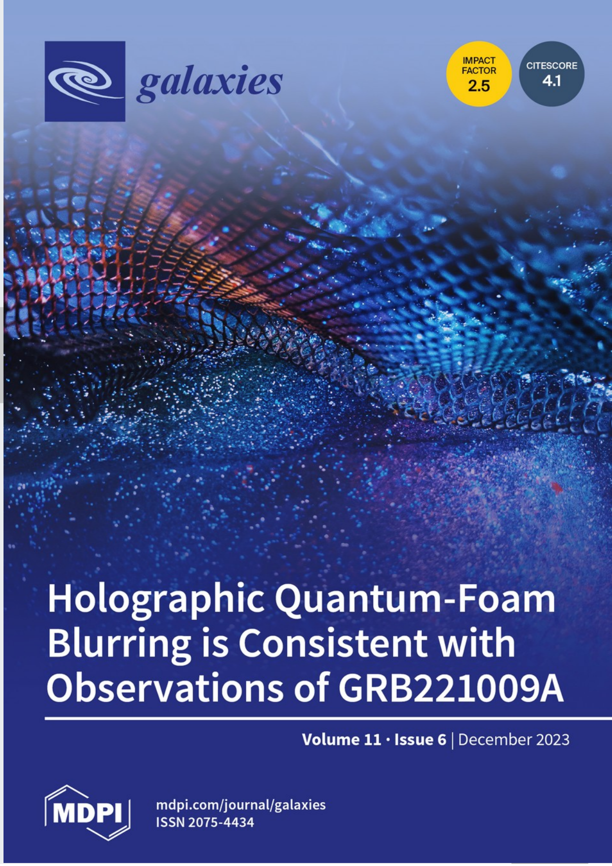
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Holographic Quantum-Foam Blurring is Consistent with Observations of GRB221009A

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Observations of Holographic Quantum-Foam Blurring

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Question: Is quantum foam real, with spacetime fundamentally quantized, and if so are effects of the Planck-scale detectable?

A proton is about a femtometer across, so 20 orders of magnitude bigger than the Planck scale.

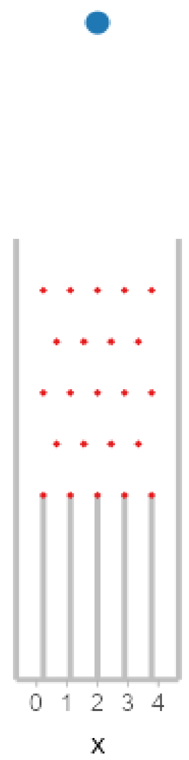
And, carrying on in a logarithmic way, the visible universe is perhaps 40 orders of magnitude or so bigger than a proton.

$$l_P \sim 10^{-35}\ \mathrm{m}$$

$$t_P \sim 10^{-44}\ \mathrm{s}$$

Let's see: Short-wavelength, high-energy photons would be the most affected by tiny random "kicks" along the path of their long transits through the foam. (How could you not look!)

A classical anology:



https://mjskay.github.io/plinko/

Photo credit: New Scientist

Review: Carlip, S. *Spacetime foam: A review.* Rep. Prog. Phys. 2023, 86, 066001

A problem: Although possibly a huge effect at high-enough energy (i.e., closer to the Planck scale), in optical light a micron in wavelength, even for distant sources it's plausibly only microradians of error in the wavefront.

Also bad: Detection requires that we look at intrinsically "small" objects, very far away, which are typically going to be faint things.

Diffraction:

$$\approx 1.22\frac{\lambda}{D}$$

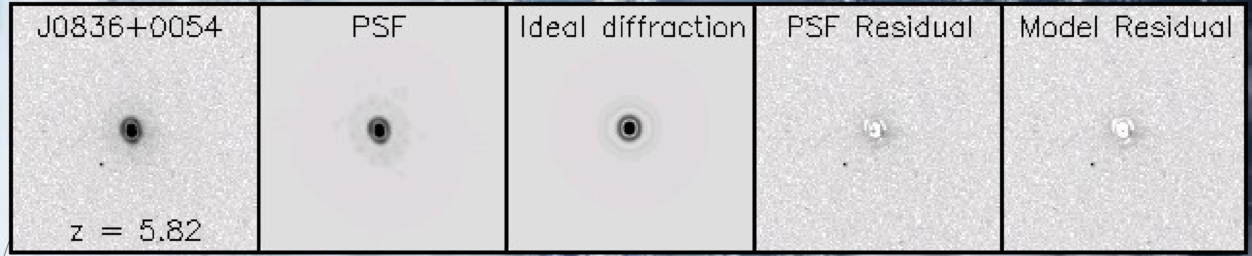
And worse: To do this, you need to use a big telescope, which has a fundamental instrumental limit, and in the optical that will also be roughly microradians of error in the wavefront.

Background photo credit: Wikipedia; "Plinko" is a trademarked brand of Fremantlemedia

Lieu and Hillman (2003) did not see loss of diffraction rings in Hubble Space Telescope (HST) images of a redshift z=0.25 active galaxy host nucleus; (Actually, it has since been found possibly to be a lens. Interesting, but not a problem here.)

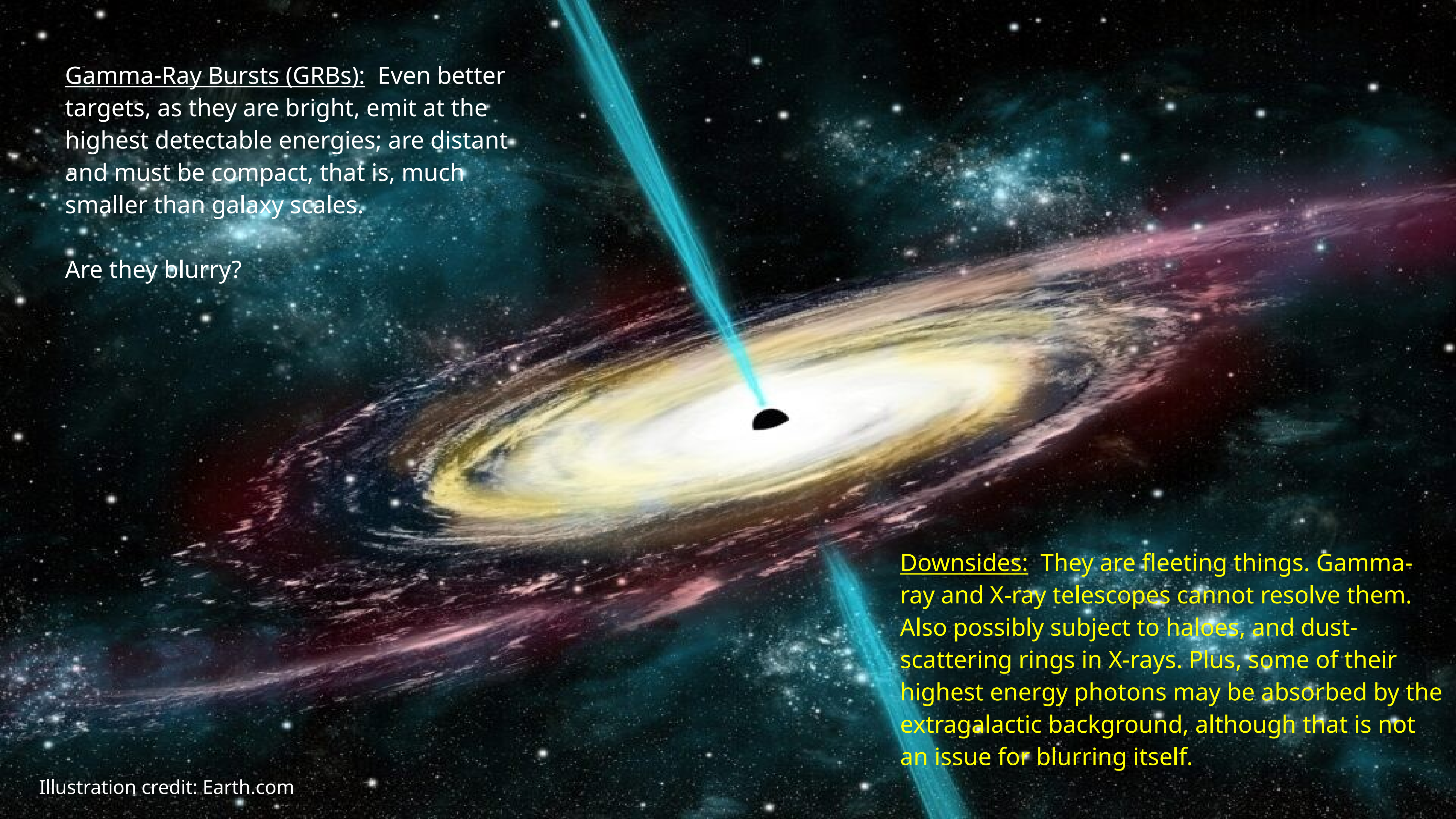
Quasars: Better targets, as they are bright up to very high redshift (z>4), especially in optical light; and fairly compact, under a kiloparsec in size.

Photo credit: NASA/ESA



Steinbring (2007) showed a slight drop in Strehl ratio (a “proxy” of blur) for HST images of the highest-z quasars known.

This is still not convincing though, as those are compact and bright only relative to their host galaxies, and because this can be confused with the signature of the optical system itself: the Point-Spread Function (PSF).



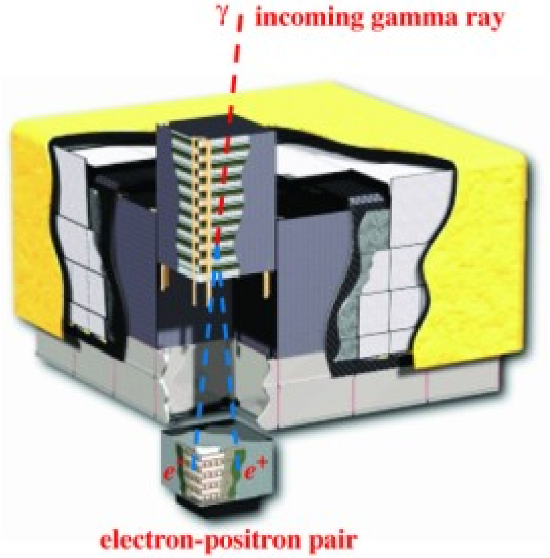
Gamma-Ray Bursts (GRBs): Even better targets, as they are bright, emit at the highest detectable energies; are distant and must be compact, that is, much smaller than galaxy scales.

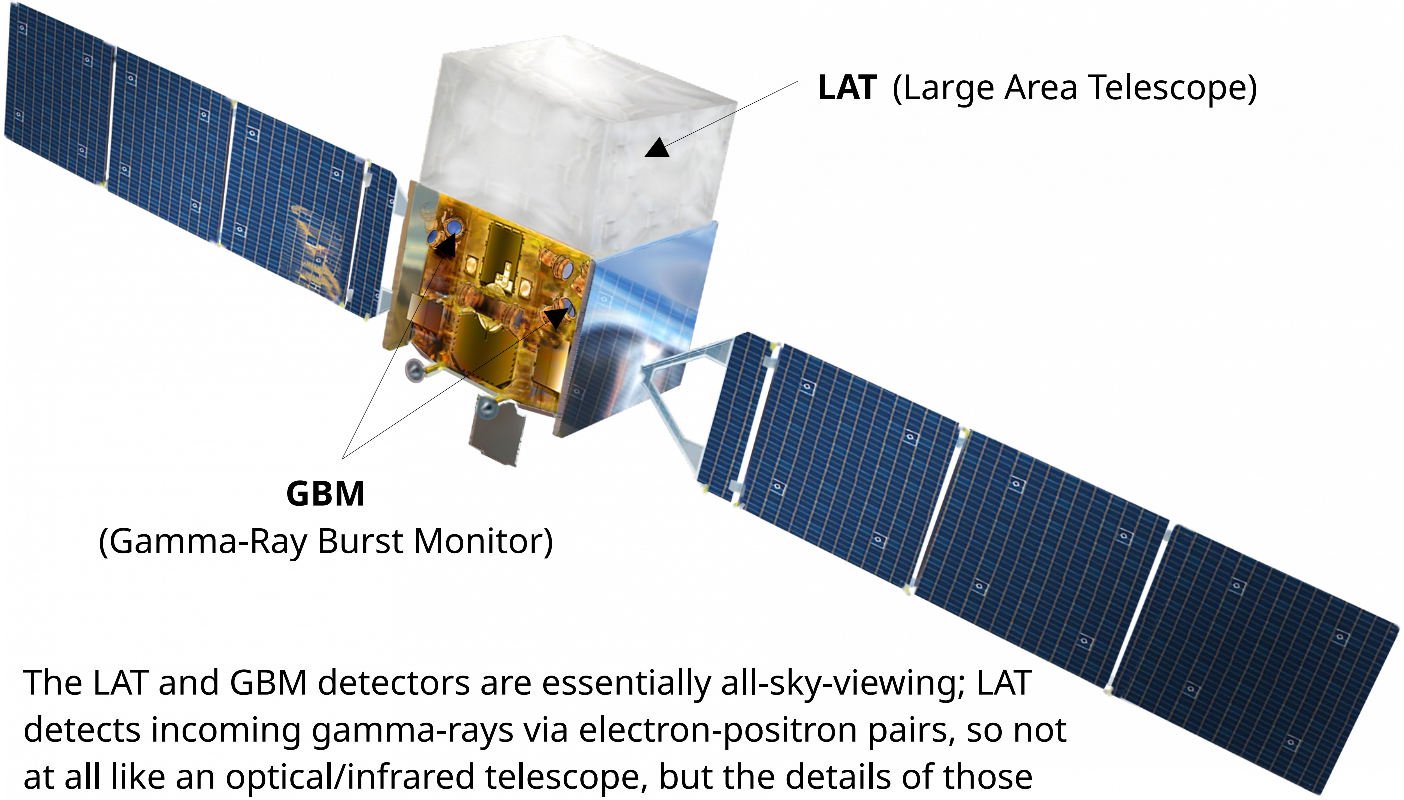
Are they blurry?

Downsides: They are fleeting things. Gamma-ray and X-ray telescopes cannot resolve them. Also possibly subject to haloes, and dust-scattering rings in X-rays. Plus, some of their highest energy photons may be absorbed by the extragalactic background, although that is not an issue for blurring itself.

Illustration credit: Earth.com

Fermi LAT and GBM:





The LAT and GBM detectors are essentially all-sky-viewing; LAT detects incoming gamma-rays via electron-positron pairs, so not at all like an optical/infrared telescope, but the details of those optics should not matter. They report either a “roll-angle”, “error-radius” or a “resolution limit.”

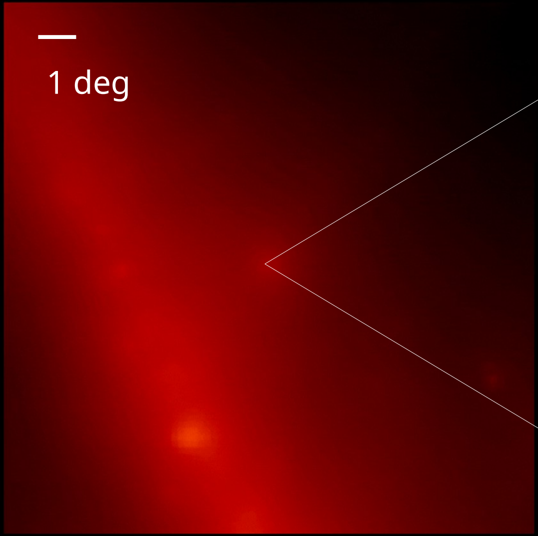
Both still have a fixed Field of View (FoV) and suffer from diffraction, althought that’s much smaller than the expected spread of gamma-rays on the sky attributable to foam-induced blurring – which can be many degrees in angle!

Illustration credit: NASA

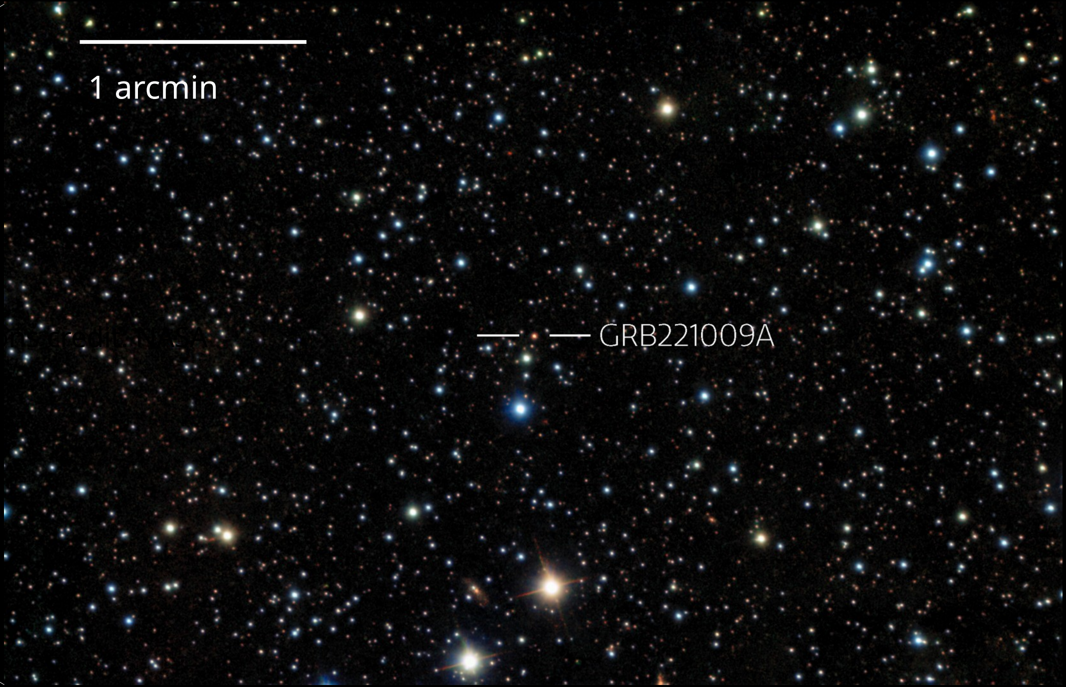
Gamma-Ray Bursts:
Artist’s conception of GRB221009A

Illustration credit: LHASSO/IHEP

GRB221009A:



Fermi LAT, ~GeV energies; 10-hour animation



Gemini South GMOS/F2, optical/near-infrared image, after trigger

GRB221009A: The brightest, most-energetic GRB ever detected, from the optical/near-infrared, through to ultraviolet, X-rays, gamma-rays, up to (perhaps) 250 TeV

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Swift J1913.1+1946/GRB 221009A: detection of a 250-TeV photon-like air shower by Carpet-2

ATel #15669; *D. D. Dzhappuev, Yu. Z. Afashokov, I. M. Dzaparova, T. A. Dzhatdoev, E. A. Gorbacheva, I. S. Karpikov, M. M. Khadzhiev, N. F. Klimenko, A. U. Kudzhaev, A. N. Kurenya, A. S. Lidvansky, O. I. Mikhailova, V. B. Petkov, E. I. Podlesnyi, N. A. Pozdnukhov, V. S. Romanenko, G. I. Rubtsov, S. V. Troitsky, I. B. Unatlokov, I. A. Vaiman, A. F. Yanin, K. V. Zhuravleva (Carpet-2 group, INR RAS)*
*on **12 Oct 2022; 13:56 UT***
Credential Certification: Sergey Troitsky (st@ms2.inr.ac.ru)

Subjects: VHE, UHE, Gamma-Ray Burst, Transient

Referred to by ATel #: 15675

Tweet

The X-ray and optical transient Swift J1913.1+1946 (ATel #15650; GCN #32632) is possibly associated with a gamma-ray burst GRB 221009A (Fermi GBM alert, GCN #32635, #32636). This bright transient has been observed by numerous instruments in optical, X-ray and gamma-ray bands (ATel #15651, #15653, #15655, #15656, #15660, #15661, #15662, #15663, #15664, #15665; GCN #32634 - #32671, #32676 - #32679, #32683 - #32686, #32688, #32690 - #32695 and counting). Tentative redshift from the observation of the afterglow emission is z=0.151 (GCN #32648, #32686). In case the GRB association is true, this event produced the most energetic GRB photon ever seen by Fermi LAT (ATel #15656), that of 99 GeV. Moreover, the same transient was detected by LHAASO during 2000 sec after the GRB trigger with photons up to 18 TeV, highest energies ever detected from a GRB (GCN #32677).

Related

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Calculation: Find the strongest possible effect of quantum-foam blurring.

Problem: This says that foam-affected photons can be spread over the whole sky. Wouldn't you then expect the inability to localize GRBs?

Perhaps, as in Perlman et al. (2015, 2022) no photon is blurred-out except with value phi-zero, and so alpha is large. But that need not be the case…

First, as in Lieu and Hillman (2003), consider a tiny perturbation to the phase of a wavefront of wavelength lambda as it passes over a "fuzzy" Planck-scale length, here sub-scripted P.

$$\Delta\phi = 2\pi\delta l/\lambda \qquad \Delta\phi_{\rm P} = 2\pi\frac{l_{\rm P}}{\lambda}$$

Following Ng, Christiansen & van Dam (2003), adding up over a co-moving distance L, we get:

$$\Delta\phi_0 = 2\pi a_0\frac{l_{\rm P}^{\alpha}}{\lambda}L^{1-\alpha}$$

$$L = (c/H_0q_0^2)[q_0z - (1-q_0)(\sqrt{1+2q_0z}-1)]/(1+z)$$

Alpha gives the formulation and so strength of that addition; it's 1/2 for a random walk (strongest), 2/3 when consistent with the holographic principle, and weaker towards unity.

$$\Delta\phi_{\rm max} = 2\pi a_0\frac{l_{\rm P}^{\alpha}}{\lambda}\Bigg\{\int_0^z L^{1-\alpha}{\rm d}z + \frac{(1-\alpha)c}{H_0q_0} \times \int_0^z (1+z)L^{-\alpha}\Bigg[1-\frac{1-q_0}{\sqrt{1+2q_0z}}\Bigg]{\rm d}z\Bigg\}$$

$$= \Delta\phi_{\rm los} + \Delta\phi_z = (1+z)\Delta\phi_0$$

It is stronger in bluer light, and so this is the maximum, even with photon redshift z included.

Steinbring, E., 2007, ApJ, 655, 714-717

Calculation: What is the effect on the PSF of a real telescope, including FoV and diffraction?

Solution: As long as there are photons to blur, some will not be scattered to the horizon, and so it can have a PSF more like a telescope on the ground, that is, as if affected by "seeing."

The first astonishing thing to notice is that this demands a universal, steep power-law of increasing strength toward shorter wavelength and higher energy.

$$\Delta\phi_{\rm max}/\Delta\phi_{\rm P} = (1+z)a_0(L/l_{\rm P})^{1-\alpha}$$

And so a little thinking about the beauty of logarithms, and some simple calculus gives us:

$$\Delta\phi\,\sigma(\Delta\phi) = 1 - A\log(\Delta\phi/\Delta\phi_{\rm P})$$

$$\frac{1}{A}\int \Delta\phi\,\sigma(\Delta\phi)\,{\rm d}\Delta\phi = (1+z)\Delta\phi_0$$

$$A = 1/\log\left[(1+z)a_0(L/l_{\rm P})^{1-\alpha}\right]$$

Let's call this Phi, shortward of where delta-phi is larger than some angle theta, plus adding "resolution" as the limit of diffraction of power rho for a telescope of diameter D:

$$\Phi = R\left(\frac{\lambda}{D}\right)^{\rho} + \int_0^{\theta} \Delta\phi\,\sigma(\Delta\phi)\,{\rm d}\Delta\phi$$

$$= \Phi_R + \Phi_\theta = AR\left(\frac{\lambda}{D}\right)^{\rho}\left[1+\log\left(\frac{2\pi l_{\rm P}D^{\rho}}{R\lambda^{\rho+1}}\right)\right]$$

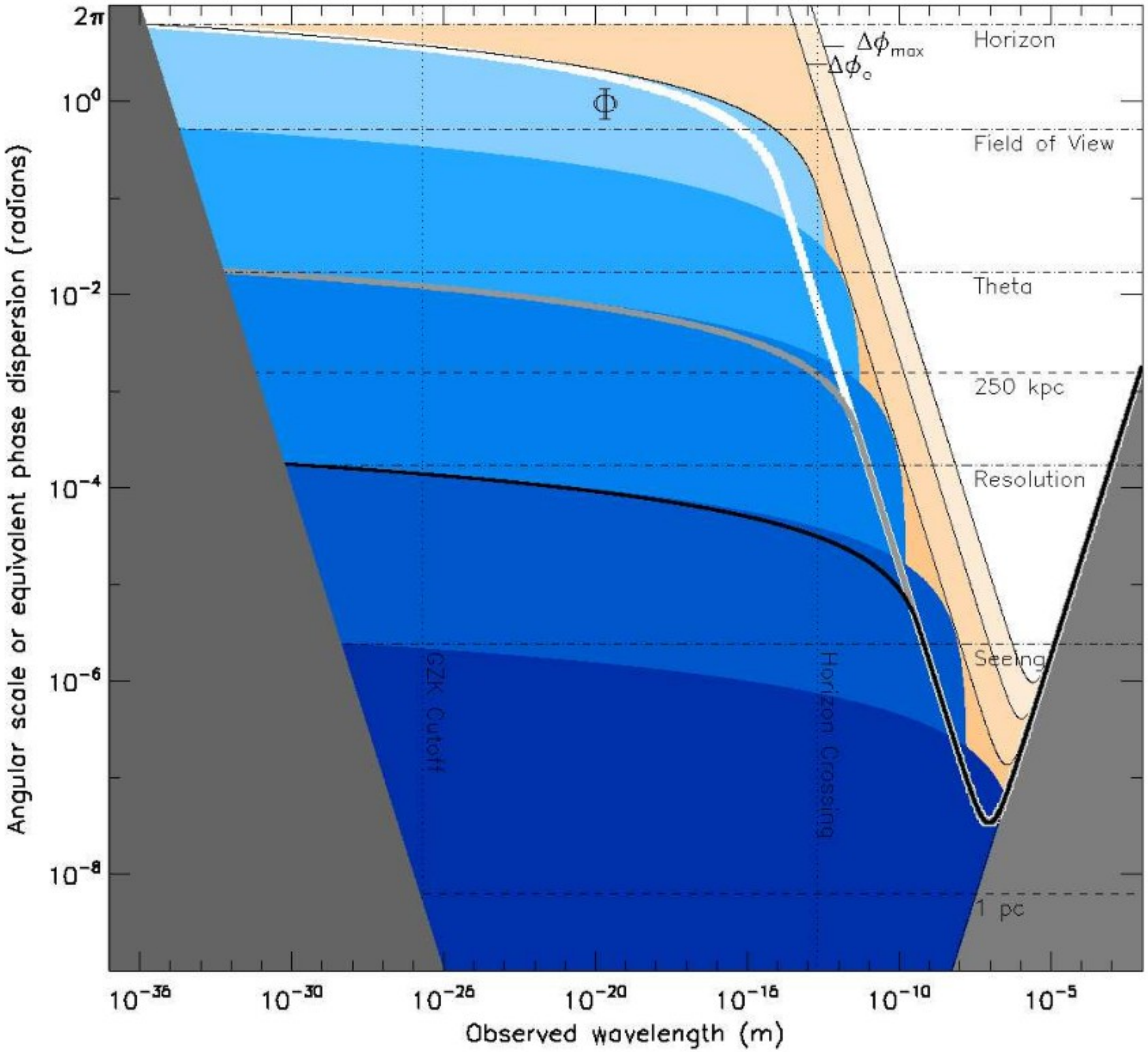
$$+\,\theta\left\{1+A\left[1+\log\left(\frac{2\pi l_{\rm P}}{\theta\lambda}\right)\right]\right\}$$

Aha! The foam-induced PSF turns over towards high energy, in X-rays.

Steinbring, E., 2015, ApJ, 802, 38-43

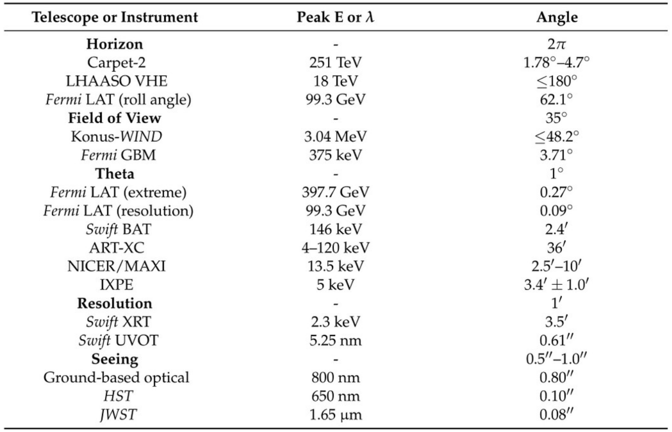
Observable: The characteristic to look for, depending on the outer-scale included in the PSF, is that it will still grow for photons shortward of the “horizon crossing” wavelength, but must tail off, flattening out towards higher energy.

For gamma-ray telescopes, the mean blurring scale turns out to be **~1 degree**, behaving something like atmospheric seeing, which is **~1 arcsecond** in the optical/near-infrared from the ground.



GRB221009A: Unprecented, extremely wide-angle and multi-wavelength observations of the same source

Table 1. *Fermi*, *Swift* or other angular limits and localization accuracies for GRB221009A.



Telescope or Instrument	Peak E or λ	Angle
Horizon	-	2π
Carpet-2	251 TeV	1.78°–4.7°
LHAASO VHE	18 TeV	≤180°
Fermi LAT (roll angle)	99.3 GeV	62.1°
Field of View	-	35°
Konus-*WIND*	3.04 MeV	≤48.2°
Fermi GBM	375 keV	3.71°
Theta	-	1°
Fermi LAT (extreme)	397.7 GeV	0.27°
Fermi LAT (resolution)	99.3 GeV	0.09°
Swift BAT	146 keV	2.4′
ART-XC	4–120 keV	36′
NICER/MAXI	13.5 keV	2.5′–10′
IXPE	5 keV	3.4′ ± 1.0′
Resolution	-	1′
Swift XRT	2.3 keV	3.5′
Swift UVOT	5.25 nm	0.61″
Seeing	-	0.5″–1.0″
Ground-based optical	800 nm	0.80″
HST	650 nm	0.10″
JWST	1.65 µm	0.08″

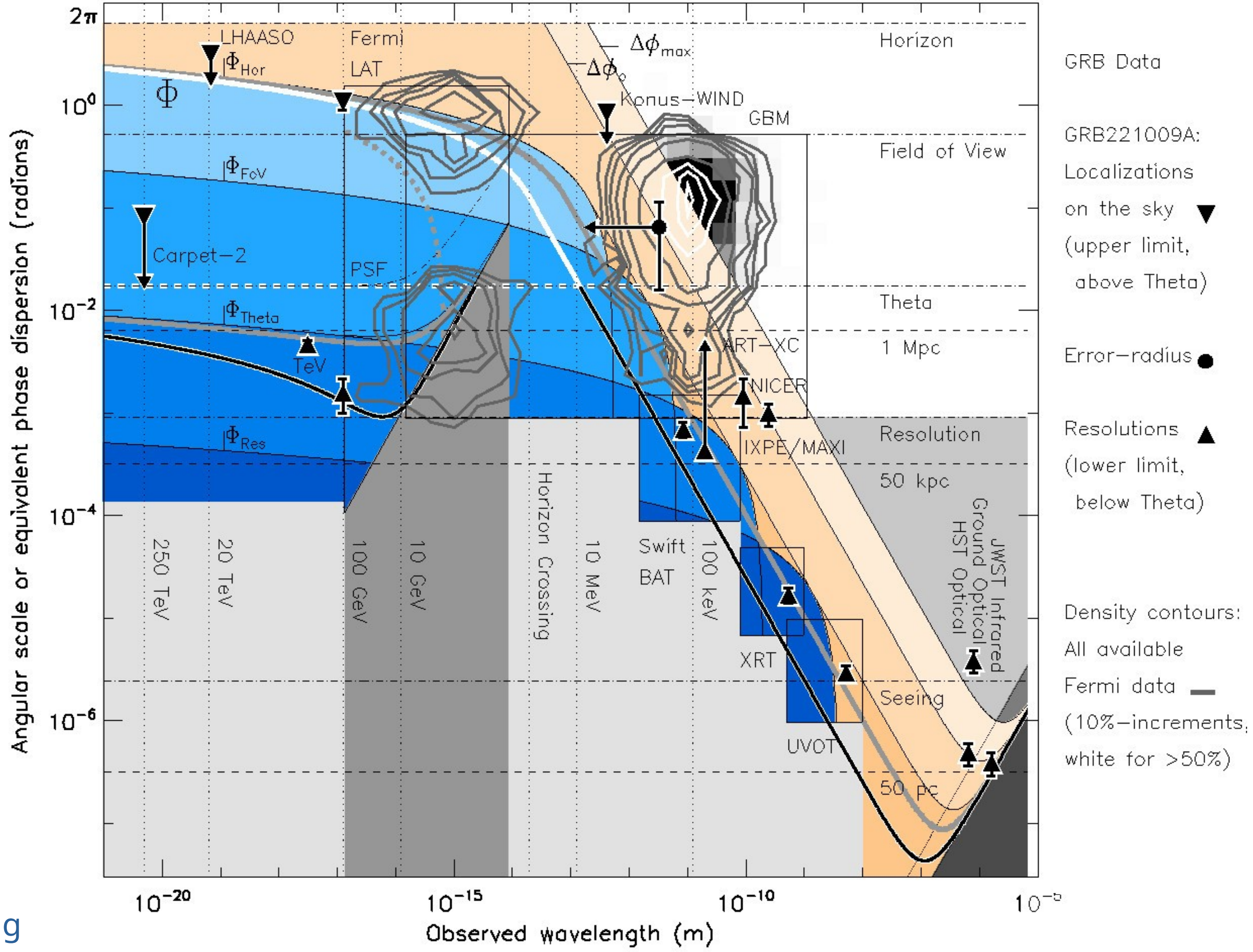
Identified in a galaxy of z = 0.151

Try for yourself!

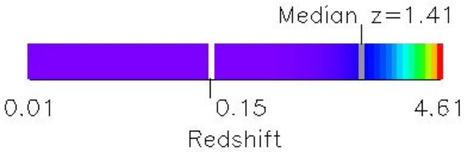
All of these data, and the IDL code that reports the curves to the right are available at:

github.com/ericsteinbring/Special-Blurring

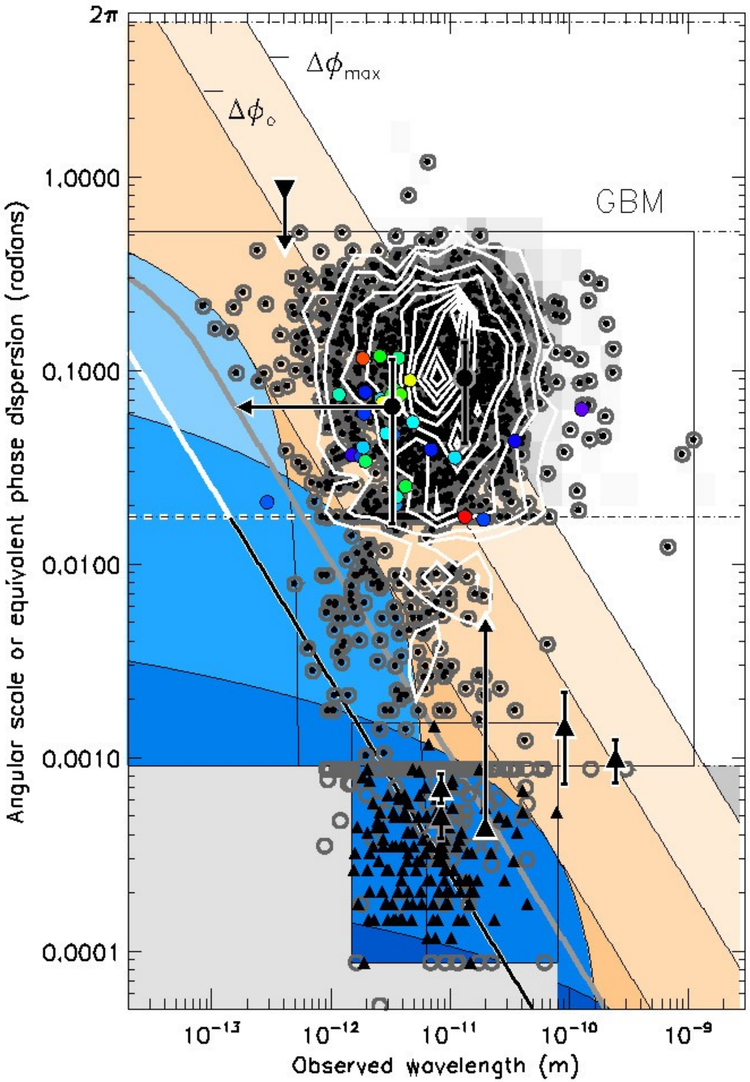
Steinbring, E., 2023, Galaxies, 11(6), 115-127



GRB221009A: Focusing-in on just the available X-ray observations



Colour-coding for each source is by its redshift, that is, scaled by transit distance where that is known from spectroscopy of the host galaxy.

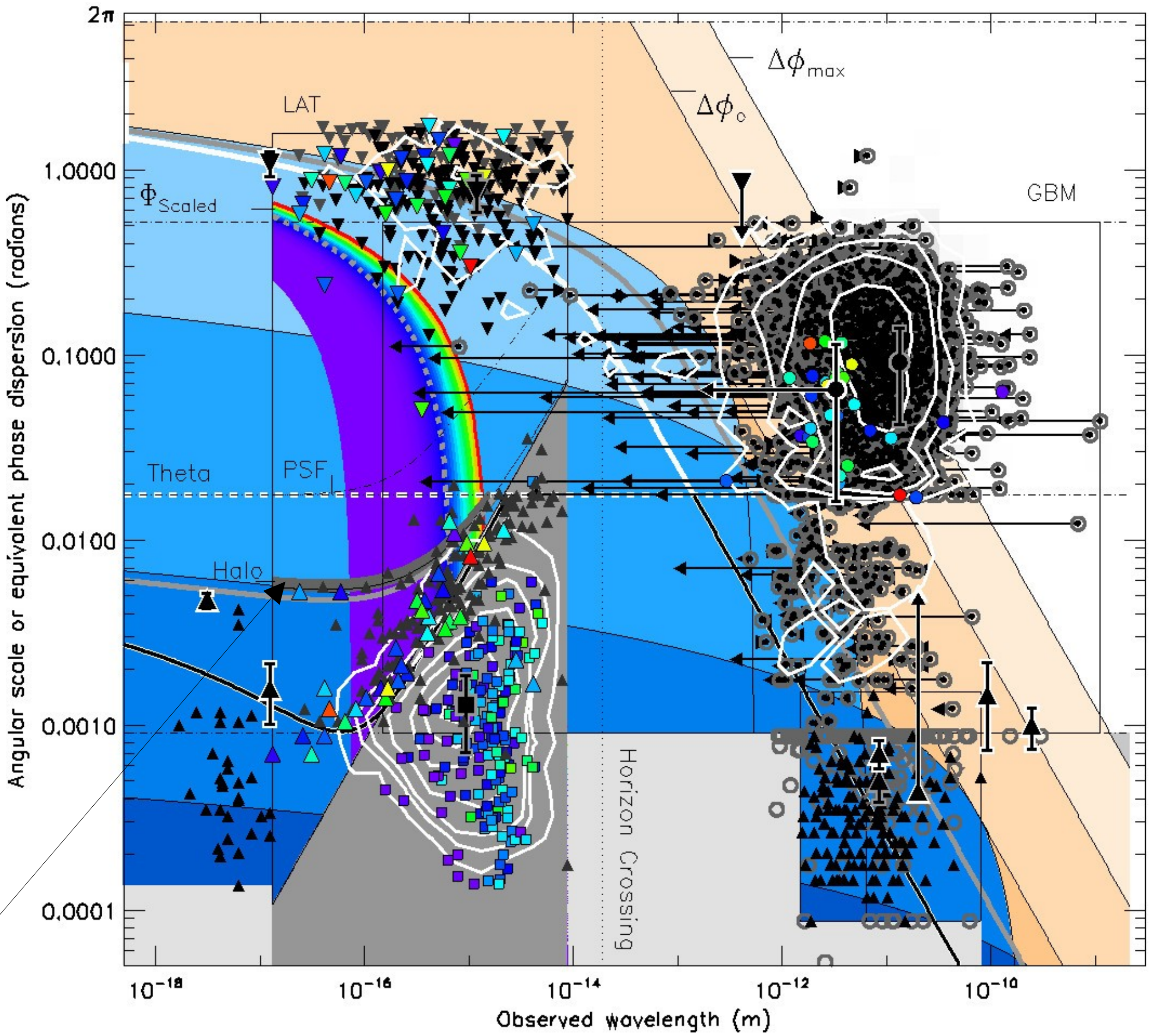


Notice this: The “red edge” of radii within which Fermi GBM X-ray sources are found as a function of their peak energy, is clearly a power-law, as expected - especially above angle “Theta.”

Steinbring, E., 2023, Galaxies, 11(6), 115-127

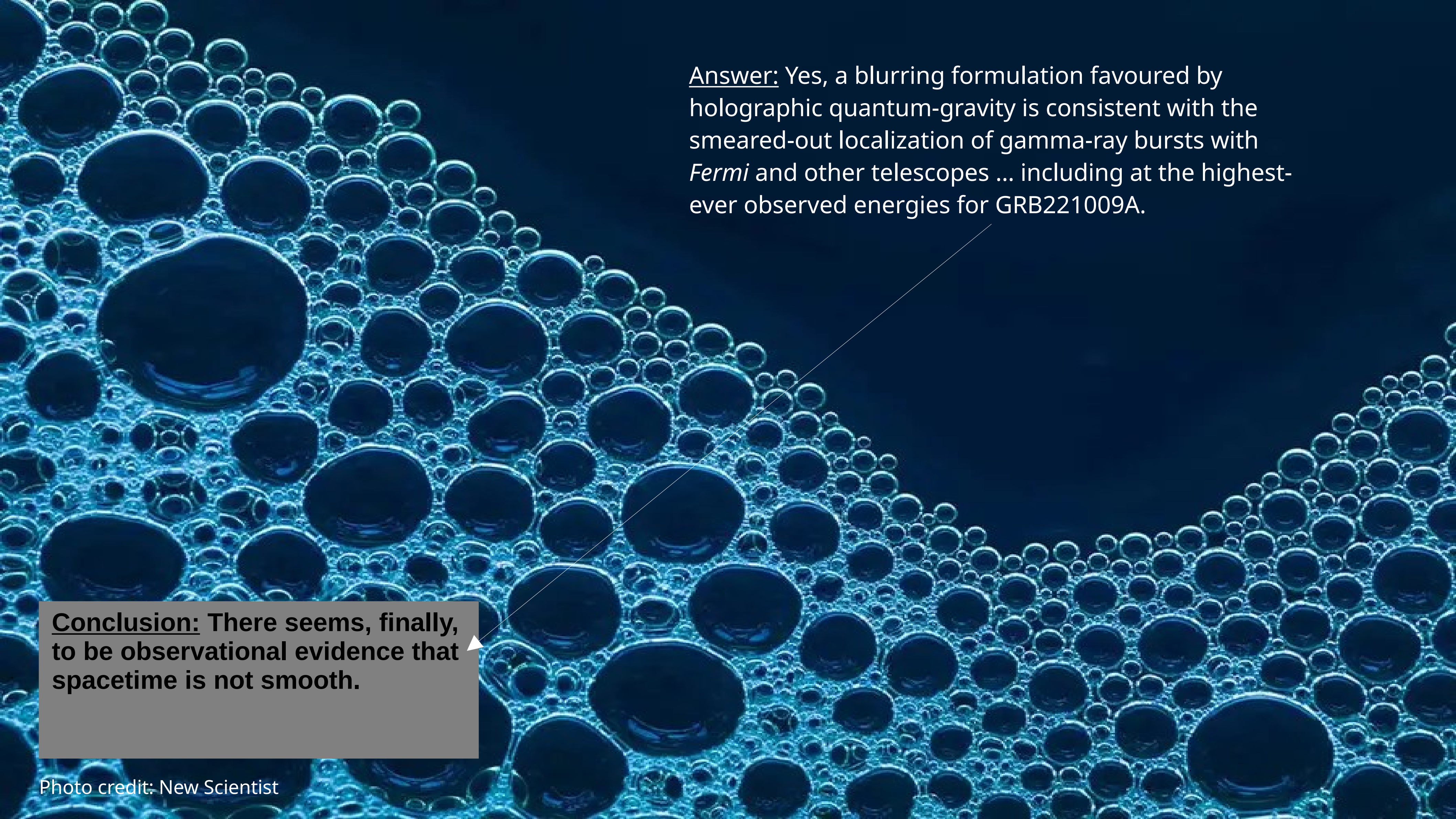
GRB221009A: Considering every available X-ray and gamma-ray observation taken together

Notice that: The “blue edge” of bluest, highest-energy GRBs in gamma-rays nicely agrees with a scaled transition between Phi assuming opening angle by instrument FoV down to the same assuming only the resolution limit. This is entirely consistent with the “middle” condition of mean-angle Theta and alpha of 2/3.



Wow! The upper limit of GRB resolutions, or “Halo” happens to match the Fermi LAT PSF scaled from the resolution limit, plus the average effect of foam.

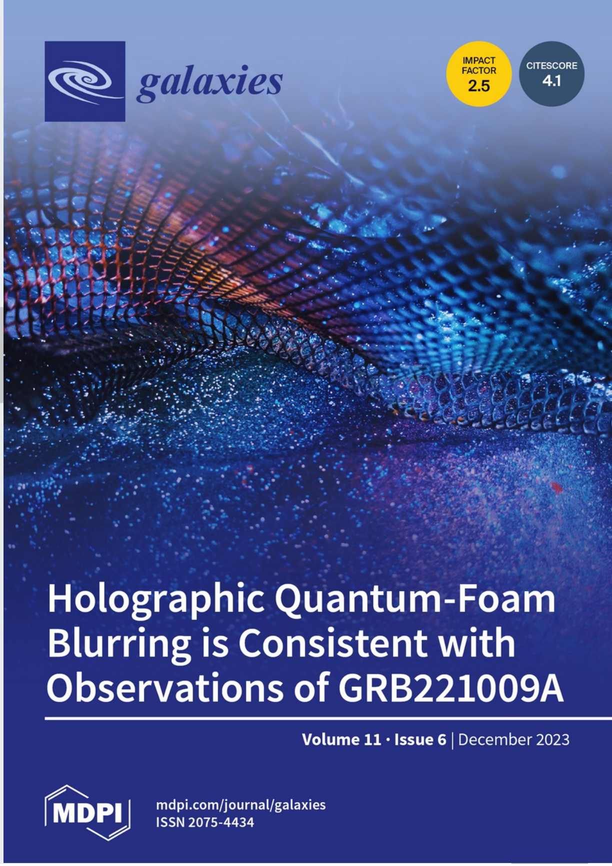
Steinbring, E., 2023, Galaxies, 11(6), 115-127



<u>Answer:</u> Yes, a blurring formulation favoured by holographic quantum-gravity is consistent with the smeared-out localization of gamma-ray bursts with *Fermi* and other telescopes … including at the highest-ever observed energies for GRB221009A.

<u>Conclusion:</u> There seems, finally, to be observational evidence that spacetime is not smooth.

Photo credit: New Scientist



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