Two Deep-space CubeSats @ CERES, PSL Space Campus

Boris Segret[1], J. Vannitsen[2], D. Hestroffer[3], and 48+ students and supervisors

[1] *LESIA-ESEP, PSL / Paris Observatory, France*
[2] *D.A.A, N.C.K.U., Taiwan*
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BIRDY **QBDIM**

6U vs. 3U for Deep-space CubeSats ?

Interplanetary science at 3U:

BIRDY: space weather wrt Hohmann-Parker spirals

QBDIM: In Situ Geodesy of Asteroids

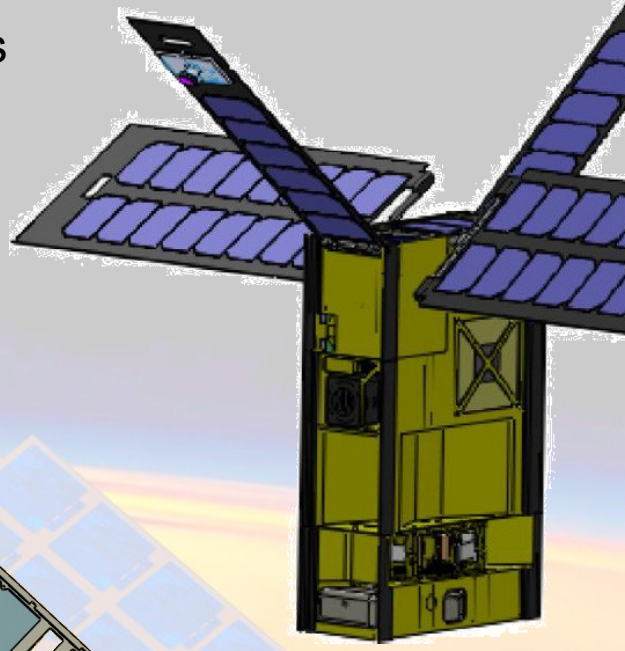
3U Form Factor:

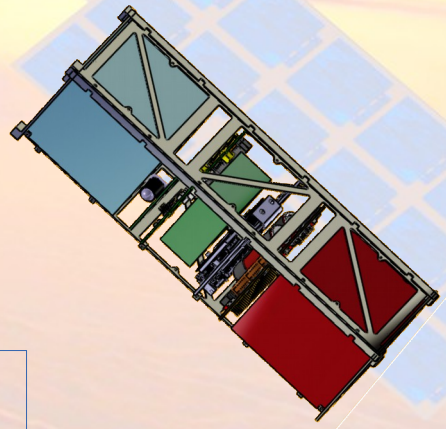
- Small payload : 2U => 1U
- Main delta-V by host mission : 2U => 0U
- Comm' Blackout or Data relay : 1U => ½U w.OBC
- AOCS with electric propulsion : 1U => ½U

Educational Engine to Scout Skills & Technos:

- CubeSat Electric Propulsion
- Autonomous Navigation
- Intersat communications

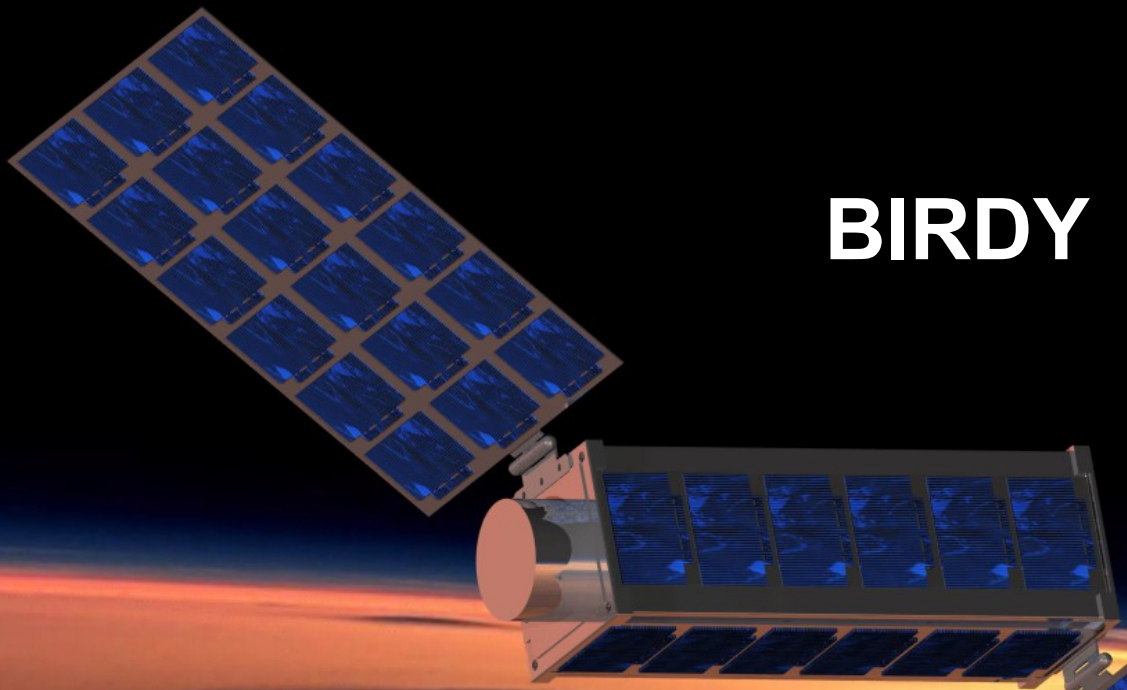
review =>  or  ?





Staehle et al. (JoSS 2013)

BIRDY



presented by:
Boris SEGRET (LESIA-ESEP, PSL / Paris Observatory, France)

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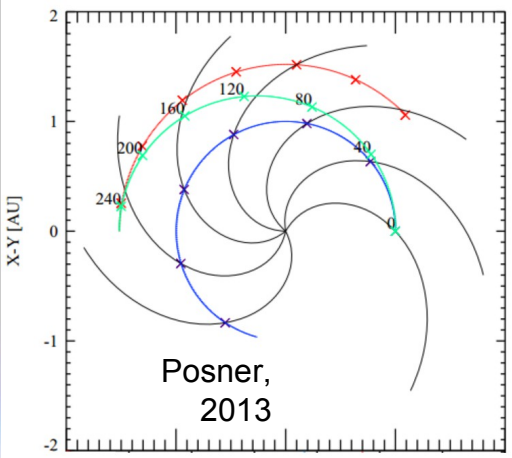
- Jordan VANNITSEN, PhD Student (NCKU - DAA)
- Jiun-Jih MIAU (NCKU - DAA)
- Jyh-Ching JUANG (NCKU – DEE)
- Kaiti WANG (NCKU – ISAPS)
- Florent DELEFLIE (IMCCE, CNRS, UPMC)

“Bleeping
I nterplanetary
R adiations
D etermination
Y o-yo”

BIRDY Science: New sensors soon



Posner, 2013

Solar Wind + Cosmic Rays

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

Specification of needs to Partnering

After RAD / MSL :

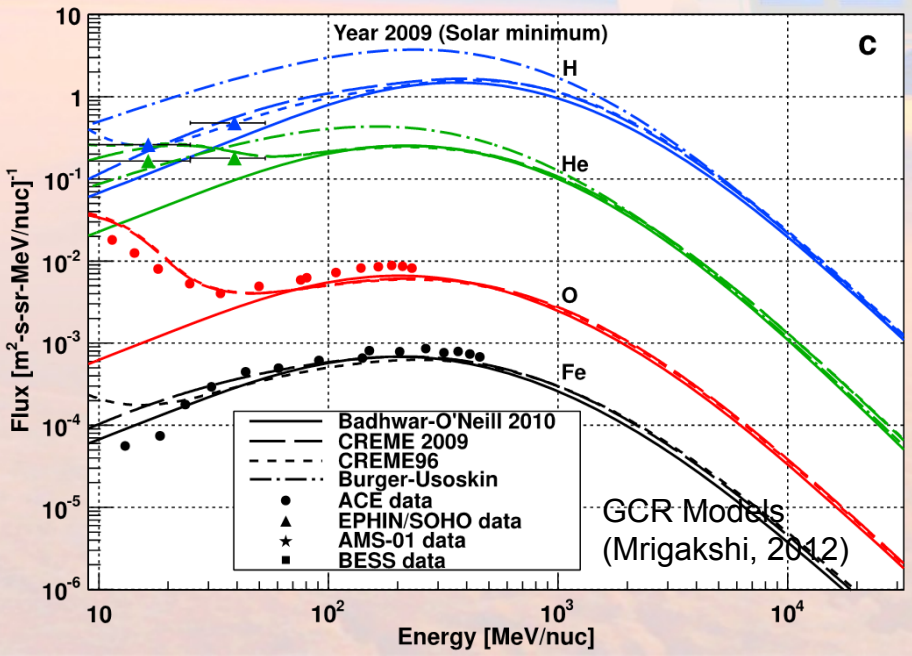
REPTile (US, 1.2kg)

HMRM (UK, 52g)

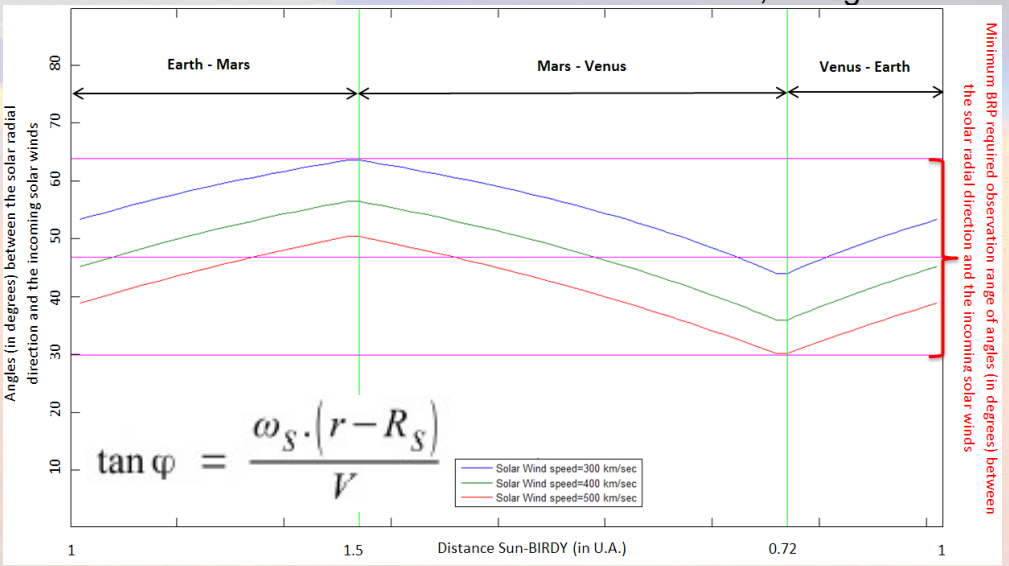
SREM (CH, 2.5kg)

NGRM (CH, 1kg)


RAD "Radiations Assessment Detector", 1.5Kg © NASA

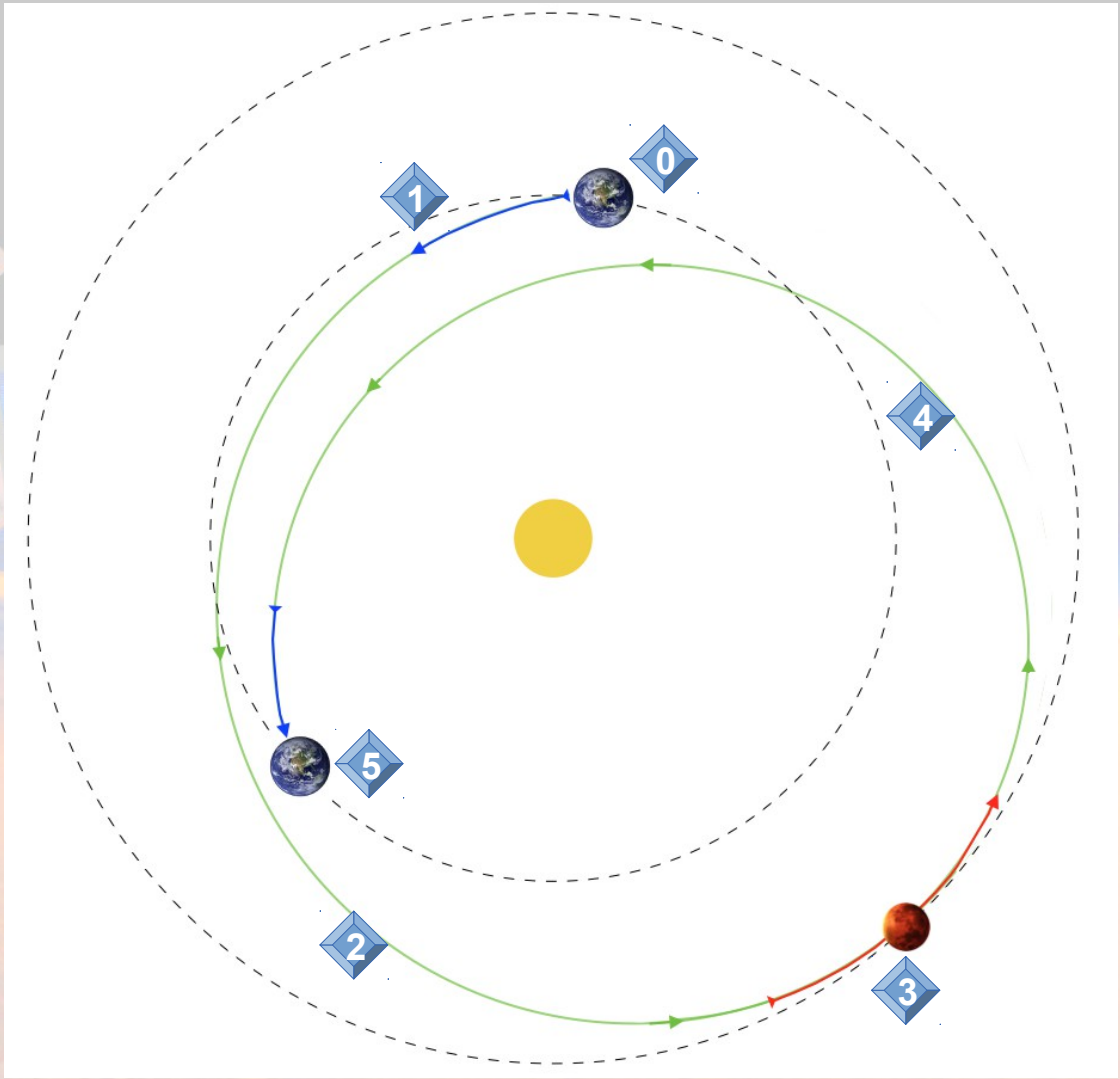


GCR Models (Mrigakshi, 2012)



Mission Profile for BIRDY: Mars Fly-by

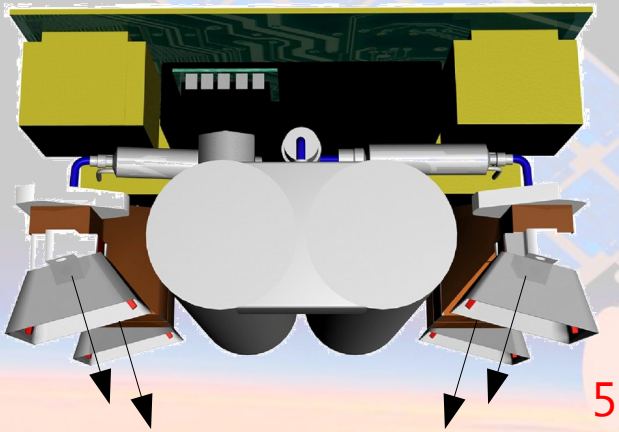
- 0 Mission Preparation
  - Launch windows
  - Reference Trajectory by GSE
- 1 Deployment after IOI
  - Delta-V by host mission
- 2 Earth-to-Mars
    - No risk on host
    - Free to spin
  - Payload « on »
  - TT&C « black-out »
  - Autonomous Navigation
  - Small Electric Propulsion
- 3 Mars Flyby
  - 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)

Electric prop. ΔV-budget (ACS+OCS)

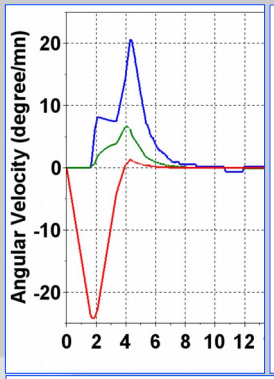
L-µPPT Consortium http://liquidppt.eu
(funded by EC/FP7 until TRL4)

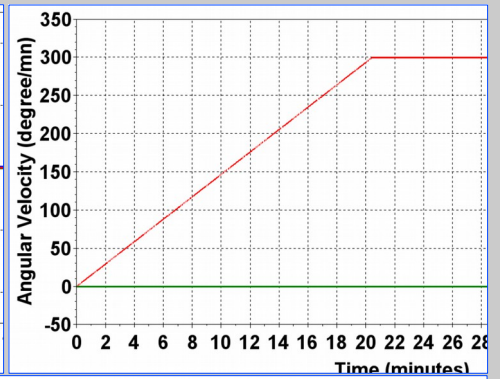


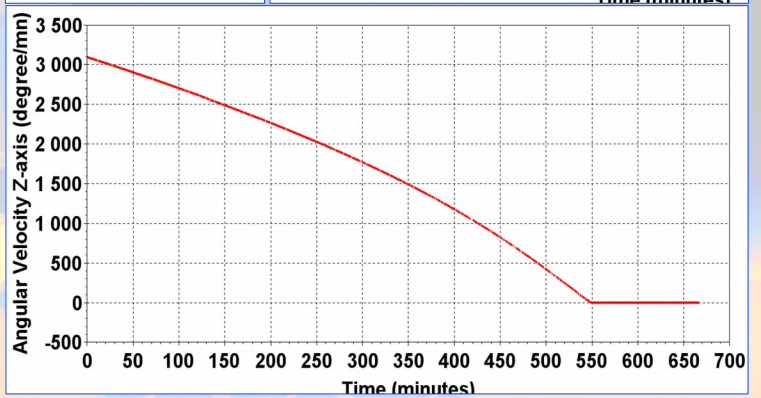
Liquid-µPulsed Plasma Thruster
4-thruster configuration for BIRDY

AOCS =

ADS: attitude sensors
+ACS: attitude actuators
+ODS: location sensors
+OCS: delta-V actuators

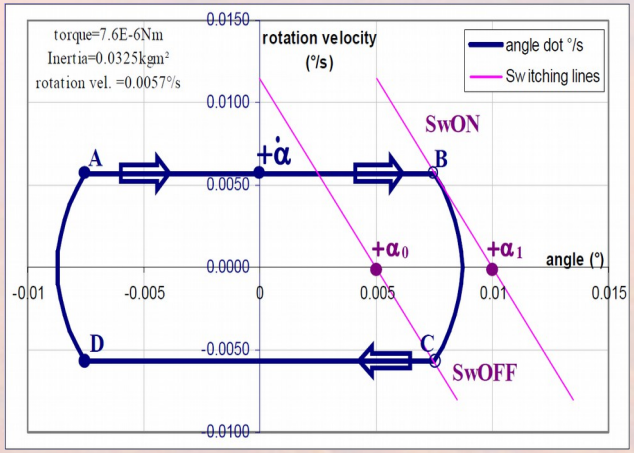




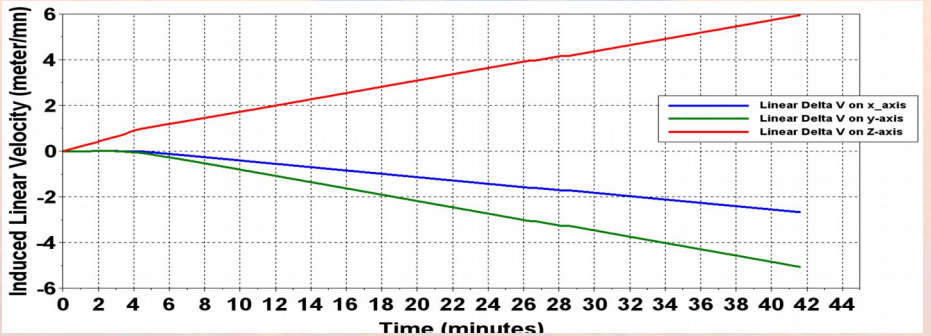


Space qualified liquid-propellant

- 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

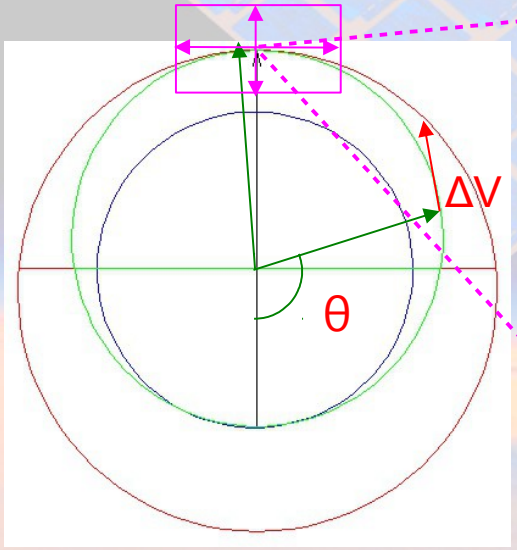


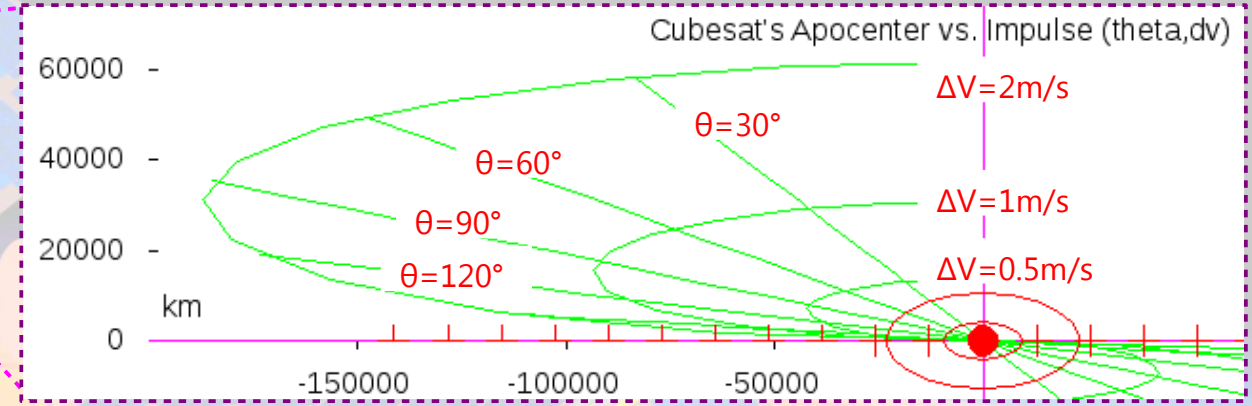
Induced Delta-V



ΔV-budget > 80m/s

175'000 x 30'000 km shift @ Mars with +2m/s, θ=100°





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

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

Flyby @ Mars:

- to transfer data to local orbiter
- to tilt the orbital plane

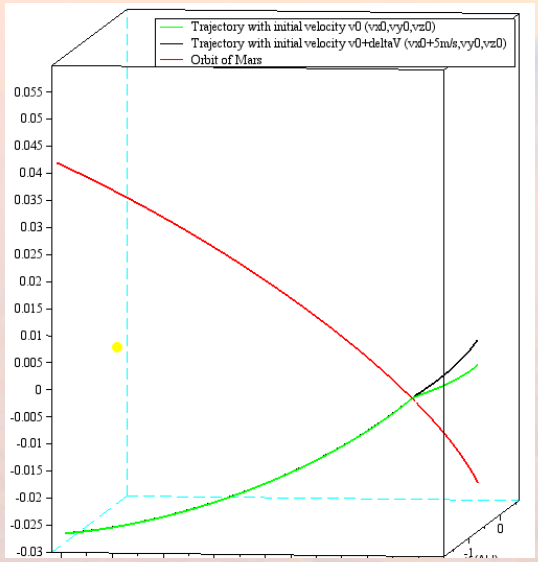
Autonomous Navigation: Accuracy ?

Trajectory Solver / Ground Segment :

- Reference Trajectory stored on-board
- Expected directions of “foreground objects”

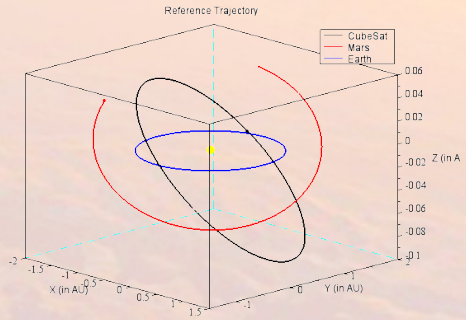
Location determination / Flight Segment

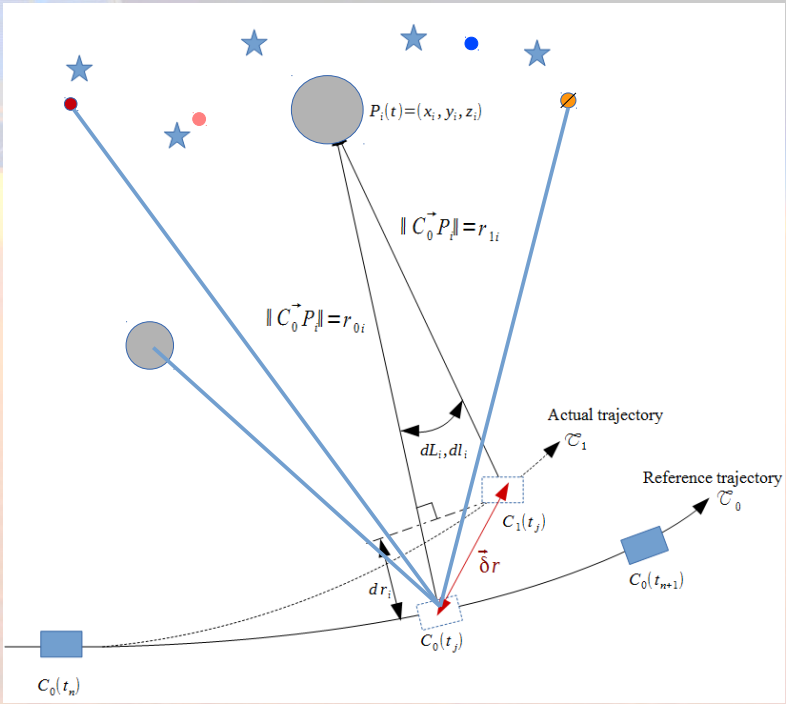
- Star Tracker (ADS) + Object Tracker (ODS)
- Accuracy needed ? Accuracy reached ?



Models-in-the-loop

- gravitational
- non-gravitational
- expected





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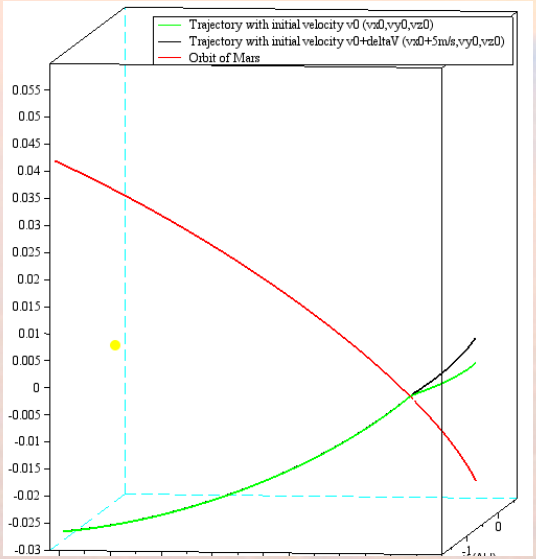

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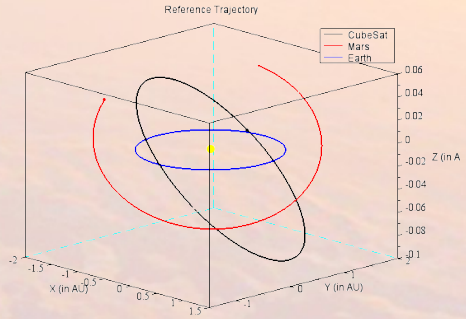
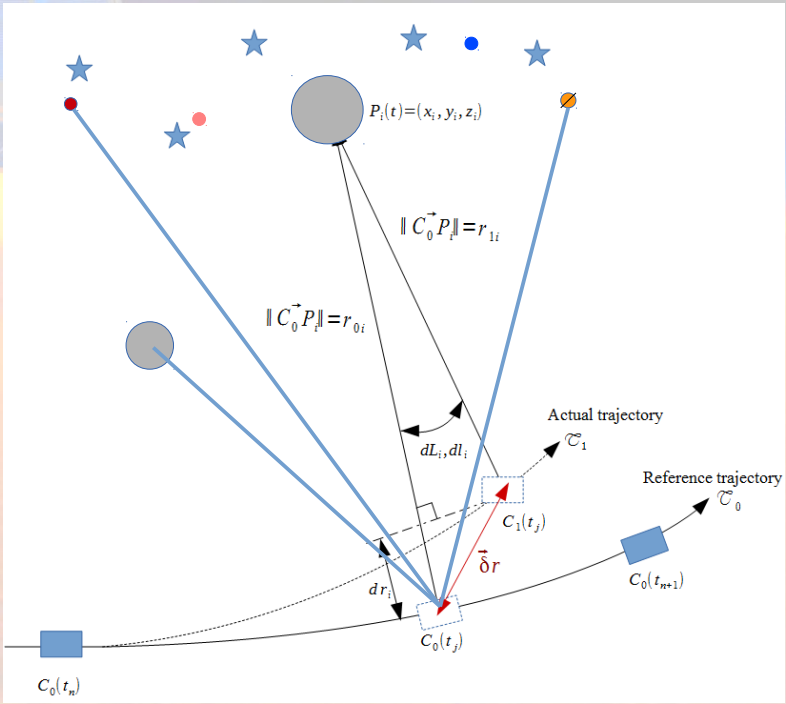
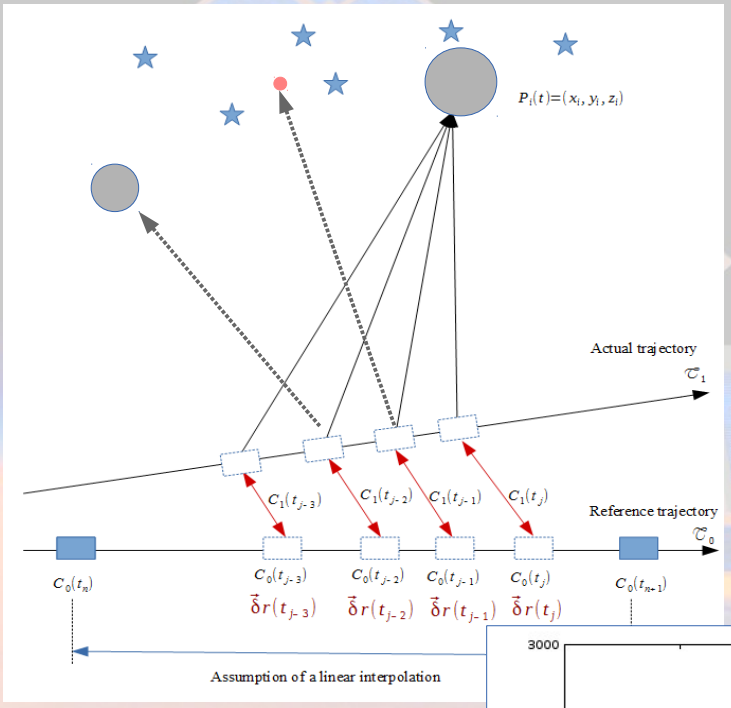




Autonomous Navigation: Accuracy ?



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

$$\chi^2(\vec{X}) = \| M * \vec{X} - \vec{C} \|^2$$

$$\min(\chi^2(\vec{X}))\ ? \Rightarrow \vec{X}\ ? \mid \vec{\nabla}\chi^2(\vec{X}) = 0$$

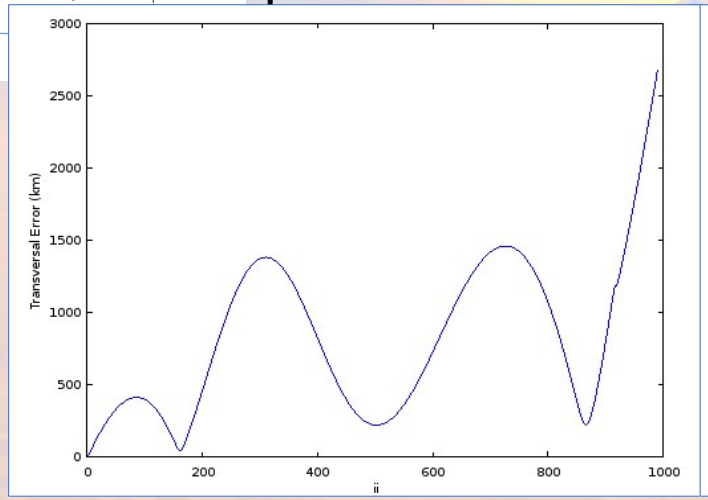
$$\begin{bmatrix}
1 & 0 & 0 & 0 & 0 & & & & & & & & & & & & & & 0 \\
0 & 1 & 0 & 0 & 0 & & & & & & & & & & & & & & 0 \\
0 & 0 & 1 & 0 & 0 & & & & & & & & & & & & & & 0 \\
0 & 0 & 0 & 1 & 0 & & & & & & & & & & & & & & 0 \\
0 & 0 & 0 & 0 & 1 & & & & & & & & & & & & & & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & S_{i,2} & 0 & 0 & 0 & & & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & CC_{i,3} & 0 & 0 & 0 & & & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & CS_{i,3} & 0 & 0 & 0 & & & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & S_{i,3} & 0 & 0 & 0 & & & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & CC_{i,4} & 0 & 0 & & & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & CS_{i,4} & 0 & 0 & & & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & S_{i,4} & 0 & 0 & & & 0 \\
1 & 0 & 0 & -1 & 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 & dt_2 & & & 0 \\
0 & 0 & 1 & 0 & 0 & -1 & 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 & dt_3 & 0 & & & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & -1 & 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 & & & dt_{j3} \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & dt_4 & 0 & & & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & dt_4 & & & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & -1 & 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
\end{bmatrix}
= \vec{0}$$

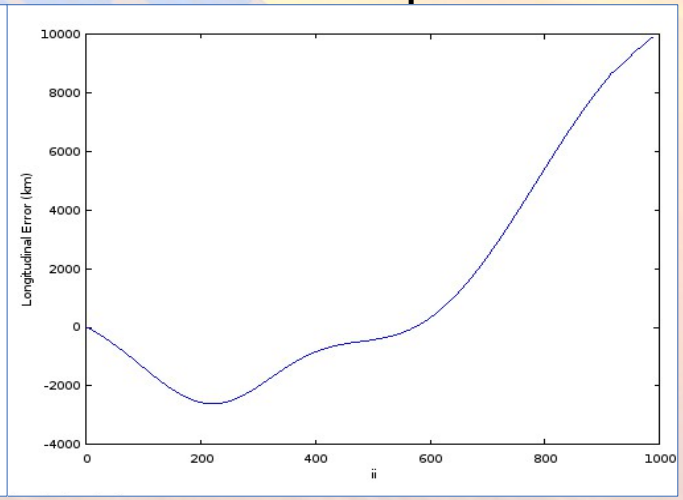
Assumption:

Constant Velocity during 4 measurements

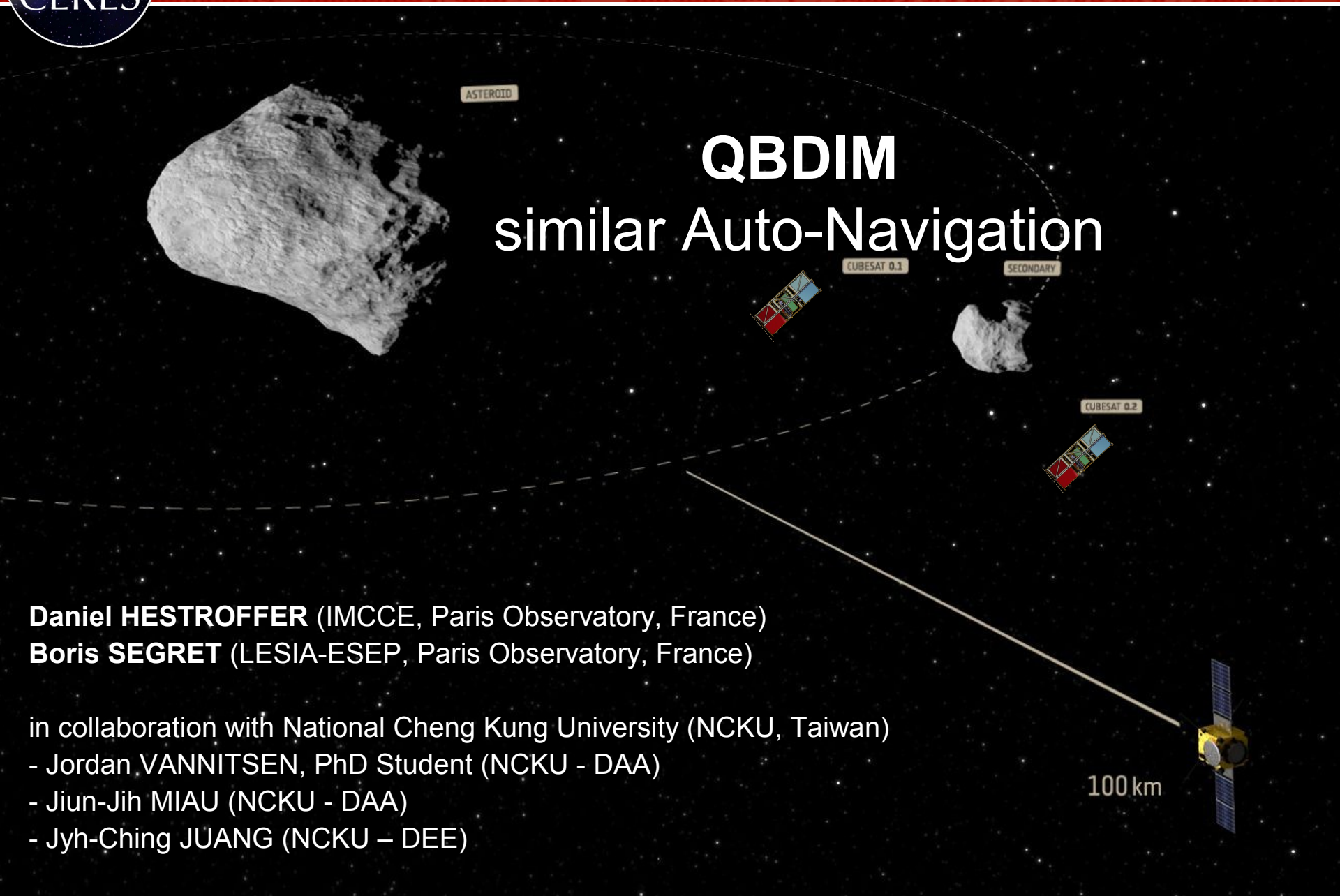
=> 19 unknowns
=> 21 equations

1st simulation on Earth-Mars:
VERY PROMISING !





QBDIM
similar Auto-Navigation



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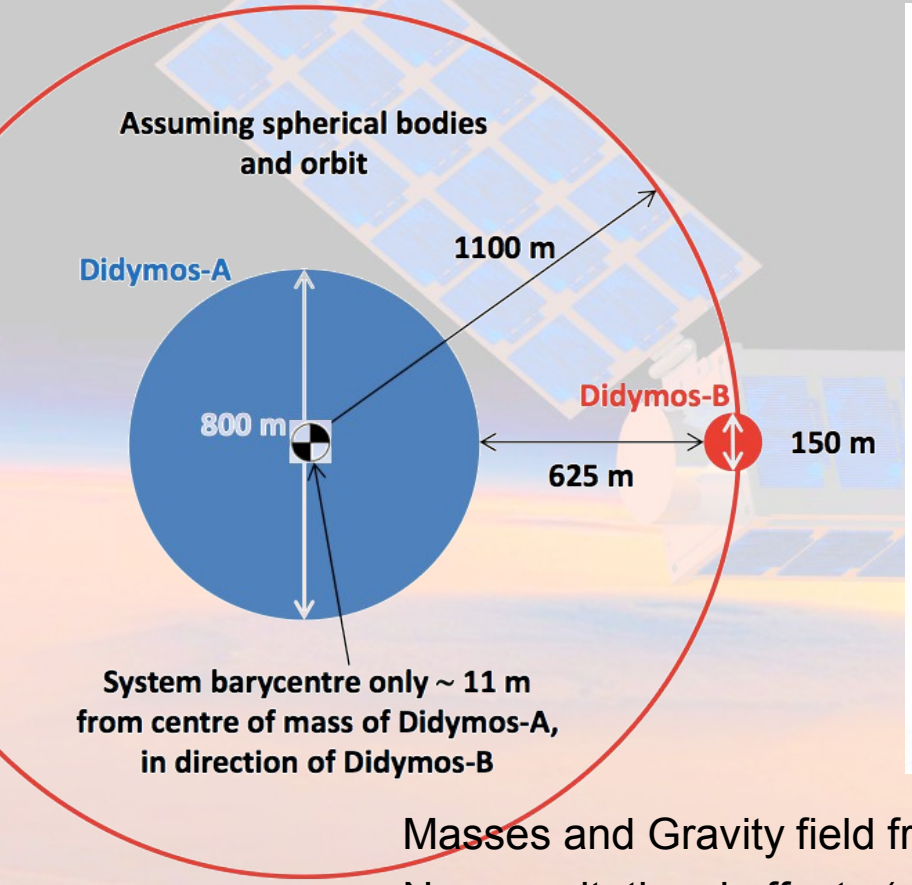
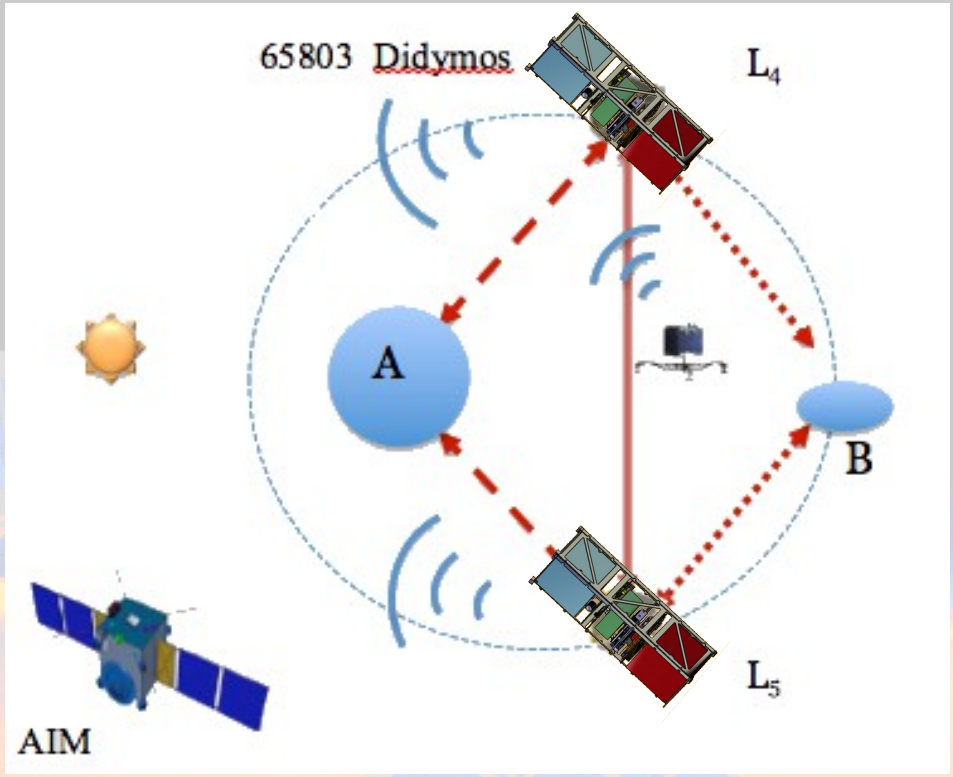
QBDIM Science: In Situ Geodesy





Caroll et al. 2015

Masses and Gravity field from radio (1D) or optical (3D) measures

Non-gravitational effects (radiation pressure, dust)

Impact effects w. DART to “B” (β-factor, orbit, proper motion)

2D-imaging (proper rotations, A-B matter transfer)

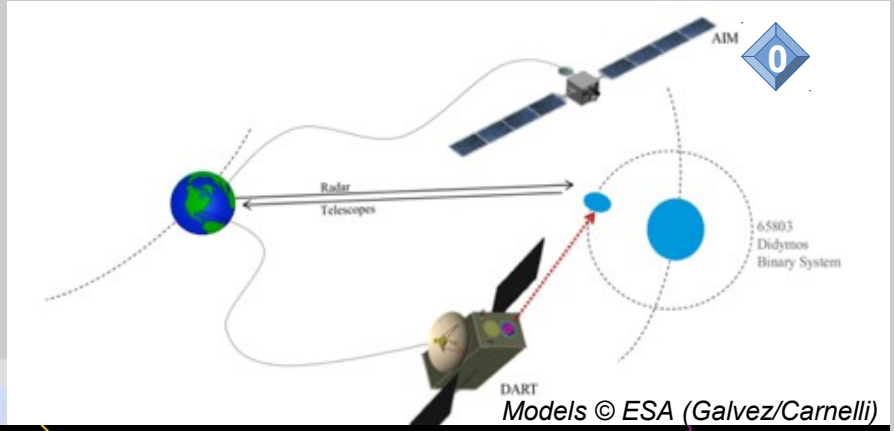
Auxiliary measures for AIM (risky areas, triangulations, lander / hovering)

Mission Profile for QBDIM: Flying-legs

0 Released in situ by Mothercraft

Ground Segment: Trajectory Solver
- Models-in-the-loop
- 2D, 1D, 3D measures

1 – Next Flying-legs to Mothercraft



Models © ESA (Galvez/Carnelli)

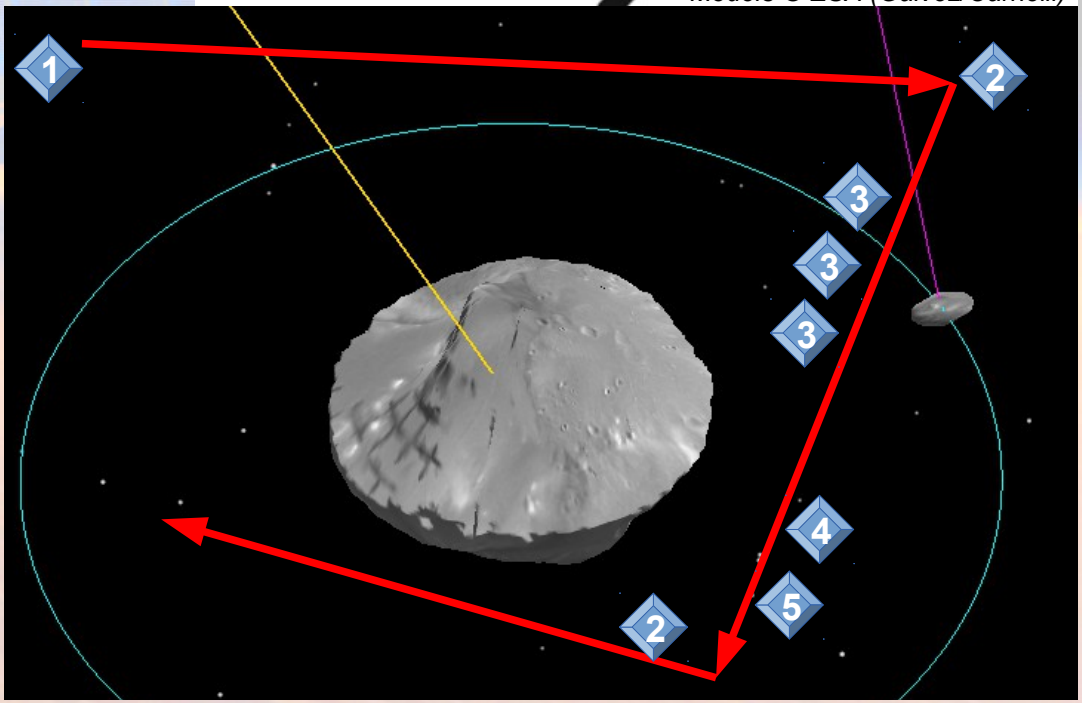
Flight Segment
- Risky approaches
- Multiple probing

2 – Establish new V~1m/s (1 day)

3 – Science Spin (1 day ~80km)
- Echo/Doppler (multiple S/C)
- Imaging surface features
- Optical astrometry

4 – Navigation Spin (ODS)

5 – S-band TT&C to Mothercraft



ΔV-budget > 80m/s

30-50 Flying-legs @ Asteroid

Flying-leg @ Asteroid:

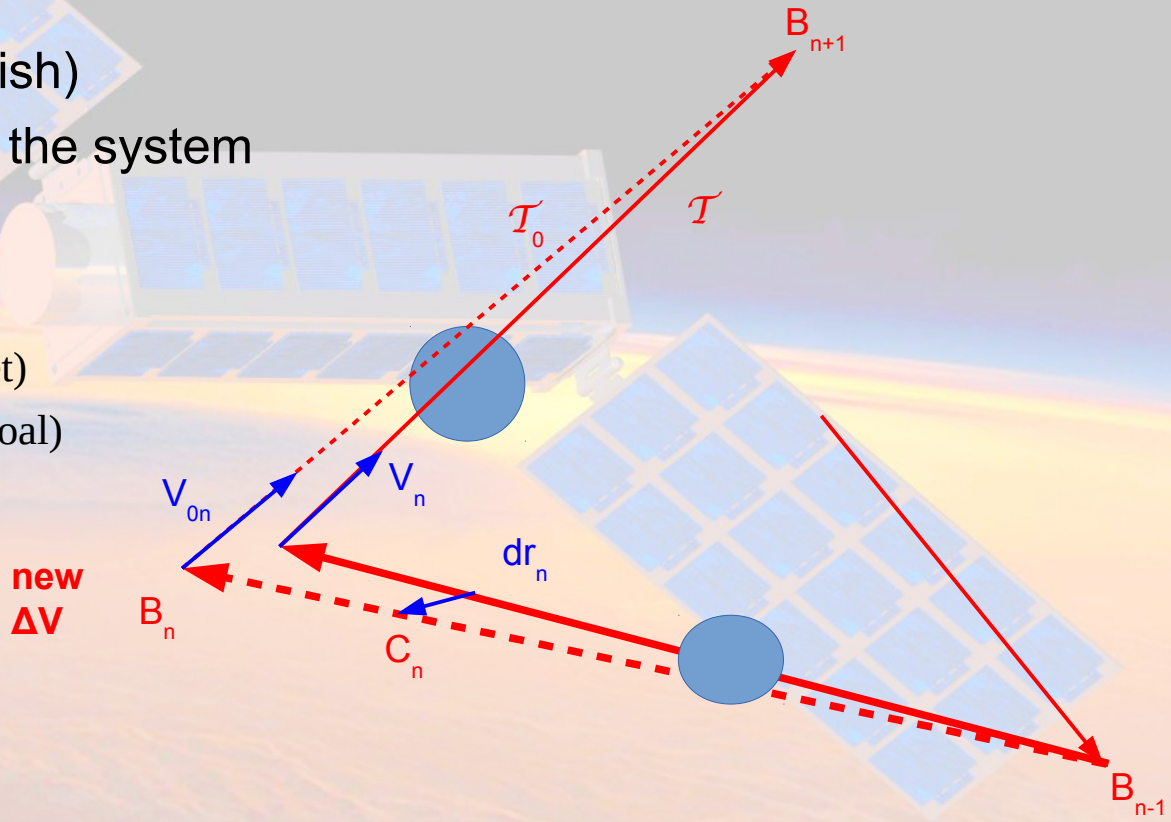
V ≈ 1m/s (1 day to establish)

1-day fly, ≈ 150km within the system

$$\vec{V}_n = \vec{V}_{0n} + \delta\vec{v}_n$$

$\vec{dr}_n$ on-board computed (target)

$\delta\vec{v}_n$ autonomously computed (goal)



PFM in HEO for both BIRDY & QBDIM

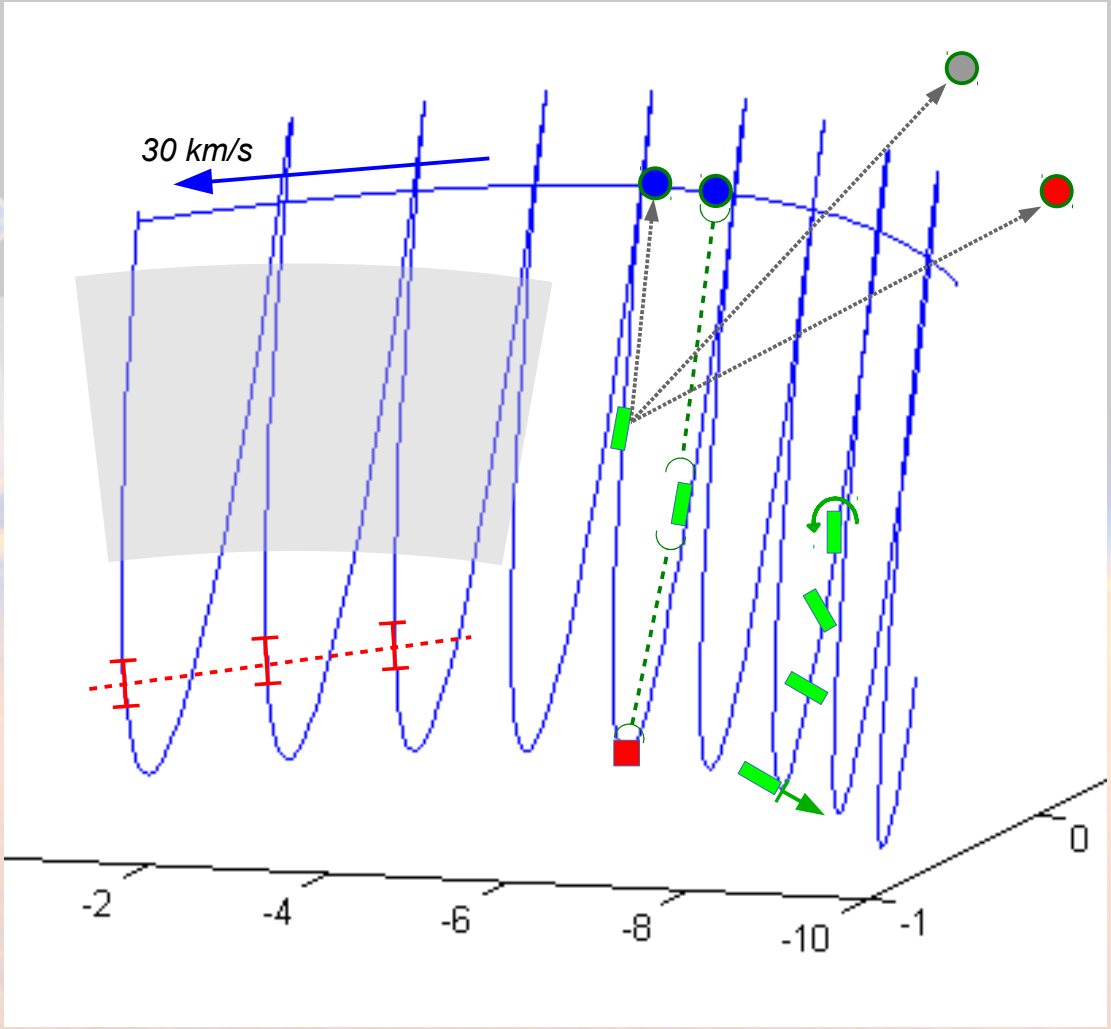
Proto-Flight Model (PFM) in Geo.Transfer Orbit or HEO

- ACS + OCS with L-µPPT
- TT& C:
  - Intersat comm to GEO/HEO
  - Long range comm to Ground
- Navigation
  - with pseudo-ref & planets
  - with Earth (down to 16°)
  - with Moon (26-40 arcmin)
  - On-board GPS receiver to validate
- RadHard (Van Allen belt in MEO)

Study Case:

=> PFM ready for flight 2018

=> FM1 in 2020/2022



Deep-space CubeSats @ CERES

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

Interplanetary Science at 3U Scale:

- ✓ Interplanetary space weather with a fly-by @ Mars
- ✓ In situ geodesy with flying-legs @ asteroids
- ✓ 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

*(**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 d'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 , 20.Ecole Centrale Paris

*(**Involved actors** in chronological order, number in brackets indicates the institution)*

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