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Results from the NASA Mass Change Designated Observable Study

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GRACE-FO Science Team Meeting | October 2021

Three Focus Areas and their Research and Applications Objectives

HYDROLOGY

H-1. How is the water cycle changing?

H-2. How do anthropogenic changes in climate, land use, water use, and water storage, interact and modify the water and energy cycles locally, regionally, and globally and what are the short- and long-term consequences?

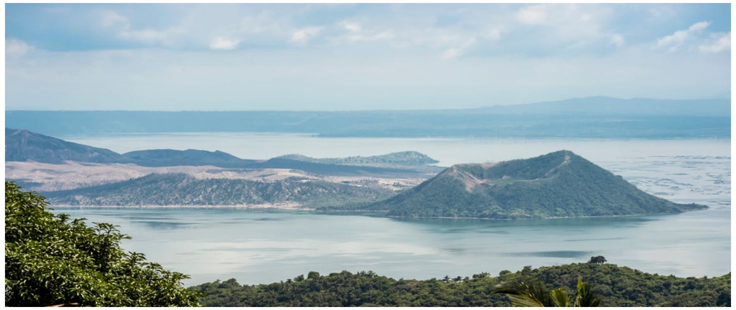
H-3. How do changes in the water cycle impact local and regional freshwater availability, alter the biotic life of streams, and affect ecosystems and the services these provide?

H-4. How does the water cycle interact with other Earth System processes to change the predictability and impacts of hazardous events and hazard-chains, and how do we improve preparedness and mitigation of water-related extreme events?

CLIMATE

C-1. How much will sea level rise globally and regionally, over the next decade and beyond, and what will be the role of ice sheets and ocean heat storage?

C-7. How are decadal scale global atmospheric and ocean circulation patterns changing, and what are the effects of these changes on seasonal climate processes, extreme events, and longer-term environmental change?



SOLID EARTH

S-1. How can large-scale geological hazards be accurately forecast in a socially relevant timeframe?

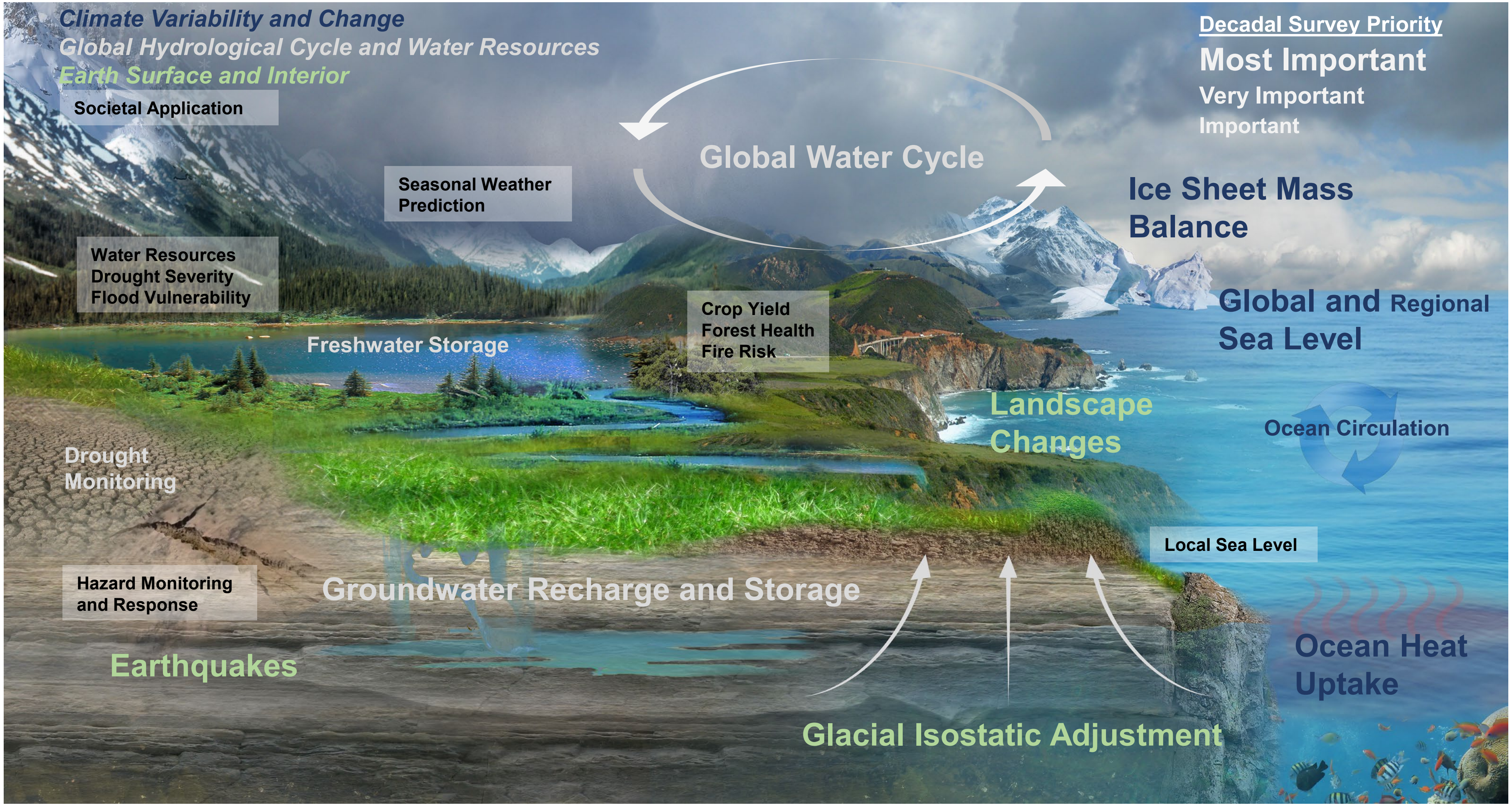
S-3. How will local sea level change along coastlines around the world in the next decade to century?

S-4. What processes and interactions determine the rates of landscape change?

S-5. How does energy flow from the core to the Earth’s surface?

S-6. How much water is traveling deep underground and how does it affect geological processes and water supplies?

Mass Change Science and Applications at a Glance



Climate Variability and Change

Global Hydrological Cycle and Water Resources

Earth Surface and Interior

Societal Application

Decadal Survey Priority

Most Important

Very Important

Important

Global Water Cycle

Seasonal Weather Prediction

Water Resources
Drought Severity
Flood Vulnerability

Ice Sheet Mass Balance

Crop Yield
Forest Health
Fire Risk

Freshwater Storage

Global and Regional Sea Level

Landscape Changes

Ocean Circulation

Drought Monitoring

Local Sea Level

Hazard Monitoring and Response

Groundwater Recharge and Storage

Ocean Heat Uptake

Earthquakes

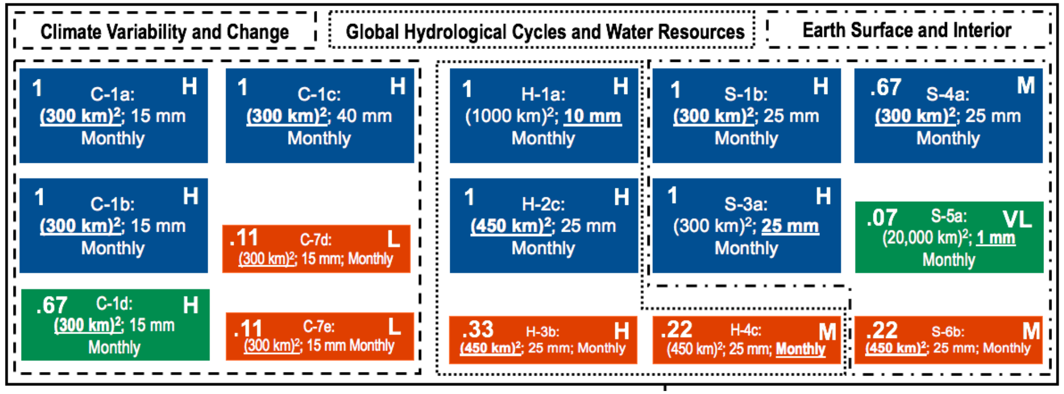
Glacial Isostatic Adjustment

Mass Change Designated Observable Study identifies high-value observing systems for implementation within the next decade

Decadal Survey

Traceability to Decadal Survey

Science and Applications Traceability Matrix (SATM) Baseline Measurement Parameters



Climate Variability and Change

1 C-1a: H
(300 km)²; 15 mm
Monthly

1 C-1c: H
(300 km)²; 40 mm
Monthly

1 C-1b: H
(300 km)²; 15 mm
Monthly

.11 C-7d: L
(300 km)²; 15 mm; Monthly

.67 C-1d: H
(300 km)²; 15 mm
Monthly

.11 C-7e: L
(300 km)²; 15 mm Monthly

Global Hydrological Cycles and Water Resources

1 H-1a: H
(1000 km)²; 10 mm
Monthly

1 H-2c: H
(450 km)²; 25 mm
Monthly

.33 H-3b: H
(450 km)²; 25 mm; Monthly

.22 H-4c: M
(450 km)²; 25 mm; Monthly

Earth Surface and Interior

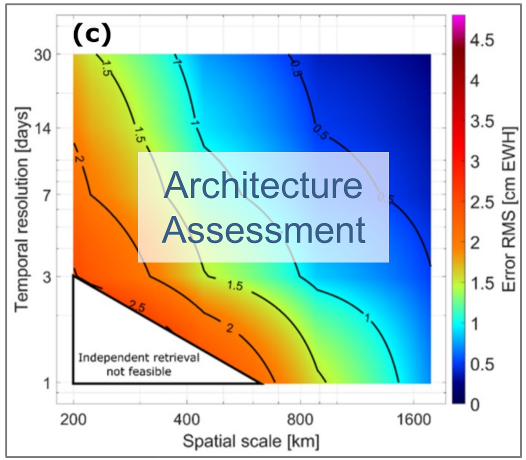
1 S-1b: H
(300 km)²; 25 mm
Monthly

1 S-3a: H
(300 km)²; 25 mm
Monthly

.67 S-4a: M
(300 km)²; 25 mm
Monthly

.07 S-5a: VL
(20,000 km)²; 1 mm
Monthly

.22 S-6b: M
(450 km)²; 25 mm; Monthly



Architecture Assessment

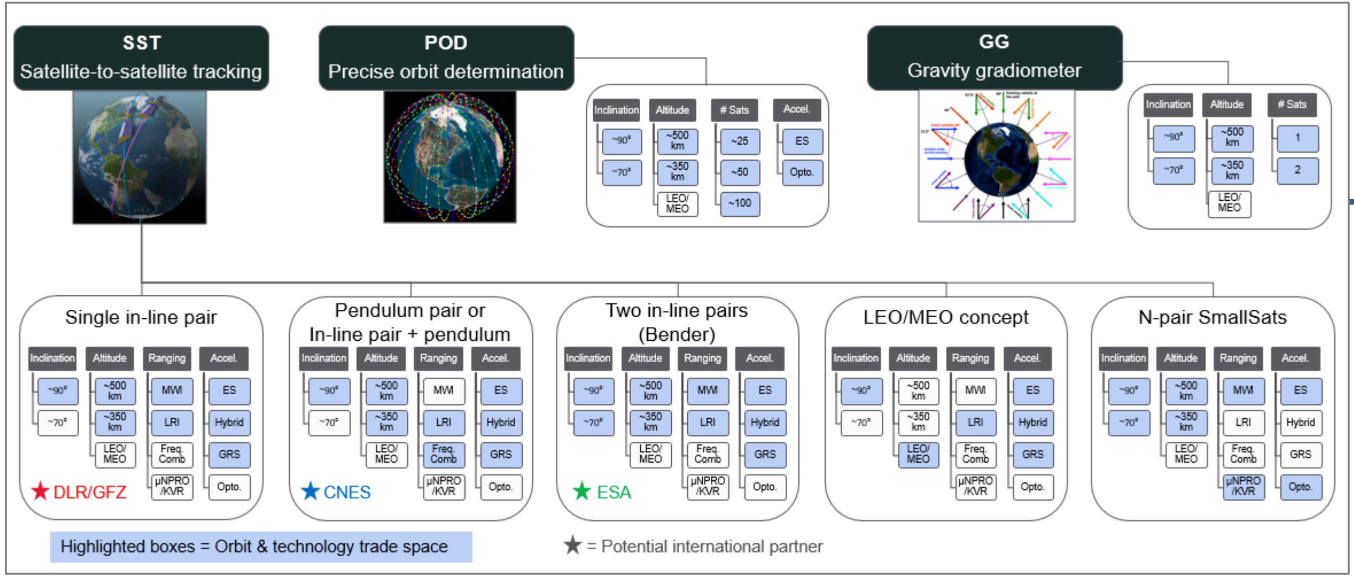
Science Value

Value Framework Process

- Cost
- Schedule
- Risk
- Partnerships

Identification of High-Value MC Observing Systems

Architecture and Technology Tradespace



Highlighted boxes = Orbit & technology trade space

★ = Potential international partner

CNES	Centre National d'Études Spatiales
DLR	Deutsches Zentrum für Luft-und Raumfahrt
ES	electrostatic
ESA	European Space Agency
EWH	equivalent water height
GFZ	German Research Centre for Geosciences
GRS	Gravitational Reference Sensor
LEO	low Earth orbit
LRI	laser ranging interferometer
MEO	medium Earth orbit
MWI	Microwave Interferometer
RMS	root mean square

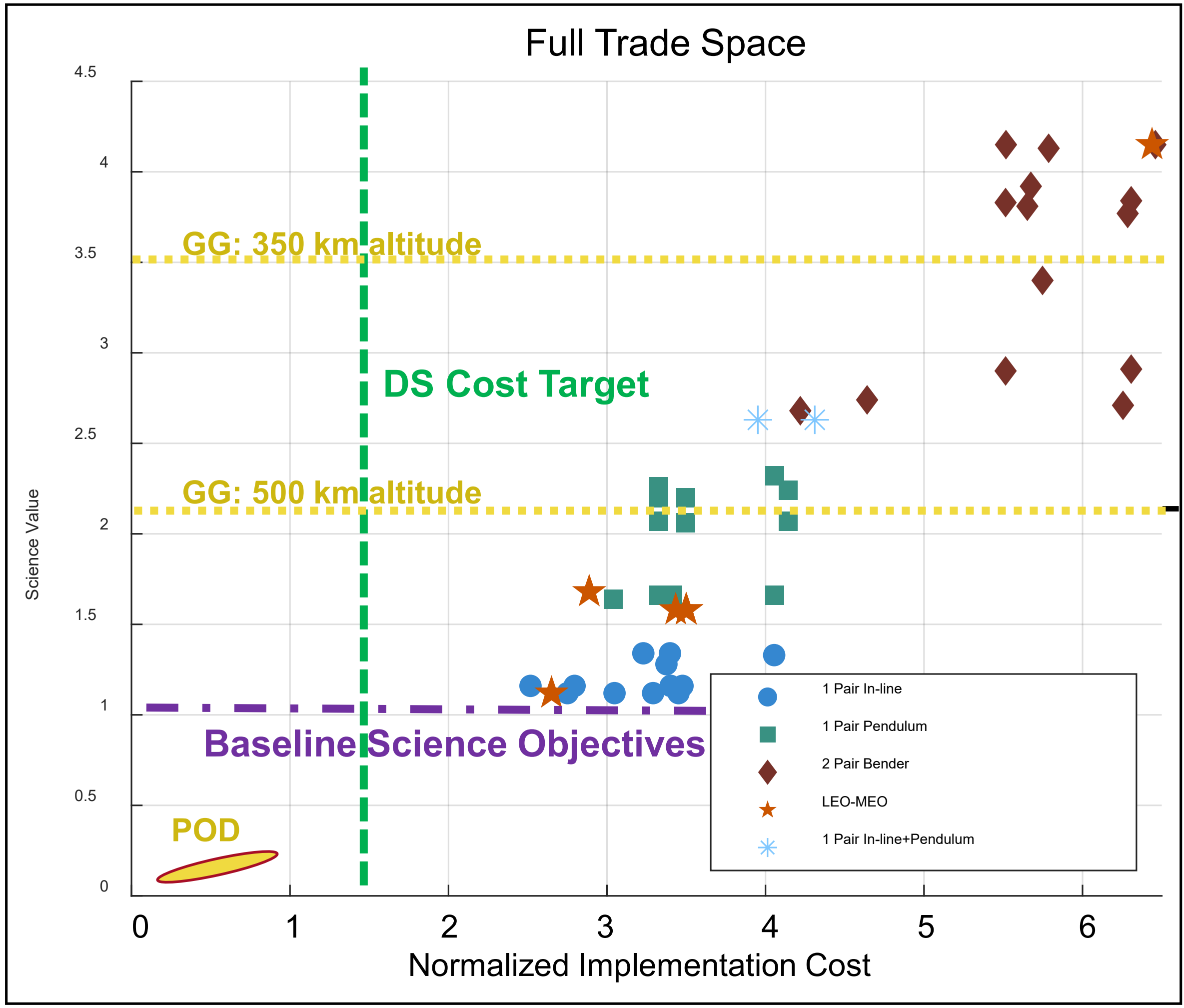
Satellite-Satellite-Tracking (SST) is the recommended architecture family for implementation as the next observing system

Architectures Pruned

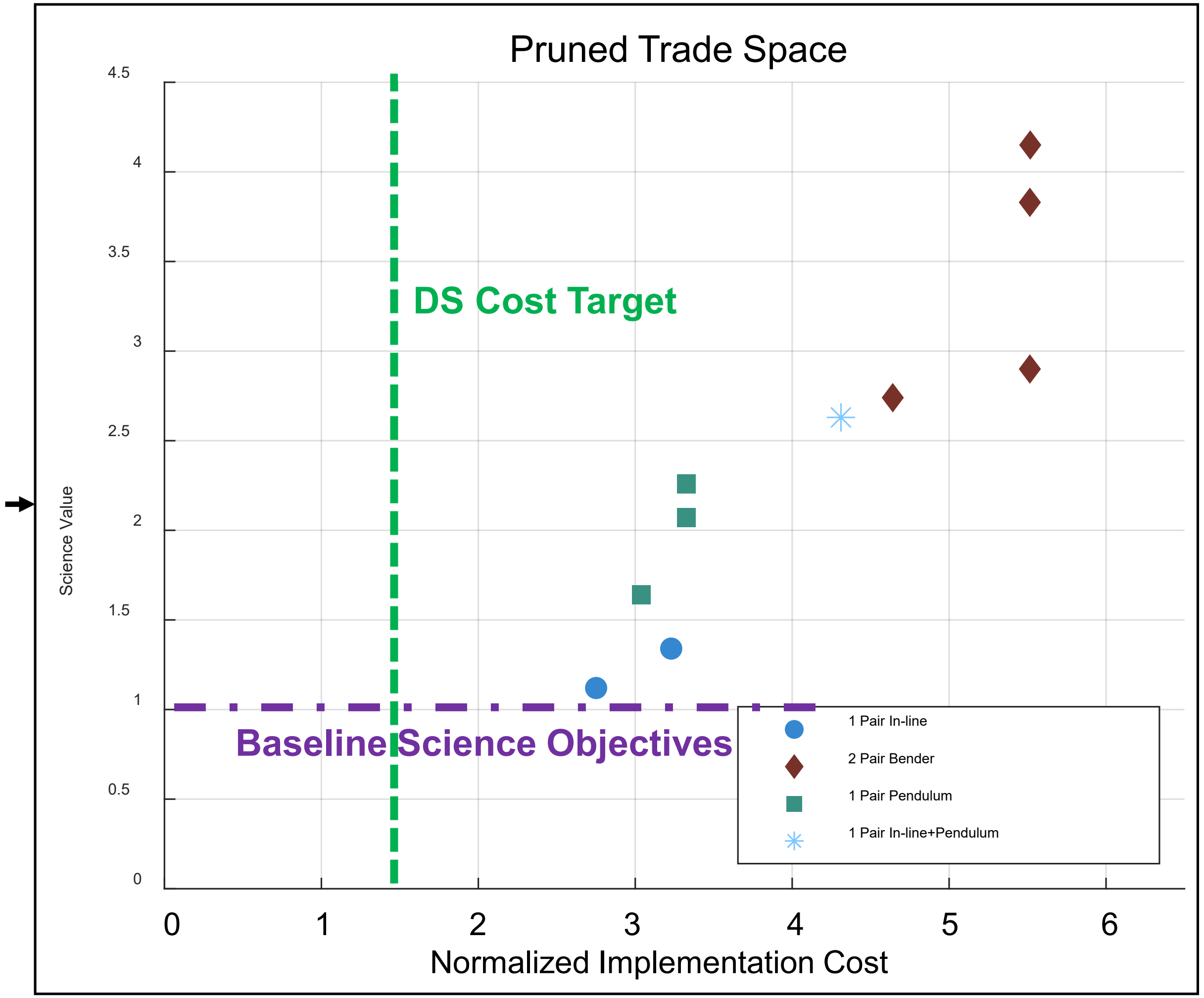
- **Precise orbit determination (POD)**: poor science value
- **Gravity gradiometry (GG)**: high science value; low technology readiness
- **SST LEO-MEO**: technical challenges; relative low science value
- **SST SmallSats**: not cost-effective

Technologies Pruned

- **Ranging System**: LRI preferred over MWI due to higher performance and successful demonstration on GRACE-FO
- **Accelerometer**: Electrostatic preferred due to technology readiness level; alternate technologies still considered as tech demo options



Pruning

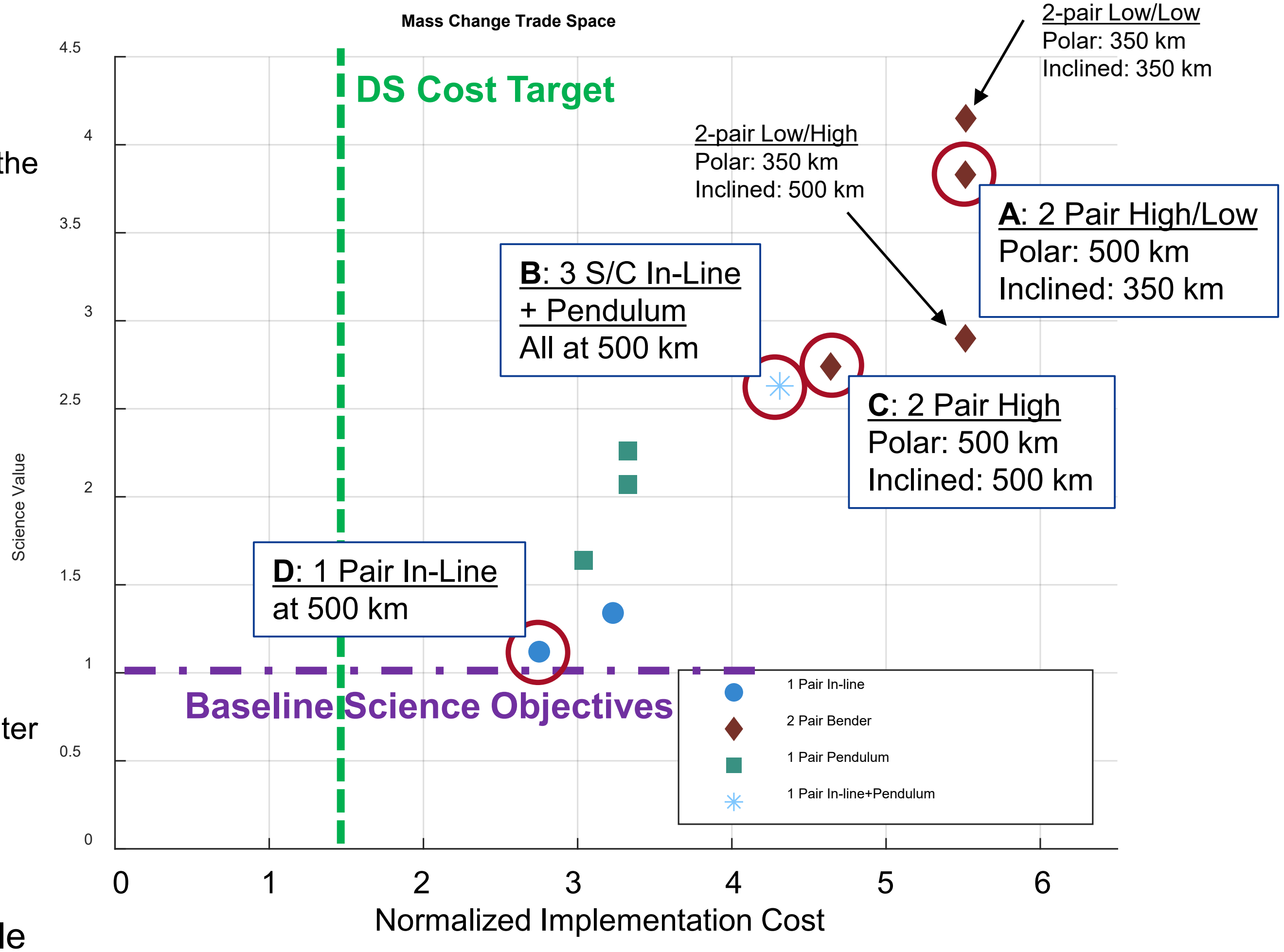


Identifying Architectures with the Highest Value—Improving Science Return While Enabling Continuity

- The Decadal Survey stressed the importance of continuity in mass change measurements
  - The Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) lifetime is more likely to be limited by system reliability than orbit lifetime
  - Schedule estimates indicate that the **single in-line pair** is likely to have the earliest launch readiness date (LRD) and is **most likely to enable continuity with GRACE-FO**

	Estimated 50th Percentile LRD	Expected GRACE-FO Reliability at LRD
Single In-Line (no drag comp.)	June 2028	50%
Pendulum (no drag comp.)	July 2029	40%
Bender (w/ drag comp.)	March 2030	35%

- Architectures (A, B, C, D) have at least one component that includes a single in-line polar pair to allow the highest likelihood of continuity with GRACE-FO
  - Implementation of Architectures A, B, and C may be staggered; Architecture D can be launched first and remaining elements launched later
- Architecture A (2-pair high/low) provides only slightly degraded science value relative to the highest-performing architecture (2-pair low/low)
- Architecture D (DLR), B (CNES), and A/C (ESA) are most compatible with interest from international partners



DS Cost Target

Baseline Science Objectives

2-pair Low/Low
Polar: 350 km
Inclined: 350 km

2-pair Low/High
Polar: 350 km
Inclined: 500 km

A: 2 Pair High/Low
Polar: 500 km
Inclined: 350 km

B: 3 S/C In-Line + Pendulum
All at 500 km

C: 2 Pair High
Polar: 500 km
Inclined: 500 km

D: 1 Pair In-Line at 500 km

MC Architecture Study Status

- MC has transitioned to Pre-Phase A
  - See next talk by Charley Dunn
- Architecture Study Team has delivered final report to NASA HQ
- Two journal articles are in preparation
  - 1) Overview of study and main conclusions
  - 2) In-depth comparison of architecture options to recovery time variable gravity