2 Non-gravitational forces in the Solar System

2.1 A brief history of non-gravitational phenomena

We present a historical 'timeline' of important discoveries connected with non-gravitational phenomena here. The list is sorted by the year of discovery and it is supplemented by several figures, explaining briefly the non-gravitational effects, which we do not discuss elsewhere in the thesis. Most of the data were taken from *Wikipedia*.

1540 Peter Apian (1495–1552) recognised cometary tails are directed away from the Sun.

1619 Johannes Kepler (1571–1630) suggested the Sun exerts a repulsive force on the cometary particles.

1835 Friedrich Wilhelm Bessel (1784–1846) noted, that the orbit of the Halley's comet might change unpredictably due to jets.

1873 James Clerk Maxwell (1831–1839) deduced the existence of a light pressure from his electromagnetic theory.

1884 Otto Boeddicker (1853–1937) measured, that the minimum of the Moon's thermal emission takes place later than the minimum of the Moon's visible light during a total lunar eclipse, what is caused by the thermal inertia of Moon's material.

1888 Ivan Osipovich Yarkovsky (1844–1902) described the non-gravitational effect now called the Yarkovsky effect (even thought in a different context we use it today; see Section 2.1.1).

1899 Pyotr Nikolaevich Lebedev (1866–1912) measured the direct effect of the radiation pressure in a laboratory.

1903 John Henry Poynting (1852–1914) suggested dust particles and even centimetre meteoroids can fall onto the Sun due to a drag force, because the light pressure is decreased behind a moving particle.

1937 Howard Percy Robertson (1903–1961) calculated the radiative drag using an appropriate relativistic theory; now it is called the *Poynting-Robertson drag* (Figure 4).

1950 Fred Lawrence Whipple (1906–2004) defined rocket effect acting on comets due to the sublimation of gases from their surfaces.

1951 Ernst Julius Öpik (1893–1985) described the force arising due to the anisotropic thermal emission, when the surface is heated by the absorption of solar radiation; he noted the original idea in Yarkovsky's pamphlet (see Section 9.3).

1952 Vladimir Vyacheslavovich Radzievskii (1911–2003) described the same effect independently.

1987 The small variations in motion of the LAGEOS artificial satellite were succesfully explained using a Yarkovsky effect theory (Rubincam (1987); Figure 5 and Table 1).

1995 D.P. Rubincam introduced a seasonal variant of the Yarkovsky effect in asteroidal dynamics (Rubincam (1995)).

1998 Paolo Farinella (1953–2000) and others pointed out the importance of the Yarkovsky effect on meteoroids and small asteroids.

2000 D.P. Rubincam calculated Yarkovsky-O'Keefe-Radzievskii-Paddack (YORP) effect, which is able to change rotational states of small asteroids (Rubincam (2000)).

2003 The Yarkovsky effect was measured for the first time on an asteroid (6489) Golevka (Chesley *et al.* (2003)).

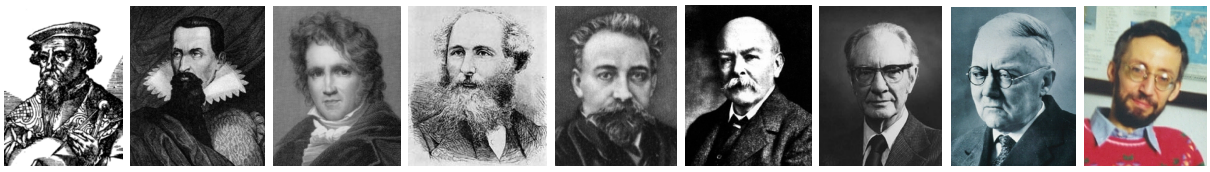

Figure 3: Some of the people involved in the explorations of non-gravitational forces. From the left: P. Apian, J. Kepler, F.W. Bessel, J.C. Maxwell, P.N. Lebedev, J.H. Poynting, F.L. Whipple, E.J. Öpik, P. Farinella. From *Wikipedia*.

See Section 2.2 for a review of recent developments in the theory and observation of non-gravitational phenomena.