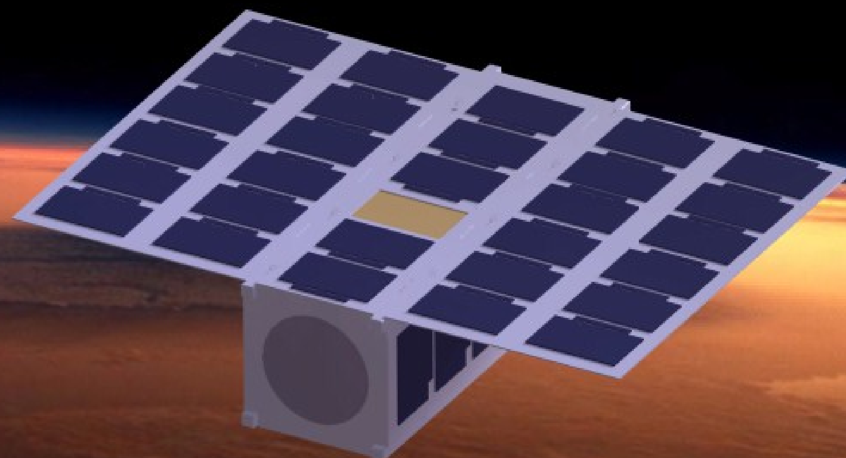
CubeSat on an Earth-Mars Free-Return Trajectory to study radiation hazards in the future manned mission



presented by:
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Planète Mars

CubeSat Standard

- CubeSat concept 1999 => Deployment standard

Bob Twiggs **Stanford University**
Jordi Puig-Suari **California Polytechnic State Univ.**

- *Many* educational missions already launched!
- *Only a few **interplanetary*** cubesat projects

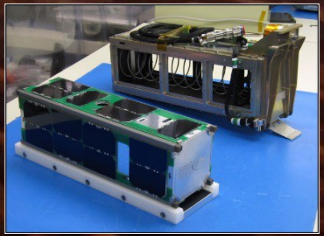
=> Interplanetary & Education & Science Data

PACE Nanosatellite © NCKU

2U: 10cmx10cmx20cm 2Kg (2.6Kg)

Robusta, MaSat-1 and PW-Sat © ESA

1U: 10cmx10cmx10cm 1Kg (1.3Kg)



CSSWE CubeSat © University of Colorado Boulder

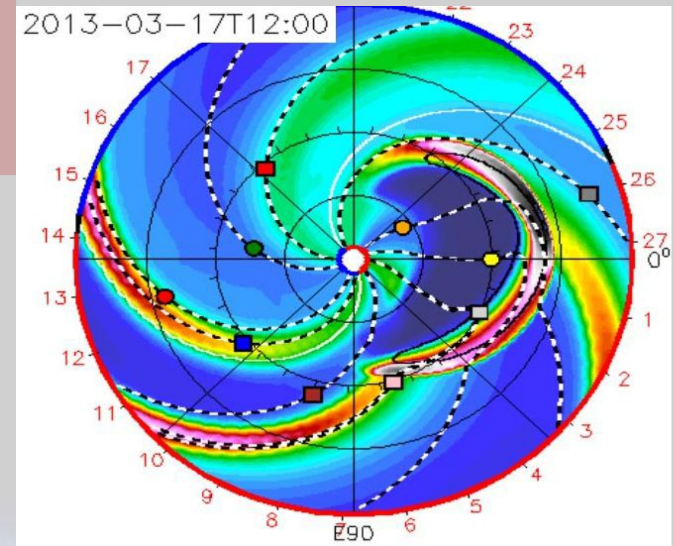
3U: 10cmx10cmx30cm 3Kg (4Kg)

Mission Objectives

Primary Objective : Radiation Measurements

- Lack of measurements between Earth and Mars.
  - **only** RAD on *CURIOSITY* was successful,
  - **only** on the way to go,
  - optimized to study **on** Mars, **not** during the cruise.
- Lessons from RAD :
  - « simultaneous multisite measurements are key-data for Space Weather understanding »
  - « Solar min.activity is a key-period to study GCR »

- **Mission Focus : Scout the Manned Mars Missions.**
  - **Future crews will be exposed to hazardous radiations : which ones are dangerous?**
  - **Catch observational data of radiation hazards during the Earth-Mars-Earth journey.**

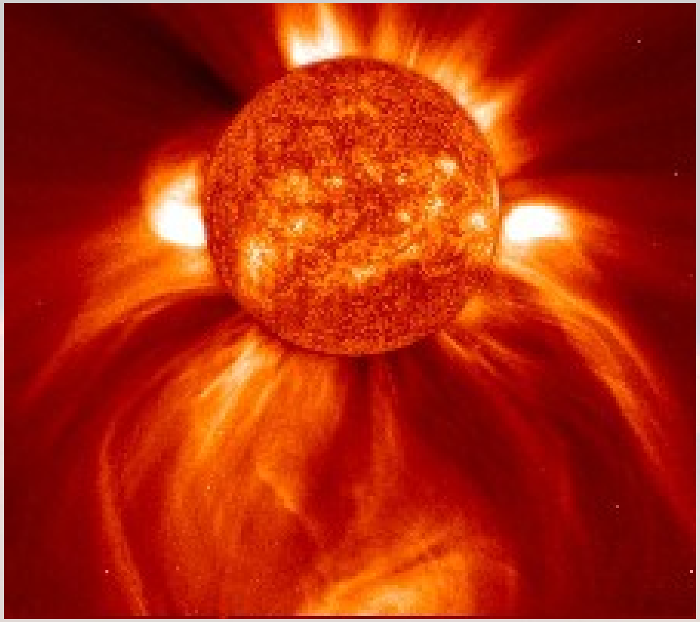


NASA Goddard Space Weather Research Center

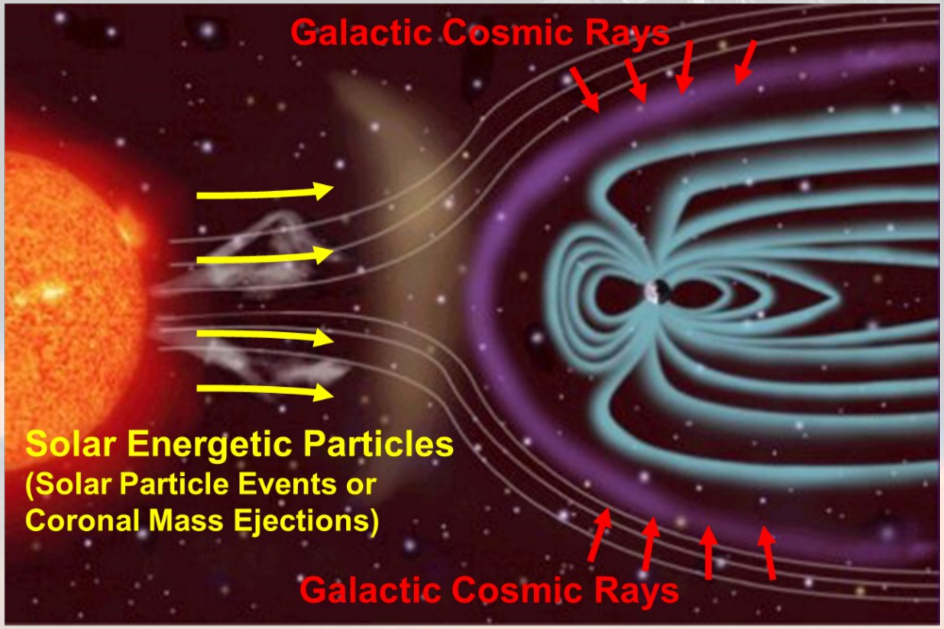

Picture of RAD Radiations Assessment Detector © NASA

MFC Primary Mission Objective

- Interplanetary Space radiations -



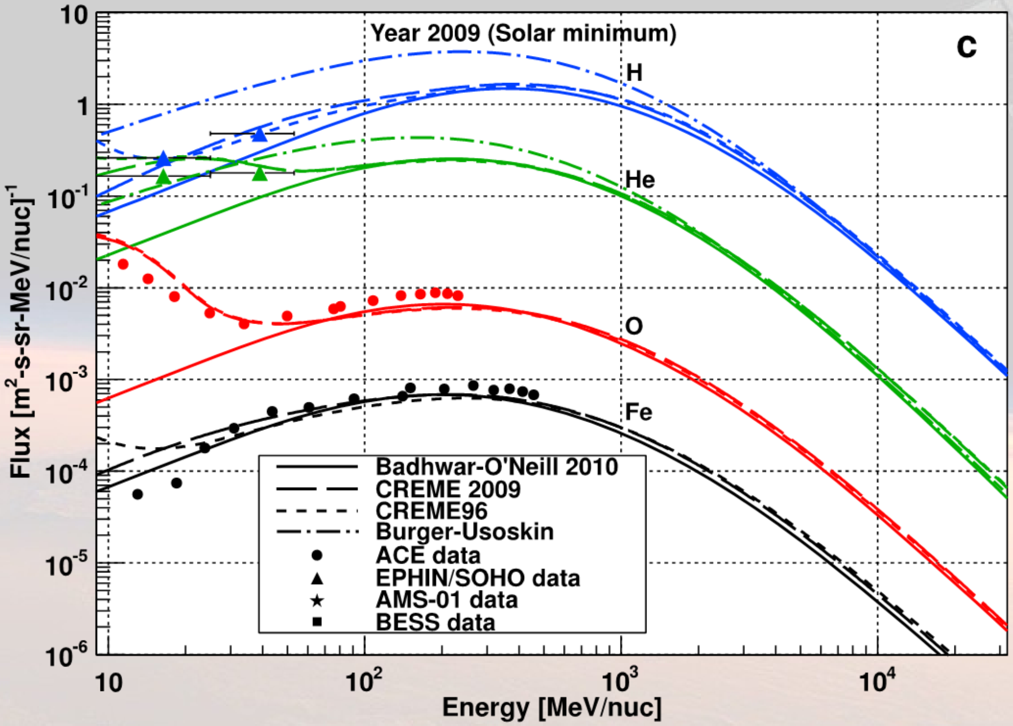
Blasting Coronal Mass Ejection © ESA/NASA/SOHO



- Galactic Cosmic Rays: Highly energetic, highly penetrating particles.
- Solar Event Particles: Dangerous for kinetic energies particles up to a few 100s MeV.
- Secondary particles: Result from collisions of primary radiation particles with S/C

Space radiations models

- GCR Models-

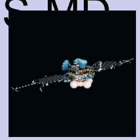
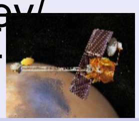


GCR Models © Mrigakshi, et al., 2012, *JGR*, **117**, A08109

- Many different GCR models are being used.
- Developing shielding against high-energy cosmic rays is a priority on the path to a manned mission to Mars.

MFC Primary Mission Objective

- History of Radiations Instruments onboard Martian Missions -

Mission/ Radiations Instrument	Radiations Instrument Main Objective	Results
Mars-96/ RADIUS-MD 	- **During transit to Mars and in Martian orbit**: Analysis of the absorbed dose and the flux on the path and around Mars behind different shielding.	Launch failure.
2001 Mars Odyssey/ MARIE 	- **In Martian orbit**: Detection of GCR and SEP particules with emphasis on SEP above about 30 MeV kinetc energy.	Has observed several SEP events and GCR particles. Some problems in the dose measurement.
Mars Science Laboratory/ RAD 	- **During transit to Mars and on Mars**: Detection and analyze of the most biologically hazardous energetic particle radiation on the Martian surface. Data has been obtained during the transit to Mars.	Has observed a full spectrum of energetic particle radiation: GCR, SEP, secondary neutrons and other particles.

Primary Mission Objective

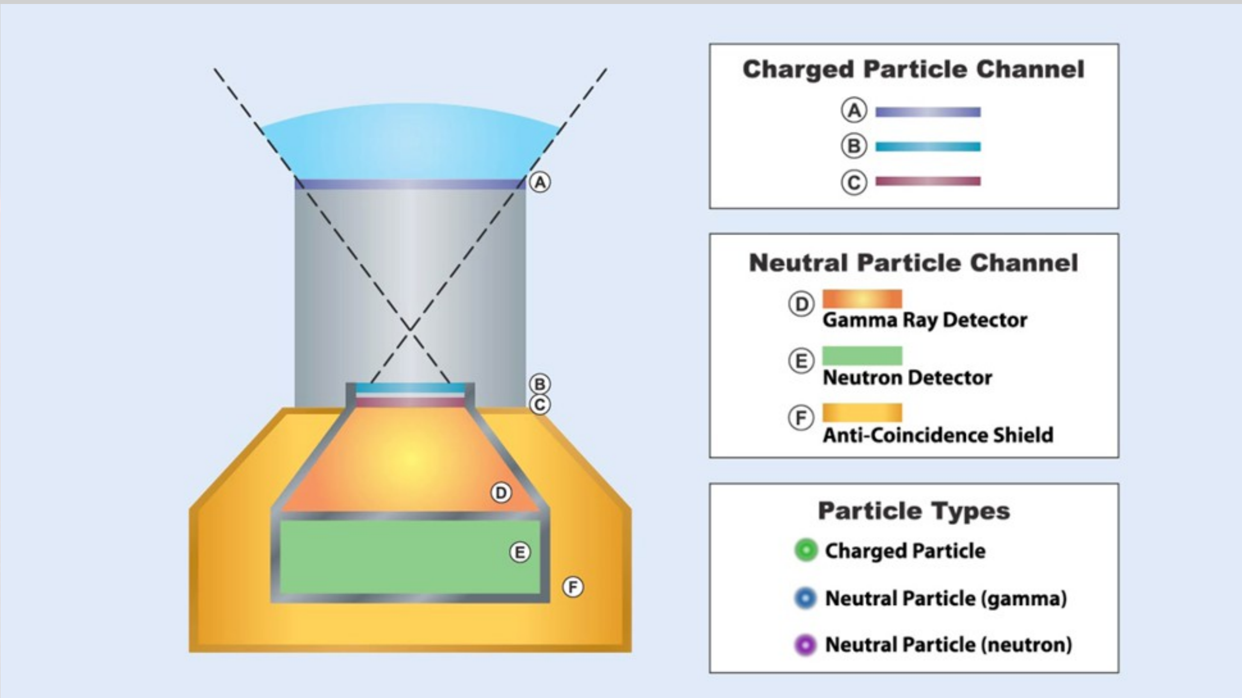
- Focus on Mars Science Laboratory/RAD -

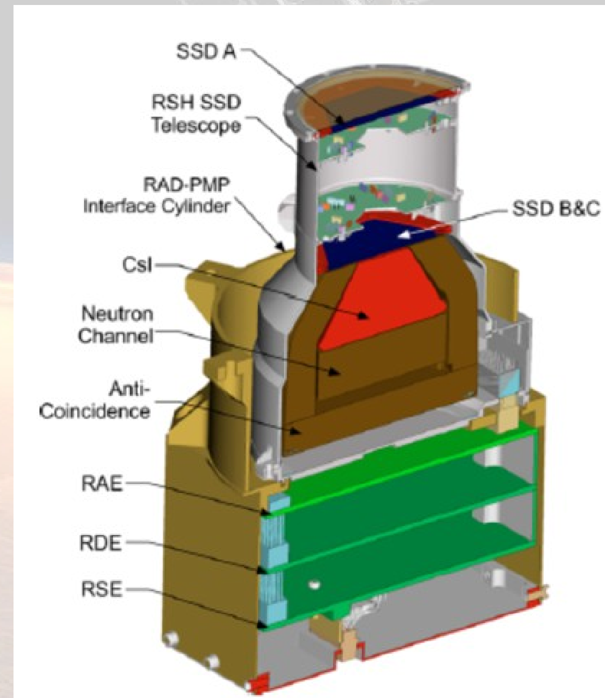
MSL and RAD © NASA

RAD made for studying radiations **on** Mars!

Primary Mission Objective

- Focus on Mars Science Laboratory/RAD -

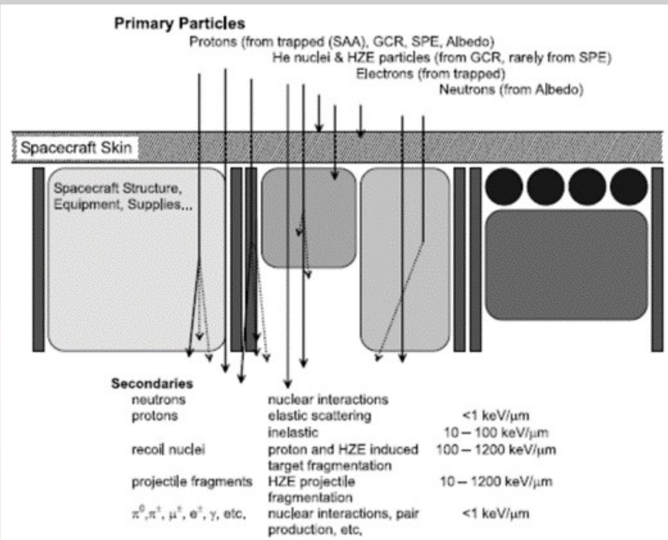




RAD overview © Donald Hassler et al.

MFC Radiations Instrument

- Particles to study -



Primary and secondary particles through spacecraft
© E. R. Benton, E.V. Benton, March 2001

Particle species	Quality factor	Relevance
Protons	1-7	Largest flux, large contributor to total dose.
He (α particles)	2-30	Large flux, high Q at low energies thus large contributor to equivalent dose.
HZE (C, O, Mg, Si)	5-30	High Q with large probability of reaction in body tissue.
HZE (Fe)	6-30	High Q with largest probability of reaction in body tissue, large contributor to equivalent and effective dose (primary astronaut safety concern).
Electrons	1	SEP precursor, highly penetrating, large fluence during SEP events (even with Q=1, large fluence contributes to large equivalent dose).

Particles to be studied by MFC

Quality factor (also weighting factor) = Quantity expressing the biological damage

Identification of ions by species (or at least by group, e.g., C–N–O) is required to use the new risk assessment tools developed by NASA.

Study primary particles causing direct damage or undirectly via secondary particles production. Goal is not to directly study the secondary particles.

Science Requirements on *RADIATIONS*

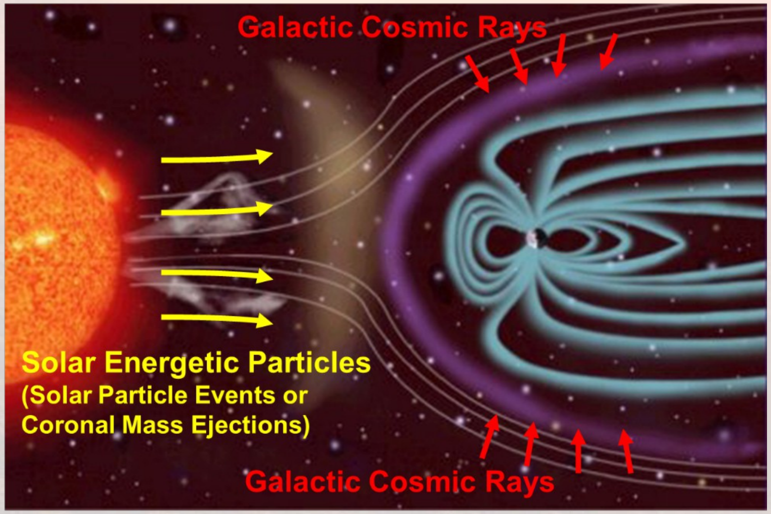
• RAD considered as a baseline to address the scientific needs and to develop a similar miniaturized payload.

• The MFC radiations instrument should fit in maximum 1,5U (10cmx10cmx15cm).

• Goal reachable: MFC will not need to study some of the radiations which are irrelevant for manned missions (mainly the low quality factor and neutral particles radiations).

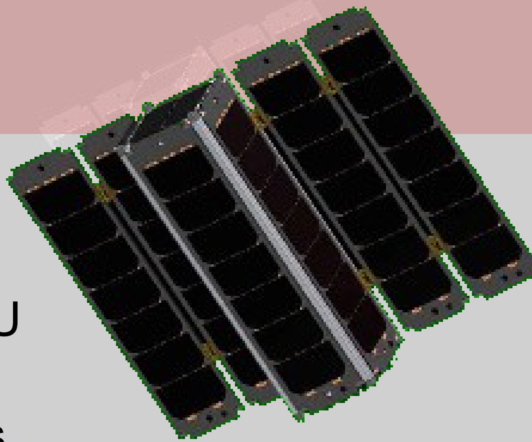
• This preliminary feasibility assessment will lead to the preparation of a specification of needs for the MFC radiation instrument.

• In the future, an announcement of opportunity will be made internationally to interested laboratories for the MFC radiations instrument conception.



Science + CubeSat

=► Mission Profile



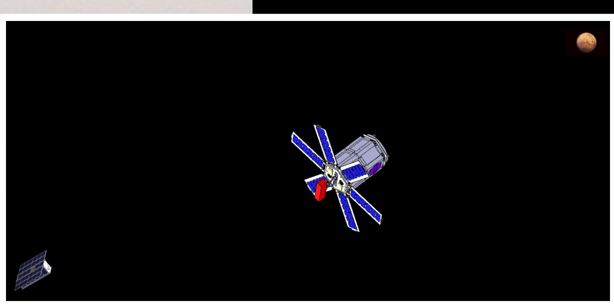
- A “3U” CubeSat for Free-Return Earth-Mars Trajectory
- Payload for Radiation Measurements to be integrated into 1.5U
- CubeSat to be « early » jettisoned from a host mission to Mars
- No interplanetary communications, full autonomy during the cruise
  - Data-relay in Mars' vicinity + when back to Earth
  - No navigation assistance during the cruise

=> Science Data :
- long duration storage (6+ months) and pre-processing if needed
- “short” distance communication with a Martian orbiter as Data-Relay

=> Navigation : optical system and on-board processing
- Tool to early assess the feasibility of trajectory corrections & flyby computation
- Electrical propulsion for ACS & OCS
- On-board image processing : clock, location, trajectory corrections

Navigation :

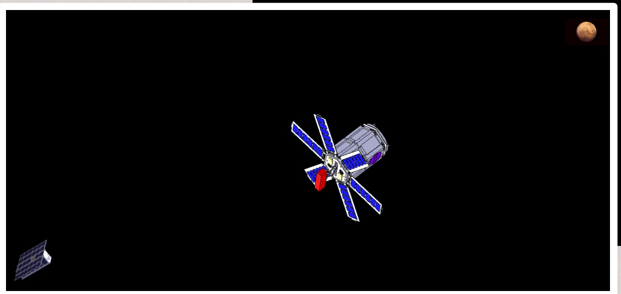
Optical Planets Tracking system + on-board processing



Martian CubeSat jettisonned from its “host” © NCKU

Navigation :

Optical Planets Tracking system + on-board processing



Martian CubeSat jettisonned from its “host” © NCKU

Main Challenges

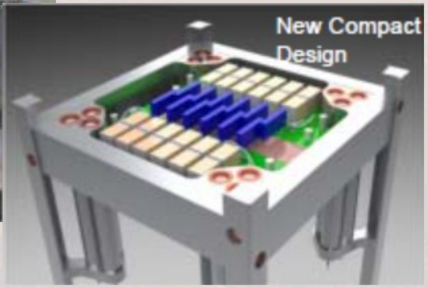
- Trajectory corrections -

- After Trans-Mars injection, only small corrections of trajectory are needed.
- Use of an electrical propulsion onboard the CubeSat for trajectory corrections and attitude control.
- Typically TRL 5 for CubeSat electrical propulsion systems.

System Volume	< 0.5 U
System Mass	< 0.55 kg
System Power	2 W (at 2 Hz firing rate)
Thrust	0.5 mN, primary 0.13 mN, ACS
ISP	700 s
Delta V (for 4kg spacecraft)	63 m/s, primary 65 m/s, ACS
TRL	5

e.g. Key Performance Characteristics,
Busek Micro-Pulsed Plasma Thruster © BUSEK

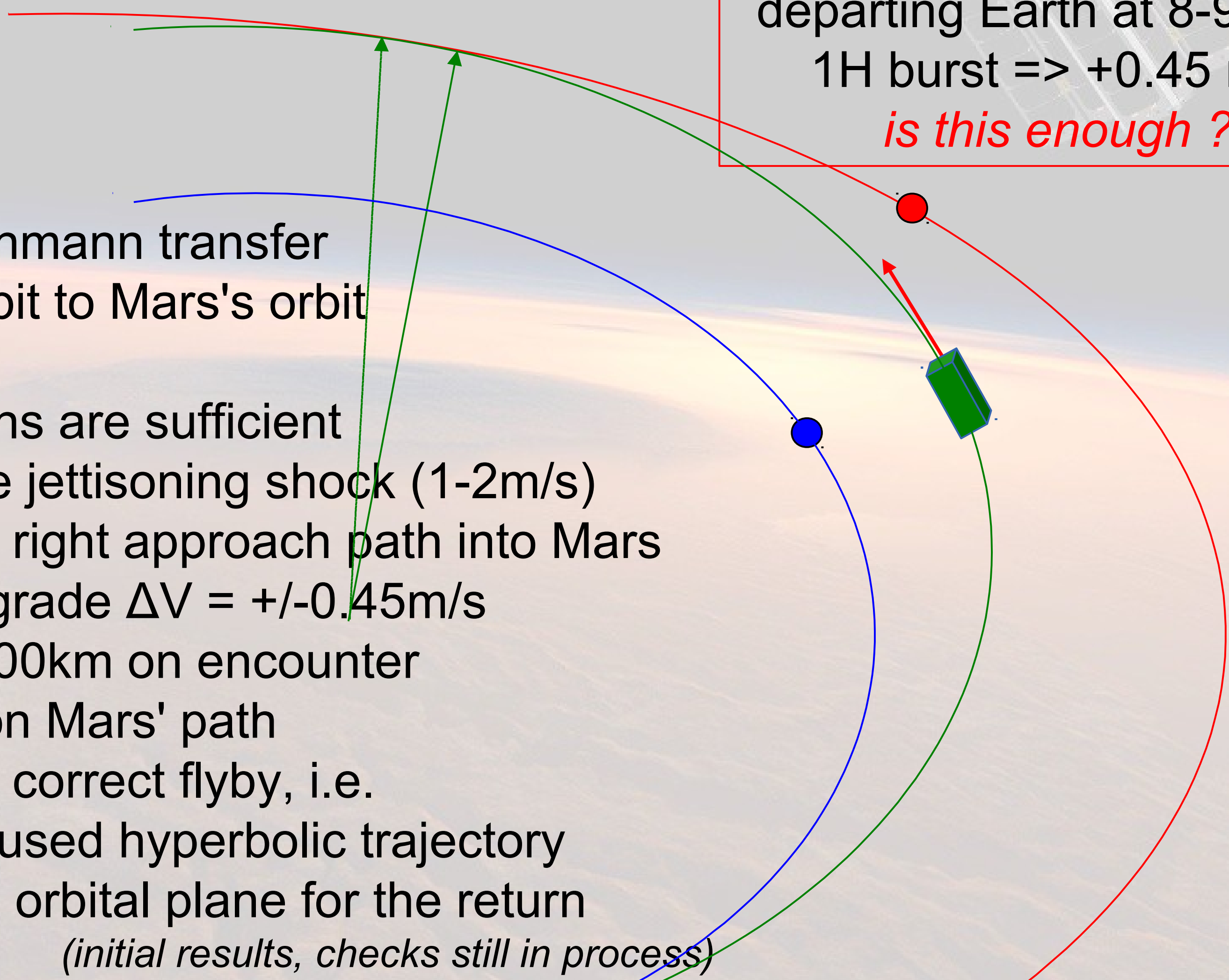
departing Earth at 8-9 km/s
1H thrust => +0.45 m/s
is this enough ?



Main Challenges

- Trajectory corrections : a few m/s for ΔV budget -

departing Earth at 8-9 km/s
1H burst => +0.45 m/s
is this enough ?



YES !

Based on a Hohmann transfer
from Earth's orbit to Mars's orbit

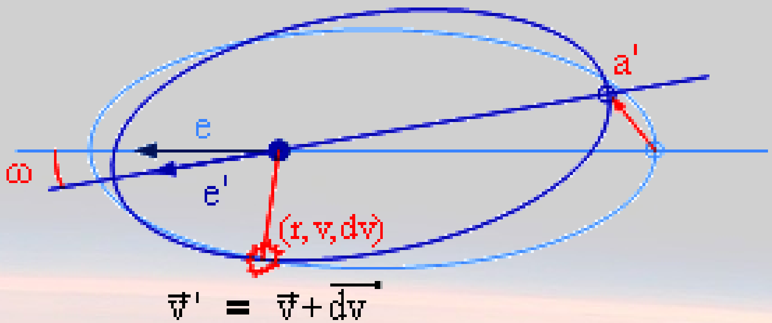
Small corrections are sufficient

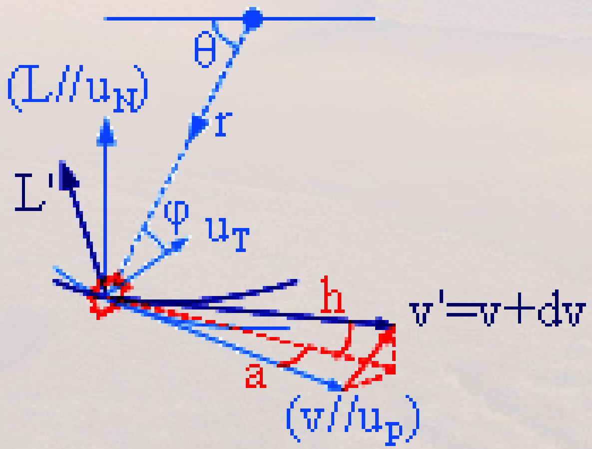
- to cancel the jettisoning shock (1-2m/s)
- to select the right approach path into Mars vicinity. Prograde ΔV = +/-0.45m/s
  - +/-40'000km on encounter
  - +/-3H on Mars' path
- to select the correct flyby, i.e.
  - Mars-focused hyperbolic trajectory
  - Twist the orbital plane for the return

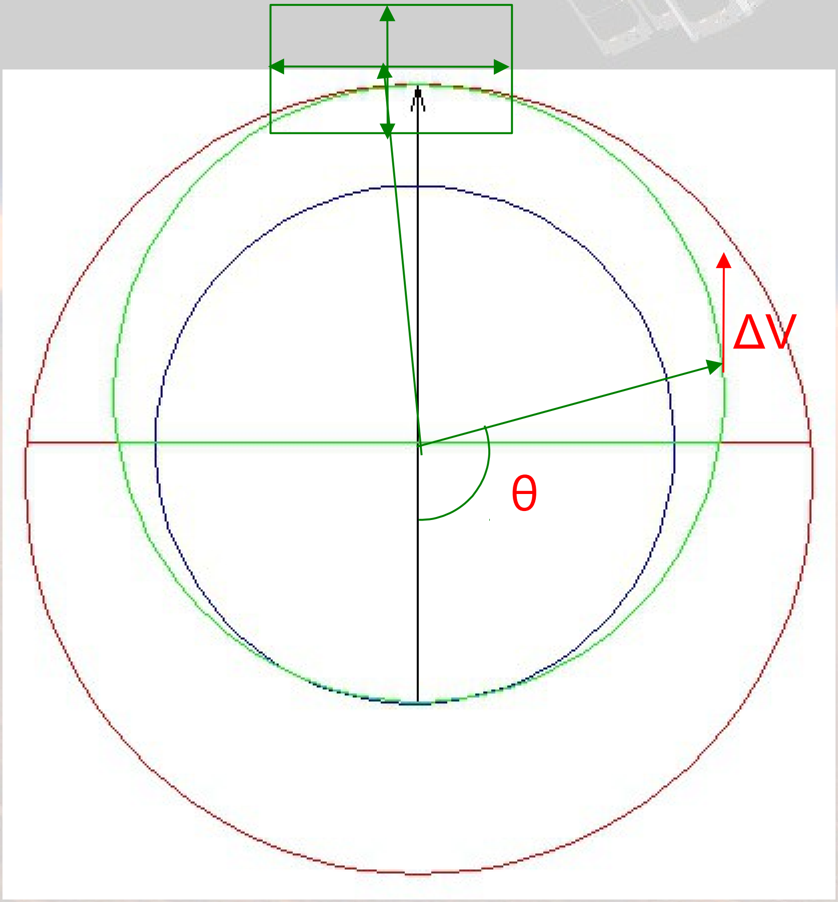
(initial results, checks still in process)

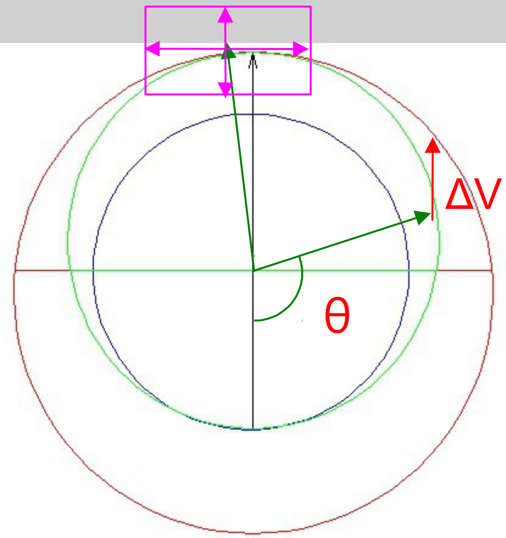
Main Challenges

- Trajectory corrections : (θ, ΔV) trade-off





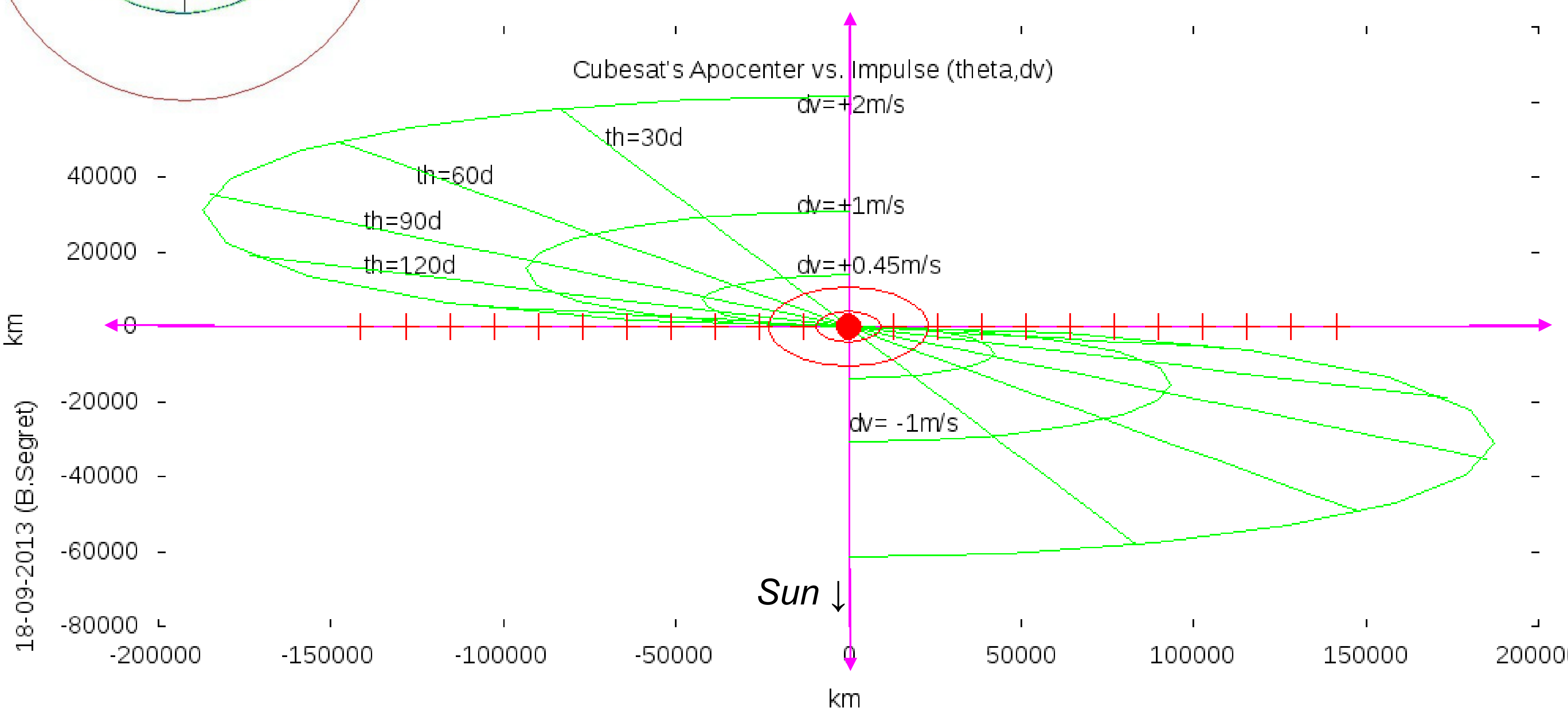




Main Challenges

-Trajectory corrections : (θ, ΔV) trade-off

(e.g.) a prograde ΔV=2m/s at θ=100° moves the apocenter by ~175'000km « left » (-x) and ~30'000km opposite to the Sun (+y)

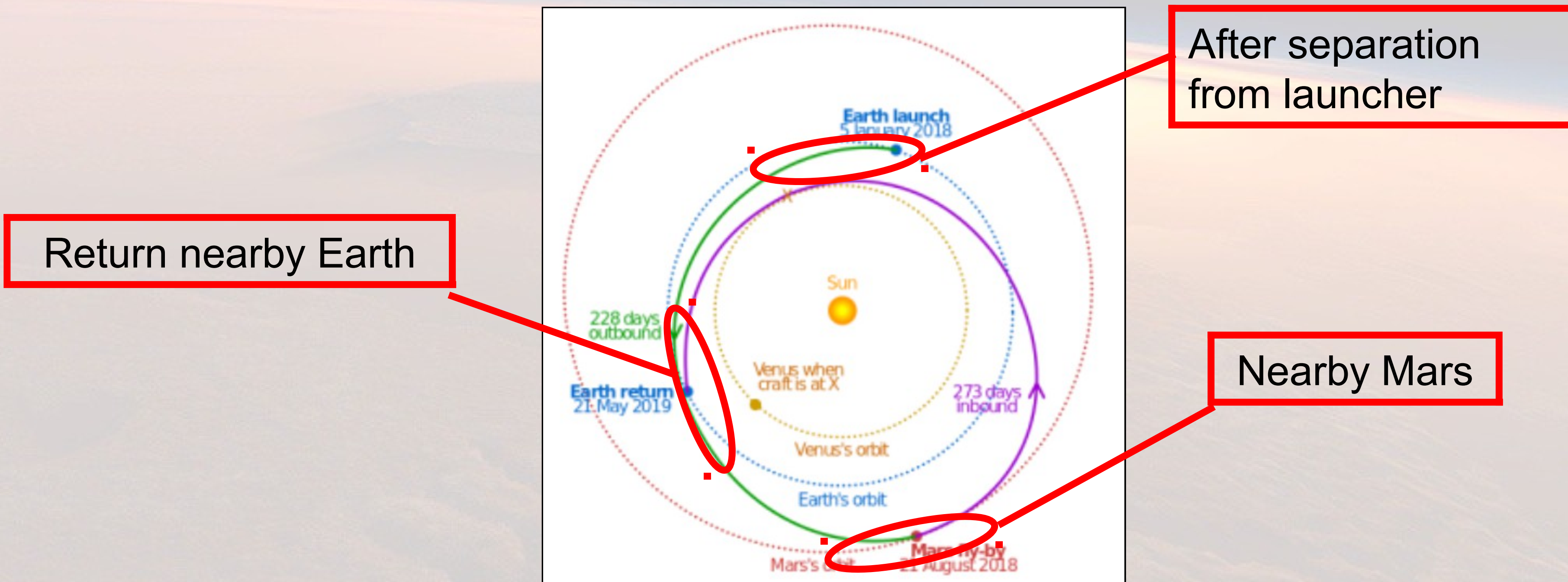


Main Challenges

- Communications -

• The CubeSat would acquire data during its way to Mars and transmit them to a Martian orbiter while approaching Mars.

• It would also acquire data on its way back to Earth and transmit them to the Ground Stations when back nearby the Earth.



Communication opportunities

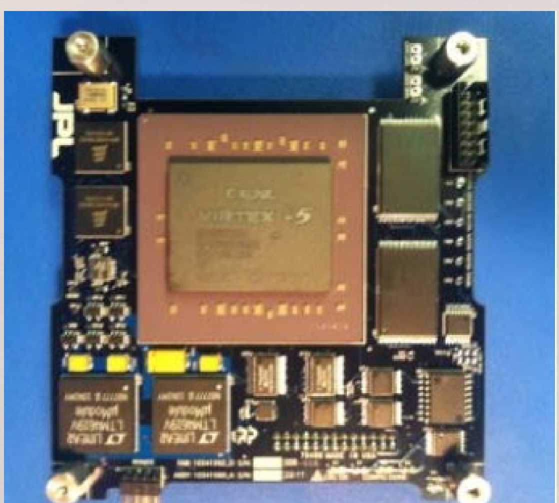
Main Challenges

- Onboard Storage and Data Processing -

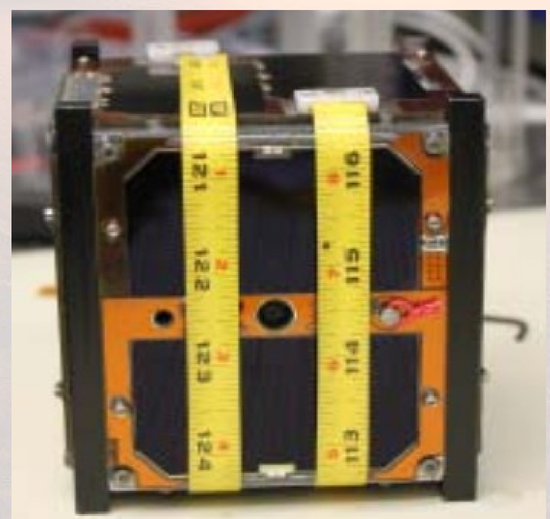
CubeSat must be autonomous due to the absence of communication

- Orbital computation from optical planets tracking : on-board
- Data to be stored 6-9 months : RAID technology (like on JUICE)
- Use of FPGA for image analysis. On-going R&T for CubeSats.

On-board processing : re-use of development tools for large missions (LEON µPro architectures on Solar Orbiter, Bepi-Colombo)



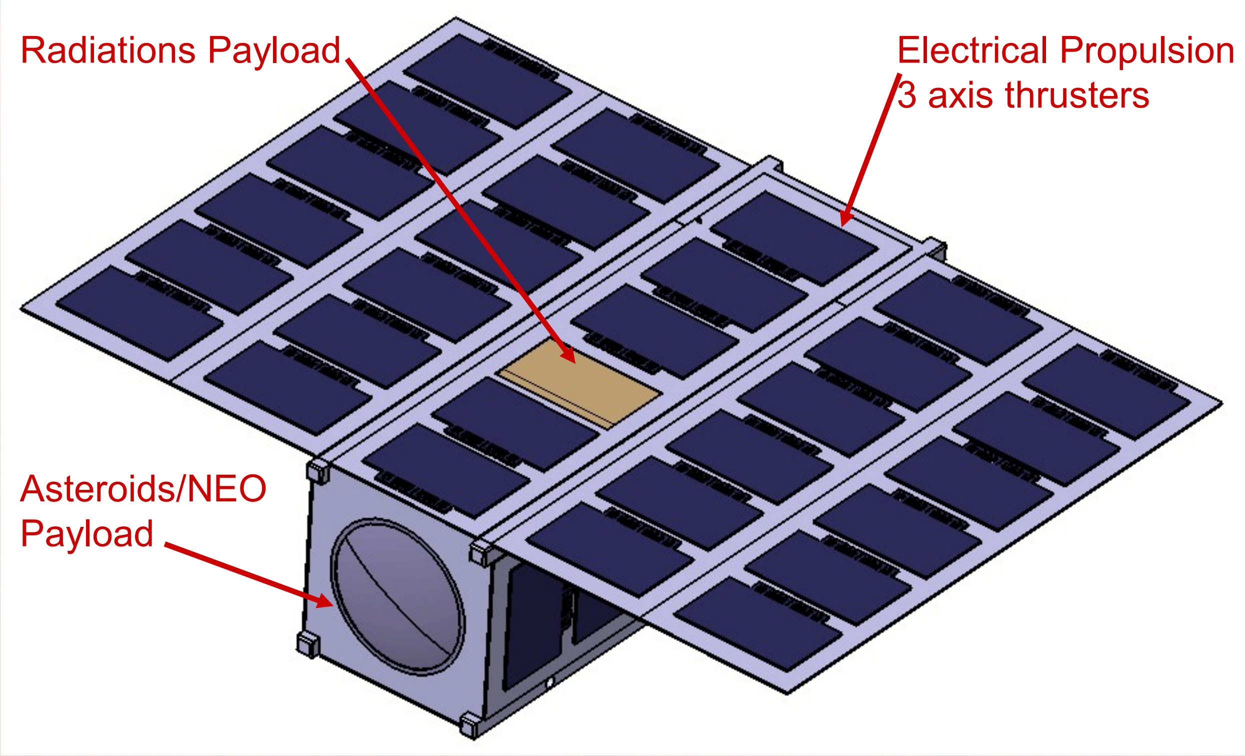
Real-Time Onboard Processing for MSPI © NASA



COVE: CubeSat Onboard processing Validation Experiment © NASA

CubeSat Design

Size	3U: 10cmx10cmx30cm
Mass	4 kg
Attitude Control	0.5U: Electrical Propulsion
OBDH + EPS + COMMS	1U
Scientific Instruments	1.5U: Radiations Payload + Asteroids/NEO Optical Detector
Life time	~ 500 days



Education – Science – Interplanetary

an ***Educational*** CubeSat for real ***Science Data*** from ***deep space***

- to **scout the manned mission to Mars** by measuring radiations in situ over the full Earth-Mars-Earth journey.

- to **demonstrate a new way** to contribute in Space Weather science

- Phase 0 : Mission Design Review 09-10/2013
- Phase A : 06/2013-... « Feasibility Assessment in 2014 »
- Phase B : from 10/2013, new students involved

Free-return trajectory opportunity in 2018.

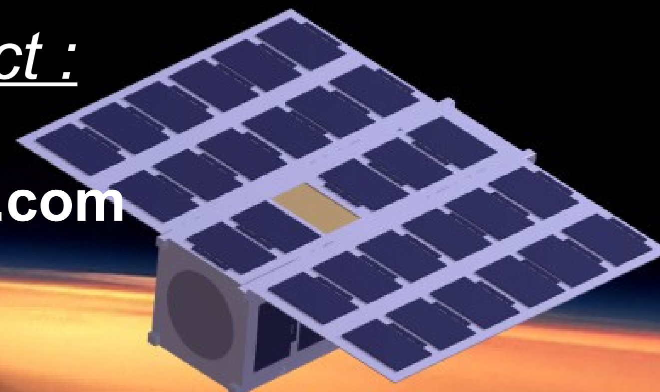
ALL MARS MISSIONS COMPATIBLE!

Thank You!

<u>Teachers & Sponsors, please contact :</u>

Project Mgr: **boris.segret @ obspm.fr**

System Mgr: **jordan.vannitsen @ gmail.com**



& mailing list

for news to any enthousiasts

Mentors, Advisors & Students:

CNRS-LATMOS : Pr. M.Cabane, D.Coscia

Mars Society Switzerland : P.Brisson

Association Planète Mars : B.Segret, R. Heidmann, J. Daniel

NCKU : Pr. J.J.Miau, Pr. J.C.Juang, Dr. K. Wang

NCKU : J.Vannitsen

ELISA : A.Ansart, N.Gerbal, Q.Tahan

Obs.de Paris : A.Porquet, A.Deligny, M.Agnan, J.Velardo, A.Lassissi, G.Quinsac

… and many others to join in the coming years!

ESEP NCKU EE Planète Mars