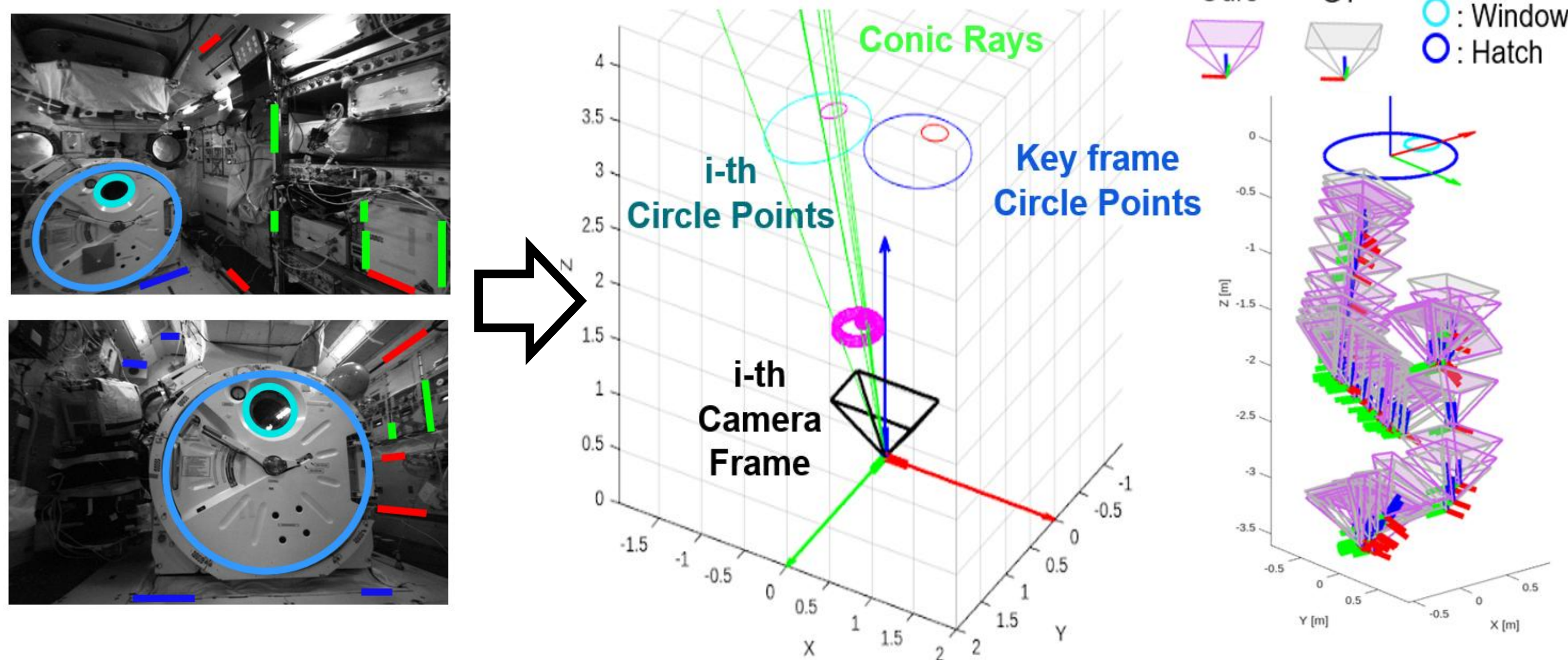


Motivation & Problem

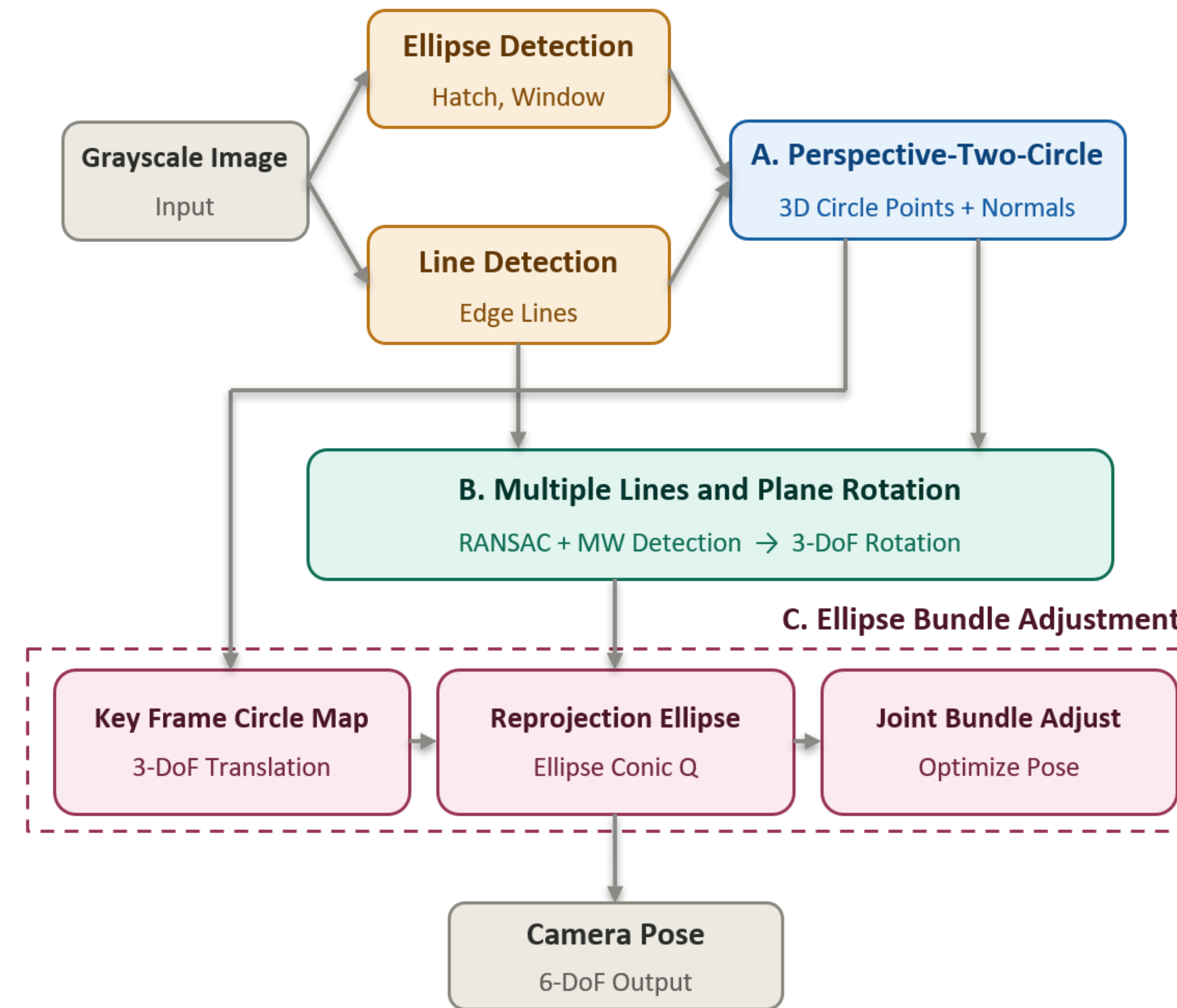
Challenge: Free-flying robots (Astrobee) on the International Space Station rely on visual localization, but suffer from:

- Illumination changes causing feature mismatch
- Frequent ISS reconfiguration invalidating pre-built maps
- SLAM methods suffering from drift without global localization

Our Insight: The ISS contains **circular landmarks (hatches, windows)** with known physical radii — purely geometric cues that are **time-invariant** and unaffected by lighting or environmental changes.



Proposed Method



① Detection Stage : Ellipse & Line Extraction

- YOLO-based ellipse detector + AAMED fitting model
- LSD line segment detector for edge lines
- **Detects ISS hatches and windows as conic ellipses**

② Perspective-Two-Circle Solver

- Eigen-decomposition of conic ray matrix Q_{cone}
- **Closed-form recovery: 3D circle center o_i and normal n_i**
- Disambiguate symmetry via strongest normal alignment
 $o_i = U o'_i$ $n_i = U n'_i$ [eigenvalues $\lambda_{1,2,3}$ and radius R]

③ MW Rotation Optimization

- Orthogonal line-to-vanishing-point distance minimization
 $\theta^* = \operatorname{argmin} \sum_{k=2}^3 \sum_{i=1}^{M_k} d_{i,k}(\theta)^2$

③ Conic Bundle Adjustment (CBA)

- Sample 3D points from estimated circles \rightarrow project to image
- Joint nonlinear least-squares over all N frames and 2 ellipses

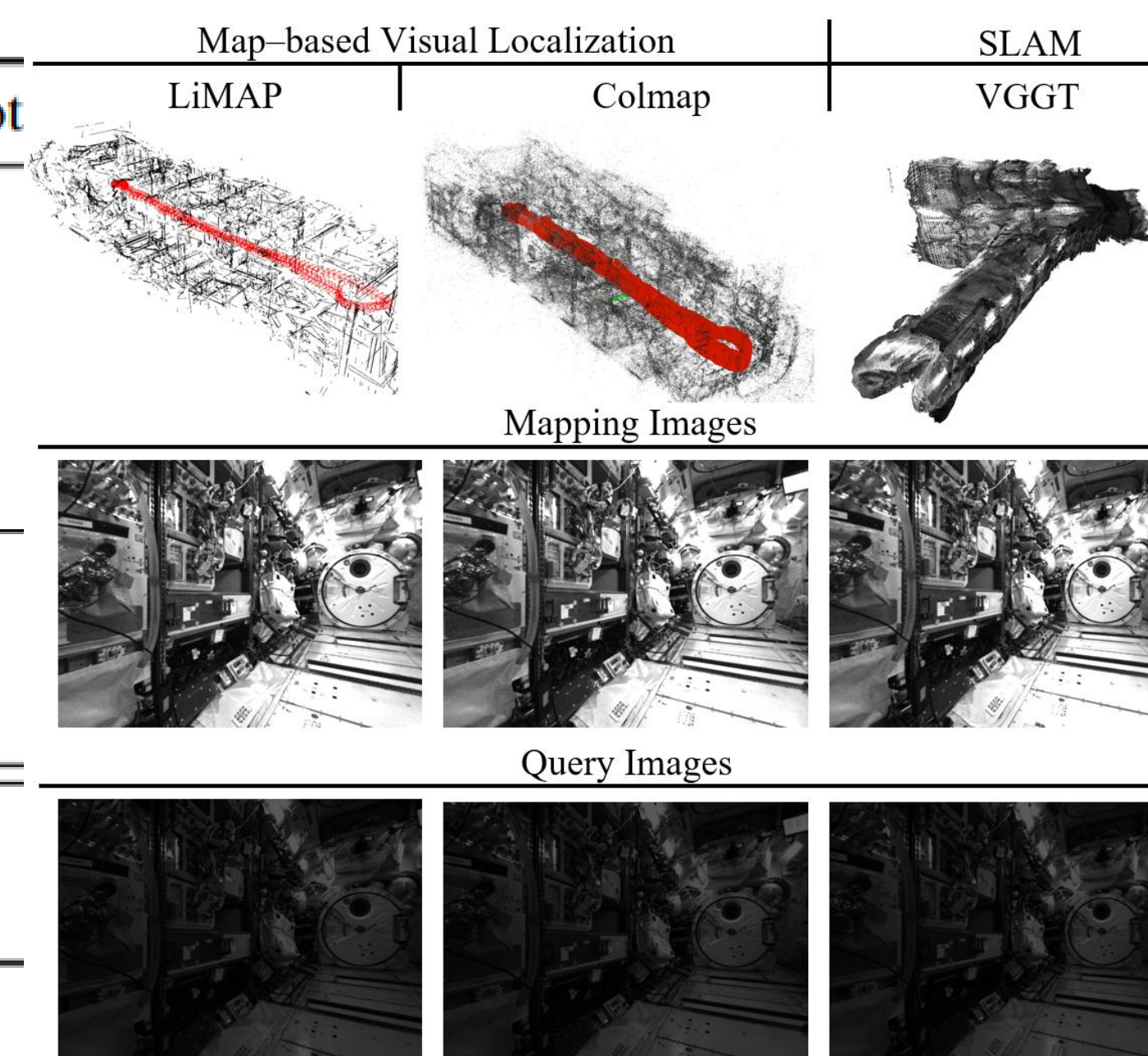
- Algebraic conic residual: $r_{ki}(\xi) = \tilde{x}_i^T Q_i \tilde{x}_i$
 $\xi^* = \operatorname{argmin} \sum_{k=1}^N \sum_i [\tilde{x}_i^T Q_i \tilde{x}_i]^2$
- **No explicit point correspondences needed**

Evaluation & Conclusion

- ATE : $\downarrow 66.7\%$ vs. AstroLoc, $\downarrow 57.3\%$ vs. AstroLoc2
- VGGT-SLAM fails due to domain gap with ISS imagery
- Comparable to COLMAP/LIMAP under illumination changes
- \rightarrow Purely geometric cues are invariant to lighting changes with no pre-built map needed.

Method	Map-based Visual Localization			SLAM		
	LiMAP	Colmap	VGGT	ff_return_forward	ff_return_left	ff_return_rot
Ours	0.088	0.087	0.104			
AstroLoc	1.065	0.159	0.281			
AstroLoc (VIO)	0.269	0.587	0.385			
AstroLoc2	0.209	0.245	0.206			
AstroLoc2 (VIO)	0.677	0.330	0.477			
ORB-SLAM3	0.298	0.145	0.107			
DROID-SLAM	0.378	0.142	0.062			
VGGT-SLAM	1.416	2.673	1.703			
COLMAP [†]	0.101	0.090	0.096			
LiMAP [†]	0.079	0.062	0.087			

[†] Evaluated on sequences with significant illumination changes.



\rightarrow Estimated trajectory (magenta) aligns better with ground truth (gray) in the global hatch frame than AstroLoc (cyan).

