Using smallsats and cubesats as ancillaries:

a low-cost strategy maximizing the science return of fly-by missions

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Summary

- Introduction: need for fly-by's
- Increasing science return
- Decreasing mother spacecraft cost
- Example: mission analysis for a distant dwarf planet fly-by, assessment of required propellant
- Conclusion

Introduction: needs for fly-by missions

- The last decade has suddenly seen the doubling of the number of known bodies above 500km in diameter in the Solar System, from 35 to about 70.

- Large transneptunian objects have been **discovered** at a sustained rate of about **four candidate dwarf planets every year on average**. This rate should further accelerate when powerful sky surveys such as PANSTARRS or LSST become fully operational.

- Combined with predictions of differentiated states for a large fraction of the largest newcomers, this calls for a better knowledge of these bodies, not just as massless dots in n-body codes simulations or as a cloud of objects to be classified in taxa, but also as **full-fledged planetary bodies** with an evolution, a structure and sometimes an extant geological or atmospheric activity.

Introduction: needs for fly-by missions

- Exploring in-situ the transneptunian Dwarf planets, the other large TNOs and moons of Uranus and Neptune remains a challenge. All combined they now account for 75% of the 100 largest bodies in our Solar System.
- In-situ exploration best served by orbiters rather than by fly-by, but required advances in performance of propulsion and mainly power generation specific mass place such orbiter missions far beyond the next decade.
- For the transneptunian dwarves, a fly-by still represents the most efficient in-situ exploration strategy in the short term.
- Low cost missions to the large moons of Uranus or Neptune only possible with fly-by's, as capture into orbit around one of these moons would require a very large delta-V or mastery of aerobraking.
- For closer targets (in Main Belt e.g.), fly-by's represent the cheapest mission as it has lowest launch mass.

Introduction: needs for fly-by missions

- NASA's New Horizons sets a precedent of a mission to a transneptunian dwarf planet
- The large number of targets and their diversity call for many New Horizons-like missions.
- New Horizons had to battle to exist despite its reasonable size and the study of as many as 4 to 6 unexplored bodies.
- Increasing the science return–to-cost ratio of a fly-by is therefore vital to get such missions to distant targets approved.

How can a mid-sized spacecraft be efficiently complemented by ancillary micro-satellites?

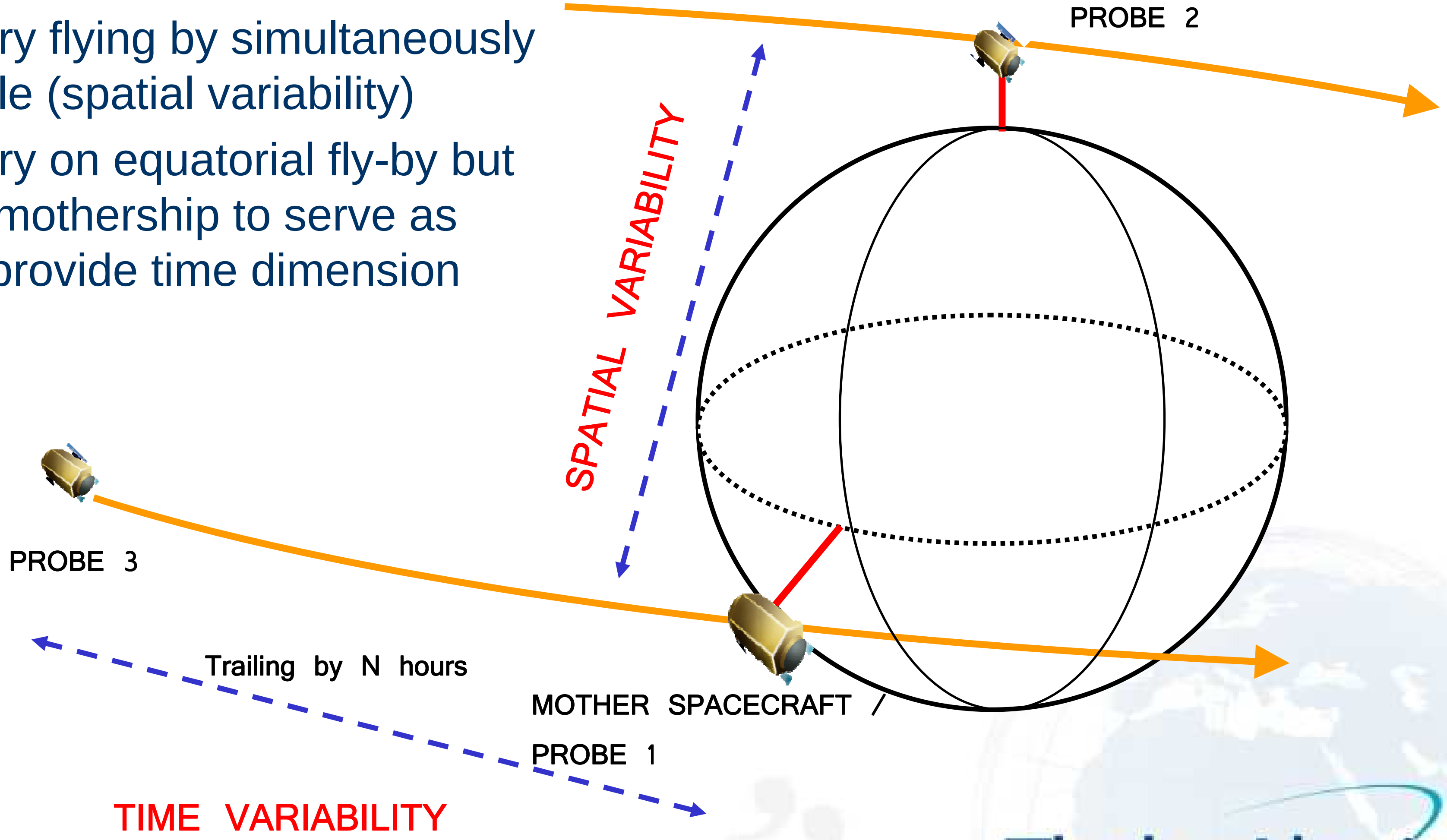
Increasing science return

- Fly-by missions science return usually limited as a single spacecraft flying by misses the time and space dimensions of the measured phenomena

- Aim of ancillaries:
  - to provide for a considerably increased spatial and/or time coverage and probing of the magnetic field, gravitational field, atmosphere or exosphere of the targets.
  - to cover all physical fields in a comprehensive way, and answer questions such as “does the object have a subsurface ocean?” *(induced fields, Saur et al. 2010)*
  - while still benefiting from the low cost of a fly-by mission.

Increasing science return: example of strategy

- Example with two ancillaries:
  - Mother spacecraft flies by at target's equator
  - One ancillary flying by simultaneously over the pole (spatial variability)
  - One ancillary on equatorial fly-by but trailing the mothership to serve as reference, provide time dimension



Increasing science return: example of strategy

- Other potential interesting ancillaries:
  - Impactors
  - Penetrators (but can be very high relative speed)
  - Additional one for equatorial fly-by, allowing the mother spacecraft to flyby at a higher altitude
    - relaxing constrains for imaging due to relative angular speed (imaging) ,
    - improving science without degrading reliability => ancillary can graze the surface whereas the mothership cannot
  - Additional one flying by at a very large altitude to measure solar fields as decoupled spatial reference at same distance from the sun

Decreasing mother spacecraft cost

- Decreasing the cost of mothership needed to compensate or over-compensate the cost increase due to the cost of the ancillaries

- Ancillaries present opportunities to decrease cost of mothership:
  - by liberating it from expensive obligations, e.g. EMC, magnetic cleanliness
  - by relaxing constrains for imaging due to relative angular speed (imaging)
  - by increasing its recurrence:
    - ancillaries can bear the specific in-situ instruments,
    - leaving mothership with remote sensing and “central heavy services” more likely to be recurring from previous planetary missions

Assessing required propellant: mission analysis run

- Extra launch mass brought by the mass of the ancillaries but also by the the propellant needed to form the multiple spacecraft fly-by "constellation"?

=> Parametric studies to assess delta-V as a function of the time at which such ancillaries would be released, so as to cope with navigation uncertainties and power supply considerations.

- Ancillaries are low-cost, low-mass items (estimated <50kg each) as they have no need for orbit control and can survive their short lifetime as independent items through primary batteries.

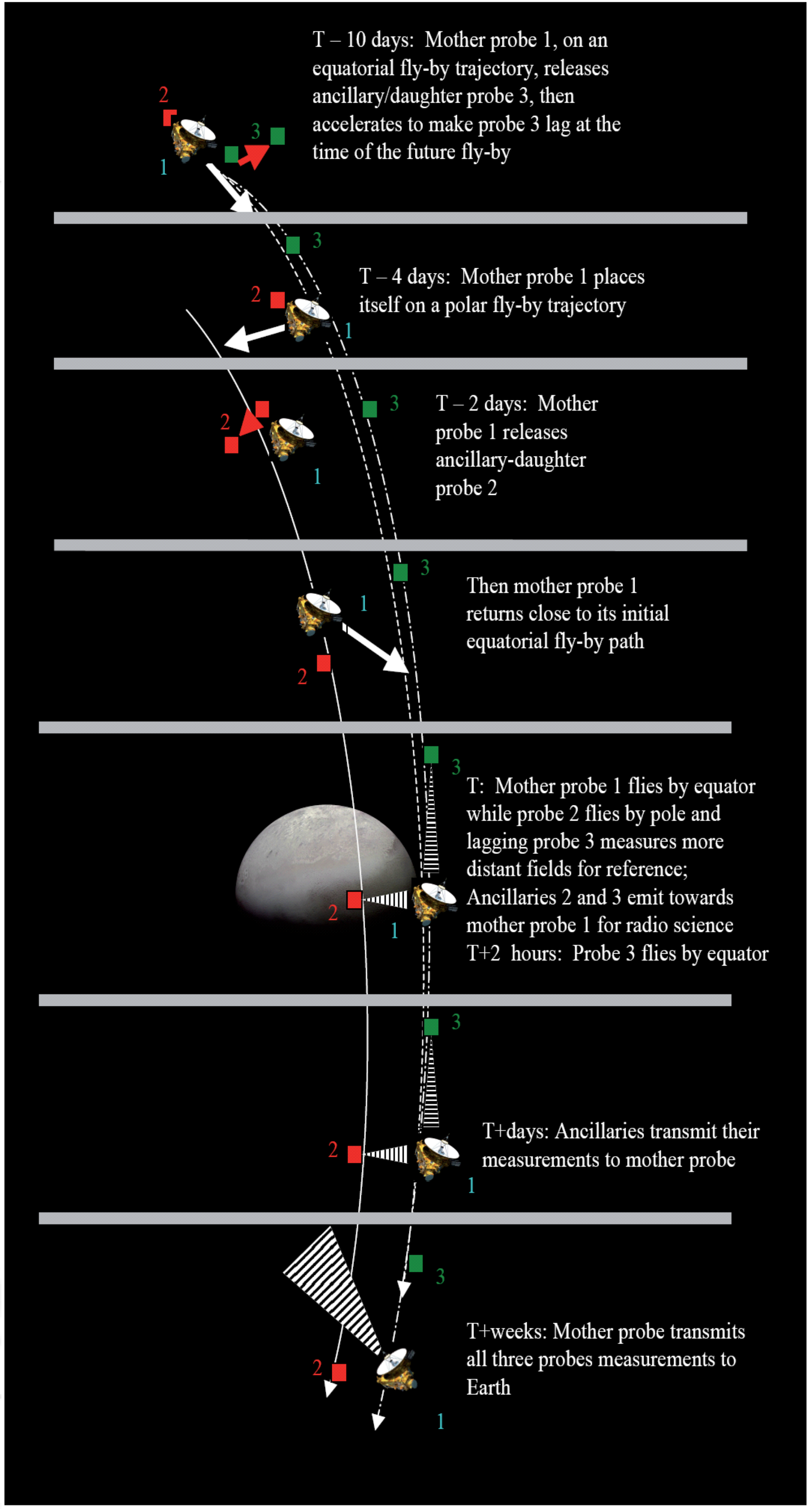
- We have computed, in the example of a New Horizons-like fly-by of dwarf planet Makemake, the needed delta-V as a function of release time and fly-by altitude in a scenario with two ancillaries.

Mission profile (1/5)

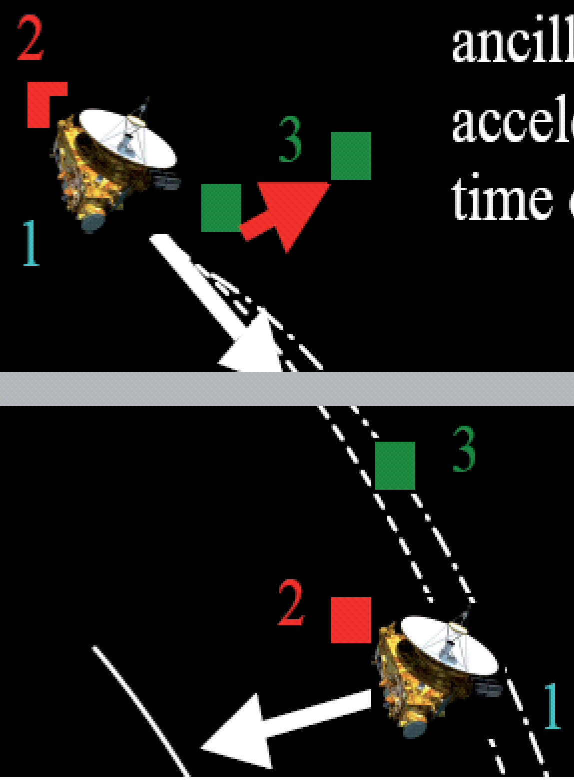
- Mother ship is assumed similar to New Horizons, with a similar relative velocity to its target.

MAKEMAKE FLY-BY DATA	
Velocity of spacecraft (km/s)	14
Velocity of Makemake (km/s)	4
Radius of Makemake (km)	750
Delay between 1-3 flyby's (hours)	2

- Studied overall mission scenario =>



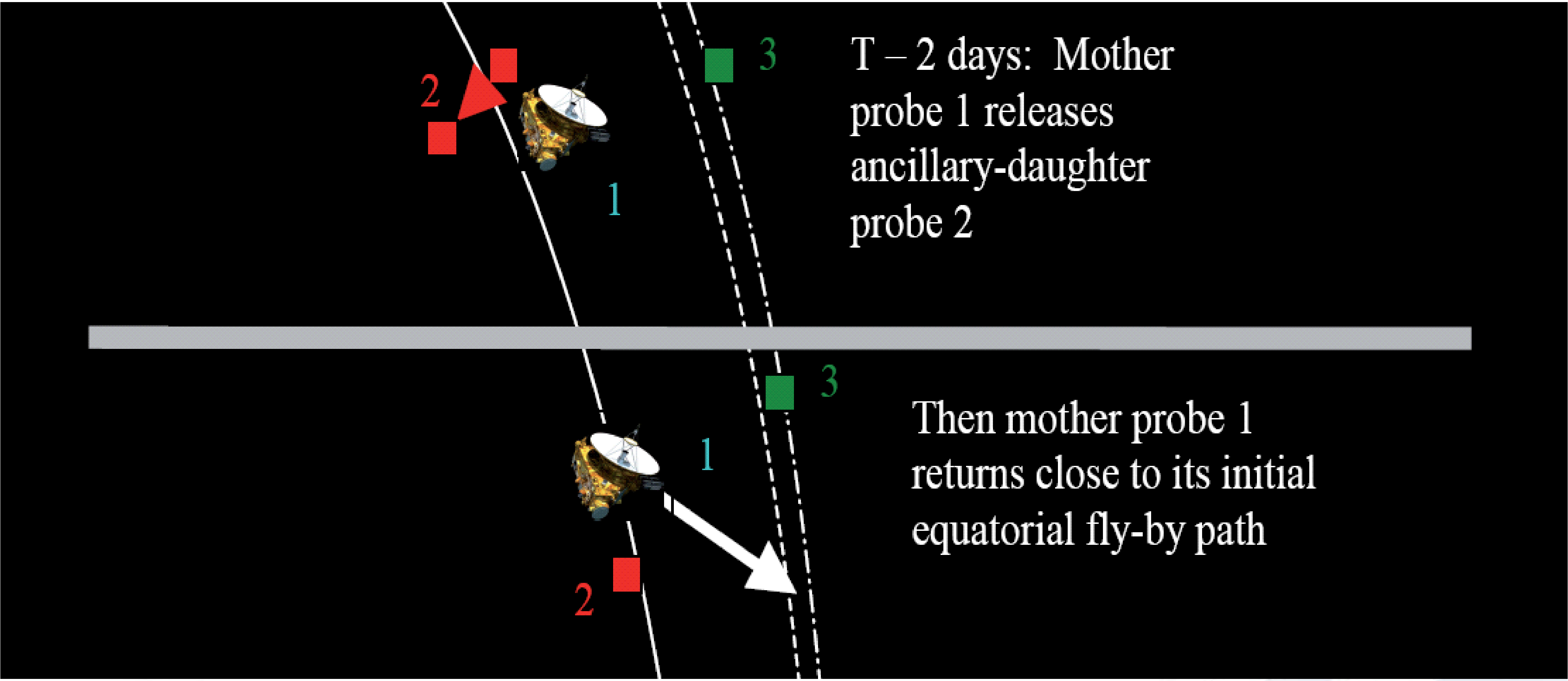
Mission profile (2/5)



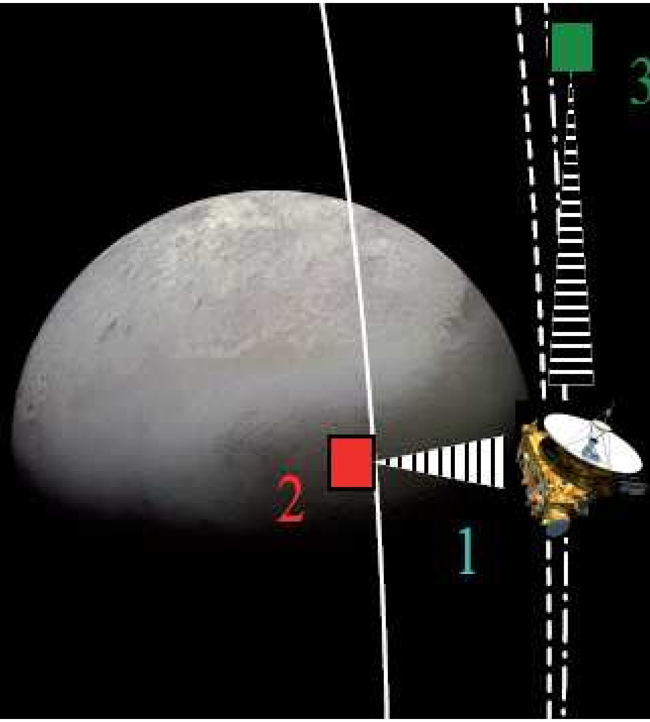
T – 10 days: Mother probe 1, on an equatorial fly-by trajectory, releases ancillary/daughter probe 3, then accelerates to make probe 3 lag at the time of the future fly-by

T – 4 days: Mother probe 1 places itself on a polar fly-by trajectory

Mission profile (3/5)

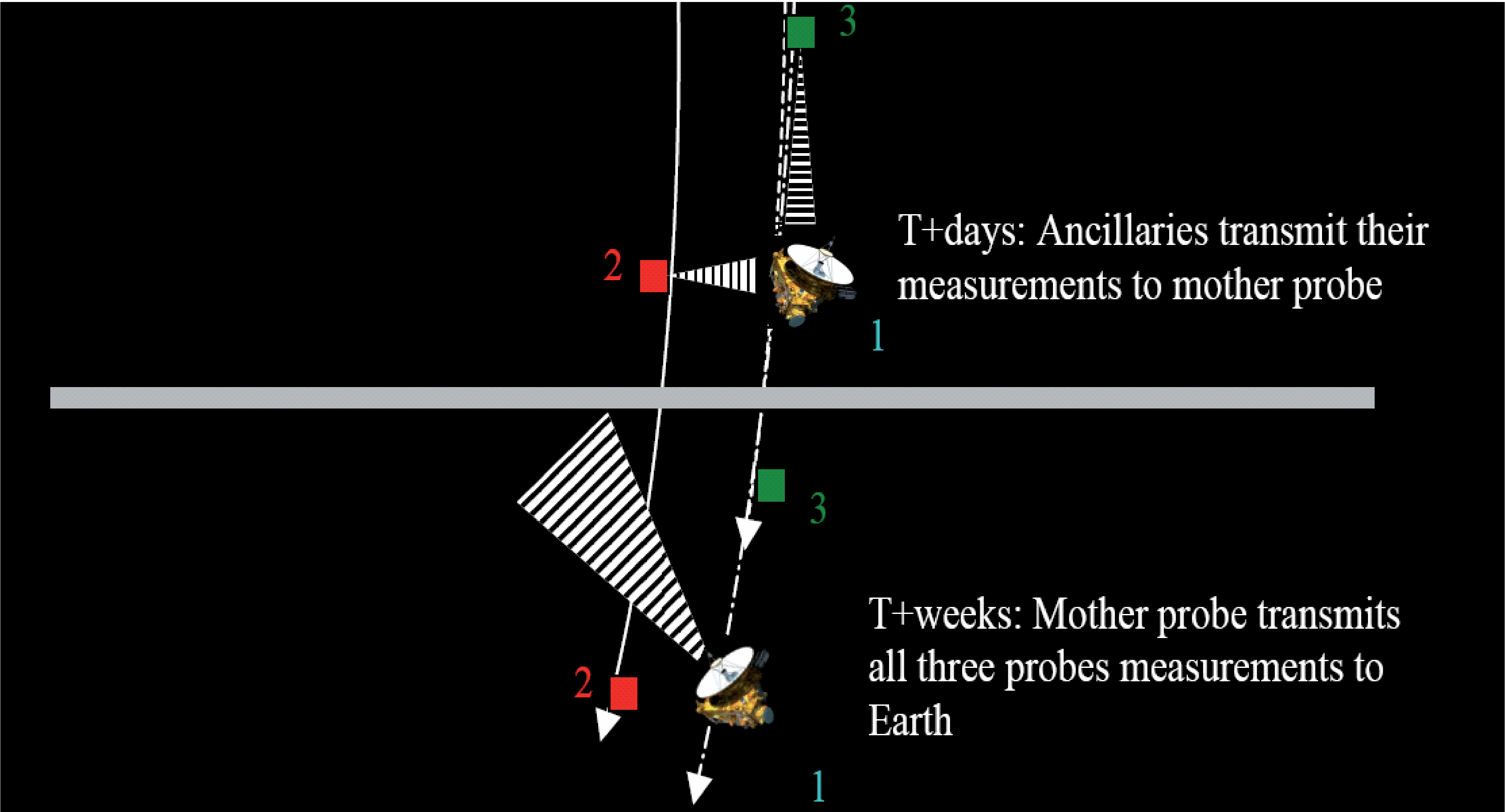


Mission profile (4/5)



T: Mother probe 1 flies by equator while probe 2 flies by pole and lagging probe 3 measures more distant fields for reference;
Ancillaries 2 and 3 emit towards mother probe 1 for radio science
T+2 hours: Probe 3 flies by equator

Mission profile (5/5)



Assessing required propellant: mission analysis run

- Delta-V computed as a function of release time and fly-by altitude

DV FOR PLACING PROBE 3 ON A 2h-LAGGING TRAJECTORY (m/s)				
	Altitude of fly-by (km)			
Time before fly-by (hours)	0	750	1250	8500
24	1500	1500	1500	1500
48	750	750	750	750
240	150	150	**150**	150

DV FOR PLACING PROBE 2 AND GOING BACK ON TRACK (m/s)				
	Altitude of fly-by (km)			
Time before fly-by (hours)	0	750	1250	8500
24	25	49	65	303
48	12	25	**33**	151
240	2	5	7	30

- *The total delta-V needed to manage the ancillaries is reasonable e.g. for a release of probe#3 ten days prior to this Makemake encounter, and a release of probe#2 two days before the encounter.*
- *The amount is then 150 + 33 = 183 m/s to be kept as a chemical reserve on board of the mother ship, for a New Horizons-like spacecraft design.*

Conclusion

- Preliminary assessment in the example of a New Horizons-like fly-by of dwarf planet Makemake, the needed delta-V as a function of release time and fly-by altitude in a scenario with two ancillaries.
- Scenario has been found feasible, for manageable increase of launch mass
- Using ancillaries enables a valuable increase of the science-to-cost ratio of fly-by missions.
- Not only an enabler for missions to distant objects, but also a source for mission cost reduction for closer unexplored targets in our Solar System.