Assessment of marine geoid models by ship-borne GNSS profiles

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FAMOS
FINALISING SURVEYS FOR THE BALTIC MOTORWAYS OF THE SEA

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INTRODUCTION

- An international cooperation project FAMOS (Finalising Surveys for the Baltic Motorways of the Sea) has been initiated to complete hydrographic surveys and improve the gravimetric quasigeoid model within the Baltic Sea region (FAMOS 2017).
- **A goal** is to improve the accuracy of GNSS-based (Global Navigation Satellite System) bathymetric measurements and navigation by computing a new 5 cm accuracy marine geoid model over the Baltic Sea (*Fig. 1*).
- The poor accuracy and density of existing gravimetric data in the Baltic Sea is not sufficient for the purpose of 5 cm geoid modelling.
- External verifications are also needed for validating the accuracy of geoid models, for instance by shipborne GNSS measurements (*see Fig. 2*).
- The poster summarizes results of the ship-borne marine gravity and GNSS campaign held on board the Estonian Maritime Administration survey vessel „Jakob Prei" (*Fig. 4a*) in West-Estonian archipelago in summer of 2016.

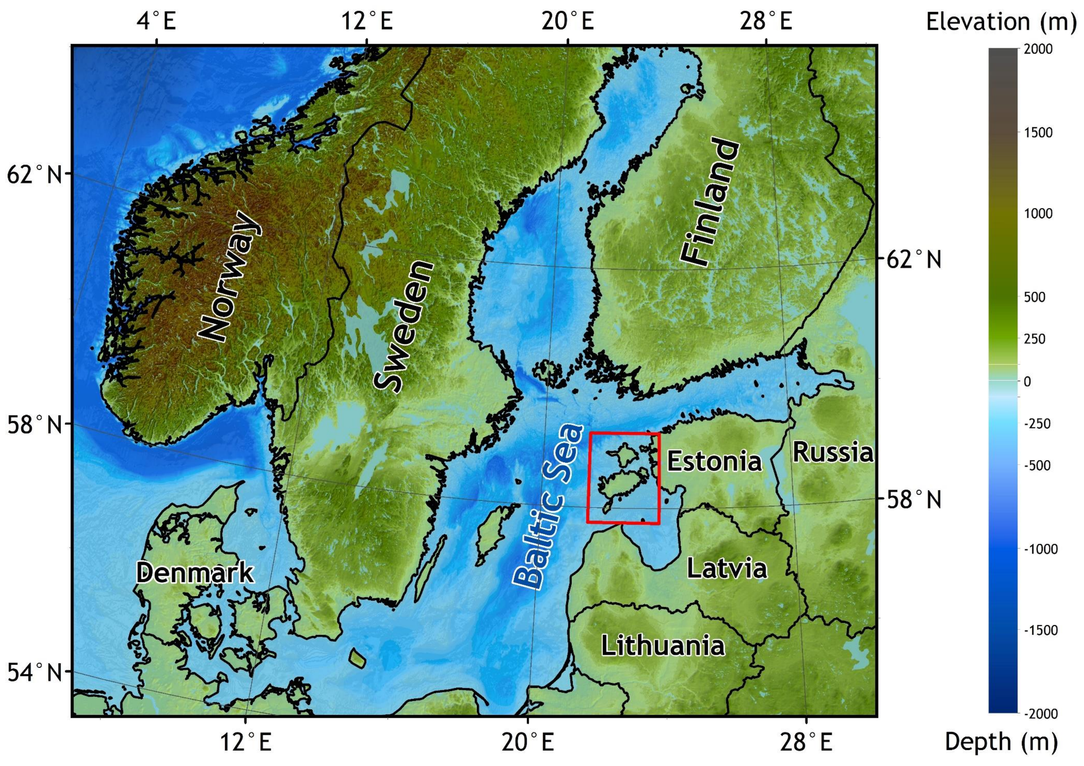

Fig. 1. Baltic Sea and the surrounding countries. Study area is marked on the map by the red rectangle.

PRINCIPLES, STUDY AREA AND DATA ACQUISITION

- Hydrographic surveys were performed on large areas West of Saaremaa and in the Gulf of Riga.
- Our current research interest focuses on transit routes (*Fig. 3*).
- Marine gravity and GNSS data were gathered during the experiment (*see Fig. 4b and Fig 6*).

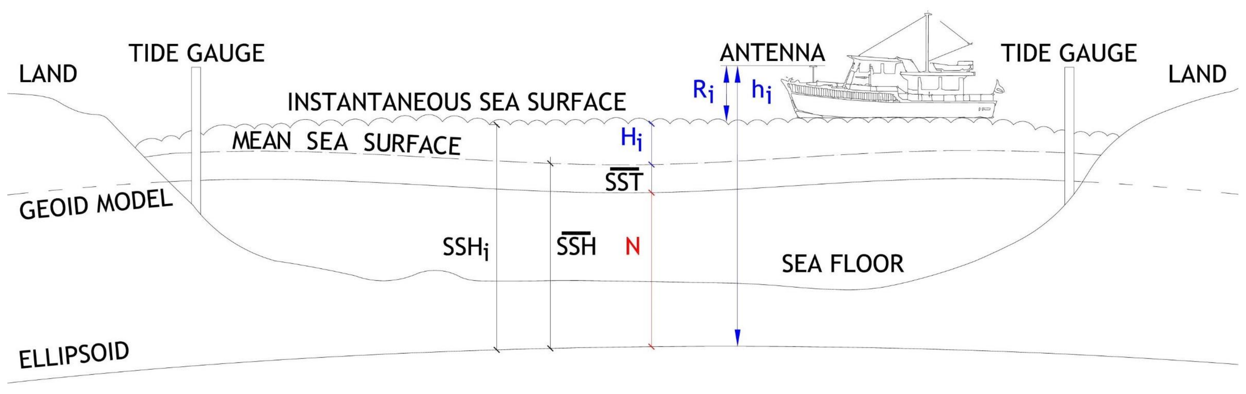

Fig. 2. Determination of sea heights (SSH) with respect to different reference surfaces. H_i - estimated sea level correction (from tide gauges); SST - sea surface topography; N - geoid height (the model to be quality assessed); h_i - height of the GNSS antenna from the reference ellipsoid (measured); R_i - range between the GNSS antenna and the instantaneous sea surface (measured).

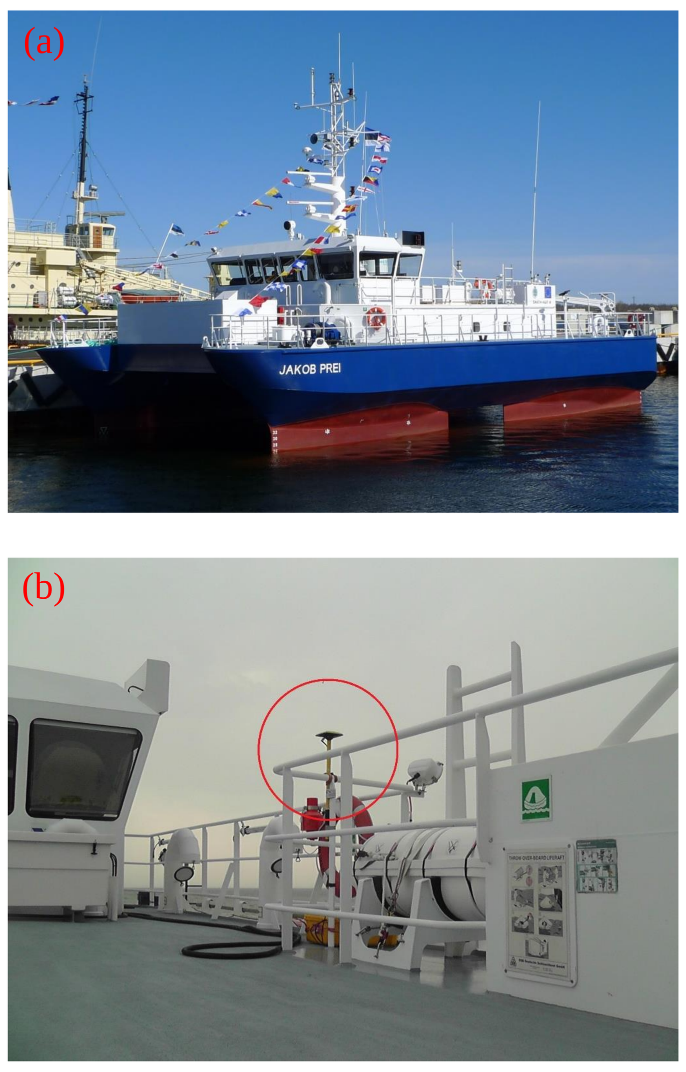

Fig. 4. (a) Estonian Maritime Administration hydrographic survey vessel „Jakob Prei" (photo L. Käärman).
(b) Standard Javad GNSS antenna attached to the railing, which was used to collect GNSS data (photo A. Ellmann).

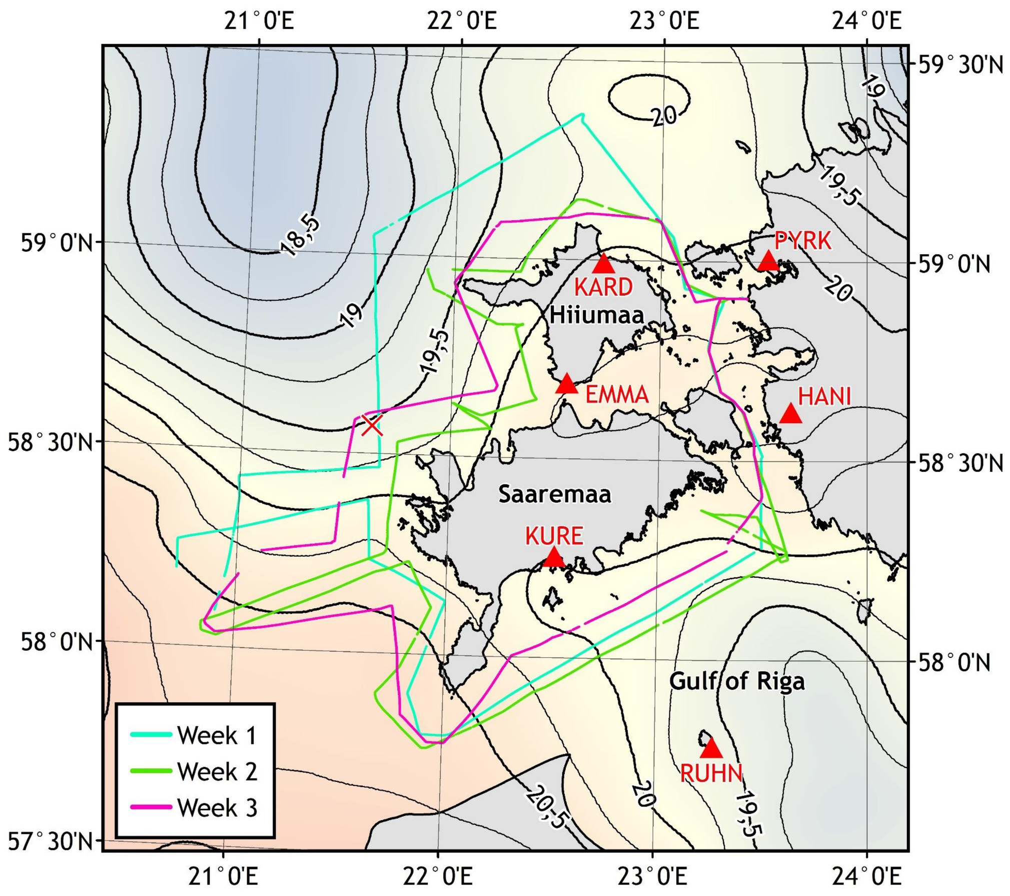

Fig. 3. Transit routes of the survey vessel and GNSS-CORS (Continuously Operating Reference Station) stations (denoted by 4-letter abbreviations). The isolines depict the NKG2015 quasigeoid model in the study area (units in metres). The red cross marks location of the shipwrecks (*see Fig. 5*) identified during hydrographic surveys.

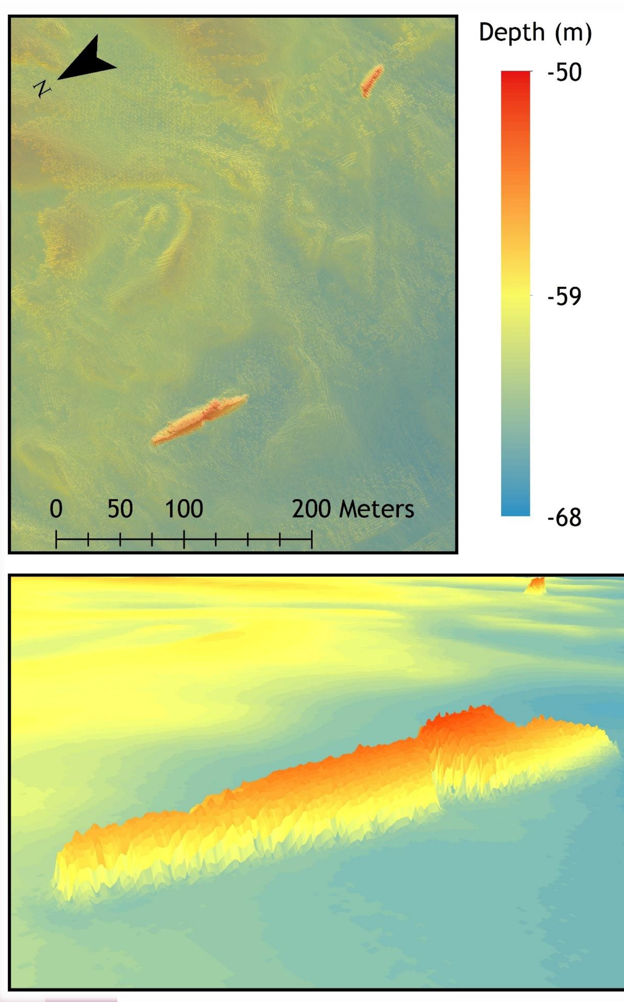

Fig. 5. Shipwrecks near the transit routes, approximately 21 km North-West of Saaremaa. Larger object is the british HMS Gentian (depicted in the lower figure, at the depth of 51,0 m) and smaller object is the bow of HMS Myrtle (at the depth of 52,2 m). Both ships sunk after hitting mines in the aftermath of the World War I in 1919.

Fig. 6. Russian „Elektropribor" manufactured gravimeter Chekan-AM for marine gravimetric data acquisition (photo A. Ellmann).

References

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GNSS DATA PROCESSING

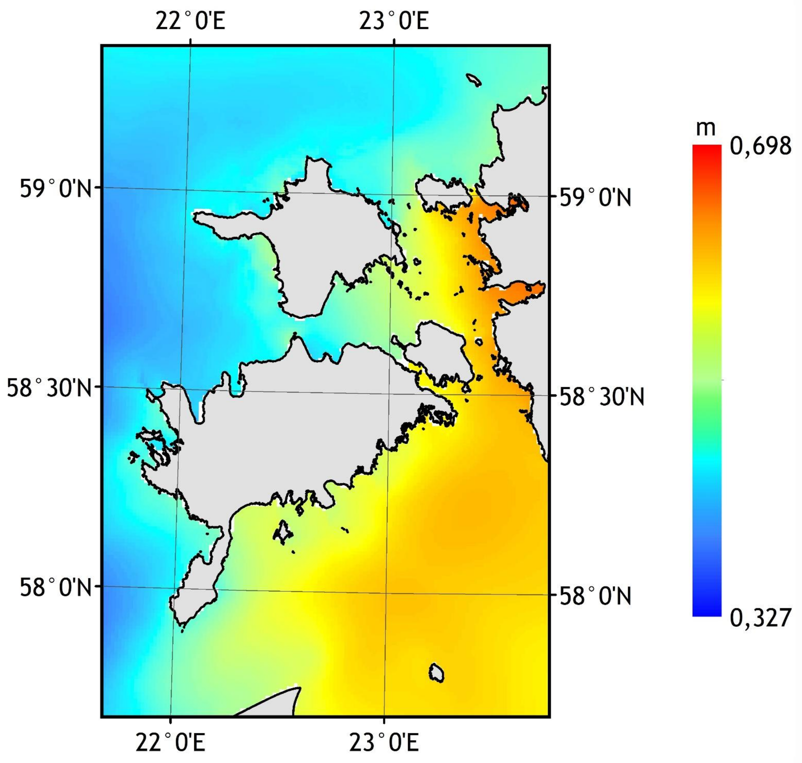

Fig. 7. A sample of HIROMB-EST hydrodynamic model depicting hourly sea surface topography (deviations from the mean sea surface), July 12th, 2016 at 21:00 UTC.

- The daily GNSS data-files were split into several sequences in a way that each single kinematic point was calculated with respect to the closest national CORS station (*see Fig. 3*).
- To reduce the sea wave effect in GNSS data, a low-pass filtering was applied. Considering the average moving speed of the ship on transit routes, a moving median of 39 measurements (approximately 1 km) was taken. From that outcome, moving average of 39 measurements was also taken to further smoothen GNSS data.
- Filtering allowed to eliminate standalone gross errors in Trimble Business Centre™ software calculations, as well as gross errors in GNSS measurements.
- The variablity of sea surface topography should be considered as a correction added to the filtered GNSS data, for instance by the hydrodynamic HIROMB-EST (Lagemaa 2012) hourly models of sea surface topography (*Fig. 7*), (to be implemented in further studies).

COMPARISON OF GNSS PROFILES WITH GEOID MODELS

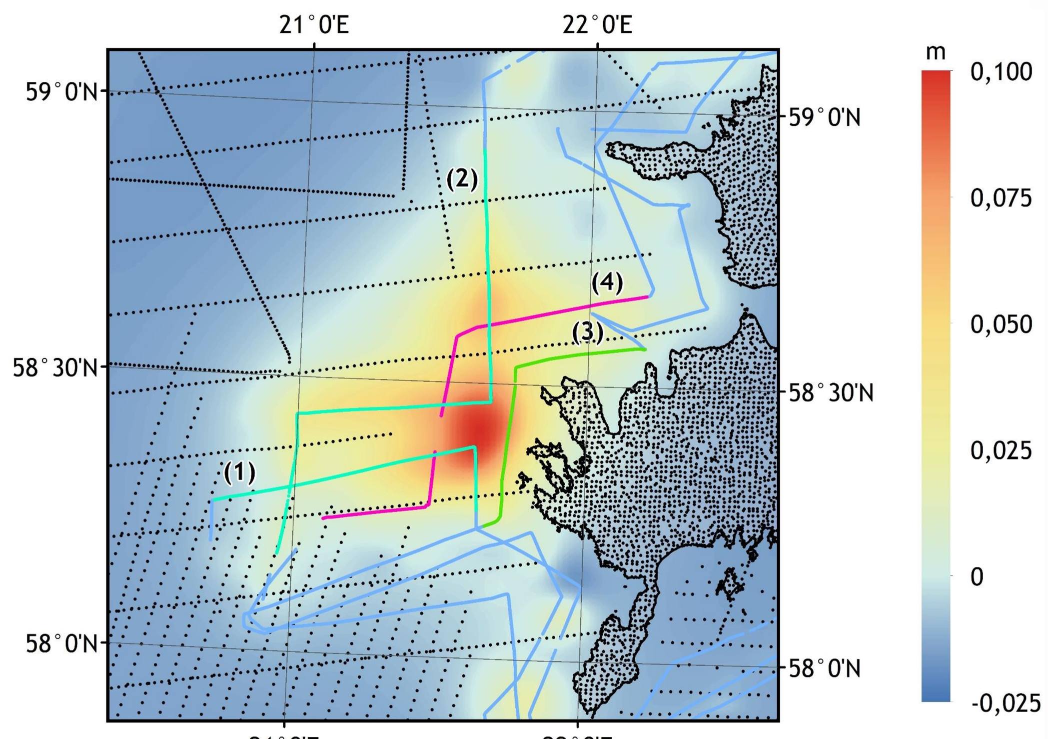

Fig. 8. Location of GNSS profiles within the area of the largest geoid model change gradient due to the newly collected „Jakob Prei" gravity data. The black dots indicate the locations of previously existing gravity data available for the geoid modelling. Red and yellow tones denote the areas where Model 2 is lower than Model 1.

- The marine geoid models to be assessed by ship-borne GNSS profiles include three models:
  - **a) The official NKG2015 quasigeoid model** (Agren *et al.* 2016) released by the Nordic Geodetic Commission (NKG);
  - **b) Model 1** – a preliminary NKG2015 quasigeoid model computed at TTÜ in 2016.
  - **c) Model 2** – another preliminary quasigeoid model computed just like Model 1 except with the newly obtained marine gravity data from the marine gravity campaign included.
- The most prominent area of geoid changes is located West of Saaremaa where differences between the geoid Model 1 and Model 2 are the largest (*Fig. 8*).

Table 1. Statistics of differences between GNSS profiles (the bright-coloured parts in *Fig. 8*) and geoid models within the area of the largest geoid model change gradient. Statistics of the profile (3) analysed in *Fig. 9* are high-lighted in red.

Geoid model	Profile number	Min (m)	Max (m)	StDev (m)
NKG2015	(1)	-0.280	0.228	**0.120**
	(2)	-0.115	0.267	**0.056**
	(3)	-0.150	0.136	**0.053**
	(4)	-0.115	0.111	**0.042**
Model 1	(1)	-0.281	0.226	**0.120**
	(2)	-0.117	0.267	**0.057**
	(3)	-0.148	0.134	**0.051**
	(4)	-0.113	0.113	**0.042**
Model 2	(1)	-0.207	0.207	**0.109**
	(2)	-0.103	0.269	**0.061**
	(3)	-0.122	0.113	**0.042**
	(4)	-0.133	0.150	**0.043**

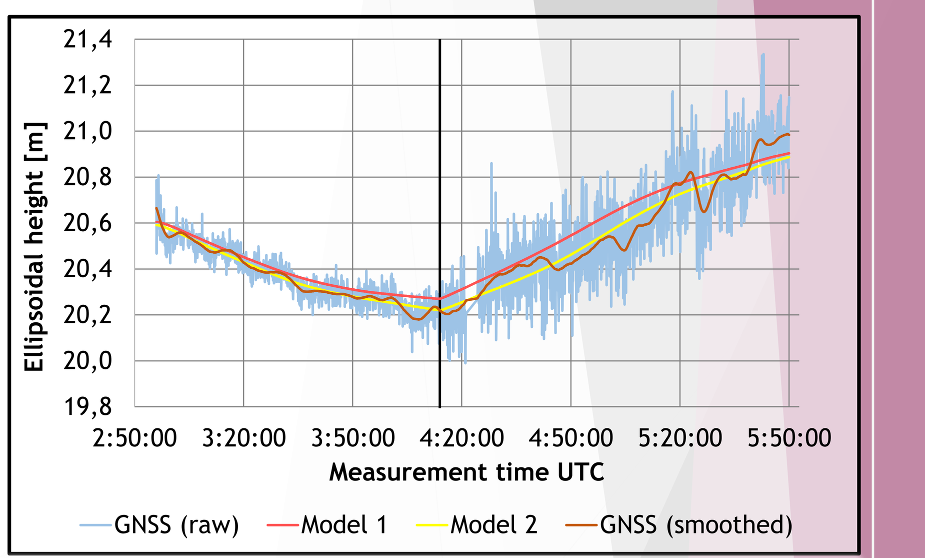

Fig. 9. An example of GNSS profile (3) compared to Model 1 and 2 geoid models (after removal of 1-dimensional offset). Sharp break in the direction of the lines from 4:13 to 4:14 indicates the turning point of the vessel.

- As seen from *Table 1*, Model 1 is comparable in precision to the official NKG2015 geoid model.
- The precision of Model 2 (with the new gravimetric data), with respect to the GNSS data, has improved at places (*see Fig. 9*).
- **The largest improvement** in the geoid model occurs in areas with previously poor coverage of g-data points (*see Fig. 8*).
- **Accuracy** of geoid models **increased** up to 11 mm as assessed from GNSS profiles.
- More details to be revealed in Varbla *et al.* (in preparation).

SUMMARY

- The GNSS height profiles were used to evaluate geoid models West of Saaremaa where the gravity data collected during the campaign had the largest effect on the resulting geoid model.
- Ship-borne GNSS profiles prove to be an **effective method** to evaluate existing geoid models.
- It was found that the model computed using the newly acquired gravity data agreed better with the GNSS profiles.
- The elaborated geoid assessment methodology to be used in further marine gravity campaigns.

Acknowledgements

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