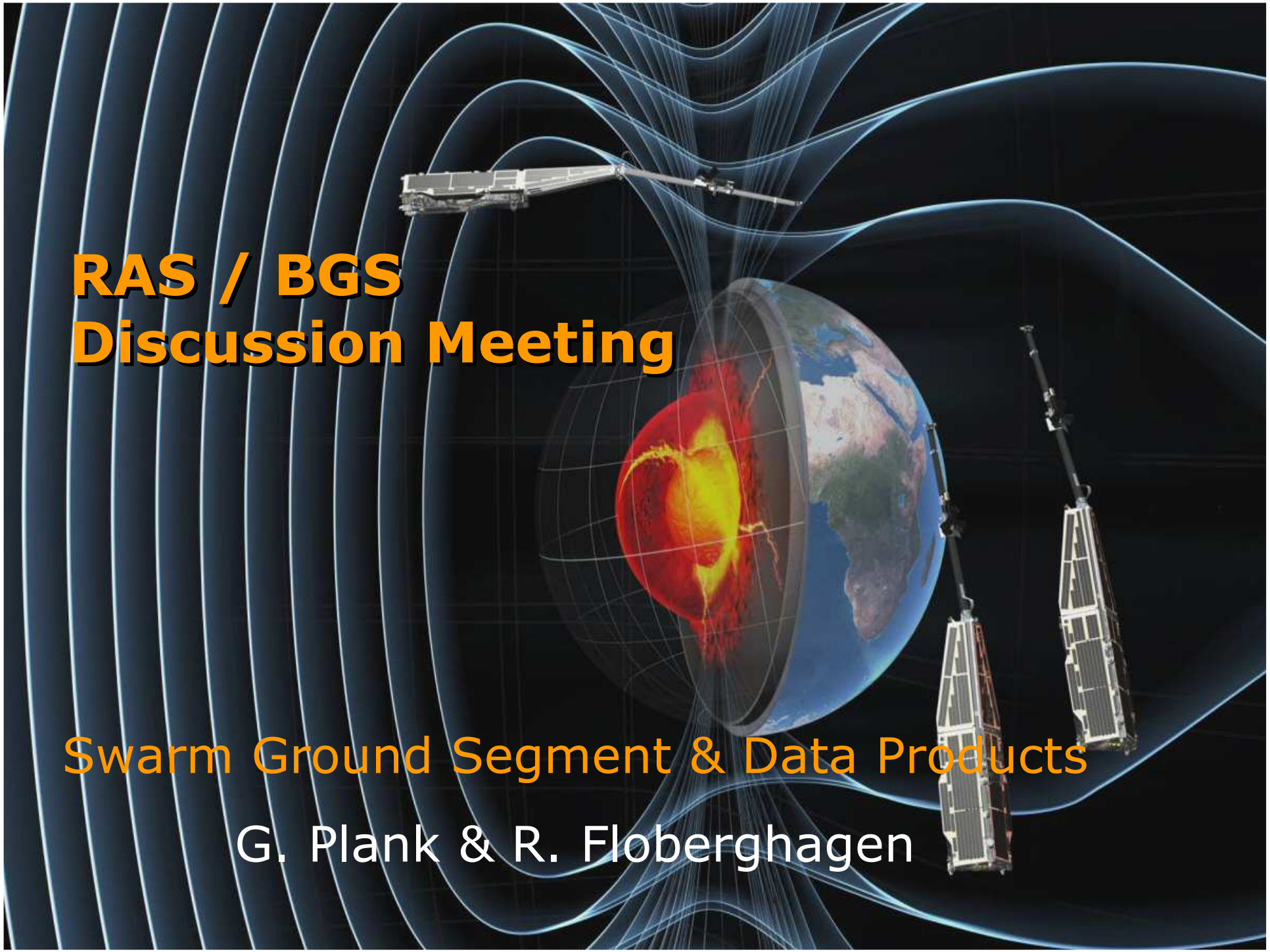


RAS / BGS Discussion Meeting

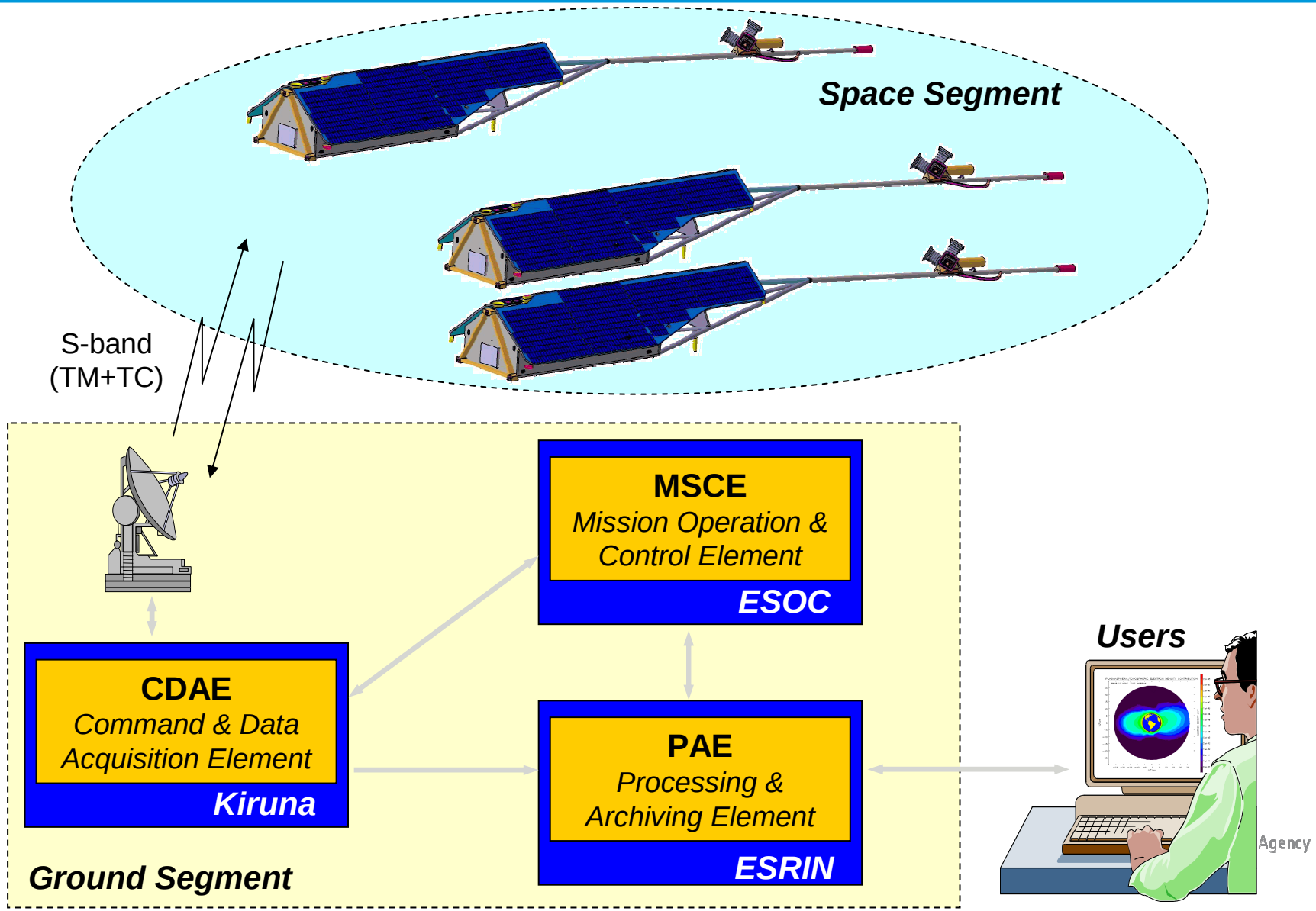
Swarm Ground Segment & Data Products

G. Plank & R. Floberghagen

Outline

- Swarm System elements (briefly)
- Ground Segment (briefly)
- Level 1b products
- Level 2 processing
- Level 2 products
- Data access

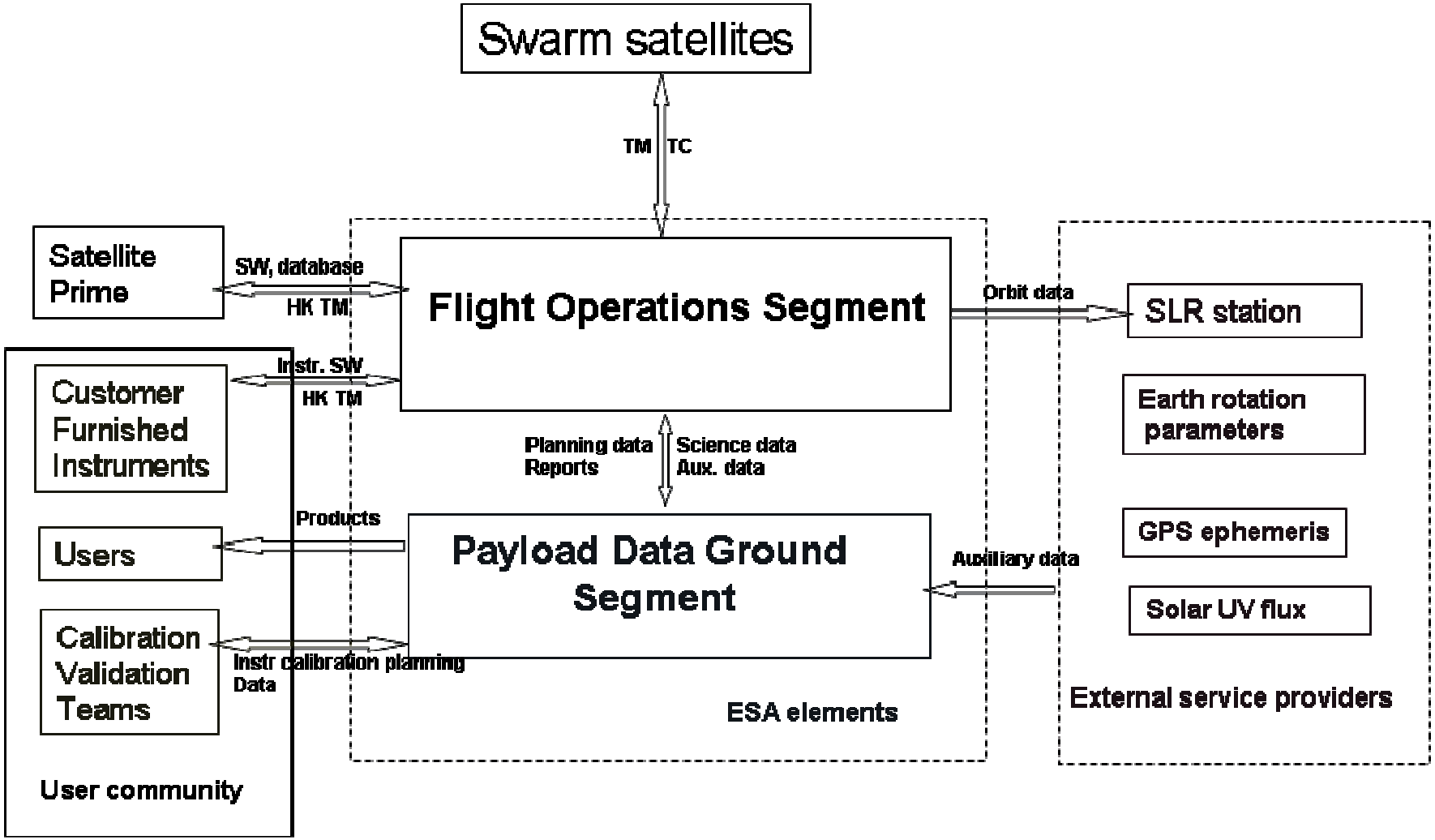
Swarm System Elements



Mission Phases

- **Launch and Early Orbit Phase** (1 week)
  - Attitude acquisition
  - S-band link acquisition
  - Initial satellite check out
- **Commissioning phase** (3 months)
  - Initial constellation establishment
  - Initial performance characterization / calibration
  - In-orbit verification of L1b performance (incl. stability)
- **Routine phase** (4 years)
  - Nominal operation of the instruments
  - Maneuvers for instrument calibration
  - Generation and validation of L1b / L2 data products
  - Data distribution to users
- **End of Life**
  - Maintain product archive 10 years after end of mission

Ground Segment Architecture 1/2



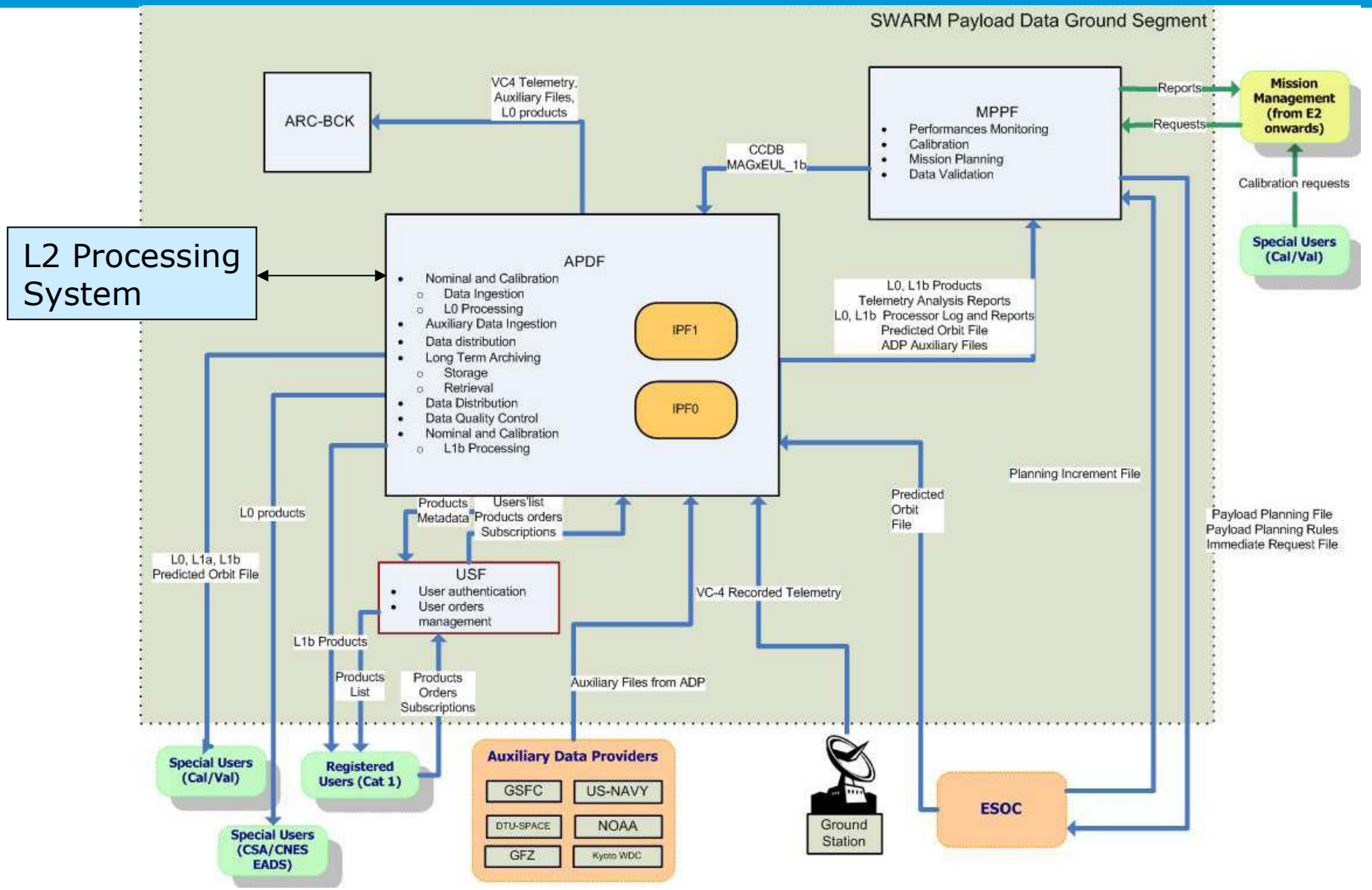
Ground Segment Architecture 2/2

- **Flight Operation Segment (FOS)**
  - Satellites Command and Control
  - Data Acquisition
  - Mission Planning
- **Payload Data Ground Segment (PDGS)**
  - Data Processing, Archiving, Dissemination and Quality Control
  - Mission Planning
  - User services
  - Calibration
- **Cal/Val team**
  - Payload Calibration activities
  - Includes selected Cal/Val AO proposals
- **External Service providers**

Swarm Data Hierarchy

Level 0	**Raw measurements and housekeeping data** (from instruments and spacecraft)
Level 1b	**Calibrated and validated instrument data**, including Magnetic field magnitude Magnetic field vector Ion drift velocity vector Electric field vector Plasma density Ion and electron temperature Acceleration vector, linear and rotational Position, velocity and attitude of spacecraft
Level2	**Validated scientific data and models**, including Magnetic field models (internal and external) Accelerometer data (incl. calibration parameter) Air density and winds

Payload Data Ground Segment 1/2



Payload Data Ground Segment 2/2

- **APDF – Archiving and Payload Data Facility:**
  - IPF0 (Instrument Processing Facility Level-0) and IPF1 (Level 1b)
  - Retrieving the VC4 Recorded Telemetry from the acquisition stations
  - Retrieving auxiliary data from external sources (including FOS) and dissemination to the MPPF
  - Archiving
- **ARC-BCK – Backup archiving facility:**
  - Replica of the main APDF archive
- **MPPF – Mission Planning and Performance Facility:**
  - Performance monitoring
  - Mission planning
- **Level 2 Processing System:**
  - Level 2 Product Generation
- **USF- User Services Facility:**
  - User interface

Level 1b Products

- Magnetic vector data, 50 Hz
- Magnetic data, 1 Hz
- Magnetic Calibration data, 0.25 Hz
- Euler angle estimation of the CRF <= VFM transformation
- Plasma data, 2 Hz
- Position and velocity of S/C, 1 Hz
- Attitude of S/C, 1 Hz
- On-board GPSR navigational solution, 1 Hz
- GPS RINEX Observation data, 0.1 Hz
- GPS RINEX Navigation data, 2 hours
- Pre-processed ACC data, 1 Hz
- ASM and VFM auxiliary data, 50 Hz

Swarm Level 2 Processing System

- All L1b data products are single satellite / instrument (e.g. no combination)
- The unique Swarm constellation is not taken into account
- But most users are interested in higher level products (e.g. magnetic field models …)
- Highly complicated algorithms used to “transform” L1b data into higher level products (Level 2)

How to fill this gap??

A little bit of history

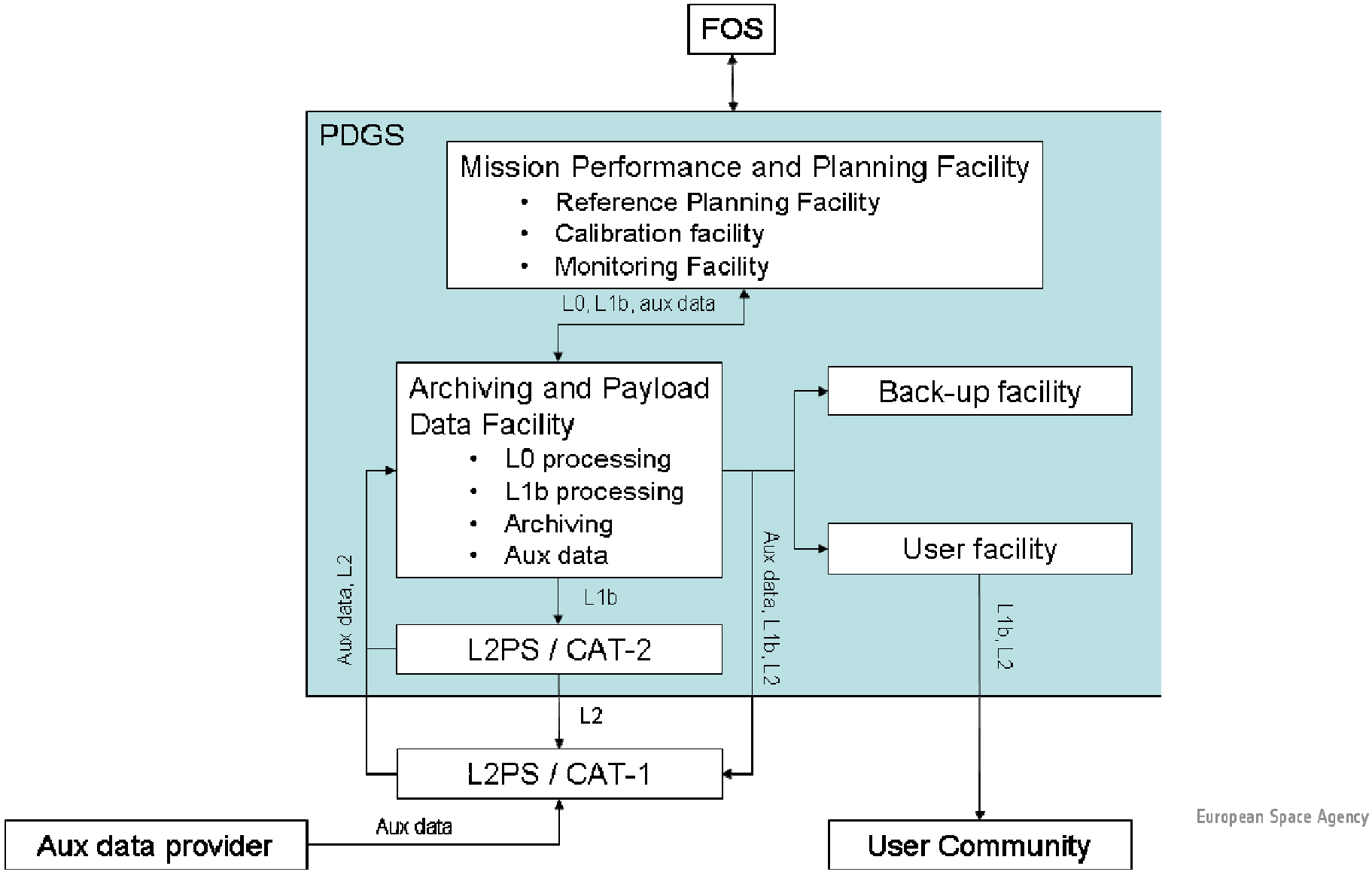
ESA study "Preparation of the Swarm Level 2 Data Processing"

- 09/2007 => 10/2008
- Supported by parallel studies (ionosphere, 3D mantle conductivity, air density)
- Definition of
  - L2 products (incl. product requirements)
  - L2 algorithms (proven concepts, different maturity of the algorithms, redundancy …)
  - Development needed for a complete Level 2 system

Based on the provided information ESA internally decided on the next steps for the L2 processing

=> Open Invitation to Tender (ITT) for the development of the Level 2 Processing System (L2PS) under preparation

Swarm Level 2 Processing System



Key data

- Planned start of development: 1st quarter 2010
- Based on distributed system with identical interfaces to the PDGS
- PDGS will manage all data flows as well as archiving
- No direct interfaces among different facilities
- 2.5 yrs development until operations
- Algorithms with a high maturity level will be prototyped, performance benchmarked and implemented
- Two types of processing chains:
  - Facilities developed and operated off line (CAT-1)
  - Fully automatic chains within PDGS (CAT-2)
- Additional studies to prove the maturity of selected algorithms (CAT-3)

Level 2 algorithms

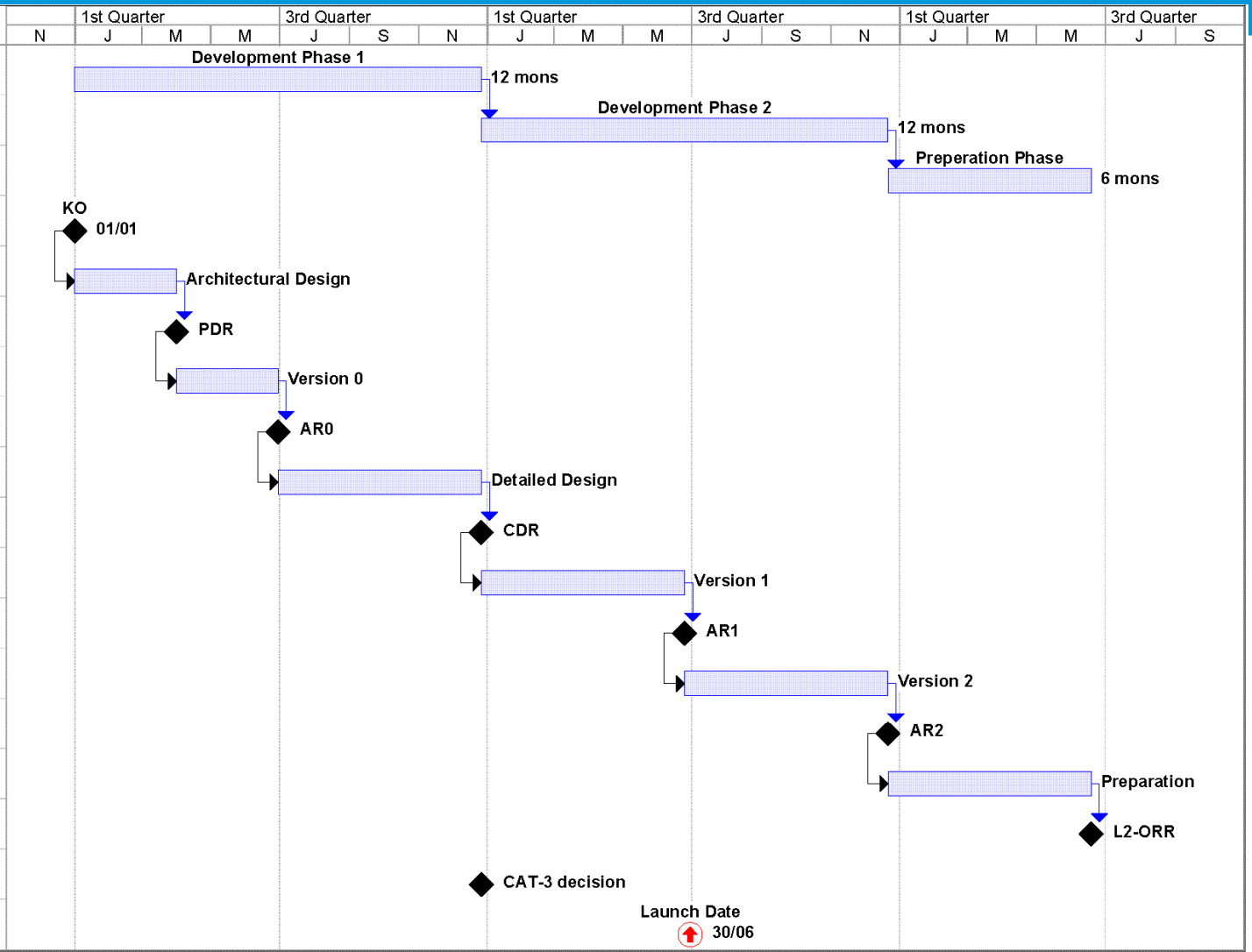
- **CAT-1 algorithms**
  - Mature and proven algorithms
  - First prototypes exist
  - Tested with real satellite data (e.g. CHAMP)
  - Already used for realistic Swarm mission simulation scenarios
  - Complex scientific interaction needed ("Scientist in the loop")

    => Operated offline
- **CAT-2 algorithms**
  - Mature and proven algorithms
  - Fast product turnaround possible
  - No scientific interaction needed during operations

    => Integral part of the PDGS
- **Development and implementation under ESA contract**

Schedule

ID	Task Name
1	Development Phase 1
2	Development Phase 2
3	Preperation Phase
4	KO
8	Architectural Design
9	PDR
10	Version 0
11	AR0
12	Detailed Design
13	CDR
14	Version 1
15	AR1
16	Version 2
17	AR2
18	Preparation
19	L2-ORR
20	CAT-3 decision
21	Launch Date



Project: L2PS
Date: 11/09/09

Task		Milestone		External Tasks	
Split		Summary		External Milestone	
Progress		Project Summary		Deadline	

Phases & Milestones

Development Phase 1 (KO => KO+12)

- Architectural Design
- First prototype (V0) for CAT-1 algorithms
- Final DPMs for CAT-2 algorithms
- All interfaces defined, documented and implemented

Development Phase 2 (KO+12 => KO+24)

- Integration of V1 and V2 of the L2PS (CAT-1 algorithms)
- "Frozen" version
- Support for the implementation of the CAT-2 chains within the PDGS

Preparation Phase (KO+24 => KO+30)

- Investigation of different failure cases
- First tests with real Swarm data

Level 2 products – CAT-1 1/3

- **Euler angles for the VFM-CRF transformation for each of the three spacecrafts**
  After 1 year: 3 arcsec standard deviation (per angle per satellite)
- **Core field model and its temporal variation**
  After 4 years: time averaged accumulated error 3 nT/year (degree 2-16)
- **Lithospheric field model**
  Accumulated error on ground 120 nT (degree 16-150)
- **Mantle conductivity model**
  Upper mantle (0 km - 400 km) – uncertainty of 1 oom;
  middle mantle (400 km – 1500 km) – 0.5 oom;
  lower mantle (1500 km – 2900 km) – 1 oom
- **C-responses**
  After 4 years: shorter periods (4 – 40 days) – relative error 15%;
  longer periods (40 – 150 days) – relative error 30%

Level 2 products – CAT-1 2/3

- **Large scale magnetospheric field and its induced counterpart**
  Ext. and int. field Spherical harmonic coefficient 1: sampling time 3 hours
  Ext. field Spherical harmonic coefficients 2,3, m=0,1; sampling time 24 hours
  Squared coherency (between true coefficients and recovered ones) > 0.5 for periods above 2 days and > 0.75 for the zonal coefficient Q10.
- **Quiet time daily geomagnetic variations at mid and low latitudes**
  Spatial resolution corresponding to spherical harmonic degree 45 in a quasi-dipole system valid between -55 and 55 latitude; it shall capture diurnal and seasonal variation. Better than 10% globally (in the validity range) averaged relative error at ground.
- **Precise Orbit Determination (POD)**
  10 cm (3D)

Level 2 products – CAT-1 3/3

- **Accelerometer calibration parameters for all three spacecrafts**
  Scale: 0.02/0.1/0.1 (X/Y/Z)
  Bias: 5/10/30 nm/s^2 (X/Y/Z)
- **Non-gravitational accelerations**
  Swarm A&B: 30/10 nm/s^2 (X/Y)
  Swarm C: 10/5 nm/s^2 (X/Y)
- **Calibrated accelerometer data**
  Non-gravitational forces:
  Bias: 5/10/30 nm/s^2 (X/Y/Z); random error in MBW 3 nm/s^2
  Aerodynamic forces:
  Bias: 15/15/30 nm/s^2 (X/Y/Z)
- **Thermospheric density & wind speed**
  Swarm A&B: Density 15%; wind 250m/s

CAT-2 products & chains

- **Ionospheric Field Aligned Currents**
  40 nA/m^2 for periods 10s to 90min on top of constant bias of <100nA/m^2, for lat. below 80°, degrading between 80° to 86°, none beyond 86°
- **Ionospheric Bubble index**
  Detection (probability = .95) >4×$10^{11}m^{-3}$, Ti + Te > 3000 K, and with a latitudinal extent of >1.5° and 20° within the latitude range ±45°
- **Ionospheric Total Electron Content**
  1 TECU on global scale for ray elevation angles 20°-90°
- **Dayside Equatorial eastwards Electric Field**
  < 0.2 mV/m precision (1 sigma)

CAT-2 chains

- Automatic processing on daily basis
- Highly autonomous algorithms (no permanent interaction needed during operation)

CAT-3 algorithms

1. **High degree magnetospheric field retrieval**
   - Coefficients at least to degree 9
   - Inclusion of observatory data
2. **3D mantle conductivity retrieval**
   - Benchmark tests for all available algorithms
   - Selection of two independent algorithms

Expected output:

- Full documentation
- Maturity of the selected algorithms
- Further development/implementation needed

Based on the provided information the Agency will decide after 12 months whether this algorithms are transformed into CAT-1 or CAT-2 algorithms/chains

Data access

Two different possibilities to get free access to Swarm data:

1. Cal/Val users
   - Special users with access to L0, L1b and L2 data
   - Calibration / Validation
   - In addition to ESA/industry also scientific expertise needed
   - Direct benefit for the mission management
2. Standard users
   - Access to L1b & L2 data products
   - Standard data access for general users

Call for proposals will be released before the launch of the satellites. Accepted proposals get the status of a Principal Investigator (PI).

Throughout the mission lifetime additional proposals can be submitted.

Summary

- Development of the Level 2 Processing System under ESA contract will start 1st quarter 2010
- Call for proposals for data exploitation will be released ~1 year before launch
- A fruitful collaboration with the scientific community is of paramount importance to get the best return from the Swarm mission, including the calibration and validation of the data
- Swarm data products (L1b & L2) will be available for free via the User Service Facility throughout the mission lifetime and beyond