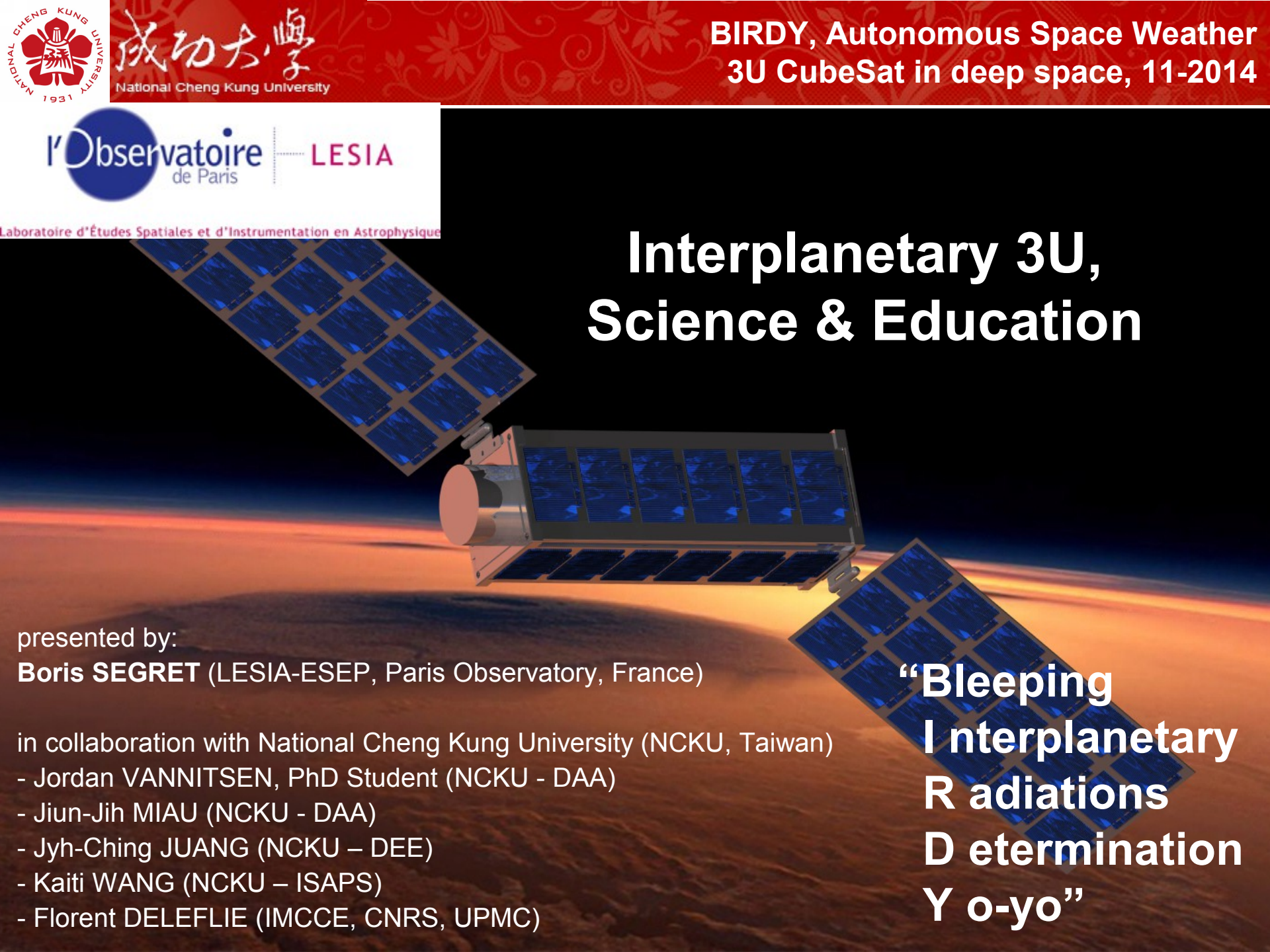
l'Observatoire de Paris — LESIA
Laboratoire d'Études Spatiales et d'Instrumentation en Astrophysique

Interplanetary 3U, Science & Education



presented by:
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in collaboration with National Cheng Kung University (NCKU, Taiwan)
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- Kaiti WANG (NCKU – ISAPS)
- Florent DELEFLIE (IMCCE, CNRS, UPMC)

"Bleeping I nterplanetary R adiations D etermination Y o-yo"

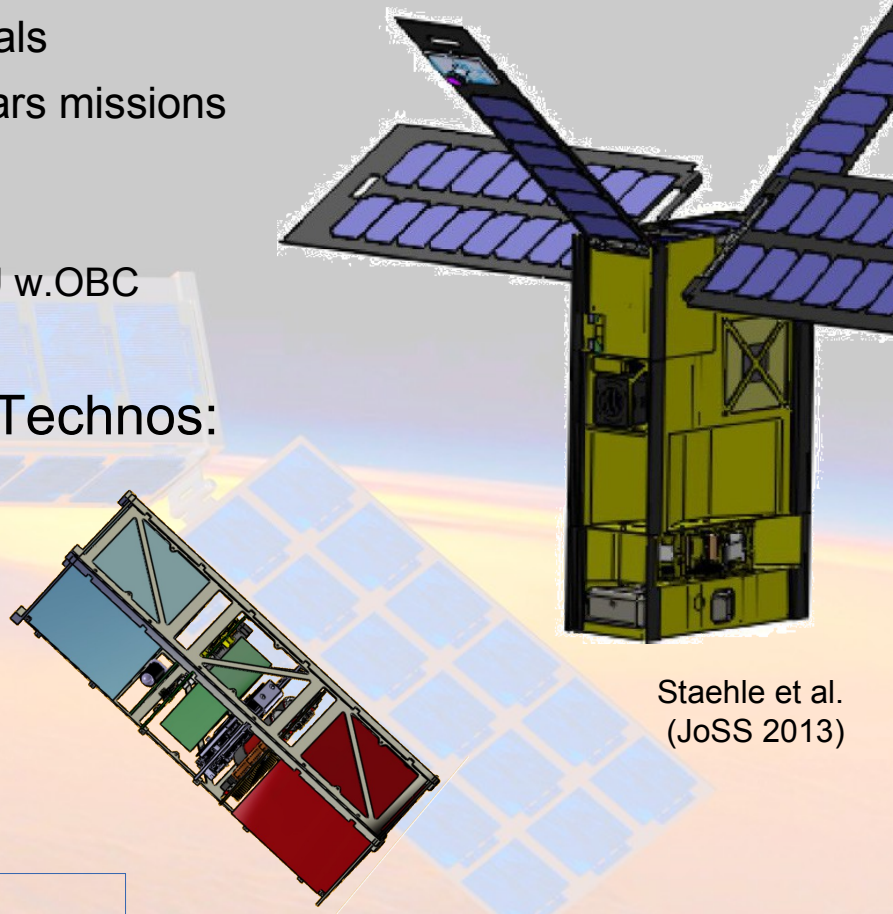
6U vs. 3U for an interplanetary CubeSat ?

Interplanetary & Mars science at 3U scale:

- Space Weather wrt Hohmann-Parker spirals
- Radiation risk assessment for manned Mars missions
  - Small payload : 2U => 1U
  - Main delta-V by host mission : 2U => 0U
  - Comm' Blackout during cruise : 1U => ½U w.OBC
  - AOCS with electric propulsion : 1U => ½U

Educational Engine to Scout Skills & Technos:

- CubeSat Electric Propulsion
- Autonomous Navigation
- Intersat communications



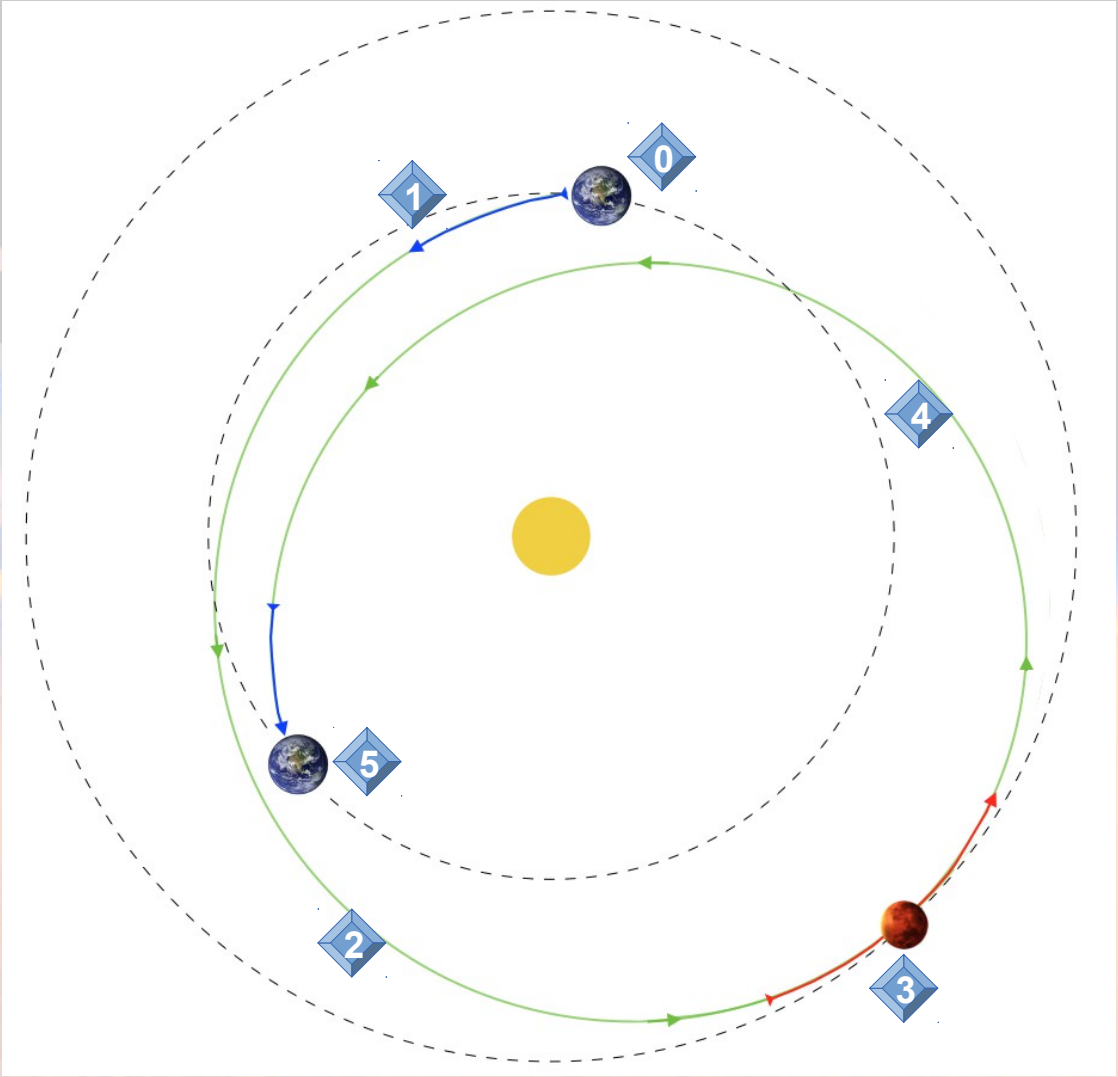
Staehle et al.
(JoSS 2013)

Proto-Flight Model in GTO

review =>  or  ?

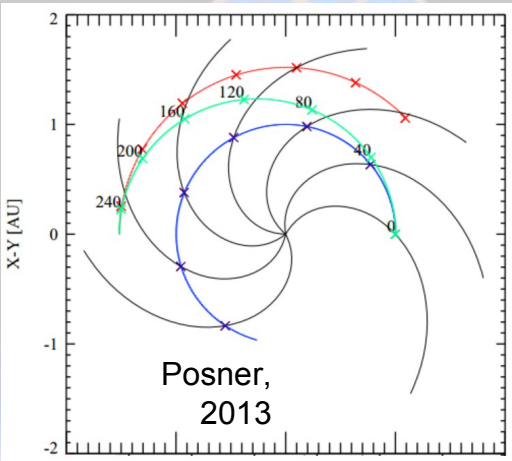
Mission Profile (Concept of Operations)

- 0 Mission Preparation
  - Launch windows
  - Reference Trajectory by GSE
- 1 Deployment after IOI
  - Delta-V by host mission
- 2 Earth-to-Mars
    - No risk on host
    - Free to spin
  - Payload « on »
  - TT&C « black-out »
  - Autonomous Navigation
  - Small Electric Propulsion
- 3 Mars Flyby
  - Tilting of orbital plane
  - Data-relay to the Earth
- 4 Mars-to-Earth = Earth-to-Mars
- 5 End of Mission : Final Datalink



(trajectory inspired by Dennis Tito for 2018)

Science: New sensors available soon



Posner, 2013

Solar Wind + Cosmic Rays

- Spin strategy for arrival direction
- « Manned Mars Mission » driver

Specification of needs to Partnering

After RAD / MSL :

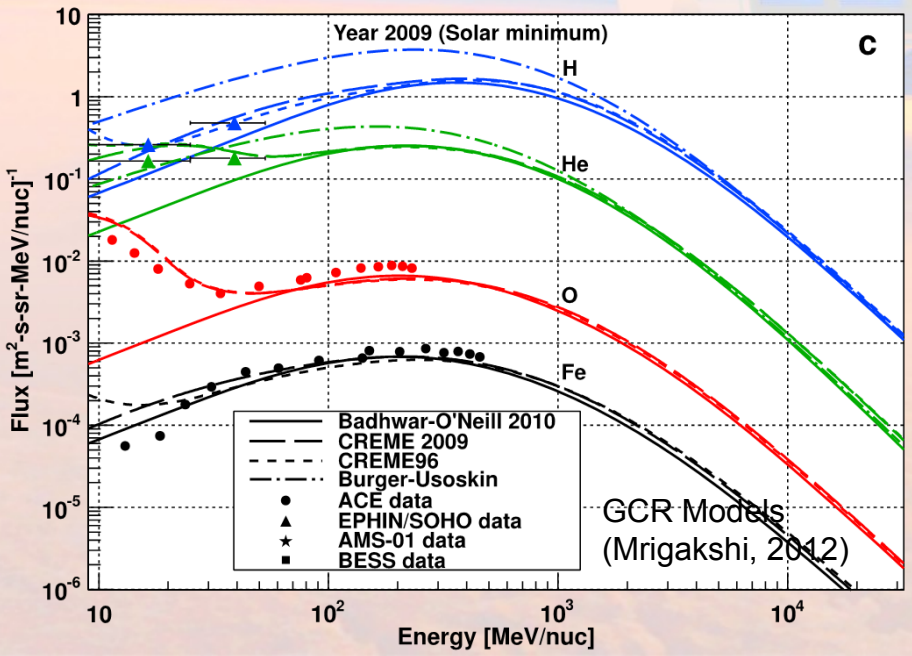
REPTile (US, 1.2kg)

HMRM (UK, 52g)

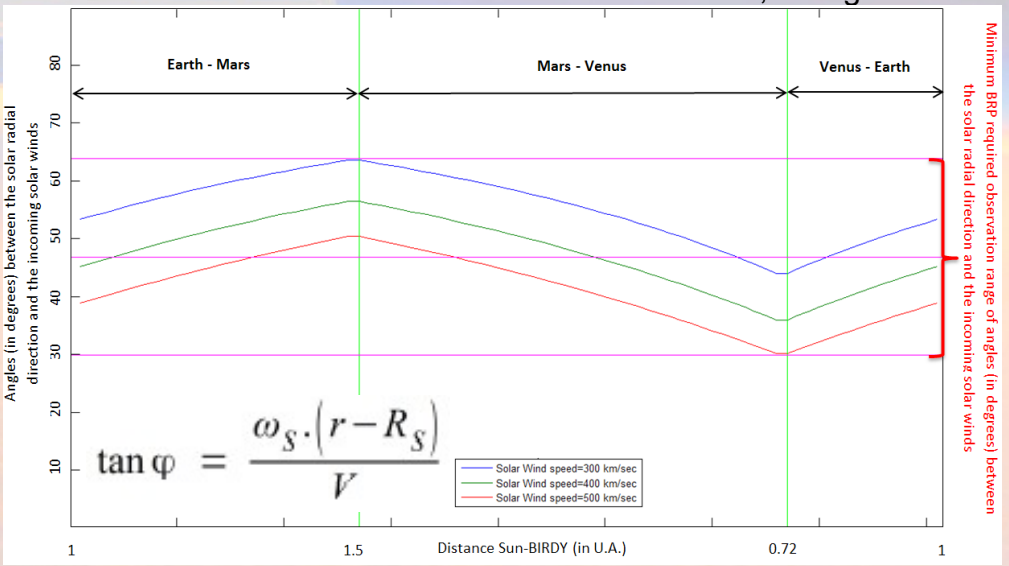
SREM (CH, 2.5kg)

NGRM (CH, 1kg)

RAD "Radiations Assessment Detector", 1.5Kg © NASA

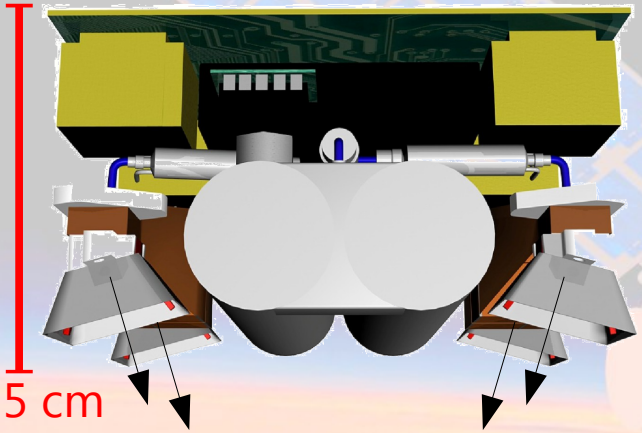


GCR Models (Mrigakshi, 2012)



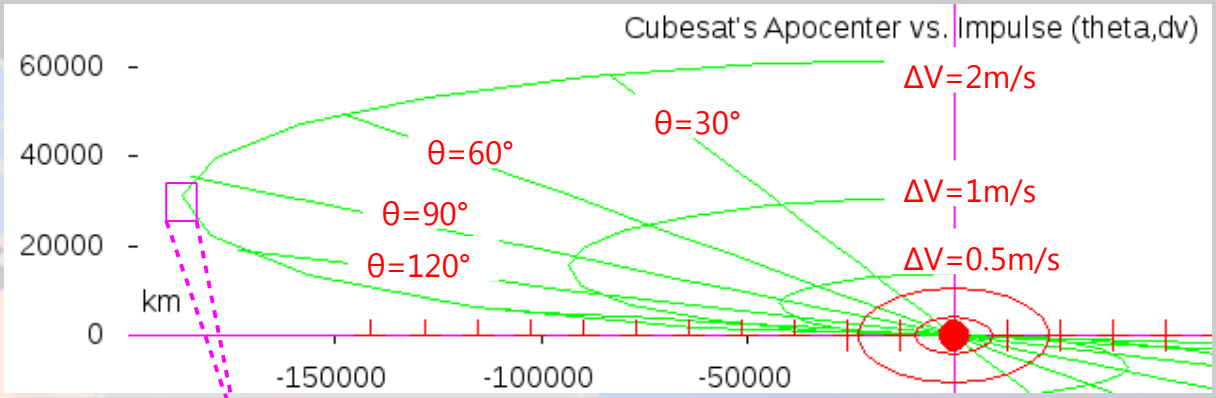
Electric Prop. ΔV-Budget (ACS+OCS)

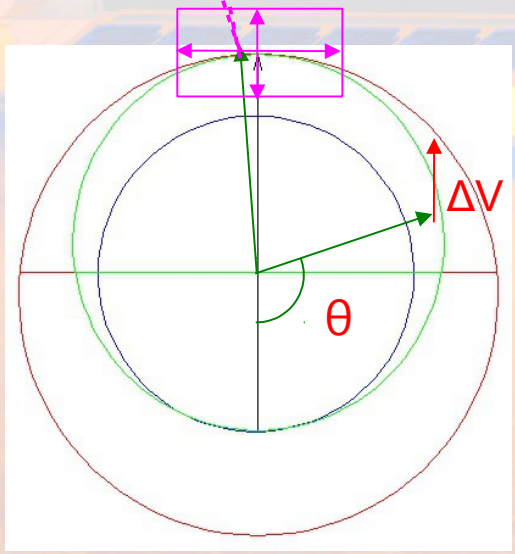
L-µPPT Consortium http://liquidppt.eu
(funded by EC/FP7 until TRL4)



Liquid-µPulsed Plasma Thruster
4-thruster configuration for BIRDY

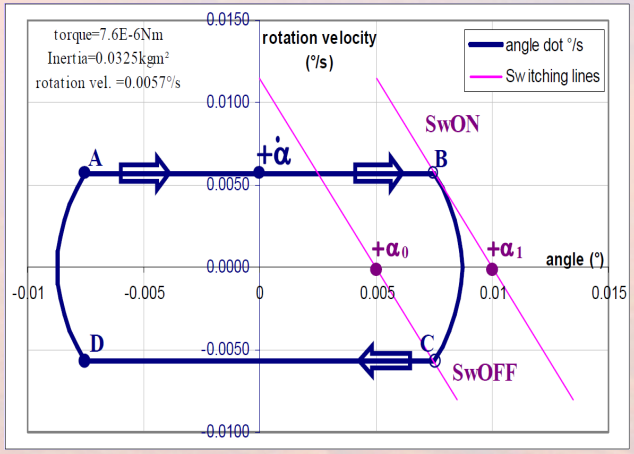
175'000 km / 30'000 km shift after +2m/s at θ~100°





Effect on apocenter of $\vec{v}' = \vec{v} + \Delta\vec{V}$ at true anomaly θ

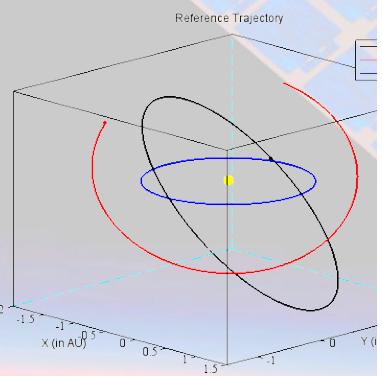
$$\vec{e}' = \frac{\vec{v}' \wedge \vec{L}'}{G.M_{\odot}.m} - \vec{e}'_r = \frac{\vec{v}'_a \wedge \vec{L}'}{G.M_{\odot}.m} - \vec{e}'_a$$

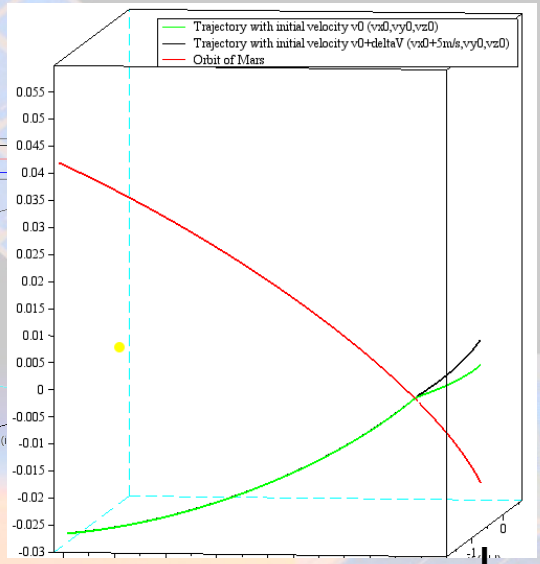


Space qualified liquid-propellant distributed in micro pulses:

- ACS still thrifty at 0.04° (Schmitt triggers) ..down to 0.01° (~30")
- OCS-only potential ΔV≈100m/s
- ΔV 2m/s in ~1 day

Autonomous Navigation: Accuracy ?





Mission Preparation :

- Reference Trajectory stored on-board
- Flyby to tilt the orbital plane and come back to Earth

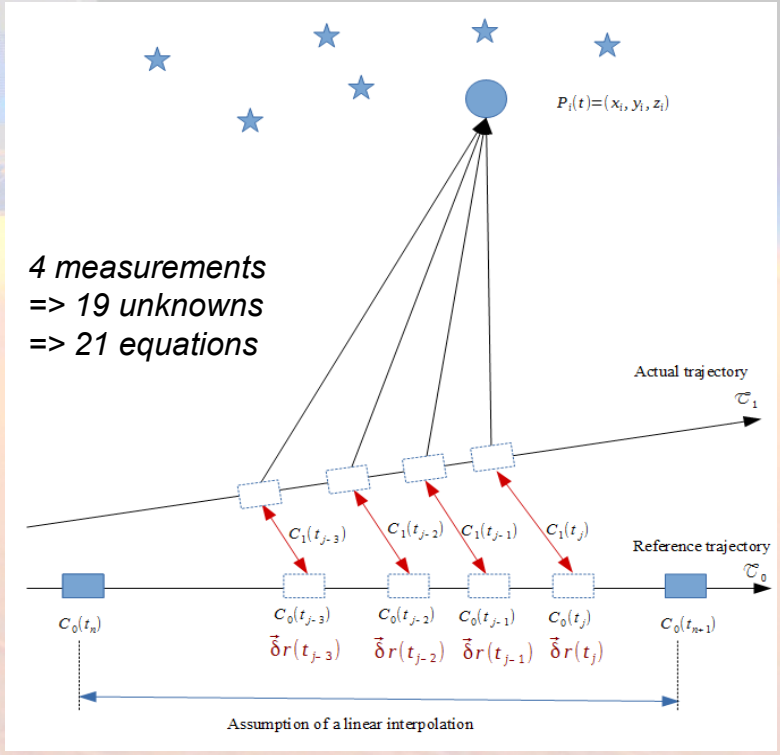
Star Tracker (ADS) + Planet Tracker (ODS)

- LµPPT to get & keep aligned with Reference
- Accuracy needed ? Accuracy reached ?

$$M * \vec{X} - \vec{C} = \vec{0}$$

$$\rightarrow \vec{X} \mid \mathrm{Min}\left(\| M * \vec{X} - \vec{C} \|\right)$$

$$\begin{bmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & CC_{i,1} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & CS_{i,1} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & S_{i,1} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & & & & & & & & & & & & & & 0 \\
0 & 0 & 0 & 0 & 1 & & & & & & & & & & & & & & 0 \\
0 & 0 & 0 & 0 & 0 & & & & & & & & & & & & & & 0 \\
0 & 0 & 0 & 0 & 0 & & & & & & & & & & & & & & 0 \\
0 & 0 & 0 & 0 & 0 & & & & & & & & & & & & & & 0 \\
0 & 0 & 0 & 0 & 0 & & & & & & & & & & & & & & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & CC_{i,4} & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & CS_{i,4} & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & S_{i,4} & 0 & 0 & 0 \\
1 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & dt_2 & 0 & 0 \\
0 & 1 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & dt_2 & 0 \\
0 & 0 & 1 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & dt_2 \\
0 & 0 & 0 & 1 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & dt_3 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & dt_3 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & dt_{j3} \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & dt_4 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & dt_4 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & dt_4
\end{bmatrix}
*
\begin{bmatrix}
\delta x_1 \\ \delta y_1 \\ \delta z_1 \\ \delta x_2 \\ \delta y_2 \\ \delta z_2 \\ \delta x_3 \\ \delta y_3 \\ \delta z_3 \\ \delta x_4 \\ \delta y_4 \\ \delta z_4 \\ dr_{i,1} \\ dr_{i,2} \\ dr_{i,3} \\ dr_{i,4} \\ V_x \\ V_y \\ V_z
\end{bmatrix}
-
\begin{bmatrix}
CSCS_{i,1} \\ CCSS_{i,1} \\ C_{i,1} \\ CSCS_{i,2} \\ CCSS_{i,2} \\ C_{i,2} \\ CSCS_{i,3} \\ CCSS_{i,3} \\ C_{i,3} \\ CSCS_{i,4} \\ CCSS_{i,4} \\ C_{i,4} \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0
\end{bmatrix}
= \vec{0}$$



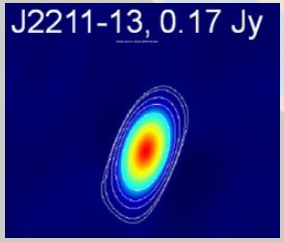
TT&C: communication relay at Mars ?

Beacon signal to VLBI: Continuous Health Status

Datalink: small data but too optimistic or too complex?

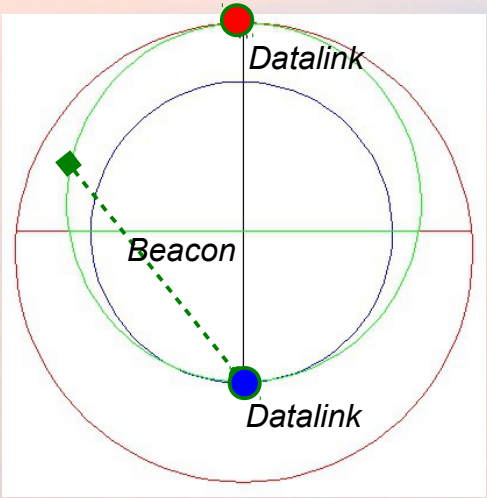
- Mars' vicinity = communication relay to an orbiter
- Back to Earth = direct communication to ground station

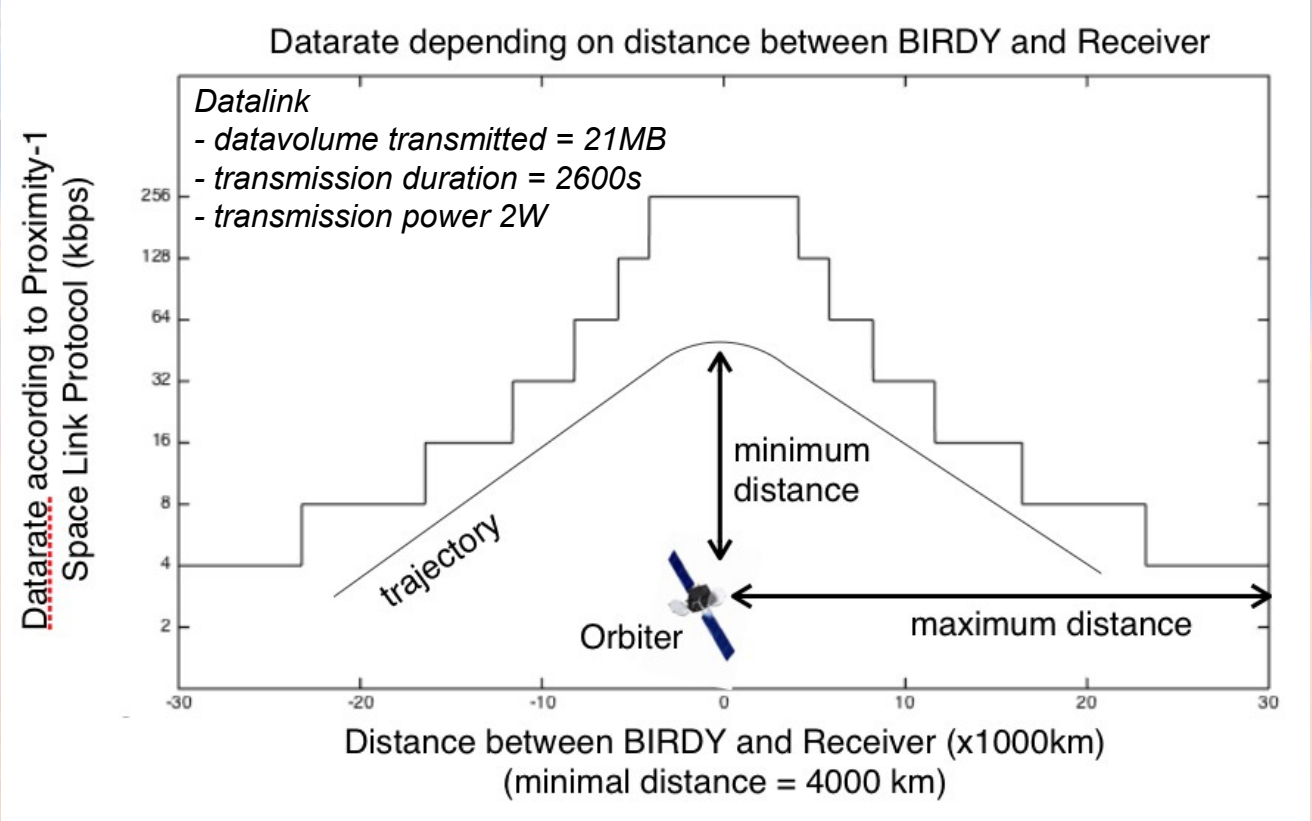
Beacon



VLBI for ESA's VEX (Dueve & al.,2012)

EUROPEAN vlbi NETWORK

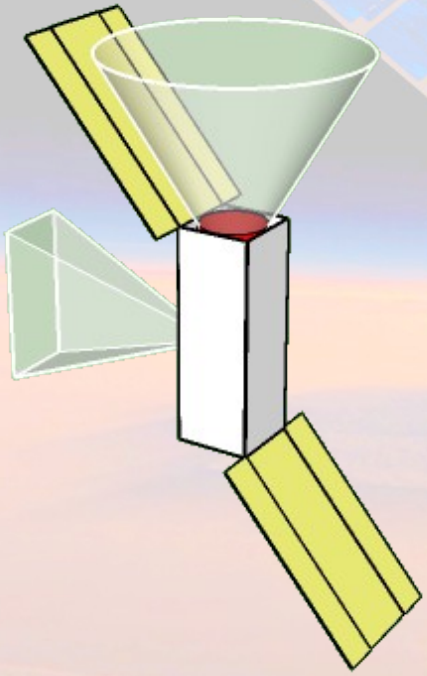




Preliminary Mass & Power budgets do not show feasibility issues

- Preliminary Mass Budget

  Tight but we are confident

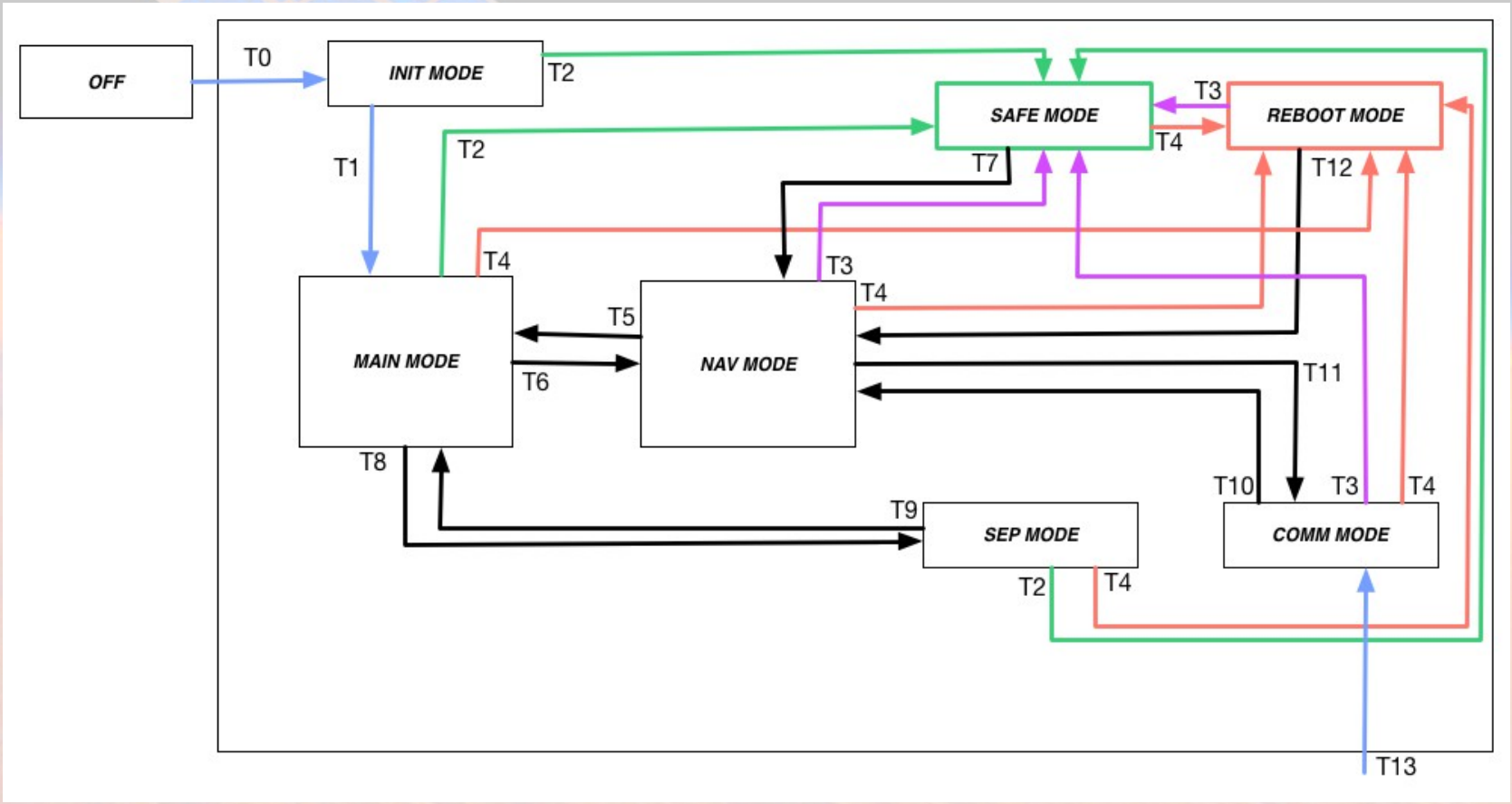


Parameters	Expected Value (kg)	Margin (%)	Marged Value (kg)
Payload:	1.00	25	1.25
AOCS:	0.47	16	0.55
OBDH:	0.15	20	0.18
EPS:	1.09	8	1.18
Communication:	0.18	10	0.20
Structure:	0.30	5	0.32
BIRDY Mass	3.19	15	3.67
Cables, Fasteners, screws…	0.16	10	0.18
Maximum BIRDY Mass	4.00	0	4.00
BIRDY Mass Margin	0.65	/	0.16

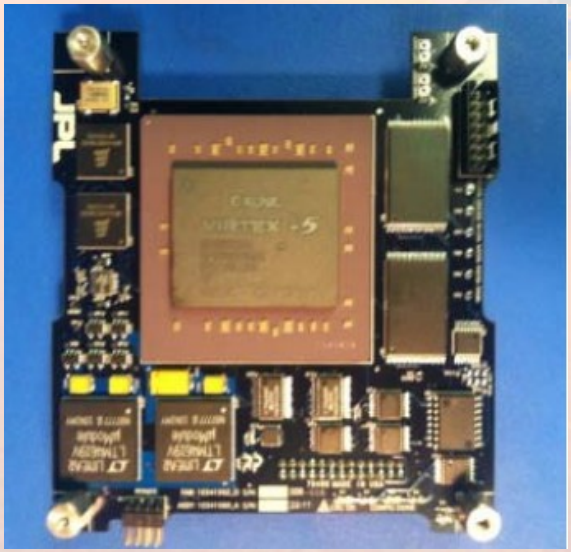
- Preliminary Power Studies :

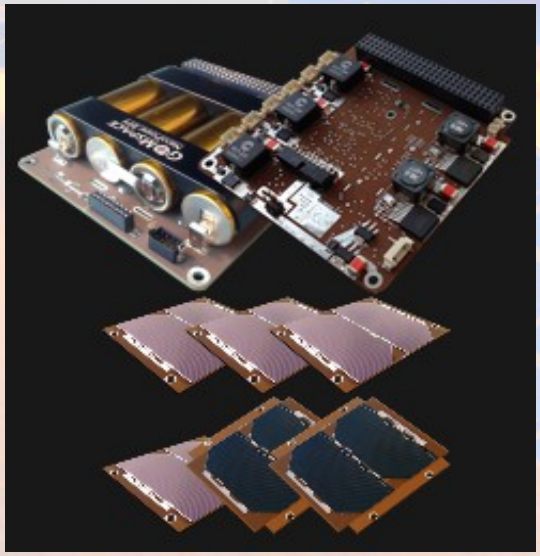
  10W available to the 7 Operation modes with 5x3U Solar Arrays in Mars' vicinity (RAD on MSL : 4.2W only)

- Preliminary Mass & Power budgets do not show feasibility issues
- **System Architecture for autonomous operations**
  - 7 operation modes
  - 13 triggers



- Preliminary Mass & Power budgets do not show feasibility issues
- System Architecture for autonomous operations
- **Hardware & System adapted to long-exposure in deep space**
  - Interplanetary less harsh than MEO/GTO
  - LEON architecture into FPGA (requires ITAR-clearance)
  - Memories (RAID?), Clock & Reboot strategy





PFM in GTO => FM1 to Mars

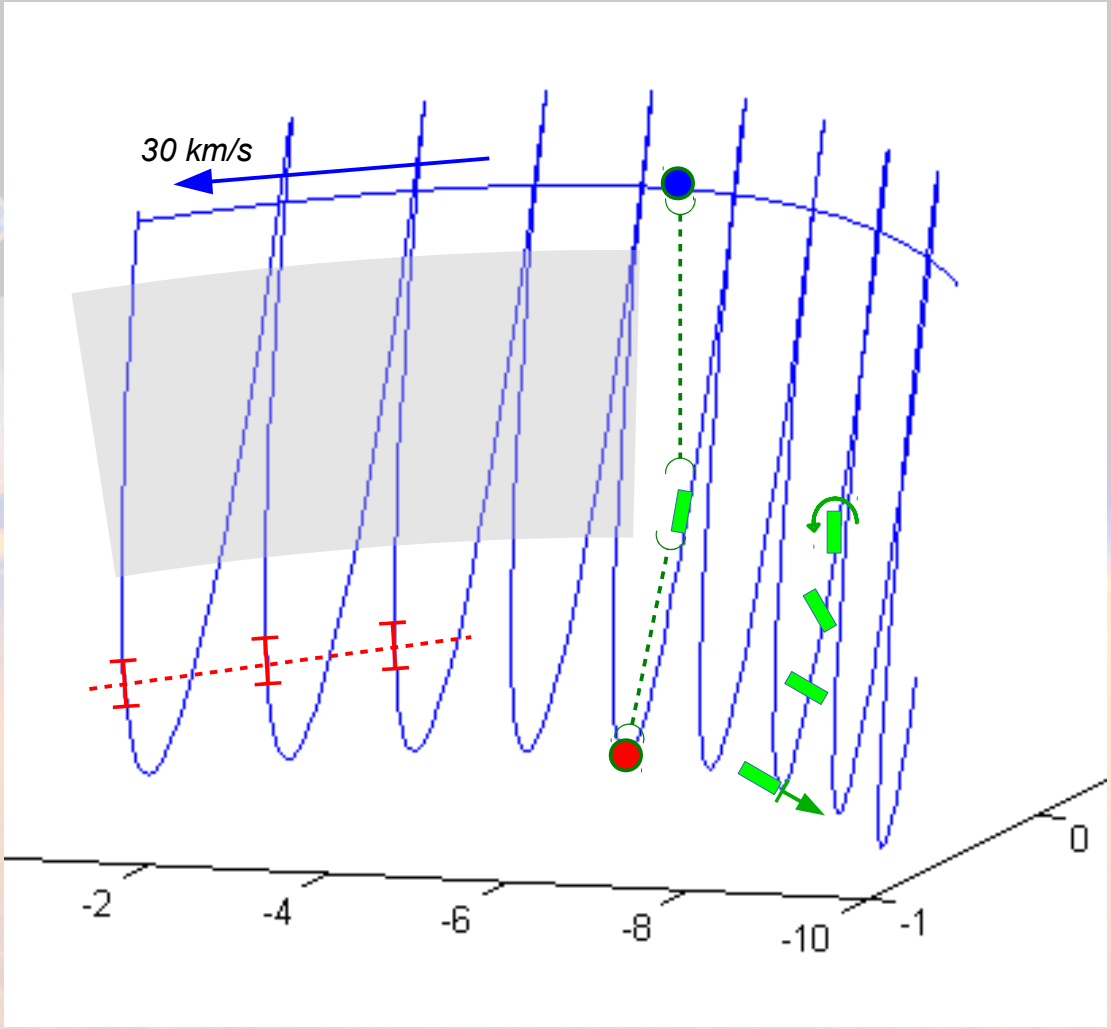
Proto-Flight Model (PFM) in Geo.Transfer Orbit

- ACS + OCS with L-µPPT
- Datalink to Ground & GEO
- Van Allen belt in MEO
- Navigation with pseudo-ref

Study Case:

=> PFM ready for flight 2018

=> FM1 in 2020



BIRDY, Autonomous Space Weather 3U CubeSat in deep space, 11-2014

Summary

Get in touch with Project Mgr: boris.segret @ obspm.fr

Interplanetary & Mars Science at 3U Scale:

- ✅ Mission profile Earth-Mars-Earth in free return
- ✅ Science: new sensors available soon
- ✅ ΔV-Budget for (ACS+OCS) with Electric Propulsion
- ⚠ Autonomous Navigation: What accuracy ?
- ⚠ TT&C: communication relay at Mars ?
- ✅ Engineering of the deep space platform
- ✅ Proto-Flight Model in GTO to test the engineering challenges

(Involved Institutions)

1.Association Planète Mars, 2.Mars Society Switzerland, 3.Observatoire de Paris, 4.Laboratoire d'Etudes Spatiales et d'Instrumentation en Astrophysique, 5.Laboratoire Atmosphères, Milieux, Observations Spatiales, 6.Centre National de la Recherche Scientifique, 7.Institut de Mécanique Céleste et de Calcul des Ephémérides, 8.National Cheng Kung University, 9.LabEx Exploration Spatiale des Environnements Planétaires, 10.Centre Etudiant pour la Recherche et l'Exploration Spatiale, 11.Research University Paris Sciences Lettres, 12.Pierre and Marie Curie University, 13.Université Lille 1 Sciences et Technologies, 14.Institut Polytechnique des Sciences Avancées, 15.École d'Ingénierie des Sciences Aérospatiales, 16.Consortium Liquid Micro Pulsed Plasma Thruster, 17.KopooS Consulting Ind., 18.Ecole Centrale Lille, 19.Joint Institute for VLBI in Europe

(Involved actors)

Students: J.Vannitsen(8), A.Ansart(15,8), Q.Tahan(15,8), M.Agnan(10,3,8), J.Velardo(10,3), A.Deligny(10,3), G.Quinsac(10,3,11), A.Porquet(10,3,7), A.Lassissi(10,3), N.Gerbal(15), O.Sleimi(14,8), S.Durand(10,3,4), R.Klajzyngier(18), J.Diby(18), T.Mallet(18), J.Foissaud(18), L.Orsatto(18), E.Colin(18), N.Heim(18), J.Lin(8), A.Tsai(8), A.Chen(8), J.Tsai(8), T.Chang(8), D.Boisseau(15,8), A.Sibue(10,11), J.Evens(10,11), H.Poincelin(10,3), A.Schnitzer(10,3), S.Thibaut(10,3). **Supervisors**: B.Segret(4,9,3,10,1), J.Vannitsen(8), B.Mosser(4,10,11), K.Wang(8), J.C.Juang(8), J.J.Miau(8), J.Daniel(1), Y.Desplanques(18), D.LePicart(18), F.Deleflie(7,3,6,12,13)