

Status of the GRACE Follow-on Mission

GRACE Science Team Meeting
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**Michael. Watkins⁽¹⁾, Frank Flechtner⁽²⁾
Phil Morton⁽¹⁾**

(1) Jet Propulsion Laboratory, California Institute of
Technology, Pasadena, CA, USA

(2) GFZ German Research Centre for Geosciences,
Potsdam, Germany



Outline

- Introduction
- Project Status
 - Programmatic Level
 - Project System and Subsystem Level focusing on
 - LRI PDR
 - Launcher Selection
 - Science Simulations KBR vs. LRI
- Summary/Outlook

Mission Objectives

The mission's **primary objective** is to continue the high-resolution monthly global models of Earth's gravity field of the original GRACE mission, for a nominal length of 5 years, with launch by 2017

- Evolved versions of the GRACE K/Ka-band microwave interferometer, GPS, and accelerometer will be used

A **secondary objective** is to demonstrate the effectiveness of a laser ranging interferometer (LRI) in improving measurement performance

- This will be the first ever inter-spacecraft laser interferometer
- This system should lead to improved spatial resolution for future gravity missions, such as GRACE-II (although the final spatial resolution will depend on aliasing, number of satellite pairs, etc)

and to continue measurements of GRACE radio occultations for operational provision of e.g. vertical temperature / humidity profiles to weather services.

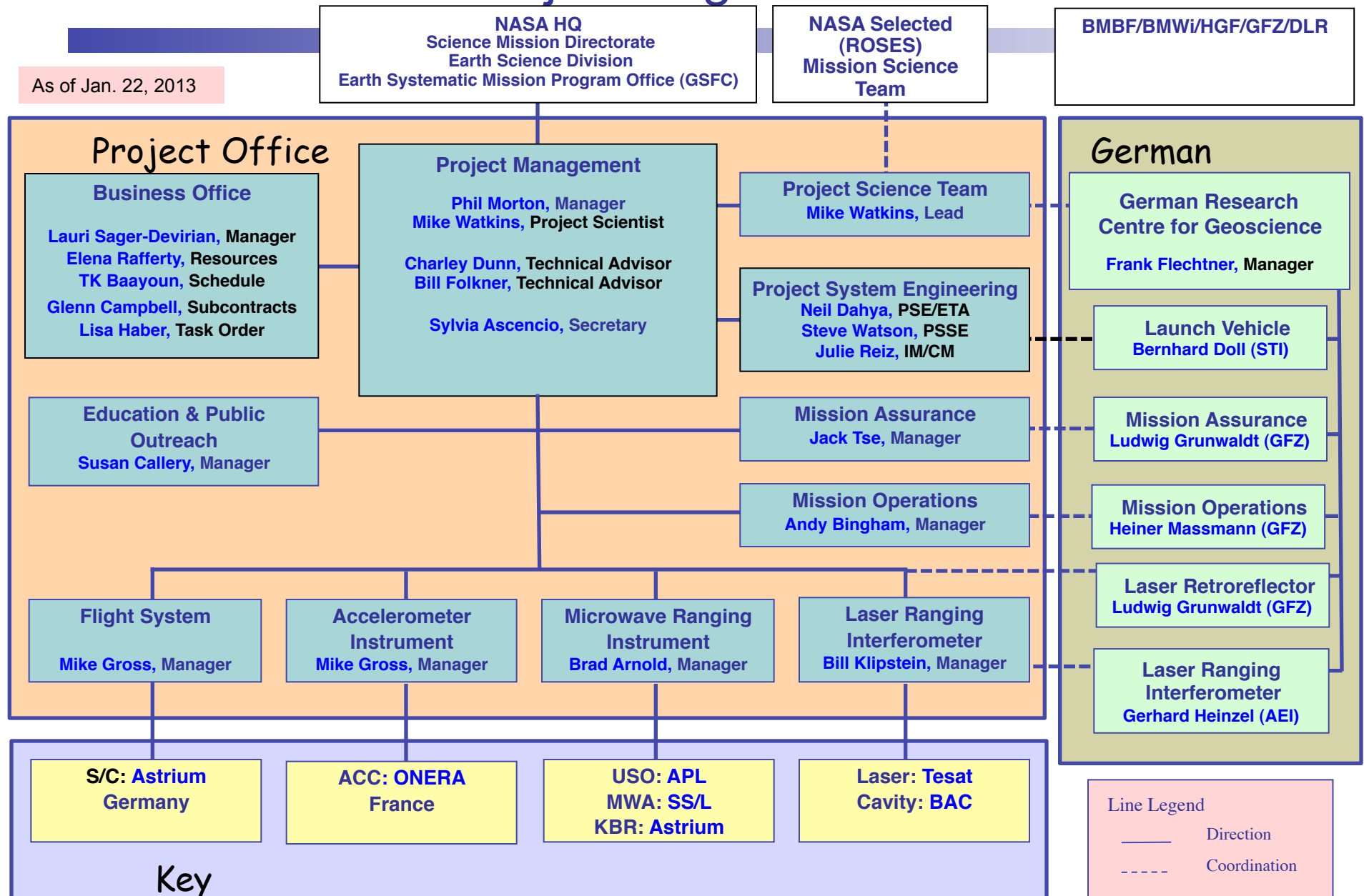
GRACE-FO Heritage and Work Breakdown

WBS Element	Contributor	Lead	GRACE Heritage	Comments
01 Project Mgmt	NASA	JPL	Yes	JPL led project (per GRACE)
02 Project Sys Eng	NASA (except LV)	JPL Germany (LV)	Yes	JPL led project (per GRACE)
02.08 LV	Germany	GFZ/STI	No	Contributed by Germany (DNEPR)
03 System & MA	NASA	JPL Astrium (S/C)		JPL led project (per GRACE)
04 Project Science	NASA / Germany	JPL	Yes	NASA supports US team, GFZ will lead European Team
05 Payload				
05.04 μ wave/IPU	NASA	JPL	Yes	3 rd generation of BlackJack used on GRACE
05.05 ACC	NASA	ONERA	Yes	Per GRACE, next generation microstar
05.06 LRI	NASA/Germany	JPL/AEI/STI/ DLR/Astrium	No	See separate slide for detail
06 Spacecraft	NASA	Astrium	Yes	3 rd gen of FlexBus used on GRACE
07 Mission Ops	Germany	GFZ	Yes	Contributed by Germany (DLR/GSOC)
09 Ground Sys	Germany	GFZ	Yes	Contributed by Germany (DLR/GSOC)
10 Systems I&T	NASA	Astrium	Yes	Included in WBS 06 S/C, Astrium
11 Education&PO	NASA	JPL	Yes	PL led project (per GRACE)

Recent NASA/Germany Programmatic Developments

GRACE-FO Project Organization

As of Jan. 22, 2013



NASA GRACE-FO Status October 2013 (1)

- Project progress at system and subsystem level continues in 2013.
Completed
 - Attitude and Orbit Control System (AOCS) PDR February 26-28 at Astrium, Germany.
 - Ultra-Stable Oscillator (USO) CDR February 28 at APL.
 - K-Band Ranging Subsystem Mechanical/Thermal PDR March 7-8 at Astrium.
 - LRI Laser Stabilization Cavity EDU CDR March 14 at Ball Aerospace.
 - MWI PDR April 29 at JPL
 - MWI Microwave Assembly CDR June 4 at Space Systems / LORAL
 - ACC Electronics PDR, Steel, France July 17-18
 - LRI Laser CDR, Tesat, Germany Aug. 7

NASA GRACE-FO Status October 2013 (2)

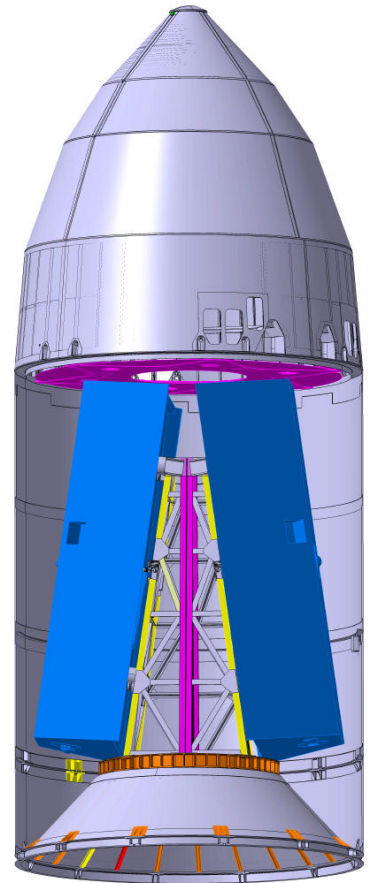
- GRACE-FO SDS Meeting held Oct. 22 before GSTM2013 (Austin, Oct 22-24)
- NASA-GFZ MOU and NASA-GFZ Cooperative Project Plan nearly completed and due for signature prior to **Project PDR in January 2014**
 - Many other gate products/plans developed in support of PDR
 - SDS Development Plan, Science Management Plan, Data Management Plan and draft MOU, etc

Recent German Programmatic Developments

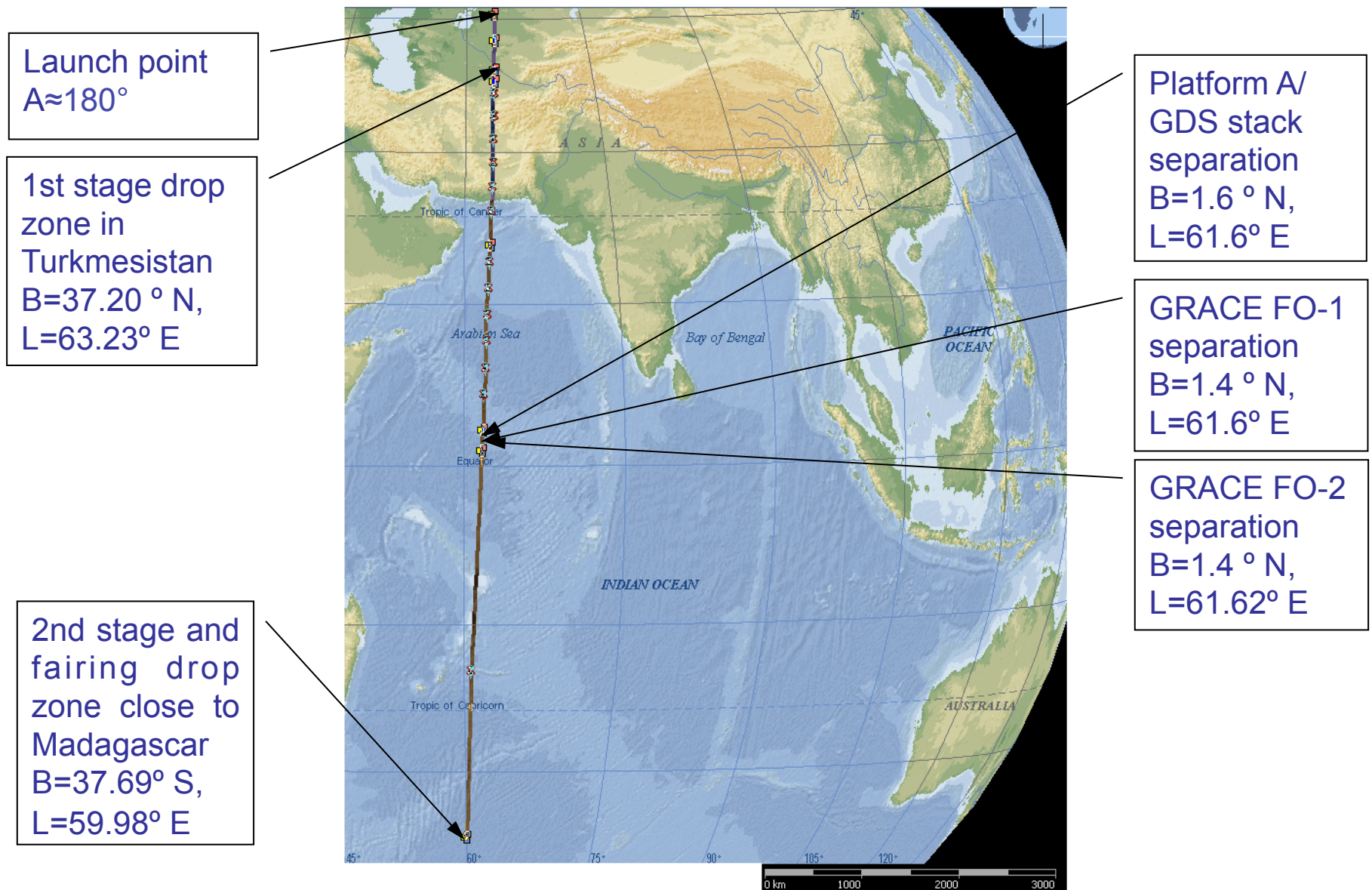
- Germany will contribute to GRACE-FO with a Launcher, major contributions to the Laser Ranging Instrument (LRI), Mission Operations, and Science.
- Management of German contributions by GFZ.
- Final funding confirmation has been received by BMBF in May 2013: Baseline for various decisions (contracts, cooperation agreements) on Launcher and LRI (see next slides).

Orbit/Launcher

- Baseline co-planar Orbit (launch 5.8.2017):
 - $a = 490 \pm 10 \text{ km}$
 - $i = 89.0 \pm 0.06^\circ$
 - $e < 0.0025$
- Launcher RfQ has been send in May 2012 to appropriate launch providers (Eurockot (ROCKOT), Kosmotras (DNEPR), ArianeSpace (VEGA)).
- Only DNEPR fulfilled German budgetary constraints.
- Initiated small study with Kosmotras to investigate various open issues (separation, adaptor, loads, drop zone etc.): Successful final presentation took place 8-10 April 2013.
- Launcher decision (jointly with NASA, JPL, KSFC and ASD): June 20 2013 at GFZ
- Contracting of Kosmotras planned for end of September 2013.
- Launcher & Launch Services Management contracted from GFZ to STI
- Successful KOMPSAT-5 launch on August 22 from Yasny launch base (Russia)



DNEPR Specifics – Drop Zones



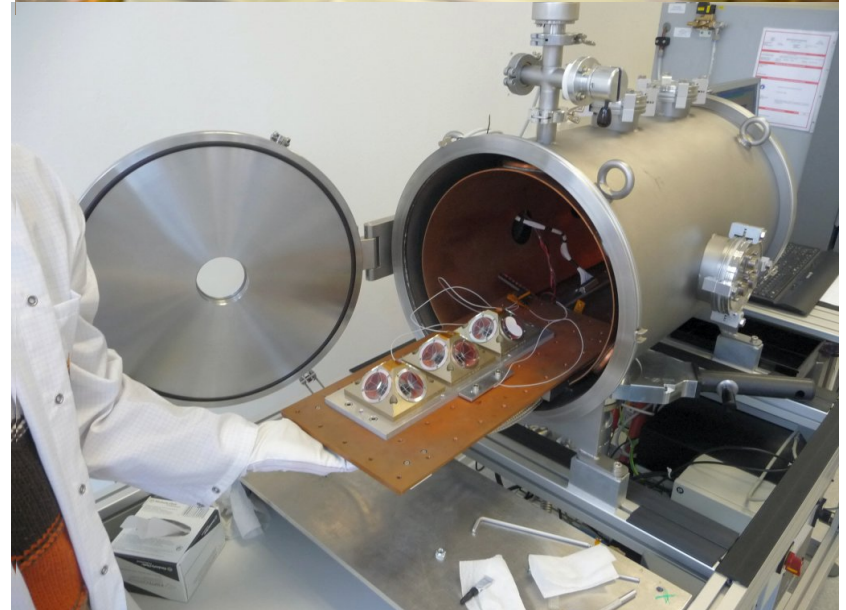
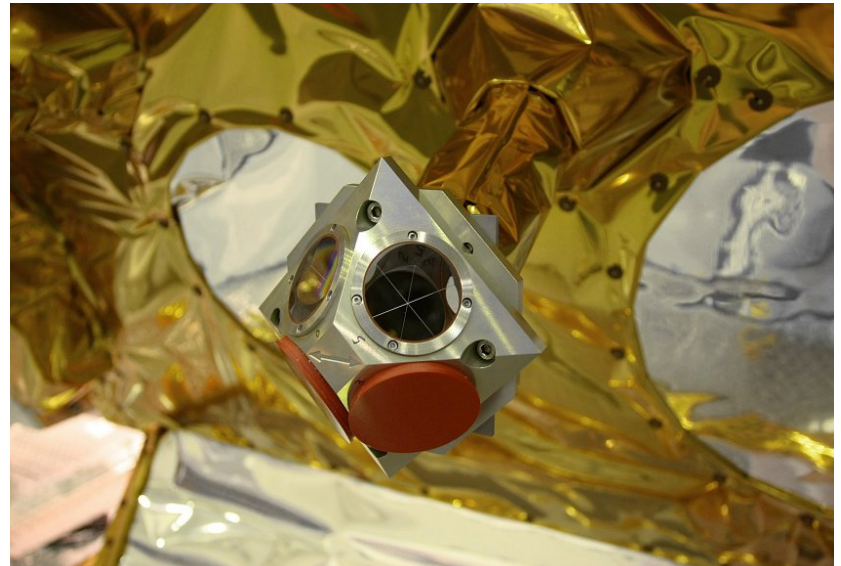
Mission Operations

- Will be funded by GFZ
- Agreement to contract DLR/GSOC be contracted for the first 5 years (Preparation, LEOP, Commissioning, Routine Ops) as for GRACE
- GFZ: Ops Mission Manager (Massmann), flight procedures and NYA receiving station (backup GSOC, RO data reception)
- Funding of additional years will be discussed within HGF mid of September
- MOS Kick-off Meeting scheduled for October 28/29 in Oberpfaffenhofen (JPL, ASD, GSOC, GFZ)
- Several documents have to be available for System PDR in January 2014
- MOS PDR: 15./16. July 2014

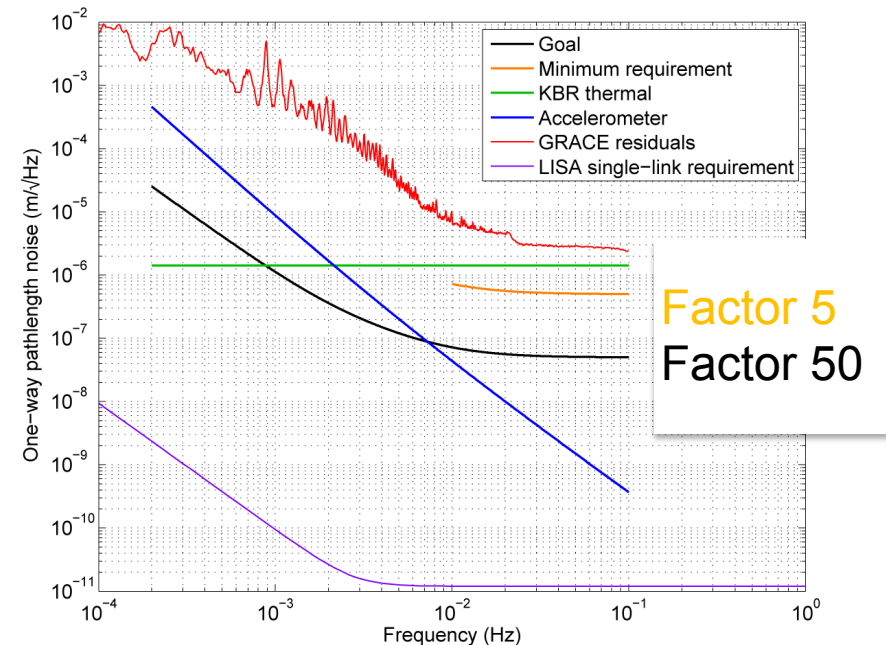
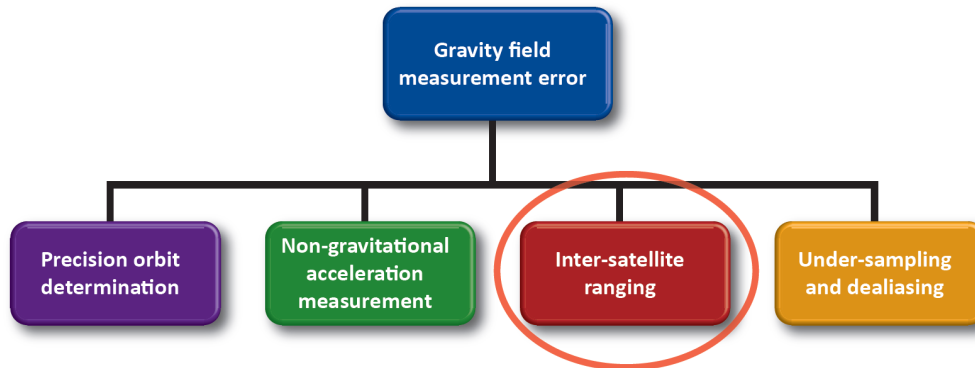


Laser Retro Reflectors

- GFZ will contribute a Laser Retro Reflector (LRR) for each of both GRACE-FO satellites as part of the scientific payload.
 - External calibration/validation of GPS-based POD
 - Design heritage from CHAMP, GRACE, TerraSAR-X and Swarm
 - Single-shot ranging accuracies of few millimeters



LRI Top Level Requirements



- LRI shall be operated in parallel to MWI

- **Minimum requirements** (“mission success criteria”)

- $\sigma_{SST}(f) = 500\text{nm}/\text{SQRT}(\text{Hz}) * \text{NSF}(f)$
- operation time = 1 year

$$10\text{mHz} < f < 100\text{mHz}$$

- **Goal**

- $\sigma_{SST}(f) = 50\text{nm}/\text{SQRT}(\text{Hz}) * \text{NSF}(f)$
- operation time = $\gg 1$ year

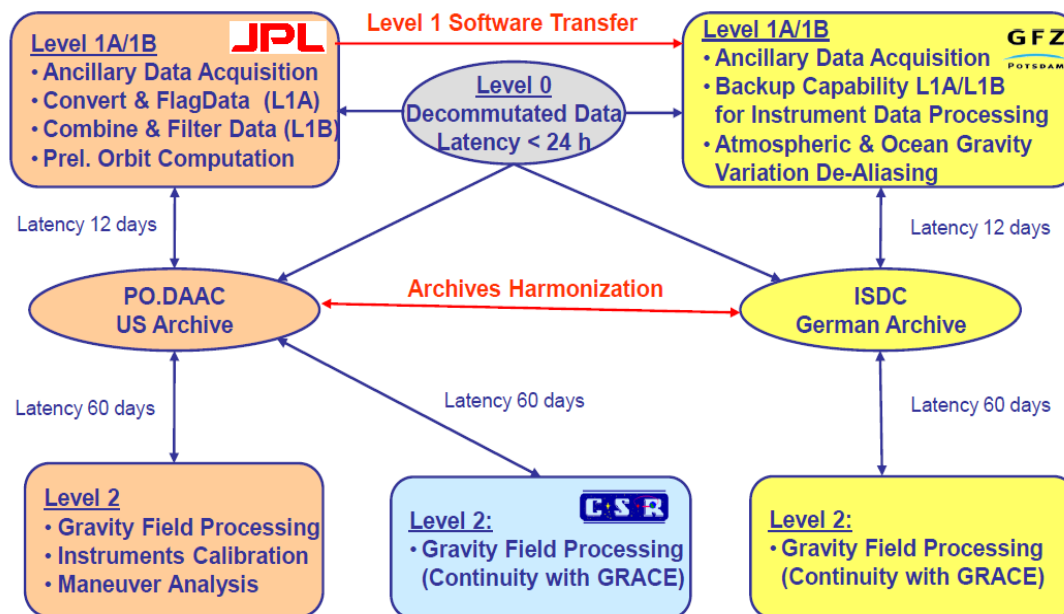
$$0.2\text{mHz} < f < 100\text{mHz}$$

Joint US/D LRI PDR (May 30/31) Board Report

- PDR incorporated and recapped the results of previously conducted LRI element peer PDRs (5 reviews) and subsystem pre-PDR reviews (5 reviews).
- The collaboration appears to be a strong one. This is largely due to the individuals from both the US and Germany who are world experts in their disciplines and are obviously very committed to the success of the effort.
- There was a large contingent from Germany at the review, indicative of their strong support for this instrument. Both US and German technical leads presented in the PDR.
- The Germans experienced a late start but now have their funding in place.
- The overall development program is sound.
- **The Board members unanimously agreed that all the Review Success Criteria have been met and that the Payload is clearly ready to proceed into Phase C/D.**

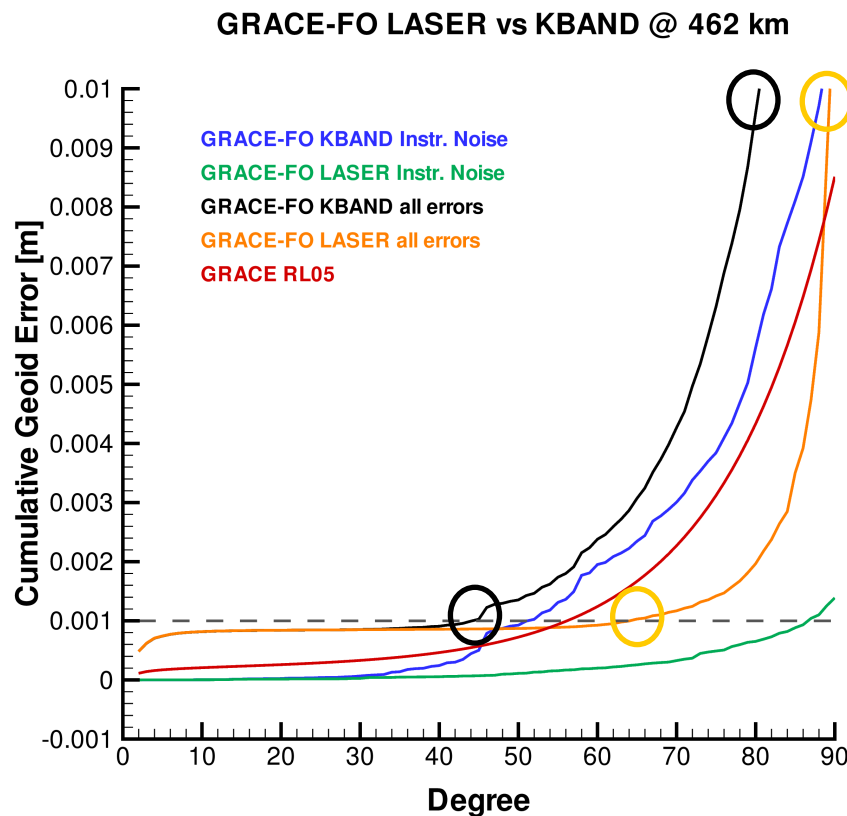
Science

- Joint US/German SDS
- Most important issues investigated till launch
 - inclusion of LRI observations
 - further reduction of aliasing errors
 - definition of L3 products



- A focused US project science group is already established
 - Open call for full team expected in 2014
- European Science Team: Initial meeting @ GSTM2012; meeting during IAG2013 in Potsdam
- GRACE-FO data will be publicly available (after validation)

System Performance (MWI vs. LRI, Preliminary)



Simulation Assumptions:

- Altitude: 462 km (mean GRACE RL05)
- Nmax: 90
- Duration: 32 days
- KBR 2.1 μm range noise (0.24 $\mu\text{m/s}$ range-rate)
- LRI 50 nm range noise (6.7 nm/s range-rate)
- ACC $1 \cdot 10^{-10} \text{ m/s}^2$ (both cases)
- Background Model Errors:
 - EIGEN-GL04C -> EGM96
 - EOT08a -> GOT4.7
 - 10% AOHIS (ESA AOD1B model)

K-Band: 1cm geoid @ $n \sim 80$

LRI: 1cm geoid @ $n \sim 90$

K-Band: 1mm geoid @ $n \sim 45$ (RL05 ~ 55)

LRI: 1mm geoid @ $n \sim 65$

Summary

- The GRACE Follow-On project is moving forward on both sides of the Atlantic towards a targeted launch in August 2017:
- MWI PDR completed 9 April 2013
- LRI PDR successfully passed on 29/30 May 2013
- Laucher (DNEPR) selected, contract ready for signature
- Mission operations will be done by DLR/GSOC, KO Meeting scheduled for 28/29 October 2013
- Project PDR planned for 20-24 January 2014
- Key Decision Point C and start of Phase C/D planned for February 21, 2014.