

# Astronomy & Astrophysics

encouraging interest in science

Denis J Sullivan

September 10, 2007

Astronomy and astrophysics .....	2
PHYS 132 (Introductory Astronomy), VUW course .....	3
Euclidian geometry is sometimes wrong! .....	4

## Astronomy and astrophysics

- Astronomy vs astrology
- Astronomy vs astrophysics
- Observational astronomy
- Stellar astrophysics
- Galaxies and the universe
- Extraterrestrials – other life in the universe?

2 / 4

## PHYS 132 (Introductory Astronomy), VUW course

- Elementary spherical astronomy
- Astronomical instruments: the telescope
- Stars and their measurable properties
- Correlations between stellar properties: the HR diagram
- The mass of stellar and sub-stellar objects
- Stellar interiors, energy sources and variability
- Stellar evolution
- Extrasolar planets
- Stellar death: white dwarfs, neutron stars & black holes
- Science history: eg black hole concept evolution
- Galaxies, cosmology and the big bang

3 / 4

## Euclidian geometry is sometimes wrong!

- Pythagorus: right angle triangles

$$c^2 = a^2 + b^2$$

- Pythagorus: any triangle – the cosine rule

$$c^2 = a^2 + b^2 - 2ab \cos \theta$$

- Spherical astronomy – the surface of a sphere

$$\cos c = \cos a \cos b + \sin a \sin b \cos C$$

- Riemann/Einstein's curved space-time

$$ds^2 = dx^2 + dy^2 \quad (\text{Euclid}) \quad \longrightarrow \quad ds^2 = g_{\mu\nu} dx_\mu dx_\nu$$

# Scientific Method & Black Hole History

Denis J Sullivan

September 10, 2007

Evolution of modern science: pre-Einstein .....	2
Evolution of modern science: post Einstein .....	3
Science evolution (continued) .....	4
Science evolution (continued) .....	5

## Evolution of modern science: pre-Einstein

~1500 ~1500 to ~1650: foundations of modern science  
Copernicus, Tycho Brahe, Kepler, Galileo:  
observation and experiment essential.

1687 Newton: modern classical mechanics formulated  
(including theory of gravity).

1783 Michell: first suggestion of black hole (BH) idea

1794 Laplace: suggests BH in 'Le Système du Monde'

1854 Riemann: develops mathematics for *curved* spaces. Pythagorus modified

$$ds^2 = dx^2 + dy^2 \quad (\text{Euclid}) \quad \longrightarrow \quad ds^2 = g_{\mu\nu} dx_\mu dx_\nu$$

1865 Maxwell: develops unified theory for magnetic and electrical phenomena;  
→ predicts E/M waves with velocity ( $c$ ) a constant.

2 / 5

## Evolution of modern science: post Einstein

1905 Einstein: publishes **Special relativity (SR)** theory, among other things,  
 $E = Mc^2$ , ..., really  $E = \gamma(Mc^2)$

1911 Rutherford: energetic  $\alpha$  radiation ( ${}^4\text{He}$  nuclei) scattered by matter.

1915 Astronomers: identify **white dwarfs** as unusual.

1915 Einstein publishes **general relativity (GR)** - new theory of gravity:

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = (8\pi G/c^4)T_{\mu\nu}$$

which means: **space-time** curvature ← **mass-energy** density, and  
particles and light follow paths in curved **space-time**

1916 Schwarzschild discovers first **BH** solution -  
part of the Schwarzschild metric for an isolated, nonrotating spherically symmetric mass.  
Schwarzschild radius (event horizon) is:

$$R_g = 2GM_\star/c^2$$

3 / 5

### Science evolution (continued)

- 1917 Rutherford: nitrogen nuclei “split” by  $\alpha$  particles from radioactive decay.
- 1919 Eddington: measures bending of starlight around Sun, predicted by GR.
- 1925 Schrodinger, Heisenberg, Pauli, ... quantum mechanics developed.
- 1926 Fowler: uses quantum mechanics (QM) to develop a WD theory – electron degeneracy pressure prevents gravitational collapse.
- 1932 Chandrasekhar: combines SR with QM to get a WD theory that predicts a maximum mass ( $\sim 1.5M_{\star}$ )
- 1932 Cockcroft & Walton (and Rutherford):  ${}^7\text{Li} + \text{p} \rightarrow {}^4\text{He} + {}^4\text{He}$
- 1932 Chadwick: discovers neutron
- 1935 Landau: develops theory of stellar mass with mainly neutrons (a NS), and independently discovers WD maximum mass.

4 / 5

### Science evolution (continued)

- 1936 Oppenheimer & Volkoff: NS model investigated, including predicted maximum mass.
- 1939 Oppenheimer & Snyder: GR theory used to investigate BHs and very compact stars.
- 1963 Astronomers: quasars discovered - BHs proposed as energy source.
- 1963 Kerr: exact GR solution for rotating BH – the Kerr metric.
- 1967 Bell & Hewish: pulsars (accidentally) discovered.
- 1968 Gold: rotating magnetic NS “lighthouse” model of pulsar proposed.
- 1968 Wheeler: coins term ‘black hole’
- 1975 Hulse & Taylor: The binary pulsar (PSR 1913+16) discovered.
- 2007 Physicists & astronomers: “accept” observational evidence for reality of BHs.

5 / 5