

INTERNATIONAL CONFERENCE

DARK MATTER AND STARS

Multi-Messenger Probes of Dark Matter and Modified Gravity

Center for Astrophysics and Gravitation (CENTRA)
Instituto Superior Técnico (IST) - University of Lisbon, Portugal

3 - 5 May 2023



A VERY BIG **THANK YOU TO ALL THE PARTICIPANTS FOR BEING HERE AND FOR THE GREAT QUALITY OF THE PRESENTED TALKS AND USEFUL DISCUSSIONS, YOU ALL MADE THIS CONFERENCE AN OUTSTANDING EVENT!**



SUMMARY OF ICDMS2023

90 participants

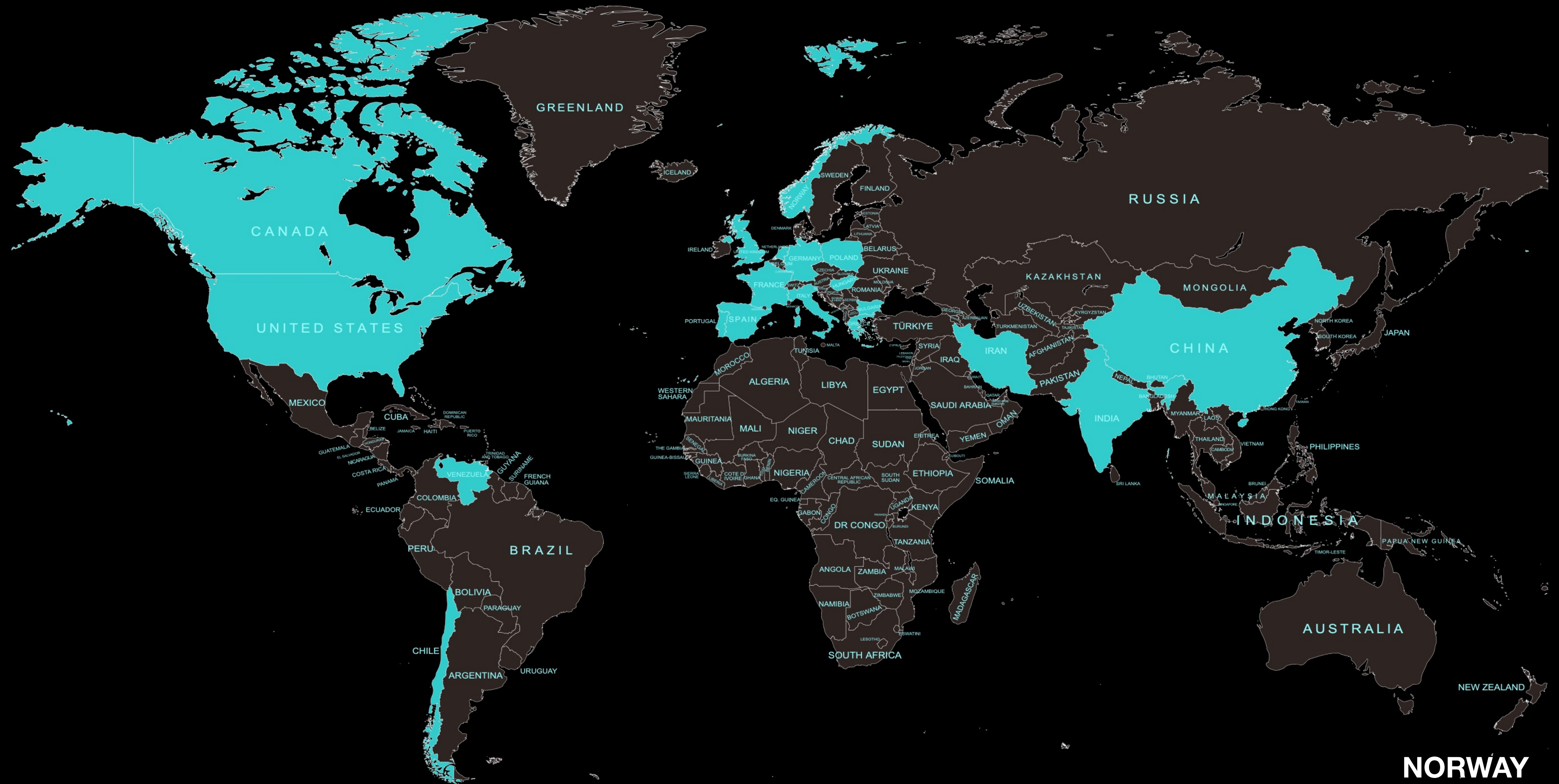
48 talks

17 posters

1 Conference dinner

1 bag lost and found twice in less than 1 hour

Ilídio Lopes
President of CENTRA, IST

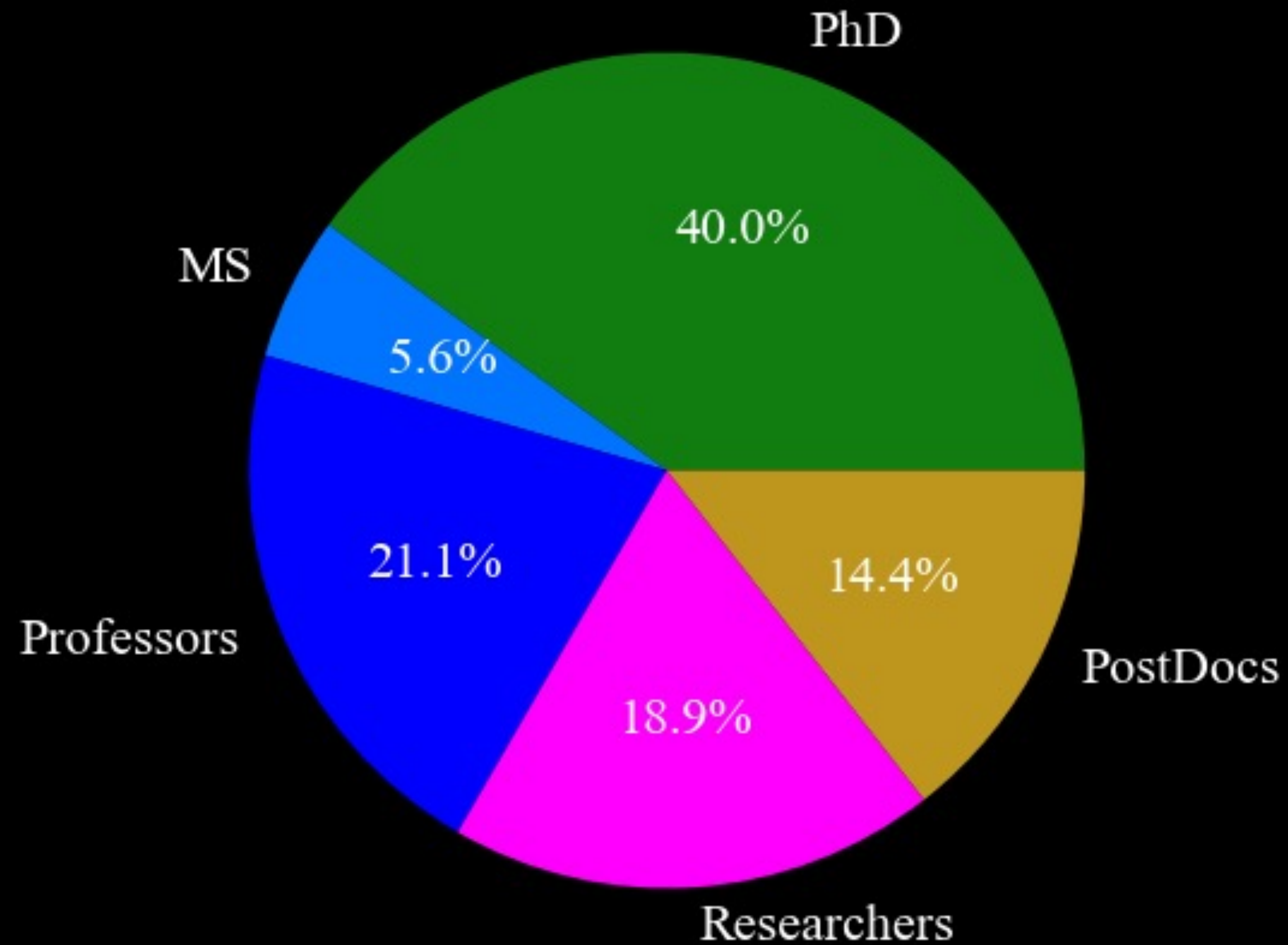


PORTUGAL	29
GERMANY	15
SPAIN	6
INDIA	5
UNITED KINGDOM	4
CANADA	4

POLAND	4
UNITED STATES	3
CHINA	3
HUNGARY	3
ITALY	3
NETHERLANDS	3

NORWAY	2
BULGARIA	1
IRAN	1
GREECE	1
FRANCE	1
CHILE	1
VENEZUELA	1

WHO ARE WE DEALING WITH?



POSTER SESSION & AWARD

THANK TO ALL POSTER PRESENTERS

2 EQUAL POSTER AWARDS

THE PRIZES ARE SPONSORED BY THE JOURNAL PARTICLES BY MDPI



Violetta Sagun
CFisUC, University of Coimbra

A BIG THANK YOU TO THE JURY MEMBERS



Can LIGO Detect Non-Annihilating Dark Matter?

Sulagna Bhattacharya*, Basudeb Dasgupta, Ranjan Laha, Anupam Ray

*Department of Theoretical Physics, Tata Institute of Fundamental Research, Mumbai

arXiv: 2302.07898

WINNER OF THE FIRST POSTER AWARD

SULAGNA BHATTACHARYA

(Tata Institute of Fundamental Research, Mumbai)

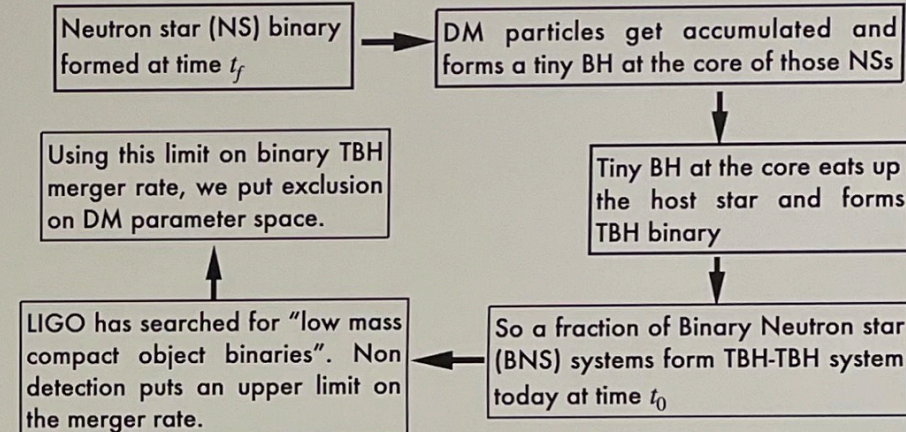
Poster Title:

Can LIGO Detect Non-Annihilating Dark Matter?

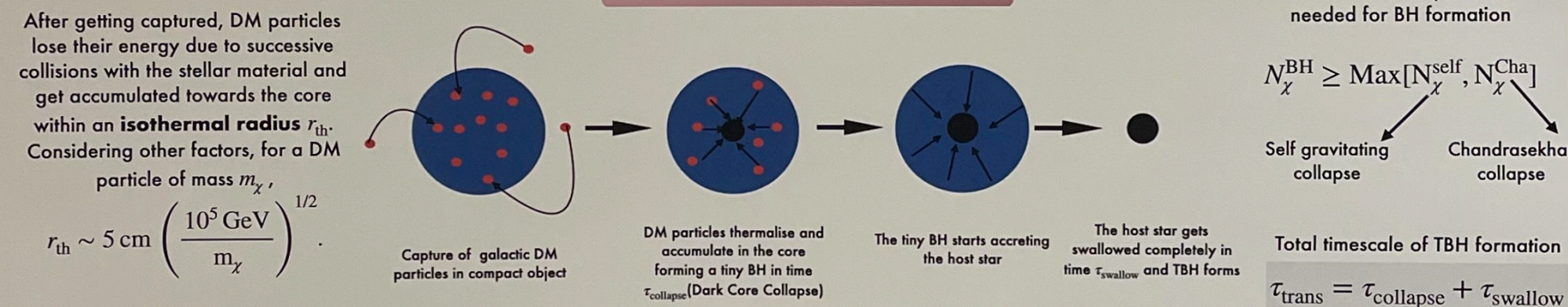
MOTIVATION

- Heavy Dark Matter (DM) particles are blindspot for the terrestrial detectors due to their **low fluxes**. [LUX-ZEPLIN,2022, XENON-1T,2018,...]
- Long **stellar lifetime** and **enormous size** of the celestial objects provide sensitivity to the low fluxes of these heavy DM particles. Huge stellar density makes Neutron Stars optimal.
- Non-annihilating DM particles owing to their **sufficient interaction** with stellar nuclei get captured inside the host star and can form a tiny black hole (BH) at the core which can eat up the host star and forms **Transmuted Black Hole (TBH)**. Existence of particular pulsars gives robust limits on DM parameters. [Kouvaris et al PRL(2011), McDermott et al PRD (2012), Dasgupta et al JCAP(2020), Garani et al JCAP (2018),...]
- **Non-Detection of Gravitational Wave (GW) signals** from these TBH mergers can put limits on DM parameter space.

OUTLINE



Transmuted BH formation



TBH-TBH Merger Rate

Binary Neutron Star (BNS) merger rate at current day t_0

$$\frac{dR_{BNS}}{dt_f}[t_0] = \frac{dP_m}{dt}[t_0 - t_f] \times \lambda \times \frac{d\rho_*}{dt}[t_f]$$

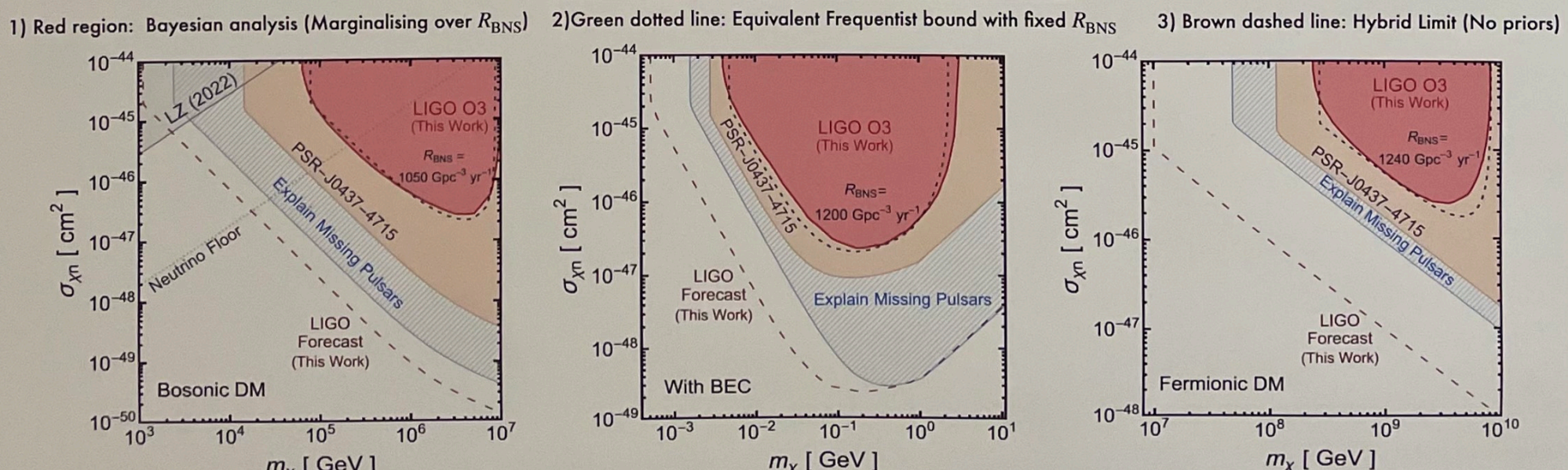
Due to scant statistics the range is very uncertain [LVK 2111.03634] $(10 - 1700) \text{ Gpc}^{-3} \text{ yr}^{-1}$.

Due to DM-capture-induced-transmutation, a fraction of this BNS system forms binary TBH system at current time.

$$R_{TBH}(t_0) = \int dr \frac{df}{dr} \int_{t_0}^{t_0 + \tau_{trans}} dt_f \frac{dR_{BNS}}{dt_f} \times \Theta[t_0 - t_f - \tau_{trans} [m_\chi, \sigma_{\chi n}, \rho_{ext}(r, t_0)]]$$

LVK observes these mergers at the present time which requires successful transmutation after binary formation $t_0 > t_f + \tau_{trans}$.

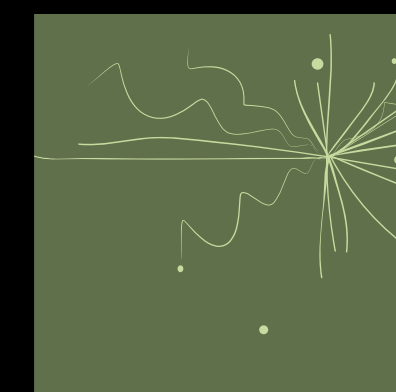
LIGO as a Dark Matter Detector



Poissonian likelihood for no events is $\exp[-\mu]$ where $\mu = R(VT)$ =no. of events. Where R is the merger rate & (VT) is the surveyed volume-time by the detector. Upper limit on μ with 90% confidence gives the upper limit on merger rate.

$$\int_{\mu_{90}}^{\infty} \exp[-\mu] d\mu = 0.1 \implies \mu_{90} = 2.303 \implies R_{90} = \frac{2.303}{(VT)}$$

Contact: sulagna@theory.tifr.res.in



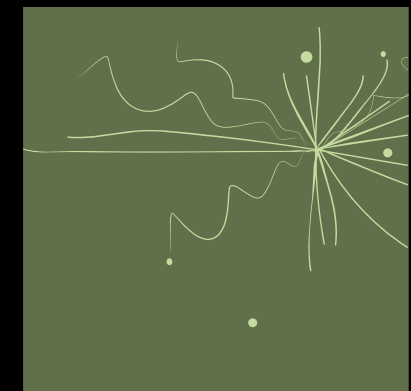
particles

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WINNER OF THE SECOND POSTER AWARD

JOSE FERREIRA
(IA / FCUL)

Poster Title:
Test Lambda-Free $f(Q)$ Cosmology



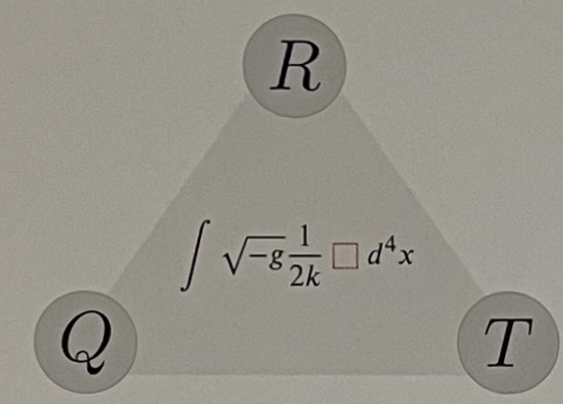
particles
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Abstract

We study a cosmological model of $f(Q)$ gravity that is able to account for the current accelerated expansion of the universe, without the need for a dark energy component. We use dynamical system techniques and constrain this model using type Ia supernova (SnlA), cosmic microwave background (CMB) data and forecast standard siren (SS) events.

1. Geometrical Theories of Gravity

Despite the successes of General Relativity (GR), which ascribes gravity to the curvature of spacetime, its geometry might not necessarily be due to curvature but due to other geometrical objects, such as torsion and non-metricity. These alternative descriptions of gravity can be used to create theories that may or may not have a GR limit [1].



$$\int \sqrt{-g} \frac{1}{2k} \square d^4x$$

We use this equivalence between curvature, represented by the Ricci scalar R , torsion, with the torsion scalar T , and non-metricity, with Q being the non-metricity scalar, as a starting point to create different theories of modified gravity. We extend the action by admitting an arbitrary function of the scalar quantity, leading us to the class of $f(R)$, $f(T)$ and $f(Q)$ theories of gravity.

1.1. $f(Q)$ Cosmology

We introduce a model of $f(Q)$ that aims to replicate the accelerated expansion of the universe by departing from GR via an extra multiplicative term, which reads [2]

$$f(Q) = Qe^{\lambda Q/Q_0} \quad (1)$$

Considering a flat FLRW universe, which implies that $Q = 6H^2 = 6H_0^2 E^2$, permeated by a perfect fluid composed solely of matter and radiation, without dark energy, the first Friedmann equation becomes

$$(E^2 - 2\lambda)e^{\lambda Q/Q_0} = \Omega_m(1+z)^3 + \Omega_r(1+z)^4 \quad (2)$$

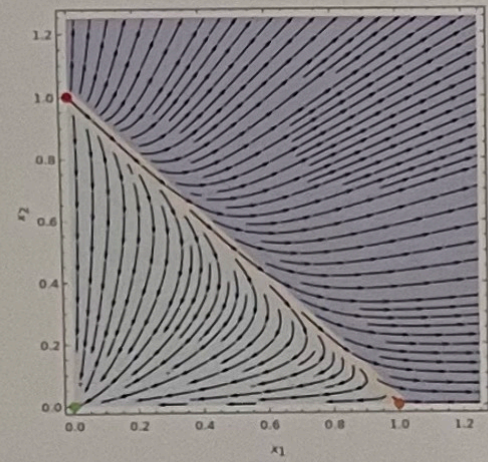
From the previous equations we can see that this model modifies the universe at late time ($E \ll 1$) while recovering GR at high redshifts ($E \gg 1$), with modified matter and radiation abundances. This type of models also modifies the cosmology at the perturbative level [3].

2. Dynamical Systems Analysis

We employ a dynamical systems analysis to assess the ability of this model of $f(Q)$ to replicate the various distinct phases that the universe has undergone. To do so we define the quantities

$$x_1 \equiv \frac{\Omega_m}{E^2 e^{\lambda Q/Q_0}}, \quad x_2 \equiv \frac{\Omega_r}{E^2 e^{\lambda Q/Q_0}} \quad (3)$$

where x_1 is related to the evolution of the matter density in the universe and x_2 with the radiation density. The trajectories and fixed points in phase space are presented in the figure below.



Fixed Points		
● (0, 0)	● (0, 1)	● (1, 1)
Stable	Saddle	Unstable
λ Dominated	Matter dominated	Radiation Dominated

Regions		
λ > 0	λ = 0	λ < 0

From the previous figure we can see that **only the trajectories in the light blue region**, corresponding to $\lambda > 0$, replicate the dynamics of the Λ CDM universe, where the system starts in a radiation dominated epoch, moving towards matter domination, and ending up in the stable fixed point, corresponding to an universe in accelerated expansion.

As for the brown region, corresponding to $\lambda = 0$, we have the dynamics of a CDM universe, and in the dark blue region, corresponding to $\lambda < 0$, we have a universe with a big crunch.

3. Datasets

In [2] the authors show that this model of $f(Q)$ is statistically equivalent to Λ CDM at low red shifts. Here, we constrain this model using both low and high redshift observables, namely SnlA, CMB and SS events.

Due to the lack of measurements of SS events, we generate mock catalogs assuming Λ CDM to assess the constraining power of the Laser Interferometer Gravitational-Wave Observatory (LIGO), the Laser Interferometer Space Antenna (LISA) and the Einstein Telescope (ET).

Standard Sirens


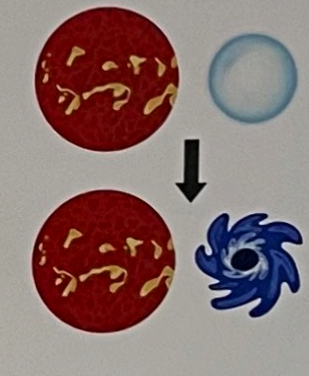


Image credits: IceCube Collaboration (Modified)

Type Ia Supernova



Cosmic Microwave Background

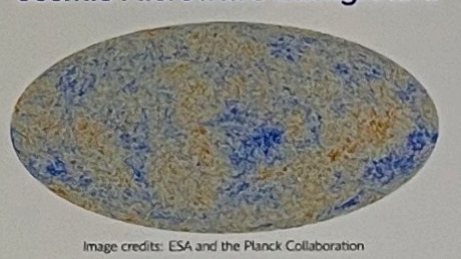
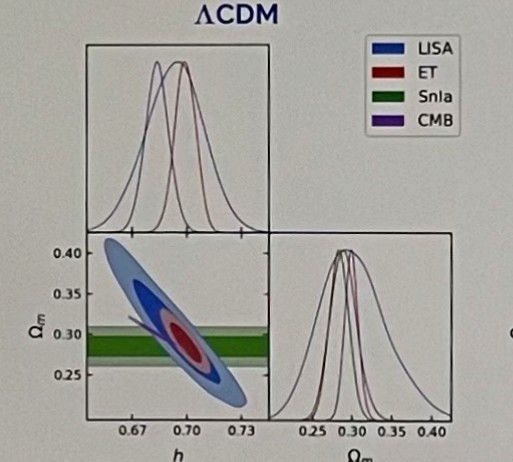


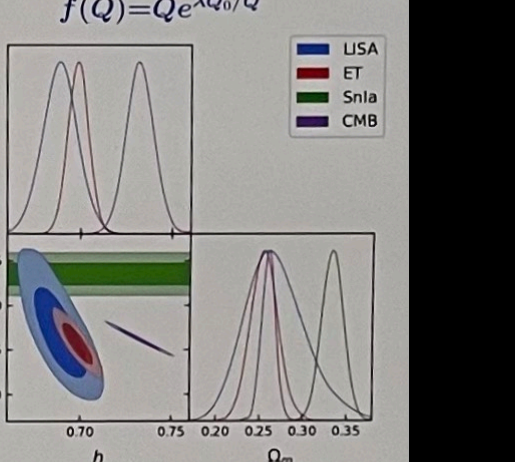
Image credits: ESA and the Planck Collaboration

4. Constraints

Λ CDM



$f(Q) = Qe^{\lambda Q/Q_0}$



In the previous figures, we can see the constraints set by each of the datasets used in this work for Λ CDM, on the left, and our model of $f(Q)$, in the right. We define the dimensionless Hubble constant as $h = H_0/100 \text{ s Mpc km}^{-1}$.

We see a tension in Ω_m between SnlA and the CMB. This happens because even though this model falls back to GR at high redshifts, the values of the abundances are modified when compared to Λ CDM, indirectly modifying the behavior of the universe at early times.

Using SS events forecast for LISA and the ET, a tension in the value of h arises, making future gravitational wave observatories prime candidates for testing this and similar models.

As for LIGO, it is not expected to be able to measure SS events that are able of providing meaningful constraints.

5. Conclusions

We conclude that **although this model of $f(Q)$ gravity is able to account for the accelerated expansion of the universe at late times, without requiring dark energy, it shows a tension between high and low redshift measurements.**

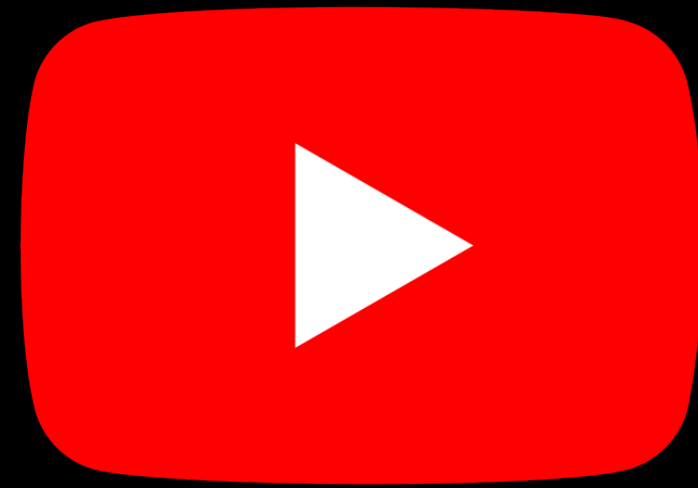
We expect that future gravitational wave observatories will be able to provide us with data that can be used to rule this model out, without relying on high redshift measurements.

References

- [1] José Beltrán Jiménez, Lavinia Heisenberg, Tomi Sebastian Koivisto, and Simon Peikar. "Cosmology in $f(Q)$ geometry". In: *Phys. Rev. D* 101, 103507 (2020) (June 2019).
- [2] Fotios K. Anagnostopoulos, Spyros Basilakos, and Emmanouil N. Saridakis. "First evidence that non-metricity $f(Q)$ gravity could challenge Λ CDM". In: 822 (*Astr.* 2021), p. 136634. ISSN: 0370-2693.
- [3] Enis Belgacem, Yves Dirian, Stefano Foffa, and Michele Maggiore. "The gravitational-wave luminosity distance in modified gravity theories". In: *Phys. Rev. D* 97, 104066 (2018) (Dec. 2017).

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 jpmferreira@ciencias.ulisboa.pt Testing Λ -Free $f(Q)$ Cosmology José Ferreira

RECORDED VIDEOS



CENTRA

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indico.cern.ch/event/1194229

Laura Sagunski
Goethe University Frankfurt

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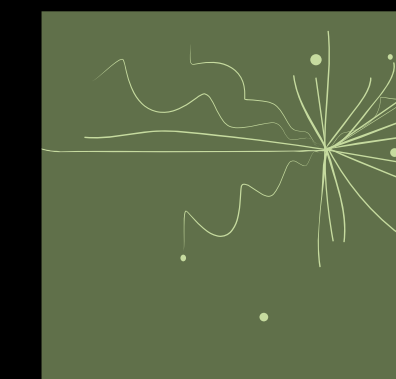
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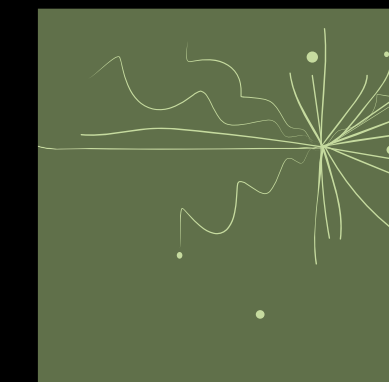
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2025

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Hint: not in Europe, next to a lake

**SEE YOU SOON
HAVE A SAFE TRAVEL**

