Looking for Stringy Bosenova

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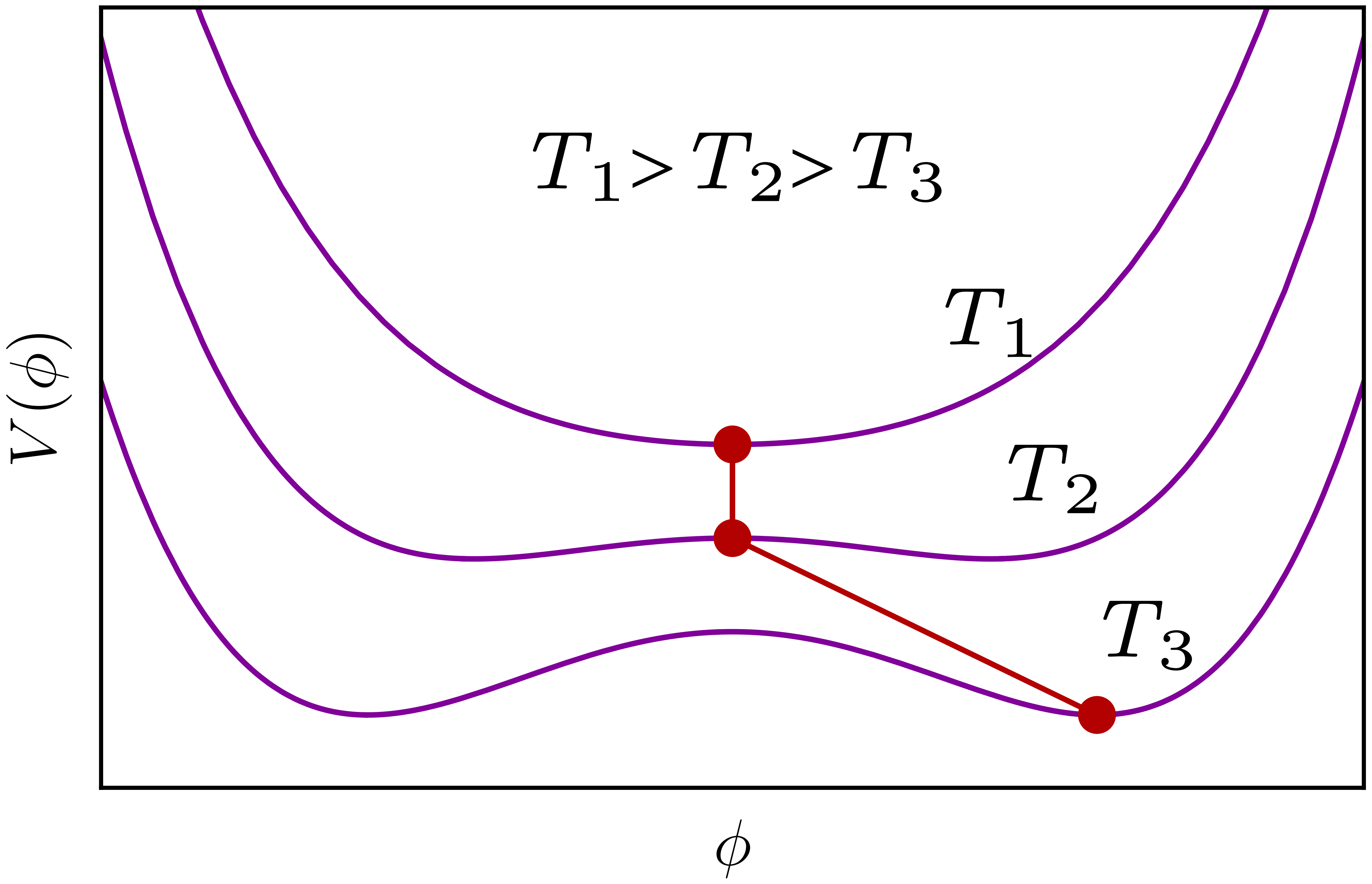
Abelian-Higgs model

$$\mathscr{L} = \left| D_\mu \Phi \right|^2 - \frac{1}{4} F'^{\mu\nu} F'_{\mu\nu} + \frac{\lambda}{4} \left(|\Phi|^2 - v^2 \right)^2$$

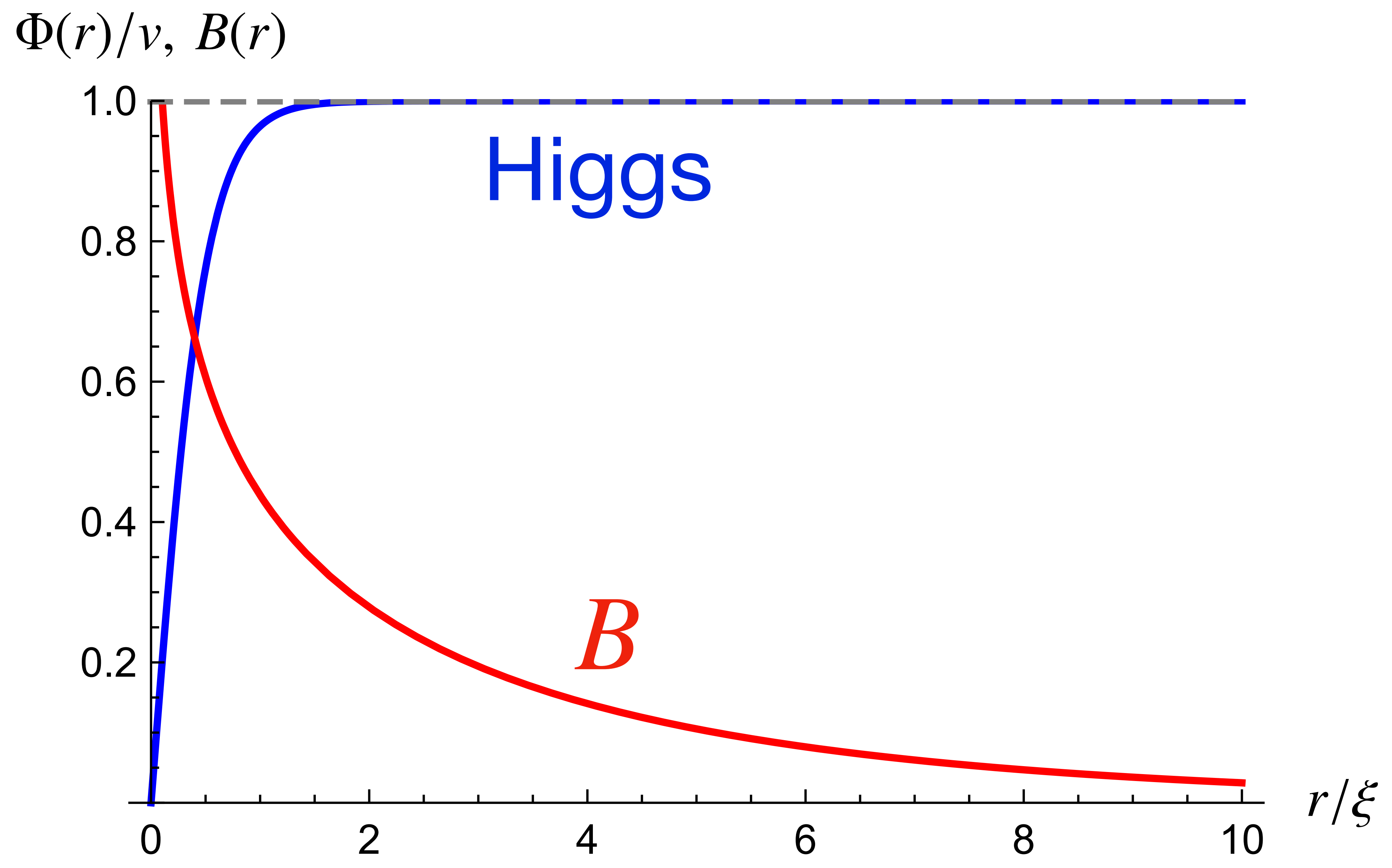
At high temperatures $\langle \Phi \rangle = 0, \quad m_{A'} = 0$

In the vacuum $\langle \Phi \rangle = v, \quad m_{A'} = gv$

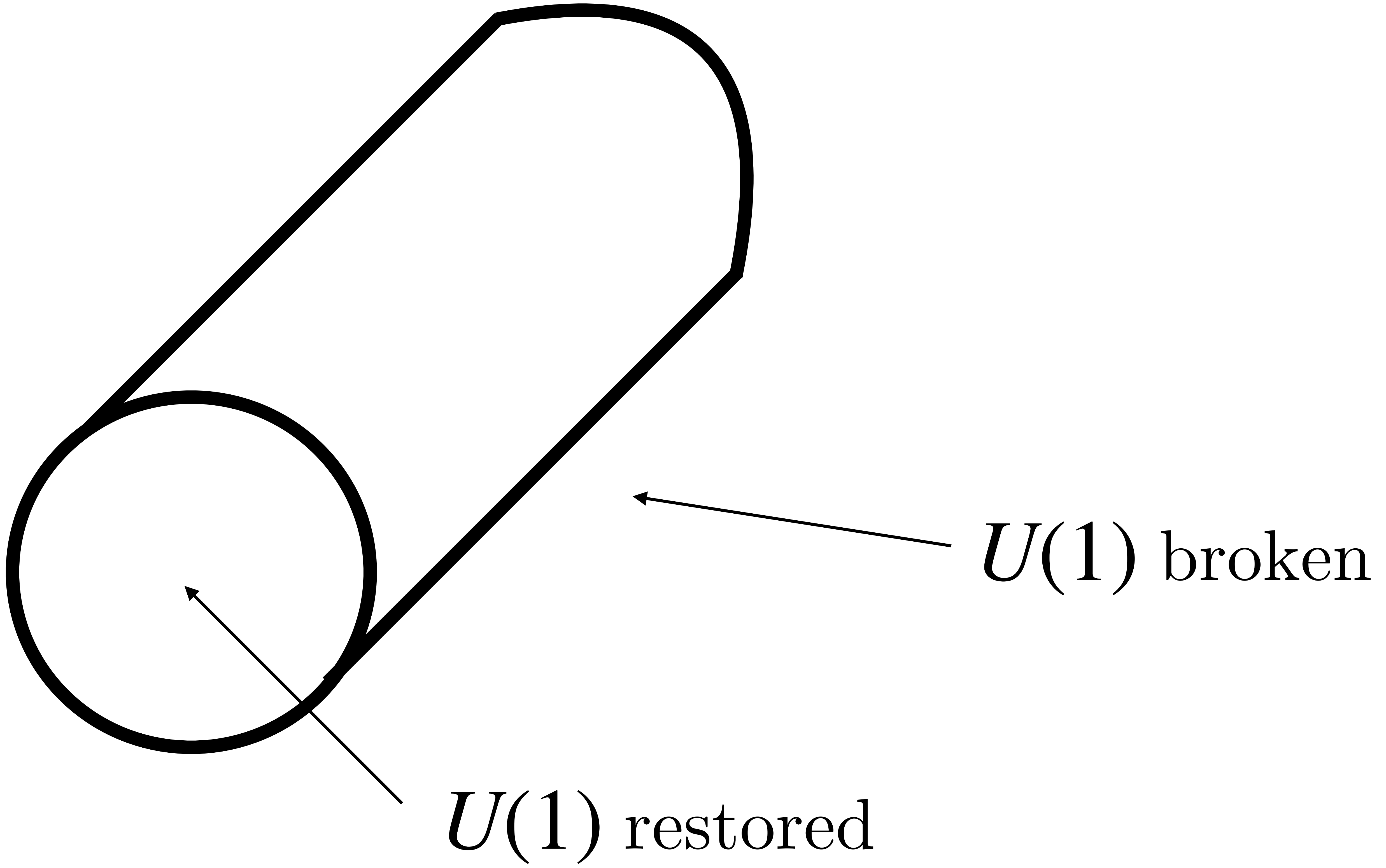


Another solution - vortices aka strings

Unstable - shrink due to emission of gauge bosons



(East, Huang, 2022)



String tension $\mu = \pi v^2$

How can we produce them in astrophysical environments?

Ground states

$$\mathscr{L} = \left| D_\mu \Phi \right|^2 - \frac{1}{4} F'^{\mu\nu} F'_{\mu\nu} + \frac{\lambda}{4} \left(|\Phi|^2 - v^2 \right)^2$$

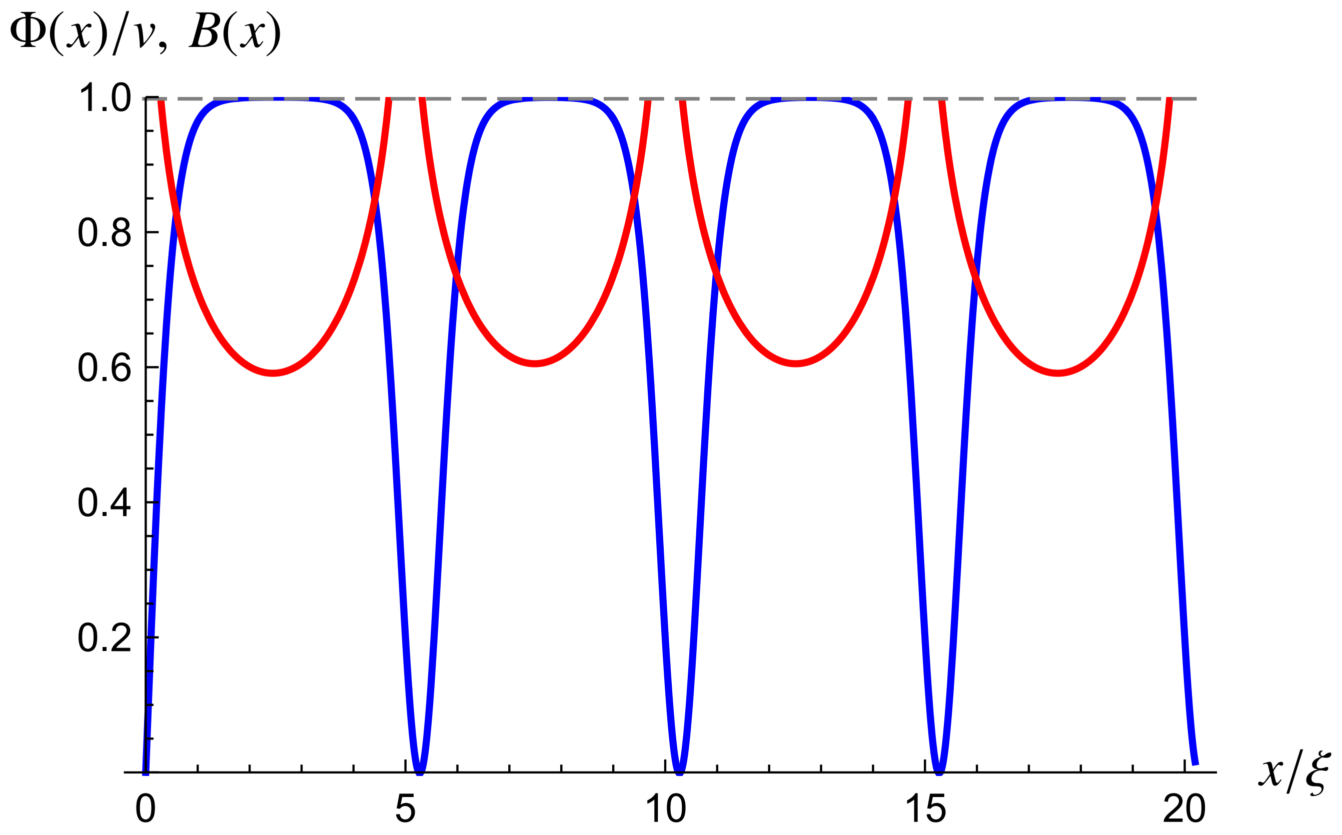
$F'^{\mu\nu}, B'$

$\frac{\lambda v^2}{g}$

Ground state: $\langle \Phi \rangle = 0, \quad m_{A'} = 0$

Phase transition: String lattice *(East, Huang, 2022)*

$\sqrt{\lambda} v^2$



Ground state: Strings *(Abrikosov, 1957)*

$g v^2$

(East, Huang, 2022)

Ground state: $\langle \Phi \rangle = v, \quad m_{A'} = g v$

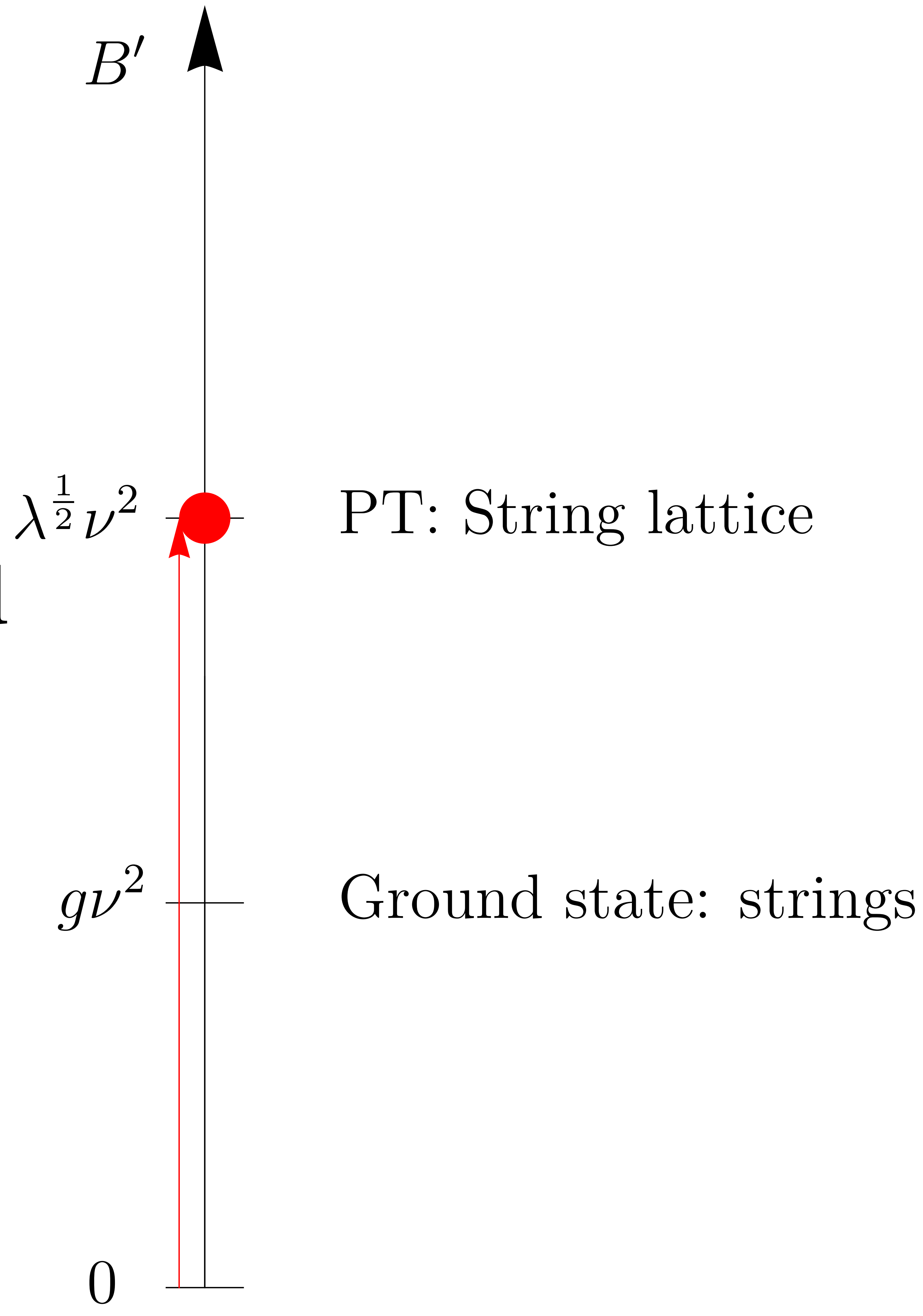
0

String production overview

In our scenario we are producing strings in an environment where initially electromagnetic fields are negligible.

The field then increases in magnitude until the threshold for the phase transition is reached.

At the phase transition the lattice of strings is formed.



Gravitational atom

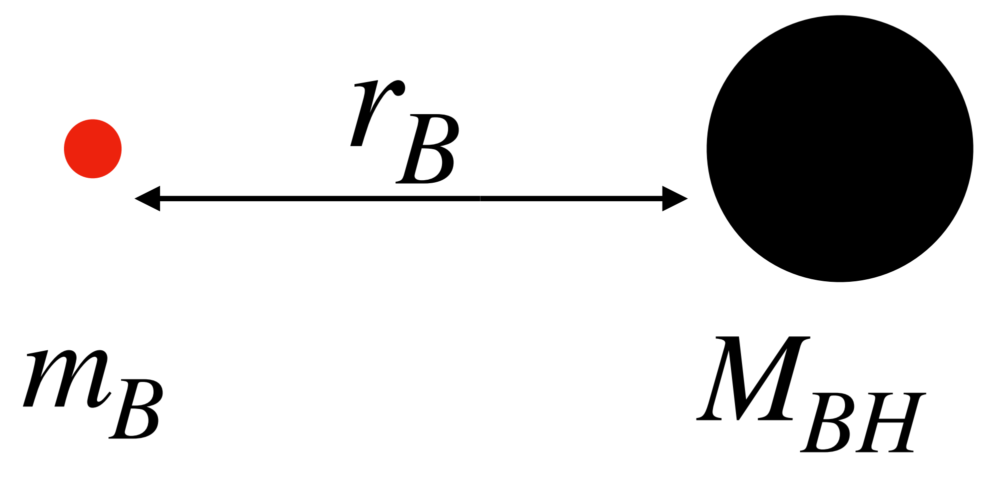
Ultralight bosons form bound states with BH

The states are indexed in a similar way to hydrogen atom, e.g. n, l, j, m

The energy of the state

$$\omega_n \simeq m_B \left(1 - \frac{\alpha_G^2}{2n^2}\right) \approx m_B$$

$$\alpha_{em} = \frac{4\pi}{e^2} \qquad \alpha_G = GM_{BH}m_B$$



$$r_H \sim \frac{1}{\alpha_{em} m_e} \rightarrow r_B \sim \frac{1}{\alpha_G m_B}$$

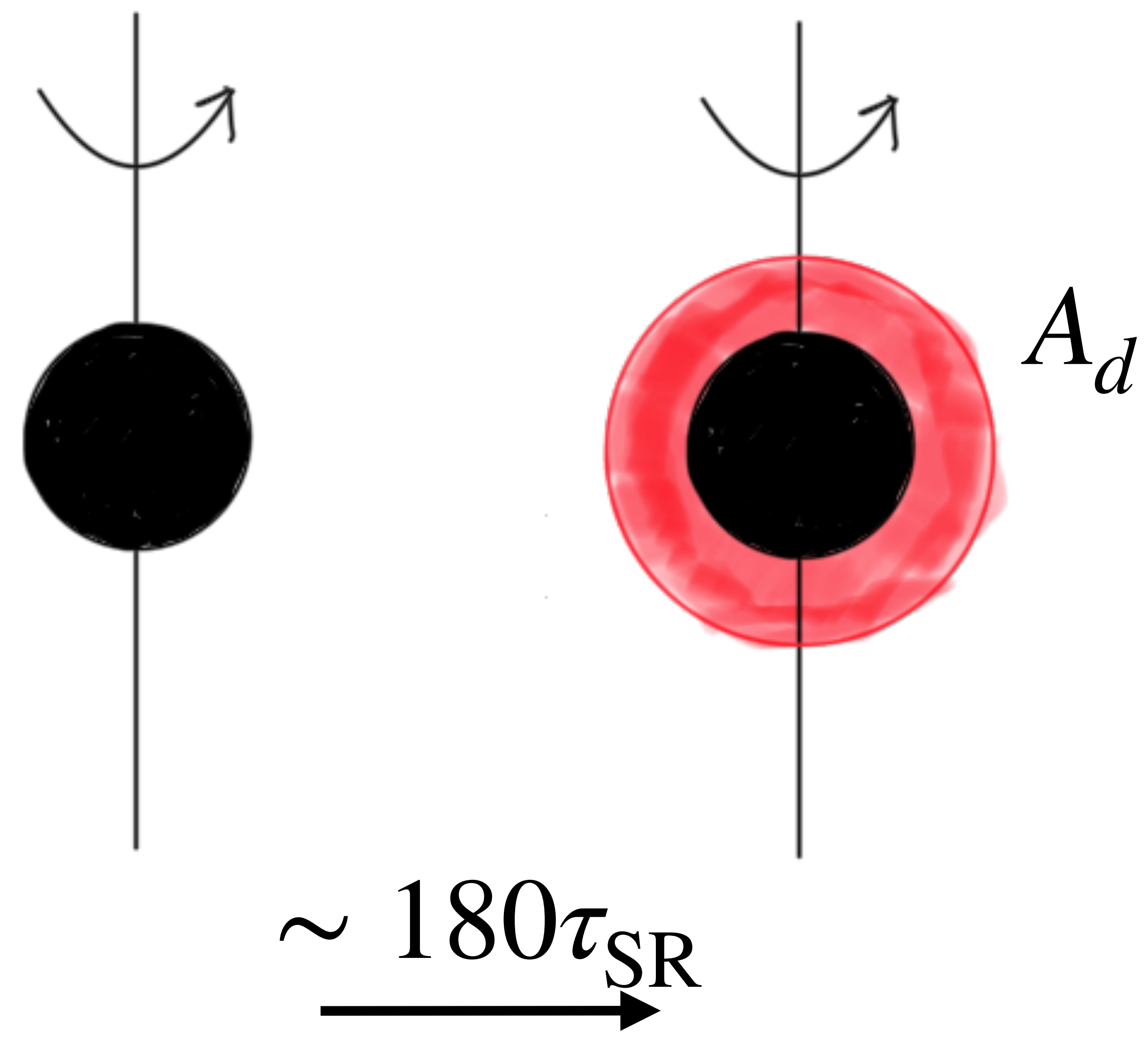
Superradiance

These bound state can be unstable to exponential growth if its energy is lower than the angular velocity of the horizon

$$\omega \leq \Omega_{\rm BH} = \frac{1}{2GM_{\rm BH}}\left(\frac{a_*}{1+\sqrt{1-a_*^2}}\right)$$

The growth happens at the rate $\tau_{\rm SR}^{-1} \simeq 4\alpha^7(\Omega_{\rm BH} - m) \simeq 4a_*\alpha^6 m$,

The superradiance cloud saturates when $\Omega_{\rm BH} = \omega$, after around 180 e-folds of growth.



Bosenova cycle

1. If $\Omega_{\rm BH} \le \omega$ is satisfied the SR starts

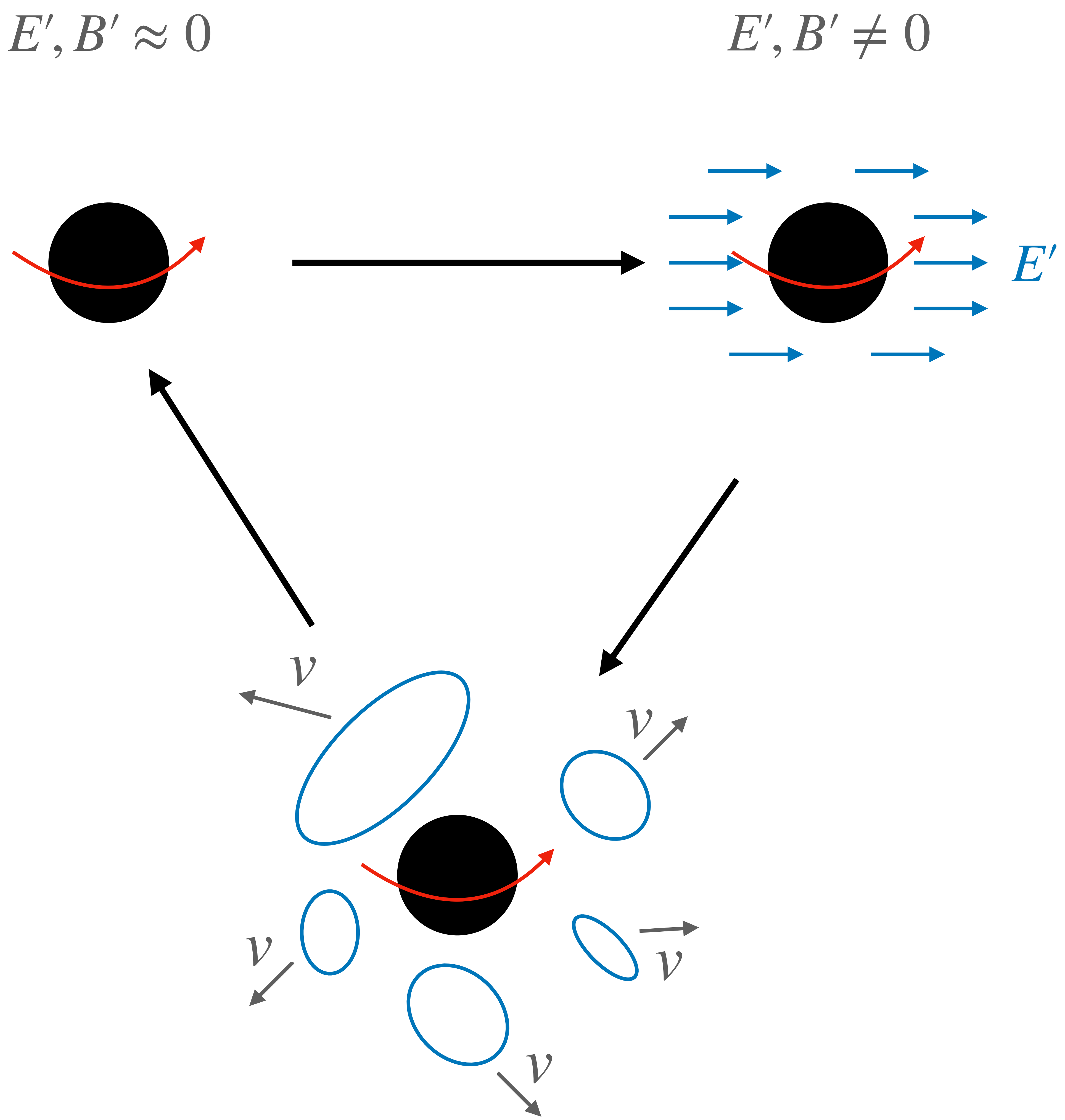
2. SR proceeds at a rate $\Gamma_{\rm SR} \simeq 4a_*\alpha^6 m$, the vector field accumulatess

3. Once $F \sim \sqrt{\lambda} v^2$, string lattice forms and absorbs electromagnetic fields from the cloud.

After that an O(1) fraction of strings gets ejected from the Black Hole.

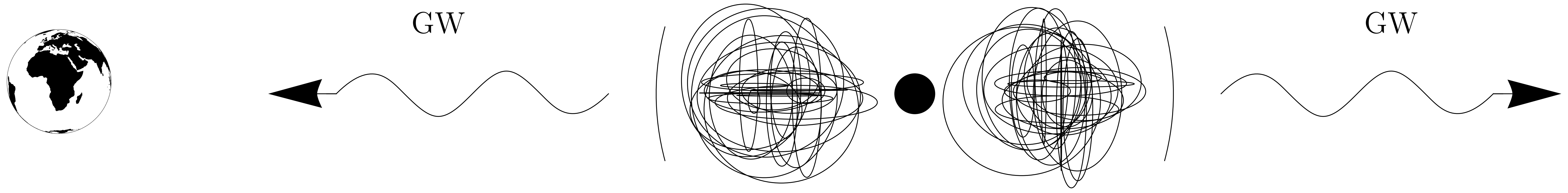
4. As long as $\Omega_{\rm BH} \le \omega$ can be satisfied the process starts again

The burst repeats every $\sim 180\tau_{\rm SR}$ until there is not enough angular momentum to initiate phase transition

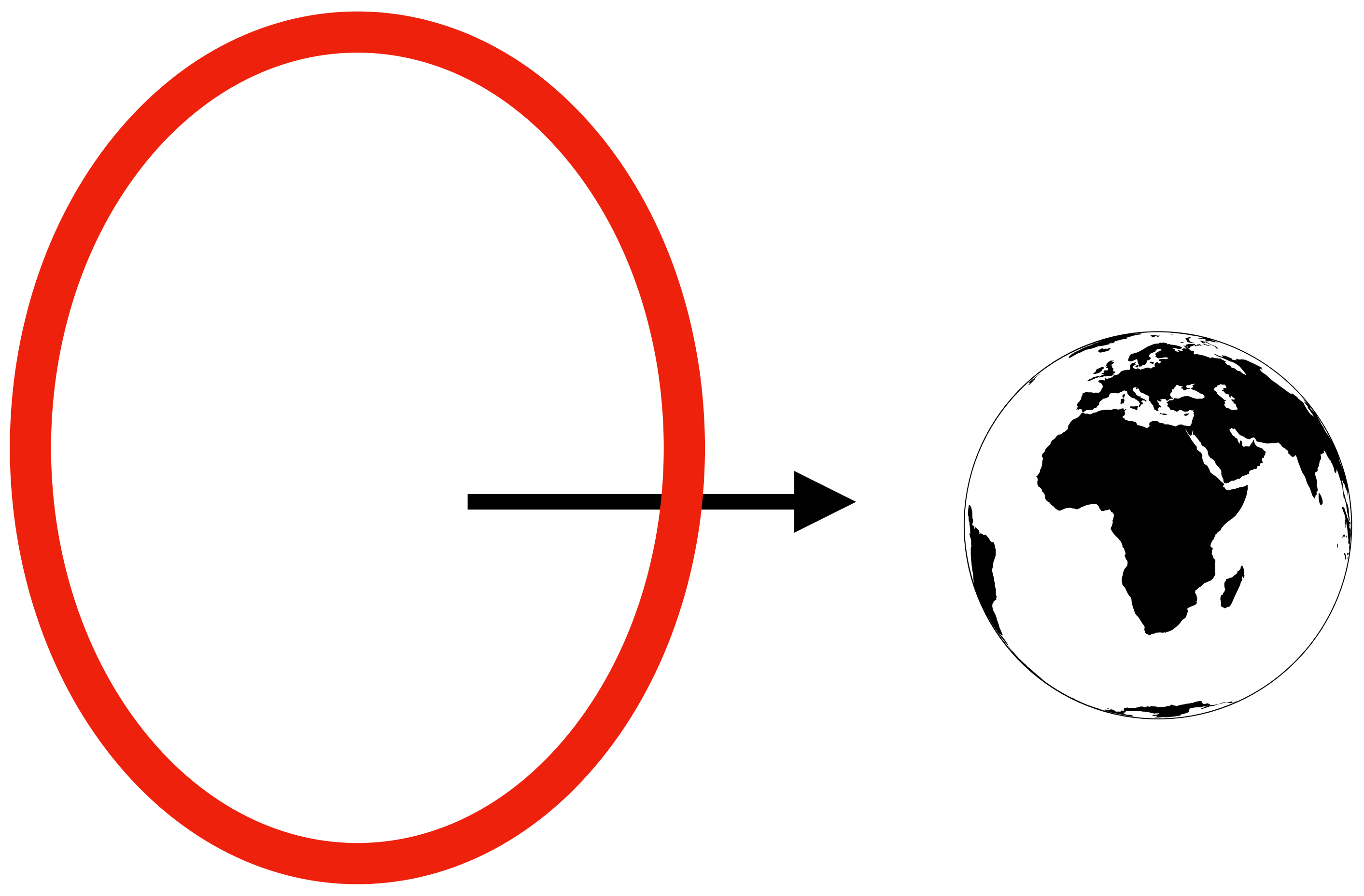


Goal: Detect strings

Indirect -> GW



Direct -> B-L passing through Earth



Gravitational signatures

Emission by the cloud

Power per string

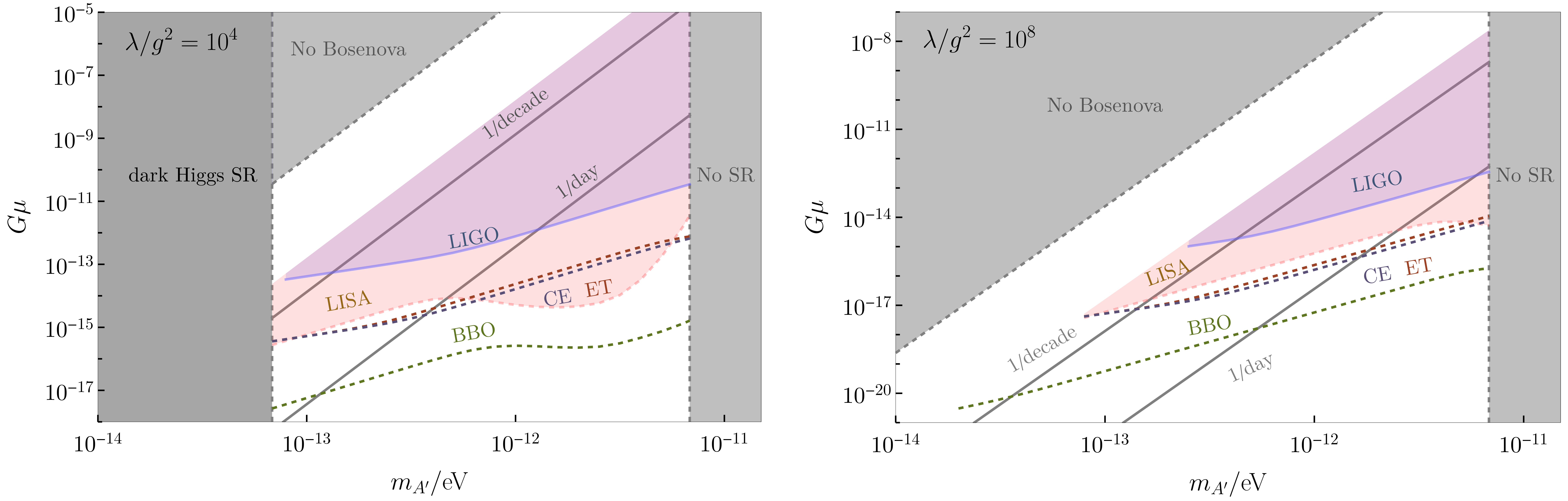
$$\frac{d\rho_{\mathrm{GW}}}{d\log f} = \frac{1}{4\pi d^2 \Delta t} \int_{t=0,\, l=0}^{t=\infty,\, l=\infty} dt \, \boxed{dl\, F_s(l,t)} \, \boxed{f \frac{dP_{\mathrm{GW}}(f,l)}{df}}$$

Number of strings

$$\frac{dP_{\mathrm{GW}}(f,l)}{df} \approx \Gamma_{\mathrm{GW}} G \mu^2 \delta\left(f - \frac{2}{l}\right)$$

The strength of the signal at a given frequency is determined by the how long the given frequency was emitted and how many strings contributed

The signal



$\lambda/g^2 = 10^4$
No Bosenova
dark Higgs SR
No SR
1/decade
1/day
LIGO
LISA
CE
ET
BBO
$G\mu$
$m_{A'}/\mathrm{eV}$
$\lambda/g^2 = 10^8$
No Bosenova
No SR
LIGO
LISA
CE
ET
BBO
1/decade
1/day
$G\mu$
$m_{A'}/\mathrm{eV}$

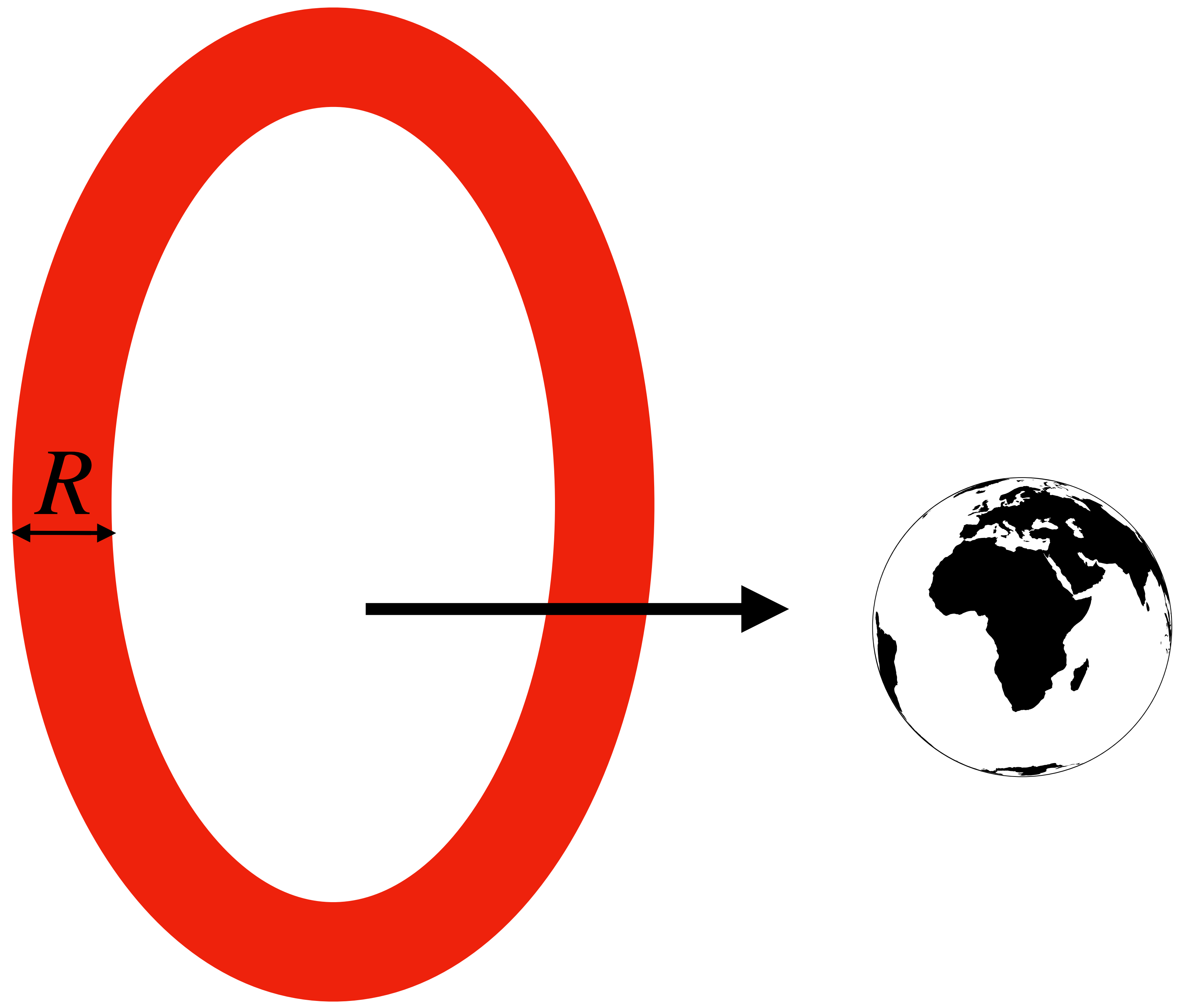
Direct detection

In order to detect the string, it has to couple to SM, e.g. B-L

The string core is comparable to Earth size 10^5 km $\gtrsim R \gtrsim 10^2$ km, as the DP mass is

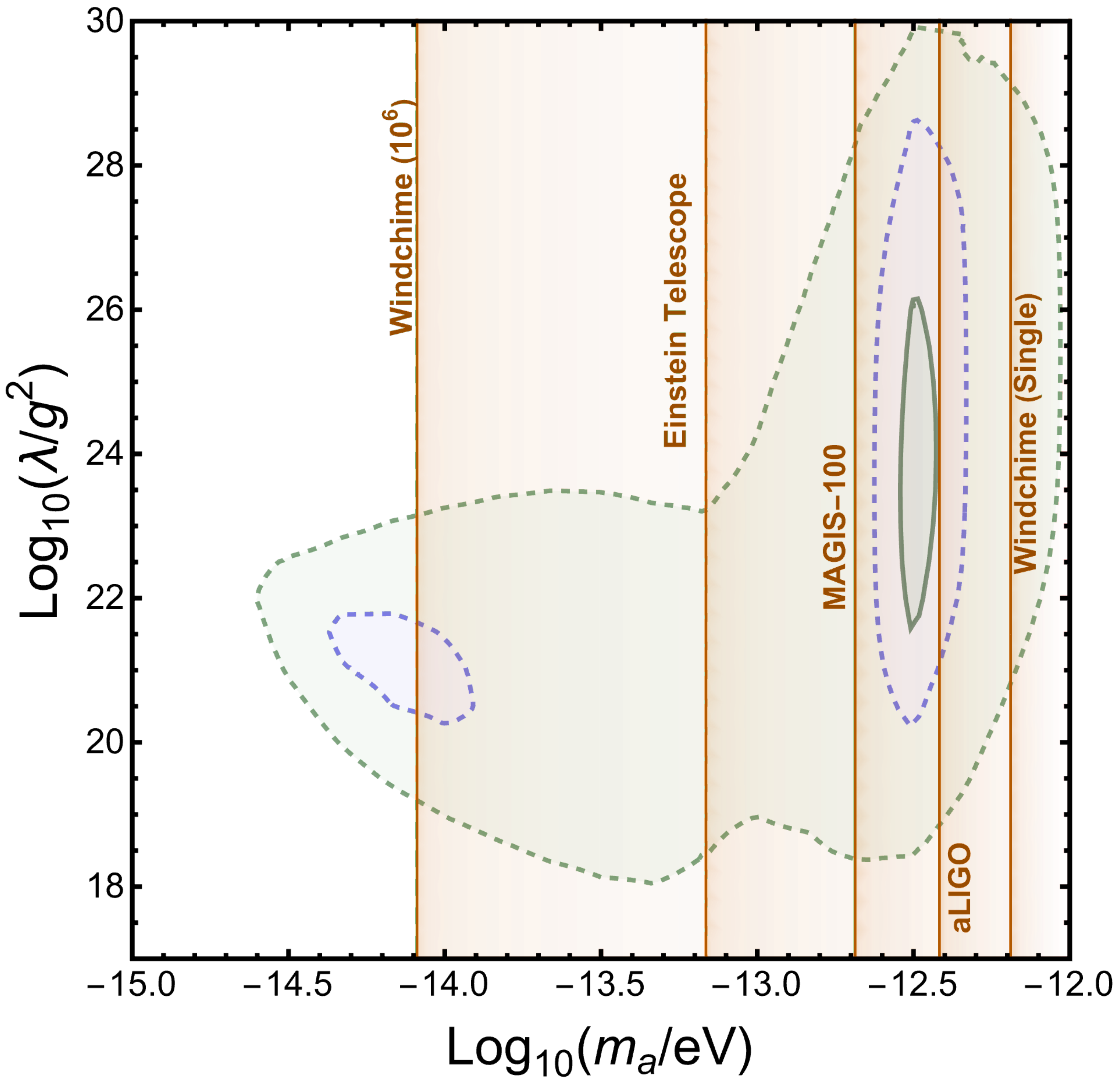
$$10^{-15}\ \text{eV} < m_{A'} < 10^{-12}\ \text{eV}$$

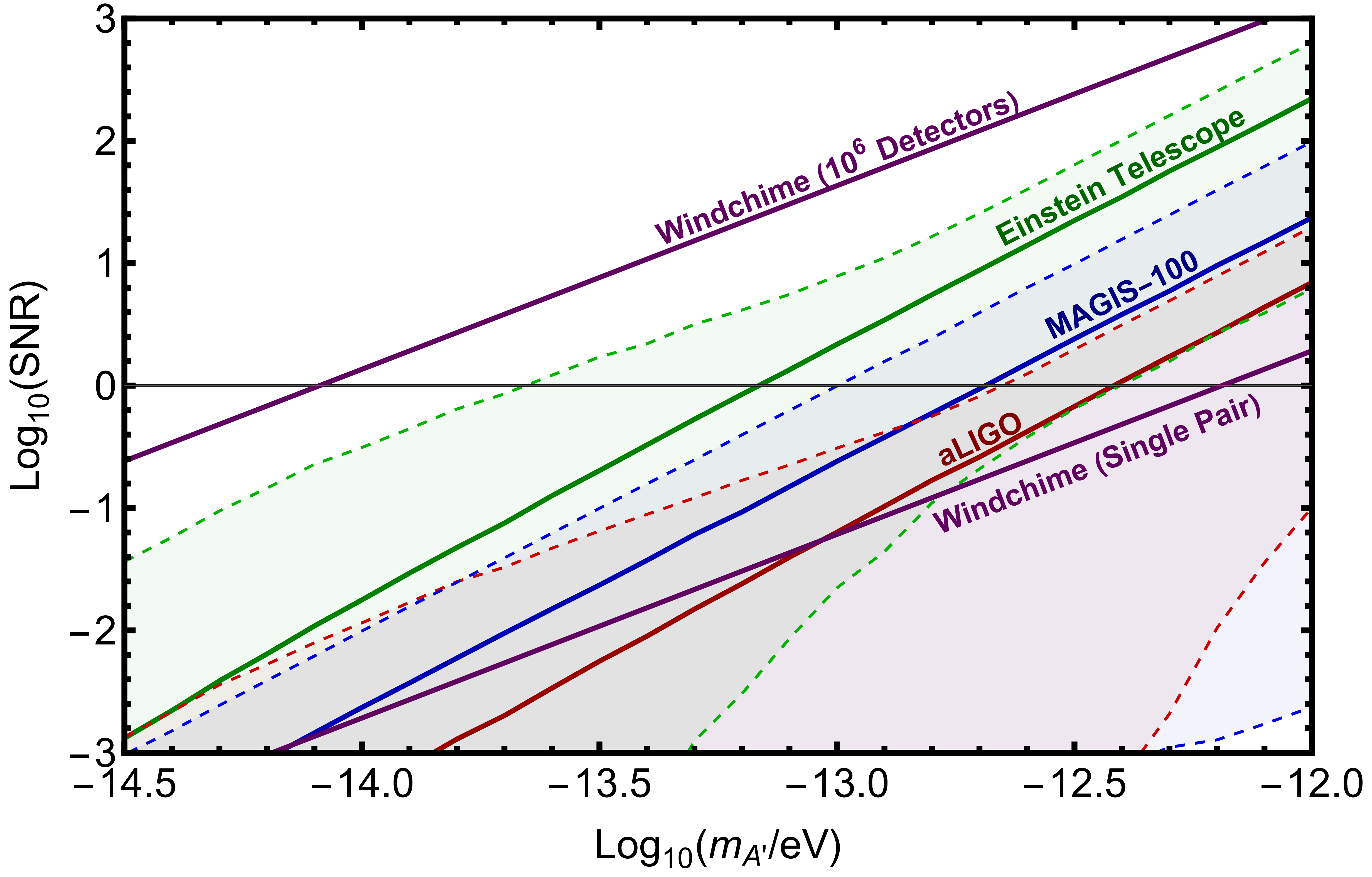
The acceleration of the test mass is independent of the coupling $a \approx \dfrac{m_{A'}^2}{2m_p}$



$\tau \gtrsim 10$ kpc $\rightarrow l \gtrsim 400$ AU

SNR and rate of events





Conclusions

String bosenova is an efficient way to produce large amounts of cosmic strings at late times.

GW emission from the cloud alone can be seen across many GW detectors and the rate can be larger than 1/day.

Direct detection is possible for long lived strings that couple to SM and future accelerometers can almost fully probe parameter space where rates are at least 1/decade.

Thank you!