The functioning of galaxies: challenges for Newtonian and Milgromian dynamics

23rd – 27th September 2019
A workshop at the University of Bonn

Organized by
The Stellar Populations and Dynamics Group at the Helmholtz Institut für Strahlen- und Kernphysik, University of Bonn

Max-Planck-Institut
für Radioastronomie

UNIVERSITÄT BONN

Contents

About this workshop

One of the greatest current unsolved problems in physics is whether gravitation, the least understood of the fundamental "forces", is universally Newtonian in the classical limit. Even the nature of gravitation is unclear: is it a force in the physical sense (with an exchange particle), an apparent force resulting from the distortion of space-time or just an emergent phenomenon due to entropy differences as suggested by Verlinde (Arxiv: 1001.0785)? Whatever the physical origin of gravitation, the empirical formulation of how a body is accelerated as a result of the mass-distribution around it can be applied to study the formation and evolution of galaxies. There are two hypotheses available for computational study now:

The hypothesis that gravitation is Newtonian, as derived empirically based on Solar-system data only, has been embedded in Einstein's interpretation of gravitation as being a geometric space-time distortion. This interpretation leads to departures from observed motions of astronomical objects when extrapolated to the scales of galaxies and beyond. These departures are usually interpreted to be due to the existence of new elementary (dark matter) particles and due to the hitherto not understood dark energy which needs to dominate the energy content of the Universe and is increasing with time.

By taking into account the new dynamical data that became available on the scale of galaxies in the late 1970s, Milgrom generalized the classical law of gravitation. The hypothesis that gravitation is Milgromian simplifies galactic astrophysics since no additional dark matter is needed and galaxies become fully self-gravitating systems based on their baryonic matter content only.

The following challenges emerge in view of the two hypotheses:

Dark matter remains elusive: There is no room for dark matter particles within the standard model of particle physics. The decades long searches in space, underground and at the Large Hadron Collider for these putative particles have all been failures, and dynamical friction on the motions of satellite and larger galaxies due to the expansive dark matter halos is not evident, as if dark matter particles are non-existent. In addition, early cosmological computations based on the Newtonian hypothesis with dark matter have already turned up major problems (e.g. the angular momentum problem, the missing satellites problem, amongst many) which have never been solved convincingly, while new problems keep emerging (the satellite planes problem, the radial acceleration relation problem, amongst many). Can this hypothesis nevertheless be made consistent with the observational data?

The Milgromian hypothesis on the other hand, while accounting for many of the above problems, is a non-linear theory and thus poses computational challenges. It has, until recently and due to a variety of reasons, not been applied to the problem of galaxy formation and it is therefore unclear if galaxies will emerge to look like the observed population in this approach.

With this meeting we aim to foster a discussion between the scientists who have been studying galaxies and cosmology in these two fundamentally different hypotheses. The aim is to achieve an exchange notably also on the technical challenges in applying both hypotheses to computational astrophysics problems in view of recent advances in understanding stellar populations, which are important for quantifying feedback processes.

Local Organizing Committee

Left to right: Elena Asencio (*University of Bonn, Germany*), Indranil Banik (*University of Bonn, Germany*), Andrea Dieball (*University of Bonn, Germany*), Hosein Haghi (*IASBS in Zanjan, Iran*), Moritz Haslbauer – Chair (*University of Bonn, Germany*), Pavel Kroupa (*University of Bonn, Germany, and Charles University in Prague, Czech Republic*), Srikanth Togere Nagesh (*University of Bonn, Germany*), Jan Pflamm-Altenburg (*University of Bonn, Germany*), Nils Wittenburg (*University of Bonn, Germany*), Akram Hasani Zonoozi (*University of Bonn, Germany, and IASBS in Zanjan, Iran*)

Victoria Schuy (*University of Bonn, Germany*)

Scientific Organizing Committee

Indranil Banik – Chair (*University of Bonn, Germany*)

Hosein Haghi (*IASBS in Zanjan, Iran*)

Pavel Kroupa – Co-chair (*University of Bonn, Germany, and Charles University in Prague, Czech Republic*)

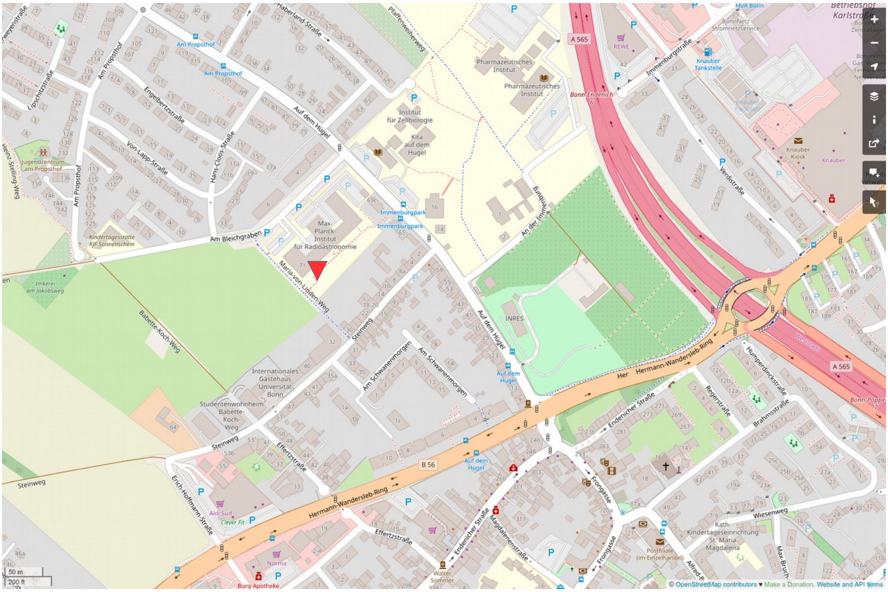
Oliver Müller (*University of Strasbourg, France*)

Xufen Wu (*Hefei, China*)

Akram Hasani Zonoozi (*University of Bonn, Germany, and IASBS in Zanjan, Iran*)

The organizers are grateful to the Max Planck Institute for Radio astronomy (MPIfR) for supporting the coffee breaks and providing poster boards.

Location of the conference



The meeting takes place at the University of Bonn's Argelander Institute of Astronomy, Auf dem Hügel 71, 53121 Bonn, with lectures in the main auditorium (Room 0.012).

Contact: gravity2019@astro.uni-bonn.de

Webpage: https://astro.uni-bonn.de/~pavel/CONFERENCES/MOND2019/website/index.html

Restaurants

Canteen of the Max Planck Institute for Radio Astronomy (MPIfR), Auf dem Hügel 69, 53121 Bonn (next to the AIfA)

The canteen is expecting most delegates to go there for lunch.

The Fiddlers Bonn, Frongasse 9, 53121 Bonn
https://www.thefiddlersbonn.com/
(Conference dinner, Wednesday, 25.09.2019)

Harmonie Bonn, Frongasse 28-30, 53121 Bonn
https://www.harmonie-bonn.de/

Gasthaus Nolden, Magdalenenstrasse 33, 53121 Bonn
https://www.gasthaus-nolden.de/

Burger Your Beef, Auf dem Hügel 63, 53121 Bonn
https://www.burgeryourbeef.de/bonn/

TAK Kee China Imbiss, Endenicher Strasse 325, 53121 Bonn

Program of the conference

Monday, 23.09.2019

08:30 – 09:00: Registration
09:00 – 09:10: Welcome & Introduction (Pavel Kroupa & Indranil Banik)

Scaling relation – observations (Chair: Stacy McGaugh)

09:10 (25 min): **Federico Lelli**, The empirical laws of galactic rotation, p. 60
09:50 (25 min): **Pengfei Li**, Fitting the radial acceleration relation to individual SPARC galaxies, p. 62
10:30 (25 min): **Harry Desmond**, Galaxy velocity & size correlations, the halo Tully-Fisher relation and tests of the External Field Effect, p. 32

11:10 – 11:40: Coffee break

Scaling relations in ΛCDM simulations (Chair: Donatella Romano)

11:40 (25 min): **Aaron A. Dutton**, Galaxy scale challenges for cold dark matter, p. 36
12:20 (25 min): **Enrico Garaldi**, The Radial Acceleration Relation of satellite galaxies, p. 42

13:00 – 14:30 Lunch break

Scaling relations – observations (Chair: Benoit Famaey)

14:30 (25 min): **Earl Schulz**, Scaling relations and the gravitational acceleration at the edge of disk galaxies, p. 88
15:10 (25 min): **Tom Richtler**, Elliptical galaxies and the Baryonic Tully-Fisher Relation (BTFR), p. 80

15:50 – 16:35: Coffee break

MOND lensing & relativistic theories (Chair: Hongsheng Zhao)

16:35 (25 min): **Richard P. Woodard**, A non-local metric realization of MOND, p. 102
17:15 (40 min): **André Maeder,** The scale invariant theory and MOND: the case of the radial acceleration relation (RAR), p. 64

18:05-18:30: Discussion (Chair: Oliver Müller)

Tuesday, 24.09.2019

MOND lensing & relativistic theories (Chair: Mordehai Milgrom)

09:00 (45 min): **Constantinos Skordis**, A relativistic theory of Modified Newtonian Dynamics, p. 90
10:00 (20 min): **Hongsheng Zhao**, The alternative way to separate the baryon peaks from the lensing peaks of the Bullet Clusters, p. 108

10:30 – 11:00: Coffee break

Lensing & dynamics (Chair: Tom Richtler)

11:00 (25 min): **Kyu-Hyun Chae**, Radial Acceleration Relation in a supercritical acceleration range, p. 26
11:40 (25 min): **Chung-Ming Ko**, Gravitational lensing by spiral and elliptical galaxies in MOND, p. 58
12:20 (25 min): **Yong Tian**, Mass discrepancy–acceleration relation in Einstein rings, p. 92

13:00 – 14:30: Lunch break

MOND & cosmology (Chair: Benoit Famaey)

14:30 (25 min): **Mordehai Milgrom**, The a_0 - Λ connection, p. 70
15:10 (25 min): **Stacy McGaugh**, Signatures of MOND in cosmology, p. 66

15:50 – 16:20 Coffee break

Other cosmological models (Chair: André Maeder)

16:20 (25 min): **Václav Vavryčuk**, CMB as thermal radiation of cosmic dust?, p. 98
17:00 (25 min): **Benoit Famaey**, Superfluid dark matter and related ideas, p. 38
17:40 (25 min): **Mahmood Roshan**, Evolution of spiral galaxies: distinction between modified gravity and particle dark matter, p. 84

18:20 – 18:40: Discussion (Chair: Emilio Romano-Diaz)

Wednesday, 25.09.2019

Wide binaries (Chair: Indranil Banik)

09:00 (25 min): **Riccardo Scarpa**, Probing Newtonian Dynamics in the low acceleration regime with wide binary stars, p. 86
09:40 (25 min): **Ricardo Adán Martín Cortés,** Challenging a Newtonian prediction through Gaia wide binaries, p. 28
10:20 (25 min): **Charalambos Pittordis**, Testing modified gravity theories with wide binaries from Gaia DR2, p. 78

11:00 – 11:25: Coffee break

ΛCDM simulations of dwarf galaxies (Chair: Akram Zonoozi)

11:25 (25 min): **François Hammer**, On the absence of dark matter in dwarf galaxies surrounding the Milky Way, p. 48
12:05 (25 min): **Donatella Romano**, Gas removal from ultrafaint dwarf galaxies – a high-resolution study, p. 82

12:45 – 14:15: Lunch break

Simulated galaxies without a dynamical discrepancy (Chair: Xufen Wu)

14:15 (25 min): **Graeme Candlish**, The external field effect on cluster disk galaxies, p. 24
14:55 (20 min): **Hosein Haghi**, The dynamics of ultra-diffuse galaxies in MOND, p. 44
15:25 (25 min): **Moritz Haslbauer**, Galaxies lacking dark matter in cosmological ΛCDM simulations, p. 50

16:05 – 16:30: Coffee break & group photo

Observations of dwarf galaxies and galaxy clusters
(Chair: Oliver Müller)

16:30 (25 min): **Steffen Mieske**, Gravity tests with dwarf galaxy structure, p. 68
17:10 (25 min): **Michael Hilker**, Kinematic complexity in a rising velocity dispersion profile around the Hydra I cluster central galaxy NGC 3311, p. 54

17:50 (25 min): **Michael Fellhauer**, Sometimes Newton is enough, p. 40

18:30 – 18:50: Discussion (Chair: Hosein Haghi)

19:30: Dinner

Thursday, 26.09.2019

Satellite planes (Chair: François Hammer)

09:00 (25 min): **Marcel Pawlowski**, Planes of satellites: observational evidence in light of Gaia DR2, and testing proposed solutions with cosmological simulations, p. 76
09:40 (25 min): **Oliver Müller**, Small-scale cosmology with dwarf galaxies, p. 72

10:20 – 10:50: Coffee break

MOND simulations (Chair: Michal Bilek)

10:50 (25 min): **Nils Wittenburg**, The formation of late-type galaxies in MOND, p. 100
11:30 (25 min): **Indranil Banik**, Simulating disk galaxies in MOND: application to M33, p. 18
12:10 (25 min): **Ingo Thies**, On the origin of the Local Group in Modified Newtonian Dynamics, p. 94

12:50 – 14:30: Lunch break

Galaxy groups (Chair: Moritz Haslbauer)

14:30 (25 min): **Yanbin Yang**, The origin of the Magellanic Clouds and their Stream, p. 106
15:10 (25 min): **Wolfgang Oehm**, Constraints on the existence of dark matter haloes by the M81 group and the Hickson compact groups of galaxies, p. 74
15:50 – 16:20: Coffee break

Elliptical galaxies (Chair: Michael Hilker)

16:20 (25 min): **Xavier Hernández**, MONDian gravity in astrophysical systems beyond rotation curves: elliptical galaxies, globular clusters and wide binaries, p. 52
17:00 (25 min): **Michal Bilek**, Gravitational fields of early-type galaxies investigated using the kinematics of globular clusters, p. 20
17:40 (25 min): **Jörg Dabringhausen**, Early-type galaxies without non-baryonic dark matter, p. 30

18:20 – 18:40: Discussion (Chair: Indranil Banik)

Friday, 27.09.2019

Star cluster and galaxy simulations (Chair: Graeme Candlish)

09:00 (25 min): **Xufen Wu**, The anisotropy of star clusters undergoing gas expulsion, p. 104
09:40 (25 min): **Guillaume Thomas**, The External Field Effect of the Milky Way and its impact on globular clusters, p. 96
10:20 (25 min): **Behnam Javanmardi**, Number of Satellites vs. Bulge Mass in ΛCDM, p. 56

11:00 – 11:30: Coffee break

11:30 – 13:00: Debate (Chair: Stacy McGaugh)

13:00 – 14:30: Lunch break

Other gravity theories (Chair: Pavel Kroupa)

14:30 (25 min): **Mariano Cadoni**, Anomalous rotation curves of galaxies as a long-range quantum gravity effect, p. 22
15:10 (25 min): **Antonaldo Diaferio,** Dynamics of DiskMass Survey galaxies in Refracted Gravity, p. 34
15:50 (25 min): **Dragan Slavkov Hajdukovic,** Gravitational polarisation of the quantum vacuum as the cause of phenomena usually attributed to dark matter, p. 46

16:30: End of conference

List of talks

Speaker: Indranil Banik, University of Bonn, Germany

Title: Simulating disk galaxies in MOND: application to M33

Abstract:
I will explain how to use a publicly available algorithm to set up a stable disk galaxy in MOND. It is now possible to include the gas component in a stable way using methods I will describe. These templates can be advanced with the public Phantom of RAMSES algorithm, an *N*-body and hydrodynamical solver for MOND. I will show how these tools can be combined to yield a realistic-looking simulation of M33 when its parameters are used to provide the initial conditions. I will then explain a special variable-mass scheme which allows a disk to be resolved out to very large radii while remaining stable. Achieving both simultaneously is vital for my ongoing project with Ingo Thies on simulating interacting galaxies. We will be happy to discuss possible application to other projects, using our experience of making very substantial alterations to the above-mentioned algorithms at a fundamental level.
The algorithm for generating stellar disks in MOND is publicly available at the central repository for MOND algorithms:
github.com/GFThomas/MOND/tree/master/init_conditions/disc
The algorithm for extracting particle data from Phantom of RAMSES simulations is available here:
github.com/GFThomas/MOND/tree/master/extract_por

Notes:

Speaker: Michal Bilek, Observatoire Astronomique de Strasbourg, France

Title: Gravitational fields of early-type galaxies investigated using the kinematics of globular clusters

Abstract:
Gravitational fields of early-type galaxies (ETGs) remain little explored beyond a few effective radii because of the lack of dynamical tracers. We collected a sample of 17 ETGs for which the radial velocities of over around 100 globular clusters (GCs) had been measured. The GC kinematics allowed us to study the gravitational fields using Jeans analysis up to 10 effective radii in the frameworks of ΛCDM and MOND. It was possible to find for every individual galaxy a ΛCDM fit that agrees with the expected stellar-to-halo mass relation and the halo mass-concentration relation. However, most galaxies in our sample deviate from the expected relations in the same direction. The reasons might be the tidal stripping of the halos, that late-type galaxies inhabit lighter halos than ETGs, or that the stellar-to-halo mass relation is poorly constrained for the most massive galaxies. Successful MOND fits were found for most galaxies. The deviation increases for galaxies that are or could previously have been in the centers of galaxy clusters and groups. The likely explanations are either a contribution of the dark matter that MOND predicts in galaxy clusters or the dynamical heating of the GC systems by recent galaxy encounters whose signs are still apparent in the deviating galaxies.

Notes:

Speaker: Mariano Cadoni, Università di Cagliari, Italy

Title: Anomalous rotation curves of galaxies as a long-range quantum gravity effect

Abstract:
We propose that long-range quantum gravity effects could play a role at galactic scales and could be responsible for the phenomenology commonly attributed to dark matter. We show that the presence of baryonic matter breaks the scale symmetry of the cosmological de Sitter spacetime, generating an infrared scale. This is the scale at which the typical dark matter effects we observe in galaxies arise. It also generates a huge number of bosonic excitations with wavelength larger than the size of the cosmological horizon and in thermal equilibrium with de Sitter spacetime. We show that above the infrared scale these excitations produce a new component for the radial acceleration of stars in galaxies which leads to the result found by McGaugh et al. by fitting a large amount of observational data, which is consistent with the MOND theory. The same result can be derived from a generalized thermal equivalence principle. It can also be obtained as the weak field limit of Einstein's general relativity sourced by an anisotropic fluid.

Notes:

Speaker: Graeme Candlish, Universidad de Valparaíso, Chile

Title: The external field effect on cluster disk galaxies

Abstract:
In this talk, I will discuss recent results of idealized simulations in MOND of disk galaxies falling into galaxy clusters and the consequences of the external field effect (EFE) on their morphology and kinematics. Furthermore, I will discuss possible unambiguous observational signatures of the EFE on cluster disk galaxies.

Notes:

Speaker: Kyu-Hyun Chae, Sejong Univ, South Korea

Title: Radial Acceleration Relation in a Supercritical Acceleration Range

Abstract:
The inner regions of massive elliptical galaxies span an interesting acceleration range from the critical acceleration a_0 up to 100 a_0. In this supercritical acceleration range, the radial acceleration relation (RAR) between baryons and the other agent – whether dark matter or phantom matter representing modification of Newtonian dynamics – has the potential to distinguish various proposals on the functioning of galaxy dynamics. Using carefully selected tens of (nearly) spherical galaxies from integral field spectroscopic surveys including ATLAS^{3D} and thousands of SDSS spherical galaxies, we constrain the ratio a_X/a_B, where a_B and a_X are radial accelerations due to baryons and dark/phantom matter, through Bayesian inferences of model parameters. In the MOND framework, the stacked ratio for all galaxies analyzed is only consistent with the Simple interpolating function, but inconsistent with other proposals including Verlinde's emergent gravity, Bekenstein's TeVeS theory, and McGaugh's fitting function introduced mainly for subcritical acceleration data of rotating galaxies. Therefore, the RAR of elliptical galaxies significantly limits the possible modification of Newton's theory. On the other hand, the RAR in the ΛCDM framework implies a strong constraint on astrophysics of galaxy formation and evolution which demands explanation.

Notes:

Speaker: Ricardo Adán Martín Cortés, Ciudad Universitaria, Mexico City

Title: Challenging a Newtonian prediction through Gaia wide binaries

Abstract:
Under Newtonian dynamics, the relative motion of the components of a binary star should follow a Keplerian scaling with separation. Once orientation effects and a distribution of orbital eccentricities are accounted for, dynamical evolution can be modeled to include the effects of Galactic tides and stellar mass perturbers, over the lifetime of the Solar neighbourhood. This furnishes a prediction for the relative velocity between the components of a binary and their projected separation. Taking a carefully selected small sample of 81 Solar neighbourhood wide binaries from the *Hipparcos* catalogue, we identify these same stars in the recent Gaia DR2, to test the prediction mentioned using the latest and most accurate astrometry available. The results are consistent with the Newtonian prediction for projected separations below 7000 AU, but inconsistent with it at larger separations, where accelerations are expected to be lower than the critical $a_0 = 1.2\times10^{-10}$ m/s^2 value of MONDian gravity. This result challenges Newtonian gravity at low accelerations and shows clearly the appearance of gravitational anomalies of the type usually attributed to dark matter at galactic scales, now at much smaller stellar scales.

Notes:

Speaker: Jörg Dabringhausen, Astronomical Institute, Charles University, Prague, Czech Republic

Title: Early-type galaxies without non-baryonic dark matter

Abstract:
Assuming virial equilibrium 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 discrepancy 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, I will discuss an alternative point of view, according to which ETGs do not contain significant amounts of non-baryonic dark matter, but (1.) their integrated galactic stellar initial mass function is a function of their star formation rate, (2.) their internal dynamics is not necessarily Newtonian and (3.) they are not necessarily in virial equilibrium. It turns out that this approach leads to very satisfactory results.

Notes:

Speaker: Harry Desmond, Astrophysics, University of Oxford, UK

Title: Galaxy velocity & size correlations, the Halo Tully-Fisher Relation, and tests of the External Field Effect

Abstract:
I present two recent works aimed at characterizing the behaviour of gravity within galaxies. The first – arxiv.org/abs/1808.00271 – explores the correlation between residuals of the Tully-Fisher and mass-size relations with velocity defined at a range of radii across the rotation curves. Generalizing results already known for V_{flat} and $V_{2.2}$ we find no significant correlation regardless of where the velocity is measured, confirming the TFR to be the optimal projection of late-type galaxies' M-V-R relation. This behaviour is reproducible with abundance matching models in ΛCDM. The second – arxiv.org/abs/1810.12347 – constructs and describes the dark matter analogues of the TFR and radial acceleration relation by replacing M_{bar} and g_{bar} with M_{halo} and g_{DM} respectively, based on fits to the SPARC rotation curves. We find both relations to have comparable scatter to their baryonic counterparts, making them of empirical use as well as theoretical interest. Finally I describe a method for quantifying galaxies' gravitational environments – arxiv.org/abs/1705.02420 – which may find application in testing the MOND External Field Effect.

Notes:

Speaker: Antonaldo Diaferio, Universita degli Studi di Torino, Italy

Title: Dynamics of DiskMass Survey Galaxies in Refracted Gravity

Abstract:
I show how Refracted Gravity shares the successes of MOND on the scale of galaxies and can describe the dynamics of disk galaxies without resorting to the presence of dark matter. Refracted Gravity is a classical theory of gravity where the standard Poisson equation is modified with the introduction of the gravitational permittivity, a universal monotonic function of the local mass density. We use the rotation curves and the radial profiles of the stellar velocity dispersion perpendicular to the galactic disks of 30 disk galaxies from the DiskMass Survey to determine the gravitational permittivity. With this unique permittivity, Refracted Gravity describes the rotation curves and the vertical velocity dispersions by requiring galaxy mass-to-light ratios in agreement with stellar population synthesis models and disk thicknesses in agreement with observations. Similarly to MOND, Refracted Gravity also describes the radial acceleration relation (RAR), between the observed centripetal acceleration derived from the rotation curve and the Newtonian gravitational acceleration originating from the baryonic mass distribution. Refracted Gravity is thus able to describe the phenomenology of disk galaxies and might deserve further investigation.

Notes:

Speaker: Aaron A. Dutton, New York University Abu Dhabi, United Arab Emirates

Title: Galaxy scale challenges for cold dark matter

Abstract:
The ΛCDM model for cosmological structure formation works extremely well on large cosmological scales. On small (galaxy) scales, there are a number of apparent tensions between theory and observation: the abundance of low mass dark matter haloes, the central structure of dark matter haloes, and the small scatter in the Radial Acceleration Relation. I will present results on these tensions from the NIHAO project of 100 cosmological zoom-in simulations of dwarf to Milky Way mass haloes. In particular I will discuss how the sub-grid model for star formation impacts the structure of ΛCDM haloes, and differences between ΛCDM and MOND predictions for the radial acceleration.

Notes:

Speaker: Benoit Famaey, Observatoire Astronomique de Strasbourg, France

Title: Superfluid dark matter and related ideas

Abstract:
We review the strengths and weaknesses of the hypothesis that the MOND relation would originate from non-standard interactions between dark matter and baryons. The most advanced idea along these lines is that dark matter Bose-Einstein condenses into a superfluid phase in the central regions of galaxy halos, and that superfluid phonon excitations in turn couple to baryons and mediate an additional long-range force. For a suitable choice of the superfluid equation of state, this fifth force can mimic MOND. We review the strengths and weaknesses of this theoretical framework, and we discuss other related ideas and possible avenues for improvement.

Notes:

Speaker: Michael Fellhauer, Universidad de Concepcion, Chile

Title: Sometimes Newton is enough

Abstract:
Our group has many years of experience in numerical simulations of small stellar systems. In the course of many years we presented models for UCDs, compact ellipticals and even dSph "galaxies" in a completely Newtonian framework without the need for dark matter. I would like to present some examples of our models to open up a third possibility between DM and MOND (at least for the objects we have studied).

Notes:

Speaker: Enrico Garaldi, Max Planck Institute for Astrophysics, Germany

Title: The Radial Acceleration Relation of satellite galaxies

Abstract:
The Radial Acceleration Relation (RAR) has recently emerged as a challenge to the ΛCDM cosmological model, that struggles at reproducing its small observed scatter. It has been suggested that the RAR is an evidence of Modified Newtonian Dynamics (MOND). Satellite galaxies represent an intriguing laboratory, since in the MOND theory they are affected by the External Field Effect, that has no analogue in ΛCDM. I will present forecasts of the RAR of ΛCDM satellite galaxies, its evolution with redshift, and its dependence on other satellite properties. I will then compare the ΛCDM predictions with available data and show that current observation are not yet precise enough to enable solid statements about the correctness of the concordance cosmological model. Nevertheless, these results reveal a new avenue to discriminate between the ΛCDM and MOND cosmological models employing local satellite galaxies.

Notes:

Speaker: Hosein Haghi, IASBS in Zanjan, Iran

Title: The dynamics of ultra-diffuse galaxies in MOND

Abstract:
The ultra-diffuse dwarf galaxy NGC 1052-DF2 (DF2) has 10 (11) measured globular clusters (GCs) with a line-of-sight velocity dispersion of $\sigma = 7.8^{+5.2}_{-2.2} km/s$ $\left(\sigma = 10.6^{+3.9}_{-2.3} km/s\right)$. Our conventional statistical analysis of the original 10 GCs gives $\sigma = 8.0^{+4.3}_{-3.0} km/s$. The overall distribution of velocities agrees well with a Gaussian of this width. Due to the non-linear Poisson equation in MOND, a dwarf galaxy has weaker self-gravity when in close proximity to a massive host. This external field effect is investigated using a new analytic formulation and fully self-consistent live *N*-body models in MOND. Our formulation agrees well with that of Famaey and McGaugh. These new simulations confirm our analytic results and suggest that DF2 may be in a deep-freeze state unique to MOND. The correctly calculated MOND velocity dispersion agrees with our inferred dispersion and that of van Dokkum et al. if DF2 is within 150 kpc of NGC 1052 and both are 20 Mpc away. The GCs of DF2 are however significantly brighter and larger than normal GCs, a problem which disappears if DF2 is significantly closer to us. A distance of 10-13 Mpc makes DF2 a normal dwarf galaxy even more consistent with MOND and the 13 Mpc distance reported by Trujillo et al.. We discuss the similar dwarf DF4, finding good agreement with MOND. We also discuss possible massive galaxies near DF2 and DF4 along with their distances and peculiar velocities, noting that NGC 1052 may lie at a distance near 10 Mpc.

Notes:

Speaker: Dragan Slavkov Hajdukovic, Institute of Physics, Astrophysics and Cosmology, Cetinje, Montenegro
Title: Gravitational polarization of the quantum vacuum as the cause of phenomena usually attributed to dark matter

Abstract:
I present some consequences of the working hypothesis that by their nature *quantum vacuum fluctuations* (which are an inherent part of the Standard Model of Particles and Fields) *are virtual gravitational dipoles*, i.e. composed of two gravitational charges of opposite sign. The major consequence is that each body immersed in the quantum vacuum creates around it a halo of the polarized quantum vacuum. Gravitational dipoles within a halo have no random orientation; instead, to some extent, dipoles are aligned with the Newtonian gravitational field of the immersed body. The key point is that a region of quantum vacuum with random orientation of dipoles is not a source of gravity, while a region with non-random orientation may act as a source of gravity. Consequently the gravitational field around a body is a sum of the Newtonian gravitational field and gravitational field of the polarized quantum vacuum; quantum vacuum appears as a so far “forgotten” source of gravity. Within this framework there is no need for dark matter and there is no need for modification of the Newtonian law of gravity. However the total gravitational field produced by baryonic matter and quantum vacuum has significant similarities with the gravitational field suggested by MOND (hence there is an apparent but not real modification of the Newton law of gravity). At the end, I give a brief overview of experiments at CERN and the eventual astronomical

observations that can prove or disprove the existence of the described gravitational effects of the quantum vacuum.

Notes:

Speaker: François Hammer, Observatoire de Paris, Paris, France

Title: On the absence of dark matter in dwarf galaxies surrounding the Milky Way

Abstract:
We present an alternative scenario to explain the observed properties of the Milky Way dwarf Spheroidals (MW dSphs). We show that instead of resulting from large amounts of Dark Matter (DM), the large velocity dispersions observed along their lines of sight can be entirely accounted for by dynamical heating of DM-free systems resulting from MW tidal shocks. Such a regime is expected if the progenitors of the MW dwarfs are infalling gas-dominated galaxies. In this case, gas lost through ram-pressure leads to a strong decrease of self-gravity, a phase during which stars can radially expand, while leaving a gas-free dSph in which tidal shocks can easily develop.

The DM content of dSphs is widely derived from the measurement of the dSphs' self-gravitational acceleration projected along the line of sight. We show that the latter strongly anti-correlates with the dSph distance from the MW, and that it is matched in amplitude by the acceleration caused by MW tidal shocks on DM-free dSphs. If correct, this implies that the MW dSphs would have negligible DM content, putting in question, e.g., their use as targets for DM direct searches, or our understanding of the Local Group mass assembly history.

Notes:

Speaker: Moritz Haslbauer, University of Bonn, Germany

Title: Galaxies lacking dark matter in cosmological ΛCDM simulations

Abstract:

Any viable cosmological model in which galaxies interact predicts the existence of primordial and tidal dwarf galaxies (TDGs). In particular, in the standard model of cosmology (ΛCDM), according to the dual dwarf galaxy theorem, there must exist both primordial dark matter-dominated and dark matter-free TDGs with different radii.

I use the hydrodynamical cosmological Illustris-1 simulation to identify tidal dwarf galaxy candidates and study their present-day physical properties. In particular, I will discuss the positions of galaxies in the radius-mass plane depending on their non-baryonic content and compare it with observational data. I will explain the implications of the dual dwarf theorem for ΛCDM cosmology. Finally, I will discuss the occurrence of NGC 1052-DF2-type objects in different cosmological hydrodynamical simulations.

Notes:

Speaker: Xavier Hernández, Ciudad Universitaria, Mexico City

Title: MONDian gravity in astrophysical systems beyond rotation curves: Elliptical galaxies, Globular clusters and Wide binaries

Abstract:
The existence of large scale gravitational anomalies at galactic scales has been well established over the past decades, mainly though the rotation curves of spiral systems. The most salient features of these anomalies are that rotation curves become flat, and stay flat, on crossing a critical radius of order $R_M = (GM/a_0)^{1/2}$, and that the amplitude of these rotation curves follow the Tully-Fisher relation, $V=(GMa_0)^{1/4}$, where M is the baryonic mass of the galaxy in question. I will review recent results extending the above phenomenology to the extended velocity dispersion profiles recently measured by the MANGA survey comprising hundreds of elliptical galaxies, globular cluster observations in the Milky Way, and very recent Gaia DR2 observations of wide binaries. Although results with binary stellar systems are currently preliminary, I will argue that the appearance of a consistent phenomenology across such a large range of systems suggests a change in gravity, rather than the existence of various independent mechanisms operating at the varied scales involved, all coincidentally yielding the empirically observed regime change at R_M.

Notes:

Speaker: Michael Hilker, ESO, Garching, Germany
Title: Kinematic complexity in a rising velocity dispersion profile around the Hydra I cluster central galaxy NGC 3311
Abstract:
NGC 3311, the central galaxy of the Hydra I cluster, shows signatures of recent infall of satellite galaxies from the cluster environment. Previous work has shown that the line-of-sight velocity dispersion of the stars and globular clusters in the extended halo of NGC 3311 rises up to the value of the cluster velocity dispersion. In the context of Jeans models, a massive dark halo with a large core is needed to explain this finding. However, new multi-object spectroscopic observations of the diffuse stellar halo of NGC 3311 show that outside 10 kpc the velocity dispersion does not simply rise but fills an increasingly large range of dispersion values with two well defined envelopes. The lower envelope is about constant at 200 km/s. The upper envelope rises smoothly, joining the velocity dispersion of the outer globular clusters and the cluster galaxies. We interpret this behaviour as the superposition of tracer populations with increasingly shallower radial distributions between the extremes of the inner stellar populations and the cluster galaxies. Simple Jeans models illustrate that a range of mass profiles can account for all observed velocity dispersions, including radial MOND models. Jeans models using one tracer population with a unique density profile are not able to explain the large range of the observed kinematics. Previous claims about the cored dark halo of NGC3311 are therefore probably not valid. This may in general apply to central cluster galaxies with rising velocity dispersion profiles, where infall processes are important.

Notes:

Speaker: Behnam Javanmardi

Title: Number of Satellites vs. Bulge Mass in ΛCDM

Abstract:
There is a correlation between the number of dwarf satellites and the bulge mass of the three main galaxies in the Local Group (i.e. M31, Milky Way, and M33). In this study (Javanmardi et al. 2019, ApJ, 870, 50), we investigate the expectations of the standard ΛCDM model of cosmology for a possible connection between these two quantities using a galaxy catalogue based on the Millennium-II simulation. We find that i) disk galaxies in heavier haloes grow on average heavier bulges and host a statistically larger number of satellites, ii) disk galaxies with similar masses can have a wide range of bulge masses independent of their number of satellites, and iii) there is no correlation between the number of satellites and the bulge-to-total (B/T) ratio of disk galaxies. In my talk, I will present the details of our sample selection, data analysis, and the above-mentioned results.

Notes:

Speaker: Chung-Ming Ko, Institute of Astronomy, National Central University, Taiwan and Department of Physics and Center of Complex Systems, National Central University, Taiwan, R.O.C.

Title: Gravitational Lensing by Spiral and Elliptical Galaxies in MOND

Abstract:
The Mass Discrepancy-Acceleration Relation (MDAR) in elliptical galaxies deduced from gravitational lensing is consistent with the result from the dynamics of spiral galaxies (Tian & Ko 2017). One possible explanation of MDAR is Modified Newtonian Dynamics (MOND). Gravitational lensing in relativistic MOND is thus worth studying. In this work, we adopt a Kuzmin-like model for spiral galaxies and Hernquist model for elliptical galaxies. We compare the lensing mass from SLACS database in the framework of MOND with the baryonic mass deduced from other methods.

Notes:

Speaker: Federico Lelli, ESO, Garching, Germany
Title: The Empirical Laws of Galactic Rotation
Abstract:
The Spitzer Photometry and Accurate Rotation Curve (SPARC) database provides detailed mass models for 175 disk galaxies (spirals and irregulars), using extended HI+Hα rotation curves and Spitzer photometry at 3.6 μm. This rich dataset enables us to characterize three empirical laws of galactic rotation:
(1) The baryonic Tully-Fisher relation (BTFR): the mean circular velocity along the outer, flat part of the rotation curve correlates with the baryonic mass with a slope close to 4.
(2) The central density relation (CDR): the dynamical-mass surface density from the inner, rising part of the rotation curve correlates with the central baryonic surface density;
(3) The radial acceleration relation (RAR): the observed centripetal acceleration at every radius correlates with the expected acceleration from the baryonic mass distribution. These relations are remarkably tight by astronomical standards, being consistent with no intrinsic scatter beyond the observational errors. Each of these relations indicates the existence of an acceleration scale in a conceptually distinct manner, but they return the same value within the errors, about 10^{-10} m/s^2. This is fully consistent with the predictions from Modified Newtonian Dynamics (MOND). Remarkably, the shapes of these distinct relations are interrelated: the shape of the RAR dictates the shape of the CDR and the slope of the BTFR. I will discuss several attempts to reproduce these relations in a ΛCDM context. I will also highlight how future surveys will allow us to study the possible dependence of these relations on redshift and/or environment.

Notes:

Speaker: Pengfei Li, Case Western Reserve University

Title: Fitting the radial acceleration relation to individual SPARC galaxies.

Abstract:
We fit the radial acceleration relation (RAR) to 175 late-type galaxies in the SPARC database using the Markov Chain Monte Carlo method marginalizing over stellar mass-to-light ratio, galaxy distance and disk inclination. Good fits to the rotation curves are found for the vast majority of the SPARC galaxies, and the RAR derived from those best fits is much tighter with an rms scatter of only 0.057 dex, which sets the upper limit for the intrinsic scatter. We also explore the possible variation of the critical acceleration scale by adding it as a fitting parameter, and find the fit goodness remains the same as that with a fixed acceleration scale. Therefore, there is no added value in allowing the acceleration constant to vary. The SPARC data are consistent with a single effective force law that is indistinguishable from MOND.

Notes:

Speaker: André Maeder, Geneva Observatory, Switzerland
Title: The scale invariant theory and MOND: the case of the radial acceleration relation (RAR)
Abstract:
MOND is based on global dilation invariance that is independent of time, while the Scale Invariant Vacuum Theory (SIVT) rests on the more general time-dependent scale invariance. Based on the Weyl Integrable Geometry, a general scale-invariant field equation and a geodesic equation have been obtained by Dirac (1973) and Canuto et al. (1977). Assuming that the macroscopic empty space (the cosmological vacuum) is scale invariant, Maeder and Bouvier (1979) obtained in the case of weak fields a modified form of the Newton equation, containing a (small) additional term. This equation accounts well for the dynamics of clusters of galaxies, of the flat rotation curves of galaxies (and for the RAR), for the increase of the stellar velocities with age in the Galaxy (Maeder, 2017c), as well as the growth of density fluctuations in the Universe (Maeder and Gueorguiev 2019). Now, when applied to the (flat) spiral galaxies and with the assumption that *these galaxies have the same age,* it can be shown that the scale-invariant equation leads to the same relation as MOND. However, contrary to MOND the SIVT also accounts for the dwarf galaxies and makes the fundamental MOND constant a_0 into a local parameter dependent on the overall local characteristics of the matter structures. Many dwarf spheroidals have uncertain dynamical data. However, the subsample of the well-measured dSphs confirms the observed relation by Lelli et al. (2017). This opens the possibility of general time-dependent scale invariance rather

than the time-independent dilation invariance of the MOND theory.

Notes:

Speaker: Stacy McGaugh, Case Western University, Cleveland, USA

Title: Signatures of MOND in Cosmology

Abstract:
Non-baryonic cold dark matter is an absolute requirement for the current cosmological paradigm, yet MOND has enjoyed considerably greater predictive success in galaxy dynamics. Usually depicted as a stark dichotomy between large and small scales, both ideas have failures and successes in both regimes. I will discuss some ways in which MOND may appear in cosmology, such as structure formation, reionization, and the microwave background, and attempt to identify critical observational tests.

Notes:

Speaker: Steffen Mieske, ESO, Santiago, Chile

Title: Gravity tests with dwarf galaxy structure

Abstract:
Recent campaigns with state-of-the art wide-field imaging facilities have allowed us to describe dwarf galaxy samples of several hundred objects with exquisite accuracy. Here I will describe the sample of dwarf galaxies in the Fornax cluster that has been identified by our group within the Fornax Deep Survey with the VST. I will show how this sample has allowed us to infer, without the need for explicit kinematical information, whether pure Newtonian gravity with or without dark matter can describe their structural parameters. I will then outline how this sample fits into the dual dwarf galaxy theorem, and what may be promising avenues to test the galaxies' structural parameters against MOND predictions.

Notes:

Speaker: Mordehai Milgrom, Weizmann Institute, Israel

Title: The a_0 - Λ connection

Abstract:
The MOND acceleration constant, a_0, is known to be near in value to some cosmologically significant accelerations. In particular, $\bar{a}_0 \equiv 2\pi a_0 \approx c(\Lambda/3)^{1/2}$, or in terms of the MOND length, $L_M \equiv c^2/a_0 \approx 2\pi L_\Lambda$ (L_Λ is the de Sitter radius corresponding to Λ). I will discuss the possible significance of this ‘coincidence’, and describe different ways in which it emerges in existing MOND schemes, with particular emphasis on a MOND-from-membrane-world picture.

Notes:

Speaker: Oliver Müller, University of Strasbourg, France

Title: Small-scale cosmology with dwarf galaxies

Abstract:
Dwarf galaxies are powerful testbeds to study cosmology on small-scales. In the Local Group, several discrepancies between theoretical predictions and observations of dwarfs have been identified and dubbed as a small-scale crisis. One of the most severe is the so-called planes-of-satellites problem, which describes the peculiar distribution and motion of dwarf galaxies around the Milky Way and the Andromeda galaxy. To extend these studies, we have conducted – and will conduct – several surveys with a multitude of small and large telescopes to probe other nearby galaxy groups and search for dwarf galaxies, ultra-diffuse galaxies, and tidal features. In my talk, I will provide evidence that some small-scale problems persist in other galaxy groups, most notably in the Centaurus A group. Furthermore, I will present how a recently developed algorithm for medical image analysis can help us discover low-surface brightness features in astronomical images and can be used to process large ongoing and upcoming surveys to get a better census of satellite systems to study cosmology on small scales.

Notes:

Speaker: Wolfgang Oehm, Bonn, Germany

Title: Constraints on the existence of dark matter haloes by the M81 group and the Hickson compact groups of galaxies

Abstract:
According to the standard model of cosmology the visible, baryonic matter of galaxies is embedded in dark matter haloes, thus extending the mass and the size of galaxies by one to two orders of magnitude. Taking into account dynamical friction between the dark matter haloes, the nearby M81 group of galaxies as well as the Hickson compact groups of galaxies are here investigated with regard to their dynamical behaviour. The results of the employment of the Markov Chain Monte Carlo method and the genetic algorithm show statistically substantial merger rates between galaxies, and long living constellations without merging galaxies comprise – apart from very few instances – initially unbound systems only. This result is derived based on three- and four-body calculations for a model of rigid Navarro-Frenk-White profiles for the dark matter haloes, but verified by comparison to randomly chosen individual solutions for the M81 galaxy group with high-resolution simulations of live self-consistent systems (*N*-body calculations). In consequence, the observed compact configurations of major galaxies are a very unlikely occurrence if dark matter haloes exist.

Notes:

Speaker: Marcel Pawlowski, AIP, Potsdam, Germany

Title: Planes of Satellites: Observational evidence in light of Gaia DR2, and testing proposed solutions with cosmological simulations.

Abstract:
The Milky Way, Andromeda, and Centaurus A host flattened distributions of satellite galaxies which exhibit coherent velocity trends indicative of rotation. I will briefly review the observational evidence for these structures, with an emphasis on the status of the Milky Way's Vast Polar Structure in light of Gaia DR2 proper motions. Comparably extreme satellite structures are very rare in cosmological ΛCDM simulations, giving rise to the "satellite plane problem". Several explanations have been proposed, such as that only host halos with some special properties contain narrow, correlated planes of satellite galaxies. I will present my investigations into such proposed solutions to the satellite plane problem and whether there are correlations between satellite plane and host halo properties in high-resolution cosmological zoom simulations. Specifically, I will discuss whether halo size, mass, concentration, or formation time; the halo environment as being situated in an isolated or host-pair configuration; or the presence of a central galaxy in a dark matter host halo (as a proxy for the leading baryonic effect on the distribution of satellites), result in more pronounced satellite planes.

Notes:

Speaker: Charalambos Pittordis, Queen Mary University of London, UK

Title: Testing modified gravity theories with wide binaries from GAIA DR2

Abstract:
Several recent studies have shown that very wide binary stars can potentially provide an interesting test for modified-gravity theories which attempt to emulate dark matter; these systems should be almost Newtonian according to standard dark-matter theories, while the predictions for MOND-like theories are distinctly different, if the various observational issues can be overcome. Here we explore an observational application of the test from the recent GAIA DR2 data release: we select a large sample of ∼24,000 candidate wide binary stars with distance <200 parsec and magnitudes *G*<16 from GAIA DR2, and estimate component masses using a main-sequence mass-luminosity relation. We then compare the frequency distribution of pairwise relative projected velocity (relative to circular-orbit value) as a function of projected separation; these distributions show a clear peak at a value close to Newtonian expectations, along with a long ‘tail' which extends to much larger velocity ratios; the ‘tail' is considerably more numerous than in control samples constructed from DR2 with randomized positions, so its origin is unclear. Comparing the velocity histograms with simulated data, we conclude that MOND-like theories without an external field effect are strongly inconsistent with the observed data since they predict a peak-shift in clear disagreement with the data; testing MOND-like theories with

an external field effect is not decisive at present, but has good prospects to become decisive in future with improved modeling or understanding of the high-velocity tail, and additional spectroscopic data.

Notes:

Speaker: Tom Richtler, Universidad de Concepcion, Chile

Title: Elliptical galaxies and the Baryonic Tully-Fisher Relation (BTFR)

Abstract:
The BTFR for elliptical galaxies is not as precisely defined as it is for disk galaxies. One finds "dark matter poor" and "dark matter rich" galaxies. Dark matter poor ellipticals are hard to explain. The ellipticals that are most deviating from the BTFR toward the "dark matter rich" side are the central galaxies in galaxy clusters. Such an environment invites to overestimate dynamical masses. A mass discrepancy in galaxy clusters at the level of the MONDian expectation only is not excluded.

Notes:

Speaker: Donatella Romano, INAF-Osservatorio di Astrofisica e Scienza dello Spazio di Bologna, Italy

Title: Gas removal from ultrafaint dwarf galaxies – a high-resolution study

Abstract:
The faintest Local Group galaxies found orbiting in and around the Milky Way halo host old stellar populations. The star formation activity did not last longer than 2 Gyr in all of these systems. A few mechanisms that might lead to such a rapid quenching have been investigated so far, without converging to a satisfactory solution. We simulate an ultrafaint dwarf galaxy loosely resembling Bootes I at very high resolution (maximum spatial resolution = 0.95 pc) and study the effects of stellar feedback alone on the ambient medium. In contrast to simple analytical estimates, most of the cold gas reservoir is retained. Simulations taking into account the combined effects of stellar feedback, ram pressure stripping and host-satellite interactions are now ongoing.

Notes:

Speaker: Mahmood Roshan, Dept. of Physics, Ferdowsi University of Mashhad, Iran

Title: Evolution of spiral galaxies: distinction between modified gravity and particle dark matter

Abstract: The long-term evolution of spiral galaxies via high-resolution simulations combined with the relevant observations may help to distinguish between particle dark matter and modified gravity theories. It turns out that there are features associated with particle dark matter which cannot be reconstructed by modified gravity. We study the evolution of spiral galaxies in two well-studied modified gravity theories. These theories are scalar-tensor-vector gravity known as MOG (Moffat 2006), and a model of nonlocal gravity (NLG) (Hehl & Mashhoon 2009). We show that the bar growth and the bar pattern speed evolve differently in modified gravity and the standard dark matter halo paradigm. More specifically, we show that the density wave dynamics on the surface of galaxies in these different viewpoints reveals significant differences. For example, disks in modified gravity host fast bars compatible with observations, while disks in the standard viewpoint host slow bars in contrast to observations.

Notes:

Speaker: Riccardo Scarpa, Instituto de Astrofísica de Canarias, Spain

Title: Probing Newtonian Dynamics in the low acceleration regime with wide binary stars

Abstract:
Extremely wide binary stars represent ideal systems to probe Newtonian dynamics in the low acceleration regimes ($\lesssim a_0$ ≈ 10^{-10} m/s^2) typical of the external regions of galaxies. Here we present a study of a GAIA DR2 selected sample of alleged wide binary stars with projected separation ranging from 0.004 to 1 pc, probing gravitational accelerations well below the limit where dark matter or modified dynamics theories set in. Radial velocities with accuracy ~100 m/s were obtained for each star, in order to constrain the true 3D orbital velocity and distinguish bound from unbound systems. Thus, even though this sample has limited size, here we present the true orbital velocities and not just the tangential component. Results show that deviations from Newtonian behaviour below a_0 are becoming evident, even though at this stage no compelling conclusions can be reached.

Notes:

Speaker: Earl Schulz, North Granby, CT 06060, USA

Title: Scaling Relations and the Gravitational Acceleration at the Edge of Disk Galaxies

Abstract:
Scaling relations were studied for the McGaugh (2015) and Courteau et al (2007) databases. Four tight correlations of total baryonic mass, velocity and radius were found which follow from a pair of more fundamental relations which define a line in log space. First, the centripetal acceleration at the edge of the stellar disk is proportional to the acceleration predicted by Newtonian physics and secondly, this acceleration is a constant which is related to Milgrom's constant.

$$\frac{V^2}{R} = C_f \frac{MG}{R^2} = A_{edge}$$

The two primary relations can be manipulated algebraically to generate the observed correlations. In fact, any plane in log space which contains the fundamental line defines a distinct scaling law. Since an infinite number of equally valid scaling laws can be obtained by rotation there is no “fundamental plane”.
The value of the C_f = 2.03 found by fitting is close to what is expected for a flat disk. The value of
A_{edge} = 6.65 $\times 10^{-11} m/s^2$ is close to Milgrom’s constant but is obtained without needing to probe the outer flat portion of the rotation curve.

Notes:

Speaker: Constantinos Skordis, Central European Institute for Cosmology

Title: A relativistic theory of Modified Newtonian Dynamics

Abstract:
I will present a new and simple relativistic theory of Modified Newtonian Dynamics, closely related to the old Bekenstein-Sanders Tensor-Vector-Scalar theory. The theory is constructed to reproduce the MOND law for small potential gradients and Newtonian gravity for large potential gradients. It is also constructed so that tensor gravitational waves (GWs) propagate at the speed of light, in agreement with GW data from LIGO/Virgo (arXiv:1905.09465). I will discuss the construction of this theory and show that it is healthy (no ghost instabilities or other pathologies). I will then present its cosmology and show that it is compatible with the CMB data from Planck. I will finally discuss future prospects.

Notes:

Speaker: Yong Tian, Institute of Astronomy, National Central University, Taiwan, R.O.C.

Title: Mass discrepancy–acceleration relation in Einstein rings

Abstract:
We study the mass discrepancy–acceleration relation (MDAR) of 57 elliptical galaxies by their Einstein rings from the Sloan Lens ACS Survey (SLACS). The mass discrepancy between the lensing mass and the baryonic mass derived from population synthesis is larger when the acceleration of the elliptical galaxy lenses is smaller. Moreover, at the Einstein ring, these lenses belong to high-surface-mass density galaxies. Similarly, we find that the discrepancy between the lensing and stellar surface mass density is small. It is consistent with the recent discovery of dynamical surface mass density discrepancy in disc galaxies where the discrepancy is smaller when surface density is larger. We also find relativistic modified Newtonian dynamics (MOND) confirms the MDAR and surface mass density discrepancy in 57 Einstein rings. Moreover, the lensing mass, the dynamical mass and the stellar mass of these galaxies are consistent with each other in the framework of MOND.

Notes:

Speaker: Ingo Thies, University of Bonn, Germany

Title: On the origin of the Local Group in Modified Newtonian Dynamics.

Abstract:
Among the unsolved riddles in extragalactic astronomy is the origin of the Local Group with the Milky Way and the Andromeda Galaxy and their satellite galaxies. The near-planar alignment of satellites around both major galaxies is strongly inconsistent with the standard model of cosmology, which predicts a random distribution of subhalos around the dark matter halos of the host galaxies. Here I present an alternative scenario of a past encounter of the Milky Way and Andromeda galaxies about 9 Gyr ago in MOND. In this model, developed in co-operation with Indranil Banik, the mutual tidal perturbation disrupts the outer regions of both galaxies, ejecting stars and gas into near-planar orbits. The orientations and the total masses of the satellite planes formed this way will be compared to observations. I will further discuss the implications of the results for cosmology with and without dark matter.

Notes:

Speaker: Guillaume Thomas, NRC Herzberg Astronomy & Astrophysics, Canada

Title: The External Field Effect of the Milky Way and its impact on the globular cluster.

Abstract:
In the MONDian framework, the External Field Effect (EFE) produced by the Milky Way plays a major role on the internal dynamics of globular clusters. Therefore this effect can significantly modify the morphology of the globular clusters and can also generate an asymmetry between the leading and the trailing arm of their tidal streams. I will present these results by comparing the predictions in the MONDian and in the Newtonian frameworks. I will present the future surveys that could be used to discriminate observationally between the predictions in these two frameworks.

Notes:

Speaker: Václav Vavryčuk, Institute of Geophysics, Czech Academy of Sciences, Prague, Czech Republic

Title: CMB as thermal radiation of cosmic dust?

Abstract:
The concept of the cosmic microwave background (CMB) as thermal radiation of intergalactic dust is revived and revisited. The model suggests that a virtually transparent local Universe becomes considerably opaque at redshifts z > 2-3. Such opacity is hardly to be detected in the Type Ia supernova data but confirmed using composite spectra of quasars. In this model, the opacity steeply increases with redshift because of a high proper density of intergalactic dust in the previous epochs. The temperature of intergalactic dust increases as (1+z) and exactly compensates the change of wavelengths due to redshift, so that the dust radiation looks like the radiation of the blackbody with a single temperature. The predicted dust temperature is T^D = 2.776 K, which differs from the CMB temperature by 1.9% only and the predicted ratio between the total CMB and EBL intensities is 13.4 which is close to 12.5 obtained from observations. The CMB temperature fluctuations are caused by fluctuations of the extragalactic background light produced by galaxy clusters and voids in the Universe. The polarization anomalies of the CMB correlated with temperature anisotropies are caused by the polarized thermal emission of conducting dust grains aligned by large-scale magnetic fields around clusters and voids.

Notes:

Speaker: Nils Wittenburg, University of Bonn, Germany

Title: The formation of late-type galaxies in MOND

Abstract:
The formation and evolution of galaxies is highly dependent on the dynamics of stars and gas, which is governed by the underlying law of gravity. To investigate how the formation and evolution of galaxies takes place in Milgromian gravity, we show full hydrodynamical simulations with the Phantom of Ramses (PoR) code in the Milgromian Dynamics (MOND) framework. These are the first galaxy formation simulations done in MOND with detailed hydrodynamics, including star formation, stellar feedback, radiative transfer and supernovae. Our models start as isolated, rotating, in effect post-Big-Bang, gas spheres. These collapse and form late-type galaxies. We show that the resulting galaxies have flat rotation curves, exponentially decreasing stellar surface mass density profiles, vertical stellar mass distributions with distinct exponential profiles (thin and thick disk) and are compatible with several observational scaling relations, which is unexpected, because the effectively stronger gravity in MOND could have led to a stronger collapse with the final objects being pressure supported and mostly Newtonian. Despite being comparable to observations, the simulations done here lack angular momentum, which is connected to the simple initial conditions and the absence of accretion. We also analyse if more complex baryonic physics changes the resulting main properties of the models and find that this is not the case. In the Milgromian framework galaxy formation and evolution

therefore does not sensitively depend on the complexity of the baryonic physics prescriptions. This work also shows that disk galaxies, with exponential profiles in both gas and stars, are a generic outcome in MOND of collapsing gas clouds, purely due to self-gravity, with star formation.

Notes:

Speaker: Richard P. Woodard, University of Florida, Gainesville, USA

Title: A Nonlocal Metric Realization of MOND

Abstract:
This talk concerns the attempt to view MOND as the static, weak field limit of some larger modified gravity theory. The baryonic Tully-Fisher relation determines the static, weak field limit of the 00 component of the field equations for any realization of MOND which is based on the metric. Two curious properties of this equation are (1) that it is quadratic in the weak fields and (2) that it has three derivatives. With the assumption of invariance, property (2) precludes the parent action from being local. A nonlocal modification of gravity could not be fundamental but it might represent the vacuum polarization of the vast ensemble of infrared gravitons produced during primordial inflation. I exhibit a model whose equations have the required form and are consistent with observed weak lensing. The 00 component of these equations has a linear term which is suppressed by time derivatives. This offers the fascinating possibility of regarding the Bullet Cluster as evidence for MOND, rather than against it.

This talk is based on arXiv:1106.4984, 1405.0393, 1608.07858 and 1804.01669.

Notes:

Speaker: Xufen Wu, Hefei, China

Title: The anisotropy of star clusters undergoing gas expulsion

Abstract:
We study the kinematics of stars in clusters undergoing gas expulsion in standard Newtonian dynamics and also in Milgromian dynamics (MOND). Gas expulsion can explain the observed line-of-sight (LoS) velocity dispersion profile of NGC 2419 in Newtonian dynamics. For a given star formation efficiency (SFE), the shapes of the velocity dispersion profiles, which are normalised by the velocity dispersion at the projected half-mass radius, are almost indistinguishable for different SFE models in Newtonian dynamics. The velocity dispersion of a star cluster in the outer halo of a galaxy can indeed have a strong radial anisotropy in Newtonian dynamics after gas expulsion. MOND displays several different properties from Newtonian dynamics. In particular, the slope of the central velocity dispersion profile is less steep in MOND for the same SFE. Moreover, for a given SFE, more massive embedded cluster models result in more rapidly declining central velocity dispersion profiles for the final star clusters, while less massive embedded cluster models lead to flatter velocity dispersion profiles for the final products. The onset of the radial-orbit instability in post-gas-expulsion MOND models is discussed. SFEs as low as a few percent, typical of molecular clouds, lead to surviving ultra-diffuse objects. Gas expulsion alone is unlikely the physical mechanism for the observed velocity dispersion profile of NGC 2419 in MOND.

Notes:

Speaker: Yanbin Yang, Paris Observatory, GEPI, France

Title: The origin of The Magellanic Clouds and its Stream

Abstract:
The origin of the Magellanic Clouds and their Stream is still challenging to explain. We have analysed the Magellanic Stream (MS) using the deepest and the most resolved HI survey of the Southern Hemisphere (the Galactic All-Sky Survey). The overall Stream is structured into two filaments, suggesting two ram-pressure tails lagging behind the Magellanic Clouds (MCs), and resembling two close, transonic, von Karman vortex streets. The past motions of the Clouds appear imprinted in them, implying almost parallel initial orbits, and then a radical change after their passage near the N(HI) peak of the MS. This is consistent with a recent collision between the MCs 200-300 Myr ago, which has stripped their gas further into small clouds, spreading them out along a gigantic bow shock, perpendicular to the MS. The Stream is formed by the interplay between stellar feedback and the ram pressure exerted by diffuse and multiphase gas in the Milky Way (MW) halo with a density 0.0001 per cubic centimetre at 50-70 kpc, a value necessary to explain the MS multiphase high-velocity clouds. These lead us to propose a “ram pressure plus collision” scenario to explain the formation of the MCs and MS. We explored this scenario with fully-solved hydrodynamic simulations. Besides reproducing most observed properties, ram-pressure combined with Kelvin-Helmholtz instabilities extracts amounts of ionized and HI gas consistent with that observed. The model is also a first for

reproducing the Bridge including the offset between young and old stars. The collision between the Clouds is responsible for the very elongated morphology of the smallest encounter along the line of sight. These successes challenge another popular scenario, such as Besla et al. 2012, in which the Stream is explained as a tidal tail due to the MCs collision.

Notes:

Speaker: Hongsheng Zhao, St. Andrews University, Scotland

Title: The alternative way to separate the baryon peaks from the lensing peaks of the Bullet clusters

Abstract:
I will discuss how in some MOND-like theories the offsets of baryon peaks from the lensing peaks are quite natural. I will test these in the case of the Bullet Clusters.

Notes:

List of posters

Authors: Vikas Jadhav Y & Arunima Banerjee

Title: The specific angular momenta of superthin galaxies: Clue to their origin?

Abstract:
Superthin galaxies are low surface brightness (LSB) bulgeless disc galaxies having stellar discs with unusually high planar-to-vertical axes ratio b/a > 10-20, the formation and evolution of which is not well understood. We calculate the specific angular momenta of a sample of six superthins and nine other bulgeless LSBs using stellar photometry, atomic hydrogen (HI) surface density, and high-resolution HI rotation curves available in the literature. We find that the stellar specific angular momentum js, and hence the stellar disc size given by the exponential stellar disc scale length RD, of three superthins and seven LSBs lie above the 95.4 per cent confidence band of the j_s – V_{rot} regression line for ordinary bulgeless disc galaxies, V_{rot} being the asymptotic rotational velocity. Further, we find that superthins and LSBs have higher j_s and R_D values for a given value of stellar mass Ms at high values of statistical significance, compared to ordinary disc galaxies. Therefore, we conclude a superthin may be distinguished by a characteristically larger disc size which could possibly explain the origin of its large planar-to-vertical axis ratio. Interestingly, we find that the median spin parameter

$\lambda = \frac{j_{stars}}{\sqrt{2} V_{vir} R_{vir}}$, V_{vir} and R_{vir} being the virial velocity and virial radius of the galaxy respectively, is 0.13 ± 0.01 for superthin galaxies which is an order of magnitude higher than those of LSBs and ordinary disc galaxies. This may have important implications for the existence of superthin stellar discs in these LSB galaxies.

Notes:

Authors: Gerhard Hensler, Bernhard Baumschlager, Patrick Steyrleithner, Simone Recchi

Title: Rapid gas accumulation in tidal arms for the formation of tidal dwarf galaxies

Abstract:
We present, for the first time, chemo-dynamical numerical simulations of formation and growth of young tidal dwarf galaxies (TDGs), including a self-consistent treatment of the tidal arm in which they are embedded. Thereby, we do not rely on idealized initial conditions, as the initial data of the presented simulation emerge from a galaxy interaction simulation. By comparing models which are either embedded in or isolated from the tidal arm, we demonstrate the importance of the tidal arm on the evolution of TDGs, as additional source of gas which can be accreted and is available for subsequent conversion into stars. During the initial collapse of the proto-TDG, with a duration of a few 100 Myr, the evolution of the embedded and isolated TDGs is indistinguishable. Significant differences appear after the collapse has halted and the further evolution is dominated by the possible accretion of material from the surrounding tidal arm. The inclusion of the tidal arm in the simulation of TDGs results in roughly a doubling of the gas mass and fraction, an increase in stellar mass by a factor of 1.5, and an approximately three times higher star-formation rate compared to the isolated case.

Moreover, we perform a parameter study on the influence of different environmental effects, i.e. the tidal field and ram pressure. Due to the orbit of the chosen initial conditions, no clear impact of the environmental effects on the evolution of TDG candidates can be found.

Although TDGs' low gravitation cannot acquire Cold Dark Matter (CDM) from the massive galaxies from phase-space arguments and, therefore, not be gravitationally supported by DM halos, surprisingly none of the models is disrupted by extreme stellar feedback, even at high SFRs. Their survival, therefore, questions the origin of the DG population in the cosmos.

This paper is published in Baumschlager et al., 2019, MNRAS, 483, 5315

Notes:

Author: Michael A. Ivanov

Title: Modified dynamics of massive bodies in the graviton background

Abstract:
The additional deceleration of massive bodies and the redshift of remote objects in the model of low-energy quantum gravity are caused by collisions with gravitons. Some results of numerical modeling of motion of bodies in the central field by the influence of this additional deceleration are described here. The two peculiarities of modified dynamics take place: an absence of closed orbits and a possibility of the non-planar motion of massive bodies in a central field.

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Author: Konstantinos Migkas

Title: Probing the anisotropy of the Universe using galaxy clusters and the eeHIFLUGCS sample

Abstract: The Cosmological Principle is a fundamental pillar of the standard cosmological model. The way we understand the Universe is heavily based on it being isotropic. Surprisingly enough however, this hypothesis still remains ambiguous. In order to introduce a new test for the isotropy of the Universe, we use a new galaxy cluster sample to investigate the directional behaviour of the X-ray luminosity-temperature (L-T) relation of galaxy clusters. A tight correlation is known to exist between these two quantities of the X-ray-emitting intracluster medium of galaxy clusters. While the luminosity measurement depends on the chosen cosmology through the luminosity distance, the temperature determination is cosmology-independent. Thus, the isotropy of the luminosity distance over the full extragalactic sky can be mirrored in the behaviour of the L-T scaling relation. The galaxy cluster sample we construct is ideal for such a study due to its large number of clusters and the uniform full-sky coverage it provides. Indeed, the behaviour of the L-T relation heavily depends on the direction of the sky. The presence of a cosmic anisotropy is detected with a $>4\sigma$ significance. Several reasons that could potentially explain this were tested, but none was able to explain the obtained results to a satisfactory degree. Other cluster samples appear to have a similar behaviour throughout the sky, while being completely independent of each other. Combining all available samples results in 842 different galaxy

clusters with independent luminosity and temperature measurements. Performing a joint analysis, the final anisotropy of the obtained Hubble constant is further intensified (5.6σ). The exact nature of the factor that causes such an anisotropic L-T behaviour is of the utmost importance.

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Author: Sitara Srinivasan, RNS institute of Technology

Title: Deducing the legitimacy of ΛCDM and MOND models by conceptual analysis of their falsification grounds

Abstract:
Science demands ruthless rationality and a complete lack of bias in every aspect of introspection, observation, and inference. While most would argue that the correctness of a theory depends on how well its predictions fit our observations, it is equally important to pay close attention to where the predictions *don't* fit. Essentially, falsification with deductive reasoning is certain, while affirmations of theories and inductive arguments are only probable.
The leading contenders that attempt to model the astronomical observations of the last several decades, while specifically extending their validity to the missing gravity problem, include the Lambda Cold Dark Matter model, and Modified Newtonian Dynamics (MOND). This paper deals with the conceptual analysis of both theories by taking into account all the existing grounds for refuting them, as well as the confidence level of these falsifications. The objective is to provide clarity while briefly reviewing the areas where the two theories diverge and the areas where they seem to agree. One must subject both theories to equal levels of scrutiny and consistency checks. We must note that the scientific community overwhelmingly leans towards the ΛCDM model, and invests most of its resources directly looking for clues to support it, thereby following an inductivist approach. An immediate observation one makes is the extent of uncertainty and loopholes that both

the models possess currently. While ΛCDM, supported by general relativistic evidence, is widely considered as standard physics, it is also a model that has needed a multitude of seemingly artificial fixes, thereby largely complicating our understanding of the universe. The lack of dynamical friction observed in stellar motions, the difficulty faced in explaining the Baryonic Tully Fisher relation, etc, seem to imply that the need for a serious modification in the ΛCDM model is irrefragable. On the other hand, MOND seems to offer an immediate solution to local galaxy dynamics and works elegantly for smaller scales, although it falters at larger scales and lacks a well developed relativistic formulation. It is clear, once we establish the areas where each of the theories fails, that something fundamental is missing in both approaches. The two models agree on the existence of an entirely new type of particle, either sterile neutrinos or a variation of WIMPs. This implies that the emergence of new physics is unavoidable. To eliminate either theory with complete confidence is going to require a whole generation of new literature based on pure critique. The absence of critical scientific literature leads to the progression of ideas that are simply wrong or those which already stand refuted. Conversely, discarding an idea without thoroughly investigating its true scope and relevance is unscientific too. Research that supports alternate theories to gravity thus need to be sustained actively and advanced, while still openly addressing their shortcomings. This paper aims to discuss these issues, and also attempts to convey the large disparity between the magnitude of effort that has gone into studying the ΛCDM model versus alternate theories of gravity.

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