Building an Onboard AI for Future Astrobiology Mission Science

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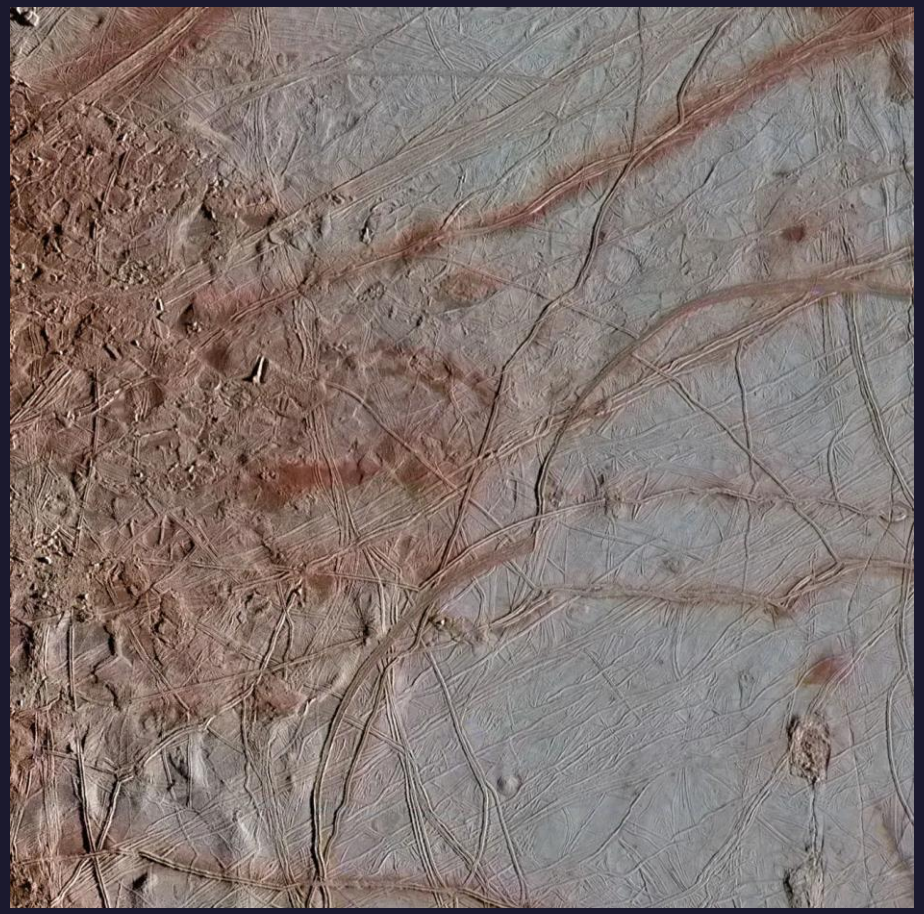
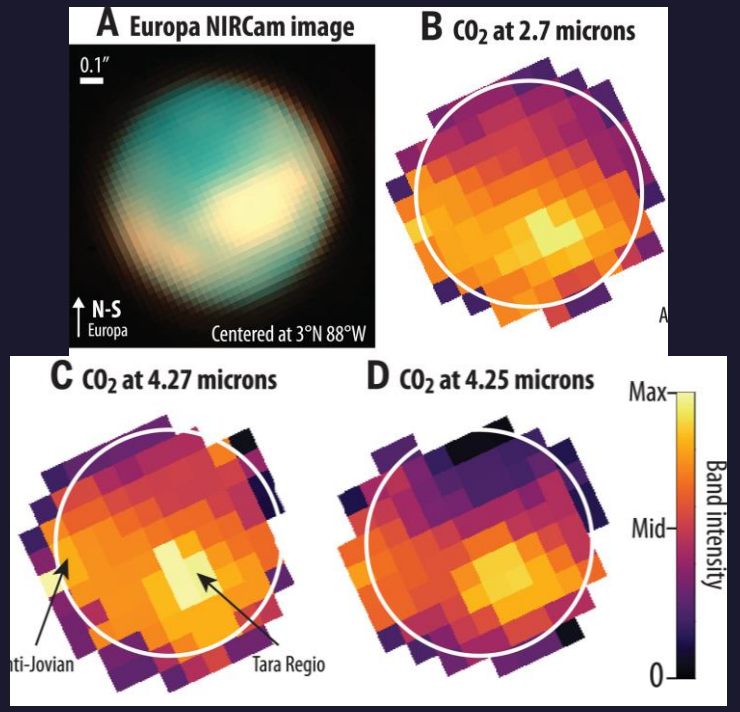
AI Capabilities Enable

Investigation of Novel Events : e.g., (cryo)tectonism / volcanism



Europa (from Gallileo):
NASA/JPL-Caltech/SETI Institute

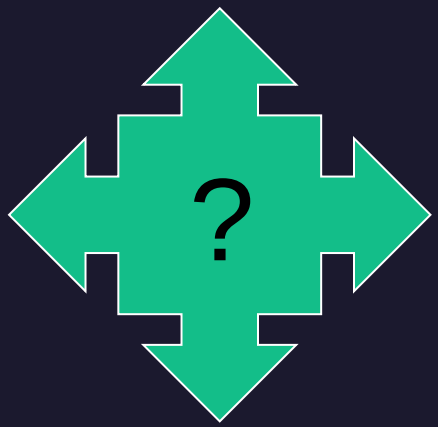
React to Observations of Interest : e.g., volatiles, plumes



CO_2 Ice detected on Europa (JWST):
Villanueva et al. (2023): Science

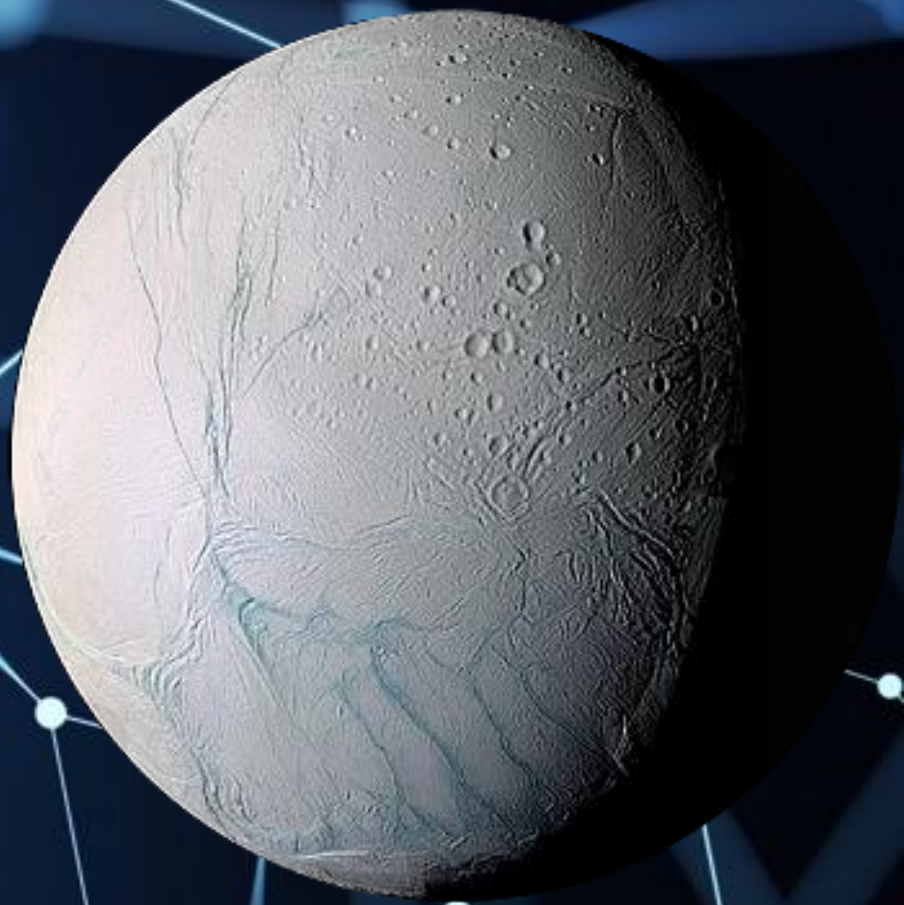
React to Potential Biosignatures

Opportunistic Science



Ocean Worlds Case Study

Enceladus



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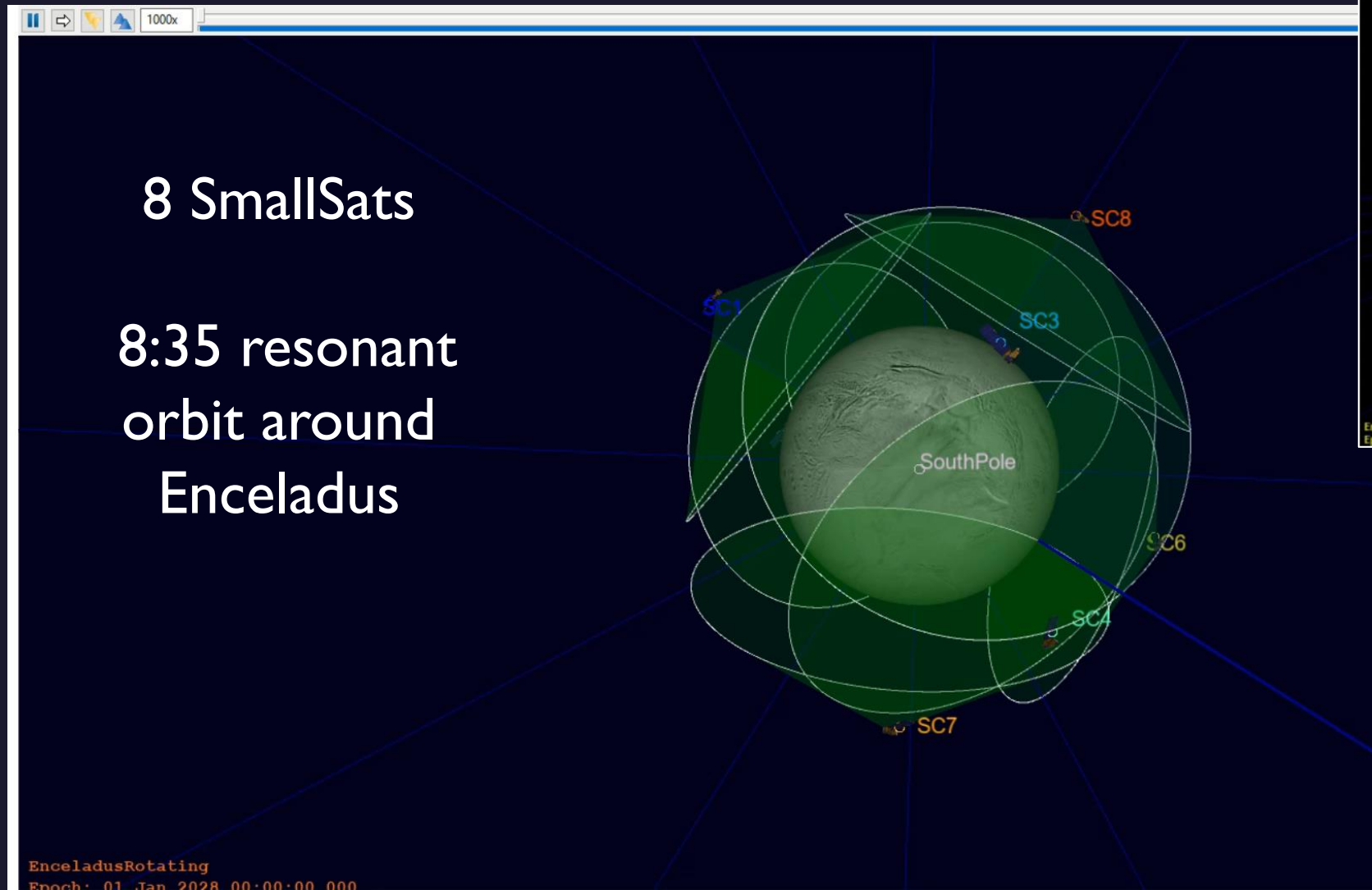
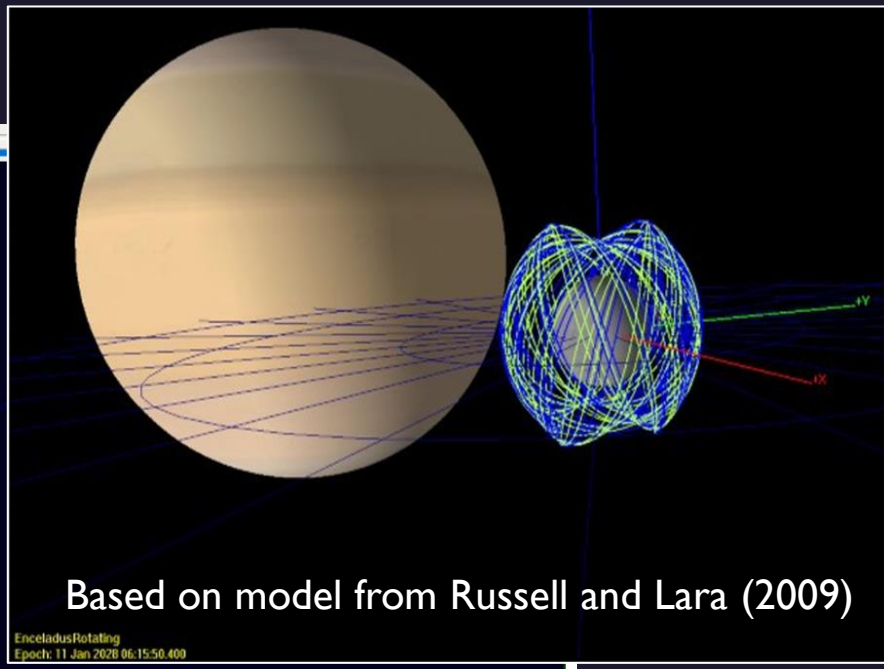
First Stable Enceladus SmallSat Constellation Model

8 SmallSats

8:35 resonant orbit around Enceladus





Based on model from Russell and Lara (2009)

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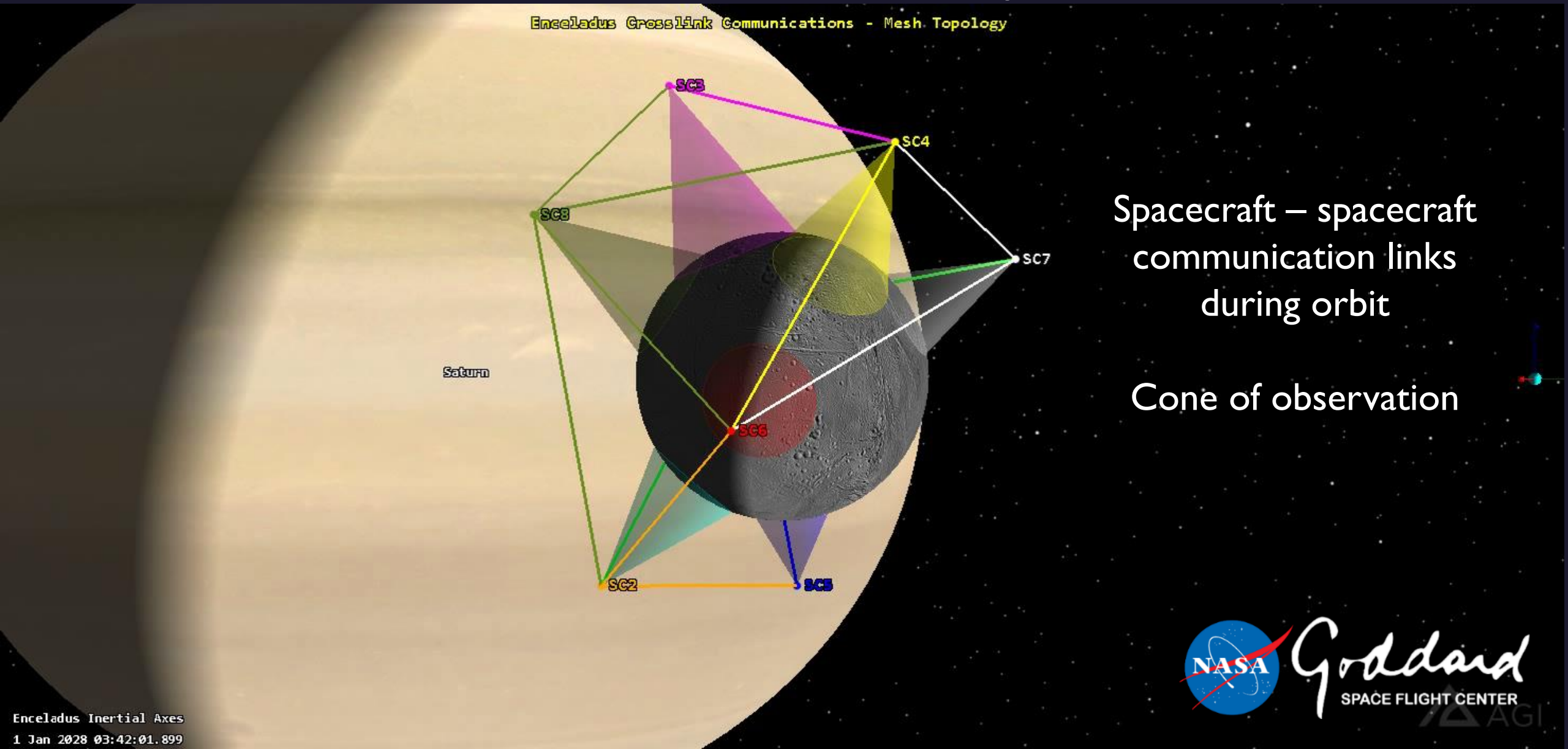
Communication Pathways Model



Spacecraft – spacecraft communication links during orbit

Cone of observation

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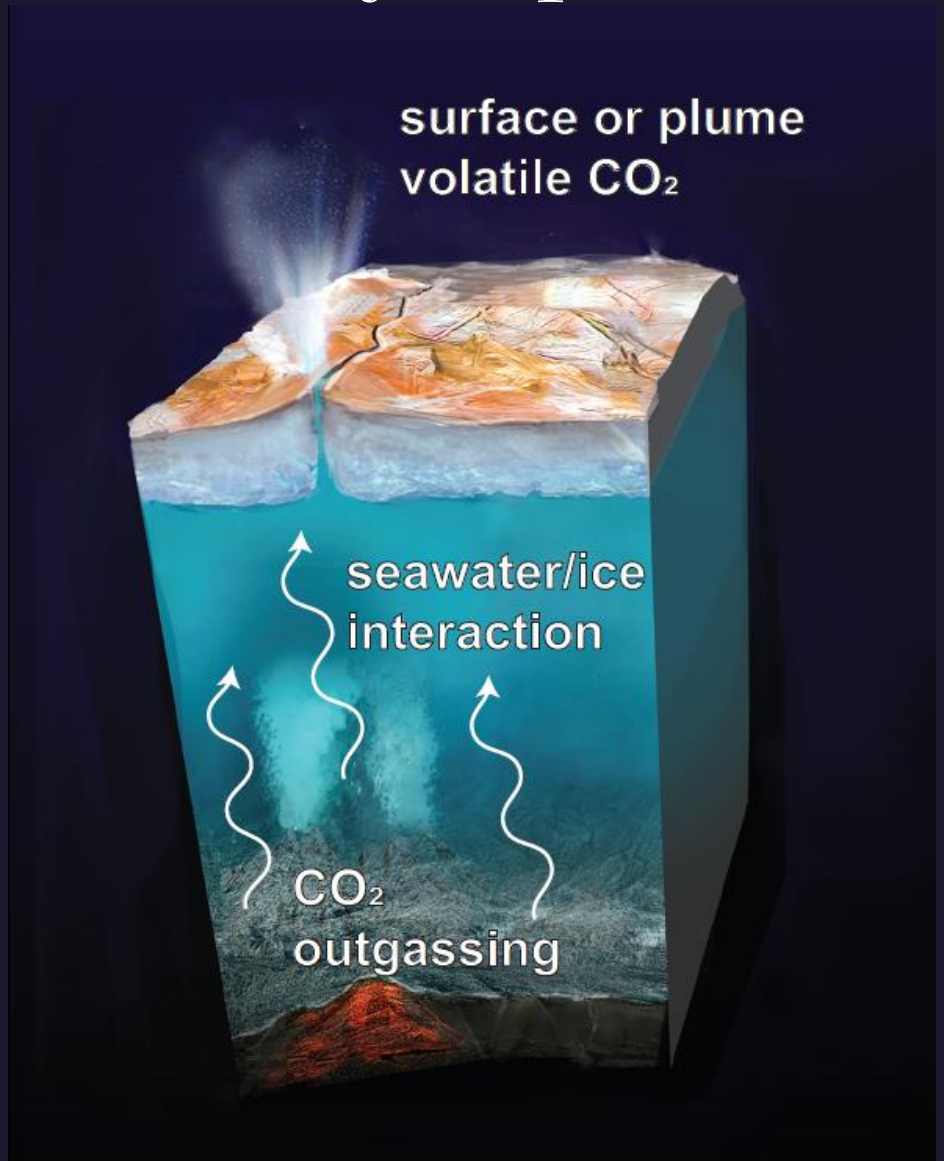
AGI

Mass spectrometry data from Enceladus (and Europa) laboratory experiments



Theiling (2021): Icarus
Da Poian et al. (2023): Frontiers Ast. Space Sci.

Theiling et al. (in prep)
Clough et al. (in prep)

Enceladus Case Study: Biosignature Detection & Response

SC 2 SC 1 Mothership

PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL PORTS python3

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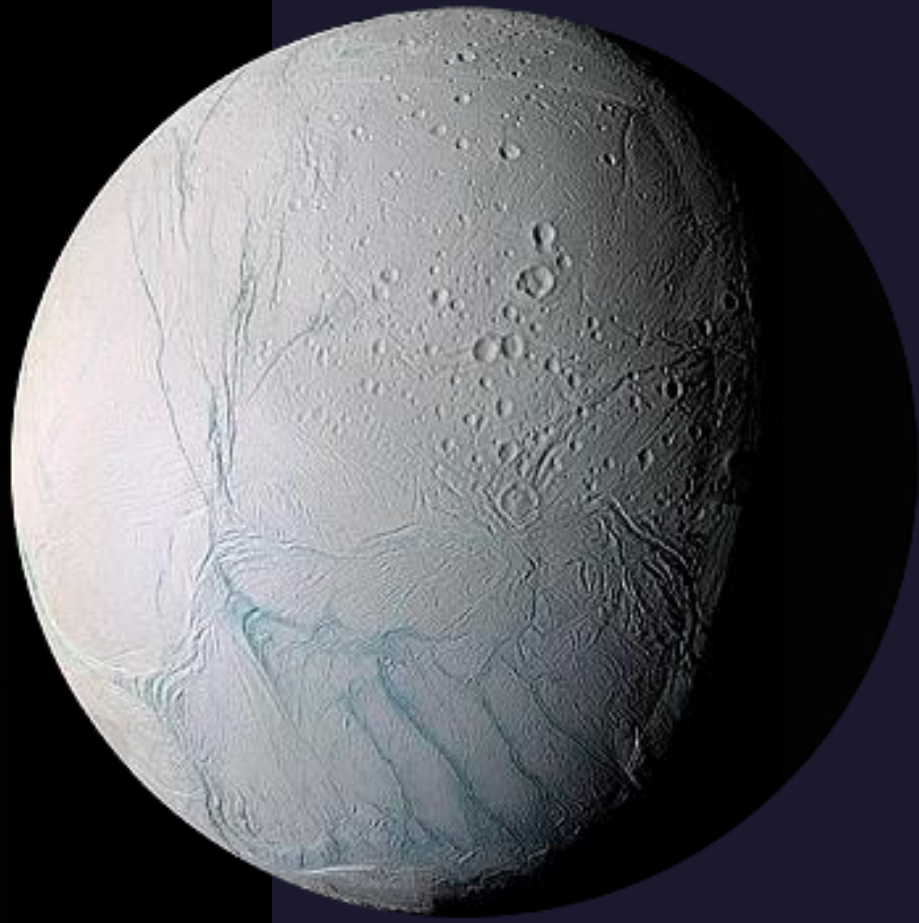


Consensus-based decision-making based on ML models

Onboard Science AI

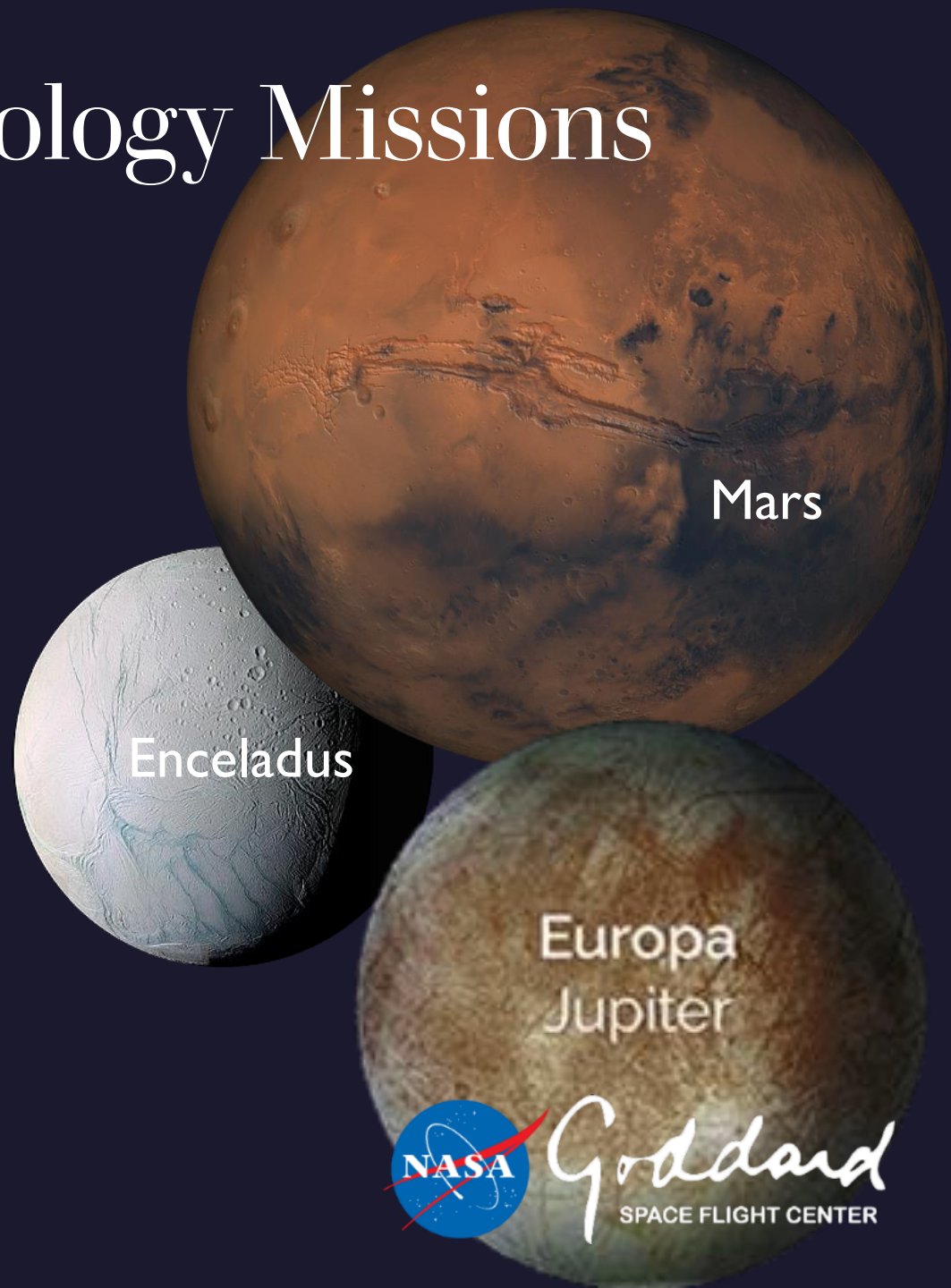
Autonomous Response to Science Observations

Using Multiple Models for a Consensus-Based Decision during a SmallSat Constellation Mission at Enceladus

Implementation for Astrobiology Missions

- Intelligent Sensing & Response
- Manage Mission Constraints
- Transfer Knowledge Across Systems
- Autonomous Navigation, Guidance, and Control
- Data Prioritization
- Mission Resilience

Whole System



Autonomous Navigation, Guidance, and Control

An onboard software application suite built on the core Flight System (cFS) and a flight hardware implementation for real-time autonomous spacecraft navigation, guidance and control

Why autoNGC?

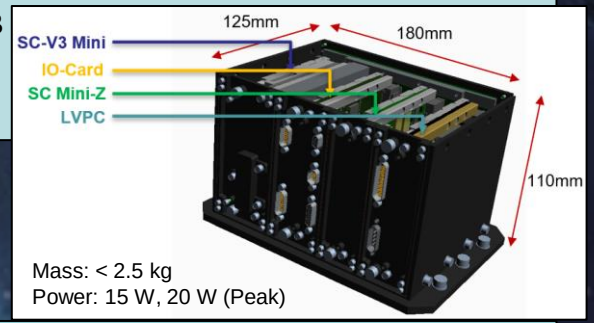
- Reduce reliance on over-subscribed ground assets for functions that are traditionally done on ground
- Enable new mission capabilities
  - Low latency mission operations
  - Complex missions at far distances
  - In-situ planning and execution
  - Distributed Systems Mission (DSMs)
  - Dynamic reallocation of orbital assets

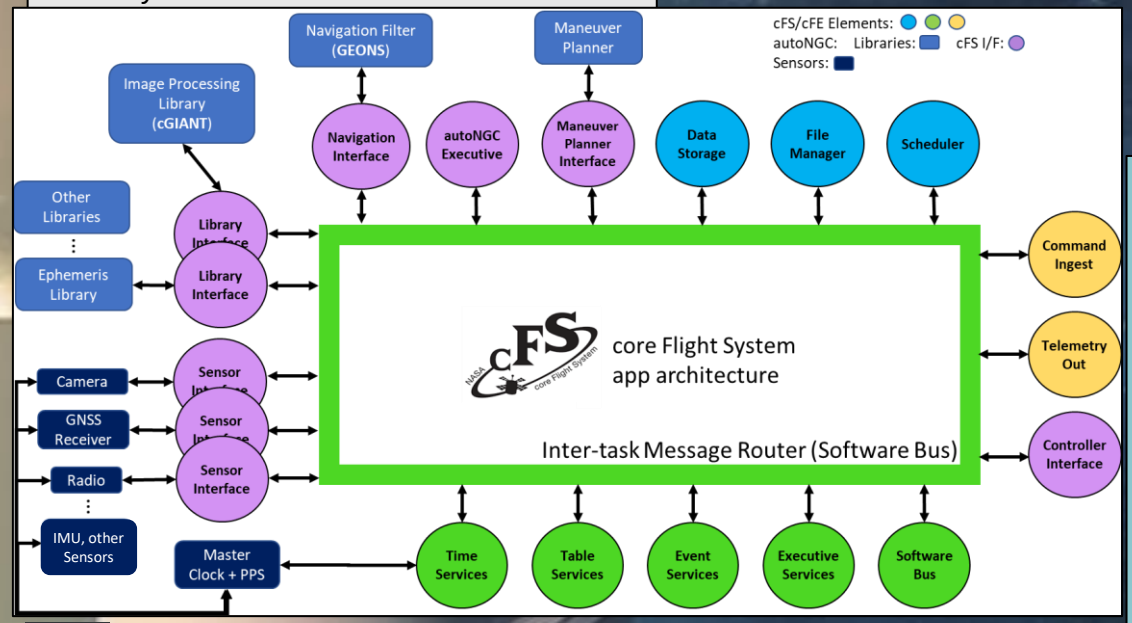
Goals of autoNGC

- Increased onboard autonomy
- Resilient navigation solutions across multiple orbit regimes
- Reduced mission cost and risk
  - Lower operations cost
  - Heritage design & architecture customizable to meet mission needs

Objectives of autoNGC

- Autonomous onboard navigation and timing
- Autonomous onboard guidance and control – executive decision/control for maneuvers
- Customizable multi-mission extensibility (plug-n-play)
- Software Class B
- Fault tolerant
- Low SWaP-C





Key autoNGC Flight Software Libraries

- Goddard Enhanced Onboard Navigation System (GEONS) – extended Kalman filter
  - Nominal and weak signal GNSS
  - Terrain Relative Navigation
  - Limb/centroiding optical navigation
  - 1-way forward and 2-way ground & relay
  - Celestial object bearing
  - Accelerometer
  - LiDAR
- cFS Goddard Image Analysis and Navigation Tool (cGIANT) – advanced image processing

autoNGCSummarySheet.pdf

Future / Next Steps

- Integrate more challenging decision-making into framework
  - Simulated environments → enables collaboration between spacecraft telemetry with science
- Deploy with hardware
- Conduct field tests

….Deploy in space!

Salt Plains State Park and Wildlife Refuge, Oklahoma

Acknowledgements

Bethany Theiling (GSFC), Lily A. Clough (GSFC/Aurora/Univ. of Tulsa), Pavel Galchenko (GSFC), Fredrick Naikal (GSFC), Victoria Da Poian (GSFC/Tyto Athene), Brett A. McKinney (Univ. of Tulsa), James MacKinnon (GSFC) and Evana Gizzi (GSFC)

The Distributed Systems Missions (DSM) Initiative Team at NASA GSFC

Undergraduate Interns:
Connor Williams (University of Tulsa)
Leyton McKinney (University of Tulsa)

Funding:
Internal Scientist Funding Model (ISFM) Fundamental Laboratory Research (FLaRe) at NASA GSFC
Internal Research and Development (IRAD) at NASA GSFC

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Thank you!

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- NASA GSFC Missions (2009 – Present)
  - James Webb Space Telescope (Flight Dynamics Lead)
  - SEXTANT: X-Ray Pulsar Navigation Tech Demo (Navigation, Filter Design, Operations)
  - ARTEMIS: 2 spacecraft Lunar Libration Orbiters (Trajectory Design, Operations)
  - MMS: 4 spacecraft Elliptical Formation Flying Mission (Trajectory Design)
- University of Maryland M.S. with Thesis 2015
  - Title, "Application of X-Ray Pulsar Navigation: A Characterization of the Earth Orbit Trade Space"

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