DSENDS:
Multi-mission Flight Dynamics Simulator for NASA Missions

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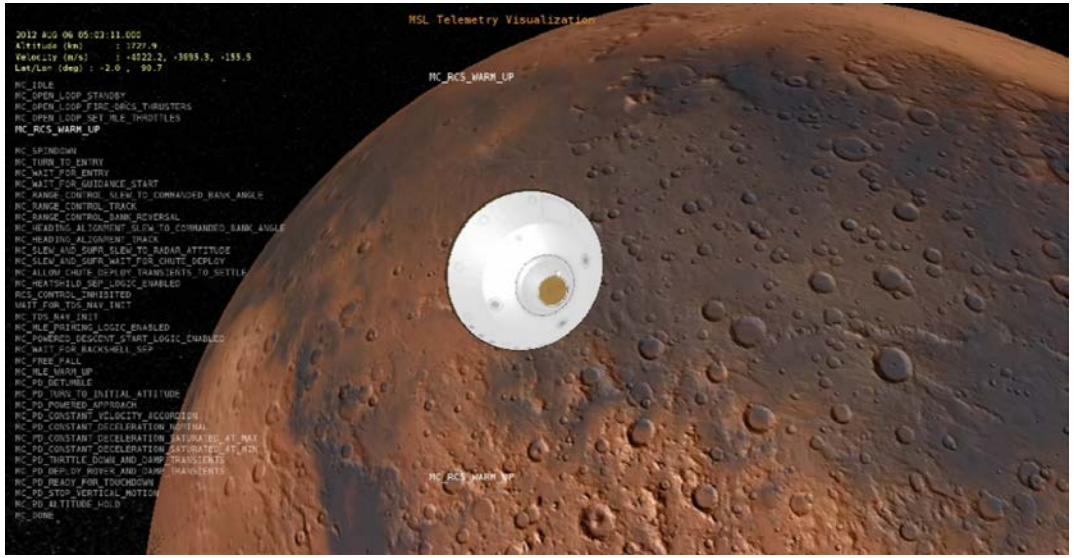
September 14, 2016

Background

Mars Science Lab landing



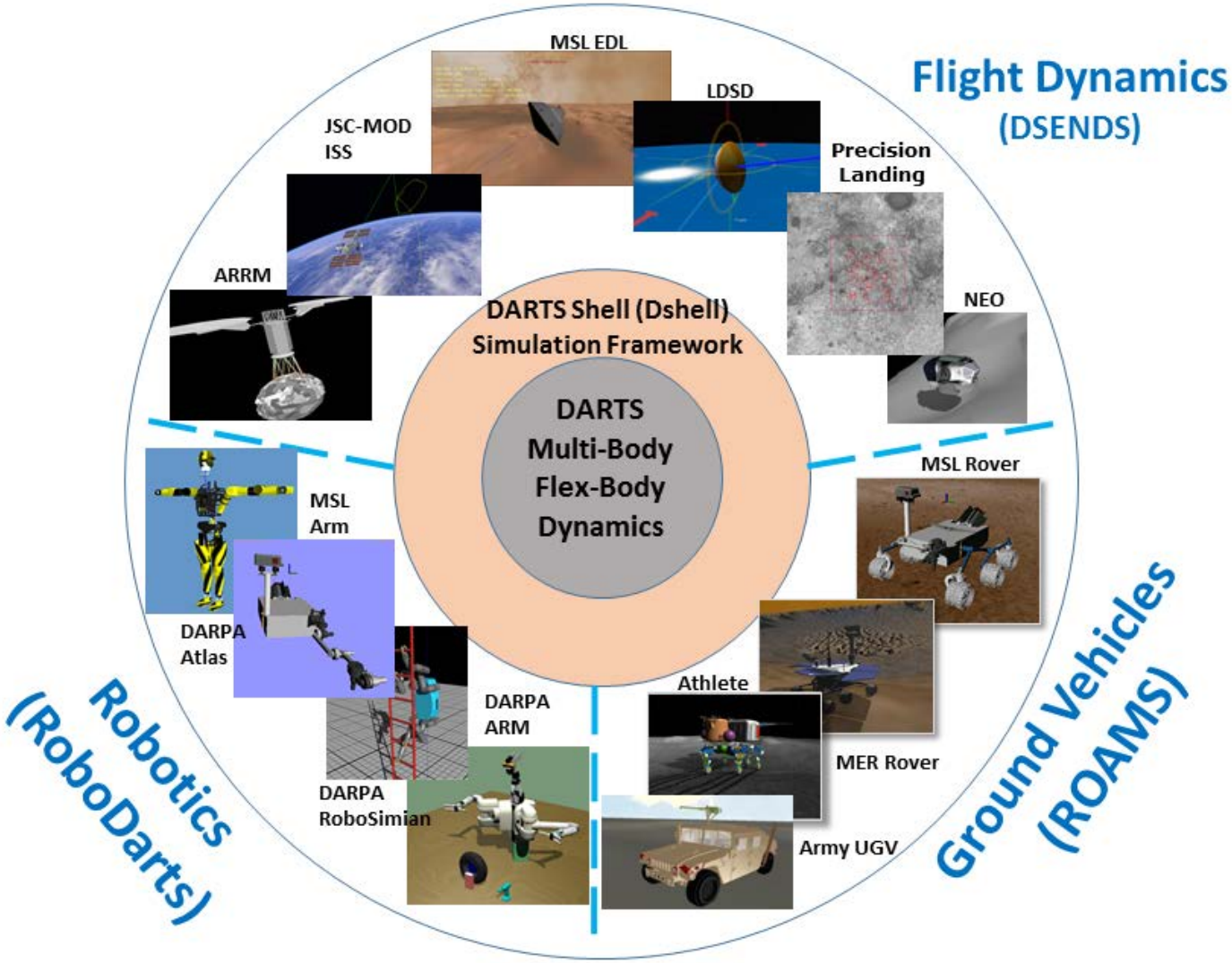
Planetary Ascent, Entry, Descent, Landing and Rendezvous requires a wide range of models

- Planetary bodies
- Orbital mechanics
- Gravity
- Aerodynamics (EDL)
- Inertial sensing (IMU)
- Surface sensing (altimeter, RADAR)
- Thrusters
- Fuel tanks and manifolds
- Deployment/separation mechanisms

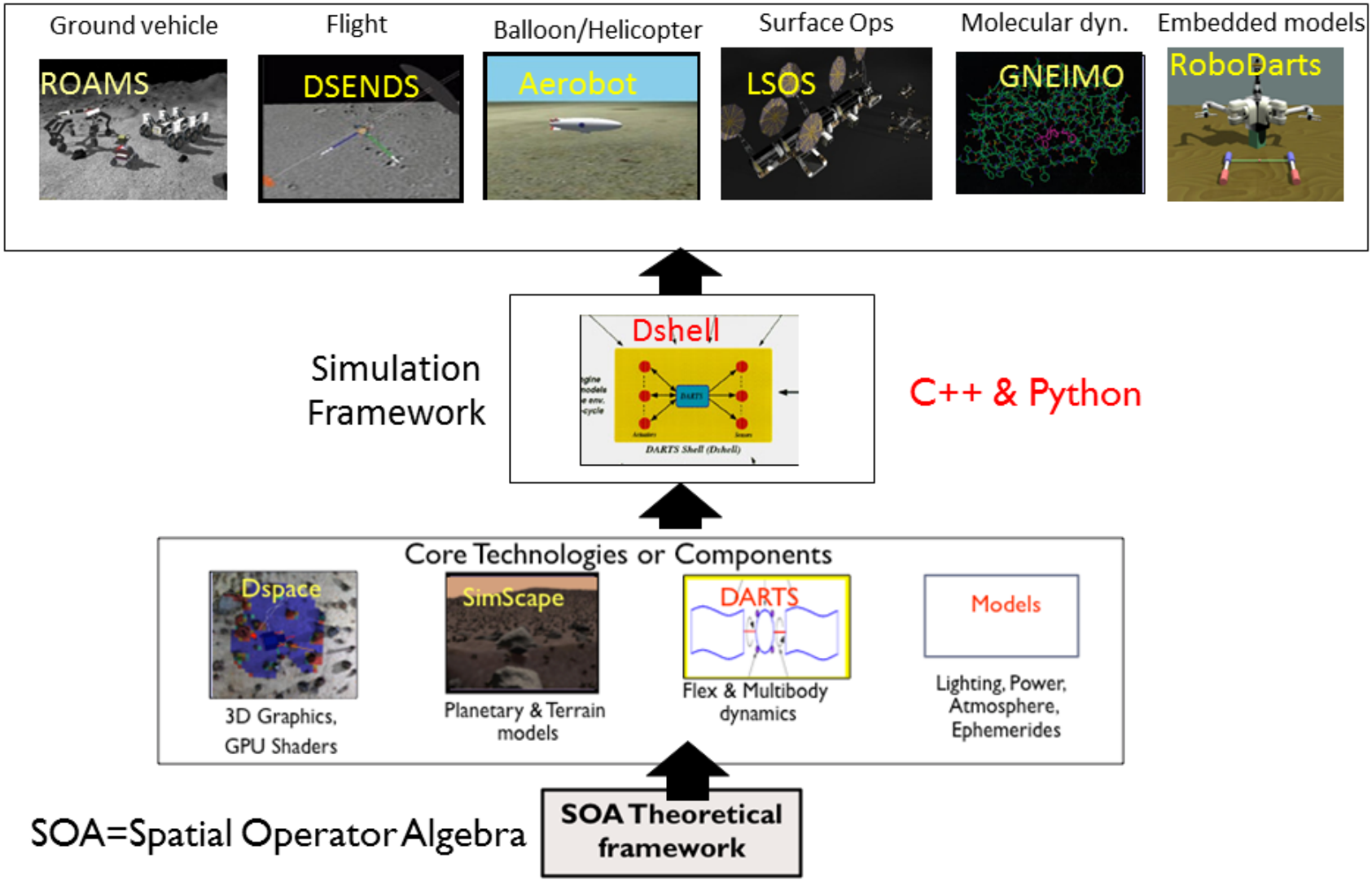
DSENDS Used for NASA Missions:

- MER
- MSL
- Phoenix
- 2020, Insight, etc

DARTS Lab Multi-Domain Simulations



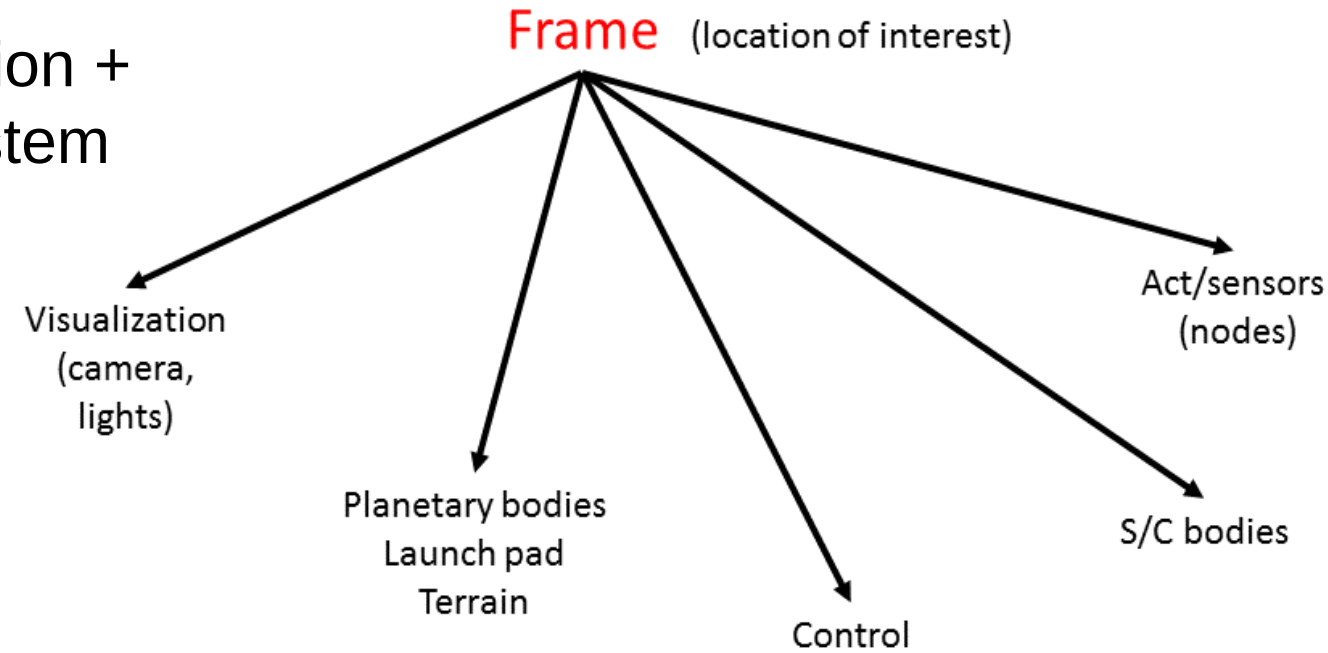
DARTS Lab Simulation Architecture



DSENDS Framework

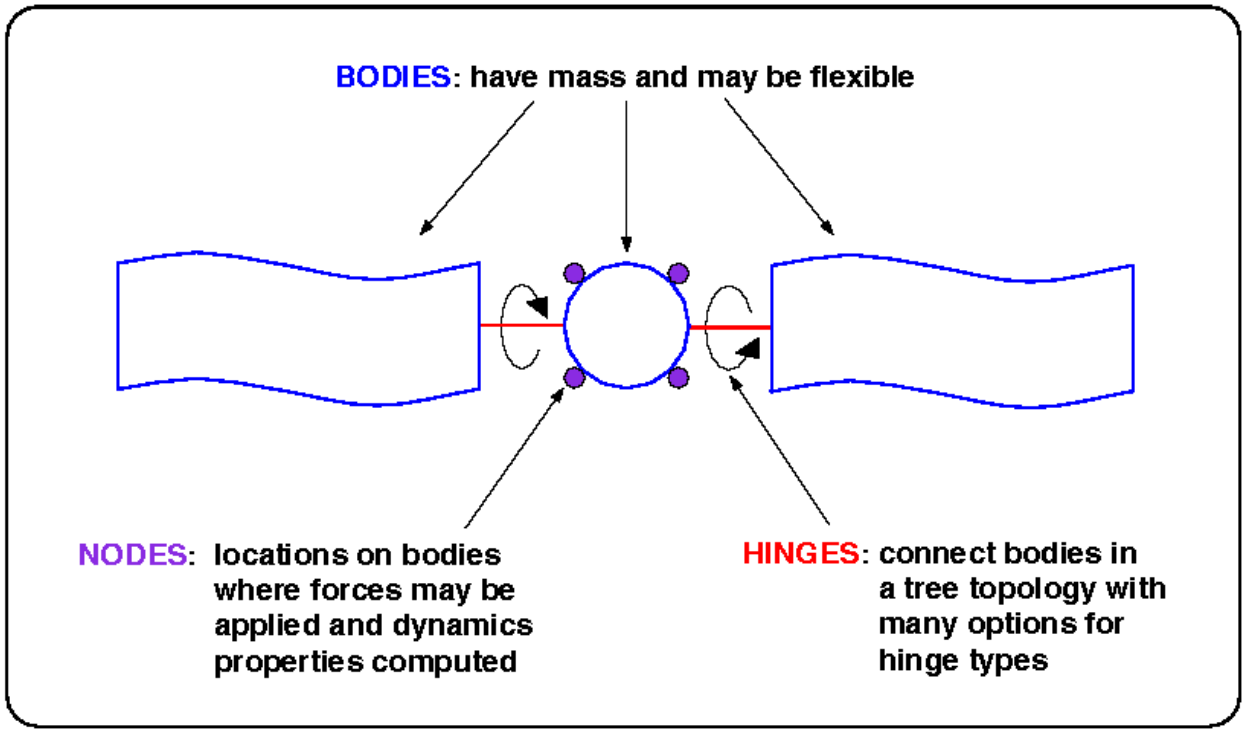
Framework: Frames

- **Frame** = location + coordinate system
- All frames in a "Frame Tree"
- Simplifies all relative pos/vel/accel calculations
- Smart caching and lazy evaluation to improve efficiency



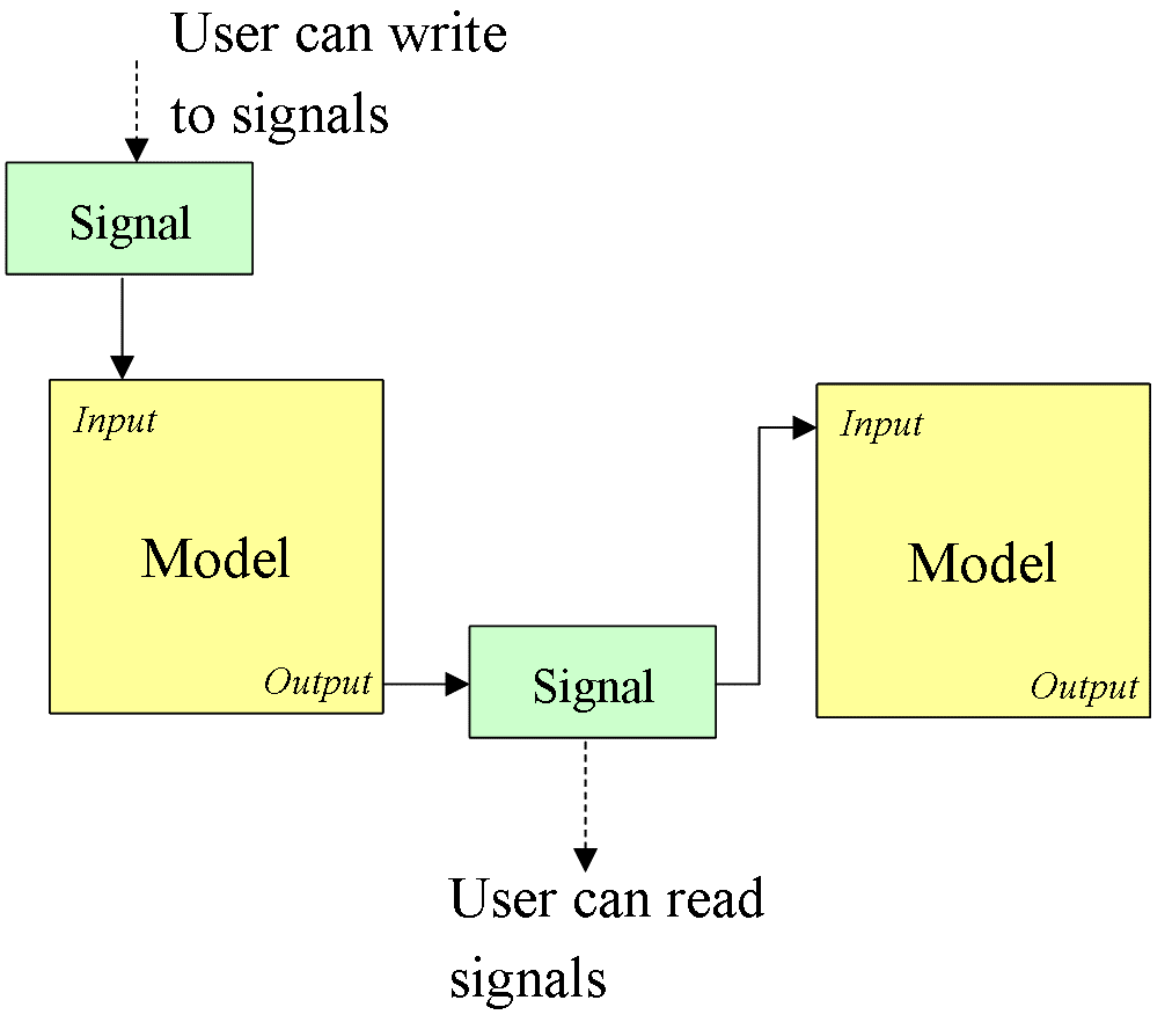
DARTS Multibody Dynamics Solver

- Rigid/flexible bodies
- Connected by hinges
- Supports tree and closed loop topologies, contact dynamics



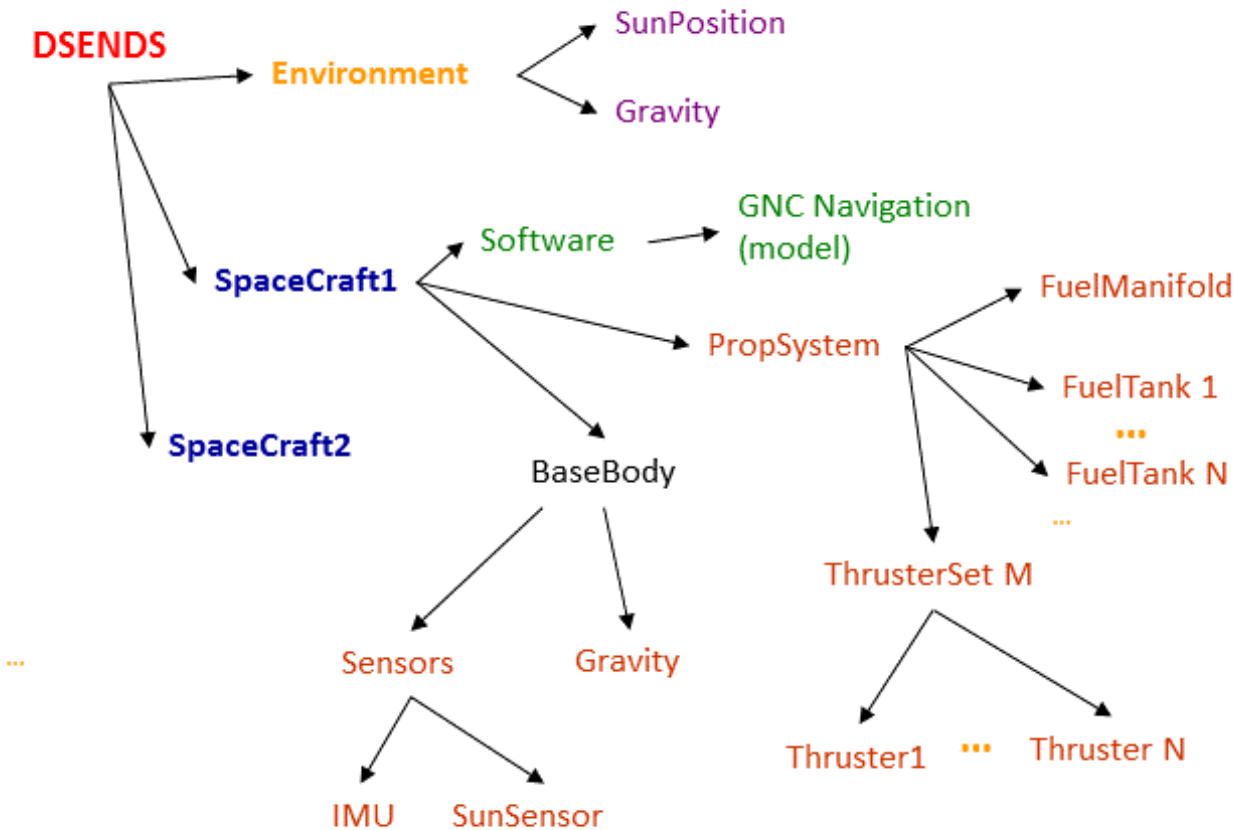
Framework: Dshell Models and Signals

- C++
- Partially auto-coded
- Parameterized models
- Connected by “signals” into a dataflow
- Users can read or write signals



Framework: Assemblies

- **Assembly:** Container with recipe for constructing sub-system of models, signals, and other sub-systems
- Knows how to set up, configure, and parameterize its components
- Re-usable
- Testable

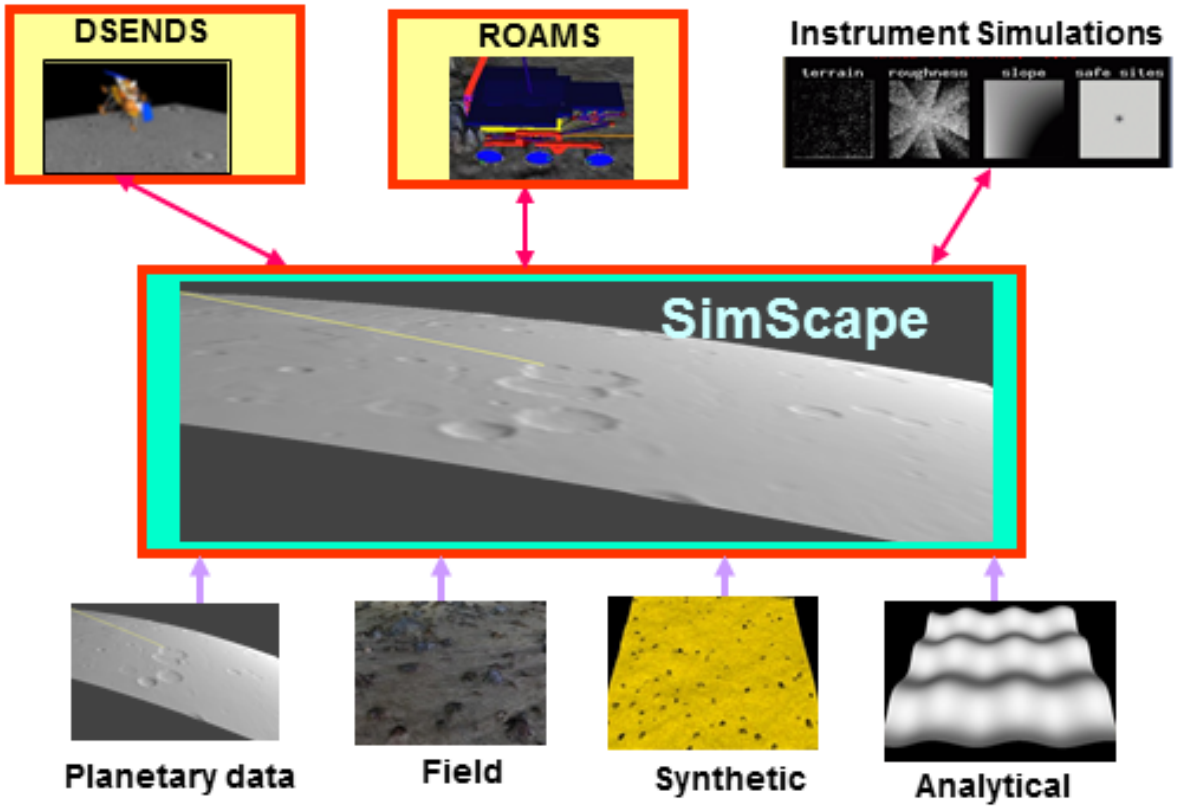


Framework: DVar for data access

- DVar provides access to all data in the simulation
  - Multibody data
  - Signals
  - Model data
  - Frames
  - Etc
- Data is available through live DVar objects or dot-notation paths
- Simplifies logging, stripcharting

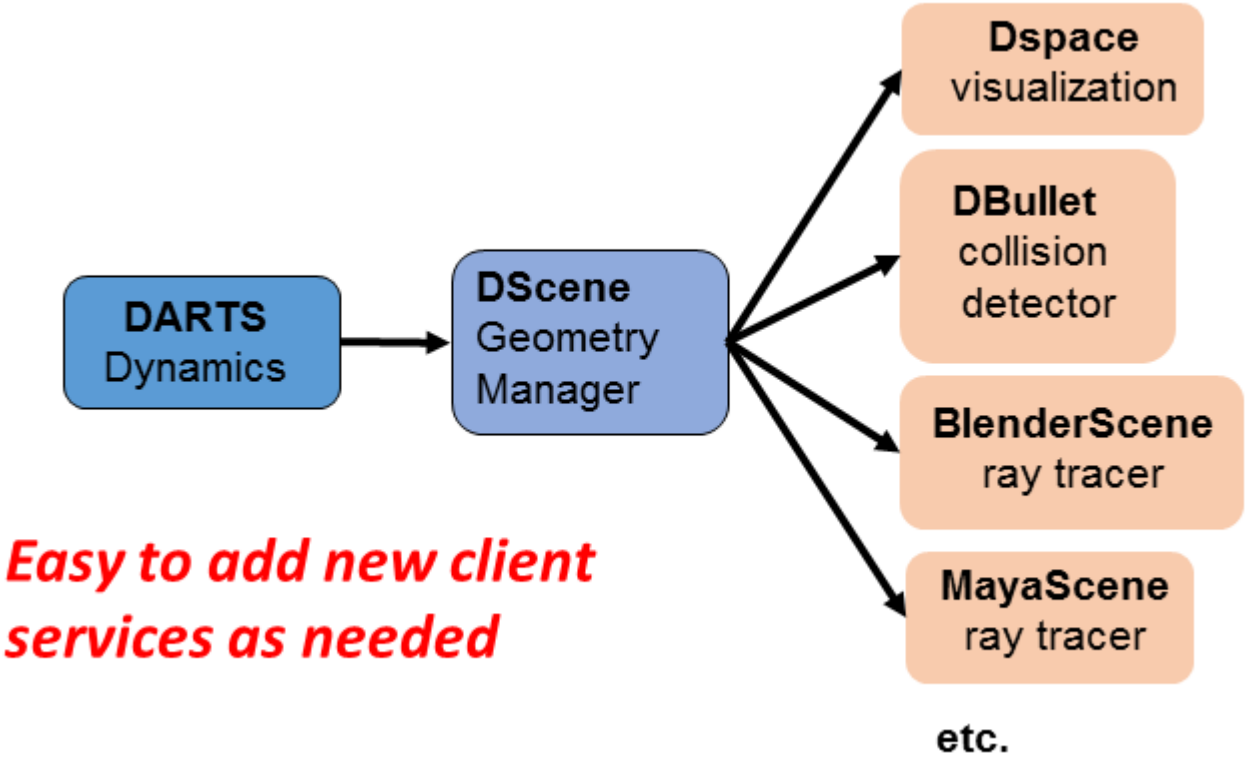
Framework: SimScape Terrain Models

- **SimScape:** Tool to
  - Process terrain data from a variety of sources
  - Use terrain data in simulations
    - LIDAR
    - Ranging devices
    - Camera images of surfaces
    - Landing events



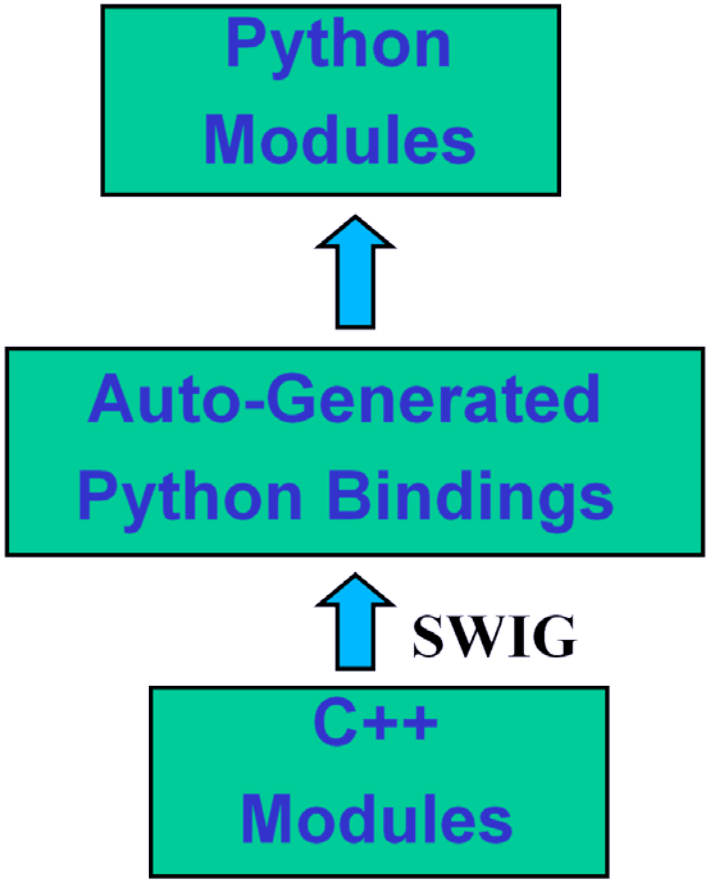
Framework: Geometry

- **DScene** = Geometry descriptions
  - Bodies
  - Terrain
- Used for
  - Visualization (Dspace)
  - Collisions (DBullet)
- Add new client services as needed



Framework: Infrastructure

- Multibody, Models, Frames, etc, run in C++ for speed
- Use SWIG to “wrap” C++ for Python access
- Setup, parameterization, in Python
- Simplifies validation and regression testing



Applications of DSENDS

COMPASS

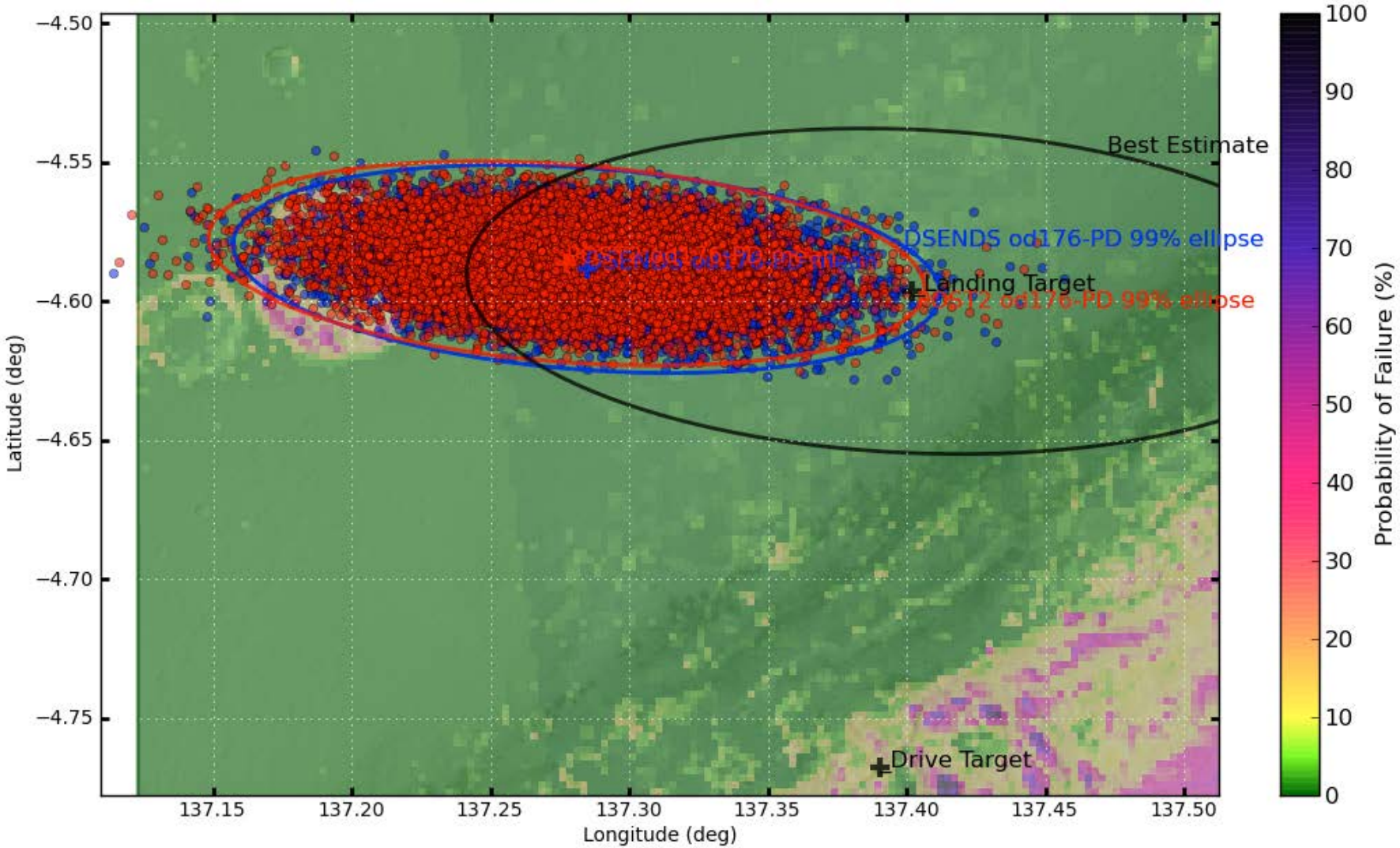
- JPL and Johnson Space Center (JSC) Flight Dynamics Division (FDD) within the Flight Operations Directorate (FOD) have been collaborating on DSENDS for over 5 years
- JSC FOD is using DSENDS as the basis for COMPASS to support flight operations
- COMPASS is being applied for International Space Station and future manned exploration mission simulations

Mars Science Laboratory (MSL)

- DSENDS was used to support MSL Entry Decent and Landing (EDL) operations.
  - Independent verification and validation of primary simulation tool POST2 (from Langley Research Center)
  - Supported development of robust closed-loop entry guidance navigation and control for precision landing
  - Used to ensure successful landing within planned landing envelope

Mars Science Laboratory

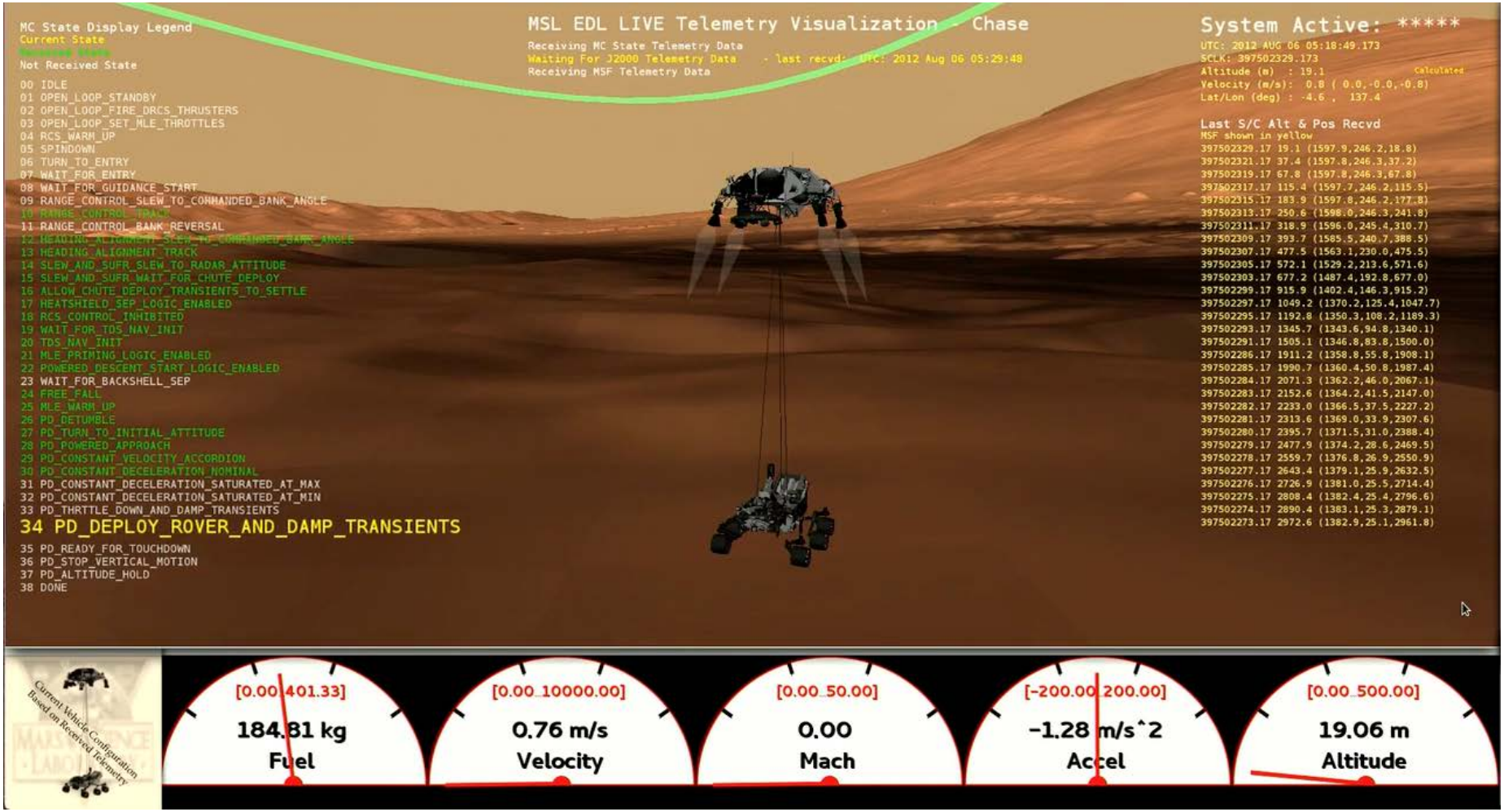
Darts Lab



DSENDS (**Blue**) vs POST2 (**Red**)

Mars Science Laboratory

Darts Lab



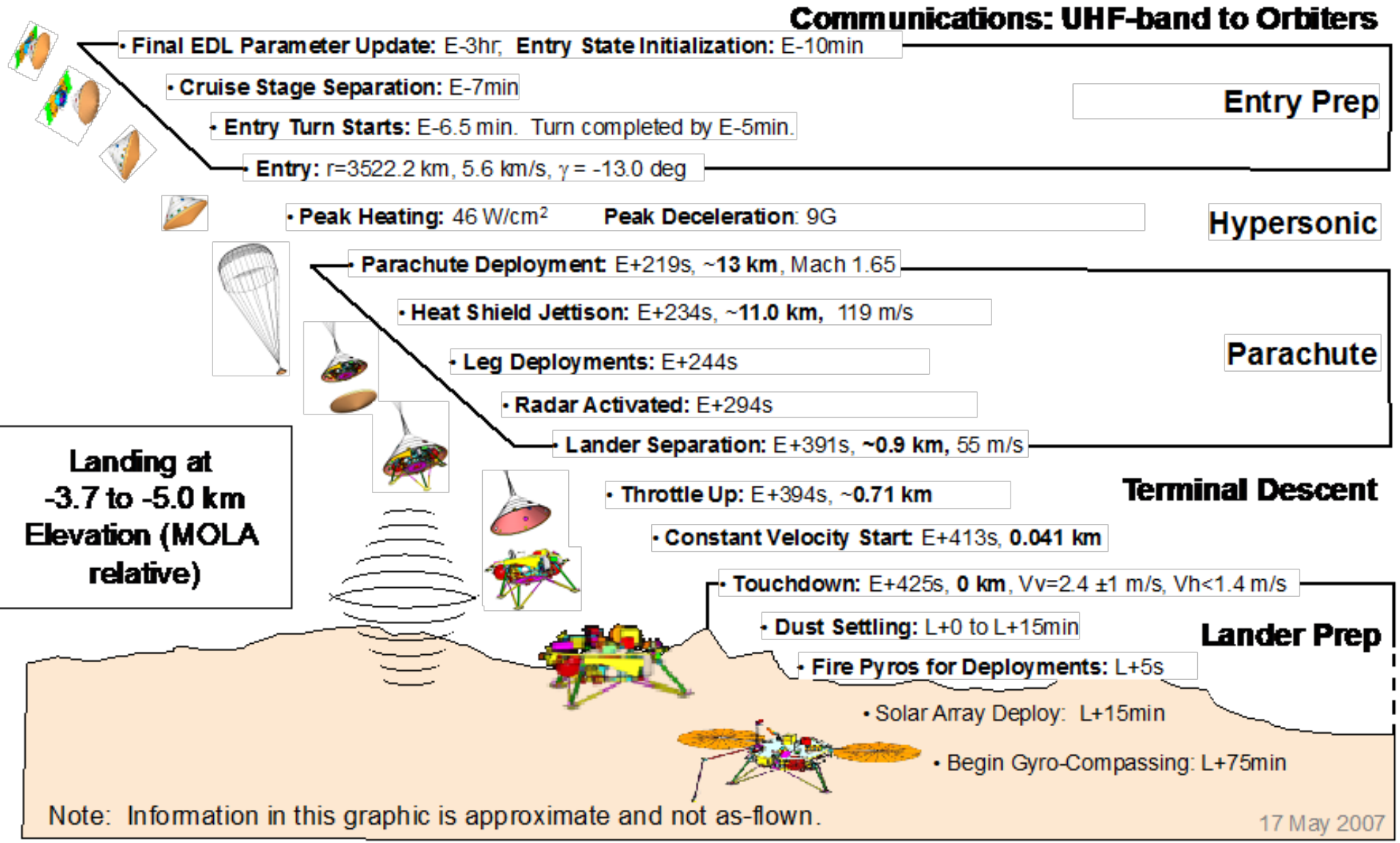
MSL Telemetry Display Using DSENDS

Phoenix and Insight Missins

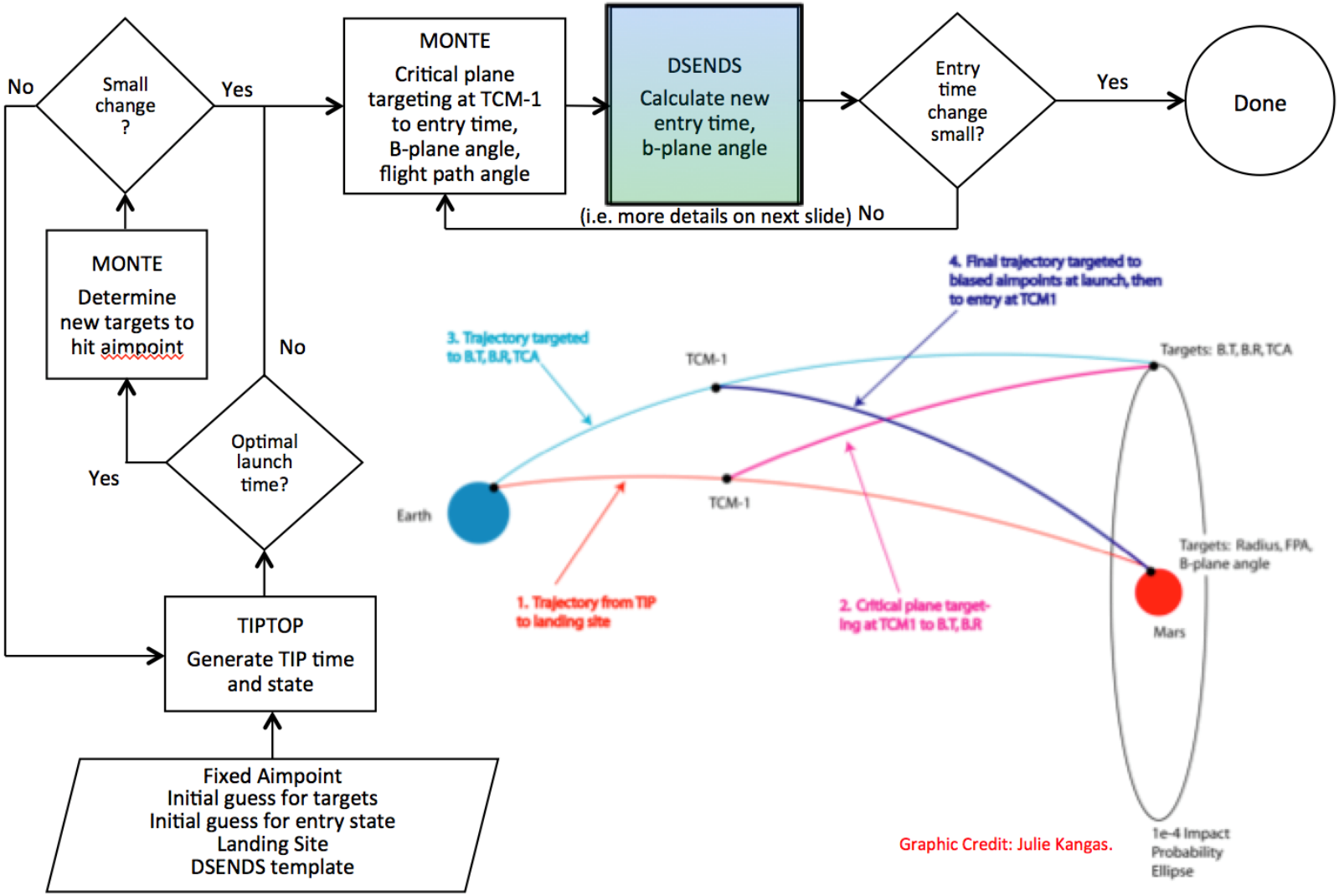
- DSENDS used for
  - maneuver design
  - landing dispersion analysis
  - trajectory targeting

Phoenix EDL Timeline

Darts Lab

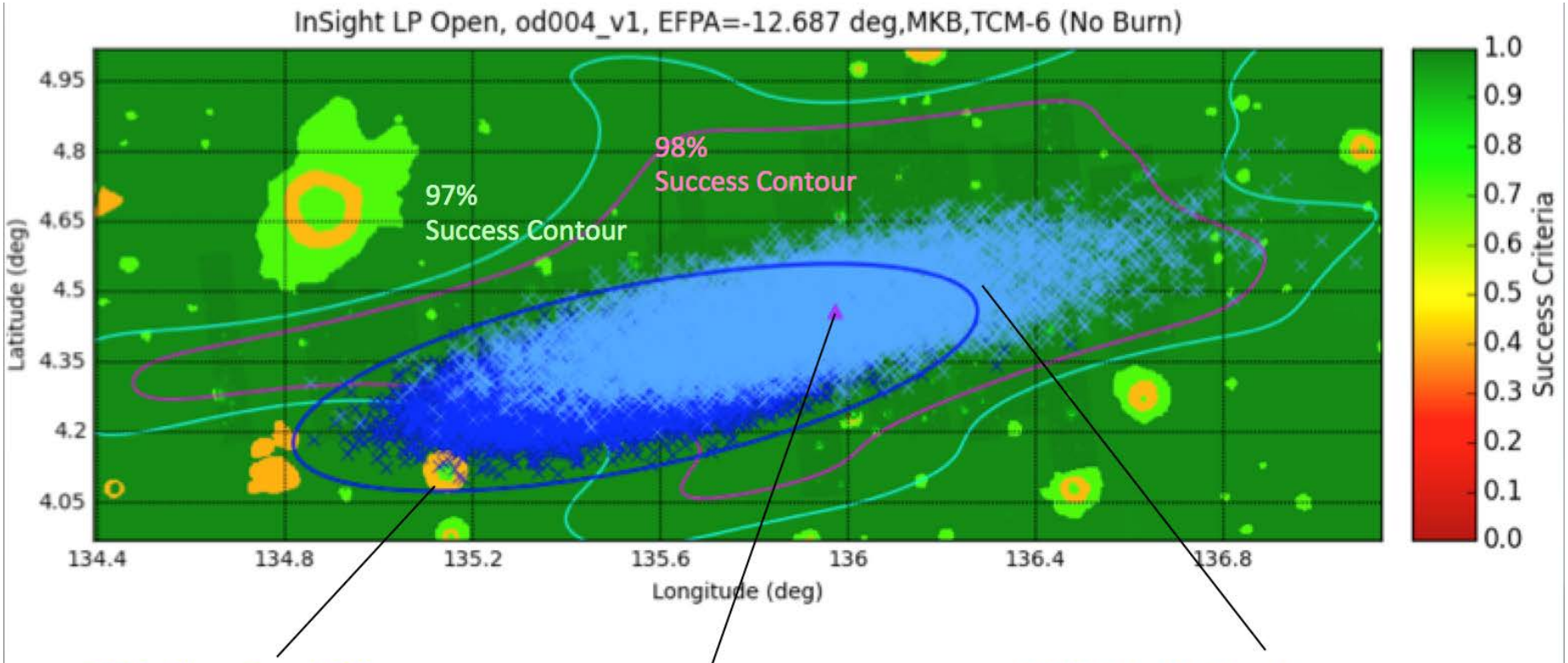


Insight Navigation Targeting



Graphic Credit: Julie Kangas.

Insight Landing Hazard Assesment



TCM-6 (no Burn) Ellipse
88X23 km
Azimuth: 78.24 deg
Center: Lat 4.317 deg, Lon:135.55 deg
Success Probability: 98.93 %

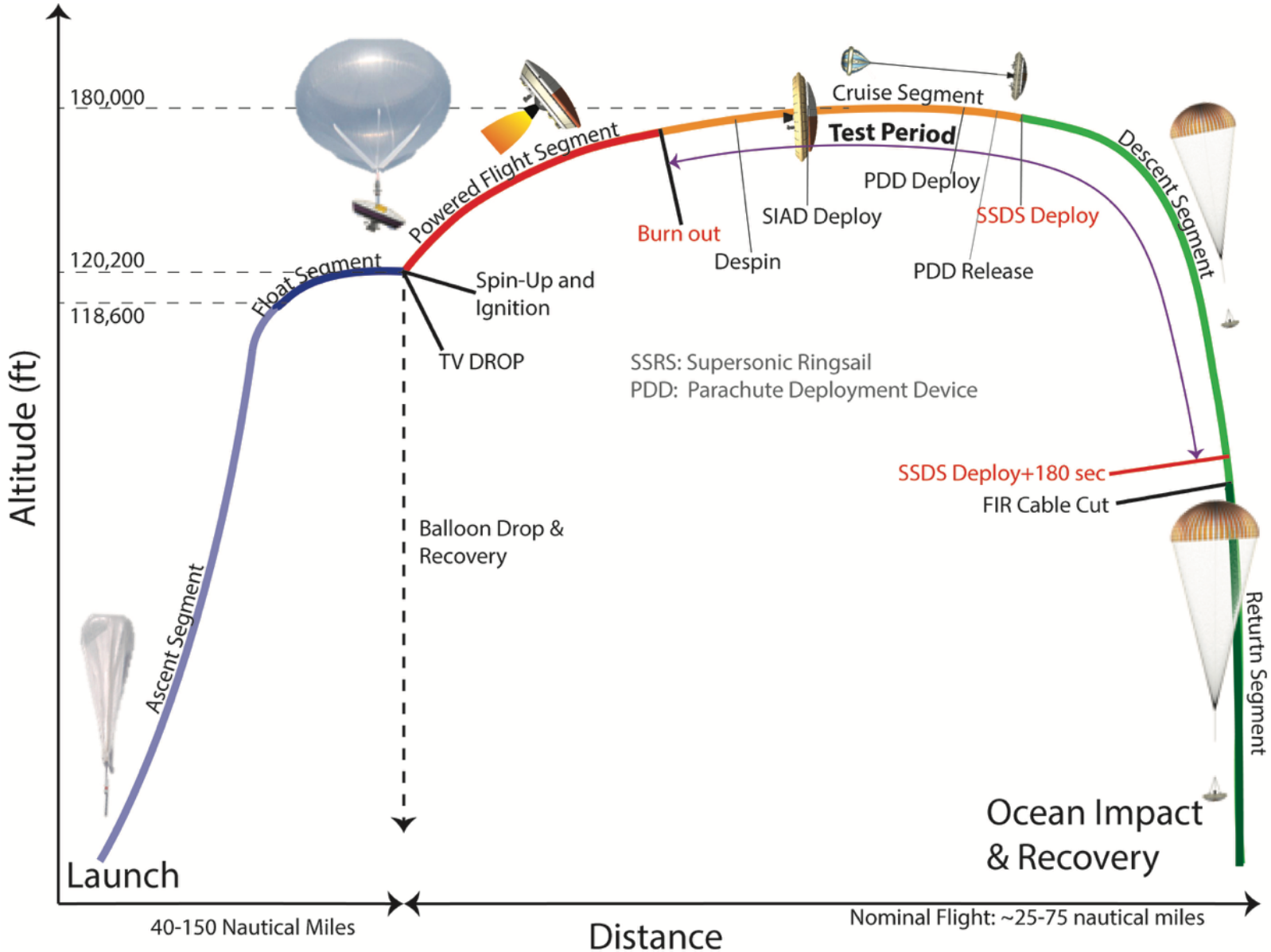
E9o Target (4.46, 135.97 deg)

TCM-6 (with Burn)
Ellipse: 111X24 km
Azimuth: 78.72 deg
Center: Lat 4.448 deg, Lon 135.90 deg
Success Probability: 99.27 %

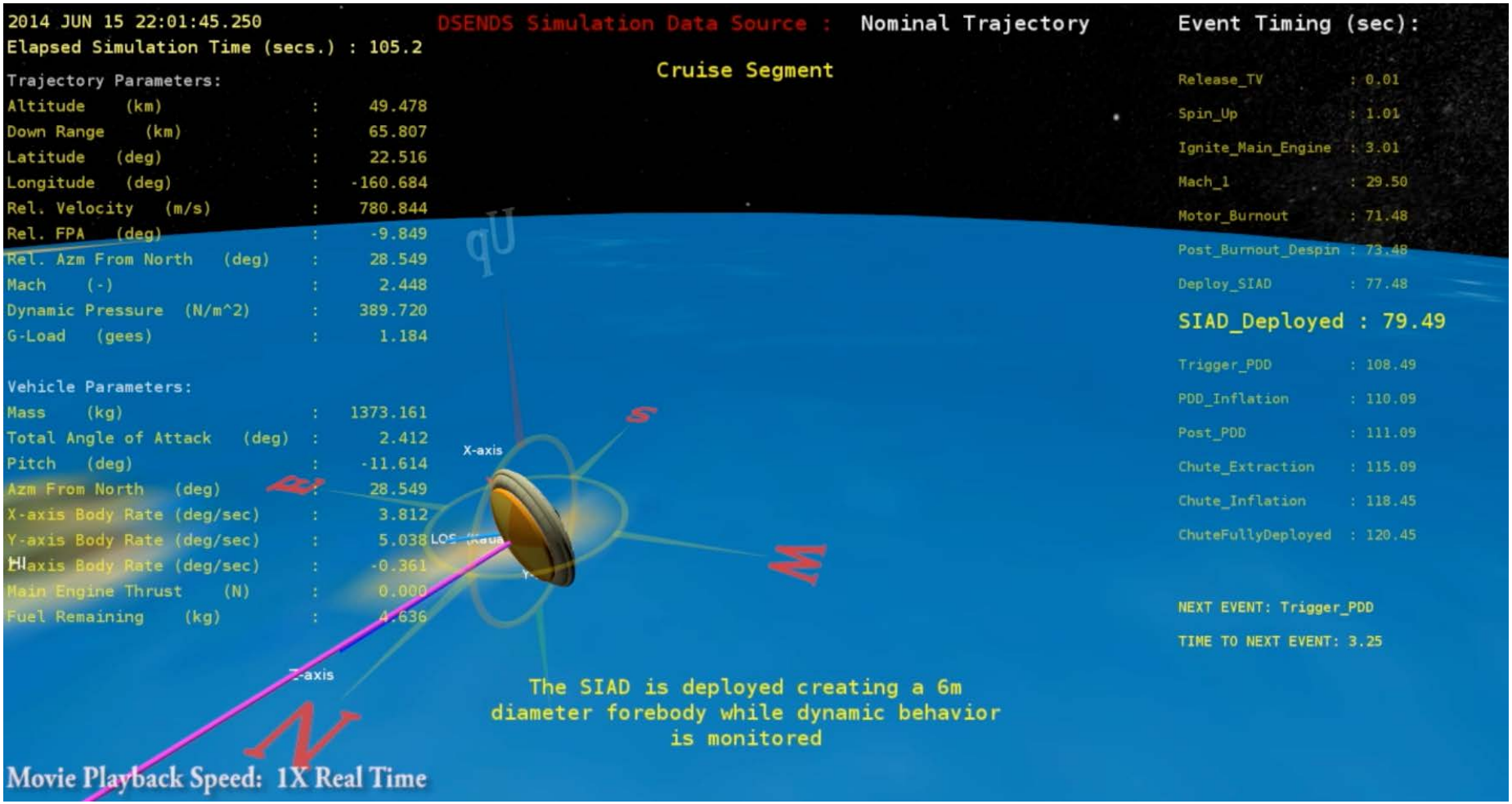
LDSD / SIAD Testing

- Aerodynamic decelerator technology development for supporting large payloads for future Mars missions
  - LDSD = Low-Density Supersonic Decelerators
  - SIAD = Supersonic Inflatable Aerodynamic Decelerators
- Tested at high Earth altitudes to simulate Mars entry conditions
- DSENDS used as primary tool for flight planning and operations

LDSD / SIAD Flight Profile



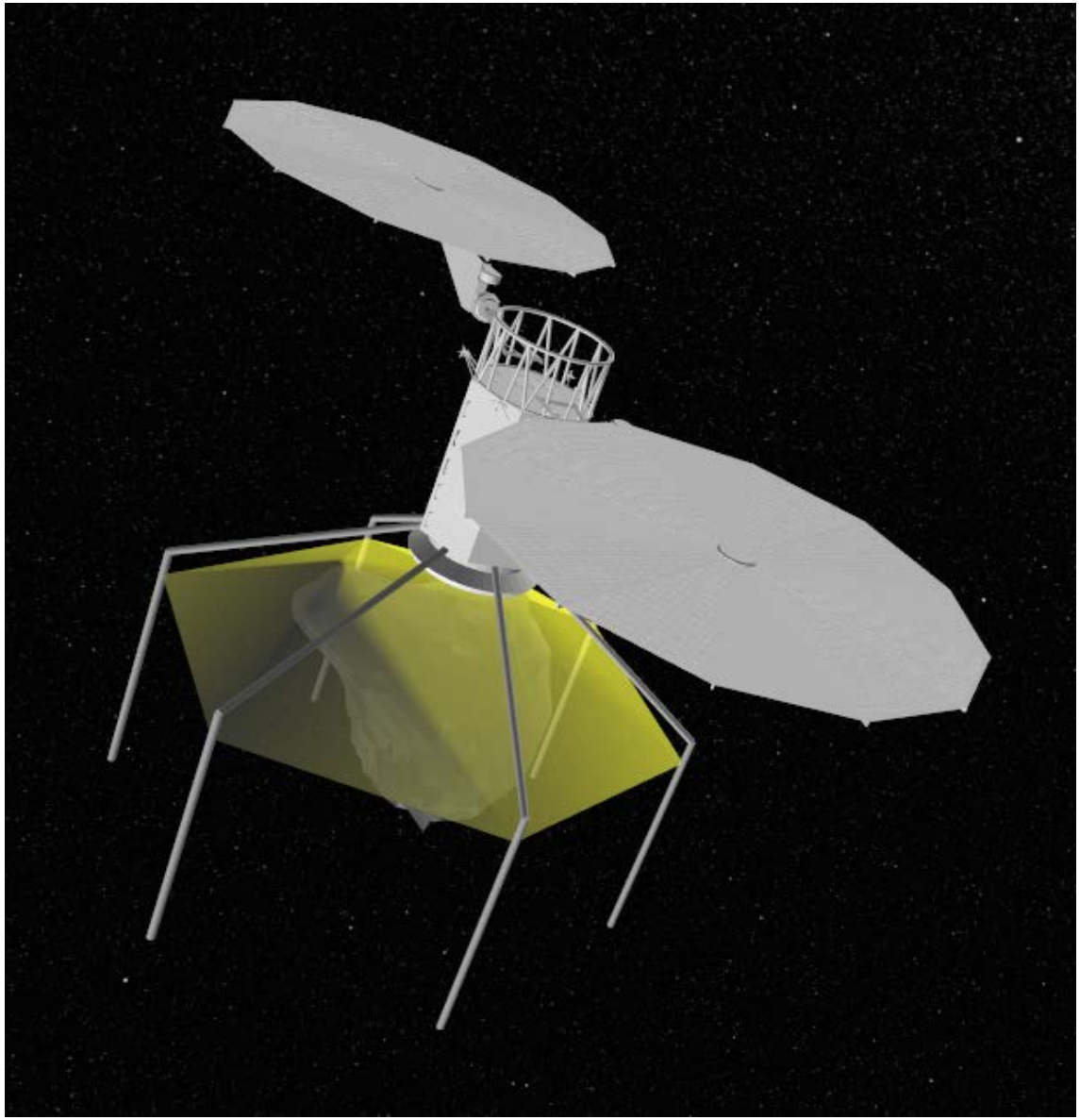
LDSD Flight Operations with DSENDS



Asteroid Redirect Robotic Mission

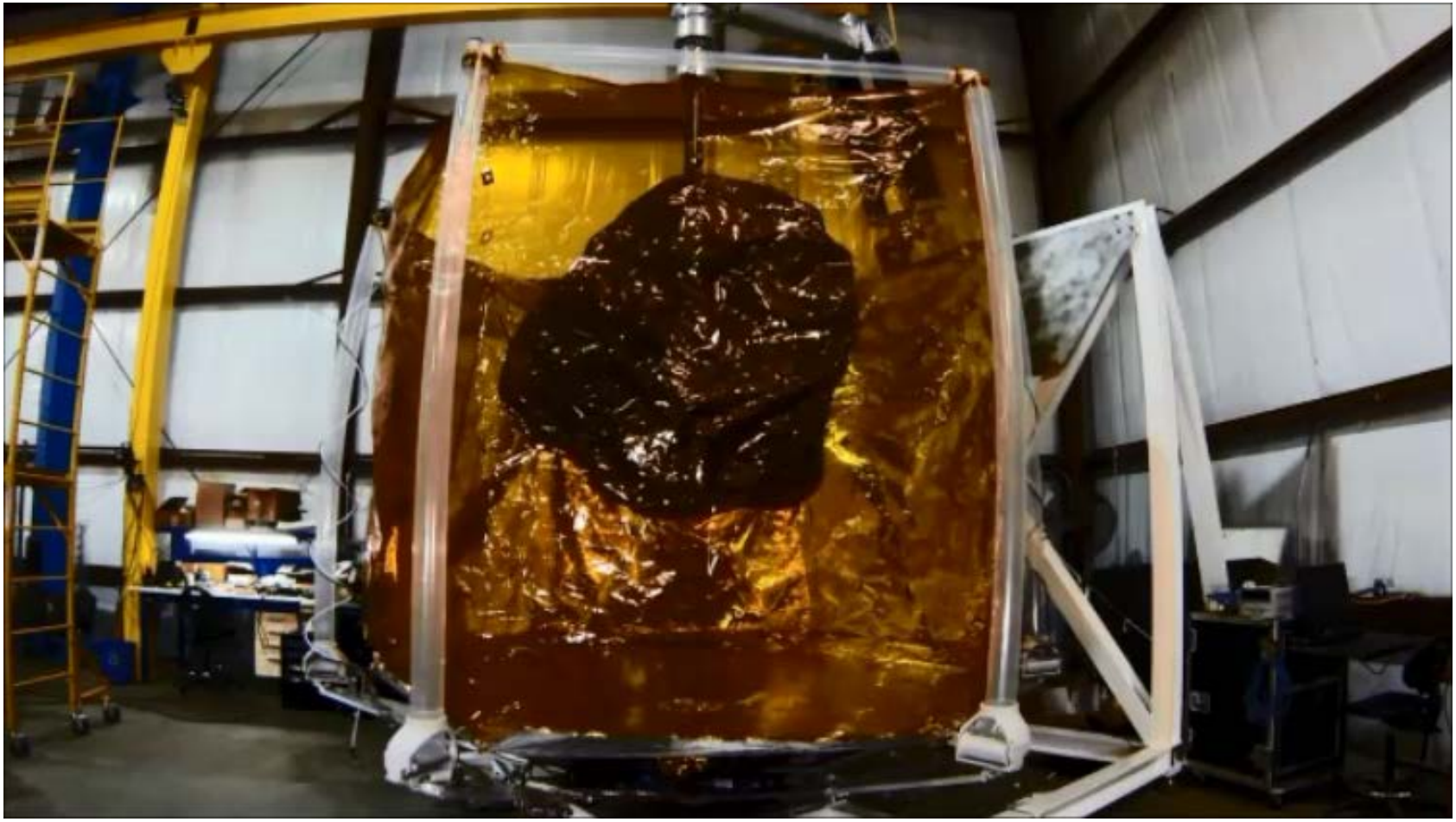
- DSENDS used to
  - Test and develop early Asteroid Redirect Robotic Mission (ARRM) mission concept for capturing a small asteroid
  - Part of real-time testbed to emulate zero gravity

Asteroid Redirect Robotic Mission



Asteroid Redirect Robotic Mission

Darts Lab



Future Applications of DSENDS

- Many uses in current and near-future NASA missions
  - EDL planning, navigation, GN&C
  - Uncertainty Quantification
  - Sensitivity Analysis
  - Monte Carlo Analysis
- In use by NASA, university, government, and commercial users

Conclusions

- DSENDS
  - Powerful and flexible design helps make DSENDS versatile simulation framework
  - Applied successfully to mission planning and operation
  - Applicable to wide range of space and ground missions