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Success by 1000 Improvements

Flight Qualification of the ST-16 Star Tracker

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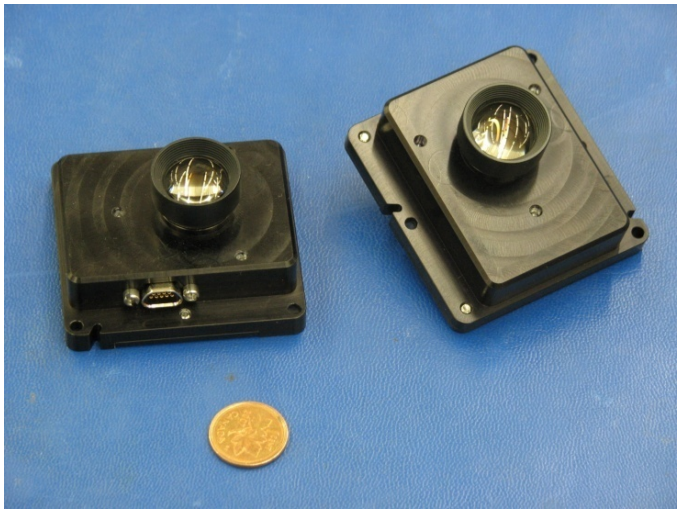
Background and Motivation

- SkySat-1 launched November 21, 2013 carrying two ST-16 star trackers.
- Sensor performance was significantly worse than expected.
- Skybox, SI, and RU embarked on a flight qualification campaign to restore sensor performance.
- This paper discusses:
  - Fault diagnosis procedures
  - Key improvements to sensor algorithms and our star catalog



Sinclair Interplanetary ST-16 Star Tracker

Accuracy	< 7 arcsecs CB < 70 arcsecs Roll
Availability	> 99.9%
Mass	≈ 90g
Size	59 x 56 x 31.5 mm
Power	< 0.5W avg

Key Specifications of the ST-16

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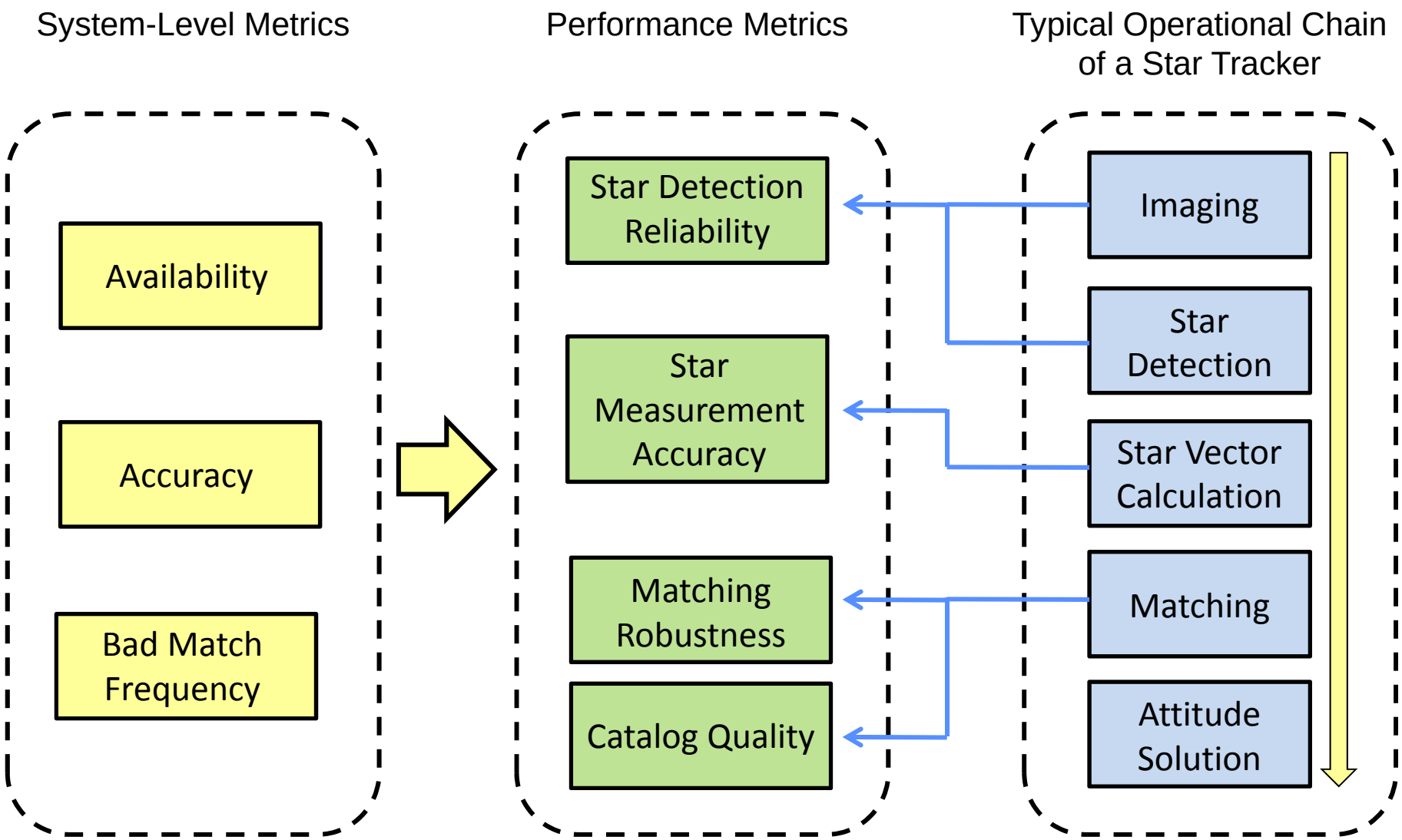
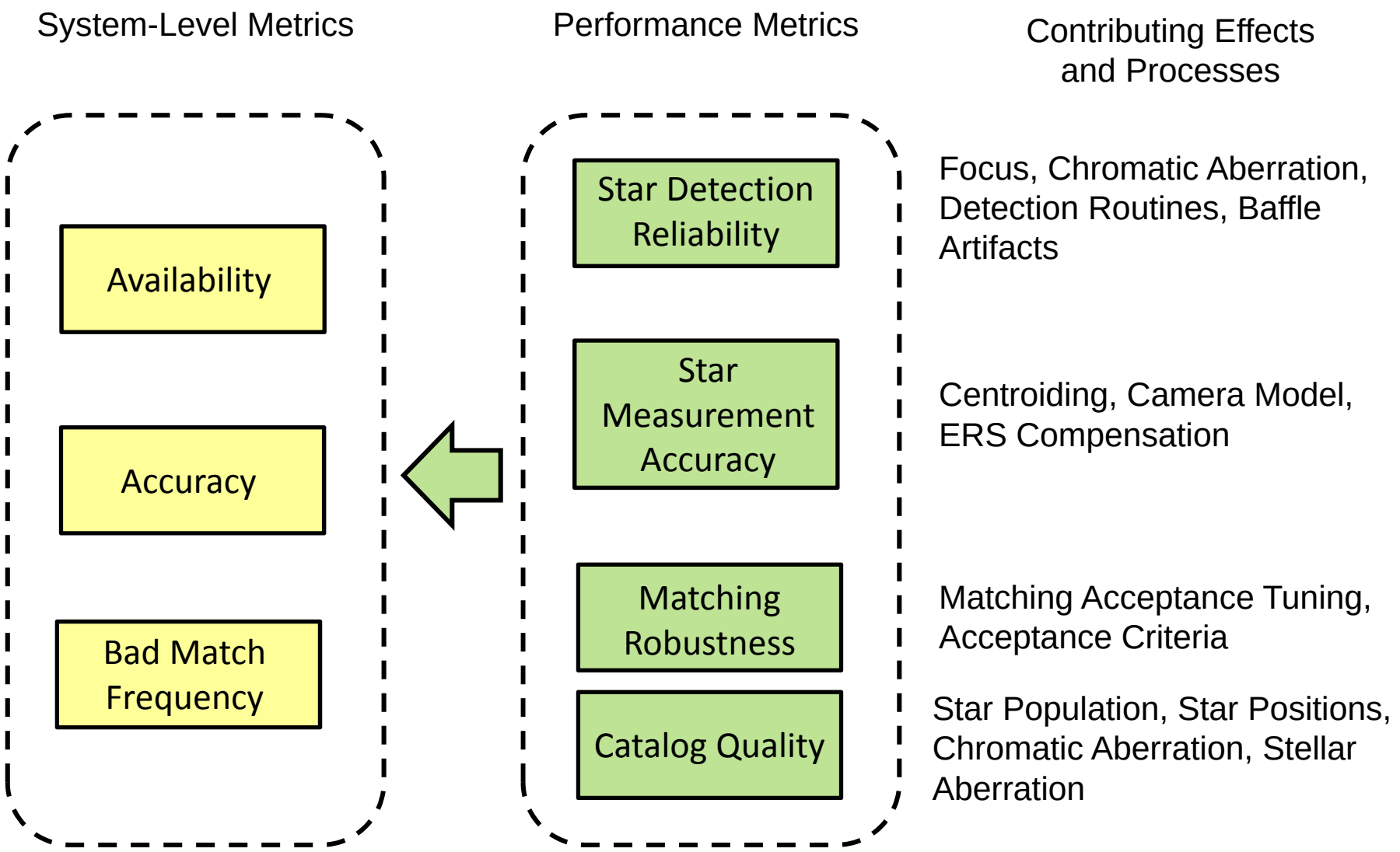
Problem Diagnosis

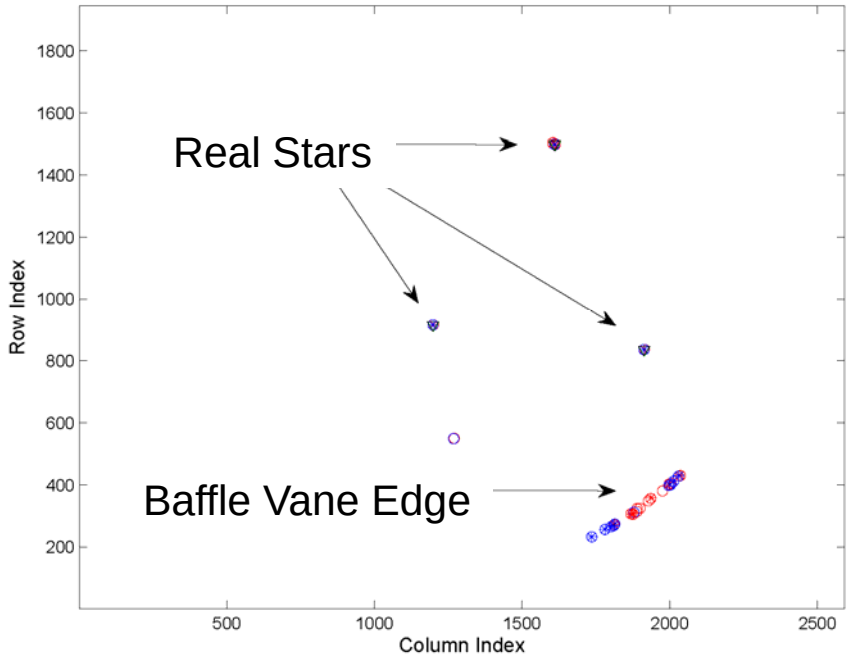


Problem Diagnosis



Baffles and Stray Light

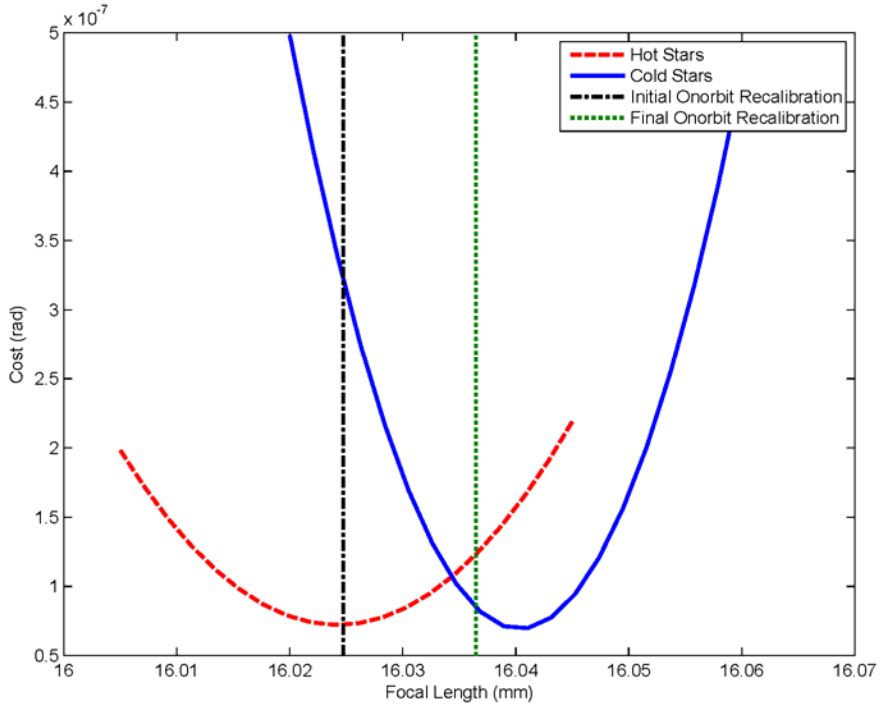
- Many sources of non-stellar light.
- Difficult to test logic on the ground.
- Flexible processing framework:
  - Adaptive Threshold Logic
  - Region of Interest Calibration
  - Large, Bright, Object Rejection
- Telemetry still showed problems.
- Analysis led to three additional improvements:
  - Star Cluster Rejection
  - Tight Matching Tolerance
  - Strict Solution Acceptance Criteria



Star cluster formed by vane reflection

Onorbit Recalibration

- ST-16 utilizes 11 camera model parameters
  - Initially determined in lab
  - Refined on orbit
- Recal. improved performance
  - still not to expected values.
- Analysis of telemetry led to two problems with our approach:



Calibration Results (focal length)

  - Some parameters were weakly-separable leading to steep minima
  - Chromatic aberration caused a star-color-based dependence on focal length.

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Need for Better Rate Estimates

- The ST-16 detector uses an electronic rolling shutter (ERS)
- Time offset between rows
- Compensation requires ω
- ω found from stars pos. in subsequent images

- Telemetry showed significant errors in the rate estimates.

- Mitigated by additional logic enabling longer sampling intervals.

	δt	Rate Err ($\times 10^{-3}$ deg)		
		σ_x	σ_y	σ_z
Single Reading (night sky)	0.1	3.89	4.03	39.6
Single Reading (on-orbit)	0.1	17	13	175
Reading-to-Reading (calculated)	0.5	3.40	2.60	35.0
Sparse Dataset (calculated)	40	0.042	0.032	0.438
Sparse Dataset (on-orbit)	40	0.211	0.168	0.614

Rate Estimator Performance

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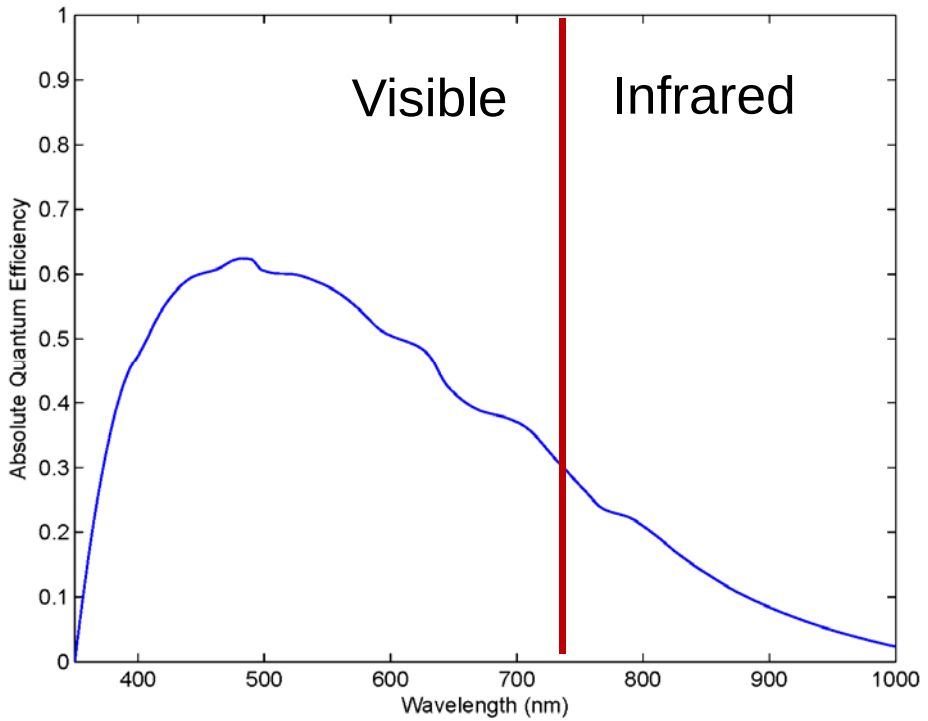
Catalog Repopulation

- Problems with our catalog:
  - Some stars we detected were not part of the ST-16 catalog.
  - Patterns formed by some stars differed from their definitions.

- Selection based on visual mag.
- Misrepresents expected response.
- New catalog:
  - Brightness determined by weighting color channels.
  - Selection based on expected response, and density of scene.



ST-16 Quantum Efficiency

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Handling Difficult Stars

- Particular stars were still not being matched due to errors between their expected and actual positions.
  - Proper Motion
  - Binary Stars
- Binary star systems were handled in three ways:
  - Apparent Binaries: Excluded from catalog.
  - Equally Bright Binaries: Binary system treated as single star, with position approximated as the magnitude weighted average.
  - Differently Bright Binaries: Binary system treated as single stars with position approximated as position of brightest star.

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Conclusions

- The flight qualification campaign made several improvements to sensor processing.
- These were successful in restoring expected performance:
  - Availability: >98%, Accuracy: 10.0, 23.0, and 74.0 arcsecs.
- Would have benefited from better allocation of qualification resources between sim, lab, and night-sky tests.
- Future improvements: smart centroid windowing (at rate), online recalibration, better rate estimation.
- A follow-on to the ST-16, the ST-16RT is currently being developed using a custom lens design with better chromatic performance.

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Thank you for your time.

Questions?