Indranil Banik

Title

Testing LambdaCDM and MOND with massive galaxy clusters - the case of El Gordo

Abstract

Galaxy clusters are the largest gravitationally bound structures in the Universe. Their formation out of small initial density fluctuations holds important clues to the behaviour of gravity over large distances and long timespans. The standard cosmological paradigm (ΛCDM) makes precise predictions for the frequency of galaxy clusters with different mass, and for how often they interact. We recently showed that these predictions are ruled out at over six standard deviations by the observed properties of El Gordo (MNRAS, 500, 5249). Such a massive pair of galaxy clusters should not have formed so early in the universe's history, as demonstrated using two statistical analysis methods focusing on how many objects similar to El Gordo are expected in the surveyed region. We also considered the main alternative to ΛCDM, which is called Milgromian dynamics (MOND). The main assumption of MOND is that once the gravity from a point mass falls below some threshold a_0, it then declines only inversely with distance instead of continuing to follow the inverse square law. In this way, MOND can explain the unexpectedly fast rotation curves of galaxies. On larger scales, MOND would significantly enhance structure formation and thereby explain El Gordo, as demonstrated using a previous cosmological MOND simulation. The lack of similarly extreme objects to El Gordo in the low-redshift Universe might indicate that we are in a large void. There is actually quite strong evidence for such a void, which would also naturally explain the unexpectedly fast local expansion of the Universe (MNRAS, 499, 2845). Blog describing these works: darkmattercrisis.wordpress.com

Curriculum vitae for Indranil Banik

Employment

❖ Postdoc (9.2021 – present): University of St Andrews (Physics dept.)
Supervisor: Dr Hongsheng Zhao
I work with Hongsheng Zhao and external collaborators on testing if Newtonian gravity works at low accelerations using mainly Gaia data on Solar neighbourhood wide binary stars in a statistical analysis that also includes close binary companions (Arxiv: 2109.03827).

❖ Humboldt postdoctoral fellowship (10.2018 – 7.2021): University of Bonn (Argelander Inst.)
Host: Professor Pavel Kroupa
Project title: *Formation of the Local Group satellite planes in modified gravity*
I worked with Ingo Thies on *N*-body hydrodynamical simulations of a past flyby between the Milky Way and Andromeda galaxies in Modified Newtonian Dynamics (MOND). The aim was to see if MOND can reproduce the observed orientations of their satellite galaxy planes.

Education

❖ PhD (09.2014 – 05.2018): Thesis University of St Andrews (Physics dept.)
Supervisor: Dr Hongsheng Zhao
Project title: *Distinguishing standard from modified gravity in the Local Group and beyond*
I considered observational signatures of a past close flyby between the Milky Way and Andromeda, focusing on how they could slingshot nearby dwarf galaxies at high speeds via three-body interactions. I found strong evidence that several dwarfs were flung out like this.

❖ MSc (10.2010 – 06.2014): Trinity College, Cambridge
Course: 1st year – Maths with Physics (Maths Tripos); later years – Natural Sciences Tripos.
Grade: 1st class in all 4 years (averages: 72%, 79%, 87% and 76%, 1st class threshold = 70%).

First-authored publications:

1. On the absence of backsplash analogues to NGC 3109 in the ΛCDM framework (MNRAS, 503, 6170 – 6186), 2021
2. The global stability of M33 in MOND (ApJ, 905, 135), 2020
3. Scale invariant dynamics in the Solar System (MNRASL, 497, L62 – L66), 2020
4. Solar System limits on gravitational dipoles (MNRAS, 495, 3974 – 3980), 2020
5. A new line on the wide binary test of gravity (MNRAS, 487, 5291 – 5303), 2019
6. Effect of the Solar dark matter wake on planets (MNRAS, 487, 4565 – 4570), 2019
7. Testing gravity with interstellar precursor missions (MNRAS, 487, 2665 – 2672), 2019
8. Directly testing gravity with Proxima Centauri (MNRAS, 487, 1653 – 1661), 2019
9. Testing gravity with wide binary stars like α Centauri (MNRAS, 480, 2660 – 2688), 2018
10. The external field dominated solution in QUMOND and AQUAL: application to tidal streams (Science Federation Journal of Astrophysics, 1, 1000008), 2018
11. Origin of the Local Group satellite planes (MNRAS, 477, 4768 – 4791), 2018
12. A plane of high-velocity galaxies across the Local Group (MNRAS, 473, 4033 – 4054), 2018
13. Escape velocity curve of the Milky Way in Modified Newtonian Dynamics (MNRAS, 473, 419 – 430), 2017
14. Dynamical history of the Local Group in ΛCDM II − Including External Perturbers in 3D (MNRAS, 467, 2180 - 2198), 2017

15. Dynamical history of the Local Group in ΛCDM (MNRAS, 459, 2237 – 2261), 2016
16. Effects of lens motion and uneven magnification on image spectra (MNRAS, 450, 3155 – 3168), 2015
17. Ice shelves as floating channel flows of viscous power-law fluids (Journal of Oceanography and Marine Research, 4, 150) – 2016, work done in 2012 project with Justas Dauparas
18. Snowball Earth (review) – Journal of Astrobiology and Outreach, 4, 153 (2016).

Co-authored publications (2nd authored publications are *italicised*):

1. *The high fraction of thin disk galaxies continues to challenge ΛCDM* (ApJ, 925, 183), 2021
2. Fast galaxy bars continue to challenge standard cosmology (MNRAS, 508, 926 – 939), 2021
3. *Barred spiral galaxies in modified gravity theories* (MNRAS, 503, 2833 – 2860), 2021
4. *The Phantom of RAMSES user guide for galaxy simulations using Milgromian and Newtonian gravity* (Canadian Journal of Physics, 99, 607 – 613), 2021
5. *A massive blow for ΛCDM – the high redshift, mass, and collision velocity of the interacting galaxy cluster El Gordo contradicts concordance cosmology* (MNRAS, 500, 5249 – 5267), 2021
6. *The KBC void and Hubble tension contradict ΛCDM on a Gpc scale – Milgromian dynamics as a possible solution* (MNRAS, 499, 2845 – 2883), 2020
7. Constraints on the star formation histories of galaxies in the Local Cosmological Volume (MNRAS, 497, 37 – 43), 2020
8. The star formation history and dynamics of the ultra-diffuse galaxy Dragonfly 44 in MOND and MOG (ApJL, 884, L25), 2019
9. *The ultra-diffuse dwarf galaxies NGC 1052-DF2 and -DF4 are in conflict with standard cosmology* (MNRAS, 489, 2634 – 2651), 2019
10. A new formulation of the external field effect in MOND and numerical simulations of ultra-diffuse dwarf galaxies – application to NGC 1052-DF2 and DF4 (MNRAS, 487, 2441 – 2454), 2019
11. Galaxies lacking dark matter in the Illustris simulation (A&A, A47), 2019
12. *A common Milgromian acceleration scale in nature* (Nature Astronomy, 2, 925 – 926), 2018
13. Does the galaxy NGC1052-DF2 falsify Milgromian dynamics? (Nature, 561, E4 – E5), 2018
14. *Ultra-relativistic oscillon collisions* (Physical Review D, 90, 085024), 2014.

Fellowships awarded:

- Humboldt fellowship (2 years in Bonn, hosted by Pavel Kroupa)
- Benoziyo fellowship at Weizmann Institute, Israel (3 years, declined offer).

Research grants & Prizes:

- Royal Astronomical Society (RAS) 8-week bursary (£1200), 04.2017
  - For hiring summer student (David O'Ryan, Glasgow)
  - To simulate formation of the Milky Way and M31 satellite galaxy planes in MOND
  - Published results (see publications list, first-authored paper #10).
- Scottish Universities' Physics Alliance (SUPA) travel grant (£1500), 05.2017
  - For one month visit to P. J. E. Peebles in Princeton to work on Local Group dynamics
  - Published results (first-authored paper #11).
- Duncombe Prize ($1000) to present first-authored paper #14 at American Astronomical Society Division on Dynamical Astronomy meeting in Nashville, 05.2016.
- Trinity College, Cambridge 12-week bursary (£2650), 06.2012

- To investigate the force balance in ice shelves in a summer project
- Gave several talks about this and later published results (first-authored paper #16).

Refereeing (peer review):

- Over 50 reviews for various journals including MNRAS: https://publons.com/author/1510352

Supervision of students:

- David O'Ryan: summer student I hired with RAS grant I applied for, worked on Local Group satellite planes, work led to first-authored paper #10 that I am currently following up with a Humboldt fellowship to do hydrodynamical MOND simulations of a past MW-M31 flyby
- Roy Truelove: masters student I supervised to produce an algorithm for generating stable disk galaxy templates in MOND, this is now available on GitHub (first-authored paper #1)
- Victoria Schuy: currently supervising masters project on dynamics of outer Solar System bodies in MOND to search for correlations claimed as evidence for a ninth planet
- Elena Asencio: currently supervising masters project on analysing dwarf galaxies in the Fornax cluster in ΛCDM and MOND, she already produced my co-authored publication #2
- Moritz Haslbauer: currently helping supervise PhD student, already produced five joint publications (co-authored publications #3, 4, 5, 6, 8), #6 mentioned in New Scientist.

Conference talks:

- Gravity 2019 (Bonn, Germany). Setting up a stable disk in MOND (first-authored paper #1).
- Cosmology 2018 (Dubrovnik, Croatia). Wide binary test of gravity (first-authored paper #8).
- American Astronomical Society DDA (Queen Mary, London) – 14.06.2017. (Video of talk)
- Dwarf galaxy conference (Cleveland, USA) – 08.06.2017. Local Group dynamics.
- American Astronomical Society Division on Dynamical Astronomy (Nashville) – 25.05.2016.
- Royal Astronomical Society specialist discussion on galaxy clusters (London) – 11.12.2015.
- SUPA annual Cormack meeting (Edinburgh) – 23.11.2015.
- First Phantom of RAMSES workshop (Strasbourg, France) – 22.09.2015
  - Solutions to MOND equations including the external field effect (first-authored paper #9).
  - Gave another talk on Local Group dynamics in ΛCDM (first-authored paper #14).
- Astrobiological Society of Britain biennial meeting (University College London).
  - Review talk on Snowball Earth (first-authored paper #17), 04.09.2015
- National Astronomy Meeting, Llandudno (Wales), 06.07.2015
  - Measuring galaxy cluster proper motions via accurate spectra of strongly lensed objects (first-authored paper #15).
  - Another talk on Local Group galaxy dynamics
- Durham-Edinburgh Exchange, Edinburgh, 09.01.2015
  - Local Group dynamics in ΛCDM and how theory does not match observations well.

Coding:

- Used Fortran for publications on oscillons and 3D ΛCDM dynamical model of Local Group
- Algorithm for making stable disk galaxy templates in MOND is based on C
- Other publications based on MATLAB, including summer project on satellite plane origin.

Press releases:

- Explains recent detection of gravitational redshift in star S2 near Galactic centre black hole:

http://theconversation.com/why-starlight-turns-red-escaping-from-black-hole-at-heart-of-milky-way-100864
- Explains how a past MW-M31 flyby in MOND can explain properties of their satellite planes: https://blog.oup.com/2018/08/modified-gravity-plane-sight/
- About how Local Group galaxies with anomalously high radial velocities in a ΛCDM context; define a thin plane and how this is expected in Modified Newtonian Dynamics (2017): https://www.st-andrews.ac.uk/news/archive/2017/title,1168412,en.php
- About my work on Local Group dynamics at the National Astronomy Meeting in 2015: http://nam2015.org/index.php/press-releases/60-sterile-neutrinos-shielded-candles-and-modified-gravity-cosmology-looks-beyond-the-standard-model

Planning workshop debating the law of gravity at low accelerations (Bonn, 09.2019):
As chair of the scientific organising committee, I helped organise a free week-long international workshop debating if the inverse square law of gravity remains valid at the low accelerations in galactic outskirts. I suggested the workshop and invited participants, setting up a questionnaire to agree dates. I designed the logo and helped schedule the talks, delegating other tasks like preparing the conference booklet. We had 44 speakers and about 75 delegates. Conference website: https://astro.uni-bonn.de/~pavel/CONFERENCES/MOND2019/website/index.html

Teaching experience:
- Led small group teaching for 1st and 2nd year astrophysics students at St Andrews
- Helped with lectures for the evening degree programme there, delivered by Hongsheng Zhao
- Led weekly lunchtime surgery at Hills Road School in Cambridge via STIMULUS for 3 years
- Organised and conducted four revision lectures for my cohort as undergraduate at Cambridge.

YouTube videos (over 7000 combined views):
- Overview of MOND for Southampton astronomy department: https://www.youtube.com/watch?v=jL09gRe1q7s
- KBC void and Hubble tension, 11.2020: https://youtube.com/watch?v=LMhjenB7V8g
- MW-M31 flyby simulations in MOND, 09.2017: https://www.youtube.com/watch?v=dxUeeOmkqKg
- High-velocity Local Group galaxies, 04.2016: https://www.youtube.com/watch?v=U3HTzJohNAw
- Overview of MOND, 04.2015: https://www.youtube.com/watch?v=PYVC0VtmpDg
- Introduction to MOND, 03.2014: https://www.youtube.com/watch?v=-eCahykEy1A

Outreach:
- Blog post about co-authored paper #2 on the KBC void and Hubble tension: https://tritonstation.com/2020/10/23/big-trouble-in-a-deep-void/
- Blog post about my US visit when I won the AAS DDA Duncombe Prize to give a talk: https://darkmattercrisis.wordpress.com/category/guest-post/
- Two articles for Eureka magazine (by Archimedeans, Cambridge University maths society):
  - Introducing the idea of MOND and some evidence underpinning it: issue 63, Sep. 2014
  - Describing breakthrough on glacier dynamics achieved with another summer student in 2012 (published later as first-authored paper #16): issue 62, December 2012

- Talks:
  - ESO Hypatia Colloquium (February 2021)
  - Various departmental talks (including Strasbourg, Southampton, Bonn, Saint Andrews)
  - One each for the astronomical societies of Dundee and Clydesdale
  - 2 talks for Edinburgh University Physics Society on motivation for MOND
  - 1 talk for them on Snowball Earth hypothesis
  - Modified gravity talks for Physics Societies at St. Andrews, Aberdeen and Glasgow (where I interested a student for a summer project that led to first-authored paper #10)
  - 9 talks at Cambridge for maths, physics and astronomy societies, some on glacier dynamics and others on modified gravity
- Other activities:
  - Former member of STEM East
    - Have been to local schools during PhD to explain about my career & entry requirements
    - Answered astronomy questions from the public at a question & answer session in Kinross, mainly targeted at children (30.09.2017)
  - Helped with the Symmetries in Light exhibition (about work of Brewster)
    - Was the only volunteer to go to Edinburgh to receive training regarding the delicate kaleidoscopes borrowed from Japan as part of the exhibition, including on the wiring
  - Also helped in University open days and Observatory open evenings.