Supernova Bounds on Hidden Photons

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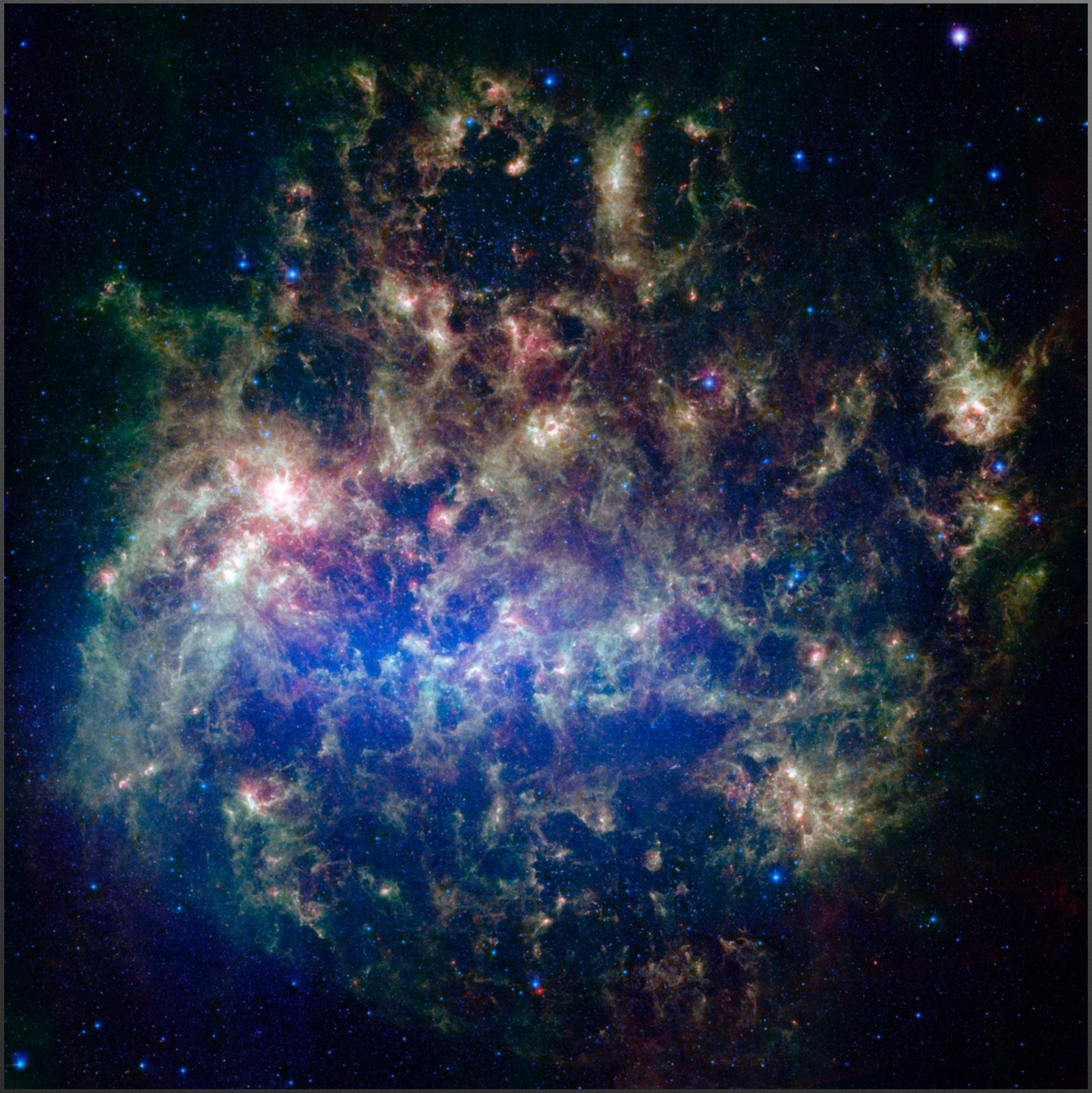
(to appear…)

Stony Brook University

Motivation

- Standard Model is finally complete
- Natural scales aren’t furnishing the evidence we hoped for; energy frontiers now seem far away
- Dark matter:
  - where can we find it?
  - supernova = intense new particle source

Supernova 1987A



Credit: NASA/JPL-Caltech/M. Meixner (STScI) & the SAGE Legacy Team

- Nearby core-collapse supernova
- "Late-time" evolution agrees roughly with analytic expectation
- New "energy sink" competes with Standard Model processes
- Limited amount of luminosity may be diverted to novel particles $\Longleftrightarrow$ bounds on new coupling with SM

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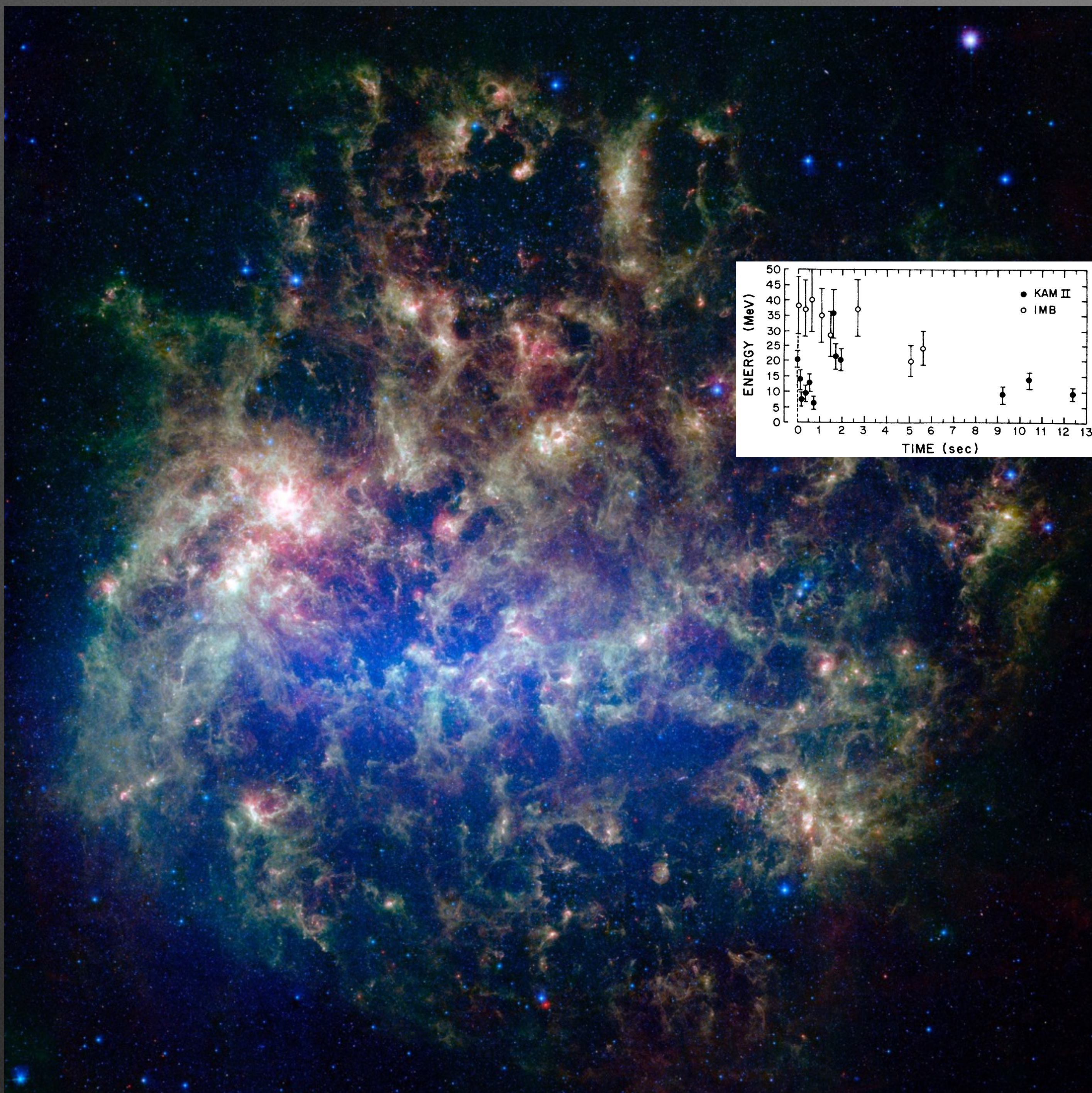

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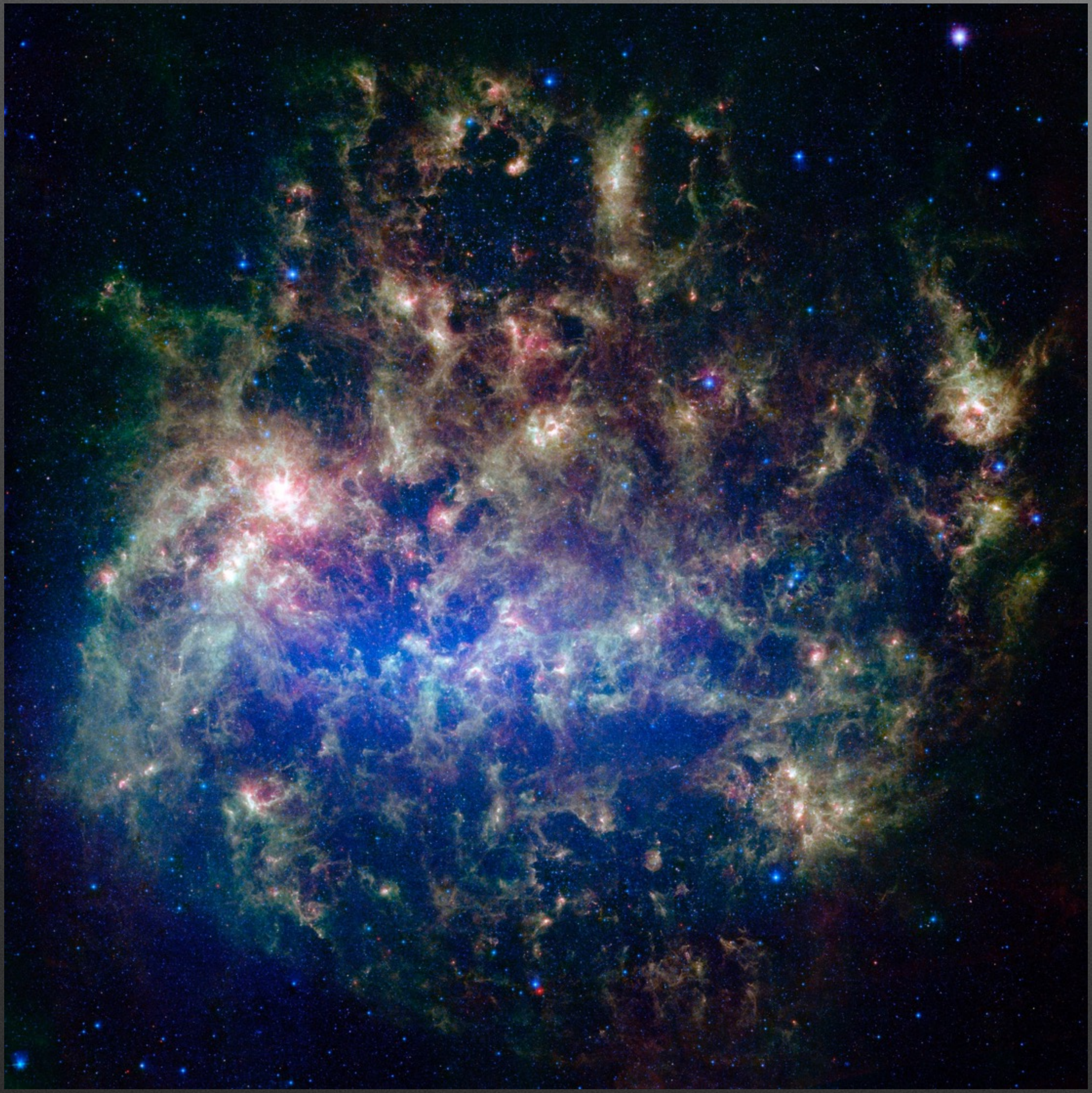

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$$L = \int d\omega\, dV\, e^{-\tau(\omega,r)} \frac{dP}{d\omega dV}$$

Outline

I. Kinetic Mixing and Finite Temperature

II. Resonance and “Trapping”

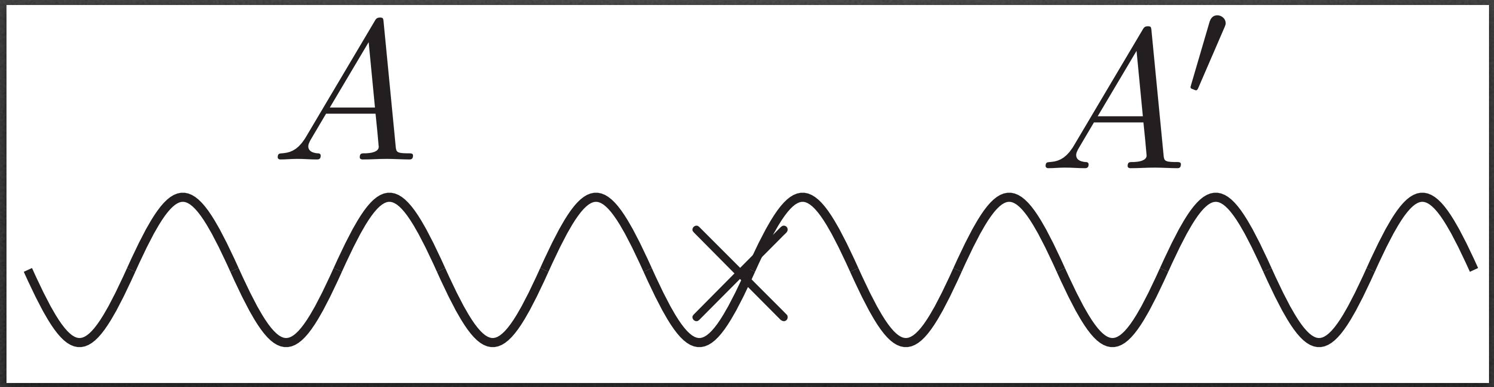
III. Current and future directions

Kinetic Mixing

in gauge eigenstate basis:

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{2} m'^2 A'_\mu A'^\mu - \frac{1}{4} F'_{\mu\nu} F'^{\mu\nu} - \frac{\epsilon}{2} F'_{\mu\nu} F^{\mu\nu}$$

allows:



Kinetic Mixing

in vacuum:

$$\mathcal{L} = \epsilon J_\mu^{(\mathrm{EM})} A'^\mu$$

in plasma:

$$\mathcal{L} = \frac{\epsilon}{1 - \Pi/m'^2} J_\mu^{(\mathrm{EM})} A'^\mu$$

SM photon self energy, $\sim(n_e/m_e)^{1/2}$

Resonant Production

all interactions go like:

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

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

can be a resonance if $\mathrm{Re}\Pi \gg \mathrm{Im}\Pi$

$\mathrm{Re}\Pi(\omega) = m'^2$ for some $\omega = \omega_{res}$

Resonant Production

on resonance, details of production mode cancel since $\mathrm{Im}\Pi \sim \Gamma'$ and $\Delta\omega \sim \Gamma'$

$$dP \sim \int d\omega dV \frac{\omega^3 \Gamma_p}{0 + (\mathrm{Im}\Pi/m'^2)^2}$$

power on the resonance is

$$\frac{dP_{\rm res}}{dV} = \frac{\epsilon^2 m'^2 \omega_{\rm res}^3 v^3}{2\pi \left(e^{\omega/T} - 1\right)} \frac{1}{2 + (m'^2 - 3\omega_p^2)/\omega^2_{\mathrm{res}|L,T}}$$

$\sim 10^{69}$ erg/s $(\varepsilon m'/\mathrm{MeV})^2$

$\sim L_\nu \, (\varepsilon/5\times10^{-9})^2 \, (m'/\mathrm{MeV})^2$

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define a luminosity $dL = e^{-\tau}\,dP$
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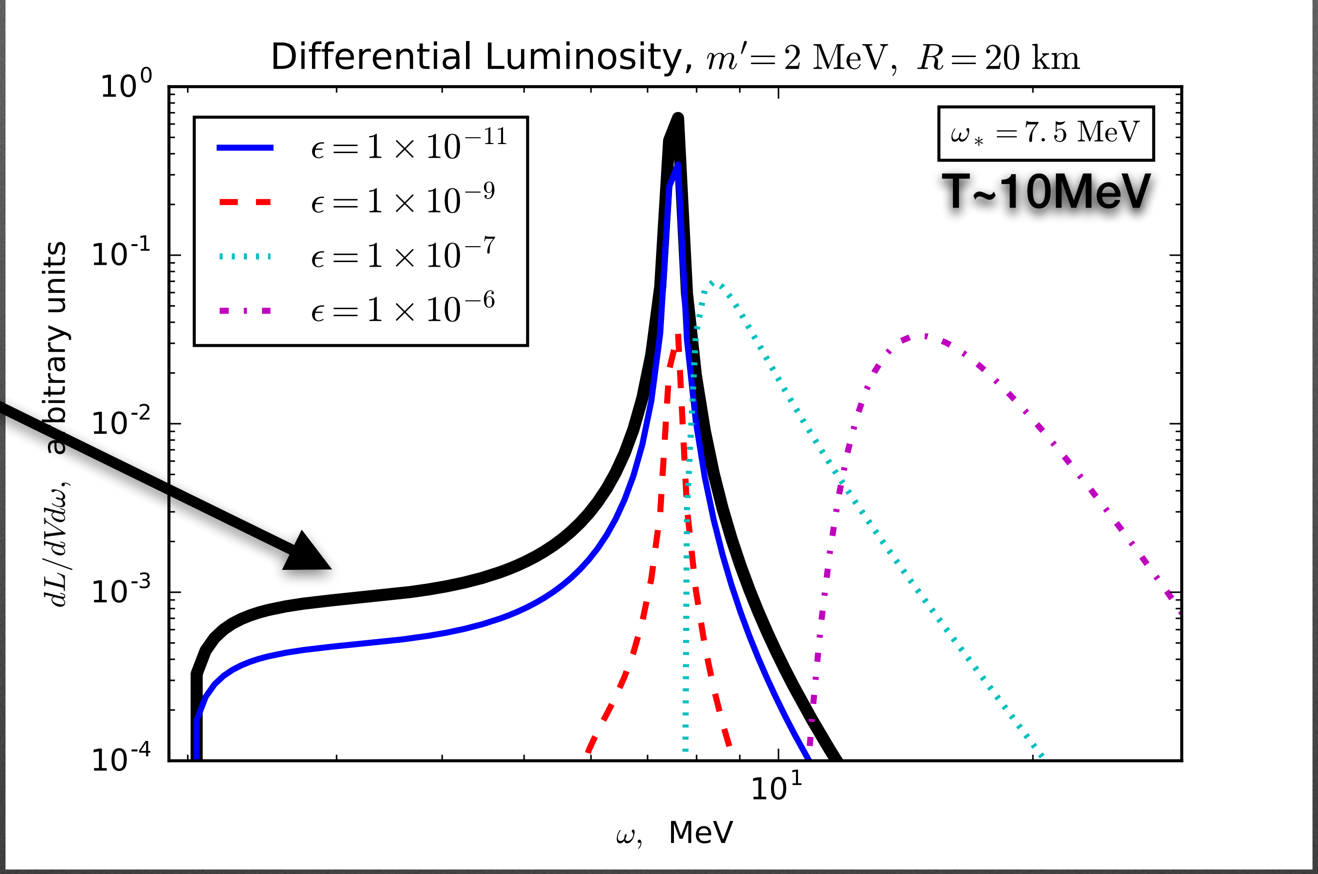
at large mixing, τ is large so dP_{res} is suppressed
is there additional power?

Energy emission at high ε

dP/dVdω



$\tau(r)=\int_r^{Rf}\Gamma'(r')\,dr'$

$\Gamma' \sim n_n n_p \sigma_{np}/\omega^3$ ⇒ high energy particles escape!

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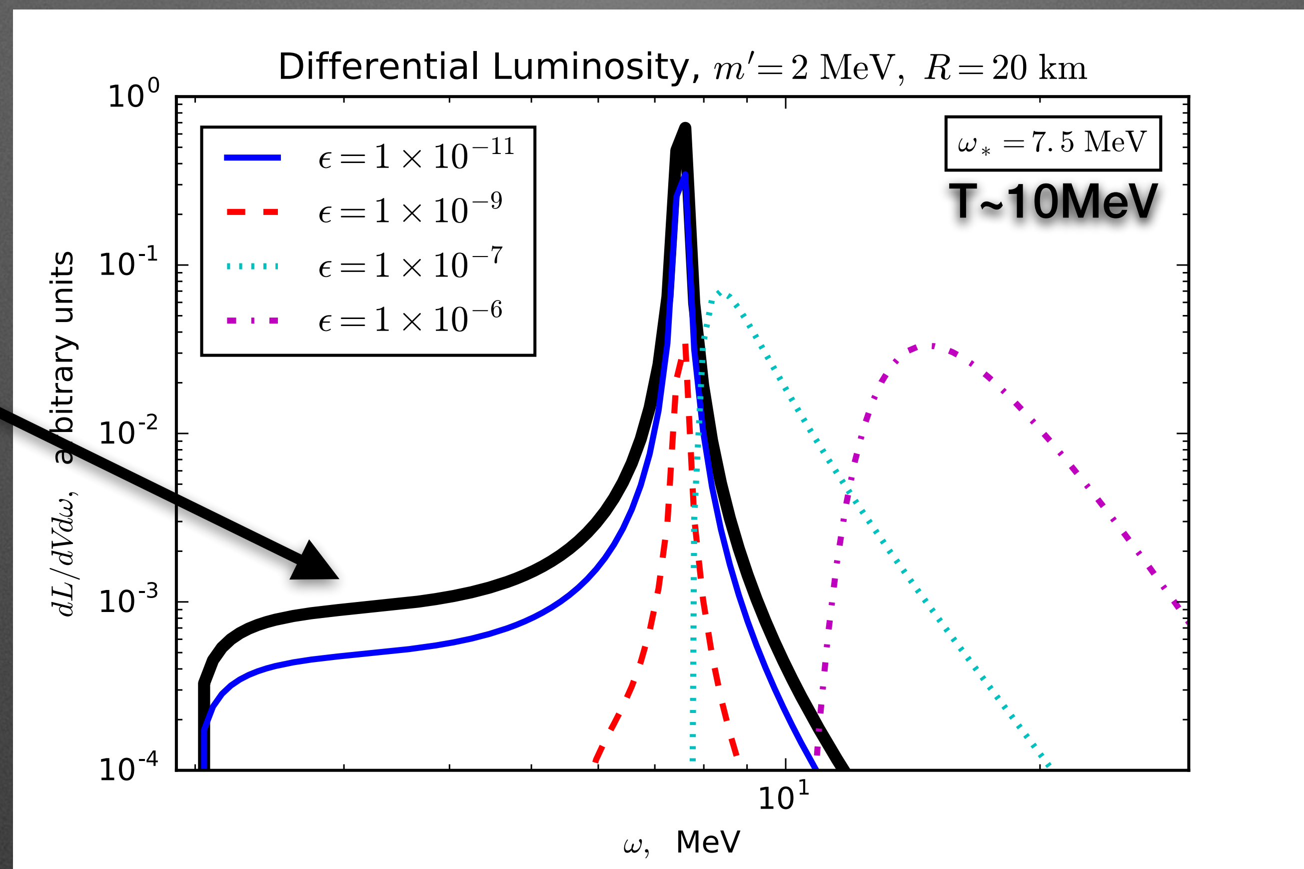

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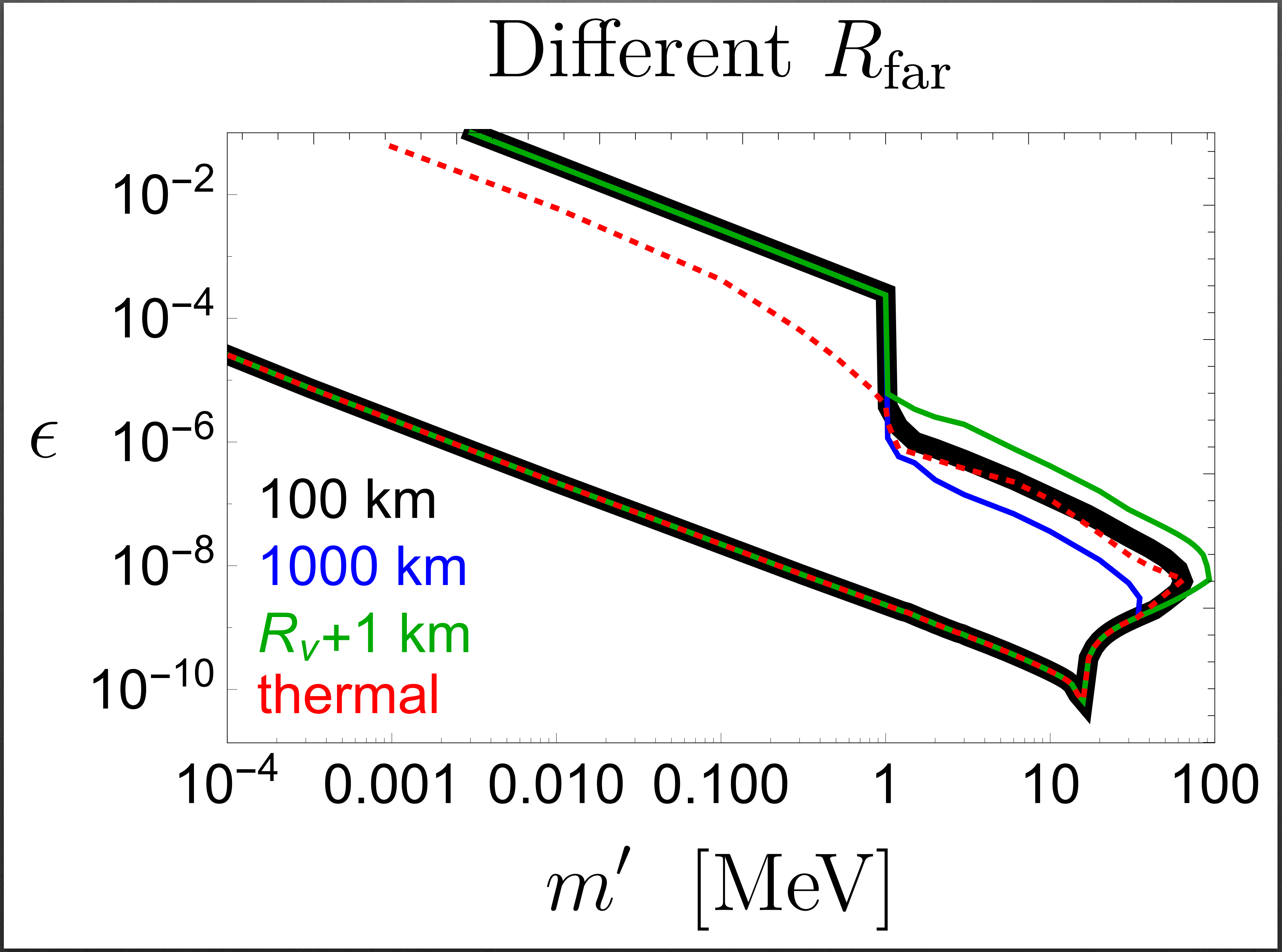
(peak is *above* T, ω_{res}!)

Results (preliminary)



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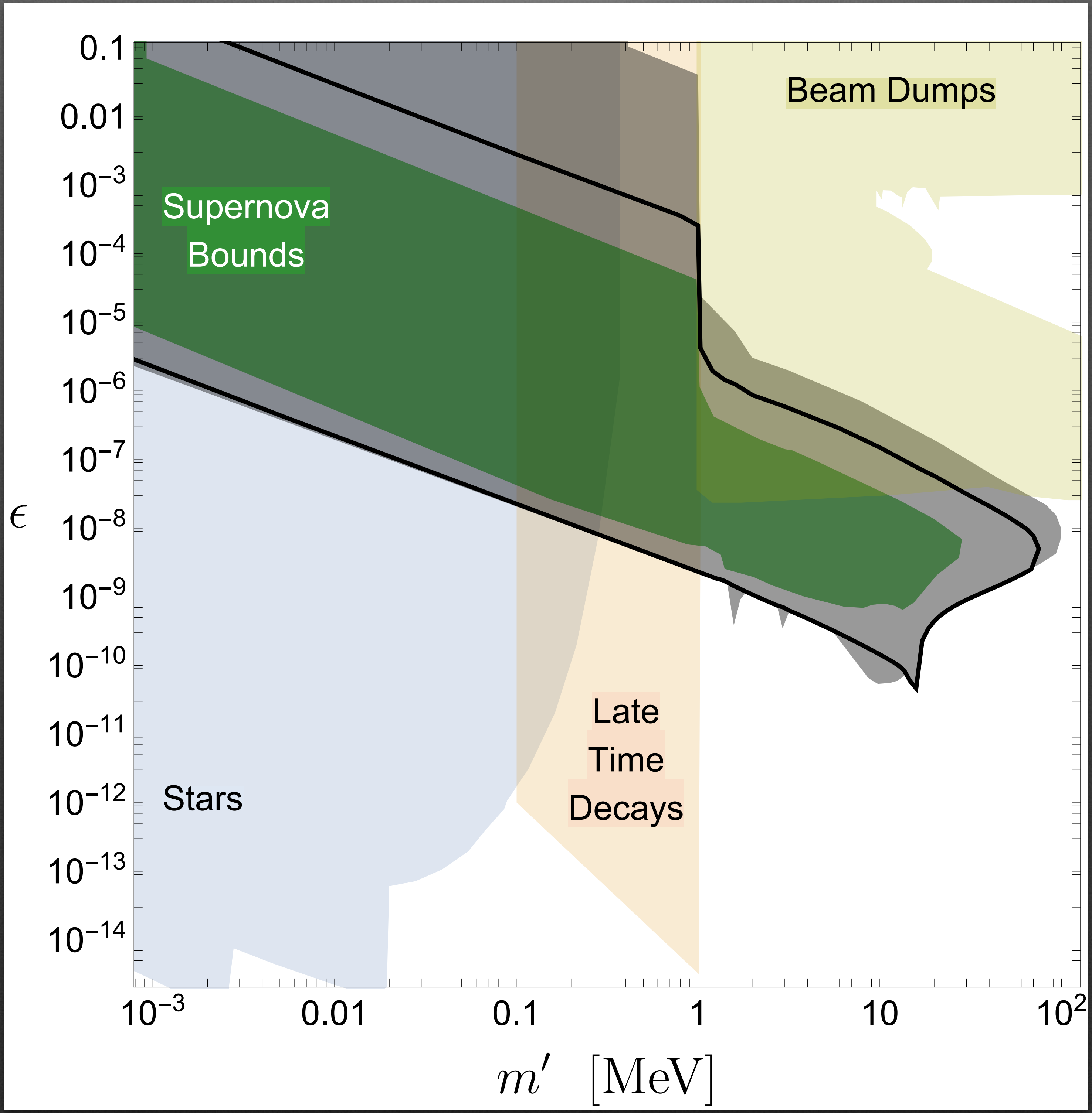

Future Directions

What if $A' \Rightarrow \psi\bar{\psi}$ is on shell? (no trapping?)

“How thermal” are axions at large mixing?

What other DM varieties can be constrained?

Thanks!