Instabilities of collective neutrino oscillations induced by non-standard neutrino interactions

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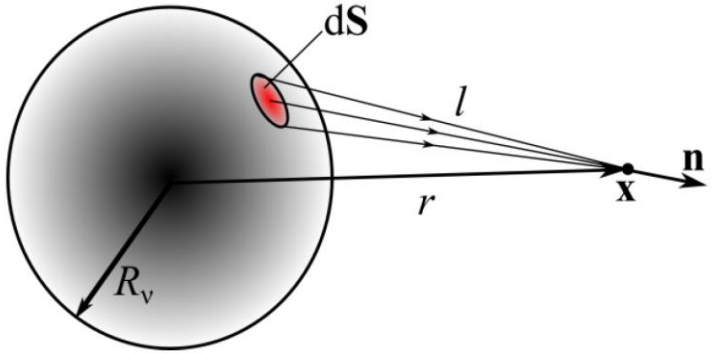
Collective neutrino oscillations under extreme conditions:

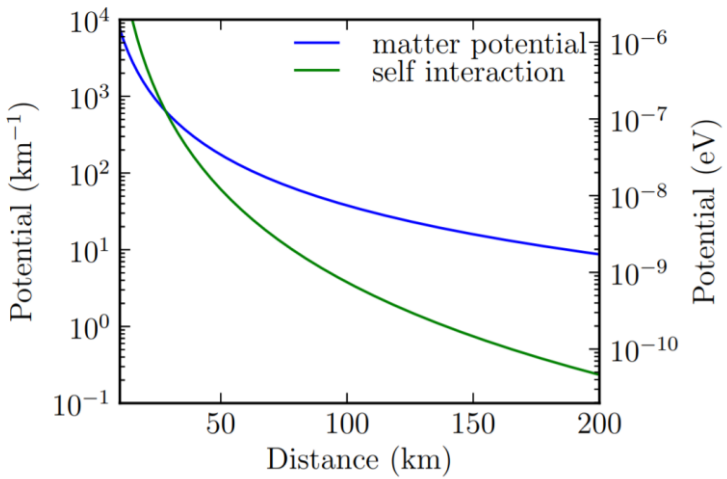
- Calculation of collective oscillations from a *supernova* explosion
- Are there any effects of:
  - Nonzero neutrino magnetic moment?
  - neutrino mass hierarchy?
  - Dirac or Majorana neutrinos?
- A ultradense neutrino medium can possibly develop and enhance instabilities in the evolution of spectra.

The Model

Single-angle scheme with mean-field $\nu\nu$ interaction

- A Protoneutron star:
  - Neutrinosphere radius $R_{NS} = 50\ km$
  - Luminosity $10^{52} - 10^{56}\ \mathrm{sec}^{-1}$
  - Dipole magnetic field $B \sim 10^{12} Gs$ at R_{NS}
  - The effective densities of matter $n_{e,n,p}(r)$ and neutrinos $n_\nu(r)$ are taken from M. T. Keil at al.
  - The initial neutrino spectrum is fixed at $r = R_{NS}$





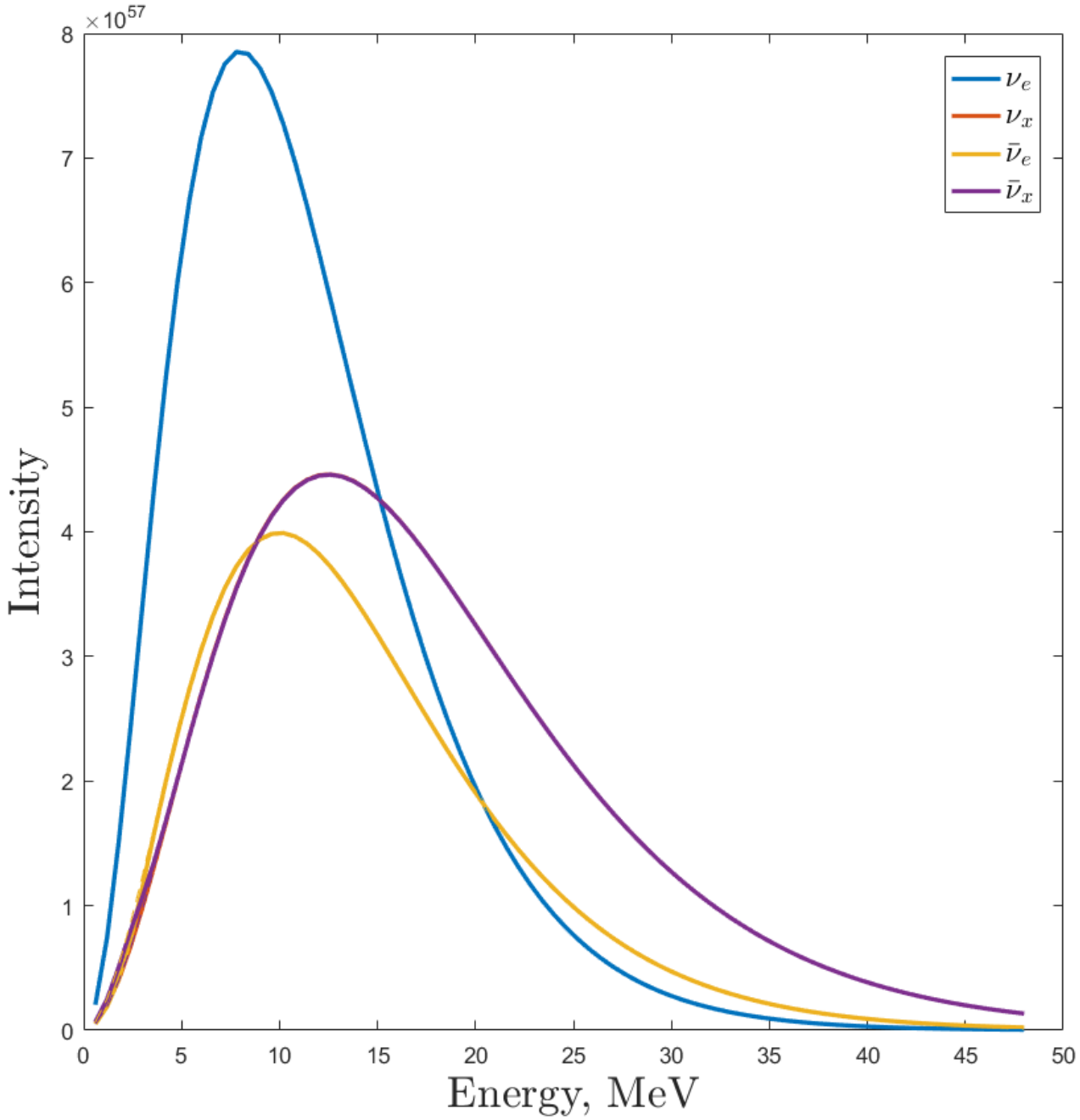
A. de Gouvea, S. Shalgar, JCAP **10 (2012)**, 027

M. T. Keil, G. G. Raffelt, and H.-T. Janka, Astrophys.J. 590, 971 (2003), astro-ph/0208035.

The Model

- Neutrino:
  - Majorana and Dirac
  - Two flavors: $\nu_e, \bar{\nu}_e, \nu_x, \bar{\nu}_x$
  - Two hierarchies NH, IH
  - Transition magnetic moment

$\mu_{12} \equiv \mu = 10^{-19} \div 10^{-15} \mu_B$



The Evolution equation

$$\frac{d\rho}{dr} = \frac{i}{\hbar c}[H, \rho]$$

$$H = H_{vac} + H_{med} + H_{amm} + H_{slf}$$

- $H_{vac} = \frac{\Delta m^2}{4E}\begin{pmatrix} M & 0 \\ 0 & M \end{pmatrix}$, $\quad M = \begin{pmatrix} -cos2\Theta & sin2\Theta \\ sin2\Theta & cos2\Theta \end{pmatrix}$
- $H_{med} = G_F\sqrt{2}(\hbar c)^3\begin{pmatrix} V & 0 \\ 0 & V \end{pmatrix}$, $V = \begin{pmatrix} n_e(x) - n_n(x)/2 & 0 \\ 0 & -n_n(x)/2 \end{pmatrix}$
- $H_{amm} = \begin{pmatrix} 0 & -\mathcal{M}B_\perp \\ \mathcal{M}B_\perp & 0 \end{pmatrix}$, $\quad \mathcal{M} = \begin{pmatrix} 0 & \mu \\ -\mu & 0 \end{pmatrix}$

Self-interaction

$$H_{slf} = G_F\sqrt{2}(\hbar c)^3 \int_0^\infty dE'\{tr(\rho(x,E')G)G + [\rho(x,E') - \rho^{cT}(x,E')]^\times\}$$

$$G = \begin{pmatrix} I & 0 \\ 0 & -I \end{pmatrix}$$

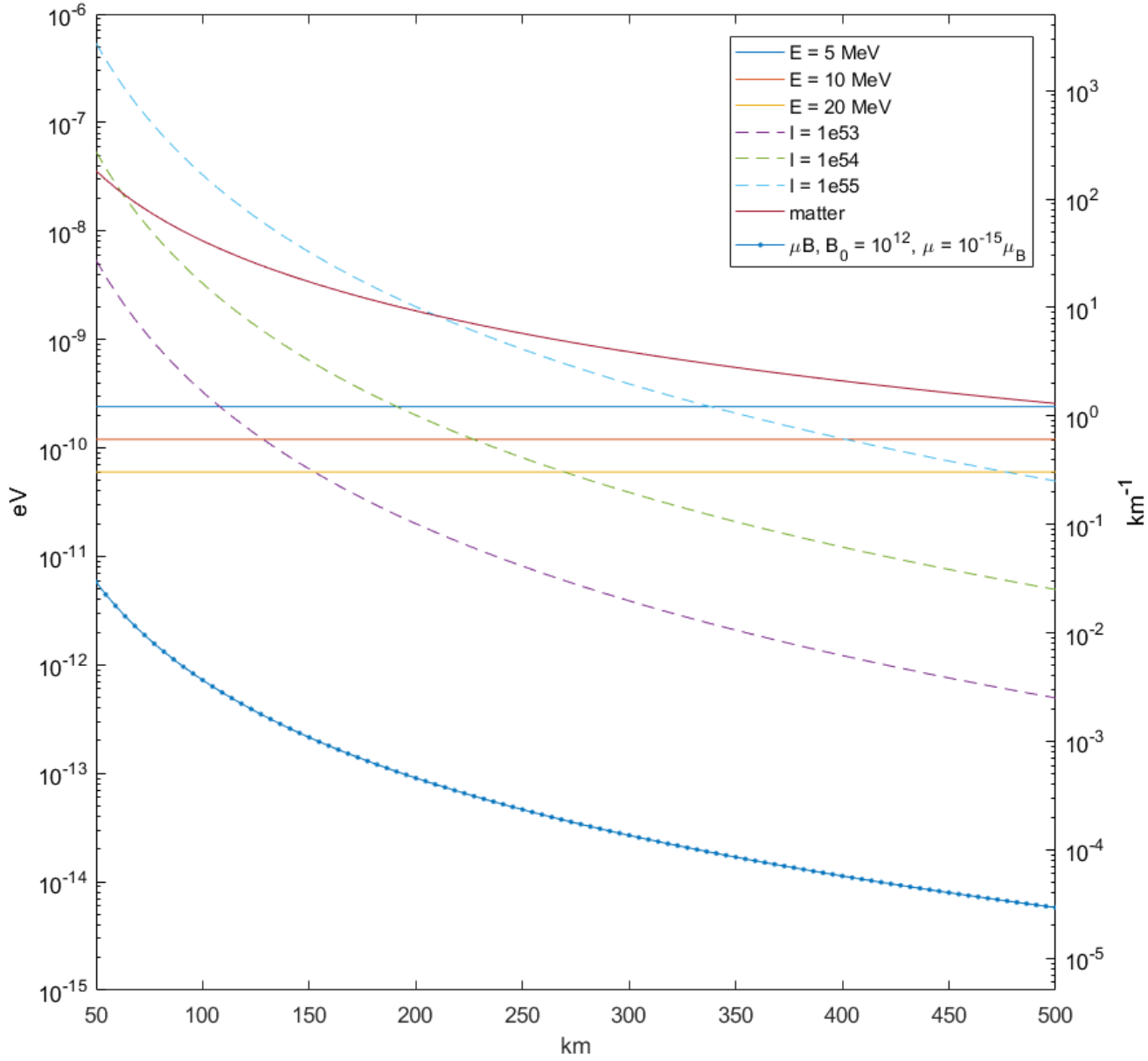
$$\rho = \begin{pmatrix} A & B \\ C & D \end{pmatrix} \Rightarrow \rho^{\mathrm{T}} = \begin{pmatrix} A^{\mathrm{T}} & C^{\mathrm{T}} \\ B^{\mathrm{T}} & D^{\mathrm{T}} \end{pmatrix}, \quad \rho^{\mathrm{c}} = \begin{pmatrix} D & C \\ B & A \end{pmatrix}, \quad \rho^{\times} = \begin{pmatrix} A & \mathbb{O} \\ \mathbb{O} & D \end{pmatrix}.$$

For details, see: 1) A. de Gouvea, S. Shalgar, JCAP **10 (2012)**, 027

2) H. Duan, G.M. Fuller, Y.-Z. Qian (2010) Vol. 60:569-594

Effective potentials

- Self-int. potential $\propto r^{-4}$
- Matter potential $\propto r^{-2}$
- The effective potential of the magnetic field μB is significantly small at all distances, but nevertheless, it can cause instabilities.



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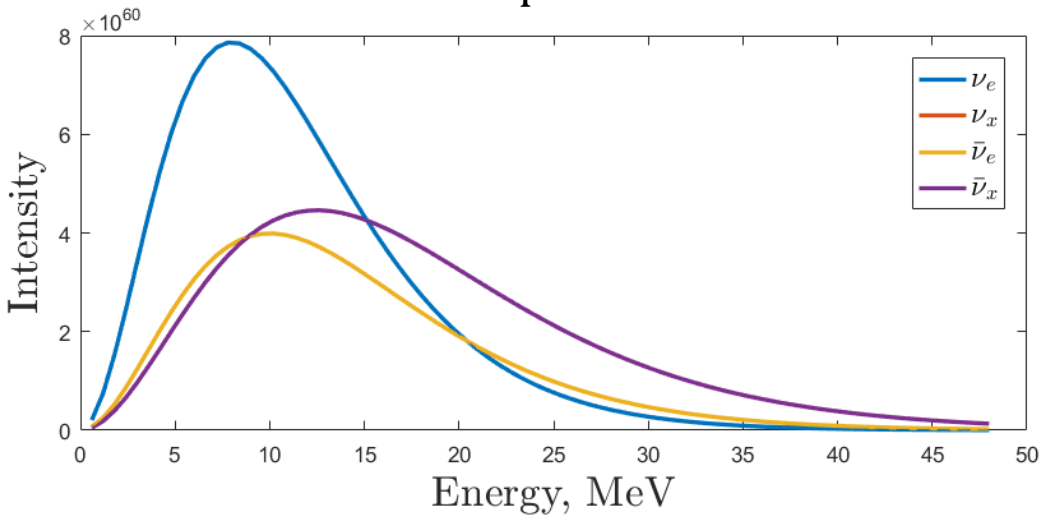
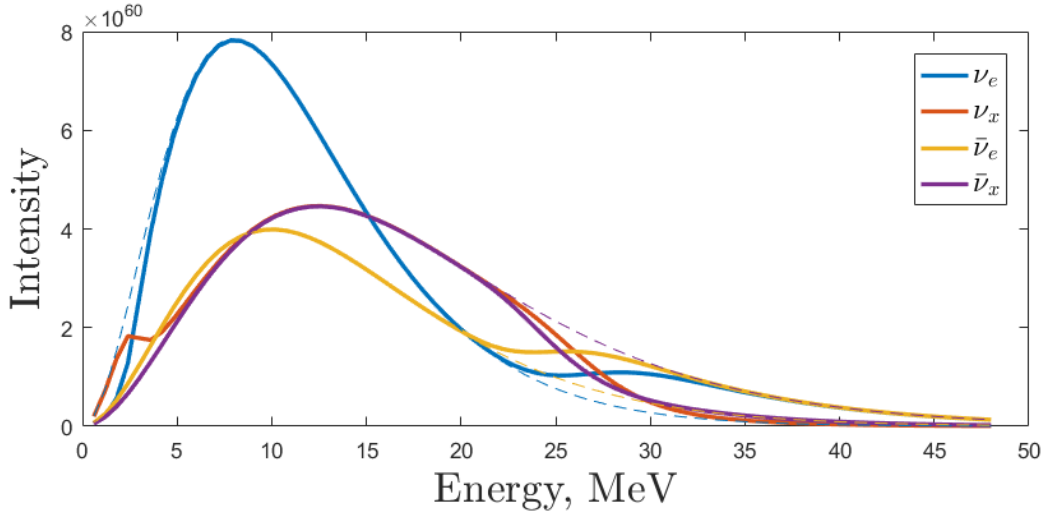
An example of neutrino spectrum evolution

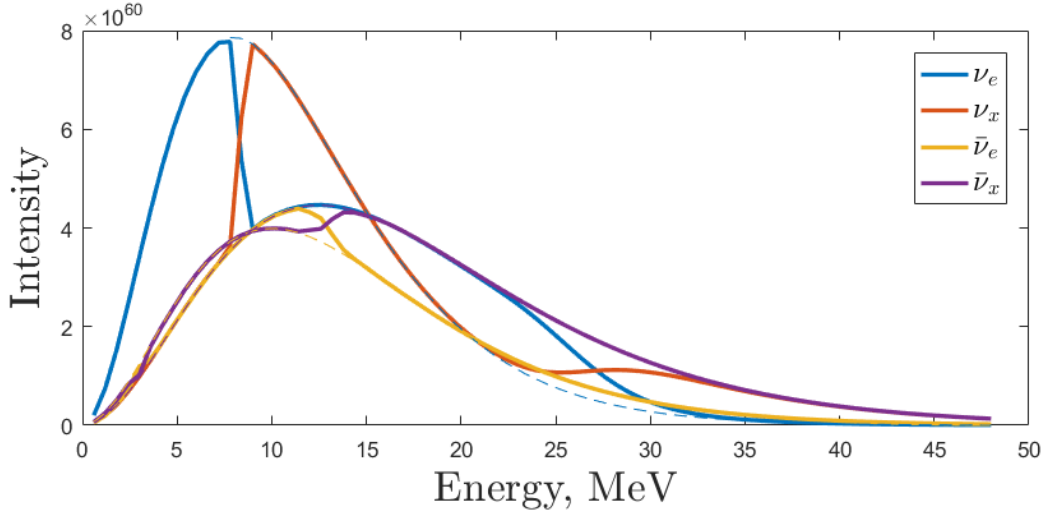
Initial spectrum



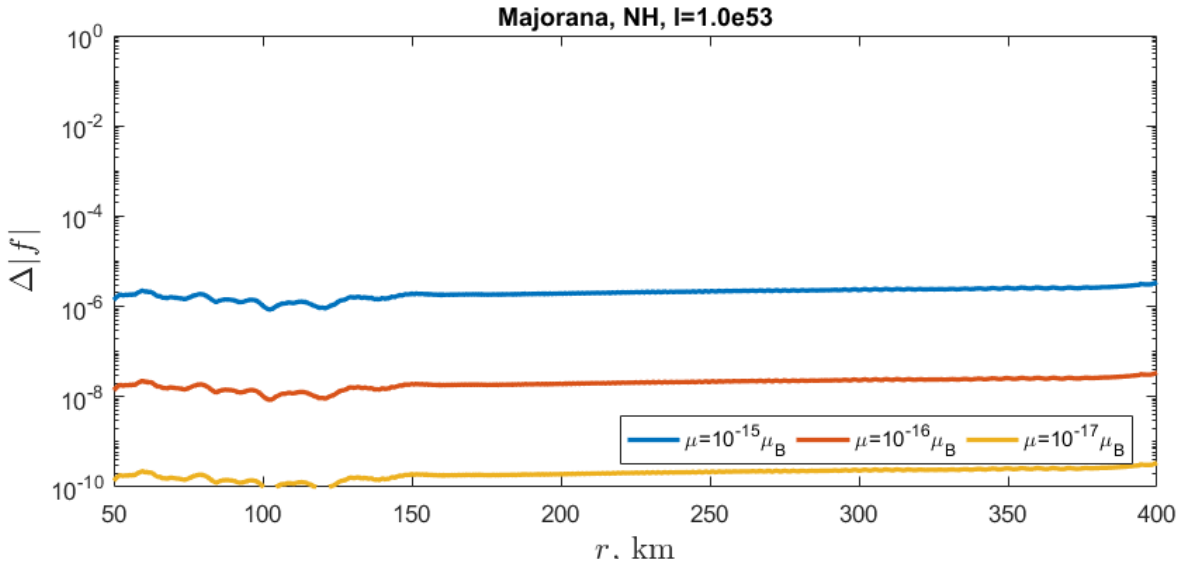
Normal hierarchy

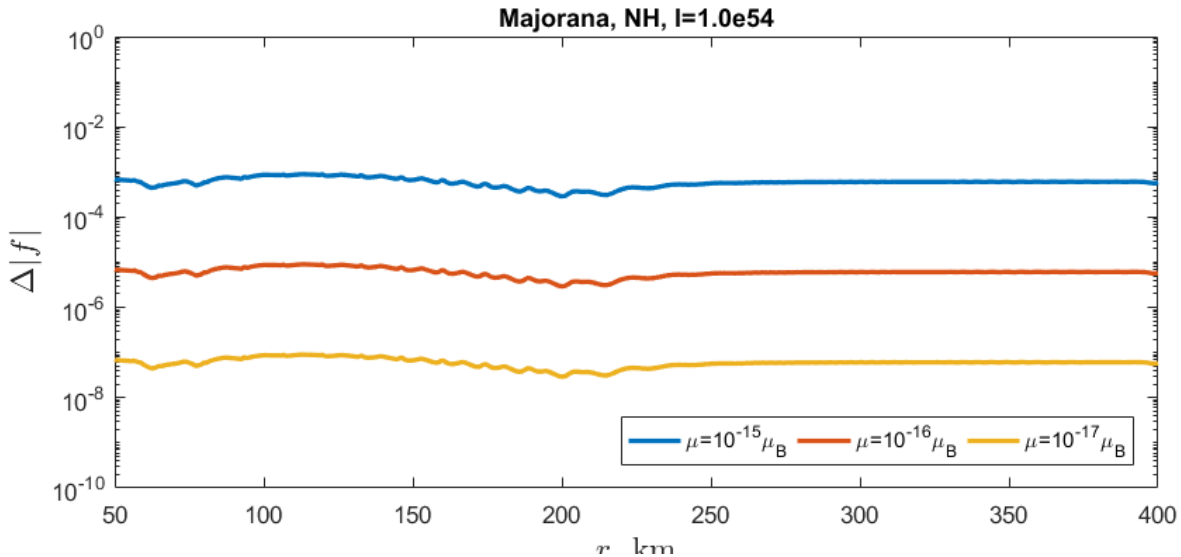


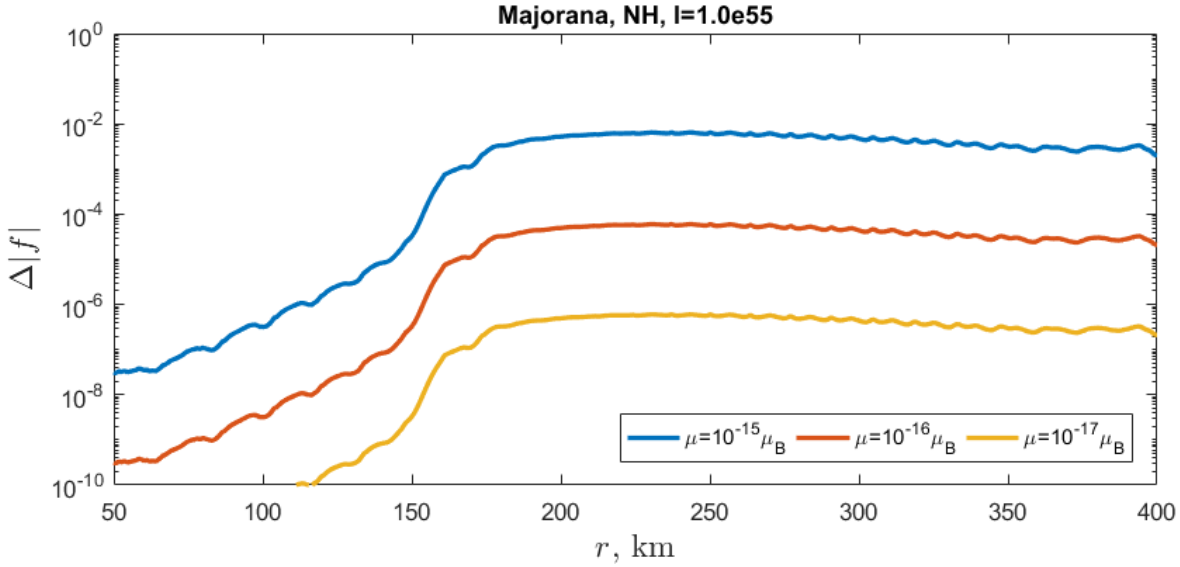
Inverted hierarchy

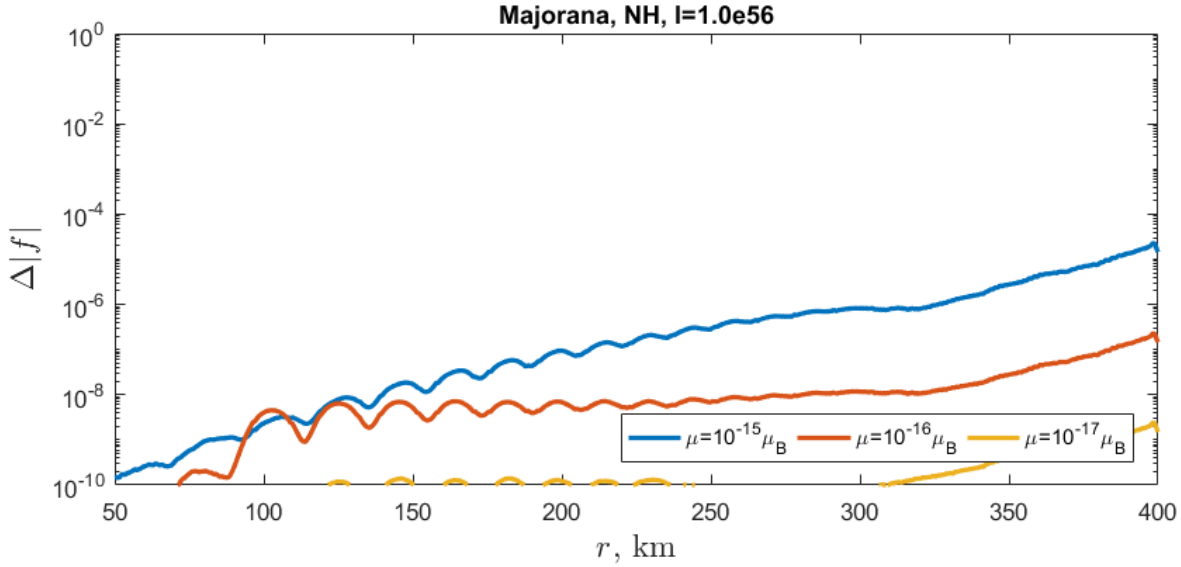


Majorana, Normal Hierarchy, $\Delta|f| = |f_{\mu=0} - f_{\mu}|$

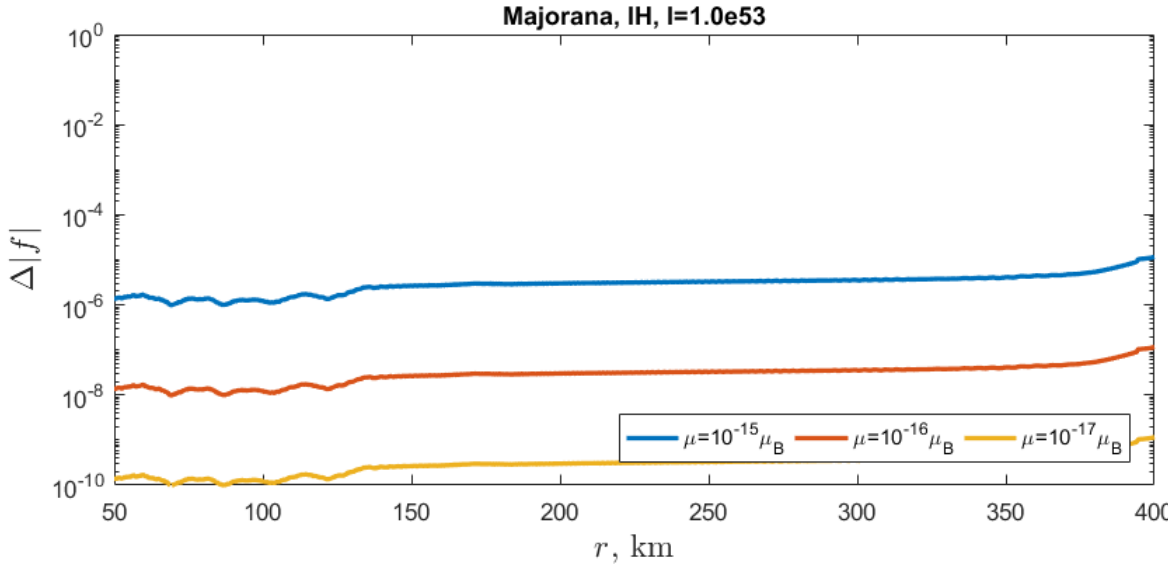


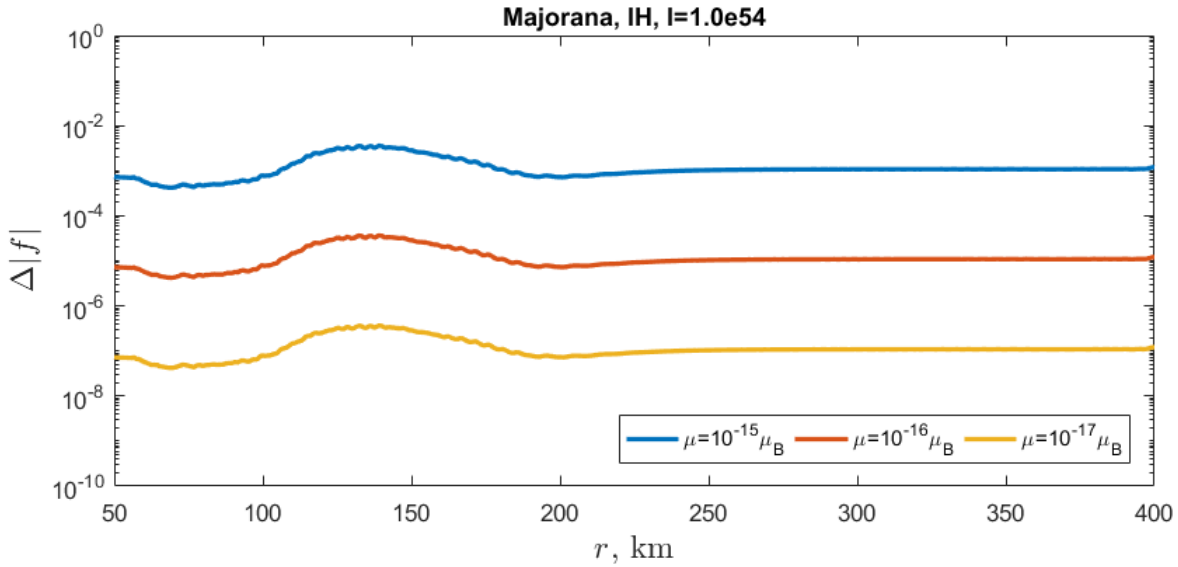


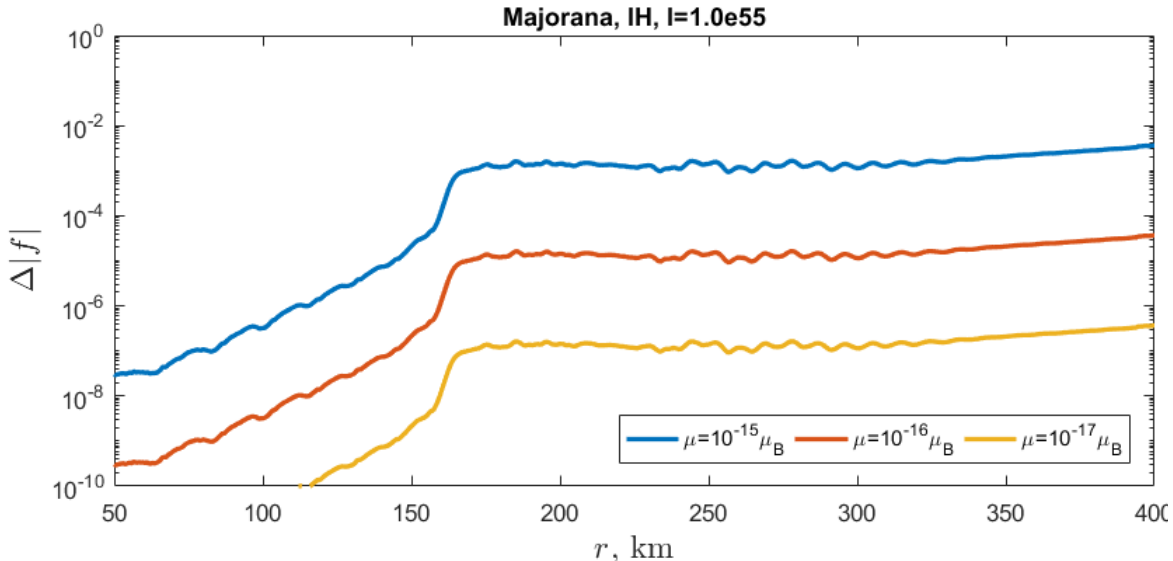


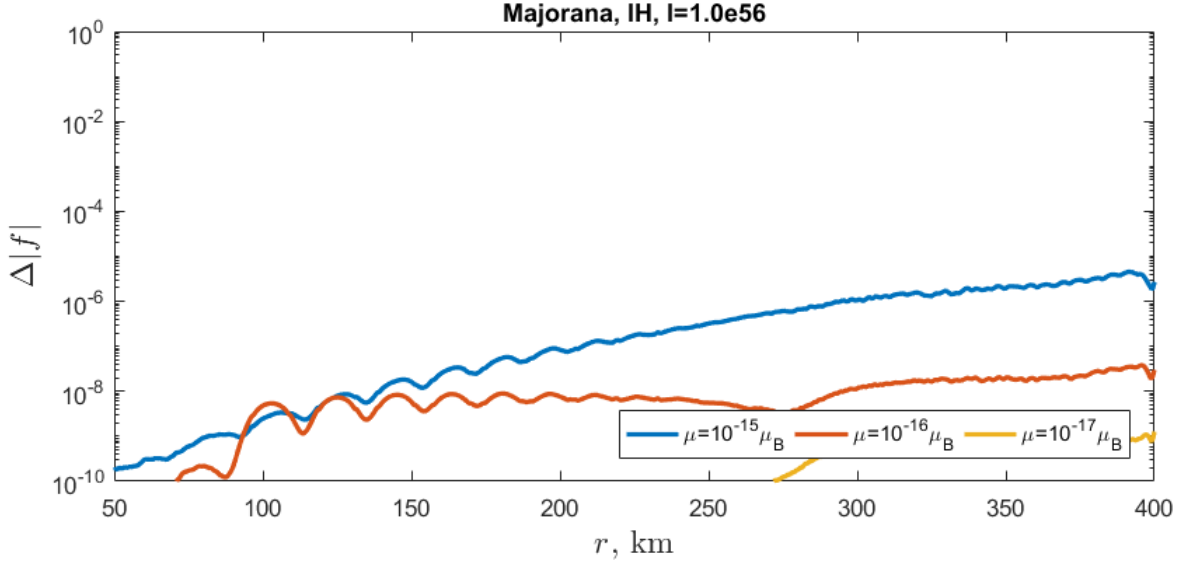


Majorana, Inverted Hierarchy, $\Delta|f| = |f_{\mu=0} - f_{\mu}|$

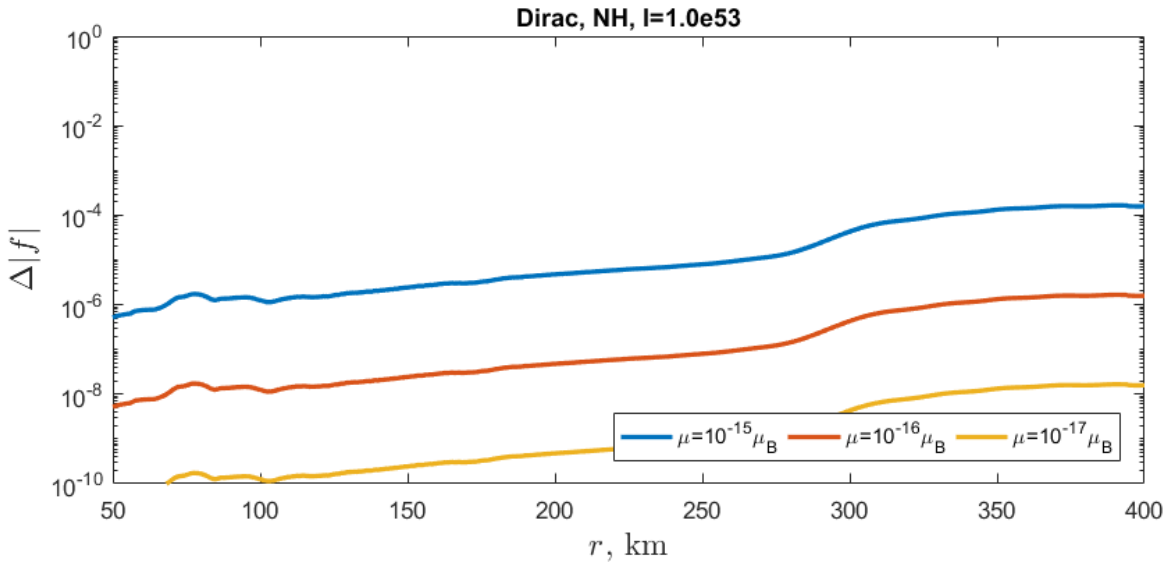


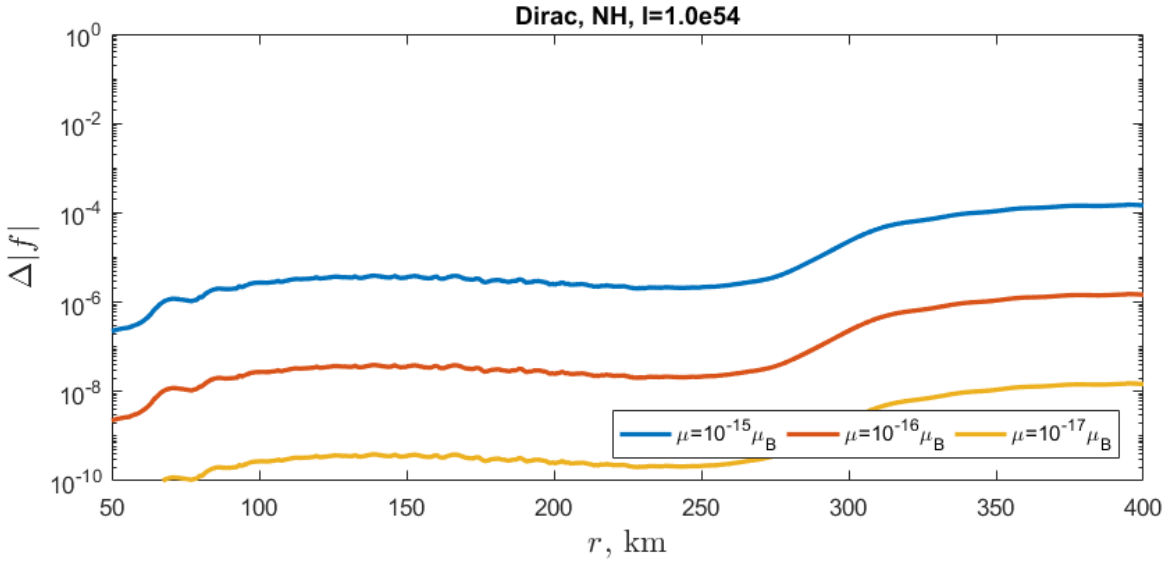


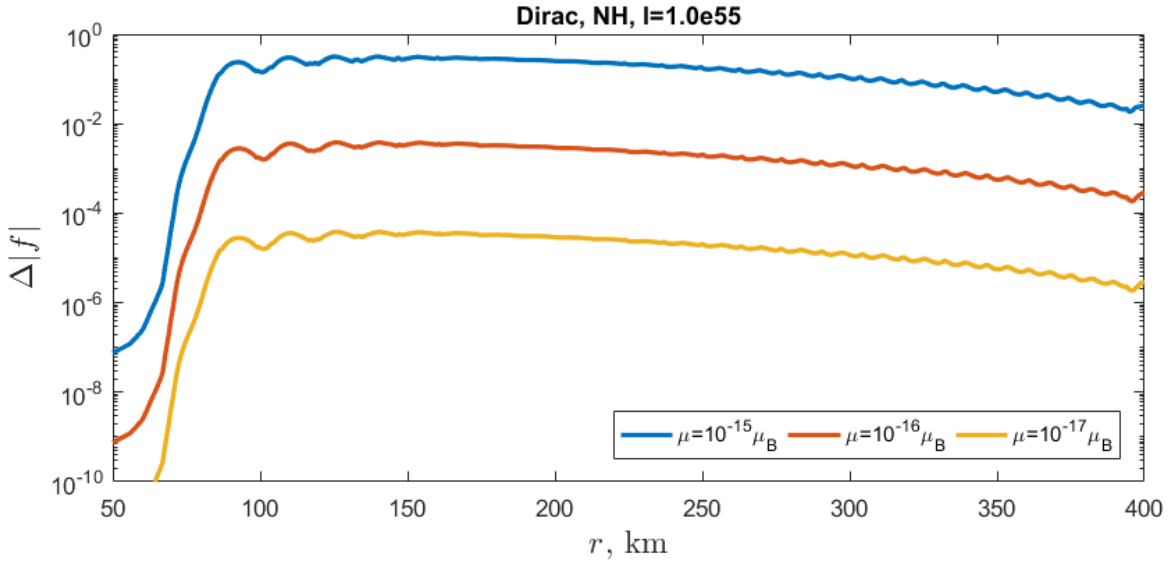


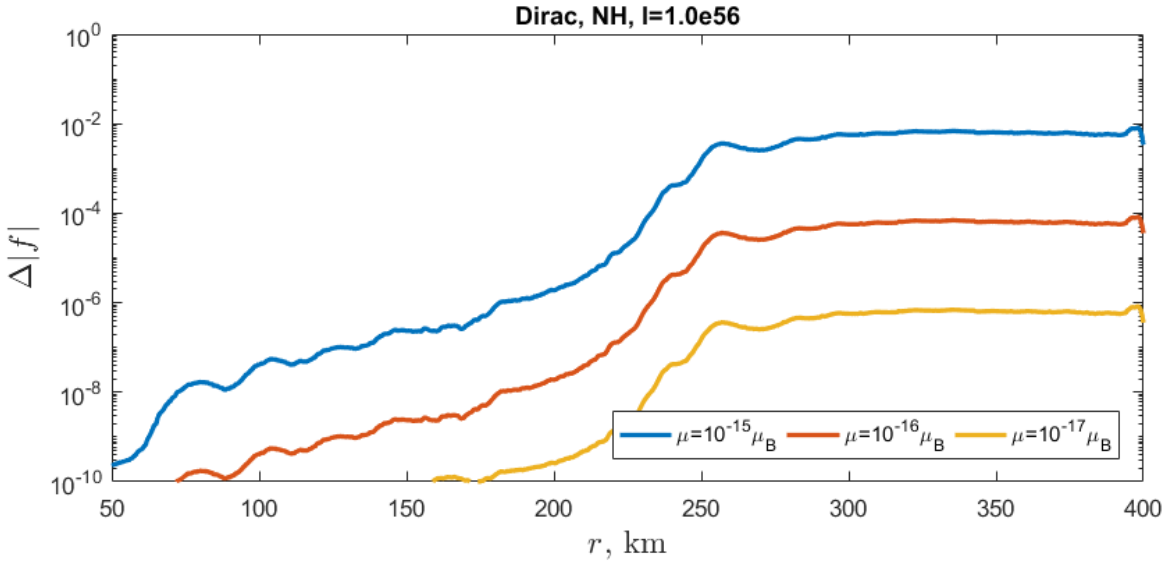


Dirac, Normal Hierarchy, $\Delta|f| = |f_{\mu=0} - f_{\mu}|$

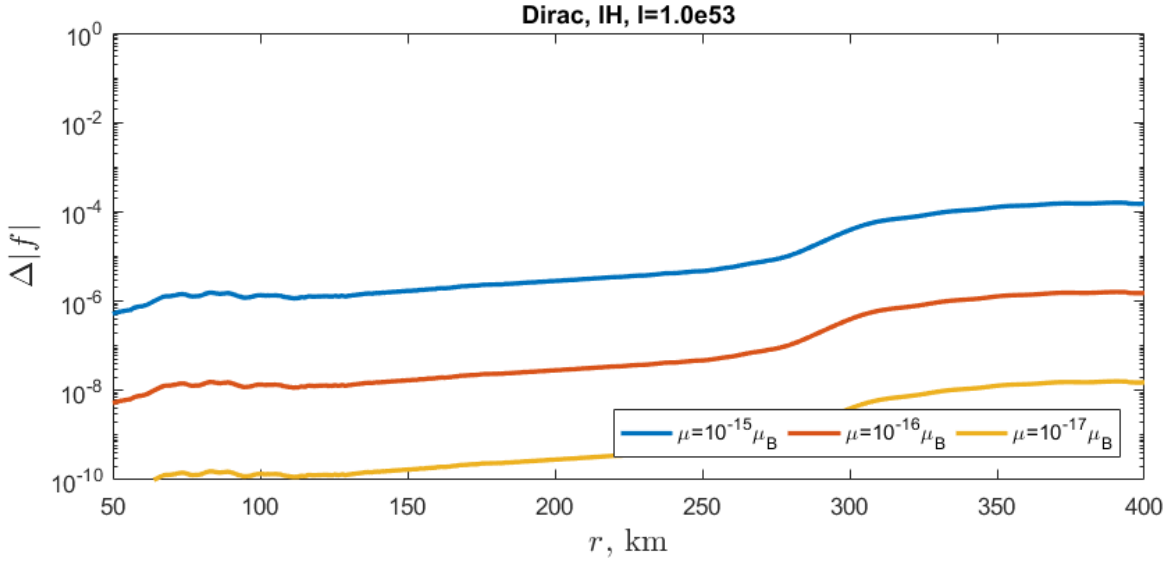


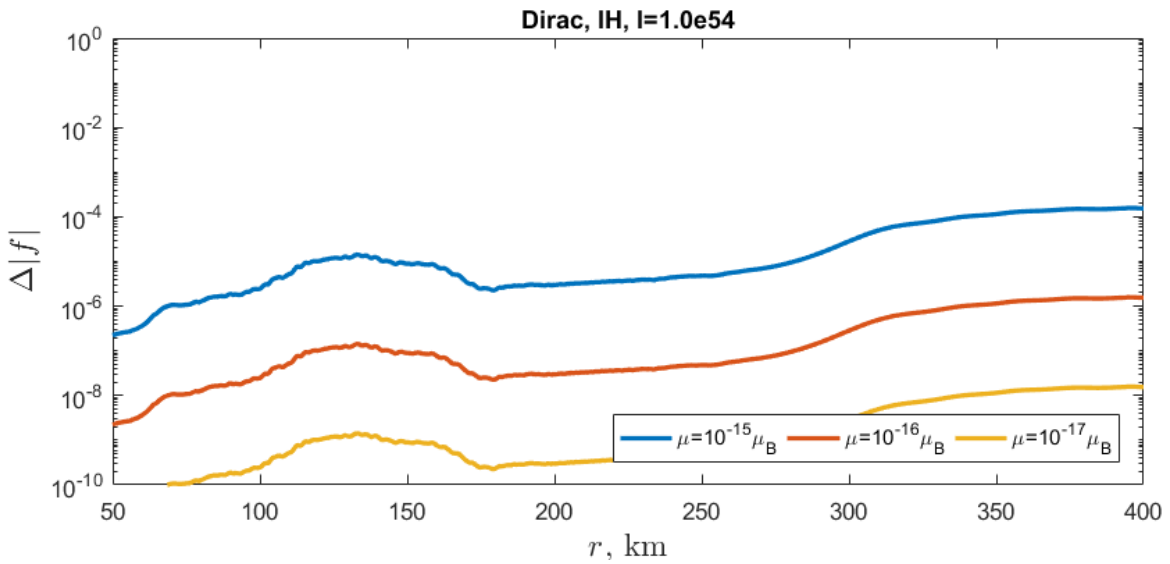


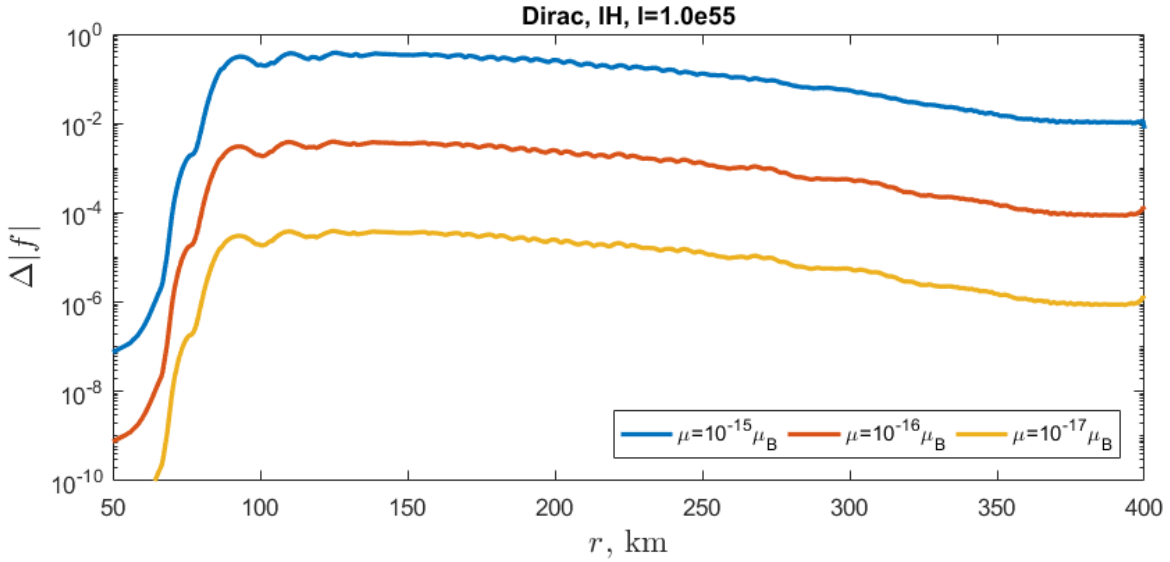


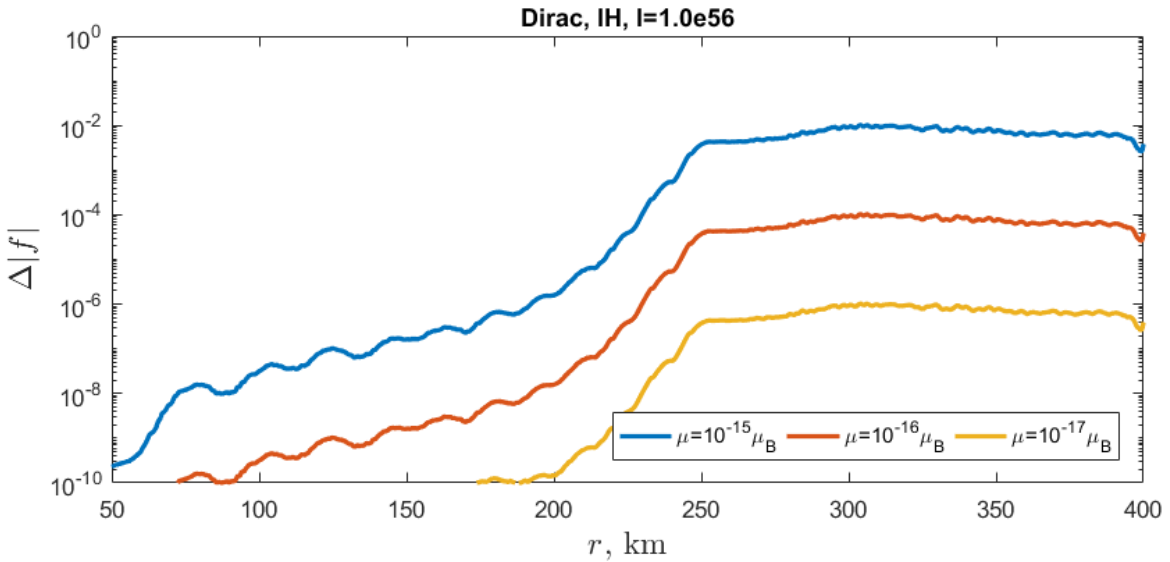


Dirac, Inverted Hierarchy, $\Delta|f| = |f_{\mu=0} - f_{\mu}|$









Conclusions

- There is an effect of the magnetic moment on collective oscillations, proportional to the magnetic moment (not the recently claimed signatures of ultra-small AMMs!)
- There is virtually no interplay between the hierarchy and the effect of nonzero AMM that could enhance the latter one
- Dirac neutrinos are much more sensitive to the presence of a magnetic moment than Majorana neutrinos.
- The level of sensitivity to neutrino magnetic moment $\sim 10^{-15}\mu_B$ for Dirac neutrinos