Saturn Swarm Study

Small Probe and CubeSat Architectures to accompany New Frontiers missions at Saturn

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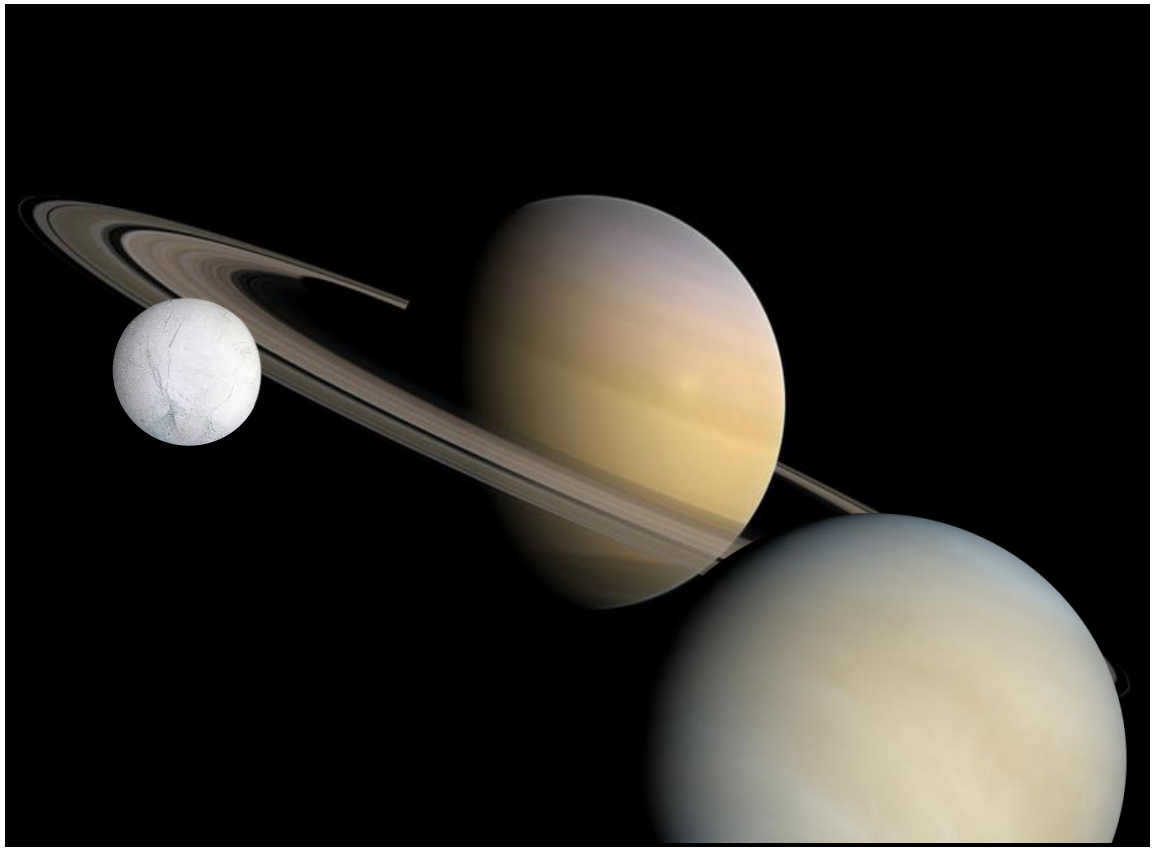
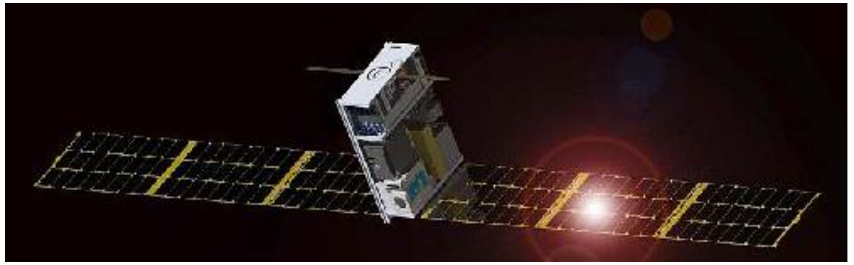
Intro

- 3 (or more) missions going to the Saturn system have been proposed for the next New Frontier Opportunity
  - Oceanus (Titan)
  - ELF (Enceladus)
  - SPRITE (Saturn Probe)
- What if one is selected and has mass margin?
- This presentation describes some possible small probe/CubeSat architecture concepts

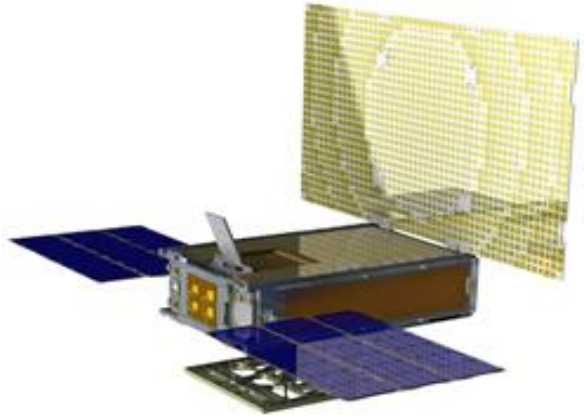


CubeSat Capabilities

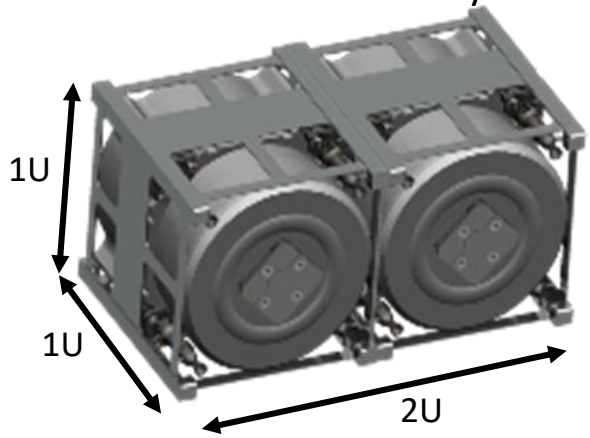
- Power
  - 1.2-2W solar power @ Saturn
    - **~ 11 days to fully charge 200 Whr capacity with 1.2 W array**
  - Up to 1200 Whr with primary batteries
- Control
  - <0.003° pointing; >35°/sec slew rates
- Communications (relay to primary)
  - X band with 5 W RF power
  - Antennas > 28 dBi gain X band
- Propulsion (chemical)
  - ~250 m/s ΔV for a 12 kg 6U
- Thermal
  - Some concepts would benefit from a compact RHU to survive thermal extremes



Lunar IceCube: 120 W @ Earth



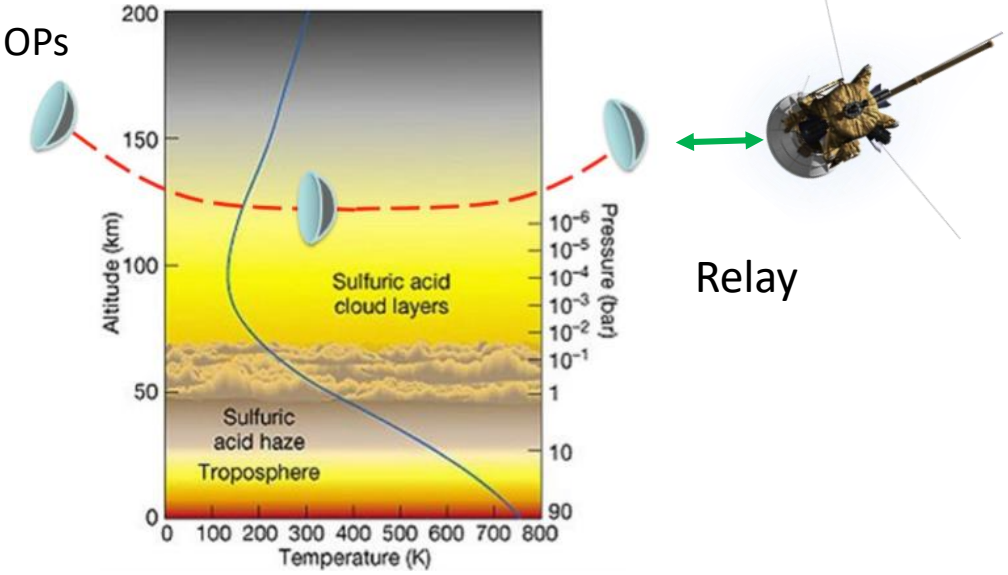
MarCo 28 dBi reflect array



Aerojet Rocketdyne MPS-120XW

Cupid's Arrow Concept (PI: C. Sotin, JPL)

CONOPs



Relay

Mission Overview

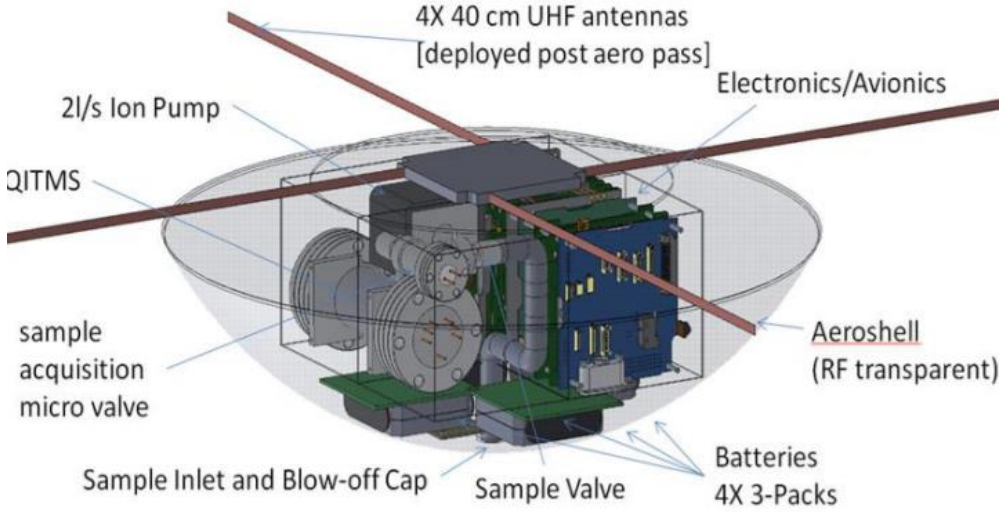
- Small (< 0.5 m) atmospheric probe
- Primary Spacecraft does **Venus Flyby enroute to Saturn**
- Primary releases probe prior to flyby
- Probe skims below homopause (~120 km) collecting sample
- Probe skips out of the atmosphere
- Probe relays data to the primary to be sent to earth after exiting atmosphere (requires UHF relay on primary)
- Probe continues into deep space

Science Overview

1. Formation and evolution of Venus atmosphere
2. Compare volatile compounds of Earth, Mars, and Venus
3. Determine the volcanic history of Venus

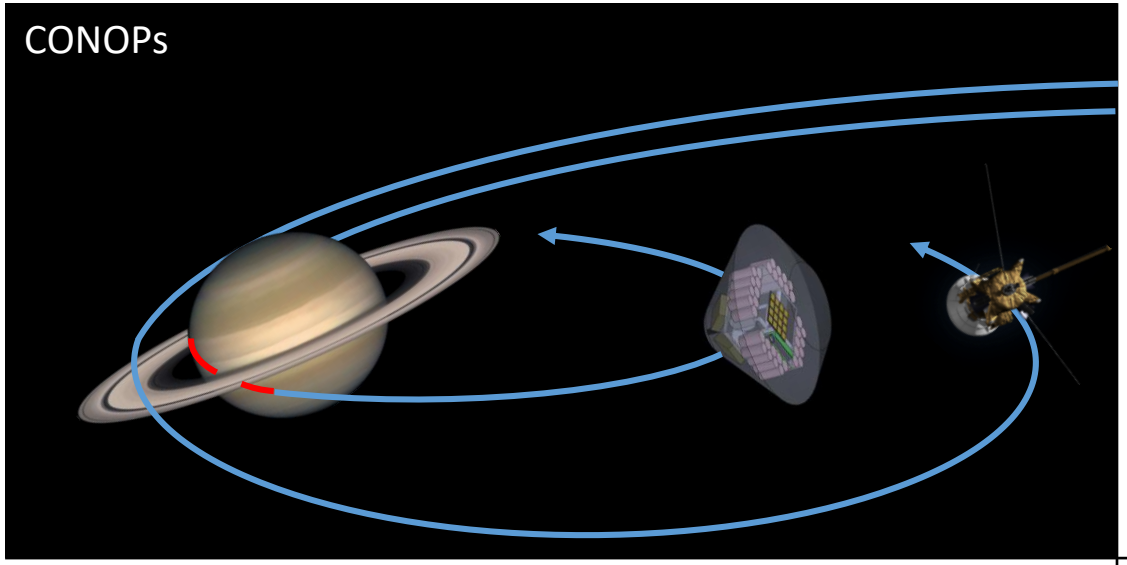
Objectives achieved by measuring the abundances of noble gases (Ne, Ar, Kr, Xe) and their isotopic ratios in Venus' atmosphere below the homopause (well mixed atmosphere)

Spacecraft Concept



Saturn Arrow Concept

CONOPs



Mission Overview

- Primary **releases probe onto entry trajectory prior to SOI**
  - Primary deflects off entry trajectory post separation
- Probe skims through atmosphere down to homopause
  - Mass spectrometer does in situ measurements
  - Probe performs aerocapture maneuver
- Probe skims through the atmosphere and exits onto Saturn orbit
- After exiting atmosphere, probe drops backshell and relays data to primary to then be sent to Earth
- Disposal into Saturn on next periapse pass

Science Overview

- No in situ measurements of Saturn's atmosphere
- Desire to compare Jupiter and Saturn atmosphere
- Desire to understand gas giant exoplanets

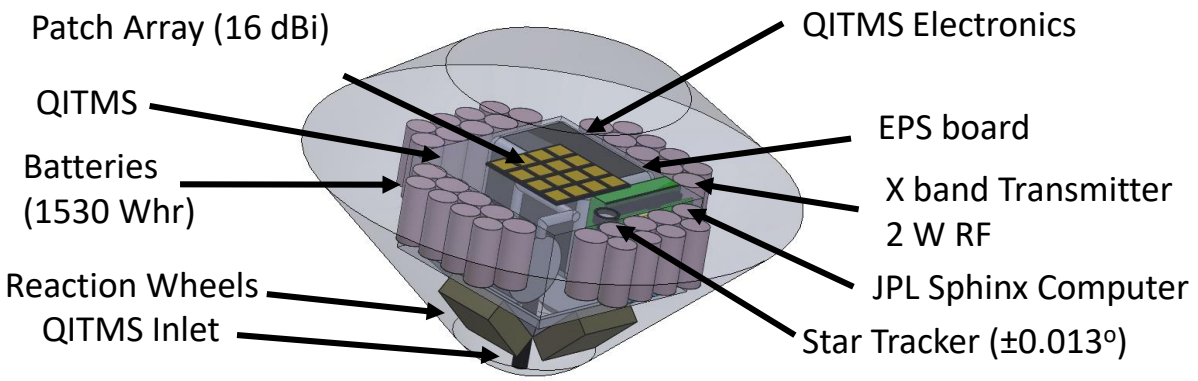
Saturn Arrow Objectives:

- Determine H/He ratio be diving through the homopause

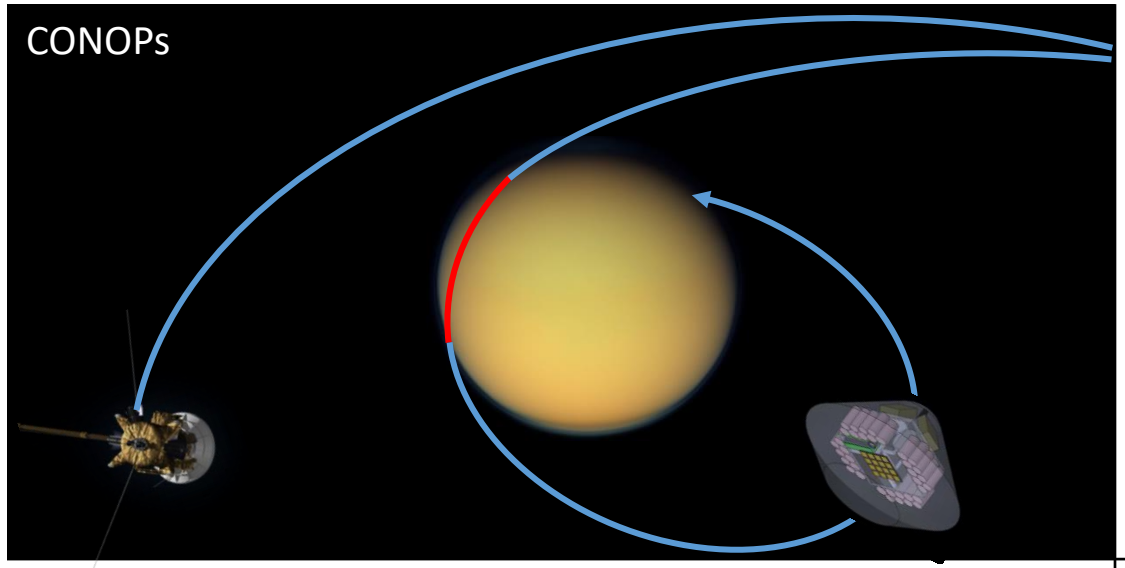
H/He ratio determined with Quadrupole Ion Trap Mass Spectrometer (QITMS) diving through homopause

Spacecraft Concept

- Cupid's Arrow probe modified for Saturn
  - Galileo based 45° sphere cone, ~0.55 m diameter, < 40 kg



Titan Arrow Concept



Mission Overview

- Primary Spacecraft, Oceanus or ELF, orbiting Saturn with flybys of Titan
- **Probe released from Primary onto spin stabilized "dive" trajectory**
  - Primary deflects from entry trajectory post separation
- Probe skims through the atmosphere down to homopause (~500 km)
  - Collects in situ samples for mass spec analysis
  - Probe performs aerocapture maneuver
- Probe exits atmosphere, drops backshell and transmits data to Primary to be sent to Earth
- Probe disposed to acceptable location on Titan on next periapse pass

Science Overview

- Huygens Probe didn't sample upper atmosphere
- Upper atmosphere data desired for complete model

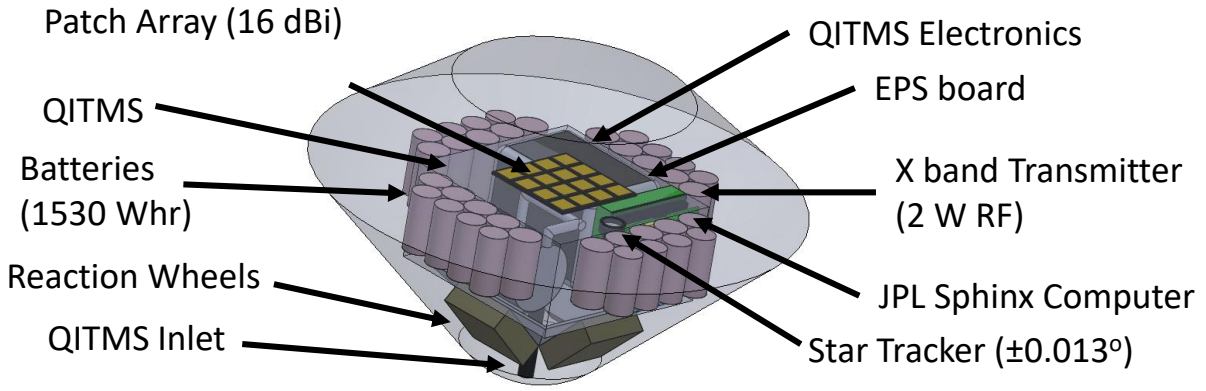
Titan Arrow Objectives:

- Determine Upper atmosphere constituents
  - Ne, Ar, Kr, Xe

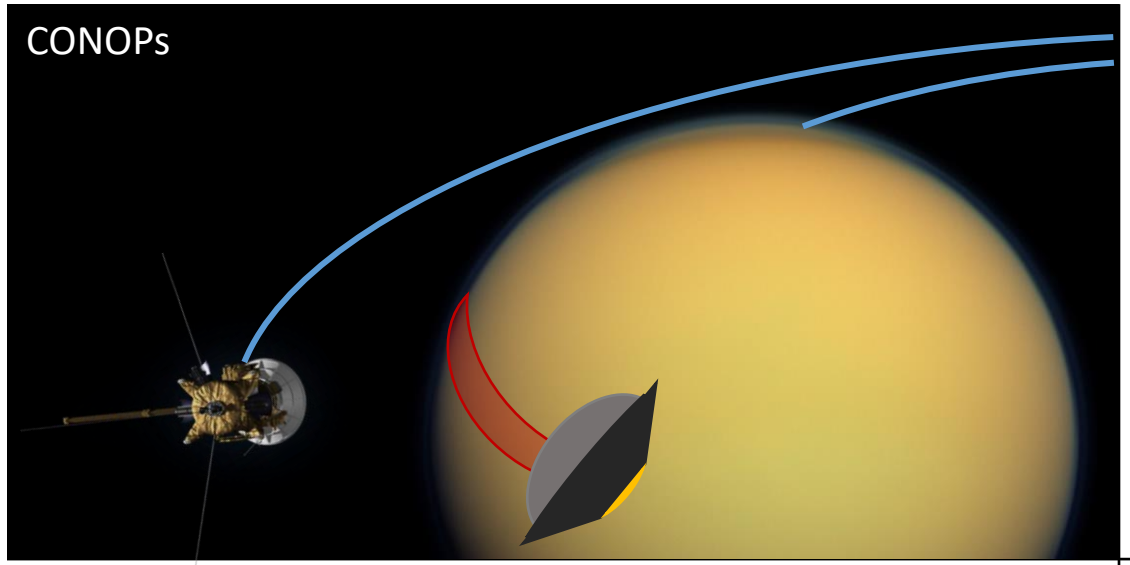
Constituents determined with Quadrupole Ion Trap Mass Spectrometer (QITMS) diving through homopause

Spacecraft Concept

- Cupid's Arrow probe modified for Saturn
  - Galileo based 45° sphere cone, ~0.55 m diameter, < 40 kg



Titan Probe Concept



Mission Overview

- Primary Spacecraft, Oceanus or ELF, orbiting Saturn with Titan flybys
- **Probe released from Primary onto spin stabilized entry trajectory**
  - Primary deflects from entry trajectory post separation
- Probe enters atmosphere and descends to the surface
  - Takes measurements with JPL QITMS mass spectrometer
  - Takes surface pictures with JPL Intellicam
  - Relays data to the Primary to be sent to Earth

Science Overview

- Second data point beyond Huygens desired
  - Atmosphere and landing location

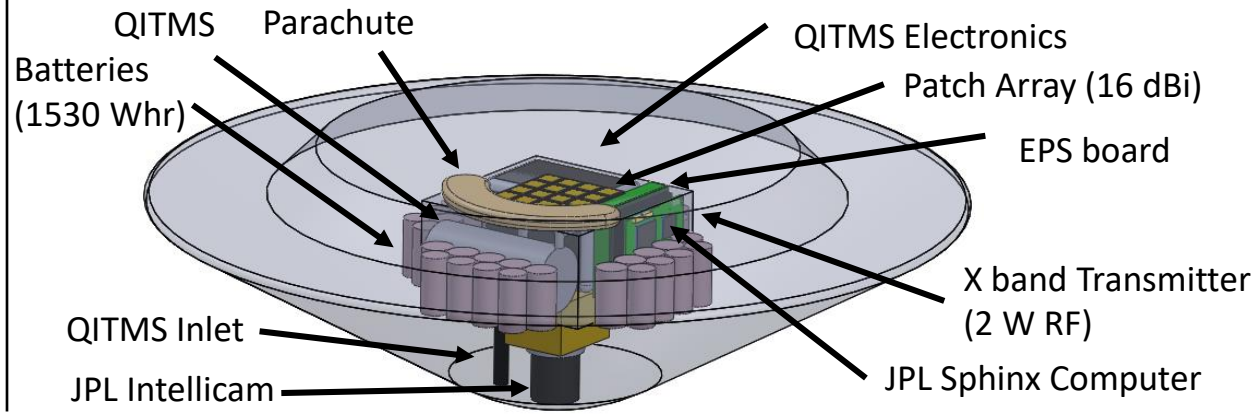
Titan Probe Objectives:

- Investigate noble gas and isotopic ratios (Ne, Ar, Kr, Xe)
- High resolution imaging of Titans surface
  - Shoreline or dunes desired

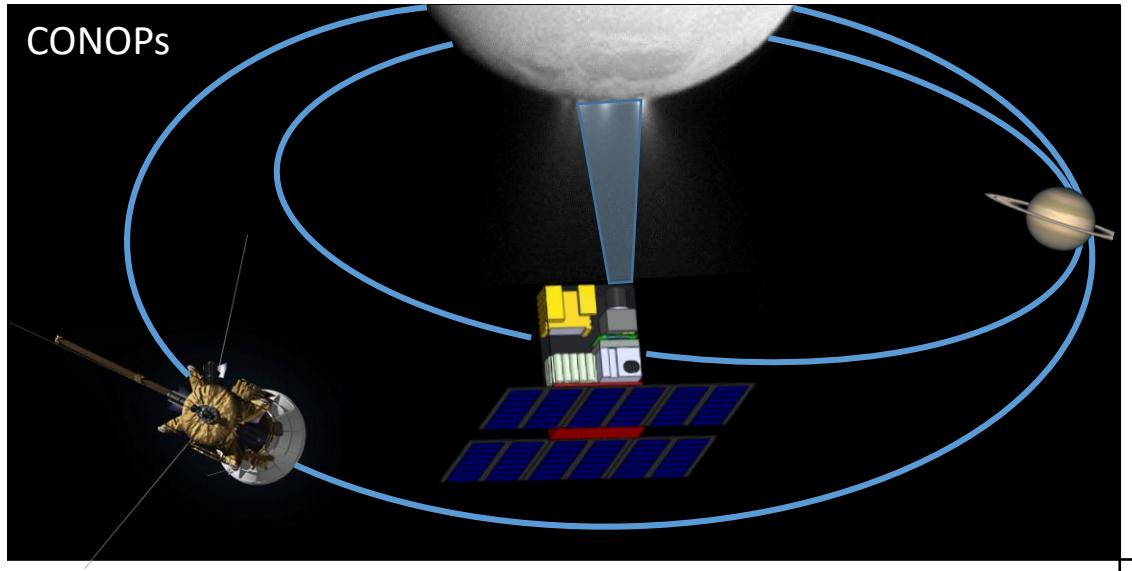
Achieved with Quadrupole Ion Trap Mass Spectrometer (QITMS) and Intellicam (10 cm resolution @ 800 m)

Spacecraft Concept

- Based on Huygens design
  - 60º sphere cone, 0.85 m diameter, 0.27 m height



Enceladus South Pole Imager Concept (ESPI)



Mission Overview

- Primary Spacecraft, ELF**, inserts into Saturn orbit for flybys of Enceladus**
- 6U Solar Powered CubeSat
- Deployed by ELF into 68 day orbit with 8 flybys of south pole
  - Flybys at ~8 km
- Short operation window, spend rest of orbit recharging and relaying data to Earth through ELF
  - To ELF via X band using ELF's Low Gain Antennas
- Disposal to Tethys

Science Overview

- Enceladus is a strong candidate to host life, future lander mission is likely
- Current best images are ~ 4m/pixel* which is inadequate for lander planning

ESPI could fill this knowledge gap by:

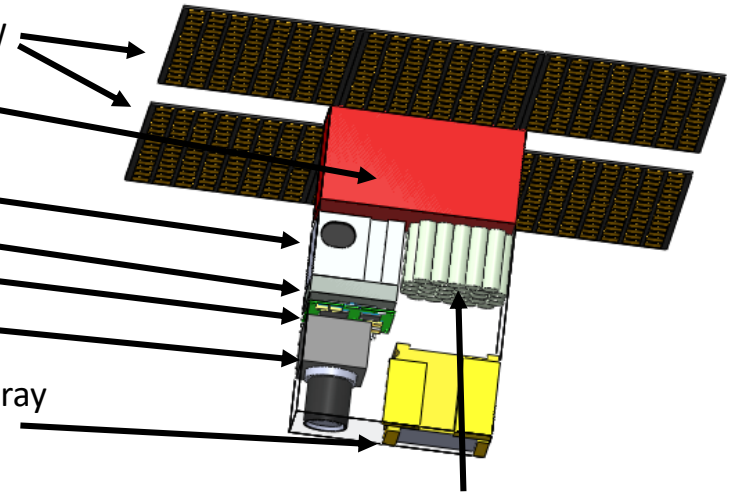
- Mapping Enceladus Tiger Stripe region for future landing probe

Mapping achieved with 1 m stereo panchromatic imaging

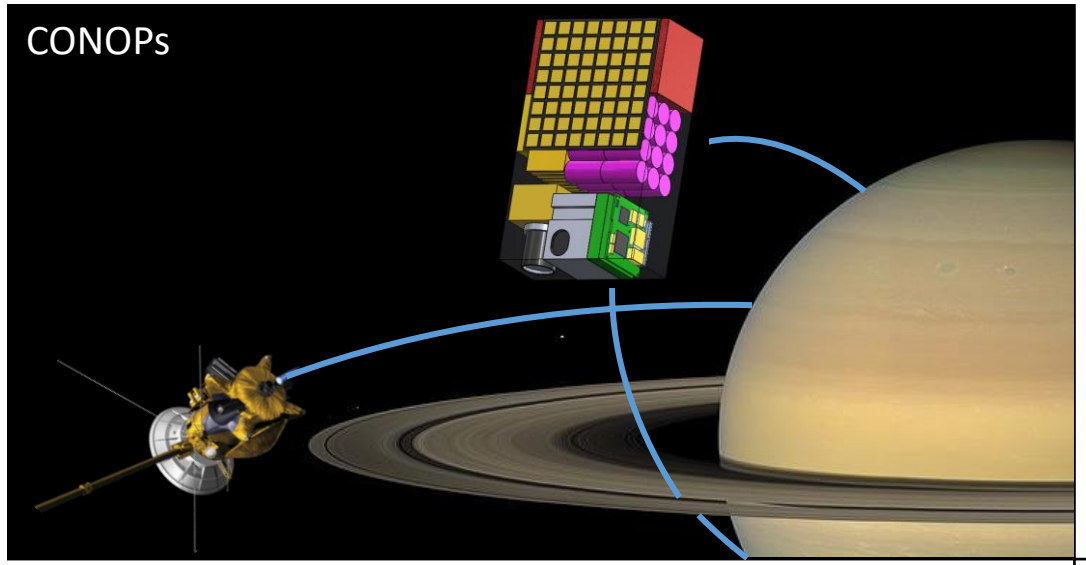
* http://science.sciencemag.org/content/sci/311/5766/1393.full.pdf

Spacecraft Concept

6 panel solar array generates 1.2W
Aerojet Rocketdyne MPS120XW
~250 m/s with AF-M315E
BCT XACT 50 (0.0017°)
GomSpace P60 EPS
JPL Sphinx computer
Modified JPL Intellicam
1 m resolution @ 8 km
IRIS 2.1 radio and MarCo reflect array
~100 kbps @3000 km
Single RHU (~1 W heat)



Saturn Ring Diver Concept



Mission Architecture

- 6U CubeSat rides along with Oceanus or ELF to Saturn
- **Released at apoapse after Primary does Saturn orbit insertion**
- CubeSat performs inclination change maneuver ~45°
  - Low translational velocity relative to rings at dive
- CubeSat dives through narrow gap in rings while taking pictures
- If it survives, it transmits images to Primary via high gain antenna
- CubeSat continues in ring diving orbit if it survives, is destroyed by rings if it doesn't

Science Overview

Ring Science Gaps

- Mass
- Age
- Structure

Ring Diver investigates the ring structure by:

- Determine density of Saturn's ring (TBD)
- Size and distribution of ring particles
- Particle Morphology

Objectives achieved with <10 cm per pixel resolution camera

Spacecraft Concept

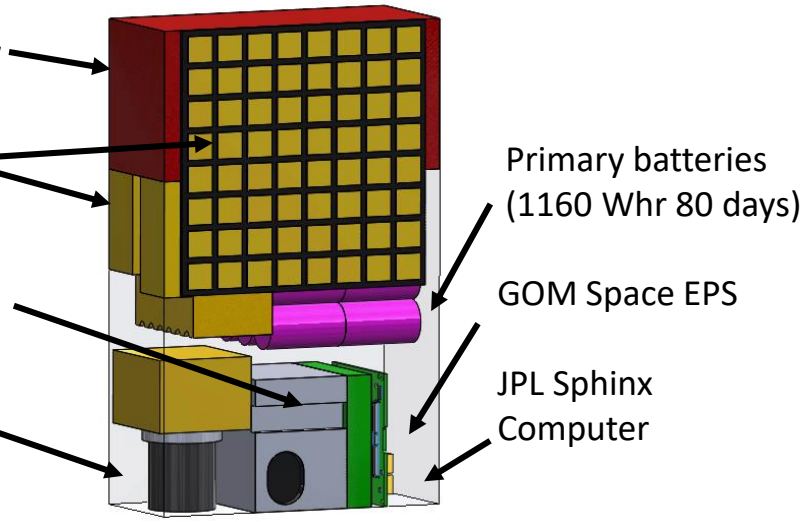
Aerojet Rocketdyne MPS120XW
(~250 m/s with AF-M315E)

IRIS Radio, 8x8 patch array
(100 kbps @150,000 km)

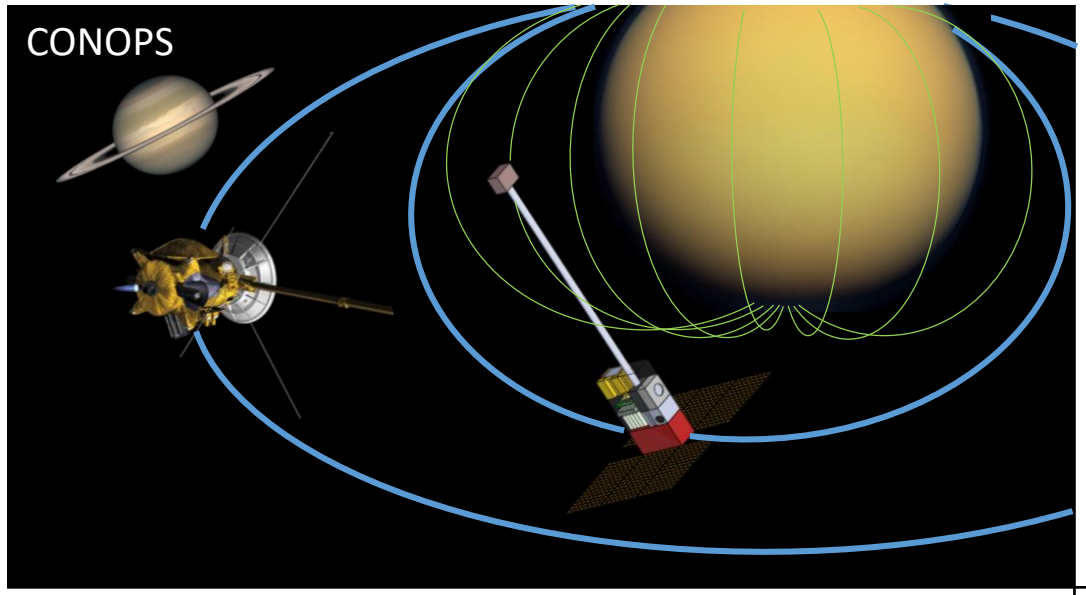
BCT XACT 50 (0.003° accuracy)

JPL Intellicam
(10cm/pixel at 800m)

Single RHU ~ 1 W heat



Titan Investigation of the Magnetosphere Concept (TIM)



Mission Overview

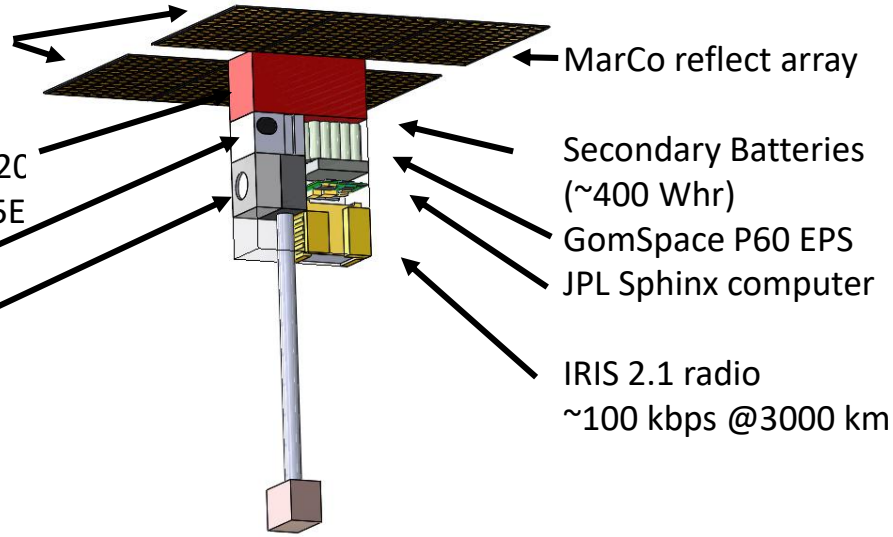
- Primary Spacecraft, Oceanus, inserts into Titan orbit
- **6U CubeSat released into orbit with Oceanus**
  - ~5.8 hour orbit
- Deploys magnetometer on 0.6m boom
- 5 orbits of 1 and 0.03 Hz measurements for the magnetometer and plasma instrument respectively
- 90 orbits recharging batteries and relaying to Oceanus via Oceanus' low gain antennas
  - Oceanus relays data back to Earth
- Disposal into Titan

Science Overview

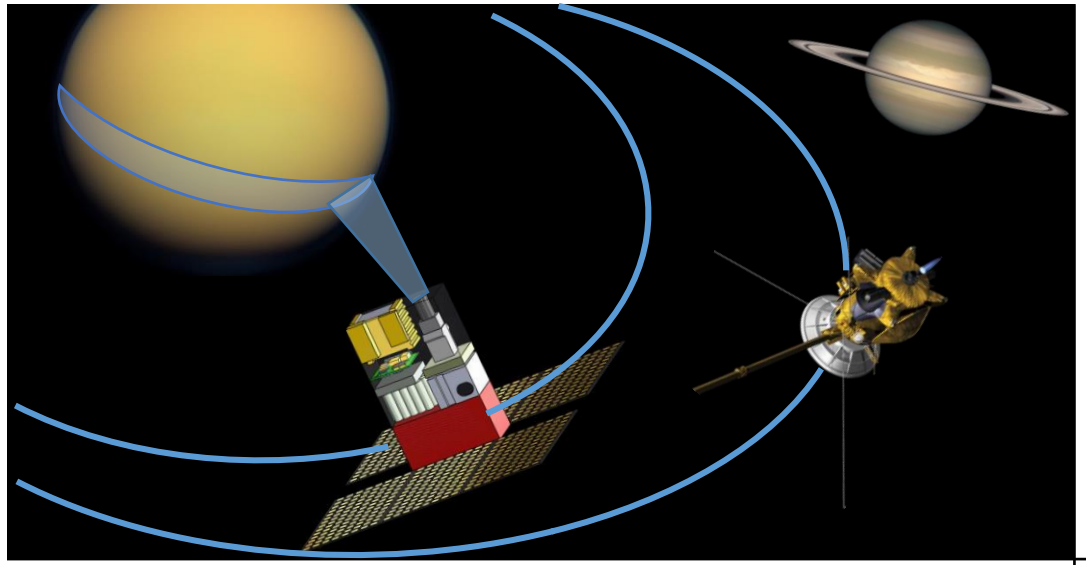
- Measure interaction of solar wind and Titan's magnetosphere
- Map Titan's magnetosphere

Objectives achieved with a Vector Helium magnetometer and Faraday Cup plasma instrument

Spacecraft Concept



SPectral Line Investigation at Titan Concept (SPLIT)



Mission Overview

- Primary Spacecraft, Oceanus, Inserts into Titan Orbit
- **6U CubeSat released into orbit with Oceanus**
  - ~5.8 hour orbit
- 3 orbits of measurements
- 50 orbits recharging batteries and relaying to Oceanus via Oceanus' Low Gain Antennas
  - Oceanus relays data back to Earth
- Disposal into Titan

Science Overview

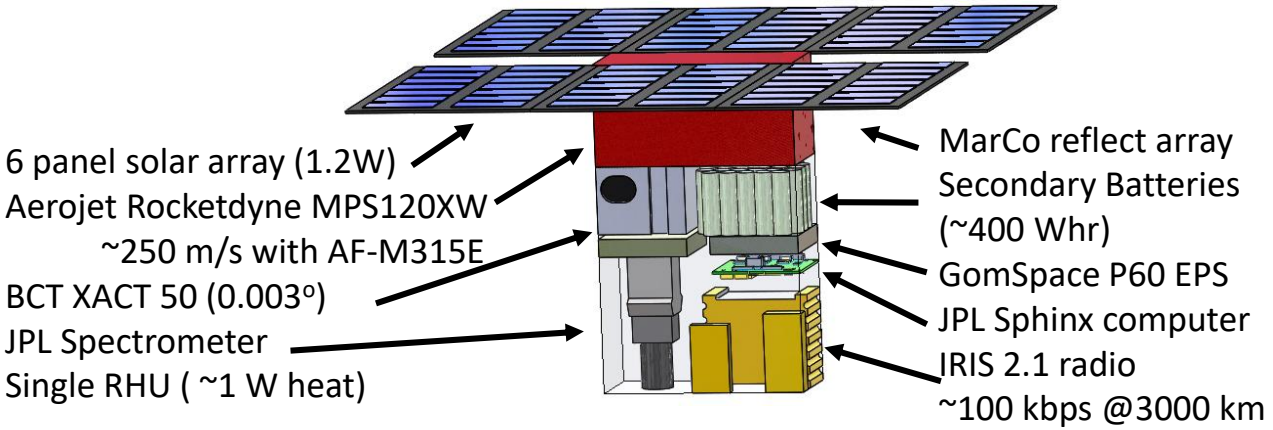
- Measure Isotropic ratios of Nitrogen and Methane in Titan's atmosphere

Objectives achieved with JPL's miniature Spatial Heterodyne Spectrometer

- Resolving power ~10,000 – 200,000
- Spectral Resolution of ~0.01 Angstroms

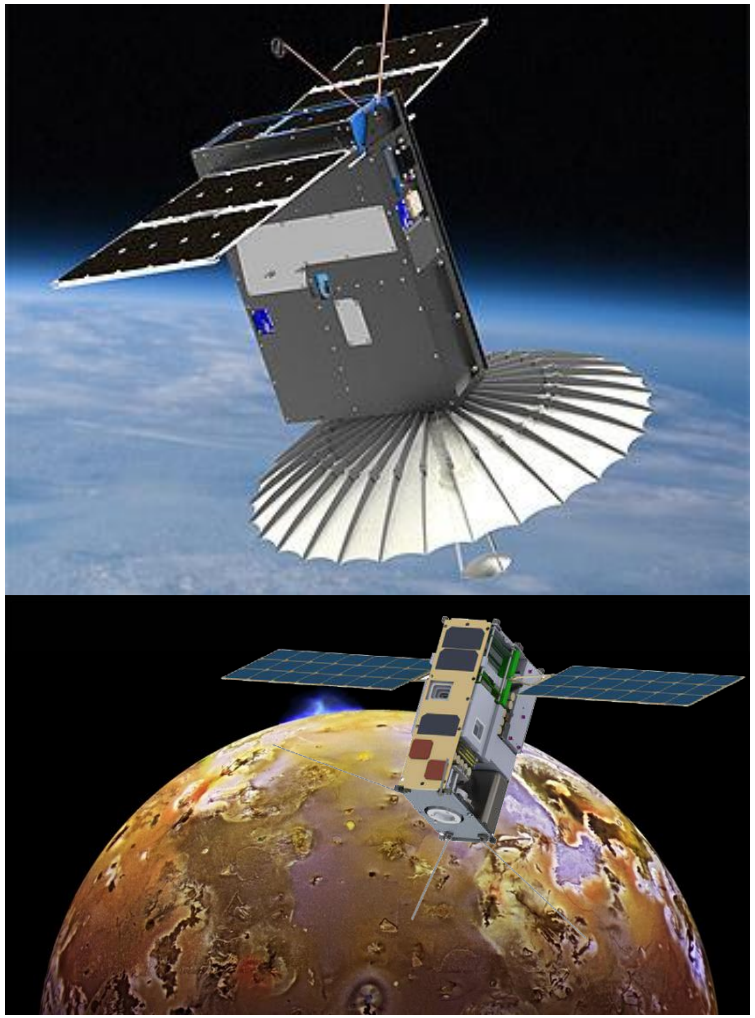
"Tunable Reflective Spatial Heterodyne Spectrometer: A Technique for High Resolving Power, Wide Field Of View Observation Of Diffuse Emission Line Sources", Sona Hosseini, Ph.D. Dissertation, University of California Davis, July (2015).

Spacecraft Concept



Other Opportunities

- Saturn
  - Titan Radar CubeSat Concept
    - Ka radar, based on RainCube developed at JPL/Tyvak
    - RainCube launching Q4 2018
    - Detect CH_4 precipitation?
- Jupiter Flyby Concept
  - Flyby over the poles
  - Magnetometer Swarm
  - Io imager



Conclusion

- All missions concepts appear feasible technically
- Regulatory and process development needed
  - Need to follow regulatory process for putting RHUs in CubeSats
  - Need to follow planetary protection processes for CubeSat cleanliness
- These mission concepts and process needs are all within the expertise of JPL

Thank You

Acknowledgements

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- John Elliott[1]
- Christophe Sotin[1]
- Morgan Cable[1]
- Sona Hosseini[1]
- Shawn Brooks[1]

[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA