Decadal Survey Mission Development Symposium

DESDynI: Deformation, Ecosystem Structure, and Dynamics of Ice

Mission Study Progress

DESDynI Pre-Project Study Team

Jet Propulsion Laboratory/Goddard Space Flight Center

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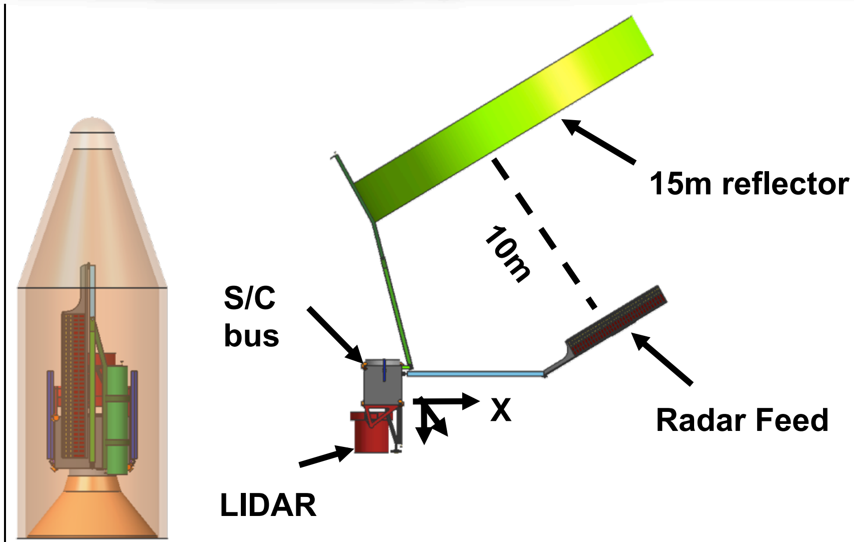
11 February 2009

DESDynI Mission Overview

- **DESDynI Mission Sciences**
  - *Deformation of Solid Earth for improving forecasts of seismic and volcanic events*
  - *Ecosystem Structure for improving carbon budgets and models and characterizing species habitats*
  - *Dynamics of Ice for improving understanding of changes in ice masses and climate*
- **DESDynI Instrumentation**
  - *Multi-beam Profiling Lidar*
  - *Fully-polarimetric Multi-mode L-band Radar*
  - *GPS receiver for precision orbit determination and reconstructions*



- **DESDynI Implementation Challenges**
  - *Accommodating multi-beam lidar and polarimetric radar on single platform*
    - Alternative: Two platforms – radar-only platform and lidar-only platform
  - *Integrating observation strategies among three sets of disciplinary science requirements with single radar and radar/lidar co-observations*
  - *Conducting flight/ground trades for orbit control for repeat-pass interferometry and for data rate/volume handling*
  - *Assessing alternate SAR techniques (ScanSAR vs. SweepSAR)*
  - *Assessing radar architecture using reflector with arrayed feed vs. planar phased array antenna*
  - *Exploring NASA mission cost reduction with foreign partners*

- **FY09 Objectives and Milestones**
  - *Antenna concept (reflector vs planar array) down-selection (Jan 2009)*
  - *Lidar instrument design definition (Dec 2008)*
  - *Team-X trade studies: radar+lidar single platform, radar-only platform and TanDEM-L (Jan 2009)*
  - *Lidar-only platform design assessment (Jan 2009)*
  - *Single vs Dual spacecraft down-selection (Mar 2009)*
  - *Mission Concept Review (Sep 2009)*
- **FY09 Deliverables**
  - *Application Workshop Report (Feb 2009)*
  - *Team-X/IDL/MDL Reports (Mar 2009)*
  - *MCR Project Documents (Sep 2009)*

Pre-Phase A Mission Study Overview

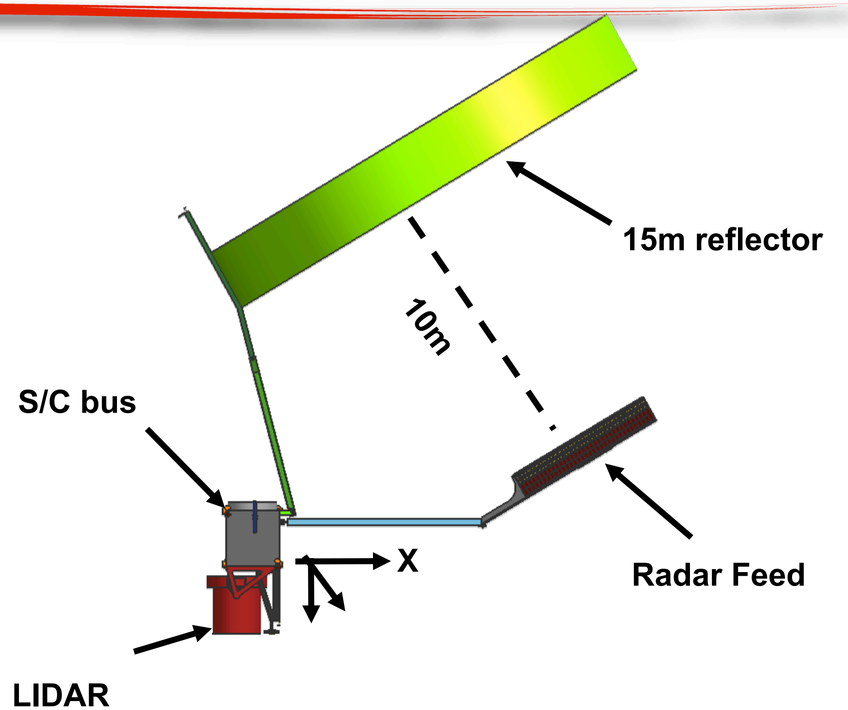
- Perform pre-phase A study with an end-to-end mission concept with life-cycle mission cost for MCR by the end of Sep ‘09, with KDP-A to follow
  - *Develop consistent set of requirements (science, mission systems) and a feasible end-to-end design that is compliant with requirements*
  - *Develop models and analysis tools; perform system sensitivity analyses and observation strategies*
  - *Perform analysis of alternates of mission architecture (one or two platforms) and instrument architecture (articulated or fixed lidar, planar or reflector antenna for radar, ScanSAR or SweepSAR)*
  - *Perform mission lifecycle cost estimate*
- Form Science Study Group to develop and integrate science requirements and observation strategies
- Technology Readiness Assessments
  - *Lidar laser in relevant environments*
  - *Mesh reflector thermal-elastic properties*
  - *New SAR technique (SweepSAR) could reduce SAR mode switching, hence contention*
  - *Large lidar aperture and gimbal design (for Co-flyer)*
- Explore international partnerships
  - *DLR on TanDEM-L for possible cost leverage in joint mission implementation*
  - *JAXA on ALOS-II for possible joint mission observation and data exchange*
  - *ESA on BIOMASS for possible joint mission observation and data exchange*
- Utilize team grass-root approach combined with JPL/GSFC concurrent design/costing capabilities
- Conduct application workshops for community engagement and buy-in

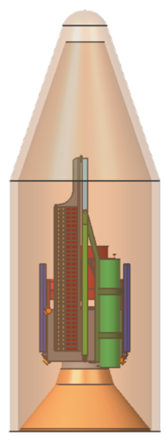
Platform Option Trades

- Option 1: Single spacecraft
  - *600 km orbit carrying lidar, synthetic aperture radar, and GPS receiver payload*
  - *(aka Co-Flyer)*
- Option 2: Two spacecraft
  - *One spacecraft in 760 km orbit carrying synthetic aperture radar and GPS receiver payload*
  - *The second spacecraft in 400 km orbit carrying lidar payload*
  - *(aka Free-Flyers)*
- Option 3: Three spacecraft
  - *Lidar free-flyer in 400km orbit*
  - *Two identical radar free-flyers in formation flight at 760km*
  - *Radar free-flyers would be in collaboration with DLR*

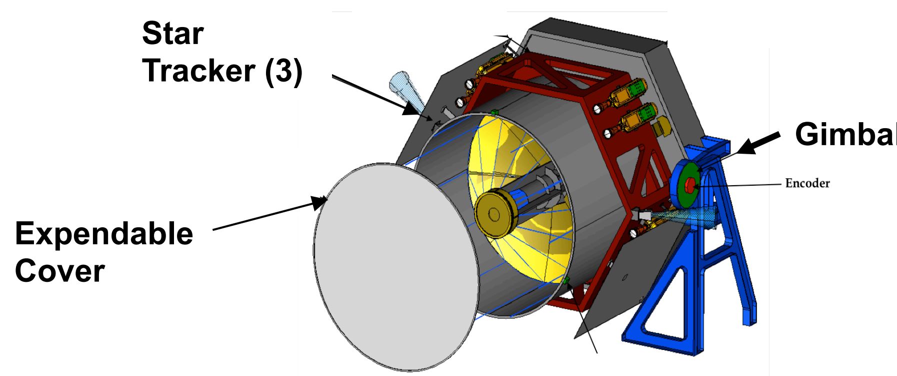
Option 1 Design

Payload	InSAR, Lidar, GPS
Orbit	600 km
Launch Mass	2947 kg
Repeat Cycle	8-12 Days
Required Power (orbit avg w/ margin)	2526 W
Payload Data Rate	Up to 2.4 Gbps Up to 0.5 Gbps Orbit avg.
Payload Risk Category	Class B
Launch Vehicle	Atlas V 501





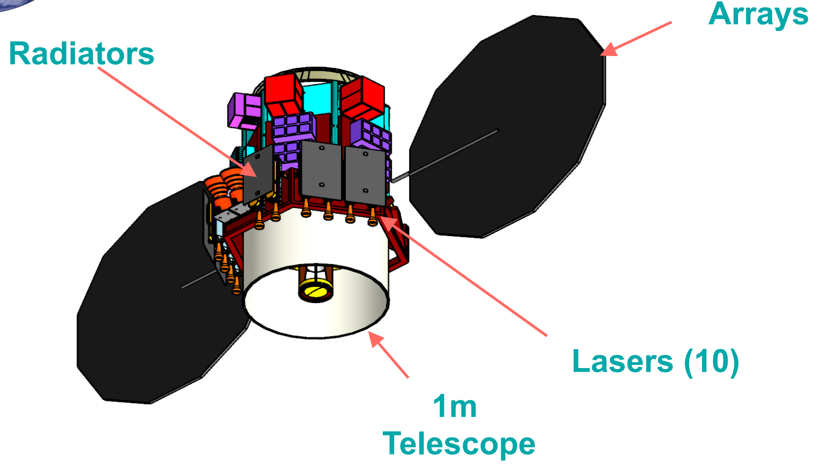
Launcher Fairing

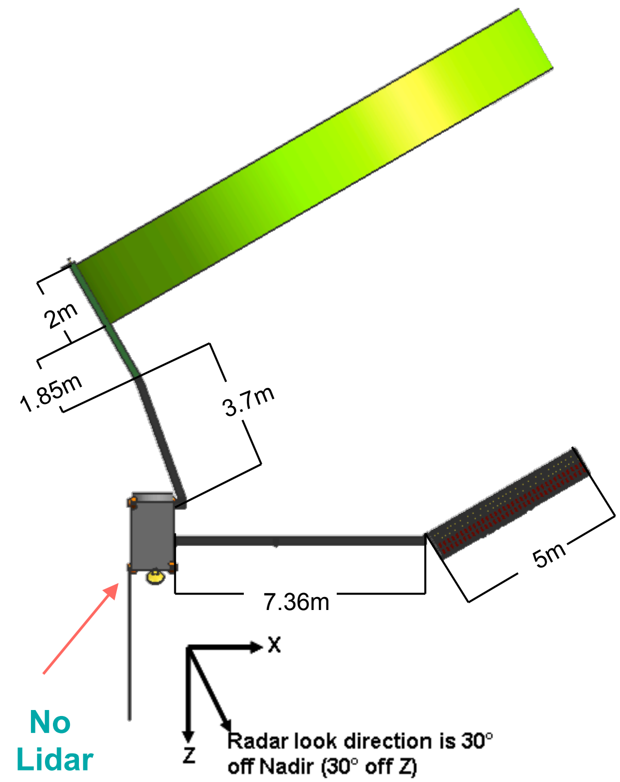


LIDAR

Option 2: Radar & Lidar Free-Flyers

Lidar Free-Flyer



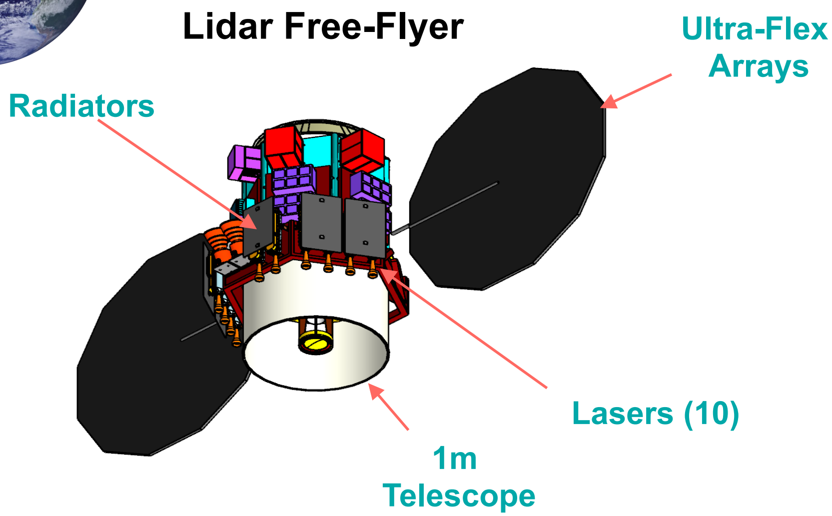


Radar Free-Flyer

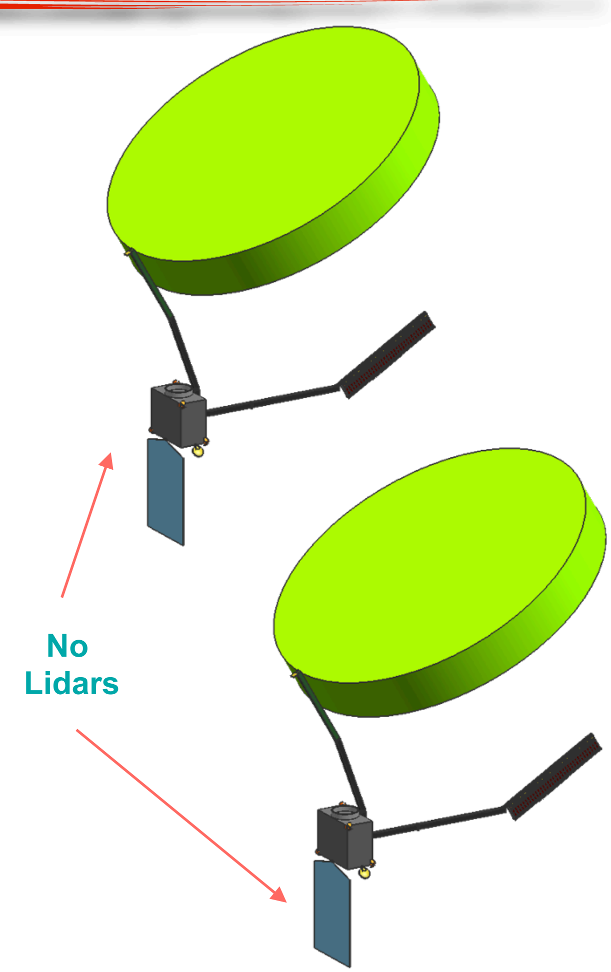
	Radar FF	LIDAR FF
Payload	InSAR, GPS	LIDAR
Orbit	760 km	400 km
Launch Mass	1964 kg	548 kg
Repeat Cycle	8 Days	90 Days
Required Power (orbit avg w/ margin)	1709 W	1117 W
Payload Data Rate	Up to 2.4 Gbps peak Up to 0.5 Gbps orbit avg.	~4 Mbps orbit avg.
Payload Risk Category	Class B	Class C (TBR)
Launch Vehicle	Atlas V 501	Taurus 3210

Option 3: Radar & Lidar Free-Flyers

Lidar Free-Flyer

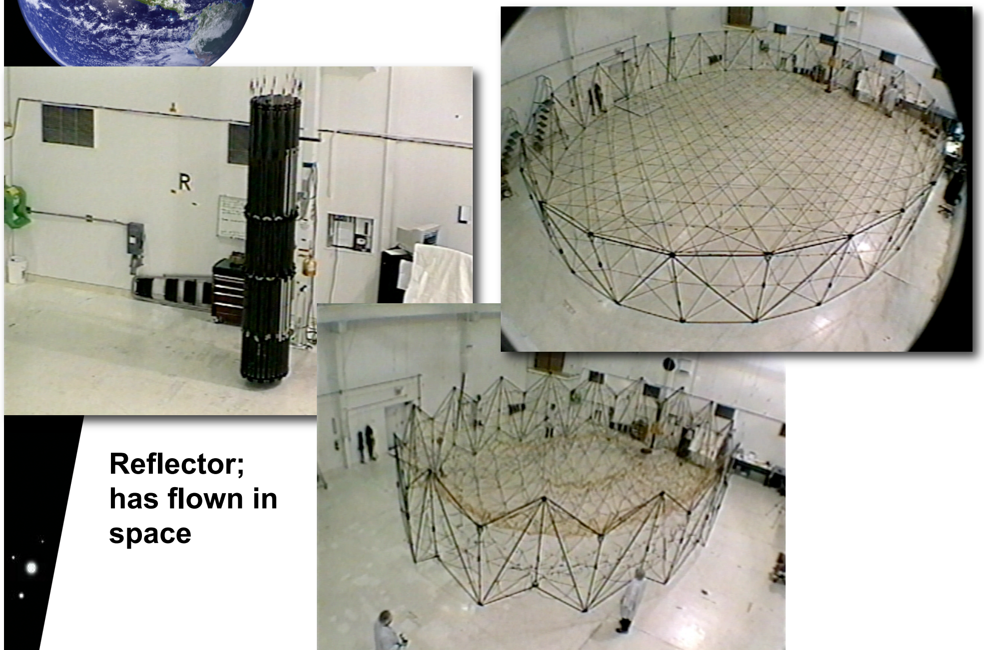


	Radar FFs (2)	LIDAR FF
Payload	InSAR, GPS, Optical Comm	LIDAR
Orbit	760 km (formation flight)	400 km
Launch Mass	4531 kg (both)	548 kg
Repeat Cycle	8 Days	90 Days
Required Power (orbit avg w/ margin)	1986 W (each)	1117 W
Payload Data Rate	Each up to 2.4 Gbps	~4 Mbps
Payload Risk Category	Class B (TBR)	Class C (TBR)
Launch Vehicle	TBD	Taurus 3210

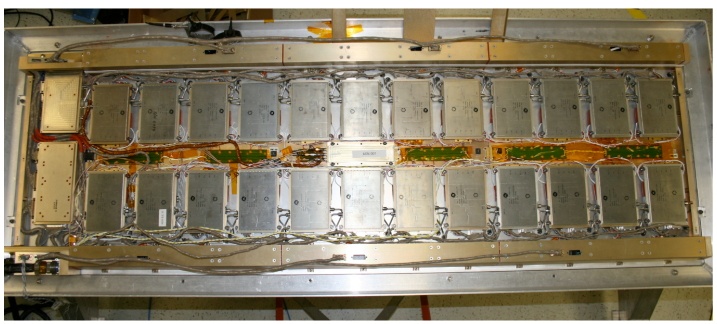


Radar Free-Flyers

DESDynI Radar Technologies

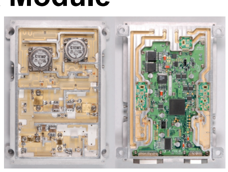


Reflector; has flown in space

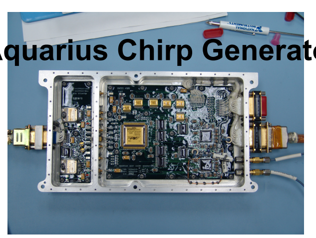


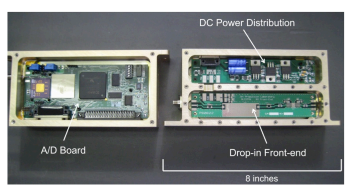
UAVSAR antenna as basis for DESDynI feed; needs engineering and packaging

UAVSAR 100 W T/R Module

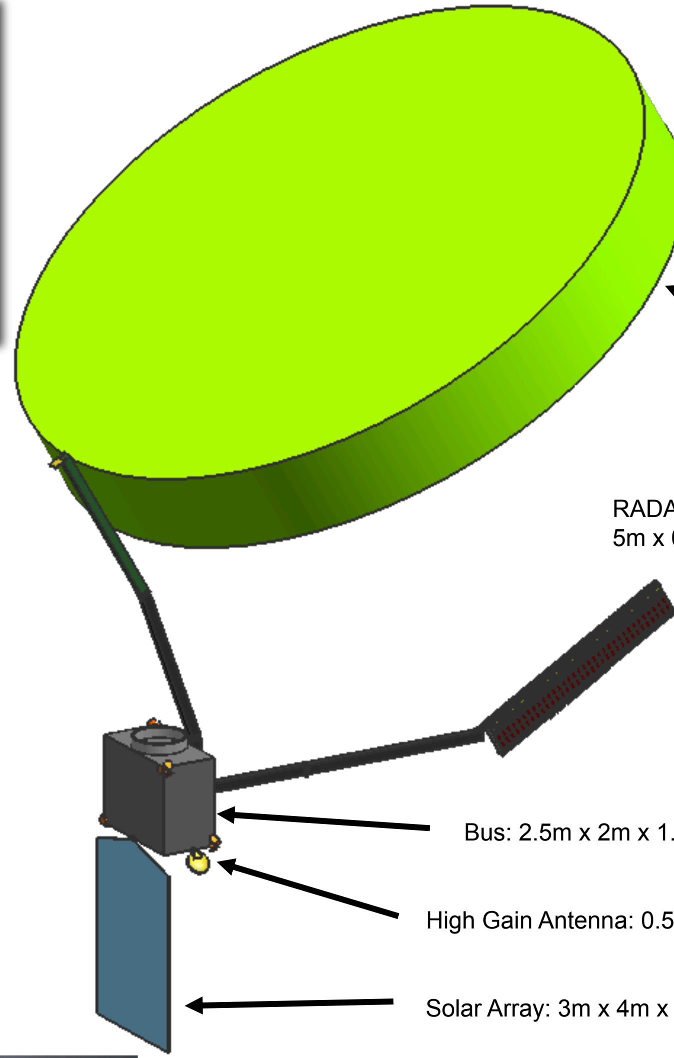


Aquarius Chirp Generator





Direct L-band Sampler (IIP)

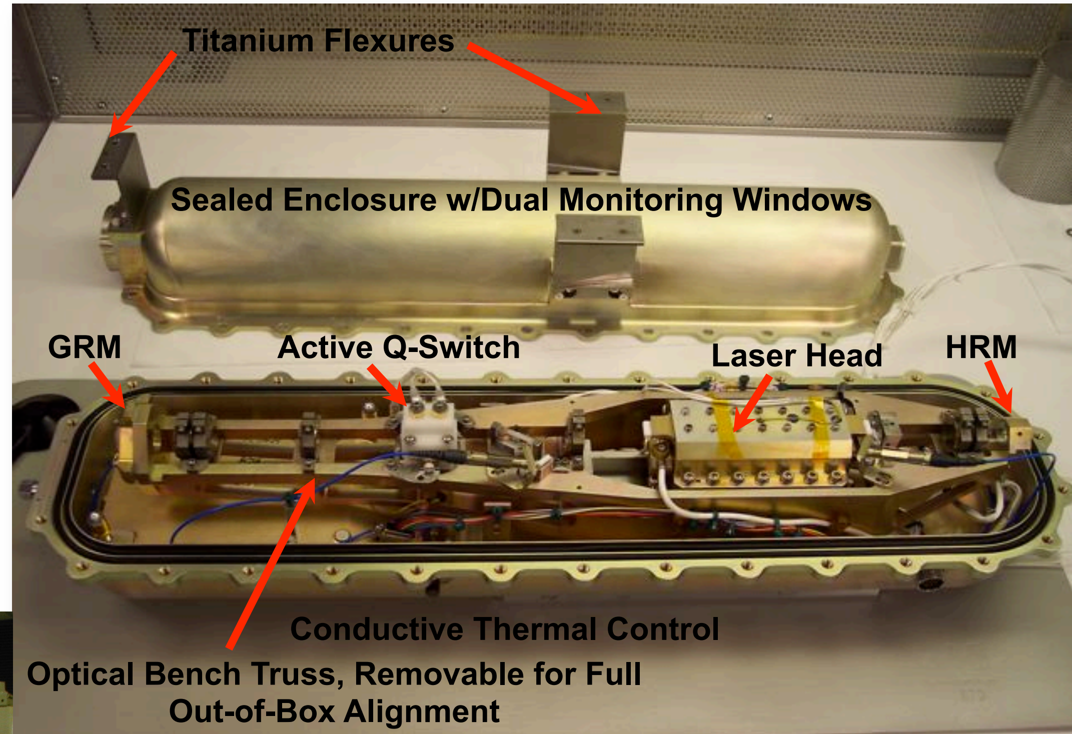


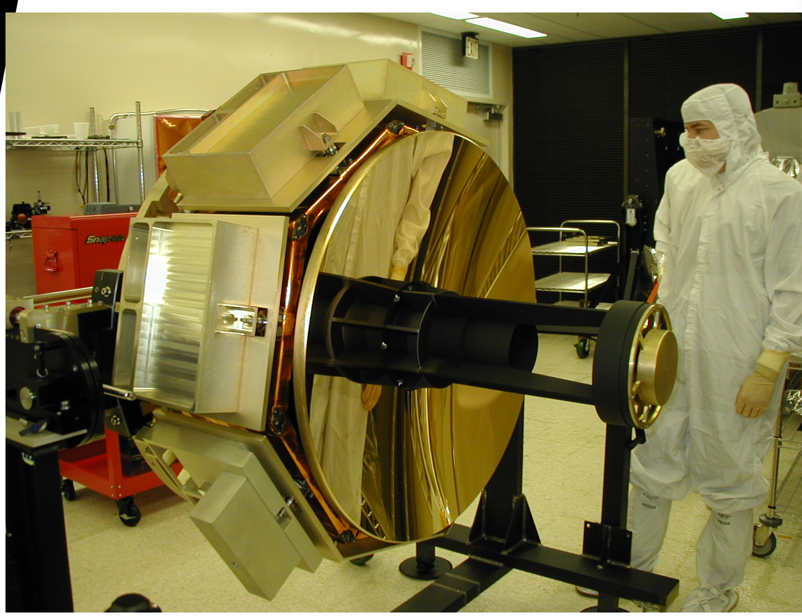
Composite tubes to RADAR feed and reflector have a square cross-section 0.2m on edge and a wall thickness of 2.5mm

DESDynI Lidar Technology

HOMER Laser

- Breadboard life-test
  - Multi-billion shots complete
- ETU Environmental tests
  - Vibe and T-VAC complete
- GSFC engineering review
  - Currently TRL-5
  - Specific tasks for achieving TRL-6 identified.





1 m diameter telescope

- GLAS heritage

Detectors

- TRL-9
- Heritage: MOLA, SLA, GLAS, MLA

To-Date Results: Accomplishments (1 of 2)

- Science
  - *Science requirements were documented in Draft Science Definition Document (Ver. 13)*
  - *Requirements traceability matrix was created*
  - *Completed comparative matrix to DLR TanDEM-L requirements (Ver. 5)*
- Science-to-Instrument Sensitivity Analysis
  - *Measurements error model defined and scoped; Error Model document drafted; Preliminary Solid Earth Error Assessment presented at Jan 09 TIM*
  - *UAVSAR flights (for repeat-pass and temporal decorrelation) planned*
  - *LVIS flights (for lidar off-pointing) conducted under R&A*
  - *Exchanged InSAR error models with DLR; agreed on the models and algorithms*
  - *Multi-Beam Lidar topography measurement studies for Cryo and solid Earth underway (FY09)- Rowlands (PI).*
  - *SAR Software Workshop held 7/28-31/08 and software development funded under AIST*
- Systems Engineering and Mission Design
  - *Completed Instrument and Mission Concept studies*
  - *Mission concept report outlined*
  - *Orbit control and error budget analyzed, meets requirement for repeat-pass InSAR*

To-Date Results: Accomplishments (2 of 2)

- Early requirements and designs of instruments & subsystems – radar, lidar, GPS receiver, and ground data systems
  - *Conducted preliminary assessment of radar architecture of using reflector with array feed vs. planar phased array, with reflector architecture selected*
  - *Contributed to reflector thermal-elastic model testing (under IPP)*
  - *Conducted vibration and thermal vacuum testing on Laser (under IRAD)*
    - GSFC internal assessment rated HOMER laser at TRL-5
- Significant progress on technology/mission options studies
  - *SweepSAR concept/technique explored for possible full-swath coverage operation to ease observation conflicts, with concept proven viable but may need simulation*
  - *DLR/TanDEM-L collaboration has been positive with good synergism,*
    - Exchanging science as well as mission/instrument design concept;
    - TanDEM-L non-zero baseline InSAR can further enhance science
  - *JAXA Collaboration possible for radiometric and orbital compatibility*
  - *Component technology at high level of maturity; some system technology is not as matured*
- Results documented
  - *DESDynI Website – desdyni.jpl.nasa.gov, to capture workshop reports, etc. now up and running for public and private (password-protected) access*
  - *DocuShare site for unreleased documents*

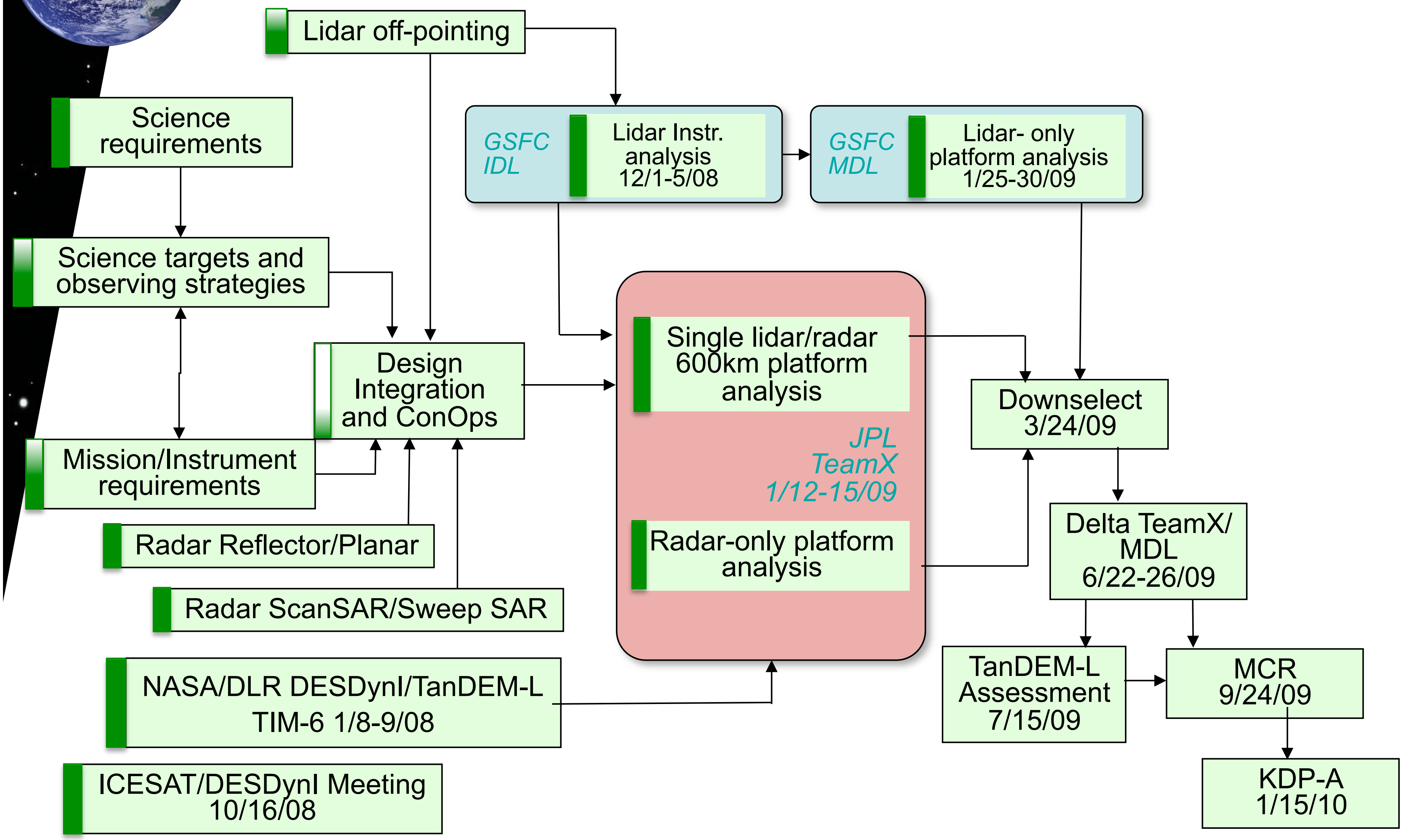
Meetings and Workshops Held

- DESDynI/TanDEM Technical Interchange Meeting (TIM) @JPL 4/7-8/08
- DESDynI Working Group Meeting @ GSFC 6/5-6/08
- DESDynI/TanDEM TIM @DLR 6/5-6/08
- DLR Science Meeting 6/9/08
- DESDynI/TanDEM TIM @Boston, following IGARSS 7/17-19/08
- DESDynI Science/Working Group Meeting @Greenbelt 10/14-15/08
- DESDynI/ICESat-II Conference 10/16/08
  - *Decision made not to further study or consider putting DESDynI lidar on ICESat-II platform*
- DESDynI Application Workshop @Sacramento 10/29-31/08
  - *Strong endorsement from multi-agency application users*
- DESDynI/TanDEM TIM and Science Meeting @ DLR 11/11-14/08
- Instrument Design lab @GSFC for Co-Flyer Lidar instrument 11/17-11/21
- DESDynI/TanDEM TIM @JPL 1/8-9/09
- TEAM-X Mission design studies of Co-flyer, Radar Only and Tandem-L architectures 1/12-15/09
- Mission Design Lab study of Free-Flying LIDAR platform 1/26-29/09

FY09 Plan

Milestone/Deliverable	Schedule
1. Preliminary set of science and measurement requirements	Complete
2. Preliminary assessment of lidar off-pointing and radar quad-pol wide swath mode	Mid-Feb 2009
3. Preliminary AoAs for US options, including findings from Team-X and IDC sessions	Complete
4. Start to prepare and solicit industrial information	Mid-Feb 2009
5. Review of US AoA options to select the most feasible option for further detailing in preparation for the MCR	Early-Mar 2009
6. Preliminary AoA for Tandem-L option	End-Mar 2009
7. Consolidating strawman requirements and design	End-Apr 2009
8. Draft programmatic documents for MCR/KDP-A	End-Jun 2009
9. Draft technical documents for MCR/KDP-A	End-Jul 2009
10. Conduct Acquisition, Strategy Planning meeting (with ESM PO and HQ)	End-Aug 2009
11. Conduct Centers and partners internal reviews	End-Aug 2009
12. Mission Concept Review with final MCR documents completed	End-Sep 2009
13. Draft Formulation Authorization Document (from HQ)	End-Nov 2009
14. KDP-A Review with final KDP-A documents completed (by HQ)	End-Jan 2010
15. HQ Approves Start of Formulation Phase (Phase A)	Begin-Apr 2010

Mission Design Study Flow/Schedule



DESDynI Study Challenges

- Single (with gimbaled lidar) versus dual platform configuration and decision criteria
  - *Science and partnering vs. operational complexity and cost*
- Integration of multi-discipline observation requirements for radar
  - *Requires prioritizing use of radar for three sets of science disciplinary requirements over the mission life cycle*
  - *Limits data acquisition for applications community*
- Radar operations and coverage are data rate/volume limited
  - *300+Mbps rate at 30% duty cycle for nominal radar modes (Quad-Pol/Dual-Pol)*
  - *> 2 Gbps rate at similar duty cycles for SweepSAR mode*
  - *Increasing downlink capacities would greatly enhance mission performance*
- Integration of TanDEM-L or ALOS-2 requirements and schedules with varying degrees of difference in
  - *Science objectives, technology infusion, schedule*
- Pre-launch V&V for test-as-you-fly-it
  - *Large deployable radar structure and system level V&V may need test facility improvement or new facility*
- FY'09 work was front-loaded to get to platform down-selection
  - *Additional funds would improve robustness of MCR products, reduce risk*

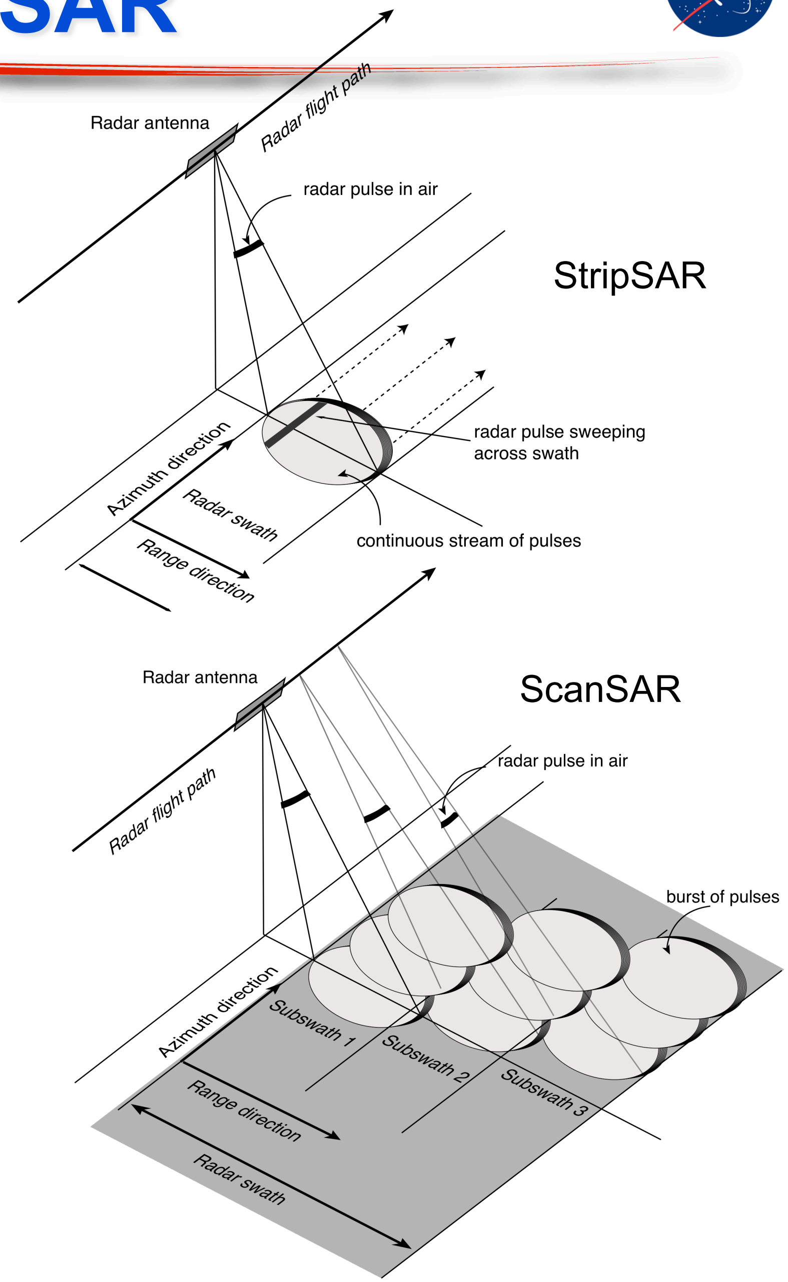
DESDynI Study Opportunities

- Opportunities for joint development for cost leverage
  - *ICESat-II Joint procurements & collaborative development*
    - For Lidar-only platform: Commonality with ICESat-II: Beryllium telescope, detectors, analog to digital converters, test facilities, procedures, MOC, SOC.
  - *With TanDEM-L for radar-only platform:*
    - Joint mission development; enhanced comm capabilities with DLR infrastructure; additional science products (DEM; interferometrically-derived 3D structure)
  - *Co-manifest launch for dual platforms*
  - *GPS RO constellation contributor*
  - *Design and architecture of SMAP, DESDynI, SWOT, (XOVWM) radar hardware*
    - Principal instrument engineer for all instrument concepts was the same person (Louise Veilleux, JPL), designing with an eye toward commonality and technology infusion
    - Many components share common designs and interfaces, and can be made unique for missions with small adjustments
  - *Explore NASA options for enhanced telecom/downlink, crucial for high data-rate missions such as DESDynI, SWOT, HyspIRI, LIST.*
  - *SWOT and DESDynI: possible shared ground processing architecture*
  - *Explore common bus procurement*
  - *Develop standards for radiometric compatibility and formation flight*
    - This could be major step towards GEOSS and CEOS constellation goals.
- Science and Technology
  - *Infusion of technology and new techniques*
  - *Radar and lidar data fusion*

Back-Up Charts

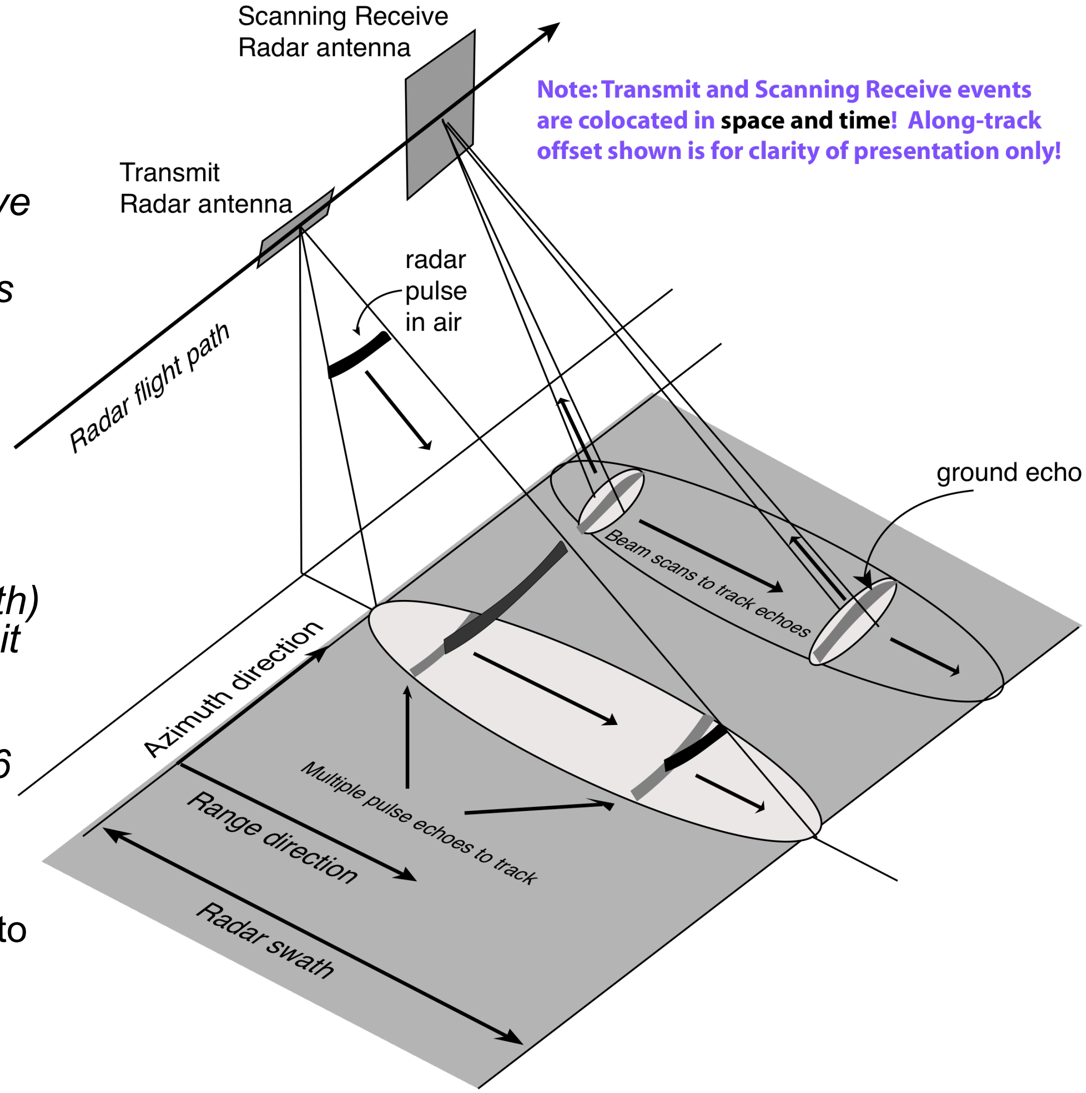
StripSAR vs ScanSAR

- What is StripSAR?
  - *Standard SAR mode*
  - *Send a pulse of energy; receive echo; repeat*
  - *Swath width limited by radar ambiguities*
- What is ScanSAR?
  - *Wider swath low resolution SAR mode*
  - *Execute sequence as follows:*
    - Send a pulse of energy; receive echo; repeat 50-100 times
    - Repoint the beam across-track to position 2 electrically (almost instantaneous)
    - Send a pulse of energy; receive echo; repeat 50-100 times
    - Repoint the beam across-track to position 3 electrically (almost instantaneous)
    - Send a pulse of energy; receive echo; repeat 50-100 times
  - *ScanSAR trades resolution (in along-track dimension) for swath: low impact on data rate*
  - *Generally poorer ambiguity and radiometric performance than Strip SAR*
- Note: For each case, pulse energy is localized in a narrow portion of the radar swath elevation beam



SweepSAR

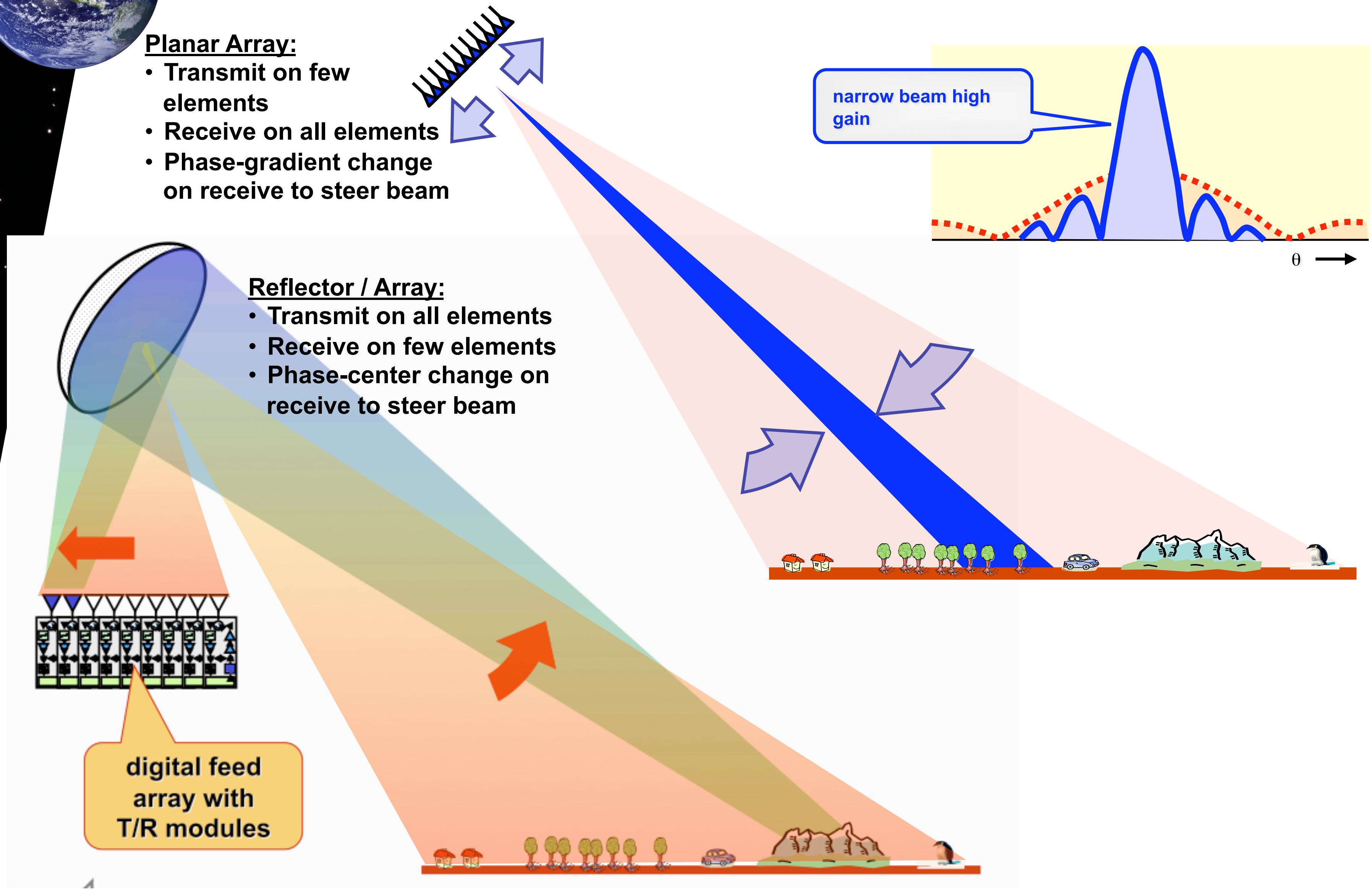
- What is SweepSAR?
  - *Transmit pulse over wide beam in elevation*
  - *Receive echo over narrow beam tracking echo with scanning receive beam*
  - *Can require multiple simultaneous receive beams to ttrack multiple echoes*
- What does SweepSAR Imply?
  - *Wide swath with no loss in resolution*
  - *Narrow gaps (about the pulse width) when receiver is off during transmit event (fixed in processing)*
  - *Data rate for equivalent StripSAR resolution increases by from 2 to 6 times*
    - Possibly multiple echoes to track simultaneously
    - 2 adjacent beams simultaneously to cover pulse transition from one beam to the next



Two forms of Scan-on-Receive

Planar Array:
- Transmit on few elements
- Receive on all elements
- Phase-gradient change on receive to steer beam

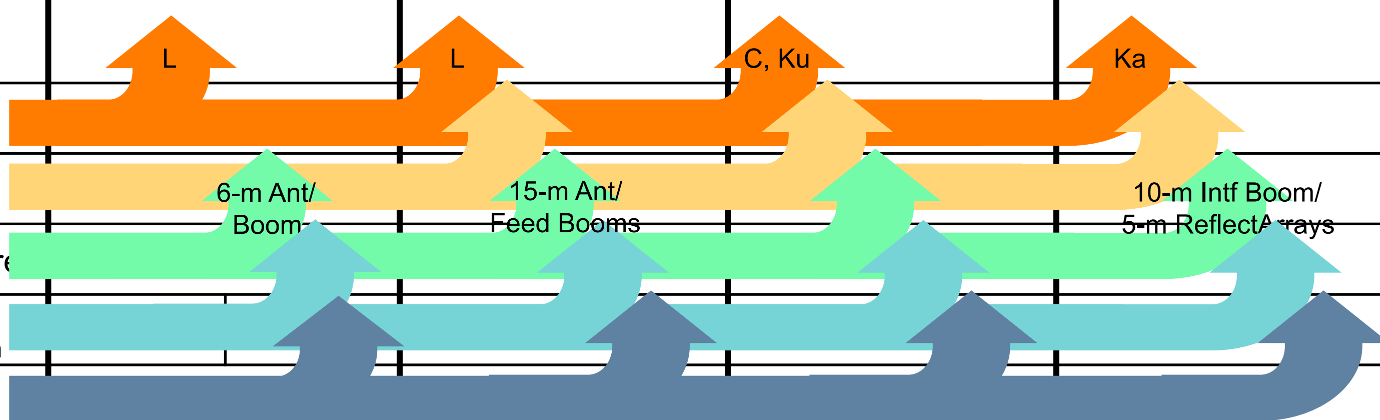
Reflector / Array:
- Transmit on all elements
- Receive on few elements
- Phase-center change on receive to steer beam



Near-Term Earth Science Missions Involving Radar

- Instrument development technical activities

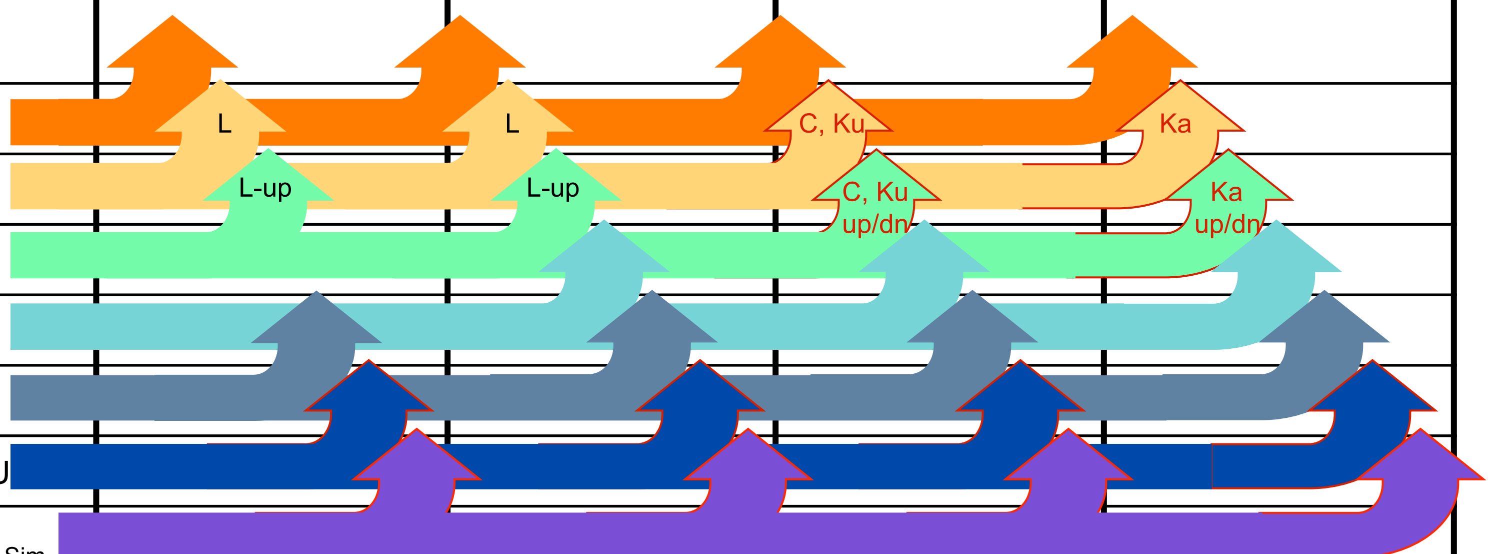
Mission (~Launch)	SMAP (13)		DESDynI (15)		DFS (17)		SWOT (17)	
Phase (~09 / ~10)	B	C	Pre-A	A	Pre-A	A	Pre-A	A
System Eng	4	5	2	3	2	3	2	3
Electronics	8	20	4	8	3	8	4	8
Mech/Thermal	8	20	3	5	2	4	3	5
Antenna	2	2	1	3	1	2	1	2
Cross-Cutting Technologies	L		L		C, Ku		Ka	
Radar Electronics								
FSW	6-m Ant/ Boom		15-m Ant/ Feed Booms				10-m Intf Boom/ 5-m Reflectarrays	
Deployable Structures								
EGSE •Target Sim •Testbed, I/F Sim								
MGSE								
Mission-Unique Technologies	•Large Spinning Reflector •Electronics Interfaces thru Slip Rings / Rotary Joint		•Large Light-Weight Reflector •Active Array Feed •High-Throughput DSPs •High-Efficiency T/Rs •Thermal-Cycle Mitigation		•C, Ku-Band TWTAs •C, Ku Loop-Back Cal •Spinning Antenna •4-Channel Rotary Joint		•Reflectarray Antennas •High-Throughput DSP •Ka EIK/TWTA •Phase-Tracking Electronics	



Near-Term Earth Science Missions Involving Radar

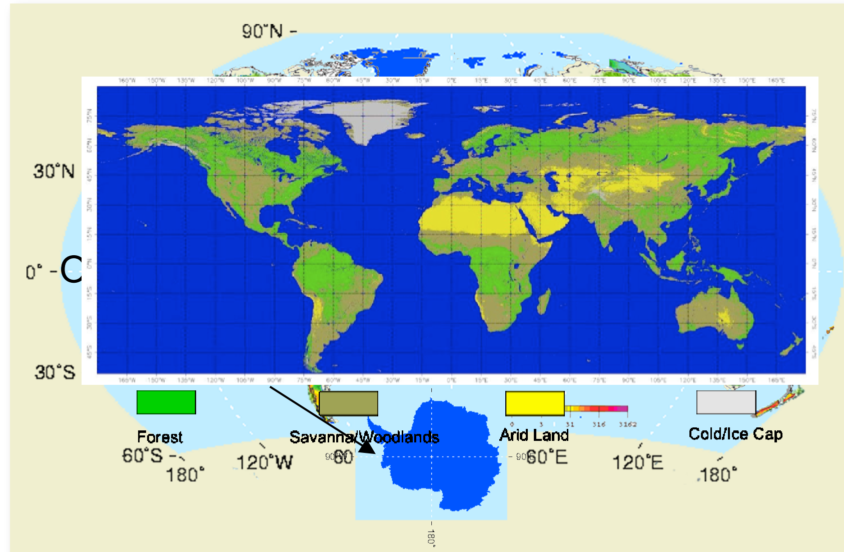
Radar development technical activities

Mission (Launch?)	SMAP (13)		DESDynI (15)		DFS (17)		SWOT (17)	
Phase (~09 / ~10)	B	C	Pre-A	A	Pre-A	A	Pre-A	A
Inst Oversight	LV 0.4	LV 0.2	LV 0.4	LV 0.6	LV 0.1	LV 0.1	LV 0.2	LV 0.2
SE - Perf	MS/CJ	MS/CJ	CC/SS	CC/SS	SD/DP	SD/DP	DF/BP	DF/BP
SE - Inst	KW/MF	KW						
RF Cog	DP	DP						
Dig Cog	MP/CC/VD	MP/CC/VD						
Cross-Cutting Technologies								
Chip Gen								
Freq Synth								
Up/Down-Conv								
CPU								
ADC								
FPGA-CTU/DPU								
EGSE •Target Sim •Testbed, I/F Sim								
Mission-Unique Technologies	•Interfaces thru Slip Rings		•High-Throughput DSPs •High-Efficiency T/R •Thermal-Cycle Mitigation		•C, Ku-Band TWTAs •C, Ku Loop-Back Cal		•High-Throughput DSP •Ka EIK/TWTA •Phase-Tracking	

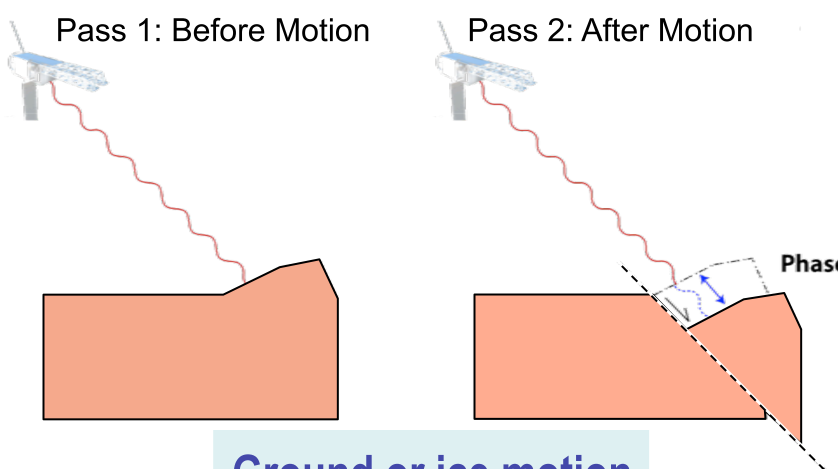


DESDynI: Deformation, Ecosystem Structure, and Dynamics of Ice

- Recommended by the NRC Decadal Survey for near-term launch to address important scientific questions of high societal impact:
- How do we manage the changing landscape caused by the massive release of energy of earthquakes and volcanoes?
- How are Earth's carbon cycle and ecosystems changing, and what are the consequences?
- What drives the changes in ice masses and how does it relate to the climate?

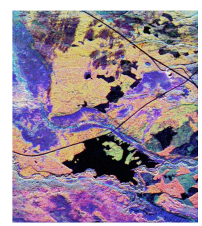


Repeat Pass InSAR

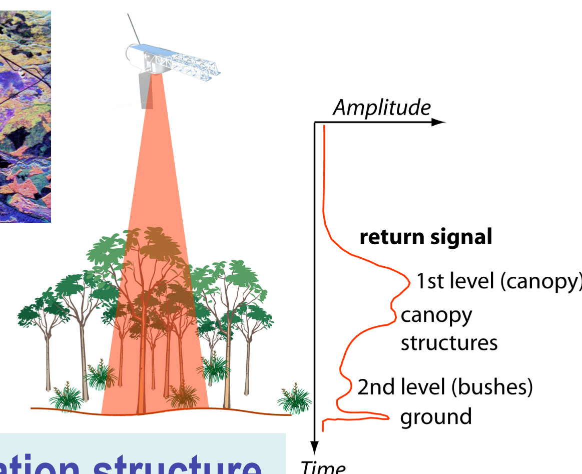


Ground or ice motion

Polarimetric SAR



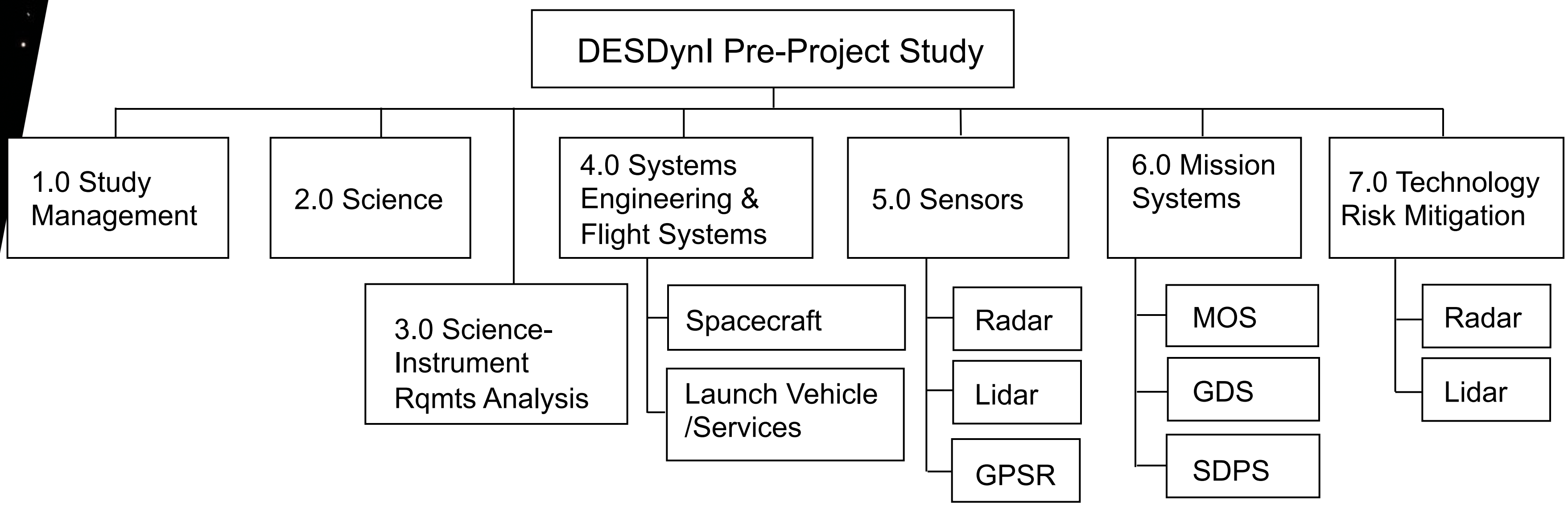
Multibeam LIDAR



Vegetation structure

Pre-Phase A Study WBS

- Pre-Phase Study WBS (Adapted from NPR 7120.5D WBS)



- Will use full L1 WBS for mission cost estimates and MCR, for either single platform (w/ radar+lidar) or dual platforms (radar-only and lidar-only)

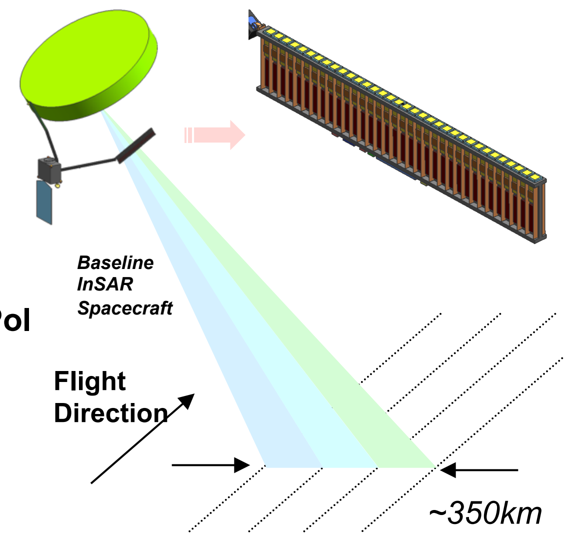
Documents and Life Cycle Schedule

- Per NASA Procedure Requirement 7120.5D “NASA Flight Project Management Processes and Requirements”
- Mission Concept Review
  - *Leve1-Level 3 Requirements*
  - *Mission Operation Concept and Design Document (with analysis of alternates)*
  - *Project Work Breakdown Structure (WBS) and Dictionary*
  - *Lifecycle Networked Schedule*
  - *Lifecycle Cost Estimate*
  - *System Acquisition Strategy/Plan*
  - *Phase A Task Plan and (JPL Internal Work Agreements)*
- Key Decision-A to enter Project into Phase-A
  - *Draft Project Formulation Authorization Document*
  - *MCR Review Report*
  - *Project and Program Recommendations*
- DESDynI implementation schedule (to be assessed, depending on funding profile, personnel availability and long-lead item development)
  - *Phase A: 5-6 months*
  - *Phase B: 8-10 months*
  - *Phase C/D: 33-39 months*
  - *Phase E: 60 months*

L-band Pol-SAR Shared Platform Concept

Configuration and Concept

L-Band SAR
Single/Dual/Quad Pol
3-Beams, Right (shown) or Left Looking
Strip Mode
ScanSAR Mode
SweepSAR Mode



Technology

Key required advanced technology investments have already been made

- L-band TR modules, antenna designs, trade studies, and modeling and simulation ($20M over 10 years
- Under ESTO, UAVSAR system for quad-pol InSAR from aircraft ($7M)
- Smaller size reflector (<12m) flown; thermal modeling and pointing under investigation

Total investment to date: $27M

Engineering and packaging tasks remain

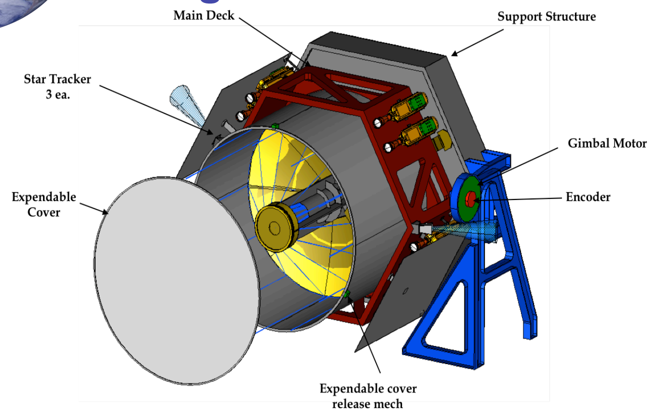
Features

- L-Band InSAR Phased Array Feed
- 15m Mesh Reflector
- Instrument is Dual Mode:
  - Single/Dual-Pol. Mode – 3 Beams, 120km Swath
  - Quad-Pol. Mode – 6 beams, 60km Swath
- 28 Patches are used in different combination to form S-Pol and Q-Pol Beams (see figure)
- Large panel area facilitates heat dissipation for the phased array
- Beams can be electronically steered for fast beam switching, or ScanSAR Mode
- SweepSAR mode leads to wider quad-pol swath, currently under investigation

Instrument Mode	L-Band S-Pol	L-Band Q-Pol
Antenna Size (m, dia)	15 (3 beams)	15 (6 Beams)
Bandwidth (Center) (MHz)	25 (1250)	25 (1250)
Peak Power (kW)	2.8	1.2
Look Angle (Deg)	25°/31°/37°	24° to 36°
PRF (Hz)	1300	2600
Swath Width (Km)	130/110/120	370 (50-77)
Res. (1 look) (m x m)	8 x 30 (scan) 8 x 8 (cont.)	11 x 8
NEσ_0 (dB)	-30	-35
Total Ambiguities (dB)	-20	-20
Data Rate (Mbps)	160/170/200	400

Multi-Beam Vegetation Shared Platform Lidar Concept

Configuration



- Lasers, Telescope, Gyro, and Star Tracker all tightly-coupled on composite optical bench
- Primary mirror diameter: 1.5m

Features of the Instrument Concept

Nadir-pointed Multi-Beam Lidar (1064 nm)

- 5- beams spaced nominally 5 km across-track
- 25 m laser footprint, 30 m along track spacing
- Multi-Beam Lidar operates as a vegetation structure sampler

Expected Multi-Beam Lidar Lifetime

- 6+ years
- Laser tested to 5 B shots.
- Diodes tested to equivalent of 3 years of operations (so far) with <1 % degradation.

Performance:

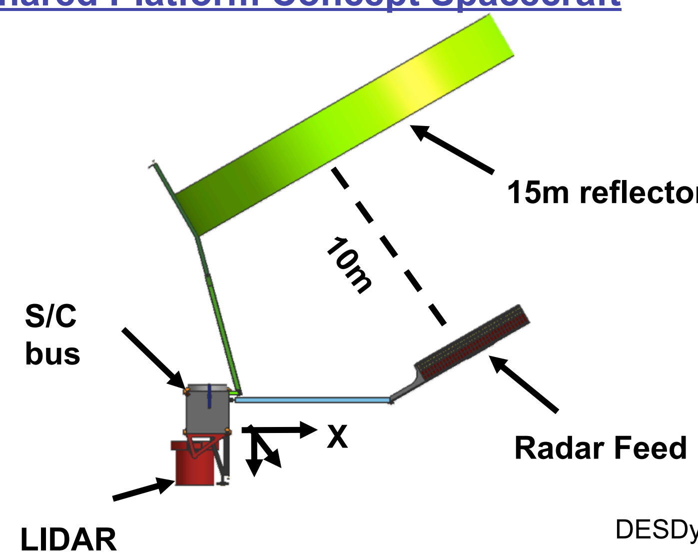
- Range Resolution: 3 cm (bare ground), 1 m (vegetation)
- Geolocation accuracy: 10m horiz., < 0.1 m vertical

Technology Development Needs

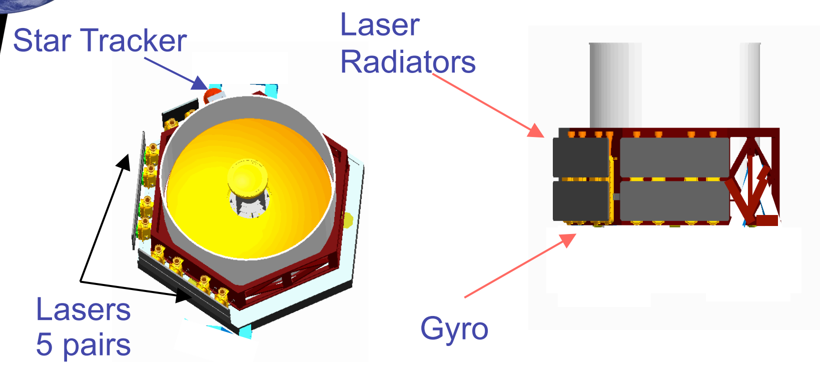
Laser transmitter is currently at TRL 5:

- GSFC-designed HOMER laser tested to full flight performance requirements (output power, rep rate, beam quality, efficiency, and lifetime)
- All components space qualified (TRL 6 or higher)
- Testing of laser ETU in FY08 has verified the Multi-Beam Lidar performance in a relevant environment (vibration, thermal vacuum, etc.) to TRL 5.

Shared Platform Concept Spacecraft



Multi-Beam Vegetation Free Flyer Lidar Concept



- Lasers, Telescope, Gyro, and Star Tracker all tightly-coupled on composite optical bench
- Primary mirror diameter: 1.0m

Features of the Instrument Concept

Nadir-pointed Multi-Beam Lidar (1064 nm)

- 5- beams spaced nominally 5 km across-track
- 25 m laser footprint, 30 m along track spacing
- Multi-Beam Lidar operates as a vegetation structure sampler

Expected Multi-Beam Lidar Lifetime

- 6+ years
- Laser tested to 5 B shots.
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Performance:

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Technology Development Needs

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- Testing of laser ETU in FY08 has verified the Multi-Beam Lidar performance in a relevant environment (vibration, thermal vacuum, etc.) to TRL 5.

Lidar Free-Flyer