has a negligibly small effect on the GPS signal, even at the highest rain rates. ASCAT is attenuated enough at the highest rain rates to severely impact its ability to retrieve surface winds. QuikScat signals are effectively blocked by heavy rain and cannot sense the surface at all.



Example of airborne GNSS retrieval of surface wind speed during a TC overpass. Intense precipitation in the eyewall of the hurricane is tracked by the sharp spikes in rain rate retrieved by the SFMR instrument (black line). GNSS-derived surface wind speed (red line) is unaffected by the rain.

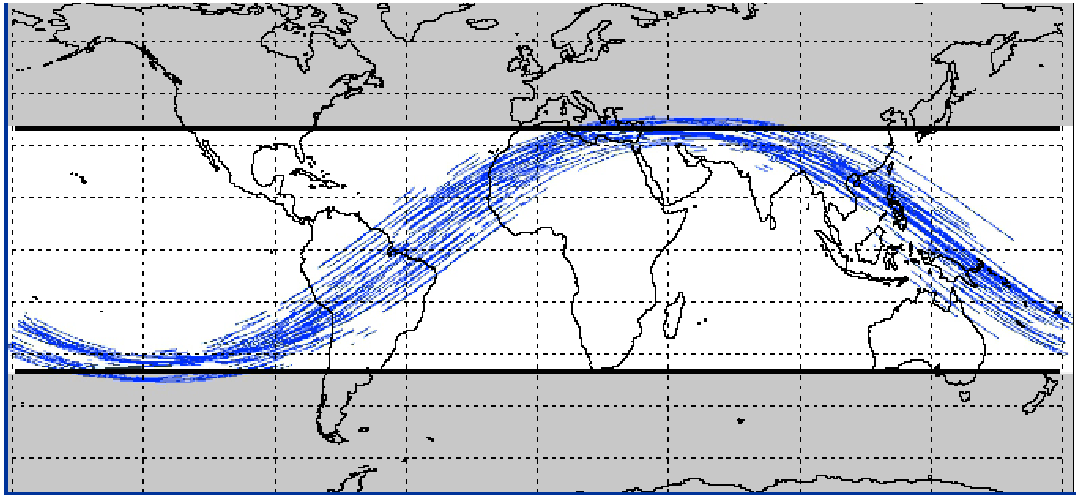
CYGNSS Constellation

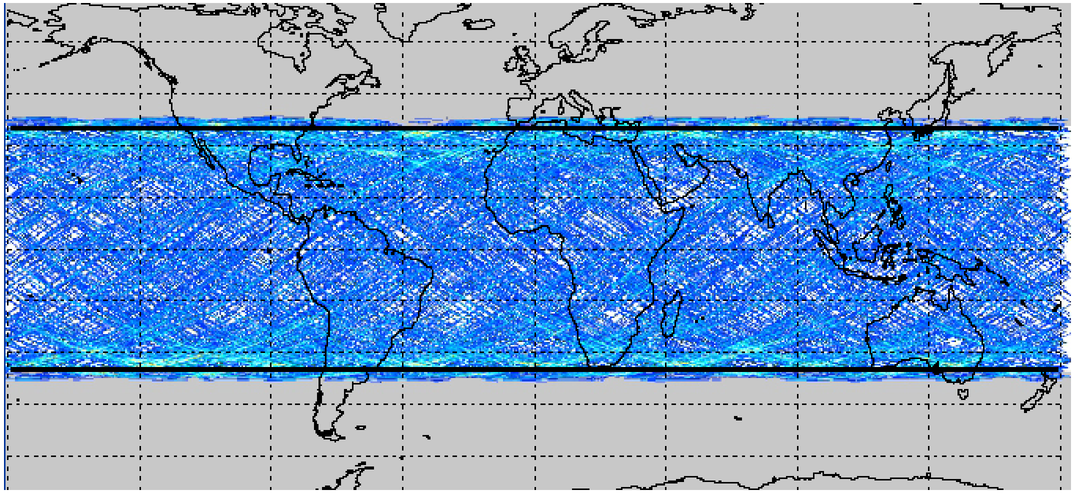




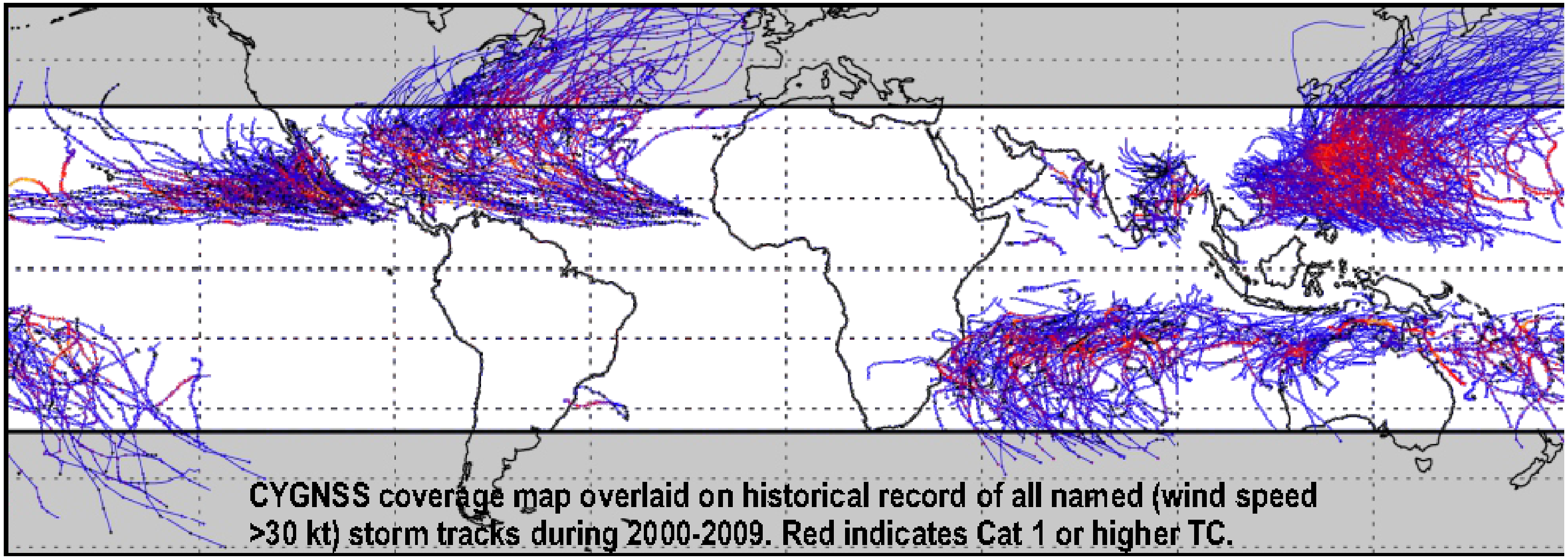
CYGNSS Earth Coverage

- 90 min (one orbit) coverage showing all specular reflection contacts by each of 8 s/c
- 24 hr coverage provides nearly gap free spatial sampling within +/- 35 deg orbit inclination





CYGNSS Historical Storm Track Overlay

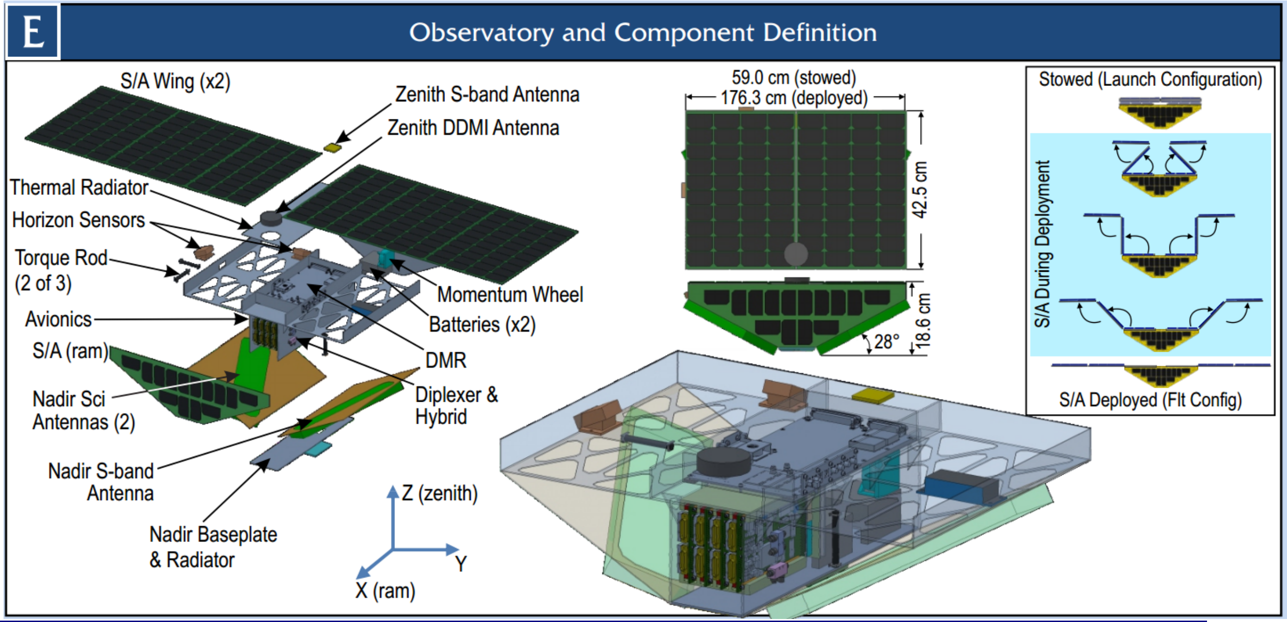


Links to CubeSats

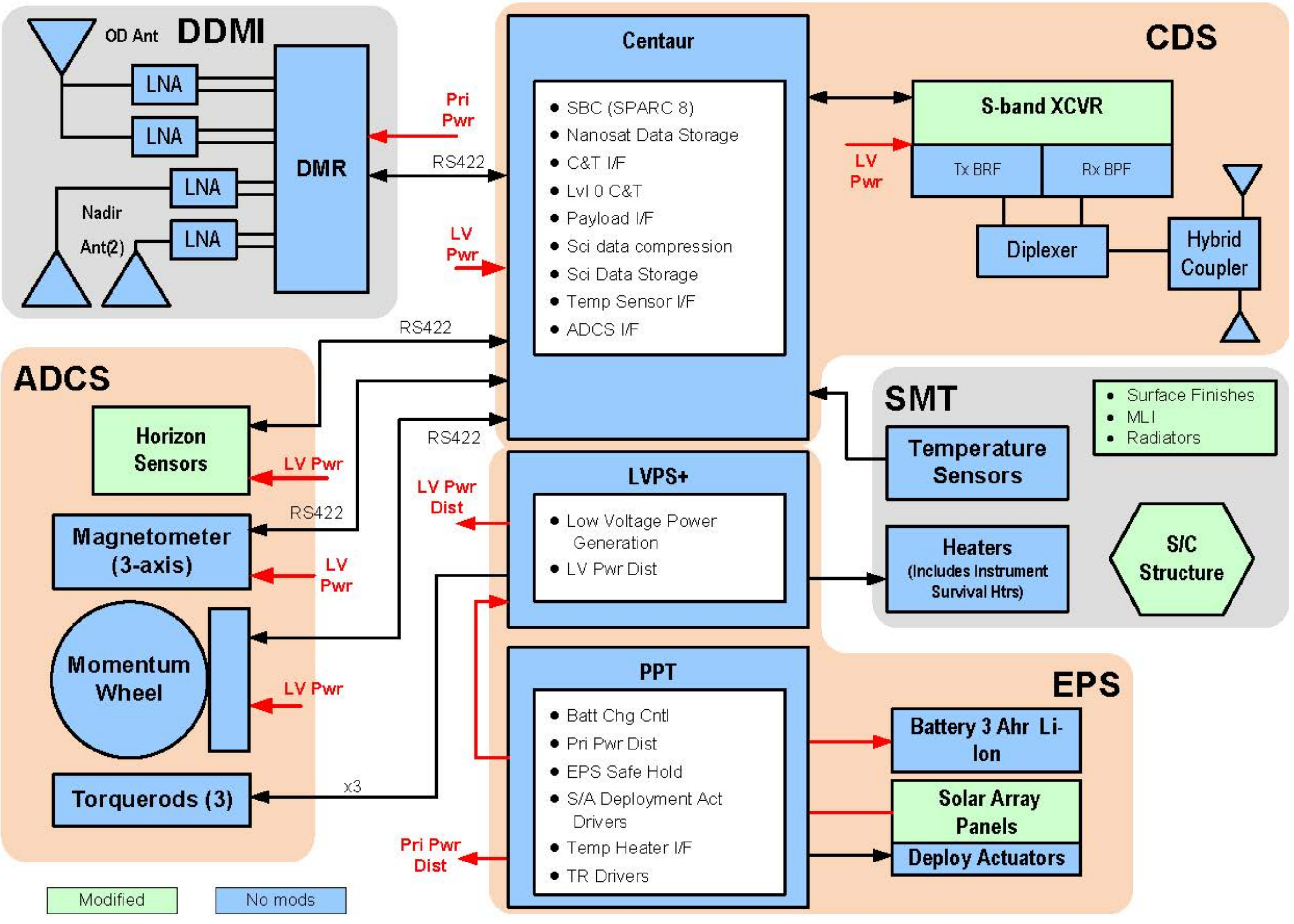
- CYGNSS began as a CubeSat concept
- CubeSats offer unique science capabilities
  - Distributed sensing
  - Improved revisit time
- CubeSats are a new way of looking at reliability
  - Observatory-level redundancy
  - If the costs are low, it is okay if you loose 1 or more
- NASA is embracing the CubeSat movement
  - The perfect answer to the sequestor

Microsat Characteristics

- Configuration: Accommodate DDMI antennas and 100% DDMI duty cycle
- Power: 48.8 W (Available: 70.1 W EOL, Margin: 30.3%)
- Attitude: 3-axis stabilized, pitch momentum-biased nadir-pointed, 2.1° (3σ) knowledge and 2.3° (3σ) control (horizon sensors, magnetometer, pitch momentum wheel, torque rods)
- Communication: 1.25 Mbps S-band with 6.7 dB margin provides 31% Science data downlink margin
- Mass (ea): 17.6 kg
- Orbit: 500 km, i=35°
- Launch:10-Sept-2016
- Bus: SwRI
- Instrument: Surrey
- Avionics: SwRI
- Deployment Module: NASA Ames
- Contract: NASA Langley

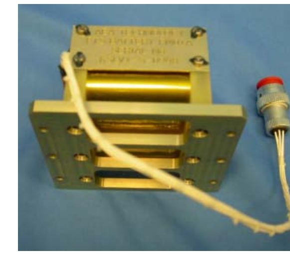


μSat Block Diagram – Avionics Highlighted



EPS Requirements

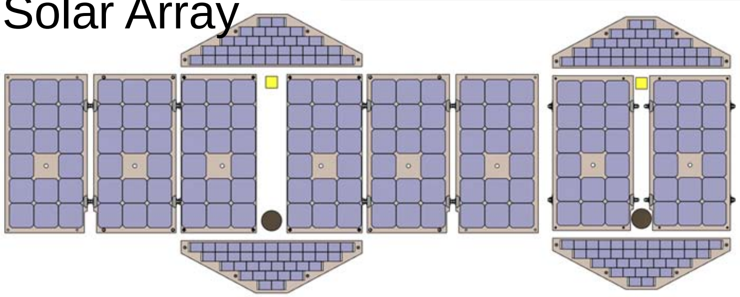
SwRI
Peak Power Tracker



EnerSys
Battery

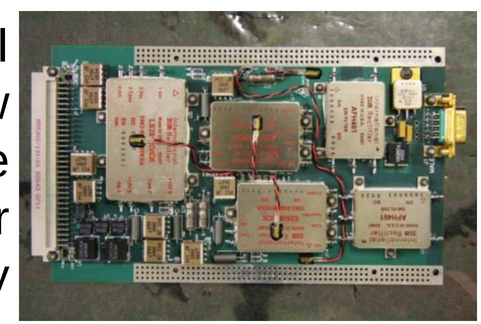
	Requirement	Performance
Instrument power (orbit avg)	10W	Complies
Instrument duty cycle	Continuous	Complies
S/A power (orbit avg, EOL worse case)	≥48.8W	70.1W
Minimum State-of-Charge (EOL @ longest eclipse)	>70%	80.7%

SNC
Solar Array

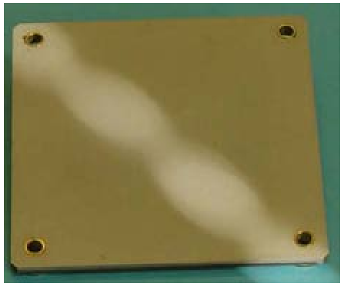


Deployed   Stowed

SwRI
Low
Voltage
Power
Supply



CDS Requirements



AntDevCo
Antenna

	Requirement	Performance
Processor performance	≥14.5 MIPS	22 MIPS (52% Margin)
Data Storage (>10 days)	370 MB	4 GB*
Max Sci data storage rate	>4.2 kbps	100 Mbps*
Max data playback rate	1.25 Mbps	300 Mbps*
Cmd Storage	>100 RTS/ATS 15 cmd sequences	Complies
All Comm links margin	>3 dB	Complies (§F.2.4.1)
* Excess capability results from the use of existing heritage designs		

SwRI
C&DH

SwRI
S-Band Transceiver

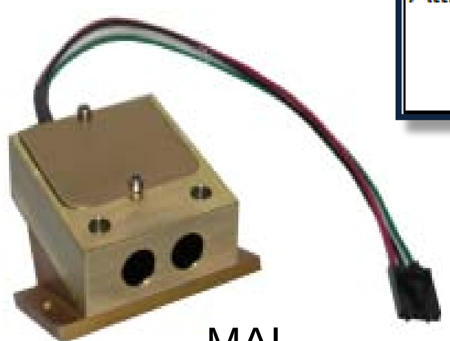
Merrimac
Coupler/Duplexer

ADCS Requirements

Honeywell Magnetometer

Sinclair Momentum Wheel

Parameter/Item		Value
Attitude Determination		Earth horizon and mag field reference
	Horizon Sensor	0.5 deg accuracy, ±5 deg range
	Magnetometer	10 nT sensitivity, +/- 50,000 nT range
Attitude Control		3-axis stabilized, momentum biased
	Mom Wheel	30 mNms @ 5600 rpm, 2mNm torque
	Torque Rods	1 Am^2, residual moment < 0.1 Am^2



MAI Horizon Sensor

SatServ Torque Rod

Lot’s of Great People

- Tim Henderson, ADCS Subsystem Engineer
- Robert Atlas, Co-I
- Paul Chang, Co-I
- James Cutler, Co-I
- James Garrison, Co-I
- Scott Gleason, Co-I
- Zorana Jelenak, Co-I
- Stephen Katzberg, Co-I
- Sharanya Majumdar, Co-I
- Manuel Martin-Neira, Co-I
- Donald Walter, Co-I
- Valery Zavorotny, Co-I
- Joel Johnson, Co-I
- John Dickinson, Comm, Data, and Power Subsystem Lead
- Brian Johnson, DDMI Program Magager
- Martin Unwin, DDMI Systems Engineer
- Robert Ricks, Deployment Module Electrical Engineer
- Elwood Agasid, Deployment Module Lead
- Abraham Rademacher, Deployment Module Lead Engineer
- Derek Posselt, Deputy PI/Co-I
- Greg Fletcher, Deputy Project Manager
- Walter Lockhart, Electrical Power Analyst
- Robert Klar, Flight Software Technical Lead
- Scott Miller, FSW Team
- Alan Henry, I & T Lead
- Aaron Ridley, Instrument Scientist/ Co-I
- Debbie Shaffer, ITAR Lead
- Joerg Gerhardus, Mission Assurance
- Jillian Redfern , Mission Operations Analyst
- Michael Vincent, Mission Operations Analyst
- Chelle Reno, Mission Operations Consultant
- Debi Rose, MOC Manager, Mission Ops Lead
- Marissa Brummitt, Other Professional
- Chris Ruf, Principal Investigator
- John Scherrer, Project Manager
- Randy Rose, Project Systems Engineer
- Andrew O'Brien, Science Team Member
- Jim Raines, SOC Engineer
- Stephen Musko, SOC Lead Engineer
- Ronnie Killough, Software Systems Lead
- John Bultena, Spacecraft SystemsAnalysis
- Jon VanNorde, Thermal Analyst
- Will Wells, Systems Analyst
- Damen Provost, UM Project Manager
- Bruce Block, UM Technical Manager

link

Shameless Plug: Check out the CubeSat Avionics Section (7.7) at the IEEE Aerospace Conference in Big Sky Montana