

# UHECR: TOP-DOWN SCENARIOS

**main motivation:** events with  $E > 1 \times 10^{20}$  eV.

# OVERVIEW

## • NEW SIGNAL CARRIERS

- STRONGLY INTERACTING NEUTRINOS ( $\nu_{SI}$ )  
(EXTRA DIMENSIONS, INSTANTON EFFECT)
- LIGHT STABLE HADRONS (eg. GLUINO)

MOTIVATION:

NO GZK CUTOFF, SMALL-ANGLE CLUSTERING,  
CORRELATION WITH BLLACS

DRAWBACKS:

EXP STATUS AND FLUXES - FOR LIGHT GLUINOS

THEORETICAL STATUS - FOR  $\nu_{SI}$

## • Z-BURSTS

(RESONANT Z-PRODUCTION:  $\nu + \bar{\nu}_{DM} \rightarrow Z^0 \rightarrow \text{hadrons}$ )

ELEM.-PARTICLE PHYSICS IS STANDARD (SM)

$$E_{\nu}^{\text{res}} = \frac{m_Z^2}{2m_{\nu}} \geq 1.8 \cdot 10^{22} \left( \frac{0.23}{m_{\nu}} \right) \text{ eV AND } E_p > 1.8 \cdot 10^{23} \text{ eV}$$

(needed for  $\nu$ -production)

- PROBLEM WITH SOURCES AND FLUXES:

$$\text{E-M CASCADE LIMIT } I_{\nu}(E) < \frac{c}{4\pi} \frac{w_{\text{cas}}}{E^2} \text{ EXCLUDES}$$

ASTROPHYSICAL SOURCES, TD and SHDH

## • TOPOLOGICAL DEFECTS

RELIABLE OBJECTS NATURALLY PRODUCED BY  
SYMMETRY BREAKING IN EARLY UNIVERSE.

RELIABLE PRODUCTION OF HE PARTICLES

MANY CANDIDATES: MONOPOLONIUM, MONOPOLES

CONNECTED BY STRINGS, ORDINARY STRINGS,

SUPERCONDUCTING STRINGS, CUSPS, VORTONS, NECKLACES

MOST OF THEM ARE EXCLUDED OR DISFAVOURED

## • SUPERHEAVY DM

QUASISTABLE PARTICLES WITH  $M_x > 1 \cdot 10^{13} \text{ GeV}$   
PRODUCED AT INFLATION AND ACCUMULATED  
IN GALACTIC HALO.  
NO GZK CUTOFF

## • LORENTZ-INVARIANCE VIOLATION

ENERGY OF CMB PHOTON IN CM-SYSTEM IS  $\Gamma E_{\text{CMB}}$   
VIOLATION OF LORENTZ-INVARIANCE CAN RESULT  
IN SMALLER  $E_{\text{CM}}$  AND GZK CUTOFF IS SHIFTED.

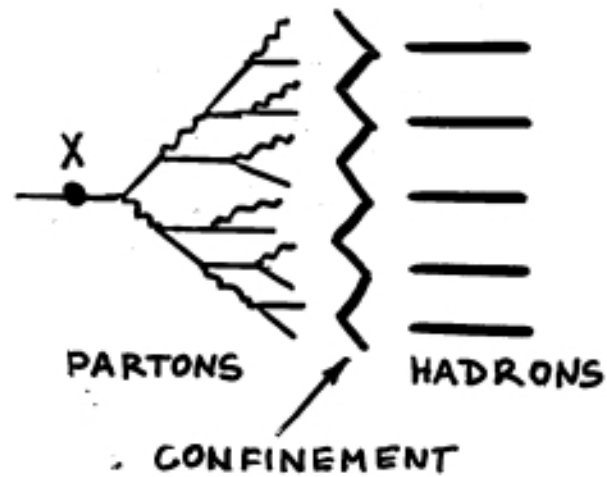
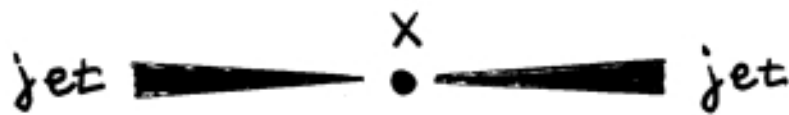
• MOST RADICAL POSSIBILITY

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# UHECR ENERGY SPECTRUM FROM X-DECAYS

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# X DECAY: ENERGY SPECTRUM



SPECTRUM IS DOMINATED BY  $\nu$ 'S AND  $\gamma$ 'S  
RATIO  $\gamma/N \sim 2-3$

# CALCULATION OF SPECTRUM

## MC SIMULATION

TWO STEPS:

- PERTURBATIVE REGIME



$$x = \frac{2E}{M_X}, \quad Q_0 \sim 1 \text{ GeV (min virtuality)}$$

- HADRONIZATION

$$D_i^h(x, M_X) = \sum_{j=q, g} \int_x^1 \frac{dz}{z} D_i^j\left(\frac{x}{z}, M_X, Q_0\right) f_j^h(z, Q_0)$$

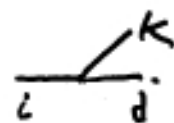
$f_j^h(x, Q_0)$  IS FOUND FROM  $D_q^h(x, M_Z)$

## DGLAP EVOLUTION

$$\partial_t D_i^h = \sum_j \frac{d_g(t)}{2\pi} P_{ij} \otimes D_j^h\left(\frac{x}{z}, t\right)$$

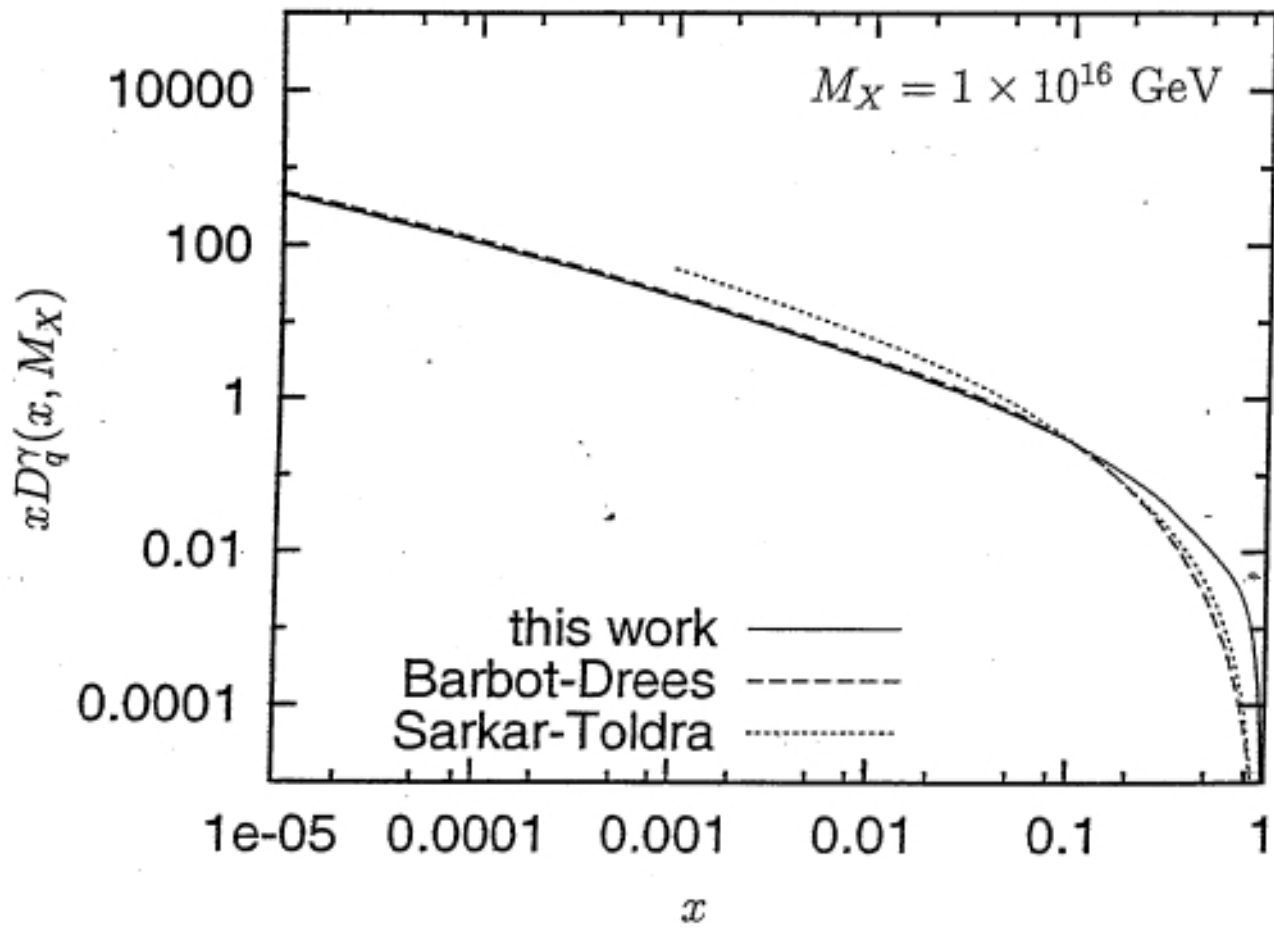
$$t = \ln s/s_0$$

$P_{ij}$  IS SPLITTING FUNCTION

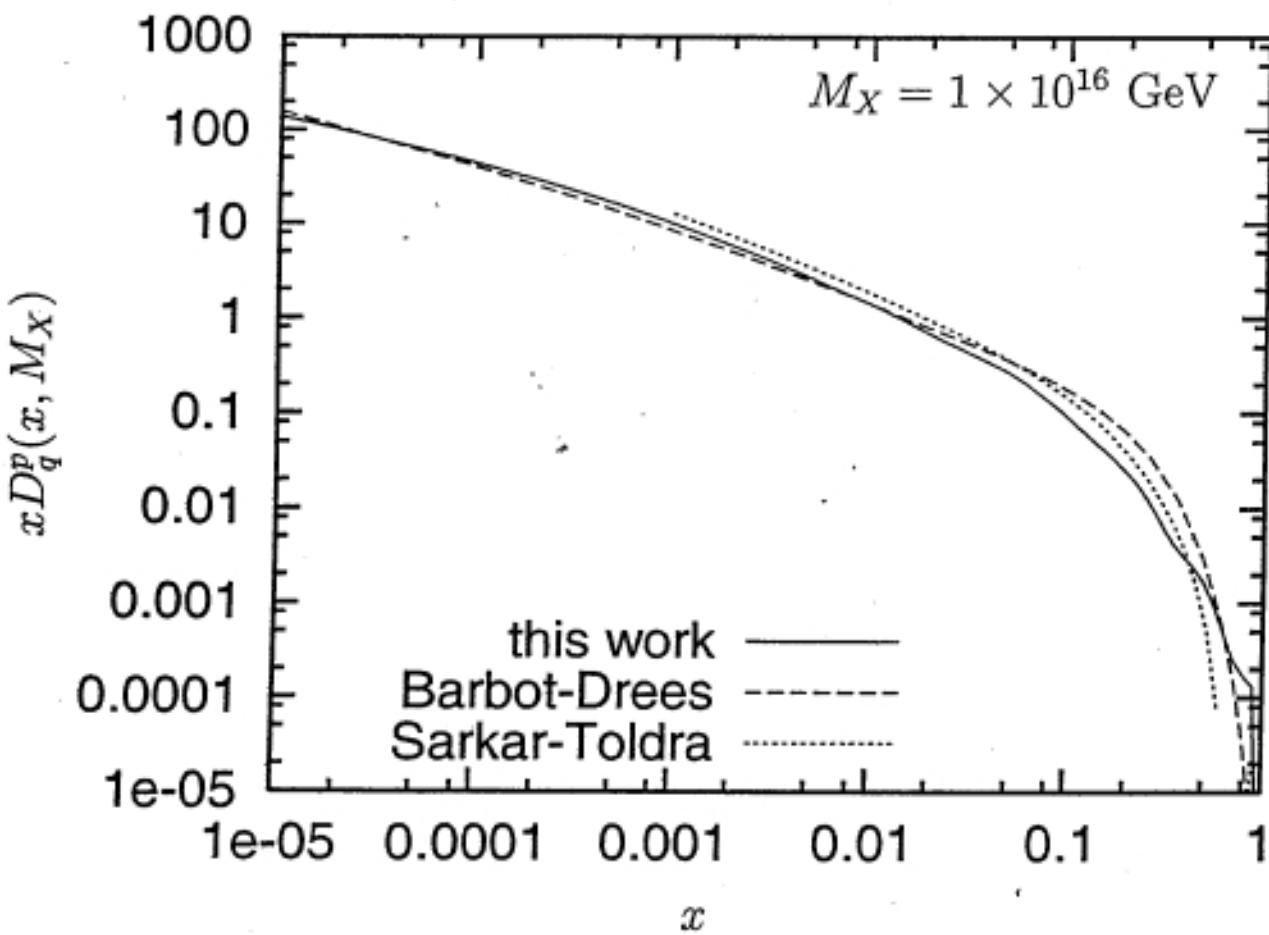


$$f \otimes g \equiv \int_z^1 \frac{dx}{x} f(x) g\left(\frac{x}{z}, t\right)$$

# SPECTRA OF PHOTONS AT THE DECAY OF SH PARTICLE



# SPECTRA OF PROTONS AT THE DECAY OF SH PARTICLE



# Z-BURSTS

Fargion et al 1991  
Weiler 1995

$$\nu + \bar{\nu}_{DM} \rightarrow Z^0 \rightarrow \text{hadrons}$$

$$E_0 = \frac{m_Z^2}{2m_\nu} = 1.8 \cdot 10^{22} \left( \frac{0.23 \text{ eV}}{m_\nu} \right) \text{ eV}$$

$$\sigma_{\nu f} = \frac{12\pi}{m_Z^2} \frac{\Gamma_\nu \Gamma_f}{(E_c - m_Z)^2 + \Gamma_Z^2/4}$$

$$\delta_Z = \frac{E_0}{m_Z} = \frac{m_Z}{2m_\nu} = 2.0 \cdot 10^{11} \left( \frac{0.23 \text{ eV}}{m_\nu} \right)$$

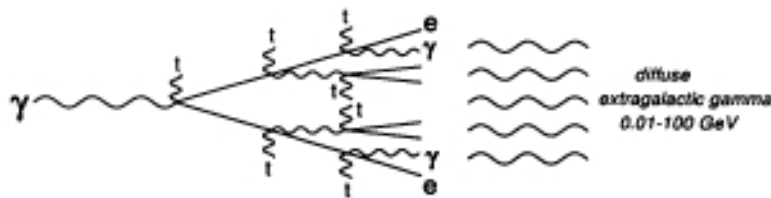
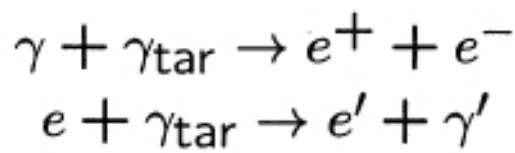
$$\dot{n}_{Z^0} = 4\pi n_{\bar{\nu}_i} \int I_{\nu_i}(E) \sigma(E) dE = 4\pi \sigma_Z n_{\bar{\nu}_i} I_{\nu_i}(E_0) E_0$$

$$\sigma_Z = 48\pi f_\nu G_F^2 = 1.29 \cdot 10^{-32} \text{ cm}^2$$

$$f_\nu = \frac{\Gamma_\nu}{G_F m_Z^3} = 0.019$$

# CASCADE UPPER LIMIT

e-m cascade on target photons



**EGRET:**  $\omega_{\gamma}^{\text{obs}} \sim (2 - 3) \times 10^{-6} \text{eV/cm}^3$

UPPER LIMIT ON THE NEUTRINO FLUX

$$\omega_{\text{cas}} > \frac{4\pi}{c} \int_E^{\infty} E J_{\nu}(E) dE > \frac{4\pi}{c} E \int_E^{\infty} J_{\nu}(E) dE \equiv \frac{4\pi}{c} E J_{\nu}(> E)$$

$$E^2 I_{\nu}(E) < \frac{4\pi}{c} \omega_{\text{cas}}$$

# PROBLEMS OF Z-BURST MODELS

$$E_\nu = E_0 = 1.8 \cdot 10^{22} \left( \frac{0.23 \text{ eV}}{m_\nu} \right) \text{ eV}$$

$$E_p > 20 E_\nu = 3.6 \cdot 10^{23} \left( \frac{0.23 \text{ eV}}{m_\nu} \right) \text{ eV}$$

IS TOO HIGH FOR ACCELERATION

DECAYS IN THE EXTRAGALACTIC SPACE (TD's, SUPERHEAVY DM PARTICLES) ARE ACCOMPANIED BY E-M CASCADE

$$I_\nu(E) < \frac{c}{4\pi} \frac{\omega_{\text{cas}}}{E^2}; \quad \omega_{\text{cas}} \leq 2 \cdot 10^{-6} \frac{\text{eV}}{\text{cm}^3} \text{ (EGRET)}$$

$$I_\nu(E_0) < \frac{c}{\pi} \omega_{\text{cas}} \frac{m_\nu^2}{m_z^4} \text{ IS TOO SMALL TO}$$

PRODUCE THE OBSERVED FLUX OF UHECR

$$\dot{n}_z = 4\pi \sigma_t n_{\nu_i} I_\nu(E_0) \cdot E_0 \leq \sigma_t n_{\nu_i} c \omega_{\text{cas}} / E_0$$

$$\dot{n}_x(E_x) < \frac{E_0}{E_x} \dot{n}_z$$

$$F_x(>E_x) = \frac{1}{4\pi} \dot{n}_x(E_x) \cdot R_x^{\text{abs}} = \frac{1}{4\pi} \sigma_t n_{\nu_i} R_x^{\text{abs}} \frac{c \omega_{\text{cas}}}{E_x}$$

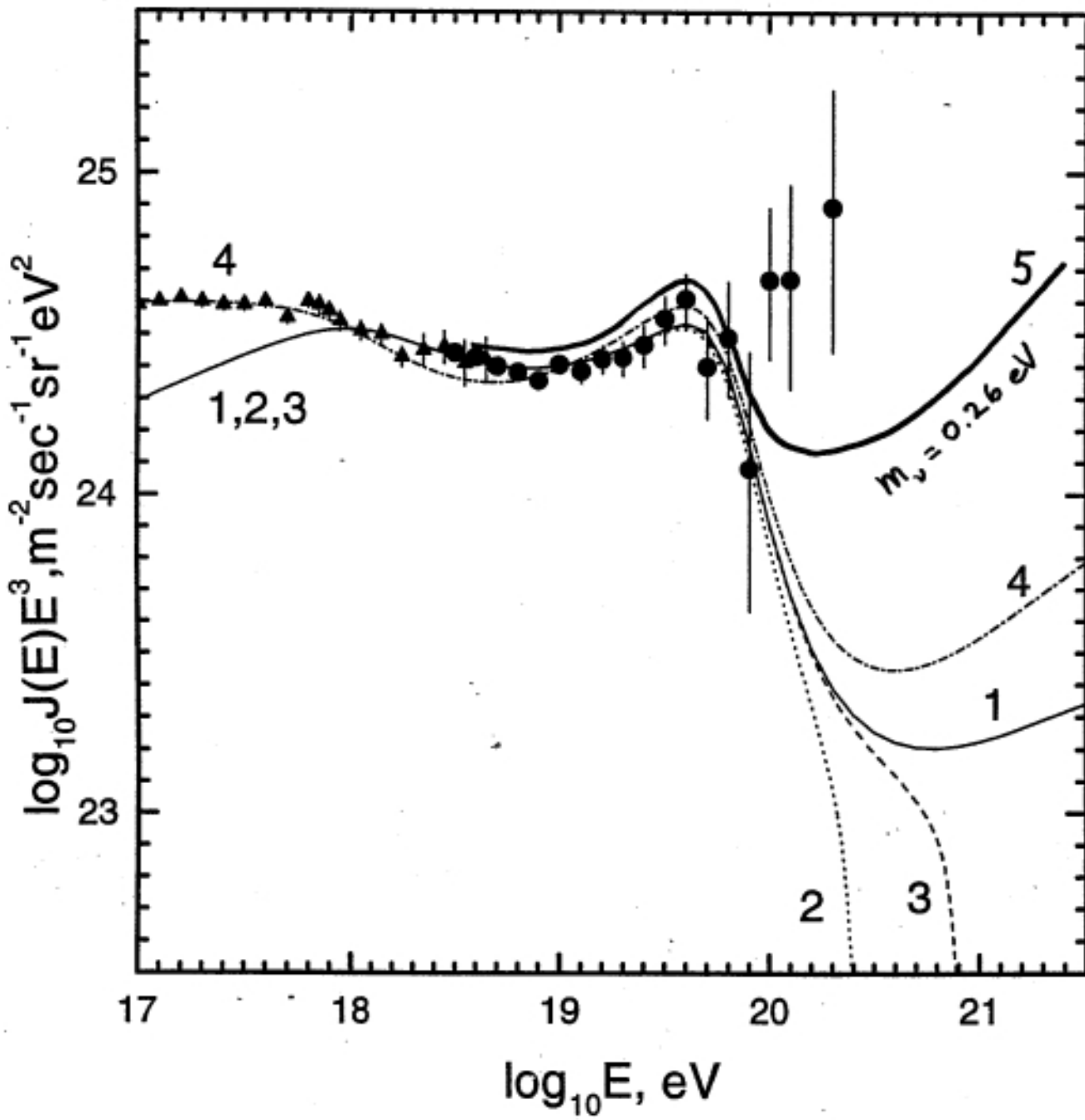
$$n_{\nu_i} = 56 \text{ cm}^{-3} \quad R_x^{\text{abs}} \leq 5 \text{ Mpc} \quad E_x = 3 \cdot 10^{19} \text{ eV}$$

$$F_x(>E_x) \lesssim 5.9 \cdot 10^{-22} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$$

i.e. 2 ORDERS OF MAGN LESS THAN OBSERVED

# Z-BURSTS

Fodor, Katz, Ringwald 2001

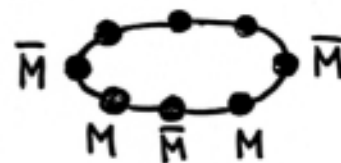


# TOPOLOGICAL DEFECTS

- SYMMETRY BREAKING IN EARLY UNIVERSE RESULTS IN PHASE TRANSITIONS (D.A. KIRZHNITZ 1972). THEY ARE ACCOMPANIED BY TOPOLOGICAL DEFECTS.
- DEPENDING ON SYMMETRY BREAKING, DEFECTS CAN BE IN FORM OF SURFACES (DOMAIN WALLS), LINES (STRINGS), AND POINTS (MONOPOLES).

## TD OF INTEREST FOR UHECR

- MONOPOLES:  $G \rightarrow H \times U(1)$
- ORDINARY STRINGS:  $U(1)$  BREAKING
- MONOPOLES CONNECTED BY STRINGS:  $G \rightarrow H \times U(1) \rightarrow H \times \mathbb{Z}_n$   
e.g. NECKLACES  $\mathbb{Z}_n = \mathbb{Z}_2$
- SUPERCONDUCTING STRINGS



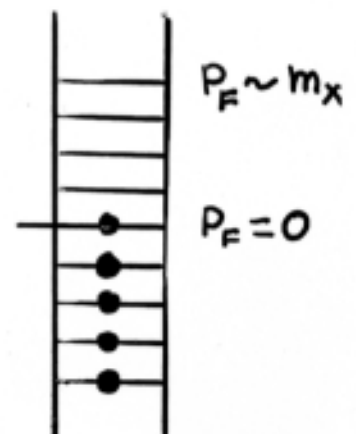
## PRODUCTION OF UHECR

- ANNIHILATION OF MONOPOLES  
 $M + \bar{M} \rightarrow$  PARTON CASCADE  $\rightarrow$  PIONS  $\rightarrow$  PHOTONS + NEUTRINOS

- SUPERCONDUCTING STRINGS

$$\frac{dP}{dt} = e\mathcal{E} \begin{cases} \rightarrow P = e\mathcal{E}t & P \sim m_x \\ \rightarrow J = e^2\mathcal{E}t & J \sim em_x \end{cases}$$

$$X \rightarrow \text{PARTON CASCADE} \rightarrow \text{PIONS} \rightarrow \gamma + \nu$$



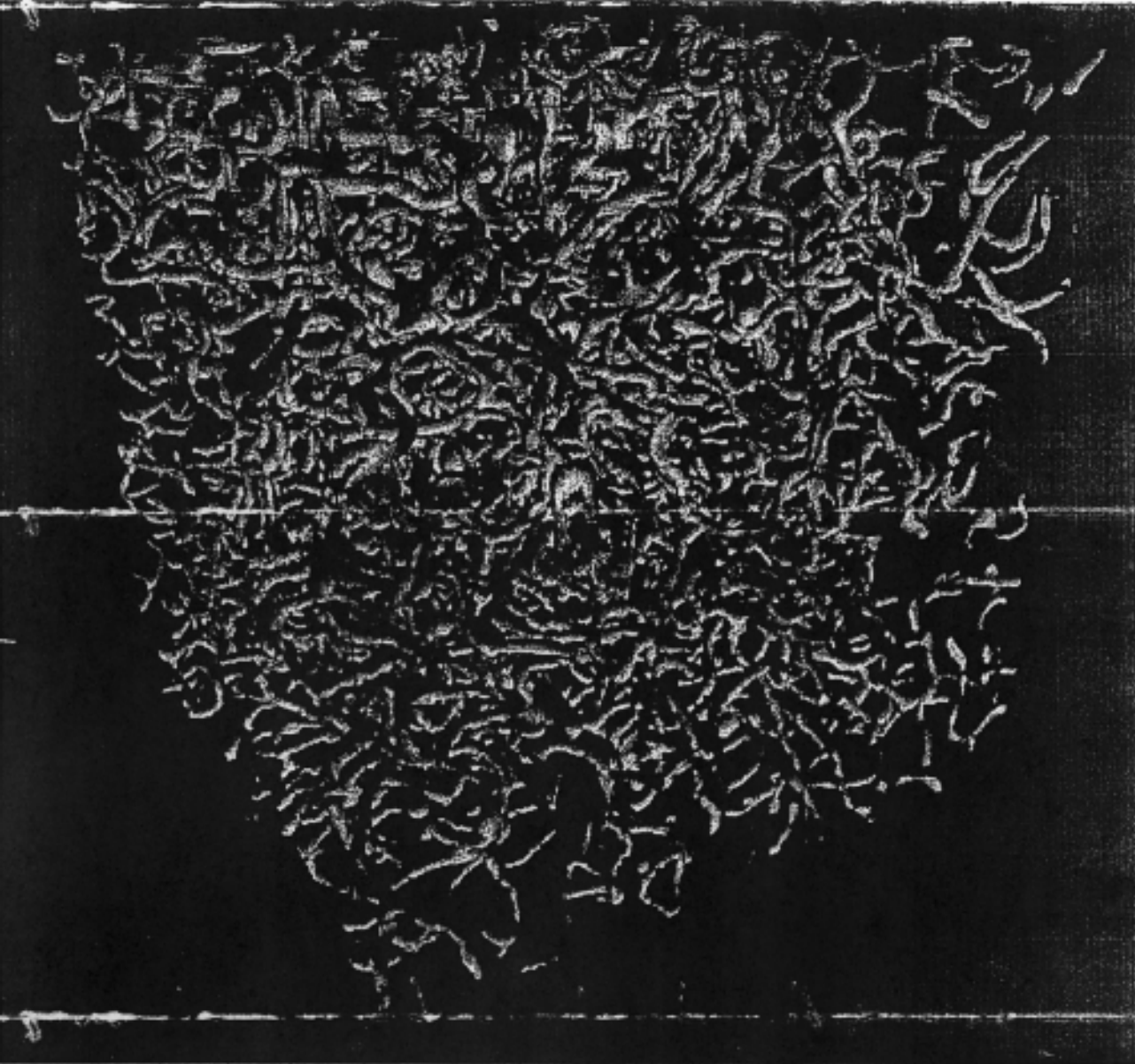
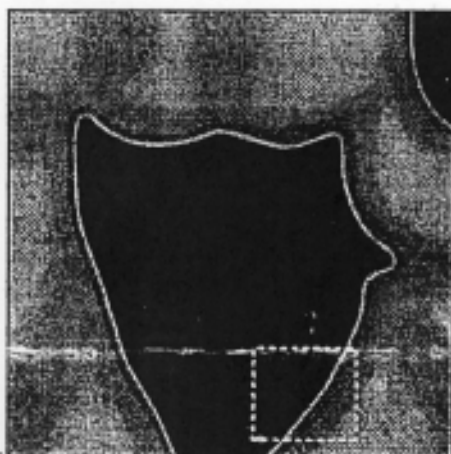
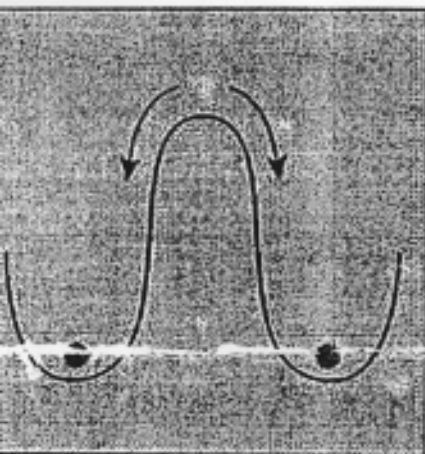


Figure 1. When a body of water freezes over, ice begins forming in many places independently. As the frozen areas grow, they create irregular boundaries between areas of crystalline ice that have different orientations. Phase transitions in the early universe can likewise create topological defects, as regions of space where the transition has proceeded independently run up against each other. The author discusses the possibility that today's universe may, as a result, be riddled with high-energy, gravitationally powerful filaments of primordial material called cosmic strings. Above, a simulation shows a step in the evolution of one region of the universe, in which cosmic strings form from a random initial distribution of phases of a hypothetical field called a Higgs field. (Image above courtesy of Paul Shellard, Cambridge University.)



↑ inset

