EGSIEM

European Gravity Service for Improved Emergency Management

Intoduction WP5 & GRACE Status

Frank Flechtner

EGSIEM Final Meeting, Bern, Switzerland

February 8, 2018

HORIZON 2020

WP5 Introduction

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- **Contributing Partners:** TU Graz, GFZ and University Luxemburg
- **Goal: Provide to the Hydrological Service (WP6)**
  - Daily and in NRT (<5d) mass redistribution products for all areas of interest
  - Regional gravity solutions with increased spatial resolution
- **T5.1 (Requirements and Concept, M01-M03):**
  - Deliverable Document D5.1 „Concept of NRT Service" (@M03, in time)
- **T5.2 (NRT Solutions, M04-M27):**
  - Based on daily Kalman filter modeling (TUG) and Radial Base Functions (GFZ)
  - Important Milestone T5.1 @M18: Service Readiness (NRT service set up)
  - Important Milestone T5.2 @M27: Operational NRT Service Readiness (Preparation work for operational NRT Service finished)
  - Deliverable Document D5.2 „NRT Service Product Report" (@M27, in time)

WP5 Introduction (cntd)

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- **T5.3 (Operational NRT Solutions, M28-M33):**
  - Planned: 6 months between April-September 2017 (together with WP6 Hydrological Service)
  - Results and duration were impacted by deteriorated health status of GRACE satellites and reduced L1B quality
  - Deliverable 5.3 “Operational NRT Service product report“(@M33, in time)
- **T5.4 (Regional Solutions: Concept and Processing, M04-M27):**
  - Deliverable 5.4 “Regional solution product report” (@M27)” was submitted to the Project Officer in September 2017 with a delay of 6 months @M33 caused by unforeseen challenges in preparation for the operational service run due to the degrading satellite health.

WP5 Agenda

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6	16:00	Flechtner	<u>WP5: NRT & Regional Service</u> • Introduction and Objectives WP5 (GFZ) • Status GRACE Mission: (GFZ) • Status GRACE-FO Mission (GFZ) • WP5 NRT & Regional Service: Results achieved by TUG and GFZ • Validation of daily NRT time series using GNSS data (ULux) • Discussion (All)

GRACE Late Mission Data (2011++)

- In January, 2011 thermal control of the satellites was inactivated to minimize battery load.
- In 2016, further battery cell failures on GRACE lead to partial orbit coverage where
  - KBR data collection is possible only in the sunlight for angles between Beta-prime = ± 20 deg and ± 60 deg
  - KBR data collection for the full orbit is possible for Beta-prime > ± 60 deg
  - For time periods ± 20 degrees from Beta'=0, the science instruments are powered off to reduce stress on the battery during the period of longest eclipse.
  - In August 2016, further battery degradation required that the heaters were activated to minimize battery overcharging during sunlight periods
- In September 2016, the accelerometer on GRACE-B was turned off to minimize battery load and the GRACE-A accelerometer data is time shifted and used for GRACE-B for all subsequent solutions.
- After January 2017, a zero pitch bias was used for both satellites to minimize differences in the surface forces.

GRACE Late Mission Data 2011++ (2)

- The operation procedures after 2010 have affected the GRACE gravity field data quality, especially the monthly SDS solutions after September 2016 and the EGSIEM daily solutions within the operational test run starting in April 2017.

- Impacts on EGSIEM solutions will be provided by Andreas Kvas.

Example: Single ACC solution June 2017

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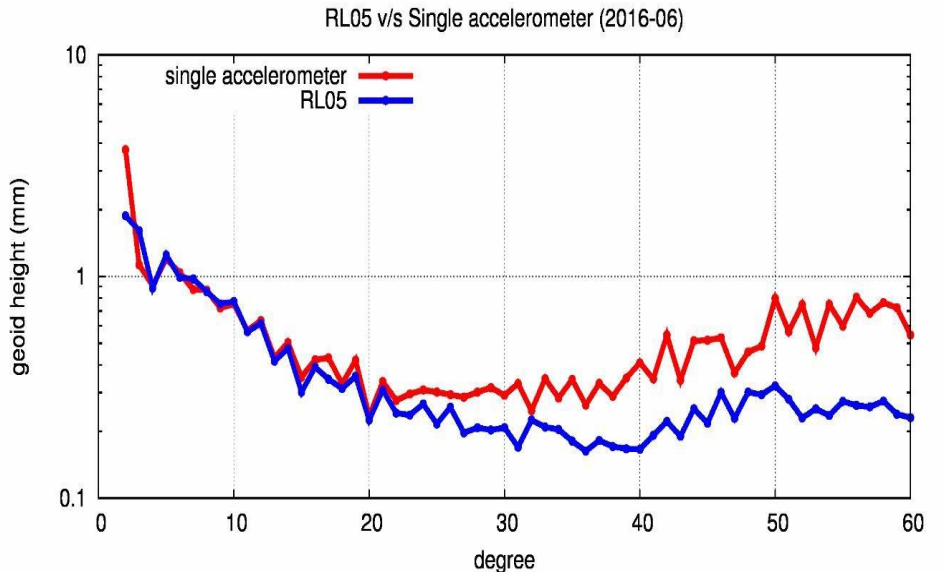

- In June 2017 both accelerometer data have been available for impact studies
- Up to deg. 20, the single accelerometer solution has comparable signal power to the RL05 solution.
- Above deg. 20, there is more noise in the signal accelerometer solution.
- The overall accuracy, between deg. 50 and 60, is a factor of 2 less accurate than the dual accelerometer results, but still provides very important science data.

GRACE Final Mission Phase (> June 2017)

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- On June 29, 2017, the mission entered the Science Hold Mode for the August 3, 2017 Beta prime = 0.
- GRACE-B was operated in the SHM until September 3, 2017, when GRACE-B dropped into the hibernation mode.
- Mission termination activities were activated on September 6, 2017. While attempting to execute mission termination, a recovery of GRACE-B was achieved on September 8, 2017.
- To save the remaining propellant for a possible last science collection, GRACE-B was placed again in the hibernation mode, with the intent of recovering from this mode on October 8, 2017 when the gaps in solar input would allow operation of the science instruments.
- The attempts to return to science mode for GRACE-B were not successful, leading to a depletion of the remaining fuel.
- On October 12, 2017, the decision was made to decommission GRACE-B and end the nominal science mission.
- Some accelerometer characterization maneuvers with GRACE-A were continued until late October and the final fuel on GRACE 1 was expended on December 1, 2017

GRACE Outcome: 159 SDS Monthly Solutions

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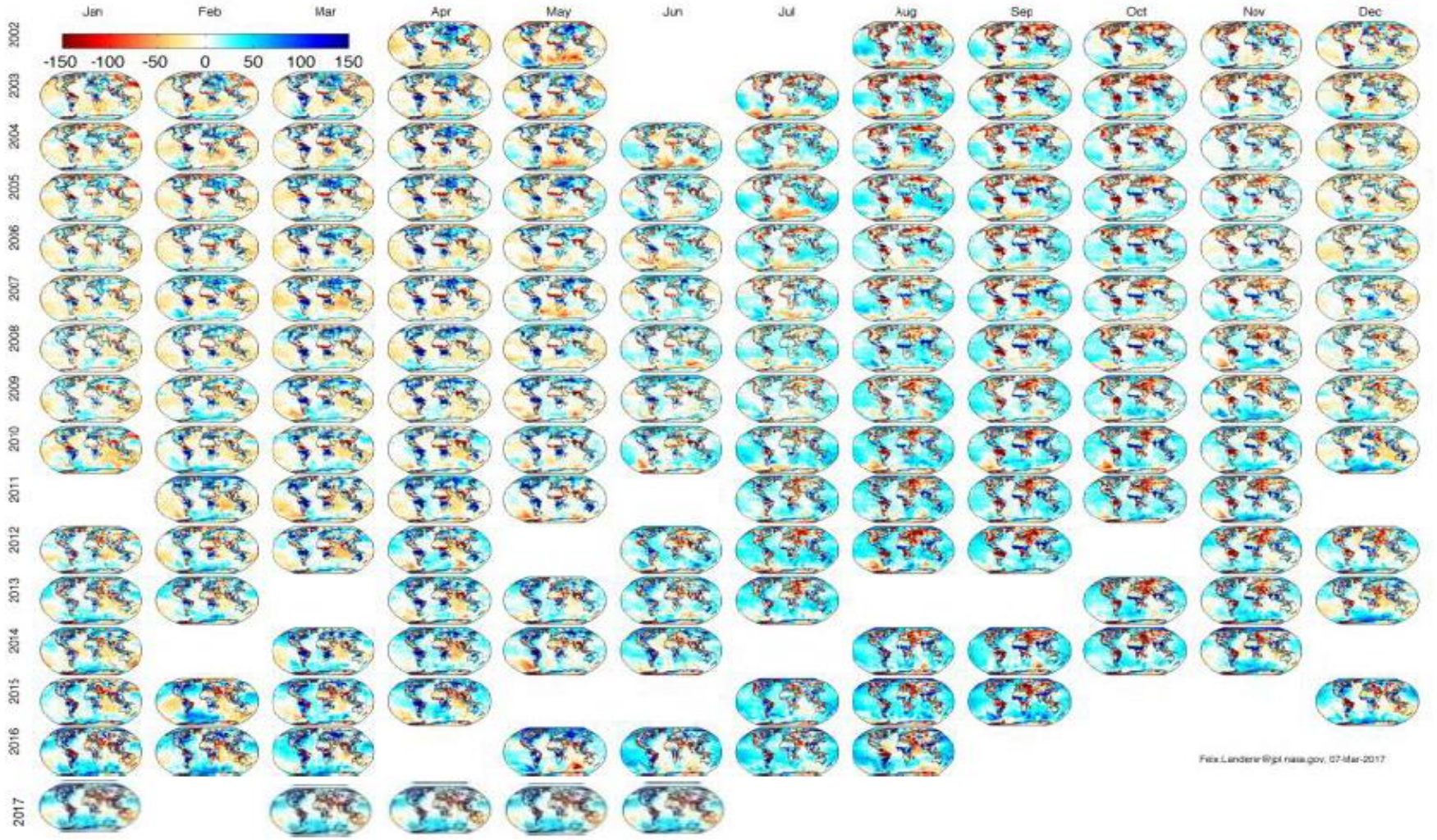

CSR RL05 Error Assessment

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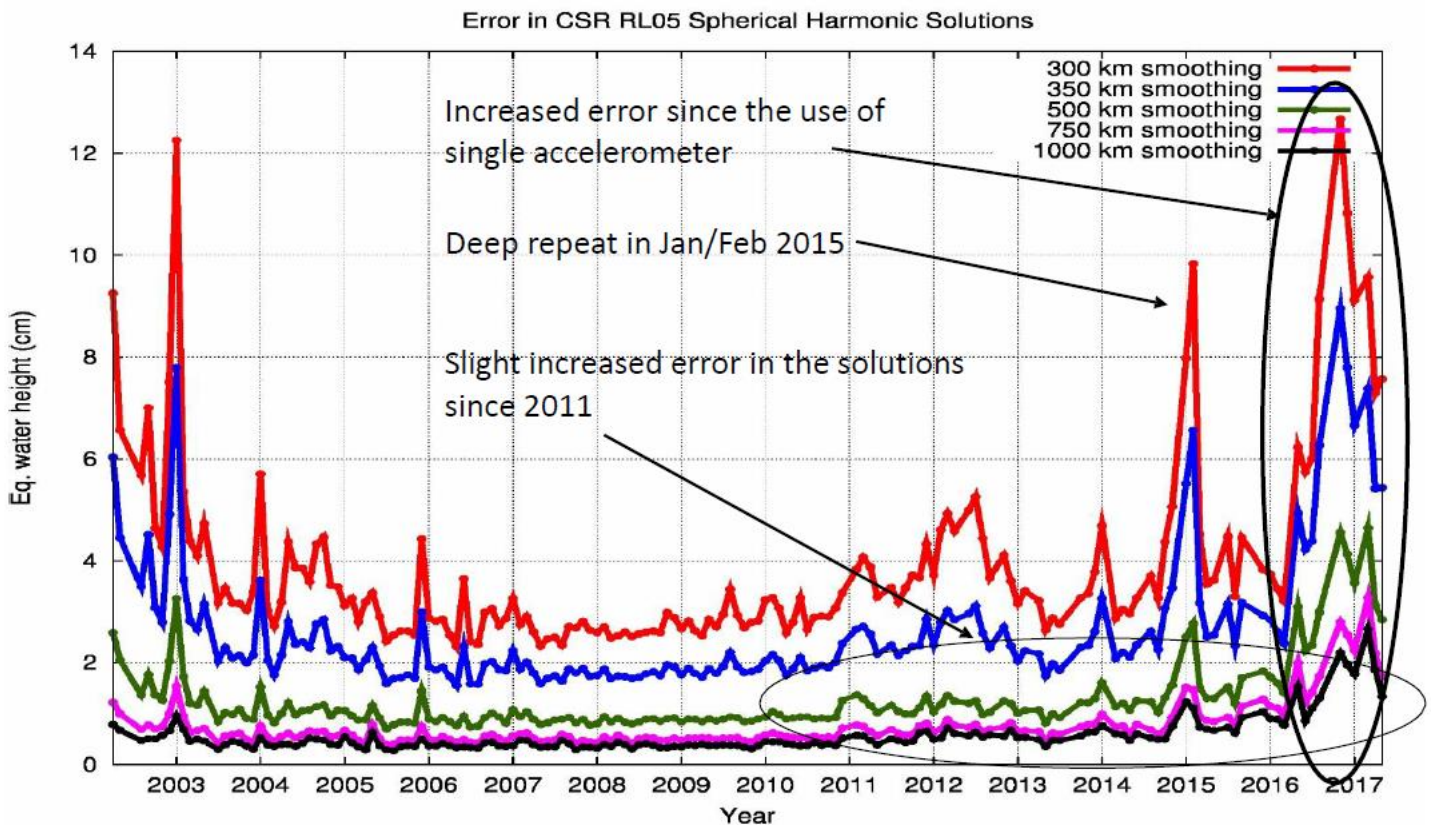

Users should use caution when using the RL05 spherical harmonic solutions after Nov 2016 for wavelengths shorter than 750 km.

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GRACE Mission Lifetime

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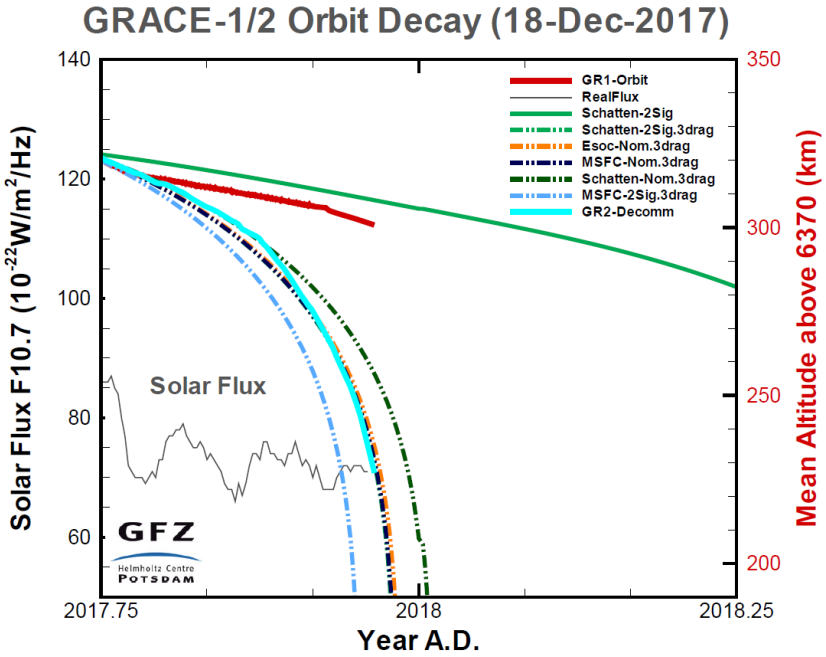
Mission lifetime was more than three times longer than originally planned because

a) the satellites and instruments behave extremely well and
b) the mission operations team (GSOC, JPL, Airbus D&S and GFZ) did a perfect job to operate GRACE-B despite of lost battery cells (at mission end 8 out of 20 had failed).



GRACE-2 burned up on Dec. 24 at 00:16 over the Norton Sound (inlet of the Bering Sea). GRACE-1 burn up is predicted for early March.

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Status of the GRACE Follow-On Mission

EGSIEM Final Meeting, Bern, CH
8 February 2018

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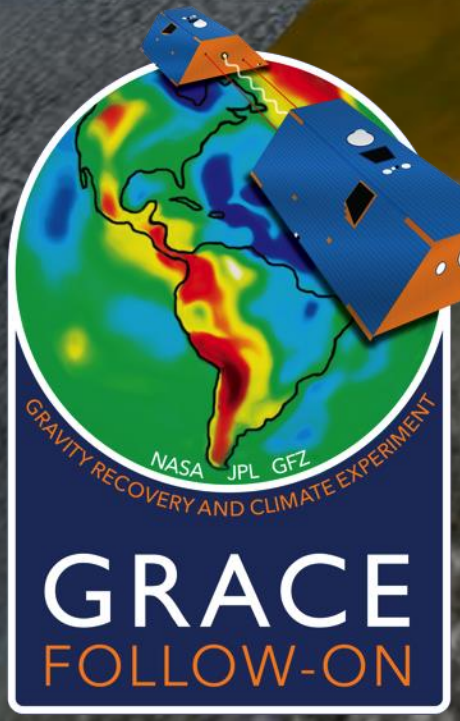
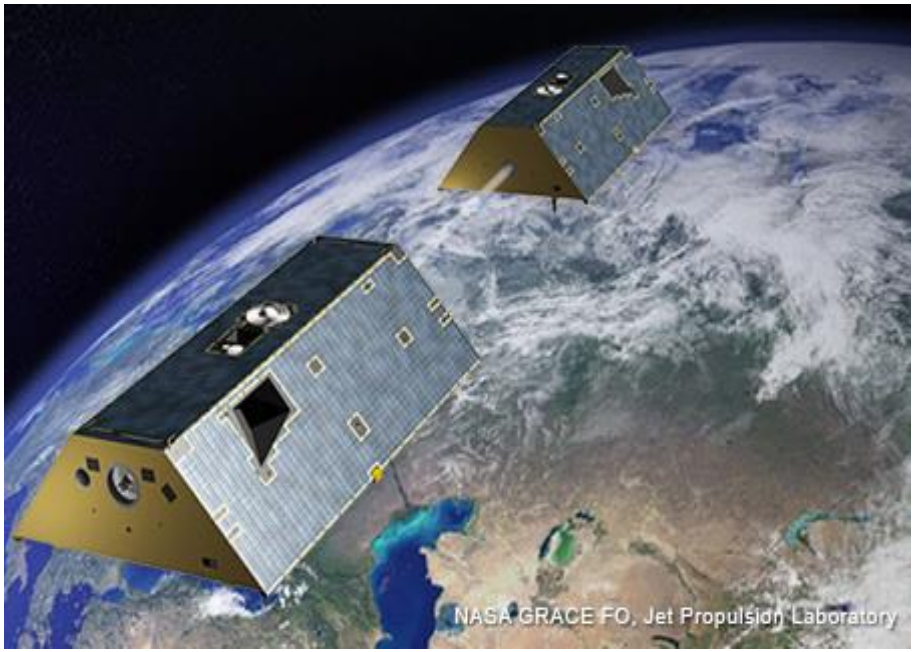


Outline

- **Background**
- **Project Status**
  - Implementation Status of Satellites and Instruments
  - Launch Vehicle
  - Mission Operations
  - Science Data System “Grand Simulation”
- **Activities after Launch**
  - LEOP, IOC, Initial Science Phase
- **Summary/Outlook**

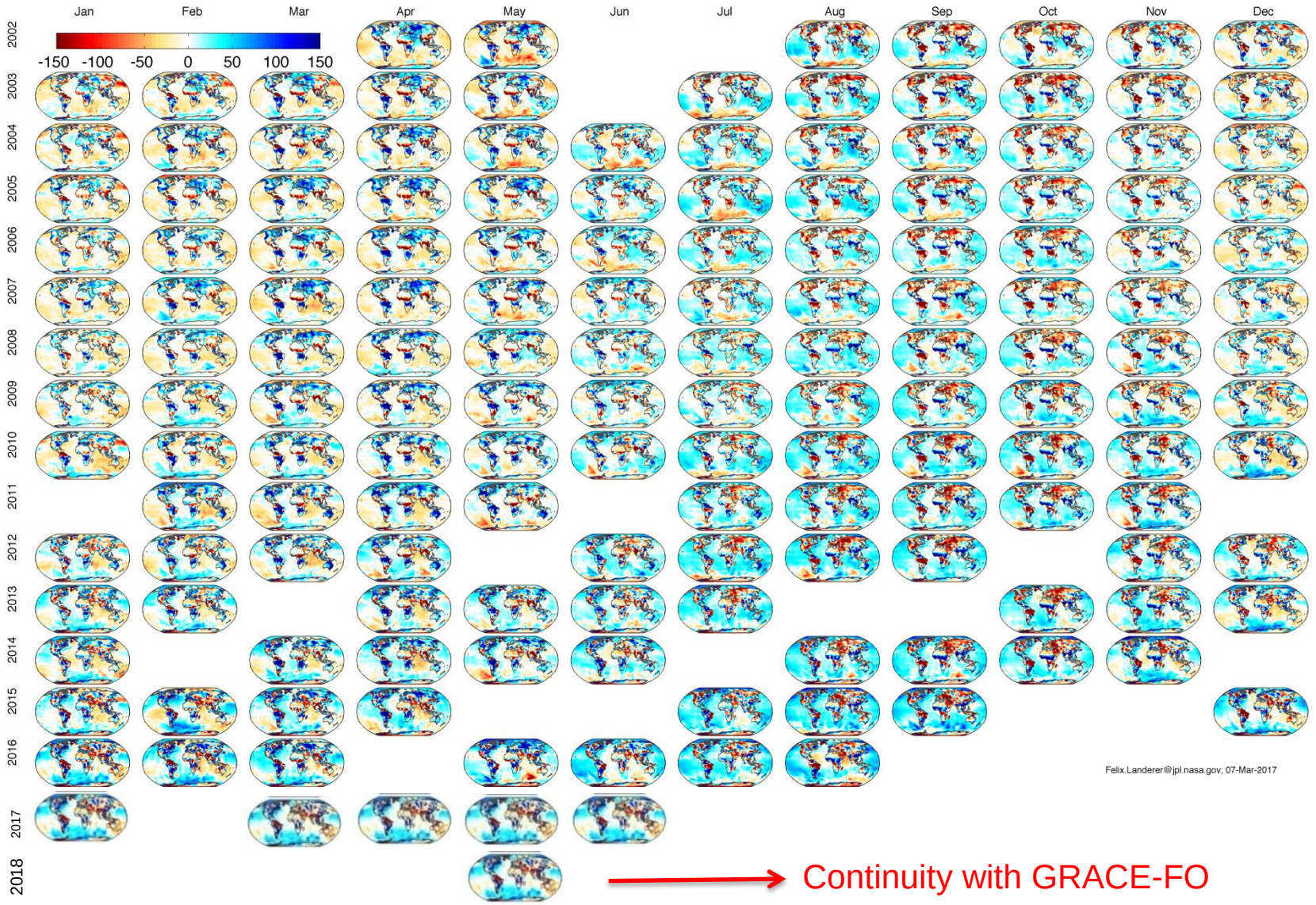


Background

- **Primary Mission Objective** is to continue to obtain the same extremely high-resolution global models of Earth's gravity field, including how it varies over time, as in the original GRACE mission, launched in 2002 and still operating.

- **GRACE-FO follows the original GRACE mission**
  - Continues the record as a gap filler between GRACE and a NGGM (e.g., GRACE-2)
  - Continues time series of RO measurements (secondary objective)
  - GRACE-FO will also demonstrate Laser Ranging Interferometer technology in support of future GRACE-like missions. This is an important component of interest to both NASA and ESA.

Continuity – from GRACE to GRACE-FO

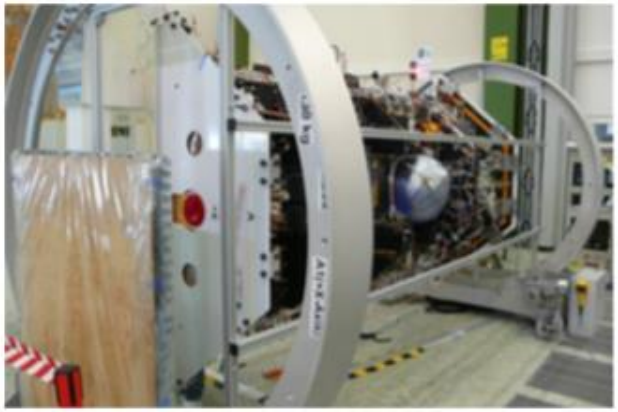


Implementation Status

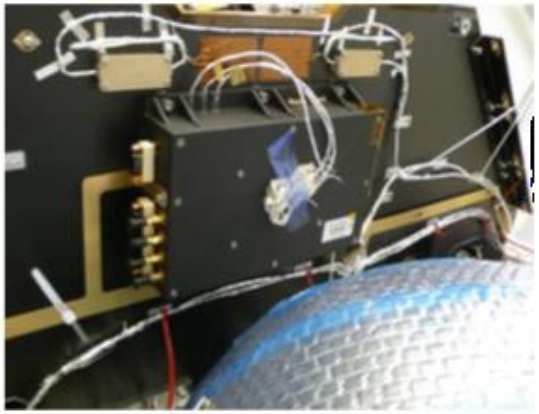
- Project is currently in ATLO (Assembly, Test, and Launch Operations) phase
  - Both flight systems (FM1 and FM2) have been fully integrated (i.e., Accelerometer, Star Cameras, MWI, LRI) till October 2016
  - All environmental testing has been completed at IABG (pre-ship Review on November 7/8, 2017)
  - Satellites have been flown to launch base VAFB, California on December 11/12, 2017
  - Integration activities started, waiting for final launch date approvement
- Following pictures show some highlights

Integration Highlights (@ Airbus D&S GmbH)

ACC/STR/TMA Integration
On FM1 with nominal shims



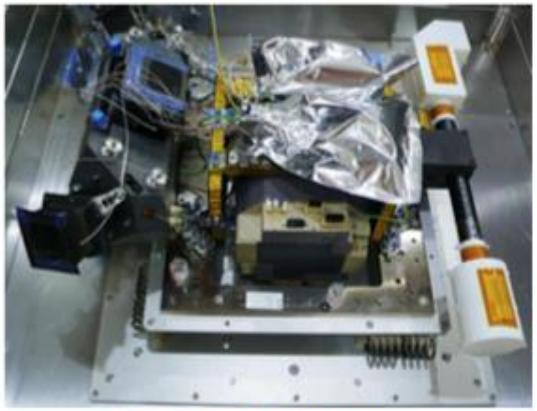
S/C FM1 Status



OBE Integration
Mechanical integration on FM1

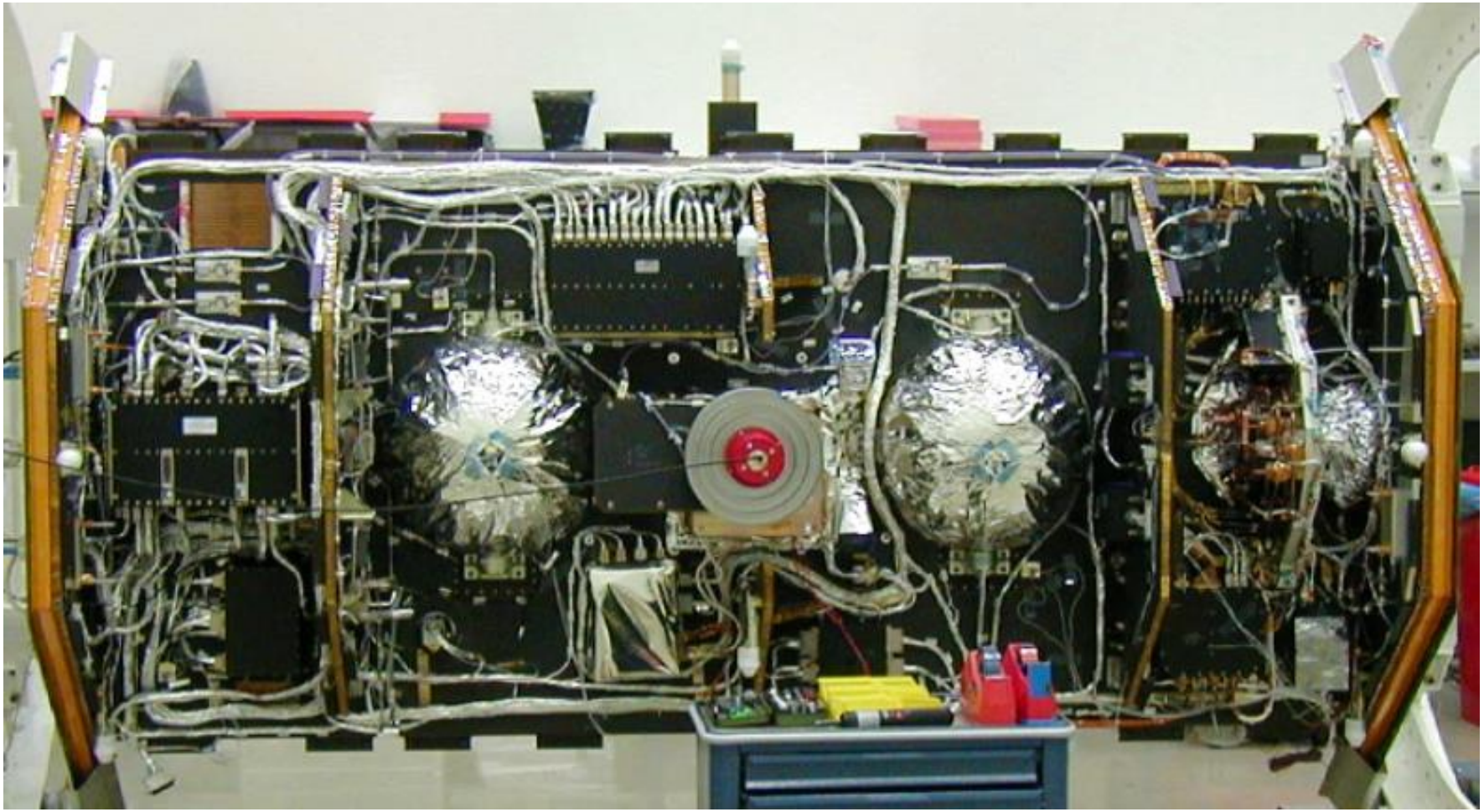
MTE integration
On FM2

MTQ Electrical Integration
During magnetic field measurement



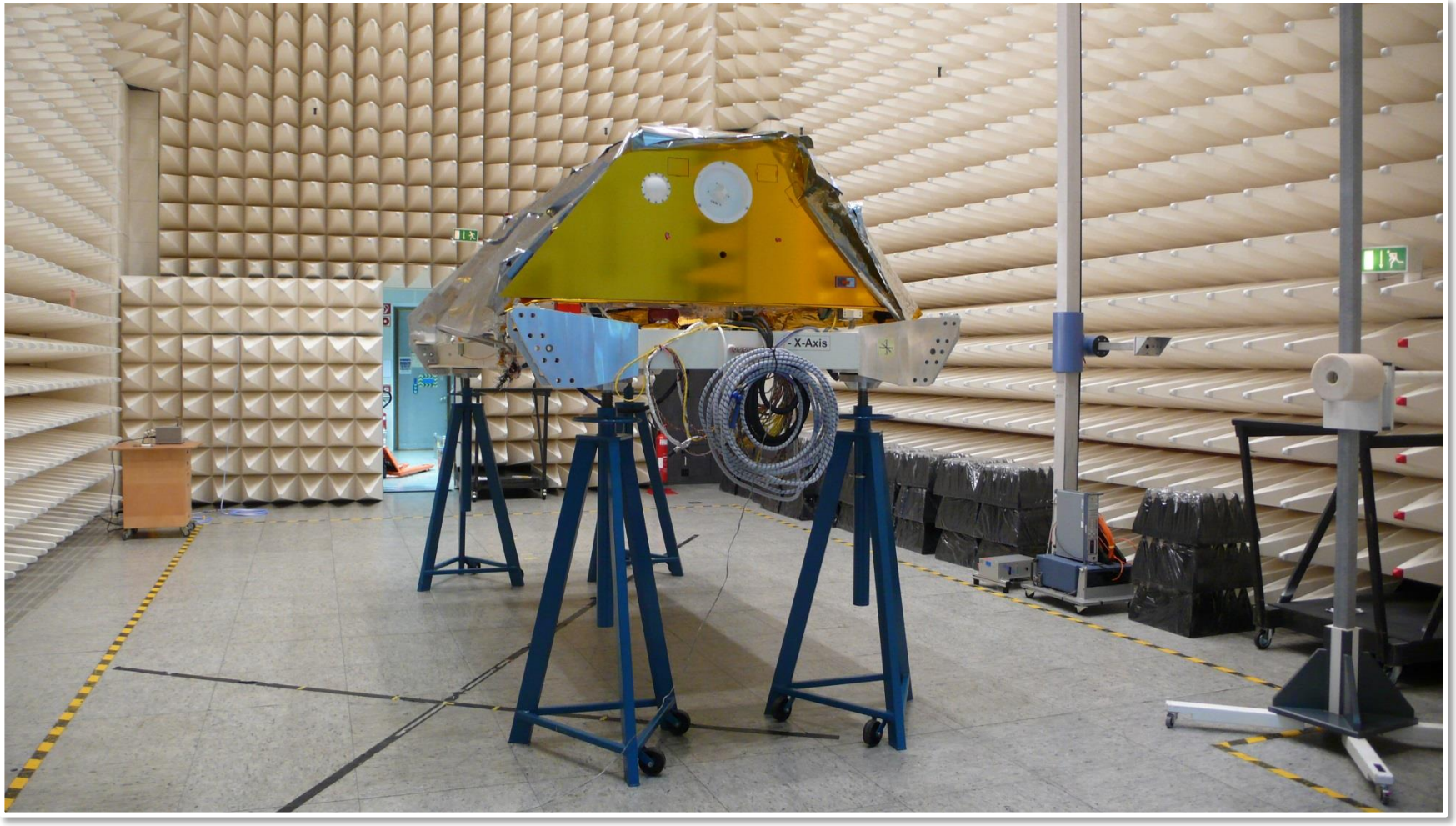
ACC/STR/TMA Integration
Final mounting of LRI TMA on FM1

FM1 during Integration (@ Airbus D&S GmbH)

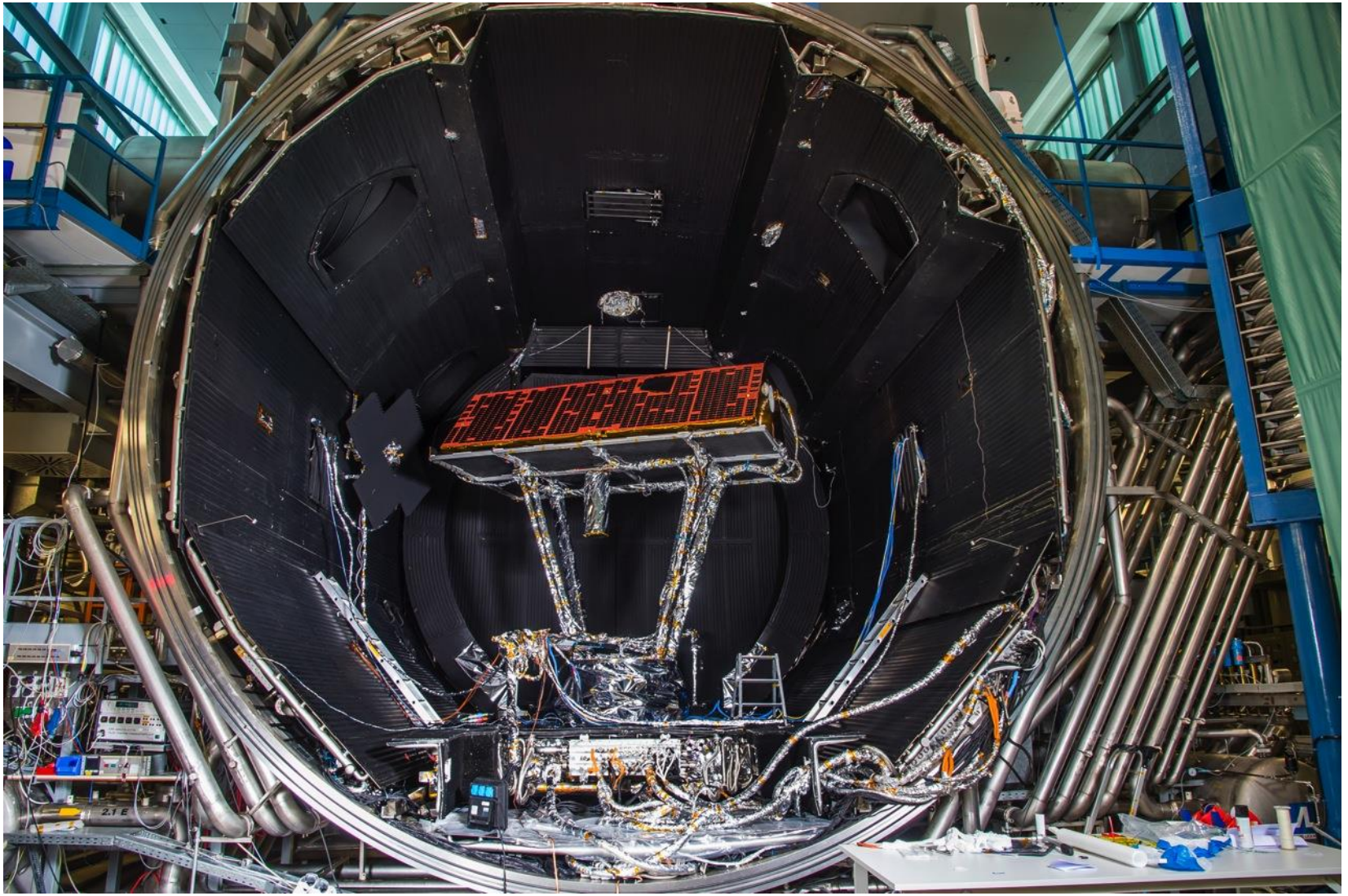


FM1 during Integration (@ Airbus D&S GmbH)

FM1 during EMC Test (@ IABG)



FM1 in Thermal Vacuum Chamber

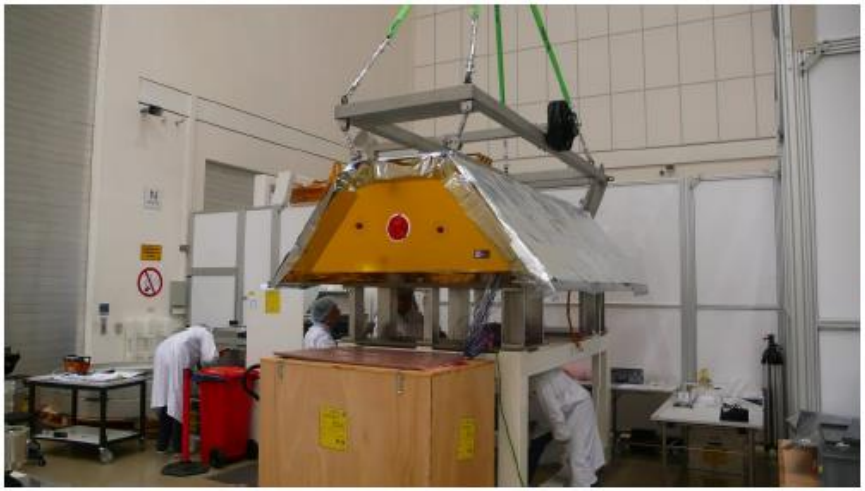


Vibe Tests & Boom Deployment Test

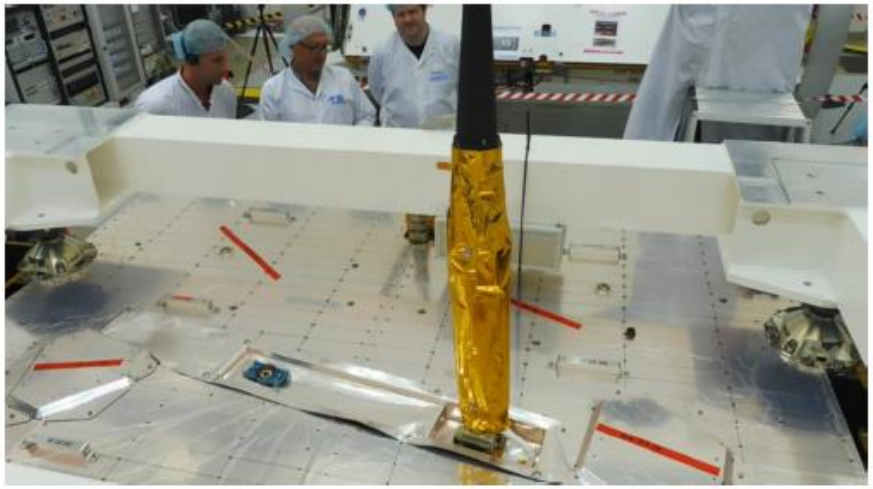
Highlights 6/2017

FM2 during sine testing (x-axis)

FM1 prepared for post-environmental alignment measurements

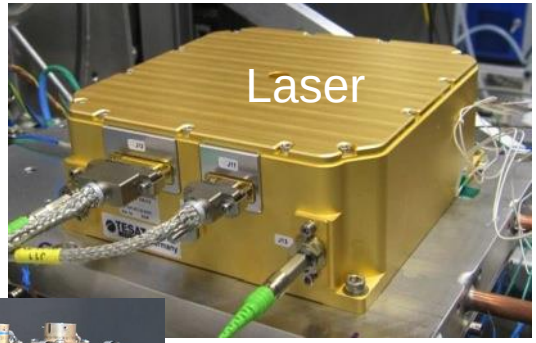


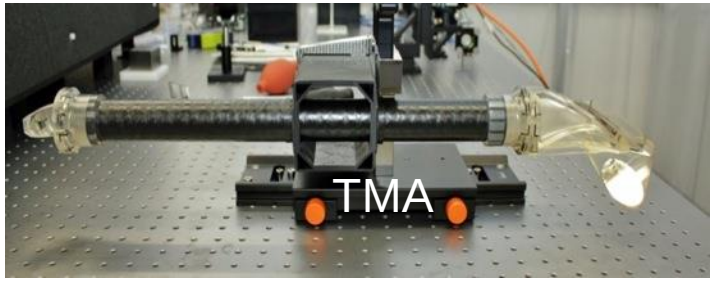
HRS removal on FM2 after sine testing

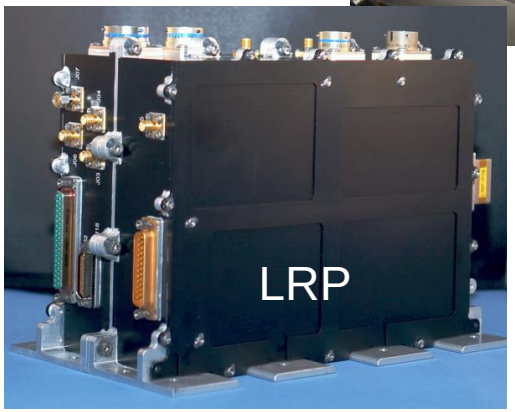


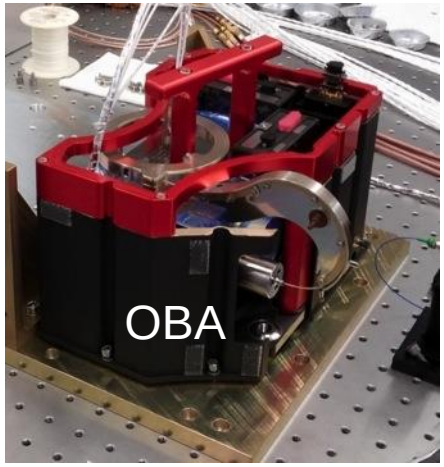
FM1 after successful boom deployment test

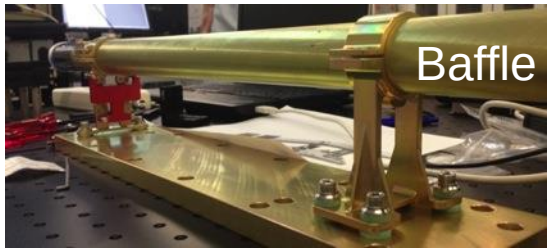
LRI components

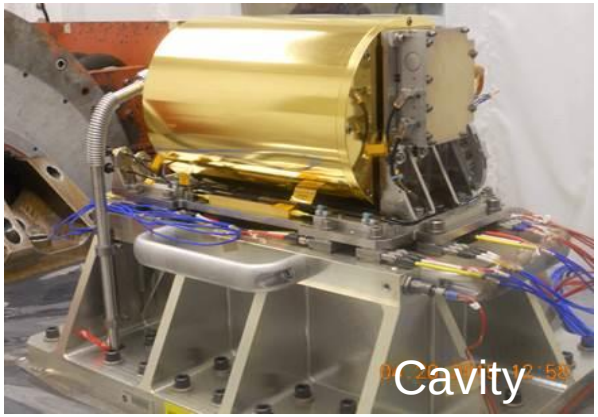












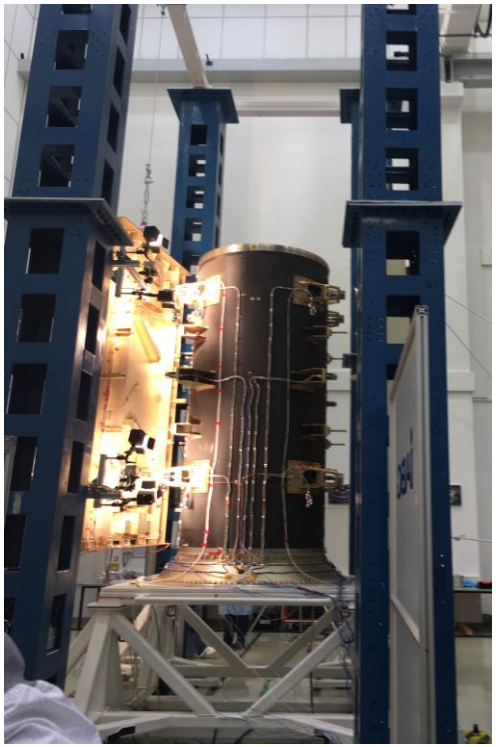
Cables not shown (complete):
LRP-CAV: power, coax (x2)
LRP-LAS: power, cmd/tel
LRP-USO: coax (x2)
OBE-LRP: coax (x4), cmd/tel
OBE-OBA: Tel, power

Launch Vehicle

- GRACE-FO is a collaboration between NASA, leading on the US side, and GFZ, leading on the German side.
  - GFZ is responsible for providing the launch services and the multi-satellite dispenser.
- GFZ was notified by Russian Foreign Ministry early 2016 that the Dnepr program is now on hold; subsequently, the GRACE-FO Project decided to pursue other launch opportunities in order to maintain schedule (original launch date was 5. August 2017).
- GFZ has signed in November 2016 a contract for a **ride-share launch with five Iridium NEXT Communications satellites** on a SpaceX Falcon 9 rocket from Vandenberg Air Force Base in California in the December 2017 – February 2018 timeframe.
- Due to reasons which are out of control of the GRACE-FO project (full order book at SpaceX, launch delays) the target launch date will now within 2nd half of April.

Multi Satellite Dispenser

- Built by CASA Espacio (Spain): long & robust history for this MSD design
- MSD delivered to IABG: July 7
- Fit check between SpaceX Payload Adapter Ring and MSD: July 18
- Fit Check MSD to S/C: July 27
- Separation Test MSD – S/C Dummies: September 19
- DRB Airbus – GFZ: September 25

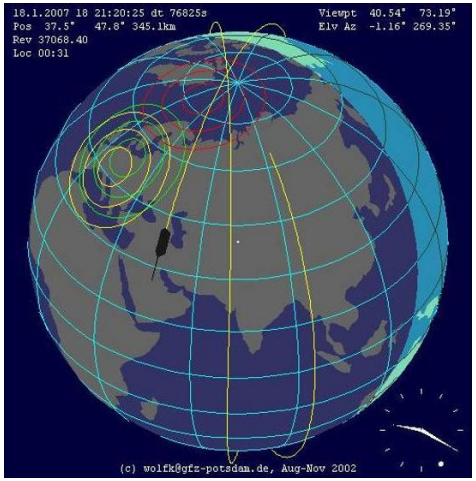


Transport to VAFB December 11/12, 2017

The GRACE-FO) satellites were loaded aboard an air freighter at Munich airport Dec. 11 and arrived at the launch site on California's central coast Tuesday, Dec. 12.

Mission Operations System (MOS)

- MOS and Phase E operations (5 years) are contributed (funded!) by GFZ
  - DLR/GSOC provides the GDS (based on existing multi-mission GDS) and Phase E operations (similar to GRACE mission) under contract to GFZ
  - GFZ provides and operates the primary downlink station at Spitzbergen and performs Flight Control Procedure (FCP) development and validation
  - DLR/GSOC & DLR/DFD provide the stations for uplink (& additional downlink)
  - NASA provides 4 NEN stations for LEOP and contingencies (up- & downlink)



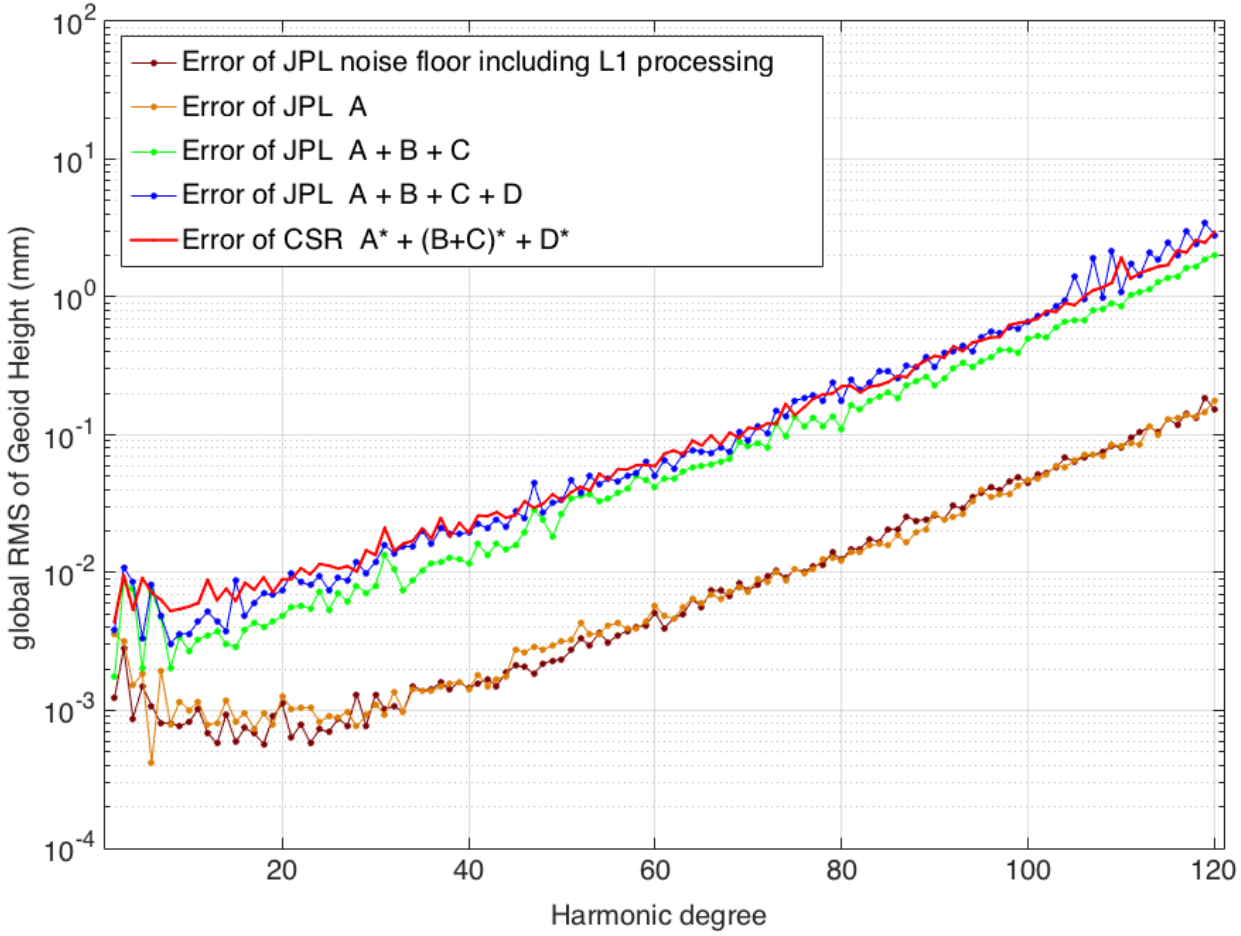
Operations Readiness Review successfully passed on 18./19. January: MOS is ready for Launch!

Science Data System (SDS): Grand Sim (1)

- Verify and Validate the SDS centers' software and interfaces using a realistic, simulated data set, including:
  - Current best estimate of instrument noise/errors: KBR, LRI, ACC, SCA & GPS
  - Timing errors, alignment errors
  - AOD product included, but no AOD errors or any other geophysical related errors
  - JPL has been conducting "Grand Simulation" tests

- "Grand simulation" data has been released to SDS end of December 2017

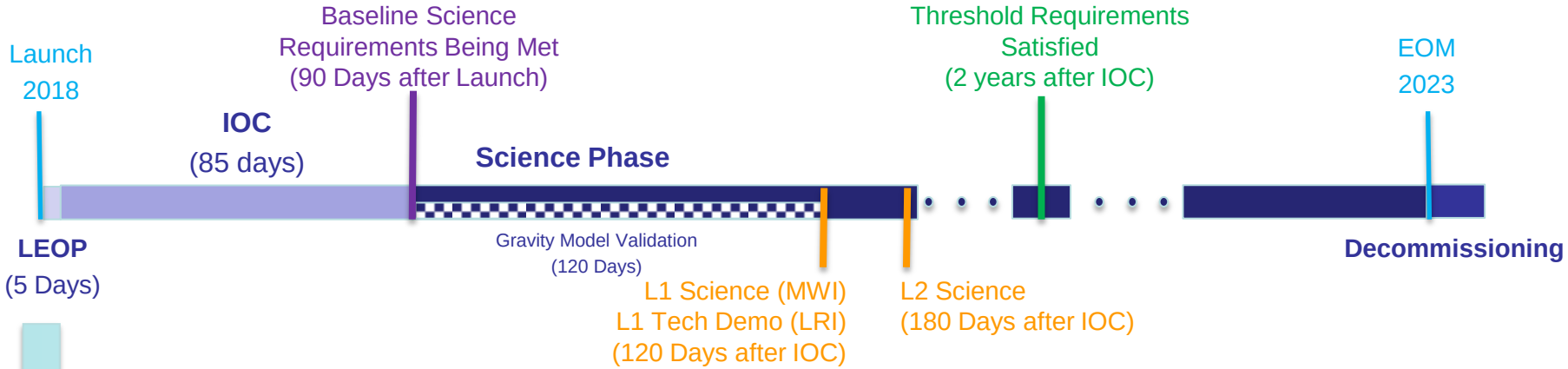
Science Data System (SDS): Grand Sim (2)



Plot shows JPL gravity errors as measurement noise sources (A,B,C,D) are successively included in the simulation

Same noise sources were provided to CSR (and GFZ) for an independent assessment for the JPL gravity error

After Launch: LEOP & IOC Activities / Time Line

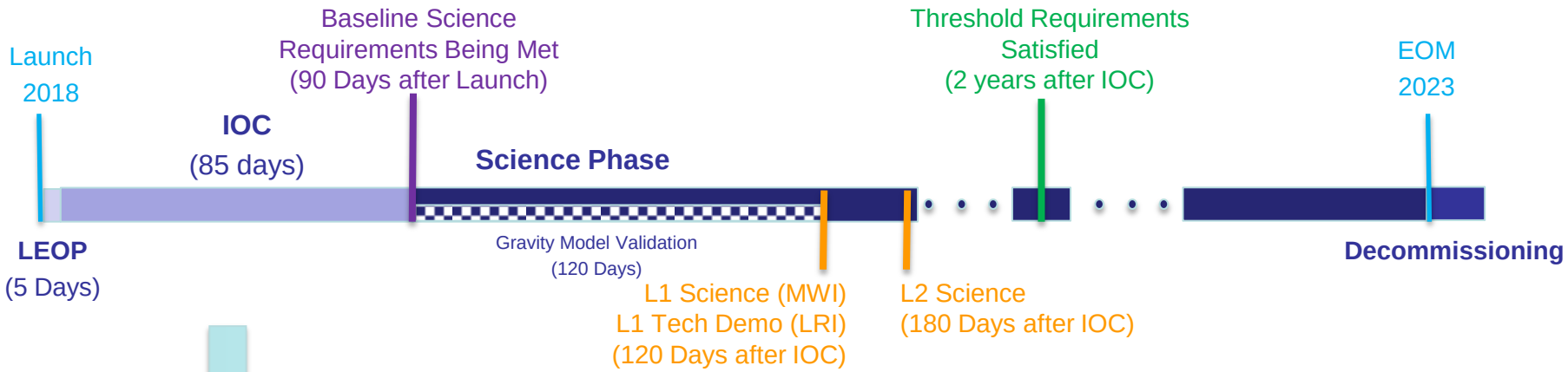


LEOP (~ 5 days)

Main Tasks:

1. Assess flight dynamics
2. Nominal uplink/downlink communications with ground stations
3. The nominal separation distance between the satellites has been achieved and stabilized
   - First GPS and SCA data
   - GPS data, clock, SCA quality analysis
   - Achieve orbit / separation specs
   - KBR baseband predicts
   - GPS-only precision orbit determination (POD)
   - AOCS performance analysis

After Launch: LEOP & IOC Activities / Time Line

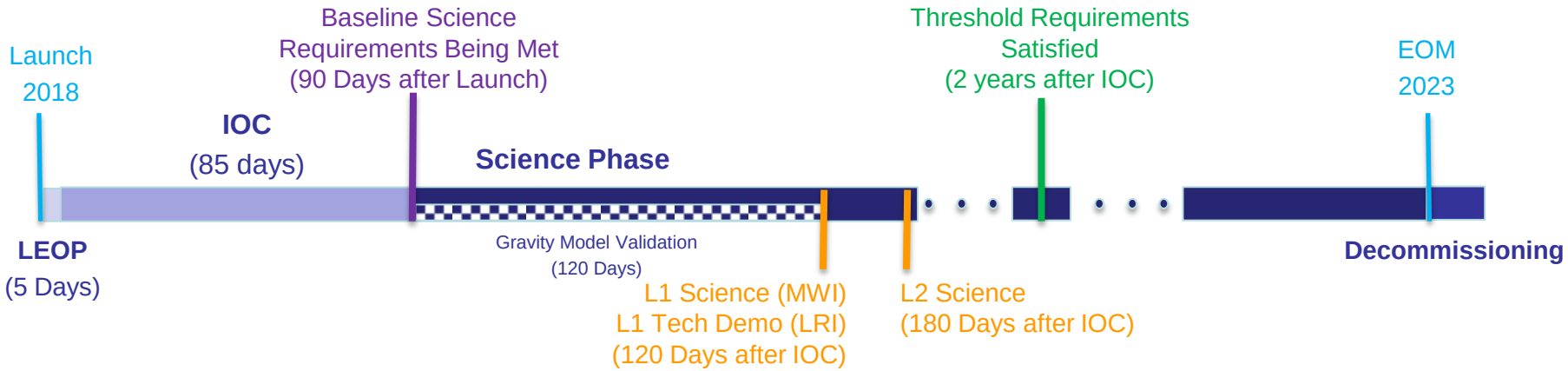


IOC (lasts 5-90 days after launch)

Main Tasks:

1. Full power-on and check-out of all systems
2. Instrument Calibrations / Characterizations
3. Achieve thermal stabilization of the 2 satellites in ops. mode
   - ACC On, 1st data analysis (temperature stable)
   - Calibration and trim of CoM offsets in three axes
   - KBR and LRI Boresights calibration
   - Turn-On LRI-1 & LRI-2: LRI initial acquisition / locking
   - Software patches and parameter updates (as required)
   - Flight system characterization
   - 1st Daily QL fields / fine tune
   - SDS inter-comparisons/validations/updates

After Launch: LEOP & IOC Activities / Time Line



Science Phase (begins 90 days after launch)

Main Tasks:

1. Validation over 120 days ***after*** IOC completion; focus on providing an end-to-end characterization of the Science Instrument and Data Systems prior to first science delivery.
   - Continuous records of science data down-linked, any data flow problems are resolved.
   - The KBR bore-sight calibration is verified.
   - Precise orbit solutions are obtained and verified using terrestrial laser tracking data.
   - Initial solutions for the gravity field, along with ACC, LRI and MWI calibration
   - gravity field solutions are verified through a combination of internal consistency checks and comparisons with in-situ data.
   - Complete 3 monthly gravity models and perform Inter-comparison
   - 120 days after IOC: first official **GRACE-FO Level-1** delivery to User Community!
   - 180 days after IOC: first official **GRACE-FO Level-2** delivery to User Community!

Summary

- GRACE-FO satellites have arrived at launch site
- MOS successfully passed ORR on January 18/19
- “Grand Simulation” – Science Data System
  - Testing the complete SDS system from science telemetry to science Level-2/3 products and serves as the V&V.
  - though somewhat delayed, SDS still plans to distribute data to community
- Launch Vehicle
  - Switched to Falcon-9 (shared ride with Iridium-Next)
  - Target launch date is 2nd half of April
- First data sets to user community 120/180 days after IOC
- GSTM2018 at GFZ in Potsdam on October 9-12, 2018