EXTENDING SMALL MISSION OPPORTUNITIES TO THE OUTER SOLAR SYSTEM THROUGH RIDESHARE. K. M. Sayanagi[1], C. L. Young[1], R. W. Ebert[2], M. L. Cable[3], M. S. Tiscareno[4], M. M. Hedman[5], D. H. Atkinson[3], and O. Mousis[6]. [1]NASA Langley Research Center (kunio.m.sayanagi@nasa.gov), [2]Southwest Research Institute, [3]NASA Jet Propulsion Laboratory, California Institute of Technology, [4]SETI Institute, [5]University of Idaho, [6]Aix-Marseille Université.

Mission Architecture: This abstract identifies a new paradigm for an outer solar system exploration in which a stand-alone Carrier-Relay Spacecraft (CRSC) delivers multiple small missions to the target system.

Target Destination: This architecture targets outer solar system destinations where solar power is viable, i.e. primarily Jupiter and Saturn.

Platform: This architecture enables fly-by measurements of outer solar system destinations. As a case study, we demonstrate that a low-cost spacecraft bus based on the Propulsive ESPA architecture, launched alongside the Dragonfly mission to Saturn, enables innovative and viable smallsat missions and achieve high-value science objectives. In our case study, the CRSC separates and flies independently after launch to reduce risk to the primary payload, and carry two small spacecraft weighing up to 130 kg each. We found that, to accommodate this architecture, the launch vehicle (LV) will require an upgrade from Dragonfly's early notional LV Atlas V 411 to Atlas V 541. We have also identified multiple high-value mission concepts that fit within the 130 kg limit. As examples, we present concepts for Saturn Probe, Saturn Ring In-Situ Explorer, Magnetospheric Explorer, and Enceladus Plume Sampler. The cost of each 130-kg payload would be similar to the ~$80M SIMPLEx cost cap recommended by the recent Decadal Survey.

Case Study: Leveraging Dragonfly Launch: Dragonfly's early published interplanetary trajectory has a total $\Delta V = 217.7$ m/s and Launch $C_3 = 16$ km^2/s^2 (from Scott et al. 2018, "Preliminary Interplanetary Mission Design and Navigation for the Dragonfly New Frontiers Mission Concept" Advances in the Astronautical Sciences 18-416).

The Carrier-Relay Spacecraft (CRSC) that delivers these small missions to the Saturn System will follow the same trajectory as Dragonfly. CRSC's ΔV and thermal management requirements will mimic those of Dragonfly so that CRSC can be launched in any potential launch window and follow the trajectory of Dragonfly. Thus, inclusion of these missions does not add any constraint on the launch window.

Carrier-Relay Spacecraft Architecture: Carrier-Relay Spacecraft (CRSC) can be designed around a Propulsive ESPA Bus (shown above from Stender et al. 2015, 31st Space Symposium). CRSC serves as a communication relay to return data collected by the small missions to Earth. Table 1 shows a notional mass breakdown of the CRSC.

Table 1.

CRSC Subsystem	Mass
Structure (Estimate)	391 kg
Solar Panels	202 kg
TCS+ACS+CDH+Comm	105 kg
RCS	46 kg
Science Payload	260 kg (x2 130 kg)
Dry Mass	**1,005 kg**
Propellant ($\Delta V = 246.6$ m/s)	128 kg
Total CRSC Launch Mass	**1,132 kg**

Launch Configuration: Dragonfly's published preliminary trajectory assumes Atlas V 411 as the notional launch vehicle. Dragonfly's mass is estimated assuming that it fills all of the Atlas V 411 launch capacity to obtain the required Launch $C_3 = 16$ km^2/s^2. Upgrading the Launch Vehicle to Atlas V 541 will enable launching the CRSC weighing 1,132 kg including two 130-kg missions to the Saturn System using the Dragonfly launch. Table 2 shows the required launch mass requirements, and Table 3 compares the launch mass with Atlas V 541's launch capacity to C_3 =16 km^2/s^2.

Table 2.

Payload Item	Mass, kg
Dragonfly Mass (Assumed)	2,780
CRSC Propulsive ESPA (Including x2 130 kg small missions)	1,132
LPF → EEPF Adjustment (Estimate)	50
Total Required	**3,962**

Table 3.

Launch Capability to $C_3 = 16$ km^2/s^2	Mass, kg
Atlas V 541 Capacity	4,095
Payload Margin	**133**

Mission Concepts: We present 4 concepts that could be carried to the Saturn System with the CRSC architecture presented here. The 4 concepts would address high-value science objectives uniquely enabled by the opportunity to share a launch with Dragonfly.

Concept 1: Saturn Probe.
The concept addresses the L1 goals of the Saturn Probe New Frontiers Theme defined in the Decadal Survey.
Science Objectives:
1. Measure noble gas abundances
2. Measure isotopic ratios of H, C, N, and O
3. Determine atmospheric structure above 1 bar

Instruments:
- Mass Spectrometer
- Atmospheric Structure Instrument

Preliminary Design with 1-m HEEET Aeroshell:

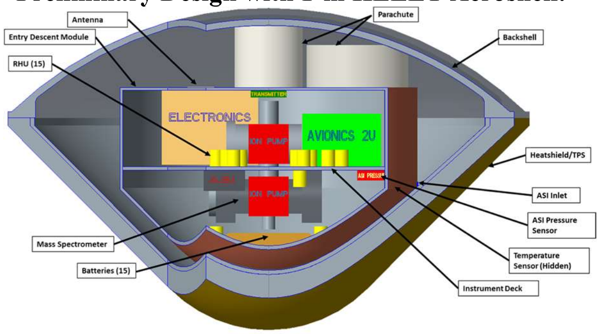

Figure 1. Preliminary Saturn Probe Design

Preliminary Mass Estimate of this concept is 135.8* kg including 30% reserve. Preliminary Cost Estimate (FY20$): $94M including 30% reserve.

Concept 2: Ring In-Situ Explorer

The concept is similar to the "Lora (Landers on Rings Array)" concept by Marty et al. (2009, Exp. Astron. 23). Table 4 shows a preliminary design concept. Multiple micro-probes will be released to explore different regions of the rings.

Science Objectives:
1. Determine size distribution of ring particles
2. Determine fine-scale structures of the rings
3. Characterize ring particles' collisional dynamics

Instrument:
- Imaging Camera

Table 4. Preliminary Ring In-Situ Explorer Design

Subsystem	Mass	Power
Camera (JunoCam-like)	3.6 kg	6 W
Avionics	1.7 kg	4 W
ACS	0.5 kg	3 W
Comm	1.5 kg	50 W
Li-Ion Batteries (168 Wh)	1.4 kg	--
Antenna	0.25 kg	--
RHU	0.2 kg	--
Structure	0.5 kg	--
30% Margin	3 kg	19 W
Total	**13 kg**	**82 W**

Concept 3: Magnetosphere Explorer.

Based on the JUMPER concept, a smallsat orbiter for magnetospheric science at Jupiter (Ebert et al. 2018, IEEE).

Science Objectives:
1. Determine how the solar wind couples to Saturn's magnetopause.
2. Determine the contribution from energetic neutral atoms (ENAs) to mass loss from Saturn's magnetosphere.

Instruments*:
- Plasma ion sensor (IES)
- Energetic neutral atom imager (NAI)
- Magnetometer (MAG)

Preliminary Design:

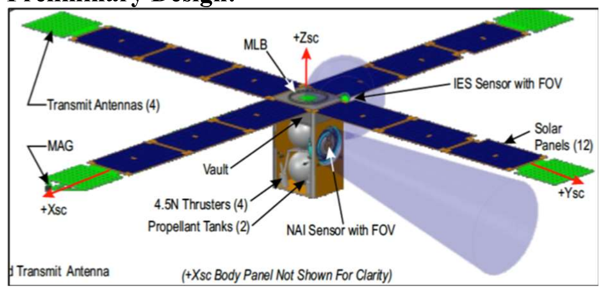

Figure 2. Preliminary Magnetosphere Explorer Design

*Science objectives, instrument selection, and spacecraft design may need refining for Saturn.

Concept 4: Enceladus Plume Sampler.

Based on the Sylph probe concept to fly through and sample the plume of Europa at low altitude (Sherwood et al. 2016).

Science Objectives:
1. Determine plume particle composition, in particular large grains at low altitude (<20 km).
2. Search for evidence of biosignatures in organic-rich plume grains.

Instruments:
- Mini-SUDA (SUrface Dust Analyzer)
- OpNav cameraPlasma ion sensor (IES)

Preliminary Design:

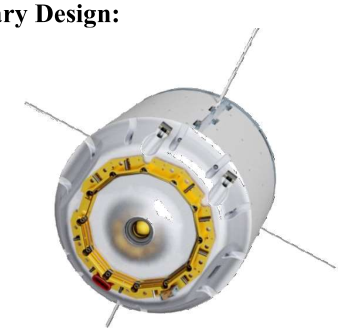

Figure 3. Preliminary Enceladus Plume Sampler Design

Preliminary Mass Estimate: 85 kg (includes probe and biobarrier dispenser)

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