Kip Thorne Black Hole Book Comments

For Second Cosmo Meeting

Dave 7/21/20 – 8/14/20

The Cosmo Book Discussion group meeting on 7/20/20 posed some interesting questions.

Tides: pages 35 and 106: few people really know this and most have misconceptions *(I know I did)* see: https://en.wikipedia.org/wiki/Theory_of_tides
"As gravitational force acts to draw the water closer to the moon, inertia attempts to keep the water in place. But the gravitational force exceeds it and the water is pulled toward the moon, causing a "bulge" of water on the near side toward the moon."
Newton tides Principia: Isaac Newton (1642–1727) was the first person to explain tides.
Also: https://oceanservice.noaa.gov/education/tutorial_tides/tides03_gravity.html

Susan Northleaf wondered if iron filings revealed true magnetic "lines of force" (Figure 1.1 p 67 in book). Faraday came up with the idea of "lines of force" as a closed circuit path; and this idea was inspired by discrete iron filing curves. B fields are continuous and smoothly varying in space, **but**, iron-filing patterns do show arcs separated by gaps. The B field orients the iron particles and enhances their own individual magnetic fields making them into tiny bar magnets that like to join end-to-end. And, their stray fields attract neighbors to produce gaps.
In Google, type iron filings magnetic field gaps between lines and view Images tab .

Nobel Prize? Yes: William Alfred Fowler (1911 –1995) was an American nuclear physicist/astrophysicist, who, with Subrahmanyan Chandrasekhar won the **1983** Nobel Prize in Physics. He is known for his theoretical and experimental research into nuclear reactions within stars and the energy elements produced in the process

Why no Nobel for Relativity (Prize 1921-22)? Before 1919, it was unproven; but then Eddington observed the deflection of starlight. Einstein was being vilified by Germans as a pacifist-Jew which in turn coupled with anti-relativity sentiment and "Jewish Physics." However, the photoelectric effect was acceptable science — except that photons as particles was still suspect by Planck and others {and continues to be suspect by some even today. But Einstein had safely called it a "heuristic" model}.

How hard is it to compress iron? ρ_{Fe} ~ 7.9 g/cc. Well, the inner core of Earth is Fe+O+S+Ni and has a density of ρ ~13.1 due to the weight of 6,400 kilometers of Earth above it (get 1.6 x density, and pressure ~ 350 GPa , 3 million atmospheres and effective T~ 6000^{o}C). Pressure on iron can also be applied by **shock**-compressibility (like explosive lenses on plutonium) and can achieve an enhancement of x3.5 (to 28g/cc where ρ_{gold} ~ 19). And that is with p~ >10^4 GPa. At the ultra-high densities of iron cores in stellar collapse, the iron is no longer familiar crystalline iron.

Kip says that the hole in a BH exists only because of non-linearity. The curvature can gravitate without the star-matter.

Familiar Names: We were fortunate in having visits and presentations to our CU physics colloquia from Maartin Schmidt and Joseph Weber in the early 1960's, Martin Ryle, Roger Penrose,.. Edward Teller gave his pro-nuclear speeches here several times….

and then Stanslaw Ulam was here in the Math department, and George Gamow was on our Physics faculty. The Gamow Lecture Series had Geoffrey Burbidge (1973), Arno Penzias (1980), Stan Ulam (1982), William Fowler (1986), Martin Rees (2000), Adam Riess (2012) and Kip in 2017.

Who found gravitational field equations first ? [page 117] – not so clear cut!
https://medium.com/cantors-paradise/einstein-and-hilberts-race-to-generalize-relativity-6885f44e3cbe
Hilbert Not There Yet, Einstein first. And Hilbert's goal was not just gravitation but a unified physics for both gravity and E&M together (and that didn't work out).

Chapter 3 p 128 Embedding diagrams – "Hyperspace:"

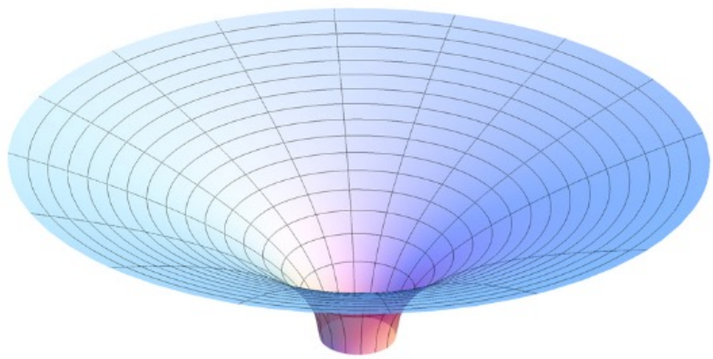

Figure 1. "**Flamm" Parabola of Revolution** [z(r), MTW page 614] from 1916.
For Schwarzschild space near a massive body.
Write this as an added vertical "Embedding Diagram" dimension z called **LIFT** versus sideways radius r. z(r): $ds^2=dz^2+dr^2 = dr^2/(1-2M/r)= dr^2[(dz/dr)^2+1]$, solve for dz/dr to get $dz = dr/[r/2M-1]^{1/2}$. Integrate this for a z function: $\int dz =z(r) = [8M/(r-2M)]^{1/2}$ which is plotted in the figure above. One can also derive a spherical cap for the bottom.

[Chapter 5] Wikipedia on Neutron Stars: "The equation of state of matter at such high densities is **not precisely known** because of the theoretical difficulties associated with extrapolating the likely behavior of quantum chromodynamics, superconductivity, and superfluidity of matter in such states. … **For example, a 1.5 $M_\odot$ neutron star could have a radius of 10.7, 11.1, 12.1 or 15.1 kilometers**

And for current readings:
[Chapter 6] Multi-MegaTon H-bombs have been strategically de-emphasized in favor of small 0.02 to 1.5 kT (kilo-Tons- of TNT) bombs up to 340 kT (called "B61's") and W88 bomb at half a MT. The B83 bomb had an upper limit of 1.2 MT. No nukes have been produced since the 1989 shut down of Rocky Flats. Oppenheimer once objected to big H-bombs because all target cities were "too small."

The Present Status of Gravitational Wave Detectors: Due to Covid, the **LIGOs** shutdown on March 27th, 2020, about a month shy of the planned end date. Still, the run was a great success, with 56 gravitational-wave candidates detected in 11 months – about one each week. A new program was started to install a series of detector upgrades called "Advanced LIGO Plus (A+) https://physicsworld.com/a/growing-the-gravitational-wave-network/

Ideal Gravitational Collapse to a Black Hole Singularity:

"Simple" intro to **Finkelstein Time t*** [See Kip **Figure 6.7** and/or *Boxes 12.1 and 12.2*]

In 1939, Hartland Sweet Snyder and Robert Oppenheimer calculated the gravitational collapse of a pressure-free sphere of dust particles [1]. This "continued contraction" surprised physicists because it went interior to the "Frozen Star" view that stopped at the event horizon for both light and infalling matter. But the paper was also difficult in the sense that it failed to make it intuitively clear how penetrating that horizon could happen. Finally, in 1958, David Finkelstein wrote a paper that provided that intuitive clarity. Yevgeny Lifshitz said: "You cannot appreciate how difficult it was for the human mind before Finkelstein to understand [the Oppenheimer-Snyder analysis of stellar implosion]."

In the usual Schwarzschild metric, the time coefficient becomes zero at the Schwarzschild radius (r_s = 2M, shorthand for $2MG/c^2$), and the coefficient of "radius" r becomes infinite. A distant observer can never see through r_s.

The initial key idea for bypassing this artificial coordinate barrier is to simply redefine r to a new parameter r* ("called a 'Tortoise' coordinate [Wheeler, 1955]) which just wipes away the singularity (no more division by zero). Just force it to happen !

Equation 1.

$$ds^2 = -\left(1-\frac{2M}{r}\right)(cdt)^2 + \frac{dr^2}{1-\frac{2M}{r}} \quad \rightarrow \quad ds^2 = -\left(1-\frac{2M}{r}\right)(cdt)^2 + \left(1-\frac{2M}{r}\right)(dr^*)^2$$

{ignoring the angular coordinates θ and ϕ ; i.e., an $r^2 d\Omega^2$ = '$r^2(d\theta^2 + \sin^2\theta d\phi^2)$' term}.

That makes 'the new radial coordinate' look just like time – both have the same "warpage" coefficients. That also means that a light ray *(where $ds^2=0$)* always has an ingoing speed dr*/dt = - c ! [and this could also be considered as another Key Idea or starting-point in forming the new metric].

What's the trick to getting Equation 1? **Begin with dr* = dr/(1-2M/r).** Then find an algebraic equation for r*(r) = ∫ dr* = r+ 2M ℓn| r/2M – 1|. At large r, r* ~ r.

If we were to make a **new "time"** also look like this, we get [3]:

"Finkelstein time" = t* = t + 2M ℓn| r/2M -1| so that dt = dt*-2Mdr/(r-2M). Eqn. 2

Kip Thorne's drawings of collapse (e.g., Fig 6.7) have this time t* increasing vertically versus ordinary Schwarzschild radius r sideways. For ingoing rays of light, dt*/dr = -1, a line tilted at 45^o , just like a trajectory in "flat" space-time. t* goes strongly negative near r = 2M, but we often show it truncated it so that t* ≥ 0. For higher r >2M, the t*(r) curve rises quickly near r =2M and then curves over to the right. Outgoing light trajectories also do this. Curves are labeled by values of constant time like t = 2M, 4M, 6M… {with units of c=1& G = 1}.

Substituting Eqn 2 into Eqn 1 gives the metric for Finkelstein time [3][4]:

$$ds^2 = -\left(1 - \frac{2M}{r}\right)(c\,dt^*)^2 + \frac{4M}{r}dt^*dr + \left(1 + \frac{2M}{r}\right)dr^2 + dr^2 d\Omega^2 \qquad Eqn. 3$$

References:

[1] [OS] Oppenheimer and Snyder 1939, "On Continued Gravitational Contraction," Physical Review 56 p 455 or at: www.weylmann.com/oppenheimer2.pdf .
[2] MTW GRAVITATION, Misner, Thorne, Wheeler, 1973 p 829, 848
[3] CalTech http://www.pmaweb.caltech.edu/Courses/ph136/yr2012/1326.1.K.pdf
[4] Radial Infall, https://www.reed.edu/physics/courses/Physics411/html/411/page2/files/Lecture.31.pdf
[5] https://www.damtp.cam.ac.uk/user/hsr1000/black_holes_lectures_2014.pdf

Added Note:

Many texts discuss an ingoing Finkelstein coordinate **v ≡ t + r*** and use it in place of t*. This describes infall so well that it is often used for gravitational collapse. It is easy to use t* as a function of r and a series of times t. Using v versus r and a set of constant times is just as easy. There are also other coordinate choices that can result in names like "Kruskal Time," "Free-Fall Time," "proper time," and "Penrose Time." A fully adequate coordinate system without any pathologies is "Kruskal-Szerkeres" which uses hyperbolic functions like cosh(t/4M) . A special Schwarzschild metric exists for describing space-time inside a non-rotating static black hole (see https://en.wikipedia.org/wiki/Interior_Schwarzschild_metric). There is no interior physical solution for the Kerr space-time.

If we re-write Equation 1 using dv = dt + dr*, then dt = dv – dr/(1-2M/r) and we get metric:
$ds^2 = -(1-2M/r)dv^2 + 2dvdr + r^2 d\Omega^2$ [4][5] for ingoing Finkelstein coordinates.
This is non-singular at $r = r_s = 2M$ and also applies interior to the horizon.