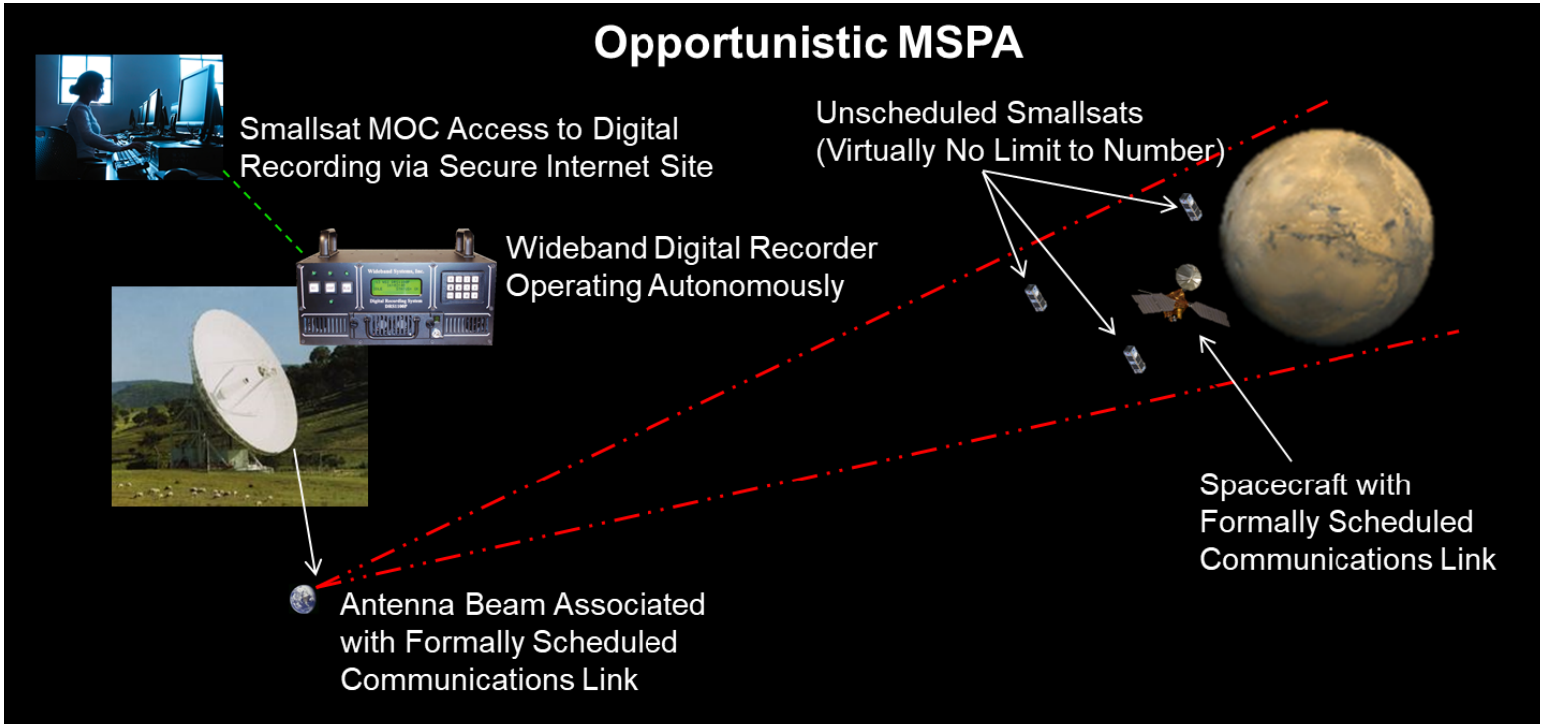
InSight/MarCO Opportunistic Multiple Spacecraft Per Antenna (OMSPA) Demonstration



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Introduction

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- As smallsats, such as CubeSats, continue to mature, their usage is being increasingly considered to complement larger, more primary NASA missions.
- A challenge with the proliferation of smallsats and other missions operating in deep space is the ability to support telemetry communications with all of them.
- One technique to help overcome this challenge, referred to as Opportunistic Multiple Spacecraft Per Antenna (OMSPA), may be well suited to smallsats operating alongside larger main satellite missions.
  - In this approach, smallsats within the scheduled ground antenna beam of some other spacecraft, make opportunistic use of beam coverage by transmitting.
  - Transmissions from all spacecraft within beam are recorded open-loop.
  - Open-loop recordings can be later retrieved and processed so that data from all relevant spacecraft can be recovered, without separate scheduling of the antenna itself.
  - Widespread use of OMSPA could lead to more efficient use of receiver antenna resources and result in dramatic increase in downlink throughput.
- An opportunity to demonstrate OMSPA occurred in May 2018, when the following spacecraft were in-beam during their launch window:
  - InSight (primary NASA robotic lander mission),
  - Mars CubeSat One (MarCO) nanospacecraft (MarCO-A & B).
- For this event, X-band downlink telemetry was recorded for all three spacecraft at both the Deep Space Network (DSN) and at Morehead State University (MSU).
- Recordings were processed at the Jet Propulsion Laboratory (JPL) using a software tool developed in MATLAB known as the OMSPA Software Receiver.

OMSPA Concept

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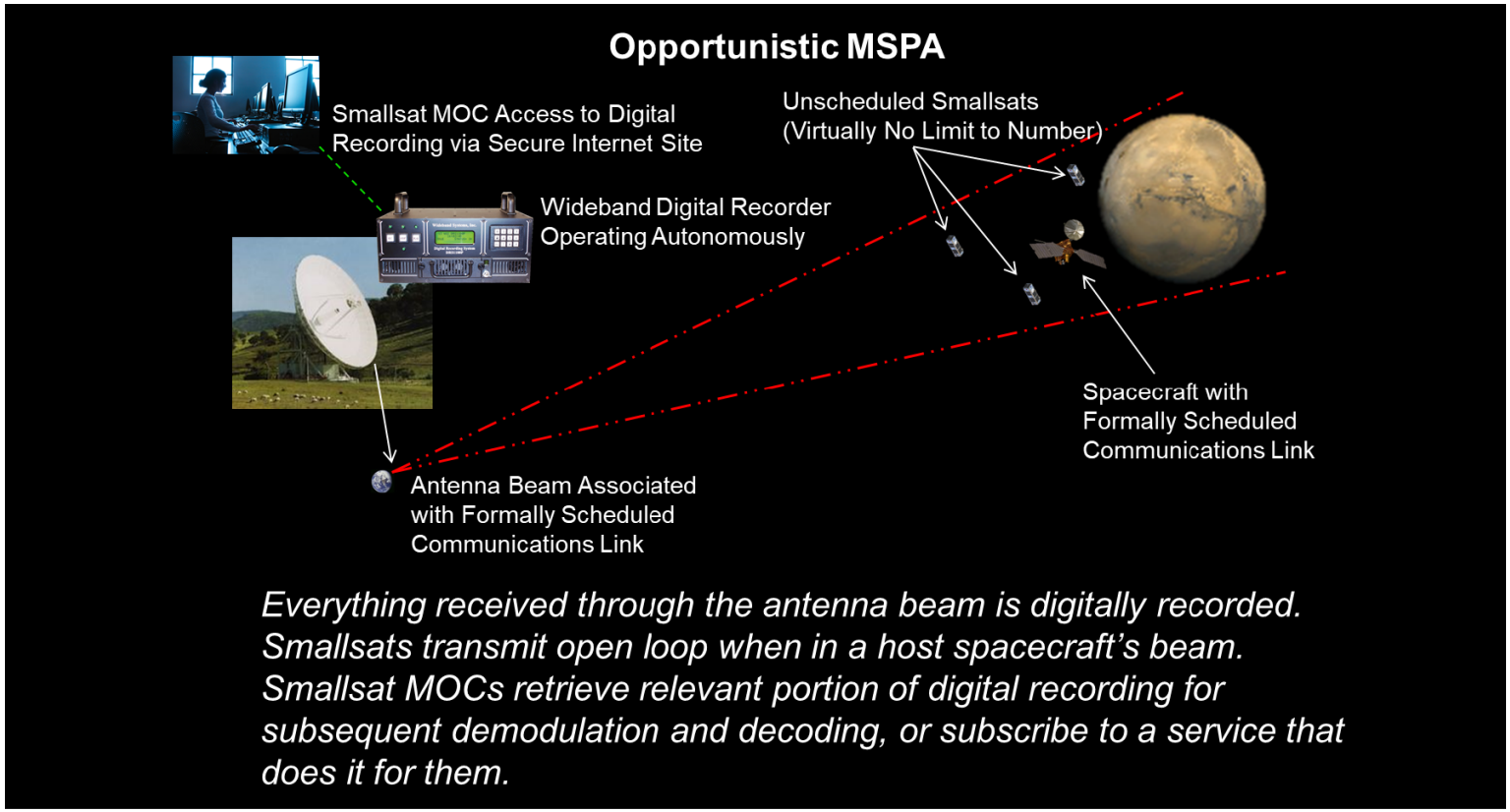

- **To determine if a smallsat is a candidate for OMSPA, factors must be considered including:**
  - **start/end time of downlink transmission,**
  - **spacecraft trajectory geometry,**
  - **sufficiency of link budget,**
  - **polarization compatibility,**
  - **applicability of ground track.**

OMSPA Signal Processing Software Receiver

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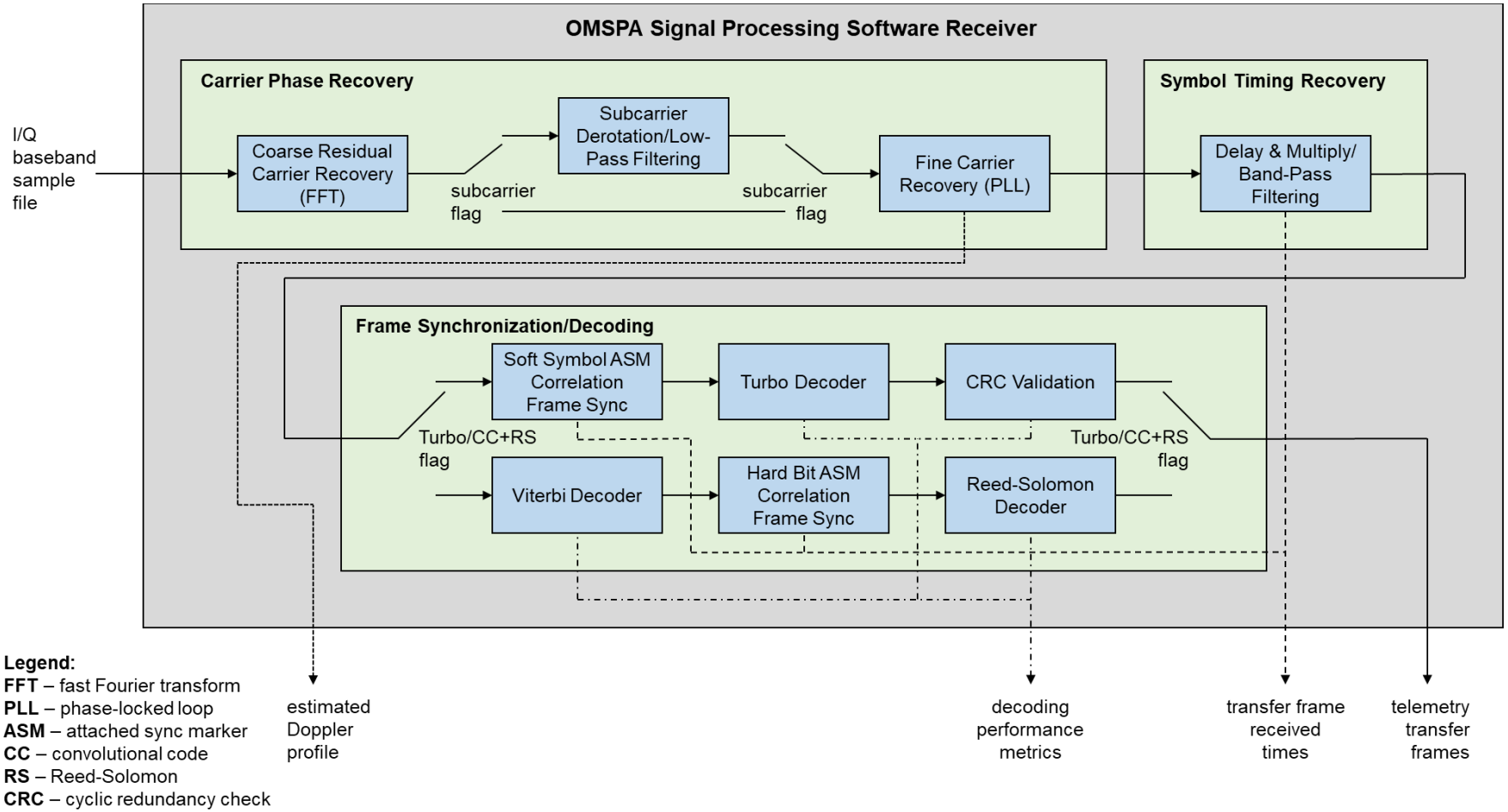

Legend:
FFT – fast Fourier transform
PLL – phase-locked loop
ASM – attached sync marker
CC – convolutional code
RS – Reed-Solomon
CRC – cyclic redundancy check

- **MATLAB based OMSPA Software Receiver designed to accommodate a variety of Consultative Committee for Space Data Systems (CCSDS) telemetry formats.**

InSight/MarCO Launch Demonstration Setup

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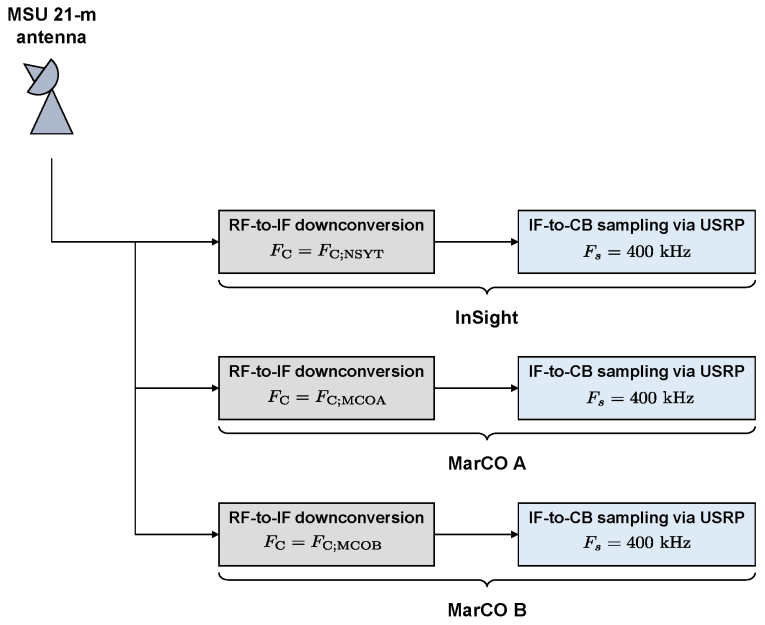
- On May 5th, 2018, 11:05 UTC, InSight and the MarCO craft (MarCO-A & B) were launched from the Atlas V 401 rocket from Vandenberg Air Force Base SLC-3E.
- For this launch window, MarCO-A and MarCO-B appeared in-beam from a deep space receiver antenna aiming at InSight.
- To test OMSPA Software Receiver for this opportunity, downlink telemetry from all three spacecraft was recorded at MSU on day-of-year (DOY) 126, 127, and 128.
- A 21-m antenna at the MSU Space Science Center was used to track the spacecraft.
- With the antenna locked on to InSight, X-band downlink telemetry from each spacecraft was recorded.
- Intermediate frequency (IF) versions of each signal were converted to complex baseband (CB) and sampled with Universal Software Radio Peripheral (USRP) devices connected to desktop computers running GNU Radio.



	InSight	MarCO-A	MarCO-B
DOY 126			
DOY 127			
DOY 128			

Legend:
- – data erroneously captured,
- – data not captured,
- – data correctly captured.

InSight/MarCO X-Band Downlink Demod Results

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	InSight	MarCO-A	MarCO-B
modulation type	PCM/PSK/PM; NRZ-L BPSK	PCM/PSK/PM; NRZ-L BPSK	PCM/PSK/PM; NRZ-L BPSK
subcarrier	yes	yes	yes
coding	CC+RS	turbo	turbo
ASM bit pattern	1ACFFC1D	25D5C0CE8990F6C9461BF79C DA2A3F31766F0936B9E40863	25D5C0CE8990F6C9461BF79C DA2A3F31766F0936B9E40863
TF length	10232	8920	8920

Nominal telemetry settings for X-Band downlink

- **InSight:**
  - **DOY 126: 2805 transfer frames (TFs), no decoding errors reported.**
- **MarCO-A:**
  - **DOY 126: 187 TFs, all passed CRC,**
  - **DOY 127: 135 TFs, all passed CRC except for 5th TF,**
  - **DOY 128: 187 TFs, all passed CRC except for 15 TFs.**
- **MarCO-B:**
  - **DOY 126: 128 TFs, all passed CRC expect for 14 TFs,**
  - **DOY 128:**
    - **TLM_LR: 46 TFs, all passed CRC except for 4th TF,**
    - **TLM_HR: 504 TFs, all passed CRC.**

	TLM_LR	TLM_HR
modulation type	PCM/PSK/PM; NRZ-L BPSK	PCM/PM; bi-phase-L BPSK
subcarrier	yes	no
coding	turbo	turbo
ASM bit pattern	25D5C0CE8990F6C9461BF79C DA2A3F31766F0936B9E40863	25D5C0CE8990F6C9461BF79C DA2A3F31766F0936B9E40863
TF length	8920	8920

Settings for MarCO lower rate TLM_LR and higher rate TLM_HR modes

InSight DOY 126 Demodulation Results

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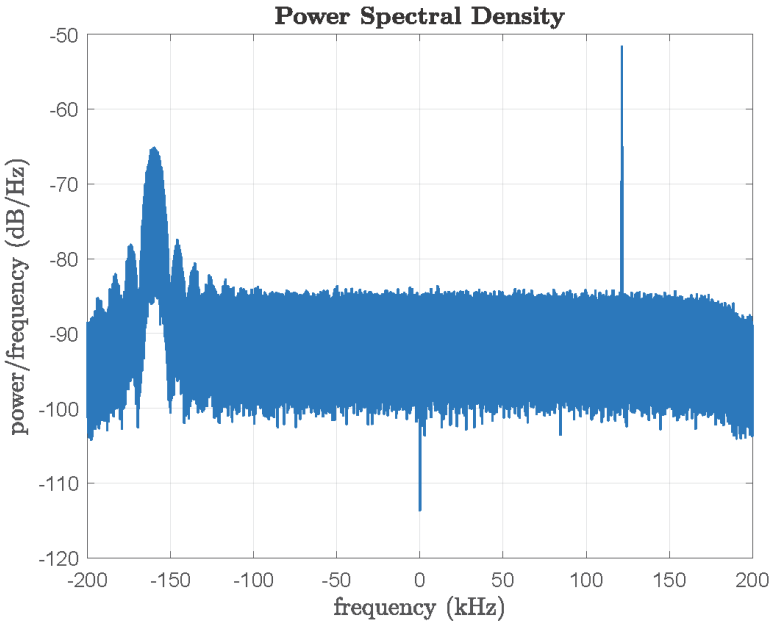

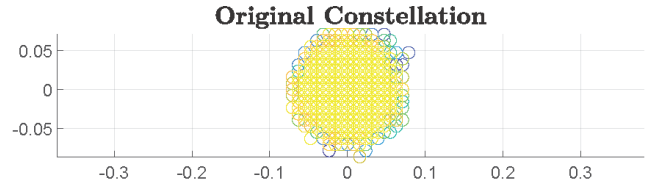

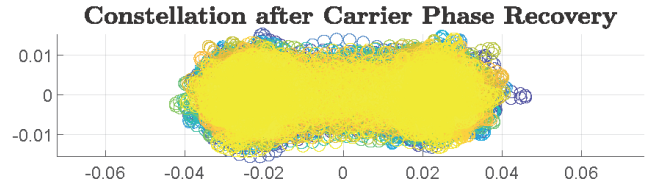

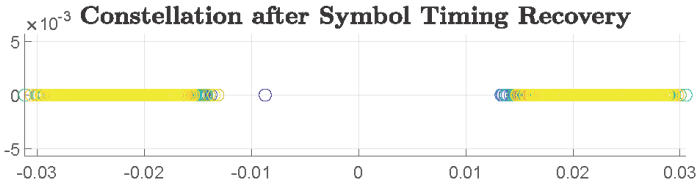

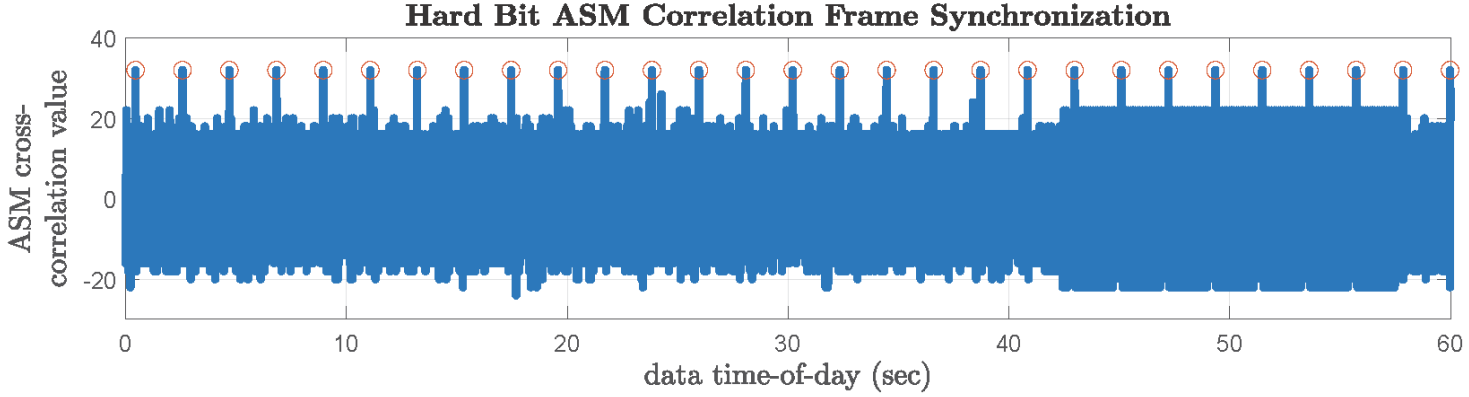

MarCO-A DOY 126 Demodulation Results

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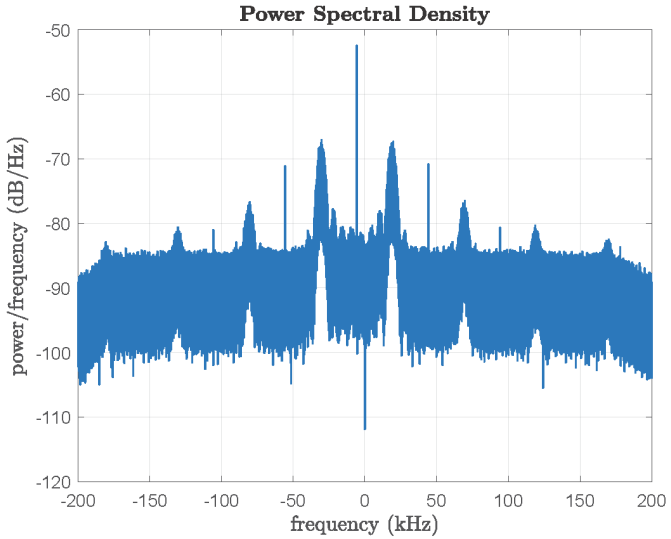

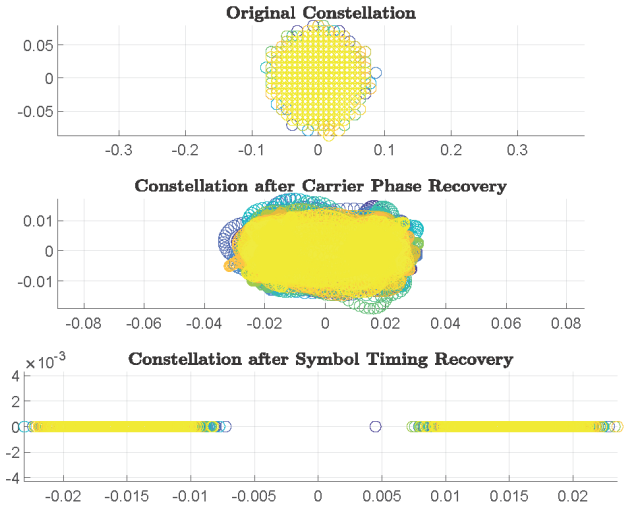

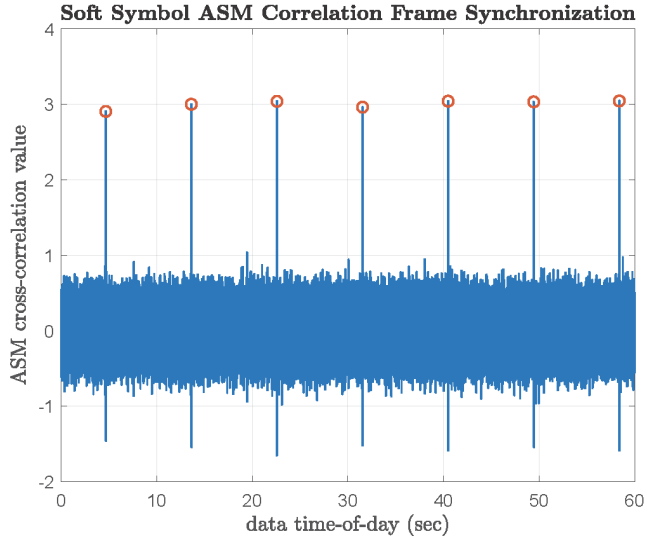

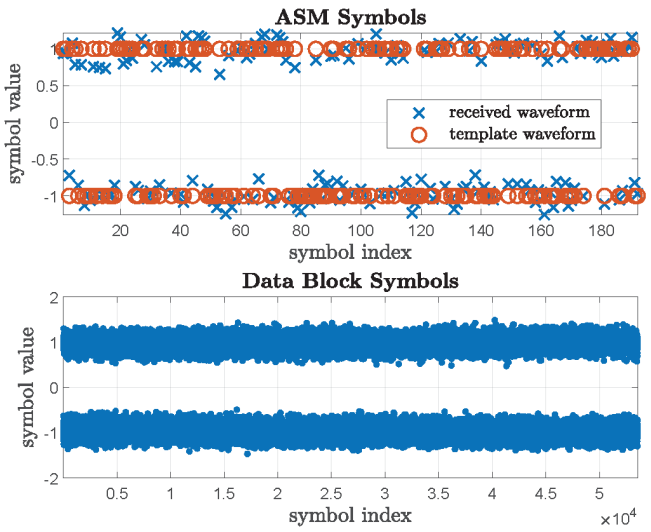

MarCO-A DOY 128 Demodulation Results

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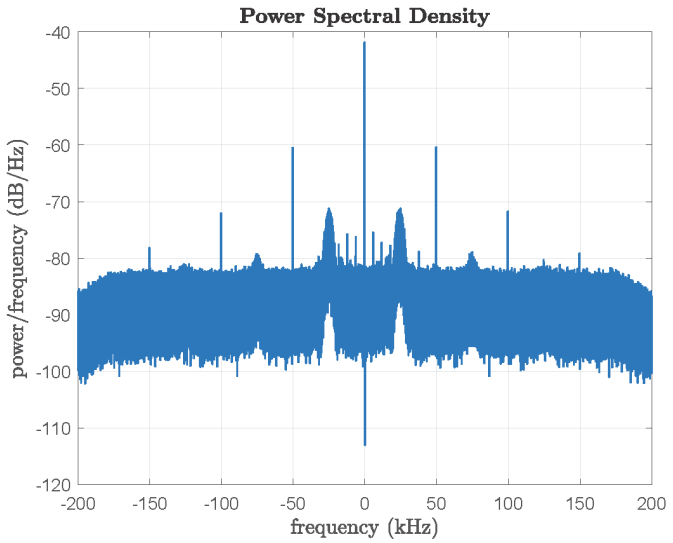

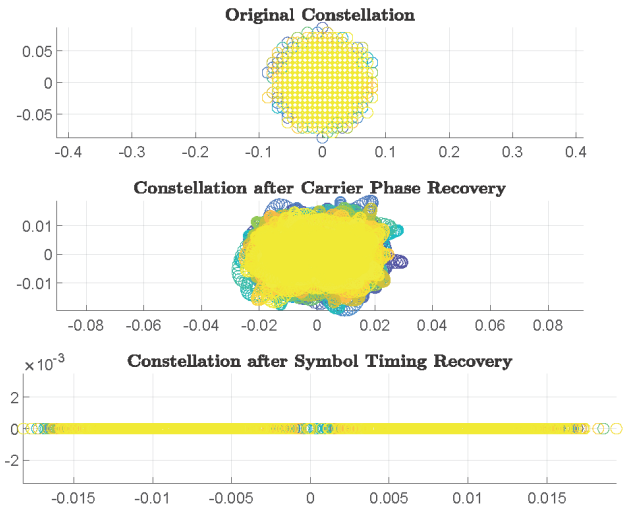

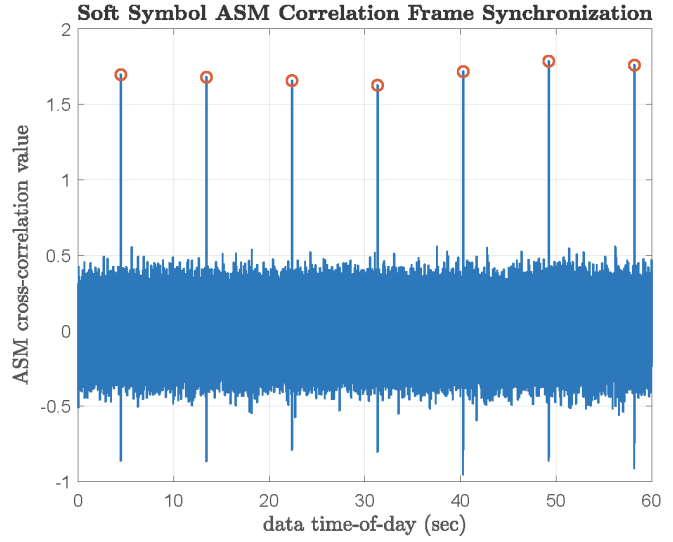

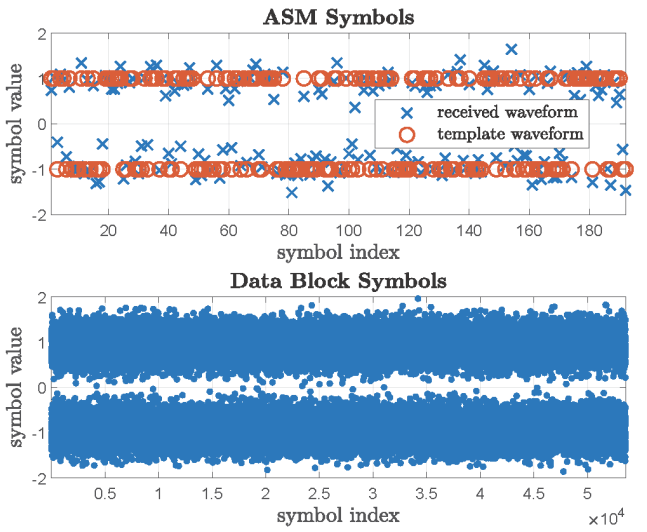

MarCO-B DOY 128 TLM_LR Demodulation Results

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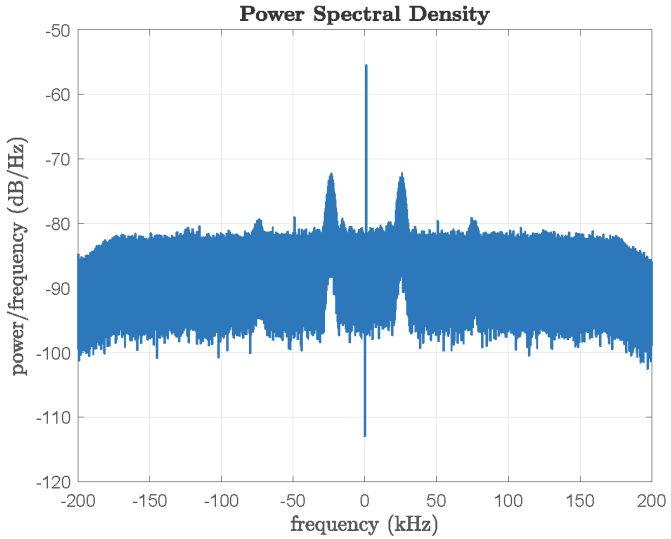

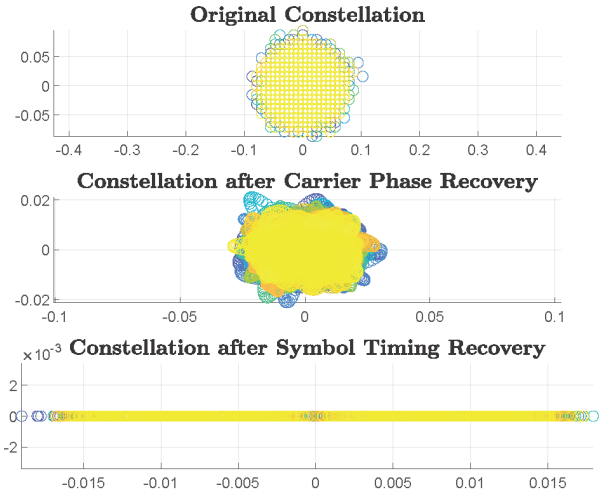

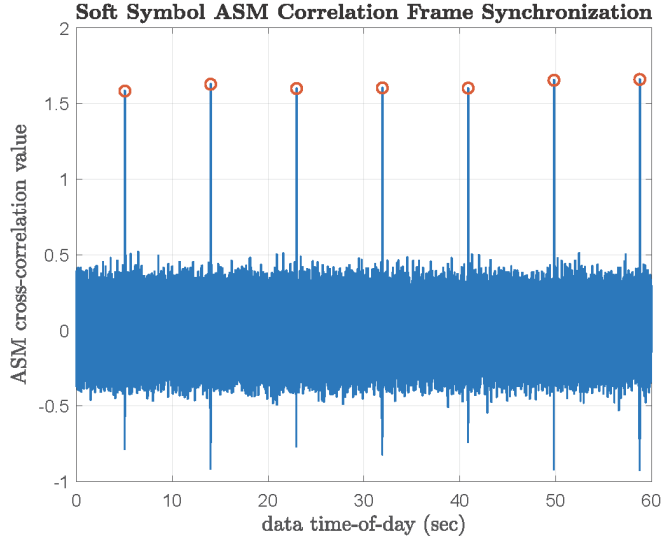

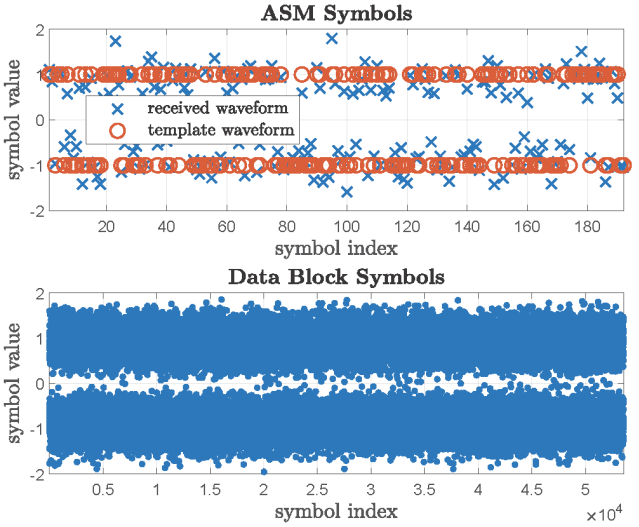

MarCO-B DOY 128 TLM_HR Demodulation Results

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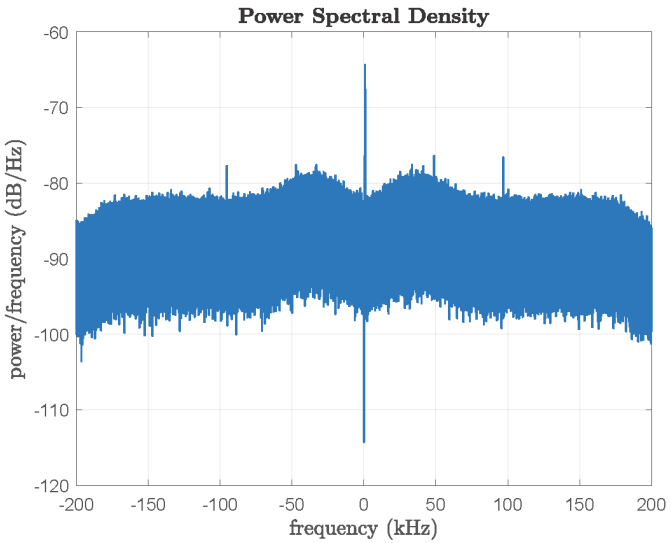

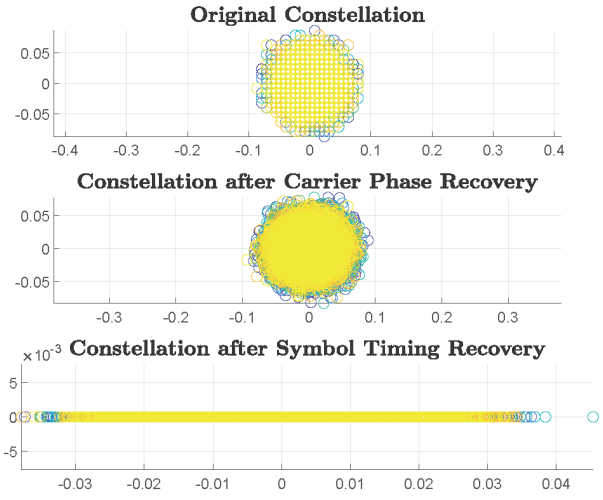

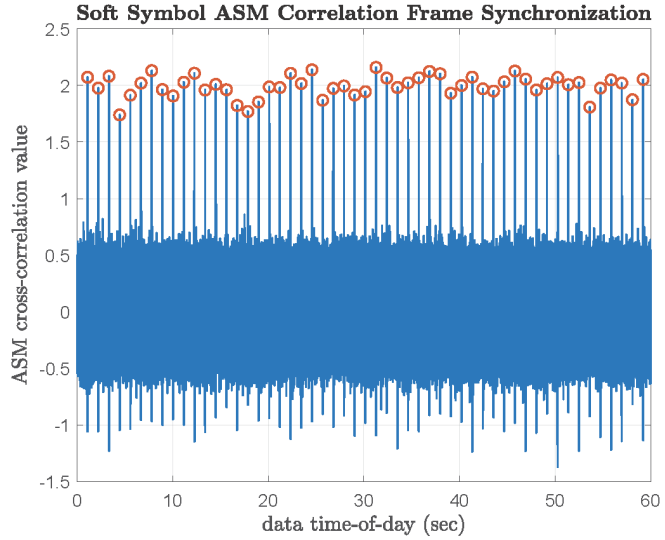

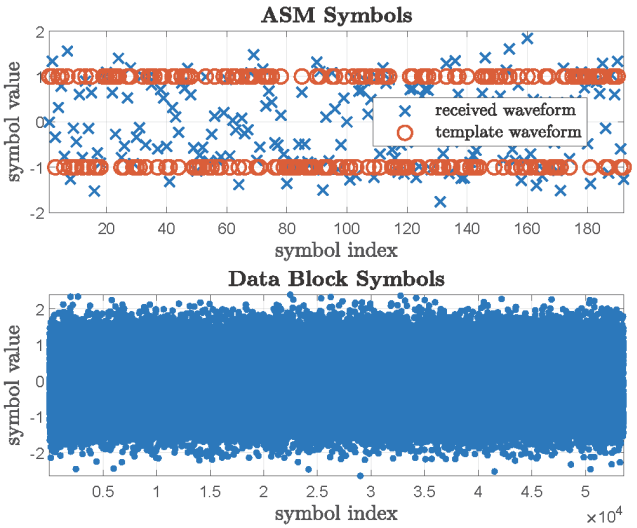

MarCO-A Validation Results

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MarCO-A 2018 DOY 126 Validation Results		
	DSN	MSU
total # of TFs recovered	571	187
TFs failing CRC	none	none
total # of TFs passing CRC	571	187
exact matches	1:69	70:138
	70:117	140:187
comments	• MSU TFs 1:69 precede start of DSN TF data record, • ERT analysis of DSN data suggests that exactly one TF is missing between DSN TF 69 and 70, which appears to be filled in by MSU TF 139.	
validation rate	100%	

MarCO-A 2018 DOY 128 Validation Results			
	DSN	WVSR	MSU
total # of TFs recovered	542	206	187
TFs failing CRC	none	none	13-18, 21-25, 27, 28, 31, 45
total # of TFs passing CRC	542	206	172
exact matches	1:181	26:206	7:187
comments	• WVSR TFs 1:25 and MSU TFs 1:6 precede start of DSN TF data record.		
validation rate	100% (WVSR), 100% (MSU)		

Validation set consisted of DSN TF data and self-consistency check using OMSPA Software Receiver on Wideband Very-Long-Baseline Interferometry (VLBI) Science Receiver (WVSR) data collected at Deep Space Station (DSS) 26 on DOY 128.

MarCO-B Validation Results

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MarCO-B 2018 DOY 126 Validation Results		
	DSN	MSU
total # of TFs recovered	393	128
TFs failing CRC	none	30, 40, 50, 86-92, 99, 115, 119, 121
total # of TFs passing CRC	393	114
exact matches	66:100	1:35
	101:193	37:128
comments	• ERT analysis of DSN data suggests exactly one TF is missing between DSN TF 100 and 101, which appears to be filled in by MSU TF 36.	
validation rate	100%	

MarCO-B 2018 DOY 128 Validation Results			
	DSN	WVSR	MSU
total # of TFs recovered	(TLM_LR): none (TLM_HR): 1024	(TLM_LR): 62 (TLM_HR): 1105	(TLM_LR): 46 (TLM_HR): 504
TFs failing CRC	(TLM_LR): none (TLM_HR): none	(TLM_LR): none (TLM_HR): none	(TLM_LR): 4 (TLM_HR): none
total # of TFs passing CRC	(TLM_LR): none (TLM_HR): 1024	(TLM_LR): 62 (TLM_HR): 1105	(TLM_LR): 45 (TLM_HR): 504
exact matches		(TLM_LR): 17:62	(TLM_LR): 1:46
		(TLM_HR): 2:505	(TLM_HR): 1:504
	(TLM_HR): 1:507	(TLM_HR): 599:1105	
comments	• WVSR TLM_LR TFs 1:16 precede the start of the MSU TLM_LR data, • WVSR TLM_HR TF 1 precedes the start of the MSU TLM_HR data, • Entire MSU data precedes start of the DSN TF data record, • WVSR TLM_HR TFs 1:598 precede the start of the DSN TF data record.		
validation rate	100% (WVSR & DSN), 100% (MSU & WVSR)		

Validation set consisted of DSN TF data and self-consistency check using OMSPA Software Receiver on WVSR data collected at DSS 26 on DOY 128.

Conclusion

- Demodulation capabilities of MATLAB-based OMSPA Software Receiver were shown for InSight/MarCO launch window.
- Specifically, while tracking InSight with 21-m antenna at MSU, X-band downlink telemetry was recovered from open-loop recordings from InSight, MarCO-A & B.
- Diagnostic outputs from OMSPA Software Receiver (i.e, power spectra, constellation, cross-correlation plots) showed demodulation process in action.
- MarCO data collected at MSU was validated against DSN and WVSR data and shown to be in agreement for all possible TFs passing CRC.
- Efforts are underway at JPL to chart a path toward infusion of the OMSPA concept into the DSN with minimal impact to current DSN operations.
- Breakdown of modules envisioned for such an OMSPA infusion are as follows:
  - OMSPA Service Management:
    - OMSPA Portal:
      - Interface through which external customers can request an OMSPA opportunity search and receive output products from demodulated passes (such as recovered TFs, one-way Doppler estimates, and a quality of service (QoS) report).
    - OMSPA Service Manager:
      - Module that calculates OMSPA opportunities, triggers open-loop recording, instantiates OMSPA Software Receiver demodulators, and transfers information between OMSPA Portal and OMSPA Signal Processing subsystems.
  - OMSPA Signal Processing:
    - Subsystem consisting of OMSPA Software Receiver instantiations that takes in telemetry parameters from OMSPA Service Manager and reads in open-loop recorded data.
    - Demodulates CB sample data and returns output products.