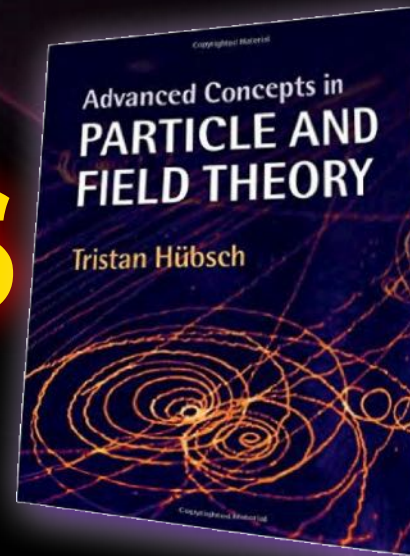


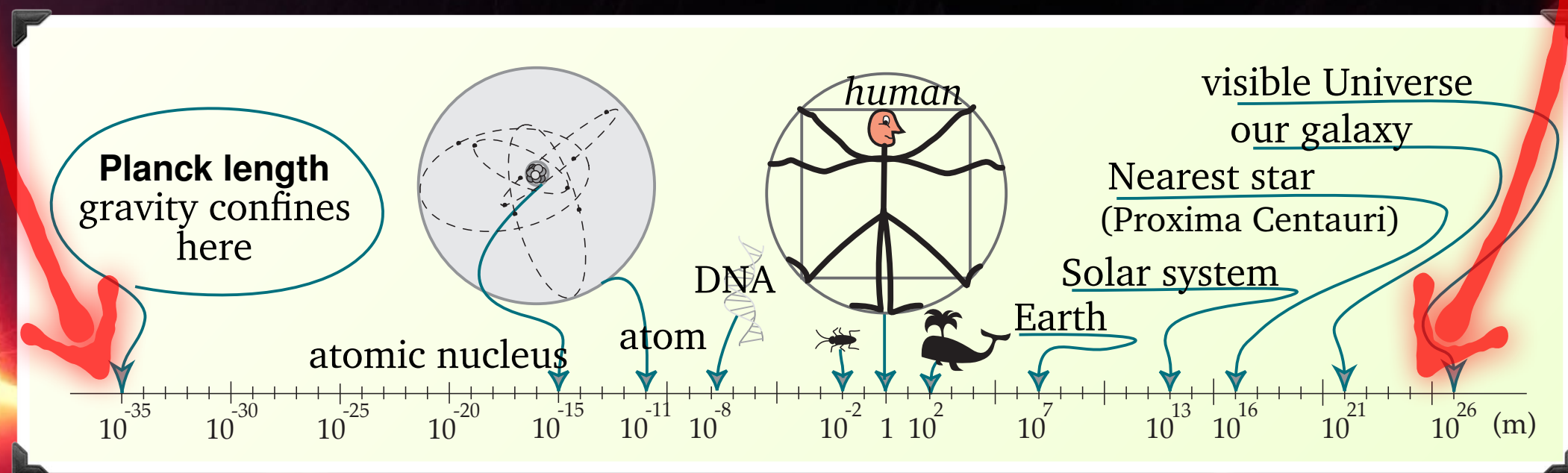
Quantum Strings & Cosmology



Tristan Hübsch

*Department of Physics and Astronomy
Howard University, Washington DC*

<https://tristan.nfshost.com/>



Strings & Cosmology

74: Standard Model w/lots of details

Fundamental forces

Fermion masses

'80: *ν -mixing*

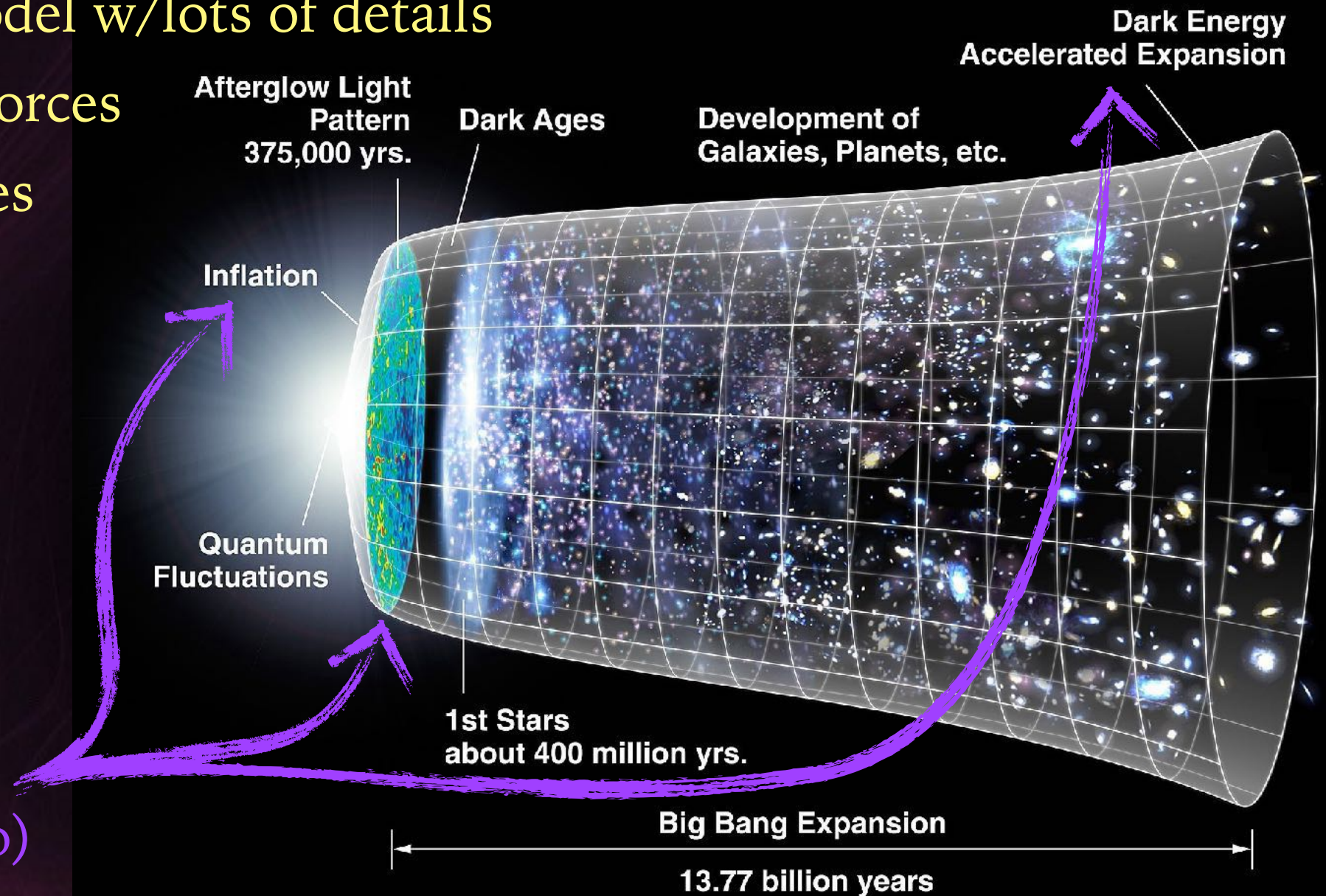
22 Years Ago...
(Λ -CDM)

Shadows of
the Invisible
(dark energy &
dark matter too)

Standard Model of Elementary Particles

three generations of matter (fermions)						SCALAR BOSONS	
I		II		III			
mass charge	$\approx 2.2 \text{ MeV}/c^2$ $2/3$	$\approx 1.28 \text{ GeV}/c^2$ $2/3$	$\approx 173.1 \text{ GeV}/c^2$ $2/3$	0 1	0 1	$\approx 125.09 \text{ GeV}/c^2$ 0	
	u up	c charm	t top	g gluon		H Higgs	
	$\approx 4.7 \text{ MeV}/c^2$ $-1/3$	$\approx 96 \text{ MeV}/c^2$ $-1/3$	$\approx 4.18 \text{ GeV}/c^2$ $-1/3$	0 1	0 1		
	d down	s strange	b bottom	γ photon			
	$\approx 0.511 \text{ MeV}/c^2$ -1	$\approx 105.66 \text{ MeV}/c^2$ -1	$\approx 1.7768 \text{ GeV}/c^2$ -1	0 1	0 1	$\approx 91.19 \text{ GeV}/c^2$ 1	
	e electron	μ muon	τ tau	Z Z boson			
	$< 2.2 \text{ eV}/c^2$ $1/2$	$< 1.7 \text{ MeV}/c^2$ $1/2$	$< 1.77 \text{ MeV}/c^2$ $1/2$	0 1	0 1	$\approx 80.39 \text{ GeV}/c^2$ 1	
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson			

LEPTONS



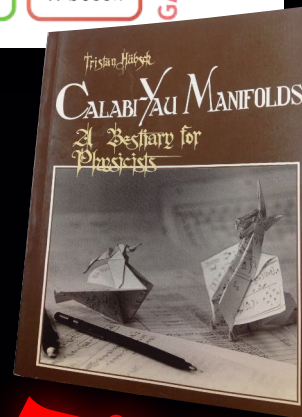
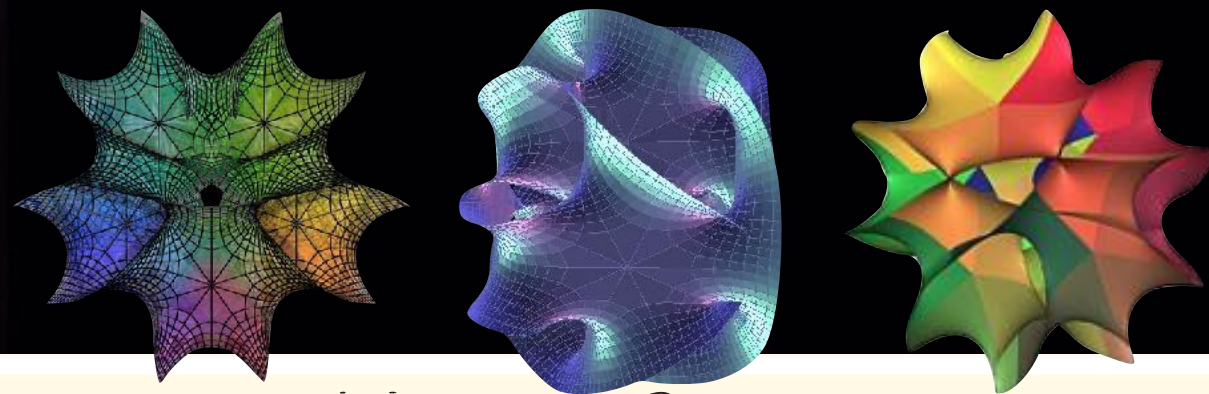
Quantum Strings

- Superstrings propagate consistently
 - in $(9+1)D$ spacetime, e.g., with $E_8 \times E_8$ gauge group
 - Can be compactified

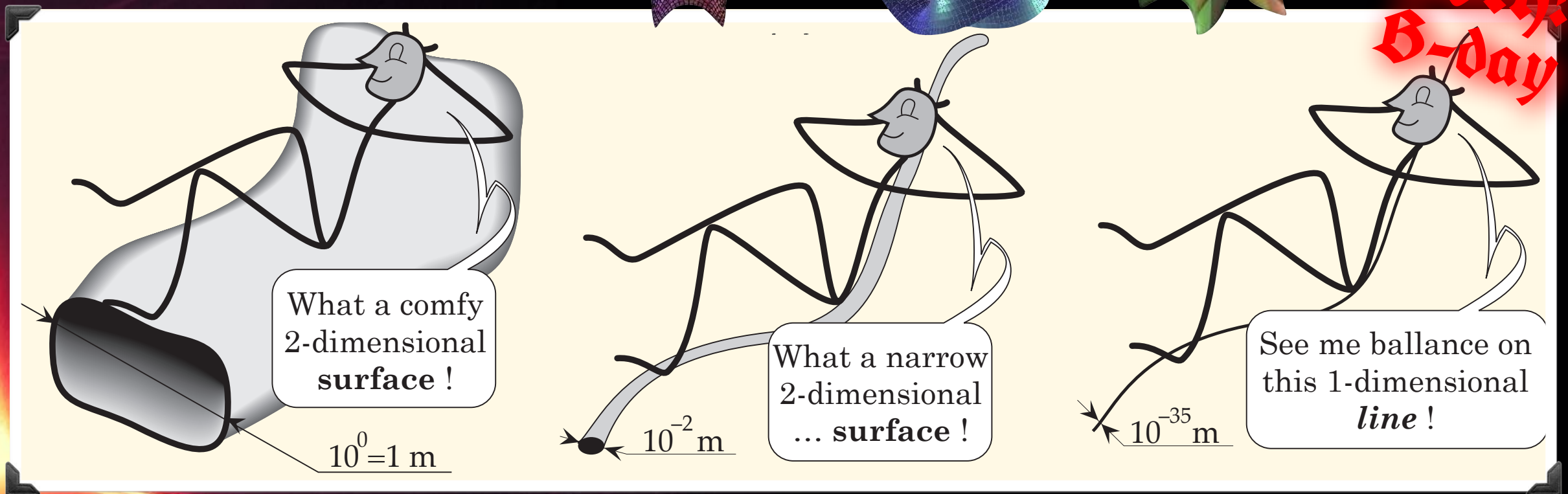
Standard Model of Elementary Particles

three generations of matter (fermions)							
I		II		III			
mass charge	$\approx 2.2 \text{ MeV}/c^2$ $2/3$	$\approx 1.28 \text{ GeV}/c^2$ $2/3$	$\approx 173.1 \text{ GeV}/c^2$ $2/3$	0 1	0 1	$\approx 125.09 \text{ GeV}/c^2$ 0	
	u up	c charm	t top	g gluon		H Higgs	
	$\approx 4.7 \text{ MeV}/c^2$ $-1/3$	$\approx 96 \text{ MeV}/c^2$ $-1/3$	$\approx 4.18 \text{ GeV}/c^2$ $-1/3$	0 1	0 1		
	d down	s strange	b bottom	γ photon			
	$\approx 0.511 \text{ MeV}/c^2$ -1	$\approx 105.66 \text{ MeV}/c^2$ -1	$\approx 1.7768 \text{ GeV}/c^2$ -1	0 1	0 1	$\approx 91.19 \text{ GeV}/c^2$ 1	
	e electron	μ muon	τ tau	Z Z boson			
	$< 2.2 \text{ eV}/c^2$ 0	$< 1.7 \text{ MeV}/c^2$ 0	$< 15.5 \text{ MeV}/c^2$ 0	$\approx 80.39 \text{ GeV}/c^2$ 1			
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson			

QUARKS (left column), LEPTONS (right column), GAUGE BOSONS (bottom row), SCALAR BOSONS (Higgs)



30th!
B-day

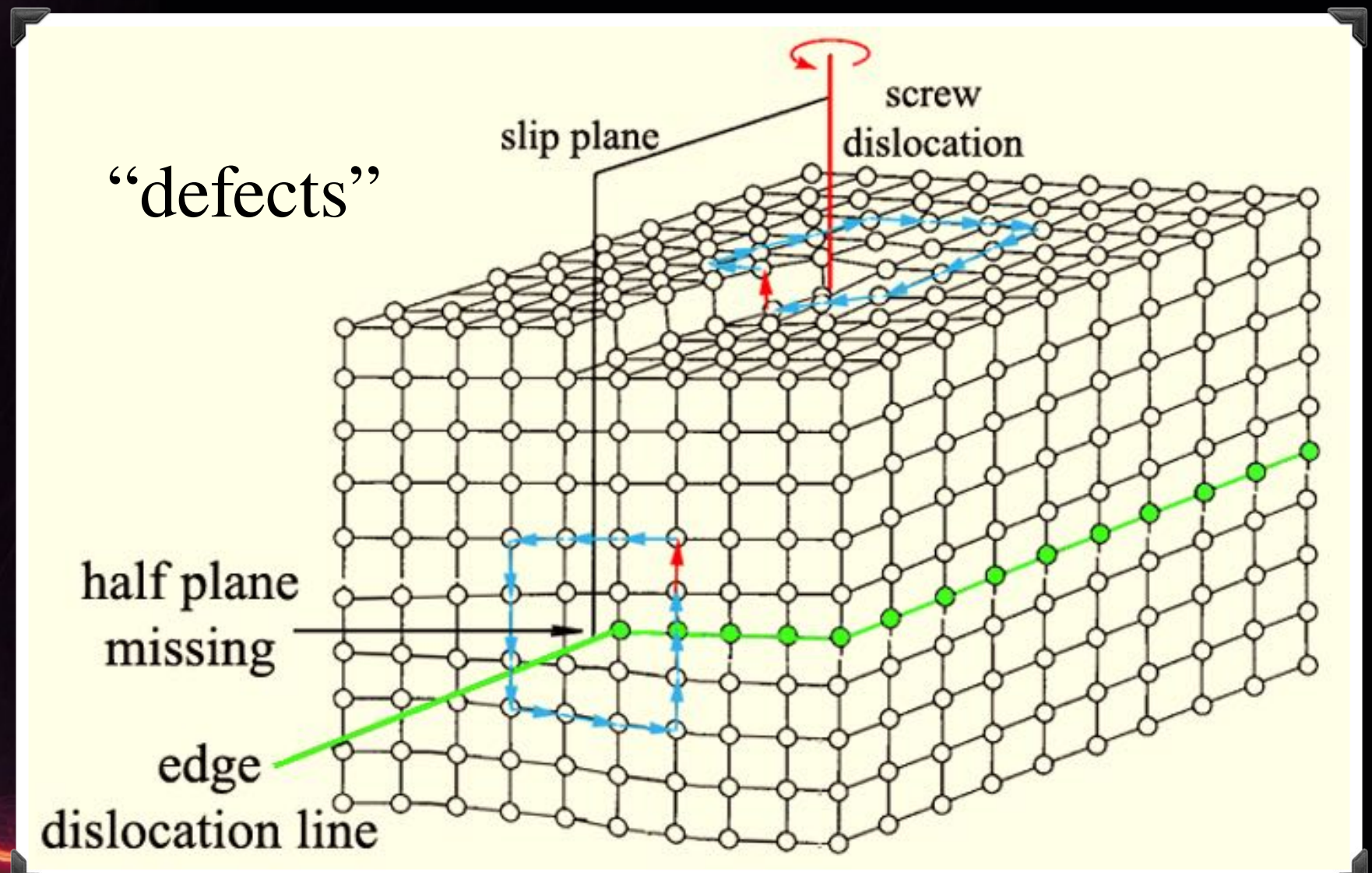


Quantum Strings

- Superstrings propagate consistently
 - in (9+1)D spacetime, e.g., with $E_8 \times E_8$ gauge group
 - Can be compactified
 - Can be creased

Standard Model of Elementary Particles

three generations of matter (fermions)						SCALAR BOSONS	
I			II			III	
mass charge	$\approx 2.2 \text{ MeV}/c^2$ 2/3	$\approx 1.28 \text{ GeV}/c^2$ 2/3	$\approx 173.1 \text{ GeV}/c^2$ 2/3	0 1	0 1	$\approx 125.09 \text{ GeV}/c^2$ 0	
	u up	c charm	t top	g gluon	H Higgs		
	$\approx 4.7 \text{ MeV}/c^2$ -1/3	$\approx 96 \text{ MeV}/c^2$ -1/3	$\approx 4.18 \text{ GeV}/c^2$ -1/3	0 1	0 1		
	d down	s strange	b bottom	γ photon			
	$\approx 0.511 \text{ MeV}/c^2$ -1	$\approx 105.66 \text{ MeV}/c^2$ -1	$\approx 1.7768 \text{ GeV}/c^2$ -1	0 1	0 1		
	e electron	μ muon	τ tau	Z Z boson			
	$< 2.2 \text{ eV}/c^2$ 0	$< 1.7 \text{ MeV}/c^2$ 0	$< 15.5 \text{ MeV}/c^2$ 0	0 1	0 1		
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson			



Quantum Strings

Standard Model of Elementary Particles

three generations of matter (fermions)					
I		II		III	
mass charge	$\approx 2.2 \text{ MeV}/c^2$ $2/3$	$\approx 1.28 \text{ GeV}/c^2$ $2/3$	$\approx 173.1 \text{ GeV}/c^2$ $2/3$	0 1	$\approx 125.09 \text{ GeV}/c^2$ 0
	u up	c charm	t top	g gluon	H Higgs
QUARKS	$\approx 4.7 \text{ MeV}/c^2$ $-1/3$ $1/2$	$\approx 96 \text{ MeV}/c^2$ $-1/3$ $1/2$	$\approx 4.18 \text{ GeV}/c^2$ $-1/3$ $1/2$	0 1	0 1
	d down	s strange	b bottom	γ photon	
	$\approx 0.511 \text{ MeV}/c^2$ -1 $1/2$	$\approx 105.66 \text{ MeV}/c^2$ -1 $1/2$	$\approx 1.7768 \text{ GeV}/c^2$ -1 $1/2$	$\approx 91.19 \text{ GeV}/c^2$ 0 1	
	e electron	μ muon	τ tau	Z Z boson	
LEPTONS	$< 2.2 \text{ eV}/c^2$ 0 $1/2$	$< 1.7 \text{ MeV}/c^2$ 0 $1/2$	$< 15.5 \text{ MeV}/c^2$ 0 $1/2$	$\approx 80.39 \text{ GeV}/c^2$ +1 1	
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	
					SCALAR BOSONS
					GAUGE BOSONS

- Superstrings propagate consistently

- in $(9+1)$ D spacetime, e.g., with $E_8 \times E_8$ gauge group

- Can be compactified

- Can be creased

} : “hide” the extra dimensions

- $E_8 \times E_8 \rightarrow SU_c(3) \times SU_{w,L}(2) \times U_y(1)$

- ...3 generations of chiral fermions, Higgs, etc.

- fermion masses spanning $\sim (10^0 \dots 10^{-11}) \langle H \rangle$

- $\begin{bmatrix} 0 & m \\ m & M \end{bmatrix} \rightarrow \approx \left\{ \frac{m^2}{M}, M \right\}; \begin{cases} m^2/M \sim 1.1 \text{ eV} \\ \Rightarrow M \geq 10^{+11} \langle H \rangle \end{cases}$

seesaw

~ ? 🤔

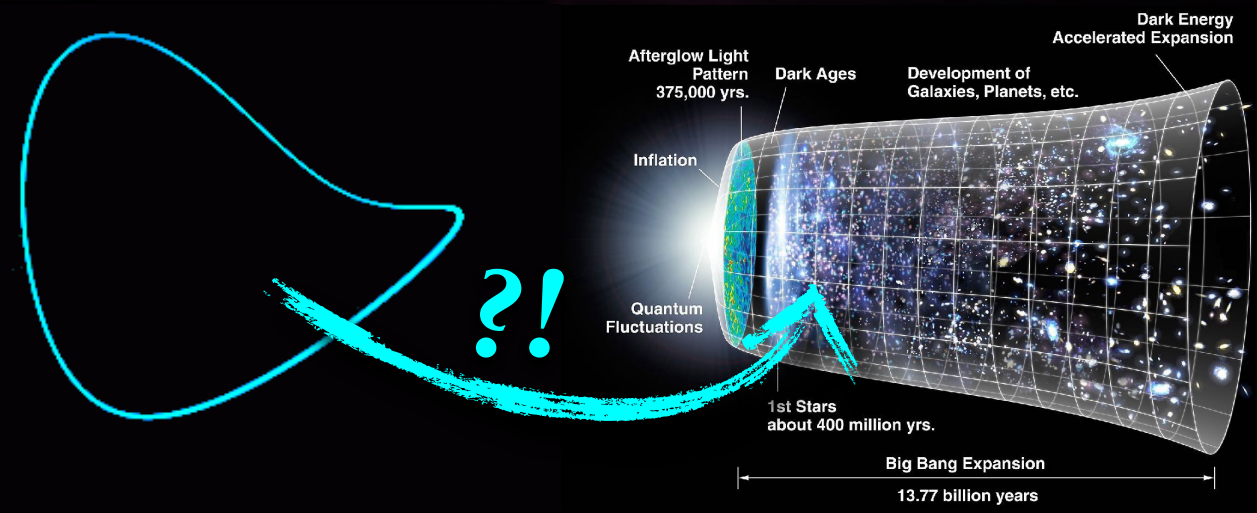
- Supersymmetry must be “broken”



somehow...

Topping the Already Tall Order

Λ -CDM
Cold Dark Matter



• Candidates in GUT and Superstring models → WiP 🙌

• 1917, A. Einstein; + 81 years: → $\Lambda \approx 1.1 \times 10^{-52} \text{ m}^{-2} > 0$

• Einstein:
$$R_{\mu\nu} = \frac{8\pi G_N}{c^4} \left[T_{\mu\nu}(\tau) - \frac{1}{D-2} g_{\mu\nu} (g^{\rho\sigma} T_{\rho\sigma}(\tau)) \right] \leftarrow g_{\mu\nu}(x; z, \theta)$$

• Peculiar, “creased” + “compactified” models

• Toy-model: axion+dilaton: $\tau = \mathbf{a} + i g_s^{-1} e^{-\Phi}$ big $\mathcal{M}^{3,1} \times Y_{\perp}^2$ $\times Y^4$ small

•
$$g^{\mu\nu} \left((\nabla_{\mu} \nabla_{\nu} \tau) + \Gamma_{\tau\tau}^{\tau} (\nabla_{\mu} \tau) (\nabla_{\nu} \tau) \right) = 0$$
 separation of variables $\leftarrow \tau(x; z, \theta)$

•
$$ds^2 = h_{\parallel}(z)^2 g_{ij}^{(dS;\Lambda)}(x) dx^i dx^j + \Lambda^{-1} h_{\perp}(z)^2 (dz^2 + d\theta^2) + (d^2 y)_{Y^4}$$

• Exponential mass-hierarchy: $M_P = M_*^2 \cdot \ell \cdot e^{+z_0/2} \cdot f(z_0)$ breaks supersymmetry

• Cosmological constant: $\Lambda = \Delta \omega^2 / 8 \ell^2 > 0$ $\rightsquigarrow M_{\Lambda} = (M_{\text{susy}}^2 / M_P)$ — seesaw!
so $M_{\text{susy}} \sim 1\text{--}10 \text{ TeV}$

Thank You!

Tristan Hübsch

Department of Physics and Astronomy

Howard University, Washington DC

<https://tristan.nfshost.com/>