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SOLAR GRAVITATIONAL MOMENTS AND SOLAR CORE DYNAMICS

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Abstract. Solar gravitational moments (J_n) reflect the internal non-homogeneous mass distribution and non-uniform angular velocity (function of the radial distance to the center and of the latitude). The result is the complex outer shape of the Sun, described by shape coefficients (c_n, also referred to as asphericities). The study of solar gravitational moments is not only crucial for solar physics, but also for astrometry (when computing light deflection in the vicinity of the Sun), celestial mechanics (relativistic precession of planets, planetary orbit inclination and spin-orbit couplings) and for future tests of alternative theories of gravitation (correlation of J_2 with Post-Newtonian parameters). A variability of c_n and J_n might be due to the temporal variation of the angular velocity which is known at the surface down to the tachocline. Regarding core dynamics, the subject is still under investigation. Space-dedicated missions, such as Golf-NG in a joint effort with SDO, should provide a new insight on the question.

1 Solar shape

a/ Oblateness estimates. It has been shown that assuming a non-rigid rotation increases solar oblateness, $\Delta R\odot \equiv R_{equ} - R_{pole} = 8.5 \pm 1.9$ marcsec, with respect to the rigid rotation case, $\Delta R\odot = 7.8 \pm 1.2$ marcsec. Today's best measurements have been obtained through observations with an heliometer at the Pic du Midi Observatory, France (Rozelot 1996; Rozelot, Lefebvre & Desnoux 2003) or SDS flights (Solar Disc Sextant; Sofia et al. 1994; Lyndon & Sofia 1996).
b/ Shape-asphericity estimates. Regarding solar shape asphericities (c_{2n}), which are the coefficients in a development, on a Legendre polynomial basis, of the shape of internal solar layers at a given depth (Rozelot et al. 2004), different models (helioseismology, stellar-state equations) converge from 0.5 to 1 $R\odot$. The $c_{2,4}$-curves as a function of depth clearly indentify the position of the tachocline and leptocline layers (Godier & Rozelot 2001; Lefebvre & Kosovitchev 2005.). Core investigations are required.

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c/ Distortions. Solar surface distortions with respect to sphericity can be explained through features of the solar rotational and gravitational potentials, since the solar "free" surface is an equiptotential level relative to the total potential. Hence, asphericities are related to solar gravitational moments (J_{2n}), which are the coefficients in a development, on a Legendre polynomial basis, of the solar outer gravitational potential (Pireaux & Rozelot 2003).

2 Astrophysical Relevance

a/ Questions still pending. What is the influence of solar core dynamics and latitudinal rotation on the values of J_n, c_n and global solar spin $\vec{J_\odot}$? How to reconcile different estimates of J_n? Do the J_n, c_n and $\vec{J_\odot}$ vary with the solar cycle?... A precise knowledge of J_n, c_n and $\vec{J_\odot}$ might be crucial to constrain solar models (differential rotation law, density inhomogeneities) or solar evolution. Those parameters are not only relevant to solar astrophysics, but their dynamical consequences in relativistic astrometry and celestial mechanics might help set constraints on solar models.
b/ Two future solar space missions GOLF-NG (Global Oscillation at Low Frequencies New Generation, 2006 and 2010-2012, ground- and space-based respectively) aims at (1) internal solar magnetic processes in the radiative region and their time evolution; (2) a solar core description through constraints on matter distribution and core dynamics; (3) a study of latitudinal rotation of the whole radiative zone. SDO (Solar Dynamics Observatory, 2008-2013) is designed to understand the Sun's influence on Earth and Near-Earth space through the study of solar atmosphere on small space/time scales, in different wavelengths simultaneously. Its goals are to (1) understand the solar cycle; (2) identify the role of the magnetic field in delivering energy to the different layers of the solar atmosphere; (3) study the space/time (from seconds to centuries) evolution of the outer regions of the Sun's atmosphere; (4) monitor solar radiation levels. Jointly, these missions will explore solar energy balance variations and the existence/cause of different cycles. However, SDS flights are crucial at least until these missions are available.

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