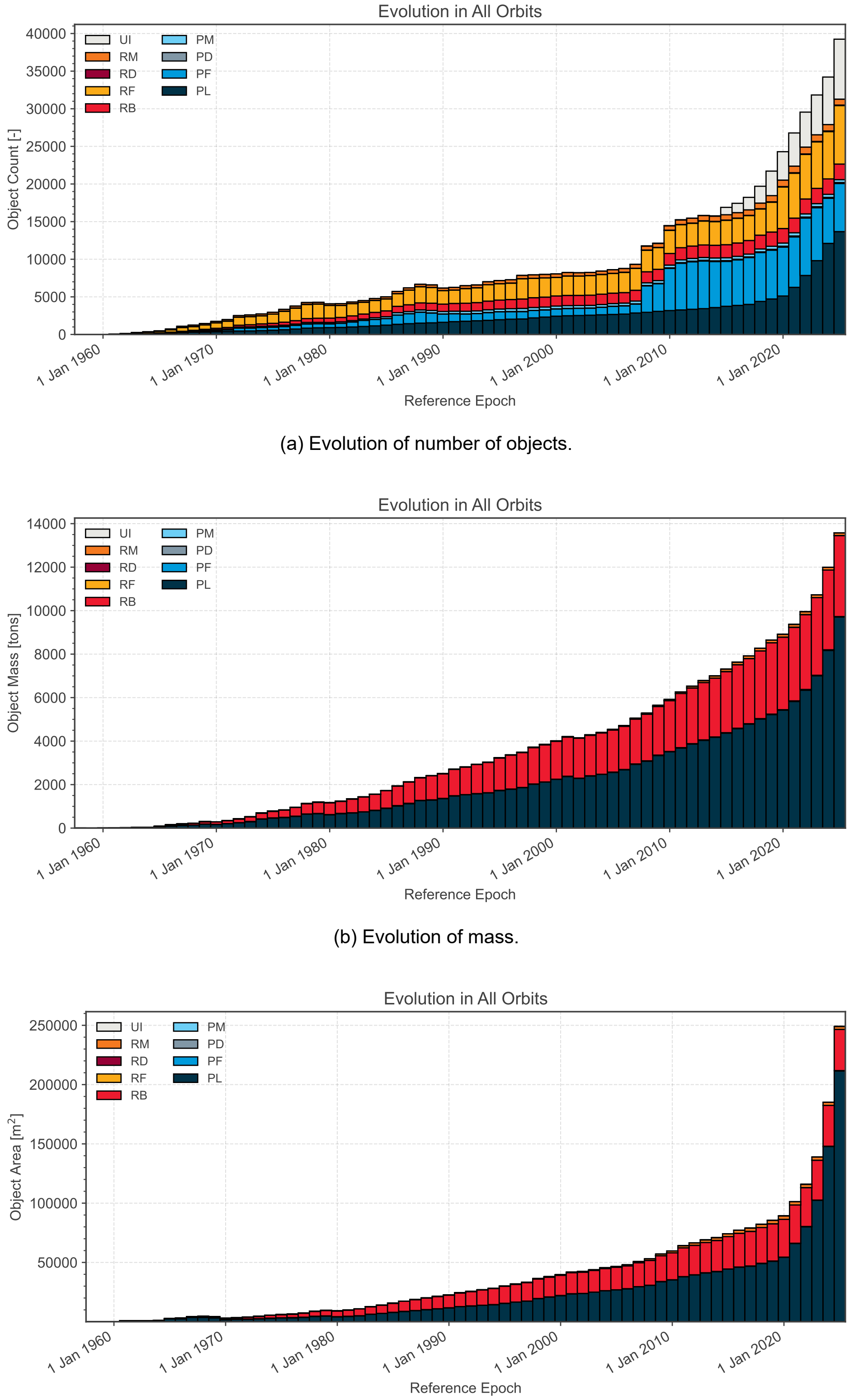
2.1. Overall Space Environment

Fig. 2.1 captures the evolution of the space environment in terms of number of objects, mass, and area in geocentric orbit by object class. This data is limited to catalogued and asserted objects, and hence at any given epoch limited to the capability of the space surveillance system in use at the time. A secondary effect hereof is that when new objects are detected due to increased sensor performance, they can generally not be traced back to an event or source and become classified as Unidentified. In Figures 2.2 the same data is presented by orbit class instead of object class. In Figures 2.3 the same data is presented in relation to the cumulative values for those properties in case they would not have been removed from orbit.

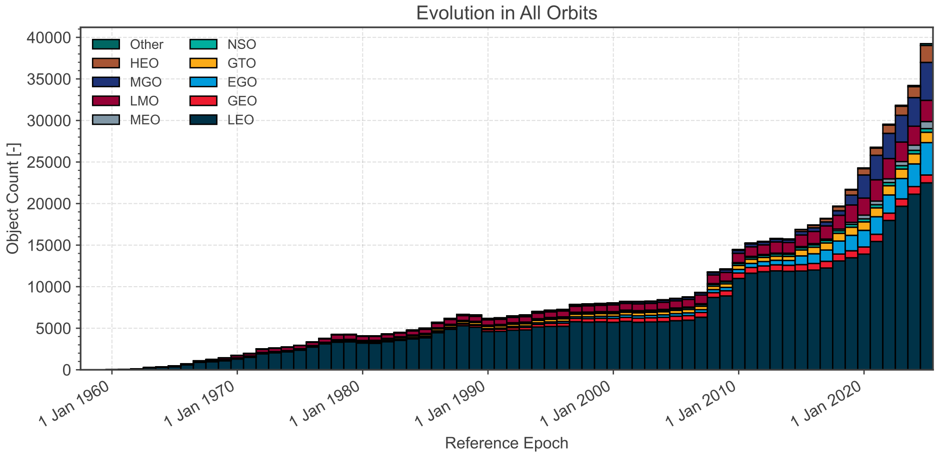


(a) Evolution of number of objects.

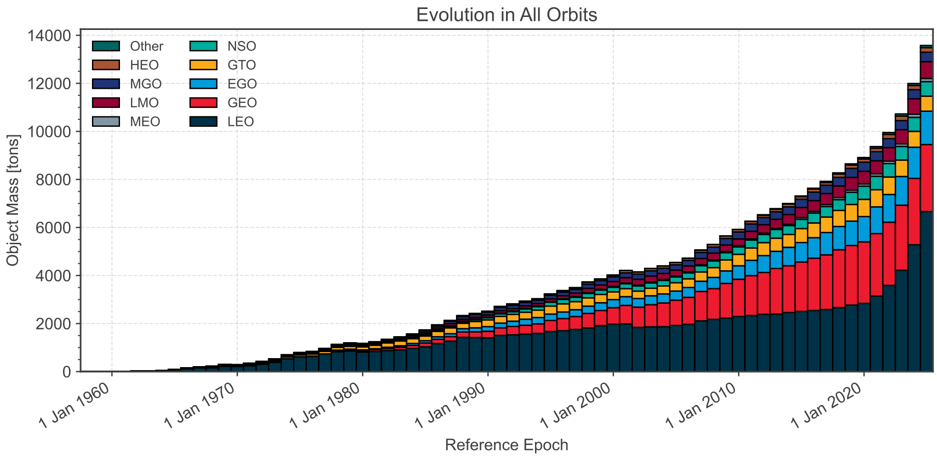
(b) Evolution of mass.

(c) Evolution of area.

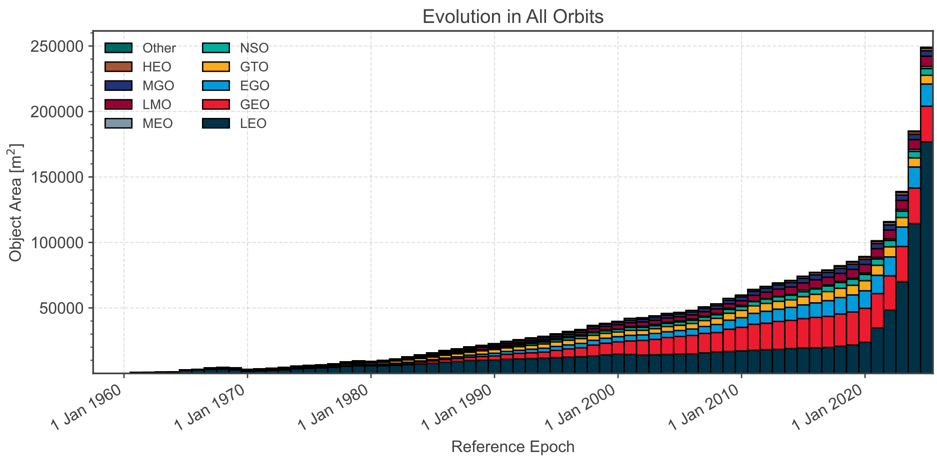
Figure 2.1: Evolution of number of objects, mass, and area in geocentric orbit by object class.



(a) Evolution of number of objects.

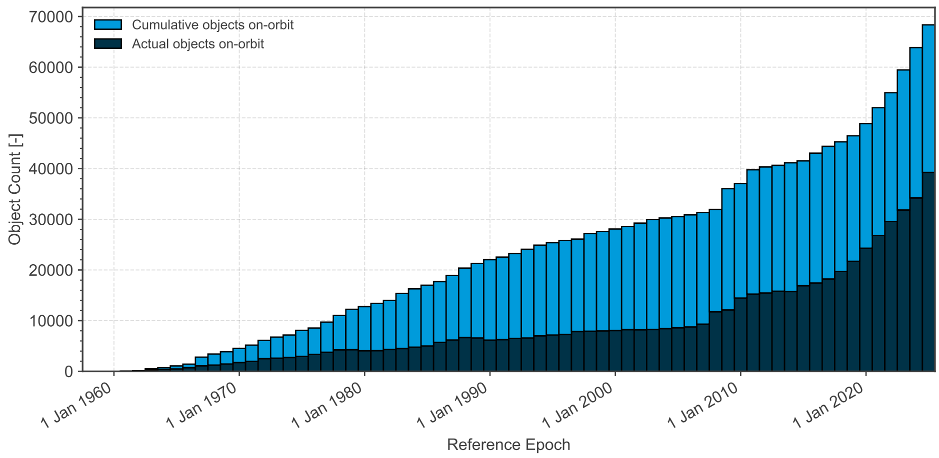


(b) Evolution of mass.

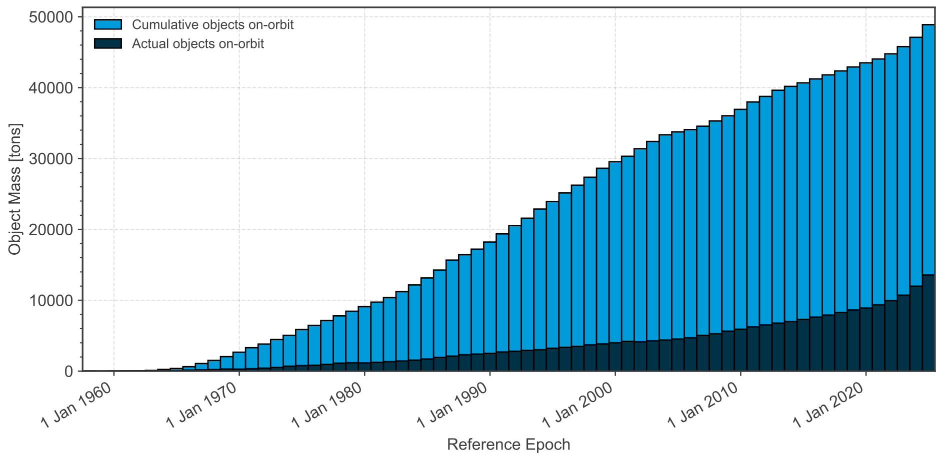


(c) Evolution of area.

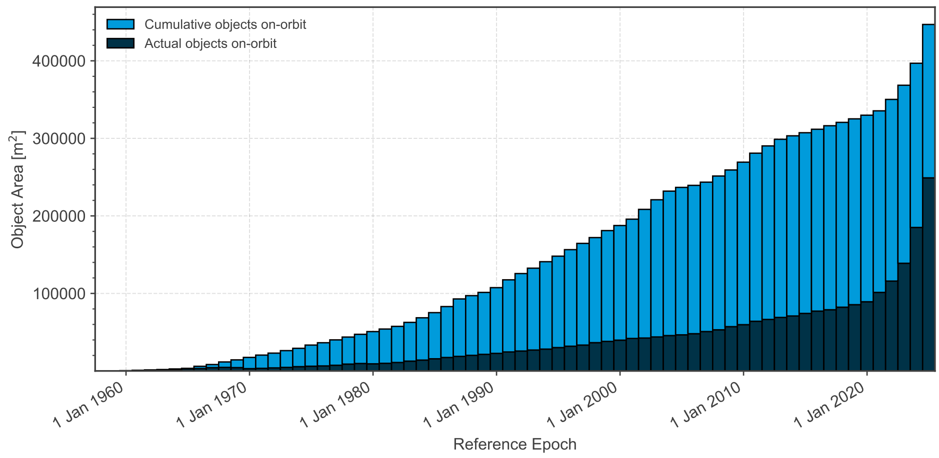
Figure 2.2: Evolution of number of objects, mass, and area in geocentric orbit by orbit class.



(a) Evolution of number of objects.



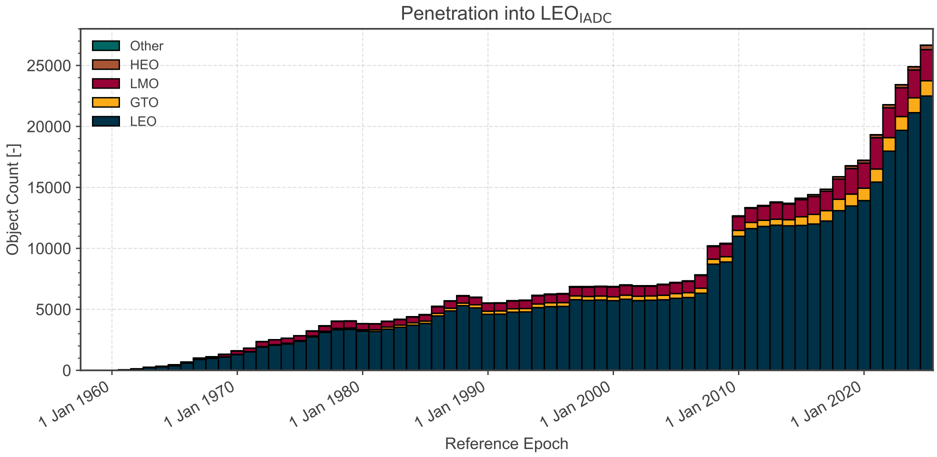
(b) Evolution of mass.



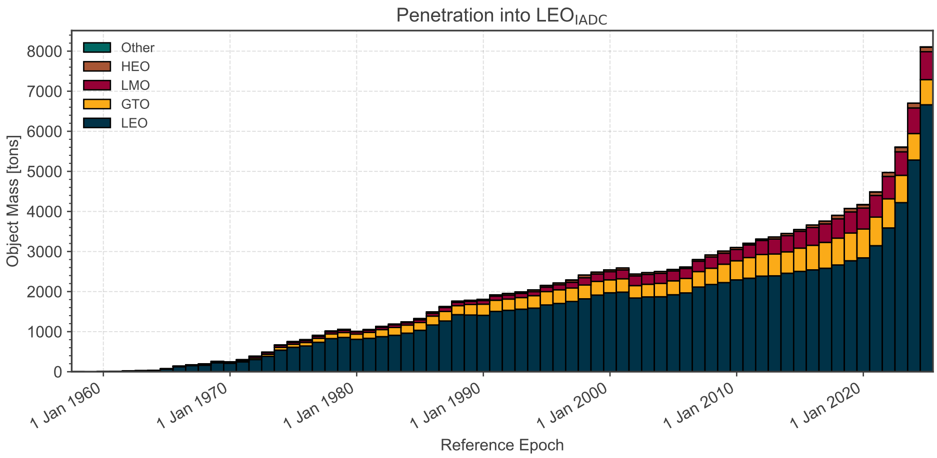
(c) Evolution of area.

Figure 2.3: Evolution of number of orbiting objects, mass, and area in geocentric orbit versus total number of objects.

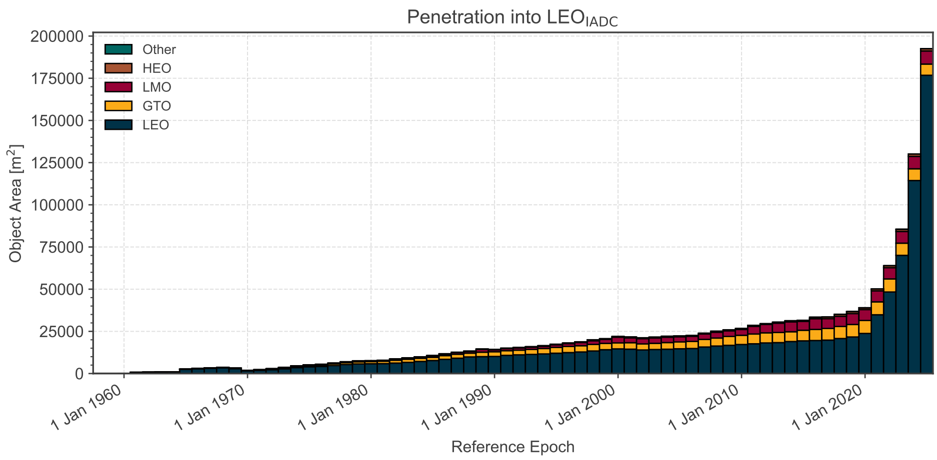
2.2. Evolution of Environment in LEO



(a) Evolution of absolute number of objects.

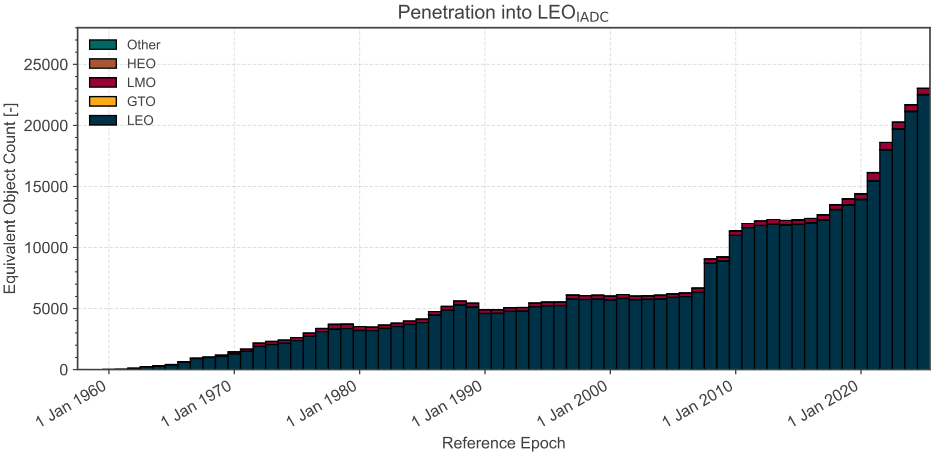


(b) Evolution of absolute mass.

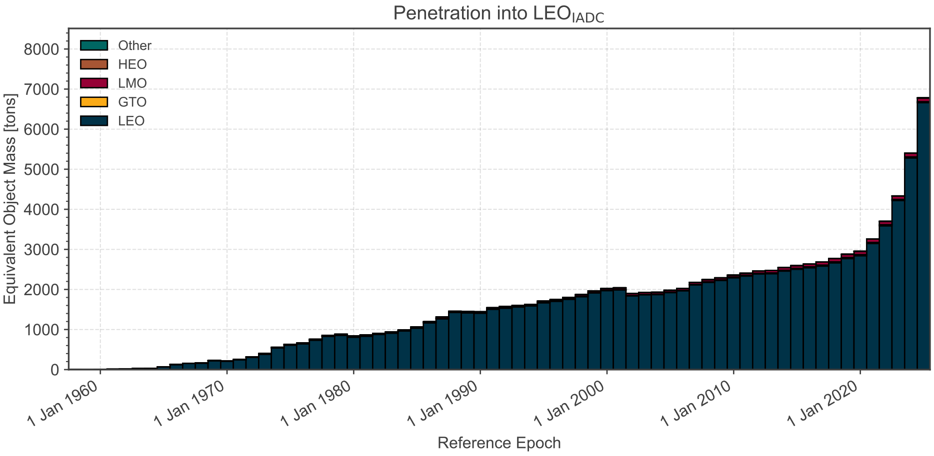


(c) Evolution of absolute area.

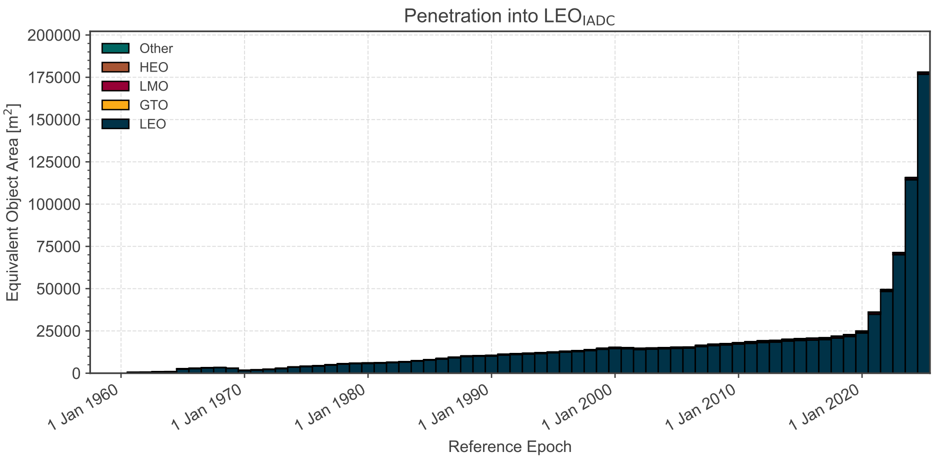
Figure 2.4: Evolution of absolute number of objects, mass and area residing in or penetrating LEO$_{IADC}$.



(a) Evolution of equivalent number of objects.



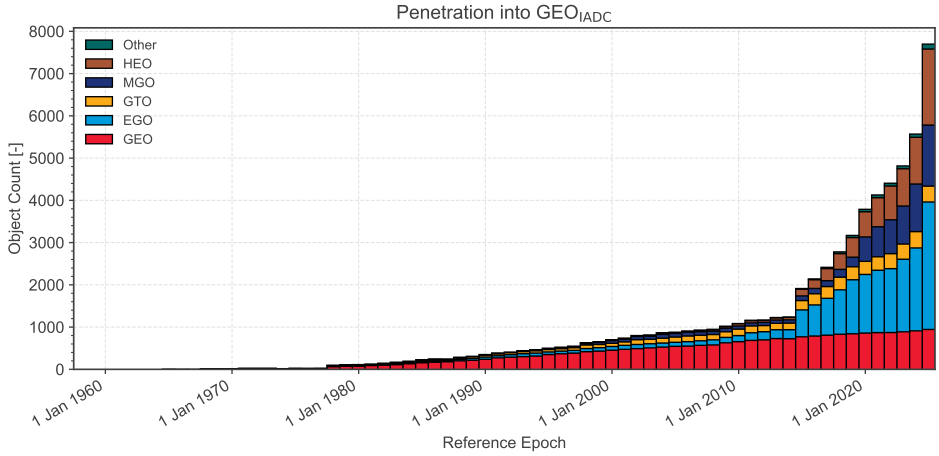
(b) Evolution of equivalent mass.



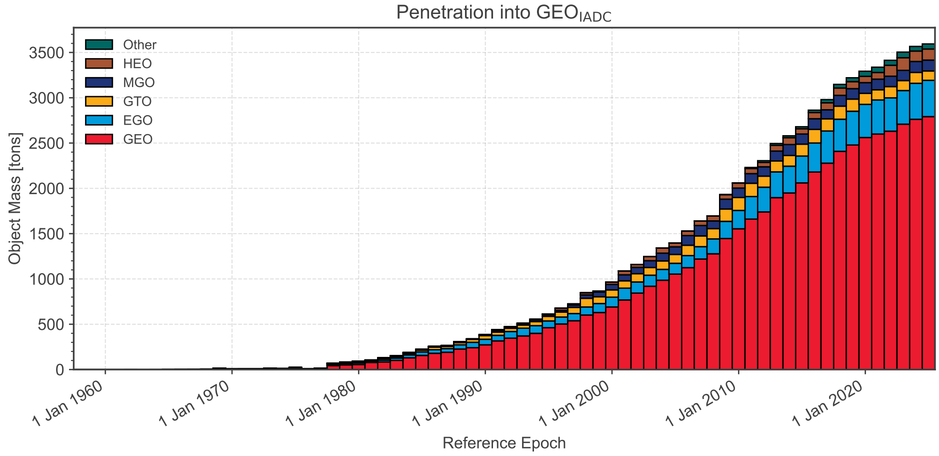
(c) Evolution of equivalent area.

Figure 2.5: Evolution of equivalent number of objects, mass and area residing in or penetrating LEO$_{IADC}$.

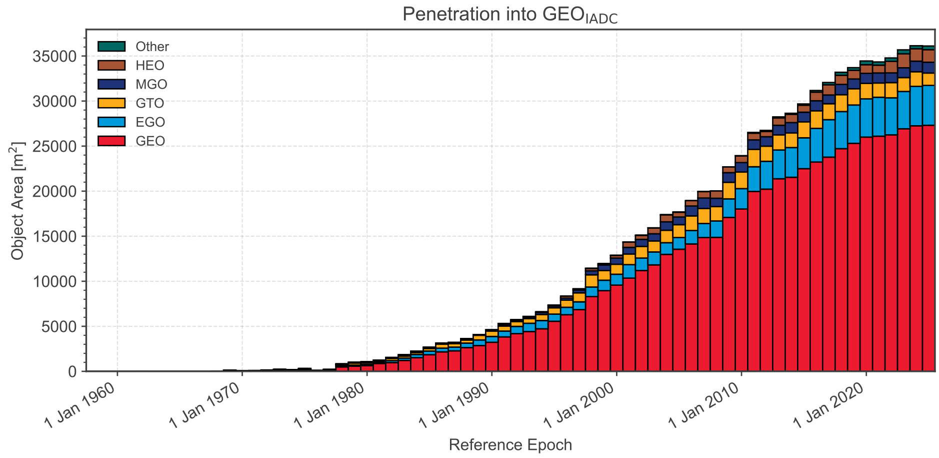
2.3. Evolution of Environment in GEO



(a) Evolution of absolute number of objects.

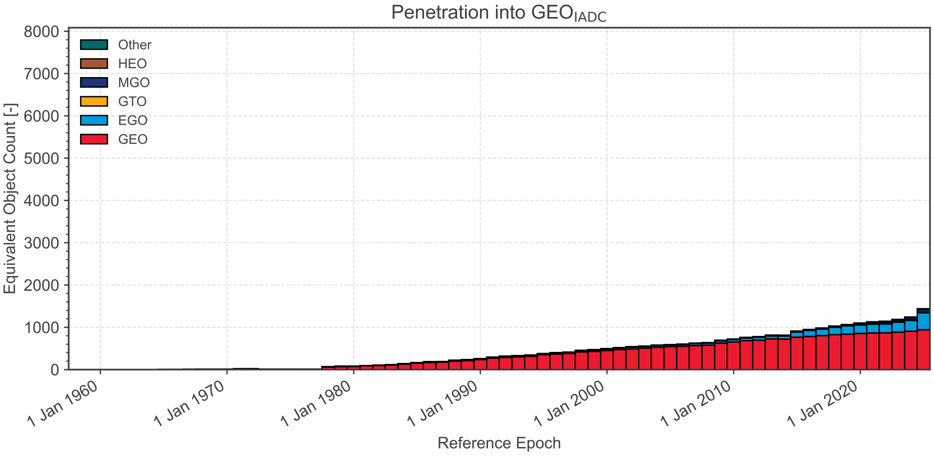


(b) Evolution of absolute mass.

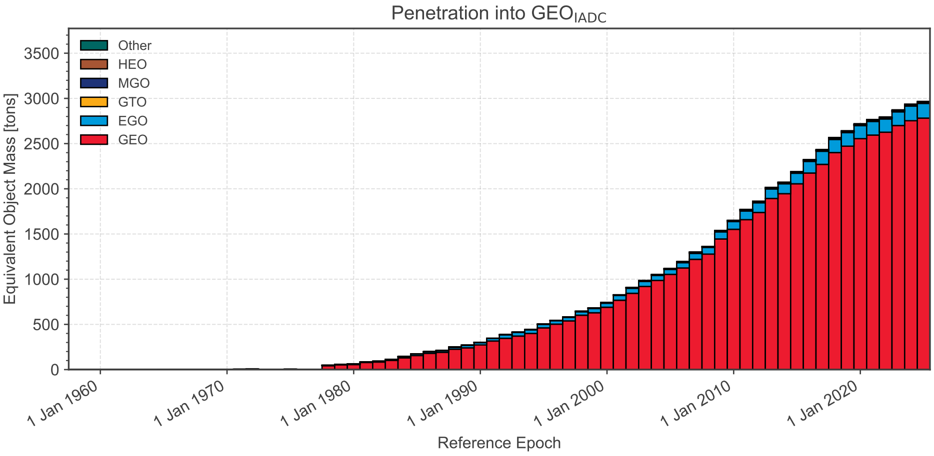


(c) Evolution of absolute area.

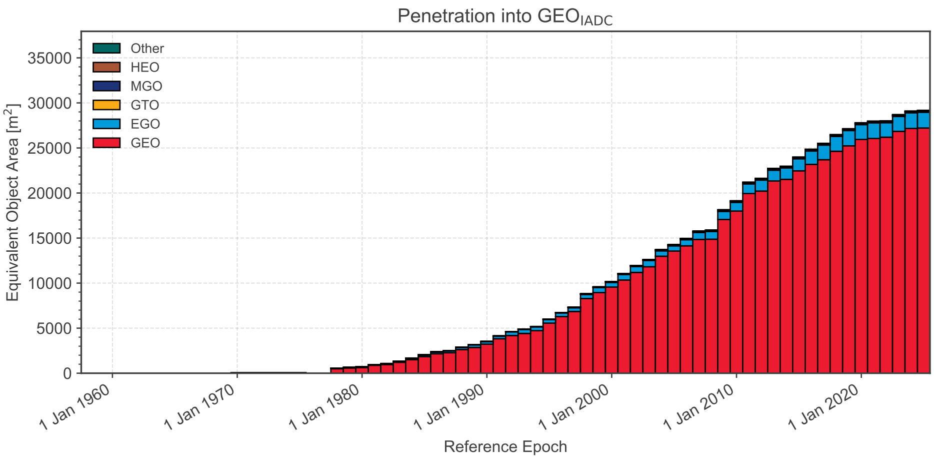
Figure 2.6: Evolution of absolute number of objects, mass and area residing in or penetrating GEO$_{IADC}$.



(a) Evolution of equivalent number of objects.



(b) Evolution of equivalent mass.



(c) Evolution of equivalent area.

Figure 2.7: Evolution of equivalent number of objects, mass and area residing in or penetrating GEO_{IADC}.

2.4. Non-catalogued and modelled objects

According to ESA's space debris environment model MASTER (Meteoroid and Space Debris Terrestrial Environment Reference), at the most recent reference epoch 1st August 2024, the estimated number of space objects in orbit in the different size ranges is the following:

- 54.000 objects greater than 10 cm (including approximately 9300 active payloads),
- 1.2 million objects from 1 cm to 10 cm,
- 130 million objects from 1 mm to 1 cm.

The distribution of the number of objects as a function of their size is shown in Fig. 2.8: the plot shows the number of objects larger than the threshold diameter indicated in x-axis, considering space objects crossing the LEO regime. Fig. 2.9 shows the density profiles with altitude corresponding to different minimum object sizes (respectively 10 cm in dark blue and 1 cm in red), considering only the LEO region. The logarithmic scale is used in the y-axis to take into account the different orders of magnitude corresponding to the two populations.

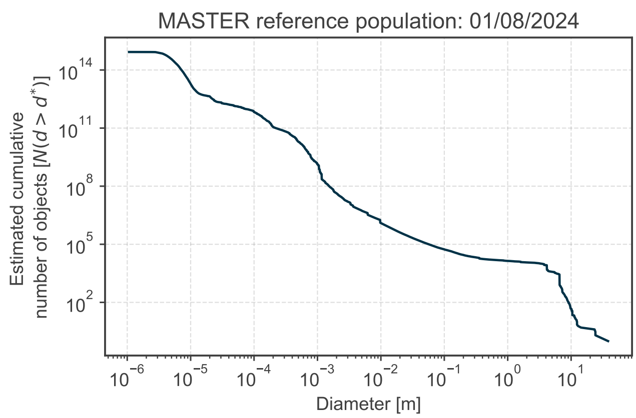


Figure 2.8: Estimated number of space objects crossing LEO as a function of the object diameter from the 01/08/2024 reference population.

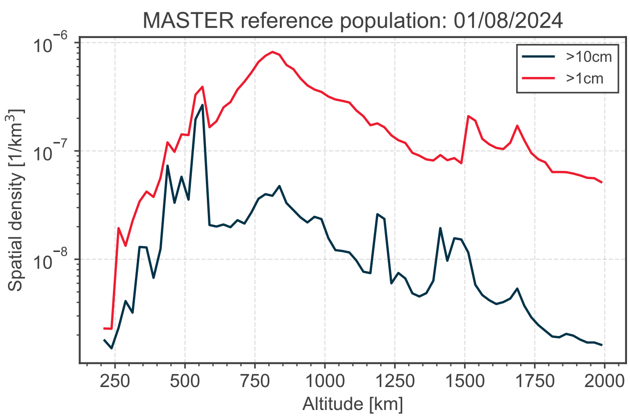


Figure 2.9: Density profiles in LEO for different space object size ranges from the 01/08/2024 reference population.

Fig. 2.10 shows the density profiles with altitude for space objects larger than 10 cm, considering only the LEO region, for the most recent reference epoch 1st August 2024, as well as for the previous MASTER population release, with reference epoch 1st November 2016. In particular, this highlights the contributions coming from constellations as well as fragmentation events.

Similarly, Fig. 2.11 shows the difference for space objects larger than 1 cm. Whereas historically, the 1 cm population mostly consisted of fragments, this paradigm has now changed for selected altitudes used by constellations, and the density of active payloads is approaching that of space debris in these heavily populated orbits.

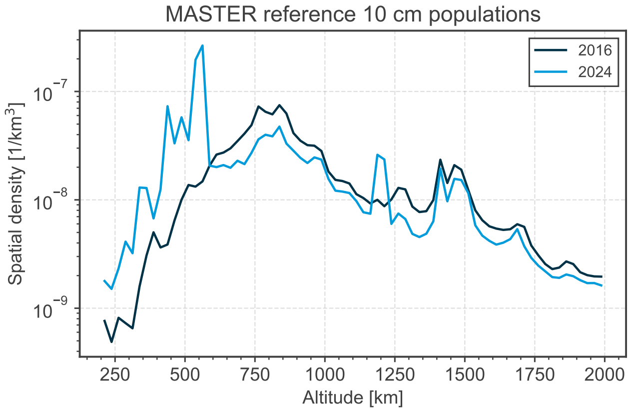


Figure 2.10: Density profiles in LEO for space objects larger than 10 cm for the 01/08/2024 and 01/11/2016 reference populations.

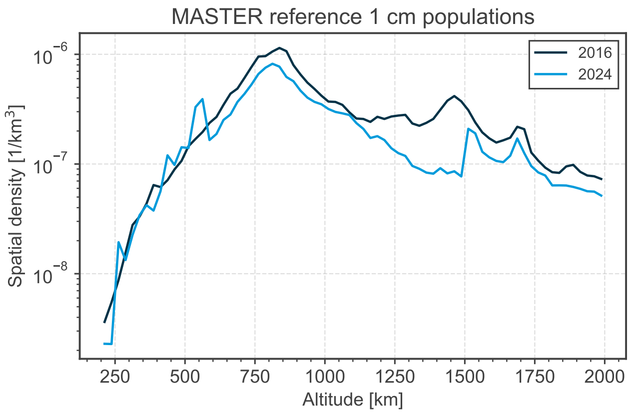


Figure 2.11: Density profiles in LEO for space objects larger than 1 cm for the 01/08/2024 and 01/11/2016 reference populations.

2.5. Usage of the Protected Regions

This section aims to provide an overview of the usage of the protected regions in terms of launch traffic as represented by object count and mass, given that the stability of the space environment is dependent on them.

From a historical point of view, the launch traffic of Payloads can be categorised in terms of the main funding source (Civil, Defence, Commercial, Amateur) or in terms of the main missions type (Communication, Imaging, Navigation, etc.). The Amateur category includes those Payloads associated by academic institutions when none of the other entities are the driving contributor. Payloads that are deployed from the International Space Station (ISS) are identified with a separate label as part of the launch traffic.

In case of Rocket Bodies, it is of importance which launcher family is generating the traffic to orbit, given that the adherence level to space debris mitigation guidelines correlates with this family identifier. These families are to be understood as major stable design versions of a launcher, e.g. covering performance improvements but not engine changes. New families can appear sporadically and in this report the most regularly used ones over recent years are identified. Earlier families of launchers are grouped under *Used earlier*.

Of increasing importance in a changing space traffic landscape are also the so-called *ride-share* launch opportunities, where a single launch vehicle carries a multitude of Payloads from different entities into orbit. For the purpose of this report, ride-share launches are defined as those launches that carry Payloads with at least three different mission domains and at least ten Payloads in total. A *mission domain* is defined by the combination of mission type, funding, and operator.

For Payload objects in LEO_{IADC}, it is instructive to analyse not only where they reside now, but also how the destination orbits that enable their operations evolve over time. In particular, as space debris mitigation measures focus on limiting orbital lifetimes, adoption of these practice leaves a noticeable imprint on the data. This imprint can distinctively visible as a function of the mission domain, in particular when distinguishing between constellation and non constellation objects.

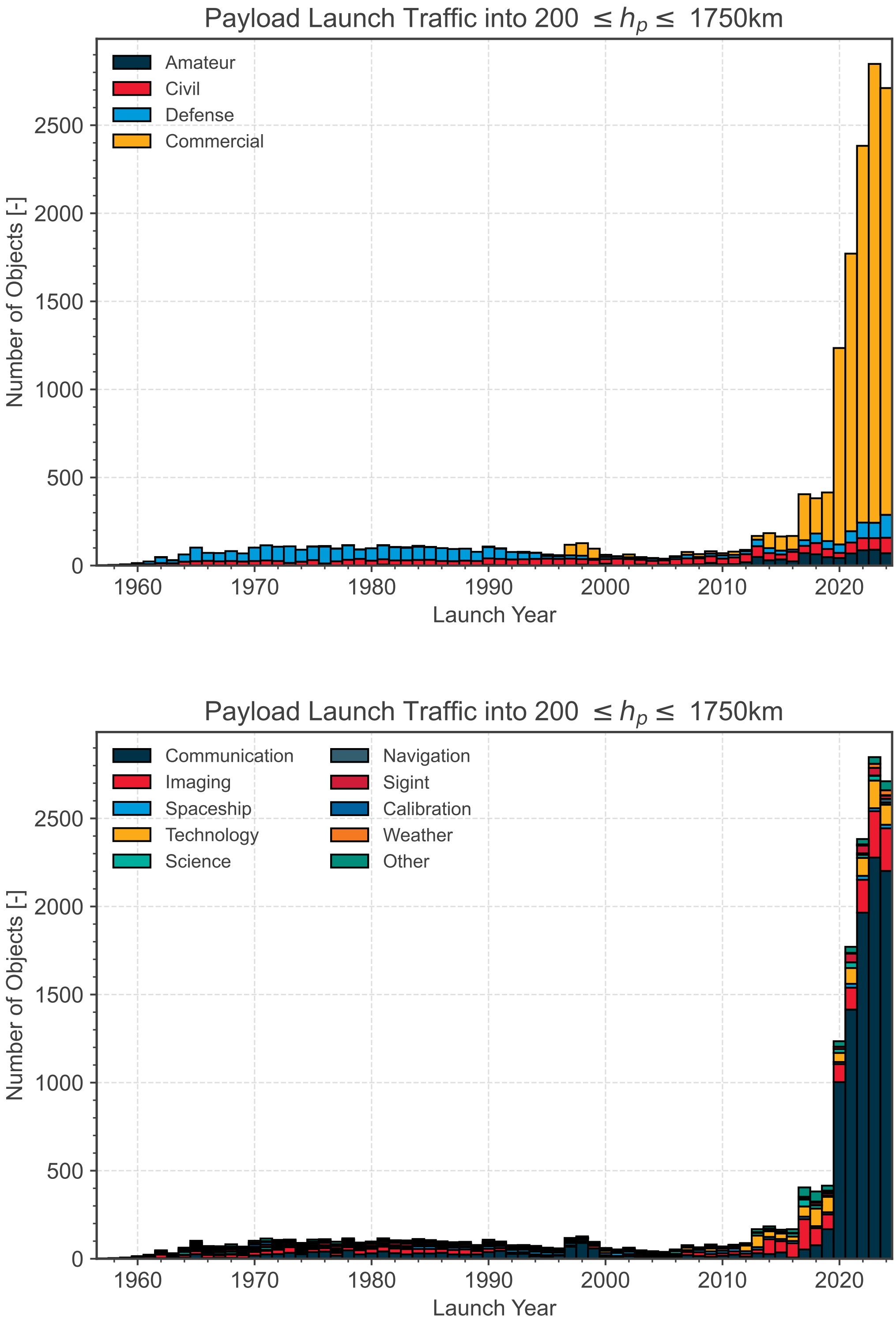


Figure 2.12: Evolution of the launch traffic near LEO_{IADC} per mission funding (top) and type (bottom).

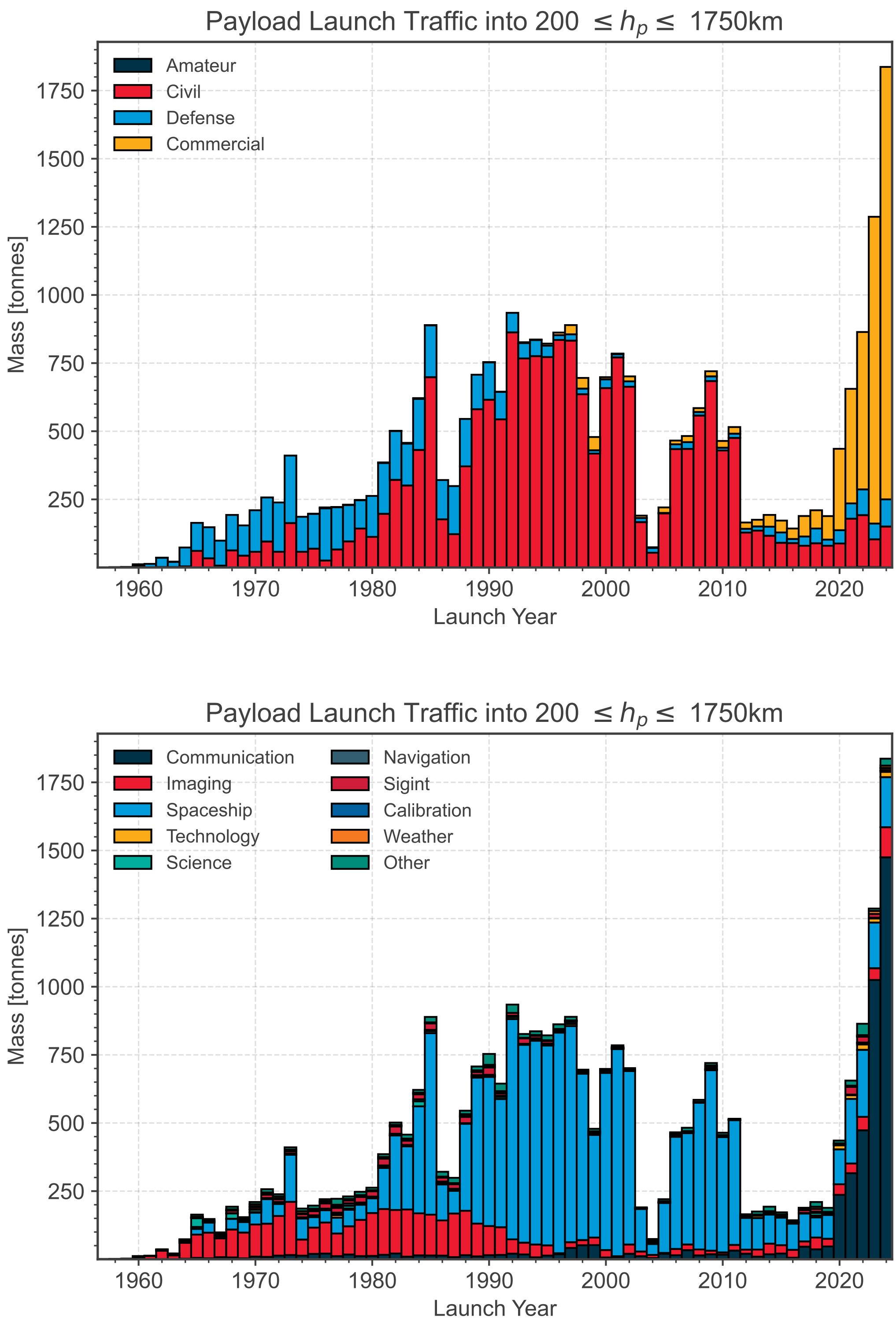
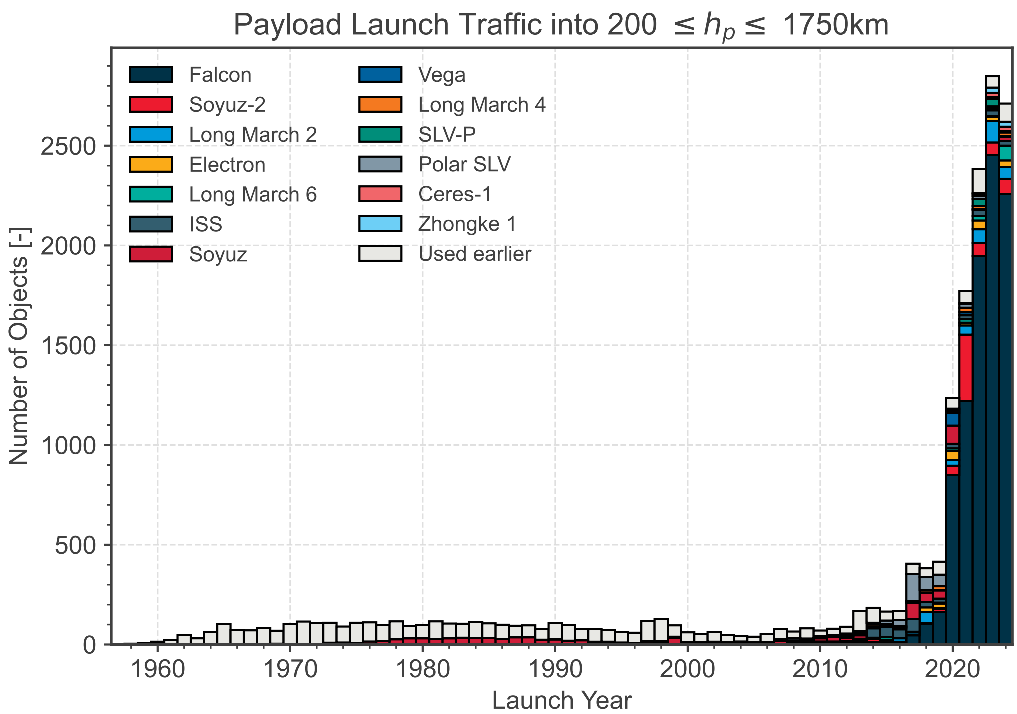


Figure 2.13: Evolution of the launch traffic near LEO_{IADC} per mission funding (top) and type (bottom) in terms of mass.



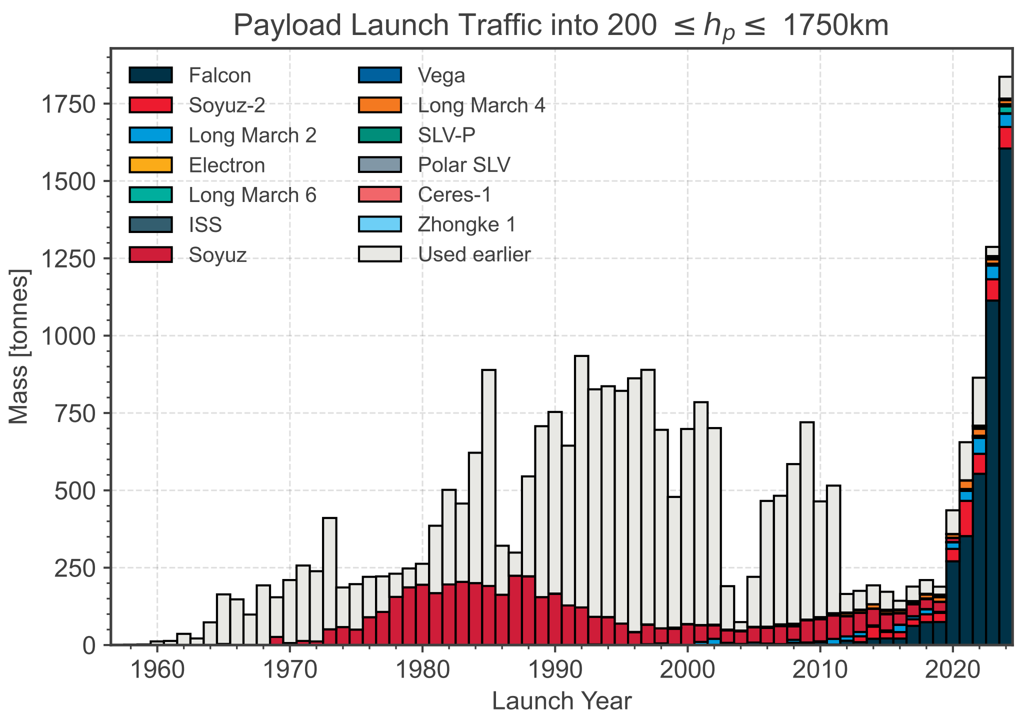
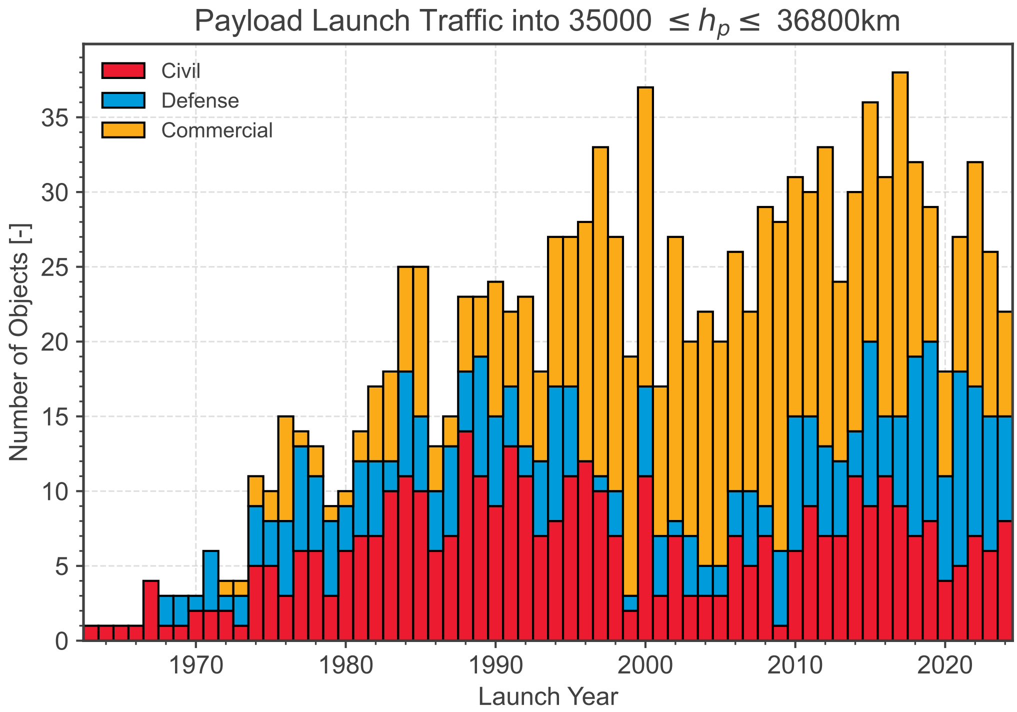


Figure 2.14: Evolution of the launch traffic near LEO_{IADC} per launcher family expressed in terms of number of objects (top) and mass (bottom).



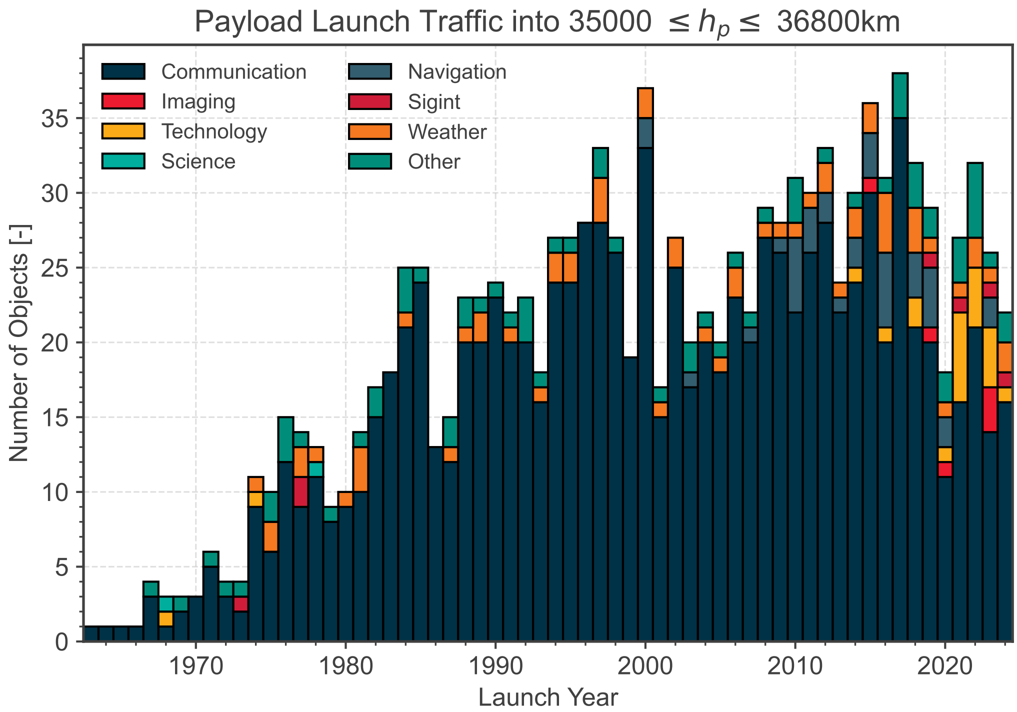
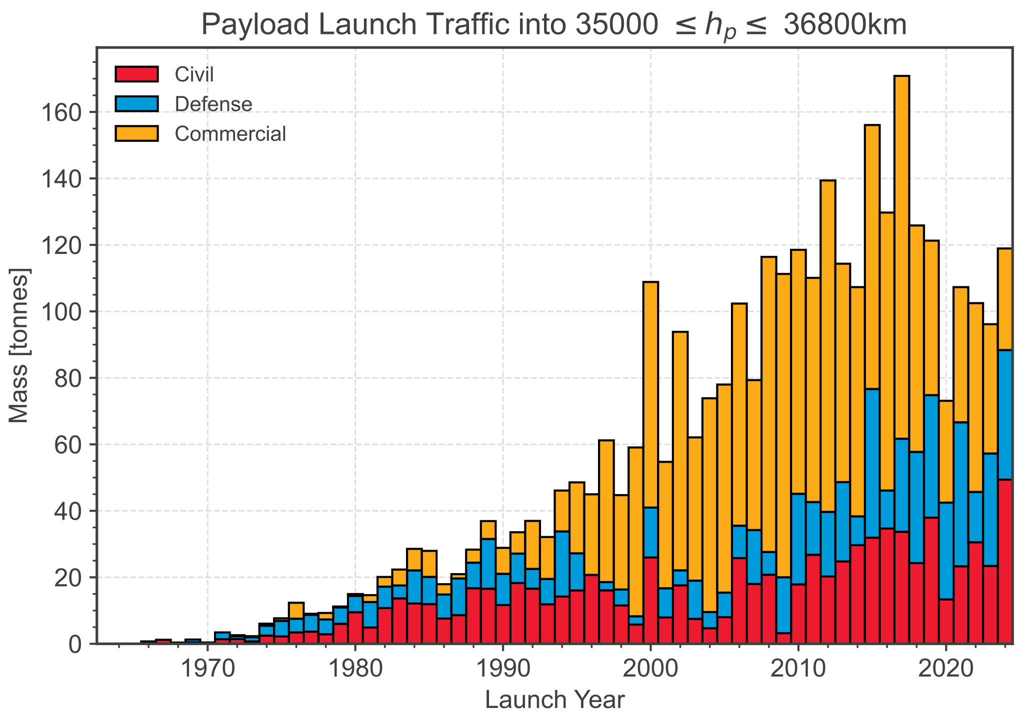


Figure 2.15: Evolution of the launch traffic near GEO_{IADC} per mission funding (top) and type (bottom).



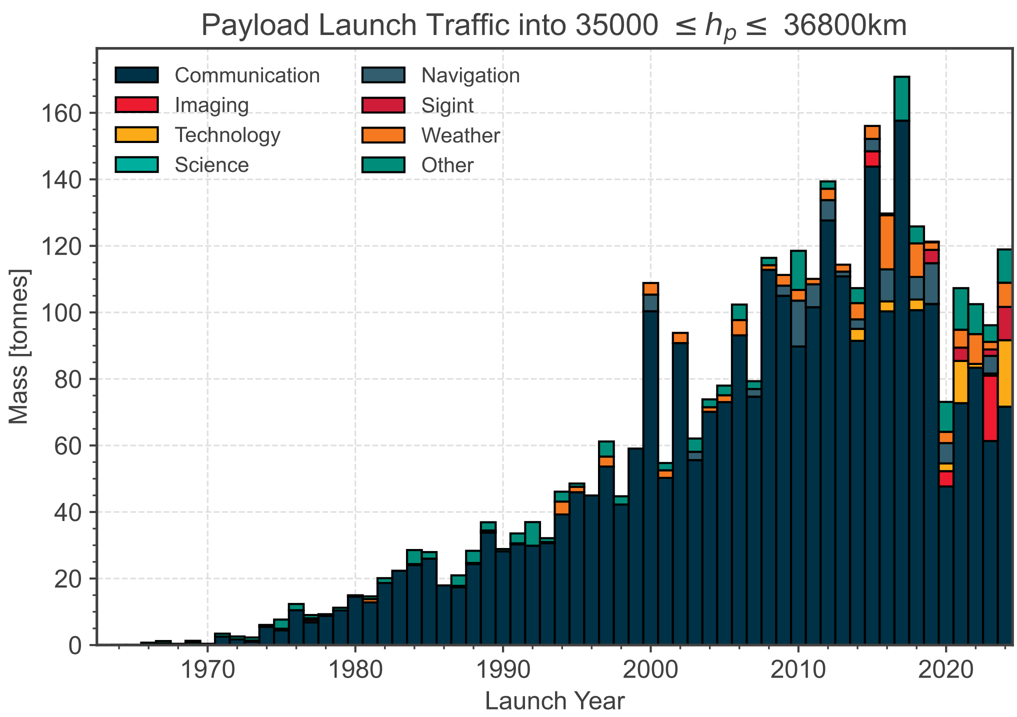
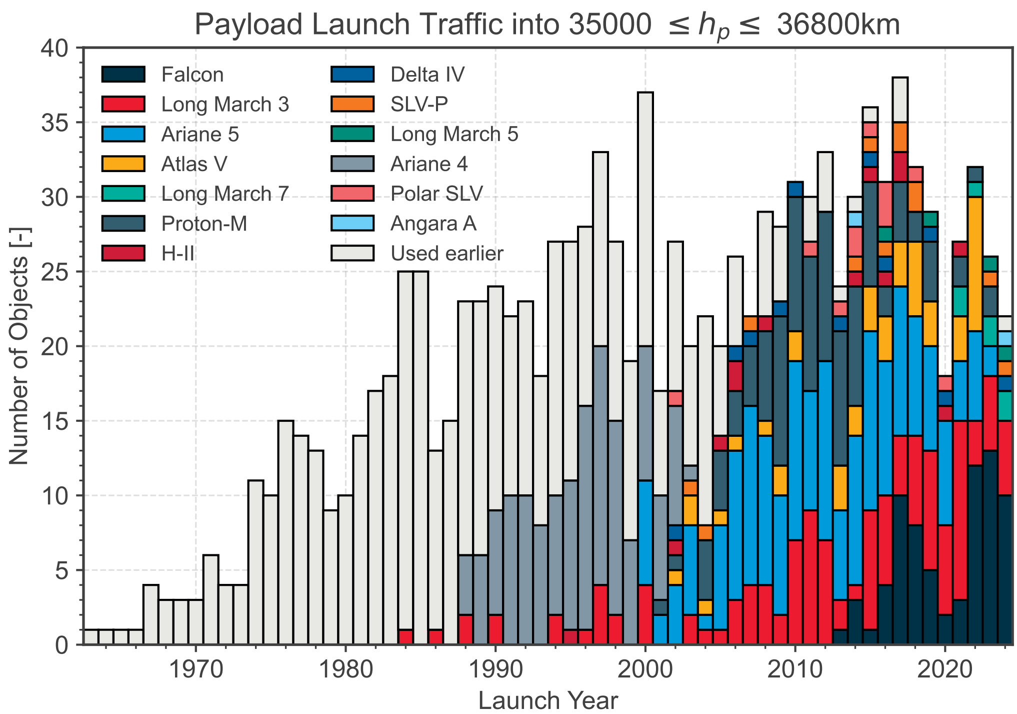


Figure 2.16: Evolution of the launch traffic near $\mathrm{GEO}_{\mathrm{IADC}}$ per mission funding (top) and type (bottom) in terms of mass.



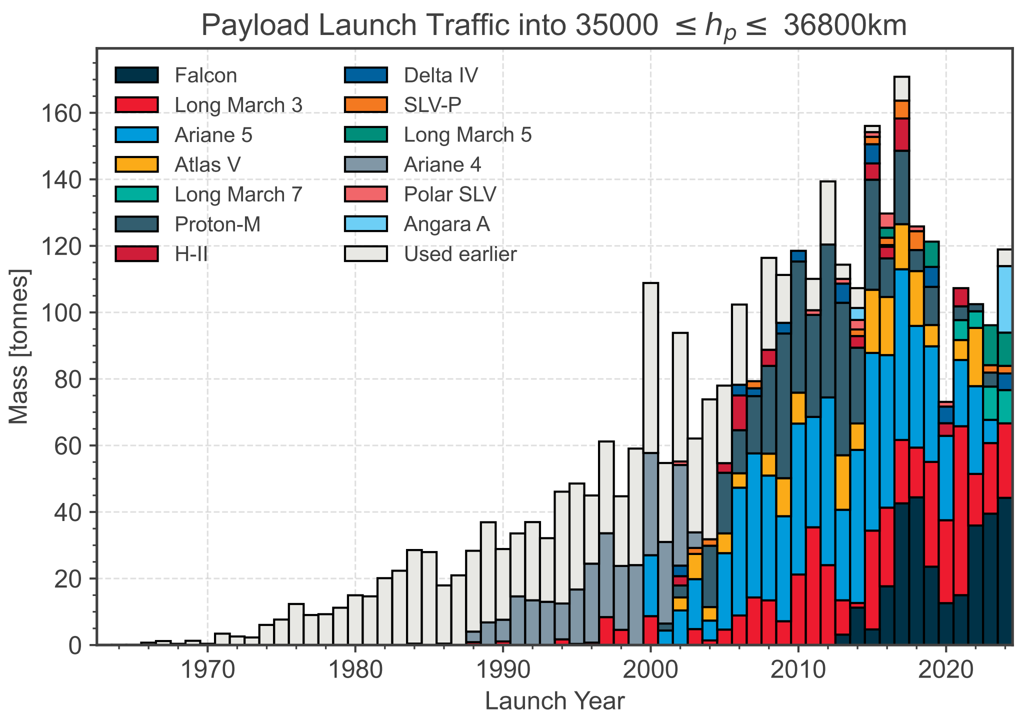
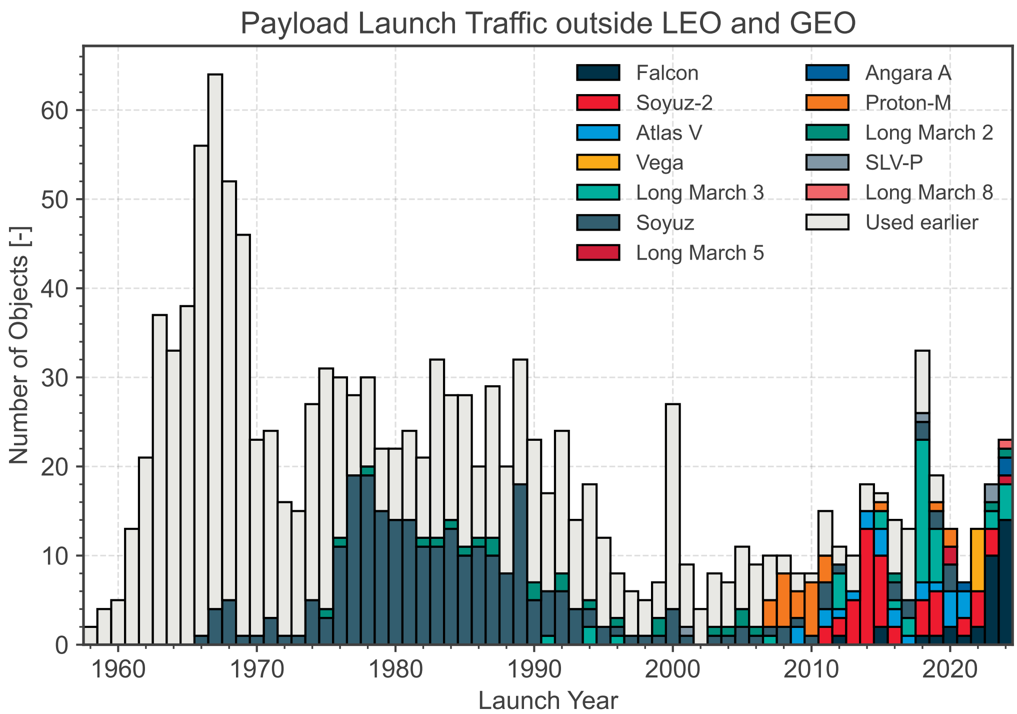


Figure 2.17: Evolution of the launch traffic near GEO_{IADC} per launcher family expressed in terms of number of objects (top) and mass (bottom).



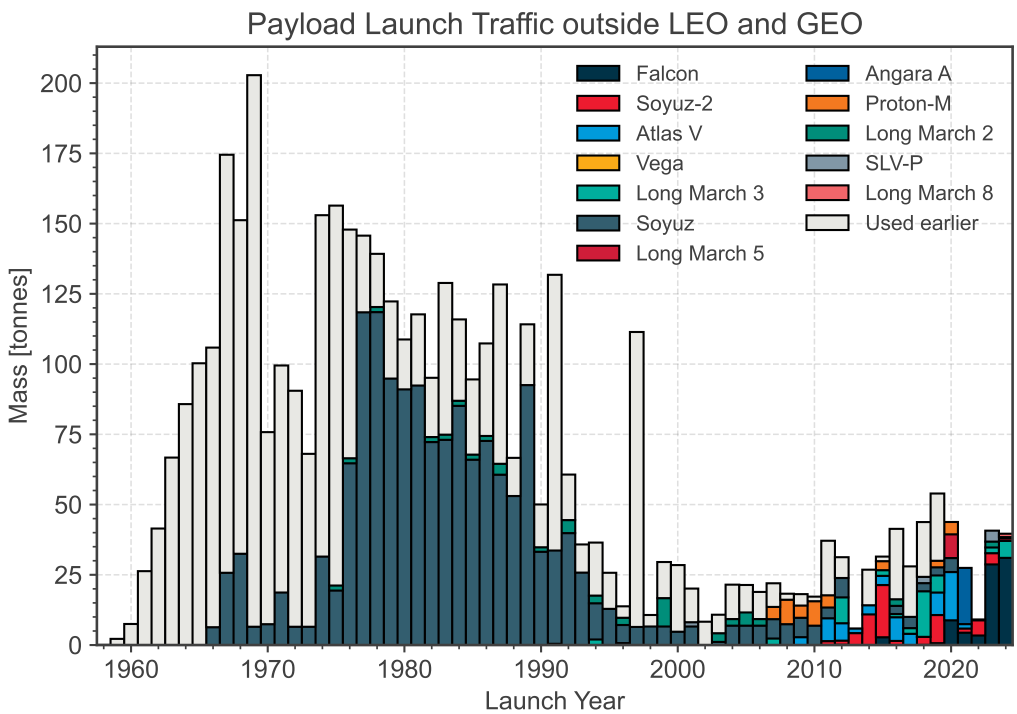
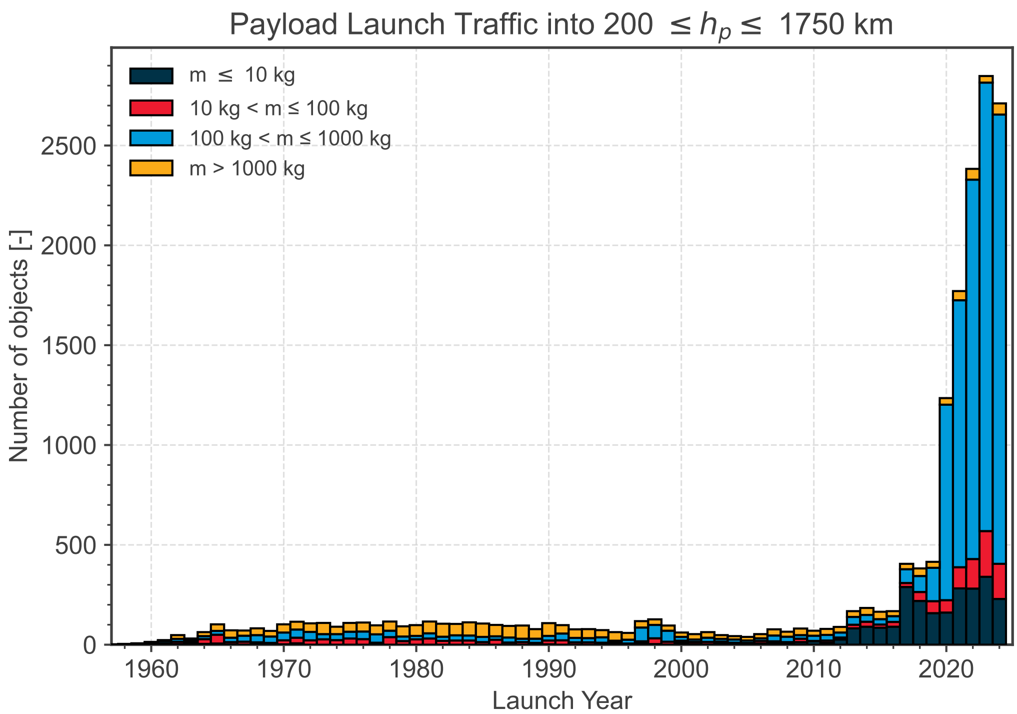


Figure 2.18: Evolution of the launch traffic outside LEO_{IADC} and GEO_{IADC} per launcher family expressed in terms of number of objects (top) and mass (bottom).



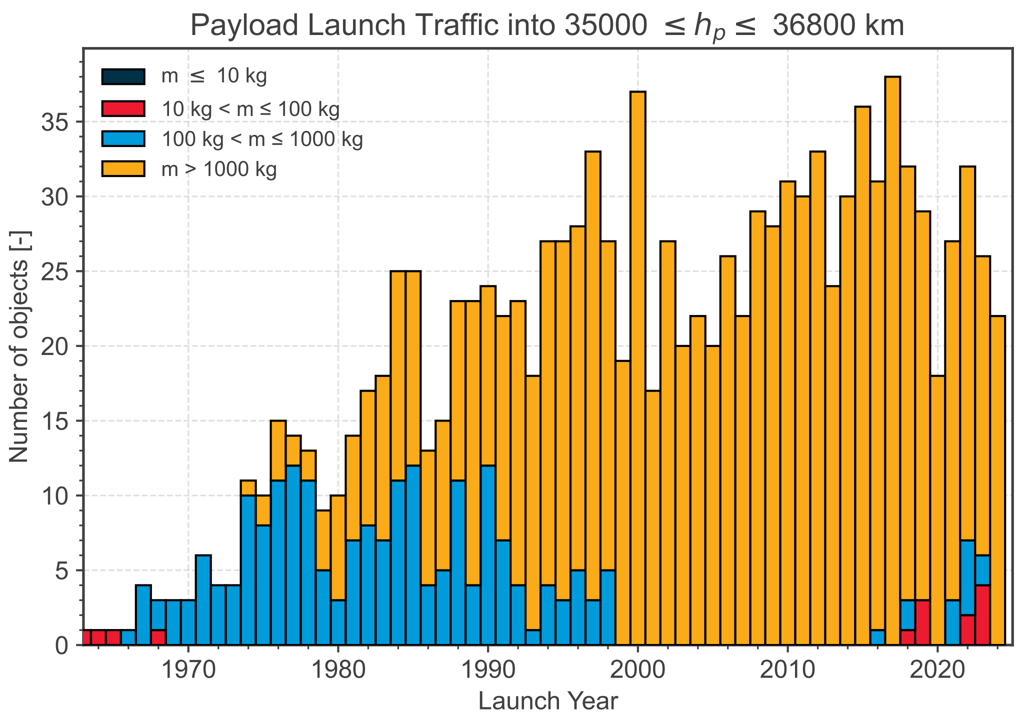
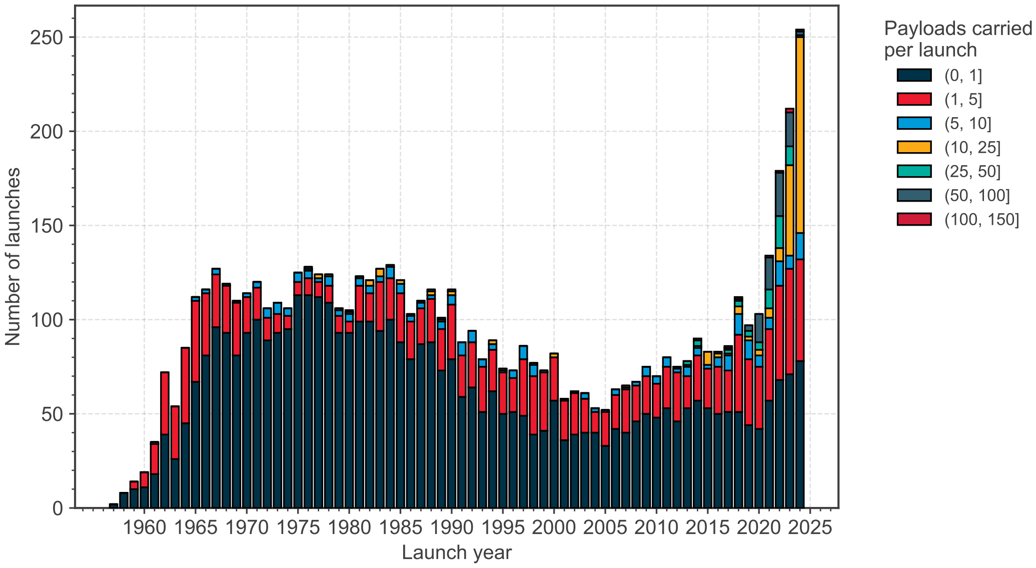
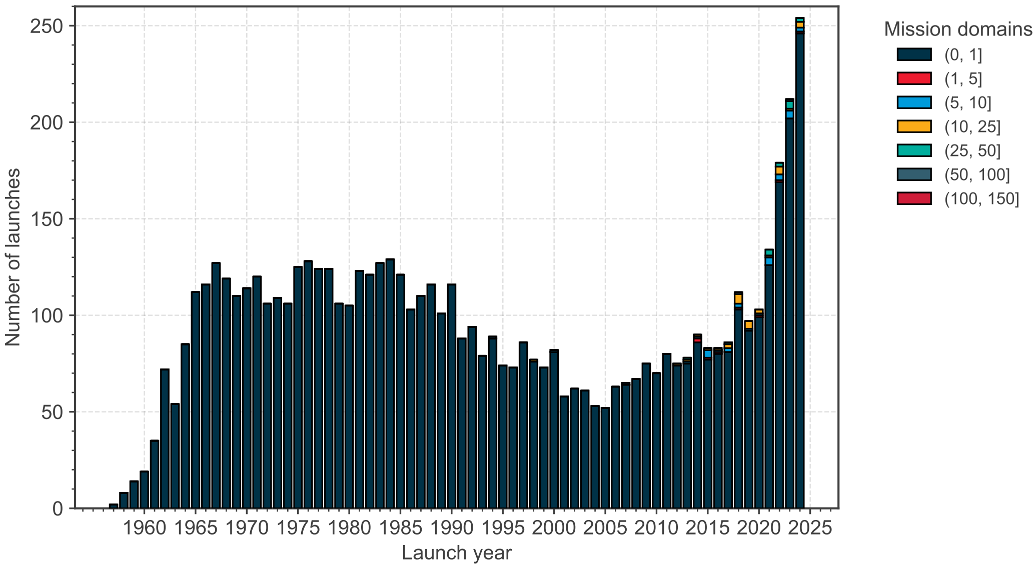


Figure 2.19: Evolution of the launch traffic per mass category in terms of number of objects in LEO_{IADC} (top) and GEO_{IADC} (bottom).



(a) Payloads



(b) Mission domains

Figure 2.20: Evolution of the launch traffic.