Quantum modified inertia : application to galaxy rotation curves

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What is Quantum modified inertia ?

Quantum Modified Inertia (QMI) is a new model [1] proposing to bound both low and high accelerations due to the presence of the Rindler horizon and the particle horizon. The theory is developed within the framework of special relativity, providing a smooth transition between the Newtonian regime and the minimal or maximal acceleration regimes. The minimal acceleration limit is observed in several astrophysical systems, including galaxies. Thus, QMI naturally reproduces galaxy rotation-curve behavior with significantly less, or even no, dark matter, by modifying inertia rather than the gravitational field.
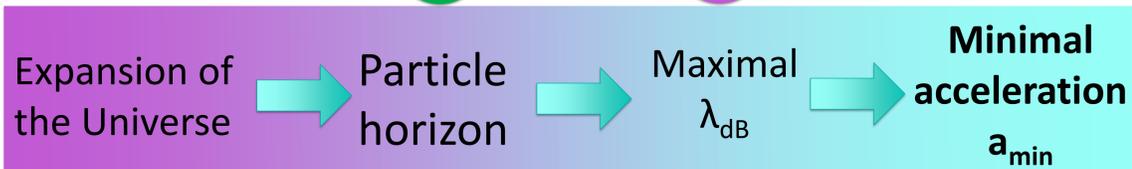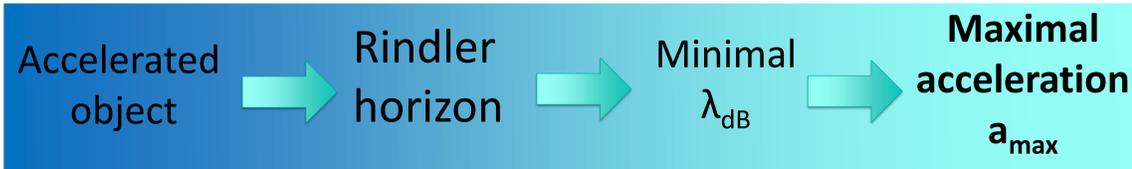
How it works ?

This model is based on **three main assumptions**:

1 The Rindler and particle horizons are equivalent causal limits.

2 The minimum time of evolution between two quantum states (quantum speed limit, cf Levitin & Margolus theorem) and the relativistic proper time are equivalent. The quantum speed limit is extended to classical regime [2].

3 The de Broglie wavelength of every object must be contained within the horizons, as inspired by [3].

Accelerated object → Rindler horizon → Minimal λ_{dB} → **Maximal acceleration a_{max}**

1   3

Expansion of the Universe → Particle horizon → Maximal λ_{dB} → **Minimal acceleration a_{min}**

	Quantum speed limit	Acceleration limit	Associated λ_{dB}
Max. bound	$\Delta\tau = \pi\hbar/2mc^2$	$a_{max} = 2mc^3/\pi\hbar$	$\lambda_{dB} = \hbar/mc$
Min. bound	$\Delta\tau = \pi R_u/c$	$a_{min} = c^2/\pi R_u$	$\lambda_{dB} = \hbar/p_{min} = 2R_u$

Table of acceleration bounds, with R_u the radius of the observable Universe.

Proper acceleration α and coordinate acceleration a:

$$\alpha = c\frac{d\eta}{d\tau} = \gamma^3\frac{dv}{dt} = \gamma^3 a \text{ and } \gamma^3 a = c\frac{d}{d\tau}\tanh\left(\frac{\alpha\tau}{c}\right)\hat{\alpha}$$

2

$$a = \frac{1}{\gamma^3}\frac{c}{\Delta\tau}\tanh\left(\frac{\alpha\Delta\tau}{c}\right)\hat{\alpha}$$

For example, maximal acceleration term:

$$a = \frac{1}{\gamma^3}\frac{2mc^3}{\pi\hbar}\tanh\left(\frac{\pi\hbar F}{2m^2c^3}\right)\hat{F}$$

Force to acceleration relation : $a = \frac{1}{\gamma^3}\left\{a_{max}\tanh\left(\frac{F}{ma_{max}}\right) + a_{min}\left[1 - \tanh\left(\frac{F}{ma_{min}}\right)\right]\right\}\hat{F}$

Modeling galaxy rotation curves

$$v = \sqrt{\frac{GM}{r} + ra_{min}\left[1 - \tanh\left(\frac{GM}{a_{min}r^2}\right)\right]}\,\hat{r}$$

Considering weak gravity, non-relativistic velocities and circular orbits.

Example of a rotation-curve modeling for the dwarf galaxy DDO 52 with the QMI theory. The galactic components (bulge, stellar disk, and gas disk) are extracted from observations [4]. The model suggests that **the minimal acceleration can fully replace dark matter in dwarf galaxies**. For massive galaxies, the required amount of dark matter is at least strongly reduced.
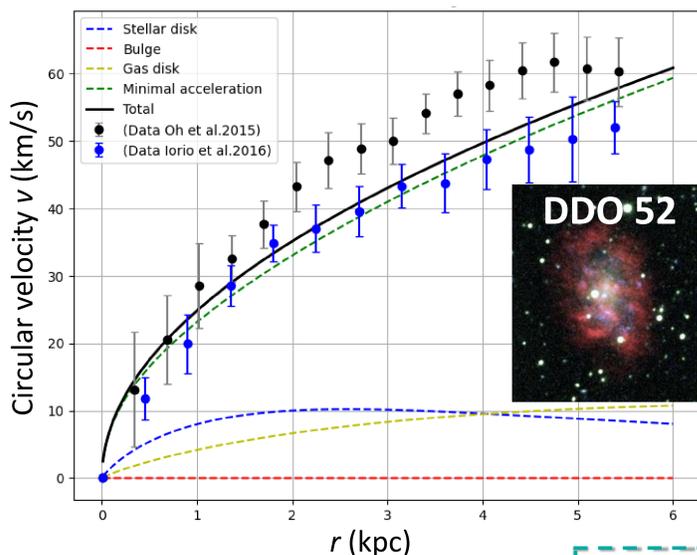
AND TULLY FISHER ? Yes ! ☺

According to the empirical Tully–Fisher relation, a spiral galaxy's luminosity or mass is proportional to roughly the power of 4 of its rotational velocity (more massive galaxies rotate faster) [7]. The model remarkably reproduces this empirical law:

$$M_{dyn} = \frac{v^4}{Ga_{min}}$$

But… MOND predicts a v^4 dependence as well! Future observations may help determine which model is better.
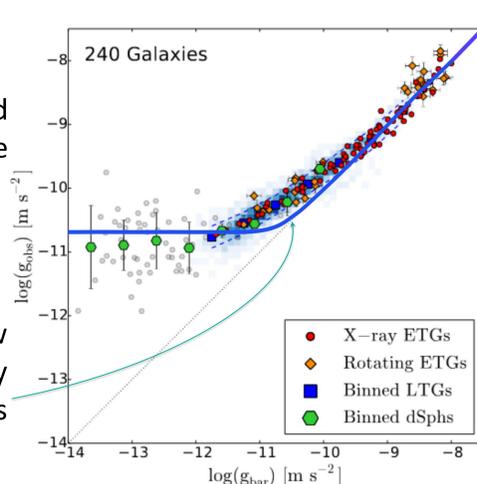
Radial acceleration relation

Centripetal acceleration tightly correlated with the acceleration predicted from the visible baryonic mass alone [5].

The QMI model (blue line) predicts a flattening of the RAR at a minimal acceleration.

The Cassini probe has shown that the low acceleration transition regime predicted by MOND is too smooth [6], while QMI respects this constraint.

Strengths of the model

✔ Tully-Fisher relation recovered.
✔ Modeling of the galaxy rotation curves.
✔ Radial acceleration relation.
✔ No *ad hoc* interpolation function.
✔ Consistency with Cassini probe constraints [6].

Points under investigation

❓ Theory : is there a mass limit for the quantum speed limit?
❓ Modeling improvements to include disk thickness, central bar, etc.
❓ Toward a generalized model beyond Newtonian gravity and flat spacetime.

References
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