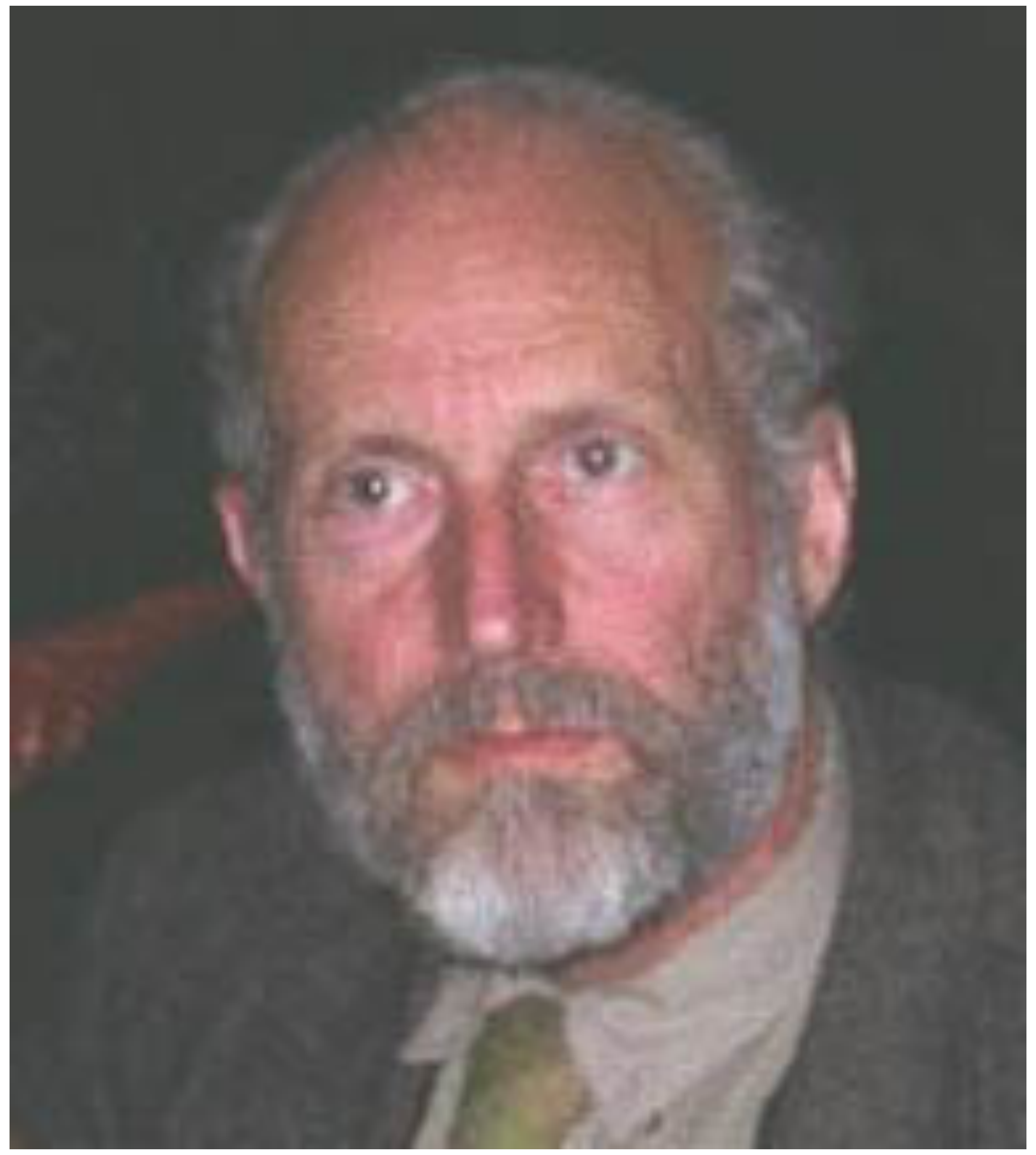
# Cosmic Vortons and Particle Physics Constraints

## with Brandon

Anne-Christine Davis, June 22

# Happy Birthday Brandon!

## Thank you for your support and collaboration



This talk is based on two papers

- Cosmic Vortons and Particle Physics Constraints — R. Brandenberger, B.Carter, ACD, M. Trodden; Phys Rev D54 (1996) 6059; hep-ph/9605382

- Chiral Vortons and Cosmological Constraints on Particle Physics — B.Carter and ACD; Phys Rev D61 (2000) 123501; hep-ph/9910560

Topological Defects are ubiquitous in nature. You can clearly see defects in crystals, in liquid He and many other systems. We have yet to see them in Particle Physics or Cosmology. They occur due to phase transition

$$G- > H$$

If

$$\Pi_1(G/H)$$

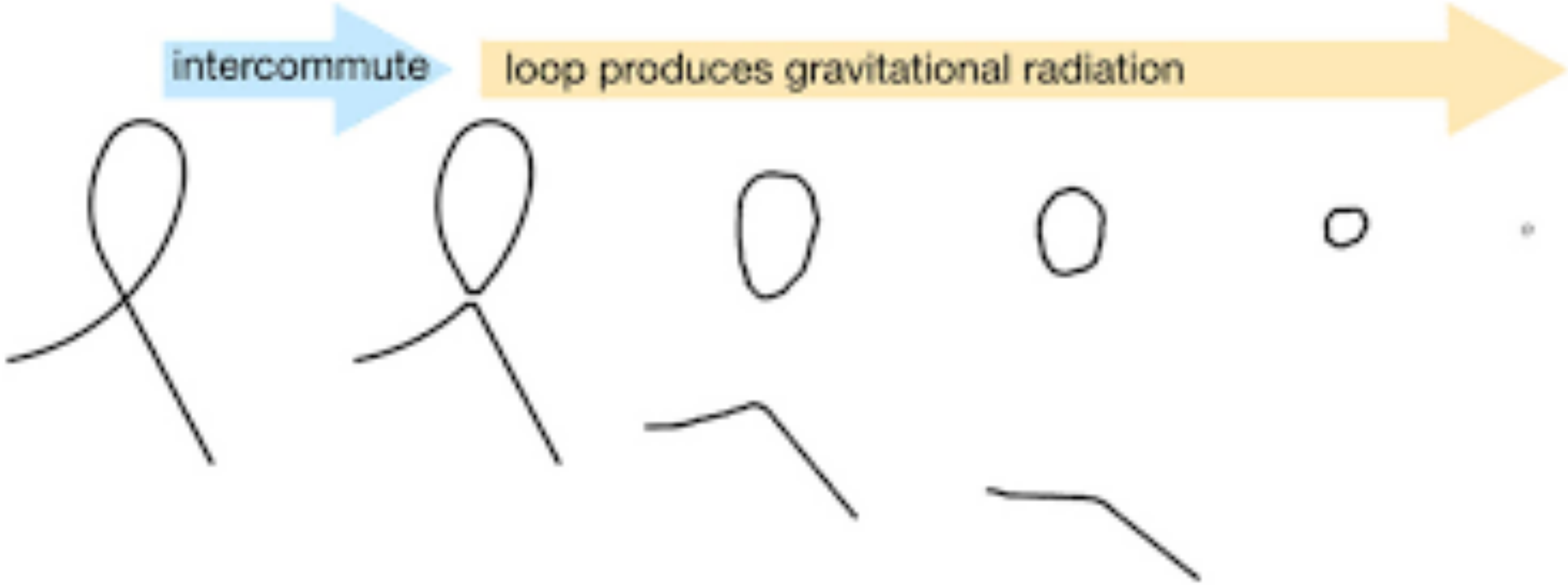
non-trivial then a line defect, or cosmic string, would be formed. They should result during a symmetry breaking transition from a grand unified theory breaking to the standard model, at say $T_X$ If there are other symmetry groups the strings can become current carrying, either at the same transition or at a lower energy scale, either by a charged boson field or fermion zero modes. Up until our work it was assumed the two scales were approximately the same. We considered the general case of two different scales.

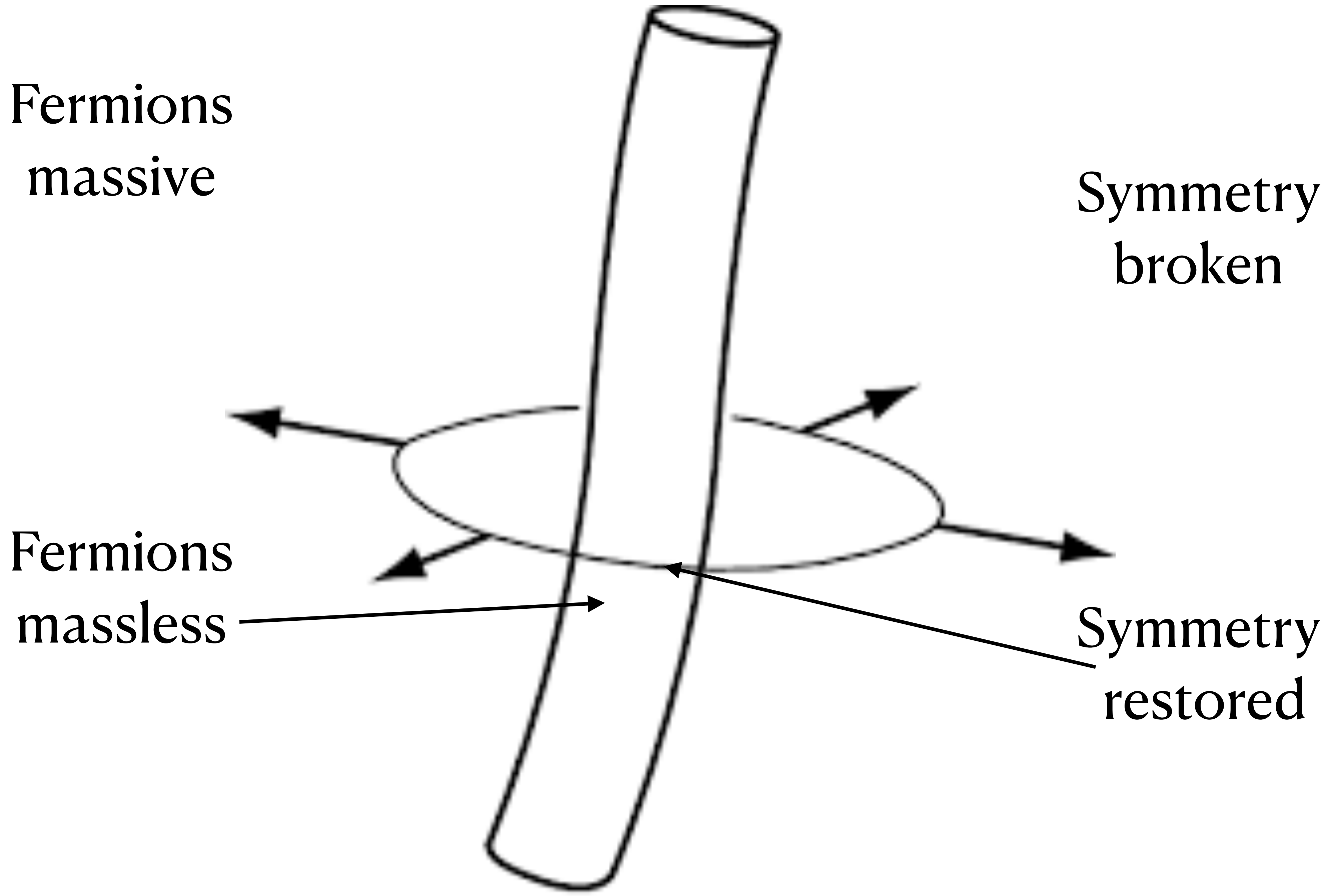
String loops usually decay via gravitational radiation and particle production. However the presence of a current changes Witten, NPB249 (1985) 557 this and leads to the possibility of stabilising the loops. Depending on details such stable loops, or vortons, could over close the Universe. R.Davis and Shellard NPB323 (1989) 209.

We placed constraints on the underlying particle physics transition resulting in the string becoming current-carrying using two conditions

The Universe was radiation dominated at nucleosynthesis - the nucleosynthesis constraint

Stable vortons do not overclose the Universe - the so-called dark matter constraint


intercommute
loop produces gravitational radiation


Fermions
massive
Symmetry
broken
Fermions
massless
Symmetry
restored

We considered strings formed at $T_X$ becoming current-carrying at $T_\sigma$

$$\mathcal{G}_{\rm GUT} \mapsto \cdots \mathcal{H} \cdots \mapsto \mathcal{G}_{\rm EW} \mapsto SU(3) \times U(1)$$

The string tension is given by $\mathcal{T} \leq m_{\rm x}^2 \leq \mathcal{E}$ where $\mathcal{E}$ is the energy density

There are two quantum numbers characterising the vorton N and Z where

$$N = \oint \tilde{j}^a d\ell_a \ , \qquad Z = \oint j^a d\ell_a$$

where $\tilde{j}^a$ is the world sheet phase current and $j_a$ is the particle number current

The critical saturation current is $|j|^2 \approx \mathcal{E} - \mathcal{T} \lesssim m_\sigma^2$

The phase angle $\theta = \omega t - k\ell$ where $\omega = \dfrac{Z}{2\tilde{\Sigma}\ell_{\rm v}}$ , $k = \dfrac{2\pi N}{\ell_{\rm v}}$

typically $|NZ|^{1/2} \gg \frac{T_{\mathrm{x}}}{T_{\sigma}}$ and $|Z| \approx N$ ;

The mass energy of the vorton $E_v \approx l_v m_X^2 \approx N m_X$

This assumes the loop length is sufficiently large compared with the Compton wavelength of the charge carrier mass $m_\sigma$

requiring $l_v >> m_\sigma^{-1}$

Protovortons that do not meet this requirement become doomed loops

# Vorton Abundance and Constraints

One expects fluctuations to give rise to a non-zero value for $|j|^2$
and hence finite values for the string quantum numbers N and Z

We discussed in detail loop formation and condensation in both friction dominated and radiation dominated regimes. From this we estimated the number density of vortons and hence the energy density given by

$$\rho_{\rm v} \approx N m_{\rm x} n_{\rm v}$$

In the friction dominated regime this becomes

$$\rho_{\rm v} \approx \nu_\star f \left(\frac{\beta T_\sigma}{m_{\rm P}}\right)^{5/4} \left(\frac{T_\sigma}{T_{\rm x}}\right)^{3/2} T_\sigma T^3$$

See our paper for the radiation dominated regime

# Constraints

## The Nucleosynthesis Constraint

Here we assumed the vortons were not completely stable but lived for a few minutes. In this case we require the Universe to be radiation dominated during nucleosynthesis and hence

$$\rho_{\mathrm{v}}(T_{\mathrm{N}}) \ll \rho_{\mathrm{N}} \qquad \text{where} \qquad \rho_{\mathrm{N}} \approx g^* T_{\mathrm{N}}^4$$

If the loops become current-carrying at formation $\qquad T_\sigma \approx T_X$

then $\qquad T_X < 10^9 GeV$

If loops become current-carrying at a lower scale, taking $T_X$ to be the GUT scale of $10^{16} GeV$

$$T_\sigma < 10^{12} GeV$$

## The Dark Matter Constraint

If vortons are sufficiently stable to live to the present time then they can't over close the Universe

$$\Omega_{\mathrm{v}} \equiv \frac{\rho_{\mathrm{v}}}{\rho_{\mathrm{c}}} \lesssim 1$$

where $\rho_c$ is the closure density

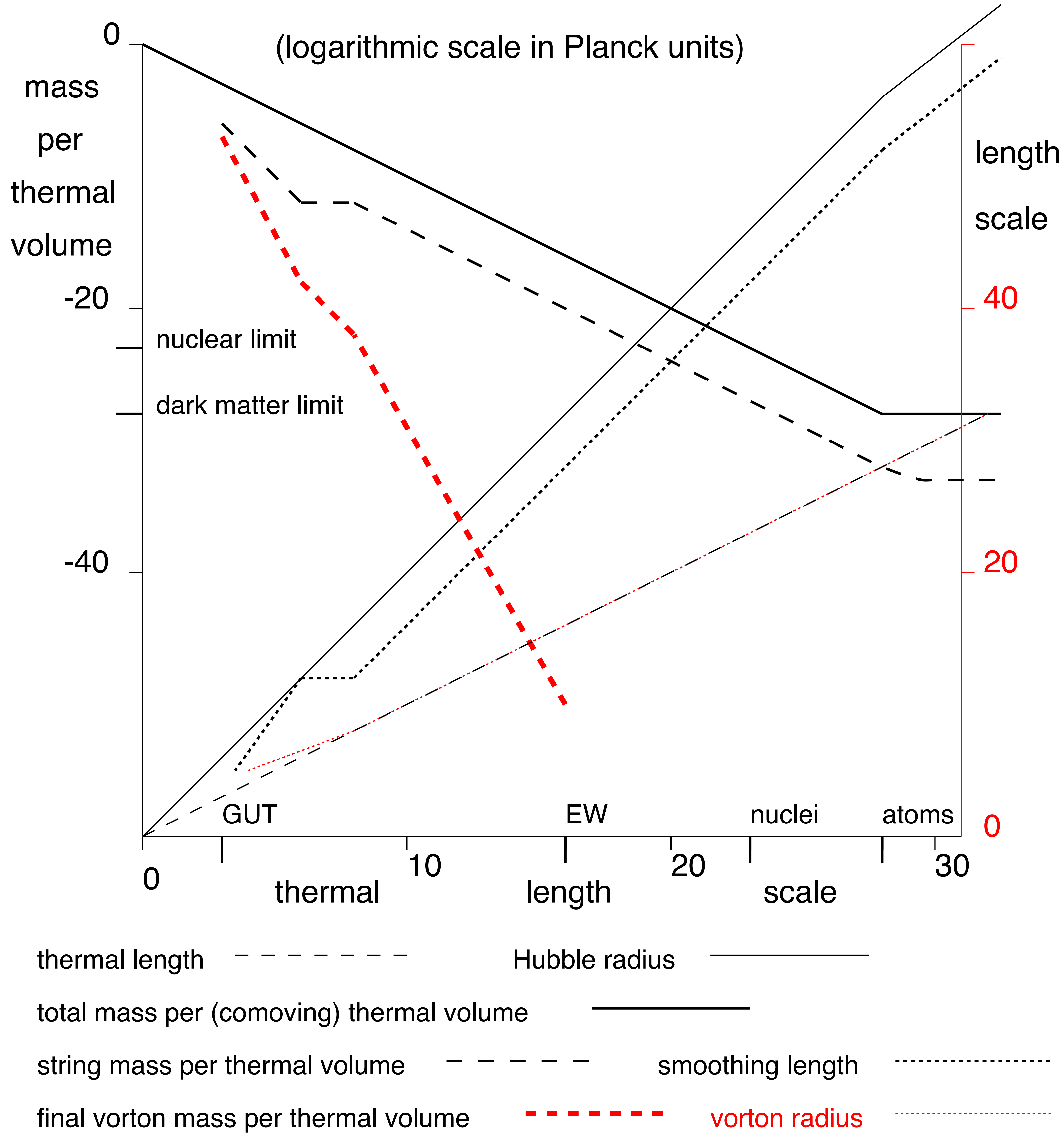
If the loops become current-carrying at formation

$$T_X < 10^7 GeV$$

If loops become current-carrying at a lower scale, taking $T_X$ to be the GUT scale of $10^{16} GeV$

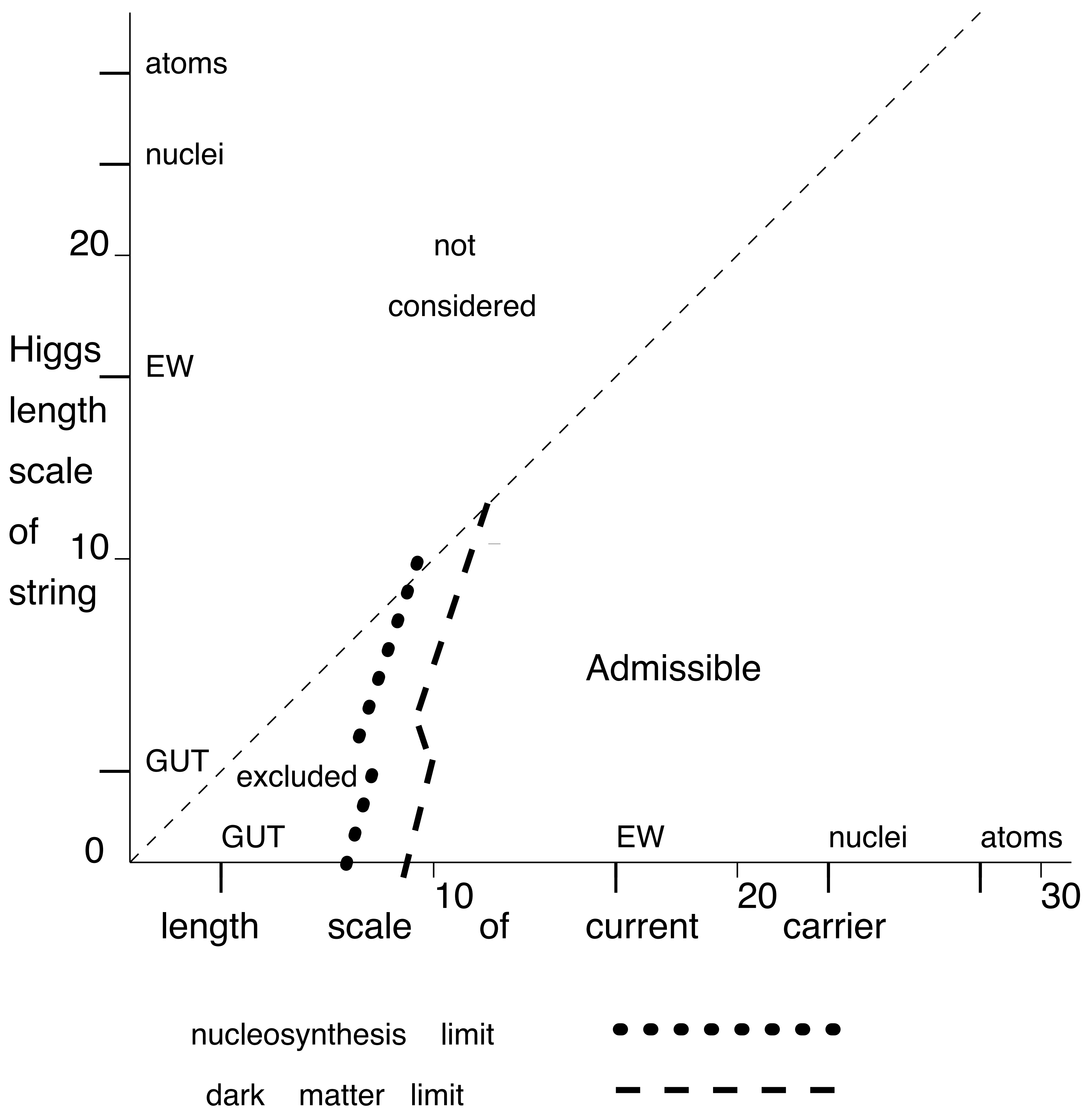
$$T_\sigma < 10^{10} GeV$$

**Vorton formation as a function of superconducting transition temperature for GUT strings.**



**Admissible range for length scales characterising string and current formation temperatures**

(logarithmic scale in Planck units)



## **Chiral Vortons**    Brandon and ACD

These arise when the theory in question has either a left- or right-moving zero mode, such as in supersymmetric theories with a D-term and SUSY broken by a Fayet-Illiopoulos term. SUSY cosmic strings were discussed in detail by S.Davis, ACD and M. Trodden, PLB405 (1997) 257, hep-ph.9711313 and PRD57 (1998) 5184, hep-ph/9702360

In such models with chiral zero modes the current is always maximal and

$$N = Z$$

Following the same analysis as previously results in stronger constraints

## The Nucleosynthesis Constraint

Chiral loops becoming current-carrying at formation then $T_X < 10^8 GeV$

and loops forming at the GUT scale becoming current-carrying at a lower scale $T_\sigma < 10^9 GeV$

## The Dark Matter Constraint

Applying the same analysis as before $T_\sigma < 10^5 GeV$

**Question — We still have very little idea about what constitutes dark matter. Could it be vortons? What would the signatures be of vorton dark matter?**

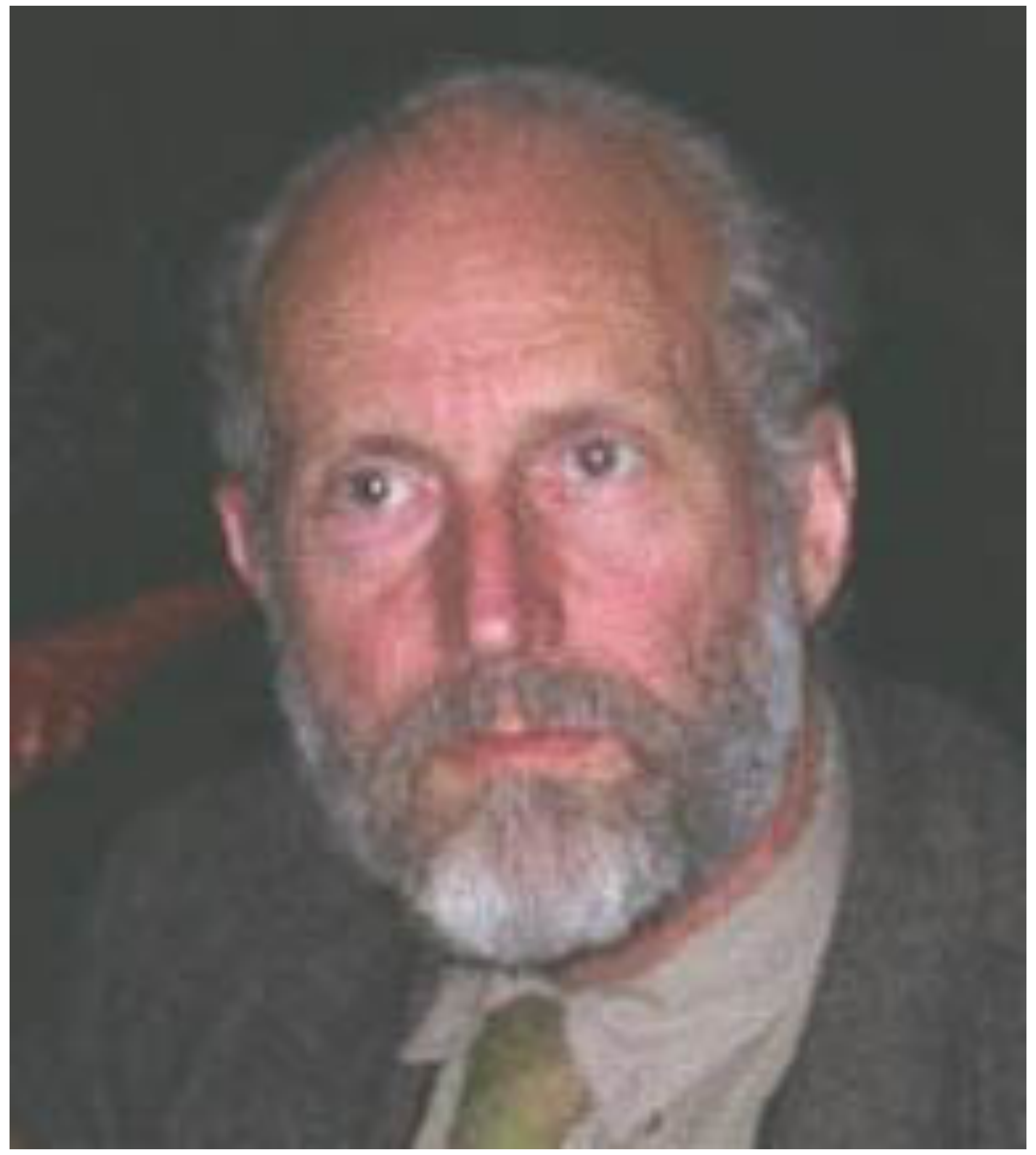
# Brandon

Working with Brandon

Influence on my career

UK Cosmology workshops

Peyresq



**Thank you Brandon**
**Happy Birthday**

# Peyresq


Admissible range for length scales characterising
string and current formation temperatures
(logarithmic scale in Planck units)
atoms
nuclei
Higgs length scale of string
EW
GUT
not considered
excluded
Admissible
length scale of current carrier
nucleosynthesis limit
dark matter limit