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Modified Electromagnetism
theories and test prospects

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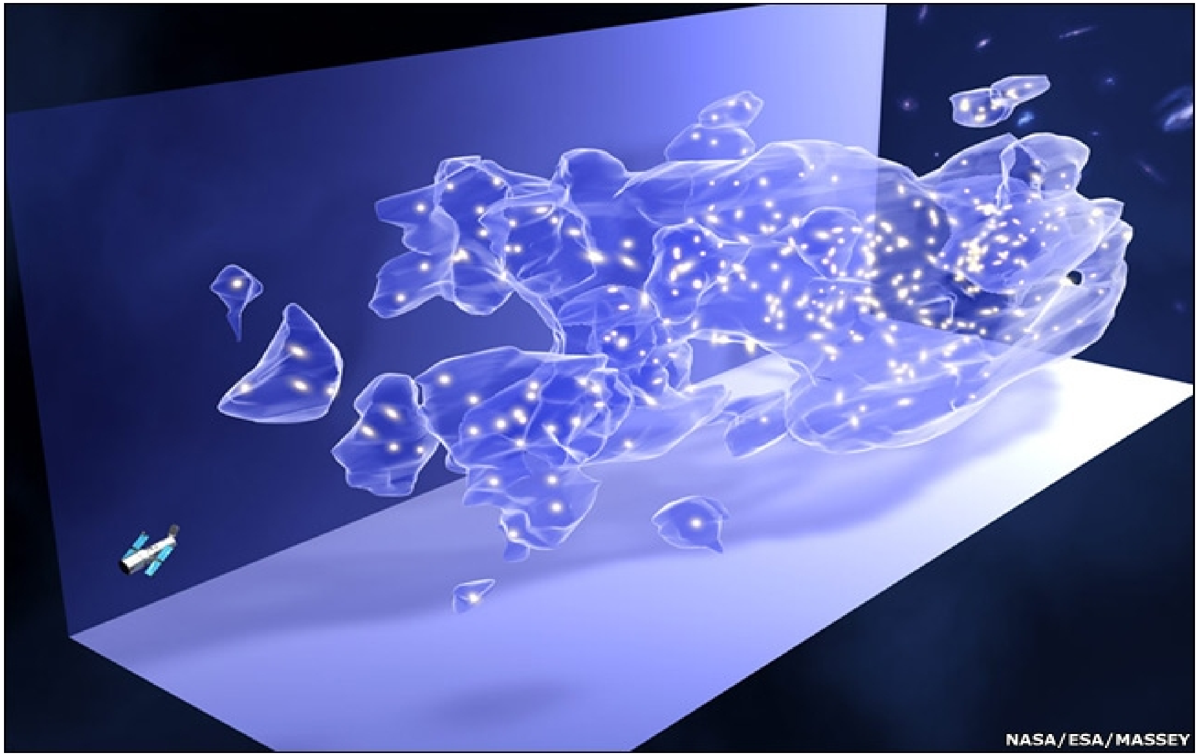
I- Introduction : astrophysical context, dark matter

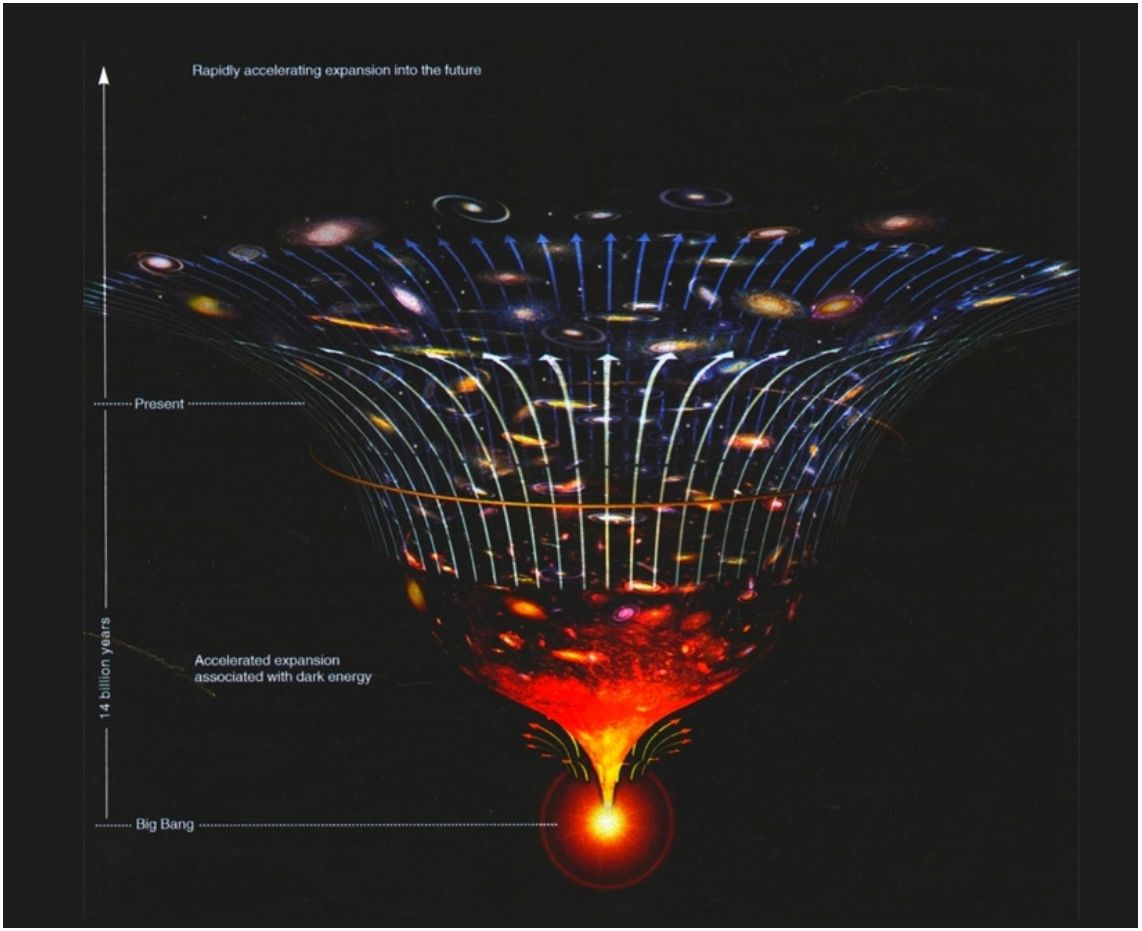
Stability of galaxies
→ equilibrium between gravitation and centrifugal force

Gravitation induced by visible matter is weaker than centrifugal forces
(galactic rotation curves)
→ lack of mass = **dark matter**

Physical nature of the dark matter ????

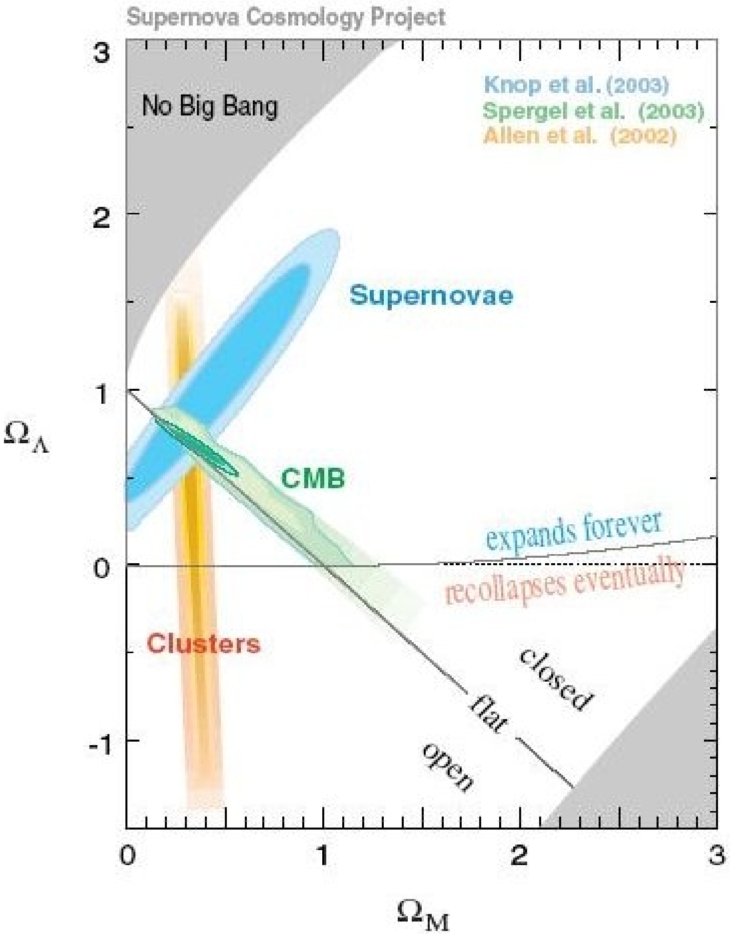


I- Introduction : astrophysical context, dark energy



Gravity must slow down the universe expansion

Cosmological observations show an acceleration
→ **dark energy** (cosmological constant)



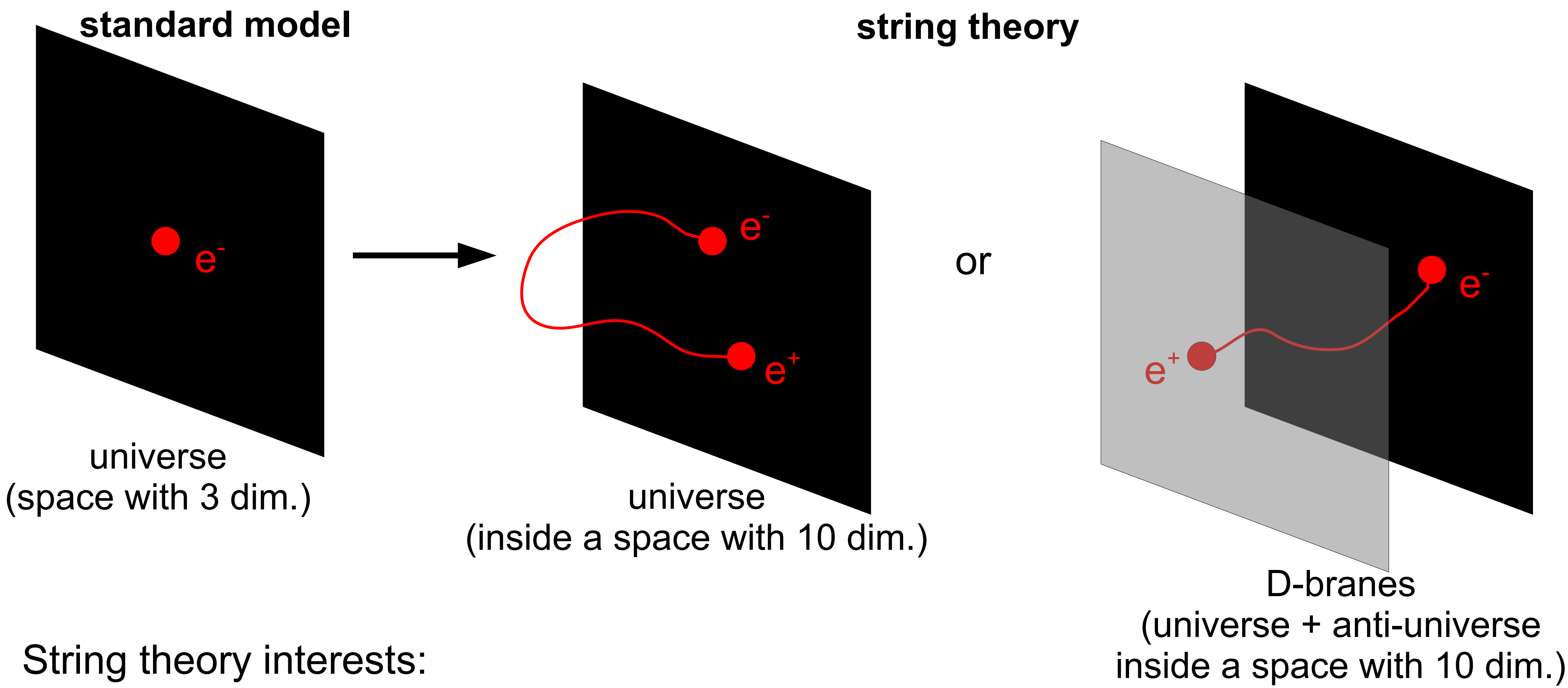
Physical nature of the dark energy ????

I- Introduction : theoretical context, two incompatible theories

Quantum field theory	*General relativity theory*
describes electromagnetic, weak nuclear and strong nuclear forces	describes gravitational and inertial forces
perceptible effects for small objects and high energy	perceptible effects for heavy (dense) objects and high energy
approximations: low energy → quantum mechanics large dimension → special relativity; low energy and large dimension → Newtonian mechanics.	approximations: low mass → special relativity; low mass and low energy → Newtonian mechanics

high energy + small characteristic dimension + large mass
(black hole, big-bang, other gravitational singularities)
→ a quantum theory of gravity is needed

I- Introduction : theoretical context, string theory



String theory interests:

- Possible unification theory between quantum field theory and general relativity
- Prediction of the existence of new weakly interacting massive particles (dark matter ?).
- Prediction of the existence of a dilaton, a particle conjugated to the graviton (dark energy ?).

Problem:
string theory cannot be directly tested by an experiment

II- The project : main idea

The main sector of string theory is the gravity sector, but other sectors can be modified, in particular the electromagnetic sector.

$$\mathcal{L}_{\text{EM,string}} \approx \mathcal{L}_{\text{EM,standard}} + \lambda\, \mathcal{L}_{\text{violations}} \qquad \lambda \ll 1$$

Possible violations of the standard model:

• Local Lorentz invariance violation
  ($\lambda = \Delta c$ *speed of light anisotropy*)

• Massive photons
  ($\lambda = m^2$ *photon mass*)

• Existence of a second kind of photons called paraphotons, weakly interacting with matter ("dark light")
  ($\lambda = \max(\chi, m^2)$ coupling constant photon-paraphoton / paraphoton mass).

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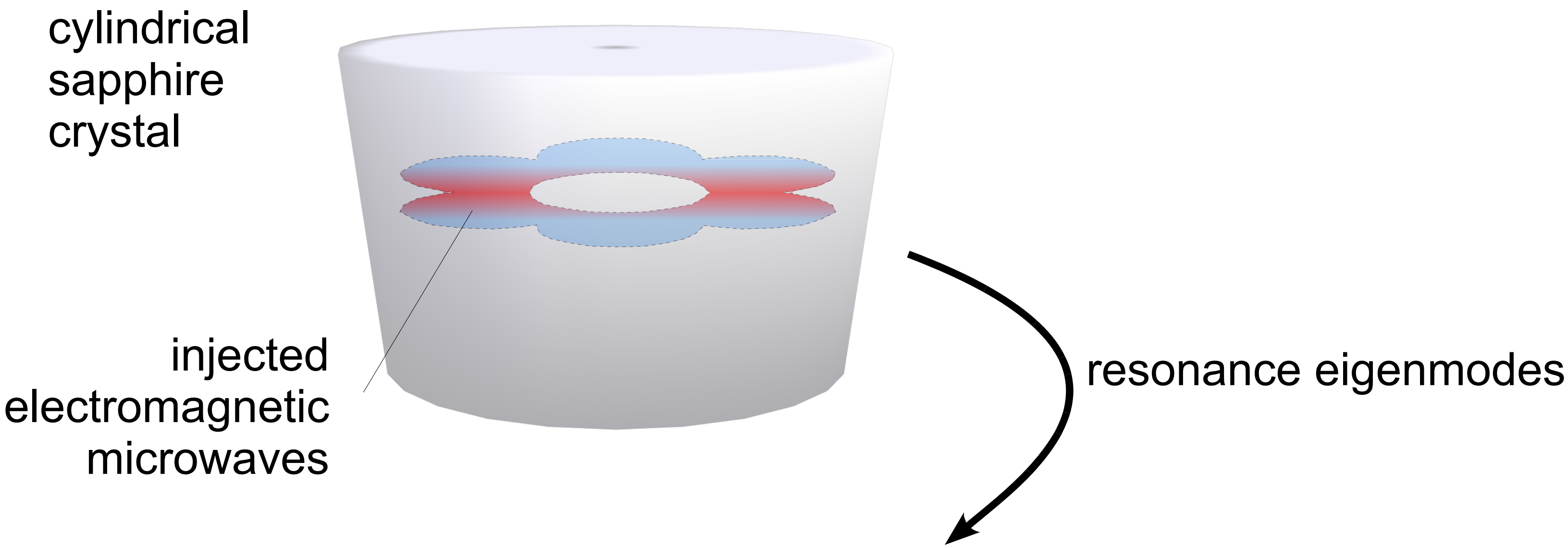
Possible violations of the standard model:

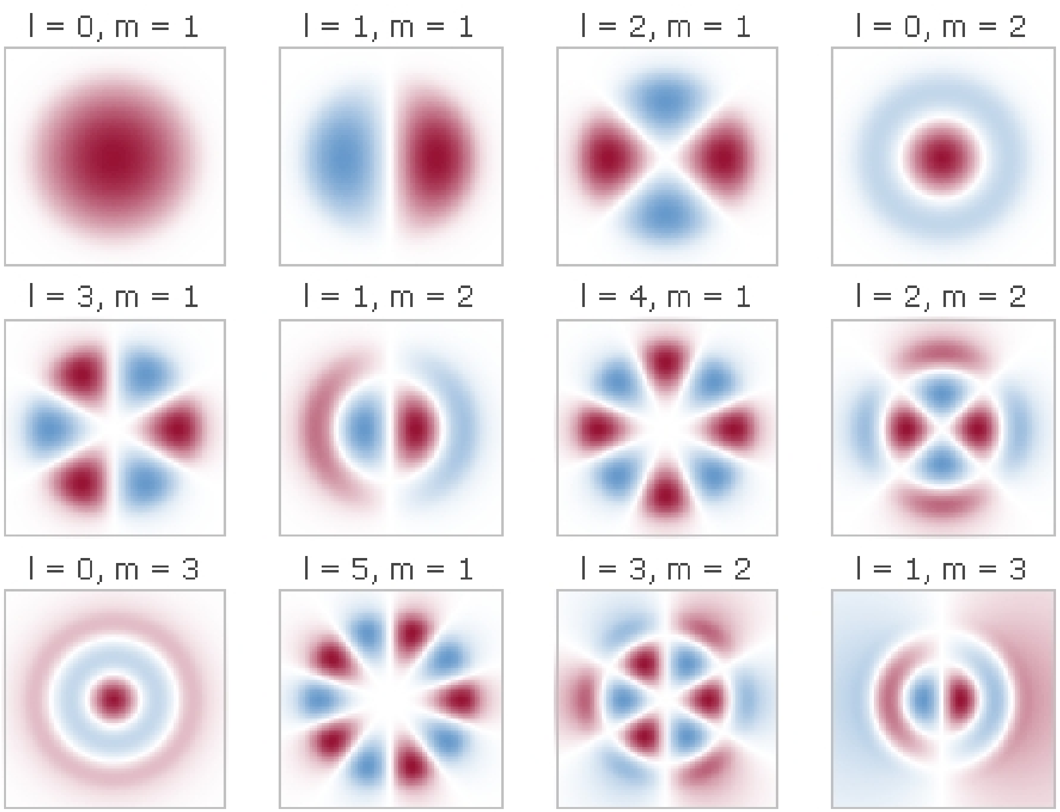
- Local Lorentz invariance violation ($\lambda = \Delta c$ *speed of light anisotropy*) — difficult experiments

- Massive photons ($\lambda = m^2$ *photon mass*) — $m=0$ highly confirmed

- Existence of a second kind of photons called paraphotons, weakly interacting with matter ("dark light") ($\lambda = \max(\chi, m^2)$ coupling constant photon-paraphoton / paraphoton mass). — possible tests with the FEMTO-ST cryogenic resonator

II- The project : experimental principle





Paraphotons effects:

• shift of the resonance eigenfrequencies

• abnormal energy loss in the resonator
(conversion of trapped photons into paraphotons which escape from the crystal)

II- The project : goals of the preliminary study

- Compute the wave equations inside the resonator for different paraelectromagnetic theoretical models (by taking into account the crystal anisotropy).

- Find if the experiment could be sufficiently accurate to measure violations of the standard model.

- Find if the experiment could distinguish the different paraelectromagnetic theoretical models (Proca, Chern-Simons, BF, Podolsky).

III- Project realization : programme

Paraelectromagnetic field
theoretical models

↓

Wave equations
inside the sapphire crystal

↓

Solve the equations :
find the eigenmodes

↓

Experiments and comparisons with
predictions

↓

Find the values (or upper
bounds) of χ and m

III- Project realization : theoretical models → wave equations

Wave equations inside the anistropic cristal have been established for different paraelectromagnetic models
(Proca, Chern-Simons, BF)

→ the photon-paraphoton coupling induces high complexity in the wave equations.

→ the effects of this coupling on the usual (measurable) electromagnetic field are (probably) independent of the paraelectromagnetic model.
The experiment cannot distinguish between the different theories even if a violation of the standard model is detected.

III- Project realization : wave equations → eigenmodes

Methods to solve the equations:

(1) Semi-analytical approach:
Based on the representation of the EM waves onto a Bessel function basis.

* Useful for the standard model.
* Accurate predictions.
* Useful for theoretical analysis.

→ several mathematical methods have been tried without success. This approach seems forbidden by the coupling.

(2) 100% numerical approaches:
° Finite elements methods
° Line methods
° FDTD
→ long programing works and adaptated computation resources are needed.

III- Project realization : outcome of the preliminary study

- The experiment cannot distinguish the different theories.
  → that closes the theoretical aspect of the project.

- The semi-analytical approach does not seem be able to solve the problem.
  → that closes the ab-initio phenomenological aspect of the project.

- Long numerical computation works are needed.
  → needed to establish the experiment accuracy.
  → needed to establish predictions for the experiment