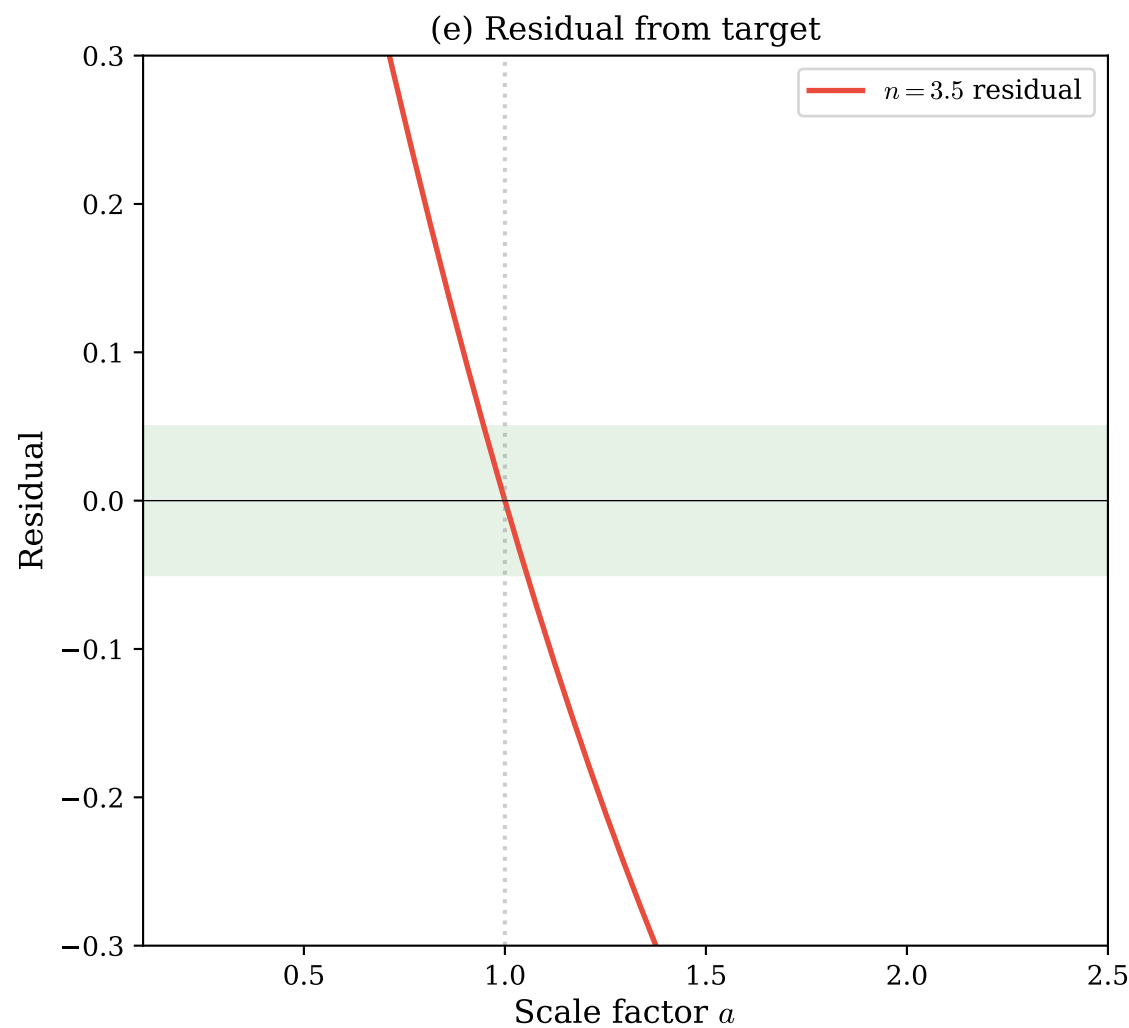
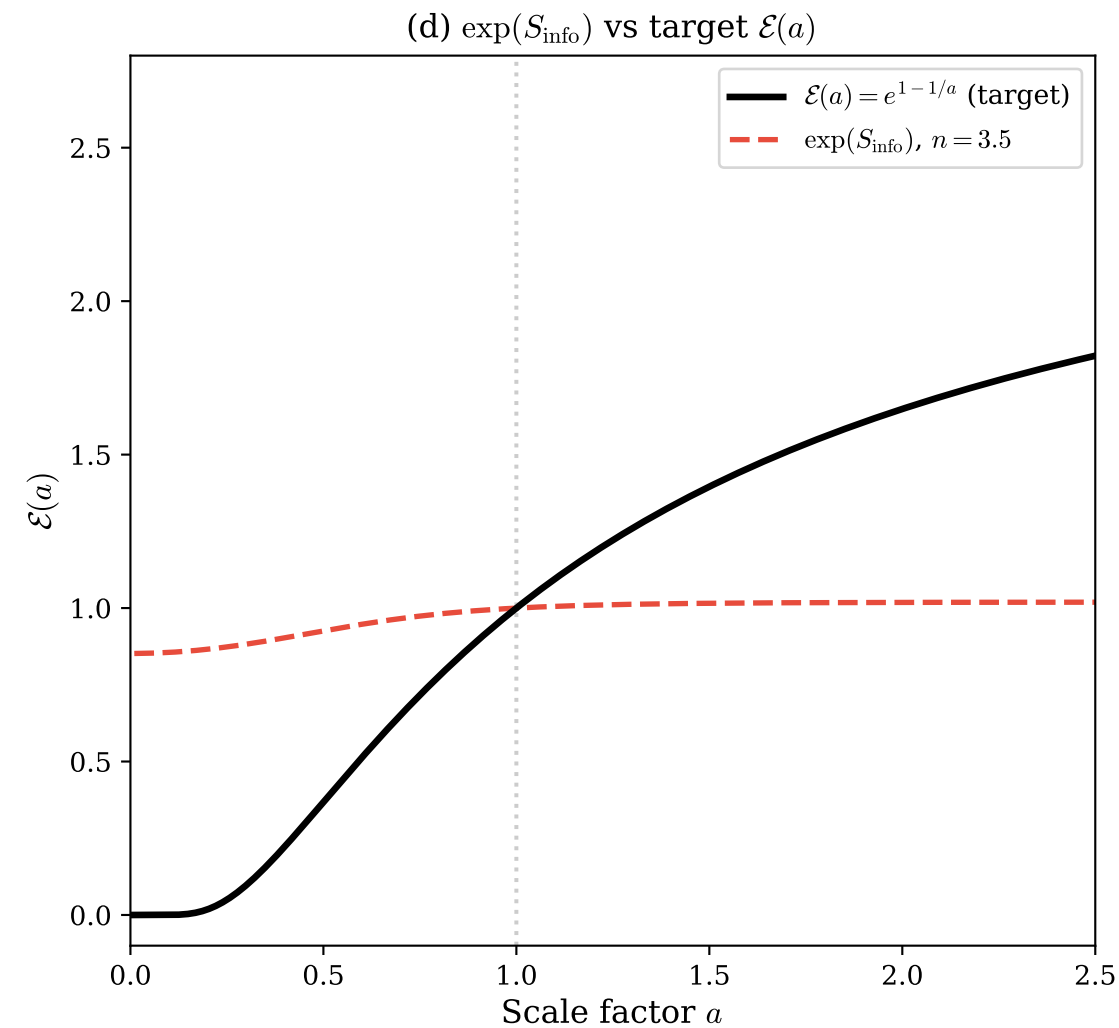
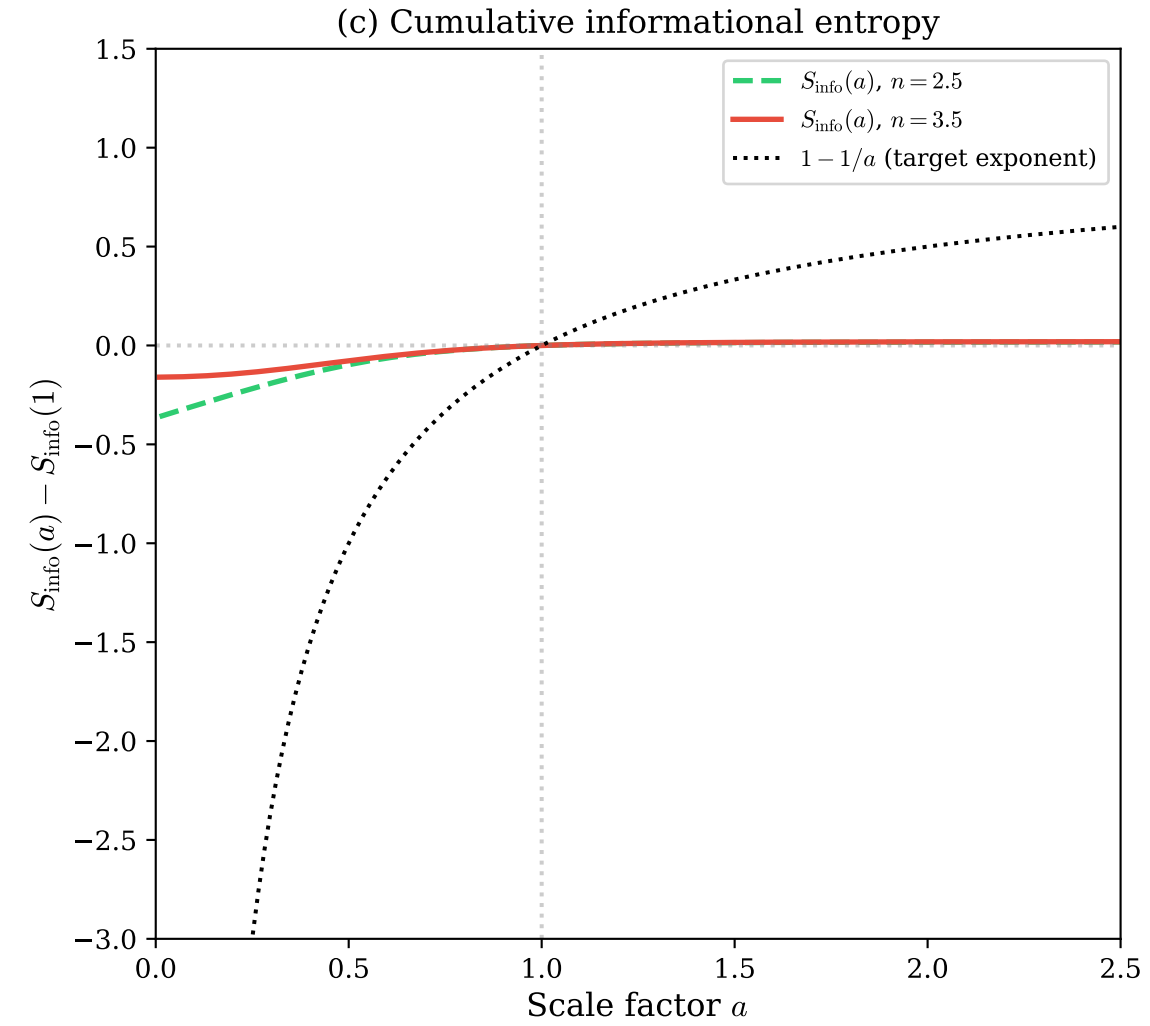
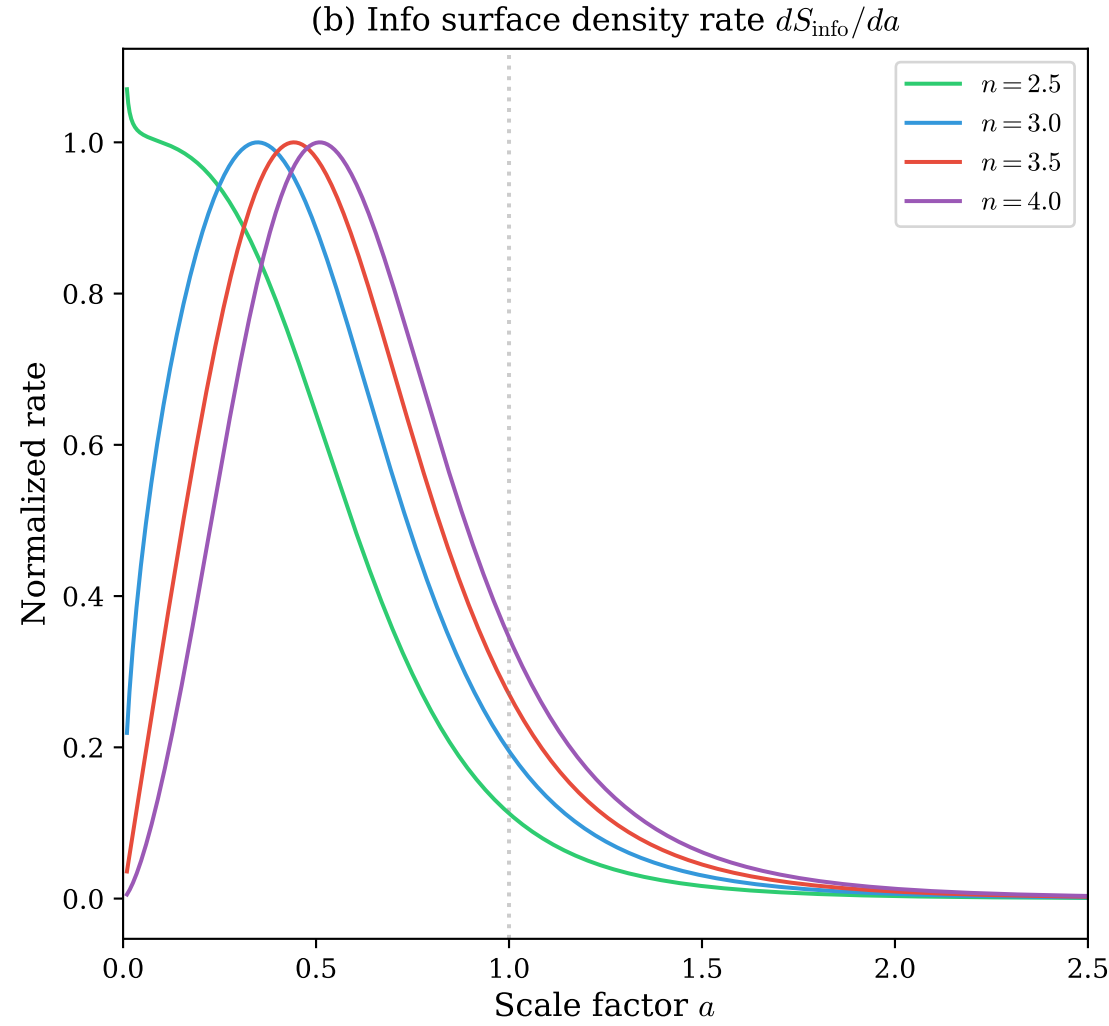
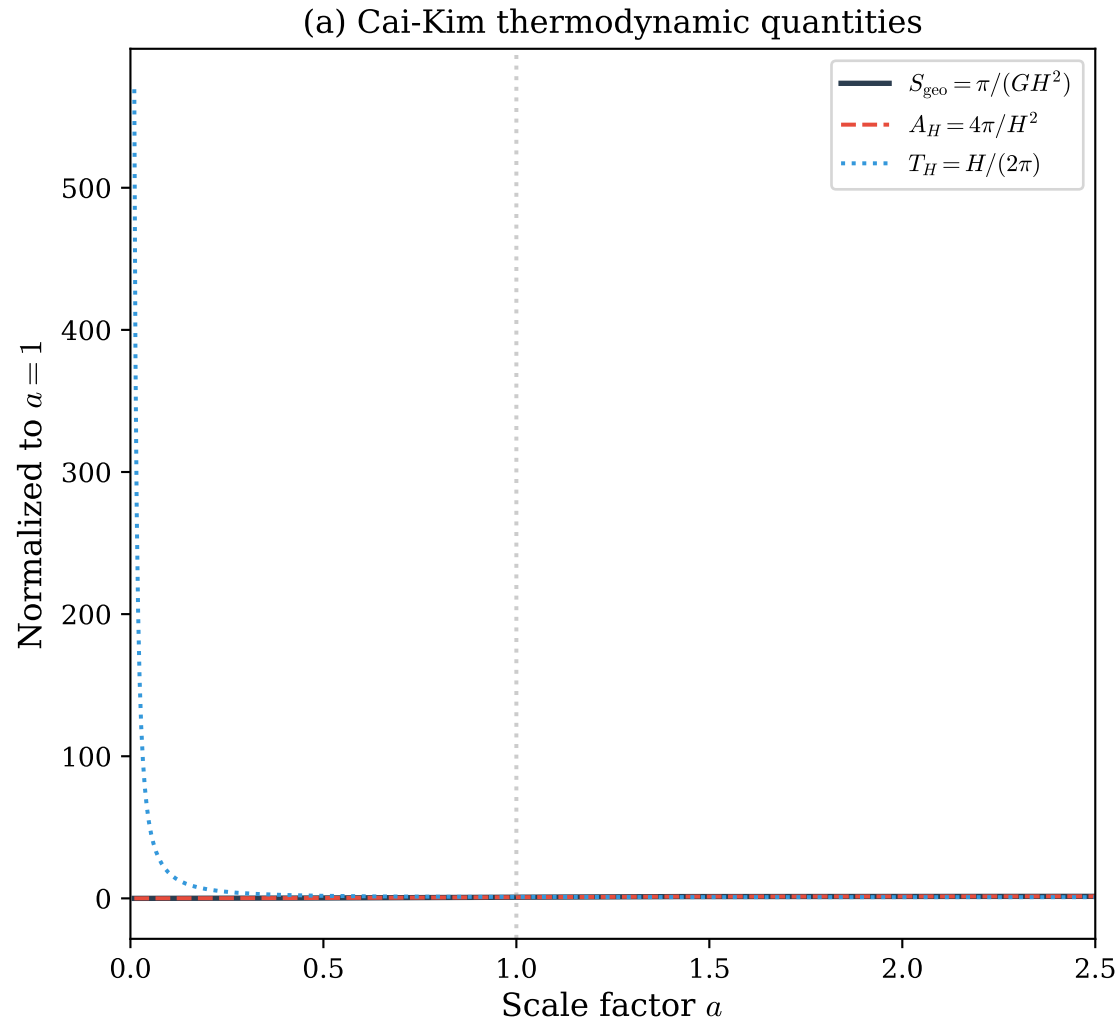


Phase 3: From Cai-Kim First Law to $\mathcal{E}(a) = e^{1-1/a}$



THE COMPLETE DERIVATION CHAIN

- JACOBSON (1995)**
 $\delta Q = T dS$ on local Rindler horizons
 $S = \eta \cdot A$
 \Rightarrow Einstein equation $G_{ab} = 8\pi G T_{ab}$
- CAI-KIM (2005)**
 $-dE = T dS$ on FRW apparent horizon
 $S_{\text{geo}} = A_H/(4G), T = H/(2\pi)$
 \Rightarrow Friedmann: $H^2 = (8\pi G/3)\rho$
- IAM (2026)**
 $-dE = T d(S_{\text{geo}} + S_{\text{info}})$
 $S_{\text{info}} = \int \dot{I}_{\text{struct}} / (T_H \cdot A_H) da$
Surface density $\propto 1/a^2 \Rightarrow S_{\text{info}} \propto -1/a + C$
 $\Rightarrow \mathcal{E}(a) = \exp(S_{\text{info}}) = e^{1-1/a}$
 $\Rightarrow H^2 = (8\pi G/3)\rho + \Lambda/3 + \beta \mathcal{E}(a)$