

Chapter 11

Energy output of active galaxies

$$F(\nu) = F_0 \nu^{-\alpha}$$

F, F_0 = energy output, and energy constant

ν = frequency (hertz)

α = varies between 0 – 1.5 (or thereabouts)

Eddington Luminosity

Measure of the maximum luminosity of a massive object (black hole)

$$L_{\text{edd}} = 3 \times 10^4 (M_{\text{bh}}/M_{\odot}) L_{\odot}$$

L_{edd} = Eddington luminosity, in units of solar luminosities

M_{bh} = Mass of the black hole in solar masses

Chapter 12

Hubble's Law

Measure of the expansion of the Universe as seen in the increasing velocities of galaxies.

$$V = H_0 d$$

V = velocity of galaxy, km/s

H_0 = Hubble constant, current value, km/s/Mpc

d = distance, Mpc

Chapter 14

| | | | | |
|---------|--------------------------------|----------------------------|--------------------------------|-------------------|
| Quarks | u – up Charge = +2/3 | c - charm Mass > s | t - top Heaviest | γ - photon |
| | d – down Charge = -1/3 | s - strange Mass > u, d | b - bottom Mass > c | g – gluon |
| Leptons | ν_e - electron neutrino | ν_{μ} - mu neutrino | ν_{τ} - tau neutrino | Z - z boson |
| | e – electron Charge = -1 | μ - muon | τ - tau (tauon) | W - W boson |

Friedmann Equation

Defines the balance between gravity and expansion. Also defines the “curvature” of the Universe.

$$H^2 - \frac{8\pi\rho G}{3} = \frac{k}{R^2}$$

H = Hubble constant (in /seconds)

ρ = density of the Universe (kg/m^3)

R = scale of the Universe (m)

k = curvature of the Universe (m^2/sec^2)

$k=0$ Flat

$k>0$ Positive

$k<0$ Negative

Critical Density

Density needed to stop the expansion of the Universe

$$\rho_{critical} = \frac{3H^2}{8\pi G} = \frac{3H_o^2}{8\pi G}$$

$\rho_{critical}$ = critical density (kg/m^3)

H, H_o = Hubble constant (in /seconds)

Einstein's formulae

$$v^2 = \left(\frac{dR}{dt} \right)^2 = \frac{8\pi\rho GR^2}{3} - k + \frac{\Lambda R^2}{3}$$

$$\frac{d^2 R}{dt^2} = -\frac{4\pi\rho GR}{3} + \frac{\Lambda R}{3}$$

Meaning same as before for most variables

Λ = cosmological constant (in $1/\text{sec}^2$)

Cosmology terms

$$\Omega = \Omega_{\Lambda} + \Omega_M$$

Ω = related to curvature, defines open/closed universe

Ω_{Λ} = same as Λ

Ω_M = Matter density of the Universe

Values usually dimensionless.

Chapter 15 – Big Bang Stuff

Energy, Pressure, Temperature, energy density of the Universe

Describes energy balance of the universe as time goes on – temperature related to size of the Universe, etc.

$$E = k T$$

E = energy of the Universe

k = Boltzmann's constant

T = temperature of the Universe

$$\Delta E = p \Delta V$$

Second law of thermodynamics

ΔE = change in energy

P = pressure

ΔV = change in volume

$$p = \frac{1}{3} e$$

e = energy density

$$e_r = \frac{hf}{V} = \frac{hc}{V\lambda} \propto \frac{1}{length^4}$$

e_r = energy density

h = Planck's constant

c = speed of light

f = frequency of light

V = volume of space

λ = wavelength of light

Planck Era relations

Characteristics at the Planck time, t_p

$$t_p = \sqrt{\frac{hG}{2c^5}} \approx 10^{-43} \text{ s.}$$

$$m_p = \frac{h}{2\pi c^2 t_p} \approx 2.5 \times 10^{-5} \text{ gm}$$

$$l_p = ct_p = 1.7 \times 10^{-33} \text{ cm}$$

m_p = Planck mass

l_p = Planck length

Big Bang Time line

| Era | Time | Temperature | Events | Domination |
|-----------------|---------------|-----------------|---|------------|
| Big Bang | 0 | ? | Big Bang, quantum gravity rules | Radiation |
| Planck | 10^{-43} s. | 10^{32} | Gravity breaks from GUT | |
| GUT ends | 10^{-35} s | 10^{28} | GUT breaks down into strong and electroweak. Inflation starts. Quarks form. | |
| | 10^{-32} s | | Inflation ends | |
| Lepton | 10^{-12} s | 10^{15} | Electroweak breaks down to E-M & weak. Leptons form. | |
| Hadron | 10^{-10} s | 10^{12} | Protons/neutrons form | |
| | 10^{-5} s | 10^{10} | Neutrinos stop interacting | |
| Nucleosynthesis | 1-3 minutes | 10^9 - 10^8 | Helium, lithium, beryllium, other forms of Hydrogen form | |
| | 1 year | | Temperature of matter/radiation evolve independently | |
| Decoupling | 380,000 | 3000 | Radiation and matter disassociate - universe becomes transparent to radiation | |