Gravitational-wave emission vs. dark matter dynamical friction in compact-star binaries

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(Based on ArXiv: 1706.06801)

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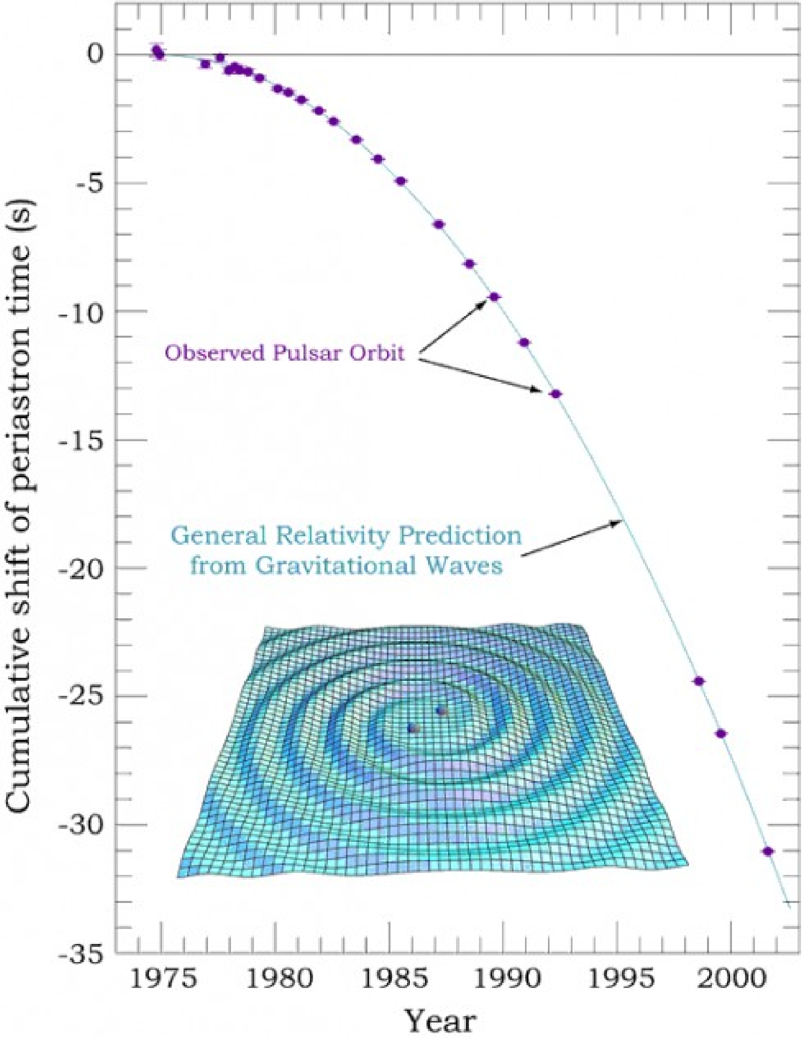
The discovery of GWs



Hulse-Taylor Binary:

Mass of companion: 1.387 Msun

Total mass of the system: 2.828378(7) Msun

P(pulsar) = 59 ms

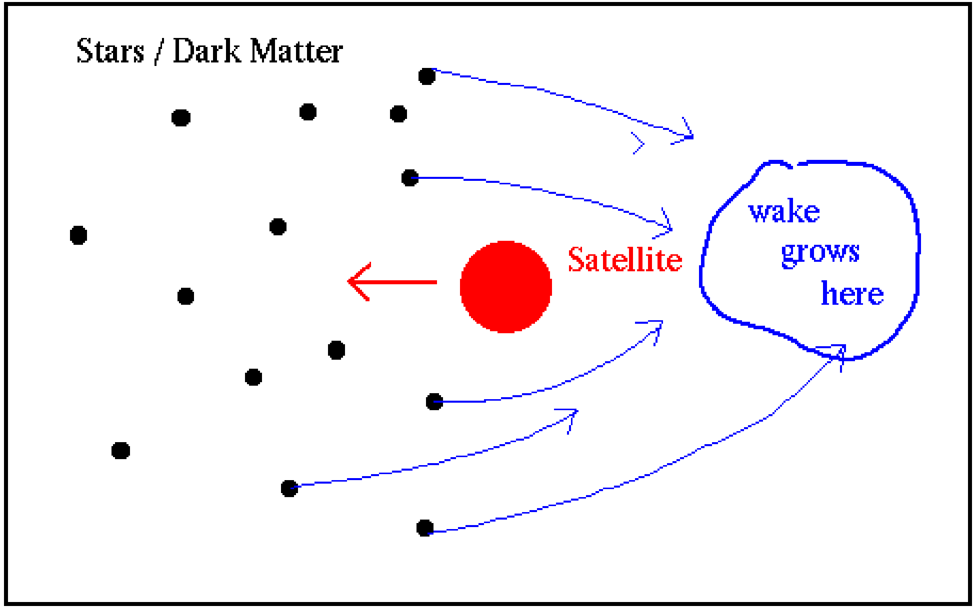
Orbital period: 7.751938773864 h

Semi-major axis: 1.95E11 cm

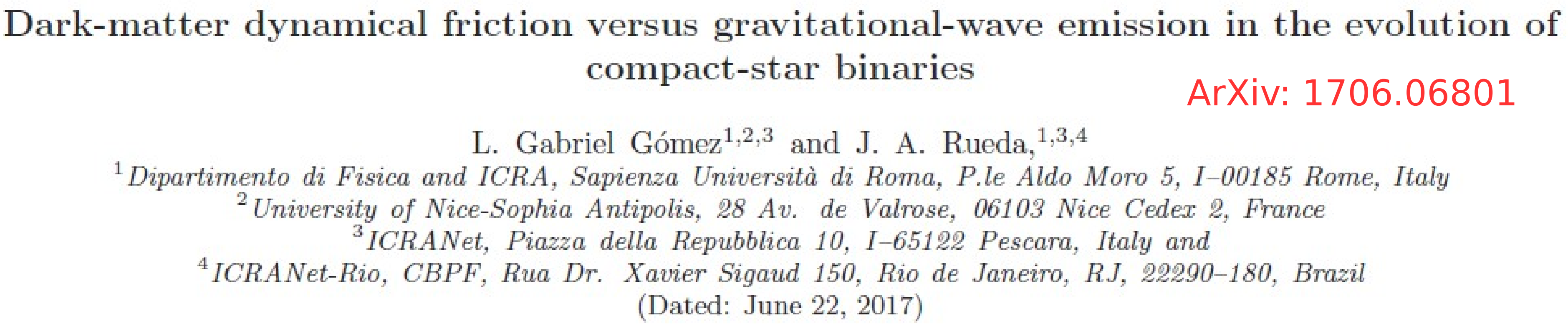
$$-\frac{dE_b}{dt} = \frac{32}{5}\frac{G^4}{c^5}\frac{(M_1+M_2)(M_1M_2)^2}{r^5}$$

$$\frac{1}{P}\frac{dP}{dt} = \frac{3}{2}\frac{1}{r}\frac{dr}{dt} = -\frac{3}{2}\frac{1}{E_b}\frac{dE_b}{dt}$$

Let's “speculate”: dark-matter dynamical-friction in galaxies



$$\xcancel{-\frac{dE_b}{dt} = \frac{32}{5}\frac{G^4}{c^5}\frac{(M_1+M_2)(M_1M_2)^2}{r^5} \qquad \frac{1}{P}\frac{dP}{dt} = \frac{3}{2}\frac{1}{r}\frac{dr}{dt} = -\frac{3}{2}\frac{1}{E_b}\frac{dE_b}{dt}}$$



Dark-matter dynamical friction versus gravitational-wave emission in the evolution of compact-star binaries

ArXiv: 1706.06801

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(Dated: June 22, 2017)

$$\mathbf{f}_{fr,i} = -4\pi G^2 m_i^2 m \left(\int_0^{v_i} d^3u f(u) \ln\left[\frac{b_{\max}}{G m_i}(v_i^2 - u^2)\right] + \int_{v_i}^{v_{\rm esc}} d^3u f(u) \left[\ln\left(\frac{u+v_i}{u-v_i}\right) - 2\frac{v_i}{u}\right]\right) \frac{\mathbf{v}_i}{\tilde{v}_i^3}$$

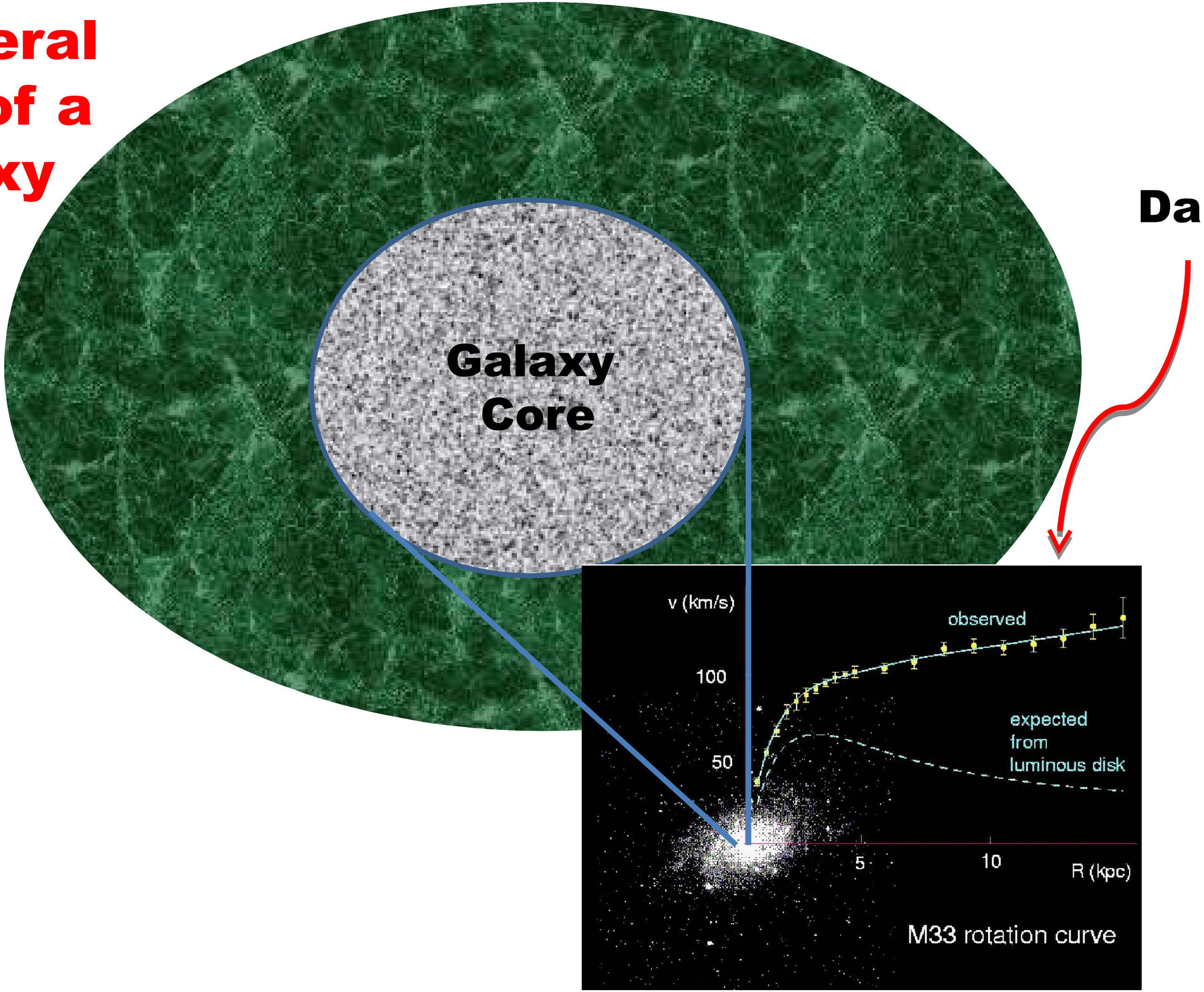
$$\Big\downarrow$$

$$\dot{P}_b(t) = \frac{3P_b}{2}[a_1\eta - a_2\Gamma \sin\beta \sin(\Omega_0 t - \alpha)]$$

Main ingredients:

- Size of the system: binary distance or binary period
- Component's velocity w.r.t. DM
- Distribution function → DM density profile
- Value of the DM density at the binary's galactic position

A general view of a galaxy



Dark Matter Halo

M33 rotation curve

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On the core-halo distribution of dark matter in galaxies

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ABSTRACT

We investigate the distribution of dark matter in galaxies by solving the equations of equilibrium of a self-gravitating system of massive fermions (‘inos’) at selected temperatures and degeneracy parameters within general relativity. Our most general solutions show, as a function of the radius, a segregation of three physical regimes: (1) an inner core of almost constant density governed by degenerate quantum statistics; (2) an intermediate region with a sharply decreasing density distribution followed by an extended plateau, implying quantum corrections; (3) an asymptotic, $\rho \propto r^{-2}$ classical Boltzmann regime fulfilling, as an eigenvalue problem, a fixed value of the flat rotation curves. This eigenvalue problem determines, for each value of the central degeneracy parameter, the mass of the ino as well as the radius and mass of the inner quantum core. Consequences of this alternative approach to the central and halo regions of galaxies, ranging from dwarf to big spirals, for SgrA*, as well as for the existing estimates of the ino mass, are outlined.

The model: on the core-halo structure

- A general relativistic self-gravitating system of semi-degenerate Dirac fermions in thermodynamic equilibrium, without any specific additional interaction.

$$f(p) = \frac{1}{e^{\frac{\epsilon(p)-\mu}{kT}}+1},$$

The equation of state (EOS) of the fermion gas is then given by Fermi statistics by

$$\begin{aligned}\rho &= m\frac{2}{h^3}\int f(p)\left[1+\frac{\epsilon(p)}{mc^2}\right] d^3p,\\ P &= \frac{1}{3}\frac{2}{h^3}\int f(p)\left[1+\frac{\epsilon(p)}{mc^2}\right]^{-1}\left[1+\frac{\epsilon(p)}{2mc^2}\right]\epsilon\, d^3p,\end{aligned}$$

- The problem is treated in a spherically symmetric metric

$$ds^2 = e^{\nu}c^2dt^2 - e^{\lambda}dr^2 - r^2d\theta^2 - r^2\sin^2\theta d\phi^2,$$

The model: on the core-halo structure

- The Einstein equations can be written can be written in the form of Tolman and Oppenheimer and Volkoff

$$\begin{aligned}\frac{d\nu}{dr} &= \frac{2G}{c^2}\frac{M+4\pi r^3 P/c^2}{r^2[1-2GM/(c^2 r)]},\\ \frac{dM}{dr} &= 4\pi r^2\rho,\\ \frac{dP}{dr} &= -\frac{1}{2}\frac{d\nu}{dr}(c^2\rho+P),\end{aligned}$$

  And λ is related to the mass M through

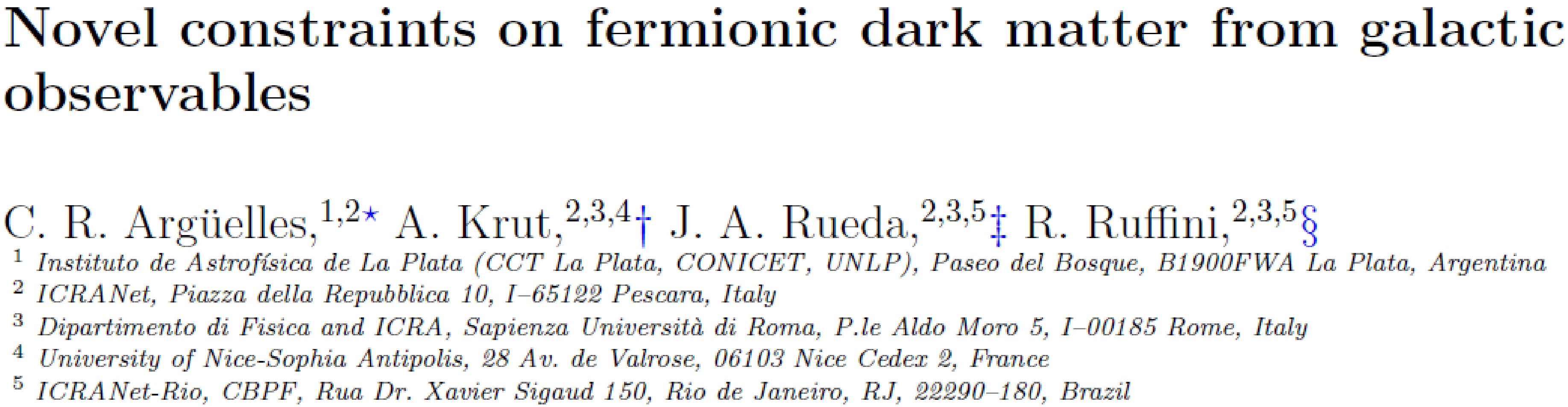
$$e^{-\lambda}=1-\frac{2GM}{c^2 r}.$$

- The hydrostatic equilibrium equation together with the first law of thermodynamics imply the Klein conditions (necessary for closure the integration of the system)

$$\begin{aligned}e^{\nu/2}T &= \text{constant},\\ e^{\nu/2}(\mu+mc^2) &= \text{constant}.\end{aligned}$$

RAR model with phase-space density-cutoff

ArXiv: 1606.07040



Novel constraints on fermionic dark matter from galactic observables

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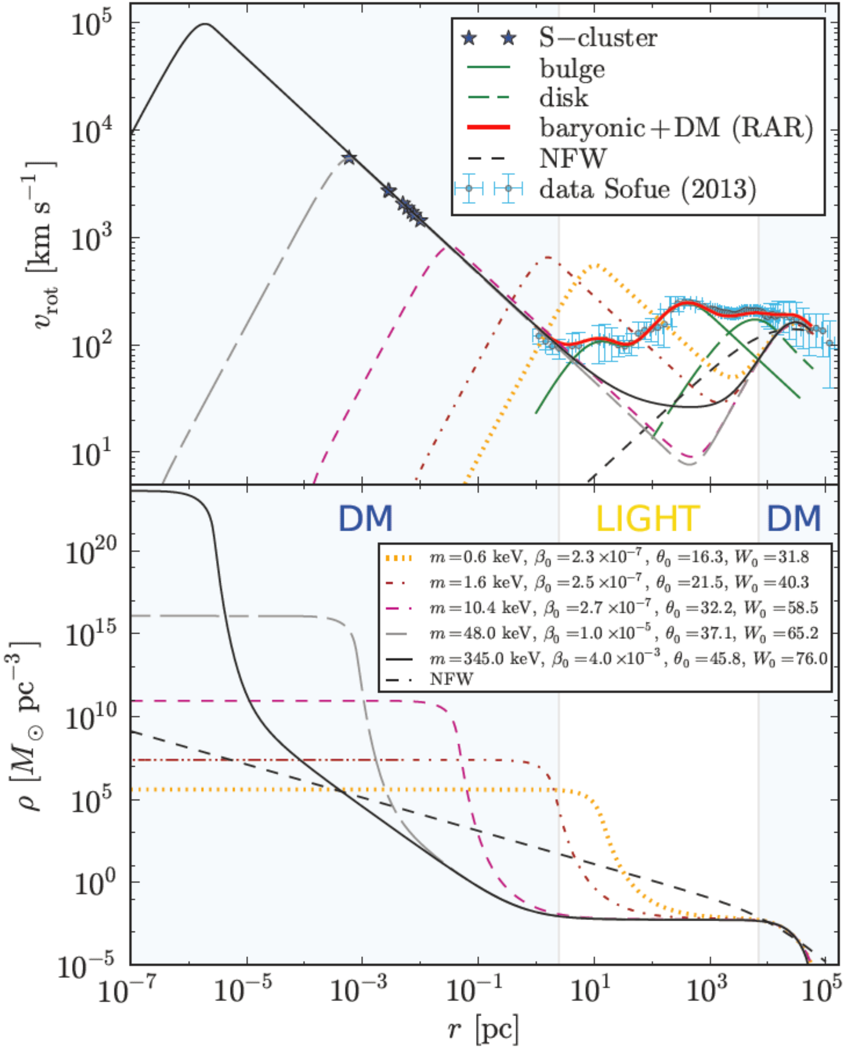
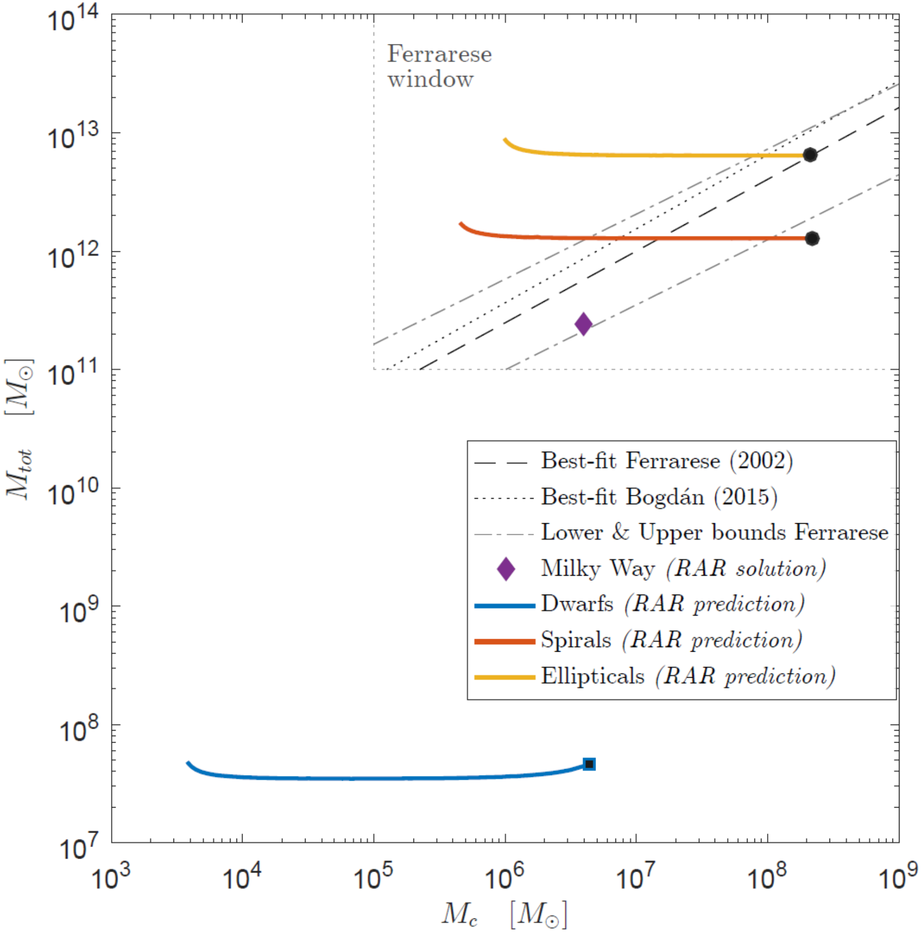
See A. Krut's talk on Thursday 6/07 (PS) for details on the galactic dark matter structure predicted by the RAR model

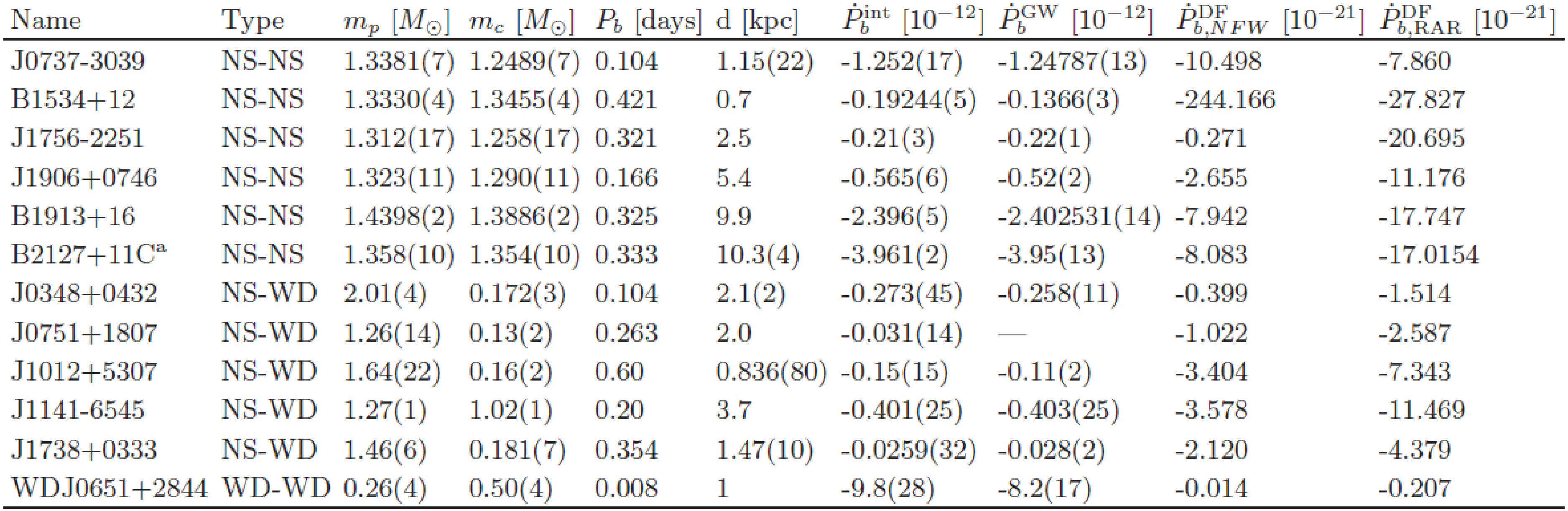
RAR model predictions





Comparison for some binaries in the Milky Way

Gomez & Rueda, ArXiv: 1706.06801

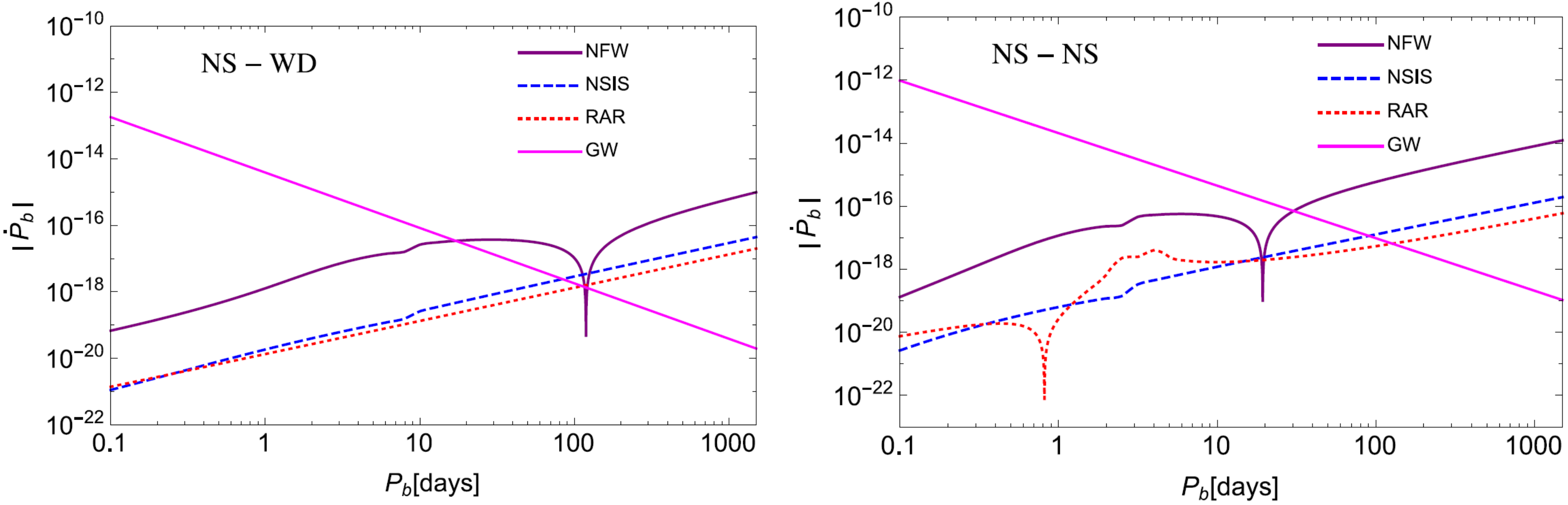


Name	Type	m_p [$M_\odot$]	m_c [$M_\odot$]	P_b [days]	d [kpc]	$\dot{P}_b^{\rm int}$ [10^{-12}]	$\dot{P}_b^{\rm GW}$ [10^{-12}]	$\dot{P}_{b,NFW}^{\rm DF}$ [10^{-21}]	$\dot{P}_{b,\rm RAR}^{\rm DF}$ [10^{-21}]
J0737-3039	NS-NS	1.3381(7)	1.2489(7)	0.104	1.15(22)	-1.252(17)	-1.24787(13)	-10.498	-7.860
B1534+12	NS-NS	1.3330(4)	1.3455(4)	0.421	0.7	-0.19244(5)	-0.1366(3)	-244.166	-27.827
J1756-2251	NS-NS	1.312(17)	1.258(17)	0.321	2.5	-0.21(3)	-0.22(1)	-0.271	-20.695
J1906+0746	NS-NS	1.323(11)	1.290(11)	0.166	5.4	-0.565(6)	-0.52(2)	-2.655	-11.176
B1913+16	NS-NS	1.4398(2)	1.3886(2)	0.325	9.9	-2.396(5)	-2.402531(14)	-7.942	-17.747
B2127+11C[a]	NS-NS	1.358(10)	1.354(10)	0.333	10.3(4)	-3.961(2)	-3.95(13)	-8.083	-17.0154
J0348+0432	NS-WD	2.01(4)	0.172(3)	0.104	2.1(2)	-0.273(45)	-0.258(11)	-0.399	-1.514
J0751+1807	NS-WD	1.26(14)	0.13(2)	0.263	2.0	-0.031(14)	—	-1.022	-2.587
J1012+5307	NS-WD	1.64(22)	0.16(2)	0.60	0.836(80)	-0.15(15)	-0.11(2)	-3.404	-7.343
J1141-6545	NS-WD	1.27(1)	1.02(1)	0.20	3.7	-0.401(25)	-0.403(25)	-3.578	-11.469
J1738+0333	NS-WD	1.46(6)	0.181(7)	0.354	1.47(10)	-0.0259(32)	-0.028(2)	-2.120	-4.379
WDJ0651+2844	WD-WD	0.26(4)	0.50(4)	0.008	1	-9.8(28)	-8.2(17)	-0.014	-0.207

In relativistic (Pb small) compact-star binaries located in the Galactic halo (low DM density) the orbital evolution is largely driven by GW emission and DMDF plays no role

Effect of the orbital period (fixed location)

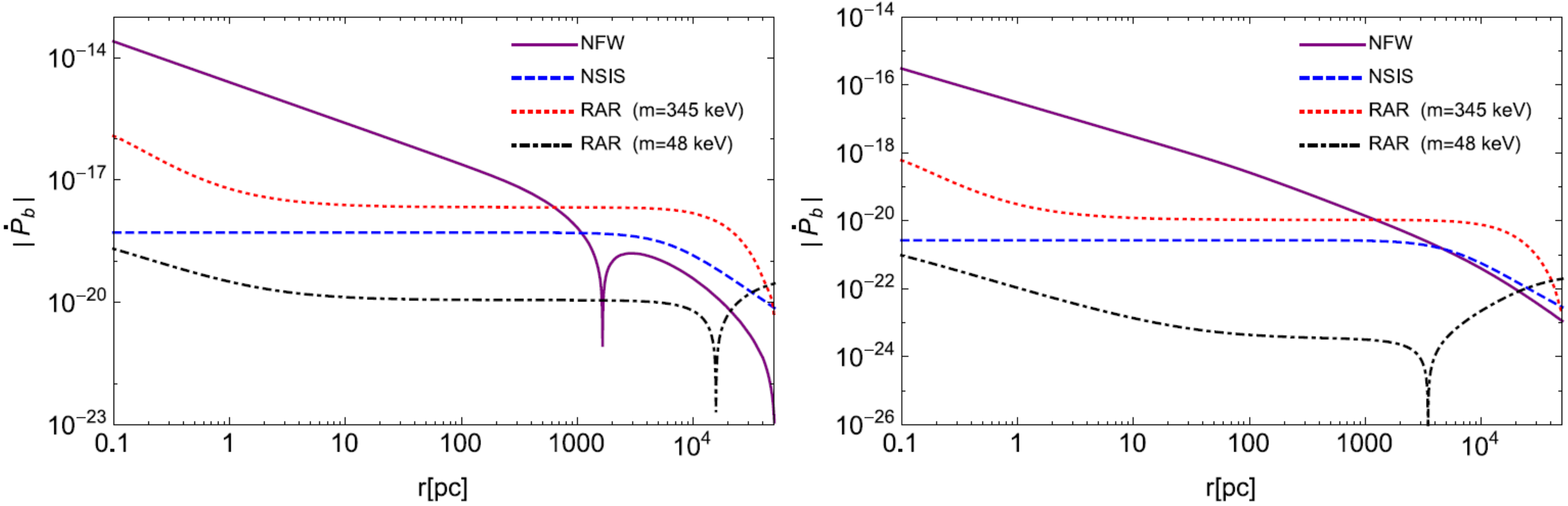
Gomez & Rueda, ArXiv: 1706.06801



Binaries at r = 0.1 kpc. For Pb small the orbital evolution is largely driven by GW emission and DMDF plays no role. For Pb larger DM friction becomes comparable to GW emission and for even larger values it overcomes the GW effect

Effect of the location (fixed period)

Gomez & Rueda, ArXiv: 1706.06801



Binaries with Pb = 0.5 days. When r is large (halo; ~kpc) the DMDF is small and the orbital evolution is largely driven by GW emission. When r is small (< 1-10 pc), the DMDF can become comparable (or overcome) the GW emission