SUSTech Southern University of Science and Technology

南方科技大学 SOUTHERN UNIVERSITY OF SCIENCE AND TECHNOLOGY

地球与空间科学系 DEPARTMENT OF EARTH AND SPACE SCIENCES

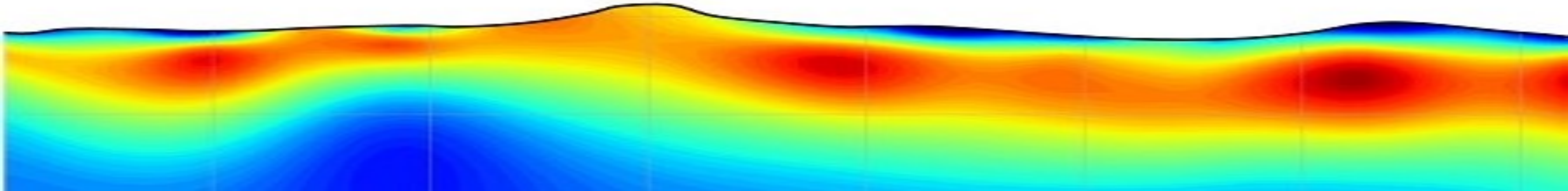
ESS302 Applied Geophysics II

Gravity, Magnetic, Electrical, Electromagnetic and Well Logging

Gravity 1: Theory

Instructor: Dikun Yang

Feb – May, 2019



Contents

- Density
- Physics in gravity
- Interactive apps exercise and discussion
- Programming assignment

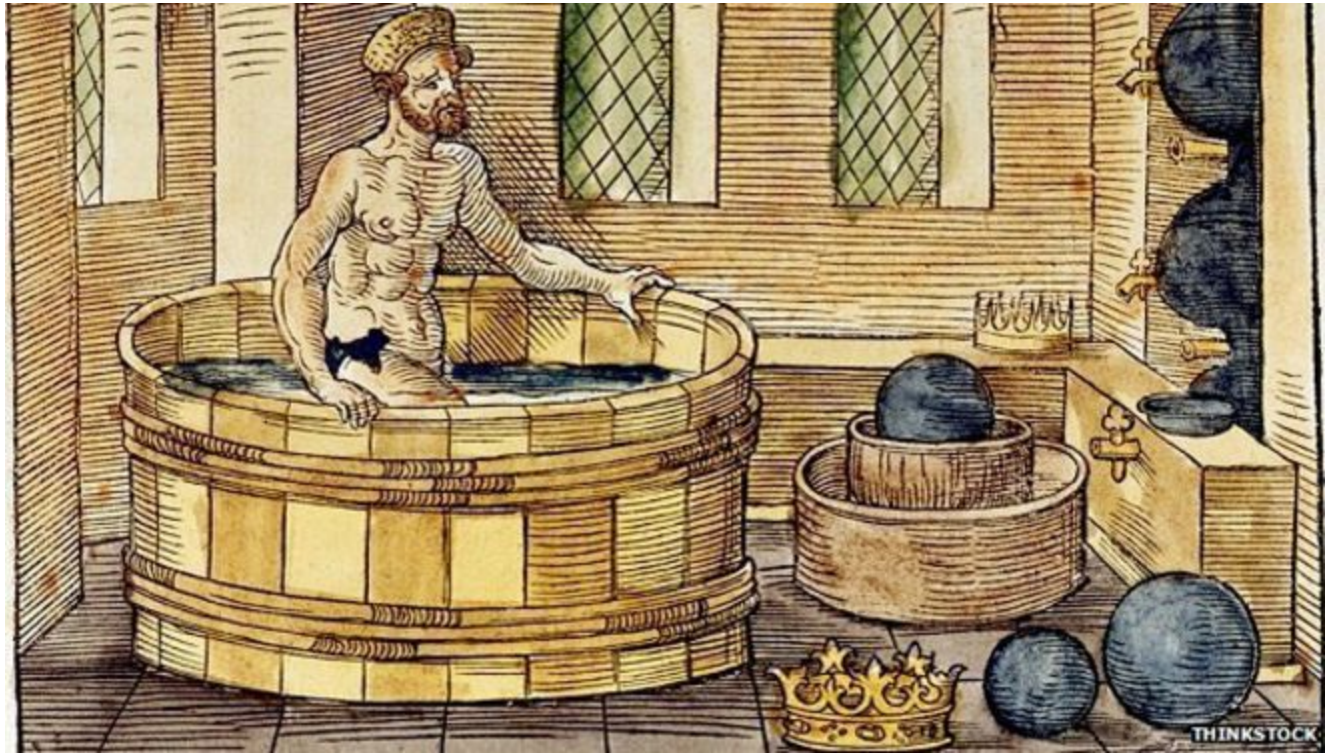
Density

$$\rho = \frac{m}{V}$$

Mass: ***m*** in **g** or **kg**

Volume: ***V*** in **cm^3** or **m^3**

Density: ***ρ*** in **g/cm^3** or **kg/m^3**



Archimedes: Pure gold? Measure the density!

Density of earth materials

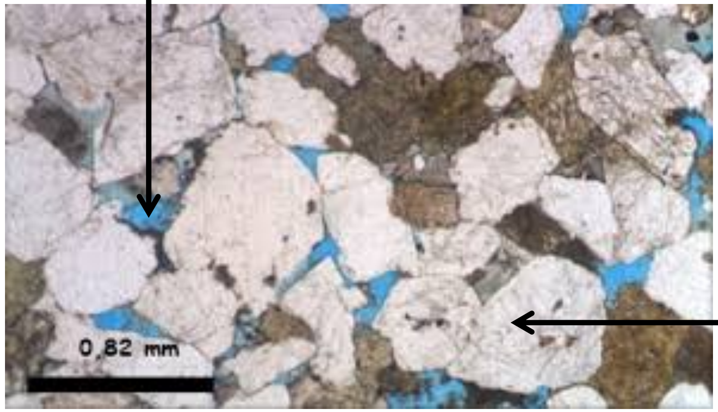
Air:	0.001225 g/cm^3
Petroleum:	0.60 - 0.90 g/cm^3
Ice:	0.917 g/cm^3
Water:	1.00 g/cm^3
Sedimentary Rocks:	1.50 - 3.30 g/cm^3
Igneous Rocks:	2.35 - 3.50 g/cm^3
Metamorphic Rocks:	2.52 - 3.54 g/cm^3
Ore-Bearing Rocks:	2.30 - 7.60 g/cm^3

Question:
In general, why do sedimentary rocks have lower density compared to other types of rock?

Porous rocks

fluid

bulk density < skeletal density



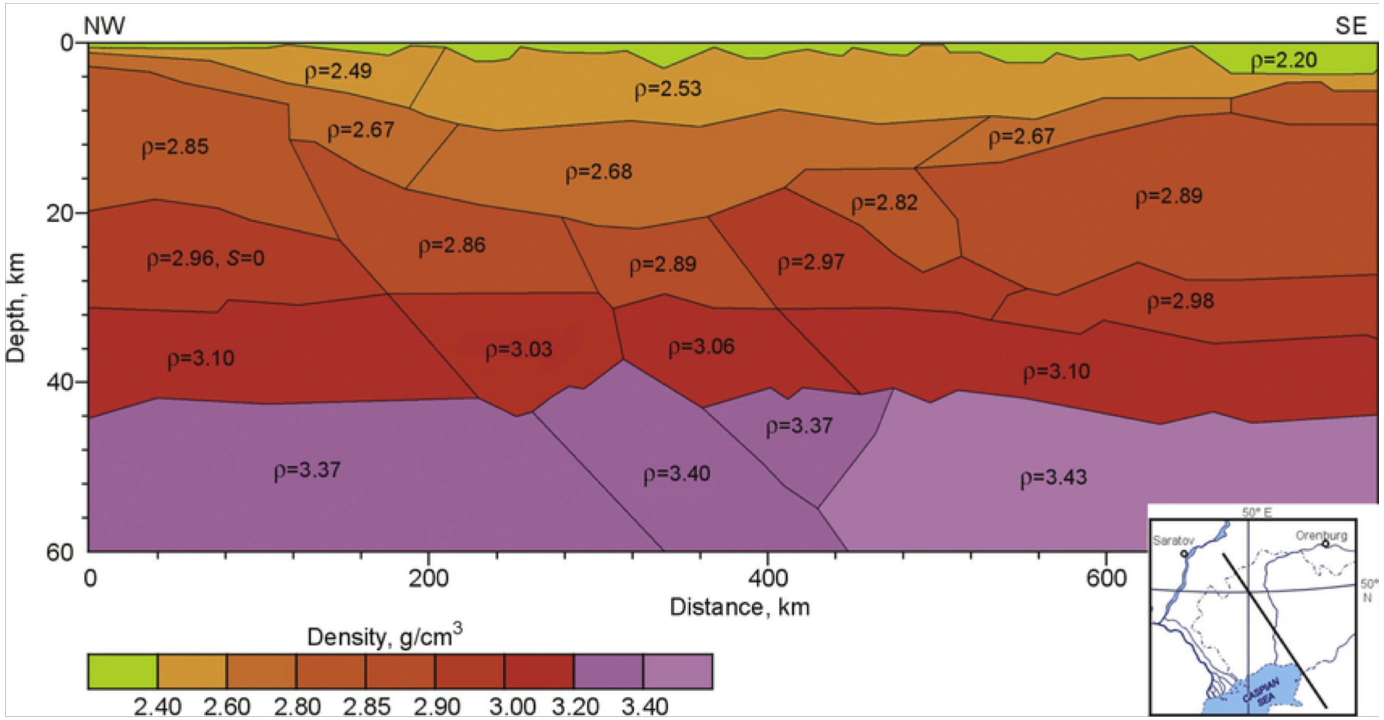
matrix

Density vs. Depth

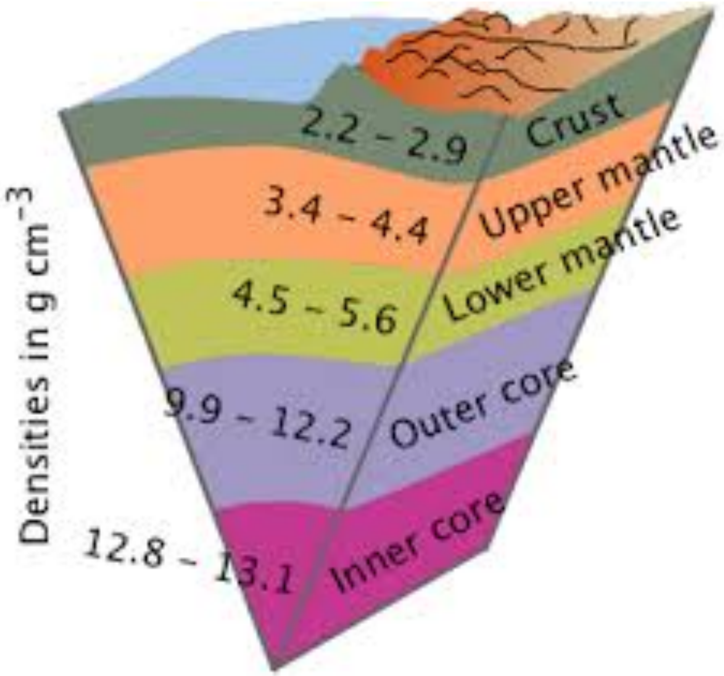
Low density

High density

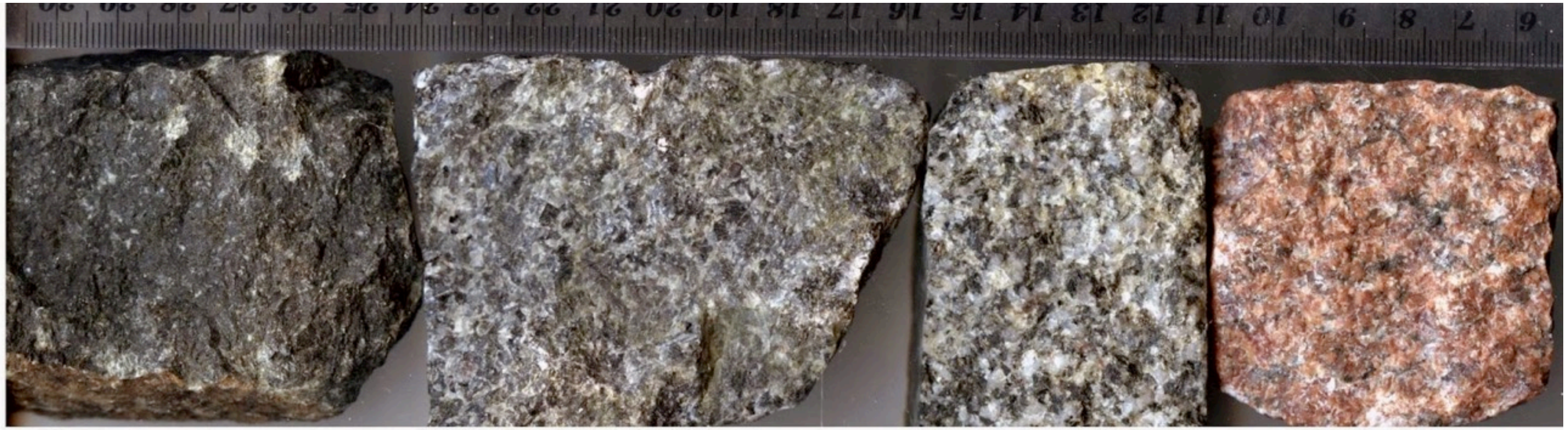
Density vs. Depth



Artyushkov et. al. 2014



Composition

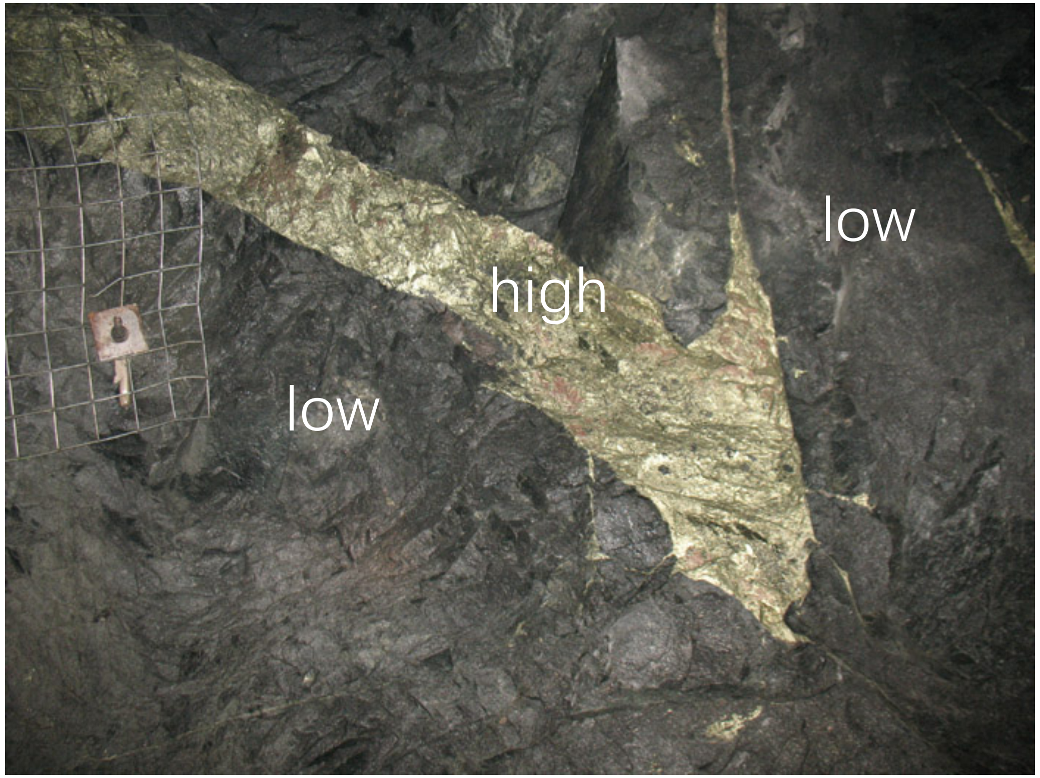


	Ultramafic	Mafic	Intermediate	Felsic
Color	Dark			Light
SiO_2	40%	50%	60%	70%
MgO	48%	15%	2.5%	0.95%

Heavy elements: magnesium, iron, lead, copper, silver, gold …

Density Contrast

Cavity

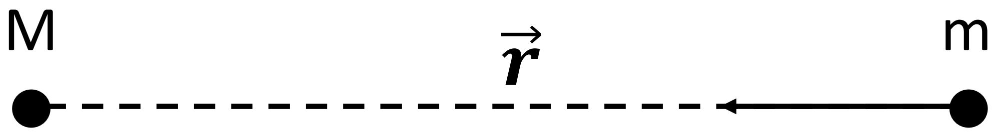


Mineralized dyke

Some Physics in Gravity

Gravitational Force

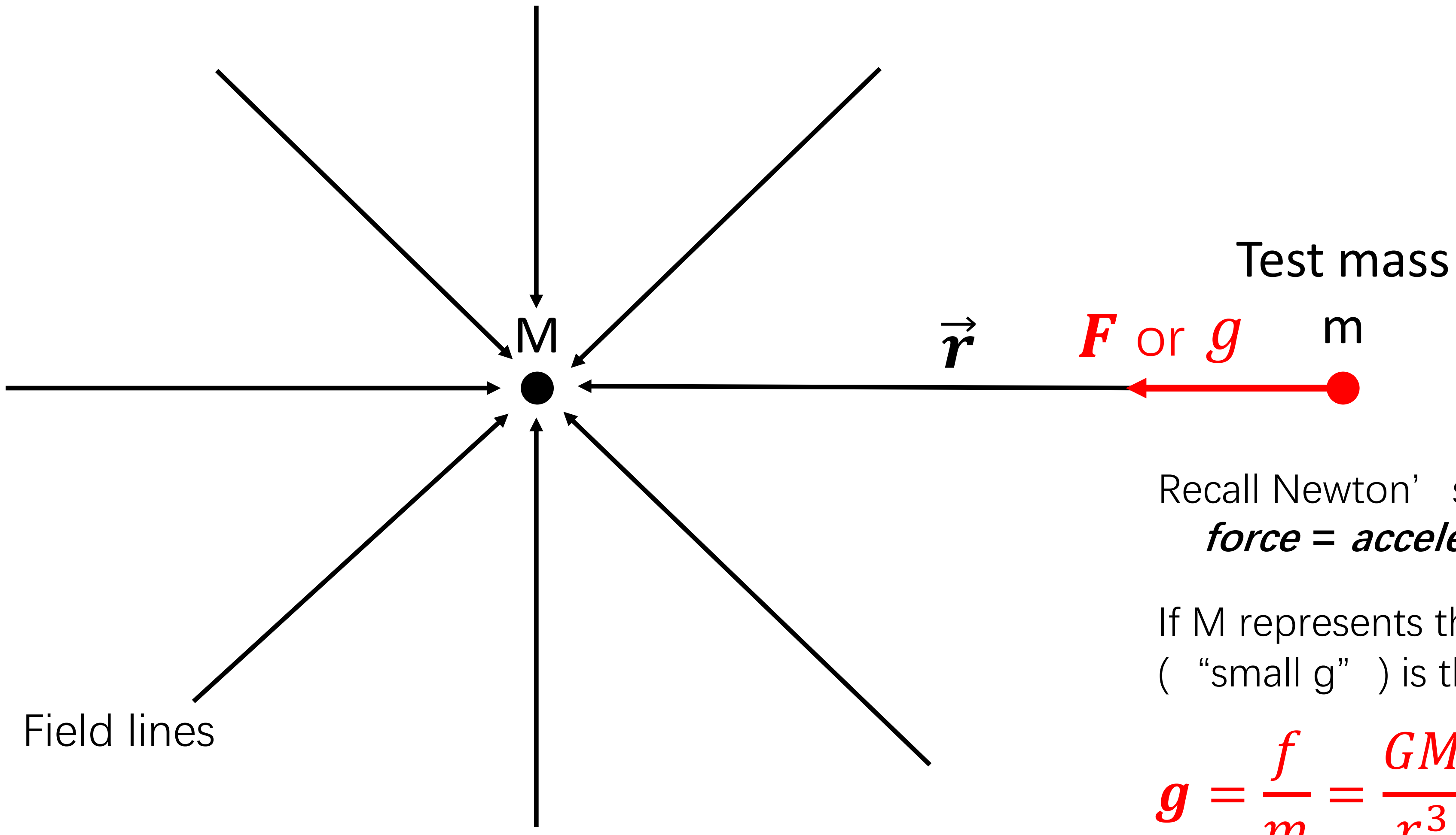
Newton's law of universal gravitation



$$f = \frac{GMm}{r^3}\vec{r}$$

Gravitational constant (Big G): $G = 6.67408(31) \times 10^{-11}\ \mathrm{m}^3\ \mathrm{kg}^{-1}\ \mathrm{s}^{-2}$

Gravitational Field



Recall Newton' s second law:

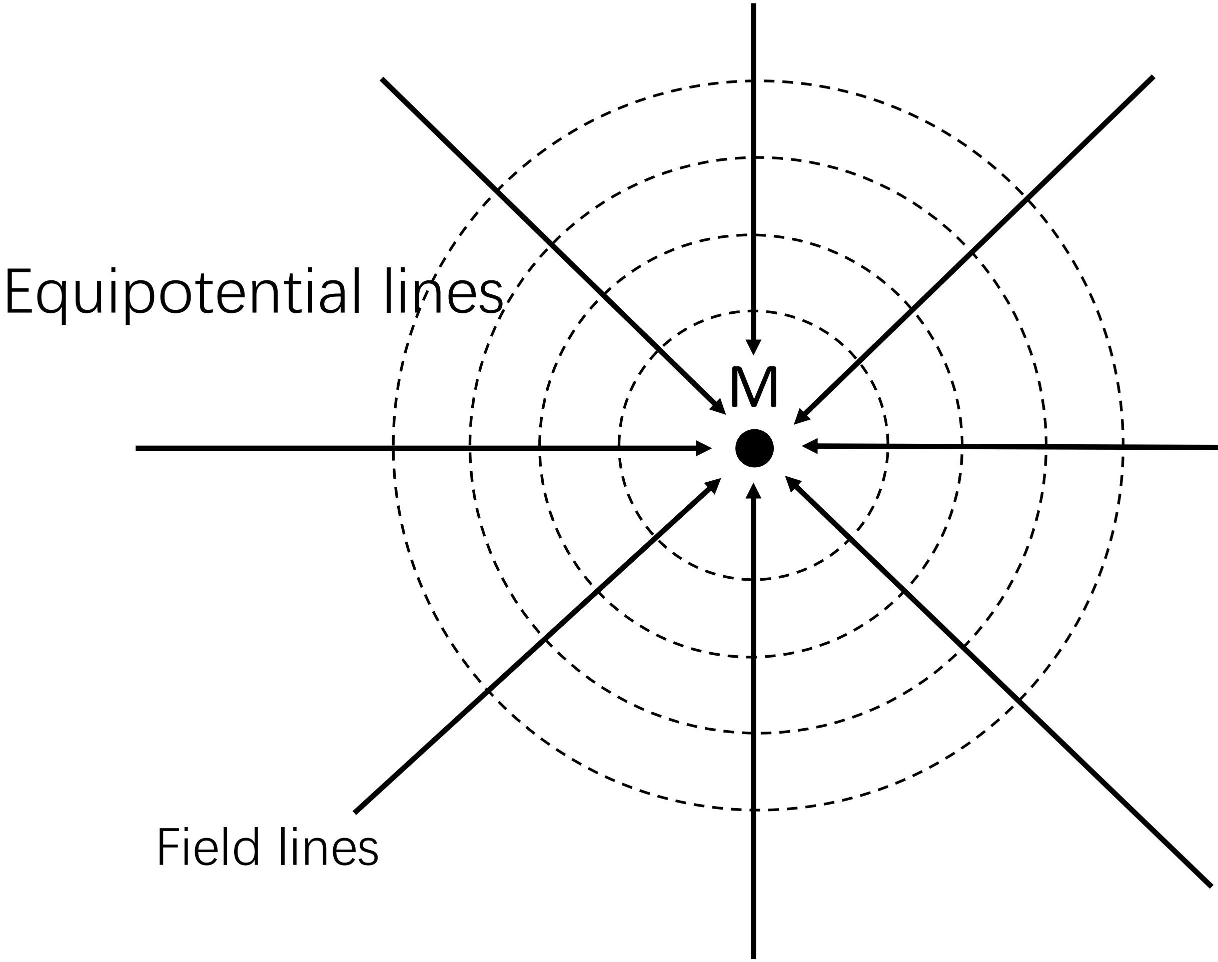
force = *acceleration* x *mass*

If M represents the **earth** mass, g ("small g") is the free-fall acceleration.

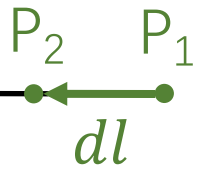
$$\boldsymbol{g} = \frac{f}{m} = \frac{GM}{r^3}\vec{\boldsymbol{r}} = \boldsymbol{F}$$

Field F caused by the source M

Gravitational Potential



Move a unit mass from P_1 to P_2



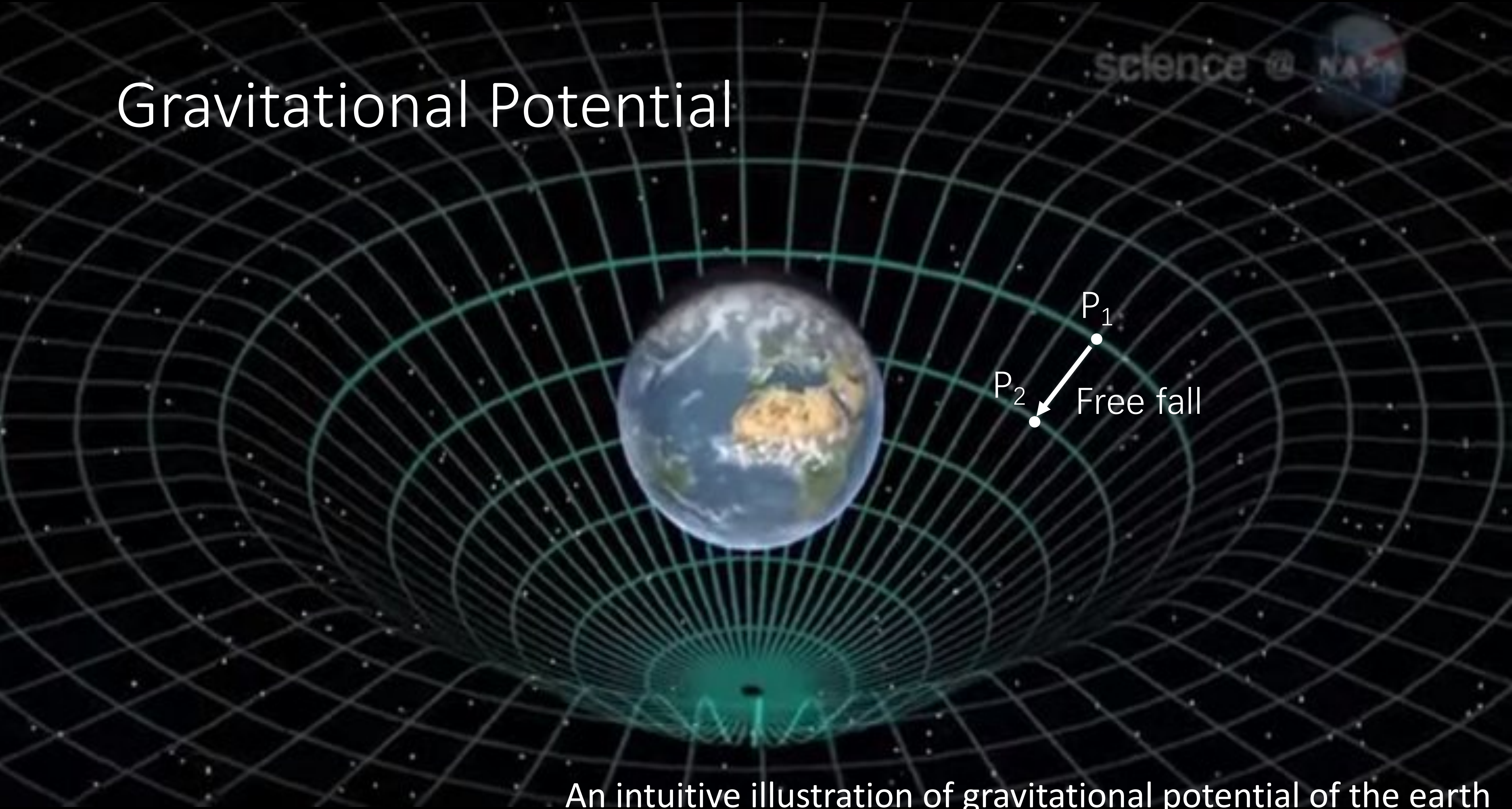
The work required to move the unit mass

$$\boldsymbol{U} = -\int_{P_1}^{P_2} f\, dl = -\int_{P_1}^{P_2} \frac{GM}{r^2}\, dl$$

$$\boldsymbol{U} = -\frac{GM}{r}$$

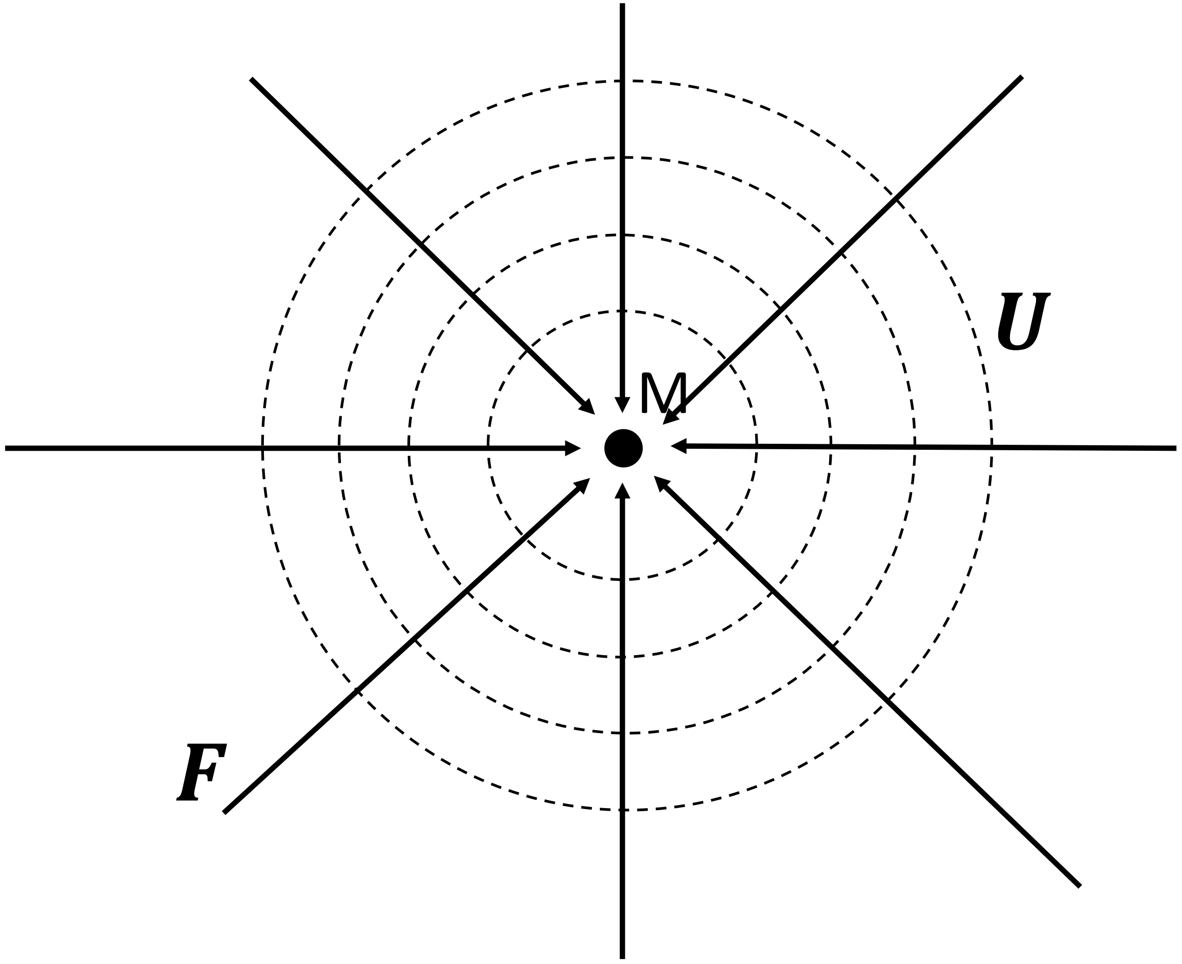
when P1 is at infinity and has zero potential

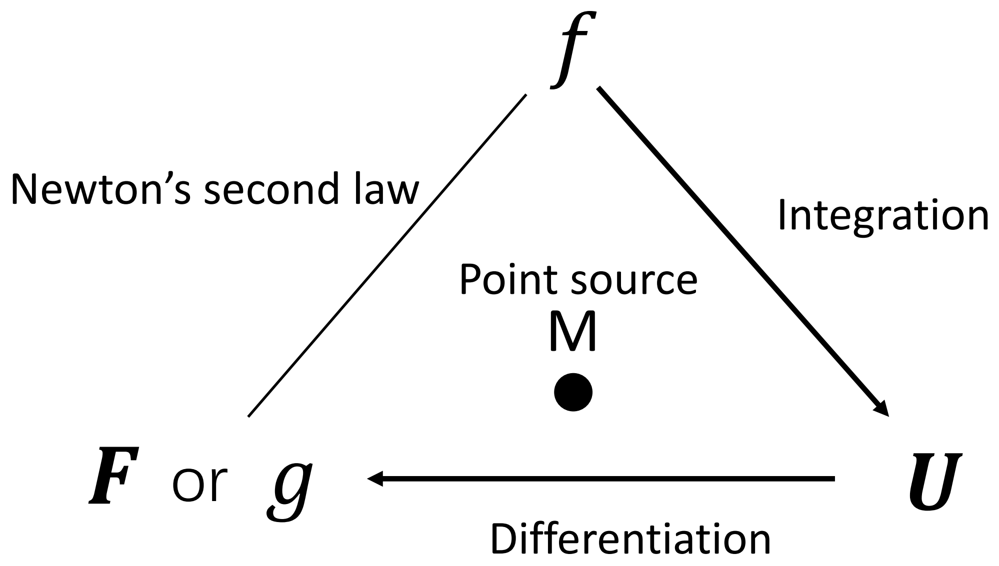
Gravitational Potential



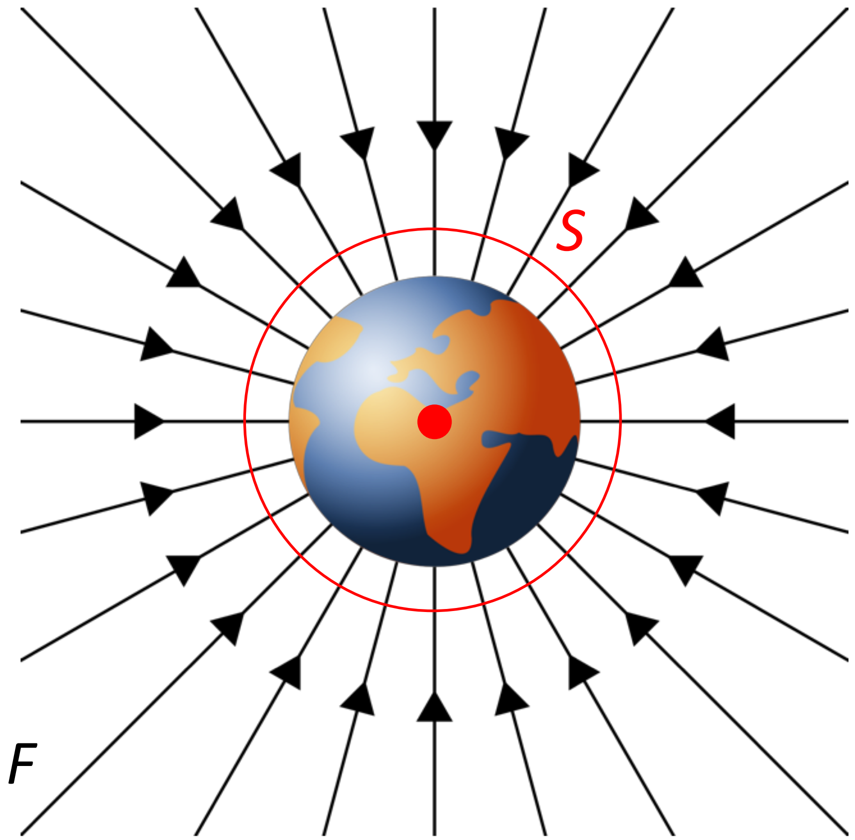
An intuitive illustration of gravitational potential of the earth

Force, field and potential





Properties of gravitational field ***F*** (or *g*)



Suppose the earth is enclosed by a spherical surface *S*

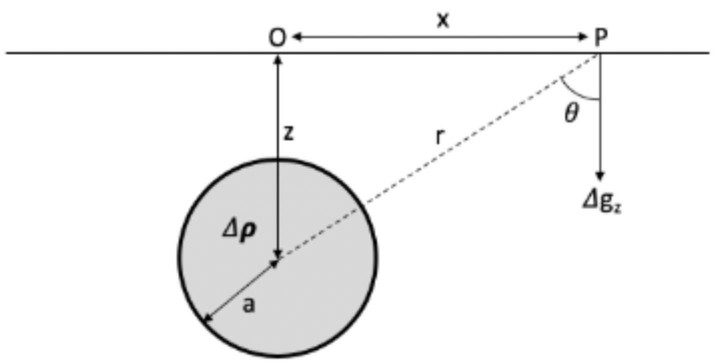
Total flux of *F* through *S* is determined by the total mass within *S*

- If the earth has a uniform density, the earth mass can be represented by a point mass at the center, and *F* is uniform on *S*
- If the density distribution of the earth is not uniform, the total flux of *F* through *S* is still the same but *F* is not uniform on *S*
- Non-uniform *F* contains anomaly and can be used to infer the density structure of the earth

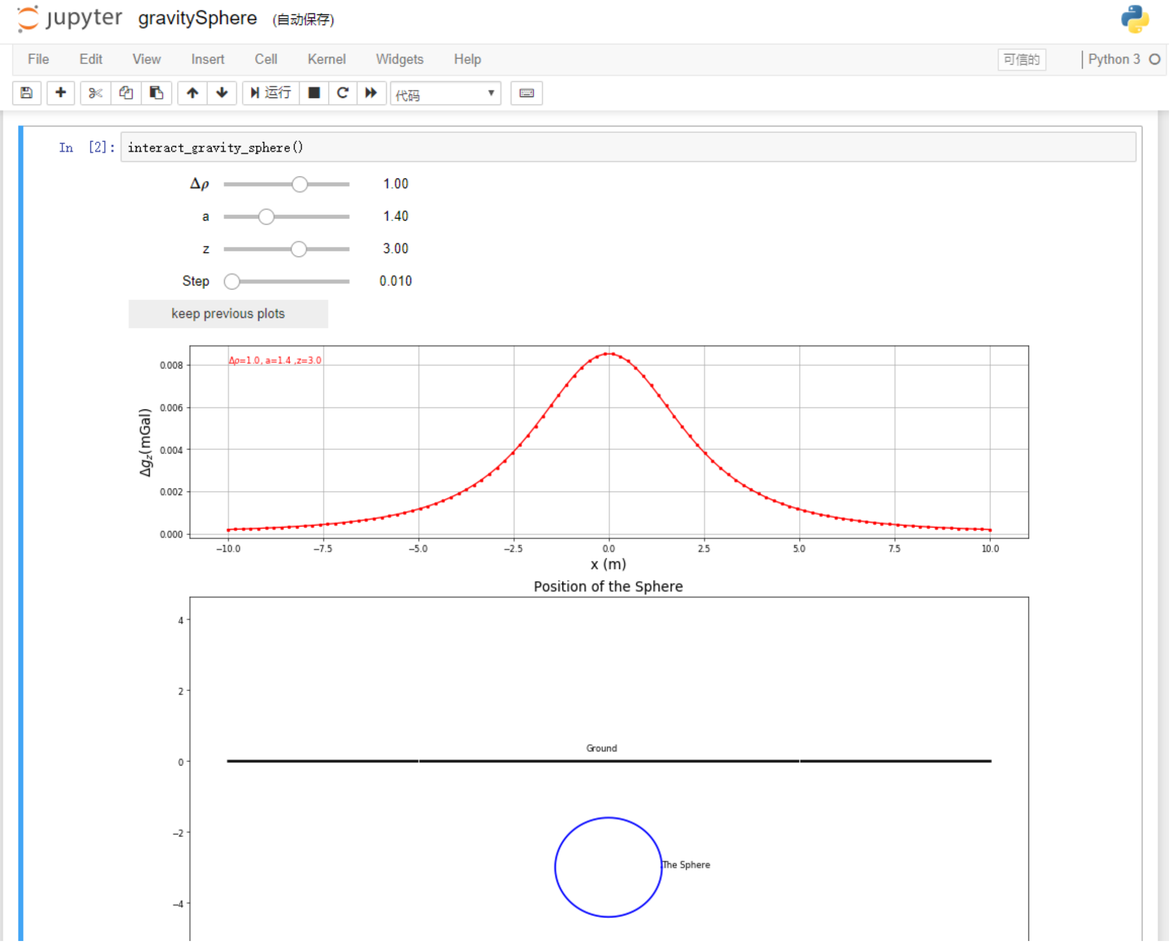
gravitySphere.ipynb

https://mybinder.org/v2/gh/geoscixyz/geosci-labs/master?filepath=notebooks%2Findex.ipynb

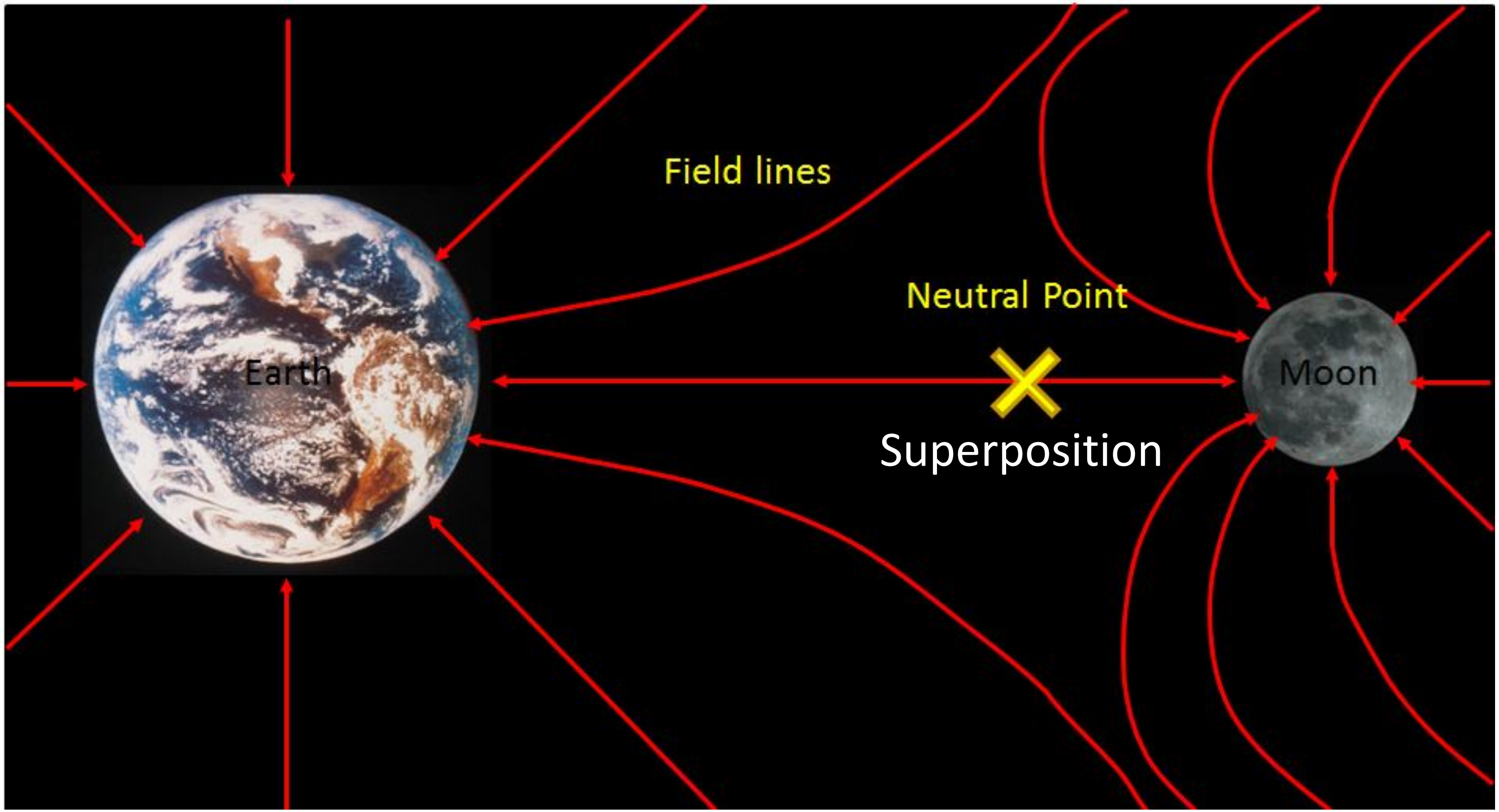
Measure g_z due to a sphere on an observation plane



- Keep z (depth) constant, explore different combinations of radius and density that produce the same g_z curve
- Keep the total mass constant, adjust z to see how the data pattern changes

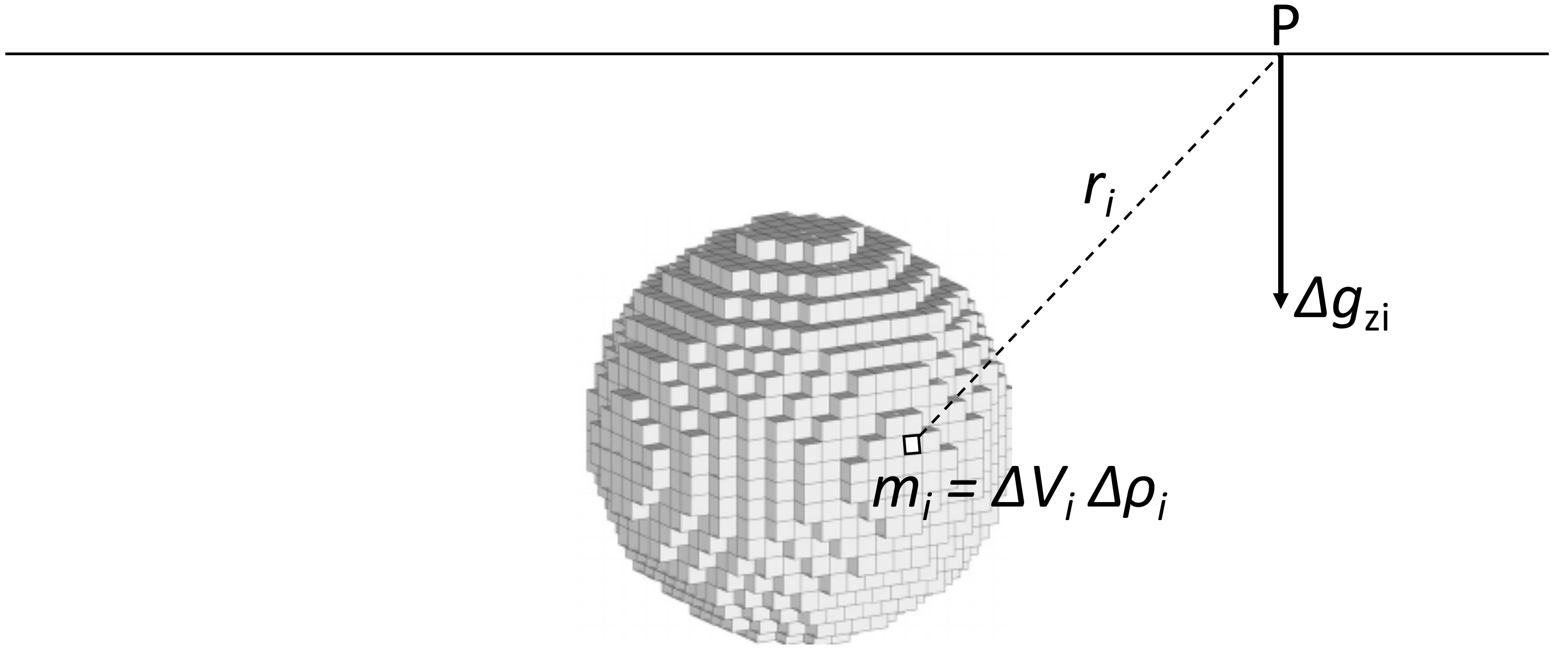


Properties of gravitational field



Non-uniform sphere (or other complex shapes)

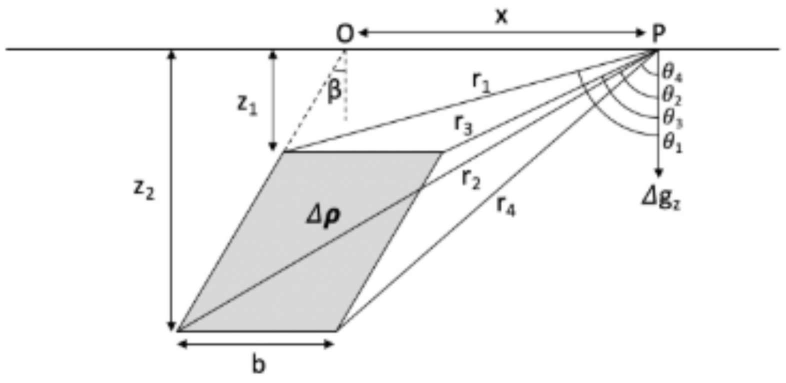
Superposition $\Delta g_z = \sum_i \Delta g_{zi}$



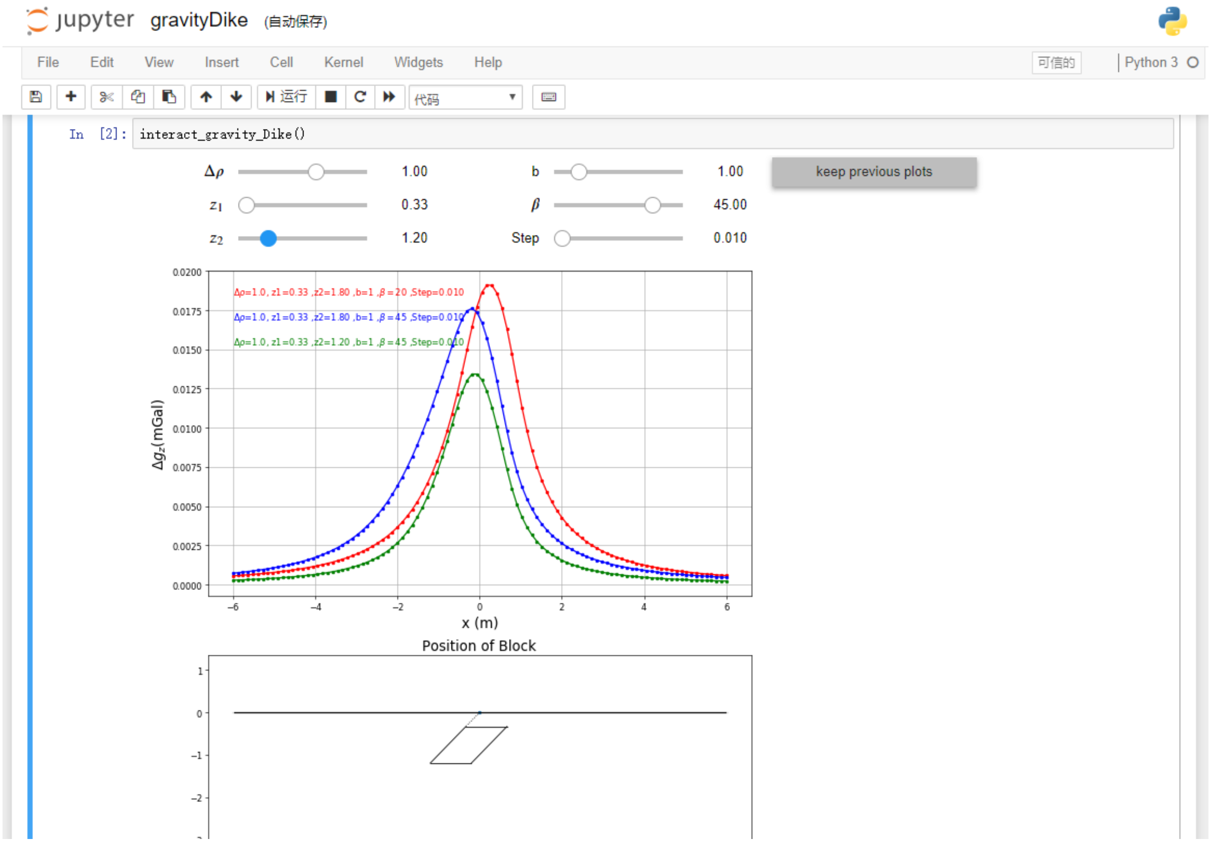
gravityDike.ipynb

https://mybinder.org/v2/gh/geoscixyz/geosci-labs/master?filepath=notebooks%2Findex.ipynb

Measure g_z due to a 2D dike on an observation plane

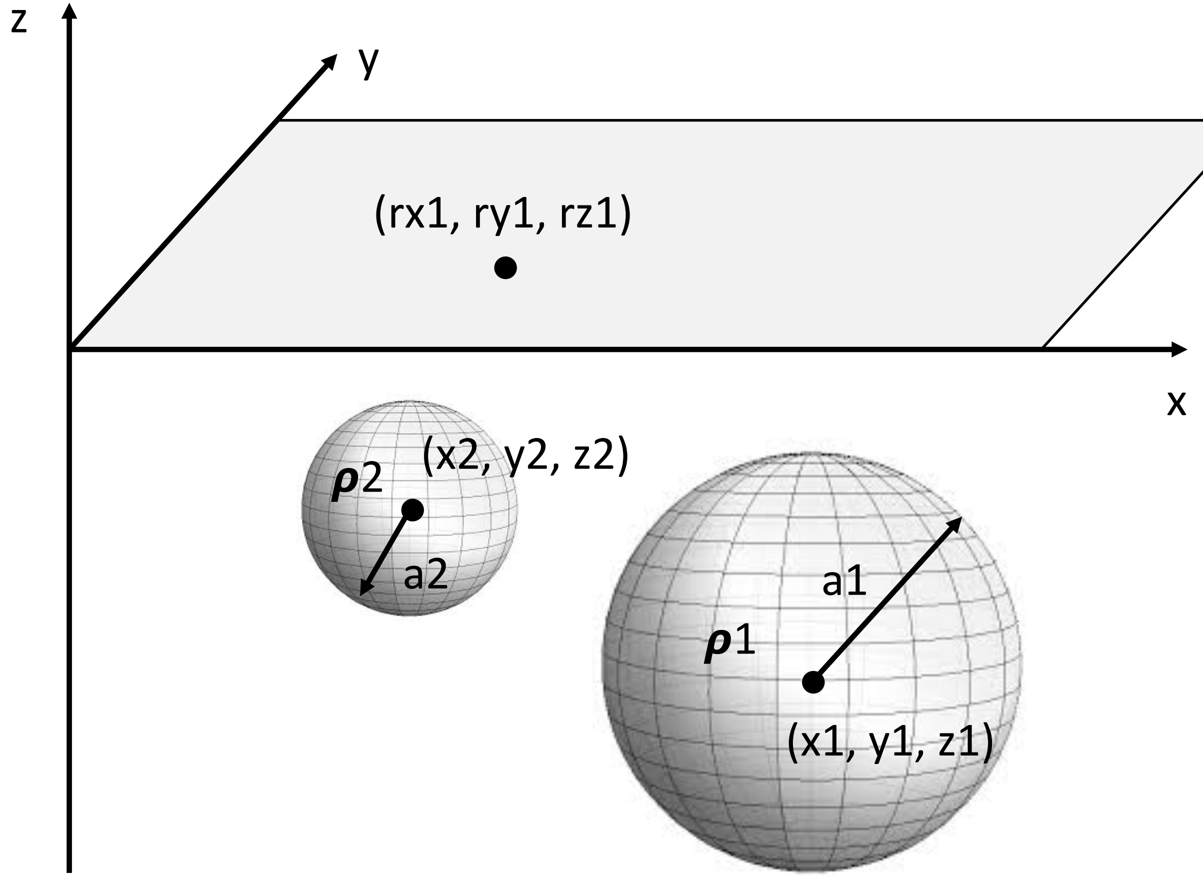


- Can you tell the dipping direction from the data plot?
- How do you explain the asymmetry in data pattern?



Programming assignment

Gravity of two (or N) spheres



N uniform spheres of different densities located in the 3D space

Be able to calculate the gravitational field F anywhere in the 3D space outside of the spheres

Bury the two spheres underground and compute g_z over a data grid on the surface and make the plot

Compute the potential U over the data grid and make the plot

Finish before next class

Further reading/watching

- The Amazing World Of Gravity (https://youtu.be/2_p2ELD7npw)
- How to Think About Gravity (https://youtu.be/lY3XV_GGV0M)
- Gravity Surveying (https://youtu.be/9P6GEpxFtSY)