Black Holes Book Comments II

Dave 8/18/20- 9/1/20

[From 2nd Cosmo meeting on Kip Thorne's Book, 8/17/20 for the next meeting on 9/21/20 – *Bill placed "Comments 1" on his http://sackett.net/ThorneBlackHoleTimeWarpNotes.pdf.*

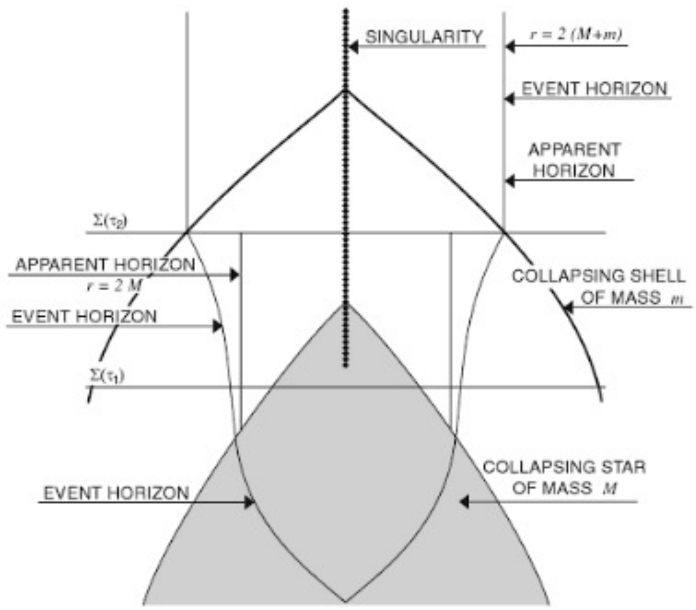

Figure 1. Radius of a collapsing massive ball with time advancing upwards on the vertical axis. Then, an additional weighty spherical mass shell falls toward the previously formed black hole horizon. The event horizon evolves continuously outwards with time beginning at the very center of the ball. *{Hawking & Ellis, The large scale structure of space-time, 1973. This figure is similar to their Figure 59 on page 321}.*

Kip Thorne BOX 12.1 (p 415) The absolute event horizon develops continuously for a collapsing ball of matter as the last outgoing ray of light that can escape to an outside observer (e.g., location C on an time versus radius plot at the center r = 0). This could also be described as envelope locations (r, t) which yield the weakest and most reddish rays of light that can be detected from the outside.

There is a confounding factor that light forms a **photon cloud orbit** near r = $3GM/c^2$ (3m to 5m) outside the Schwarzschild radius (2m).

{See article by Kip Thorne from 1968 that also gives a formula for the free fall of the surface of a collapsing star, eqn. 4b --http://articles.adsabs.harvard.edu/cgi-bin/nph-iarticle_query?1968ApJ...151..659A&defaultprint=YES&page_ind=0&filetype=.pdf , "The Optical Appearance of a star that is collapsing through its gravitational radius." }

Is the absolute event horizon, "EH," real ?

Largely, it is an idealization like the freshman physics problem of a ball falling freely in simple harmonic motion through a hole through the Earth. Regardless of initial drop height, the ball reaches the center at the same time (called "isochronous" or "cycloid" motion). Similarly, in the Oppenheimer-Snyder collapse for a ball of dust, all shells reach the center at the same time.

The idealizations in this collapsing star scenario are: the collapsing matter is treated as **transparent,** spherically symmetric, and non-rotating, and we ignore other orbiting matter. For ideal "Oppenheimer-Snyder" [1939] collapse, the star is pressureless dust. Observers are distant and not in free fall, and the EH is only observed relative to these receivers – the EH boundary doesn't exist for a free-falling observer. Observers do not see the direct origins of photons that make it out. Many of these are in an *orbiting photon cloud* and take a long time escaping. An observer mainly sees a cross-section of this cloud as an optical disk that is bright and blue at apparent radii near 2.5 times the Schwarzschild radius but redshift-weakening and decaying in brilliance interior to that outermost rim. Photons escape from a very strong and deep gravitational potential well.

Prior to the central event horizon vertex C at time t_C, light can escape. This initial vertex event occurs well before final collapse and berfore the formation of an *Apparent* horizon at $r = r_s$. After t_C, all light from the center is trapped – but some light can still escape at distances $r > 0$ away from the center. The evolving concave-up profile of the event horizon covers the future formation of a singularity; it clothes or hides it before it forms.

Kip Thorne stresses the importance of Hawking's new continuously evolving absolute event horizon concept over the previous views (for frozen stars). It plays a helpful role in discussing the horizon area increases for coalescing black holes. Page 417 calls his view "teleological" as present views depend on future behaviors.
Once formed, the central singularity and its warped environment take the place of all the matter than formed it. It is the source of all the externally observed gravitation with no "actual mass" still existing.

Gravitational Waves from Chapter 10 are discussed more fully in Janna Levin's book, Black Hole Blues, 2016 (240 pages). It updates our 1995 book by 20 years up to the first detection by LIGO in September of 2015. What we really want to know are details about how LIGO achieved its incredible precision – no popular book can do justice to that. And what we desire most next is another clear merging of two neutron stars.

An Older Note from our first meeting: [Previous **Box 2.4** on Understanding Gravitational Time Dilation p. 102]. Somehow, the wording here seems hard to follow. There is a related example in a popular paper by Leonard Schiff:
"On Experimental Tests of the General Theory of Relativity," 1960 {free pdf at http://eotvos.dm.unipi.it/documents/SchiffDickeEtAlPapers/Schiff1960AJPSchiff-2.pdf }
What's great about this paper is that some basic concepts in GRT can become intuitive without having to use formal tensor calculus. Discovering this paper was a very pleasant surprise.

Peter was asking about Inertial **Frame Dragging from a rotating black hole** *(the Kerr Metric, the 'Lense-Thirring' effect [1918], a 'gravito-magnetic field').*

The easiest first-order analogy for understanding this is to first consider the old familiar magnetic vector potential **A** as a dragging of "electromagnetic" space by a moving charge or current {as in $\mathbf{A} = (\mu_o/4\pi) \int d^3x\, \mathbf{J}/r$, where J is current density}. Finding **A** first often makes E&M a lot more "intuitive." This A field has its own kind of

<u>inertia</u> in the sense that if it decaying in some region and there are conductive wire loops nearby, then they will experience an electric field E = - dA/dt which causes a new current flow that produces its own new $A'_{response}$ field that counteracts and tries to sustain the original A field ("induction").

For a broadcasting dipole-antenna, vector flow **A** propagates away at speed c, locally tracks the up-and-down the current flow, and falls off as ℓn|r| – Then the fields E = -dA/dt and B = $\nabla \times$A can be found <u>afterwards</u>. For **a rotating current flow**, the A field outside a solenoid follows the rotating current as $A_\phi = \mu_o nIR^2/2r$ {which falls off like 1/r ; and this causes the Aharonov-Bohm effect with no external B field present}. Outside a rotating charged Ball, A_ϕ drops as $1/r^2$. It produces an effective B field lying along the axis of the ball and spreads out continuously from one pole to the other. If a charged particle is thrown towards the ball, it gets deflected according to the Lorentz force, F = ma = qv× B.

In weak-field linearized GRT for plane gravitational waves, a little perturbation field, h(x,y,z), is added to the flat metric tensor: $g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}$ where h behaves a lot like A. This is usually our first introduction to "off-diagonal metrics."
{**gravito**-$A_i = ch_{io} = -(4G/c^2) \int \rho v^i \, d^3x/r$}. It looks just like A for a source current through a wire or a solenoid but now from **<u>moving mass currents</u>** rather than moving charge and with a different coefficient. If a mass is thrown towards a rotating mass, it gets deflected in a way similar to the Lorentz force. This is really more like a Coriolis force due to being in the wrong frame of reference – a rotating inertial space. For strong gravitational fields, the equations become nonlinear and calculations are much more difficult.

https://en.wikipedia.org/wiki/Frame-dragging equatorial Kerr frame dragging at far distance goes as $\Omega = [r_sJ/M]/r^3 = v/r$, $v = [r_sJ/M]/r^2$.
https://physicspages.com/pdf/Griffiths%20EM/Griffiths%20Problems%2005.29.pdf

Chela forwarded three historical articles (links in email 8/17/20) that discussed some great mathematical milestones in modern differential geometry for general relativity (with which few of us are familiar). These papers had some interesting points:

One was that the rejection rate of Annalen der Physik in 1905 was only 5-10%, and that Max Planck was very accepting of submitted papers. *We had been wondering if Planck had some special fondness for Einstein.* In contrast, America's <u>Physical Review</u> was more selective and used referees { this was new to Einstein, and he did not like it !}. Also Einstein didn't try to keep up with physics literature and hardly bothered with the convention of showing references.

Another point was that in 1936, Einstein believed that weak field plane polarized gravitational **waves were unreal**—but his objections turned out to involve artificial coordinate singularities that were merely apparent. This view effectively blocked gravitational wave studies until 1957 when full field GRT articles finally said that these waves do carry energy and travel at light speed.

Another statement [AMS 2017 p 689] was that "even in Maxwell theory, radiation is a **nonlocal** phenomenon." (!). The energy which is radiated from the sources must scatter to infinity but not from infinity to the field (a 'Sommerfeld condition'). Proper gravitational waves have to satisfy special boundary conditions at infinity.

[For more discussion see] Mathias Frisch, "Non-Locality in Classical Electrodynamics," 2002. Maxwell-Lorentz electrodynamics is inconsistent. Dirac

electrodynamics is backwards causal and causally nonlocal. The Lorentz law ignores any effects on the motion of a charge due to its own radiation.
https://pdfs.semanticscholar.org/c5e6/5ee4effeb70b4209488d169bb26257b04ecd.pdf

Box 12.5 "**Laws of quantum field theory in curved spacetime"** {are a first approximation to quantum gravity but are not yet fundamental nor renormalizable}. "The concept of a "real particle" {and of the "Vacuum state"} is relative, not absolute; that is it depends on one's reference frame." Some details are discussed in: https://arxiv.org/pdf/1401.2026.pdf {Robert Wald, 2014, *difficult*}.

Steven Hawking Area Theorem: "The area of the final hole's horizon must always be larger than the sum of the areas of the original hole's horizons." Entropy $S = Ac^3k/4G\hbar \propto A$ where $A = 4\pi R^2$ and Schwarzschild $R = 2MG/c^2$, so $A \propto M^2$. $S > S_1+S_2 \Rightarrow A > A_1+A_2$ for two merging black holes.

A note on this { C**hapter 12, pg 413. Note #1}** has an Error *(e-page 525).*

Kip said $M_1^2+M_2^2 > M_f^2$ (wrong) which allows $M_f < M_1+M_2$ which allows gravitational wave radiation from the missing mass in the merger of two black holes.

Chela and Susan caught this error back in April. Kip just got sloppy here, and the first relation should be < .

That is: (e.g., if $M_1=M_2=2$(suns), then $4+4 < (2+2)^2$.
If $M_1+M_2 \rightarrow M + E$ (excess energy), $E = M_2+M_2 - M$. For the example masses=2, the constraint on M is $M \geq (4+4)^{1/2} = 2.8$. So the final M could be somewhere between 2.8 and 4.0 and that allows E to be between 0 and 1.2 positive energy radiated away. Detailed numerical relativity pins down the real number. Indeed, LIGO GW150914 lost 5% of its merged mass as gravitational radiation.

The term "standard quantum limit" usually refers to the minimum level of quantum noise which is obtainable without squeezed states.

Planck Units {see https://en.wikipedia.org/wiki/Planck_units }.

Our book *(Ch: pg., ...) = (Ch 12: 426 &442, Planck-Wheeler area), (Ch 13: 476, footnote 2 on time), (Ch 14 494 footnote 6 & 518, Planck length and quantum foam).*

These new and extreme units for time, length, mass and temperature were originally proposed in 1899 by Max Planck using the universal physical constants c, G, Boltzmann's constant k_B , and h or $\hbar$ [Note, this was before the black body law of 1900; and "h" came from "Wien's Law" which says that the peak frequency of a black body curve is $f_{peak} \sim 2.82k_BT/h$ for temperature in Kelvins above absolute zero].

Kip's book stresses the Planck Area = $\ell_p^2 = \hbar G/c^3 \sim 10^{-70}$ m^2. So Planck length is $\ell_p \sim 10^{-35}$ m. Planck time $t_p \sim 10^{-44}$ s, Temperature $T_p \sim 10^{32}$ K, and mass/energy is $m_p \sim 10^{19}$ GeV or 2.2×10^{-5} grams. A maximum frequency is $f_p \equiv c/\ell_p \sim 10^{43}$ Hz. Beyond these limits supposedly lie "quantum foam" where our known physical world breaks down. Modern particle physics often uses units that set fundamental constants equal to 1 {most often $c \equiv 1$, $\hbar \equiv 1$ and sometimes $G \equiv 1$ or $k_B \equiv 1$}. Then all Planck units can be viewed as having the value one. Recall that the Schwarzschild metric is often written with the shortened term mass 'M' or 'm' standing for $MG/c^2 = M(1/1^2)$. Some physicists believe the GUT scale is "real" where $M_{GUT} \sim 10^{15}$ GeV – and that's getting closer to the Planck mass.

<u>BIG CONUNDRUM</u>: *some major food for thought !!*

Shouldn't there be a maximum value for a mass which is no longer quantum but rather now "classical?" And shouldn't that maximum mass be the Planck mass, m_p~10 $^{-5}$ grams?

KIP states that Weber's big aluminum cylinders are considered as quantum objects that obey the uncertainty principle! {pgs. 372-374} "and that their quantum mechanical nature will ultimately cause problems for gravitational wave detection." "Quantum Laws are the Ultimate Rulers of our Universe." {And even for LIGO, unwanted quantum uncertainty noise is close to the needed gravitational wave signal – but this quantum uncertainty doesn't pertain to the heavy mirrors but rather to the random incident light photons}.

A statement of the Uncertainty Principle is $\boldsymbol{\sigma_x \sigma_p \geq \hbar/2}$. But p = h/λ =$\hbar$k where wavenumber k ≡ 2π/λ; and p=h/λ is called a de Broglie relation. Notice that $\sigma_x \sigma_{\hbar k}$ = $\hbar\sigma_x\sigma_k$ so that $\boldsymbol{\sigma_x \sigma_k \geq}$ **½.** This is just a result from <u>standard</u> Fourier Transform theory; so that is the essence of the uncertainty principle (rather than a Heisenberg-microscope-disturbance).

The relation p = h/λ leads to the quantum uncertainty principle. But that in turn is a consequence of special relativity and the basic relation E_o= hf_o = m_oc^2 -- that all particle mass/energies can be expressed as a <u>fundamental rest vibration.</u> The vibration IS the mass.

Boost this rest vibration to a velocity V using a Lorentz transformation: the 4-vector (E_o, $\mathbf{p_o}$c) = (E_o, 0) → a new boosted 4-vector (E, **p**c) where new E = γE_o and the new pc = $\gamma\beta E_o$= h(γ f_o)V/c = hf V/c.
See http://hyperphysics.phy-astr.gsu.edu/hbase/Relativ/vec4.html Lorentz transforms.

But, phase velocity is $v_\phi \equiv f\lambda$, and $v_\phi V_{group} = c^2$ in special relativity.
So, boosted pc = hfc^2/v_ϕc = hc/λ , <u>or</u> **p = h/λ !** {**<u>Derived</u>**, rather than postulated}.

<u>OK. So, what's the problem?</u>

We are now aware from many experiments that big macro-molecules passing through {the equivalent of } double slits have wave superposition and interference as if their summed mass obeyed λ = h/P = h/[VM_{total}]. The large molecules now being tested are much more massive than the older "buckyballs" C_{60}'s (and now have masses near than 40,000 amu's or 10 $^{-19}$ grams). Even a proton is a composite particle; and somehow all the composite parts add together for a final particle mass and wavelength. The wavelength λ encompasses the relatively huge extent of the molecule and beyond it – the source is not localized.

But the composite particle mass/vibration cannot be greater than the Planck mass of 10 $^{-5}$ grams or a vibration of 10 ^{43} Hz. How big can one go and still have an effective de Broglie wavelength that can result in path interference? I assume that some sort of phase coherence exists throughout the molecule – But, a large aluminum cylinder should be an assembly of myriad grains and lack any such coherence. **How and Why should it be quantum?**

It was pointed in our discussion out that superfluids are macro-masses that also have a collective wavelength. However, that wavelength comes not from total mass but rather depends on the mass of each boson particle in thermal motion (and then these bosons then get entrained with all their friends). So this is somewhat different.

There have been claims that the massive 40 kg mirrors in LIGO obey quantum mechanics. But their Δp momentum kicks come from the randomness of discrete photons hitting the mirrors. These quantum fluctuations are significant and can displace the mirrors by 10^{-20} m when needed precision is 10^{-21} m.

Reference: https://www.ligo.caltech.edu/news/ligo20200701 Quantum fluctuations can jiggle objects on the human scale Feature Story • July 1, 2020

"We too, every nanosecond of our existence, are being kicked around, buffeted by these quantum fluctuations. It's just that the jitter of our existence, our thermal energy, is too large for these quantum vacuum fluctuations to affect our motion measurably. With LIGO's mirrors, we've done all this work to isolate them so that they are now sensitive enough to be kicked around by quantum fluctuations, and this spooky popcorn of the universe" -- quantum noise generated among the photons in LIGO's laser.

"This quantum fluctuation in the laser's light can cause a radiation pressure that can actually kick an object. The object in our case is a 40-kilogram mirror, which is a billion times heavier than the nanoscale objects that other groups have measured this quantum effect in."
http://sitn.hms.harvard.edu/flash/2016/quest-gravitational-waves-pushes-boundaries-quantum-optics/ SEPTEMBER 6, 2016 BLOG
"How the Quest for Gravitational Waves Pushes the Boundaries of Quantum Optics."

The Heisenberg uncertainty principle also applies to light waves. If the light's oscillating electric field has a well-defined amplitude, then its phase (when the field crosses through zero) must be ill defined, and vice versa.

The Heisenberg uncertainty principle, however, only sets a lower limit on the product of the phase noise and amplitude noise, not on either one individually. Physicists can therefore reduce one type of noise at the expense of increasing the other type, creating what is known as squeezed light. Essentially, they can squeeze the uncertainty out of the component, either the light's phase or amplitude, to which the experiment is sensitive and put it in the component to which the experiment is relatively insensitive."

There are other large object tests using things like mechanical oscillators or piezoelectric quantum resonators that can be visible to the human eye and that reveal superpositions. http://news.bbc.co.uk/2/hi/8570836.stm

Or, see "Testing the limits of quantum mechanical superpositions," Markus Arndt, https://arxiv.org/pdf/1410.0270.pdf

And, Big Extrapolations to Big Macrophysics, The Cosmos:

Worse than all this is the claim that *there is rigorous proof that* the **Big Bang** could "have occurred spontaneously because of quantum fluctuations" based on solutions to the Wheeler-DeWitt equation. The Heisenberg uncertainty principle "allows a small empty space to come into existence probabilistically due to fluctuations in what physicists call the metastable false vacuum."

E.g., arxiv.org/abs/1404.1207 : "Spontaneous Creation Of The Universe From Nothing."

And Also "quantum fluctuations in the **Inflaton field** φ lead to a local time delay, when Inflation ends (see figure 1). So different regions inflate by a different amount, which leads to density perturbations and ultimately to the temperature fluctuations in the CMB." *(and then to galaxy formation and cosmic webwork).*

https://www.thphys.uni-heidelberg.de/~witkowski/curved/talk7.pdf

The timeline history at the end of this book is quite nice.

<u>Next Books ??:</u>

I haven't had many good ideas for the last few years and can only think of the following:
1. **<u>The Second Creation,</u>** 480 pages, Robert Crease and Charles Mann, without equations, 1986-1996 – I've read this book <u>five times</u>; it is very informative, well written and is my favorite history of particle physics.

2. **Lonely Hearts of the Cosmos,** the story of the scientific quest for the secret of the universe, 438 pages, 1991. Dennis Overbye is a good writer and science reporter; and this book is historical fun (But, dated-- before dark energy [1998-2006]). In 1986, Dark Matter was accepted, but computer simulated cosmic matter webworks were still failing to match observations. { Page 357} Peebles [Nobel, 2019] pointed out that a "way to make the universe flat and reconcile theory and observations was to **reinvent the cosmological constant"** an idea that had almost no fans.

And this book just now came out but is not yet recommended: P. J. E. **Peebles**, Cosmology's Century: An Inside History of Our Modern Understanding of the Universe, 403 pages, ~$30 – has equations but seems "dry." 3.8 stars/5 – see review complaints. {Peebles Principles of Physical Cosmology, Princeton, 1993 was also quite dry}.