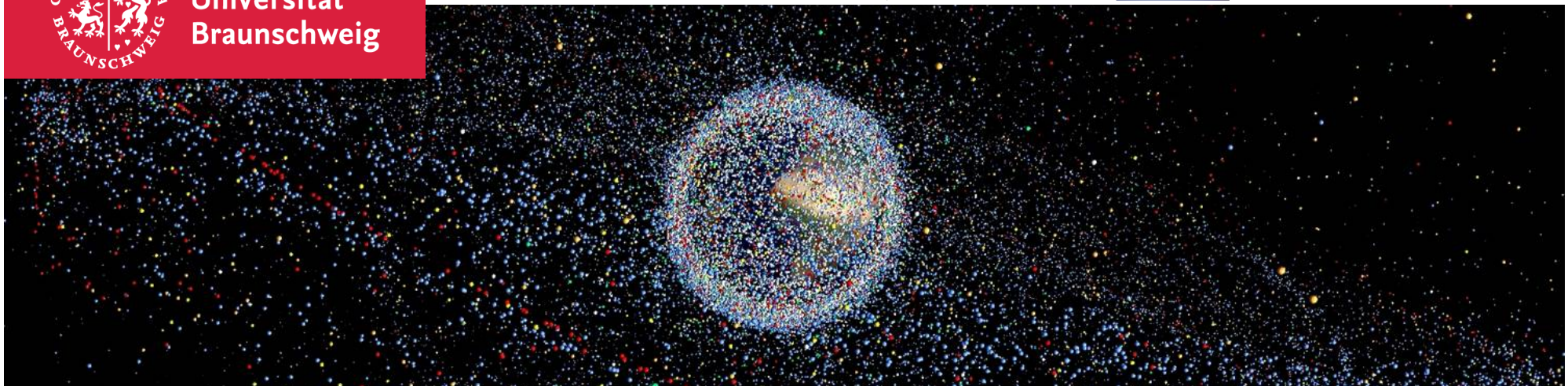
Technische Universität Braunschweig

Institute of Space Systems

esa



Final Presentation
ESA-MASTER

Enhancement of S/C Fragmentation and Environment Evolution Models

March 21st, 2019

Presenter: André Horstmann

Agenda

- Stakeholder and Project Team
- Overview
- Updated event lists
- Population evaluation
- Population validation
- New user features
- Time for questions

Stakeholder and Project Team

European Space Agency / Space Debris Office
Dr. Holger Krag / Technical Officer

Institute of Space Systems / TU Braunschweig
Prof. Dr.-Ing. Enrico Stoll, B.Sc. (Head of Institute)
Dr. Carsten Wiedemann (Senior Scientist)
André Horstmann, M.Sc. (Project Manager, Developer)
Sebastian Hesselbach, M.Sc. (Developer)

Consultants:
Dr.-Ing. Sven Flegel (MASTER-2009 project manager)
Dr.-Ing. Michael Oswald (Airbus Defence and Space)

Research and development of over 3 years
Multiple PhD-thesis contributed to the MASTER model for the past 24 years

MASTER system requirements

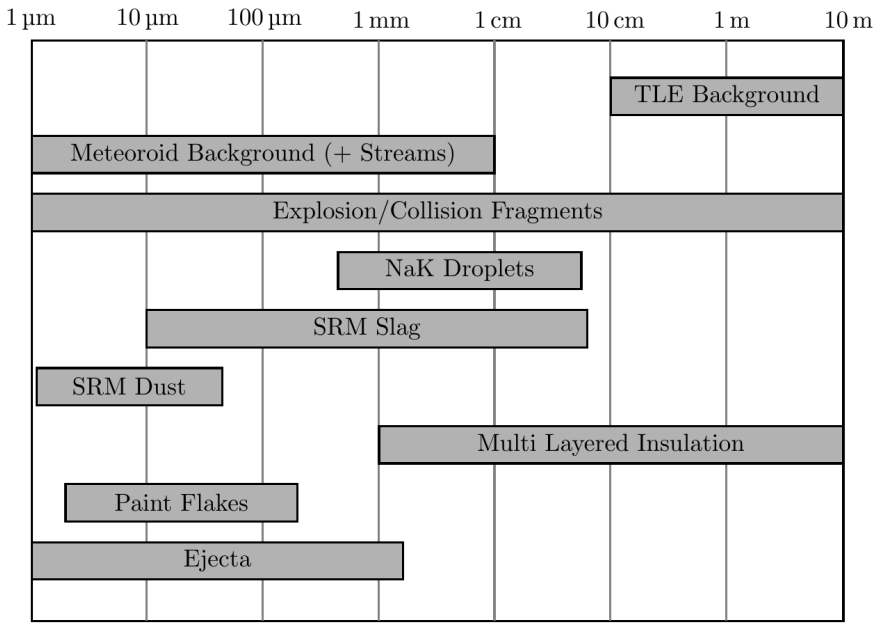
Hardware Requirements

- **CPU:** 1 Ghz or faster
- **RAM:** 2 GB (recommended)
- **Disc space**: 190+ MB

Software Requirements:

- **Windows:** Windows 7 (64 bit), Windows 10 (64 bit)
- **Linux:** openSuSE , Ubuntu 10.10 or equivalent distribution, Debian 8+ (32 bit / 64 bit) ; KDE, GNOME or similar window manager
- **MacOS:** MacOS 10.12 or higher (64 bit)
- **Java Runtime Environment:** 1.8.0

Overview



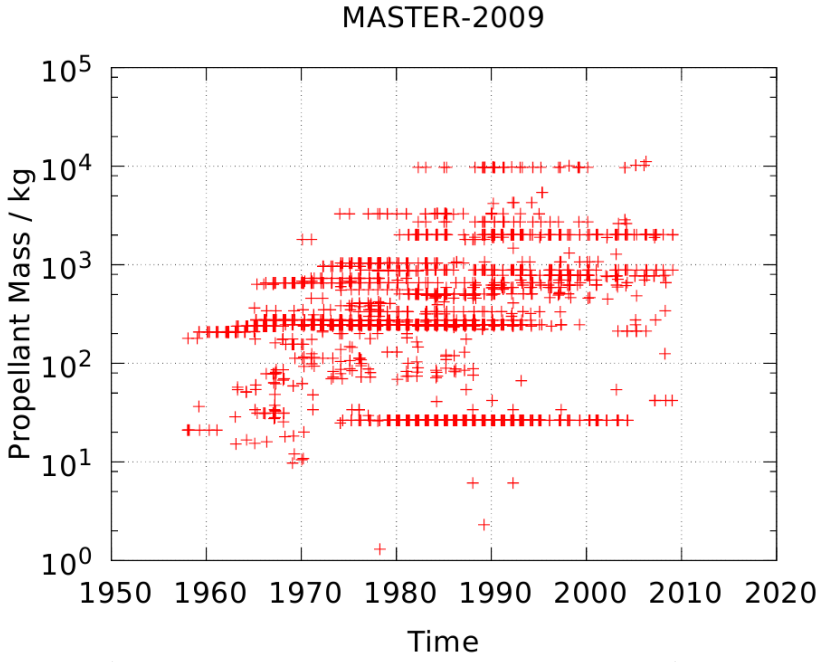
MASTER

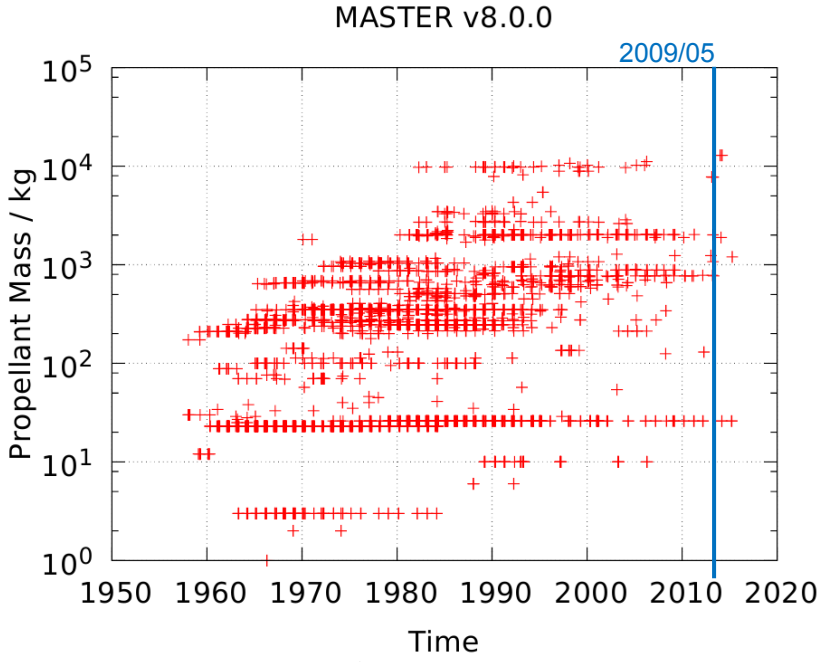
Reference Epoch
November 2016

	MASTER-2009	MASTER v8.0.0
Release		
Size	> 1 µm	> 1 µm
Altitude	LEO–GEO	LEO–lunar alt. (new)
Time	*continuous* 1957 to 2060	*continuous* 1958 to 2067
Debris Sources	TLE background Fragments (rev) SRM dust/slag (rev) NaK droplets (rev) Paintflakes (rev) Ejecta (rev) Clusters MLI foils	TLE background Fragments SRM dust/slag NaK droplets (new) Paintflakes Ejecta MLI foils (rev) Condensed population (new)
Meteoroid BG	Divine-Staubach	Divine-Staubach Grün
Meteoroid Streams	Jenniskens-McBride Cour-Palais	Jenniskens-McBride Cour-Palais
Model core features	Multiple target orbits Flux to spheres Oriented surfaces Spatial density GUI (upgrade) Time Browser	Multiple target orbits Flux to spheres Oriented surfaces Spatial density (rev) GUI (upgrade) Time Browser Target orbit propagation (new) Uncertainty bars (new) Flux in Lagrange points (new)
Validation	LDEF,CME HST (SM1,SM3B) EuReCa PROOF	LDEF,CME HST (SM1,SM3B) EuReCa PROOF

Updated event lists

Updated event lists (SRM firings)





	MASTER-2009 (until 2009/05)	MASTER v8.0.0 (until 2009/05)	MASTER v8.0.0 (until 2016/11)
No. of firings	**1964**	**2402**	**2437**
Prop. mass	**1318.11 tons**	**1361.04 tons**	**1424.42 tons**

Updated event lists (fragmentations)

- PhD thesis Dr. Sven Flegel
- General maintenance
- GEO validation
- LEO validation

COSPAR	Description	MASTER-2009	MASTER v8.0.0
		DC	
1965-027A	Snapshot (NPP)	n.a.	157
1979-104B	Ariane 1 H10 R/B	15	200
1988-040B	Ariane 2 H10 R/B	4	200
1992-021C	Ariane 44LP H10 R/B	12	200
1991-015C	Ariane 44LP H10 R/B	10	200
1991-003C	Ariane 4 H10 R/B	10	200
1988-109C	Ariane 44LP H10 R/B	11	100
1989-006B	Ariane 2 H10 R/B	28	200
1991-075B	Ariane 4 H10 R/B	10	200
1992-041C	Ariane 4 H10 R/B	2	200
1979-087A	Ekran-4	1	0
1985-056B	Ariane 1 R/B	0	200
1981-802A		2	0
1981-803A		0	2
1999-025A	FengYun-1C	1000	3425
1993-036A	Cosmos 2251	1050	1667
1997-051C	Iridium-33	467	628
		RCS-Factor	
1966-053J	Titan 3C Transtage 11	1.00	0.33
1968-081E	Titan 3C Transtage 5	1.00	0.97
1987-095A	TV Sat 1	1.00	0.33
1938-030A	SatCom 1R	1.00	0.33
1938-030A	Fengyun-1C	0.38	0.24
		Launch date	
1987-095A	TV Sat 1	87325.00	88011.00
1938-030A	SatCom 1R	83100.00	88001.00
		Mass	
2006-006B	Briz-M	11000	2370

Updated event lists (fragmentations)

- PhD thesis Dr. Sven Flegel
- General maintenance
- GEO validation
- LEO validation

TLE catalog

Fengyun-1C: 1000 → 3425
(+ 242.5 %)

Cosmos-2251: 1050 → 1667
(+58.7%)

COSPAR	Description	MASTER-2009	MASTER v8.0.0
		DC	
1965-027A	Snapshot (NPP)	n.a.	157
1979-104B	Ariane 1 H10 R/B	15	200
1988-040B	Ariane 2 H10 R/B	4	200
1992-021C	Ariane 44LP H10 R/B	12	200
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1979-087A	Ekran-4	1	0
1985-056B	Ariane 1 R/B	0	200
1981-802A		2	0
1981-803A		0	2
1999-025A	FengYun-1C	1000	3425
1993-036A	Cosmos 2251	1050	1667
1997-051C	Iridium-33	467	628
		RCS-Factor	
1966-053J	Titan 3C Transtage 11	1.00	0.33
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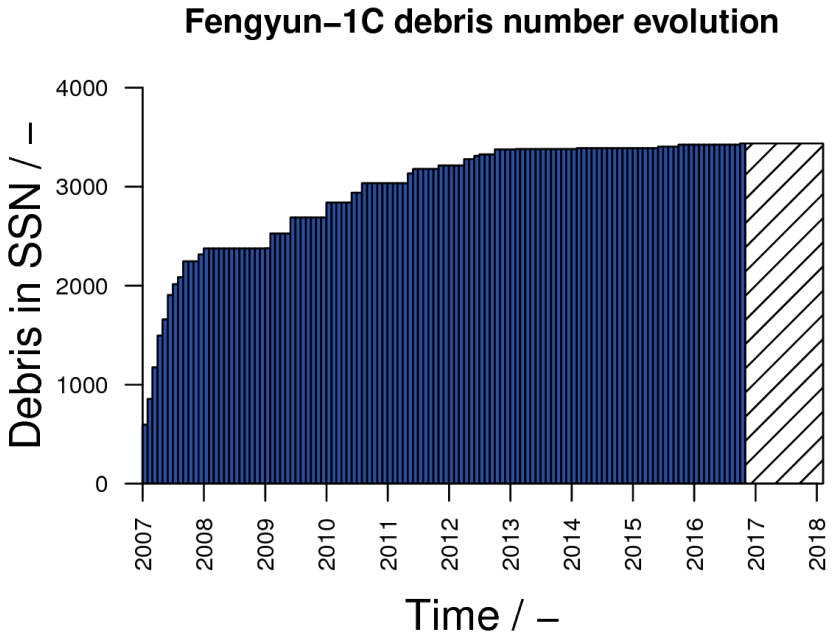
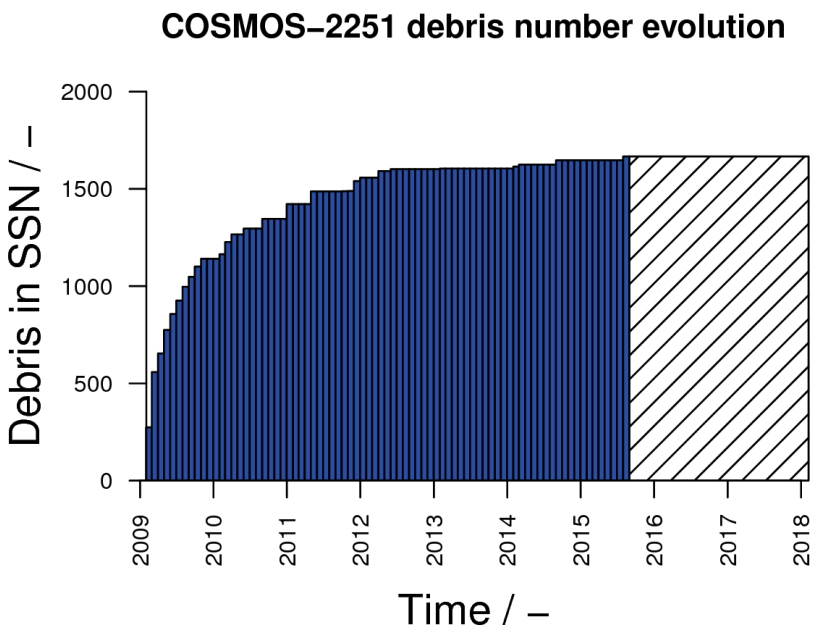
1938-030A	SatCom 1R	83100.00	88001.00
		Mass	
2006-006B	Briz-M	11000	2370

Updated event lists (fragmentations)

Numer of catalogued debris over time for selected payloads





→ Number of catalogued debris seem to stabilize after almost a decade of observation

Updated event lists (fragmentations)

38 new fragmentations since May 2009:

- 2 Collisions
- 15 Explosions
- 15 Unknown
- 6 Aerodynamic

COSPAR	BU-Epoch	Assessed BU-cause	Mass / kg	DC	Reference
1967-116A	09242.0000	Unknown	800.	20.	ODQNv13i4
2006-015A	10035.0000	Unknown	2700.	7.	ODQNv14i2
2009-042C	10202.0000	Aerodynamics	1000.	91.	ODQNv14i4
2008-011B	10286.0000	Propulsion	2600.	115.	ODQNv15i1
2010-057B	10305.0000	Unknown	2800.	51.	ODQNv15i1
1988-089A	10328.0000	Unknown	1005.	2.	ODQNv15i1
2007-005E	10357.0000	Aerodynamics	300.	10.	ODQNv15i1
2007-065G	11230.0000	Propulsion	56.	11.	ODQNv16i1
1990-045F	11321.0000	Unknown	55.	7.	ODQNv16i1
2011-077B	11353.0000	Unknown	2800.	32.	ODQNv16i1
2012-008B	12057.0000	Unknown	2800.	48.	ODQNv16i2
2012-044C	12290.0000	Unknown	2370.	700.	ODQNv17i1
2009-049G	13022.0000	Collision	7.	1.	ODQNv17i2
1999-008D	14120.0000	Collision	919.	7.	ODQNv18i3
2008-046H	14128.0000	Propulsion	55.	8.	ODQNv18i3
1994-076G	14128.0000	Propulsion	55.	15.	ODQNv18i3
2007-029A	14130.0000	Unknown	3250.	17.	ODQNv18i3
1976-105F	14135.0000	Aerodynamics	1.	16.	ODQNv18i3
1969-013B	14155.7166	Propulsion	1486.	5.	ODQNv18i3
1997-082C	14158.0000	Unknown	661.	10.	ODQNv19i1
2011-043A	14187.0000	Unknown	360.	4.	ODQNv19i1

continued ...

Updated event lists (fragmentations)

38 new fragmentations since May 2009:

- 2 Collisions
- 15 Explosions
- 15 Unknown
- 6 Aerodynamic

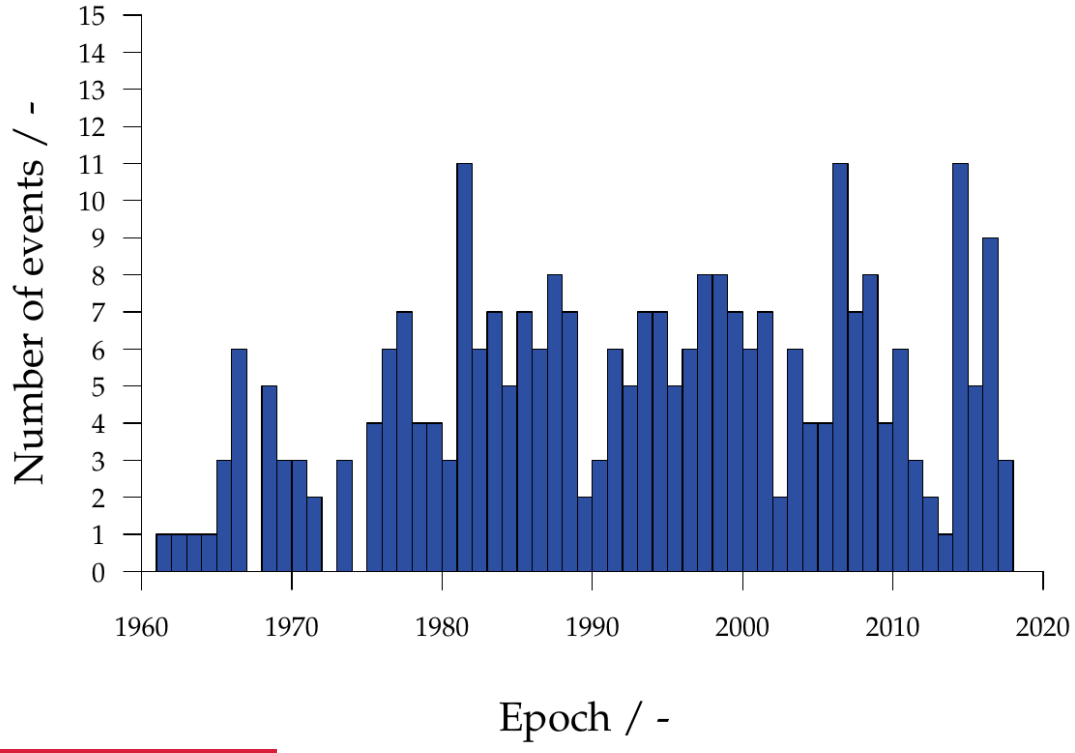
→ mean of over 5 fragmentations per year

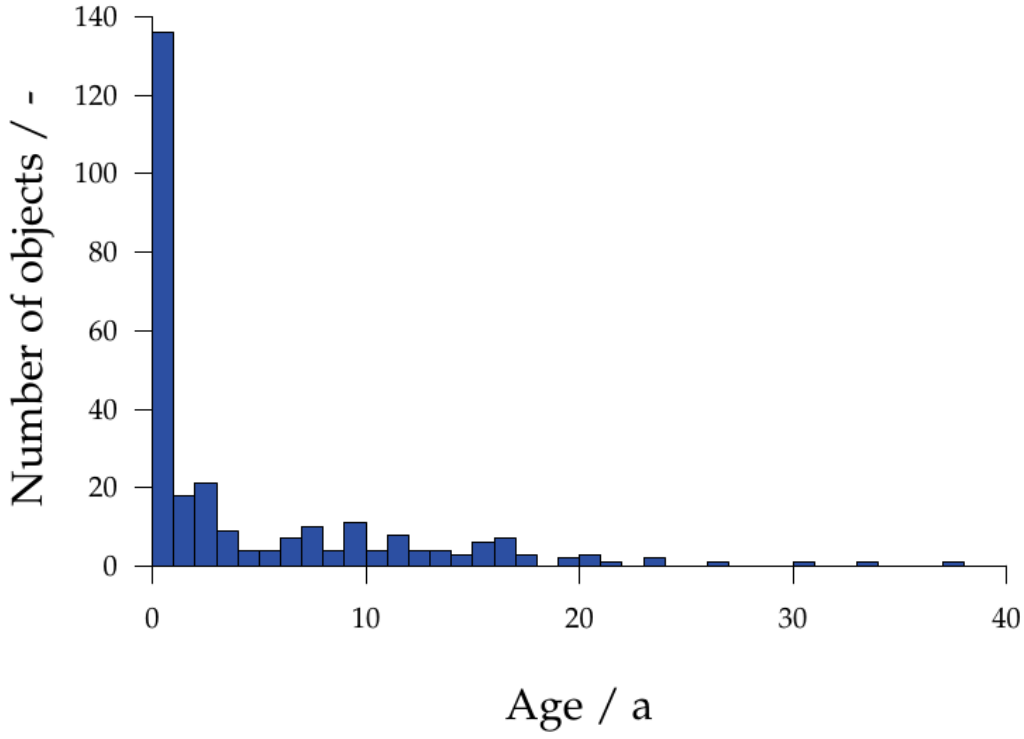
. . . continued

COSPAR	BU-Epoch	Assessed BU-cause	Mass / kg	DC	Reference
2010-007G	14190.0000	Propulsion	56.	16.	ODQNv18i4
2007-052F	14226.0000	Propulsion	56.	70.	ODQNv18i4
2002-005A	14334.0000	Propulsion	655.	4.	ODQNv18i4
1995-015A	15034.7361	Battery-related	815.	161.	ODQNv19i1
2014-064C	15168.0000	Aerodynamics	1000.	90.	ODQNv19i2
2011-037B	15220.0000	Unknown	360.	24.	ODQNv19i3
2000-055A	15329.3444	Battery-related	1403.	357.	ODQNv20i1-2
2012-026B	15357.0000	Unknown	1000.	8.	ODQNv20i1
2015-075B	16016.0000	Propulsion	1600.	10.	ODQNv20i1-2
2016-012A	16086.7416	Aerodynamics	2700.	10.	ODQNv20i2-1
2008-067G	16086.0000	Propulsion	56.	21.	ODQNv20i2
2008-067H	16153.0000	Propulsion	56.	20.	ODQNv20i3
2004-005A	16106.5417	Aerodynamic	1600.	13.	ODQNv20i3
2006-062G	16209.0549	Propulsion	56.	16.	ODQNv20i4
2009-018A	16181.0000	Propulsion	1700.	5.	ODQNv20i4
2009-055A	16200.9527	Unknown	2615.	11.	ODQNv20i4
2012-017A	16274.1667	Unknown	1858.	12.	ODQNv20i4

Updated event lists (fragmentations)

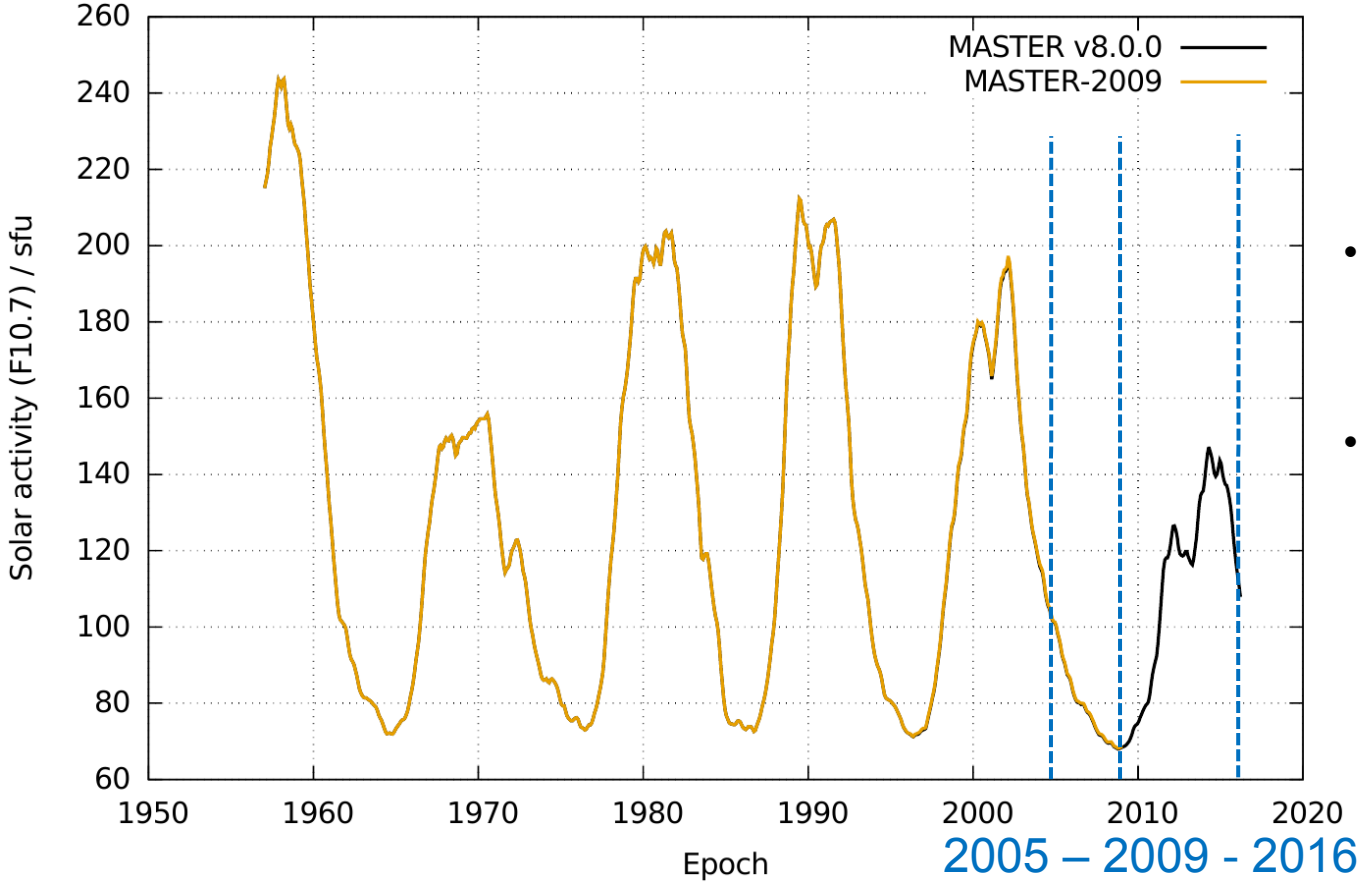
261 confirmed fragmentations in database (up to 2016/11)





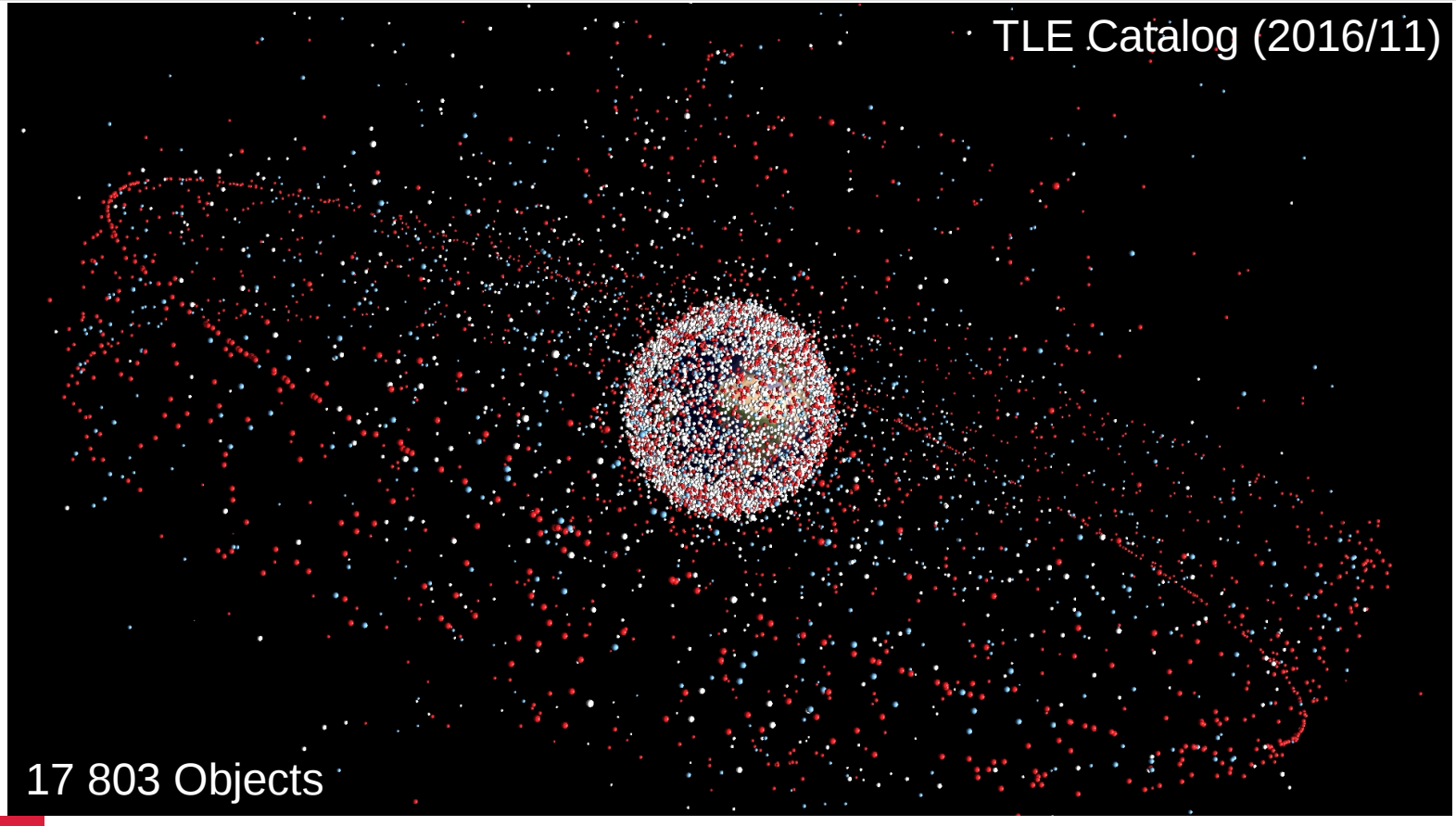
Population evaluation

Population evaluation

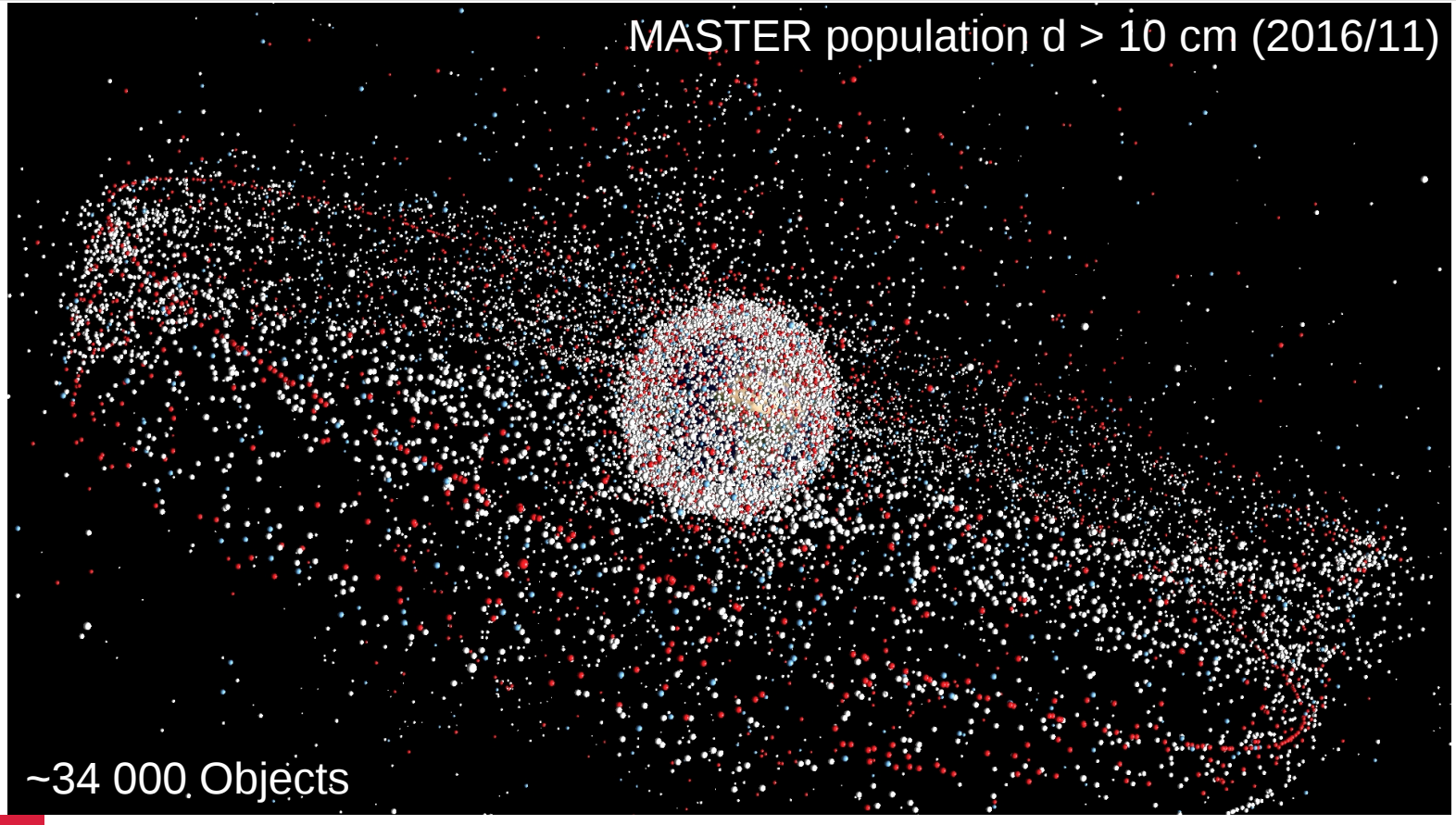


- Influence on small debris in low altitudes
- Local solar high in 2014/2015

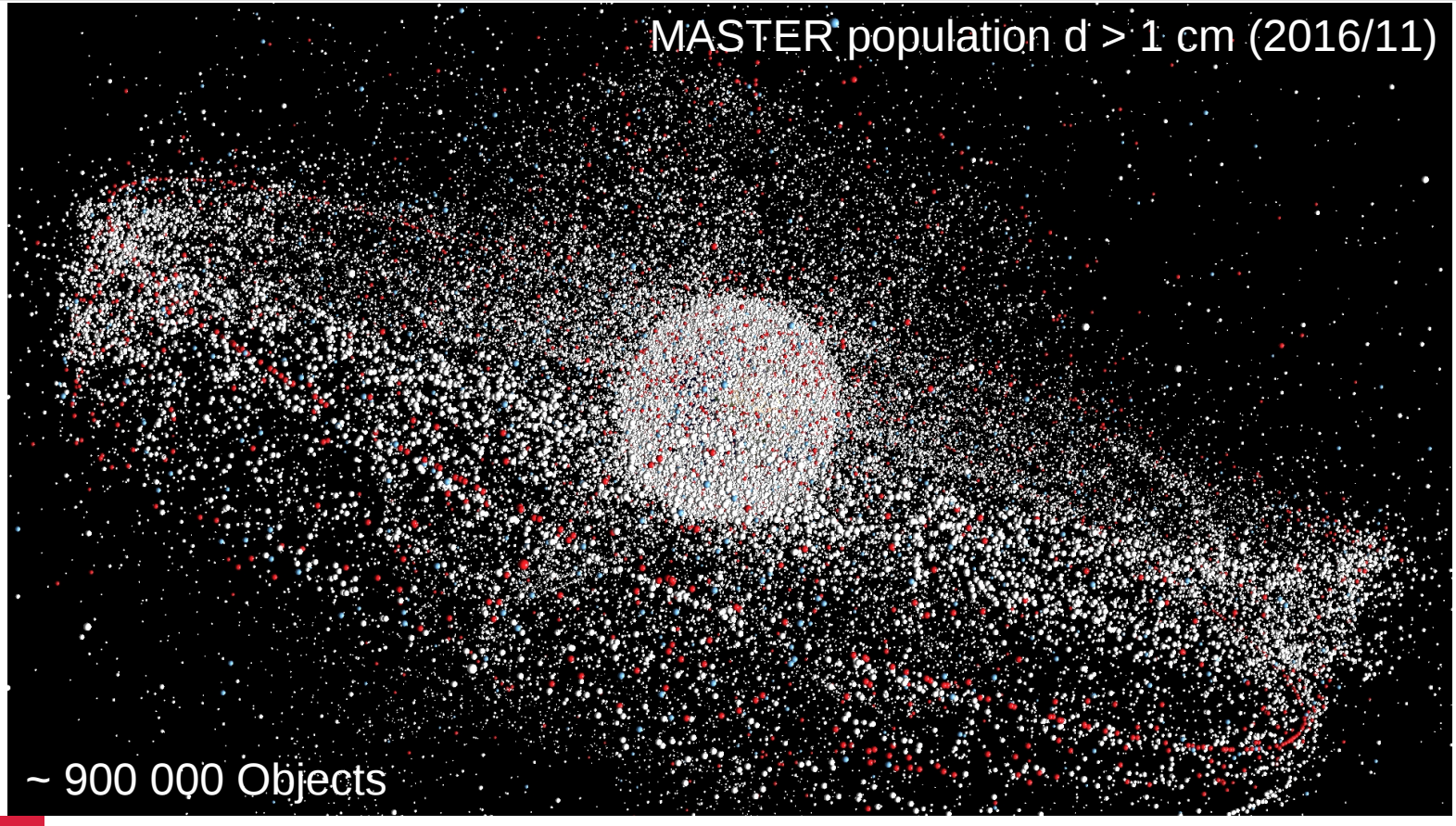
Population evaluation



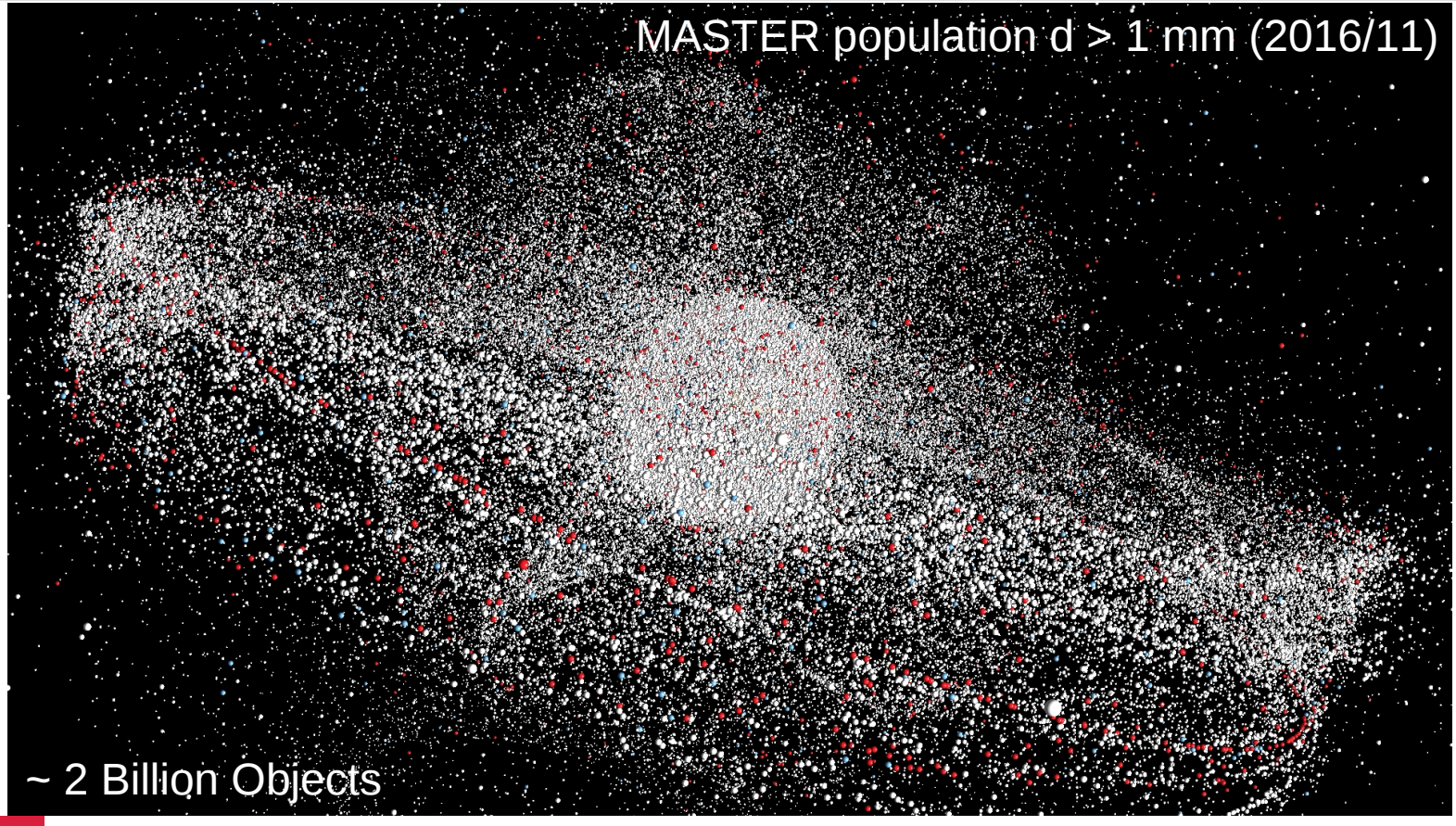
Population evaluation



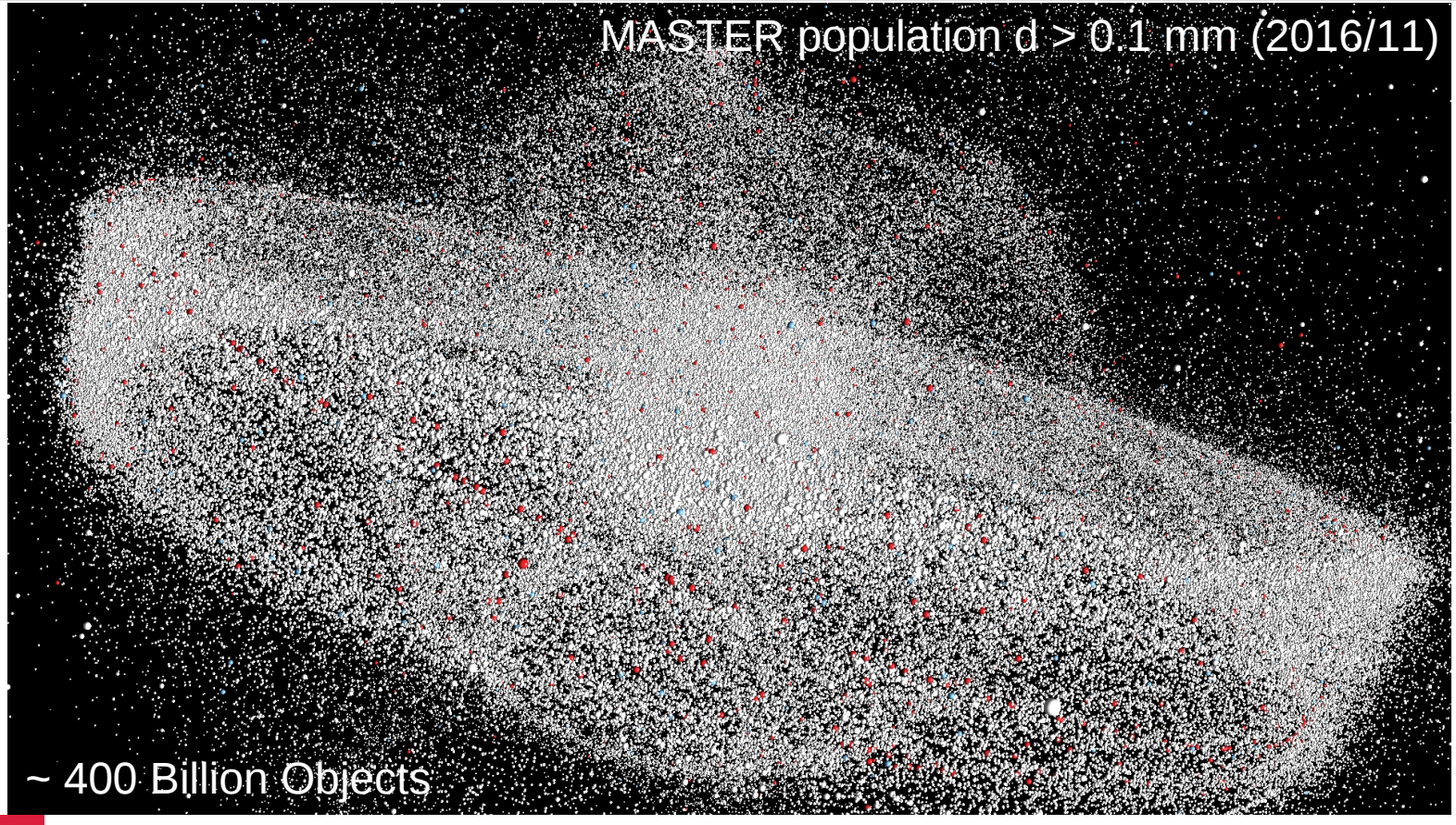
Population evaluation



Population evaluation



Population evaluation



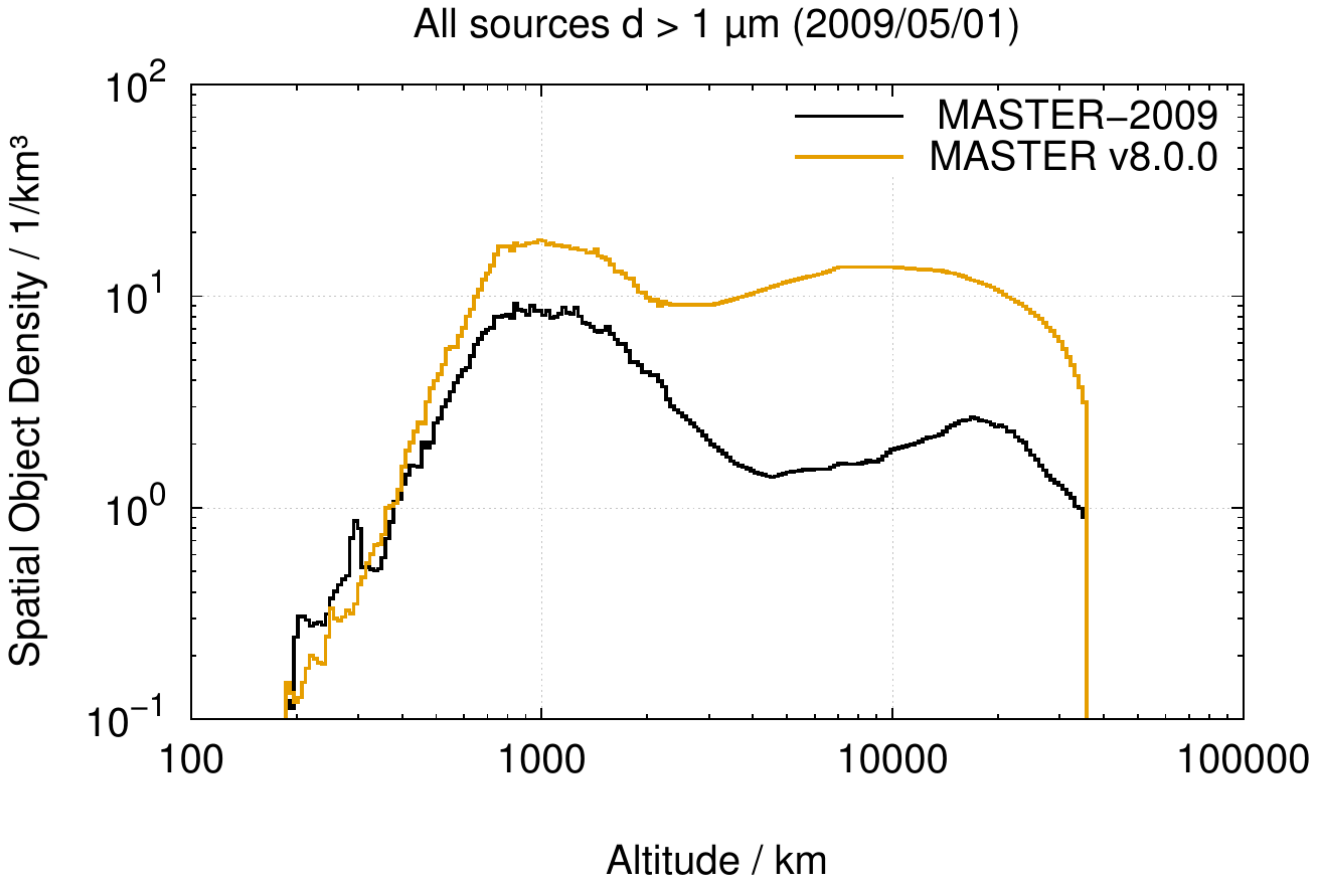
Population evaluation

Comparison between

MASTER-2009

and

MASTER v8.0.0



Population evaluation

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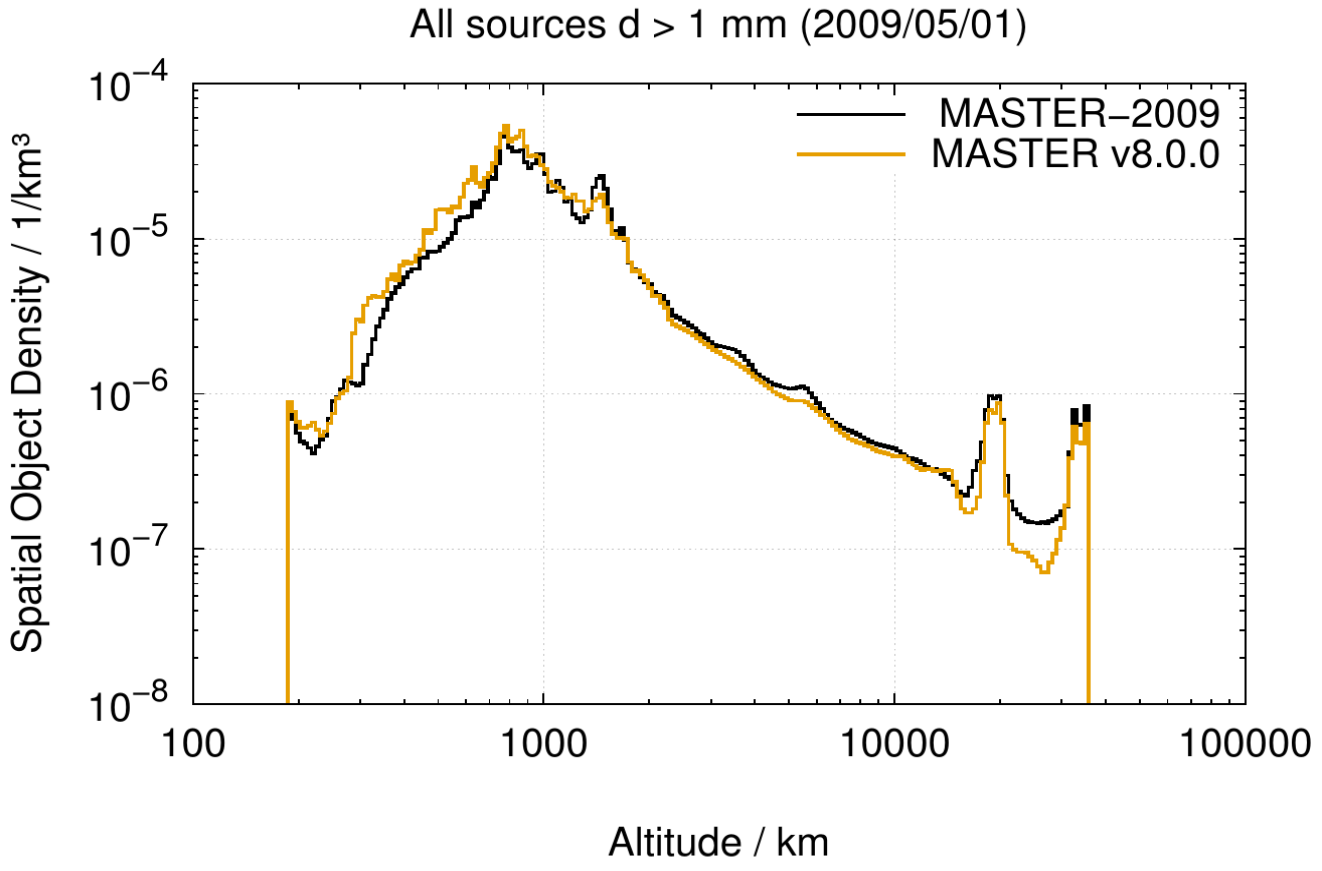


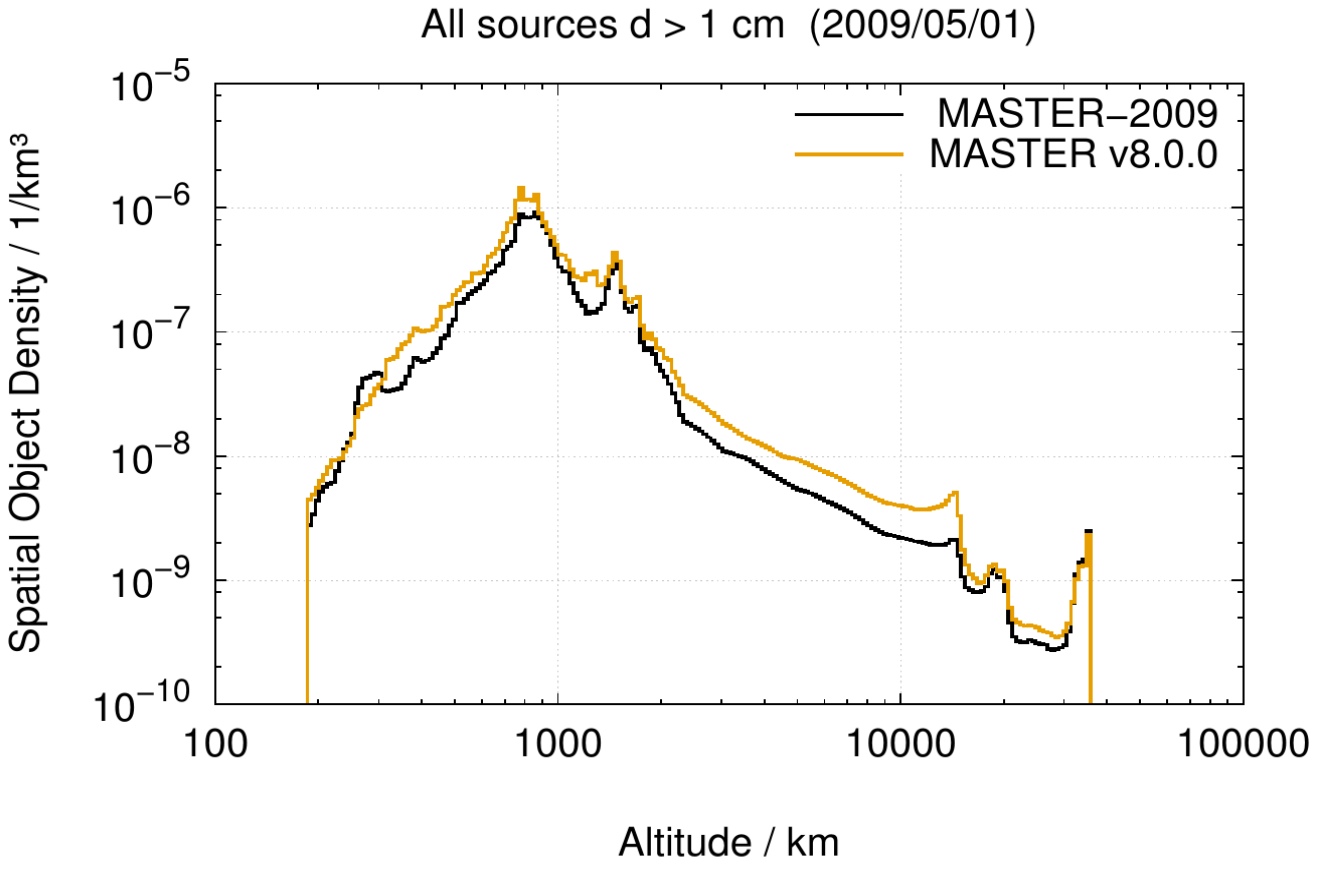
Population evaluation

Comparison between

MASTER-2009

and

MASTER v8.0.0



Population evaluation

Comparison between

MASTER-2009

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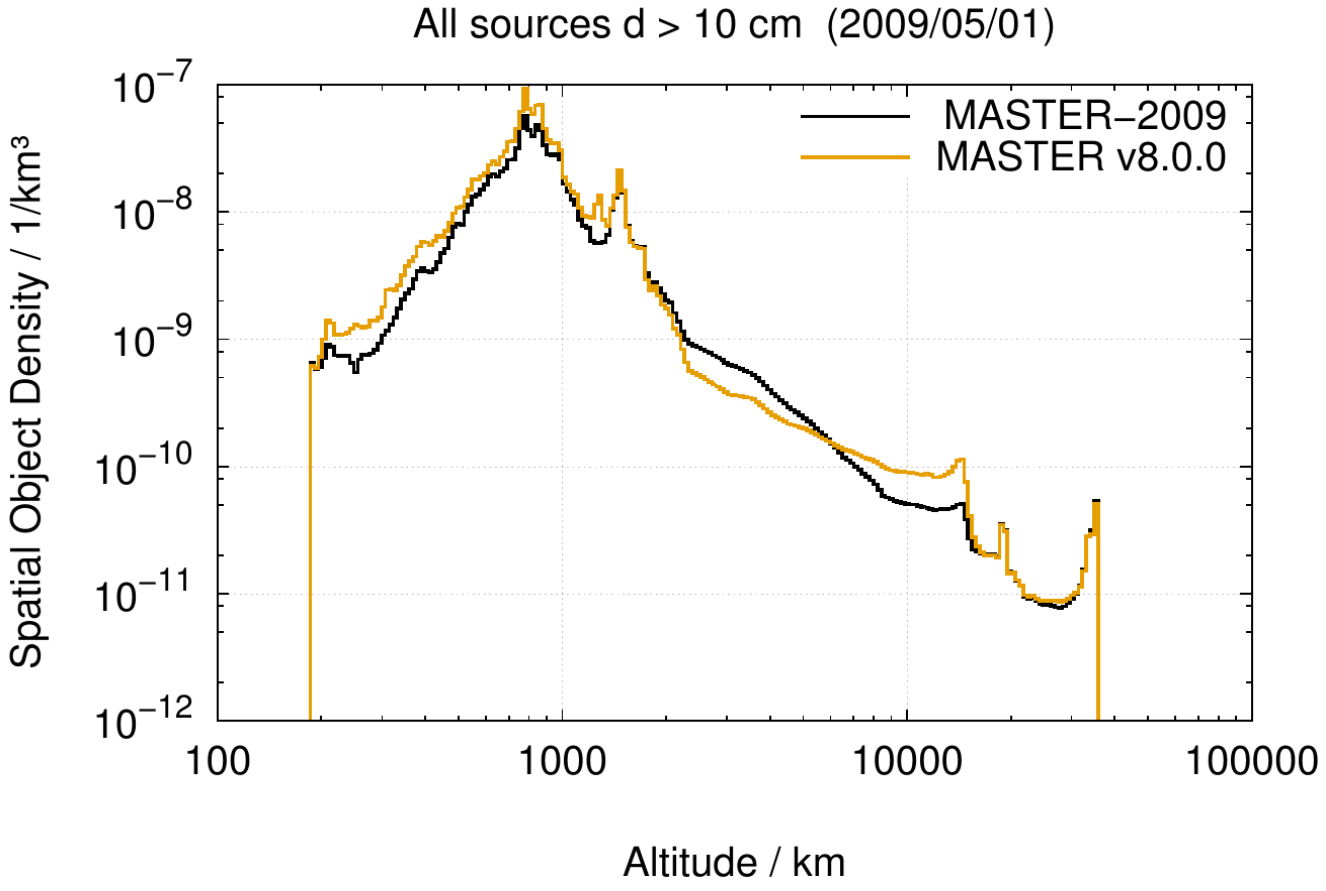
MASTER v8.0.0



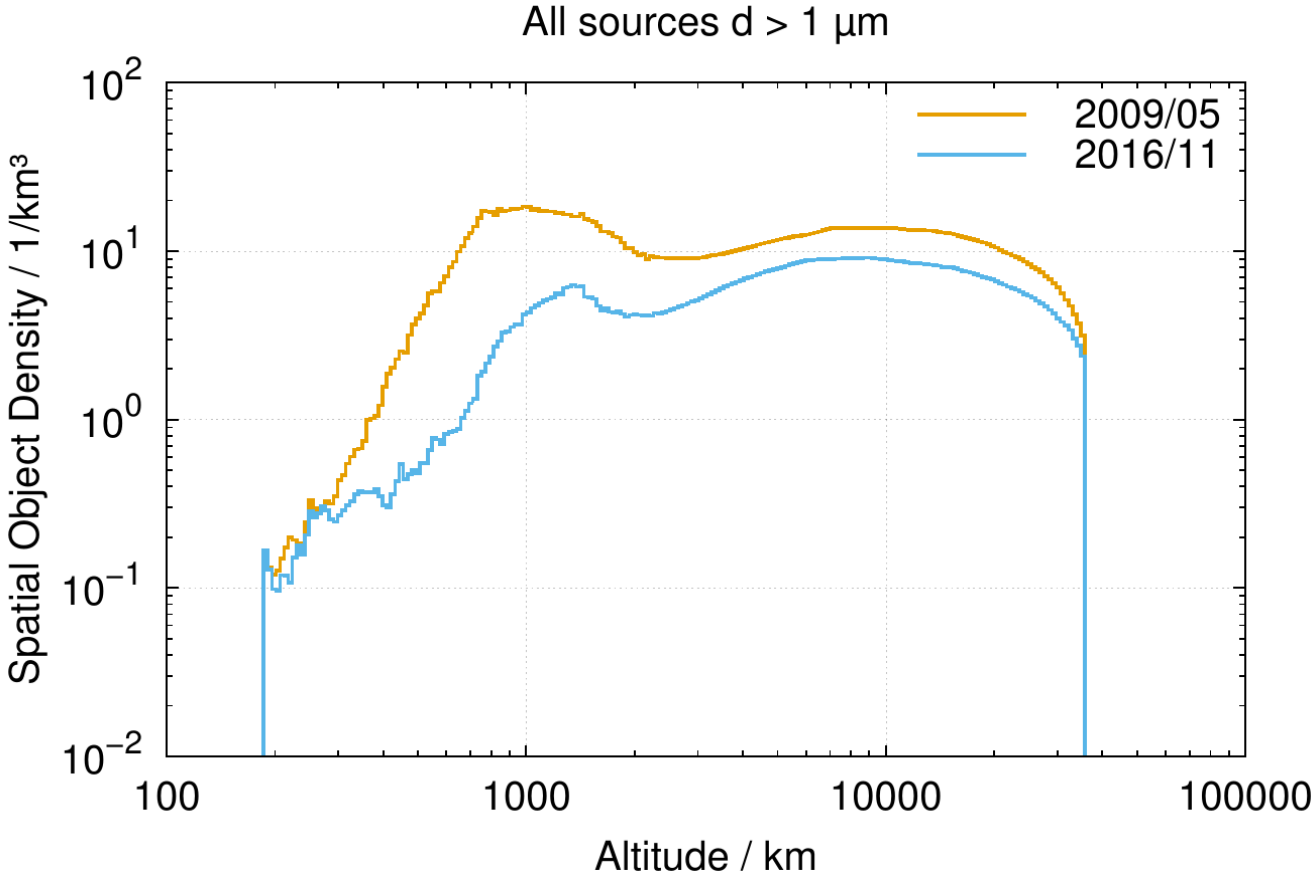
Population evaluation

Comparison of MASTER v8.0.0
on

May 2009

and

November 2016



Population evaluation

Comparison of MASTER v8.0.0 on

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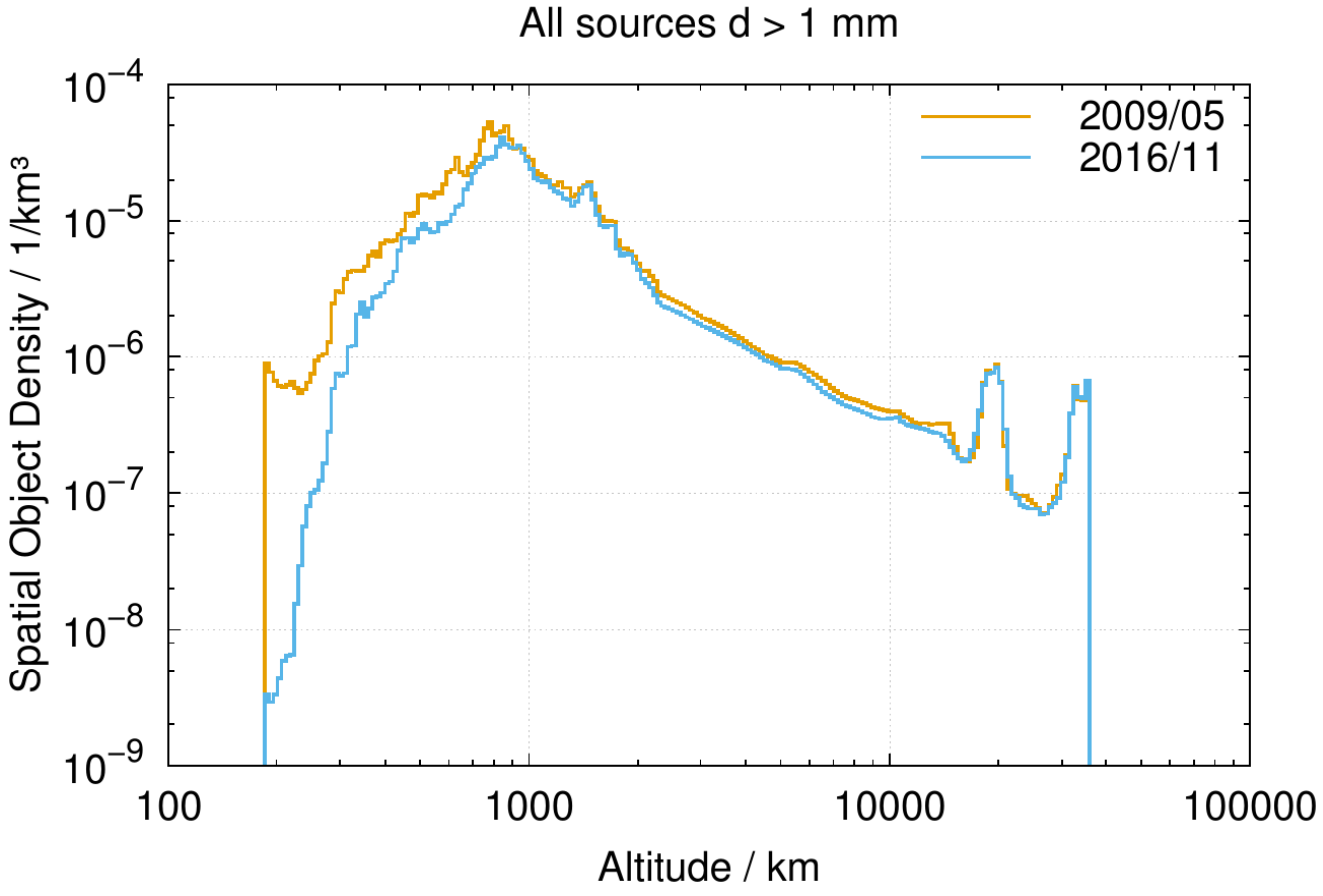


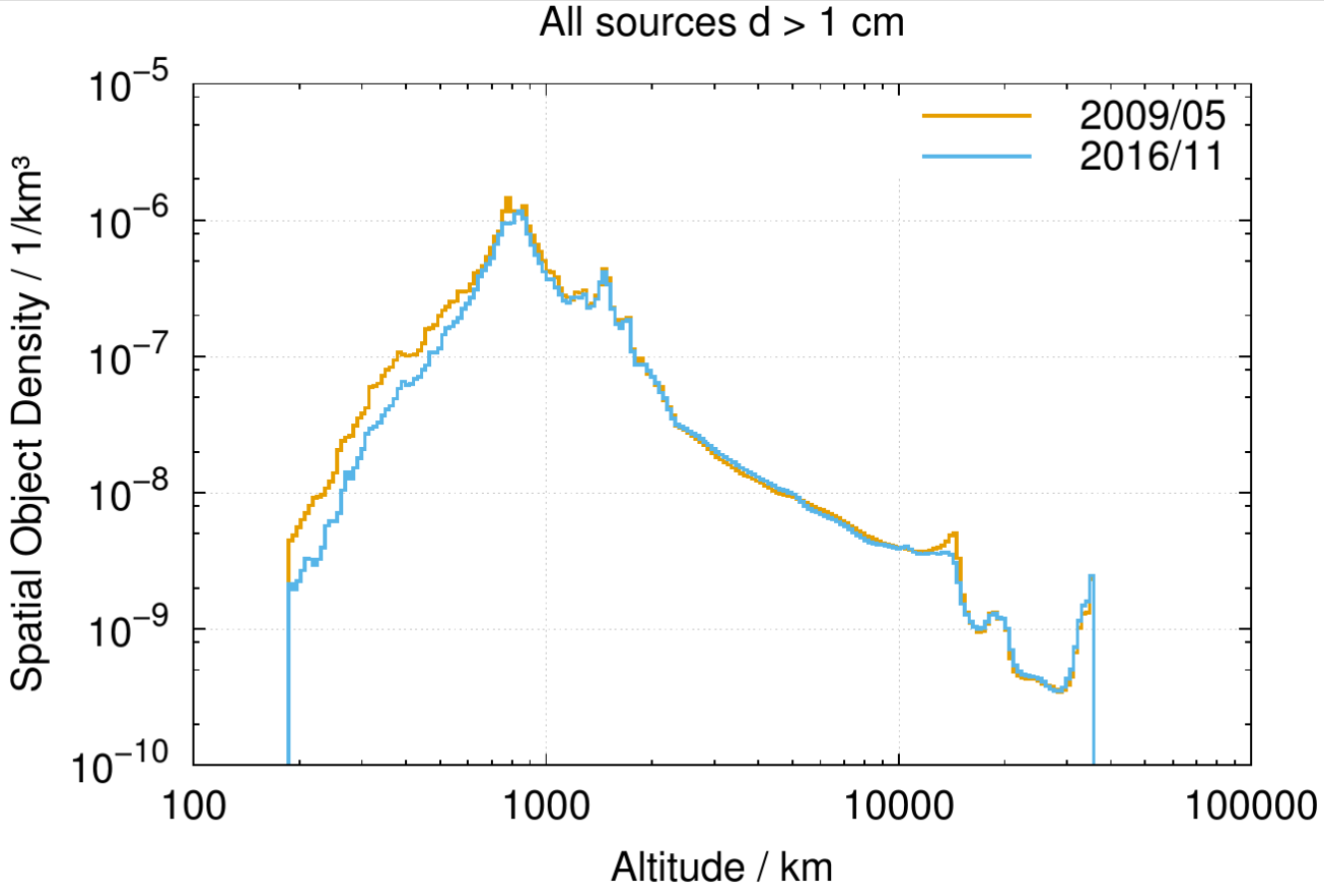
Population evaluation

Comparison of MASTER v8.0.0
on

May 2009

and

November 2016



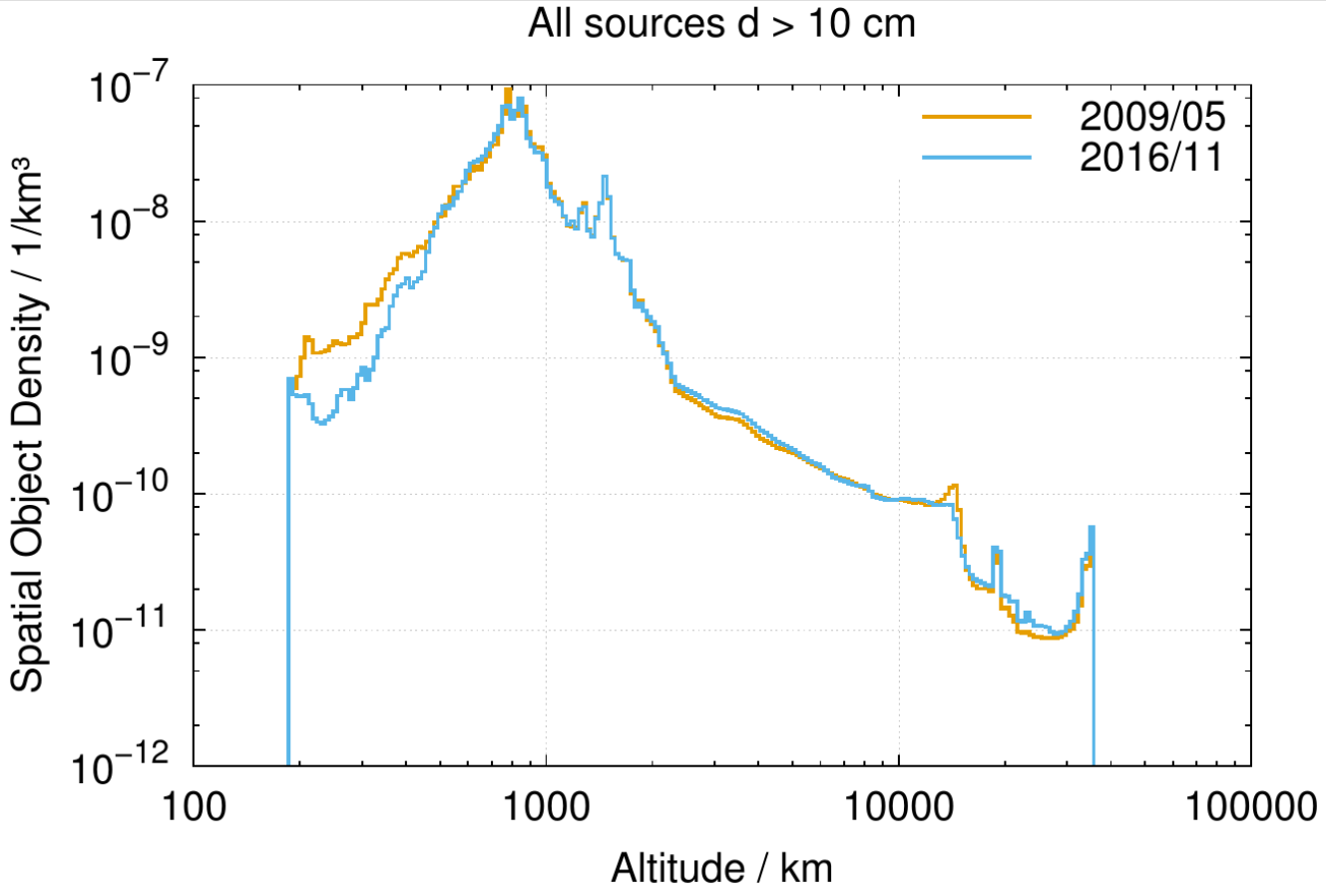
Population evaluation

Comparison of MASTER v8.0.0
on

May 2009

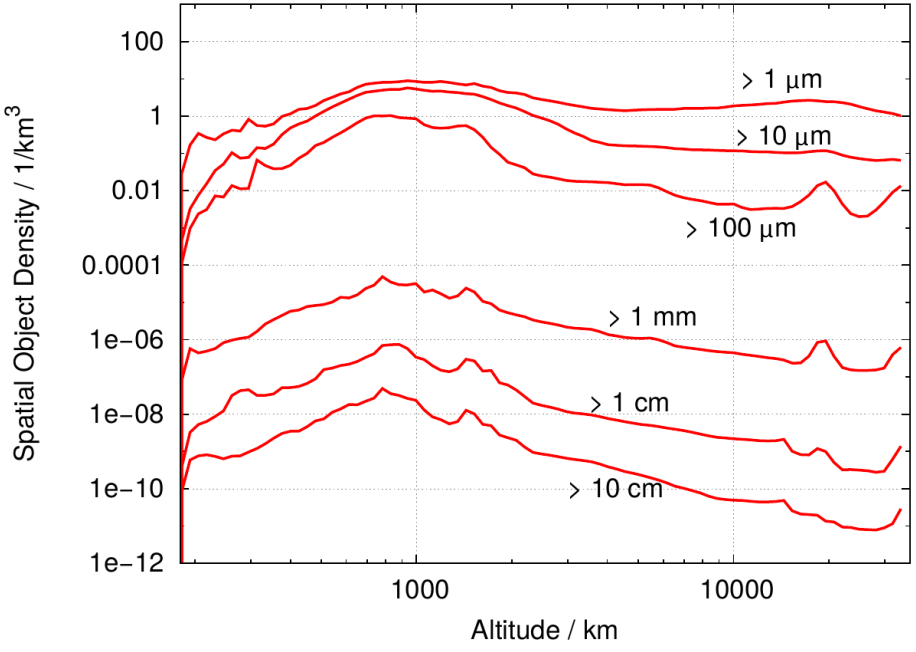
and

November 2016



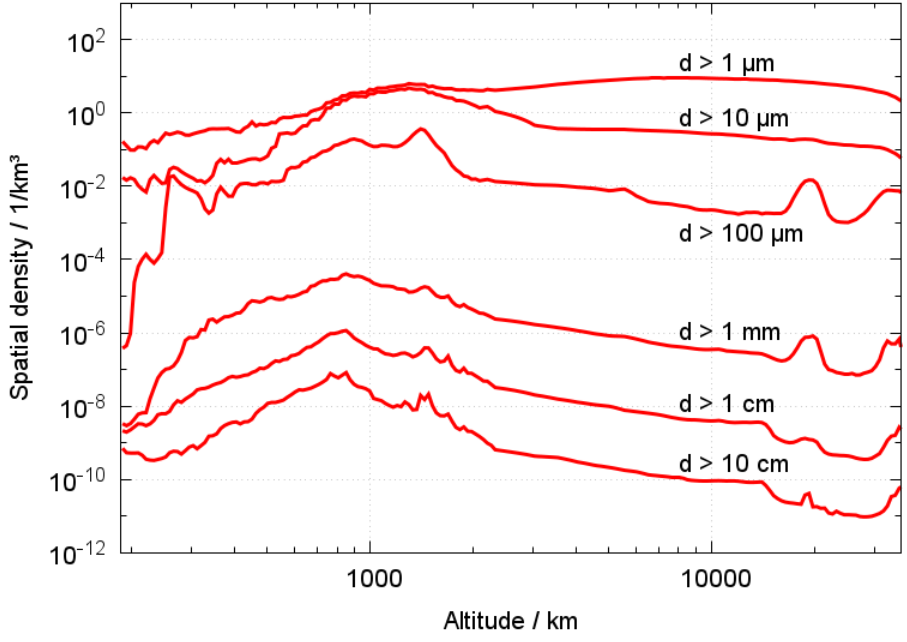
Population evaluation

MASTER-2009



1 May 2009

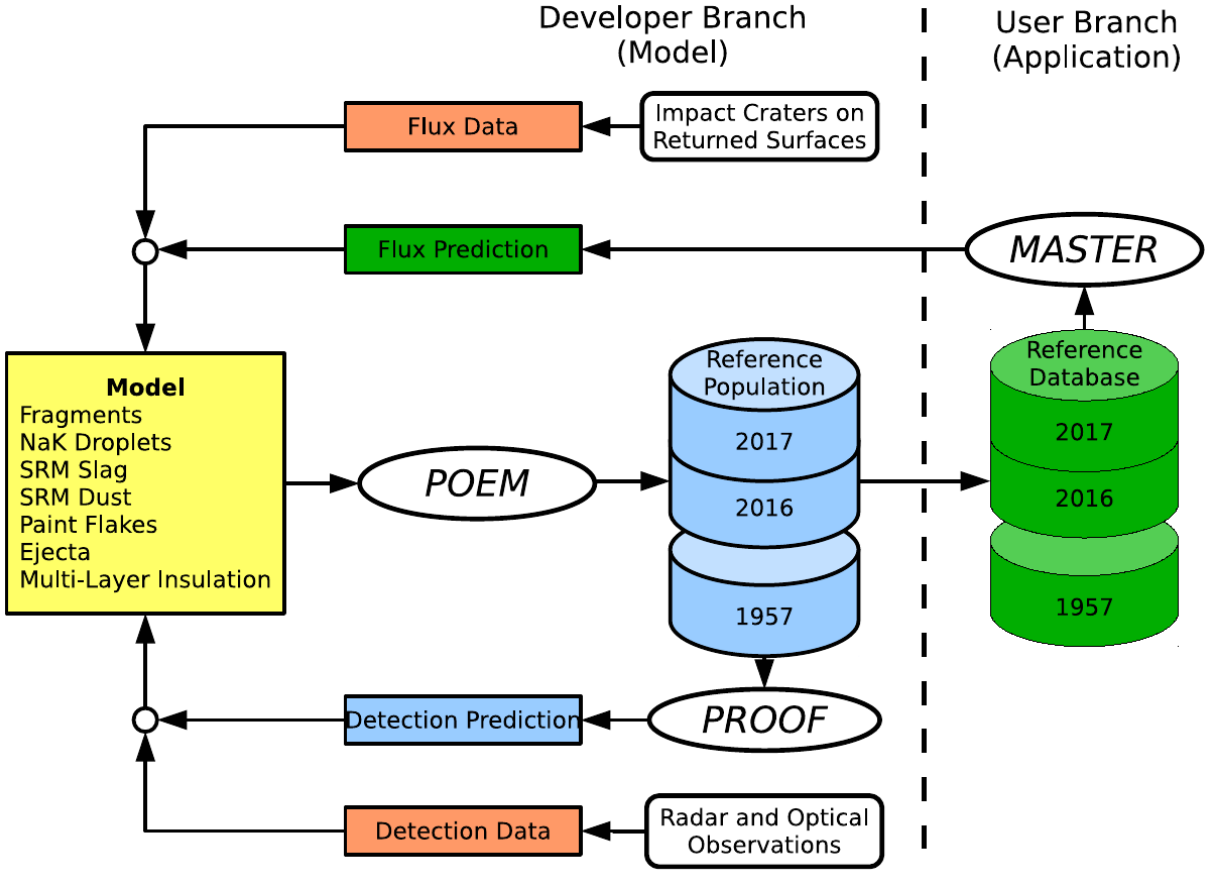
MASTER v8.0.0



1 November 2016

Population validation

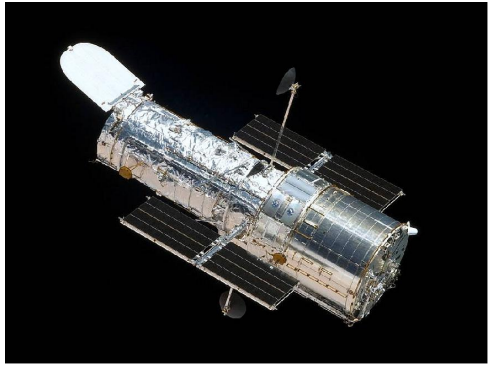
Population validation



Population validation

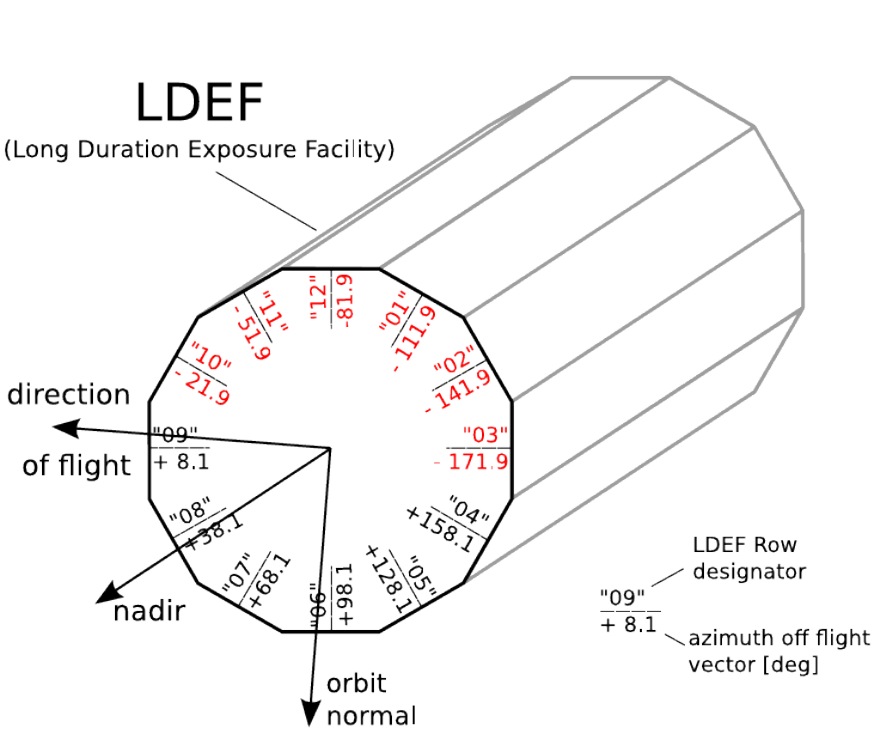
Small object validation

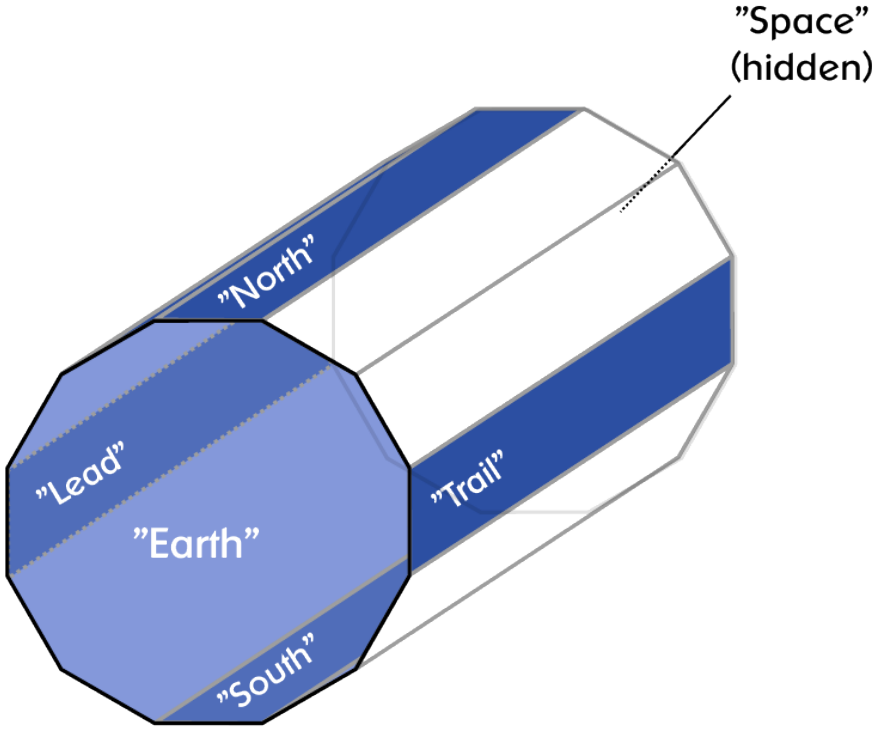
Mission	Deployment	Retrieval	On-orbit duration	Altitude	Inc.	RAAN
LDEF	1984 Apr 06	1990 Jan 14	5y 9m 6d	457 km	28.5 °	240 °
EuReCa	1992 Aug 01	1993 Jun 24	10m 23d	495 km	28.5 °	0 °
HST-SM1	1990 Apr 24	1993 Dec 08	3y 7m 14d	614 km	28.5 °	0 °
HST-SM3B	1993 Dec 04	2002 Mar 03	8y 2m 28d	614 km	28.5 °	0 °



(images taken from https://directory.eoportal.org)

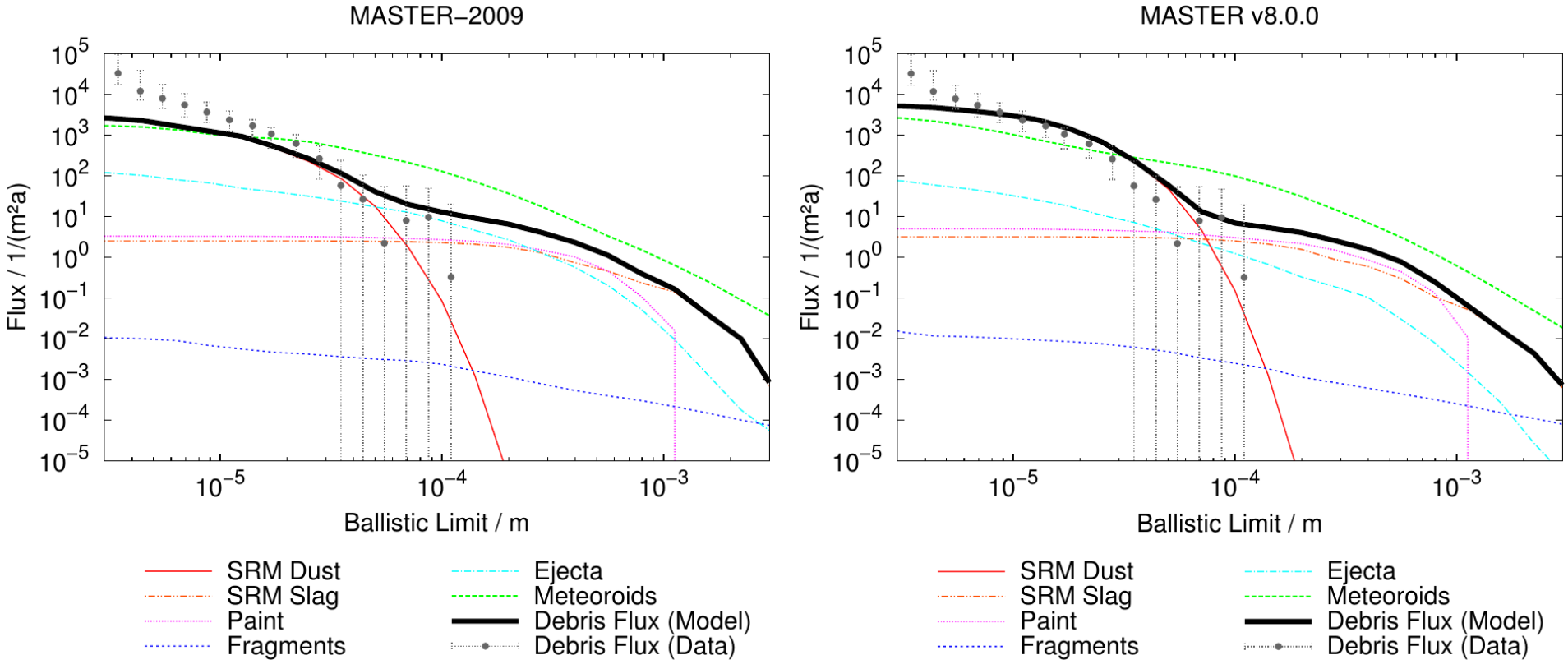
Population validation





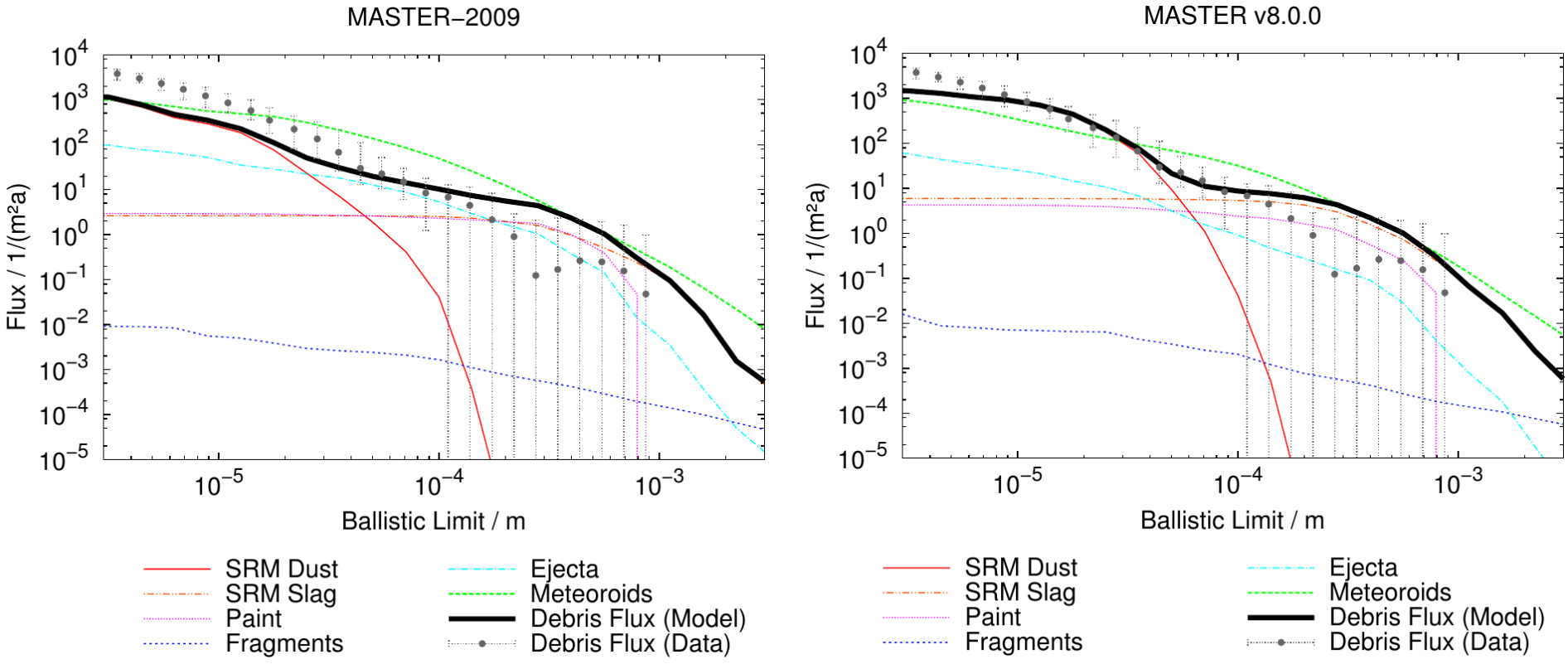
Population validation

Lead surface



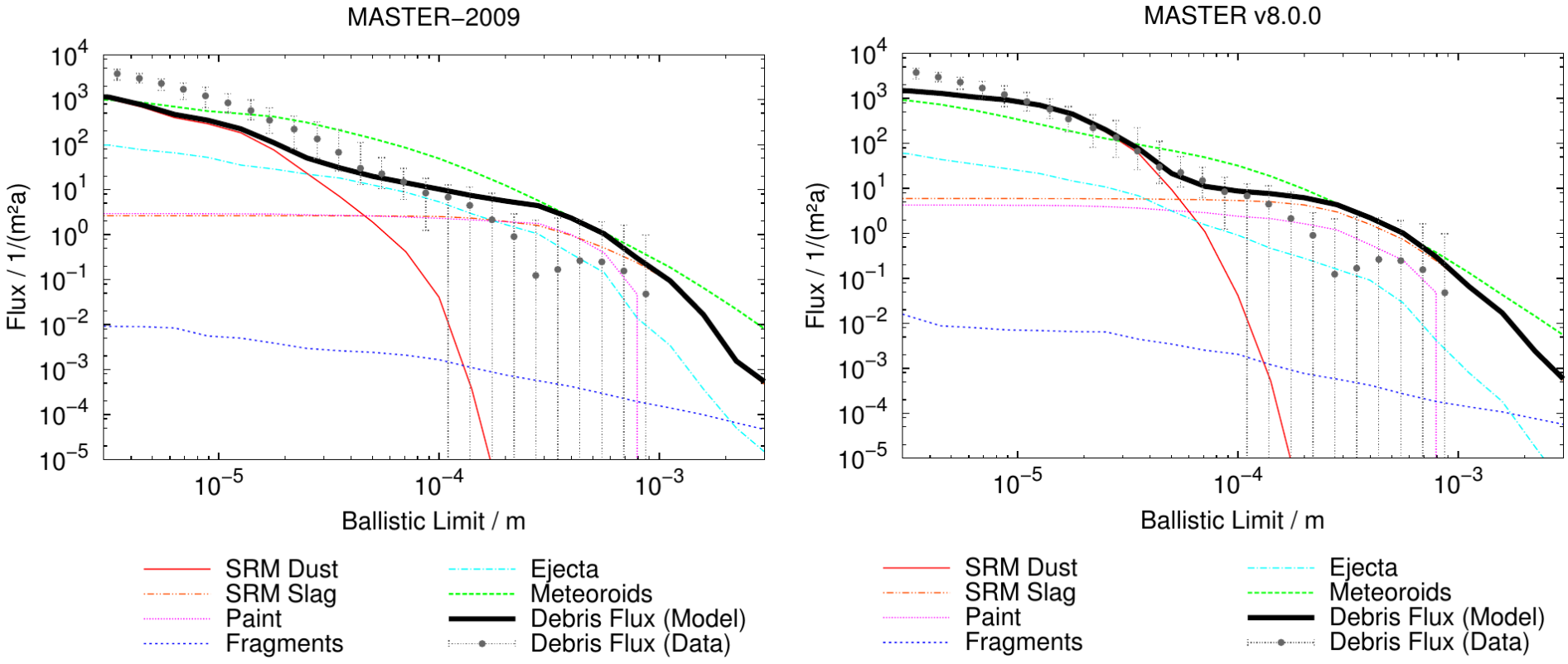
Population validation

North surface



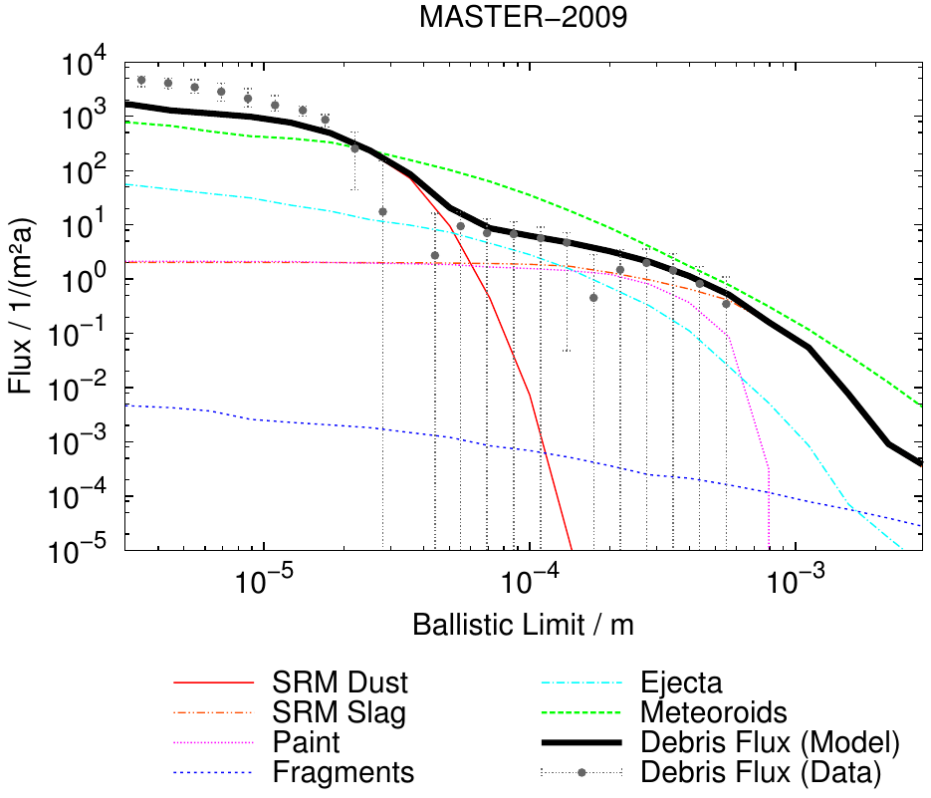
Population validation

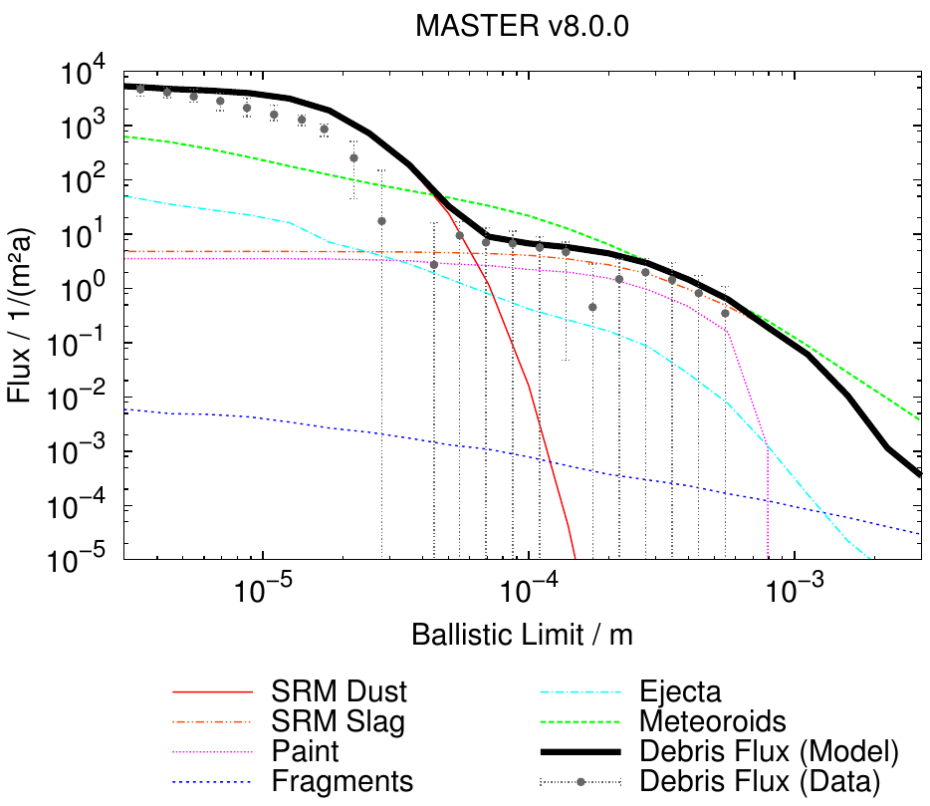
North surface



Population validation

South surface

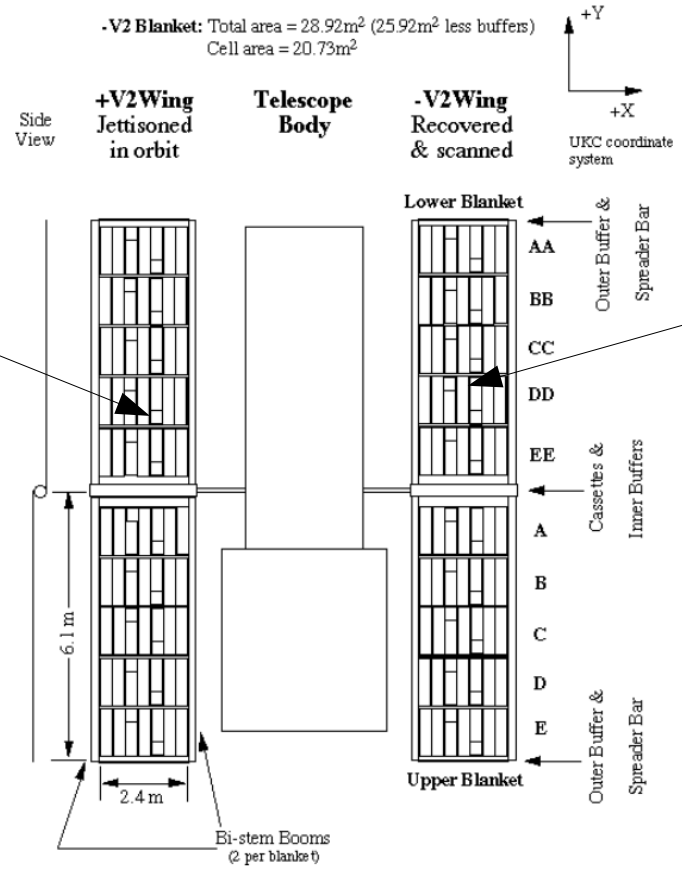




Population validation

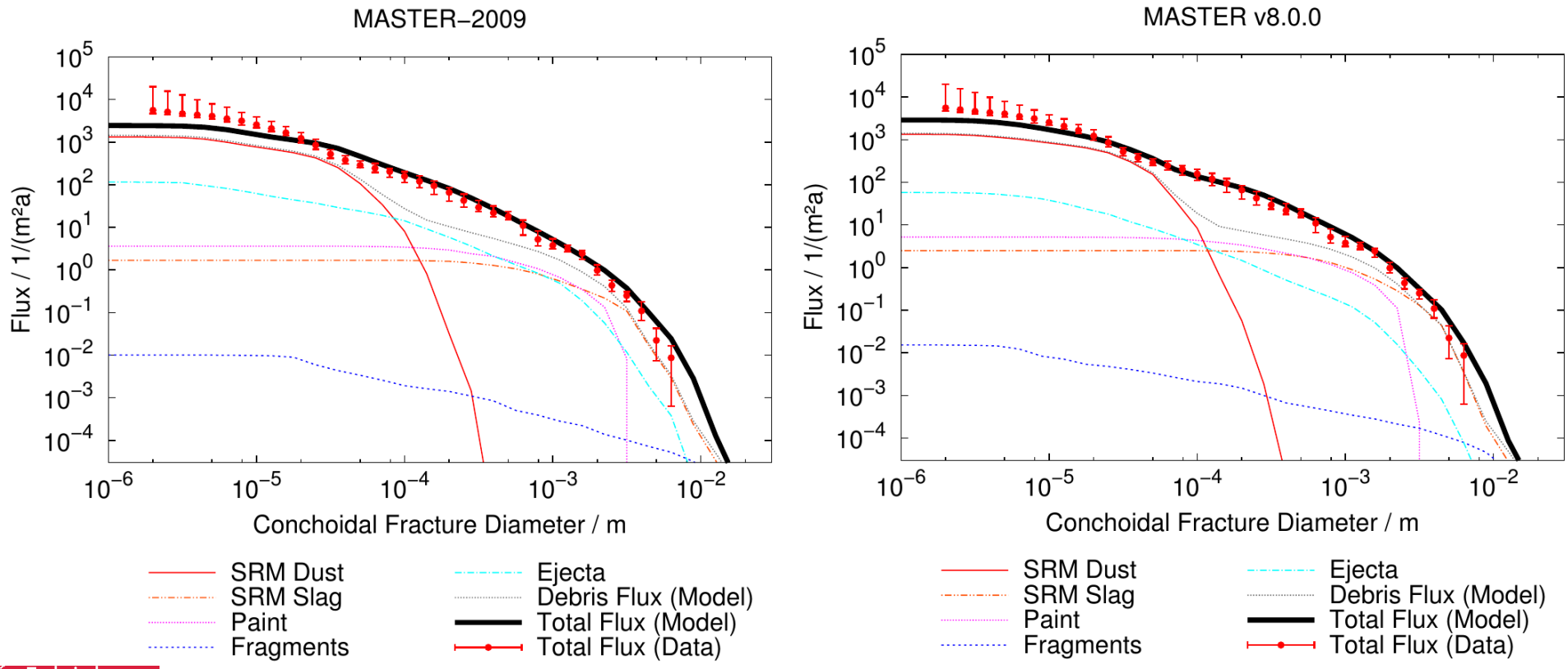
Impact measurements

Impact measurements



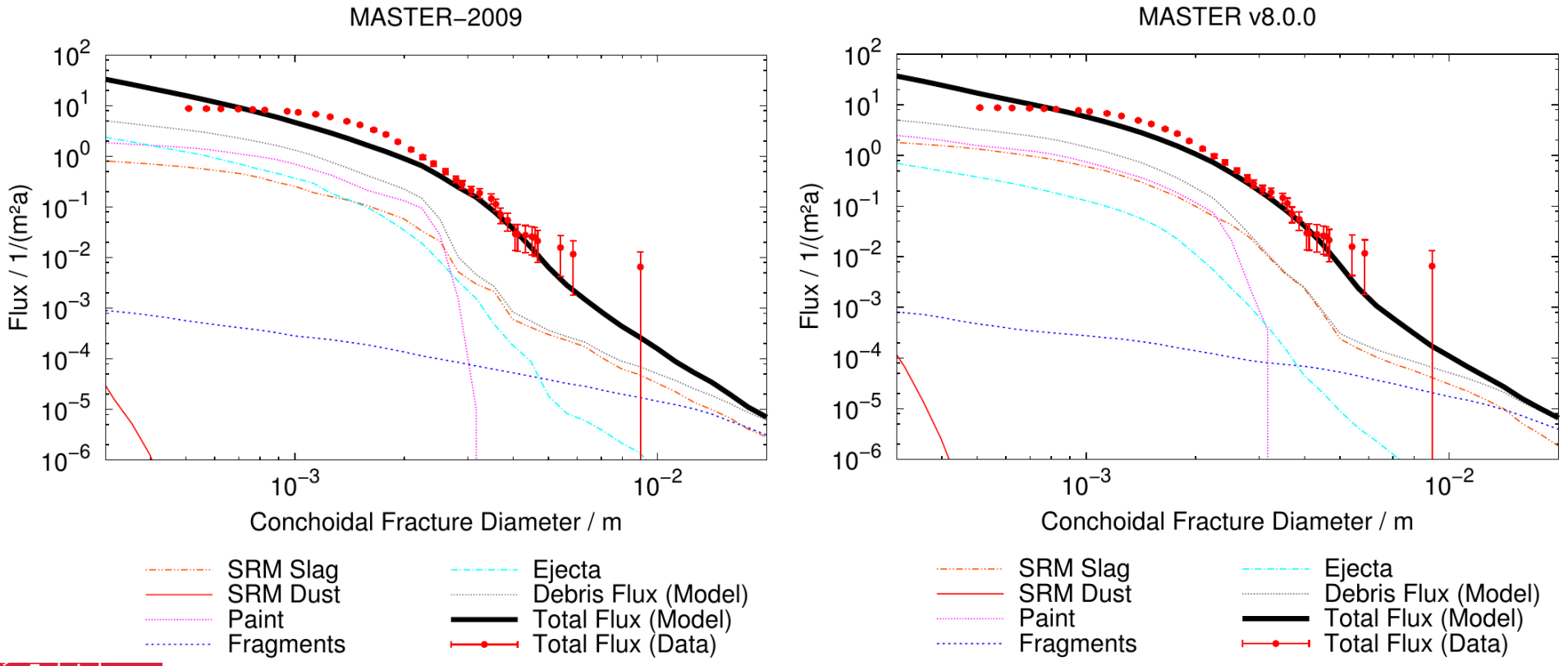
Population validation

HST-SM1 Front Top solar array



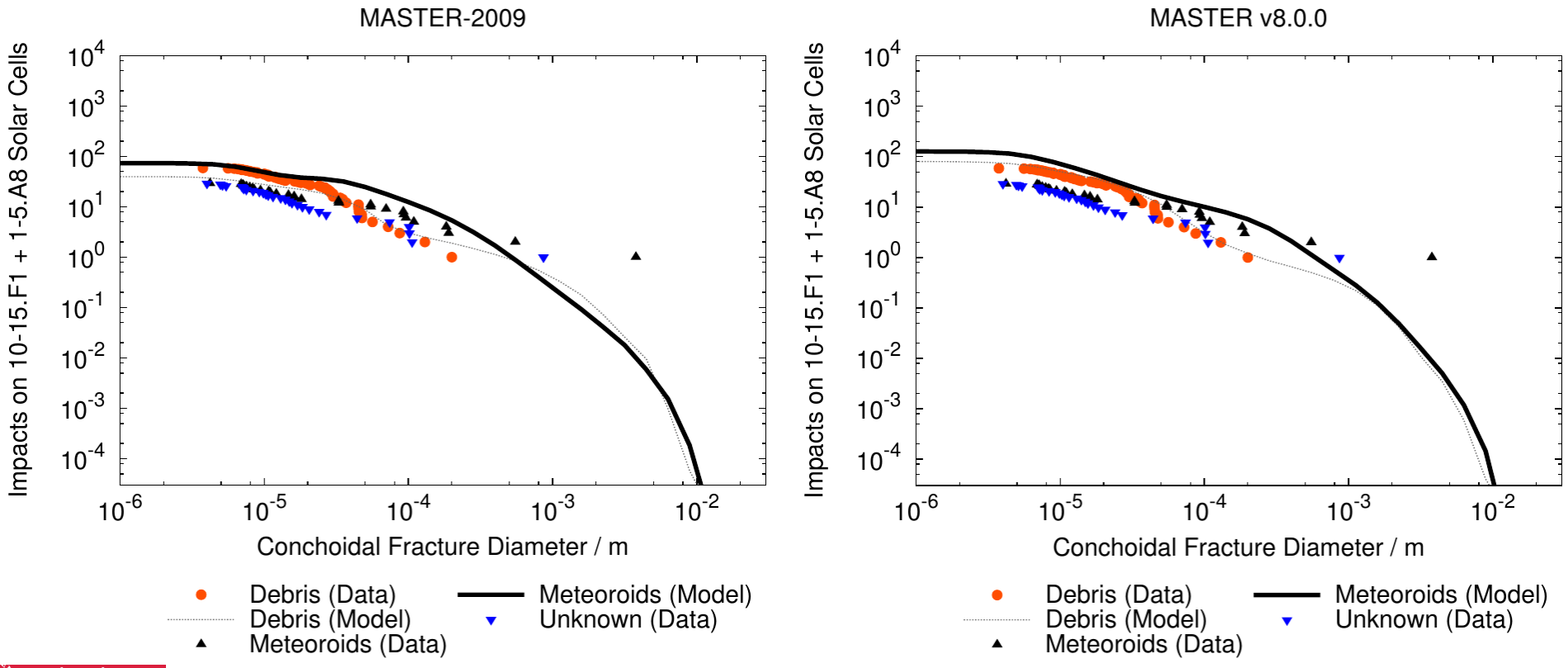
Population validation

HST-SM1 Rear Top solar array



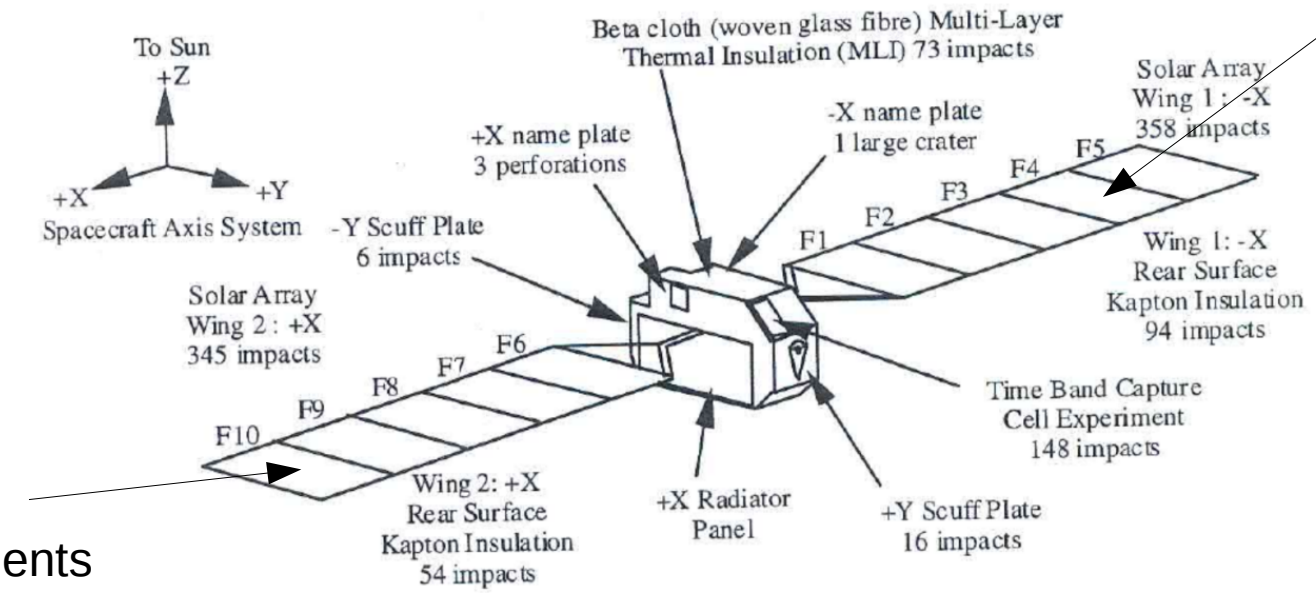
Population validation

HST-SM3B Front Top solar array



Population validation

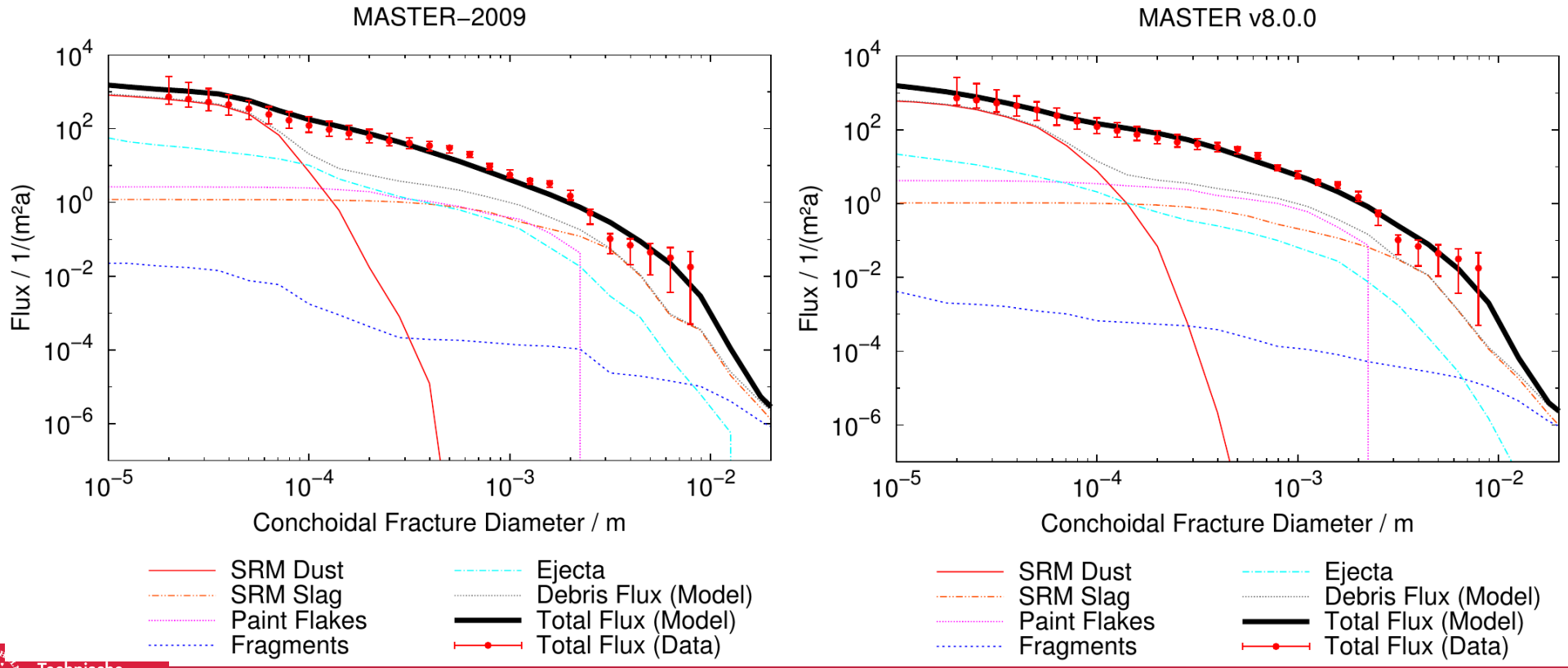
Impact measurements



Impact measurements

Population validation

EuReCa Front Top solar array



Population validation

Population validation

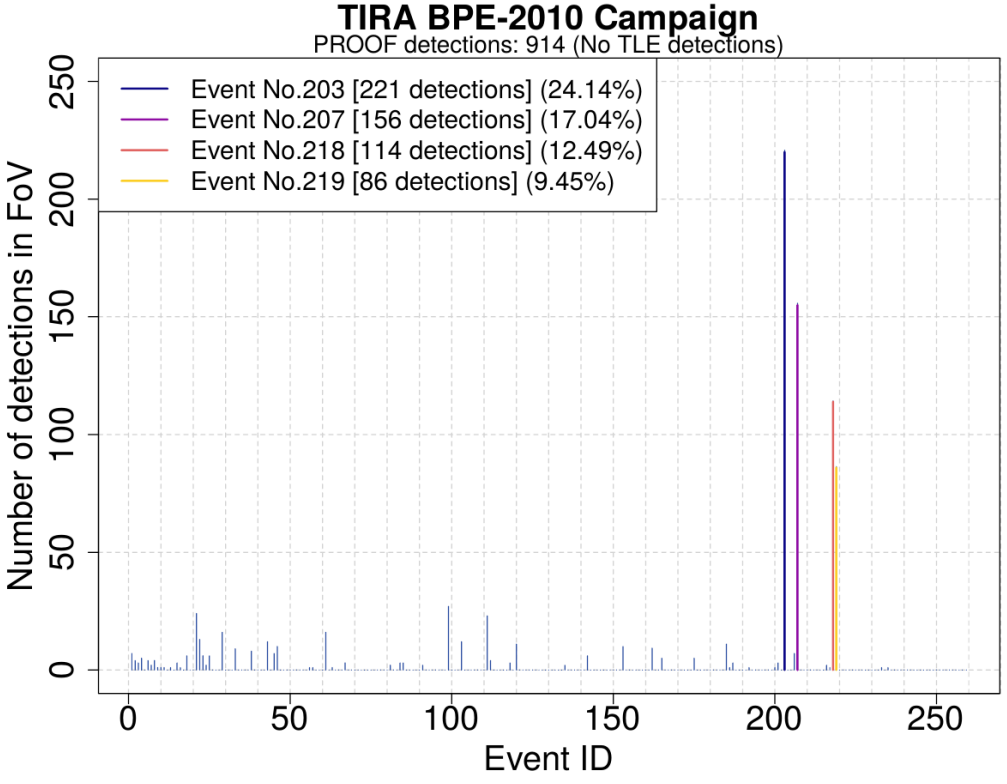
Campaign	TIRA Detections	PROOF-2009 Detections	Duration / h
2000	471	508	24
2001	566	466	24
2003	513	464	24
2004	538	459	24
2004	529	473	24
2005	533	461	24
2006	494	481	24
2007	585	850	24
2010	849	922	24
2013	626	649	18
2015	378	487	24

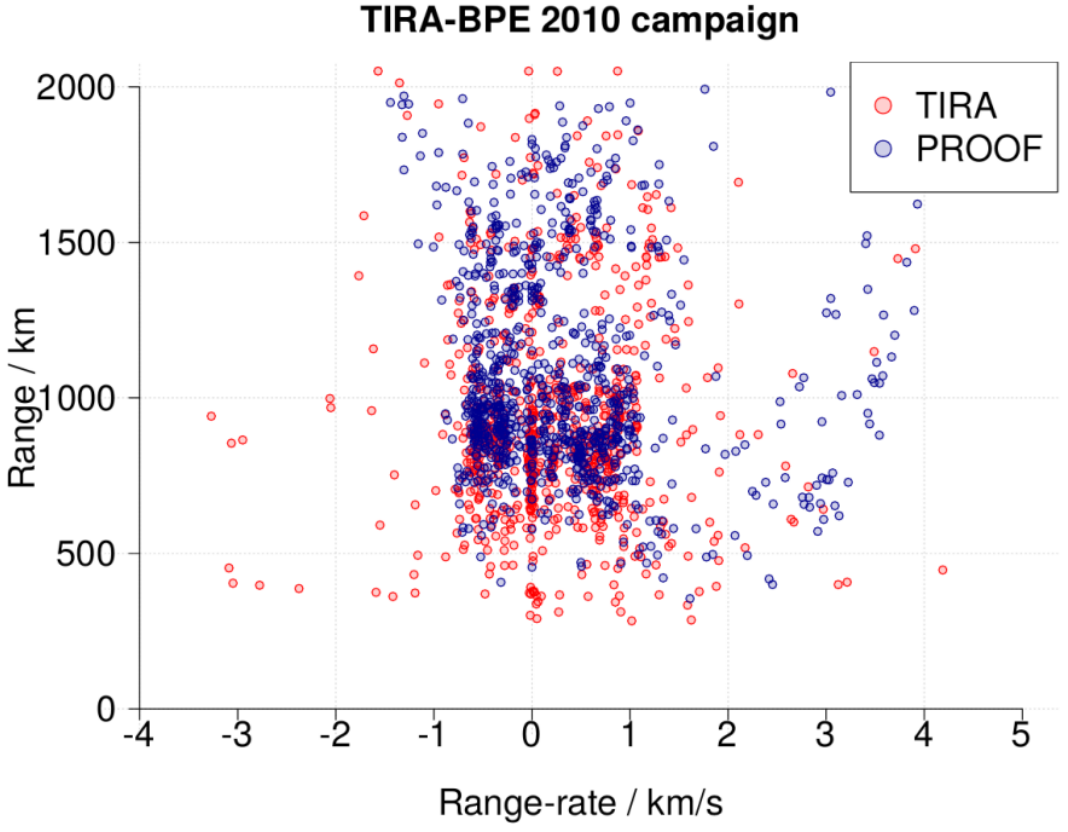
new data

Major Field-of-View contributors:

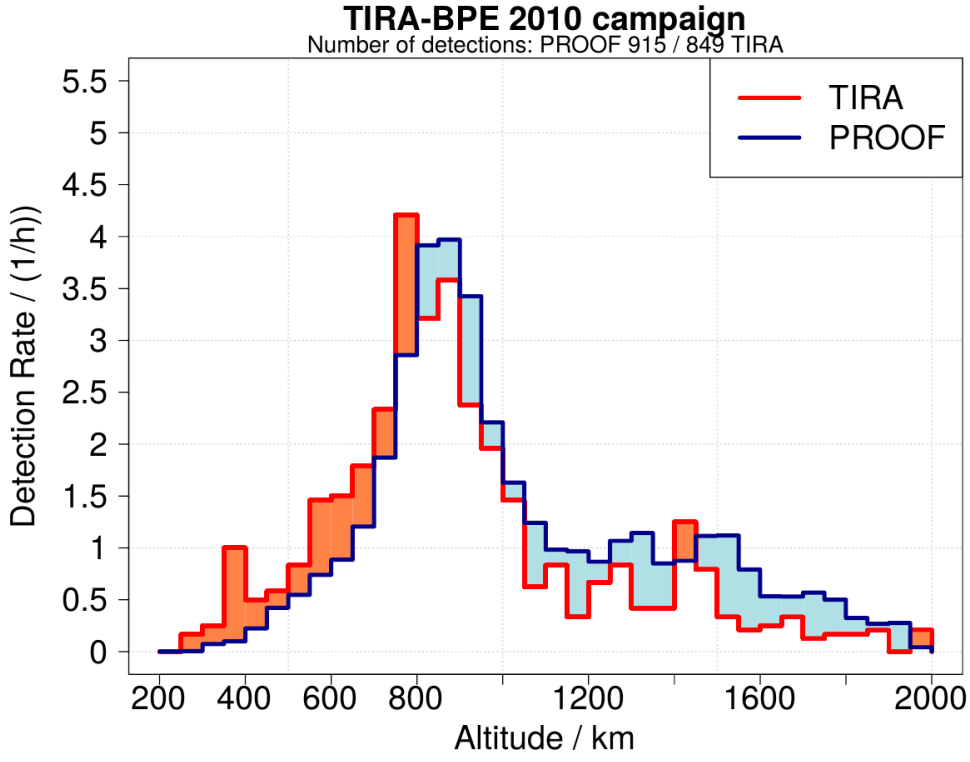
- Fengyun-1C (1999-025A)
- Briz-M (2006-006B)
- Cosmos-2251 (1993-036A)
- Iridium-33 (1997-051C)

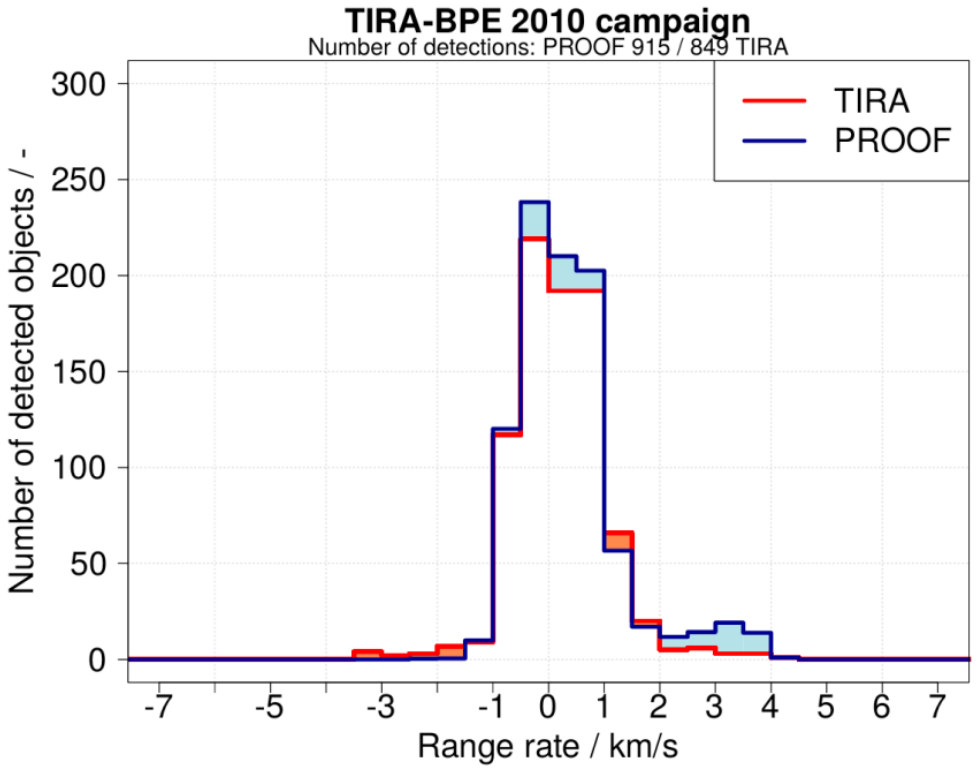
Population validation



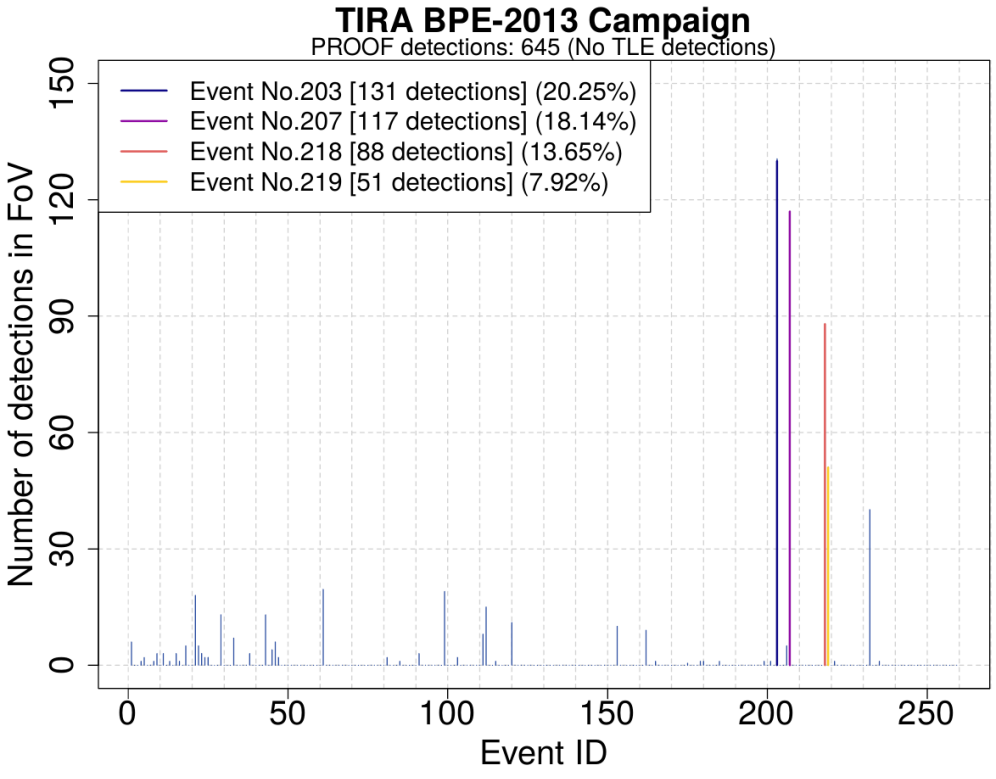


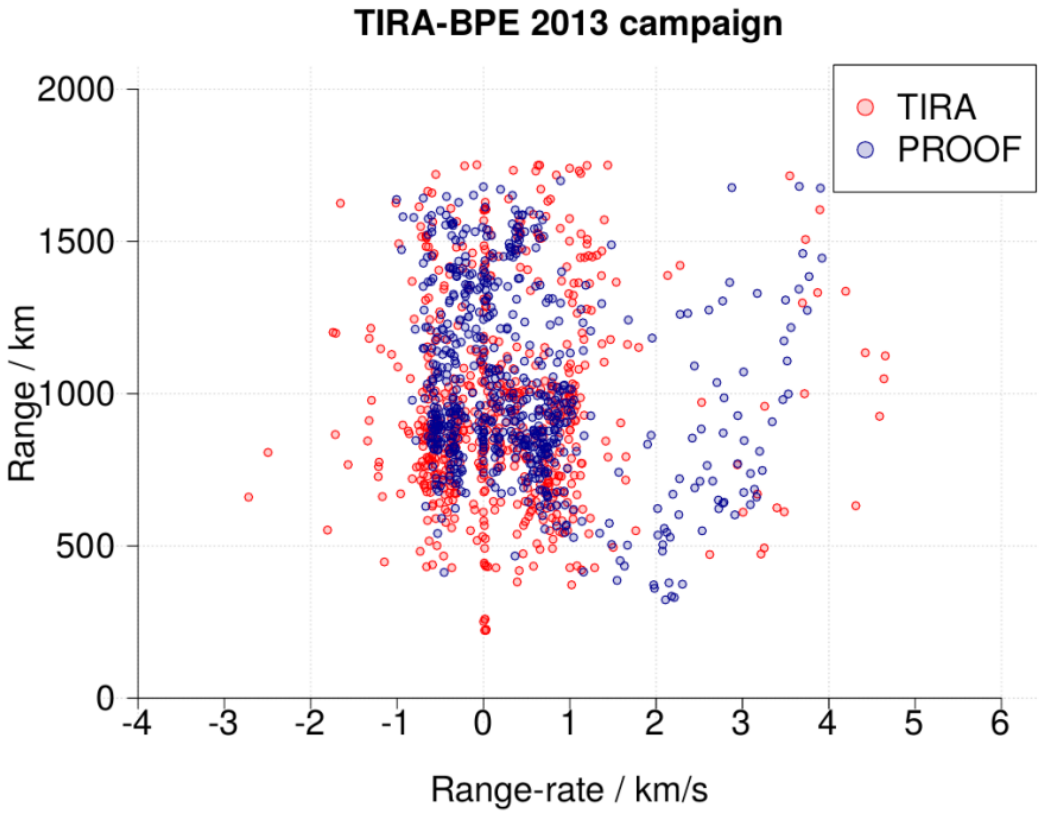
Population validation



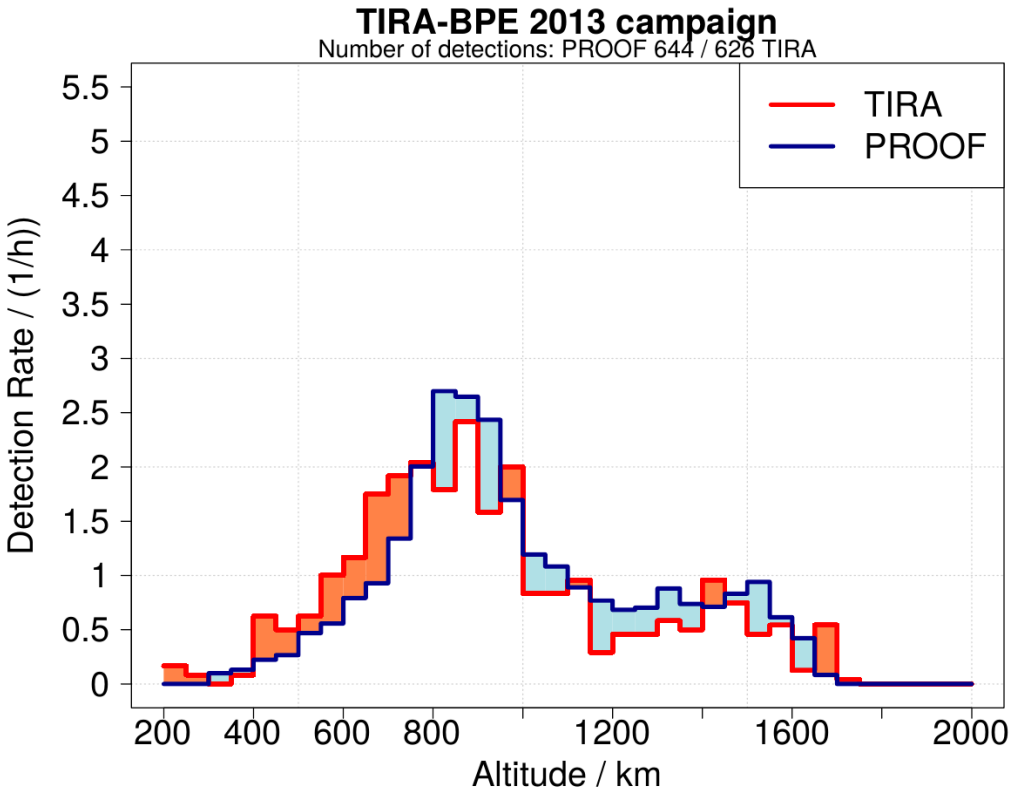


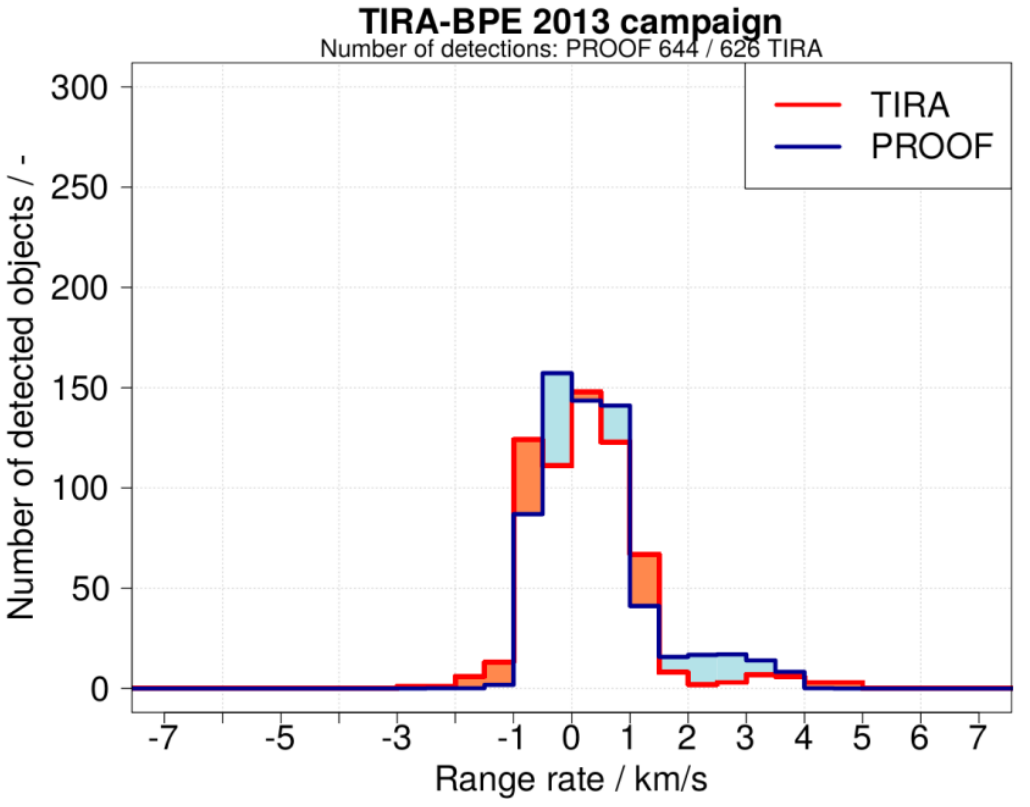
Population validation



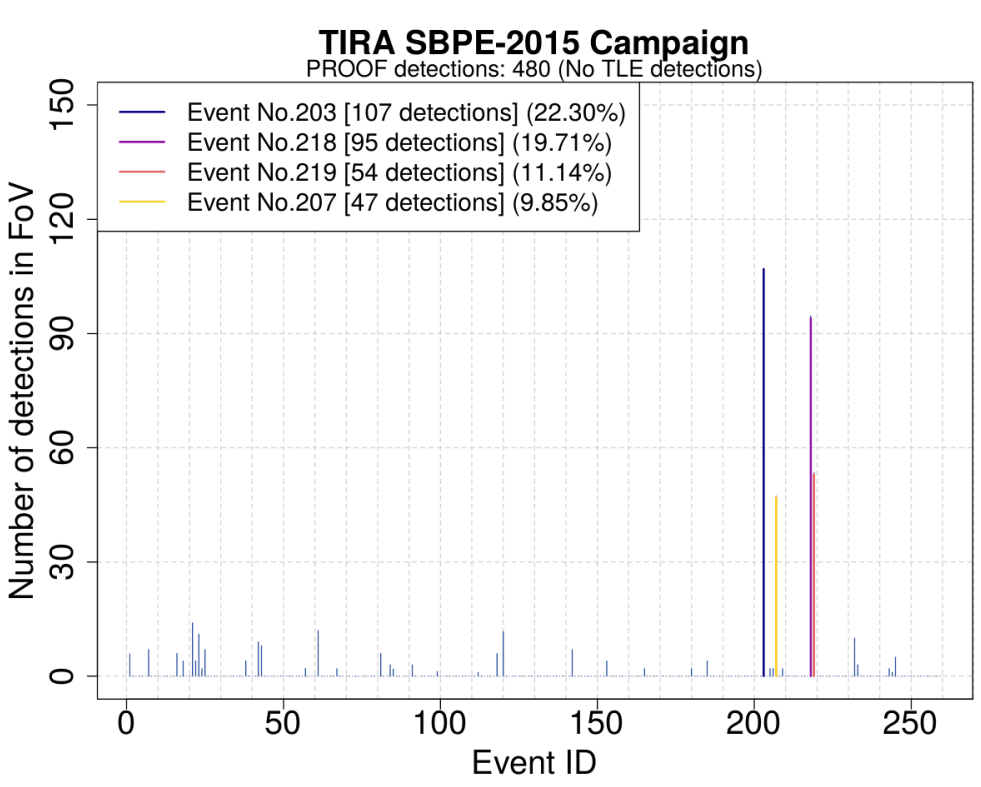


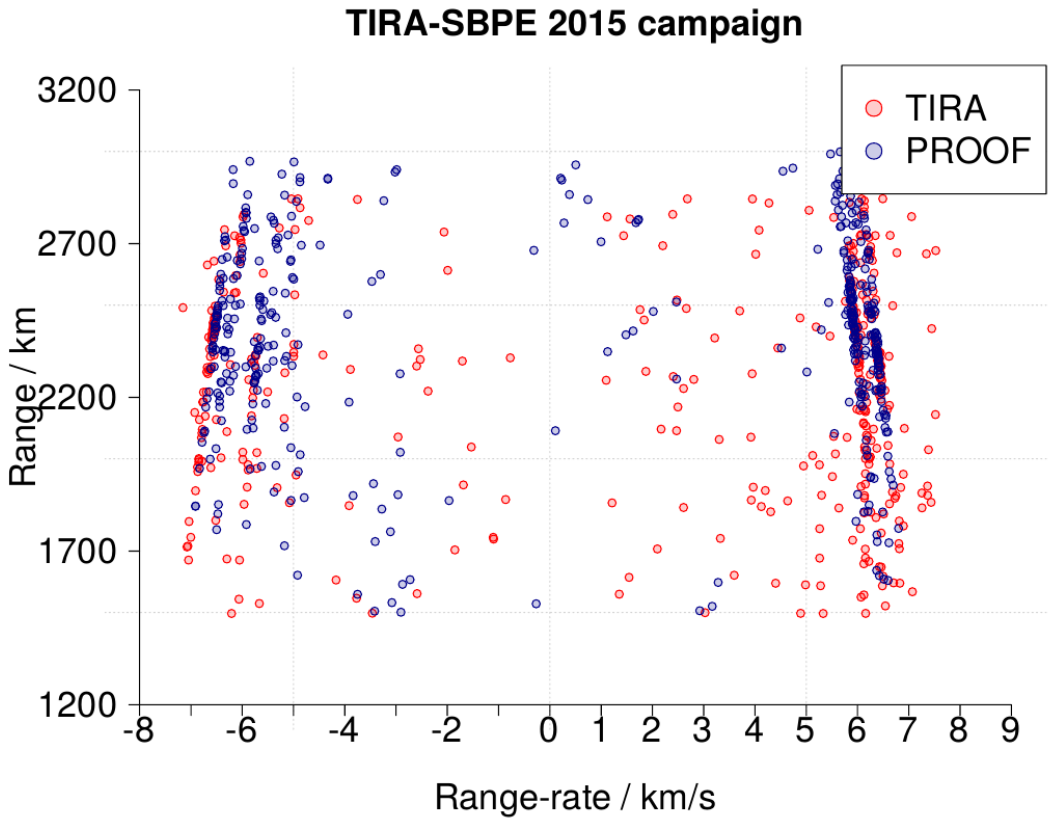
Population validation



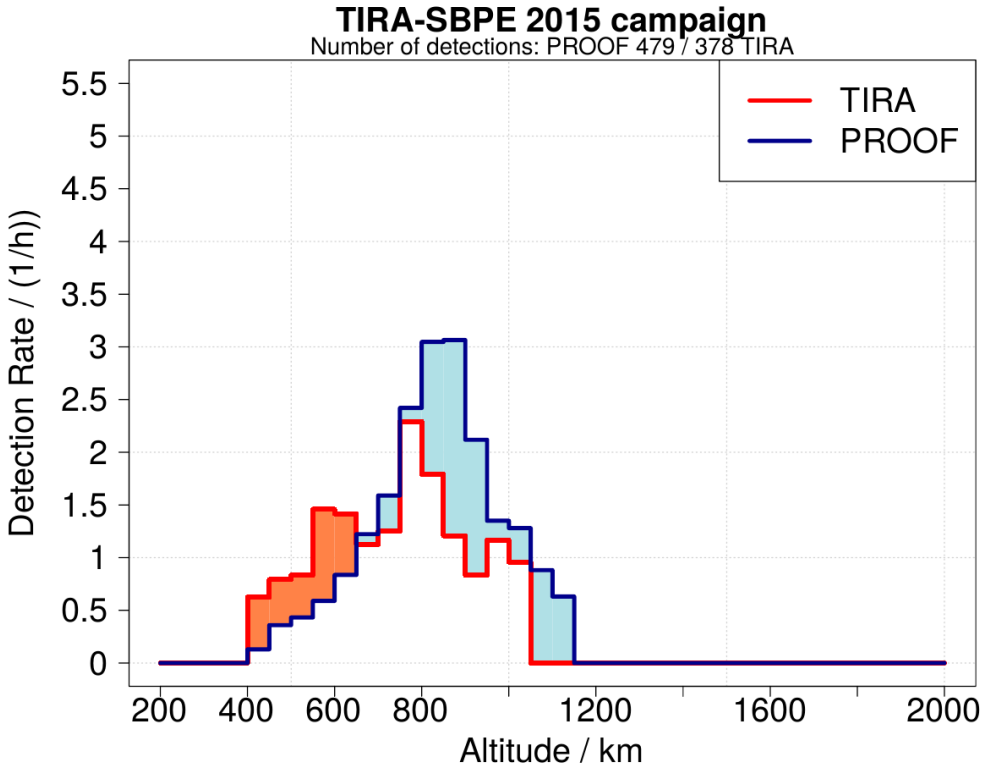


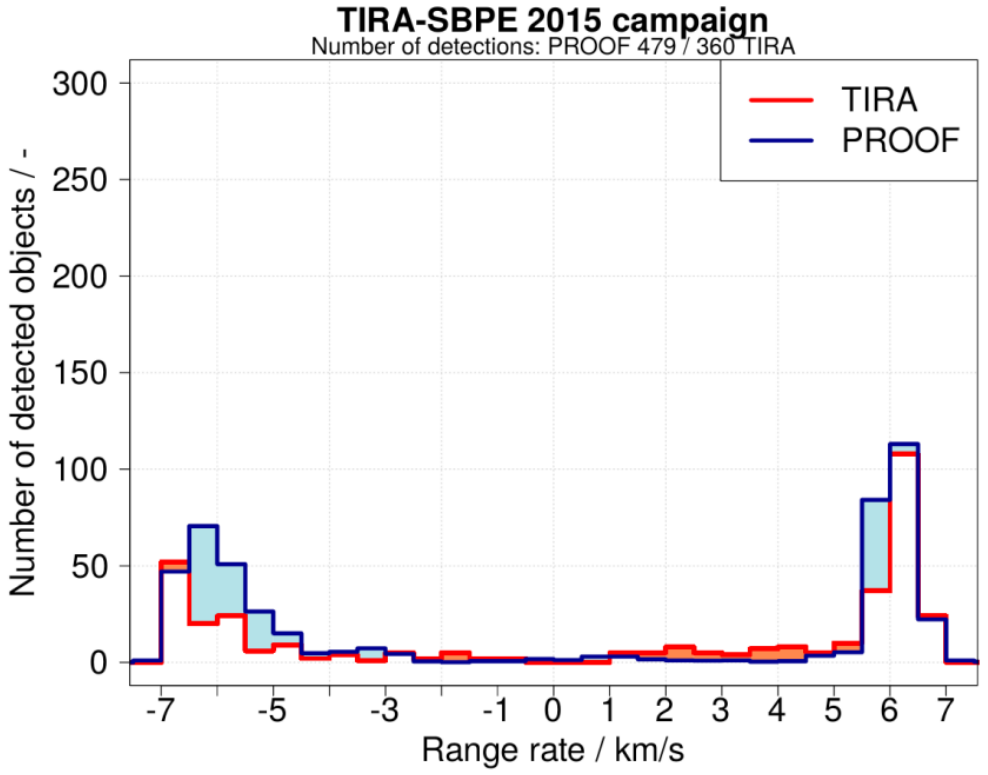
Population validation





Population validation



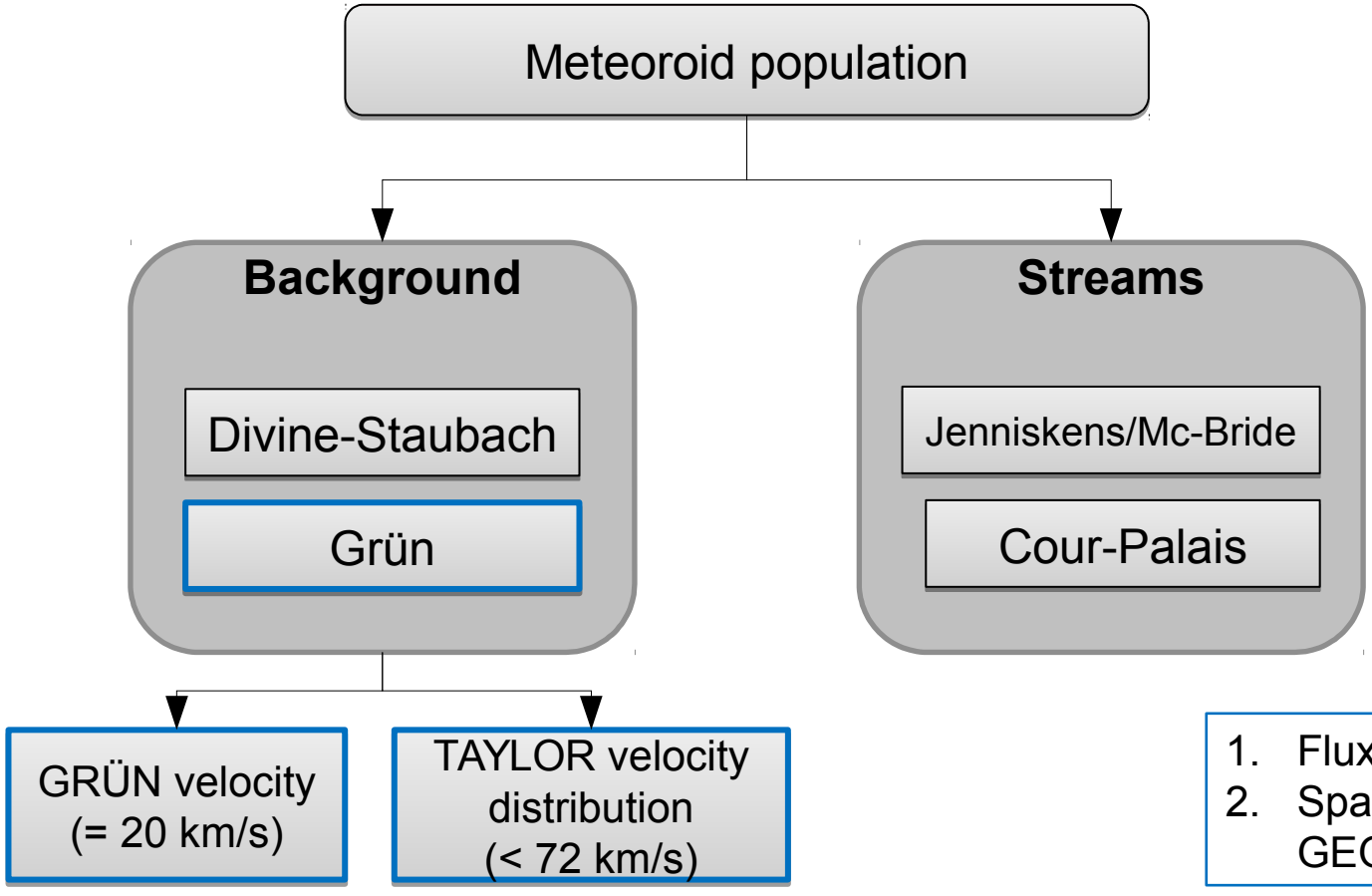


New user features

Overview:

1. Grün Meteoroid Model
2. Flux in Lagrange points
3. Target orbit propagation
4. Revised output
5. Uncertainty indicators
6. Coorporate design

New user features



1. Flux up to lunar altitude
2. Spatial Density up to GEO

New user features

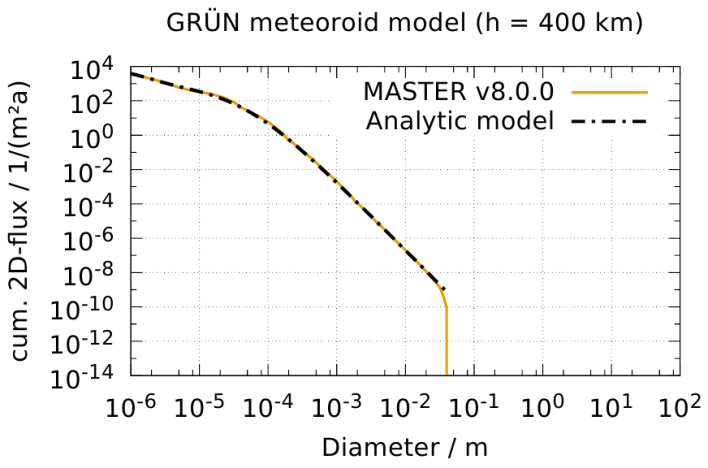
GRÜN meteoroid model

Gravitational focussing

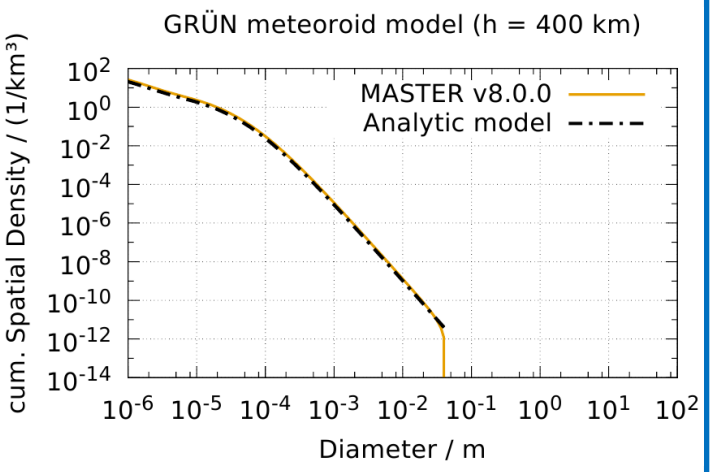
Planetary shielding

MASTER flux + spatial density results

Verification

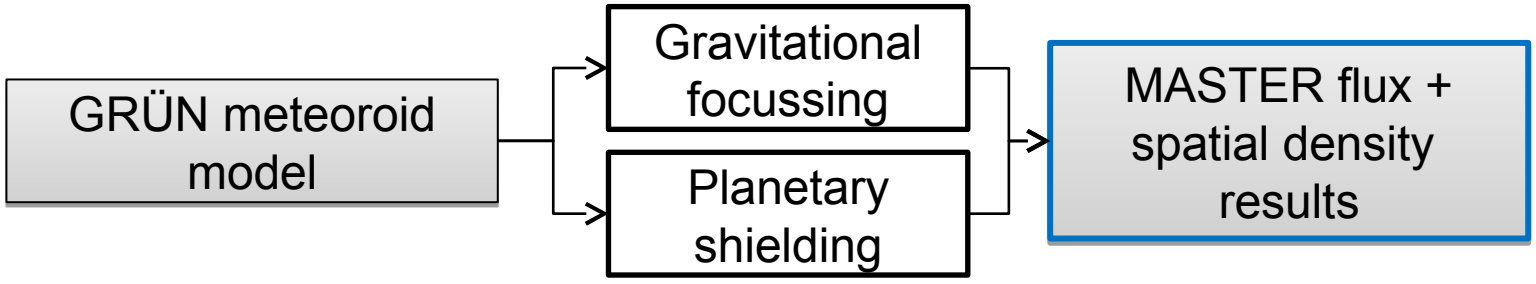


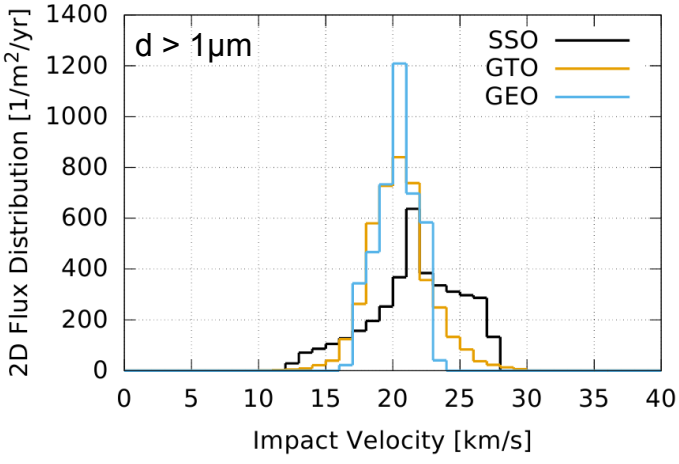
Flux



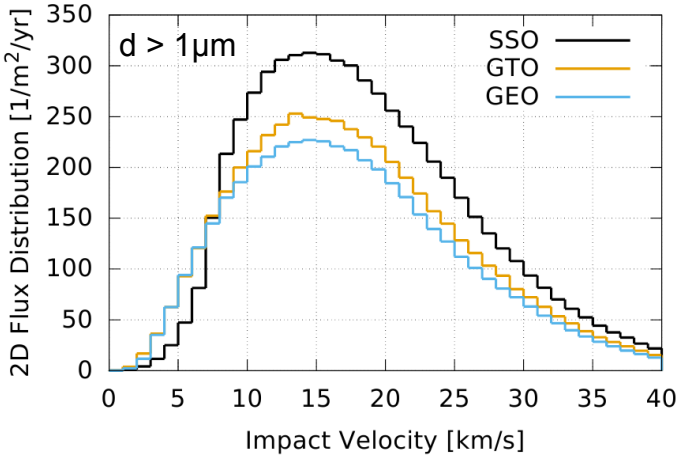
Spatial density

New user features



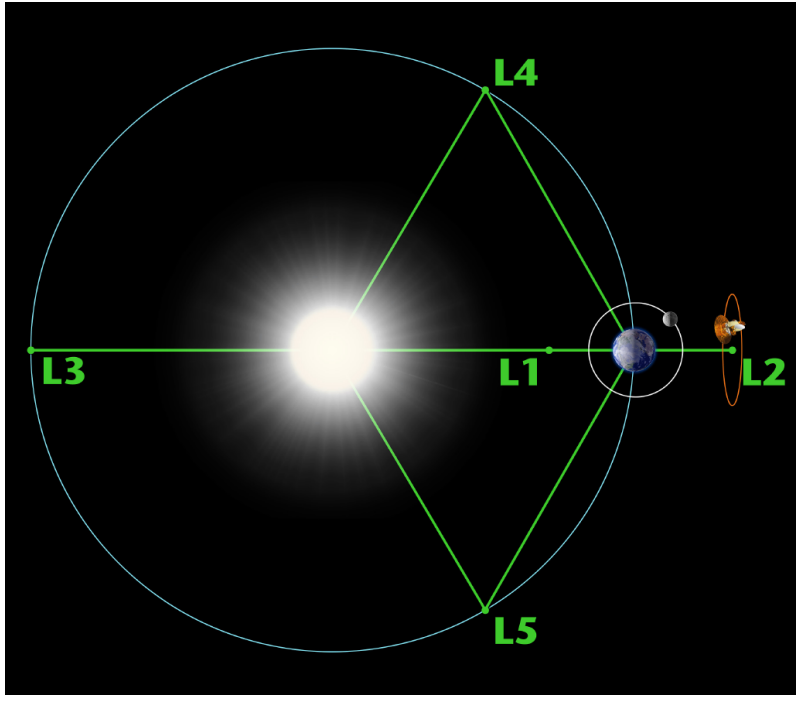


Constant velocity (GRÜN)



Velocity distribution (TAYLOR)

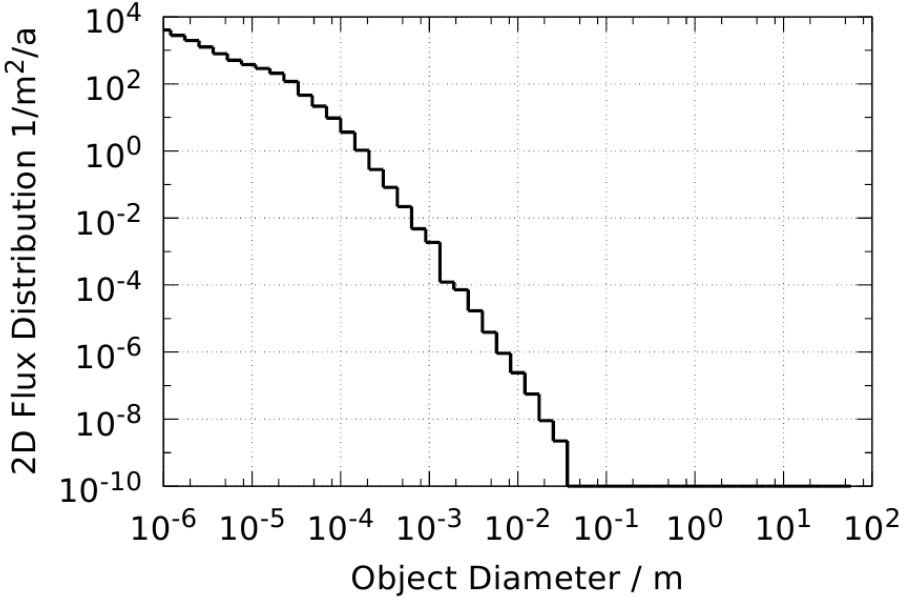
New user features

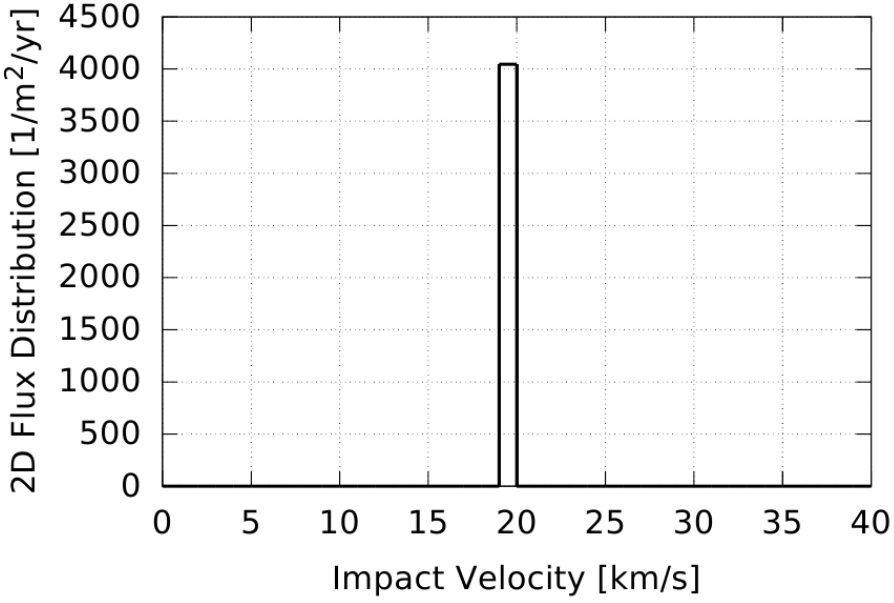


Meteoroid flux in Lagrange points at 1AU
exclusively provided by GRÜN model

New user features

- Almost pure GRÜN flux model F(m)
- Focussing and shielding still evaluated, but marginal change in flux

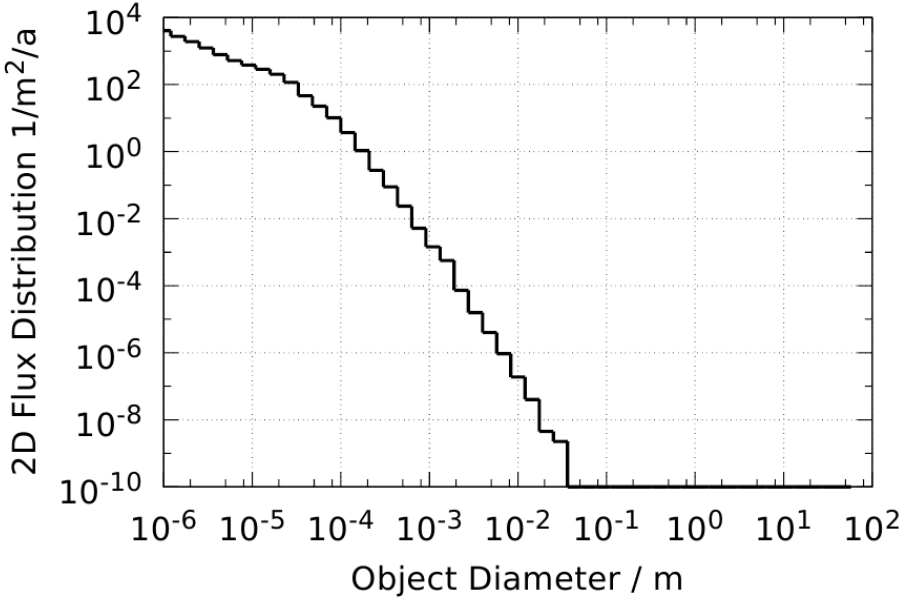


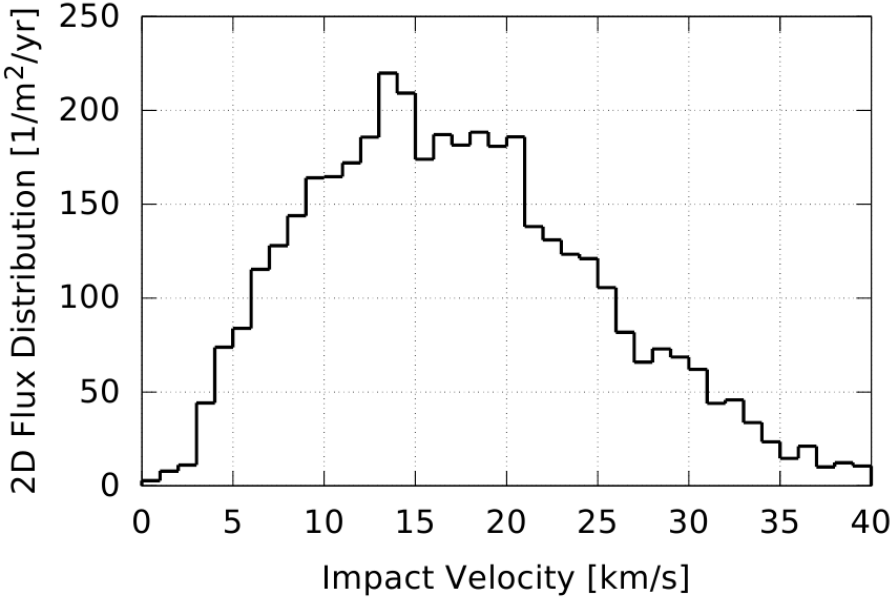


GRÜN meteoroid velocity

New user features

- Almost pure GRÜN flux model F(m)
- Focussing and shielding still evaluated, but marginal change in flux





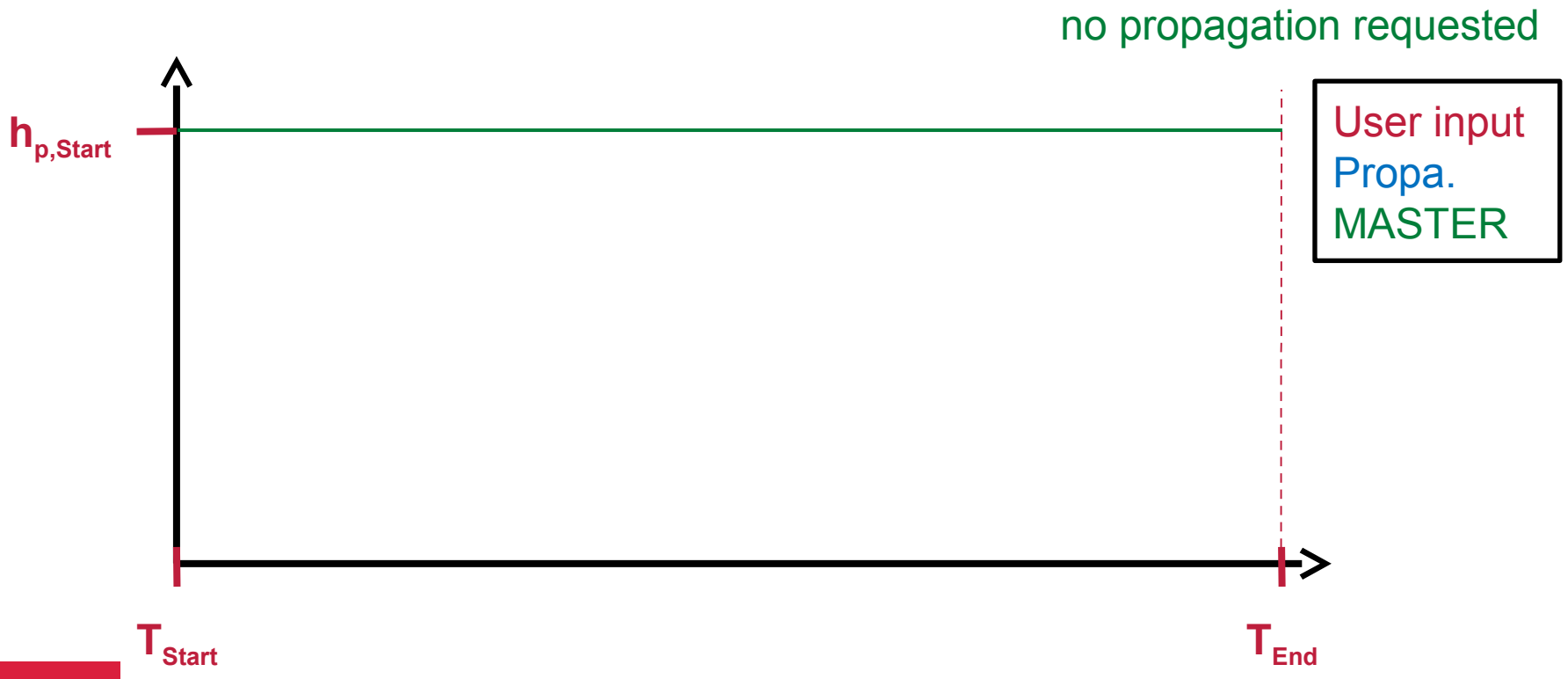
TAYLOR meteoroid velocity distribution

New user features

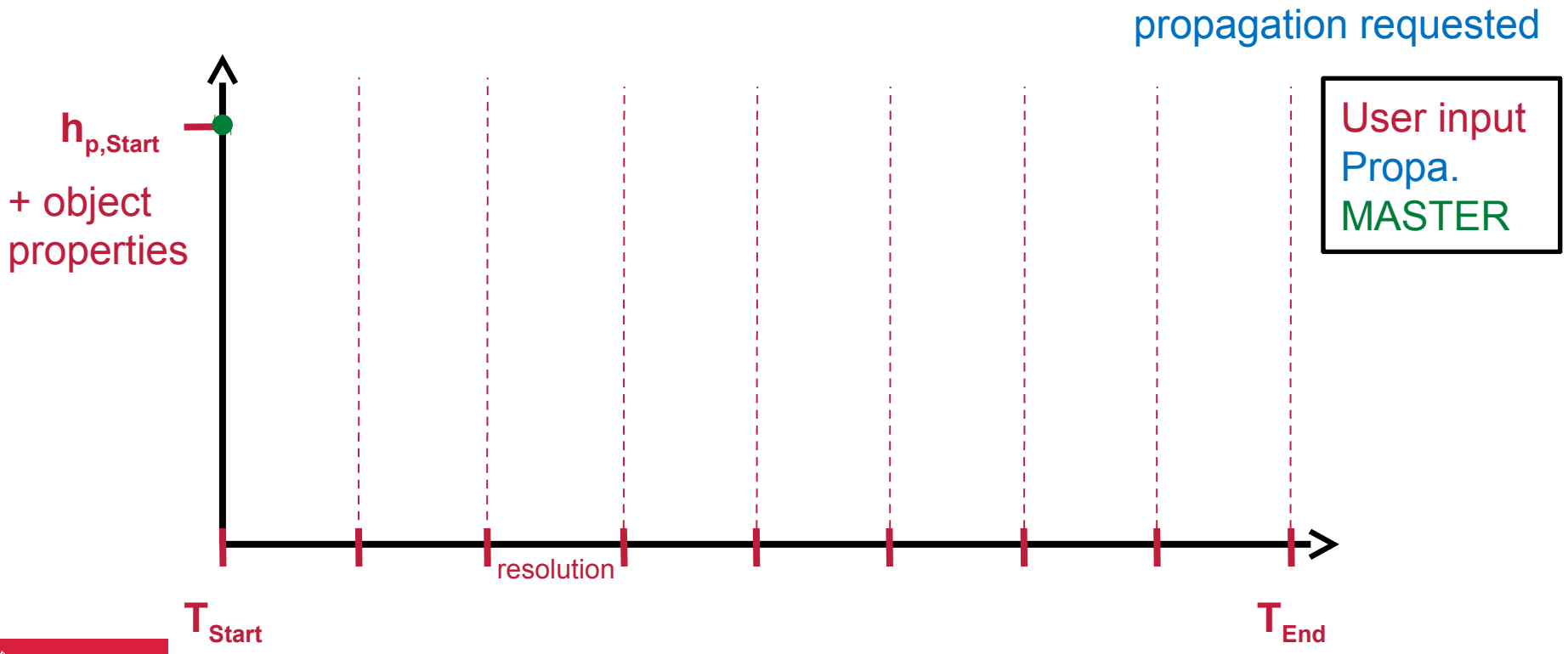
Key features for the optional propagation of target orbits:

- Up to 300 internal target orbits possible (25 years with 1 month resolution)
- apo,peri [0 km;500.000 km) → approx. lunar altitude
- Flux above GEO+1000km → meteoroids only!
- Flux below 186 km → no contribution!
- Re-entry handling

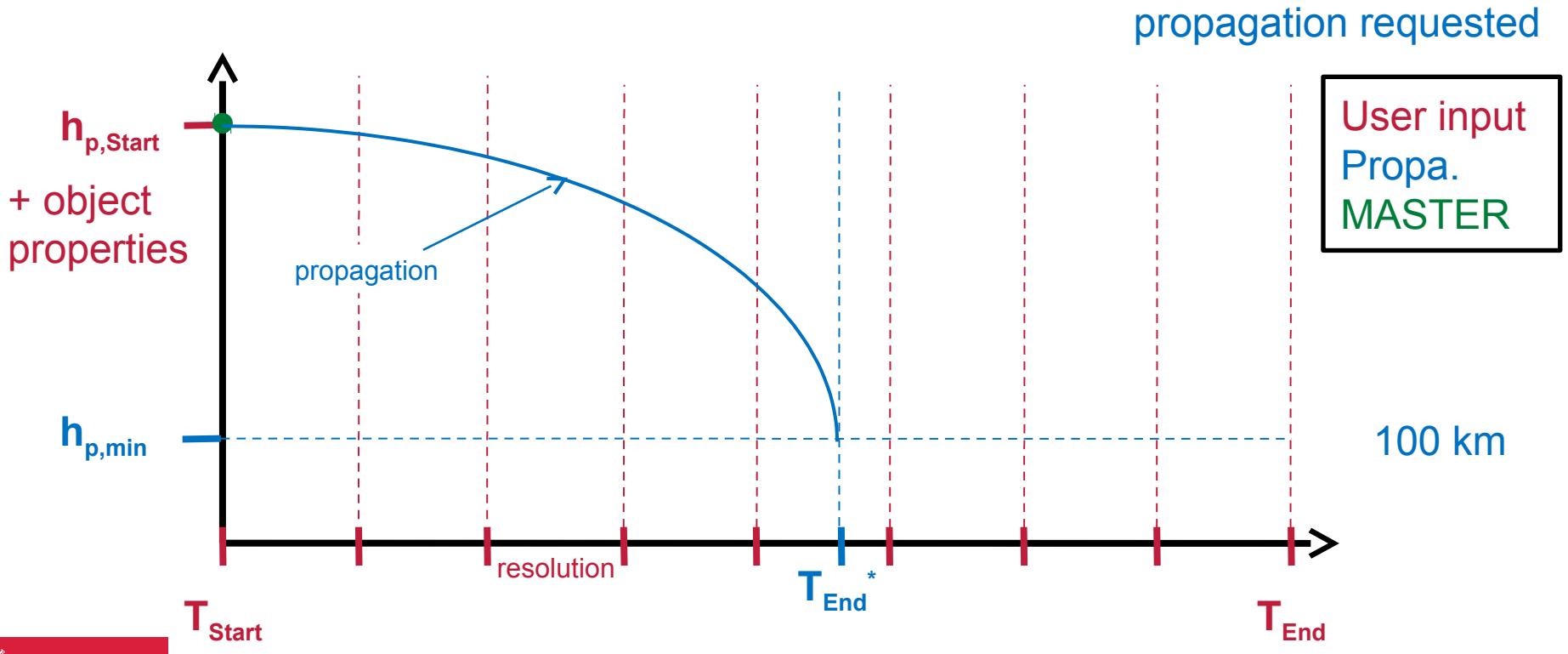
New user features



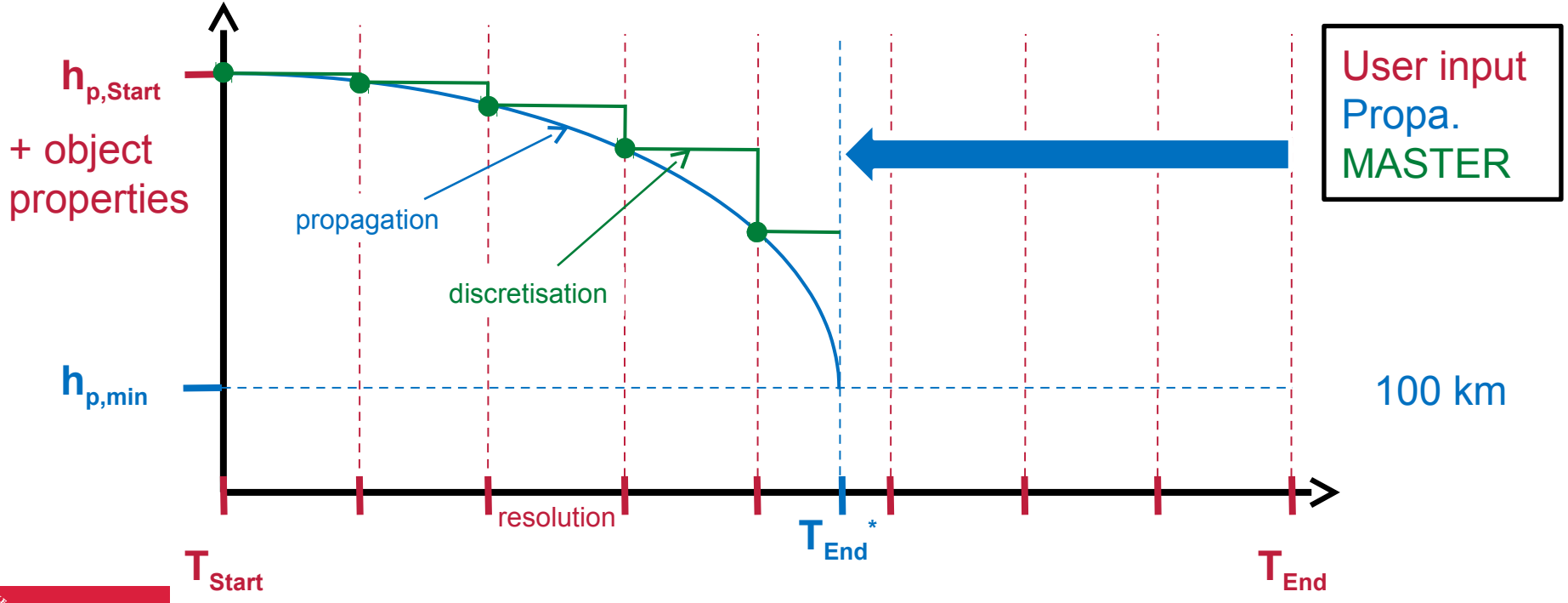
New user features



New user features



New user features



New user features

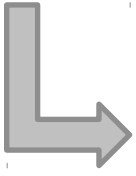
New additional information in the output files:

- Derived most recent reference epoch
- List of procssed data files
- Data file version

} Header

- New source-column arrangement

} Data output



No direct compatibility between MASTER-2009 and MASTER v8.0.0 output

New user features

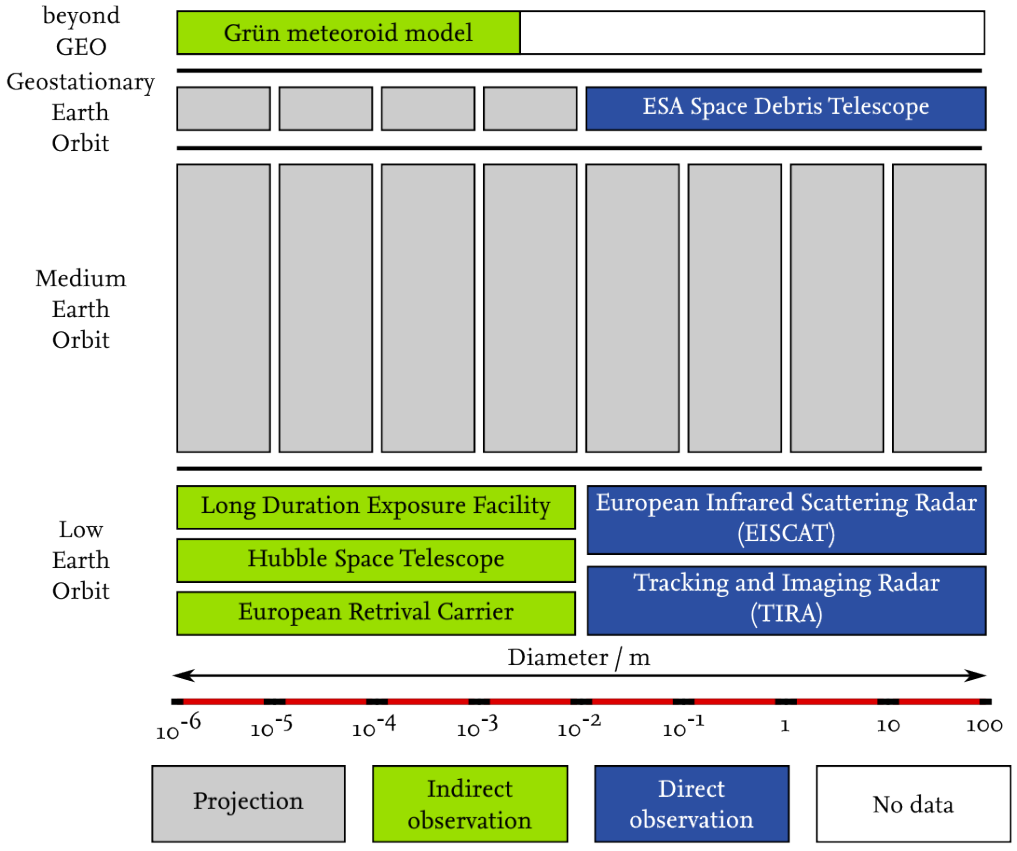
First uncertainty assessments by NASA in 1994:

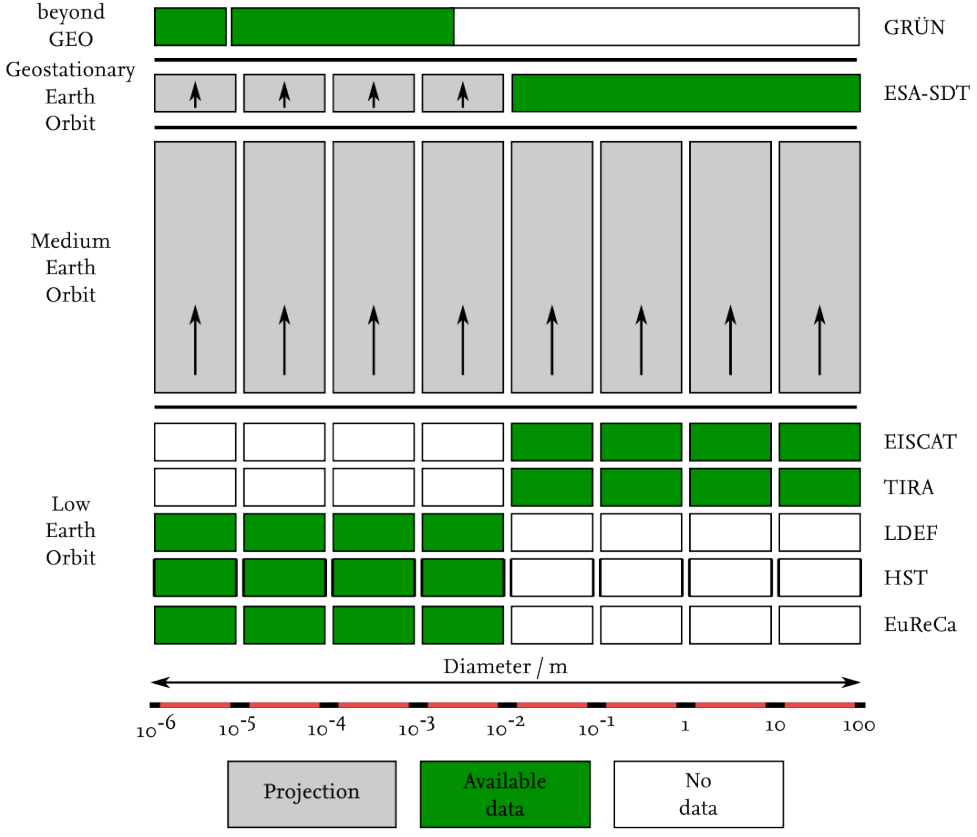
Meteoroids		Artificial debris				
Flux (factors)		Flux (factors)			Spatial density (factors)	
$d < 91.42\,\mu m$	$d > 91.42\,\mu m$	$d < 0.05\,cm$	$0.05\,cm < d < 10\,cm$	$d > 10\,cm$	$d < 10\,cm$	$d > 10\,cm$
0.33 to 3	0.1 to 10	0.5 to 1.5	0.33 to 3.0	0.5 to 2.0	0.5 to 2.0	0.2 to 5.0

GRÜN model inherent

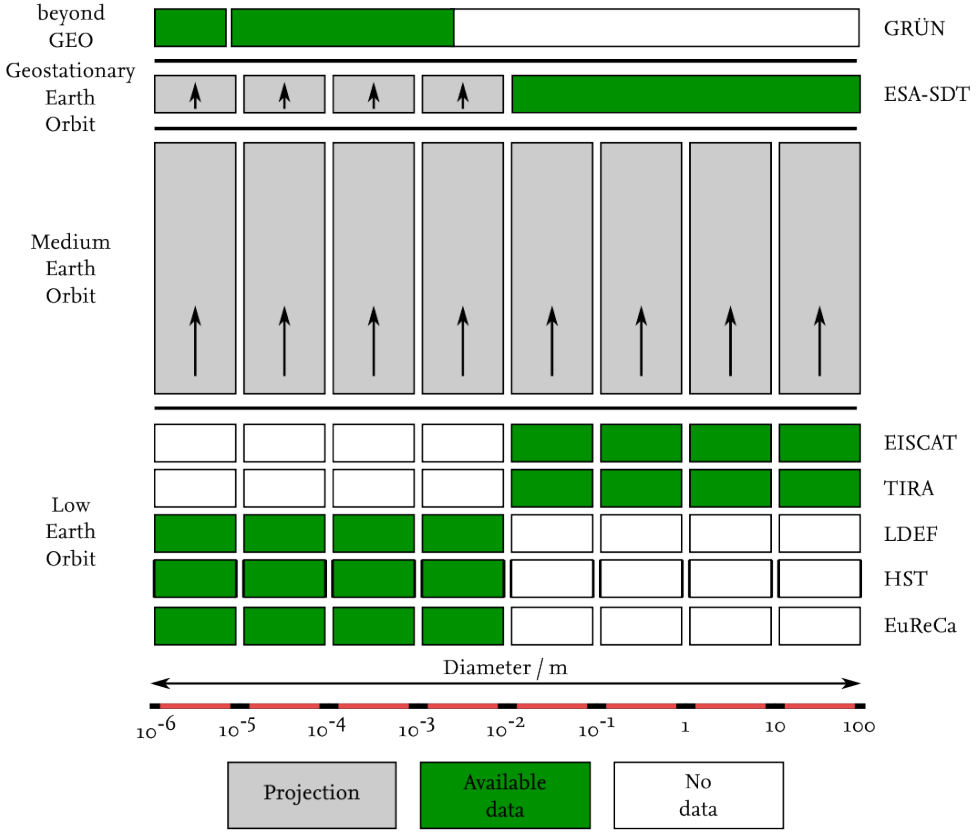
Best guessing…

New user features





New user features

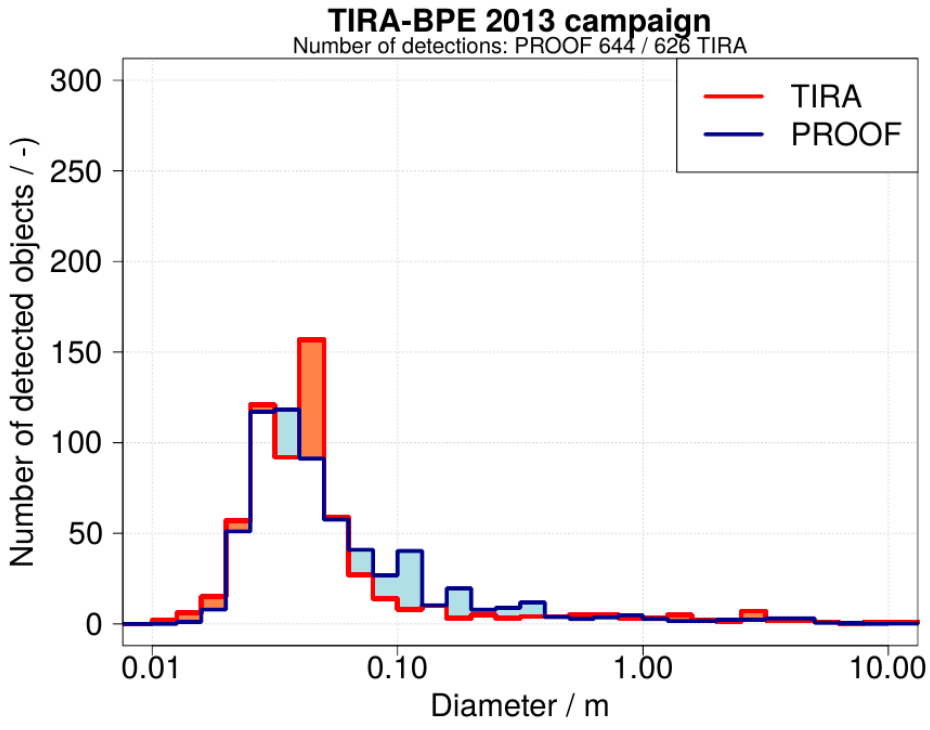


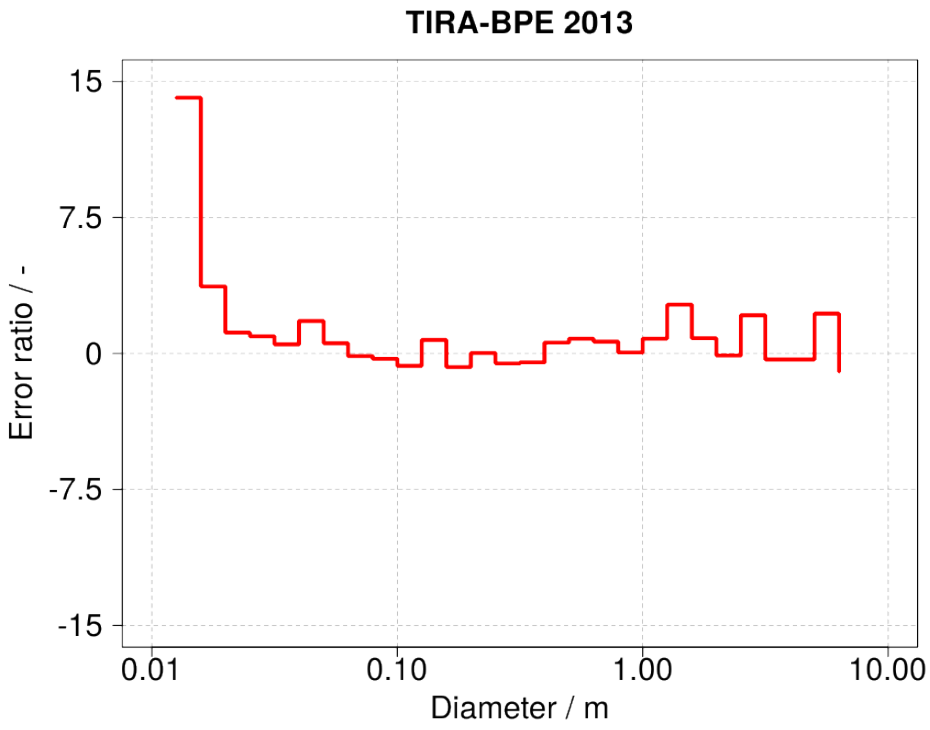
Provided spectra:

1. Spatial Density vs. Altitude
2. Flux vs. Diameter
3. Flux vs. Mass

New user features

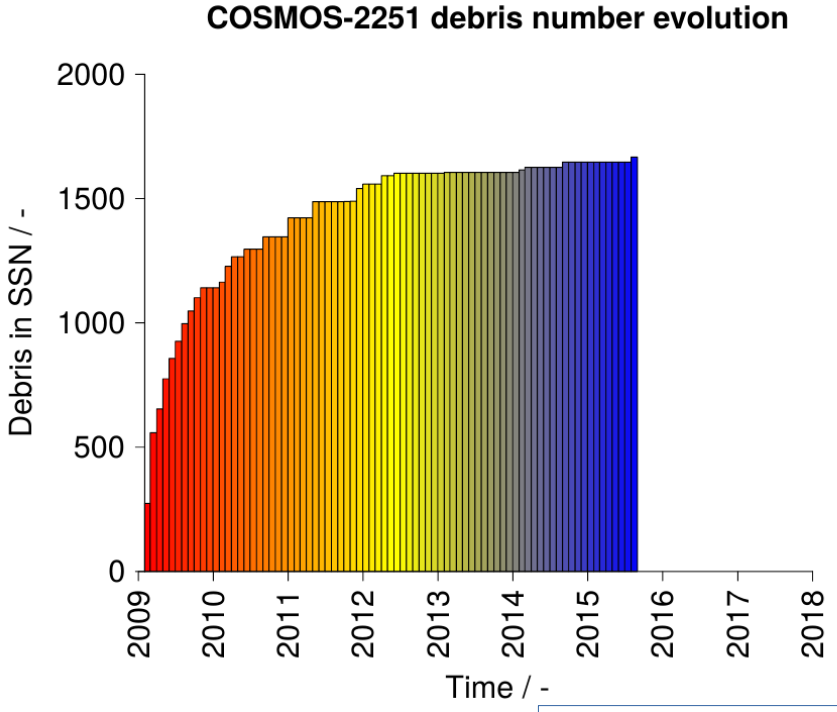
Large object uncertainties (TIRA-BPE 2013 as example case)

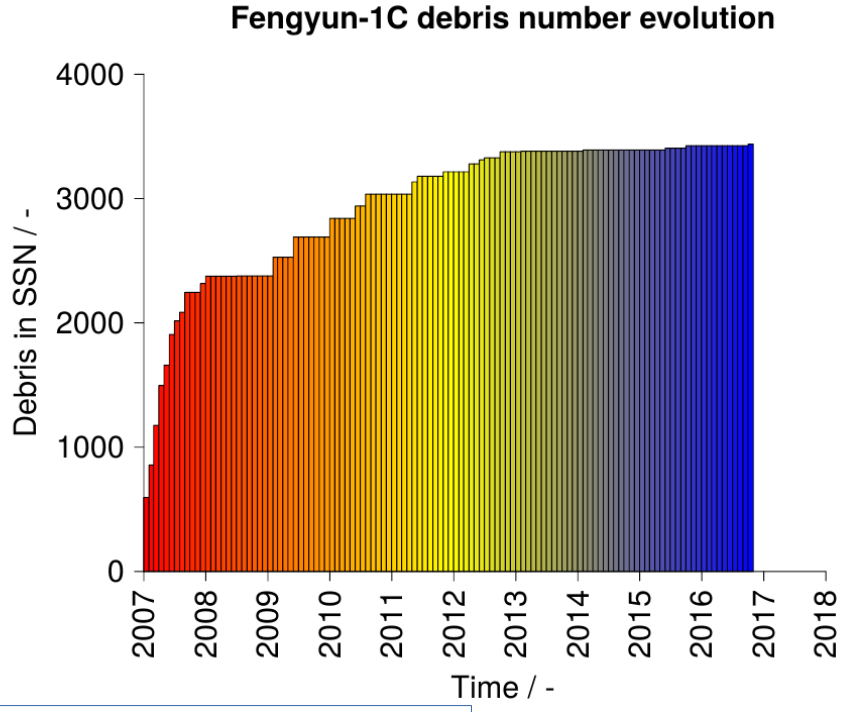




New user features

Crucial factor: Time difference between fragmentation epoch and campaign epoch

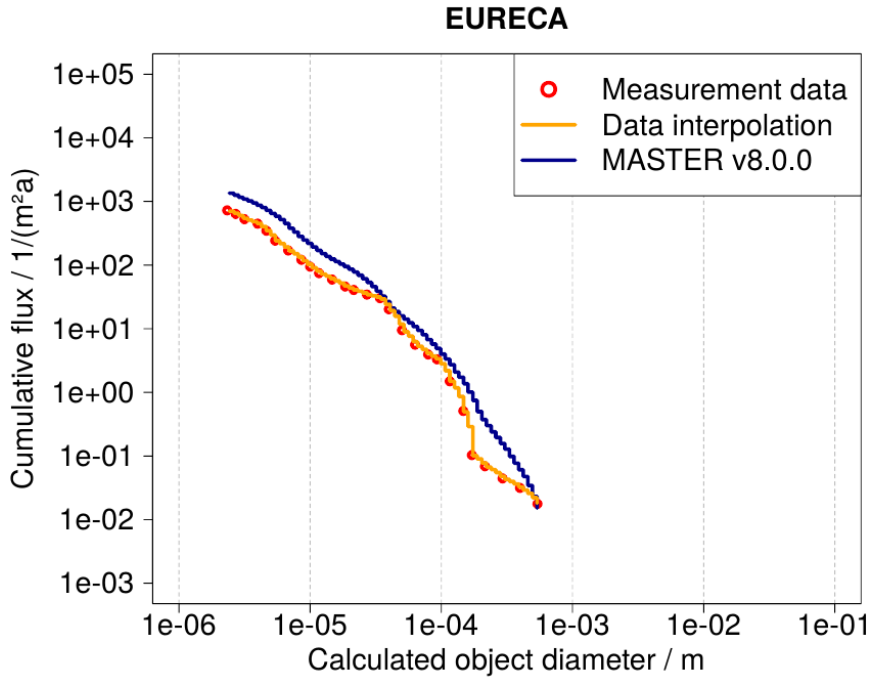


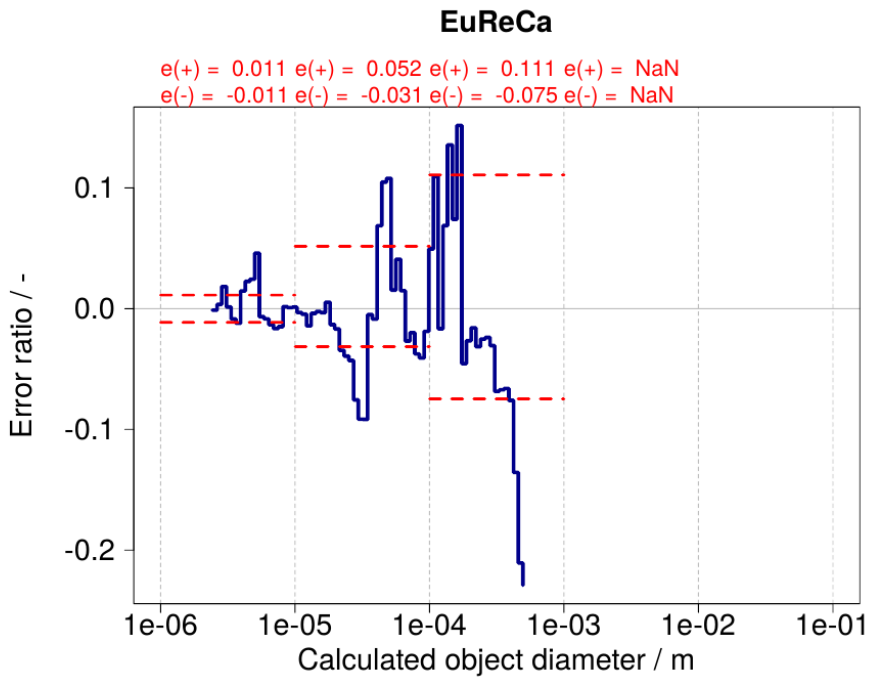


Red: Strong increase in number of tracked debris
Blue: Settlement in number of tracked debris

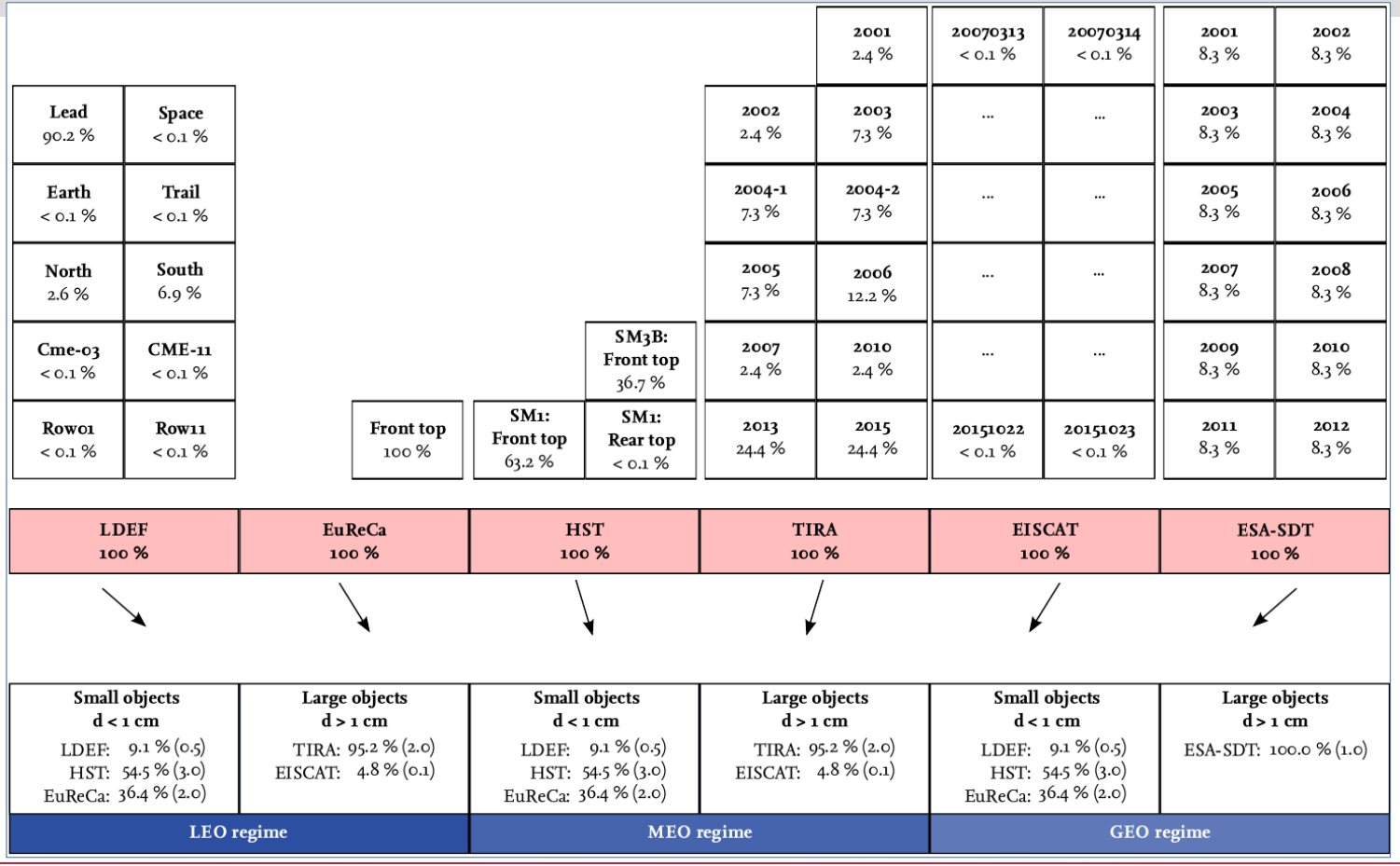
New user features

Small object uncertainties (EuReCa as an example case)

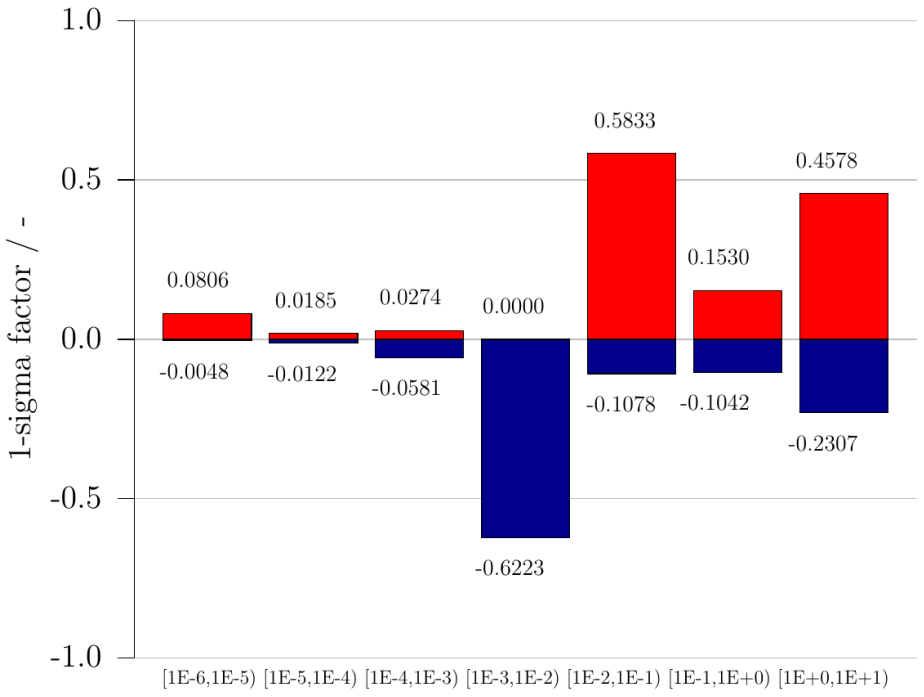




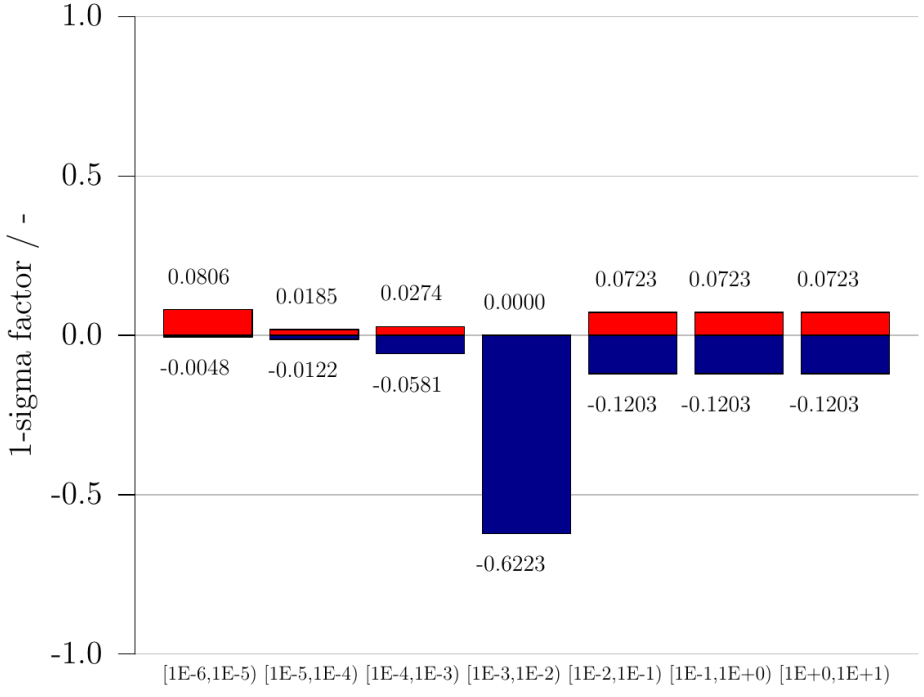
New user features



New user features



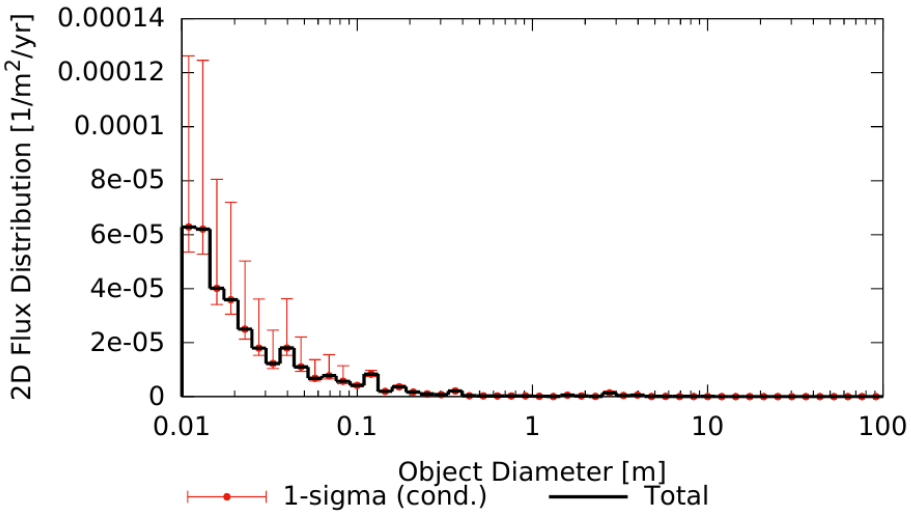
LEO/MEO uncertainties

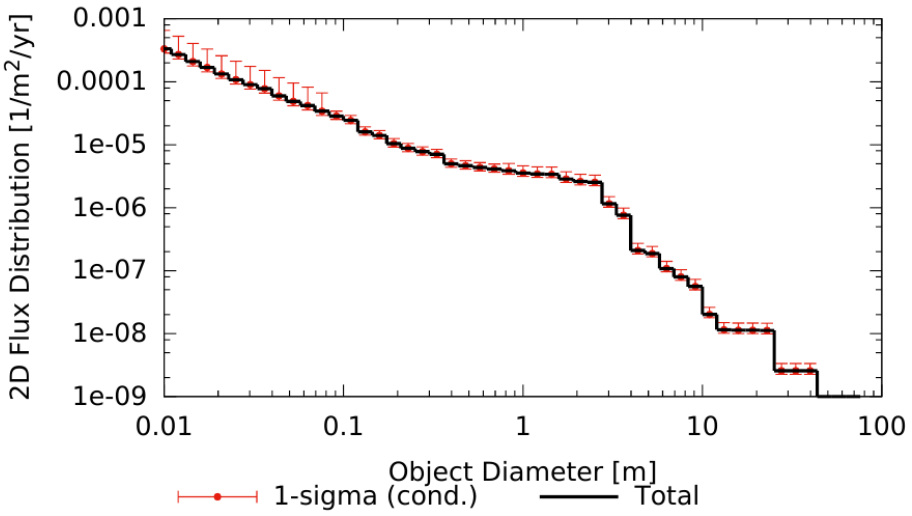


GEO uncertainties

New user features

Graphical Output

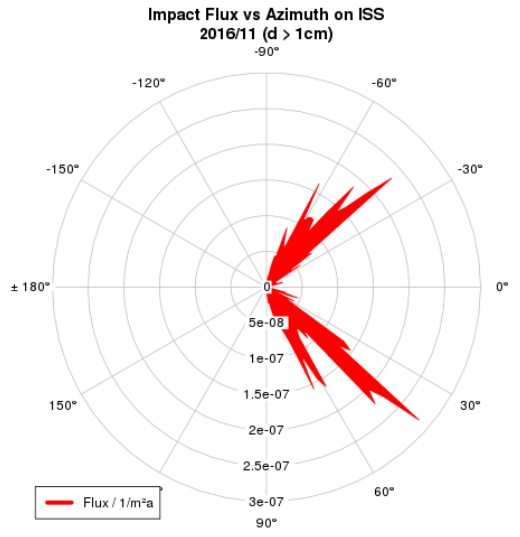




Provided spectra:

1. Spatial density vs. Altitude
2. 2D-Flux vs. Diameter
3. 2D-Flux vs. Mass

Thank you! Time for questions(?)



MASTER