THE COSMOLOGICAL CONSTANT

Data from Berkeley-Nagoya Rocket Flight, 1987

CMB Data in 1975

Original COBE Measurement of the CMB Spectrum, Jan 1990. Energy density is in units of electron volts per cubic meter per gigahertz.

\[ \frac{d^2a}{dt^2} = - \frac{4\pi}{3} G \left( \rho + \frac{3p}{c^2} \right) a. \]

Vacuum Energy and the Cosmological Constant:

\[ u_{\text{vac}} = \rho_{\text{vac}} c^2 = \frac{\Lambda c^4}{8\pi G}. \]

\[ \dot{\rho}_{\text{vac}} = 0 \implies p_{\text{vac}} = -\rho_{\text{vac}} c^2 = -\frac{\Lambda c^4}{8\pi G}. \]

Dominance of vacuum energy at late time implies

\[ H \to H_{\text{vac}} = \sqrt{\frac{8\pi}{3} G \rho_{\text{vac}}}, \]

\[ a(t) \propto e^{H_{\text{vac}}t}. \]

The age of an open (\( \Omega < 1 \)), closed (\( \Omega > 1 \)), or flat (\( \Omega = 1 \)) universe containing only nonrelativistic matter.
The age of a flat universe containing nonrelativistic matter and vacuum energy.