Space Capacity Allocation For The Sustainability Of Space Activities Workshop
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Fragmentation, Loss-of-Control and Other Acute Space-based Hazards Score – **FLASH** – For Fragmentation Hazard Oriented Ground Based Observations

1. CONTEXT & SOTA

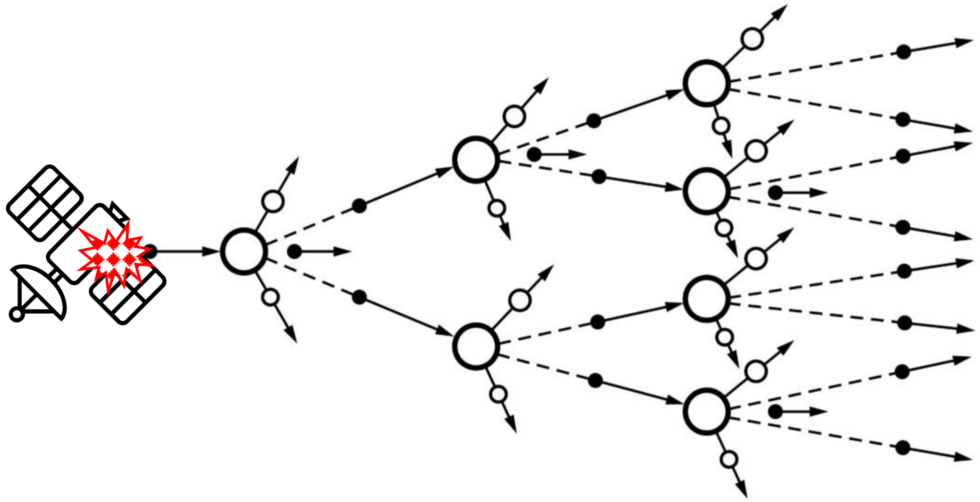
A. The Kessler Syndrome and spatial density

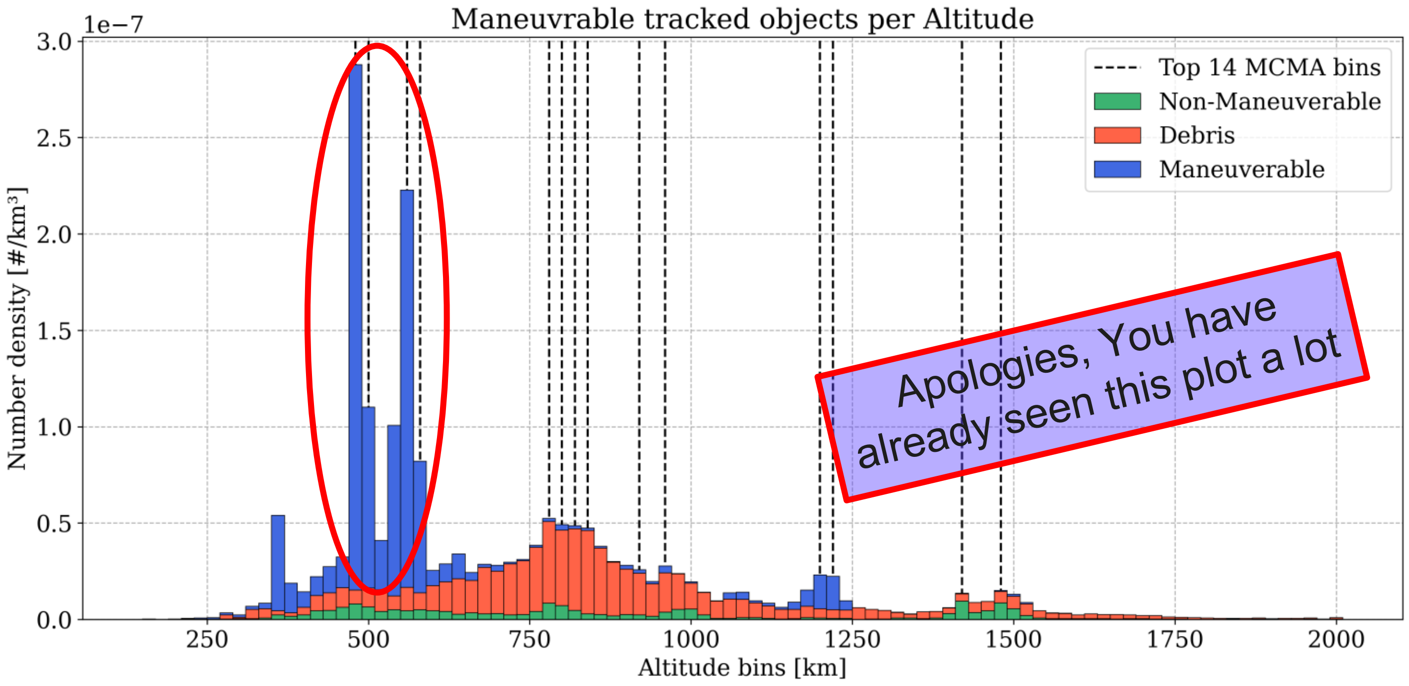
B. Motivation

1. Context and SOTA

A. The Kessler syndrome and spatial density

- The KESSLER SYNDROME
  - **> 25 %** of fragmentation related to explosions from residual propellant





Starlink constellation

1. Context and SOTA

B. Motivation

CURRENT INDICES HAVE LIMITATIONS FOR DAILY USE

- Data availability
- Computational limitations for efficiency purposes
- Methodological inadequacies – specific to certain type of fragmentation
- Flexibility requirements

FLASH Score :

combination of *probability* and *consequence* for **explosion** and **collision**, plus an object **properties** related component, through PUBLIC database

$$I_{\mathrm{FLASH}} = \tilde{I}_e + \tilde{I}_c + \tilde{I}_p$$

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2. THEORETICAL FOUNDATION AND EQUATIONS

A. Explosion component equation

B. Properties component equation

C. Collision component equation

2. FLASH theoretical foundations and equations

A. Explosion component equation

- **Explosion** component :

$$\boxed{I_e = P_{\mathrm{KM}} \cdot E_{risk}}$$

- ***P*KM** = Probability of explosion

Survival analysis *with Kaplan-Meier reliability estimator*
Given failure data, estimate the probability of failures at a given time t

- ***Erisk*** = Severity of impact of explosion
  - *Number of fragment from explosion (NASA Standard Break-Up Model)*
  - *Persistence (Remaining lifetime estimation)*
  - *Density of current orbit altitude*
  - *Crossing orbit density exposure*

- **Properties** hazard component :

Combination of *mass factor, inclination risk dependance, activity statut factor, orbital persistence and percentage of orbital time spent under 2000km*

2. FLASH theoretical foundations and equations

B. Properties component equation

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B. Collision component equation

$$I_{\text{collision}} = \widetilde{C}_{\text{risk}} \cdot P_{\text{collision}} \cdot N_{\text{orbital}}$$

- **P collision** = Collision probability term: analytical probability inspired by Kinetic Theory

$$p_c = 1 - \exp(-\rho \Delta V A \Delta t)$$

- estimated for different crossed altitude along with percentage of time spent in each

$$P_{\text{collision}} = \frac{\delta t_{\text{current}}}{T} \cdot \widetilde{p}_{\text{col}} + \sum_{i \in \mathcal{MCMA}} \frac{\delta t_i}{T} \cdot \widetilde{p}_{\text{col,cross},i}$$

- **C risk** = Severity of impact on space orbit:

$$C_{\text{risk}} = \sum_j R_j + N_{\text{cross}} + \rho_{\text{cross}}$$

- *Rj* variables : NASA Standard Break-Up model for collision related variables

- ***N orbital*** variable :

related to orbital regime stability and uncertainty, and traceability factors (size and activity) and maneuvrability

The more information on object = lower N orbital

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3. RESULTS AND DISCUSSION

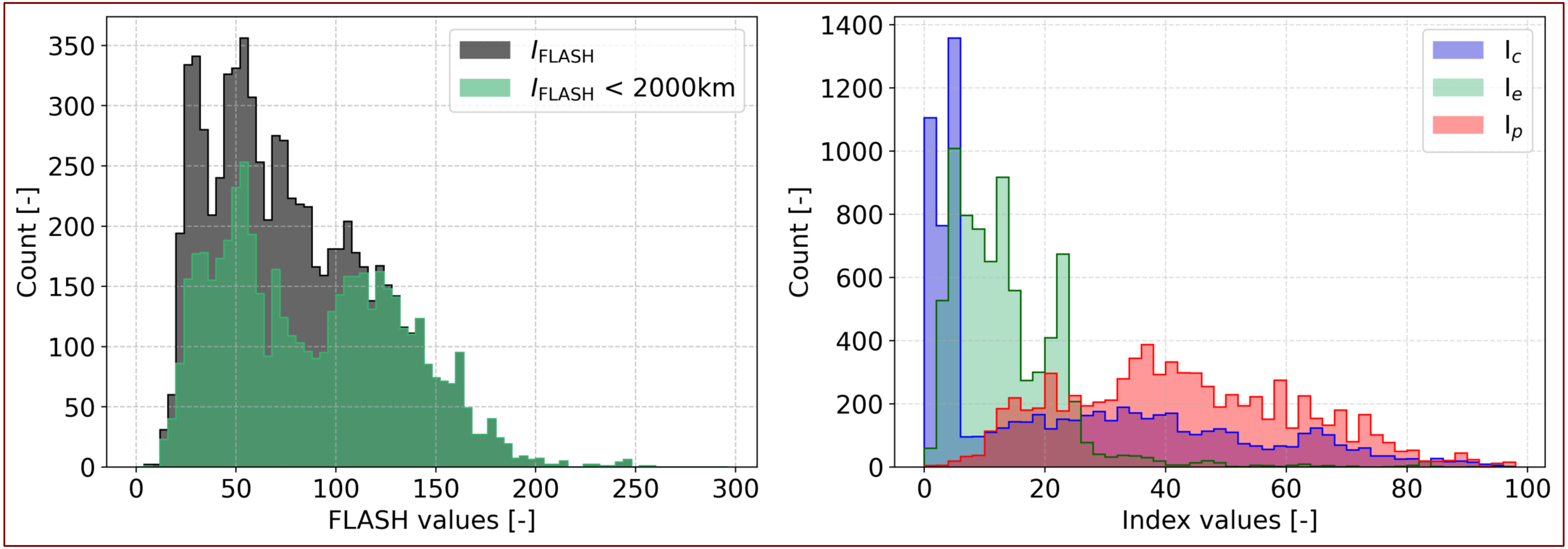
A. FLASH values distribution

B. FLASH spatial behavior

C. FLASH top 200 and comparison

3. Results and Discussion

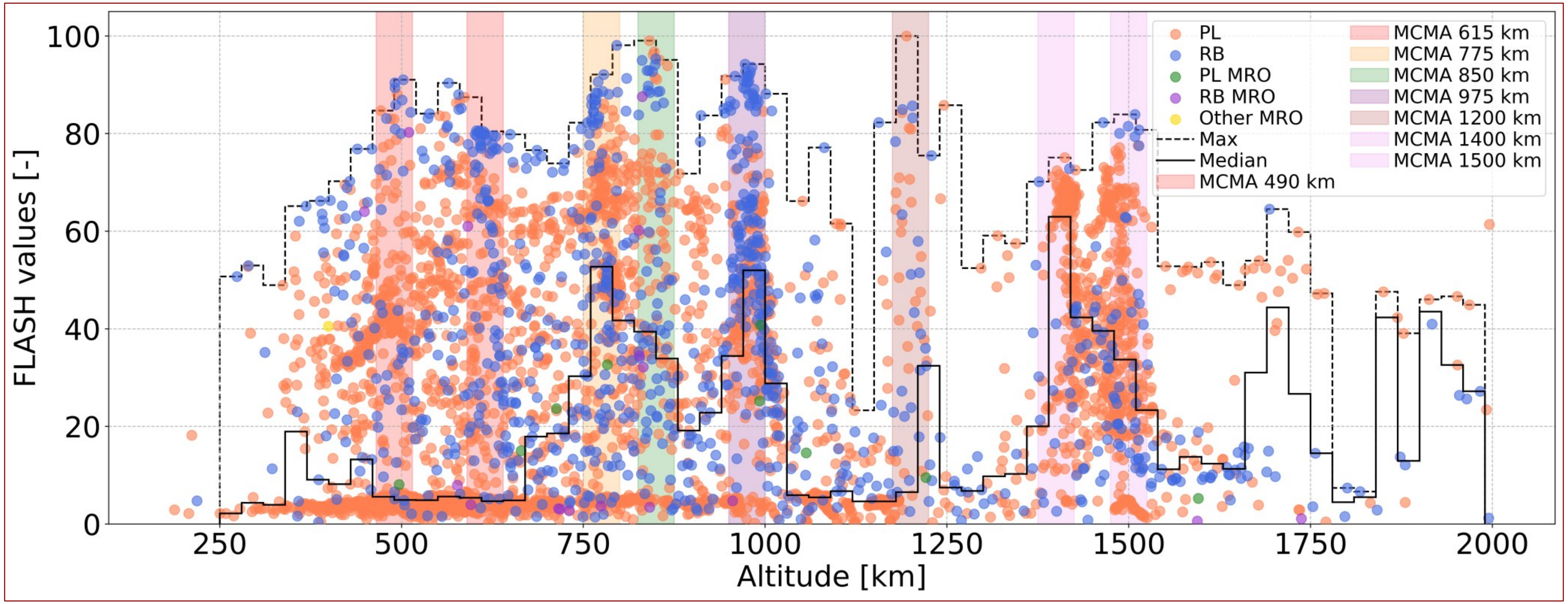
A. FLASH values distribution



- Distribution of FLASH values and of its 3 components
- Highly skewed distribution for collision and explosion component

3. Results and Discussion

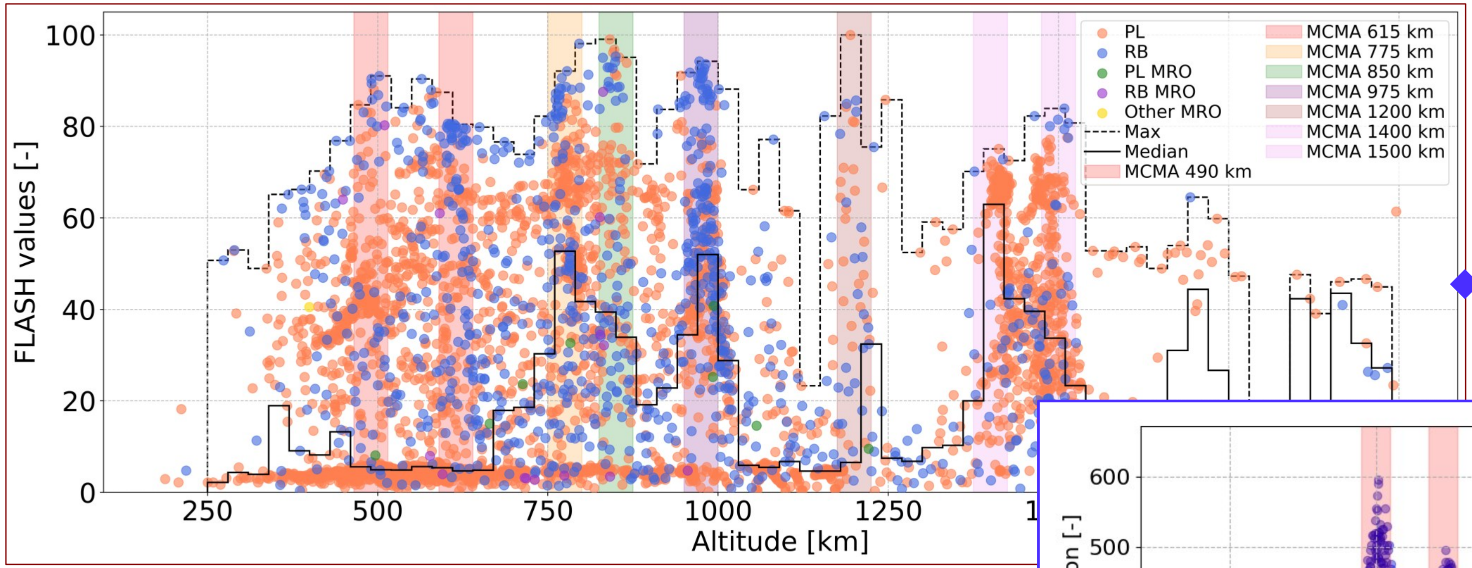
B. FLASH spatial behavior



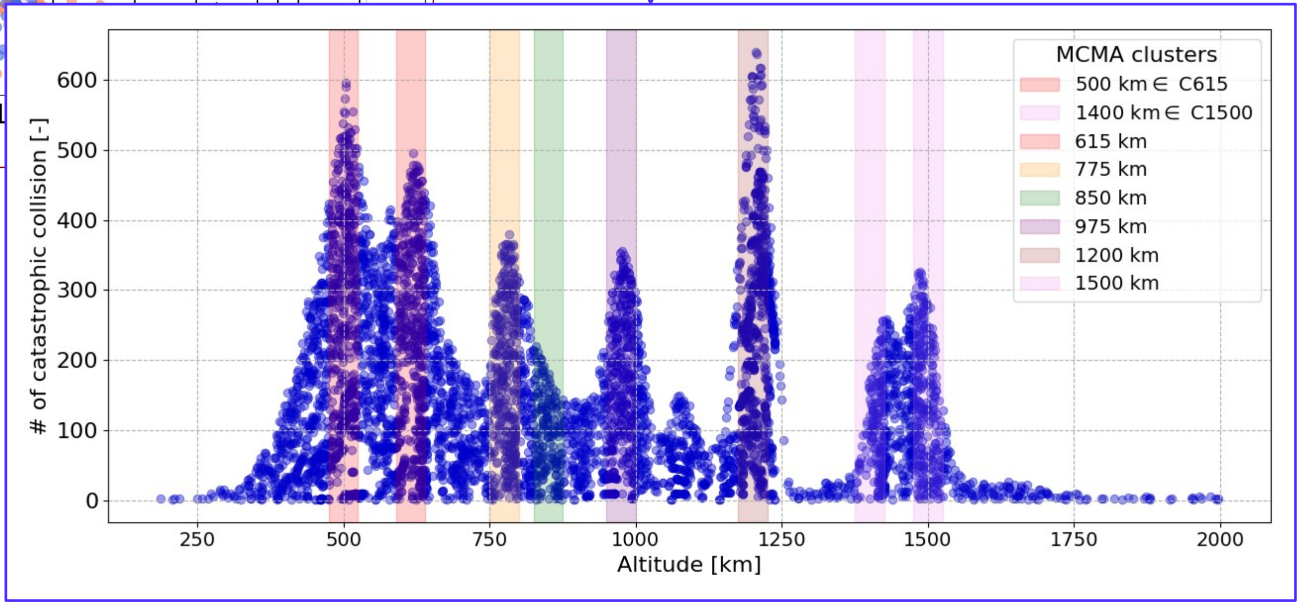
- FLASH score altitude plot for objects in LEO and bar plot of maximum values per altitude bins compared to MCMA cluster's location

3. Results and Discussion

B. FLASH spatial behavior



Number of catastrophic event per object at their respective altitude



MCMA cluster patterns are present in FLASH due to the NASA SBM

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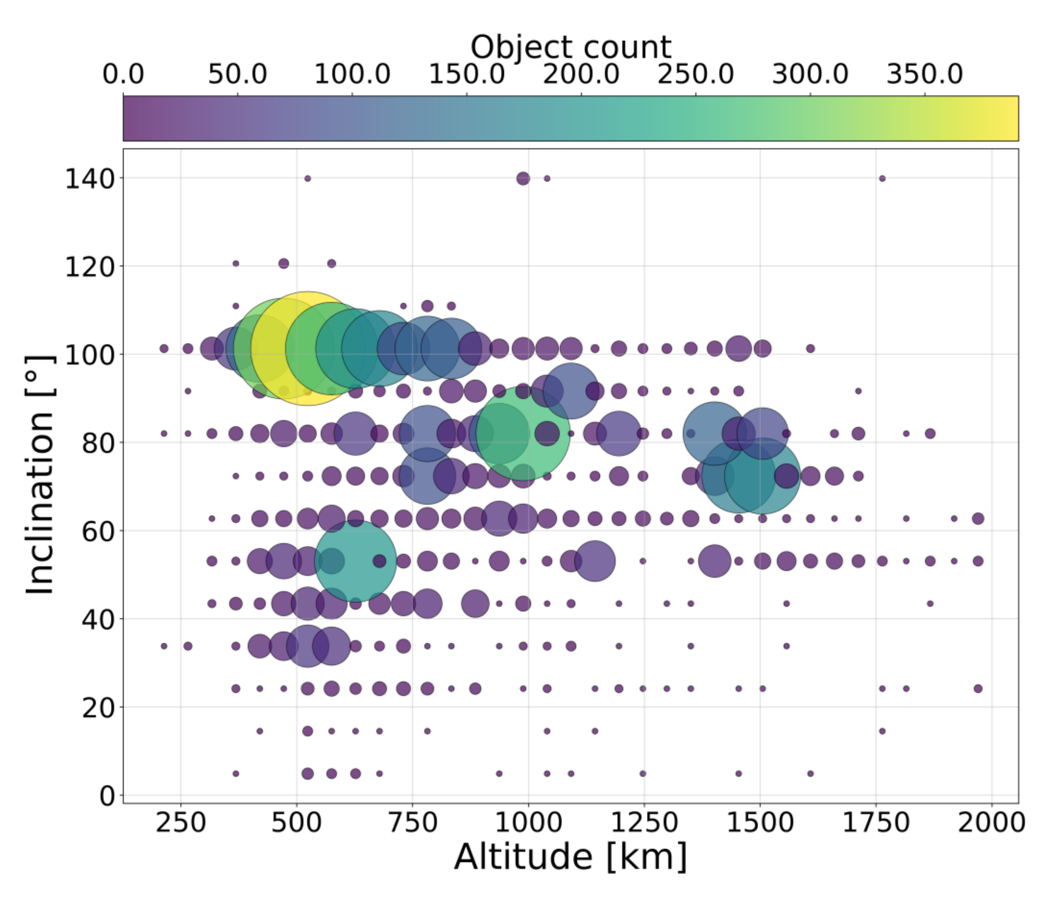

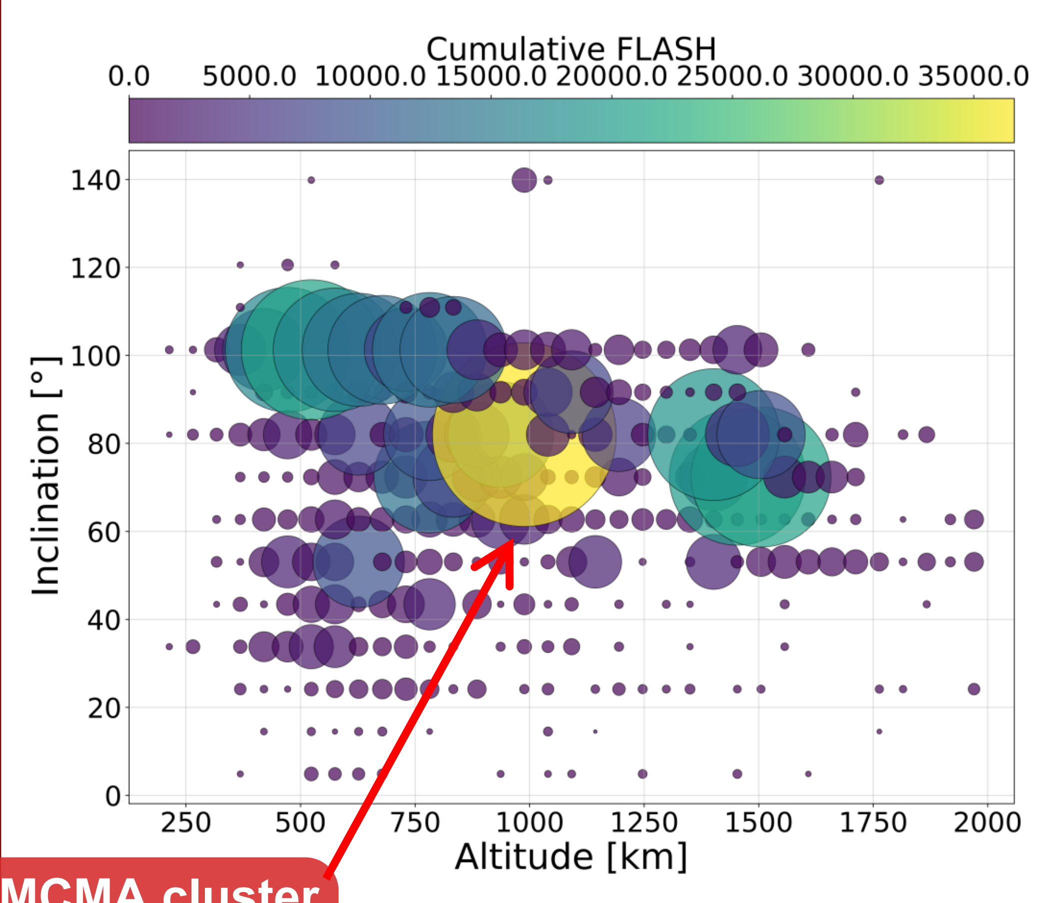

C975 km MCMA cluster seems confirmed by FLASH

3. Results and Discussion

C. FLASH Score top 200 and comparison

Satellite Name	Count	Mass sum [kg]	I_{FLASH} sum	I_{FLASH} min	I_{FLASH} max	1st NORAD	Mass [kg]	Type
SL-16 R/B	21	176189.5	4930.4	201.6	259.9	17590	8226.0	RB
METEOR 3-*	6	12700.0	1228.6	174.6	231.7	16191	1750.0	PL
METEOR 2-*	11	16500.0	2056.7	170.3	214.9	17290	1500.0	PL
SL-12 R/B(AUX MOTOR)	2	111.0	398.5	186.0	212.5	15338	55.5	RB
TRANSIT 5B-2	1	74.3	209.6	209.6	209.6	704	74.3	PL
DELTA 1 R/B	3	1969.9	568.4	174.4	209.1	6921	845.0	RB
COSMOS (m=3221kg)	9	28989.1	1648.4	170.7	203.7	22565	3221.0	PL
SL-8 R/B	53	75592.7	9542.5	167.8	203.4	6149	1434.0	RB
SL-14 R/B	15	20825.1	2792.0	171.2	200.9	21233	1387.5	RB
ARIANE 40+ R/B	1	1764.1	194.7	194.7	194.7	23561	1764.1	RB
ARIANE 40 R/B	5	8296.5	917.8	174.3	192.5	21610	1764.1	RB
METEOR 1-*	7	8960.0	1244.0	170.8	191.8	5917	1280.0	PL
DMSP 5D-2 F13 (USA 109)	1	1487.0	191.2	191.2	191.2	23533	1487.0	PL
NOAA *	8	7291.8	1397.7	167.4	190.6	6920	303.3	PL
IDEFIX/ARIANE 42P	1	1820.0	188.0	188.0	188.0	27422	1820.0	PL
COSMOS (m=223kg)	19	4236.8	3378.2	167.4	186.9	15469	223.0	PL
PSLV R/B	1	920.0	186.8	186.8	186.8	41878	920.0	RB
CBERS 1	1	1450.0	185.5	185.5	185.5	25940	1450.0	PL
COSMOS 2242	1	1750.0	185.2	185.2	185.2	22626	1750.0	PL
COSMOS 2360	1	3171.5	183.2	183.2	183.2	25406	3171.5	PL
COSMOS 2298	1	892.0	182.7	182.7	182.7	23431	892.0	PL
COSMOS 1809	1	693.8	182.4	182.4	182.4	17241	693.8	PL
COSMOS (m=803kg)	3	2408.3	521.7	168.4	181.8	18129	802.8	PL
COSMOS 2239	1	817.6	181.2	181.2	181.2	22590	817.6	PL
SPOT 3	1	1891.0	181.1	181.1	181.1	22823	1891.0	PL
COSMOS (m=1487kg)	3	4459.9	529.2	167.9	180.7	17177	1486.6	PL
SL-12 R/B(2)	1	2120.9	179.8	179.8	179.8	15334	2120.9	RB
COSMOS (m=40kg)	4	158.6	701.6	169.7	179.8	17139	39.6	PL
TRANSIT 5E 3	1	52.5	179.7	179.7	179.7	705	52.5	PL

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Most classes of objects from DISCOS fragmentation database appears within the top 200

30% to 42% similarity in the Top 50 with alternative indices

4. CONCLUSIONS, LIMITATIONS & FUTURE WORK

A. Summary of Findings

B. Data accessibility and availability

C. Future work

4. Conclusions, limitations and future work

A. Summary of Findings

I. FLASH accounts for Explosion AND Collision patterns

II. Patterns of FLASH validate the MCMA Clusters location

III. Code computationally efficient for daily computation

i. Inclusion of high rates of explosion objects classes in the most hazardeous objects

ii. Highest risk altitudes have a good representation of dangerous objects in FLASH

iii. Efficient for ground based observers to set a priority list

4. Conclusions, limitations and future work

B. Data accessibility and availability

- Passivation status & PMD success rate: indicate additional information regarding explosion risk
- Complete CDMs database: compare theoretical collision probabilities with current record of CDMs.
- Absence of technological progress aspect within the Survival Analysis (biased)
- Fragmentation database incomplete and imprecise

4. Conclusions, limitations and future work

C. Future work

Make a comparative analysis and in depth study of FLASH behavior

Evaluation of Starlink influence on index components

- *Complete, partial removal or inclusion of constellation*

Analysis of FLASH behavior

- *Analysis of parameters correlation to FLASH*
- *Compare efficiency of evaluation for high orbits*

Adapt to high orbit objects case

- *replace SGP4 with SDP4*

Add space population evolutionary model

- *Determine Carrying capacity factor for orbital shells*
- *Assessment of long-term impact of a break-up on orbital population*

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THANK YOU