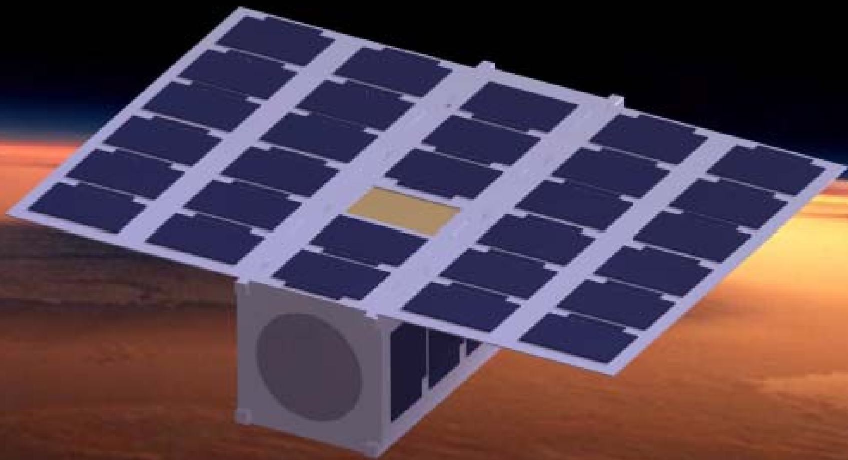
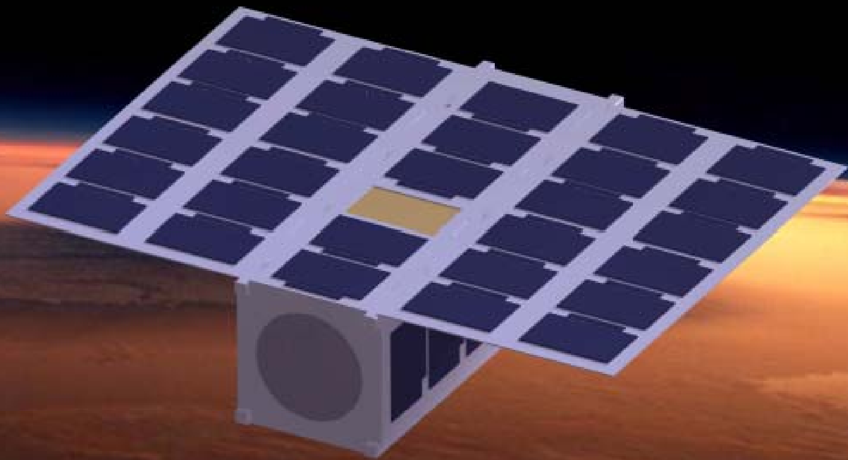
CubeSat on an Earth-Mars Free-Return Trajectory to study radiation hazards in the future manned mission



presented by:
Jordan VANNITSEN (NCKU, DAA)

in collaboration with:
Boris SEGRET (ESEP, LESIA - Observatoire de Paris)
Jiun-Jih MIAU (NCKU - DAA)
Jyh-Ching JUANG (NCKU - DEE)

MFC – Mars Flyby CubeSat
(temporary name)



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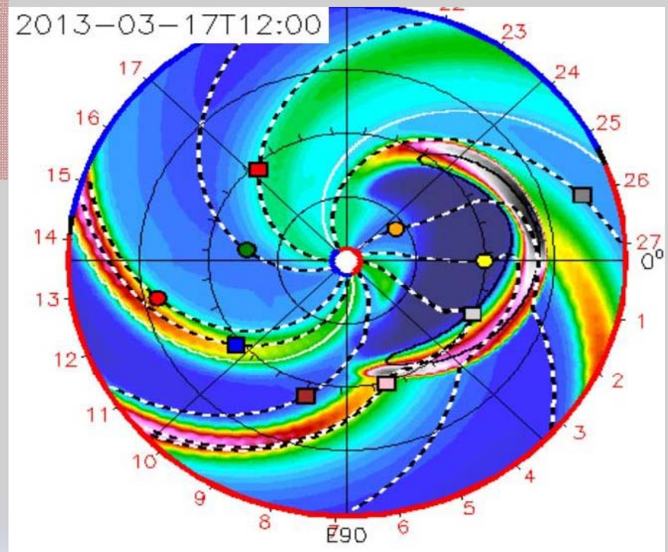
MFR Primary Mission Objective

- 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 »
- **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.**
  - **Data useful for Space Weather.**

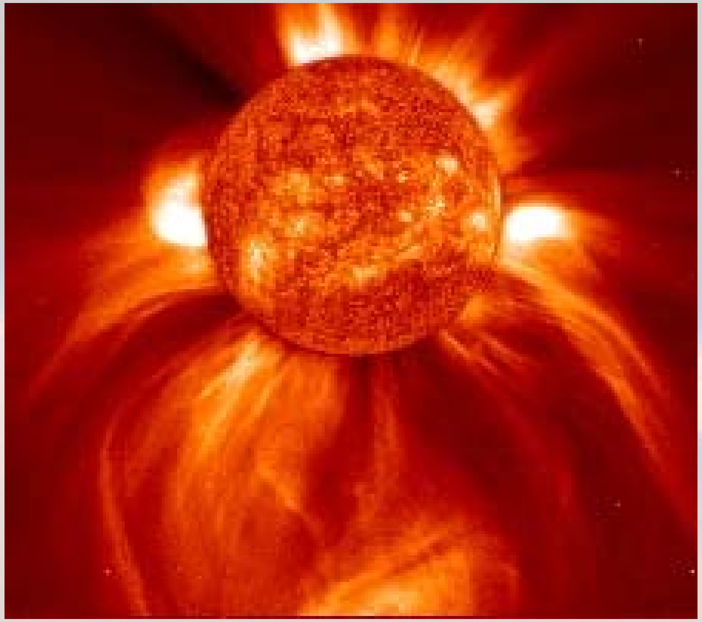


NASA Goddard Space Weather Research Center

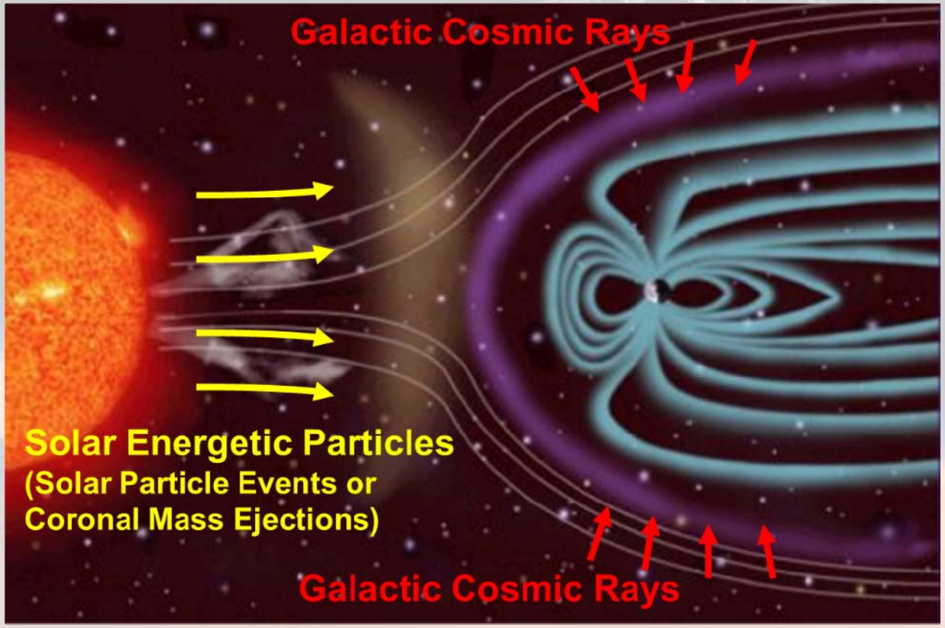
Picture of RAD Radiations Assessment Detector © NASA

MFC Primary Mission Objective

- Interplanetary Space radiations -



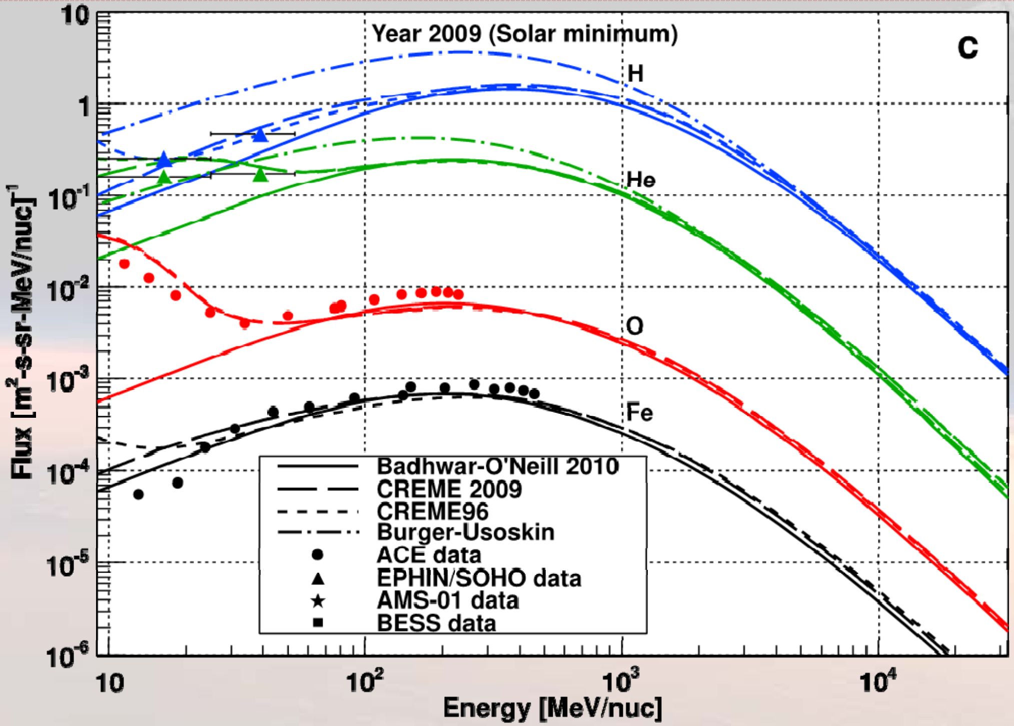
Blasting Coronal Mass Ejection © ESA/NASA/SOHO



- Galactic Cosmic Rays: Highly energetic, highly penetrating particles. The contribution becomes more significant as the mission duration increases.
- Solar Event Particles: Can deliver a very high radiation dose in a short time. Flux trajectory subjected to interplanetary field direction.
- Secondary particles: Result from collisions of primary radiation particles with S/C

MFC Primary Mission Objective

- GCR Models-

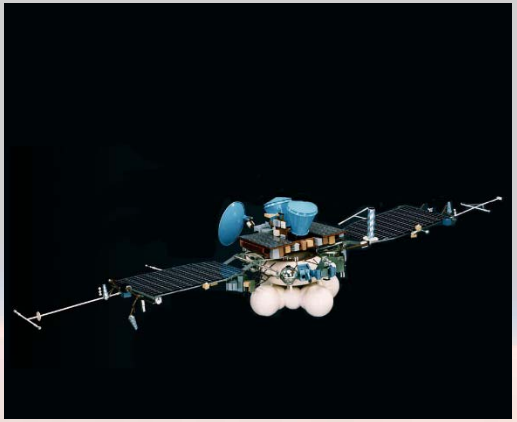


GCR Models © Mrigakshi, et al., 2012, *JGR*,**117**, A08109

- 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 -



Mars-96	2001 Mars Odyssey	Curiosity/RAD
Transit + Mars orbit.	Mars orbit.	Transit + Mars ground.
Absorbed dose behind different shielding.	GCR + SEP (>30 MeV).	Full spectrum.
Launch failure.	Observed SEP + GCR. Problems in dose measurements.	Most biologically hazardous particles on Martian surface. Turned on during transit.

MFC Primary Mission Objective

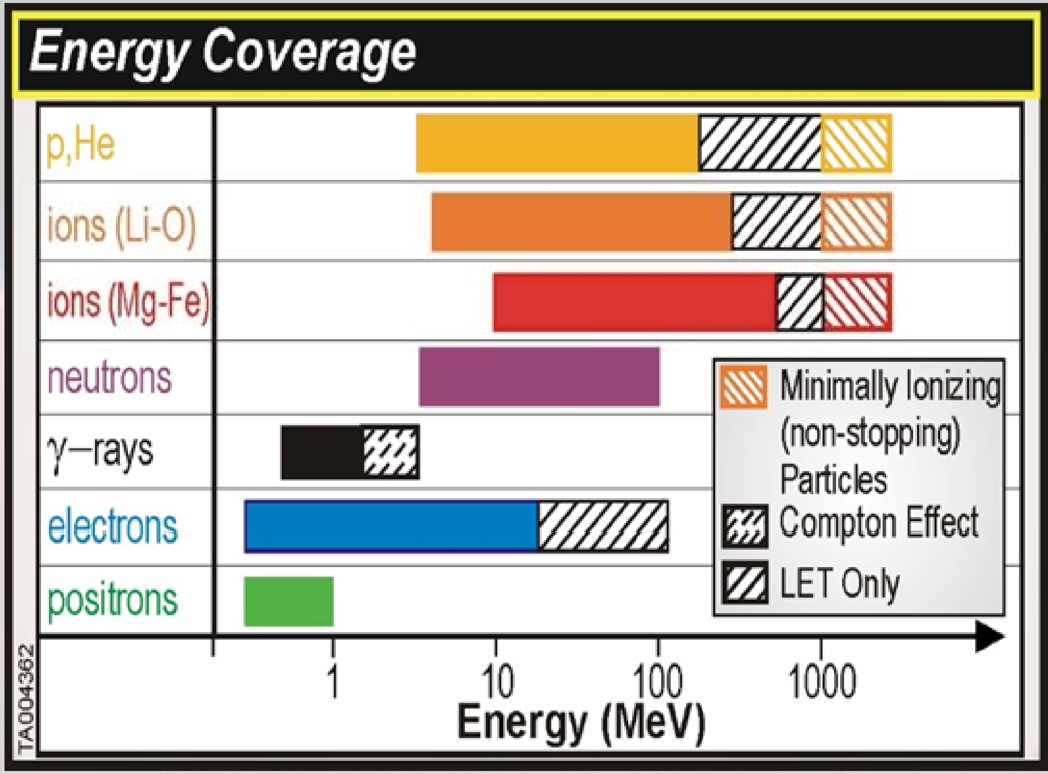
- Focus on Mars Science Laboratory/RAD -

MSL and RAD © NASA

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

A Space radiations instrument

- Focus on Radiation Assessment Detector (RAD/Curiosity) -



RAD energy coverage © Donald Hassler et al.

Relevant near regolith and within teneous atmosphere

Relevant to Mars geology

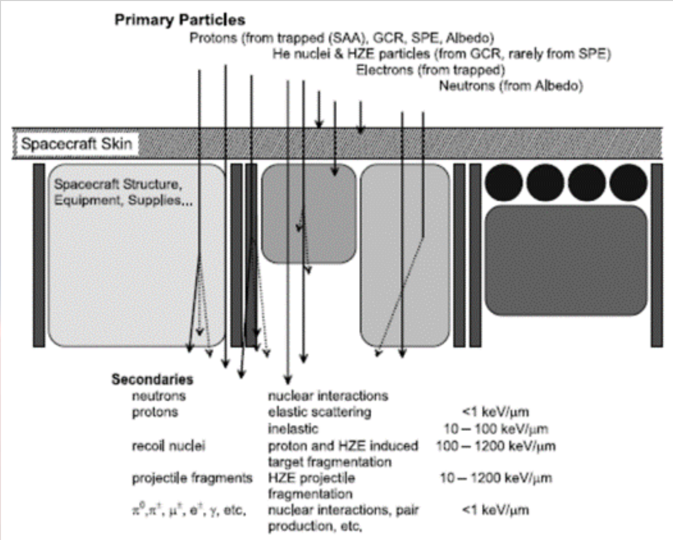
Required for radiation transport model validation

Irrelevant for Martian Cubesat mission

- RAD made for studying radiations **on** Mars!
- Range of particles studied too wide for our mission.
- Shall be **specialized** & **miniaturized** to focus on radiations during cruise.

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.

MFC Radiations Instrument

- Science Requirements on *RADIATIONS* -

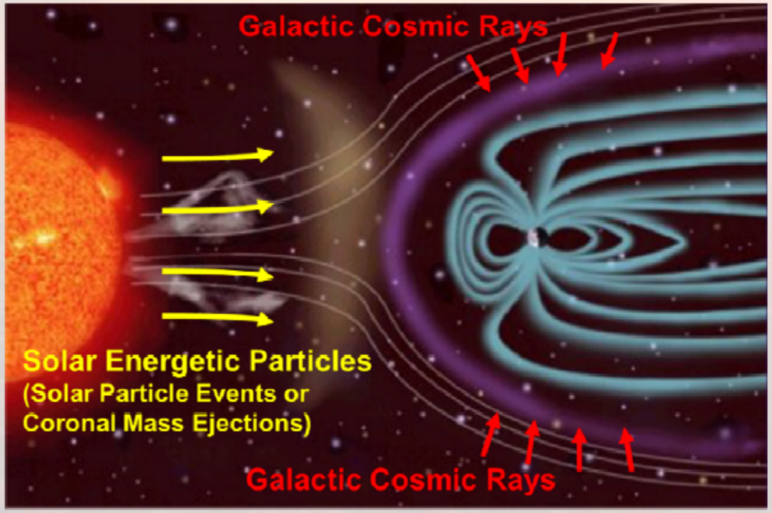
- RAD considered as a baseline to address the scientific needs and to develop a similar miniaturized payload.

- The MFC radiations instrument: max. 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).

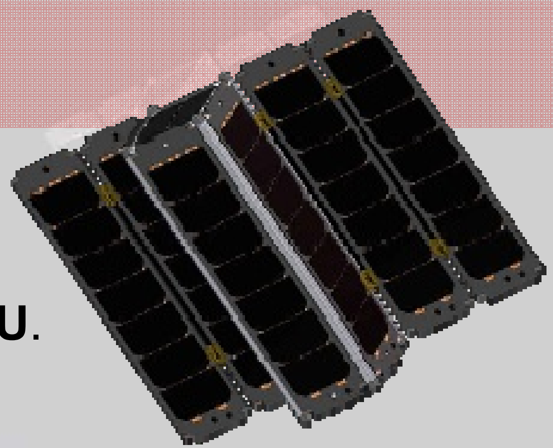
- Specification of needs for the MFC radiation instrument ongoing.

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



Science + CubeSat

=► Mission Profile



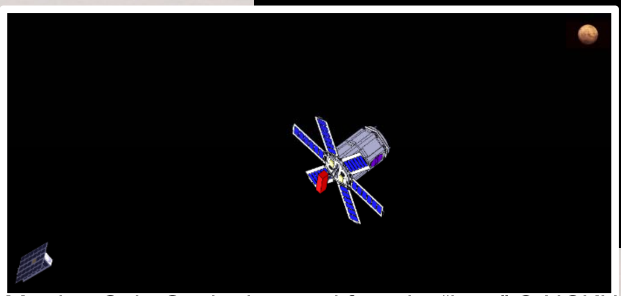
- A **3U CubeSat** for Free-Return Earth-Mars Trajectory.
- Payload for Radiation Measurements to be integrated into **1.5U**.
- « **Early** » jettisoned from a host mission to Mars.
- **No interplanetary communications**, full autonomy during the cruise.
  - Data-relay in Mars' vicinity + when back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

=> **Science Data** :
- long duration storage (6+ months) and pre-processing is 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 AOCS.
- On-board image processing : clock, location, trajectory corrections.

Navigation

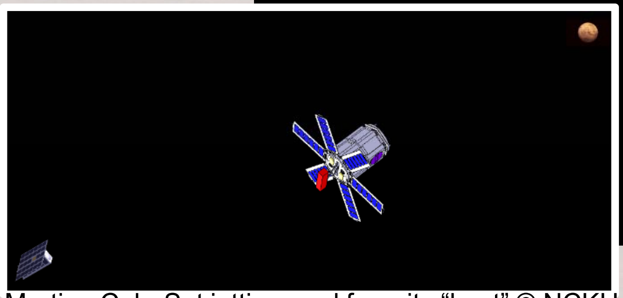
- Optical Planets Tracking system + on-board processing -



Martian CubeSat jettisonned from its “host” © NCKU

Navigation

- Optical Planets Tracking system + on-board processing -



Martian CubeSat jettisonned from its “host” © NCKU

Main Challenges

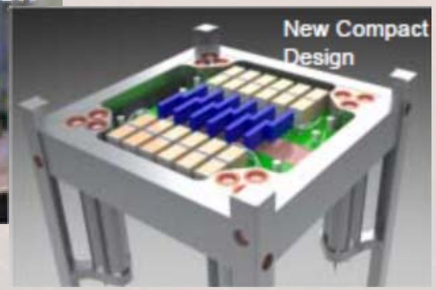
- Trajectory corrections -

- 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

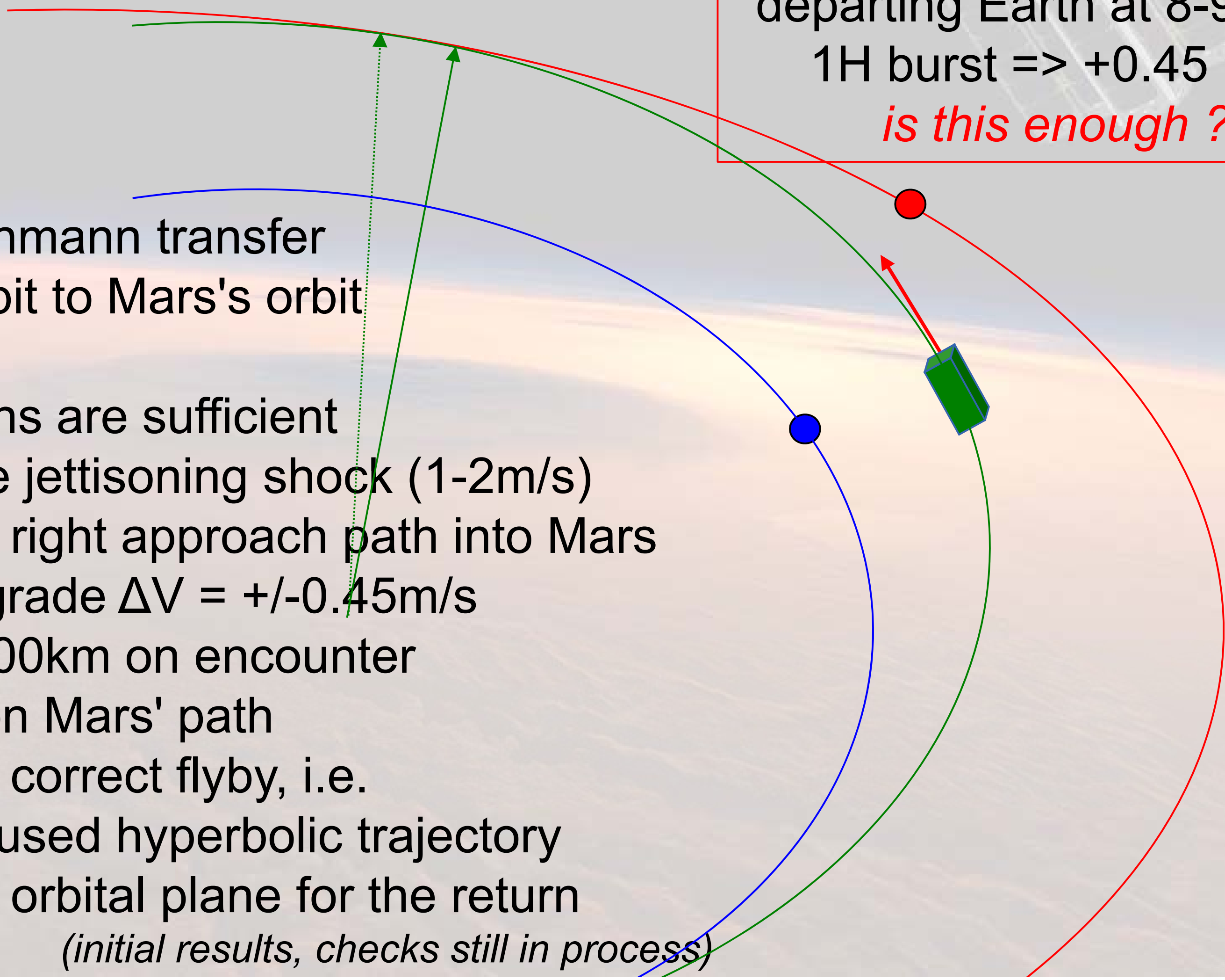
departing Earth at 8-9 km/s
1H thrust => +0.45 m/s
is this enough ?



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

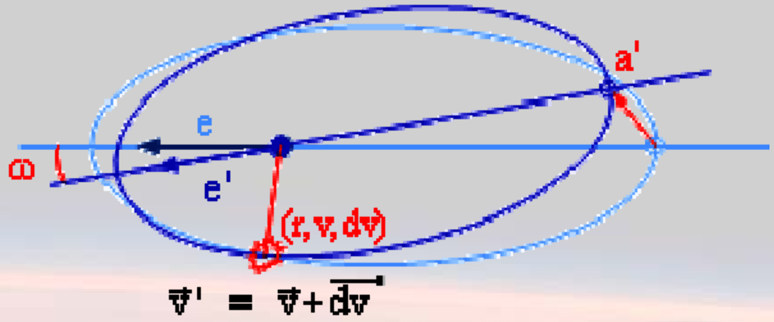
Small corrections are sufficient

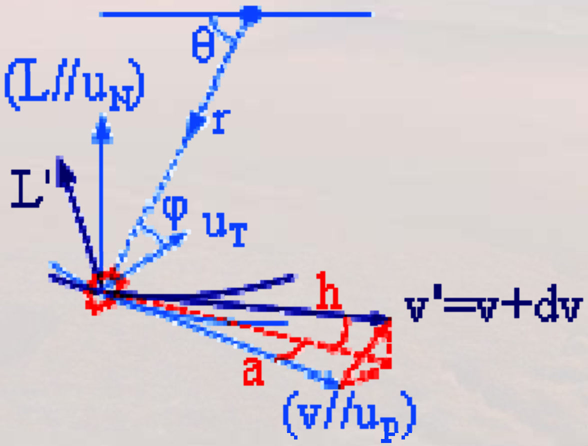
- to cancel the jettisoning shock (1-2m/s)
- to select the right approach path into Mars vicinity. Prograde ΔV = +/-0.45m/s
  - +/-40'000km on encounter
  - +/-3H on Mars' path
- to select the correct flyby, i.e.
  - Mars-focused hyperbolic trajectory
  - Twist the orbital plane for the return

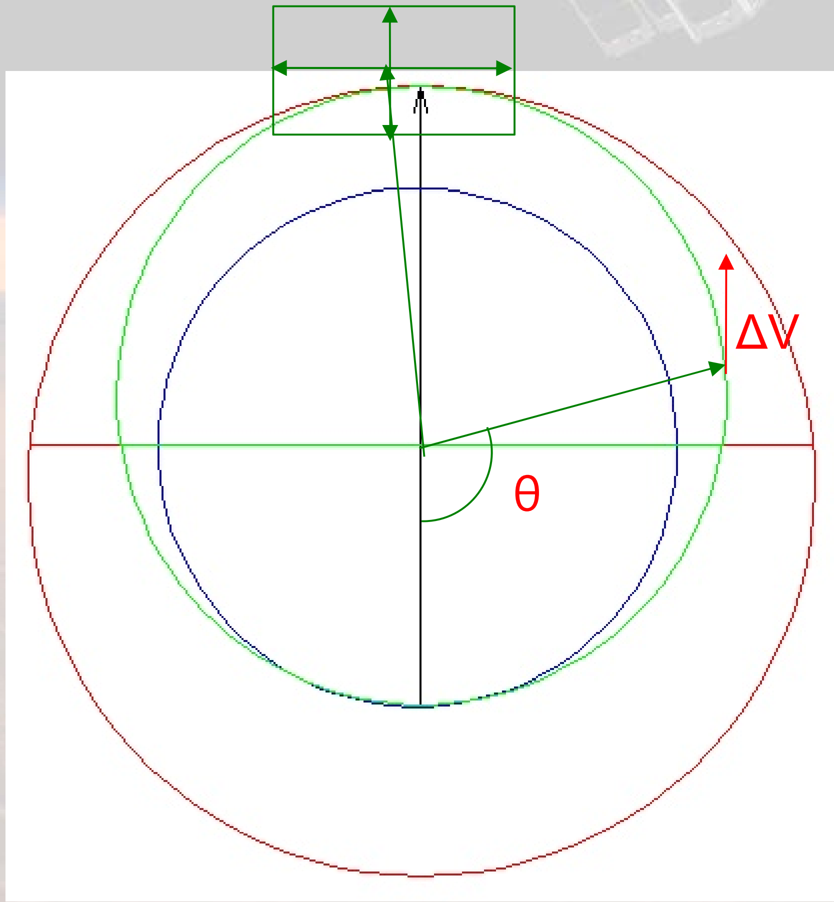
(initial results, checks still in process)

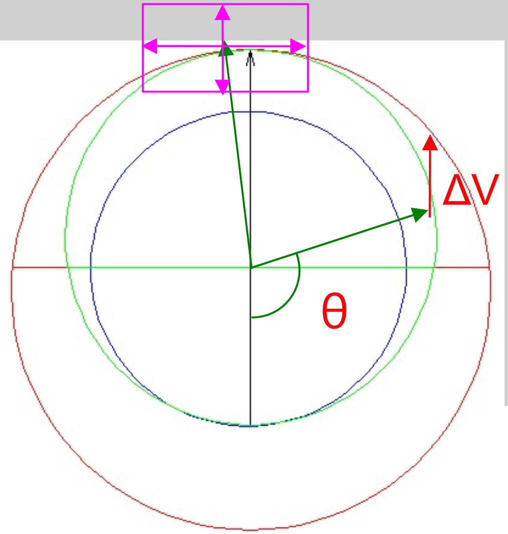
Main Challenges

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





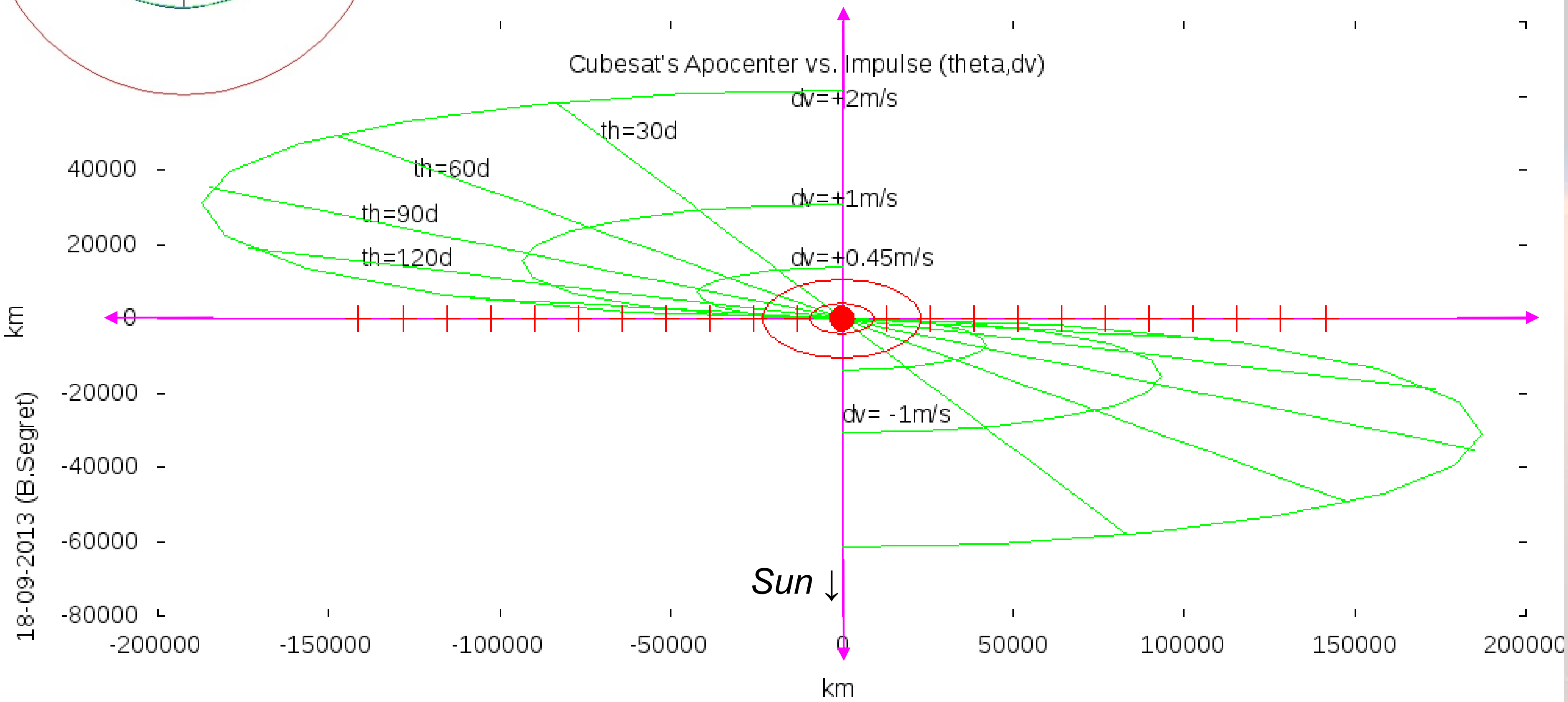




Main Challenges

-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)

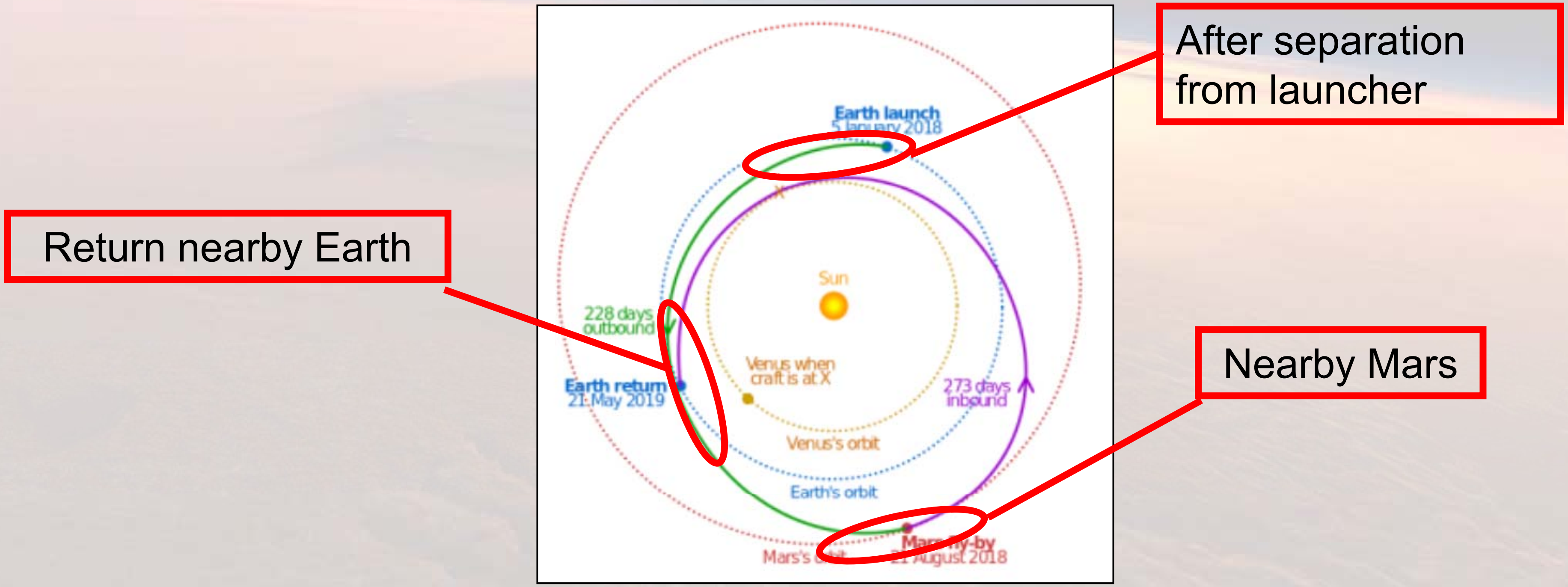


Main Challenges

- 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.

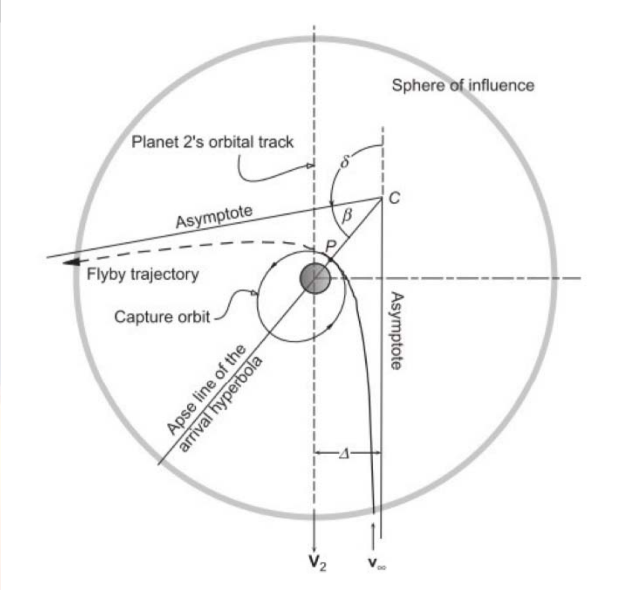


Communication opportunities

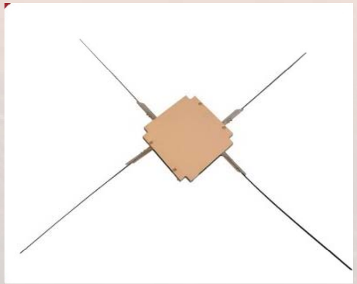
Main Challenges

- Communications nearby Mars -

- One-way radiation profile will take up to 11 Mo.
- Mars orbiters communication protocole is:
    - UHF (between 300MHz & 3GHz) for short ranges (Rovers/Orbiters comm)
    - X-BAND (between 8 and 12 GHz) for high ranges (Orbiters/Earth comm)
- Many COTS (Commercial Off The Shelf) solutions but not designed for interplanetary missions.
- Hybrid UHF/X-BAND solutions are currently on development.



Trajectory in Mars vicinity. The probe will be in the Mars sphere of influence at least 30 hours.



Deployable COTS solution for UHF and VHF communications

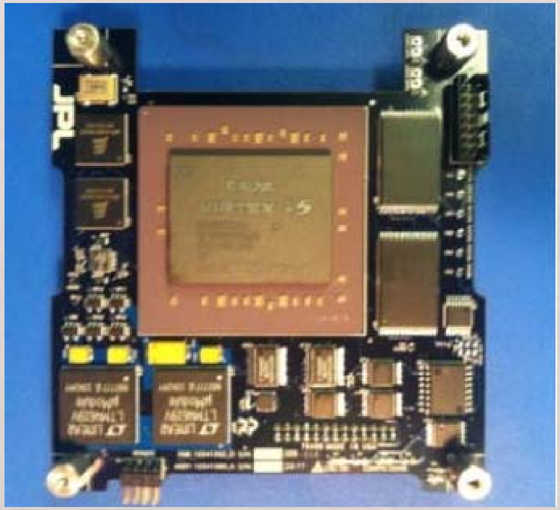
Main Challenges

- Onboard Storage and Data Processing -

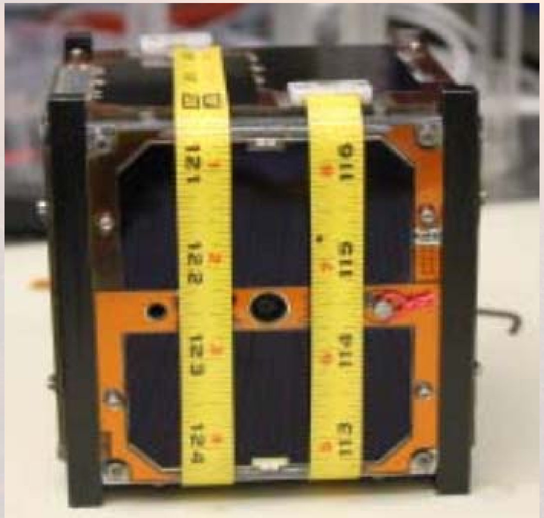
CubeSat must be autonomous due to the absence of communication.

- 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).

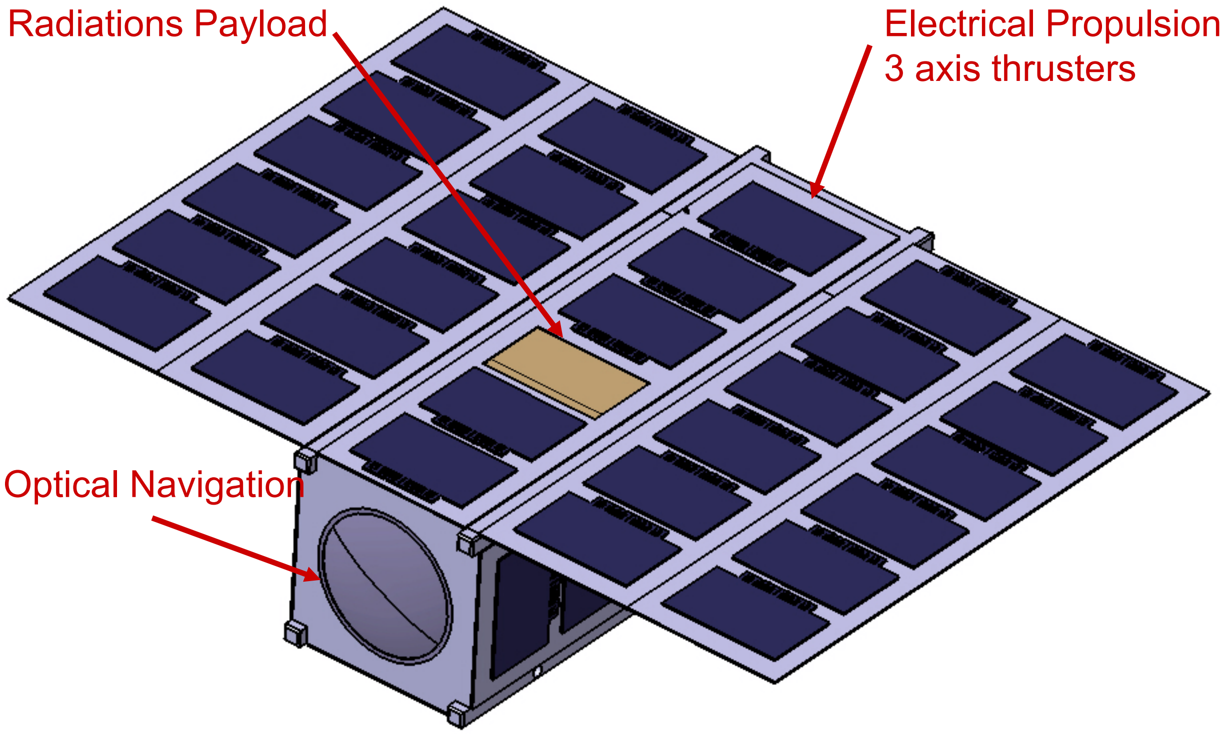


Real-Time Onboard Processing for MSPI © NASA


COVE: CubeSat Onboard processing Validation Experiment © NASA

MFC Preliminary Design

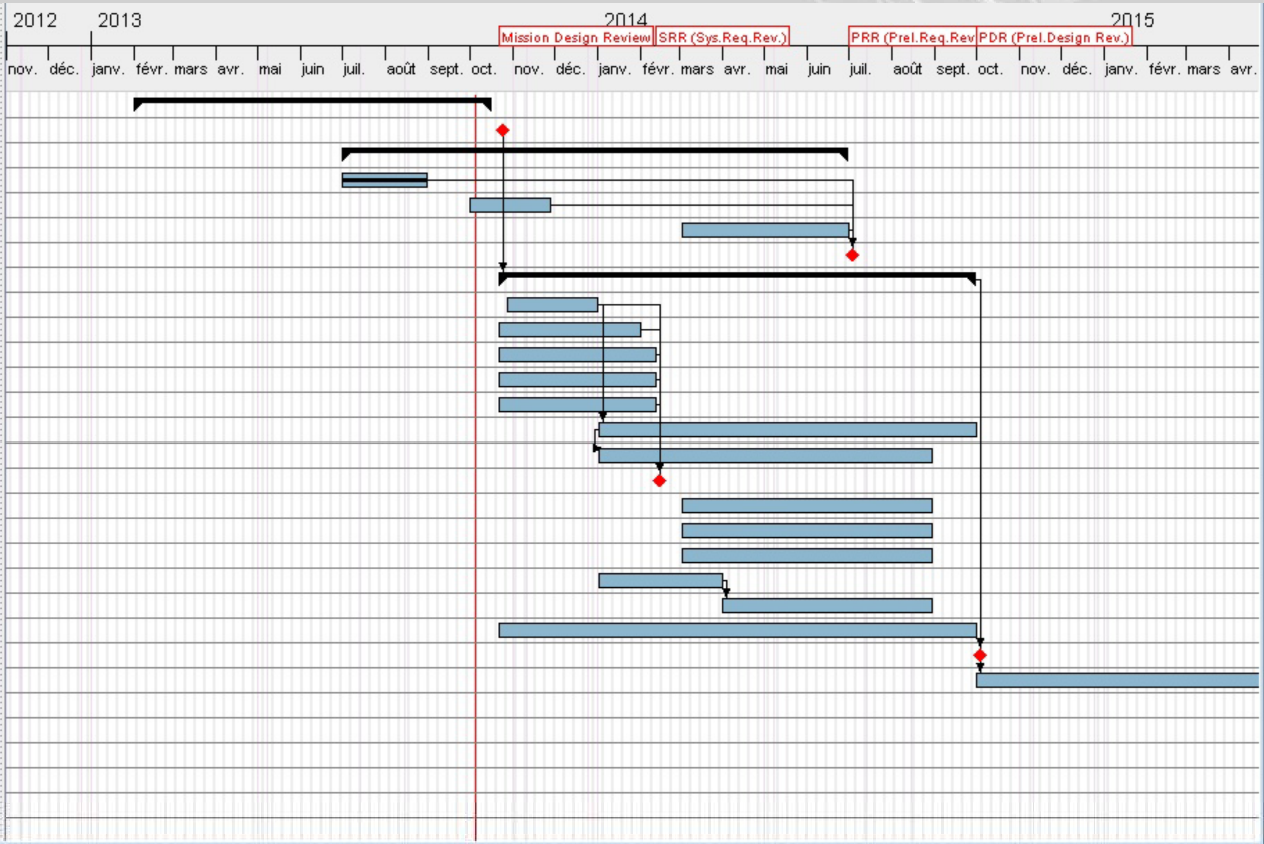
Size	3U: 10cmx10cmx30cm
Mass	4 kg
AOCS	0.5 U (Electrical Propulsion)
OBDH + EPS + TT&C	1U
Payload	1,5 U (Radiations Payload)
Lifetime	~ 500 days



MFC Schedule

GANTT project

Nom	Date de fin
Ph.0: Mission analysis	16/10/13
Mission Design Review	22/10/13
Ph.A: focused feasibility studies	30/06/14
Propulsion feasibility (tech & fi)	30/08/13
Flyby feasibility	27/11/13
Navigation feasibility (4 month internship)	30/06/14
PRR (Prel.Req.Rev.)	01/07/14
Ph.B: preliminary design	30/09/14
Radiations : Spec of Needs	31/12/13
Propulsion-Navigation integration	31/01/14
Communication Budget	11/02/14
Power Budget for LEON	11/02/14
Navigation Function : I/O, Test Needs	11/02/14
Functional Analysis : Budgets & SoW	30/09/14
Risk Analysis & mitigation	29/08/14
SRR (Sys.Req.Rev.)	12/02/14
Numeric System Architecture (µPro+FPGA)	29/08/14
GSE & OBSW : trajectory solver (CIC)	29/08/14
Sub-systems requirements (optics, telcom, power & s.a.)	29/08/14
Méchanical pre-Design	31/03/14
Mechanical Design	29/08/14
Mgt & Fi. Plan	30/09/14
PDR (Prel.Design Rev.)	01/10/14
Phase C	31/08/15
CDR (Crit.Design Rev.)	01/09/15
Phase D	31/08/16
Delivery for Launch	01/09/16
Phase E : Utilization	01/09/20
End of Mission	02/09/20



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 to Space Weather science.

• Phase 0 : Mission Design Review 10/2013.
• Phase A : 06/2013-... « Feasibility Assessment in 2014 ».
• Phase B : Since 10/2013, new students involved (NCKU, UPMC/Observatoire de Paris, ELISA).

Free-return trajectory opportunity in 2018.

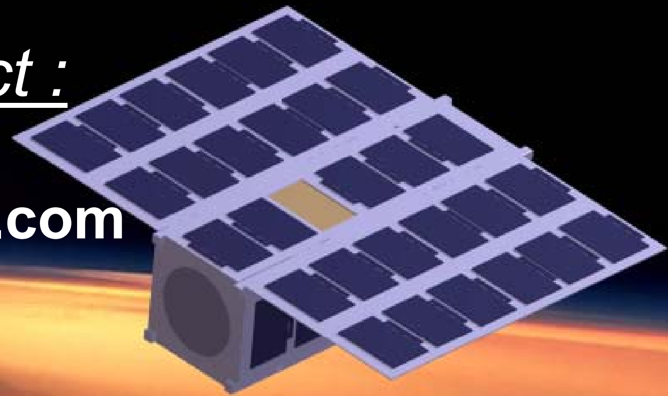
ALL MARS MISSIONS COMPATIBLE!

Dust devil hunters © 2005 - Association Planète Mars / Manchu

Thank You!

Teachers & Sponsors, please contact :

Project Mgr: **boris.segret @ obspm.fr**
System Mgr: **jordan.vannitsen @ gmail.com**



& mailing list
for news to any enthusiasts

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 l'Observatoire de Paris LESIA NCKU Planète Mars