Transactions IAU, Volume XXVIIA
Reports on Astronomy 2006–2009
Karel A. van der Hucht, ed.

doi:10.1017/S1743921308025246

COMMISSION 7 CELESTIAL MECHANICS AND DYNAMICAL ASTRONOMY

MÉCHANIQUE CÉLESTE ET ASTRONOMIE DYNAMIQUE

PRESIDENT	**Joseph A. Burns**
VICE-PRESIDENT	**Zoran Knežević**
PAST PRESIDENT	**Andrea Milani**
SECRETARY	**David Vokrouhlický**
ORGANIZING COMMITTEE	**Evangelia Athanassoula, Christian Beaugé, Bálint Érdi, Anne Lemaitre, Andrzej J. Maciejewski, Renu Malhotra, Alessandro Morbidelli, Stanton J. Peale, Miloš Šidlichovský, Ji-Lin Zhou**

TRIENNIAL REPORT 2006–2009

1. Bars and bar-halo interactions in disc galaxies

(Evangelia Athanassoula & Albert Bosma)

The interplay of the disc and the dark halo resonances governs the secular evolution of disc galaxies, and the properties of their bar component (Athanassoula 2002). Martinez-Valpuesta *et al.* (2006), Ceverino & Klypin (2007) and Athanassoula (2007b) confirm and extend this work. Ceverino & Klypin (2007) calculate the orbital frequencies of each particle over the whole temporal evolution, and thus find much broader frequency peaks. In all cases, it is the same resonances that come into play, and, as in Athanassoula 2002, the angular momentum is emitted by near-resonant material in the bar region and absorbed by near-resonant material in the halo and the outer disc. The relative importance of each resonance, however, varies from one case to another. Furthermore, the second and third of the above mentioned studies examine the location of resonant orbits in configuration space and find compatible results.

Bar orbits can become vertically unstable, giving rise to a buckling and a subsequent thickening of part of the bar, which takes on a boxy or peanut shape. This results in a weakening of the bar strength. Martinez-Valpuesta *et al.* (2006) find that, following the initial buckling, the bar resumes its growth from deep inside the corotation radius and follows the ultraharmonic radius thereafter. Athanassoula & Martinez-Valpuesta (2008) find that the strength of the bar and of the peanut correlate and that stronger peanuts form in simulations that have experienced two or more bucklings. Finally, Athanassoula (2008) links the strength and the properties of the bar with those of the halo.

The halo, responding to the bar, forms a bar itself, called the halobar or the dark matter bar. Its properties, noted already in Athanassoula (2005), were studied by Berentzen & Shlosman (2006), Colin *et al.* 2006 and, more extensively, by Athanassoula (2007a). It lags the disc bar by only a few degrees at all radii and the difference between the two bar phases increases with distance from the centre. The two bars turn with roughly the same pattern speed. The length of the halo bar can be estimated by its phase difference with the disc bar and/or from the radius at which the halo shape turns from prolate to oblate. The inner parts of the halo rotate, but considerably less than the disc component.

Angular-momentum transfer within a galaxy could lessen or remove the central cusp in the halo mass distribution. Following previous work, Weinberg & Katz (2007a,b) (WK) and Sellwood (2006, 2008) consider this process using a simple model with a rigid bar in a galaxy with a live halo and no disc. Their results disagree. WK claim that about 10^8 particles are necessary for such simulations, while Sellwood finds converging results for particle numbers above a mere 10^5, and argues that the two studies differ because WK do not take into account resonant broadening due to the time dependence of the perturbation. Both parties agree that a very strong bar is necessary to remove a cusp. Fully self-consistent simulations (e.g., Colin *et al.* 2006) show that, as expected, the inwards concentration of the disc baryonic material during the secular evolution pulls the halo material inwards, thus increasing its central density.

Maciejewski & Athanassoula (2007, 2008) study the orbital structure in double-barred galaxies and show that the parent orbits are double-frequency orbits that do not close in any reference frame, but map onto closed curves called loops. Debattista & Shen (2007) and Shen & Debattista (2007) report on simulations showing that the inner bars pulsate, with their amplitude and pattern speed oscillating as they rotate through the primary bars. Heller *et al.* (2007) show that double bars can form naturally in *ab initio* simulations. The system evolves through successive dynamical couplings and decouplings, forcing gas inwards, and settles in a state of resonant coupling.

Manos & Athanassoula (2008) measure the fraction of chaotic orbits in various barred galaxy models, to see how this depends on parameters such as the bar strength and pattern speed, and outline the regions which are mainly populated by regular/chaotic orbits, guiding future observational studies. Voglis *et al.* (2007) use a combination of two different methods to measure chaos in self-consistent simulations.

Athanassoula & Beaton (2006) compare four fiducial N-body models with M31 observations, in particular isodensity shapes and radial light profiles in the near infrared. They argue that M31 has a sizable bar and constrain its length, strength and properties. The vertically thin part of the bar extends considerably further than the boxy bulge and gives information on the type of orbits that may compose it.

Tiret & Combes (2007a, b) compare bar formation in disc galaxies with dark matter and in disc galaxies following the MOND prescription for gravity. In the latter, bar formation is faster. They also show that gas speeds up the evolution.

Since cosmological simulations predict triaxial, rather than spherical, haloes, recently attention has been given to the evolution of discs embedded in such haloes. Berentzen & Shlosman (2006) (see also Berentzen *et al.* 2006) grow a disc in a triaxial halo, which responds adiabatically and, provided the disc is sufficiently massive, can become axisymmetric. In the *ab initio* simulations of Heller *et al.* (2007) the halo forms triaxial shapes and triggers what could be a first generation of bars. The evolution of the system is largely influenced by chaos introduced by the interaction of multiple nonaxisymmetric components (halo, oval disc, inner and outer bar). The halo does not tumble but its triaxiality evolves with time.

2. Architectures of extrasolar planetary systems (Eric B. Ford)

Radial-velocity observations dominate the observational constraints on the masses and orbital properties of exoplanets (Butler *et al.* 2006). The distribution of masses and orbital elements (Cumming *et al.* 2008) can be compared to parameterized theoretical models (Alibert *et al.* 2005; Armitage 2007; Ida & Lin 2008). Experience continues to demonstrate the value of observers publishing radial velocity data sets, as independent analyses often provide more detailed understanding of the full range of allowed orbital configurations and plausible formation scenarios. Independent analyses have revealed qualitatively different orbital solutions (Gozdziewski *et al.* 2007, 2008a; Gozdziewski & Konacki 2006; Beauge *et al.* 2008; Short *et al.* 2008). Refinements in computational techniques for Bayesian parameter estimation make rigorous Bayesian analyses routine for single planet systems and well-constrained multiple planet systems with negligible planet-planet interactions (Ford 2006; Gregory 2007a). Further research is needed into Bayesian model comparisons for establishing the significance of planet detections and orbital properties (Ford & Gregory 2007; Ford 2008; Gregory 2007b).

Computational limitations still leave the details of planetary migration in a gas disk uncertain, but mass growth and interactions between planets may explain the survival of planetary systems (Chambers 2006; Matsumura *et al.* 2007; Thommes *et al.* 2007; Morbidelli *et al.* 2008). Some models predict that migration will frequently place planets in mean-motion resonances (Kley *et al.* 2005; Beauge *et al.* 2006; Cresswell & Nelson 2008; Mandell *et al.* 2007; Crida *et al.* 2008), while other studies disagree (Quillen 2006; Lee *et al.* 2008; Thommes *et al.* 2008b; Adams *et al.* 2008). This distinction may be valuable in discriminating between migration models.

The eccentricity distribution of exoplanets remains a key observational constraint. Despite progress towards understanding disk- induced eccentricity growth (D'Angelo *et al.* 2006; Ogilvie & Lubow 2006; Cresswell *et al.* 2007; Britsch *et al.* 2008; Moorhead & Adams 2008), it is unclear whether single planets may emerge on eccentric orbits. N-body simulations exploring the late stages of evolution of dynamically active planetary systems suggest that late-stage planet-scattering may explain much of the observed eccentricity distribution, but the abundance of low-eccentricity planets suggests that disks might provide dissipation following the epoch of planet-scattering (Chatterjee *et al.* 2008; Ford & Rasio 2008; Juric & Tremaine 2008) and has inspired simulations of planet scattering in the presence of a disk (Moorhead & Adams 2005; Raymond *et al.* 2006; Kokubo & Ida 2007; Zhou *et al.* 2007; Chatterjee *et al.* 2008; Morishima *et al.* 2008; Thommes *et al.* 2008a). While correlations between eccentricity and other parameters could provide clues regarding planet-formation processes (Ribas & Miralda-Escude 2007; Ford & Rasio 2008), effects of uncertainties in orbital elements (Ford 2006) and measurement biases (Shen & Turner 2008) need to be better understood.

Many planetary systems exhibit significant secular eccentricity evolution (Barnes & Greenberg 2006; Libert & Henrard 2006) which can place constraints on their orbital histories and additional planets (Ford *et al.* 2005; Adams & Laughlin 2006; Sandor *et al.* 2007). Several multiple planet systems appear to be strongly influenced by mean-motion resonances. Assuming long-term dynamical stability (Lee *et al.* 2006; Gozdziewski *et al.* 2007, 2008; Michtchenko *et al.* 2008) implies that several systems are indeed participating in resonances. The secular evolution of these systems raises the possibility of diverse formation scenarios (Sandor & Kley 2006; Sandor *et al.* 2007). The 1:1 mean motion resonance has attracted particular attention due to viable alternative fits to radial velocity data (Gozdziewski *et al.* 2006), but observations already provide strong constraints on Trojans of transitting planets (Ford & Gaudi 2006; Croll *et al.* 2007).

A few planetary systems have inspired detailed studies thanks to complementary observations. *Spitzer* detections of debris disks around planet-host stars constrain formation histories (Alibert *et al.* 2006; Moro-Martin 2007). The combination of radial velocity and transit data constrain planets' physical properties (Torres *et al.* 2008). Spectroscopic measurements during transit constrain the inclination between the stellar spin axis and a planet's orbital angular momentum. Several systems appear to be well aligned (Winn *et al.* 2006; Wolf *et al.* 2006), but a few appear misaligned (Hebrard *et al.* 2008). While disk migration produces well-aligned systems, misaligned systems could arise due to either planet scattering (Chatterjee *et al.* 2008; Nagasawa *et al.* 2008) or interactions with a distant companion (Fabrycky & Tremaine 2007; Wu *et al.* 2007).

Looking forward, several detection techniques are closing in on terrestrial-mass planets. Measuring their frequency and orbital properties will test theoretical predictions for the distribution of masses and orbits of terrestrial planets (Veras & Armitage 2006; Ford *et al.* 2008; Raymond *et al.* 2008; Thommes *et al.* 2008a). Of particular interest for dynamicists, measurements of transit times are already sufficiently precise to detect Earth-mass planets (Agol *et al.* 2005; Holman & Murray 2005). Dynamicists are expected to play a key role in the interpretation of complex transit-timing signatures.

3. Solar System binaries: observations, characterizations, formations

(Daniel J. Scheeres)

The large percentage of binaries among the asteroid and trans-Neptunian populations allows us to infer that small bodies readily form binary or multiple component systems. A detailed review of binary systems appeared recently (Richardson and Walsh 2006), so my short summary will focus on the latest developments related to observation, characterization, and the formation and evolution of these binary systems.

Observations:

The number of observed binary systems in all realms of the solar system has increased to the point where it is feasible to draw statistical inferences about the density, shapes, strength and angular momentum content in these systems. The population of Kuiper Belt Binaries has been reviewed in Noll *et al.* (2008), the small Main Belt and Near-Earth binaries were summarized by Pravec *et al.* (2006, 2007), and the larger Main Belt binaries were described by Marchis *et al.* (2008a, 2008b). Statistics of how many NEA bodies are binaries remain relatively unchanged from Margot (2002), while those of small MB binaries have been rising with increased observations (Pravec *et al.* 2006). A number of multiple-body systems have been discovered in the Kuiper and Main Belts (Weaver *et al.* 2006, Marchis *et al.* 2005) as well as in the NEA population (Nolan *et al.* 2008). In addition to orbital binaries, contact binary bodies, which may represent a population of "failed binaries," have also been observed to be common among observed bodies (Benner *et al.* 2006, Kaasalainen *et al.* 2002, Mann *et al.* 2007, Lacerda *et al.* 2007). The asteroid Itokawa was described as a contact binary in Demura *et al.* (2006) and, if spun to fission, would form a highly unstable but gravitationally bound binary that would have a tendency to re-impact (Scheeres *et al.* 2007). There is also a recently discovered population of 'common origin' asteroids in the Main Belt (Vokrouhlicky and Nesvorny 2008), which have similar orbits today but had a predicted past close passage to one another; they may represent binary systems disrupted either by internal dynamics or by exogenous non-gravitational or gravitational perturbations.

Characterizations:

Densities of the Kuiper Belt population are ~ 2–3 g/cm^3 for larger bodies and ~ 1 g/cm^3 for smaller bodies, indicating compositional trends with size (Noll *et al.* 2008).

Low-density bodies have also been found among the Trojans with Patroclus' density being $\sim 0.8\,\mathrm{g/cm^3}$ (Marchis *et al.* 2006) while those of NEA binaries lie between 1.3 and $2.1\,\mathrm{g/cm^3}$ (Pravec *et al.* 2006). The best characterized NEA binary system to date is 1999 KW4 with detailed shape, spin and orbit information (Ostro *et al.* 2006; Scheeres *et al.* 2006; Fahnestock & Scheeres 2008a). Results include: a determination that the primary spins at its surface disruption limit, meaning that loose particles at the equator are close to or at orbital speeds; a significant density disparity between the two components, with the secondary being 40% denser than the primary; a precise characterization of the proto-typical 'spheroidal' primary shape and 'ellipsoidal' secondary shape which has been a noted feature of NEA binary systems (Pravec *et al.* 2006). These results show that the detailed structure of NEA binaries contain significant inhomogeneities in shape and mass distribution.

Some researchers have used classical Jacobi, Roche & Darwin ellipsoids to understand the likely shapes and, in some cases, densities of bodies (Mann *et al.* 2007, Lacerda *et al.* 2007, Descamps & Marchis 2008). Holsapple and Michel (2008) and Sharma *et al.* (2006) have developed extensions of classical theories that incorporate the effect of friction and strength to model aggregates in an averaged sense. Holsapple's studies show that larger bodies may follow classical results while smaller bodies will be dominated by material strength. Relevant to these studies are results from Pravec & Harris (2007) and Descamps & Marchis (2008) which show that the total angular momentum content of binary systems is consistent with the stability limits of rotating bodies. At the smaller size scales Scheeres (2007, 2008) has studied the mechanics of rigid bodies in contact, finding that they can change relative orientation or fission into binary systems as the rotation rate of the body evolves.

Formation and evolution:
Different formation mechanisms appear to be at play in different regimes of the solar system. For the Kuiper Belt, research has focused on 3-body effects and a variety of detailed mechanisms have been proposed (Goldreich *et al.* 2002; Funato *et al.* 2004; Lee *et al.* 2007; Schlichting & Sari 2008); however a clear consensus of which mechanism dominates is yet to be achieved (Richardson & Walsh 2006). In the Main Belt, theories have generally focused on formation in impact events (Merline *et al.* 2002), although recent speculation for smaller binary systems has focused on spin fission. Impact-created binaries now seem relatively well understood (Durda *et al.* 2004) with observational support for the different classes of binaries formed by such cataclysmic events among the larger binaries in the Main Belt (Richardson & Walsh 2006). Until recently the favored formation mechanism for NEA binaries was via tidal flybys (Walsh & Richardson 2006). However a statistical analysis by Scheeres *et al.* (2004) indicated that the disruption rate of asteroids due to close planetary flybys was inconsistent with the observed statistics and detailed simulations of binary creation and destruction by Walsh and Richardson (2008) could not produce the observed binary statistics of the NEA binary population. With the validation of the YORP effect (Lowry *et al.* 2007; Taylor *et al.* 2007; Kaasalainen *et al.* 2007), attention has focused on fission from YORP spin-up as a mechanism for creating binaries and controlling some aspects of the shapes of asteroids in general (Scheeres 2007; Pravec & Harris 2007; Walsh *et al.* 2008). This mechanism should also extend into the Main Belt and can explain some of the smaller binary systems there (Pravec *et al.* 2006).

Evolution of binary systems provides life-time limits and constrains the production rate of these systems. Classical evolutionary mechanisms that focus on angular momentum transfer via tidal friction are still the probable mechanism for larger bodies, although great uncertainty remains in the appropriate empirical constants controlling this mechanism (Margot *et al.* 2002; Goldreich & Sari 2007). Among the small NEA and Main Belt binary populations, new mechanisms for evolution involving non-gravitational effects have been proposed. The Binary YORP (BYORP) effect (Cuk & Burns 2005) consists of non-gravitational forces acting on a binary secondary, causing the orbit to expand or contract with binary lifetimes predicted to be as short as 10^5 years (Cuk 2007), orders of magnitude faster than tidal evolution. More recently hypothesized is YORP induced expansion, introduced as an explanation for why the 1999 KW4 primary was at its spin disruption limit (Scheeres *et al.* 2006), where continued YORP spin-up of the primary can cause material to be lofted and angular momentum to be transferred to the orbit. Expansion times for this effect may be an order of magnitude faster than tidal evolution (Fahnestock & Scheeres 2008b; Harris, *et al.* 2008). As neither of these evolutionary mechanisms has been validated as of yet for small binaries, additional research and observations are needed. For any of these effects acting on NEA, close planetary flybys continue to remain an important contributor, essentially randomizing these more systematic effects (Walsh & Richardson 2008). However, MB binaries should be shielded from these randomizing effects and thus may represent a cleaner picture of binary evolution.

4. Spin - obit dynamics (Anne Lemaitre)

The field of spin - orbit dynamics has been renewed recently through theoretical, analytical and observational papers, owing to several space missions, and increases in the precision required for all the motions. The bodies of any mass can no longer be considered as point masses and the explanation of their present state needs very long-term integrations, including migrations and disk interactions, as well as the linking of orbital and rotational contributions. Recent contributions concern of course Mercury, but also the giant planets, the Moon, the Galilean and Saturnian satellites and asteroids.

The gravity field coefficients J_2 and C_{22} of Mercury are known with an uncertainty of 30% and 50%. The two space missions scheduled to Mercury (*Messenger* and *Bepi-Colombo*) should lead to a better knowledge of the gravitational potential, and through a precise observation of the rotation, of the interior of the planet (like the existence of a liquid core).

First, the probability for Mercury to be captured in a 3:2 spin - orbit resonance was calculated to be 52% by Correia & Laskar (2004), who explored a large variety of scenarios and initial conditions, and introduced planetary perturbations of the orbital and rotational motions.

Second, Mercury should theoretically be in a Cassini state, which means geometrically that its orbit pole, spin vector and normal to the inertial planes are coplanar; the dynamical interpretation is that all the free (also called proper) librations, depending on the initial conditions of the rotation, should have disappeared with time. Peale (2005) showed that core-mantle friction or tidal effects would drive the spin to its equilibrium value in less than 1 My and that even the excitation due to a potential impact should have been completely damped in less than 1 yr. Analytical rigid-body models (D'Hoedt & Lemaitre 2004) calculated the values of the three free frequencies of Mercury's rotational motion (of the libration in longitude, i.e., the resonant spin - orbit angle, of the node commensurability and of the wobble) as functions of C_{22}, and C (the third moment of inertia) in a rigid body, or C_m (the third moment of inertia of the mantle) for a liquid-core hypothesis.

The Cassini state is presently characterized by a small obliquity of about 2 arcminutes, mainly due to the precession of the orbital node and dependent on the present values of the eccentricity and the inclination. Numerical investigations, performed by Yseboodt & Margot (2006) and including planetary secular perturbations, have shown that the planet should follow the Cassini state, even if its position is time-evolving ; this behavior can also be explained by an adiabatic model developed by Peale (2006) and generalized to two degrees of freedom by D'Hoedt & Lemaitre (2008).

Following theoretical approaches, the short periodic orbital terms (88 days) induce forced oscillations on the libration in longitude, with amplitudes proportional to C_{22}/C_m. Observations of radar speckle patterns by Margot & *et al.* (2007) established that the planet occupied a Cassini state with an obliquity of 2.11 arcminutes and that the largest amplitudes of the oscillations in longitude were of 35.8 arcseconds; this value, even with the uncertainty of the value of C_{22} clearly shows a difference between C_m and C, which means that the mantle and the core are decoupled, and confirms the existence of a molten core.

The next step was to include planetary perturbations on Mercury's orbital motion (in addition to the 88 days forced libration). The contributions of Peale, Yseboodt & Margot (2007) and of Dufey, Lemaitre & Rambaux (2008) agree for the main terms (due to Venus and Jupiter orbital motions) but show divergences for the smaller contributions, due to the Earth or Saturn, for example. An interesting resonance, between the spin-orbit resonant frequency and the orbital motion of Jupiter, was mentioned in both papers.

The first flyby of Mercury by the probe Messenger in January 2008 (Solomon *et al.* 2008) should give much more precise values of J_2 and C_{22}, allowing a check on the different scenarios and hypotheses.

Saturn's obliquity (26.73°) also received new attention; the reason for such a high value (Jupiter's obliquity is only 3.12°) is not only explained by the obliquity of the core. A new mechanism was proposed by Ward & Hamilton (2004), based on a 1:1 commensurability between Saturn's spin-axis precession rate and the ν_{18} secular frequency of Neptune's orbital node, confirmed numerically by Hamilton & Ward (2004). The authors discussed different scenarios of circumplanetary disk dispersal, showing, for all the giant planets, how the sweeping of secular resonances could be followed by adiabatic tools and result in the increase of several degrees of the initial small obliquities. The lunar spin-axis dynamics was also revisited. Wisdom (2006) showed how the introduction of a non-constant orbital inclination and a non-uniform regression of the orbital node complicated the dynamics, by the introduction of new resonances and the apparition of local chaotic regions.

Following the models developed in the seventies to understand the Moon's libration, Henrard (2005a) proposed a three-dimensional rigid model of rotation for the Galilean satellites Europa and Io (Henrard 2005c), and estimated the values of the so-called free (or proper) frequencies. Thanks to the injection of the synthetic orbital theory of Layney, Arlot & Vienne (2004) in the model, Henrard (2005b) computed the main forced contributions induced by the other satellites' gravitational effects. The case of Io is particularly complex, due to its proximity to Jupiter and its capture in the Laplacian resonance with Europa and Ganymede. Its rotational behavior is far from a uniform oscillation around a Cassini equilibrium. Moreover Io's volcanic activity shows that a rigid-body model is surely not adequate. The last contribution of Henrard (2008) was to develop an analytical theory (based on the idea of Poincare 1910) to take into account the presence of a liquid core contained in a cavity filled by a non-viscid fluid of constant density; the presence of this supplementary degree of freedom (the spin of the core) in the problem, introducing possible new commensurabilities between the frequencies, may lead to chaotic motion in the vicinity of the Cassini state, for some values of the unknown core parameters.

The space mission *Cassini-Huygens* provided new data for Titan, showing in particular its slight super-synchronous rotation (+0.004%). Observers (Stiles *et al.* 2008 and Lorenz *et al.* (2008) interpreted it as a potential signature of the presence of an internal ocean, that would dissociate the rotation of Titan's crust from this of the core. Using Henrard's model, Noyelles, Lemaitre & Vienne (2008) calculated analytically the three proper frequencies of Titan's rotation and the main forced terms; in a second paper Noyelles (2008) showed that a dynamical forcing of the wobble frequency could have affected the measurement of Titan's spin rate, and could also be at the origin of the non-exact synchronism.

The minor planet dynamics, on very long periods of time, is strongly dependent on the thermal (Yarkovski) forces and their spin-vector evolution is influenced by the YORP torque, in particular, as shown by Nesvorný, & Vokrouhlický (2007), in the chronology and understanding of the asteroid families – like Erigone, Massalia, Merxia or Astrid – which likely results from catastrophic collisions, as identified in backward integrations.

Joseph A. Burns
president of the Commission

References

Section 1

Athanassoula, E. 2002, *ApJ*, 104, 340
Athanassoula, E. 2005, *Cel. Mech. & Dyn. Astr.*, 91, 9
Athanassoula, E. 2007a, *MNRAS*, 377, 1569
Athanassoula, E. 2007b, in: R. S. de Jong (ed.) *Island Universes, Astrophysics and Space Science Proceedings* (Dordrecht: Springer), p. 195
Athanassoula, E. 2008, in: M. Bureau, E. Athanassoula, & B. Barbuy (eds.) *Galactic Bulges, IAU Symposium No. 245* (Cambridge: CUP), p. 93
Athanassoula, E. & Beaton, R. L. 2006, *MNRAS*, 370, 1499
Athanassoula, E. & Martinez-Valpuesta, I. 2008, *MNRAS* (submitted)
Berentzen, I. & Shlosman, I. 2006a, *ApJ*, 648, 807
Berentzen, I. & Shlosman, I. 2006b, *ApJ*, 637, 582
Ceverino, D. & Klypin, A. 2007, *MNRAS*, 379, 1155
Colin, P., Valenzuela, O., & Klypin, A. 2006, *ApJ*, 644, 687
Debattista, V. P. & Shen, J. 2007, *ApJ*, 654, L127
Heller, C., Shlosman, I., & Athanassoula, E. 2007, *ApJ*, 657, L65 and *ApJ*, 671, 226
Maciejewski, W. & Athanassoula, E. 2007, *MNRAS*, 380, 999, and 2008, *MNRAS*, 389, 545
Manos, T. & Athanassoula, E. 2008, *MNRAS*, 2008arXiv0806.3563B
Martinez-Valpuesta, I., Shlosman, I., & Heller, C. 2006, *ApJ*, 637, 214
Sellwood, J. A. 2006, *ApJ* 637, 567 and 2008, *ApJ*, 639, 868
Shen, J., & Debattista, V. P. 2007, *ApJ*, 690, 758
Tiret, O. & Combes, F. 2007a, *A&A*, 464, 517 and 2007b, *A&A*, 483, 719
Voglis, N., Harsoula, M., & Contopoulos, G. 2007, *MNRAS*, 381, 575
Weinberg, M. & Katz, N. 2007, *MNRAS*, 375, 425 & 460

Section 2

Adams, F. C., Laughlin, G., & Bloch, A. M. 2008, *ApJ* 683, 1117
Agol, E., Steffen, J., Sari, R., & Clarkson, W. 2005, *MNRAS*, 359, 567
Alibert, Y., Mordasini, C., Benz, W., & Winisdoerffer, C. 2005, *A&A*, 434, 343
Alibert, Y., *et al.* 2006, *A&A*, 455, L25

Armitage, P. J. 2007, *ApJ*, 665, 1381
Barnes, R. & Greenberg, R. 2006, *ApJ*, 652, L53
Beaugé, C., Giuppone, C. A., Ferraz-Mello, S., & Michtchenko, T. A. 2008, *MNRAS*, 385, 2151
Beaugé, C., Michtchenko, T. A., & Ferraz-Mello, S. 2006, *MNRAS*, 365, 1160
Britsch, M., Clarke, C. J., & Lodato, G. 2008, *MNRAS*, 385, 1067
Butler, R. P., *et al.* 2006, *ApJ*, 646, 505
Chambers, J. E. 2006, *ApJ*, 652, L133
Chatterjee, S., Ford, E. B., Matsumura, S., & Rasio, F. A. 2008, *ApJ*, 686, 580
Cresswell, P., Dirksen, G., Kley, W., & Nelson, R. P. 2007, *A&A*, 473, 329
Cresswell, P. & Nelson, R. P. 2008, *A&A*, 482, 677
Crida, A., Sándor, Z., & Kley, W. 2008, *A&A*, 483, 325
Croll, B., *et al.* 2007, *ApJ*, 658, 1328
Cumming, A., Butler, R. P., Marcy, G. W., Vogt, S. S., Wright, J. T., & Fischer, D. A. 2008, *PASP*, 120, 531
D'Angelo, G., Lubow, S. H., & Bate, M. R. 2006, *ApJ*, 652, 1698
Fabrycky, D. & Tremaine, S. 2007, *ApJ*, 669, 1298
Ford, E. B. 2006, *ApJ*, 642, 505
Ford, E. B. 2008, *AJ*, 135, 1008
Ford, E. B. & Gaudi, B. S. 2006, *ApJ*, 652, L137
Ford, E. B. & Gregory, P. C. 2007, *ASPC*, 371, 189
Ford, E. B. & Rasio, F. A. 2006, *ApJ*, 638, L45
Ford, E. B. & Rasio, F. A. 2008, *ApJ*, 686, 621
Ford, E. B., Lystad, V., & Rasio, F. A. 2005, *Nature*, 434, 873
Ford, E. B., Quinn, S. N., & Veras, D. 2008, *ApJ*, 678, 1407
Goździewski, K. & Konacki, M. 2006, *ApJ*, 647, 573
Goździewski, K., Maciejewski, A. J., & Migaszewski, C. 2007, *ApJ*, 657, 546
Goździewski, K., Migaszewski, C., & Konacki, M. 2008b, *MNRAS*, 385, 957
Gregory, P. C. 2007b, *MNRAS*, 374, 1321
Gregory, P. C. 2007a, *MNRAS*, 381, 1607
Hébrard, G., Bouchy, F., Pont, F., *et al.* 2008, *A&A*, 488, 763
Holman, M. J. & Murray, N. W. 2005, *Sci*, 307, 1288
Ida, S. & Lin, D. N. C. 2008a, *ApJ*, 673, 487
Juric, M. & Tremaine, S. 2008, *ApJ*, 686, 603
Kley, W., Lee, M. H., Murray, N., & Peale, S. J. 2005, *A&A*, 437, 727
Kokubo, E. & Ida, S. 2007, *ApJ*, 671, 2082
Lee, A. T., Thommes, E. W., & Rasio, F. A. 2008, *arXiv* 801, 1926
Lee, M. H., Butler, R. P., Fischer, D. A., Marcy, G. W., & Vogt, S. S. 2006, *ApJ*, 641, 1178
Libert, A.-S. & Henrard, J. 2006, *Icarus* 183, 186
Mandell, A. M., Raymond, S. N., & Sigurdsson, S. 2007, *ApJ*, 660, 823
Matsumura, S., Pudritz, R. E., & Thommes, E. W. 2007, *ApJ*, 660, 1609
Michtchenko, T. A., Beaugé, C., & Ferraz-Mello, S. 2008, *MNRAS*, 387, 747
Moorhead, A. V. & Adams, F. C. 2008, *Icarus*, 193, 475
Moorhead, A. V. & Adams, F. C. 2005, *Icarus*, 178, 517
Morbidelli, A., Crida, A., Masset, F., & Nelson, R. P. 2008, *A&A*, 478, 929
Morishima, R., Schmidt, M. W., Stadel, J., & Moore, B. 2008, *ApJ*, 685, 1247
Moro-Martín, A., *et al.* 2007, *ApJ*, 668, 1165
Nagasawa, M., Ida, S., & Bessho, T. 2008, *ApJ*, 678, 498
Ogilvie, G. I. & Lubow, S. H. 2006, *MNRAS*, 370, 784
Quillen, A. C. 2006, *MNRAS*, 365, 1367
Raymond, S. N., Barnes, R., & Mandell, A. M. 2008, *MNRAS*, 384, 663
Raymond, S. N., Quinn, T., & Lunine, J. I. 2006, *Icarus*, 183, 265
Ribas, I. & Miralda-Escudé, J. 2007, *A&A*, 464, 779
Sándor, Z., & Kley, W. 2006, *A&A*, 451, L31
Sándor, Z., Kley, W., & Klagyivik, P. 2007, *A&A*, 472, 981

Shen, Y. & Turner, E. L. 2008, *ApJ*, 685, 553
Short, D., Windmiller, G., & Orosz, J. A. 2008, *MNRAS*, 386, L43
Thommes, E., Nagasawa, M., & Lin, D. N. C. 2008a, *ApJ*, 676, 728
Thommes, E. W., Bryden, G., Wu, Y., & Rasio, F. A. 2008b, *ApJ*, 675, 1538
Thommes, E. W., Nilsson, L., & Murray, N. 2007, *ApJ*, 656, L25
Torres, G., Winn, J. N., & Holman, M. J. 2008, *ApJ*, 677, 1324
Veras, D. & Armitage, P. J. 2006, *ApJ*, 645, 1509
Winn, J. N., *et al.* 2006, *ApJ*, 653, L69
Wolf, A. S., Laughlin, G., Henry, G. W., Fischer, D. A., Marcy, G., Butler, P., & Vogt, S. 2007, *ApJ*, 667, 549
Wu, Y., Murray, N. W., & Ramsahai, J. M. 2007, *ApJ*, 670, 820
Zhou, J.-L., Lin, D. N. C., & Sun, Y.-S. 2007, *ApJ*, 666, 423

Section 3
Benner, L. A. M., Nolan, M. C., Ostro, S. J., *et al.* 2006, *Icarus*, 182, 474
Cuk, M. 2007, *ApJ*, 659, L57
Cuk, M. & Burns, J. A. 2005, *Icarus*, 176, 418
Demura, H., Kobayashi, S., Nemoto, E., *et al.* 2006, *Science*, 312, 1347
Descamps, P. & Marchis, F. 2008, *Icarus*, 193, 74
Durda, D. D., Bottke, W. F., Enke, B. L., *et al.* 2004, *Icarus*, 170, 243
Fahnestock, E. G. & Scheeres, D. J. 2008a, *Icarus*, 194, 410
Fahnestock, E. G. & Scheeres, D. J. 2008b *BAAS*, 40, #2.02
Funato, Y., Makino, J., Hut, P., *et al.* 2004, *Nature*, 427, 518
Goldreich, P., Lithwick, Y., & Sari, R. 2002, *Nature*, 420, 643
Goldreich, P. & Sari, R. 2007, *arXiv* 0712.0446
Harris, A. W., Fahnestock, E. G., & Pravec, P. 2008, *BAAS-DDA*, 40, #14.01
Holsapple, K. A. & Michel, P. 2008, *Icarus*, 193, 283
Kaasalainen, M., Durech, J., Warner, B. D., *et al.* 2007, *Nature*, 446, 420
Lacerda, P. & Jewitt, D. C. 2007, *AJ*, 133, 1393
Lee, E. A., Astakhov, S. A., & Farrelly, D. 2007, *MNRAS*, 379, 229
Lowry, S. C., Fitzsimmons, A., Pravec, P., *et al.* 2007, *Science*, 316, 272
Mann, R. K., Jewitt, D., & Lacerda, P. 2007, *AJ*, 134, 1133
Marchis, F., Descamps, P., Hestroffer, D., & Berthier, J. 2005, *Nature*, 436, 822
Marchis, F., Hestroffer, D., Descamps, P., *et al.* 2006, *Nature*, 439, 565
Marchis, F., Descamps, P., Baek, M., *et al.* 2008a, *Icarus*, 196, 97
Marchis, F., Descamps, P., Berthier, J., *et al.* 2008b, *Icarus*, 195, 295
Margot, J. L., Nolan, M. C., Benner, L. A. M., *et al.* 2002, *Science*, 296, 1445
Merline, W. J., Weidenschilling, S. J., Durda, D. D., *et al.* 2002, *in Asteroids III*, W. F. Bottke Jr. *et al.* (eds), U. Arizona Press, Tucson, 289
Nolan, M. C., Howell E. S., Benner, L. A. M., *et al.* 2008, IAUC 8921 '(153591) 2001 SN 263' (Feb 2008)
Noll, K. S., Grundy, W. M., Chiang, E. I., *et al.* 2008 *in The Solar System Beyond Neptune*, M. A. Barucci *et al.* (eds.), U. Arizona Press, Tucson, 345
Ostro, S. J., Margot, J.-L., Benner, L. A. M., *et al.* 2006, *Science*, 314, 1276
Pravec, P. & Harris, A. W. 2007, *Icarus*, 190, 250
Pravec, P., Scheirich, P., Kusnirak, P., *et al.* 2006, *Icarus*, 181, 63
Richardson, D. C. & Walsh, K. J. 2006, *Ann. Rev. Earth & Planet. Sci.*, 34, 47
Scheeres, D. J. 2007, *Icarus*, 189, 370
Scheeres, D. J. 2008, *PSS*, in press
Scheeres, D. J., Marzari, F., & Rossi, A. 2004, *Icarus*, 170, 312
Scheeres, D. J., Fahnestock, E. G., Ostro, S. J., *et al.* 2006, *Science*, 314, 1280
Scheeres, D. J., Abe, M, Yoshikawa, M., *et al.* 2007, *Icarus* 188, 425
Schlichting, H. E. & Sari, R. 2008, *ApJ*, 673, 1218
Sharma, I., Jenkins, J. T. & Burns, J. A. 2006, *Icarus*, 183, 312
Taylor, P. A., Margot, J.-L., Vokrouhlicky, D., *et al.* 2007, *Science*, 316, 274

Vokrouhlicky, D. & Nesvorny, D. 2008, *AJ*, 136, 280
Walsh, K. J. & Richardson, D. C. 2006, *Icarus*, 180, 201
Walsh, K. J. & Richardson, D. C. 2008, *Icarus*, 193, 553
Walsh, K. J., Richardson, D. C., & Michel, P. 2008, *Nature*, 454, 188
Weaver, H. A., Stern, S. A., Mutchler, M. J., *et al.* 2006, *Nature*, 439, 943

Section 4
Correia, A. & Laskar, J. 2004, *Nature*, 429, 848
D'Hoedt, S. & Lemaitre, A. 2004, *CM&DA*, 89, 267
D'Hoedt, S. & Lemaitre, A. 2008, *CM&DA*, 101,127
Dufey, J., Lemaitre, A., & Rambaux, N. 2008, *CM&DA*, 101,141
Hamilton, D. P. & Ward, W. R. 2004, *AJ*, 128, 2510
Henrard, J. 2005a, *CM&DA*, 91,131
Henrard, J. 2005b, *CM&DA*, 93,101
Henrard, J. 2005c, *Icarus*, 178,144
Henrard, J. 2008, *CM&DA*, 101, 1
Layney, V., Arlot, J. E., & Vienne 2004, *A&A*, 427, 371
Lorenz, R. D., Stiles, B. W., Kirk, R. L. *et al.* 2008, *Science*, 319, 1649
Margot, J. L., Peale, S. J., Jurgens, R. F., Slade, M. A., & Holin I.V. 2007, *Science*, 316, 710
Nesvorný, D. & Vokrouhlický, D. 2007, *AJ*, 134, 1750
Noyelles, B. 2008, *CM&DA*, 101, 13
Noyelles, B., Lemaitre, A., & Vienne, A. 2008, *A&A*, 478, 959
Peale, S. J. 2005, *Icarus*, 178, 4
Peale, S. J. 2006, *Icarus*, 181, 338
Peale, S. J., Yseboodt, M., & Margot, J. L. 2007, *Icarus*, 187, 365
Poincaré, H. 1910, *Bull. Astron.*, 27, 321
Solomon, S. C., McNutt, R. L., Watters, T. R., *et al.* 2008, *Science*, 321, 59
Stiles, B. W., Kirk, R. L., Lorenz, R. D., *et al.* 2008, *AJ*, 135, 1669
Ward, W. R. & Hamilton, D. P. 2004, *AJ*, 128, 2501
Wisdom, J. 2006, *AJ*, 131, 1864
Yseboodt, M. & Margot, J. L. 2006, *Icarus*, 181, 327