International Ocean Vector Wind Science Team Meeting
Kailua-Kona, Hawaii USA
6-8 May 2013

The NASA EV-2 Cyclone Global Navigation Satellite System (CYGNSS) Mission

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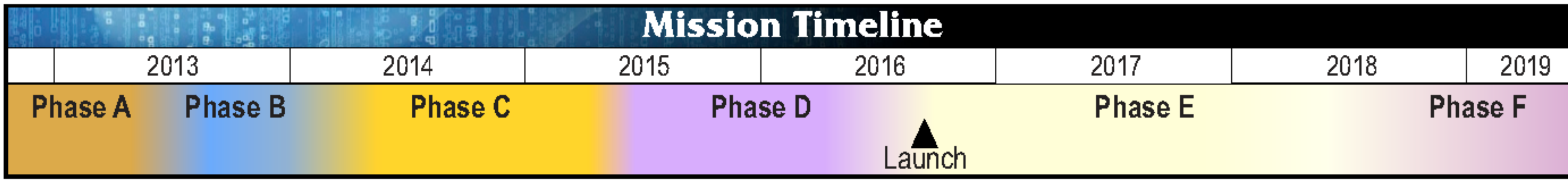
For more information: http://cygnss-michigan.org

CYGNSS Team

- **University of Michigan**
  - Chris Ruf (PI), Derek Posselt (Deputy PI), Aaron Ridley (Instrument Scientist)
  - Damen Provost (UM Project Mgr), Linda Chadwick (UM Business Mgr), Bruce Block (UM Technical Mgr)
- **Southwest Research Institute**
  - John Scherrer (Project Mgr), Randy Rose (Systems Eng), John Eterno (Spacecraft), Debbie Rose (Mission Ops)
- **Surrey Satellite Technology US**
  - Brian Johnson (DDMI)
- **NASA Ames Research Center**
  - James Chartres (Deployment Module)
- **Science Team**
  - Bob Atlas, NOAA; Paul Chang, NOAA; Maria Paola Clarizia (UM/NOC); James Garrison, Purdue U; Scott Gleason, Concordia U; Joel Johnson, Ohio State U; Stephen Katzberg, NASA LaRC (retired); Sharan Majumdar, U-Miami; Perry Samson, UM; Donald Walter, S. Carolina State U; Valery Zavorotny, NOAA; Zorana Jelenak, NOAA

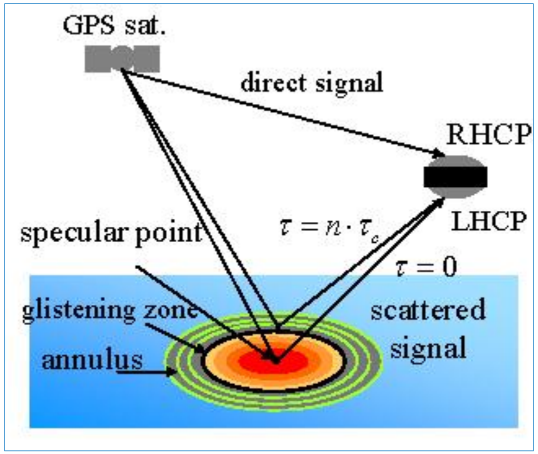
CYGNSS Schedule



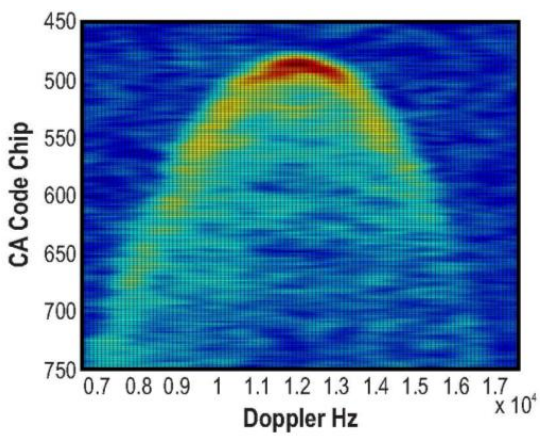
CYGNSS Science Goals & Objectives

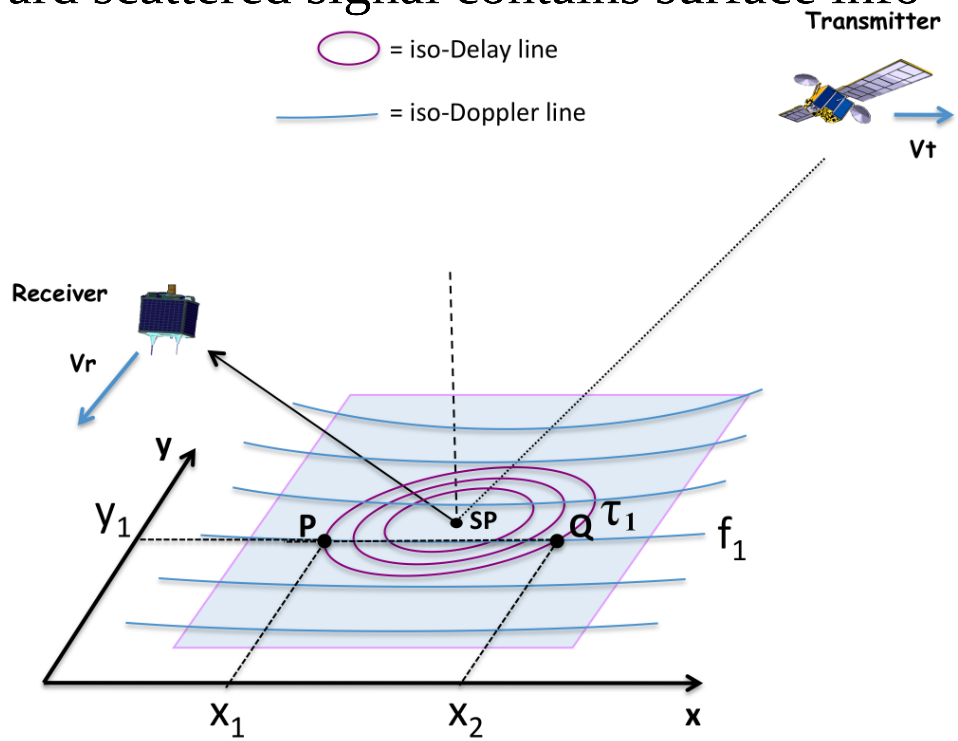
- **CYGNSS Science Goal**
  - Understand the coupling between ocean surface properties, moist atmospheric thermodynamics, radiation, and convective dynamics in the inner core of a tropical cyclone (TC)
- **CYGNSS Objectives**
  - Measure ocean surface wind speed **in all precipitating conditions**, including 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**
- **Limitations of current spaceborne ocean surface wind sensors**
  - Traditional satellite remote sensing channels for ocean surface winds are significantly attenuated by intense precipitation
  - Traditional LEO polar orbiters have revisit times that are infrequent relative to time scale of rapid intensification phase of TC development
- **CYGNSS Uses a new measurement technique and a new satellite mission architecture**

GNSS-R Bistatic Radar
Quasi-Specular Surface Scattering



- GPS direct signal provides reference
- Forward scattered signal contains surface info

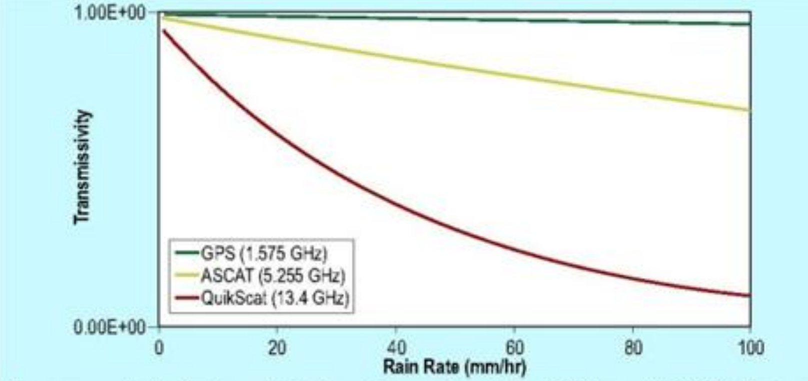




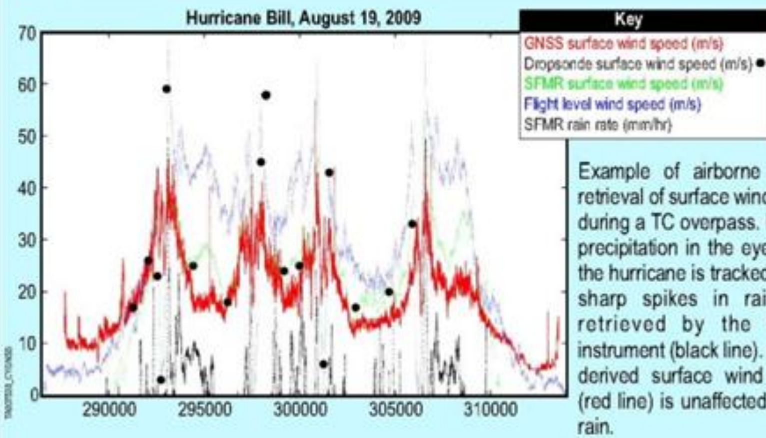
- Scattering cross-section image measured by UK-DMC-1 spaceborne mission with variable lag correlation and Doppler shift

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 noticably 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.

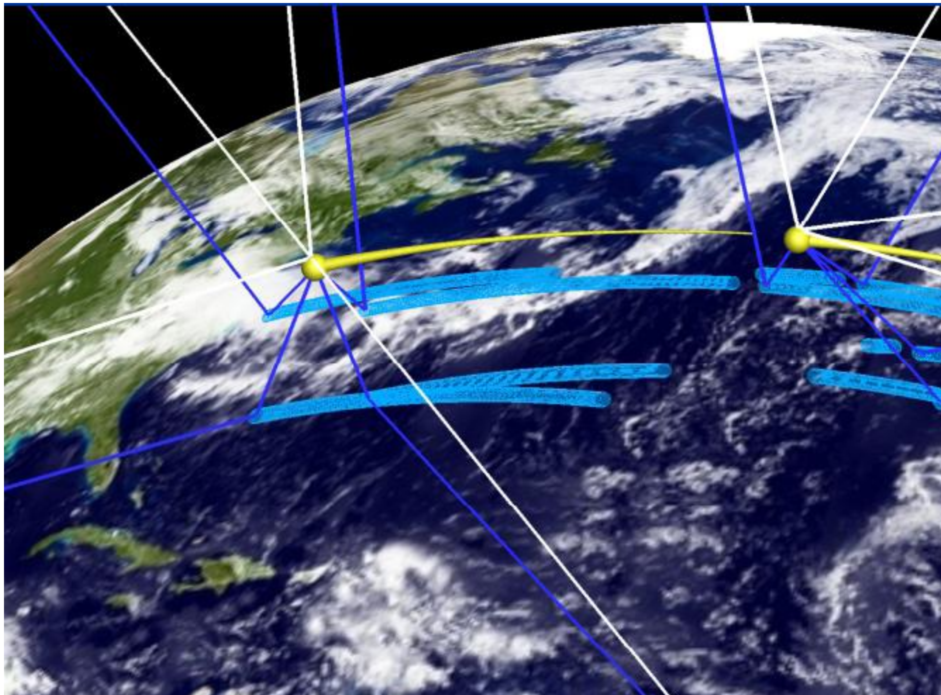


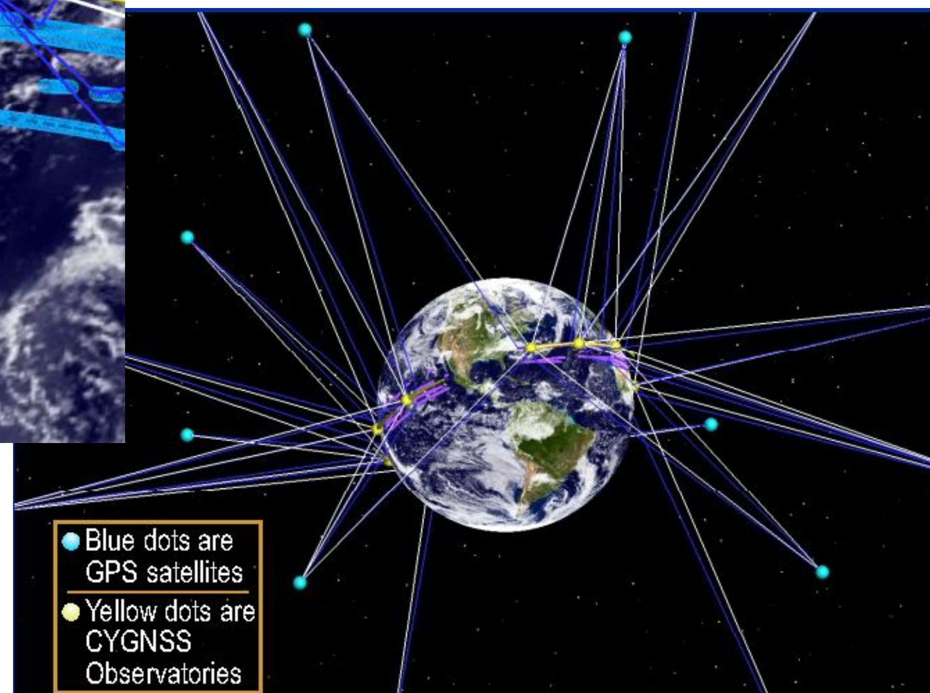
Example of airborne GNSS retrieval of surface wind speed during a TC overpass. Intense precipitation in the eyewall of the hurricane is tracked by the sharp spikes in rain rate retrieved by the SFMR instrument (black line). GNSS-derived surface wind speed (red line) is unaffected by the rain.

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 25-50 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

CYGNSS Constellation

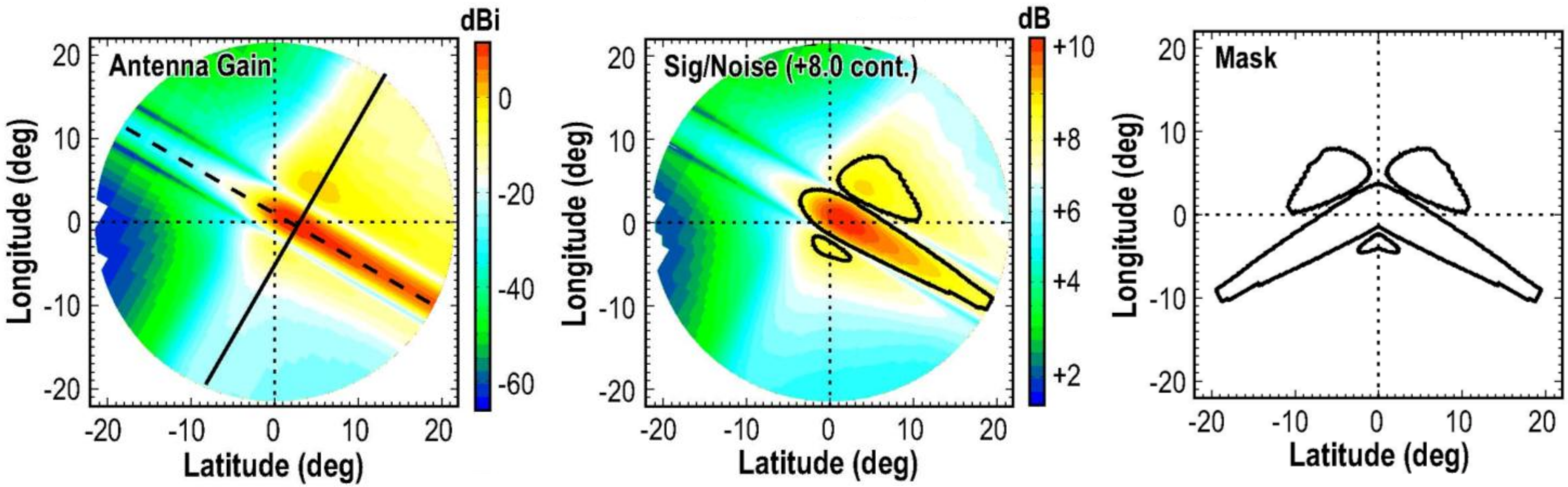




CYGNSS End-to-End Simulator

- **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

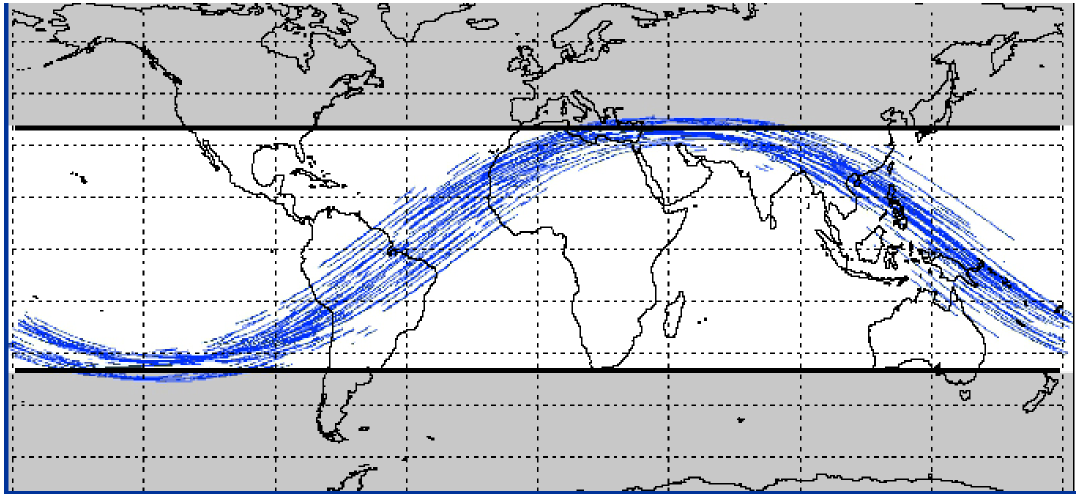
Deriving Coverage Mask



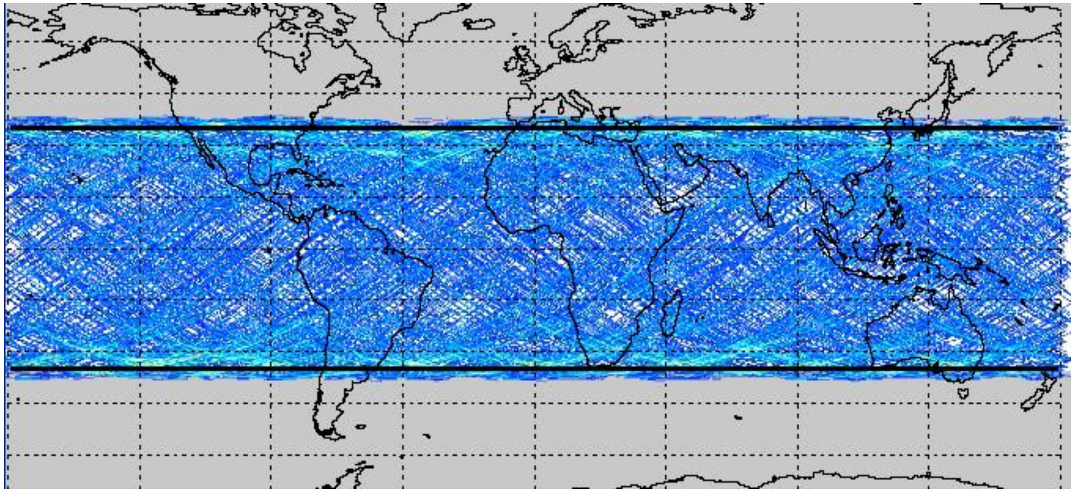
- (left) One of 2 nadir antenna patterns projected onto Earth (altitude 500 km, 60^o rotation, 28^o tilt)
- (center) SNR of received signal (10 m/s WS, 45^o inc. angle)
- (right) +8 dB SNR contour with both antennas (meets WS retrieval uncertainty requirement)

CYGNSS Earth Coverage

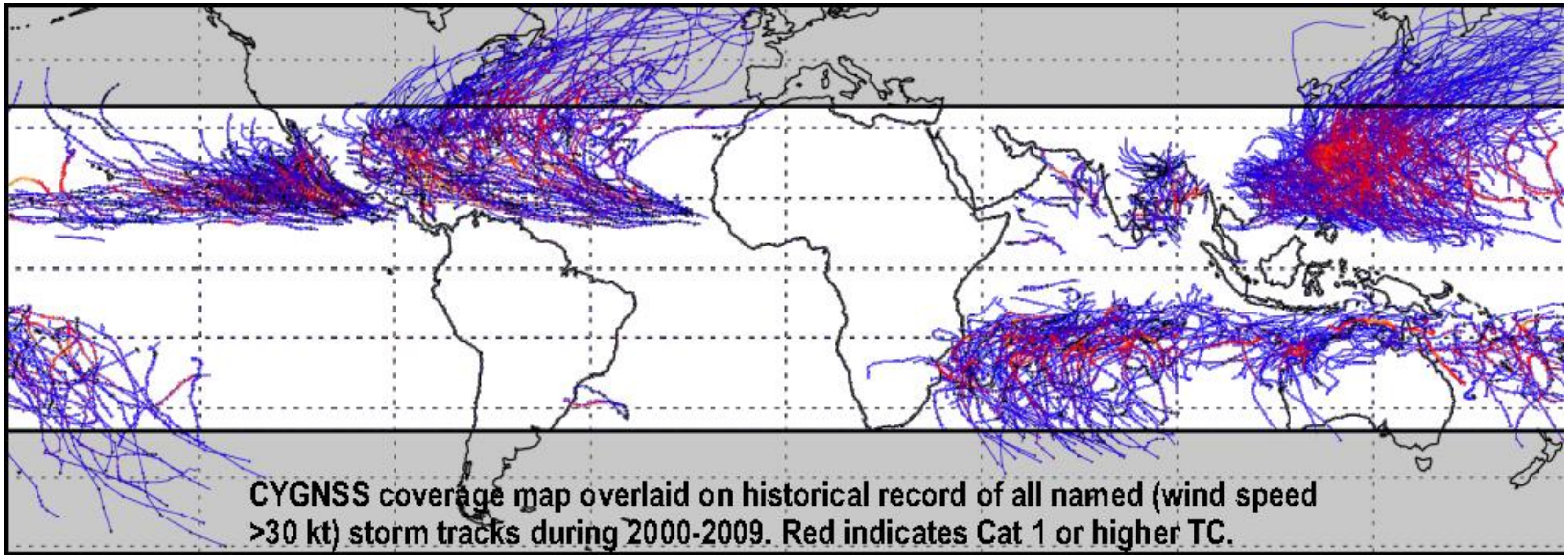
- 90 min (one orbit) coverage showing all specular reflection contacts by each of 8 s/c



- 24 hr coverage provides nearly gap free spatial sampling within +/- 35 deg orbit inclination



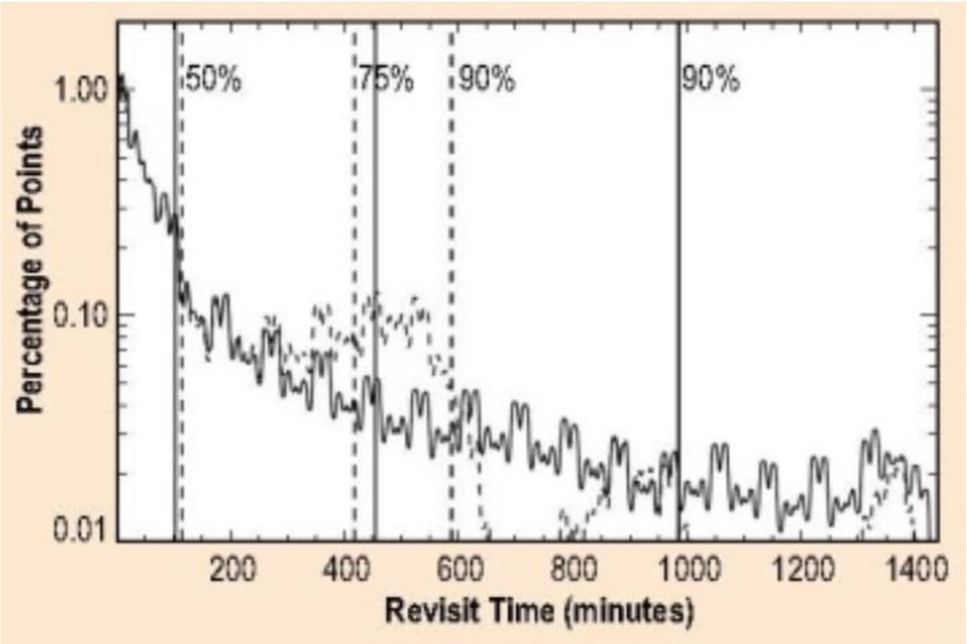
CYGNSS Historical Storm Track Overlay



CYGNSS coverage map overlaid on historical record of all named (wind speed >30 kt) storm tracks during 2000-2009. Red indicates Cat 1 or higher TC.

CYGNSS Revisit Time
Requirement is 12 hr mean revisit

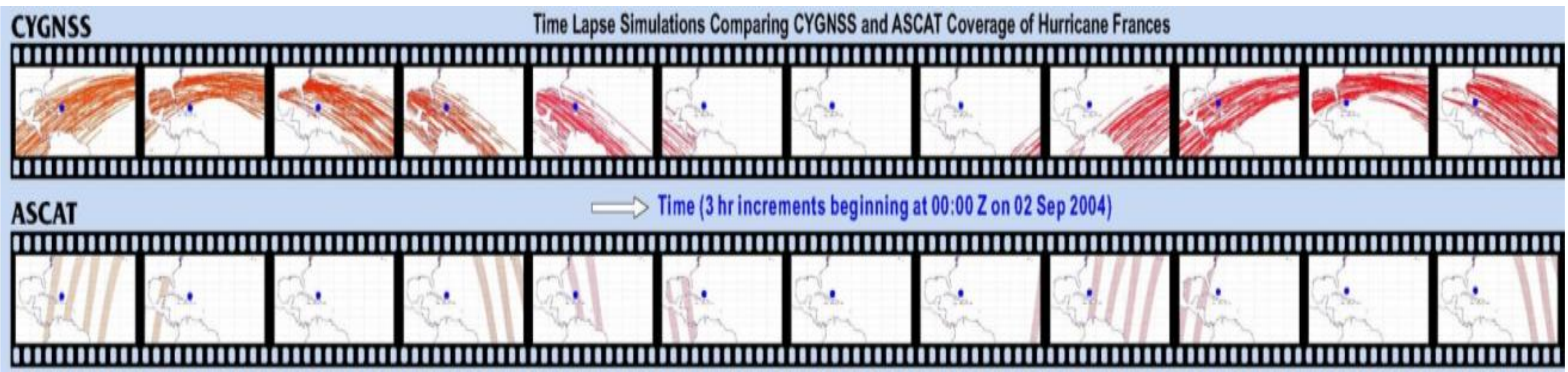
- Probability distribution of revisit time for all Earth samples within +/-35° (solid) and for samples of historical storm tracks (dashed).
- Revisit stats derived from PDF demonstrate 4 hr mean storm revisit and ~9 hr to revisit 90% of all storms



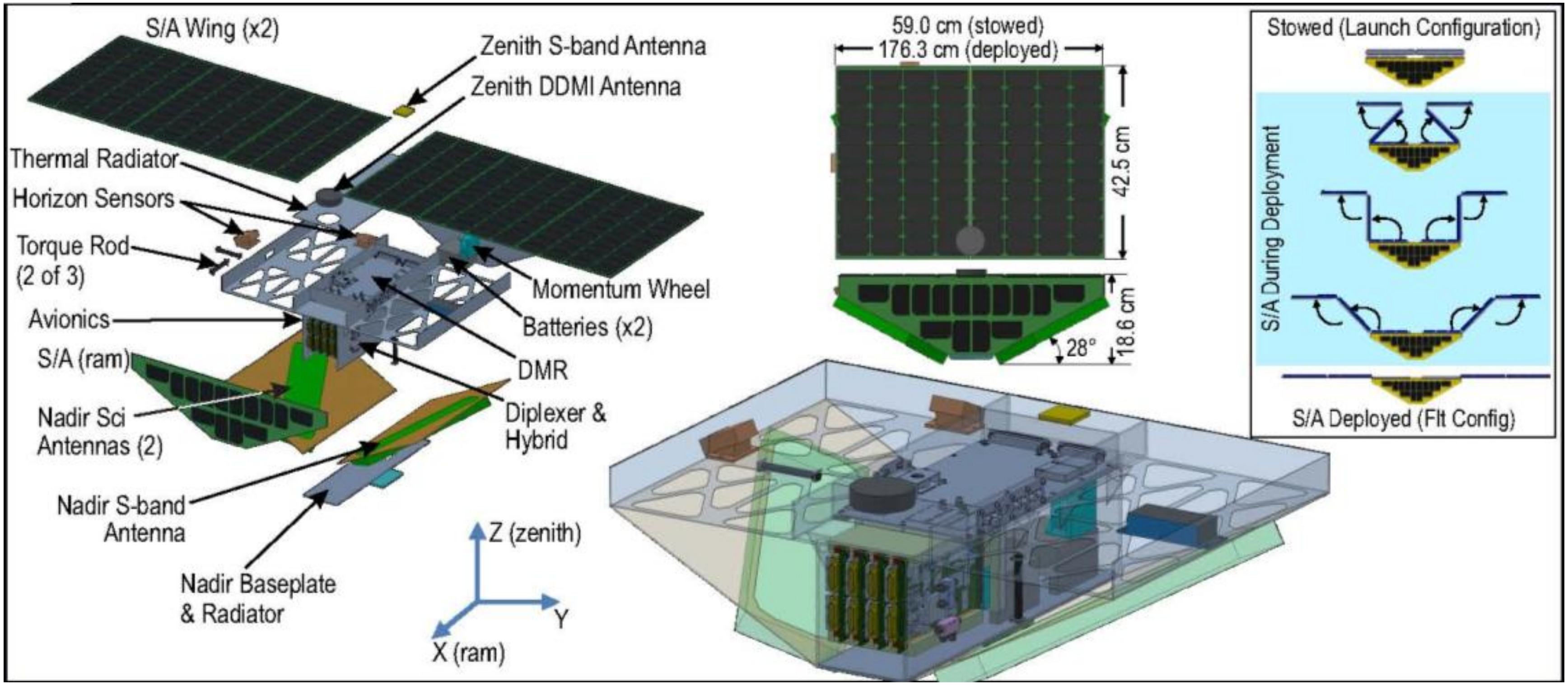
Revisit Statistics	Median	Mean	90% Cumulative
All Samples	1.6 hr	4.8 hr	14.4 hr
Storms Only	1.5 hr	4.0 hr	9.3 hr

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

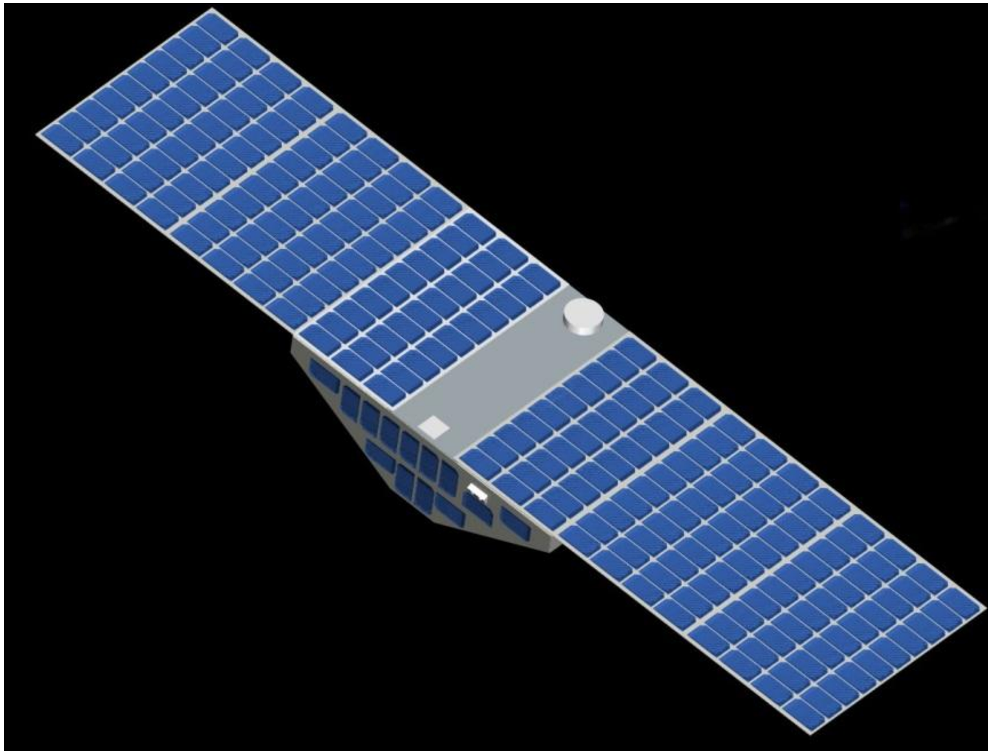


CYGNSS Observatory (exploded view)

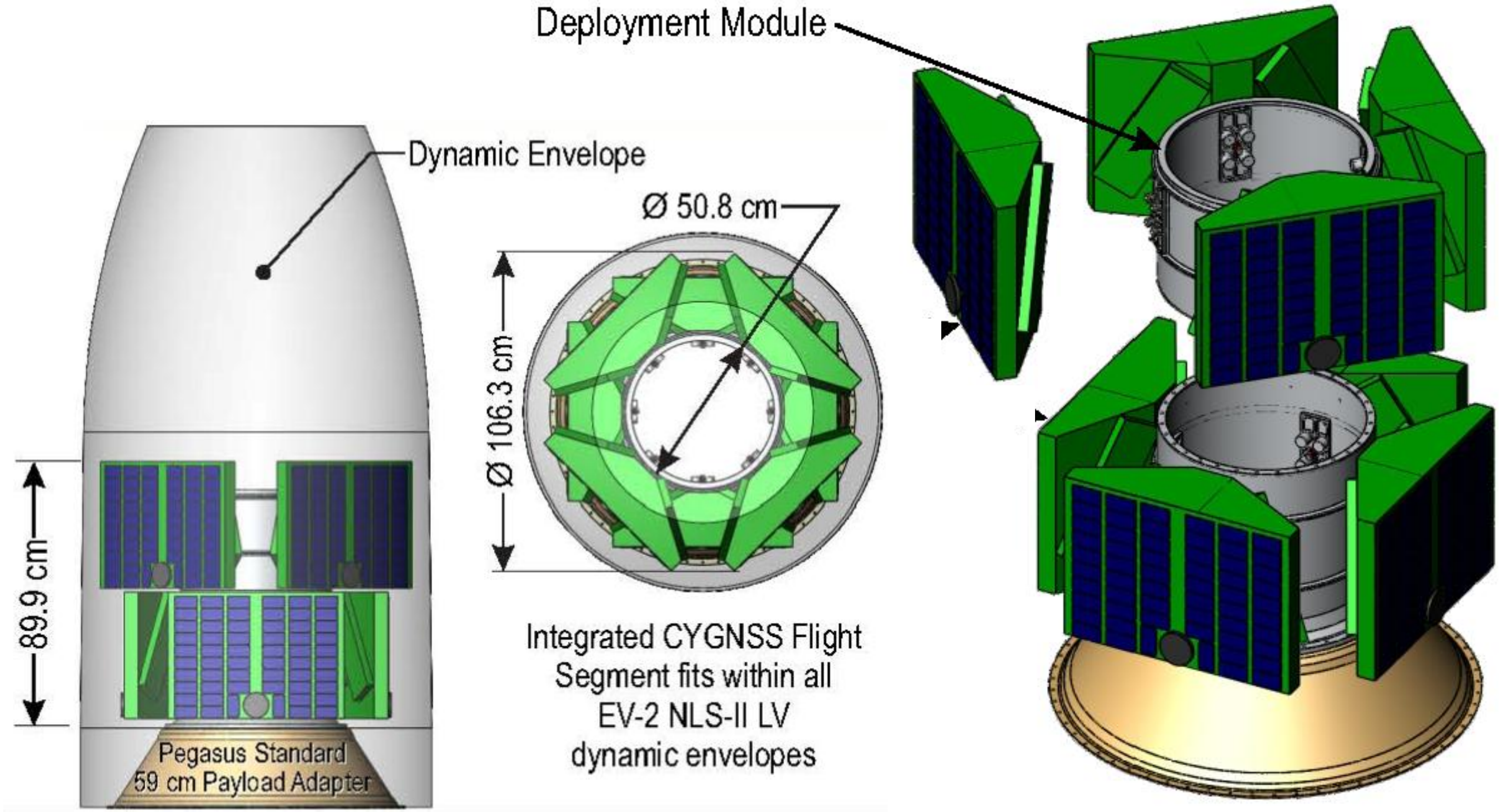


CYGNSS Observatory (1 of 8)

- **Observatory**
  - Power: 48.8 W (EOL margin 30.3%)
  - Comm: 1.25 Mbps S-Band (31% link margin)
  - Mass: 17.6 kg
- **Orbit**
  - Altitude: 500 km
  - Inclination: 35 deg
- **Launch**
  - 6 Oct 2016



Complete Flight Segment with Deployment Module



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