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Limits to Seeing High-Redshift Galaxies Due to Planck-Scale-Induced Blurring

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If spacetime is "foamy" travel along a lightpath must be subject to continual, random distance fluctuations $\pm\delta l$ proportional to Planck length $l_{\rm P} \sim 10^{-35}$ m (Lieu & Hillman 2003). Although each "kick" by itself is tiny, these may accumulate. Accounting for redshifted (bluer) emitted photons, over a cosmological distance $L = (1+z)L_{\rm C}$ for co-moving distance $L_{\rm C}$, the resultant phase perturbations $\Delta\phi = 2\pi\delta l/\lambda$ at observed wavelength λ could grow independently of telescope diameter D to a maximum of $\Delta\phi_{\rm max} = (1+z)\Delta\phi_0$ (Steinbring 2007) where $\Delta\phi_0 = 2\pi a_0 (l_{\rm P}^{\alpha}/\lambda)L^{1-\alpha}$ follows Ng *et al.* (2003). Here $a_0 \sim 1$ and α specifies the quantum-gravity model: 1/2 implies a random walk and 2/3 is consistent with the holographic principle; a vanishingly small $\Delta\phi_{\rm P} = \Delta\phi_{\rm max}/[(1+z)a_0(L/l_{\rm P})^{1-\alpha}] = 2\pi l_{\rm P}/\lambda$ is approached when $\alpha = 1$.

The highest-resolution Nyquist-sampled images of $z \approx 6$ active galactic nucleii (AGN) ever obtained are suggestive although do not show clear evidence of $\Delta\phi_{\rm max}$ for $\alpha = 2/3$ (Steinbring 2007; Tamburini *et al.* 2011). That level of blurring, however, would imply an image full-width at half maximum (FWHM) just at the diffraction limit of the 2.4-m diameter *Hubble Space Telescope* (*HST*). It might be that α is larger or that these phase errors become invisible as they approach the wavelength of observed light (e.g. Perlman *et al.* 2015). But it can be shown by taking a linear superposition of all phase-error amplitudes $\Delta\phi\ \sigma(\Delta\phi) = 1 - A\log(\Delta\phi/\Delta\phi_{\rm P})$ that $(1/A)\int \Delta\phi\ \sigma(\Delta\phi)\ {\rm d}\Delta\phi = (1+z)\Delta\phi_0$ is recovered for $A = 1/\log\left[(1+z)(L/l_{\rm P})^{1-\alpha}\right]$. If correct, any pointlike source viewed by a diffraction-limited telescope for which $\Delta\phi_{\rm max}$ is visible must be inflated to a lesser mean width of

$$\Phi = 1.22\frac{\lambda}{D} + \int \Delta\phi\ \sigma(\Delta\phi)\ {\rm d}\Delta\phi \approx 1.22\frac{\lambda}{D} + 2\pi\frac{l_{\rm P}}{\lambda}Ae^{1/A}.$$

That is consistent with the *HST* results as well as *Fermi* observations of $z < 4$ gamma-ray bursts (GRBs; Steinbring 2015). Unfortunately, those and current ground-based telescopes employing adaptive optics (AO) are unable to reliably resolve structures much below 0.3 kpc wide at $z = 1$ to 4 (assuming a cosmology with $\Omega_\Lambda = 0.7$, $\Omega_{\rm M} = 0.3$, and $H_0 = 70$ km s^{-1} Mpc^{-1}). Future optical/near-infrared AO and space telescopes viewing out to $z = 6$ to 8 will do better. In a long exposure, the minimal angular extent of known pointlike galaxy structures would be noticeably enlarged - a FWHM expanded by more than a few percent - and possibly also embedded within an extra halo of scattered "fuzz." For example, with $z = 6.0$, $\alpha = 0.667$, and $D = 6.5$ m no AGN or GRB, despite being physically much smaller, would be found with an apparent size less than about 0.1 kpc in the restframe, 0.025 arcsec across, or consistently 8% larger than diffraction at 0.6 μm, the shortest wavelength to be visible with the *James Webb Space Telescope*.

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