Testing Space-Time fuzziness with high-energy γ-ray detectors

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What is space-time fuzziness

On of the pillars of the of the general theory of the relativity, inherited by the Newtonian theory, is that the space time is a smooth entity.
That implies that the photons travel along smooth geodesic lines.
Yet this picture is in contradiction with another pillar of moder physics: quantum mechanics (QM).
Even if a fully consistent theory combining general relativity and QM is still missing, all attempts of defining a space-time structure consistent with QM suggest that the space-time is fuzzy (or foamy).

In a fuzzy space-time, photons do not travel along smooth geodesic lines, but follow zig-zag trajectories. The basic unit of length defining the scale of non-smoothness is the Planck length $l_p = (hG/2\pi c^3)^{1/2} \sim 10^{-35}$ m (G is the Newton constant of gravity, h/2π the reduced Planck constant and c the speed of light).

This implies that the limiting accuracy for measuring a length l is $\delta l \sim N l^{(1-\alpha)} l_p^{\alpha}$ where N~1 and α defines the Quantum Gravity model under study: usually values between 1/2 and 2/3 are considered.

That has two important consequences: the time travel of photons along a geodesic fluctuates (longitudinal fluctuations) and the the phase of the electromagnetic wave associated to the photon fluctuates (transverse fluctuations).

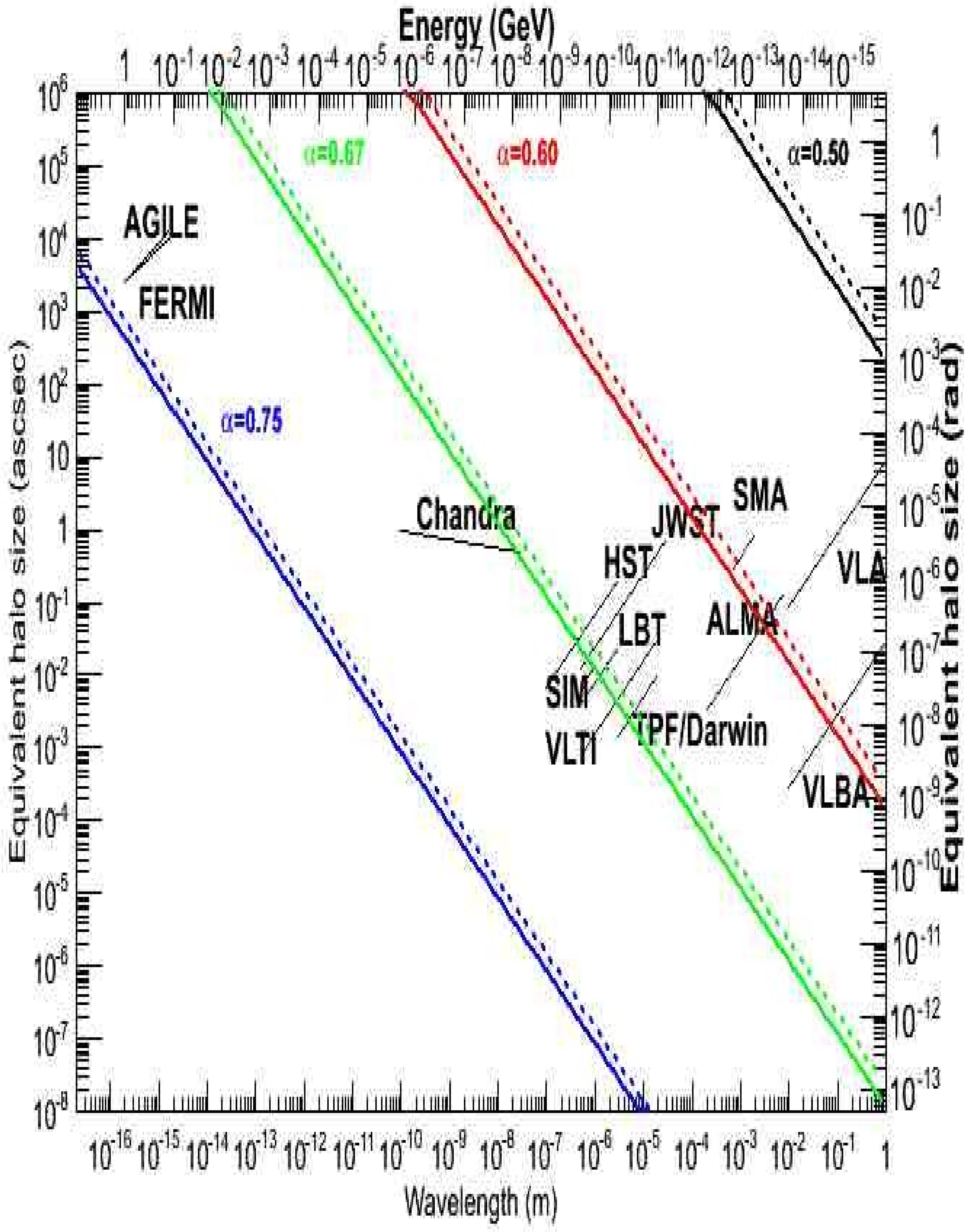
The first effect translates into a spread in arrival times from distant impulsive source like e.g. GRB. This is a very small effect and, in spite of precise measurement on GRB signal time dispersion, only models with $\alpha < 0.3$ can be excluded.

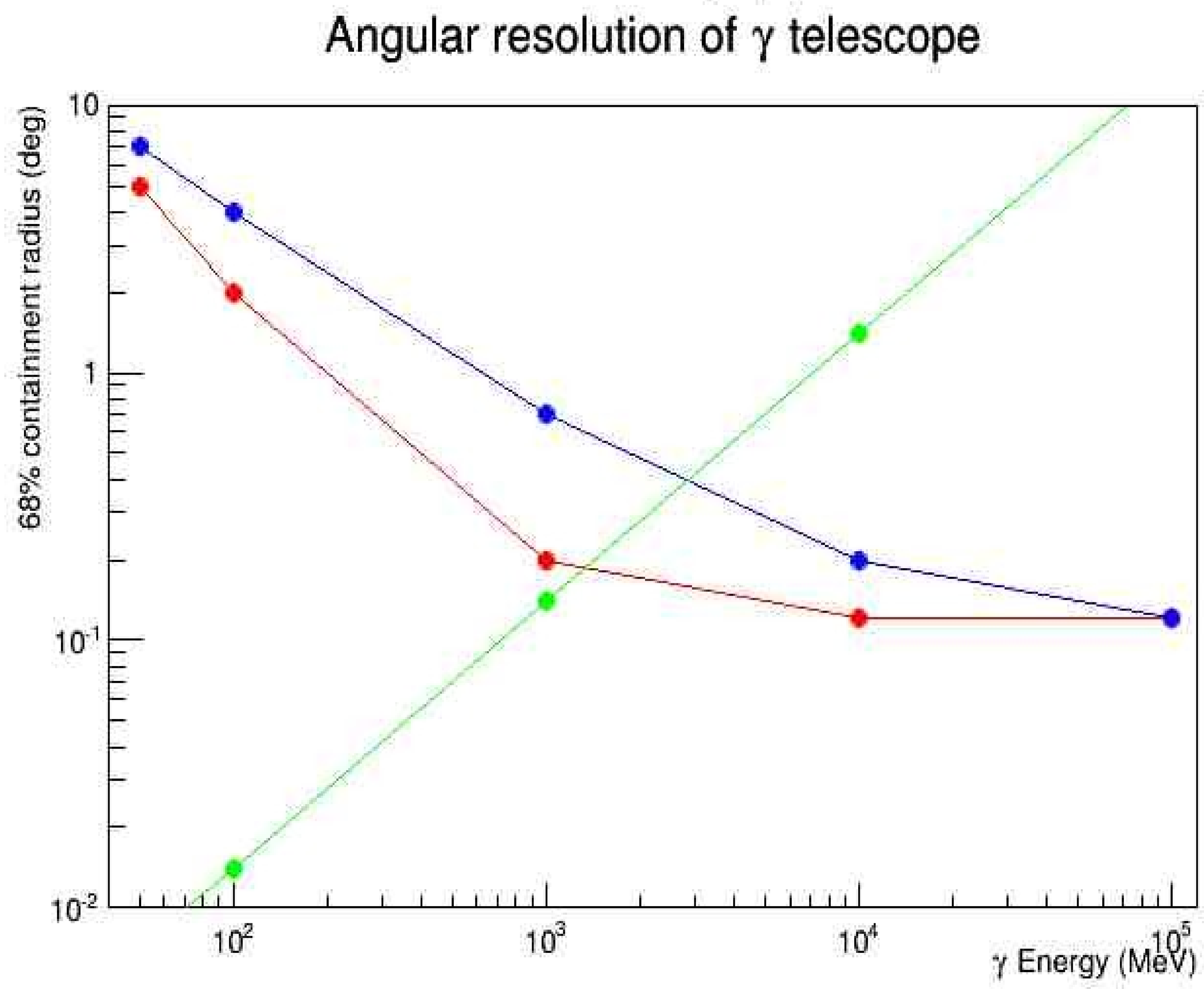
As to the transverse fluctuations, different parts of the photon wavefront traverse different parts of the space time foam and experience different path length fluctuations. That results in a random variation of the direction of the detected photon and in additional angular uncertainty on the measurement of the source direction:

$\delta\psi \sim N(l/\lambda)^{(1-\alpha)}(l_p/\lambda)^{\alpha}$

where λ is the photon wavelength.
If the detector has an angular resolution smaller, the source spot will appear larger than expected and will have this specific dependence on the photon energy.

Therefore high energy γ–ray detectors with high angular resolution are particularly fit for detecting such effect. Mainly, because their resolution improves with the increase of the energy while the angular blurring due to the foam follows the opposite trend.





Angular resolution estimated of the FERMI detector (blue), expected for the GAMMA400 detector (red) and the blurring of the source due to the foam.

References:
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