The Lighter Side of Gravity

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Of the four basic forces gravity is the oldest known
...yet it is the least understood!

Law of Gravitation:

\[ F = G \frac{M_1 \times M_2}{r^2} \]
Law of Gravitation:

It successfully explained the motion of the Moon, Kepler’s laws of planetary motion, the arrival of a comet, etc., and led to the discovery of a new planet *Neptune*… but left many conceptual questions unanswered…

Why inverse square law?
Why action at a distance?
Why universal?
We will now highlight some strange aspects of gravity…

…aspects that set it apart from other forces in nature.
Negative energy behaviour:

Laws of dynamics tell us that

\[ \text{Kinetic Energy} + \text{Potential energy} = \text{constant} \]

In a normal interaction, as the physical system yields to the applied force, the force begins to lose strength. The work done by the force increases the potential energy. The system therefore loses kinetic energy and eventually comes to rest.

- Stretched spring
- Normal spring
- No force
Negative energy behaviour:

In the case of gravity, the potential energy is *negative* and the force *gains* in strength as the system yields to it.

Gravity is a dictator that thrives on systems submitting to it.
A “thought experiment”

- Connect two metal spheres A and B with a conducting wire.

- A is hotter than B

- Heat will pass from A to B until they both have the same temperature.
A “thought experiment”

- Now connect a hot star A to a cold star B by a conducting wire!

- Heat will pass from the hot star to the cold star.
A “thought experiment”

- When A loses heat, its internal pressure falls…the pressure may be from gas as well as radiation.
- The overall equilibrium of A is maintained by the opposing forces of pressure and gravity.
- Because pressure falls, the star shrinks.
- And because of contraction its gas (and radiation) heats up. So A gets hotter.
- The reverse happens to B: it expands and cools. So the hot star gets hotter and the cool star gets cooler!
Something like this happens in a red giant star...

Its core shrinks and gets hotter while its envelope expands and gets cooler.
How important are pressures for stellar equilibrium?

Very!

Delete all pressures and what happens?
…The star shrinks rapidly…

\[ \frac{d^2r}{dt^2} = -\frac{GM}{r^2} \]

This integrates to give the time of free fall (collapse) from the present radius \( R \) to ‘zero’ size as

\[ T = \left(\frac{\pi}{2}\right) \sqrt{\frac{R^3}{2GM}} \]

In the case of the Sun the answer is around 29 minutes!
Gravitational Collapse:

- The Sun’s example is an extreme one…but in other contexts it may be realistic!

- In a star, the thermo-nuclear effects are $\propto M$ (the mass of the star) but gravitational effect is $\propto M^2$. So for a very massive star the internal thermal or radiation pressure is inadequate to balance gravitational contraction…

- Also, as we saw earlier, the smaller the size the larger is the gravitational attraction.
Gravitational Collapse:

- So, a contracting star ultimately contracts very fast in a ‘run-away’ fashion and this is known as gravitational collapse!

What is the end-state of such a collapse?
Eddington vs Chandrasekhar
A more dramatic end for a star comes, in the form of a supernova. The core of an exploded star will contract and if massive enough, it will undergo a gravitational collapse!
Black hole is an end state of gravitational collapse...

- Signal communication from a collapsing object
Schwarzschild barrier and event horizon...
Black hole as a source of energy...

Spinning black hole and energy extraction from the ergosphere illustrated
Black hole in Cygnus X-1?
White holes as energy machines...?

Pictures of some explosive phenomena

Jets in Radio Galaxies

Jet from AGN in M87

Nebula of Crab Pulsar
Does Light bend gravity?

Do not Bodies act upon Light at a distance, and by their action bend its Rays; and is not this action (caeteris paribus) strongest at the least distance?
The 1919 Solar Eclipse confirmed that light from stars is bent by the Sun...
The 1919 Solar Eclipse

Eddington, et al. in two teams measured the displacement of stellar images at the time of the eclipse seen at Sobral, Brazil and Principe, an island in the Gulf of Guinea...

The results supported Einstein’s general relativity rather than Newton’s law of gravitation.
It was Fritz Zwicky who in 1937 suggested that light bending by gravity could occur on the scale of galaxies and their clusters. But he was vindicated only after four decades…

1979: The discovery of the double-image lens in quasar 0957+561 A,B. Pictures in optical and radio
Images of some other lensed objects.

Multiple lenses in Abell 2218 galaxy cluster
Images of some other lensed objects.

Einstein’s Ring in Q1938+666

Einstein’s Cross in Q2237+0305
Gravitational microlensing...

- Foreground objects of stellar mass or smaller may also act as lenses for the images of background sources.
- Gravitational lensing on these smaller scale is known as gravitational microlensing. This may be useful in detecting low mass objects in the Galaxy.
For a suitable lens configuration, the image of the source may brighten considerably and stay that way till the foreground object moves past. This may take a few days.
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What is Gravity?

The question still remains unanswered despite the many applications of the force in real life. Its effects on matter and light have been perceived widely but their origin remains an enigma...