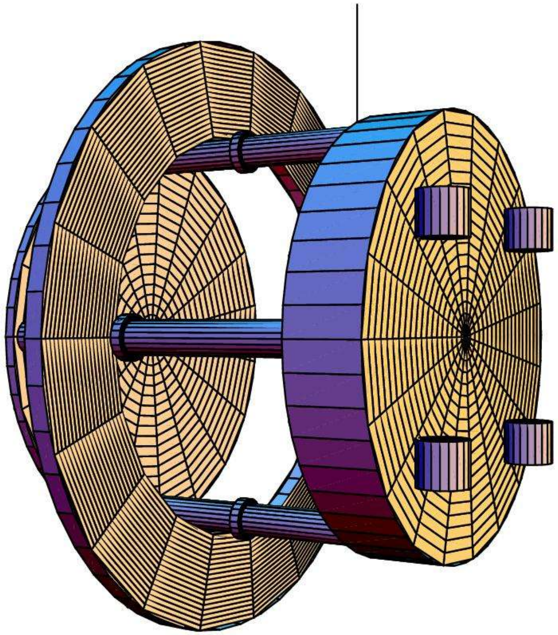
Fundamental Gravitation Physics with a Torsion Pendulum



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Princeton Physics Seminar

March 27, 2007

Fundamental Gravitation Physics with a Torsion Pendulum

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I

What Does "non-Newtonian" Look Like?

$$V = -\frac{Gm}{r}\left(1 + \alpha e^{-r/\lambda}\right)$$

What Does “non-Newtonian” Look Like?

interaction length

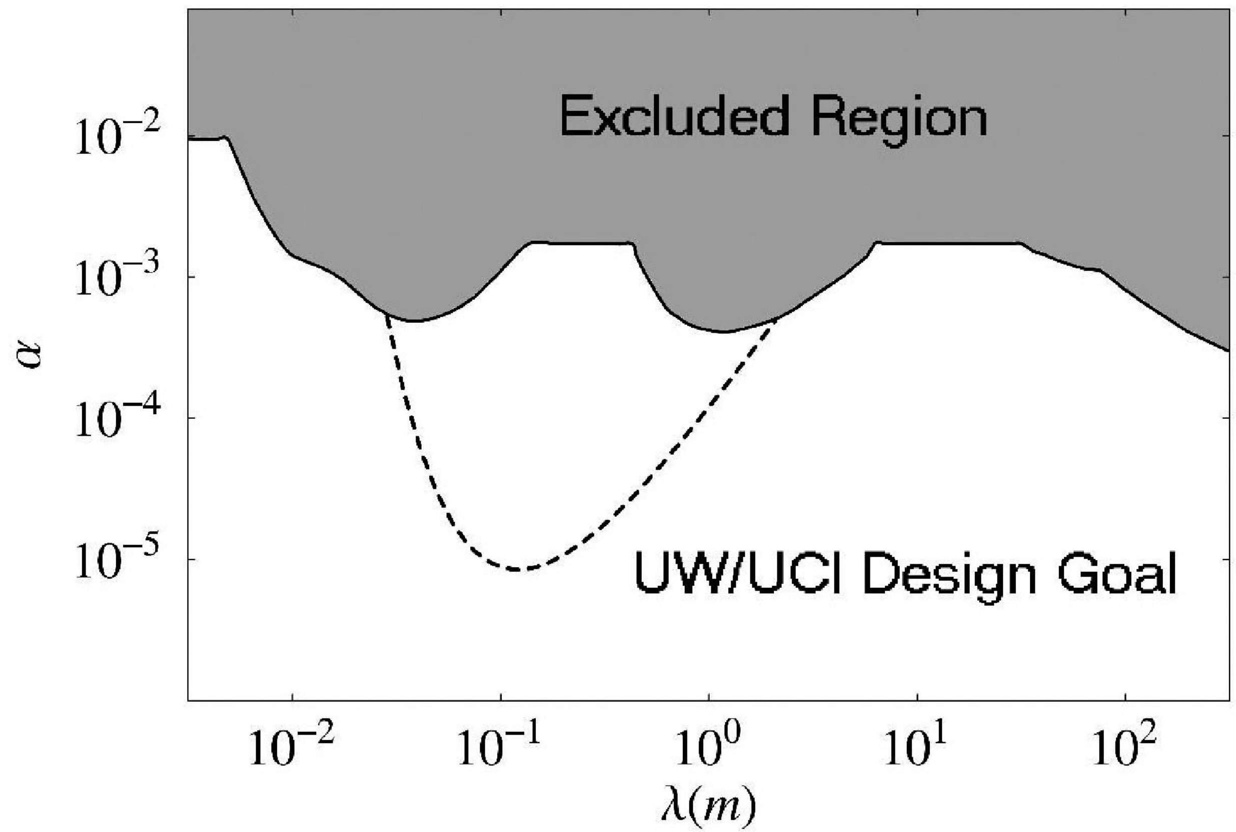
$$V = -\frac{Gm}{r}\left(1 + \alpha e^{-r/\lambda}\right)$$

regular gravity

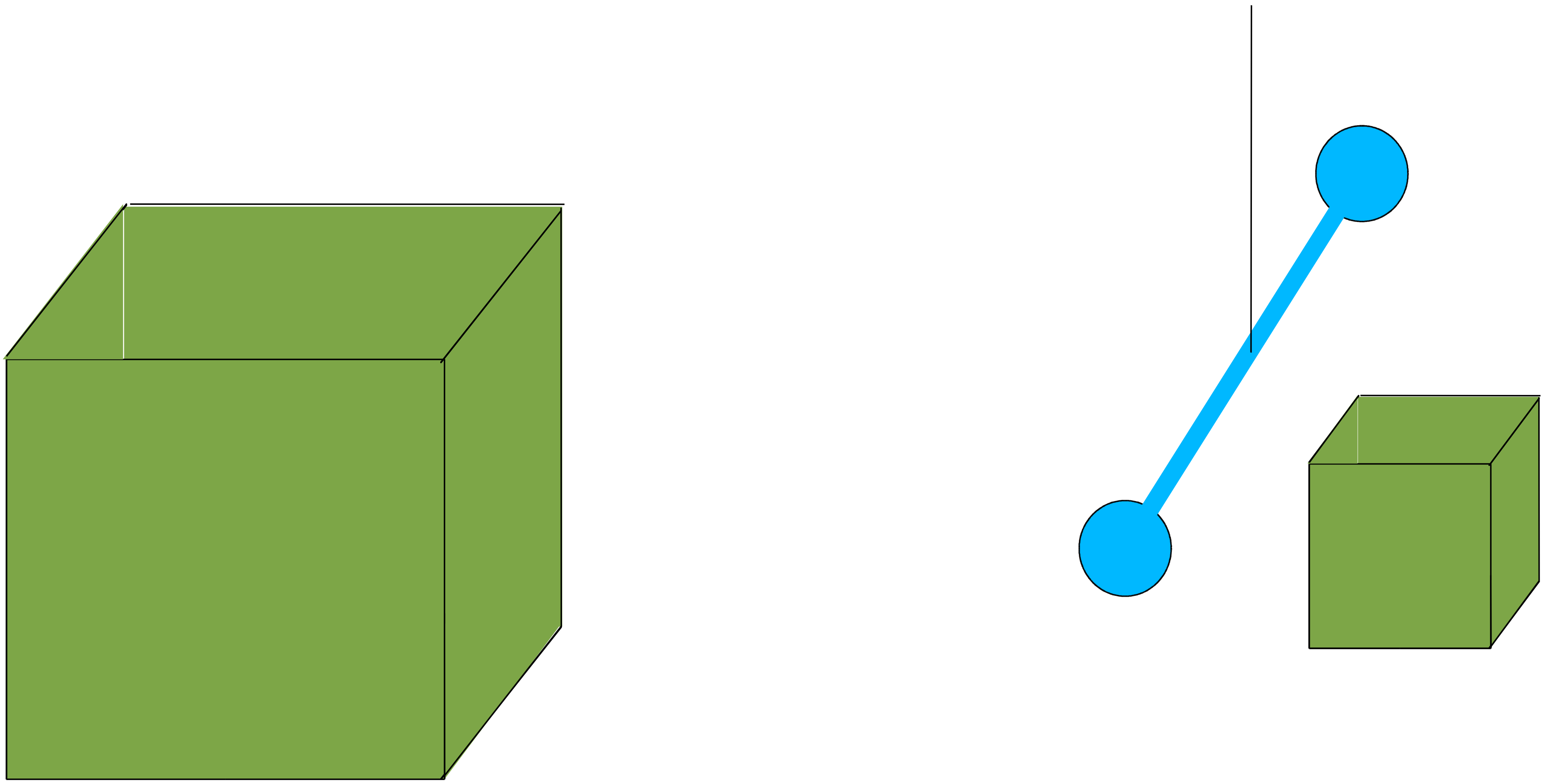
strength relative to gravity

What Does “non-Newtonian” Look Like?

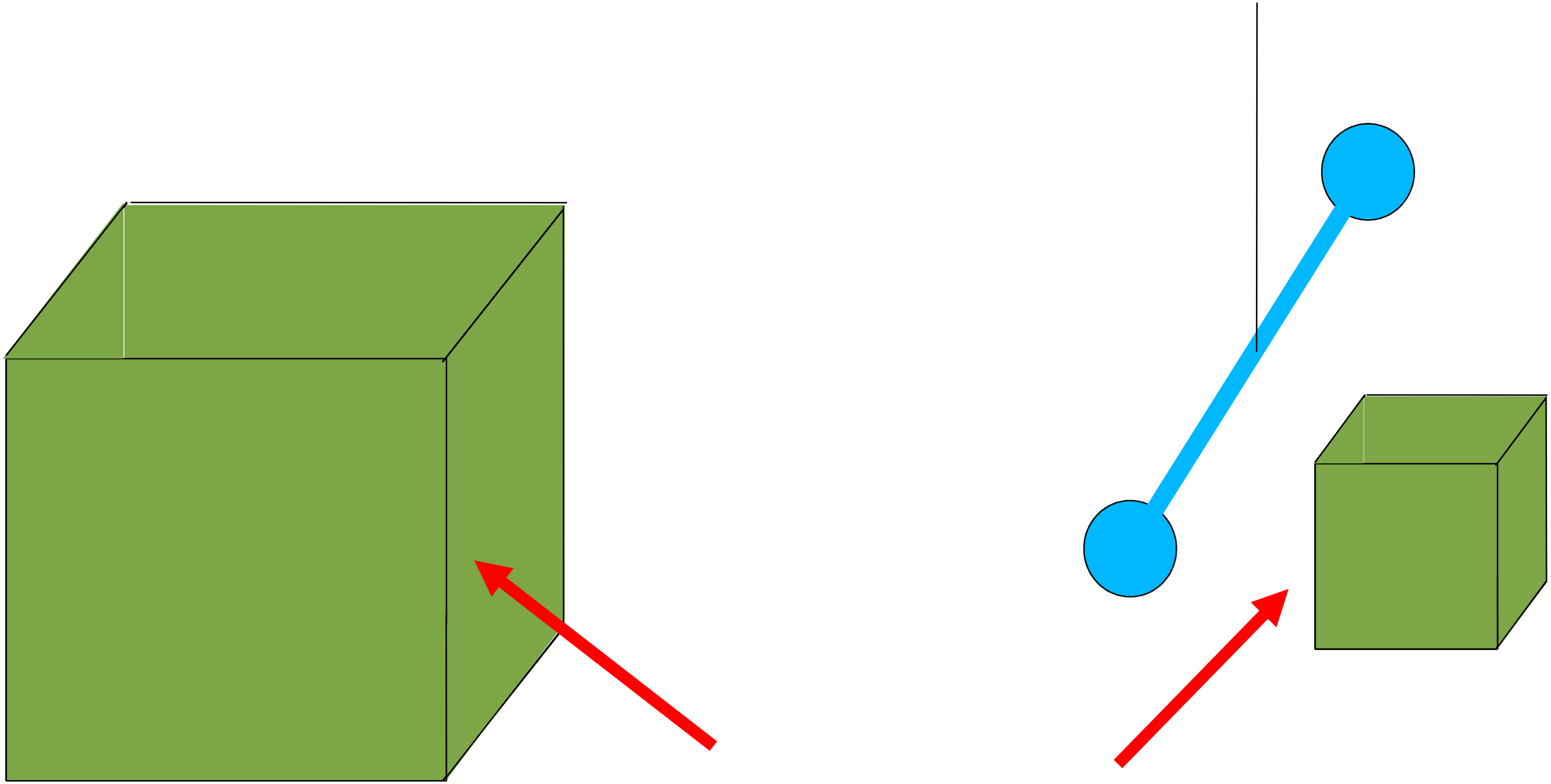
$$V = -\frac{Gm}{r}\left(1 + \alpha e^{-r/\lambda}\right)$$



Detecting non-Newtonian Interactions



Detecting non-Newtonian Interactions



Newtonian gravity should cancel
leaving residual non-Newtonian interaction

Identifying the Leading Systematic Effect

$$
\begin{aligned}
U &= \int \rho V \, d^3 r \\
&= \int \rho \left(1 + x\frac{d}{dx} + y\frac{d}{dy} + z\frac{d}{dz} + x^2\frac{d^2}{dx^2} + \cdots \right) V \, dxdydz \\
&\vdots \\
&\text{algebra} \\
&\vdots \\
&= \sum_{nlm} M_{nlm} V_{nlm}
\end{aligned}
$$

Identifying the Leading Systematic Effect

$$U = \int \rho V \, d^3 r$$

$$= \int \rho \left(1 + x\frac{d}{dx} + y\frac{d}{dy} + z\frac{d}{dz} + x^2\frac{d^2}{dx^2} + \cdots \right) V \, dx dy dz$$

$$\vdots$$

$$\text{algebra}$$

$$\vdots$$

$$= \sum_{nlm} M_{nlm} V_{nlm}$$

symmetries of electron orbitals

field moments

mass moments

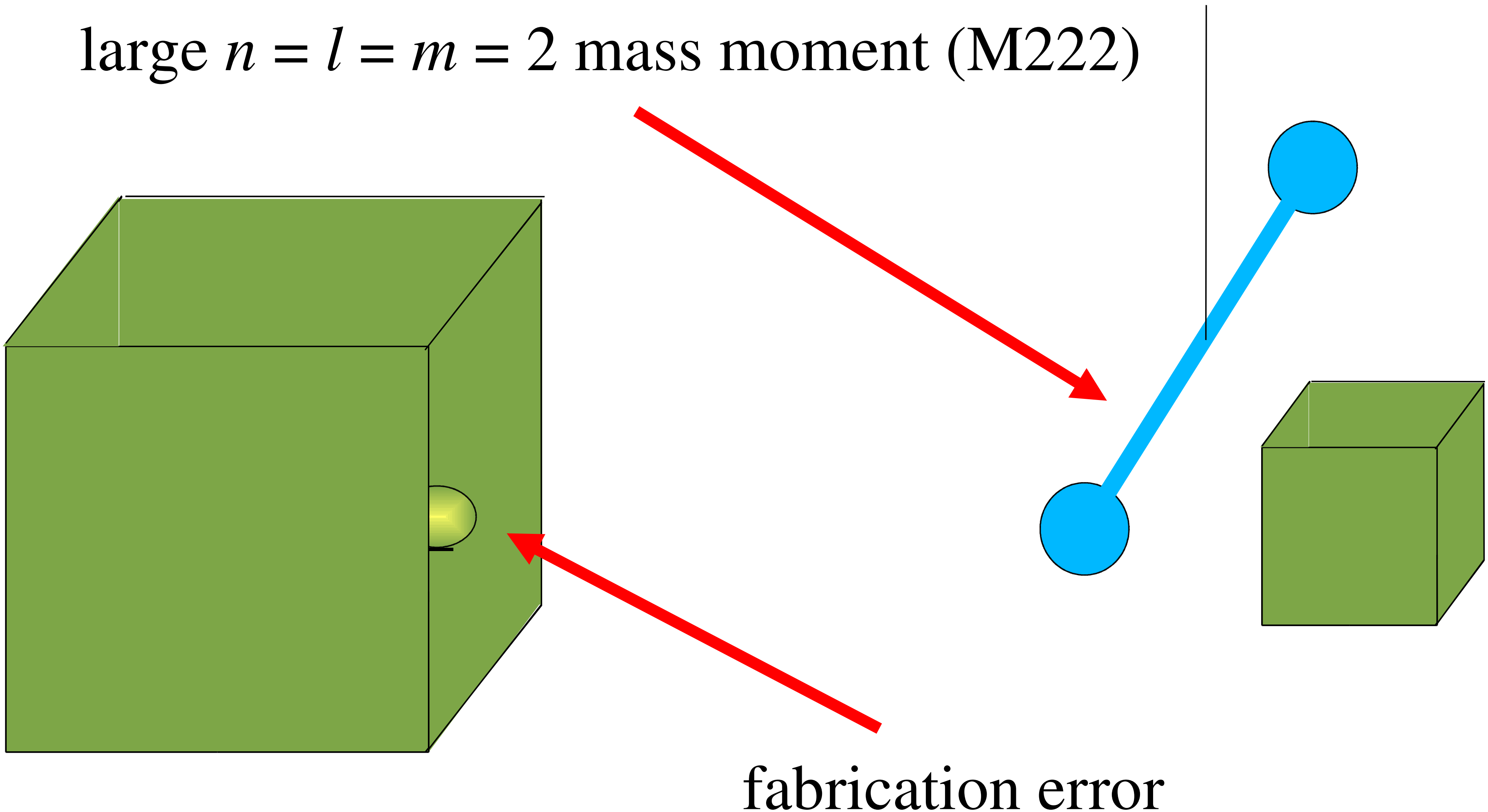
Identifying the Leading Systematic Effect

Newtonian gravity satisfies Laplace's Equation. Thus, only terms for which $n = l$ contribute to the interaction. Call these "Newtonian Moments".

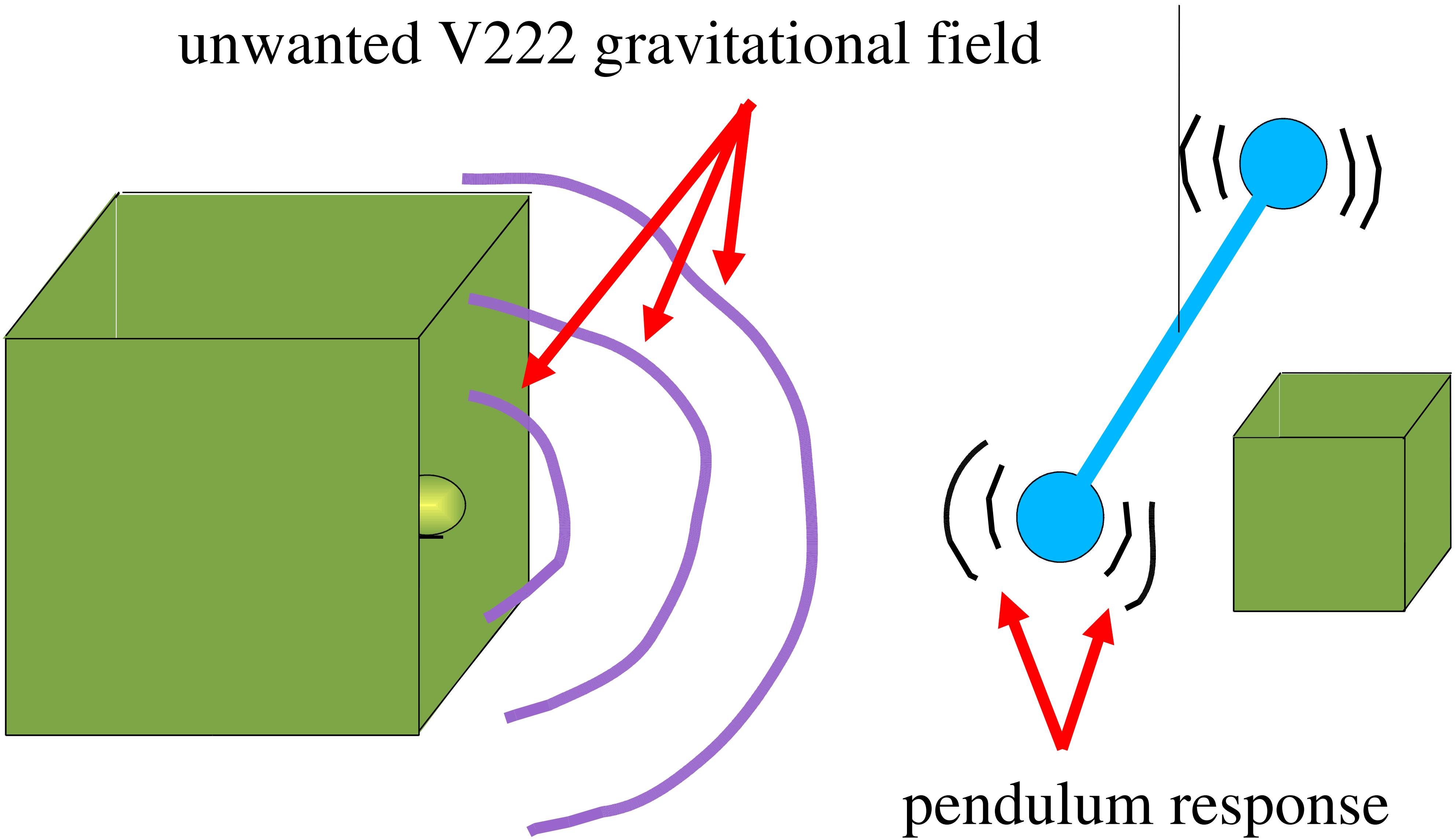
Non-Newtonian forces do not satisfy Laplace's Equation and can contribute to the interaction for any combination of n and l.

When $n \neq l$, call these "non-Newtonian".

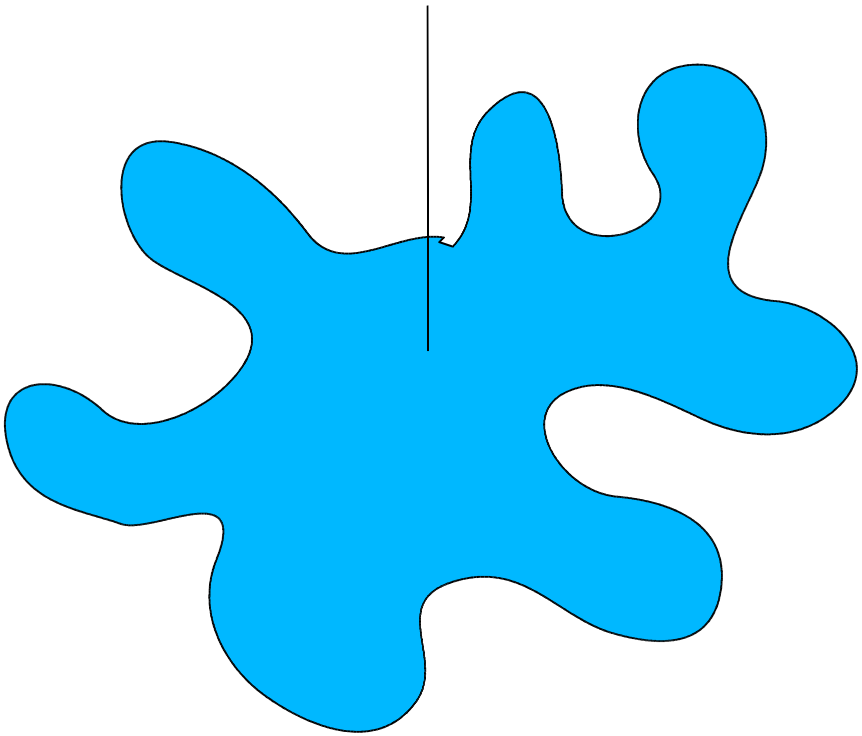
Identifying the Leading Systematic Effect



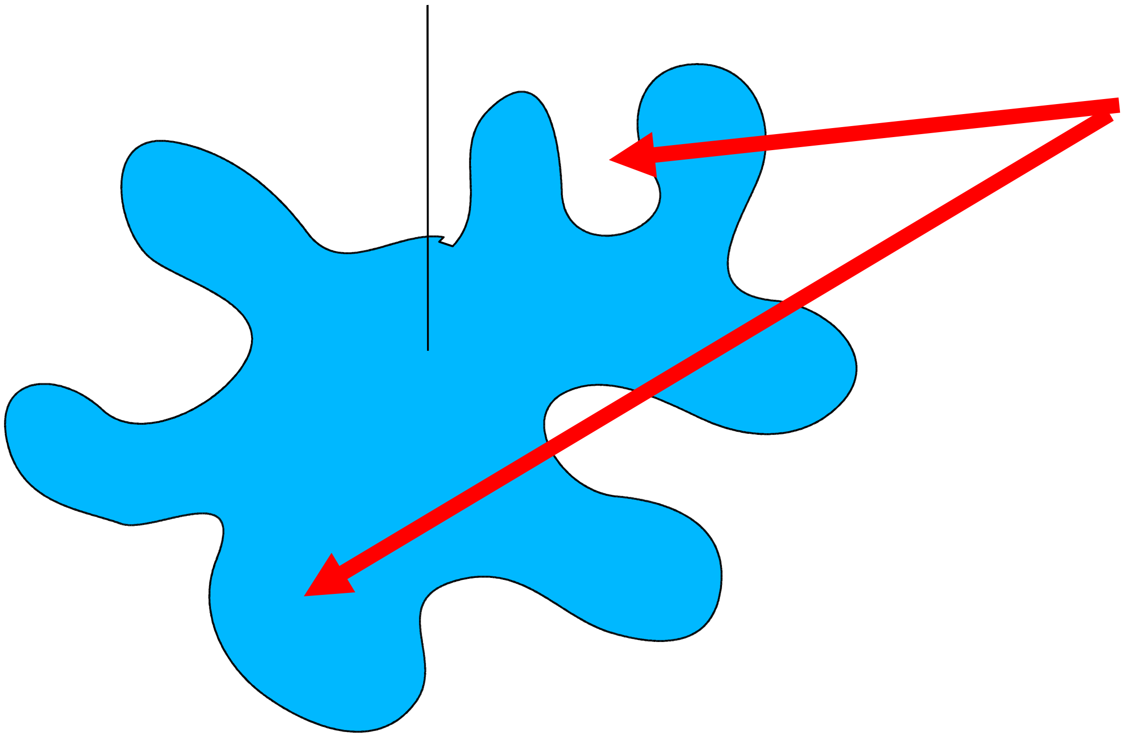
Identifying the Leading Systematic Effect



What would be nice...

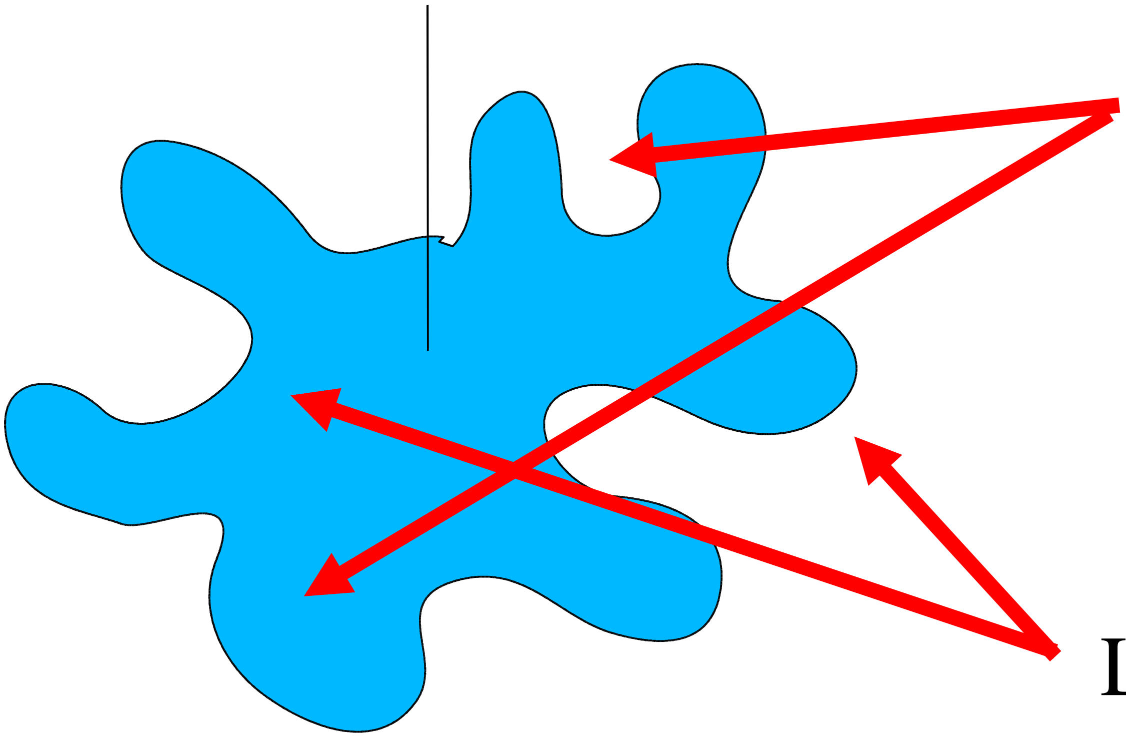


What would be nice...



No Newtonian
mass moments.

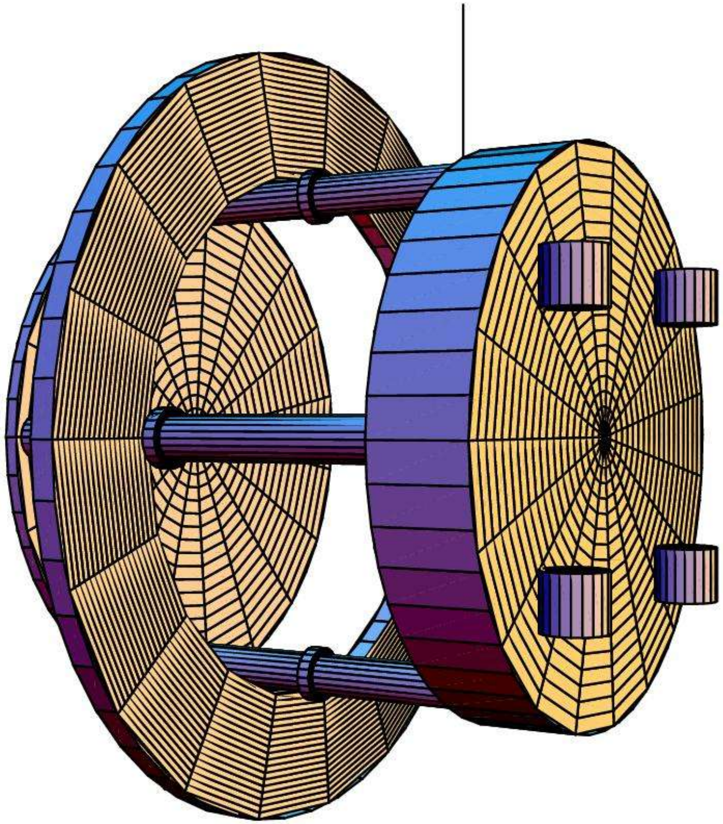
What would be nice...



No Newtonian
mass moments.

Large non-Newtonian
mass moments.

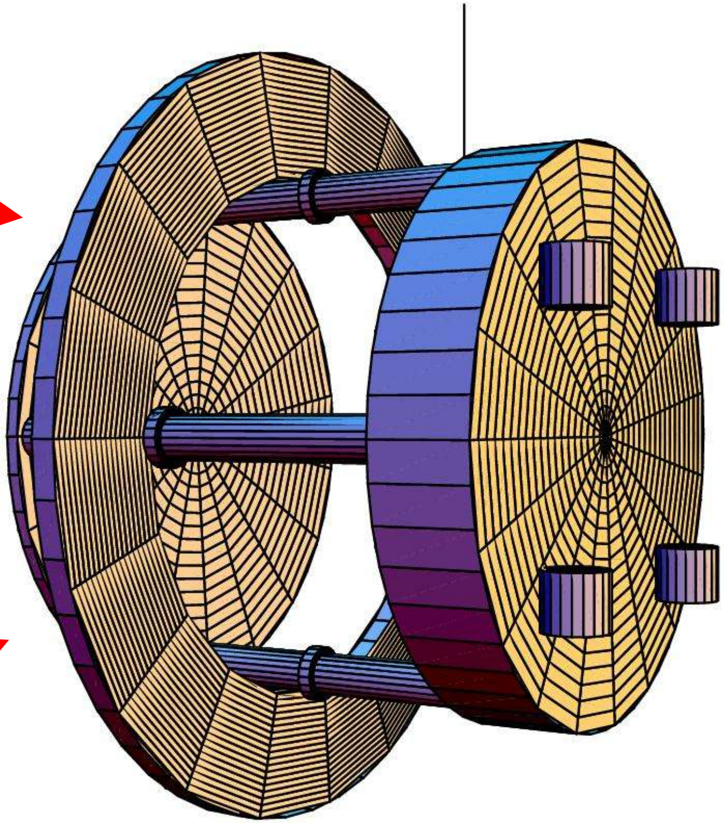
What will do...



What will do...

No low-order Newtonian mass moments

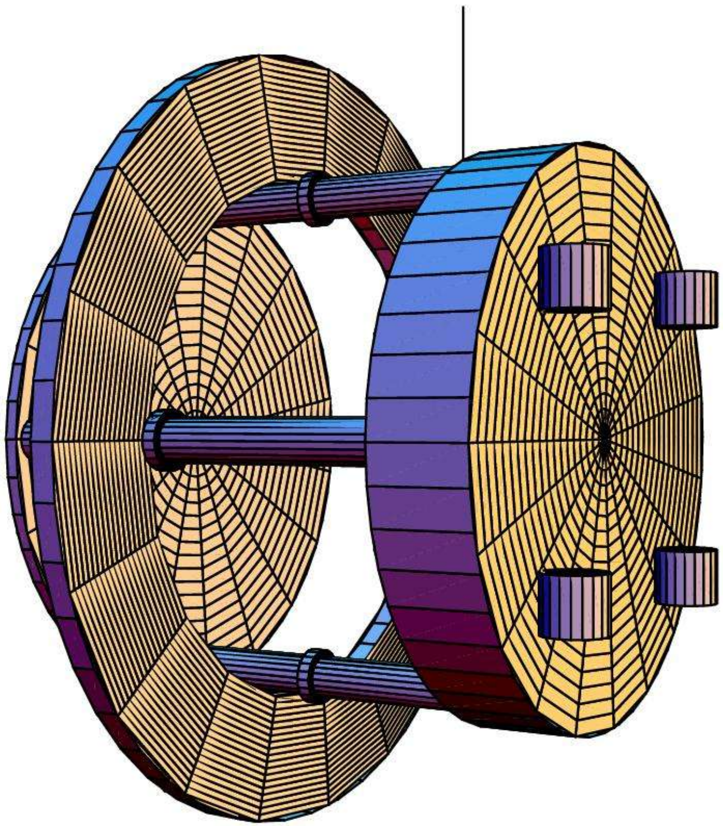
One large, low-order non-Newtonian mass moment



What will do...

Newtonian mass moments:

V22m = 0
V33m = 0 } (for all m)
V44m = 0
V551 = 0
V661 = 0
V771 = 0
V881 = 0

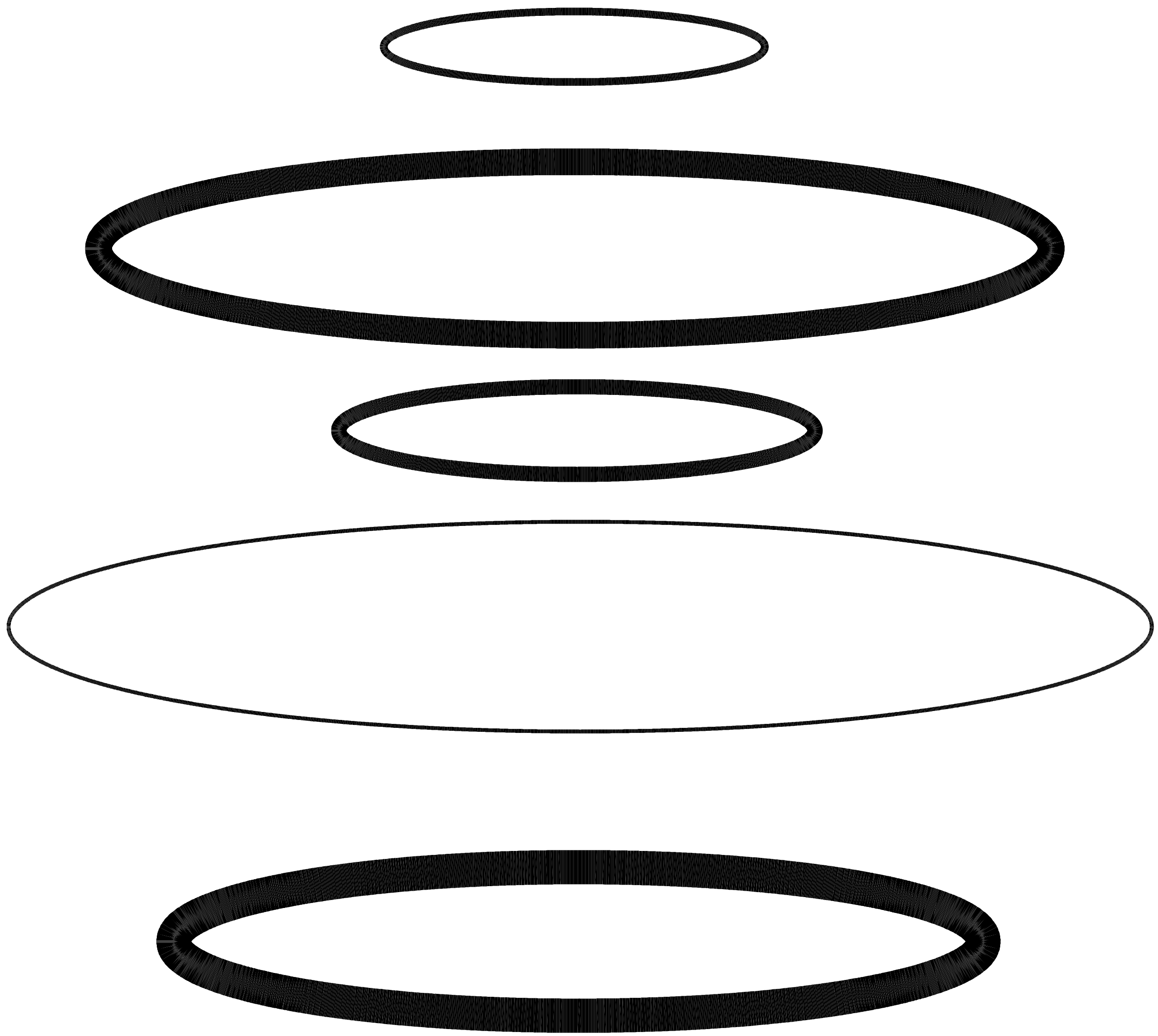


non-Newtonian moment:

V311 = Large

How to design what will do...

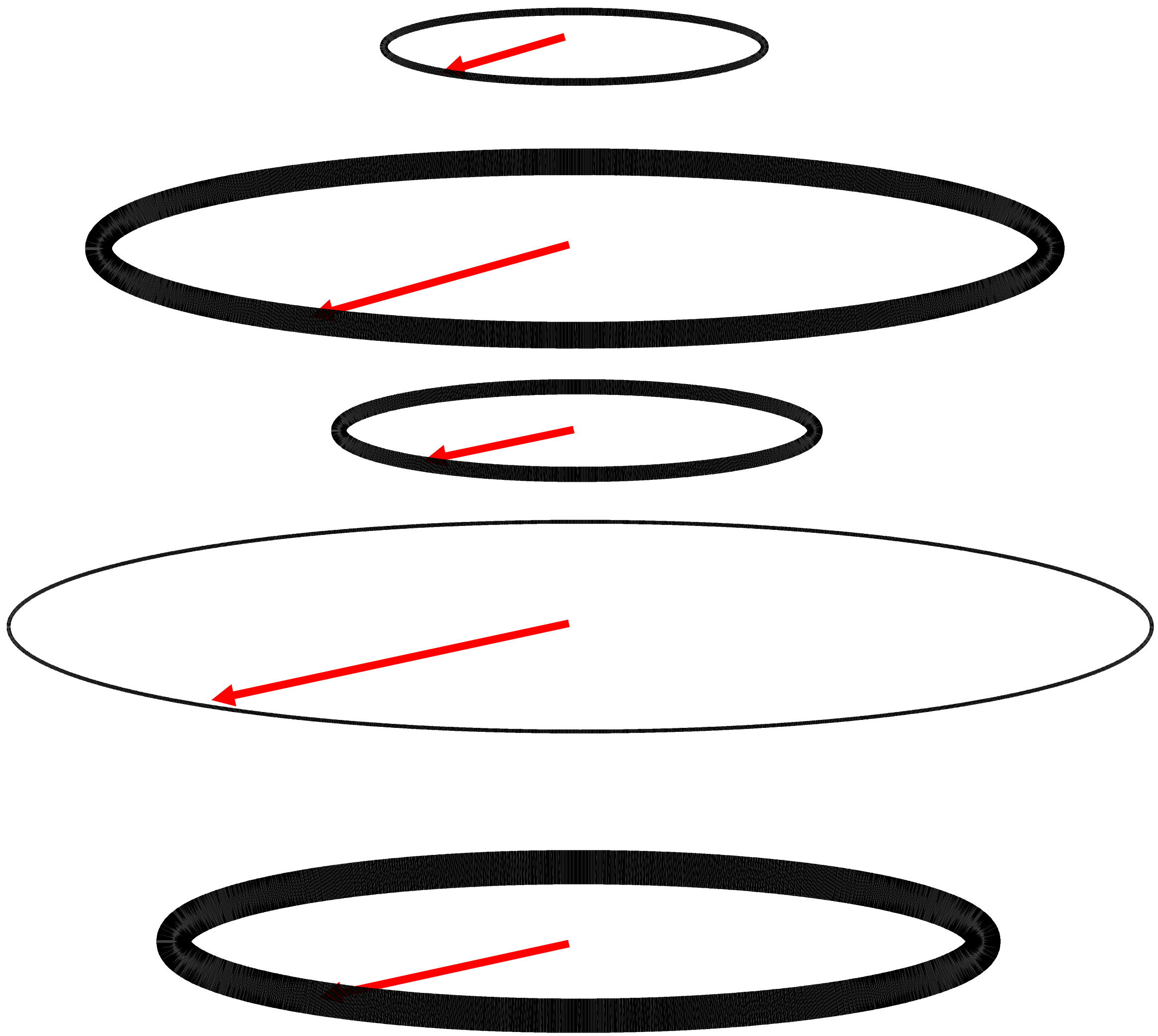
Start with 5 rings.



How to design what will do...

Start with 5 rings.

5 radii

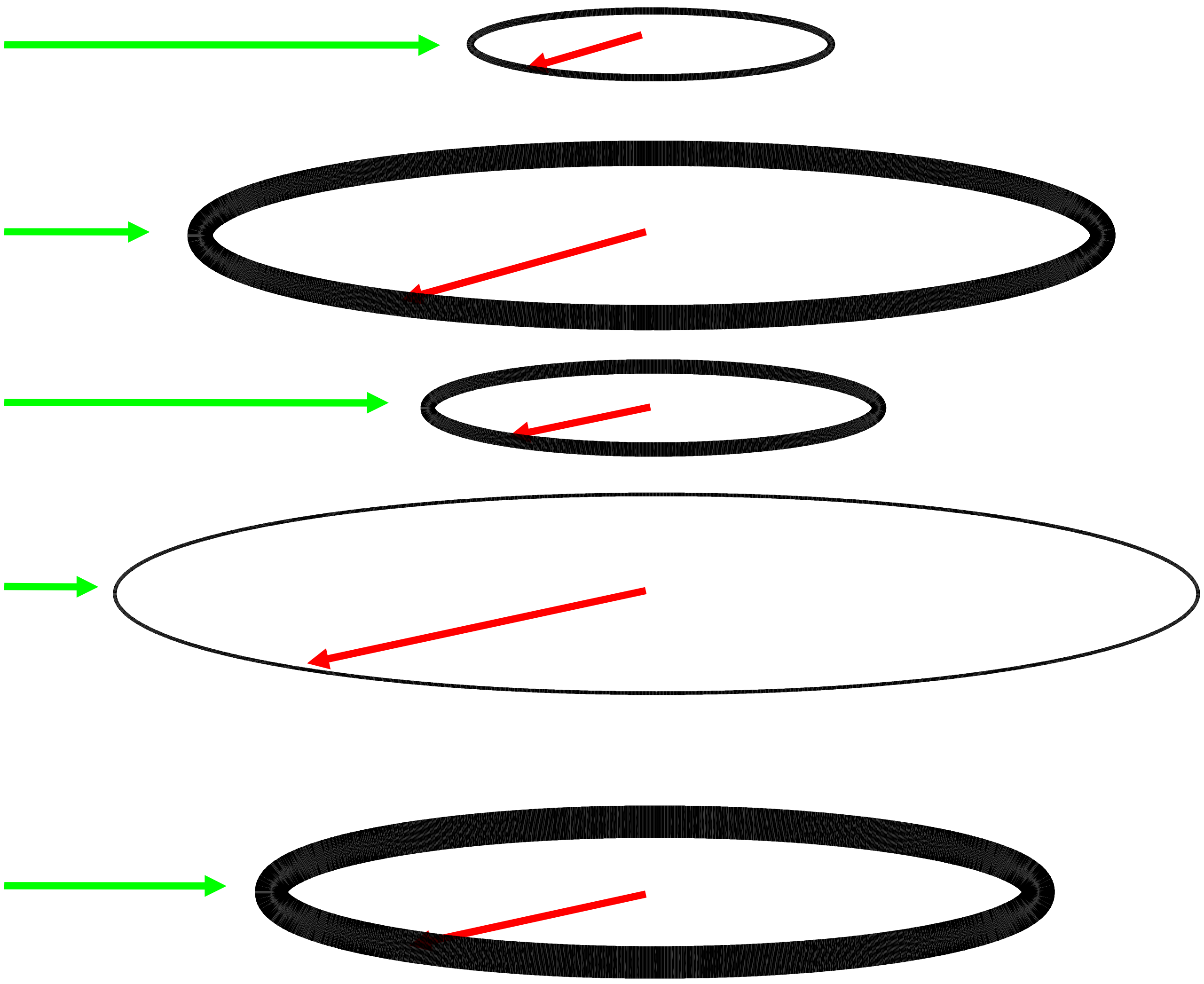


How to design what will do...

Start with 5 rings.

5 radii

5 heights



How to design what will do...

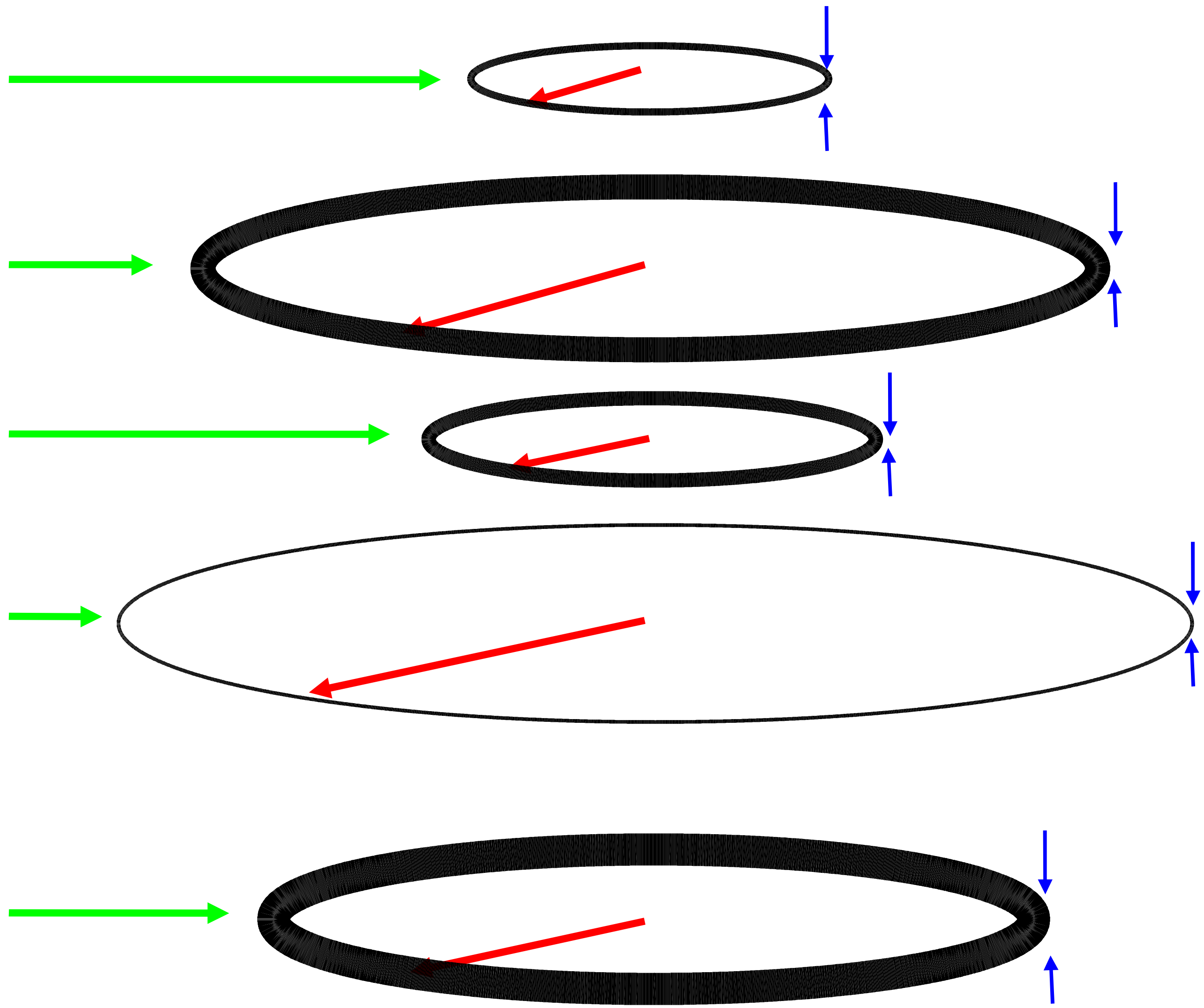
Start with 5 rings.

5 radii

5 heights

5 masses

15 parameters



Only $m = 0$ moments.

Use parameters to null

Newtonian moments and

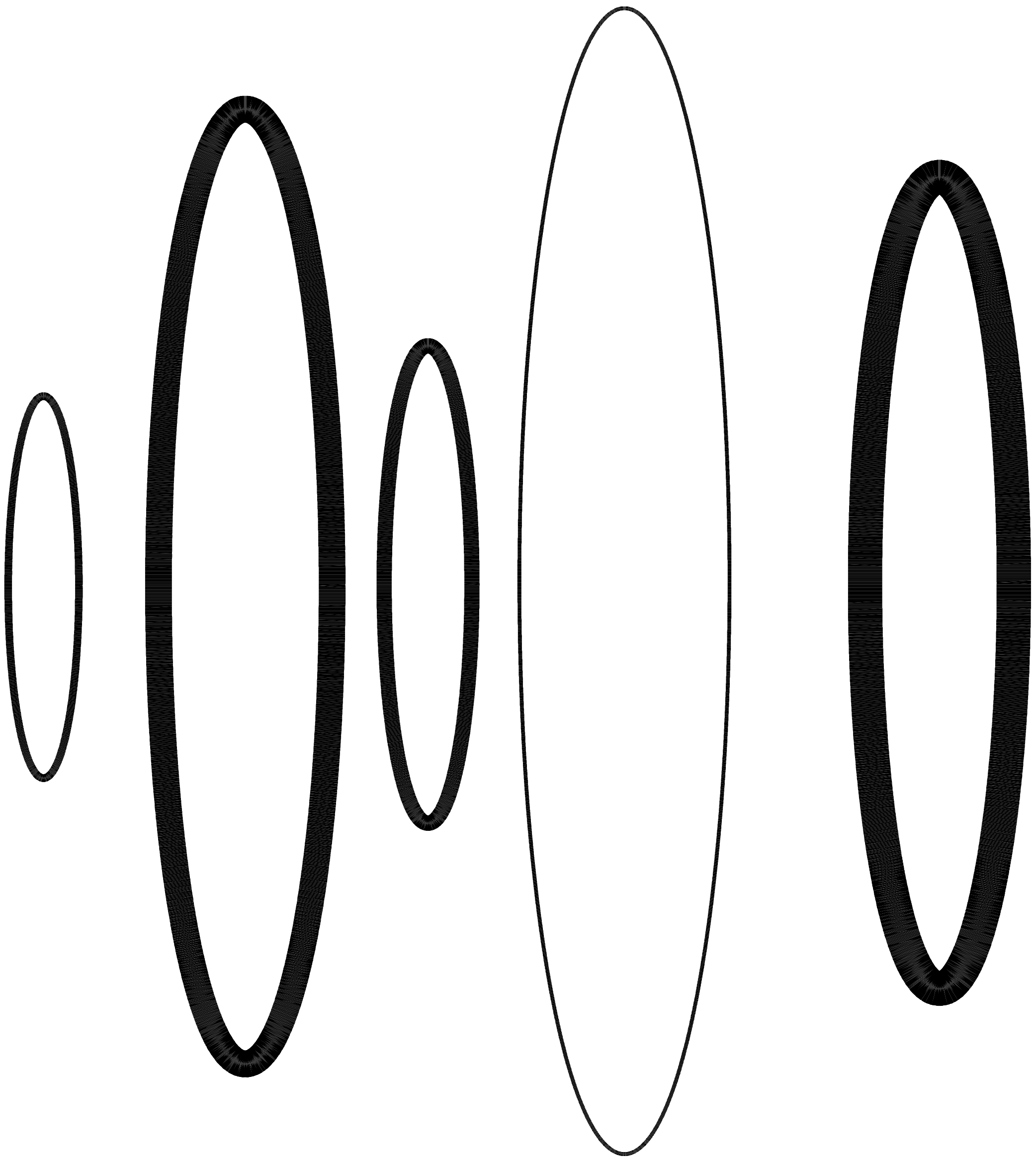
to maximize 310 moment.

How to design what will do...

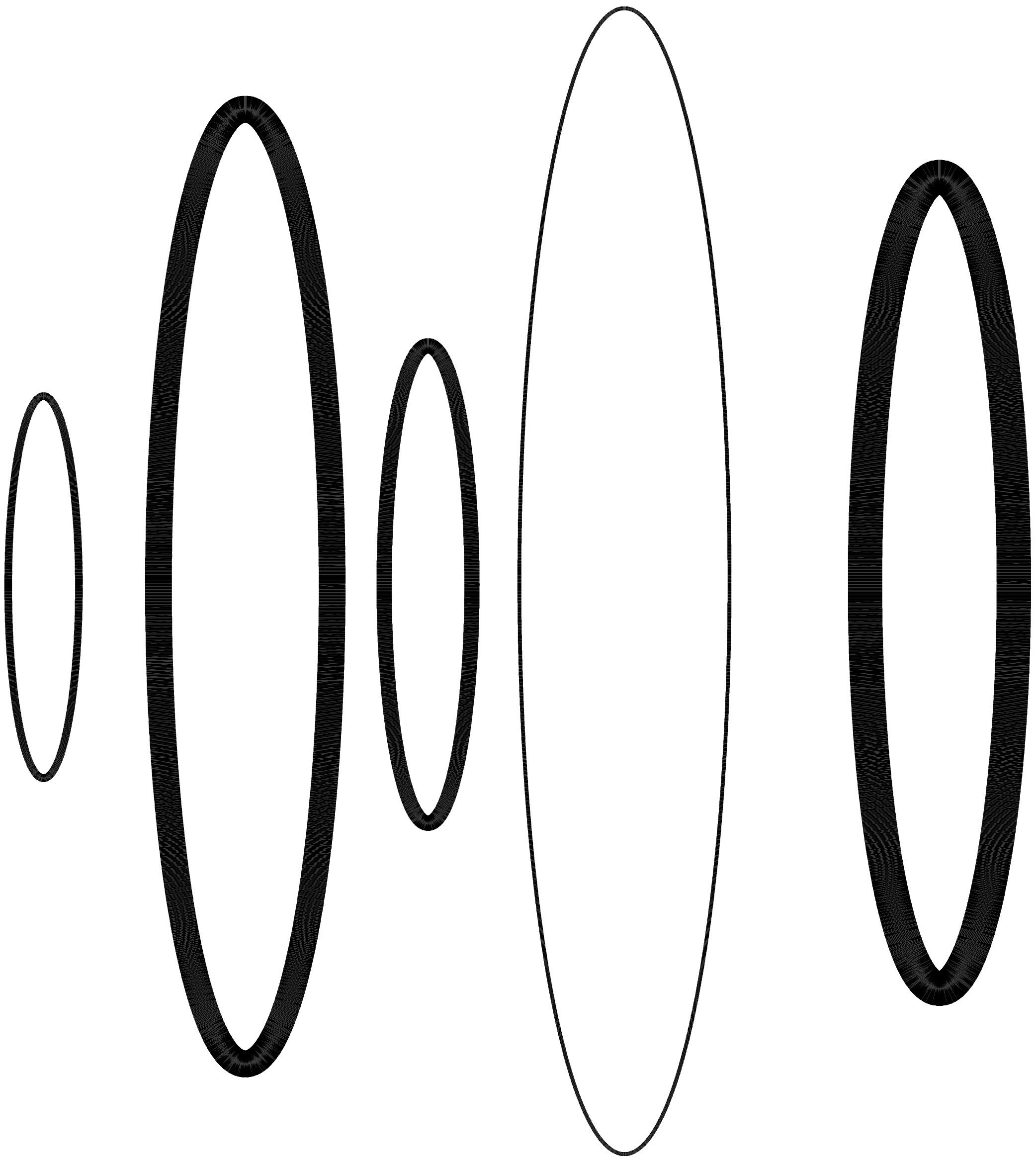
Now rotate by 90 degrees.

Nulled Newtonian moments remain zero.

Large 310 moment rotates into a large 311 moment.



How to design what will do...



Now for the Source Mass

Newtonian Potentials:

V22m = 0 (for all m)

V331 = 0

V441 = 0

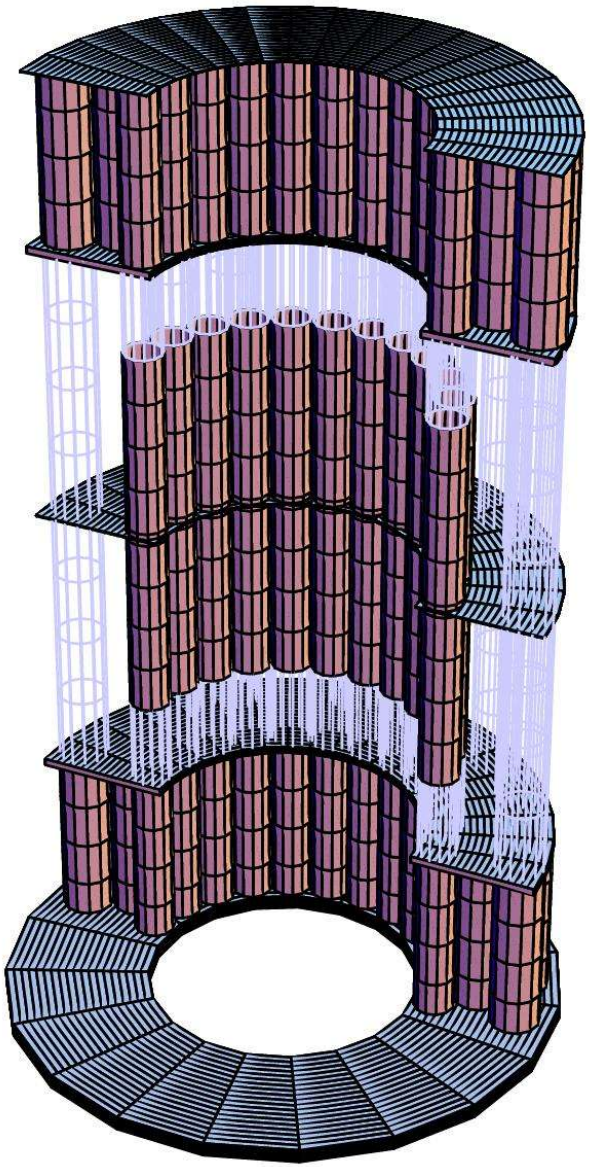
V551 = 0

V661 = 0

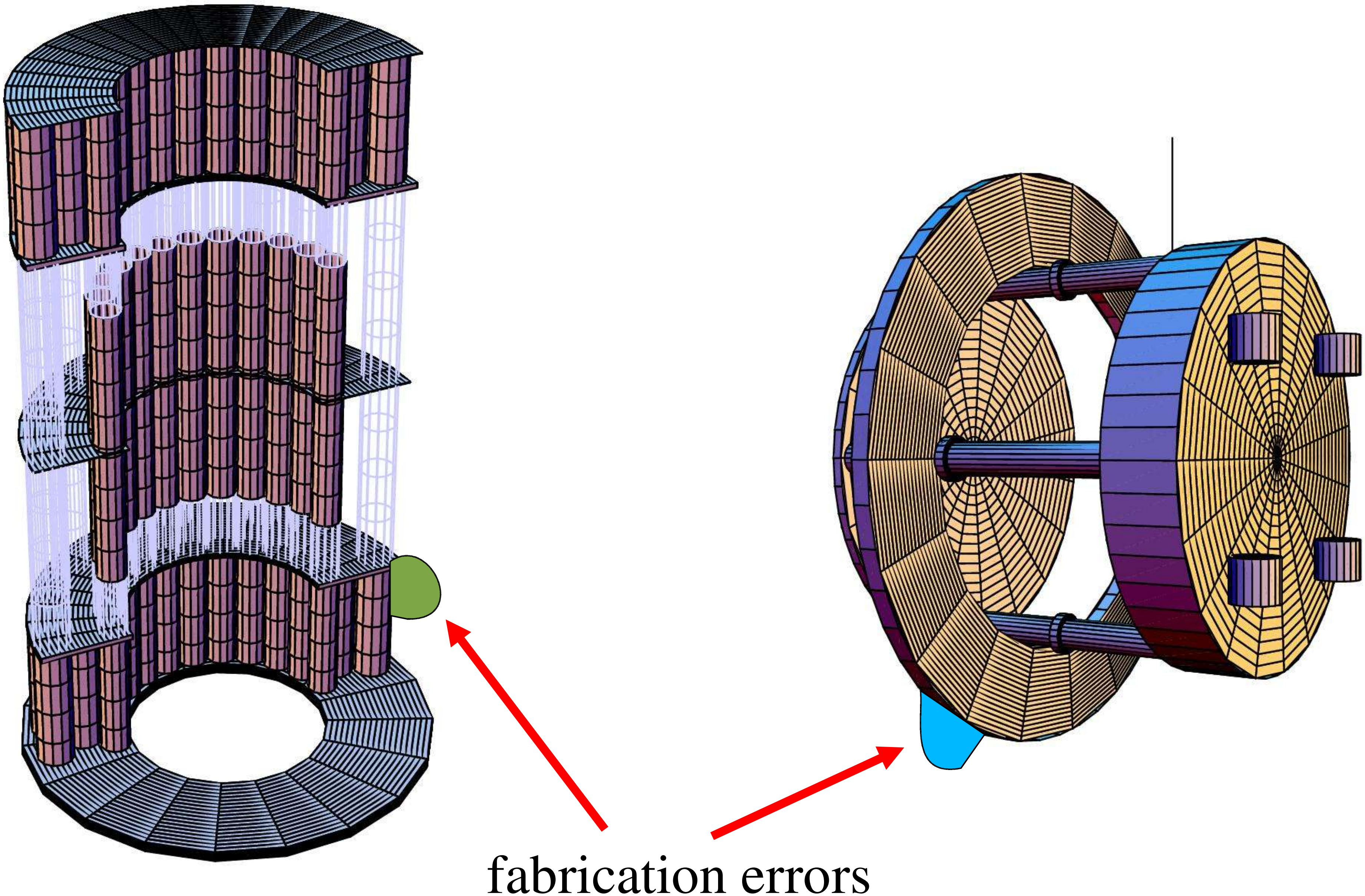
V771 = 0

non-Newtonian Potential:

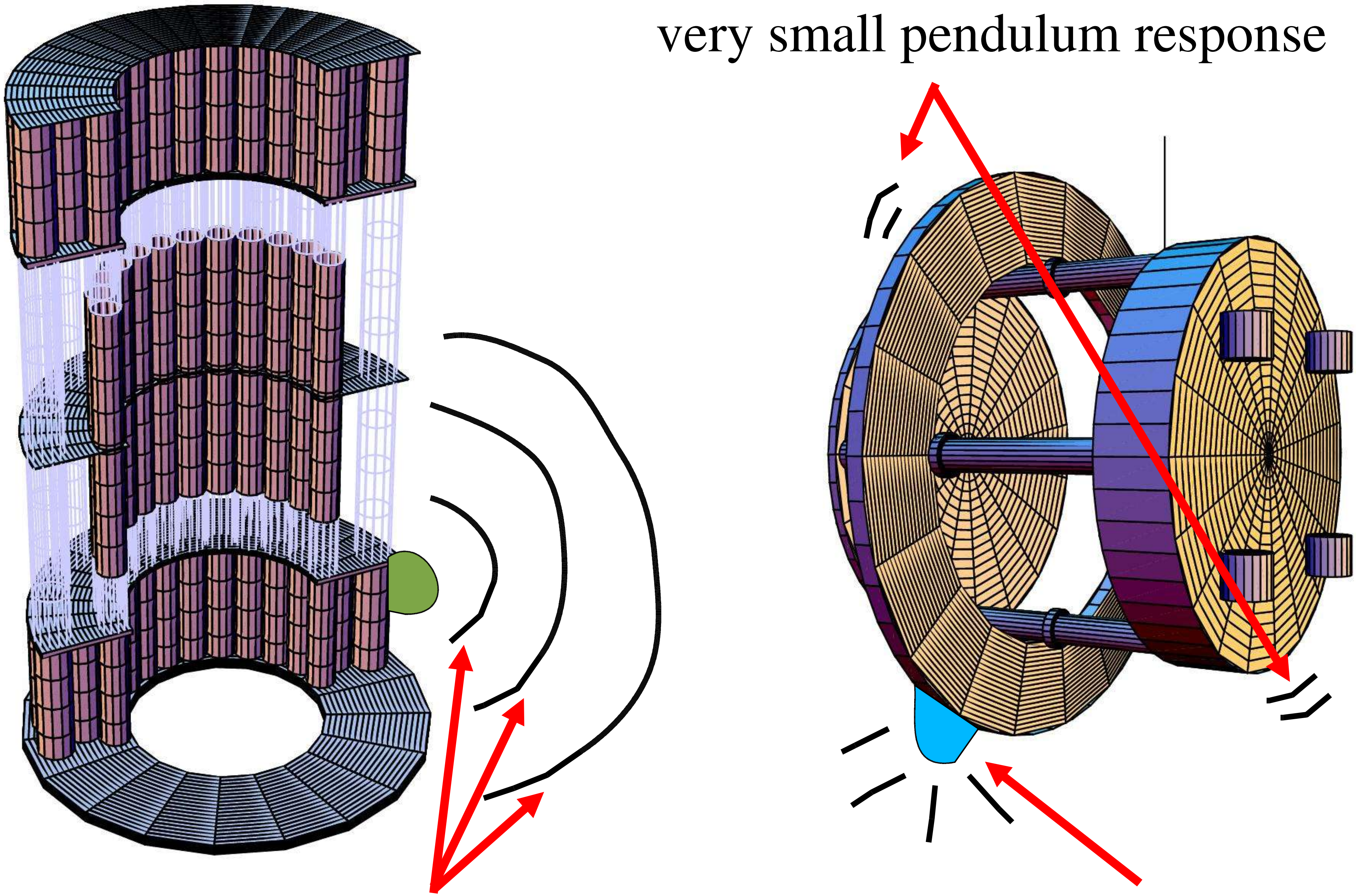
V311 = Large



Leading Systematic Effect

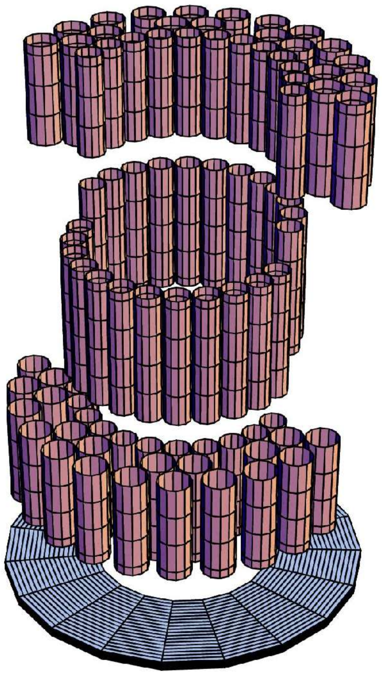


Leading Systematic Effect

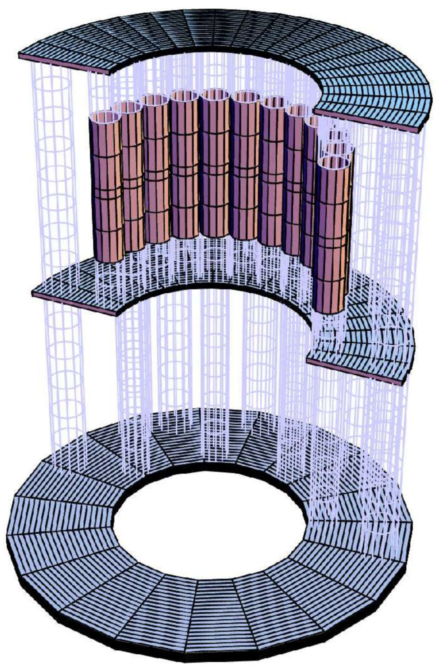


Minimizing the Leading Systematic Effect

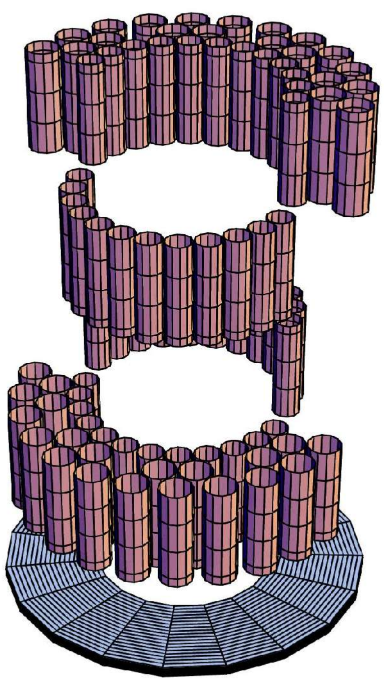
Exaggerated Source Mass Configurations



221



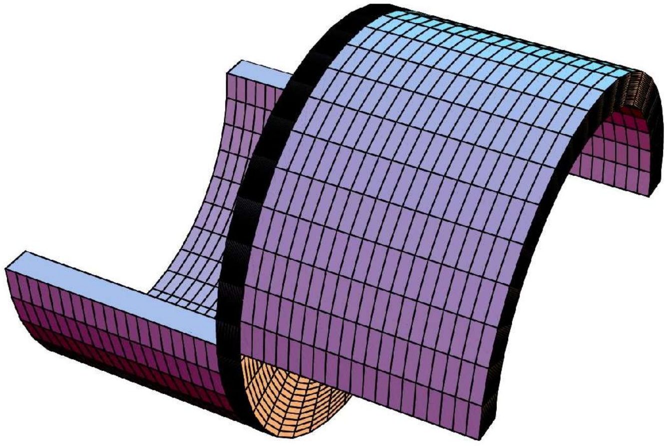
331



441

Minimizing the Leading Systematic Effect

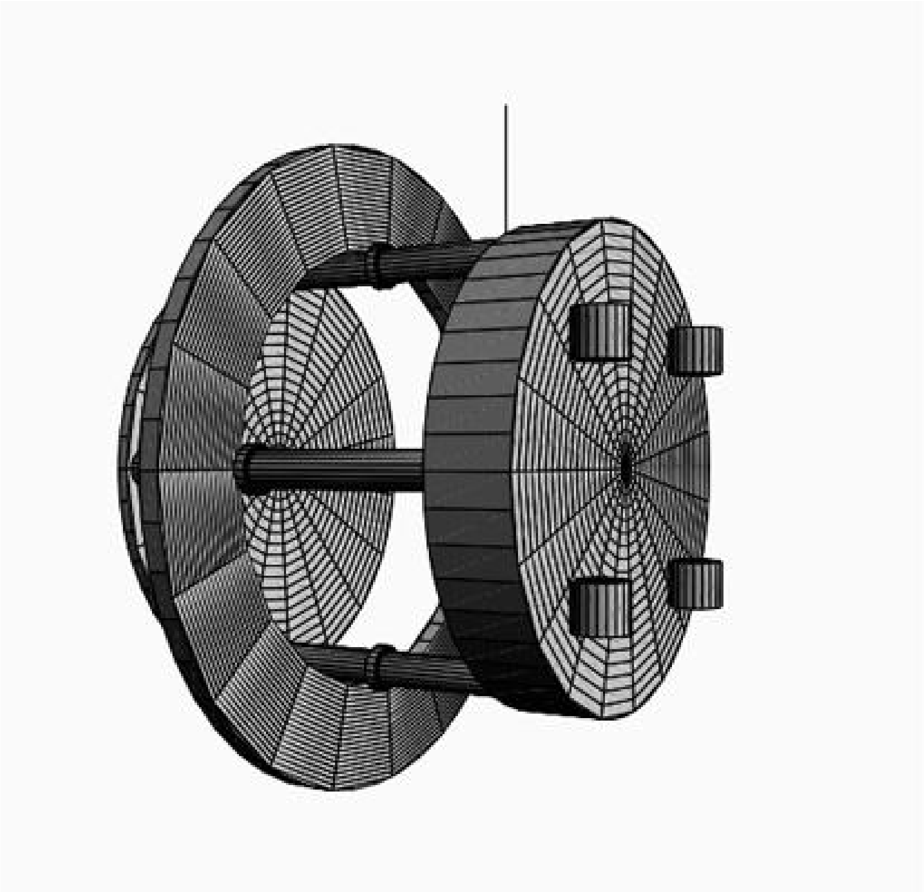
Exaggerated Pendulum

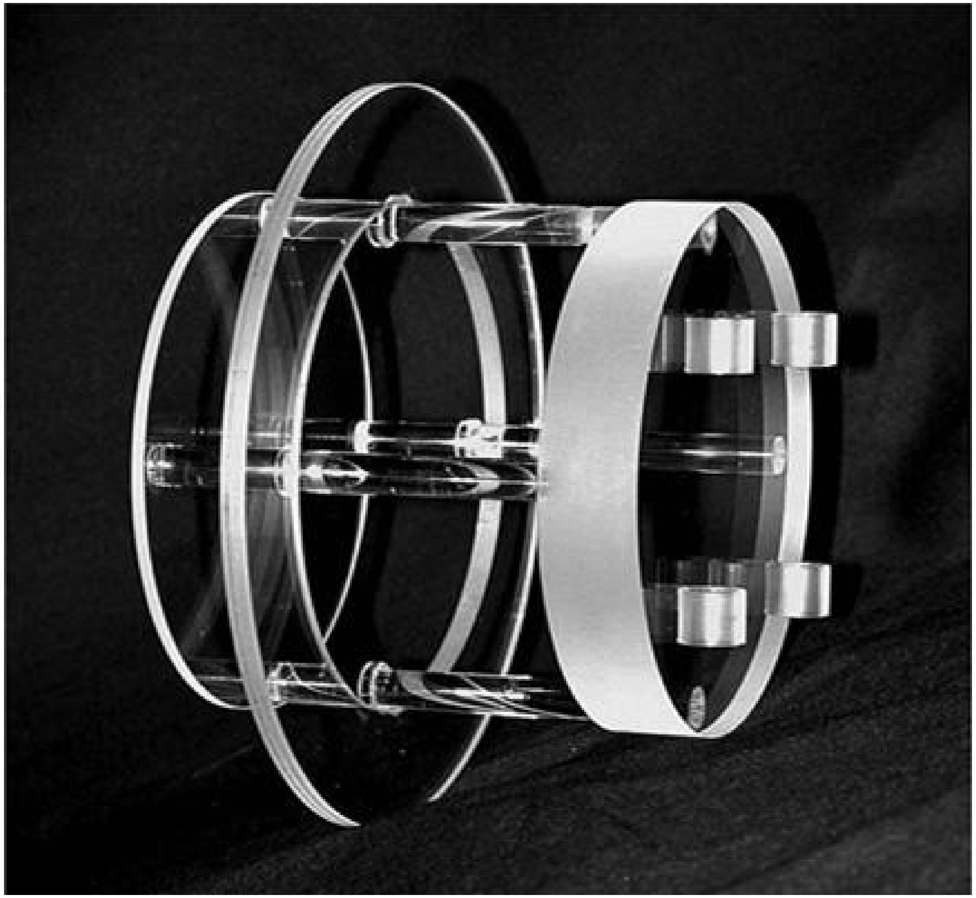


221 pendulum

$$V441 = \frac{d}{dz}V331 = \frac{d^2}{dz^2}V221$$

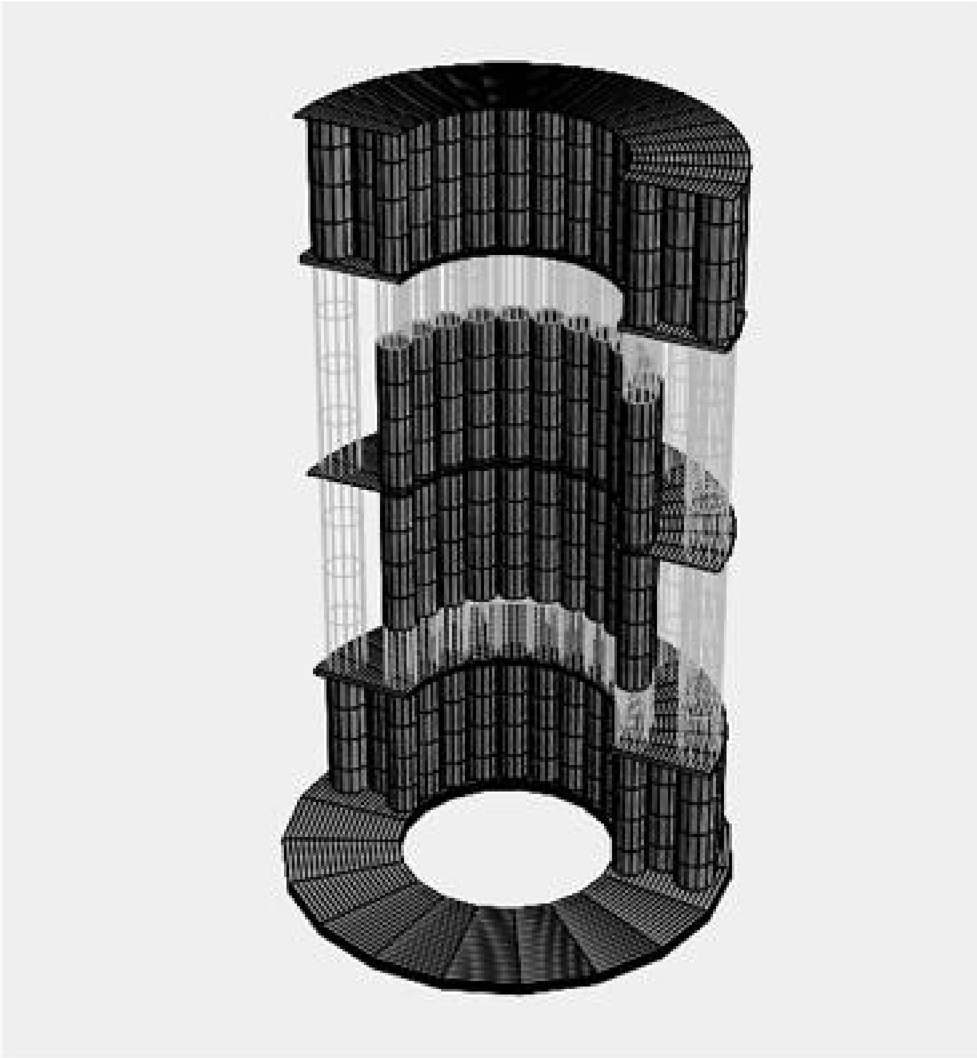
Parts List: ISLV Pendulum

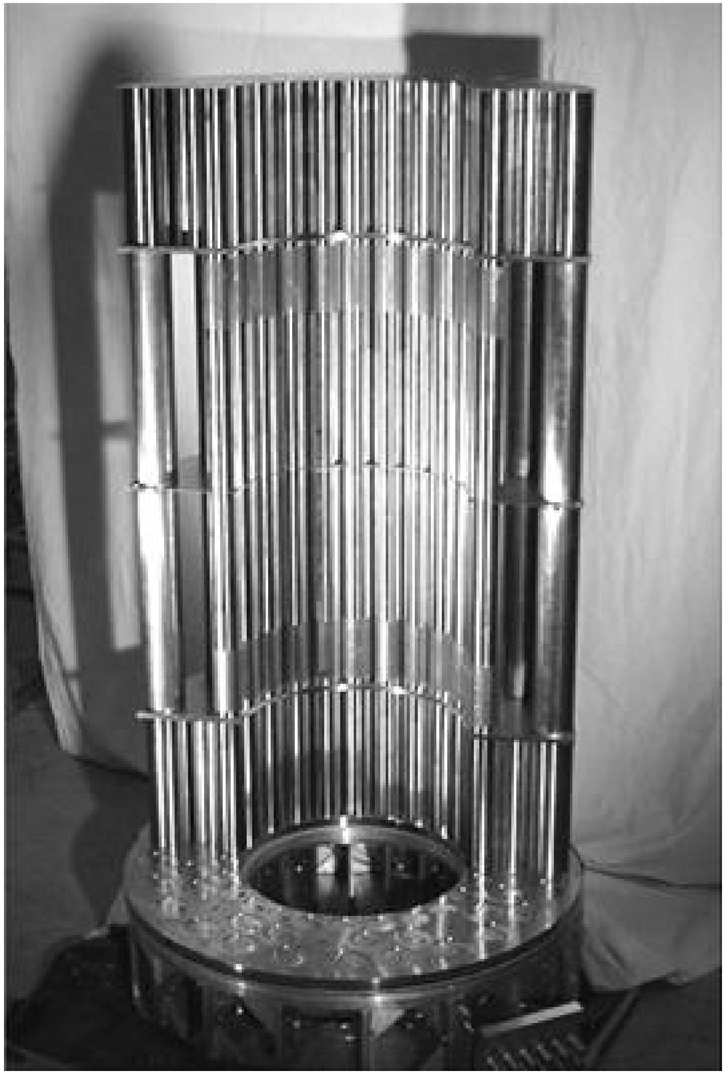




gold coated, fused silica, 240 grams

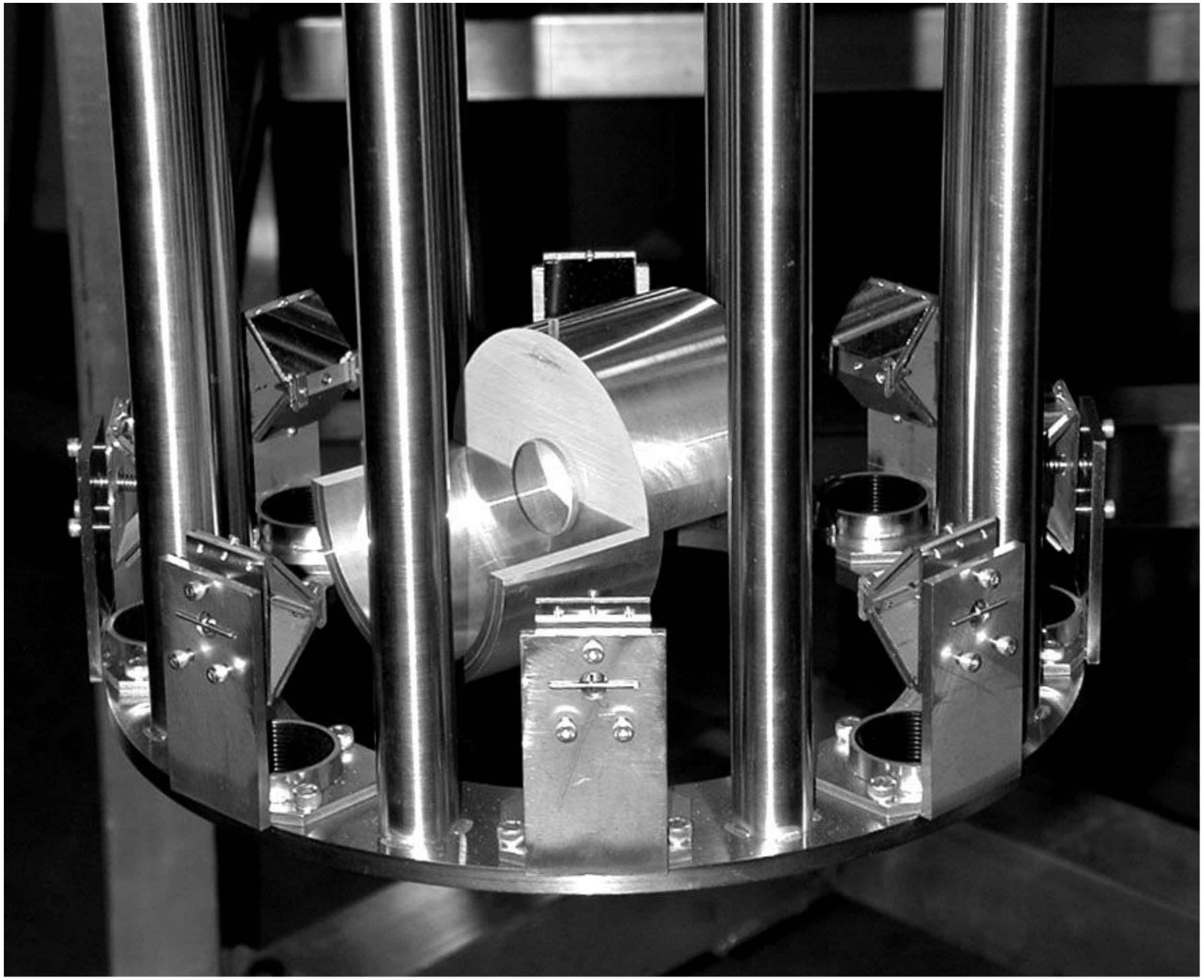
Parts List: ISLV Source Mass





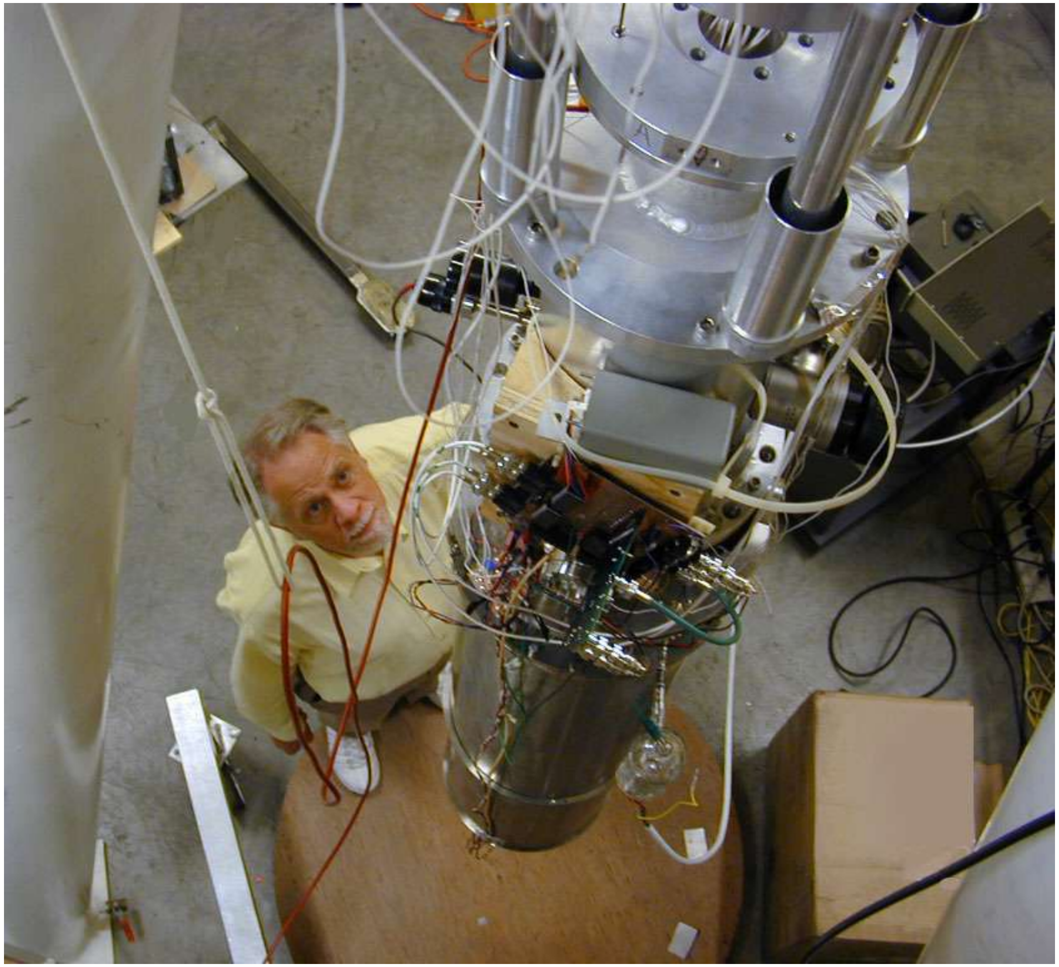
stainless steel, 1500 kg

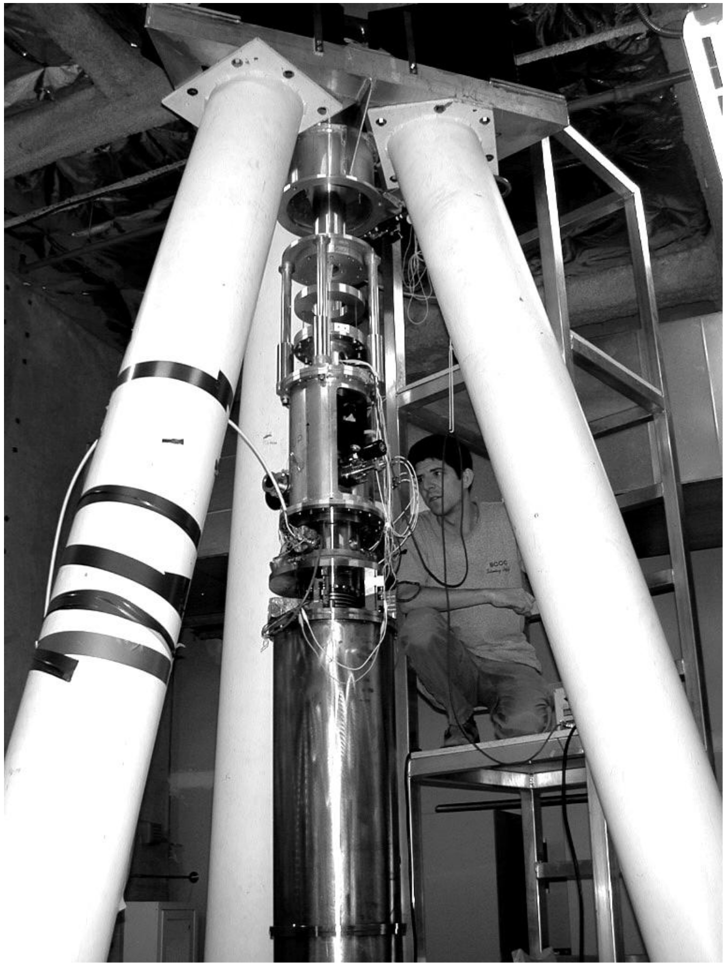
Parts List: Exaggerated 221 Pendulum



aluminum, 240 grams

Parts List: Instrumentation



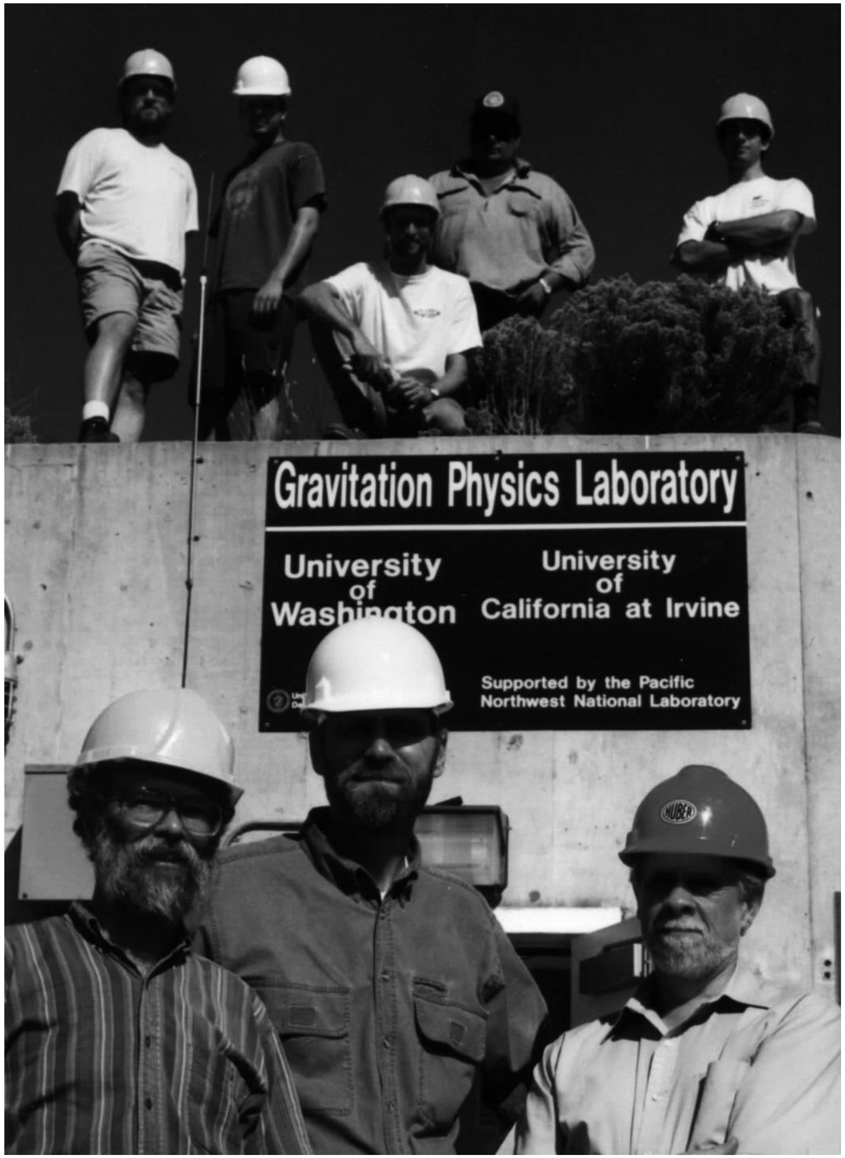


Room Temperature Apparatus

Parts List: Instrumentation

Cryogenic Apparatus

Parts List: Batelle Facility



Nike Missile Bunker

State of the System

- Both cryogenic and ambient temperature instruments are operating at BGPL
- Optimization and calibration will require another 3 to 4 months
- ISLV measurement tasks will begin in the summer of 2007
- Completion expected by spring of 2009

Conclusions

- Second-order sensitive to fabrication errors
  - Source mass produces no low-order Newtonian fields by design
  - Pendulum is not sensitive to low-order Newtonian fields by design
  - Both pendulum and source are maximally sensitive to a gradient of the Laplacian of the non-Newtonian potential
- Cryogenic apparatus to reduce thermal noise and improve magnetic shielding
- Quiet both geologically and anthropogenically