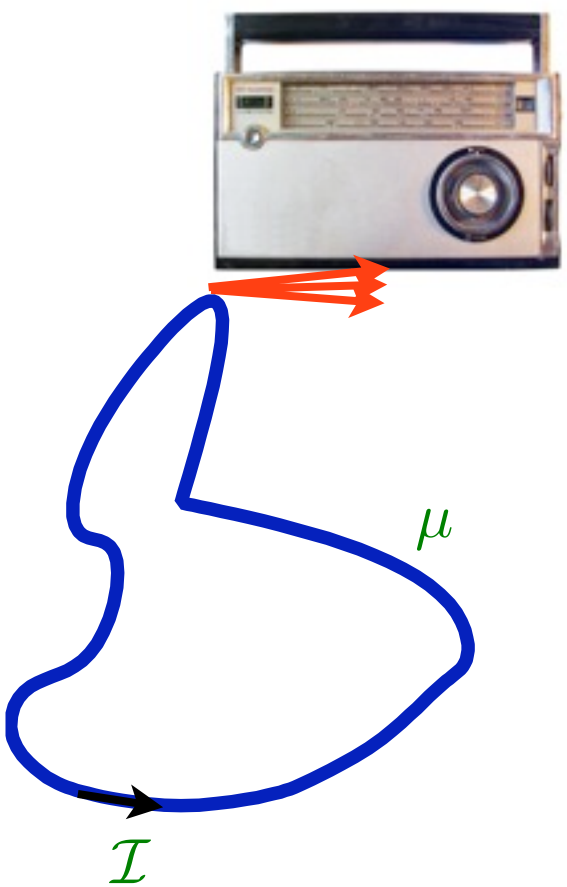
Radio Broadcasts from Superconducting strings



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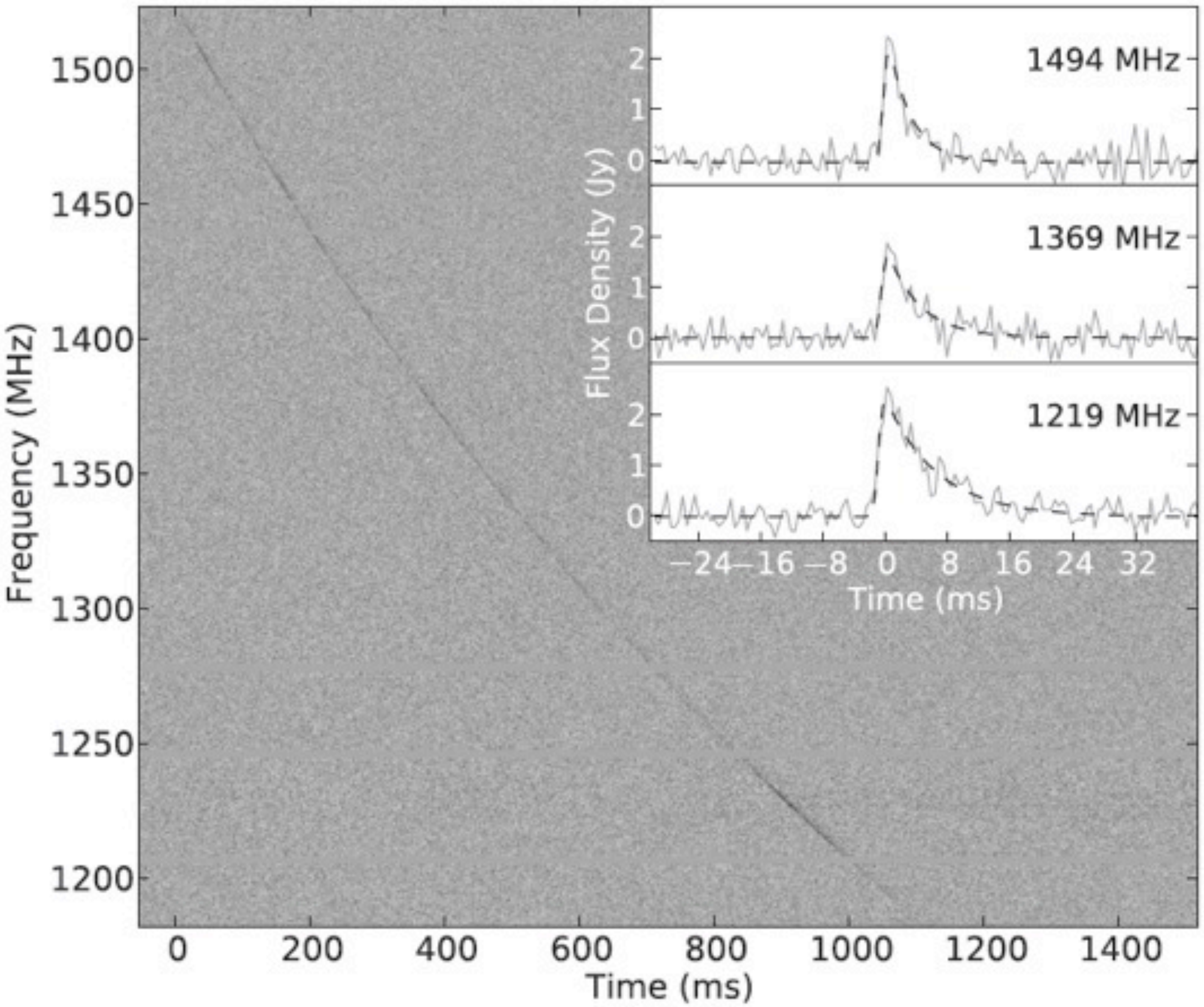
[D.Thornton et al, 1307.1628, Science; D.Lorimer et al, 0709.4301, Science]

A population of fast radio bursts at cosmological distances



$$1\text{Jy} = 10^{-26}\frac{\text{W}}{\text{m}^2\text{Hz}}$$

Brightest astronomical radio sources: $1 \sim 100\text{Jy}$

Redshifts *z~ 0.5-1*. Comoving distances ≤1 Gpc. Isolated bursts, rate < 0.025/hour.

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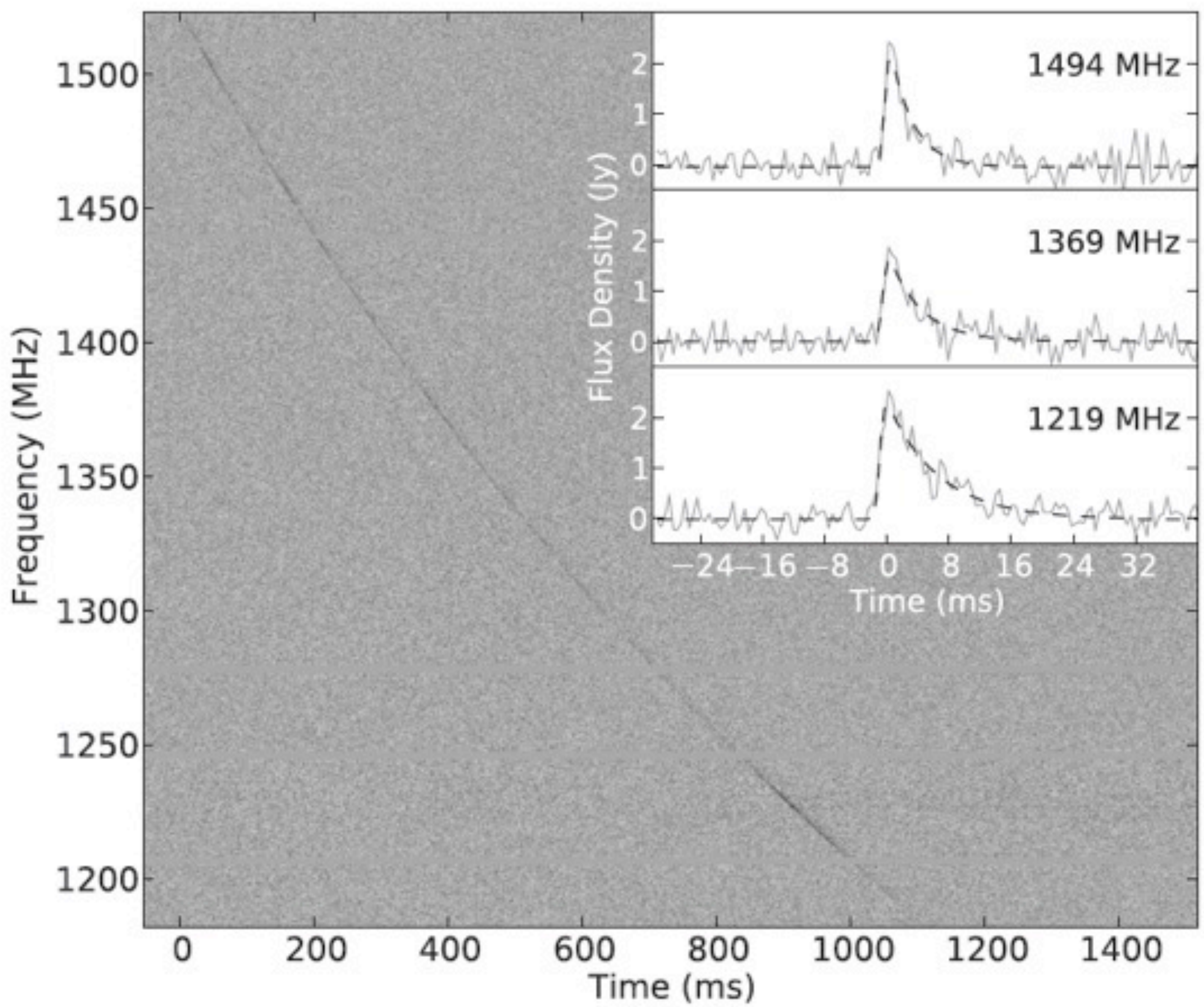

$$1\text{Jy} = 10^{-26}\frac{\text{W}}{\text{m}^2\text{Hz}}$$

Brightest astronomical radio sources:
$1 \sim 100\text{Jy}$

Radio frequency interference
from a mobile phone 1km away
transmitting 0.5W at 1800MHz
$\sim 10^9\text{Jy}$

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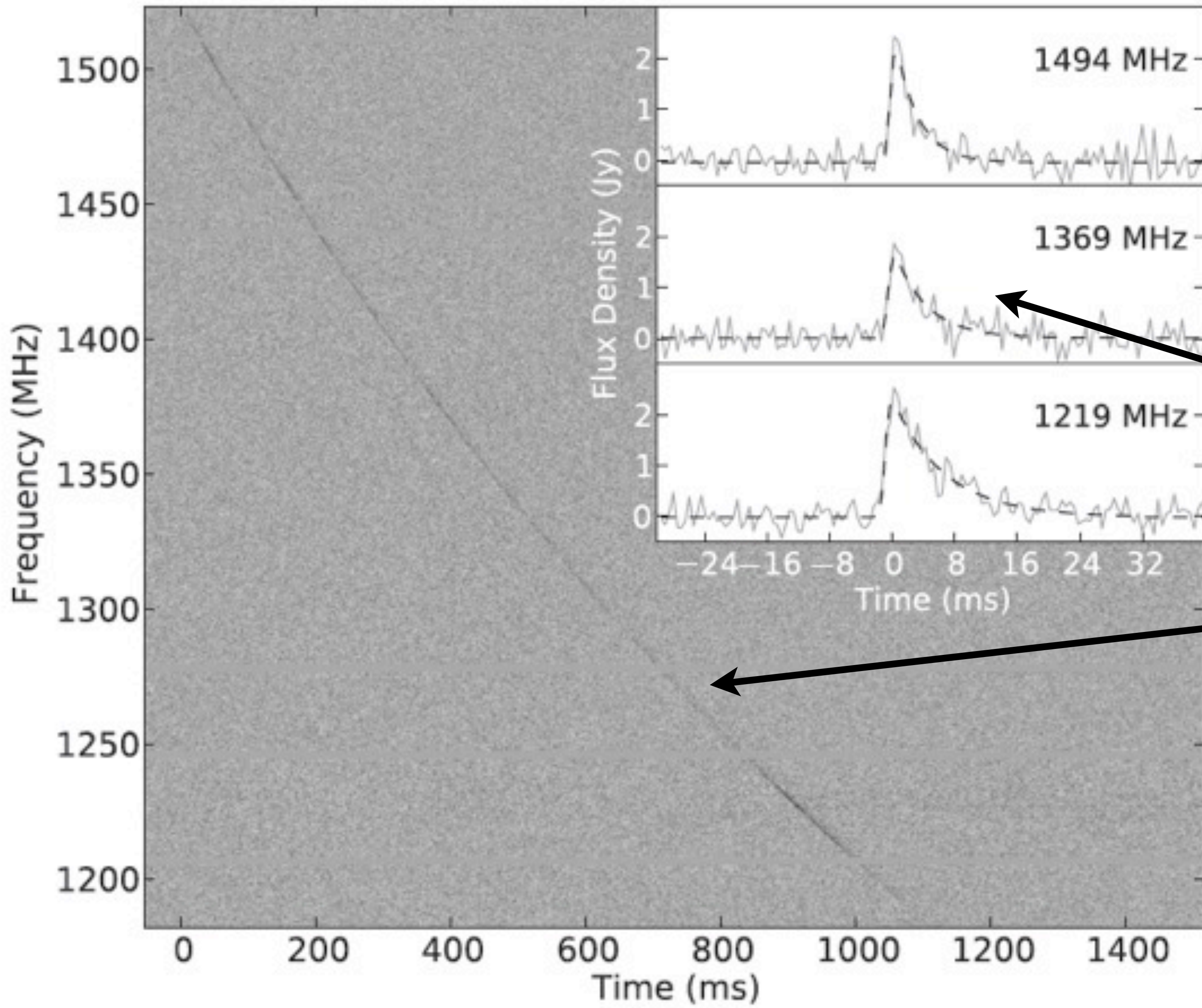

Characteristic dispersion in frequency due to scattering of radio waves as propagate through ionized turbulent galactic medium

$\Delta t_s \sim \nu^{-4}$

[Lee and Jokipii 1976,...]

SOURCE?

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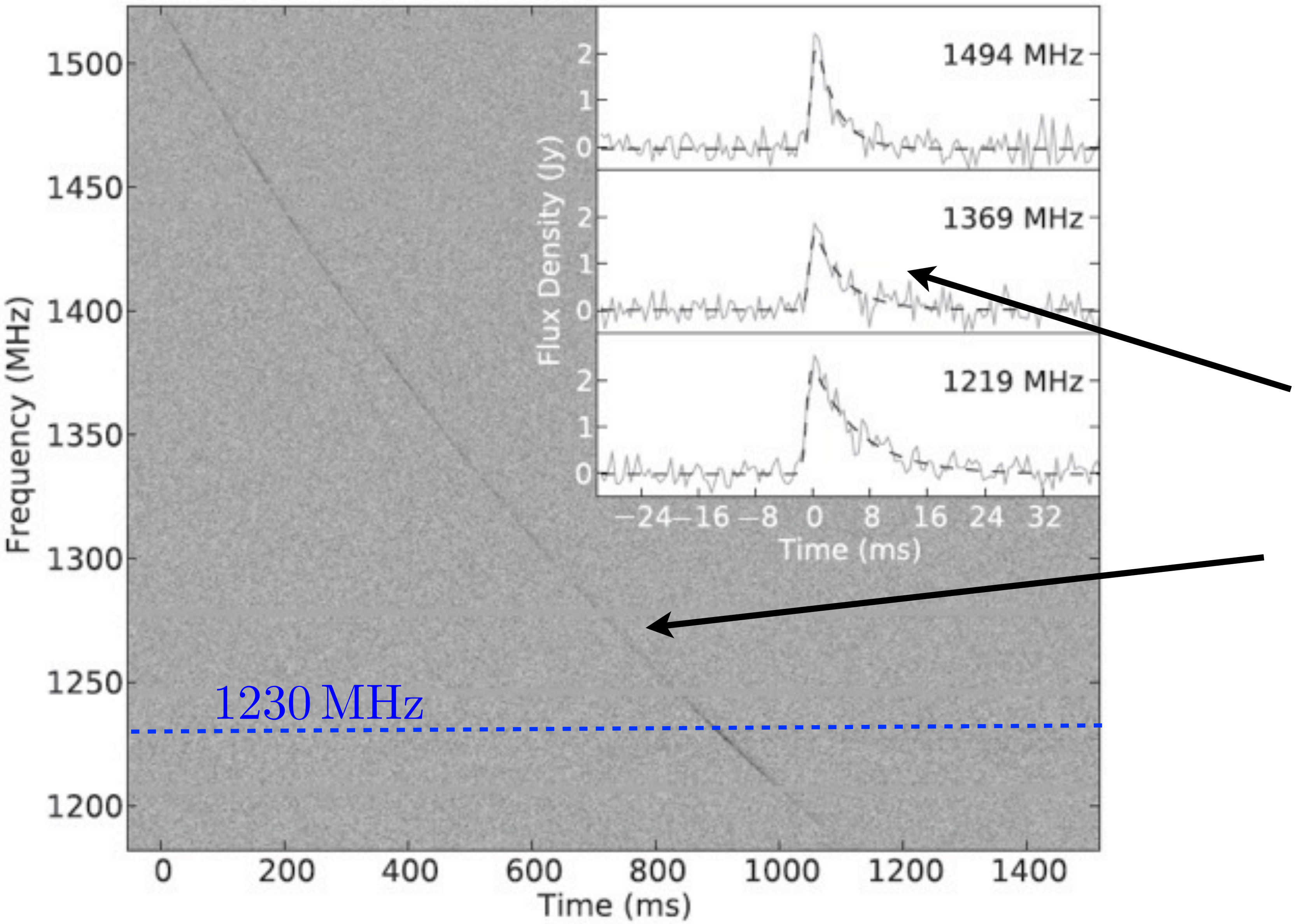

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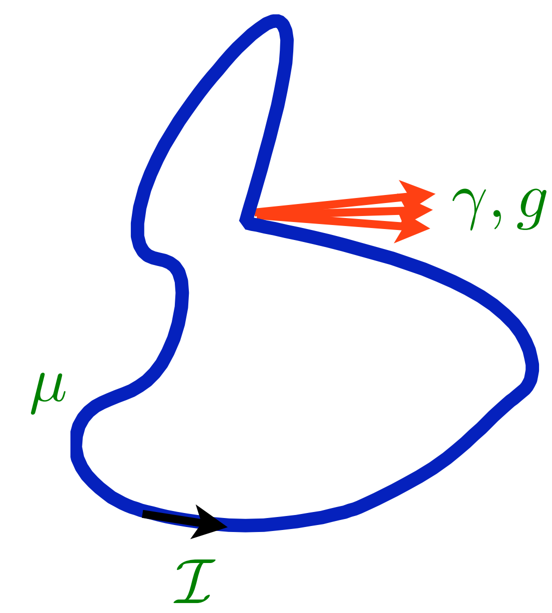
- Oscillating loops of superconducting cosmic strings?



- Act as antennas. Emit EM radiation in wide range of frequencies ω, from radio to gamma *[Vilenkin&Vachaspati, Blanco-Pillado&Olum, Berezinsky et al, Cheng et al, Cai et al....]*

- Also emit GWs *[Vachaspati&Vilenkin, Damour&Vilenkin,....]*

  – Power emitted from a loop of length L decays exponentially with ω for $\omega L \gg 1$

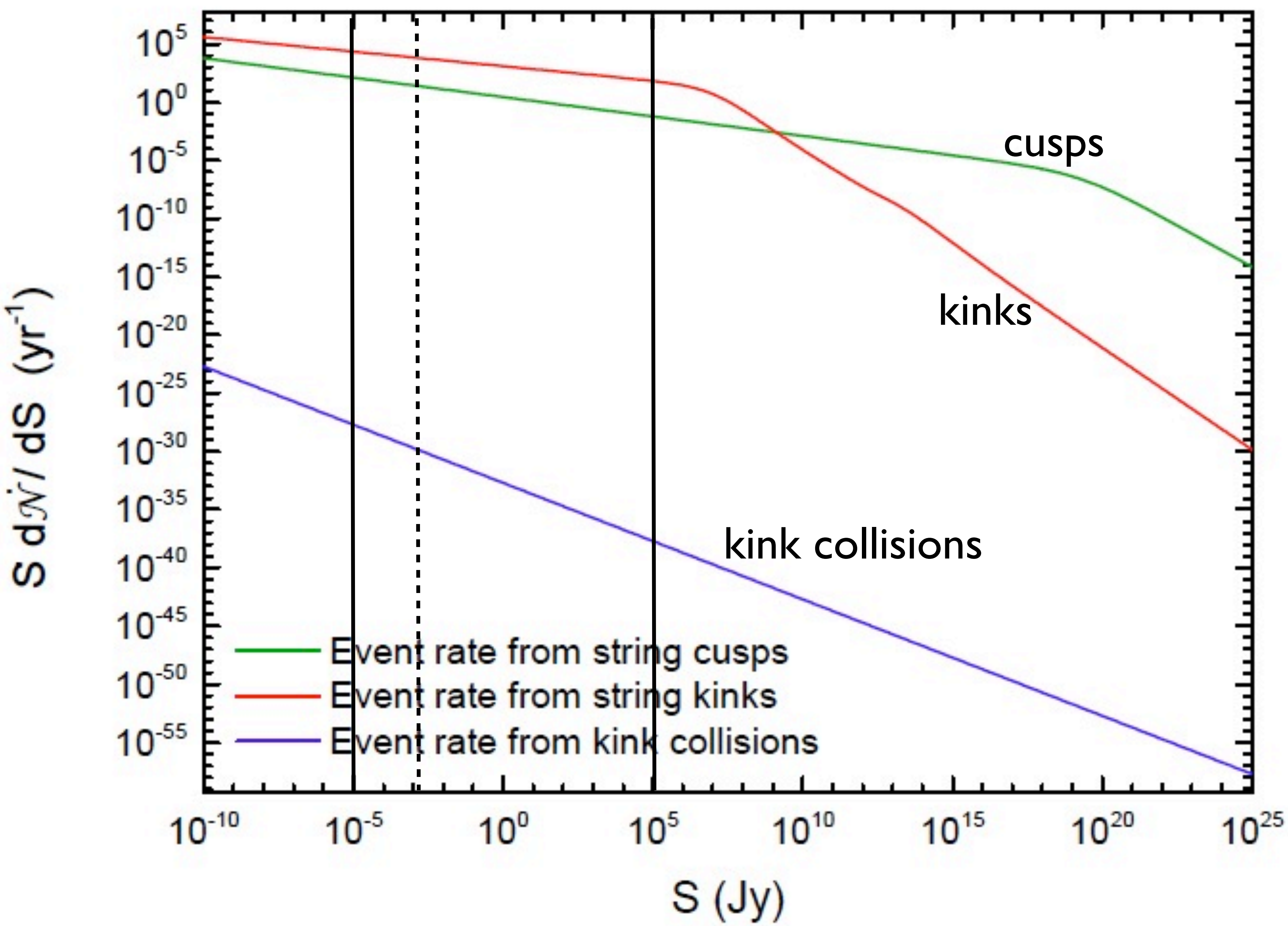
  – exception: from cusps and kinks and kink-kink collisions, which emit short bursts of radiation in certain special directions

  – If an observer/experiment lies in one of those directions : stronger signal

- How many radio bursts of observed duration Δ and flux S can be expected from a cosmological network of loops of superconducting strings of tension μ, carrying current I?

Event rate of radio bursts from superconducting string loops

- fixed observed frequency $\nu_0 = 1230\,\mathrm{MHz}$
- integrated over duration of bursts
- chosen values of parameters: $G\mu = 10^{-10}, \mathcal{I} = 10^5\,\mathrm{GeV}$



An experiment sensitive to mJy fluxes would observe

~100 radio bursts from kinks/day

~1/day from cusps

1) Dynamics of superconducting strings: assumptions

two free parameters $\mu, \mathcal{I}$

2) Power emitted in photons

$$L(t) = L_i - \Gamma G\mu(t - t_i)$$

$\Gamma_\gamma + \Gamma_g$

3) Event rate from from cusps/kinks/kink-kink collisions as a function of : $S = \text{observed flux}$

$\Delta = \text{observed burst duration}$

1) Dynamics of superconducting strings: assumptions

- Models with extra fields can often support currents in the string core

[Witten '85, P. Peter '92, '93, B.Carter, C.Ringeval, Davis&Shellard, Hindmarsh, Baboul&Piran&Spergel...]

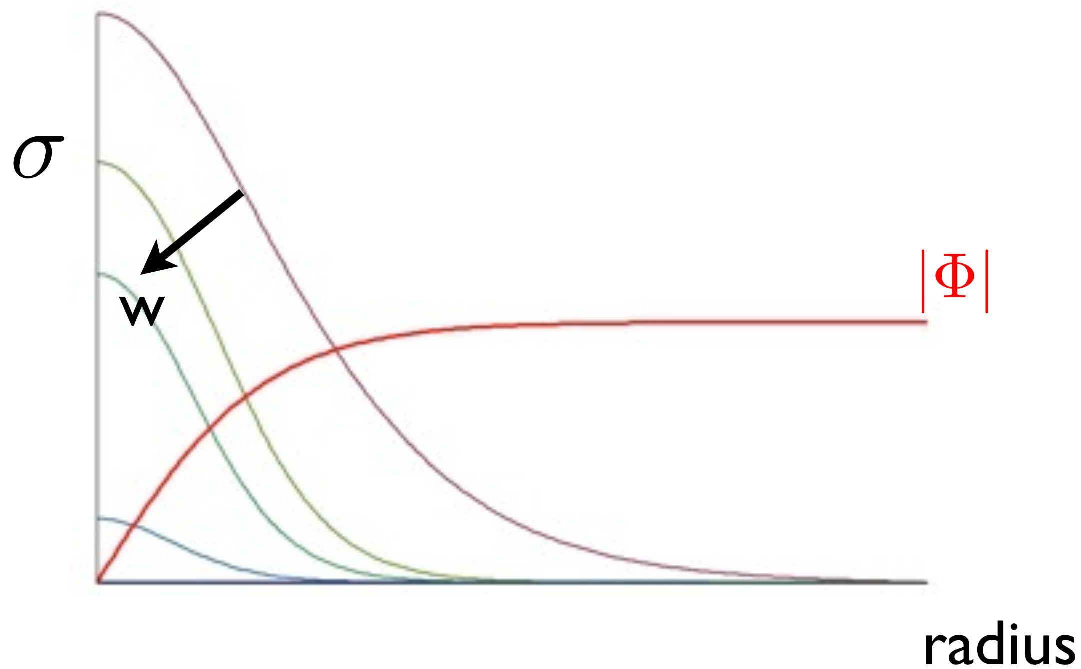
- Microphysics complicated, **backreaction** generally non-negligible; determining effective action **hard**

- eg: U(1) x U(1)

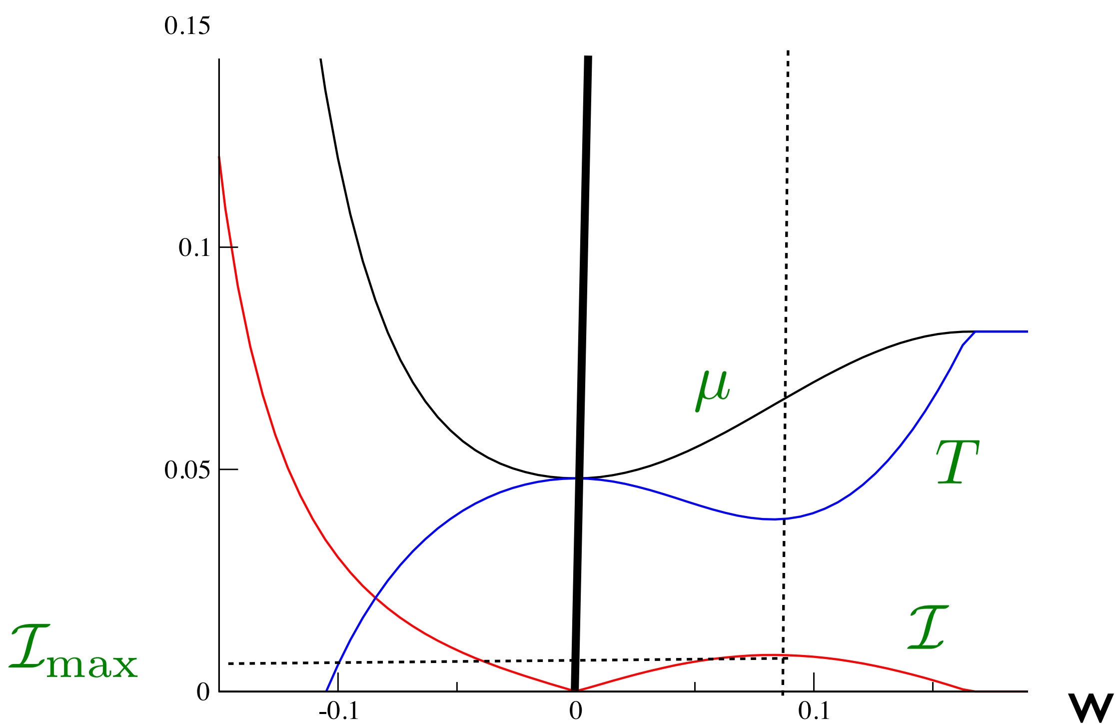
string ← U(1), U(1) → condensate

string (Φ, B_μ)

condensate $\Sigma = \sigma(r)e^{i\phi(t,z)}$, A_μ



$$w = (\partial_z\phi)^2 - (\partial_t\phi)^2$$



[P. Peter]

- space-like currents (w>0)

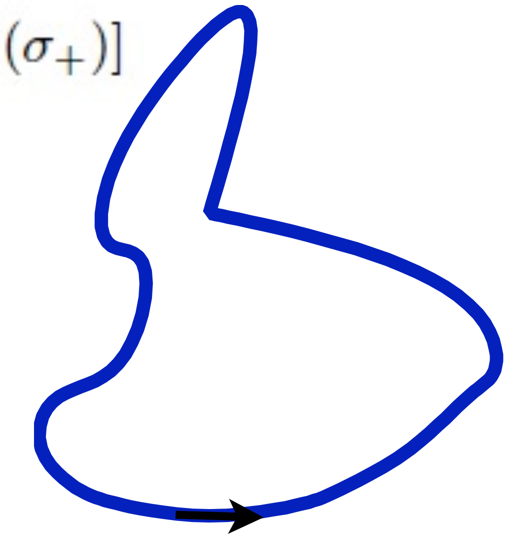
- Important point: **maximum current** $\mathcal{I}_{\max}$

$$c_L^2 = -\frac{dT}{d\mu}$$

- Assumptions:

1) string dynamics given by NG action. $\mu = T$ $X^\mu(t,\sigma) = \frac{1}{2}[X^\mu_-(\sigma_-) + X^\mu_+(\sigma_+)]$

$\sigma_\pm = \sigma \pm t,$



2) Strings all carry *same constant* current $\mathcal{I}$ with $\mathcal{I}_{\rm max} \sim q\sqrt{\mu}$

Corresponding current density

$$J^\mu(t,\vec{x}) = \mathcal{I}\int d\sigma\ X^\mu_{,\sigma}\ \delta^{(3)}(\vec{x} - \vec{X}(t,\sigma))$$

- Typical values we shall take

$G\mu = 10^{-10}$ $\mathcal{I} = 10^5 \mathrm{GeV}$ $\mathcal{I}_{\rm max} \sim 10^{12}\mathrm{GeV}$

2) Power emitted in photons

- Power emitted per unit frequency, per unit solid angle $\dfrac{\mathrm{d}^2 P_\gamma}{\mathrm{d}\omega \mathrm{d}\Omega} = \dfrac{\omega^2}{2\pi}\dfrac{L}{4\pi}|J^\mu_\omega|^2 \,.$

$\propto \mathcal{I}$, $M^\mu_\pm(\vec{k}) = \int_0^L d\sigma_\pm e^{ik\cdot X_\pm/2} X'^\mu_\pm \,,$

- (Nearly) standard saddle-point/discontinuity analysis in $\omega L \gg 1$ limit

  – **cusp** $\dfrac{\mathrm{d}P^c_\gamma}{\mathrm{d}\omega \mathrm{d}\Omega} \sim \mathcal{I}^2 L$ emitted in a cone of opening angle $\theta_\omega = (\omega L)^{-2/3}$

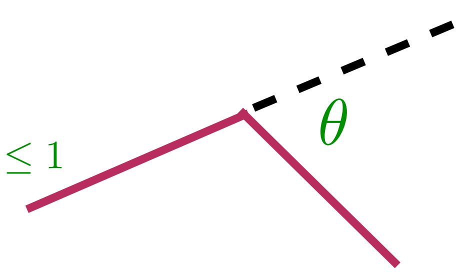
  burst of duration $\delta t \sim L^{2/3}\omega^{-1/3}$

  – **kink** $\dfrac{\mathrm{d}P^k_\gamma}{\mathrm{d}\omega \mathrm{d}\Omega} \sim \dfrac{\mathcal{I}^2 L \psi}{(\omega L)^{2/3}}$ emitted in a fan-shape of solid angle $\Omega \sim 2\pi\theta_\omega$

  burst of duration $\sim 1/\omega$

  – **kink-kink** $\dfrac{\mathrm{d}P^k_\gamma}{\mathrm{d}\omega \mathrm{d}\Omega} \sim \dfrac{\mathcal{I}^2 L \psi^2}{(\omega L)^2}$ emitted in all directions

$0 \le \psi = \sin^2(\theta/2) \le 1$



- Integrating $P_\gamma \sim P^c_\gamma = \Gamma_\gamma \mathcal{I}\sqrt{\mu}$

~ 10

$I_* \sim 10^5 \mathrm{GeV}$

- Power emitted in GW: $P_g = \Gamma_g G\mu$

3) Estimated event rate of radio bursts from cusps/kinks/kink-kink collisions as a function of S, Δ

- Number/unit time/unit spatial volume of cusp, kink, and kink-kink bursts of OBSERVED frequency ν_o from loops of length L at redshift z

$$d\dot{\mathcal{N}}(L,z) \simeq N^p \frac{(\theta_{\nu_o})^{\tilde{m}}}{L(1+z)} dn(L,z)\, dV(z)$$

$$p=0\,, \quad \tilde{m}=2 \quad \text{for cusp}$$
$$p=1\,, \quad \tilde{m}=1 \quad \text{for kink}$$
$$p=2\,, \quad \tilde{m}=0 \quad \text{for kink kink.}$$

$$\theta_{\nu_o} \equiv [\nu_o(1+z)L]^{-1/3}$$

Loop distribution in matter era

physical volume element in matter era

- Leading to

$$d\dot{\mathcal{N}}(L,z) = \ldots\ \nu_0^{-\tilde{m}/3}\ \ldots \frac{C_L(z)}{[L+\Gamma G\mu t_0(1+z)^{-3/2}]^2} dL\, dz$$

"standard" [Vilenkin+ Shellard] loops distribution

- Event rate higher the lower the frequency (radio).

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S, Δ

"standard" [Vilenkin+ Shellard] loops distribution

- Event rate higher the lower the frequency (radio).

- Observed duration of burst

$$\Delta = \sqrt{\Delta t^2 + \Delta t_s^2}$$

- Observed intrinsic duration $1/\nu_0$
- time delays generated by scattering of radio waves in intergalactic medium

(z, ν_0)

- Observed energy flux per frequency interval from cusp/kink/kink-kink bursts on a loop of length L at a distance $r(z)$ from loop

$$S \approx \frac{1}{r(z)^2} \frac{L}{2\Delta} \frac{\mathrm{d}^2 P}{\mathrm{d}\nu_o \mathrm{d}\Omega}$$

- giving finally $\mathrm{d}\dot{\mathcal{N}}(S, \Delta)$

So.................

Range of observable parameters for the Parkes survey:

$$\nu_o \in (1.230, 1.518)\ \mathrm{GHz}\ ,$$
$$\Delta \in (10^{-3}, 1)\ \mathrm{s}\ ,$$
$$S \in (10^{-5}, 10^{5})\ \mathrm{Jy}\ ,$$

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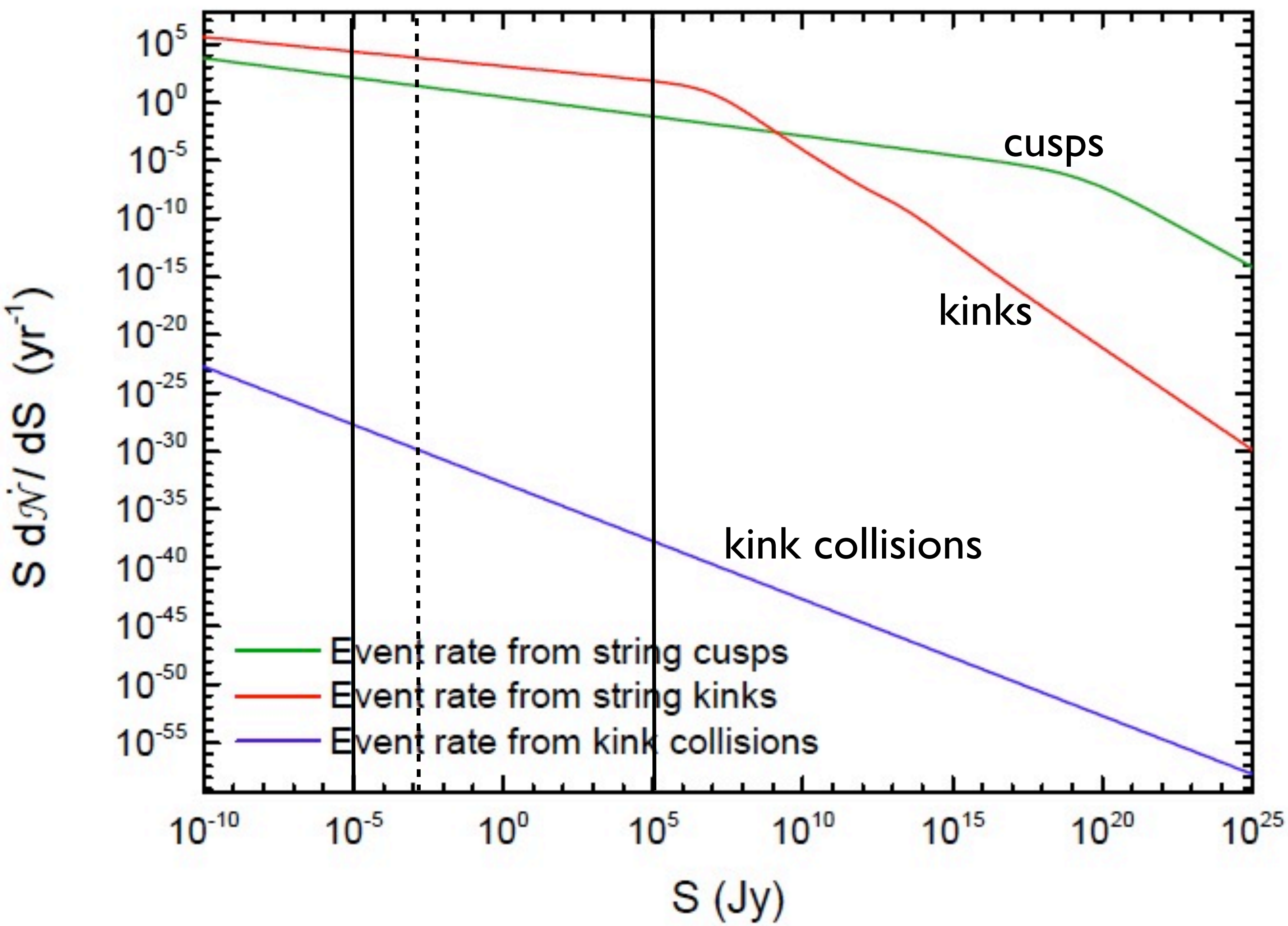

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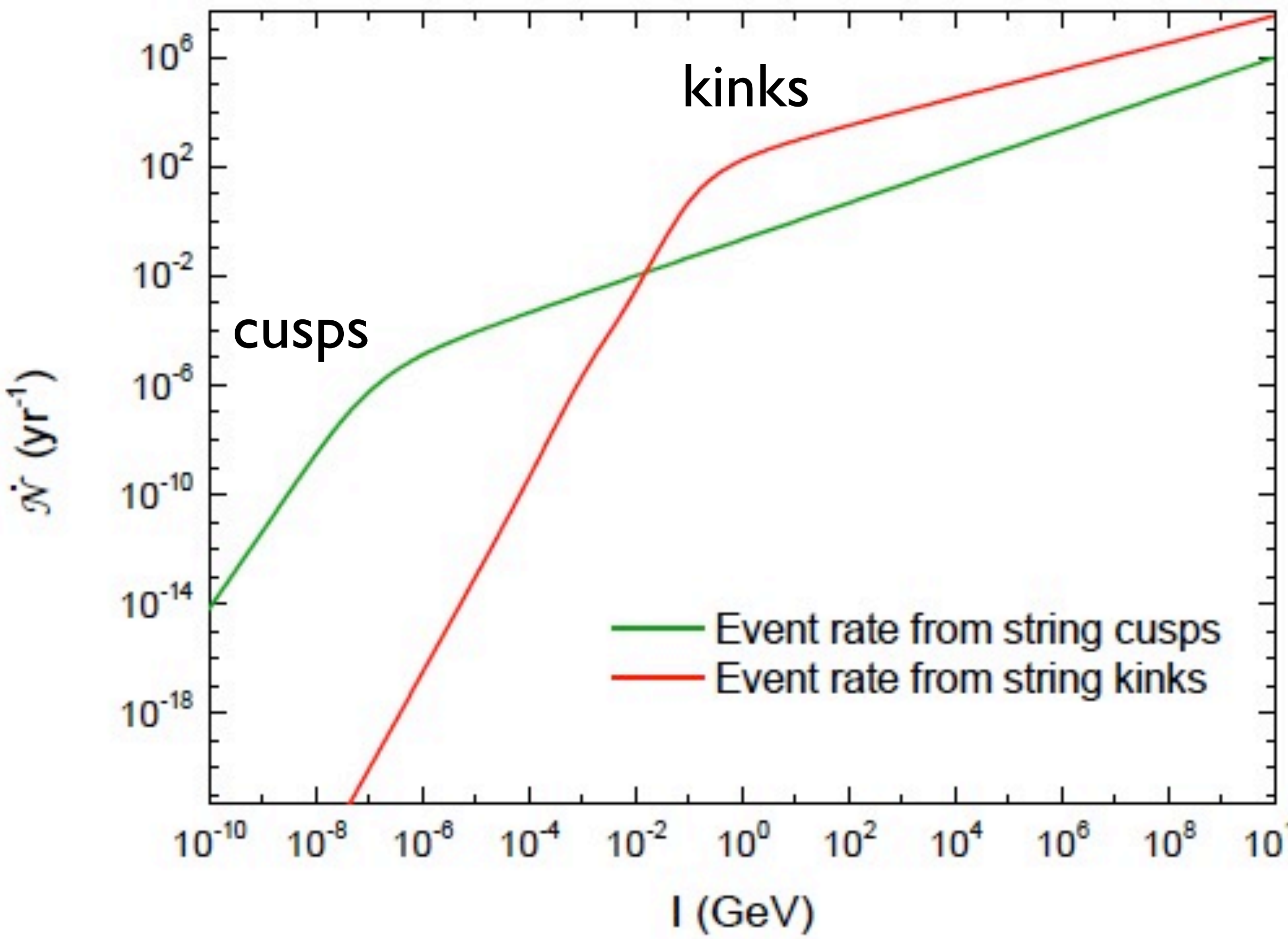
Integrating out over duration and flux



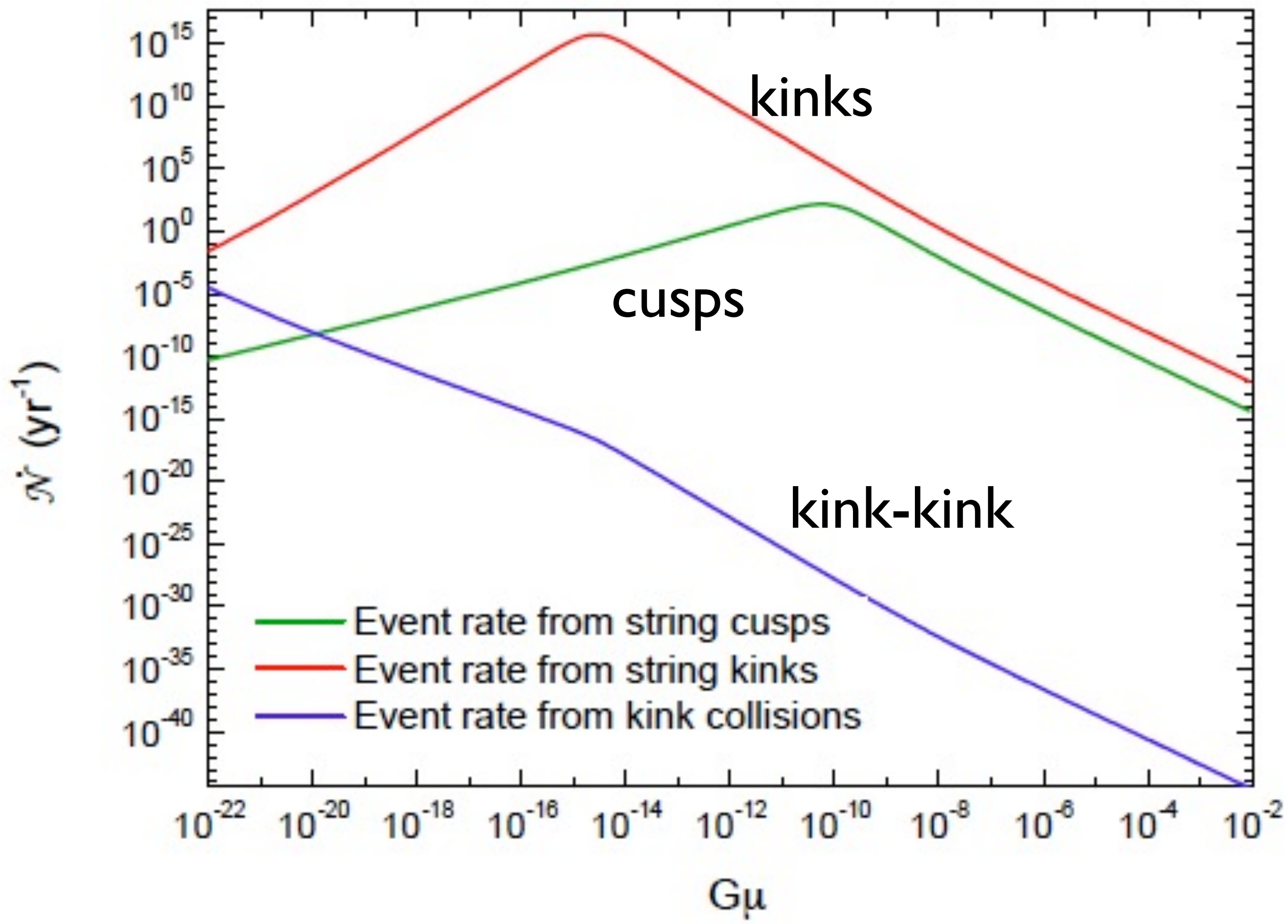


FIG. 3: The event rate of radio bursts from superconducting string loops with fixed observed frequency, $\nu_o = 1.23$GHz as functions of $G\mu$. The current is taken to be $I = 10^5$ GeV. The

FIG. 2: The event rates of radio bursts from cusps and kinks (for one kink/loop) on superconducting string loops at fixed observed frequency, $\nu_o = 1.23$GHz, as functions of the current $\mathcal{I}$. The string tension is taken to be $G\mu = 10^{-10}$. The green

Conclusion

- 3 kinds of transient EM bursts from superconducting strings:
  - bursts from cusps are strong and highly beamed
  - bursts from kinks are weaker and less beamed
  - bursts from kink-kink collisions are the weakest and not beamed
- Bursts occur in all frequency bands, but are wide in radio, thin in gamma rays
- So event rate is largest for radio => radio transients most likely to find superconducting strings
- For canonical parameters, event rates are high ~ several a day a 1 Jy flux for chosen $\mathcal{I}, \mu$
- If none are observed => constraints on $\mathcal{I}, \mu$
- Radiation is linearly polarised, which may be used to distinguish it from other astrophysical sources

Might expect bursts at other frequencies, GW bursts, and perhaps an accompanying burst of neutrinos....

$$S = \int \mathrm{d}\sigma \mathrm{d}\tau \sqrt{-\gamma} \left\{ -\mu + \frac{\kappa}{2} \gamma^{ab} \phi_a \phi_b - q A_\mu X^\mu_{,a} J^a \right\} - \frac{1}{16\pi} \int \mathrm{d}^4 x \sqrt{-g} F_{\mu\nu} F^{\mu\nu}$$

$$\kappa = 2\pi \int \mathrm{d}r \left[r \sigma(r)^2 \right] \qquad J^a = q \epsilon^{ab} \phi_{,b} / \sqrt{-\gamma}$$