Erasure of Defects

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Outline

- GUTs and the Cosmological Monopole Problem
  - Sweeping Away the Monopole Problem
- Erasure of non-topological Defects: DLV Mechanism
- The ϕ^6-Model
  - Domain Walls, and Coulomb Vacuum Layers
  - Vortex Lines
  - Erasure of Vortexes by Coulomb Vacuum Layers
- Conclusions and Outlook

Grand Unified Theories

- In GUT, the three SM gauge interactions are merged into one-gauge interaction, G.
- G is spontaneously broken at $T_{GUT} \sim 10^{15}$GeV, to the SM group when a Higgs-like field, ϕ, acquires a VEV.
- If $T > T_{GUT}$, in the very early universe there was a GUT-epoch

The Cosmological Monopole Problem

- As the universe expands and cools down, it undergoes a phase transitions at T_{GUT}.
- During this phase transition different ***topological defects*** may be produced. For example:
  - Domain Walls
  - Cosmic Strings
  - Magnetic Monopoles

The Cosmological Monopole Problem

- Monopole configurations are a common feature of GUTs.
- The estimated concentration of monopoles is unacceptably large in comparison to observations[1].
- Different solutions for this tension were proposed:
  - Inflation
    A. H. Guth, Phys. Rev. D 23, 347 (1981)
  - Langacker & Pi mechanism
    P. Langacker and S.Y. Pi, Phys. Rev. Lett. 45, 1 (1980)
  - Non-restoration of the grand unified symmetry
    G. Dvali, A. Melfo, and G. Senjanovic, Phys. Rev. Lett. 75, 4559 (1995)

[1]Y. Zeldovich and M. Khlopov, Phys. Lett. B79, 239–241 (1978)
J. Preskill, Phys. Rev. Lett.43, 1365 (1979)

Sweeping Away the Monopole Problem

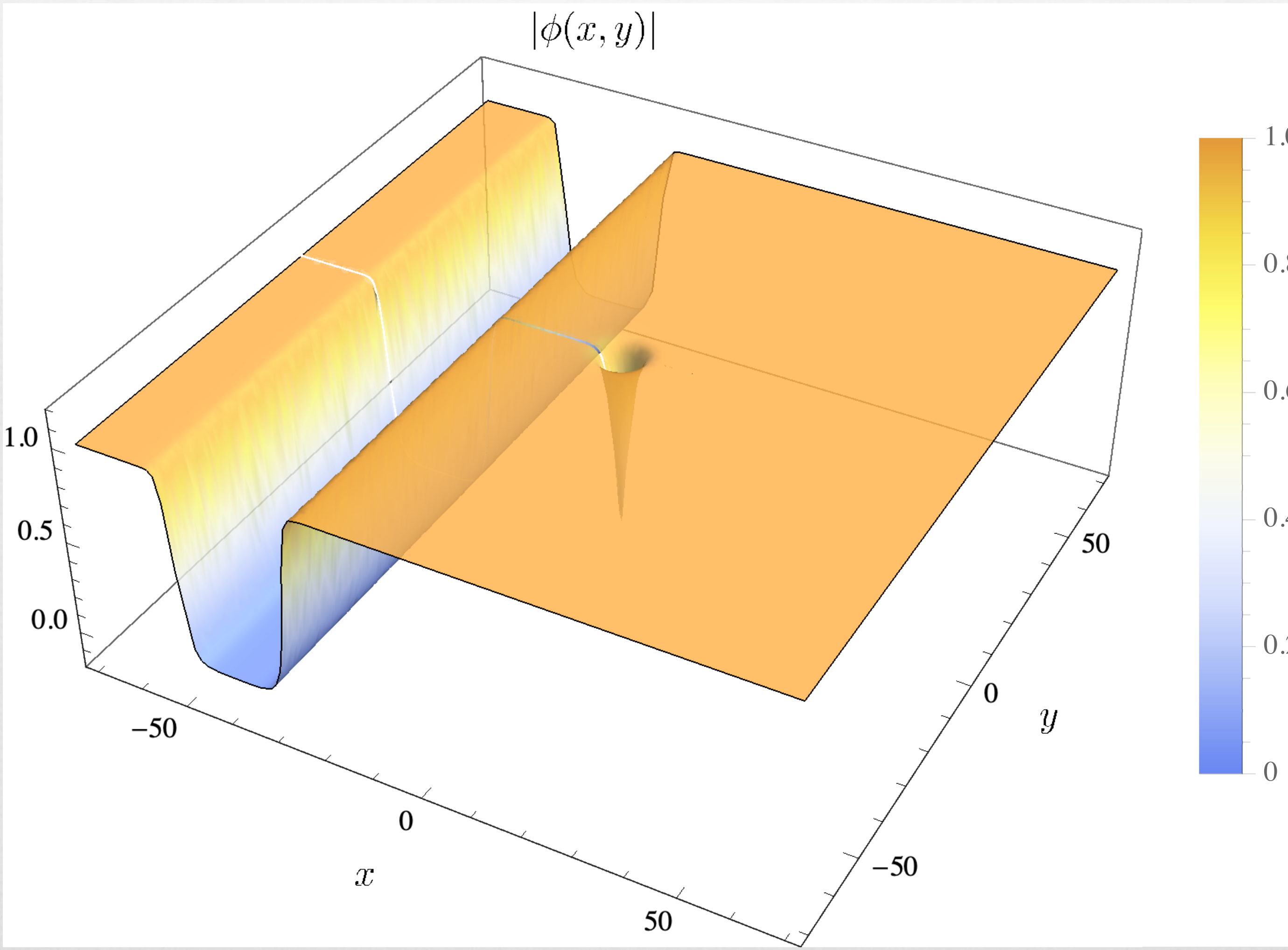
- Solution: DLV Mechanism:[3]

  $$Domain\ Walls + Magnetic\ Monopoles\ \ interaction \rightarrow\ \boldsymbol{Erasure\ of\ Monopoles}$$

- Basic idea:
  - The same phase transition produces
    - **Magnetic Monopoles**
    - **Domain Walls**
  - The domain walls move through space and sweep up the monopoles.
  - When a monopole encounters a wall, it *unwinds* and *dissipates.*
  - The walls are unstable at a lower energy scale, and hence collapse and go away.

[3]G. Dvali, H. Liu, and T. Vachaspati, Phys. Rev. Lett. 80, 2281–2284 (1998).

Erasure of Defects: The DLV Mechanism



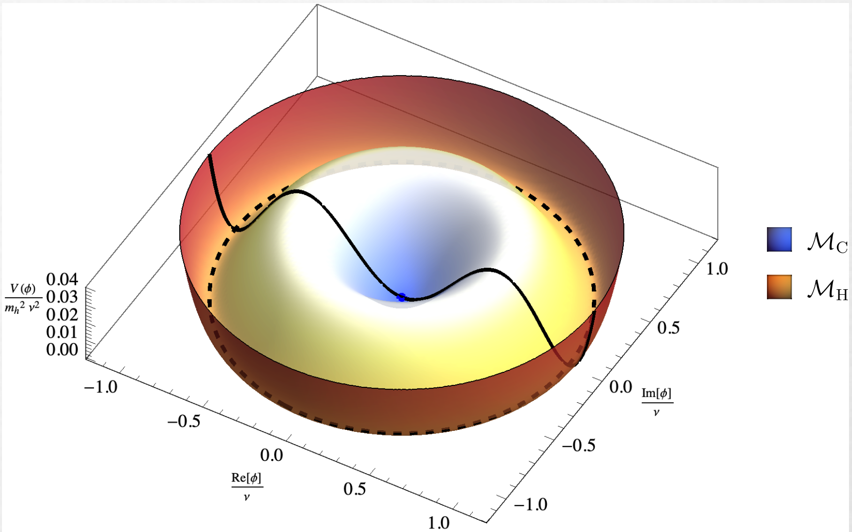
Erasure of a Vortex by a Coulomb Vacuum Layer

The ϕ^6-Model

$$\mathcal{L}[\phi, A_\mu] = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + (D_\mu\phi)^* D^\mu\phi - V(\phi),$$

$$G = U(1)$$

$$V(\phi) = \lambda^2\phi\phi^*(\phi\phi^* - \nu^2)^2.$$



$$\mathcal{M} \equiv \mathcal{M}_C \dot{\cup} \mathcal{M}_H$$

	Coulomb Phase: $\langle\phi\rangle = 0$	**Higgs Phase:** $\langle\phi\rangle = \nu$
Vacuum Manifold	$\mathcal{M}_C = G/H_0 = 1$	$\mathcal{M}_H = G/H_\nu = U(1)$
Spectrum	$m_\phi = \lambda\nu^2$	$m_h = 2\lambda\nu^2$
	$m_A = 0$	$m_v = \sqrt{2}e\nu$

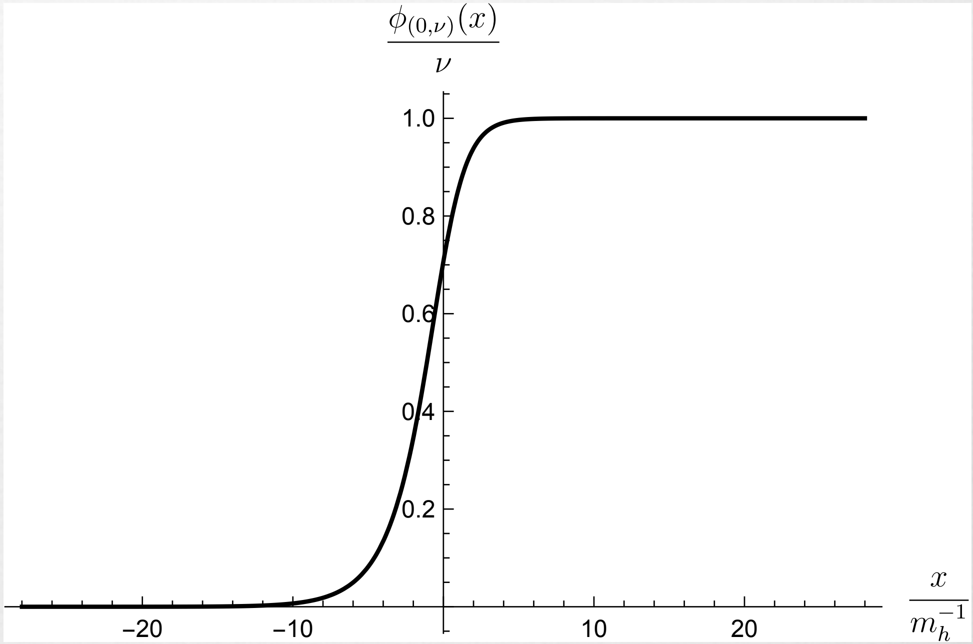
Domain Walls in the ϕ^6-Model

Domain Walls in the ϕ^6-Model

- $\pi_0(\mathcal{M}) = \mathbb{Z}_2$
- (1+1)-dimensions
- Solitonic configurations interpolating between the Coulomb and the Higgs phases[4]

$$\phi_{(\pm\nu,0)}(x) \equiv \pm\nu\sqrt{\frac{1}{1+e^{m_h x}}}$$

$$\phi_{(0,\pm\nu)}(x) \equiv \pm\nu\sqrt{\frac{1}{1+e^{-m_h x}}}$$



[4]V. A. Gani, A. E. Kudryavtsev, and M. A. Lizunov, Phys. Rev. D 89, 125009,(2014)

Coulomb Vacuum Layer

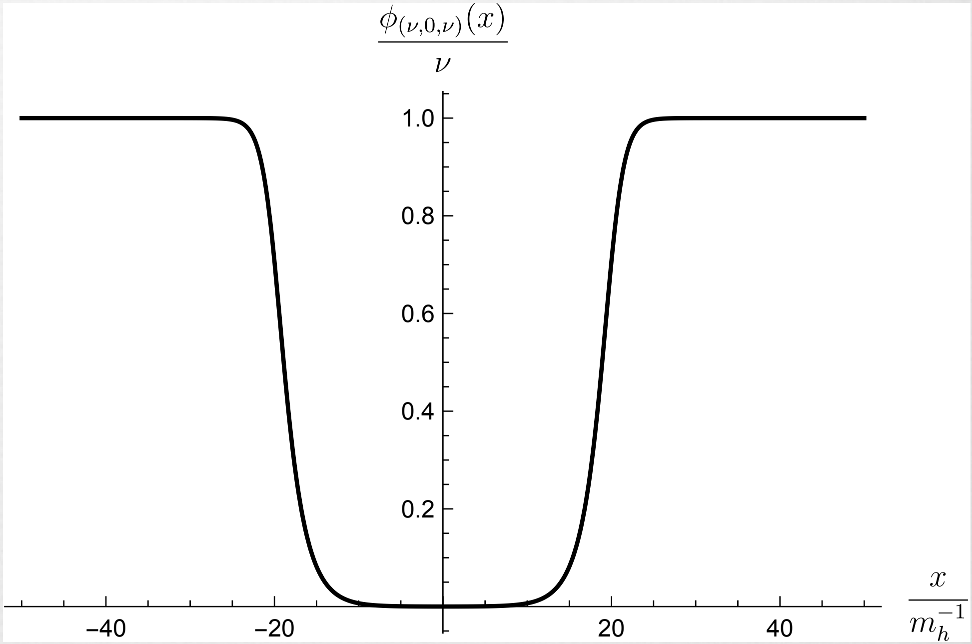
$(\nu, 0, \nu)$-Domain Wall

- Profile ansatz

$$\phi_{(\nu,0,\nu)}(x) = \phi_{(\nu,0)}\left(x + \frac{l}{2}\right) + \phi_{(0,\nu)}\left(x - \frac{l}{2}\right)$$

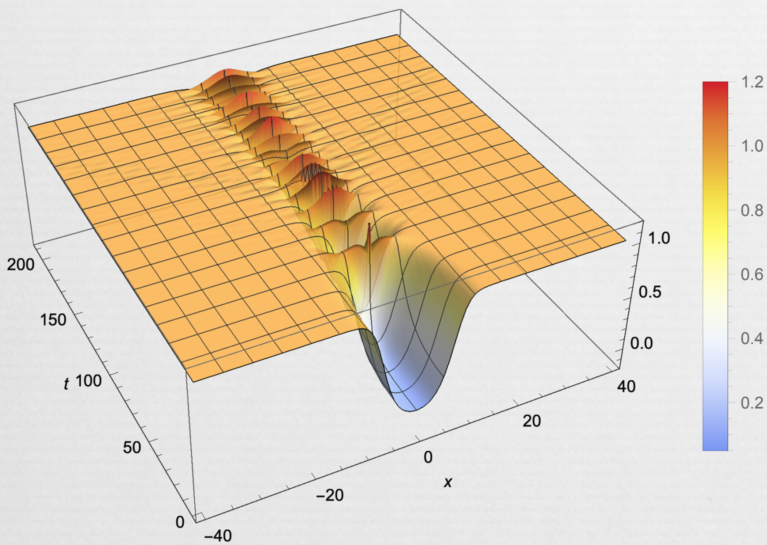
- Distance between the walls:

$$l > m_h^{-1}$$

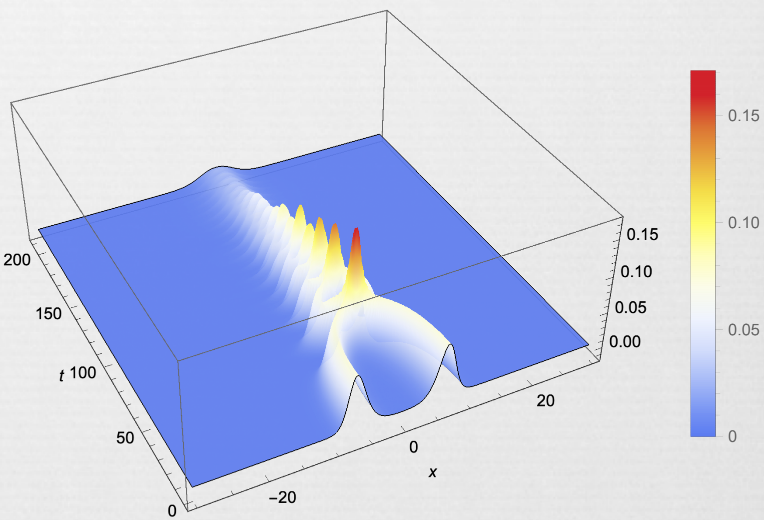


Time Evolution: $(v, 0, v)$-Domain Wall

$$l = 15 m_h^{-1}$$



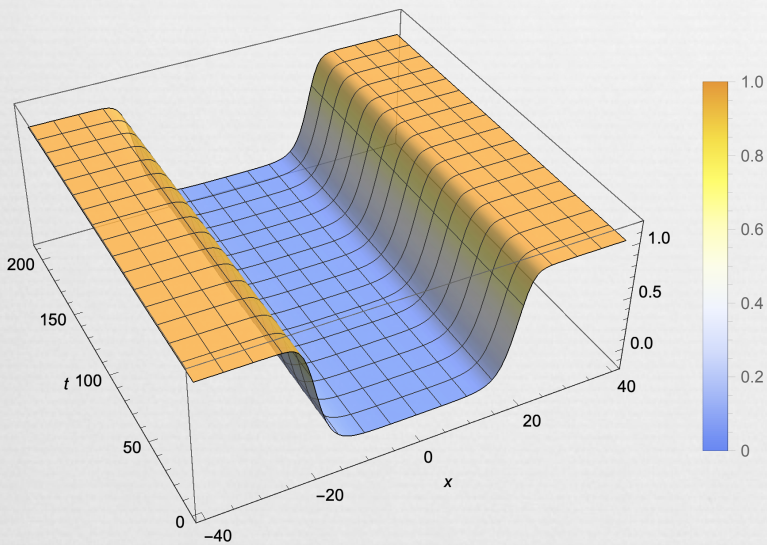
Field Profile
$\phi(x,t)$



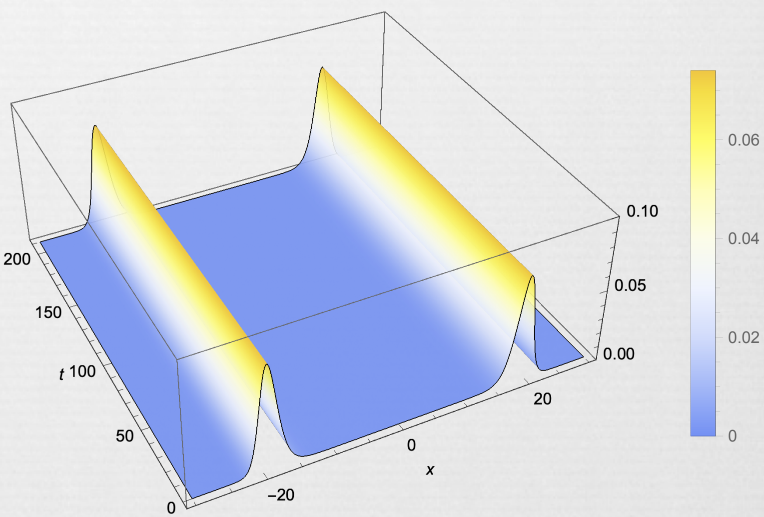
Energy density
$E(x,t)$

Time Evolution: $(v, 0, v)$-Domain Wall.

$$l = 40 m_h^{-1}$$



Field Profile
$\phi(x, t)$



Energy density
$E(x, t)$

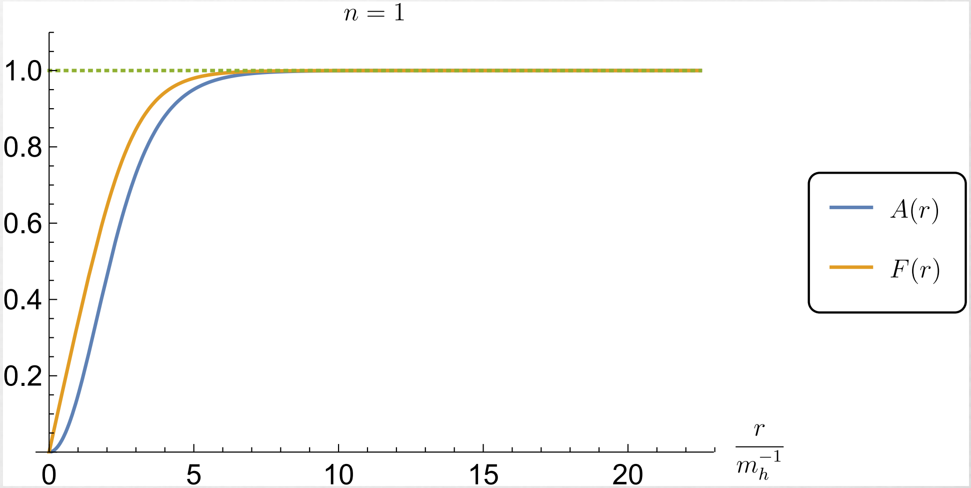
Vortex in the ϕ^6-Model

Vortex Profile

- $\pi_1(\mathcal{M}_{\mathrm{H}}) = \mathbb{Z}$
- In (2+1) dimensions
- Ansatz[4]

$$\phi(r,\theta) = \nu e^{in\theta} F(r)$$
$$A_i(r,\theta) = -\frac{n}{er}\epsilon_{ij} n_j A(r)$$

where $n \in \mathbb{Z}$ is the *winding number.*

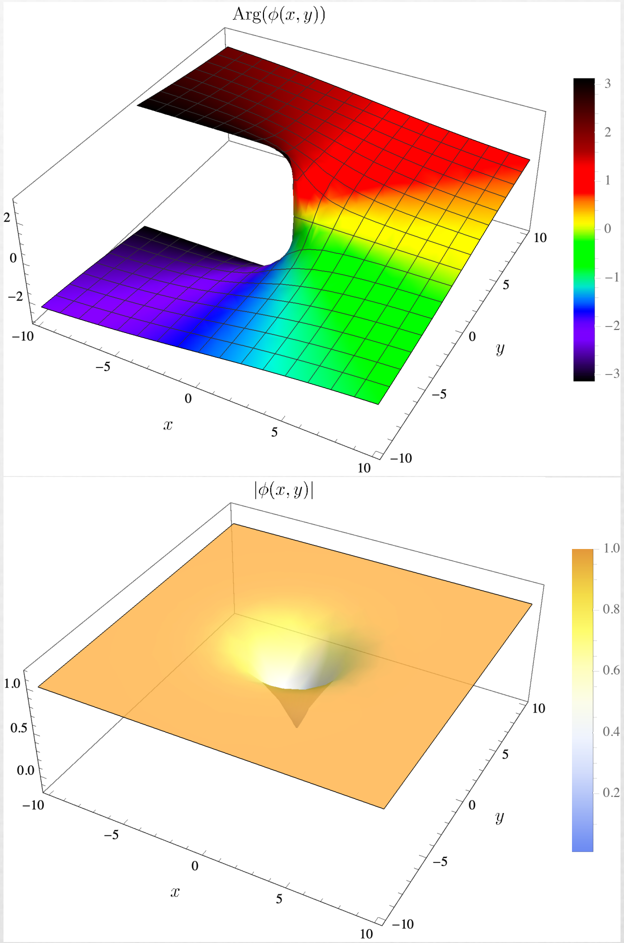


[4]H.B. Nielsen, P. Olesen, Nuc. Phys. B, Vol. 61, 45-61, (1973)

Vortex: ϕ

- $m_h = 1$
- $m_v = 1$
- $n = 1$
- Scalar Field:

$$\phi(r,\theta) = \nu e^{in\theta} F(r)$$

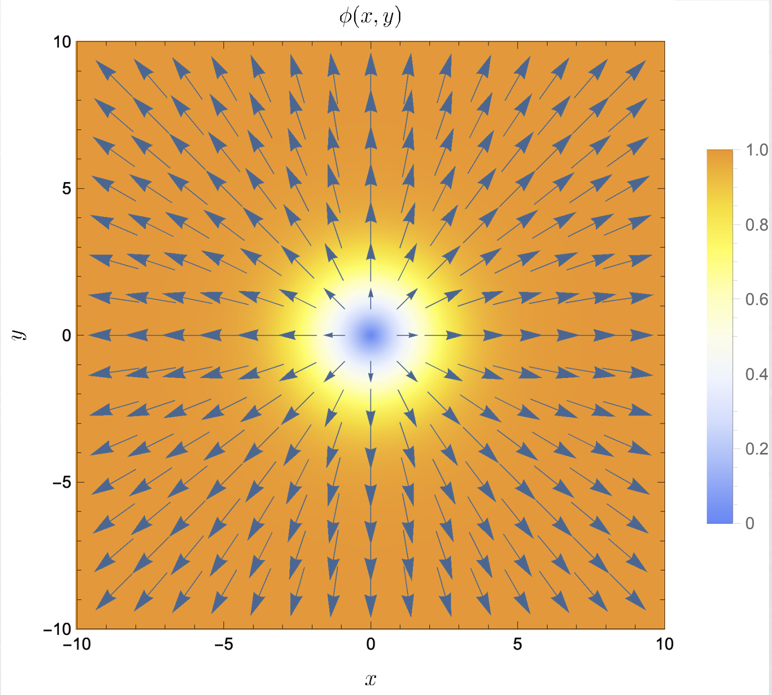


Vortex: ϕ

- $m_h = 1$
- $m_v = 1$
- $n = 1$
- Scalar Field:

$$\phi(r,\theta) = \nu e^{in\theta} F(r)$$

- $n = \dfrac{1}{2\pi i \nu^2} \oint dx^i \phi^* \partial_i \phi$

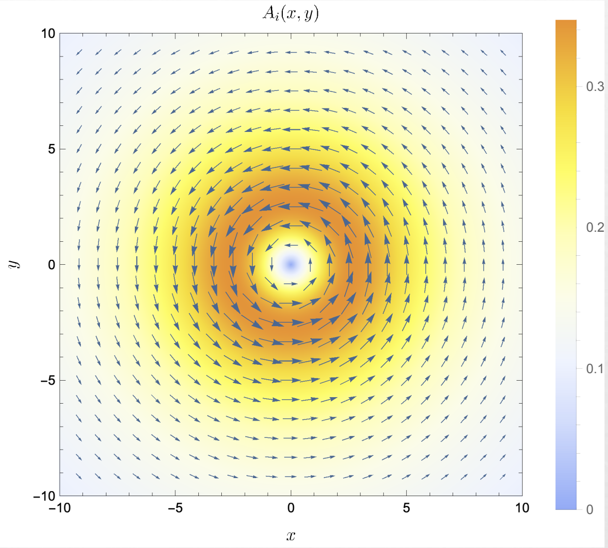


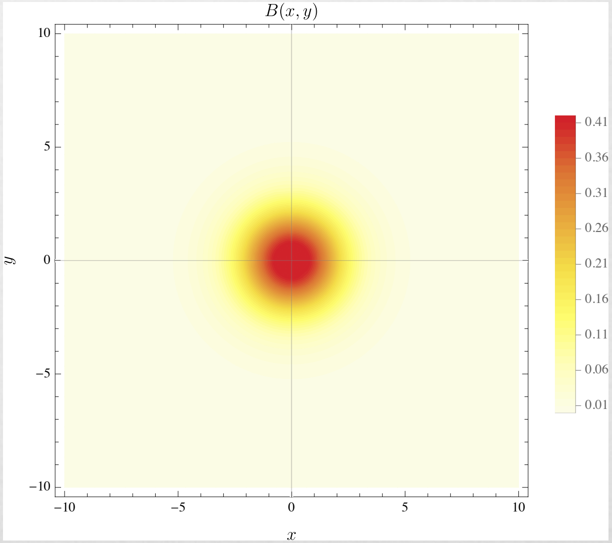
Vortex: A_i

- $m_h = 1$
- $m_v = 1$
- $n = 1$
- Gauge Field:

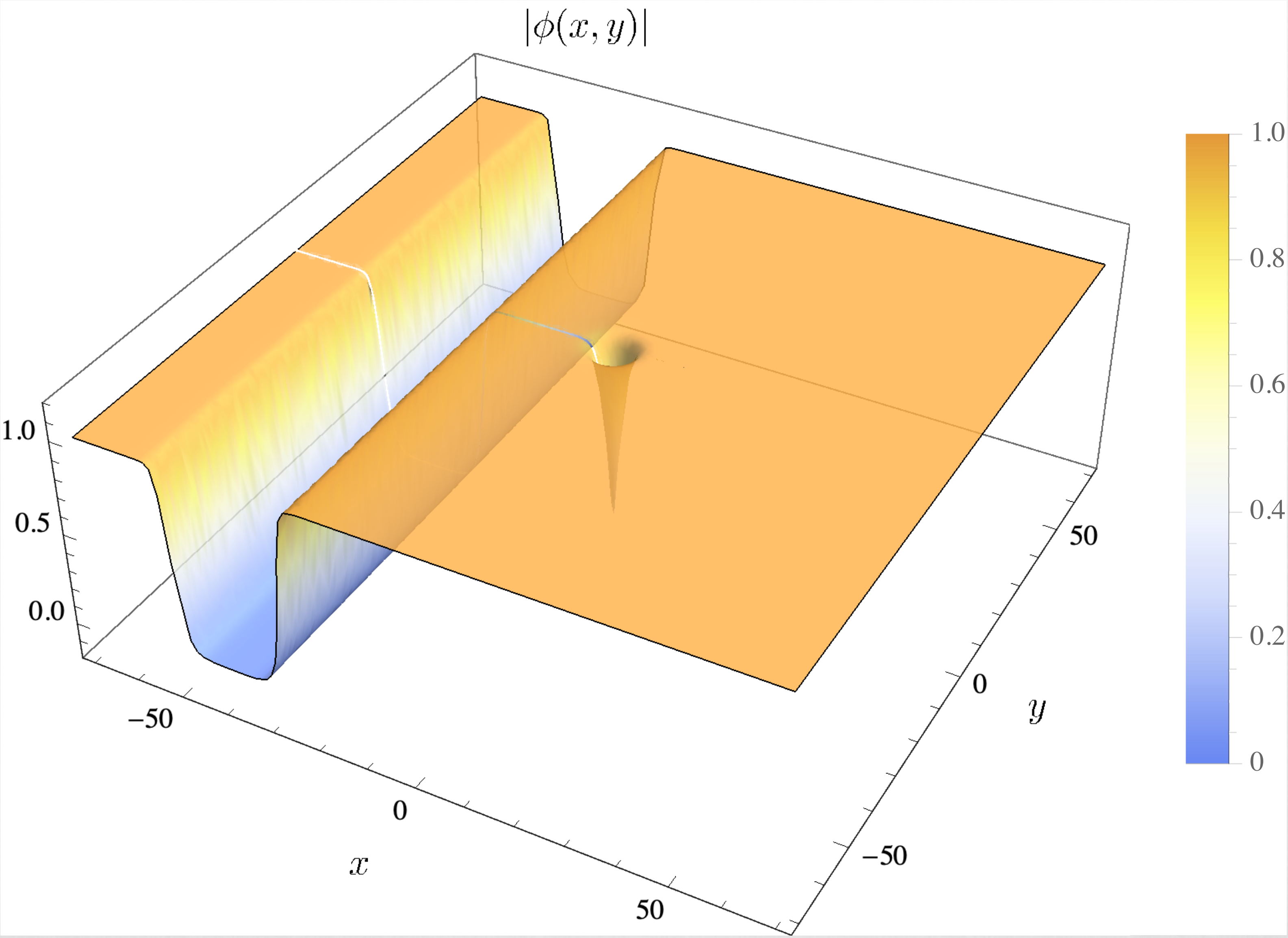
$$A_i(r,\theta) = -\frac{n}{er}\epsilon_{ij}n_j A(r)$$

- $n = \frac{e}{2\pi}\int B d^2x$





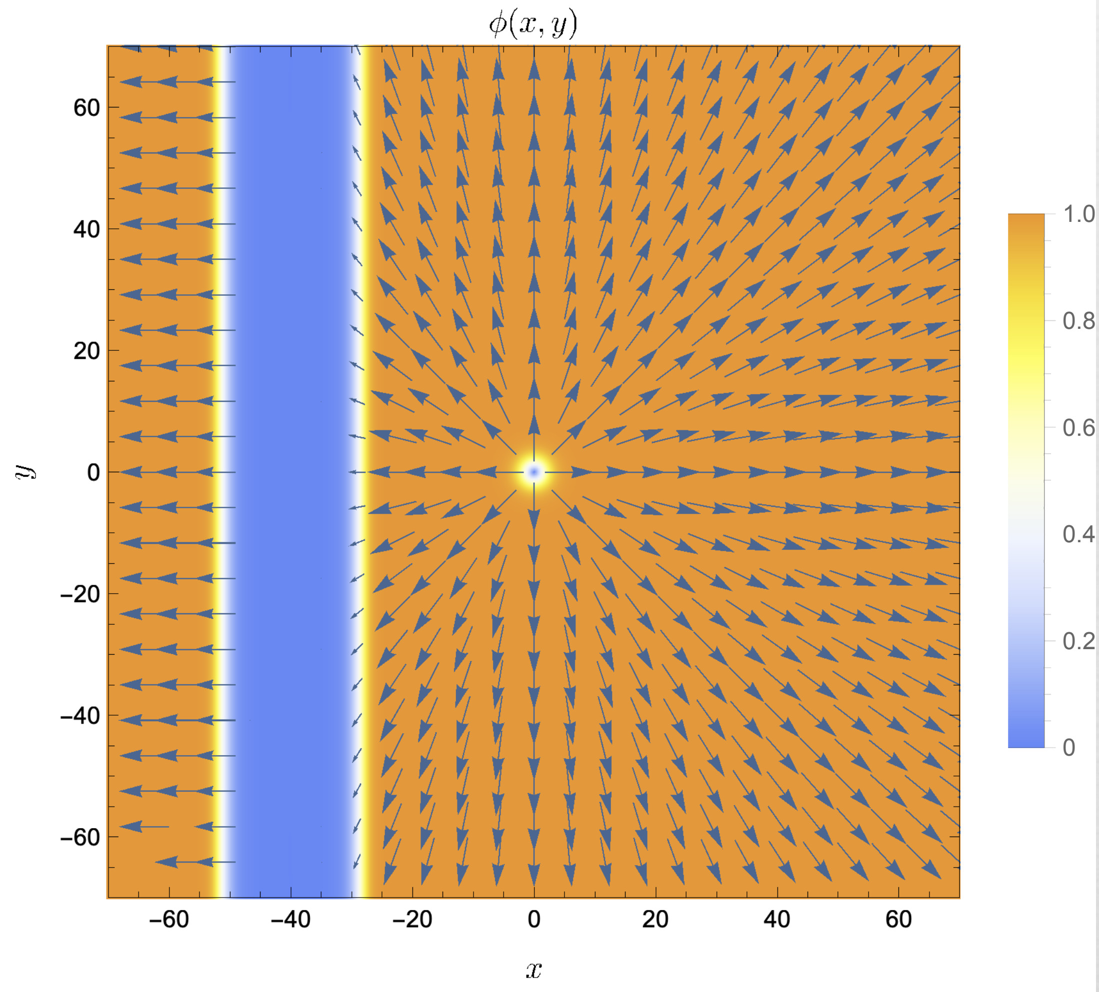
Erasure of a Vortex by a Coulomb Vacuum Layer



$|\phi(x,y)|$
1.0
0.5
0.0
−50
0
50
x
−50
0
50
y
1.0
0.8
0.6
0.4
0.2
0

Initial Conditions
$\phi(x, y)$

$$m_h = 1$$
$$m_v = 1$$
$$n = 1$$
$$l = 40 m_h^{-1}$$
$$v_0 = 1$$



Initial Conditions $\mathrm{Arg}(\phi(x,y))$

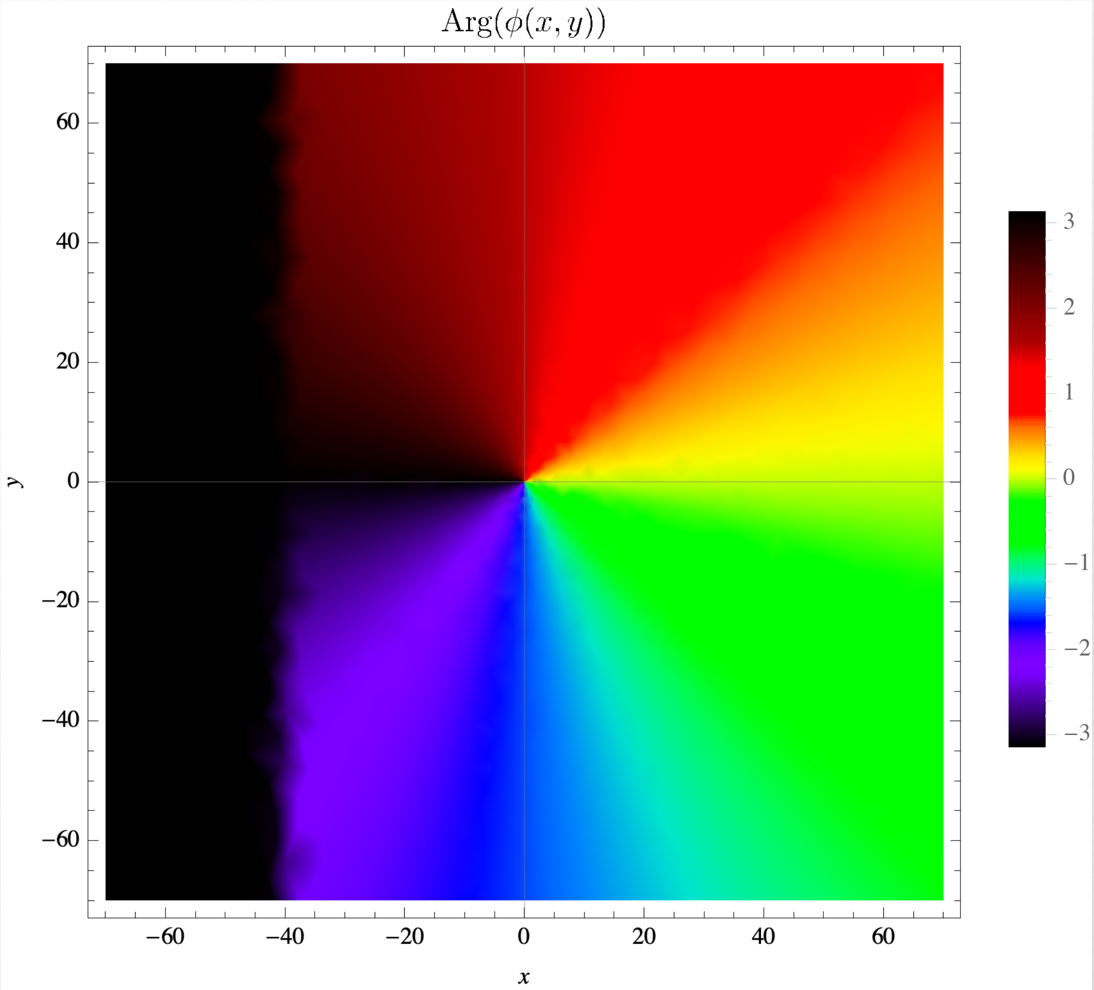
$$m_h = 1$$

$$m_v = 1$$

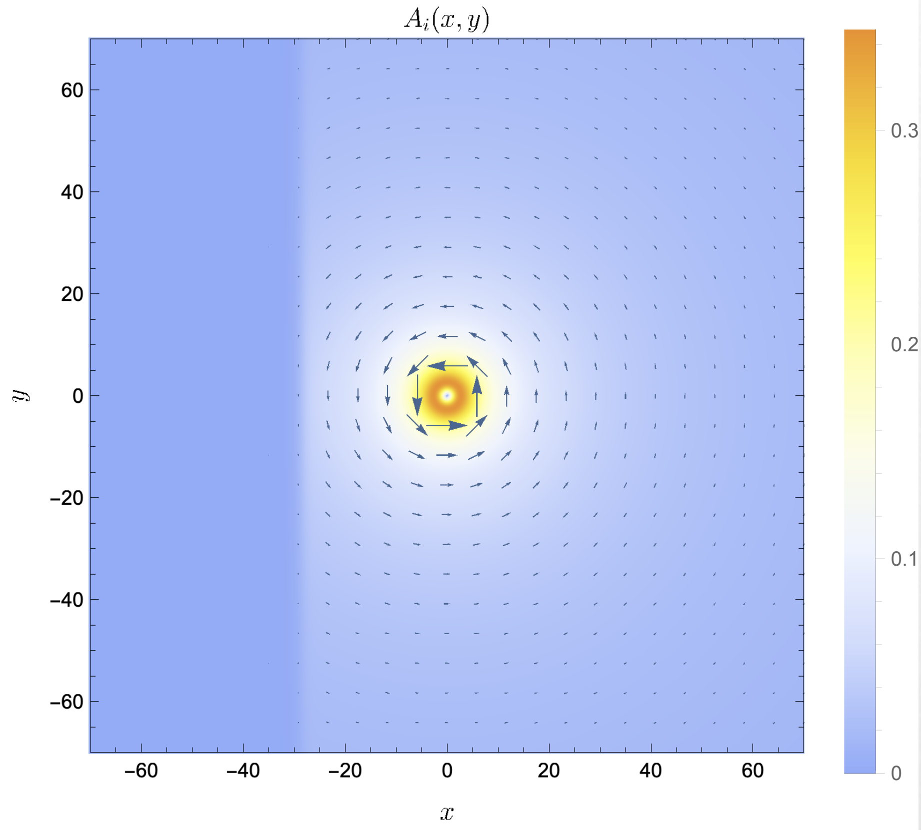
$$n = 1$$

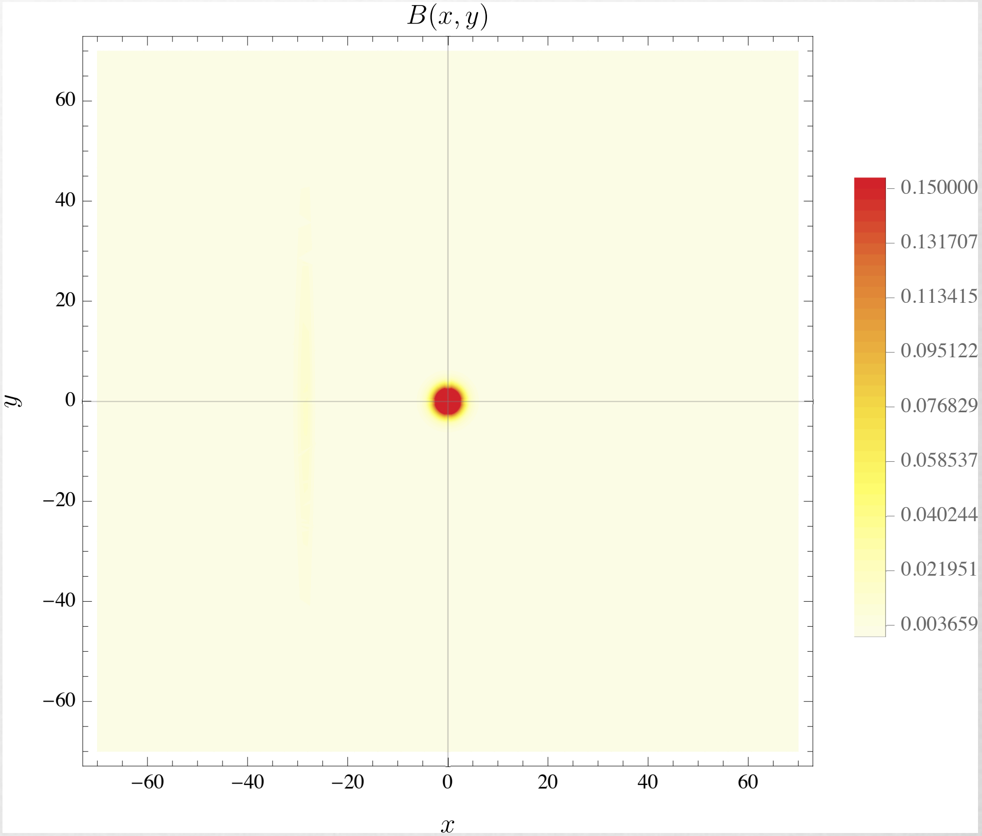
$$l = 40 m_h^{-1}$$

$$v_0 = 1$$

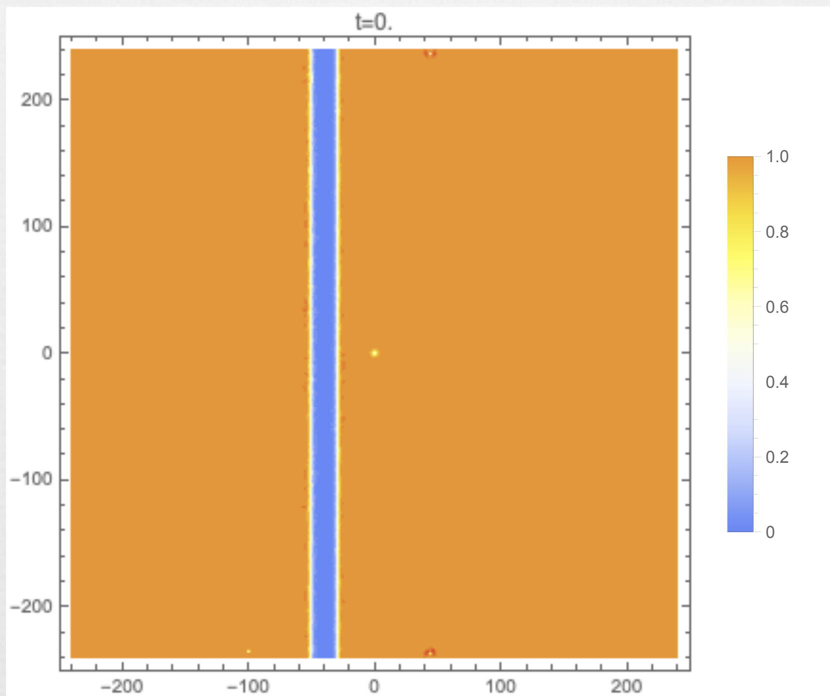


Initial Conditions $A_i(x,y)$ & $B(x,y)$

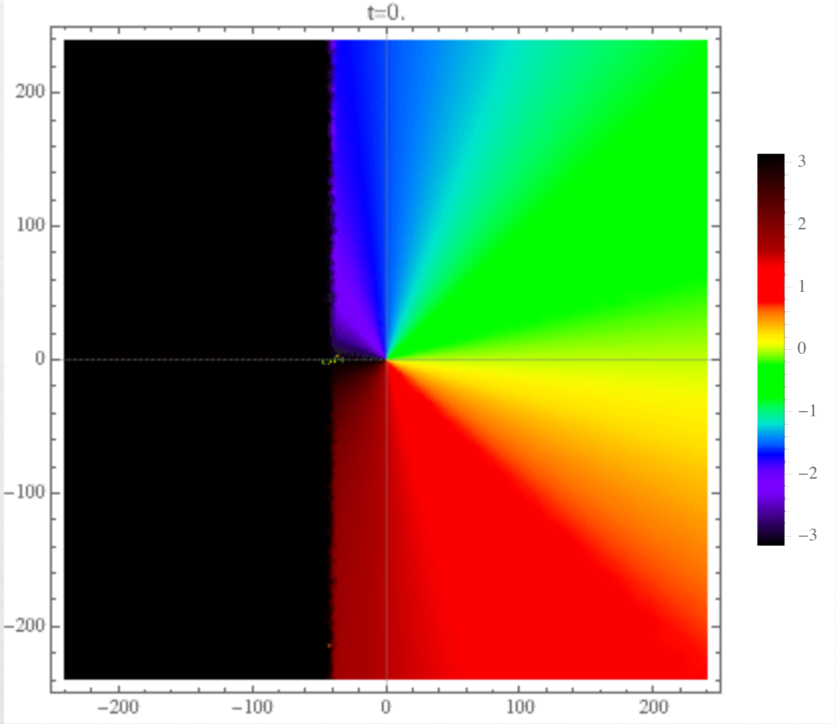




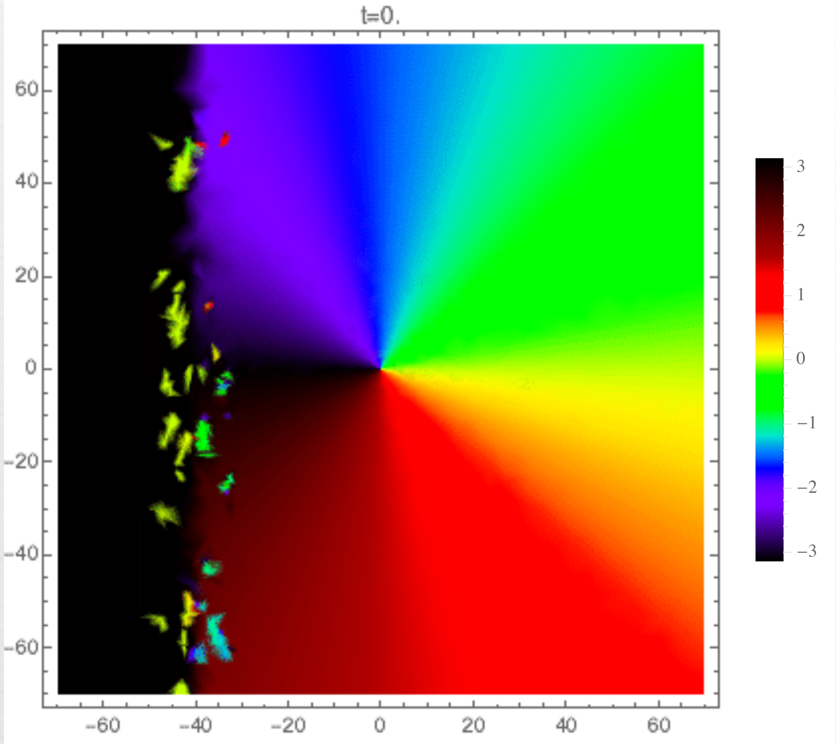
Time Evoultion $|\phi(x, y)|$



Time Evoultion $Arg(\phi(x, y))$

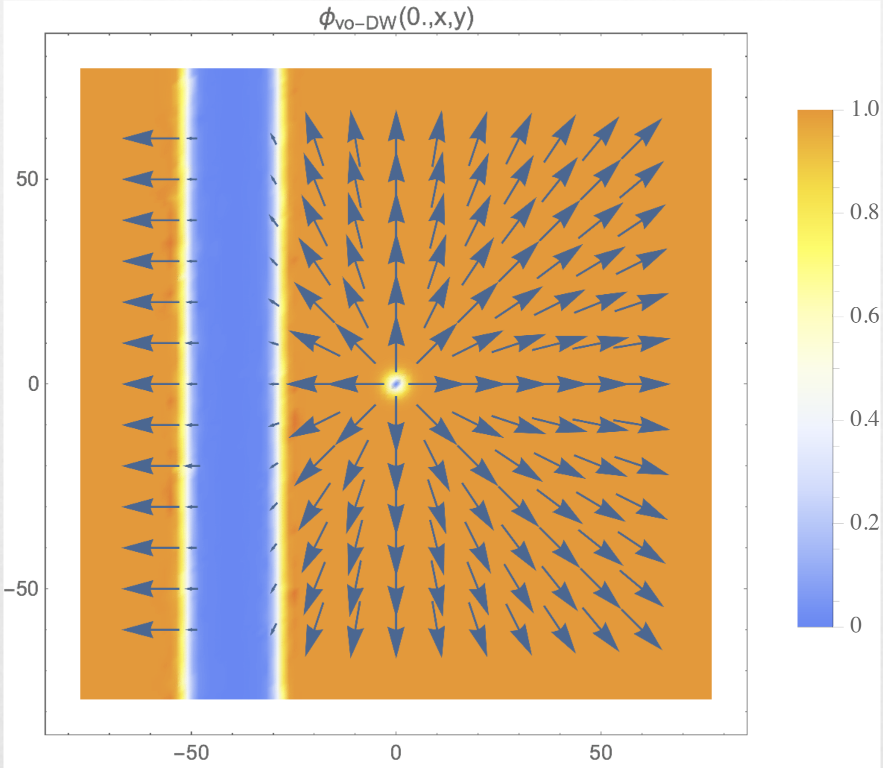


Time Evoultion
$Arg(\phi(x,y))$



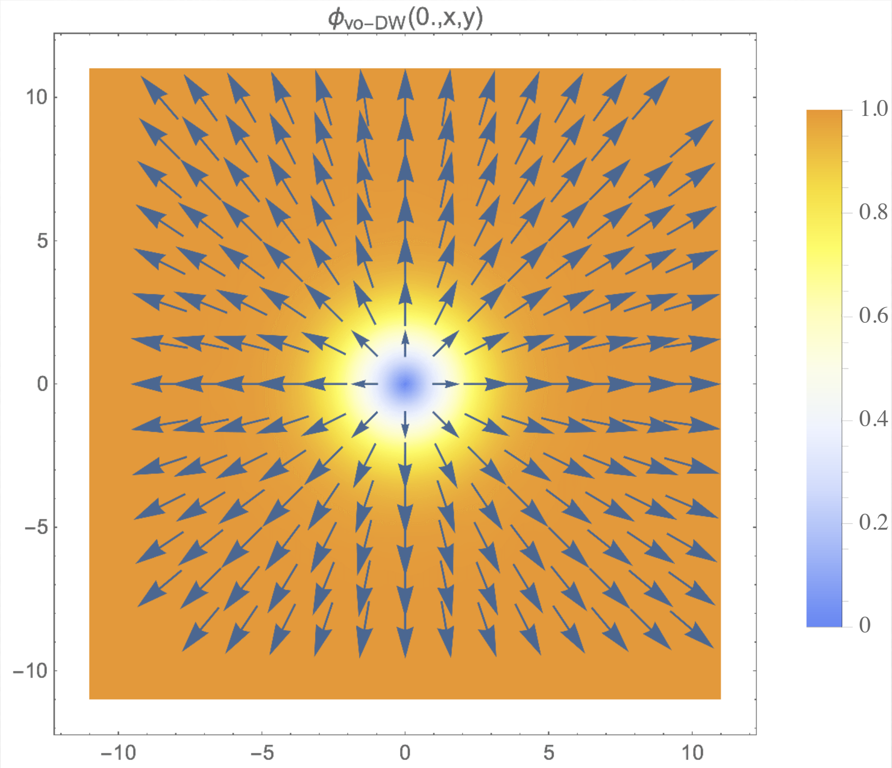
Time Evoultion

$$\phi(x, y)$$



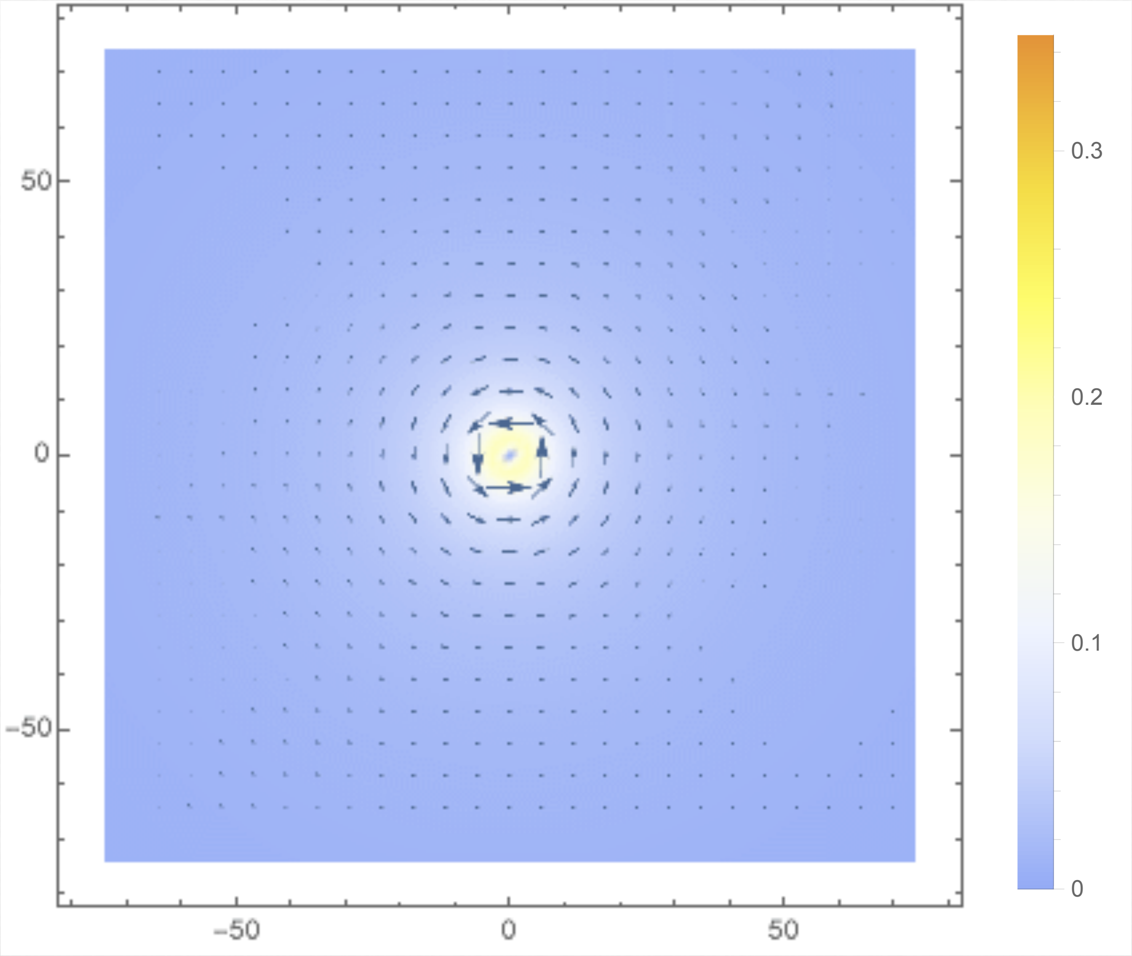
Time Evoultion

$$\phi(x, y)$$



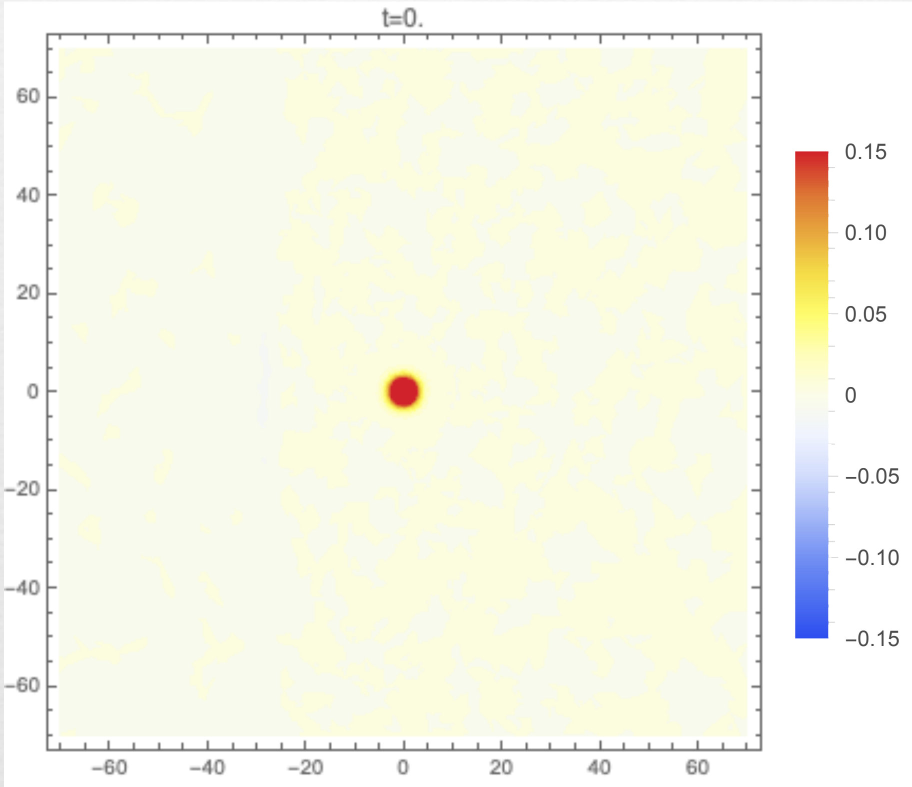
Time Evoultion

$$A_\mu(x, y)$$



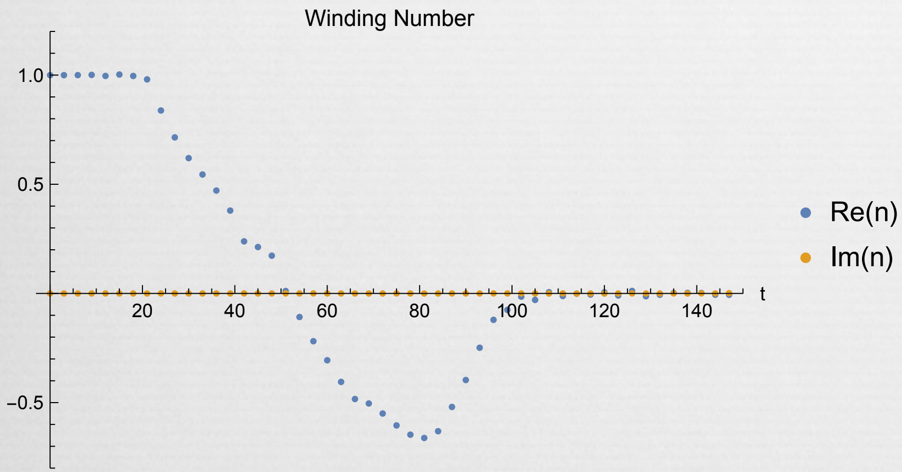
Time Evoultion

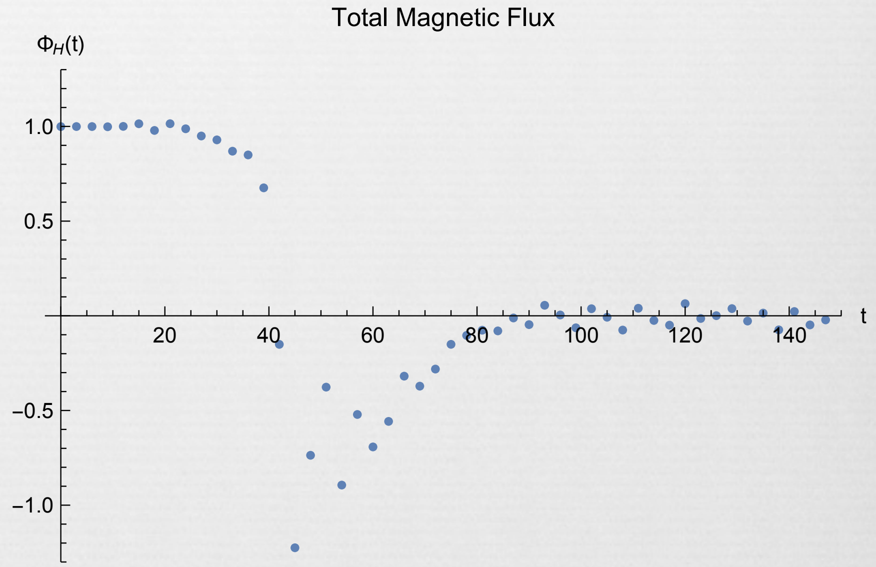
$$B(x, y)$$



Time Evoultion

n

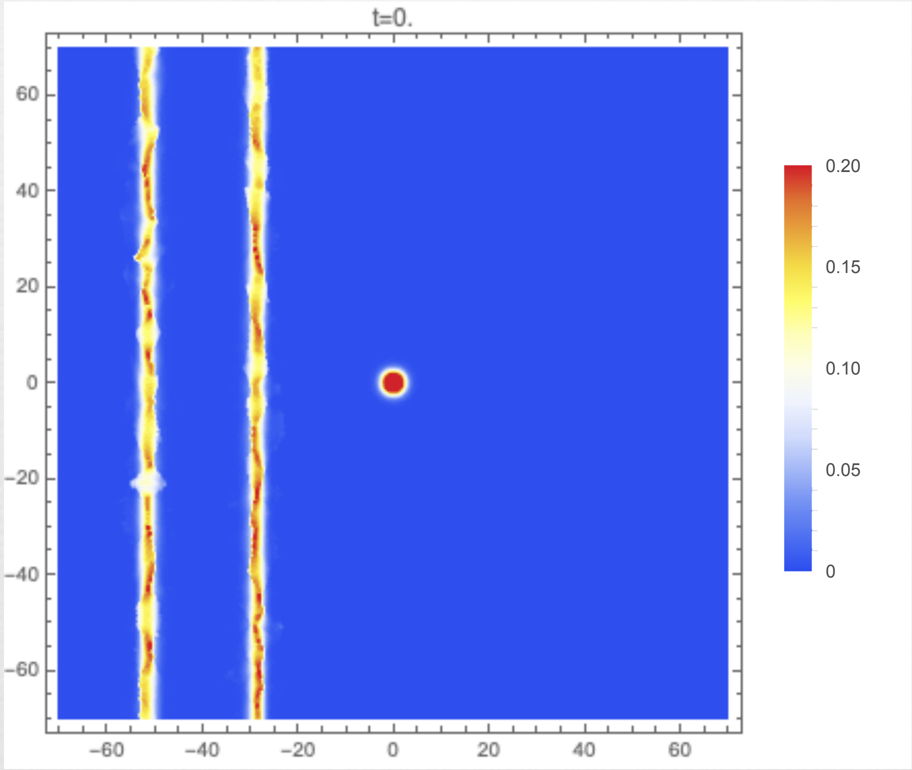




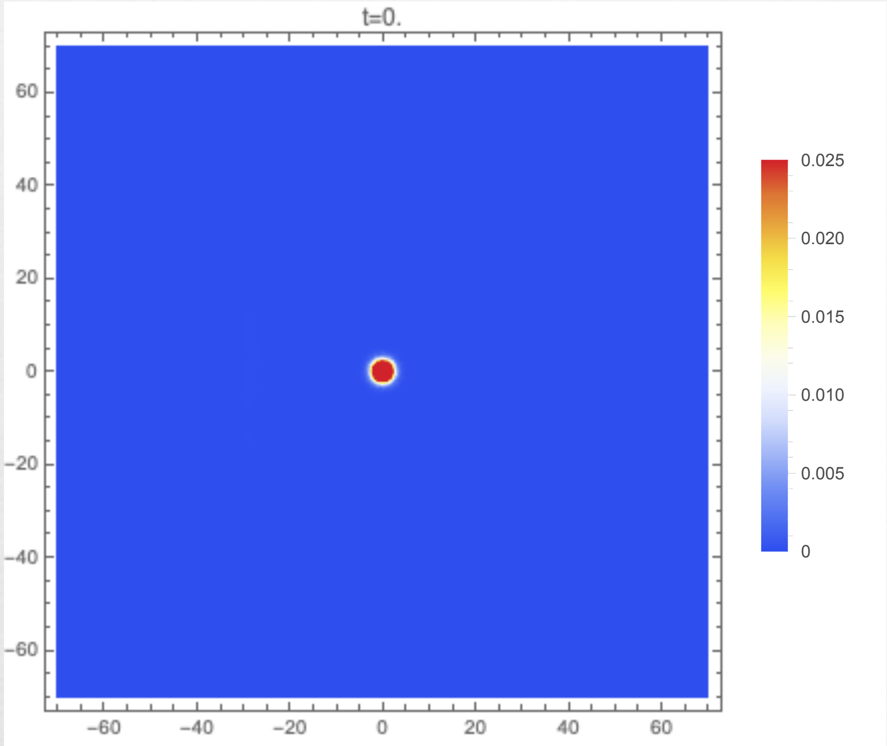
$$n = \frac{1}{2\pi i \nu^2} \oint dx^i \phi^* \partial_i \phi$$

$$n = \frac{e}{2\pi} \int B d^2 x$$

Time Evoultion: Energy Density



Time Evoultion: EM Energy Density

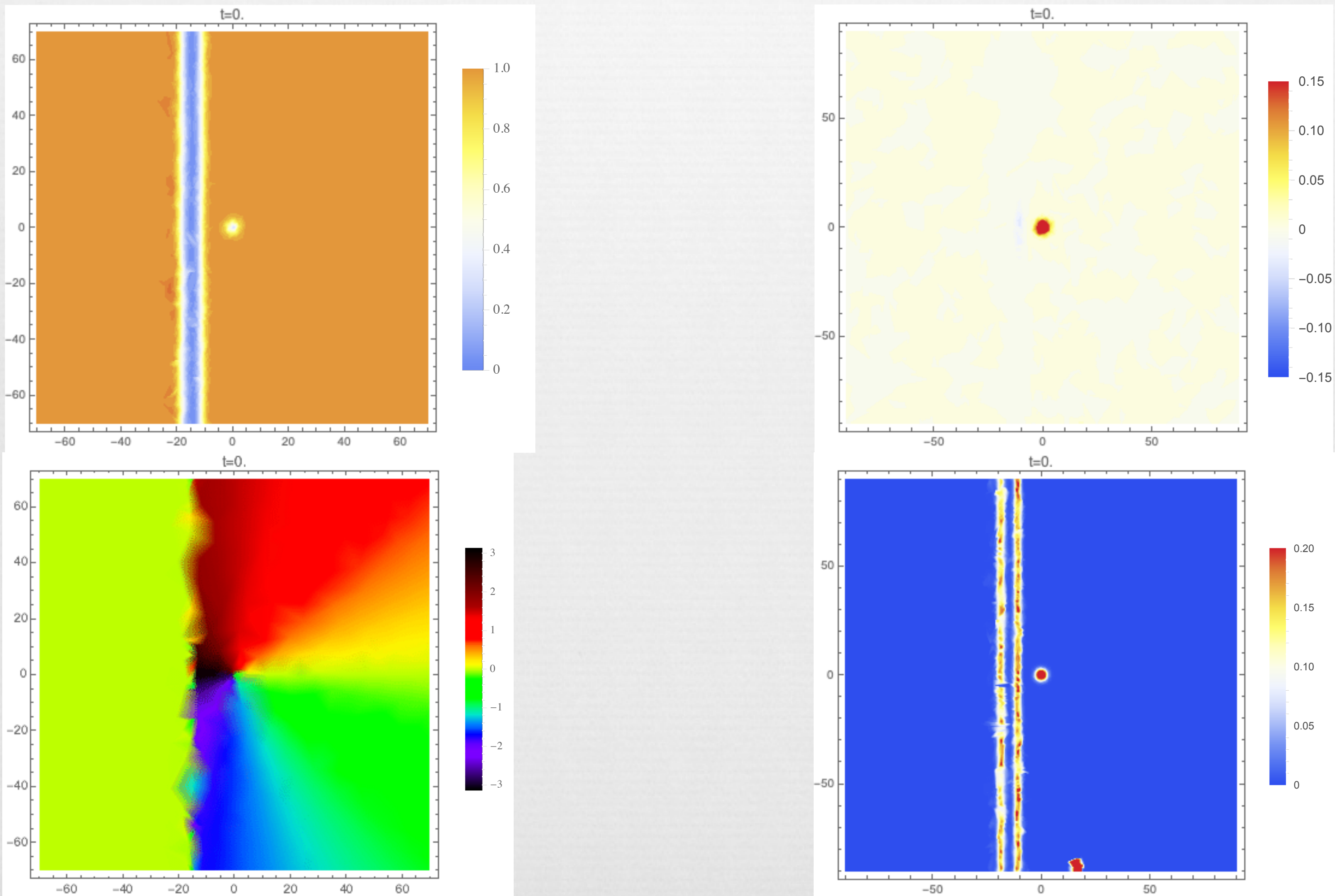


Conclusions and Outlook

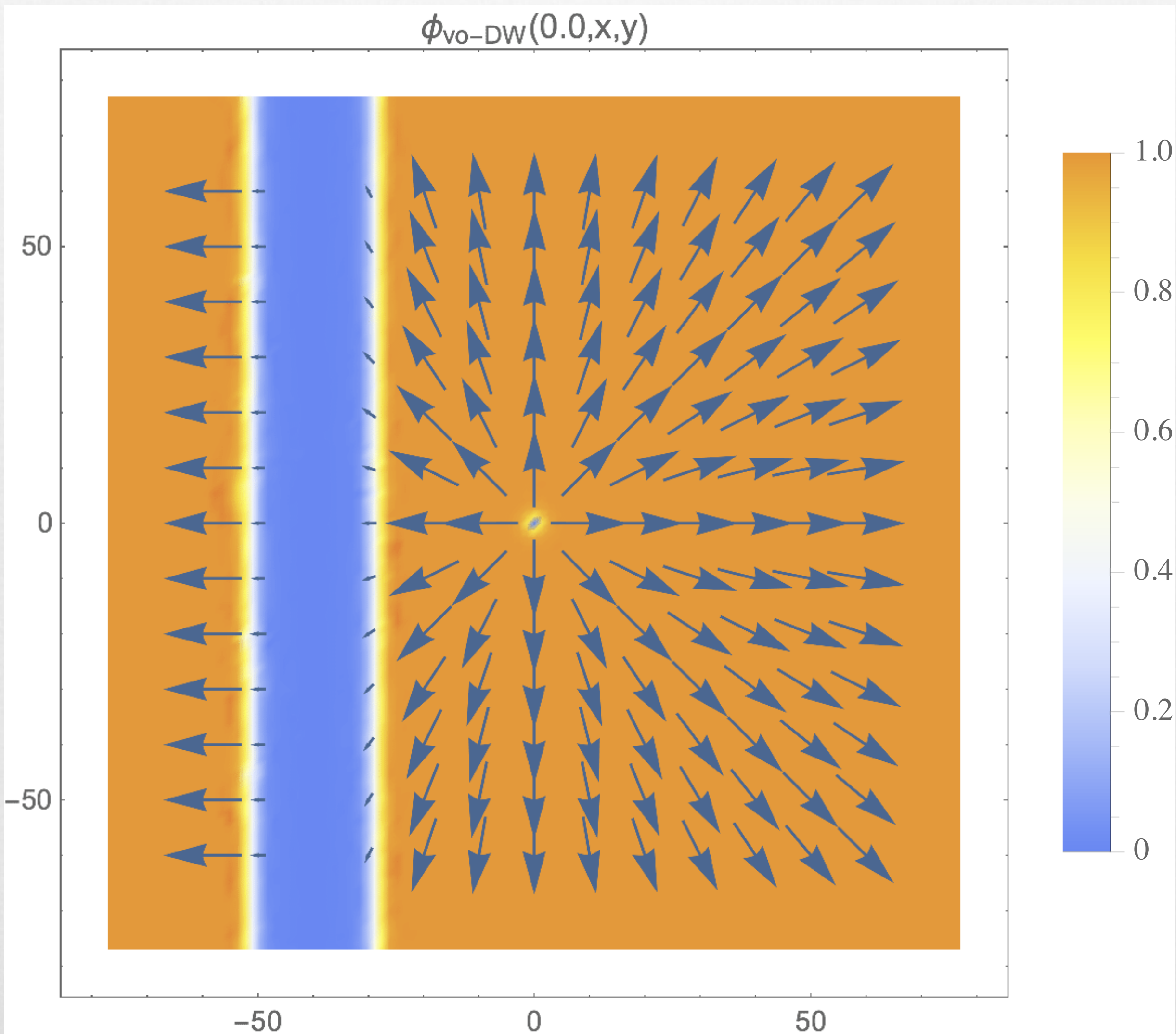
- Dvali-Liu-Vachaspati mechanism is borne out in the ϕ^6-model.
- None of the studied regimes presented a case in which the vortex survive.
- This mechanism can be generalized to other models, and higher dimensions.
- Further evidence for this mechanism includes Interactions between
  - Monopoles and Domain Walls,
  - Skyrmions and Domain Walls,
  - Vortices and Domain Walls in ^3He
- The DLV mechanism suggests that interactions of topological defects lead to the erasure of defects.

Thank You

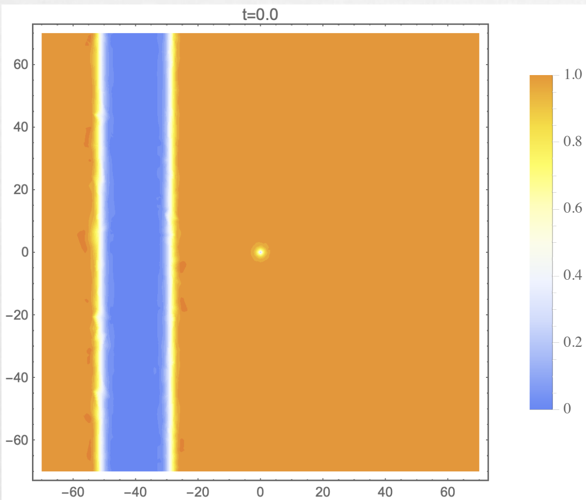
$$l = 15 m_h^{-1}$$



$$m_h < m_v$$



$$m_h < m_v$$



t=0.0
60
40
20
0
−20
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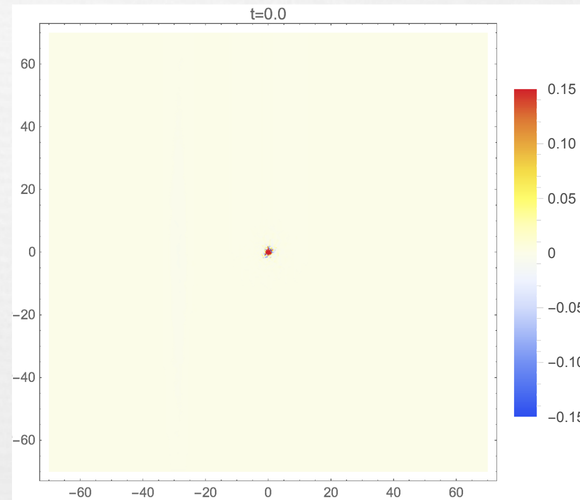
−40
−20
0
20
40
60
1.0
0.8
0.6
0.4
0.2
0



t=0.0
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0.15
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−0.10
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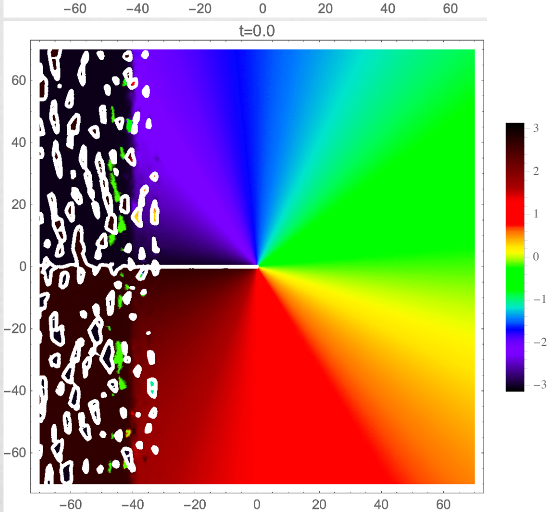

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−60
−40
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0
20
40
60
3
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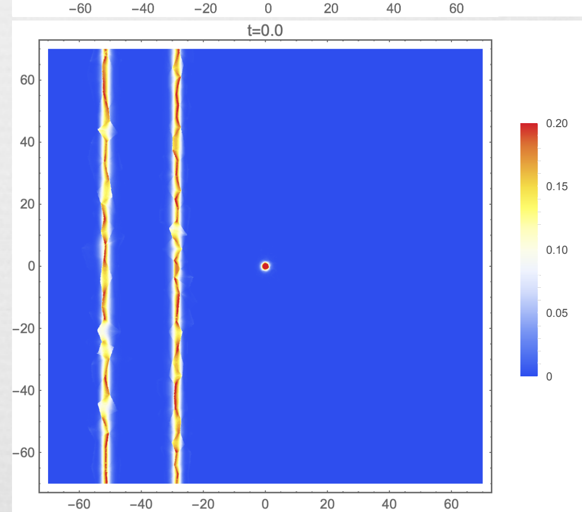
0
−1
−2
−3



t=0.0
60
40
20
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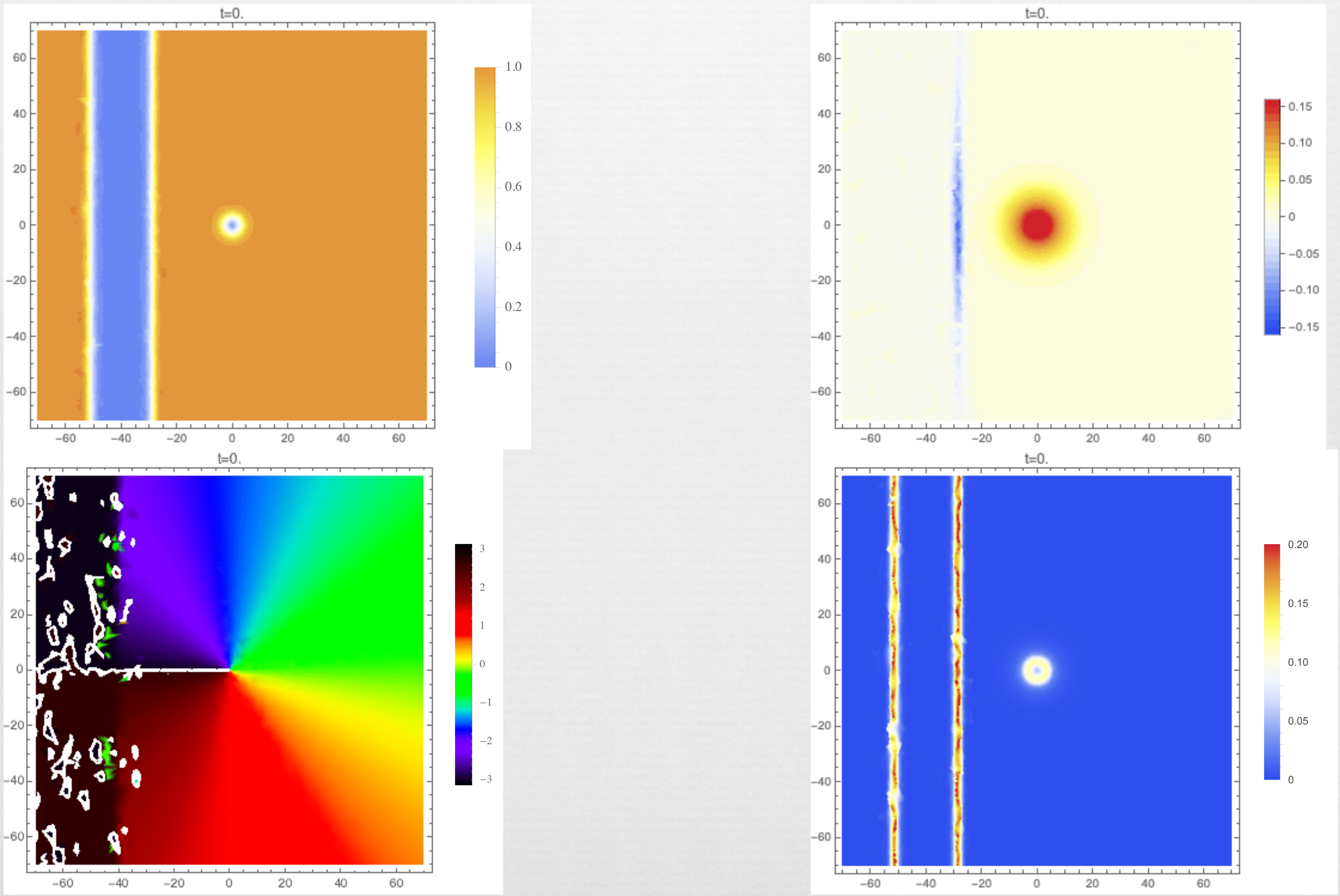
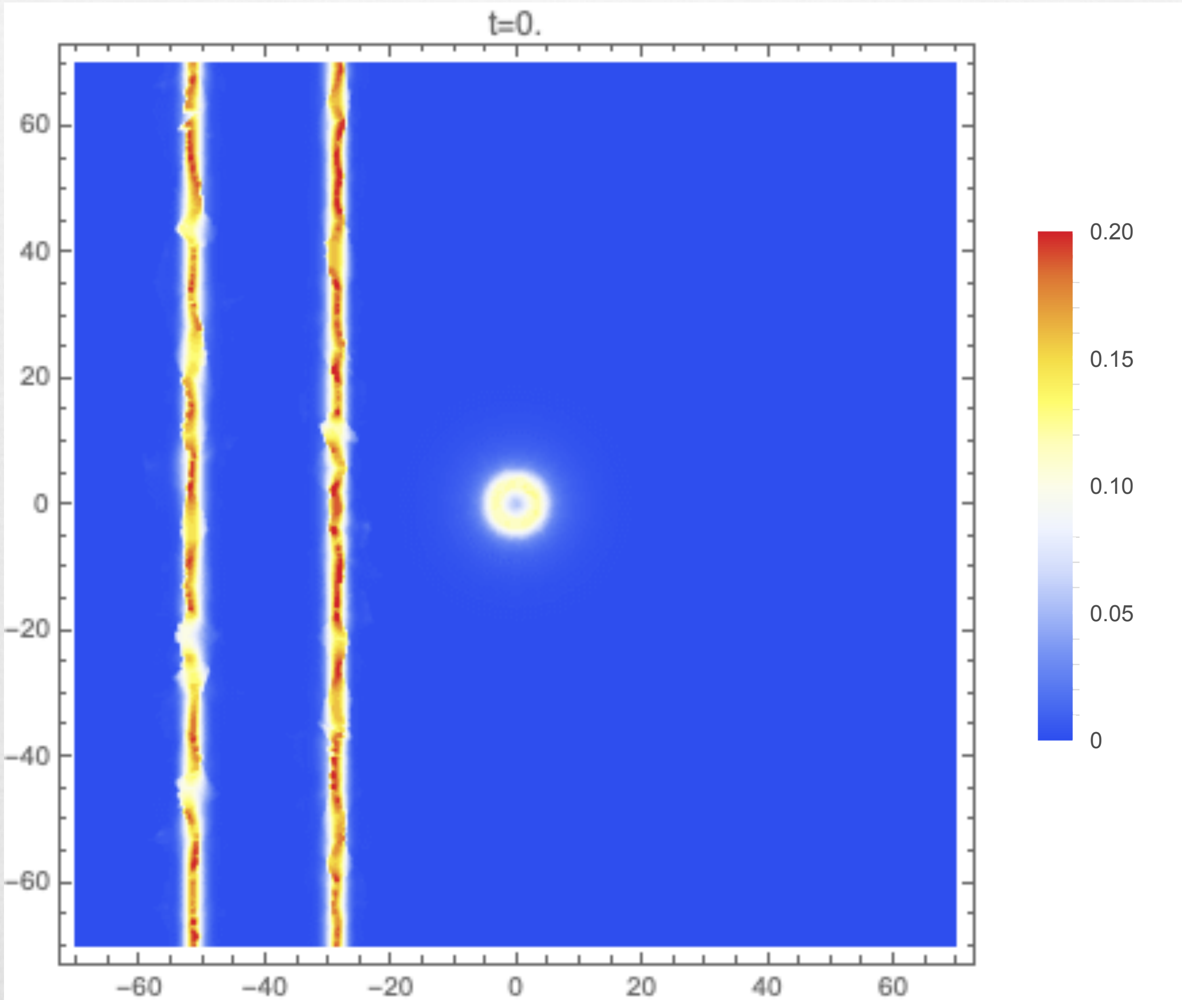
0.20
0.15
0.10
0.05
0

$$m_h > m_v$$

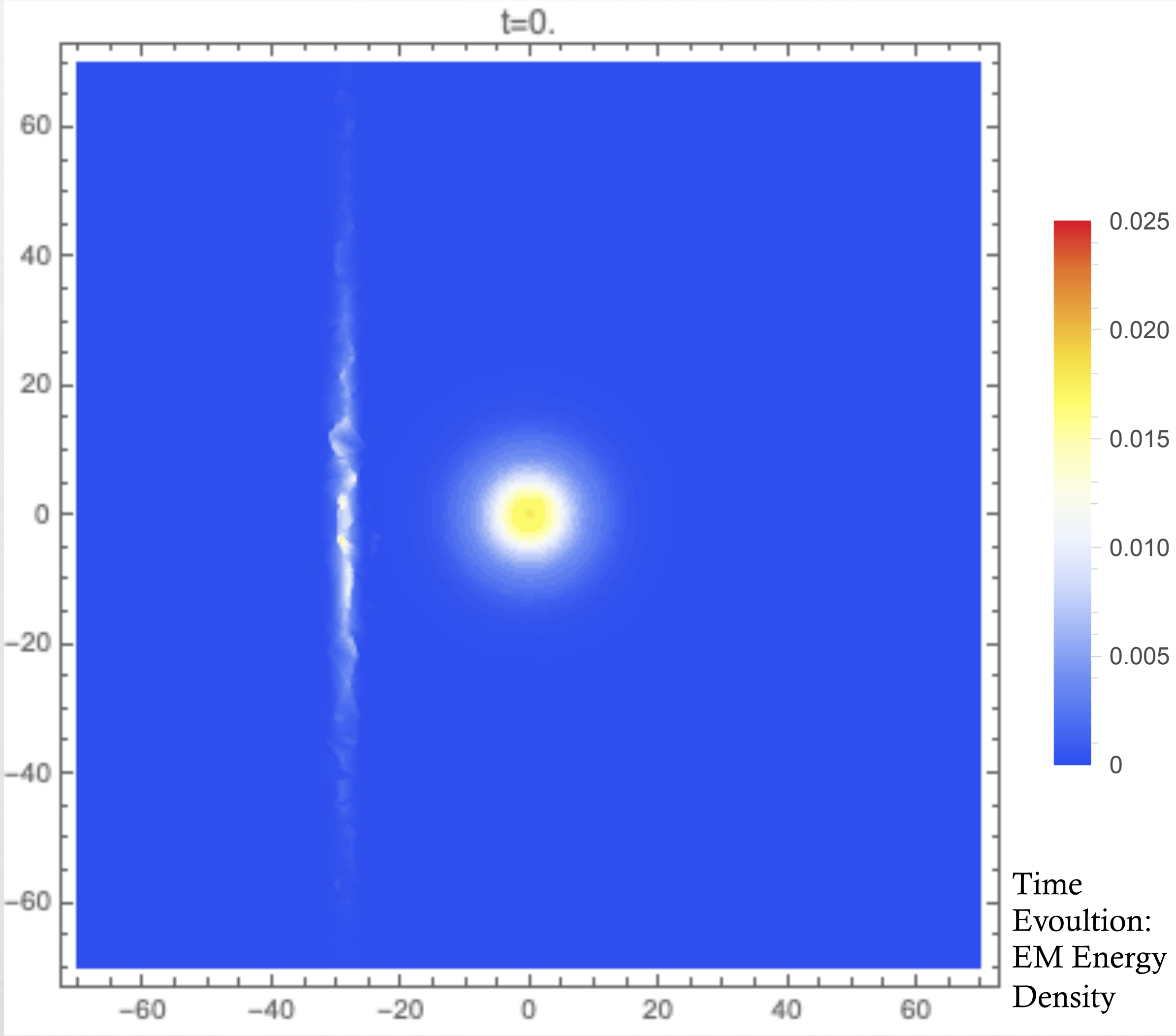


t=0.
1.0
0.8
0.6
0.4
0.2
0
0.15
0.10
0.05
0
−0.05
−0.10
−0.15
3
2
1
0
−1
−2
−3
0.20
0.15
0.10
0.05
0

$$m_h > m_v$$

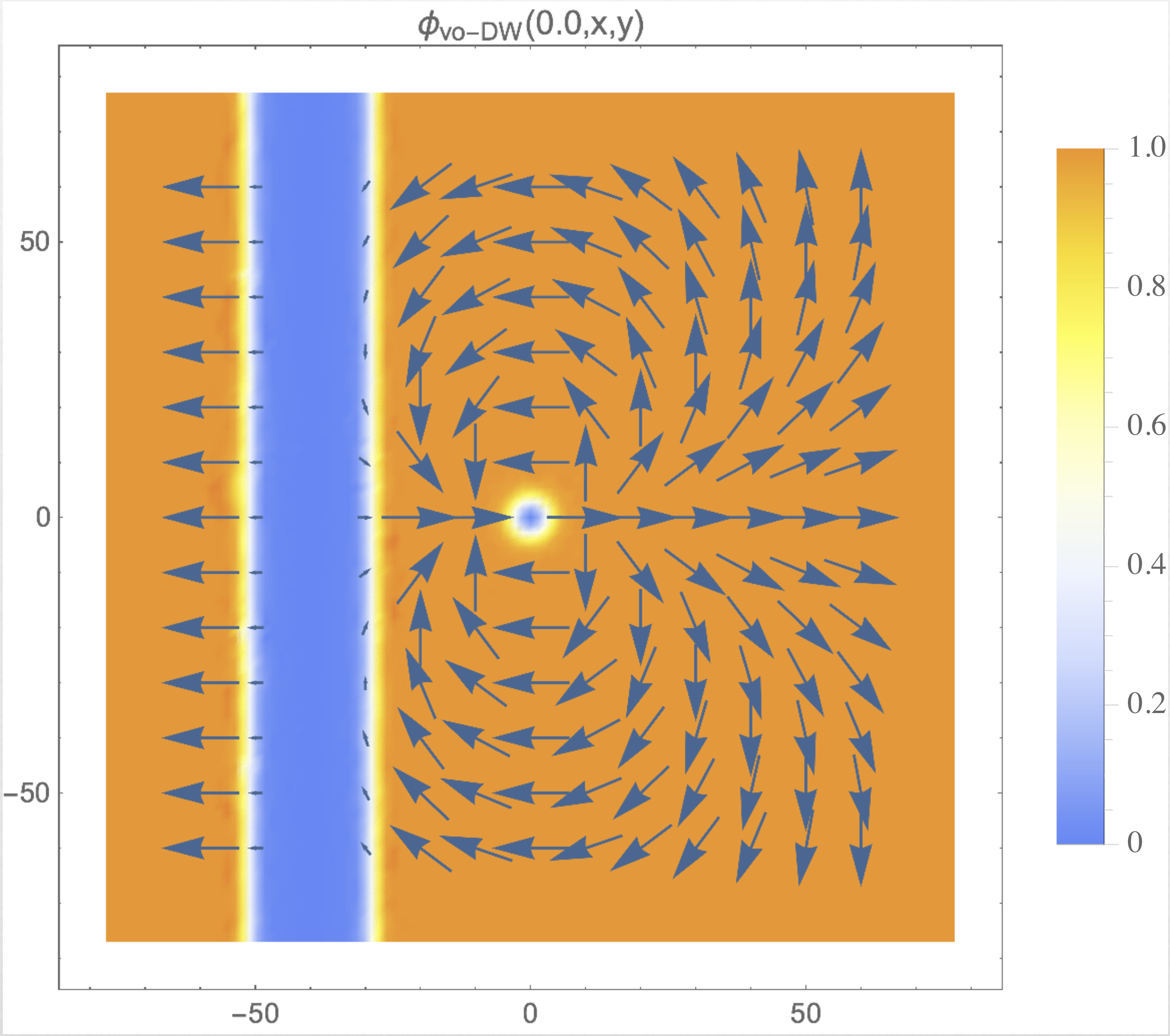


$$m_h > m_v$$



Time Evoultion: EM Energy Density

n=2



Topological Defects in the ϕ^6-Model

- The topology of the vacuum manifold $\mathcal{M}$ determines the spectrum of defects of the model.

Domain Walls: $\pi_0(\mathcal{M}) = \mathbb{Z}_2$

$$\pi_1(\mathcal{M}_\mathrm{C}) = 0$$

Vortex Lines: $\pi_1(\mathcal{M}_\mathrm{H}) = \mathbb{Z}_2$

$$\pi_n(\mathcal{M}_\mathrm{C}) = 0,\ n \geq 2$$
$$\pi_n(\mathcal{M}_\mathrm{H}) = 0,\ n \geq 2$$

Domain Walls in the ϕ^6-Model

- (1+1)-dimensions
- Constraining the field ϕ to be a real field: $\phi = \frac{\chi}{\sqrt{2}}$

$$\mathcal{L}_{DW} = \frac{1}{2}\partial_\mu \chi \partial^\mu \chi - \lambda^2 \frac{\chi^2}{2}\left(\frac{\chi^2}{2} - \nu^2\right)^2 .$$

- Domain walls are solitonic configurations of $\chi(x)$, with the following asymptotic behavior

$$\lim_{x \to -\infty} \chi(x) = 0$$

$$\lim_{x \to \infty} \chi(x) = \pm\sqrt{2}\nu$$

Vortex in the ϕ^6-Model

- In (2+1) dimensions
- Asymptotic Field Configuration as $r \to \infty$

$$\phi \to \nu e^{ig(\theta)} = \nu e^{in\theta}$$

$$A_i \to \frac{1}{e}\partial_i g(\theta) = -\frac{n}{er}\epsilon_{ij}n_j$$

where $n \in \mathbb{Z}$ is the *winding number.*

Vortex in the ϕ^6-Model

- Ansatz[4] for Vortex Profile

$$\phi(r,\theta) = \nu e^{in\theta} F(r)$$

$$A_i(r,\theta) = -\frac{n}{er}\epsilon_{ij} n_j A(r)$$

- The field equations

$$\Box\phi + \frac{\partial V(\phi)}{\partial \phi^*} = 0,$$

$$\partial_\mu F^{\mu\nu} = j^\nu,$$

[4] H.B. Nielsen, P. Olesen, Nuc. Phys. B, Vol. 61, 45-61, (1973)

Vortex in the ϕ^6-Model

- The field equations become:

$$0 = -\,rF''(r) - F'(r) + \frac{(1-A(r))^2}{r} n^2 F(r) + \frac{m_h^2}{4} rF(r)\left(F(r)^2 - 1\right)\left(3F(r)^2 - 1\right)$$

$$0 = -\frac{A''(r)}{r} + \frac{A'(r)}{r^2} - \frac{m_v^2}{r}(1 - A(r))F(r)^2$$