# ABSTRACTS

## Programmed motion in the presence of homogeneity

*G. Bozis and M. C. Anisiu*

The programmed motion related to the inverse problem of dynamics was considered by Bozis (1996). A related case was solved by Anisiu and Bozis (2000) for a simple family of orbits. We study here the following problem: given a planar region described by one inequality, are there monoparametric families of orbits produced by certain potentials precisely in that region? To ease the mathematics, hypotheses of homogeneity on the function describing the region and on the slope function which characterizes the family are added. If the functions satisfy certain conditions, the slope function is obtained as common solution of two polynomial equations.

## Resonant Exoplanetary Systems: From Orbital Determination to Periodic Orbits

*Cristián Beaugé*

In this presentation, we review some dynamical properties of resonant extrasolar planetary systems, with special attention to those problems that are still not well understood. We briefly describe the orbital characteristics of the known resonant systems and compare them to the rest of the exoplanets population. We discuss the reliability of the current orbital fits, and how the underlying observational uncertainties may condition our ideas about their origin and/or past evolution. In particular, we discuss the cases of 55 Cnc, HD 82943 and HD 73526. The possible existence of exoplanets in Trojan configurations is also addressed. Finally, we discuss the diversity of dynamical behavior inside the planetary 2/1 mean-motion resonance, including the occurrence of stationary solutions, periodic orbits and secondary resonances.

## Parametric dependence of the phase-space volume of regions of trapped motion

*L. Benet and O. Merlo*

The phase--space volume of regions of regular or trapped motion, for bounded or scattering systems with two degrees of freedom respectively, displays universal properties. In particular, sudden reductions in the phase-space volume or gaps are observed at specific values of the parameter which tunes the dynamics. These locations are given by the stability resonances, defined by a resonant condition on the stability exponents of a central stable periodic orbit. We show that, for more than two degrees of freedom, these resonances can be excited opening up the gaps, which effectively separates and shrinks the regions of trapped motion in phase space. Using the scattering approach to narrow rings and a billiard system as example, this mechanism yields rings with two or more components, which in addition may display arcs.

## Inverse problem, precessing orbits and autonomous forces

*Cristina Blaga*

In the frame of inverse problem of Dynamics we investigate the compatibility between two-parametric families of precessing orbits and autonomous force fields. In a previous work we obtained that if the force is a central one, then, for a suitable choise of the parameters, the force is conservative and it derives from the Manev potential. In this work we argue about the compatibility between two-parametric families of precessing orbits and autonomous forces.

## Certain aspects of the inverse and the direct problem of Dynamics

*George Bozis*

We present the version of the inverse problem of Dynamics dealing with one material point moving in an inertial frame, in two or three dimensions. We are given monoparametric or two-parametric families of orbits and we require the autonomous force field (conservative or not) which can produce these orbits, for adequate initial conditions. We give the basic tools (PDEs) to face this problem and make certain comments on their applicability. With the above PDEs we then look at the question of integrability of two dimensional potentials from the inverse and the direct-problem viewpoint. We also discuss shortly how the inverse problem can help in establishing criteria for the totality of two-parametric spatial families of orbits which can be traced in the presence of a Newtonian potential in the exterior of any material distribution.

## Chaos in a BL-Lac dynamical model

*N. Caranicolas*

We construct a dynamical model in order to study the motion in a BL-Lac active galaxy. The model consists of a logarithmic potential with an internal perturbation. Two cases are investigated: (i) The time independent model and (ii) the evolving model. A large number of orbits are chaotic in both cases. Responsible for the chaotic motion are the internal perturbation, the flattening parameter and the dense nucleus. Theoretical arguments support the numerical outcomes. Comparison of the results with data from observations is also made.

## Gravitational Far Fields and Dark Matter

*A. Carati and L. Galgani*

It was recently proposed that the gravitational action of the far galaxies may be a substitute for the local action of dark matter, if one takes into account the retarded character of gravitation, and also the correlated nature of the positions of the galaxies. Some further problems in this connection are here discussed.

## Dynamical aspects of dumbbell and tether satellites

*A. Celletti*

We investigate the dynamics of two rotational models, known as the dumbbell and the tether satellites. The dumbbell satellite consists of two point masses connected by a massless rod; the barycenter moves on a Keplerian orbit around an attracting center, but the distance between the point masses is assumed to be much smaller than the distance between the satellite's center of mass and the attracting center. The second model differs in that the two masses are connected by an extensible, massless tether. We study the satellite's attitude dynamics with reference to circular orbits (which admit a stable relative equilibrium), elliptic orbits (no stable equilibrium positions are found even for small values of the eccentricity), out-of-plane perturbations, etc. Normal form theory, complemented by numerical integrations, is the basic tool for such investigation. The work is done in collaboration with V.V. Sidorenko.

## Orbits in Galaxies: A historical perspective

*G. Contopoulos*

We describe the development of the theory of orbits in galaxies with emphasis on the distinction between ordered and chaotic orbits. A recent development refers to the outer spiral arms of barred galaxies, which are density waves consisting mainly of chaotic orbits.

## Dynamics of high area-to-mass ratios GEO space debris and secondary resonances

*N. Delsate, S. Valk, T. Carletti, A. Lemaitre*

Recent optical surveys in high-altitude orbits, performed by the European Space Agency 1 m telescope in Tenerife (Canary islands), have discovered a new unexpected population of 10 cm size space debris near the geostationary orbit (GEO). These objects sometimes present highly eccentric orbits with eccentricities as high as 0.55 (Schildknecht et al., 2004, 2005). Recent numerical and analytical investigations (Anselmo and Pardini, 2005; Liou and Weaver, 2005) prove that this new population consists of near geosynchronous objects with high area-to-mass ratios. The large area-to-mass ratios space debris have a dynamical behavior dominated by the solar radiation pressure. Starting with very small eccentricities and inclinations, they can reach very high values over a few years. These uncommon objects dynamics has been treated by a number of authors. However, no concern about the intrinsic stability of such uncharacteristic orbits has been given so far. We propose an analytical investigation and a systematic numerical study (with chaos indicator and frequencies analysis) showing large chaotic zones and small islands of stability, identified as secondary resonances.

## Planetary perturbations on the rotation of Mercury

*Julien Dufey, Anne Lemaitre, Benoit Noyelles, Nicolas Rambaux*

In this study, we use an analytical method to introduce indirect planetary perturbations on the rotation of Mercury. Using a perturbation theory based on the Lie triangle, we are able to re-introduce short periodic terms in the averaged Hamiltonian and compute the evolution of the variables. In the first part we consider a simplified problem: all the inclinations of the planets are zero and Mercury is a non-spherical body with a spherical liquid core. The perturbations on Mercury's forced libration in longitude mainly come from the orbital motion of Mercury, completed by various effects from Jupiter, Venus, Saturn and the Earth. The amplitudes of the oscillations due to Jupiter and Venus are approximately 33% and 10% of those from the orbital motion of Mercury and the amplitudes of the oscillations due to Saturn and the Earth are approximately 3% and 2%. We compare the analytical results with the solution obtained from the spin-orbit numerical model SONYR. In the second part the planets' inclinations are not zero any more and we study the planetary perturbations on Mercury's obliquity and the resonant angle between the orbital and rotational nodes. The analytical results are also compared to solutions obtained with numerical integrations and frequency analysis.

## Asteroids and terrestrial planets in multiplanetary systems

*R.Dvorak and A. Suli*

Multiplanetary systems are quite interesting from the point of view of the orbital dynamics. The planets in these systems (extrasolar planetary systems = EPS) are very massive and comparable in size and mass to the gas giants in our planetary system. Because of the uncertainty of the orbital parameters of the EPS it is rather difficult to draw conclusions for the stability of additional bodies. We tried a simpler method of finding out stable regions for such bodies (asteroids or terrestrial planets) inside the inner planet, in between two giants and outside the outer planet. We compare these results with numerical integrations which fully take into account the dynamics of the system.

## The Dynamics of Doubly Resonant Domains

*C. Efthymiopoulos*

In a domain of the action space where two resonances intersect, the Hamiltonian of a system of three degrees of freedom can be transformed locally into the sum of a normal form and an exponentially small remainder. The normal form is a Hamiltonian of two degrees of freedom, thus it exhibits in general chaotic motions which drive the Arnold diffusion locally. We shall explore this type of dynamics in a particular example of doubly-resonant domain of the model Hamiltonian introduced by Froeschlé et al. (2000) in the study of Arnold diffusion. In particular, we shall investigate the existence of lower-dimensional tori and of their `whiskers', i.e., asymptotic manifolds, as well as the patterns created in the action space by such manifolds. In this study we use a computer program to generate the normal form and remainder functions up to an optimal order of normalization, with respect to a suitably defined small parameter.

## High-eccentrcity Asteroids and Comets in the Edge of the 2:1 Resonance

*S. Ferraz-Mello, M.J. Carvano and D. Lazzaro*

We present some results on the dynamics of asteroids and comets situated in a domain of the a-e space that makes them have perihelia near the orbit of Mars and aphelia near the orbit of Jupiter. This exact condition is situated at a~3.337 AU and e~0.545 and is inside the 2:1 resonance domain. These objects have Tisserand parameter T<3 and the asteroids selected for this study belong to the so-called ACOs (asteroids in cometary orbits). Among the studied objects (11 asteroids and 7 comets), most of the asteroids and some comets show libration of the critical angle of the 2/1 resonance for long times. 2 asteroids, however, (5201) Ferraz-Mello and 2005 YR 50, remain in the resonance only for very short time and show many close approaches to Mars and to Jupiter. Their orbital elements vary in a very irregular way. They are dynamically identical to several comets among which 71P/Clark and 9P/Tempel 1. All these objects lie on the edge of the 2/1 resonance. The physical observation of (5201) Ferraz-Mello with the U.S.-Brazil telescope SOAR, during the 2007 opposition, showed that it belongs to taxonomic class D. The reflectance spectrum of this asteroid is unusual, with a steep spectral gradient that is more similar to Centaurs and TNOs than to main-belt D-type asteroids, but with a relative increase in the reflectance in the visible domain which is not typically found in the former populations. A tentative explanation for this unusual spectrum is the presence of a faint dust coma (however, not apparent in our images). Together, the unusual spectrum and dynamical behavior of (5201) Ferraz-Mello strongly suggests that this object is in fact an extinct/dormant comet of Jupiter family.

## Investigation on the individual effects of star encounters with the Sun on the Oort cloud comets

*Marc Fouchard, Giovanni B. Valsecchi, Hans Rickman, Ch.Froeschlé*

The dynamics of the Oort cloud comets is mainly governed by the Galactic tide and the stars passing close to the Sun. In order to evaluate the effect of individual star, we have performed different simulations with a sequence of stellar passages characterized by one encounter with the Sun every 250 Myr on an initial Oort cloud containing $10^6$ comets. For each sequence the stellar type is the same but the geometry of the encounters with the Sun is at random. Then two evolutions of the cloud are modeled, one with the stellar perturbations alone, and one with the combined effects of the stars and of the Galactic tide. We aim to evaluate the strength of the comet showers, {\it i.e.} the flux from the Oort cloud toward the observable region induced by the stellar perturbations, with respect to the encounter parameters (the stellar type, the star velocity and the impact distance with the Sun). Using the data obtained with the combined effects we should be able to evaluate also the synergy which takes place between the two perturbers.

## Hyperbolic manifolds supporting Arnold diffusion in quasi-integrable systems

*Froeschlé C., Lega E., Guzzo M.*

We review the Arnold's model of exponentially slow diffusion. For a quasi-integrable Hamiltonian satisfying both KAM and Nekhoroshev theorem we compute numerically a diffusion coefficient in agreement with the exponential behaviour predicted by the Nekhoroshev theorem. We show, using the Fast Lyapunov Indicator, that such a diffusion can also have a global character and occurs on the peculiar structure of the Arnold'sweb. We investigate the topology of stable and unstable manifolds. We show that such manifolds appear to be characterized by peculiar 'flower-like' structures. We detect different transitions in the topology. We show that they are related to the variations in the diffusion coefficient with respect to the perturbing parameter. We also measure an exponential decrease of the size of the lobes of the manifolds in agreement with Nekhoroshev theorem. Finally, we measure a spread of the asymptotic manifolds which seems to be significant to explain diffusion.

## Comparison of fast Lyapunov chaos indicators for Celestial Mechanics

*Julien Frouard*

By now, fast numerical indicators of chaoticity in Celestial Mechanics are widely used to avoid the direct computation of the LCEs. Here we present a comparison in terms of precision, CPU speed, and practicability of several of these indicators based on the theory of Lyapunov exponents; the FLI, MEGNO, and the GALI. While the two first have been commonly used, the GALI has not yet been applicated to Celestial Mechanics. However, this indicator has its own qualities and specificities. The final aim of the comparison of these indicators is the production of stability maps in the case of irregular satellites of giant planets, the examples and applications are shown in this sense.

## On the numerical computabililty of Lyapunov times

*Enrico Gerlach*

Chaos indicators, like the Lyapunov exponent $\lambda$, are widely used in celestial mechanics to characterize the dynamical behavior of bodies. The stability of their orbit can be determined by the calculation of the local exponential divergence of arbitrarily close initial conditions in phase space. As the equations to calculate $\lambda$ are given, a straight prediction of the orbital stability should be possible. However, one finds in the literature a lot of discrepancies between different studies dedicated to the same object. As a possible explanation for this we investigated in the presented work the effects of the used computer hardware and integration methods on the outcome of such stability computations. Therefore we calculated the Lyapunov time $T\_L=1/\lambda$ of different asteroids as a measure of chaoticity. Exploring the very fine structure of the nearby phase space of the initial conditions, we are able to explain the reason of the differences in the published T_L for some objects. Applying methods of robust statistics we introduce the computability index $\kappa$ as a measure of repeatability of the results. This $\kappa$ gives an estimate, how much the obtained Lyapunov time will change, e.g. when repeating the same calculations with a different integration method.

## Nekhoroshev's stability for the Sun--Jupiter--Saturn system

*Antonio Giorgilli, Ugo Locatelli and Marco Sansottera*

We investigate the stability in Nekhoroshev's sense of the problem of three bodies with the masses and orbital parameters of Jupiter and Saturn. We show that a positive result of stability for a time interval comparable with the age of the universe shoud be attained provided we have enough computer power available.

## The dynamics of two-planet system hosted by a red giant star

*K. Gozdziewski, A. Niedzielski, M. Konacki and A. Wolszczan*

We perform the dynamical analysis of the radial velocity observations of a red giant star observed in the programme of PSU/TCfA Search for Planets around Evolved Stars. We found an evidence of two planet system. However, due to technical reasons, the data points are sparse and irregularly sampled. We found that a few concurrent best fit solutions are possible. In this work, we perform the quasi-global search for stable configurations and we try to determine the long-term orbital and physical evolution of the system.

## Orbit Determination with the Two-Body Integrals

*G.F. Gronchi, L. Dimare, A. Milani*

With the new observational techniques, to be used in the next generation surveys like Pan-STARRS, the number of detected moving objects per night is expected to increase by two orders of magnitude with respect to the current surveys. To deal with this huge amount of data the interest in the study of orbit determination methods has been renewed, both from the theoretical and computational point of view. We present a method to compute a finite set of preliminary orbits of Solar System bodies using the energy and angular momentum integrals of the two-body problem. This method is thought for the applications to the modern sets of astrometric observations, where often the observables allow to compute by interpolation two angular positions of the observed body and their velocities at a given epoch; we call this set of data `attributable'. Given two attributables of the same body at two different epochs the energy and angular momentum integrals are used to write a system of polynomial equations in the topocentric distance and radial velocity of the body at the two epochs. The modern techniques of Algebraic Geometry allow to define an algorithm for the computation of the solutions. The main differences with the procedures using only two nights of observations is that there is no constraint on the computed orbit, like in Vaisala method. We also expect that this algorithm is suitable to be used when the two epochs are well separated, i.e. of the order of one orbital period. The same method can be also used for the orbit determination of space debris: in that case the unknowns may be different, depending on the use of optical or radar devices.

## Hyperbolic manifolds and Arnold diffusion in *a priori* unstable dynamical systems

*M. Guzzo*

We describe the global and local properties of the hyperbolic manifolds in the a priori unstable dynamical systems which are correlated to the diffusion properties. We measure a spread of the asymptotic manifolds which is significant to explain diffusion. We show that the stable and unstable manifolds have a topological transition when the Melnikov approximation looses its accuracy. This transition is correlated to a change of the law of dependence of the diffusion coefficient on the perturbing parameter. This suggests that the Melnikov approximation is not only a technical tool which allows one to compute accurate approximations of the manifolds at small values of the perturbing parameters, but is related to a dynamical regime.

## Homoclinic Connections in the Hill Problem with Radiation

*A.E. Perdiou, C.N. Douskos and V.S. Kalantonis*

Asymptotic motion around the collinear equilibrium points of the Hill problem is considered when the primary is radiating. Specifically, asymptotic orbits to the collinear equilibrium points and to Lyapunov orbits are determined. Transversality of the latter is achieved by construction of appropriate surface of section portraits of the unstable manifolds.

## Remarkable Dynamical Features in Exosolar Kuiper Belts

*Paul Kalas*

Fine structure in exosolar Kuiper Belts has now been resolved around nearly two dozen stars using thermal and scattered light imaging. In many cases we observe a surprising diversity in belt structure, and the links to planetary dynamics are still purely qualitative. I will present several newly resolved exosolar Kuiper Belts, with a focus on the unexplained features that require new theoretical work.

## The Copenhagen case when the primaries are oblate spheroids with dipole-type magnetic fields

*Tilemahos Kalvouridis*

A look back over a century of investigation of a charged particle dynamics in an electromagnetic field and the various phenomena associated with it that occur in the neighbourhood of Earth reveals an era of rigorous growth not only in depth but also in sheer volume. This growth reflects an accumulation of knowledge and an additive experience that lighten new roads of research. From the simple Stormer's problem at the beginning of the 20th century until the most complex models of the last decade, many configurations, theories, experiments and mathematical processes have been proposed and carried out in order to enrich our knowledge and to give universal answers. Moving in this framework, some years ago a model commonly known as the magnetic-binary problem or, otherwise, problem of two rotating magnetic dipoles was proposed. It was based on the combination of both old Stormer's problem and the restricted three-body problem. The fundamental configuration consists of two massive bodies with dipole-type magnetic fields that rotate around their common center of mass in circular orbits with constant angular velocity under their mutual Newtonian attraction. A small charged mass-less particle moves in the created by the primaries electromagnetic field. After the discovery of many extra-solar planetary systems during the last 15 years, this model comes again on stage and acquires theoretical interest since many of these systems have two members and some of them may dispose magnetic fields. In this presentation we further elaborate on the problem by assuming that the two primaries are oblate spheroids with equal masses and we present some aspects of it that are related to the parametric evolution of the regions where 2-D or 3-D particle motions exist.

## Fulfillment of the conditions for application of Nekhoroshev's theorem in the vicinity of the resonance

*Rade Pavlović and Zoran Knežević*

A semianalytical procedure to check the fulfillment of the conditions for application of Nekhoroshev's theorem has been recently developed and applied to the non resonant domain of a real dynamical system (Pavlović and Guzzo, 2008, MNRAS **384**, 1575). Here the analogous procedure has been applied to the single resonance domain, in the vicinity of the resonance located in the main asteroid belt. By means of the suitable transformations, the asteroid's Hamiltonian is expressed in the resonant normal form, and the conditions of convexity, quasi—convexity and 3-jet non-degeneracy checked.

## Chaotic diffusion in the Solar System

*Jacques Laskar*

The discovery of the chaotic behavior of the planetary orbits in the Solar System [Laskar, J., 1989, Nature 338, 237-238; Laskar, J., 1990. Icarus 88, 266-291] was obtained using numerical integration of averaged equations. In Laskar [Laskar, J., 1994. Astron. Astrophys. 287, L9-L12], these same equations are integrated over several Gyr and show the evidence of very large possible increase of the eccentricity of Mercury through chaotic diffusion. On the other hand, in the direct numerical integration of Ito and Tanikawa [Ito, T., Tanikawa, K., 2002. Mon. Not. R. Astron. Soc. 336, 483-500] performed without general relativity over 4 Gyr, the eccentricity of Mercury presented some chaotic diffusion, but with a maximal excursion smaller than about 0.35. In the present work, a statistical analysis is performed over more than 1001 different integrations of the secular equations over 5 Gyr. This allows to obtain for each planet, the probability for the eccentricity to reach large values. In particular, we obtain that the probability of the eccentricity of Mercury to increase beyond 0.6 in 5 Gyr is about 1 to 2%, which is relatively large. In order to compare with Ito and Tanikawa [Ito, T., Tanikawa, K., 2002. Mon. Not. R. Astron. Soc. 336, 483-500], we have performed the same analysis without general relativity, and obtained even more orbits of large eccentricity for Mercury. In order to clarify these differences, we have performed as well a direct integration of the planetary orbits, without averaging, for a dynamical model that do not include the Moon or general relativity with 10 very close initial conditions over 3 Gyr. The statistics obtained with this reduced set are comparable to the statistics of the secular equations, and in particular we obtain two trajectories for which the eccentricity of Mercury increases beyond 0.8 in less than 1.3 and 2.8 Gyr, respectively. These strong instabilities in the orbital motion of Mercury results from secular resonance between the perihelion of Jupiter and Mercury that are facilitated by the absence of general relativity. The statistical analysis of the 1001 orbits of the secular equations also provides probability density functions (PDF) for the eccentricity and inclination of the terrestrial planets (Mercury, Venus, the Earth and Mars) that are very well approximated by Rice PDF. This provides a very simple representation of the planetary PDF over 5 Gyr. On this time-scale the evolution of the PDF of the terrestrial planets is found to be similar to the one of a diffusive process. As shown in Laskar [Laskar, J., 1994, Astron. Astrophys. 287, L9-L12], the outer planets orbital elements do not present significant diffusion, and the PDFs of their eccentricities and inclinations are well represented by the PDF of quasiperiodic motions with a few periodic terms.

## Singularity Analysis: The Elements of Implementation and the Essence of Interpretation of the Results

*P.G.L. Leach*

Singularity analysis of differential equations is an important tool in the determination of the possible integrability of the equations. Unfortunately the interpretation of the results obtained by the analysis has been and is frequently imperfect. We present a brief outline of the procedure of the analysis and demonstrate the interpretation of the results by means of a model equation which is integrable in closed form. We construct an integrable system, similar in complexity to that of the Bianchi IX model, commonly known as the Mixmaster Universe, for which the singularity analysis gives similar results and compare the results.

## Modelling the Formation of Giant Planet Cores

*H.F. Levison, M.J. Duncan, E. Thommes*

It is ironic that the most massive planets in the Solar System had to have formed in the least amount of time. Jupiter and Saturn, for example, which are made mainly of hydrogen and helium, must have accreted this gas before the solar nebula dispersed in the first ~1-10 Myr. Thus, one of the most challenging problems we face in our understanding of planet formation is how Jupiter and Saturn could have formed so quickly. The most popular model of giant planet formation is the so-called *core accretion* model. In this model a large planetary embryo formed first, mainly by two-body accretion. This is then followed by a period of inflow of nebular gas directly onto the growing planet. The core accretion model has an Achilles heel, namely the very first step. The accretion of a massive atmosphere requires a solid core $\sim 10\,M_{\oplus}$ in mass. Assembling such a large body, it turns out, offers some serious challenges to the theory of planet formation as it currently stands. The difficulties are threefold: First, the accretion process has to be efficient enough to concentrate such a large mass in (at least) one single body. Second, everything has to happen fast enough ($\sim 10^7$ yr). The final problem concerns migration due to planet-disk tidal interactions, which threatens to drop core-sized bodies into the central star faster than they can accrete. We have undertaken the most comprehensive study of this problem to date. This is a numerical study where we numerically integrate the orbits of a number of planetary embryos embedded in a swarm of planetesimals. In these experiments we have included a large number of physical processes that might enhance accretion. In particular, we have included: 1) aerodynamic gas drag, 2) collisional damping between planetesimals, 3) enhanced embryo cross-sections due to their atmospheres, 4) planetsimal fragmentation, and 5) planetesimal driven migration. In this talk, we will present preliminary results from this study.

## Kozai resonance in extrasolar systems

*Anne-Sophie Libert and Kleomenis Tsiganis*

We study the possibility that extrasolar systems, composed of two planets revolving around a star, are in a stable Kozai-resonant state. In particular, five real two-planet systems that are not in mean motion resonance (MMR) are treated. To aim this goal, a parametric study is undertaken, integrating several sets of orbits of the two planets obtained by varying the (unknown) inclination of their orbital planes and their nodal longitudes, thus changing their masses and mutual inclination. We also take into account the observational errors on the orbital elements. We find that four of these systems can be in principle in Kozai resonance, provided that their mutual inclination is of order ~ 45 deg. These numerical results are verified using the analytical secular theory of Libert & Henrard (2007) developed for systems in the Laplace plane reference frame, and a new characterization (based on frequency analysis) of the Kozai resonance for systems in a general reference frame. Moreover, different physical mechanisms that could generate these large mutual inclinations are studied: (a) Type II migration and MMR interactions (gas-dominated phase), and (b) multi-planet scattering, caused by the presence of an additional planet (see e.g. Ford et al. 2005 for the 2-D case). For the systems under consideration, only mechanism (b), i.e. the same as the one invoked to produce the large eccentricities observed in many systems, can actually pump the mutual inclination up to the desired level and produce a similar range of semi-major axes for the two remaining planets. Following these ideas, a 3-D model of three planets trapped in multiple resonance due to Type II migration will be investigated.

## A Jupiter-Saturn analogon: OGLE-06-109L

*E. Pilat-Lohinger*

The multi-planetary system OGLE-06-109L was detected by microlensing recently. According to the observation, this system shows similarities with the Jupiter-Saturn configuration of our Solar system. Moreover, the Web-site of J. Schneider (http://exoplanet.eu) indicates a high inclination for the outer planet. Therefore, the orbital stability in both systems is studied for various inclinations of the outer giant planet and the influence on the motion of terrestrial-like planets in the so-called habitable zone is shown.

## The secular dynamics of generalized coplanar, non-resonant planetary system

*Cezary Migaszewski and Krzysztof Gozdziewski*

In a recent work (Migaszewski & Gozdziewski, MNRAS 2008a) we present a simple method for averaging perturbations to the Keplerian motions. First, we construct a secular theory of non-resonant, coplanar system of N-planets, taking into account Newtonian point-to-point interactions between the companions (the classic model). We expand the perturbing Hamiltonian in Taylor series with respect to the ratio of the semi-major axes. Next, we average out the resulting series with the help of an appropriate change of the integration variables. We obtain the high-order (24) secular theory, without direct restrictions on the eccentricity. In the next paper, (Migaszewski & Gozdziewski, MNRAS, 2008b), we apply this theory to study the effects of general relativity and quadrupole moment of the star in the secular dynamics of coplanar, non-resonant planetary system (the generalized model). We show, that these apparent ``corrections" to the point-to-point Newtonian interactions between planets are critically important for the long-term dynamics. In general, they change the qualitative view of the phase space and can influence the dynamical stability of the system. We focus on stationary solutions in the secular problem. We found that equilibria permitted in the classic model may be strongly affected by the additional perturbations. We found new, non-classic equilibria in the generalized problem and we determine their Lyapunov stability.

## Reasons to study the gravitational N body problem

*Andrea Milani Comparetti*

Hadjidemetriou has dedicated most of his career to explore the 3 (and 4) body problem; others, including myself, have done a similar choice. There needs to be a very good reason for such a dedication. Among the conservative dynamical systems, the N body problem with attractive potential inversely proportional to the distance has a special place in the history of mathematics and astronomy. However, is the relevance of this problem purely historical? The answers depends upon the effectivness of the N body problem as a model of the motion of solar system bodies, both natural and artificial. We will discuss the consistency and extraordinary accuracy of this model, which depends upon the physical properties of our planetary system. At the level of accuracy of the state of the art interplanetary measurements, the Newtonian model is not anymore adequate: it requires to add some small but measurable perturbations, resulting from non gravitational perturbations and from generalrelativity. The latter can be expressed in a linearized Lagrangian formalism, called Parametric Post Newtonian. As a an extreme example of the accuracy needed in a dynamical model directly compared with state of the art measurements, we will discuss the observables of an orbit determination experiemnt of the next generation, the Mercury Orbiter Radioscience Experiment of the BepiColombo mission to Mercury. In this way we will show the difficulties to be met in the domains of mathematics (including numerical error), physics and technology, in this state of the art application of a modern version of the N body problem.

## What is wrong with the Nice Model?

*Alessandro Morbidelli*

The `Nice model' is a comprehensive scenario of the evolution of the outer solar system that seems to explain fairly well a number of observational constraints: the Late Heavy Bombardment of the Moon, the current orbital architecture of the giant planets, the existence and the orbits of the Trojans of Jupiter, the basic structure of the Kuiper belt, the irregular satellites of Neptune, Uranus and Saturn. A new version of this model has been made, in which initial conditions of the planets are derived from hydro-dynamical simulations. I will briefly review this model in both its versions but, rather than insisting on its successes, I think that it will be more stimulating to focus on the issues which seem to be wrong (or not understood) so far. It is unclear if these open issues are enough to invalidate the model as a whole, of if they can be solved by adopting suitable variants to the general scheme of the Nice model. Active research is ongoing to answer this question. As the Old Latins said `verba volant, scripta manent', so the list of open issues won't appear in this abstract....

## The YORP effect

*D. Nesvorný*

The YORP effect is produced when the surface of a small object in the interplanetary space is heated by sunlight and re-radiates the absorbed energy in thermal wavelengths. The emitted photons produce tiny torques on the small body which can change its spin rate and obliquity over planetary timescales. Direct detection of the YORP effect has been achieved in 2007 by photometric and radar observations of asteroids (54509) YORP and (1862) Apollo. I will review the theory of the YORP effect and its applications to asteroid spin dynamics.

## Resonance analysis for Hamiltonian systems

*A. Noullez*

Frequency analysis has proven to be a very powerful technique to characterize the transition to chaos in dissipative and conservative dynamical systems. Accurate frequency determination however requires very delicate numerical methods that are also computationaly expensive. In this talk, I will present an alternative method for frequency analysis, based on the construction of an approximate linear differential equation of high order, best representing (in the least-squares sense) an observed time series. The signal frequencies are then obtained as the eigenfrequencies of this differential equation, by solving its characteristic polynomial. The corresponding power spectrum

then consists in a rational function of the complex frequencies, with a finite number of poles corresponding to approximate resonances present in the signal. This kind of representation is thus very well suited to Hamiltonian systems time series, and examples from simple dynamical systems like the standard map will be presented.

## Local diffusion characteristics and the age of the asteroid family

*Bojan Novaković, Kleomenis Tsiganis and Zoran Knežević*

Members of the asteroid families, located in the dynamically active regions of the Main Asteroid Belt, have been dispersed over the time due to the chaotic diffusion, gravitational and non-gravitational perturbations. These mechanisms have changed the original shapes of the families produced in collisions, and consequently have complicated physical studies of high-velocity collisions. Here we present detailed study of the local diffusion characteristics in the region of Veritas family. Using these characteristics we developed a model, based on Markov Chain Monte Carlo technique which use combined action of the Yarkovsky/YORP drift and chaotic diffusion, so as to be able to simulate evolution of the family and to estimate its age. Our results about local diffusion reveal a complexity of the phase space in the presence of resonances. On the other hand, results obtained by using our random walk model led to two conclusions: firstly, that so called *chaotic chronology* method could be modified to date more reliable asteroid families, and that the estimate of the age of family is improved when local diffusion characteristics are used; secondly, this method could be used to improve our knowledge about the origin of the shapes of asteroid families and to help in the reconstruction of the original ejection velocity fields.

## Asymmetric periodic solutions in the restricted three-body problem

*K. Papadakis*

A systematic numerical exploration of the families of asymmetric periodic orbits of the restricted three-body problem when the primary bodies are equal, is presented. Decades families of asymmetric periodic solutions were found and three of the simplest ones are illustrated. All of these families consist of periodic orbits which are asymmetric with respect to x-axis while are simple symmetric periodic orbits with respect to y-axis (i.e. the orbit has only one perpendicular intersection at half period with y-axis). Many asymmetric peri- odic orbits, members of these families, are calculated and plotted. We studied the stability of all the asymmetric periodic orbits we found. The three simplest asymmetric families consist, mainly, of unstable periodic solutions but there exist very small, with respect to x, intervals where these families have stable periodic orbits. We also found, using appropriate Poincare surface of sections, that the orbits close to all these stable asymmetric periodic orbits are chaotic.

## A formation scenario of co-orbital terrestrial planets

*Zs. Sandor and C. Beauge*

We studied the formation of a hypothetical terrestrial-type planet in the equilateral Lagrangian points of a star -- giant planet system. Starting from a swarm of planetesimals moving in stable tadpole orbits, we studied its dynamical and collisional evolution under a wide range of different initial conditions. Additionally, we analyzed the effects of gas drag from the interaction of the planetesimals with the protoplanetary disk. The formation process was simulated with an N-body code considering full gravitational interactions between the planetesimals, in which non conservative drag forces were also included. The drag coefficients were chosen following the results of full hydrodynamic simulations with the 2D hydro-code FARGO. We were able to form terrestrial-type planet in a stable tadpole orbit around the Lagrangian point L4 of the star -- giant planet system. However, due to the gravitational instabilities within the swarm, the efficiency of the accretion was reduced, and the final mass of the planet never exceeded ~0.6 Earth masses. Finally, we also demonstrated that the formation could also happen when the giant planet migrated inward. This mechanism (type II migration) could bring the Trojan-type planet to the habitable zone of the hosting star.

## Close encounters in the Caledonian Symmetric Four Body Problem

*A. Sivasankaran and B.A. Steves*

The Caledonian Astro-dynamics Research Group has developed the Caledonian Symmetric Four Body Problem (CSFBP) which is a restricted four body system with a symmetrically reduced phase space. The main limitation of the CSFBP model is that, the equations of motion of the problem contain singularities which cause numerical integration algorithms to fail as the system approaches a close encounter. In order to study the close encounters and collision events occurring in the CSFBP, we derive a regularization method for the CSFBP and apply it to determine the regularized equations of motion. The resulting equations of motion can be efficiently integrated by any higher order integrator. The effectiveness of this approach is illustrated for a set of CSFBP orbits.

## The Generalized Alignment Index (GALI) Method of Chaos Detection: Theory and Applications.

*Ch. Skokos*

We investigate the dynamics of conservative dynamical systems by studying the evolution of volume elements formed by deviation vectors about their orbits. The behavior of these volumes is strongly influenced by the regular or chaotic nature of the motion. The different time evolution of these volumes is used to identify rapidly and efficiently the nature of the dynamics. In particular, we define the Generalized Alignment Index of order $k$ (GALI_$k$), with $k$>1, as the volume of a generalized parallelepiped, whose edges are $k$ initially linearly independent unit deviation vectors from the studied orbit and we compute GALI_k by an efficient numerical scheme based on the Singular Value Decomposition (SVD) algorithm. We show analytically and verify numerically on particular examples of Hamiltonian systems and symplectic mappings that, for chaotic orbits, GALI_$k$ tends exponentially to zero with exponents that involve the values of several Lyapunov exponents, while in the case of regular orbits GALI_$k$ fluctuates around non-zero values or goes to zero following power laws that depend on the dimension of the torus. Finally, we show how the indices can be used for identifying quasiperiodic motion on low--dimensional tori.

## Negative Mass and Repulsive Gravity in Newtonian Theory and Consequences

*N.K. Spyrou*

In the context of the Newtonian theory of gravity, the dynamical equivalence of hydrodynamic flows with geodesic lines, in the interior of a bounded, gravitating perfect-fluid source, results in the possibility of negative mass and, hence, of repulsive gravity. The consequences are outlined for the overall picture of the Solar System and the large-scale cosmological, structures, and some predictions are attempted based on some current and mostly unexplained so far observational data.

## Numerical investigation of the diffusion in a 4 dimensional steep map

*N. Todorović, M. Guzzo, E. Lega and C. Froeschle*

We study numerically a 4 dimensional steep map.Using the Fast Lyapunov Indicator we detect the resonant structure and select chaotic initial conditions to study diffusion. We show preliminary results about the influence of steepness on the diffusion properties in the system.

## Quasi-critical orbits for artificial Lunar satellites

*S. Tzirti and K. Tsiganis*

We study the problem of critical inclination orbits for artificial Lunar satellites, under the combined effects of the $J_2$ and $C_{22}$ terms of the lunar potential and lunar rotation. We show that, apart from the very limited set of fixed points of the averaged Hamiltonian, in which the inclination remains constant and the precession of the pericenter may freeze, there are *quasi-critical solutions*, for which the line of apsides librates. These solutions represent smooth curves in phase space, which determine the dependence of the quasi-critical inclination on the initial nodal phase. The amplitude of libration of the apsidal line would be quite large for a non-rotating Moon, but reduces to $<1$ deg, when a uniform rotation of the Moon is taken into account.

## Periodic orbits in the Main Lunar Problem

*G. B. Valsecchi, E. Perozzi, A. E. Roy and B. A. Steves*

The study of near commensurabilities among lunar months has led to the discovery that the lunar orbit is very close to a set of 8 periodic orbits of the restricted circular 3-dimensional Sun-Earth-Moon problem. In these periodic orbits 223 synodic months are equal to 239 anomalistic and 242 nodical ones, a relationship that approximately holds in the case of the observed Saros cycle, and the various orbits differ from each other for the initial phases. The periodic orbits associated with the Saros cycle, even if of long duration when compared to those usually found in literature, are by no means the longest ones that can be found close to that of the Moon; according to a famous conjecture put forward by Poincaré, there should be infinitely many periodic orbits, of longer and longer period. It is possible to show, with the help of Delaunay's expressions for the motion of the lunar perigee and node, that the longer periodic orbits are arranged in the eccentricity-inclination plane in a rather characteristic pattern that is simply a deformation of the arrangement, in frequency space, of the set of points corresponding to the frequencies of the periodic orbits themselves. This

allows to set up a numerical procedure to find periodic orbits in an efficient way. We use his tool to make a systematic exploration of the Main Lunar Problem.

## Formation and Dynamics of Planetary System OGLE-2006-BLG-109L

*Ji-Lin Zhou, Su Wang and Gang Zhao*

Recently observation by gravitational microlensing reveals that OGLE-2006-BLG-109L harbors two planets with masses 0.71 and 0.27 times of Jupiter mass at 2.3 AU and 4.6AU from the host star, respectively. The configuration of the two planets is though to be a striking resemblance to our solar system. In this work the formation scenario of the planet system and its dynamics, especially on the existence of Earth-like planets, is studied. Due to the small mass host star (0.5 solar mass), the snowline of the system is around 0.68AU. We found it is possible to have stable orbits in the habitable region of the system. We study the post-oligarchic evolution of a model planet system, which includes the type-I migration of small embryos, gas accretion of giant embryos, type-II migration of gas giant planets, etc. Some preliminary results of the simulation with applications to the OGLE-2006-BLG-109L will be presented.