1 Introduction

When the Pioneer 10 spacecraft entered the interplanetary space beyond Jupiter’s orbit, it detected an almost constant flux of impacts by dust particles larger than 10 \( \mu m \). This was unexpected, as the dust from comets, which were the only potential sources of dust known at the time, is believed to be less concentrated at larger heliocentric distances. At the time, an exotic distribution of cometary orbits had to be introduced in order to explain the Pioneer data. Dust from outside the solar system can not explain the constant flux detected by the Pioneer experiments, because the interstellar flux of dust particles large enough to be detectable by the Pioneer instruments is at least an order of magnitude lower than the detected flux. The discovery of objects in the Edgeworth-Kuiper belt (EKB) offered the possibility for another dust source: The objects in the EKB should produce dust by mutual collisions and by collisions with interstellar dust particles, forming a disk of dust around the Sun. Modelling the evolution of the orbits of dust grains from the EKB showed, that indeed the Pioneer data can only be explained by dust migrating in from the EKB under the influence of the Poynting-Robertson drag.

Unfortunately the Pioneer dust measurements extend only to a heliocentric distance of 18 AU, where the instrument ceased function. Consequently, Pioneer detected merely the inner edge of the solar system dust disk. Here the question arises, what the radial density profile of the solar system dust disk is and what processes govern the evolution of the dust grains after the release from the parent body. Because we do not know the collisional lifetime of dust grains from the EKB, it is unclear, what fraction of EKB dust grains survives the evolution to inside the orbit of Uranus, where Pioneer 10 made its far most measurements. We present a prediction of the dust detection rate of the planned New Horizons mission using the same model that was employed to analyse the Pioneer data. We show what the signature of different dust lifetimes will be in the data collected by this mission.

2 Modelling the Solar System Dust Disk

The evolution of a dust grain released by an EKB object depends mainly on two parameters: it’s collisional lifetime, and its susceptibility to solar radiation pressure, which is parameterised by the constant ratio \( \beta \) of radiation pressure force to gravity. Here we assume values of \( \beta \) of 0.03, 0.08, 0.2, and 0.5. The value of \( \beta \) is mainly controlled by the grain size. Assuming a homogeneous spherical grain with a bulk mass density of 1 g cm\(^{-3}\), the value \( \beta = 0.03 \) corresponds to a grain diameter of 16 \( \mu m \), \( \beta = 0.08 \) to a diameter of 6 \( \mu m \), \( \beta = 0.2 \) to a diameter of 3 \( \mu m \), and \( \beta = 0.5 \) to a diameter of 1 \( \mu m \). For the sources of the dust grains we assume all 420 trans-Neptunian objects listed with the Minor Planet Center of the IAU that have been observed at more than one opposition. Upon release the dust grains acquire orbits different from those of their parent bodies due to the effect of solar radiation pressure.

The grain’s orbits evolve under the effect of the Poynting-Robertson drag towards the inner solar system. On the way inwards they can be trapped in mean motion resonances (MMRs), or can be destroyed by a collision with an interstellar or another EKB dust grain. Using the same method as we have simulated the evolution of grains with \( \beta = 0.03 \) for a collisional lifetime of \( 10^6 \) a. In panel b) the distribution for grains with \( \beta = 0.03 \) is shown if no collisions are considered. Panel f) shows the orbits of Jupiter, Saturn, Uranus, Neptune, and Pluto, and the positions of EKB objects predicted for the epoch of the planned fly-by of Pluto by the New Horizons mission in 2016.

Figure 1: Spatial density distribution of dust from EKB objects (normalised logarithmic colour scale: blue=0.001, red=1) in a 120 AU x 120 AU sub-plane of the ecliptic. Panels a), c), d), and e) show the distribution of grains with \( \beta = 0.03, 0.08, 0.2, \) and 0.5 respectively for a collisional lifetime of \( 10^6 \) a. In panel f) the distribution for grains with \( \beta = 0.03 \) is shown if no collisions are considered.
the dust grains is determined by ejection from the solar system by a close encounter with a giant planet or by falling into the Sun. Figure 1 shows the spatial density distributions for the different values of $\beta$ and also for the case without collisions.

The simulation shows that the larger grains (with smaller values of $\beta$) are concentrated in a ring near the source region. For larger values of $\beta$ the disk becomes more extended and distributed with lower peak densities. This is because the grains with higher $\beta$ exhibit high eccentricities and large semi-major axes (typically 150 AU for $\beta = 0.5$) immediately after their release. If there were no collisions even these grains would ultimately circle towards the Sun. The case without collisions (figure 1 b)) demonstrates this effect. The inner solar system is well populated, especially MMRs with the giant planets, which show up as concentric rings in the figure.

Figure 2: Prediction of impactor flux (normalised) onto the dust instrument of the New Horizons mission. The blue curve shows the prediction for dust grains with $\beta = 0.03$ and a collisional lifetime of $10^6$ a, and the green curve for grains with $\beta = 0.03$ that are not subject to collisional destruction.

4 Conclusion

We have simulated the evolution of the distribution of cosmic dust generated by EKB objects using realistic initial orbits and considering various values for the strength of radiation pressure and the collisional lifetime. The simulation together with the measurements of dust by the Pioneer spacecraft allows a prediction of the expected impactor flux on the future New Horizons mission.

New Horizons will be able to distinguish two different kinds of dust evolution in the EKB: driven by collisions or orbit migration under Poynting-Robertson drag. The main unknown here is the rate of collisions with interstellar dust particles. If not collisions but Poynting-Robertson dominate the evolution of EKB dust, the dust flux measured by New Horizons beyond 20 AU can be expected to be constant at the level that was measured by Pioneer 10. If, on the other hand, the flux of interstellar dust grains larger than 1 $\mu$m is $10^{-4}$ m$^{-2}$ s$^{-1}$ in the outer solar system, equal to the flux measured by the Ulysses mission inside the orbit of Jupiter, then the average collision rate on a EKB dust grain with a diameter of 16 $\mu$m is about one every $10^6$ years. The curve in figure 2 shows that the dust population detected by Pioneer 10 at a heliocentric distance of 18 AU is then merely a tiny fraction of the dust that is more abundant by two orders of magnitude outside 30 AU, closer to its sources. In that case New Horizons can expect to find a very high flux of more than $10^{-4}$ m$^{-2}$ s$^{-1}$, or about 10 hits per day for each square meter of sensitive area.

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