UNIVERSE simulation with COSMOGRAVITY
Instructions for use

Evolution of the scale factor of the universe a(t)

REMINDER. With general relativity and the cosmological principle the curve a(t) of the space scale factor is determined by the value of three of the four density parameters Ω_i (i = radiation, matter, cosmological constant, spatial curvature) and the present value of the space expansion rate H_0 (the *Hubble-Lemaître constant*) .

1. By opening **Universe > simulation > cosmological constant** tab, the simulation of the standard model (Planck 2015 collaboration values) is launched and displays its a(t).

2. You may simulate **different universes** by changing the present values (t= t_0) of the Ω_i density and expansion rate parameters. Note: The radiation density parameter Ω_{r0} it is calculated from the present temperature T_0 of the CMB which is in the inputs. **Then click on "Plot" to start the new simulation.**

3. By default the a(t) is calculated and displayed between a_{min} = 0 and a_{max} = 5. You may change these values ... and click on **Plot**.

4. You may also use the **interactive diagram** to modify Ω_{m0} and $\Omega_{\Lambda 0}$.

5. In all cases you can **save your entries and resulting graph** by clicking on **Save**.

6. The **Flat Universe option** force Ω_k = 0 (by automatically adjusting $\Omega_{\Lambda 0}$)

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<u>Appendix calculations</u>: the observer's toolbox in cosmology

Clicking on Calculations opens a new window: The entries in the main window are recalled and the densities $\rho_{\Lambda 0}$, ρ_{m0} and ρ_{r0} are computed.

1. By entering one (or two) z (and a photometric intensity) and pressing **calculate** you start the calculation of the parameters as well as those of the metric distances corresponding to z_1 (and z_2) (and the luminosities, luminosity distances, apparent diameter distances, flashes).
2. By then selecting z_1 or z_2 you can calculate the **apparent diameter** θ in seconds of arc corresponding to a **real diameter** D (in m or pc) or the inverse calculation by entering θ in seconds of arc.
3. Other inverse calculations are available: **z (d_m), z(t)**
4. Finally, a **graphics generator** for educational purposes:
    1. **Four distances** as a function of z: metric distance, luminosity distance, apparent diameter distance, time-light distance on the same graph between z_{min} and z_{max}.
    2. **The four density parameters Ω_i** as a function of z between z_{min} and z_{max}
    3. **Cosmic time** as a function of z between z_{min} and z_{max}

<u>Constants</u> : a click on **Constants** in the main window opens a new window
Here you can change the default values of the **fundamental constants** of physics: c, k, h, G ... and choose the definition of the time unit year.