PROGRAM:

(version 25.09.2015)

First Workshop on Progress in Modelling Galaxy Formation and Evolution in Milgromian dynamics – first results achieved with the Phantom of Ramses (PoR) code

Observatoire astronomique de Strasbourg, 21.09.-25.09.2015

PoR-code talks are scheduled for the afternoons allowing for discussion and learning time. A few scientific talks relevant to the mass-deficit problem are scheduled for the mornings.

******* **Sunday, 20th September**

evening, approximately 18:00-
Meet for drink and food at Au Brasseur
http://www.aubrasseur.fr/

******* **Monday, 21st September**

10:00 MORNING COFFEE

10:30 Welcome/Introduction/First presentation and discussion:
Setting the scene:
1. Why is the dark-matter approach ill-fated? (Pavel Kroupa)
2. The basics of Milgromian dynamics/MOND (Benoit Famaey)

LUNCH (12:15-14:45)

15:00-16:15
1. The PoR code (Fabian Lueghausen)
2. Setting up a stable disc galaxy in PoR (Ingo Thies)

16:30 AFTERNOON TEA

17:00-18:00 Open Discussion

******* **Tuesday, 22nd September**

10:00 MORNING COFFEE

10:45-11:15 (30 minutes) The DiskMass Survey's implications for MOND, CDM and itself (Garry Angus)

LUNCH (12:15-14:45)

14:45-15:15 (30 minutes) The External Field Effect In QUMOND: Application To Tidal Streams (Indranil Banik)

16:10 AFTERNOON TEA

16:30 Simulating Tidal Streams with PoR (Guillaume Thomas)

17:00-18:00 Open Discussion

******* **Wednesday, 23rd September**

10:00 MORNING COFFEE

10:45-11:15 (30 minutes) Reproducing properties of MW dSphs as descendants of DM-free TDGs (Yanbin Yang)

MEETING PHOTO (12:15)
LUNCH (12:20-14:45)

14:15-14:45 The sub-subhalo connection to M31’s plane of satellites (Garry Angus)

14:45-15:15 (30 minutes) Small-scale problems of cosmology and how modified dynamics might address them (Marcel Pawlowski)

16:00 AFTERNOON TEA

16:30 Gravitation-triggered star formation in interacting galaxies (Florent Renaud)

17:30-18:00 Open Discussion

18:30-- Workshop dinner at Au Brasseur
http://www.aubrasseur.fr/

******* **Thursday, 24th September**

10:30 MORNING COFFEE

10:45-11:15 (30 minutes) EMOND (Extended MOND) and effective galaxy cluster masses (Alistair Hudson)

11:30-12:00 Preliminary results on QMOND forces between point masses (HongSheng Zhao)

LUNCH (12:15-14:45)

14:45-15:15 The tangential motion of the Andromeda System (Jean-Babtiste Salomon)

15:15-15:45 Early-type galaxies in Milgromian dynamics (Joerg Dabringhausen, remotely from Concepcion, Chile)

16:15 AFTERNOON TEA

16:45-17:15 Evidence for Dynamical Heating in The Local Group (Indranil Banik)

17:15-18:00 Open Discussion

******* **Friday, 25th September**

10:00 MORNING COFFEE

10:30-12:00 Main Seminar of the Observatory:
Is the stellar IMF a probability distribution function, or is star formation highly regulated? (Pavel Kroupa)

LUNCH (12:15-14:45)

15:00 Final discussion and FAREWELL

ABSTRACTS

Garry Angus (Brussel, Belgium)
The DiskMass Survey's implications for MOND, CDM and itself

The DiskMass Survey is a kinematic survey of nearly face-on spiral galaxies, comprising simultaneous measurements of the rotation curves and stellar vertical velocity dispersion profiles. The goal of the survey was to dynamically measure the stellar mass-to-light ratio. We explore a large parameter space to investigate whether MOND can fit the DiskMass data while remaining consistent with constraints of disk oblateness. To do this, the potentials of the galaxies were computed using a particle-mesh Poisson solver operating on the 3D density found numerically from the surface brightness profile. We then indirectly look at the reliability of the data by re-checking the results for the the standard paradigm beyond the zeroth order approach previous used.

Garry Angus (Brussel, Belgium)
The sub-subhalo connection to M31's plane of satellites

The Andromeda galaxy is observed to have a system of 14 satellite galaxies that are currently co-rotating in a thin plane, in addition to 2 counter-rotating satellite galaxies that we assume to be interlopers. We explore the consistency of those observations with a scenario where the majority of the co-rotating satellite galaxies originated from a subhalo group, where NGC 205 was the host and the satellite galaxies occupied dark matter sub-subhalos. We ran N-body simulations of a close encounter between NGC 205 and M31, where the former was surrounded by 200k particles representing the typical distribution of subhalos found by the Aquarius project. We found the best agreement between the observed distribution of satellite galaxies and the simulated sub-subhalos occurred during pericentre - specifically pericentres between 40 and 90 kpc.

Indranil Banik (St Andrews, Scotland)
The External Field Effect In QUMOND: Application To Tidal Streams

Observations on galactic scales reveal a discrepancy between the accelerations expected of objects in Newtonian gravity and those inferred from their position and velocity (e.g. the rotation curve in a rotating disk galaxy). One possible solution is to modify Newtonian gravity at very low acceleration. This theory is called Modified Newtonian Dynamics (MOND).

The Phantom of RAMSES algorithm implements the quasi-linear formulation of MOND (QUMOND). This is much more computer-friendly than the older aquadratic Lagrangian formulation (AQUAL). In both cases, the field equation of gravity is non-linear. Thus, adding a constant external field to a system does not affect it trivially (unlike in Newtonian gravity).

I derive the analytic solution for a point mass in a dominating external field in AQUAL, which was first done in 1986. I then show the analogous derivation in QUMOND. This is generalised to the case of an external field which slowly varies with position, as if it is due to a distant point mass. The external field can be of any strength, although the dynamics becomes almost Newtonian if it is much stronger than a_0.

I apply these solutions to the tidal stream of the disrupting Sagittarius dwarf spheroidal galaxy. I use a non-interacting test particle model, which has been shown to work fairly well in Newtonian gravity. If possible, I will present some results showing which parameters lead to a simulated tidal stream best matching the observed one (calculations in progress).

The gravitational field strength is not always dominated by the external field. Thus, I derive the perturbation to the gravity from a point mass in the presence of a weak external field. This is done in the cases where, if the mass was isolated, its gravity would be much weaker or much stronger than a_0. I derive a differential equation (and its boundary conditions) which needs to be solved in intermediate cases.

Indranil Banik (St.Andrews, Scotland)

Evidence for Dynamical Heating in The Local Group

Cosmic expansion has locally been slowed down or even reversed by the gravity of the Milky Way (MW) and Andromeda (M31), which dominate the mass of the Local Group (LG). Here, we present a detailed timing argument analysis of it, using restricted N-body simulations. The MW & M31 along with thousands of test particles are started co-moving with the Hubble flow, centred on the LG barycentre. The final resulting velocity field is then projected onto the direction towards us. This radial velocity prediction is compared with observations of non-satellite galaxies. We find that no plausible combination of masses can account for the observations. The main reason is the simulated velocity field is fairly smooth but observations suggest a disturbed velocity field. Our model suggests that extra velocity dispersion along the line of sight of ~50 km/s is required to reconcile the model with the data. This value seems unphysical within the context of LCDM, because LG dwarf galaxies typically have much smaller rotation velocities/velocity dispersions. MOND implies a past encounter between the Milky Way and Andromeda. This would have caused substantial dynamical heating of the Local Group, which may help to explain the observations. We will show results from a simulation which approximately incorporates this modification to gravity.

Joerg Dabringhausen (Concepcion, Chile)
Early-type galaxies in Milgromian dynamics

Assuming virial equlibrium and Newtonian dynamics, the observed velocity dispersions of early-type galaxies (ETGs) are usually larger than the predictions for their velocity dispersions based on the amount of baryonic matter they contain. This descrepancy is particularly large at the faint end of the luminosity function of ETGs. The conventional interpretation of this finding is that ETGs contain non-baryonic matter, and that the faintest ETGs consist almost exclusively of this exotic type of matter. Using an extensive catalogue of ETGs and two simple analytic approximations, I will show that the internal dynamics of ETGs can also be understood very well from their baryonic content alone. The first analytic approximation quantifies the effect of Milgromian dynamics on the internal dynamics of the ETGs. The second analytic approximation implements the effect of binary stars on the observed velocity dispersions of ETGs. With the PoR-code, more precise tests of Milgromian dynamics in ETGs will be possible.

Benoit Famaey (Strasbourg, France)
The basics of Milgromian dynamics/MOND

In this short review talk, we summarize the observational evidence for an intimate connection between the baryonic surface density and the total gravitational field in disk galaxies. We then present the interpretation of this relation in terms of Modified Newtonian Dynamics (MOND), and summarize the current problems and challenges that need to be addressed within this approach.

Alistair Hodson (St. Andrews, Scotland)
EMOND (Extended MOND) and effective galaxy cluster masses

MOND has had great success in describing the dynamics of systems on the galaxy scale, but has had limited success when trying to fit galaxy clusters. In order to work well with clusters, it has been postulated that there could be some missing mass component, for example neutrinos, which can increase the mass budget of a cluster. It has also been noted that if the MOND scale, a0, was not in fact constant but larger in clusters, MOND could be used to describe galaxy clusters with no additional dark component. I will present work along this vein which examines EMOND, Extended MOND. I will show how EMOND can be used to calculate effective galaxy cluster masses and discuss implications of using this extension of MOND.

Rodrigo Ibata/Jean-Babtiste Solomon (Strasbourg, France)
The tangential motion of the Andromeda System

We present a dynamical measurement of the tangential motion of the Andromeda system, the ensemble consisting of the Andromeda Galaxy (M31) and its satellites. The system is modelled as a structure with cosmologically-motivated velocity dispersion and density profiles, and we show that our method works well when tested using the most massive substructures in high-resolution LCDM simulations. Applied to the sample of 40 currently-known galaxies of this system, we find a value for the transverse velocity of 164.4 +/-61.8 km/s, significantly higher than previous estimates of the proper motion of M31 itself. This result has significant implications on estimates of the mass of the Local Group, as well as on its past and future history.

Pavel Kroupa (Bonn, Germany)
Why is the dark-matter approach ill-fated?

I will briefly discuss some of the main observational evidence which contradicts the existence of dark matter particles. This evidence includes the incapability of standard structure formation models to account for the observed rotation curves, the extreme correlation and fine-tuning between the dark matter halo properties and the baryonic components of galaxies, the lack of bulge-dominated disk galaxies, the lack of an increase in the fraction of the number of elliptical to disk galaxies per co-moving volume over cosmic time, the proliferation of disk-of-satellite systems, but perhaps most convincingly, the lack of evidence for dynamical friction through the dark matter halos and, last not least and despite decades of search on a grand scale, the very absence of direct experimental verification of dark matter particles. And I emphasize that a particularly major challenge for any theory of cosmology is the incredibly symmetrical structure of the Local Group of galaxies, and the major under density of matter within a region spanning about 300 Mpc around the Galaxy.

Pavel Kroupa (Bonn, Germany)
(Friday Observatoire Main Colloquium)
Is the stellar IMF a probability distribution function, or is star formation highly regulated?

The stellar initial mass function (IMF) is usually assumed to be a probability density distribution function. Recent data appear to question this interpretation though, and I will discuss alternative applications and results concerning the possibly true nature of the IMF. Empirical evidence has emerged that the IMF becomes top-heavy in intense star bursts and at low metallicity. Related to the IMF are binary star distribution functions, and these evolve through dynamical processes in embedded star clusters. The insights gained from these considerations lead to a mathematically computable method for calculating stellar populations in galaxies, with possibly important implications for the matter cycle in galaxies. It turns out that the galaxy-wide IMF, the IGIMF, becomes increasingly top-heavy with increasing galaxy-wide star formation rate, while at the same time the binary fraction in the galactic field decreases.

Fabian Lueghausen (Bonn, Germany)
The PoR code

The Phantom of RAMSES code is quickly introduced. It is explained how this RAMSES patch works in general, and what details should be regarded when using it (e.g., boundary conditions). Finally, I want to share a method to set up MONDian disk galaxies (with optional bulge). An additional gaseous disk could (and should) be included in the future. *Optionally:* if somebody is interested, I could also present (and share) a small C program that initializes spherically symmetric MONDian (isolated) objects. (I know that e.g. Guillaume has written his own code to set up MONDian King models.)

Marcel Pawlowski (Cleveland, USA)
Small-scale problems of cosmology and how modified dynamics might address them

Comparisons between simulations assuming the LCDM model of cosmology and the observed properties of nearby galaxies have revealed a number of small-scale problems. Some of these might simply indicate shortcomings in the cosmological simulations, solvable by more accurately modelling baryonic physics. Others, such as the satellite plane problem, seem to be much less prone to baryonic influences and thus appear to be much more severe challenge to the cosmological model itself. I will discuss some of these problems, and possible approaches to study (and potentially solve them) within a modified dynamics framework. This just now becomes possible with the PoR code, but will require the development of additional tools and a deeper understanding of differences in the behavior of fundamental dynamical processes such as dynamical friction.

Florent Renaud (Surrey, UK)
Gravitation-triggered star formation in interacting galaxies

Gravitation is the main driver of mass assembly and formation of structures, at all astrophysics scales. In particular, it is playing a key role in the formation of molecular clouds and their collapse leading to star formation. Such activity is enhanced in interacting galaxies during starburst episodes. In these environments, a second aspect of gravitation, namely the tidal field, appears to also be of paramount importance. The galaxy-galaxy interaction changes the nature of tides, making them compressive over kpc scales. This translates into a modification of the interstellar medium turbulence, which in turn boosts the star formation rate over large volumes. This theory has been proposed in the context of Newtonian dynamics, with the mean of parsec-resolution hydrodynamical simulations of interacting galaxies. To fully test this idea, one needs to monitor the response of the star formation activity to an alteration of the initial trigger, i.e. the tidal field. One way of doing this is to modify the law of gravity, just like the MOND paradigm does. In this context, the POR code provides a perfect framework to carry direct comparisons between the

Newtonian and MONDian cases, by simply running the same galaxy setup. Such a suite of simulations also produces a number of byproduct results, e.g. on the formation and properties of tidal dwarf galaxies, a key topic in the MONDian world. In this talk, I will review the framework of gravity-driven star formation, present the results from Newtonian dynamics and introduce the first results obtained by the POR code in the context of interacting galaxies.

Ingo Thies (Bonn, Germany)
Setting up a stable disc galaxy in PoR

Since its publication 1983, Milgromian modified Newtonian dynamics(MOND) has been very successful in modelling the gravitational potential of galaxies from baryonic matter alone. However, the dynamical modelling has long been an unsolved issue. In particular, the setup of a stable galaxy for Milgromian N-body calculations still poses a major challenge. Here, I will show a way to set up disc galaxies in MOND for calculations in the PHANTOM OF RAMSES (POR) code by Lüghausen (2015) and Teyssier (2002). The method is done by solving the QUMOND Poisson equations based on a baryonic and a phantom dark matter term. The resulting galaxy models are stable after a brief settling period for a large mass and size range.

Guillaume Thomas (Strasbourg, France)
Tidal Streams with PoR

Since its formulation in 1983, the MONDian paradigm has been a huge success in spiral galaxies, especially with the uncannily successful prediction of rotation curves. It is therefore important to test the paradigm with other observations in spirals. Tidal streams provide a perfect test of the shape of the gravitational potential outside of the plane of such galaxies. Therefore, we are currently studying both the accretion history of the Sagittarius dwarf spheroidal (dSph Sgr) galaxy by the Milky Way and its tidal stream, and the tidal stream of Pal5, with the PoR code. Encouraging preliminary results will be presented.

Yanbin Yang (Paris, France)
Reproducing properties of MW dSphs as descendants of DM-free TDGs

The Milky Way (MW) dwarf spheroidal (dSph) galaxies are thought to be the most dark-matter (DM) dominated galaxies. This comes from the assumption that dwarfs are dynamically supported by their observed velocity dispersions. However, their spatial distributions around the MW are not at random and this could challenge their origin, previously assumed to be residues of primordial galaxies accreted by the MW potential. Here, we show that, alternatively, dSphs could be the residue of tidal dwarf galaxies (TDGs), which would have interacted with the Galactic hot gaseous halo and disc. TDGs are gas rich and have been formed in a tidal tail produced during an ancient merger event at the M31 location, and expelled towards the MW. Our simulations show that low-mass TDGs are fragile to an interaction with the MW disc and halo hot gas. During the interaction, their stellar content is progressively driven out of equilibrium and strongly expands, leading to low surface brightness feature and mimicking high dynamical M/L ratios. Our modelling can reproduce the properties, including the kinematics, of classical MW dwarfs within the mass range of the Magellanic Clouds to Draco. An ancient gas-rich merger at the M31 location could then challenge the currently assumed high content of DM in dwarf galaxies. Our scenario predicts that MW dSphs are strongly expanding, which should not be observed within the current theoretical framework.

HongSheng Zhao (St. Andrews, Scotland)
Preliminary results on QMOND forces between point masses

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