FFIORD demonstration versus missions and thematics

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PRISMA / FFIORD perspectives
Questions to be addressed

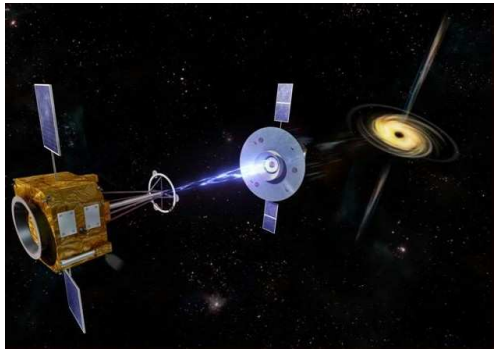
- **What technologies / functionalities were demonstrated ?**
- **What are the remaining critical technologies ?**
- **How PRISMA could still be of any help ?**
- **What other flight demonstrations would be required (*FFIORD team technical point of view*) ?**

Mission main characteristics

Missions		Orbit	Metrology	Functionalities
Formation flying	**Radar interferometry**	LEO	GPS	Formation maintenance and reconfiguration, Low positioning accuracy
	Large focal telescope	L2	FFRF, FFOS	Formation acquisition (2 satellites), maintenance, reconfiguration High relative positioning accuracy
	Optical Interferometry	L2	FFRF, FFOS, High accuracy optical sensors, payload	Formation acquisition (3+ satellites), maintenance, reconfiguration High relative positioning accuracy at platform level with payload in the loop
RDV with cooperative object	**Servicing**	LEO,MEO, GEO	GPS, Lidar, camera	Optical navigation (orbit dependent) Fine positioning during final approach
RDV with non cooperative object	**MSR**	LEO	Camera, Lidar	Long range detection, optical navigation first with angles only then angles + range Fine positioning during final approach
	Orbital debris removal	LEO	Camera, Lidar, radar ?	Optical navigation down to capture (platform + grappling device) Fine positioning during final approach

FFOS: Formation Flying Optical Sensor (Coarse Lateral Sensor + distance)

Future Formation flying missions
Long focal telescope (1)



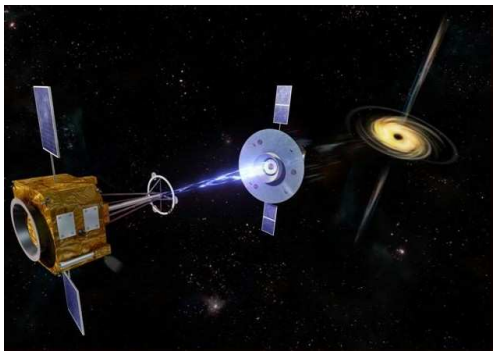
Main technical challenges (RDV / FF perspective)

- Formation acquisition / reconfiguration (FFRF based activities)
- Accurate positioning during instrument data acquisition:
  - ➔ Optical based navigation (incl. Transition between FFRF & FFOS)
- Accurate pointing during instrument data acquisition (a few arcsecs)
- Formation safety

PRISMA / FFIORD demonstration

- All FFRF related operations in LEO with extrapolable performance for the most part
- Transition between FFRF and optical metrology (navigation & control)
- Positioning control exercised with a FFOS like instrument (VBS) and assessment of the metrology constraints ➔ *high performance accuracy not demonstrated*
- Collision avoidance capability (guidance with centralized approach)

Future Formation flying missions
Long focal telescope (2)



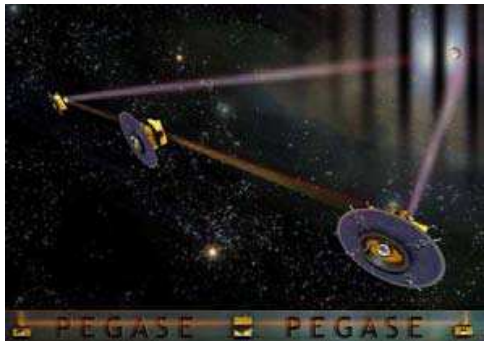
Remaining critical technologies

- FFOS not flown yet but technology similar to Videometer or VBS
- Actuation for fine positioning (ex: cold gas)

Other demonstrations ?

- Fine actuation demonstrated on other missions (ex: Cryosat 2 / Gaia)
- FFOS ground characterization appears sufficient to allow validation of the fine positioning with numeric simulators
- Proba 3 would go a step further by demonstrating desired performance in flight

Future Formation flying missions Interferometry



Main technical challenges (RDV / FF perspective)

- Long focal telescope challenges +
- High relative positioning / pointing accuracy and stability with **new optical metrology** (range and lateral position measurement)
- High relative positioning / pointing accuracy and stability **with payload in the loop** (range and lateral position measurement)

PRISMA: not fit for such challenges

Other demonstrations ?

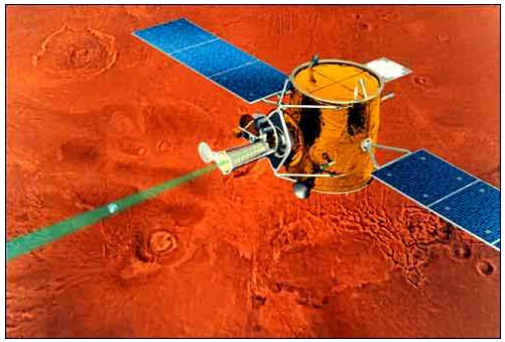
- Proba 3 constitutes a valid step to demonstrate optical metrology and accurate positioning in flight → coronograph instrument data used for accuracy evaluation
- Demonstration constraint: the introduction of higher performance capabilities (new metrology stages) implies the presence of reference measurements that can be only provided by the payload

  → demonstration = real mission

RDV with non cooperative objects
Sample Return mission (1)

Main technical challenges (RDV perspective)

- **Orbital sample detection**
- **Optical navigation from several 100 km to capture**
  - camera based - down to a few km or less
  - Lidar based - down to a ~1 m
- **Accurate control during the pre-capture phase**



PRISMA / FFIORD demonstration

- Target detection capability up to 30 km (with a non dedicated instrument)
- Camera based navigation capability down to 50 m with a 1-2% range accuracy
  → range could go down to a few meters for a small spherical object demonstrated with permanent observability
- Accurate control achieved with a Lidar « like » instrument (FFRF) which accuracy was much coarser (limited by actuation resolution)

RDV with non cooperative objects
Sample Return mission (2)

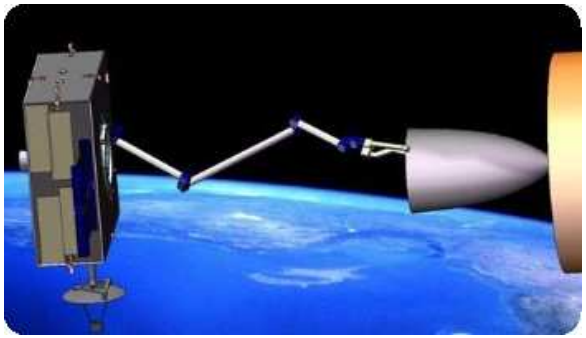
- **Remaining critical technologies**
  - **Lidar metrology**
    (from a European perspective) → already validated on US missions (ex: Orbital Express)

- **Other demonstrations ?**
  - Fine actuation demonstrated on other missions (ex: Cryosat 2 / Gaia
  - Ground demonstration relevant using a dynamic simulator with Lidar in the loop or a numeric simulator with a realistic Lidar model (from dedicated instrument characterization)
  - Dedicated flight demonstration in LEO not justified
    → If any, it should include the demonstration of orbital debris capture functionalities

RDV with non cooperative objects orbital debris (1)

Main technical challenges (RDV perspective)

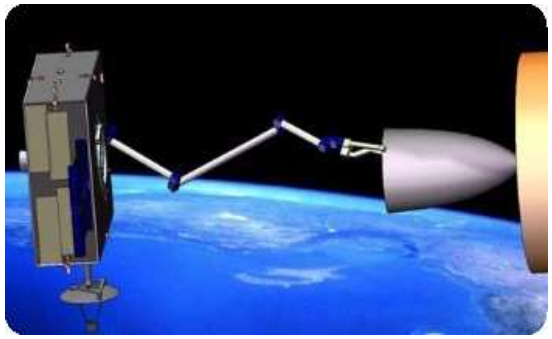
- Optical navigation from several 10 km to capture
  - camera based - down to a few km or less (with image processing)
  - Lidar based - down to a ~1 m
- Debris characterization (ground processing)
- Approach and positioning with compensation of debris residual rotation



PRISMA / FFIORD demonstration

- Camera based navigation capability down to 50 m with a 1-2% range accuracy (→ range could go down to a few meters for a small spherical object)
- Relative forced trajectories for satellite inspection (mainly by SSC)
- Accurate control achieved with a Lidar like instrument (FFRF) which accuracy was much coarser (limited by actuation resolution)
- Allowed to acquire real images for image processing techniques evaluation

RDV with non cooperative objects orbital debris (2)



Remaining critical technologies / functionalities

- Lidar instrument to be flight qualified
- Relative position and pose estimation using Lidar measurements
- Relative position and pose estimation via image processing
- Accurate satellite 6D control (strong position / attitude coupling due to capture device deployment and/or satellite spin)

PRISMA can be used to validate image processing techniques

- VBS image acquisition (rate = 1/120 Hz) for ground image processing

Other demonstrations ?

- Ground testing possible of metrology / data processing algorithms → robustness of short range optical navigation must be proven on the ground
- Ground demonstration relevant using a dynamic simulator with metrology in the loop or a numeric simulator with realistic metrology model (but image representativeness issues)
- Flight demonstration required to qualify the short range navigation functionalities and their integrated use in real capture scenarios (with a real debris or a deployed target)

Synthesis

Formation flying

- Radar interferometry: already flying (PRISMA demonstrated new generation)
- Large focal telescope: FFIORD regarded sufficient but Proba3 would provide consolidation
- Optical Interferometry: Proba3 relevant demonstration for high accuracy metrology stages and positioning

RDV with cooperative object

- Inspection capability demonstrated on PRISMA with GPS and VBS → going further is questionable without any servicing purpose (ex: refueling).

RDV with non cooperative object

- MSR: some parts demonstrated on PRISMA/FFIORD → No dedicated demonstration appears justified
- Orbital debris removal: PRISMA/FFIORD is a good starting point but additional techniques must be demonstrated on the ground. Next, a flight demonstration would have to involve capture as well (debris inspection is not enough).

Discussion