What Breaks Monocular SLAM in Microgravity?

An Initial Benchmark on Rotation-Dominant Astrobee ISS Sequences

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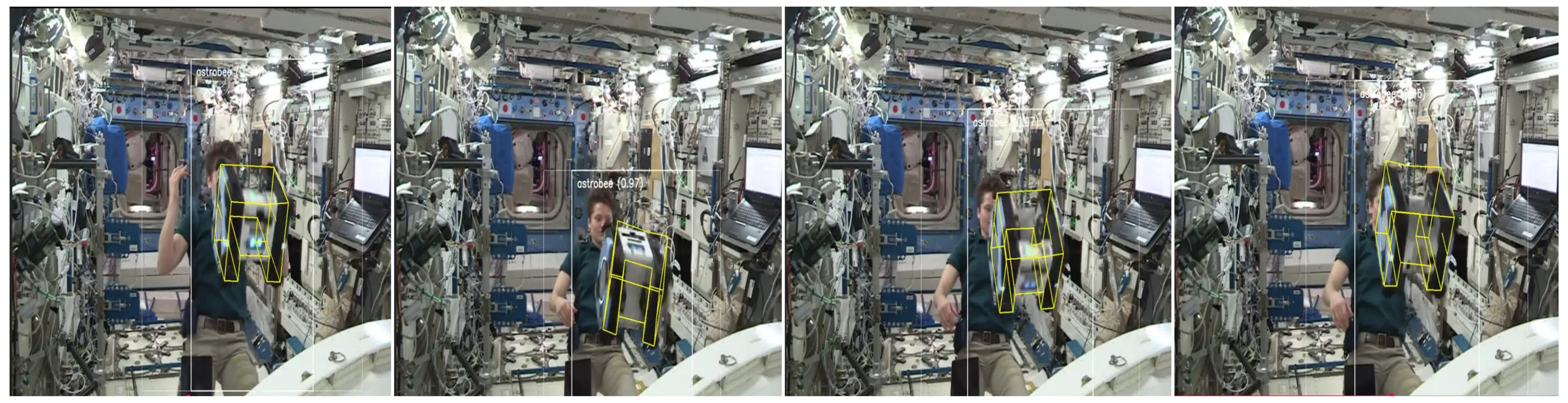
Motivation



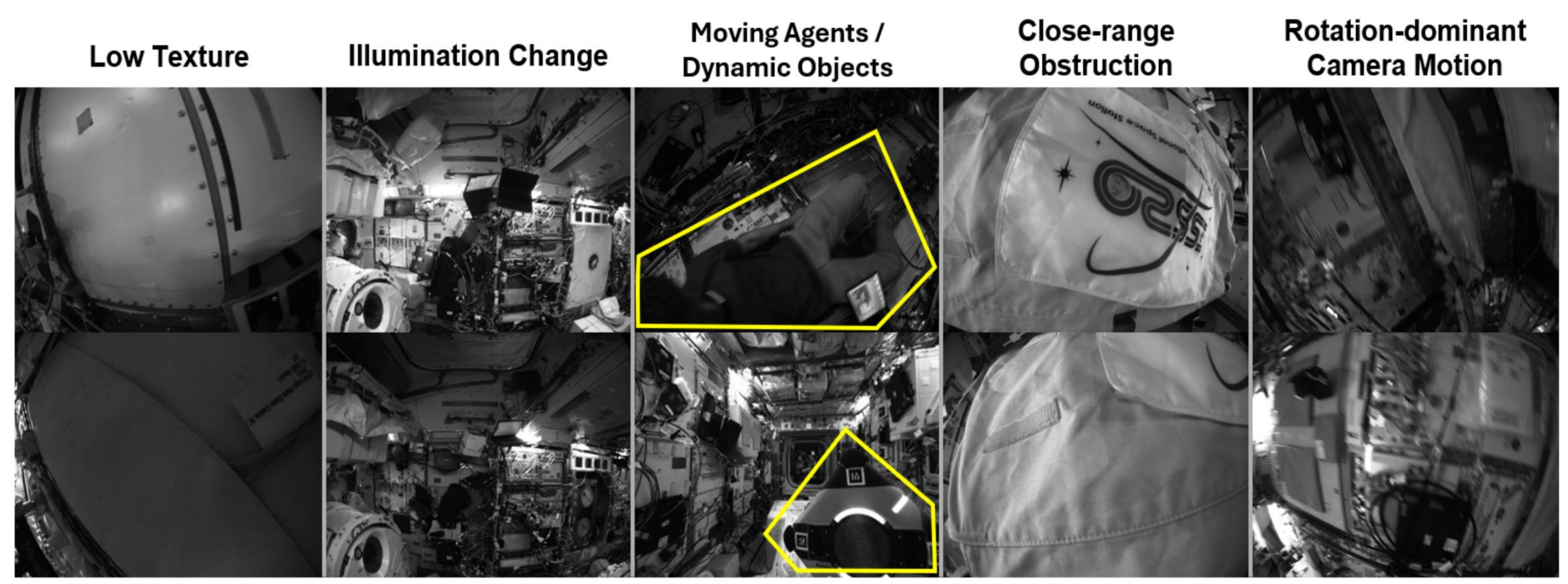
Free-flyers undergo **unrestricted 360° rotation**

- **Root Causes of SLAM Failure:** Unrestricted rotation hides prior-map landmarks, and motion blur breaks local correspondences.
- **Baseline Degradation:** This primary failure mode severely degrades the AstroLoc2 onboard system.

Contributions

1. **Visual challenge taxonomy** for Astrobee ISS imagery as a challenge-aware benchmark framework.
2. **Challenge-oriented benchmark** — comparing 3DGS SLAM vs. geometric foundation models on rotation-dominant ISS sequences.

Visual Challenge Taxonomy for Astrobee Datasets



Five visual challenge categories — this study focuses on the **rotation-dominant subset** (rightmost):

Methods & Setup

Dataset: Astrobee ISS Free-Flyer Dataset
Sequences: iva_kibo_rot, ff_return_rot

3DGS-Based SLAM

- **MonoGS** — vanilla 3DGS SLAM
- **HI-SLAM2** — depth + normal priors
  pose-graph BA + loop closure
- **WildGS-SLAM** — uncertainty-weighted BA
  DINOv2 reliability

Geometric Foundation Model

- **MUSt3R** — feed-forward 3D pointmaps
  no temporal coupling
- **MASt3R-SLAM** — pointmaps + dense matches
  tightly-coupled tracking + BA

Quantitative Results on Astrobee ISS Dataset

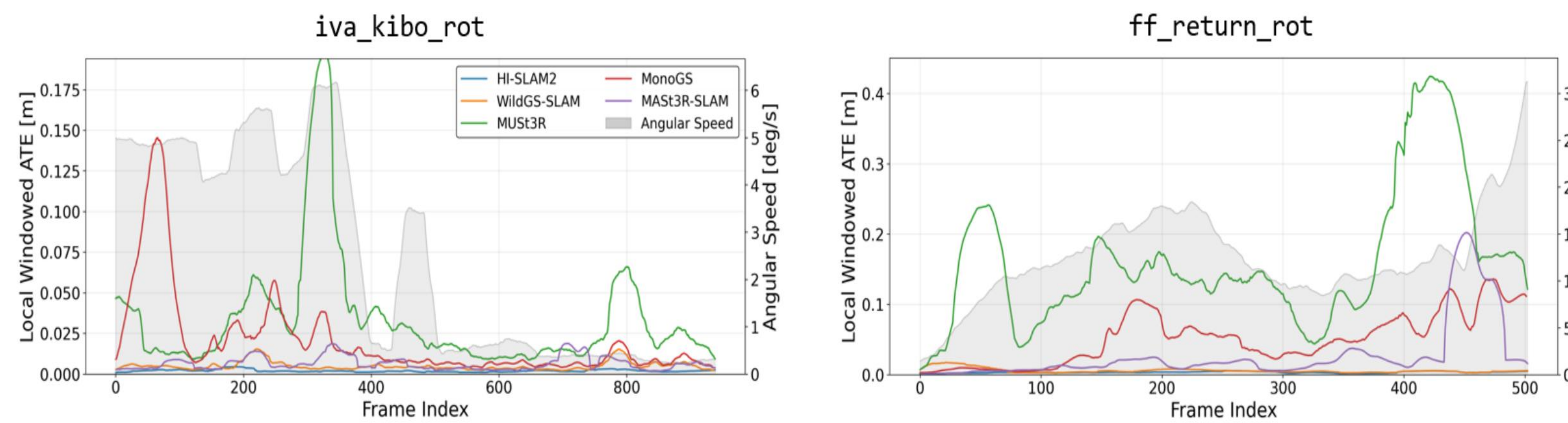
Table I. Global ATE RMSE [m]

Method	iva_kibo_rot	ff_return_rot
HI-SLAM2 [16]	**0.013**	**0.006**
WildGS-SLAM [17]	0.087	0.015
MUSt3R [20]	0.169	1.001
MASt3R-SLAM [19]	0.196	0.682
MonoGS [15]	0.462	1.223

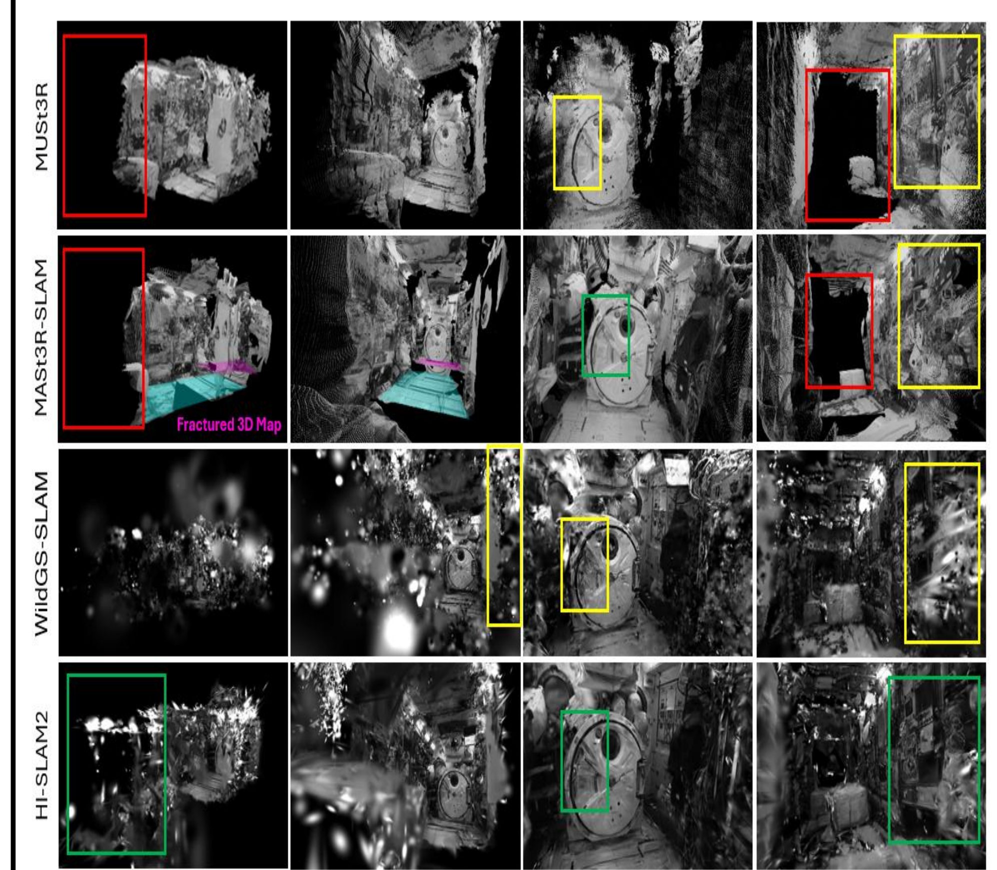
Key finding: Robustness is local and motion-conditioned — local errors spike at high-rotation intervals (gray).

- **3DGS SLAM: Structural constraints and global optimization (e.g., HI-SLAM2) are essential to prevent tracking failure during extreme rotation.**
- **Foundation Models: Feed-forward priors alone cause large local error spikes, which require sequential temporal tracking to mitigate.**

Local Windowed ATE vs. Angular Speed



Qualitative Results & Takeaways



1. **HI-SLAM2** (best)
2. WildGS-SLAM
3. MUSt3R
4. MASt3R-SLAM
5. **MonoGS** (collapses)

unreconstructed *floaters / blur* *faithful recovery*

Three failure modes under large rotation:

(i) MonoGS loses tracking on weak-overlap motion.

(ii) MUSt3R spikes locally without temporal integration.

(iii) MASt3R-SLAM tracks well, but loop closure fractures the 3D map.

HI-SLAM2 — strongest local robustness and most coherent reconstruction.