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The Possible Anisotropy Of The Unruh Radiation:

A Screened Detector in (3+1)D Space-Time.

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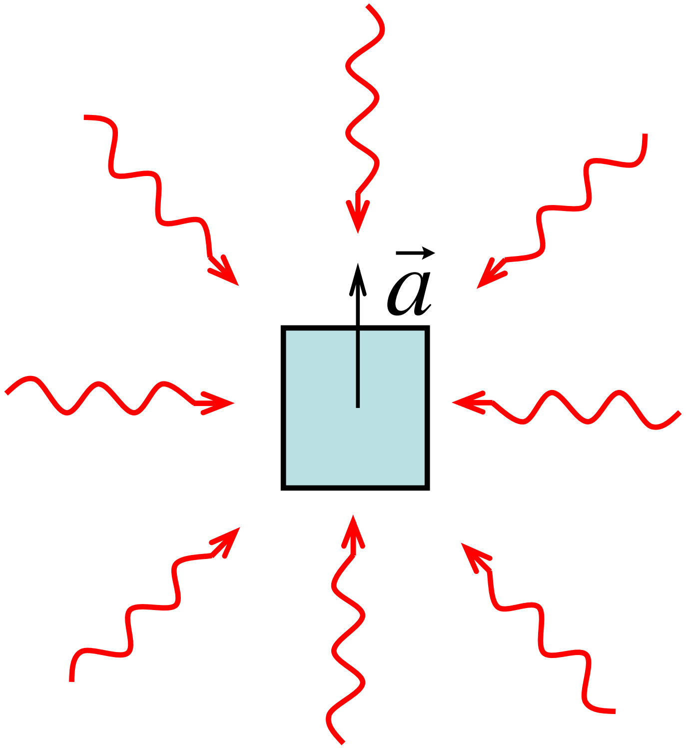
Introduction

Almost a half of century ago Unruh (1976) predicted theoretically that the accelerated detector in vacuum should observe the thermal radiation.

$$T = \frac{\hbar a}{2\pi c k_B}$$



The effect is very subtle: for the acceleration of 1g the temperature is about $4 \cdot 10^{-20}$ K

Despite the presence of preferred direction, ***a***,
the effect is believed to be isotropic!

Previous investigations of anisotropy of the Unruh radiation

- Gerlach, Phys. Rev. D, 27, 2310 (1983)
- Grove and Ottewill, Class. and Quant. Grav., 2, 373, (1985)

Distribution of the Unruh radiation is totally isotropic

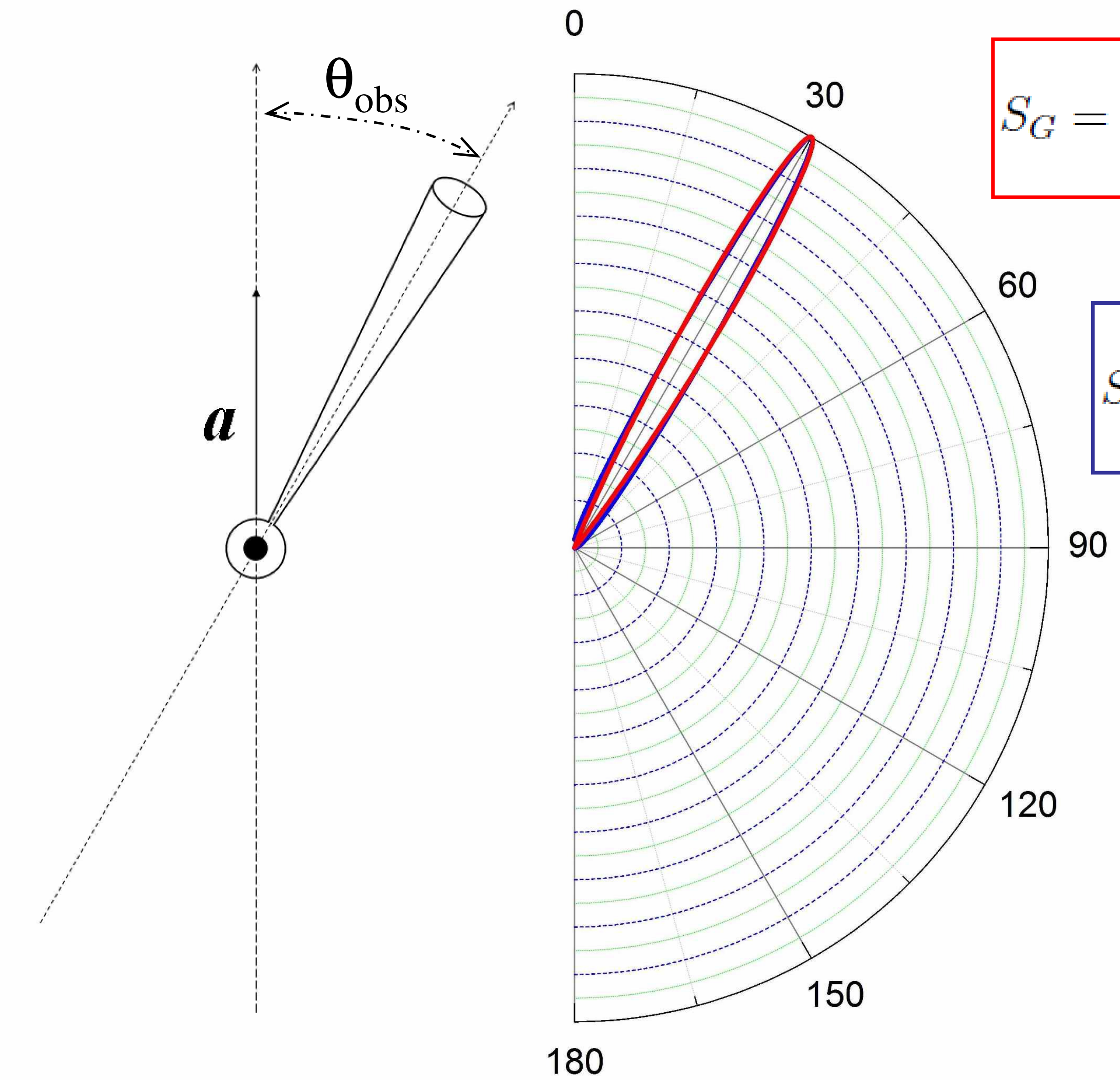
- Hinton et al., Physics Letters B, 120, 88 (1983)
- Israel and Nester, Physics Letters A, 98, 329 (1983)
- Sanchez, Physics Letters A, 112, 133 (1985)
- Kolbenstvedt, Physics Letters A, 122, 292 (1987)

Distribution of the Unruh radiation is anisotropic

Full consensus on isotropy/anisotropy of the Unruh radiation has not been achieved. Despite this fact, the presence of ``thermal signature'' in energy spectrum of Unruh radiation appears such ``a strong argument'' that the other properties (in particular, angular distribution) of Unruh radiation are also considered to be determined by the thermal distribution.

Thus commonly accepted point of view: the Unruh radiation is isotropic.

One of the evident and promising methods to reveal the possible Unruh radiation anisotropy is the calculation with the model of monopole detector shielded by some screen allowing registration of this radiation from specific directions and preventing the registration from other directions. Despite several works (e.g. Hinton et al. 1983, Israel&Nester 1983, Sanchez 1985, Grove&Ottewill 1985) considering this method in more or less degree the final answer has not been obtained due to different reasons.



$$S_G = \exp\left(-4\ln 2\left(\frac{\theta_R - \theta_{obs}}{\Delta\theta}\right)^2\right)$$

$$S_L = \left(1 + 4\left(\frac{\theta_R - \theta_{obs}}{\Delta\theta}\right)^2\right)^{-1}$$

Left panel: The sketch of the detection system.
Right panel: Dependencies of screening function in polar coordinates (directivity pattern) at observation angle θ_{obs}=30^0 and at width of screening function $\Delta\theta$=8^0.

Detector response from the Fermi golden rule:

$$\frac{dW}{d\mu \Delta\Omega} = \left(\overline{\Delta \cos\theta_R}\right)^{-1} \int \left|F_{\mathrm{k}}\left(\mu\right)\right|^2 \frac{k_\perp dk_\perp}{16\pi^3}$$

Screened transition amplitude:

$$F_{\mathrm{k}}\left(\mu\right) = \int_{-\infty}^{+\infty} S\left(\theta_R\left(\Theta_C\right)\right) \exp\left(i\left[b \sinh\left(\Theta_C\right) + \mu\Theta_C\right]\right) d\Theta_C$$

$$b \;=\; \left(k_y^2 + k_z^2 + m^2\right)^{1/2}$$

Rapidity: $$\Theta_C = -\mathrm{asinh}\left(\frac{k_\perp}{b}\cot\theta_R\right)$$

Typical "inclined" width: $$\overline{\Delta \cos\theta_R} = \int S\left(\theta_R\right) \sin\theta_R d\theta_R$$

The integral for transition amplitude is difficult to calculate.

It has been calculated numerically and estimated analytically for massless field.

Results

For Lorentzian Screen: $$\boxed{\left(\frac{dW}{d\mu\Delta\Omega}\right)_L \simeq \frac{\sin\theta_{obs}}{32\pi^2\Delta\theta}\exp\left(-\frac{\mu\Delta\theta}{\sin\theta_{obs}}\right)}$$

For Gaussian Screen:

$$\boxed{\left(\frac{dW}{d\mu\Delta\Omega}\right)_G \simeq \frac{\sqrt{\ln 2}\sin\theta_{obs}}{8\pi^{5/2}\Delta\theta}\left(\exp\left(-\frac{(\mu\Delta\theta)^2}{8\ln 2\sin^2\theta_{obs}}\right) - \frac{\mu\Delta\theta\sqrt{\pi}}{2\sqrt{2\ln 2}}\left[1-\mathrm{erf}\left(\frac{\mu\Delta\theta}{\sqrt{8\ln 2}\sin\theta_{obs}}\right)\right]\right)}$$

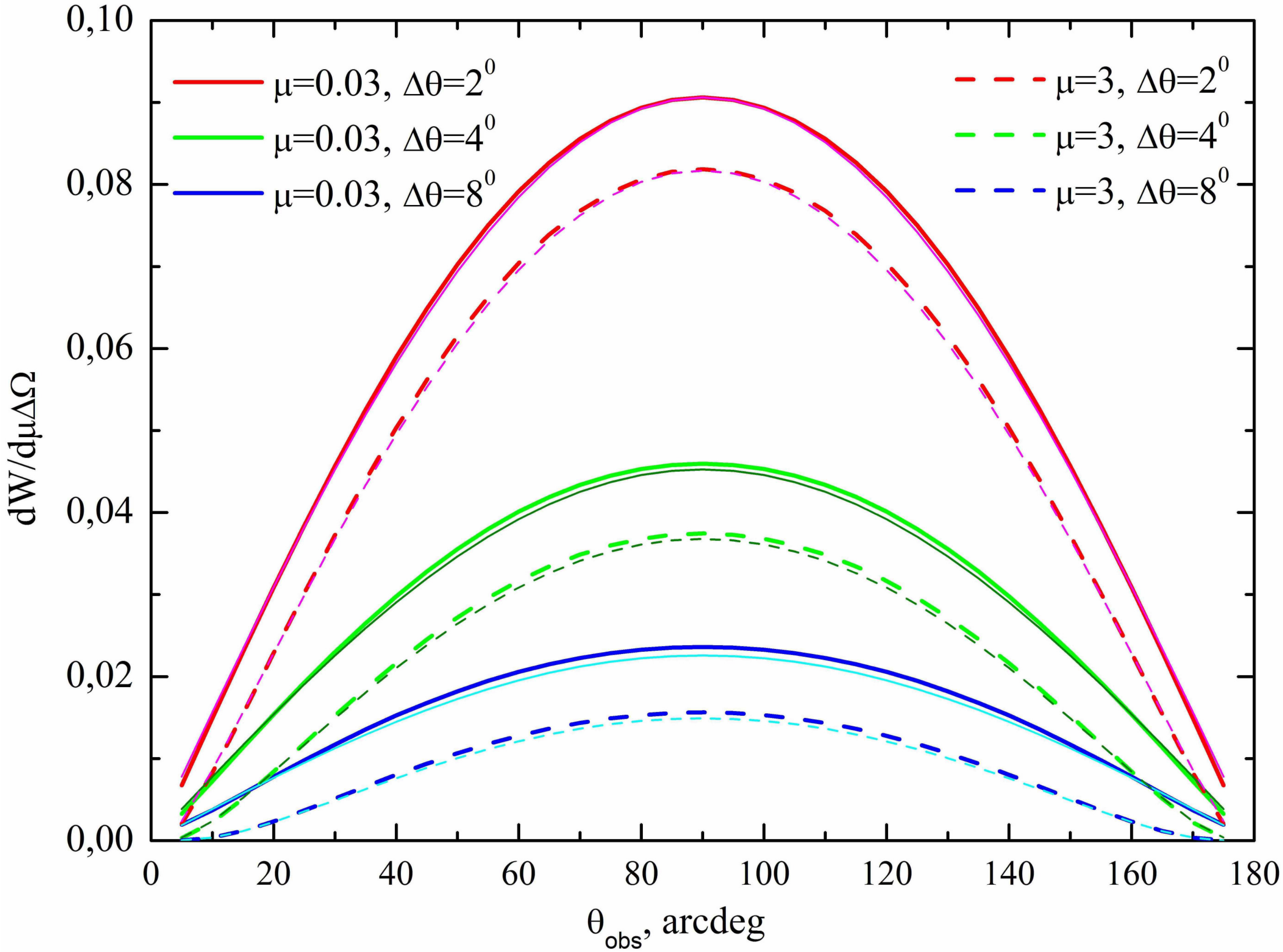
Thermal (equilibrium) response: $$\left(\frac{dW}{d\mu d\Omega}\right)_{th} = \frac{\mu}{8\pi^2}\frac{1}{\exp(2\pi\mu)-1}$$

Comparison of response magnitudes at $\theta_{obs}=90^0$ and low energy μ:

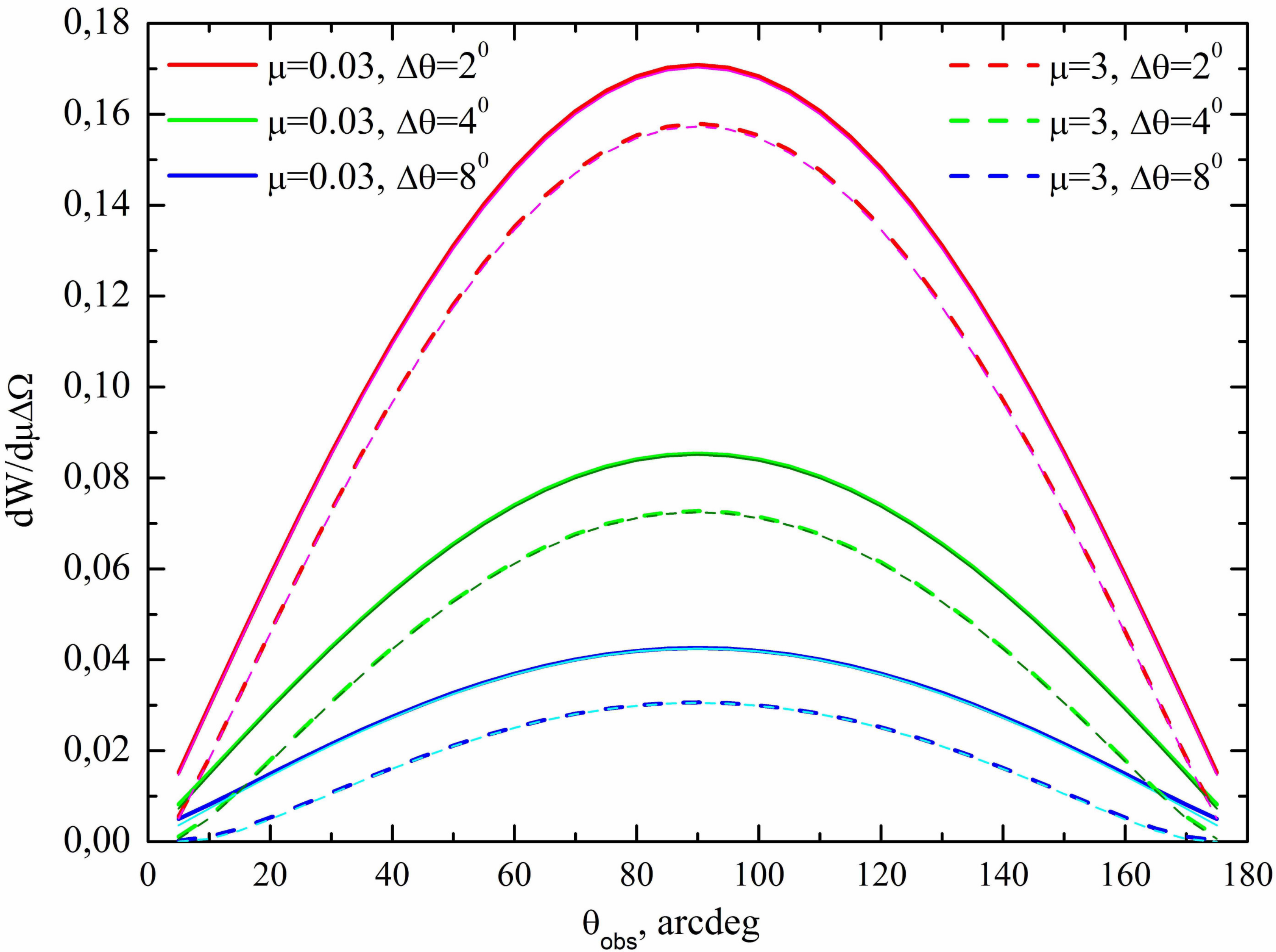
$$\left(\frac{dW}{d\mu d\Omega}\right)_L \Big/ \left(\frac{dW}{d\mu d\Omega}\right)_{th} = \frac{\pi}{2\Delta\theta} \qquad \left(\frac{dW}{d\mu d\Omega}\right)_G \Big/ \left(\frac{dW}{d\mu d\Omega}\right)_{th} = \frac{2\sqrt{\pi}\ln 2}{\Delta\theta}$$

Typical energy scale of response decrease:

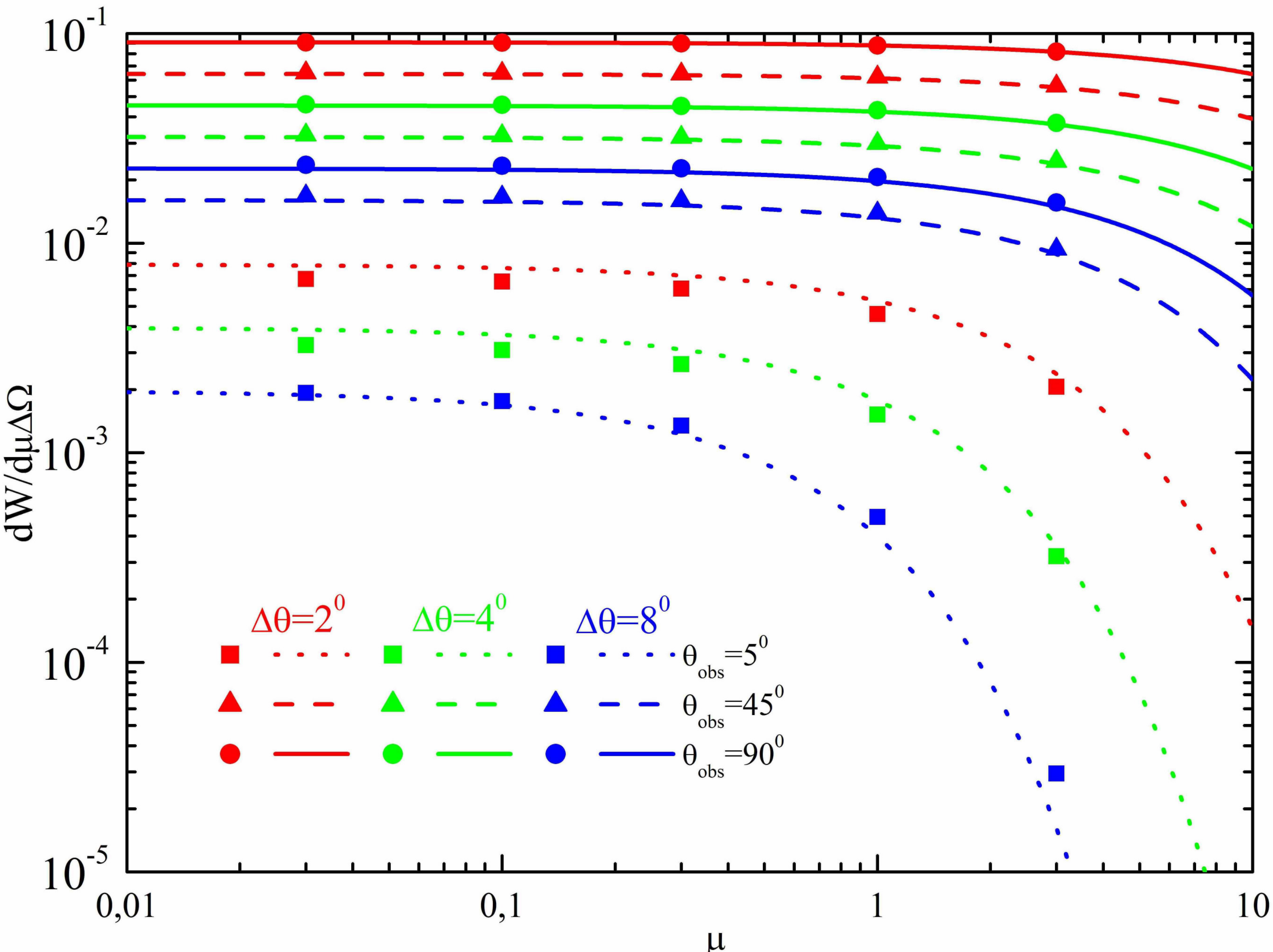
For Lorentzian screen: $\sin\theta_{obs}/\Delta\theta$ For Gaussian screen: $2.35\sin\theta_{obs}/\Delta\theta$



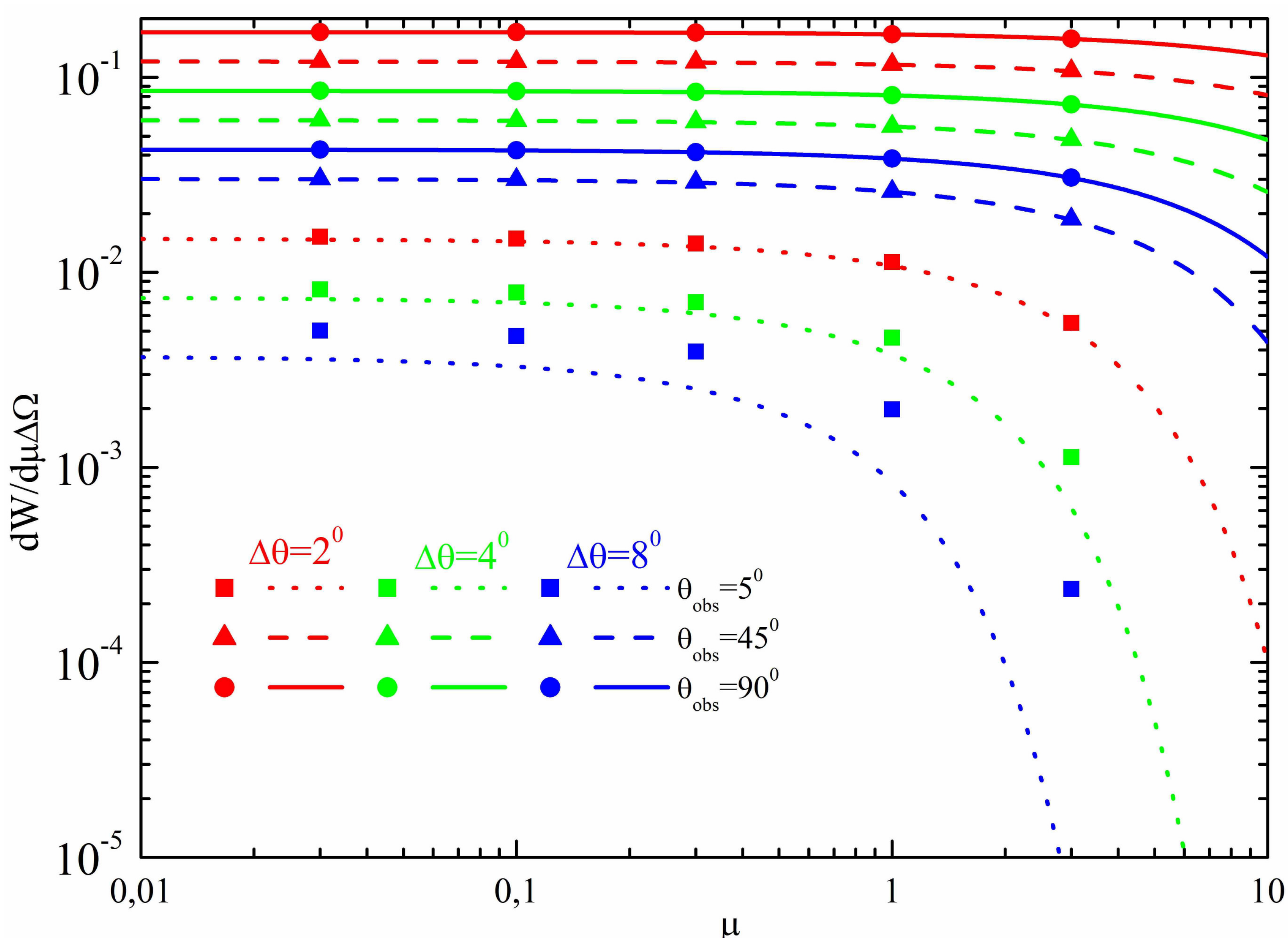
Numerically estimated dependencies of screened detector response on the observation angle θ_{obs} at observation energies μ=0.03 (solid curves) and μ=3 (dashed curves) for different values of Lorentzian screening function width: $\Delta\theta=2^0$ (red curves), $\Delta\theta=4^0$ (green curves), and $\Delta\theta=8^0$ (blue curves). Accompanying thin curves correspond to analytical approximation.



Numerically estimated dependencies of screened detector response on the observation angle θ_{obs} at observation energies μ=0.03 (solid curves) and μ=3 (dashed curves) for different values of Gaussian screening function width: $\Delta\theta=2^0$ (red curves), $\Delta\theta=4^0$ (green curves), and $\Delta\theta=8^0$ (blue curves). Accompanying thin curves correspond to analytical approximation.



Numerically (symbols) and analytically (smooth curves, approximation) estimated dependencies of screened detector response on the observation energy μ at different observation angles $\theta_{obs}=90^0$ (circles, solid curves), $\theta_{obs}=45^0$ (triangles, dashed curves) and $\theta_{obs}=5^0$ (squares, dotted curves) for different values of Lorentzian screening function width: $\Delta\theta=2^0$ (red), $\Delta\theta=4^0$ (green), and $\Delta\theta=8^0$ (blue).



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Conclusion

•The model of pointlike monopole detector shielded by a screen providing narrow directivity pattern $\Delta\theta<<1$ has been considered.

•The angular response (i.e. response per solid angle) of this detector on the Unruh radiation has been calculated numerically for massive and massless scalar quantum fields in (3+1)D space-time and estimated analytically for massless quantum field with typical accuracy 1 – 5% in angle interval $[15^0;165^0]$ and energy interval [0.03;3].

•It has been shown that corresponding stationary dependencies of the angular response on observation angle in first approximation at low energies can be described by the function $\sim\sin\theta_{obs}$ and, thus, demonstrate significant anisotropy of the observed Unruh radiation. The dependencies on particle energy show that the value of angular response decreases at energy increase with typical scale $\sim\sin\theta_{obs}/\Delta\theta$ which significantly differs from the Unruh temperature $(2\pi)^{-1}$.

•The specific form of distribution of the angular response over particle energy is strongly dependent on the shape of screening function and, in any case, does not correspond to thermal response.

•All these features of obtained angular response confirm that the Unruh radiation cannot be considered as thermal (equilibrium) radiation.

Thank you for your attention!