Search for spacetime anisotropy with the MICROSCOPE mission

Journées SF2A 2017

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Testing Lorentz symmetry

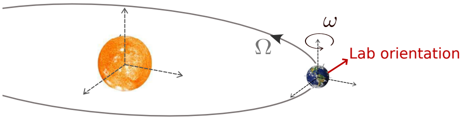
Local Lorentz Invariance

The outcome of an experiment is independent of the boost and orientation changes

- Observer invariance - invariance under coordinate changes
- Particle invariance - invariance under rotations and boost performed in a given observer frame

Lorentz symmetry breaking : spacetime anisotropy

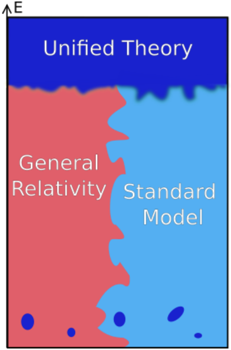
- Observer invariance holds
- Particle invariance is violated



Standard Model Extension (SME) framework

What is SME?

- Effective field theory built from SM fields & in curved spacetime
- General framework describing low-energy effects of a spontaneous Lorentz violation (LV) occurring at Planck scale



Main features

- Includes all possible observer-independent LV built from SM fields and background coefficients in the Lagrangian
- These coefficients vanish if the symmetry is preserved
- LV terms are expected to be strongly suppressed compared with non violating terms
- Phenomenological, not quantitatively predictive
- Enables the derivation of experimental observables

[Kostelecky *et al.*, PRD 51, 1995], [Kostelecky *et al.*, PRD 58, 1998]

Characteristic

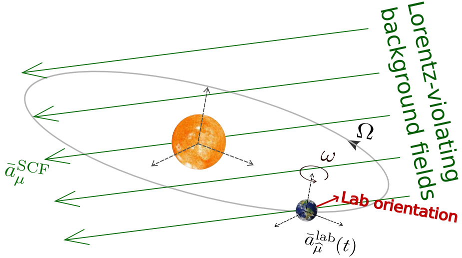
- Lorentz violations arise from interaction with LV background coefficients
- Amplitude of deviations parametrized by SME background coefficients

About SME coefficients and violation signals

- SME coefficients are coordinate dependent
- In the lab frame coefficients are time dependent, leading to time dependent observables
- They are assumed to be constant in a cosmological frame and therefore in the SCF over the timescale of the experiment
- By convention all experiments are compared using SCF coefficients

$$c_{ij}^{\mathrm{lab}}(t) \xrightarrow[T]{} c_{IJ}^{\mathrm{SCF}}$$

(coordinate transformation from lab frame to an inertial frame)



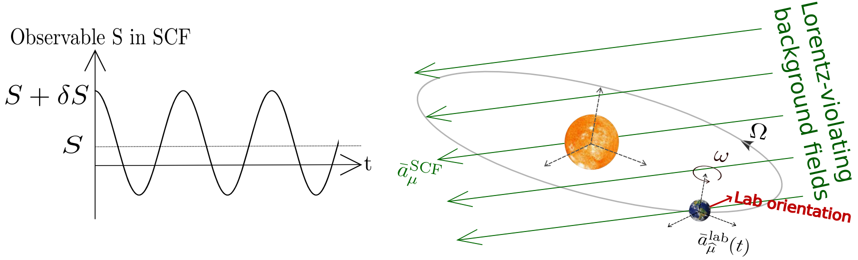
LLI violation signals in the SME

Lab frame observable:

$$\delta S(t,\vec{x}) = f\left(\bar{a}_i^{\text{lab}}(t)\right)$$

Sun Centered Frame (SCF) observable:

$$\delta S(t,\vec{x}) = \sum_n A_n\left(\bar{a}_l^{\text{SCF}}\right)\cos(\omega_n t) + B_n\left(\bar{a}_l^{\text{SCF}}\right)\sin(\omega_n t)$$



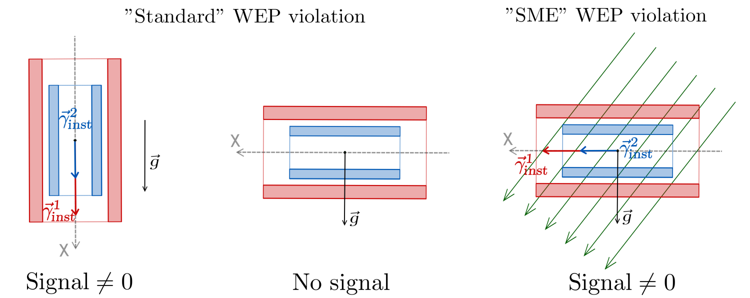
SME model for MICROSCOPE

Standard WEP :

$$2\vec{\gamma}^{(d)} = \delta\vec{g} + ([T] - [In])\vec{\Delta} - 2[\Omega]\dot{\vec{\Delta}} - \ddot{\vec{\Delta}}$$

SME WEP:

$$2\vec{\gamma}^{(d)} = A\,\underbrace{\Delta\bar{a}_t^{\mathrm{GCRF}}}_{\text{SME equivalent to } \delta}\,\vec{g} + ([T] - [In])\vec{\Delta} - 2[\Omega]\dot{\vec{\Delta}} - \ddot{\vec{\Delta}}\underbrace{- \frac{B}{5cr^5} R^T \vec{r}\,(\vec{\omega}\wedge\vec{r})^k \Delta\bar{a}_k^{\mathrm{GCRF}} + \frac{C}{5cr^3} R^T \vec{\nabla}\,(\vec{\omega}\wedge\vec{r})^k \Delta\bar{a}_k^{\mathrm{GCRF}}}_{\text{Analogous to a gravitomagnetic term}}$$



SME observable with SCF coefficients

$$2\vec{\gamma}^{(d)} = 2\left(\Delta\bar{a}_{\tilde{T}}^{SCF} + \frac{\dot{x}_\oplus}{c}\Delta\bar{a}_{\tilde{x}}^{SCF} + \frac{\dot{y}_\oplus}{c}\Delta\bar{a}_{\tilde{y}}^{SCF} + \frac{\dot{z}_\oplus}{c}\Delta\bar{a}_{\tilde{z}}^{SCF}\right)\vec{g} + ([T]-[In])\vec{\Delta} - 2[\Omega]\dot{\vec{\Delta}} - \ddot{\vec{\Delta}}$$
$$- \frac{6GMR_\oplus^2}{5cr^5}R^T\vec{r}\,(\vec{\omega}\wedge\vec{r})^k\,\Delta a_k^{SCF} + \frac{2GMR_\oplus^2}{5cr^3}R^T\vec{\nabla}\,(\vec{\omega}\wedge\vec{r})^k\,\Delta a_k^{SCF}$$

- Acceleration Tsage : 3 differential accelerations & time scale
- SME model parameters
- Earth's boost components (INPOP)
- Gravity file : 3 acceleration & 6 gradients
- Angular velocity (3) and acceleration (3)
- Attitude file : 4 components of quaternions
- Orbito file : 3 positions

Lorentz invariance vs "standard" WEP test

Frequencies

Suppression	SME coefficients	Frequency
1	$\Delta\bar{a}^{SCF}_{\tilde{T}}$	ω_{ep}
10^{-4}	$\Delta\bar{a}^{SCF}_{\tilde{X},\tilde{Y}}$	$\omega_{ep}\pm\Omega$
10^{-6}	$\Delta\bar{a}^{SCF}_{\tilde{Z}}$	$\omega_{ep}\pm\Omega$
10^{-6}	$\Delta\bar{a}^{SCF}_{\tilde{X},\tilde{Y}}$	$\omega_{ep}\pm(\omega_{orb}\pm\Omega)$
		$\omega_{spin}\pm\Omega$

Main limitations - test masses offcenterings Δ

- Offcenterings could mimic LV signals due to gravity gradient
- Fitted as parameters of the analysis
- Investigate correlations between SME coefficients and offcenterings

First SME model [Kostelecky and Tasson, PRD 83, 2011]

SME Microscope proposal (SYRTE, LKB, J. Tasson, Q. Bailey) in 2015

Lorentz violating coefficients

- $\bar{c}_{\mu\nu}$ and $\bar{a}_{\mu}$ lead to composition dependent trajectories of the test masses
- $\bar{c}_{\mu\nu}$ have already been strongly constrained with clocks
- Potential improvement by up to 3 orders of magnitude on several $\bar{a}_{\mu}$ coefficients depending on the noise and systematics

Status

SME model

- ✓ Analytical derivation of the instrument observable in terms of GCRF violating coefficients and in-flight parameters
- ✓ Same thing for the instrument observable in terms of SCF coefficients
- Transformation from GCRF to SCF coefficients using INPOP ephemerides for Earth's position and boost

Data analysis

- Toy-model adjustment on simulated data provided by OCA/ONERA
  - ✓ Without noise (least-squares) : no WEP violation, offcentrings $\Delta_x = 20\mu m$ and $\Delta_z = 20\mu m$
  - With a realistic noise and a noise model (MC simulations - **On going**)
  - Blind tests on simulated data with/without WEP violation and offcenterings, with a realistic noise and gaps
- Full SME test on real data

Thank you for your attention!

Thanks to Gilles Métris for providing simulated data and related documentation