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PHYC90012 General Relativity

Course Summary

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1 Syllabus

1.1 Part I

1. Introduction to gravity
    - Order of magnitude estimates
    - Small amount of quantum gravity
2. Equivalence principle + experimental foundations
3. Geometric objects
    - Need to understand geomtric components of GR
    - Vectors, metric, etc. that live on manifolds
    - Laws of nature do not depend on coordinates chosen
    - Hence can write laws of nature in terms of geometric objects w/o reference to coordinates
4. Kinematics
    - Time dilation, length contraction in GR framework
5. Calculus in curvilinear coordinates
    - Mass and energy curve spacetime
    - Hence geometric objects moved on curved manifolds
    - Distances are not only spatial but temporal; need to use mathematics of small change = calculus
    - Uses the covariant derivative (a geomtetric object; independent of basis/coordinate independent)
    - This point of the course we will not be considering curved space, but instead only curvilinear coords
        - A flat space can be covered (represented?) by curved coordinates, but an intrinsically curved surface cannot be covered by flat coordinates
6. Curved spaces
    - Manifolds
    - How to calculate lengths, volumes, angles in curved spaces
    - Introduces the idea of parallel transport ⇒ leads to curvature
    - Define the Riemann tensor, and its children etc. Ricci tensor, ...; these satisfy the Bianchi identities
7. Einsten's field equations
    - Stress-energy tensor
8. Weak-field limit
    - Gauge transformations

1.2 Part II - Applications

9. GR phenomena revisited
   - GPS, Mercury's orbit, gravitational lensing, gravittional redshift, ...
10. Gravitational waves
    - Propagation (phase speed, polarisation, ...)
    - Generation*
    - Detection*
      - * = "antenna problem"
11. Relativisitic stars
    - neutron stars
    - equation of state (cannot study on Earth because largest nuclei only have 200 elements or so; need more density)
12. Black holes
    - Event horizons, singularities, ...
13. Cosmology
    - Friedman-Robertson-Walker (FRW) metric - describes a homogeneous, isotropic universe
      - We will derive this and the Friedman equations

2 Introduction to gravity

2.1 Strength of gravity

- Weak! Weakest of all fundamental forces
- Long-ranged force (like EM)
- Weakness determined by coupling constant
- Coupling constant = Newton's gravitational constant

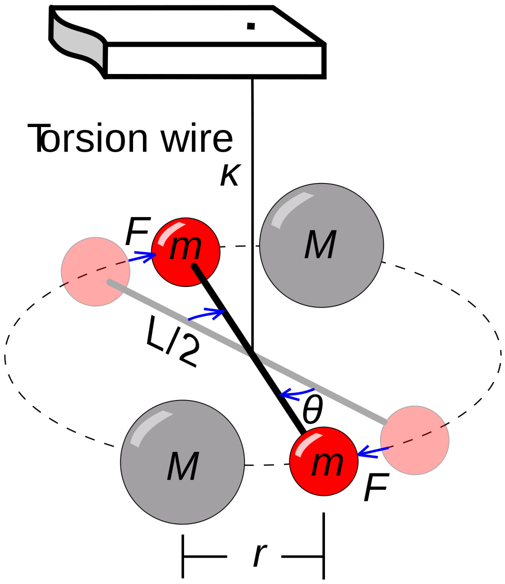
$$\vec{F} = \frac{Gm_1 m_2}{r_{12}^2}\hat{r} \tag{1}$$

- G is hard to measure; least well known of coupling constants

In 1797-98, Cavendish used torsion balls (1.8m torsion balance) with rod of big masses and rod of small masses.

- Spring constant of torsion balance was measuredfrom free oscillation

- ten introduced 158kg balls
- measured delfection angle of balance ⇒ force
  - using a mini-telescope against Vernier scale
- rearrange Newton's law to get G



Exercise: Show that Cavendish also measured density if Earth as a bonus at the same time

- Modern $G = 6.67384(80) \times 10^{-11} Nm^2kg^{-2} = kg^{-1}m^3s^{-2}$

- Product GM is known to 1 part in 10^{10} from astrophysics observations

  ⇒ mass is hard to measure gravitationally
- We need a dimensionless number to characterise strength
- Newton: $\Phi = \frac{GM}{r}$ (potential)
- In free fall: $\frac{KE}{mass}$, v^2 $\frac{GM}{r}$
- We claim gravity is strong is free-fall is relativistic, i.e. v c
- This is an order of magnitude estimate