Supernovae, Hypernovae and Binary Driven Hypernovae

An Adriatic Workshop

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Induced compression of WDs by angular momentum loss and I-Love-Q relations in WDs

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in collaboration with

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How will isolated white dwarfs evolve by losing angular momentum?

Super-Chandrasekhar WDs

will they slow down ? -> no

will they explode as a type Ia supernova ? - > ?, yes

will they collapse into a neutron star ? - > ?, yes

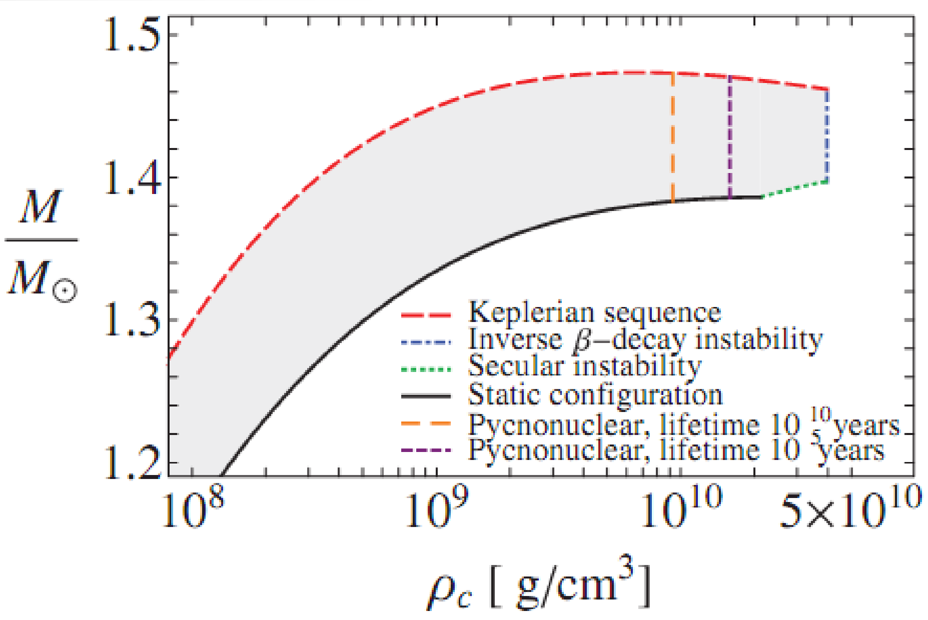
Sub-Chandrasekhar WDs

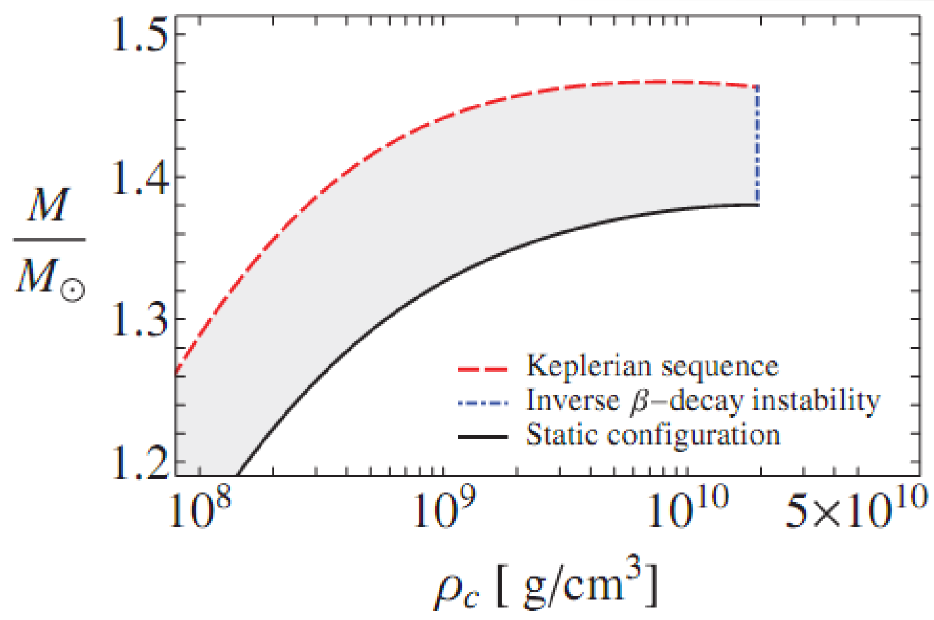
will they slow down ? - > yes

will they live forever ? - > yes

Equilibrium WD configurations

Boshkayev, Rueda, Ruffini, Siutsou, ApJ 2013, 762, 117



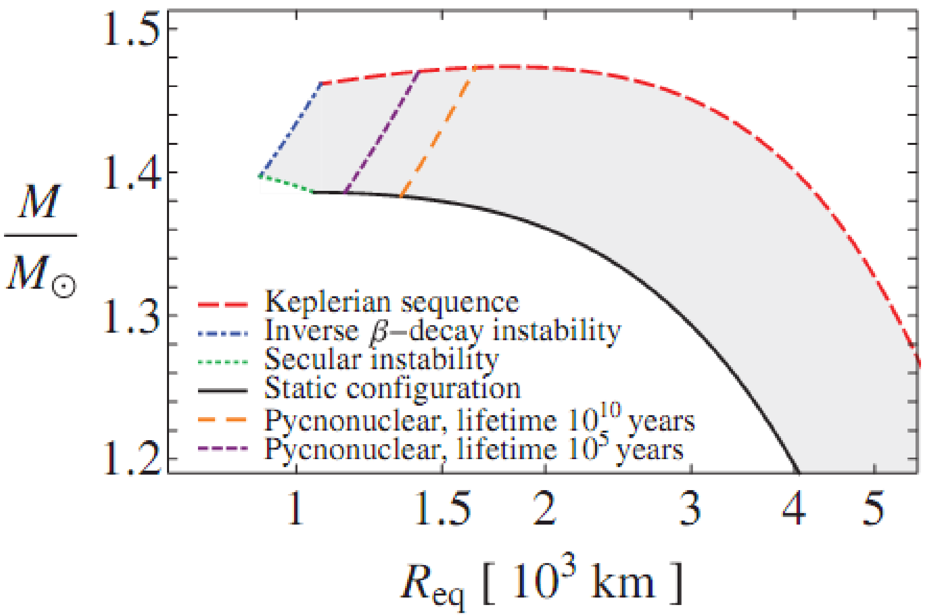


Carbon WD for RFMT EoS.

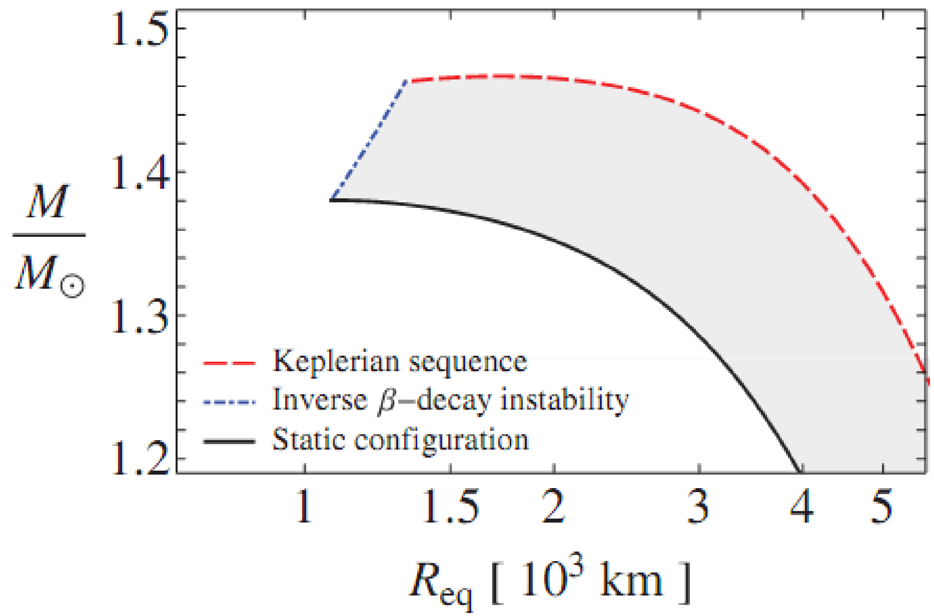
Oxygen WD for RFMT EoS.

Equilibrium WD configurations

Boshkayev, Rueda, Ruffini, Siutsou, ApJ 2013, 762, 117



Carbon WD for RFMT EoS.



Oxygen WD for RFMT EoS.

Rotating WD properties

Composition	$\rho_{M_{max}^{J\neq0}}$	k	$M_{max}^{J=0}/M_\odot$	$R_{M_{max}^{J=0}}$	σ	P_{min}
^{4}He	5.46×10^9	1.0646	1.40906	1163	0.26952	0.284
^{12}C	6.95×10^9	1.0632	1.38603	1051	0.54692	0.501
^{16}O	7.68×10^9	1.0626	1.38024	1076	0.72343	0.687
^{56}Fe	1.18×10^9	1.0864	1.10618	2181	0.71685	2.195

Maximum Mass and Minimum Period

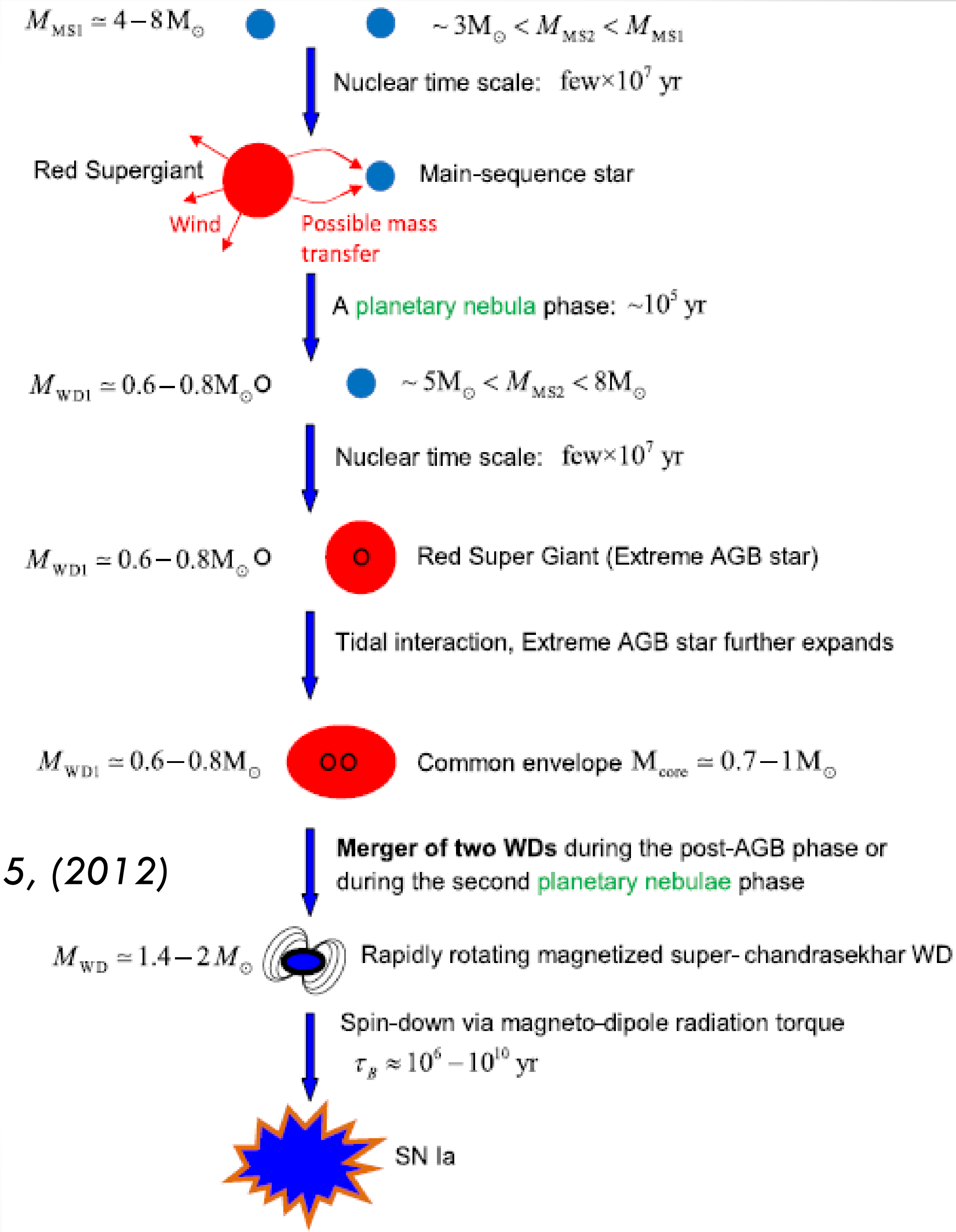
$$M_{max}^{J\neq0} = k\, M_{max}^{J=0} \sim 1.500,\ 1.474,\ 1.467,\ 1.202\ M_\odot$$

$$P_{min} = \sigma \left(\frac{M_\odot}{M_{max}^{J=0}}\right)^{\frac{1}{2}} \left(\frac{R_{M_{max}^{J=0}}}{10^3\,\mathrm{km}}\right)^{\frac{3}{2}} \mathrm{sec} \sim 0.3, 0.5, 0.7, 2.2\ \mathrm{sec}$$

Boshkayev, Rueda, Ruffini, Siutsou, ApJ 2013, 762, 117

Astrophysical Implications of WDs

Type Ia Supernovae From Very Long Delayed Explosion of Core-WD Merger



M. Ilkov and N. Soker. MNRAS 419, 1695, (2012)

It is assumed that J is proportional to Ω, i.e. the moment of inertia I is constant.

Type Ia Supernovae From Very Long Delayed Explosion of Core-WD Merger

M. Ilkov and N. Soker. MNRAS 419, 1695, (2012)

$$\dot{E}_{rot} = \Omega \frac{dJ}{d\Omega}\frac{d\Omega}{dt} = -4\pi^2 I \frac{\dot{P}}{P^3} \qquad \dot{E}_{EM} = -\frac{2}{3}\frac{B^2R^6}{c^3}\Omega^4 = -\frac{32\pi^4}{3}\frac{B^2}{c^3}\frac{R^6}{P^4}$$

$$\tau_{\rm B} \simeq \frac{Ic^3}{B^2R^6\Omega_c^2}\left[1-\left(\frac{\tilde{\Omega}_0}{\tilde{\Omega}_c}\right)^{-2}\right](\sin\delta)^{-2} \approx 10^8 \left(\frac{B}{10^8~{\rm G}}\right)^{-2}\left(\frac{\tilde{\Omega}_c}{0.7\Omega_{\rm Kep}}\right)^{-2}$$
$$\times \left(\frac{R}{4000~{\rm km}}\right)^{-1}\left(\frac{\sin\delta}{0.1}\right)^{-2}\left(\frac{\beta_I}{0.3}\right)\left[1-\left(\frac{\tilde{\Omega}_0}{\tilde{\Omega}_c}\right)^{-2}\right]~{\rm yr},$$

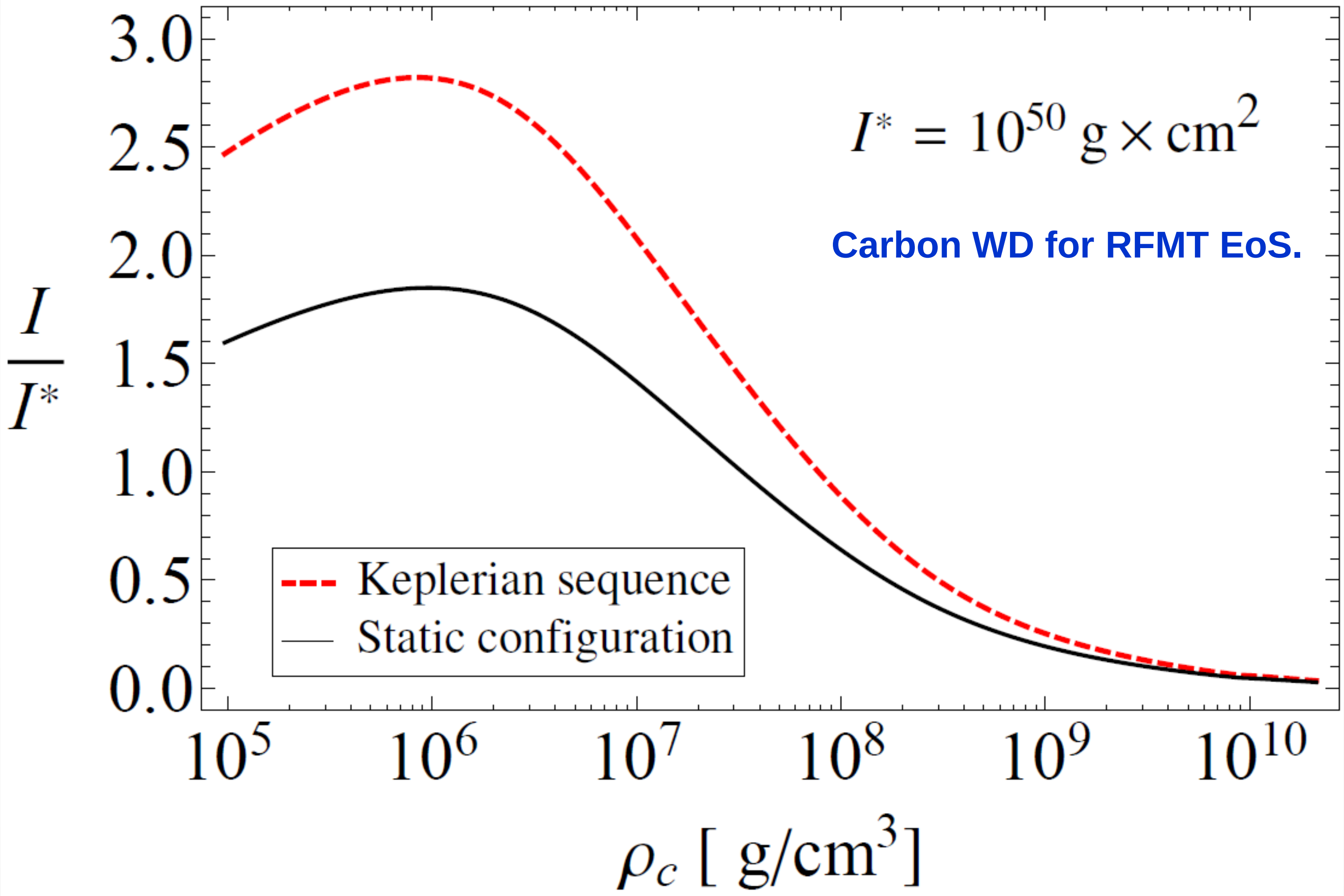
It is assumed that J is proportional to Ω, i.e. the moment of inertia I is constant.

The result…

$$10^6~{\rm G} \lesssim {\rm B}\sin\delta \lesssim 10^8~{\rm G}$$

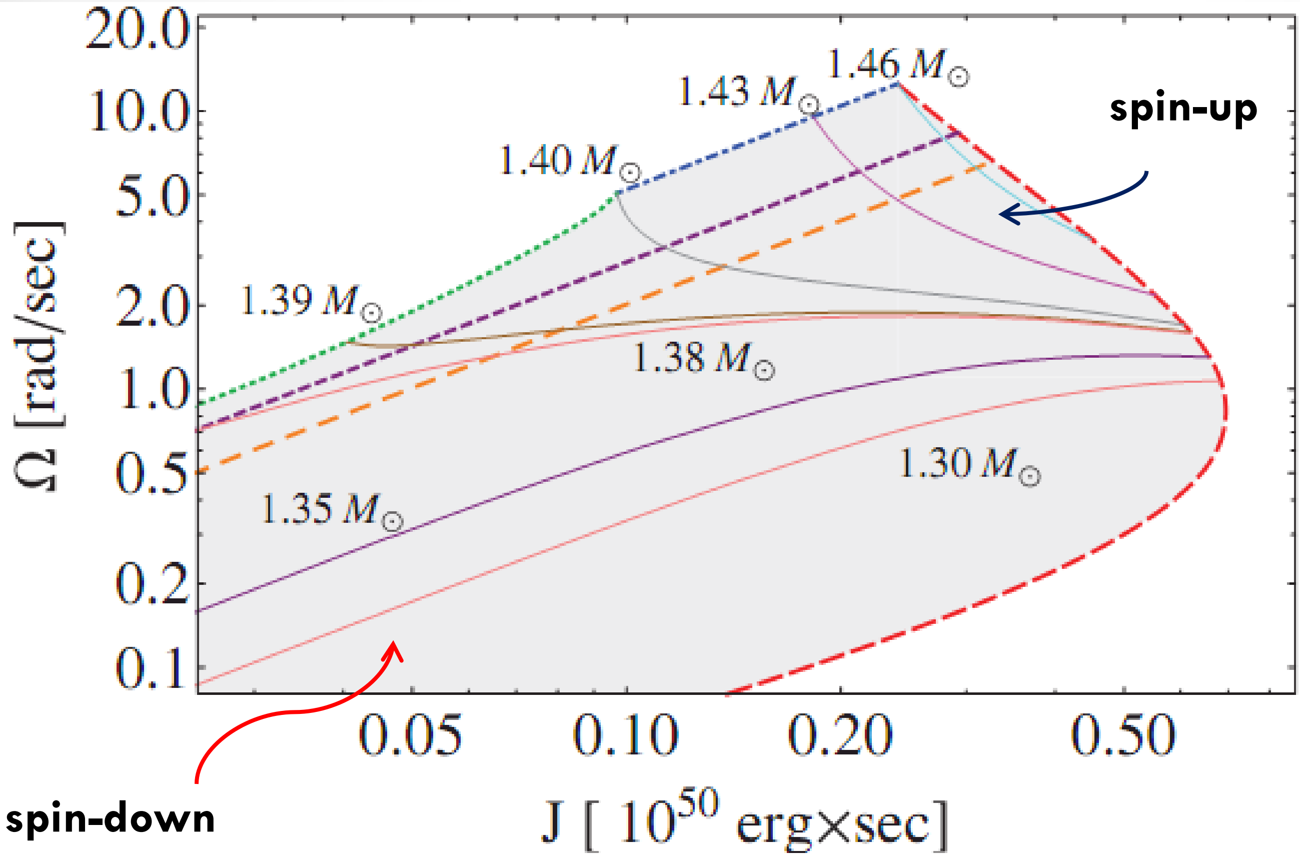
$$10^7 \lesssim t \lesssim 10^{10}~{\rm yr}$$

Moment of Inertia of NR and RWDs



•*Hartle, J. B. 1973, Astrophys. Space Science, 24, 385*

Spin-up and spin-down stages

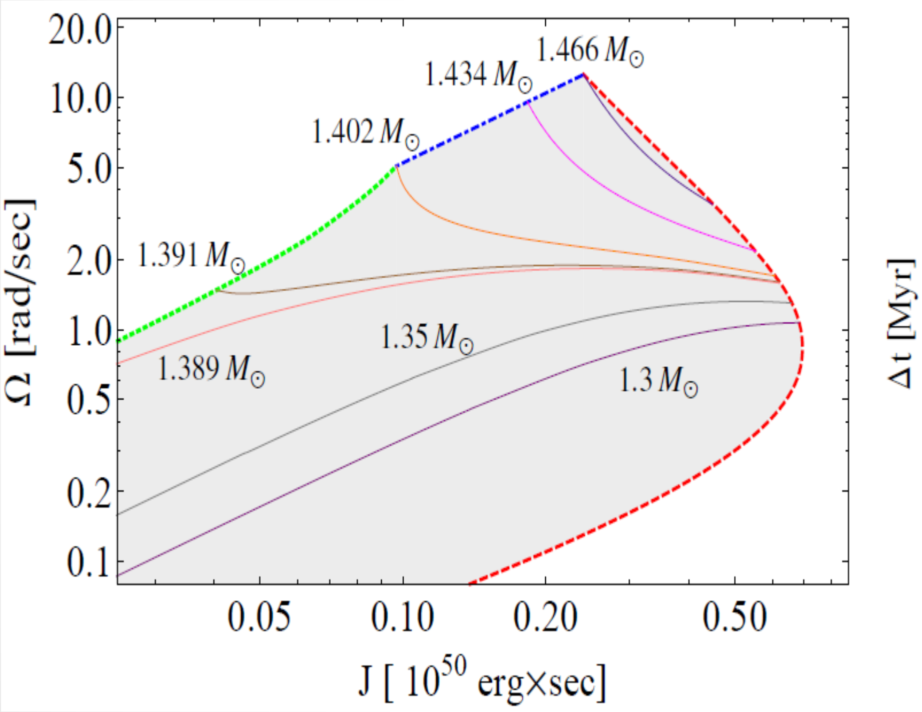


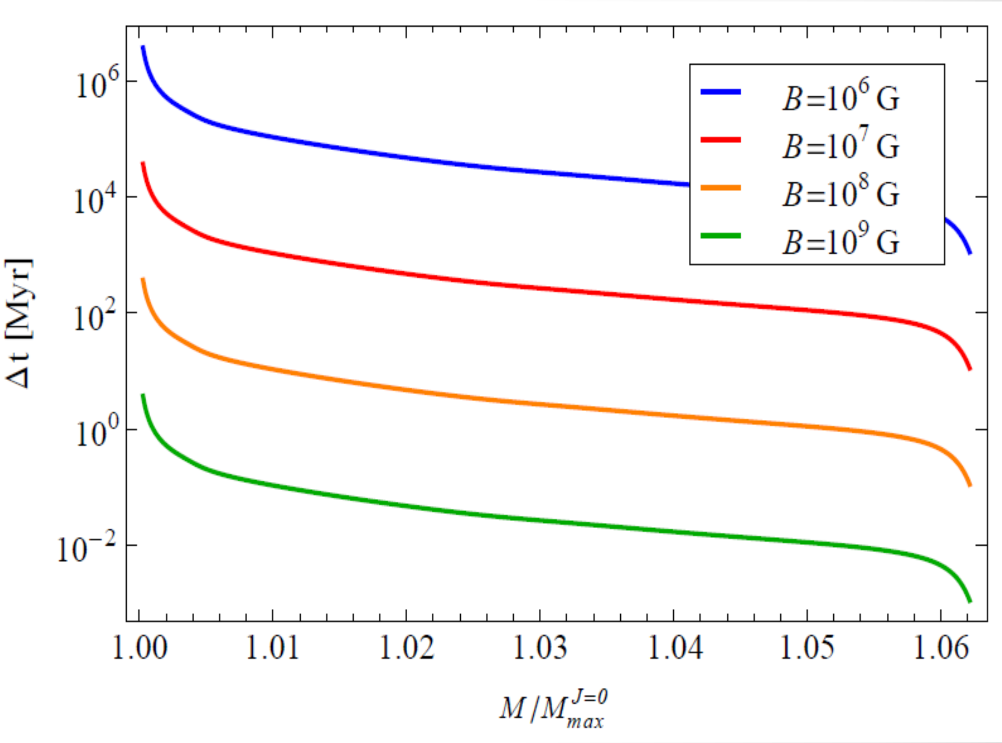
$$\dot{\Omega} = \frac{\dot{E}}{\Omega}\left(\frac{\partial \Omega}{\partial J}\right)_{M_0,S,Z,A}$$

•Shapiro, S. L., Teukolsky, S. A., & Nakamura, T. 1990, Ap. J., 357, L17
•Geroyannis, V. S. & Papasotiriou, P. J. 2000, Astrophys. J., 534, 359

•*Boshkayev, Rueda, Ruffini, Siutsou, ApJ 2013, 762, 117*

Delayed gravitational collapse of Super Chandrasekhar WDs

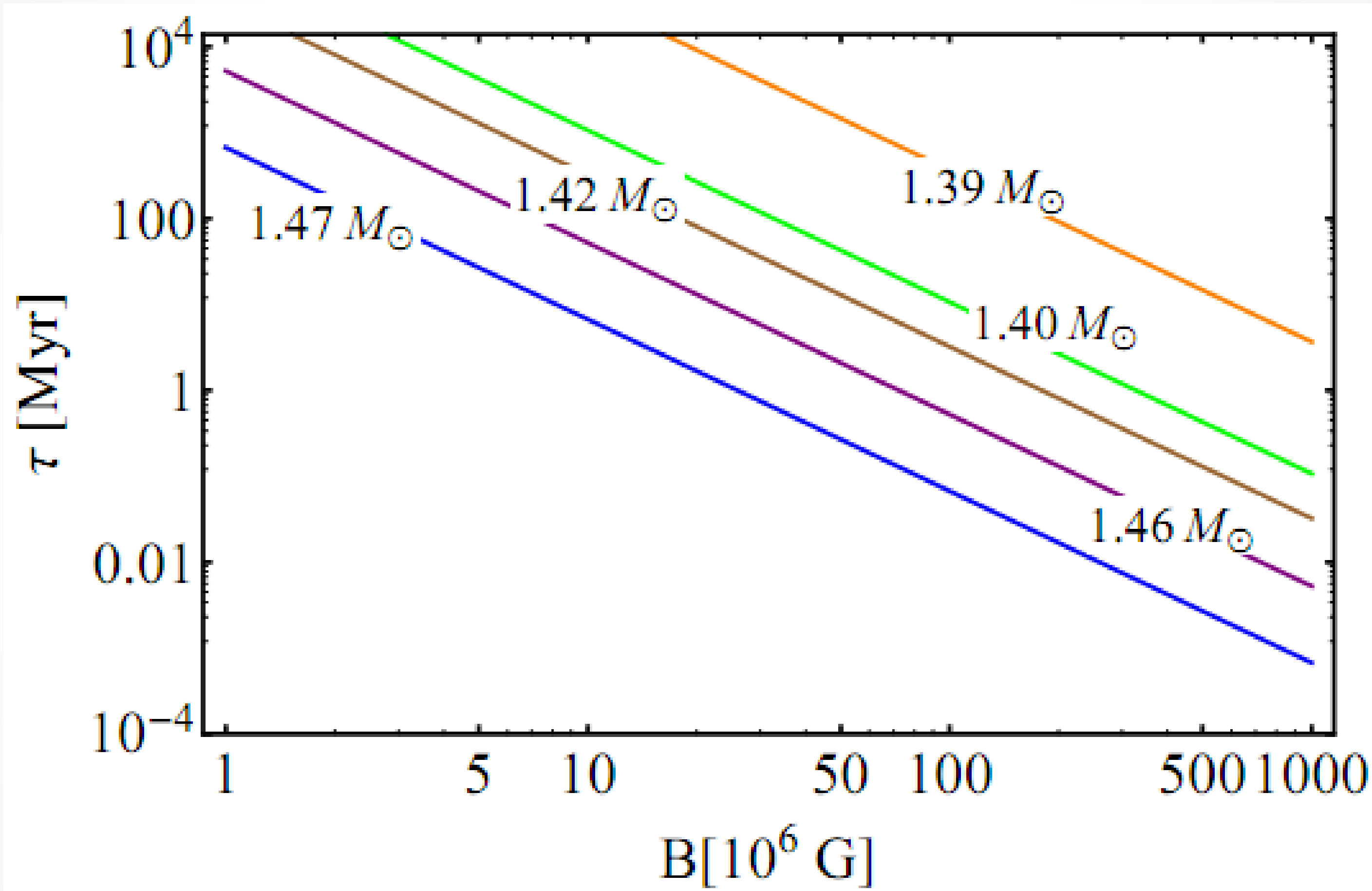




$$t = -\frac{3}{2}\frac{c^3}{B^2}\int_{J_{max}}^{J_{min}} \frac{1}{R^6}\frac{dJ}{\Omega^3}, \quad R = R(\rho, J), \quad \Omega = \Omega(\rho, J)$$

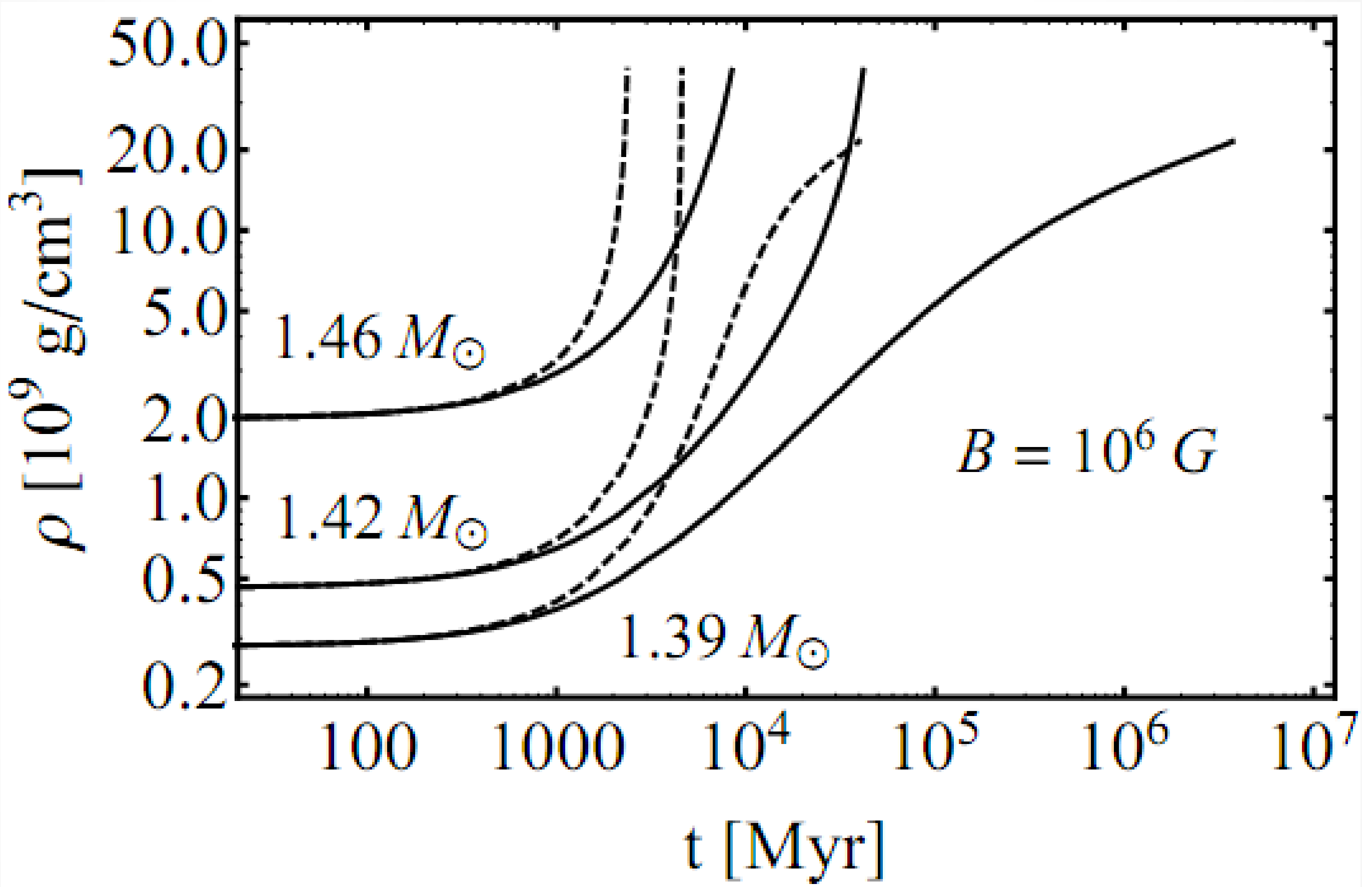
Proceedings of the Italian Korean Symposium 2013

Time versus magnetic field



Assuming constant B over the course of time

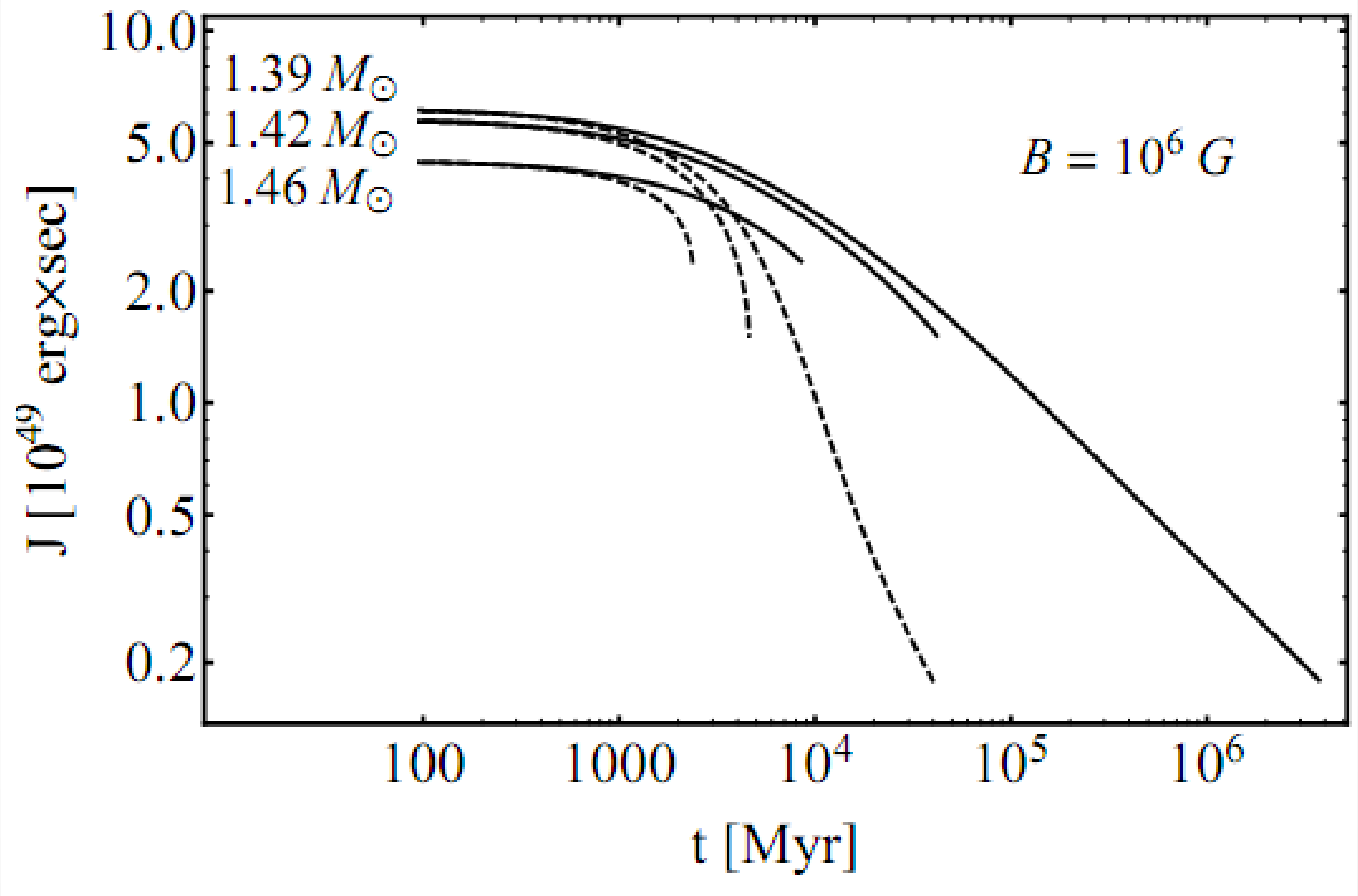
Central density versus time



Solid curves - assuming constant B with time

Dashed curves - assuming magnetic flux conservation with time

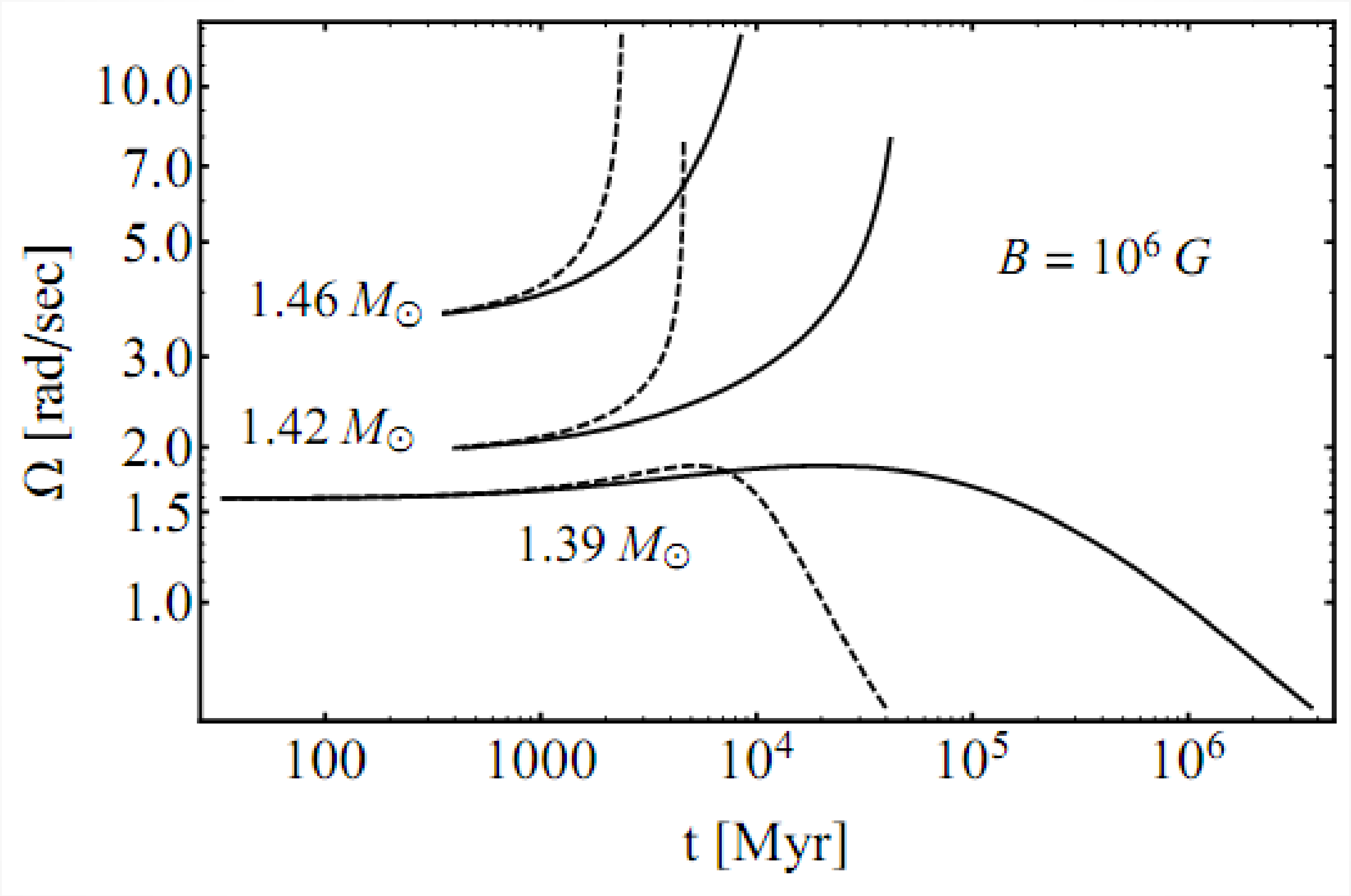
Angular momentum versus time



Solid curves - assuming constant B with time

Dashed curves - assuming magnetic flux conservation with time

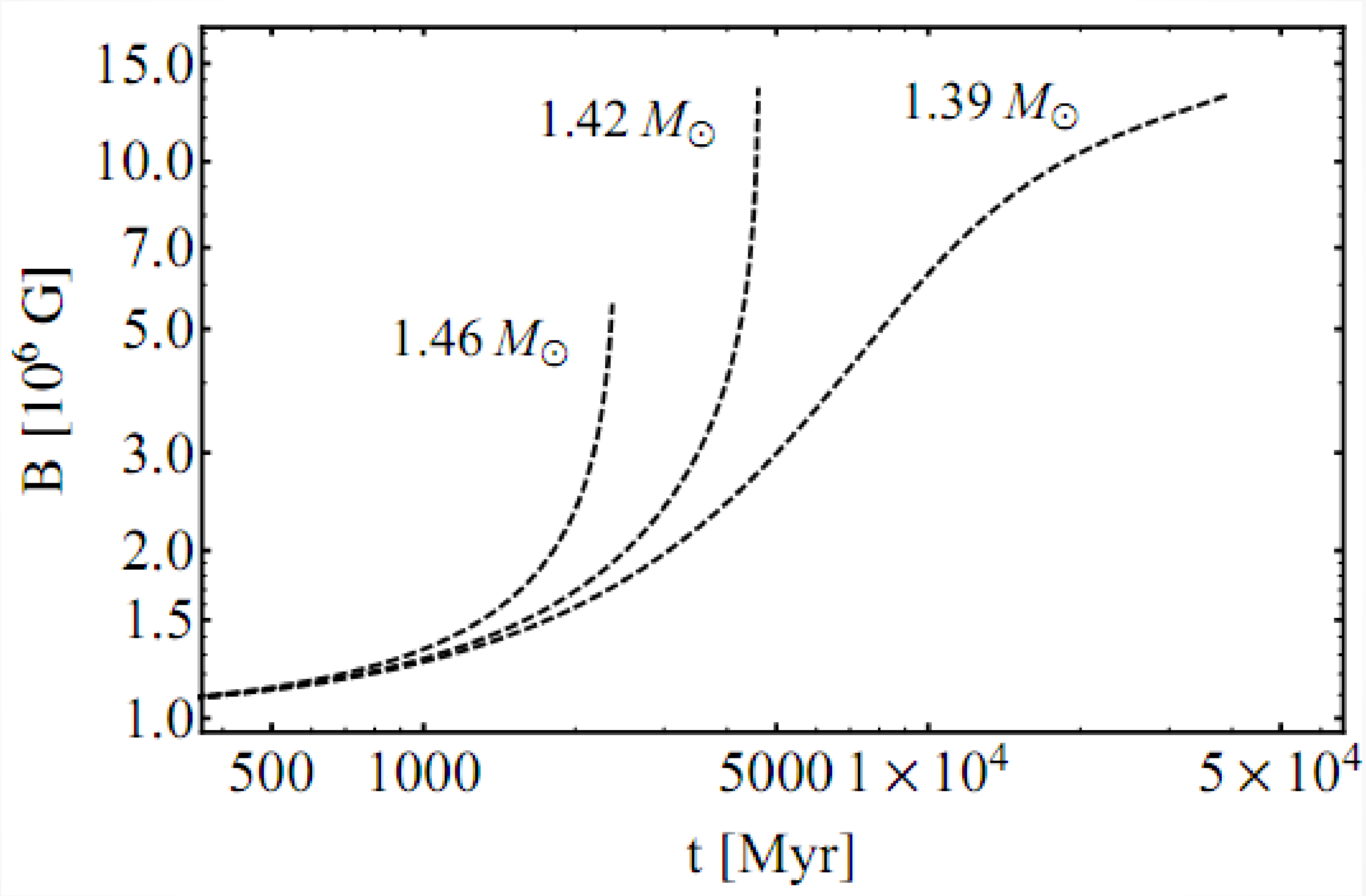
Angular velocity versus time



Solid curves - assuming constant B with time

Dashed curves - assuming magnetic flux conservation with time

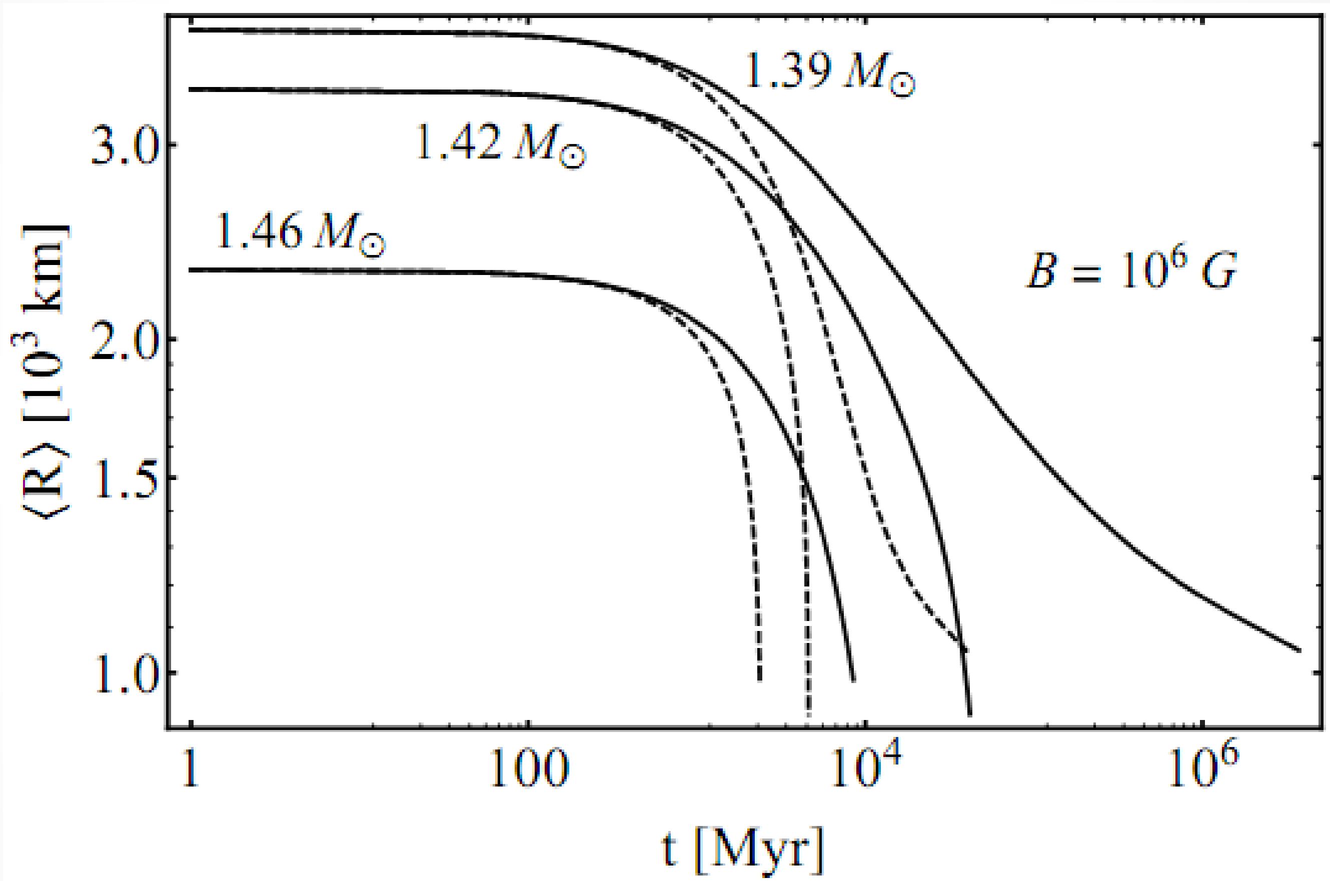
Magnetic field versus time



Solid curves - assuming constant B with time

Dashed curves - assuming magnetic flux conservation with time

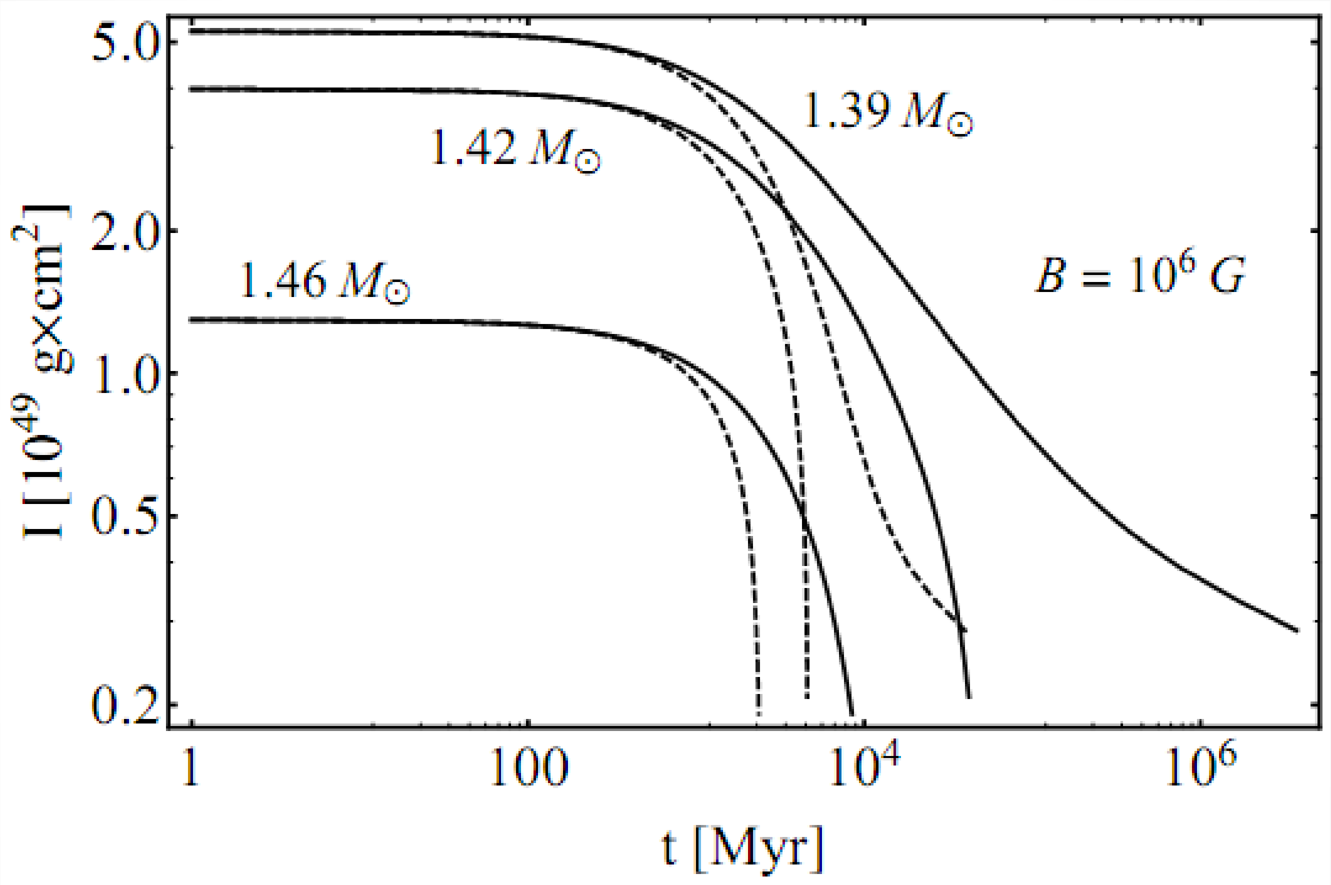
Mean radius versus time



Solid curves - assuming constant B with time

Dashed curves - assuming magnetic flux conservation with time

Moment of inertia versus time



Solid curves - assuming constant B with time

Dashed curves - assuming magnetic flux conservation with time

Concluding remarks

- *Stability of rotating WDs is a delicate matter: all mass-shedding, inverse beta decay, and secular instability play role*
- *Both spin-down and spin-up stages by loosing angular momentum are possible in WDs*
- *Super Chandrasekhar WDs can only spin up by angular momentum loss*
- *The delayed time for gravitational collapse of a WD via magnetic braking is comprised in a variety of ranges upon the magnetic field value*
- *We showed that WDs composed of light elements (Helium, Carbon) are unstable against axisymmetric secular instability, whereas WDs with heavy elements (Oxygen,.., Iron) are stable.*
- *Evolution of the physical parameters of WDs over time due to the angular momentum loss.*
- *The magnetic flux conservation shortens the lifespan of WDs .*
- *It will be interesting to consider the effects of temperature.*
- *Work in progress*

I-Love-Q relations for WDs

1	2013PhRvD..88b3009Y	100.000	07/2013	A E X R C	Yagi, Kent; Yunes, Nicolás	I-Love-Q relations in neutron stars and their applications to astrophysics, gravitational
2	2013Sci...341..365Y	99.270	07/2013	A E F X R C	Yagi, Kent; Yunes, Nicolás	I-Love-Q: Unexpected Universal Relations for Neutron Stars and Quark Stars
3	2014PhRvL.112l1101P	96.620	03/2014	A E X R C	Pappas, George; Apostolatos, Theocharis A.	Effectively Universal Behavior of Rotating Neutron Stars in General Relativity Makes
4	2014PhRvD..90b4025P	95.730	07/2014	A E X R C	Pani, Paolo; Berti, Emanuele	Slowly rotating neutron stars in scalar-tensor theories
5	2014MNRAS.438L..71H	95.440	02/2014	A E F X R C S	Haskell, B.; Ciolfi, R.; Pannarale, F.; Rezzolla, L.	On the universality of I-Love-Q relations in magnetized neutron stars
6	2014ApJ...781L...6D	95.440	01/2014	A E F X R C	Doneva, Daniela D.; Yazadjiev, Stoytcho S.; Stergioulas, Nikolaos; Kokkotas, Kostas D.	Breakdown of I-Love-Q Universality in Rapidly Rotating Relativistic Stars
7	2014ApJ...781...66S	93.640	02/2014	A E F X R C S	Sham, Y.-H.; Lin, L.-M.; Leung, P. T.	Testing Universal Relations of Neutron Stars with a Nonlinear Matter-Gravity Couplin
8	2015PhRvD..92l4030P	92.930	12/2015	A E X R C	Pani, Paolo	I-Love-Q relations for gravastars and the approach to the black-hole limit
9	2014PhRvD..90f3010Y	91.940	09/2014	A E X R C	Yagi, Kent; Stein, Leo C.; Pappas, George; Yunes, Nicolás; Apostolatos, Theocharis A.	Why I-Love-Q: Explaining why universality emerges in compact objects
10	2015PhRvD..91l3008Y	87.410	06/2015	A E X R C	Yagi, Kent; Yunes, Nicolás	I-Love-Q anisotropically: Universal relations for compact stars with scalar pressure an

PHYSICAL REVIEW D **88**, 023009 (2013)

I-Love-Q relations in neutron stars and their applications to astrophysics, gravitational waves, and fundamental physics

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(Received 6 March 2013; published 19 July 2013)

$$\bar{I} \equiv \frac{I}{M_*^3} \qquad \bar{Q} \equiv -\frac{Q^{(\mathrm{rot})}}{M_*^3 \chi^2} \qquad \chi \equiv S/M_*^2 \qquad \bar{\lambda}^{(\mathrm{rot})} \equiv \frac{\lambda^{(\mathrm{rot})}}{M_*^5}$$

$$\bar{\lambda}^{(\mathrm{rot})} = \bar{I}^2 \bar{Q}.$$

In GR

$$\bar{\lambda}^{(\mathrm{tid})} \neq \bar{\lambda}^{(\mathrm{rot})}$$

In classical physics

$$\bar{\lambda}^{(\mathrm{tid}),\mathrm{N}} = \bar{\lambda}^{(\mathrm{rot}),\mathrm{N}}$$

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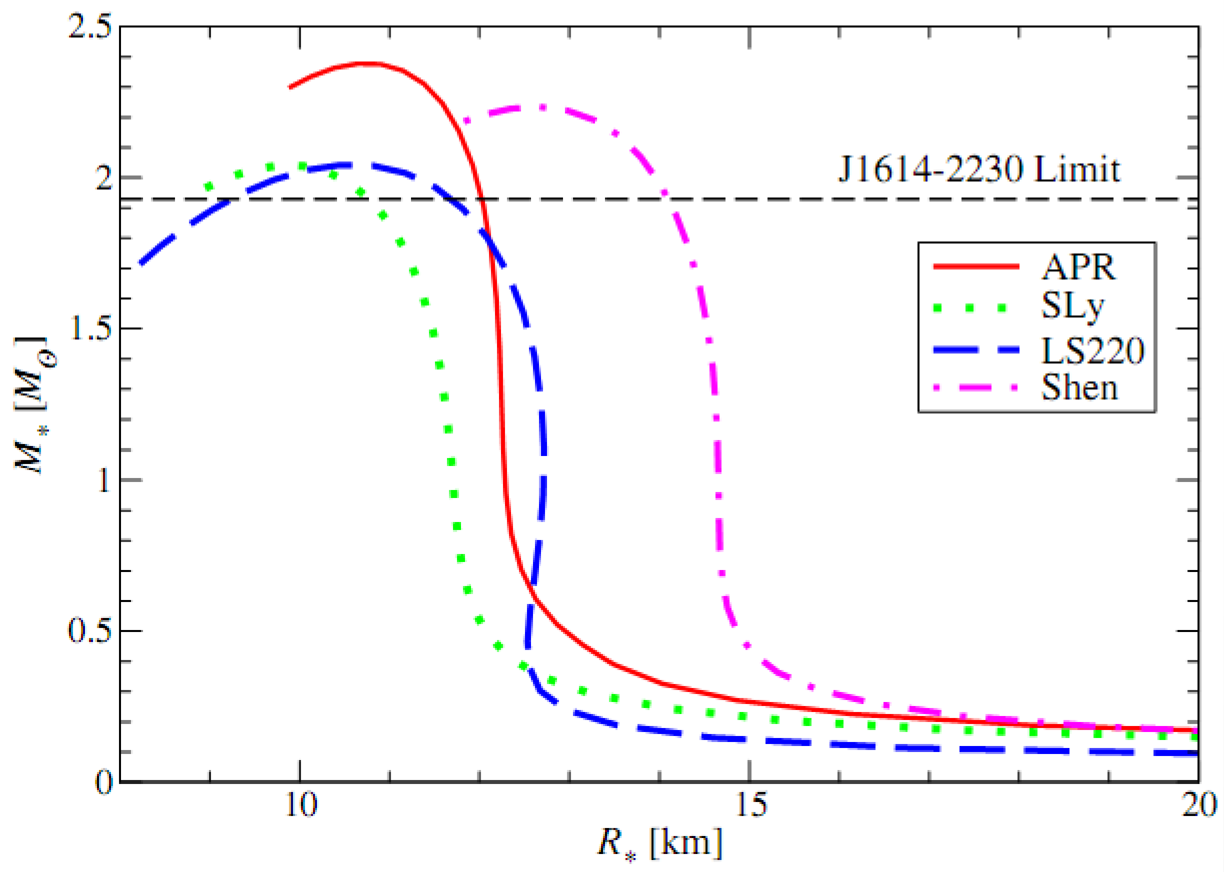

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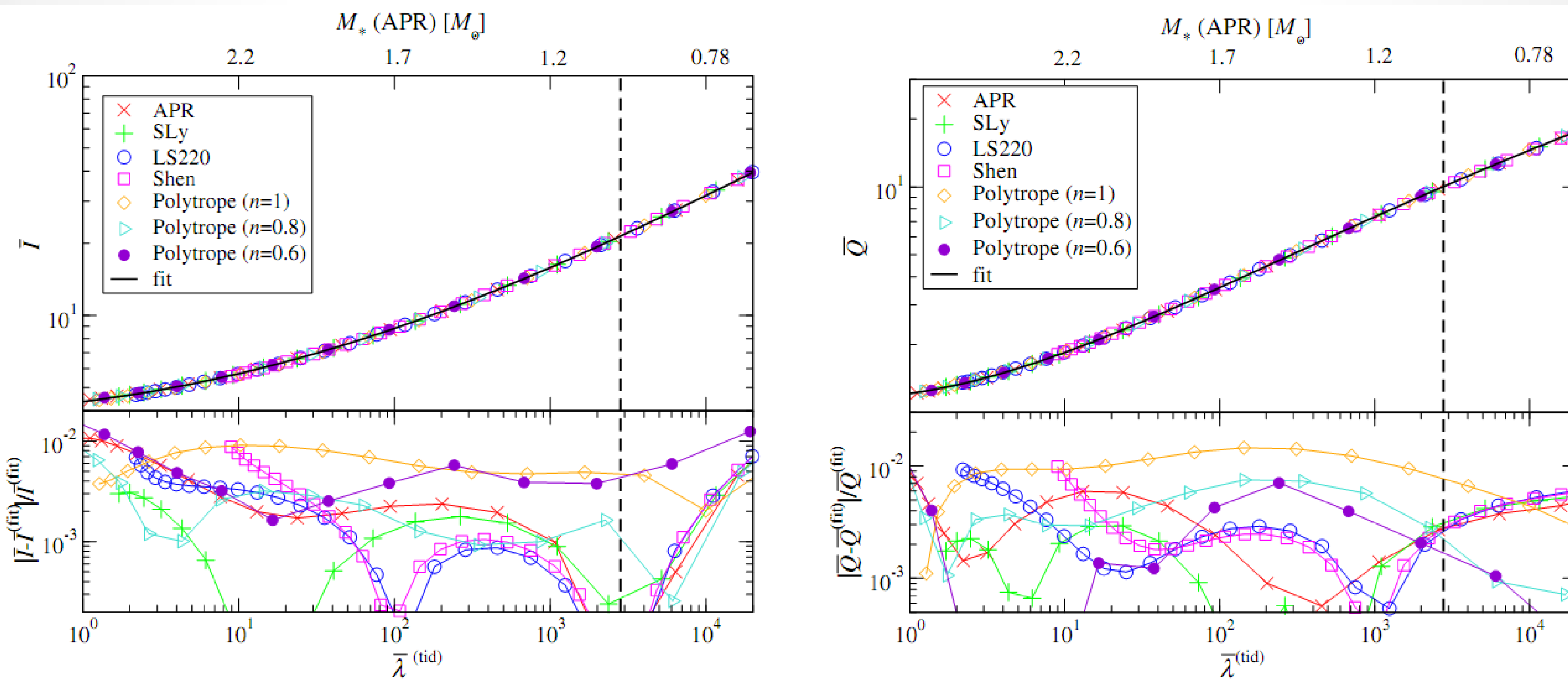

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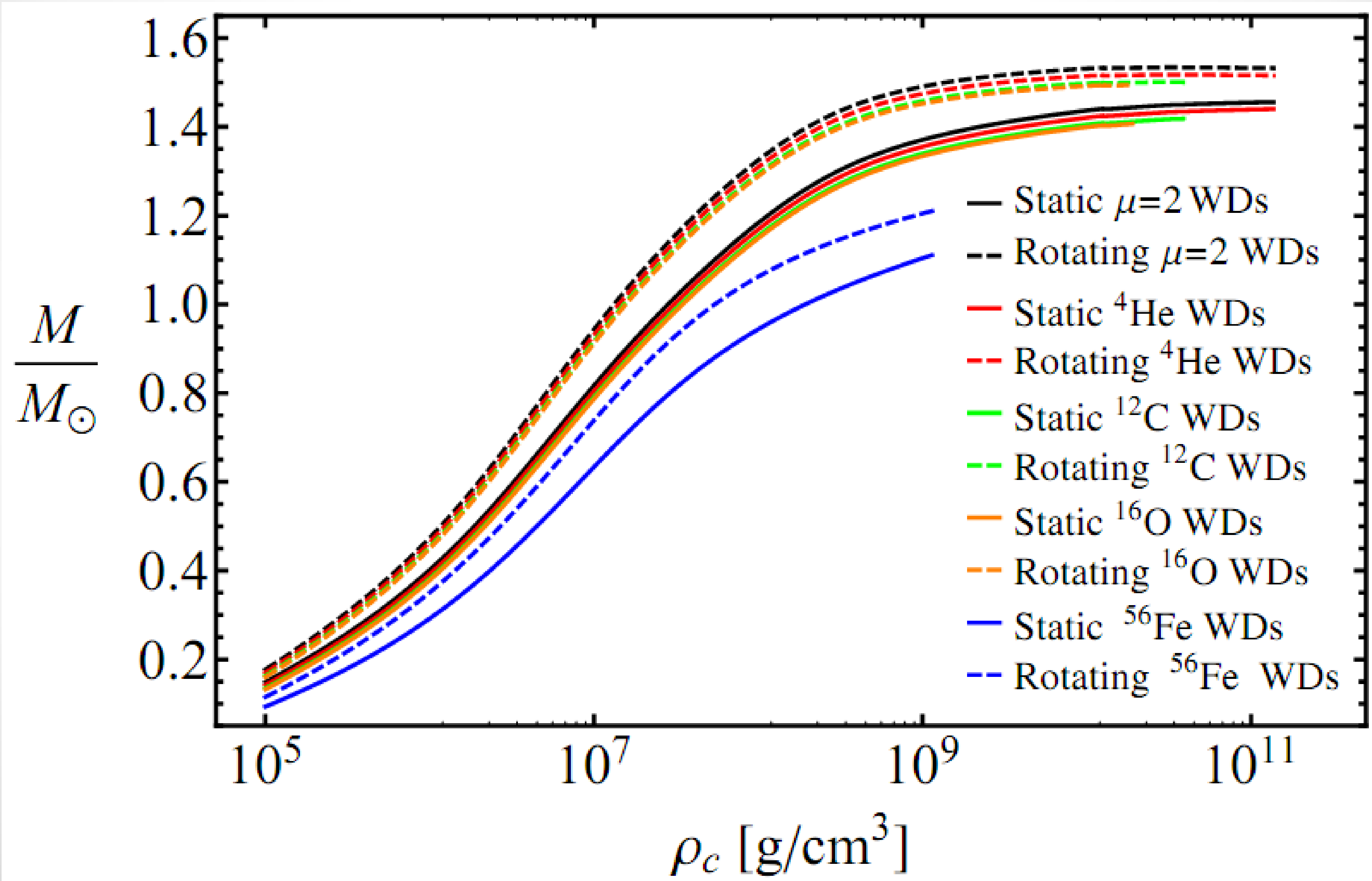

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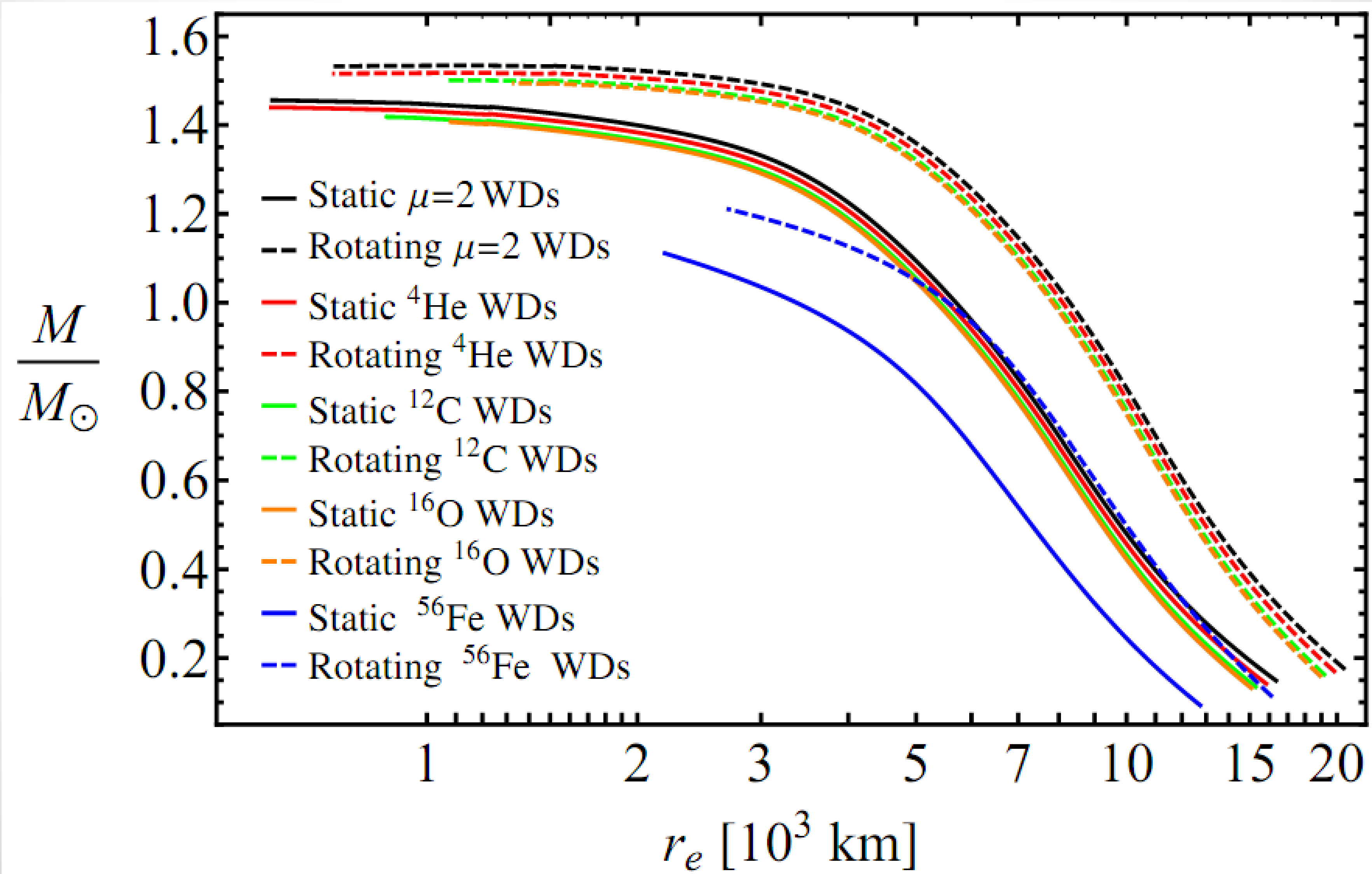

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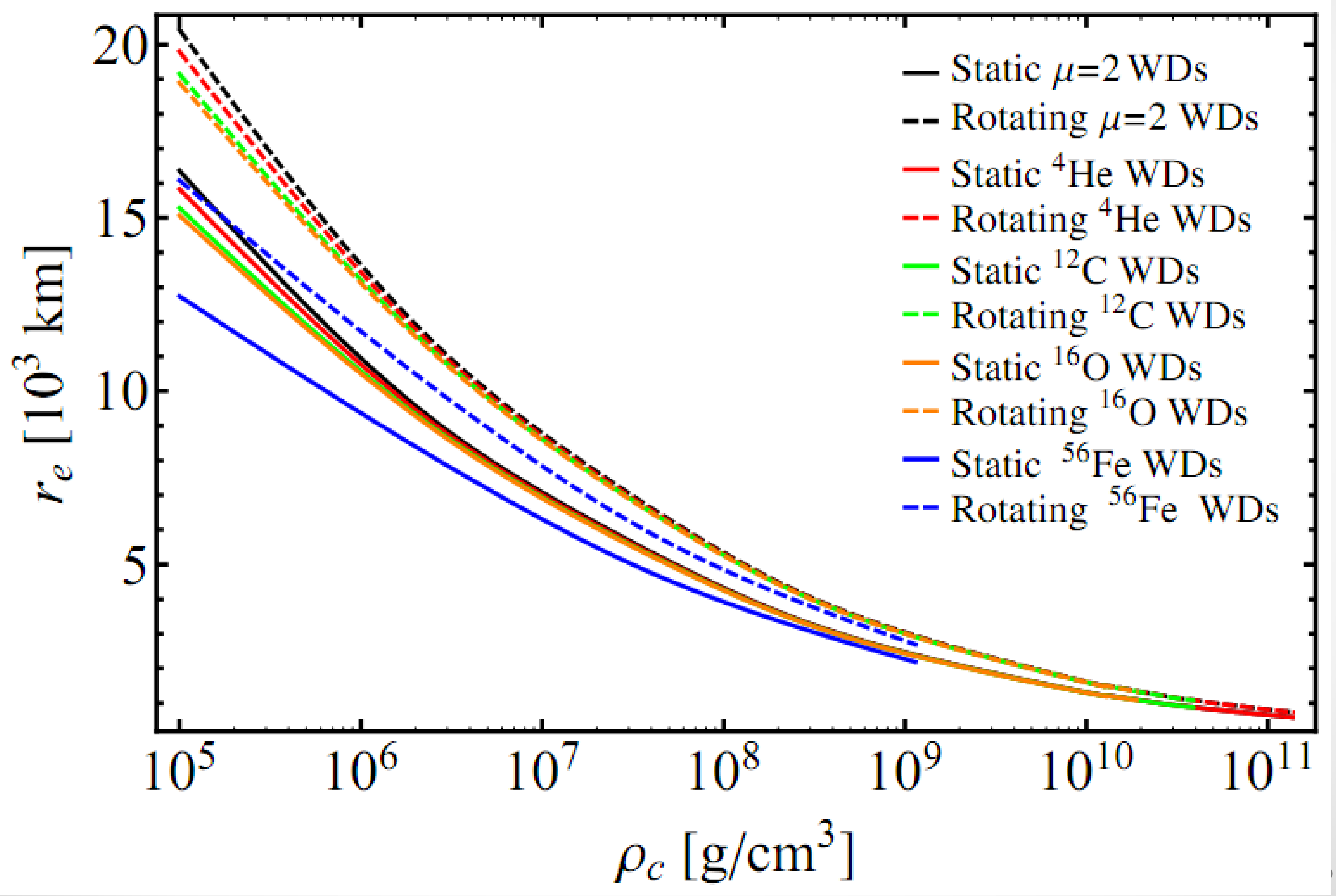

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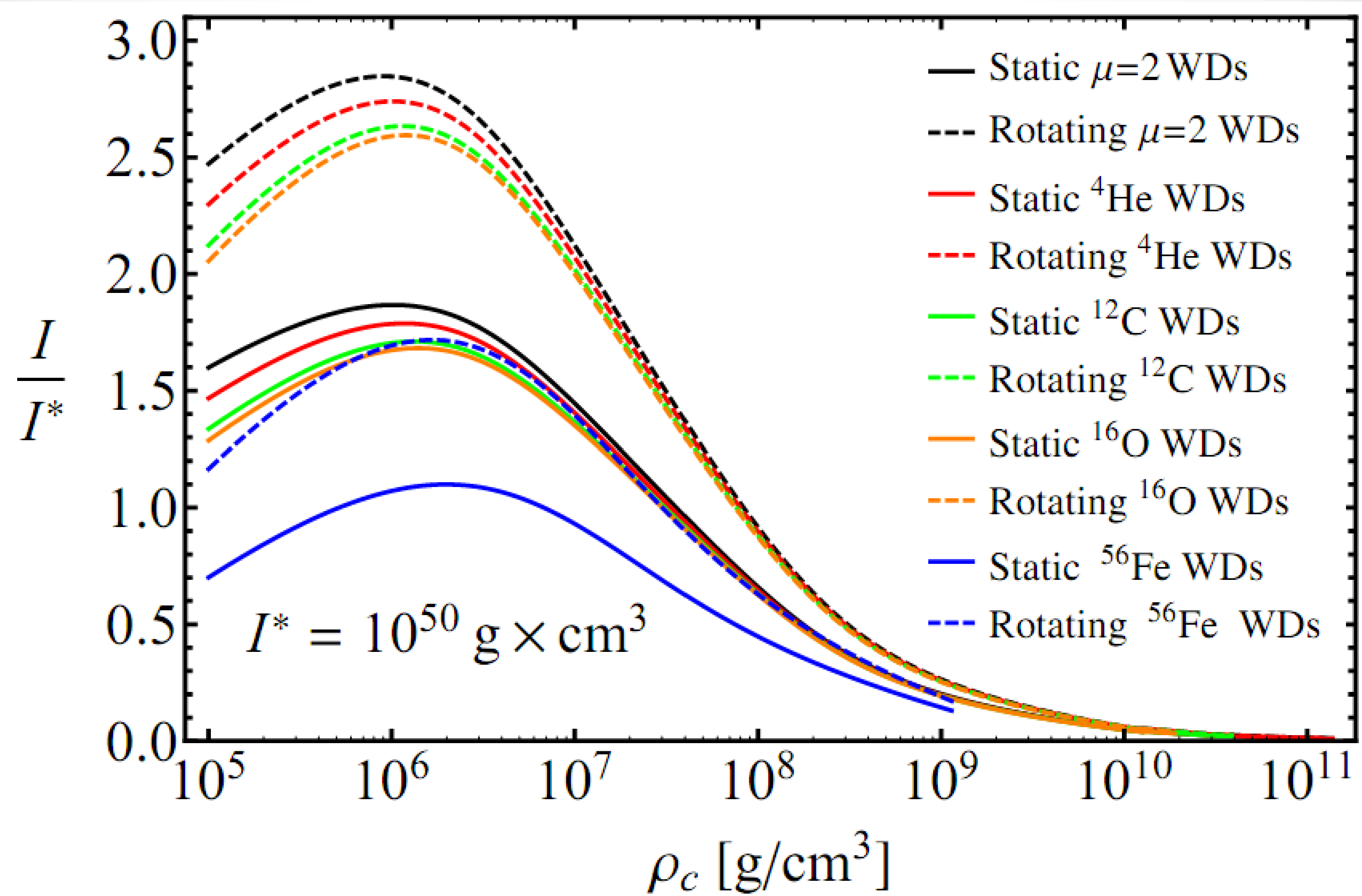

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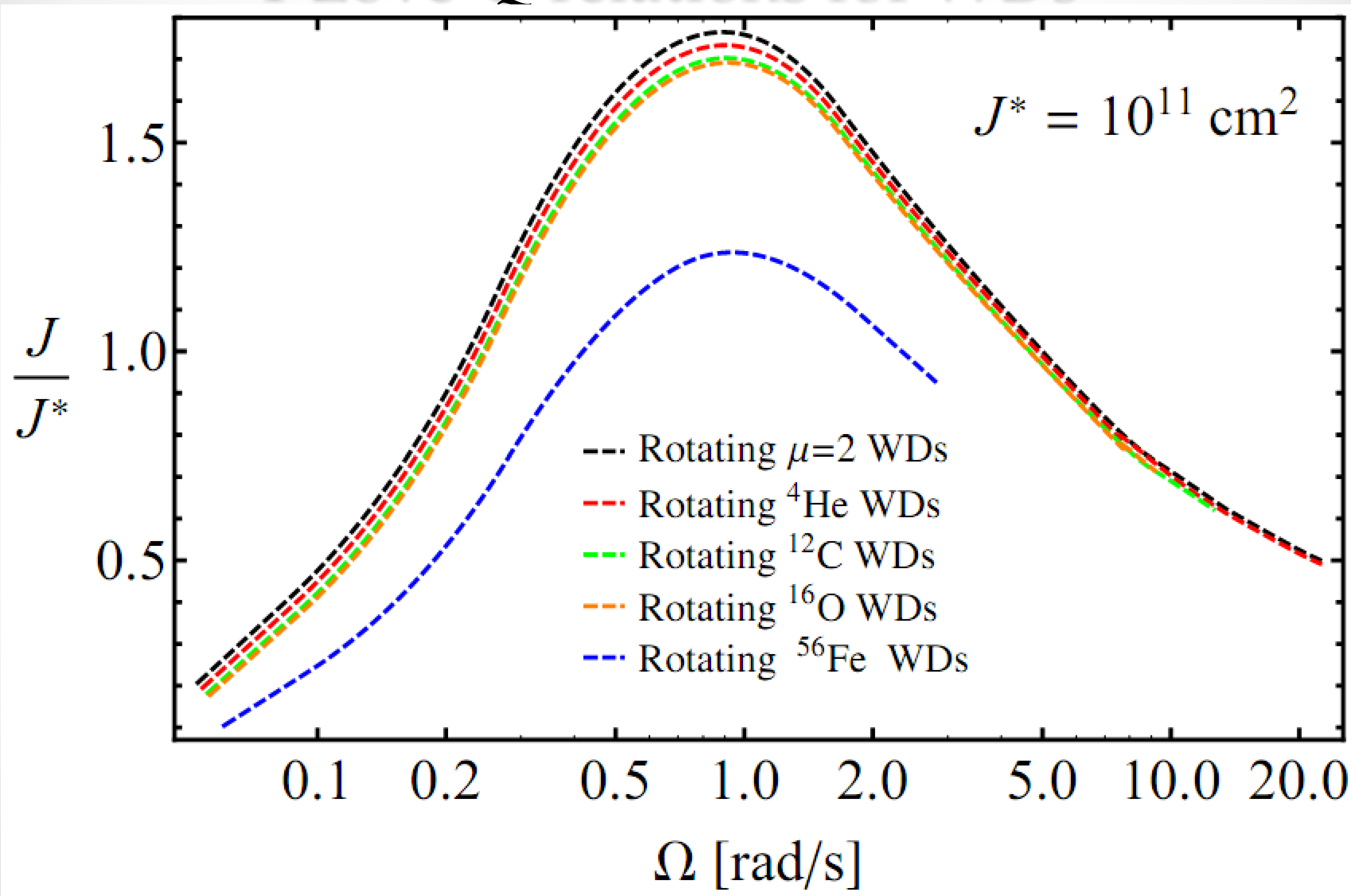

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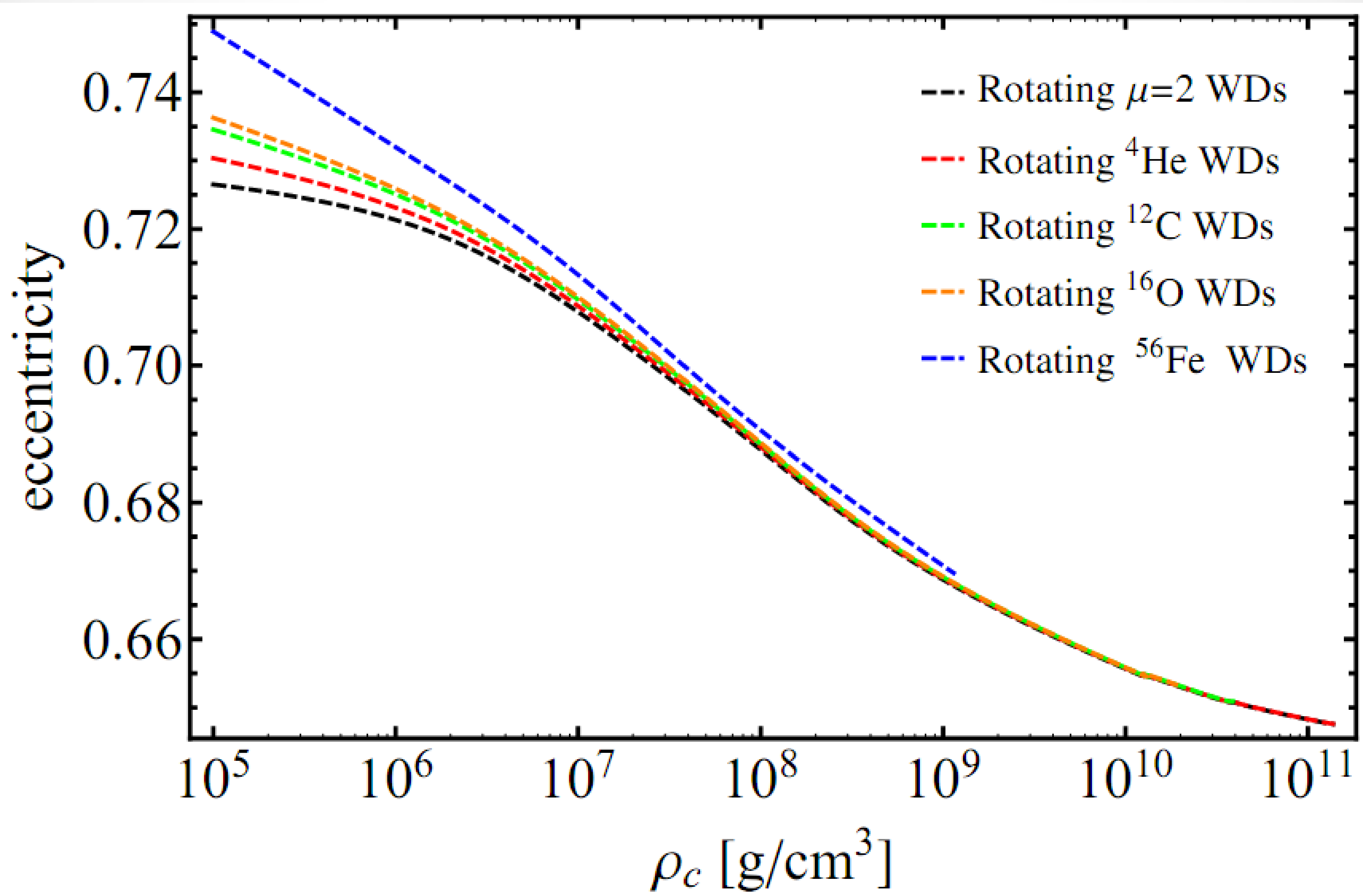

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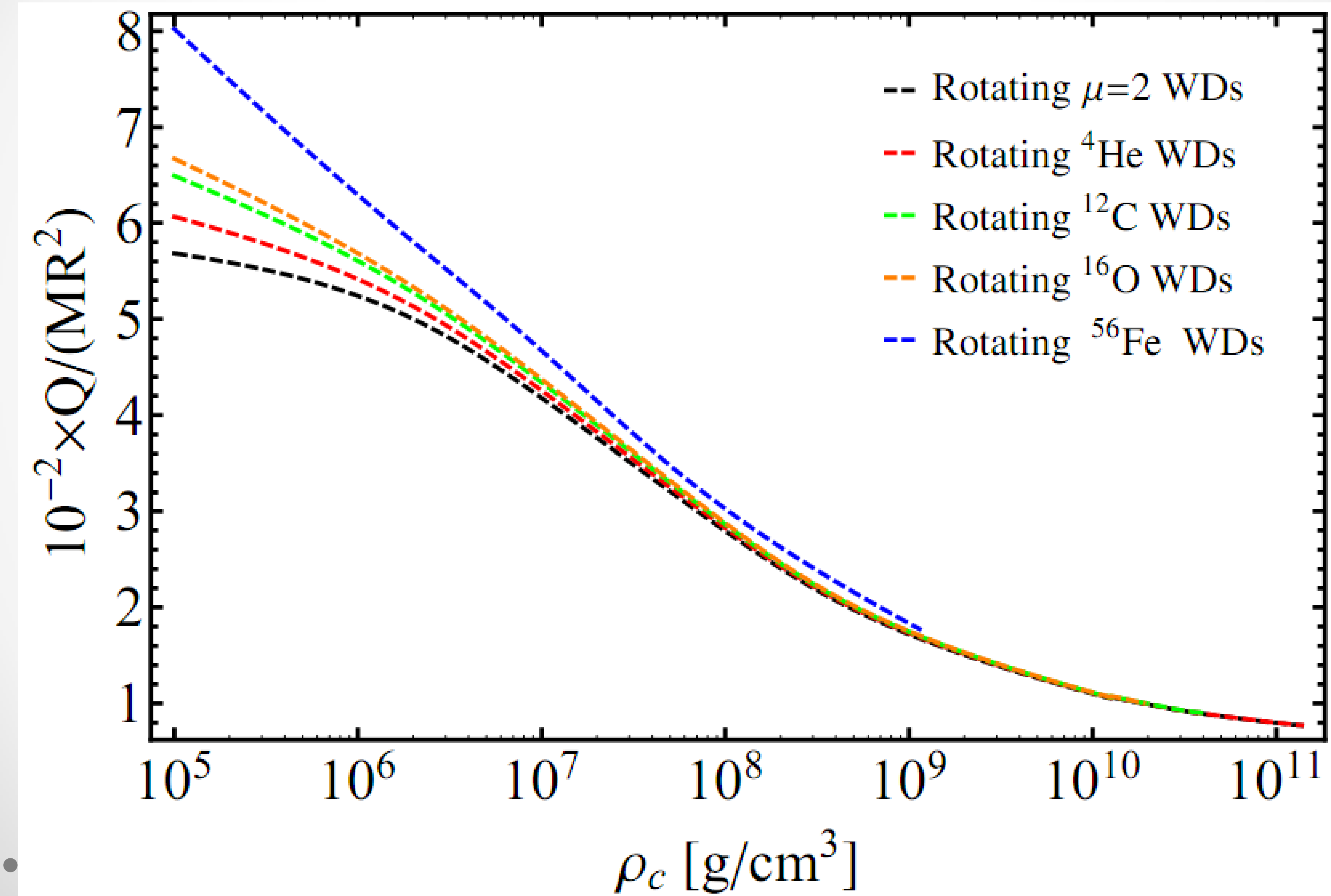

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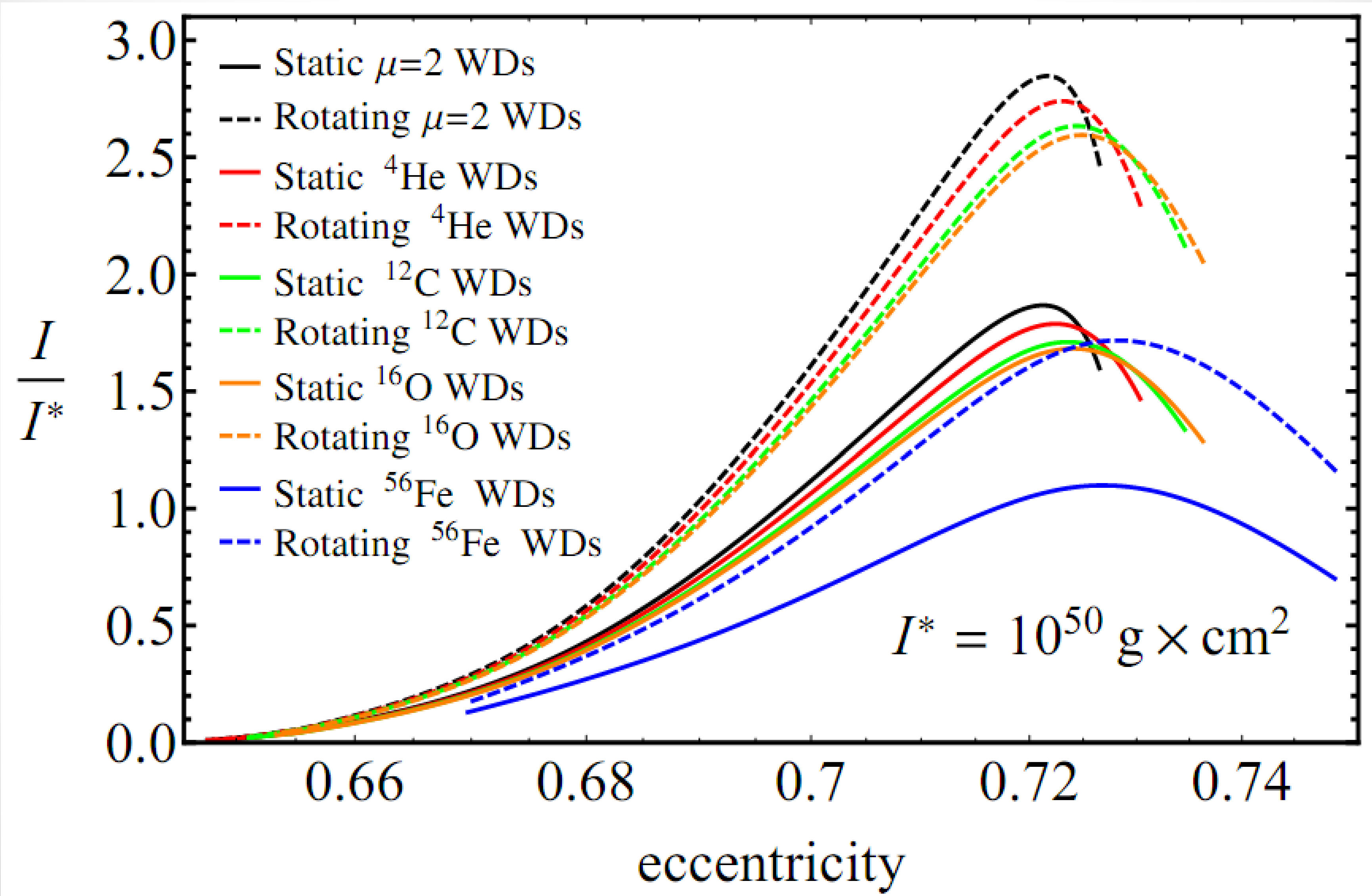

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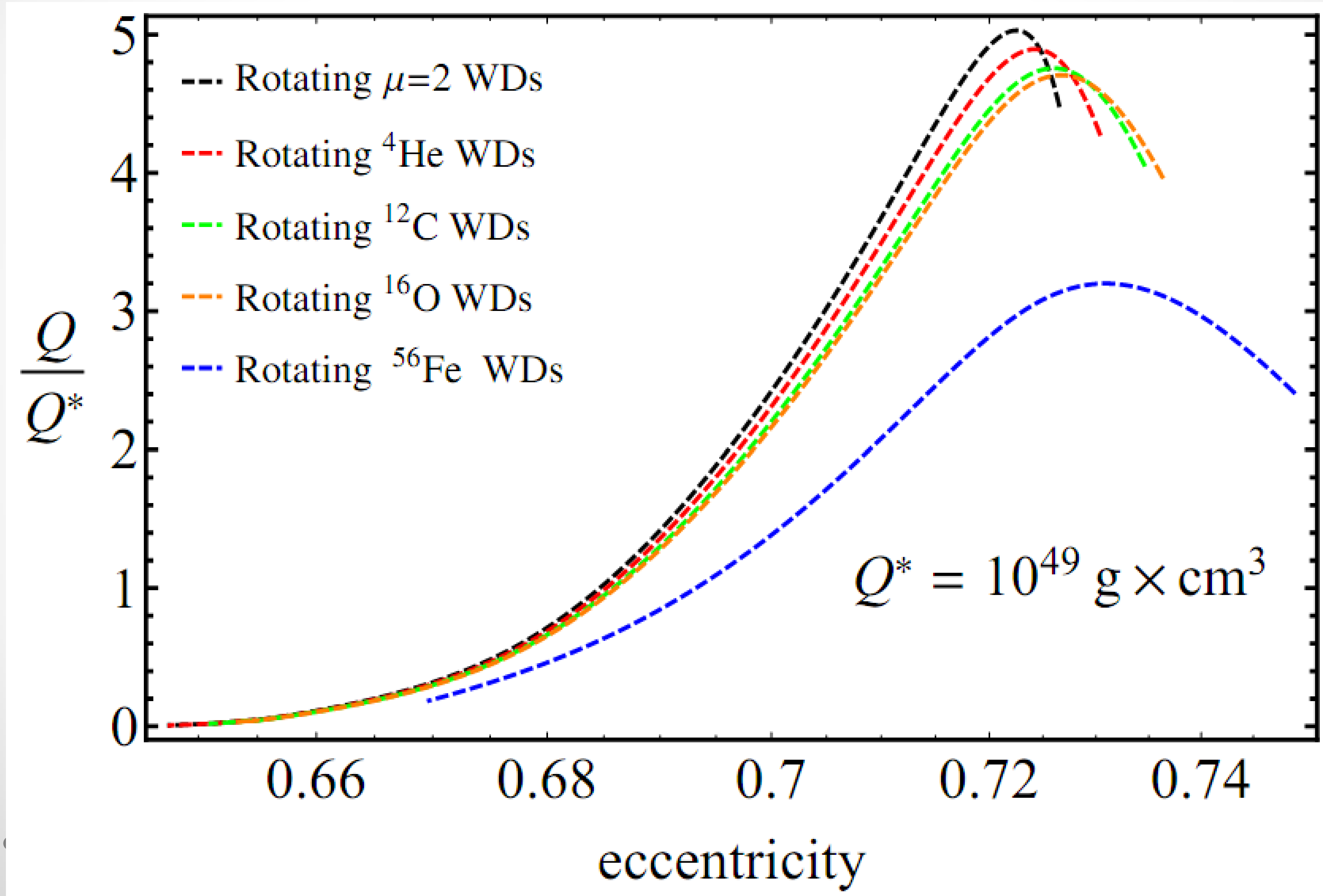

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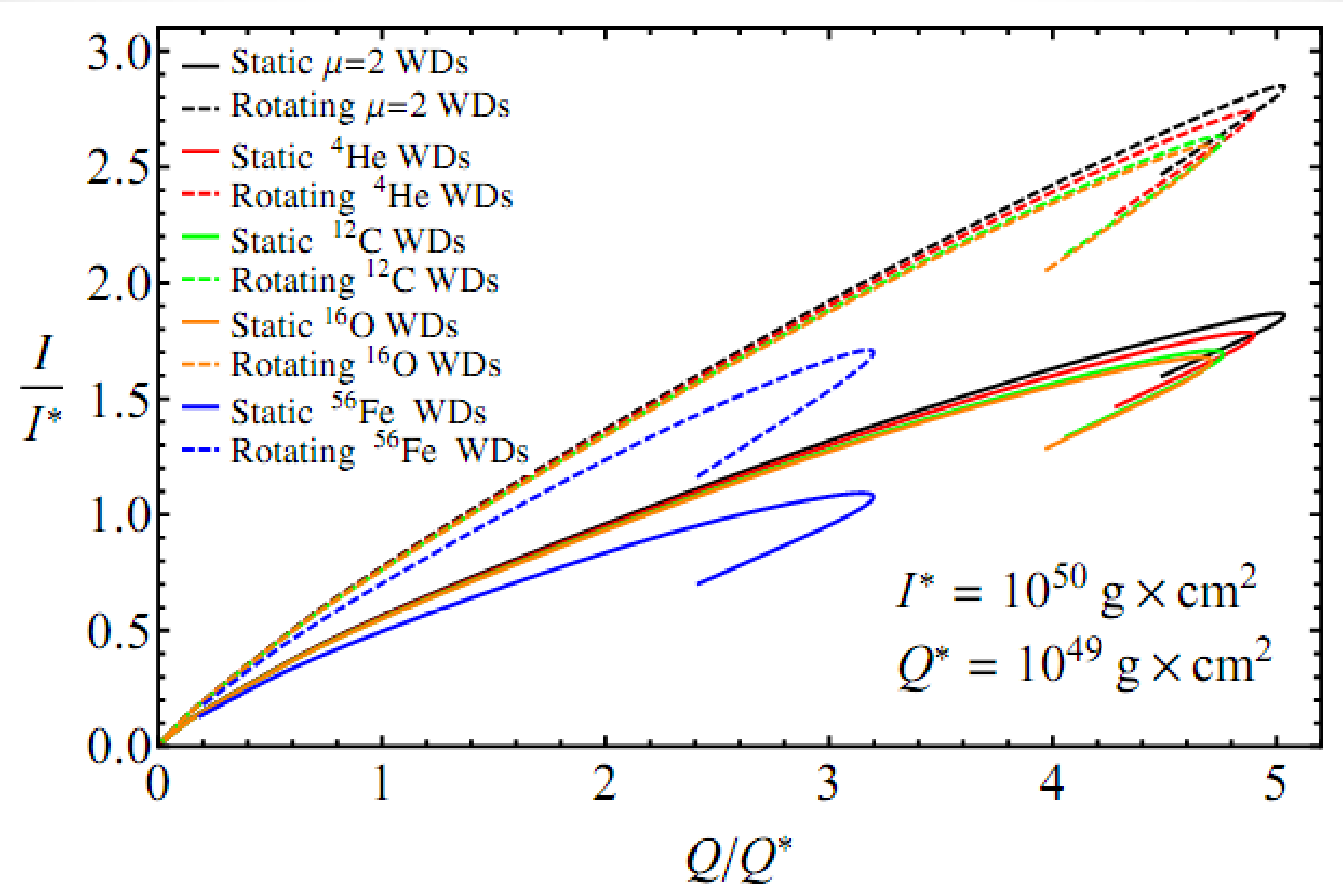

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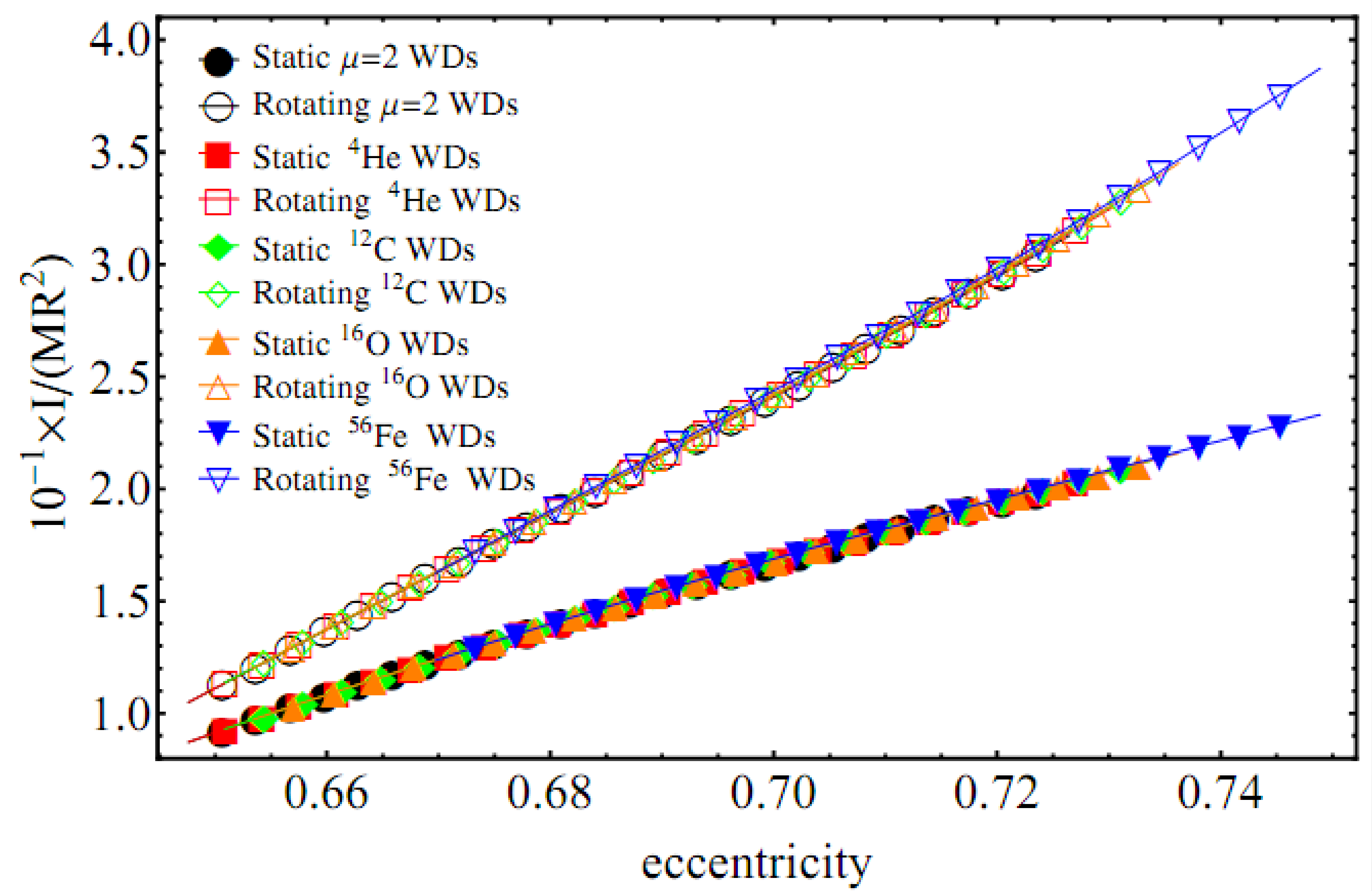

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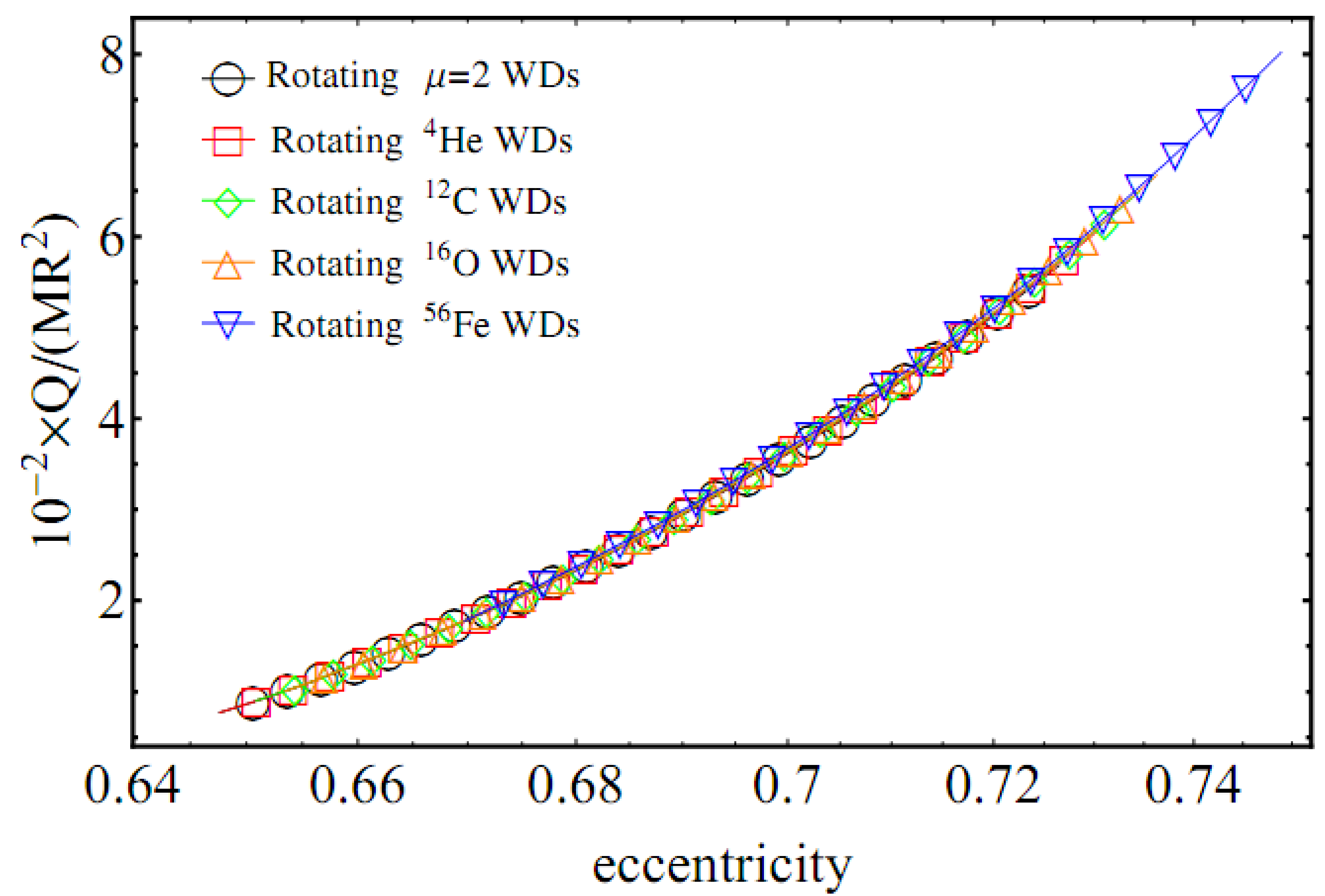

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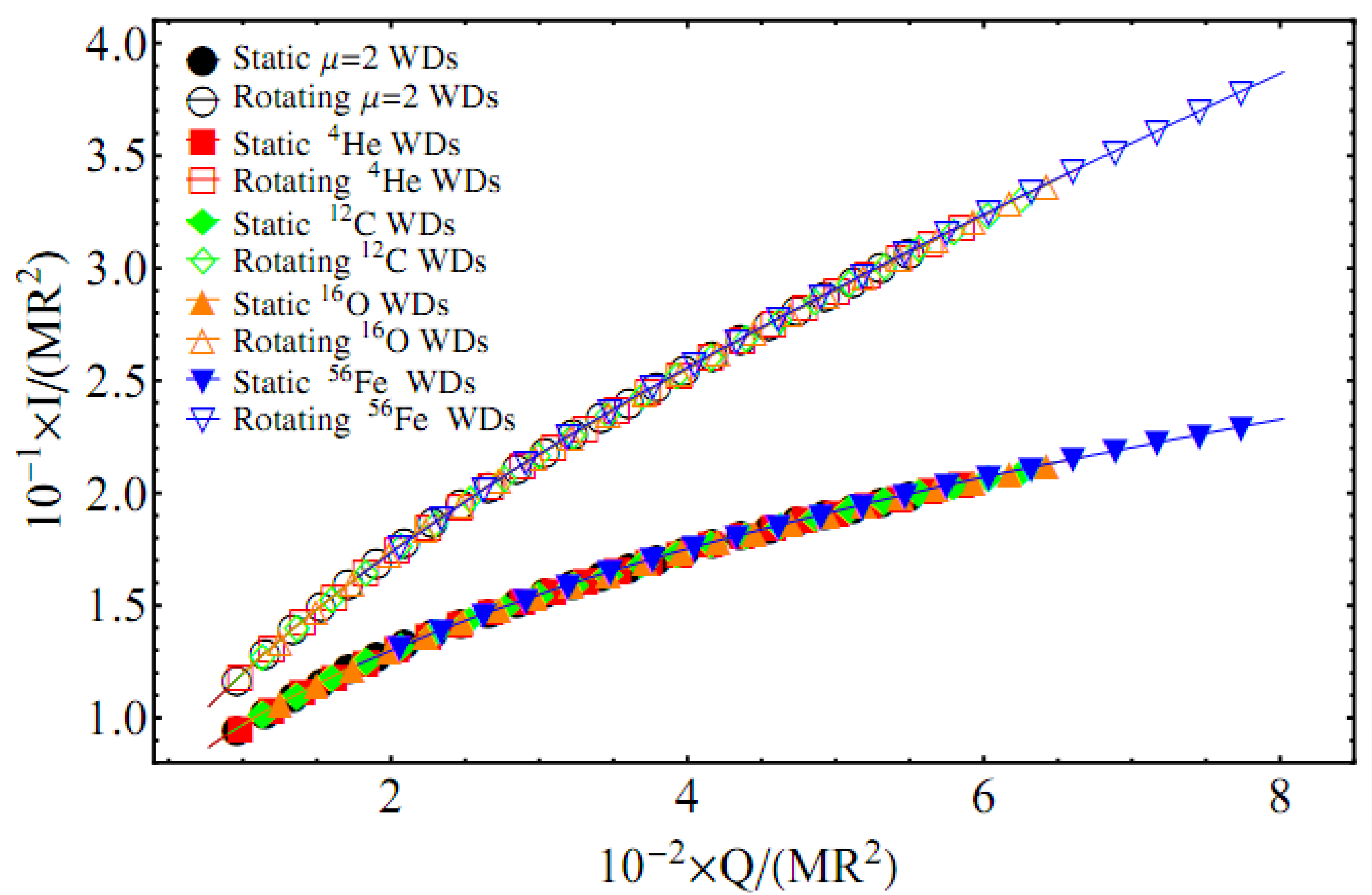

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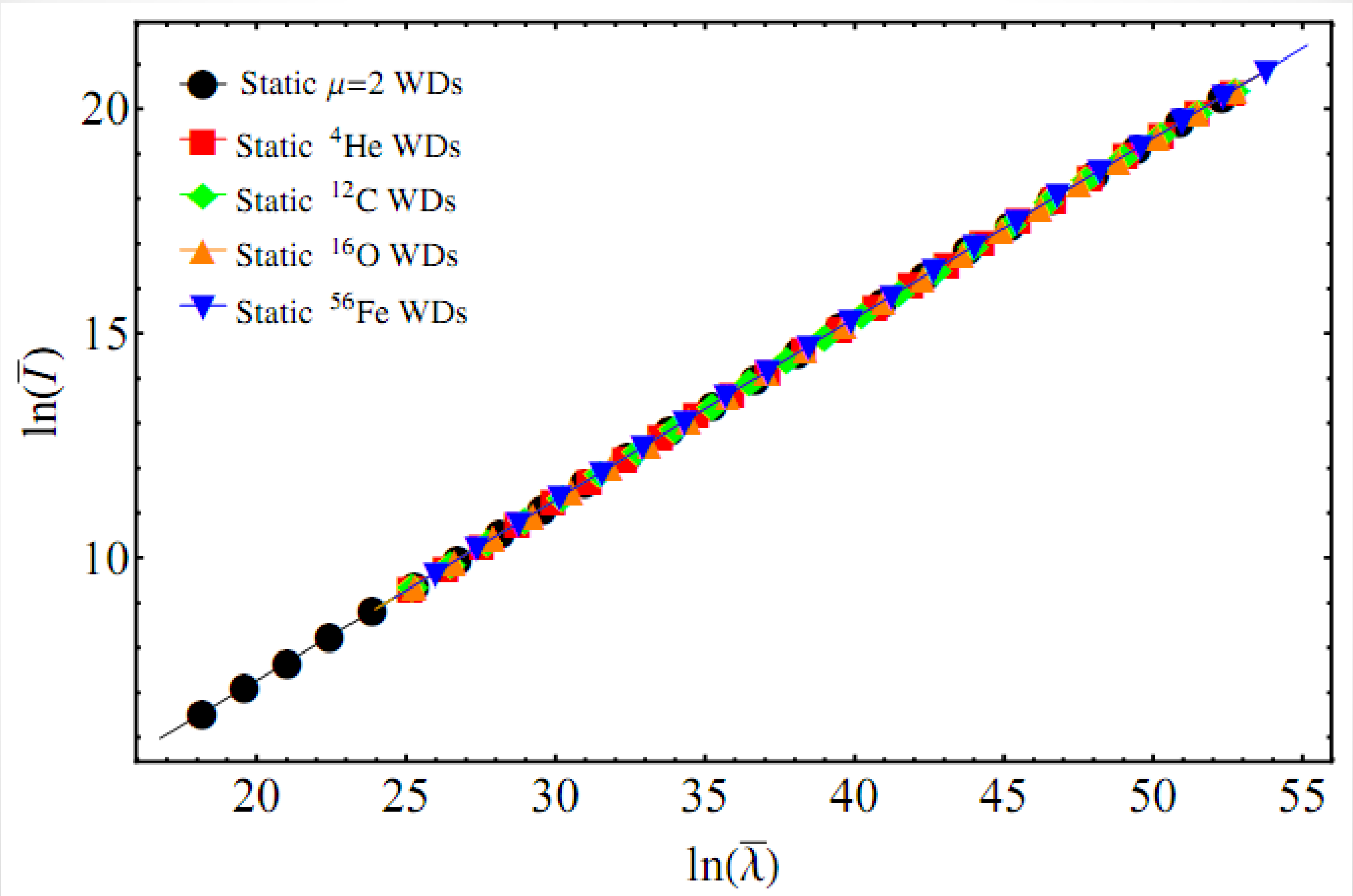

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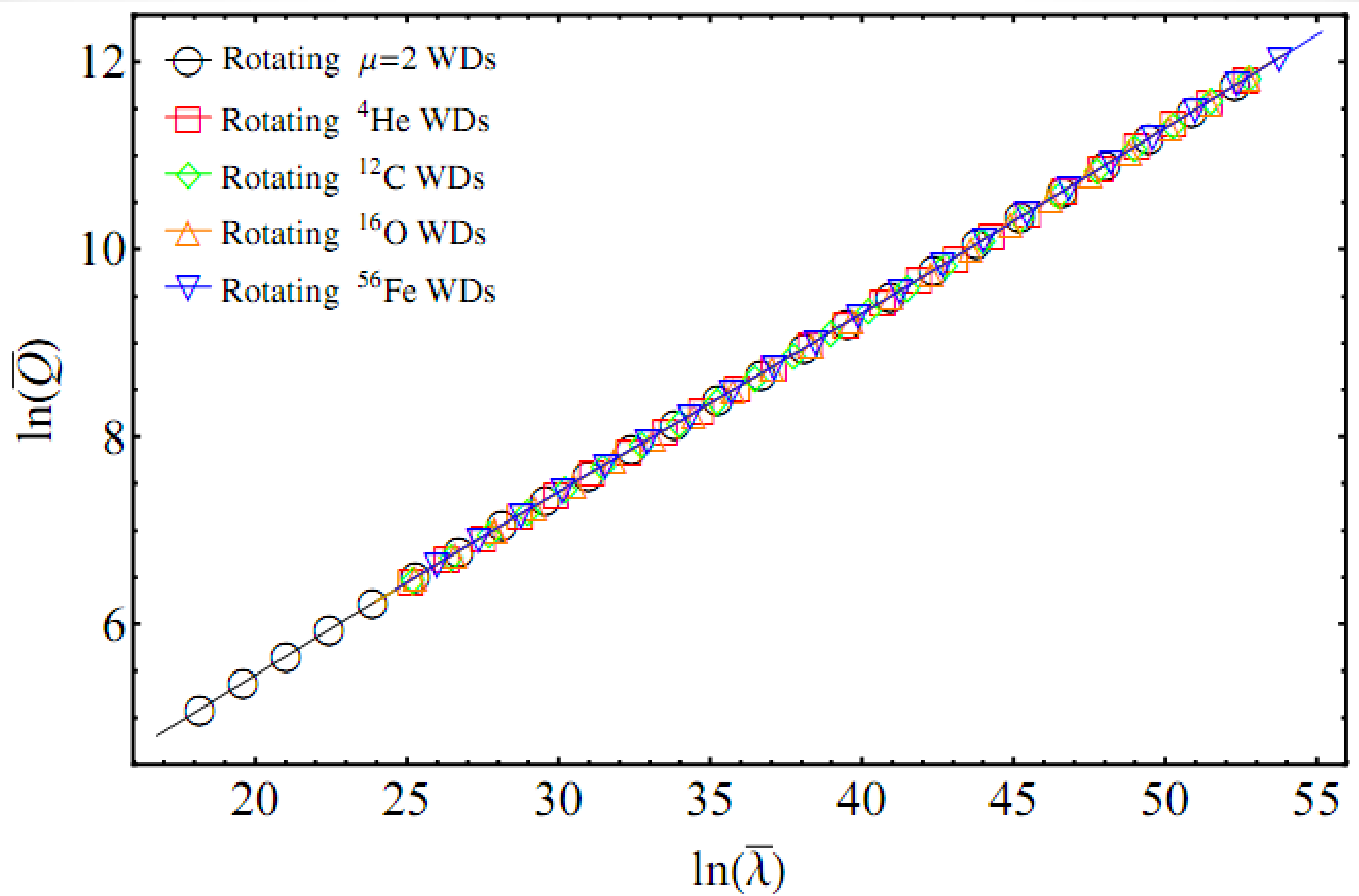

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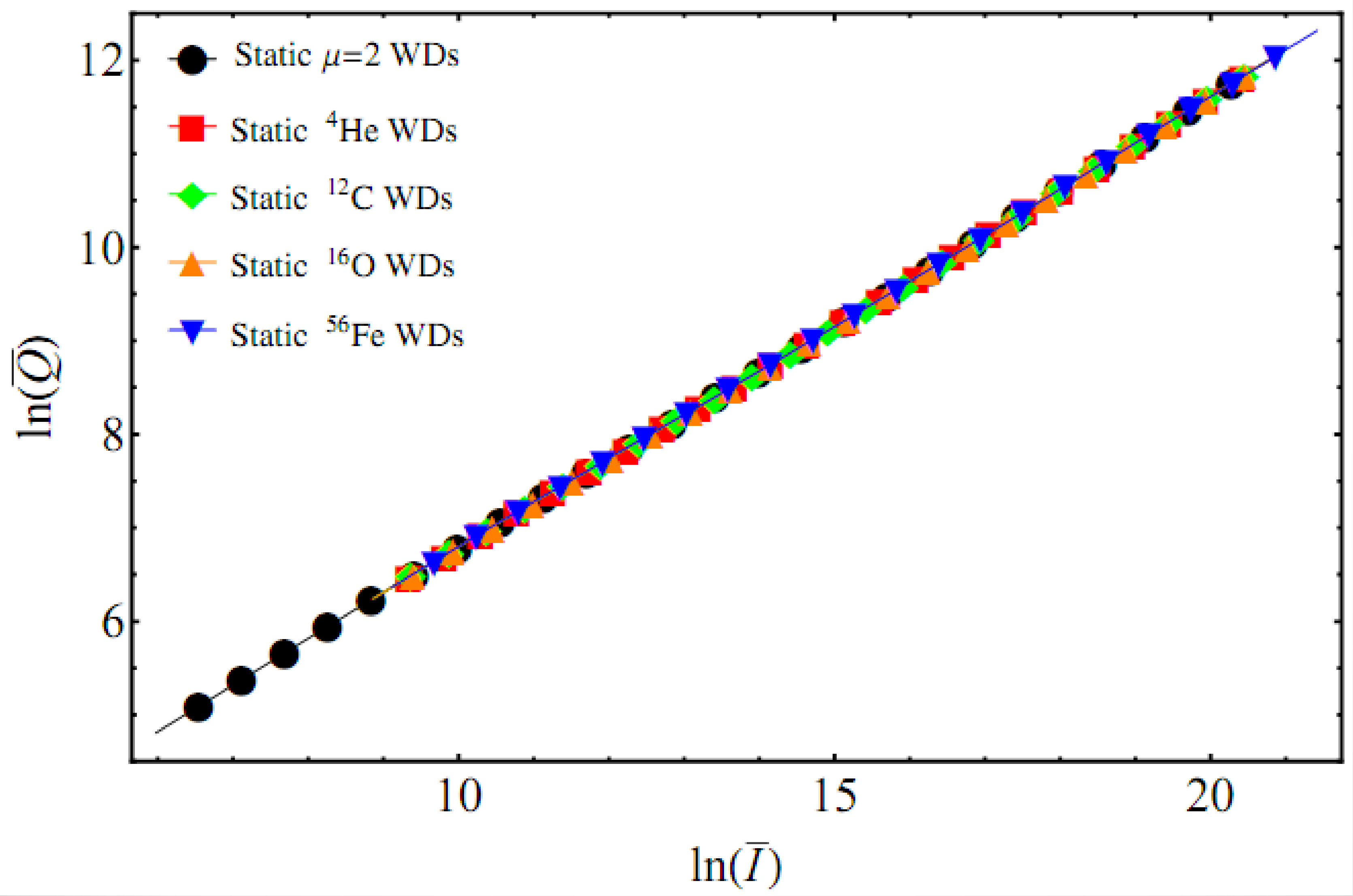

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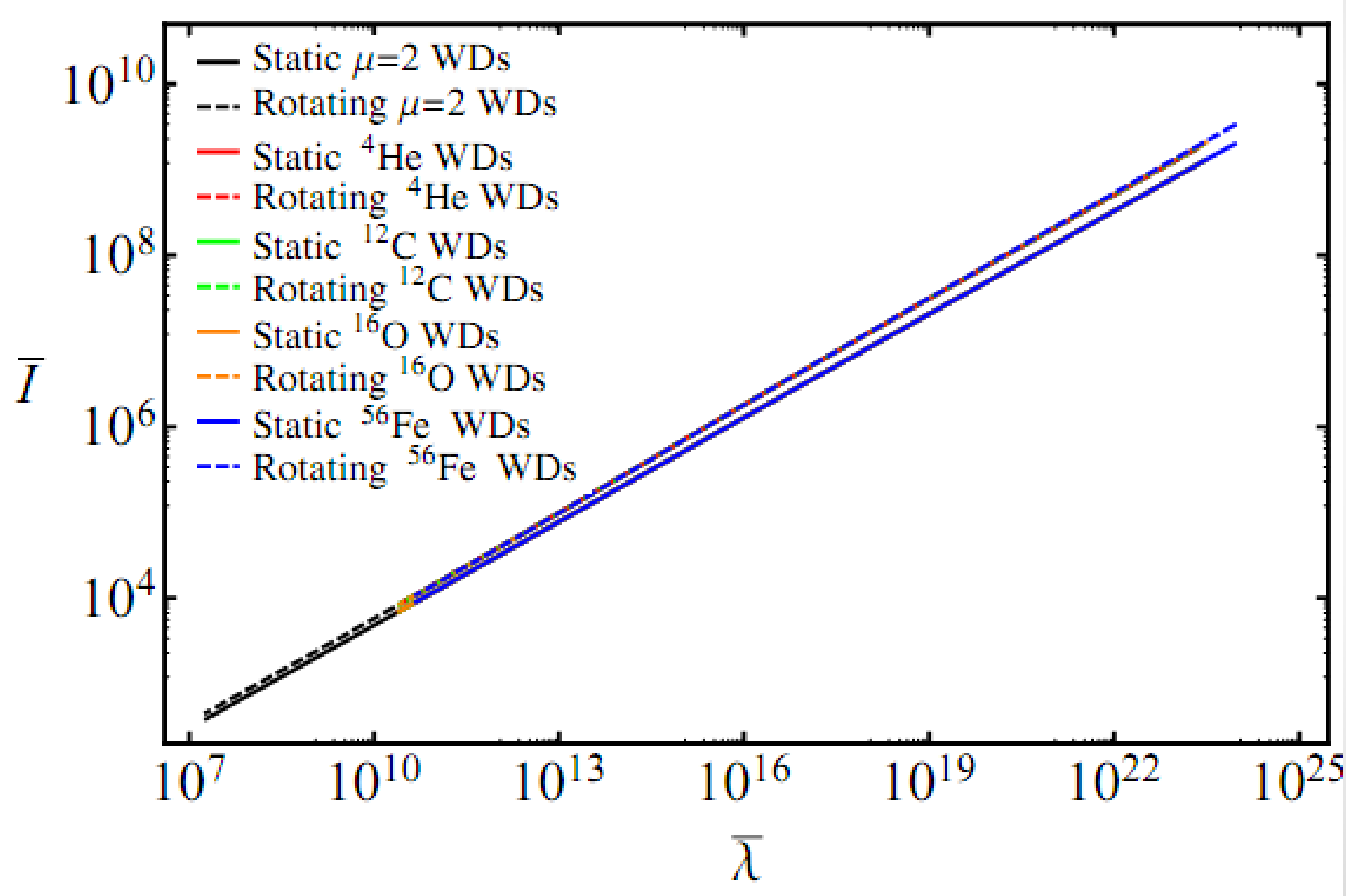

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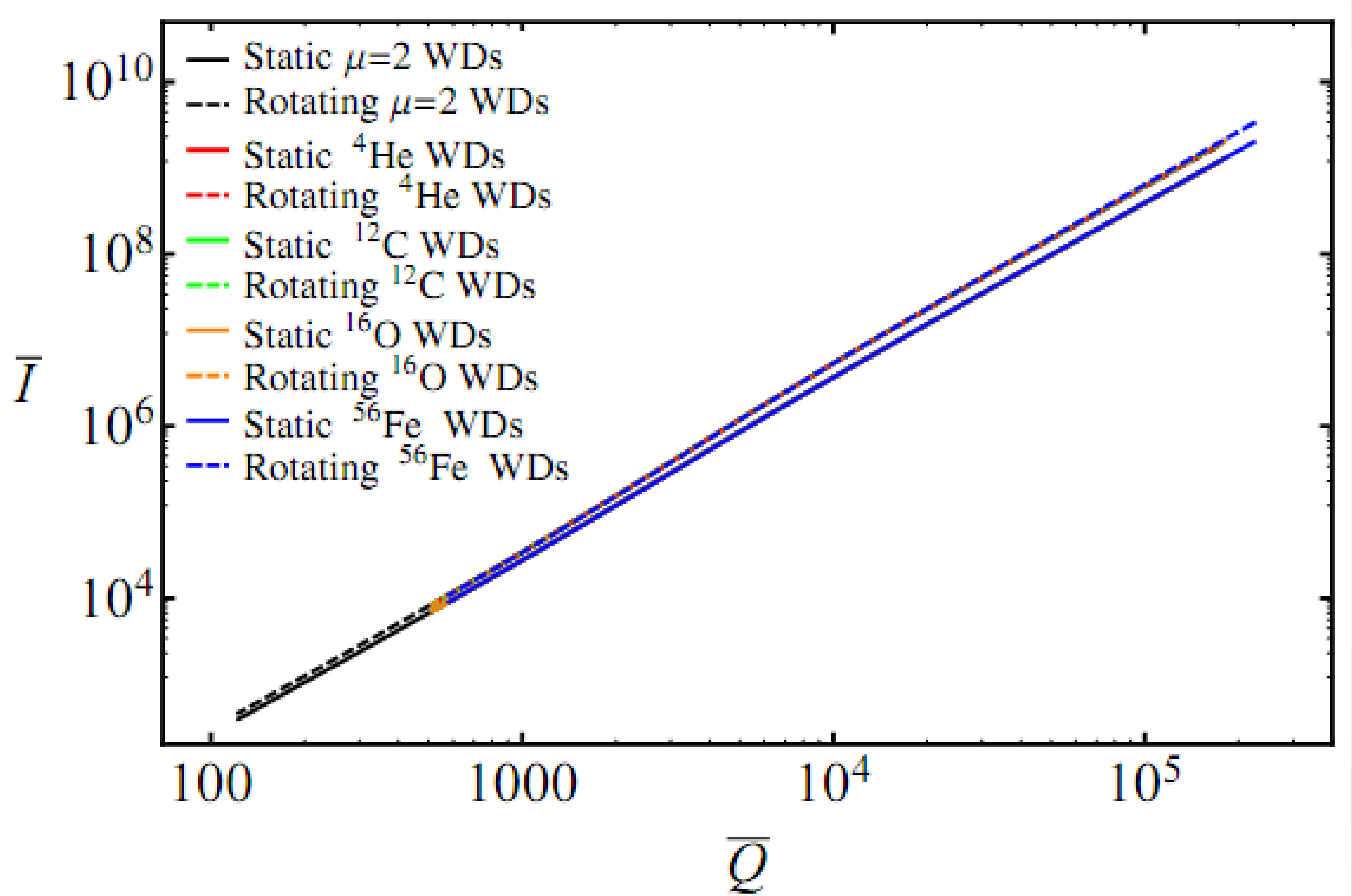

I-Love-Q relations for WDs

$$\lambda = \frac{Q}{\Omega^2}, \qquad GI_{02} = -\frac{2}{3}\sqrt{\frac{5}{4\pi}}k_2\Omega^2 a^5,$$

book by Poisson and Will [24] on page 118

$$-I_{02}\sqrt{4\pi/5} = Q \qquad (2/3)k_2 a^5/G = \lambda$$

I-Love-Q-e relations for WDs

$$J_2 = \frac{2}{3}\frac{k_2}{1+2k_2}e^2, \qquad J_2 = Q/(Ma^2)$$

Poisson and Will [24] on page 119

[24] E. Poisson, C.M. Will, Gravity: Newtonian, Post-Newtonian, Relativistic. (2014).

Thank you
for your attention!