Workshop Dynamics and kinetic theory of self-gravitating systems
Abstract book

IHP Gravasco Trimester

2013, November 4 to 8

Monday, November 4

Gerhard Rein

Bayreuth University, Germany

Steady states of the Vlasov-Poisson and Einstein-Vlasov systems

Galaxies or globular clusters are often modeled as collisionless ensembles of particles which interact only by the gravitational field which they create collectively. Since many of these astrophysical systems are in some sort of equilibrium (or close to one), the steady states of the corresponding mathematical models are of interest.

We will give a review which will show that both the Vlasov-Poisson and the Einstein-Vlasov systems possess plenty of steady states. Most of these are spherically symmetric, and we will make some comments on the existence of steady states without spherical symmetry.

Cyril Rigault

IRMAR, University of Rennes, France

The Vlasov-Manev system : stability of ground states and self-similar blow-up solutions.

The gravitational Vlasov-Manev system is a kinetic model which has a similar Vlasov structure as the classical Vlasov-Poisson system, but is coupled to a potential in $1/r$, $1/r^2$ (Manev potential) instead of the usual gravitational potential in $1/r$, and in particular the potential field does not satisfy a Poisson equation but a fractional- Laplacian equation. This modification of the potential is a relativistic correction, which can be seen as a alternative to the classical relativistic model.

I will first talk about the orbital stability of the ground states type solutions which are constructed as minimizers of the Hamiltonian, following the classical strategy: compactness of the minimizing sequences and the rigidity of the flow. However, in driving this analysis, there are two mathematical obstacles: the first one is related to the possible blow-up of solutions to the VM system, which we overcome by imposing a sub-critical condition on the constraints of the variational problem. The second difficulty (and the most important) is related to the nature of the Euler-Lagrange equations (fractional-Laplacian equations) to which classical results for the Poisson equation do not extend. We overcome this difficulty by proving the uniqueness of the minimizer under equimeasurabilty constraints, using only the regularity of the potential and not the fractional- Laplacian Euler-Lagrange equations itself.

In the second part of my talk, I will give the strategy of the proof of the existence of exact self-similar blow-up solutions to the Vlasov-Manev equation in the "pur case", with initial data arbitrarily close to ground states. This construction is based on a suitable variational problem with equimeasurability constraints

Maxime Hauray

CMI, University of Marseille, France

Mean-field limit and stability for self-gravitating systems with weakly singular interaction

We will present a result obtain in collaboration with Pierre-Emmanuel Jabin, about the mean field limit for self gravitating system with weakly singular interaction in dimension 3. Precisely, the interaction force near zero should be less singular than $1/|x|$. In that case, the interaction potential is bounded near zero, so that there are no real "collisions". This explains why this case is much simpler that the true gravitational one. In fact, we are able to prove some result of convergence towards the collisionless Boltzmann (aka Vlasov) equation. This is a kind of stability result around solution of the Vlasov equation, valid only for finite times and not to large singularities. We shall also present some very partial results valid for larger time and stronger singularities (a collaboration involving also Julien Barré).

Vladimir Salnikov

Insa Rouen, France

Qualitative analysis of dynamical systems: effective numerical methods

I am going to discuss some approaches to describing the qualitative behavior of dynamical systems inspired by the problem of their integrability. These approaches are based on the topological and algebraic properties of integrable and close to integrable systems. Since they employ essentially numerical methods I will comment on the details of their efficient implementation. I'm also going to present some results of application of these methods to the systems originating from physics.

Mahir Hadzic (with Gerhard Rein)

Dep. Of Math., MIT, USA

Stability problem for the Einstein-Vlasov system

In the first part of the talk I will introduce the Einstein-Vlasov system and survey some of the known mathematical results for this non-linear coupled system of equations. I will then formulate the question of nonlinear stability/instability of steady state galaxies and present a coercivity result for the second variation of the ADM-mass. As a consequence, we obtain the linear stability assuming that the central red-shift of the steady state galaxy is suitably small. This is consistent with the numerical observations of Zeldovich et al. from 1960's, that additionally suggest an instability when the central red-shift is large.

Jean Dolbeault

Ceremade, Paris-Dauphine University, France

Poster session

Tuesday, November 5

Pierre-Henri Chavanis

Theoretical Physics Laboratory, University of Toulouse, France

Kinetic theory of Hamiltonian and Brownian self-gravitating systems

I will discuss the kinetic equations governing the evolution of isolated and dissipative self-gravitating systems. Isolated Hamiltonian systems like stellar systems are described by the Vlasov equation in the collisionless regime (relevant to elliptical galaxies) and by the Landau or Lenard-Balescu equation in the collisional regime (relevant to globular clusters). The evolution of dissipative self-gravitating Brownian particles in contact with a thermal bath is described by the Kramers-Poisson system or, in the strong friction limit, by the Smoluchowski-Poisson system. In that case, it is possible to solve the collapse dynamics analytically. The system first undergoes a self-similar collapse leading to a finite time singularity: the central density becomes infinite in a finite time. Then, in a post-collapse regime, a Dirac peak grows at the center of the system and eventually accumulates all the mass. I will mention some analogies with the Bose-Einstein condensation and with the chemotaxis of bacterial populations in biology.

Wahb Ettoumi and Marie-Christine Firpo

Plasma Physics Laboratory, Ecole Polytechnique, Palaiseau, France

Lifetime of quasistationary states in the Hamiltonian Mean Field model

Using the Hamiltonian Mean Field model as a toy model for long-range interacting systems, we exhibit how its deterministic dynamics give rise to Quasi-Qtationary States (QSSs). We investigate and predict their lifetimes with respect to the number of particles by the means of a phenomenological stochastic approach, based on one-particle phase space exploration.

Julien Barre

University of Nice, France

Perturbing a non homogeneous stationary state of the Vlasov equation

There has been several remarkable progresses recently in the mathematical analysis of the Vlasov equation. I will first briefly introduce the results of Mouhot and Villani on non linear Landau damping, and present those of Lin and Zeng, who give a partial converse: they show that a complete exponential damping of all perturbations is impossible in some cases. Unfortunately, these nice results hold only for homogeneous systems, which excludes the cases of interest in astrophysics. I will highlight the difficulties of generalizations to self-gravitating systems, and present a first result in this direction, in the spirit of Lin and Zeng. Although it is obtained on a toy model, it hints at the fact that inhomogeneous stationary states may be, in a sense that I will make precise, more difficult to destabilize than homogeneous ones.

Clifford M. Will

University of Florida and Institut d'Astrophysique de Paris

Testing the black-hole no-hair theorem at the galactic center: Perturbing effects of distributions of stars or dark matter.

If future observations using advanced IR adaptive optics telescopes discover stars orbiting the central black hole in our galaxy with periods of order months, then it may be possible to test the no-hair theorem of black holes by observing the precessions of their orbital planes with 10 microarcseconds/year accuracy. These orbits will be perturbed by other stars in the central cluster and by a potential spike of dark matter near the black hole. Using a combination of $N-$body simulations and semi-analytic techniques, we estimate that, for a range of possible stellar distributions, the perturbations caused by other stars will comprise a "noise" smaller than the general relativistic precessions, as long as the target star's semi-major axis is less than about 0.2 milliparsecs. To assess the effect of a dark matter spike, we carried out a fully general relativistic calculation of the adiabatic growth of a massive black hole in a pre-existing dark matter distribution, extending an earlier quasi-Newtonian calculation by Gondolo and Silk (GS). We find that the distribution is not cut off at $r = 8Gm/c^2$ as found by GS, but extends inward to $r = 4Gm/c^2$ and is significantly more spiked. Using a Hernquist profile scaled to a total dark-matter halo mass of 10^{12} solar masses as the initial distribution, we show that the pericenter advances induced on no-hair target stars by the mass distribution of the dark matter spike will be much smaller than the relativistic precession effects.

Freddy Bouchet

Ecole Normale Supérieure ENS-Lyon and CNRS, France

Large deviations and non-equilibrium phase transitions in plasmas and gravitating systems

We will discuss the generalization of the classical kinetic theory of systems with long range interactions (Vlasov and Lenard-Balescu equations) to dynamics with stochastic external forces. Emphasize will be put on non-equilibrium cases (without detailed balance). Using the kinetic approach and large deviation theory, we will derive the corresponding non-equilibrium kinetic equations and predict non-equilibrium phase transitions.

Angel Alastuey, Maxime Champion, Thierry Dauxois and Stefano Ruffo,

Theoretical physics Laboratoy, ENS Lyon, France

Gravitation in the Microcanonical Ensemble: Scaling with Fixed Mass Density and the Hydrostatic Approach

We introduce a simple model of hard spheres with gravitational interactions. We study a scaling limit where the mass density is kept fixed, which is well-suited in view of applications to astrophysical situations. Usual extensive properties are maintained notwithstanding the long range nature of gravitational interaction. Within a microcanonical description of the stationary state, we show that the local density is given by a Boltzmann formula in terms of the mean gravitational potential, where the average kinetic energy per particle plays the role of temperature. At the local level, we have then to consider pure hard spheres at thermal equilibrium submitted to that gravitational potential created by the whole system. In the considered scaling limit, as the result of the large separation of the various characteristic length scales, the density profile can be exactly determined within a hydrostatic approach, at least at sufficiently high energies per particle. We argue about the possible failure of the hydrostatic approach at sufficiently low energies, in relation with the emergence of phase transitions or collapse phenomena.

Julien Carron

Institute of astronomy, University of Hawai, USA

Statistical ensembles of virialized halo matter density profiles

Numerical simulations of cosmological structure formation predict that dark matter aggregates in haloes with remarkably universal density profiles, well described by so-called NFW haloes.

I will describe a recent attempt at an understanding of this universality through statistical ensembles of spherically symmetric haloes, including only spatial degrees of freedom, that can be viewed as the statistical mechanics of a gravitationally interacting system on a spherically symmetric lattice. These ensembles can be solved exactly. While systems with virial radius larger than gravitational radius exhibit a localization of a finite fraction of the energy in the very center, the universal logarithmic inner slope of unity of the NFW haloes is predicted at any mass and energy if an upper bound is set to the maximal depth of the potential well. In this case, the profiles single out by the ensembles compare well to the NFW profiles, especially massive haloes.

Reference: this is entirely based on http://arxiv.org/abs/1301.6760, to appear in MNRAS

Wednesday, November 6

Jihad Touma

American University of Beirut, Physics Department, Lebanon

From Onsager to Gauss and back: the statistical mechanics of gaussian rings

Inspired by Onsager's classic work on "Statistical Hydrodynamics" (1949), we explored the statistical mechanics of systems of self-gravitating particles dominated by a central body, in a plausible secular limit where the interaction between two particles (Gaussian rings) is logarithmic. We describe some of what we learned in the process, including properties of micro-canonical axisymmetric equilibria and a remarkable phase transition to lopsided distributions, over a broad range of energies and angular momenta. Time permitting, we will discuss the relation between thermal and dynamical instability in such systems.

Dong-Biao Kang

Xinjiang Astronomical Observatory,Chinese Academy of Sciences.

Explanations for the surface brightness profile of the stellar disk from statistical mechanics

Currently the exponential surface brightness profiles (SBP) of disk galaxies still has not been completely settled. Different from other works, we temporally neglect the role of the conservation of angular momentum and aim to explain it from the point of statistical mechanics. We generalize our previous works to study the vertical structure and the radial SBP of the disk respectively. The asymmetric components such as warps, spiral arms and bars can contribute to the nonzero gravitation force at the center, and effects of the classical bulge can be considered into by that the disk in fact is not 2 dimensional. Then we find that the form of the equation of state we obtained is similar with the spherical system, and our results can fit the SBP of typical disks well. Finally, we also further confirm our previous works' conclusion about the not globally maximized entropy.

Evgeny Polyachenko

Institute of Astronomy of Russian Academy of Sciences, Russia

On the radial orbit instability

In the talk various interpretations of the radial orbit instability (ROI) is reviewed. A two-parameter family of models is offered, that allows to explore ROI for systems in the range from isotropic to purely radial ones. Some results of theoretical investigation and numerical simulations is presented.

Lapo Casetti

Center for study of Complex Dynamics, Unversity of Florence, Italy

Caloric curve of King models with a short-distance cutoff on the interactions

Self-gravitating systems, such as globular clusters or elliptical galaxies, are the prototypes of many-body systems with long-range interactions, and should be the natural arena in which to test theoretical predictions on the statistical behavior of long-range-interacting systems. Systems of classical self-gravitating particles can be studied with the standard tools of equilibrium statistical mechanics, provided the potential is regularized at small length scales and the system is confined in a box. The confinement condition looks rather unphysical in general, so that it is natural to ask whether what we learn with these studies is relevant to real self-gravitating systems. In order to provide an answer to this question, we consider a basic, simple, yet effective model of globular clusters: the King model. This model describes a self-consistently confined system, without the need of any external box, but the stationary state is a nonthermal one. In particular, we consider the King model with a short-distance cutoff on the interactions, and we discuss how such a cutoff affects the caloric curve, i.e., the relation between temperature and energy. We find that the cutoff stabilizes a low-energy phase, which is absent in the King model without cutoff; the caloric curve of the model with cutoff turns out to be very similar to that of previously studied confined and regularized models, but for the absence of a high-energy gaslike phase. We briefly discuss the possible phenomenological as well as theoretical implications of these results.

[L. Casetti and C. Nardini, Phys. Rev. E 85, 061105 (2012)]

Leonid Ossipkov

St Petersburgh University, Russia

Dynamics of star clusters in the galactic field

Dynamics of cluster moving along circular orbit in the axisymmetric steady Galaxy is studied. The equations of star motion in the joint field of the Galaxy and a cluster are analyzed and libration points are found. The stability condition for the center of cluster coincides with Bok's stability condition generalized for non-uniform systems. Orbit calculations show that retrograde orbits are more stable. The hierarchy of gross-dynamics equations was deduced, and some theorems on cluster evolution were proved. The dependence of the equilibrium form of the cluster on velocity anisotropy is analyzed. Small "virial" oscillations relative to the equilibrium were studied and eigen-frequencies of oscillations were found. Possible generalizations for clusters on non-circular orbits are discussed.

Olivier Bienaymé

Observatory of Strasbourg, France

Aproximate integral of motions

We determine aproximate numerical integrals of motion of 2D symmetric Hamiltonian systems. We show for a few gravitational potentials that a wide range of regular orbits are accurately modelled with a unique approximate integral of motion.

Erez Michaely and Hagai B. Perets

Physics Department, Technion, Israel Institute of Technology, Haifa, Israel

Secular evolution and mass loss in evolved triple systems

Recent studies have shown that secular evolution of triple systems can play a major role in the formation and evolution of compact binaries. In particular, they could lead to the production of unique gravitational wave sources and to the collisions and mergers of compact objects. Much less study have been focused on the stellar evolution of triple systems which lead to the formation of the compact objects in these systems, and in particular to the mass loss phase in the red-giant and asymptotic giant branch phase of the evolving stellar components. Here we study the dynamical secular evolution of hierarchical triple systems undergoing mass loss, using a newly developed secular evolution code which includes the effects of mass loss (but no mass transfer) while accounting for general relativisitc (GR) effects. We present various evolutionary routes in such systems, and discuss both the effects of mass loss in the inner binary system as well as mass loss from the outer third companions. We show that mass loss can both induce and quench high amplitude variations in the eccentricity and inclination of the inner binaries of evolving triples, and we discuss the implications of such evolution on the on the long term evolution and final outcome of the inner binaries.

A. Trova, J.-M.Huré, F. Hersant

Astrophysics Laboratory of Bordeaux, France

The softening length in $3D-$fluids

In hydrodynamic simulations, discs are usually discretised into homogeneous (cylindrical) cells, each cell having its own density. To our knowledge, the self-gravitating potential of such cells is not known in closed-form. Authors generally use ' softened gravity' in order to avoid the singularity of Green's kernel. In this theory actually, Newton's law is modified by including a parameter λ in the relative separation $|r' - r|$, but its value remains arbitrary, typically 60% of the disc thickness.

By applying the Green's theorem, we have determined an exact expression for the potential of $3D$ curved cells in the form of a contour (i.e., $1D$) integral with a regular integrand. From this calculus, we have estimated the appropriate softening length λ, which is not constant but a function peaking in the cell's interior. We will present these results fornumerical resolutions typical of current hydrodynamical simulations.

José Lages

Besançon Observatory, France

Chaotic dark matter in the Solar system and galaxies

We have shown that the Solar System if full of chaotic dark matter captured by Jupiter rotation from the galactic wind. The capture cross-section is much larger than the area of Jupiter orbit being inversely diverging at small particle energy. This divergence is weaker than the divergence of the Rutherford scattering cross section but it is still significantly strong to accumulate a lot of dark matter in the Solar System. The dynamics of captured dark matter particles is found to be chaotic and well described by a simple symplectic

dark map. This dark map description allows to simulate the scattering and dynamics of 10^{14} dark matter particles during the life time of the Solar System and to determine dark matter density profile as a function of distance from the Sun. The mass of captured dark matter in the radius of Neptune orbit is estimated to be 2.10ˆ^{15}g. The radial density of captured dark matter is found to be approximately constant behind Jupiter orbit being similar to the density profile found in galaxies. The average density around Jupiter is by thousands times larger than the galactic dark matter density in the velocity range that can be captured by Jupiter. The developed theory predicts that stars on a distance of Schwarzschild radius from black holes can work as some kind of black hole accelerators generating high velocity dark matter particles and compact wandering black holes crossing the Universe at high velocity.

Reference: J. Lages and D. L. Shepelyansky, Dark matter chaos in the Solar system, MNRAS (March 1, 2013) 430 (1): L25-L29

Thursday, November 7

Douglas Heggie

Edimburgh University, Scotland

Stellar-mass black holes in globular star clusters

At one time it was thought that globular star clusters should now contain essentially no stellar-mass black holes, because the black holes would mass-segregate, forming a dense central system with a very short relaxation time, and then three-body interactions would cause rapid ejection of black holes. But simulations, theory and observation now make clear that black holes can survive much longer than previously thought. In this talk I explain why the older theories were misleading, and present an improved theory, which also gives a comprehensive general picture of the dynamical evolution of a simple globular star cluster.

Guido Moyano Loyola

Centre for Astrophysics and Supercomputing, Swinburne University, Australia

Stars on the run: escaping from stellar clusters

It is believed that most stars are born in stellar clusters, which dissolve over time so that the members become part of the disc and halo population of the Galaxy.

In the present work we will assume that these young stellar clusters live mainly within the disc of the Galaxy. We have explored four different primordial binary percentages: 0%, 10% and 50%. We have quantified the contribution of these escaping stars to the Galaxy population by analysing their escape velocity and evolutionary stage at the moment of escape. In this way we could analyse the mechanisms that produced these escapers, whether evaporation through weak two-body encounters, energetic close encounters or stellar evolution events, e.g. supernovae.

We could also infer that dissolving stellar clusters such as those that we have modeled can populate the Galactic halo with giants stars for which the progenitors were stars of up to 2.4 $M_{\odot}$. Furthermore, choices made for the velocity kicks of remnants do influence the production of hyper-velocity stars.

E.Yu.Bannikova

Institute of Radio Astronomy of the National Academy of Sciences of Ukraine, Karazin Kharkov National University

N-body simulation of a self-gravitating torus: application to active galactic nuclei

The gravitational properties of a torus composed of clouds moving in orbits with different inclinations and eccentricities are investigated. We start with an idealized case, considering clouds in an approximation of test particles moving on Keplerian orbits in the gravitational field of a central mass (Keplerian torus). We use obtained solution for a Keplerian torus as initial conditions in the N-body problem. In this case the interactions between particles are taken into account. The simulation showed that a thick self-gravitating torus is stable on a time-scale comparable to the lifetimes of astrophysical objects. The stability of thick torus is achieved by the fact that the clouds in the torus move in inclined orbits. The equilibrium cross-section of the torus has an oval shape with Gaussian density distribution. The obtained results are used for the interpretation of the observed features of the obscuring tori in active galactic nuclei.

Alessandra Mastrobuono-Battisti & Hagai B. Perets

Physics Department, Technion - Israel Institute of Technology, Haifa, Israel

The early evolution of dense young clusters

Globular clusters (GCs) and many nuclear clusters (NCs) show evidence for hosting multiple generations of stellar populations. Younger stellar populations in NCs appear to reside in disk like structures, including the nuclear cluster in our own Galactic center as well as in M31. Kinematic studies of the anomalous globular cluster Omega Centauri, thought to possibly be a former dwarf galaxy (or a galactic nucleus), show evidence for its hosting of a central, kinematically cold disk component. These observations suggest that formation of second (or multiple) generation stars may occur in flattened disk like structures. Here we present detailed N-body simulations to explore the possible evolution of such stellar disks, embedded in globular clusters. We follow the long term evolution of a disk like structure similar to that observed in Omega Centauri and study its properties. We find that a stellar-disk like origin for second generation stellar populations can leave behind significant kinematic signatures in properties of the clusters, including an anisotropic distribution, and lower velocity dispersions, which can be used to constrain the origin of second generations stars and their dynamical evolution.

Hosein Haghi

Institute for Advanced Studies in Basic Sciences(IASBS), Teheran, Iran

The remote Galactic globular clusters as a tool to test gravity models and direct N-body simulation

The more distant diffused globular clusters (GCs)are excellent cases to test modified Newtonian dynamics (MOND). According to MOND, Newtonian dynamics breaks down for accelerations lower than $a_0 = 10^{-10} ms^{-2}$. In the distant halo of our Milky Way there exist several low mass GCs where both internal and external accelerations of stars are significantly below the critical acceleration parameter a_0 of MOND. Because GCs are assumed to be dark-matter-free, if MOND is true, the motions of stars must deviate from the standard Newtonian dynamics. On the other hand, the progresses in simulation techniques and development of the hardware which allows to simulate the evolution of star clusters with increasingly larger particle numbers. However, only within the last few years, with the introduction of GPU-accelerated N-body codes such as Nbody6 it has become feasible to compute the dynamical evolution of a globular cluster-sized system over its entire life time on a star-by-star basis. For our analysis we chose the outer-halo globular cluster Palomar 14 and 4, due to its relatively low mass and its large half-mass radius. In the first part of this talk I present the prediction of MOND and Newtonian dynamics on the velocity dispersion of six distant clusters of the MW. In the second part I present our recent results on the direct N-body simulation of two Milky-Way globular cluster over a Hubble time.

James Binney

Rudolf Peierls Centre for Theoretical Physics, Oxford University, UK

Diffusion of stars through action space

Many, perhaps all of the stars that form the disc of our Galaxy were born on near-circular orbits in the Galactic plane. From these orbits,which occupy a narrow tube along one edge of 3d action space, they diffuse into the body of action space. The "heating" of the disc that is caused by this diffusion has long been recognised by astronomers and was beautifully quantified by the Hipparcos mission. Until recently the assiciated diffusion in Lz, called "radial migration" was neglected. The talk will decribe the physics of diffusion through action space and the key role it must play in chemodynamical models of Galactic evolution.

Daniel Pfenniger

Geneva Observatory, Switzerland

What has been learned from barred galaxies as gravitating systems mixing order and chaos

Tjarda Boekholt

Leiden Observatory, The Netherlands

Arbitrary-Precision N-body Simulations: Fighting Exponential Divergence

The general consensus in the N-body community is that statistical results of an ensemble of N-body simulations are accurate, even though individual simulations are not. A way to test this hypothesis is to make a direct comparison with statistical results obtained by an ensemble of true solutions. In order to make this possible, we write a N-body code called Brutus, which uses arbitrary-precision arithmetic. Together with the Bulirsch-Stoer method, this code is able to obtain converged solutions, which are true up to an arbitrary number of digits.

We perform three-body simulations with conventional methods which use double-precision and with Brutus; both have the same set of initial conditions and initial realizations. The ensemble of solutions from the conventional and the converged simulations are compared directly, both on a global basis and on an individual basis to determine the distribution of the errors. We find that on average about 50% of the conventional simulations diverge from the converged solution. The error distribution however, is centered around zero and symmetric; the errors are unbiased. For three-body simulations, we conclude that the hypothesis mentioned at the beginning is correct.

Michel Tagger

University of Orleans, France

What does amplify the spirals ?

The amplification of spiral perturbations in disk galaxies was described and reduced to the solution of a 2nd order ODE 50 years ago in the pioneering works of Goldreich and Lynden-Bell; yet its physical origin and basic mechanism have not yet been explained in a fully convincing manner. Two main lines of thought have lead to the competing and sometimes conflicting SWING (Goldreich and Lynden-Bell, 1965; Toomre, 1981) and WASER (Mark, 1976; Bertin et al., 1989) mechanisms.

We will present a more detailed analysis that shows that these explanations both miss certain ingredients. From a purely analytic description we find, hidden in the numerical solution, how these mechanisms rely on the short-range and long-range action of the gravitational force; we find that they must coexist and complement each other to result in the very strong amplification obtained when Toomre's Q parameter gets close to 1.hat does amplify the spirals ?

Friday, November 8

David Merritt

Rochester Institute of Technology, USA

Relativistic dynamics of nuclear star clusters

1. Encounters between stars and stellar remnants at the centers of galaxies drive many important processes. The fact that these encounters take place near a supermassive black hole (SBH) alters the dynamics in a number of ways: The orbital motion is quasi-Keplerian so that correlations are maintained for much longer than in purely random encounters;

2. Relativity affects the motion, through mechanisms like precession of the periastron and frame dragging;

3. The SBH spin is affected, directly by capture and indirectly by spin-orbit torques.

The interplay between these processes is just now beginning to be understood, but a key result is that relativity can be crucially important even at distances that are a substantial fraction of the SMBH influence radius. I will discuss this work and its implications for stellar captures, for the evolution of SMBH spins, and for the long-term evolution of galactic nuclei.

Eugene Vasiliev

Lebedev Physical Institute, Moscow, Russia

The role of chaos in secular evolution of galaxies

I discuss various aspects of slow, or secular, evolution of isolated triaxial non-rotating galaxies due to the influence of chaotic orbits. It appears that the resonant structure of the phase space of a given potential plays an important role in the rate of such evolution. Models that are constructed to be self-consistent on the dynamical timescale (for instance, with the Schwarzschild's method) may exhibit secular changes in the shape because of diffusion of chaotic orbits. For triaxial galaxies with central black holes such evolution of shape may lead to a substantial change in the number of centrophilic orbits which feed the black hole. I discuss possible ways to simulate this evolution, based on the time-smoothed extension of the self-consistent field method.

Simon Karl

Cambridge University, UK

"CHINE" – a new code for accurate modeling of massive black hole dynamics in numerical simulations of galaxy formation

Nowadays, there is firm consensus that super-massive black holes are key-players in the process of galaxy formation and evolution. Super-massive black holes are ubiquitous components of galactic nuclei and the energy imparted onto galaxies and their surrounding intergalactic medium during the formation and growth of super-massive black holes had a significant impact on how gas assembled to form galaxies and clusters of galaxies over cosmic time. In this context, the role of gravitational dynamical interactions of stars with super-massive black holes is an important but mostly neglected means of liberating (gravitational binding) energy by which black holes can directly impact the structure of galaxies in addition to the now frequently studied feedback due to the emission of radiation released by accretion. However, the numerical treatment of super-massive black holes within galaxies in present-day simulations of structure formation is still rather approximate due to difficulties to interconnect simulation results obtained over the huge range of scales, required to study super-massive black holes in the context of their galactic environments. Here I present details of the development and first results of a novel simulation code employing AR chain regularization in the N-body/SPH tree-code VINE, which allows for an accurate modeling of the dynamics of stars close to the central super-massive black holes in numerical simulations of the formation and evolution of galaxies in a full galaxy-scale setting.

Brunetto Ziosi

University of Padova, Department of Physics and Astronomy, Italy

Influence of dynamics and metallicity on the formation and evolution of black-hole binaries in star clusters

Following recent theoretical models of wind mass-loss and core-collapse supernovae, we assume that the mass of the stellar remnants depends on the metallicity of the progenitor stars.

We find that gravitational three-body encounters dominate the formation and evolution of BH-BH binaries. In particular, the vast majority of BH-BH binaries form through dynamical exchanges. The rate of formation of BH-BH binaries (˜0.04 Myr^{-1} per star cluster) is ˜2 orders of magnitude higher than the formation rate of NS-NS binaries, because dynamical exchanges enhance the formation of massive BH-BH binaries, while they suppress the formation of lighter binaries.

Danor Aharon & Hagai B. Perets

Physics Department, Technion, Israel Institute of Technology, Haifa, Israel

The evolution of stellar populations in galactic nuclei

Most galactic nuclei contain massive black holes (MBHs) hosted by dense nuclear stellar clusters (NSCs). Relaxed NSCs with a single population of stars are expected to have a steep power-law number density distribution ($n \propto r^{-7/4}$) Realistic nuclei such as our own Galactic center (GC), are known to host multi- ple stellar populations with a wide age distribution. Here we model such realistic nuclei by including the effect of star formation on the structure and the evolu- tion of the NSC. We model the interaction between an old background stellar population and several young stellar populations arising from star formation. We find that the presence and dynamics of young populations reduce the time at which the old population reaches steady state, and affect the processes in the inner parsecs of galactic nuclei.

Sesh Sridhar

Raman Research Institute of Bangalore, India

Secular Modes of Keplerian Stellar Systems and their Excitation

In this joint work with Jihad Touma, I will present a formulation of the collisionless Boltzmann equation describing the self-consistent secular dynamics of stellar systems around a massive black hole. We describe a rich variety of stationary distribution functions (DFs), and derive the integral equation governing linear perturbations. Some new results are: (i) Spherically symmetric DFs with isotropic velocity distributions are stable to all secular perturbations. (ii) Axisymmetric razor-thin discs have DFs which are functions of the Keplerian energy and angular momentum. We prove that discs with DFs that are increasing functions of the angular momentum are stable to all slow (in-plane) perturbations. We consider the problem of the resonant excitation of secular modes by an external perturber, and illustrate this with the example of exoplanets in binary stellar systems.

Gary Mamon

Institute of Astrophysics of Paris, France

The velocity structure of cluster-mass halos without and with gas

Abstract: The knowledge of the velocity structure of the halos of galaxies and clusters is important for 2 reasons:

1. It affects the determination of the mass and cross-section of WIMP dark matter particles;
2. It helps in estimating the radial profiles of mass and velocity anisotropy from observations of the distribution of tracers in projected phase space.

Here, we analyze the 3D velocity distribution of dark matter particles in cluster-mass halos. We propose a joint distribution to the radial and tangential motions using an extension of the q-Gaussian family (also called Tsallis) of non-Gaussian models. We measure how the non-Gaussianity parameter varies with distance from the halo center. We compare the radial profiles of non-Gaussianity in stacked halos of dissipationless and hydrodynamical cosmological simulations. We explore the improvements on the measurement of mass and velocity anisotropy profiles from observations using this non-Gaussian model of the 3D velocity distribution, by analyzing a series of mock stacked projected phase spaces.

Raphael Sadoun, Roya Mohayaee, Jacques Colin

Institute of Astrophysics of Paris, France

M3 : Giant stream and warp

We propose that the accretion of a dwarf spheroidal galaxy provides a common origin for the giant southern stream and the warp of M31. We run about 40 full N-body simulations with live M31, infalling galaxies with varying masses and density profiles, and cosmologically-plausible initial orbital parameters. Excellent agreement with a full range of observational data is obtained for a model in which a dark-matter-rich dwarf spheroidal, whose trajectory lies on the thin plane of corotating satellites of M31, is accreted from its turnaround radius of about 200 kpcs into M31 at approximately 3 Gyrs ago. The satellite is disrupted as it orbits in the potential well of the galaxy and forms the giant stream and in return heats and warps the disk of M31. We show that our cosmologically-motivated model is favoured by the kinematic data over the phenomenological models in which the satellite starts its infall from a close distance of M31. Our model predicts that the remnant of the disrupted satellite resides in the region of the North-Eastern shelf of M31. The results here suggest that the surviving satellites of M31 that orbit on the same thin plane, as the disrupted satellite once did, could have all been accreted from an intergalactic filament.

Farhang HABIBI

Institute for Research in Fundamental Sciences, Teheran, Iran

Search for missing baryons by inter-stellar scintillation

Molecular hydrogen clouds may be one the ultimate candidates for the missing baryons at the galactic scales. The turbulence-induced refractive properties of such transparent clouds can distort the crossing wave front of any background star.

The distorted wave front propagates to the observer and make a 2D interference pattern. The pattern sweeps the observer's plane due to the relative motion of the sightline and a telescope can observe the scintillation of the background star. We have simulated the scintillation effect in detail and obtained a promising result to detect it. Moreover, we found a scintillation candidate from a feasibility observation by the ESO-NTT that is compatibale with our simulation results