From Measurement to Uncertainties to Understanding

The MASTER population

Agenda

1. Brief History
2. Why providing uncertainties?
3. From measurement to uncertainties

Brief History

First approaches 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

Former ECSS standards

"Constant uncertainty factors of 0.33 to 3"

- Rough estimation with no statistical evaluation of underlying data
- No discrimination between visible and non-visible spectrum

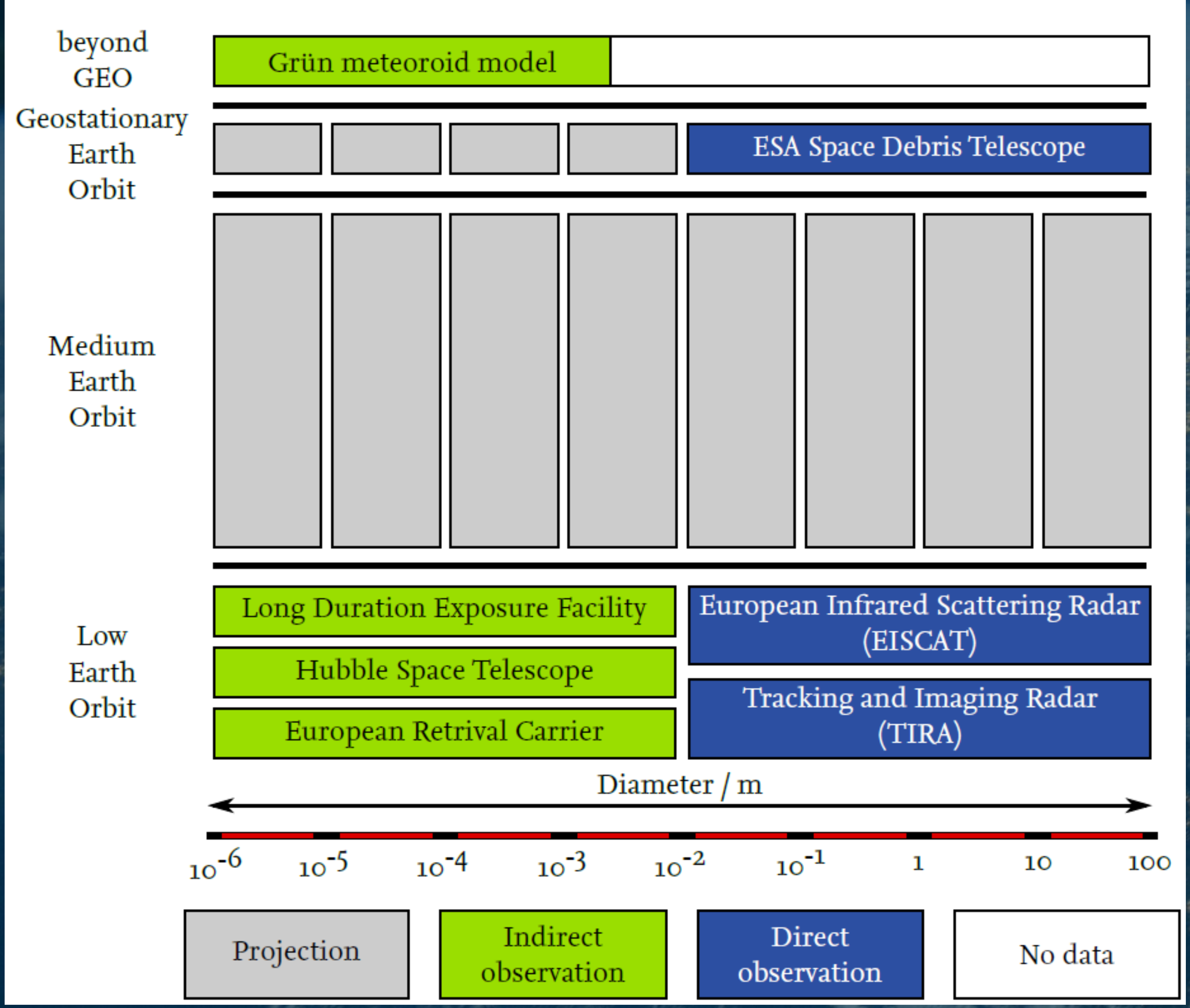
→ No justified quantification!

Why providing uncertainties?

“Knowing what you don’t know has a higher value than ignoring the unknown.”

- Safety factors in mission design
- Indication for the quality of the model
- Uncovering shortcomings as well as best applications of the model

From measurement to uncertainties



Data used for uncertainty estimation

Uncertainties shall be:

- Diameter dependent
- Regime dependent

After validation of the historic population, uncertainties are derived based on statistical evaluation of the calibration results.

From measurement to uncertainties

Results obtained by sensors

$$\varepsilon = \frac{Measurement - Model}{Model}$$

"Error-ratio"

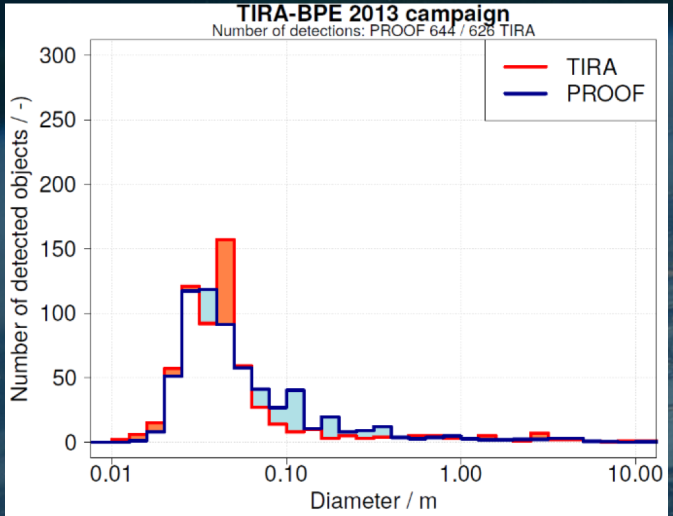
Results obtained by the model

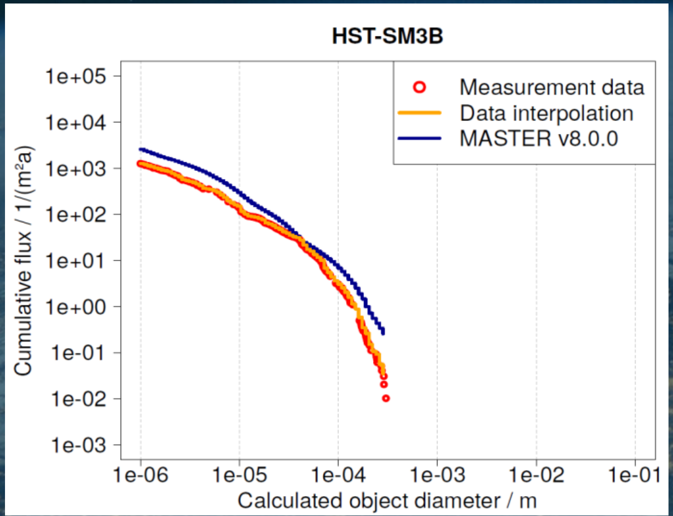
"Error-ratio":

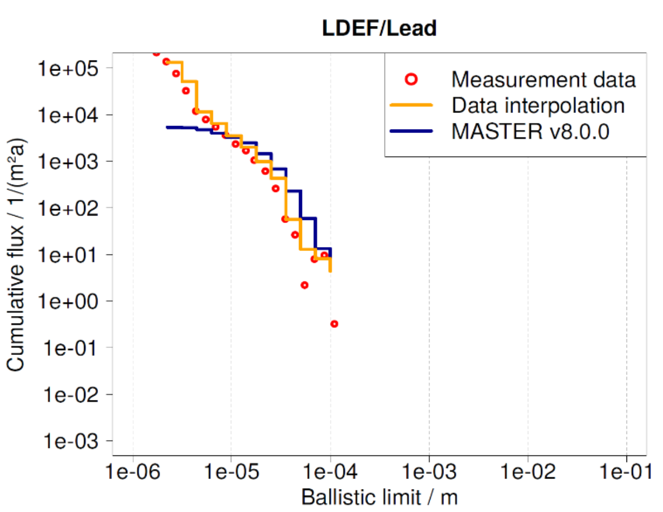
- Dimensionless key figure that quantifies the deviation
- It allows to indicate nominal value at the MASTER output and error values as a factor of the nominal value

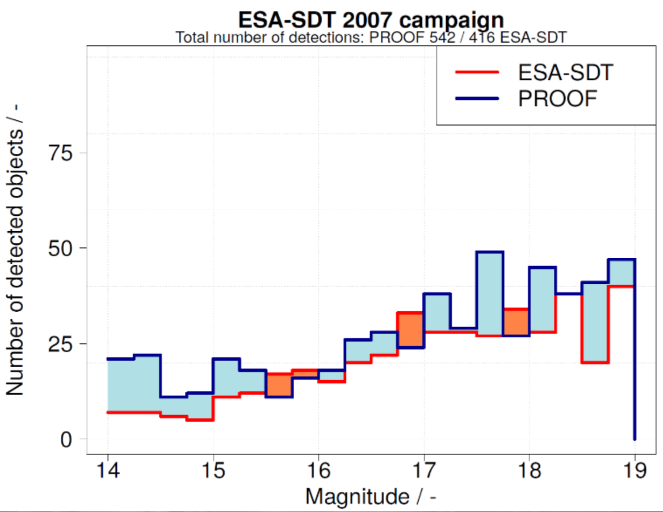
- Measurement > Model: $\varepsilon > 0$
- Measurement < Model: $\varepsilon < 0$
- Model = 0: almost non-existent (< 0.3% of datasets), neglected
- Measurement = Model: $\varepsilon = 0$

From measurement to uncertainties







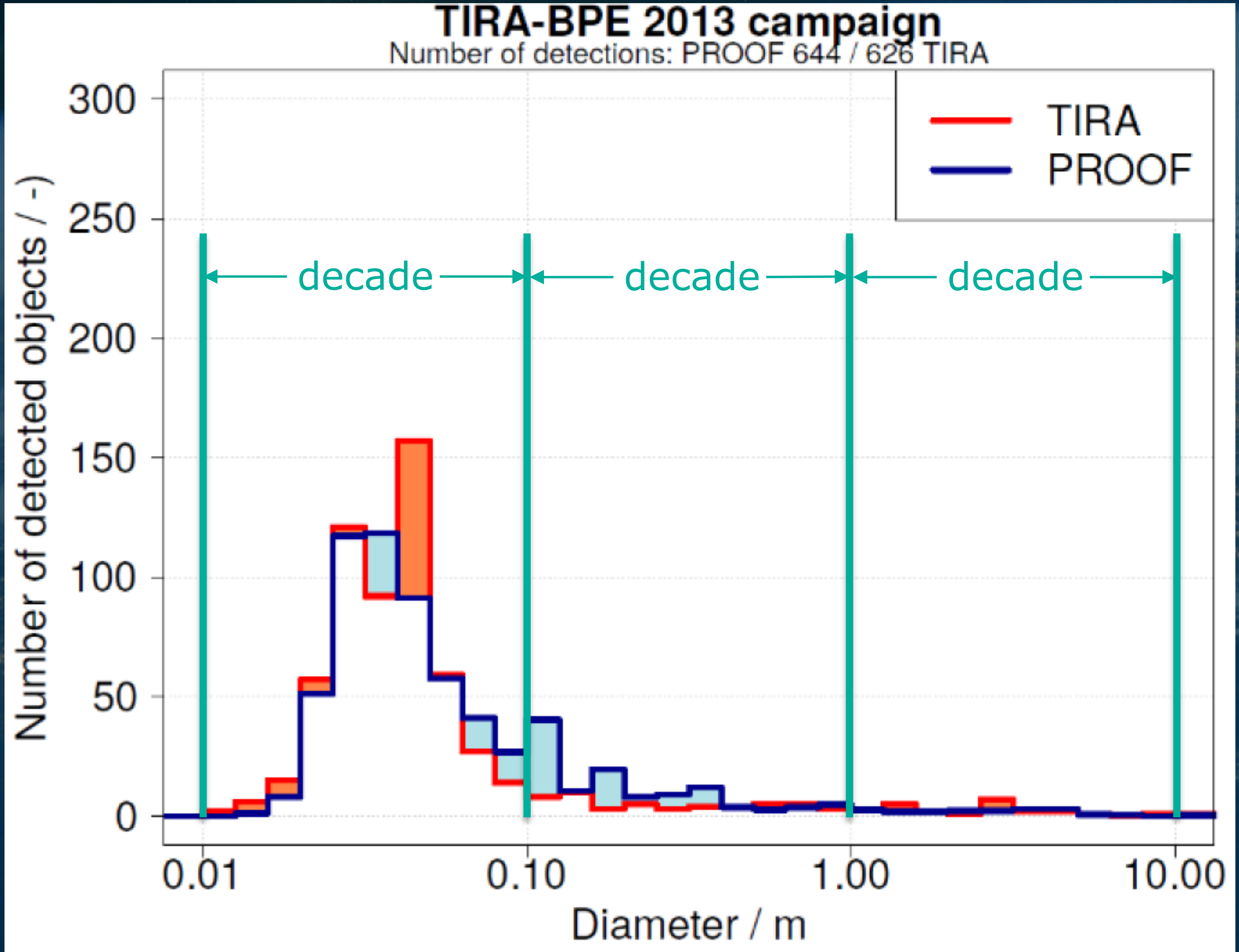


Evaluation of size spectra of validation results

Blue: MASTER (Model)

Red: Sensor (Measurement)

From measurement to uncertainties

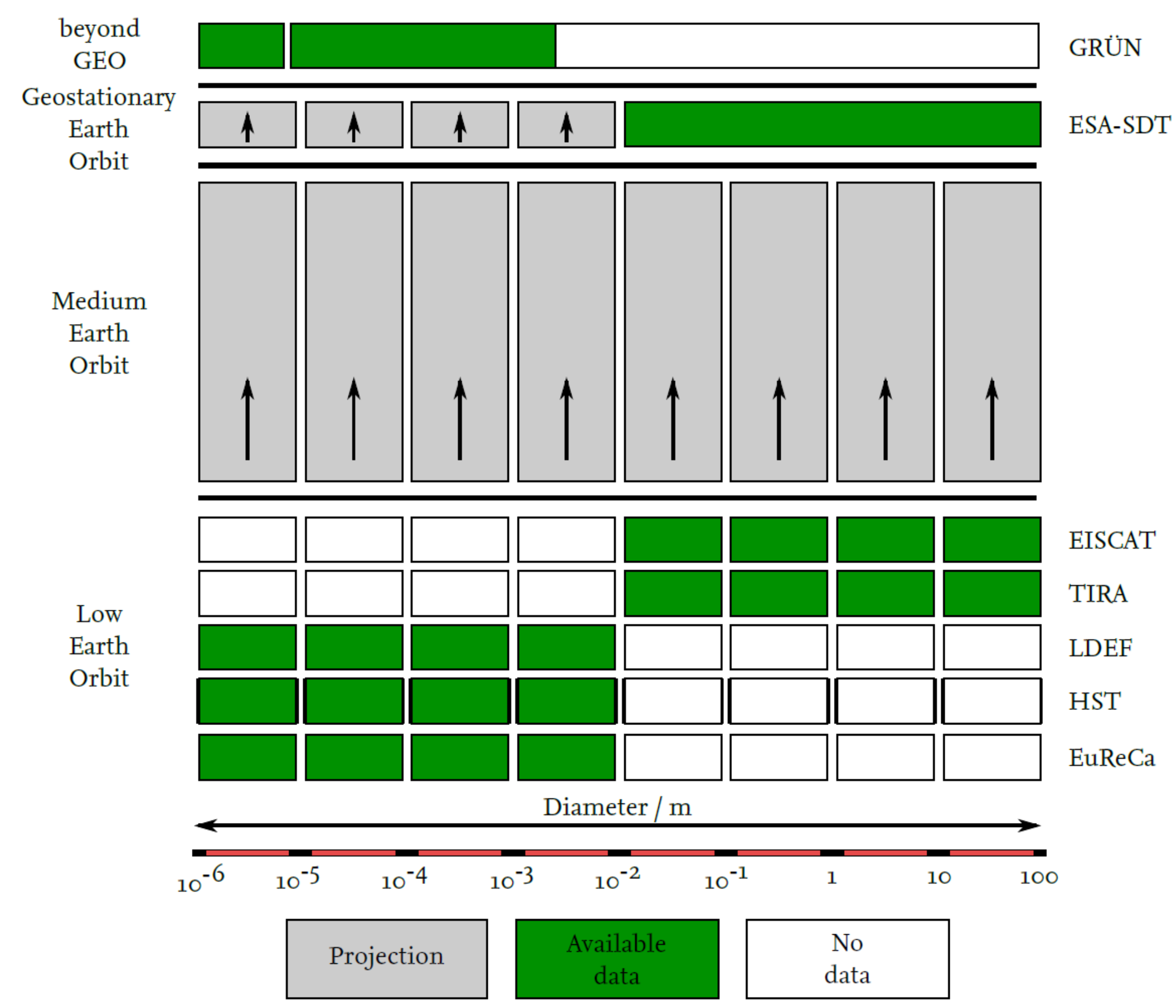


Weighting and data merging

Error-ratio calculated for each diameter bin

1. Differentiation of positive and negative error-ratios
2. Calculating mean error-ratios (positive and negative) for each diameter decade
3. Combining the mean error-ratios of all available validation campaigns into two distinct mean error-ratios (positive and negative).

From measurement to uncertainties



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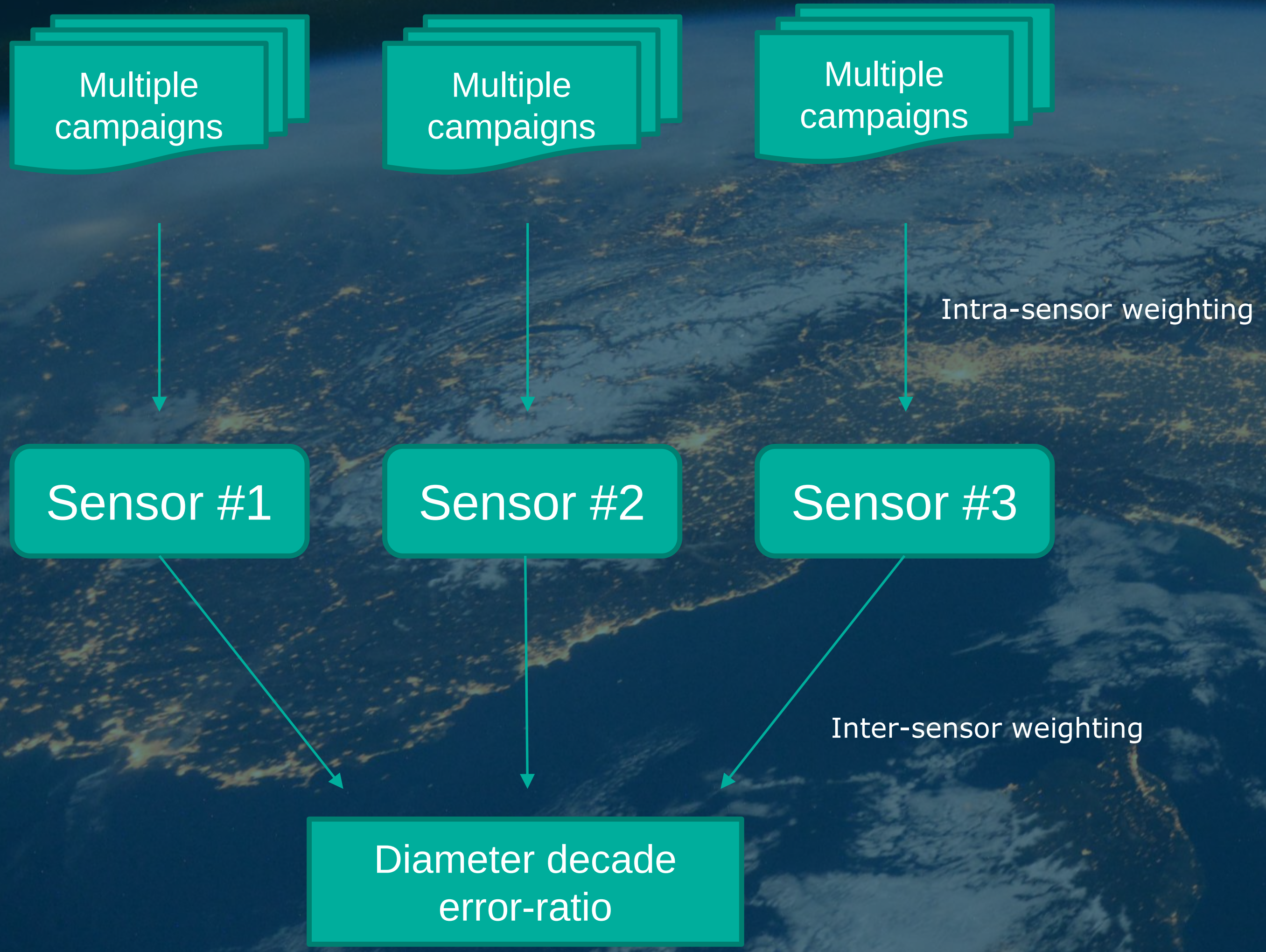
From measurement to uncertainties

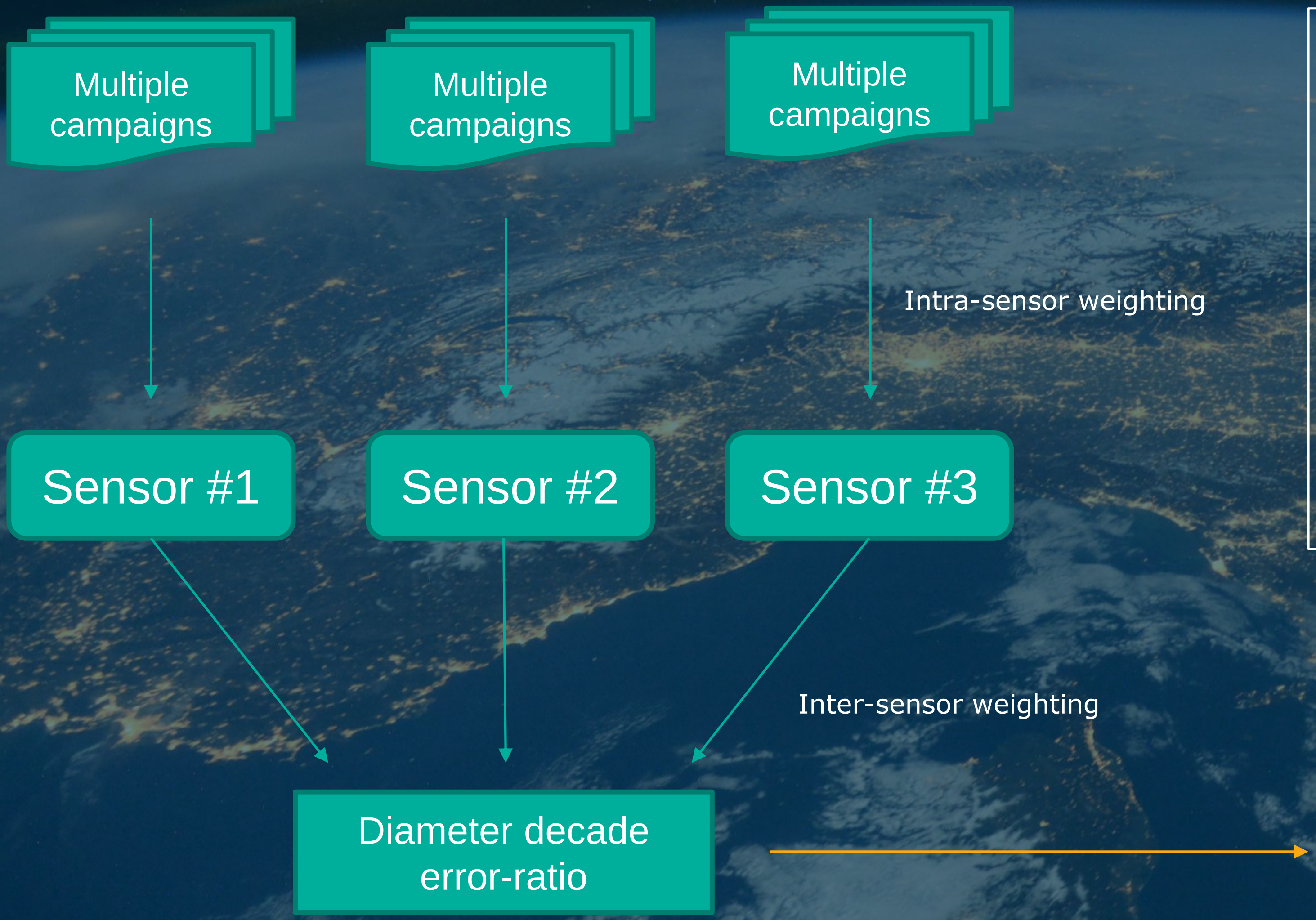


Inter- vs. Intra-sensor weighting

Weighting based on e.g.:

- Diameter spectrum contribution
- Sensor campaign age w.r.t. reference epoch
- Number of detections
- Data quality
- …

From measurement to uncertainties



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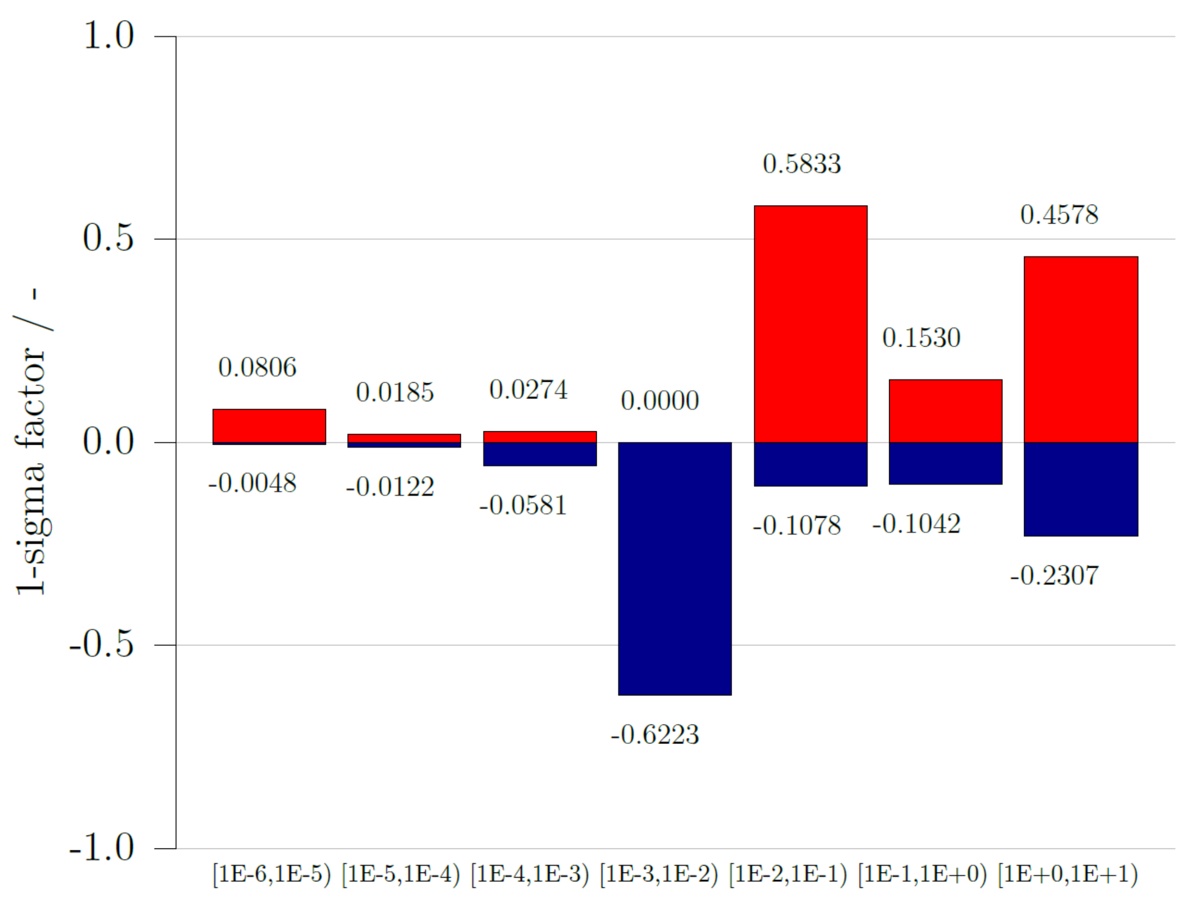
Assuming normal distribution* to obtain 1σ environment

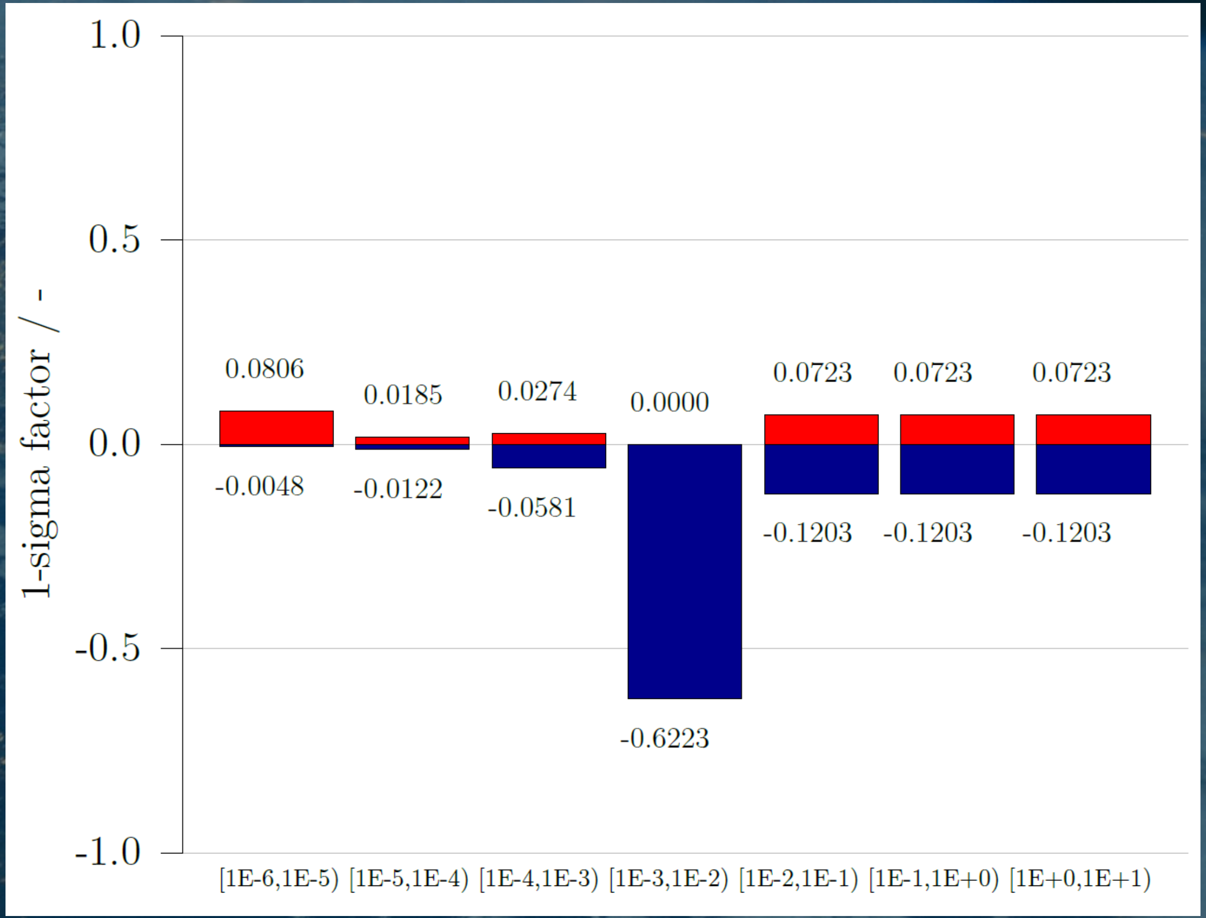
* Currently under revision

From measurement to uncertainties

LEO and MEO



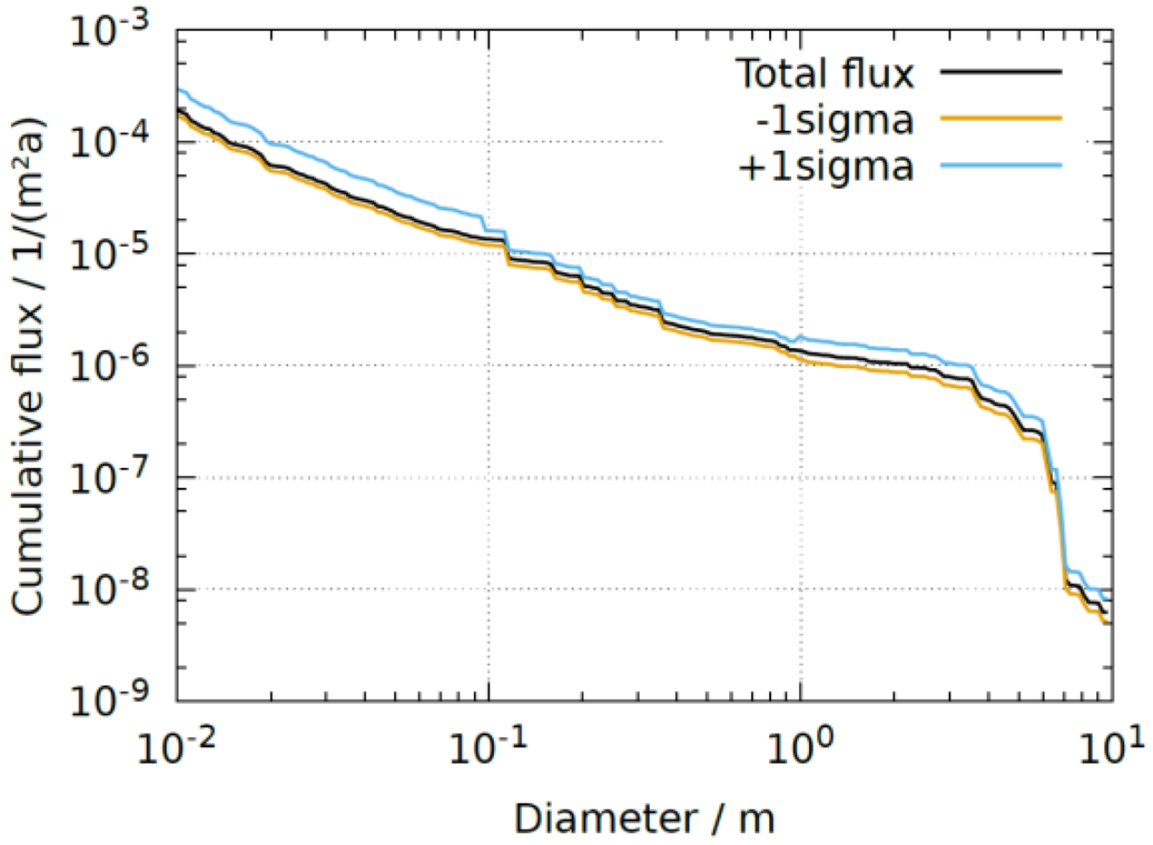
GEO



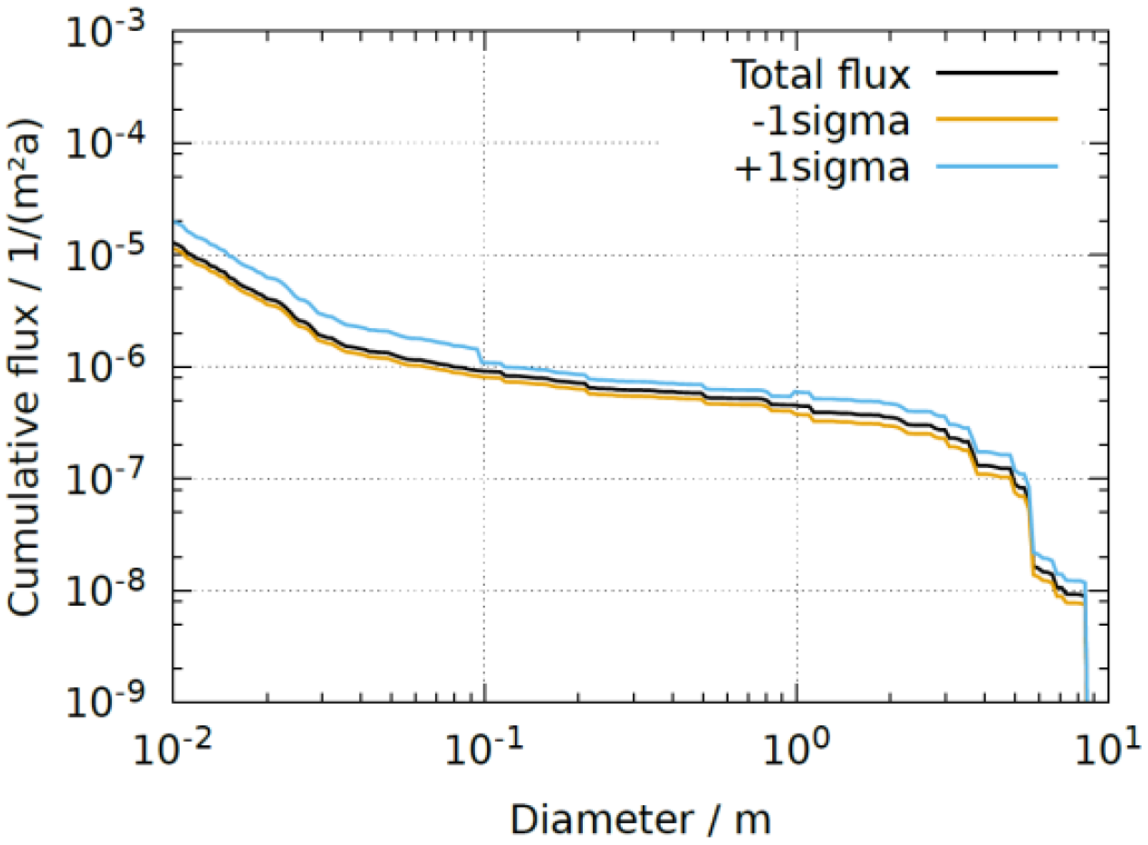
Factors applied to nominal flux (and spatial density) output

From measurement to uncertainties

SSO at 750 km



ISS orbit



Thank you!

As of November 2020

Number of rocket launches since the start of the space age in 1957
About 5990 (excluding failures)

Number of satellites these rocket launches have placed into Earth orbit
About 10490

Number of these still in space
About 6090

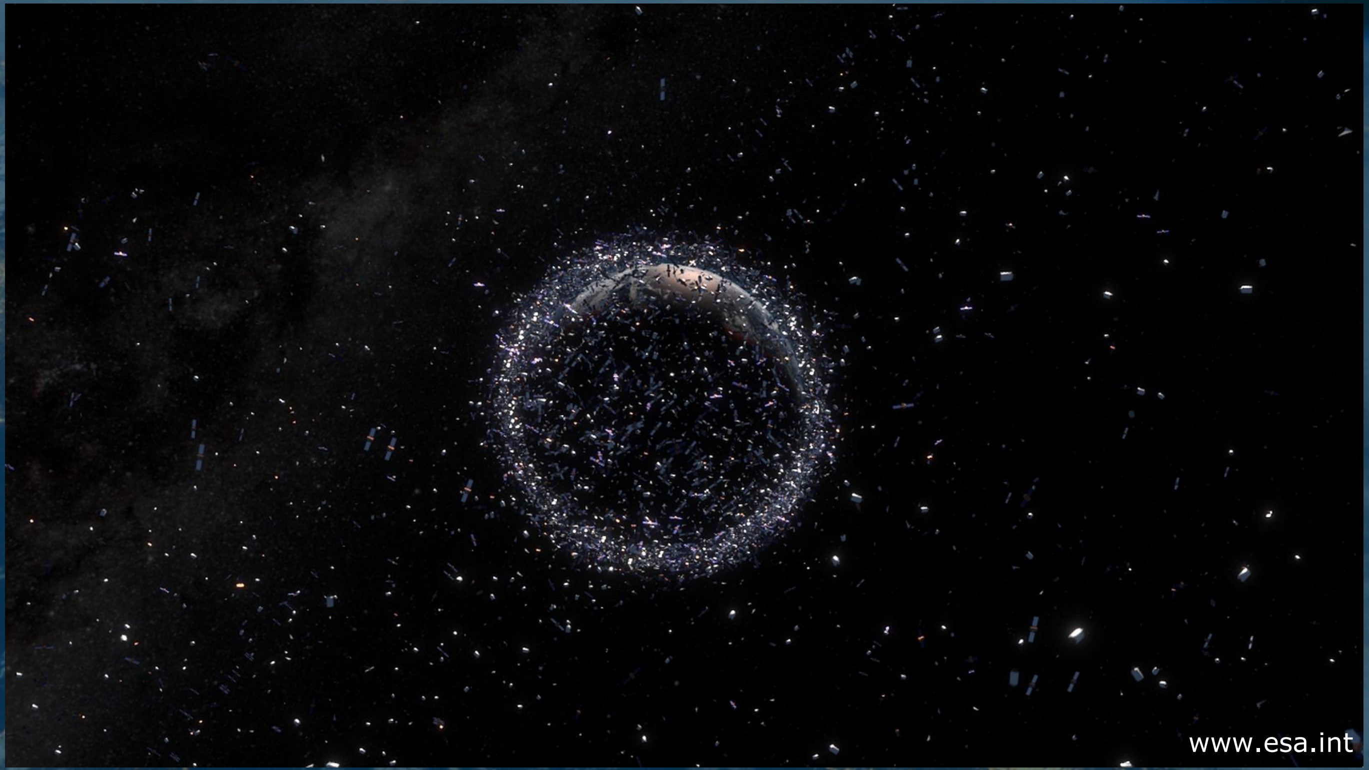
Number of these still functioning
About 3300

Number of debris objects regularly tracked by Space Surveillance Networks and maintained in their catalogue
About 28290

Estimated number of break-ups, explosions, collisions, or anomalous events resulting in fragmentation
More than 550

Total mass of all space objects in Earth orbit
More than 9100 tons

Number of debris objects estimated by statistical models to be in orbit
34000 objects greater than 10 cm
900 000 objects from greater than 1 cm to 10 cm
128 million objects from greater than 1 mm to 1 cm



www.esa.int – Space Debris by the Numbers