A Space Multi-Beam Multi-Link Capable Laser Communications Terminal for Satellites [PPT]

Spaander, Joshua; Guo, J.

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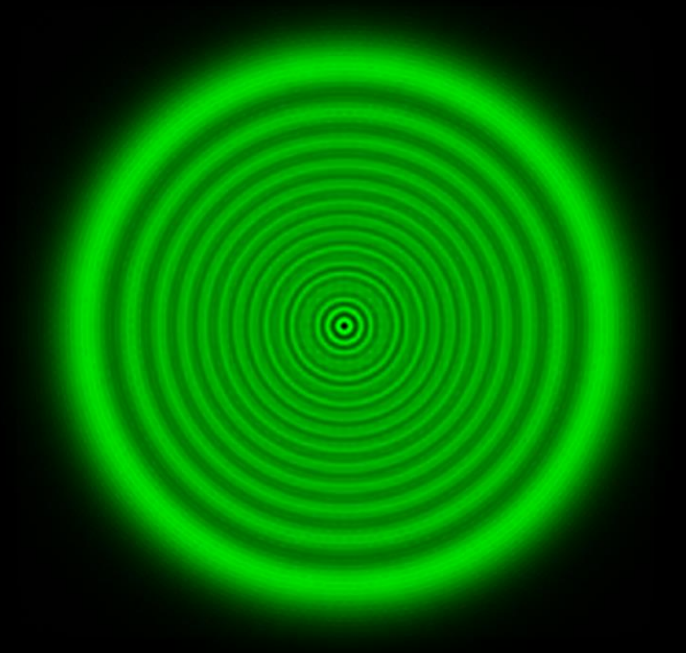
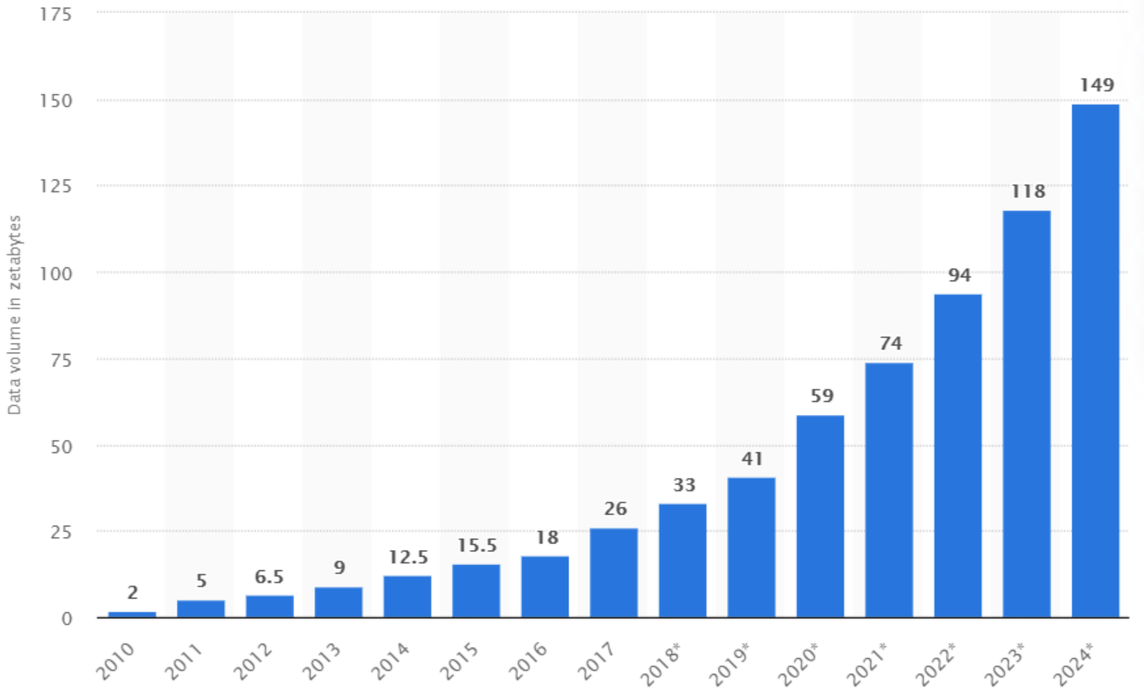
Multi-Beam Terminal Design



By Joshua Spaander

Background

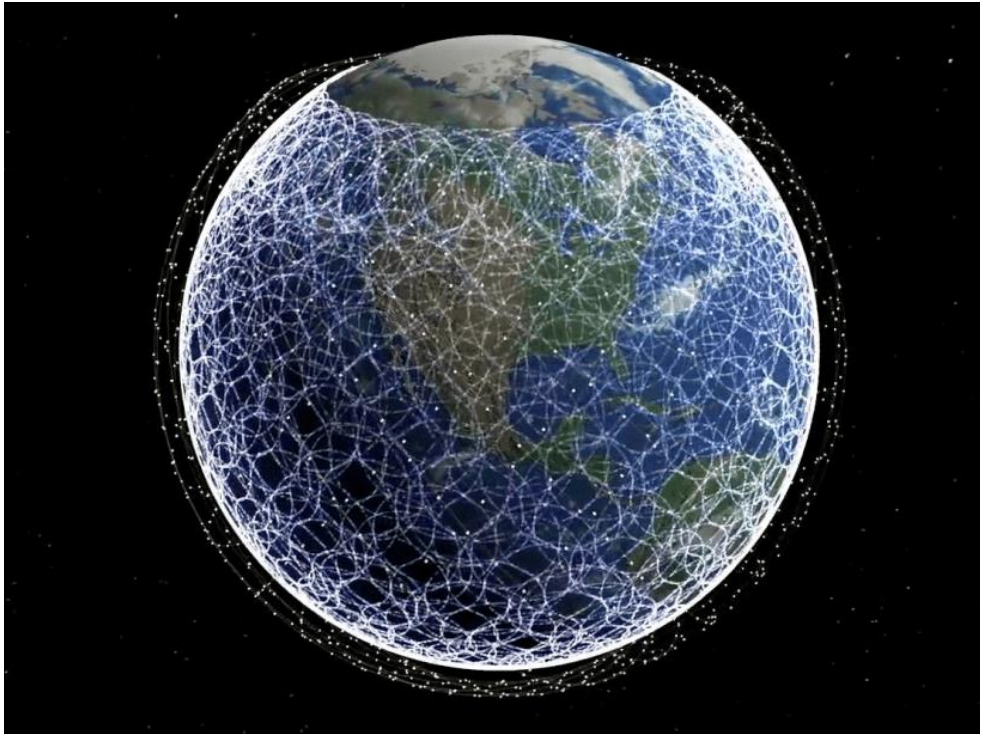
Volume of data/information created, captured, copied, and consumed worldwide from 2010 to 2024 in (in zettabytes)



https://www.statista.com/statistics/871513/worldwide-data-created/

TU Delft

Background



https://vividcomm.com/2020/07/29/starlink-internet-from-space/

Background

https://everydayastronaut.com/starlink-14-falcon-9-block-5/
https://hackaday.com/2020/02/20/how-does-starlink-work-anyway/

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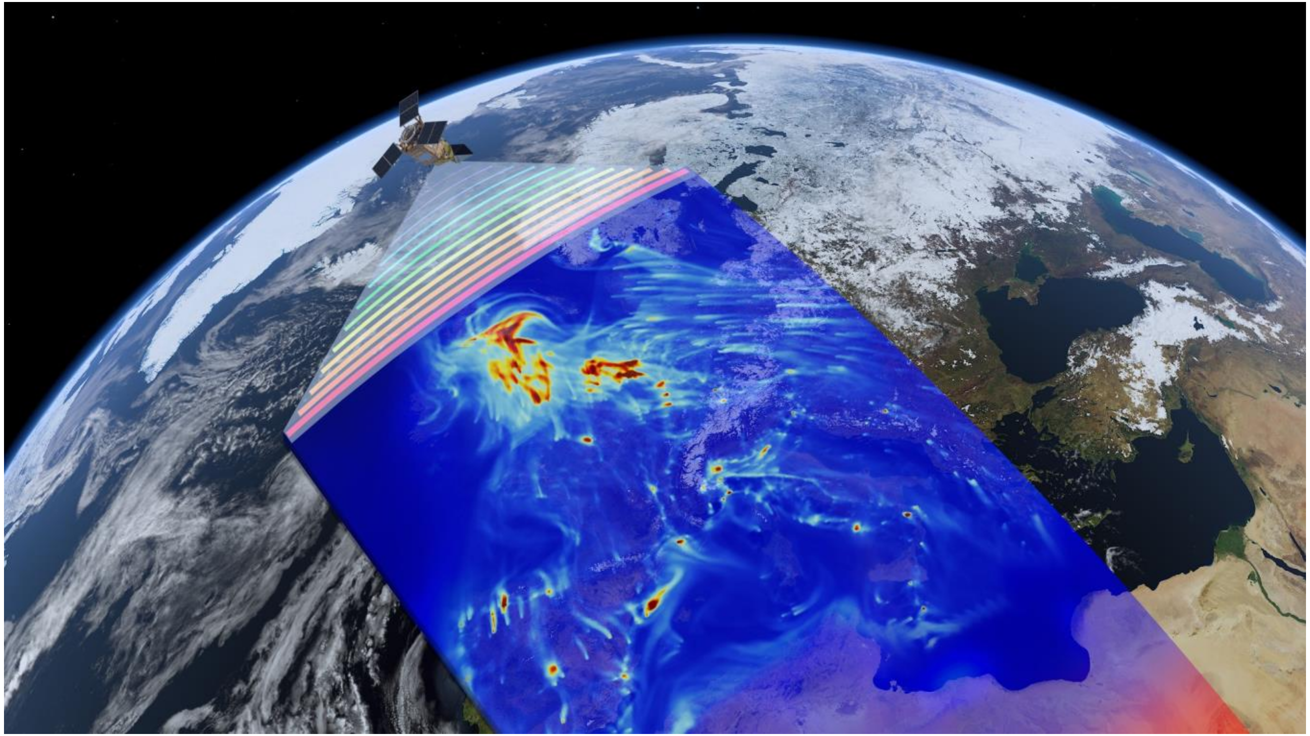

http://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P/Air_quality-monitoring_satellite_in_orbit

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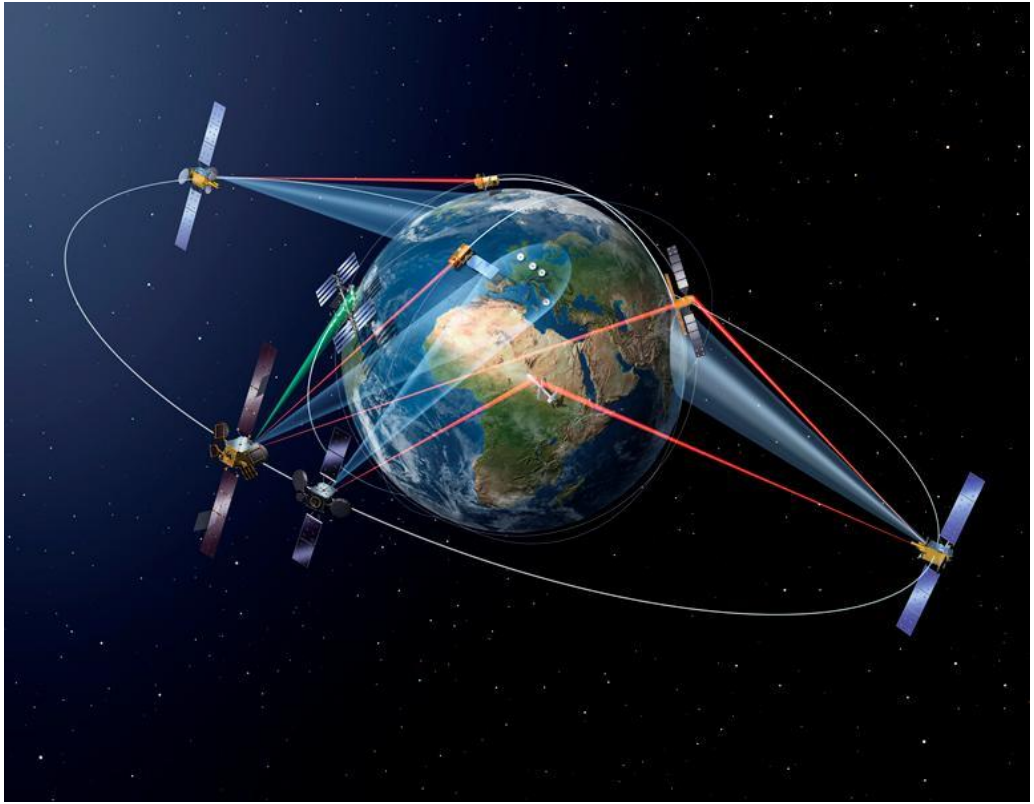

https://www.dlr.de/content/en/images/2016/1/the-european-data-relay-system-edrs_21712.html

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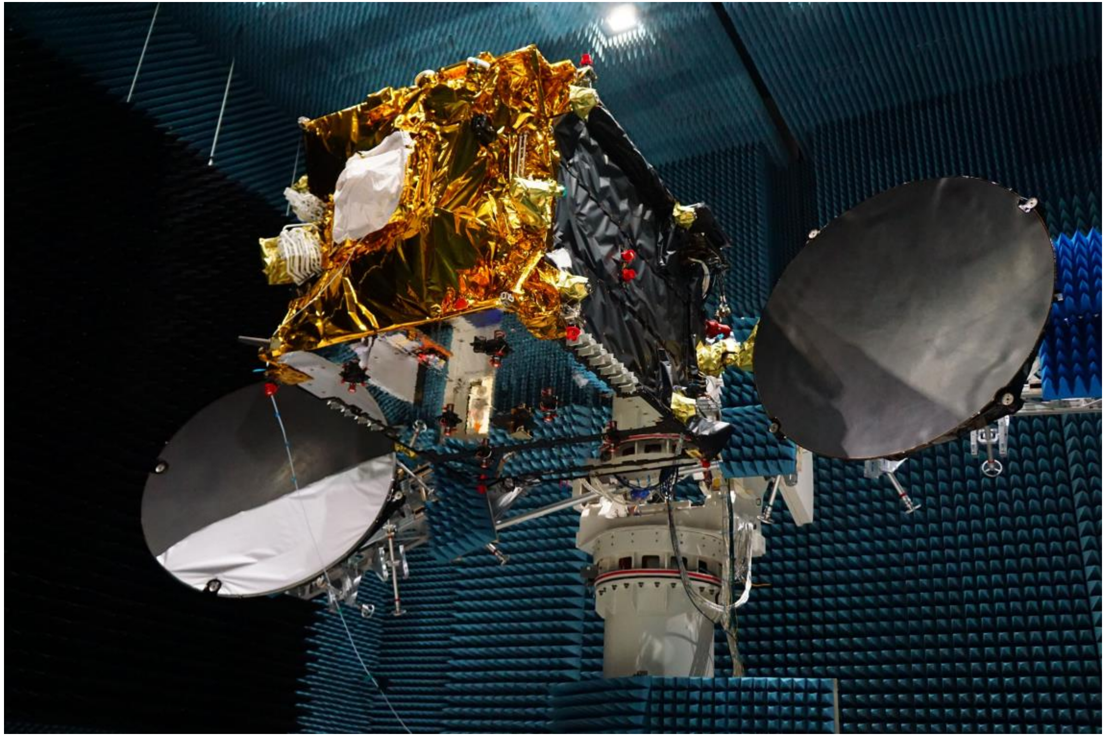

https://www.airbus.com/newsroom/press-releases/en/2019/05/launch-of-the-second-spacedatahighway-satellite.html

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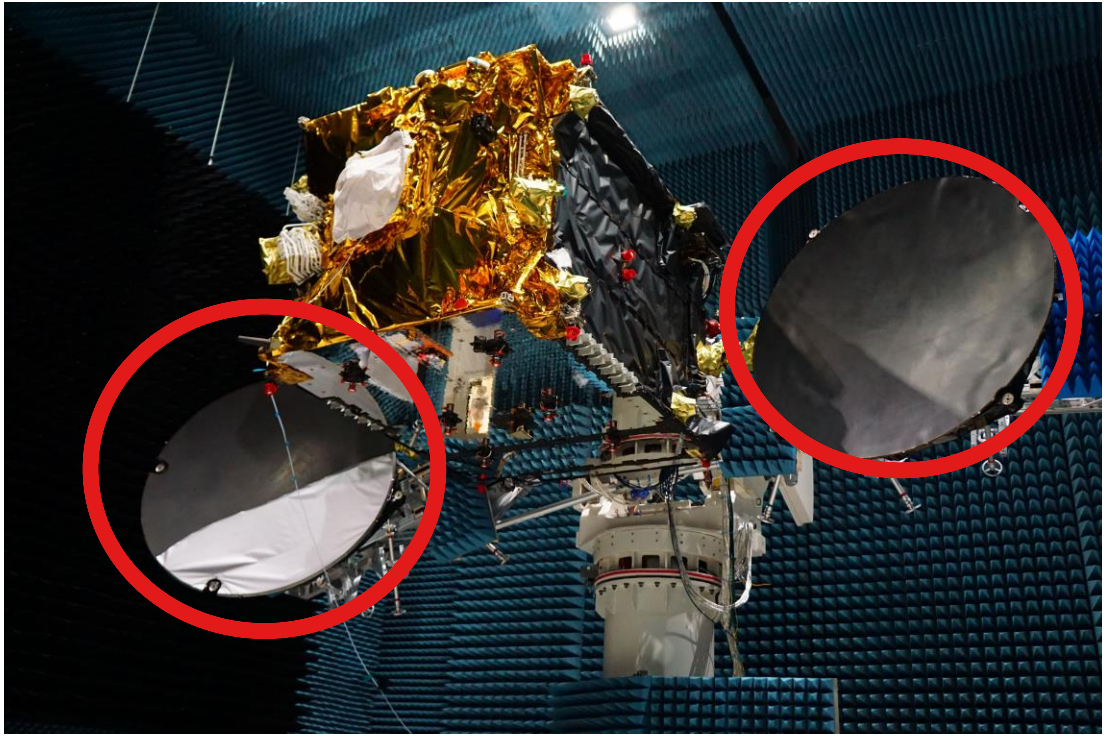

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Background

https://spacenews.com/arianespace-seeks-greater-support-from-european-governments/

Background

Ariane V Launch Costs:

- Cost for launch: $165 million
- Launch capacity: 18,000 kg
- Cost per kg: 9,167 $/kg

https://spacenews.com/arianespace-seeks-greater-support-from-european-governments/
https://www.yumpu.com/en/document/read/36996100/space-transportation-costs-trends-in-price-per-pound-to-orbit-

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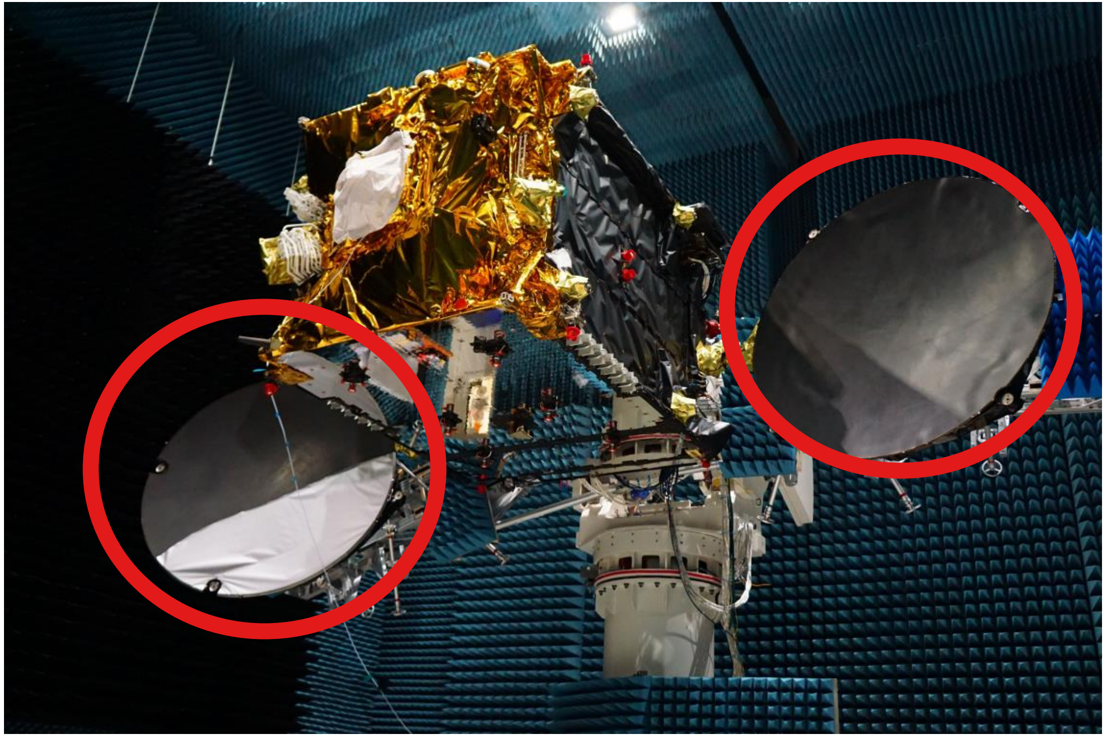

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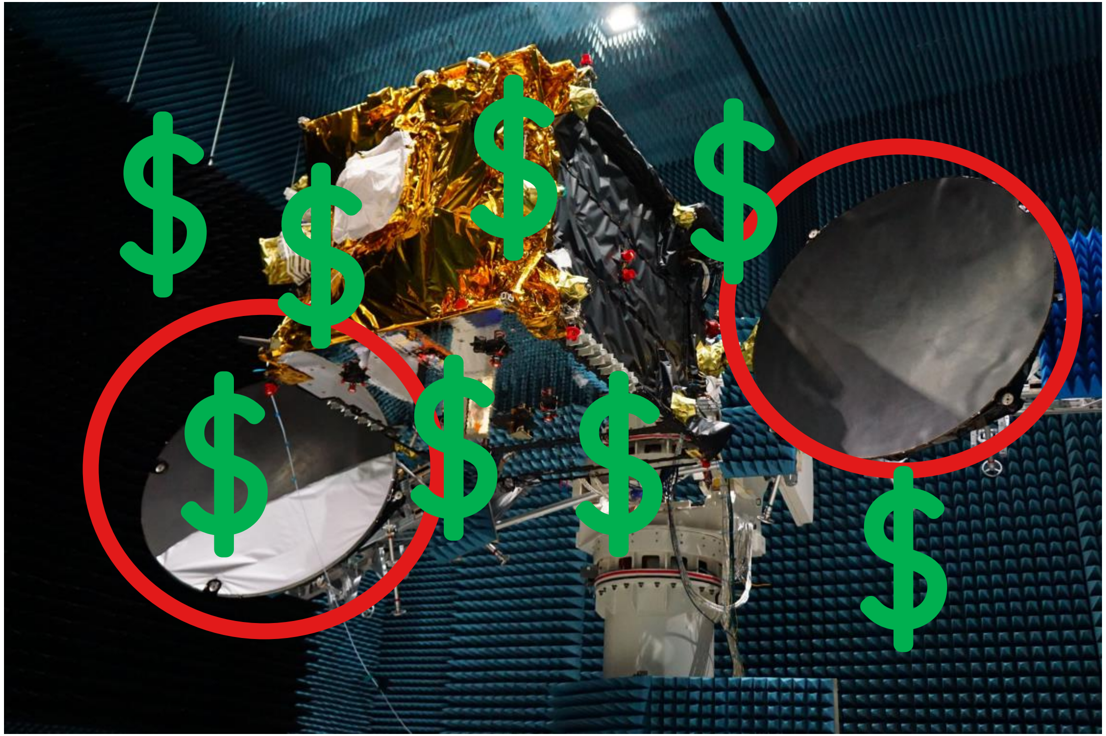

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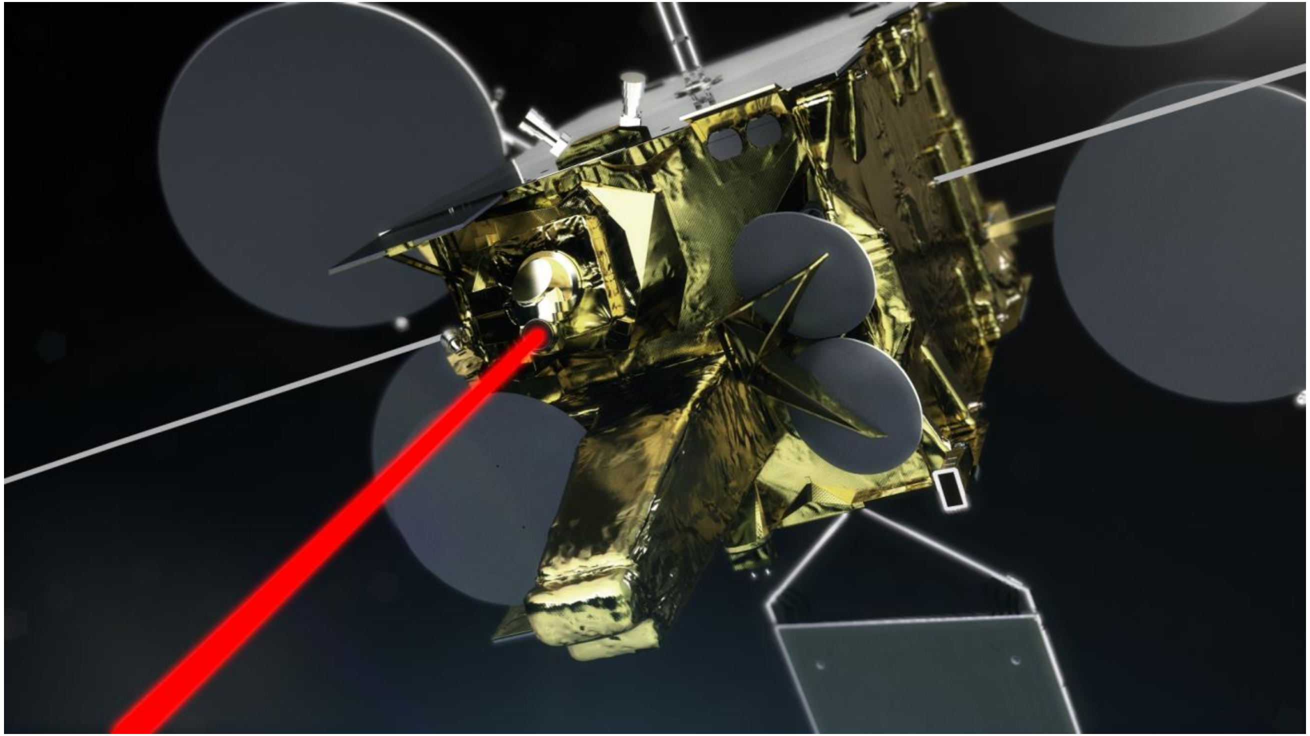

https://www.esa.int/ESA_Multimedia/Images/2016/03/EDRS-A

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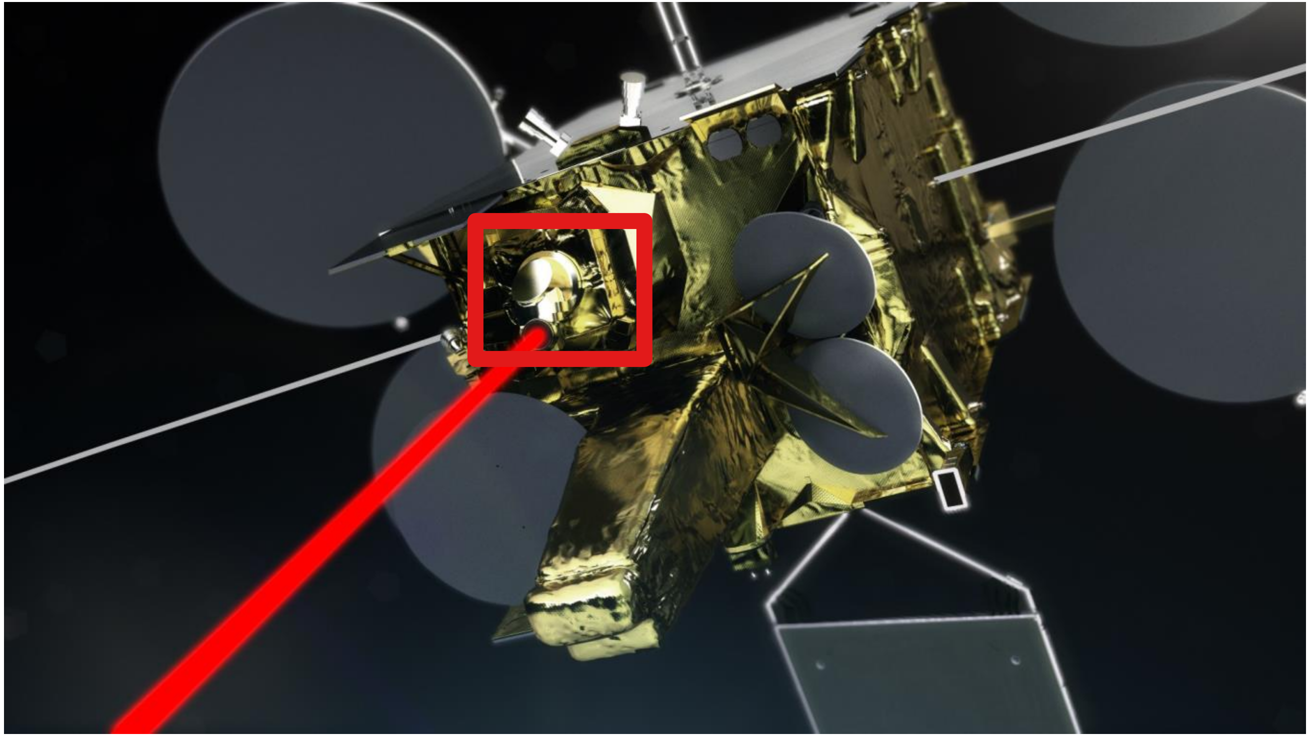

https://www.esa.int/ESA_Multimedia/Images/2016/03/EDRS-A

Introduction and Background

Radio vs Optical Communications: 10 Mbps

- Radio:
  - Mass: 20.7 kg
  - Power: 104 W
- Optical:
  - Mass: 0.5 kg
  - Power: 10 W

SMAD pages 635 and 639
Ryan W Kingsbury. Optical Communications for Small Satellites. Technology, (2015):127, 2015. URL https://dspace.mit.edu/handle/1721.1/101444.

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Introduction and Background

	Lunar Laser Communications Demonstration (MIT LL)	Optical Payload for Lasercom Science (JPL)	Optical Communication and Sensor Demonstration (The Aerospace Corporation)	Nanosatellite Optical Downlink Experiment (MIT)
Data Rate	622 Mbps	50 Mbps	40 Mbps /300 Mbps	10 Mbps / 100 Mbps
Tx Power	0.5 W	2.5 W	6 W	200 mW
Orbit	Lunar	LEO (ISS)	LEO	LEO
Payload mass	30 kg	180 kg	2 kg	1 kg
Beamwidth	2.5 urad	~0.01 deg	0.30 deg	1.3 mrad
Ground station	White Sands	OCTL 1-m	MOCAM / MAFIOT	PorTeL / OCTL

K Cahoy. Laser Communication with CubeSats. Technical report, 2018. URL https:// directory.eoportal.org/web/eoportal/s.

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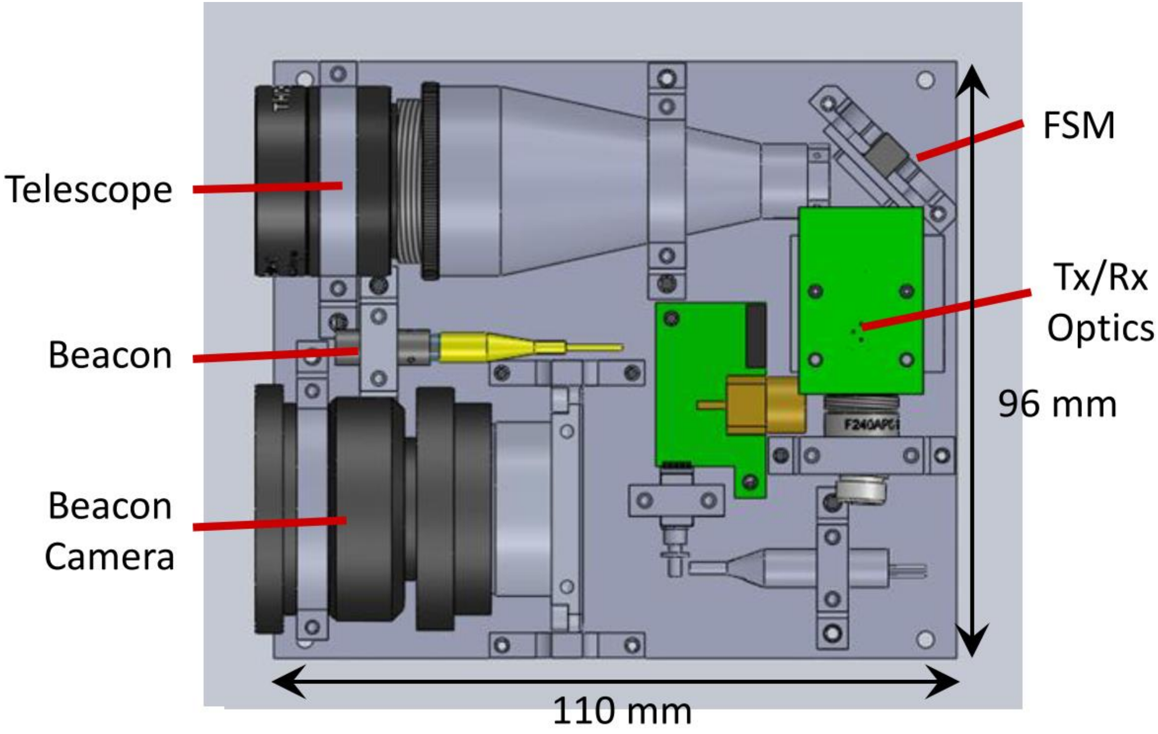

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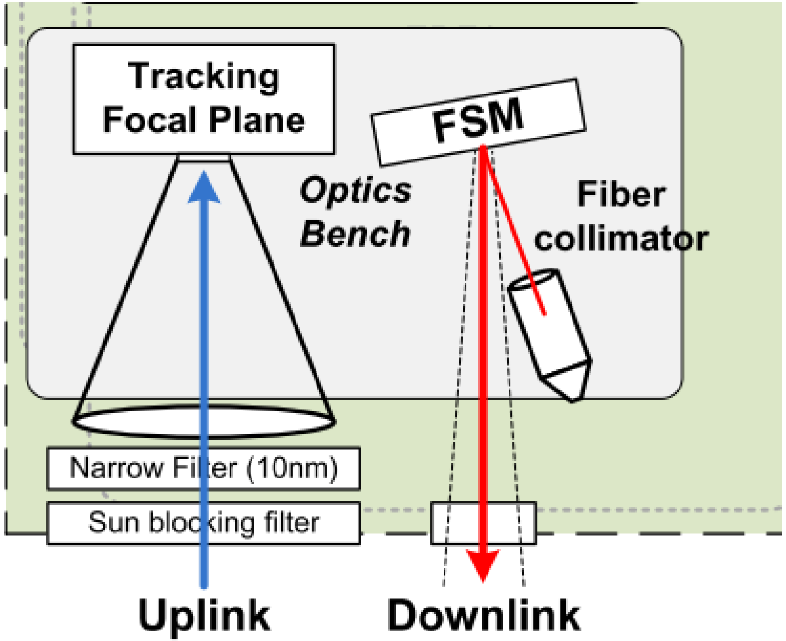

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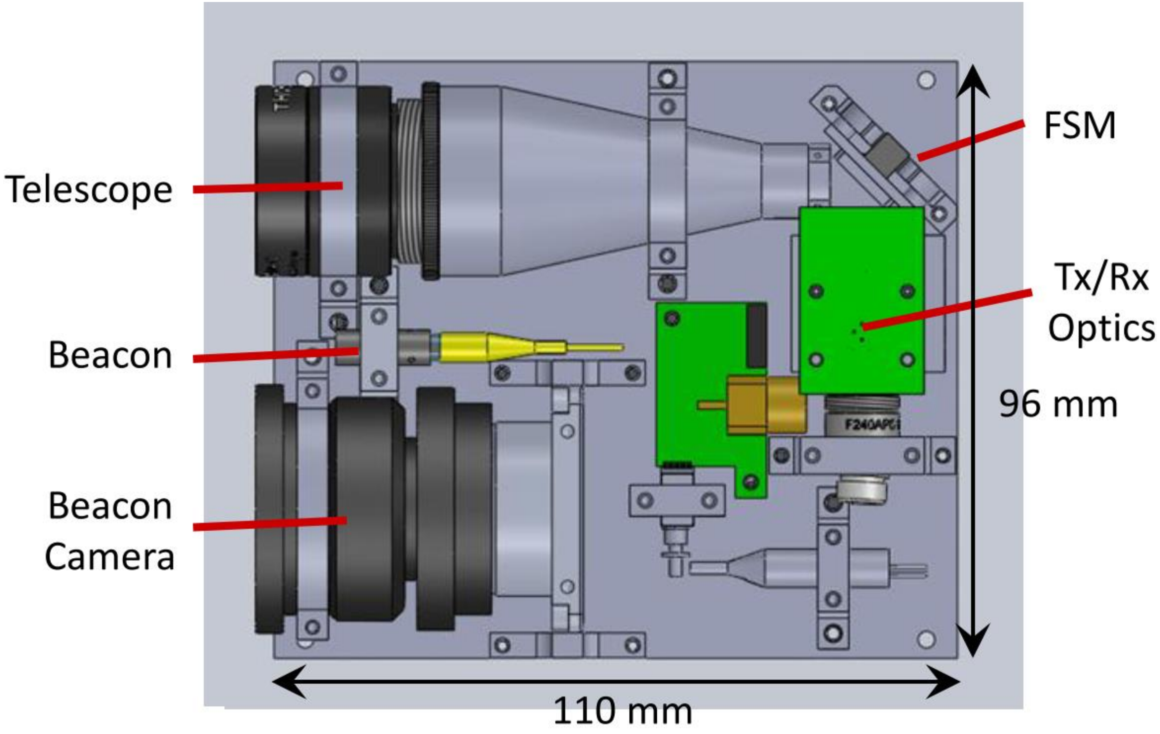

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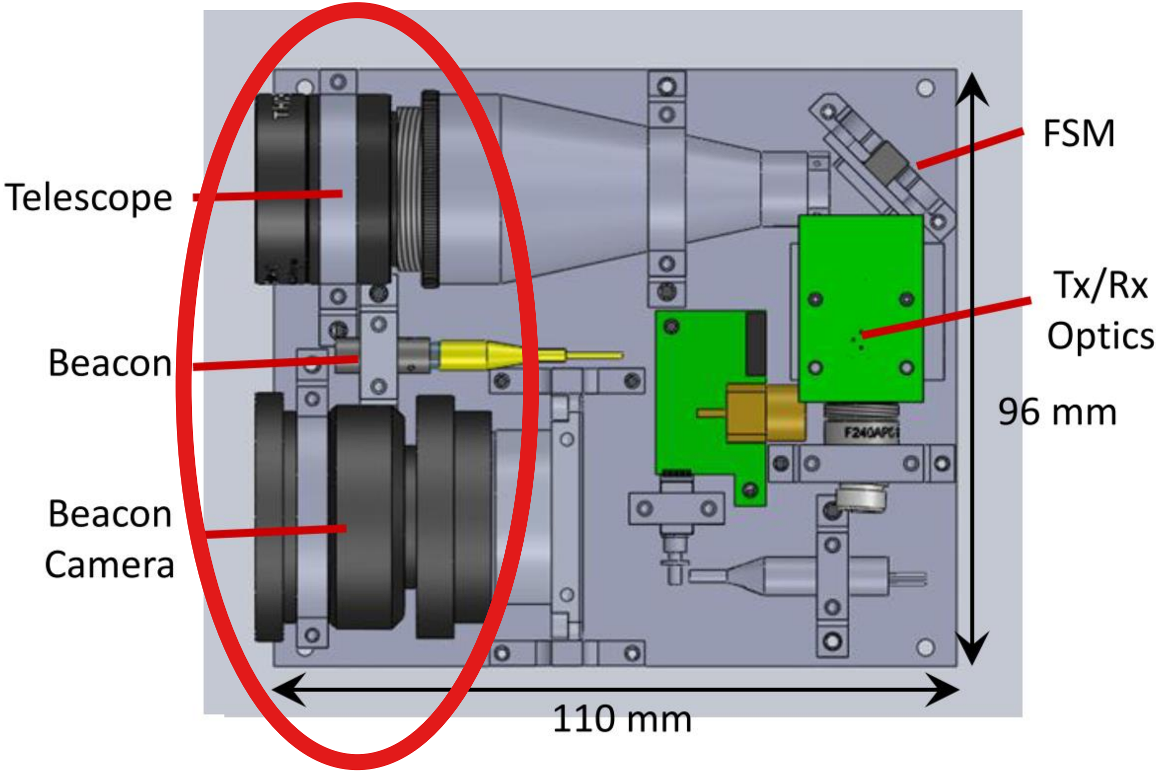

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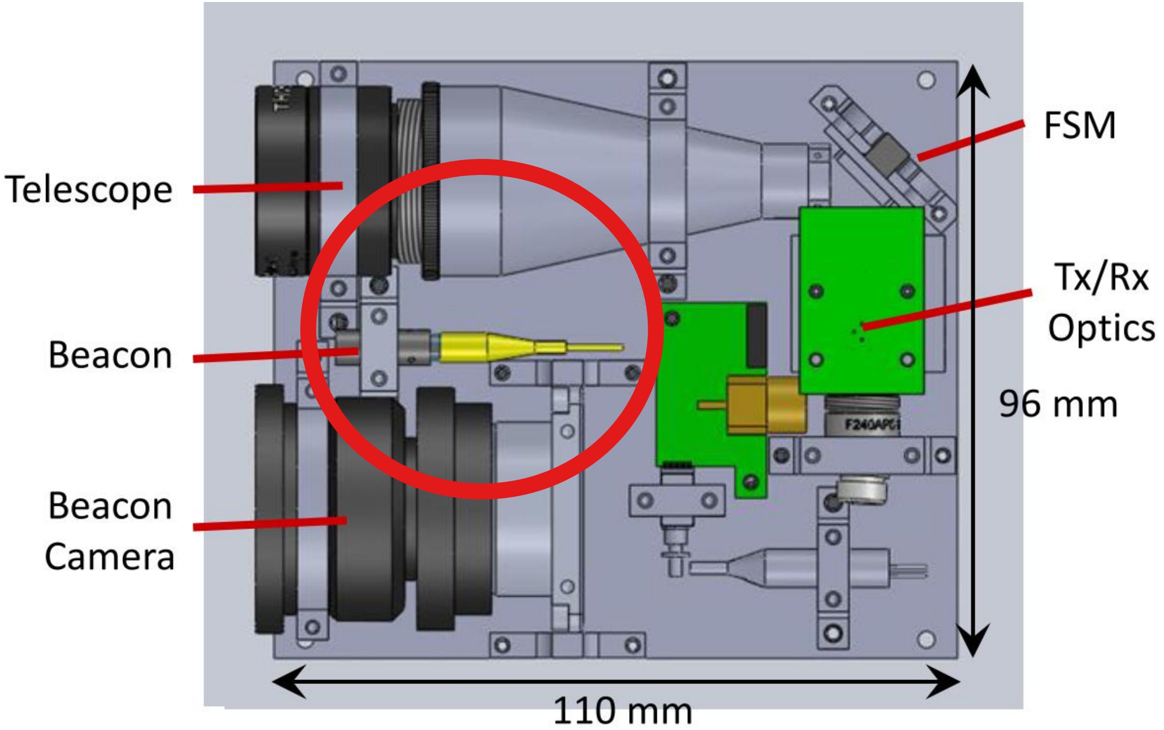

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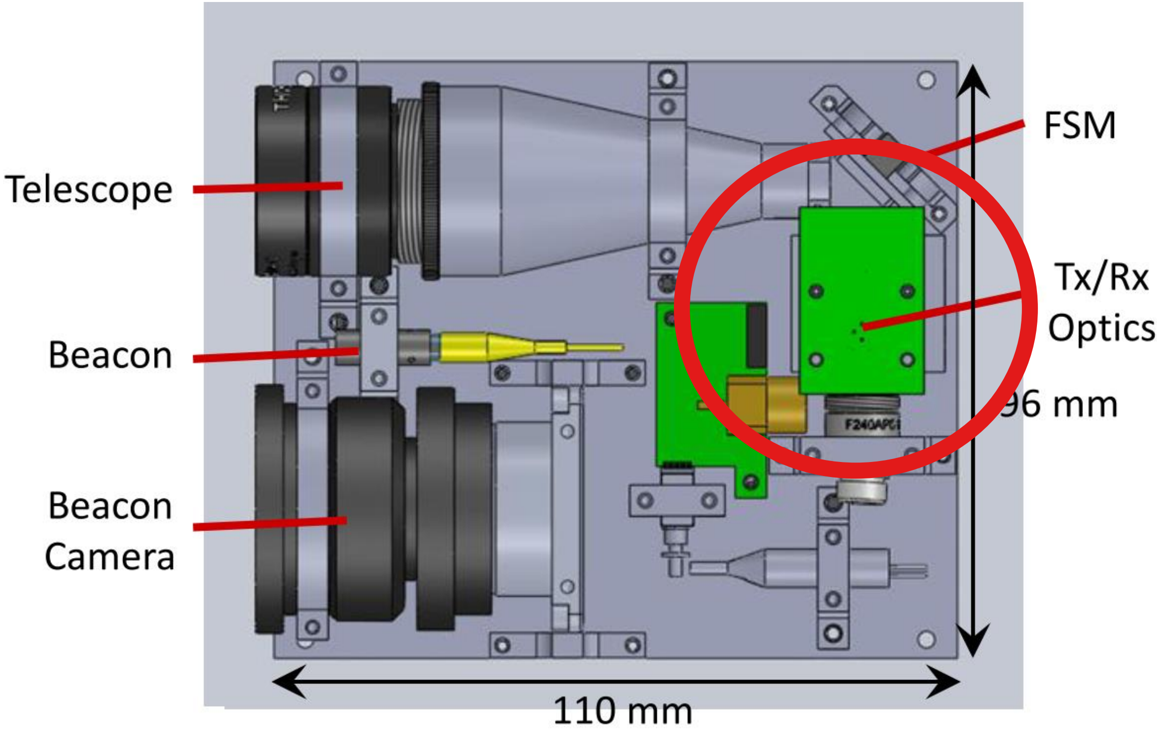


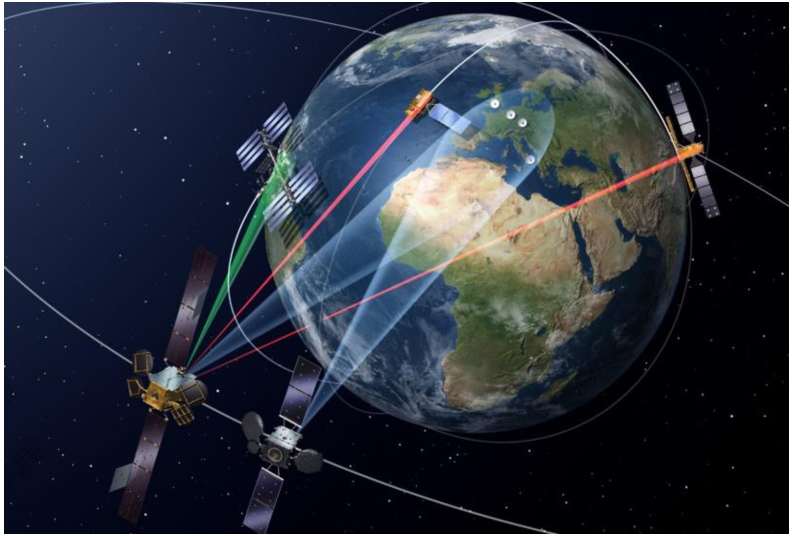
K Cahoy. Laser Communication with CubeSats. Technical report, 2018. URL https:// directory.eoportal.org/web/eoportal/s.

Introduction and Background

Goal:

Combine all the laser links into one Size, Weight and Power (SWaP) friendlier package.

Using off the shelf components and implementing some improvements



https://www.esa.int/Applications/Telecommunications_Integrated_Applications/EDRS

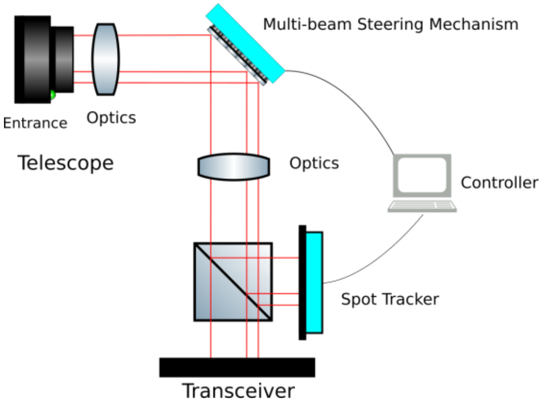
Introduction and Background

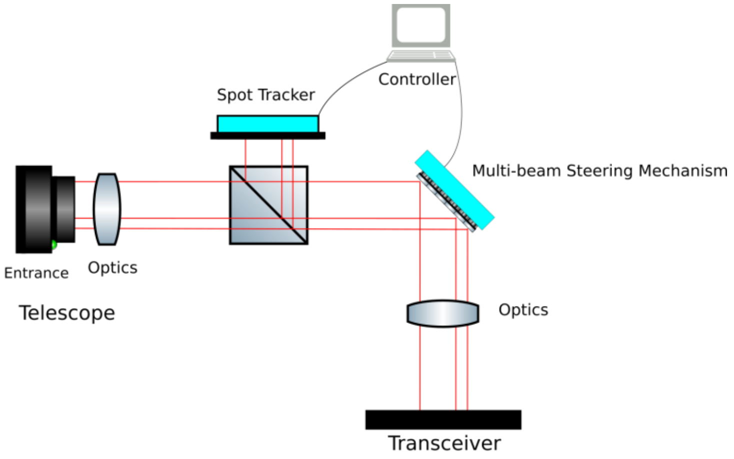
List of design goals:

- Closed feedback loop
- Multi-beam steering mechanism
- Shared components between all beams
- No required beacon
- Handle 2-way (duplex) communications
- Designed using only Commercial Of The Shelf (COTS) parts
- Make the SWaP per link similar to that of systems such as NODE

System Design

- Trade-off Steering Orientation

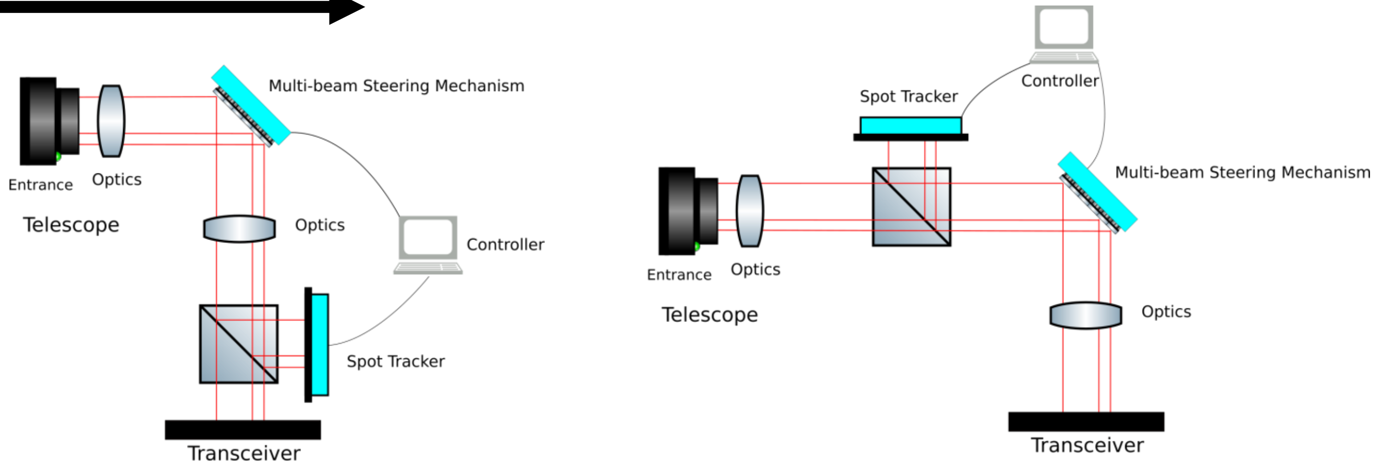




Incoming Beam Direction

System Design

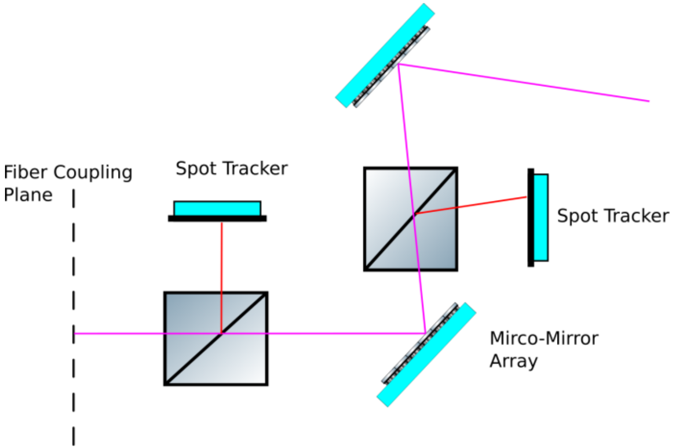
Incoming Beam Direction →



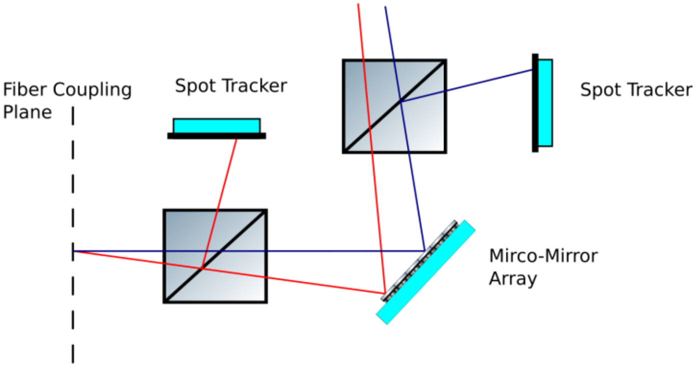
Configuration	Incoming Beam Steering	Outgoing Beam Steering
Feasibility	Feasable	Feasable
Splitter Complexity	Low	High
Steering Complexity	Low	High
Number of Spots Tracked	High	Low

System Design

- Differences between same-path and multi-path methods. (Incoming = Red Outgoing = Blue)



Same-Path



Multi-Path

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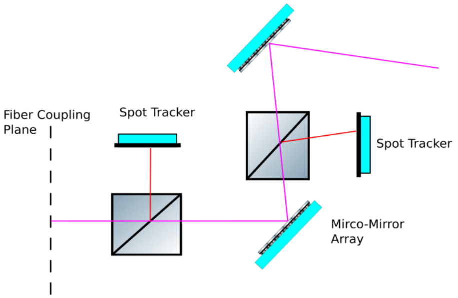
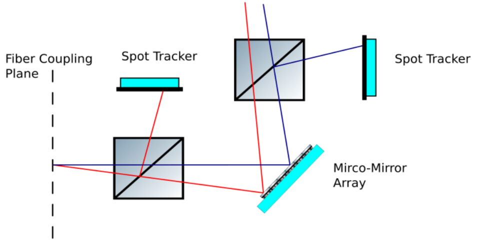
System Design



Same-Path



Multi-Path

Criteria	Single Path 2 Steering Stages	Dual Path 1 Steering Stage	Weights
Feedback Complexity	1	0	4
Number of Components	0	1	2
Design Flexibility	1	0	4
Number of Beams To Track	1	0	4
Maximum Number of Steerable Beams	1	0	4
Mass	0	1	3
Power	0	1	1
Singal Power Efficiency	0	1	5
Total	16	11	27

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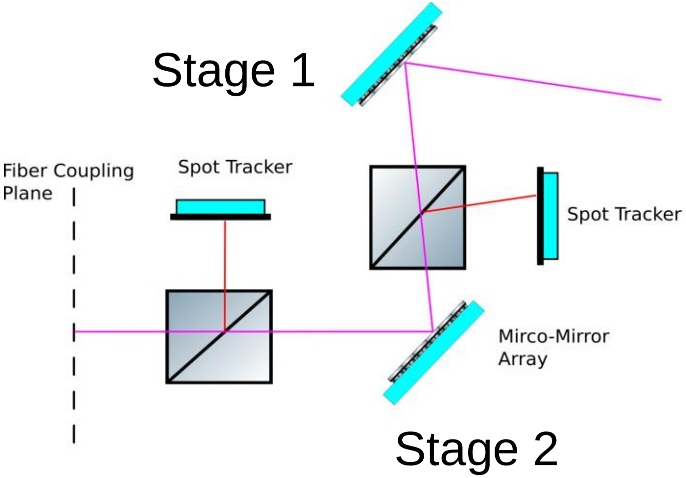
System Design



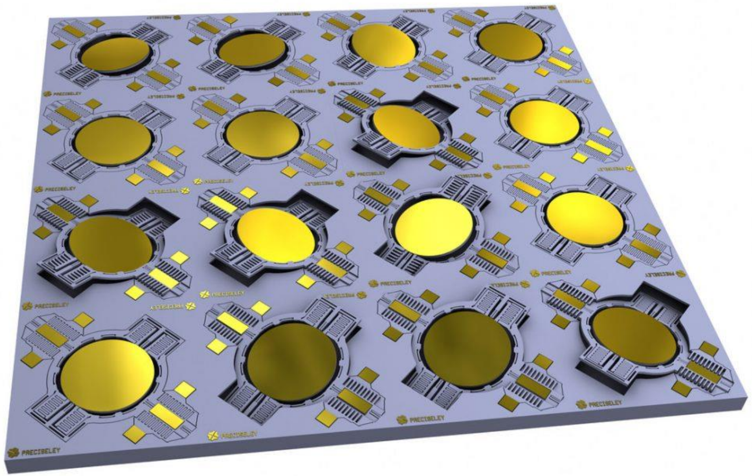
2 steering systems also allows for combining the best of both worlds of MMA's and SLM's.

This makes the speed of the system more than sufficient.

Criteria	MMA	SLM	Weight Stage 1	Weight Stage 2
Speed	>300 Hz	<200 Hz & >60 Hz	1	1
Resolution	~10 x 10	>1920 x 1080	2	0
Weighted Total Stage 1	1	2		
Weighted Total Stage 2	1	0		

System Design

- 10x10 MMA’s are 10 times smaller than FSM’s and almost as fast.



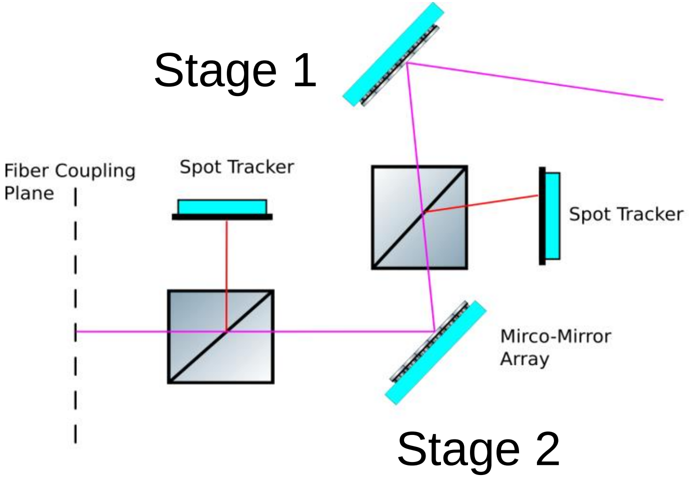
https://preciseley.com/mems-mirror-array/

System Design

- SLM's (Spatial Light Modulators) where chosen because of their high resolutions.

HOLOEYE. Spatial Light Modulators.

System Design



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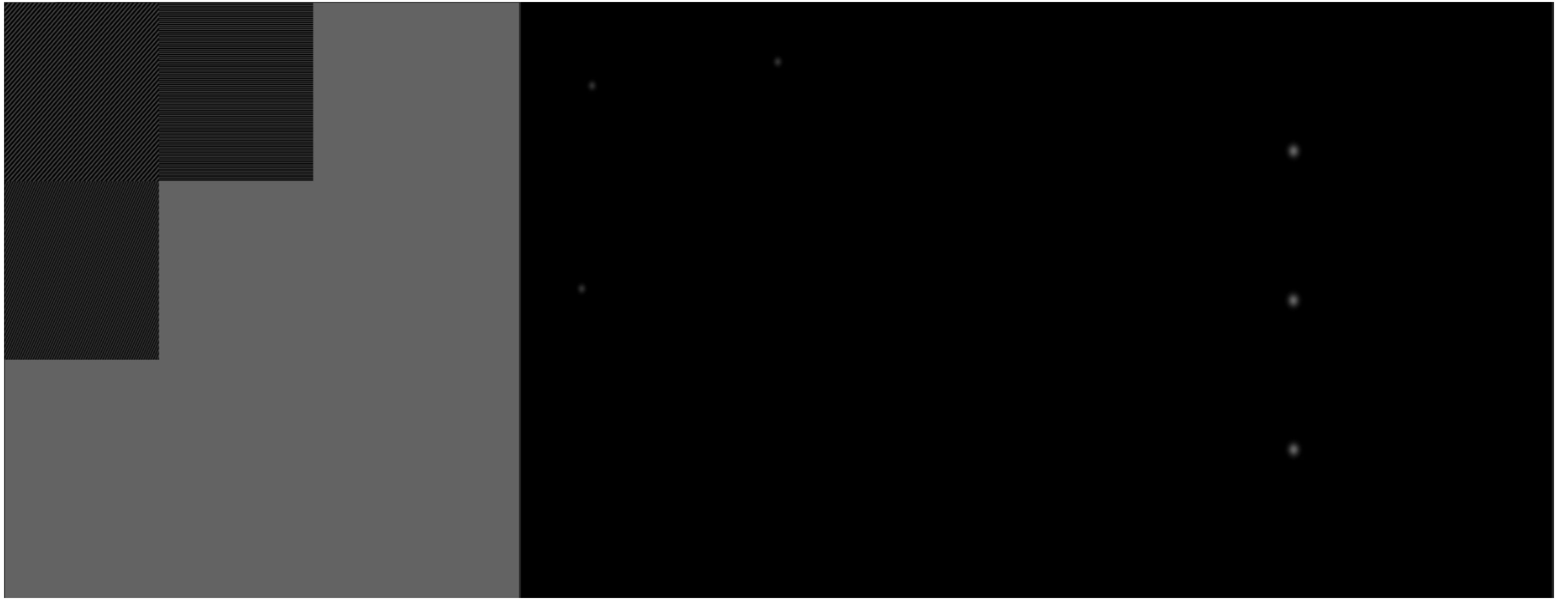
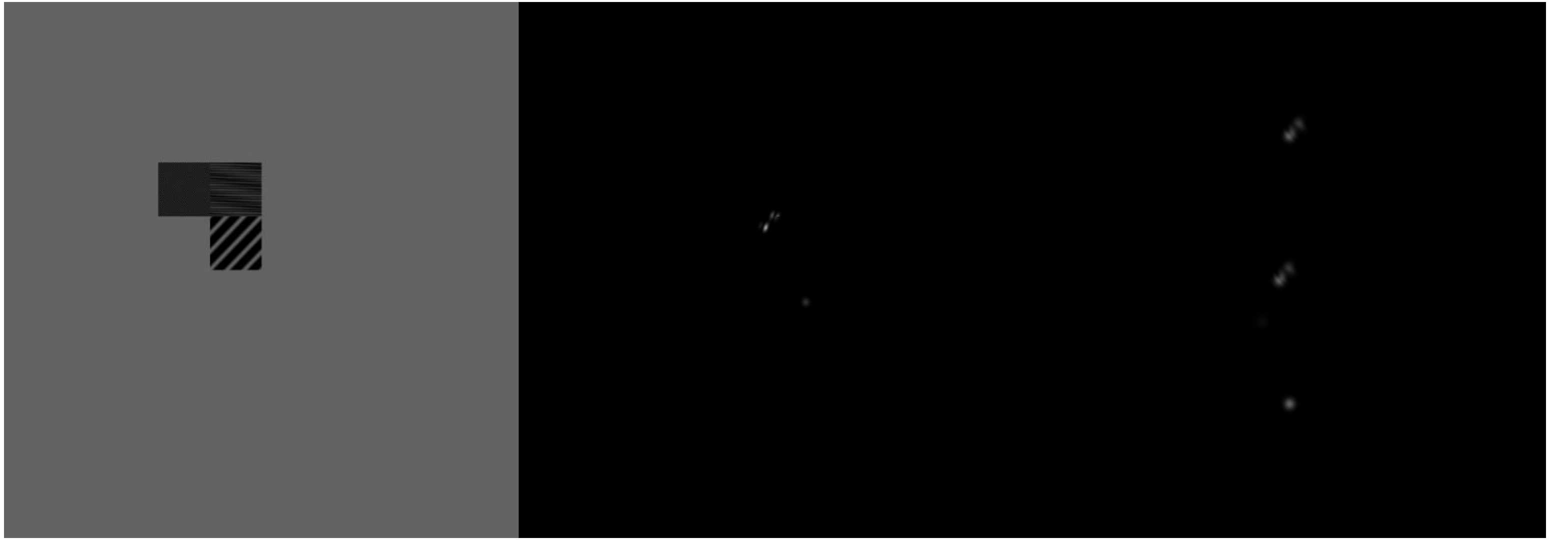
System Design

- High resolution vs low resolution steering



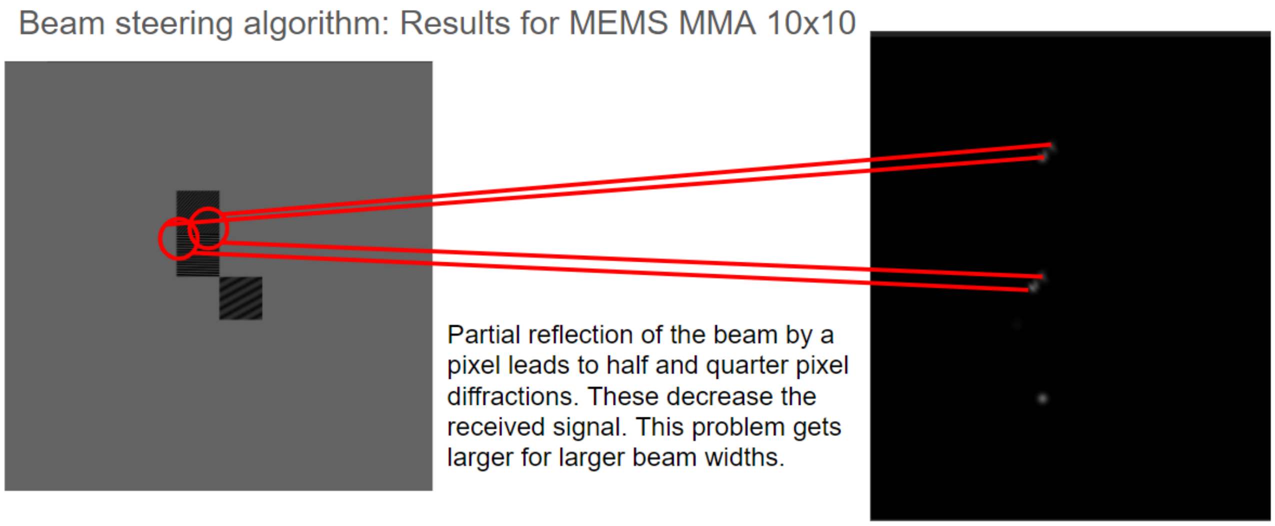
System Design

- High resolution vs low resolution steering



System Design

- High resolution vs low resolution steering



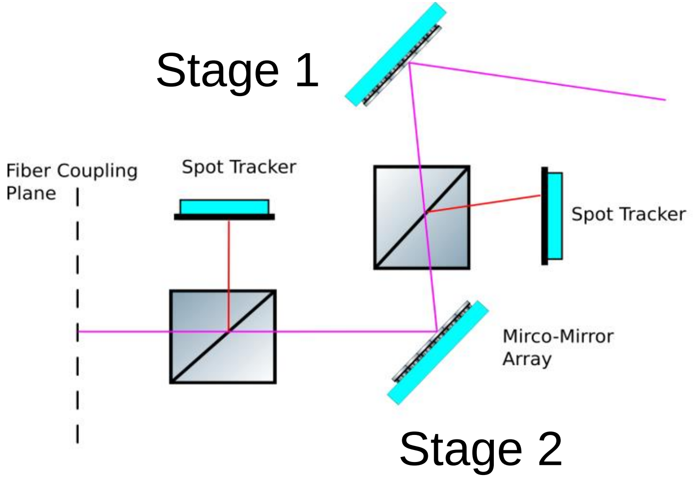
This results in diffraction losses

System Design

- High resolution vs low resolution steering

Higher resolutions have less issues with diffraction losses

System Design



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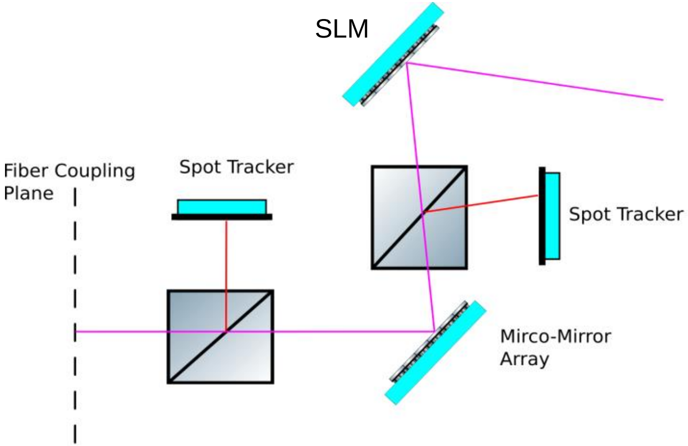
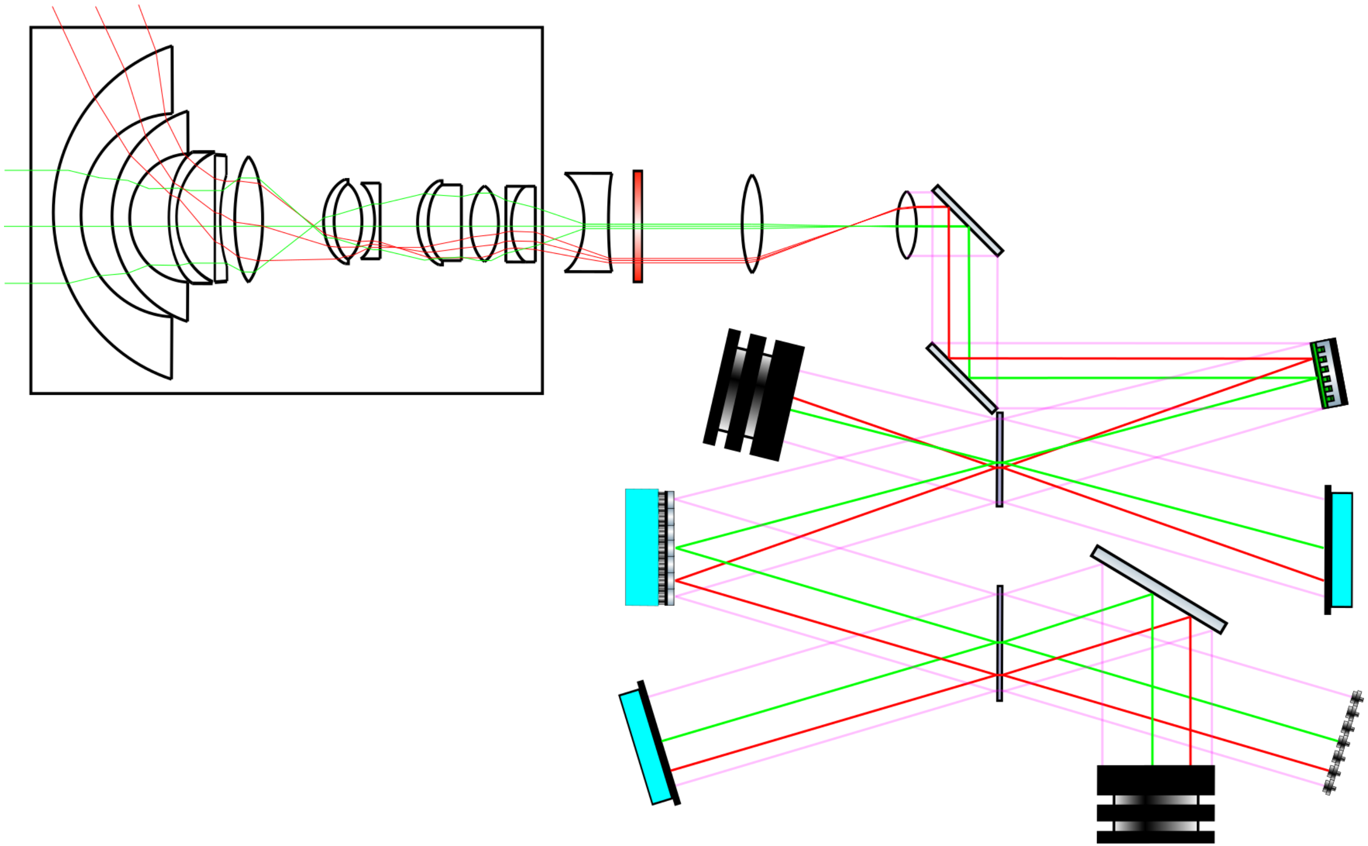
System Design



The use of the same-path approach implies very high-performance COTS fiber hardware can be used.

System Design



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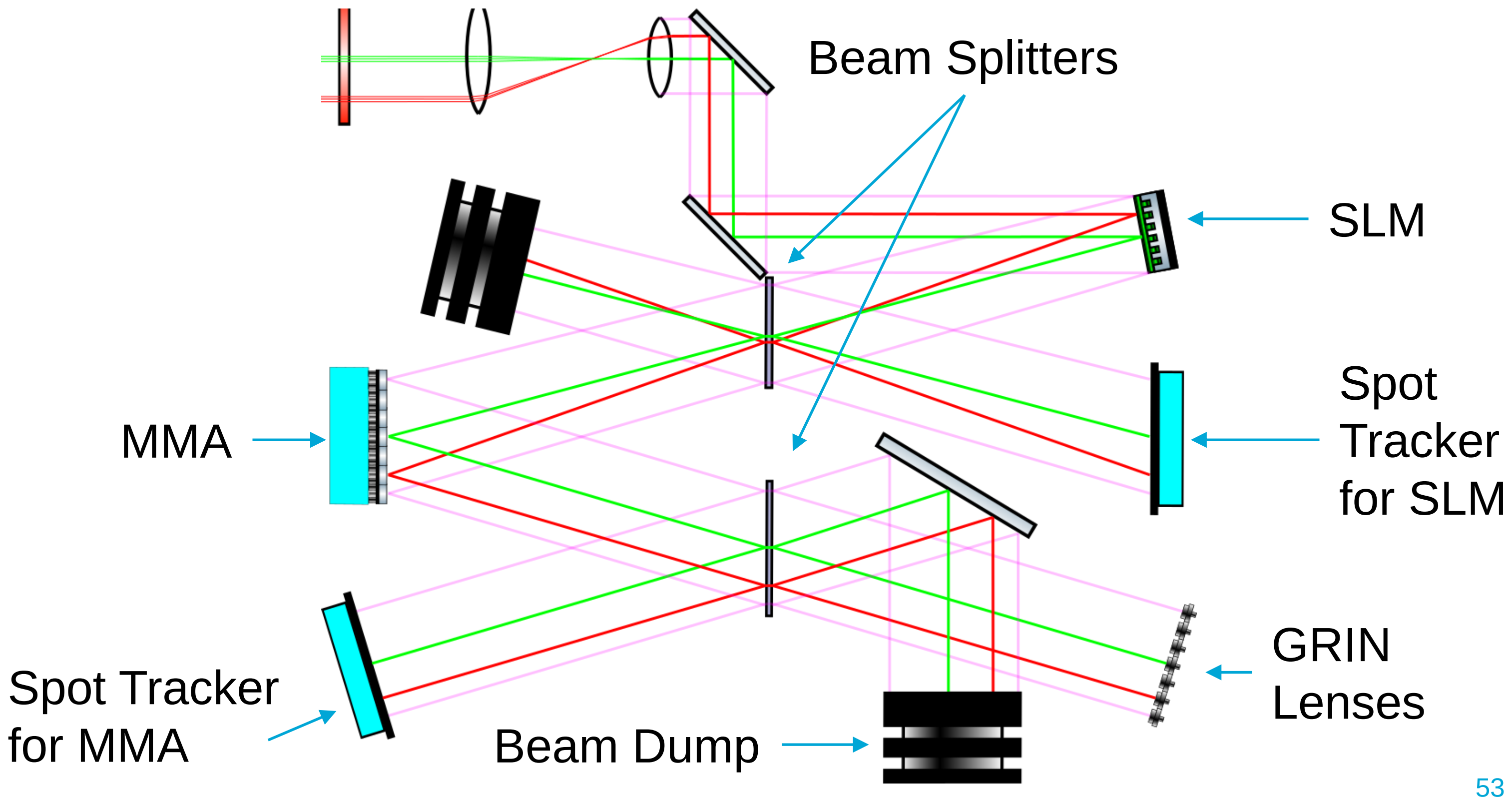

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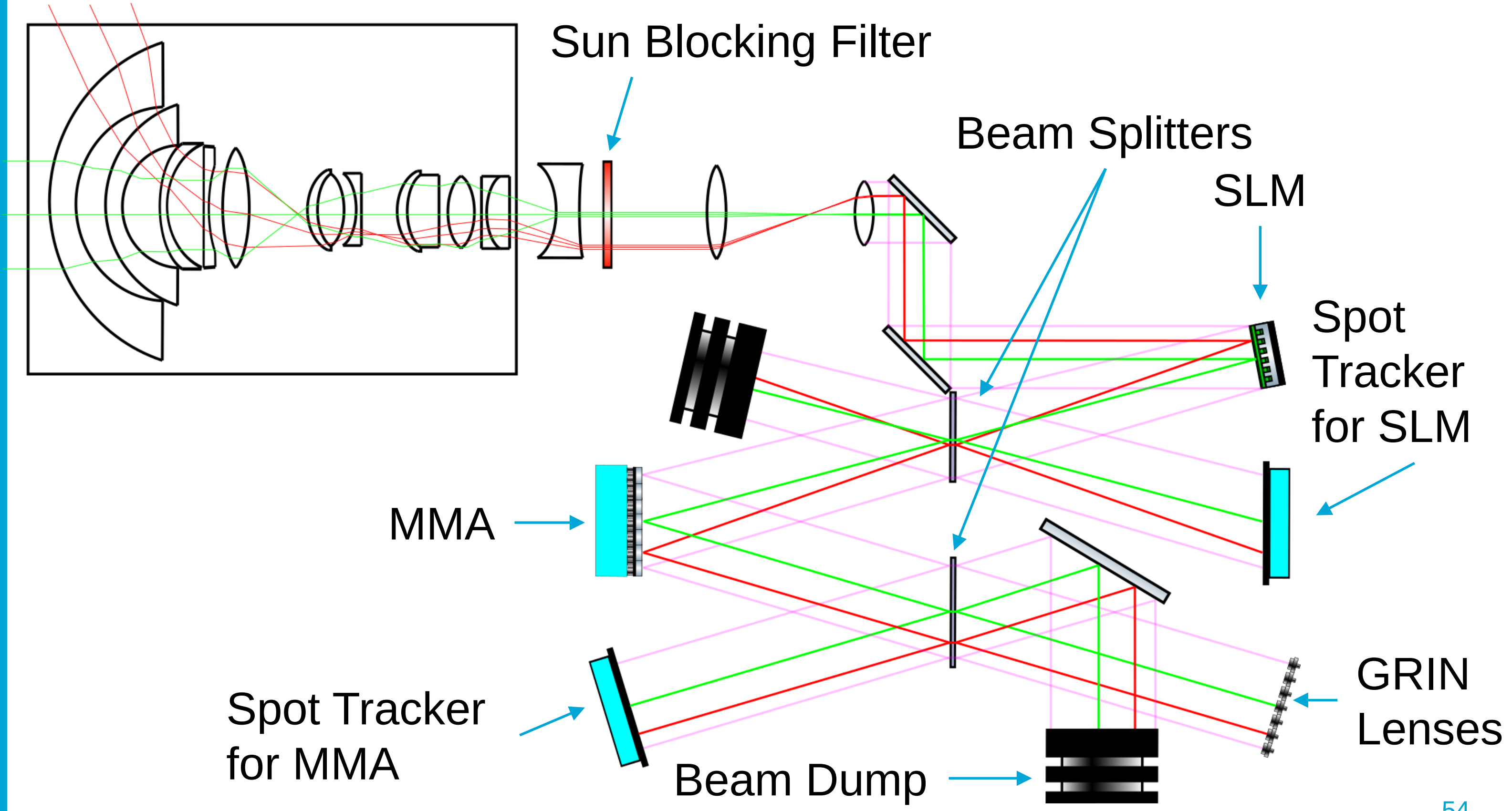

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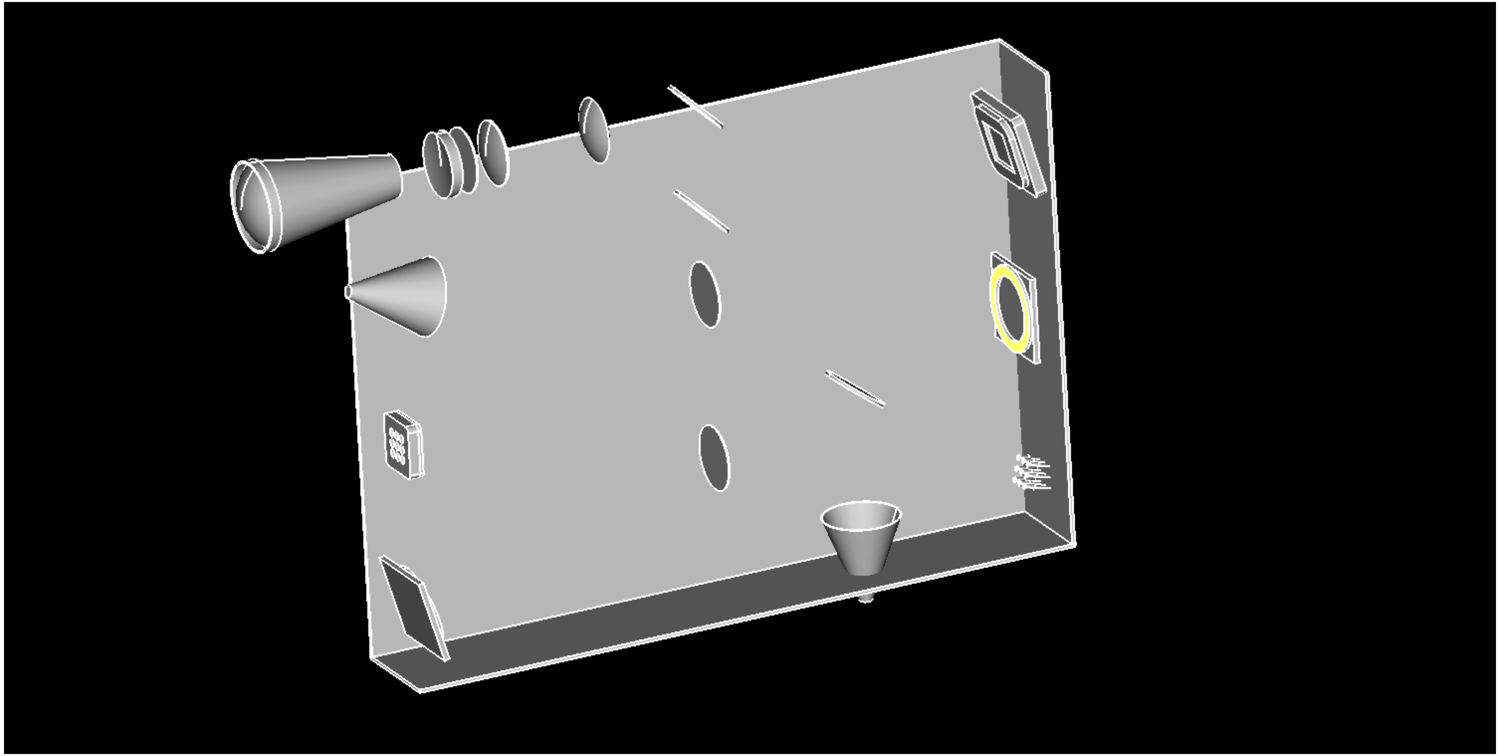
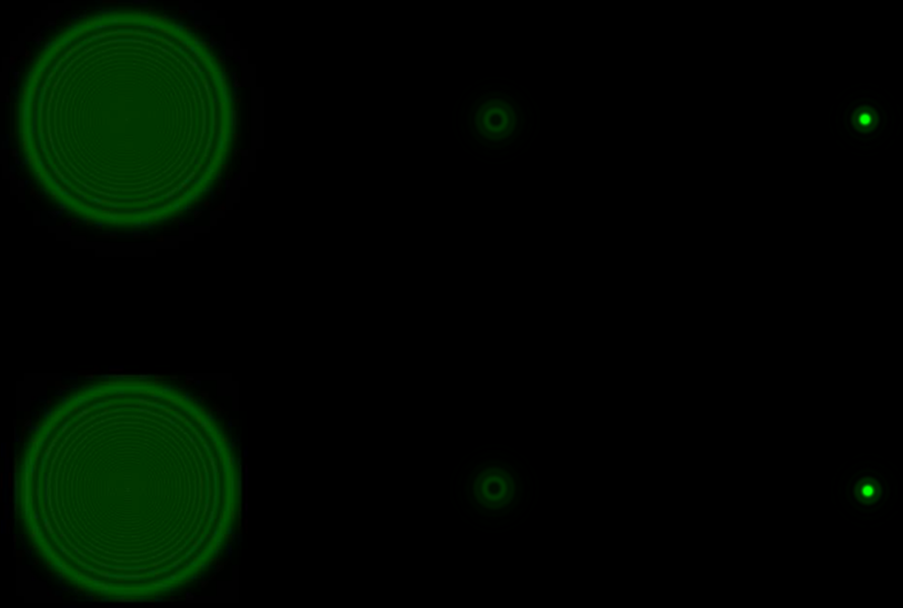
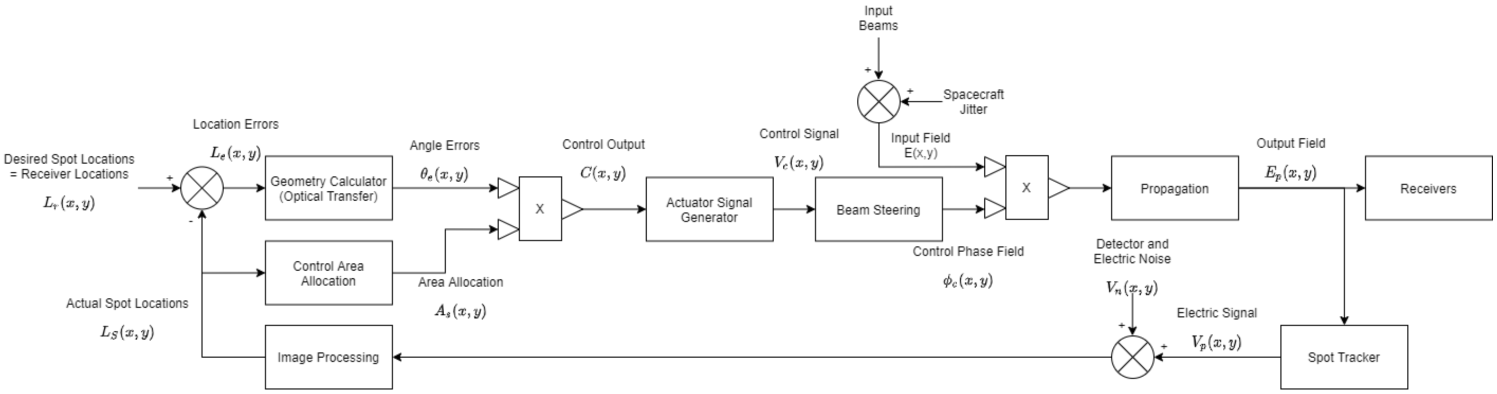


Modeling and Simulations



Full System Simulation



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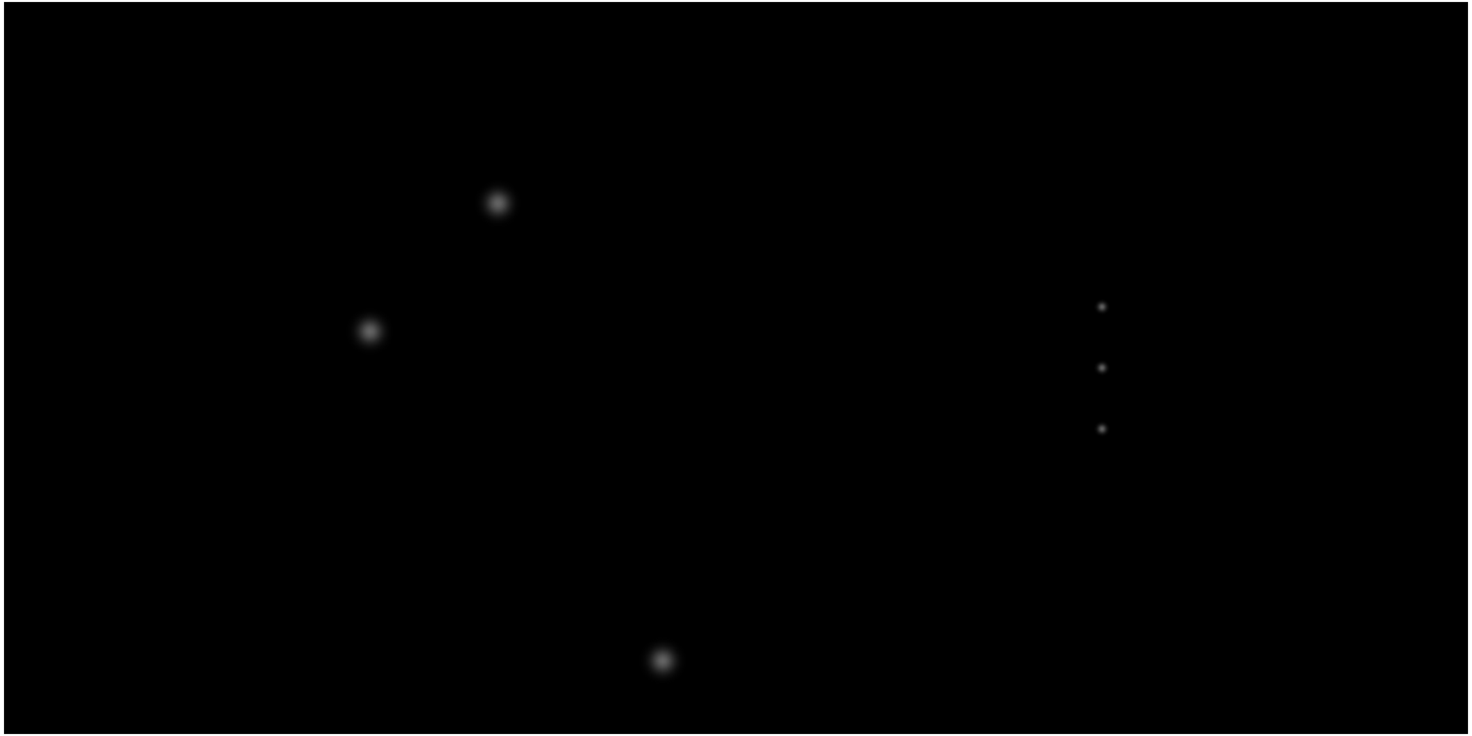

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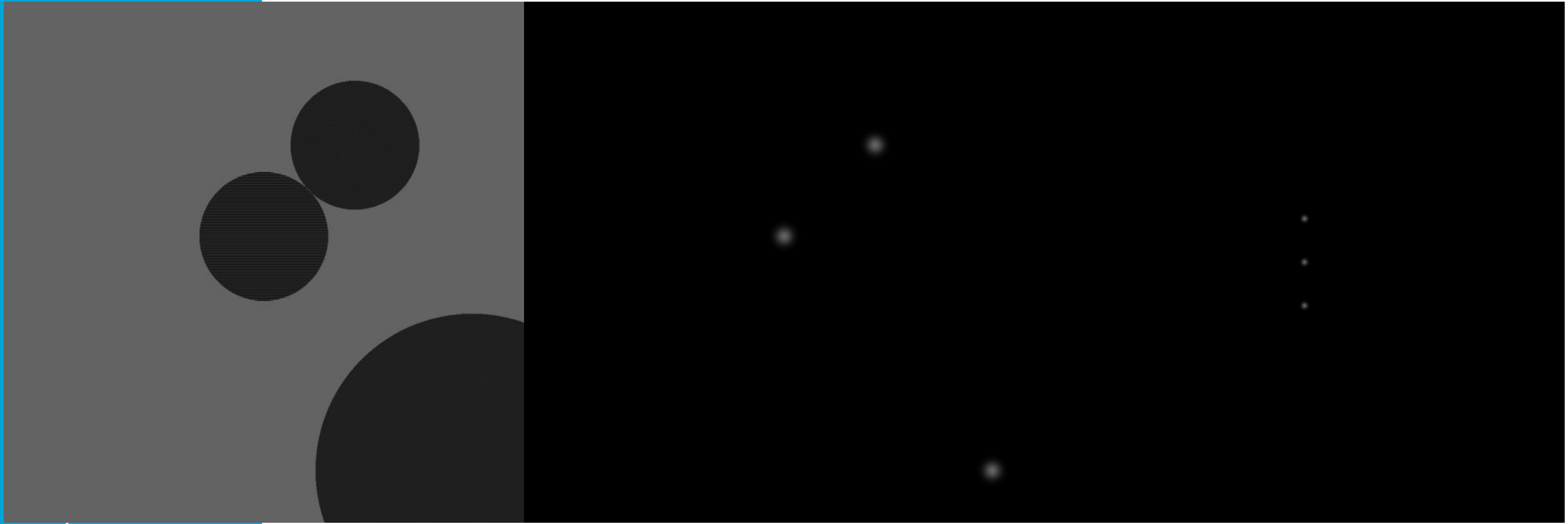

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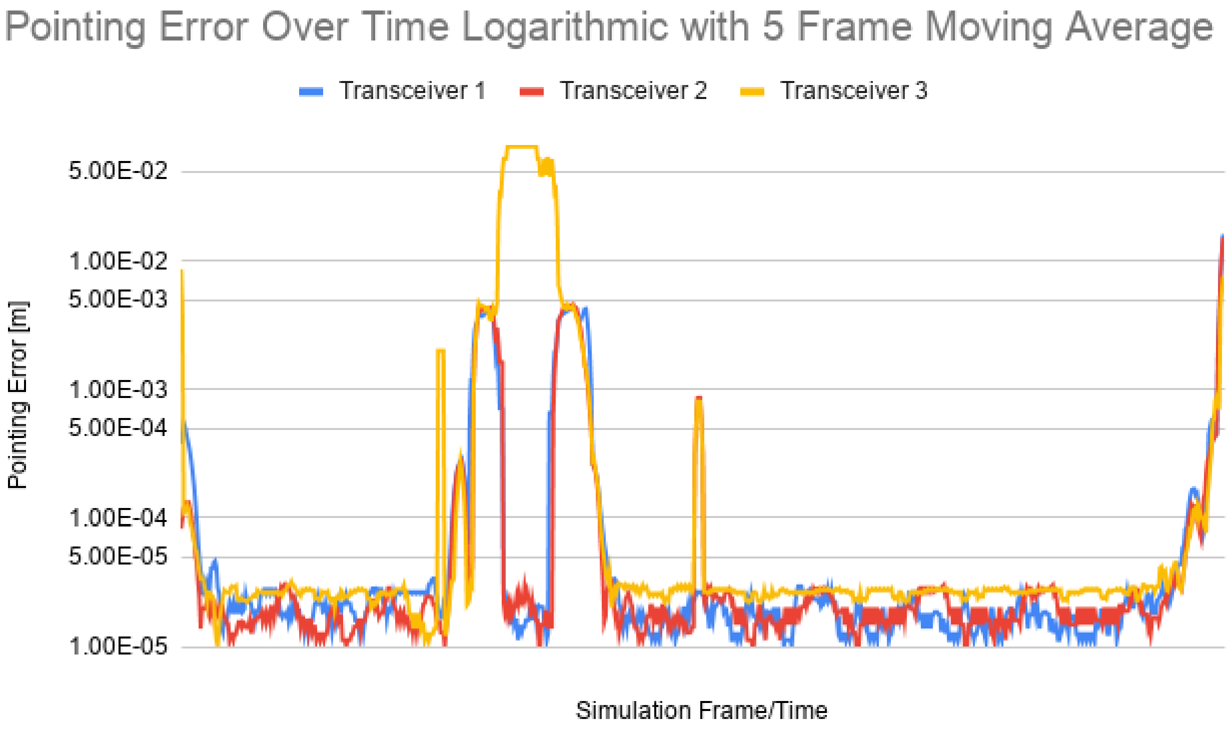

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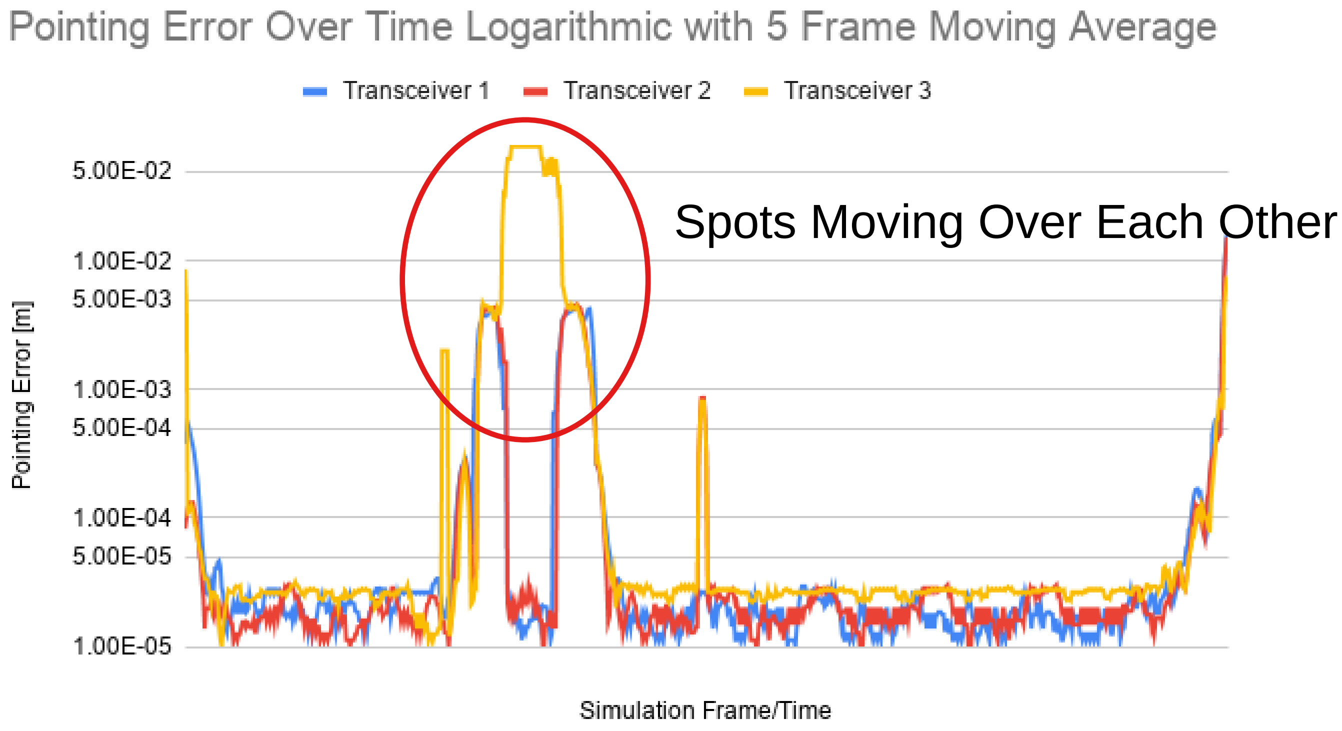

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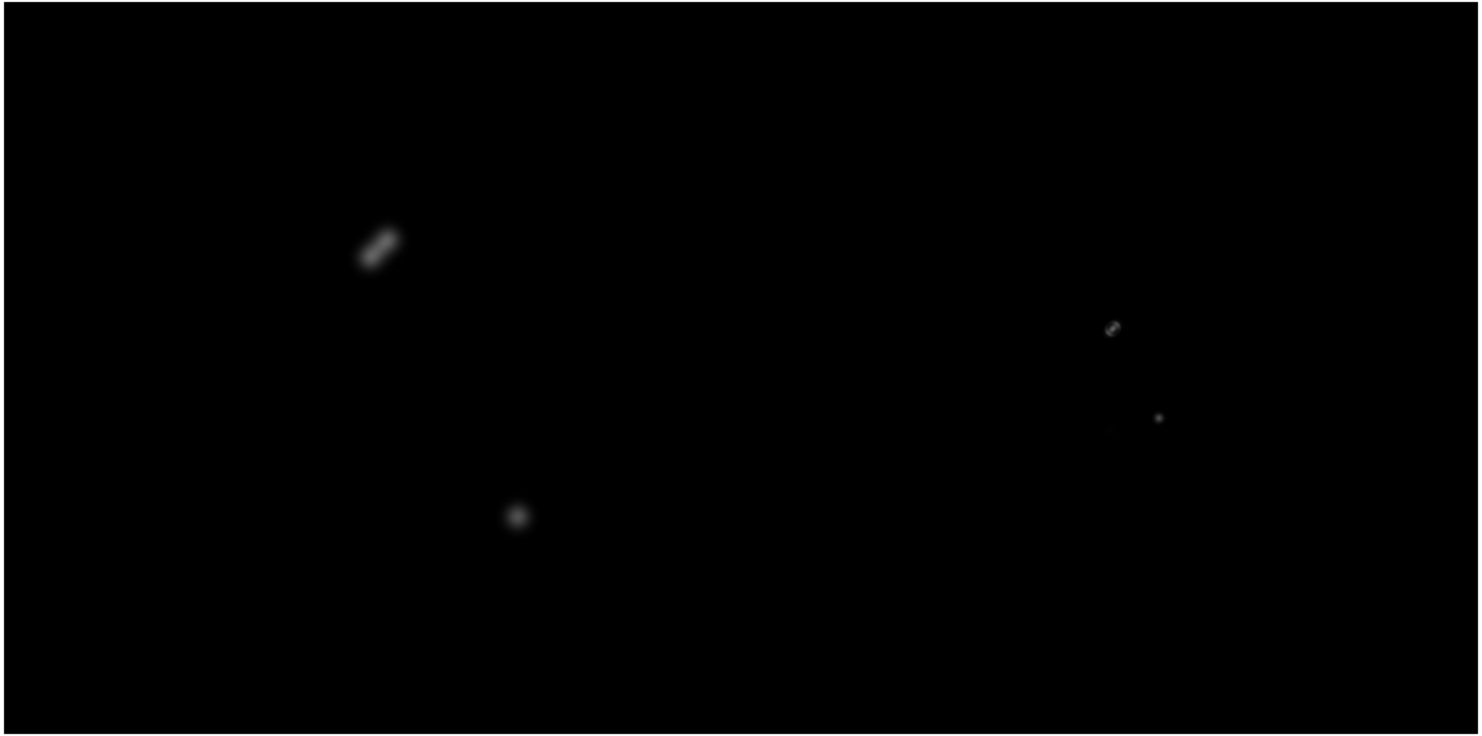

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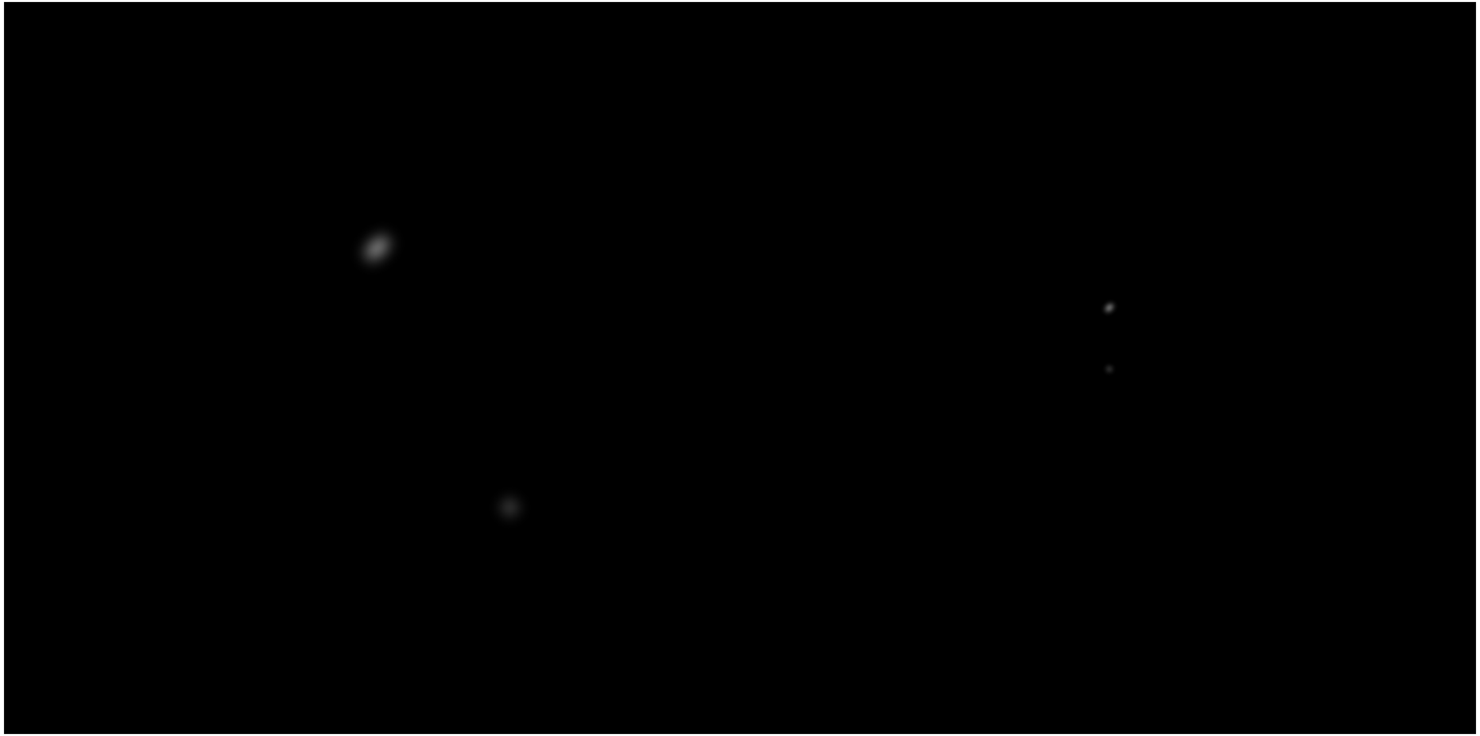

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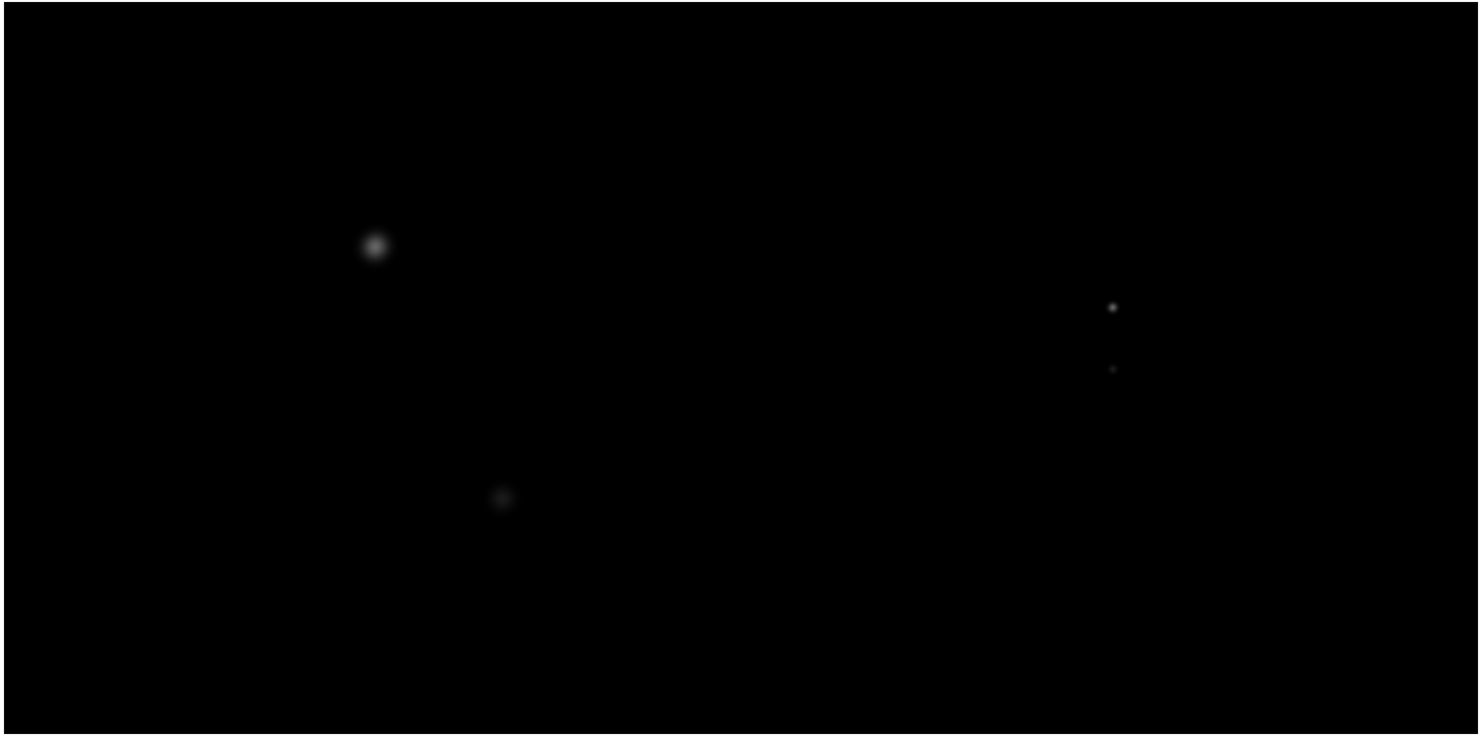

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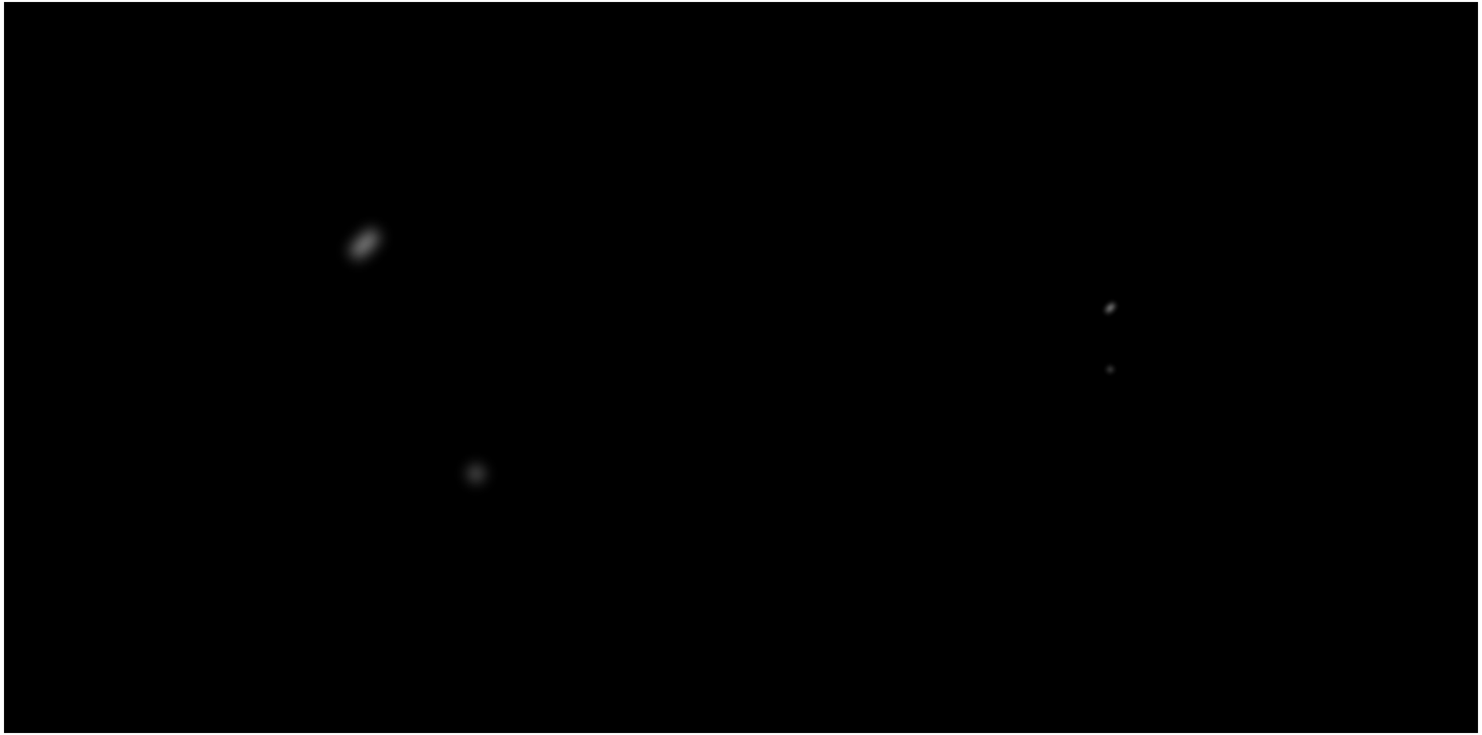

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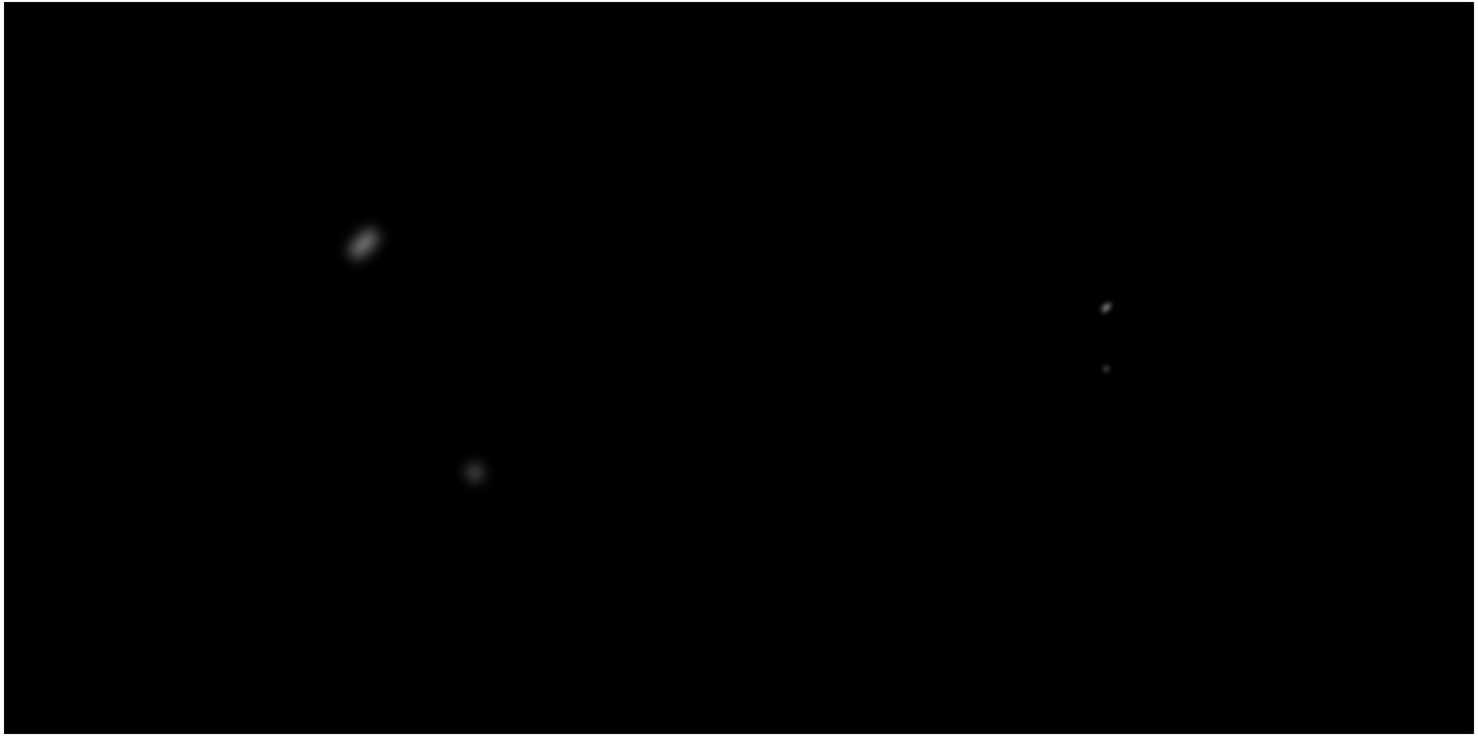

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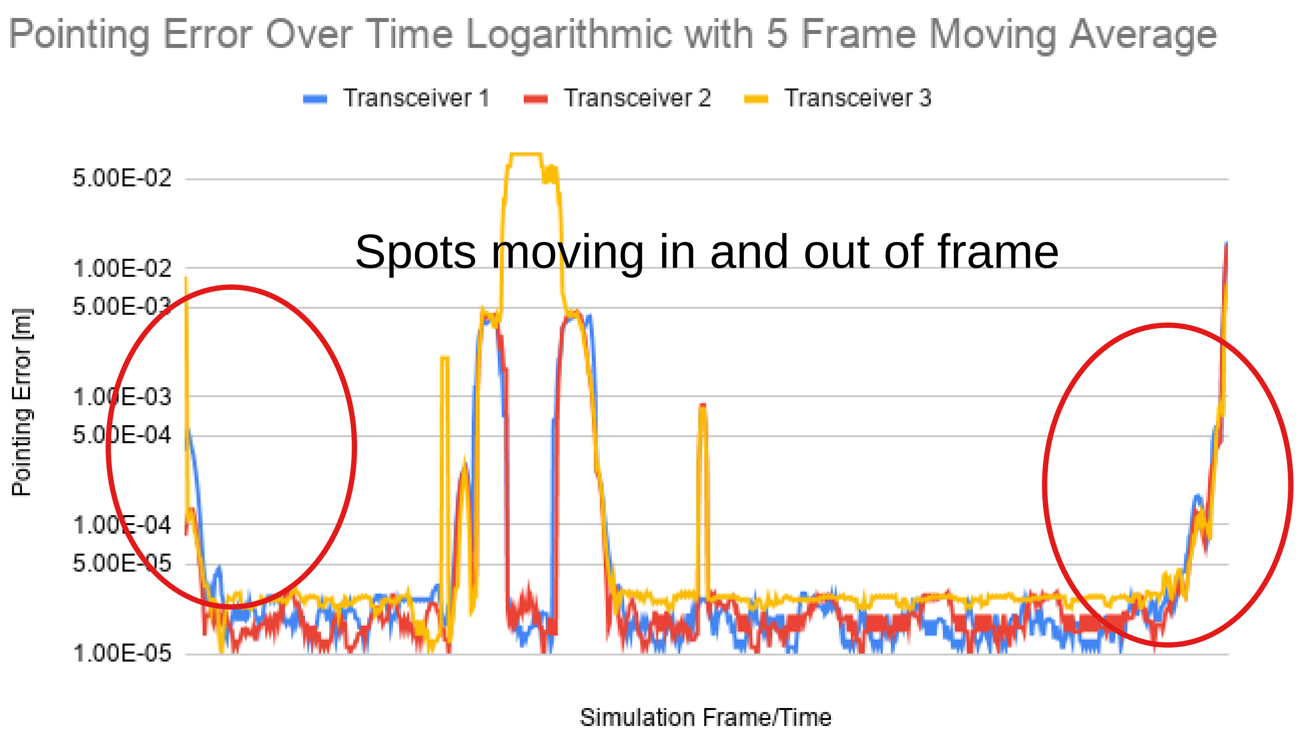

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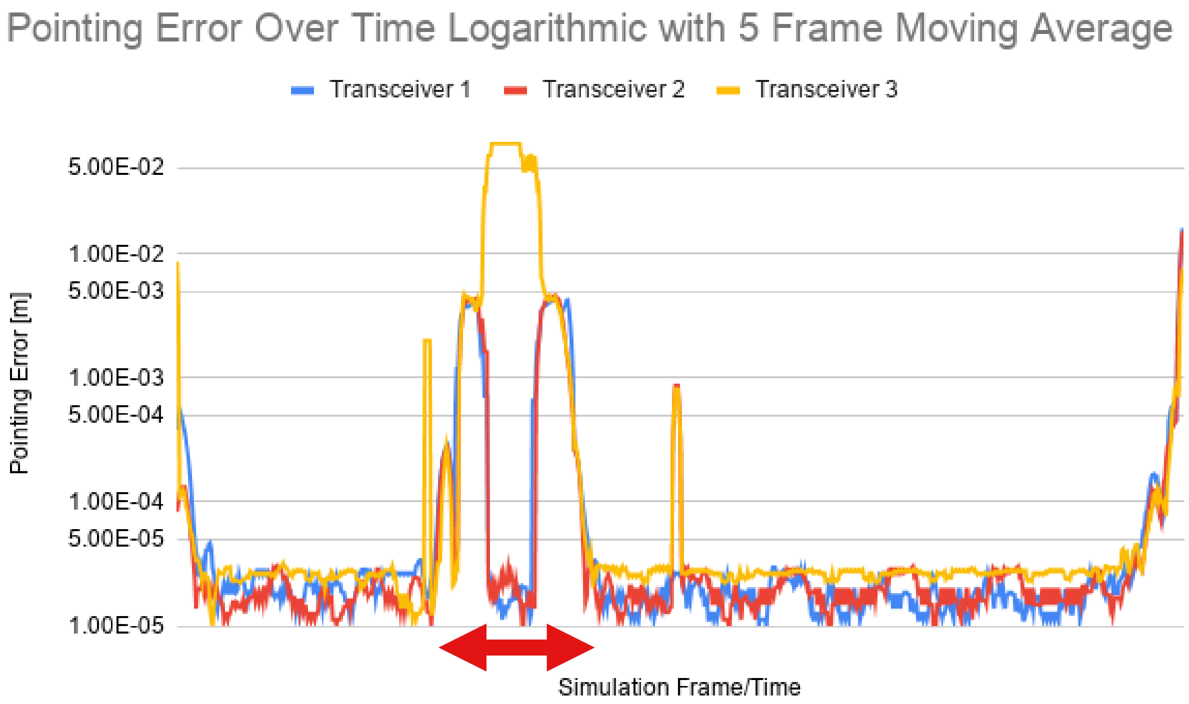

11% of the time spots where crossing

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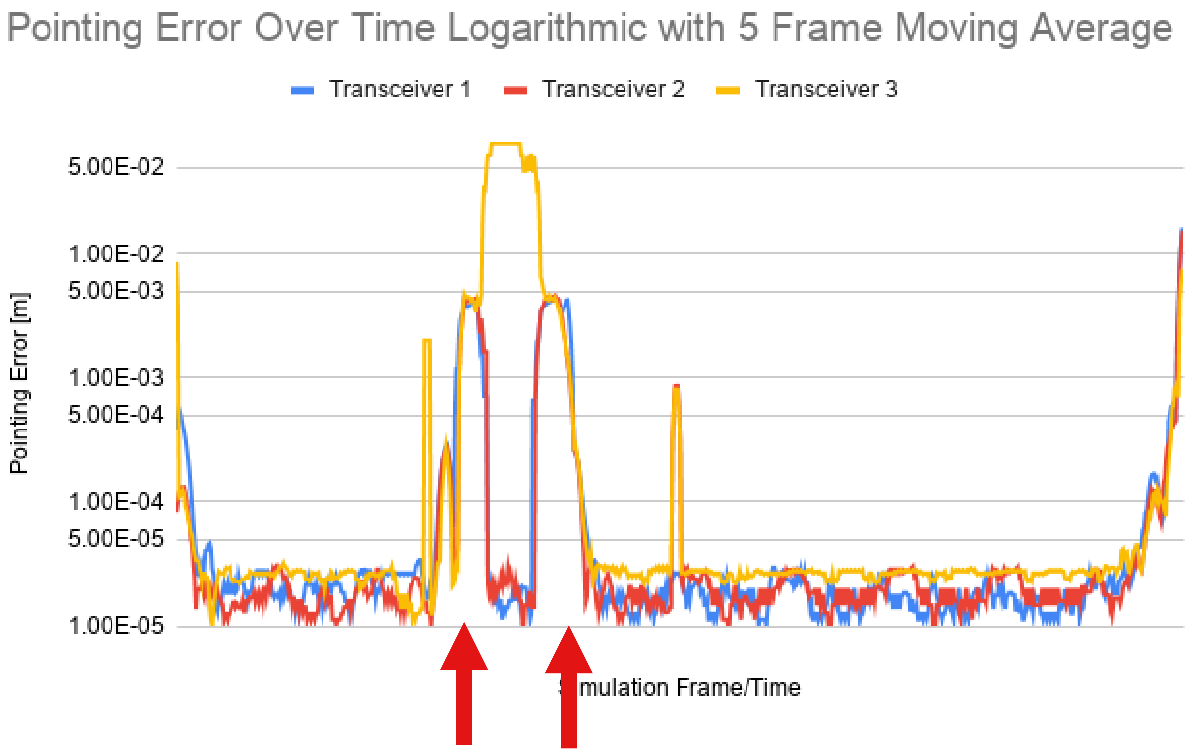

5% down time unaffiliated spot

Thank you!