Stellar Constraints on Dark Matter and Dark Sectors

Sam McDermott

1611.03864 & 1803.00993 (+ Rouven Essig & Jae Hyeok Chang)
& ongoing…

August 5, 2019

Fermilab

Big Picture, ca. 2009

10 GeV 100 TeV

we knew the dark matter mass!

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lower limit: Lee-Weinberg bound $\langle \sigma v \rangle_{ann} > m^2/m_W^2$

upper limit: unitarity $\Longrightarrow \langle \sigma v \rangle_{ann} < 4\pi/m^2 v$

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Big Picture, ca. 2009

μeV 10 meV 10 GeV 100 TeV 10^{-16} $M_\odot$ 100 $M_\odot$

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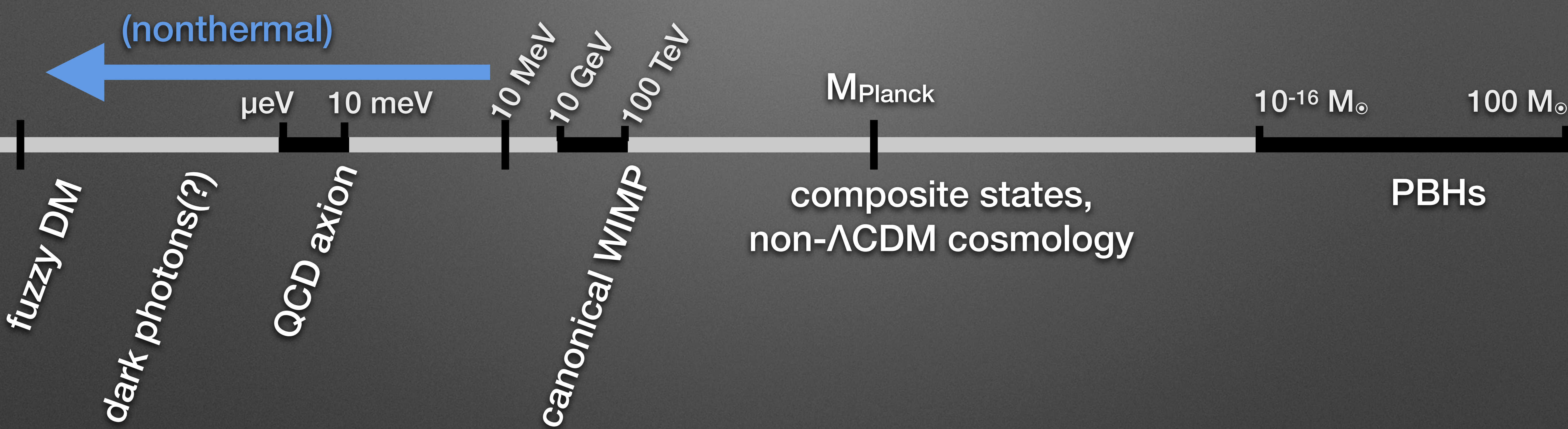
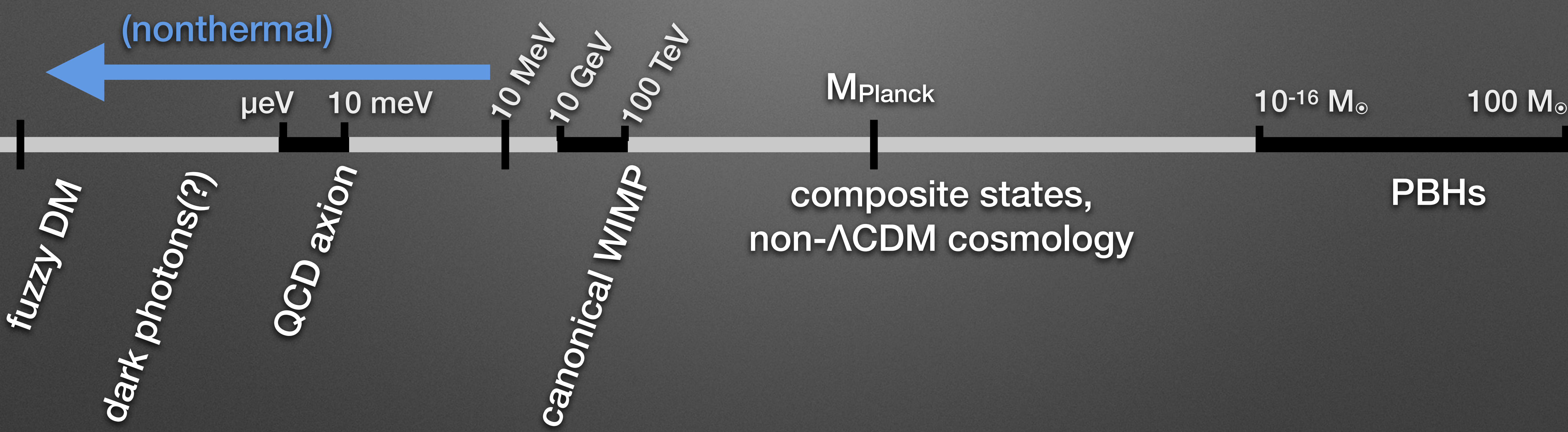
[**well okay, maybe it's primordial black holes]

Big Picture, ca. 2019



the dark matter can be anything!

Big Picture, ca. 2019



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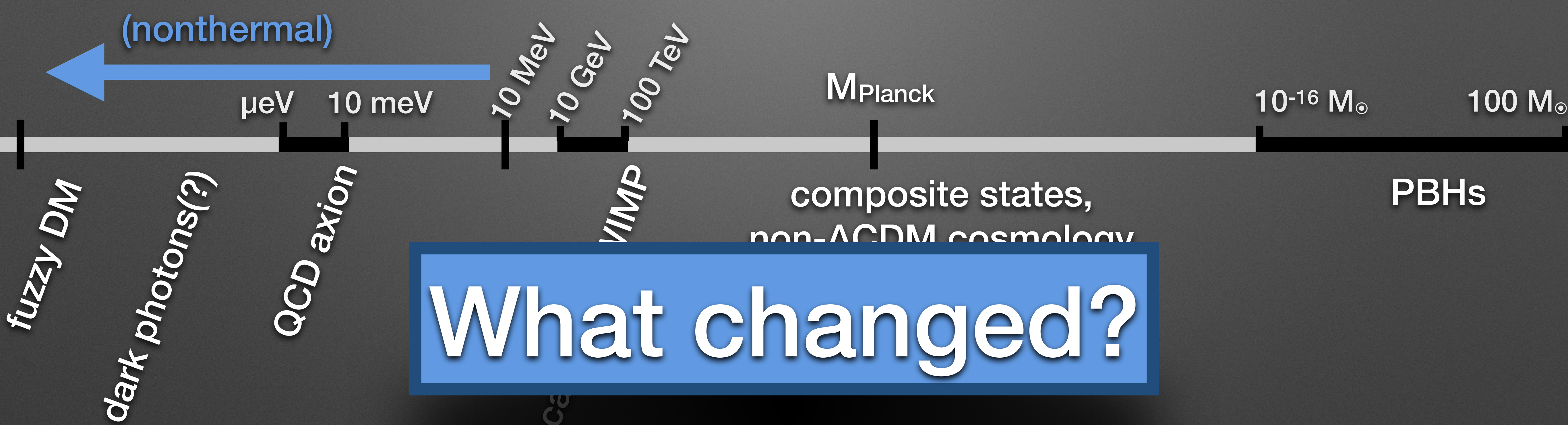
lower bound: does it fit in a galaxy?

upper bound: gravitational effects

Big Picture, ca. 2019



What changed?

the dark matter can be anything!

lower bound: does it fit in a galaxy?

upper bound: gravitational effects

Two Pheno Developments

1. Hidden Sectors
   - evade the Lee-Weinberg bound $\langle\sigma v\rangle_{ann} > m^2/m_W^2$ if there is a new force that allows annihilations with mass scale $m_{NP} \ll m_W$
   - Bjorken, Essig, Schuster, Toro 0906.0580 & PRD; Morrissey, Poland, Zurek 0904.2567 & JHEP; Cheung, Ruderman, Wang, Yavin 0902.3246 & PRD
2. Asymmetric Dark Matter
   - the dark matter abundance is not set by (symmetric) thermal freezeout
   - Kaplan, Luty, Zurek 0901.4117 (earlier work by Kitano et al, Nussinov…)

Information | References (16) | Citations (391) | Files | Plots

Technocosmology: Could A Technibaryon Excess Provide A 'natural' Missing Mass Candidate?

S. Nussinov (Cornell U., LNS & Tel Aviv U.)

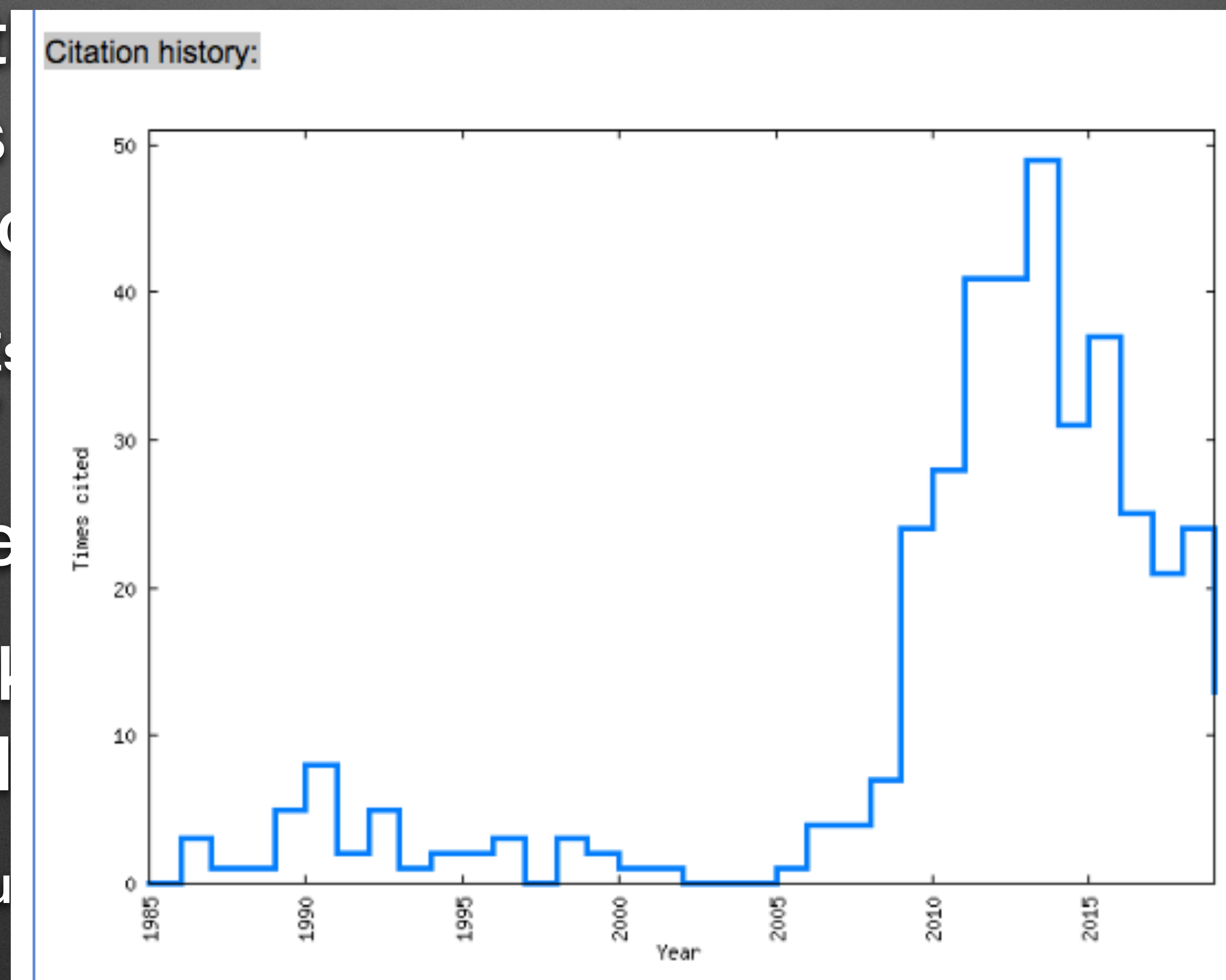
Oct 1985 - 4 pages

Phys.Lett. 165B (1985) 55-58
(1985)
DOI: 10.1016/0370-2693(85)90689-6
CLNS-85/703

- evade t… $^2/m_W^2$ if there is… s with mass sc…
  - Bjorken, Es… Poland, Zurek 0904.2567 … 46 & PRD

2. Asymme…

- the dark… ymmetric) thermal…
  - Kaplan, Lu… ussinov…)



Two Pheno Developments

1. Hidden Sectors

- evade the Lee-Weinberg bound $\langle \sigma v \rangle_{ann} \gtrsim m^2/m_W^2$ if

implication: new low mass particles

mass scale $m_{NP} \ll m_W$

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2. Asymmetric Dark Matter
   - the dark matter abundance is not set by (symmetric)

     implication: DM doesn’t annihilate
   - Kaplan, Luty, Zurek 0901.4117 (earlier work by Kitano et al, Nussinov...)

How to look for DM in stars?

	Canonical DM (WIMP, QCD axion)	Asymmetric DM	Hidden Sectors (including light bosons)
Solar System Objects	Press & Spergel Apj; Edsjö hep-ph/9504205; Mack, Beacom, Bertone 0705.4298 & PRD; Peter 0902.1347 & PRD	Frandsen + Sarkar 1003.4505 & PRL; Vincent, Serenelli, Scott 1504.04378 + 1605.06502 & JCAP	Farrar and Wadekar, 1903.12190
Stellar Populations	Friedland, Giannotti, Wise 1210.1271 & PRL; Heger et al. 0809.4703 & ApJ	Zentner and Hearin 1110.5919 & PRD	Friedland + Giannotti 0709.2164; Redondo + Postma 0811.0326; An, Pospelov, Pradler 1302.3884; Hardy and Lasenby 1611.05852
Dense Objects (WDs, NSs, …)	Baryakhtar et al., 1704.01577 & PRL	*SDM*, Yu, Zurek 1103.5472 & PRD; Kouvaris et al.; Bramante et al., …	Bramante + Linden 1405.1031 & PRL
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Part 1

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Part 2

SN1987A: Zeroth Order Facts

Supernova 1987A:

~ 99% of the grav. binding energy of a collapsing blue supergiant radiated away in the form of neutrinos over the course of ~ 10s

spacetelescope.org

Supernova at the Order of Magnitude Level

$\rho_c = m_N (110\ \mathrm{MeV})^3$, $T_c = 30\ \mathrm{MeV}$, $\omega_{p,c} \approx 13\ \mathrm{MeV}$

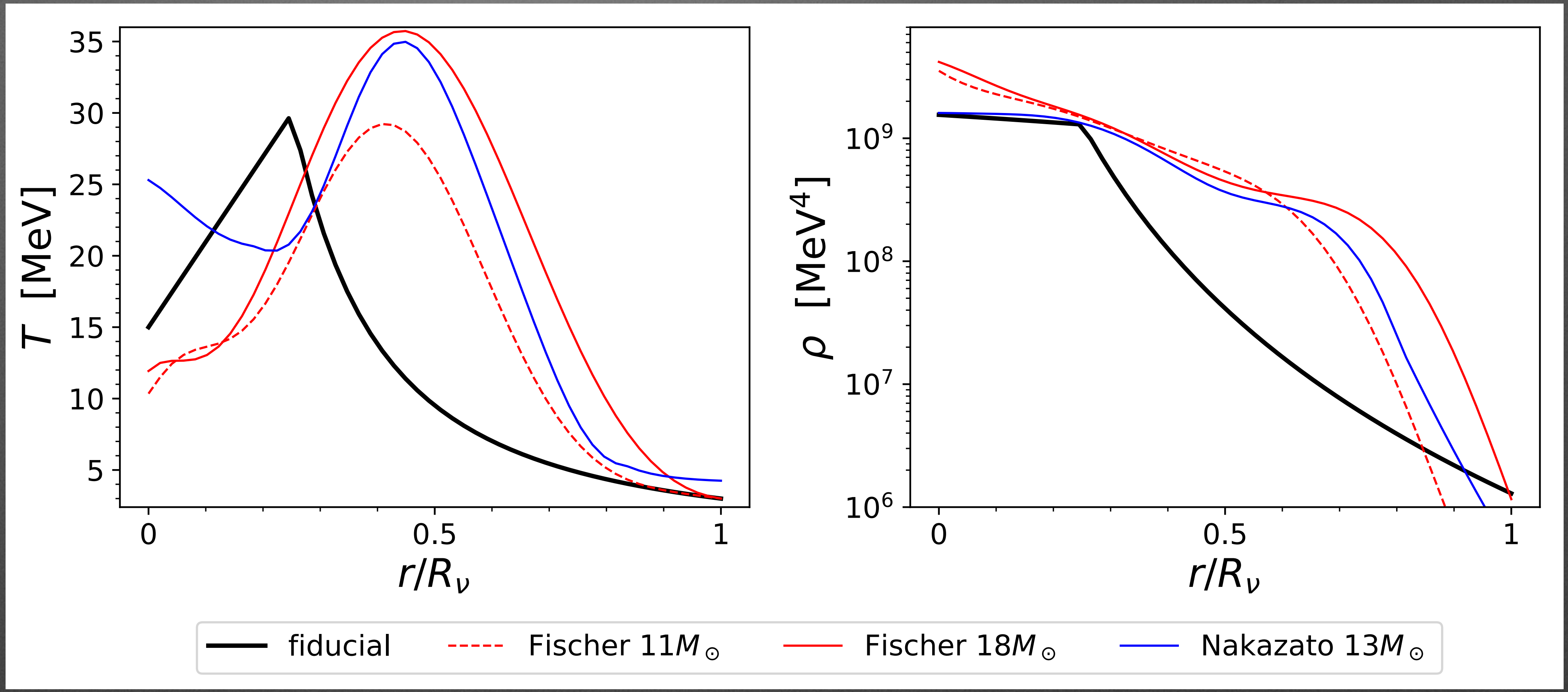
$$\rho(r) = \rho_c \times \begin{cases} 1 + k_\rho (1 - r/R_c) & r < R_c \\ (r/R_c)^{-\nu} & r \geq R_c \end{cases}$$

$$T(r) = T_c \times \begin{cases} 1 + k_T (1 - r/R_c) & r < R_c \\ (r/R_c)^{-\nu/3} & r \geq R_c \end{cases}$$

"fiducial model"
(Raffelt, 1995)

Numerical Models

"fiducial model" differs from sims by ~O(10):

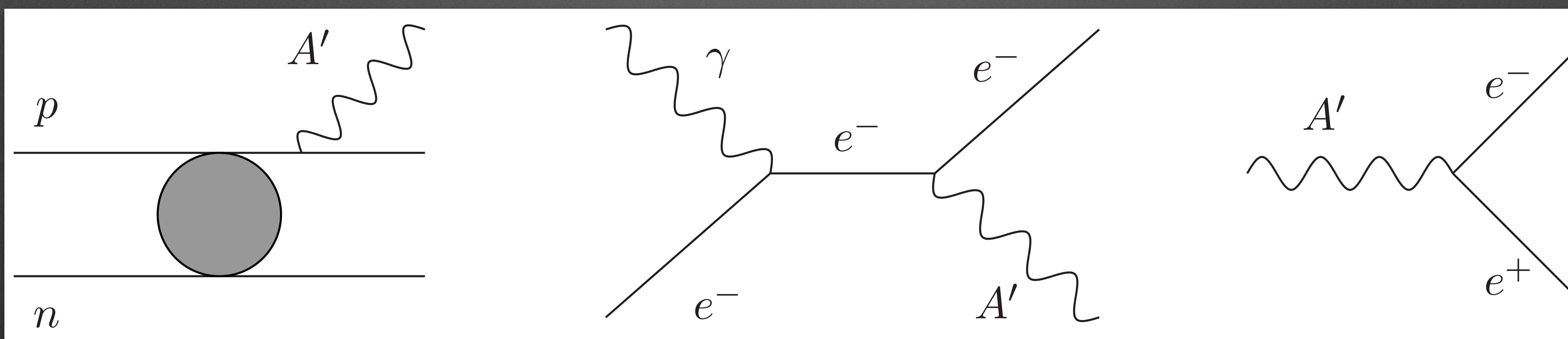


value of R_f (important for optical depth, $\tau(r)=\int_r^{R_f} \Gamma'(r')\,dr'$)

Possible values for $R_{\rm far}$	distance
$R_{\rm gain}$	100 km
$R_{\rm shock}$	1000 km

This Talk: Dark Photons

vector boson of a new U(1) gauge group, kinetically mixed with Standard Model photon



Dark photons get produced / absorbed in EM interactions (~ε^2 as often as photons)

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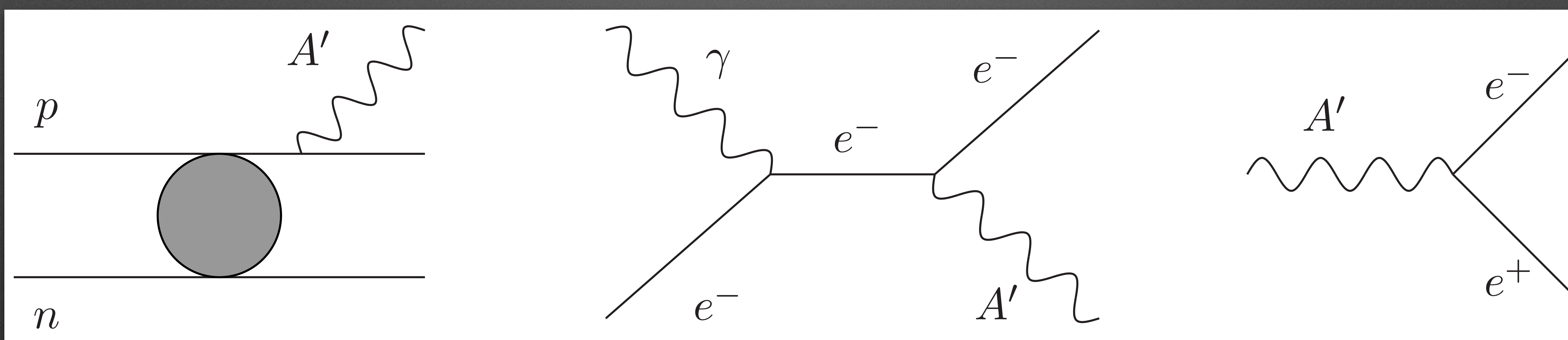

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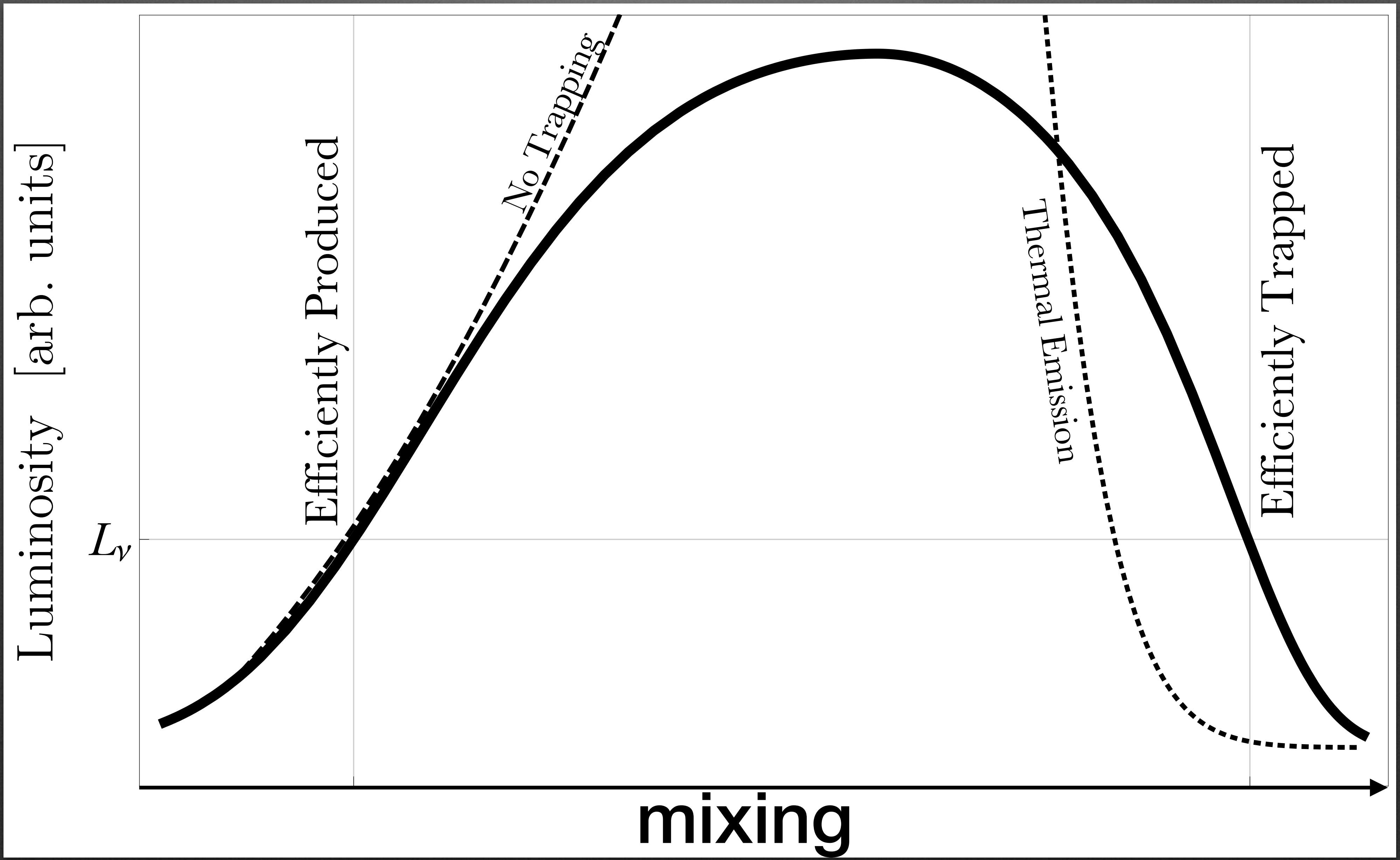
Luminosity vs. mixing angle



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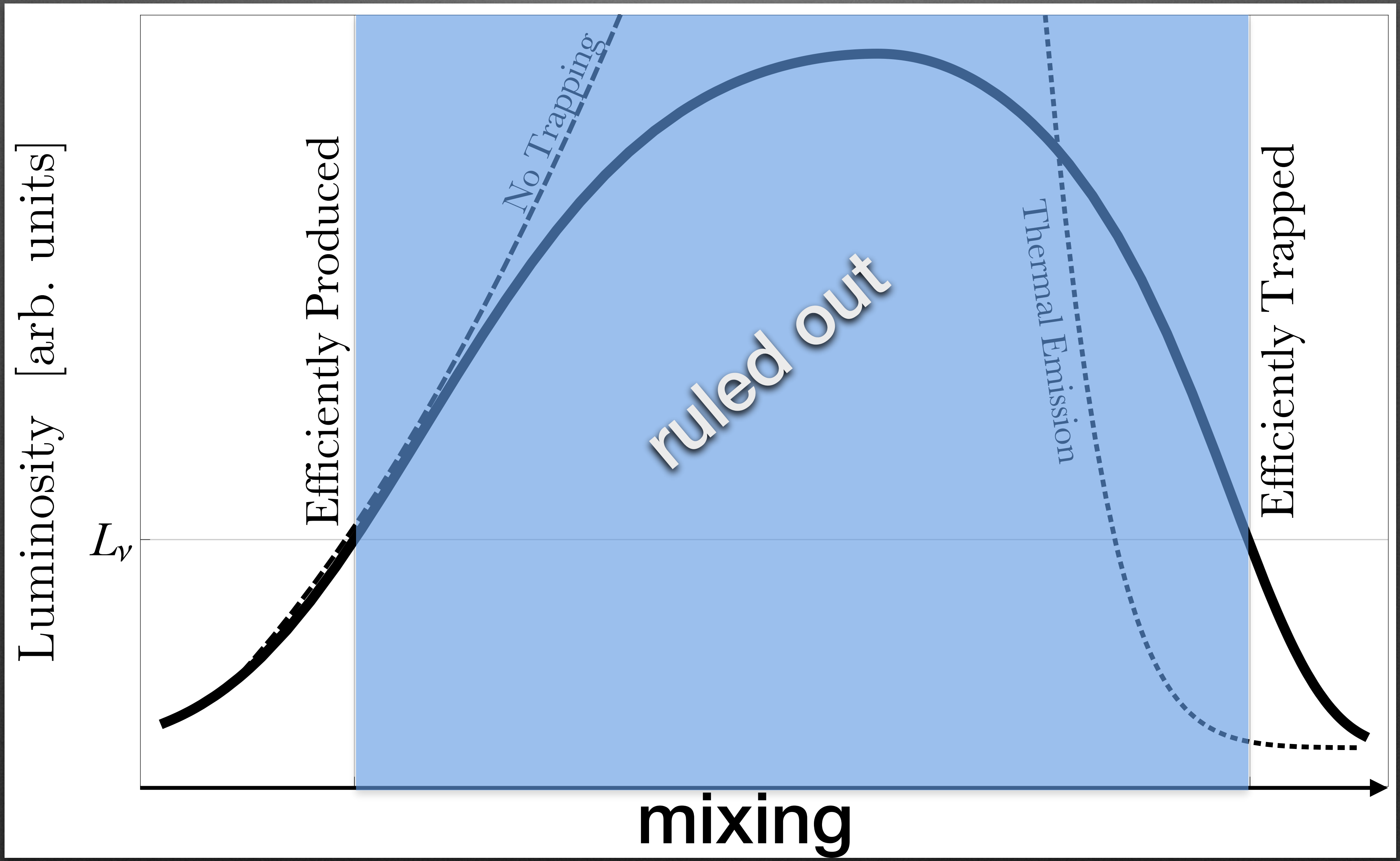

Kinetic Mixing

gauge invariant product of field strengths

$$\mathcal{L} \supset \epsilon F_{1\mu\nu} F_2^{\mu\nu}/2 \Longleftrightarrow$$

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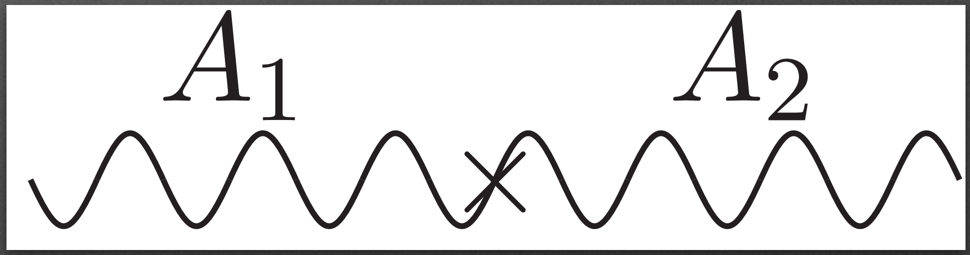

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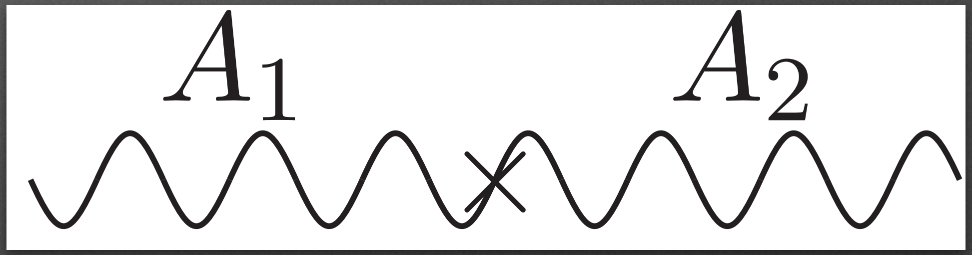
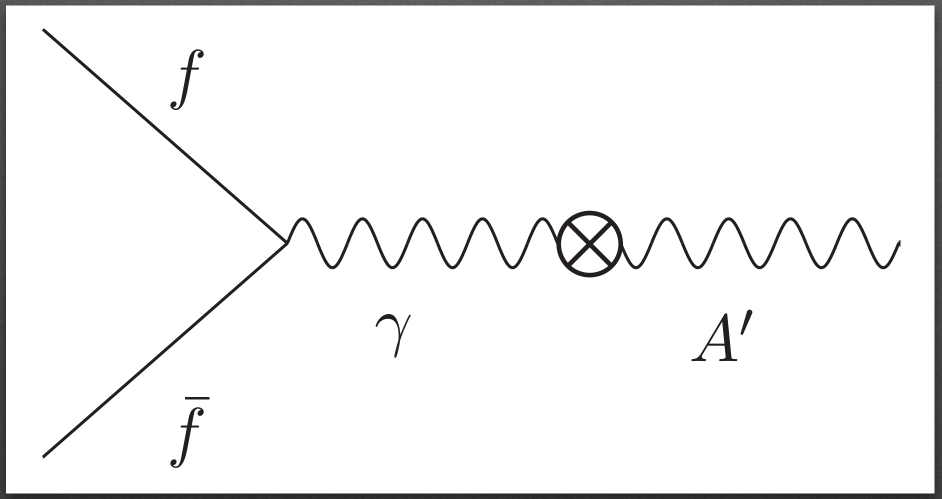


implicitly ~ q^2

*("EFT tells me to write down")

Coupling to Dark Photon

in vacuum:



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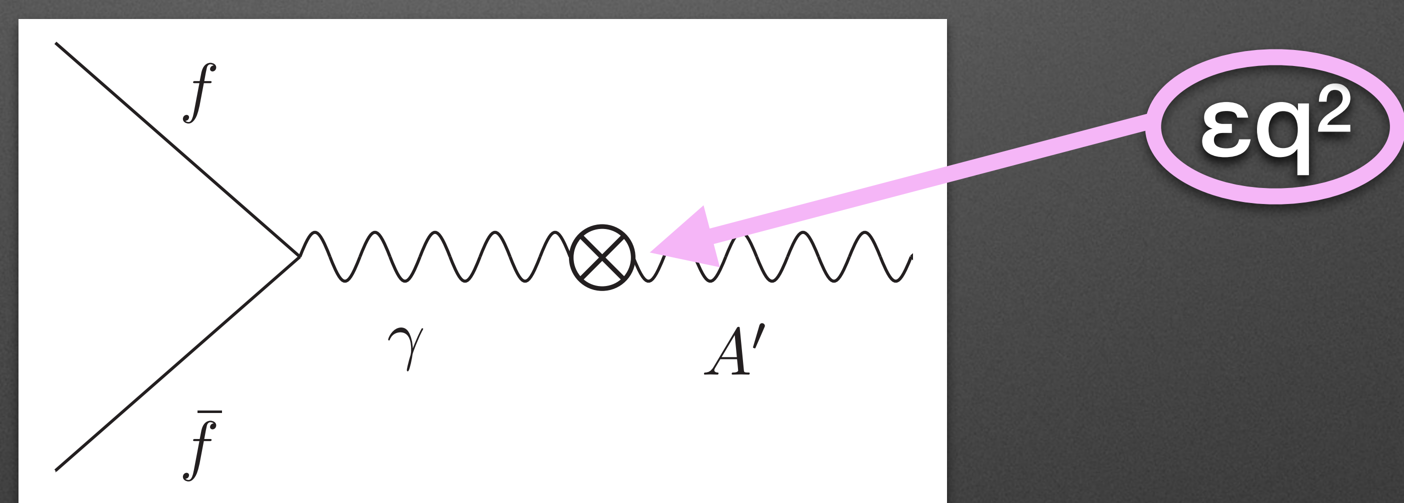

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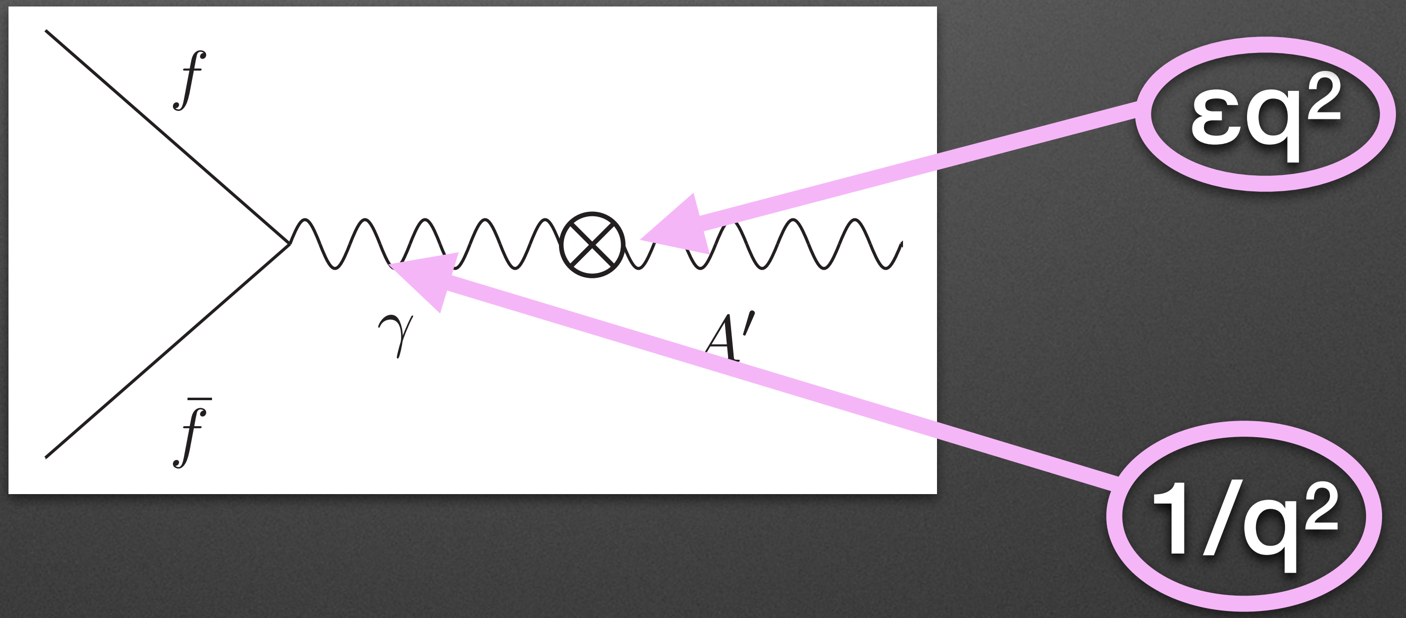
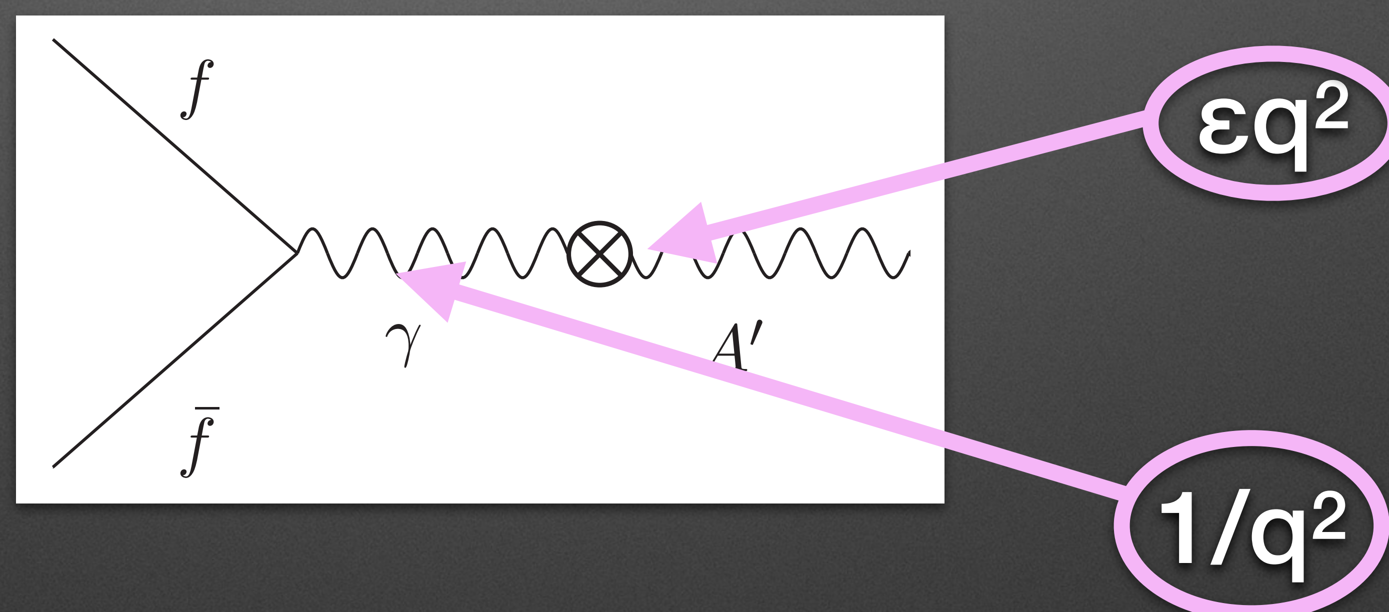


Coupling to Dark Photon

in vacuum:

$$\mathcal{L} \supset \epsilon J_\mu^{\rm SM} A'^\mu$$



“Plasmas Give Photon a Mass”

high density of charge carriers modifies the SM photon dispersion relation:

$$\omega^2 = k^2 + \mathrm{Re}\Pi(k^2, \omega^2, n_e) \quad K^\mu = (\omega, k)$$

at low k, Π equals the “plasma mass” ω_p

$$\lim_{k\to 0} \Pi = \omega_p^2(n_e) \simeq \frac{4\pi\alpha n_e}{E_F}$$

$$\omega_p^2(n_e) = \int \frac{4\pi\alpha\, d^3p}{(2\pi)^3 2E}\left(1 - \frac{p^2}{3E^2}\right)[f_{e^-}(E) + f_{e^+}(E)]$$

Coupling to Dark Photon

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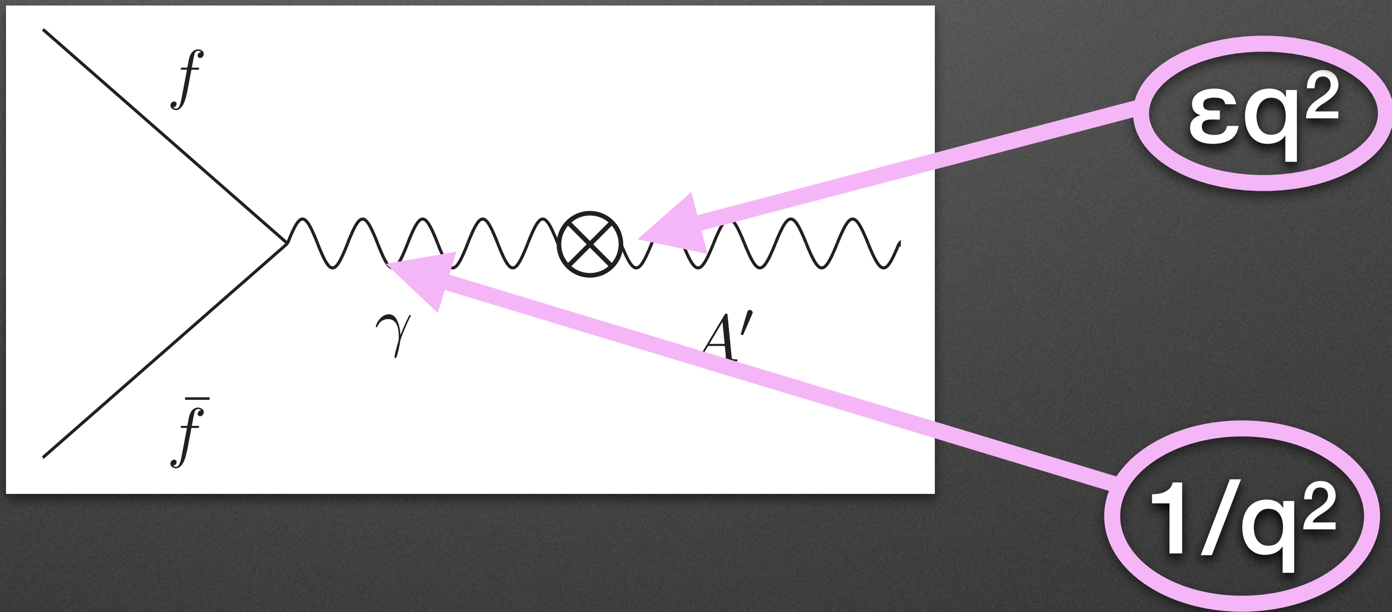

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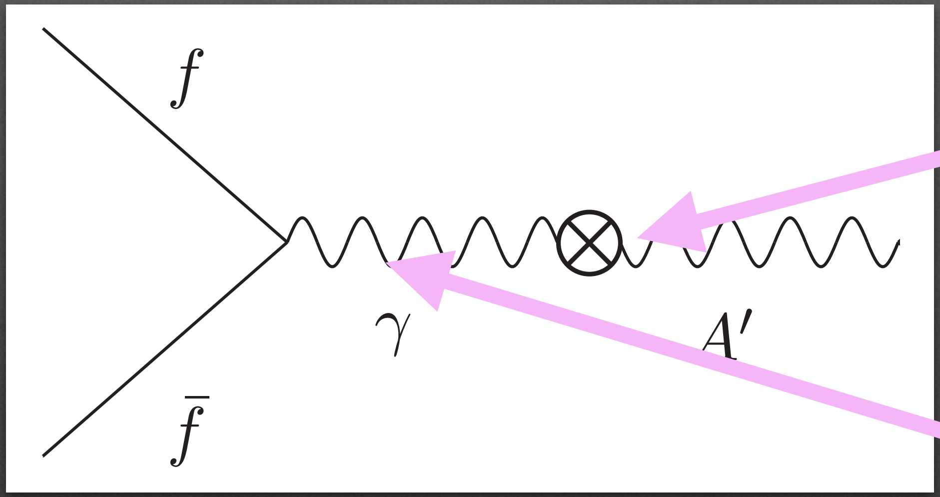

εq²

1/(q²-Π)

in plasma:

$$\mathcal{L} \supset \frac{\epsilon q^2}{q^2 - \Pi} J_\mu^{\rm SM} A'^\mu$$

Coupling to Dark Photon

in vacuum:

$$\mathcal{L} \supset \epsilon J_\mu^{\mathrm{SM}} A'^\mu$$

in plasma, on-shell:

$$\mathcal{L} \supset \frac{\epsilon}{1 - \Pi/m'^2} J_\mu^{\mathrm{SM}} A'^\mu$$

Rates for A's

dark photon rates $\propto$ SM photon rates:

$$\Gamma'_p = \left|\frac{\epsilon}{1 - \Pi/m'^2}\right|^2 \Gamma_p$$

$$= \frac{\epsilon^2 \Gamma_p}{(1 - \mathrm{Re}\Pi/m'^2)^2 + (\mathrm{Im}\Pi/m'^2)^2}$$

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[*resonance if $m'^2 \gg \mathrm{Im}\Pi$ and $\exists\ \omega_{res}$ with $\mathrm{Re}\Pi(\omega_{res}) = m'^2$]

Photon Self-Energy

$$\mathrm{Re}\Pi = \begin{cases} \frac{3\omega_p^2}{v^2}(1-v^2)\left[\frac{1}{2v}\ln\left(\frac{1+v}{1-v}\right)-1\right] & L \\ \frac{3\omega_p^2}{2v^2}\left[1-\frac{1-v^2}{2v}\ln\left(\frac{1+v}{1-v}\right)\right] & T \end{cases}$$

(v=|k|/ω)

different dispersion relations for *L* and *T* modes

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($v=|k|/\omega$)

different dispersion relations for *L* and *T* modes

ImΠ ~ rate at which photon thermalizes:

$$\mathrm{Im}\Pi = \omega\left(\Gamma_{\rm prod} - \Gamma_{\rm abs}\right)$$

Particle Luminosity

$$dL = e^{-\tau} dP$$

Particle Luminosity

energy lost
in A's per
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odds of escaping

Power and Optical Depth

differential power is the integral of production rate:

$$\frac{dP}{dV} = \int \frac{d^3k}{(2\pi)^3}\omega\Gamma_{\rm prod}$$

not all power gets out because of a nonzero "optical" depth:

$$\tau = \int_r^{R_{\rm far}} \Gamma_{\rm abs}(r')dr'$$

by detailed balance, $\Gamma_{\rm prod} = e^{-\omega/T}\,\Gamma_{\rm abs}$, so calculate $\Gamma_{\rm abs}$ only

Differential Luminosity

$$\frac{dL}{dV} = \int \frac{d\omega}{2\pi^2} \frac{\epsilon^2 \omega^3 v e^{-\omega/T} \Gamma_{\rm abs}(\omega, r)\, e^{-\frac{\epsilon^2}{\left[1-\frac{{\rm Re}\Pi(\omega,r)}{m'^2}\right]^2+\left[\frac{{\rm Im}\Pi(\omega,r)}{m'^2}\right]^2}\int dr \Gamma_{\rm abs}(\omega,r)}}{\left[1-\frac{{\rm Re}\Pi(\omega,r)}{m'^2}\right]^2+\left[\frac{{\rm Im}\Pi(\omega,r)}{m'^2}\right]^2}$$

Differential Luminosity

(for small ε) ~1

$$\frac{dL}{dV} = \int \frac{d\omega}{2\pi^2} \frac{\epsilon^2 \omega^3 v e^{-\omega/T} \Gamma_{\rm abs}(\omega, r)\, e^{\cancel{-\frac{\epsilon^2}{\left[1-\frac{\mathrm{Re}\Pi(\omega,r)}{m'^2}\right]^2+\left[\frac{\mathrm{Im}\Pi(\omega,r)}{m'^2}\right]^2}\int dr \Gamma_{\rm abs}(\omega,r)}}}{\left[1-\frac{\mathrm{Re}\Pi(\omega,r)}{m'^2}\right]^2+\left[\frac{\mathrm{Im}\Pi(\omega,r)}{m'^2}\right]^2}$$

Differential Luminosity

(for $\mathrm{Im}\Pi_{\mathrm{res}} << m'^2$)

(for small ε)

~1

$$\frac{dL}{dV} \simeq \frac{\Delta\omega_{\mathrm{res}}}{2\pi^2} \frac{\epsilon^2 \omega^3 v e^{-\omega/T} \Gamma_{\mathrm{abs}}(\omega, r)}{0 + [\mathrm{Im}\Pi(\omega, r)/m'^2]^2} \cancel{e^{-\epsilon^2 \cdots}}$$

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rates cancel since ImΠ~Γ, $\Delta\omega_{res}$~Γ

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rates cancel since $\mathrm{Im}\Pi \sim \Gamma$, $\Delta\omega_{res} \sim \Gamma$

at low mixing, resonant luminosity is

$$\frac{dL_{\mathrm{res}}}{dV} \simeq \frac{\epsilon^2 m'^2 \omega_{\mathrm{res}}^3 v^3}{2\pi \left(e^{\omega/T} - 1\right)} \Longrightarrow \frac{dL_{\mathrm{res}}}{dV} \times \mathrm{Vol} \sim L_\nu (\varepsilon/5\mathrm{x}10^{-9})^2 (m'/\mathrm{MeV})^2$$

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bounds not flat in ε-m' plane

at low mixing, resonant luminosity is

$$\frac{dL_{\rm res}}{dV} \simeq \frac{\epsilon^2 m'^2 \omega_{\rm res}^3 v^3}{2\pi \left(e^{\omega/T} - 1\right)} \implies \frac{dL_{\rm res}}{dV} \times \mathrm{Vol} \sim L_\nu\, (\varepsilon/5\times10^{-9})^2\, (m'/\mathrm{MeV})^2$$

Higher Mixing

at large mixing: τ is large, dP_{res} is suppressed

differential luminosity $dL = e^{-\tau}\, dP \neq dP$

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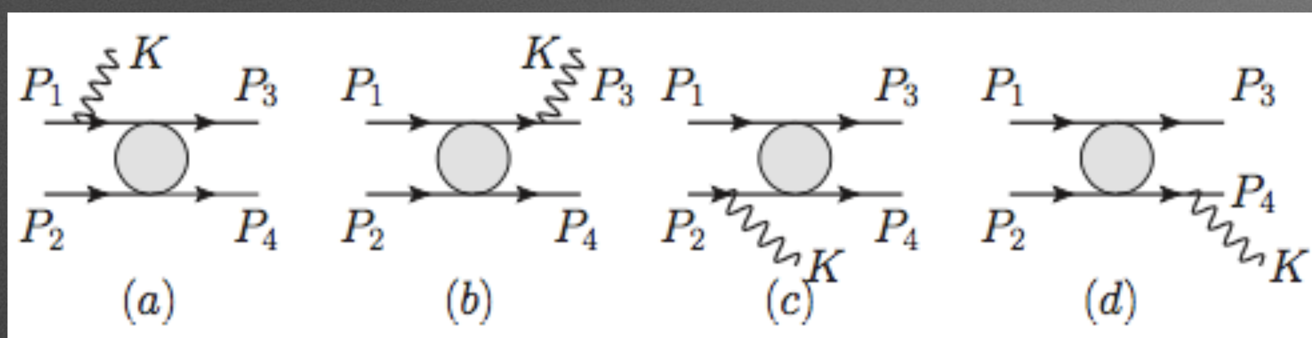
need to know Γ for all r and ω

Soft Radiation Approximation

use *np* scattering data with soft emission:



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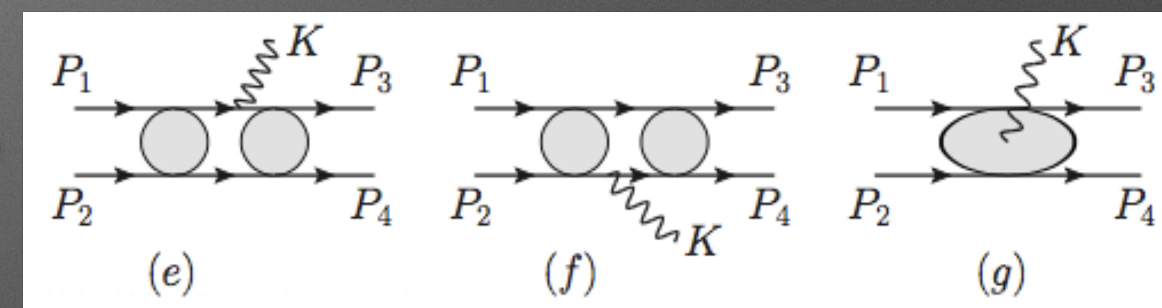

Rrapaj & Reddy, 1511.09136

$$\Gamma'_{\mathrm{br.}|L,T} = \frac{32}{3\pi}\frac{\alpha_{\mathrm{EM}}(\epsilon_{\mathrm{m}})^2_{L,T}\, n_n n_p}{\omega^3}\left(\frac{\pi T}{m_N}\right)^{3/2}\langle\sigma^{(2)}_{np}\rangle\left[\frac{m'^2}{\omega^2}\right]_L$$

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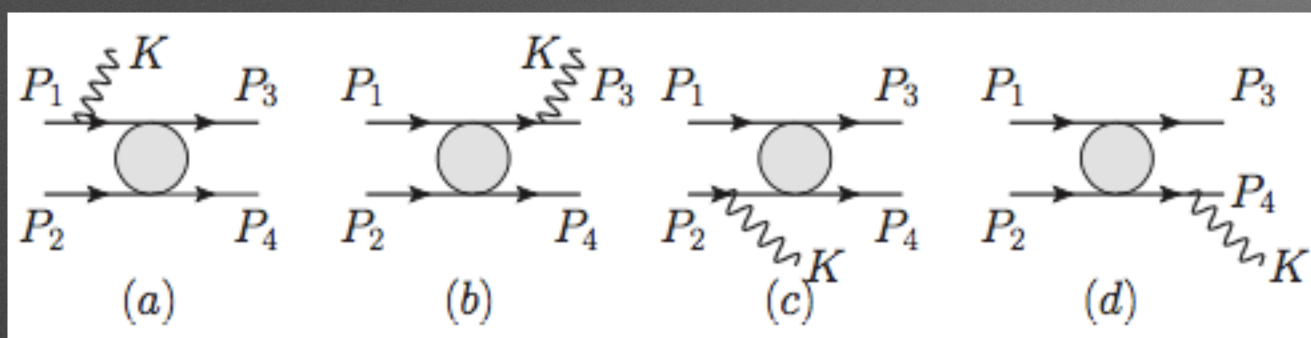

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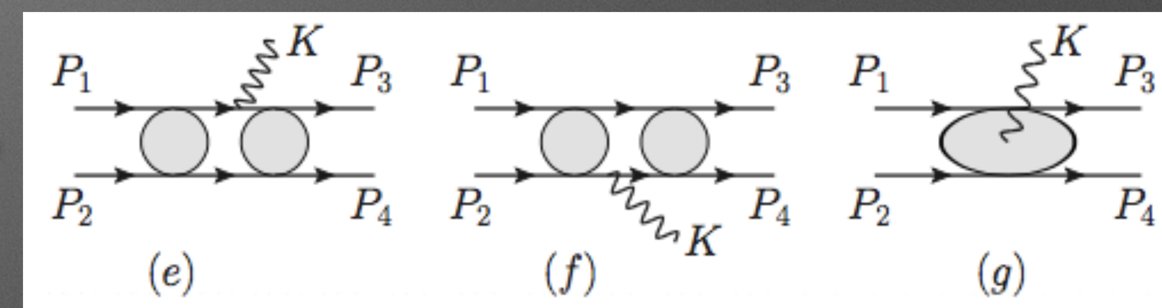


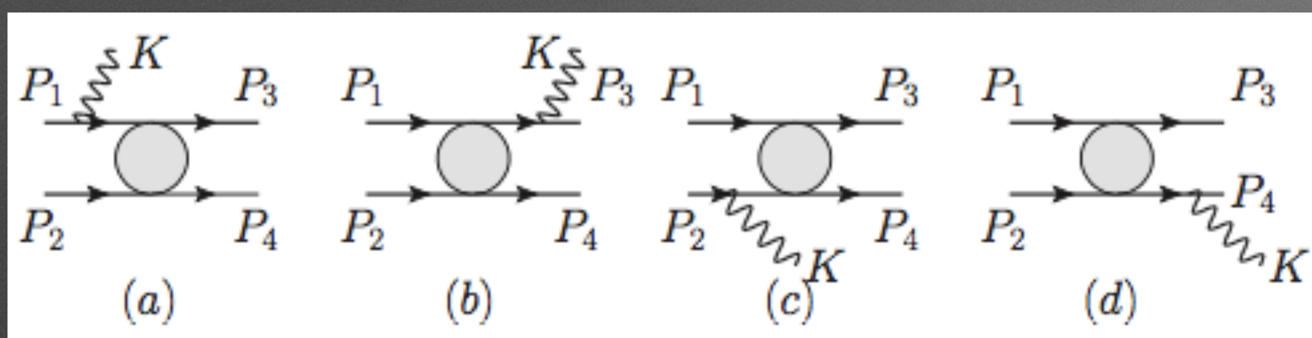
Rrapaj & Reddy, 1511.09136

$$\Gamma'_{\mathrm{br.}|L,T} = \frac{32}{3\pi} \frac{\alpha_{\mathrm{EM}} (\epsilon_{\mathrm{m}})^2_{L,T} n_n n_p}{\omega^3} \left(\frac{\pi T}{m_N} \right)^{3/2} \langle \sigma_{np}^{(2)} \rangle \left[\frac{m'^2}{\omega^2} \right]_L$$

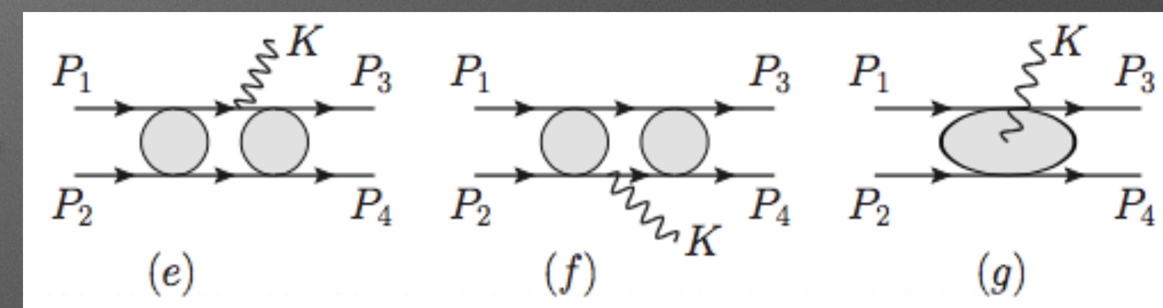
key point: falls sharply with ω

Soft Radiation Approximation

use *np* scattering data with soft emission:



$\gg$



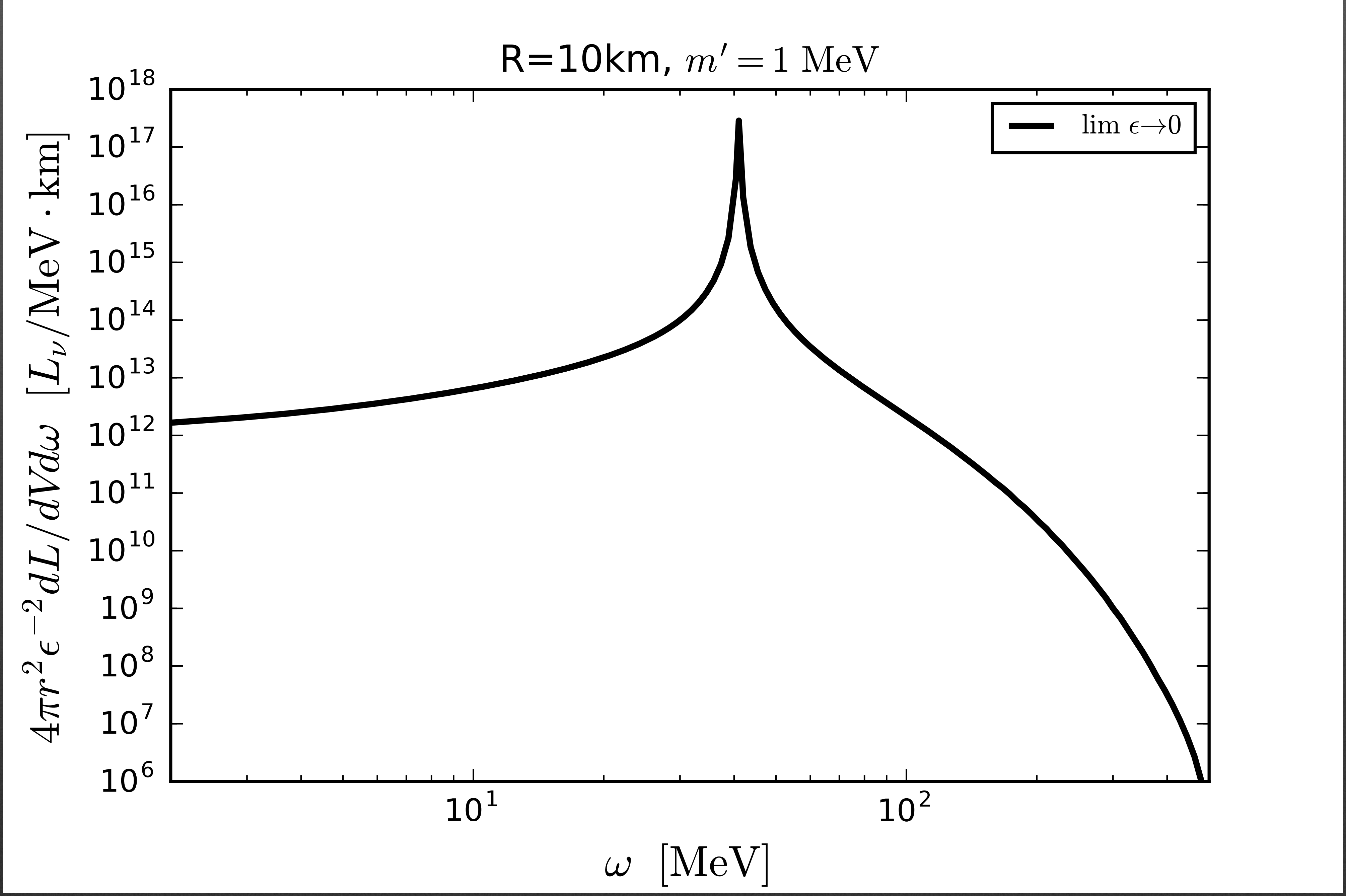
Rrapaj & Reddy, 1511.09136

$$\Gamma'_{\mathrm{br.}|L,T} = \frac{32}{3\pi}\frac{\alpha_{\mathrm{EM}}(\epsilon_{\mathrm{m}})^2_{L,T}\, n_n n_p}{\omega^3}\left(\frac{\pi T}{m_N}\right)^{3/2}\langle\sigma^{(2)}_{np}\rangle\left[\frac{m'^2}{\omega^2}\right]_L$$

key point: falls sharply with ω

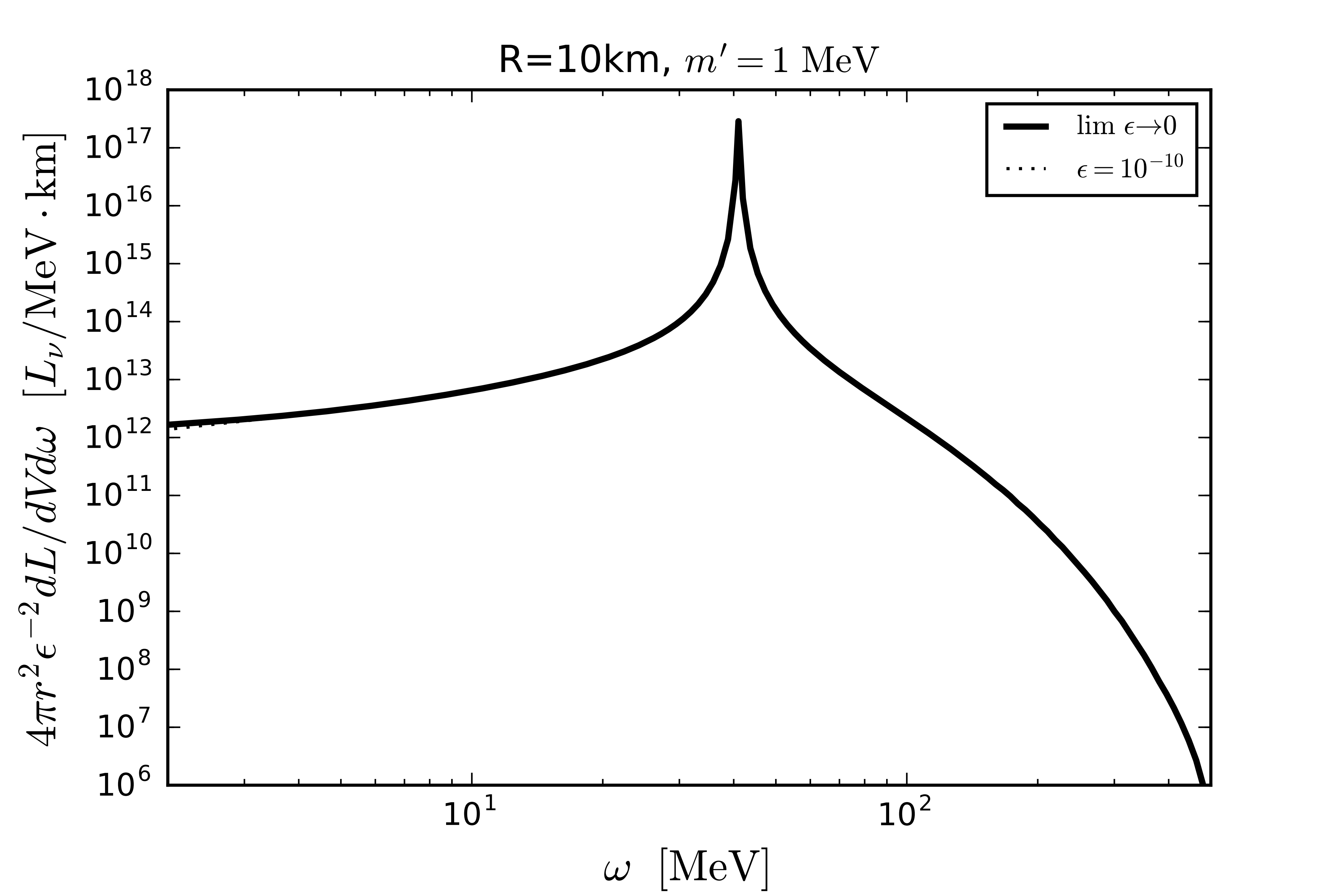
(⇒lower optical depth at high ω)

dL/dV/dω/ε²



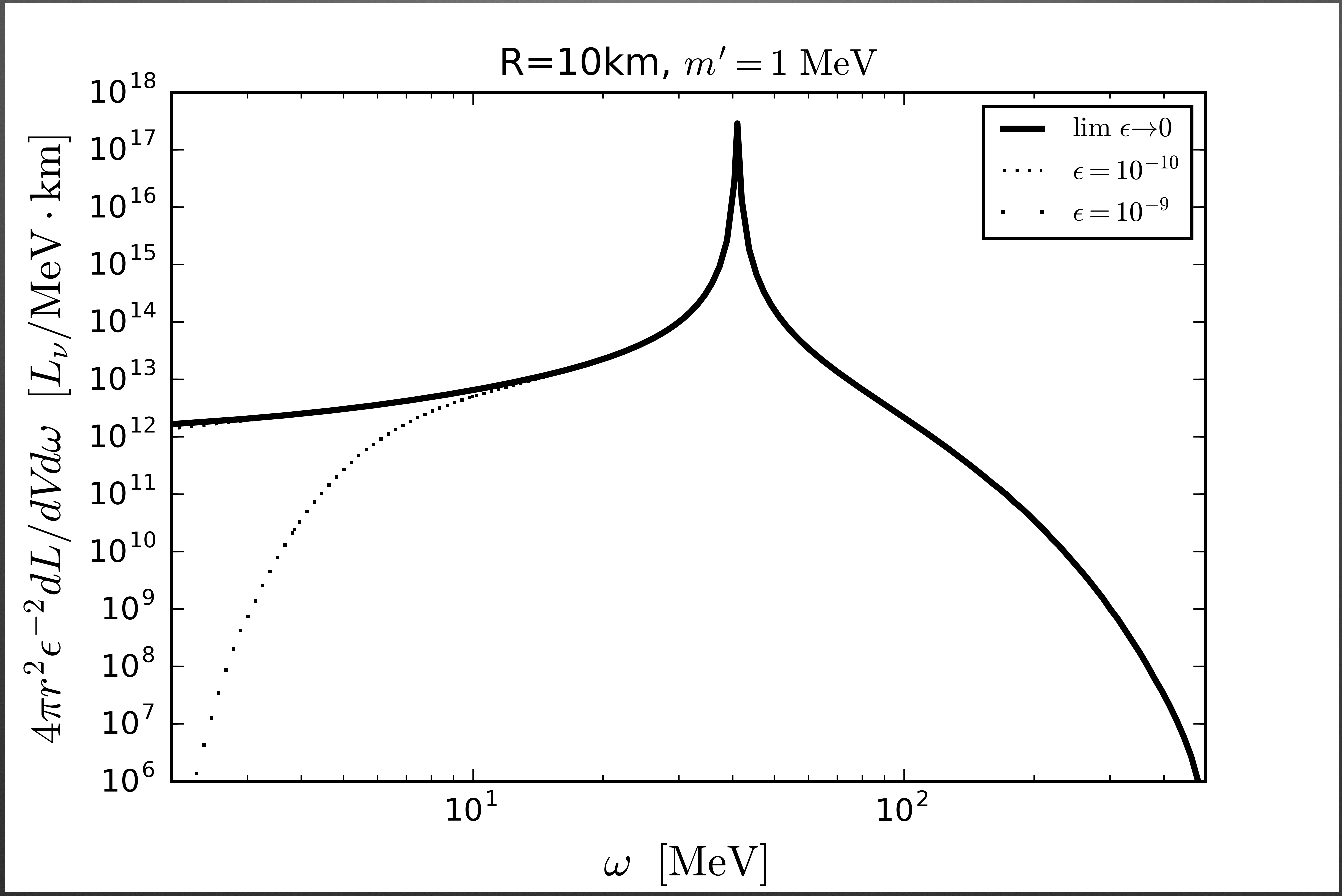
R=10km, $m' = 1$ MeV
$\lim \epsilon \to 0$
$4\pi r^2 \epsilon^{-2} dL/dVd\omega$ $[L_\nu/\mathrm{MeV}\cdot\mathrm{km}]$
ω [MeV]
10^{18}
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{1}
10^{2}

dL/dV/dω/ε²



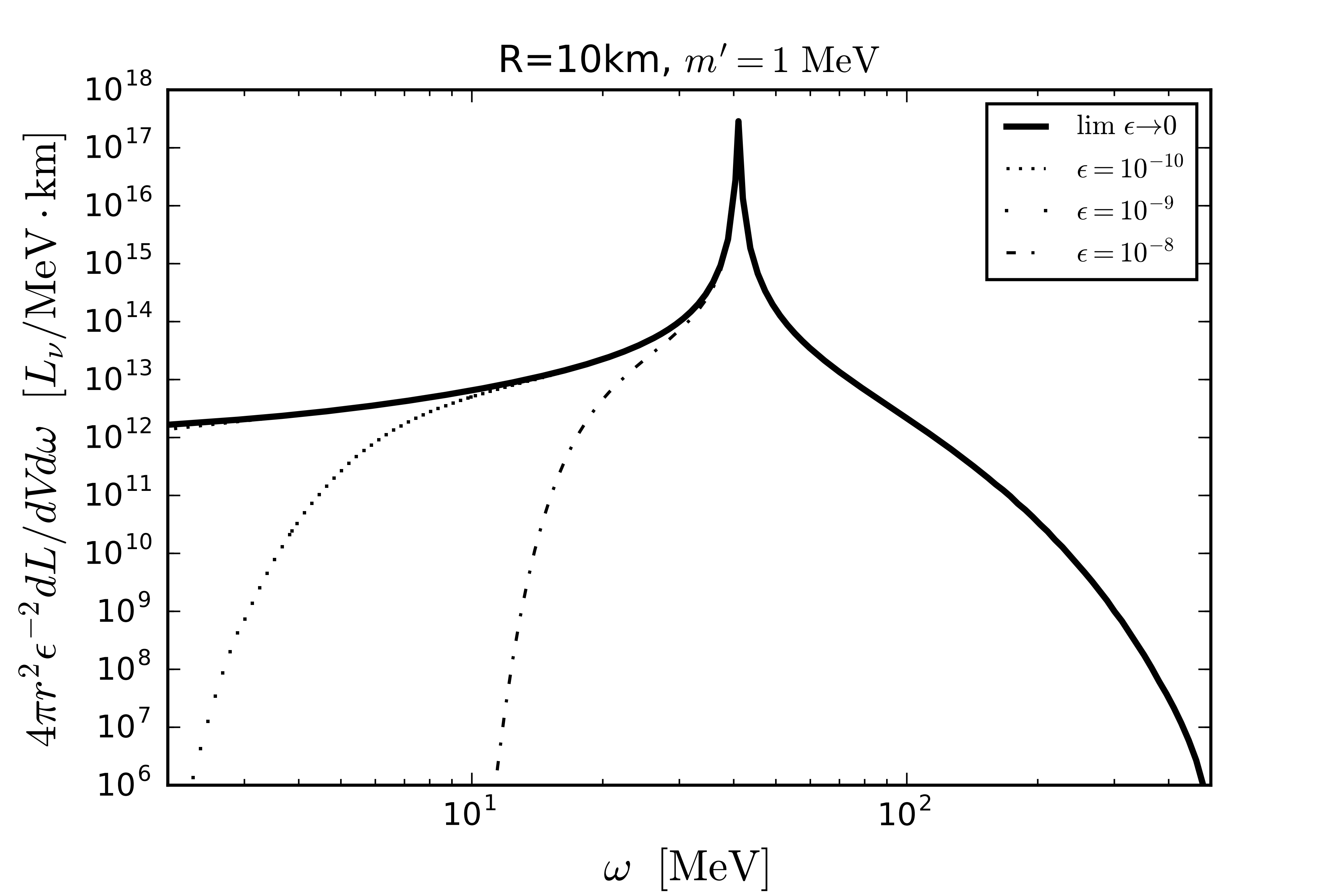
R=10km, $m' = 1$ MeV
$\lim \epsilon \to 0$
$\epsilon = 10^{-10}$
$4\pi r^2 \epsilon^{-2} dL/dVd\omega \ [L_\nu/\mathrm{MeV} \cdot \mathrm{km}]$
ω [MeV]
10^{18}
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{1}
10^{2}

dL/dV/dω/ε²



R=10km, $m' = 1$ MeV
$4\pi r^2 \epsilon^{-2} dL/dVd\omega$ $[L_\nu/\mathrm{MeV}\cdot\mathrm{km}]$
ω [MeV]
lim $\epsilon \to 0$
$\epsilon = 10^{-10}$
$\epsilon = 10^{-9}$
10^{18}
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{1}
10^{2}

dL/dV/dω/ε²



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ω [MeV]
$\lim \epsilon \to 0$
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$\epsilon = 10^{-9}$
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10^{17}
10^{16}
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10^{11}
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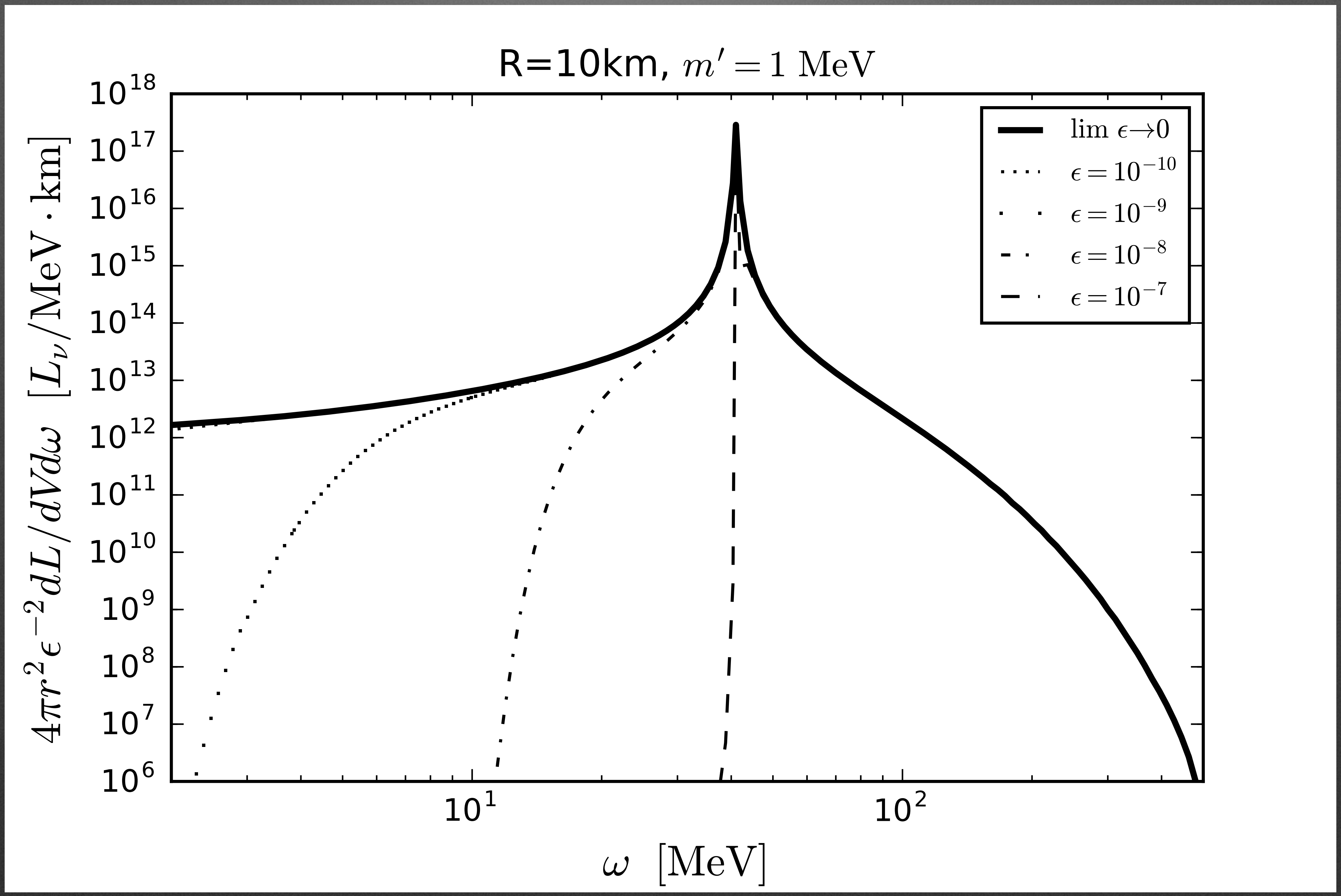
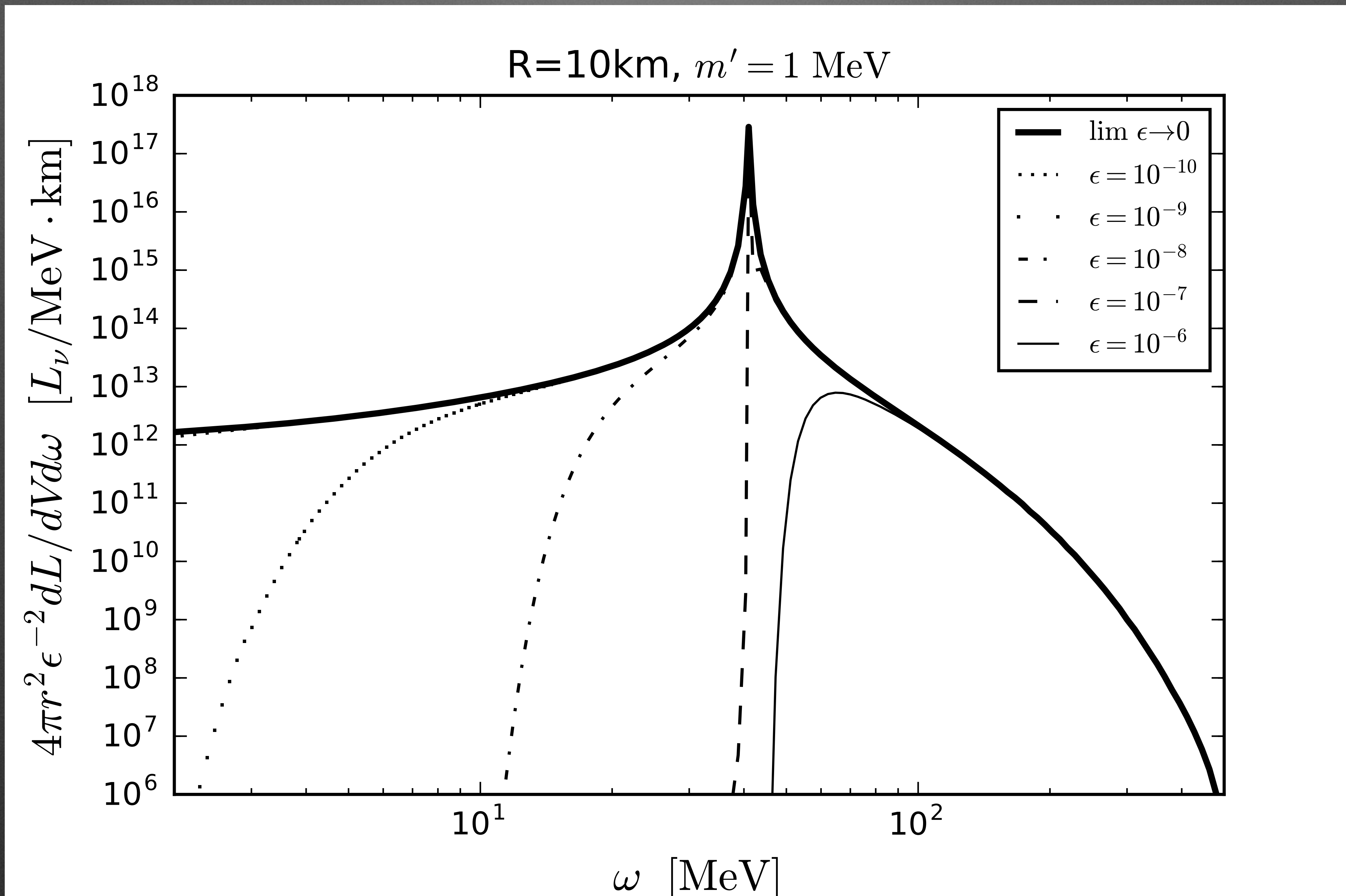
10^{8}
10^{7}
10^{6}
10^{1}
10^{2}

dL/dV/dω/ε²



R=10km, $m' = 1$ MeV
$4\pi r^2 \epsilon^{-2} dL/dVd\omega \ [L_\nu/\mathrm{MeV}\cdot\mathrm{km}]$
ω [MeV]
10^{6}
10^{7}
10^{8}
10^{9}
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{1}
10^{2}
lim $\epsilon \to 0$
$\epsilon = 10^{-10}$
$\epsilon = 10^{-9}$
$\epsilon = 10^{-8}$
$\epsilon = 10^{-7}$

dL/dV/dω/ε²



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ω [MeV]
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10^{7}
10^{8}
10^{9}
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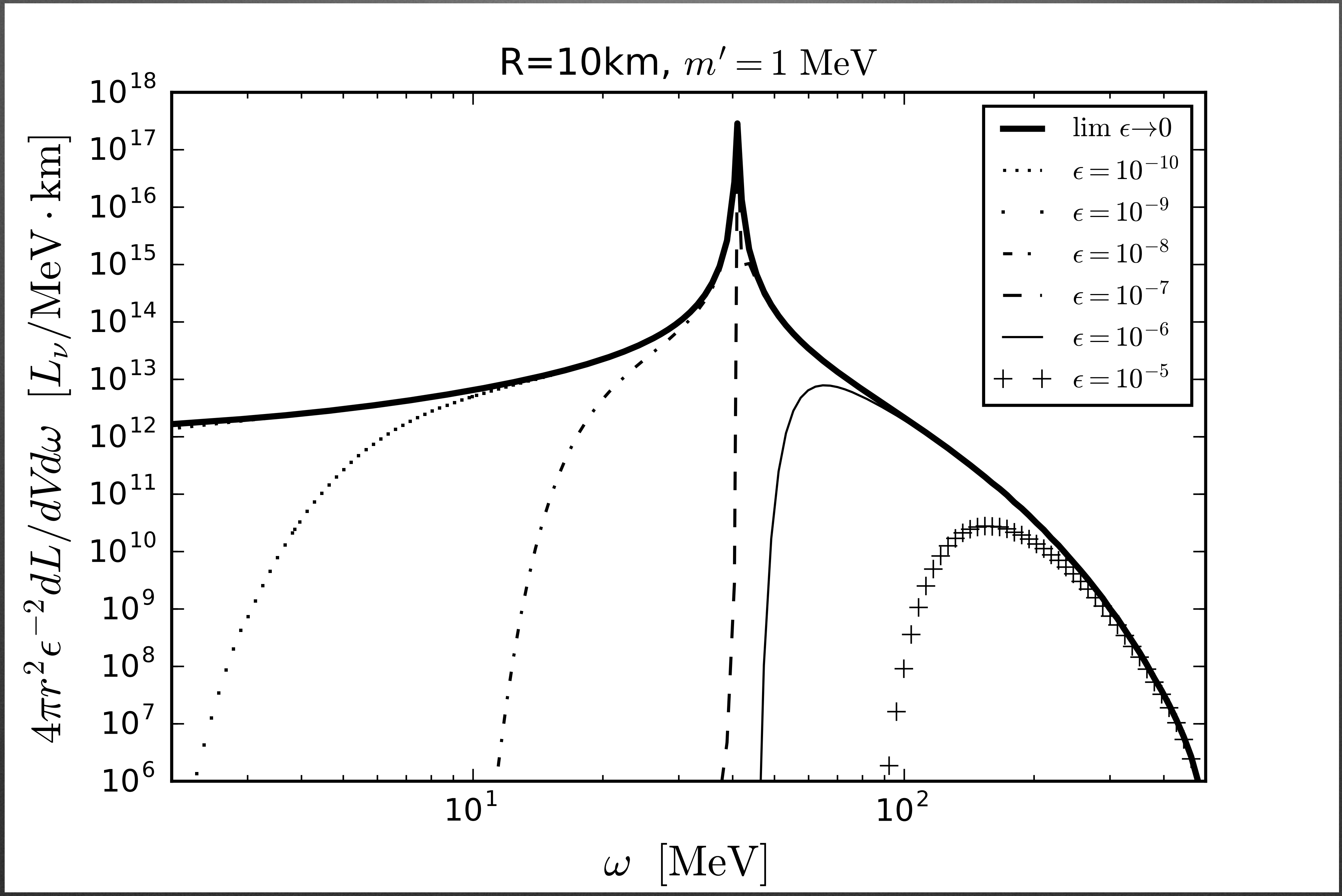
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{1}
10^{2}
lim $\epsilon \to 0$
$\epsilon = 10^{-10}$
$\epsilon = 10^{-9}$
$\epsilon = 10^{-8}$
$\epsilon = 10^{-7}$
$\epsilon = 10^{-6}$

dL/dV/dω/ε²



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$\lim \epsilon \to 0$
$\epsilon = 10^{-10}$
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$\epsilon = 10^{-8}$
$\epsilon = 10^{-7}$
$\epsilon = 10^{-6}$
$\epsilon = 10^{-5}$
10^{18}
10^{17}
10^{16}
10^{15}
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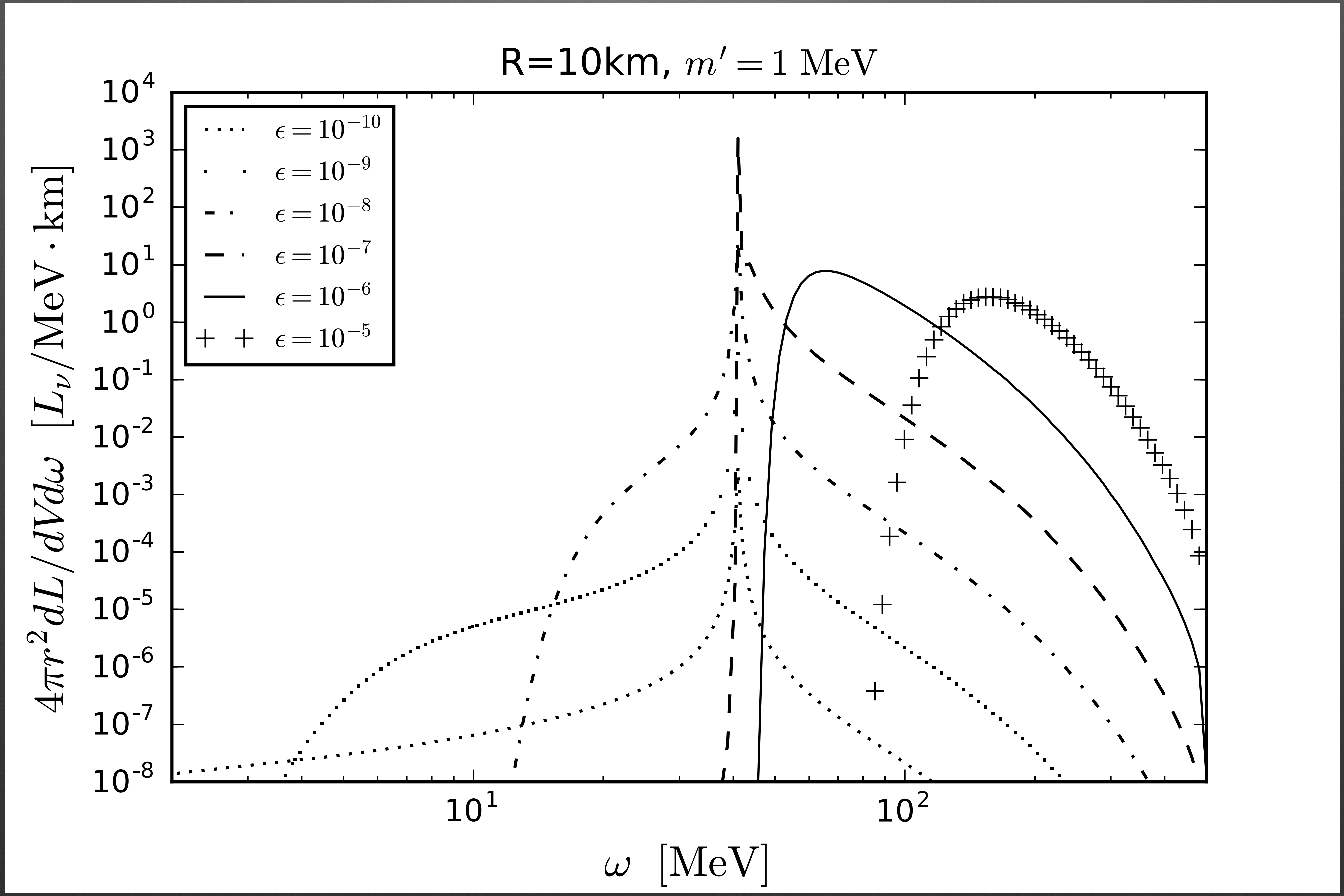
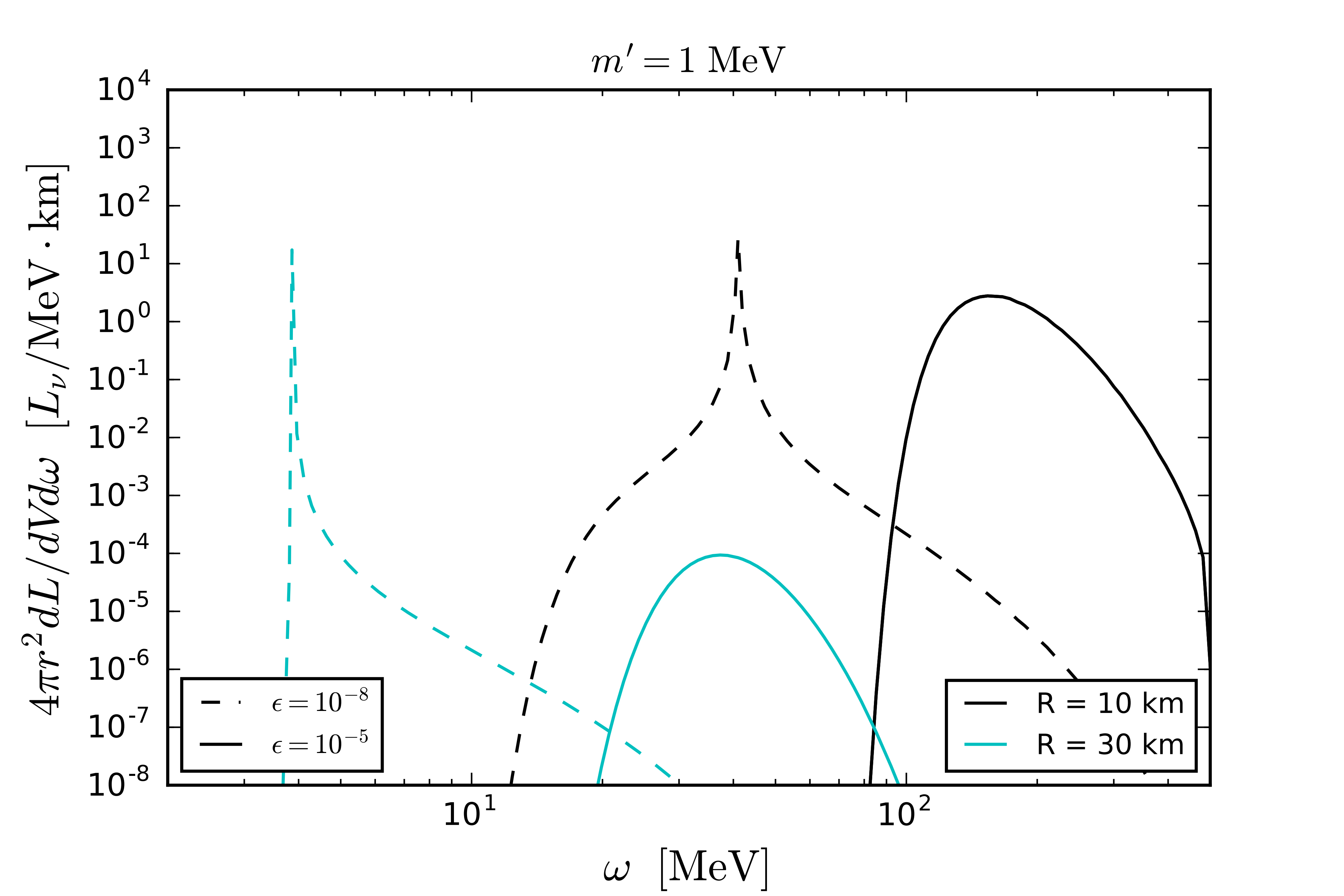
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{1}
10^{2}

dL/dV/dω



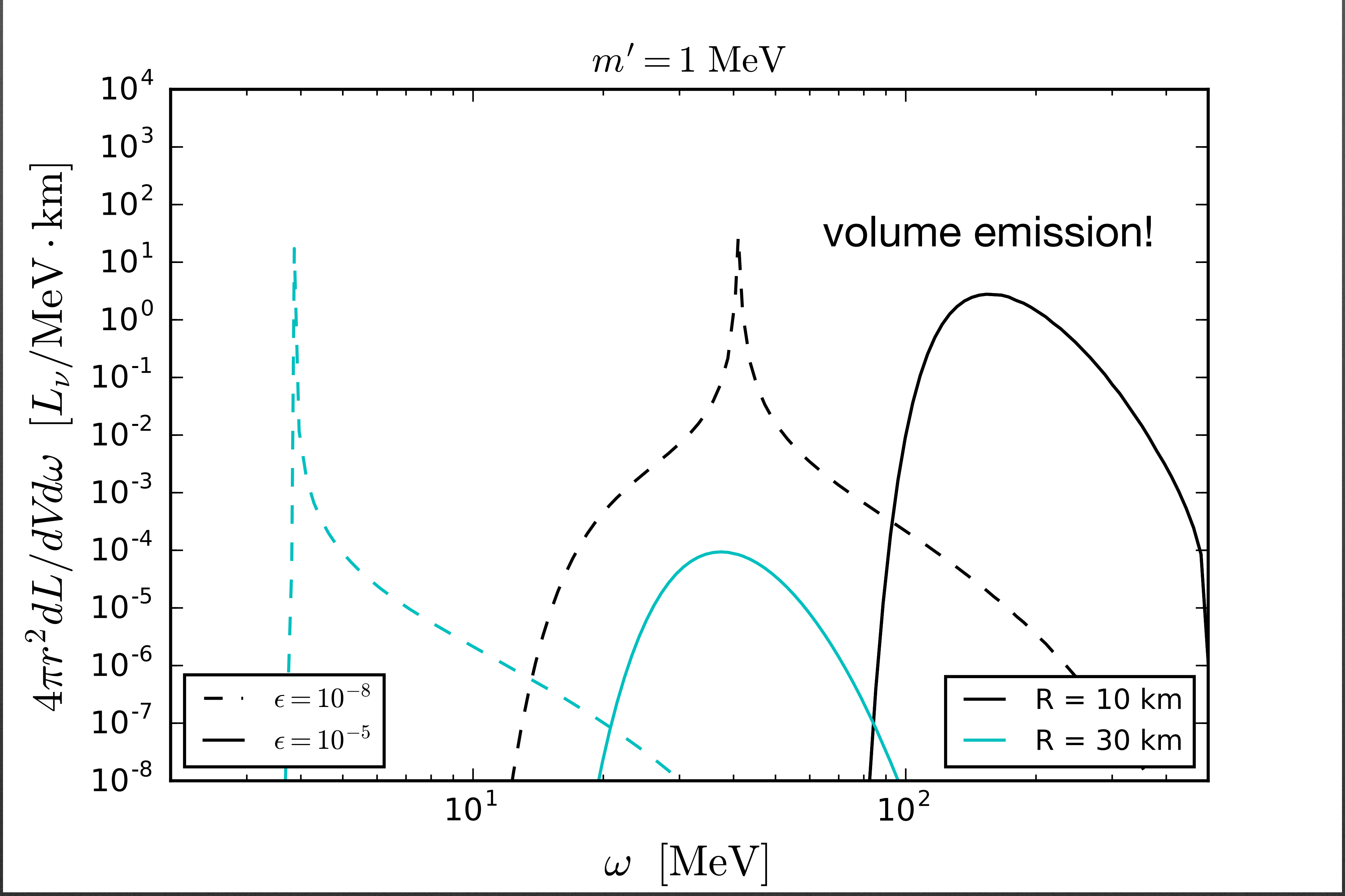
R=10km, $m' = 1$ MeV
$\epsilon = 10^{-10}$
$\epsilon = 10^{-9}$
$\epsilon = 10^{-8}$
$\epsilon = 10^{-7}$
$\epsilon = 10^{-6}$
$\epsilon = 10^{-5}$
$4\pi r^2 dL/dVd\omega \;\; [L_\nu/\mathrm{MeV}\cdot\mathrm{km}]$
$\omega \;\; [\mathrm{MeV}]$
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^1
10^2

dL/dV/dω



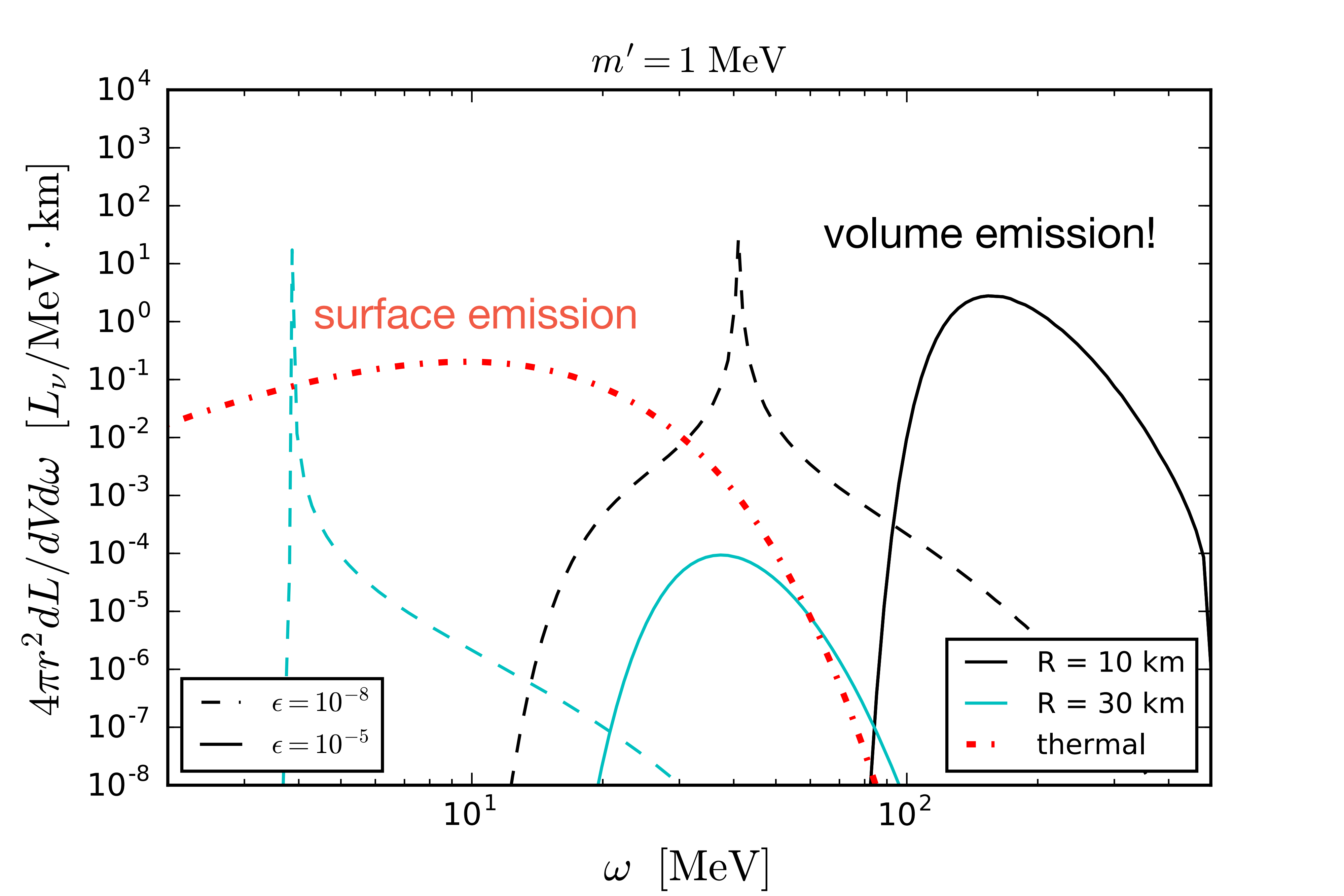
$m' = 1$ MeV
$4\pi r^2 dL/dVd\omega \quad [L_\nu/\mathrm{MeV}\cdot\mathrm{km}]$
$\omega \quad [\mathrm{MeV}]$
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^1
10^2
$\epsilon = 10^{-8}$
$\epsilon = 10^{-5}$
R = 10 km
R = 30 km

dL/dV/dω



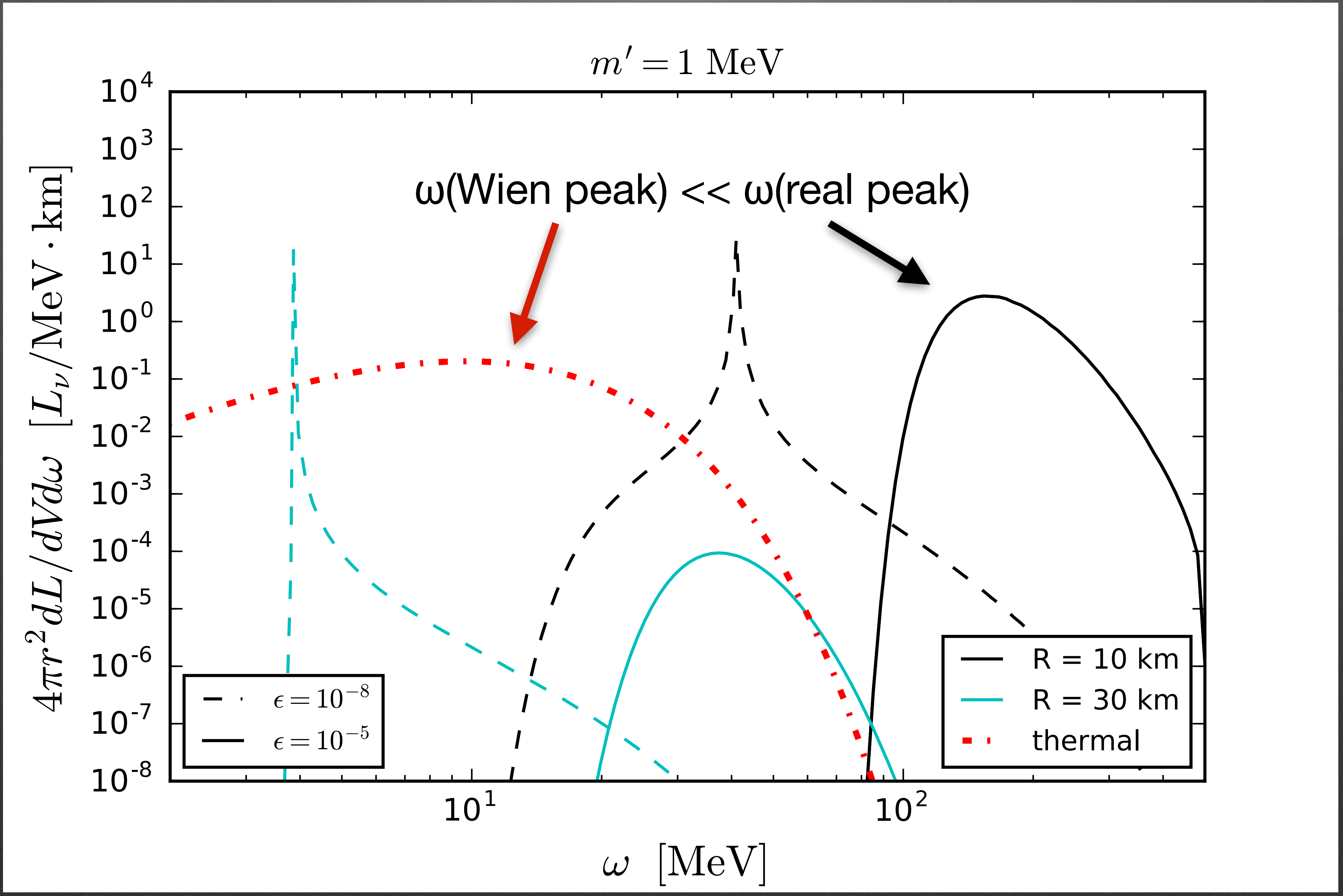
$m' = 1$ MeV
volume emission!
$4\pi r^2 dL/dVd\omega \;\; [L_\nu/\mathrm{MeV}\cdot\mathrm{km}]$
$\omega \;\; [\mathrm{MeV}]$
$\epsilon = 10^{-8}$
$\epsilon = 10^{-5}$
R = 10 km
R = 30 km
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^1
10^2

dL/dV/dω



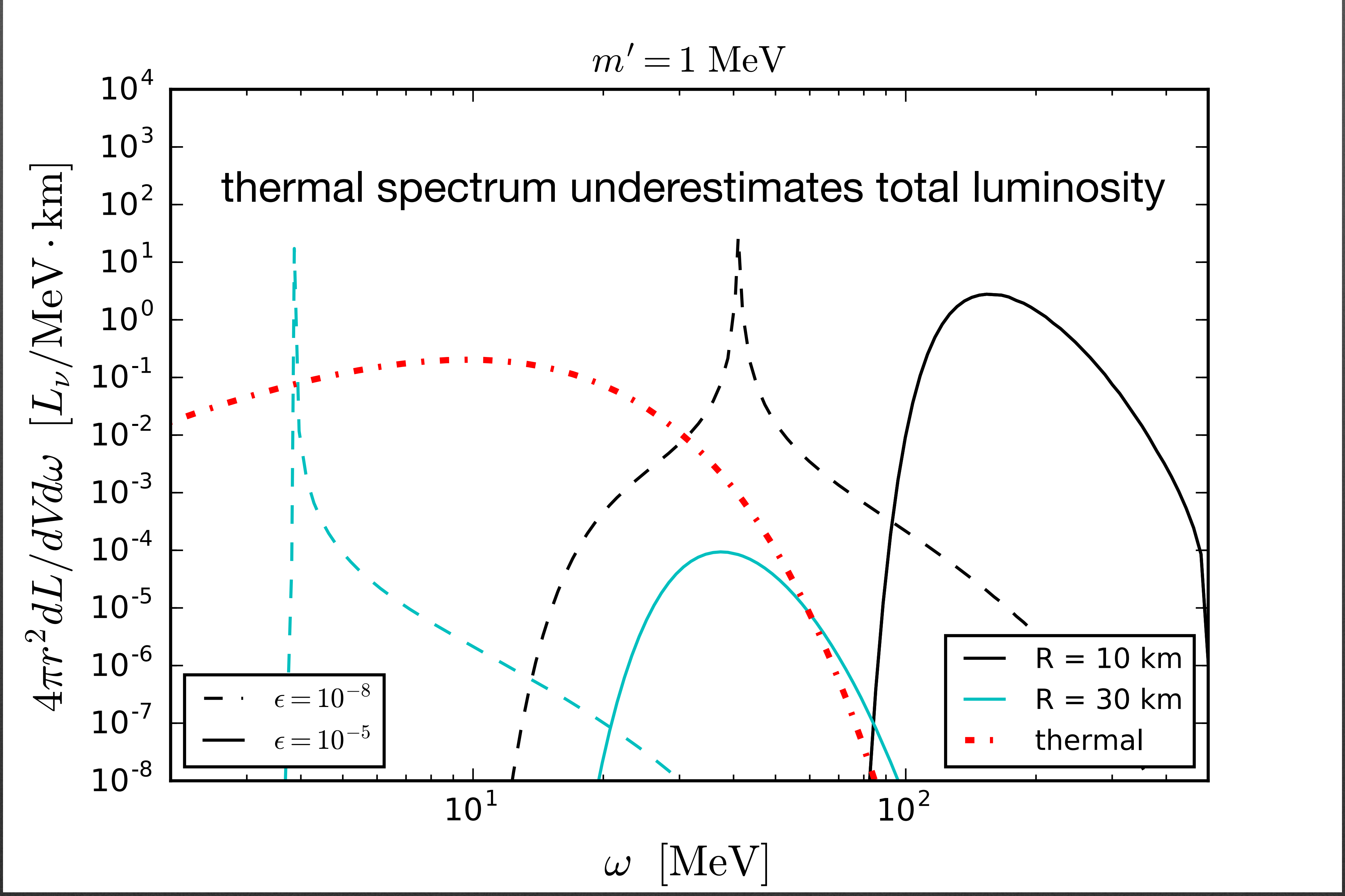
$m' = 1$ MeV
volume emission!
surface emission
$\epsilon = 10^{-8}$
$\epsilon = 10^{-5}$
R = 10 km
R = 30 km
thermal
$4\pi r^2 dL/dVd\omega \;\; [L_\nu/\mathrm{MeV}\cdot\mathrm{km}]$
$\omega \;\; [\mathrm{MeV}]$

dL/dV/dω



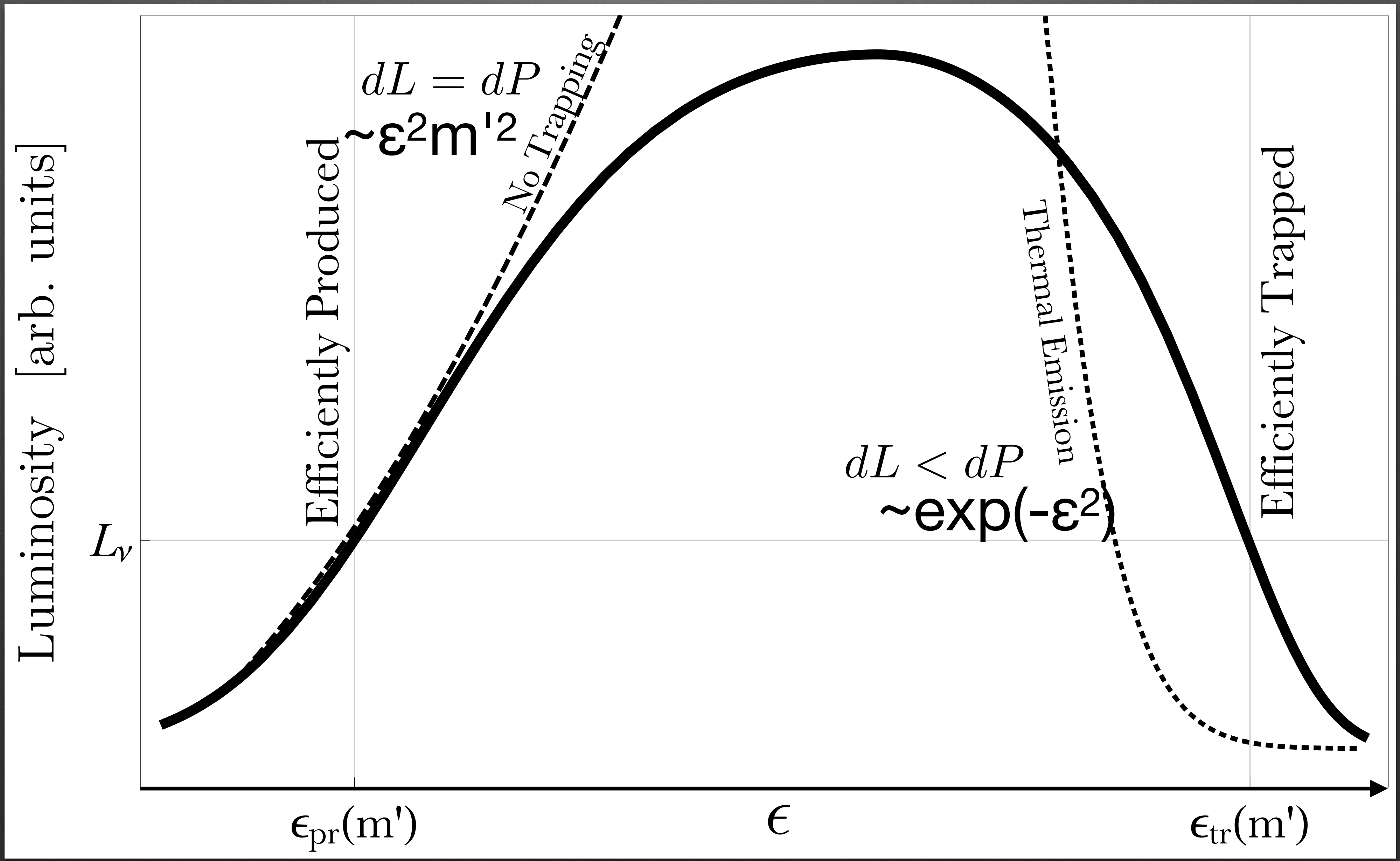
$m' = 1$ MeV
ω(Wien peak) << ω(real peak)
$4\pi r^2 dL/dVd\omega$ $[L_\nu/\mathrm{MeV}\cdot\mathrm{km}]$
ω [MeV]
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^1
10^2
$\epsilon = 10^{-8}$
$\epsilon = 10^{-5}$
R = 10 km
R = 30 km
thermal

dL/dV/dω



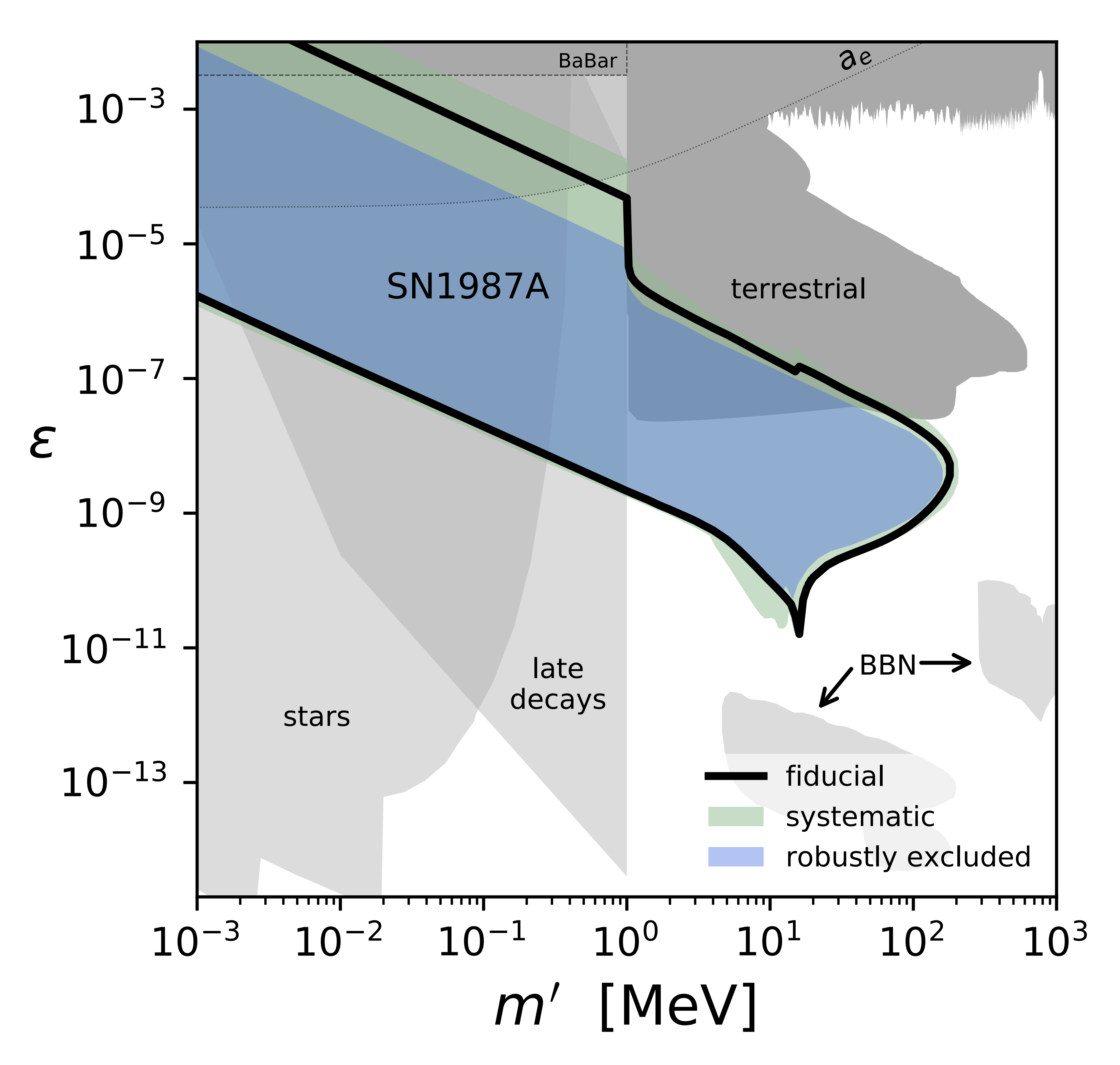
$m' = 1$ MeV
thermal spectrum underestimates total luminosity
$4\pi r^2 dL/dVd\omega$ $[L_\nu/\mathrm{MeV}\cdot\mathrm{km}]$
ω [MeV]
$\epsilon = 10^{-8}$
$\epsilon = 10^{-5}$
R = 10 km
R = 30 km
thermal

$$dL = e^{-\tau} dP$$



$dL = dP$
~ε²m'²
No Trapping
Efficiently Produced
Luminosity [arb. units]
L_ν
Thermal Emission
Efficiently Trapped
$dL < dP$
~exp(-ε²)
$\epsilon_{pr}(m')$
ϵ
$\epsilon_{tr}(m')$

Results


BaBar
a_e
SN1987A
terrestrial
stars
late decays
BBN
fiducial
systematic
robustly excluded
10^{-3}
10^{-5}
10^{-7}
10^{-9}
10^{-11}
10^{-13}
ε
10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2} 10^{3}
m' [MeV]

Part II: Dark Pair Instability

Very small coupling

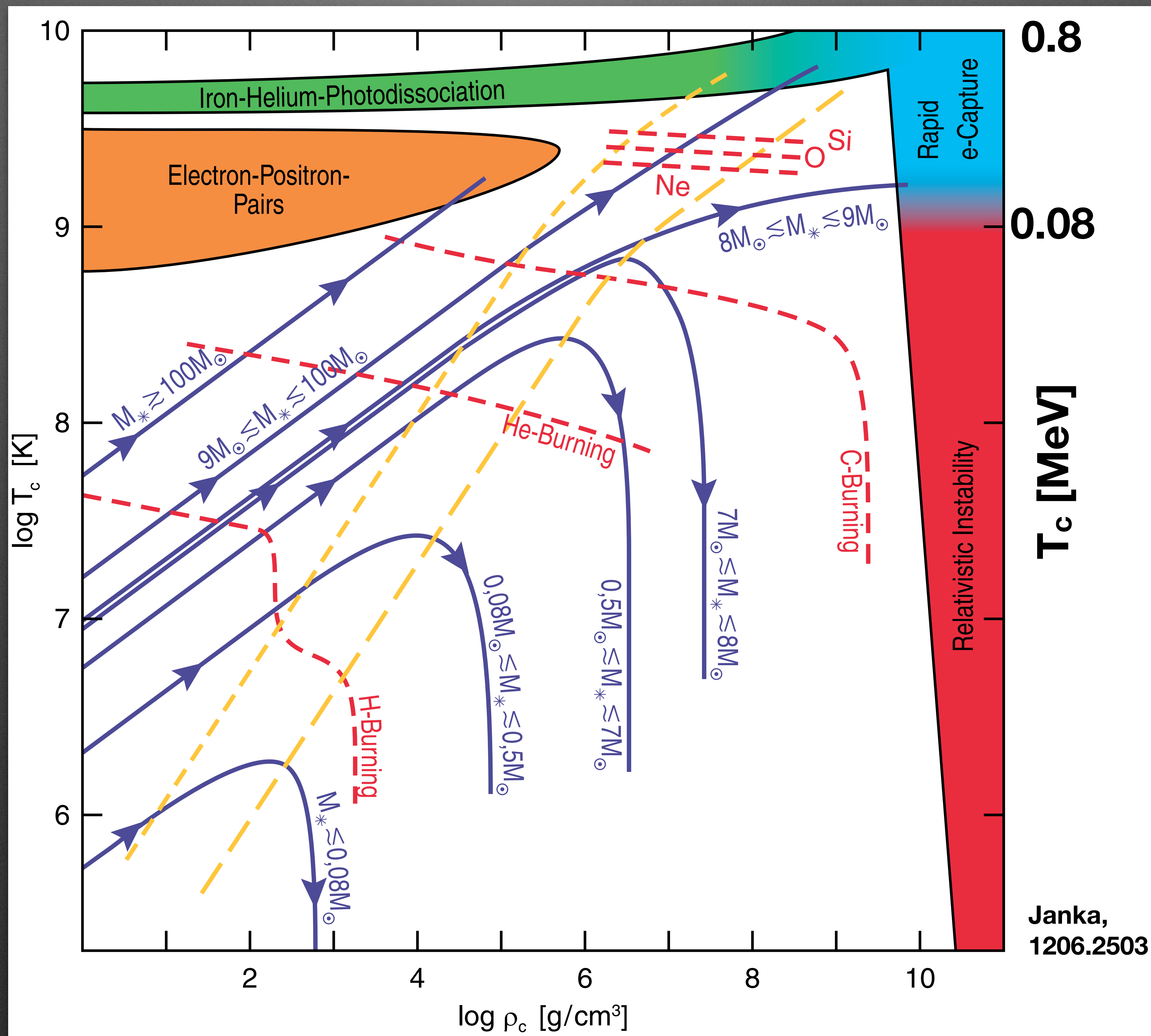
A' production rate competes with SM photon or neutrino rate

Very small coupling

A’ production
rate competes
with SM photon
or neutrino rate

nonrelativistic
A’ produced at
very low rates

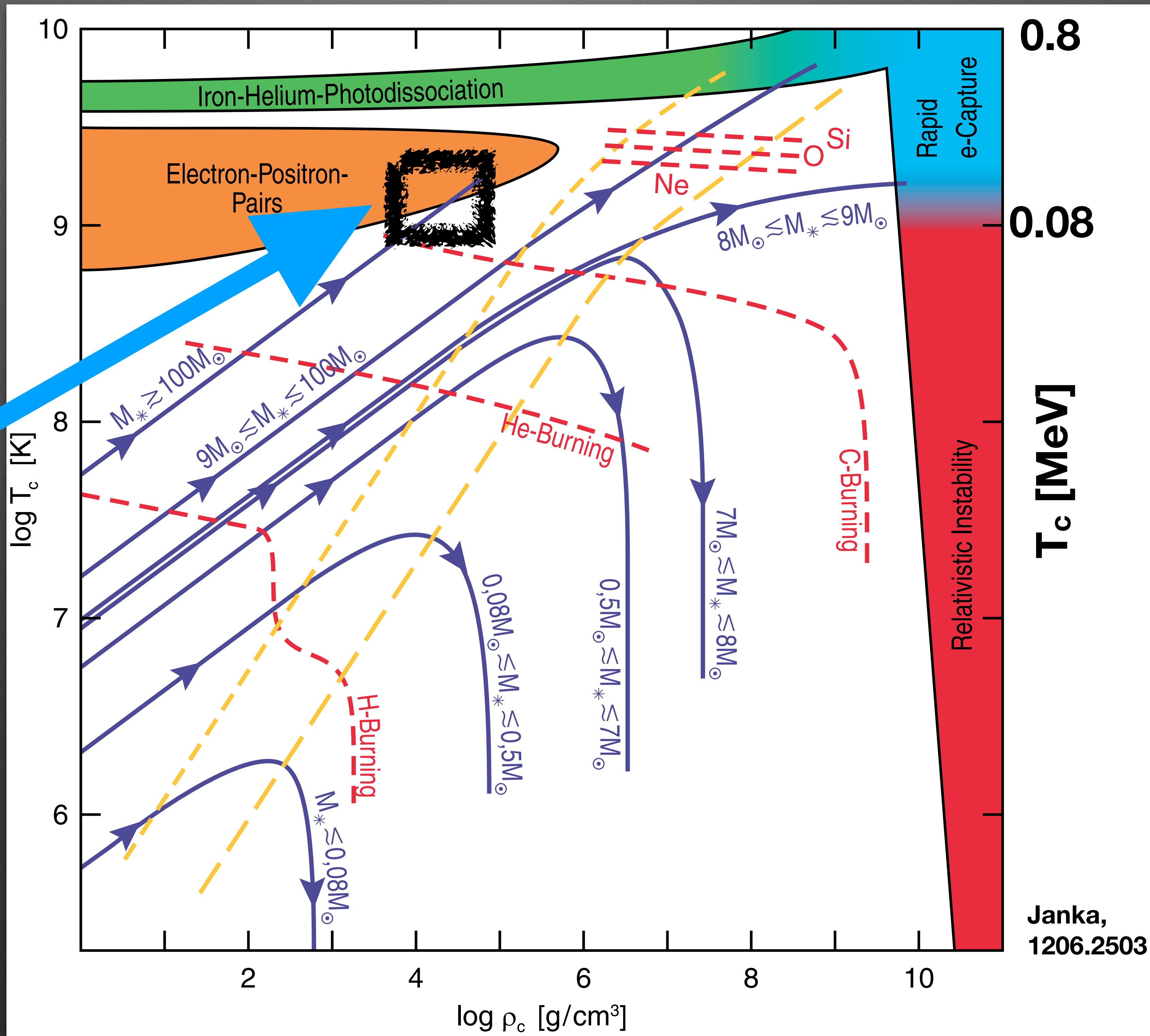
Pair Instability SNe



Janka, 1206.2503

Pair Instability SNe

Appearance of non-relativistic e+e- pairs (catastrophically) causes adiabatic index to fall below 4/3 (n.b.: this has nontrivial ρ-dependence due to Pauli blocking at high ρ)

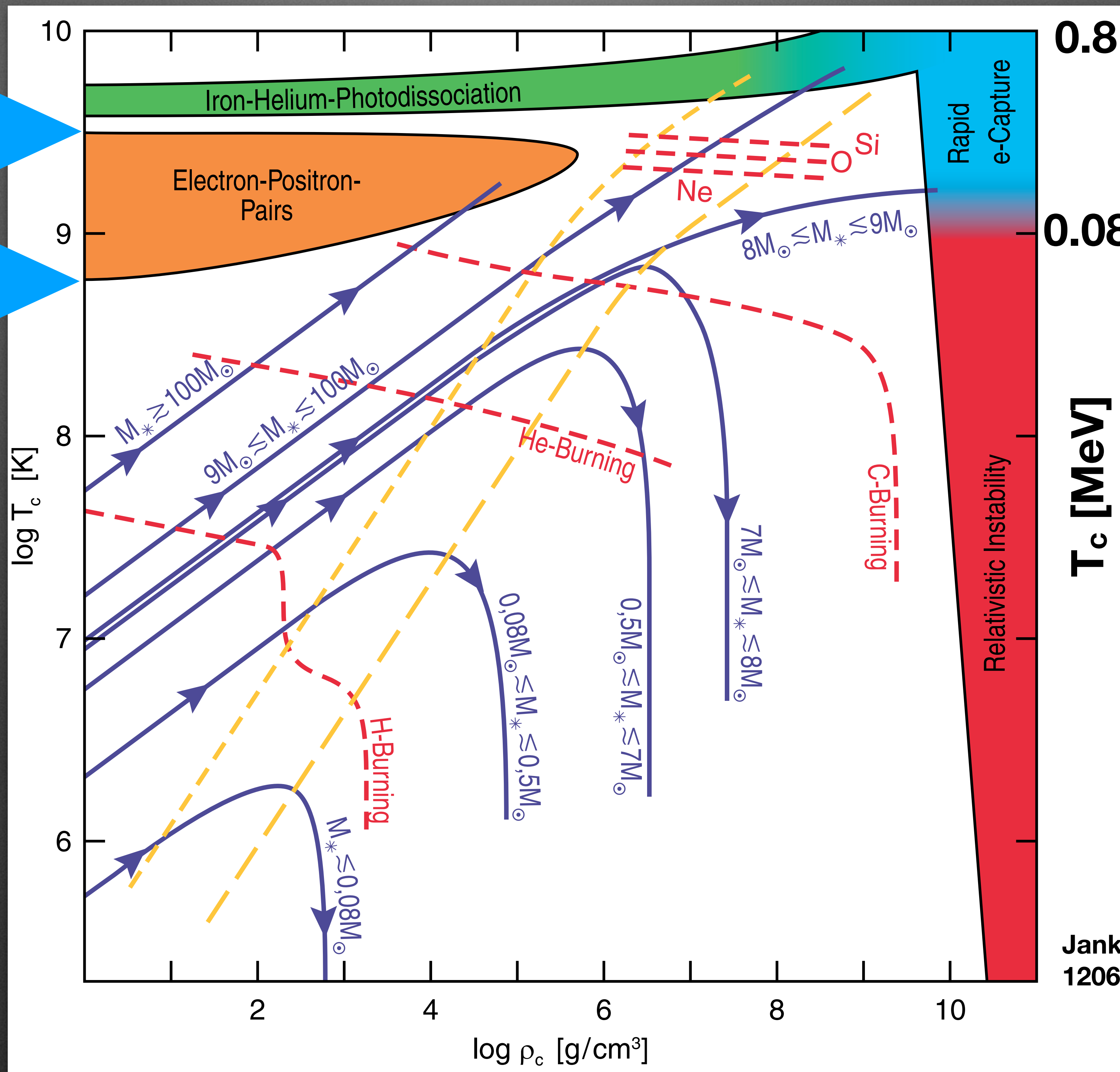


Pair Instability SNe

0.5 m_e

0.1 m_e

if T_c much less than m_e, too few "missing photons" to matter



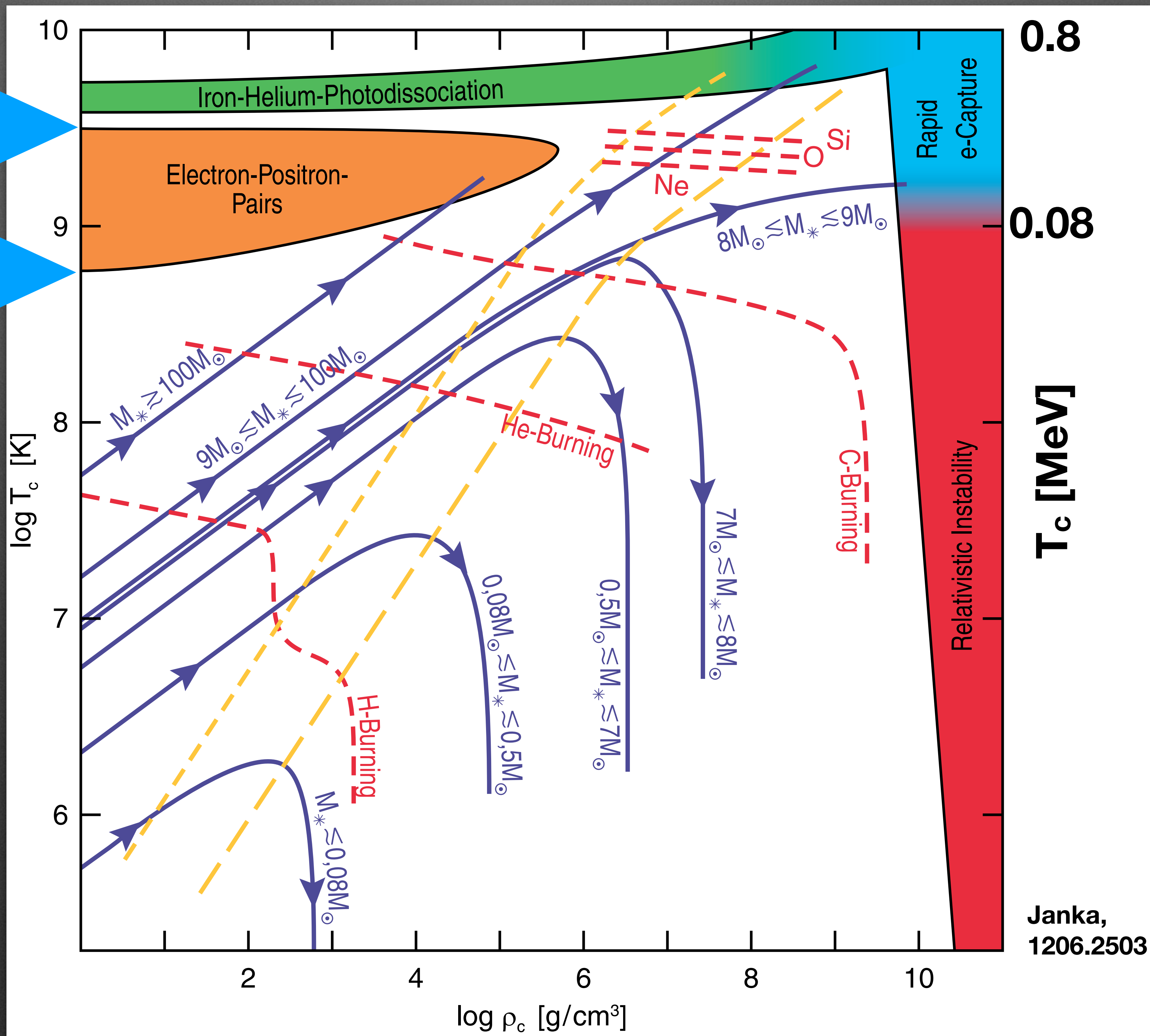
Janka, 1206.2503

Pair Instability SNe

0.5 m_e

0.1 m_e

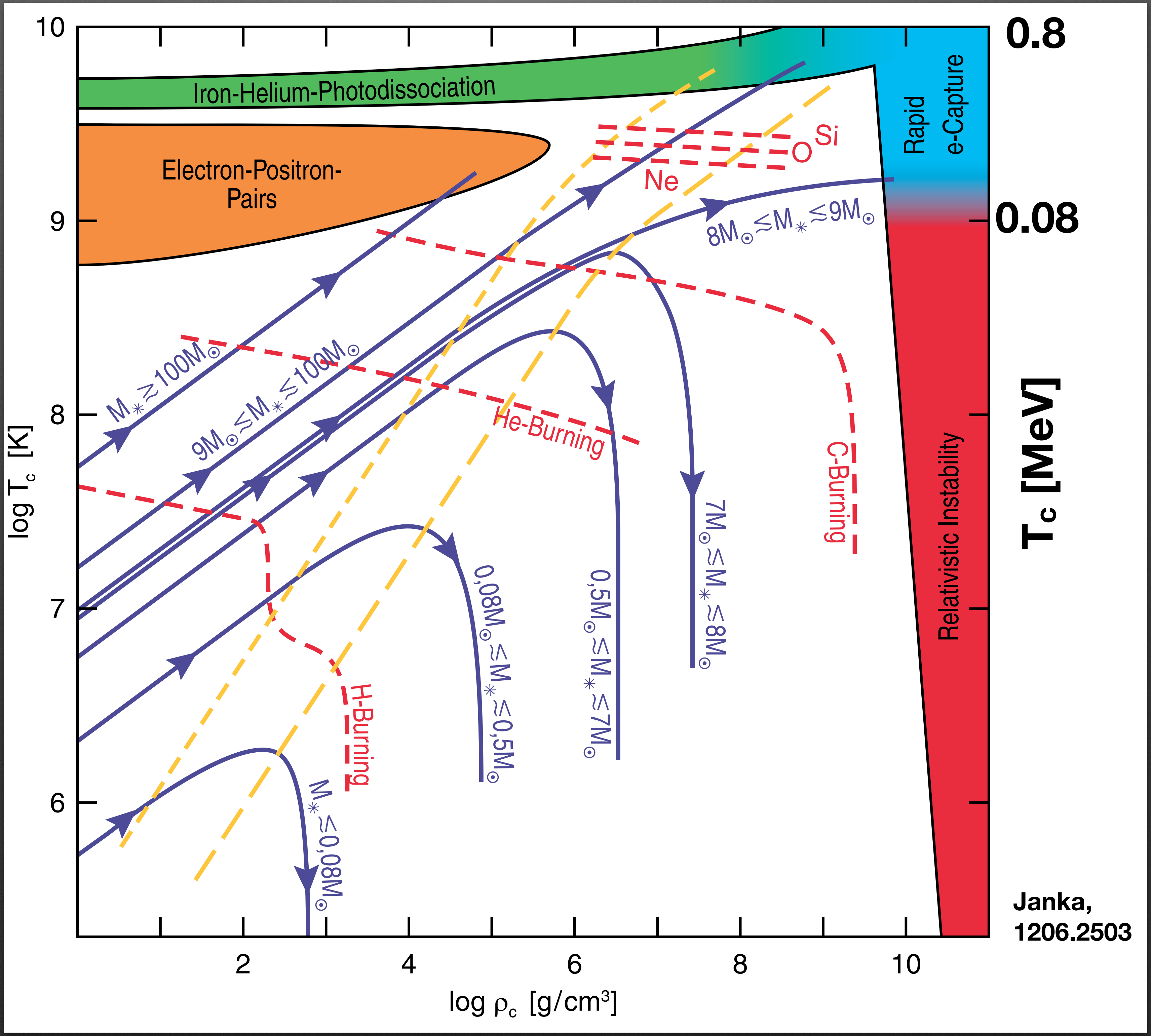
if T_c greatly in excess of m_e, all electrons are relativistic and adiabatic index climbs again



Janka, 1206.2503

Tightly Coupled Dark States

Could a new particle (with or w/o pre-collapse abundance) have a similar effect?



Tightly Coupled Dark States

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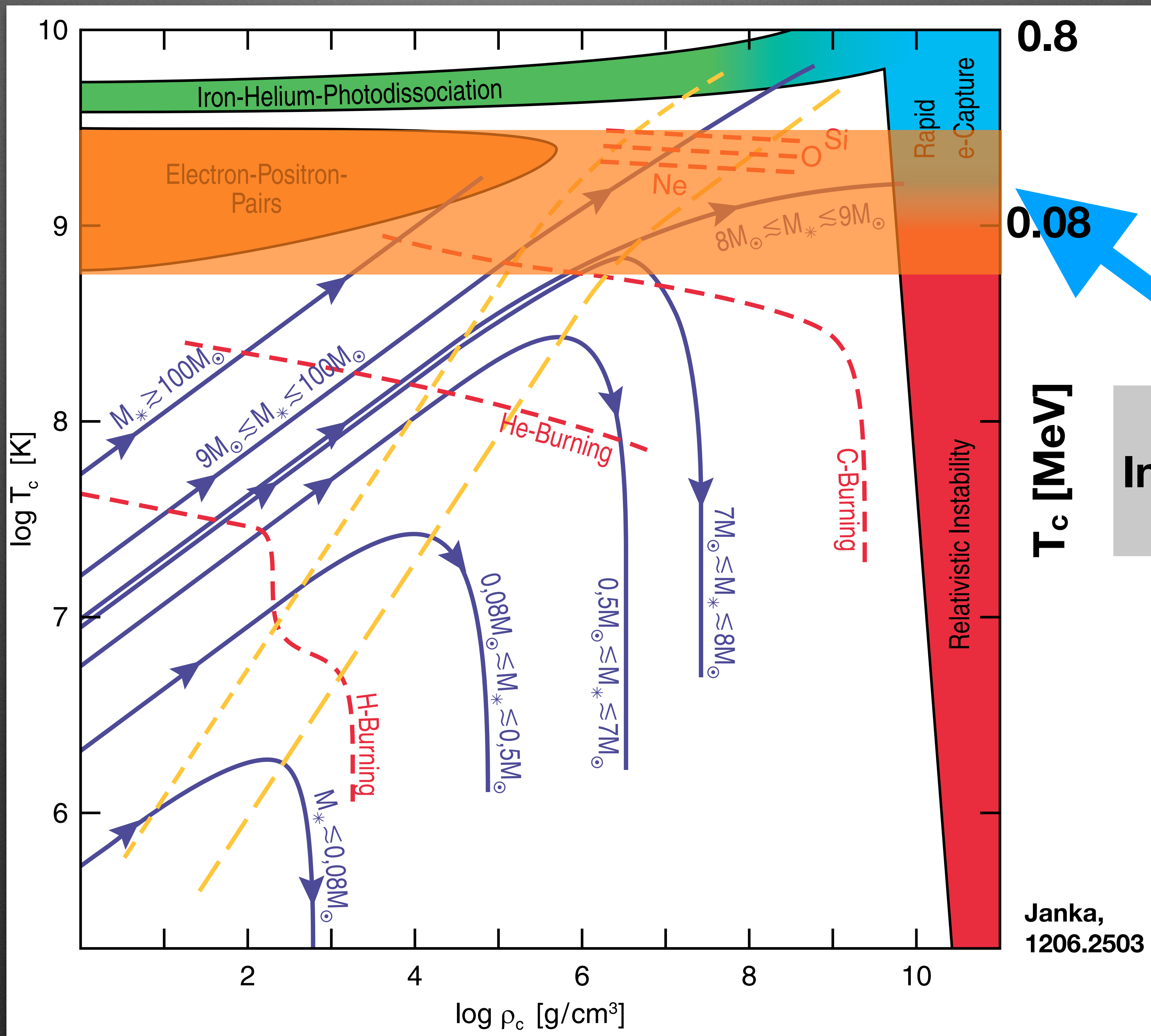
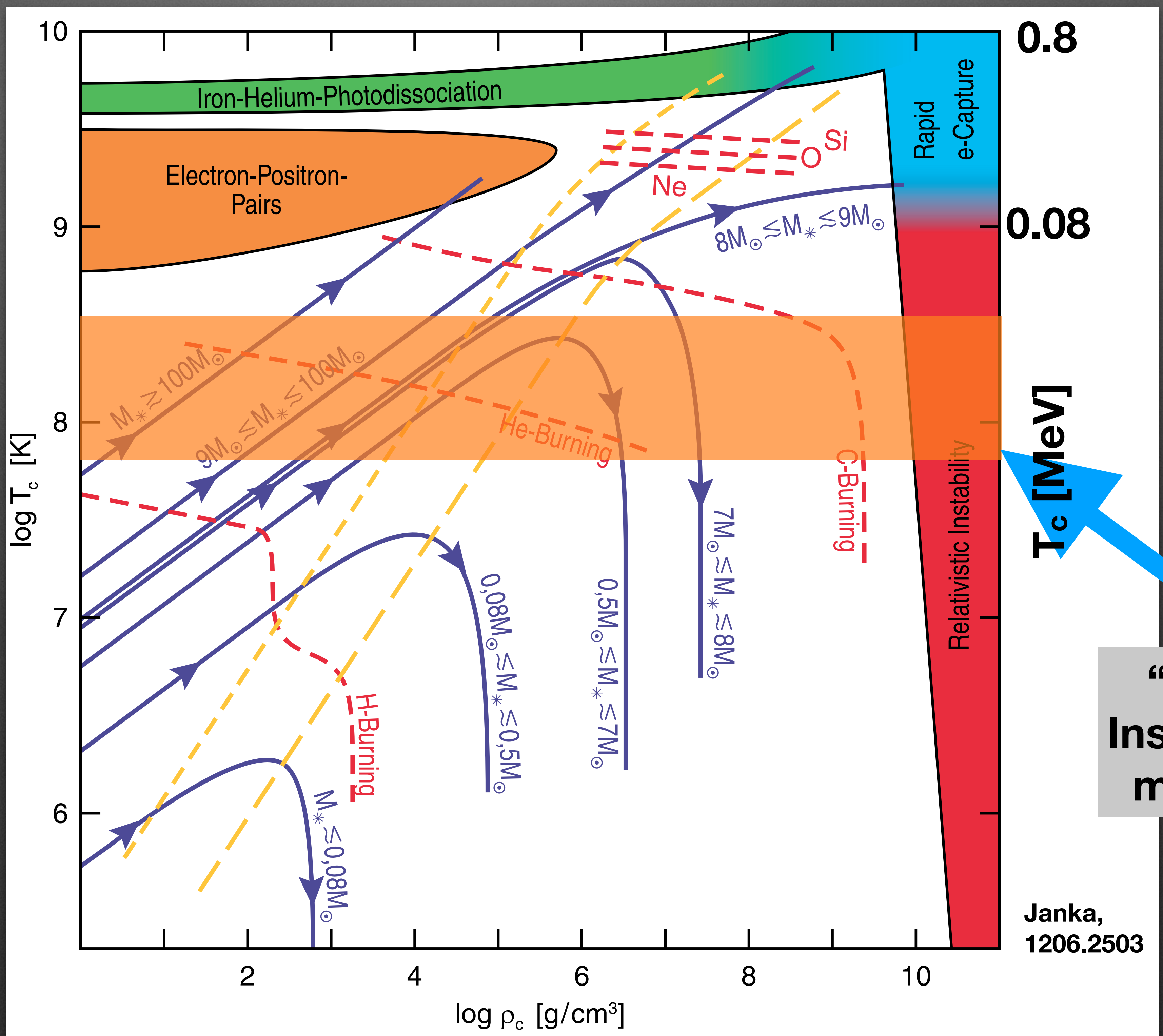


"Dark Pair Instability" for $m_{A'} \sim m_e$

Janka, 1206.2503

Tightly Coupled Dark States

Could a new particle (with or w/o pre-collapse abundance) have a similar effect?

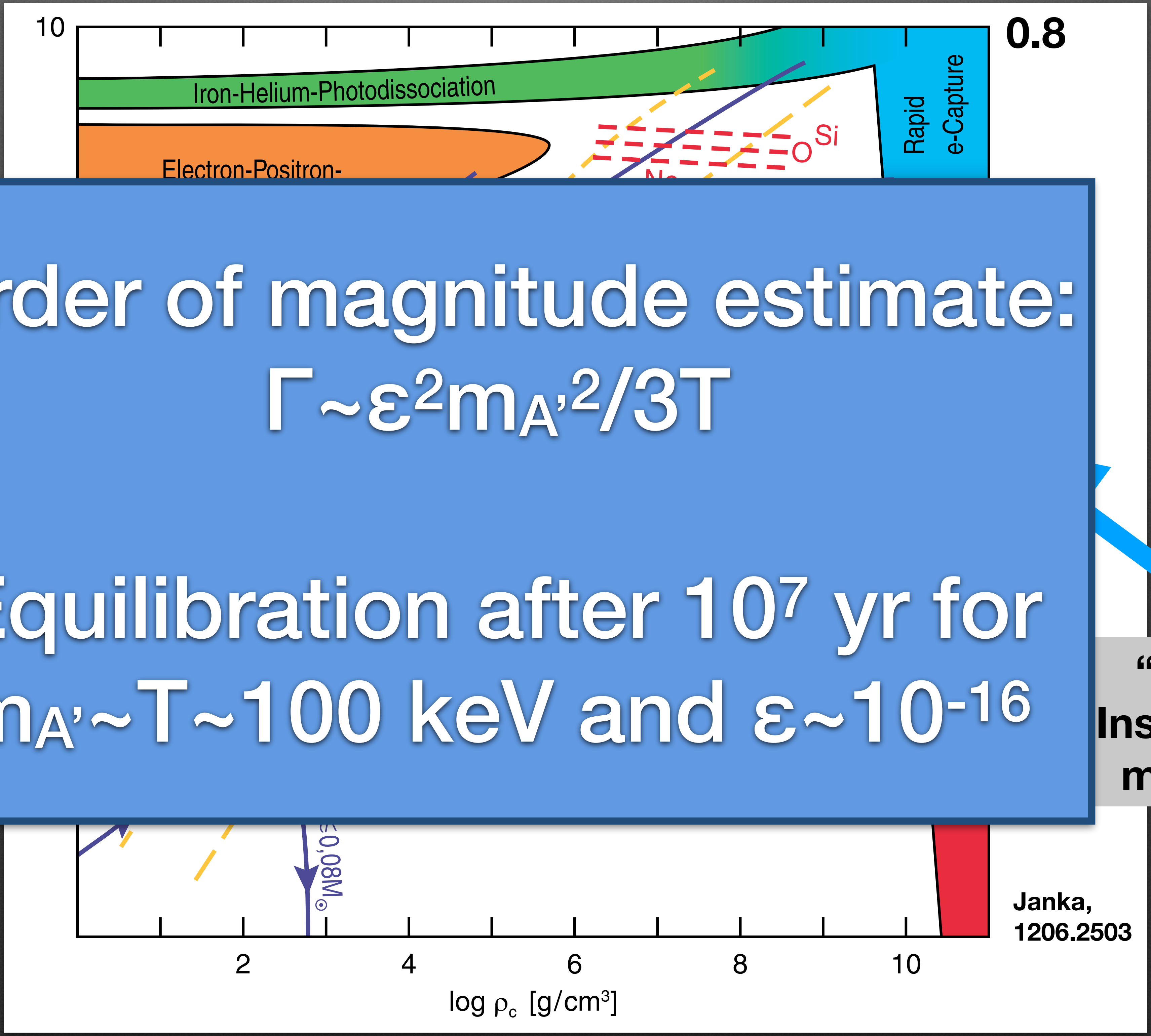


“Dark Pair Instability” for $m_{A'} \sim 0.1\ m_e$

Janka, 1206.2503

Tightly Coupled Dark States

Could a new particle (with w/o pre-colla abundance) h a similar effe



Order of magnitude estimate:
$\Gamma \sim \varepsilon^2 m_{A'}^2/3T$

Equilibration after 10^7 yr for $m_{A'} \sim T \sim 100$ keV and $\varepsilon \sim 10^{-16}$

"Dark Pair Instability" for $m_{A'} \sim 0.1\ m_e$

How to look for DM in stars?

	Canonical DM (WIMP, QCD axion)	Asymmetric DM	Hidden Sectors (including light bosons)
Solar System Objects	Press & Spergel Apj; Edsjö hep-ph/9504205; Mack, Beacom, Bertone 0705.4298 & PRD; Peter 0902.1347 & PRD	Frandsen + Sarkar 1003.4505 & PRL; Vincent, Serenelli, Scott 1504.04378 + 1605.06502 & JCAP	Farrar and Wadekar, 1903.12190
Stellar Populations	Friedland, Giannotti, Wise 1210.1271 & PRL; Heger et al. 0809.4703 & ApJ	Zentner and Hearin 1110.5919 & PRD	Friedland + Giannotti 0709.2164; Redondo + Postma 0811.0326; An, Pospelov, Pradler 1302.3884; Hardy and Lasenby 1611.05852
Dense Objects (WDs, NSs, …)	Baryakhtar et al., 1704.01577 & PRL	*SDM*, Yu, Zurek 1103.5472 & PRD; Kouvaris et al.; Bramante et al., …	Bramante + Linden 1405.1031 & PRL
Supernova	Turner et al. + Raffelt et al., 1988 - 1996; Chang, Essig, *SDM* 1803.00993 & JHEP	Zhang 1404.7172 & JCAP; Chang, Essig, *SDM* 1803.00993 & JHEP	Chang, Essig, *SDM* 1803.00993 + 1611.03864 & JHEP; Hardy and Lasenby 1611.05852 & JHEP

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talks tomorrow by Giannotti and Raen

How to look for DM in stars?

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Exciting opportunities for crosstalk between theorists / experimentalists / observationalists / modelers / etc.!