JPL Science Visitor and Colloquium – Earth Science Seminar
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The NASA EV-2 Cyclone Global Navigation Satellite System (CYGNSS) Mission

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CYGNSS Science Motivation

- **Tropical cyclone track forecasts have improved in accuracy by ~50% since 1990, largely as a result of improved mesoscale and synoptic modeling and data assimilation. In that same period, there has been essentially no improvement in the accuracy of intensity forecasts.**

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 TC precipitating conditions
  - 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 better understand of the complex feedback between mass and energy interchange processes
    - Combine with 3 hr revisit precipitation fields by GPM

CYGNSS Core Team

- **University of Michigan**
  - Chris Ruf (PI), Aaron Ridley (Project Scientist)
  - Damen Provost (UM Project Mgr), Linda Chadwick (Business Mgr), Bruce Block (Technical Mgr)

- **Southwest Research Institute**
  - John Scherrer (CYGNSS Project Manager), Randy Rose (System Engineer), John Eterno (Spacecraft), Debbie Rose (Mission Ops)

- **Surrey Satellite Technology US**
  - Brian Johnson (DDMI)

- **NASA Ames Research Center**
  - Elwood Agasid (Deployment Module

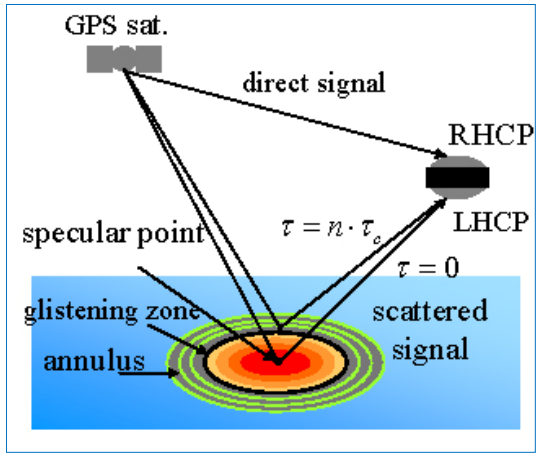
- **Science Team**
  - Bob Atlas <NOAA>, Paul Chang <NOAA>, James Garrison <Purdue>, Scott Gleason <Concordia Univ>, Joel Johnson <Ohio State U>, Stephen Katzberg <NASA LaRC, retired>, Sharan Majumdar <U-Miami>, Derek Posselt <UM>, Perry Samson <UM>, Donald Walter <S. Carolina State Univ>, Valery Zavorotny <NOAA>, Zorana Jelenak <NOAA>

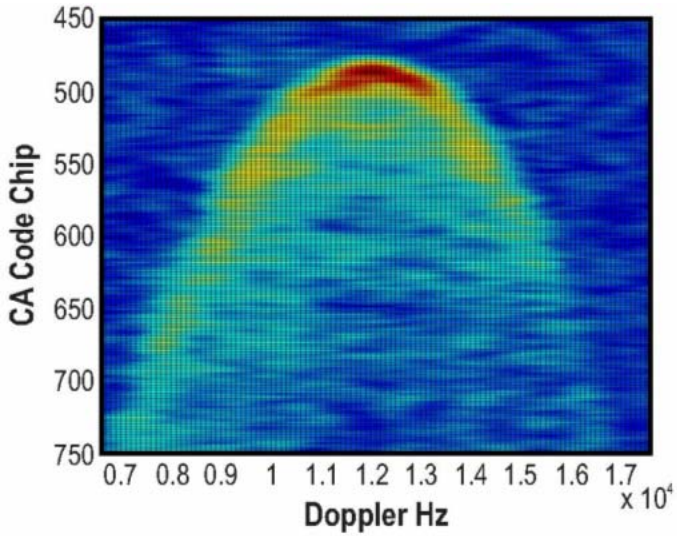
GNSS Scientific Measurements

Science Objective	Scientific Measurement Estimated Performance	
	Observable	Physical Parameter
Measure ocean surface winds under TC conditions	Precip	< 100 mm/hr (25 km footprint)
	Windspeed uncertainty	Greater of 2 m/s or 10% of windspeed
	Spatial resolution	Variable 5-50 km (ground processing)
	Windspeed dynamic range	< 70 m/s (Cat 5)
Measure ocean surface winds in TC inner core with high temporal frequency	Mean revisit time	4 hr
	Earth coverage	> 70% coverage of all historical TC storm tracks

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

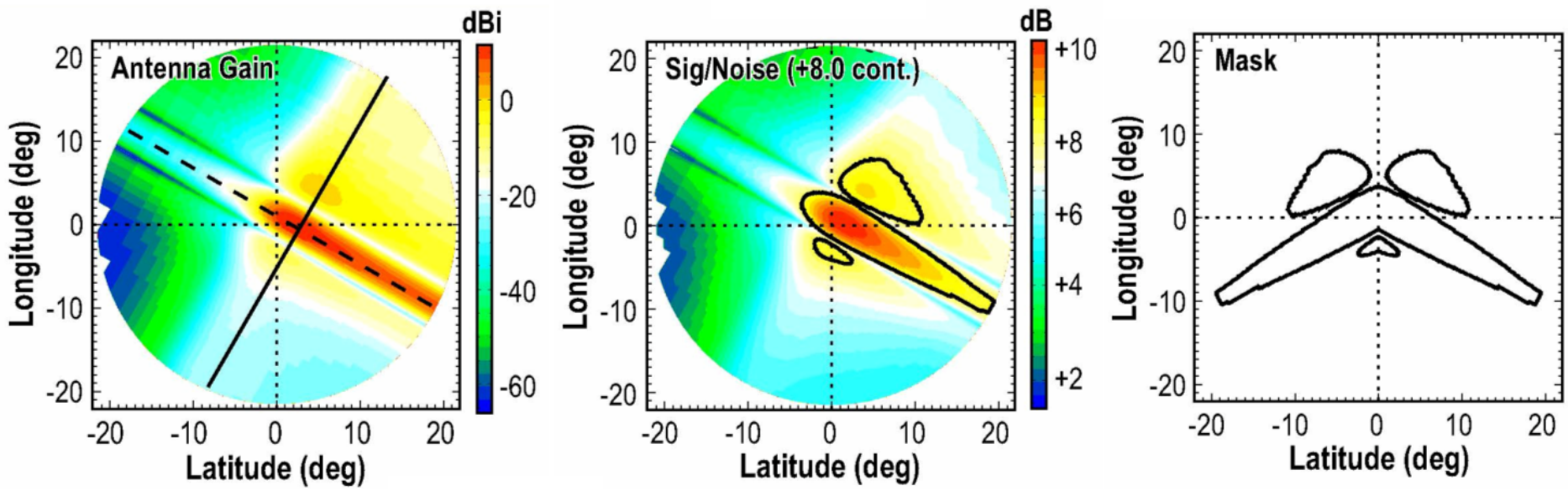




CYGNSS End-to-End Simulator

- **Software model of all critical steps in the wind speed retrieval process:**
  - Dynamic orbit propagators for GPS and CYGNSS constellations
  - Signal generation by GPS transmitter satellites
  - Free space propagation to the specular reflection point on the Earth surface
  - Bi-static forward scattering from the wind driven, roughened ocean surface
  - Receive antenna gain pattern projected onto the Earth surface
  - Link budget for received signal strength
  - Fading and thermal noise statistics of received signal
  - Accuracy, precision and resolution of Delay Doppler Map data product
  - Wind speed retrieval algorithm

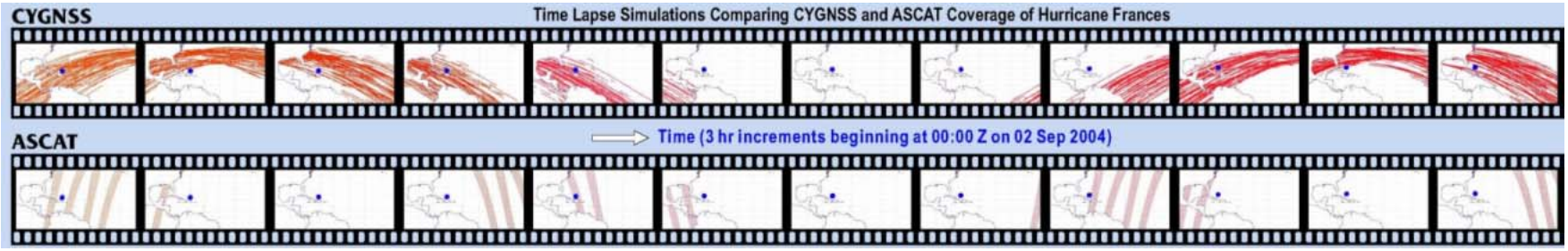
Deriving Coverage Mask



- (left) One of 2 nadir antenna patterns projected onto Earth (altitude 500 km, 60° rotation, 28° tilt)
- (center) SNR of received signal (10 m/s WS, 45° inc. angle)
- (right) +8 dB SNR contour with both antennas (meets WS retrieval uncertainty requirement)

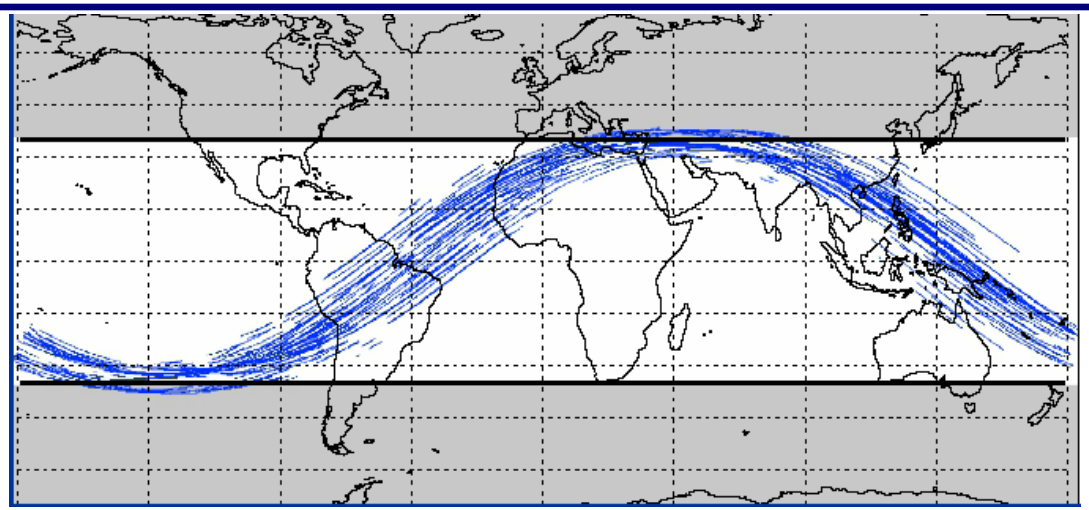
Hurricane Overpass Case Study

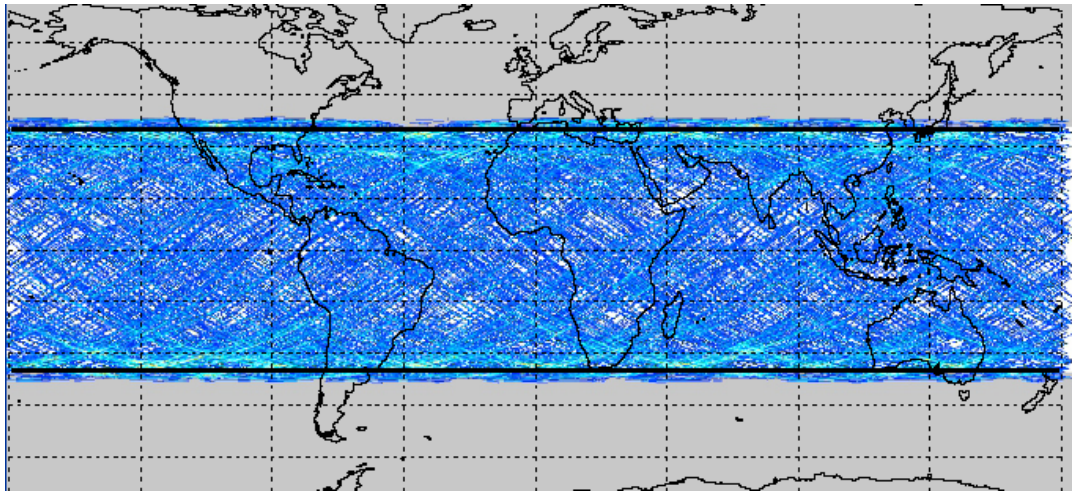
- Time lapse simulation comparing CYGNSS and ASCAT coverage of Hurricane Frances just before landfall
- Snapshots of all samples taken in 3 hour intervals
- Hurricane inner core shown as large blue dot



CYGNSS Earth Coverage

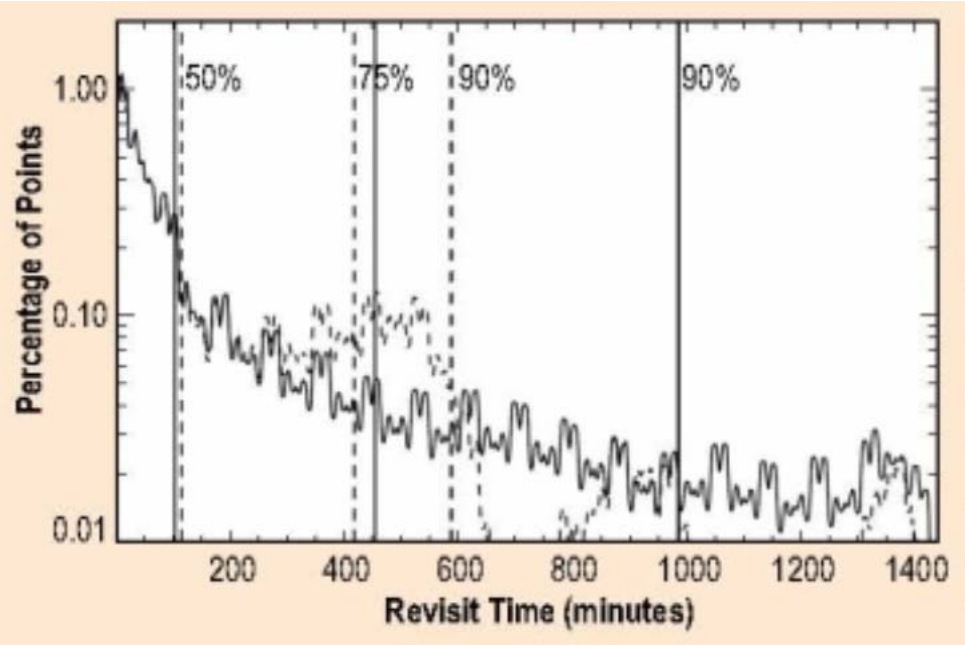
- 90 min (one orbit) coverage showing all specular reflection contacts by each of 8 s/c
- 24 hr coverage provides nearly gap free spatial sampling within +/- 35 deg orbit inclination





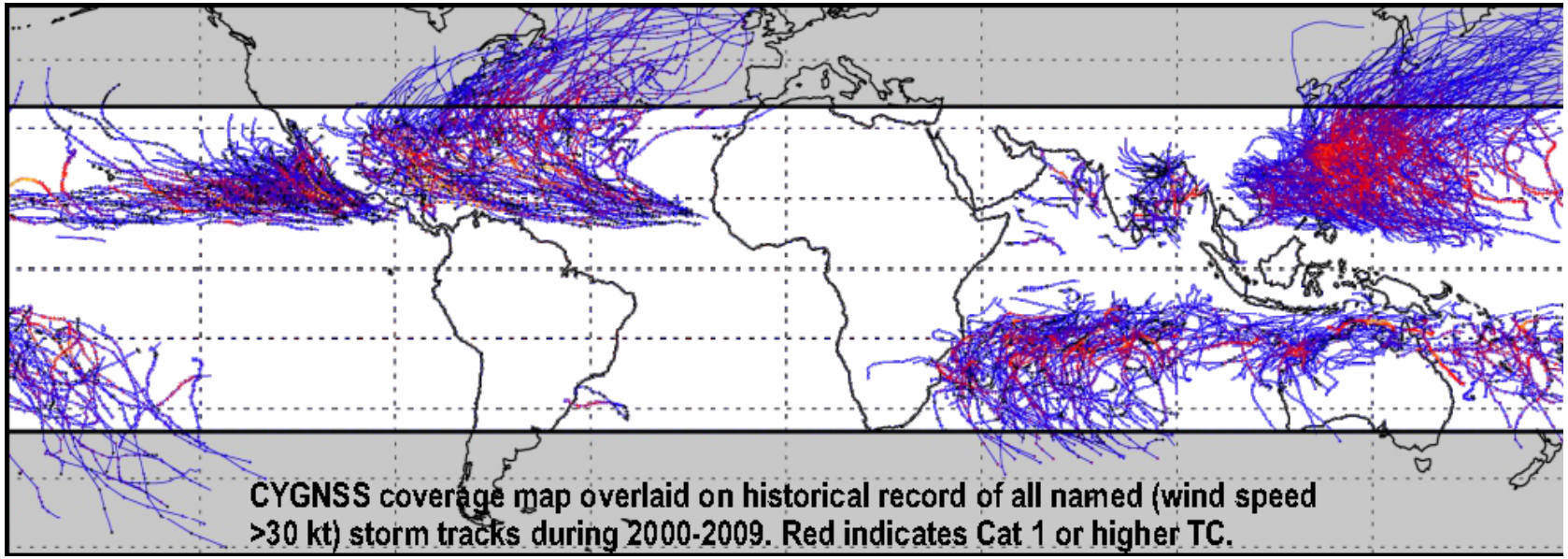
CYGNSS Revisit Time
Requirement is 12 hr mean revisit

- Probability distribution of revisit time for all Earth samples within +/-35° (solid) and for samples of historical storm tracks (dashed).
- Revisit stats derived from PDF demonstrate 4 hr mean storm revisit and ~9 hr to revisit 90% of all storms



Revisit Statistics	Median	Mean	90% Cumulative
All Samples	1.6 hr	4.8 hr	14.4 hr
Storms Only	1.5 hr	4.0 hr	9.3 hr

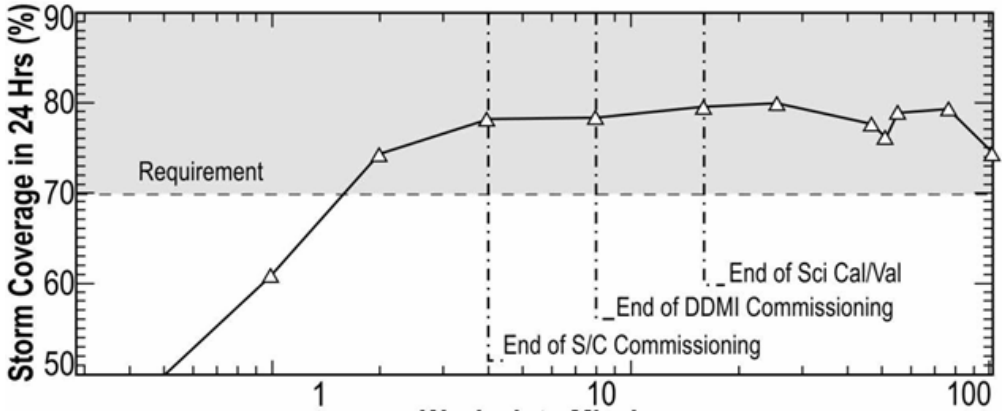
CYGNSS Historical Storm Track Overlay



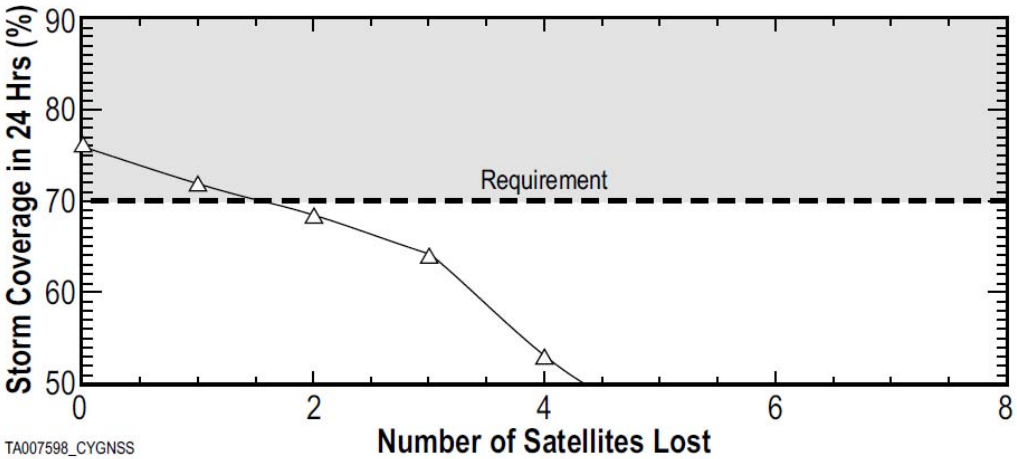
CYGNSS Spatial Coverage

Baseline Requirement is 70%

- Spacecraft dispersion after initial deployment spreads apart s/c and improves coverage

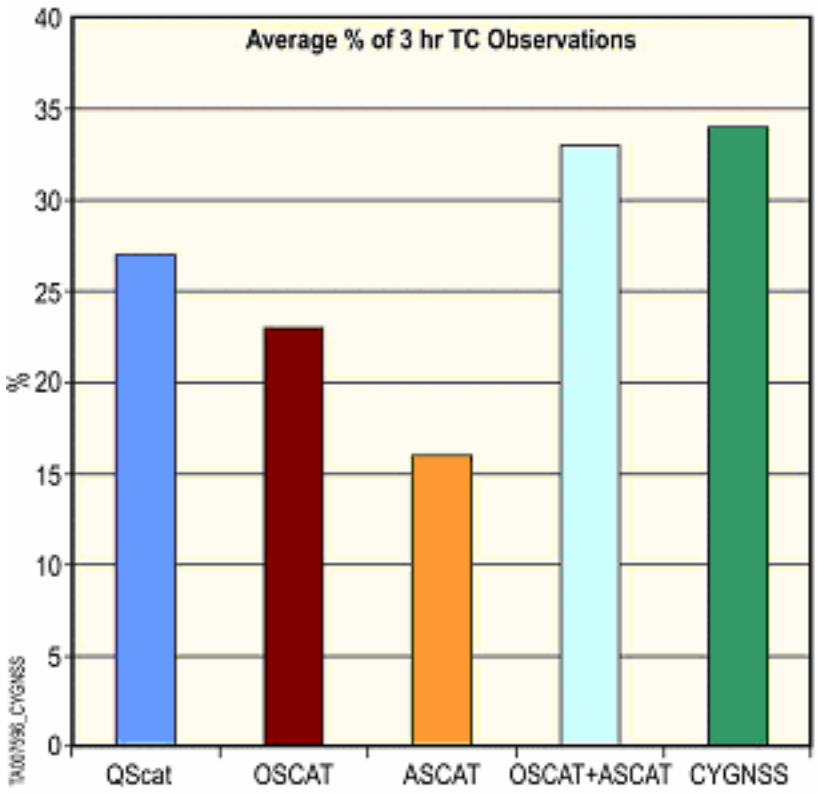


- Constellation-level redundancy allows for s/c failures while still meeting coverage requirement



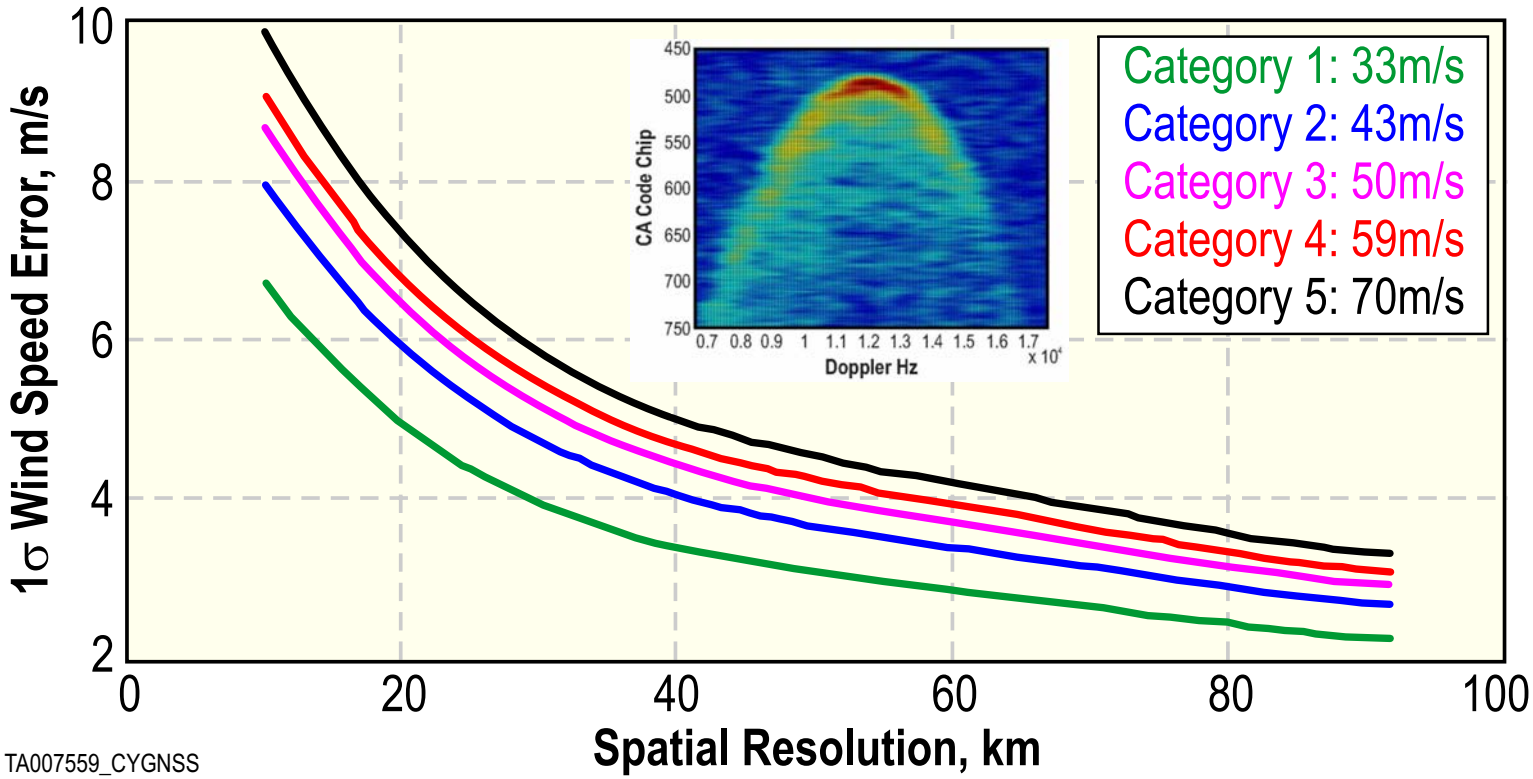
Tropical Cyclone Inner Core Sampling Capability

- Figure shows the percentage of 3 hr intervals during the 2005 Atlantic hurricane season in which each of three ocean wind scatterometers (QuikScat on NASA SeaWinds, OSCAT on ISRO OceanSat-2, and ASCAT on EUMETSAT Metop) would have sampled the inner core region of every TC that occurred that year
- Also shown is the percentage sampled by the combined OSCAT+ASCAT constellation and the percentage that would have been sampled by CYGNSS



WS Uncertainty v. Spatial Resolution

- CYGNSS software simulator using truncated Delay Doppler Map



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Wind Speed Retrieval Uncertainty
Requirement is the greater of 2 m/s or 10% of wind speed

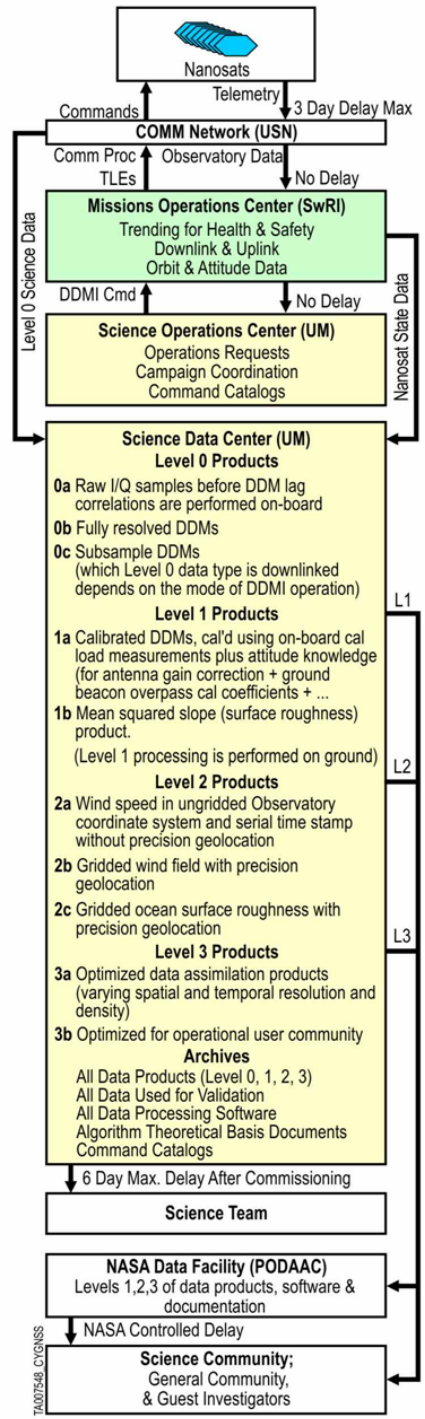
- CYGNSS software simulator developed to model WS retrieval performance on any platform and in all wind conditions
  - Airborne (P-3) flights demonstrations for WS<40 m/s
  - Spaceborne (UK-DMC-1) flight demo for WS<10 m/s

CYGNSS Simulator Validation and Performance Predictions

Platform	Altitude (km)	Wind speed (m/s)	Science antenna gain (dBi)	Incidence angle of specular point (°)	Empirical wind speed uncertainty (m/s)	Model wind speed uncertainty (m/s)
P-3	**3**	**10**	**3**	**45**	**±1.2**	**±0.9**
P-3	**3**	**40**	**3**	**45**	**±4.8**	**±3.7**
UK-DMC-1	**680**	**10**	**11**	**45**	**±2.3**	**± 2.0**
CYGNSS	**500**	**10**	**11**	**45**	**To be completed after CYGNSS on-orbit cal/val**	**±0.7***
CYGNSS	**500**	**33 (Cat 1)**	**11**	**45**		**±4.23***
CYGNSS	**500**	**50 (Cat 3)**	**11**	**45**		**±5.73***
CYGNSS	**500**	**70 (Cat 5)**	**11**	**45**		**±6.8***

(* Assumes 25x25 km CYGNSS spatial resolution)

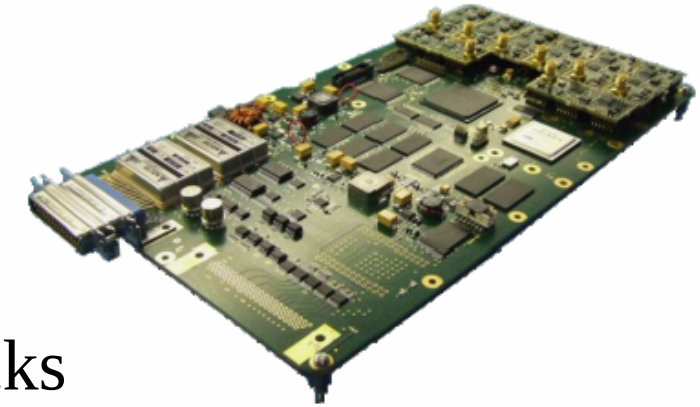
- Data Flow Plan and Science Data Products



CYGNSS Science Payload

- Next generation version of the UK Surrey Delay Mapping Receiver flown on the UK-DMC-1 mission
- Simultaneously tracks and generates Delay Doppler Maps from up to 4 GPS s/c transmitters
  - 60 ns Delay res
  - 250 Hz Doppler res

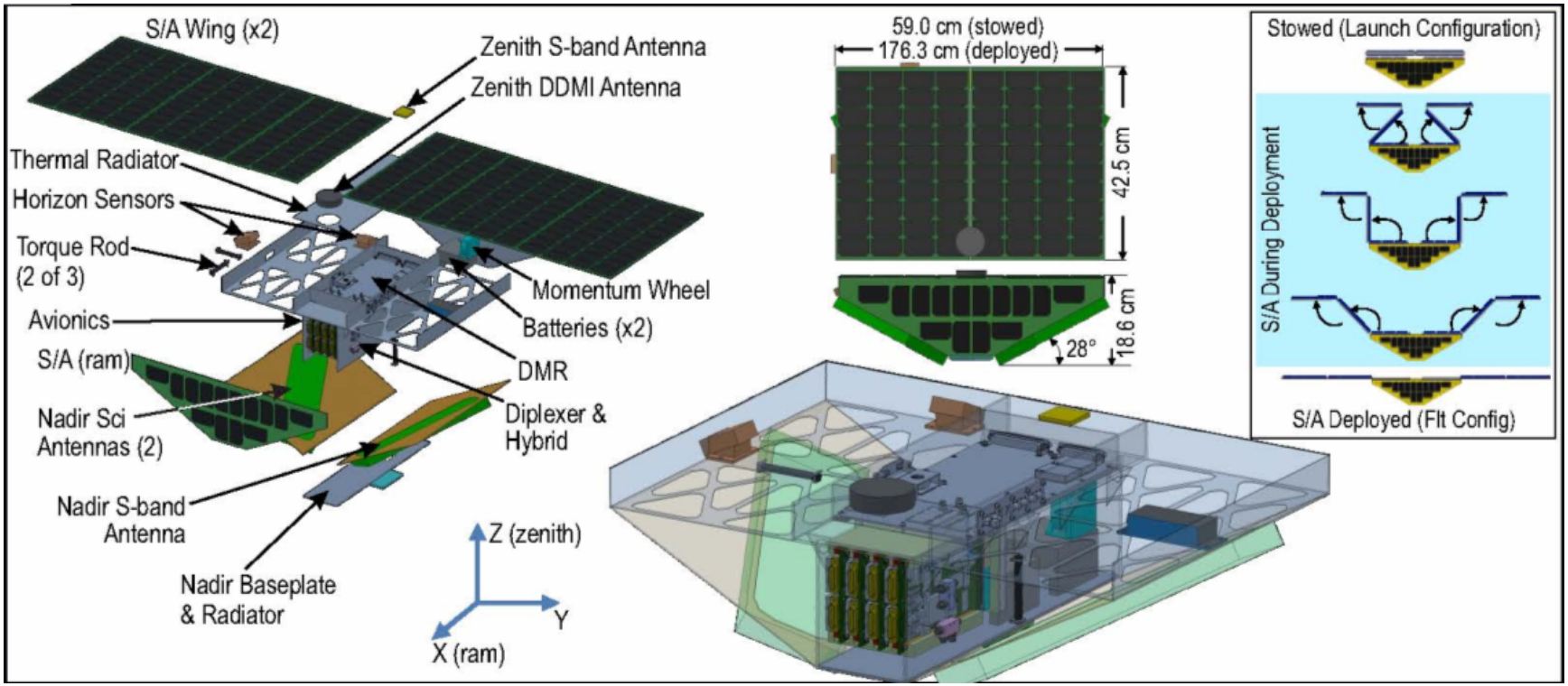
Delay Mapping Receiver (DMR)



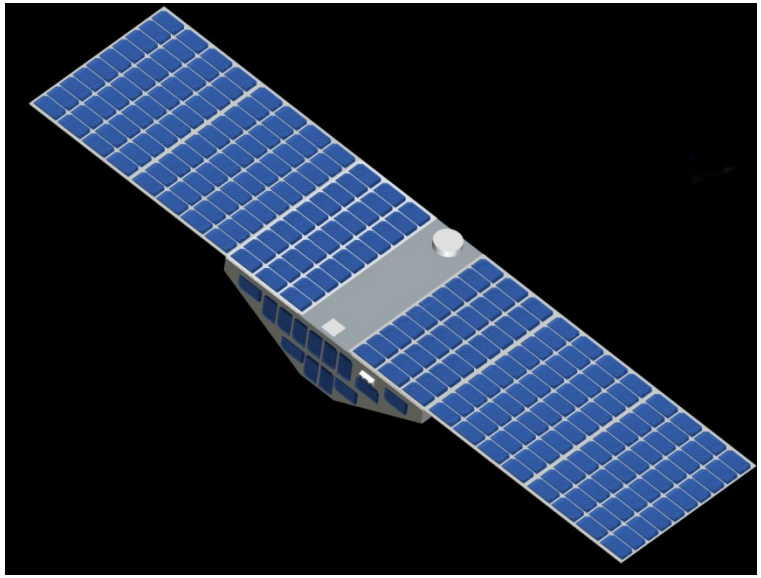
Zenith S-band Ant

Nadir Science Antennas

CYGNSS Observatory (exploded view)



CYGNSS Observatory (fully integrated)



Key Flight Segment Characteristics

Observatory

- *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 2.8° (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 (Margin: 59%)

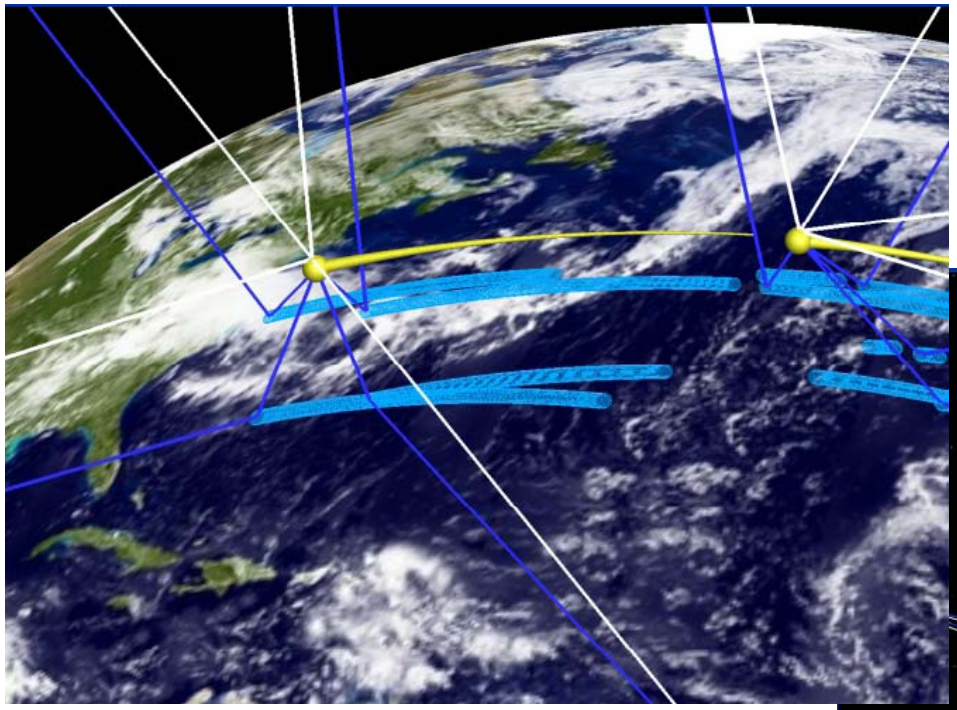
Launch Vehicle (LV), NASA (GFE)

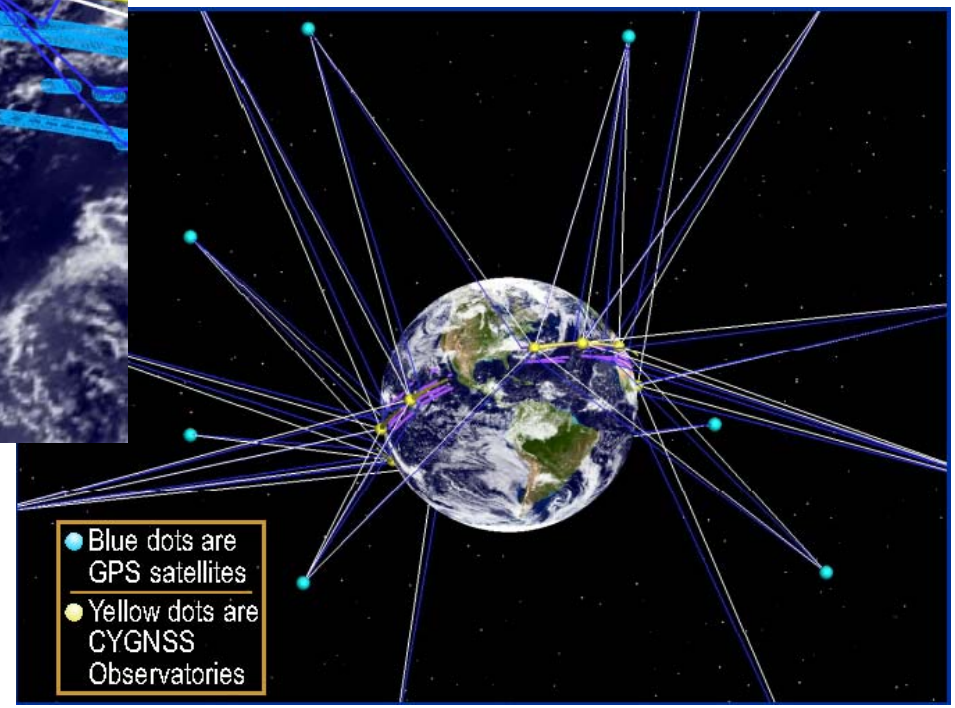
- *Altitude:* 500 km
- *Inclination:* 35°
- *Injection mass:* 174.6 kg
- *LV Margin (Pegasus):* 106%
- *Launch:* 10-Feb-2016

Deployment Module (DM)

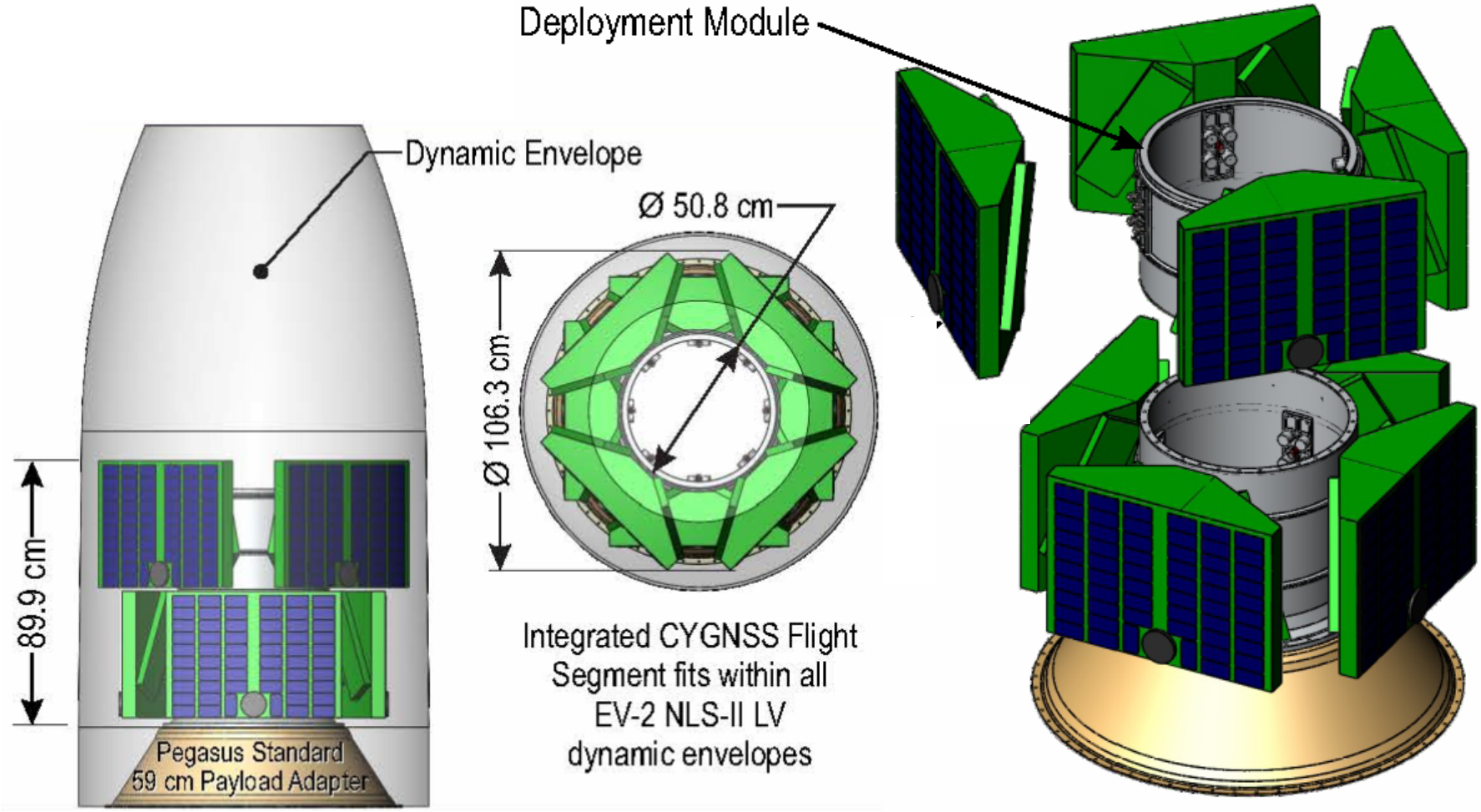
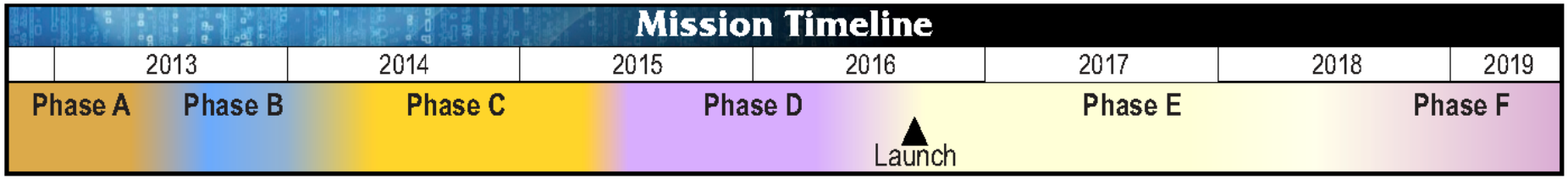
- 8 observatory deployment
- Provides pre-launch S/C Command & Telemetry, and battery trickle charge interface
- 2 tier design to facilitate I&T

CYGNSS Constellation





Complete Flight Segment with Deployment Module



CYGNSS Schedule