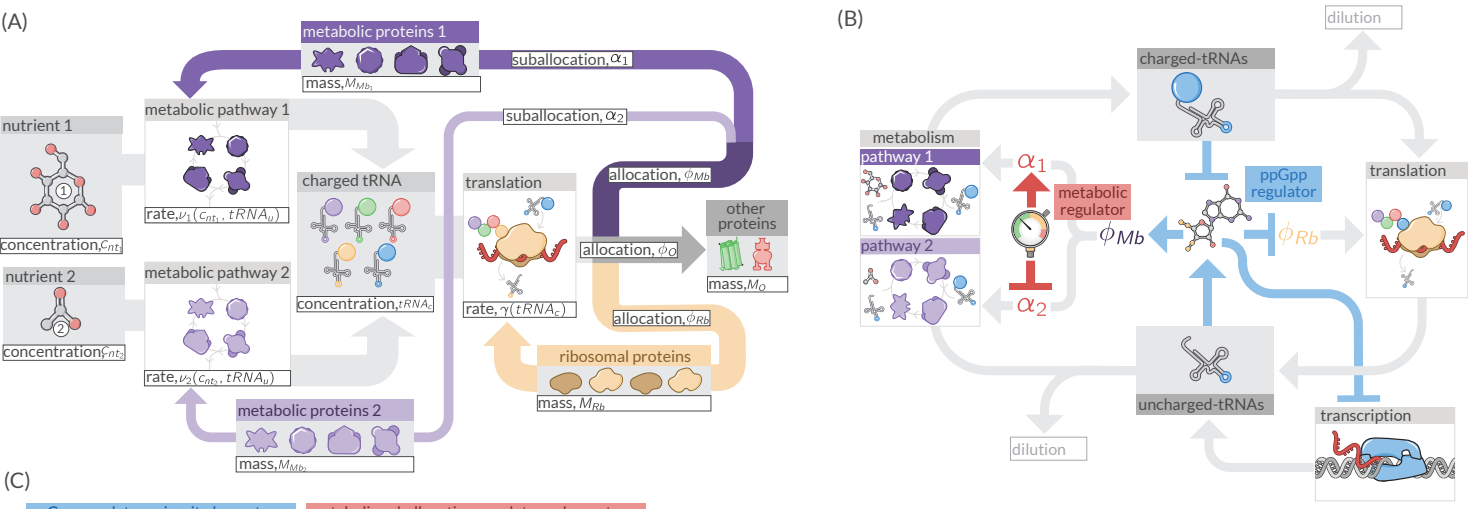

(C)

ppGpp regulatory circuit elements | metabolic suballocation regulatory elements

tRNA dynamics

$$\frac{dtRNA_u}{dt} = \underbrace{\kappa\left(\frac{tRNA_c}{tRNA_u}\right)}_{\text{transcription}} - \underbrace{\left(\frac{\nu_1(c_{nt_1}, tRNA_u)M_{Mb_1}}{M} + \frac{\nu_2(c_{nt_2}, tRNA_u)M_{Mb_2}}{M}\right)}_{\text{combined metabolism}} + \underbrace{\frac{\gamma(tRNA_c)M_{Rb}}{M}(1 - tRNA_u)}_{\text{translation and dilution}}$$

$$\frac{dtRNA_c}{dt} = \underbrace{\left(\frac{\nu_1(c_{nt_1}, tRNA_u)M_{Mb_1}}{M} + \frac{\nu_2(c_{nt_2}, tRNA_u)M_{Mb_2}}{M}\right)}_{\text{combined metabolism}} - \underbrace{\frac{\gamma(tRNA_c)M_{Rb}}{M}(1 + tRNA_c)}_{\text{translation and dilution}}$$

biomass dynamics

$$\frac{dM_{Rb}}{dt} = \phi_{Rb}\left(\frac{tRNA_c}{tRNA_u}\right)\gamma(tRNA_c)M_{Rb}$$

$$\frac{dM_{Mb_1}}{dt} = \alpha_1\left[1 - \phi_O - \phi_{Rb}\left(\frac{tRNA_c}{tRNA_u}\right)\right]\gamma(tRNA_c)M_{Rb}$$

$$\frac{dM_{Mb_2}}{dt} = \alpha_2\left[1 - \phi_O - \phi_{Rb}\left(\frac{tRNA_c}{tRNA_u}\right)\right]\gamma(tRNA_c)M_{Rb}$$

$$\frac{dM_O}{dt} = \phi_O\gamma(tRNA_c)M_{Rb}$$

nutrient dynamics

$$\frac{dc_{nt_i}}{dt} = -\frac{\nu_i(c_{nt_i}, tRNA_u)M_{Mb_i}}{Y_i}$$

allocation and suballocation constraints

$$\phi_{Mb} = 1 - \phi_O - \phi_{Rb}\left(\frac{tRNA_c}{tRNA_u}\right); \alpha_2 = 1 - \alpha_1$$

flux-parity regulatory functions

$$\phi_{Rb}\left(\frac{tRNA_c}{tRNA_u}\right) = (1 - \phi_O)\frac{tRNA_c/tRNA_u}{1 + tRNA_c/tRNA_u}$$

$$\kappa\left(\frac{tRNA_c}{tRNA_u}\right) = \kappa_{max}\frac{tRNA_c/tRNA_u}{1 + tRNA_c/tRNA_u}$$

biochemical rate regulatory functions

$$\nu_i = \nu_{max_i}\left(\frac{tRNA_u}{tRNA_u + K_D}\right)\left(\frac{c_{nt,i}}{c_{nt_i} + K_{M_i}}\right)$$

$$\gamma(tRNA_c) = \gamma_{max}\left(\frac{tRNA_c}{tRNA_c + K_D}\right)$$