Self-gravitating Systems of Dark Matter Particles

Contents

1 Topics

The problem of the distribution of stars in globular clusters, and more general in galactic systems, has implied one of the results of most profound interest in classical astronomy. The pioneering works of Michie (1963) and King (1966) considered the effects of collisional relaxation and tidal cutoff by studying solutions of the Fokker-Planck equation. There, it was shown that stationary solutions are well described by pseudo-isothermal sphere models, based on simple Maxwell energy distribution functions with a constant subtracting term interpreted as an energy cutoff. An extension of this statistical analysis with thermodynamic considerations, which includes the effects of violent (collisionless) relaxation, was studied by Lynden-Bell (1967) with important implications to the problem of virialization of dark matter (DM) halos which are still of current interest.

Later on, in a series of works by R. Ruffini and collaborators (see, e.g., Ruffini and Stella, 1983 in Newtonian gravity and Gao et al., 1990 in GR), the emphasis changed from self-gravitating systems of classic stars (which verify Maxwellian distributions) to systems of fermionic particles, with the aim of describing galactic DM halos. In this line, an important contribution was given by Chavanis (2004), who studied generalized kinetic theories accounting for collisionless relaxation processes, obtaining a class of generalized Fokker-Planck equation for fermions with applications to DM halo formation. It was there explicitly shown the possibility to obtain, out of general thermodynamic principles, a generalized Fermi-Dirac distribution function including an energy cutoff, extending the former results by Michie and King to quantum particles.

Within this field of research, our group aims to contribute to the understanding of the DM nature. In particular, we mainly focus on a possible fermionic nature of the DM particles, and its consequences in astrophysics and cosmology.

Specific topics treated in 2023 together with the number of papers published on each topic are:

- Fermionic dark matter and galactic structures: phenomenology and theory (3 papers).
- Galaxy center: the nature of SgrA* (1 paper).
- Supermassive black holes: nature and formation channels (2 papers).

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3 Highlighted Publications 2023

3.1 Fermionic dark matter and galactic structures: phenomenology and theory

3.1.1 Galaxy rotation curves and scaling relations

How the total mass budget on galaxy scales distributes with respect to the luminous mass content is still a challenging open question in the field. The new and more precise data gathered in the last decade covering broader radial galaxy extents across different Hubble types (Lelli et al., 2016), makes it possible to test different DM halo models. Any halo model either obtained from N-body simulations or built from first principle physics, need to explain several universal relations existing between different pairs of galaxy parameters:

- On outer halo scales: the baryonic Tully-Fisher relation (BTFR) (McGaugh et al., 2000), the DM Surface Density Relation (SDR) (Donato et al., 2009), the Radial Acceleration Relation (McGaugh et al., 2016), and the Mass Discrepancy Acceleration Relation (MDAR) (McGaugh, 2004), which are indeed all closely related (McGaugh, 2004; Salucci, 2018);
- On central halo scales: the M-σ relation between the bulge's dispersion velocity and the central object mass (Ferrarese and Merritt, 2000);
- On outer and central halo regimes: the Ferrarese relation (Ferrarese, 2002) between the total halo mass and its supermassive central object ma

With the aim to further test our *first principle physics* model for DM halos and compare with results obtained from traditional N-body simulations, this year we have extended in Krut et al. (2023) previous results on the subject (see

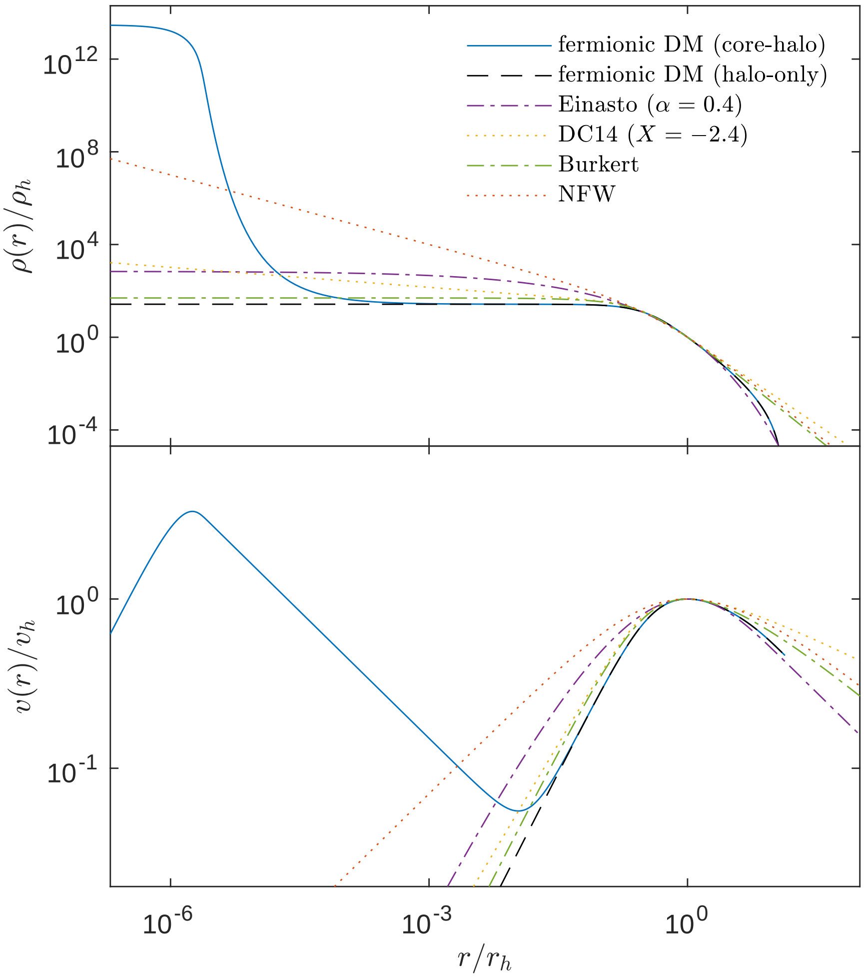

Figure 3.1: Illustrations of DM models: density profile (top) and rotation curve (bottom). Shown are typical core-halo RAR solutions for free model parameters as obtained in Krut et al. (2023) for disk galaxies. For comparison, other DM models (NEW, DC14, Burkert, Einasto) are added. All profiles are normalized with respect to the halo radius r_h, defined at the halo velocity maximum, with $\rho_h = r(r_h)$ and $v_h = v(r_h)$.

e.g. Argüelles et al. (2019)). We have analyzed the above relations assuming that dark matter (DM) halos are formed through a Maximum Entropy Principle (MEP) in which the fermionic (quantum) nature of the DM particles is dully accounted for. In particular, we compared the fermionic DM halo model given by the Ruffini–Argüelles–Rueda (RAR) theory, with other phenomenologicla profiles from literature: the NFW model, a generalized NFW model accounting for baryonic feedback, the Einasto model and the Burkert model (see Fig. 3.1). For this task, we use a large sample of 120 galaxies taken from the Spitzer Photometry and Accurate Rotation Curves (SPARC) data-set, from which we infer the DM content to compare with the models. We find that the Radial Acceleration Relation and MDAR are well explained by all the models with comparable accuracy (see Fig. 3.2), while the fits to the individual rotation curves, in contrast, show that cored DM halos are statistically preferred with respect to the cuspy NFW profile (see Fig. 3.3), in agreement with independent analysis from literature.

3.1.2 Numerical methods for galaxy rotation curve fitting: machine learning tools

The widely used technique of galaxy rotation curve (RC) fitting, typically assumes underlying DM density profiles obtained from classical N-body simulations with given analytic expressions. However, other kinds of realistic DM profiles with no analytic formulae can be obtained from first-principle physics (i.e., thermodynamics and statistical mechanics) while accounting for the quantum nature of the particles, such as the RAR model for fermions, or bosonic DM profiles (see e.g. Robles et al. (2019)).

When applied to real galaxies, in the recent past the RAR model were solved for given halo-mass boundary conditions taken from observations (see Argüelles et al. (2018) for the case of the Milky Way). Since the RAR model has four free-parameters, once the particle was fixed within the range[1] $(48, 345)$ keV, there exists one *core-halo* solution for such a particle mass (i.e., three boundary conditions for three remaining free-parameters) fulfilling with the constraints. Clearly, a more refined phenomenological analysis of the rel-

[1]compactness of the fermion-core is inversely proportional to m Argüelles et al. (2018), and thus it is shown that for $m < 48$ keV the core is too extended to fit within the S-2 star pericenter, while for $m > 345$ keV the solutions are unstable since the critical value for collapse to a BH is reached at $m = 345$ keV.

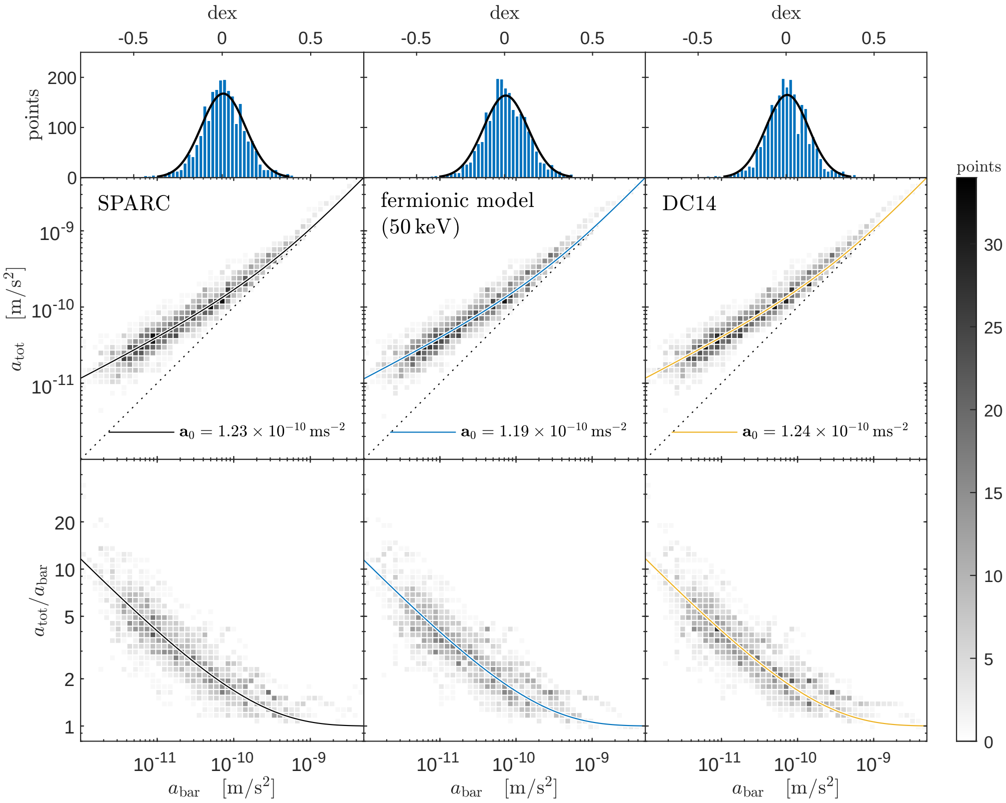

Figure 3.2: Radial acceleration relation (top) and mass discrepancy acceleration relation (bottom) for SPARC data and competing DM halo models. Each plot is divided in 50x50 equal bins. The baryonic centripetal acceleration is inferred from luminosity observables while the total acceleration is inferred independently from velocity fields. For DM halo models the total acceleration is composed of the predicted dark and inferred baryonic components, i.e. $a_{tot} = a_{bar} + a_{DM}$. The corresponding solid curves are the best fits characterized by a specific $\mathfrak{a}_0$. The histogram plots (upper row) show a Gaussian distribution of $\log_{10}(a_{tot}/\mathfrak{a}_0)$. The grayscale legend shows the number of points per bin (of a total 2396 for the 120 SPARC-galaxies used).

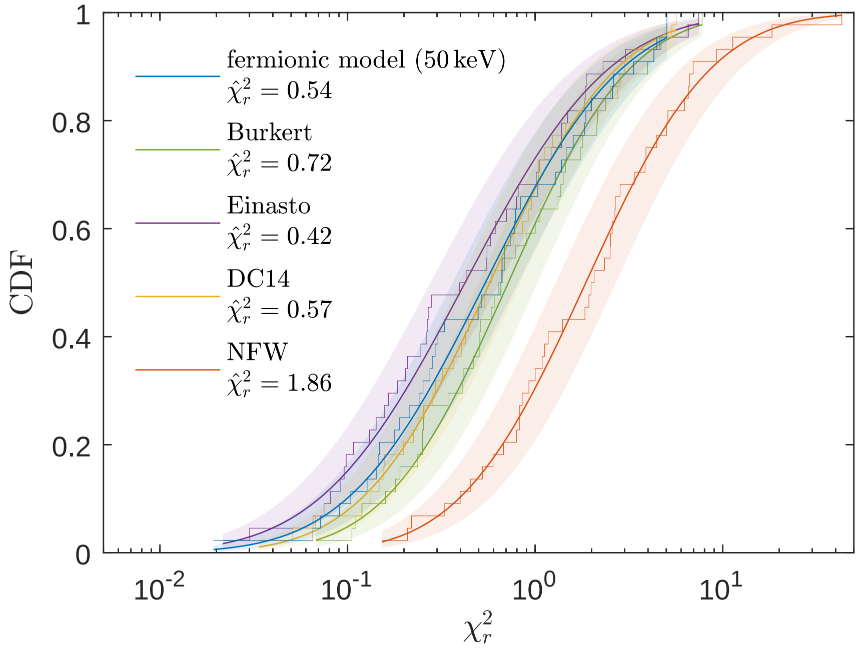

Figure 3.3: Goodness of model analysis for galaxies showing one clear maximum in the outer halo RC, where DM typically dominates. This condition is fulfilled by 44 galaxies. We count the population of fitted galaxies having a reduced χ^2 smaller than a given one. The normalized population (step-like) follows nearly a log-normal distribution (solid) characterized by the mean value $\hat{\chi}_r^2$. The shaded regions span the 95% confidence interval of the best-fitted $\hat{\chi}_r^2$.

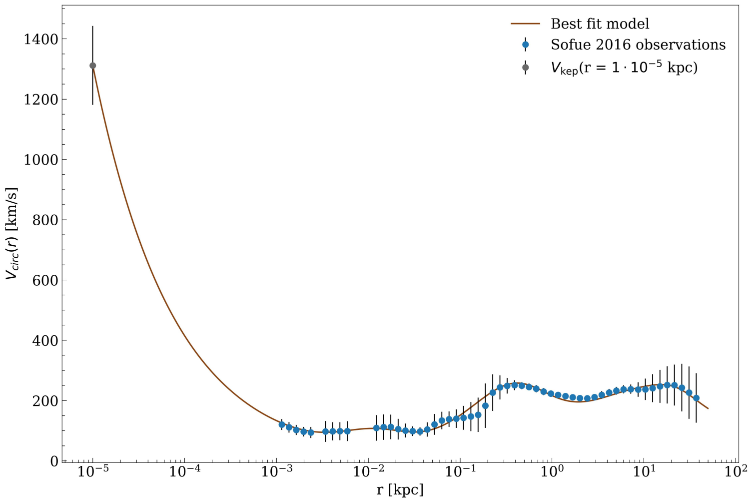

Figure 3.4: Best-fit circular velocity curve result of the implementation of the gradient descent method. It is remarkable the very good precision achieved in almost all the data-points in few hours CPU time, despite some minor deficiencies at the $\sim 10^{-1}$ kpc scale.

ativistic RAR model would require a best-fit procedure using the full data points of the corresponding RC including their errors (e.g., using MCMC or grid-coverage methods). Such kind of analysis has recently been performed in Krut et al. (2023) within an MCMC method for a large sample of 120 galaxies of the SPARC catalog, with explicit χ^2 minimization and corresponding parameter posteriors for a fixed particle mass fixed at $m = 50$ keV. However, in such an approach, besides fixing m, the baryonic mass models were fixed according to the SPARC-catalog (for each galaxy). Thus, it is of interest to develop a numerical technique which, for non-analytic DM models such as RAR, makes it possible to provide best-fits to the full RC-data when including for a larger free parameter-space: i.e., full DM + baryonic model parameters in a few hours of CPU-time.

This year, and for the first time up to our knowledge within the RC problem, a new RC best-fitting method based on state-of-the-art machine learning tools was introduced in Argüelles et al. (2023a). It uses a gradient descent method based on a progressive sequence of steps to minimize a function under the PyTorch package Paszke et al. (2019), which is an open-source machine learning framework. Since it resides on computing a gradient, it is less sensitive to the dimension of the parameter space than the MCMC. The latter method have 'to walk' around all over the subspace of parameters, increasing their computing time drastically for high-dimensional spaces (e.g. such the 6 free parameters used here). Thus, this has allowed us to include for baryonic free parameters together with the full four free-RAR model parameters. As an iconic example we have focused our attention in the so-called Grand RC of the Milky Way as studied in Sofue (2017), further including for with innermost data coming from the S-cluster stars orbiting SgrA*, thus covering in total about seven orders of magnitude in galactocentric-radius (e.g., within $\sim 10^{-2}$–10^{5} pc). In Fig. 3.4 we show the exquisite best fit RC of the Grand RC of the Milky Way.

3.1.3 Role of fermionic DM in physics, astrophysics and cosmology

In Argüelles et al. (2023a) we have published a Review paper covering several aspects of fermionic DM, with special attention to the general relativistic RAR model for DM halos. The work focuses on the interconnection between the microphysics of the neutral fermions and the macrophysical structure of galactic halos, including their formation both in the linear and non-linear cosmological regimes. We discuss the model applications to the Milky Way, the possibility that the Galactic center harbors a DM core instead of a supermassive black hole (SMBH) (see also next topic), the S-cluster stellar orbits with an in-depth analysis of the S2's orbit including precession, as well as the application of the RAR model to other galaxy types. We also connect the RAR model fermions with particle physics DM candidates, constraints on the fermion mass, self-interactions, and galactic observable constraints. We further discussed the formation and stability of such femrionic structures predicted by the RAR model and their relations to warm DM cosmologies. This review also set the basis for future research on the field, highlighting the following cases (all of them already started by out team):

- to study the problem of disk-accretion around such DM-cores starting with the generalization of the Zakura & Suntaev disk equations in the presence of a high concentration of regular matter (i.e. instead of a singularity);
- to use fully relativistic ray-tracing techniques to predict the correspond-

ing shadow-like images around these fermion cores, and compare with the shape and sizes of the ones obtained bt the EHT (first results on this work were recently presented by Carlos R. Argüelles in the prestigious workshop 'Fundamental physics at the Galactic Centre' workshop in december 2023, Portugal);

- The search for a signature of a fermionic DM candidate in the 100 keV domain within direct DM detection techniques (e.g. DM - electron recoil), using right handed neutrinos beyond SM particle physics.

3.2 Galaxy center: the nature of SgrA*

The extensive and continuous monitoring of the closest stars to the Galactic center has been producing over decades a large amount of high-quality data of their positions and velocities. The explanation of these data, especially the S2 star motion, reveals the presence of a compact source, Sagittarius A* (Sgr A*), whose mass must be about $4 \times 10^6\ M_\odot$. This result has been protagonist of the awarded Nobel Prize in Physics 2020 to Reinhard Genzel and Andrea Ghez "*for the discovery of a supermassive compact object at the centre of our galaxy*". Traditionally, the nature of Sgr A* has been attributed to a supermassive black hole (SMBH), even though a robust proof of its existence is absent.

We have advanced within the RAR model in Argüelles et al. (2018) and in Becerra-Vergara et al. (2020, 2021); Argüelles et al. (2021a, 2022) an alternative scenario that identifies the nature of the supermassive compact object in the Milky Way center, with a highly concentrated core of DM made of fermions. This has allowed to explain the measured relativistic effects on the S-2 star caused by the central object, that is, the relativistic redshift (Becerra-Vergara et al., 2020) and the periapsis precession (Argüelles et al., 2022), with similar accuracy than the Schwarzschild BH scenario. However such a statistical comparison between the two models was made only through the (averaged) ^{2} (both on the position in the sky and radial velocity), and no access to, for example, the errors in the orbital parameters of the S-2 star were provided. For the first time this year, we have applied in Crespi et al. (2023) a more robust (though more time consuming) statistical method to best-fit the S-star orbits: A Monte Carlo Markov Chain (MCMC) algorithm as provided in *emcee* by Foreman-Mackey et al. (2013), which allow to obtain the posteriors on the

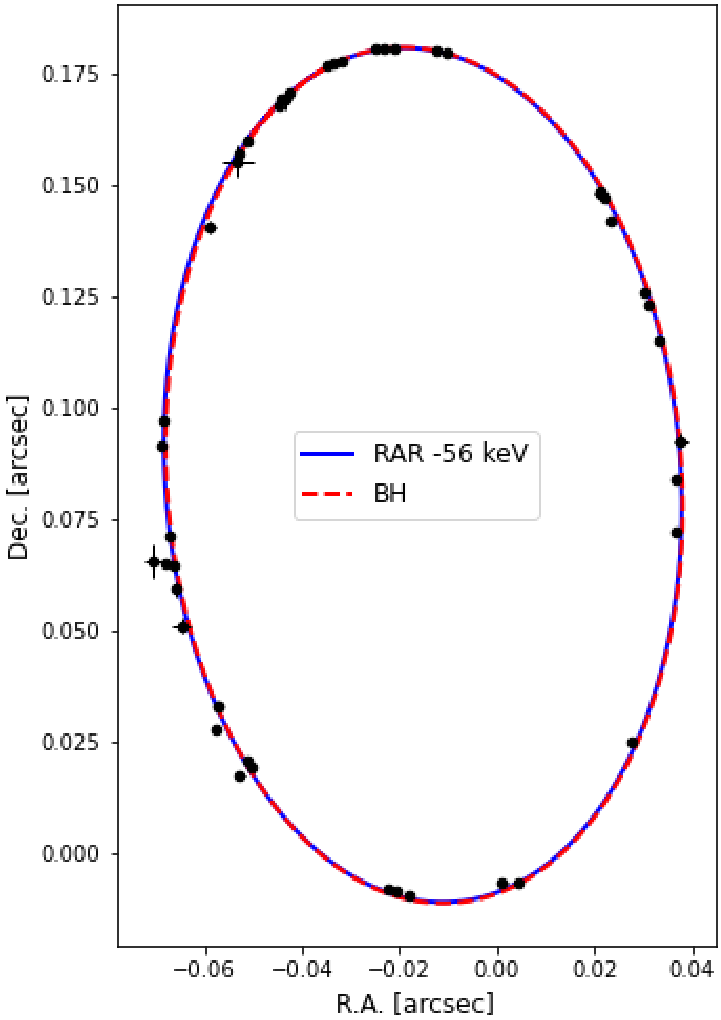

Figure 3.5: S2 star orbit in the plane of the sky. The RAR dark matter model corresponds to $m = 56$ keV (solid blue) and the Schwarzschild BH model of $M_{BH} = 4.075 \times 10^6 M_{\odot}$ (dashed red). The astrometric data were taken from Do et al. (2019).

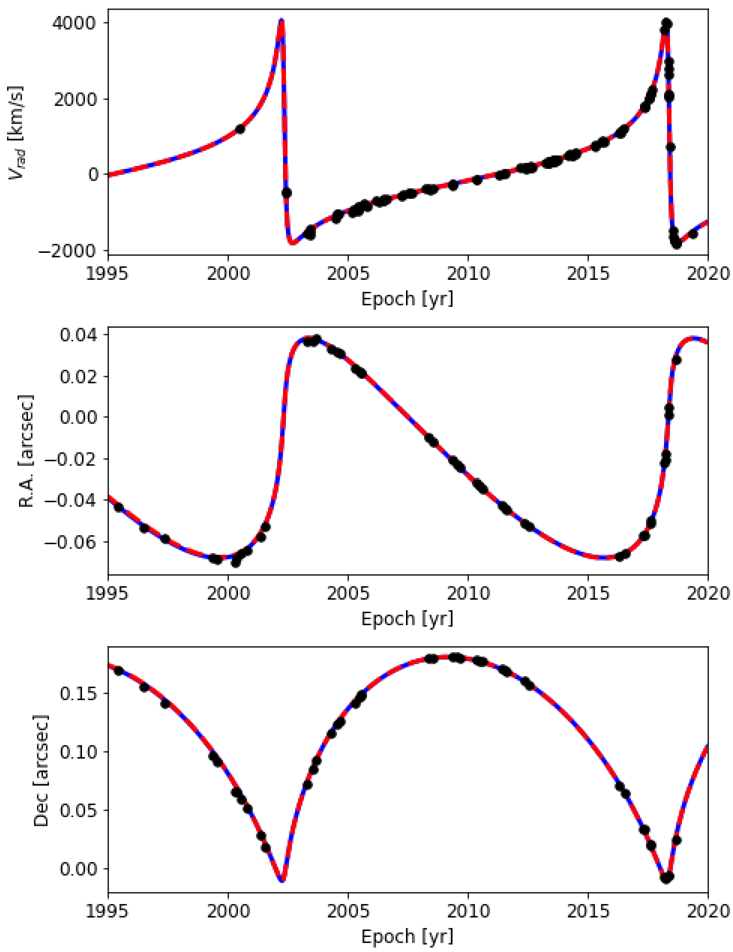

Figure 3.6: Radial velocity, Right Ascension and Declination respectively as a function of time for RAR dark matter model of $m = 56$ keV (solid blue) and Schwarzschild BH model of $M_{BH} = 4.075 \times 10^6 M_\odot$ (dashed red).

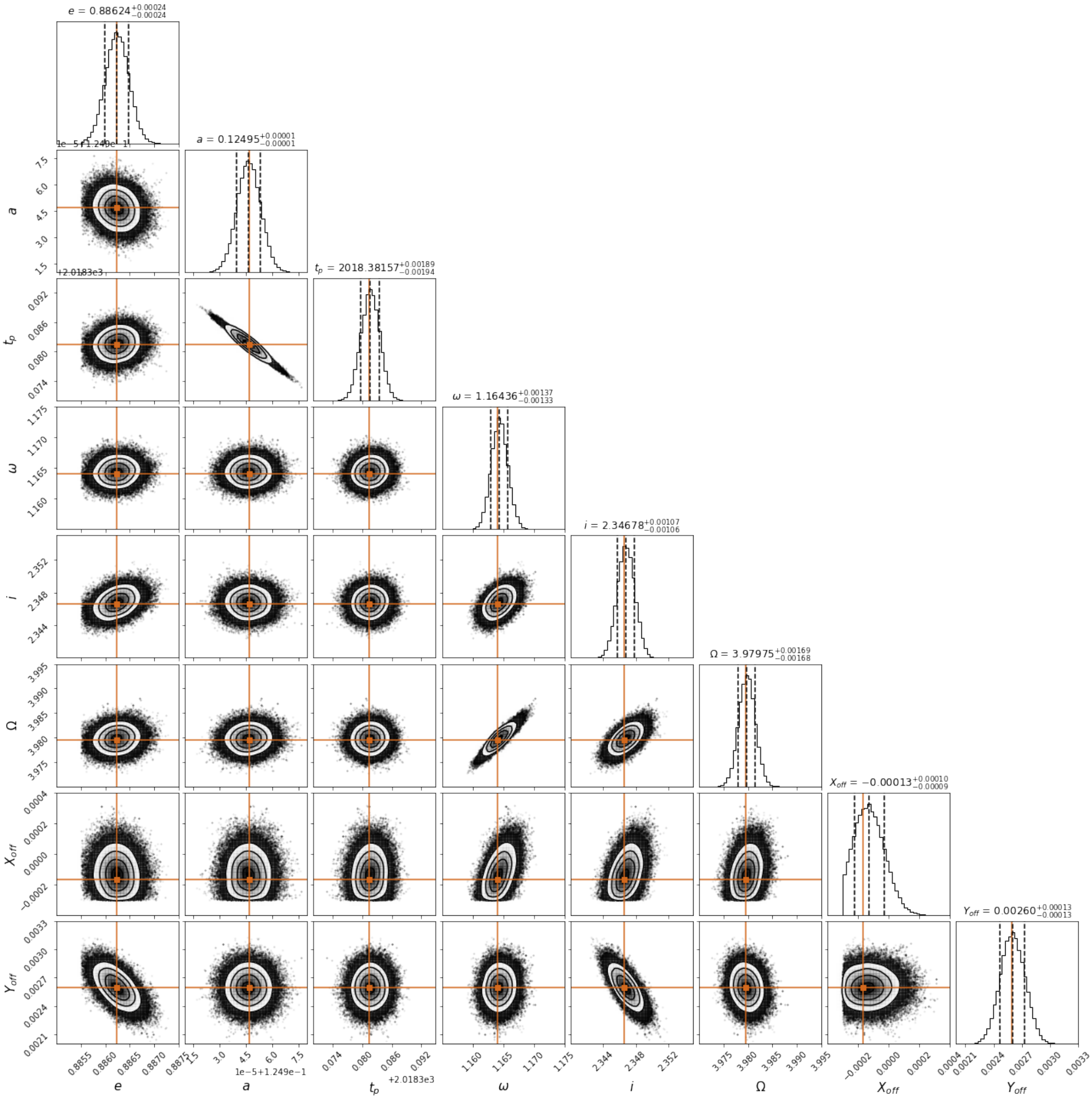

Figure 3.7: Corner plots corresponding to the 8-dimensional posterior probability space for the S2 star orbital parameters consistent with the RAR model for fermion mass of $m = 56$ keV. Solid lines correspond to the most probable set of parameters listed in Table 1 of Crespi et al. (2023), and dashed lines correspond to the mean and 1σ significance level.

orbital parameters of the star (see Fig. 5,6, together with Fig. 7 for both the position and velocity best-fits for S-2 star, and the posteriors on the parameters respectively.). This procedure open the path to test more stars with even closer pericentre than the S-2 star, which will certainly provide even tighter constraints to the compacity (and thus in the particle mass) of the fermion core.

3.3 Supermassive black holes: nature and formation channels

As it was demonstrated in Argüelles et al. (2021b) from a stability analysis in full General Relativity of fermionic RAR solutions, it exist a last stable *core–halo* configuration leading to the core-collapse into a supermassive BH typical of active galaxies. This year we have presented new calculations on this topic applied to the problem of early growth of SMBHs in the early Universe, with direct relevance in light of the recent JWST data. On general grounds, our new results lead to a novel channel for SMBH formation that is not relying in massive stars (i.e. Pop. III stars) nor in primordial cosmology, but on DM.

In a first work Argüelles et al. (2023b), we studied the subsequent growth of such recently formed BH seeds from an accretion disk, while allowing us to provide original insights in the following questions: (i) how can the massive BHs grow so large and so fast to be present in the farthest distant quasars; and (ii) what is the nature and mass of BH seeds that grow to form the SMBHs of $\sim 10^8$–$10^9 M_\odot$ in the high-z Universe, and what is the nature of the connection between the total mass of a host galaxy and the mass of its central SMBH. This was done for fermion particle masses of about 100 keV, where such SMBH seeds grow to $\sim 10^9$-$\sim 10^{10} M_\odot$ in the first Gyr of the lifetime of the Universe without invoking unrealistic (or fine-tuned) accretion rates. See for example Fig. 3.8 showing such a fast growth for different initial SMBH seeds for Eddington-limited accretion factor (i.e. $\beta = 1$).

In a second work recently published in Arguelles et al. (2023), we have answered three relevant questions of paramount relevance left open in Argüelles et al. (2023b): 1) how does the dark matter core of fermions reach the point of gravitational collapse?; 2) how long does it take to the core to reach that point? and 3) are those conditions attainable in astrophysical and cosmological setups?

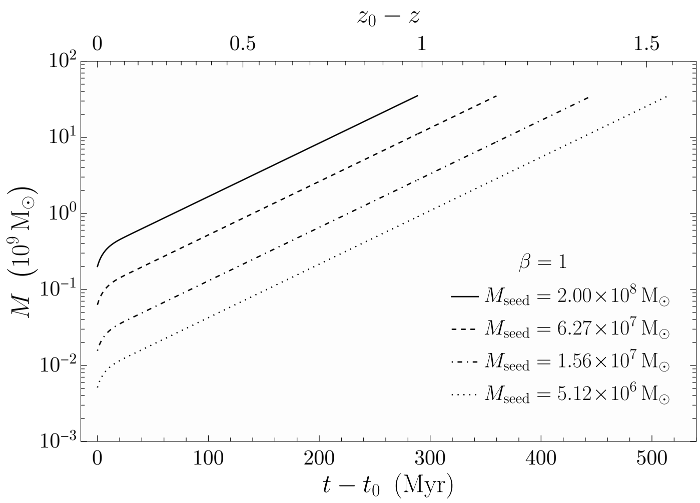

Figure 3.8: BH mass evolution in time for different BH seeds and $\beta = 1$. Initial conditions are $\alpha_i = 0$ and darkino masses 56 keV, 100 keV, 200 keV, and 350 keV. The spin parameter does not depend on the BH mass. The initial redshift is $z_0 = 5.5$ with $t_0 = 1022$ Myr for a halo mass $M_{vir} = 5 \times 10^{11} M_\odot$.

The answer to these questions arises from the fact that galaxy halos are not only made of dark matter but have a non-negligible amount of baryonic, i.e., ordinary matter. The infall of baryonic matter into the potential well of the dark matter core modifies its equilibrium state. Thus in this second paper, we calculated those new equilibrium configurations with the presence of baryonic matter and establish the existence of a critical mass for the gravitational collapse that depends upon the amount of baryonic matter settled in the core. We then have shown that SMBHs of $10^7 M_\odot$ can be formed from the baryon-induced collapse of dark matter cores in timescales shorter than a Gyr, for baryonic inner densities and velocities as obtained in cosmological simulations and observations.

Interestingly, SMBH formation from this new mechanism can occur in galaxy mergers supporting the association of relativistic jets and SMBHs (as in the Seyfert galaxy TXS 2116–077 there studied), while can also explain the formation of the $\sim 10^7$-$10^8 M_\odot$ farthest quasar, observed by the *Chandra* satellite at the center of the *JWST*-detected galaxy UHZ1 at $z = 10.3$. The same conclusions apply to the *little red dots*, the SMBHs at $z \approx 4$–6 also observed by *JWST*. Fig. 3.9 shows the time evolution of the DM core mass while accreting baryonic matter for two different initially stable cores as detailed in Arguelles et al. (2023).

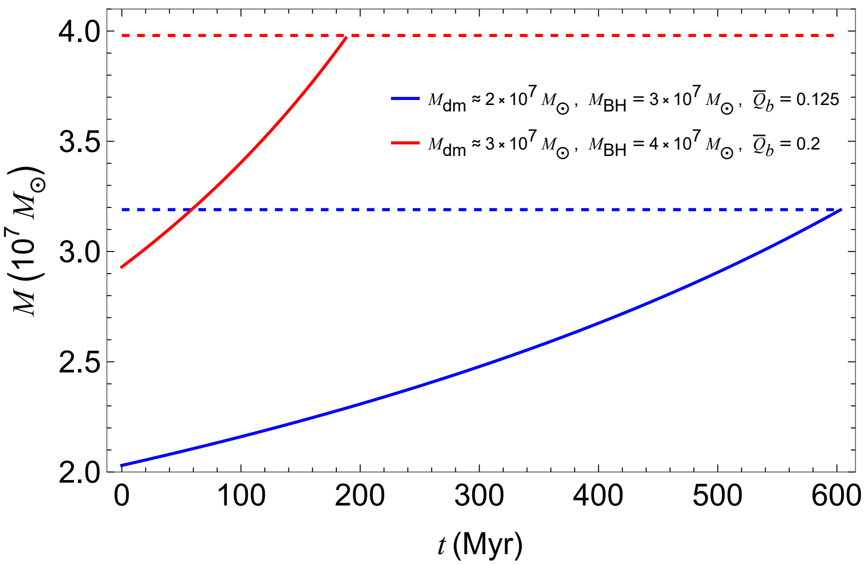

Figure 3.9: Time evolution of the dark matter core mass while accreting baryonic matter for two examples. The blue curve is the evolution of the dark matter core of the left panel figure. The dashed lines indicate the SMBH mass formed. The baryonic contribution is given in Q_b defined as the the baryon density divided by the cube of the baryonic dispersion velocity as in Arguelles et al. (2023).

4 Publications 2023

1. Krut, A.; Argüelles, Chavanis P.-H.; Rueda, J. A.; Ruffini, R., "Galaxy rotation curves and universal scaling relations: comparison between phenomenological and fermionic dark matter profiles", The Astrophysical Journal (2023), Volume 945, Issue 1, id.1, 16 pp.

   Galaxies show different halo scaling relations such as the Radial Acceleration Relation, the Mass Discrepancy Acceleration Relation (MDAR) or the dark matter Surface Density Relation (SDR). At difference with traditional studies using phenomenological ΛCDM halos, we analyze the above relations assuming that dark matter (DM) halos are formed through a Maximum Entropy Principle (MEP) in which the fermionic (quantum) nature of the DM particles is dully accounted for. For the first time a competitive DM model based on first physical principles, such as (quantum) statistical-mechanics and thermodynamics, is tested against a large data-set of galactic observables. In particular, we compare the fermionic DM model with empirical DM profiles: the NFW model, a generalized NFW model accounting for baryonic feedback, the Einasto model and the Burkert model. For this task, we use a large sample of 120 galaxies taken from the Spitzer Photometry and Accurate Rotation Curves (SPARC) data-set, from which we infer the DM content to compare with the models. We find that the Radial Acceleration Relation and MDAR are well explained by all the models with comparable accuracy, while the fits to the individual rotation curves, in contrast, show that cored DM halos are statistically preferred with respect to the cuspy NFW profile. However, very different physical principles justify the flat inner halo slope in the most favored DM profiles: while generalized NFW or Einasto models rely on complex baryonic feedback processes, the MEP scenario involves a quasi-thermodynamic equilibrium of the DM particles.

2. Argüelles, C. R., Collazo S."Galaxy Rotation Curve Fitting Using Machine Learning Tools", Universe (2023), Volume 9, Issue 8, id.372.

   Galaxy rotation curve (RC) fitting is an important technique which allows the placement of constraints on different kinds of dark matter (DM) halo models. In the case of non-phenomenological DM profiles with no analytic expressions, the art of finding RC best-fits including the full baryonic + DM free parameters can be difficult and time-consuming. In the present work, we use a gradient descent method used in the backpropagation process of training a neural network, to fit the so-called Grand Rotation Curve of the Milky Way (MW) ranging from $\sim$1 pc all the way to $\sim 10^5$ pc. We model the mass distribution of our Galaxy including a bulge (inner + main), a disk, and a fermionic dark matter (DM) halo known as the Ruffini-Argüelles-Rueda (RAR) model. This is a semi-analytical model built from first-principle physics such as (quantum) statistical mechanics and thermodynamics, whose more general density profile has a *dense core – diluted halo* morphology with no analytic expression. As shown recently and further verified here, the dark and compact fermion-core can work as an alternative to the central black hole in SgrA* when including data at milliparsec scales from the S-cluster stars. Thus, we show the ability of this state-of-the-art machine learning tool in providing the best-fit parameters to the overall MW RC in the 10^{-2}–10^5 pc range, in a few hours of CPU time.

3. Argüelles, C. R.; Becerra-Vergara E. A.; Rueda, J. A.; Ruffini, R., "Fermionic dark matter: physics, astrophysics, and cosmology", Universe (2023), Volume 9, Issue 4, id.197.

   The nature of dark matter (DM) is one of the most relevant questions in modern astrophysics. We present a brief overview of recent results that inquire into a possible fermionic quantum nature of the DM particles, focusing mainly on the interconnection between the microphysics of the neutral fermions and the macrophysical structure of galactic halos, including their formation both in the linear and non-linear cosmological regimes. We discuss the general relativistic Ruffini-Argüelles-Rueda (RAR) model of fermionic DM in galaxies, its applications to the Milky Way, the possibility that the Galactic center harbors a DM core instead of a supermassive black hole (SMBH), the S-cluster stellar orbits with an in-depth analysis of the S2's orbit including precession, the application of the RAR model to other galaxy types (dwarf, elliptic, big elliptic and galaxy clusters), and universal galaxy relations. All the above focusing on the model parameters constraints, most relevant to the fermion mass. We also connect the RAR model fermions with particle physics DM candidates, self-interactions, and galactic observables constraints. The formation and stability of core-halo galactic structures predicted by the RAR model and their relation to warm DM cosmologies are also treated. Finally, we provide a brief discussion on how gravitational lensing, dynamical friction, and the formation of SMBHs can also probe the DM nature.

4. Crespi, V.; Argüelles, C. R.; Mestre, M. F., "Testing the nature of Sgr A* with the S-2 star orbit data", Boletín de la Asociación Argentina de Astronomía. Edited by R.D. Rohrmann, C.H. Mandrini, C.E. Boeris and M.A. Sgró. (2023) Vol. 64, p. 274-276.

   The stars of the S-cluster orbiting the Galactic center provide one of the best astrophysical observables to infer the gravitational potential generated by the central source Sgr A*, traditionally assumed to be a Black Hole (BH). An alternative model for Sgr A* is the Ruffini-Argüelles-Rueda (RAR) model, based on a self-gravitating system of neutral fermions in the framework of General Relativity. It predicts the existence of a dense core of highly degenerate fermions able to mimic the BH, which is surrounded by a more dilute atmosphere that is consistent with the dark matter (DM) halo of the Galaxy. In this work we study the dynamics of the most important star in the S-cluster, assuming that it moves around the compact DM core predicted by the RAR model. For the first time we fit the orbital parameters of the S-2 star with a Markov Chain Monte Carlo (MCMC) technique, and compare the results with the ones obtained in the BH paradigm.

5. Argüelles, C. R.; Boshkayev, K.; Krut, A.; Nurbakhyt, G.; Rueda, J. A.; Ruffini, R.; Uribe-Suárez, J. D.; Yunis, R., "On the growth of supermassive black holes formed from the gravitational collapse of fermionic dark matter cores", Monthly Notices of the Royal Astronomical Society (2023), Volume 523, Issue 2, pp.2209-2218.

   Observations support the idea that supermassive black holes (SMBHs) power the emission at the center of active galaxies. However, contrary to stellar-mass BHs, there is a poor understanding of their origin and physical formation channel. In this article, we propose a new process of SMBH formation in the early Universe that is not associated with baryonic matter (massive stars) or primordial cosmology. In this novel approach, SMBH seeds originate from the gravitational collapse of fermionic dense dark matter (DM) cores that arise at the center of DM halos as they form. We show that such a DM formation channel can occur before star formation, leading to heavier BH seeds than standard baryonic channels. The SMBH seeds subsequently grow by accretion. We compute the evolution of the mass and angular momentum of the BH using a geodesic general relativistic disk accretion model. We show that these SMBH seeds grow to $\sim 10^9$-$10^{10} M_\odot$ in the first Gyr of the lifetime of the Universe without invoking unrealistic (or fine-tuned) accretion rates.

6. Argüelles, C. R.; Rueda, J. A.; Ruffini, R., "Baryon-induced collapse of dark matter cores into supermassive black holes", Accepted for publication in The Astrophysical Journal Letters (2023), eprint arXiv:2312.07461.

   Non-linear structure formation for fermionic dark matter particles leads to dark matter density profiles with a degenerate compact core surrounded by a diluted halo. For fermion masses ~ 100 keV$/c^2$, the dark matter core has a critical mass of $\sim 10^7 M_\odot$ to collapse to a supermassive black hole (SMBH). We study the stability of the core while it accumulates baryonic (ordinary) matter, and demonstrate it collapses at a threshold of the baryonic mass amount. The SMBH mass from the baryon-induced collapse is lower than the critical mass of a pure-dark-matter core but still of the same order. The accretion at sub-Eddington rates of surrounding gas with typical inner densities and velocities, inferred from cosmological hydro-simulations and observations, triggers the SMBH formation in timescales shorter than a Gyr. Further, it suggests that the baryon-induced collapse of dark matter cores could explain the birth of active galactic nuclei observed in galaxy mergers. We show this scenario agrees with the observed merging process of TXS 2116–077 with another nearby galaxy: the baryon-induced collapse can form the observed $3 \times 10^7 M_\odot$ SMBH in 0.6 Gyr, consistent with the estimated 0.5–2 Gyr merging timescale and the younger relativistic jet. A new research avenue, verifiable with the James Webb Space Telescope and Euclid data, is now open to constrain the possible dark matter fermion nature and the inception of SMBH formation.

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