Technische Universität Braunschweig

Institute of Space Systems

esa

Final Presentation
ESA-MASTER: Hands-on

Enhancement of S/C Fragmentation and Environment Evolution Models

March 21st, 2019

Presenter: André Horstmann and Sebastian Hesselbach

Things covered during this demo presentation

- Basics: General overview
- Basics: Spatial Density in LEO
- Basics: Lagrange flux calculation
- Basics: Flux evaluation (d > 1mm) on a SSO
- Basics: Comparison of collision probability for different size thresholds

- Advanced: Impact velocity/azimuth on defined oriented surface (2D + 3D)
- Advanced: Spatial density – declination vs. altitude (3D)

Basics: General overview

Basics: General Overview

ESA MASTER is available as download from:

https://sdup.esoc.esa.int/

To make the MASTER installer leaner, it contains only the reference population (November 11, 2016 for MASTER-8).
To add additional population files, download them here and unzip them into <MASTER installation directory>/data/.

Supported platforms are:

- Windows
- Linux (32bit / 64 bit)
- macOS/OSX

Basics: General Overview

ESA MASTER is available as download from:

https://sdup.esoc.esa.int/

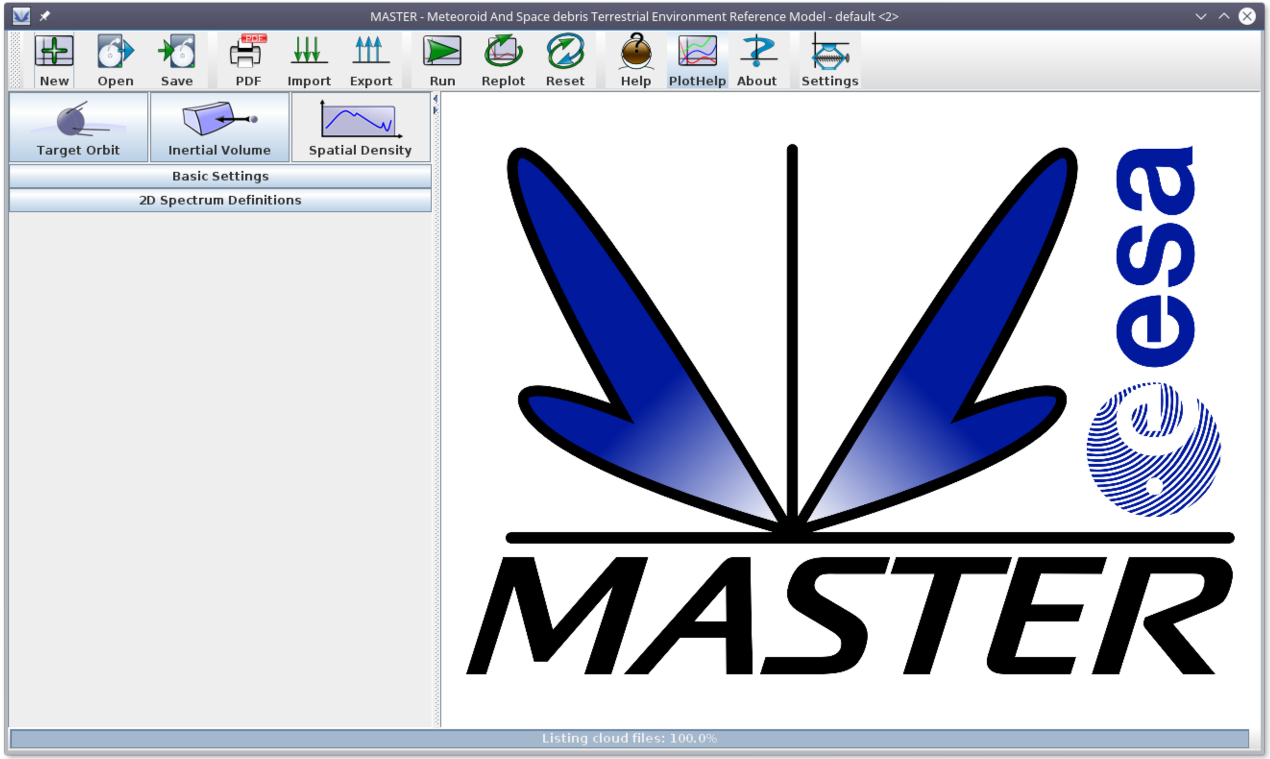
Also available:

- **Software User Manual**
- **License Agreement**

→ Launching ESA MASTER ...

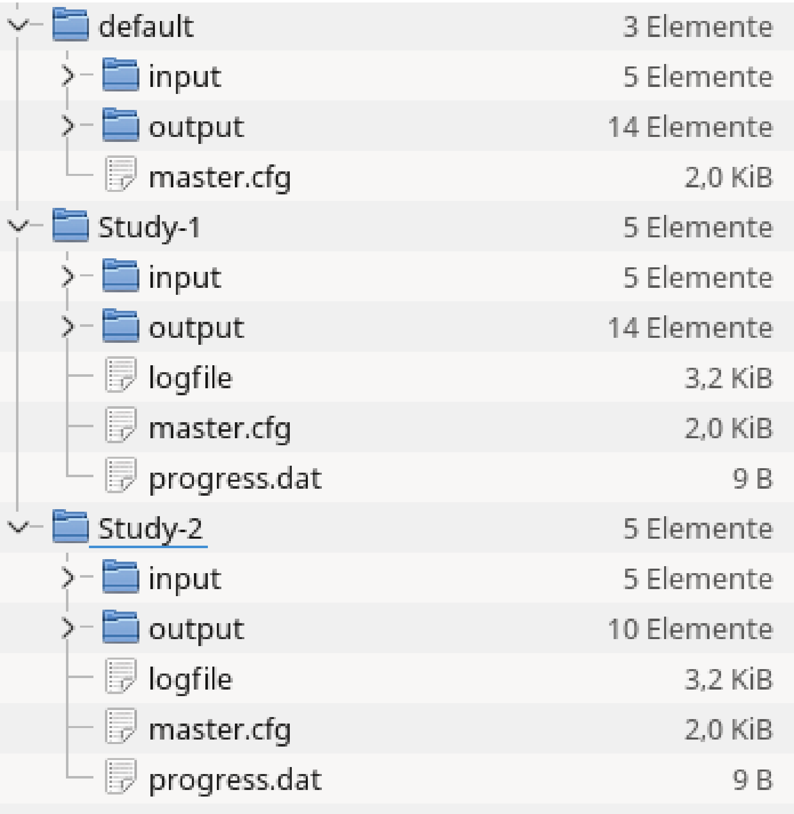
Basics: General Overview

- New MASTER Logo
- Clean user interface
- Left: User input
  - Basic Settings
  - 2D-Spectrum definitions
- Middle: Presentation of results
- Right: Output selection
- Three Scenarios



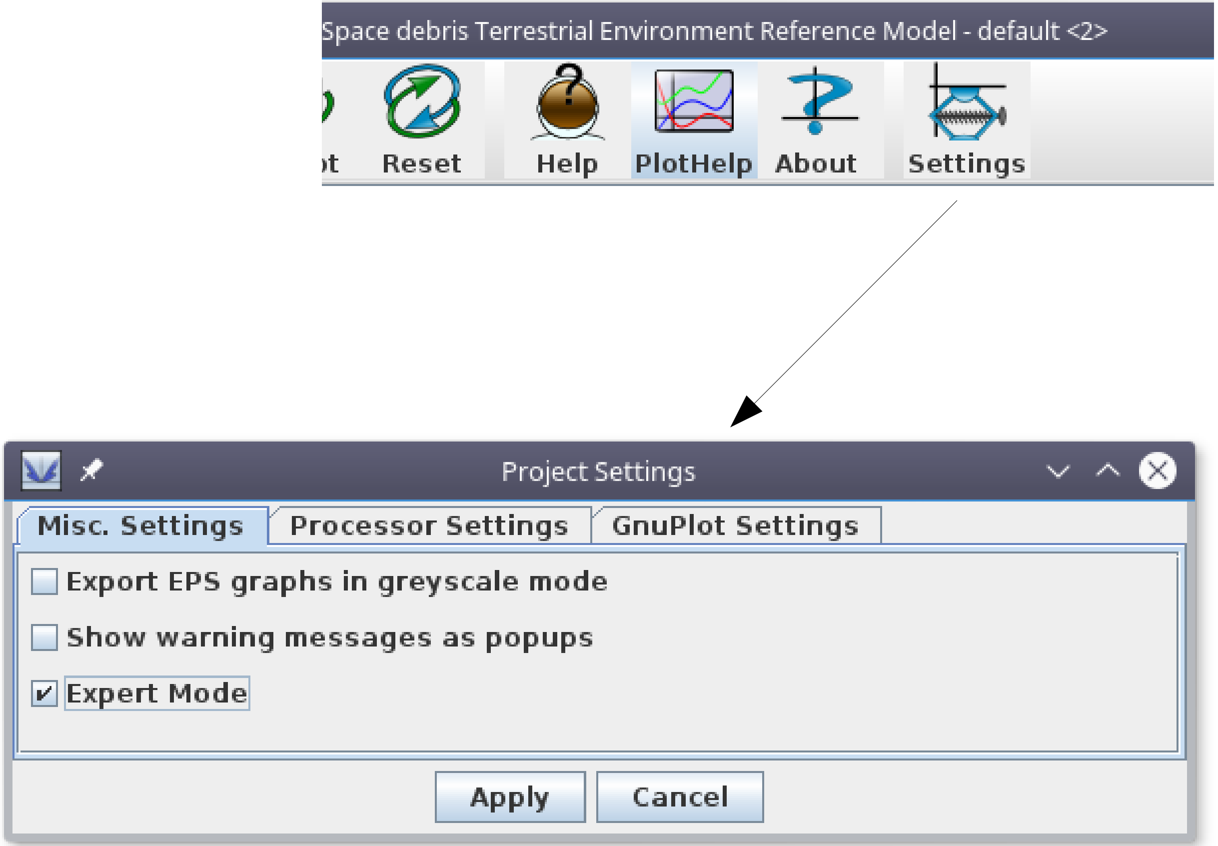
Basics: General Overview

- Handing of multiple projects
- Clean workspace environment
- Output includes raw data output



Basics: General Overview

- Handing of multiple projects
- Clean workspace environment
- Output includes raw data output
- Two different modes:
  - Basic Mode
  - Expert Mode



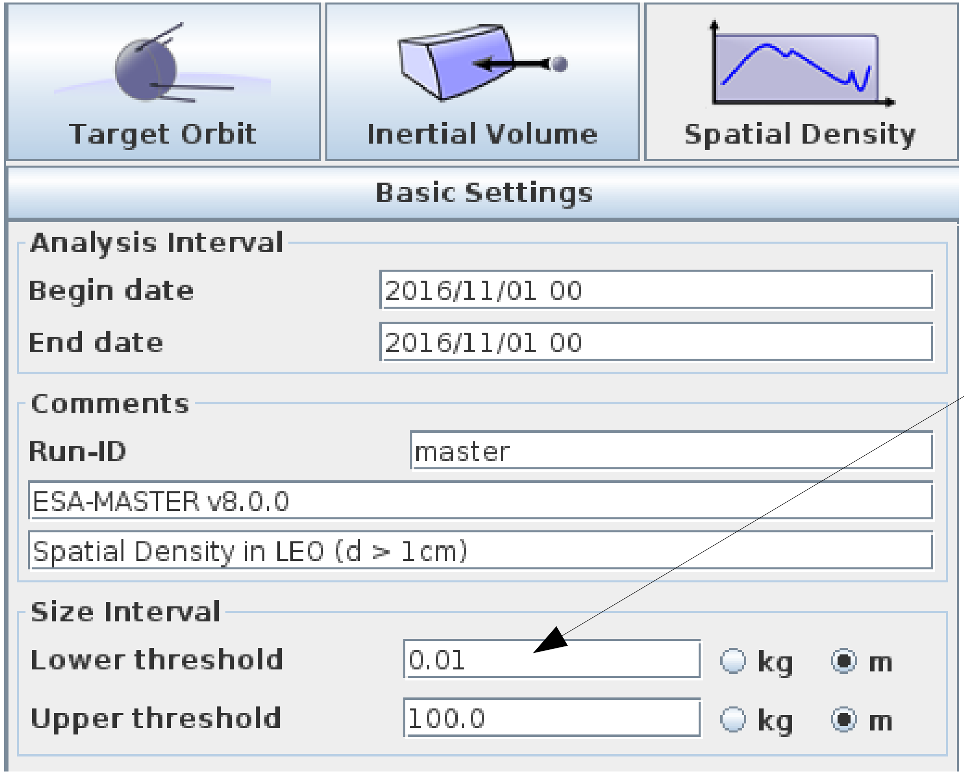
<u>Basics:</u> Spatial Density in LEO

Basics: Spatial Density in LEO

Task	Obtain a 2D Spatial Density plot for LEO (200 km – 2000 km) and objects larger then 1cm in diameter at November 1st, 2016
Steps	1) Set object size intervall in 'Basic Settings' 2) Set desired output spectrum in '2D Spectrum Definitions' 3) Click 'Run'
Result	A 2D-plot showing Spatial Density vs. Altitude in LEO at November 1st, 2016 (with and without uncertainty bars).

Basics: Spatial Density in LEO

1) Set object size intervall in 'Basic Settings'

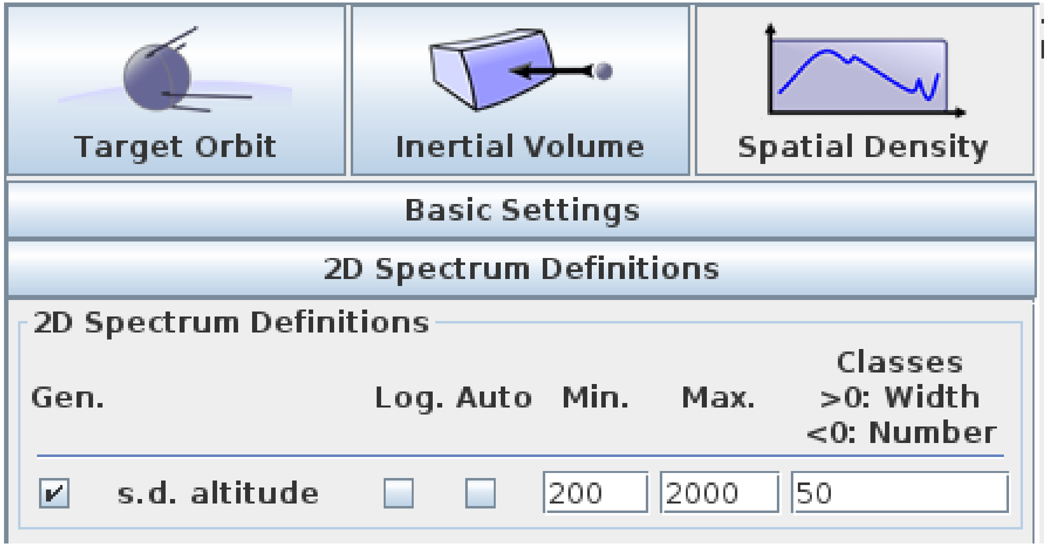


0.01 meters

Click 'Apply' to save changes!

Basics: Spatial Density in LEO

2) Set desired output spectrum in '2D Spectrum Definitions'

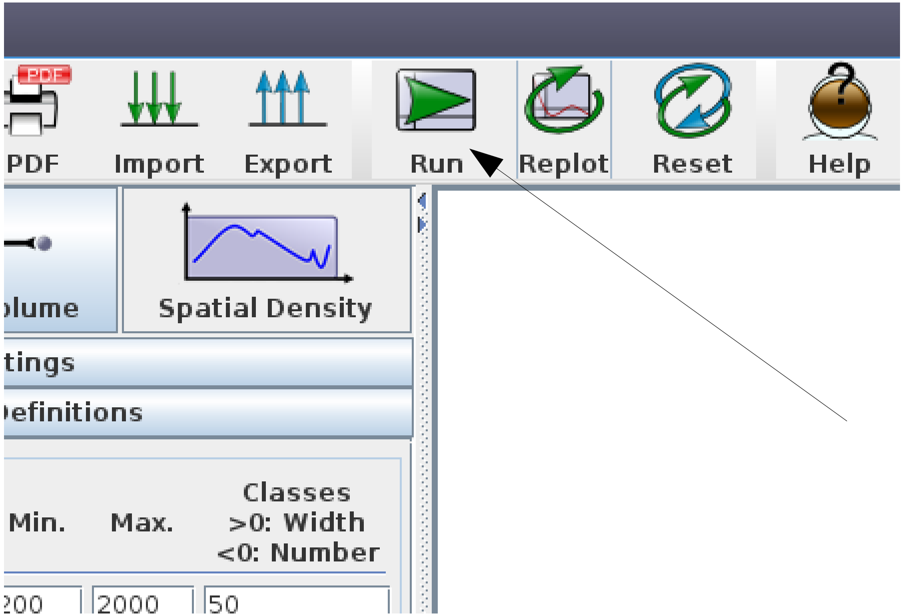


Minimum altitude: 200 km
Maximum altitude: 2000 km
Altitude stepswidth: 50 km
Linear scale

Click 'Apply' to save changes!

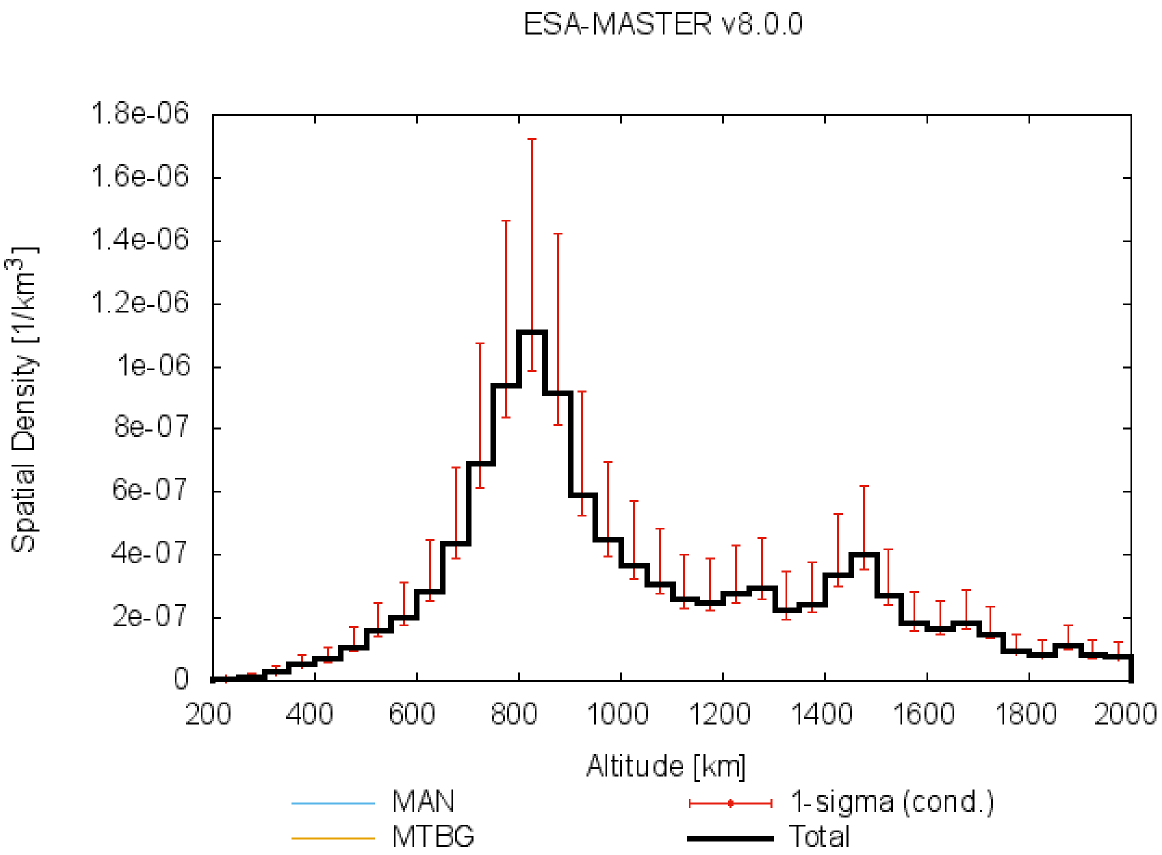
Basics: Spatial Density in LEO

3) Click 'Run'



Result:

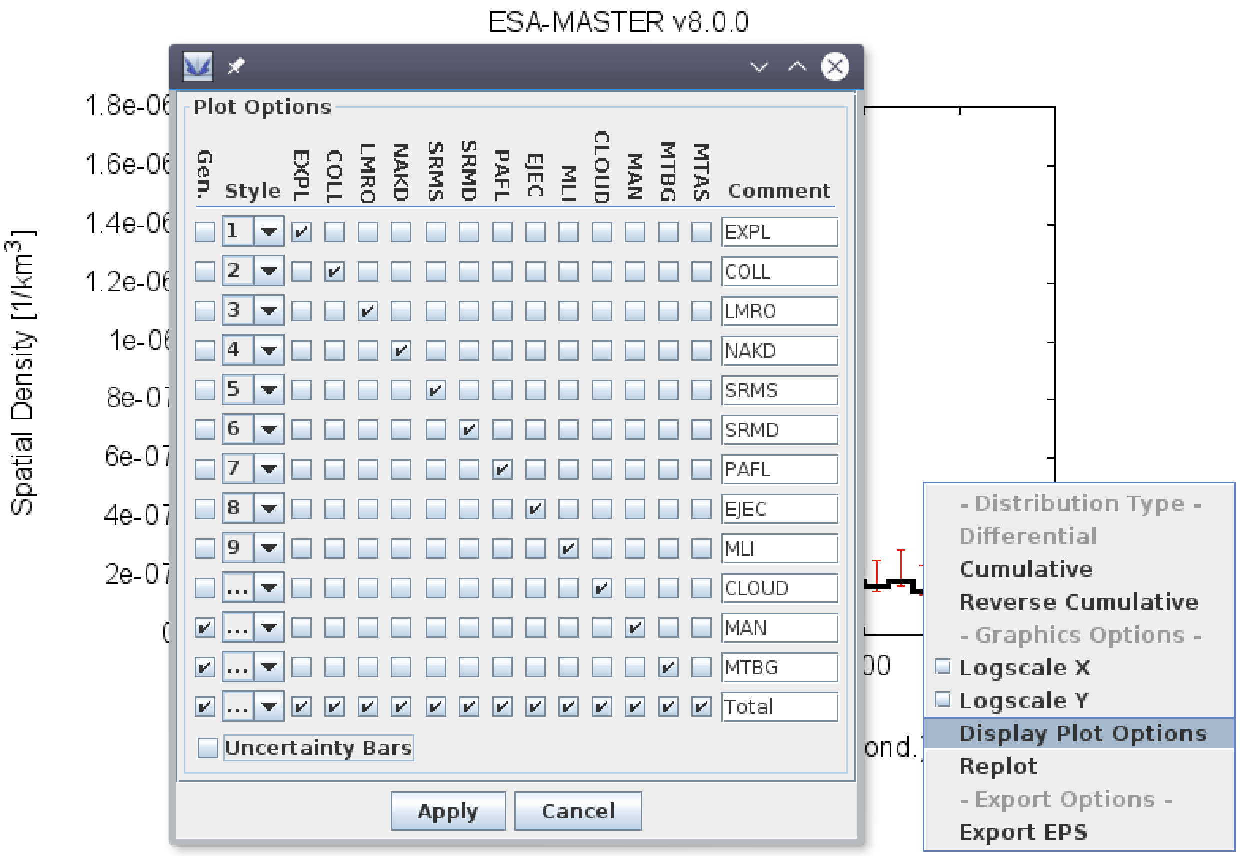
Spatial density in LEO (200 km to 2000 km) for objects with diamter d > 1cm at November 2016 (with uncertainty bars).



Basics: Spatial Density in LEO

Result:

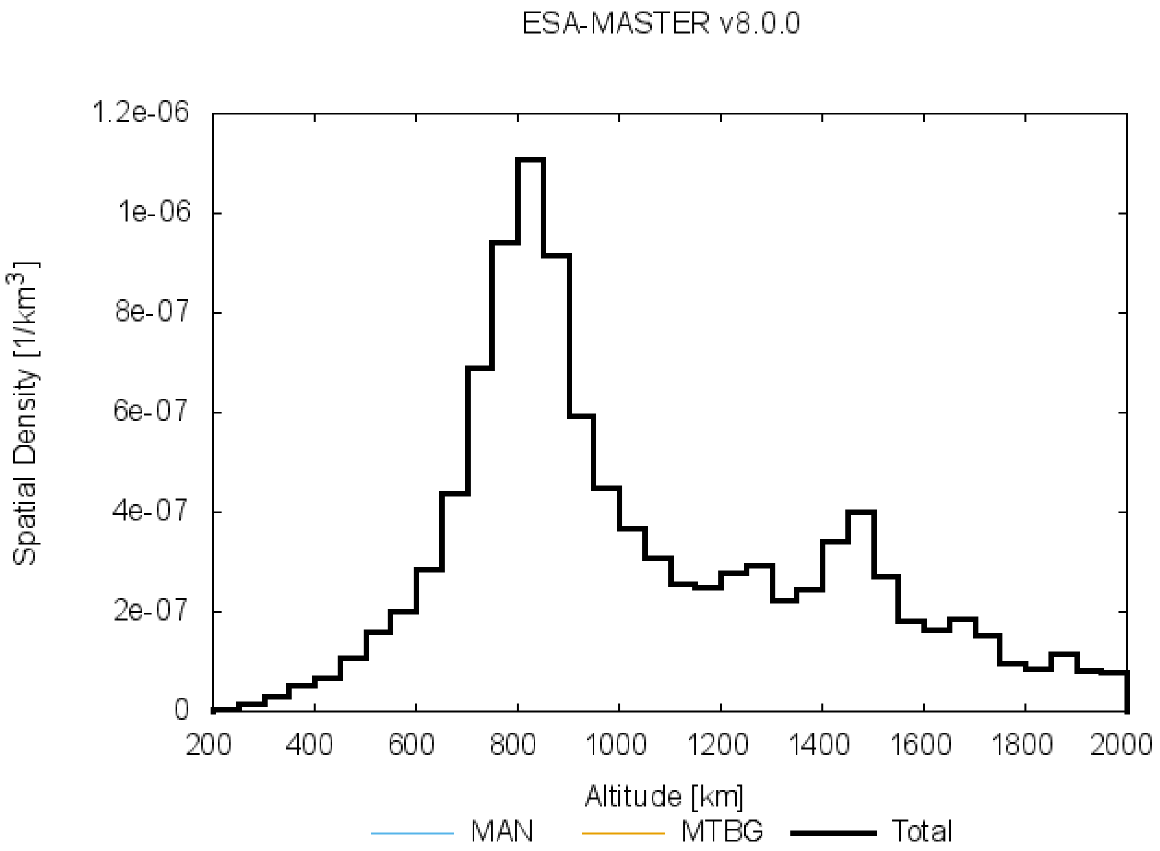
if you do not want to show the uncertainty bars →
Right-click on the plot area



Basics: Spatial Density in LEO

Result:

Spatial density in LEO (200 km to 2000 km) for objects with diamter d > 1cm at November 2016 (without uncertainty bars).

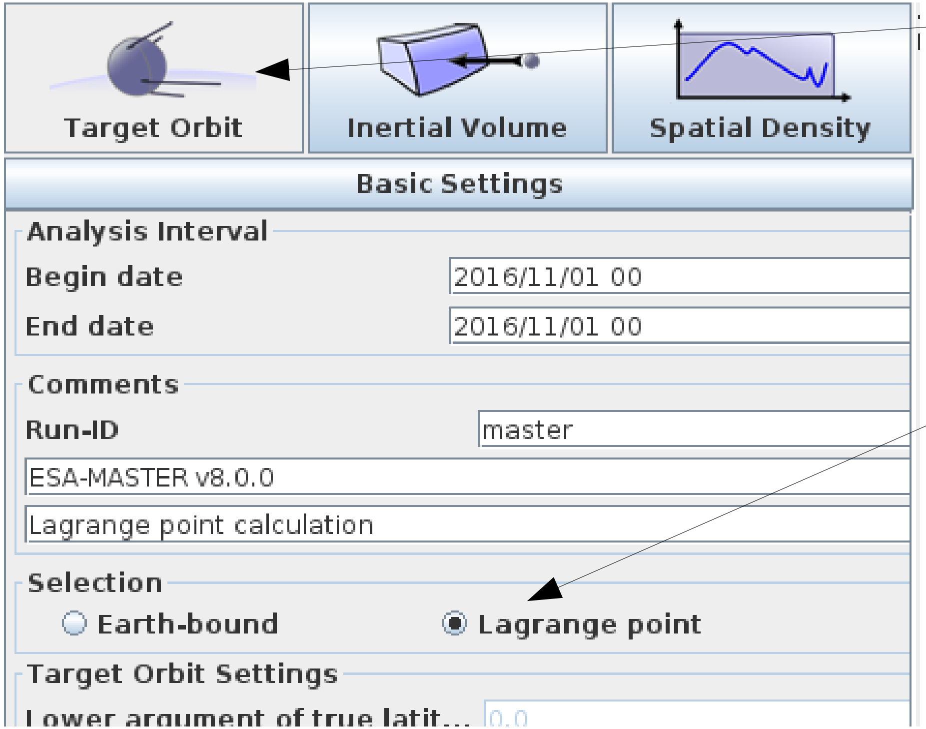


Basics: Lagrange flux calculation

Basics: Lagrange flux calculation

Task	Obtain a 2D-Flux plot for a Lagrange point and objects larger then 1µm in diameter
Steps	1) Selecting 'Target Orbit' as scenario 2) Switching from 'Earth-bound' to 'Lagrange point' 3) Set desired output spectrum in '2D Spectrum Definitions' 4) Click 'Run'
Result	A 2D-plot showing 2D-flux vs. Diameter in a Lagrange point.

Basics: Lagrange flux calculation

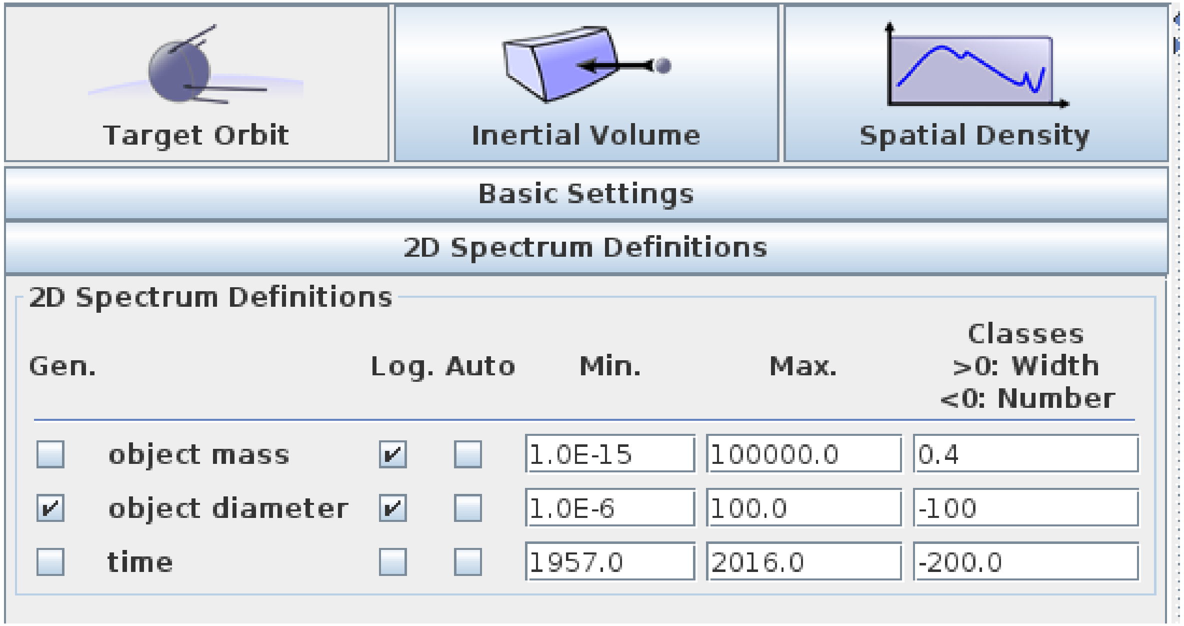


1) Switching to 'Target Orbit'

2) Selecting 'Lagrange point'

Click 'Apply' to save changes!

Basics: Lagrange flux calculation

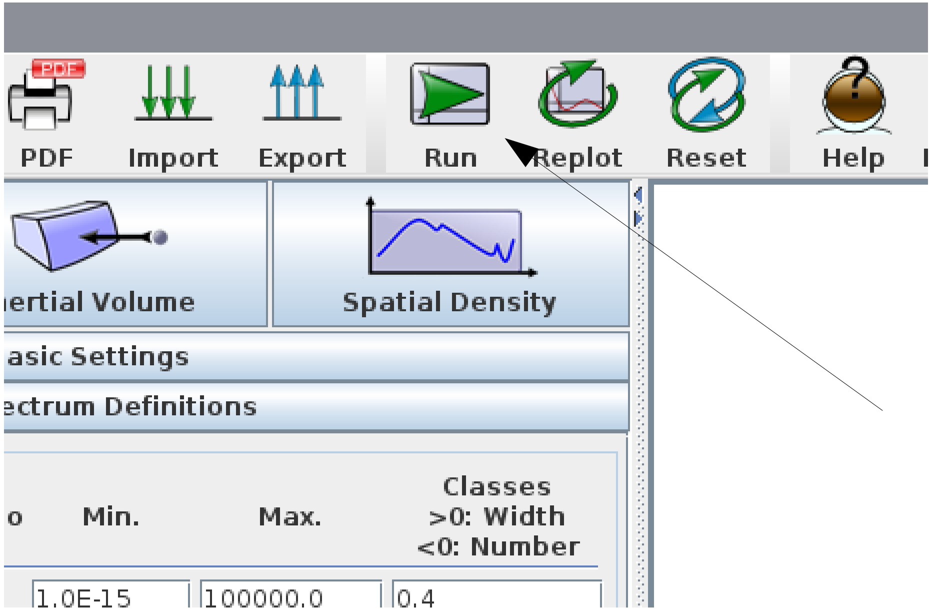


3)
Logarithmic scale
Minimum diameter: 1 µm
Maximum diameter: 100 m
Diameter steps: 100 steps!

Click 'Apply' to save changes!

Basics: Lagrange flux calculation

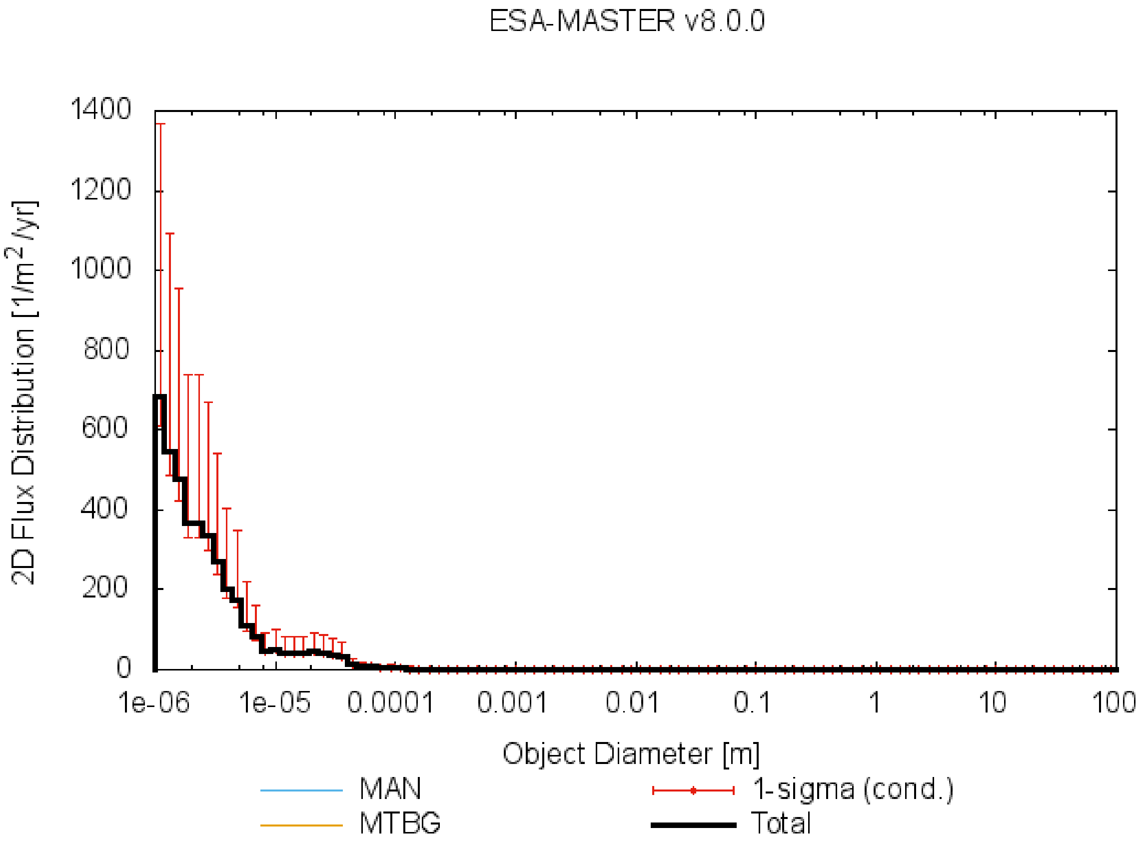
4) Click 'Run'



<u>Basics:</u> Lagrange flux calculation

Result:

2D-plot showing 2D-flux vs. Diameter in a Lagrange point.



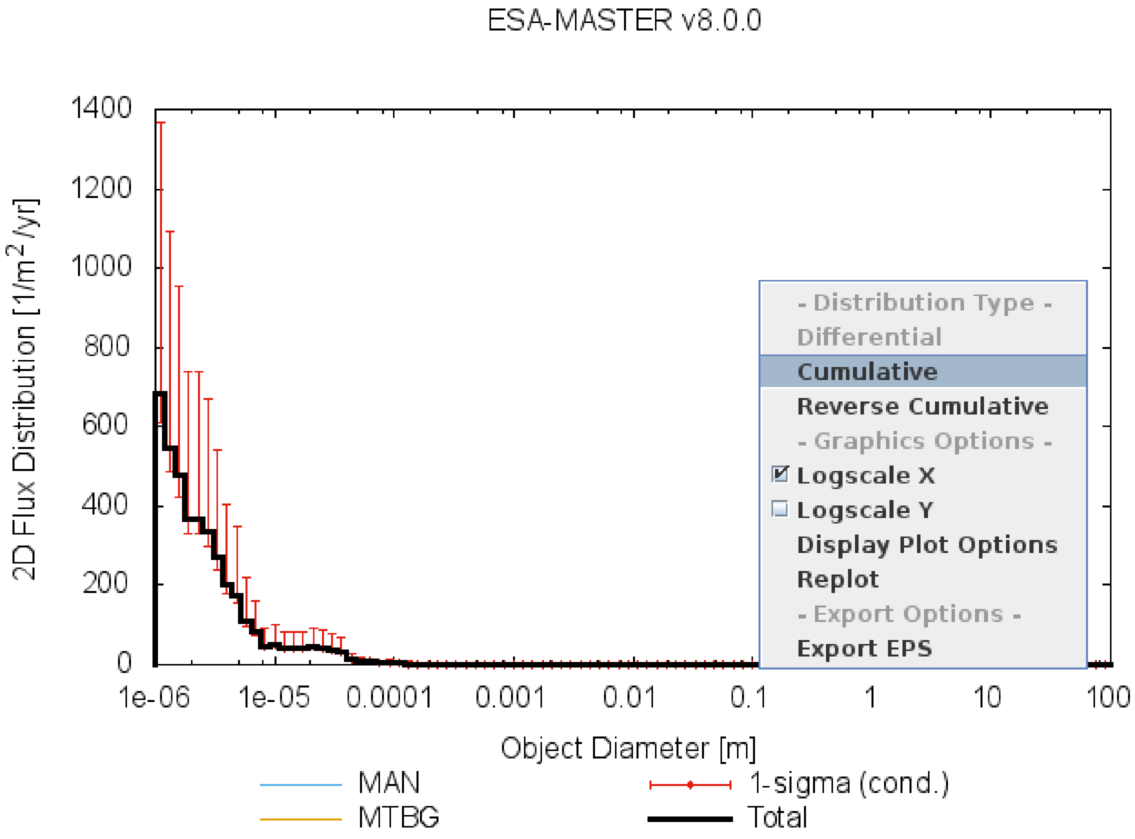
Basics: Lagrange flux calculation

Result:

2D-plot showing 2D-flux vs. Diameter in a Lagrange point.

(optional)
→ *Right-click on plot area*
→ *Select 'Cumulative'*

→ *Right-click on plot area*
→ *Select 'Logscale Y'*



<u>Basics:</u> Lagrange flux calculation

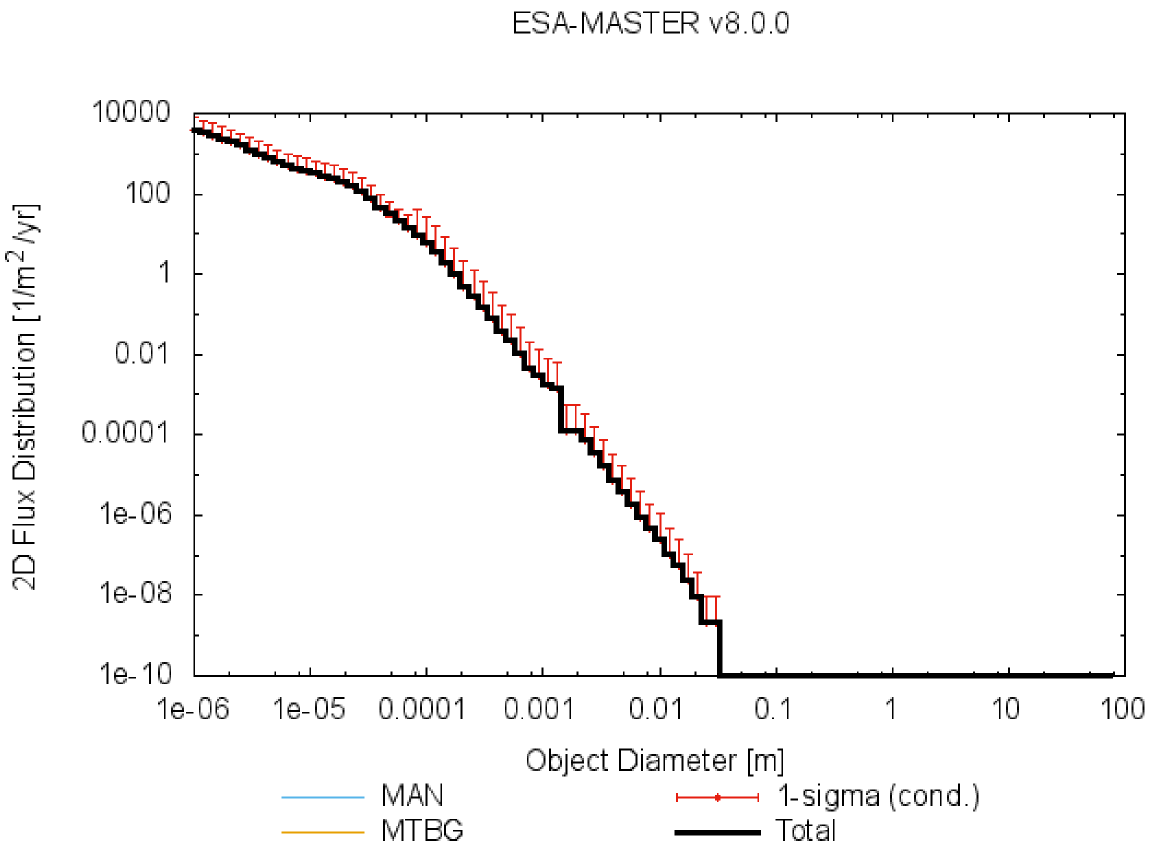
Result:

2D-plot showing 2D-flux vs. Diameter in a Lagrange point.

(optional)
→ *Right-click on plot area*
→ *Select 'Cumulative'*

→ *Right-click on plot area*
→ *Select 'Logscale Y'*

Done!



Basics: Flux evaluation (d > 1mm) on a SSO

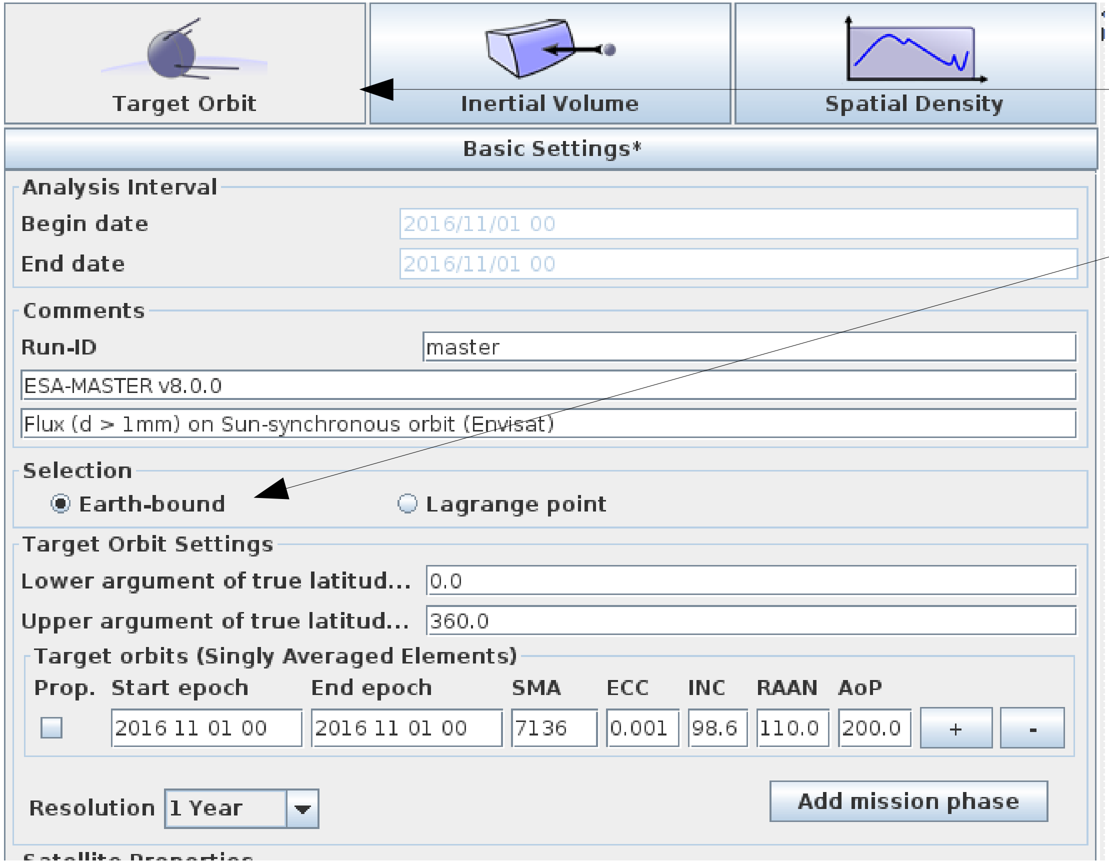
Basics: Flux evaluations (d > 1mm) on a SSO

Task	Obtain a 2D-Flux plot for a Sun-synchronous orbit and objects larger then 1mm in diameter in November 2016.
Steps	1) 'Target Orbit' scenario already selected 2) Switching from 'Lagrange point' to 'Earth-bound' in Basic Settings 3) Define a SSO of your choice, e.g. **Envisat** Orbit • Semi-major axis: 7136 km • Eccentricity: 0.001 • Inclination: 98.6° • RAAN: 110.0° • AoP: 200.0° 4) Set desired output spectrum in '2D Spectrum Definitions' 5) Click 'Run'
Result	A 2D-plot showing 2D-flux vs. Diameter on a SSO, here: on an Envisat orbit.

<u>Basics:</u> Flux evaluations (d > 1mm) on a SSO

- **Envi**ronment **Sat**ellite
- Launched in 2002
- 8110 kg (incl. 319 kg hydrazine)
- Average crossection: 75 m²
- Un-controlled state
- Current altitude: 765 km
- 150 years remaining lifetime (aerodynamic decay)
- Top priority target for active debris removal missions

Basics: Flux evaluations (d > 1mm) on a SSO

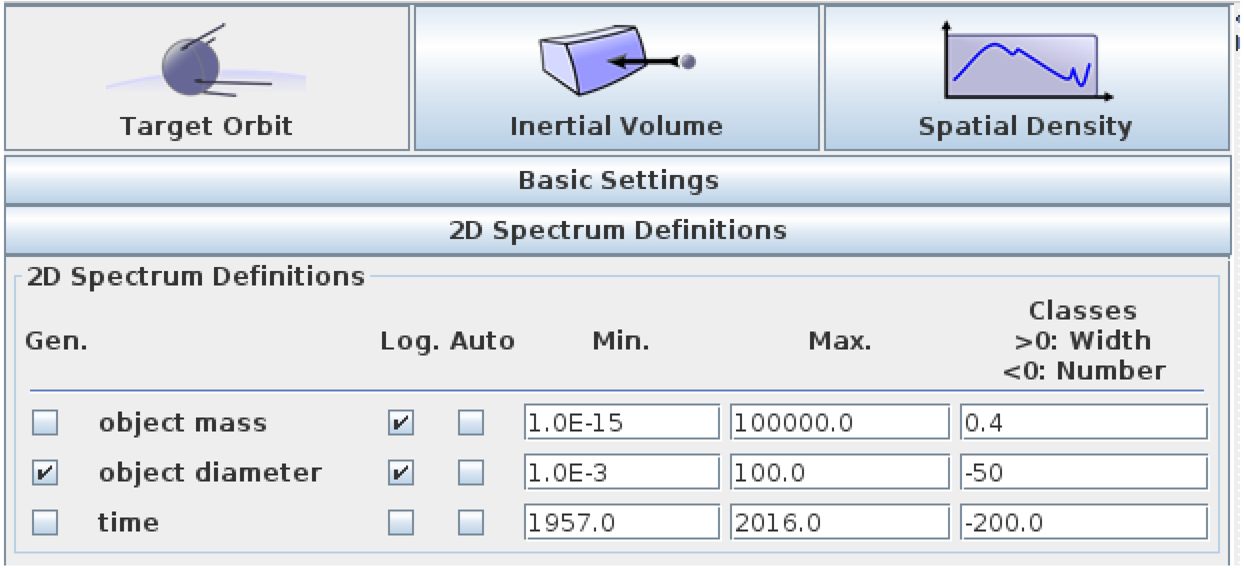


1) 'Target Orbit' selected

2) Switching back to 'Earth-bound'

3)
SMA / km: 7136
ECC / -: 0.001
INC / °: 98.6
RAAN / °: not used
AoP / °: 200

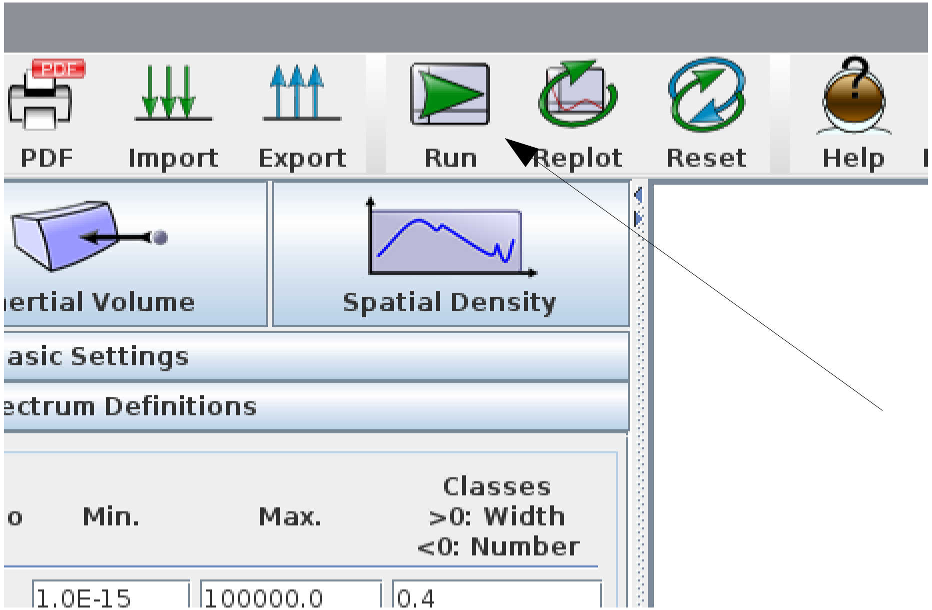
Basics: Flux evaluations (d > 1mm) on a SSO



4)
Minimum diameter: 1 mm
Maximum diameter: 100 m
Diameter steps: 50 steps!
Logarithmic scale

Basics: Flux evaluations (d > 1mm) on a SSO

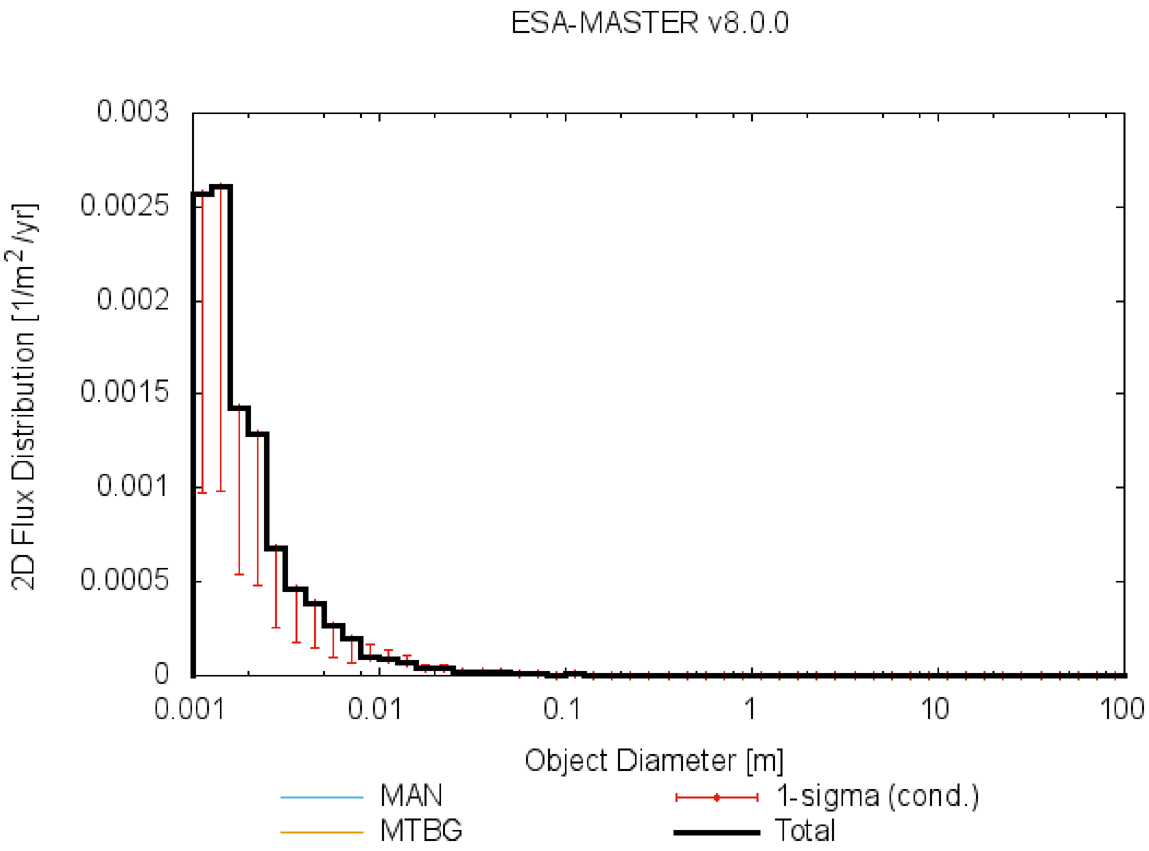
5) Click 'Run'



Basics: Flux evaluations (d > 1mm) on a SSO

Result:

2D-plot showing 2D-flux vs. Diameter on a SSO orbit in November 2016. In this example on an Envisat orbit.



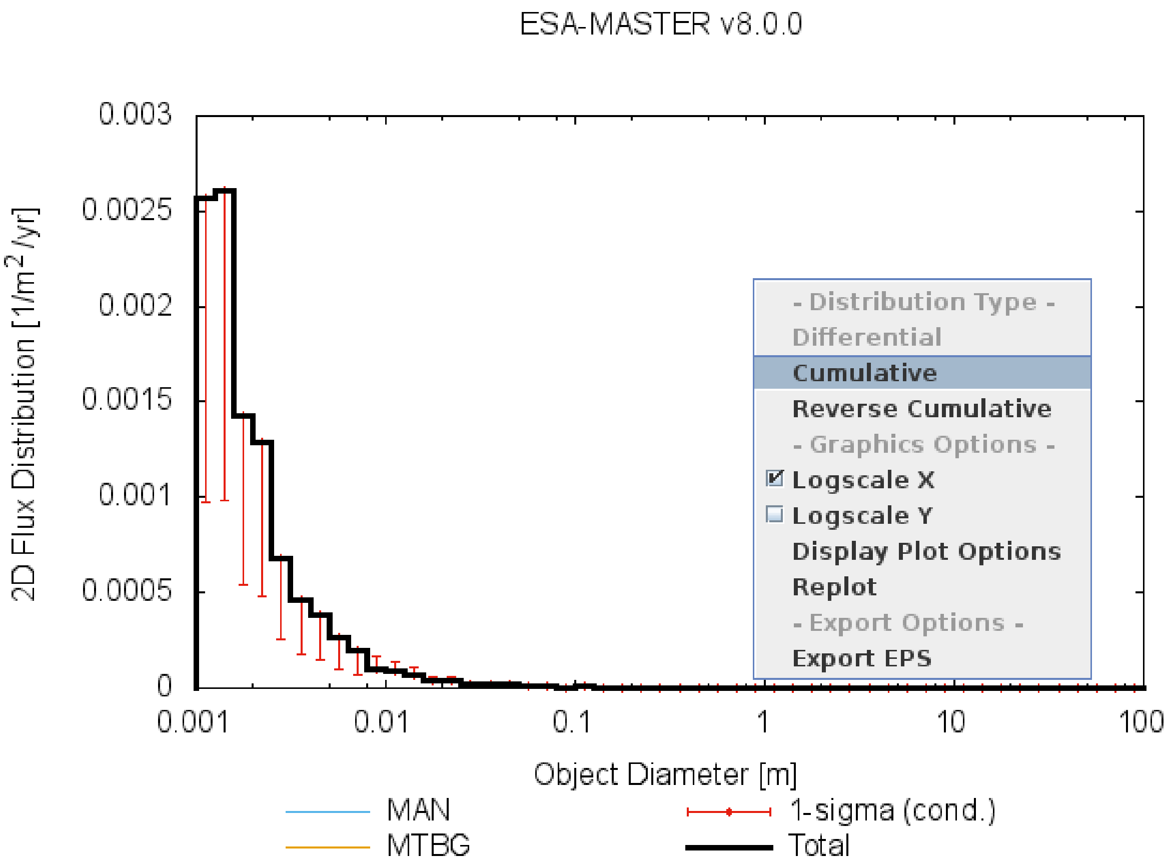
Basics: Flux evaluations (d > 1mm) on a SSO

Result:

2D-plot showing 2D-flux vs. Diameter on a SSO orbit in November 2016. In this example on an Envisat orbit.

(optional)
→ *Right-click on plot area*
→ *Select 'Cumulative'*

→ *Right-click on plot area*
→ *Select 'Logscale Y'*



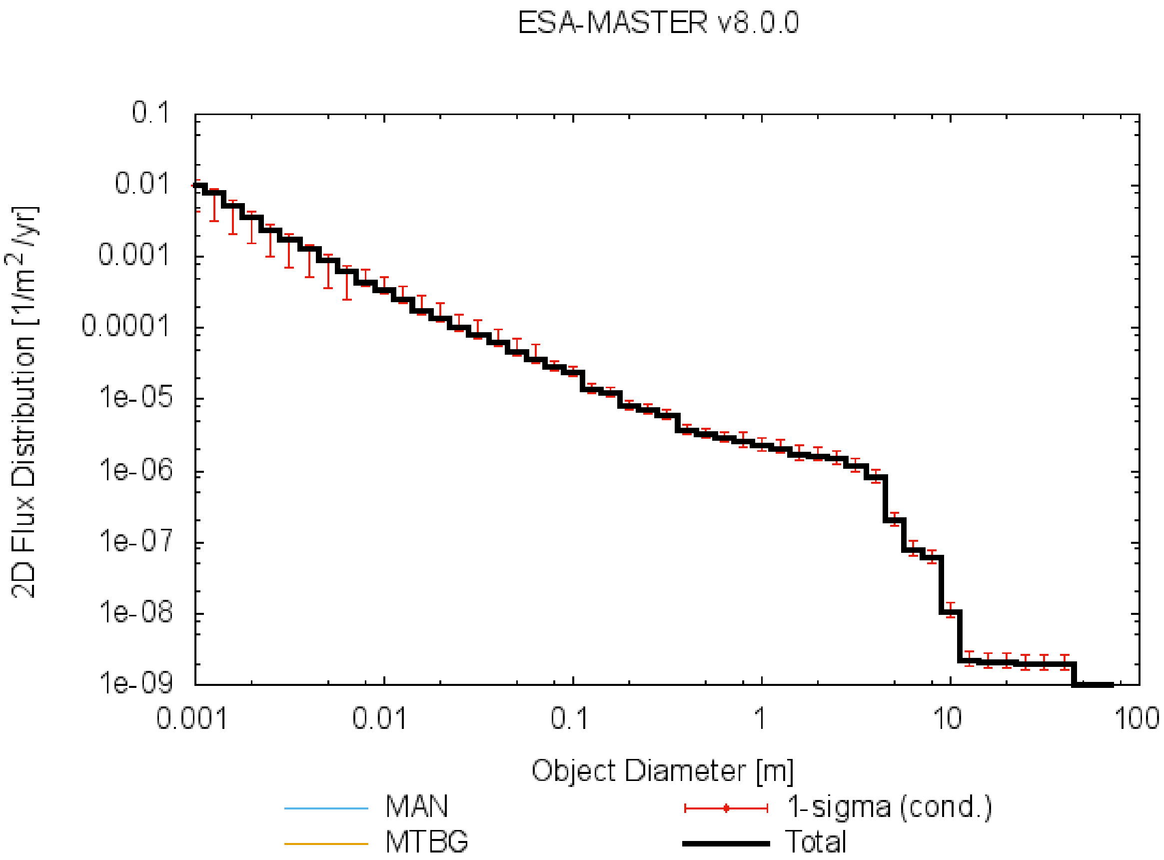
Result:

2D-plot showing 2D-flux vs. Diameter on a SSO orbit in November 2016. In this example on an Envisat orbit.

(optional)
→ *Right-click on plot area*
→ *Select 'Cumulative'*

→ *Right-click on plot area*
→ *Select 'Logscale Y'*

Done!



Basics: Using MASTER to calculate flux-based collision probablility

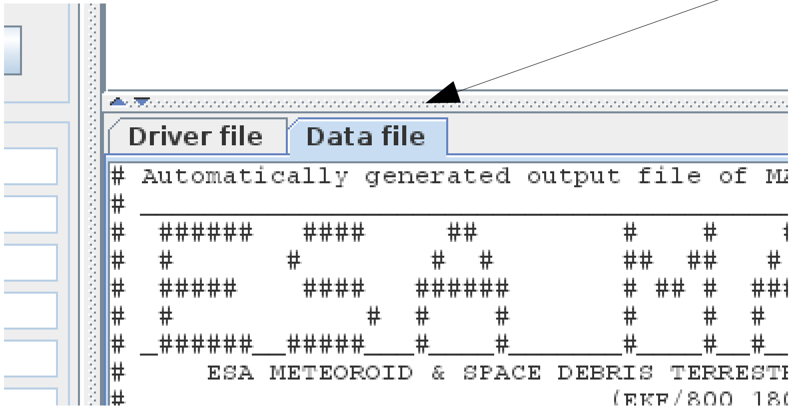
<u>Basics:</u> Using MASTER to calculate flux-based collision probability

Task	Calculate the flux-based collision probability for different size thresholds on Envisat using the MASTER output of 2D-flux.
Steps	1) Make sure to use cumulative spectrum (flux values for d > d*) 2) Access the MASTER output datafile 3) Isolating flux values for selected diameter thresholds d*, e.g. for 1mm, 5mm, 1cm, 5cm and 10cm. 4) Lookup required satellite properties 5) Making assumption that flux was constant over the mission duration**(!)** 6) Use flux-based collision probability formula to calculate collision probability
Result	Collision probabilities for Envisat covering different threshold diameters

Basics: Using MASTER to calculate flux-based collision probability

1) Cumulatve spectrum still selected

2) Select 'Data file' to access the MASTER output



Basics: Using MASTER to calculate flux-based collision probability

Driver file | Data file

```
#
#   Title:              2D flux distribution vs. Object Diameter
#
#----------------------------------------------------------------------------------------------------------------
#   Scale:              logarithmic
#   x Data:             Object Diameter  [m]
#   y Data:             Object Flux [1/m^2/yr]
#   Discretisation:      50 classes from  0.10000E-02 m to  0.10000E+03 m,  0.10000E+00 logarithmic class width
#----------------------------------------------------------------------------------------------------------------
#  Diameter      Expl-Fragm Coll-Fragm Launch/Mis NaK-Drops   SRM-Slag   SRM-Dust  Paint Flks   Ejecta      MLI
#_____[m]________[1/m^2/yr]_[1/m^2/yr]_[1/m^2/yr]_[1/m^2/yr]_[1/m^2/yr]_[1/m^2/yr]_[1/m^2/yr]_[1/m^2/yr]_[1/m^2/yr]
    0.001000          0          0          0          0          0          0          0          0          0
    0.001259          0          0          0          0          0          0          0          0          0
    0.001585          0          0          0          0          0          0          0          0          0
    0.001995          0          0          0          0          0          0          0          0          0
    0.002512          0          0          0          0          0          0          0          0          0
    0.003162          0          0          0          0          0          0          0          0          0
    0.003981          0          0          0          0          0          0          0          0          0
    0.005012          0          0          0          0          0          0          0          0          0
    0.006310          0          0          0          0          0          0          0          0          0
    0.007943          0          0          0          0          0          0          0          0          0
    0.010000          0          0          0          0          0          0          0          0          0
    0.012589          0          0          0          0          0          0          0          0          0
    0.015849          0          0          0          0          0          0          0          0          0
```

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.
.

1) Cumulatve spectrum still selected

3) Isolating lines for desired diameter thresholds

Basics: Using MASTER to calculate flux-based collision probability

Driver file | Data file

```
#
#   Title:             2D flux distribution vs. Object Diameter
#
#------------------------------------------------------------------
#   Scale:             logarithmic
#   x Data:            Object Diameter  [m]
#   y Data:            Object Flux [1/m^2/yr]
#   Discretisation:     50 classes from  0.10000E-02 m to   0.10000
#------------------------------------------------------------------
```

Diameter [m]	Expl-Fragm [1/m^2/yr]	Coll-Fragm [1/m^2/yr]	Launch/Mis [1/m^2/yr]	NaK-Drops [1/m^2/yr]	SRM- [1/m^	Cloud 5 [1/m^2/yr]	Man-made [1/m^2/yr]	Meteoroids [1/m^2/yr]	Streams [1/m^2/yr]	Total [1/m^2/yr]
0.001000	0	0	0	0		0	0.1031E-01	0	0	0.1031E-01
0.001259	0	0	0	0		0	0.7742E-02	0	0	0.7742E-02
0.001585	0	0	0	0		0	0.5134E-02	0	0	0.5134E-02
0.001995	0	0	0	0		0	0.3707E-02	0	0	0.3707E-02
0.002512	0	0	0	0		0	0.2419E-02	0	0	0.2419E-02
0.003162	0	0	0	0		0	0.1743E-02	0	0	0.1743E-02
0.003981	0	0	0	0		0	0.1277E-02	0	0	0.1277E-02
0.005012	0	0	0	0		0	0.8943E-03	0	0	0.8943E-03
0.006310	0	0	0	0		0	0.6280E-03	0	0	0.6280E-03
0.007943	0	0	0	0		0	0.4360E-03	0	0	0.4360E-03
0.010000	0	0	0	0		0	0.3330E-03	0	0	0.3330E-03
0.012589	0	0	0	0		0	0.2485E-03	0	0	0.2485E-03
0.015849	0	0	0	0		0	0.1801E-03	0	0	0.1801E-03

3) Isolating lines for desired diameter thresholds

Basics: Using MASTER to calculate flux-based collision probability

Flux-based collision probability

$$P(d>d^*) = 1 - \exp(- F(d>d^*) * A * \Delta t)$$

- $P(d>d^*)$ → Collision probability
- $F(d>d^*)$ → MASTER flux Output (cumulative)
- A → Mean area of Envisat
- Δt → Applicable mission duration

4) Satellite properties:
$A = 75\ m^2$
$\Delta t = 14$ years (2002 - 2016)

Basics: Using MASTER to calculate flux-based collision probability

$$P(d>d^*) = 1 - \exp(-F(d>d^*) * A * \Delta t)$$

Diameter d*	Cum. Flux	Mean area	Mission duration	Coll. Prob.
1 mm	$0.1031 * 10^{-1}$ 1/(m²a)	75 m²	14 a	99.99 %
5 mm	$0.8943 * 10^{-3}$ 1/(m²a)			60.89 %
1 cm	$0.3330 * 10^{-3}$ 1/(m²a)			29.50 %
5 cm	$0.4693 * 10^{-4}$ 1/(m²a)			4.80 %
10 cm	$0.2392 * 10^{-4}$ 1/(m²a)			2.48 %

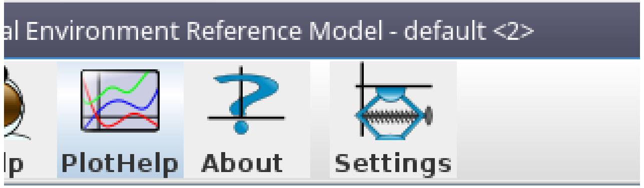
Advanced: Impact velocity/azimuth on defined oriented surface

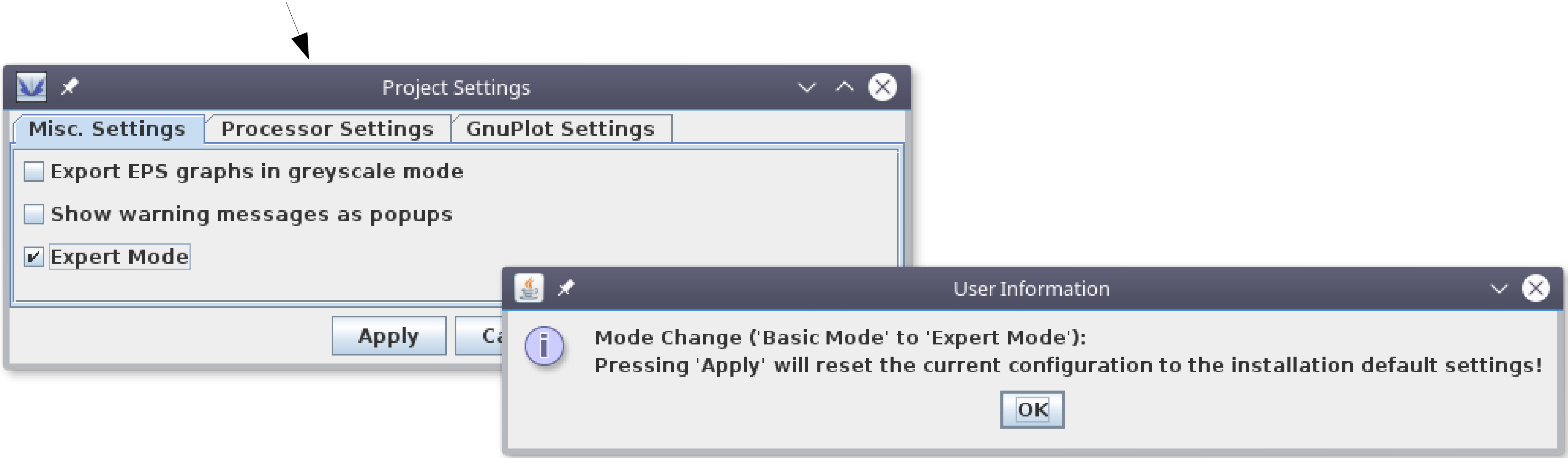
Advanced: Impact velocity/azimuth on defined oriented surface

Task	Calculate the 2D-flux (d > 1cm) dependent on impact velocity and impact azimuth on a oriented surface in LEO, facing the leading direction (in direction of motion).
Steps	1) Enabling 'Expert Mode' 2) Switch to 'Target Orbit' Mode 3) Define target orbit, e.g. **ISS** Orbit 4) Set diameter size interval to larger then 1cm 5) Define oriented surface 6) Set desired output spectrum in '2D Spectrum Definitions' and '3D Spectrum Definitions' 7) Click 'Run'
Result	Three plots showing (1) 2D-flux vs. impact velocity (2) 2D-flux vs. impact azimuth and (3) 3D-flux vs. impact velocity vs. impact azimuth

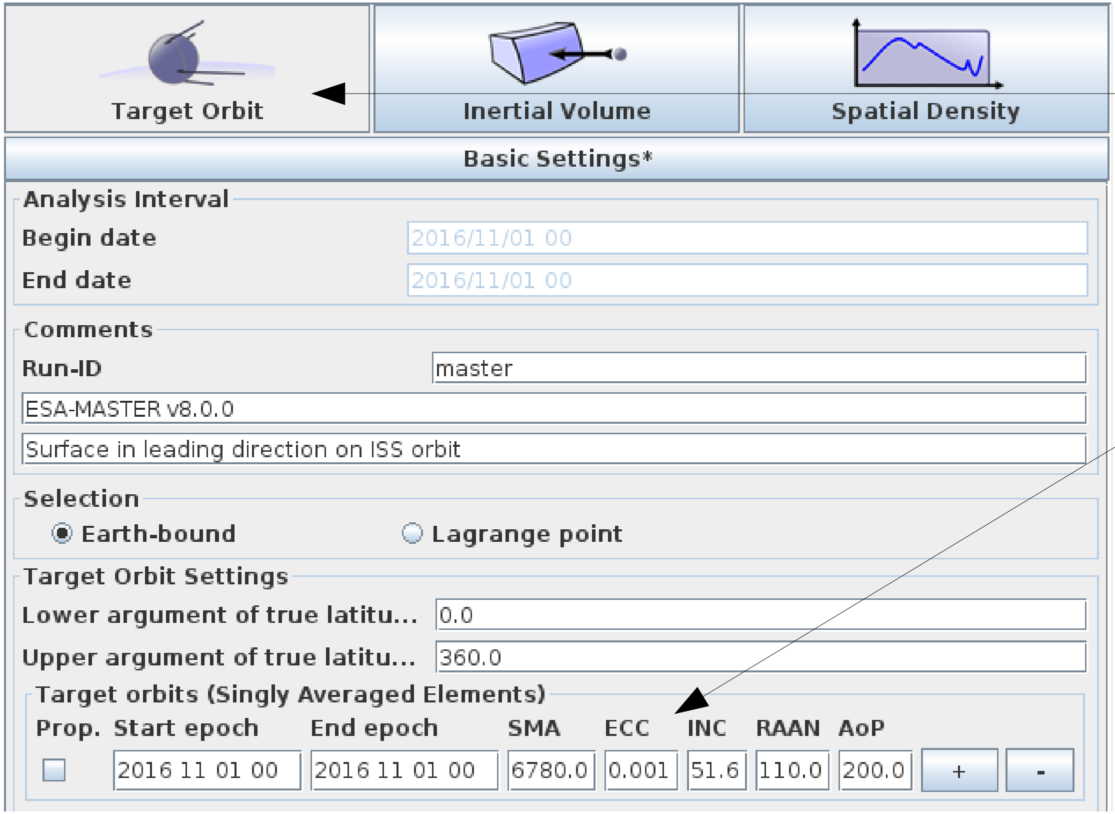
Advanced: Impact velocity/azimuth on defined oriented surface

1) Enabling 'Expert Mode'





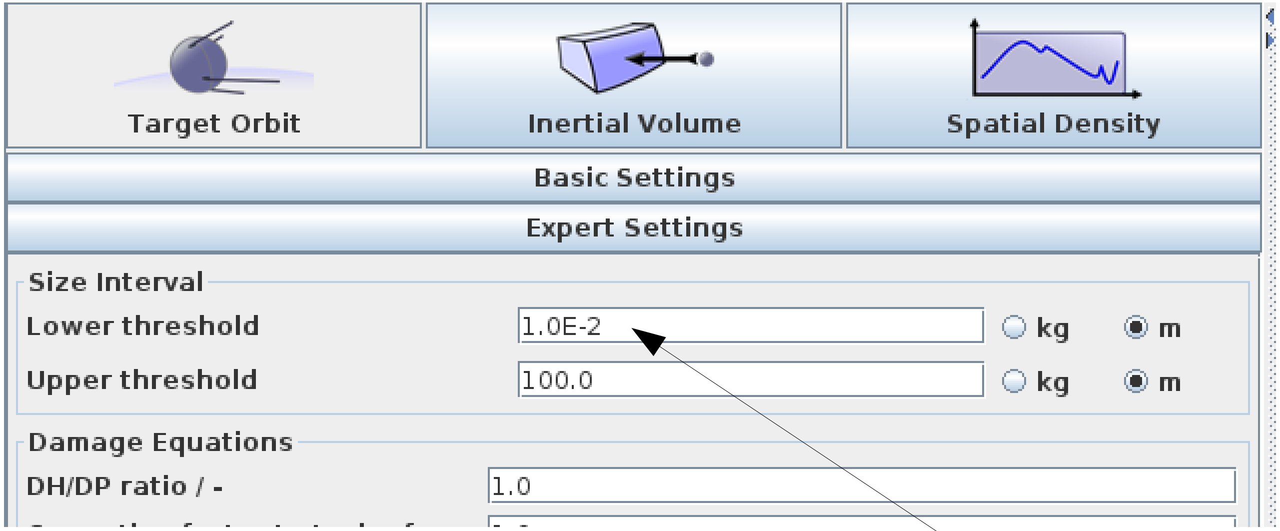
Advanced: Impact velocity/azimuth on defined oriented surface



2) Switch to 'Target Orbit Mode'

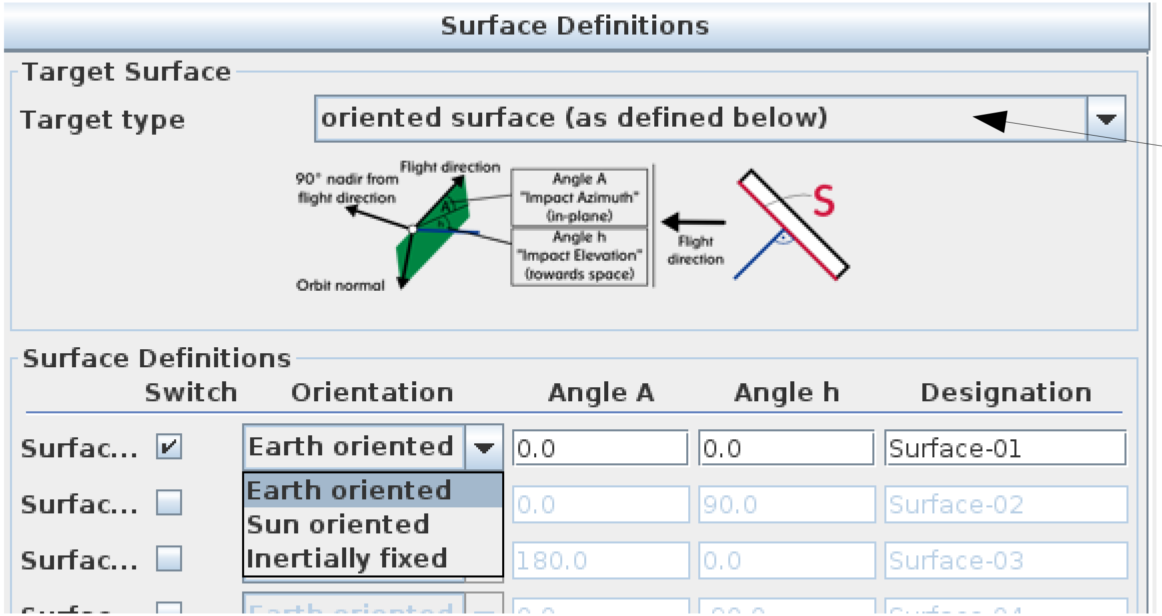
3) Define **ISS** Orbit:
SMA / km: 6780
ECC / -: 0.001
INC / °: 51.6
RAAN / °: not used
AoP / °: 200

Advanced: Impact velocity/azimuth on defined oriented surface



4) Set simulation minumum to 1cm

Advanced: Impact velocity/azimuth on defined oriented surface



5) Define oriented surface

Select 'oriented surface'

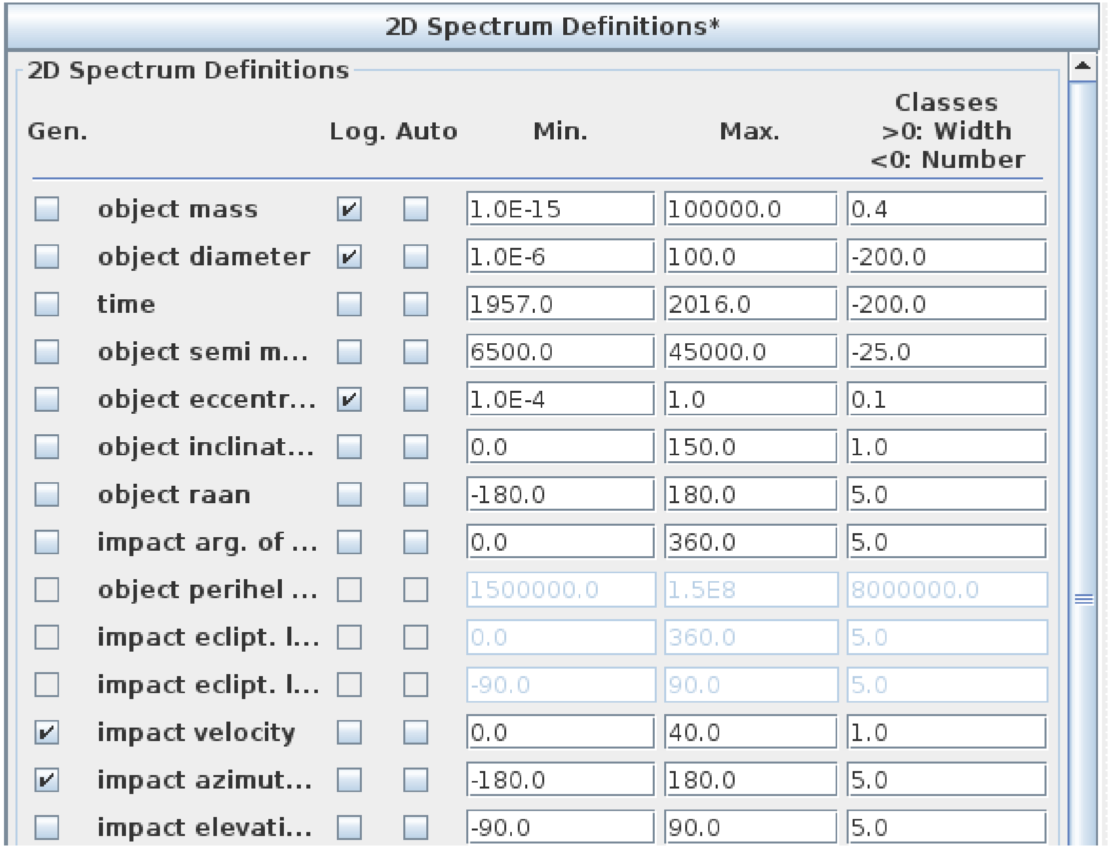
Check only a single surface

Orientation 'Earth oriented'

Orientation angles:
Azimuth: 0°
Elevation: 0°

→ in direction of motion

Advanced: Impact velocity/azimuth on defined oriented surface



2D Spectrum Definitions*

2D Spectrum Definitions

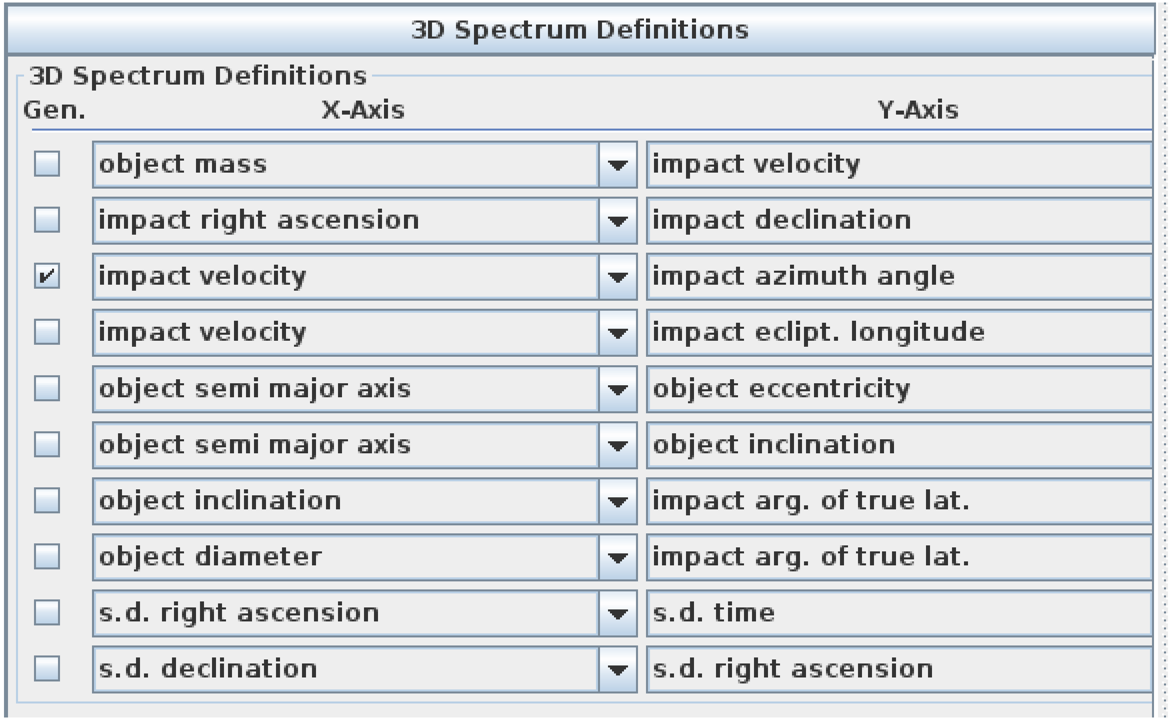
Gen.		Log.	Auto	Min.	Max.	Classes >0: Width <0: Number
[ ]	object mass	[x]	[ ]	1.0E-15	100000.0	0.4
[ ]	object diameter	[x]	[ ]	1.0E-6	100.0	-200.0
[ ]	time	[ ]	[ ]	1957.0	2016.0	-200.0
[ ]	object semi m...	[ ]	[ ]	6500.0	45000.0	-25.0
[ ]	object eccentr...	[x]	[ ]	1.0E-4	1.0	0.1
[ ]	object inclinat...	[ ]	[ ]	0.0	150.0	1.0
[ ]	object raan	[ ]	[ ]	-180.0	180.0	5.0
[ ]	impact arg. of ...	[ ]	[ ]	0.0	360.0	5.0
[ ]	object perihel ...	[ ]	[ ]	1500000.0	1.5E8	8000000.0
[ ]	impact eclipt. l...	[ ]	[ ]	0.0	360.0	5.0
[ ]	impact eclipt. l...	[ ]	[ ]	-90.0	90.0	5.0
[x]	impact velocity	[ ]	[ ]	0.0	40.0	1.0
[x]	impact azimut...	[ ]	[ ]	-180.0	180.0	5.0
[ ]	impact elevati...	[ ]	[ ]	-90.0	90.0	5.0

6a) Set desired output spectrum in '2D Spectrum Definitions'

disable

enable

Advanced: Impact velocity/azimuth on defined oriented surface

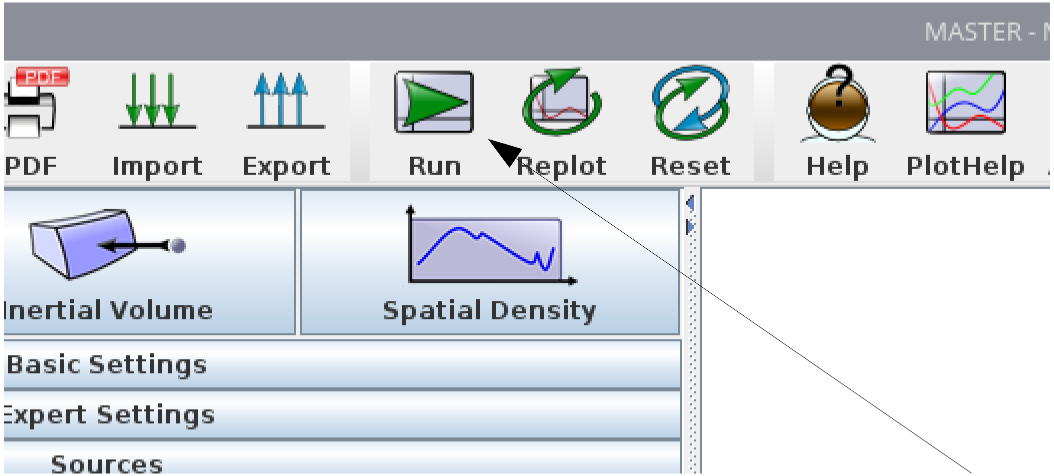


6b) Set desired output spectrum in '3D Spectrum Definitions'

enable

Advanced: Impact velocity/azimuth on defined oriented surface

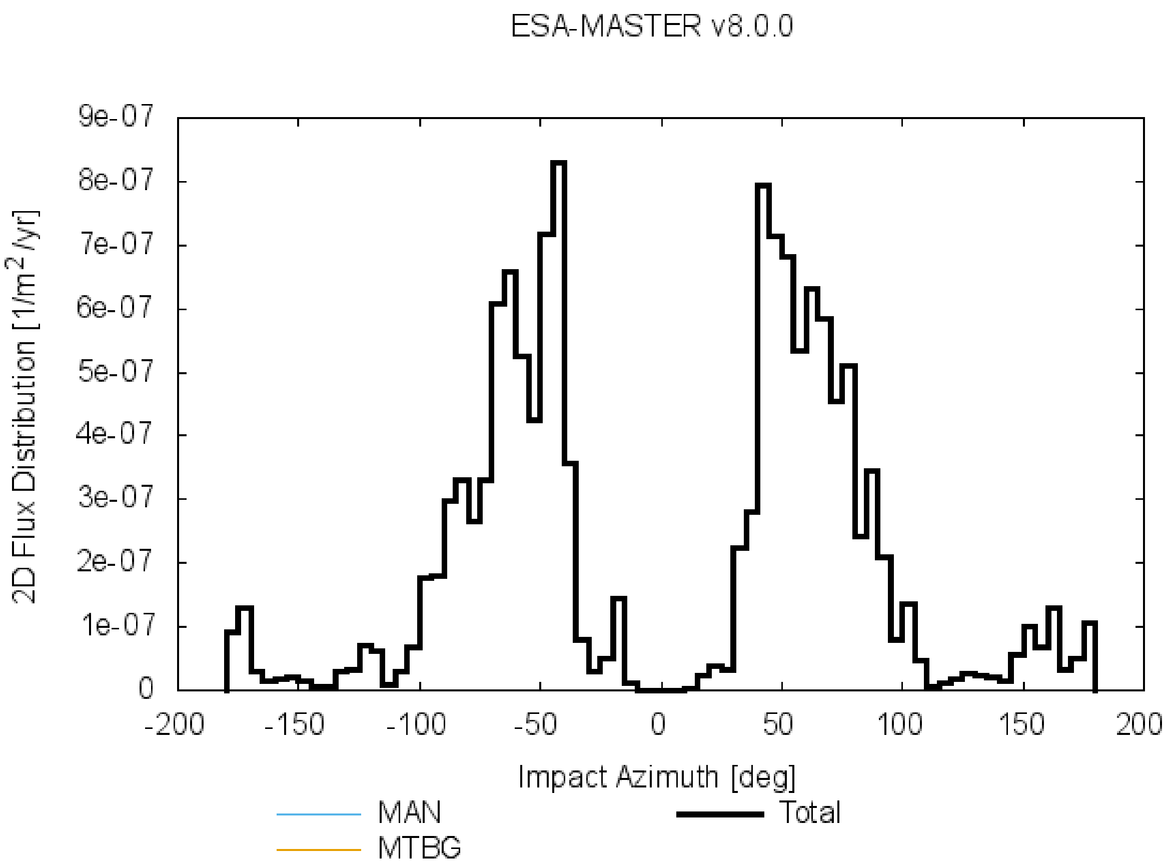
7) Click 'Run'



Advanced: Impact velocity/azimuth on defined oriented surface

Result:

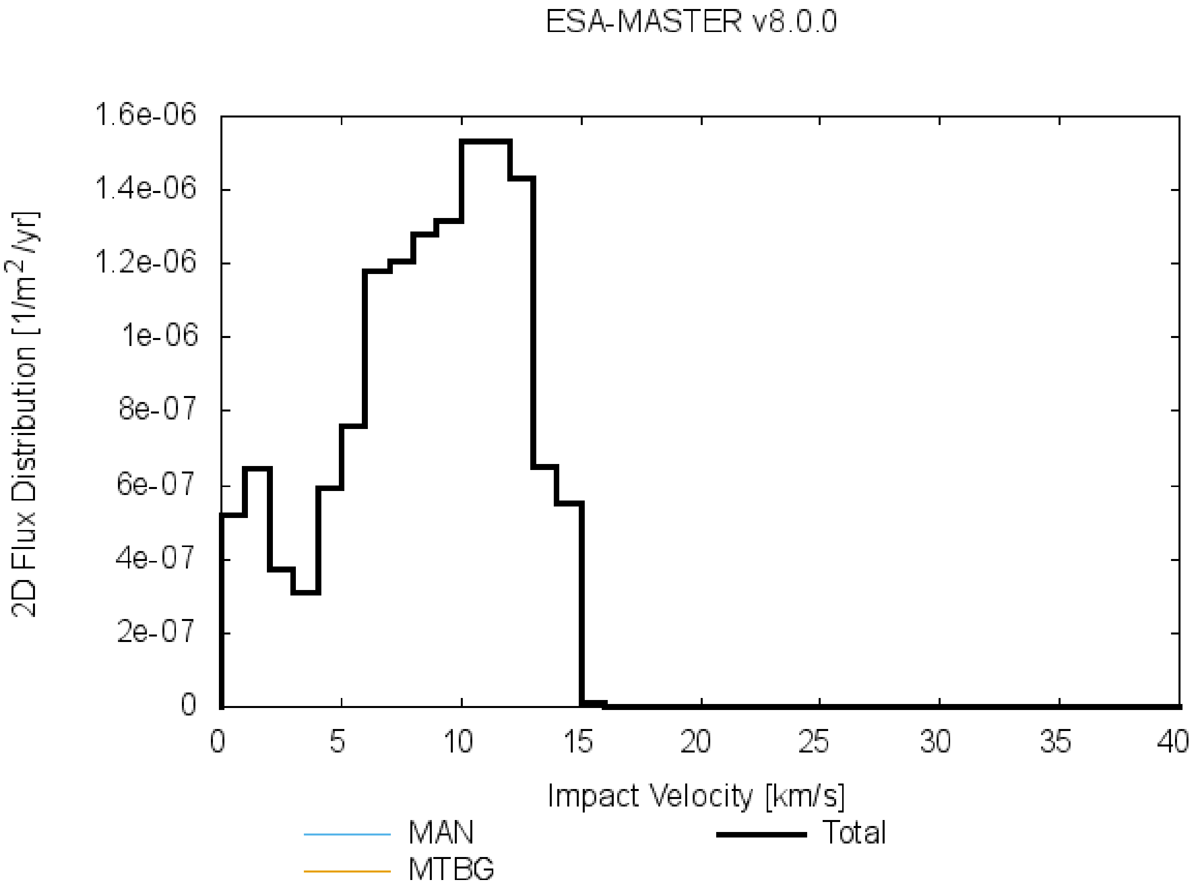
(1) 2D-Flux vs. impact azimuth
(2) 2D-Flux vs. impact velocity
(3) 3D-Flux vs. impact velocity vs. impact azimuth



Advanced: Impact velocity/azimuth on defined oriented surface

Result:

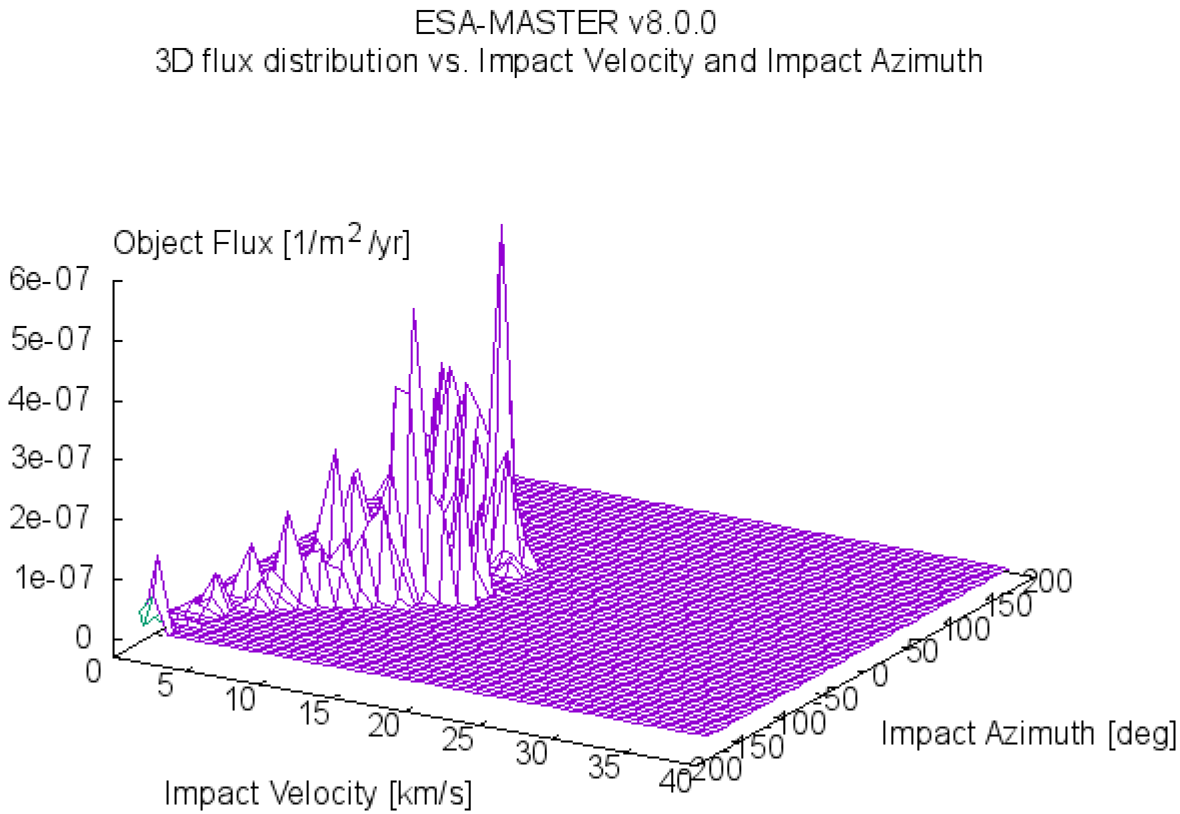
(1) 2D-Flux vs. impact azimuth
(2) 2D-Flux vs. impact velocity
(3) 3D-Flux vs. impact velocity vs. impact azimuth



<u>Advanced:</u> Impact velocity/azimuth on defined oriented surface

Result:

(1) 2D-Flux vs. impact velocity
(2) 2D-Flux vs. impact azimuth
(3) 3D-Flux vs. impact velocity vs. impact azimuth

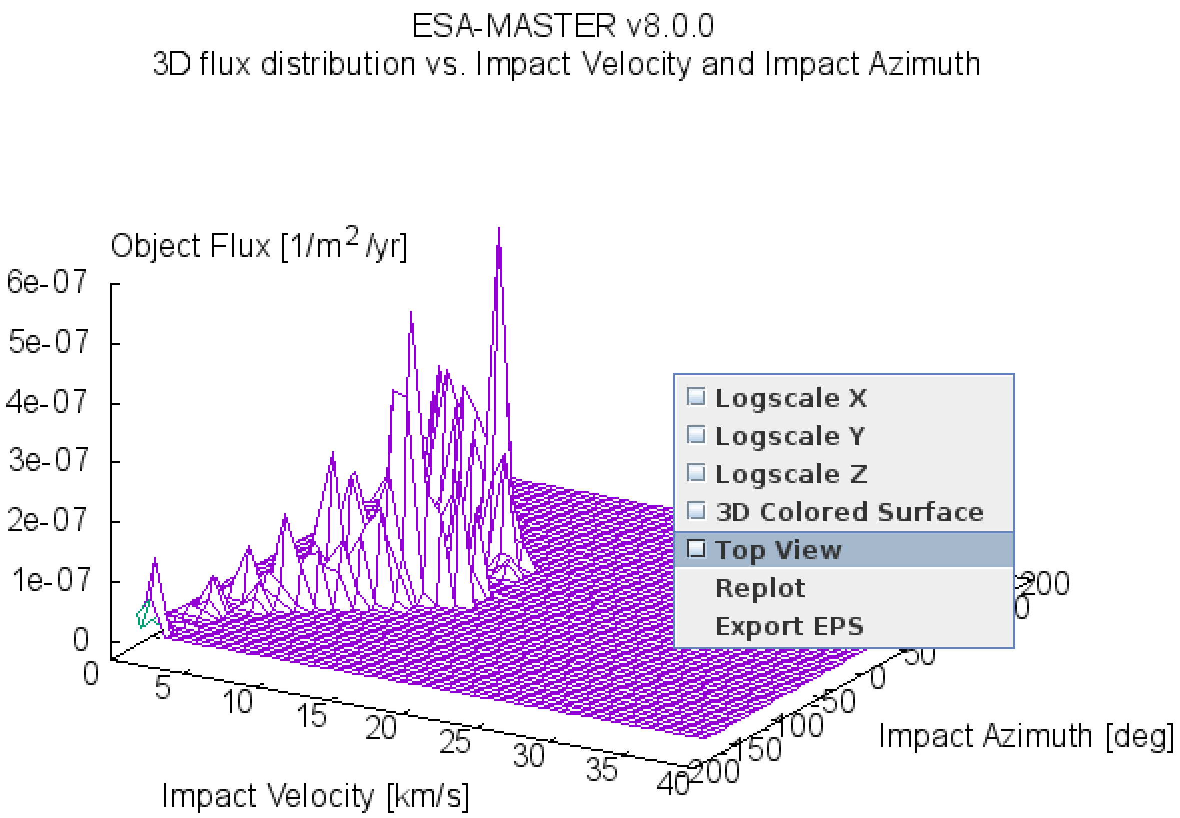


Advanced: Impact velocity/azimuth on defined oriented surface

Result:

(1) 2D-Flux vs. impact velocity
(2) 2D-Flux vs. impact azimuth
(3) 3D-Flux vs. impact velocity vs. impact azimuth

→ *Right click on plot area*
→ *Select 'Top View'*



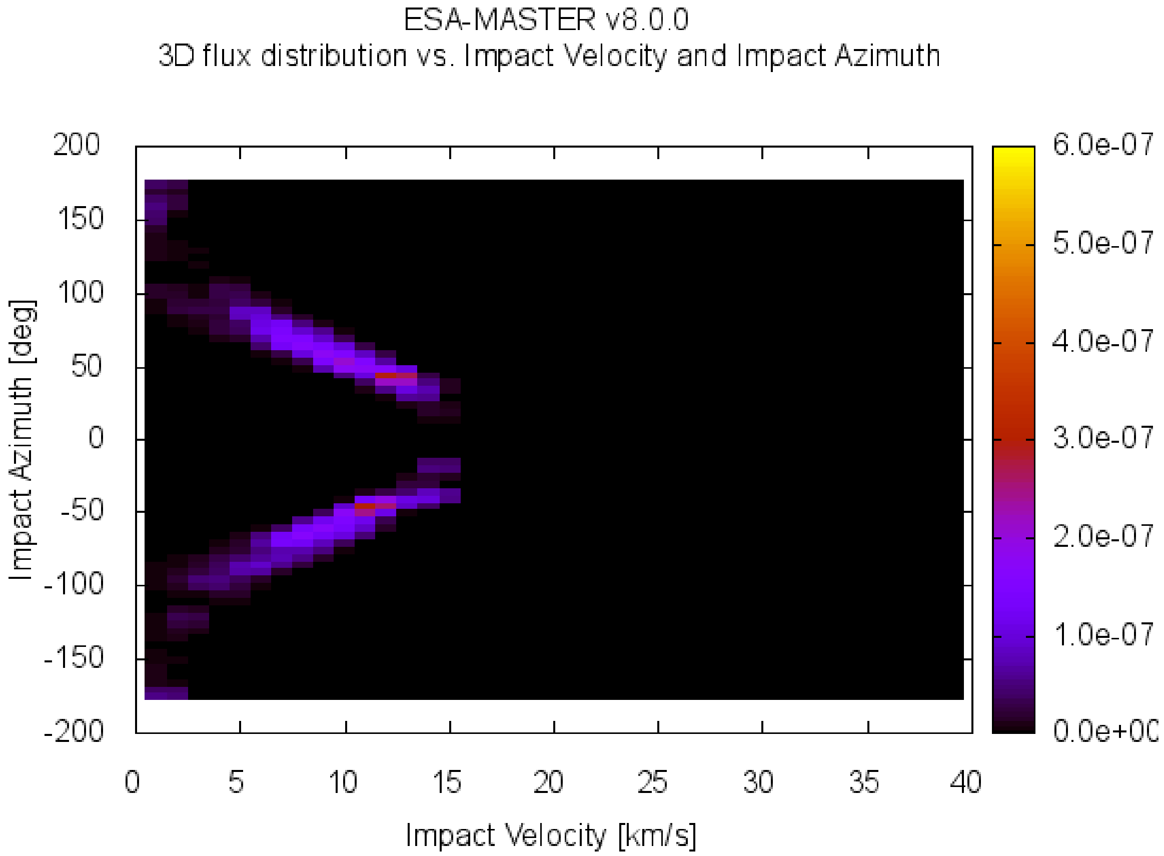
<u>Advanced:</u> Impact velocity/azimuth on defined oriented surface

Result:

(1) 2D-Flux vs. impact velocity
(2) 2D-Flux vs. impact azimuth
(3) 3D-Flux vs. impact velocity vs. impact azimuth

→ *Right click on plot area*
→ *Select 'Top View'*

Done!

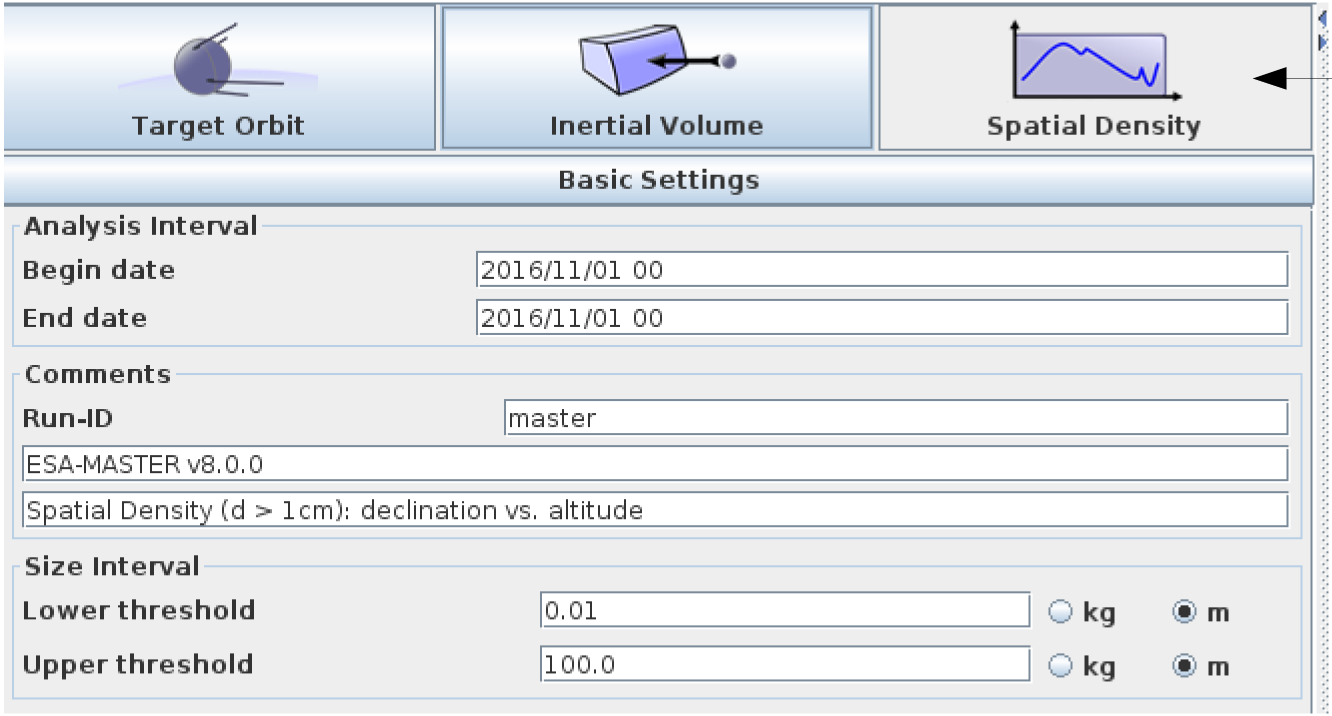


Advanced: Spatial density – declination vs. altitude

Advanced: Spatial density – declination vs. altitude

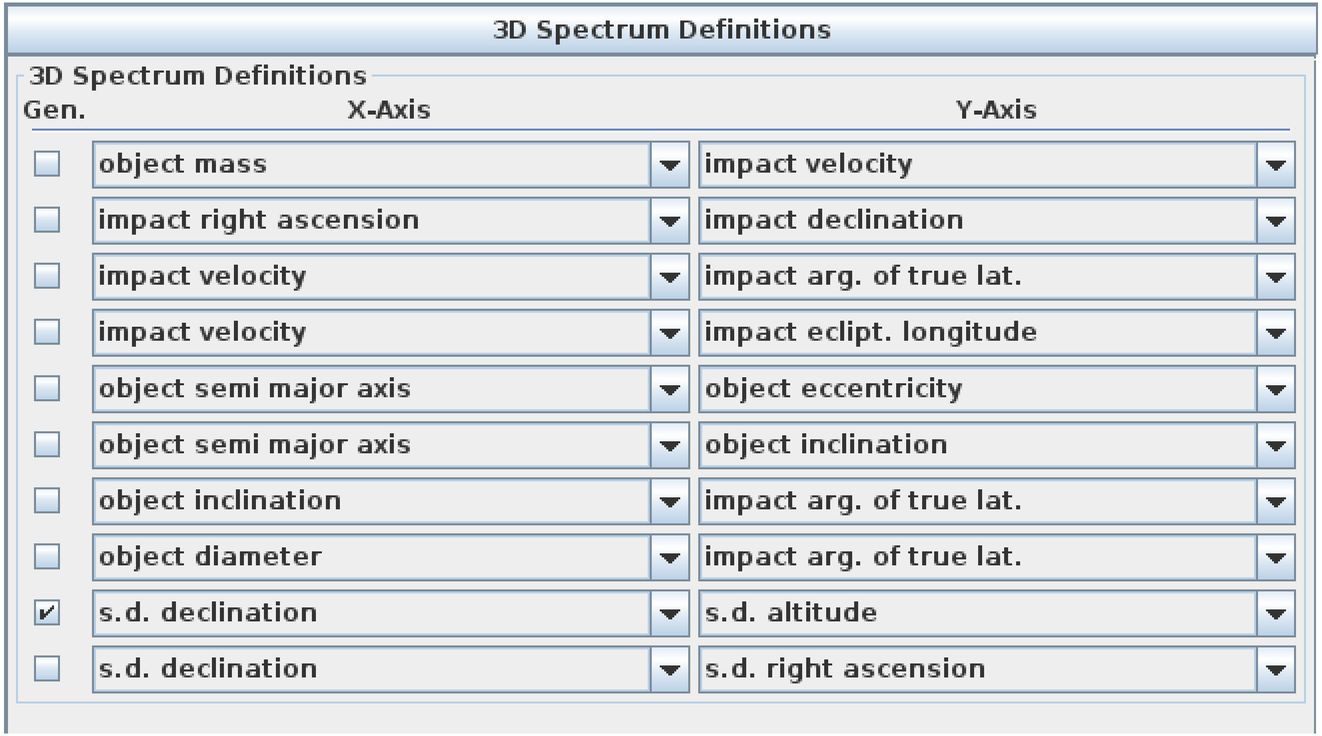
Task	Calculate the 3D-Spatial density (d > 1cm) dependent on declination and altitude in LEO.
Steps	1) Switch back to 'Spatial Density' Mode 2) Set desired output spectrum in '3D Spectrum Definitions' 3) Click 'Run'
Result	Single plot showing 3D-Spatial Density vs. declination vs. altitude

Advanced: Spatial density – declination vs. altitude



1) Select Spatial Density

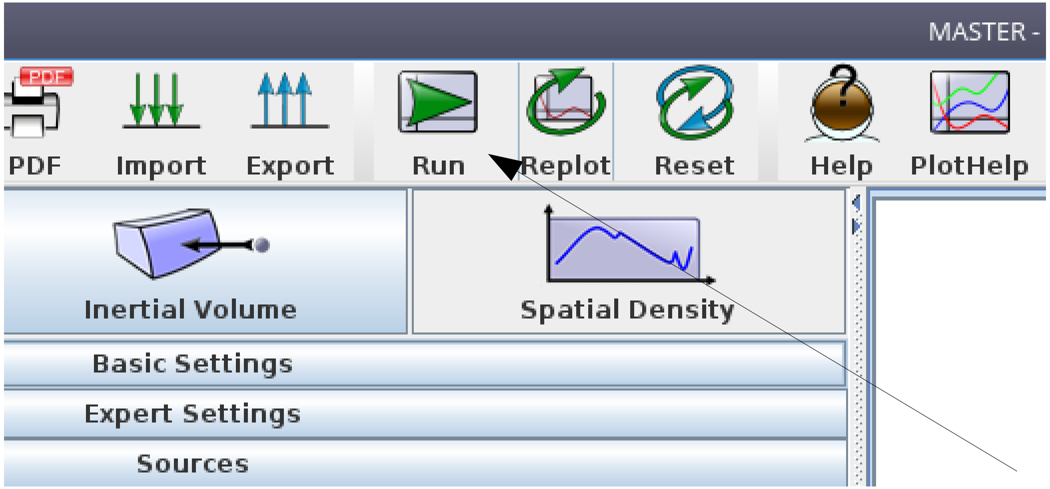
Advanced: Spatial density – declination vs. altitude



2) Set desired output spectrum

Advanced: Spatial density – declination vs. altitude

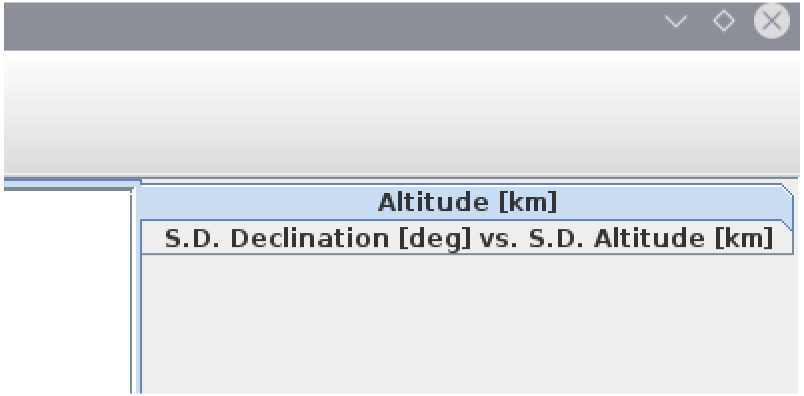
3) Click 'Run'



<u>Advanced:</u> Spatial density – declination vs. altitude

Result:

Plot showing 3D-Spatial Density vs. declination vs. altitude



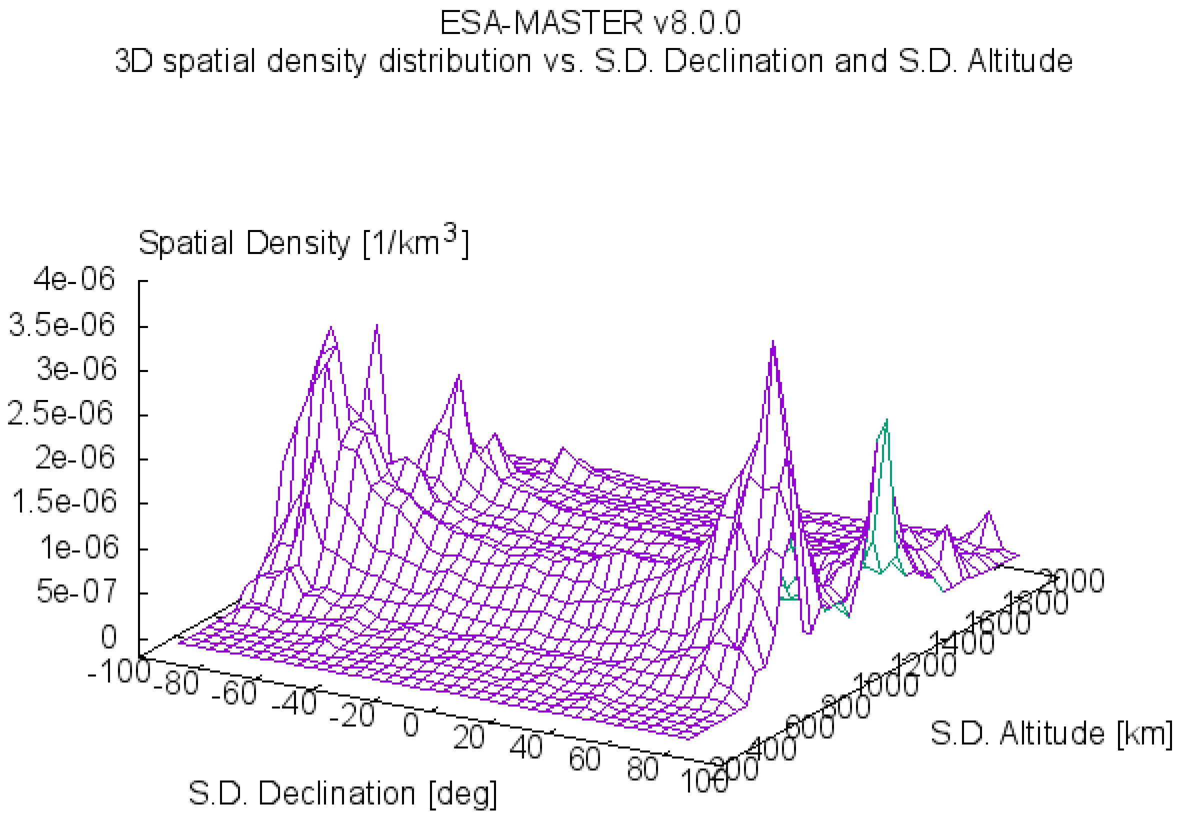
Default spectrum in 2D Spectrum definitions

Requested 3D spectrum

Advanced: Spatial density – declination vs. altitude

Result:

Plot showing 3D-Spatial Density vs. declination vs. altitude

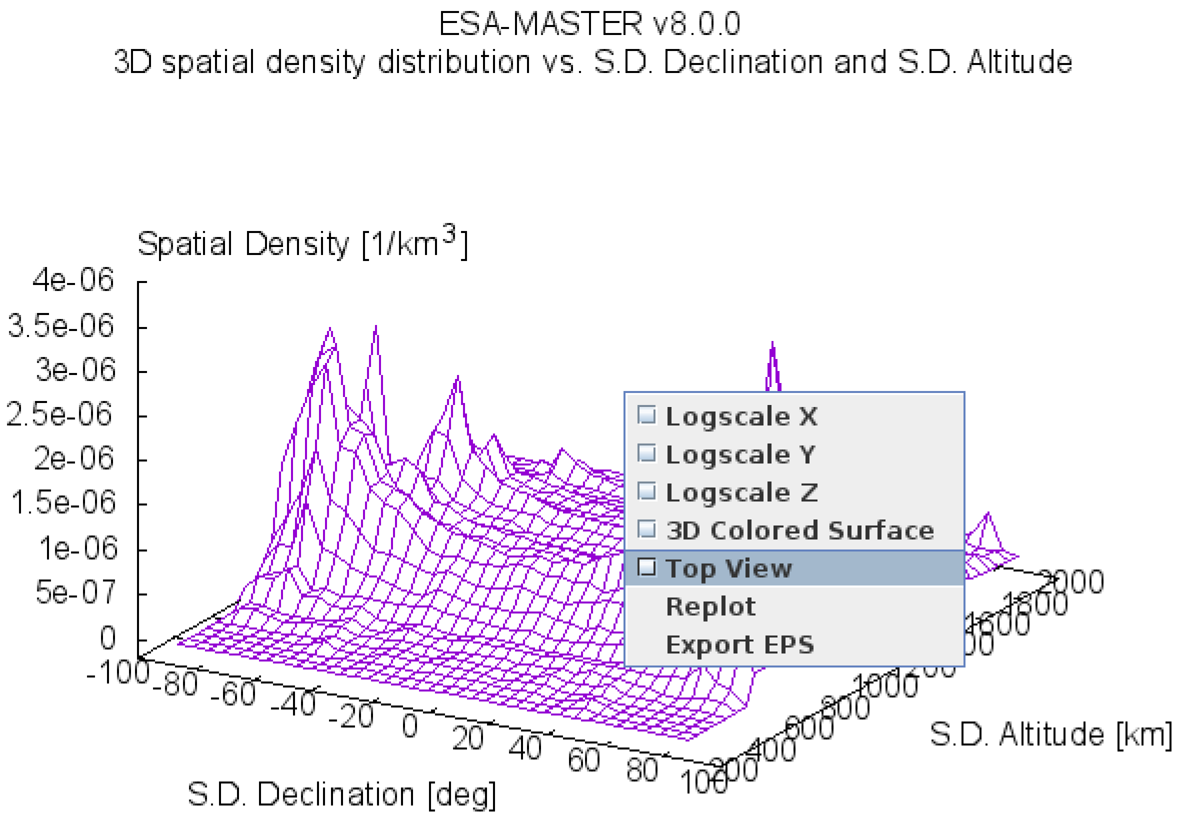


<u>Advanced:</u> Spatial density – declination vs. altitude

Result:

Plot showing 3D-Spatial Density vs. declination vs. altitude

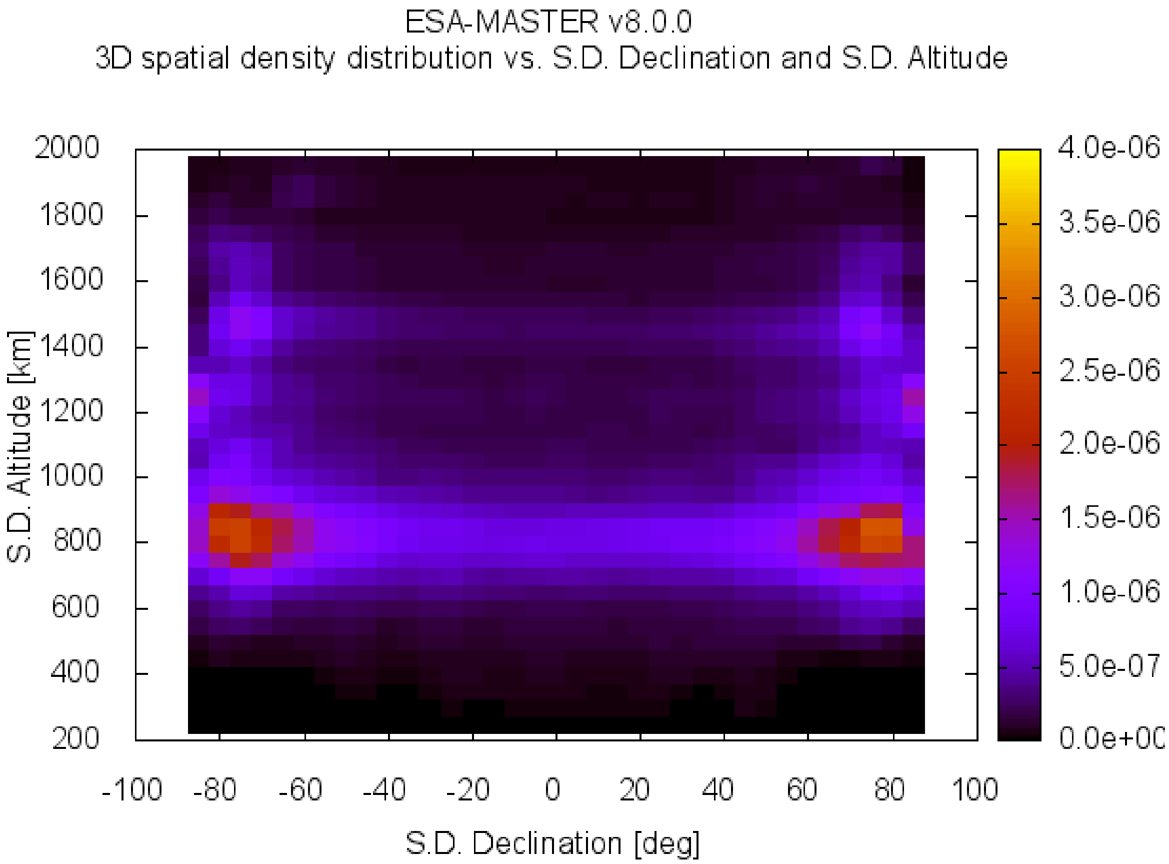
→ *Right click on plot area*
→ *Select 'Top View'*



<u>Advanced:</u> Spatial density – declination vs. altitude

Result:

Plot showing 3D-Spatial Density vs. declination vs. altitude



→ *Right click on plot area*
→ *Select 'Top View'*

Done!

Thank you!

More information:
Software User Manual

Additional population data:
https://sdup.esoc.esa.int/