The evolution of the multiverse

Jeremy Mould

Director's lunch

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The Challenge to 21st century astrophysics

Physics rules !

Astronomers' name	Supporting particle
O star	Photon
White dwarf	Electron
Pulsar	Neutron
Black hole	(unsupported)

Post-Feynman

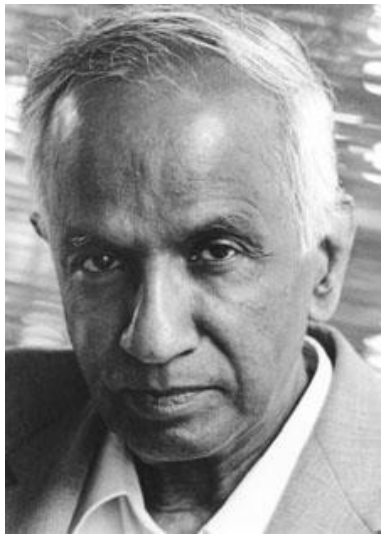
Astronomers' name	Supporting particle
Galaxy	Dark matter
Universe	Dark energy
Multiverse	Neuron

Upper mass limit for main sequence

- By equating radiation pressure to gravity, Eddington (1917) showed that the maximum mass of a dwarf star is $\sqrt{(1-\beta)}\beta^{-2}(hc/G)^{3/2}\ m_p^{-2}$
- β is the ratio of gas pressure to radiation pressure
- The dimensional part of this expression can be written m^3_{Planck}/m^2_p

Upper mass limit of white dwarfs

- By equating degeneracy pressure to gravity, Chandrasekhar showed that the maximum mass of a degenerate star is $(hc/G)^{3/2}\ m_p^{-2}$
- also m^3_{Planck}/m^2_p



QM vs Gravity

- Ratioing the two maximum masses for small β
- M(star)/M(WD) = β^{-2}
- $\beta = (lhc/kT)^3$
- l is mean separation of protons in the star
- T is their temperature
- G has disappeared from the ratio !

Size of a neutron star

- Pulsars were discovered by Jocelyn Bell and Antony Hewish
- The anthropomorphic explanation did not endure
- The size of a neutron star is 10 km if the density is that of the atomic nucleus

Size of a black hole

- In 1915, the same year that Einstein introduced general relativity, Karl Schwarzschild worked out its radius, the event horizon of a non-rotating black hole, $R = 2GM/c^2$
- Name coined by John Wheeler
- Minimum BH mass is the Planck mass, because $\Delta p \Delta R \sim h/2\pi$

Question: why does the Planck mass keep coming up?

Answer: Because stars are a competition between gravity and QM

Dark Matter

- Dark matter holds galaxies and clusters together
- Name due to Fritz Zwicky
- Cold dark matter predicts the large scale structure of the Universe
- Warm dark matter or baryonic physics counters the substructure problem
- Hot dark matter (an extra neutrino) can change the ratio of H(CMB) to H(z=0)

Dark Energy

- Dark energy is responsible for the expansion of the Universe
- Name coined by Mike Turner
- This is QM vs gravity on a larger scale

Multiverse

- An end run around the fine tuning of Λ to its very special value is to suppose that there are many universes with different values. The value leading to galaxy formation is selected
- Name coined by philosopher William James
- It took 40,000 years for *homo sapiens* to discard geocenticity
- It took 400 years for forget that

Monoverse

- Before Λ was measured, <u>one</u> Universe was the standard model and probably still should be !
- One large universe
- Many observers, each of whom see a small portion
- One physics with Λ(early universe) given by GUT
- Satisfies Occam's razor
- Λ (current epoch) may be different physics or nonstandard gravity

This table should be your standard model, not the multiverse version

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Astronomers' name	Supporting particle
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More physics needed

Astronomers' name	Supporting particle or field
Galaxy	Dark matter
Universe	Dark energy
Monoverse	Inflaton