SYSTEM DESIGN CONCEPT OF MARS INTELLIGENT IMAGING & ATMOSPHERIC RESEARCH CUBESAT CONSTELLATION USING DISTRIBUTED DEEP LEARNING (MIIAR)

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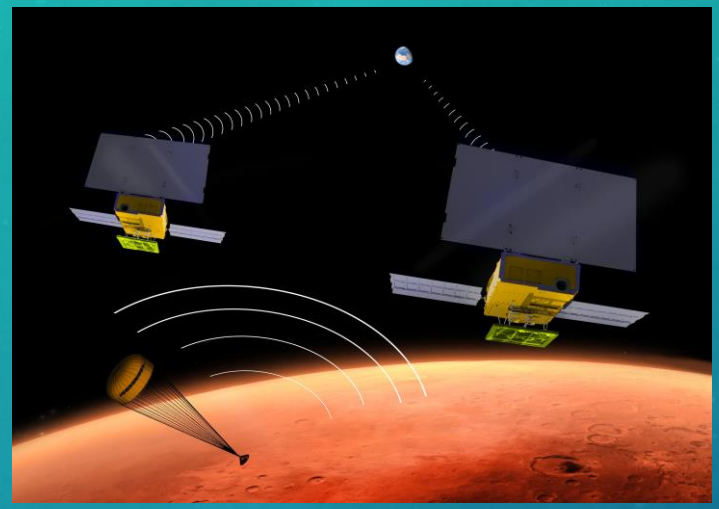
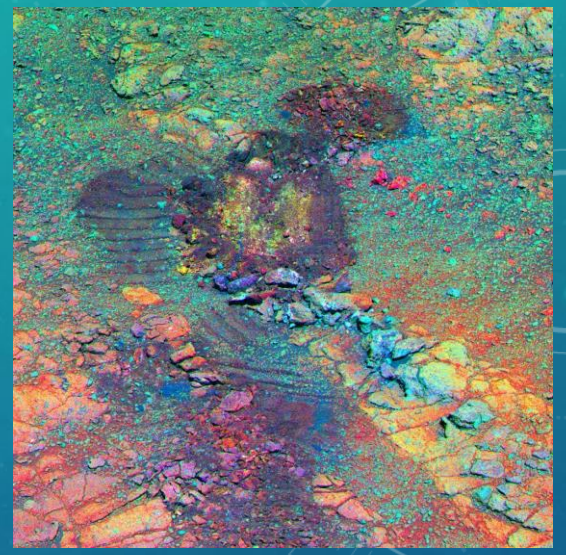
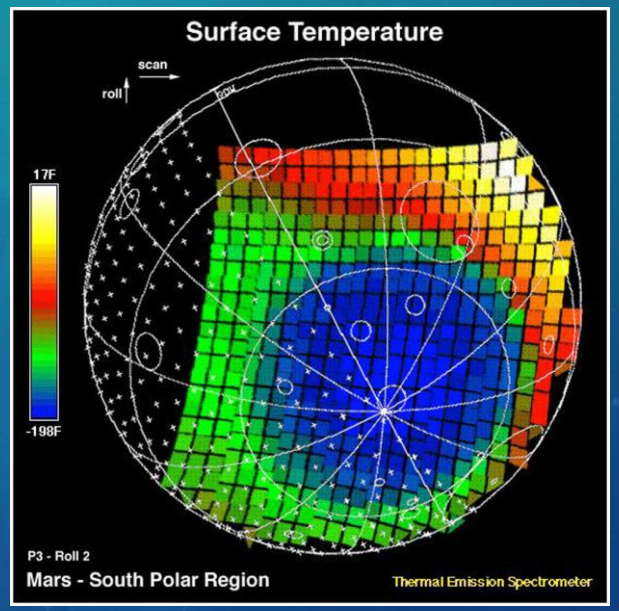
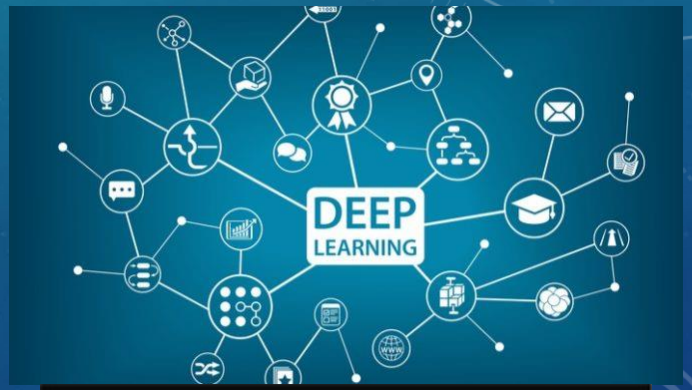
OBJECTIVE

- Interplanetary Observational CubeSat Constellation
- Study of Mars surface using Hyperspectral Imaging
- Atmospheric study of Mar’s atmosphere & thermosphere using Thermal IR Emission Imaging Spectrometer
- Onboard AI pre-processing of collected data
- Creating a Distributed Deep Learning platform on satellite constellation
- Deep Space Communication



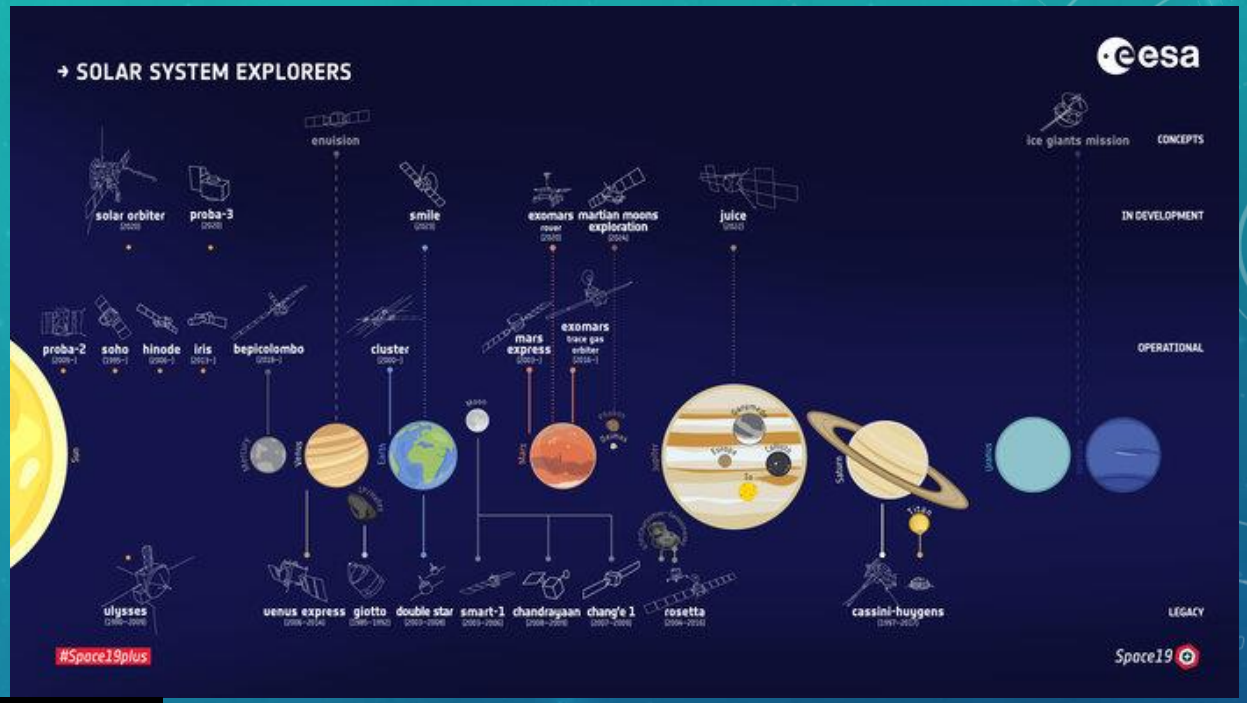


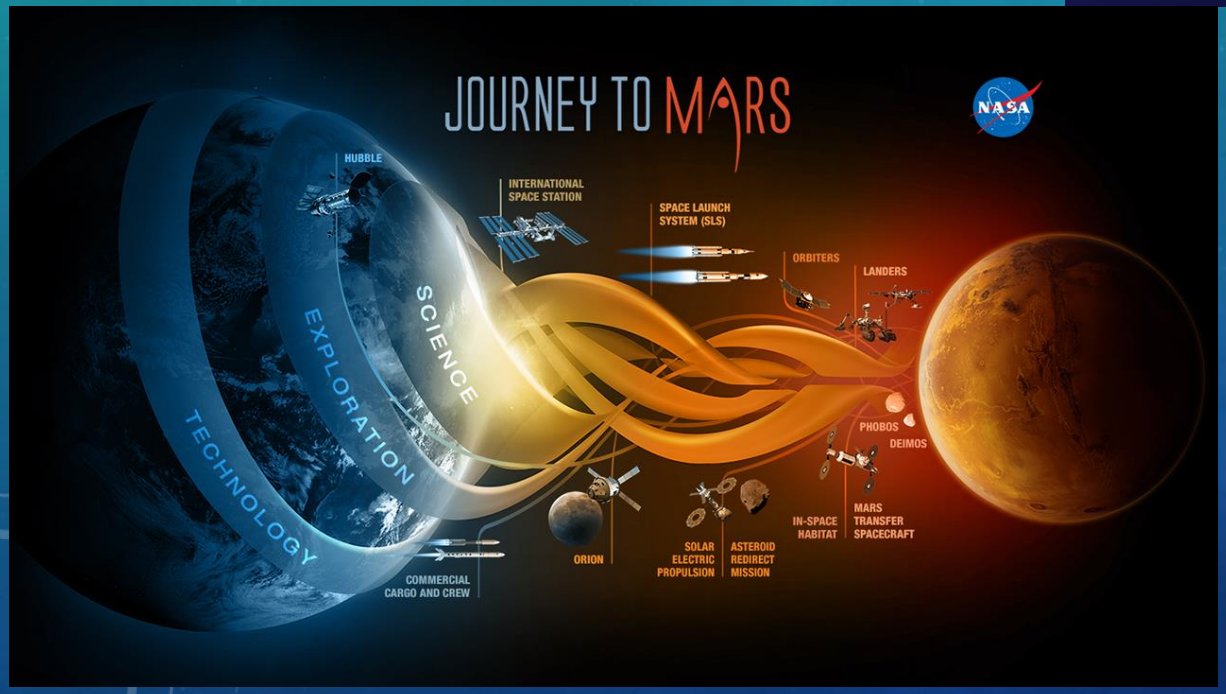


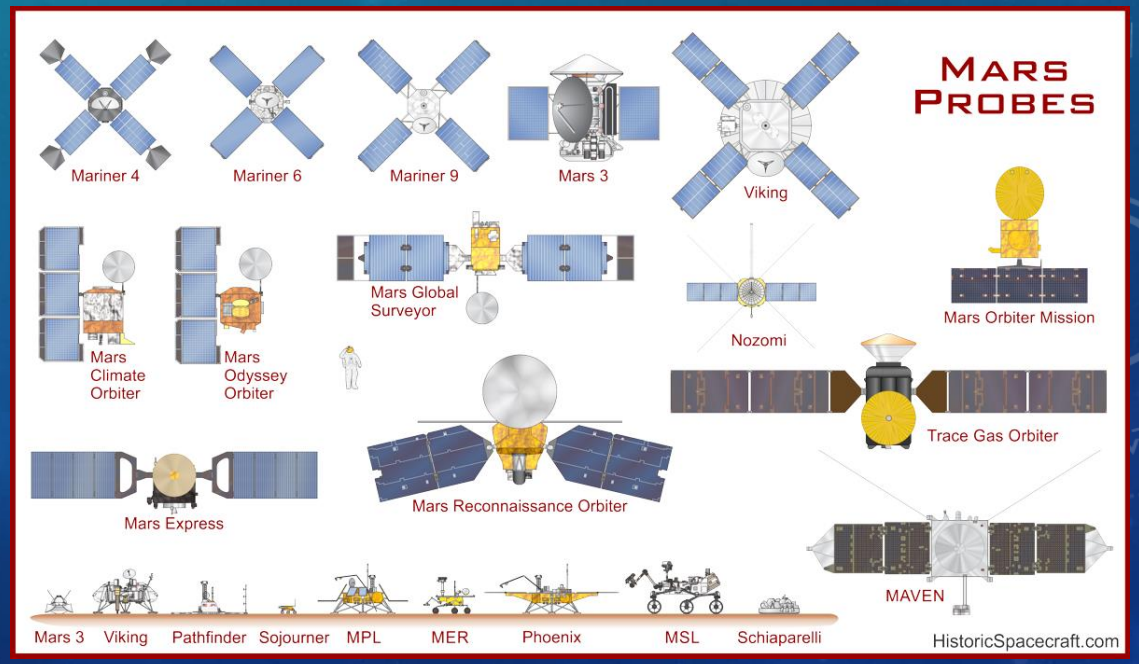


BACKGROUND

- Past & Present Mars observational missions
- Future planned missions on Mars

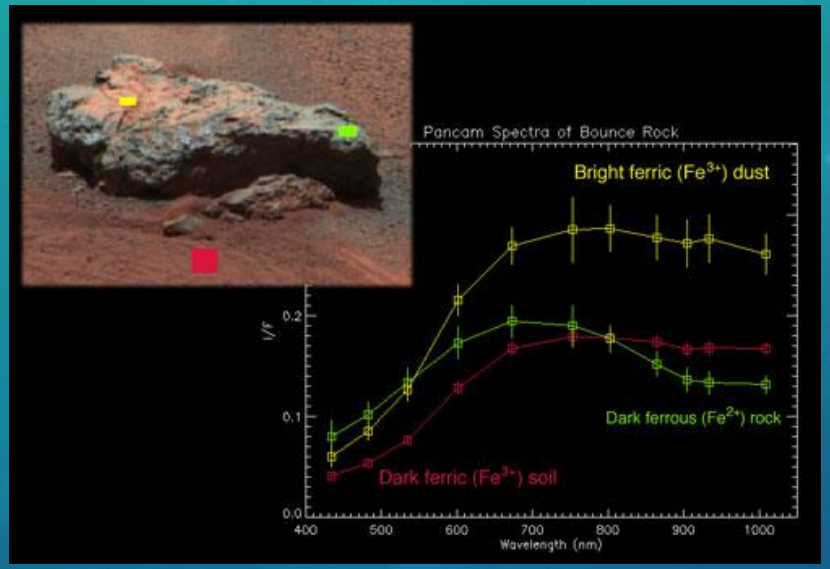


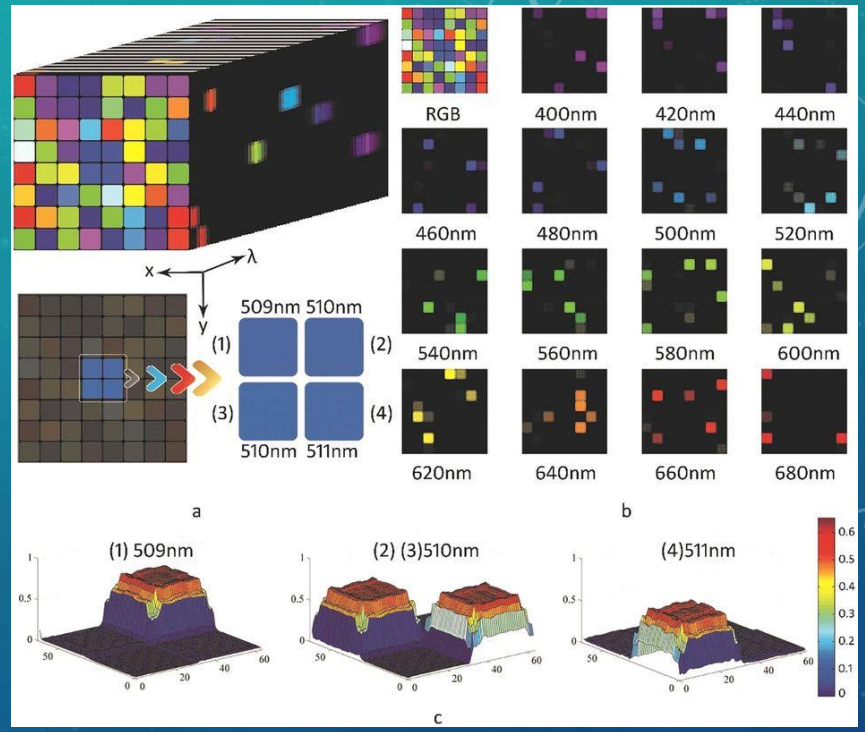


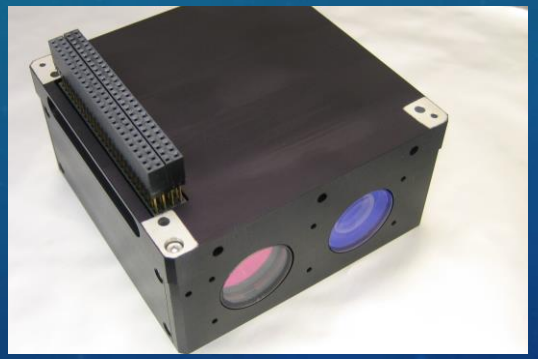


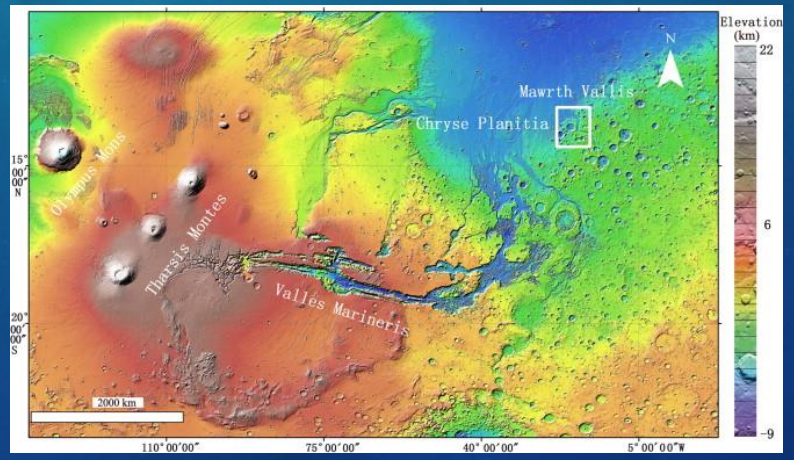
HYPERSPECTRAL IMAGING OF MARS

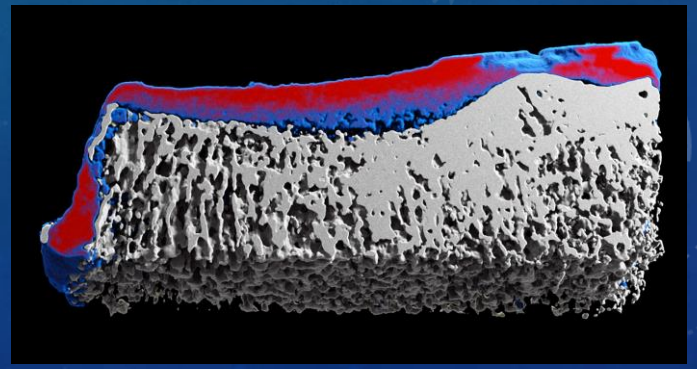
- Types of data acquired
- Instrument used
- Method





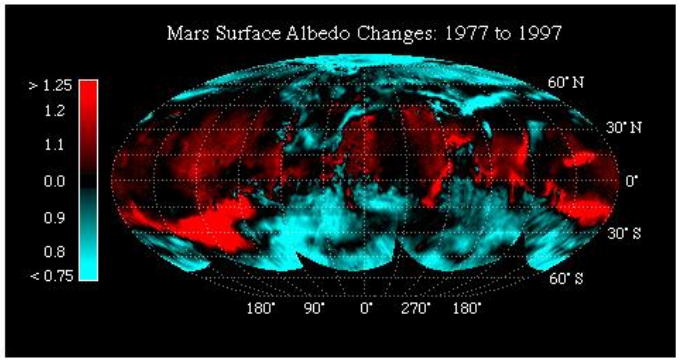


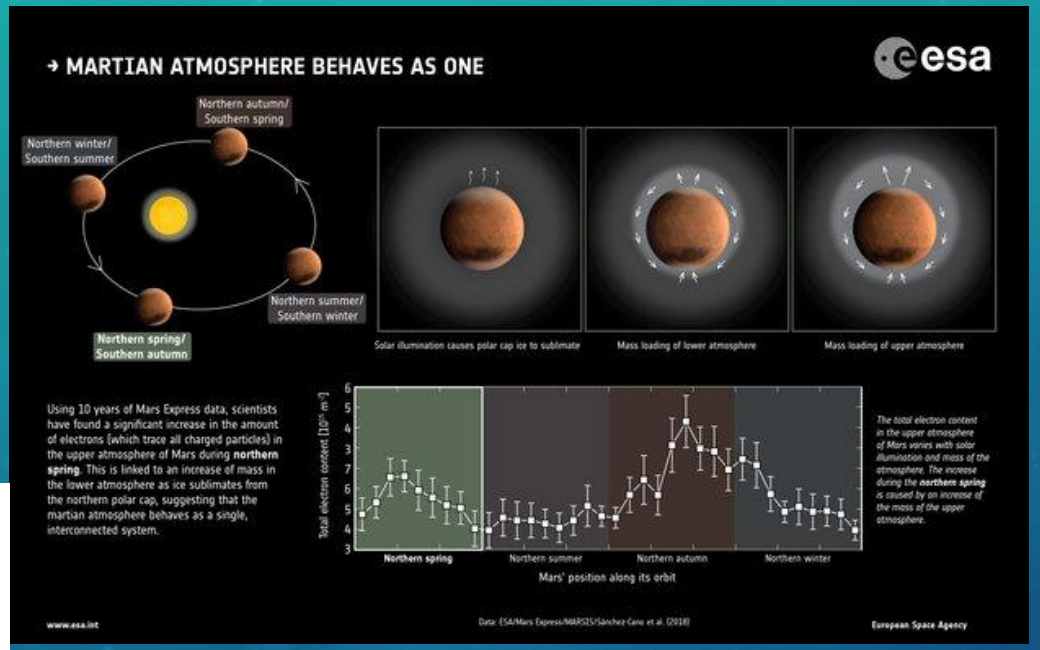


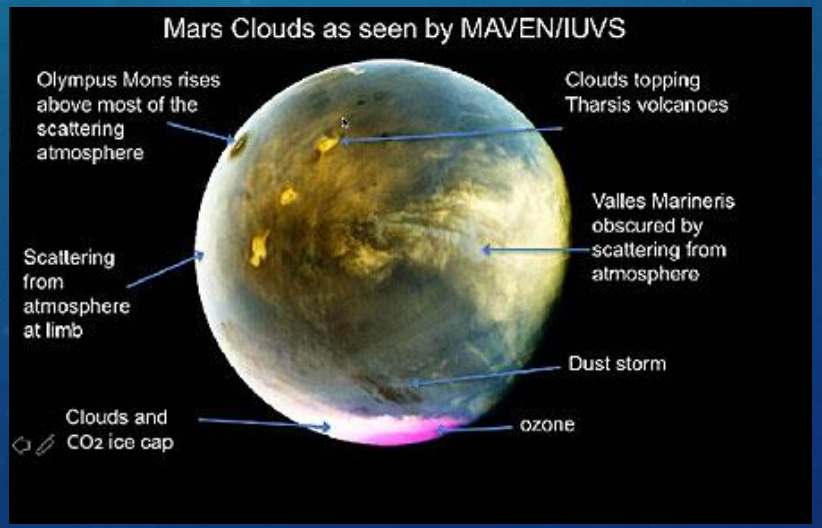


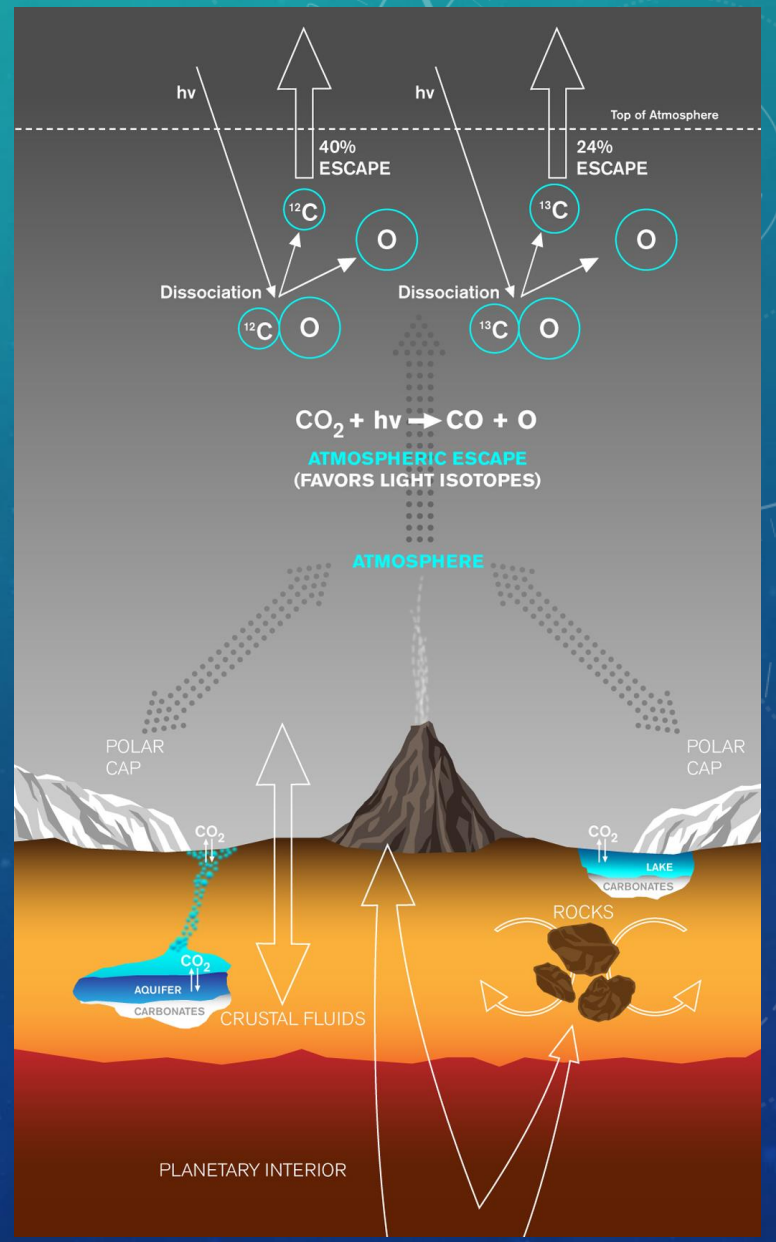
ATMOSPHERIC STUDY OF MARS

- Types of data acquired
- Instrument used
  - Reflective IR Spectroscopy
- Method



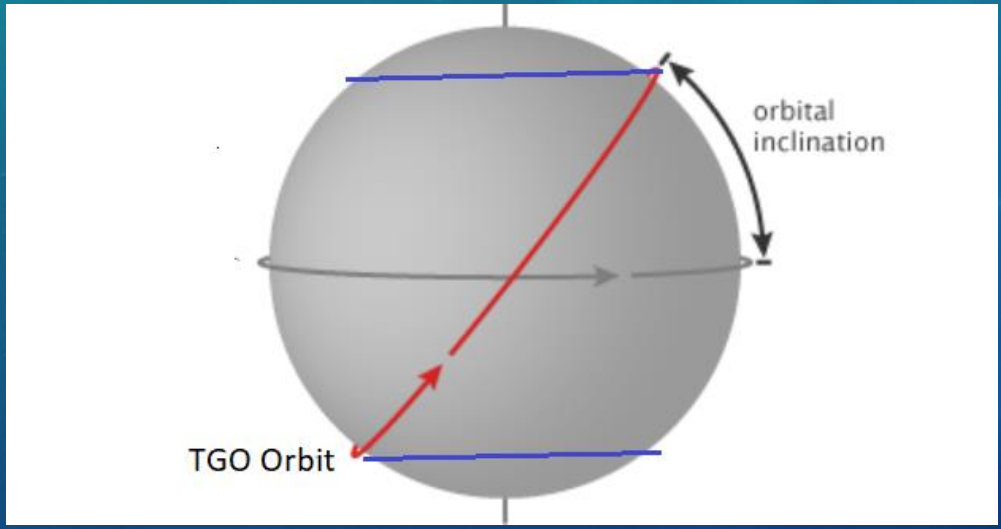


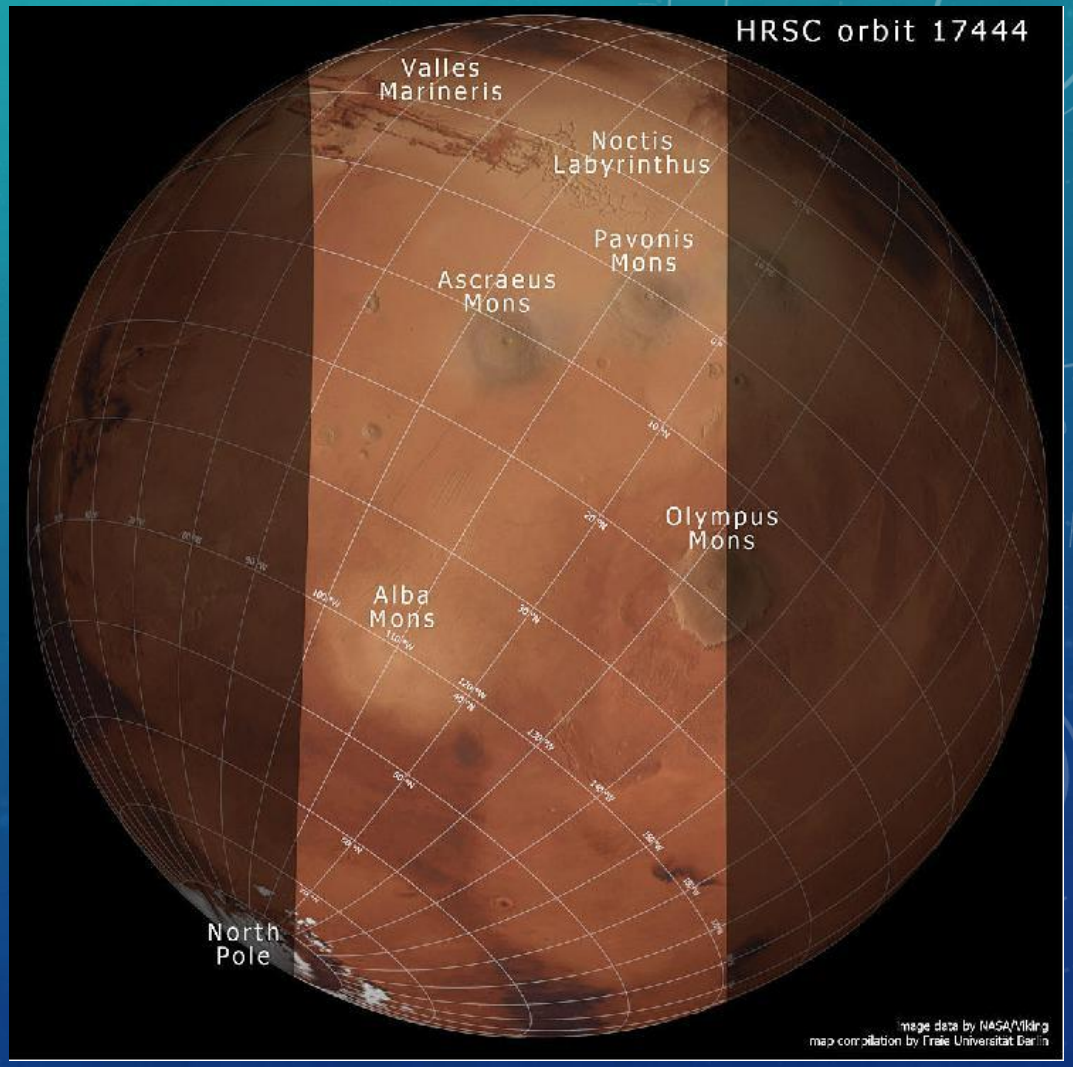




ORBITAL ANALYSIS & RECOMMENDATION

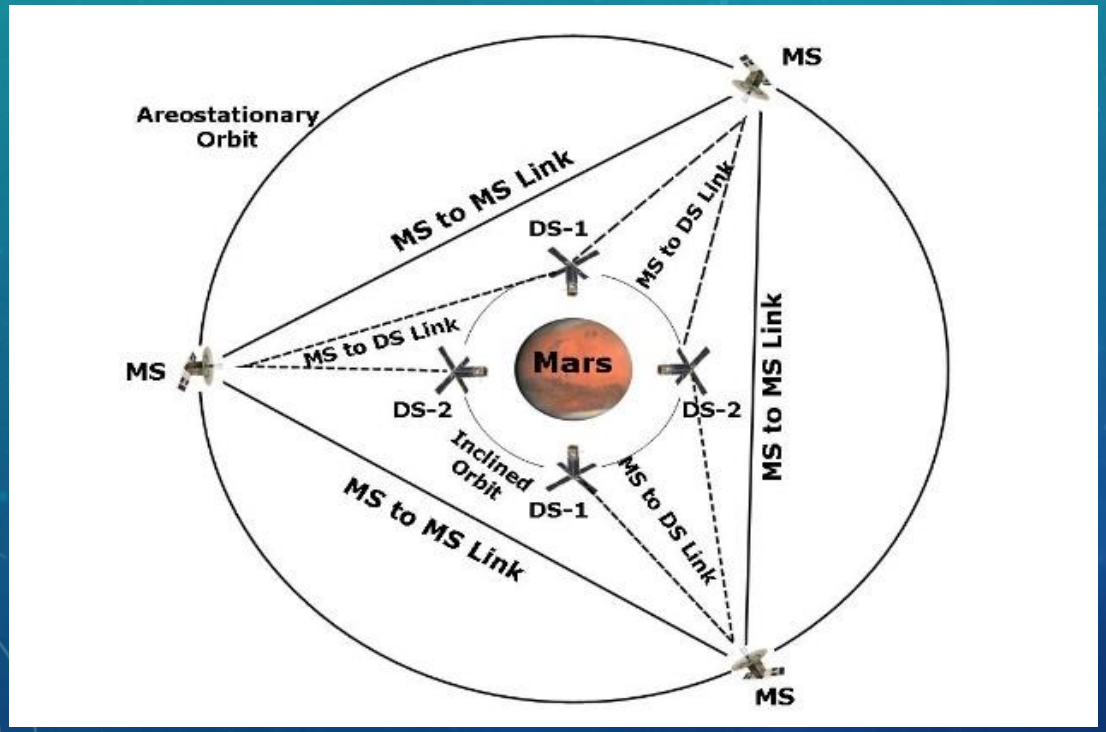
- High inclined orbits
  - 4 x 6U DaughterShip Type I & II
  - Ideal for hyperspectral imaging & atmospheric data research

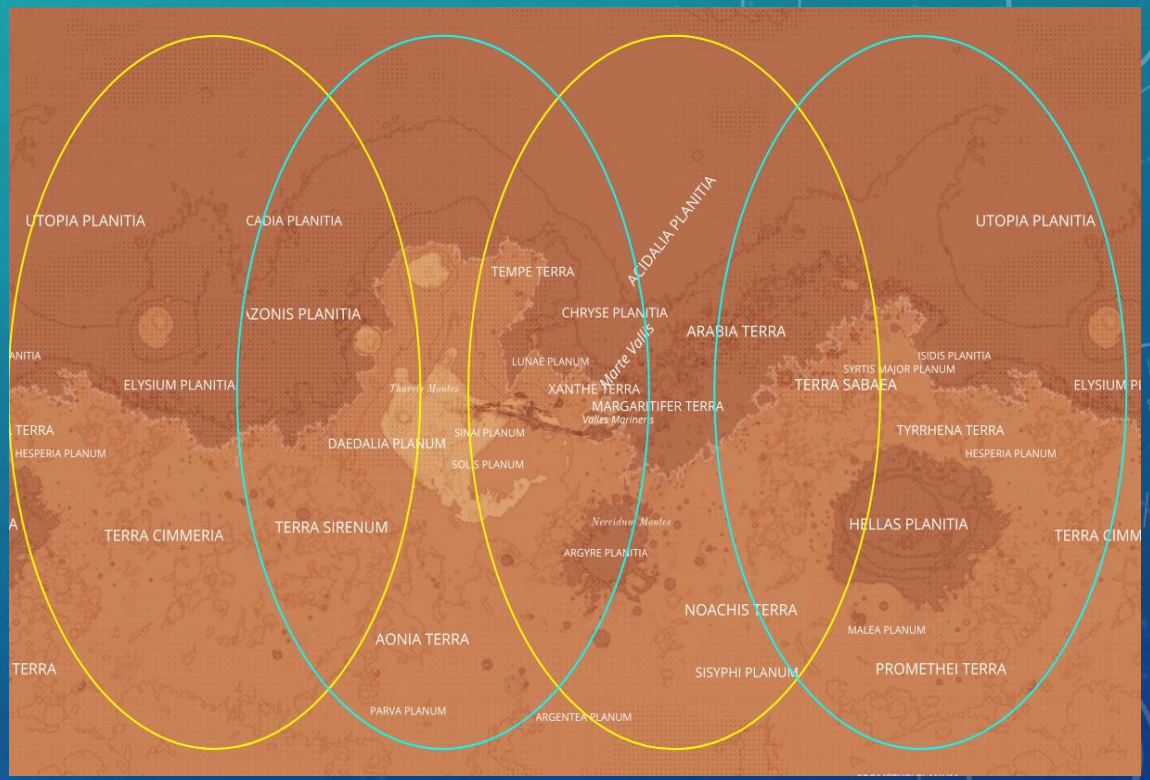




ORBITAL ANALYSIS & RECOMMENDATION

- Areostationary orbits
  - 3 x 12U MotherShip (MS-DRS)
  - Ideal for full coverage of communication





SCIENCE GOAL & REQUIREMENTS

Data attributes	Instrument type
High Resolution Imaging	Hyperspectral Imaging Camera
Daily global mapping	Hyperspectral Imaging Camera
Atmospheric water concentration	Thermal IR Emission Imaging Spectrometer
Relative humidity	Thermal IR Emission Imaging Spectrometer
Temperature	Thermal IR Emission Imaging Spectrometer
CO^2 density and bulk pressure versus height in atmosphere	Thermal IR Emission Imaging Spectrometer
Targeted Obs. & Multi-spectral Survey Emission Phase Functions	Thermal IR Emission Imaging Spectrometer
Dust and ice concentration on atmosphere	Thermal IR Emission Imaging Spectrometer
Simultaneous Communications relay in mixed frequency band	UHF,VHF, K, and X band
Experimental Optical relay Communications	Optical communication module
Trajectory control and management to keep the constellation working for Continuous and possible real time data relay	Micropropulsion, processing software, advanced engineering techniques for navigation, guidance, control

SCIENCE GOAL & REQUIREMENTS (CONT…)

- Onboard Machine Learning
  - Classification & Analysis of images using Distributed Deep Learning with Data Parallelism

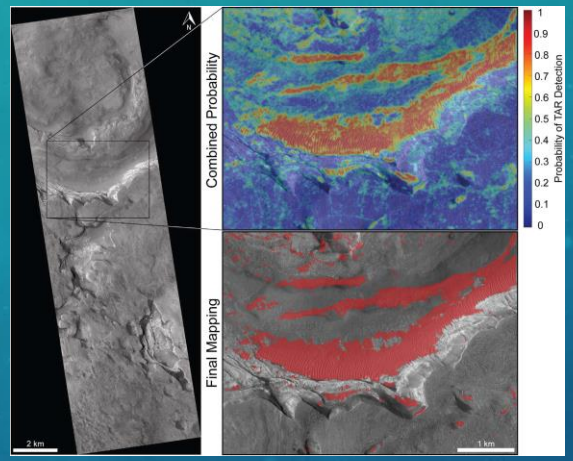
  (J. Liu, B. Luo, S. Doute, and J. Chanussot "Exploration of Planetary Hyperspectral Images with Unsupervised Spectral Unmixing: A Case Study of Planet Mars," *Remote Sensing,* vol 10, issue 737, 2018.)

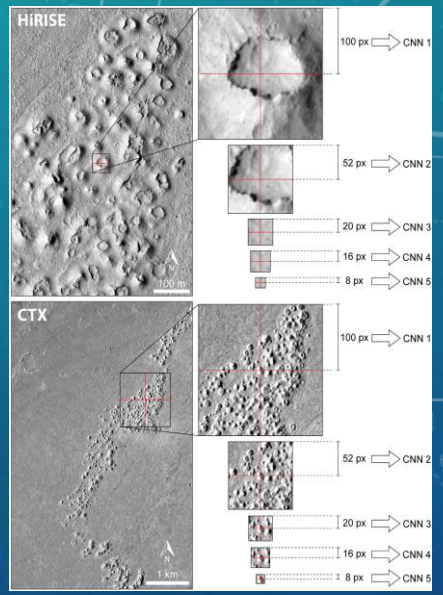
  - Detection Algorithm for geological landforms on Mars using Convoluted Neural Network (CNN)

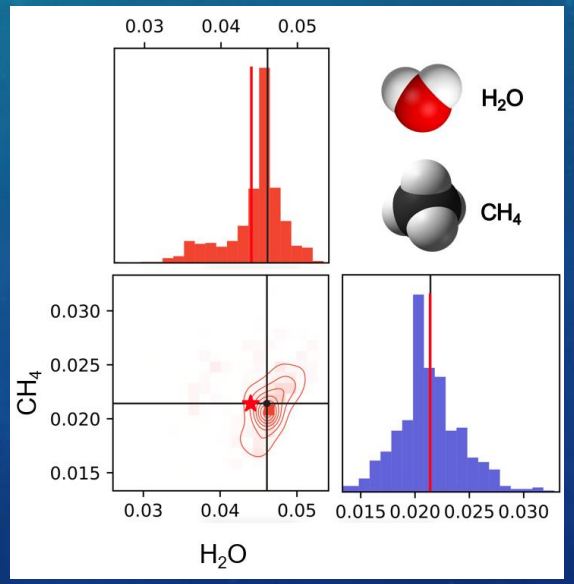
  (L. F. Palafox, C. W. Hamilton, S. P. Scheidt, and A. M. Alvarez "Automated detection of geological landforms on Mars using Convolutional Neural Networks," *Computers & Geosciences, vol 101, pp 48-56, 2017.)*

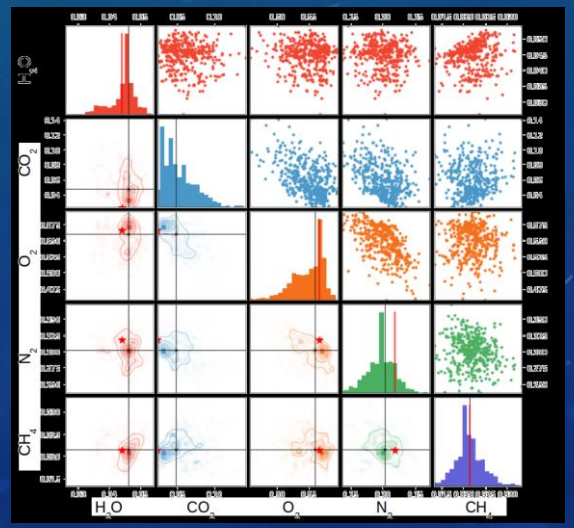
  - Atmospheric data retrieval framework using Machine Learning

  (F. Soboczenski, M. D. Himes, M. D. O'Beirne, and S. Zorzan et el. "Bayesian Deep Learning for Exoplanet Atmospheric Retrieval," *Third Workshop on Bayesian Deep Learning,* 2018.)



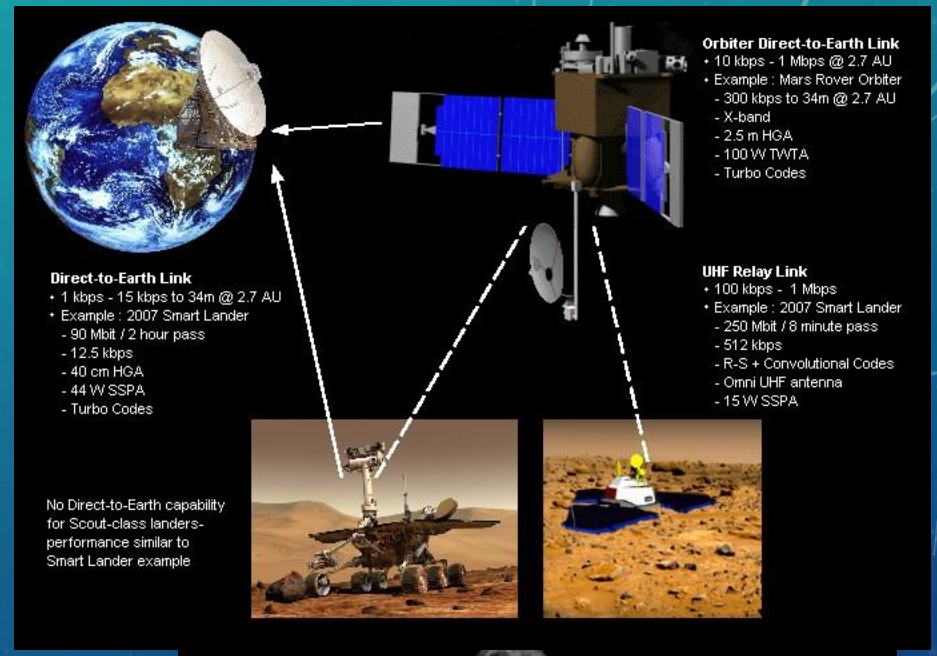


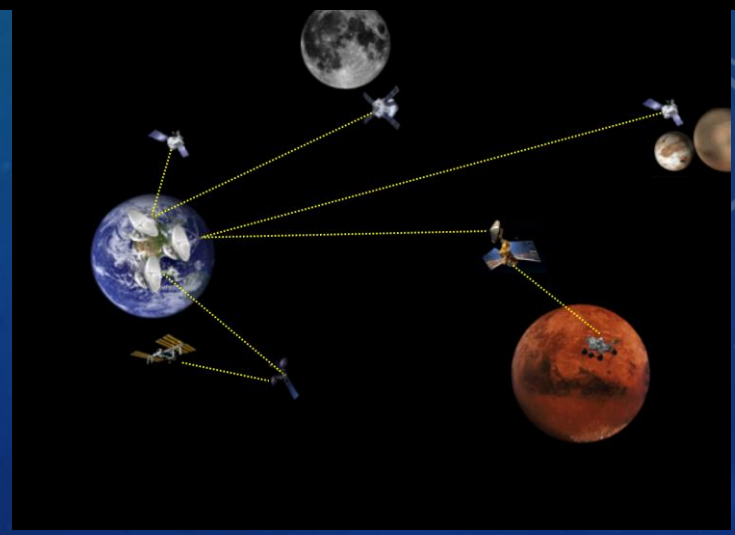




DEEP SPACE COMMUNICATION INTRODUCTION

- Purpose:-
  - Acquire telemetry data from spacecraft.
  - Transmit commands to spacecraft.
  - Gather science data.
  - Monitor and control the performance of the network

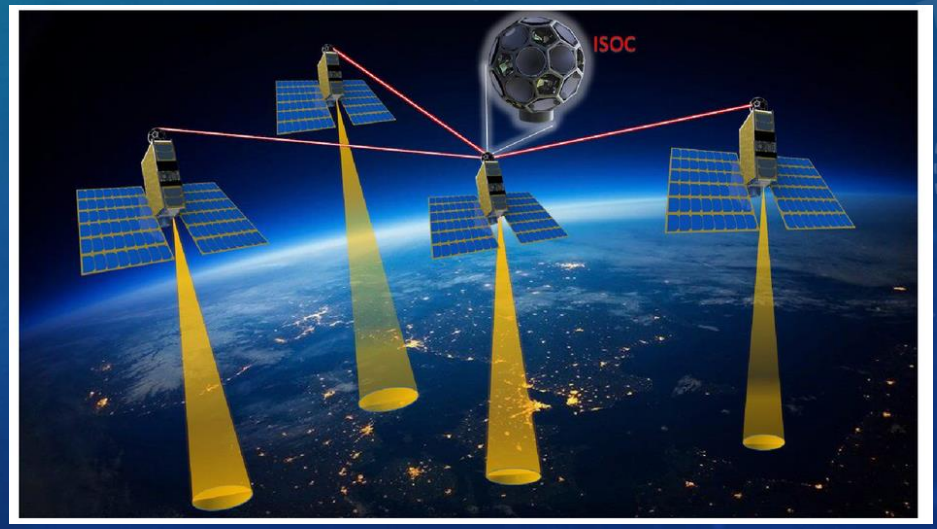




- Direct To Earth (DTE) Communication
- Inter-Satellite Optical Wireless Communication

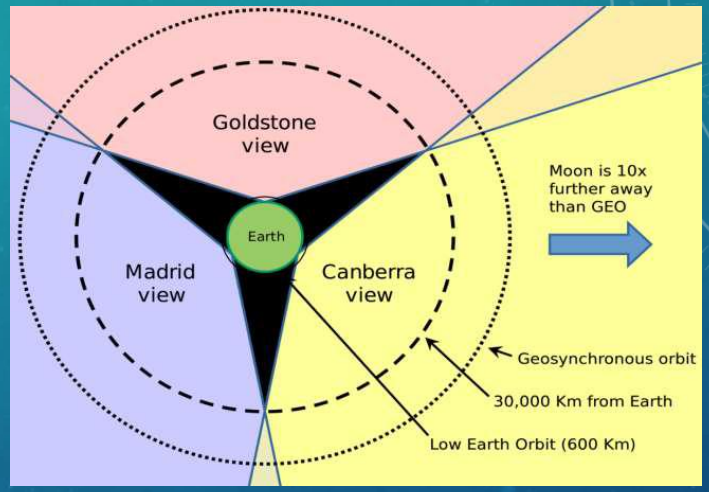
DEEP SPACE COMMUNICATION INTRODUCTION

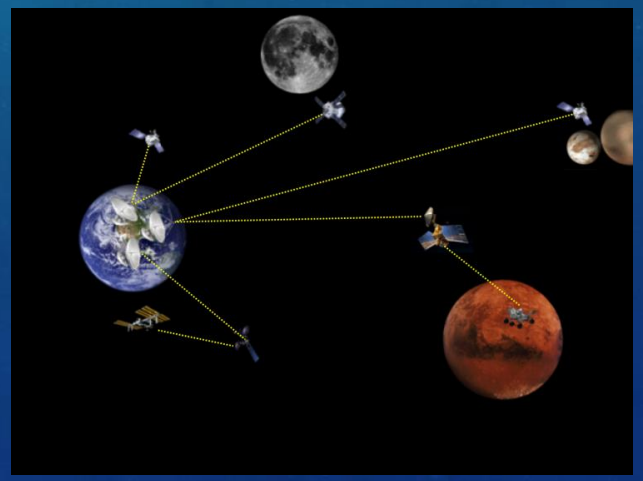
- Inter Satellite Optical Wireless Communication
  - High data rates
  - Low power
  - High efficiency
  - Small antenna size
  - Line of Sight (LOS) required
  - Will be used for transfer of data from DaughterShip (DS) to MotherShip (MS-DRS) & between the MotherShips (MS-DRS)



DIRECT TO EARTH COMMUNICATION INTRODUCTION

- DTE Communication links
  - MotherShip (MS-DRS) to Earth
    - Used for data transfer & acquiring telemetry command
    - Received by ground antennas on Earth by NASA's DSN or ESA's ESTRACK
    - Using Ka band
  - DaughterShip Type I/II to Earth
    - Used for backup/alternative telemetry command link
    - Using Ka band



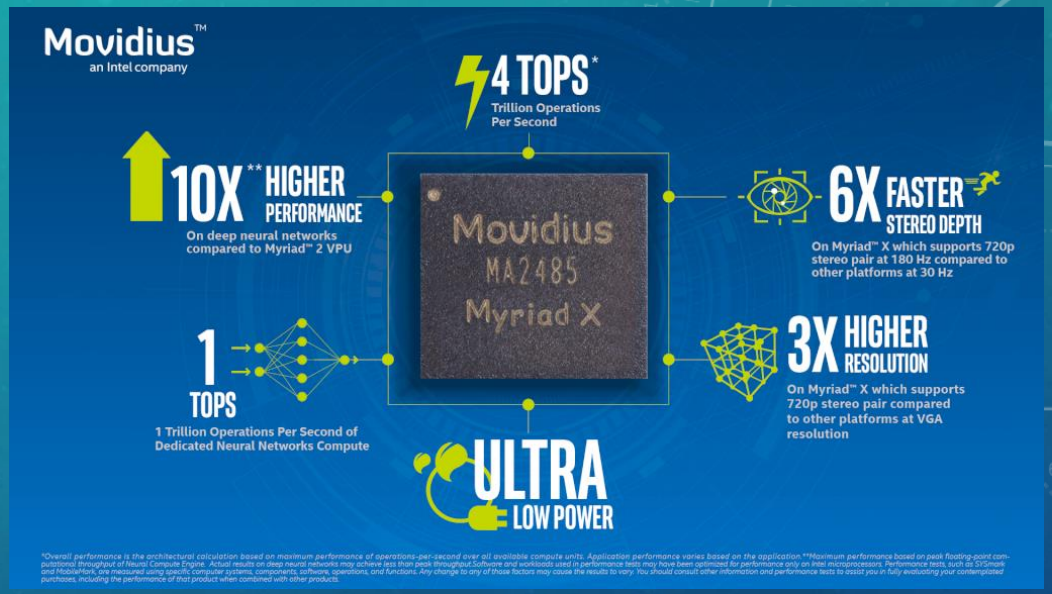


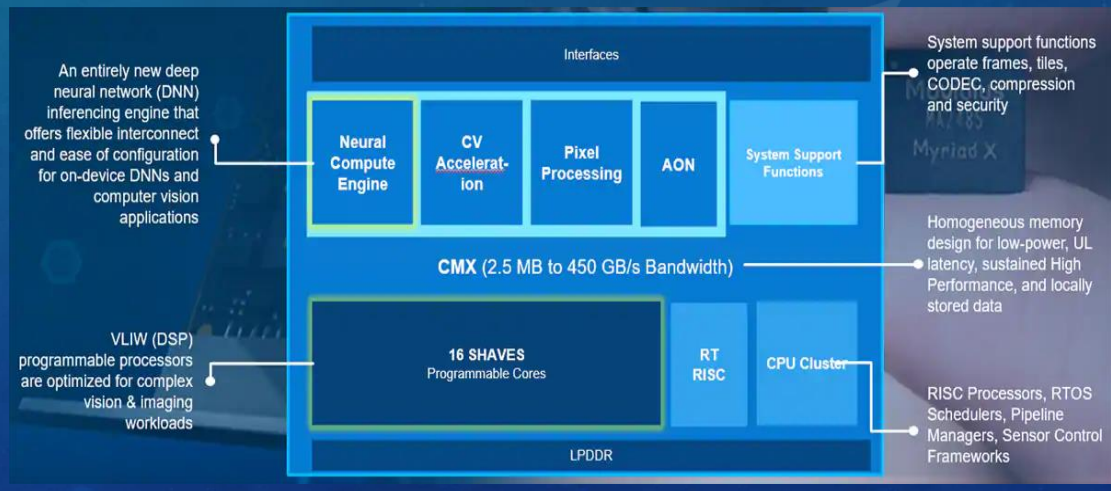
VISUAL PROCESSING UNIT (VPU) OVERVIEW

- A microprocessor designed to accelerate machine vision tasks in a low powered environment.
- Suitable for running machine vision algorithms such as CNN (Convolutional Neural Network).

- Overview of Intel Movidius Myriad 2
  - An ultra low power design
  - High performance processor
  - Programmable architecture
  - Small area footprint

- Purpose of using Machine learning in a satellite
  - Onboard analysis and classification of images taken by the payload cameras.
  - Object detection

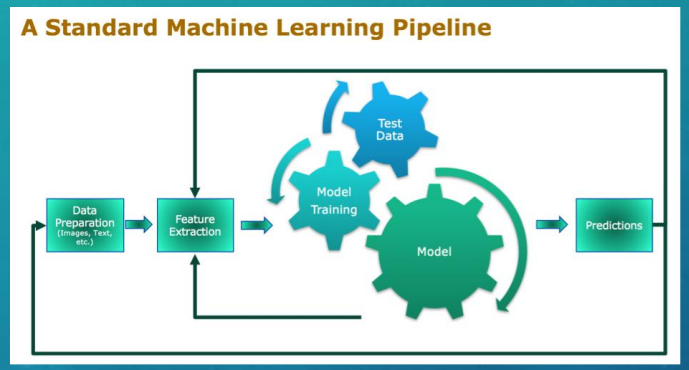




DISTRIBUTED DEEP LEARNING & ML INTRODUCTION

- Machine Learning:-
  - Use of algorithms & statistical models
  - For performing specific task
  - Without using specific instructions
  - Relying on patterns and inference of the data

- Distributed Deep Learning:-
  - Distributed or Parallel training of models in multiple nodes.
  - Shared and distributed among multiple nodes through multiple servers
  - Using data or model parallelism
  - Use of distributed storage



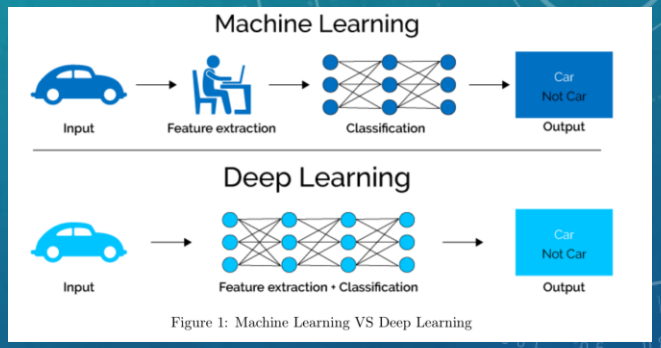
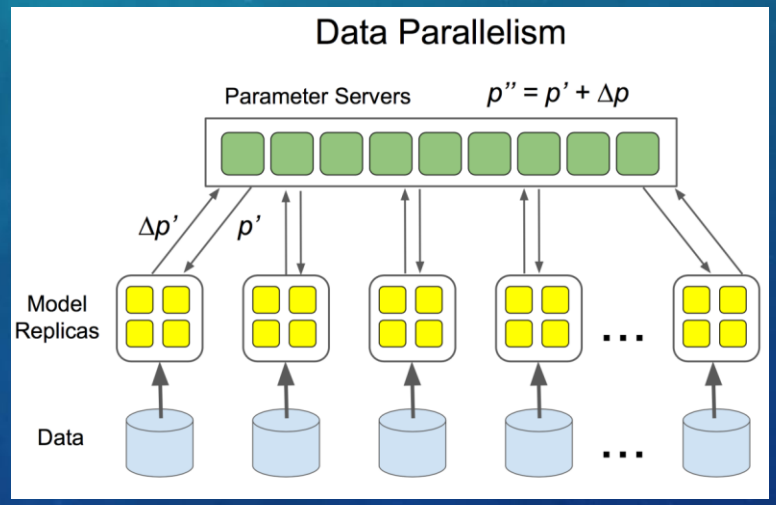
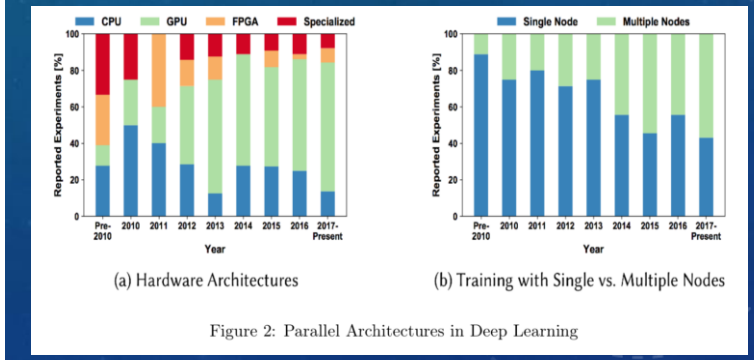


Figure 1: Machine Learning VS Deep Learning

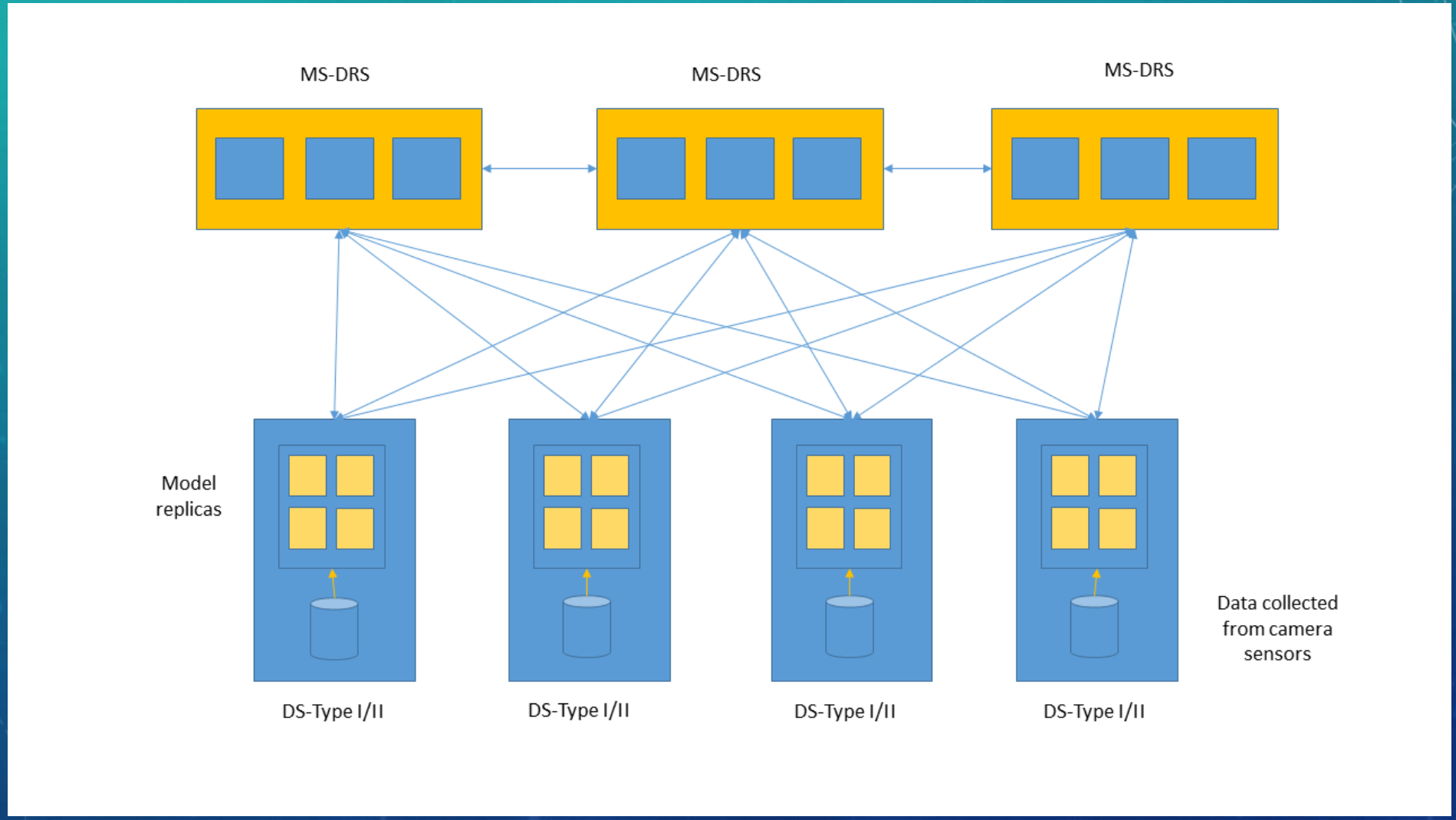




(a) Hardware Architectures (b) Training with Single vs. Multiple Nodes

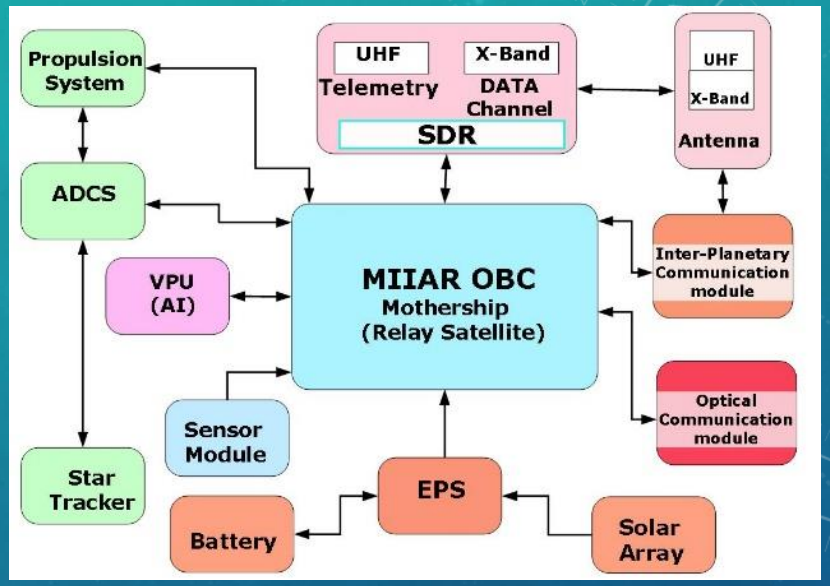
Figure 2: Parallel Architectures in Deep Learning

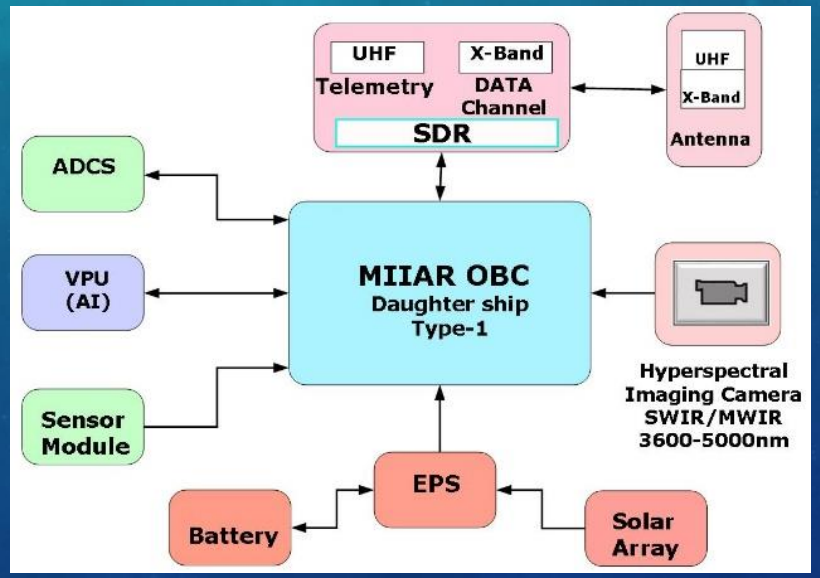
IMPLEMENTATION OF DISTRIBUTED DEEP LEARNING IN THE CONSTELLATION

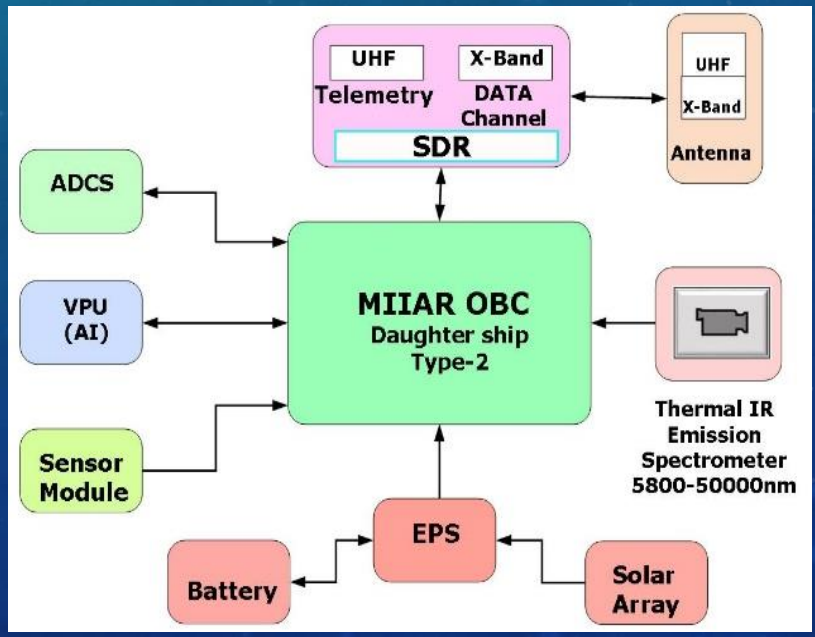


SYSTEM DESIGN OVERVIEW

- MotherShip (MS-DRS)
  - Three 12U Cubesats
  - Used for relaying data between Earth and Mars
  - SDR
  - Inter-Satellite Optical Wireless Communication link
  - VPU
- DaughterShip (DS-I & DS-II)
  - Four 6U Cubesats
  - Hyperspectral Imaging camera
  - Thermal IR emission Spectrometer
  - SDR
  - VPU

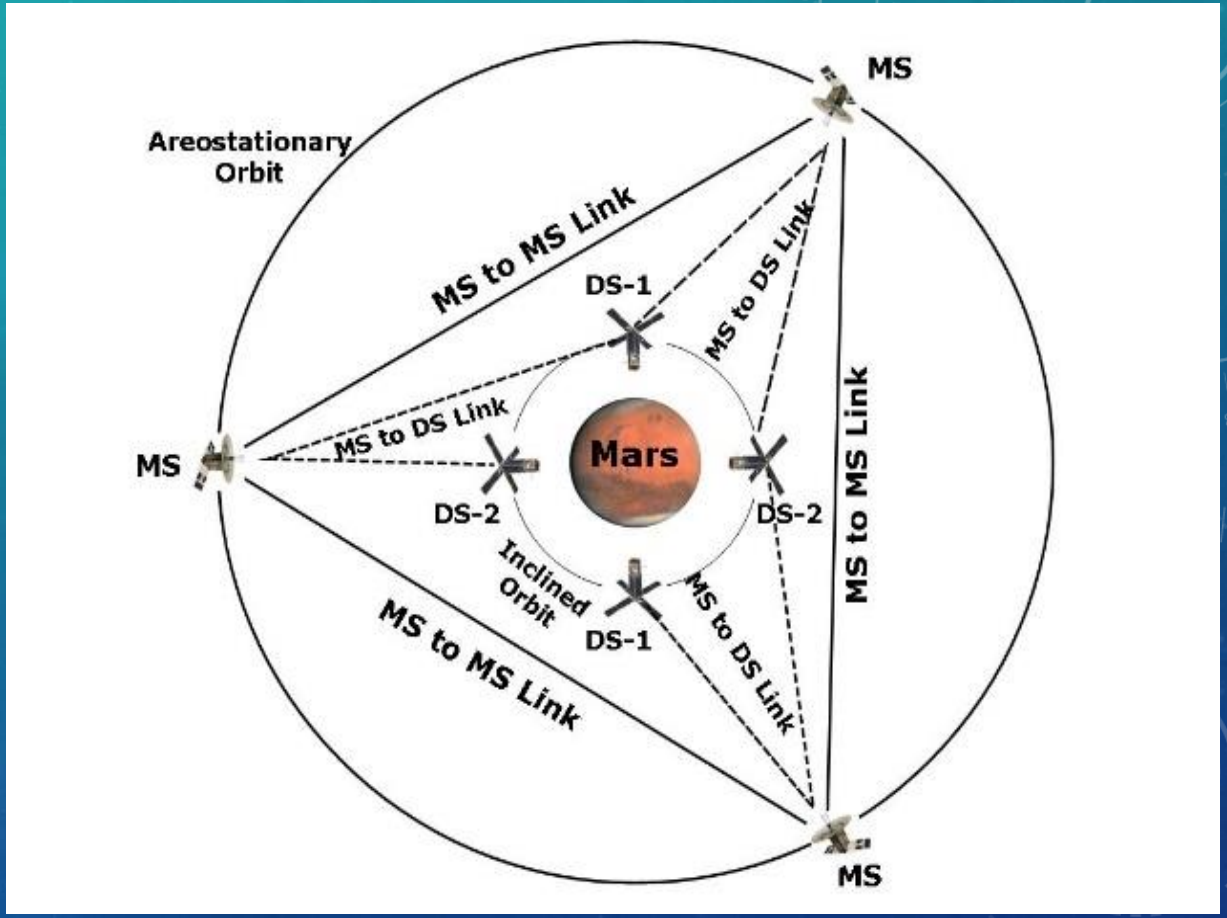






CONCEPT OF OPERATIONS

- Launch of the DaughterShip CubeSat (Type I & 2) clusters in high inclined orbit of Mars
- Launch of the MotherShip Data Relay CubeSat (MS-DRS) clusters in high inclined orbit of Mars
- Initialization of OBC
- Detumbling starts until the targeted orientation is reached
- Initialization of the communication module and establish connection with the MotherShip cubesat constellation in range
- Begin science missions
    - Acquiring images from the two Hyperspectral camera sensors
    - Pre-processing the data acquired using various Machine Learning models as planned
- Activates the SDR for transmission of data to the MotherShip CubeSat constellation
- The MS-DRS collects all pre-processed data sent by the DS and share among the MS clusters to function as a Distributed Deep Learning platform
- Activates SDR for transmission of data to Earth through the Deep Space Network



CONCLUSION

- Limitations
  - Lack of hands on experience of CubeSat
  - Compatibility issues
  - Not enough data on the targeted orbitals
  - Lack of testing for implementation of Distributed Deep Learning on satellites
  - Lack of testing on power-mass-volume constraints
  - Funding
- Future work
  - Finalizing of the design
  - Building of prototype
  - Testing of the onboard AI accelerator in space

THANK YOU FOR LISTENING

ANY QUESTIONS?